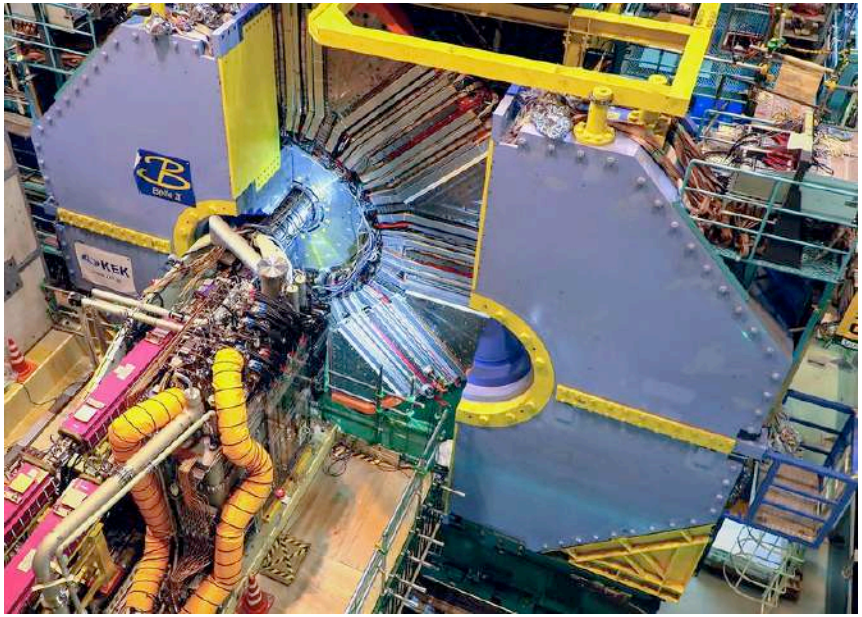
Belle II@SuperKEKB Status and Prospects for NP

Tom Browder, University of Hawai'i at Manoa



The complex superconducting final focus is partially visible here (before closing the endcap).

Vertex detector before installation

Introduction & The Home Team

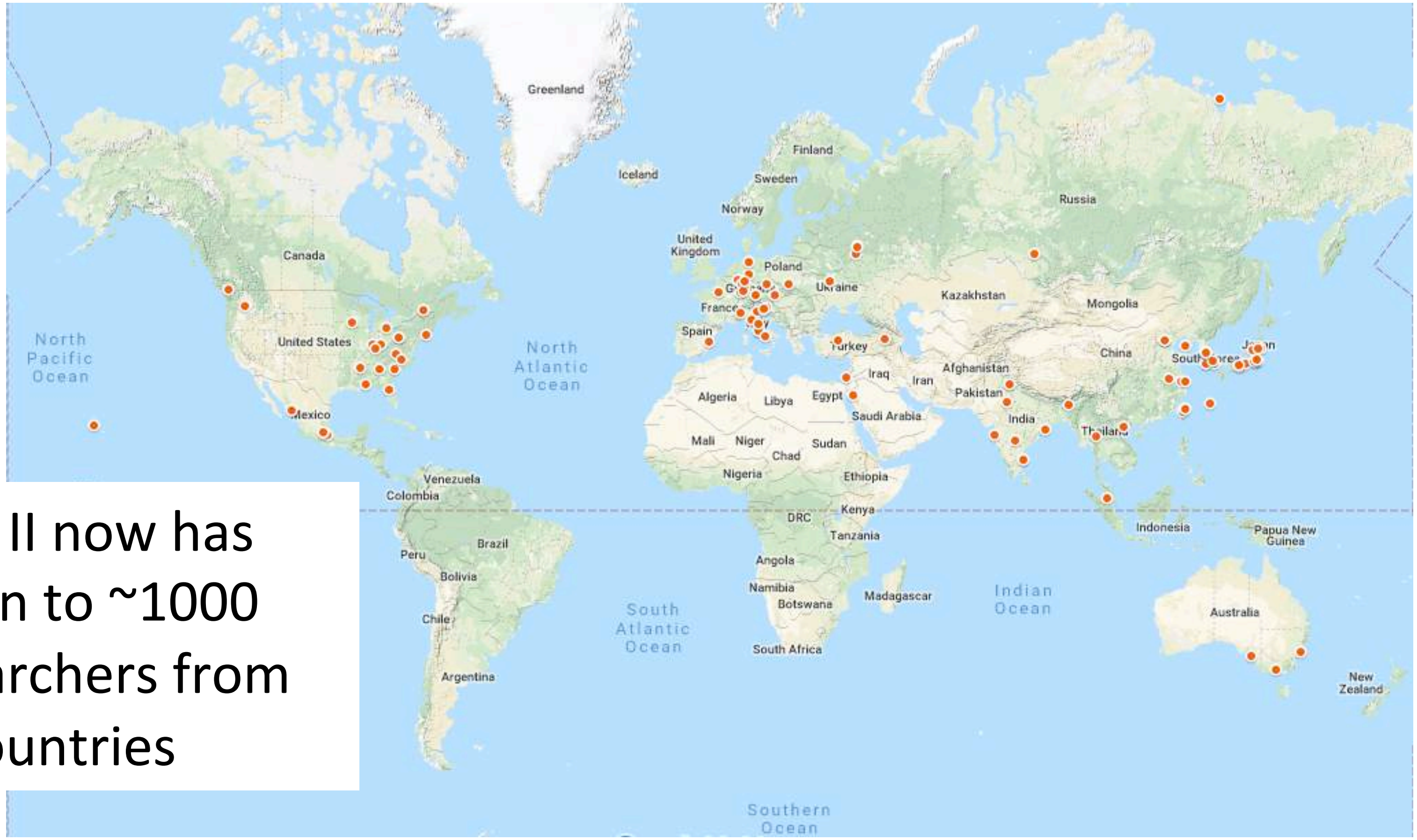
Highlights from the last Belle II Physics Run which concluded on July 5th. (L_{peak}=3.1 x 10^{34}/ cm^2/sec, new world record)

Early Physics Results from Belle II: Dark Sector , B physics, charm physics and tau physics.

The Road Ahead to high luminosity and cutting edge physics.

The Geography of the International Belle II collaboration

Belle II



Belle II now has grown to ~1000 researchers from 26 countries

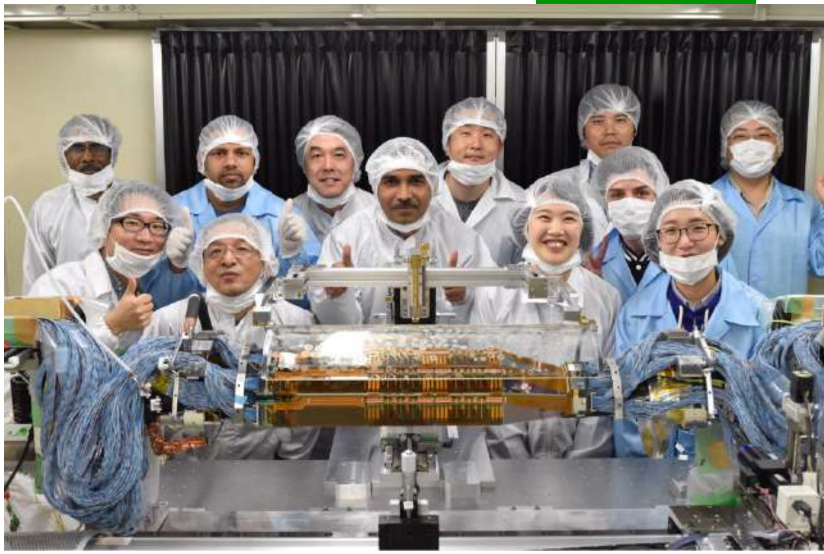
This is rather unique in Japan. The only comparable example is the T2K experiment at JPARC, which is also an international collaboration

Youth and potential: There are ~330 graduate students in the collaboration

MNIT Jaipur
(Prof. K. Lalwani)
Indian Institute of Science Education and Research (IISER) Mohali
(Prof. V. Bhardwaj)
Indian Institute of Technology, Bhubaneswar
(Prof. S. Bahinipati)
Indian Institute of Technology, Guwahati
(Prof. B. Bhuyan, D. Kalita)
Indian Institute of Technology, Hyderabad
(Prof. A. Giri, Prof. S. Sandilya)
Indian Institute of Technology, Madras
(Prof. P Behera, Prof. J. Libby)
Institute of Mathematical and Sciences, Chennai
(Prof. R. Sinha)
Panjab Univ. Chandigarh + Panjab Agricultural Univ.
(Prof. S. Bansal, Prof. J.B. Singh+ R. Kumar)
Tata Institute of Fundamental Research, Mumbai
(Prof. G. Mohanty, Dr. P. Krishnan, K. Rao,
S. Mayakar, P. Shingade))

Indian contributions to rare B decays, γ /φ_3 measurements and charm physics on Belle (II)
+ *major impact on Belle II early physics*

Belle II India



L4 (+x clamshell) of the Belle II Silicon Vertex Detector

India *built* layer 4 of the Belle II silicon vertex detector. Major GRID computing planned.

+ 23 graduate students (13 women, 10 men)

The B Factories focused on establishing large CP violation in the B Meson System in the SM and constraints on the CKM matrix. PEP II/ BaBar stopped in 2008 while KEKB/Belle completed operations in 2010.

Parameters			PEP-II	KEKB
Beam energy		(GeV)	9.0 (e^-), 3.1 (e^+)	8.0 (e^-), 3.5 (e^+)
Beam current		(A)	1.8 (e^-), 2.7 (e^+)	1.2 (e^-), 1.6 (e^+)
Beam size at IP	x	(μm)	140	80
	y	(μm)	3	1
	z	(mm)	8.5	5
Luminosity		($\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$)	1.2×10^{34}	2.1×10^{34}
Number of beam bunches			1732	1584
Bunch spacing		(m)	1.25	1.84
Beam crossing angle		(mrad)	0 (head-on)	± 11 (crab-crossing)

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \qquad V_{\mathrm{CKM}} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

A single irreducible complex phase explains all CPV

Revisionist History and Paradigm Shift

The B factory experiments, Belle and BaBar, discovered large CP violation in the B system in 2001, compatible with the SM and provided a large range of CKM measurements. These provided the experimental foundation for the 2008 Nobel Prize to Kobayashi and Maskawa.

In the meantime, the LHC was constructed in 2008, ATLAS and CMS completely changed the nature of high energy physics. Of particular importance was the landmark discovery in 2012 of the Higgs boson.

This discovery was recognized by the 2013 Physics Nobel Prize to Englert and Higgs.

In addition, the high pT experiments, established tight constraints on direct production of high mass particles (e.g. M(Z'), M(W')>3 TeV, vector-like fermions > 800 GeV) and limits on SUSY. This *noble search* continues with the high luminosity LHC.

Paradigm shift: inspired by intriguing results from LHCb and the potential of Belle II, the possibility of finding new physics in flavor has emerged as a *complementary* route to the LHC.

Younger theorists: Dark Sector may be another path.

ESG report

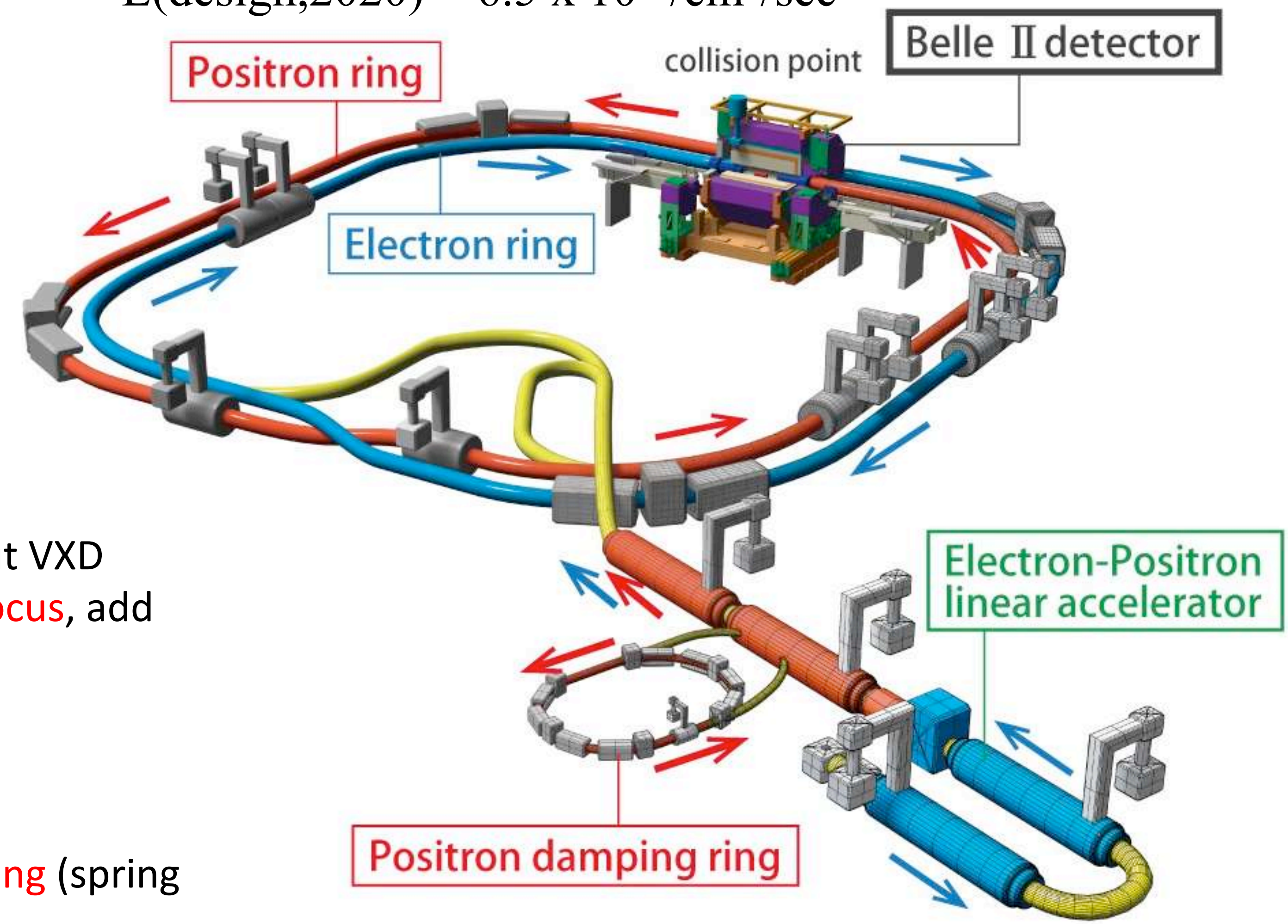
The quest for dark matter and the exploration of flavour and fundamental symmetries are crucial components of the search for new physics. This search can be done in many ways, for example through precision measurements of flavour physics and electric or magnetic dipole moments, and searches for axions, dark sector candidates and feebly interacting particles. There are many options to address such physics topics including energy-frontier colliders, accelerator and non-accelerator experiments. A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics Strategy. ***Experiments in such diverse areas that offer potential high-impact particle physics programmes at laboratories in Europe should be supported, as well as participation in such experiments in other regions of the world.***

The observed pattern of masses and mixings of the fundamental constituents of matter, quarks and leptons, remains a puzzle in spite of the plethora of new experimental results obtained since the last Strategy update. Studying the flavour puzzle may indicate the way to new physics with sensitivity far beyond what is reachable in direct searches, e.g. the evidence for the existence of the top quark that followed from the study of B-meson mixing. In addition, flavour physics and CP violation, which play a vital role in determining the parameters of the Standard Model, are explored by a wide spectrum of experiments all over the world. These include measurements of electric or magnetic dipole moments of charged and neutral particles, atoms and molecules, rare muon decays with high intensity muon beams at PSI, FNAL and KEK, rare kaon decays at CERN and KEK, and a variety of charm and/or beauty particle decays at the LHC, in particular with the LHCb experiment. New results are expected in the near future from the Belle II experiment at KEK in Japan and from LHCb (currently undergoing an upgrade) at CERN.

SuperKEKB, the first new collider in particle physics since the LHC in 2008 (electron-positron (e^+e^-) rather than proton-proton (pp)). Operates on the Upsilon(4S) resonance with 7 GeV(e-) on 4 GeV(e+) beams.

Super KEKB

$L(\text{design},2020) = 6.5 \times 10^{35}/\text{cm}^2/\text{sec}$



Phase 1:
Background, Optics Commissioning Feb-June 2016.
Brand new 3 km positron ring.

Phase 2: Pilot run without VXD Superconducting Final Focus, add positron damping ring, First Collisions (0.5 fb^{-1}). April 27-July 17, 2018

Phase 3: → Physics running (spring 2019 to present). Have integrated 213 fb^{-1} so far.

Accelerator innovations: nano-beams and crab waist optics (*rather than large beam currents*)

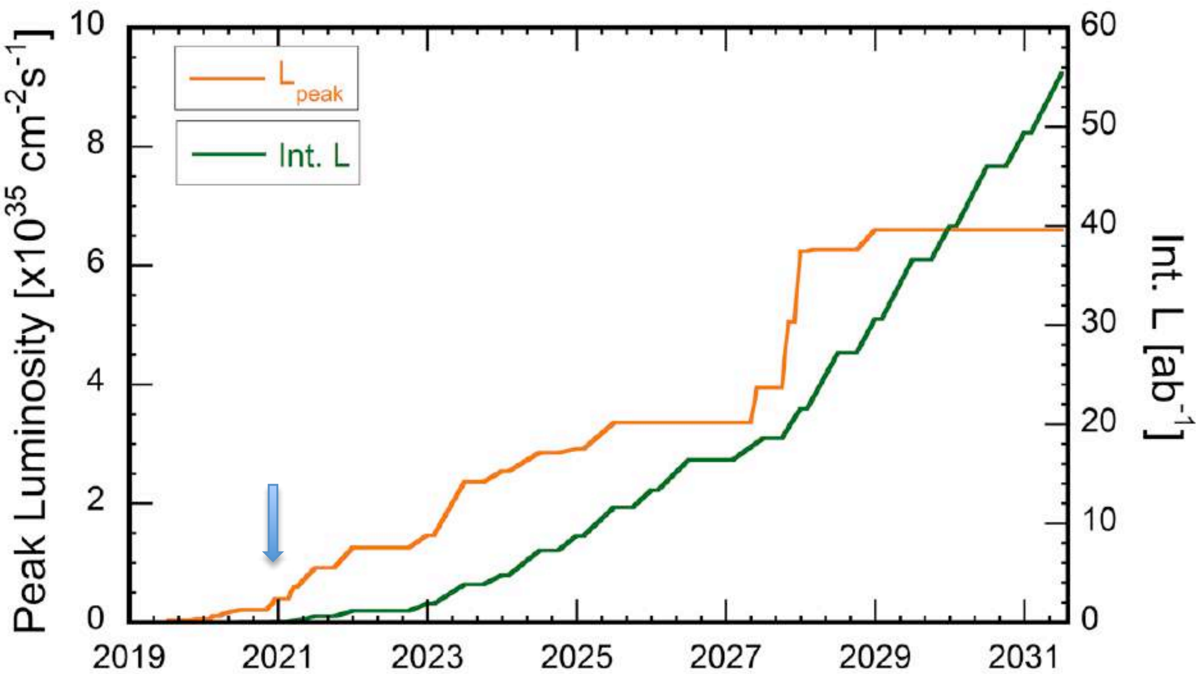
SuperKEKB/Belle II Luminosity Profile

Belle/KEKB recorded ~1000 fb^{-1} . Now have to change units on the y-axis to ab^{-1}

Beam currents *only* a factor of two higher than KEKB (~ PEPII)

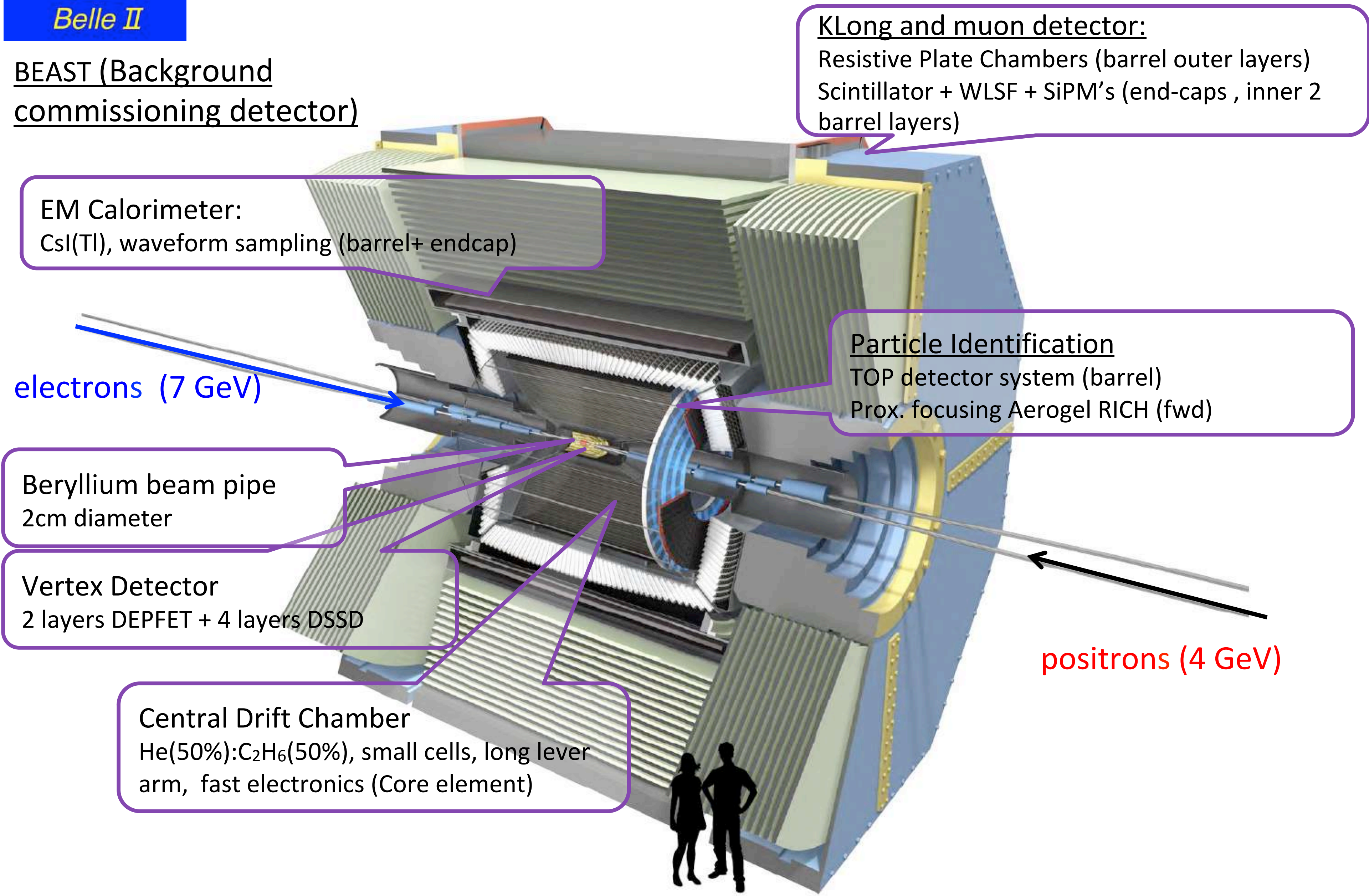
"nano-beams" are the key; vertical beam size is 50nm at the IP

Superconducting Final Focus and IR (Interaction Region) need to be upgraded in ~2026 or so. (COVID delays ?)



N.B. To realize this steep turn-on will require lots of ***running time***, close cooperation between Belle II and SuperKEKB [and much more ***international collaboration*** on the accelerator, including the US and Europe]: BNL built the corrector coils for the SuperKEKB superconducting final focus, LAL Orsay does *fast* luminosity monitoring, DESY built the RVC (Remote Vacuum Connection)].

Belle II Detector



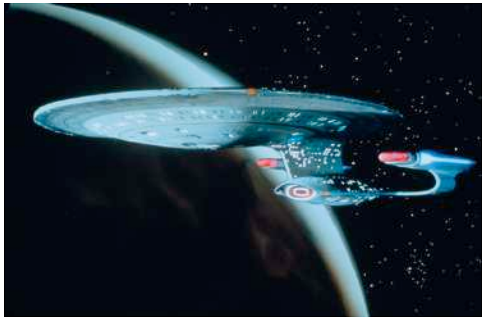
Advanced & Innovative Technologies used in Belle II

<u>Pixelated photo-sensors play a central role</u>

Belle II

MCP-PMTs in the iTOP
HAPDs in the ARICH
SiPMs in the KLM

Collaboration with Industry



DEPFET pixel sensors

<u>Waveform sampling with precise timing is "saving our butts".</u>

Front-end custom ASICs for most subsystems

→ DAQ with high performance network switches, large HLT software trigger farm

→ <u>a 21st century HEP experiment.</u>

KLM *(TARGETX* ASIC*)*

ECL (New waveform sampling backend with good timing)

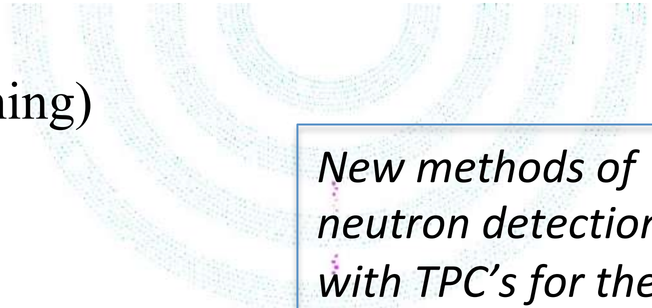
TOP *(IRSX* ASIC*)*

ARICH (KEK custom ASIC)

CDC (KEK custom ASIC)

SVD (APV2.5 readout chip adapted from CMS)

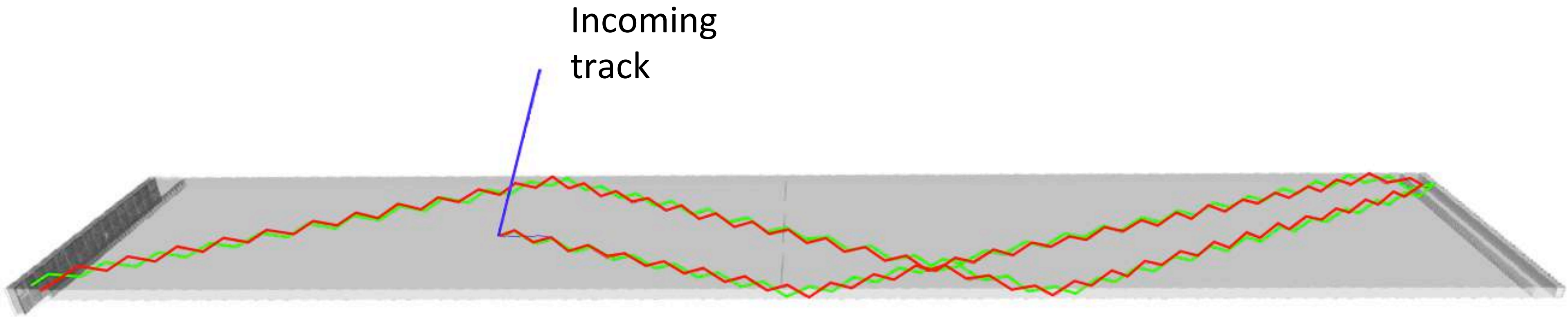
PXD (3 Readout ASICs)



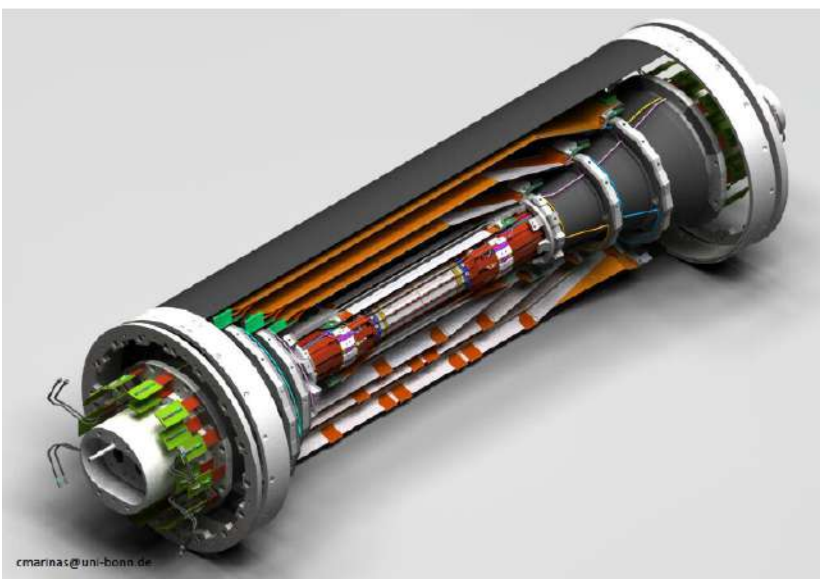
New methods of neutron detection with TPC's for the background. Directionality !

Barrel Particle Identification (uses Cherenkov radiation)

The paths of Cherenkov photons from a 2 GeV pion and kaon interacting in a TOP quartz bar. (Japan, US, Slovenia, Italy)



Vertexing/Inner Tracking



Beampipe r= 10 mm

DEPFET pixels (Germany, Czech Republic…)

- Layer 1 r=14 mm
- Layer 2 r= 22 mm

DSSD (double sided silicon detectors)

- Layer 3 r=38 mm (Australia)
- Layer 4 r=80 mm (India)
- Layer 5 r=115 mm (Austria)
- Layer 6 r=140 mm (Japan)

FWD/BWD
Italy

+Poland, Korea

FAQ: How do Belle II at KEK and LHCb at CERN capabilities compare ?

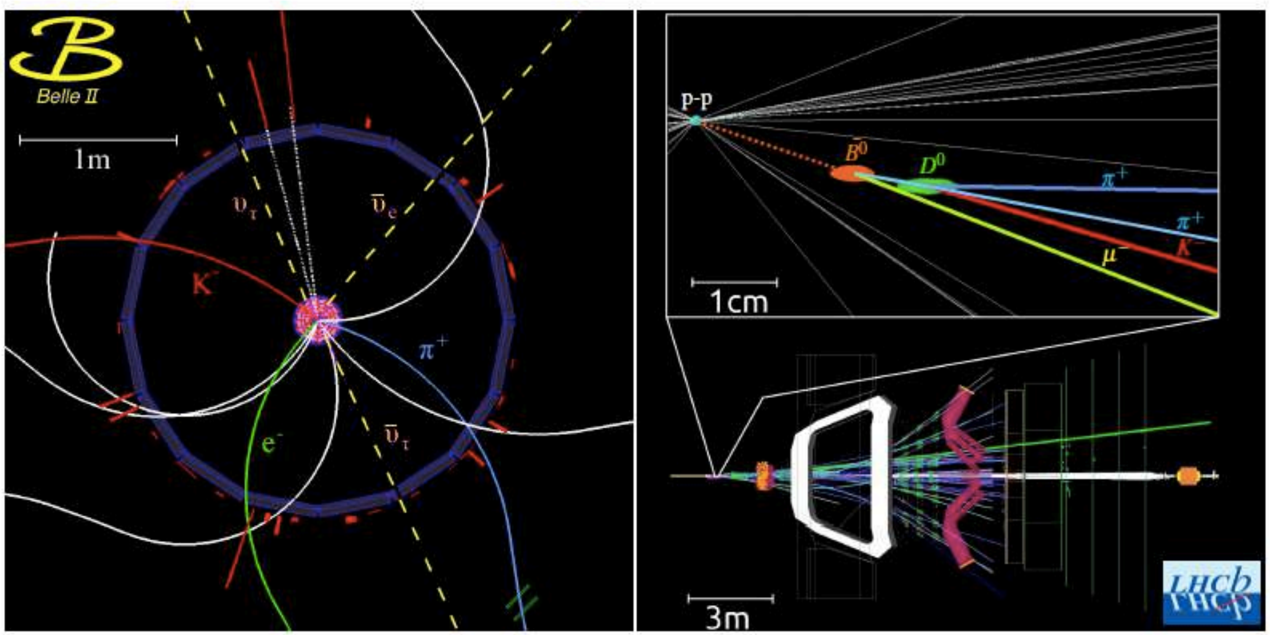


Figure credit:
G. Ciezarak et al,
Nature
546, 227 (2017)

++Belle II can do the dark sector

1. LHCB has a large b bbar cross-section (hundreds of microbarns versus nanobarns) and good sensitivity, signal to background, for modes with dimuons, and all charged final states using vertexing. Triggering and flavor tagging effs. are much lower than in e+e-.

2. Belle II has a simple event environment with B-anti B pairs produced in *a coherent QM state with no additional particles*.

3. Belle II can measure inclusive processes

4. Belle II can measure electrons as well as muons. (important for lepton universality checks).

Rule of thumb for statistics in this case:
1 fb^{-1} at LHCb is 1 ab^{-1} at Belle II.
(➔Need very good SuperKEKB performance)

5. Belle II can measure final states with γ's, Kshorts and missing neutrinos well.

FAQ: How can an international experiment and accelerator operate during a global pandemic ?

SuperKEKB/Belle II was and is operating during the COVID-19 pandemic with protocols in place to maximize safety and minimize the risk of infection. Difficult with travel restrictions and a very heavy load on a skeleton crew at KEK (~40 people). E.g. this included ~5-10 people onsite from the US.

Developed a "social distancing" scheme for on-site shifts in the Belle II and SuperKEKB control rooms. Mobilized remote shifters around the world – depended heavily on internet chat utilities for communication and monitoring.

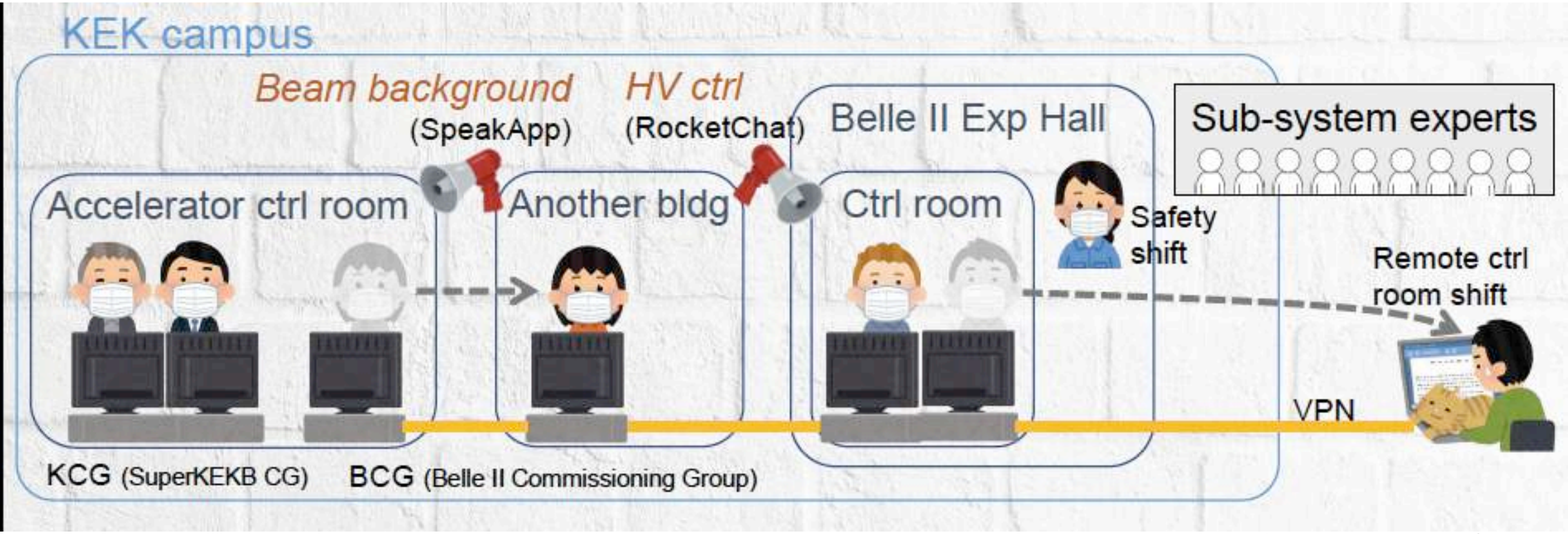
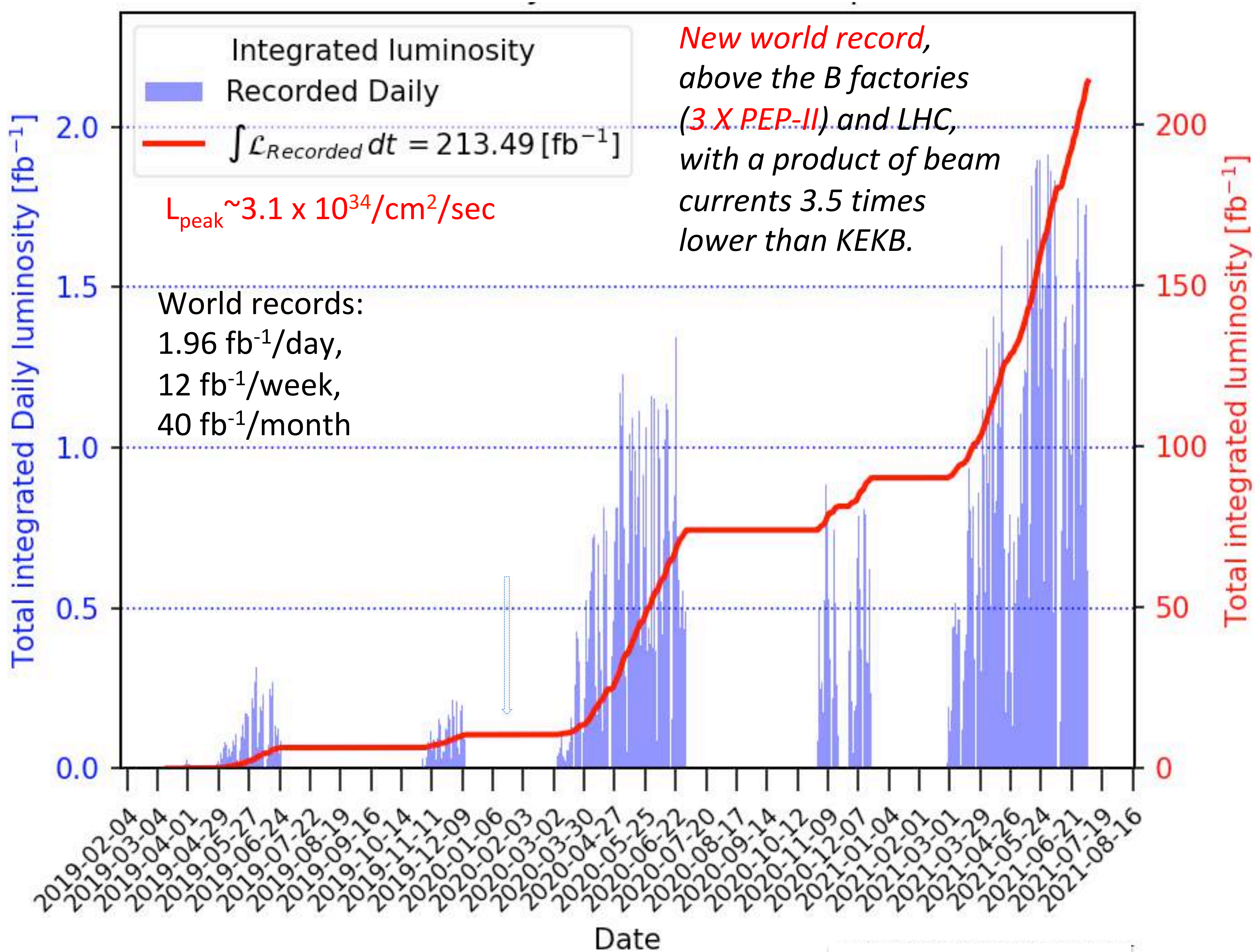


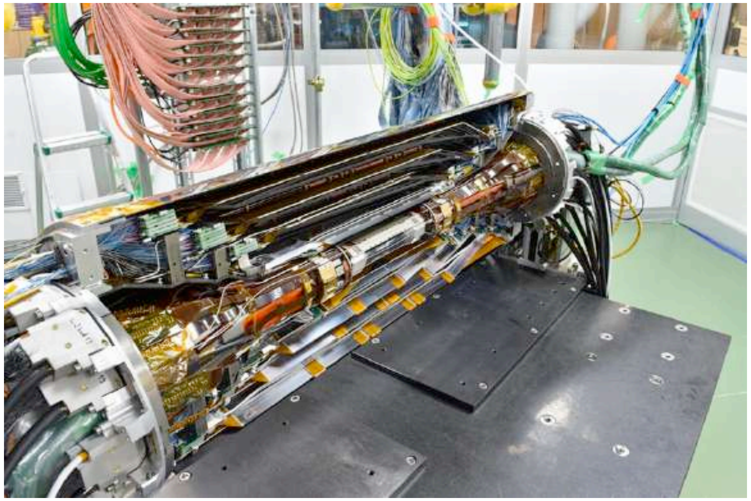
Figure credit: K. Matsuoka

Belle II Integrated Luminosity



Belle II/SuperKEKB Phase 3 (Physics Run) Goals

Early aims: Demonstrate SuperKEKB Physics running with acceptable backgrounds, and all the detector, readout , DAQ and trigger capabilities of Belle II including tracking, electron/muon id, high momentum PID, and especially the *ability to do time-dependent measurements needed for CP violation.*

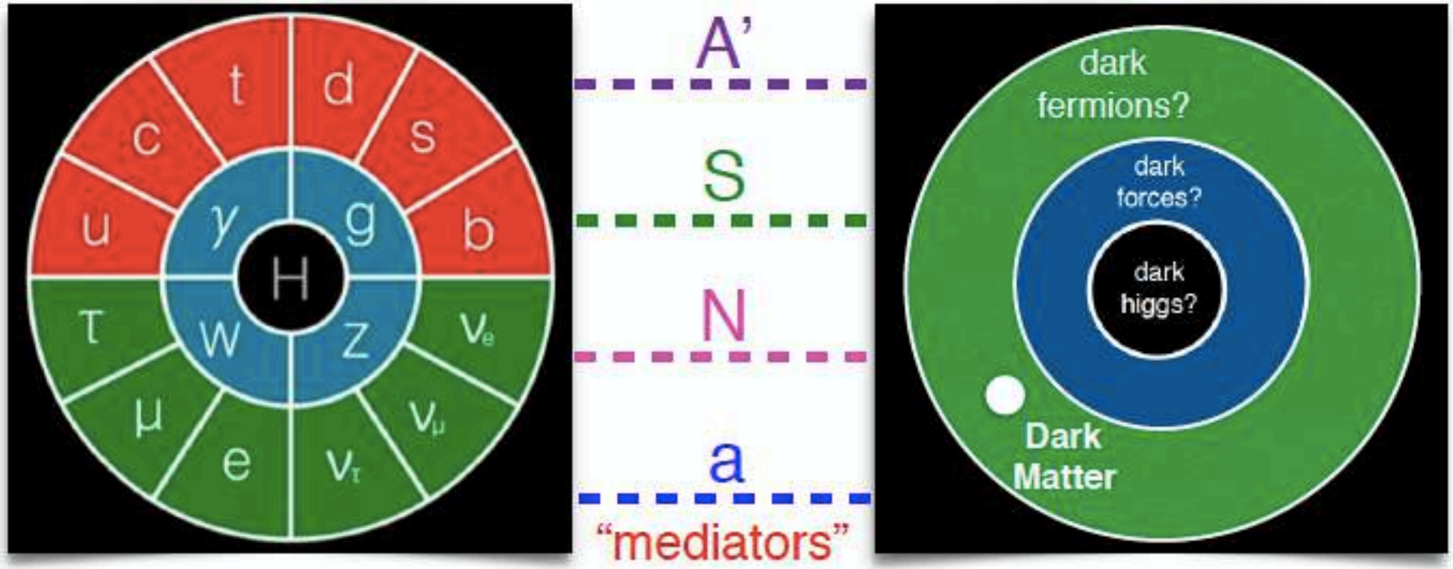


Carry out innovative and world leading dark sector searches/ measurements. Publish first papers on B Physics and D lifetimes.

Long term: *Integrate the world's largest e^+e^- data samples and observe or constrain New Physics in B decays, charm and tau decays.*

From a pre-Snowmass meeting

How to gain access to the dark sector?



Only a few interactions exist that are allowed by Standard Model symmetries:

We will look at several examples of these mediators in early Belle II data including a special Z' and an axion. Prospects for a dark photon will be mentioned.

"mediators"	"portal interactions"
Dark photon	$\epsilon B^{\mu\nu} A'_{\mu\nu}$
Higgs	$\kappa \vert H\vert^2 \vert S\vert^2$
Neutrino	$y H L N$
Axion	$g_{a\gamma} a \tilde{F}_{\mu\nu} F^{\mu\nu}$

S.Gori

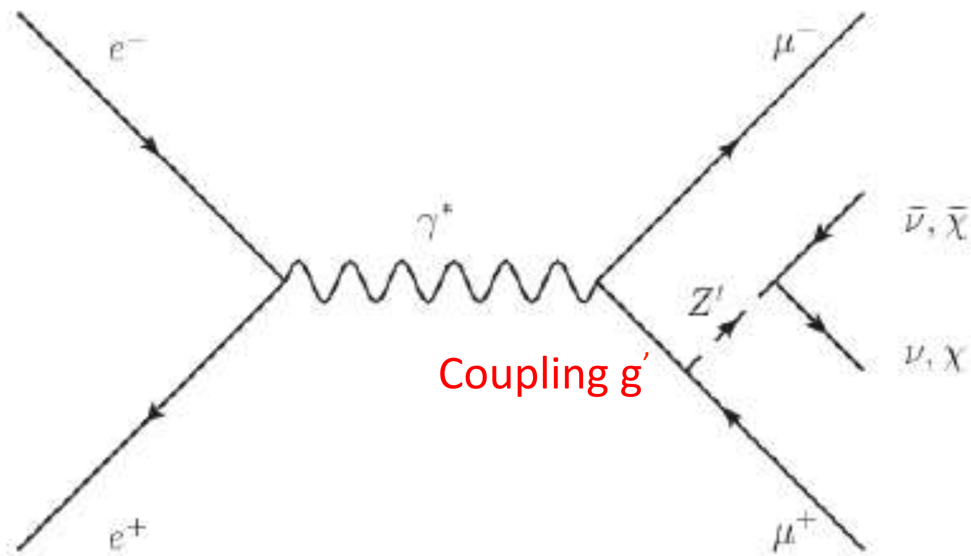
Dark Sector:

Previously limited by Triggering, QED backgrounds and theoretical imagination. *Now new possibilities of triggering, more bandwidth*.

There are a variety of possible dark sector portal particles: Vector, Scalar, Pseudo-scalars.

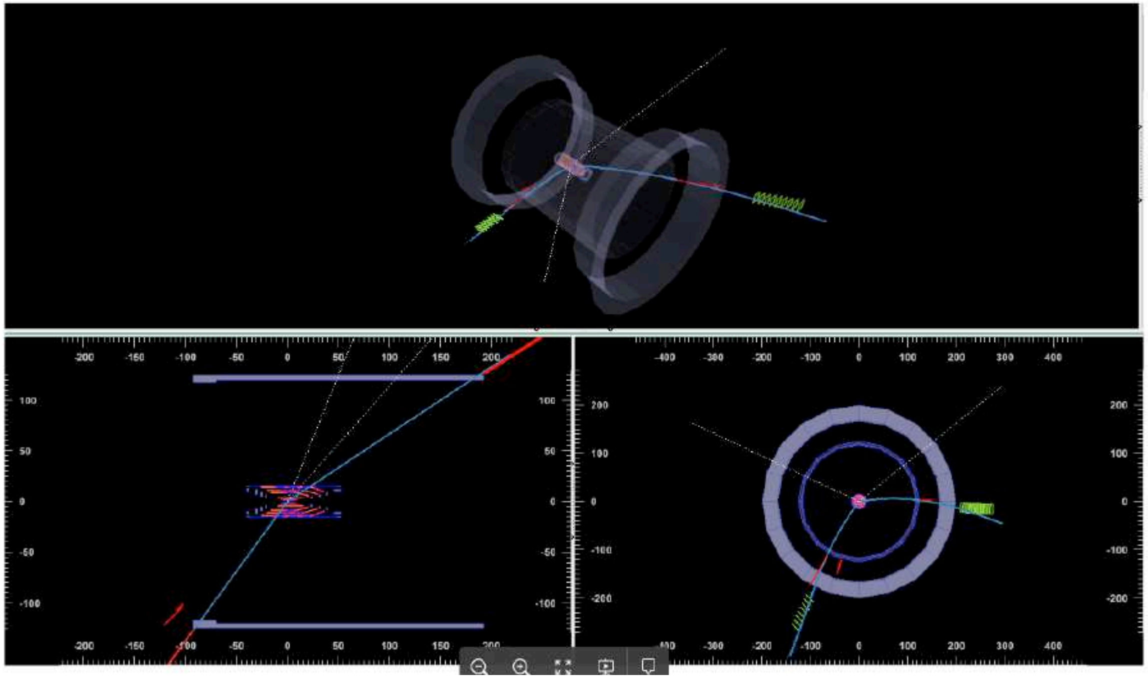
They may decay to lepton pairs, photon pairs, or Invisible particles

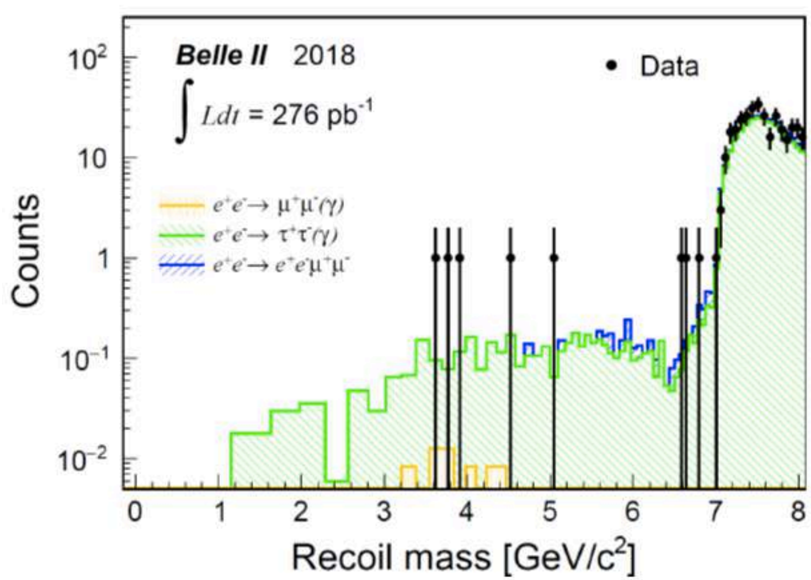
Belle II First Physics. A novel result on the dark sector (Z' →nothing) recoiling against di-muons *or* an electron-muon pair. *Both possibilities are poorly constrained at low Z' mass and in the first case, could explain the muon g-2 anomaly.*



Also examine a *lepton flavor violating* NP signature in the dark sector

Monte Carlo simulation of a Z' →invisible event

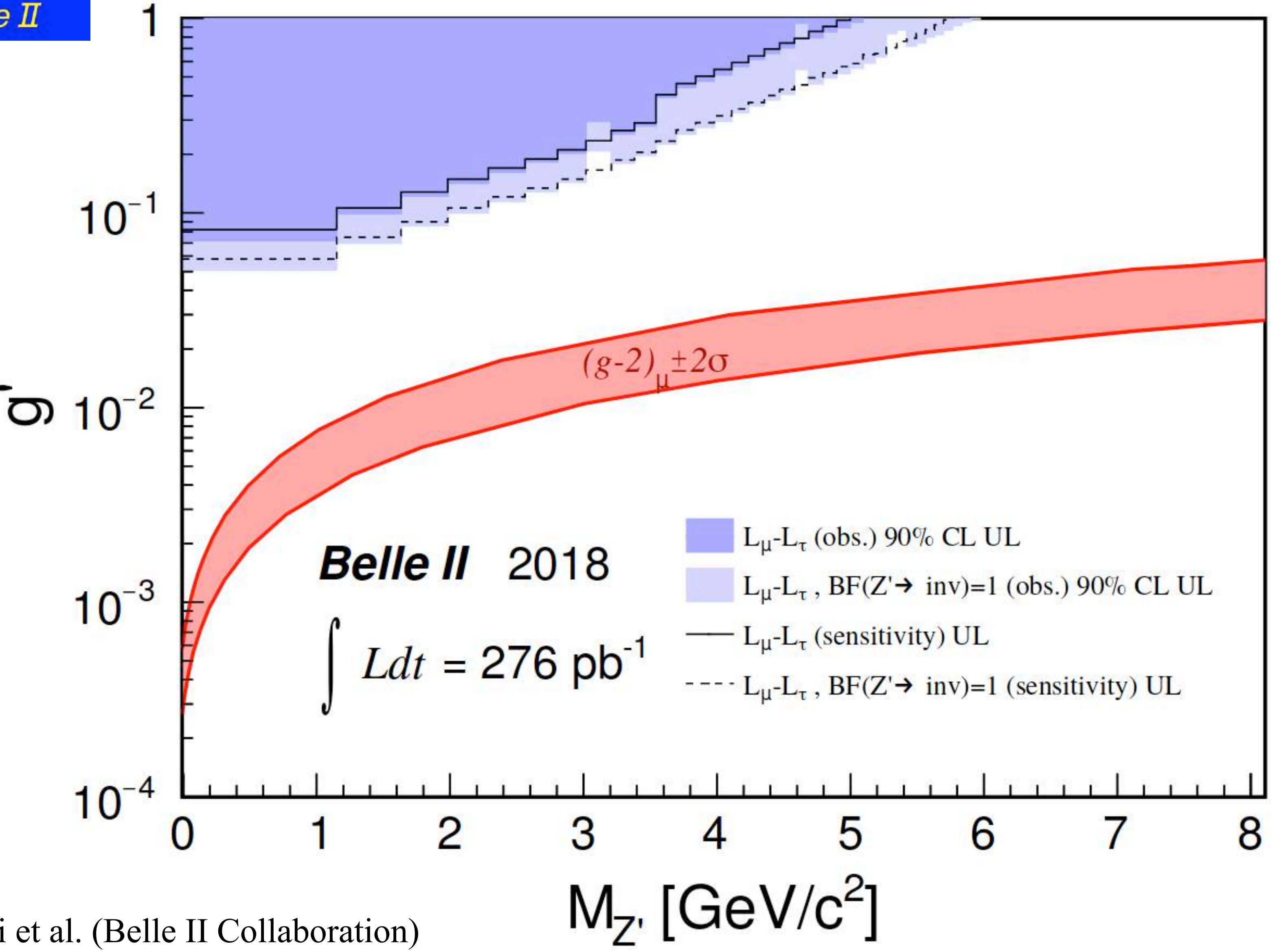




However, in data we do not find any excess in recoil mass.

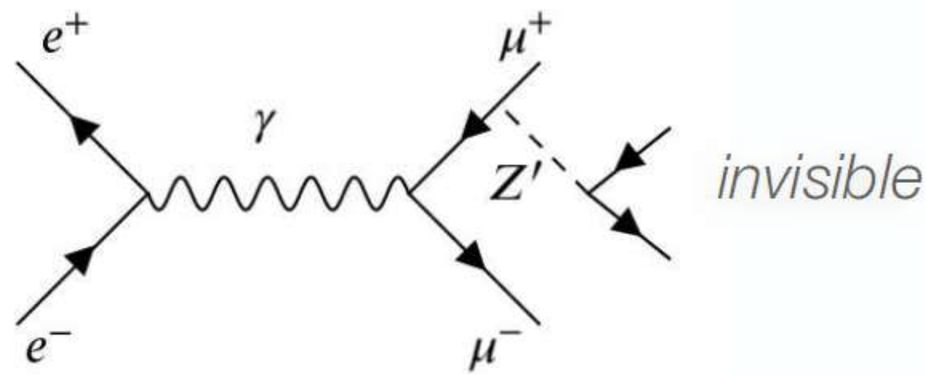
Bkg dominated by $e^+e^- \rightarrow \tau+ \tau- \gamma$

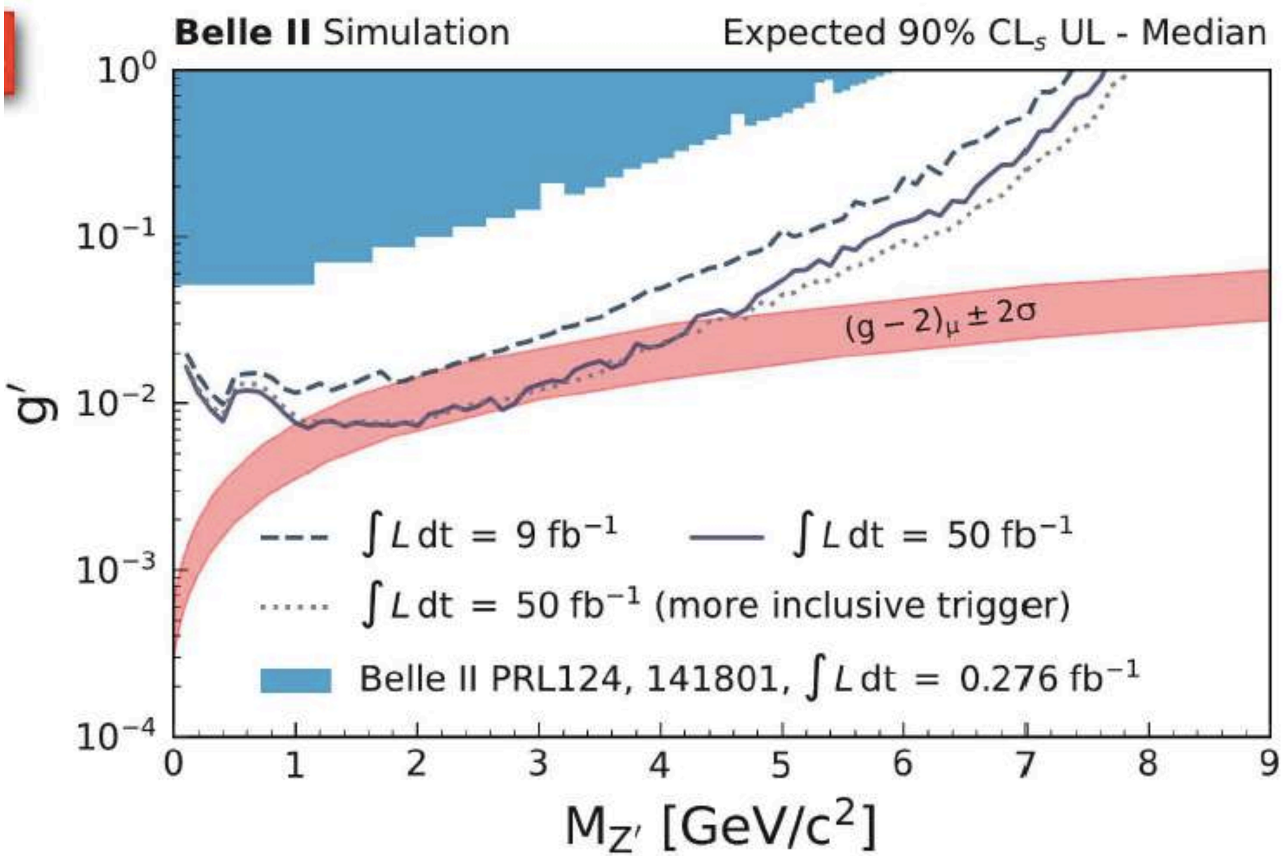
With 278 pb^{-1} from the Phase 2 "pilot run"



I. Adachi et al. (Belle II Collaboration)
Phys. Rev. Lett. 124, 141801 – PRL Editor's Choice

Near term prospects for Z' →invisible

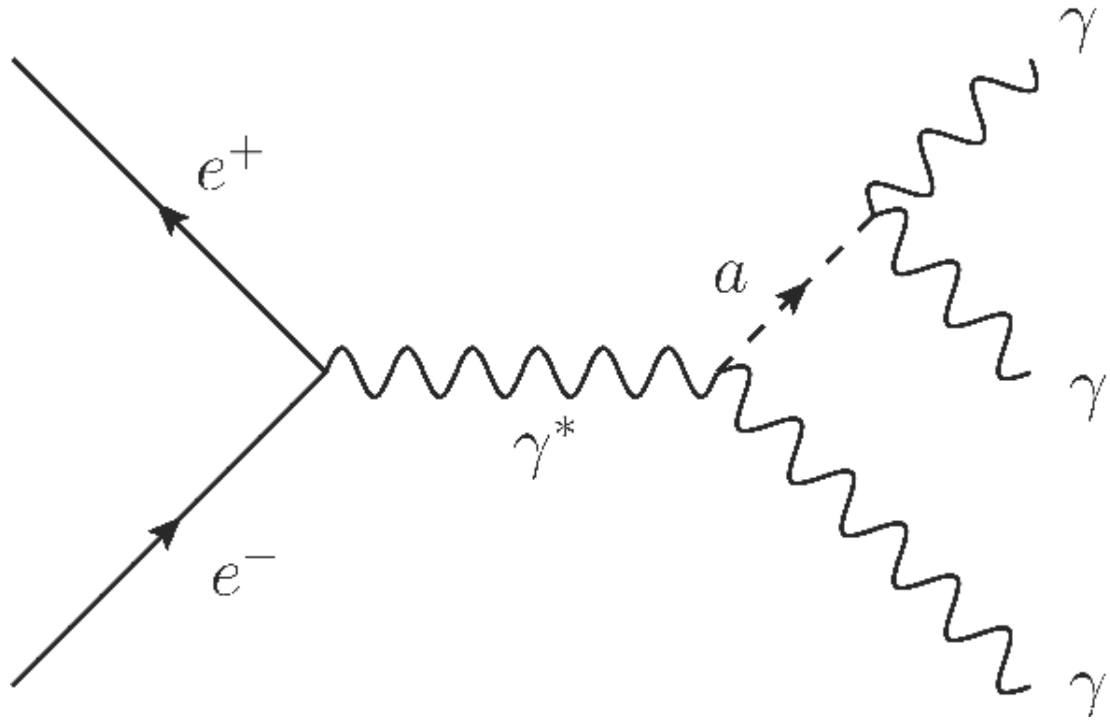




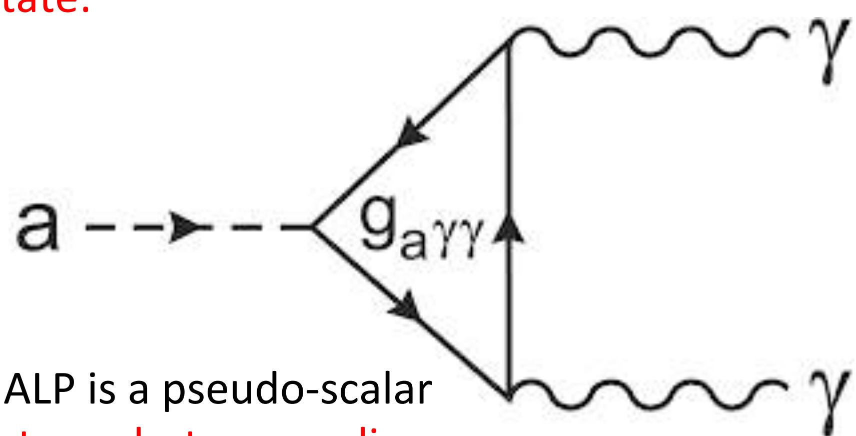
Uses Phase 3 data on tape. Adding in KLM triggers may allow us to “break through” the g-2 band.

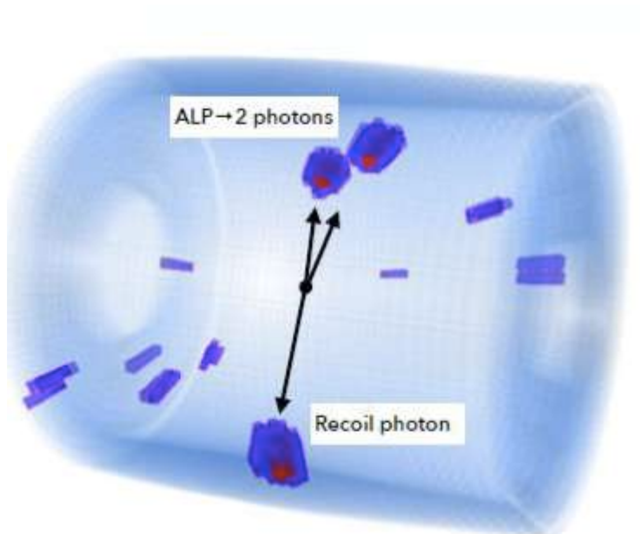
Search for ALPs (Axion Like Particles) at Belle II

An extra term was introduced in the QCD Lagrangian by Peccei, Quinn to solve the strong CP problem in 1977. Wilczek introduced a particle interpretation called the Axion. Expected to be very light (microeV or millieV).



Examine the three photon final state:





The ALP is a pseudo-scalar with two-photon coupling

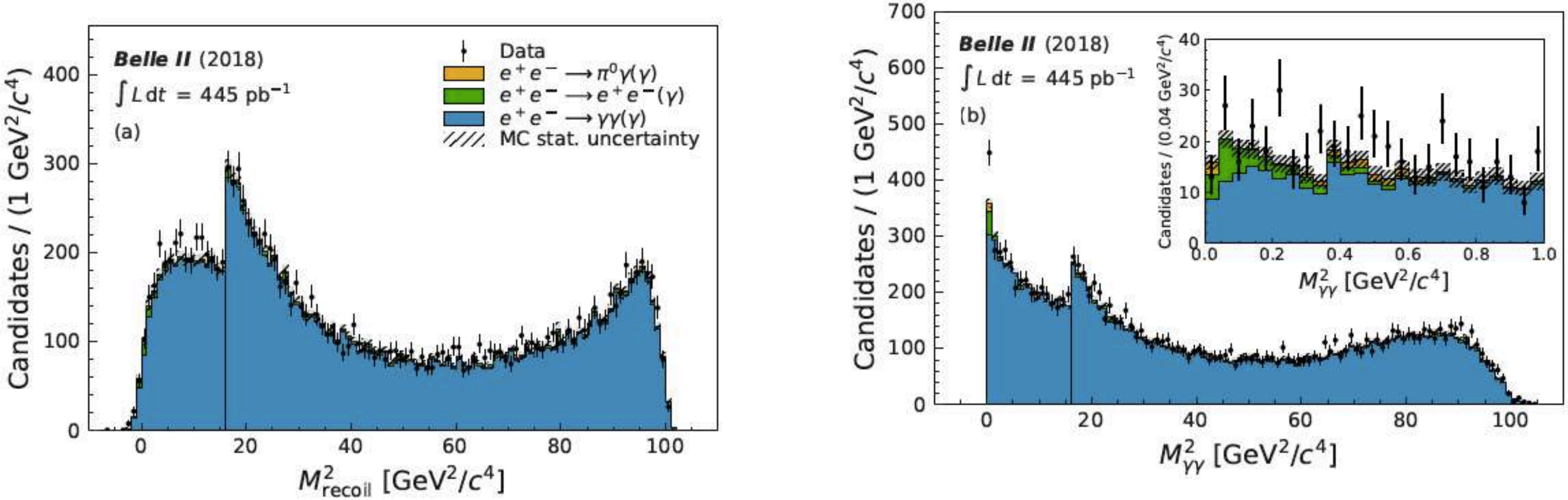


FIG. 1. $M^2_{\rm recoil}$ distribution (a) and $M^2_{\gamma\gamma}$ distribution (b) together with the stacked contributions from the different simulated SM background samples. For $M^2 \leq 16\ {\rm GeV}^2/c^4$, the selection is $E_\gamma > 1.0$ GeV; for $M^2 > 16\ {\rm GeV}^2/c^4$, it is $E_\gamma > 0.65$ GeV. Simulation is normalized to luminosity. The inset in (b) shows a zoom of the low-mass region $M^2_{\gamma\gamma} < 1\,{\rm GeV}^2/c^4$.

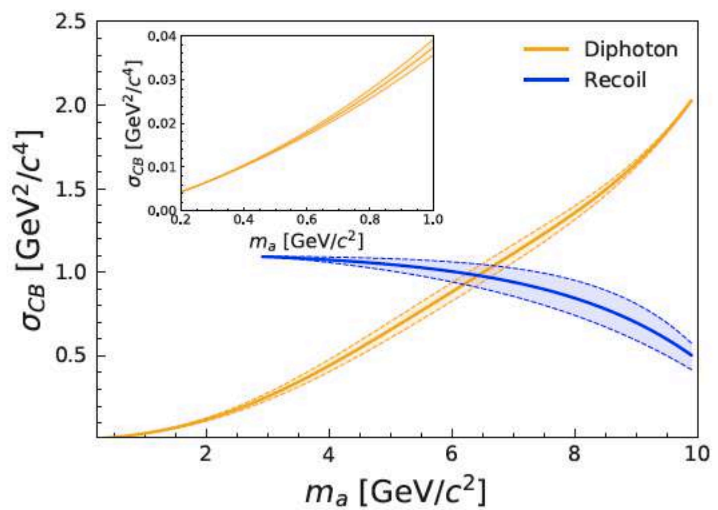
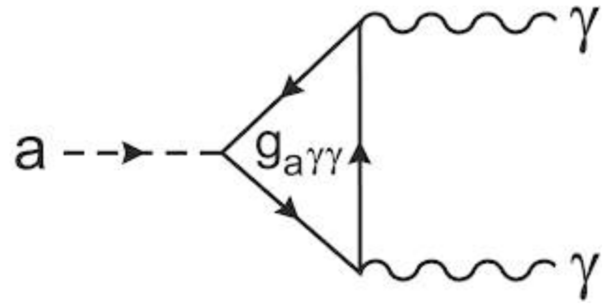


FIG. 2. $M^2_{\gamma\gamma}$ and $M^2_{\rm recoil}$ resolutions with uncertainty as a function of ALP mass m_a. The inset shows a zoom of the low-mass region $m_a < 1\,{\rm GeV}/c^2$.

$$e^+e^- \to \gamma a \to \gamma(\gamma\gamma)$$

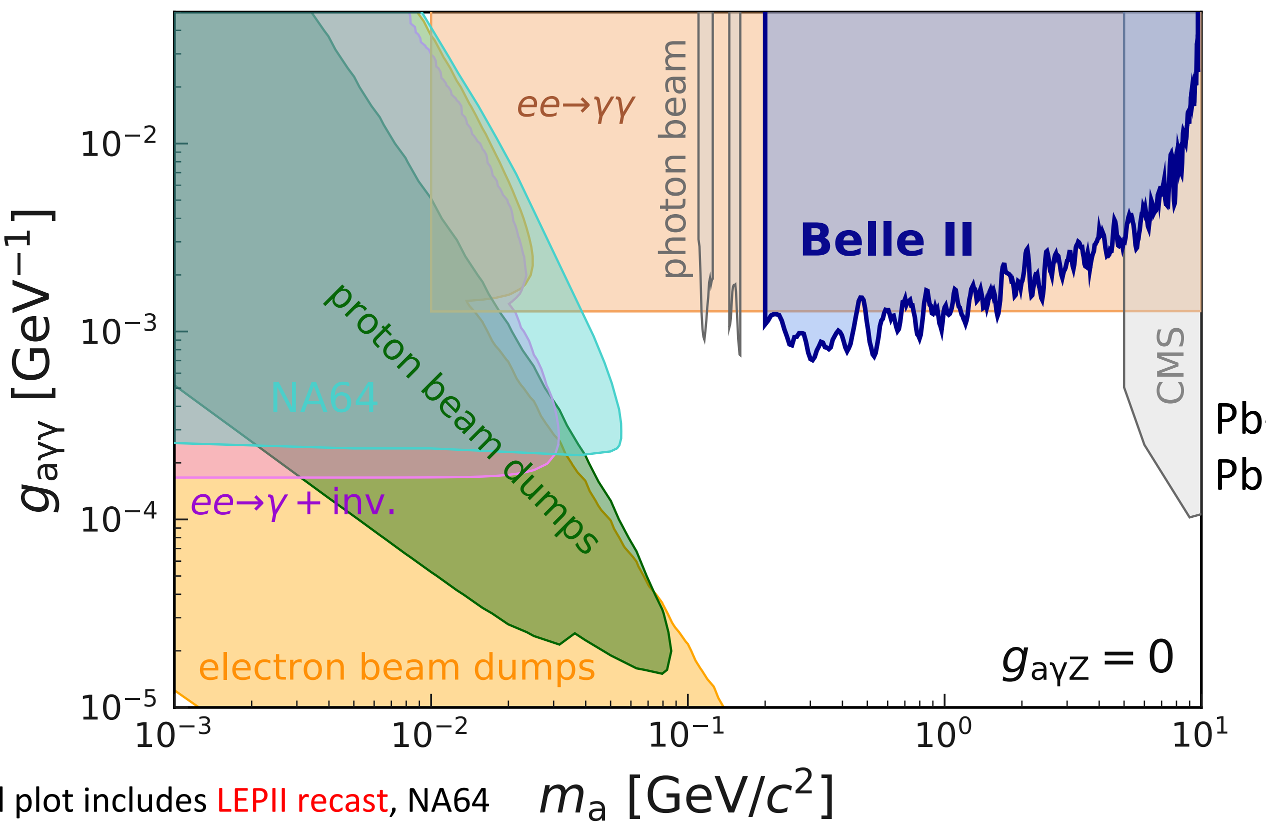
We fit M(γγ)^2 in bins at low mass and M(recoil)^2 at high mass. No significant excess is found.

The Belle II mass range is *200 MeV to 9.7 GeV*, *far above* the keV mass range suggested by the Xenon1T excess. https://arxiv.org/abs/2006.09721



F. Abudinén *et al.* (Belle II Collaboration)
Phys. Rev. Lett. 125, 161806 (2020)

Final ALPS results with 445 pb^{-1} of pilot run (Phase 2) data

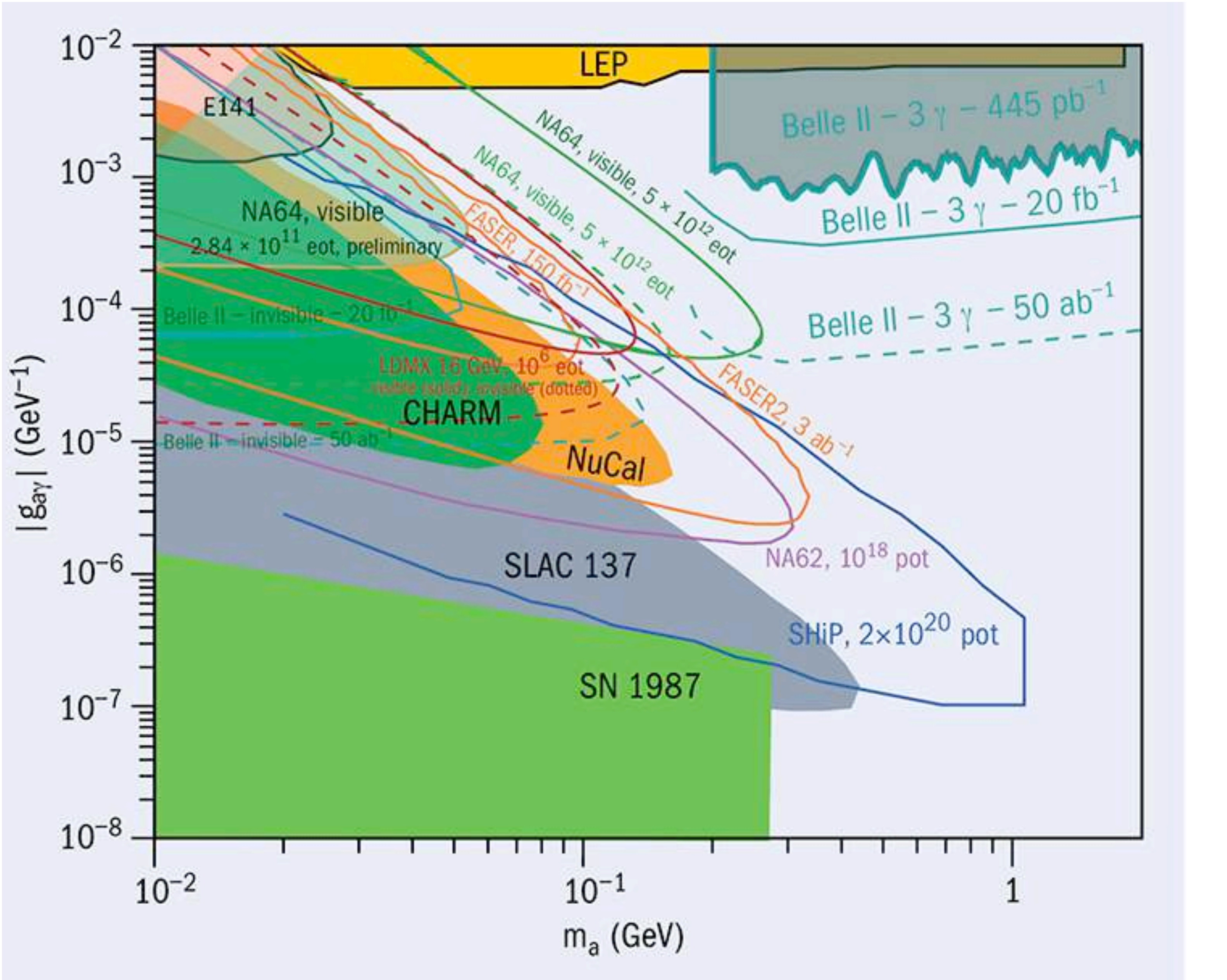


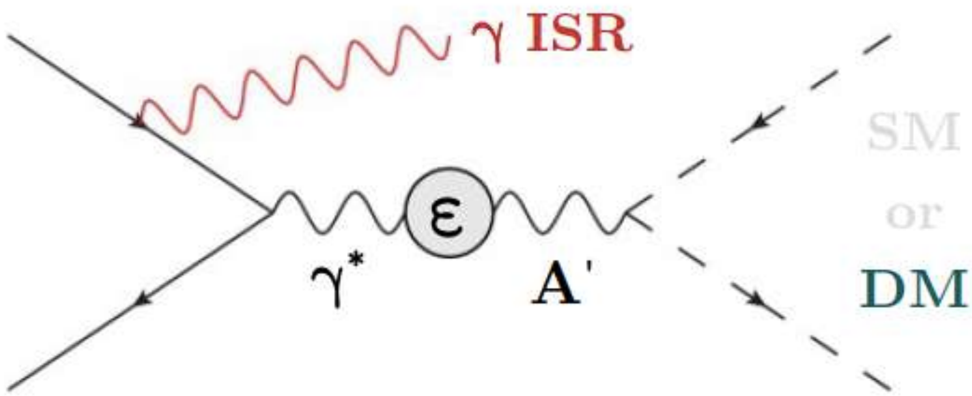
Revised plot includes LEPII recast, NA64

Plan to update with two orders of magnitude more data→one order of magnitude improvement in g

Future Prospects for ALPS

Figure credit: CERN Courier



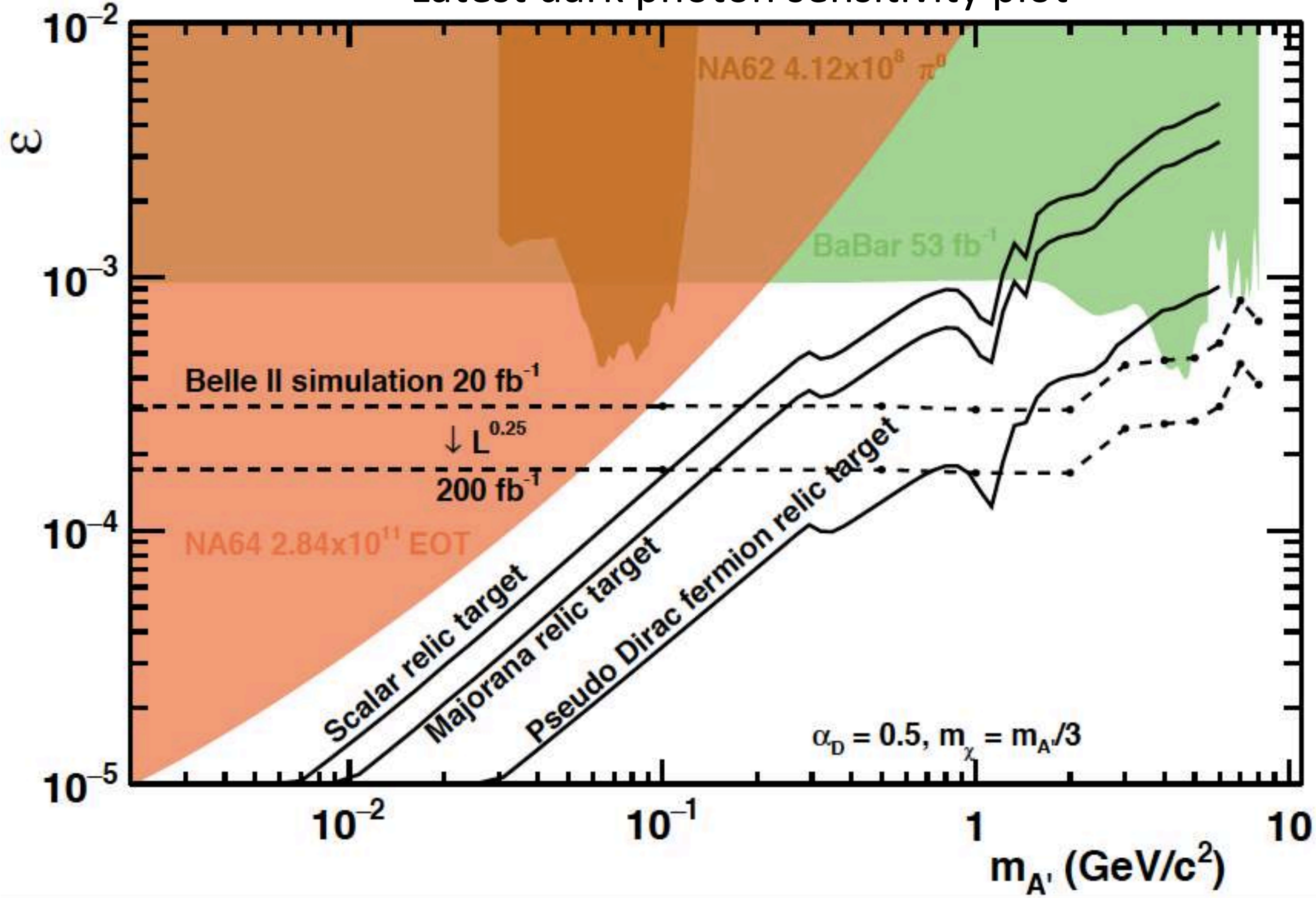


Sensitivity for the "dark photon" with the signature: $e^+e^- \rightarrow \gamma$ + nothing

- a bump in the recoil mass:

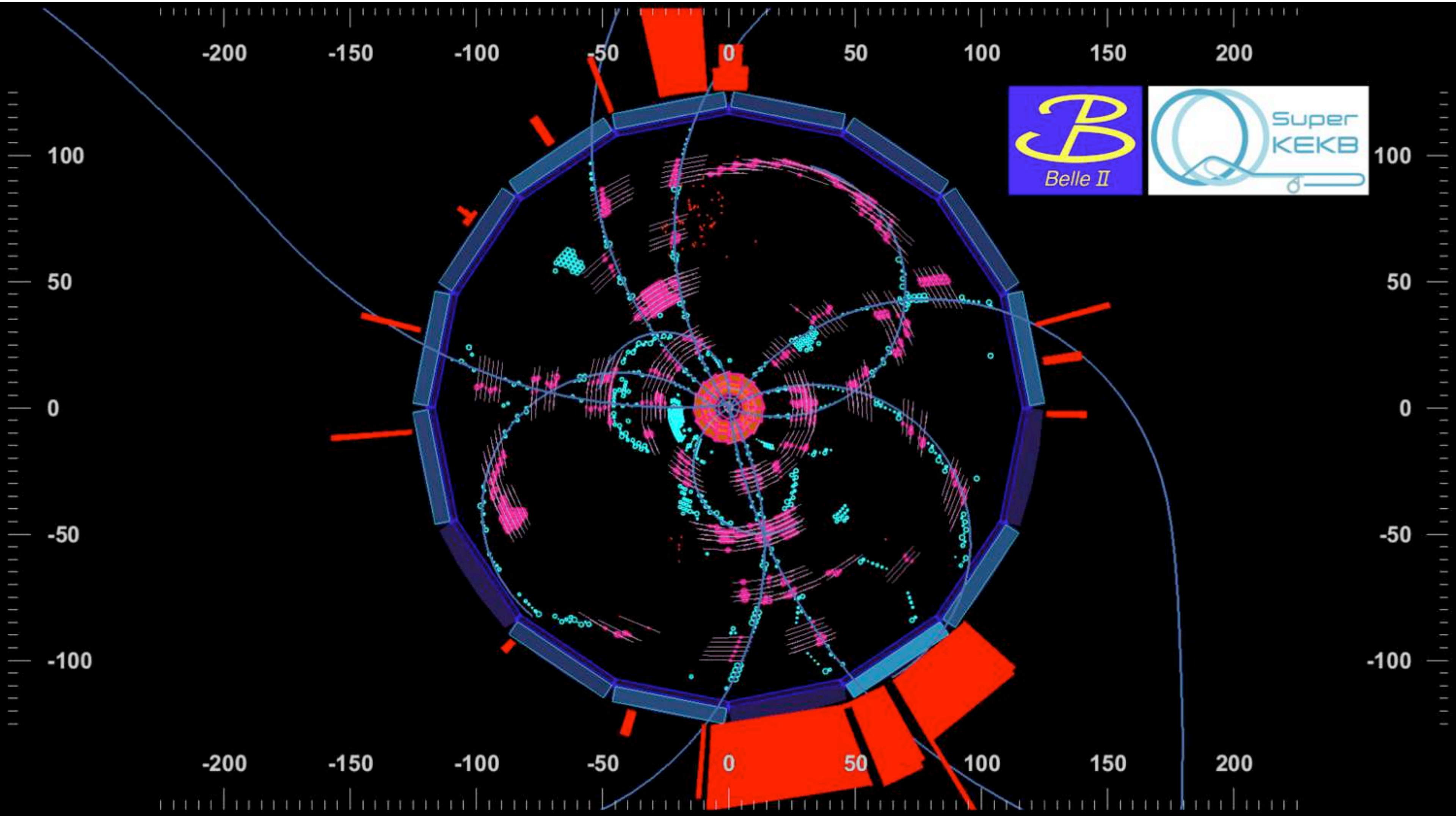
$$E_\gamma = \frac{s - m^2_{A'}}{2\sqrt{s}}$$

Latest dark photon sensitivity plot



This is the most difficult dark sector signature (in progress).

Flavor Results from the Physics Run (“Phase 3”)



Time Dependent Measurements at Belle II

Belle II VXD installed on Nov 21, 2018. (PXD L1 and two ladders of L2. and the SVD (4 layers))

The B-anti B meson pairs at the Upsilon(4S) are produced in a coherent, *entangled* **quantum mechanical state**.

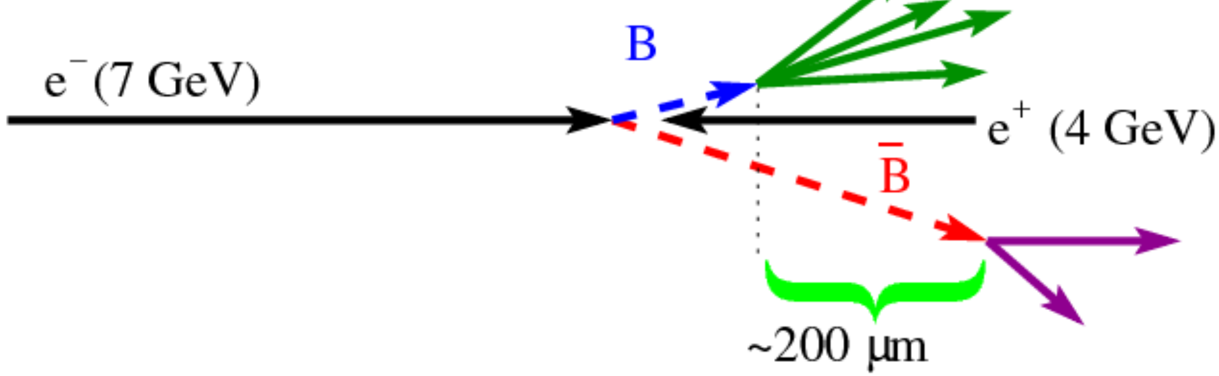
(Note the minus sign)

$$|\Psi>=|B^0(t_1,f_1)\overline{B^0}(t_2,f_2)> - |B^0(t_2,f_2)\overline{B^0}(t_1,f_1)>$$

Need to measure decay times to observe CP violation (particle-antiparticle asymmetry).

One B decays →collapses the flavor wavefunction of the other anti-B. (N.B. One B must decay before the other can mix)

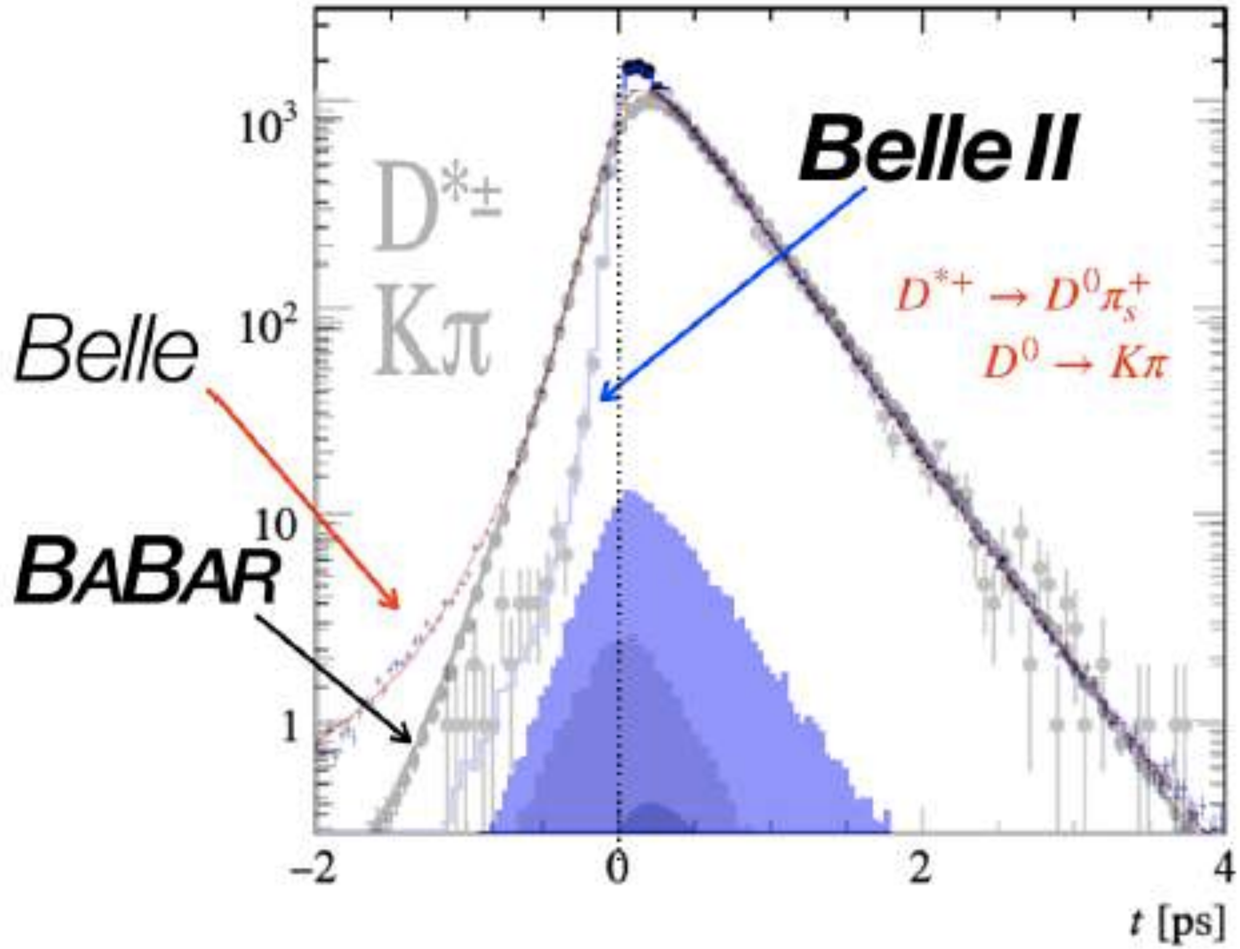
Asymmetric Collider



Not to scale

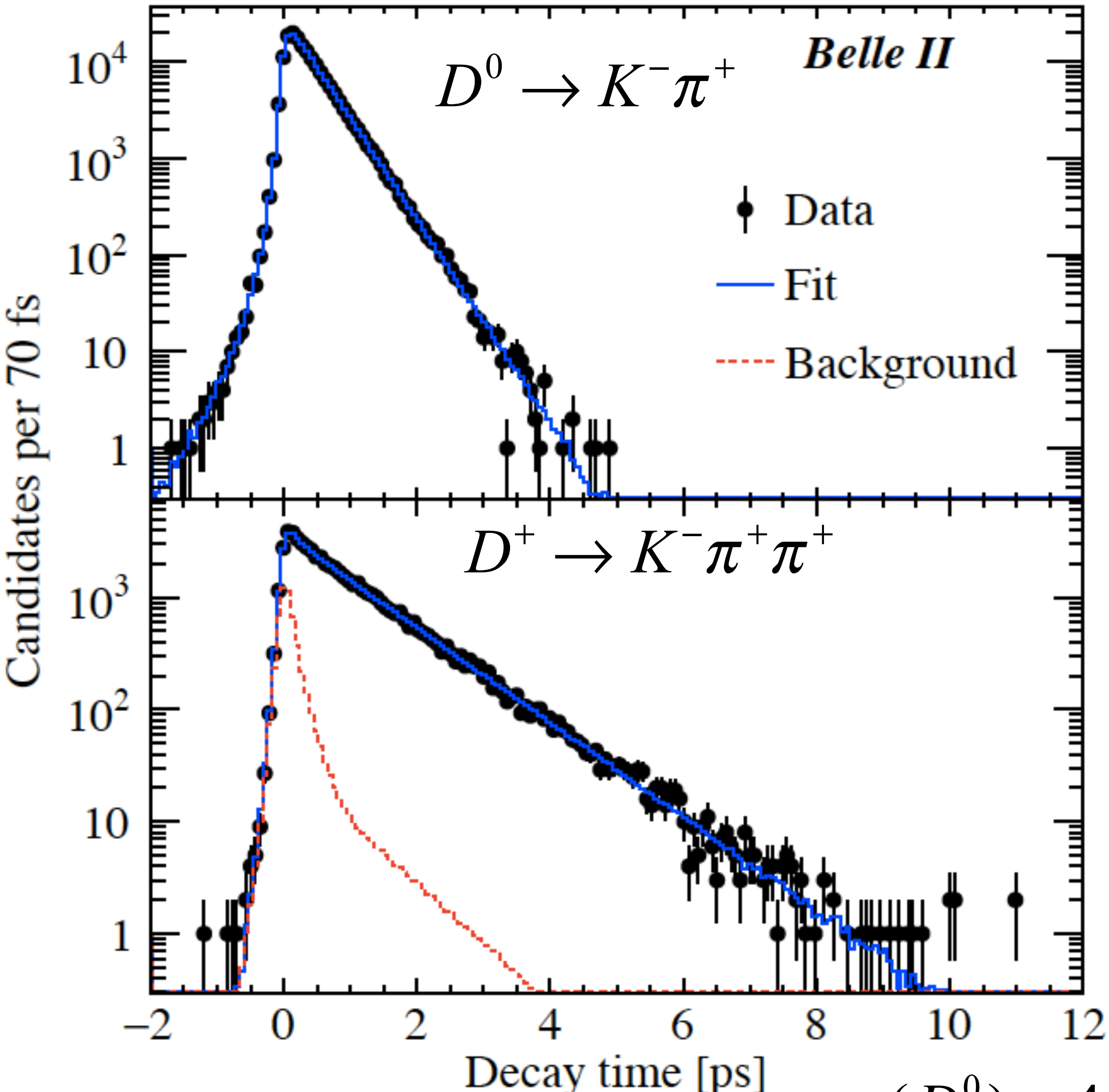
The beam energies are asymmetric (7 on 4 GeV)

The decay distance is increased by around a factor ~7



The addition of the pixel detector and moving the beampipe to r= 1cm gives a factor of two improvement in vertex/time resolution.

Check time-dependent capabilities: Precise D lifetime results.



Uses Belle II $e^+e^- \rightarrow c\ \bar{c}$ data (no B's !)

Note semi-log vertical scale.

Time resolution parameterization can be determined from data.

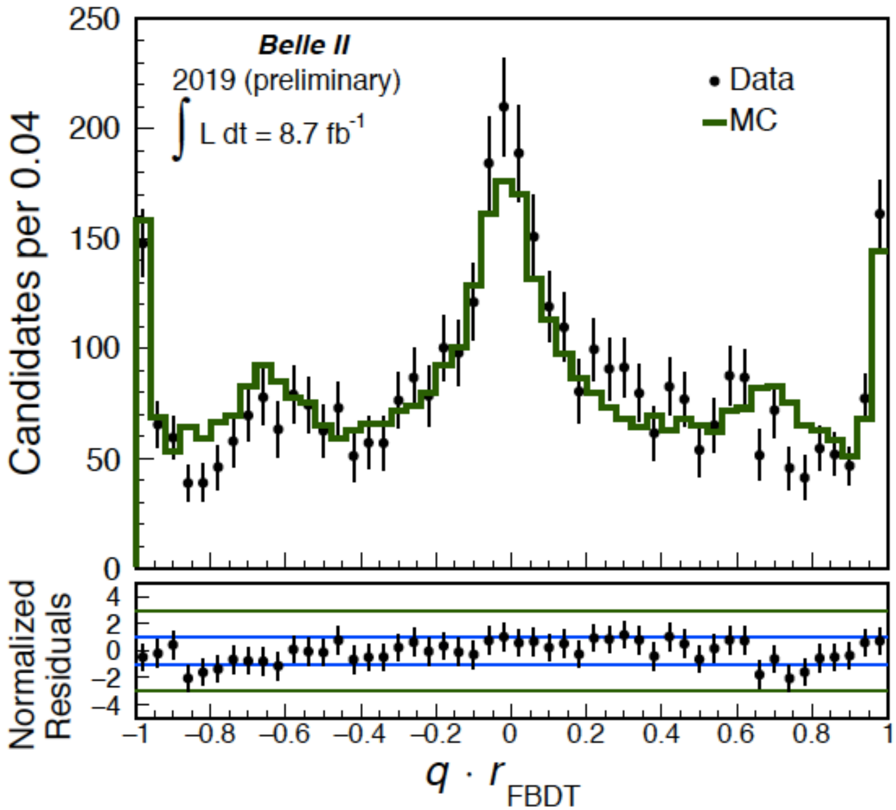
Alignment systematics have been carefully studied.

1 fs = 1 x 10^{-15} second

$$\tau(D^0) = 410.5 \pm 1.1(stat) \pm 0.8(sys)\ fs$$

$$\tau(D^+) = 1030.4 \pm 4.7(stat) \pm 3.1(sys)\ fs$$

Flavor Tagging (b quark or anti-b quark ?)



Categories	Targets for $\overline{B}^0$
Electron	e^-
Intermediate Electron	e^+
Muon	μ^-
Intermediate Muon	μ^+
Kinetic Lepton	l^-
Intermediate Kinetic Lepton	l^+
Kaon	K^-
Kaon-Pion	K^-, π^+
Slow Pion	π^+
Maximum P*	l^-, π^-
Fast-Slow-Correlated (FSC)	l^-, π^+
Fast Hadron	π^-, K^-
Lambda	Λ

Underlying decay modes

$\overline{B}^0 \to D^{*+}\ \overline{\nu}_\ell\ \ell^-$
$\quad \hookrightarrow D^0\ \pi^+$
$\qquad \hookrightarrow X\ K^-$

$\overline{B}^0 \to D^+\ \pi^-\ (K^-)$
$\quad \hookrightarrow K^0\ \nu_\ell\ \ell^+$

$\overline{B}^0 \to \Lambda_c^+\ X^-$
$\quad \hookrightarrow \Lambda\ \pi^+$
$\qquad \hookrightarrow p\ \pi^-$

$B^0 \to D^{(*)-}h^+$	$\varepsilon_i \pm \delta\varepsilon_i$		$w_i \pm \delta w_i$		$\varepsilon_{\text{eff},i} \pm \delta\varepsilon_{\text{eff},i}$	
r- Interval	Belle II	Belle	Belle II	Belle	Belle II	Belle
0.000 – 0.100	20.3 ± 1.8	22.2 ± 0.4	47.4 ± 4.2	50.0	0.1 ± 0.2	0.0
0.100 – 0.250	17.4 ± 0.9	14.5 ± 0.3	42.8 ± 4.4	41.9 ± 0.4	0.4 ± 0.4	0.4 ± 0.1
0.250 – 0.500	21.2 ± 1.0	17.7 ± 0.4	26.9 ± 3.7	31.9 ± 0.3	4.5 ± 1.5	2.3 ± 0.1
0.500 – 0.625	11.1 ± 0.7	11.5 ± 0.3	16.7 ± 5.5	22.3 ± 0.4	4.9 ± 1.7	3.5 ± 0.1
0.625 – 0.750	9.6 ± 0.9	10.2 ± 0.3	9.2 ± 6.5	16.3 ± 0.4	6.4 ± 2.1	4.6 ± 0.2
0.750 – 0.875	7.0 ± 0.6	8.7 ± 0.3	1.2 ± 5.7	10.4 ± 0.4	4.0 ± 1.2	5.5 ± 0.1
0.875 – 1.000	13.4 ± 0.8	15.3 ± 0.3	0.0 ± 3.3	2.5 ± 0.3	13.4 ± 1.9	13.8 ± 0.3
Total	$\varepsilon_{\text{eff}} = \sum_i \varepsilon_i \cdot (1-2w_i)^2 =$				33.8 ± 3.9	30.1 ± 0.4

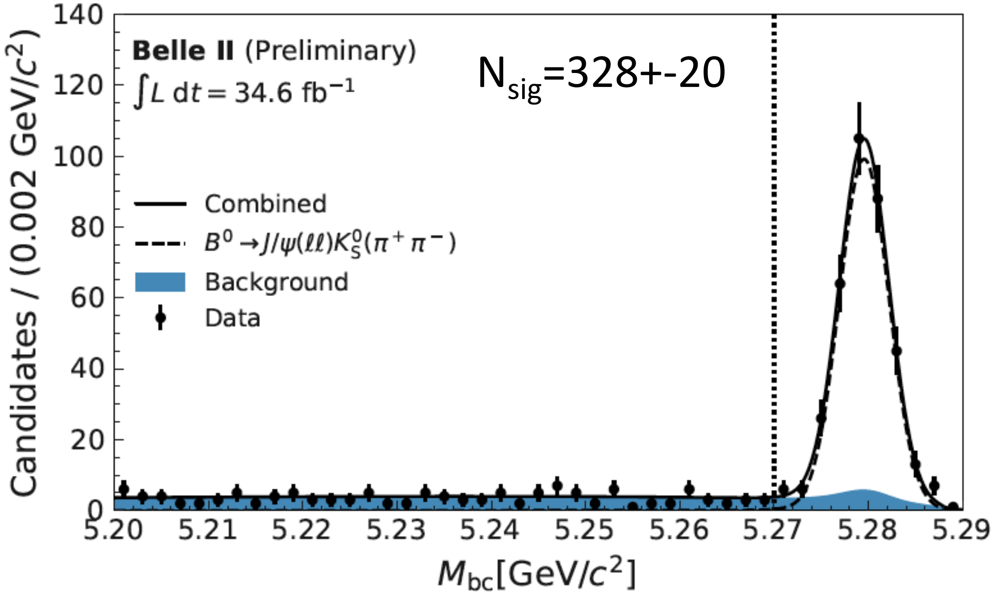
An update is coming soon with higher statistics.

We obtain epsilon_eff = epsilon(1-2 w)^2 = 33.8+-3.9 %, which is a slight improvement over the Belle result of 30.1+-0.4%

BELLE2-CONF-2020-018

https://arxiv.org/abs/2008.02707

Observation of B→J/ψ K_S and the road to CPV



A "Golden" CP Eigenstate

About 15% of the Phase 3 data sample.

Now apply a *simplified analysis:*

1) Only one CP eigenstate
2) No beam spot constraint
3) Flavor tagging does not separate r-bins

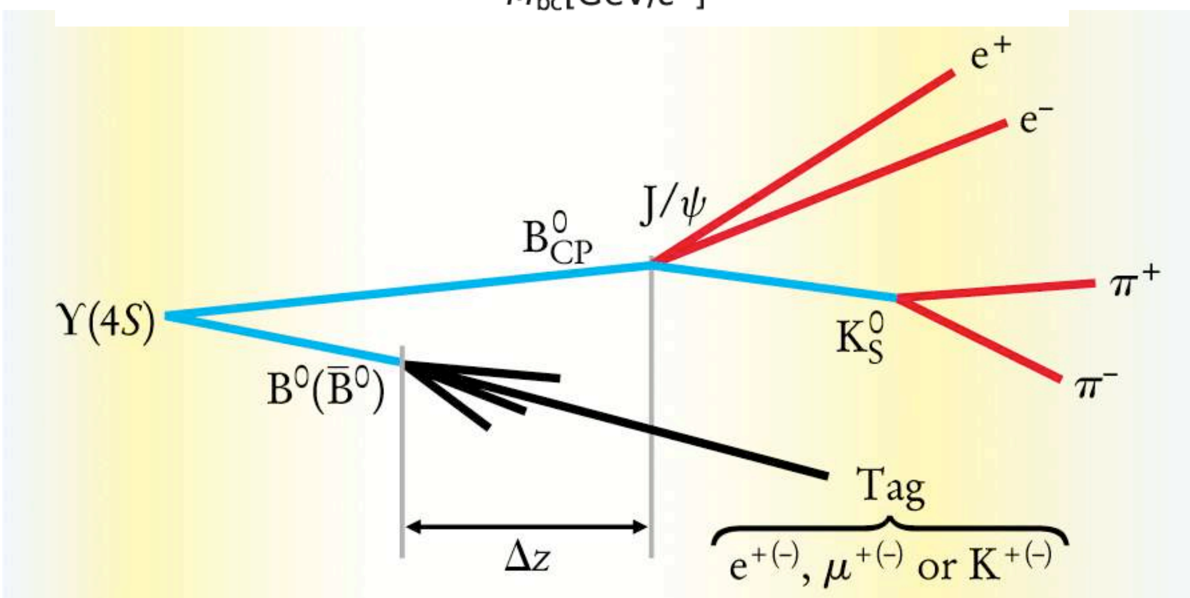


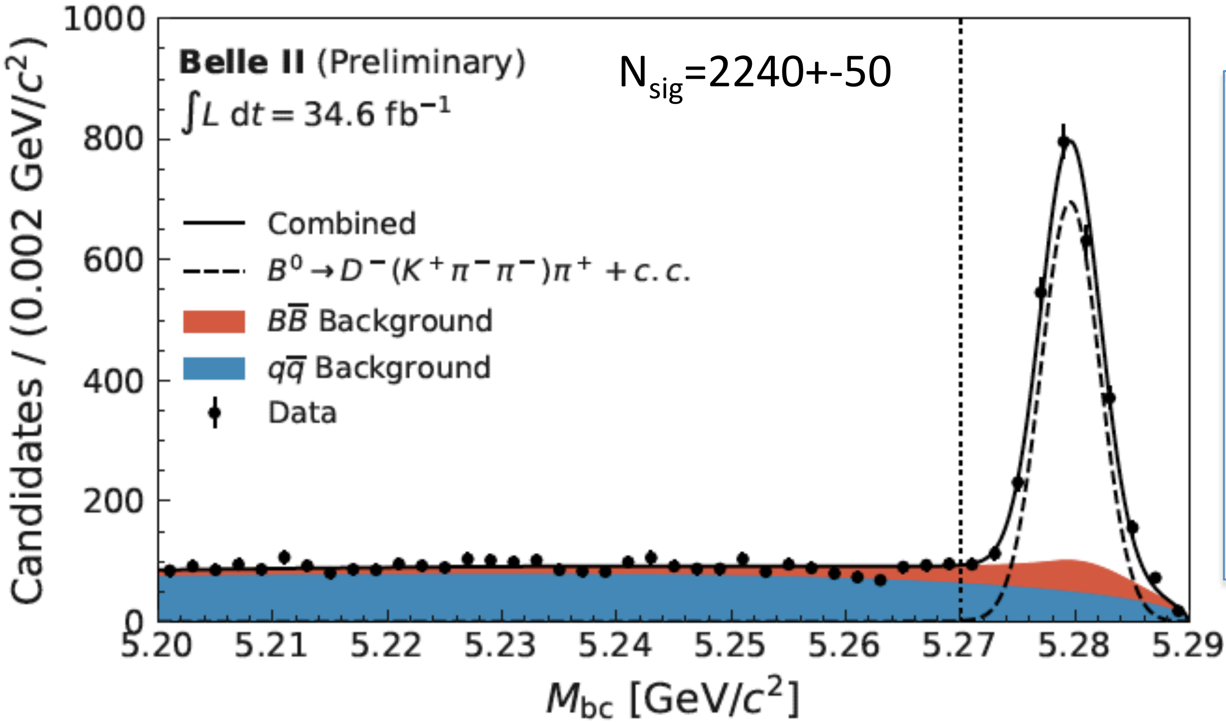
Figure credit: Physics Today

$$\Delta t \approx \frac{\Delta z}{\beta\gamma}$$

$$B^0 \to f\ ;\ B^0 \to \overline{B^0} \to f$$

This is a flavor-specific B decay mode with a charged track topology similar to the $B \rightarrow J/\psi\ K_S$ signal.

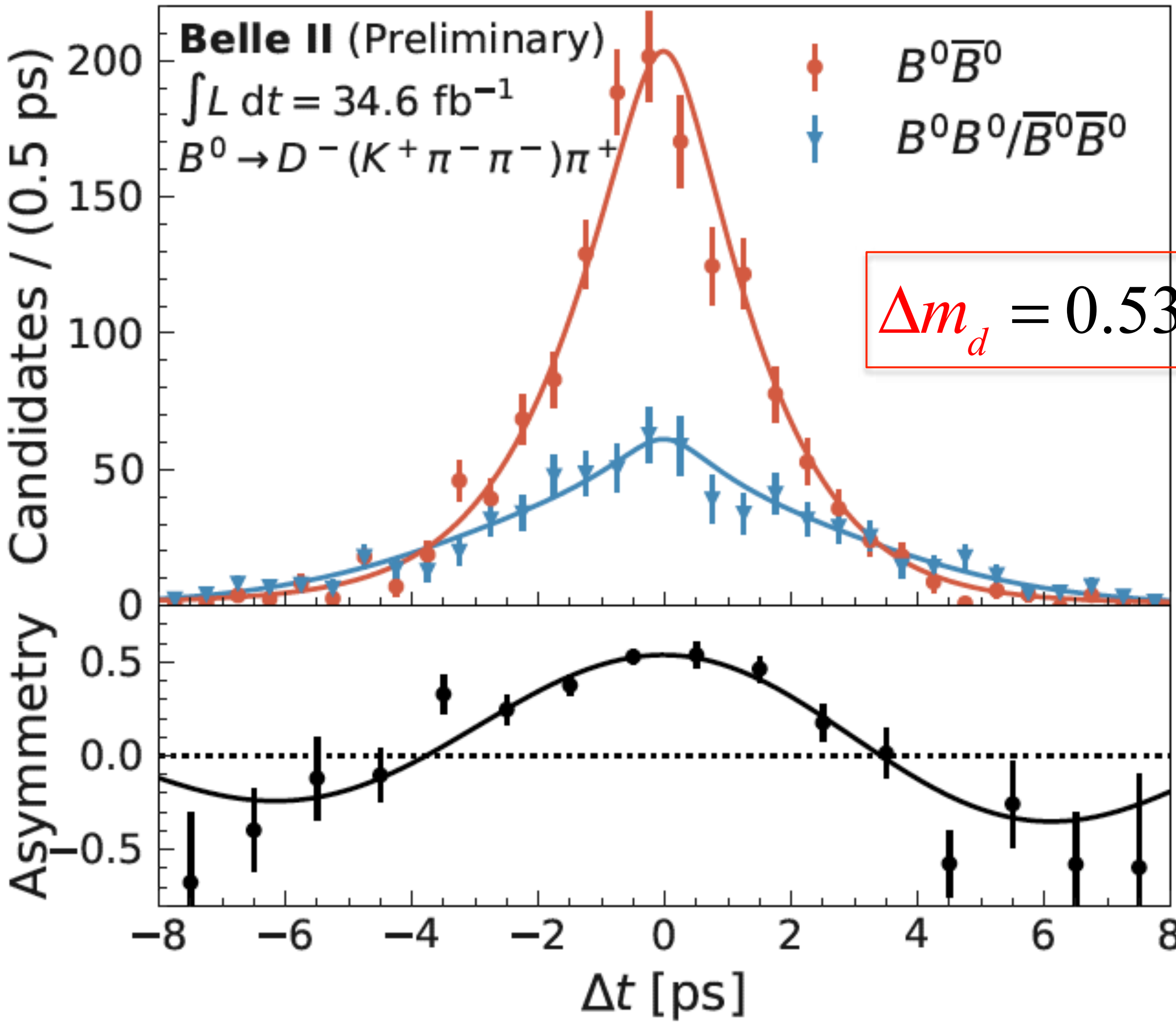
$B^0 \rightarrow D^- \pi^+$ is not self-conjugate and is not a CP eigenstate (but can be used to check time-dependence of B-Bbar mixing).



Start with a B^0 (wait a while, ~a few x 10^{-12} sec).

There is a large probability that the B^0 will turn into its anti-particle, an anti-B^0 (discovered by ARGUS at DESY in 1987)

Time Dependent Mixing asymmetry (not CPV)



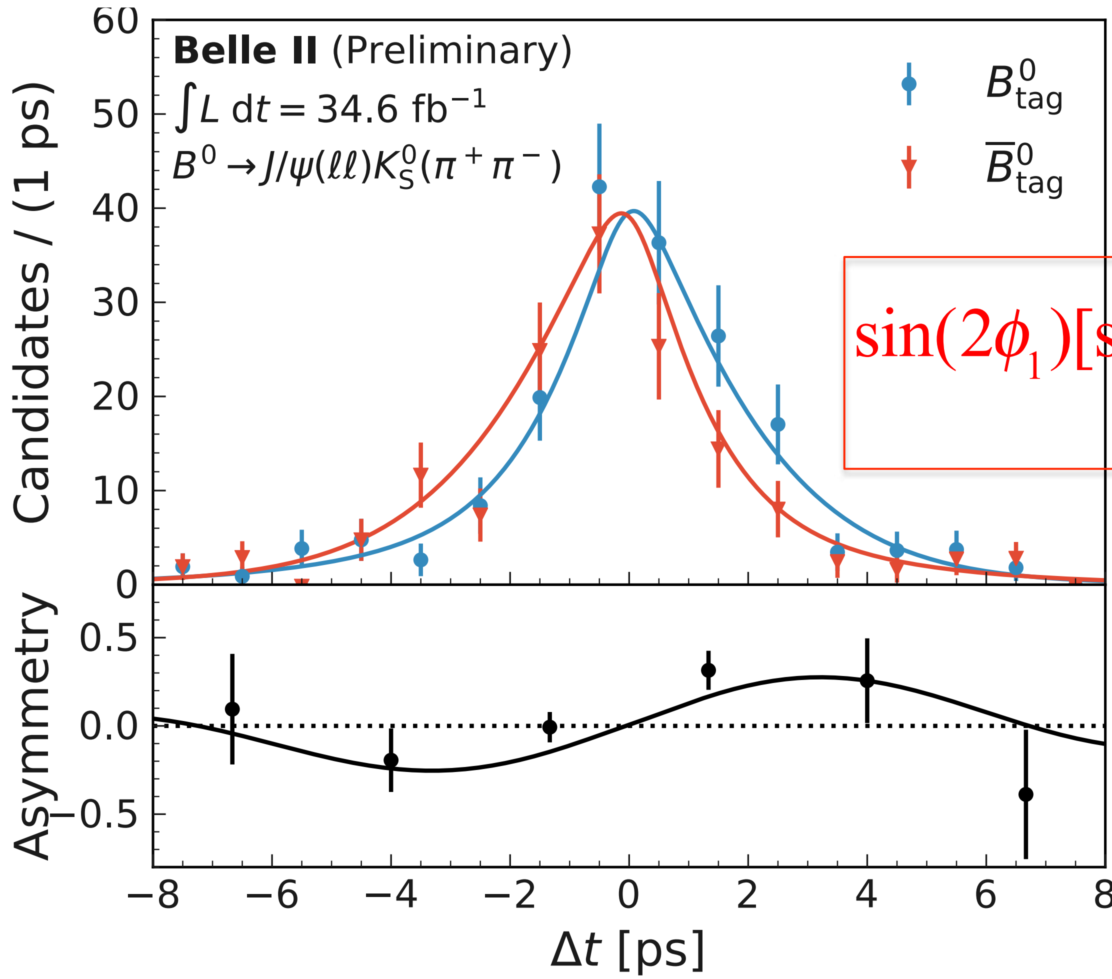
$$\Delta m_d = 0.531 \pm 0.046 \pm 0.013\, ps^{-1}$$

(WA=0.5065 ±0.019 ps^{-1})

$$Asym(mixing) = \frac{OF - SF}{OF + SF}$$

$$N_{SF/OF} \sim \frac{\exp(-|\Delta t|/\tau)}{4\tau}[1 \pm (1-2w)\cos(\Delta m_d \Delta t)] \otimes R(\Delta t)$$

Hint of time-dependent CPV from Belle II (2.7σ significance)



Will update and publish with the current data set.

$$\sin(2\phi_1)[\sin(2\beta)] = 0.55 \pm 0.21 \pm 0.04$$

(WA=0.685±0.019)

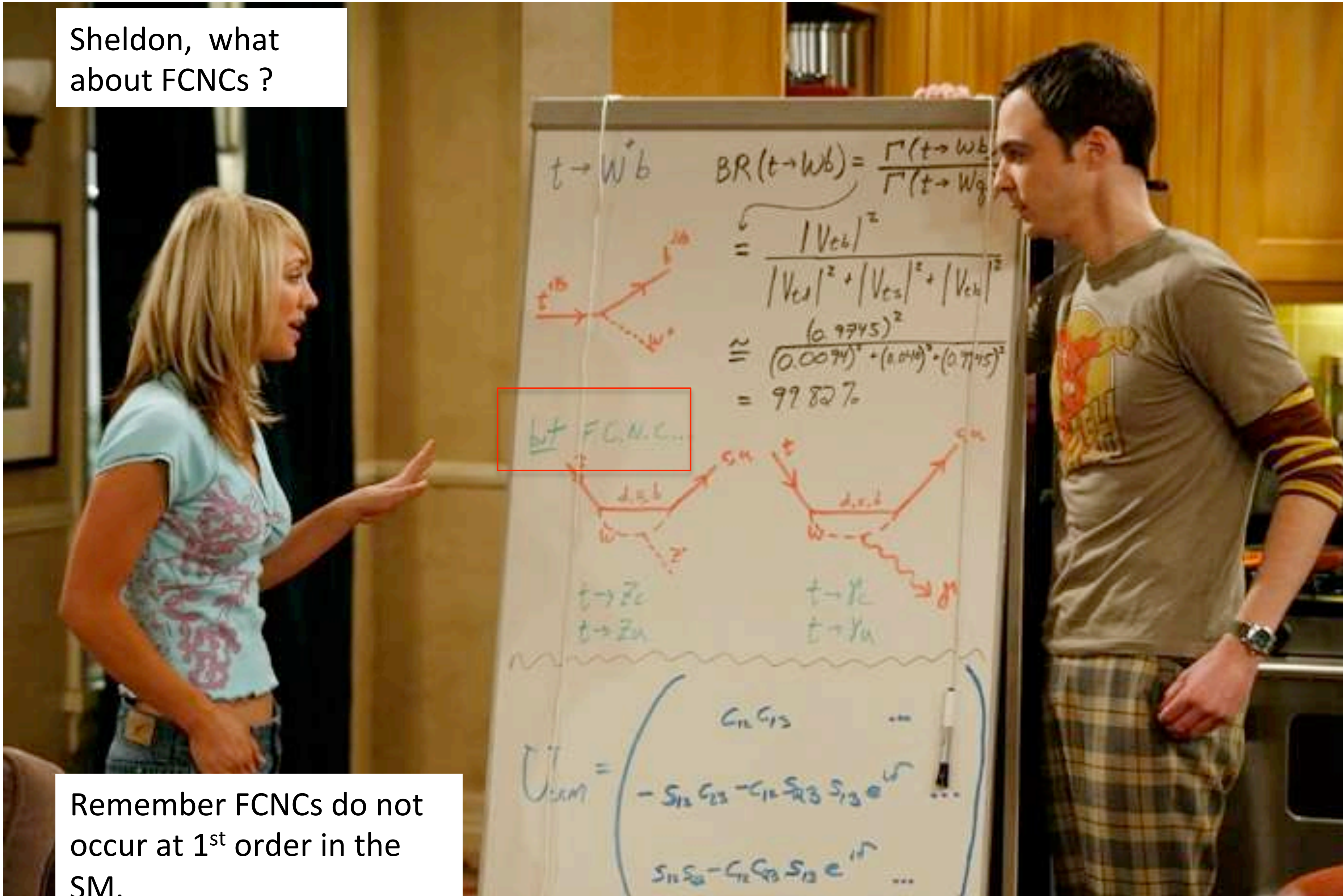
Based on the interference of

$$B^0 \to f_{CP} \; ; B^0 \to \overline{B^0} \to f_{CP}$$

$$N_{+/-} \sim \frac{\exp(-|\Delta t|/\tau)}{4\tau}\left\{1 \pm (1-2w)\sin(2\phi_1)\sin(\Delta m_d \Delta t)\right\} \otimes R(\Delta t)$$

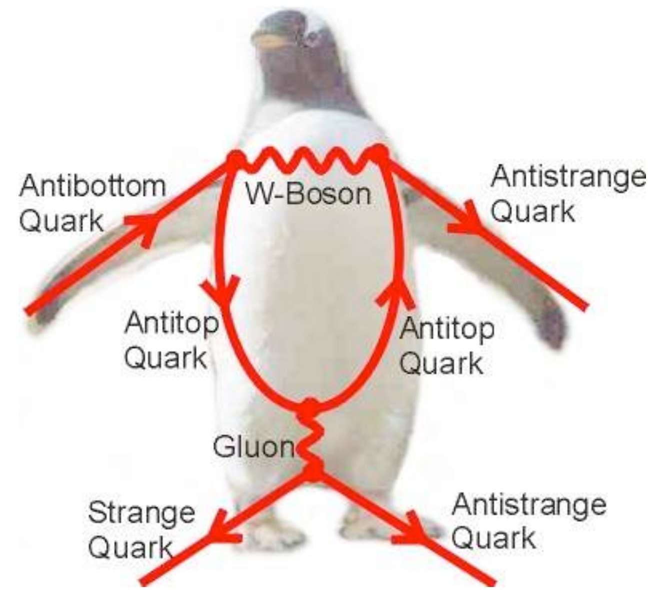
US TV Show, Big Bang Theory (Flavor Changing Neutral Currents)

Sheldon, what about FCNCs ?



Remember FCNCs do not occur at 1st order in the SM.

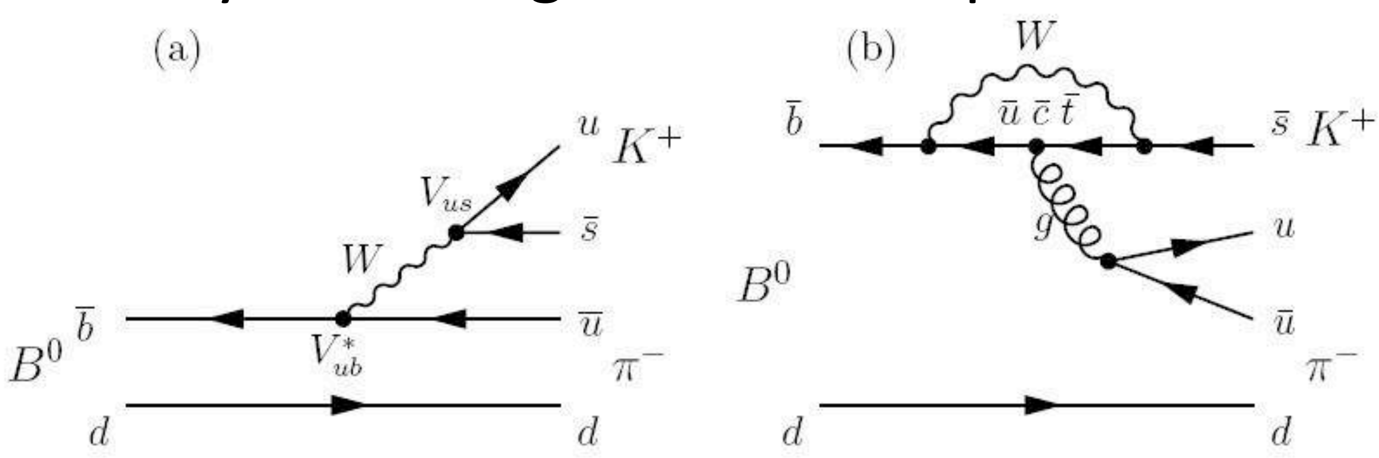
Rare Decay Mascot



Let’s consider

$$B^0 \to \pi^- K^+$$

Feynman diagrams for this process



Feynman tree (a) and penguin (b) diagrams for the $B^0_d \to K^+\pi^-$ decay

Both amplitudes contribute, but the Penguin is larger and has a different weak phase.

The isospin sum rule

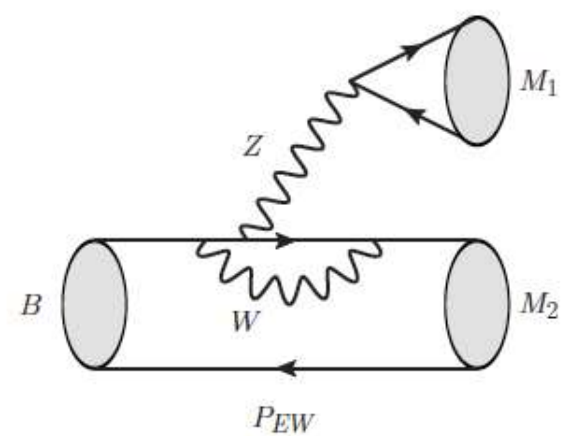
https://arxiv.org/abs/hep-ph/0508047

$$A_{\rm CP}(K^+\pi^-) + A_{\rm CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = A_{\rm CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + A_{\rm CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

A_{CP}			
Mode	BaBar	Belle	LHCb
$K^+\pi^-$	$-0.107 \pm 0.016^{+0.006}_{-0.004}$	$-0.069 \pm 0.014 \pm 0.007$	$-0.080 \pm 0.007 \pm 0.003$
$K^+\pi^0$	$0.030 \pm 0.039 \pm 0.010$	$0.043 \pm 0.024 \pm 0.002$	
$K^0\pi^+$	$-0.029 \pm 0.039 \pm 0.010$	$-0.011 \pm 0.021 \pm 0.006$	$-0.022 \pm 0.025 \pm 0.010$
$K^0\pi^0$	$-0.13 \pm 0.13 \pm 0.03$	$0.14 \pm 0.13 \pm 0.06$	

K pi puzzle.

To check for new physics from electroweak penguins in the B→Kπ system in a model-independent manner using the isospin sum rule, need to measure all *four final states* and their CP asymmetries. Need to measure modes with π^0's and Kshort's.



Examples of hadronic penguins (b→s gluon) at Belle II.

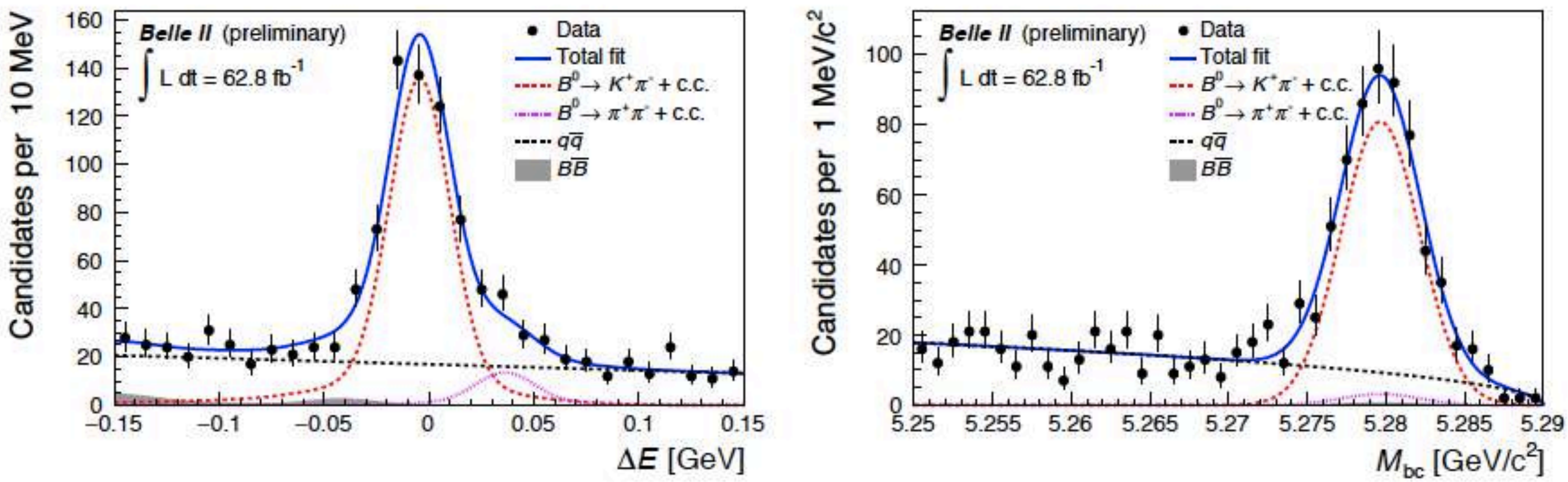
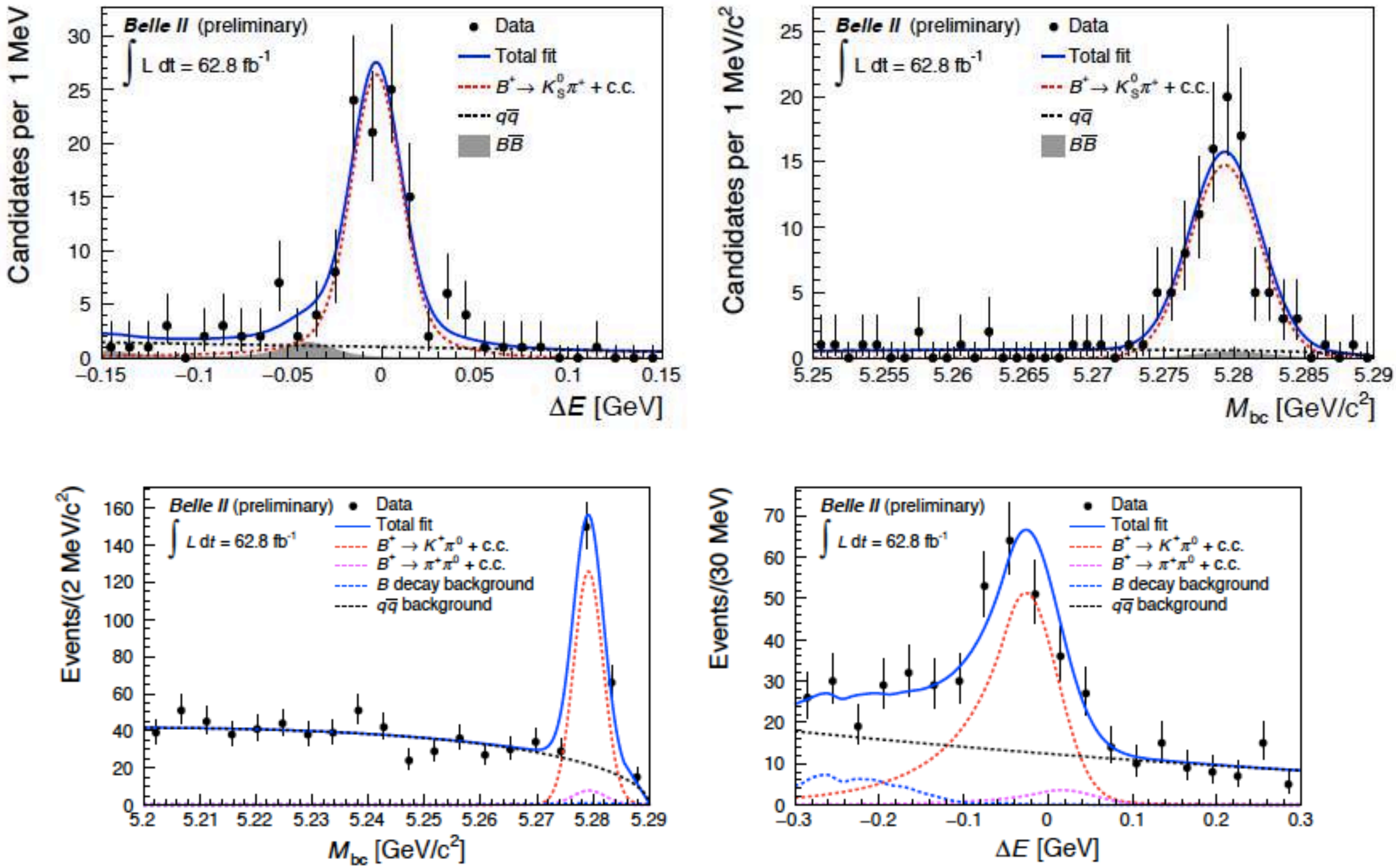


FIG. 2. Distributions of ΔE (left) and $M_{\rm bc}$ (right) for $B^0 \to K^+\pi^-$ candidates reconstructed in 2019–2020 Belle II data, selected with an optimized continuum-suppression and kaon-enriching selection. The distributions are shown in signal-enriched regions of $5.273 < M_{\rm bc} < 5.286$ GeV$/c^2$ and $-0.04 < \Delta E < 0.03$ GeV, respectively. Fit projections are overlaid.

Details in https://arxiv.org/abs/2106.03766

More examples of hadronic penguins (b→s gluon) at Belle II.



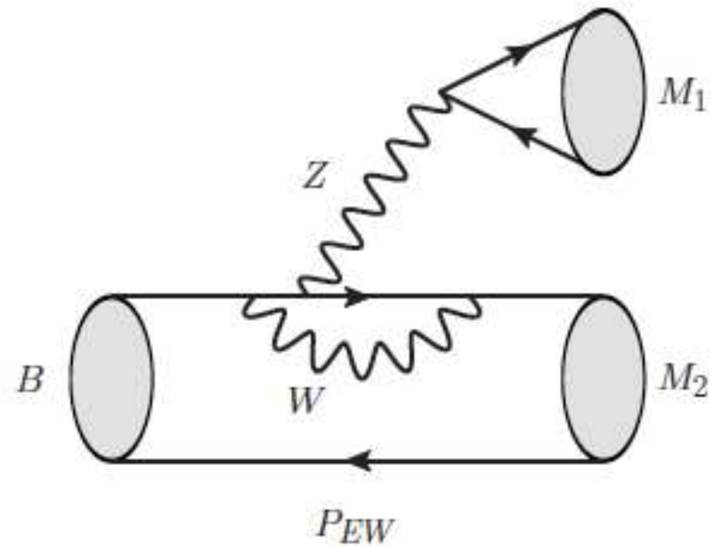
Details in https://arxiv.org/abs/2106.03766 ; https://arxiv.org/abs/2105.04111

"Trapping" the Electroweak Penguin in B→K π

The isospin sum rule

$$I_{K\pi} = \mathcal{A}_{K^+\pi^-} + \mathcal{A}_{K^0\pi^+}\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^+\pi^0}\frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^0\pi^0}\frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

NP can enter through this type of diagram.



Have now observed the four B→K π modes, needed for the isospin sum rule test of NP. This includes the difficult mode B→K_S π^0. Now have A_{CP} for all 4 modes and sensitivity estimates for the future.

Belle II's first result on $A_{CP}(B^0 \to K^0 \pi^0)$

About 50 events with 62 fb^{-1}

Not self-tagging.

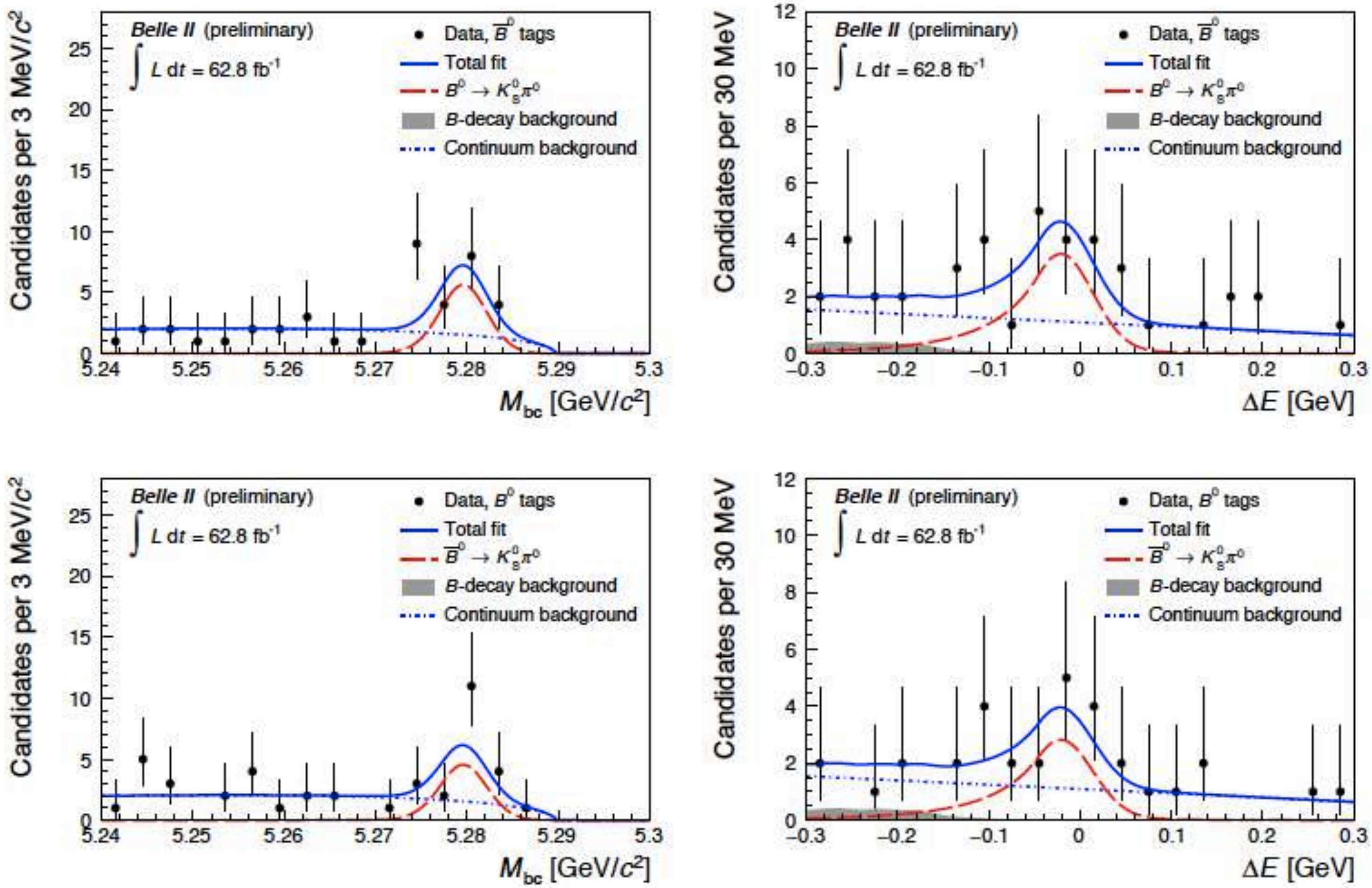
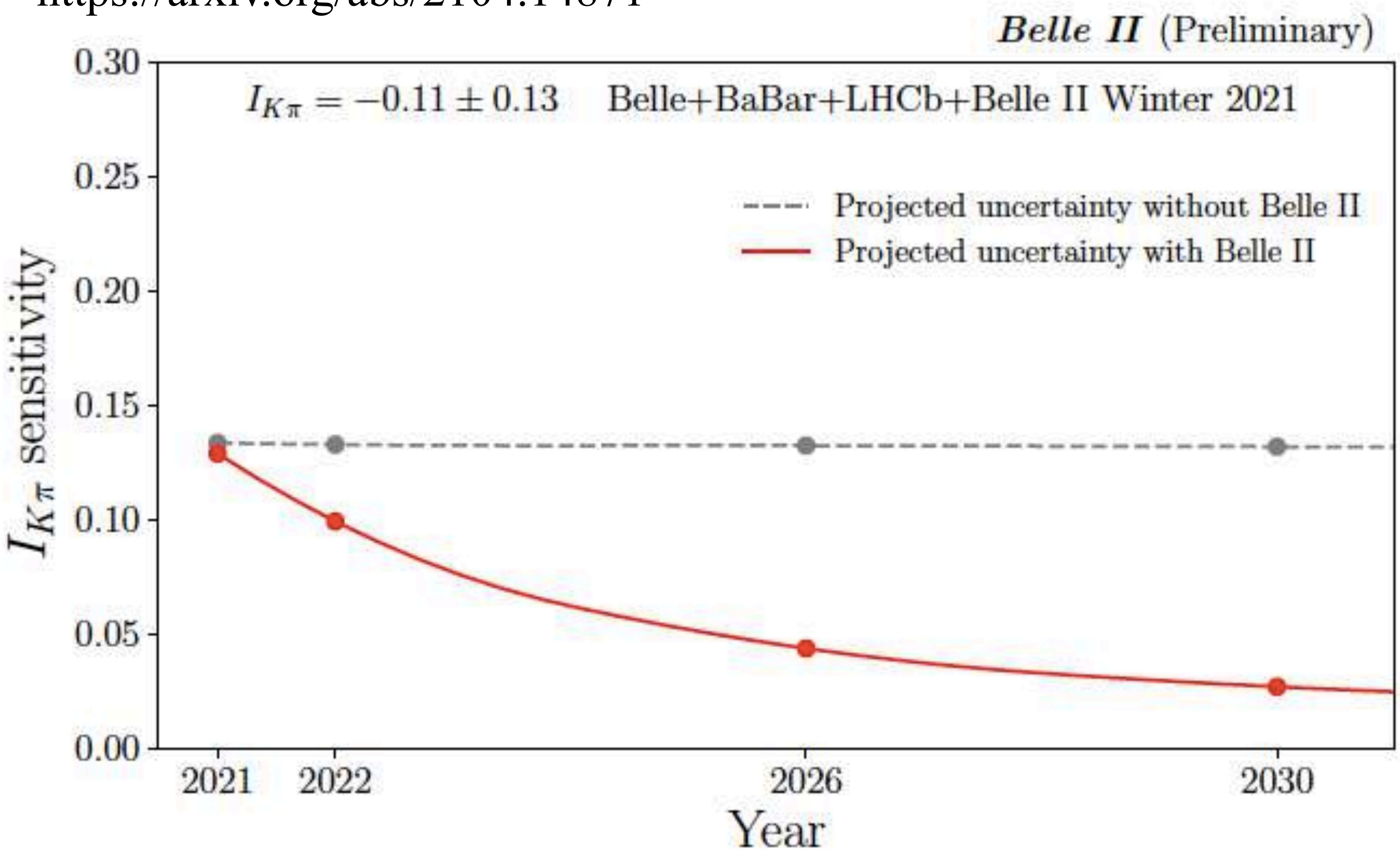


FIG. 3. Flavor-specific ($M_{\rm bc}$, ΔE) projections on 2019-2020 Belle II data. The top panel shows candidates where $B_{\rm tag}$ is tagged as a $\bar{B}^0$ (signal-side: B^0) and the bottom panel for candidates where $B_{\rm tag}$ is tagged as a B^0 (signal-side: $\overline{B}^0$). The distribution and fit are integrated over r-bin in the good tag region $0.25 \le r \le 1$ and in the signal region (left panel: $-0.16 < \Delta E < 0.08$ GeV, right panel: $M_{\rm bc} > 5.27\,{\rm GeV}/c^2$).

Details in https://arxiv.org/abs/2104.14871

https://arxiv.org/abs/2104.14871



Without Belle II measurements of $A_{CP}(B^0 \rightarrow K^0 \pi^0)$, we are stuck.

FIG. 4. The projected uncertainty on $I_{K\pi}$ with and without Belle II inputs. The inputs for $I_{K\pi}$ are averages of the estimated updates from ongoing LHCb and Belle II experiments with current world averages [10]. The red curve shows a projection when updates on the complete set of $K\pi$ measurements are considered, and the grey curve is the case if only $A_{K^+\pi^-}, A_{K^+\pi^0}, A_{K^0\pi^+}$ are updated by LHCb. The projection corresponds to the luminosity plans from LHCb and Belle II.

A unique contribution of Belle II to testing the K π isospin sum rule

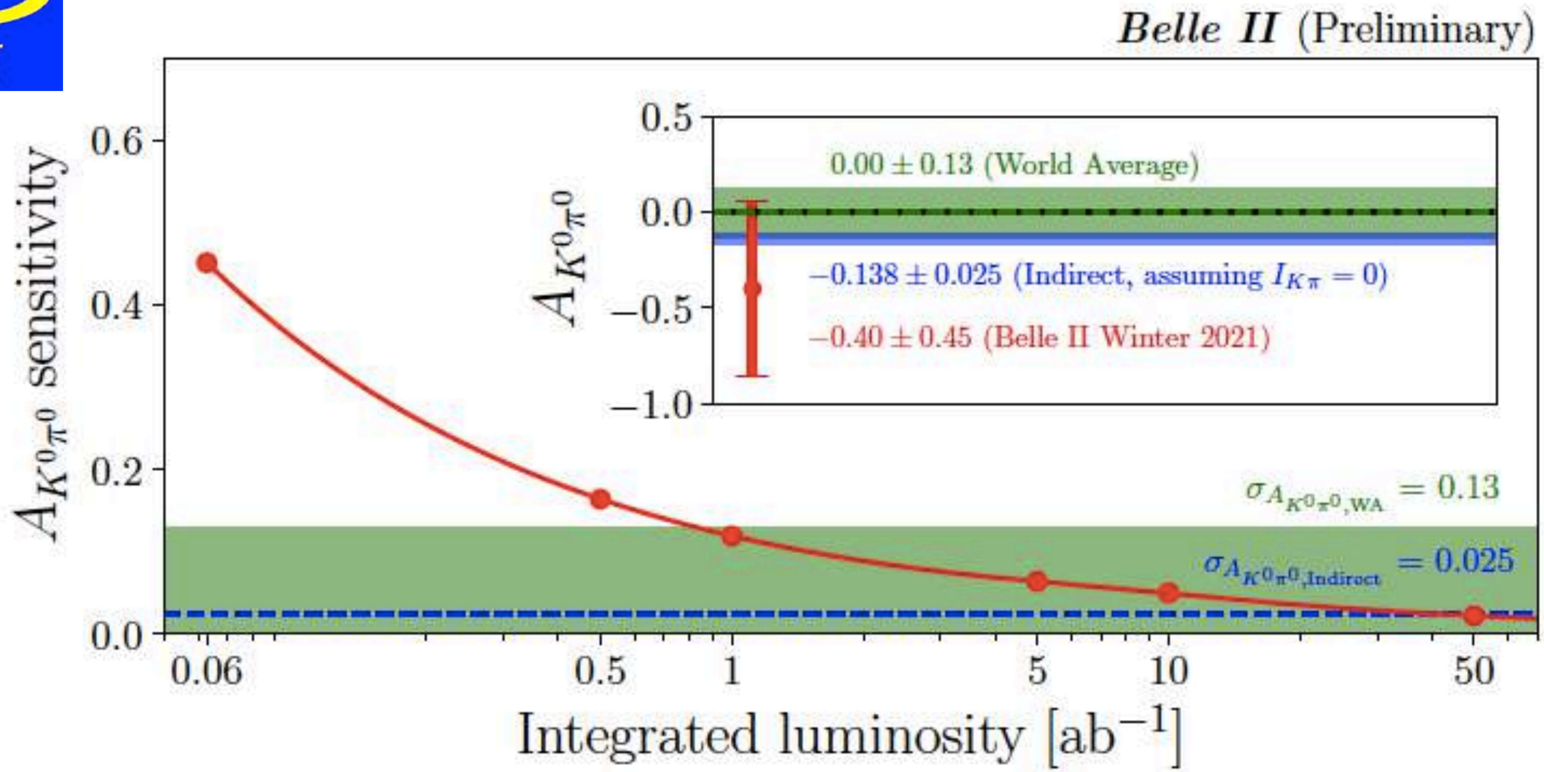
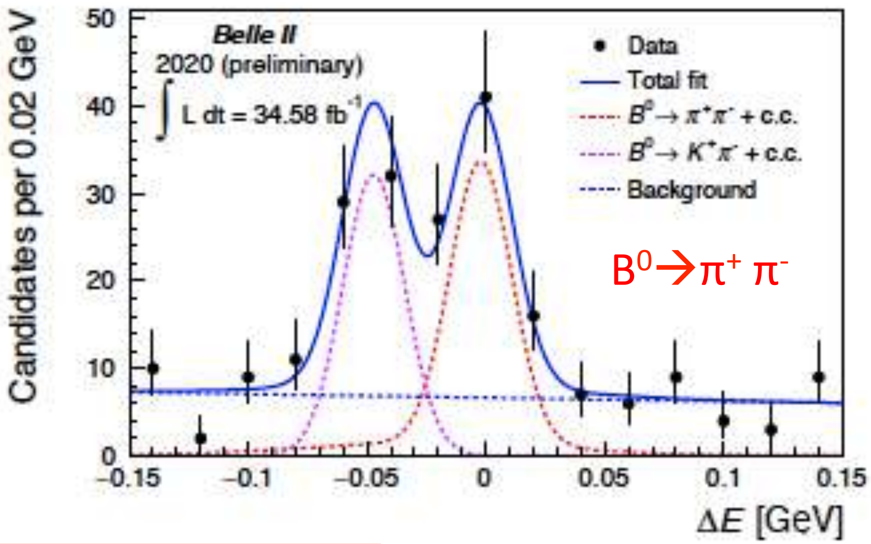
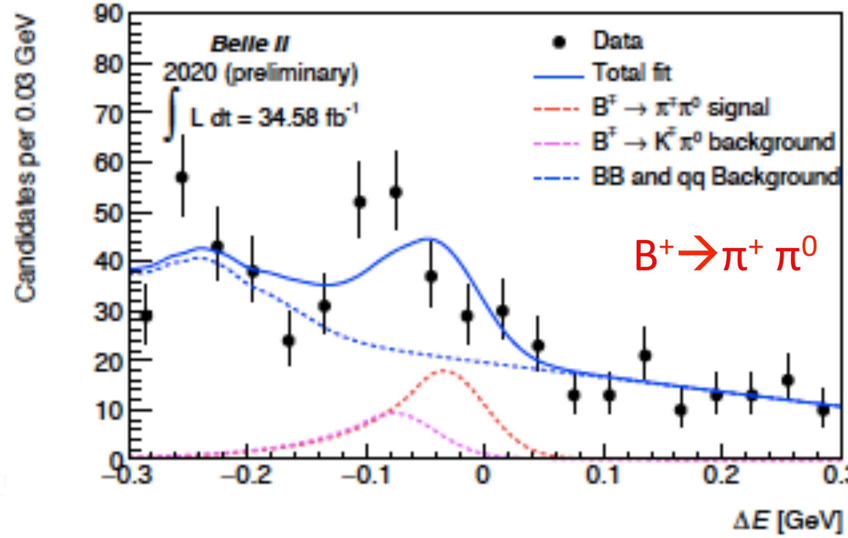


FIG. 5. The projected uncertainty on $\mathcal{A}_{K^0\pi^0}$ measurement. The inset panel shows the comparison of (red marker) the measurement reported here with (green band) the world average value, and (blue band) the indirect determination from Eq. 1 assuming $I_{K\pi} = 0$ and world average values for the other inputs. The red curve in the main panel is Belle II's expected uncertainty on the $\mathcal{A}_{K^0\pi^0}$ measurement as a function of the integrated luminosity, while the green and blue dashed lines are the uncertainties of the world average value and of the indirect determination, respectively.

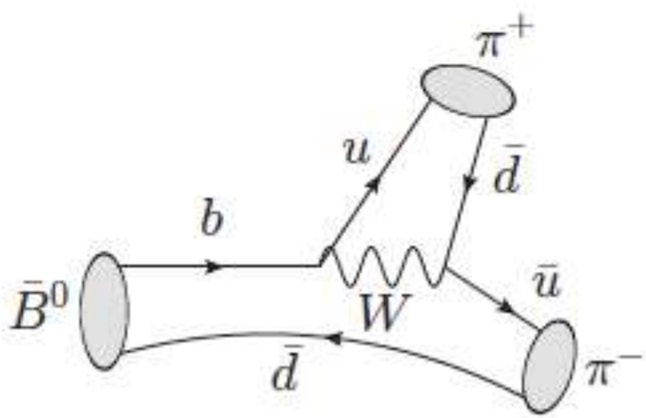
Details in https://arxiv.org/abs/2104.14871

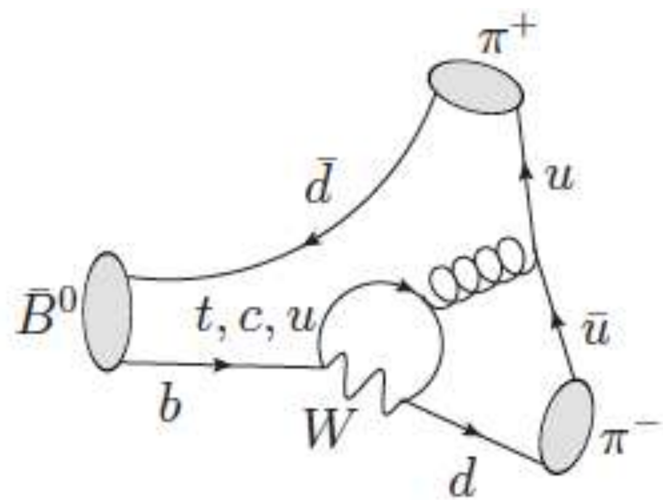
Have now established all B→ππ modes needed for the isospin triangle and the α/ϕ_2 CKM angle determination. Now have a $B \to \pi^0 \pi^0$ signal.



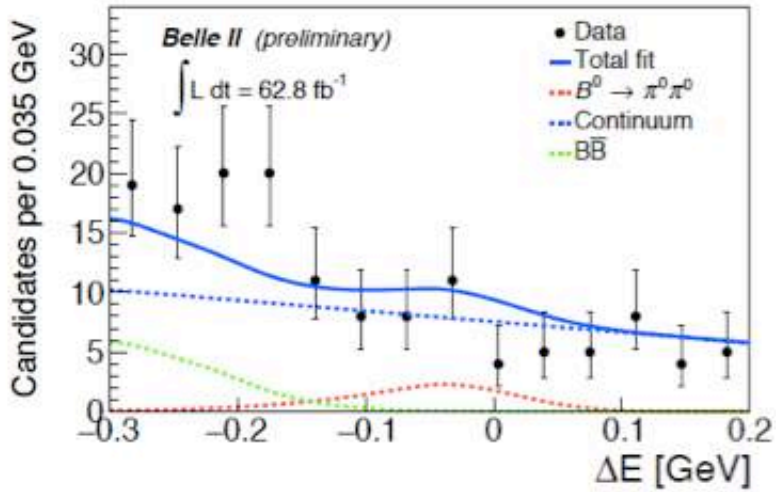


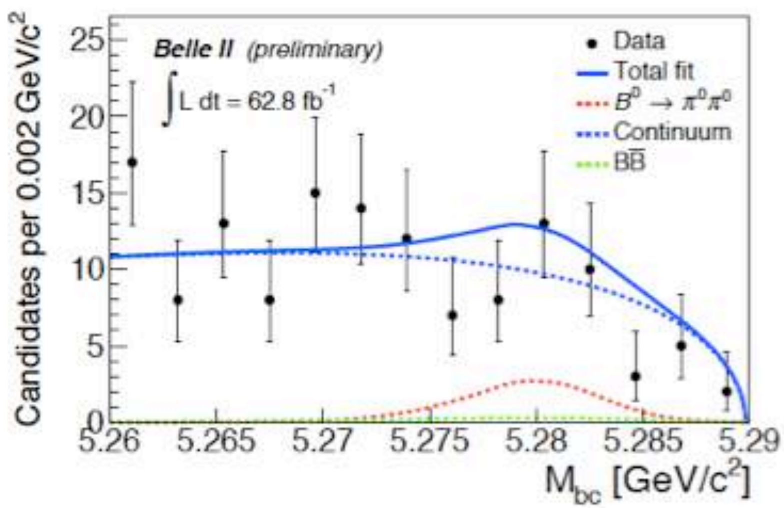
Need to separate the b→u tree and b→d penguin contributions to extract fundamental parameters.





First Belle II Evidence for $B \rightarrow \pi^0 \pi^0$





Reconstructed in the all neutral four-photon final state.

Signal significance is 3.4 σ

Next up is the CP asymmetry for this all neutral mode.

Details in https://arxiv.org/abs/2107.02373

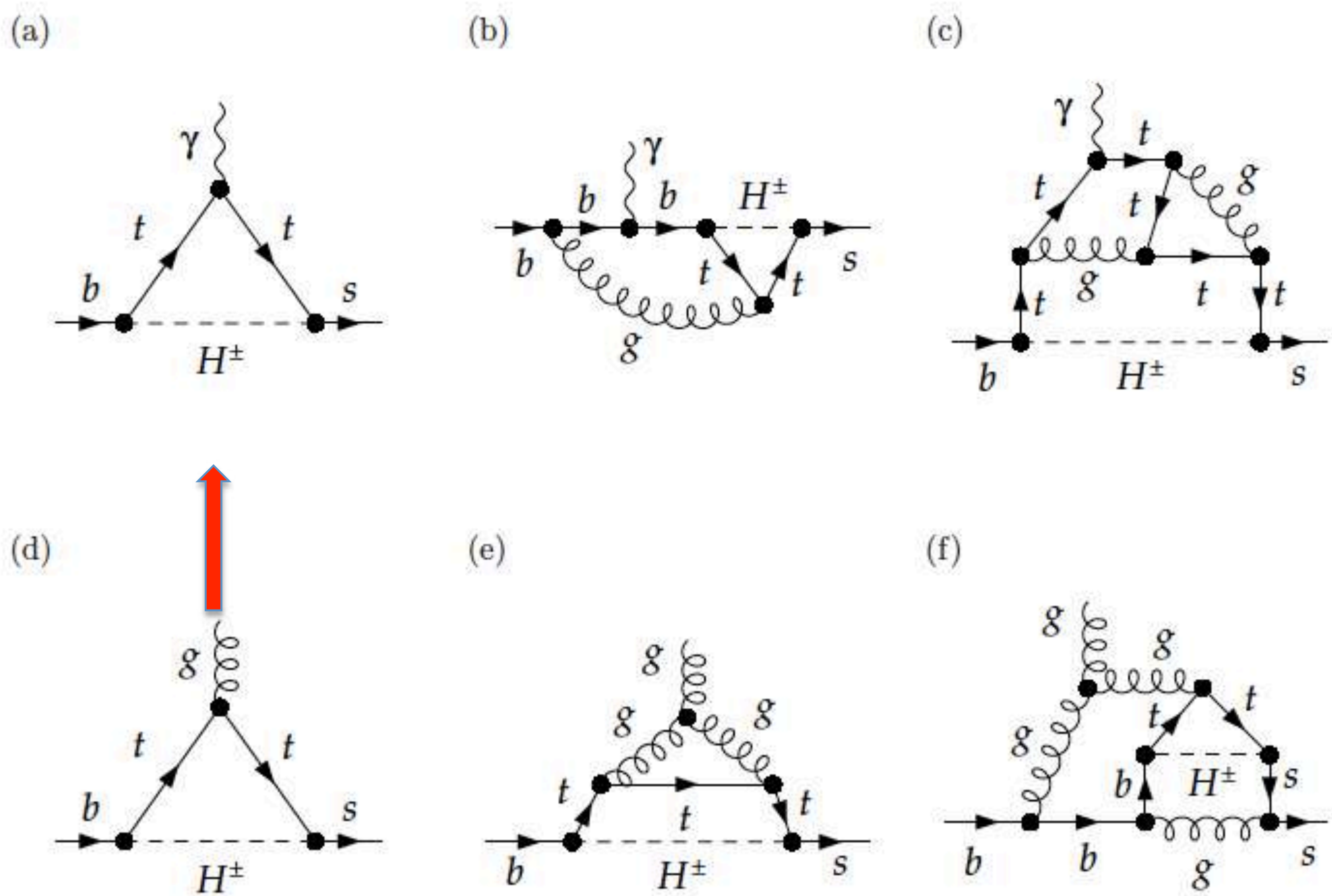
Some New Physics Topics from rare B decays.

University of Hawai'i Football Mascot
(Rainbow Warriors)

New Physics (NP)

Currently inclusive b to sγ rules out charged Higgs, m_{H+} below ~570 GeV/c^2 range (independent of tanβ)

Replace virtual W in the penguin by a charged Higgs from NP.

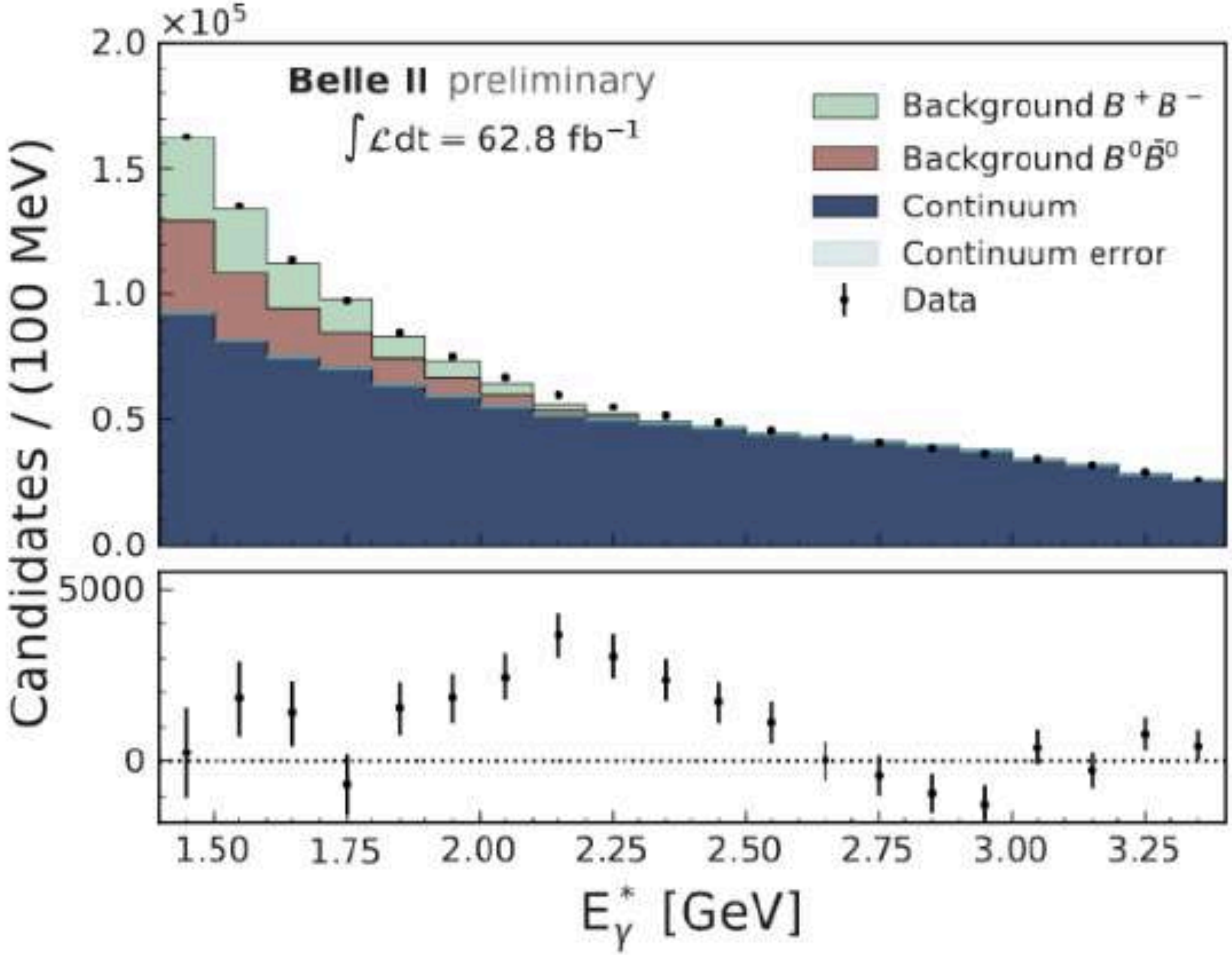


Misiak et al.

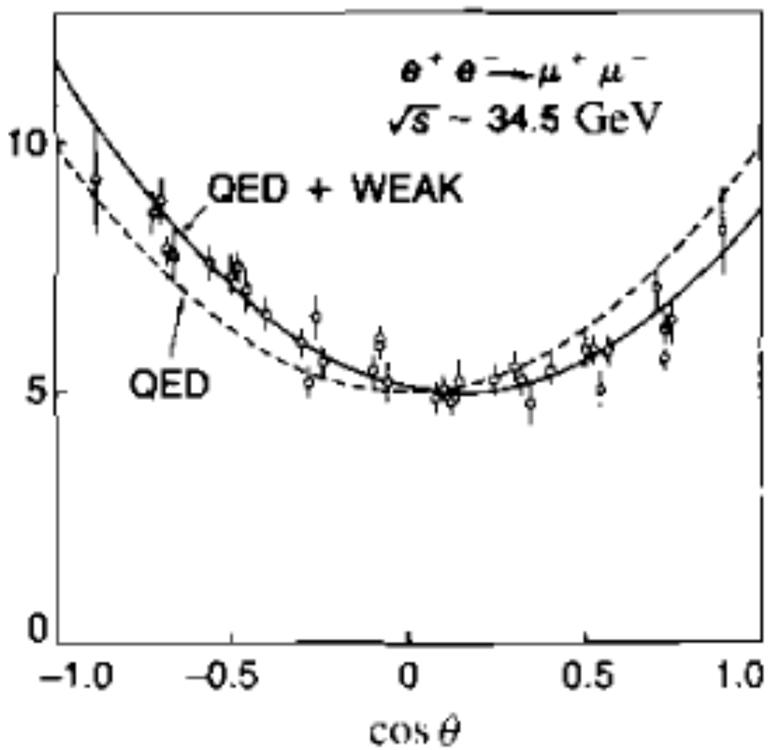
https://arxiv.org/abs/1702.04571

Early inclusive b→s γ signal from Belle II

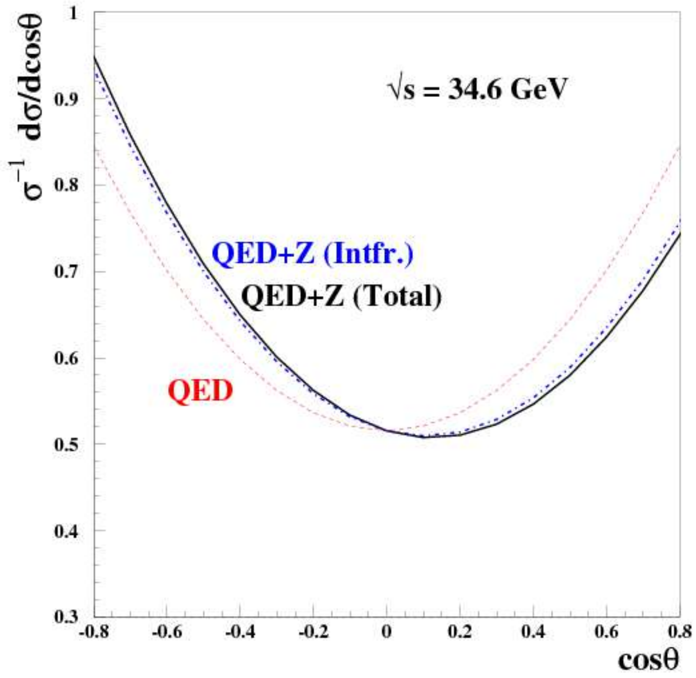
At a Super B factory, can observe the monochromatic photon line



High Energy Physics History: finding NP in A_{FB} (using interference)



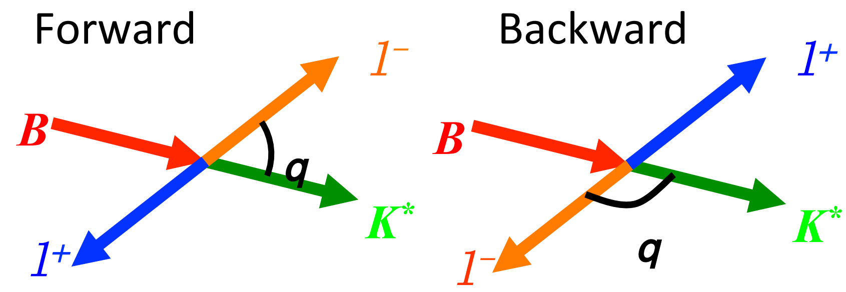
a fit including the weak interaction (solid line).



Conclusion: There is a Z boson at higher energy even though colliders of the time did not have enough $\sqrt{s}$ to produce it

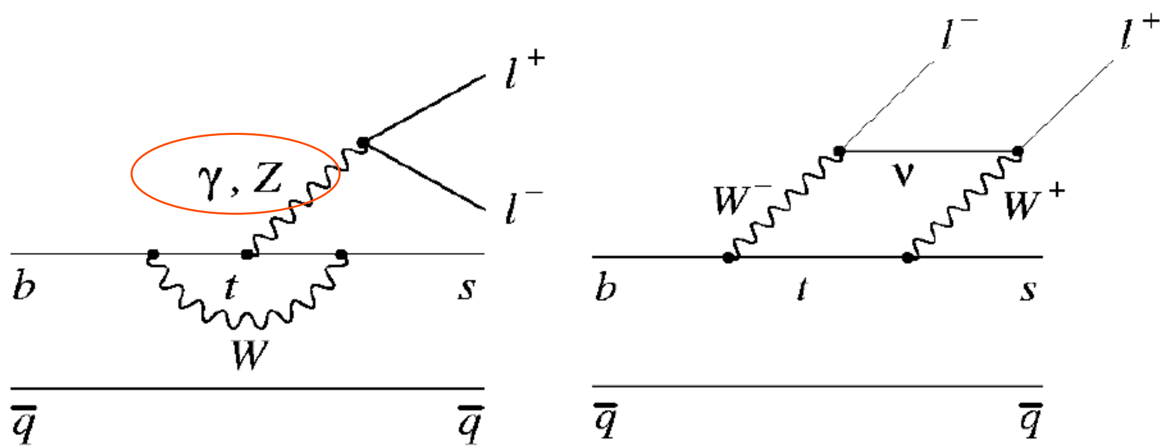
$A_{FB}(B \rightarrow K^* l^+ l^-)(q^2)$

The SM forward-backward asymmetry in $b \rightarrow s\ l^+\ l^-$ arises from the ***interference*** *between γ and Z^0 contributions.*



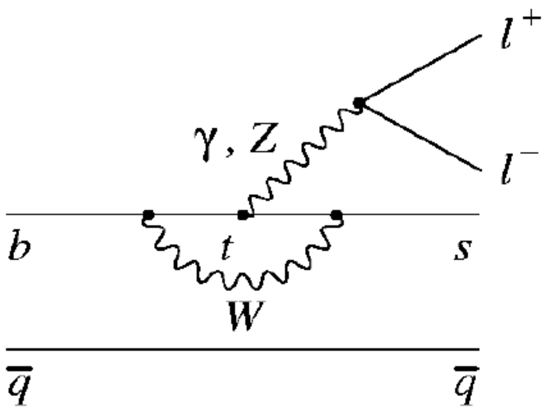
$$A_{FB}(B \to K^* \ell^+ \ell^-) = -C_{10}\xi(q^2)\left[Re(C_9)F_1 + \frac{1}{q^2}C_7F_2\right]$$

Ali, Mannel, Morozumi, PLB273, 505 (1991)



Note that all the heavy particles of the SM (W, Z, top) enter in this decay.

More on $A_{FB}(B \to K^* l^+ l^-)(q^2)$



Can in effect vary √s for NP

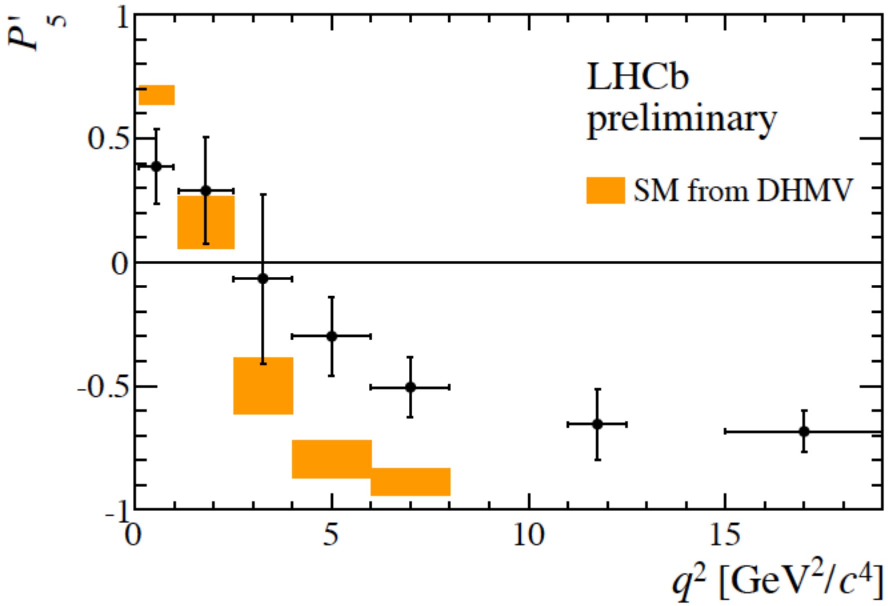
A_{FB} depends on $q^2 = M^2(l^+l^-)$

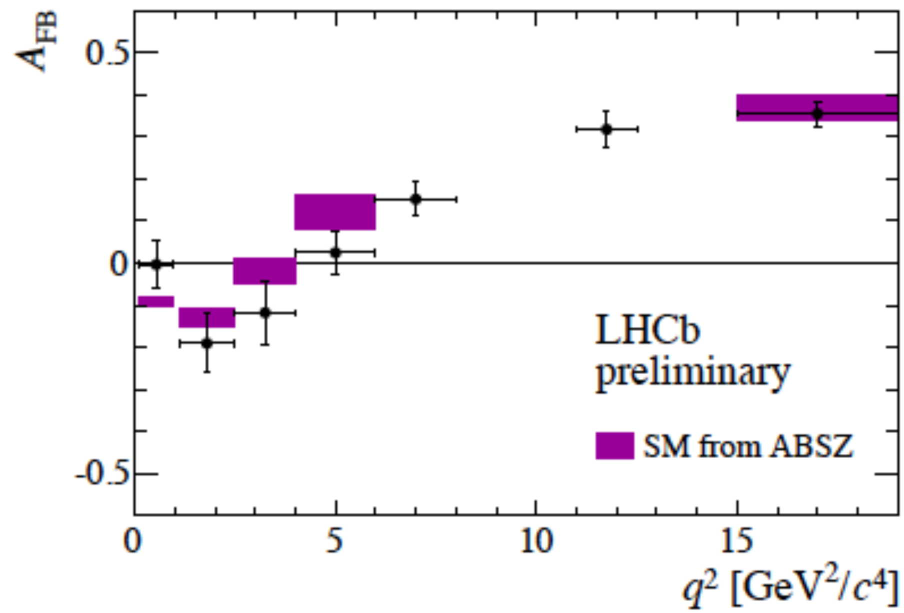
$$A_{FB}(B \to K^* \ell^+ \ell^-) = -C_{10}\xi(q^2)\left[Re(C_9)F_1 + \frac{1}{q^2}C_7F_2\right]$$

Ali, Mannel, Morozumi, PLB273, 505 (1991)

The "zero-crossing" of A_{FB} depends only on a ratio of form factors and is a *clean* observable.

LHCb 3fb^{-1} results on $B \rightarrow K^* \mu^+\mu^-$ (q^2)





"The P_5' measurements <u>are only compatible with the SM prediction at a level of 3.7σ</u>…..A mild tension can also be seen in the A_{FB} distribution, where the measurements are systematically <=1σ below the SM prediction in the region $1.1<q^2< 6.0$ GeV^2"

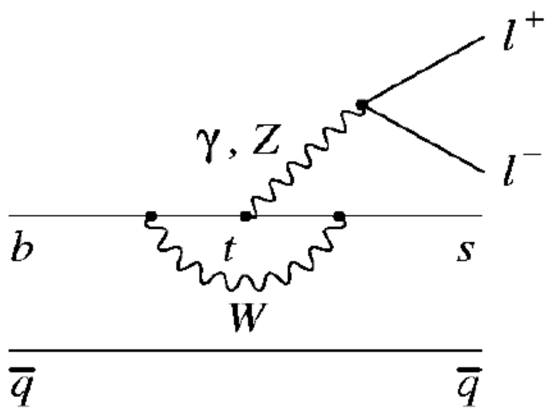
These angular asymmetries persist in 2021

Theory from http://arxiv.org/abs/1407.8526 Experiment from LHCb-CONF-2015-002

LHCb results on $B \rightarrow K^* \mu^+\mu^- (q^2)$

<u>Is HEP History repeating itself ?</u> [but make sure this is not a tricky SM long distance effect.]

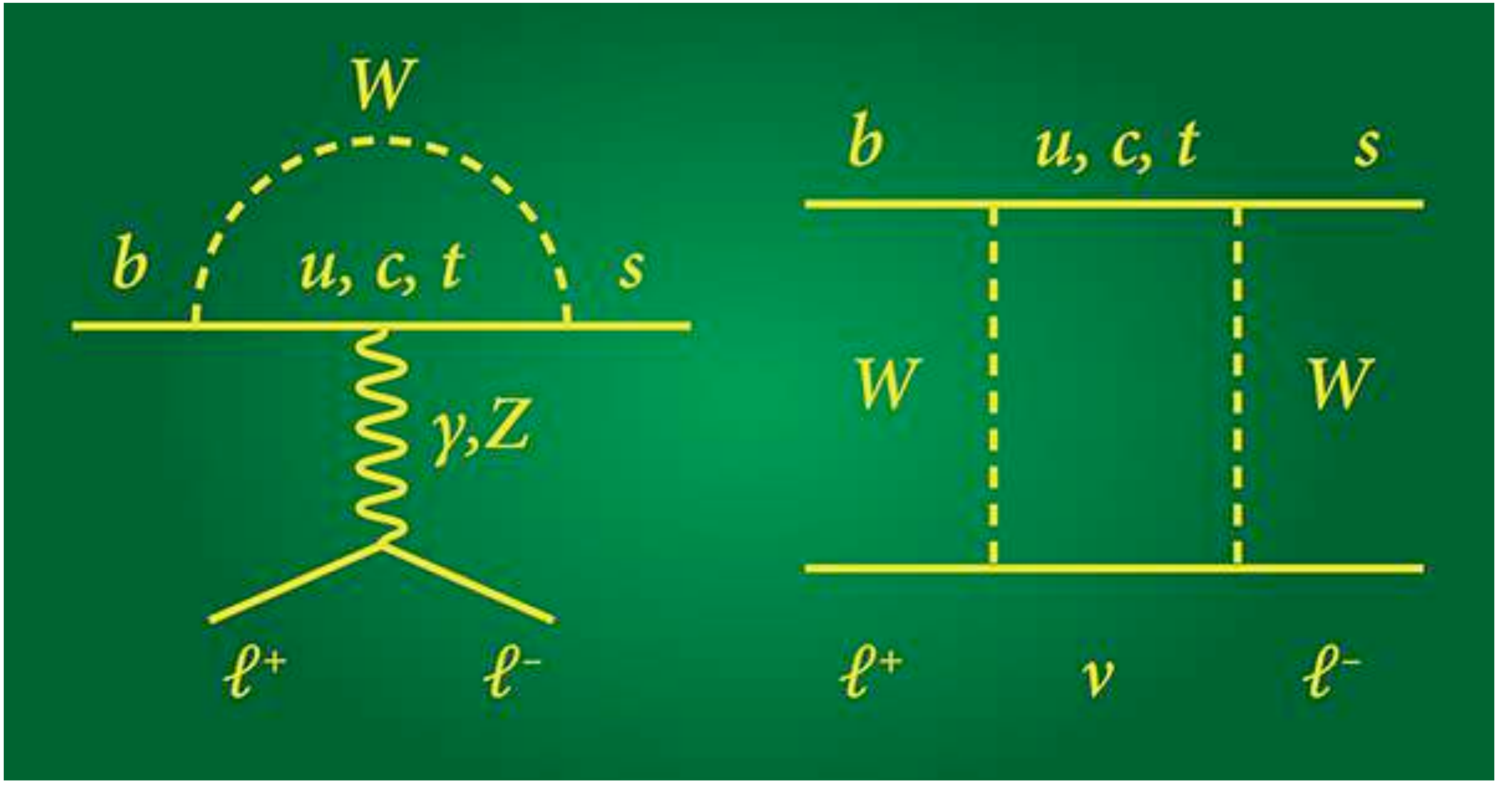
Why does NP appear first in this mode (and not others) ?



Possible answer: All the heavy particles of the SM (t, W, Z) and maybe NP (except the Higgs) appear here. Sensitive to NP via interference (<u>linear effects</u>).

In addition,

Test of Lepton Universality in b→s l+ l- transitions by the LHCb experiment at CERN, reported recently.



Test of Lepton Universality in b→s l+ l- transitions by the LHCb experiment at CERN, reported a few months ago.

https://arxiv.org/abs/2103.11769

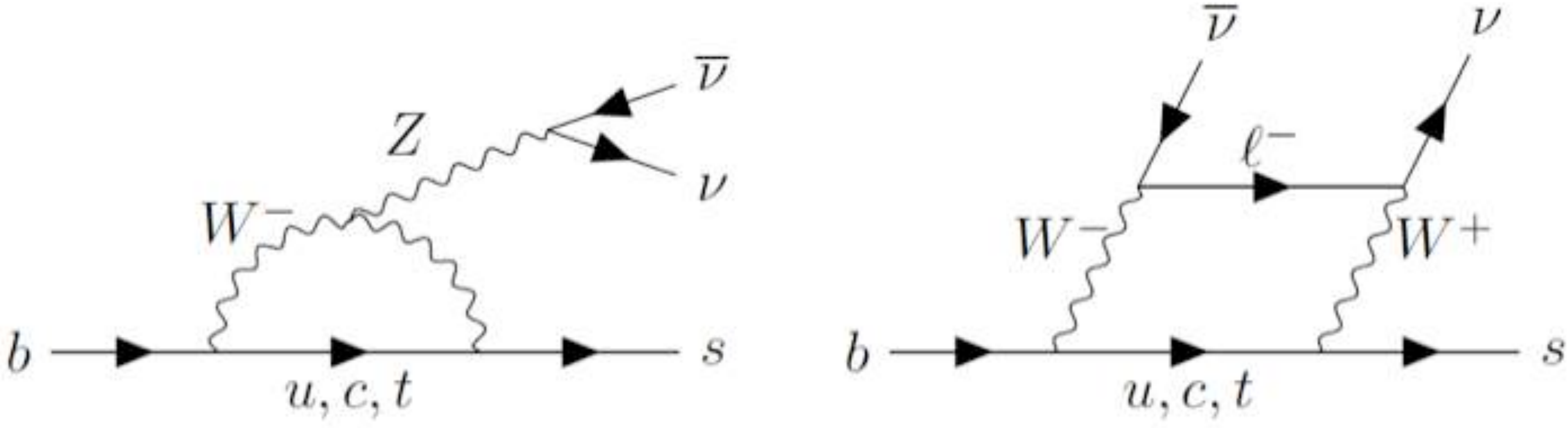
$$R_K = \frac{BF(B^+ \to K^+ \mu^+ \mu^-)}{BF(B^+ \to J/\psi(\to \mu^+ \mu^-)K^+} \Big/ \frac{BF(B^+ \to K^+ e^+ e^-)}{BF(B^+ \to J/\psi(\to e^+ e^-)K^+}$$

$$R_K(1.1 < q^2 < 6.0\ \mathrm{GeV}^2/\mathrm{c}^4) = 0.846^{+0.042+0.013}_{-0.039-0.012}$$

<1 (lepton universality prediction)

Possible breakdown of the Standard Model of Particle Physics. (3.1 standard deviations)

B→K ν νbar: NP without hadronic uncertainties



(a) Penguin diagram (b) Box diagram

Note that in contrast to B→K$^{(*)}$ l^+ l^- angular asymmetries, there are NO long distance (charm annihilation) contributions from B→J/ψ K$^{(*)}$ and B→ψ(2S) K$^{(*)}$

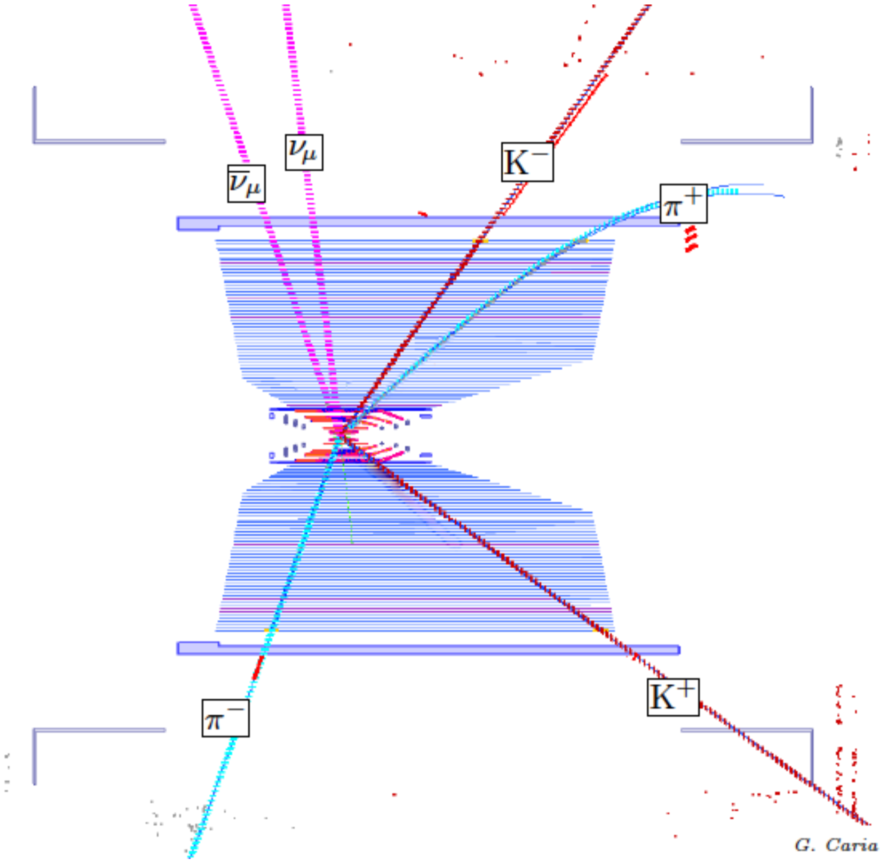
What's Ahead ?

"Missing Energy Decay" in a Belle II GEANT4 MC simulation

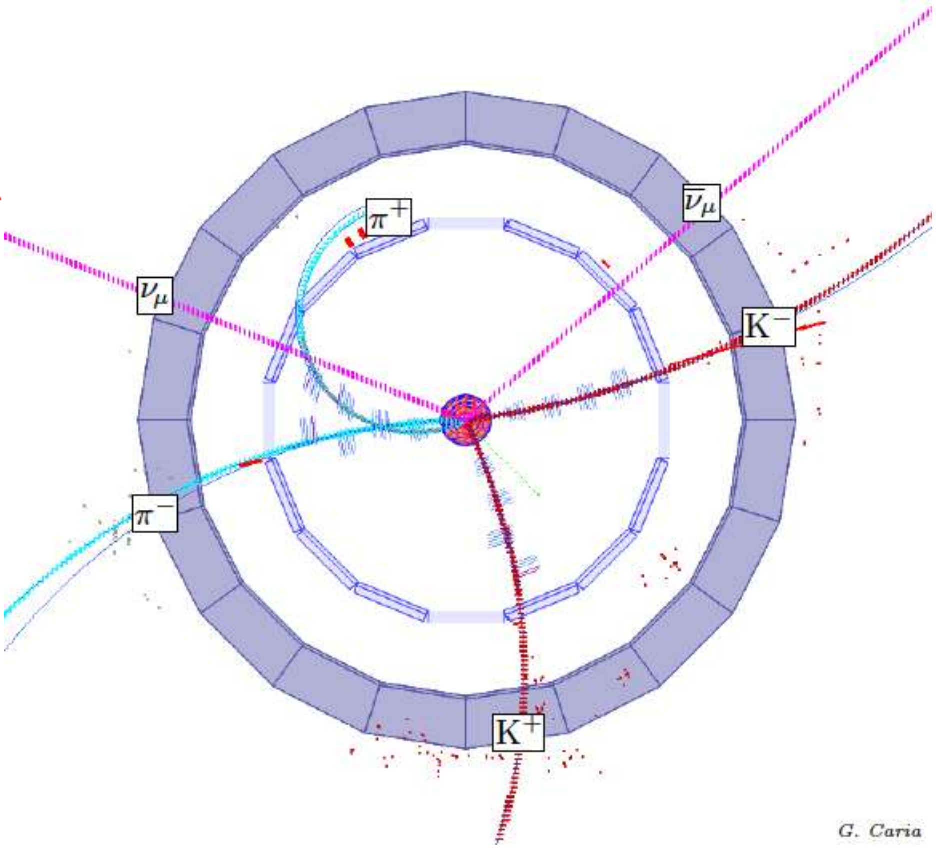
Signal: B→K ν ν

tag mode: B→Dπ; D→Kπ

View in r-z



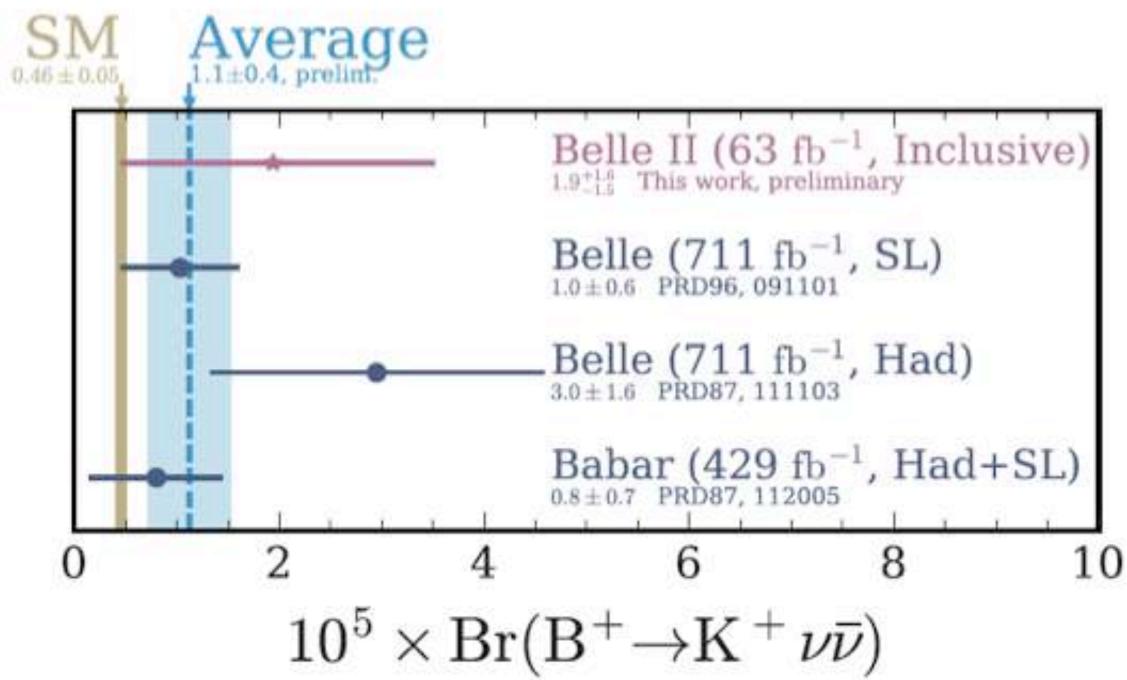
Zoomed view of the vertex region in r--phi



B→K ν νbar: NP without hadronic uncertainties

- This measurement represents the first search for $B^+ \to K^+ \nu\bar{\nu}$ performed with an inclusive tag.
- No signal observed yet, but an observed upper limit on the branching ratio of 4.1×10^{-5} is set at the 90% CL.
- With $63\ \mathrm{fb}^{-1}$ of $\Upsilon(4S)$ data recorded by the Belle II experiment, the inclusive tagging is competitive with the previous searches despite the much lower integrated luminosity.

New Technique from Belle II



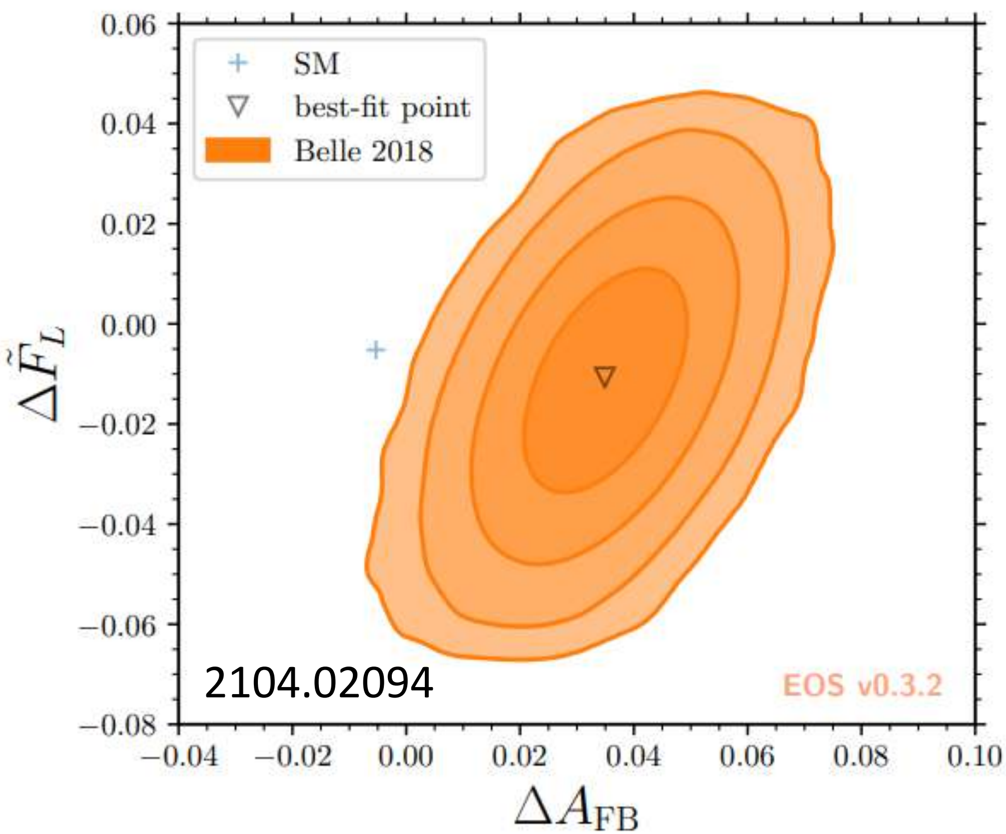
This is the most likely way that Belle II could discover NP.

More details in this theory preprint (TEB, Deshpande, Mandal, Sinha): https://arxiv.org/abs/2107.01080

Slide from A. Crivellin, Belle II summer school, Virginia Tech

Hot and New: ΔA_{FB} in $b \to c\, l\, \nu$

- $\Delta A_{FB} = A_{FB}(b \to c\mu\nu) - A_{FB}(b \to ce\nu)$
- 4σ deviation found by 2104.02094 based on Belle data 1809.03290
- Scalar and/or tensor operators required for an angular asymmetry
- g-2 and $b \to s\, \mu^+ \mu^-$ motivate new physics related to muons



Hint for scalar/tensor NP in $b \to c\mu\nu$

Preparing for Snowmass 2022 (International Physics Rodeo)

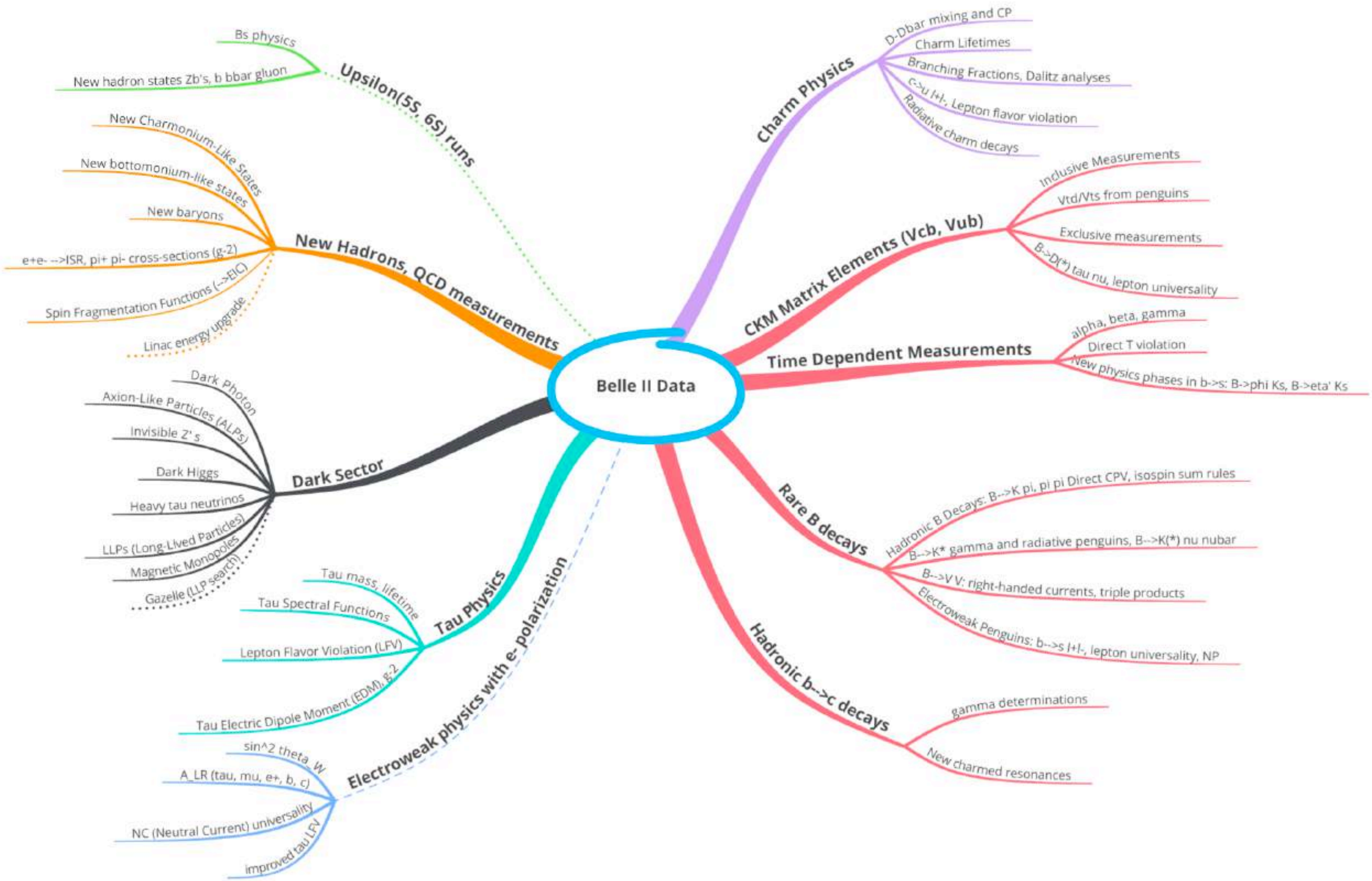
Scenes from the actual Snowmass Rodeo in Colorado

N.B. Snowmass 2022 to be held in Seattle, Washington in summer of 2021 and the last one was held in Minneapolis, Minnesota in 2013. It is unlikely that there will ever be another month-long planning meeting in Snowmass, CO.

Historical note: <u>Young(ish) Scientist Pier Oddone</u> (originally from Peru/ Italy) introduced the concept and first proposal for an asymmetric energy B-factory to the broad HEP community at a Snowmass in 1988.

Belle II Physics "Mind Map" for Snowmass 2022

Wealth of new physics possibilities in different domains of HEP (weak, strong, electroweak interactions). Many opportunities for *initiatives* by young scientists.



Dashed lines indicate extensions to SuperKEKB/Belle II that can enhance the physics reach of the facility. LOIs: https://confluence.desy.de/display/BI/Snowmass+2021

Conclusions

- Belle II is working well and is now producing physics. SuperKEKB has broken the world-luminosity record and is now a "Super B Factory".
- *World-leading results already on the dark sector* (Search for Z' → invisible and ALPs PRL's)
- A number of b → s processes have hints of NP. (New: pay attention to B → K ν νbar, Belle II has demonstrated improved sensitivity). Along with $B \to D^{(*)} \tau \nu$, these will be studied in detail at Belle II in the coming years.
- *A decade-long program of discoveries ahead*. Belle II is fully engaged in the rare and precision and dark sector frontiers, and instrumentation, computing and accelerator frontiers. *Great and unique opportunities for young Indian scientists*.

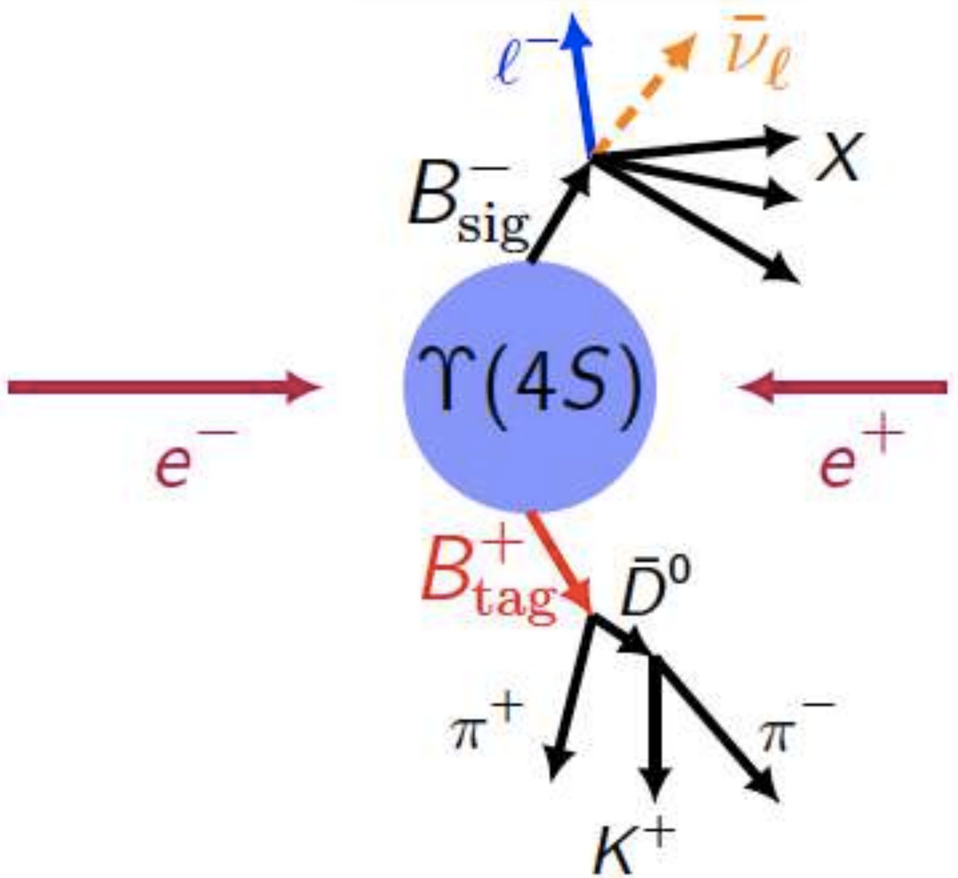
Some critical Belle II capabilities for flavor (B, D, tau) physics

Full and equally strong capabilities for electrons and muons

Photons, K_S's with excellent resolution and efficiency

Neutrinos via "missing energy" and missing momentum. Hermeticity.

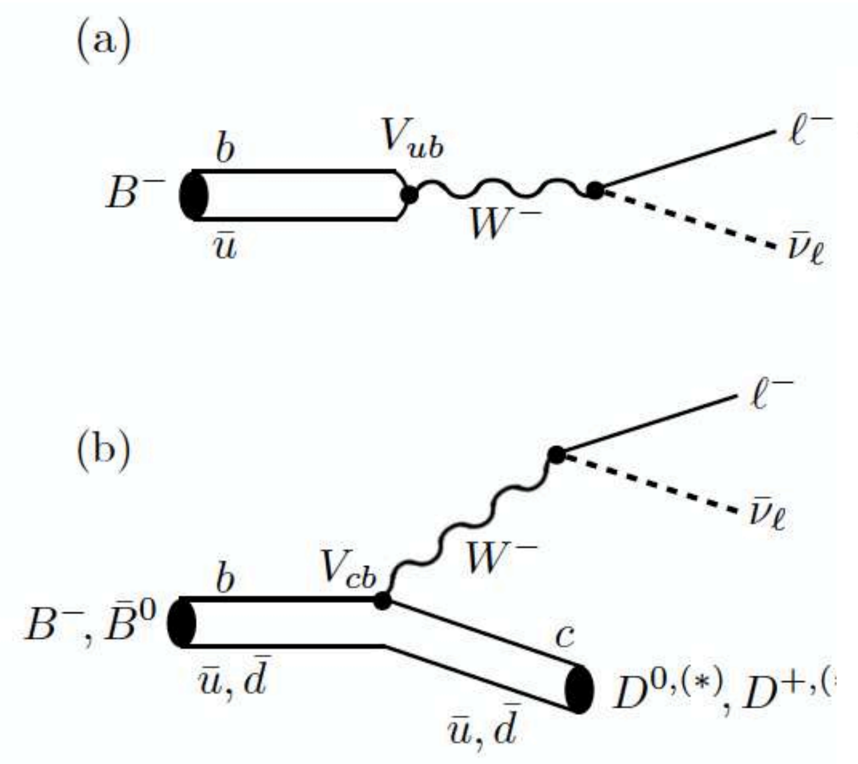
https://arxiv.org/abs/2008.06096

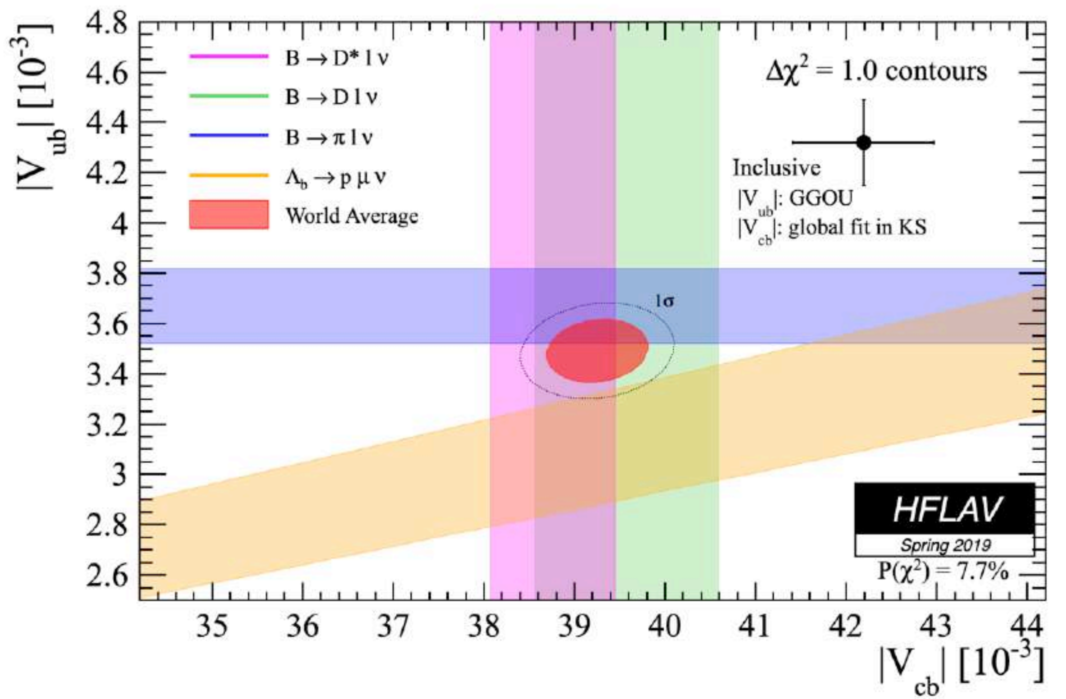


This is now called FEI "Full Event Interpretation" and uses large numbers of tag modes via a BDT (Boosted Decision Tree). About a factor of two improvement compared to Belle is expected.

T. Keck et al., Comput. Softw. Big Sci. 3, 6 (2019), arXiv:1807.08680 [hep-ex].

Motivation for semileptonic decays: V_{cb} , V_{ub}





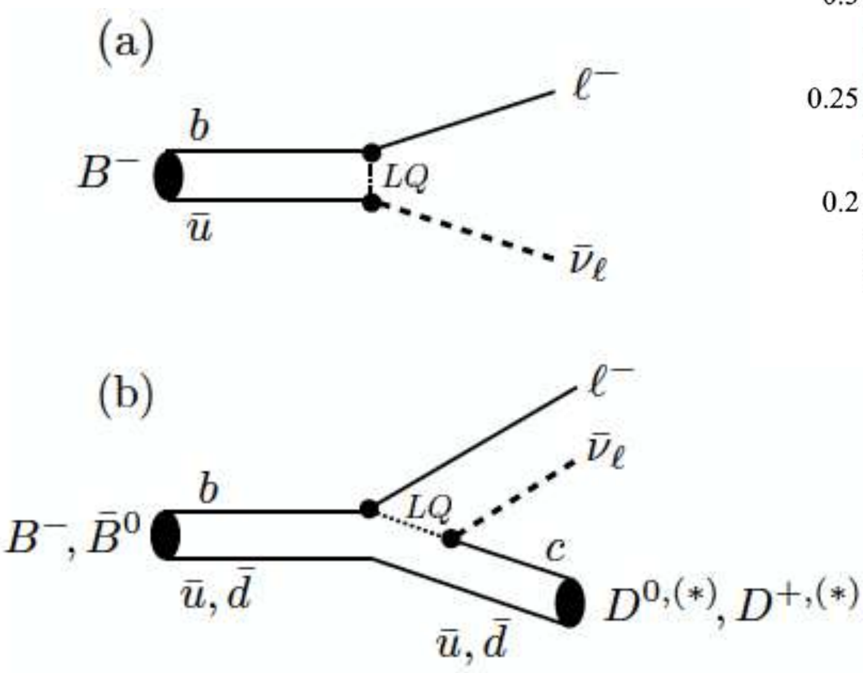
a) Purely leptonic decays e.g. $B^+ \rightarrow \tau^+ \nu$
b) Semileptonic decays e.g. $B \rightarrow D^{(*)} \tau\nu$ or $B \rightarrow D^{(*)} l \nu$

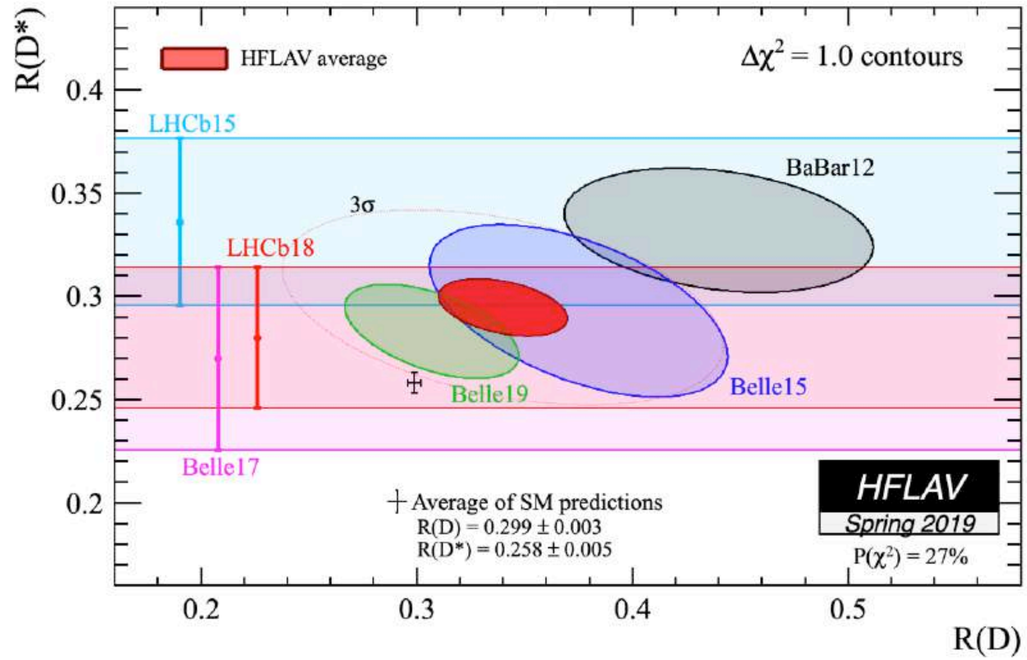
Tensions persist between exclusive and inclusive (e+e-) measurements of fundamental CKM elements $|V_{cb}|$, $|V_{ub}|$

Figure credit:
https://www.nature.com/articles/nature22346

$B \rightarrow D^{(*)} \tau \nu$, lepton universality and NP

Some new physics possibilities (leptoquarks (LQ), charged Higgs type 3 etc..):

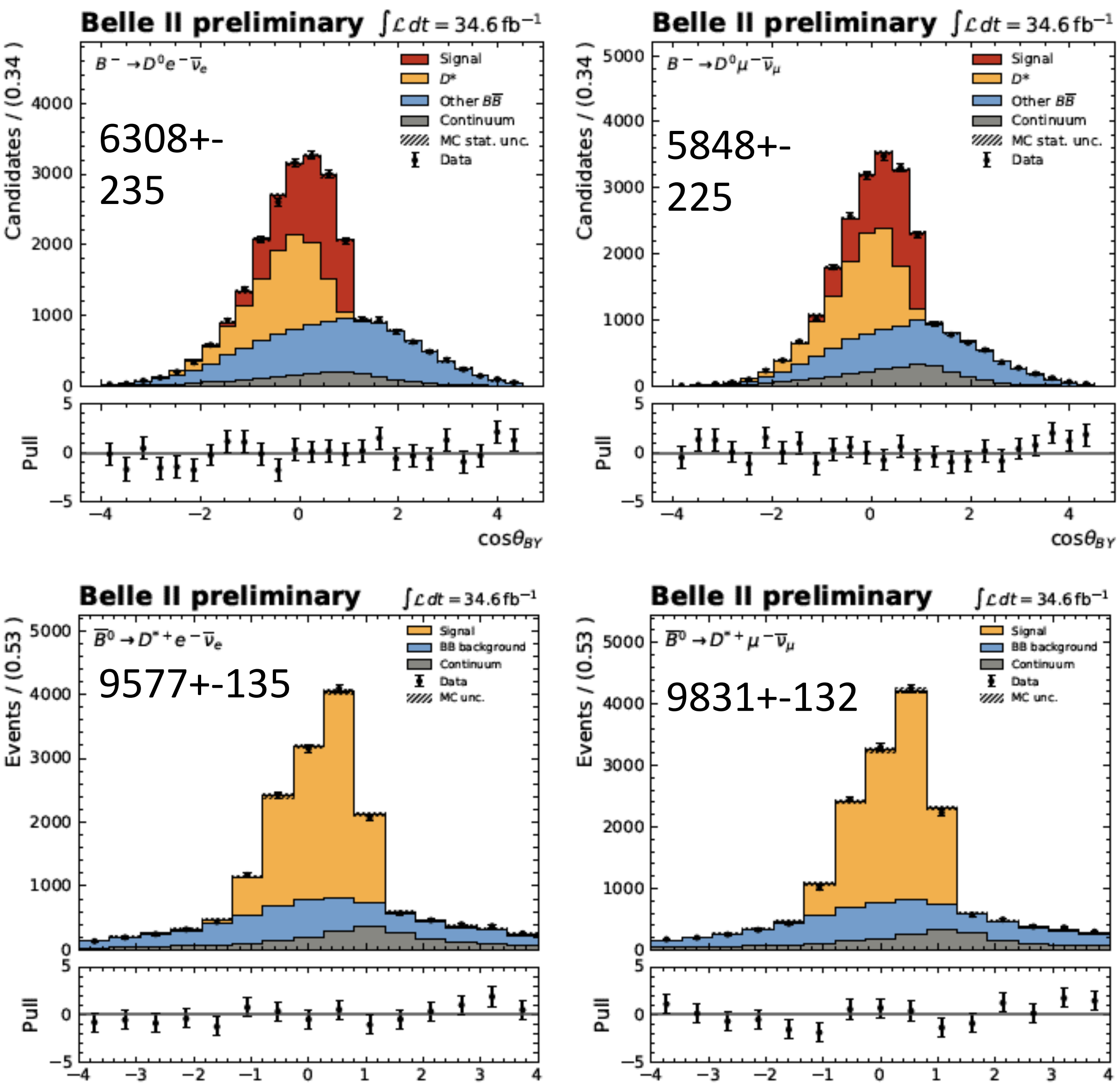




With current data from Belle, LHCb and BaBar:

Evidence of lepton universality breakdown in semileptonic B decays with τ leptons. Latest Belle measurement with semileptonic tags brings down to the WA discrepancy to $4 \rightarrow 3\sigma$

$B \rightarrow D^{*+} l^- \nu$ and $D^0 l^- \nu$ (untagged)



$$\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_l) = (4.59 \pm 0.05_{\text{stat}} \pm 0.18_{\text{syst}} \pm 0.45_{\pi_s})\,\%$$

Can already measure B meson branching fractions.

Have to work more on the systematic uncertainty from slow pion detection.

Rather than missing-mass squared, we fit cos θ_{BY}, peaks at zero in [-1,1] for correctly reconstructed signal

$$R_{e/\mu} = \frac{BF(B \to D^{*-} e^+ \nu_e)}{BF(B \to D^{*-} \mu^+ \nu_\mu)} = 0.99 \pm 0.03$$

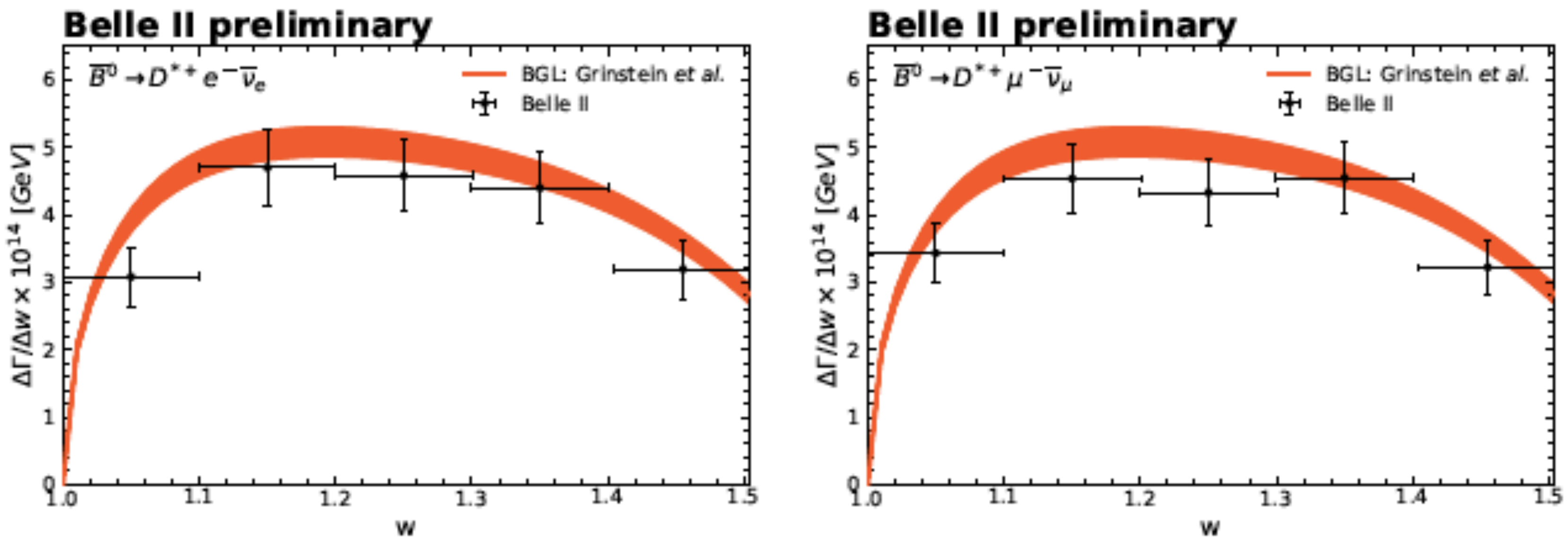
Ready for lepton universality checks.

https://arxiv.org/abs/2008.07198

BELLE2-CONF-2020-022

$B \rightarrow D^{*+} l^- \nu$ (untagged)

Warning: Not a fit! ; this merely shows that a $|V_{cb}|$ extraction will be possible in the near future.



Zero recoil point

Zero recoil point

FIG. 5. The measured partial decay rates for electrons and muons are compared to the BGL form factor parameters of Ref. [17, 18].

$$w = \frac{m_B^2 - m_{D^{*+}}^2 - q^2}{2 m_B m_{D^{*+}}} = v_B \cdot v_{D^{*+}}$$

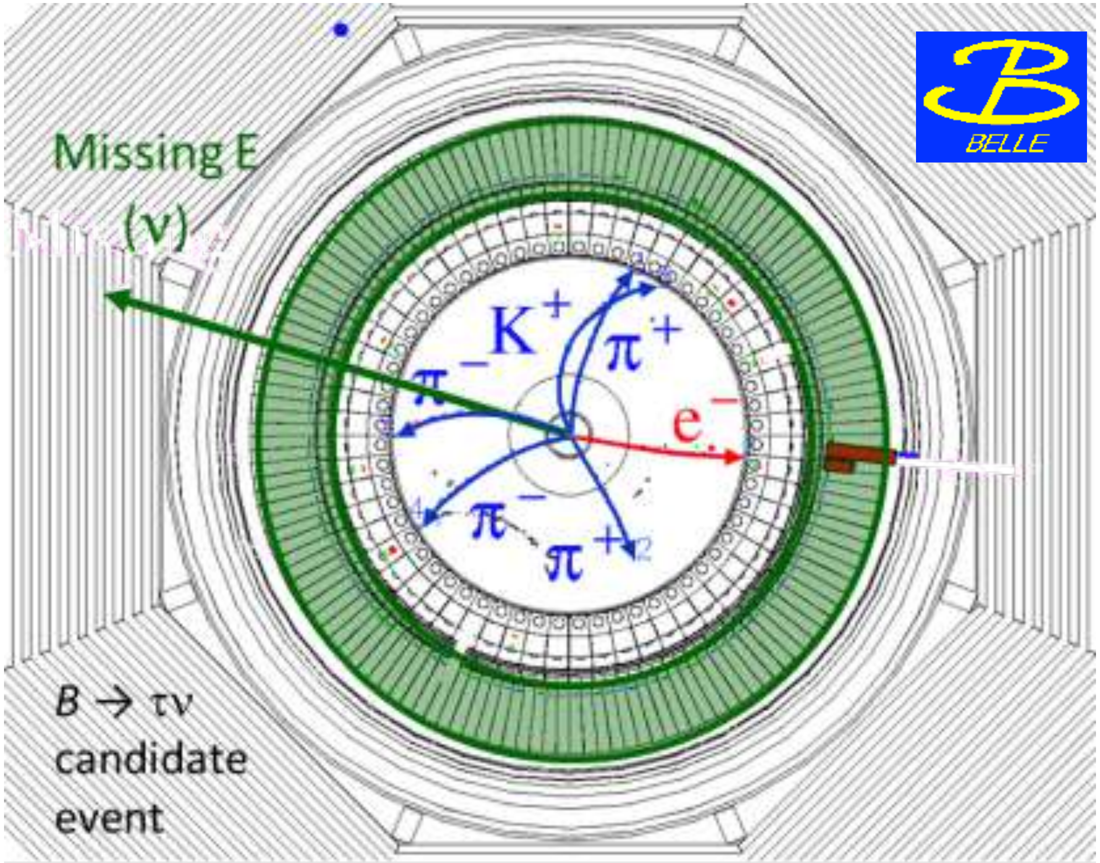
$$\mathcal{B}(\overline{B}^0 \to D^{*+} \ell^- \overline{\nu}_l) = (4.59 \pm 0.05_{\text{stat}} \pm 0.18_{\text{syst}} \pm 0.45_{\pi_s})\ \%$$

At w=1 (zero recoil), a nearly model independent determination of $|V_{cb}|$ is possible.

https://arxiv.org/abs/2008.07198
BELLE2-CONF-2020-022

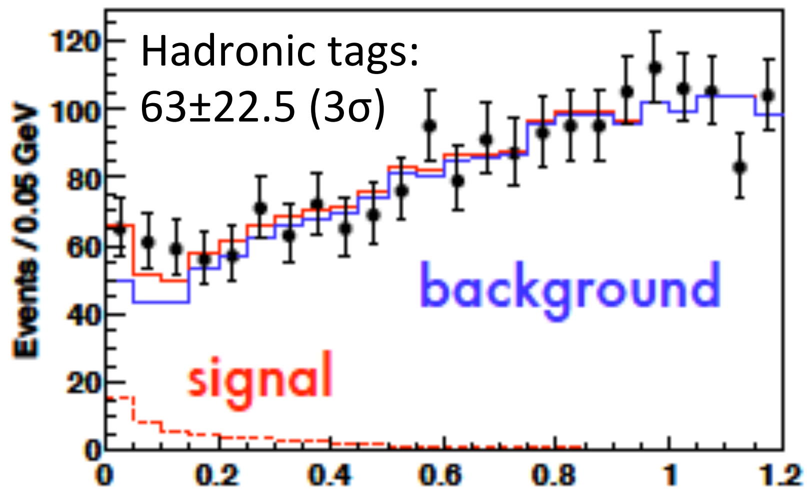
Example of a Missing Energy Decay (B→τν) *in old Belle Data* (recorded before 2010)

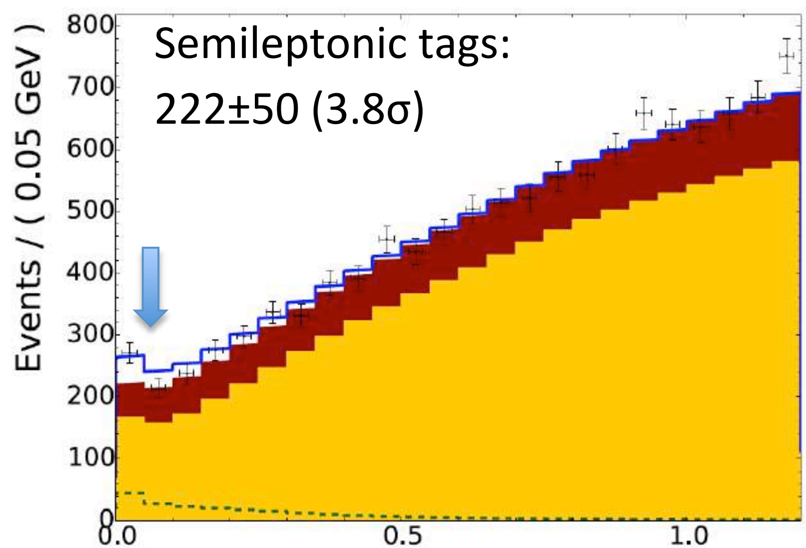
$$B^+ \to D^0 \pi^+$$
$$(\to K\pi^-\pi^+\pi^-)$$
$$B^- \to \tau(\to e\nu\bar{\nu})\nu$$

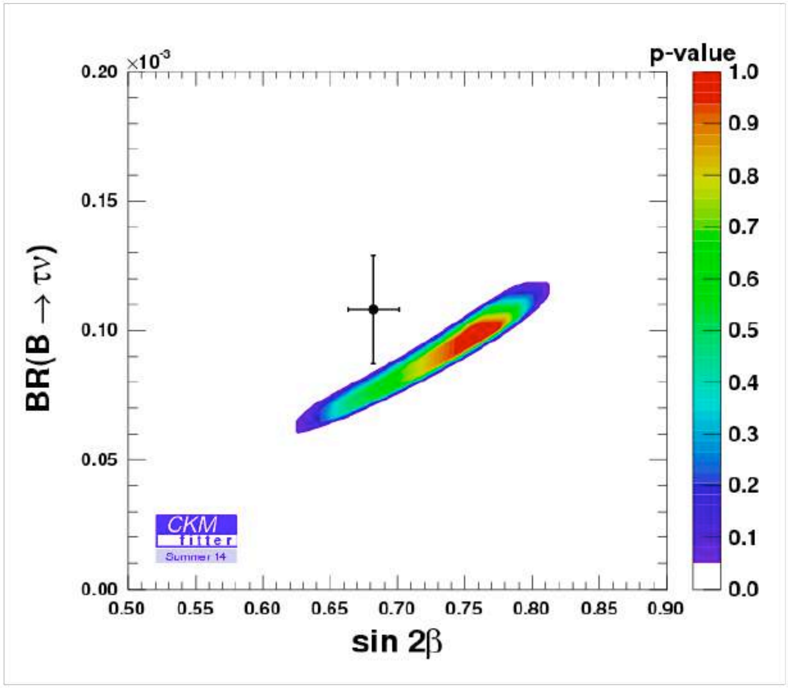


The clean e+e- environment (and the CsI(Tl) crystal calorimeter) makes this possible.

Example: old Belle B→τν results with full *reprocessed* data sample: either hadronic or semileptonic tags (PRD 92, 051102 (2015))



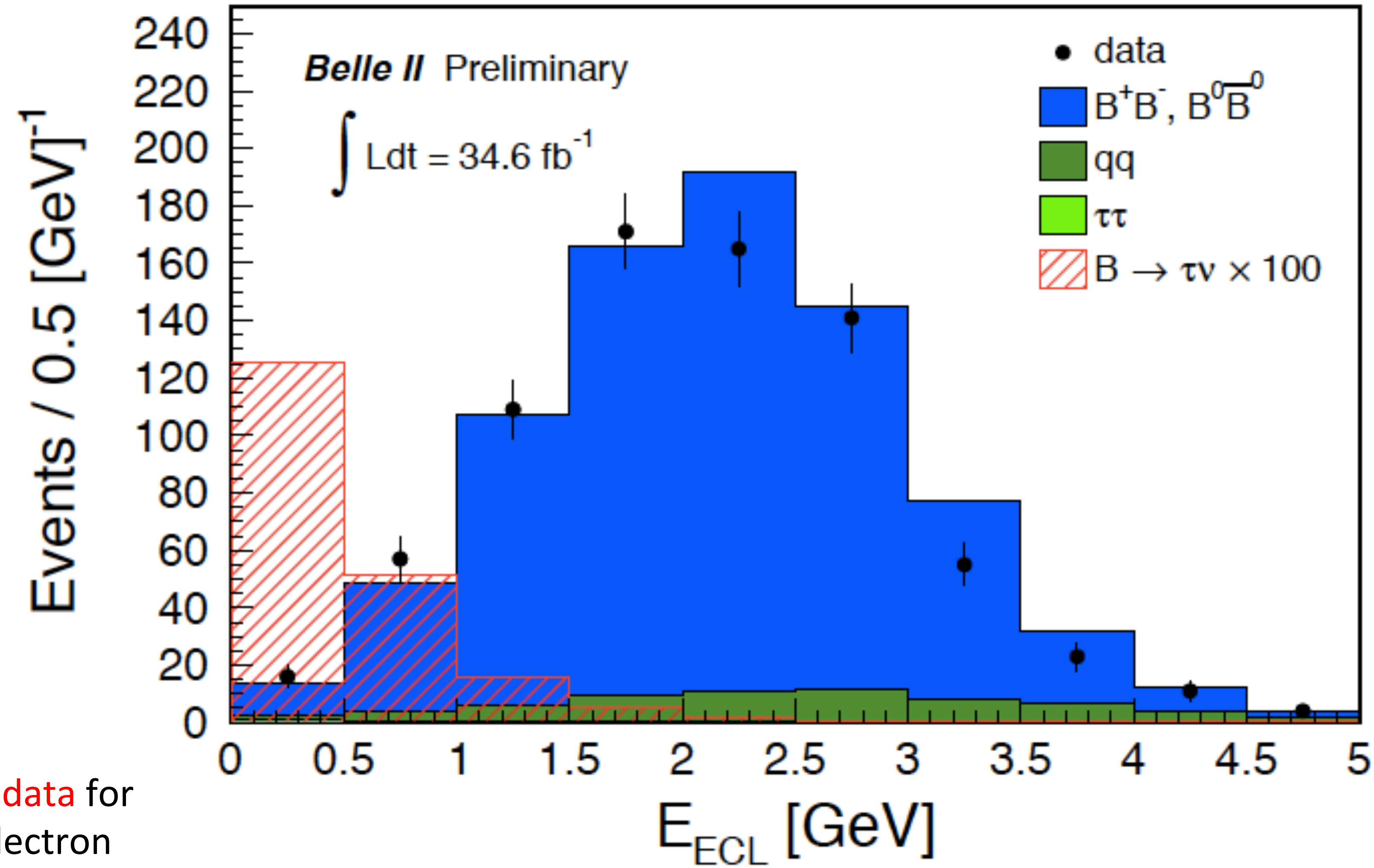




With the full B factory statistics only "evidence". No single observation from either Belle or BaBar.

➔The horizontal axis is the "Extra Calorimeter Energy" or E_{ECL}

E_{ECL} (extra energy in the calorimeter) is one of the critical variables for $B \to \tau\nu$. FAQ: Does this work for Belle II ?

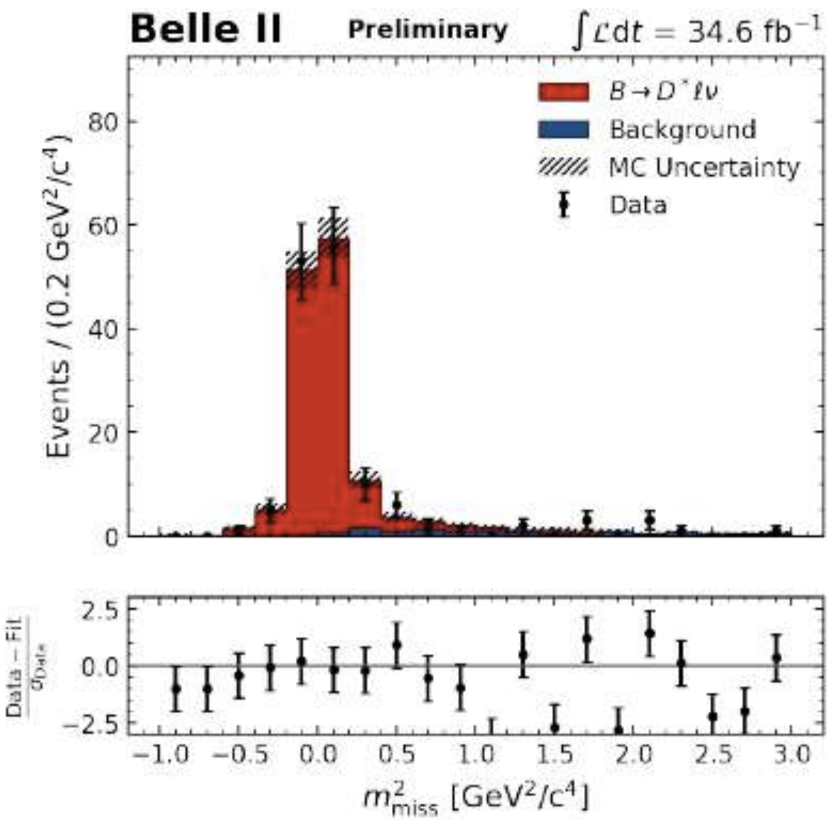


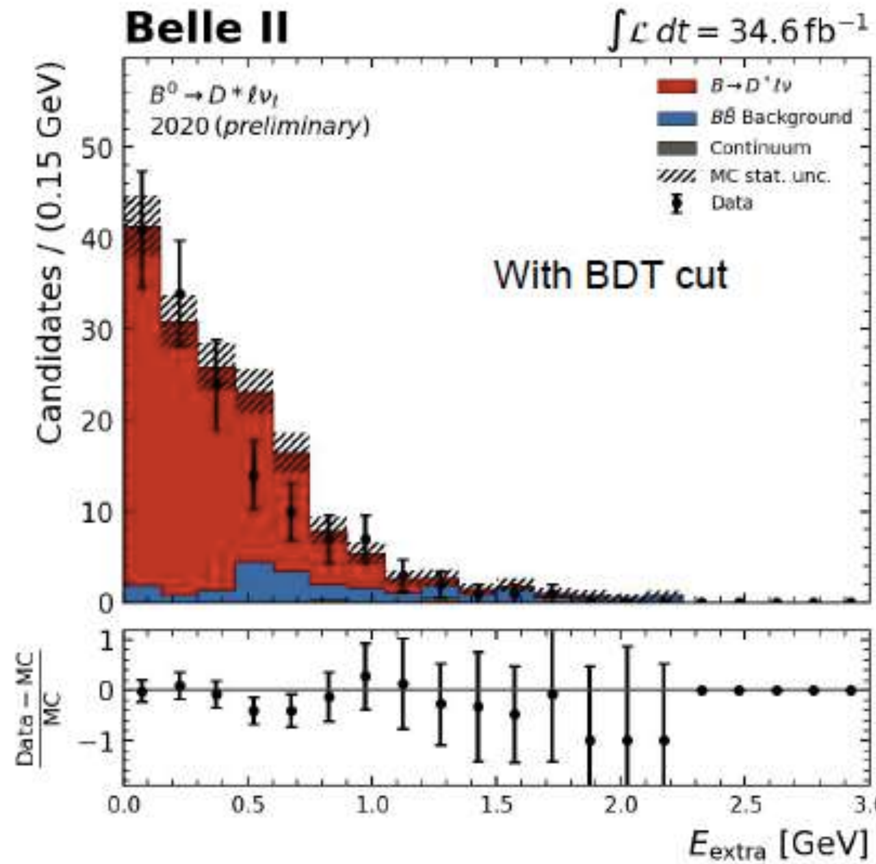
Check in data for the τ→electron channel and with FEI.

BELLE2-CONF-2020-027

FAQ: E_{ECL}, Does this work for Belle II ?
Verification of E_{ECL} in data using $B^0 \rightarrow D^{*-} l^+ \nu_l$ with FEI

Low background with FEI



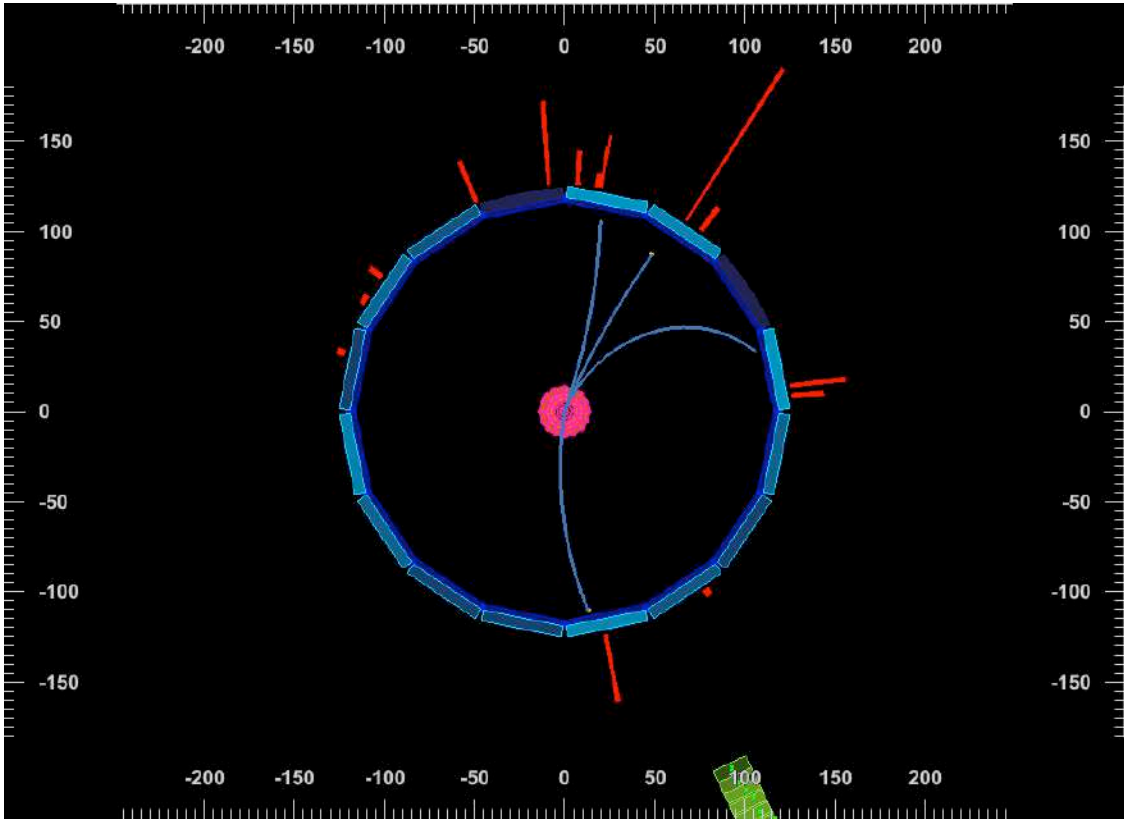


$$\mathcal{B}(\overline{B}^0 \rightarrow D^{*+}\ell^-\overline{\nu}_l) = (4.45 \pm 0.40_{\rm stat} \pm 0.53_{\rm syst})\ \%$$

BELLE2-CONF-2020-023

https://arxiv.org/abs/2008.10299

tau and charm physics highlight(s)

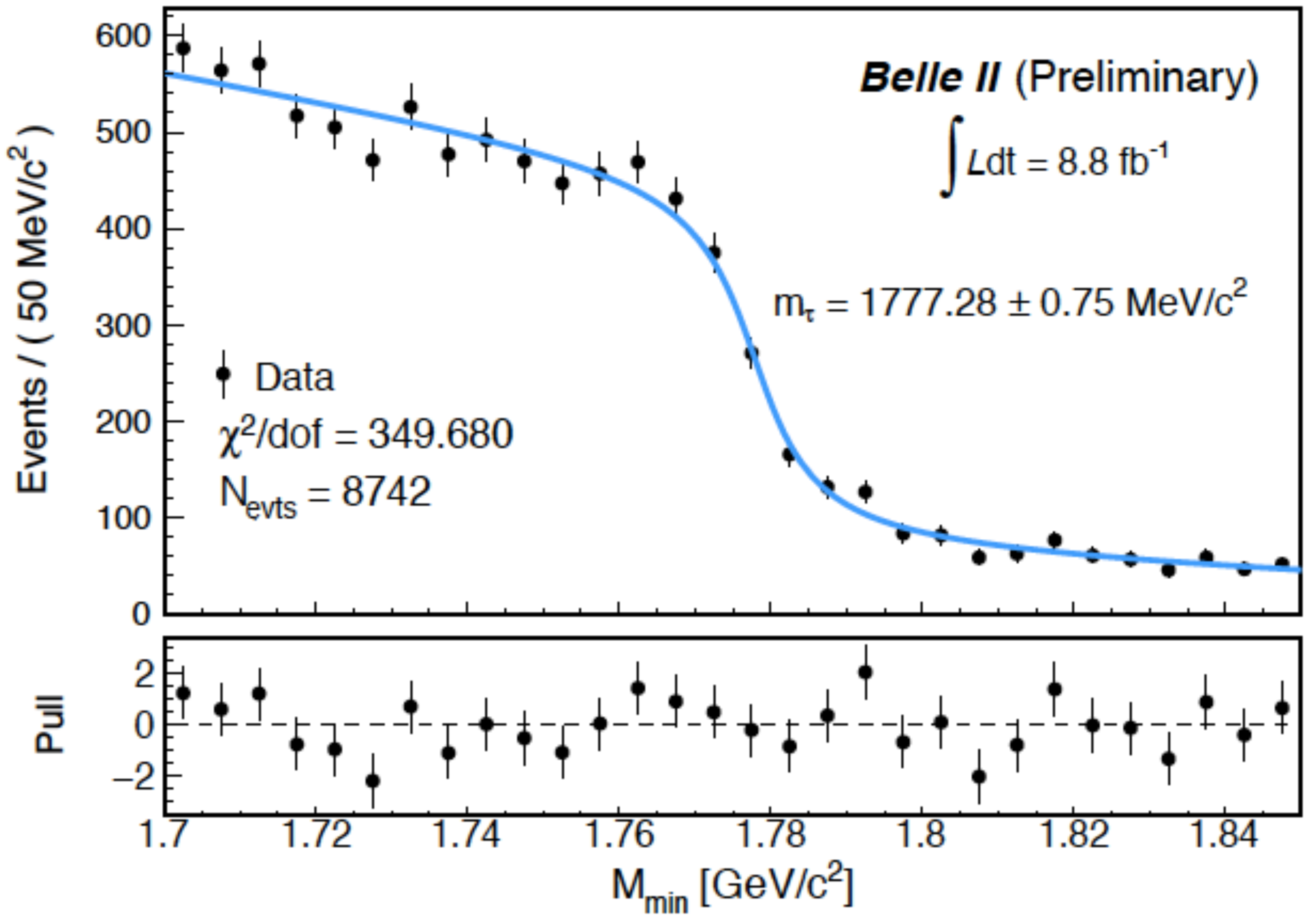


An example of a 1-prong vs 3 prong e+e- $\rightarrow \tau^{+} \tau^{-}$ at Belle II

At least two neutrinos are missing.

Tau Mass Measurement

Use 1 prong vs 3-prong tau pair events from e+e- →$\tau^+ \tau^-$



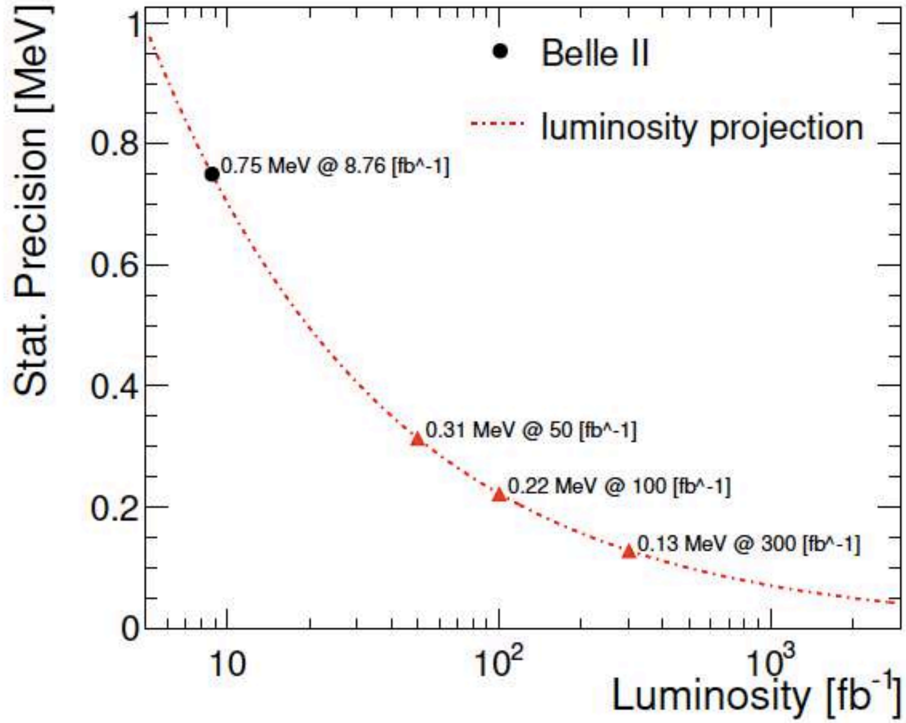
$$M_{\min} = \sqrt{M_{3\pi}^2 + 2(E_{\text{beam}} - E_{3\pi})(E_{3\pi} - P_{3\pi})} \leq m_\tau$$

$$m(\tau) = 1777.28 \pm 0.75(stat) \pm 0.33(sys)\,\text{MeV/c}^2$$

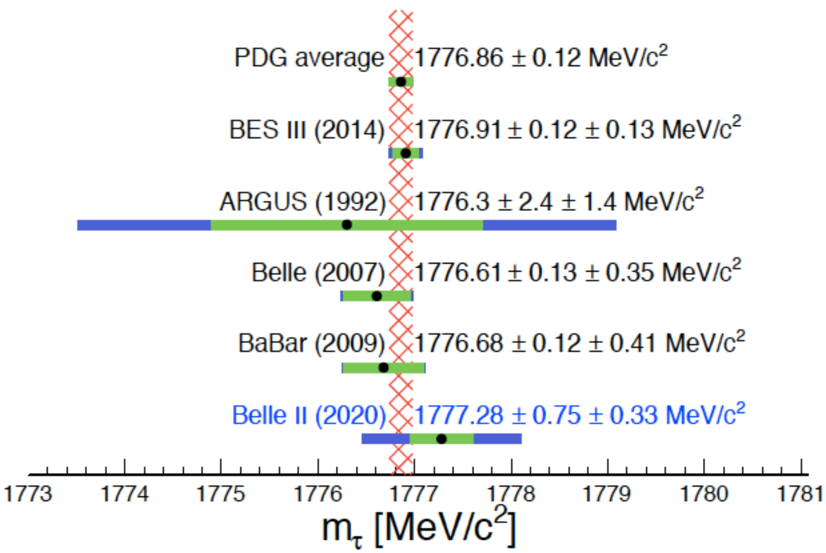
BELLE2-CONF-2020-024

https://arxiv.org/abs/2008.04665

Systematic uncertainty	MeV/c^2
Momentum shift due to the B-field map	0.29
Estimator bias	0.12
Choice of p.d.f.	0.08
Fit window	0.04
Beam energy shifts	0.03
Mass dependence of bias	0.02
Trigger efficiency	≤ 0.01
Initial parameters	≤ 0.01
Background processes	≤ 0.01
Tracking efficiency	≤ 0.01
Decay model	-



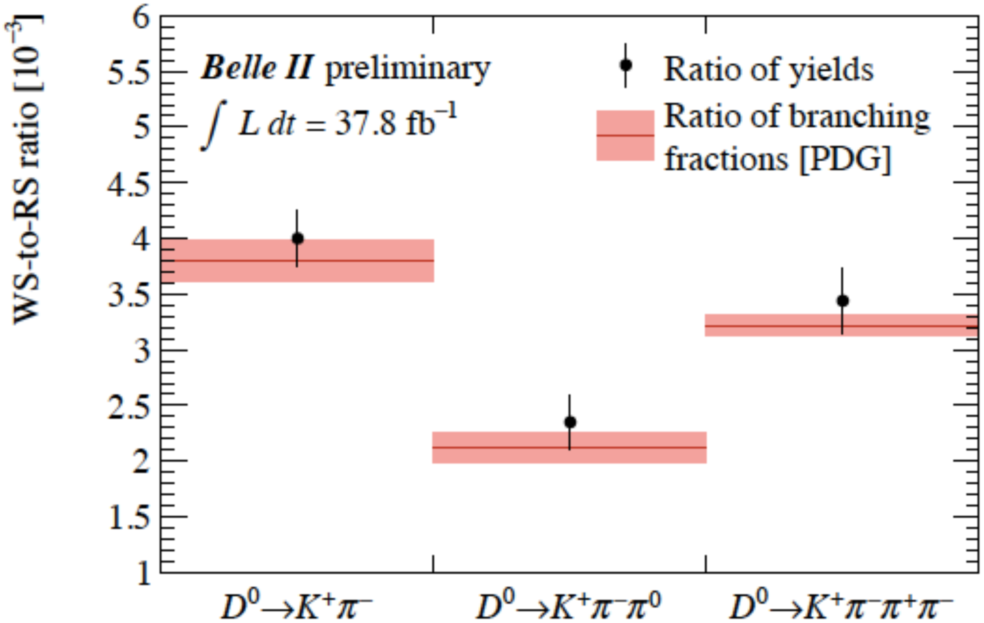
Currently BESIII dominates the world average.

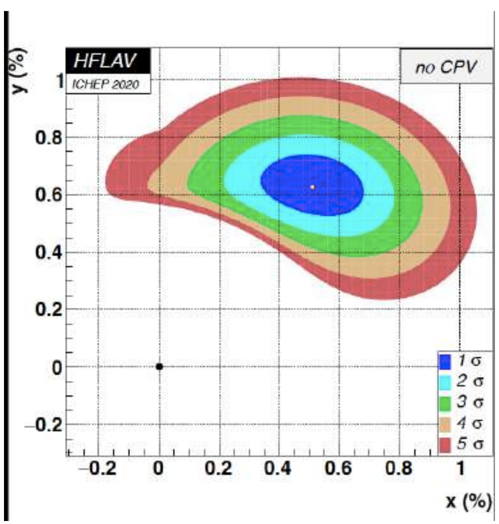


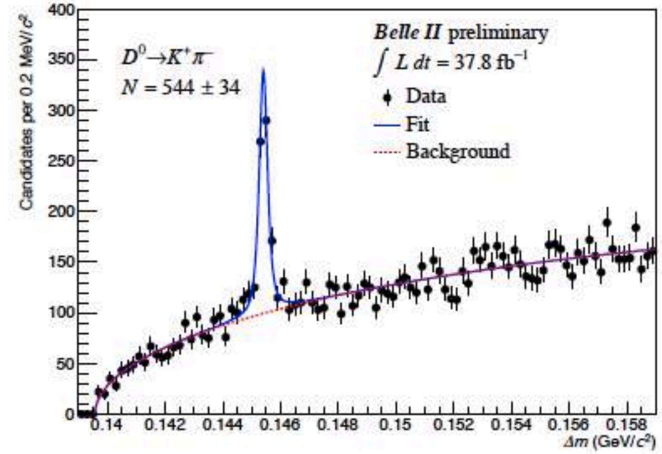
BELLE2-CONF-2020-024

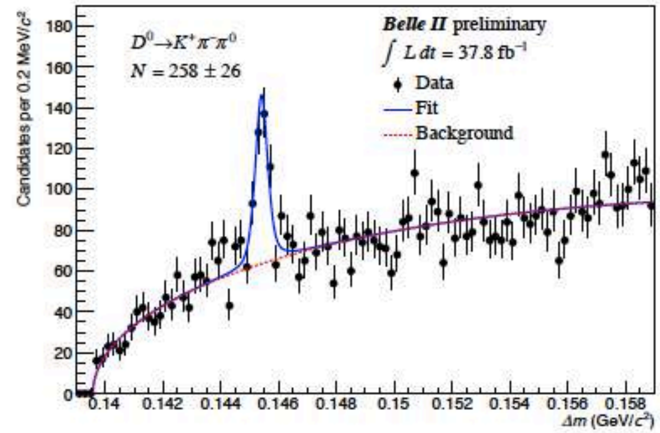
https://arxiv.org/abs/2008.04665

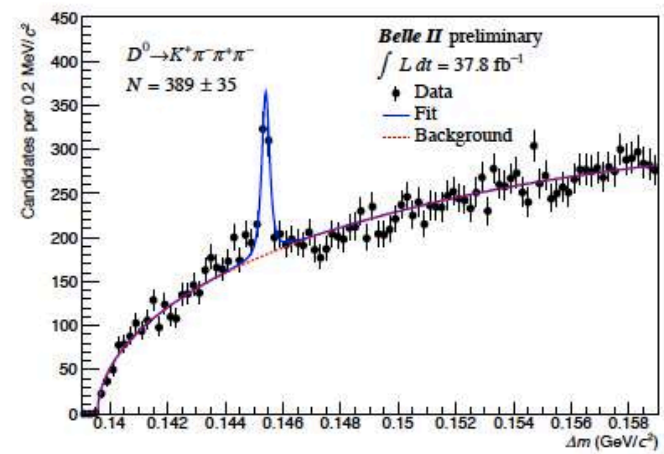
Three wrong-sign D decay modes clearly observed. These can be used for D-Dbar mixing measurements in the future.



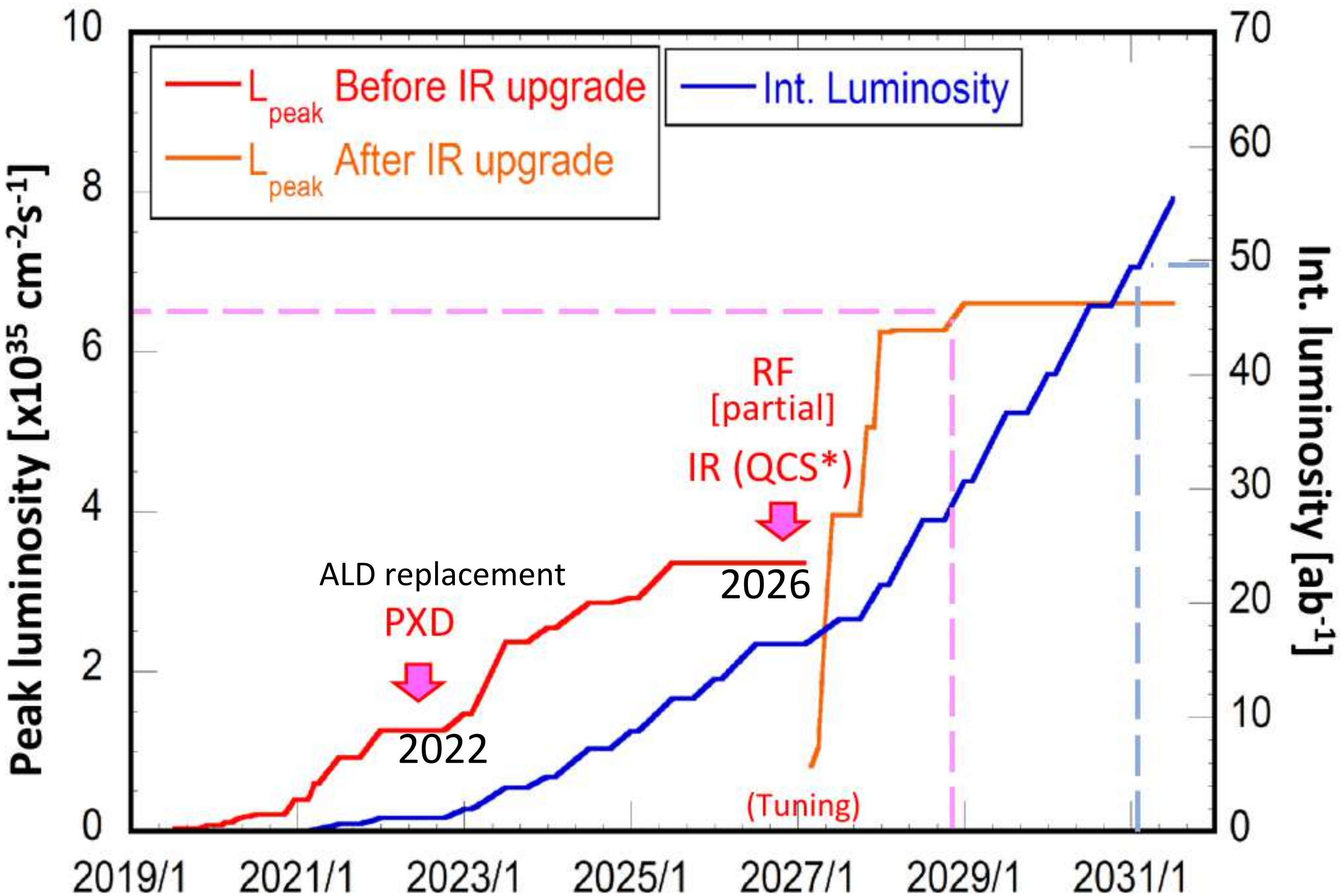








Updated plan for SuperKEKB (Roadmap 2020)



Two steps: *Intermediate luminosity* (1-2 x 10^{35} /cm^2/sec, 5-10 ab^{-1});
High Luminosity (6.5 x 10^{35}/cm^2/sec, 50 ab^{-1}) with a detector upgrade
Future steps: Polarization Upgrade, Advanced R&D
Ultra high luminosity (4 x 10^{36}/cm^2/sec, 250 ab^{-1}), R&D Project

Backup slides

https://arxiv.org/abs/1808.10567

Outcome of the B2TIP (Belle II Theory Interface) Workshops (2014-2018)
Emphasis is on New Physics (NP) reach.

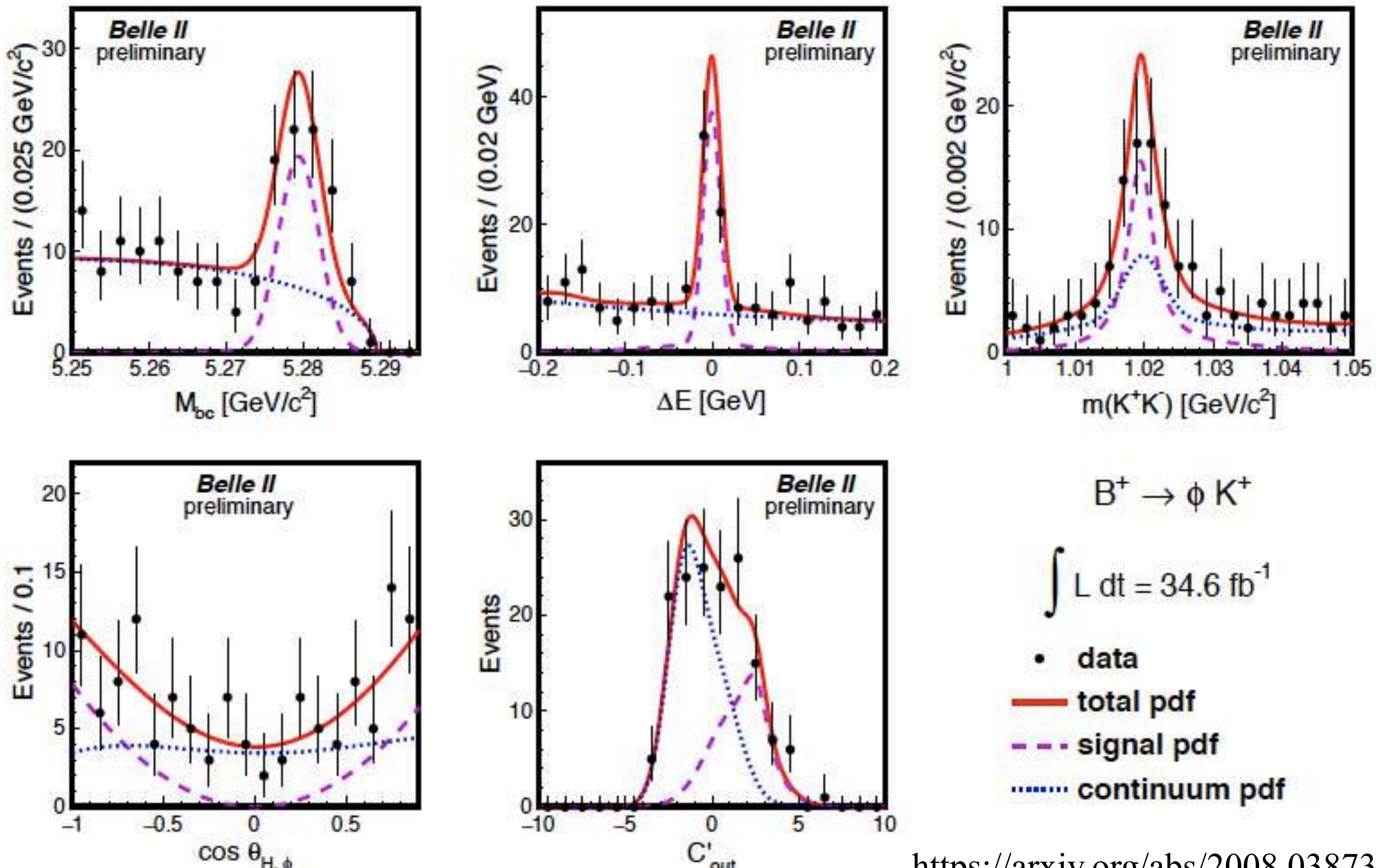
Strong participation from theory community,
lattice QCD community and Belle II experimenters.
689 pages, published by Oxford University Press

First steps toward realizing this program at ICHEP2020 in Prague, Czech Republic

The Belle II Physics Book

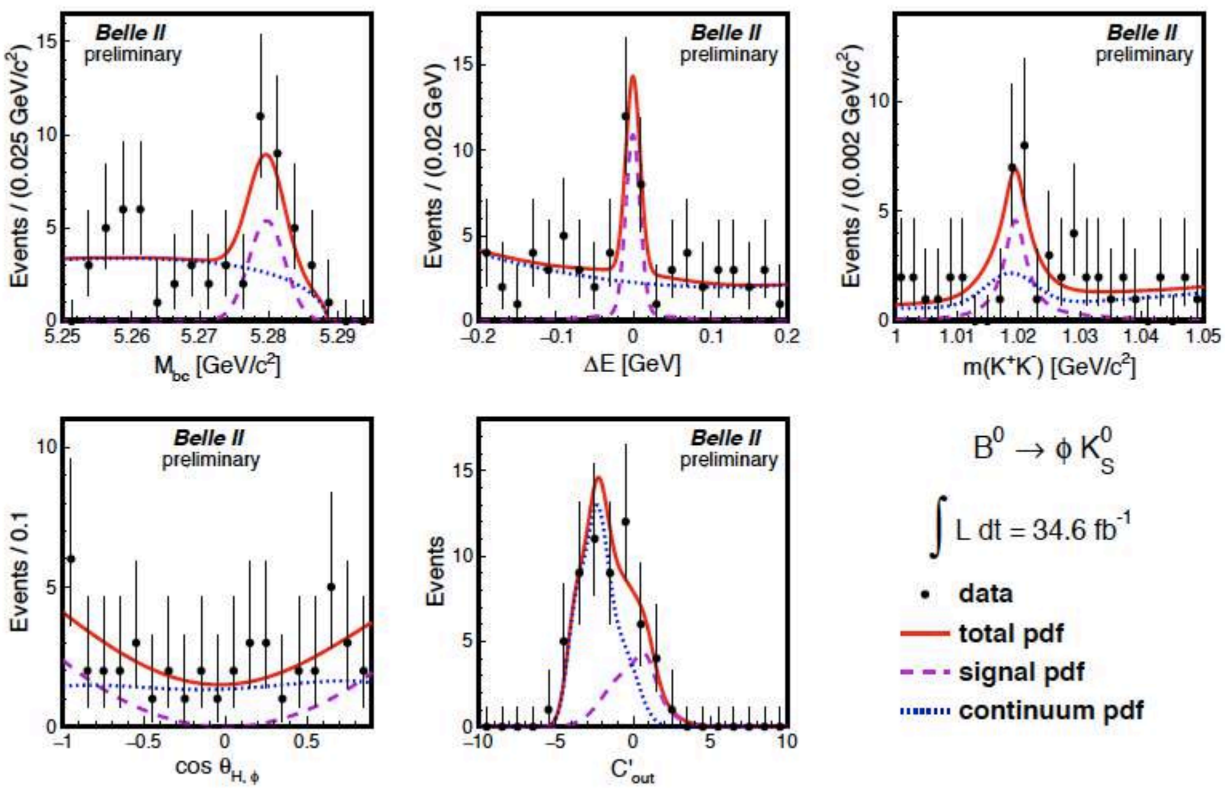
E. Kou[74,¶,†], P. Urquijo[143,§,†], W. Altmannshofer[133,¶], F. Beaujean[78,¶], G. Bell[120,¶], M. Beneke[112,¶], I. I. Bigi[146,¶], F. Bishara[148,16,¶], M. Blanke[49,50,¶], C. Bobeth[111,112,¶], M. Bona[150,¶], N. Brambilla[112,¶], V. M. Braun[43,¶], J. Brod[110,133,¶], A. J. Buras[113,¶], H. Y. Cheng[44,¶], C. W. Chiang[91,¶], M. Ciuchini[58,¶], G. Colangelo[126,¶], H. Czyz[154,29,¶], A. Datta[144,¶], F. De Fazio[52,¶], T. Deppisch[50,¶], M. J. Dolan[143,¶], J. Evans[133,¶], S. Fajfer[107,139,¶], T. Feldmann[120,¶], S. Godfrey[7,¶], M. Gronau[61,¶], Y. Grossman[15,¶], F. K. Guo[41,132,¶], U. Haisch[148,11,¶], C. Hanhart[21,¶], S. Hashimoto[30,26,¶], S. Hirose[88,¶], J. Hisano[88,89,¶], L. Hofer[125,¶], M. Hoferichter[166,¶], W. S. Hou[91,¶], T. Huber[120,¶], S. Jaeger[157,¶], S. Jahn[82,¶], M. Jamin[124,¶], J. Jones[102,¶], M. Jung[111,¶], A. L. Kagan[133,¶], F. Kahlhoefer[1,¶], J. F. Kamenik[107,139,¶], T. Kaneko[30,26,¶], Y. Kiyo[63,¶], A. Kokulu[112,138,¶], N. Kosnik[107,139,¶], A. S. Kronfeld[20,¶], Z. Ligeti[19,¶], H. Logan[7,¶], C. D. Lu[41,¶], V. Lubicz[151,¶], F. Mahmoudi[140,¶], K. Maltman[171,¶], S. Mishima[30,¶], M. Misiak[164,¶],

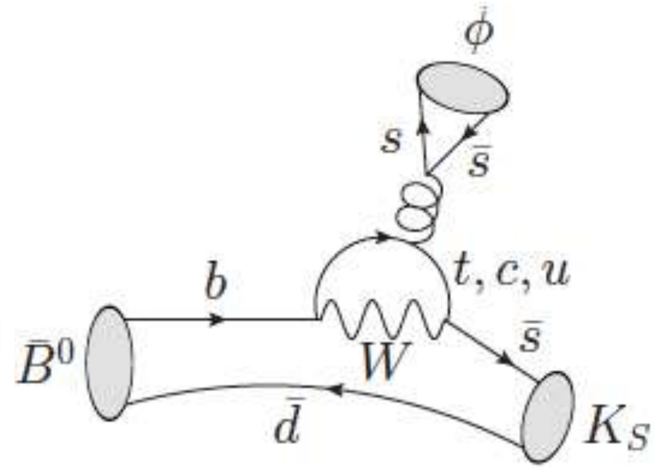
Rediscovery of B→ϕ K^+ mode



https://arxiv.org/abs/2008.03873

Rediscovery of B→ϕ K_S (a b→s CP eigenstate)



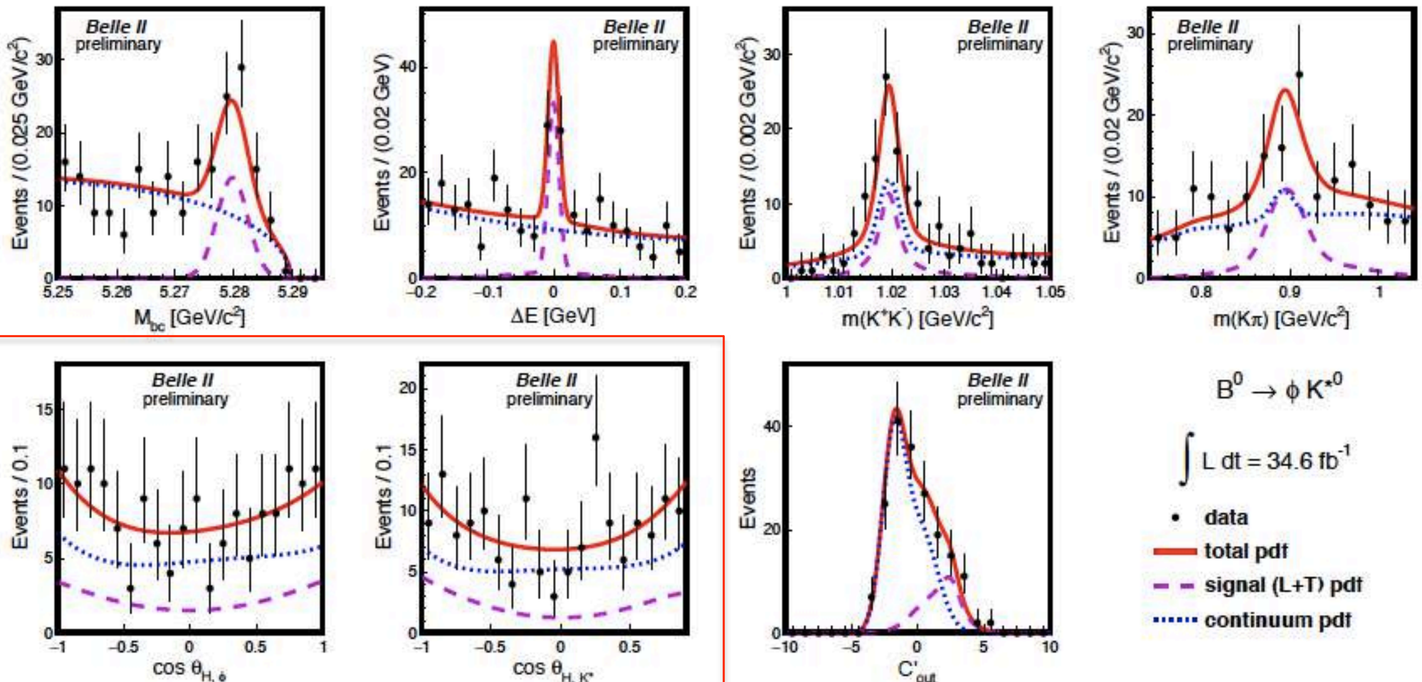


Here is the dominant b→s gluon transition.

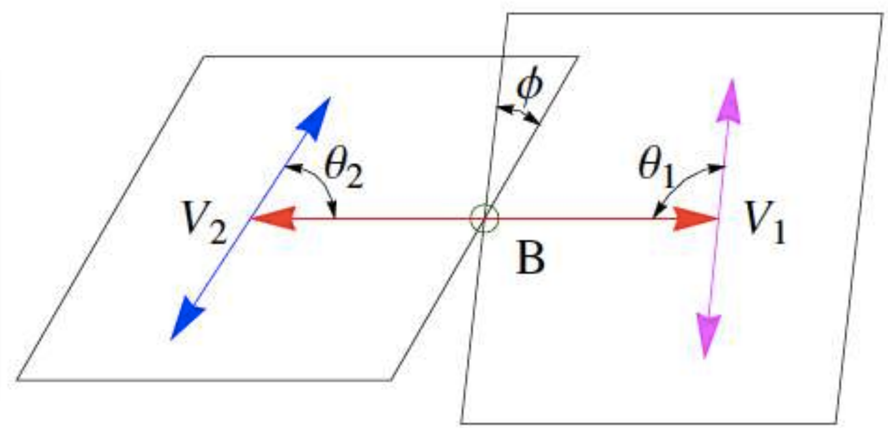
https://arxiv.org/abs/2008.03873

Polarization in B→V V penguin mode: B→φ K^{*0}

https://arxiv.org/abs/2008.03873



Rediscovery: The fraction of longitudinal polarization (f_L~0.5) rather than fully polarized (naïve QCD expectation, f_L~1).



Summary of B→φ K^(*) Results

Table 5: Summary of the results obtained in this analysis.

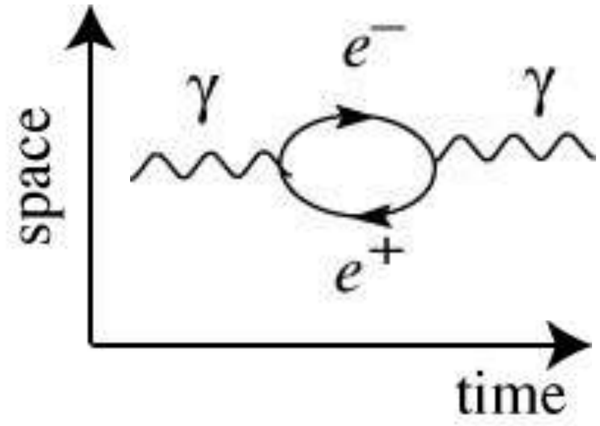
	This analysis	World Average [2]
$\mathcal{B}(\times 10^{-6})$		
ϕK^+	$6.7 \pm 1.1 \pm 0.5$	8.8 ± 0.7
ϕK^0	$5.9 \pm 1.8 \pm 0.7$	7.3 ± 0.7
$I_{\phi K}$	$1.1 \pm 0.4 \pm 0.2$	1.21 ± 0.15
ϕK^{*+}	$21.7 \pm 4.6 \pm 1.9$	10.0 ± 2.0
ϕK^{*0}	$11.0 \pm 2.1 \pm 1.1$	10.0 ± 0.5
$I_{\phi K^*}$	$2.0 \pm 0.6 \pm 0.3$	1.00 ± 0.21
f_L		
ϕK^{*+}	$0.58 \pm 0.23 \pm 0.02$	0.50 ± 0.05
ϕK^{*0}	$0.57 \pm 0.20 \pm 0.04$	0.497 ± 0.017

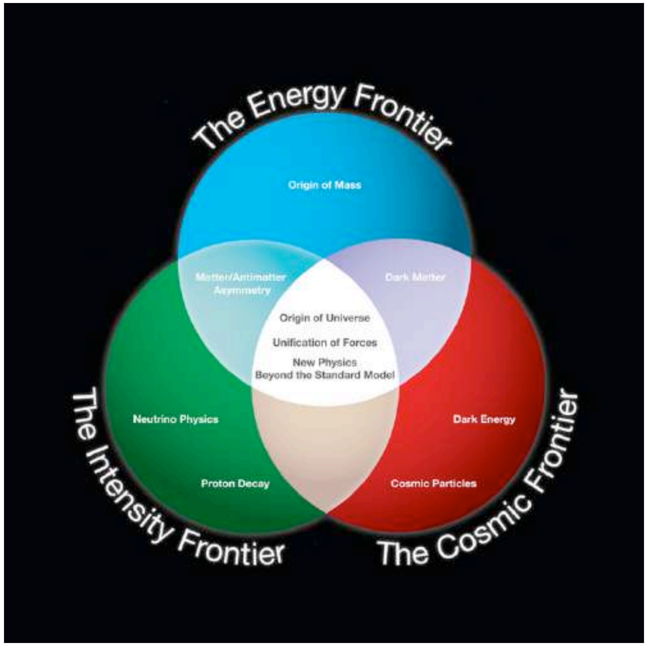
CPV studies, more advanced B->VV angular analyses for T violation and right-handed currents are possible with more data.

BELLE2-CONF-2020-20

https://arxiv.org/abs/2008.03873

NP: Quantum Mechanical (QM) Finesse versus Brute Force





Energy conservation ?

$$\Delta E \Delta t \geq \hbar / 2$$

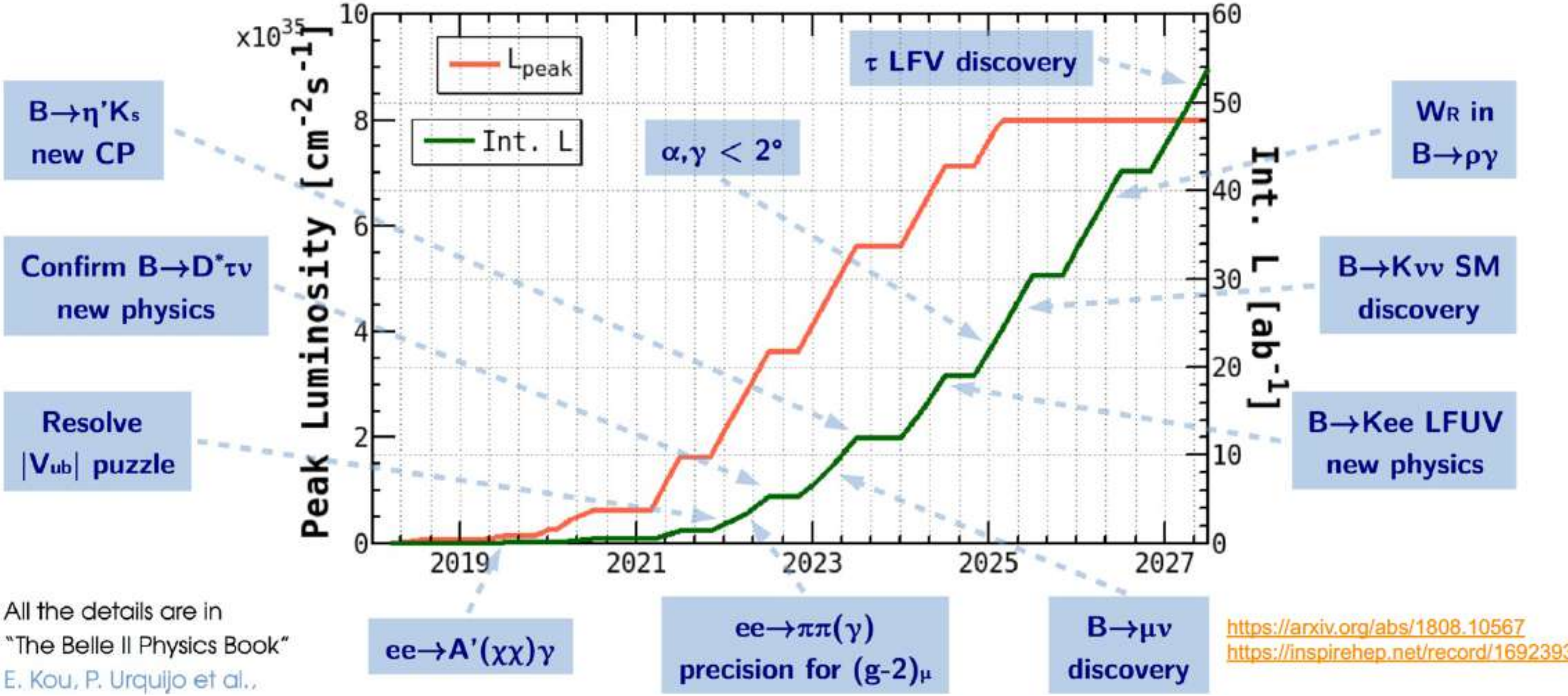
<u>Banking Analogy</u> (may be easier to understand):
At the Heisenberg Quantum Mechanical bank, customers with no collateral may take out billion Euro loans if they return the full loan within a billionth of a second.

If a *beautiful but rare* customer takes out such huge loans very frequently, the bank will take notice. *Looks odd (or asymmetric) in the bank's special full length mirror.*

N.B. Sometimes it is much better to have a large collateral and pay back the loan *directly* after a longer time.

Werner Heisenberg, Physicist and QM banker

Long term prospects of Belle II (based on the Belle II physics book).

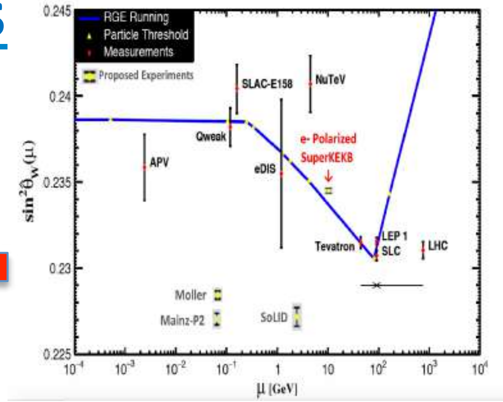


All the details are in
"The Belle II Physics Book"
E. Kou, P. Urquijo et al.,

https://arxiv.org/abs/1808.10567
https://inspirehep.net/record/1692393/

Visualization by
F. Forti

Upgrading SuperKEKB with Polarized e- Beams



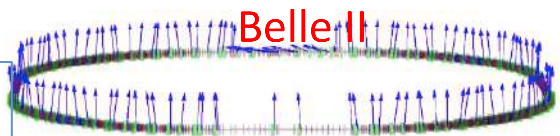
Physics case: precision $\sin^2 \theta_W$ measurements from b, c, e, μ & τ, probing its running and universality (*White Paper in Preparation by M. Roney*).

Planning 70% polarization with 80% polarized source.

NEW HARDWARE FOR POLARIZATION UPGRADE:

- **Low emittance polarized Source:** electron helicity can be flipped bunch-to-bunch by controlling circular polarization of source laser illuminating a GaAs photocathode (à la SLC). Inject vertically polarized electrons into the 7 GeV e- Ring, needs low enough emittance source to be able to inject.
- **Spin rotators:** Rotate spin to longitudinal before Interaction Point (IP) in Belle II, and then back to vertical after IP using solenoidal and dipole fields
- **Compton polarimeter:** monitors longitudinal polarization with <1% absolute precision, higher for relative measurements (arXiv:1009.6178) - provides real time polarimetry. → Use tau decays from $e^+e^- \rightarrow \tau^+ \tau^-$ measured in Belle II to provide high precision absolute average polarization at IP.

Planning for implementation ~2026 in mid-decade upgrade window for new final focus; This upgrade proposal to be included in KEK Roadmap for MEXT to be submitted 2021

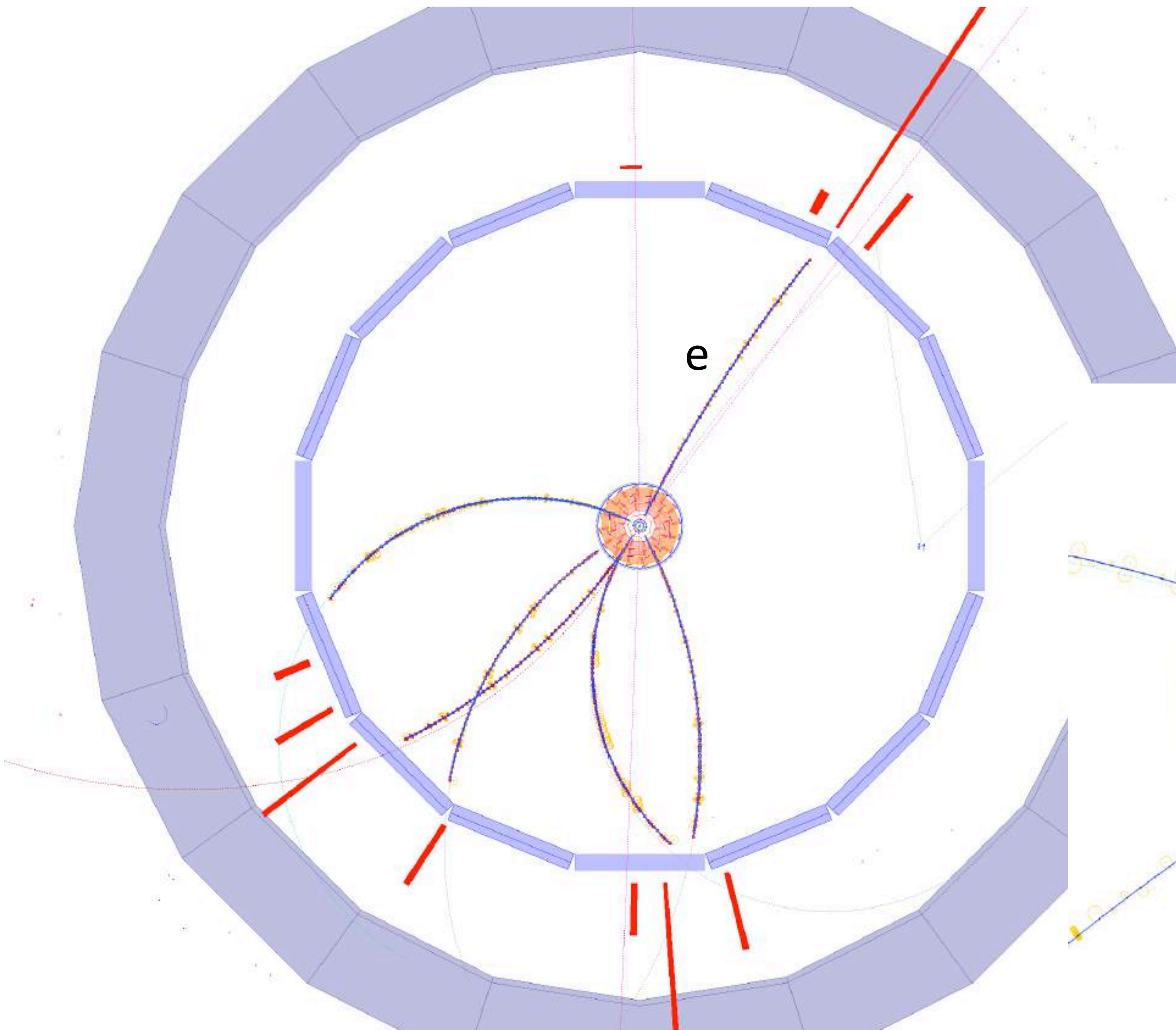


e- spin vector around ring

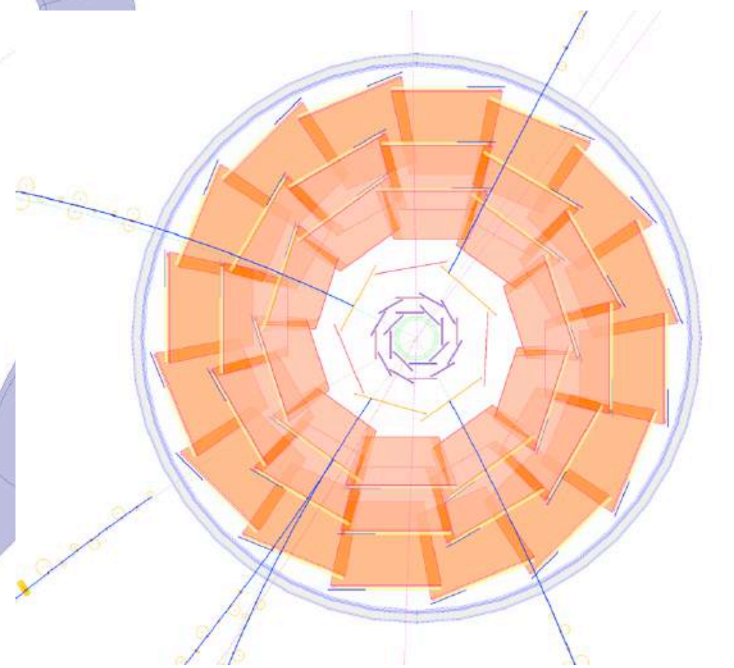
"Missing Energy Decay" in a Belle II GEANT4 MC simulation

$B \rightarrow \tau\nu$, $\tau \rightarrow e\nu\nu$ $\quad$ $B \rightarrow D\pi$, $D \rightarrow K\pi\pi\pi$

(Hermiticity and E_{ECL} critical)



Zoomed view of the vertex region



https://arxiv.org/abs/1808.10567

Outcome of the B2TIP (Belle II Theory Interface) Workshops
Emphasis is on New Physics (NP) reach.

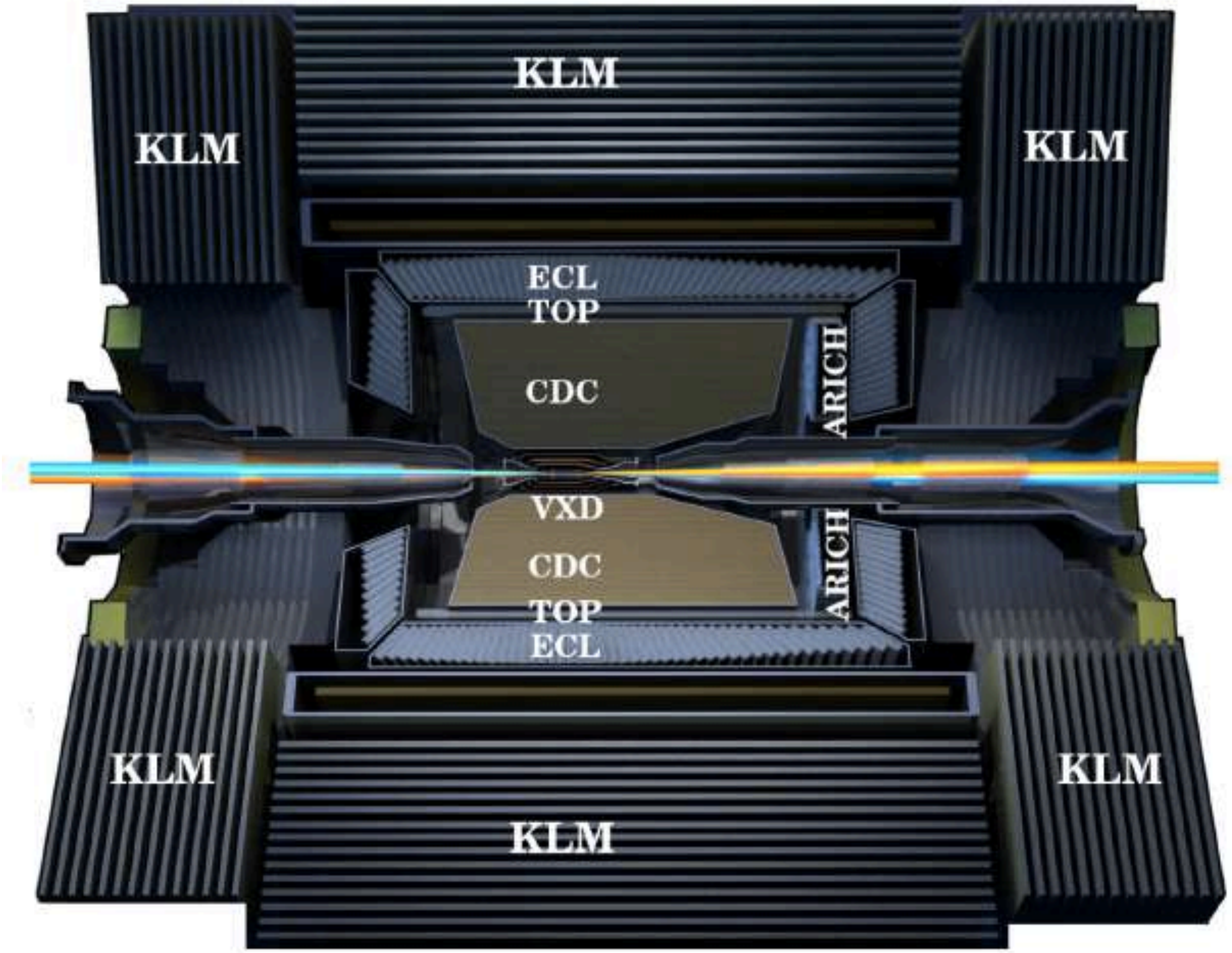
Strong participation from theory community,
lattice QCD community and Belle II experimenters.
689 pages, published by Oxford University Press

KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047
UWThPh 2018-26

The Belle II Physics Book

E. Kou[74,¶,†], P. Urquijo[143,§,†], W. Altmannshofer[133,¶], F. Beaujean[78,¶], G. Bell[120,¶], M. Beneke[112,¶], I. I. Bigi[146,¶], F. Bishara[148,16,¶], M. Blanke[49,50,¶], C. Bobeth[111,112,¶], M. Bona[150,¶], N. Brambilla[112,¶], V. M. Braun[43,¶], J. Brod[110,133,¶], A. J. Buras[113,¶], H. Y. Cheng[44,¶], C. W. Chiang[91,¶], M. Ciuchini[58,¶], G. Colangelo[126,¶], H. Czyz[154,29,¶], A. Datta[144,¶], F. De Fazio[52,¶], T. Deppisch[50,¶], M. J. Dolan[143,¶], J. Evans[133,¶], S. Fajfer[107,139,¶], T. Feldmann[120,¶], S. Godfrey[7,¶], M. Gronau[61,¶], Y. Grossman[15,¶], F. K. Guo[41,132,¶], U. Haisch[148,11,¶], C. Hanhart[21,¶], S. Hashimoto[30,26,¶], S. Hirose[88,¶], J. Hisano[88,89,¶], L. Hofer[125,¶], M. Hoferichter[166,¶], W. S. Hou[91,¶], T. Huber[120,¶], S. Jaeger[157,¶], S. Jahn[82,¶], M. Jamin[124,¶], J. Jones[102,¶], M. Jung[111,¶], A. L. Kagan[133,¶], F. Kahlhoefer[1,¶], J. F. Kamenik[107,139,¶], T. Kaneko[30,26,¶], Y. Kiyo[63,¶], A. Kokulu[112,138,¶], N. Kosnik[107,139,¶], A. S. Kronfeld[20,¶], Z. Ligeti[19,¶], H. Logan[7,¶], C. D. Lu[41,¶], V. Lubicz[151,¶], F. Mahmoudi[140,¶], K. Maltman[171,¶], S. Mishima[30,¶], M. Misiak[164,¶],

Slide from J. Hewett/ HEPAP DOE


KLM
KLM
KLM
ECL
TOP
CDC
ARICH
VXD
ARICH
CDC
TOP
ECL
KLM
KLM
KLM

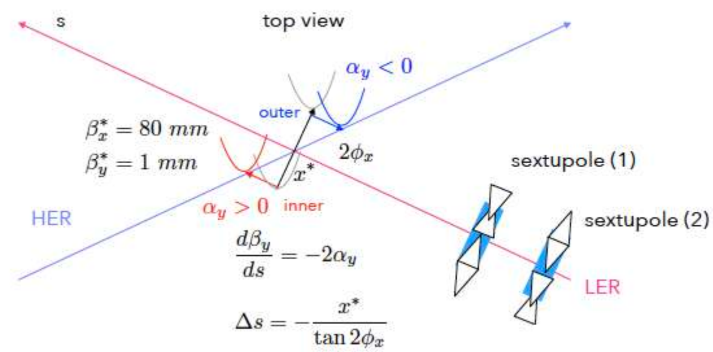
SuperKEKB Luminosity in 2020a,b

- Max current = 770mA(LER) / 660mA(HER)
- L_{peak} = 2.4 x $10^{34} cm^{-2}s^{-1}$ (world highest)
- Int. luminosity/day = 1.346 fb^{-1}/1.498 fb^{-1}
  recorded delivered

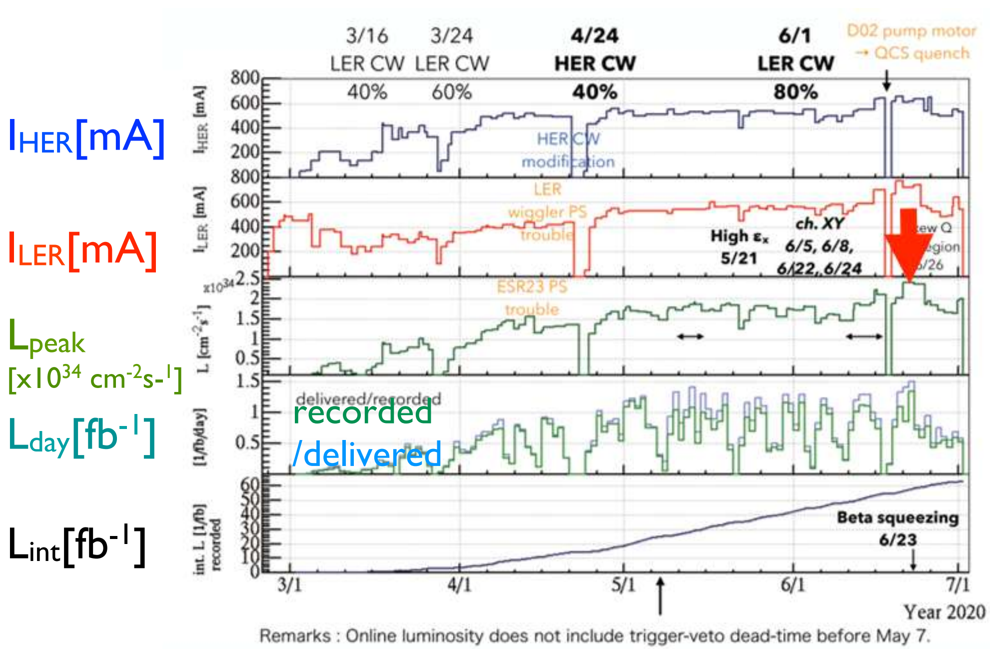
KEKB record
- L_{peak} = 2.11 x $10^{34} cm^{-2}s^{-1}$
- $L_{day}^{rec.}$ = 1.48 fb^{-1} (2009.6.14)

- LER: β_x^*/β_y^* = 80mm/1mm → 60mm/0.8mm
- HER: β_x^*/β_y^* = 60mm/1mm → 60mm/0.8mm

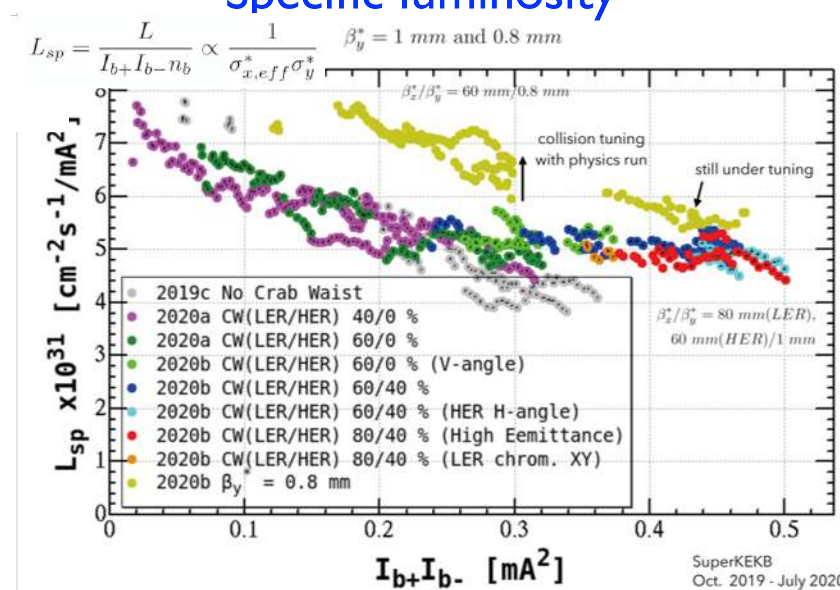
"Crab Waist" scheme



Operation history in 2020a,b



Specific luminosity



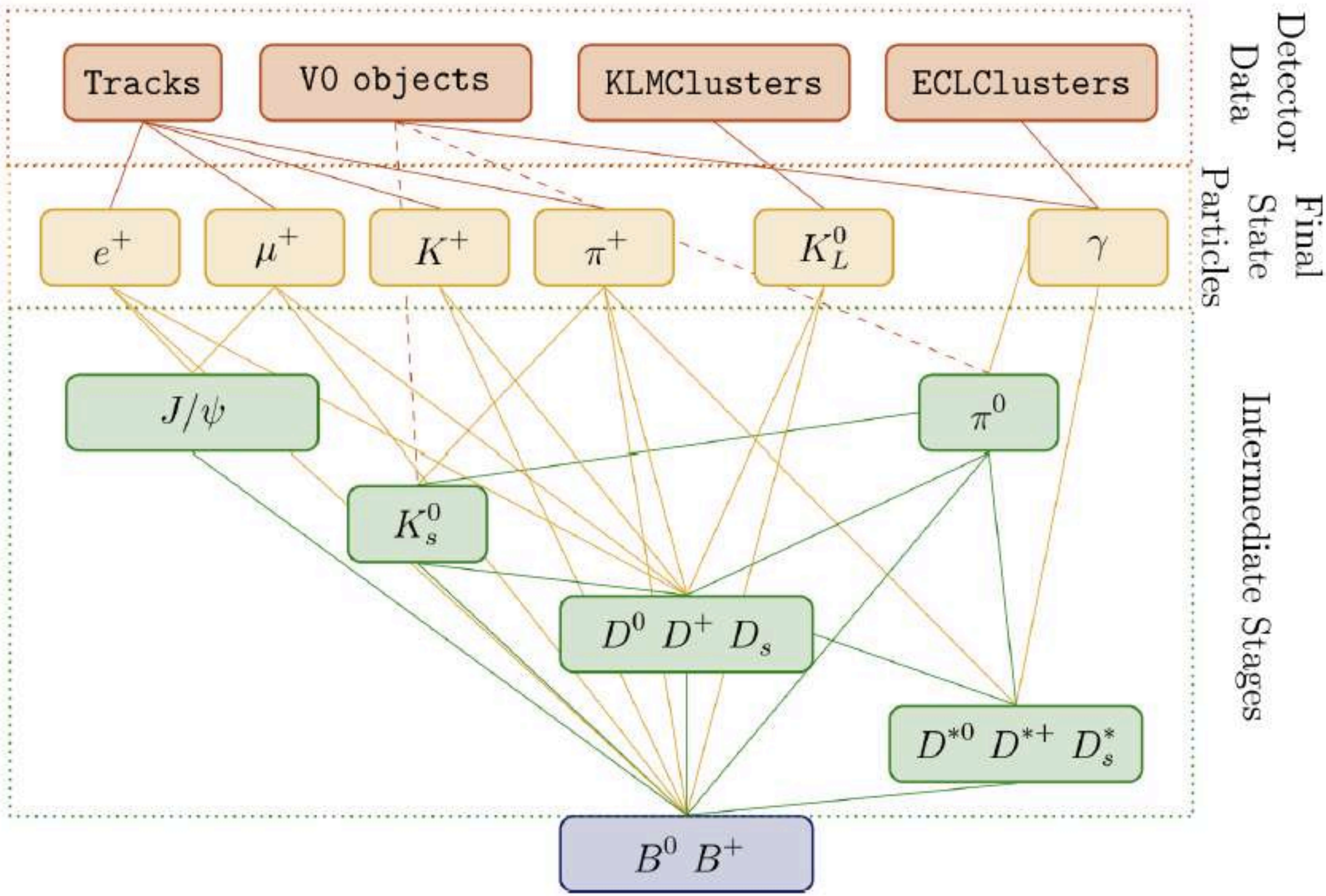


Fig. 50: Hierarchy of the Full Event Interpretation algorithm.

Table 28: Tag-side efficiency defined as the number of correctly reconstructed tag-side B mesons divided by the total number of $\Upsilon(4S)$ events. The presented efficiencies depend on the used BASF2 release (7.2), MC campaign (MC 7) and FEI training configuration.

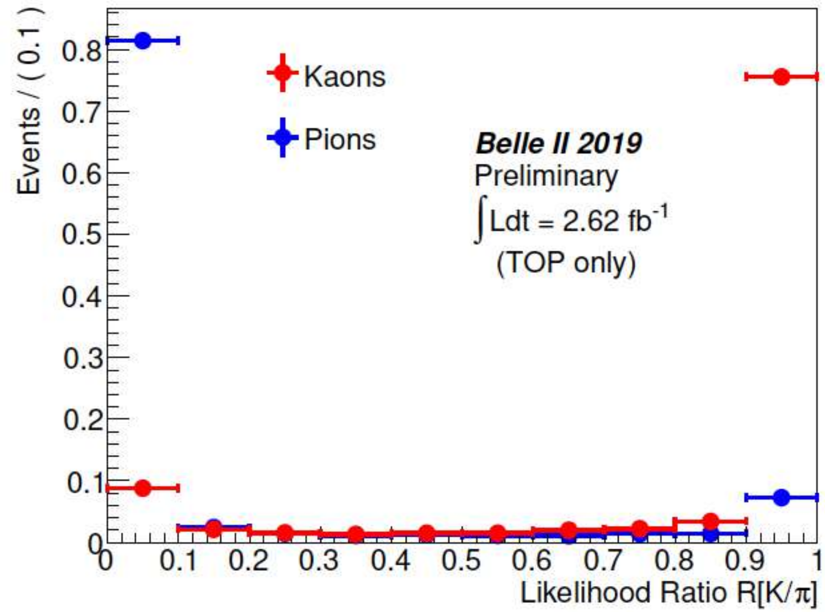
Tag	FR[10] @ Belle	FEI @ Belle MC	FEI @ Belle II MC
Hadronic B^+	0.28 %	0.49 %	0.61 %
Semileptonic B^+	0.67 %	1.42 %	1.45 %
Hadronic B^0	0.18 %	0.33%	0.34 %
Semileptonic B^0	0.63 %	1.33%	1.25 %

Here are some *results* involving charged tracks and TOP particle id in Phase 3

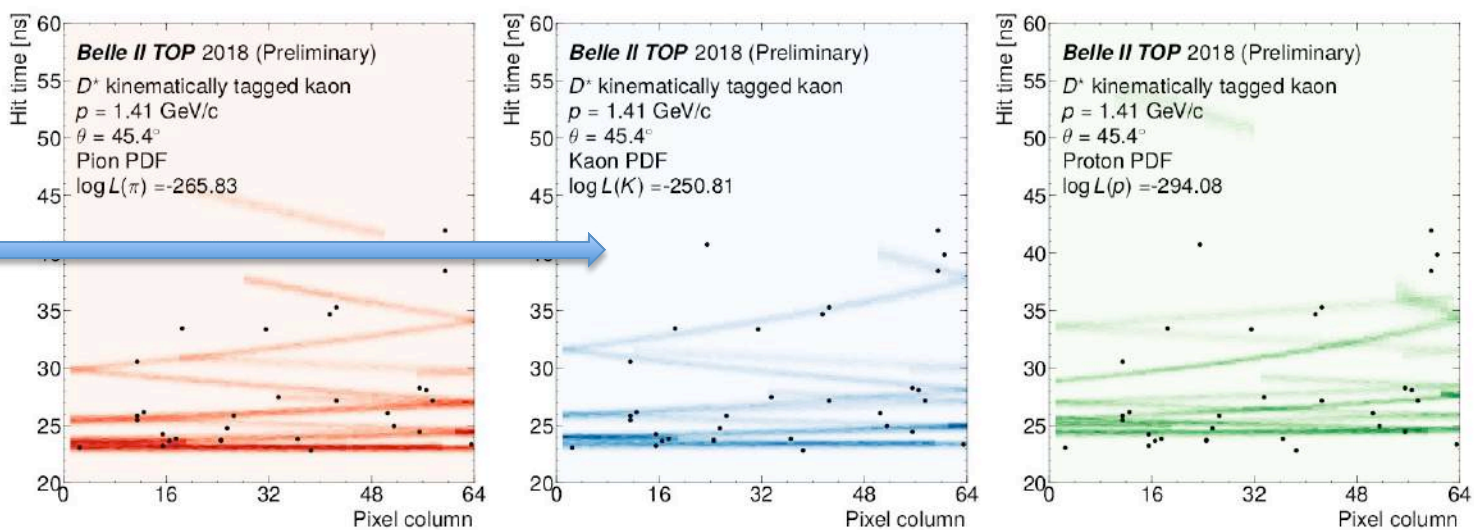
Use kinematically identified kaons and pions from D's*

$$D^{*+} \rightarrow D^0 \pi_s^{\ +} ; D^0 \rightarrow K^- \pi^+$$

Note the charge correlation between the kaon and pion and the "slow pion"



Kaon in the TOP; Cherenkov x vs t pattern



June 2020: Current High Momentum PID Performance in Belle II

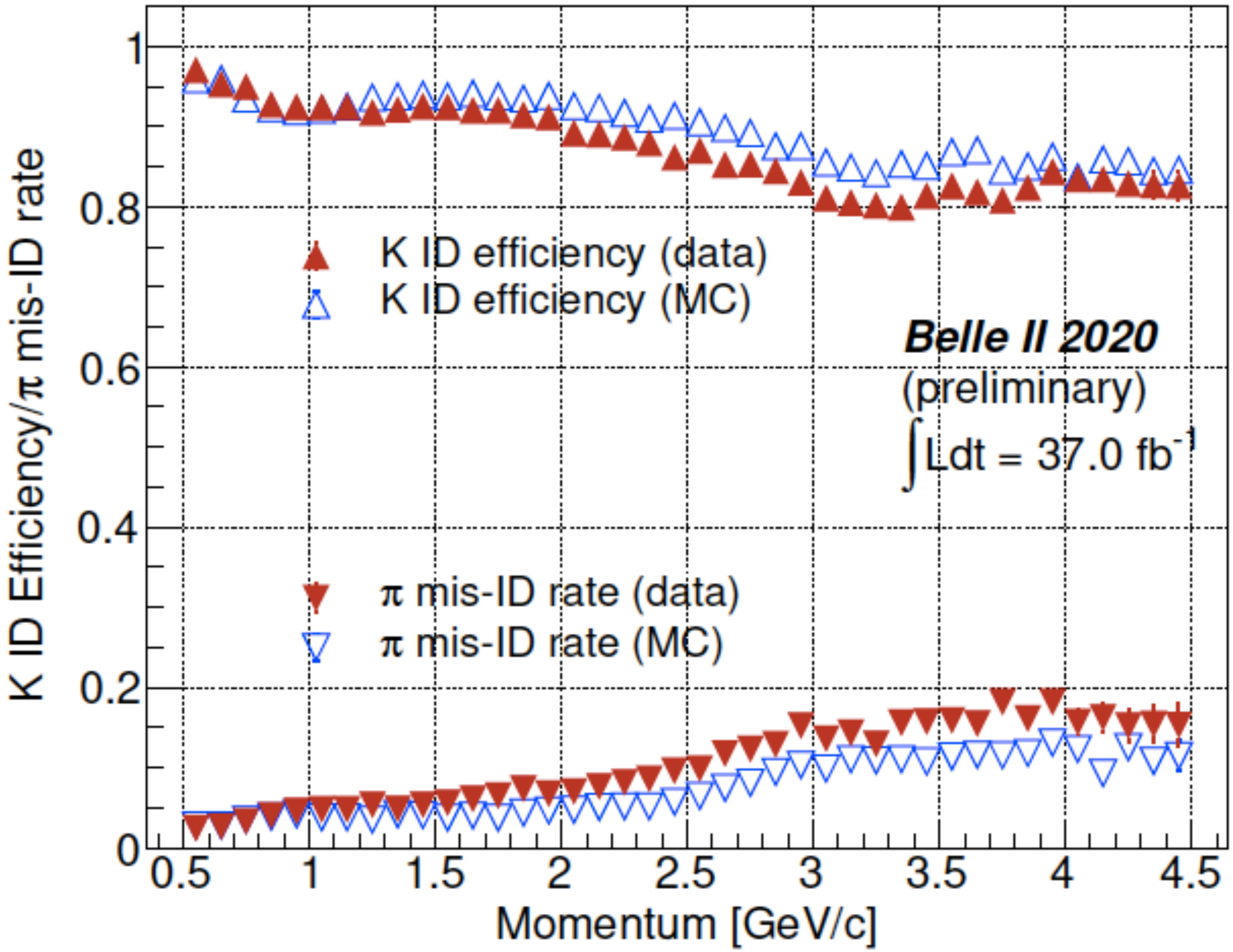


FIG. 6: Kaon efficiency and pion mis-ID rate for the PID criterion $\mathcal{R}_{K/\pi} > 0.5$ using the decay $D^{*+} \to D^0[K^-\pi^+]\pi^+$ in the bins of laboratory frame momentum of the tracks which produces atleast produce hit in ARICH or TOP detector.

June 2020: Current PID Performance in Belle II

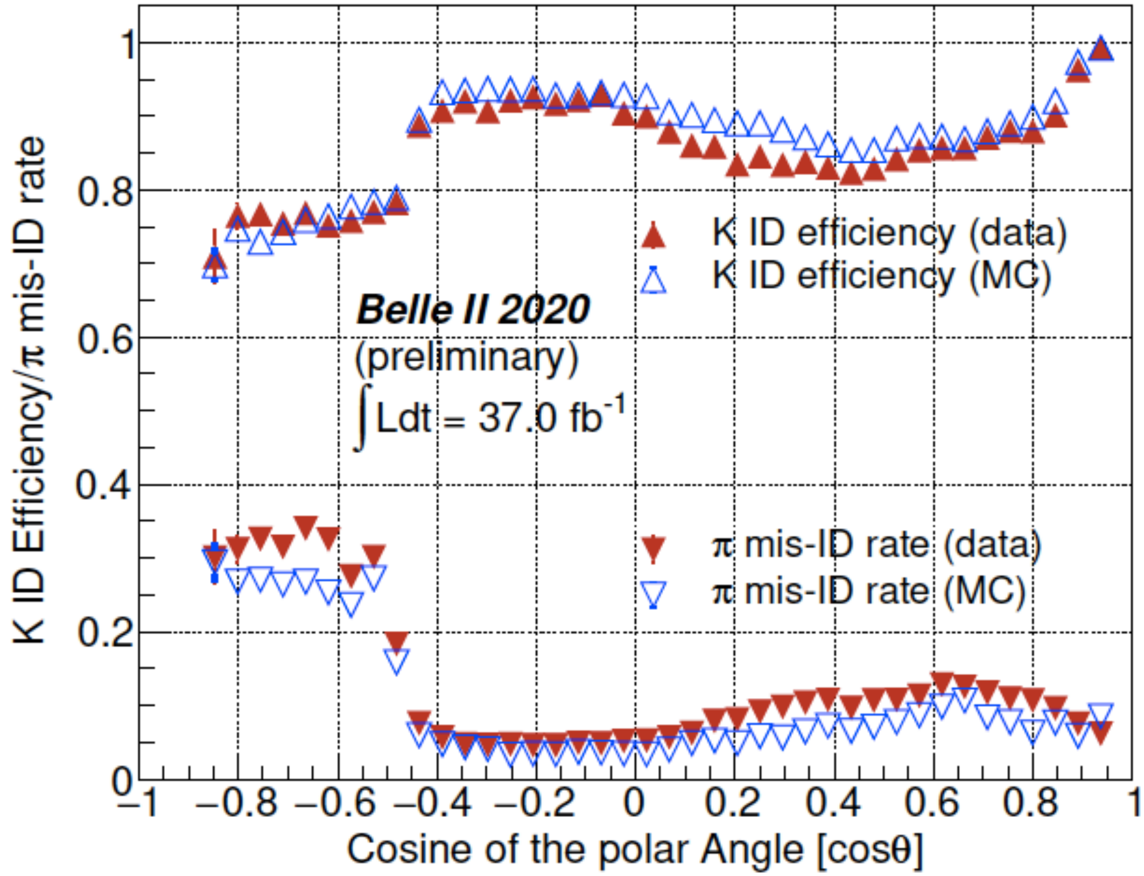
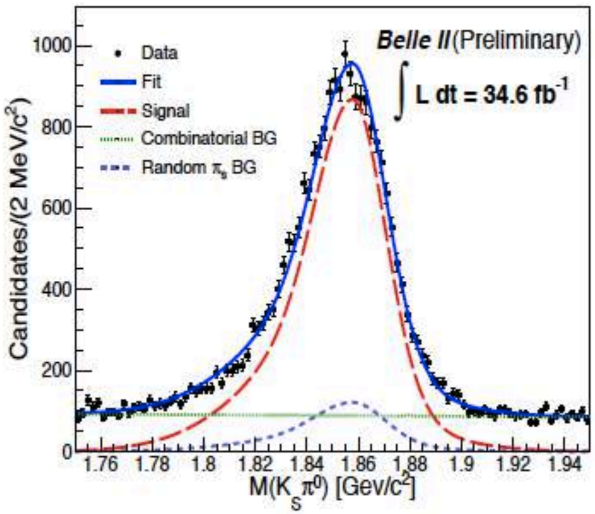
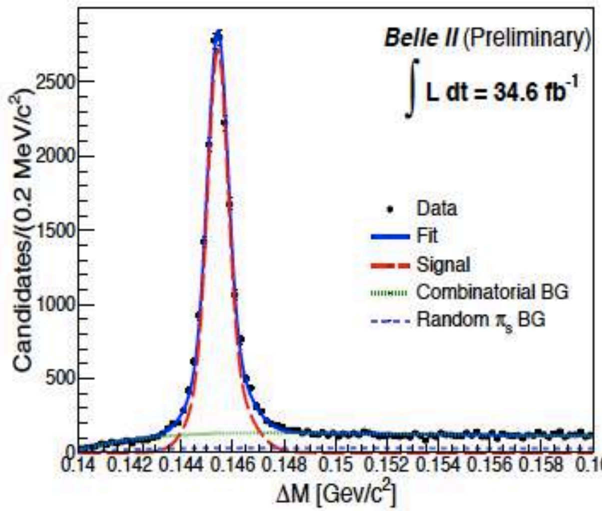


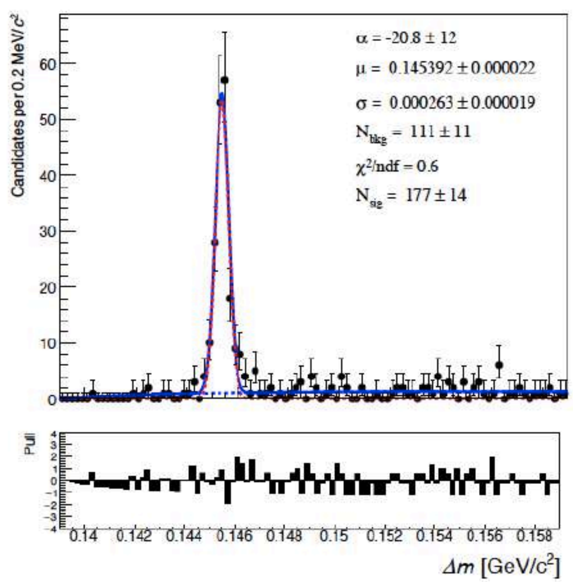
FIG. 5: Kaon efficiency and pion mis-ID rate for the PID criterion $\mathcal{R}_{K/\pi} > 0.5$ using the decay $D^{*+} \to D^0[K^-\pi^+]\pi^+$ in the bins of polar angle (laboratory frame) of the tracks. Note that the acceptance regions of CDC, TOP and ARICH in polar angle ($\cos\theta$) are $[-0.87, 0.96]$, $[-0.48, 0.82]$, and $[0.87, 0.97]$, respectively.

D→Ks pi0, D→Ks Ks
CP eigenstates of the D



(a)





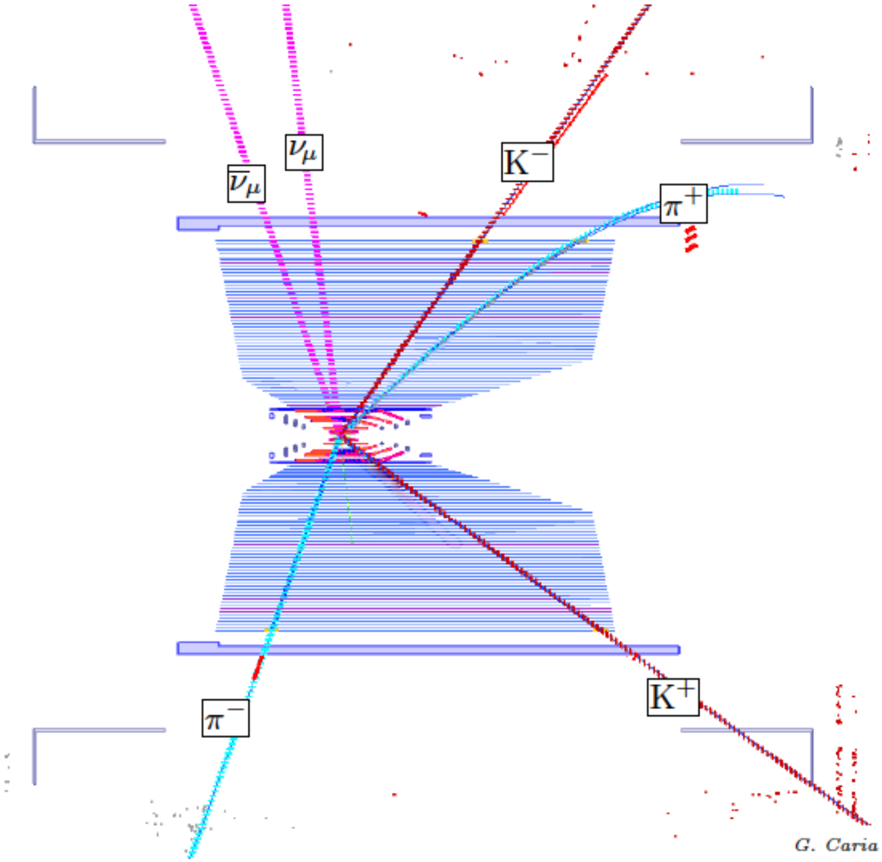
Prospects for the angle gamma/phi_3

Example of Belle II Physics studies (Need E_{ECL} here too)

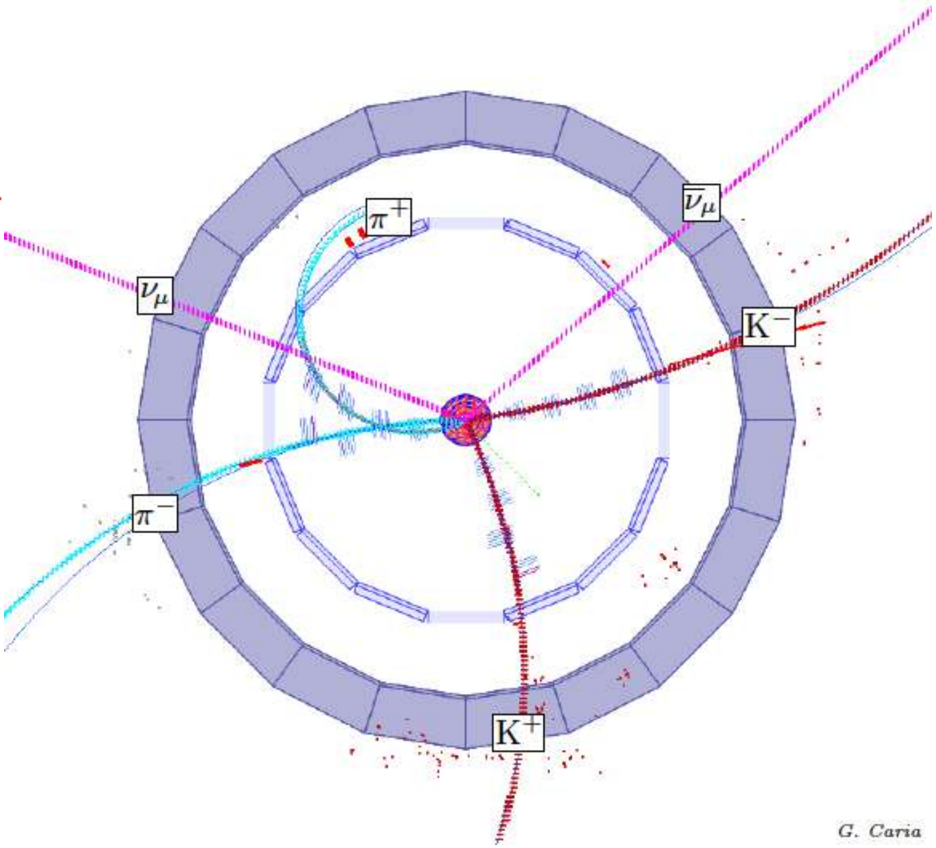
"Missing Energy Decay" in a Belle II GEANT4 MC simulation

Signal B→K ν ν tag mode: B→Dπ; D→Kπ

View in r-z



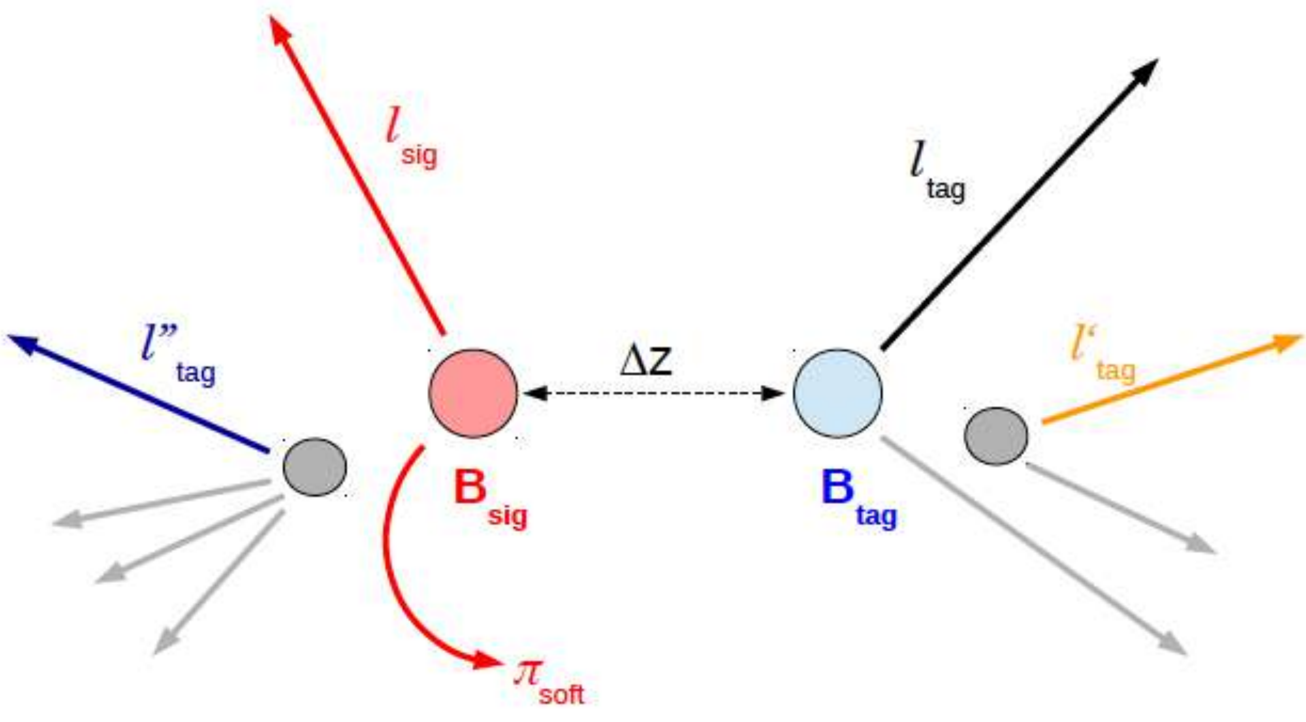
Zoomed view of the vertex region in r--phi



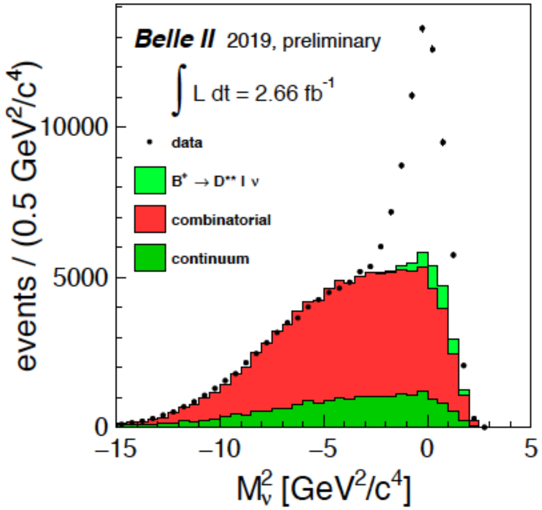
Particle Anti-Particle Mixing
(a remarkable and useful phenomenon).

Start with a B^0 (wait a while, ~a few x 10^{-12} sec).

There is a large probability that the B^0 will turn into its anti-particle, an anti-B^0 (discovered by ARGUS at DESY in 1987)

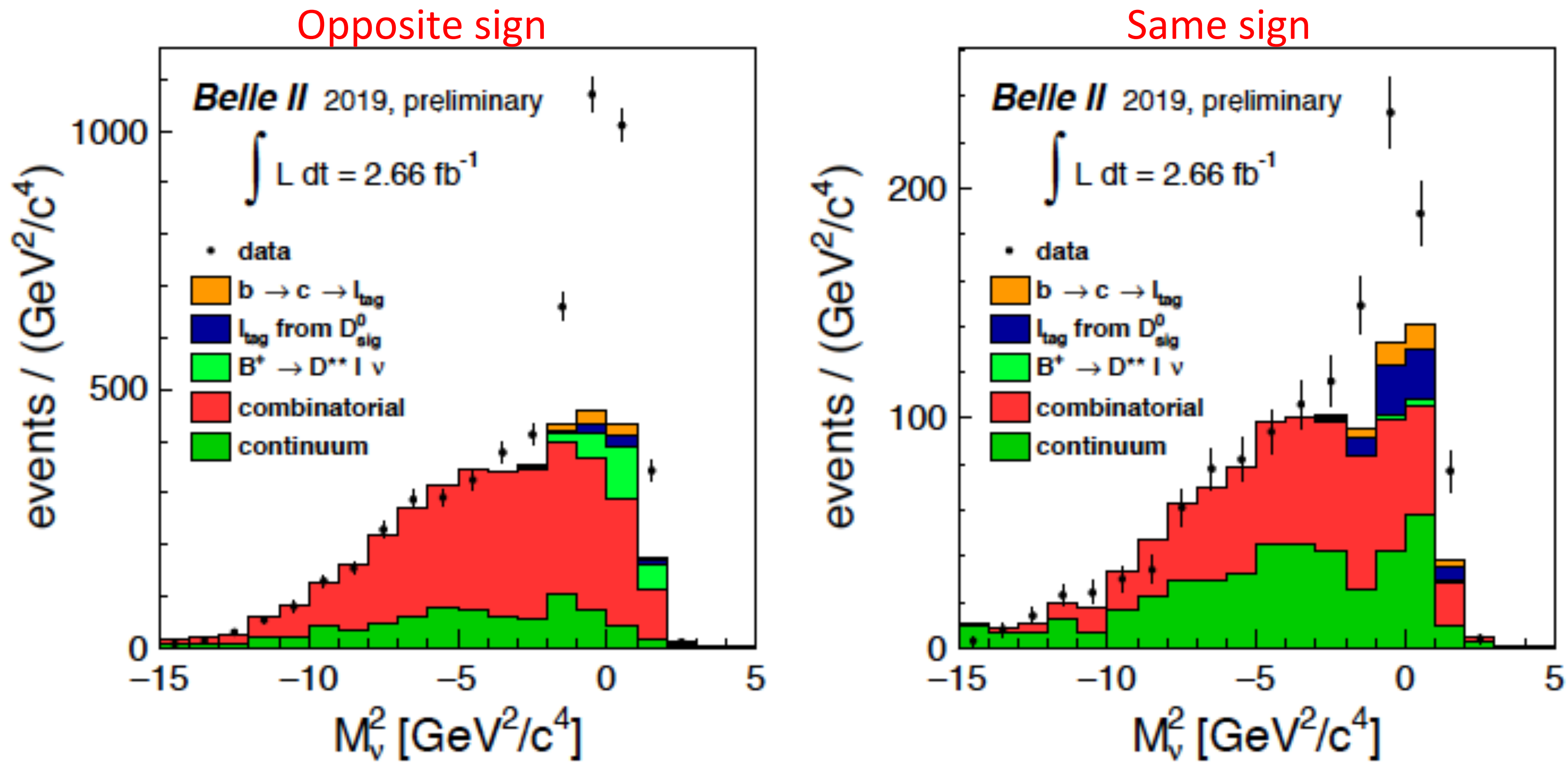


Large B--.D l ν signal from partial reconstruction: 35492±2209



The leptons may come from the B weak decay or (primed case) from a cascade decay B→D→l decay.

Time Integrated Mixing Analysis



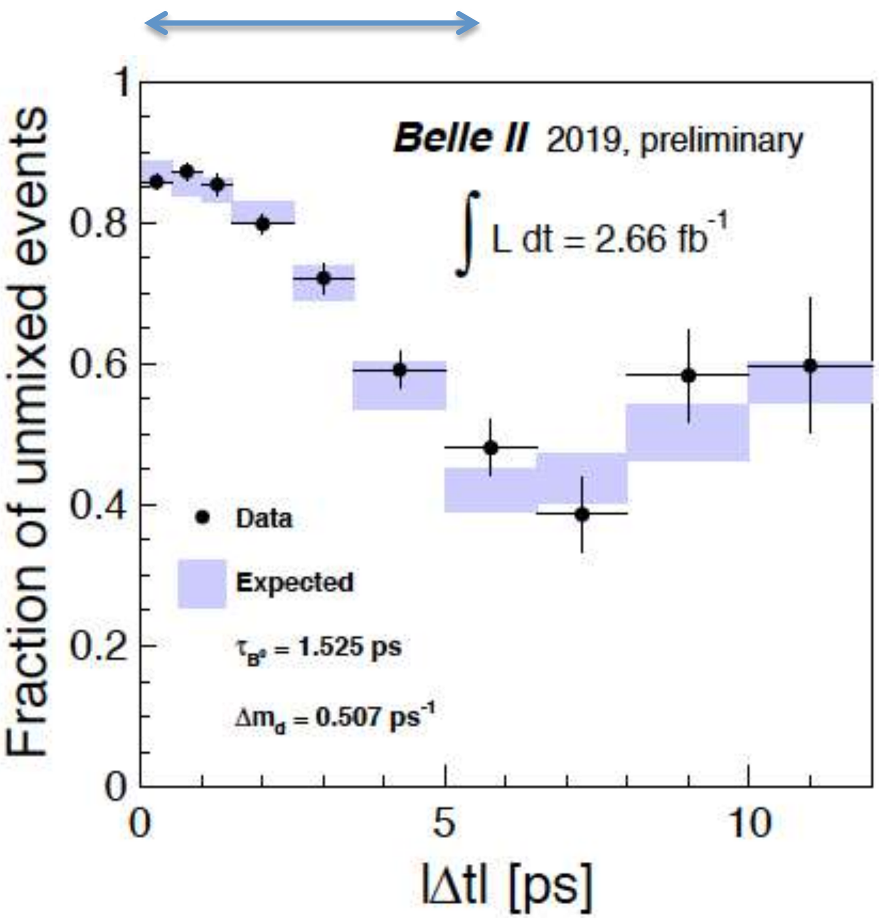
Channel	Data
Untagged e only	18514 ± 1128
Untagged μ only	16625 ± 1111
Untagged (e or μ)	35492 ± 2209
Tagged unmixed (N_U)	1642 ± 133
Tagged mixed (N_M)	253 ± 45
($\varepsilon_U/\varepsilon_M$) correction factor	1.35 ± 0.10
χ_d (fraction of mixed events)	$(17.2 \pm 3.6)\%$

Component	Untagged	ℓ tagged	
		Unmixed	Mixed
$B^{\pm} \to D^{*}\pi\ell\nu$	8.4%	11.1%	2.1%
$b \to c \to \ell_{tag}$	-	3.8%	8.3%
ℓ_{tag} from D^0_{sig}	-	2.7%	17.0%

WA=
18.6%

Time-dependent B-Bbar mixing signature

First oscillation



$$\overline{B}^0 \to D^{*+}\ell^-\nu \to (D^0)\pi_s^+\ell^-\nu$$

Partial reconstruction and time determination uses only Lepton tagging. (Belle II data)

Check Mv^2 sideband (consistent with MC) and continuum with loose cuts (no oscillation)

Not CP violating:

$f_{unmix}(t)= K\,[1+ \cos(\Delta m_d\ \Delta t)]$

Use flavor specific final states but requires tagging. Verifies Belle II VXD capabilities for CP violation.

Belle II jargon (Phase 1, Phase 2, Phase 3)

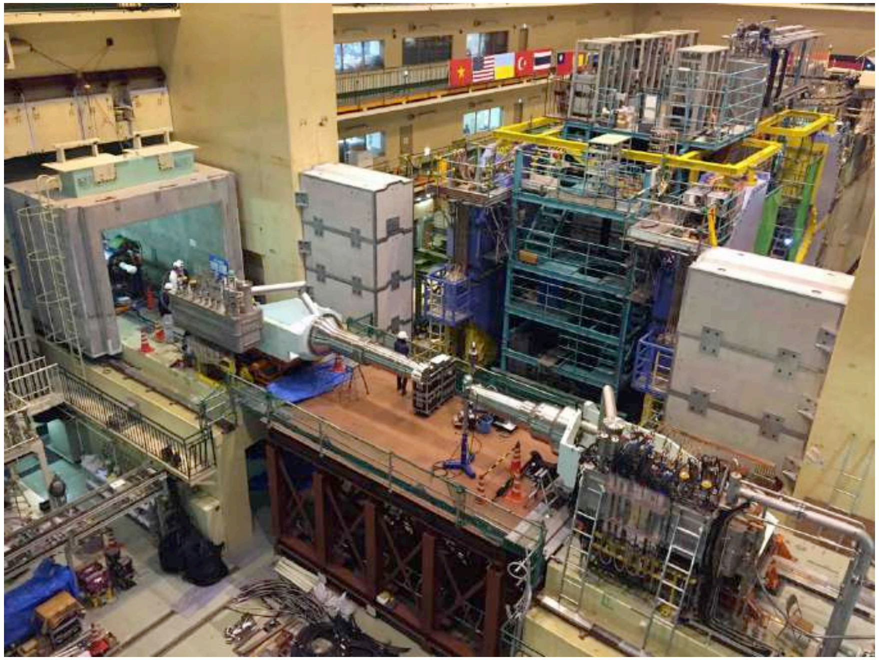
Phase 1: Simple background commissioning detector (diodes, diamonds TPCs, crystals…) BEAST II. No final focus. Only *single* beam background studies possible [started in Feb 2016 and completed in June 2016].

Large crossing angle, 83mrad, is visible

Comprehensive study of beam bkgs published in Jan 2019 issue of NIMA, vol 914, 69 (2019)

Belle II was "rolled-in" in 2017 after delivery of the superconducting final focus.
This was followed by the Phase 2 run in 2018.

Belle II jargon (Phase 2, Phase 3)



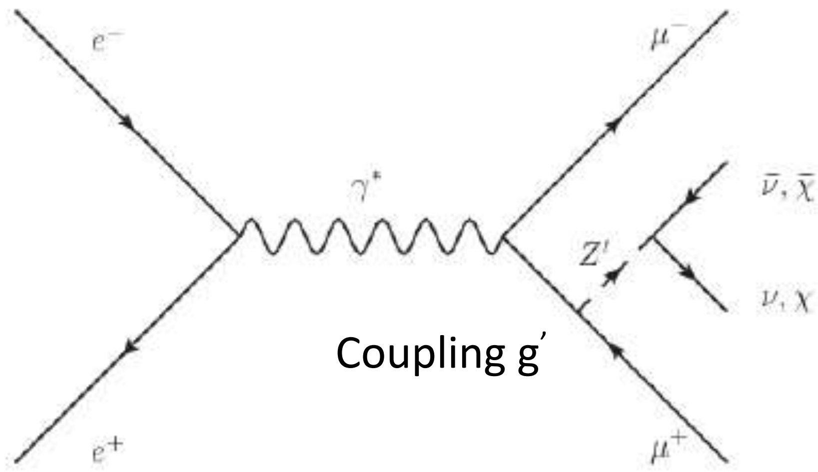
<u>Phase 2</u>: A pilot run with a more elaborate inner background commissioning detector (VXD samples). <u>Full Belle II *outer* detector</u>. Full superconducting final focus. *No vertex detectors*. *Collisions !* *[Phase 2 collisions: April 26-July 17, 2018]*

Phase 3: <u>Installed the VXD in Belle II</u>. First Physics Run with the full Belle II detector [March 26-July 1, 2019]

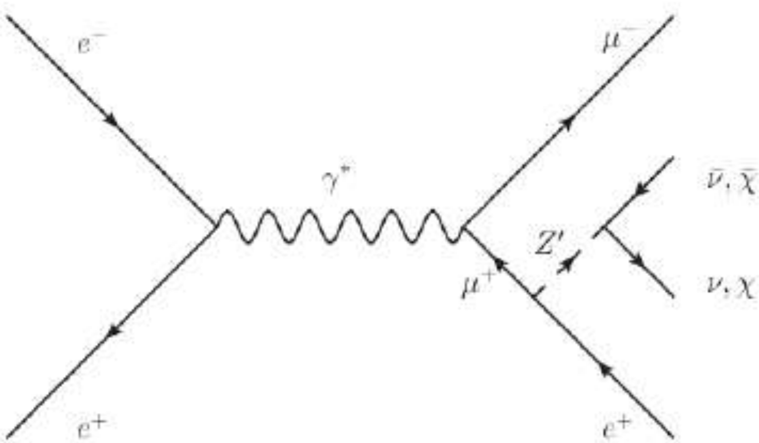
Dark Sector:

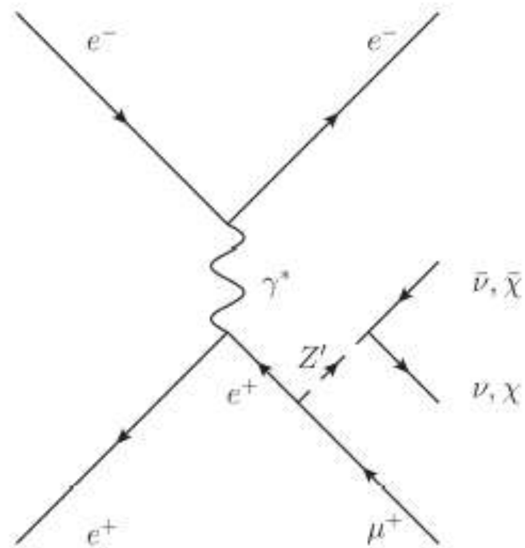
Previously limited by Triggering, QED backgrounds and theoretical imagination. *Now new possibilities of triggering, more bandwidth.*

Belle II First Physics. A novel result on the dark sector (Z' →nothing) recoiling against di-muons *or* an electron-muon pair. *Both possibilities are poorly constrained at low Z' mass and in the first case, could explain the muon g-2 anomaly.*

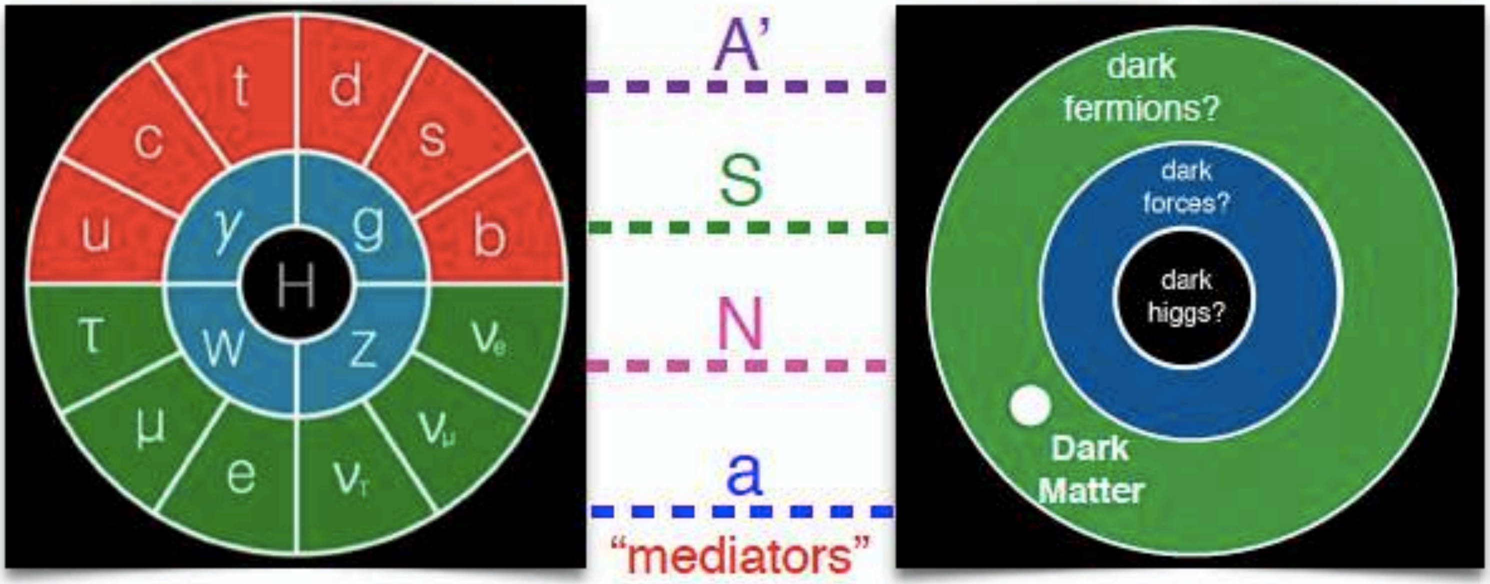


Also examine a lepton flavor violating NP signature in the dark sector





How to gain access to the dark sector?



Only a few interactions exist that are allowed by Standard Model symmetries:

+ possible new dark gauge bosons obtained gauging e.g. B-L, L_μ-L_τ, …

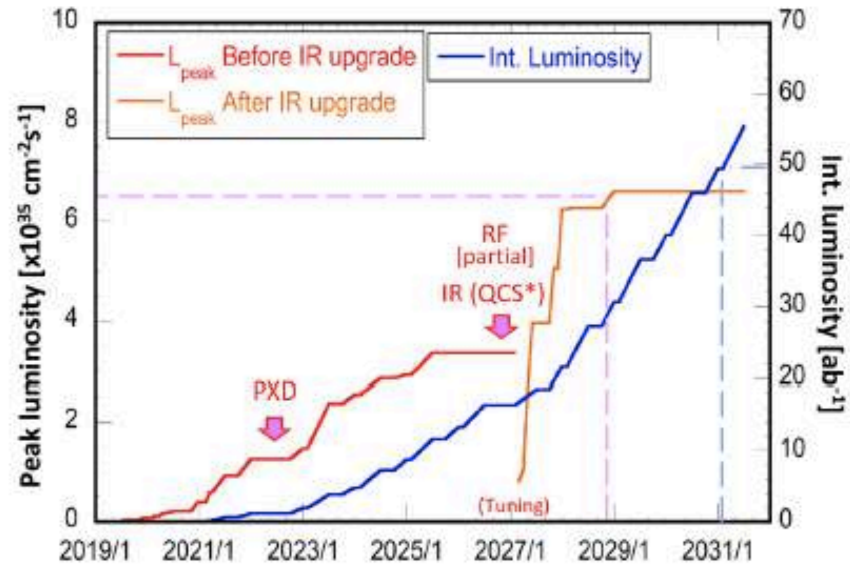
"mediators"	"portal interactions"
Dark photon	$\epsilon B^{\mu\nu} A'_{\mu\nu}$
Higgs	$\kappa \lvert H\rvert^2 \lvert S\rvert^2$
Neutrino	$y H L N$
Axion	$g_{a\gamma} a \tilde{F}_{\mu\nu} F^{\mu\nu}$

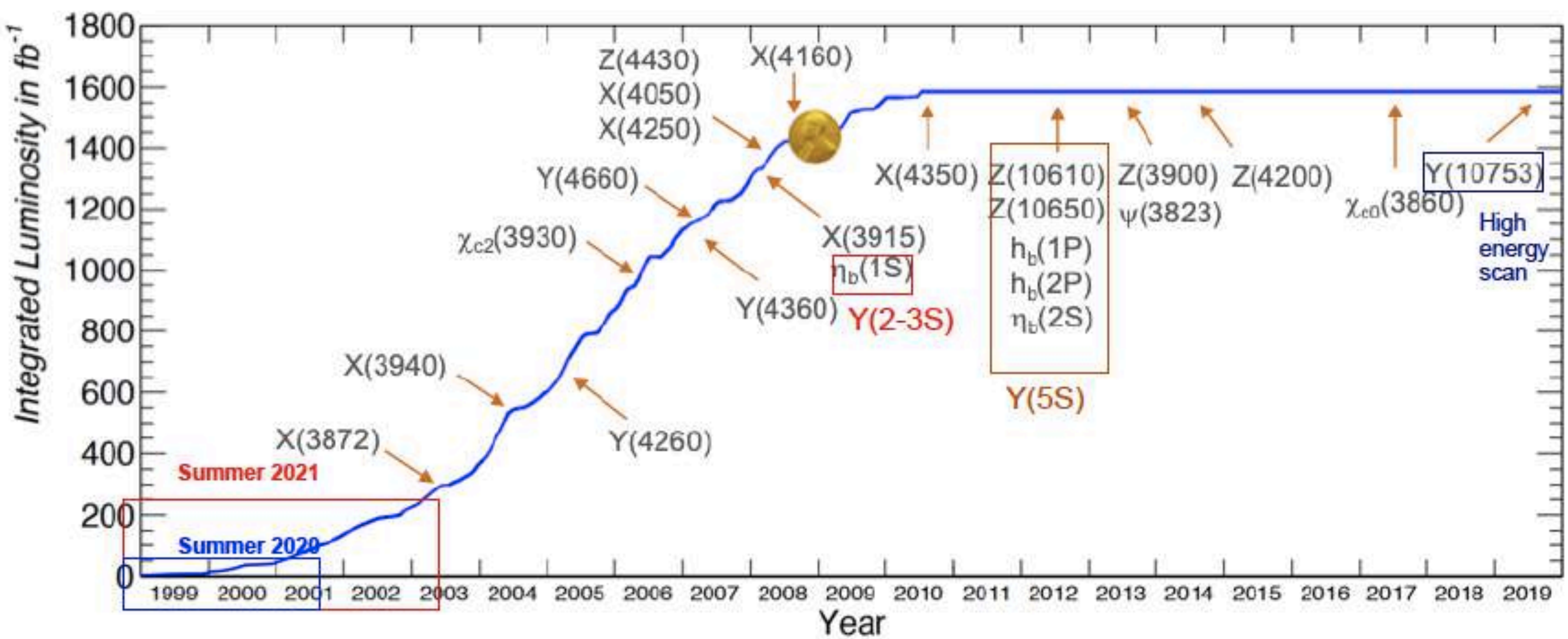
S.Gori

Just warming up the engines

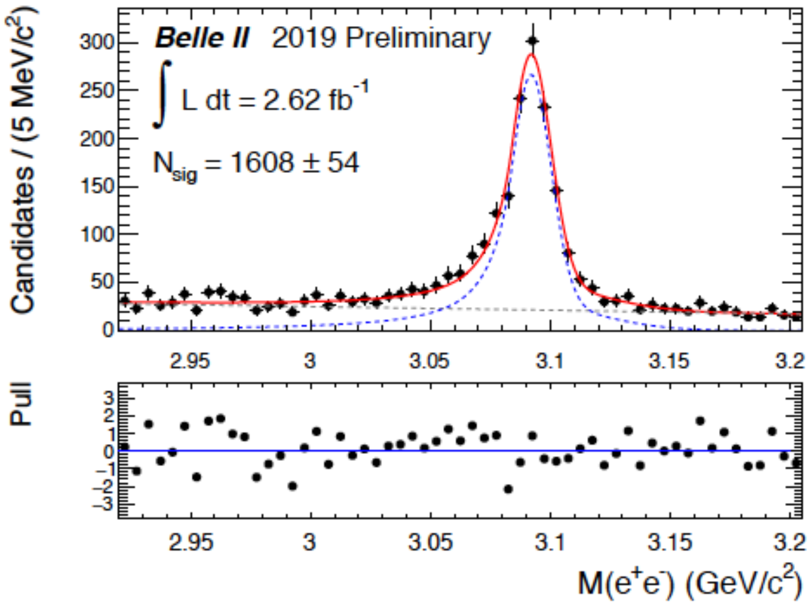
Rediscovery of most surprises from B factories expected after 250 fb^{-1}

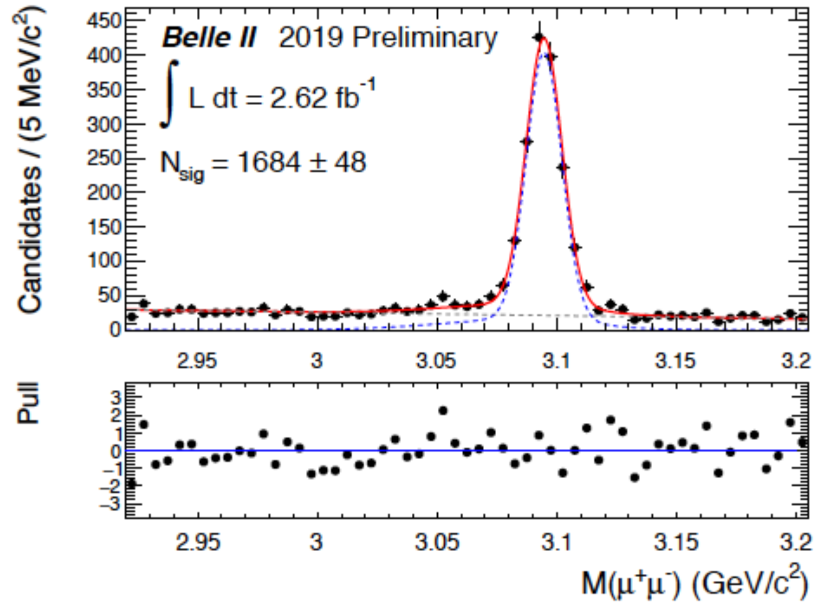
- Stay tuned for Summer 2021 conferences
- First ab^{-1} before 2022 shutdown
- Data taking at 10.75 under discussion





Signals for B→J/ψ X in Phase 3 data

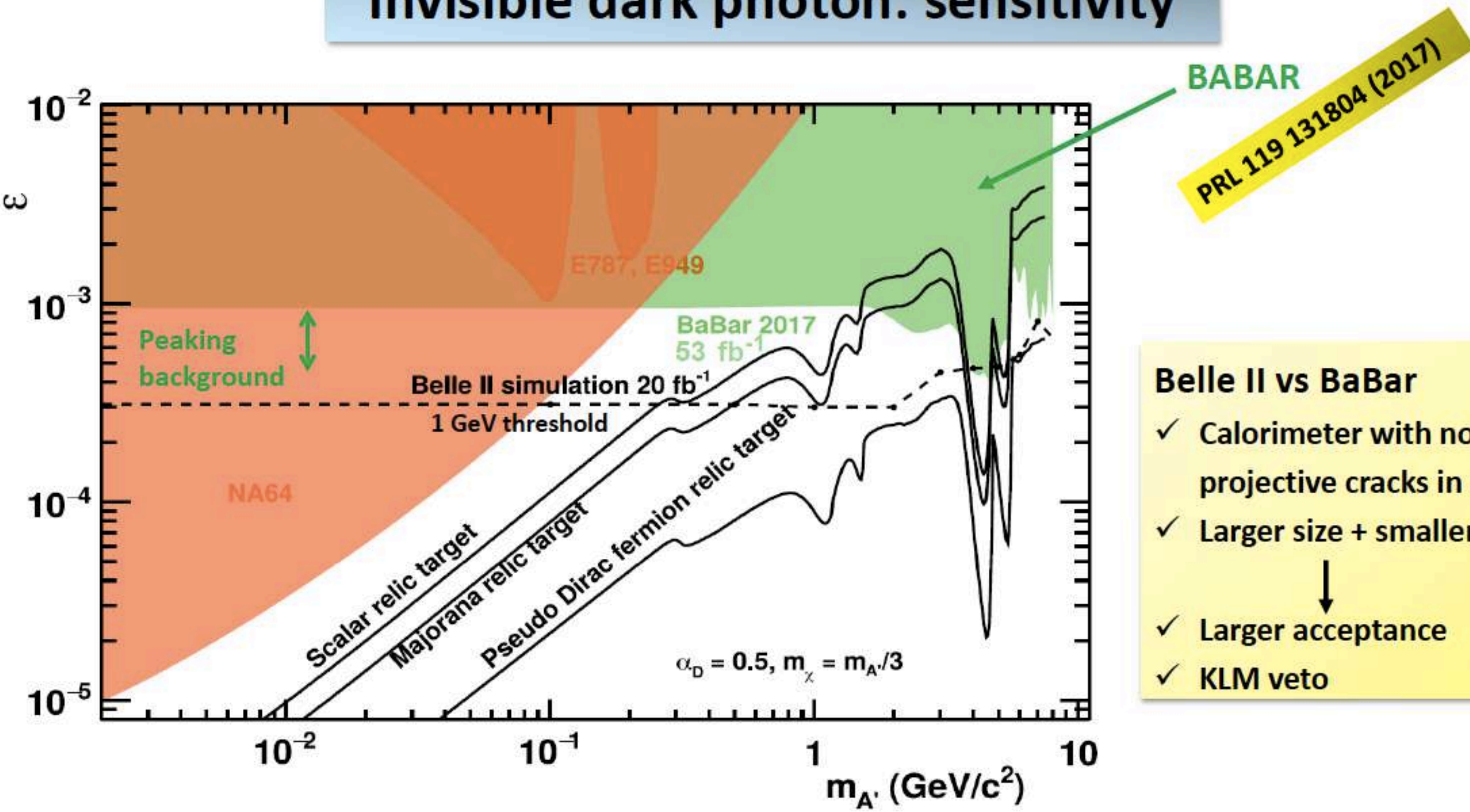




Clear signals for B→J/ψ X in ~1/2 of Phase 3 data. Note the small radiative tail on the di-electrons (does include bremsstrahlung recovery).

→*Belle II has equally strong capabilities for electrons and muons.*

Invisible dark photon: sensitivity



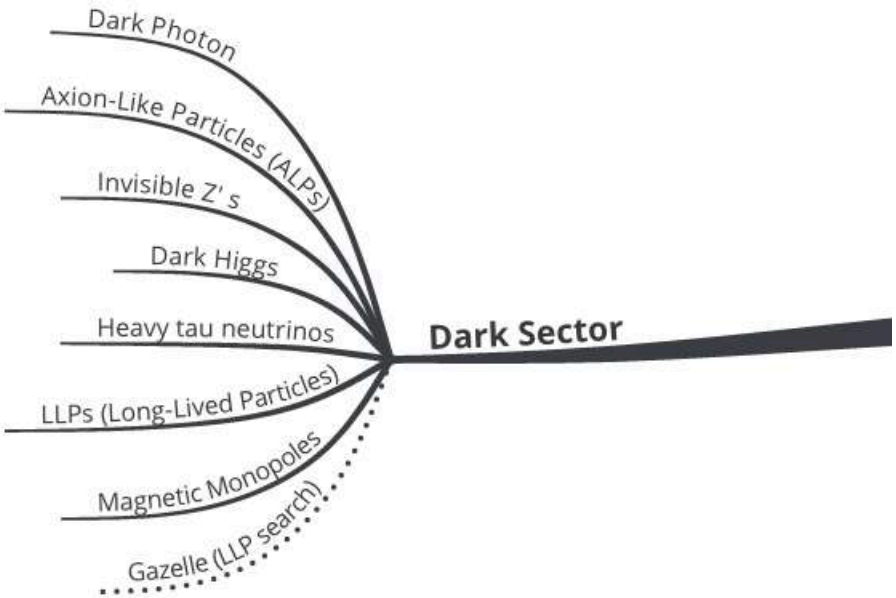
Belle II vs BaBar

- ✓ Calorimeter with no projective cracks in φ
- ✓ Larger size + smaller boost

↓

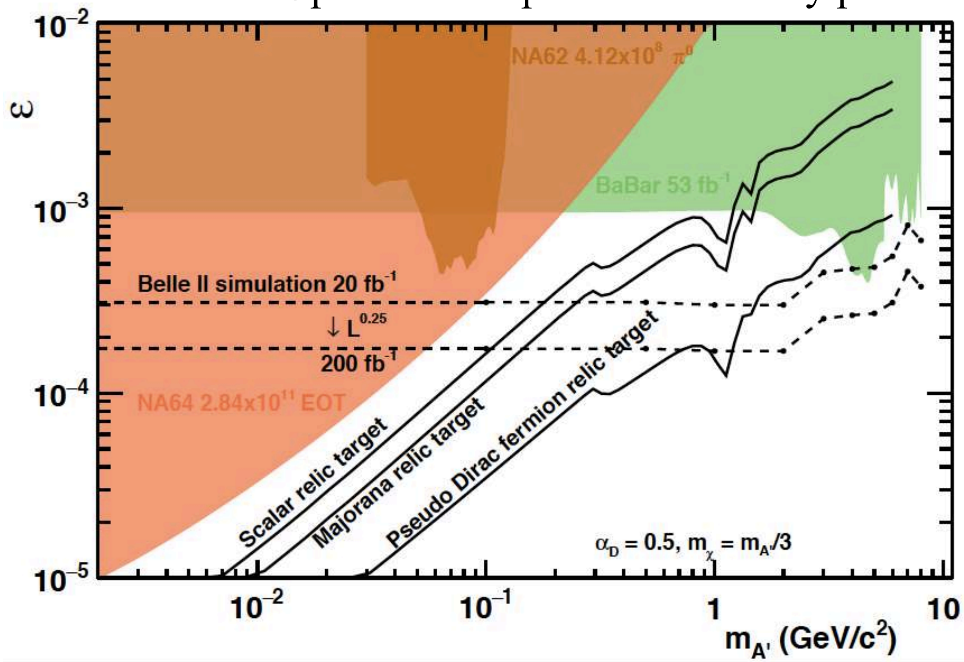
- ✓ Larger acceptance
- ✓ KLM veto

Zoom in on the Dark Sector



LLP White Paper (including the Gazelle proposal): Torben Ferber, Suzanne Westhof et al

Updated dark photon sensitivity plot



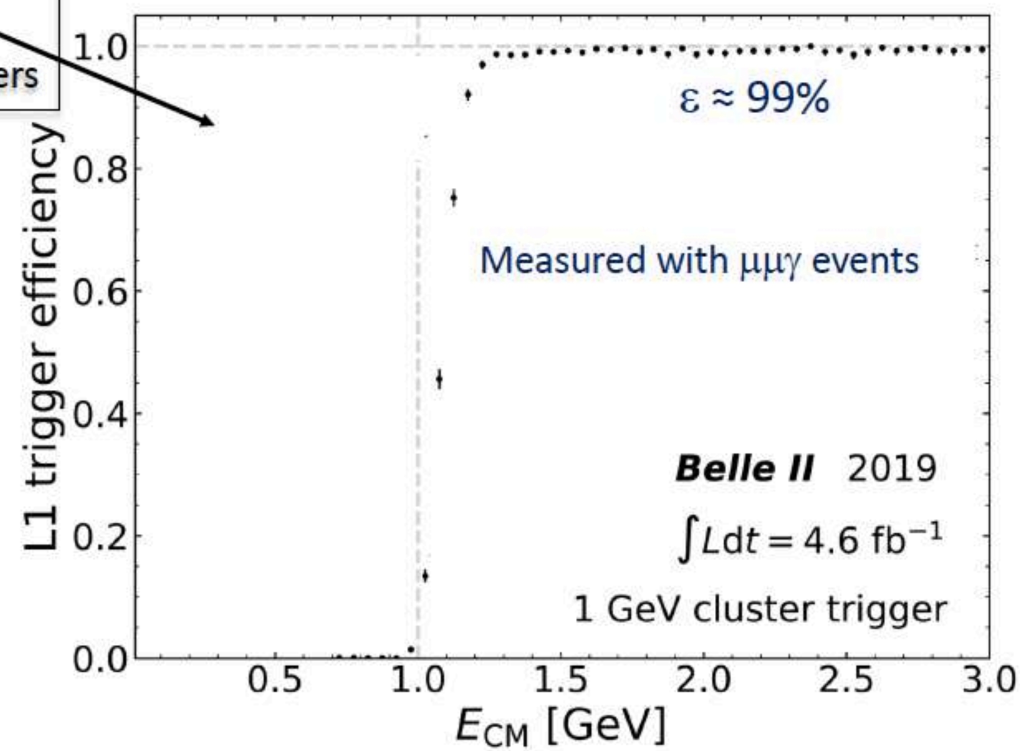
Dark Sector Capabilities of Belle II White Paper, Chris Hearty, Kevin Flood et al.

Invisible dark photon: single photon trigger

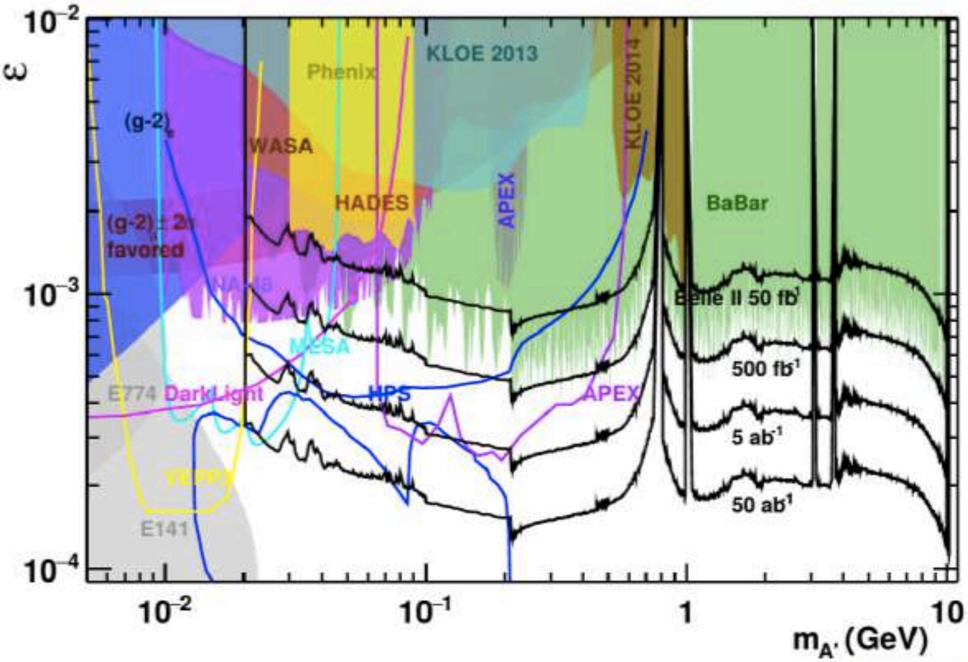
- **E_{CM} > 2 GeV**
- **E_{CM} > 1 GeV** in barrel + no other clusters
- **E_{CM} > 0.5 GeV** in central barrel + no other clusters

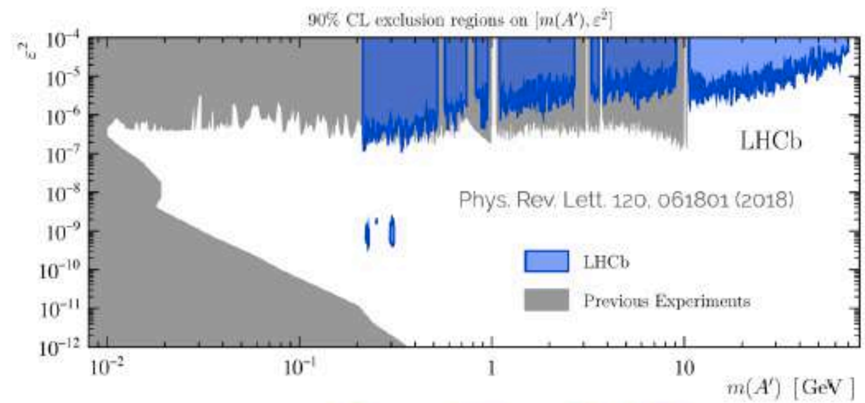
Would extend the search range up to $M_{A'} <\approx 10$ GeV (psycological threshold)

Much more aggressive than originally expected. Good conditions to perform the measurement as soon as possible.



Visible dark photon: sensitivity





PRL 113, 201801 (2014)

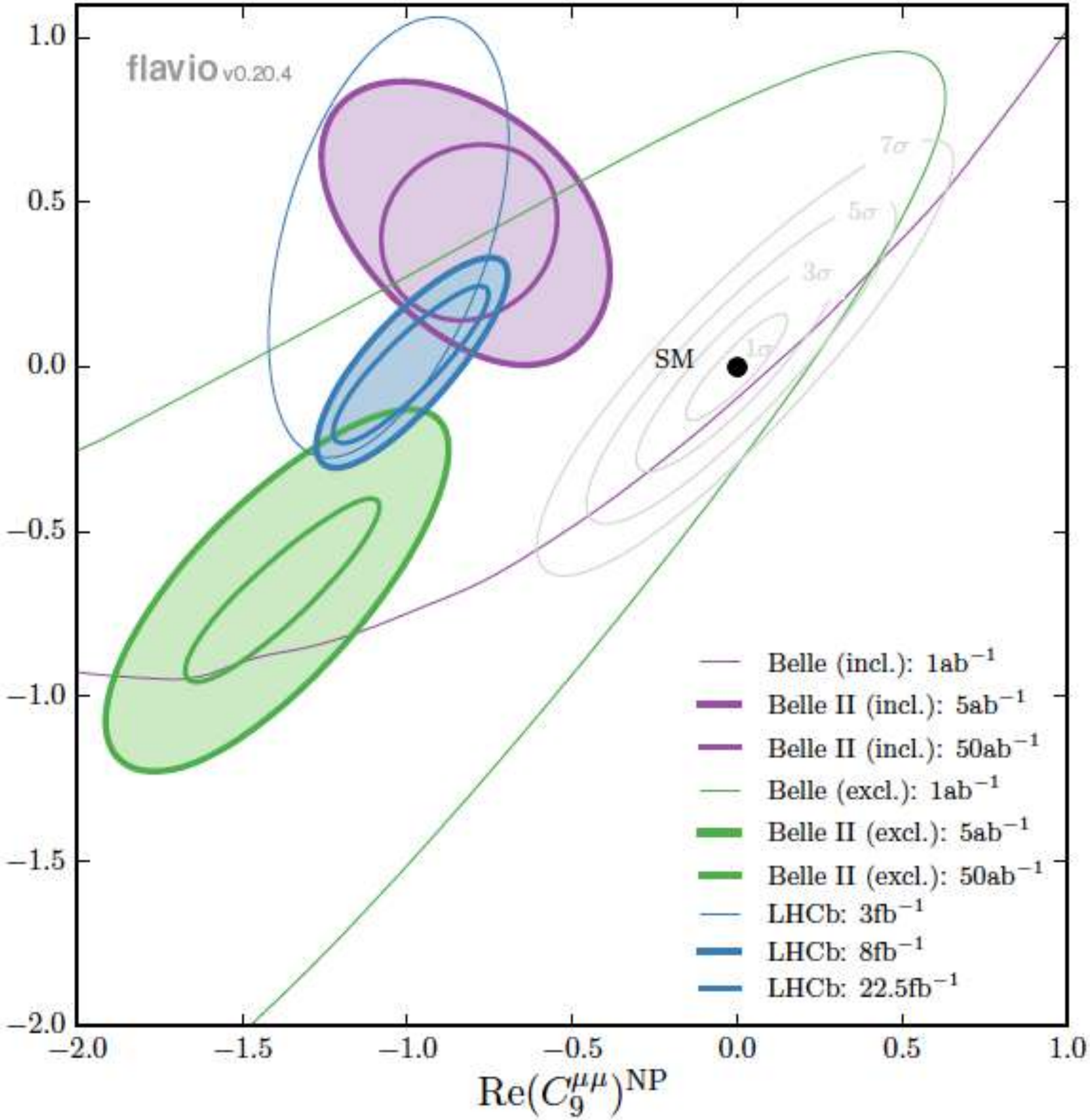
Competition with LHCb:

Drell-Yan processes
Displaced vertices
$D^* \rightarrow D A'$, $A' \rightarrow ee$

Best limits in the GeV region from **BaBar**
Belle had no suitable low mutiplicity triggers for this search
Hadronic and ττ final states much harder

Belle II needs some years of data for leading sensitivity: search currently in preparation

NP in b→s l^+l^-



NP Wilson Coefficient for electrons

New Physics Wilson Coefficient for muons

Prepared by D. Straub et al. for the Belle II Physics Book (edited by P. Urquijo and E. Kou)

Belle II can do both <u>inclusive</u> and exclusive. Equally strong capabilities for electrons and muons.

Snowmass 2021 Letter of Interest:
B Physics at Belle II

on behalf of the U.S. Belle II Collaboration

D. M. Asner[1], Sw. Banerjee[2], J. V. Bennett[3], G. Bonvicini[4], R. A. Briere[5], T. E. Browder[6], D. N. Brown[2], C. Chen[7], D. Cinabro[4], J. Cochran[7], L. M. Cremaldi[3], A. Di Canto[1], K. Flood[6], B. G. Fulsom[8], R. Godang[9], W. W. Jacobs[10], D. E. Jaffe[1], K. Kinoshita[11], R. Kroeger[3], R. Kulasiri[12], P. J. Laycock[1], K. A. Nishimura[6], T. K. Pedlar[13], L. E. Piilonen[14], S. Prell[7], C. Rosenfeld[15], D. A. Sanders[3], V. Savinov[16], A. J. Schwartz[11], J. Strube[8], D. J. Summers[3], S. E. Vahsen[6], G. S. Varner[6], A. Vossen[17], L. Wood[8], and J. Yelton[18]

[1]*Brookhaven National Laboratory, Upton, New York 11973*
[2]*University of Louisville, Louisville, Kentucky 40292*
[3]*University of Mississippi, University, Mississippi 38677*
[4]*Wayne State University, Detroit, Michigan 48202*
[5]*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213*
[6]*University of Hawaii, Honolulu, Hawaii 96822*
[7]*Iowa State University, Ames, Iowa 50011*
[8]*Pacific Northwest National Laboratory, Richland, Washington 99352*
[9]*University of South Alabama, Mobile, Alabama 36688*
[10]*Indiana University, Bloomington, Indiana 47408*
[11]*University of Cincinnati, Cincinnati, Ohio 45221*
[12]*Kennesaw State University, Kennesaw, Georgia 30144*
[13]*Luther College, Decorah, Iowa 52101*
[14]*Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061*
[15]*University of South Carolina, Columbia, South Carolina 29208*
[16]*University of Pittsburgh, Pittsburgh, Pennsylvania 15260*
[17]*Duke University, Durham, North Carolina 27708*
[18]*University of Florida, Gainesville, Florida 32611*

Corresponding Author:
Soeren Prell (Iowa State University), prell@iastate.edu

Thematic Area(s):

■ (RF01) Weak Decays of b and c Quarks

Snowmass 2021 Letter of Interest: Dark sector studies at Belle II

on behalf of the U.S. Belle II Collaboration

D. M. Asner[1], Sw. Banerjee[2], J. V. Bennett[3], G. Bonvicini[4], R. A. Briere[5], T. E. Browder[6], D. N. Brown[2], C. Chen[7], D. Cinabro[4], J. Cochran[7], L. M. Cremaldi[3], A. Di Canto[1], K. Flood[6], B. G. Fulsom[8], R. Godang[9], W. W. Jacobs[10], D. E. Jaffe[1], K. Kinoshita[11], R. Kroeger[3], R. Kulasiri[12], P. J. Laycock[1], K. A. Nishimura[6], T. K. Pedlar[13], L. E. Piilonen[14], S. Prell[7], C. Rosenfeld[15], D. A. Sanders[3], V. Savinov[16], A. J. Schwartz[11], J. Strube[8], D. J. Summers[3], S. E. Vahsen[6], G. S. Varner[6], A. Vossen[17], L. Wood[8], and J. Yelton[18]

[1]*Brookhaven National Laboratory, Upton, New York 11973*
[2]*University of Louisville, Louisville, Kentucky 40292*
[3]*University of Mississippi, University, Mississippi 38677*
[4]*Wayne State University, Detroit, Michigan 48202*
[5]*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213*
[6]*University of Hawaii, Honolulu, Hawaii 96822*
[7]*Iowa State University, Ames, Iowa 50011*
[8]*Pacific Northwest National Laboratory, Richland, Washington 99352*
[9]*University of South Alabama, Mobile, Alabama 36688*
[10]*Indiana University, Bloomington, Indiana 47408*
[11]*University of Cincinnati, Cincinnati, Ohio 45221*
[12]*Kennesaw State University, Kennesaw, Georgia 30144*
[13]*Luther College, Decorah, Iowa 52101*
[14]*Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061*
[15]*University of South Carolina, Columbia, South Carolina 29208*
[16]*University of Pittsburgh, Pittsburgh, Pennsylvania 15260*
[17]*Duke University, Durham, North Carolina 27708*
[18]*University of Florida, Gainesville, Florida 32611*

Corresponding Authors:
Christopher Hearty (University of British Columbia / IPP), hearty@physics.ubc.ca
Kevin Flood (University of Hawaii), kflood@hawaii.edu

Thematic Area(s):

■ (RF06) Dark Sector at Low Energies

Snowmass 2021 Letter of Interest:
Belle II Detector Upgrades

on behalf of the U.S. Belle II Collaboration

D. M. Asner[1], Sw. Banerjee[2], J. V. Bennett[3], G. Bonvicini[4], R. A. Briere[5], T. E. Browder[6], D. N. Brown[2], C. Chen[7], D. Cinabro[4], J. Cochran[7], L. M. Cremaldi[3], A. Di Canto[1], K. Flood[6], B. G. Fulsom[8], R. Godang[9], W. W. Jacobs[10], D. E. Jaffe[1], K. Kinoshita[11], R. Kroeger[3], R. Kulasiri[12], P. J. Laycock[1], K. A. Nishimura[6], T. K. Pedlar[13], L. E. Piilonen[14], S. Prell[7], C. Rosenfeld[15], D. A. Sanders[3], V. Savinov[16], A. J. Schwartz[11], J. Strube[8], D. J. Summers[3], S. E. Vahsen[6], G. S. Varner[6], A. Vossen[17], L. Wood[8], and J. Yelton[18]

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[16]*University of Pittsburgh, Pittsburgh, Pennsylvania 15260*
[17]*Duke University, Durham, North Carolina 27708*
[18]*University of Florida, Gainesville, Florida 32611*

Corresponding Authors:
Sven Vahsen (University of Hawaii), sevahsen@hawaii.edu
Gary Varner (University of Hawaii)
Francesco Forti (INFN and University of Pisa)

Snowmass 2021 Letter of Interest: Computing, Software, and Data Analysis at Belle II

on behalf of the U.S. Belle II Collaboration

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[15]Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061
[16]University of South Carolina, Columbia, South Carolina 29208
[17]University of Pittsburgh, Pittsburgh, Pennsylvania 15260
[18]University of Florida, Gainesville, Florida 32611

Corresponding Author:
J. V. Bennett (University of Mississippi), jvbennet@olemiss.edu

ODDONE: And then there are several interesting things about the

Japan decided to do one also, and they had a remarkably similar situat

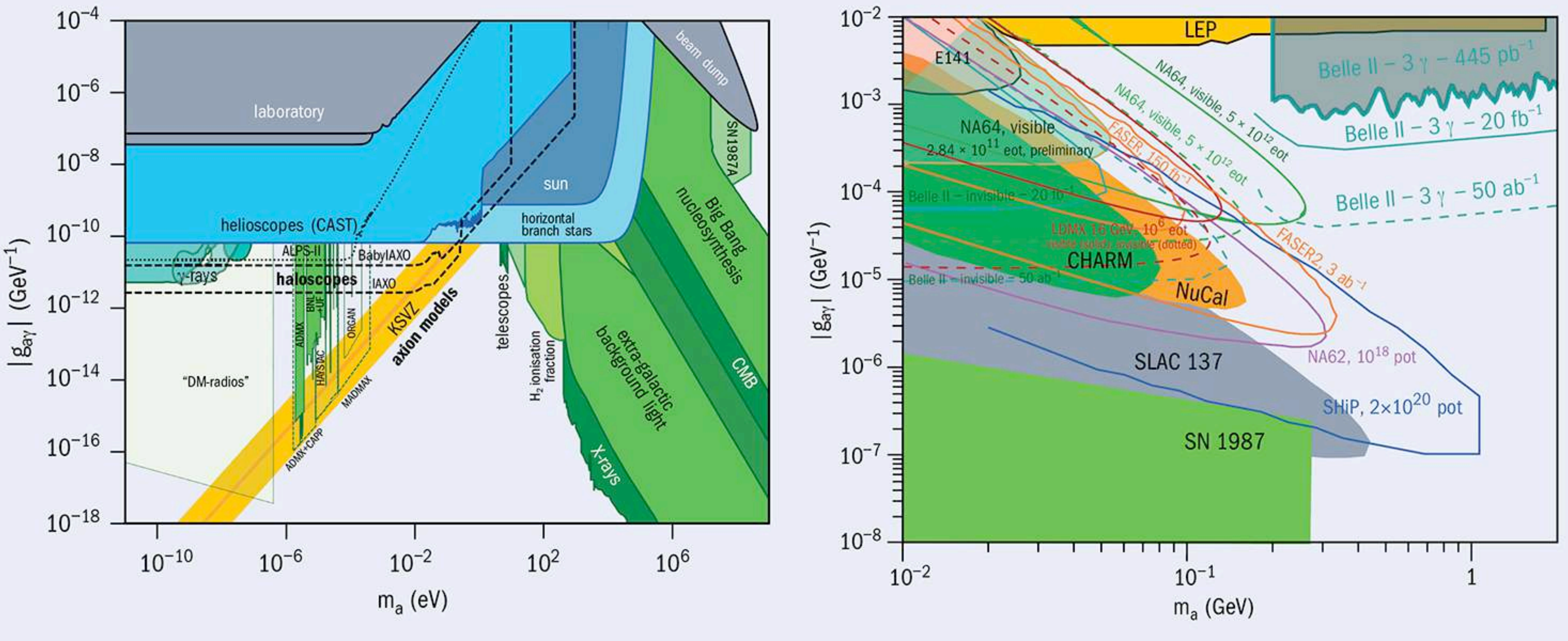
extraordinary is that KEKB, the Japanese machine, and the Asymmet

neck and neck the whole way through to the discovery of CP violatio

Former Fermilab director Pier Oddone at his vineyard in California. CREDIT: Barbara Oddone

ODDONE: These are complicated machines. There were lots of things to do that could go wrong. It's so easy to fall out of sequence with some component so that you would be six months behind. But it didn't happen. It was neck and neck the whole five years of building the machine, the detectors, all the way to the discovery paper. So, at the end, they have been very, very productive machines. The Asymmetric B Factory got killed probably prematurely with the budget crisis in 2008. The Japanese went ahead and have built SuperKEKB, the successor to KEKB, which is starting to work now to get even 40 times more luminosity than the Asymmetric B Factory. We'll see how far they get. It's not clear. And, of course, there was very productive B physics with CDF at the Tevatron and now with LHCb at CERN.

Interview May 2020



laboratory
beam dump
SN1987A
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helioscopes (CAST)
horizontal branch stars
Big Bang nucleosynthesis
ALPS-II
BabyIAXO
γ-rays
haloscopes
IAXO
KSVZ
axion models
ADMX
BNL +UF
HAYSTAC
ORGAN
MADMAX
ADMX+CAPP
"DM-radios"
telescopes
H2 ionisation fraction
extra-galactic background light
CMB
X-rays
10−4
10−6
10−8
10−10
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10−16
10−18
10−10
10−6
10−2
102
106
|gaγ| (GeV−1)
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LEP
E141
Belle II – 3 γ – 445 pb−1
NA64, visible, 5 × 1012 eot
NA64, visible, 5 × 1012 eot
Belle II – 3 γ – 20 fb−1
NA64, visible
2.84 × 1011 eot, preliminary
FASER, 150 fb−1
Belle II – invisible – 20 fb−1
Belle II – 3 γ – 50 ab−1
LDMX 16 GeV, 1016 eot
CHARM
FASER2, 3 ab−1
Belle II – invisible – 50 ab−1
NuCal
NA62, 1018 pot
SLAC 137
SHiP, 2×1020 pot
SN 1987
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1
|gaγ| (GeV−1)
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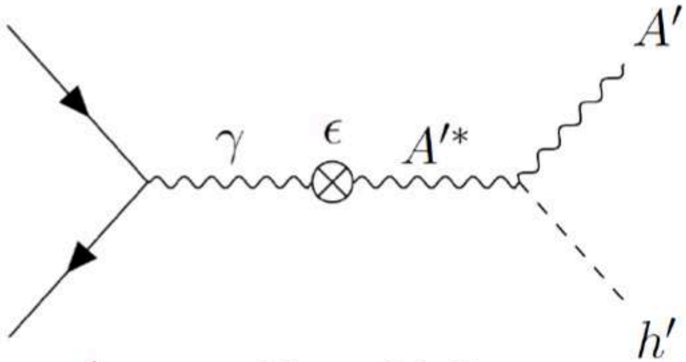
Dark Higgsstrahlung Sensitivity

There are a variety of possible dark sector portal particles: Vector, Scalar, Pseudo-scalars.

They may decay to lepton pairs, photon pairs, or Invisible particles



$e^+e^- \rightarrow A'^* \rightarrow h'\,A'$

$\quad\quad\quad\quad\quad\quad \hookrightarrow \mu^+\mu^-$

Here Ex is the asymmetry of the muon energies; the background from radiative tau pairs peaks near one and the signal is flat.

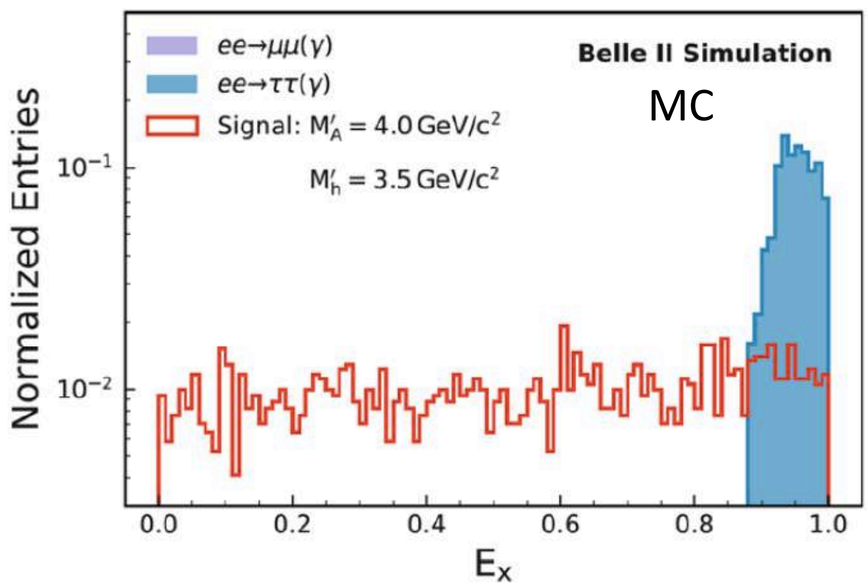
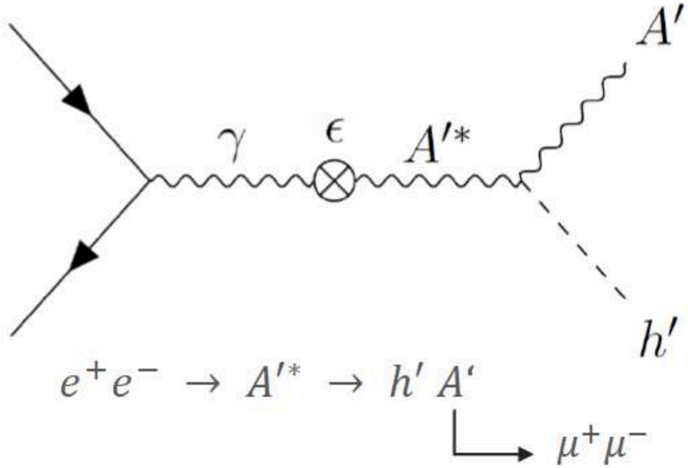


FIG. 3: Distribution of the final background suppression variable E_x. E_x is the absolute value of the asymmetry computed along the line described by the distribution $E_{\mu 1}^{CMS}$ vs $E_{\mu 0}^{CMS}$ in a mass window. Here $M_{A'} = 3.5\,GeV/c^2$, $M_{h'} = 4.0\,GeV/c^2$. The background here is dominated by the $\tau\tau(\gamma)$ contribution.

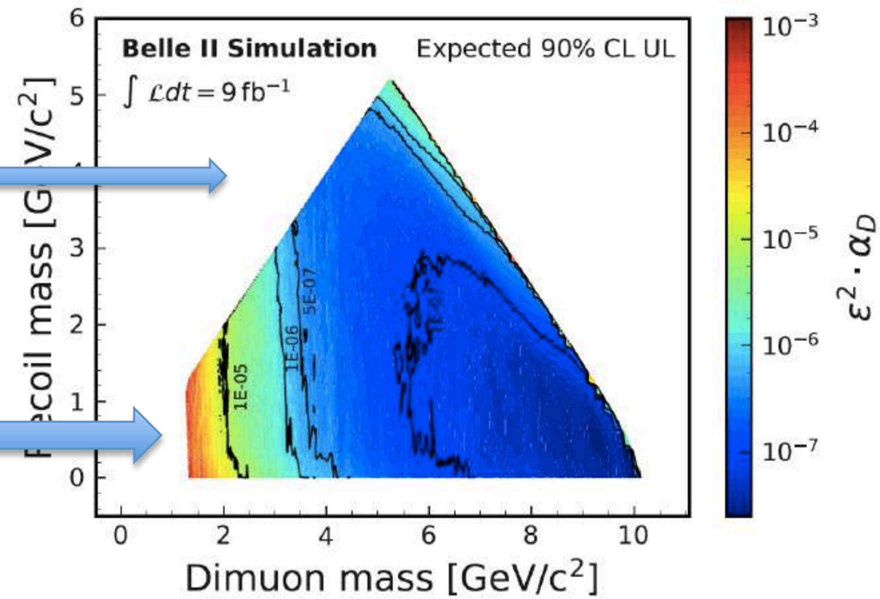
Dark Higgsstrahlung Sensitivity



Final state similar to Z' →invisible but with a much different matrix element and kinematics.

Recast of Belle and BaBar multi-lepton dark searches

Low Belle II trigger efficiency but covered by KLOE.



Expected sensitivities in $\epsilon^2 \cdot \alpha_D$ the final background suppression (E_x selection) estimated with a Bayesian counting technique. Preliminary conservative systematics considered. Smoothed version.

Upper left side:
PRL 108, 211801 (2012) BaBar; PRL 114, 211801 (2015) Belle