Interplay between Particle and Astroparticle physics 2022

TU Wien, 5-9 September 2022

Significant LHCb results and plans for the future

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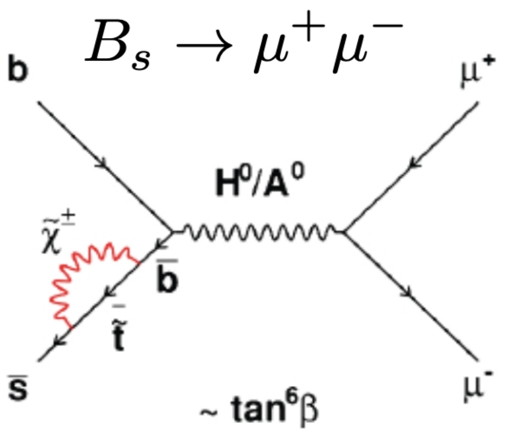
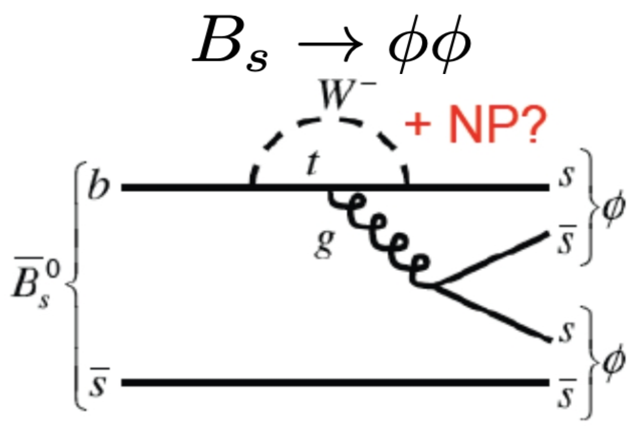
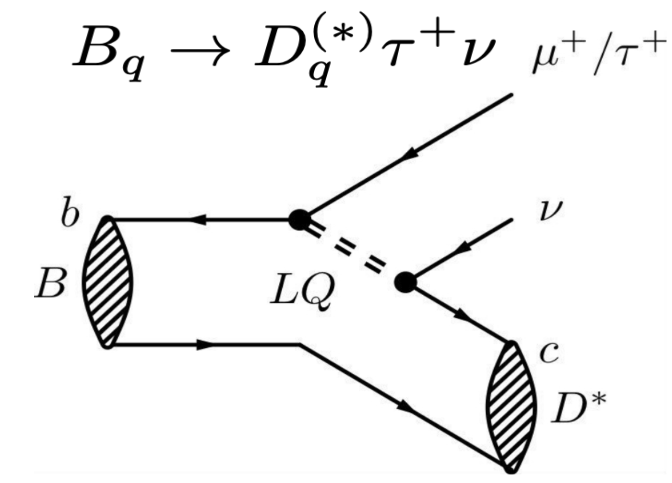
On behalf of LHCb Collaboration

The flavor physics program

- New Physics evidence may appear in measurement of CP violation, rare decays or in tree level process with final states not fully explored in the past



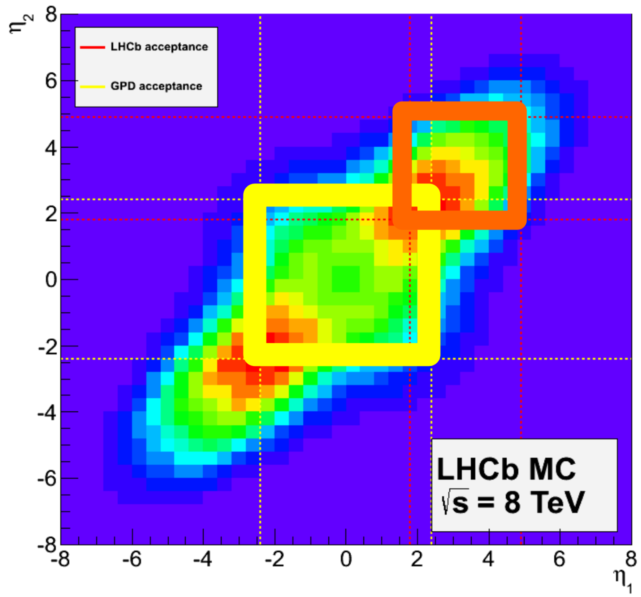




- "High intensity frontier" is sensitive to high mass scale
- Complementary to direct searches (ATLAS & CMS)
  - When NP will be discovered, its structure need to be determined: flavor physics!

The 2010-2018 LHCb Apparatus

JINST 3 (2008) S08005



- Huge $b\bar{b}$ cross section from pp collisions

$$\sigma(b\bar{b})(7\ TeV) = 295\mu b$$

$$\sigma(b\bar{b})(13\ TeV) = 560\mu b$$

PLB 118, 052992(2017)

- Charm ~ 20 x Beauty — JHEP 03(2016)159
- Production of $b\bar{b}$ / $c\bar{c}$ mostly in the forward direction
  - **2<η< 5**: 4% of solid angle, 25% of $b\bar{b}$ acceptance (7 TeV)

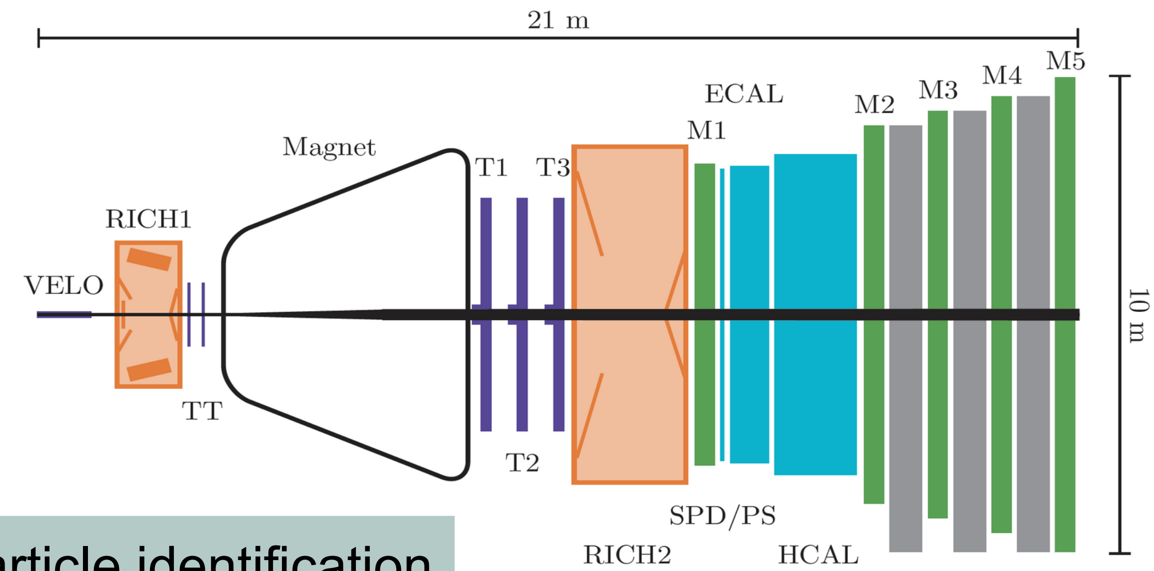


Diagram by T. Boettcher

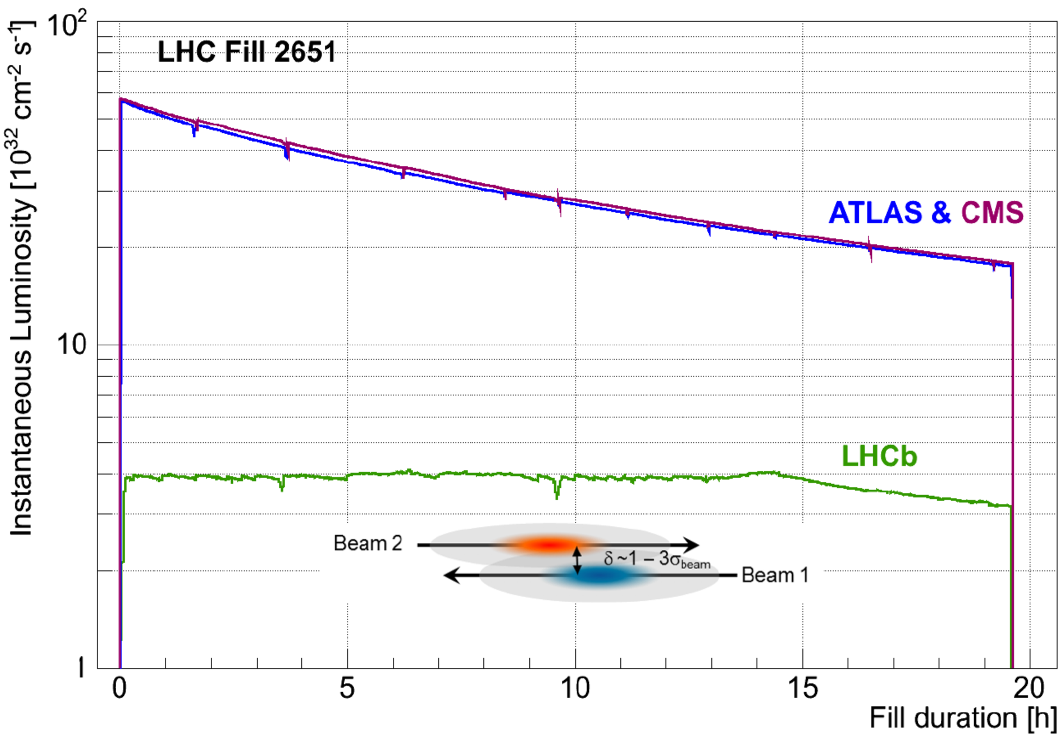
LHCb: a general purpose spectrometer in the forward direction (2 <η< 5) optimized for high-precision heavy-flavor physics

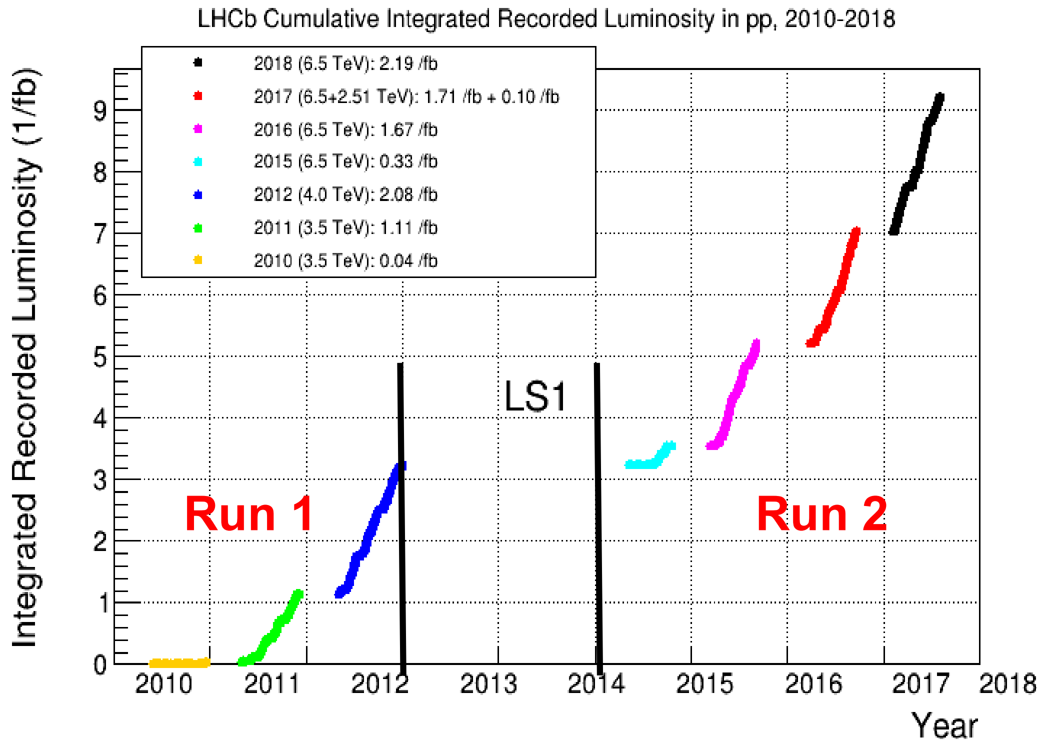
- Excellent vertexing, tracking and particle identification (K, π, p, μ, e, γ)
- Low trigger threshold on hadrons, muons and photons
- Produce all types of b- and c- hadrons
- Huge cross section and large boost

LHCb Detector Operations: Run1 & Run2

- LHCb designed to run at lower instantaneous luminosity compared to ATLAS and CMS
  - pp beams displaced to reduce L
    - $4 \times 10^{32}\ cm^{-2}s^{-1}$
  - Mean number of interactions per bunch crossing ~1-2

IJMP A30 (2015) 1530022





- $1\ fb^{-1}$ pf pp collisions at 7 TeV
- $2\ fb^{-1}$ of pp collisions at 8 TeV
- $6\ fb^{-1}$ of pp collisions at 13 TeV
- Total at end of Run2: $9\ fb^{-1}$

LHCb flavour physics program

CKM and CP violation	Sin2β, γ, Φ_s, $|V_{ub}|/|V_{cb}|$, semileptonics, CPV in B^0, B_s, D^0, b-baryons...
Rare decays	$B_{d,s}\to\mu\mu$, $B_{d,s}\to\tau\tau$, $B_s\to\gamma\gamma$, $B_{d,s}\to\tau\mu$, $b\to s\mu^+\mu^-$, $b\to se^+e^-$, $K\to\mu\mu$, $D\to\mu\mu$
Spectroscopy	Tetraquarks, pentaquarks, double-heavy hadrons, excited states...
Electroweak, QCD	Z, W, top, H→bb, H→cc, proton structure…
Ion physics, fixed target	Heavy ions, p-Pb, p-Gas (SMOG) ...
Dark Sector	Long lived particles, dark photon...

Inclusive channels, or channels with many neutrals are difficult in LHCb

Complementarity with Belle-II

Outline

CKM and CP violation

γ, Φ_s, $|V_{ub}|/|V_{cb}|$, anomalies In $b \to c$

Rare decays

Spectroscopy

Status and news states

Electroweak, QCD

Ion physics, fixed target

p-Pb, p-Gas (SMOG)

Dark Sector

LHCb: preparation for Run3
Upgrade II

LHCb talks

Ying-Rui Hou: Rare B decays and flavour anomalies at LHCb

Federico Lazzari: LHCb charm physics

CKM and CP Violation (and a bit of LFU)

CKM and Unitarity Triangle

- Up to O(λ^6) the CKM matrix is

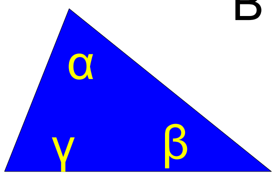
Single phase: responsible for all know CPV
In the Standard Model

$$V_{\text{CKM}} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\bar\rho - i\bar\eta) \\ -\lambda+\frac{1}{2}A^2\lambda^5[1-2(\bar\rho+i\bar\eta)] & 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4(1+4A^2) & A\lambda^2 \\ A\lambda^3[1-(\bar\rho+i\bar\eta)] & -A\lambda^2+\frac{1}{2}A\lambda^4[1-2(\bar\rho+i\bar\eta)] & 1-\frac{1}{2}A^2\lambda^4 \end{pmatrix}$$

- Many relations from Unitarity

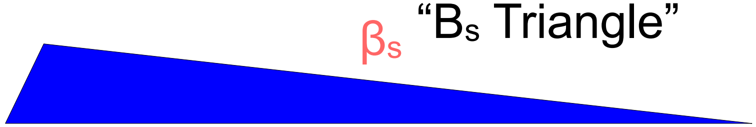
$$\underset{1\cdot\lambda^3}{V_{ud}V_{ub}^*} + \underset{\lambda\cdot\lambda^2}{V_{cd}V_{cb}^*} + \underset{\lambda^3\cdot 1}{V_{td}V_{tb}^*} = 0$$

"B Triangle", - the - UT



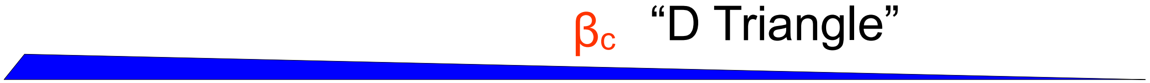
$$\underset{\lambda\cdot\lambda^3}{V_{us}V_{ub}^*} + \underset{1\cdot\lambda^2}{V_{cs}V_{cb}^*} + \underset{\lambda^2\cdot 1}{V_{ts}V_{tb}^*} = 0$$

"B$_s$ Triangle"



$$\underset{1\cdot\lambda}{V_{ud}V_{us}^*} + \underset{\lambda\cdot 1}{V_{cd}V_{cs}^*} + \underset{\lambda^3\cdot\lambda^2}{V_{td}V_{ts}^*} = 0$$

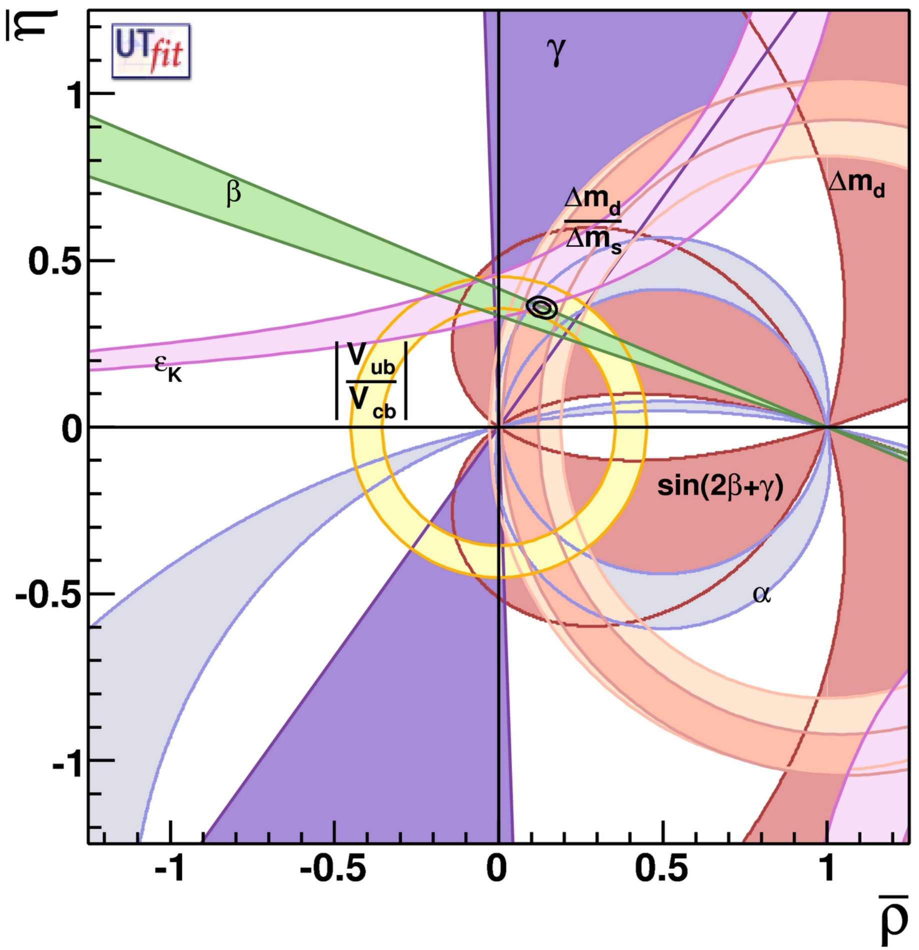
"D Triangle"



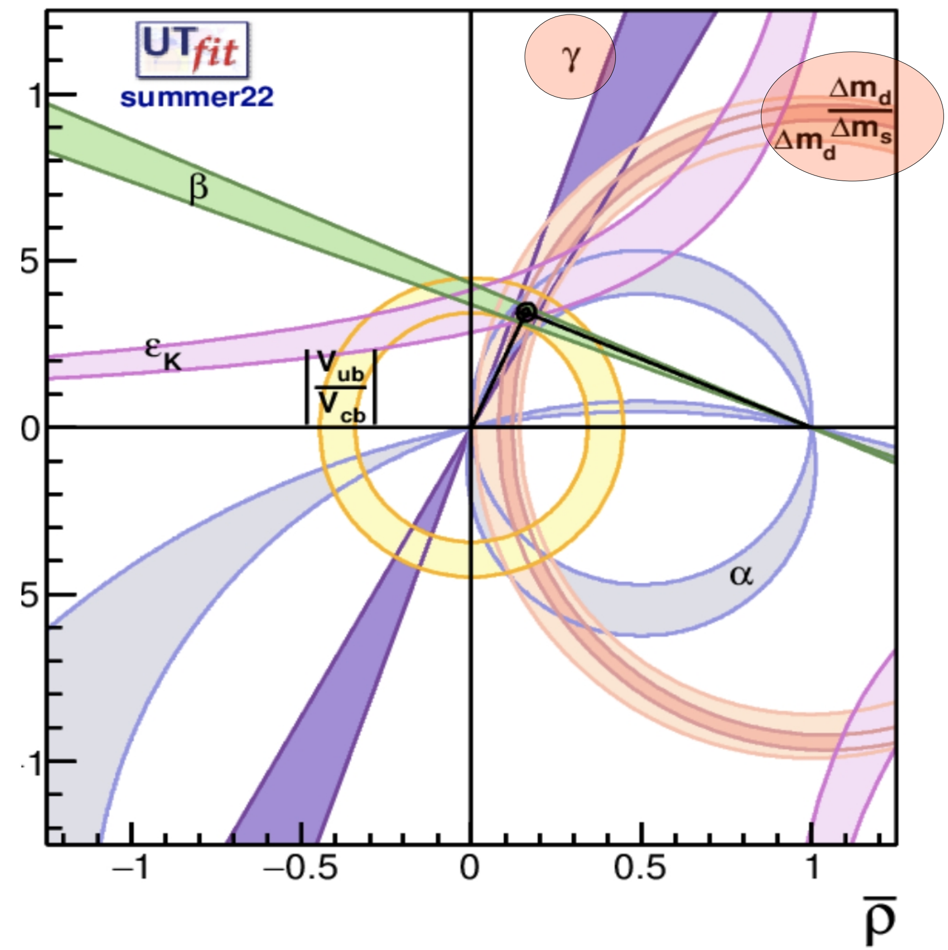
- Measure CKM quantities from loop and tree level processes → overconstrain the UTs, check the SM

UT: immense progresses

2010



2022



- Crucial inputs from LHCb
  - Measurements of γ (Φ3)
  - B_s oscillations

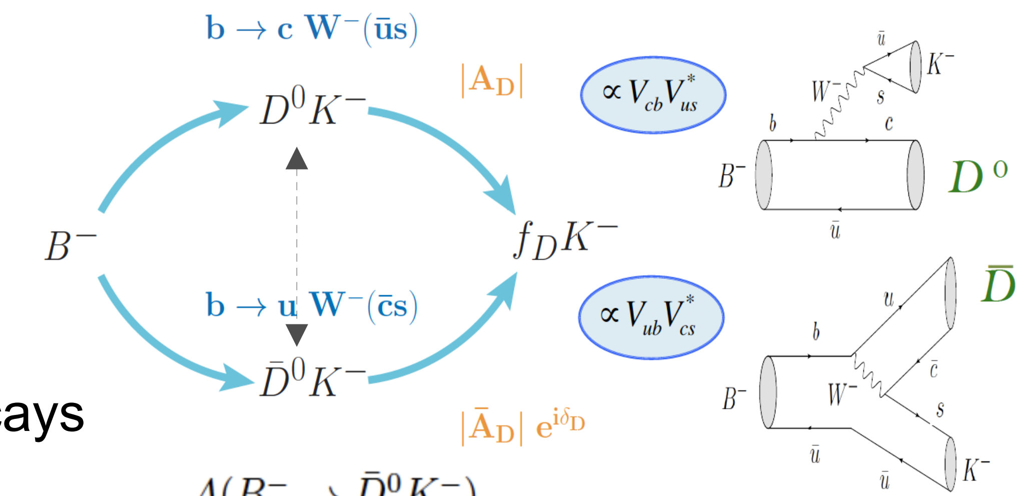
M. Bona's talk
'CKM metrology"

Angle γ

- From tree level processes
- Exploit interference between amplitudes

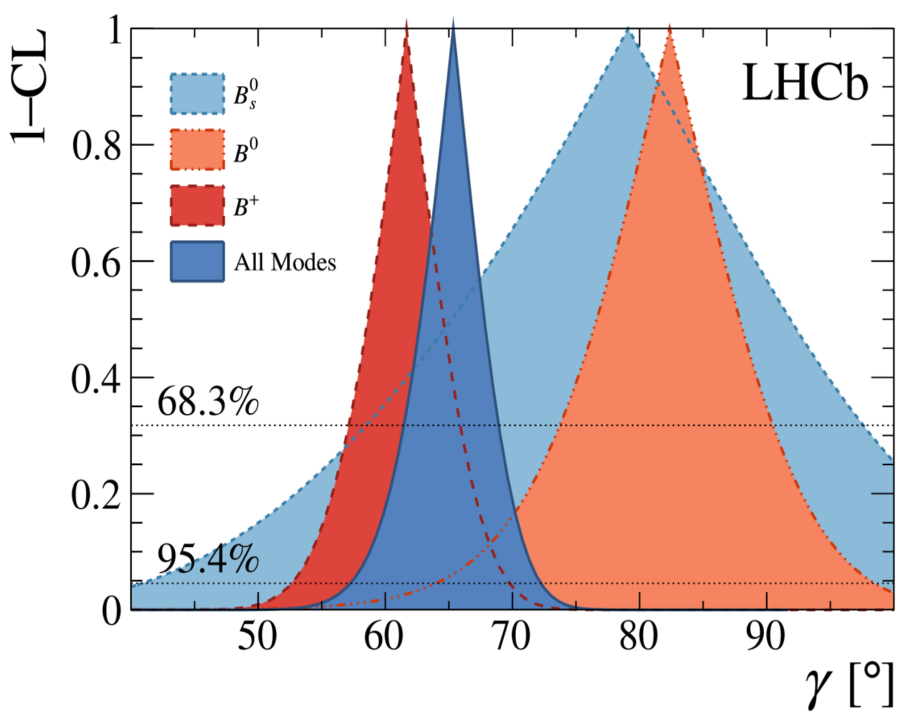
$f_D = \pi^+\pi^-, K^+K^-$	GLW
$K^+\pi^-$	ADS
$K^0_S\pi^+\pi^-$	GGSZ

- Combination of 15 B-decays and 9 D-decays LHCb measurements
  - Simultaneous fit of γ and D⁰ mixing parameters (x = ΔM/Γ and y=ΔΓ/2Γ)



$$\frac{A(B^- \to \bar{D}^0 K^-)}{A(B^+ \to D^0 K^+)} \equiv r_B e^{i(\delta_B - \gamma)}$$

JHEP 12(2021) 141



$$\gamma = (65.4^{+3.8}_{-4.2})^\circ$$

$\gamma_{\mathrm{indirect}} \approx (65.5^{+1}_{-2})^\circ$

- Critical input from BES-III (CLEO-c) for D decay parameters
- Some B decays not updated yet to the full Run1+2 dataset
- Improved determination of D-mixing parameters!

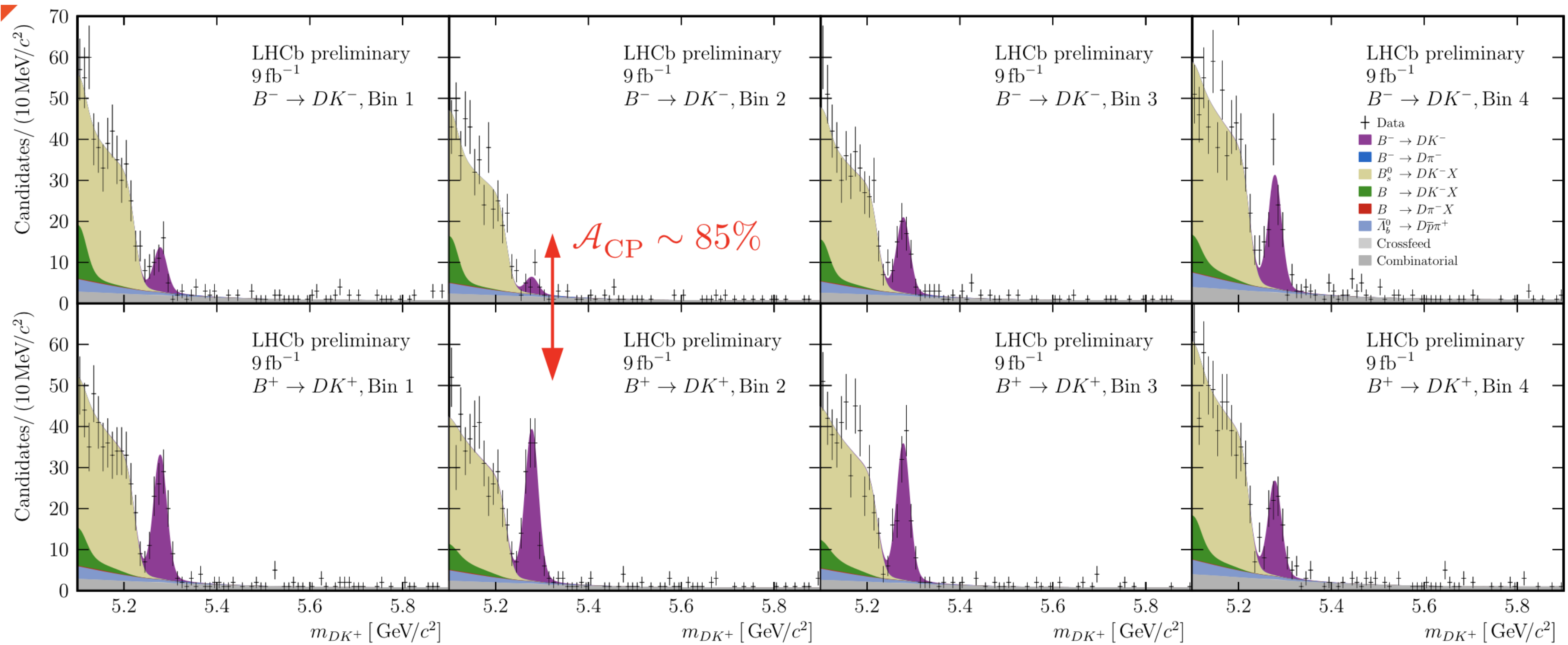
Angle γ from $B^{\pm}\to D^0K^{\pm}$, $D^0\to K3\pi$

LHCb-PAPER-2022-017
in preparation

- Analysis based on T.Evans et al. Phys.Lett.B 802 (2020) 135188
  - D decay hadronic parameters from CLEO-c, BES III, LHCb

JHEP05(2021)164

Bin	Limits ($\tilde{\delta}_{K3\pi}$)
1	$-180° < \tilde{\delta}_{K3\pi} \leq -39°$
2	$-39° < \tilde{\delta}_{K3\pi} \leq 0°$
3	$0° < \tilde{\delta}_{K3\pi} \leq 43°$
4	$43° < \tilde{\delta}_{K3\pi} \leq 180°$



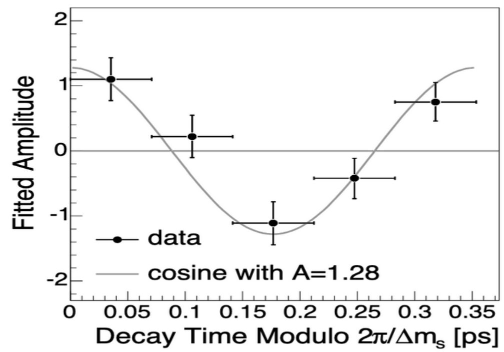
$$\gamma = (54.8^{+6.0}_{-5.8}\ {}^{+0.6}_{-0.6}\ {}^{+6.7}_{-4.3})°$$

Improvement expected from incoming 20fb^{-1} of BESIII data at $\psi(3770)$

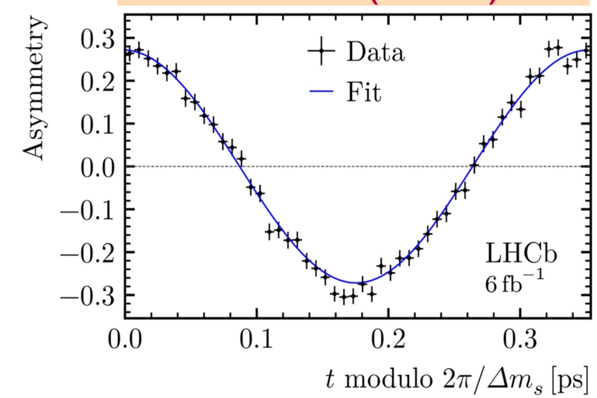
Textbook measurement: B_s oscillation

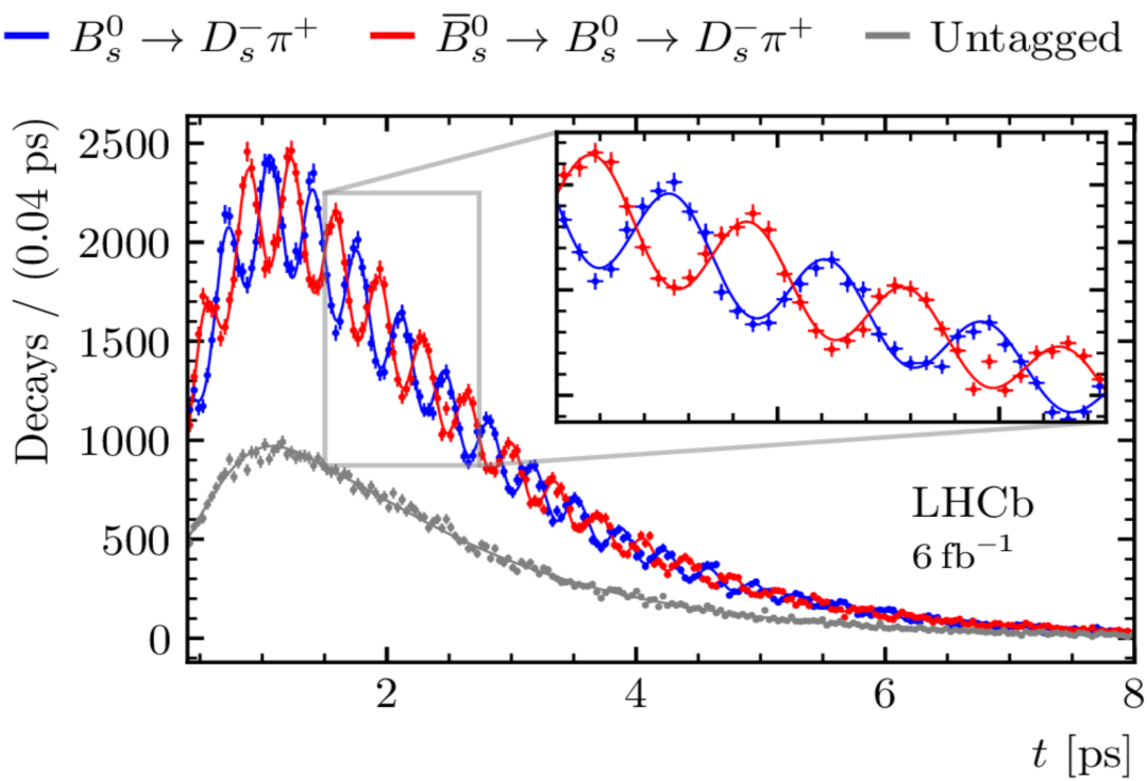
- Measurement of $\Delta m_s = m_H - m_L$ is crucial for γ measurements with time dependent $B_s \to D_s K(2\pi)$ measurements
  - Crucial constraint to UT (together with L-QCD inputs)

CDF
Pioneering first observation
of B_s oscillation
PRL97(2006) 242003



LHCb legacy
Nature 18 (2022) 1-5





$$\Delta m_s = 17.7683 \pm 0.0051 \pm 0.0032\ \text{ps}^{-1}$$

Consistent with other LHCb determinations and predictions based on Lattice and QCD - Sum Rules

$$\Delta m_s(\text{SM}) = 18.4^{+0.7}_{-1.2}\text{ps}^{-1}$$

L. Di Luzio et al.
JHEP 12 (2019) 009

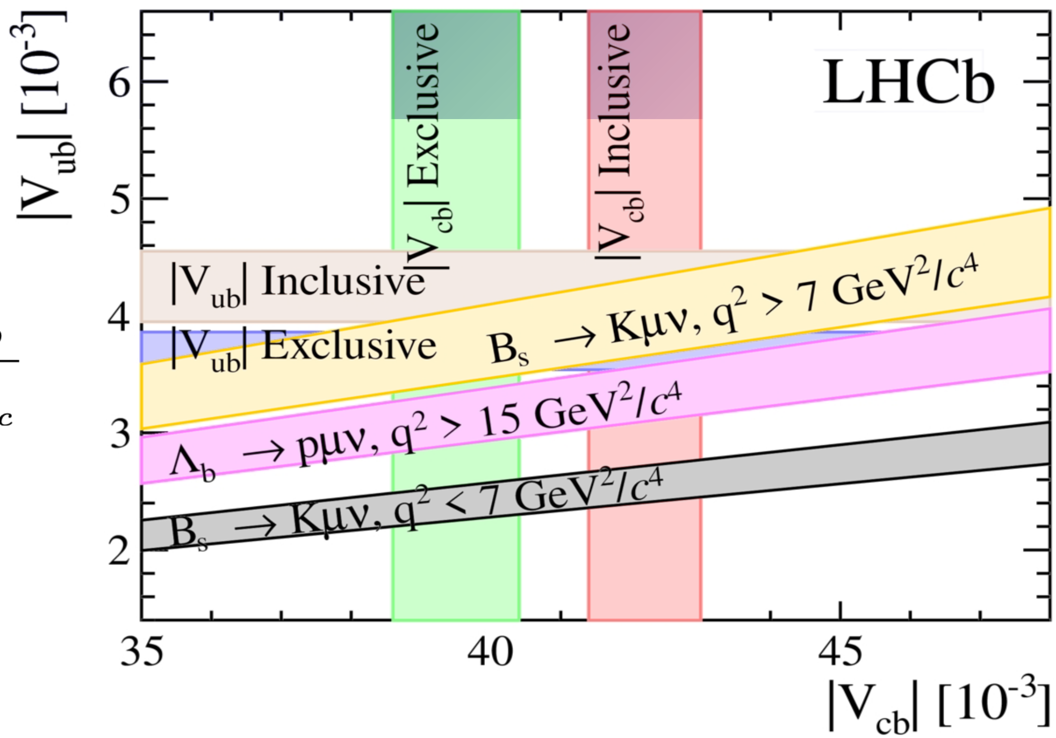
Sides of UT

- Pioneering result on $|V_{ub}|/|V_{cb}|$ using Λ_b semileptonic decays

$$R_{BF} = \frac{\mathcal{B}(\Lambda_b \to p\mu\nu)}{\mathcal{B}(\Lambda_b \to \Lambda_c\mu\nu)} \propto \frac{|V_{ub}|^2}{|V_{cb}|^2} \times \frac{FF_p}{FF_{\Lambda_c}}$$

Nature Physics 11 (2015) 743

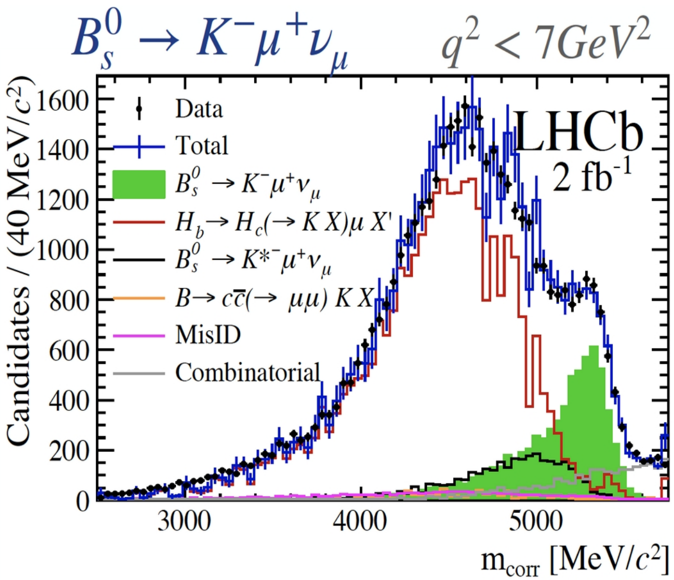
  - Only 1 LQCD calculation available!

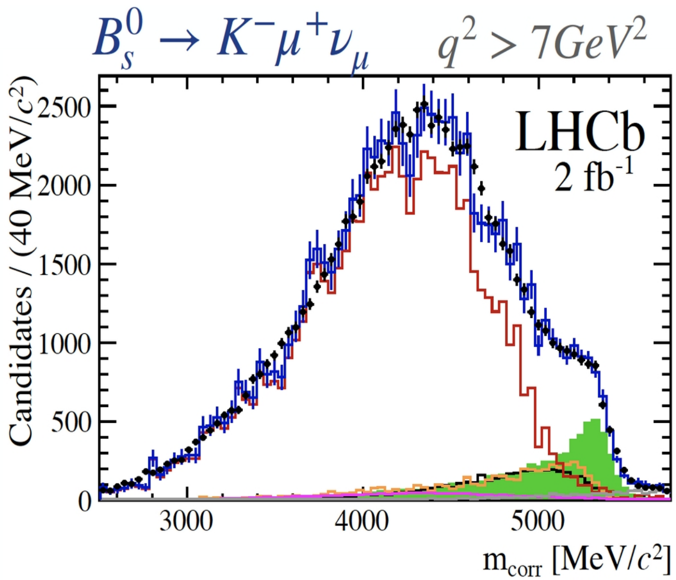


Phys.Rev.Lett. 126 (2021) 081804

- Similar measurement with B_s decays

$$R_{BF} = \frac{\mathcal{B}(B_b \to K\mu\nu)}{\mathcal{B}(B_s \to D_s\mu\nu)} \propto \frac{|V_{ub}|^2}{|V_{cb}|^2} \times \frac{FF_K}{FF_{D_s}}$$





Discrepancy between low and high q^2 regions needs to be understood

For LQCD: golden mode!

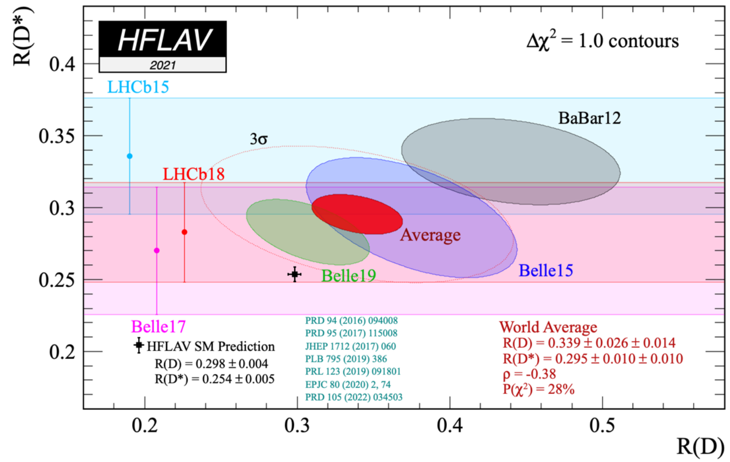
LHCb also measured $|V_{cb}|$ with $B_s \to D_s^{(*)}$decays

PRD101 (2020) 072004

LFU in b → c transitions

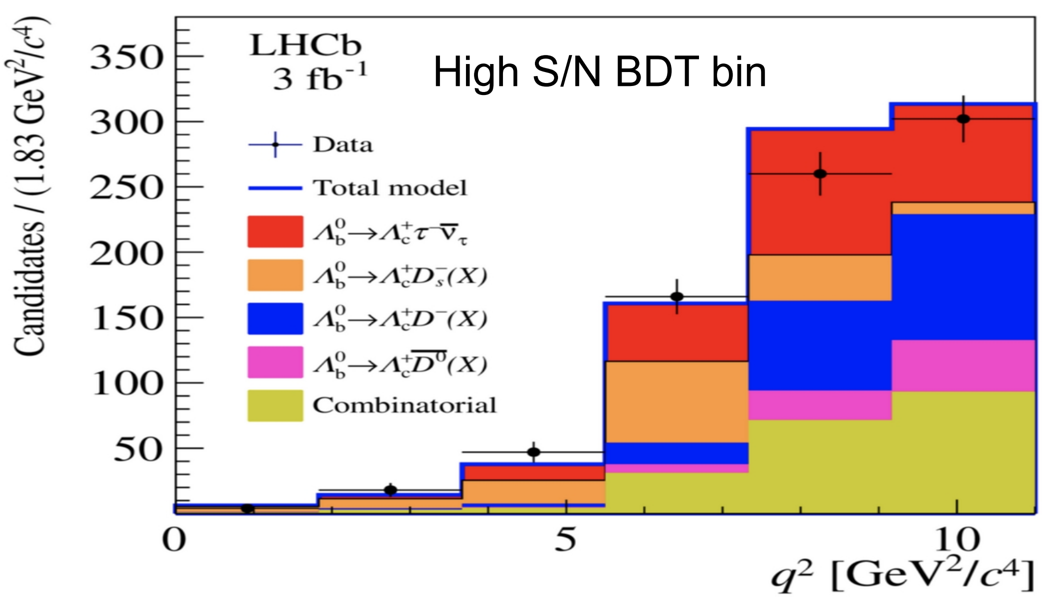
- Intriguing tension in R(D*)
  - Tree-level process
  - NP coupling to 3rd generation?
  - Possibile connetions with b → s l^+l^- anomalies

$$R(D^{(*)}) = \frac{\mathcal{B}(B^0 \to D^{(*)-}\tau^+\nu_\tau)}{\mathcal{B}(B^0 \to D^{(*)-}\mu^+\nu_\mu)}$$



- First measurement using baryons (only Run1)
  - 1st observation of $\Lambda_b \to \Lambda_c \tau \nu$
  - Tau reconstructed in $\tau \to 3\pi\nu$

Phys.Rev.Lett. 128 (2022) 191803



$$R(\Lambda_c) = 0.242 \pm 0.026 \pm 0.040 \pm 0.059_{ext}$$

Run1 + Run2

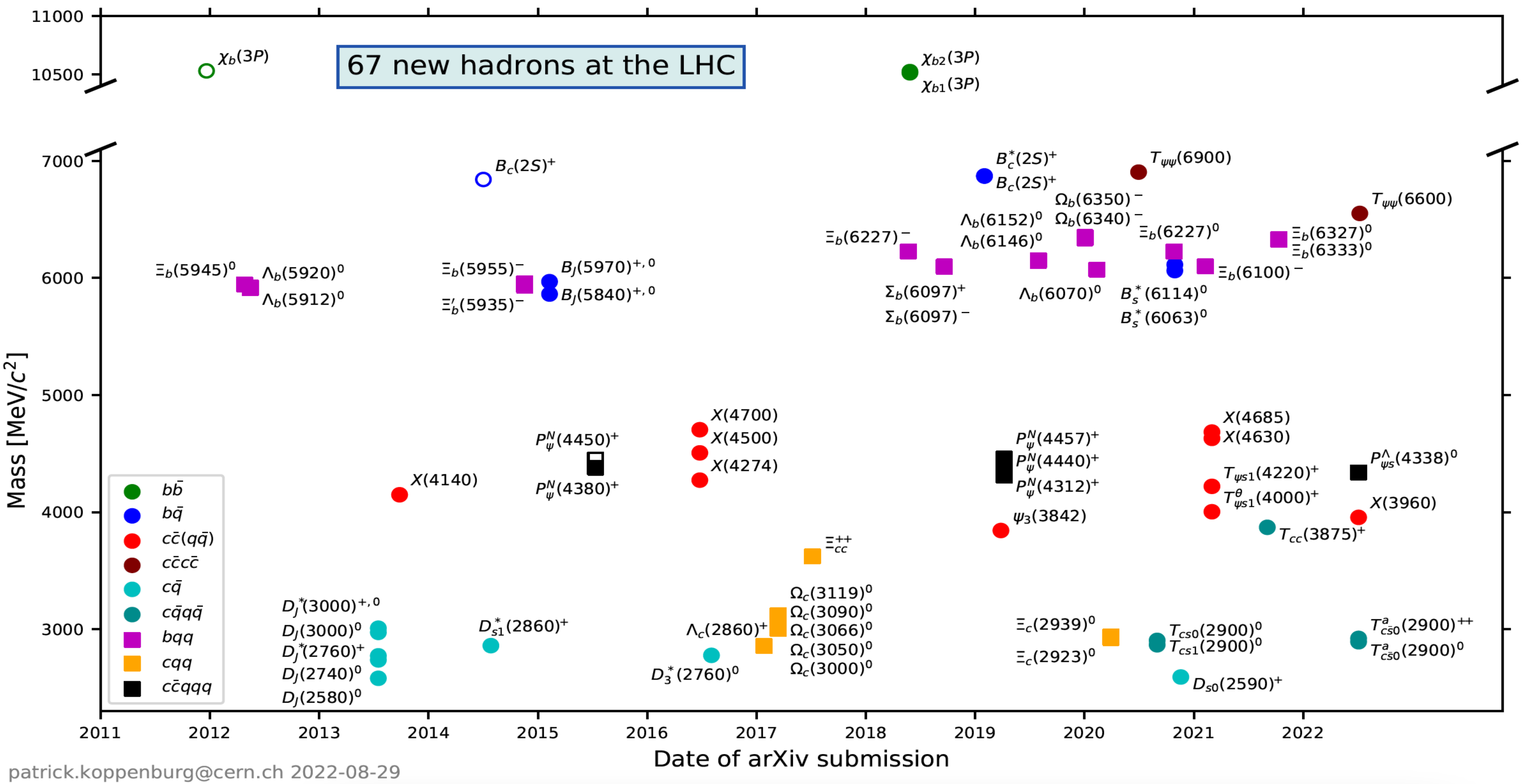
- $R(D^+)$
- $R(D^*)$ - $(e-\mu)$
- Combined $R(D^*) - R(D^0)$
- $R(D^{**})$
- $R(D_s^*)$
- $R(\Lambda_c^{**})$

+ additional observables with angular distributions

Exotic hadron states

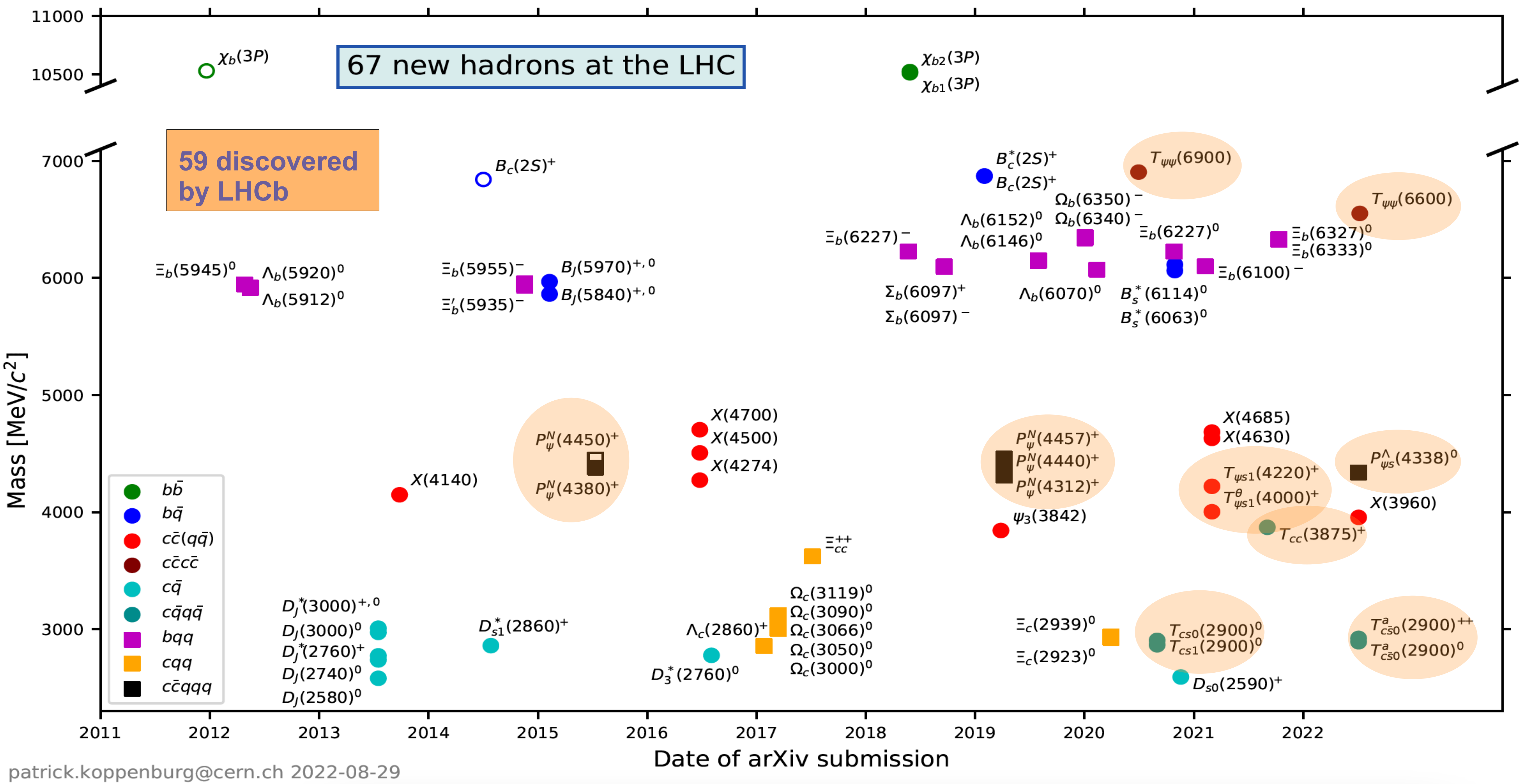
Hadron states

LHC experiments steadily deliver new discoveries of conventional and exotic hadrons



Hadron states

LHC experiments steadily deliver new discoveries of conventional and exotic hadrons

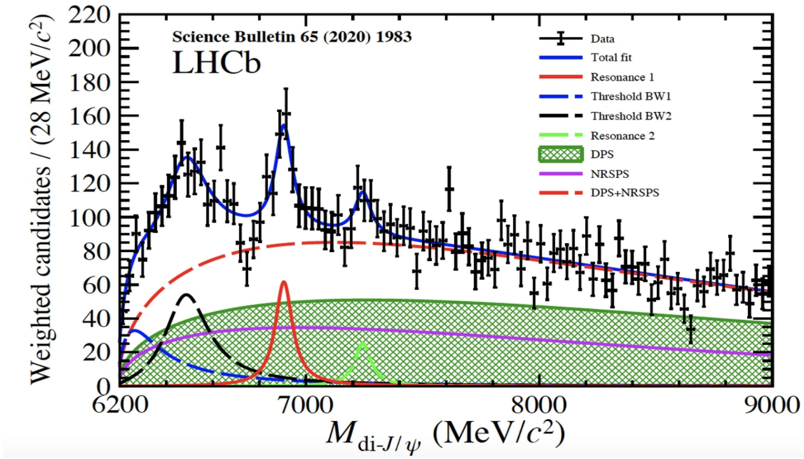


New quark combinations

New naming scheme proposed by LHCb
arXiv:2206.15233

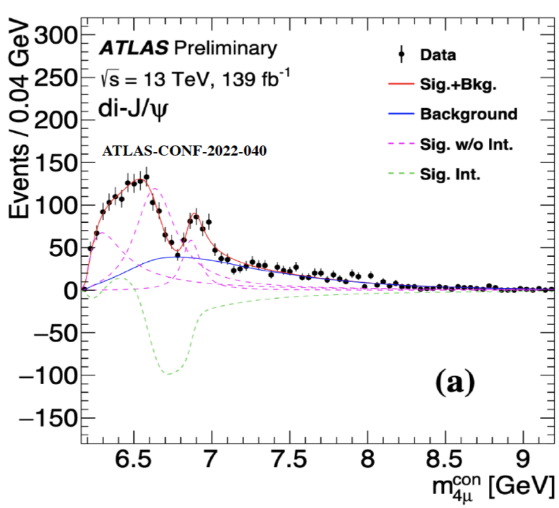
Hadron states

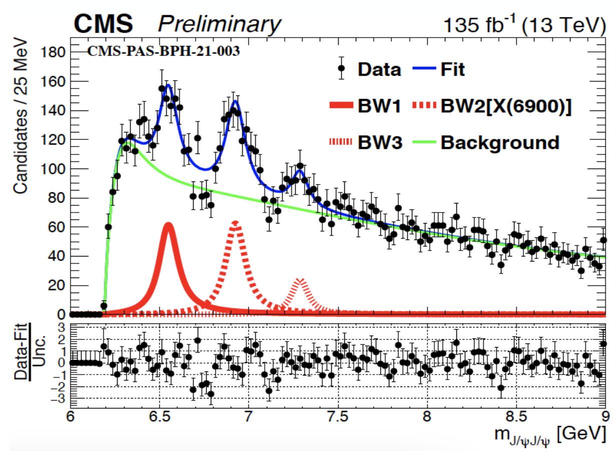
X(6900)=$c c \bar{c} \bar{c}$ →$T_{\psi\psi}$(6900)



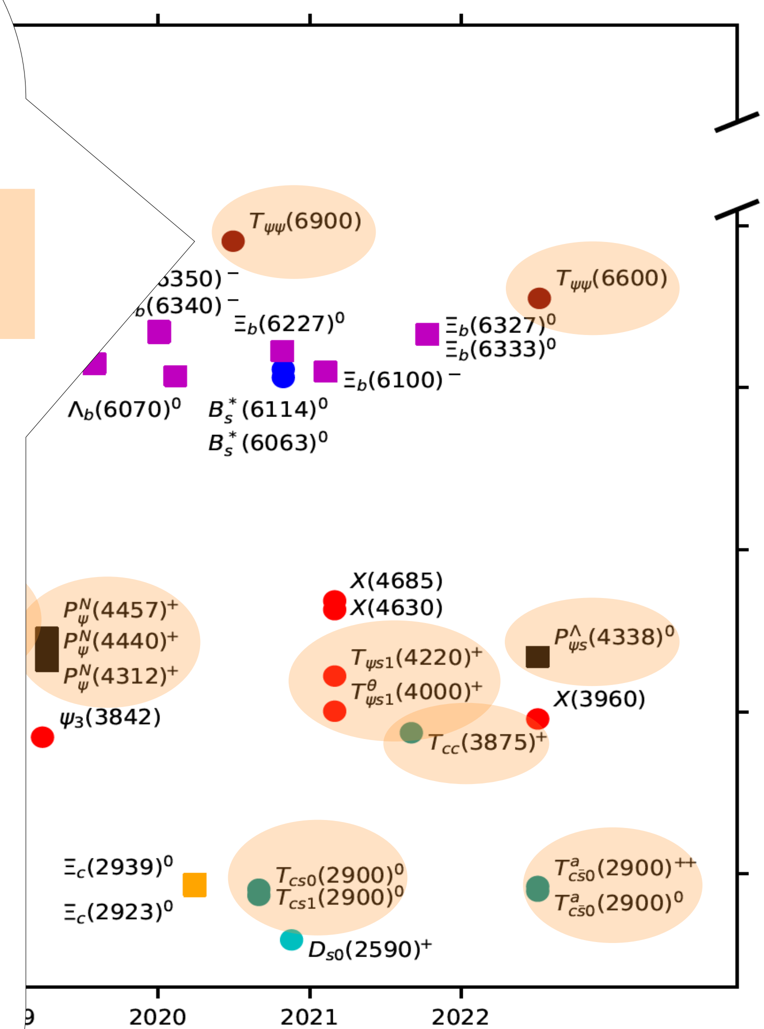
Science Bulletin, 65 (2020) 1983-93

Confirmed by ATLAS and CMS (at ICHEP): evidence for additional structures?





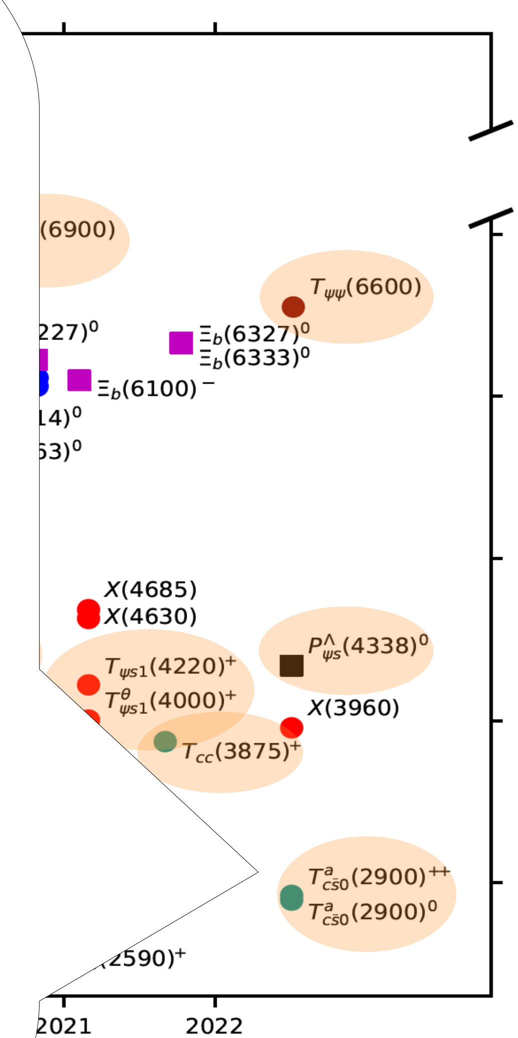
...ntional and exotic hadrons



...naming scheme proposed by LHCb
arXiv:2206.15233

Hadron states

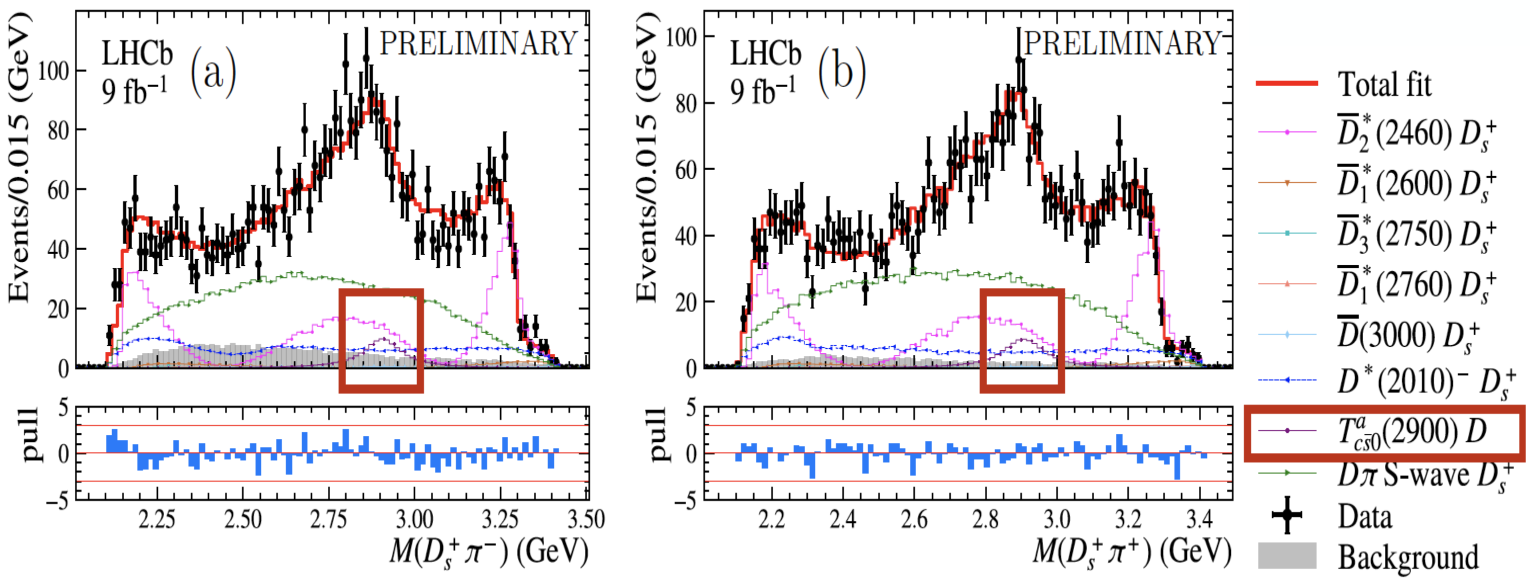
exotic hadrons



$T_{cs0}(2900)^{++}$ ($c\,\bar{s}\,u\,\bar{d}$), $T_{cs0}(2900)^0$ ($c\,\bar{s}\,\bar{u}\,d$)

- Isospin pair of double charged and neutral tetraquark

$B^0 \to \overline{D}^0 D_s^+ \pi^-$ $\quad$ $B^+ \to D^- D_s^+ \pi^+$



LHCb-PAPER-2022-026/027 in preparation

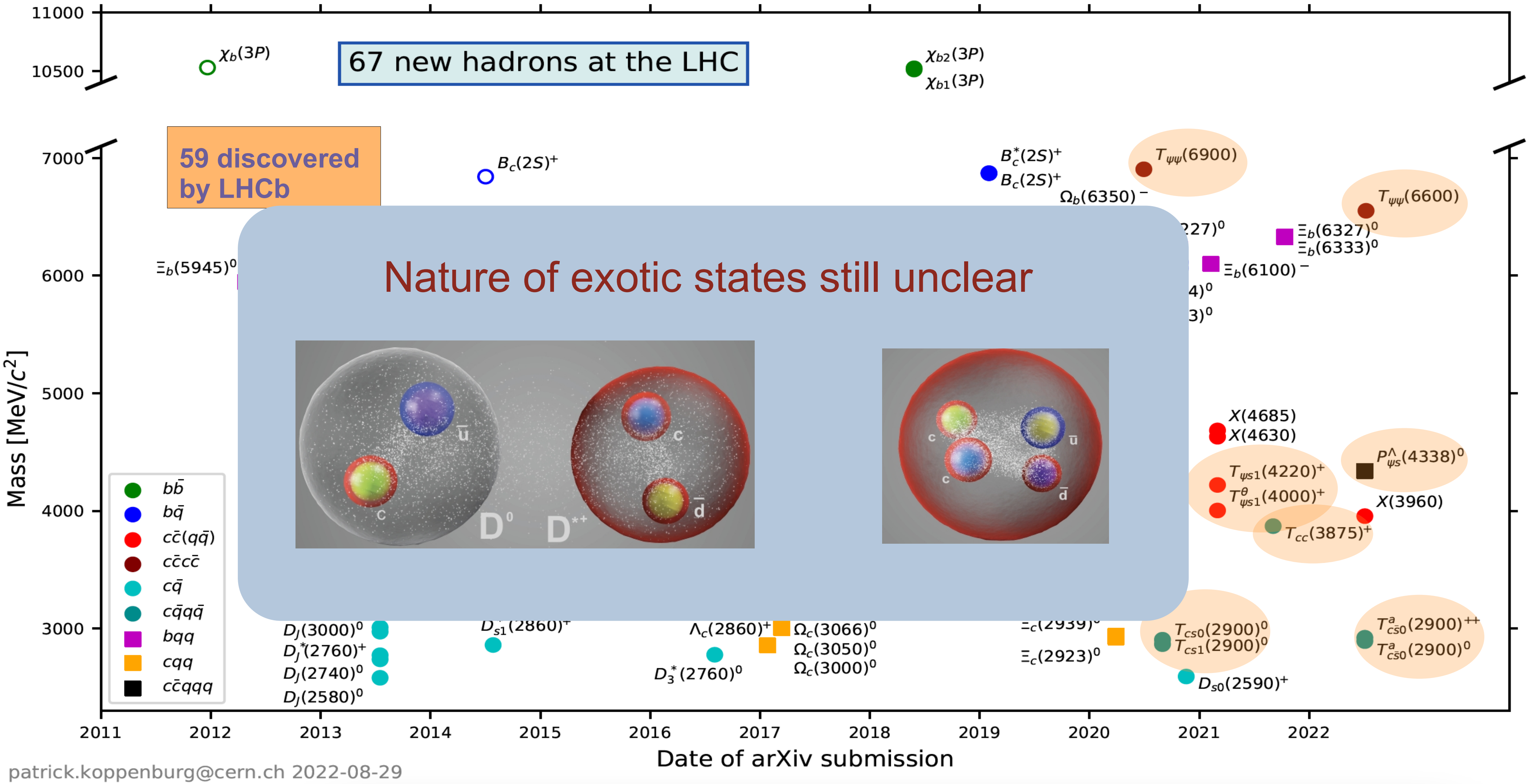
$T_{cs0}(2900)^0$ and $T_{cs1}(2900)^0$ ($c\,s\,\bar{u}\,\bar{d}$) previously found by LHCb in DK mass spectrum

$B^+ \to D^+ D^- K^+$ PRL125 (2020) 242001

heme proposed by LHCb
arXiv:2206.15233

Hadron states

LHC experiments steadily deliver new discoveries of conventional and exotic hadrons



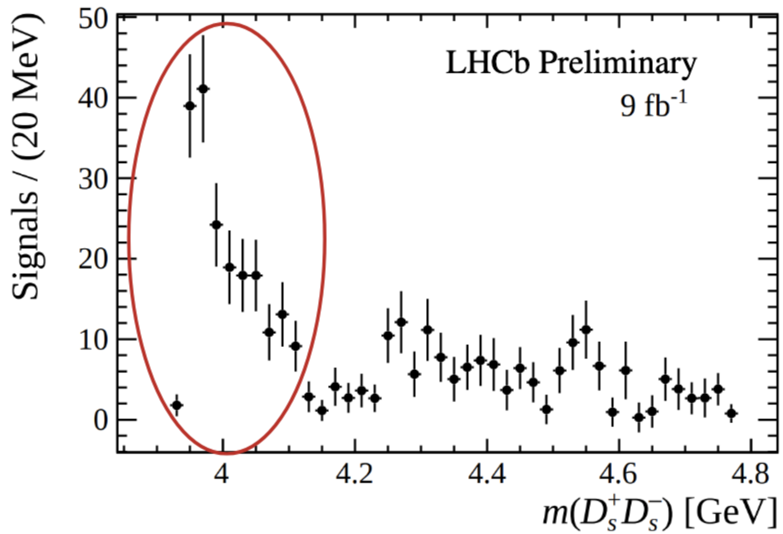
New quark combinations

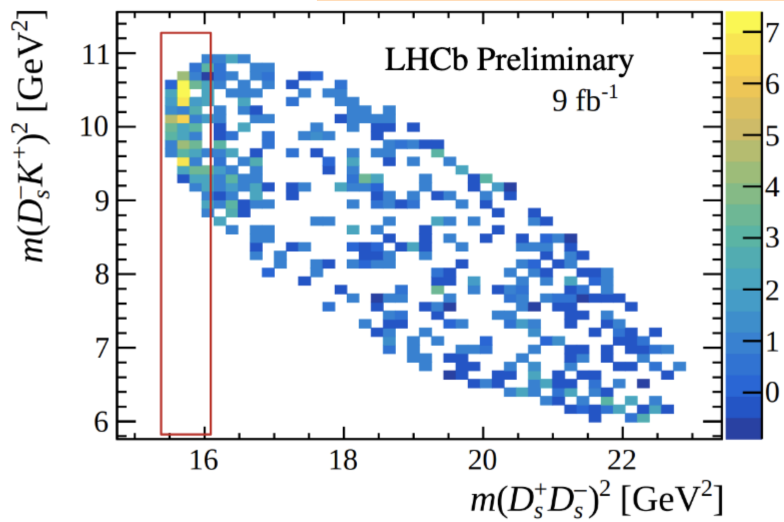
New naming scheme proposed by LHCb
arXiv:2206.15233

New entries in the arena

- Resonant structure near $D_s^+D_s^-$ threshold $B^+ \to D_s^+ D_s^- K^-$
  - Amplitude analysis favors exotic ($c\bar{c}s\bar{s}$) state with $J^{PC}=1^{++}$

LHCb-PAPER-2022-018 in preparation



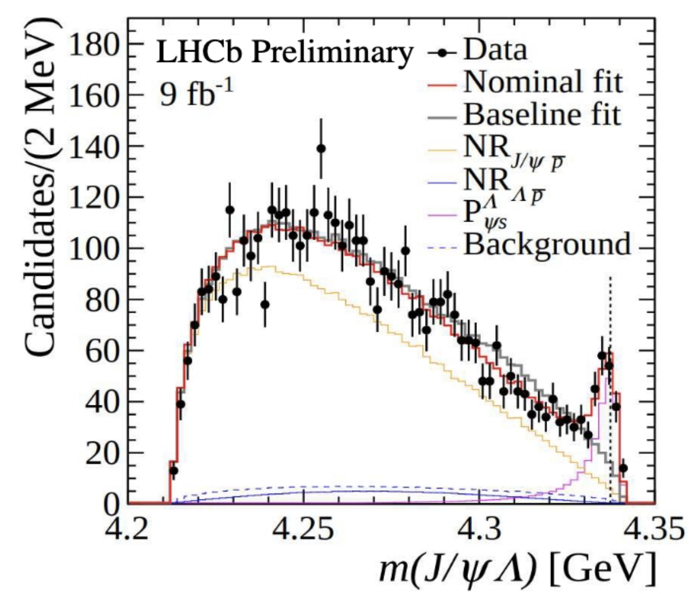


- First strange pentaquark $P^{\Lambda}_{\psi s}(4338)$ ($c\bar{c}uds$)?

$$B^- \to J/\psi \Lambda \bar{p}$$

  - Structure of a Jpsi/Λ resonance
  - J^P = ½+ is preferred

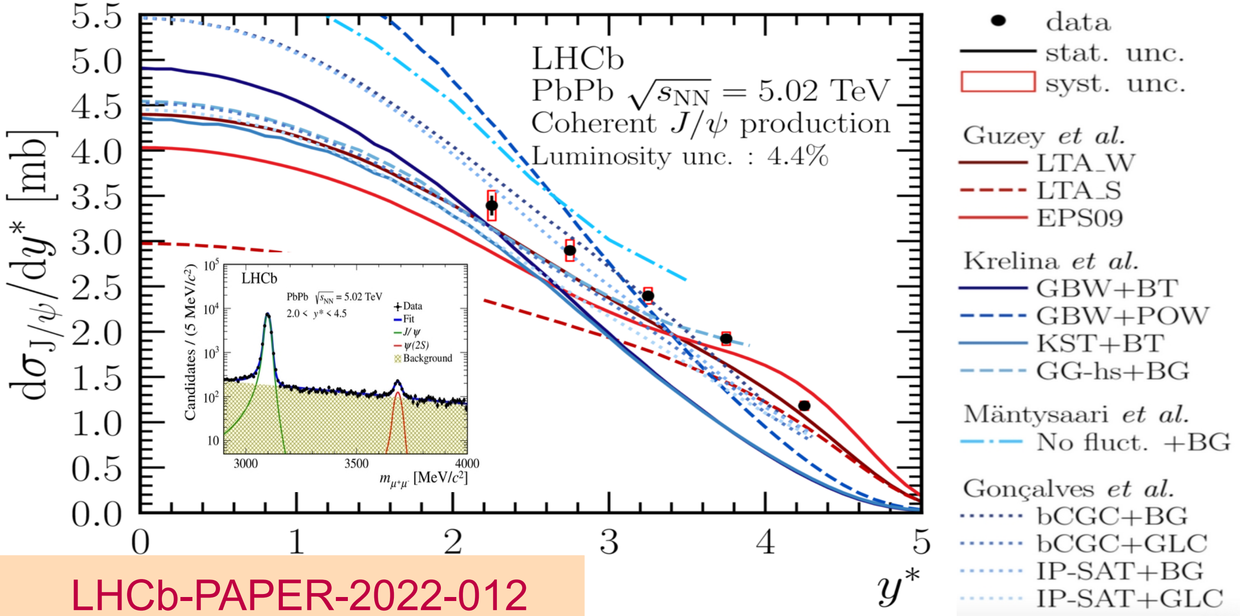
LHCb-PAPER-2022-031 in preparation



Heavy ions

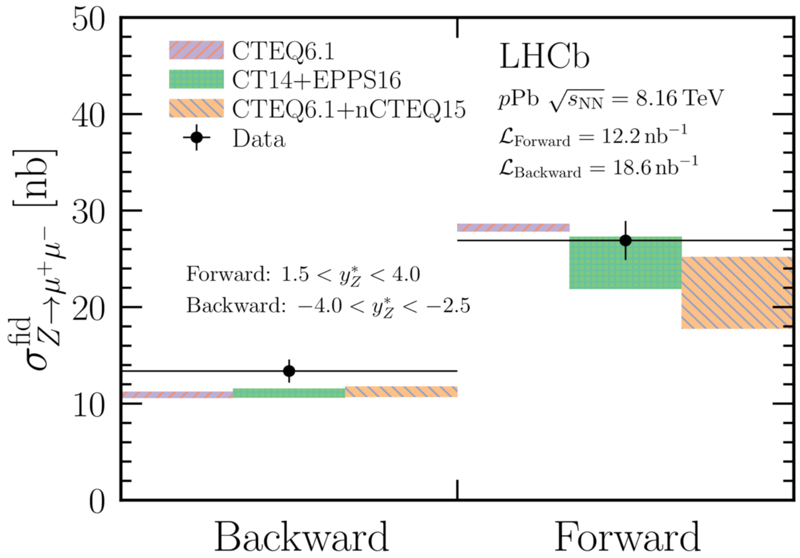
Heavy ions and fixed target

- Charmonium production in UPC PbPb at 8.16 TeV



LHCb-PAPER-2022-012

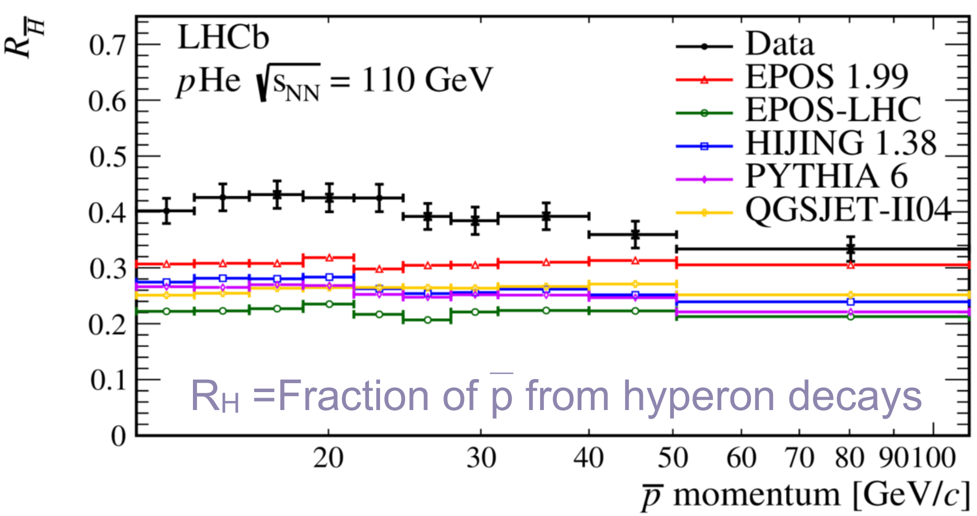
- Z production in pPb at 8.16 TeV



LHCb-PAPER-2022-009

- SMOG: Gas injected system for fixed-target physics

arXiv:2205.09009 accepted by EPJC



- Important input for $\overline{p}$ flux calculation in cosmic rays
- Event generators used in cosmic rays physics consistently underestimate the data
- Consistent with pp result from ALICE and CMS

Beyond LS2

LHCb Upgrade I: Run3 and Run4

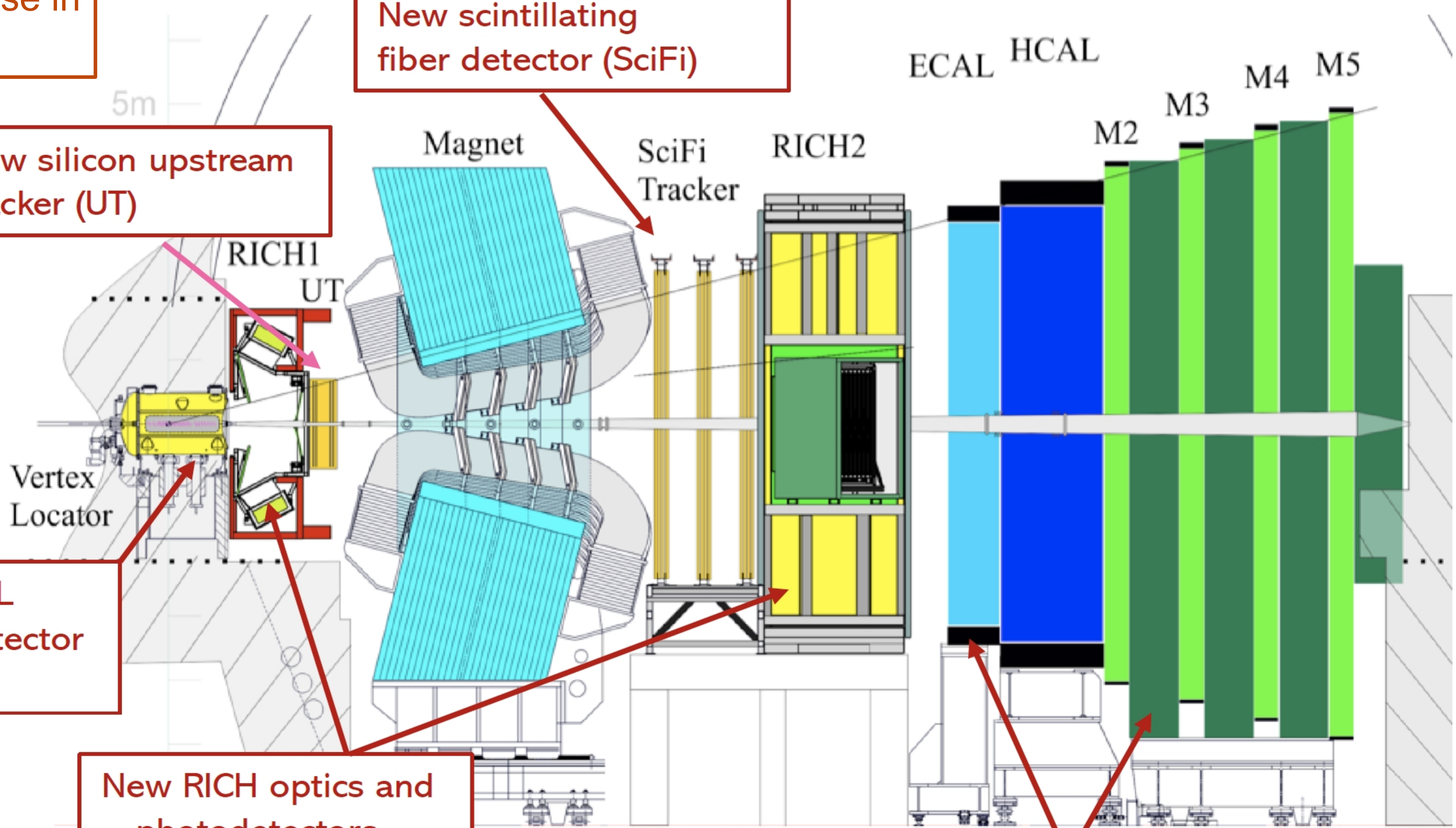
Target L_{peak}=20 x 10^{32} cm^{-2}s^{-2}
Pile-up ~ 5

Remove the first-level hardware trigger:
Trigger-less 40MHz readout in all sub-detectors

SMOG2: new gas cell upstream of the VELO. Up to 100× increase in gas pressure

New scintillating fiber detector (SciFi)

New silicon upstream tracker (UT)



New PIXEL vertex detector (VELO)

New RICH optics and photodetectors

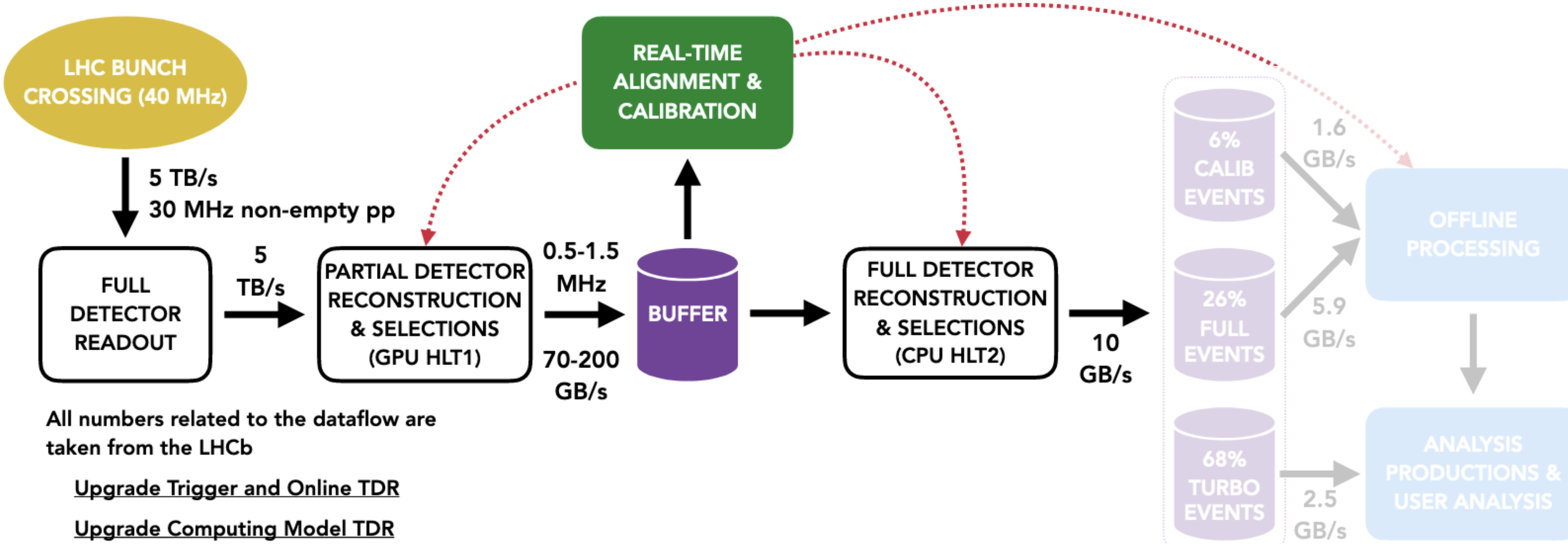
New electronics for muon and calorimeter systems

CERN-LHCC-2011-001

Fully software trigger

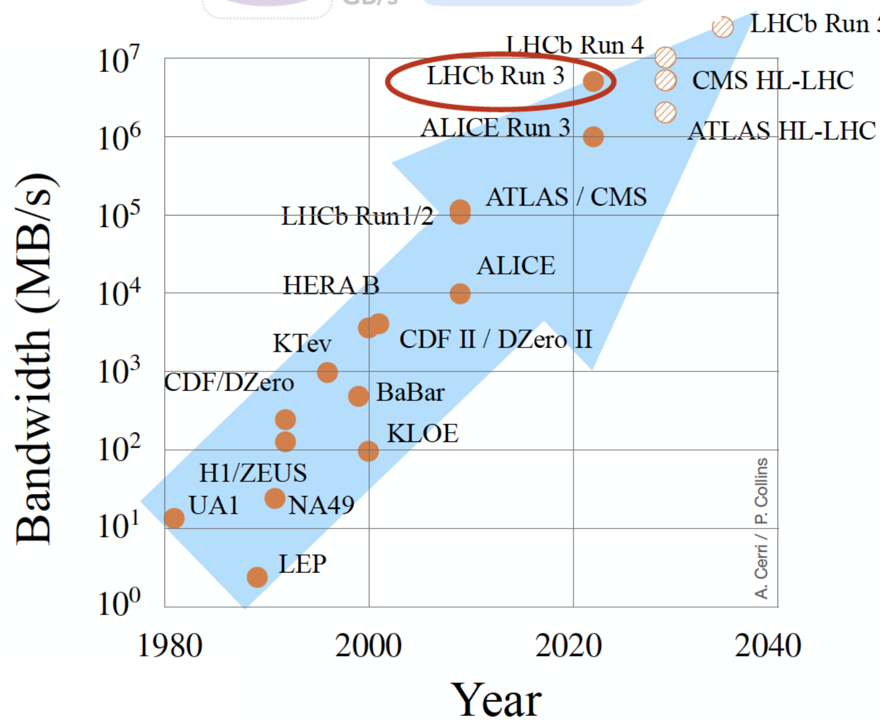
- All sub-detector readout at 40 MHz → fully software trigger

CERN-LHCC-2014-016
CERN-LHCC-2020-006

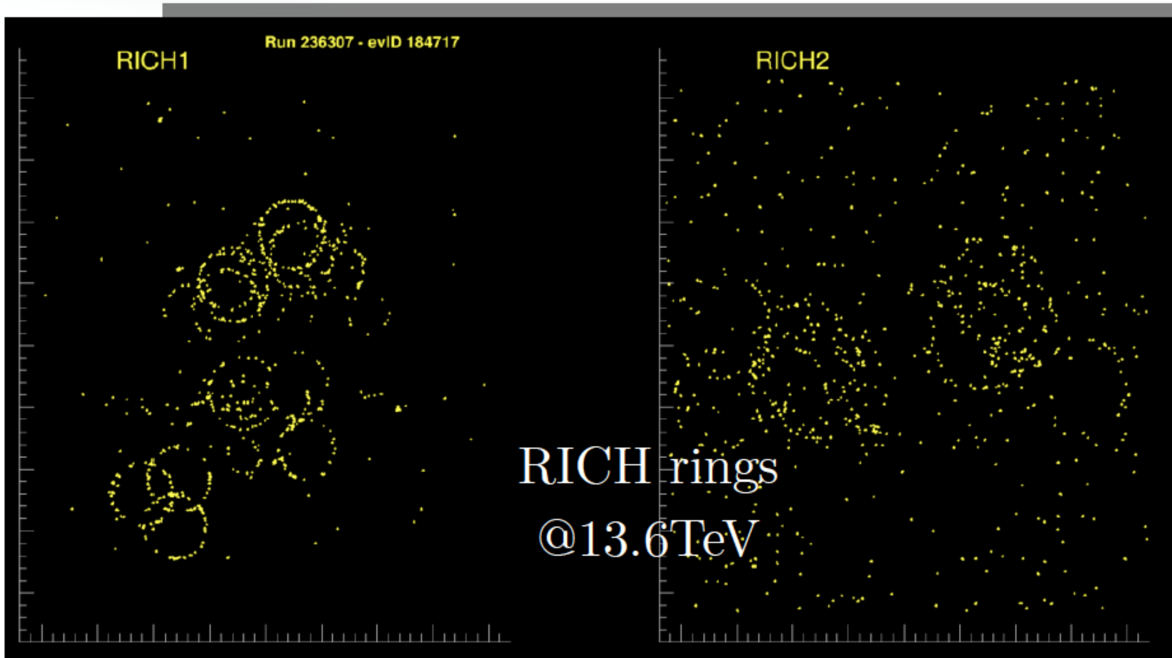


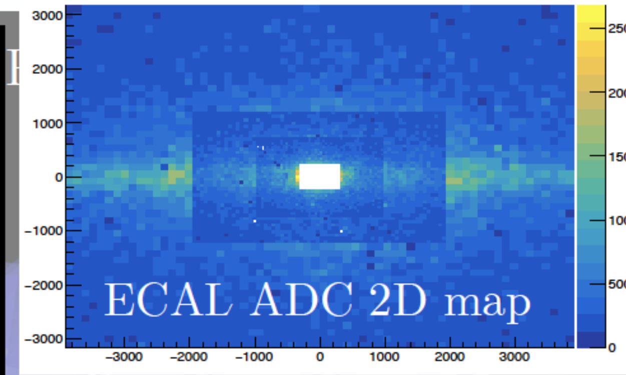
- 30MHz of inelastic collisions reduced to 1MHz in HLT1
  - Running on GPU cards
- Factor of ~10 increase expected in hadronic yields at Run3

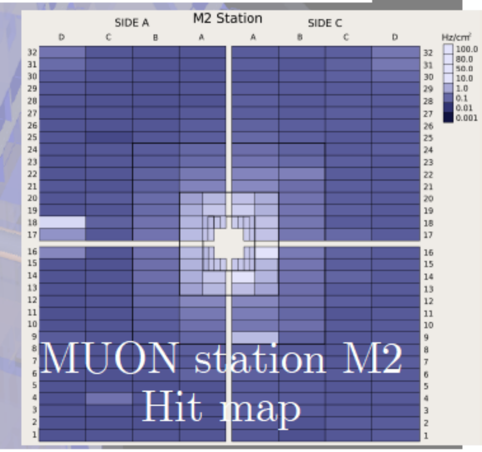
Highest throughput of any HEP experiment

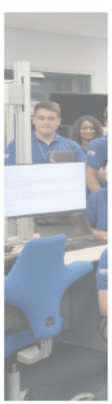


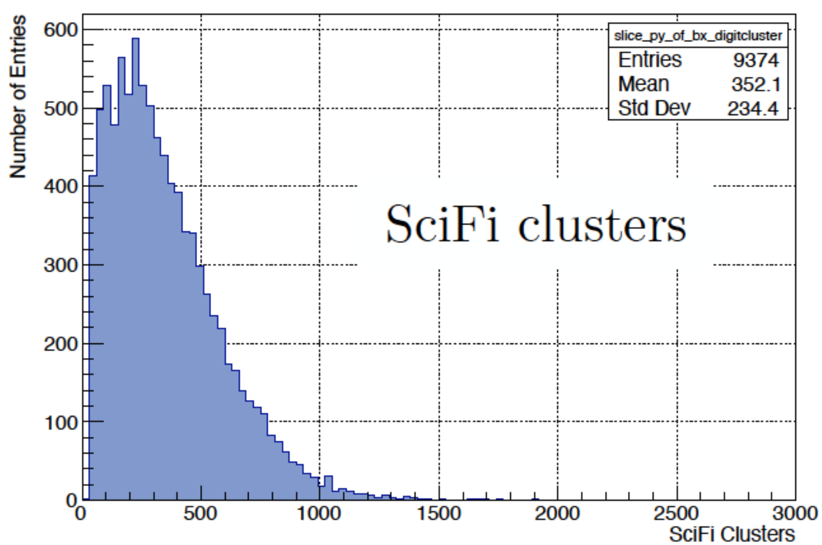
First data at 13.6 TeV

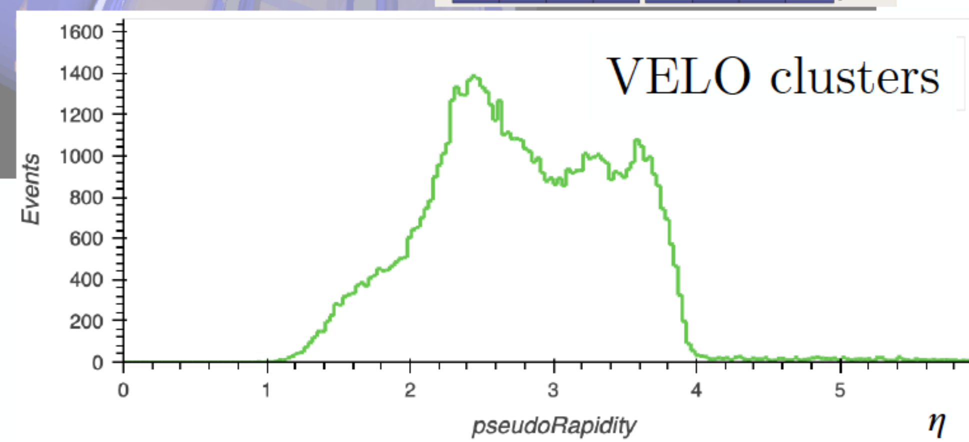












LHCb Upgrade I: Physics Case

LHCC-2021-012

Observable	Current LHCb (up to 9 fb^{-1})		Upgrade I (23 fb^{-1})	Upgrade I (50 fb^{-1})
CKM tests				
γ ($B \to DK$, *etc.*)	4°	[9, 10]	1.5°	1°
ϕ_s ($B^0_s \to J/\psi\phi$)	32 mrad	[8]	14 mrad	10 mrad
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ ($\Lambda^0_b \to p\mu^-\overline{\nu}_\mu$, *etc.*)	6%	[29, 30]	3%	2%
$a^d_{\rm sl}$ ($B^0 \to D^-\mu^+\nu_\mu$)	36×10^{-4}	[34]	8×10^{-4}	5×10^{-4}
$a^s_{\rm sl}$ ($B^0_s \to D^-_s\mu^+\nu_\mu$)	33×10^{-4}	[35]	10×10^{-4}	7×10^{-4}
Charm				
ΔA_{CP} ($D^0 \to K^+K^-, \pi^+\pi^-$)	29×10^{-5}	[5]	13×10^{-5}	8×10^{-5}
A_Γ ($D^0 \to K^+K^-, \pi^+\pi^-$)	11×10^{-5}	[38]	5×10^{-5}	3.2×10^{-5}
Δx ($D^0 \to K^0_{\rm S}\pi^+\pi^-$)	18×10^{-5}	[37]	6.3×10^{-5}	4.1×10^{-5}
Rare Decays				
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B^0_s \to \mu^+\mu^-)$	69%	[40, 41]	41%	27%
$S_{\mu\mu}$ ($B^0_s \to \mu^+\mu^-$)	—		—	—
$A^{(2)}_{\rm T}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043
$A^{\rm Im}_{\rm T}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043
$\mathcal{A}^{\Delta\Gamma}_{\phi\gamma}(B^0_s \to \phi\gamma)$	$^{+0.41}_{-0.44}$	[51]	0.124	0.083
$S_{\phi\gamma}(B^0_s \to \phi\gamma)$	0.32	[51]	0.093	0.062
$\alpha_\gamma(\Lambda^0_b \to \Lambda\gamma)$	$^{+0.17}_{-0.29}$	[53]	0.148	0.097
Lepton Universality Tests				
R_K ($B^+ \to K^+\ell^+\ell^-$)	0.044	[12]	0.025	0.017
R_{K^*} ($B^0 \to K^{*0}\ell^+\ell^-$)	0.12	[61]	0.034	0.022
$R(D^*)$ ($B^0 \to D^{*-}\ell^+\nu_\ell$)	0.026	[62, 64]	0.007	0.005

Belle-II:
1) Unique capability to perform inclusive measurements
2) precise studies with modes involving many neutrals

LHCb at HL-LHC (LS4)

9 fb^{-1}

Goal: 50 fb^{-1}

Goal: 300 fb^{-1}

Upgrade I

Consolidation

Upgrade II

Run 1	**LS1**	Run 2	**LS2**		Run 3	**LS3**	Run 4	**LS4**	Run 5	**LS5**	Run 6
2011 2012	2013 2014	2015 2016 2017 2018	2019 2020 2021	2022	2023 2024 2025	2026 2027 2028	2029 2030 2031 2032	2033 2034	2035 2036 2037 2039	2040	2041 2042

HL - LHC

LHCb at HL-LHC (LS4)

9 fb^{-1} — Goal: 50 fb^{-1} — Goal: 300 fb^{-1}

Upgrade I — Consolidation — Upgrade II

Run 1	LS1	Run 2	LS2		Run 3	LS3	Run 4	LS4	Run 5	LS5	Run 6
2011 2012	2013 2014	2015 2016 2017 2018	2019 2020 2021	2022	2023 2024 2025	2026 2027 2028	2029 2030 2031 2032	2033 2034	2035 2036 2037 2039	2040	2041 2042

- Fully exploit the HL-LHC for flavor physics & beyond
- Upgrade II for Run 5 and 6
  - L_{peak}=1.5 x 10^{34} $cm^{-2}s^{-2}$
  - Pile-up ~40
  - L_{int}=300 fb^{-1}

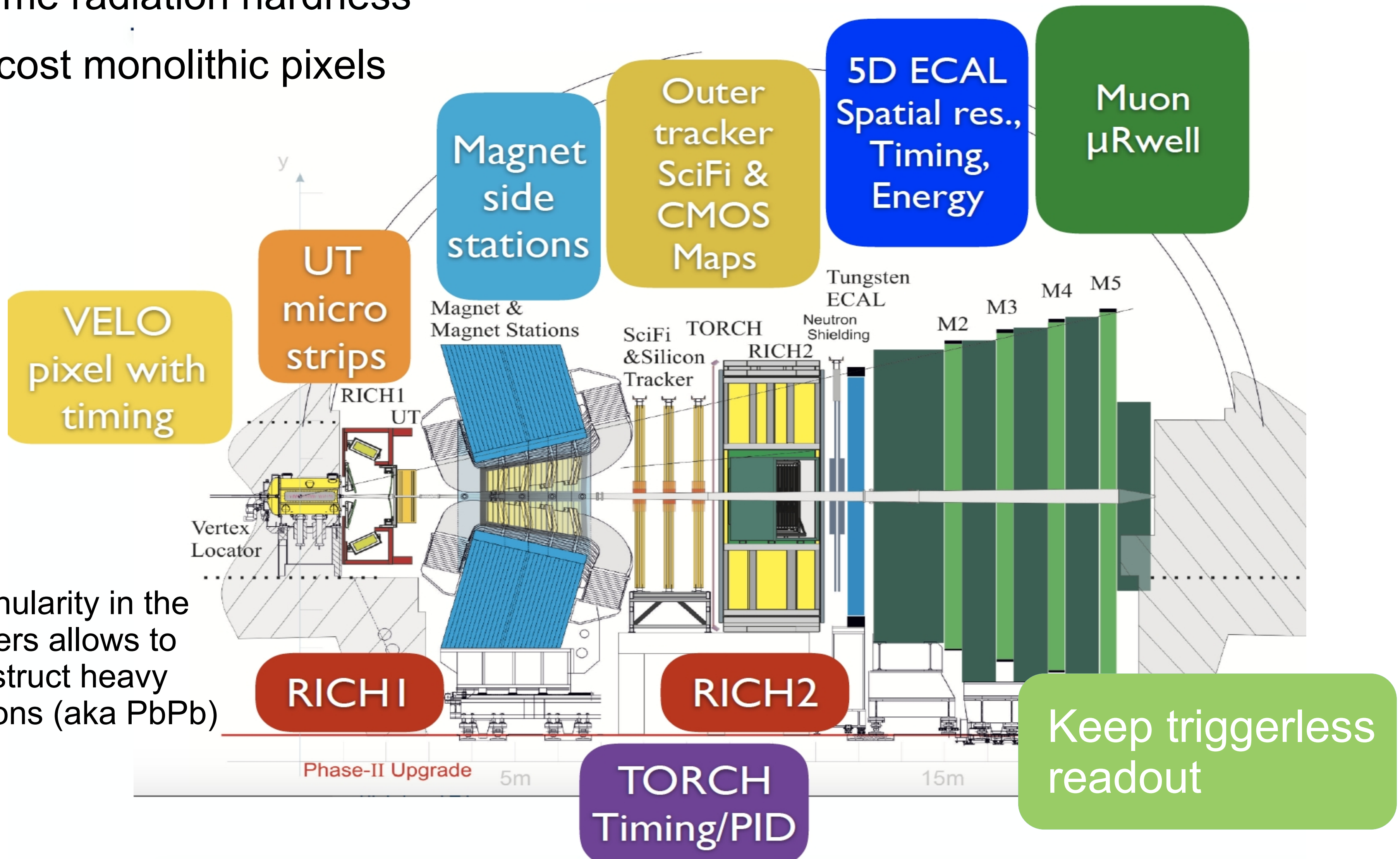
- **F-TDR approved by LHCC**
  - Target same performances as Run3
  - New detector technologies are needed
  - Subdetector TDRs at start of LS3
- **News collaborators welcome!**

LHCb Upgrade II detector

CERN-LHCC-2017-003

- R&D phase of new technologies
  - Precise timing for tracking and PID ECAL
  - Extreme radiation hardness
  - Low-cost monolithic pixels

Detector must be faster, harder, finer, smarter

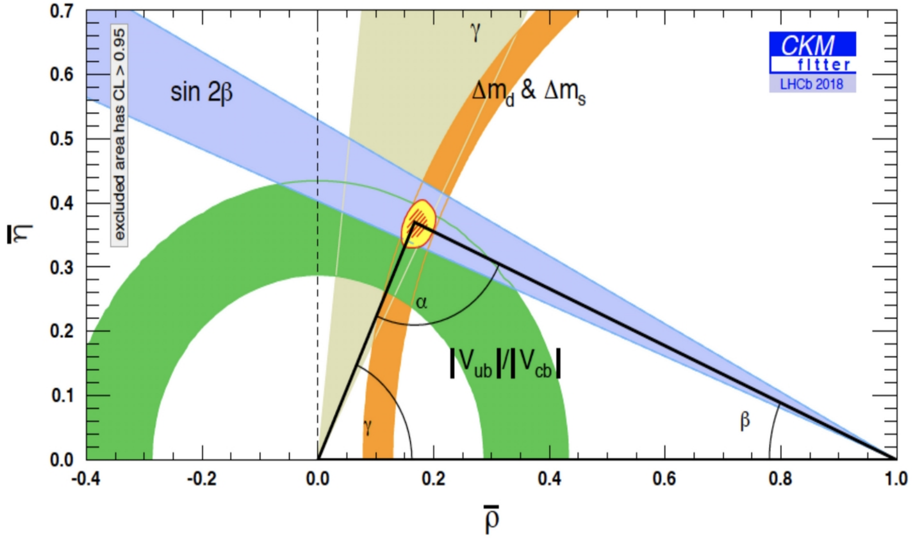


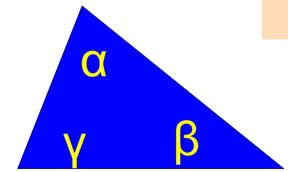
- Higher granularity in the inner trackers allows to fully reconstruct heavy ions collisions (aka PbPb)

The B -Triangle: LHCb + Belle II (50 ab^{-1})

arXiv:1808.08865

CKM 2018

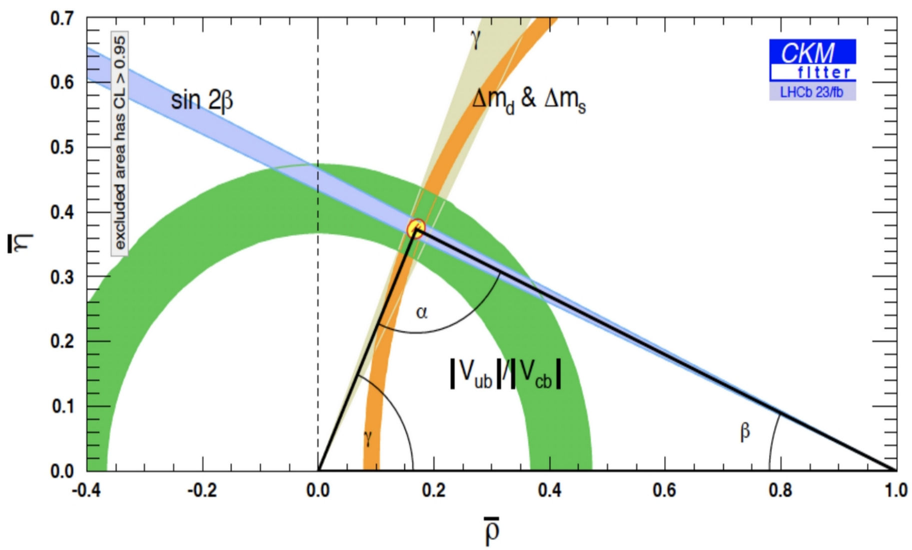




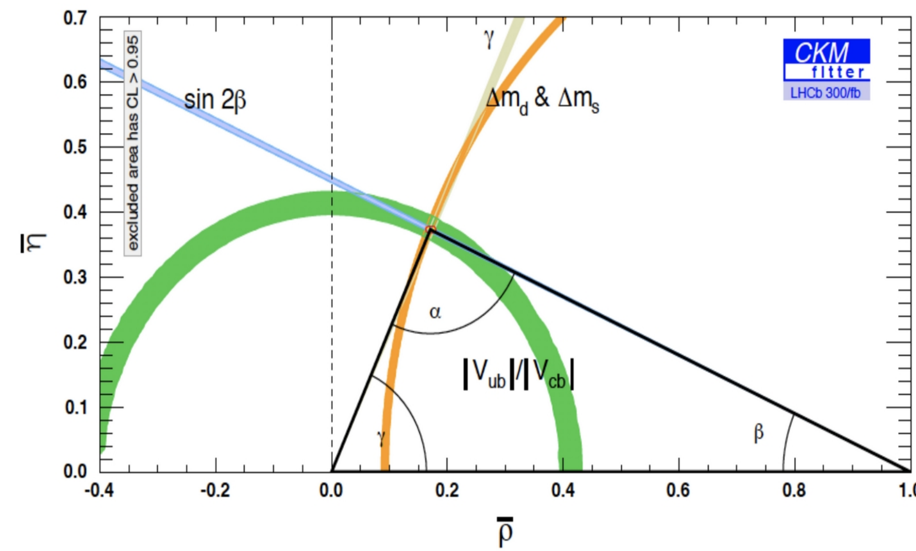
External crucial inputs:
- improvements from Lattice QCD
- improvements on external inputs

Branching ratios ($\Lambda_c \to pK\pi$): **BelleII, BESIII**
Strong phases over Dalitz of D decays: **BESIII**

Pre-HL-LHC



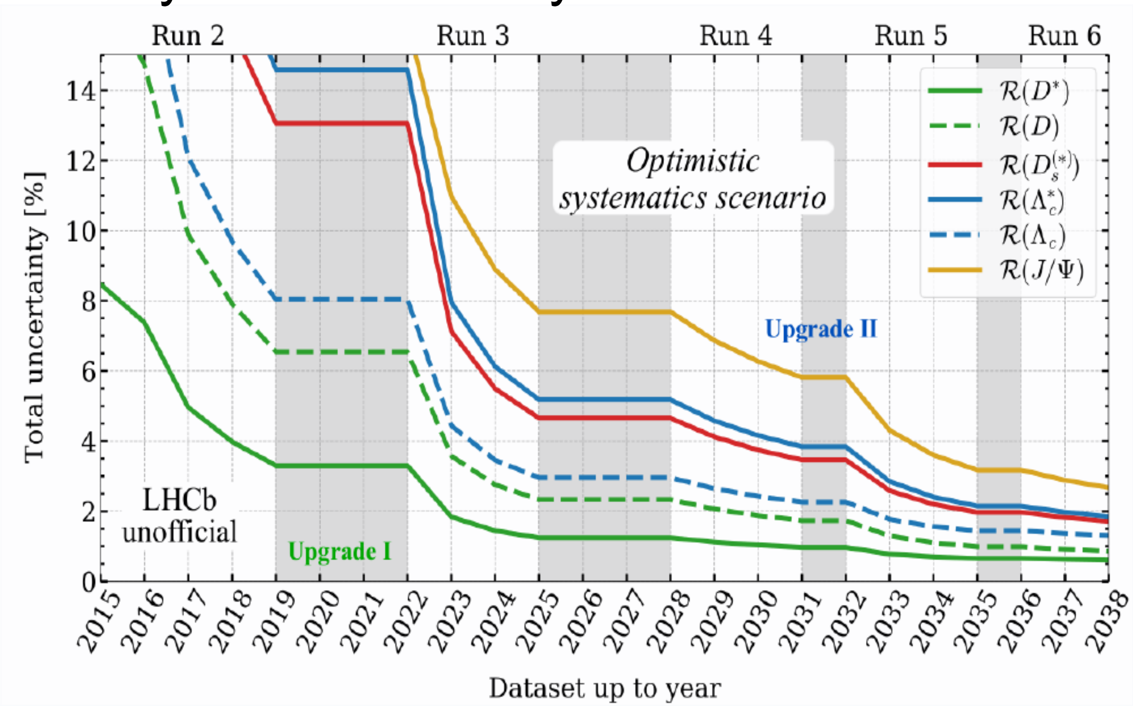
Post-HL-LHC



Prospects on LFU and Anomalies

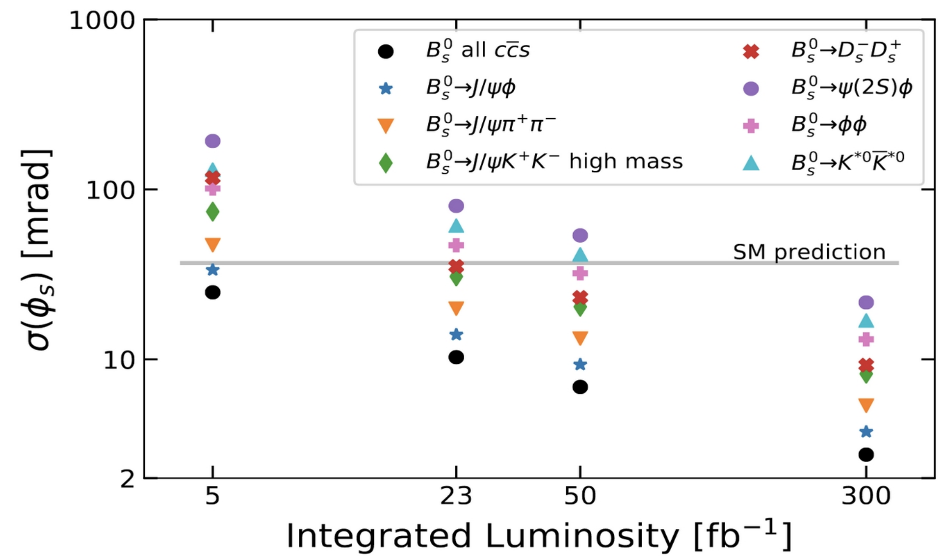
ArXiv:1812.07638
CERN-LPCC-2018-06

- Many b → c SL decays accessible

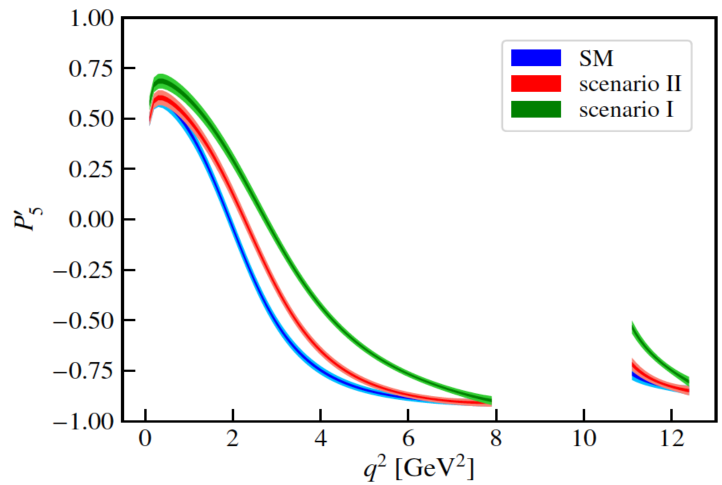


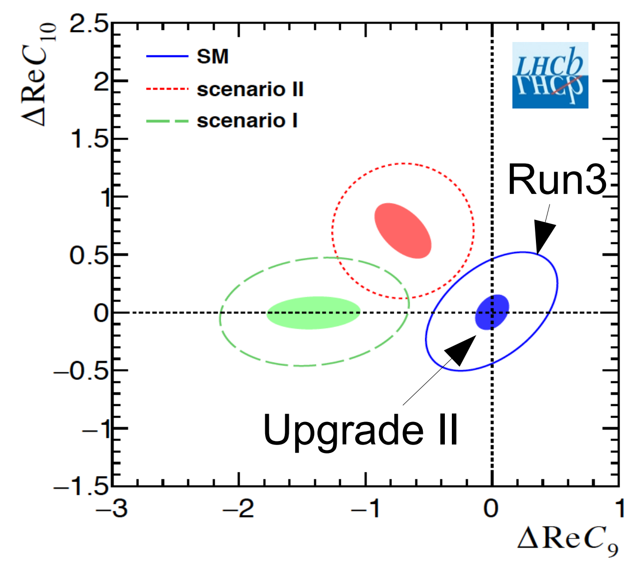
[arXiv:2101.08326, arXiv:1808.08865]

- Measurement of 'Bs triangle'



- With higher statistics: full angular analysis of B→ K* in finer binning





Conclusion

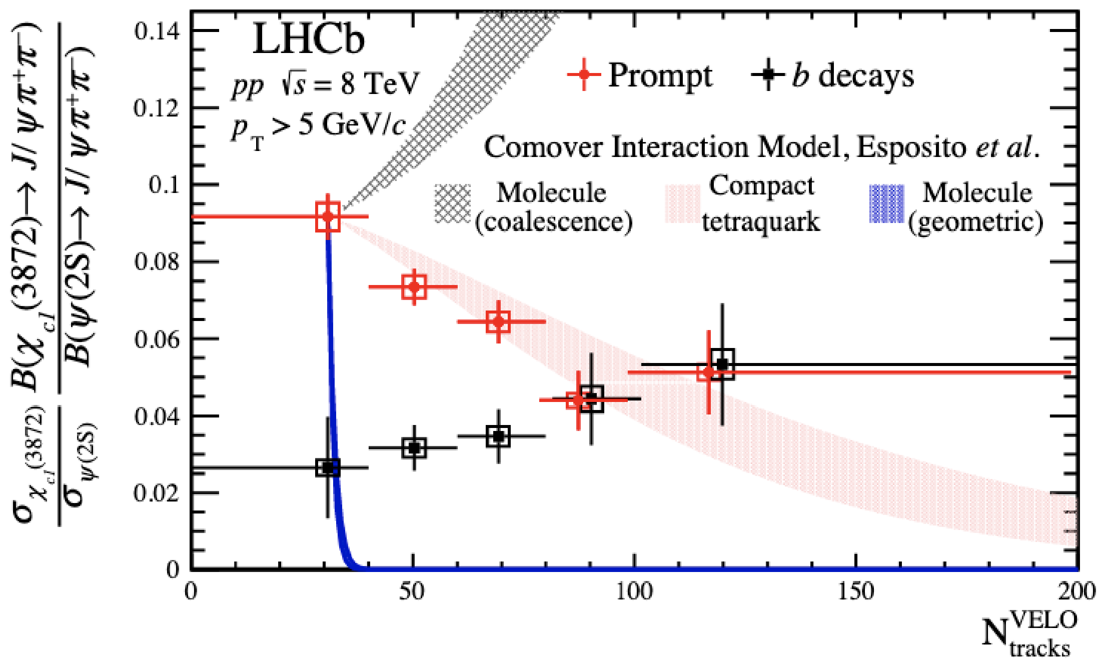
- Successful Run1 and Run2: 3+6 fb^{-1}, still many analysis ongoing
- Upgrade Phase I: commissioning ongoing
  - 10 times more data (20 times more hadronic events)
  - Complementarity with Belle
  - Synergy between LHCb, ATLAS and CMS on some important channels
- Upgrade Phase II: integrate overall sample larger than 300fb^{-1}
  - Several theoretically-clean observables can be drastically improved
  - New Physics scale probed will be highly increased
  - Widen the set of observables under study to search and characterize new physics (semitauonic, $b \rightarrow sll$,...)
  - Many technological challenges, not all the answers yet:
    - You are welcome to join the enterprise!
- Strong program beyond flavour exploiting unique acceptance
  - Spectroscopy, electroweak, nuclear physics

Backup

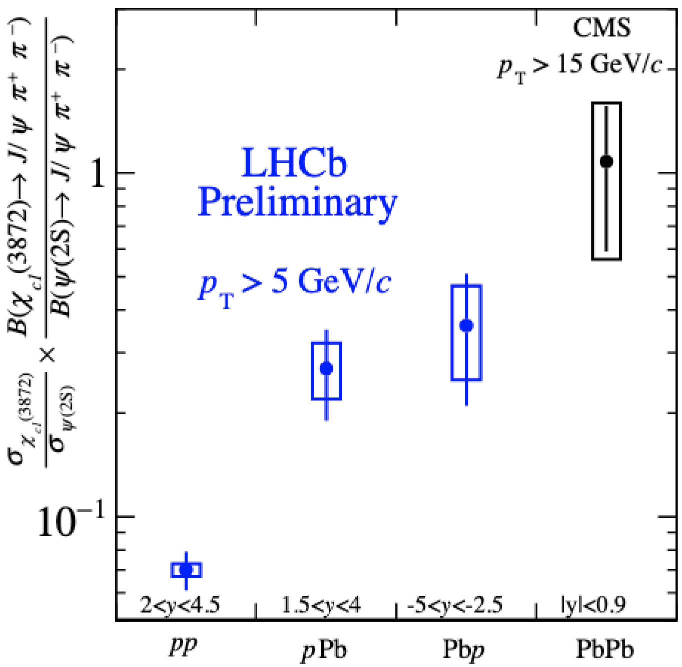
χ_{c1}(3872) in pp and pPb collisions

Production mechanism provides information about the structure of exotic hadrons.

PRL 126, 092001 (2021)



LHCb-CONF-2022-001

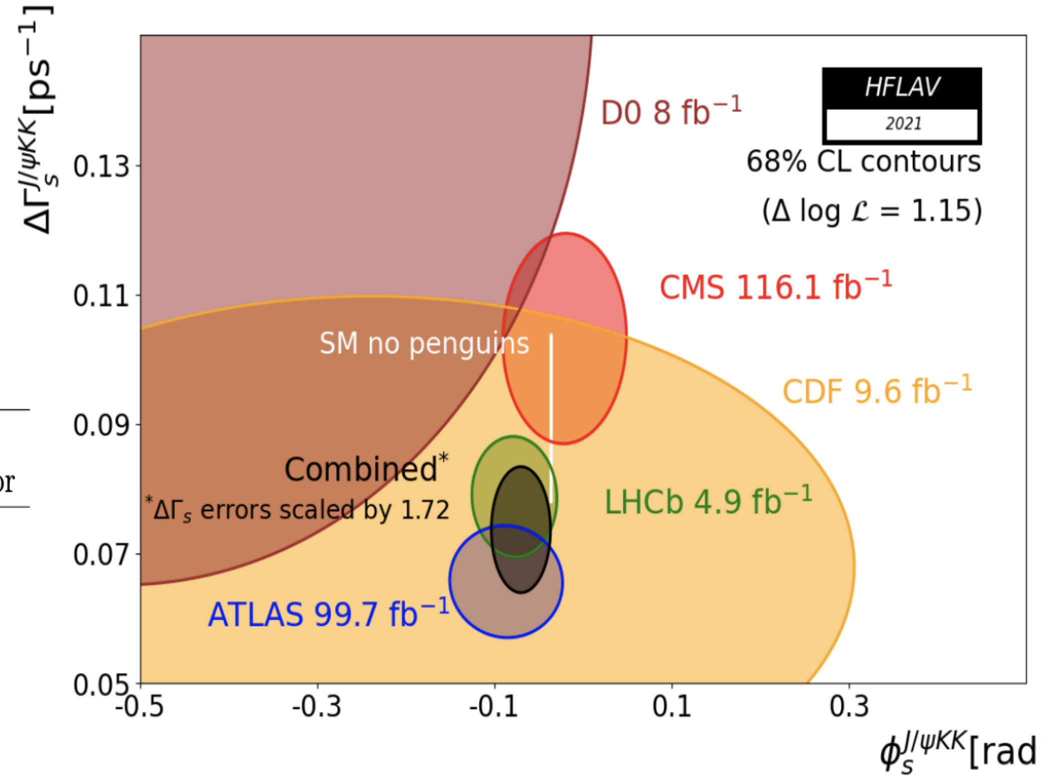


First evidence of $\chi_{c1}(3872)$ production in pPb collisions. $\sigma_{\chi_{c1}(3872)}/\sigma_{\psi(2S)}$ appears to decrease with multiplicity in pp, but increase with increasing collision system size.

Current status: Φs with $B_s \to J/\psi\ K^+K^-$

- $B_s \to J/\psi\ K^+K^-$ requires a full angular analysis because of the presence of scalar K^+K^- contribution
- LHCb added also $J/\psi\ \pi^+\pi^-$, $\psi(2S)\ K^+K^-$, $D_s^+D_s^-$

Parameter	all $b \to c\bar{c}s$		$B_s^0 \to J/\psi\phi$	
	fit result	scale factor	fit result	scale factor
$\lvert A_0\rvert^2$	0.520 ± 0.003	1.46	0.519 ± 0.003	1.46
$\lvert A_\perp\rvert^2$	0.253 ± 0.006	2.45	0.254 ± 0.006	2.37
$\lvert A_S\rvert^2$	0.030 ± 0.005	1.00	0.030 ± 0.005	1.00
$\delta_\parallel$	3.18 ± 0.06	1.46	3.18 ± 0.06	1.46
$\delta_\perp$	3.08 ± 0.12	2.04	3.08 ± 0.13	2.07
$\delta_S - \delta_\perp$	0.23 ± 0.05	1.00	0.23 ± 0.05	1.00
Γ_s	$0.663 \pm 0.004\ \text{ps}^{-1}$	2.60	$0.664 \pm 0.004\ \text{ps}^{-1}$	2.44
$\Delta\Gamma_s$	$+0.077 \pm 0.006\ \text{ps}^{-1}$	1.78	$+0.074 \pm 0.006\ \text{ps}^{-1}$	1.72
ϕ_s	-0.049 ± 0.019	1.00	-0.070 ± 0.022	1.00



- LHCb, ATLAS and CMS have not analyzed the full Run2 yet

Tagging performances

LHCb

Category	$\varepsilon_{tag}(\%)$	$\mathcal{D}^2$	$\varepsilon_{tag}\mathcal{D}^2(\%)$
OS-only	11.35	0.078	0.88 ± 0.04
SSK-only	42.57	0.032	1.38 ± 0.30
OS&SSK	23.84	0.104	2.47 ± 0.15
Total	77.76	0.061	4.73 ± 0.34

ATLAS

Tag method	Efficiency [%]	Effective Dilution [%]	Tagging Power [%]
Tight muon	4.50 ± 0.01	43.8 ± 0.2	0.862 ± 0.009
Electron	1.57 ± 0.01	41.8 ± 0.2	0.274 ± 0.004
Low-p_T muon	3.12 ± 0.01	29.9 ± 0.2	0.278 ± 0.006
Jet	5.54 ± 0.01	20.4 ± 0.1	0.231 ± 0.005
Total	14.74 ± 0.02	33.4 ± 0.1	1.65 ± 0.01

LHCb Upgrade II: Physics Case

arXiv:1808.08865

Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II
EW Penguins				
R_K $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [274]	0.025	0.036	0.007
R_{K^*} $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [275]	0.031	0.032	0.008
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	–	0.02, 0.02, 0.05
CKM tests				
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [136]	4°	–	1°
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]	1.5°	1.5°	0.35°
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [609]	0.011	0.005	0.003
ϕ_s, with $B_s^0 \to J/\psi\phi$	49 mrad [44]	14 mrad	–	4 mrad
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [49]	35 mrad	–	9 mrad
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [94]	39 mrad	–	11 mrad
a_{sl}^s	33×10^{-4} [211]	10×10^{-4}	–	3×10^{-4}
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6% [201]	3%	1%	1%
$\boldsymbol{B_s^0, B^0 \to \mu^+\mu^-}$				
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [264]	34%	–	10%
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [264]	8%	–	2%
$S_{\mu\mu}$	–	–	–	0.2
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**				
$R(D^*)$	0.026 [215, 217]	0.0072	0.005	0.002
$R(J/\psi)$	0.24 [220]	0.071	–	0.02
Charm				
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [613]	1.7×10^{-4}	5.4×10^{-4}	3.0×10^{-5}
A_Γ $(\approx x\sin\phi)$	2.8×10^{-4} [240]	4.3×10^{-5}	3.5×10^{-4}	1.0×10^{-5}
$x\sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [228]	3.2×10^{-4}	4.6×10^{-4}	8.0×10^{-5}
$x\sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K_S^0\pi\pi)$ 1.2×10^{-4}	$(K3\pi)$ 8.0×10^{-6}

The 2010-2018 LHCb Apparatus

JINST 3 (2008) S08005

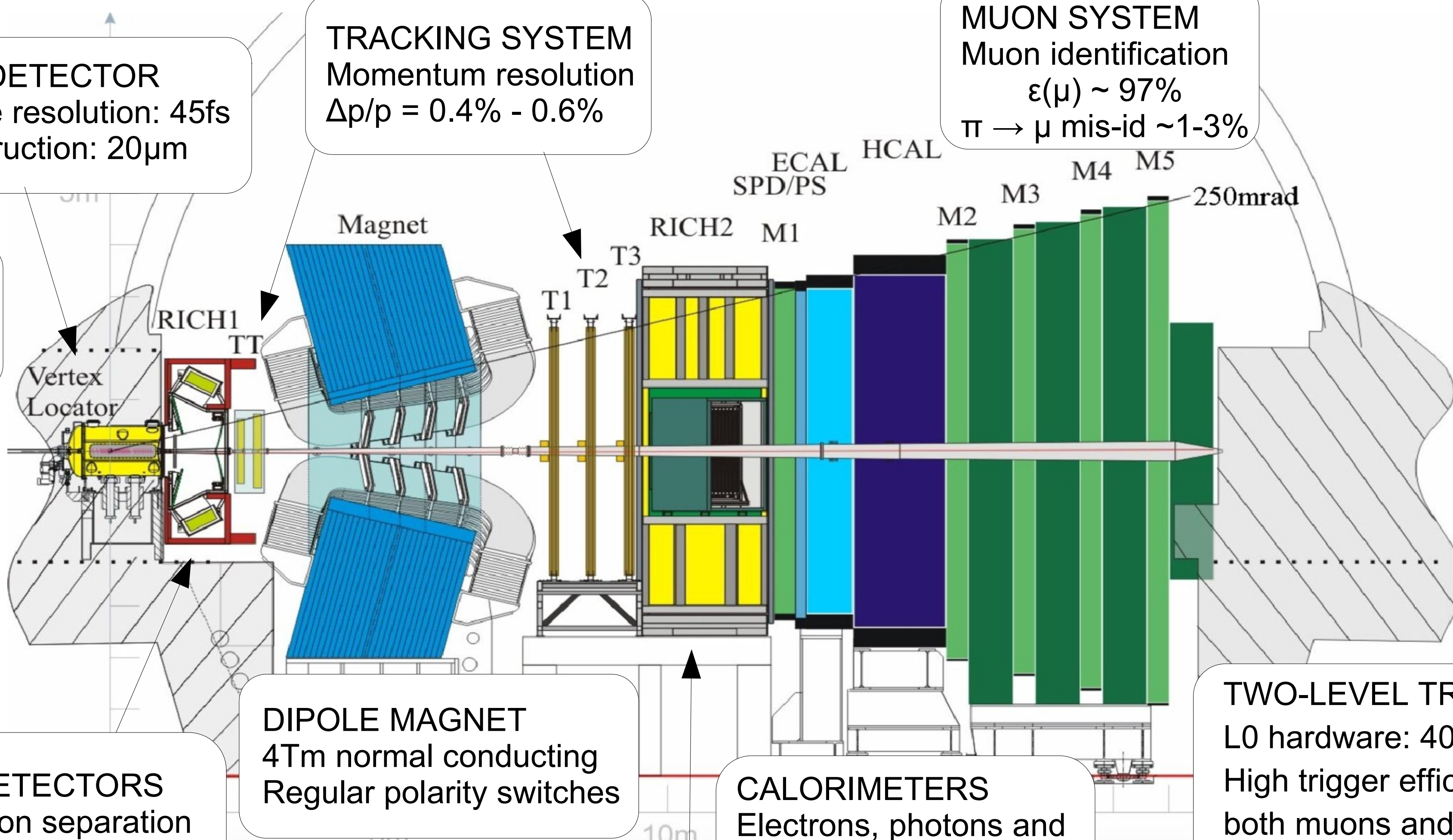
LHCb: a general purpose spectrometer in the forward direction optimized for high-precision heavy-flavor physics

VERTEX DETECTOR
decay time resolution: 45fs
IP reconstruction: 20μm

TRACKING SYSTEM
Momentum resolution
$\Delta p/p$ = 0.4% - 0.6%

MUON SYSTEM
Muon identification
$\varepsilon(\mu)$ ~ 97%
$\pi \rightarrow \mu$ mis-id ~1-3%

L_Z ~ 20m
L_Y ~ 10m
L_X ~ 13m



RICH DETECTORS
K/π/proton separation
$\varepsilon(K)$ ~ 95%
$\pi \rightarrow K$ mis-id ~5%

DIPOLE MAGNET
4Tm normal conducting
Regular polarity switches

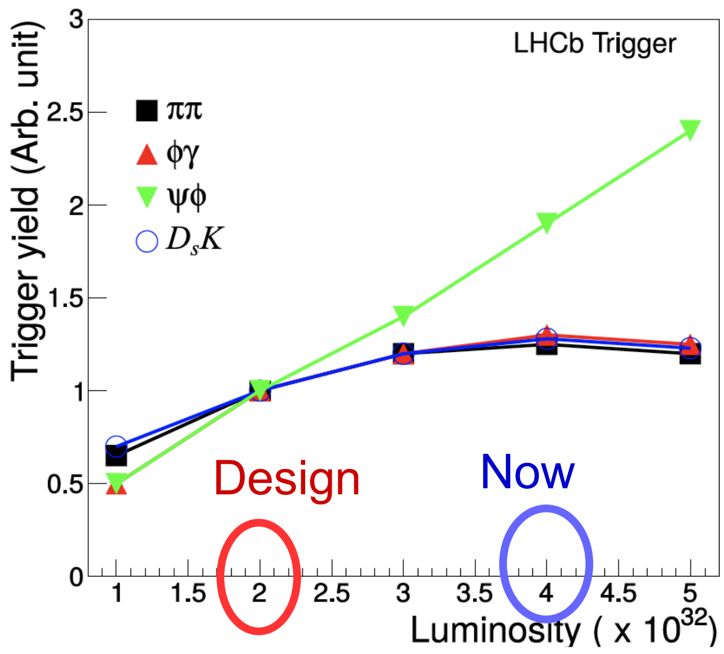
CALORIMETERS
Electrons, photons and hadrons identification
ε(electron) ~ 97%
$e \rightarrow \pi$ mis-id ~5%

TWO-LEVEL TRIGGER
L0 hardware: 40 →1 MHz
High trigger efficiencies for both muons and hadrons.
Low momentum thresholds.

LHCb Upgrade I

CERN-LHCC-2011-001

- Excellent results from Run-I and Run-II physics data analysis
- In most of the case the precision is limited by statistical uncertainties
  - Hardware trigger limited @1MHz rate
  - The high p_T and E_T cuts saturate hadronic channels



- At higher luminosity the current LHCb could not perform successfully track reconstruction and PID information
  - Larger number of primary vertexes: much higher track multiplicity
  - Higher occupancy in the detector
  - Processing time in the online farm too high

- $L = 20 \times 10^{32}$ $cm^{-2}s^{-1}$