Rare B decays with leptons at Belle

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On behalf of the Belle collaboration

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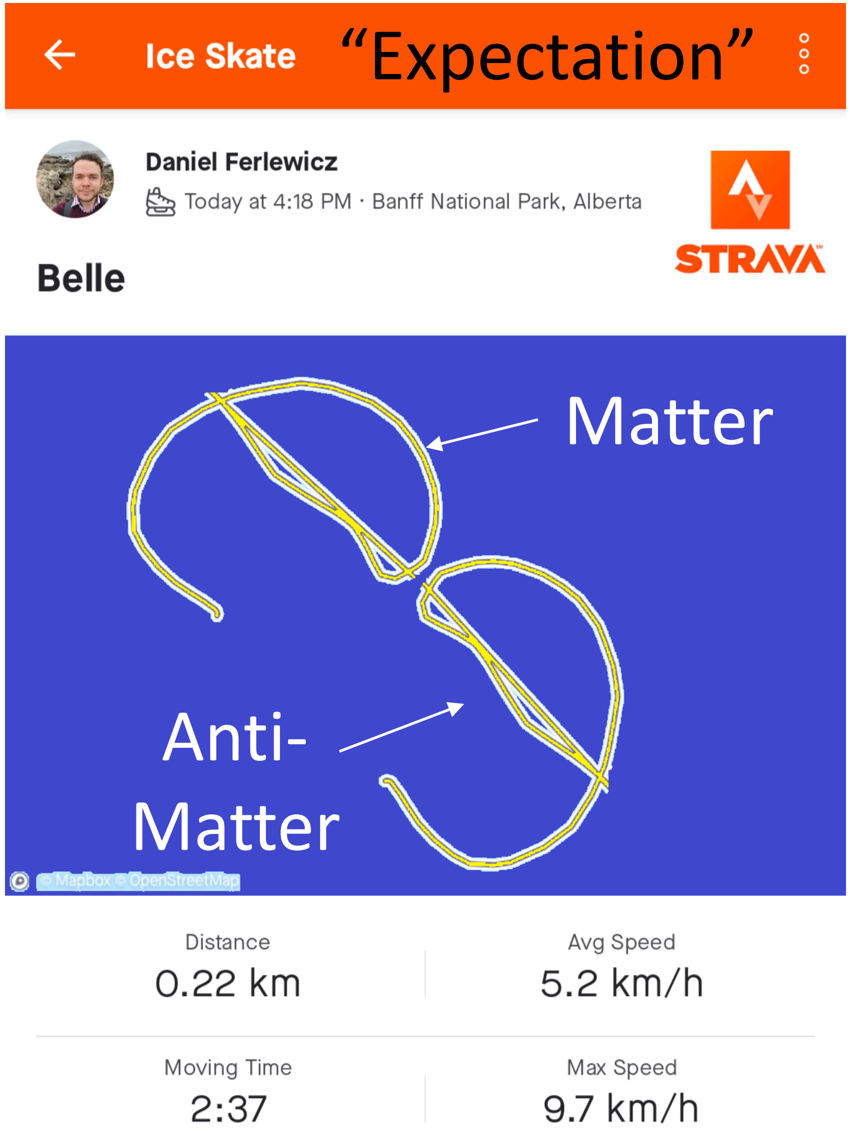
Big questions for flavour physics

Is each generation of fermions just a heavier copy of the last?

Why does the universe appear left-handed?

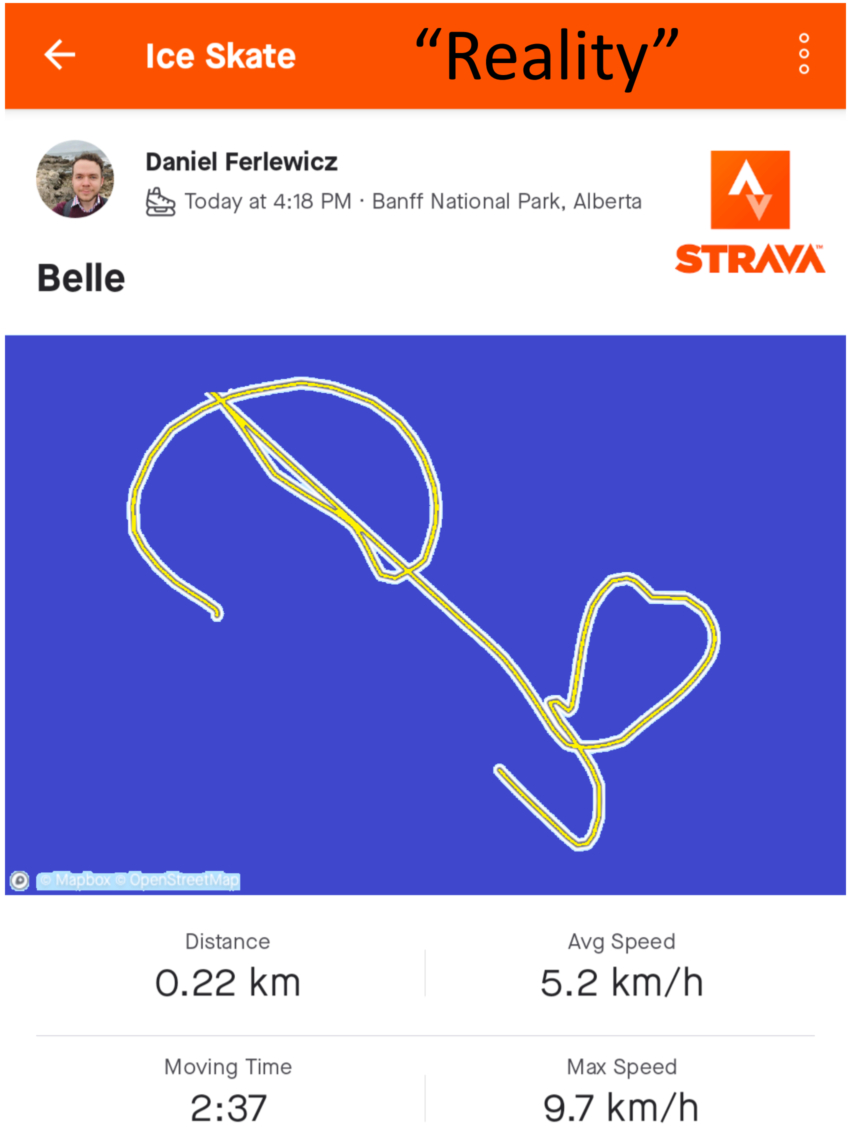
Is there some sort of structure or relationship in the CKM and PMNS matrices?

Where is all the CP violation?

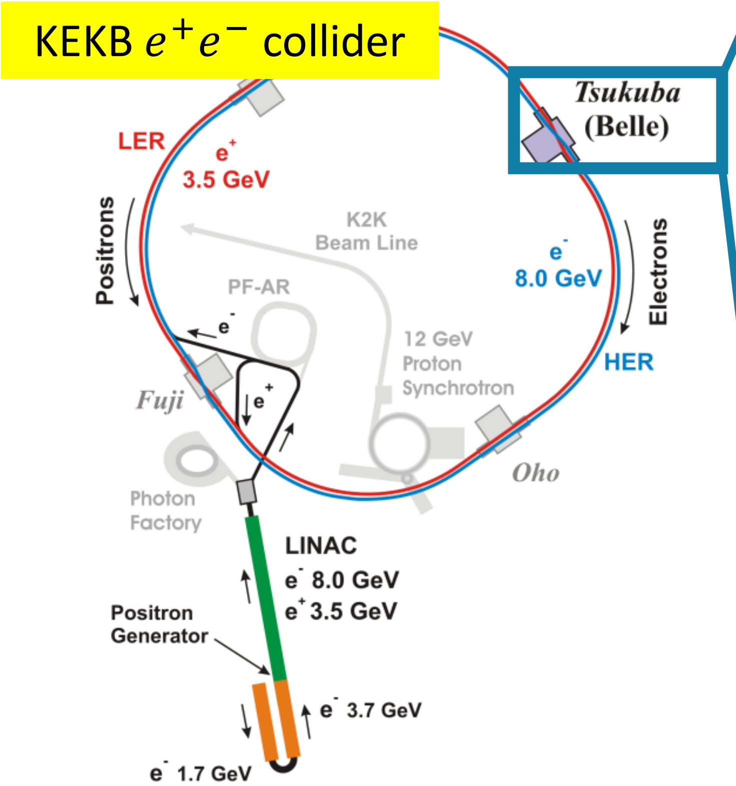


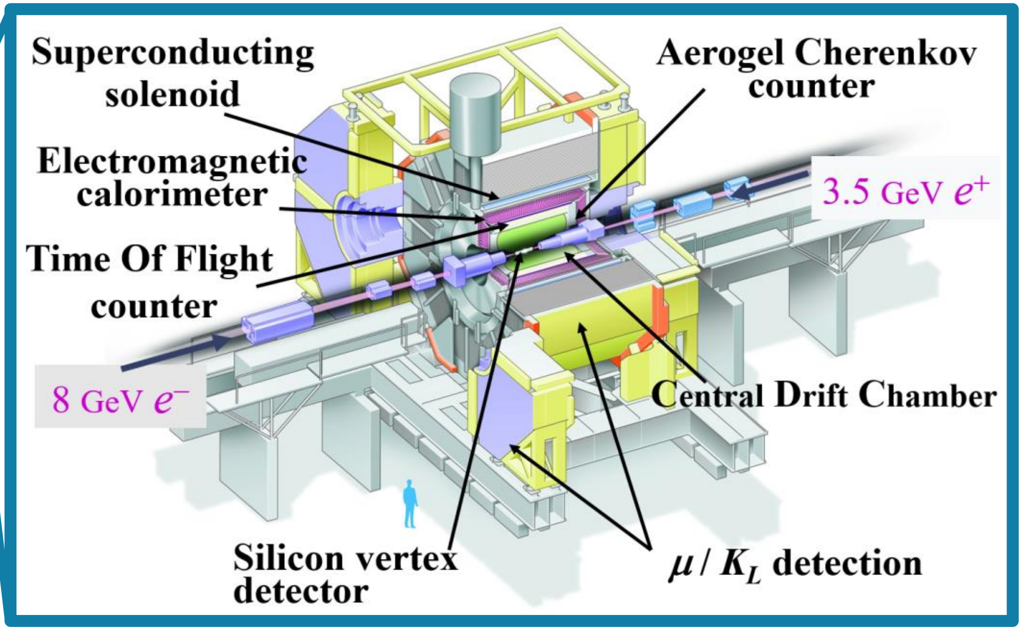
Big questions for flavour physics

- There is an asymmetry in the matter and anti-matter in the observed universe
- CP violation means that matter and anti-matter can behave differently
- Belle's main goal was to search for CP violation in B-decays

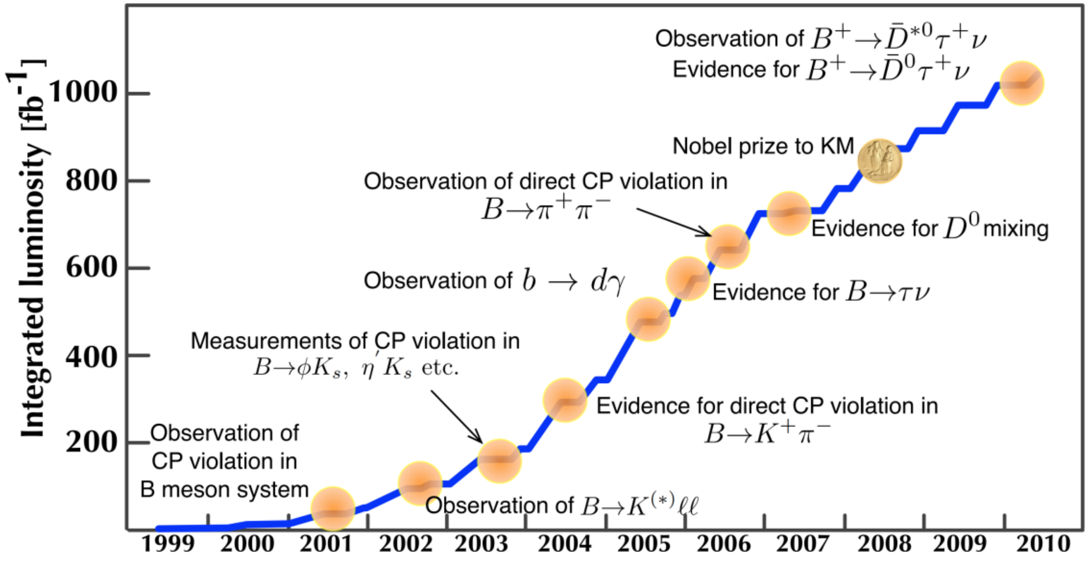


The Belle experiment





- Was located at the KEK facility in Tsukuba, Japan (Belle II operations commenced in 2018)

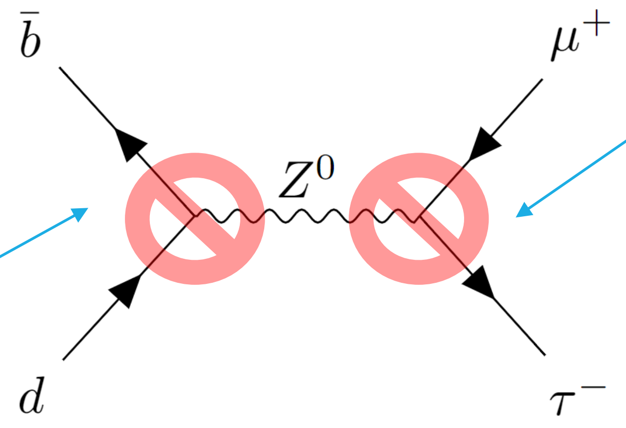


Process	Luminosity (fb^{-1})	No. of pairs
$e^+e^- \to \Upsilon(4S)$	711	772×10^6 $B\bar{B}$
$e^+e^- \to \Upsilon(5S)$	121.4	7.1×10^6 $B_s\bar{B}_s$

- Also scanned through the $1S$-$3S$ resonances

Lepton flavour violation

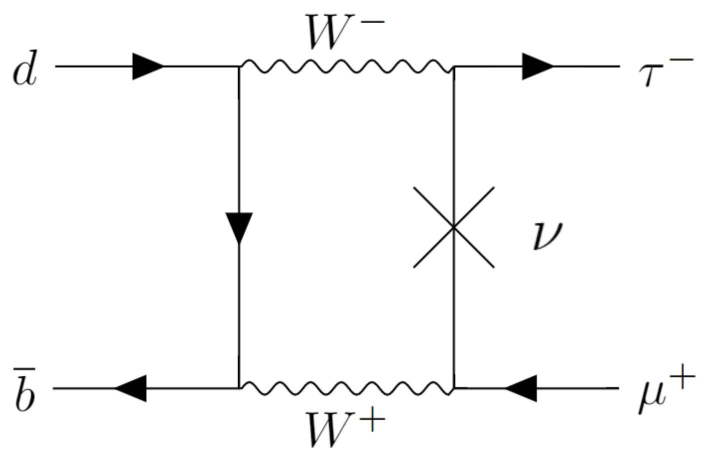
In the Standard Model:



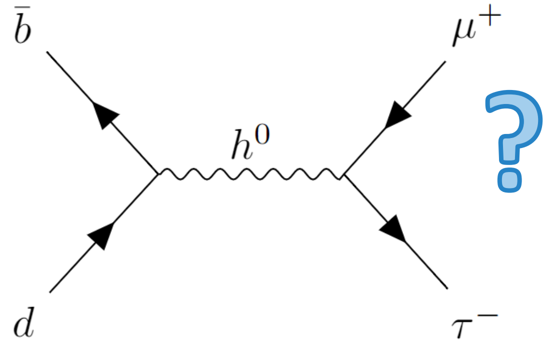
Lepton number is conserved without neutrino oscillations

No flavour changing neutral currents

LFV possible in principle with neutrino mixing:



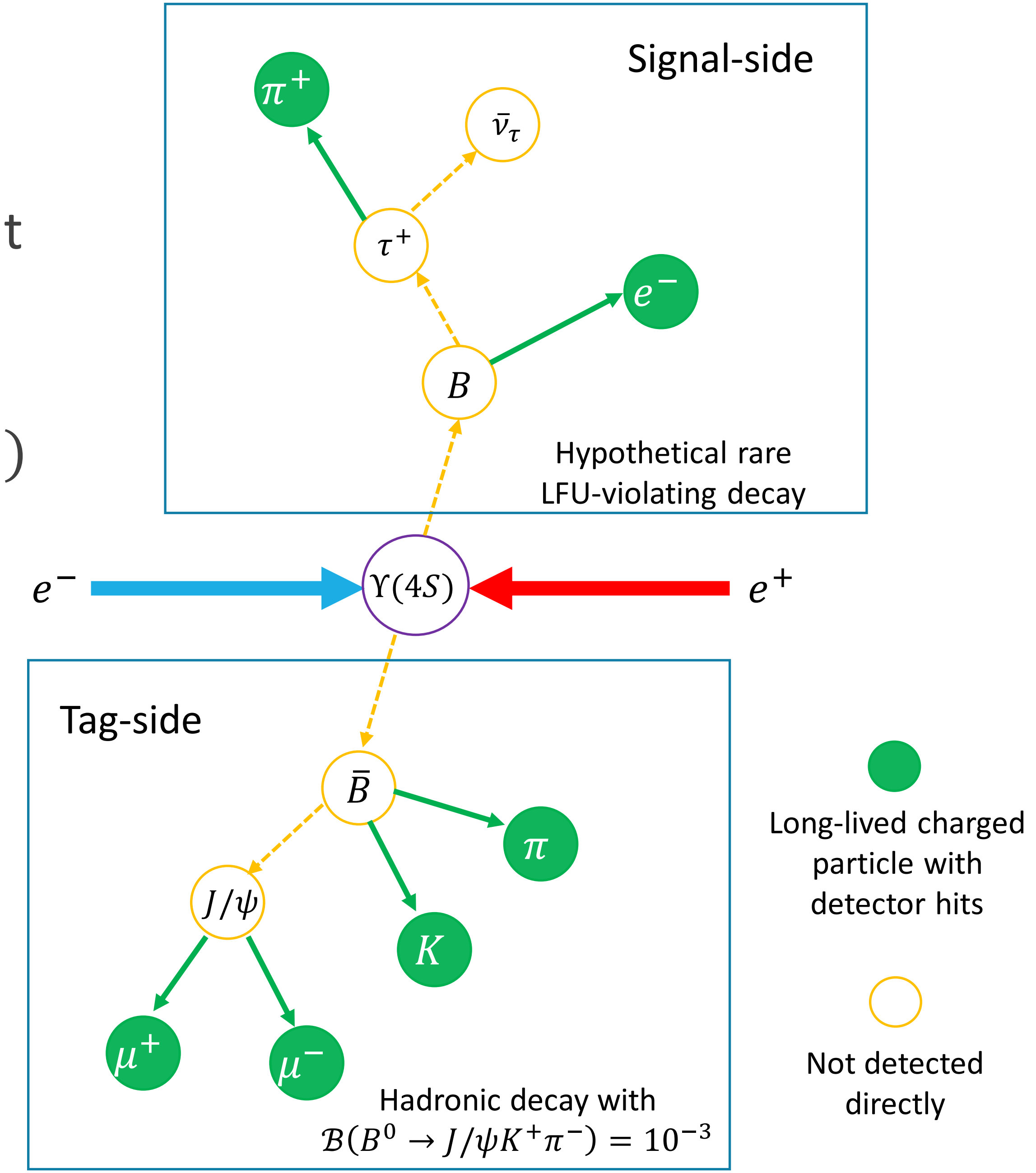
- SM rate is significantly below any current experimental sensitivity.
- New physics models such as Higgs-mediation [1] can predict higher rates at $\mathcal{B} \approx 10^{-9}$



[1] Dedes, et al. Phys.Lett.B 549 (2002)

Tagging

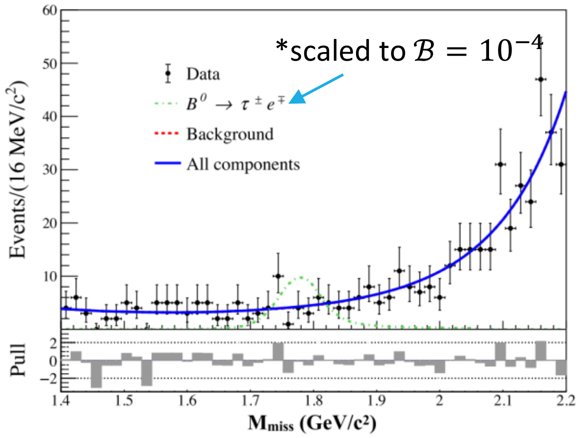
- Fully reconstruct one of the B-mesons, "Full Event Interpretation", which can be used to determine missing momentum
- Tag-side can be reconstructed from one of $\mathcal{O}(10^3)$ hadronic modes in a neural network [2,3]
- Efficiency between $0.1 - 0.3\%$ depending on desired purity (confidence score)
- Also useful for determining B-meson flavour for CP-violation measurements



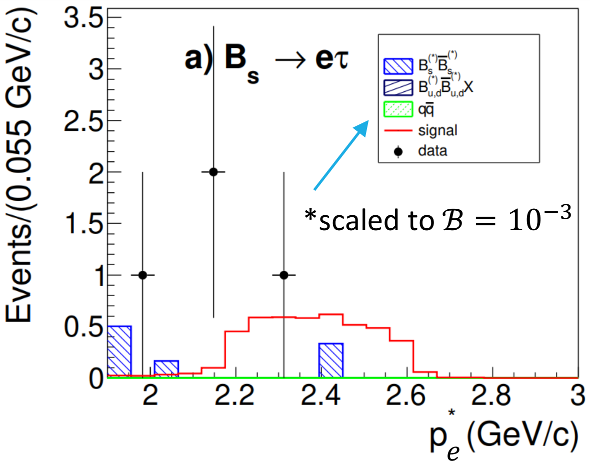
[2] Feindt, et al. NIM A 654, 432 (2011)
[3] Keck, et al. Comput. Softw. Big Sci. 3 (2019) 1, 6

$B^0_{(s)} \to \tau^\pm \ell^\mp$

- $B^0 \to \tau^\pm \ell^\mp$:
  - Hadronic tagging algorithm threshold determined with Punzi Figure of Merit
  - Only the light lepton on the signal-side is reconstructed
  - Fit to the missing mass



- $B_s^0 \to \tau^\pm \ell^\mp$: New result!
  - Measured using $e^+e^- \to \Upsilon(5S) \to B_s^{(*)0}\bar{B}_s^{(*)0}$, $B_s^{*0} \to B_s^0\gamma$ ($\sim 16.6 \times 10^6$ B_s mesons)
  - $B_s^0 \to D_s^+ \ell^- (X) \bar{\nu}_\ell$ used as a tag, reconstructed ℓ from $\tau^+ \to \ell^+ \bar{\nu}_\tau \nu_\ell$
  - Classifier trained for signal against continuum and combinatorial background
  - Fit to the primary light lepton momentum



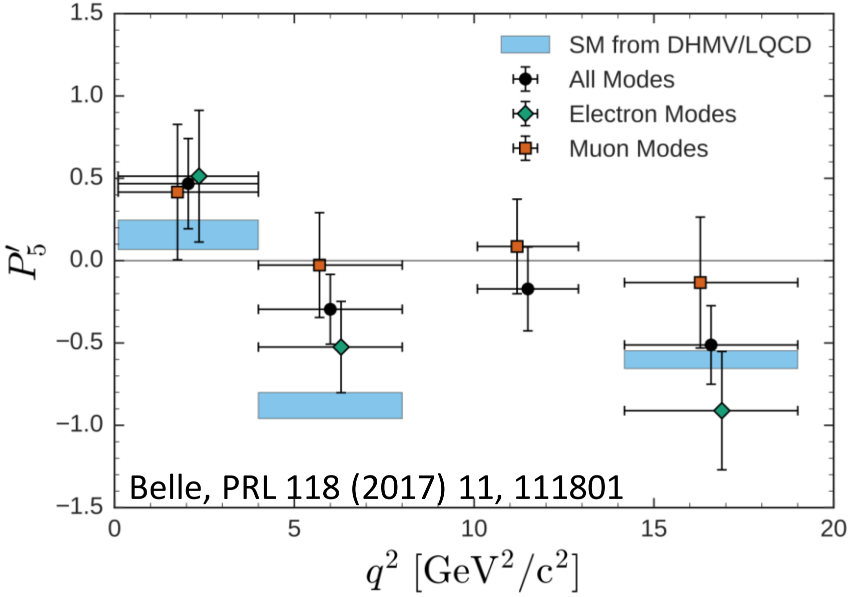
	BaBar	CLEO	LHCb	Belle
$B_s^0 \to \tau^\mp e^\pm$	-	-	-	$< 14.1 \times 10^{-4}$ arXiv:2301.10989
$B_s^0 \to \tau^\mp \mu^\pm$	-	-	$< 3.4 \times 10^{-5}$ PRL 123, 211801 (2019)	$< 7.3 \times 10^{-4}$ arXiv:2301.10989
$B_d^0 \to \tau^\mp e^\pm$	$< 2.8 \times 10^{-5}$ PRD 77, 091104R (2008)	$< 1.3 \times 10^{-4}$ PRL 93, 241802 (2004)	-	$< 1.6 \times 10^{-5}$ PRD 104, L091105 (2021)
$B_d^0 \to \tau^\mp \mu^\pm$	$< 2.2 \times 10^{-5}$ PRD 77, 091104R (2008)	$< 3.8 \times 10^{-5}$ PRL 93, 241802 (2004)	$< 1.2 \times 10^{-5}$ PRL 123, 211801 (2019)	$< 1.6 \times 10^{-5}$ PRD 104, L091105 (2021)

Leading systematic uncertainties

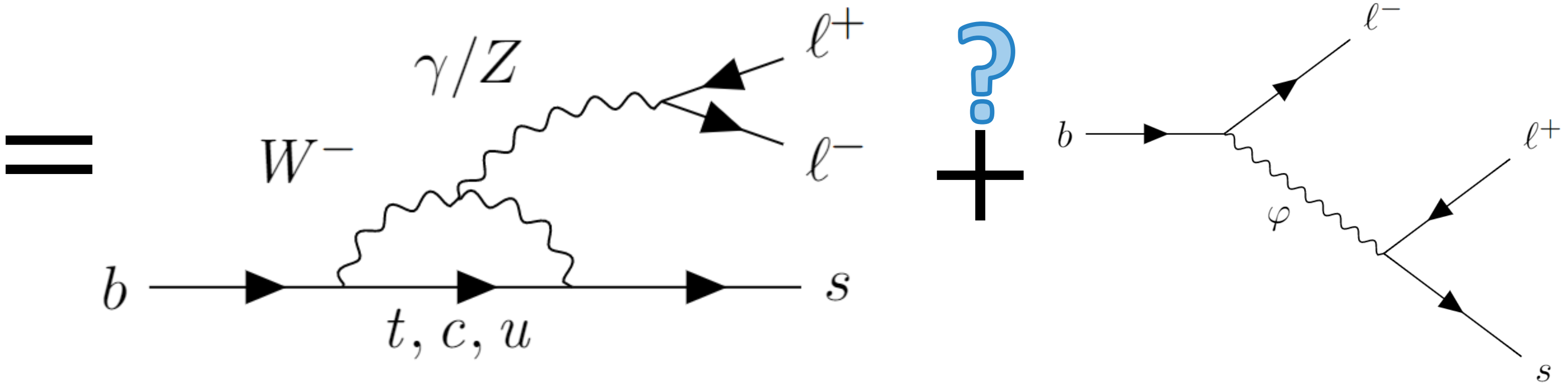
$B^0 \to \tau^\pm e^\mp$	$B_s^0 \to \tau^\pm e^\mp$
Tagging (4.5%)	$N_{B_s\bar{B}_s}$ (16.1%)
Lepton ID (1.6%)	Tagging (15%)
$N_{B\bar{B}}$ (1.4%)	Lepton ID (4.3%)

Electroweak penguin decays

- Rarity of the $b \to s$ loop transition means these decays are an excellent probe for physics beyond the Standard Model
- Tensions in lepton flavour universality tests have reduced [4], but tension from angular analyses remains

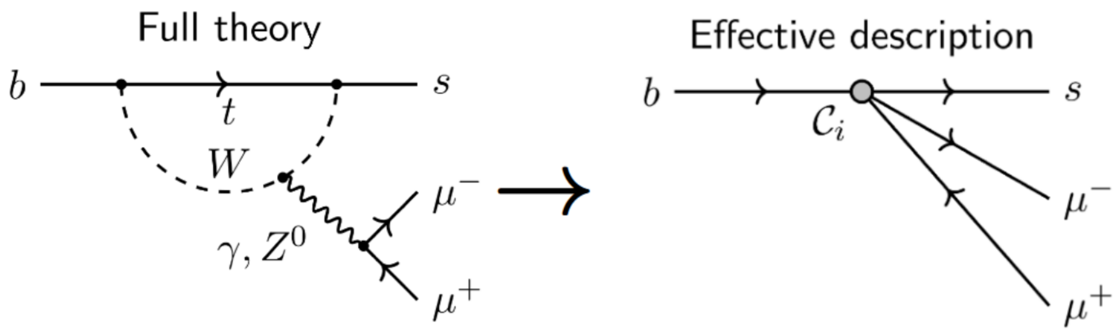


Belle, PRL 118 (2017) 11, 111801



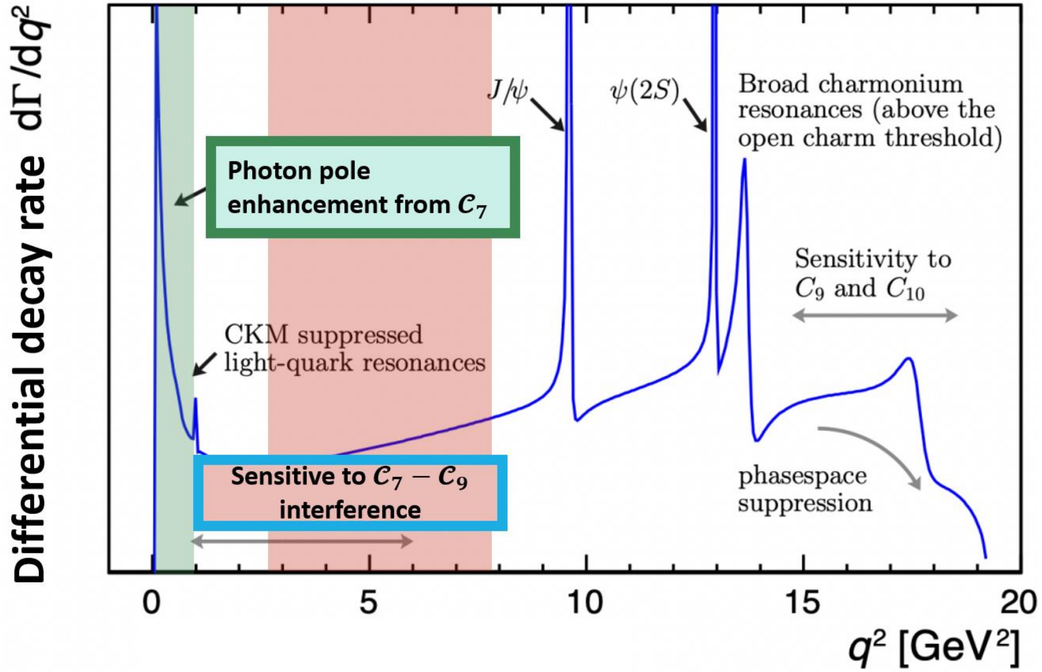
[4] LHCb, arXiv:2212.09152 (2022)

Effective theories



$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} (\mathcal{C}_i(\mu)\mathcal{O}_i(\mu) + \mathcal{C}'_i(\mu)\mathcal{O}'_i(\mu))$$

Right-handed contribution
(suppressed in SM)

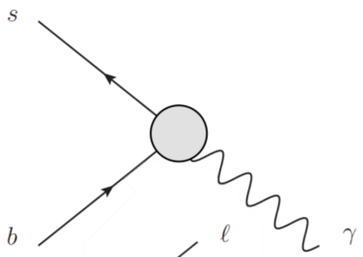


Wilson coefficients

Operators

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b \bar{s}_L \sigma_{\mu\nu} F^{\mu\nu} b_R,$$

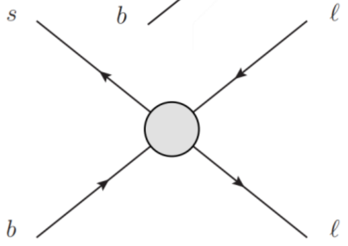
Electromagnetic penguin operator



$$\mathcal{O}_9 = \frac{\alpha_s}{4\pi} (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \ell),$$

$$\mathcal{O}_{10} = \frac{\alpha_s}{4\pi} (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \gamma^5 \ell),$$

Semileptonic operators



New Physics scenarios:

$\mathcal{C}_{\rm pseudo/scalar} \neq 0$

$\mathcal{C}' \neq 0$

$B \to K^{(*)}\ell\ell$

- Tests of lepton flavour universality:

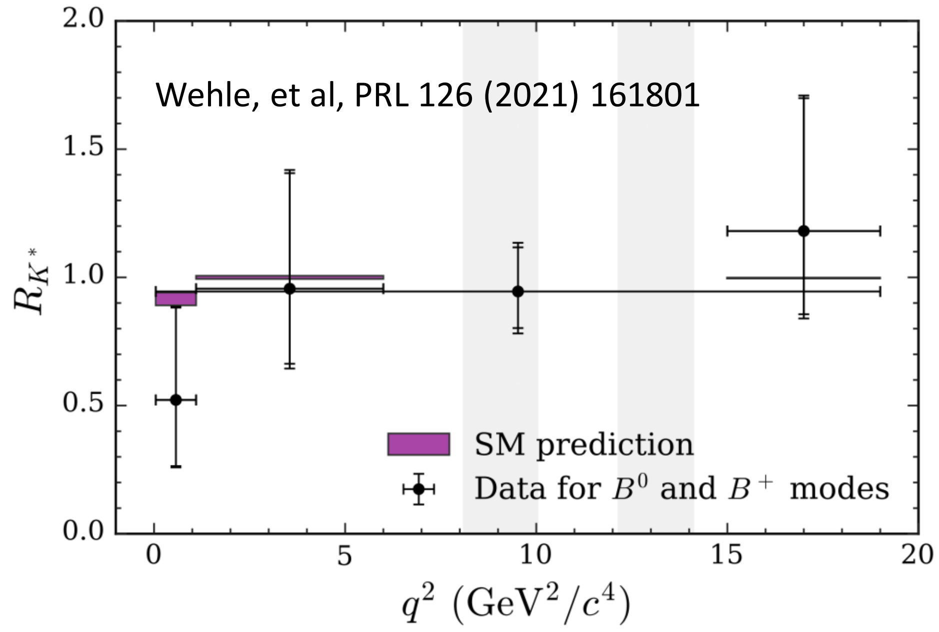
$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)}$$

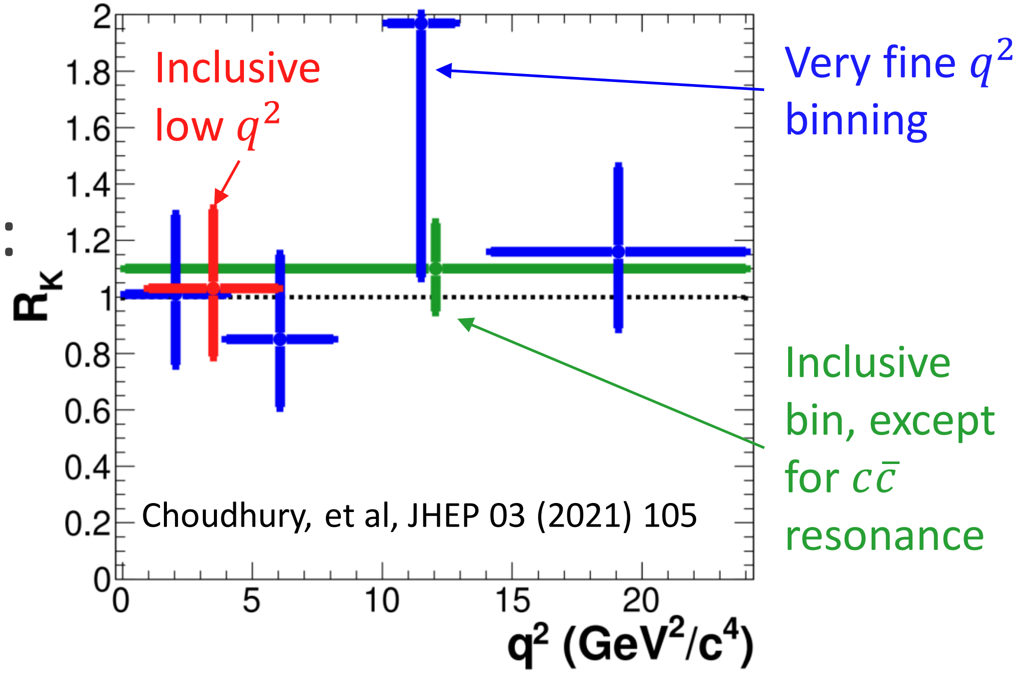
- Results found away from $c\bar{c}$ resonances are consistent with SM predictions

- In both studies lepton ID is dominant of the few remaining uncertainties

- Lepton flavour violation study also performed:

Decay	BaBar PRD 73, 092001 (2006)	Belle JHEP 03 (2021) 105
$B^+ \to K^+\mu^+e^-$	$< 1.3 \times 10^{-7}$	$< 8.5 \times 10^{-8}$
$B^+ \to K^+\mu^-e^+$	$< 9.1 \times 10^{-8}$	$< 3.0 \times 10^{-8}$
$B^0 \to K^+\mu^\pm e^\mp$	$< 2.7 \times 10^{-7}$	$< 3.8 \times 10^{-8}$

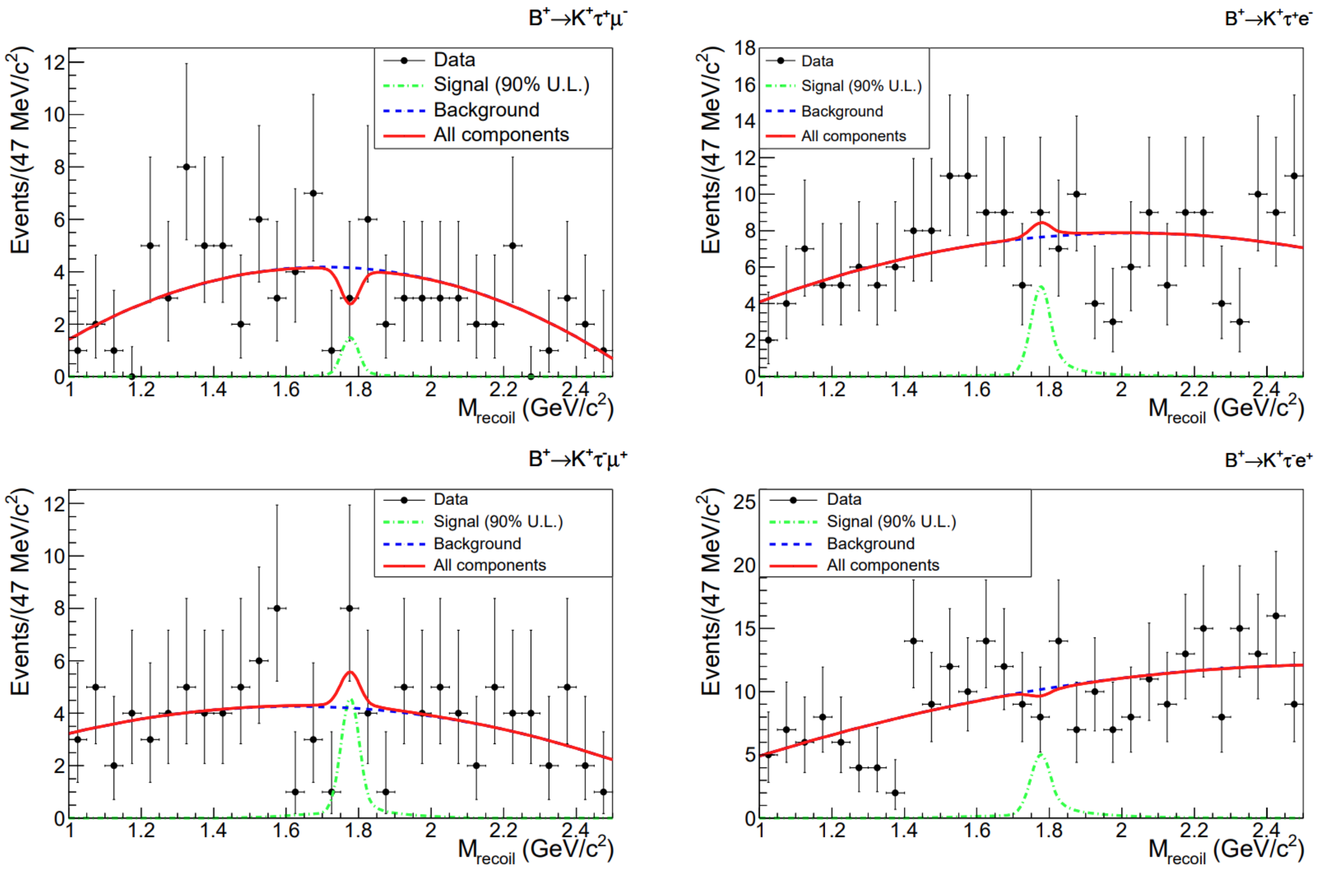




$B^+ \to K^+\tau^\pm\ell^\mp$

- Translate Belle data into the Belle II analysis software framework [5] so that the newer hadronic tag FEI can be used
- Trained machine learning classifiers for $B\bar{B}$ and continuum suppression
- Fit to the recoil mass

Decay	Collaboration	BR 90% upper C.L.
$B^+ \to K^+\tau^\pm\ell^\mp$	BaBar PRD 86, 012004 (2012)	$< 4.5 \times 10^{-5}$
$B^+ \to K^+\tau^\pm\mu^\mp$	LHCb JHEP 06 129 (2020)	$< 3.9 \times 10^{-5}$
$B^+ \to K^+\tau^+\mu^-$	Belle arXiv:2212.04128 (2022)	$< 0.59 \times 10^{-5}$
$B^+ \to K^+\tau^-\mu^+$		$< 2.45 \times 10^{-5}$
$B^+ \to K^+\tau^+e^-$		$< 1.51 \times 10^{-5}$
$B^+ \to K^+\tau^-e^+$		$< 1.53 \times 10^{-5}$



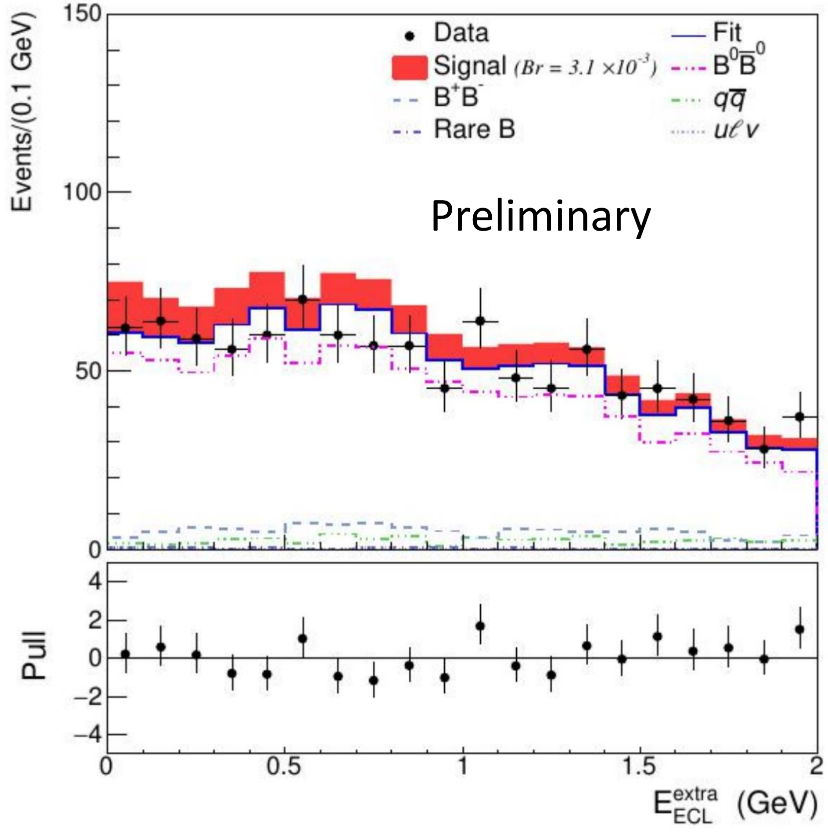
Leading systematic uncertainties
$B^+ \to K^+\tau^+e^-$
$B\bar{B}$ BDT selection (10.0%)
$q\bar{q}$ BDT selection (8.6%)
Tagging (5.9%)

[5] Gelb, et al. Comput. Softw. Big Sci. 2 (2018) 1, 9

$B \to K^* \tau^+ \tau^-$

- Can be used with $R(K^*)$ results for more LFU tests
- Signal reconstructed with $\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$, $\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$ and $\tau^+ \to \pi^+ \bar{\nu}_\tau$; 6 unique combinations
- Further continuum suppression with thresholds on event-shape variables
- Binned fit to the extra energy in the ECL
- First ever measurement of this mode!

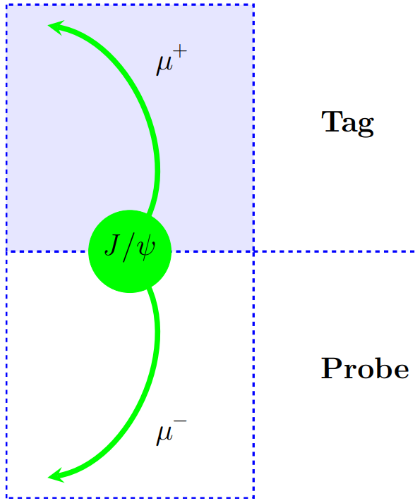
Decay	BR 90% C.L.
$B^+ \to K^+ \tau^+ \tau^-$ BaBar, PRL 118, 031802 (2017)	$< 2.25 \times 10^{-3}$
$B^0 \to K^{*0} \tau^+ \tau^-$ Belle, arXiv:2110.03871 (2017)	$< 2.0 \times 10^{-3}$ (Preliminary)



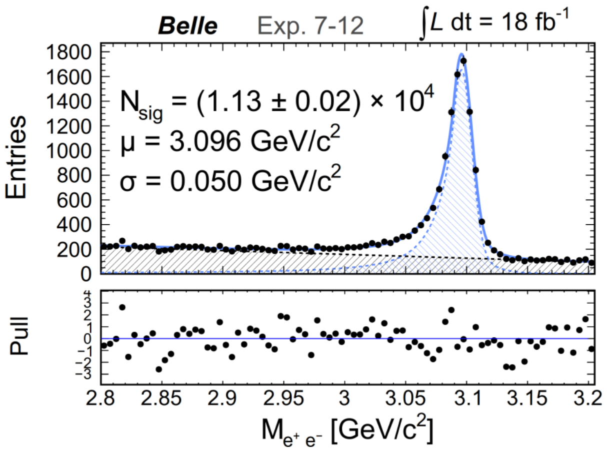
Leading systematic uncertainties
Tagging (4.6%)
Electron ID (2.48%)
Muon ID (2.03%)

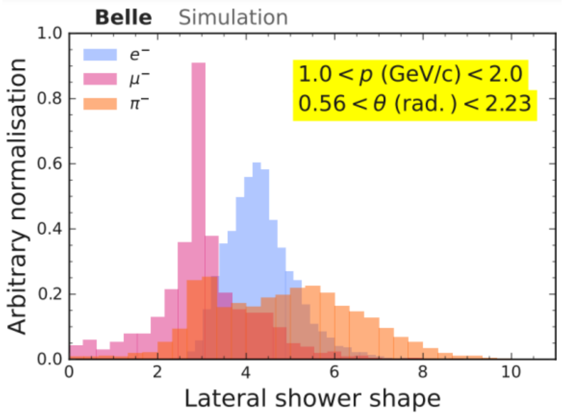
Improving lepton identification

- Modern machine learning techniques can be used to boost performance

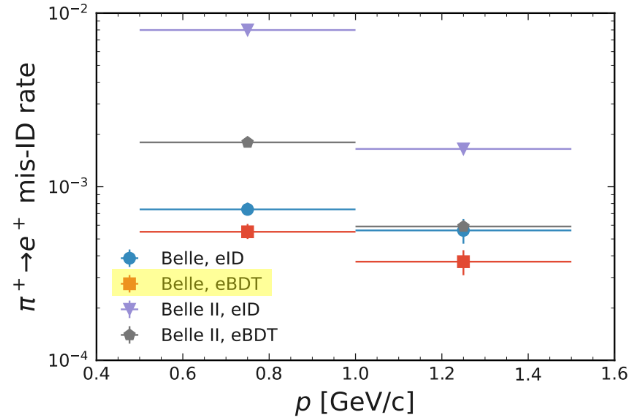


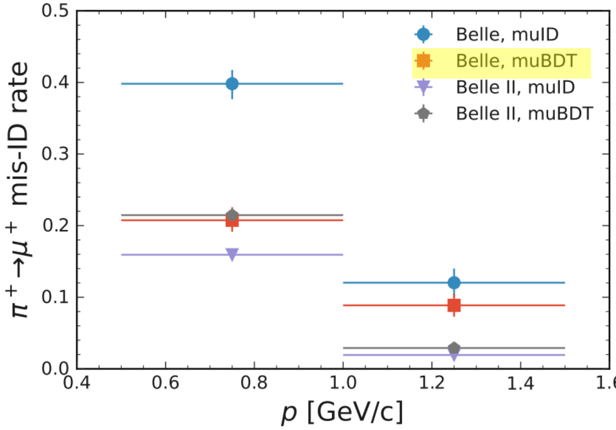
- Tight leptonID selection criteria
- Only apply phase space cut to ensure there is no bias
- Fit invariant mass before and after a leptonID cut to determine efficiency





BDT input variables
Ratio of ECL energy between 3×3 and 5×5 crystal grid
Ratio of energy deposited and momentum
Measurement of lateral shower shape
Number of crystals hit in the ECL
Total ECL energy of the particle
Binary likelihood of each particle hypothesis from CDC, TOF, ACC

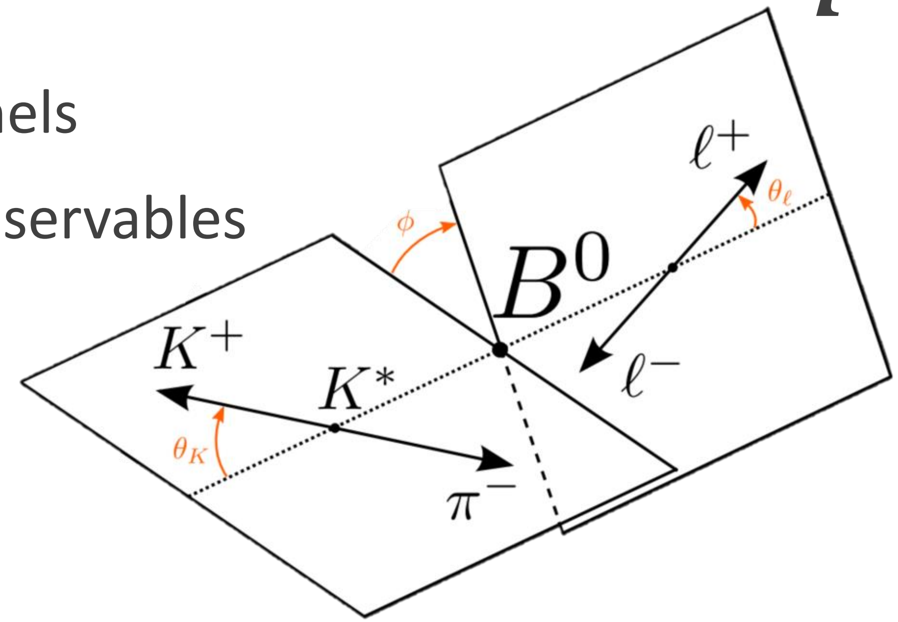




- By matching the efficiency of different algorithms, the mis-identification rate is measured to be a factor ~0.7 smaller

Angular analysis of $B \to K^* e^+ e^-$ at low q^2

- Reconstruct with $K^{*0} \to K^+\pi^-$ and $K^{*+} \to K_S^0\pi^+$ channels
- Fit the differential decay rate as a function of angular observables



$$\left\langle \frac{d^4\Gamma}{dq^2 d\cos\theta_\ell d\cos\theta_K d\phi} \right\rangle_{\rm CP} = \frac{9}{16\pi}\Big(\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K$$
$$+ \big(\frac{1}{4}(1-F_L)\sin^2\theta_K - F_L\cos^2\theta_K\big)\cos 2\theta_\ell$$
$$+ \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ (1-F_L)A_T^{\rm Re}\sin^2\theta_K\cos\theta_\ell$$
$$+ \frac{1}{2}(1-F_L)A_T^{\rm Im}\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big).$$

$$A_T^{\rm Re} = \frac{I_6^s}{4I_2^s} = \frac{4A_{\rm FB}}{3(1-F_L)}$$

Forward-backward asymmetry ($A_{\rm FB}$)

Longitudinal polarisation of K^* (F_L)

$$A_T^{\rm Im} = \frac{I_9}{2I_2^s} \overset{q^2\to 0}{=} \frac{2\Im(C_7^{\rm eff}C_7^{\prime\rm eff*})}{|C_7^{\rm eff}|^2 + |C_7^{\prime\rm eff*}|^2}$$

Expected to be zero unless there is some complex phase being introduced

$$A_T^{(2)} = \frac{I_3}{2I_2^s} \overset{q^2\to 0}{=} \frac{2\Re(C_7^{\rm eff}C_7^{\prime\rm eff*})}{|C_7^{\rm eff}|^2 + |C_7^{\prime\rm eff*}|^2}$$

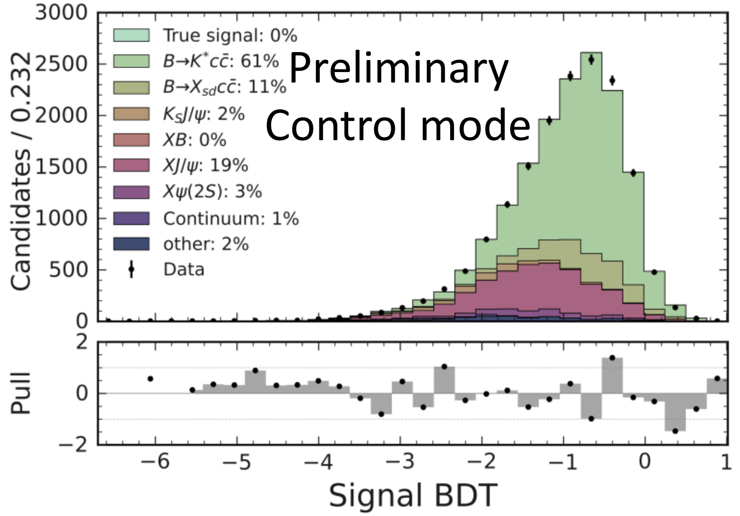
Expected to be zero unless there is a right-handed current contribution

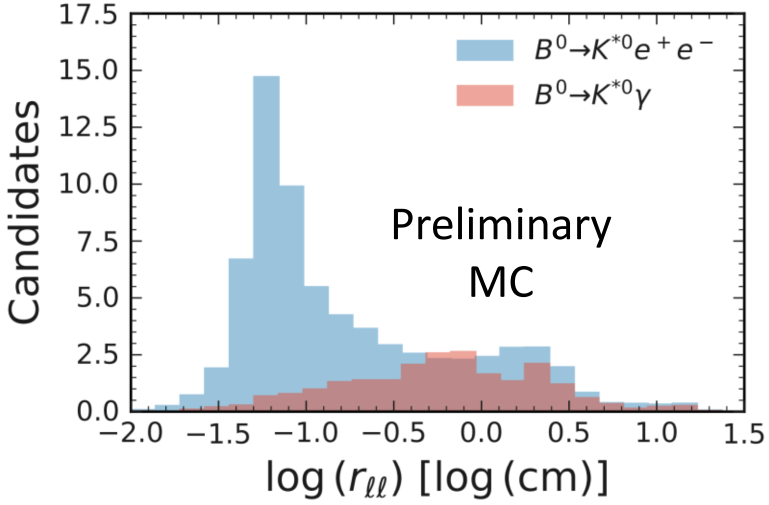
- Independent check of LHCb result [6] with improved lepton ID
- $0.0008 < q^2 < 1.12\ \mathrm{GeV}^2/c^4$ used to match upper threshold from 2015 LHCb analysis [7]

[6] LHCb, JHEP 12 (2020) 081
[7] LHCb, JHEP 04 (2015) 064

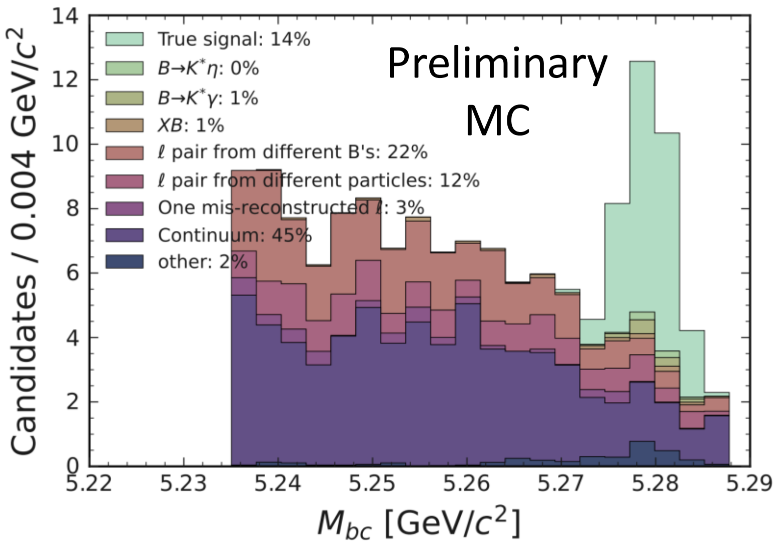
Signal selection

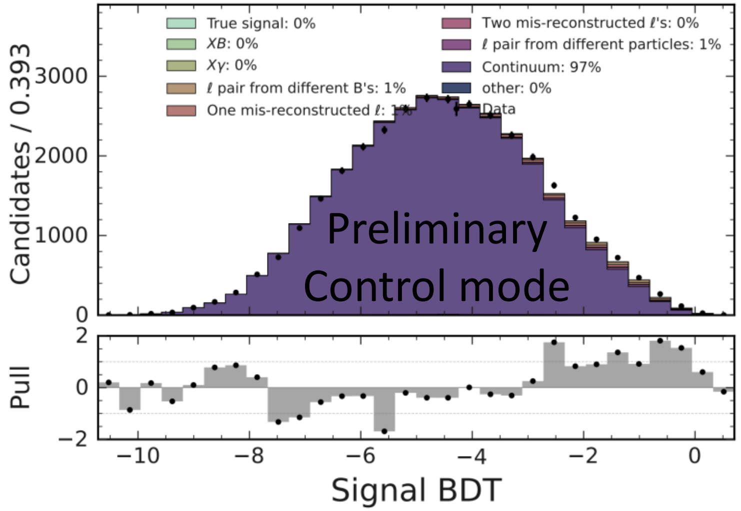
- BDTs developed for continuum suppression and signal selection
- Vertexing and q^2 threshold used to remove $B \to K^*\gamma(\to e^+e^-)$ events





Radius of the dilepton vertex in the xy-plane

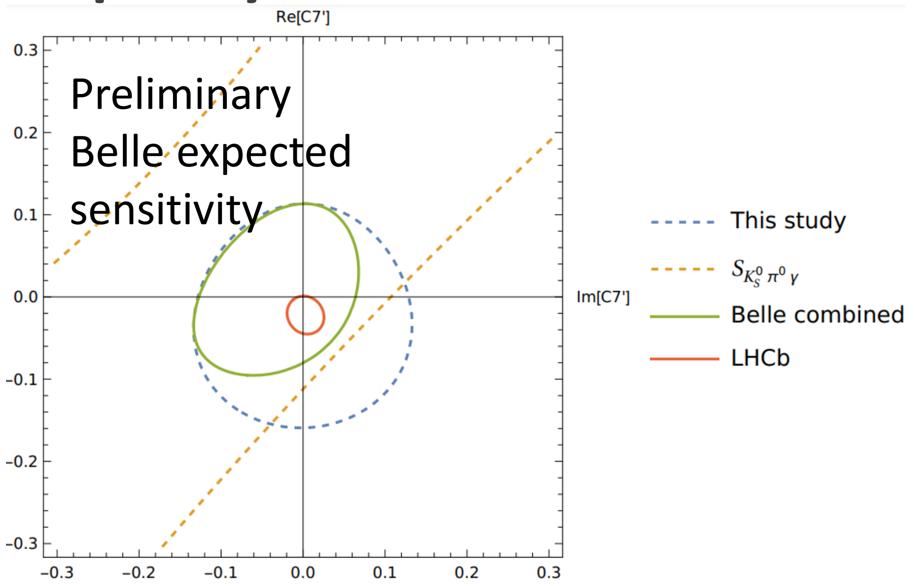




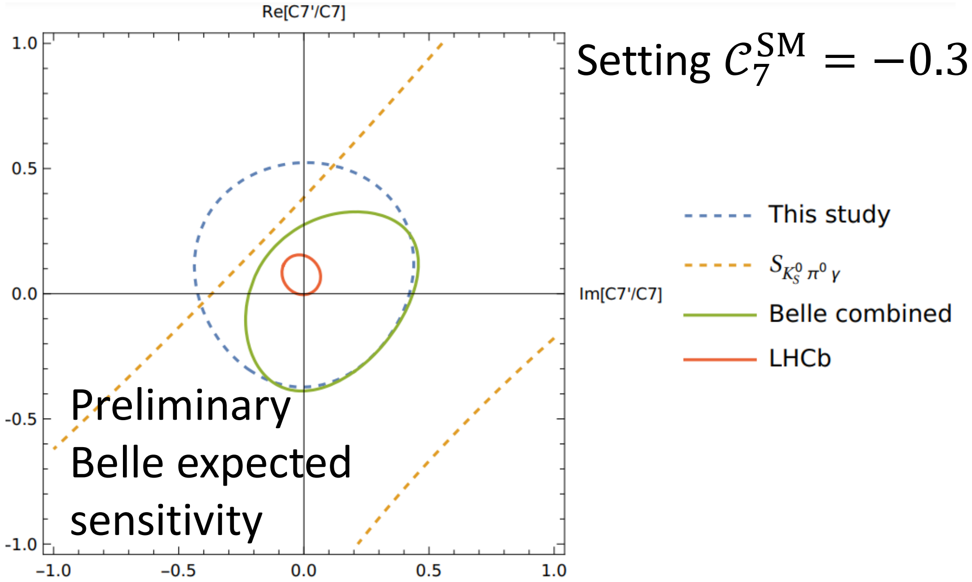
- 22 expected events using the BDT compared to 12 when using the old lepton ID

Expected sensitivity to new physics

- Fit to the differential decay rate and use results to constrain $\mathcal{C}_7^{(\prime)}$
- Ready for unblinding soon
- Potential future inclusion of $B \to K^*\gamma(\to e^+e^-)$ for additional constraint on photon polarisation looks viable



Setting $\mathcal{C}_7^{\mathrm{SM}} = -0.304$

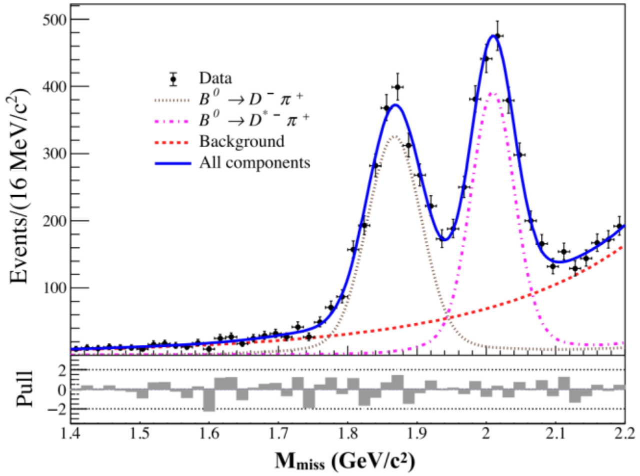


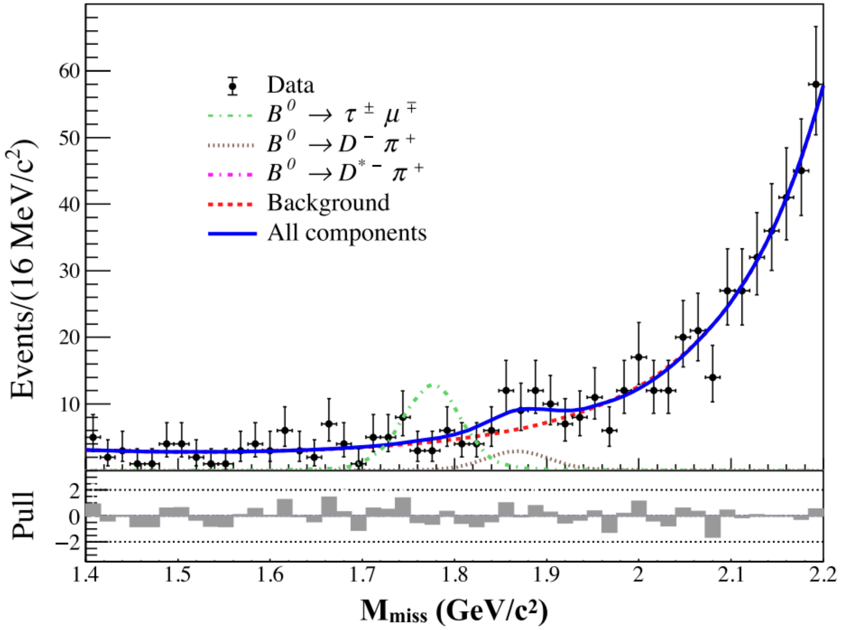
Summary

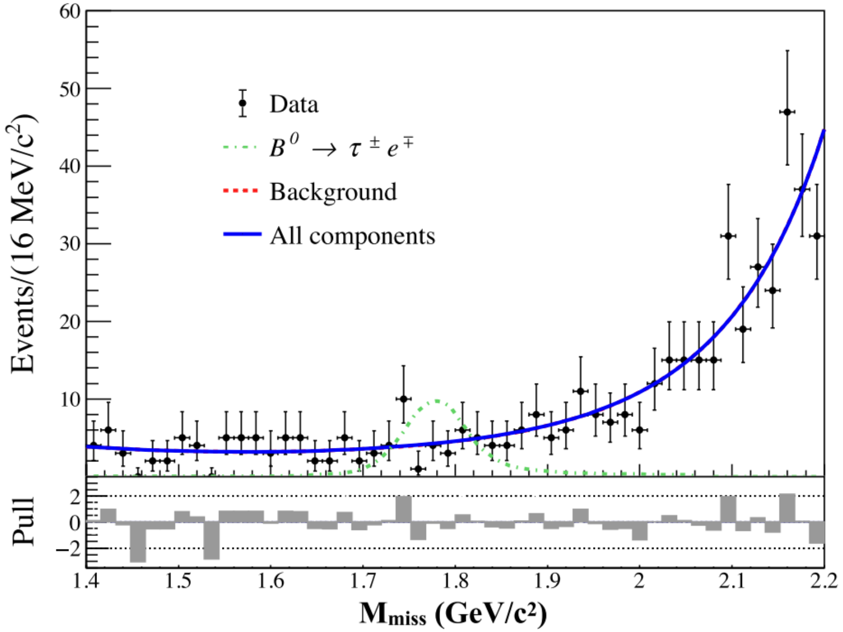
- Lots of recent results of rare B decays!
- Lepton flavour violation studies:
  - $\mathcal{B}(B^0_{(s)} \to \tau^\pm \ell^\mp)$ – first search for $B^0_s \to \tau^\pm e^\mp$
  - $\mathcal{B}(B^+ \to K^+ \tau^\pm \ell^\mp)$ – broken down into all $\tau^\pm \ell^\mp$ combinations
  - $\mathcal{B}(B \to K \mu^\pm e^\mp)$ – best constraints to date
- Lepton flavour universality
  - $R(K^{(*)})$ has remained consistent with the Standard Model
  - $\mathcal{B}(B \to K^* \tau^\pm \tau^\mp)$ – first constraint for this decay mode
- $B \to K^* e^+ e^-$ angular analysis for low q^2 - unblinding soon
- Upgraded Belle lepton ID will help push Belle + Belle II studies in the future

Back up

$B^0 \to \tau^{\mp}\ell^{\pm}$



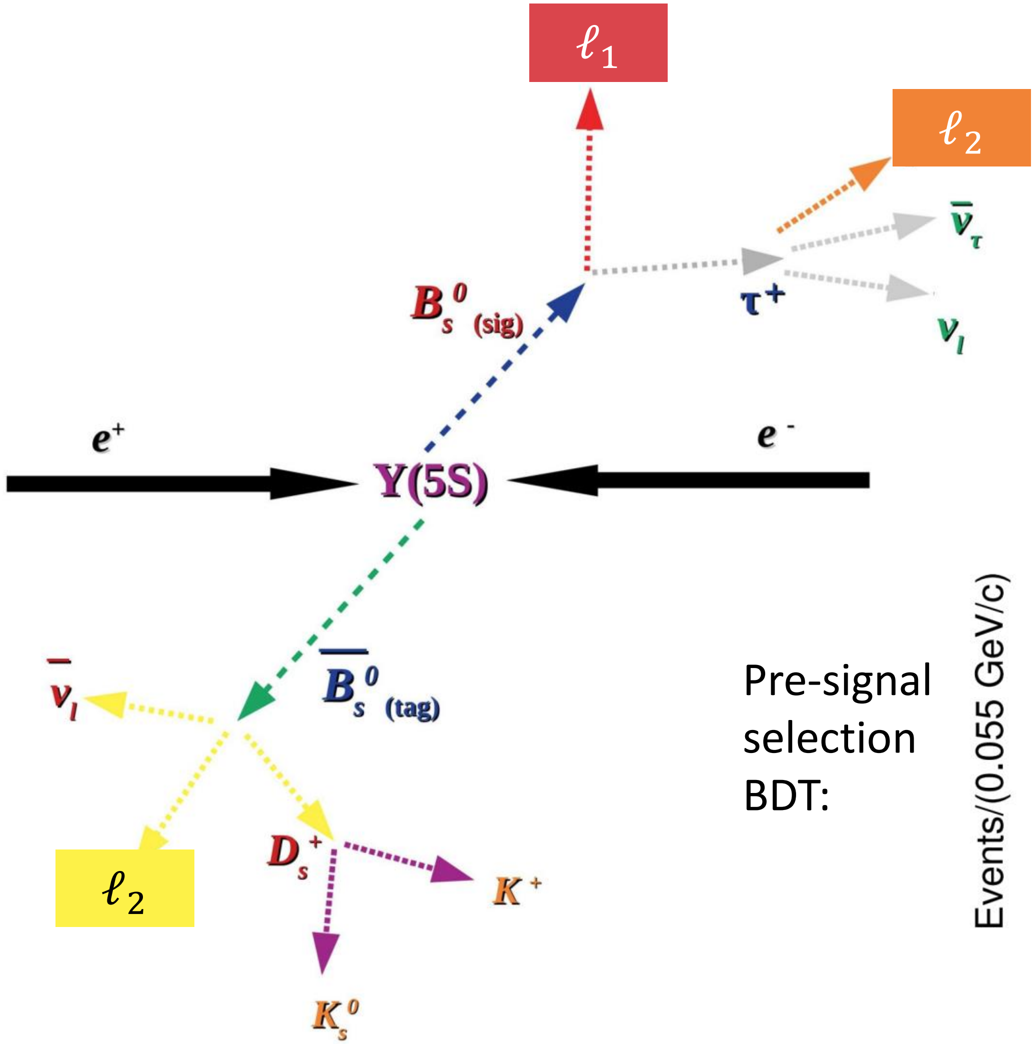




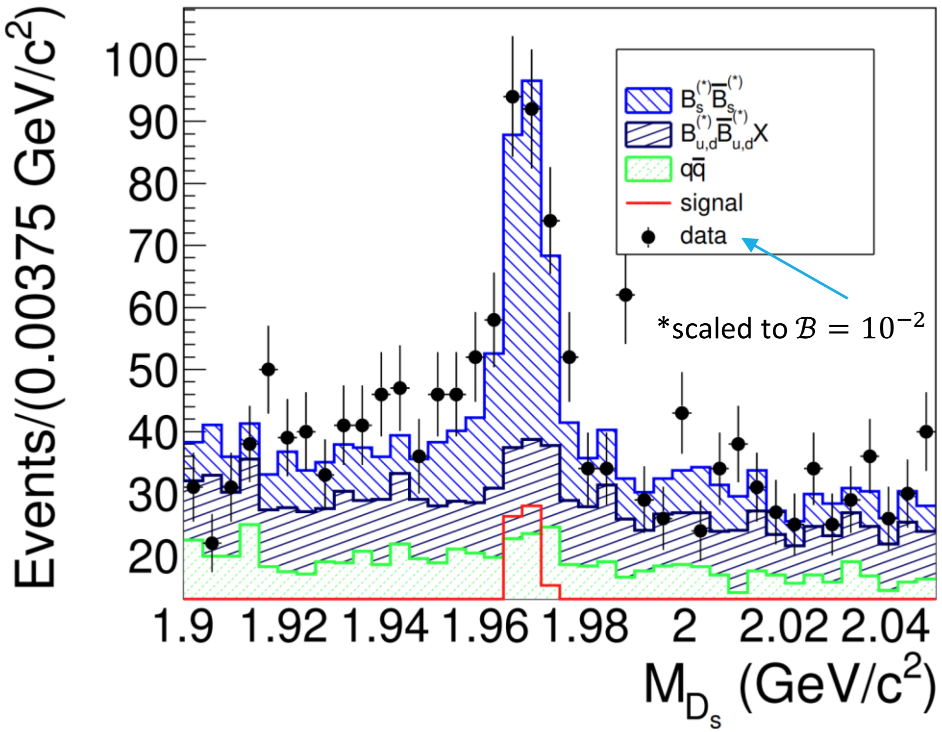
Source	$B^0 \to \tau^{\pm}\mu^{\mp}$	$B^0 \to \tau^{\pm}e^{\mp}$
PDF shapes	0.7	0.3
Self-cross-feed fraction	< 0.1	0.1
Total (events)	0.7	0.3
B_{tag}	4.5	4.5
Track reconstruction	0.3	0.3
Lepton identification	1.6	1.8
MC statistics	< 0.1	< 0.1
Number of $B\bar{B}$ pairs	1.4	1.4
f^{00} ($B\bar{B} \to B^0\bar{B}^0$ fraction)	1.2	1.2
Total (%)	5.1	5.2

Mode	ε ($\times 10^{-4}$)	N_{sig}	N_{sig}^{UL}	$\mathcal{B}^{UL}$ ($\times 10^{-5}$)
$B^0 \to \tau^{\pm}\mu^{\mp}$	11.0	$1.8^{+8.2}_{-7.6}$	12.4	1.5
$B^0 \to \tau^{\pm}e^{\mp}$	9.8	$0.3^{+8.8}_{-8.2}$	11.6	1.6

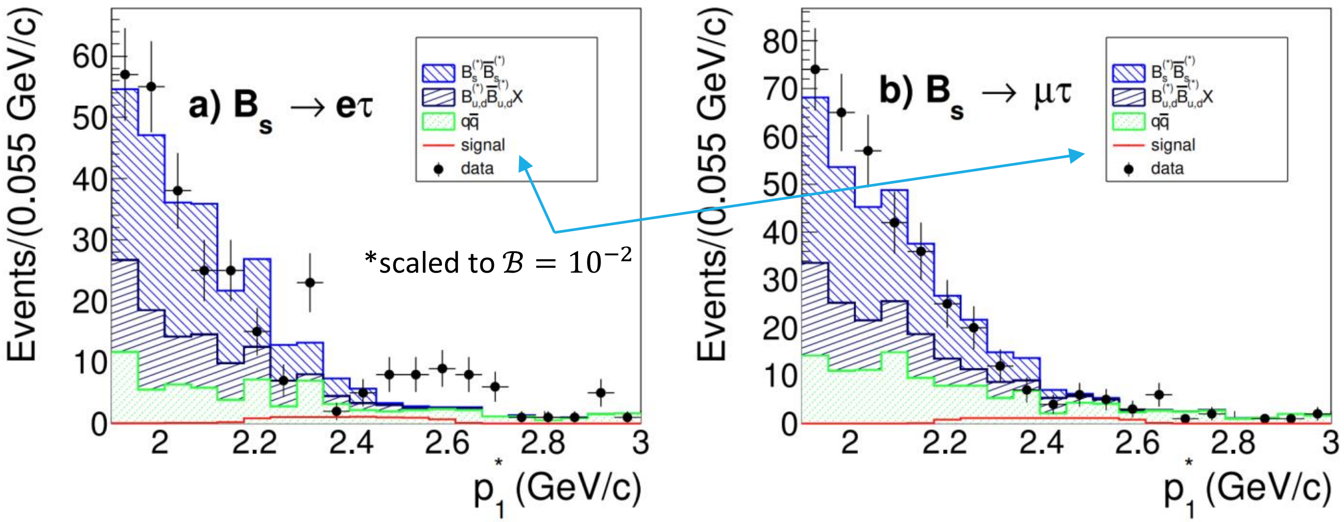
$B_s^0 \to \tau^{\pm}\ell^{\mp}$



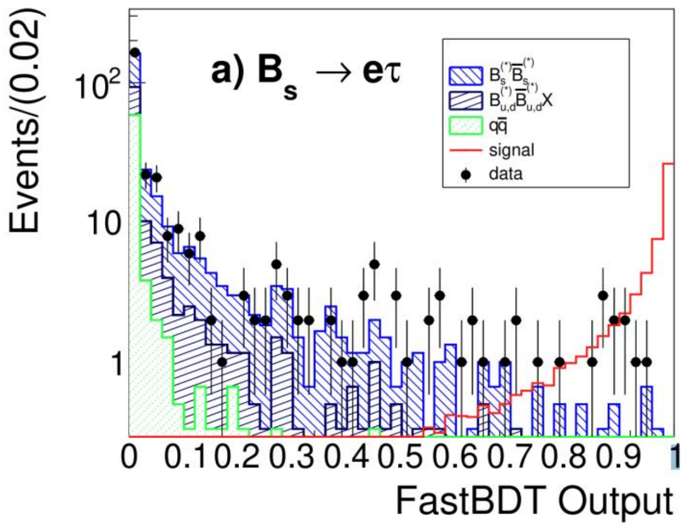
Tag-side:

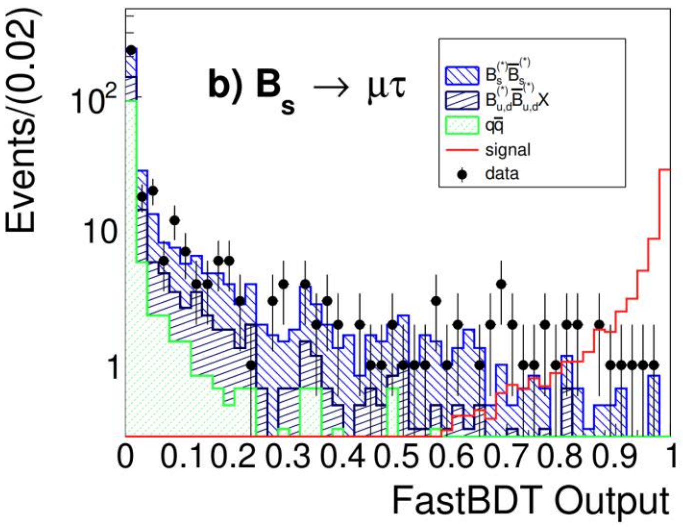


Pre-signal selection BDT:



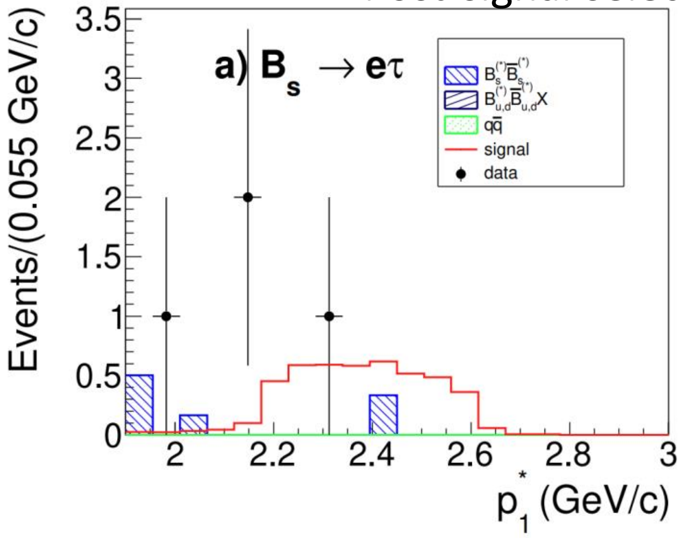
$B_s^0 \to \tau^\pm \ell^\mp$

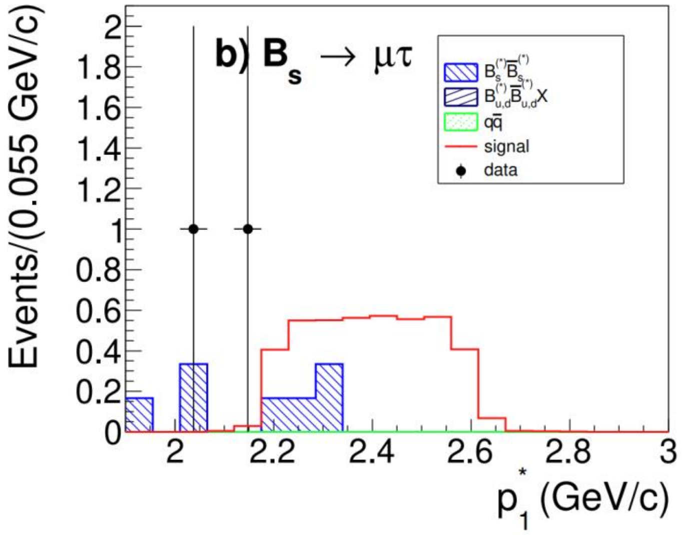




- BDT inputs:
  - Non-primary lepton momenta
  - Extra energy from non-reconstructed tracks and clusters
  - Sum of energy of tracks and clusters
  - Missing energy
  - Absolute missing invariant mass squared
  - Cosine of angle between ℓ_1 and ℓ_2
  - D_s^+ mass
  - Modified Fox-Wolfram moments

Post-signal selection BDT:





Source	$B_s \to e^-\tau^+$	$B_s \to \mu^-\tau^+$
$\overline{B}_s^0 \to D_s^+\ell^-\overline{\nu}_\ell$ tag	15.0	15.0
FastBDT selection	3.3	3.7
Lepton ID	4.3	3.5
Tracking	0.7	0.7
$\tau \to \ell\nu_\tau\overline{\nu}_\ell$ branching fraction	0.2	0.2
Number of B_s	16.1	16.1
Total	22.7	22.6

	ϵ (%)	$N_{\text{bkg}}^{\text{exp}}$	N_{obs}	$\mathcal{B}$ $(\times 10^{-4})$	$f_s \times \mathcal{B}$ $(\times 10^{-4})$
$B_s \to e^-\tau^+$	0.0312 ± 0.0071	0.68 ± 0.69	3	< 14.1	< 5.5
$B_s \to \mu^-\tau^+$	0.0303 ± 0.0068	0.77 ± 0.78	1	< 7.3	< 2.9

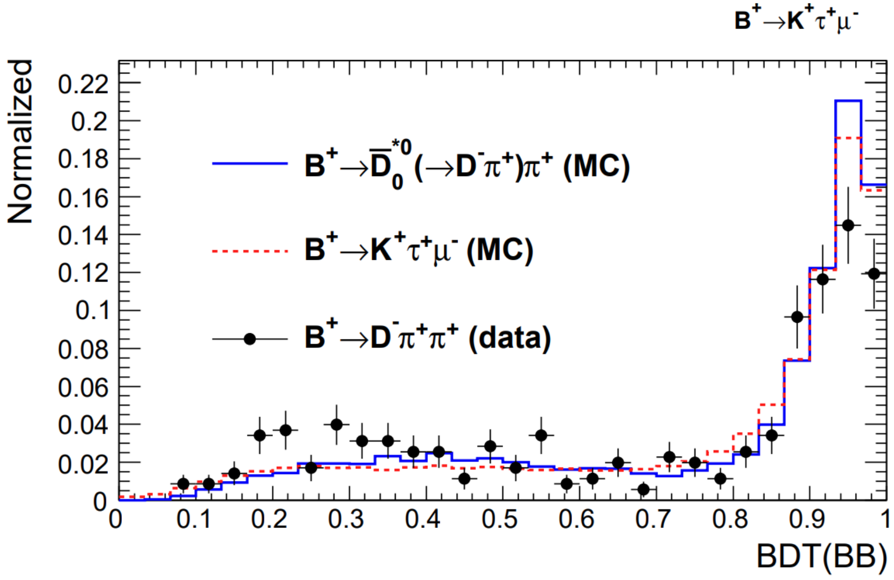
$B^+ \to K^+\tau^\pm\ell^\mp$

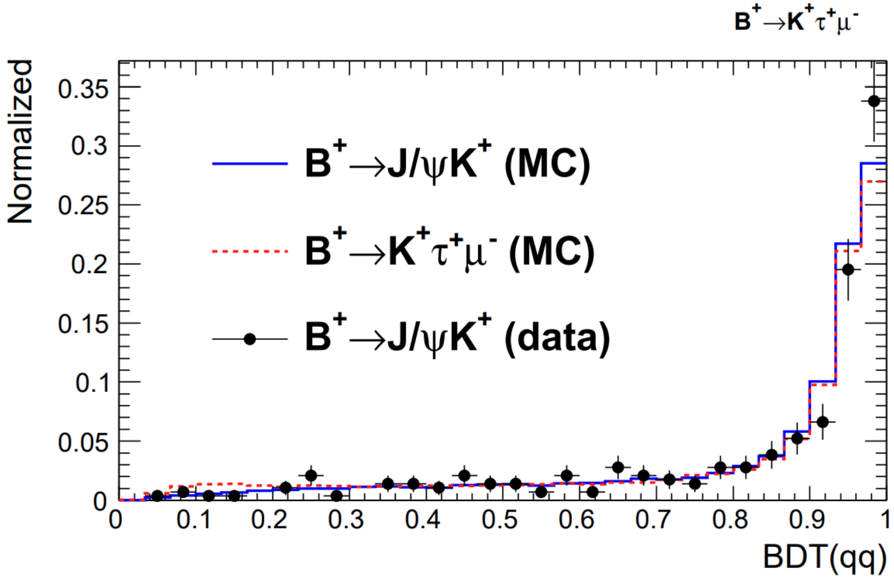
$$\mathcal{B}^{\mathrm{UL}} = \frac{N_{\mathrm{sig}}^{\mathrm{UL}}}{N_{B\overline{B}} \times 2 \times f^{+-} \times \varepsilon}$$

Mode	ε (%)	$\varepsilon^{\mathrm{NP}}$ (%)	N_{sig}	$\mathcal{B}^{\mathrm{UL}}$ (10^{-5})
$B^+ \to K^+\tau^+\mu^-$	0.064	0.058	-2.1 ± 2.9	0.59 (0.65)
$B^+ \to K^+\tau^+e^-$	0.084	0.074	1.5 ± 5.5	1.51 (1.71)
$B^+ \to K^+\tau^-\mu^+$	0.046	0.038	2.3 ± 4.1	2.45 (2.97)
$B^+ \to K^+\tau^-e^+$	0.079	0.058	-1.1 ± 7.4	1.53 (2.08)

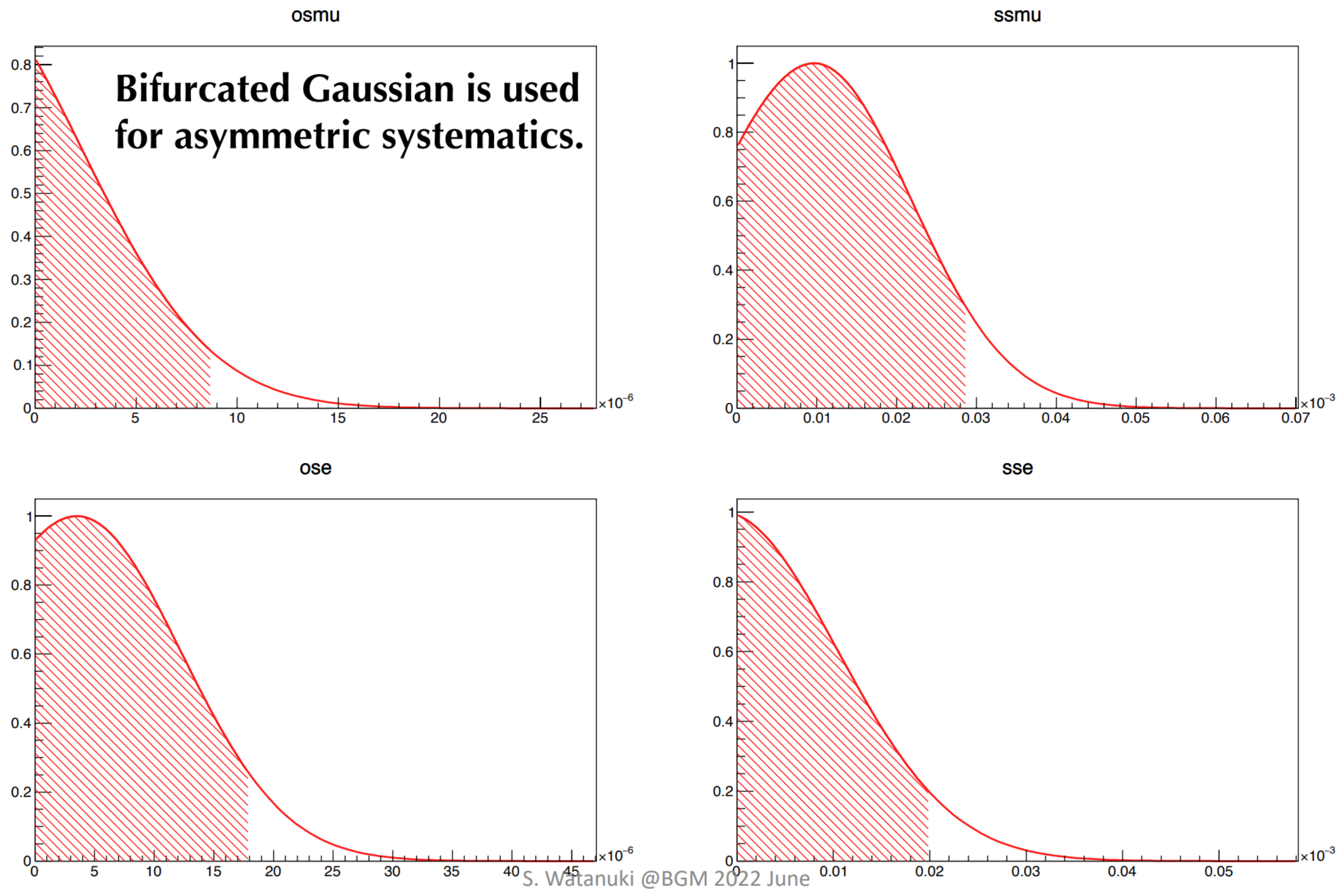
- $B\bar{B}$ BDT inputs:
  - Kaon-track invariant mass
  - No. ECL clusters and energy in rest of event
  - Extended Fox-wolfram moments
  - Decay vertex distances
  - Distance between kaon and each other signal track

- $q\bar{q}$ BDT inputs:
  - R_2
  - CLEO cones
  - Thrust axis angle
  - Other event shape variables





$B^+ \to K^+\tau^\pm\ell^\mp$

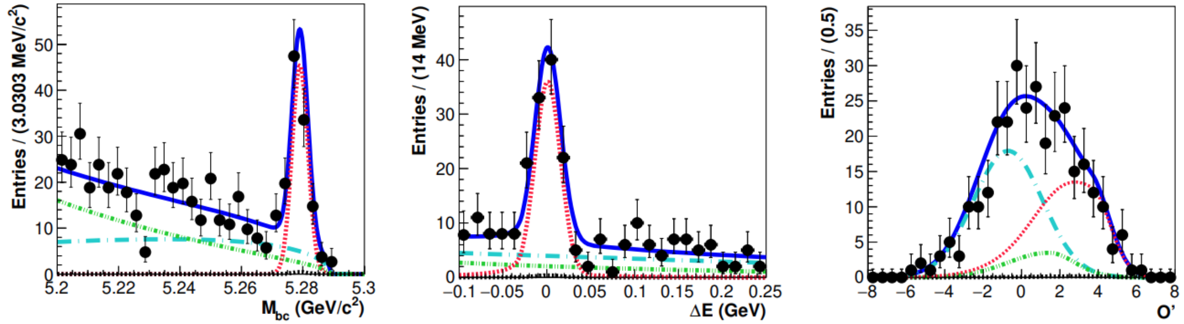


Source	$K^+\tau^+\mu^-$	$K^+\tau^+e^-$	$K^+\tau^-\mu^+$	$K^+\tau^-e^+$
Additive (events)				
PDF shape (mean)	0.09	0.01	0.08	0.08
PDF shape (width)	0.02	0.08	0.04	0.07
PDF shape (f_{sig})	0.28	0.16	0.11	0.16
Linearity	0.03	0.04	0.02	0.04
Total	0.30	0.18	0.14	0.20
Multiplicative (%)				
B_{tag} calibration	5.9	5.9	5.9	5.9
Track reconstruction	1.1	1.1	1.1	1.1
Kaon id.	1.3	1.4	1.3	1.3
Lepton id.	0.3	0.4	0.3	0.4
τ daughter id.	0.7	0.7	0.6	0.6
MC statistics	1.0	1.5	1.2	1.0
Number of $B\overline{B}$ pairs	1.4	1.4	1.4	1.4
BDT $B\overline{B}$ selection	10.6	10.0	12.7	12.6
BDT $q\overline{q}$ selection	8.8	8.6	9.2	6.6
f^{+-}	1.2	1.2	1.2	1.2
Total	15.3	14.8	17.0	15.7

$B \to K\ell\ell$

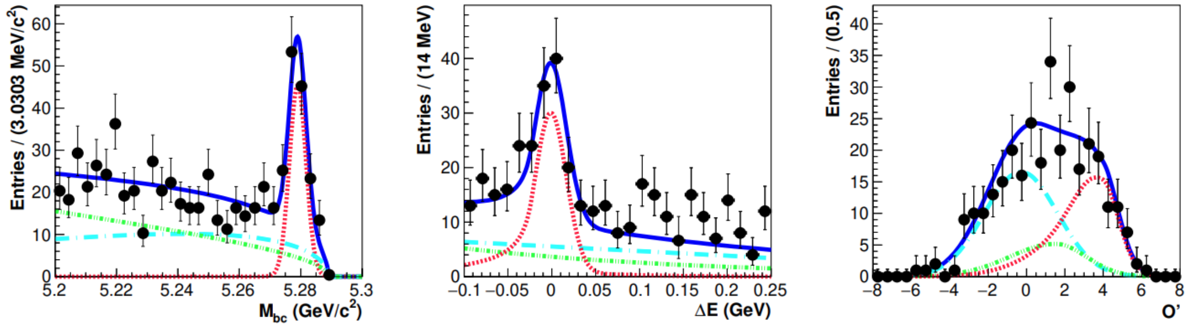
Sources	$B^+ \to J/\psi K^+$	$B^0 \to J/\psi K_S^0$	$R_{K^+}(J/\psi)$	$R_{K^0}(J/\psi)$	$A_I(J/\psi K)$
Lepton identification	± 0.68	± 0.68	± 0.97	± 0.97	—
Kaon identification	± 0.80	—	—	—	± 0.007
K_S^0 identification	—	± 1.57	—	—	± 0.002
Track reconstruction	± 1.05	± 1.40	—	—	± 0.002
Efficiency calculation	± 0.14	± 0.18	± 0.20	± 0.25	± 0.001
Number of $B\bar{B}$ pairs	± 1.40	± 1.40	—	—	—
$f^{+-(00)}$	± 1.20	± 1.20	—	—	± 0.012
$\mathcal{O}_{\min}$	± 0.16	± 0.28	± 0.24	± 0.39	± 0.001
PDF shape parameters	$^{+0.15}_{-0.20}$	$^{+0.05}_{-0.10}$	$^{+0.22}_{-0.31}$	$^{+0.10}_{-0.20}$	± 0.002
Total	± 2.38	± 2.90	$^{+1.05}_{-1.07}$	$^{+1.08}_{-1.09}$	± 0.014

Continuum and $B\bar{B}$ suppression with a neural net, $\mathcal{O}'$. Included event-shape variables, decay vertex information and flavour-tagging confidence



Muon mode

Mode	ε (%)	N_{sig}	$N_{\text{sig}}^{\text{UL}}$	$\mathcal{B}^{(\text{UL})}$ (10^{-8})
$B^+ \to K^+\mu^+e^-$	29.4	$11.6^{+6.1}_{-5.5}$	19.9	8.5
$B^+ \to K^+\mu^-e^+$	31.2	$1.7^{+3.6}_{-2.2}$	7.5	3.0
$B^0 \to K^0\mu^\pm e^\mp$	20.9	$-3.3^{+4.0}_{-2.8}$	3.0	3.8

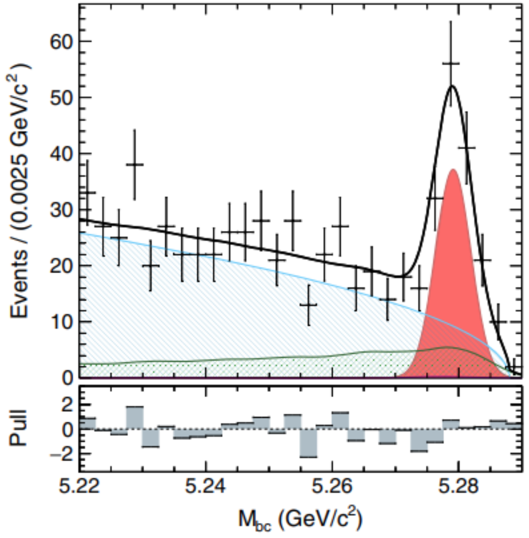


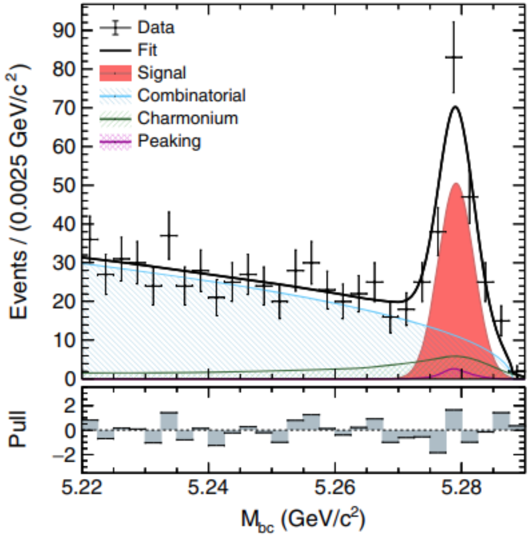
Electron mode

$B \to K\ell\ell$

q^2 (GeV^2/c^4)	$B \to$ mode	ε (%)	N_{sig}	$\mathcal{B}$ (10^{-7})	A_I (individual)	A_I (combined)	R_K (individual)	R_K (combined)
(0.1,4.0)	$K^+\mu^+\mu^-$	20.4	$28.4^{+6.6}_{-5.9}$	$1.76^{+0.41}_{-0.37} \pm 0.04$	$A_I(\mu\mu) =$	$-0.22^{+0.14}_{-0.12} \pm 0.01$	$R_{K^+} =$	$1.01^{+0.28}_{-0.25} \pm 0.02$
	$K^0_S\mu^+\mu^-$	14.7	$6.8^{+3.3}_{-2.6}$	$0.62^{+0.30}_{-0.23} \pm 0.02$	$-0.11^{+0.20}_{-0.17} \pm 0.01$		$0.98^{+0.29}_{-0.26} \pm 0.02$	
	$K^+e^+e^-$	29.1	$41.5^{+7.7}_{-7.0}$	$1.80^{+0.33}_{-0.30} \pm 0.05$	$A_I(ee) =$		$R_{K^0_S} =$	
	$K^0_Se^+e^-$	19.3	$5.5^{+3.6}_{-2.7}$	$0.38^{+0.25}_{-0.19} \pm 0.01$	$-0.35^{+0.21}_{-0.17} \pm 0.01$		$1.62^{+1.31}_{-1.01} \pm 0.02$	
(4.00,8.12)	$K^+\mu^+\mu^-$	29.0	$28.4^{+6.4}_{-5.7}$	$1.24^{+0.28}_{-0.25} \pm 0.03$	$A_I(\mu\mu) =$	$-0.09^{+0.15}_{-0.12} \pm 0.01$	$R_{K^+} =$	$0.85^{+0.30}_{-0.24} \pm 0.01$
	$K^0_S\mu^+\mu^-$	21.0	$4.2^{+4.2}_{-3.5}$	$0.27^{+0.18}_{-0.13} \pm 0.01$	$-0.34^{+0.23}_{-0.19} \pm 0.01$		$1.29^{+0.44}_{-0.39} \pm 0.02$	
	$K^+e^+e^-$	35.4	$26.9^{+6.9}_{-6.1}$	$0.96^{+0.24}_{-0.22} \pm 0.03$	$A_I(ee) =$		$R_{K^0_S} =$	
	$K^0_Se^+e^-$	23.9	$9.3^{+3.7}_{-3.0}$	$0.52^{+0.21}_{-0.17} \pm 0.02$	$0.10^{+0.20}_{-0.16} \pm 0.01$		$0.51^{+0.41}_{-0.31} \pm 0.01$	
(1.0,6.0)	$K^+\mu^+\mu^-$	23.2	$42.3^{+7.6}_{-6.9}$	$2.30^{+0.41}_{-0.38} \pm 0.05$	$A_I(\mu\mu) =$	$-0.31^{+0.13}_{-0.11} \pm 0.01$	$R_{K^+} =$	$1.03^{+0.28}_{-0.24} \pm 0.01$
	$K^0_S\mu^+\mu^-$	16.8	$3.9^{+2.7}_{-2.0}$	$0.31^{+0.22}_{-0.16} \pm 0.01$	$-0.53^{+0.20}_{-0.17} \pm 0.02$		$1.39^{+0.36}_{-0.33} \pm 0.02$	
	$K^+e^+e^-$	31.7	$41.7^{+8.0}_{-7.2}$	$1.66^{+0.32}_{-0.29} \pm 0.04$	$A_I(ee) =$		$R_{K^0_S} =$	
	$K^0_Se^+e^-$	21.1	$8.9^{+4.0}_{-3.2}$	$0.56^{+0.25}_{-0.20} \pm 0.02$	$-0.13^{+0.18}_{-0.15} \pm 0.01$		$0.55^{+0.46}_{-0.34} \pm 0.01$	
(10.2,12.8)	$K^+\mu^+\mu^-$	35.6	$24.3^{+6.3}_{-5.5}$	$0.86^{+0.22}_{-0.20} \pm 0.02$	$A_I(\mu\mu) =$	$-0.18^{+0.22}_{-0.18} \pm 0.01$	$R_{K^+} =$	$1.97^{+1.03}_{-0.89} \pm 0.02$
	$K^0_S\mu^+\mu^-$	26.5	$5.7^{+3.4}_{-2.6}$	$0.29^{+0.17}_{-0.13} \pm 0.01$	$-0.14^{+0.24}_{-0.19} \pm 0.01$		$1.96^{+1.03}_{-0.89} \pm 0.02$	
	$K^+e^+e^-$	40.3	$14.0^{+6.4}_{-5.5}$	$0.44^{+0.20}_{-0.17} \pm 0.01$	$A_I(ee) =$		$R_{K^0_S} =$	
	$K^0_Se^+e^-$	26.5	$1.1^{+3.7}_{-3.0}$	$0.06^{+0.19}_{-0.15} \pm 0.01$	$-0.55^{+0.73}_{-0.60} \pm 0.01$		$5.18^{+17.69}_{-14.32} \pm 0.06$	
> 14.18	$K^+\mu^+\mu^-$	45.2	$47.9^{+8.6}_{-7.8}$	$1.34^{+0.24}_{-0.22} \pm 0.03$	$A_I(\mu\mu) =$	$-0.14^{+0.14}_{-0.12} \pm 0.01$	$R_{K^+} =$	$1.16^{+0.30}_{-0.27} \pm 0.01$
	$K^0_S\mu^+\mu^-$	25.7	$9.6^{+4.2}_{-3.5}$	$0.49^{+0.22}_{-0.18} \pm 0.01$	$-0.08^{+0.17}_{-0.15} \pm 0.01$		$1.13^{+0.31}_{-0.28} \pm 0.01$	
	$K^+e^+e^-$	46.2	$43.2^{+9.1}_{-8.3}$	$1.18^{+0.25}_{-0.22} \pm 0.03$	$A_I(ee) =$		$R_{K^0_S} =$	
	$K^0_Se^+e^-$	24.9	$5.9^{+4.0}_{-3.1}$	$0.32^{+0.21}_{-0.17} \pm 0.01$	$-0.24^{+0.23}_{-0.19} \pm 0.01$		$1.57^{+1.28}_{-1.00} \pm 0.02$	
whole q^2	$K^+\mu^+\mu^-$	27.8	$137.0^{+14.2}_{-13.5}$	$6.24^{+0.65}_{-0.61} \pm 0.16$	$A_I(\mu\mu) =$	$-0.19^{+0.07}_{-0.06} \pm 0.01$	$R_{K^+} =$	$1.10^{+0.16}_{-0.15} \pm 0.02$
	$K^0_S\mu^+\mu^-$	18.5	$27.3^{+6.6}_{-5.9}$	$1.97^{+0.48}_{-0.42} \pm 0.06$	$-0.16^{+0.09}_{-0.08} \pm 0.01$		$1.08^{+0.16}_{-0.15} \pm 0.02$	
	$K^+e^+e^-$	30.3	$138.0^{+15.5}_{-14.7}$	$5.75^{+0.64}_{-0.61} \pm 0.15$	$A_I(ee) =$		$R_{K^0_S} =$	
	$K^0_Se^+e^-$	19.0	$21.8^{+7.0}_{-6.1}$	$1.53^{+0.49}_{-0.43} \pm 0.04$	$-0.24^{+0.11}_{-0.10} \pm 0.01$		$1.29^{+0.52}_{-0.45} \pm 0.01$	

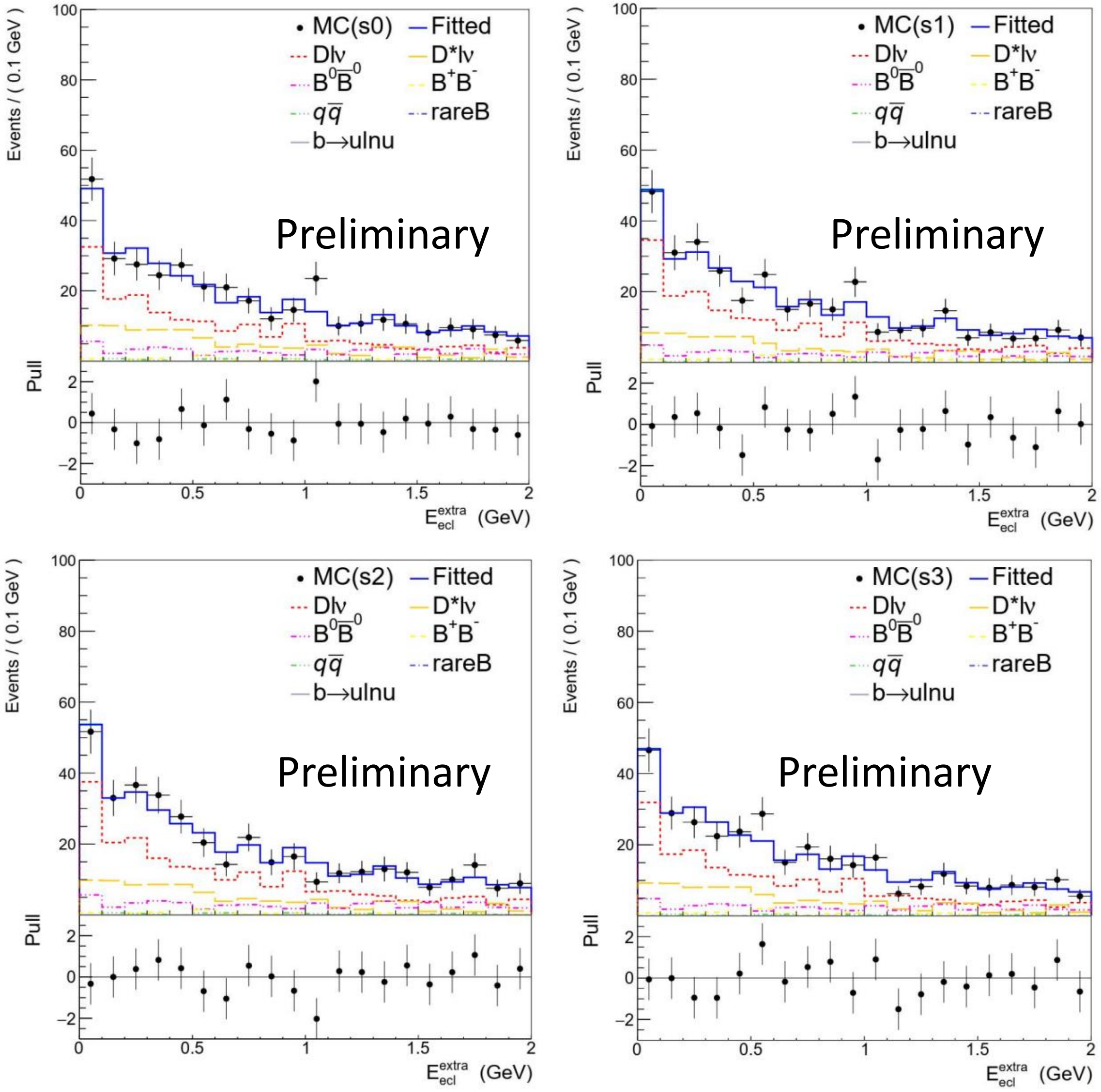
$B \to K^*\ell\ell$





q^2 (GeV$^2/c^4$)	Signal shape	Peaking backgrounds	Charmonium backgrounds	e, μ efficiency	Classifier	MC size	Total
All modes							
[0.045, 1.1]	0.017	0.026	0.001	0.027	0.030	0.006	0.051
[1.1, 6]	0.020	0.070	0.013	0.065	0.038	0.008	0.106
[0.1, 8]	0.023	0.054	0.051	0.058	0.024	0.005	0.101
[15, 19]	0.019	0.003	0.003	0.090	0.047	0.012	0.104
[0.045, 19]	0.025	0.031	0.023	0.061	0.026	0.004	0.080
B^0 modes							
[0.045, 1.1]	0.010	0.049	0.001	0.024	0.112	0.007	0.126
[1.1, 6]	0.014	0.070	0.012	0.082	0.062	0.010	0.126
[0.1, 8]	0.013	0.033	0.018	0.058	0.049	0.006	0.086
[15, 19]	0.006	0.007	0.001	0.091	0.032	0.013	0.098
[0.045, 19]	0.012	0.031	0.021	0.073	0.033	0.006	0.090
B^+ modes							
[0.045, 1.1]	0.011	0.006	0.000	0.033	0.060	0.013	0.071
[1.1, 6]	0.017	0.086	0.009	0.045	0.092	0.010	0.135
[0.1, 8]	0.013	0.048	0.107	0.060	0.023	0.010	0.135
[15, 19]	0.007	0.008	0.002	0.089	0.052	0.028	0.108
[0.045, 19]	0.011	0.025	0.023	0.044	0.015	0.005	0.059

$B \to K^* \tau^+ \tau^-$

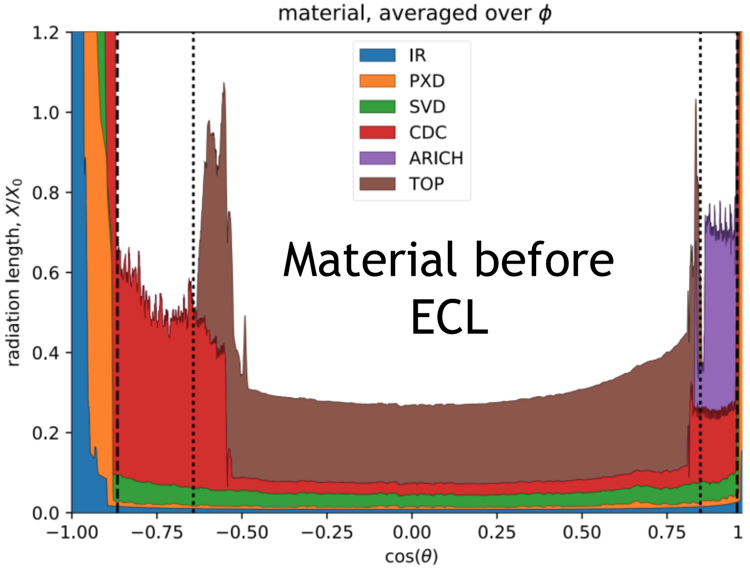


Source	error(%)
statistics	5.2
Number of $B^0\bar{B}^0$	1.8
Tag efficiency	4.6
Tracking	1.4
K-ID	1.25
π-ID	1.32
e-ID	2.48
μ-ID	2.03
K-short veto	0.17
π^0 veto	1.56
Sum	8.33

Preliminary

The Belle (II) electromagnetic calorimeter

- Made up of 8736 CsI(Tl) $\sim 30\text{cm}$ crystals, equivalent to 16 radiation lengths (X_0) for electrons and photons

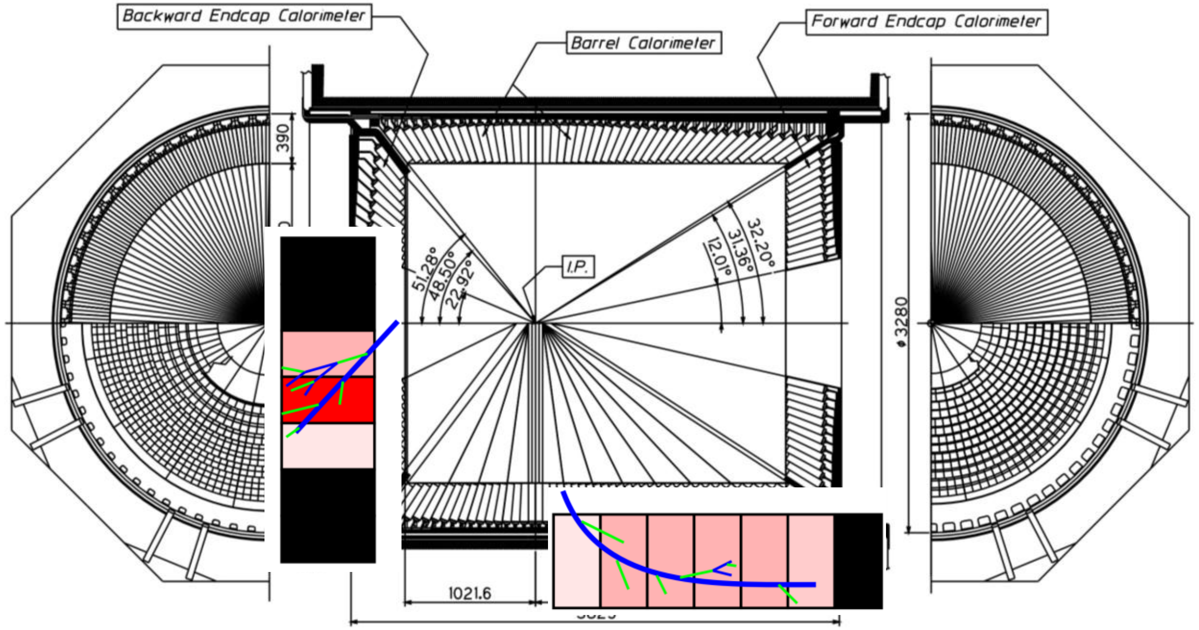


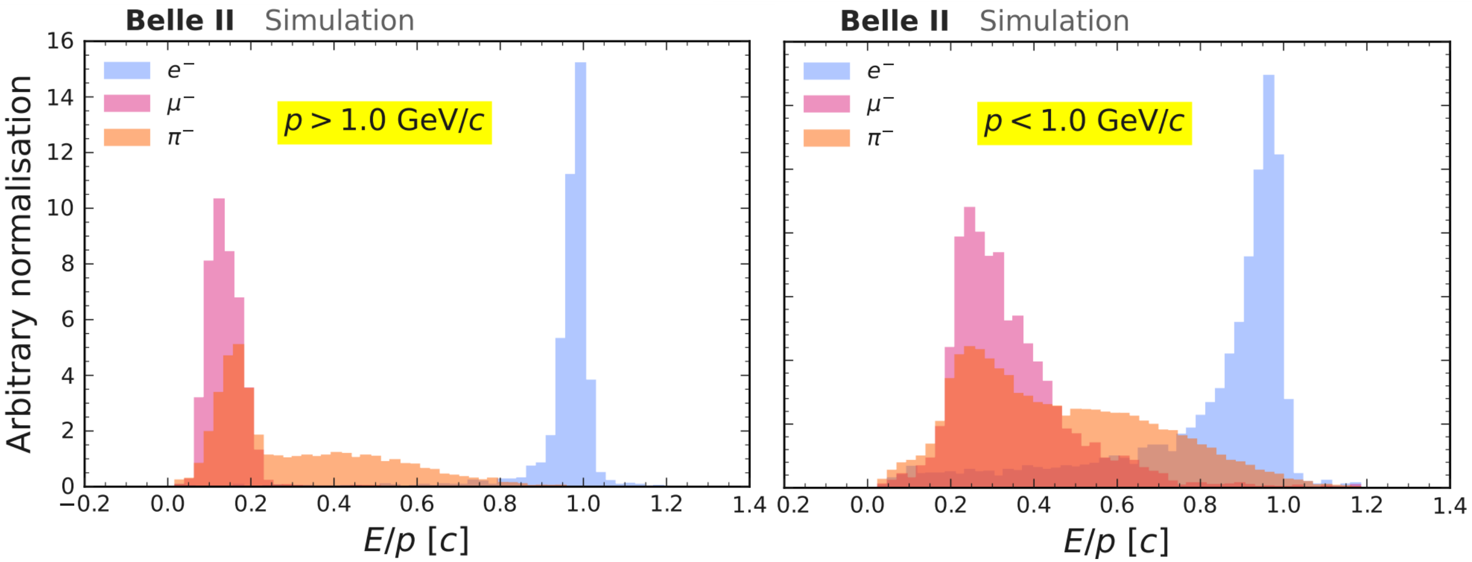
Compared to $2.5X_0$ before LHCB's ECAL

Belle II: $\frac{E}{E_0} = e^{-X/X_0} \approx e^{-0.3} = 74\%$

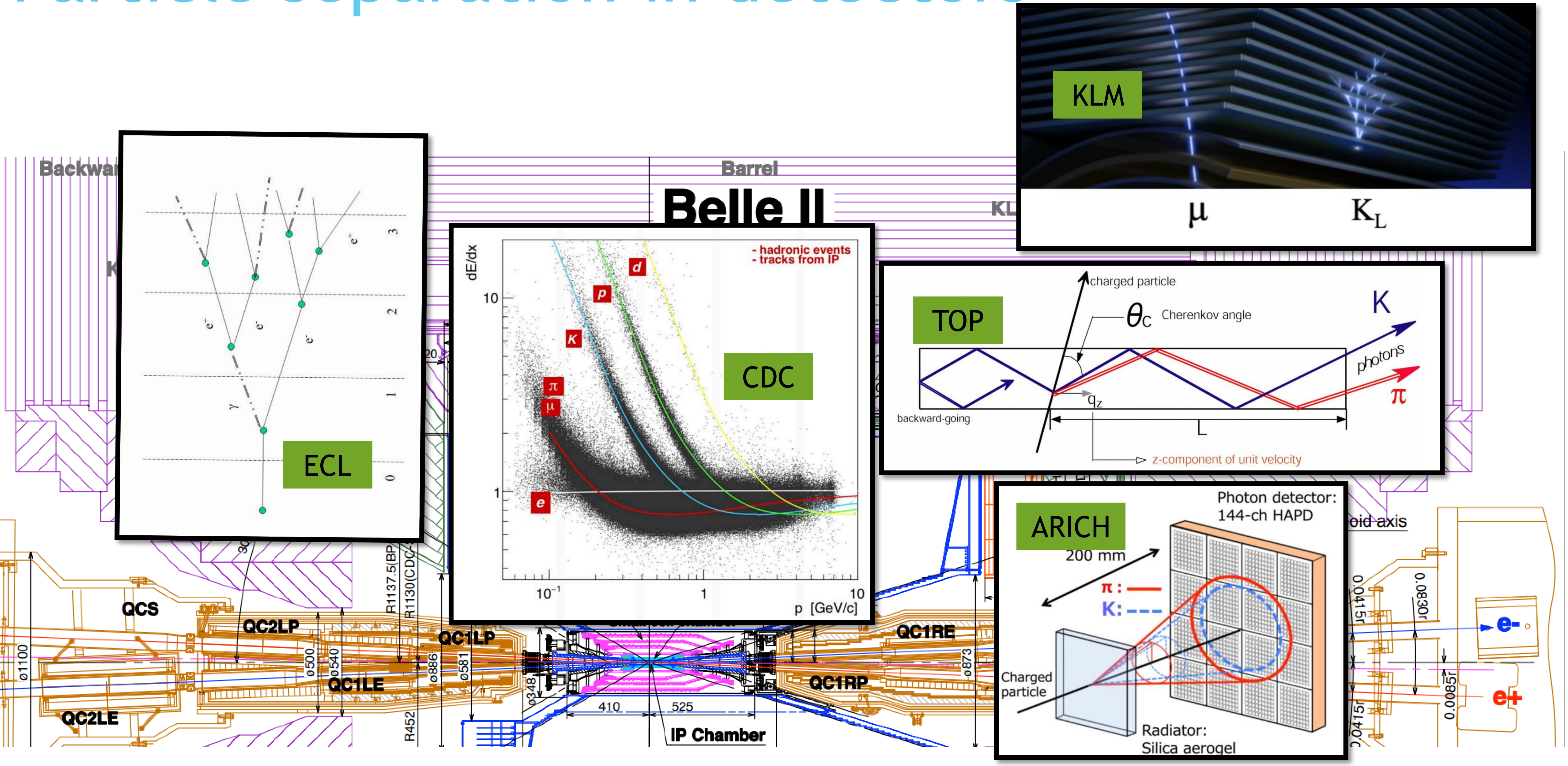
LHCb: $\frac{E}{E_0} = e^{-2.5} = 8\%$

Better timing resolution at Belle (II) also allows for better bremsstrahlung recovery



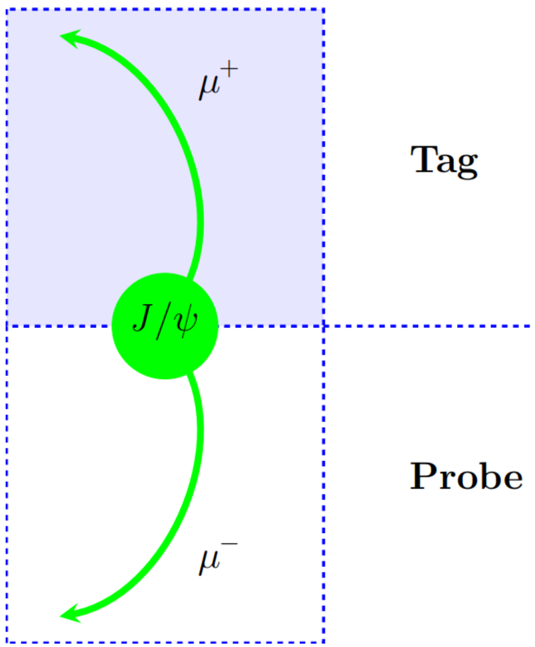


Particle separation in detectors



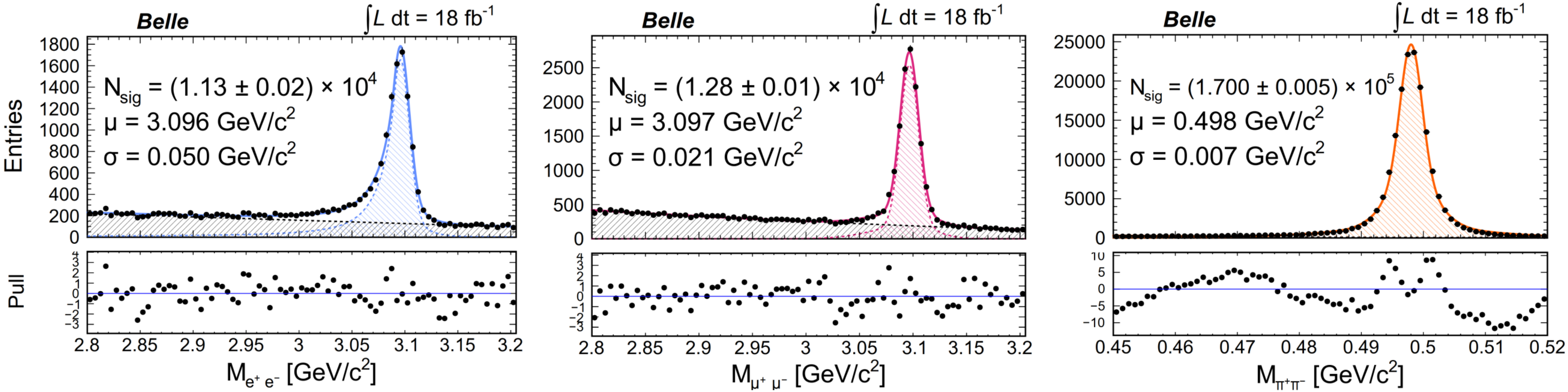
Verifying Lepton ID

- Test the BDT using standard candles $J/\Psi \to \ell^+\ell^-$ and $K_S^0 \to \pi^+\pi^-$
- LFUV tests require high precision (with uncertainty $< 1\%$)



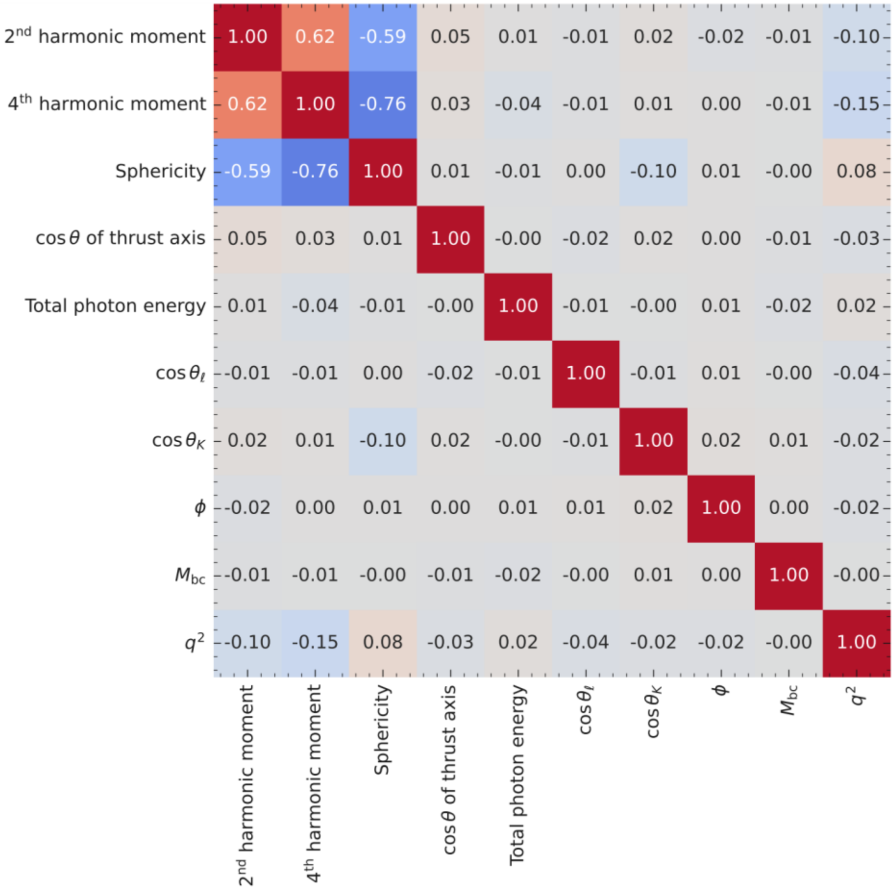
- Tight leptonID selection criteria

- Only apply phase space cut to ensure there is no bias
- Fit invariant mass before and after a leptonID cut to determine efficiency



Continuum suppression BDT

Continuum suppression BDT input variables
Fox-Wolfram R1-R4
Harmonic Moment Thrust 0-4
Sphericity
Aplanarity
Thrust axis cos theta
Missing mass^2 of event
Visible energy of event
Total photon energy of event



Signal event classifier

Signal selection BDT input variables
ΔE
Continuum suppression BDT
Δz_0 of the two electrons
Δd_0 of the two electrons
Distance of dilepton vertex
Significance of distance of dilepton vertex
Missing mass[2] and visible energy of event
Log of dilepton vertex radius