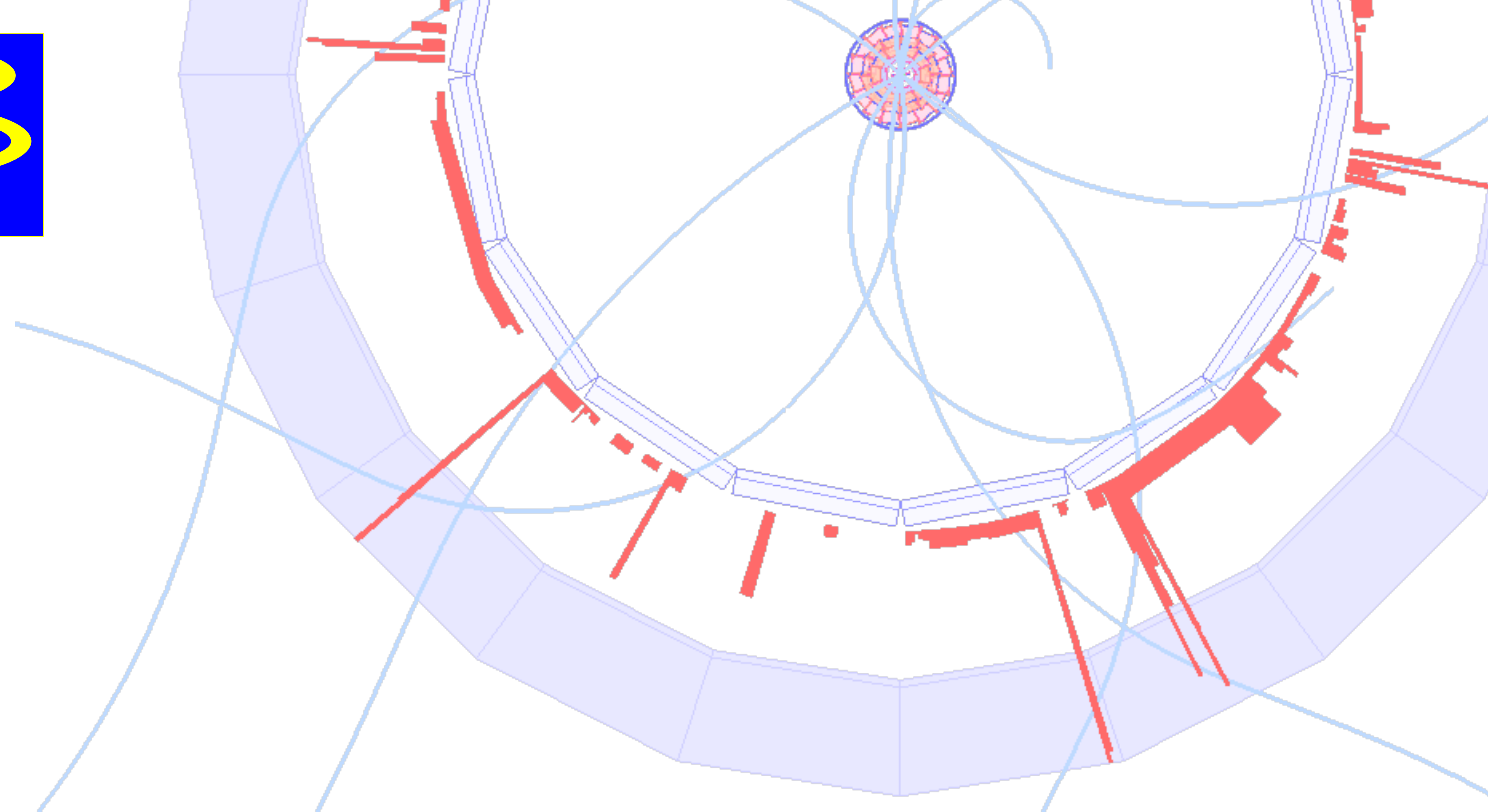
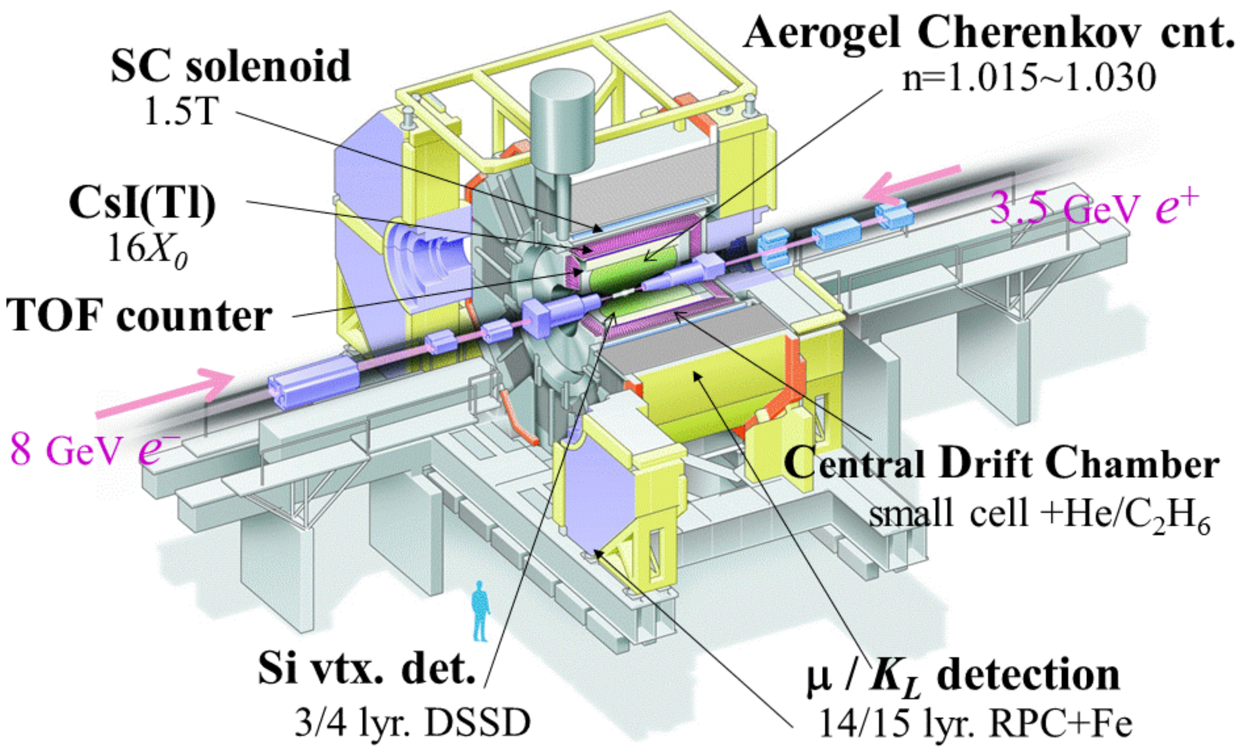


Search for baryon-number-violating and lepton-flavor-violating decays at Belle

ICHEP BOLOGNA - 2022.07.09

Gaetano de Marino
on behalf of the Belle collaboration

BELLE EXPERIMENT @ KEKB

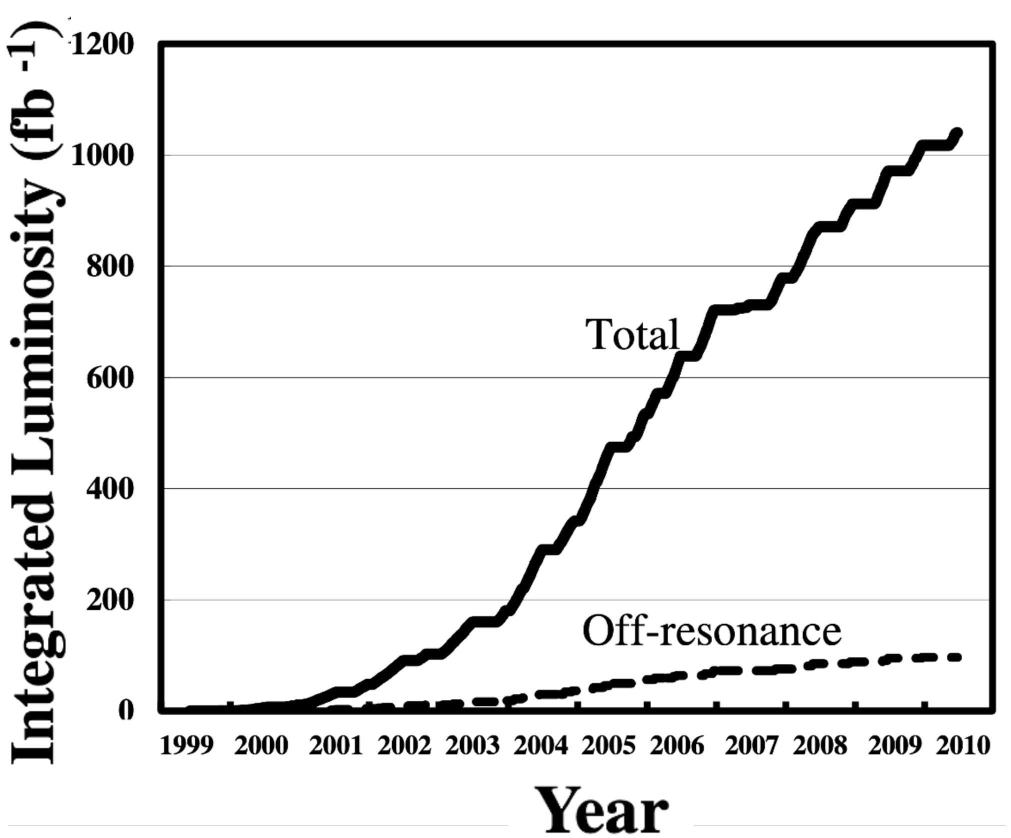


Belle detector

- Good momentum and vertex resolution
- Well-known initial state (up to ISR)
- Excellent calorimetry
- Sophisticated particle ID

  K/π separation

  Lepton identification (μ/π mis-ID)



Operation finished >10 years ago
but still steady flow of results

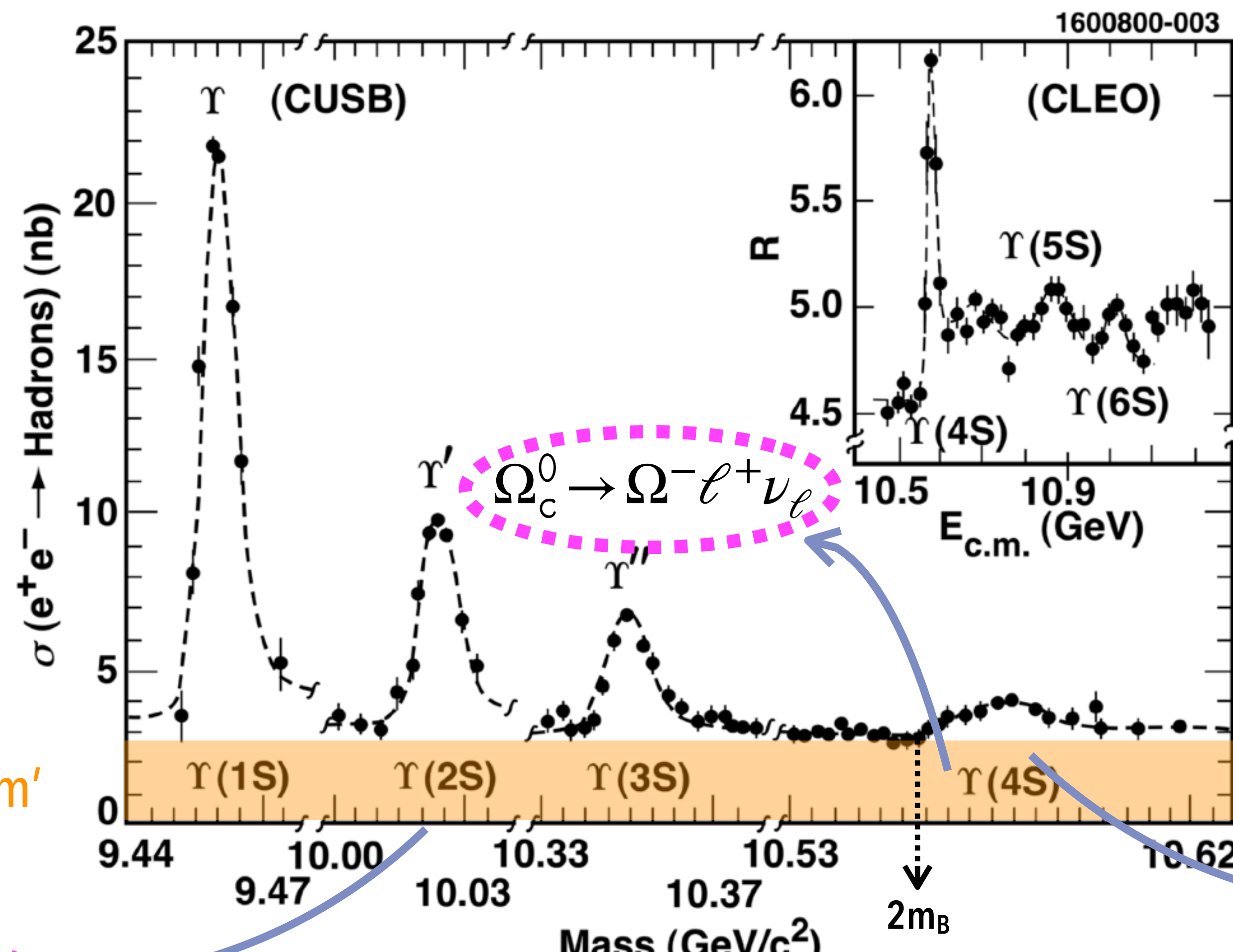
OUTLINE

- **L**epton **F**lavor **V**iolation **Searches**
- **B**aryon **N**umber **V**iolation
- **L**epton **F**lavor **U**niversality **Test**

Largest $\Upsilon(\mathrm{nS})$ $(\mathrm{n} = 1, 2, 4, 5)$ samples collected so far! $\Upsilon \equiv \{b\bar{b}\}$

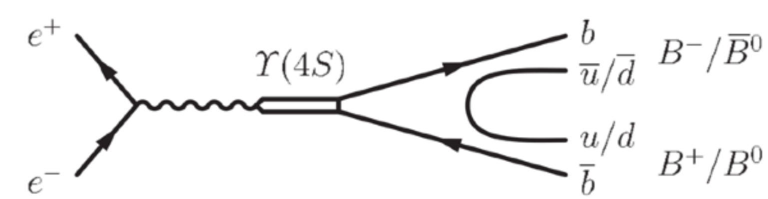
Resonance	On-resonance Luminosity (fb^{-1})	Off-resonance Luminosity (fb^{-1})	Υ number (10^6)
$\Upsilon(5S)$	121.4	1.7	7
$\Upsilon(4S)$	711.0	73.8	772
$\Upsilon(3S)$	2.9	0.2	11
$\Upsilon(2S)$	24.9	1.7	158
$\Upsilon(1S)$	5.7	1.8	119

Covered today!



$\Omega_c^0 \to \Omega^- \ell^+ \nu_\ell$

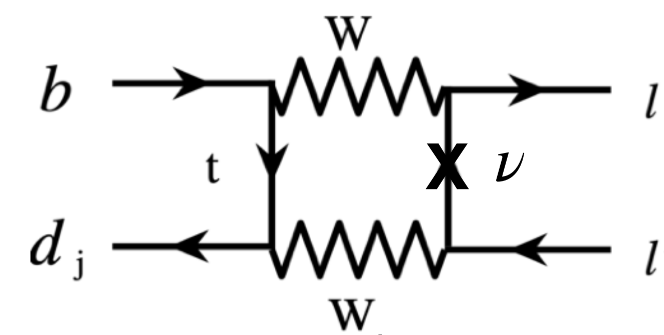
$\Upsilon(2S) \to \Upsilon(1S)(\to \ell\ell')\pi\pi$



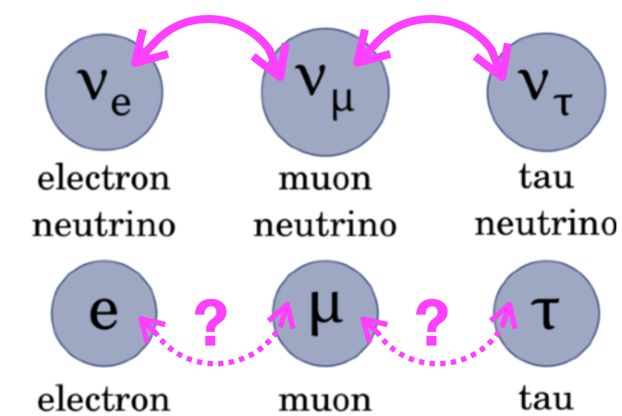
$B \to \tau\ell$

$B \to \Lambda + \mathrm{DM}$

(charged) LEPTON FLAVOR VIOLATION



PhysRevD.70.113011



- Neutrino mass and neutrino oscillations → the accidental lepton family symmetry in the SM is broken → family lepton number can be violated
- Charged LFV can occur through oscillations in loops but it is suppressed by $(\Delta m_{ij}/m_W)^4$ – b.r.~10^{-54}
- Deviations from LFU have been measured in charged AND neutral current B-decays
- No known symmetry principle protects lepton flavor conservation in the presence of lepton non-universality PRL114,091801

LFV searches in many sectors and many experiments… (LEP, LHC, BEPCII, B-factories)

$$\mu \to e\gamma, \mu \to 3e, \mu N \to eN$$

$$\tau \to 3\mu, \tau \to \mu V \quad V \in \{\rho, \Omega, \phi, K^{*0}\}$$

Covered by K. Uno in "Tau physics at Belle"

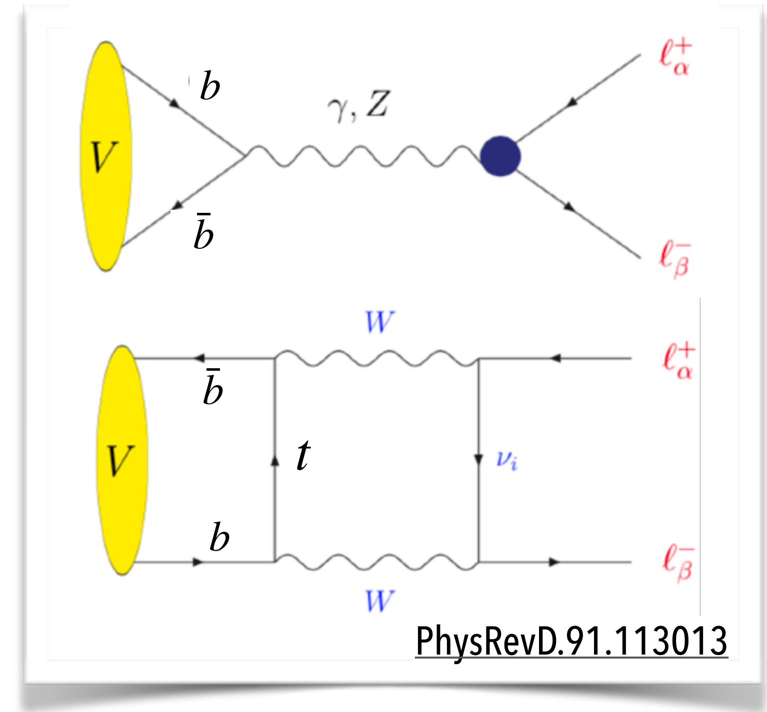
$$\left.\begin{array}{l} H \to \ell\ell' \\ B \to K\tau\ell, B_{(s)} \to \tau\ell \\ V \to \ell\ell' \quad \ell^{(\prime)} \in \{e, \mu, \tau\}, \; V \in \{\Upsilon(nS), Z, J/\psi ...\} \end{array}\right\} \text{LFV in final states}$$

… not observed yet, though!

It would be a clear signal of new physics!

$\Upsilon(1S) \to \ell\ell'$ - MOTIVATION&STRATEGY

- $\Upsilon(1S) \to \ell^{\pm}\ell'^{\mp}$: Two-body vector meson cLFV process
  → probing the vector and tensor operators of the effective Lagrangian for NP
- $\Upsilon(1S) \to \gamma\ell^{\pm}\ell'^{\mp}$: First study of three-body radiative cLFV
  → complementary access to NP Hazard, Petrov, PRD 94, 074023 (2016)



- $\Upsilon(2S) \to \Upsilon(1S)\pi\pi$ events preferred over $\Upsilon(1S)$

PROS

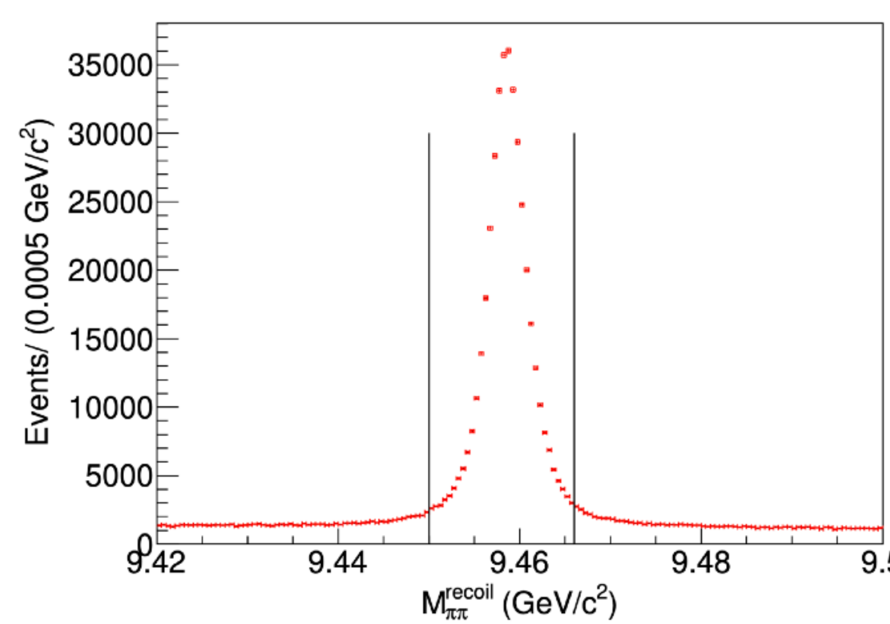
- higher trigger efficiency (two more tracks in the event)
- easier QED background suppression

CONS

- Smaller statistics (28M vs 119M) due to $\mathscr{B}(\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)) \sim 18\,\%$

Resonance	Υ number (10^6)	
$\Upsilon(2S)$	158	$\times 0.18 \sim 28M$
$\Upsilon(1S)$	119	

$\pi\pi$ recoil consistent with $\Upsilon(1S)$ mass



$$M_{\pi\pi}^{recoil} = \sqrt{(E_{e^+e^-} - E_{\pi\pi})^2 - |\vec{p}_{\pi\pi}|^2}$$

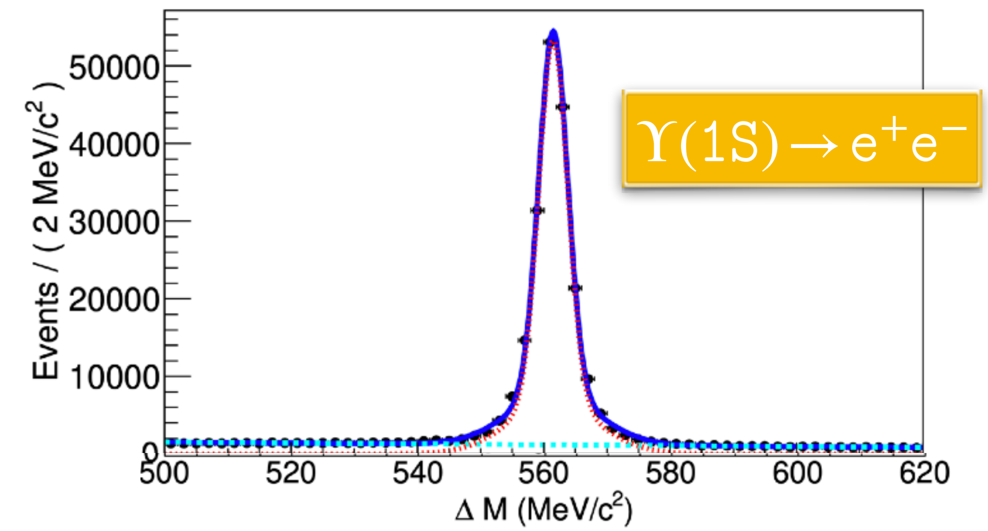
$$M_{\pi\pi}^{recoil} \in (9.45, 9.466)\ \mathrm{GeV}/c^2$$

$\Upsilon(1S) \to \ell\ell'$ - THE ANALYSIS

- **$e\mu$ case**

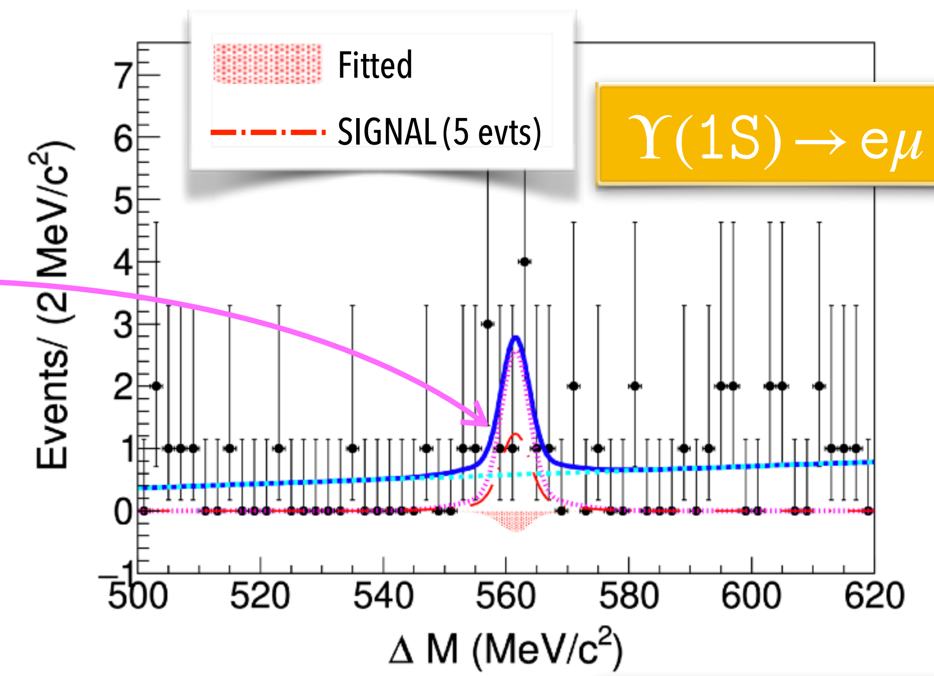
$$\Delta M = M_{\Upsilon(2S)} - M_{\Upsilon(1S)} \sim 560\ \mathrm{MeV}$$
$$= M_{\pi\pi(\gamma)\ell\ell} - M_{(\gamma)\ell\ell}$$

LFC decays are used for calibration;
The b.r.'s are compared to world average



LFV decays $\Upsilon(1S) \to e\mu$: signal events will still peak in ΔM

Expected ~9 peaking bg events from $\Upsilon(1S) \to \mu\mu$ ($\mu \leftrightarrow e$ mis-ID evaluated from di-muon events)



- **$\ell\tau$ case**

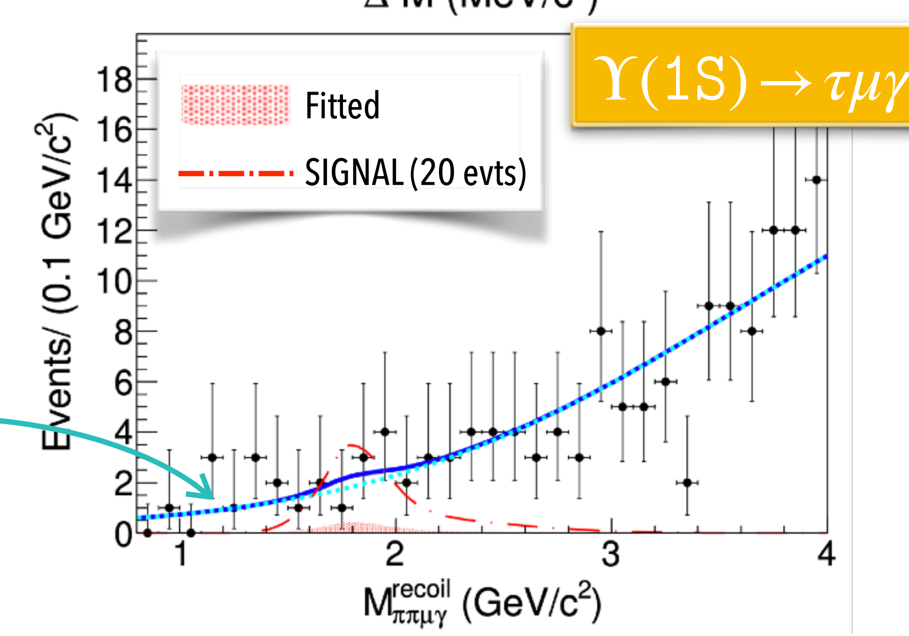
The τ cannot be fully reconstructed:
- The following modes are chosen to reduce $\Upsilon(1S) \to \ell\ell$ background

$$e\tau:\ \tau \to \mu\nu\bar{\nu}/3\pi\nu$$
$$\mu\tau:\ \tau \to e\nu\bar{\nu}/3\pi\nu$$

- The 4-momentum of the τ is inferred from initial e^+e^- and $\pi\pi\ell\ell(\gamma)$ system

$$M^{\mathrm{recoil}}_{\pi\pi\ell(\gamma)} \sim m_\tau$$

Dominant bg from $\Upsilon(1S) \to \tau(\to \ell\nu/\pi\nu)\tau$



$\Upsilon(1S)\to\ell\ell'$ - THE RESULTS

Signal is not found in any of the channels and the upper limit on the b.r.'s are estimated as:

$$\mathscr{B}[\Upsilon(1S)\to\ell^{\pm}\ell'^{\mp}] < \frac{N^{UL}_{sig}}{N_{\Upsilon(2S)}\times\mathscr{B}[\Upsilon(2S)\to\pi^{+}\pi^{-}\Upsilon(1S)]\times\varepsilon}$$

$(\gamma)e\mu$: 20–30 %

$(\gamma)\ell\tau$: 5–9 %

Generation model: VLL vs PHSP

The first is chosen as it is more conservative (8% lower efficiency)

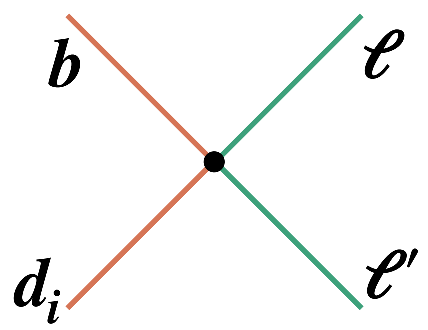
Decay	ϵ (%)	N_{sig}^{fit}	N_{sig}^{UL}	$\mathcal{B}^{UL}$	PDG result
$\Upsilon(1S)\to e^{\pm}\mu^{\mp}$	32.5	-1.3 ± 3.7	3.6	3.9×10^{-7}	–
$\Upsilon(1S)\to \mu^{\pm}\tau^{\mp}$	8.8	-1.5 ± 4.3	6.8	2.7×10^{-6}	6.0×10^{-6}
$\Upsilon(1S)\to e^{\pm}\tau^{\mp}$	7.1	-3.5 ± 2.7	5.3	2.7×10^{-6}	–
$\Upsilon(1S)\to \gamma e^{\pm}\mu^{\mp}$	24.6	$+0.8\pm1.5$	2.9	4.2×10^{-7}	–
$\Upsilon(1S)\to \gamma\mu^{\pm}\tau^{\mp}$	5.8	$+2.1\pm5.9$	10.0	6.1×10^{-6}	–
$\Upsilon(1S)\to \gamma e^{\pm}\tau^{\mp}$	5.0	-9.5 ± 6.3	9.1	6.5×10^{-6}	–

- All the U.L.'s are dominated by statistical uncertainty
- The largest source of systematic uncertainty (2%) comes from $N_{\Upsilon(2S)}$

~2x more stringent than the previous result from CLEO

The other modes are searched for the first time

$b \to d_i \ell \ell'$ TRANSITIONS d_i=d,s



$\ell, \ell' = \{e, \mu, \tau\}$

$d_i = \{d, s\}$

$B_{d_i} \to \ell\ell'$ **2-body dynamics**

Leptons energy is monochromatic

ℓ has p* almost beyond endpoint of SL B decays

$B \to K\ell\ell'$ **3-body dynamics**

The final states resemble $b \to cW^*$ modes

$\Rightarrow$ large backgrounds

When $\ell, \ell' \neq \tau$

- Limits are very stringent
- Competitive or better than LHCb (neutral modes)

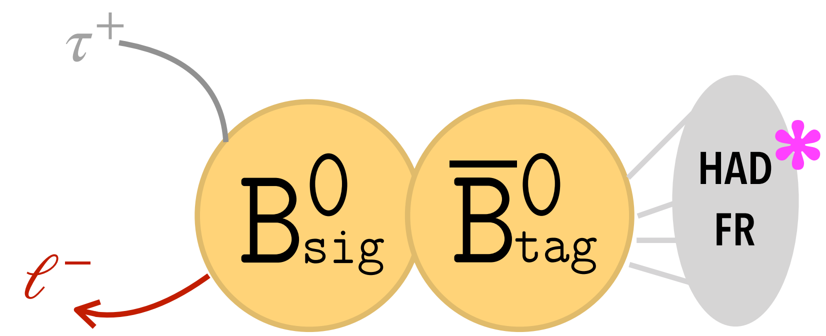
		best limits
$B^+ \to K^+ e\mu$	10^{-9}	LHCb
$B^0 \to K^0 e\mu$	10^{-8}	Belle
$B^0 \to K^{*0} e\mu$	10^{-8}	LHCb

Otherwise…

- Limits are much less precise $\mathcal{O}(10^{-5})$
- τ's generally require special techniques due to the presence of missing energy and lack of a distinctive signature

B-tagging is commonly used (full reconstruction of one B)

$B^0 \to \tau\ell$ SEARCH



N_{BB} = 772 x 10⁶

Reminder

$$E^*_{B_{tag}} = E^*_{B_{sig}} = \sqrt{s}/2$$
$$\vec{p}^{\,*}_{B_{tag}} = -\vec{p}^{\,*}_{B_{sig}}$$

@ B-factories we exploit the knowledge of the initial 4-momentum

Beam energy transferred to $B\overline{B}$ pair:

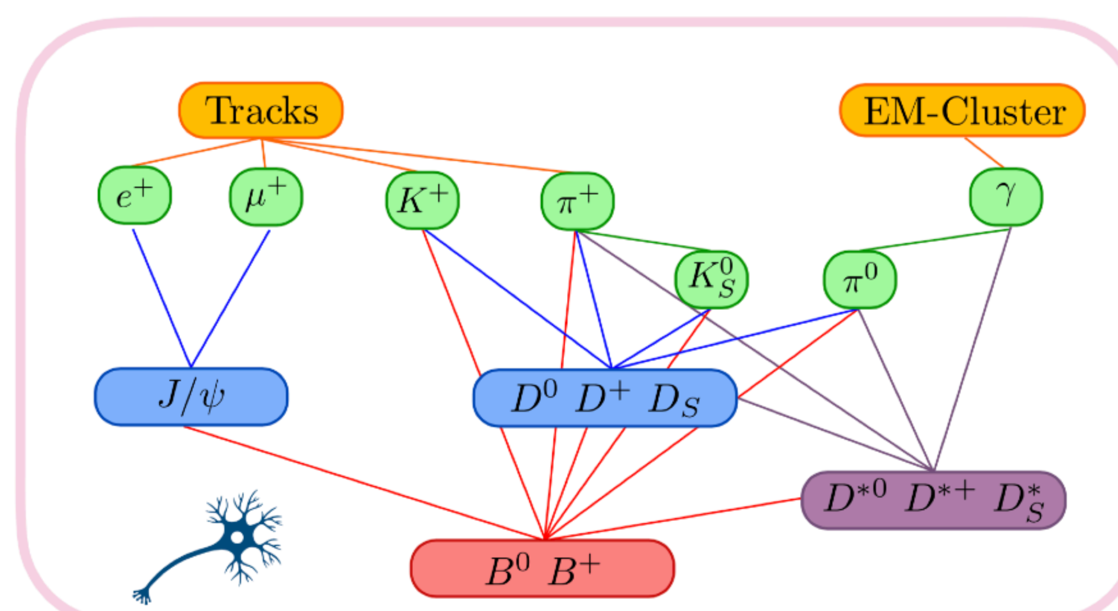
$$e^+e^- \to \Upsilon(4S) \to B_{sig}\overline{B}_{tag}$$

Full reconstruction of one of the B and look for signal signature in the other B $\leftrightarrow$ the 4-momentum of the τ

$$M^2_{miss} = [(\sqrt{s}, \mathbf{0}) - (E^*_B, \vec{\mathbf{p}}^{\,*}_B) - (E^*_\ell, \vec{\mathbf{p}}^{\,*}_\ell)]^2$$

* **F**ull **R**econstruction (Belle tagging algorithm)

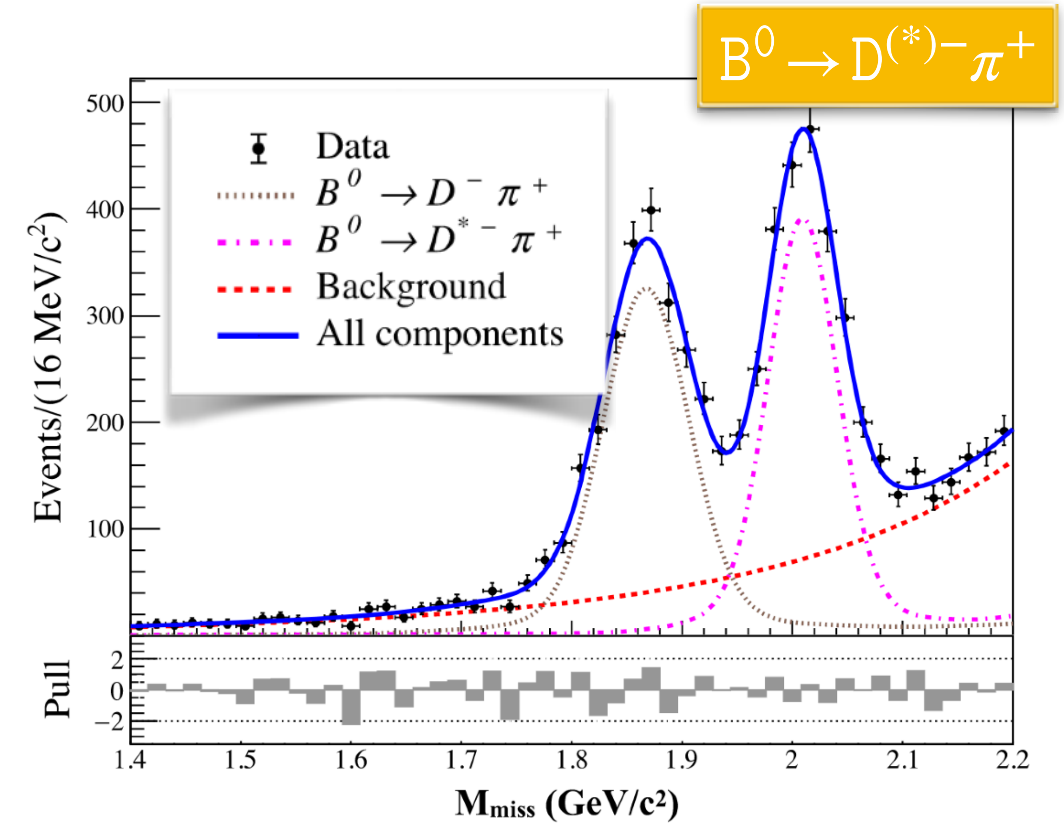
- Hadronic B-modes are reconstructed in a hierarchical approach
- 1104 decay cascades
- Use of neural networks
- Typical efficiencies 0.28% (0.18%) for B^+ (B^0)



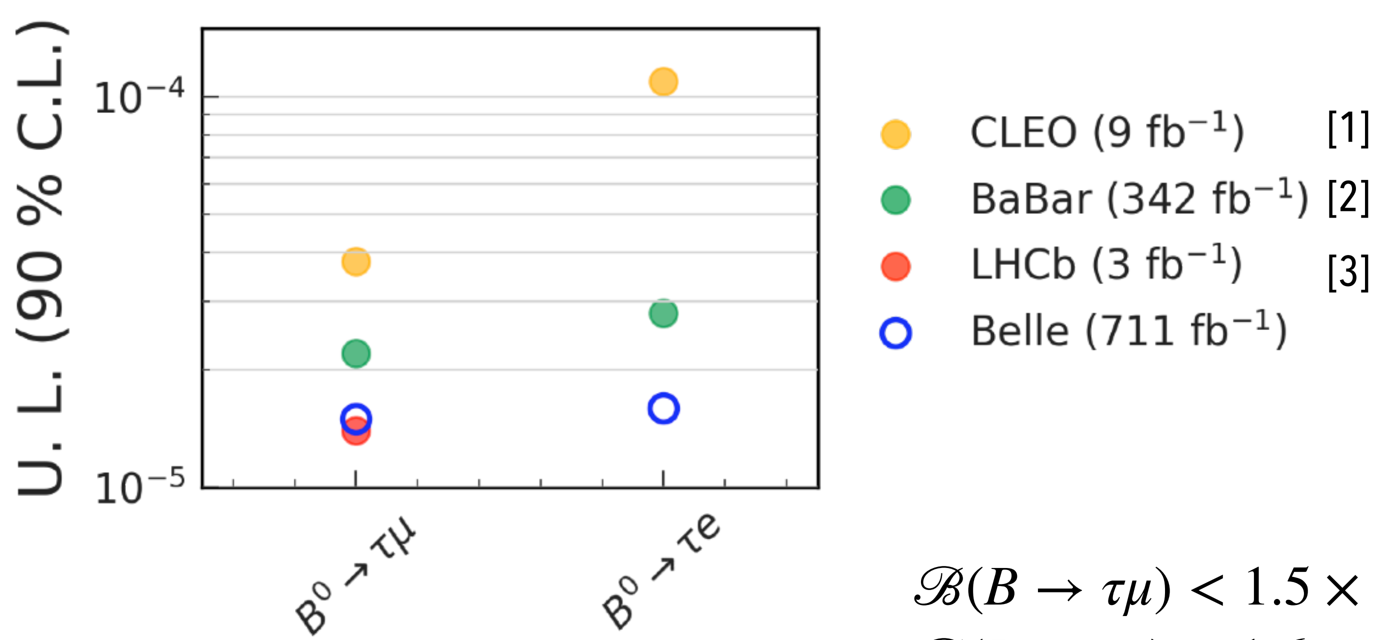
FR: 1102.3876

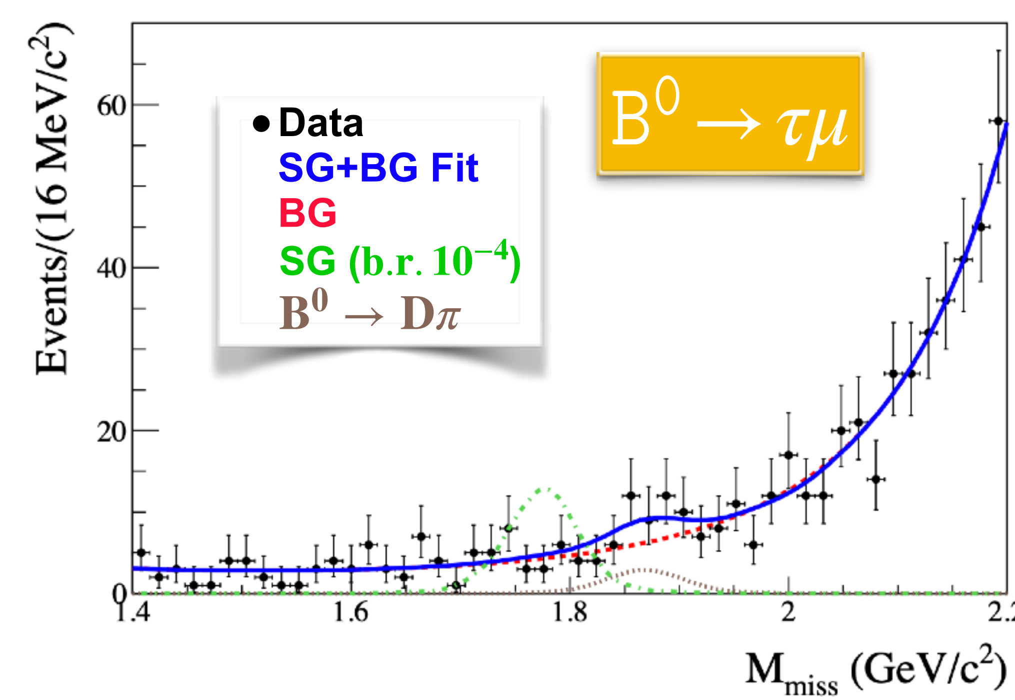
$B^0 \to \tau\ell$ SEARCH

- $B_{tag}\ell$ with $M_{miss} \in [1.4, 2.2]$ GeV/c^2
- (Smooth) Background mainly from $b \to cW^*/u\ell\nu$
- Peaking background due to $B^0 \to D^{(*)-}\pi^+$ in $\tau\mu$ channel
- $B^0 \to D^{(*)-}\pi^+$ as control sample. Reconstruct π^+ instead of leptons. High efficiency because of high b.r. .
  Used to determine correction factors for data fit (LFV case)



- Unbinned extended ML fit to M_{miss} distribution





$\mathscr{B}(B \to \tau\mu) < 1.5 \times 10^{-5}$
$\mathscr{B}(B \to \tau e) < 1.6 \times 10^{-5}$ Best limit

[1] → [PRL 93, 241802 (2004)]
[2] → [PRD 77, 091104(R) (2008)]
[3] → [PRL 123, 211801 (2019)]

LFU TEST IN Ω_c DECAYS

- Theoretical predictions of $\mathscr{B}(\Omega_c^0 \to \Omega^- \ell^+ \nu_\ell)$ are uncertain
- Only previous observation of $\Omega_c^0 \to \Omega^- e^+ \nu_e$ was performed by CLEO PRL.89.171803

The study of charmed baryon decays is statistically limited due to low production rates and/or high background

Search for Ω_c^0 from $c\bar{c}$ in the decay chain:

$$e^+e^- \to c\bar{c} \to \Omega_c^0 X$$
$$\hookrightarrow \Omega^- \ell^+ \nu_\ell$$
$$\hookrightarrow \Lambda K^-$$
$$\hookrightarrow p\pi^-$$

Background sources

1. Mis-reconstructed Ω^- (shape obtained from M_Ω sidebands)

2. BB combinatorial

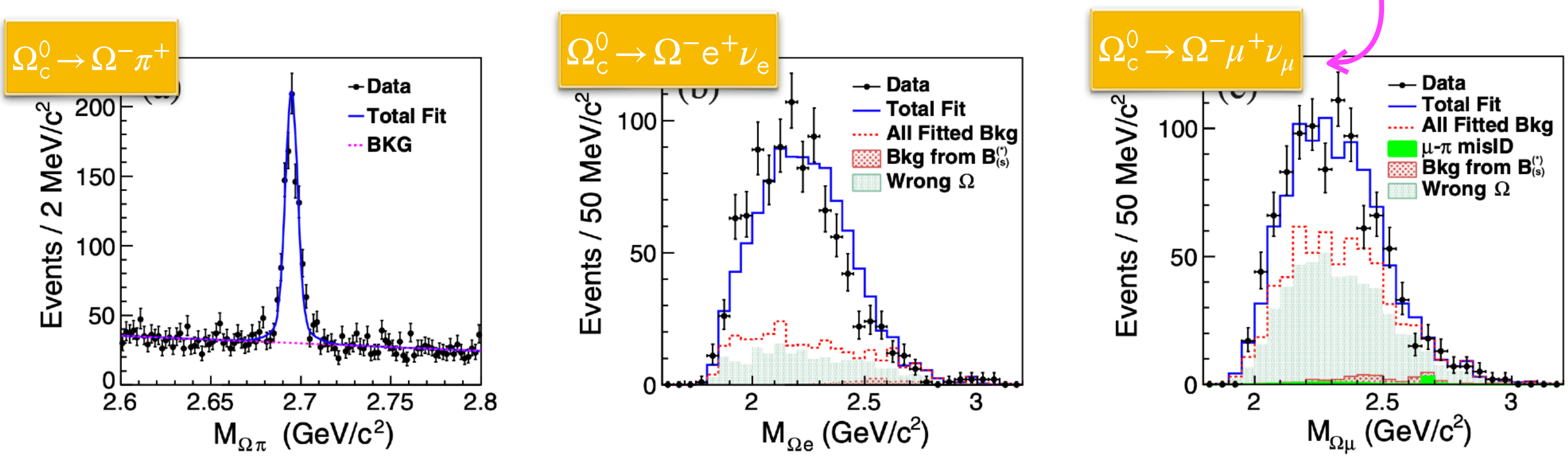
$$e^+e^- \to \Upsilon(nS) \to B_{(s)}^{(*)} \overline{B}_{(s)}^{(*)}$$
$$\ell^+ X \hookleftarrow \quad \hookrightarrow \Omega^- X$$

3. $\Omega^- \pi^+ X$ with $\mu \leftrightarrow \pi$ mis-ID

LFU TEST IN Ω_c DECAYS

Binned maximum-likelihood fits to the spectra $M_{\Omega\pi}$, $M_{\Omega e}$, $M_{\Omega\mu}$

First observation!



The significances for the $\Omega_c^0 \to \Omega^- \ell^+ \nu_\ell$ modes are both larger than 10σ

$$\frac{\mathscr{B}(\Omega_c^0 \to \Omega^- e^+ \nu_e)}{\mathscr{B}(\Omega_c^0 \to \Omega^- \mu^+ \nu_\mu)} = 1.02 \pm 0.10(\mathrm{stat}) \pm 0.02(\mathrm{syst})$$

Agrees with the expectation of LFU !

This ratio will help constraining the parameters of phenomenological models and lattice QCD calculations
More inputs will be given from absolute b.r. measurements

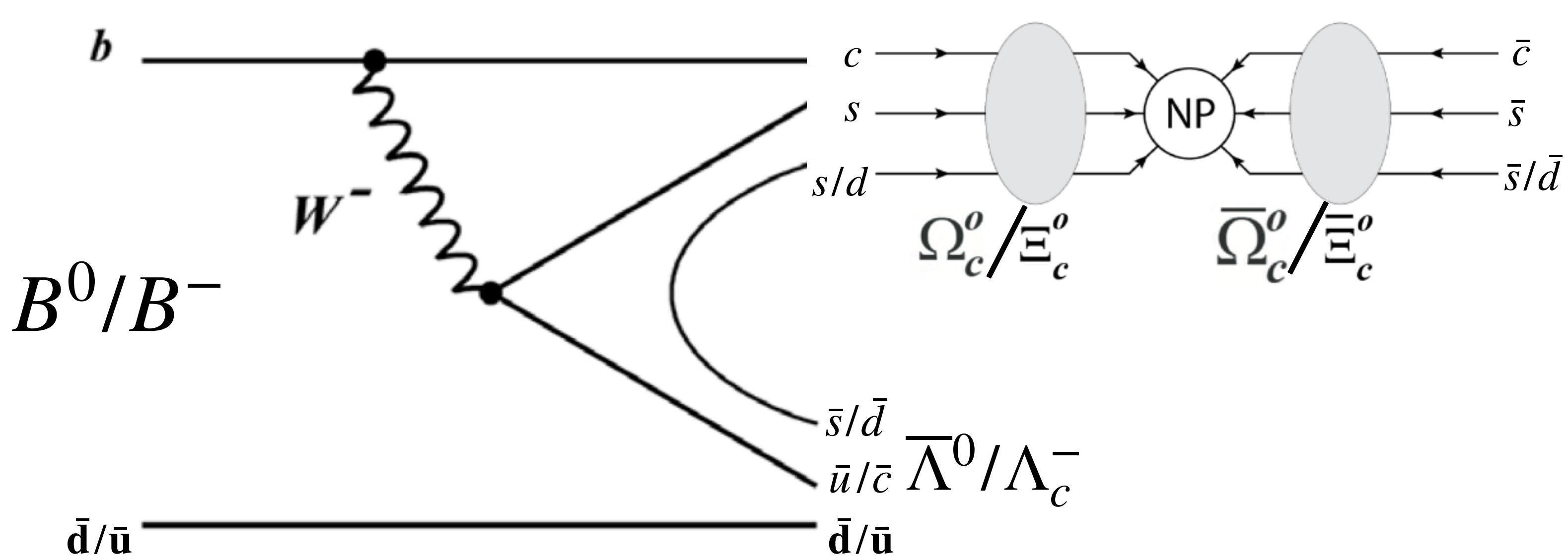
BARYON STUDIES

Baryonic B decays can be used to search for

1. Baryon Number Violation (BNV)

CP violation as described in SM does not explain the matter-antimatter asymmetry, which is at the basis of baryogenesis. One of the conditions for baryogengesis is BNV (A. Sakharov)

Theory suggests that baryon number violation could arise from charmed baryon oscillations
→ study it via decays of B mesons

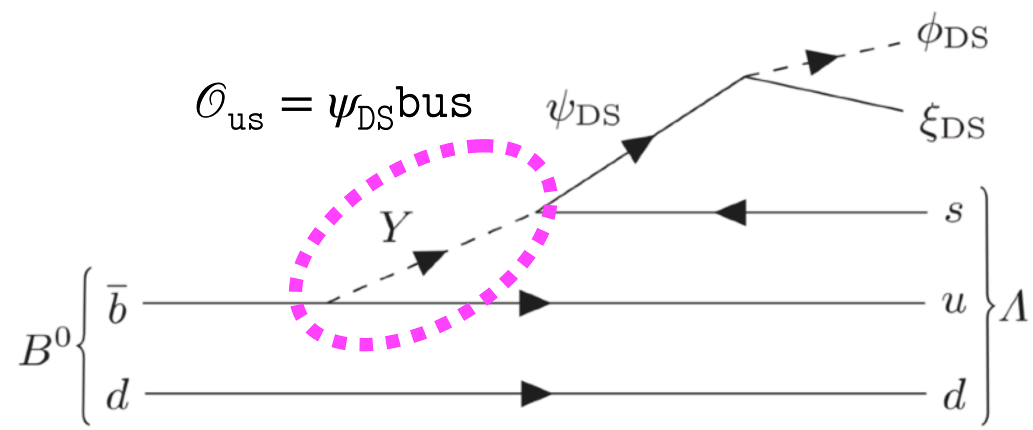


Expected sensitivities of $B^0 \rightarrow \bar{\Lambda}^0 \Omega_c^{(*)0}$ and $B^- \rightarrow \Lambda_c^- \Xi_c^0$ ~(2-5) x 10^{-5} (from MC studies)

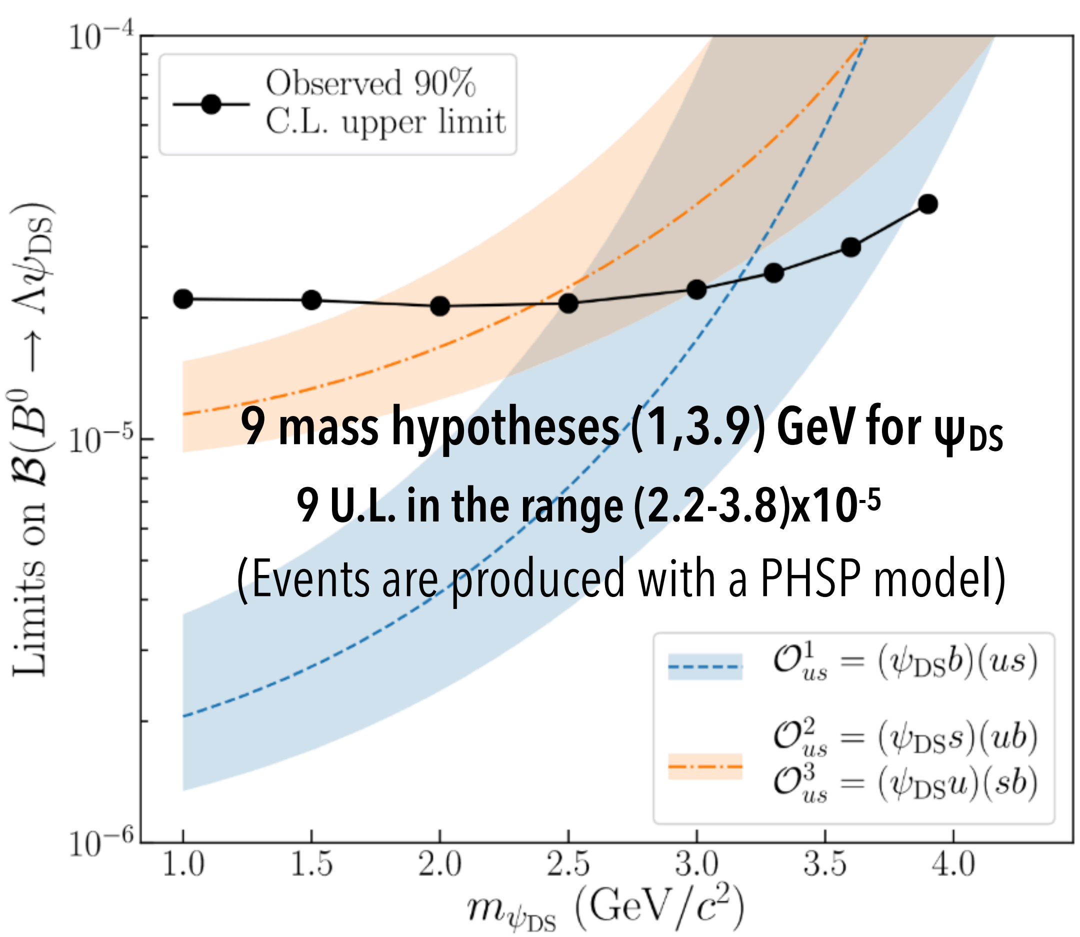
BARYON STUDIES

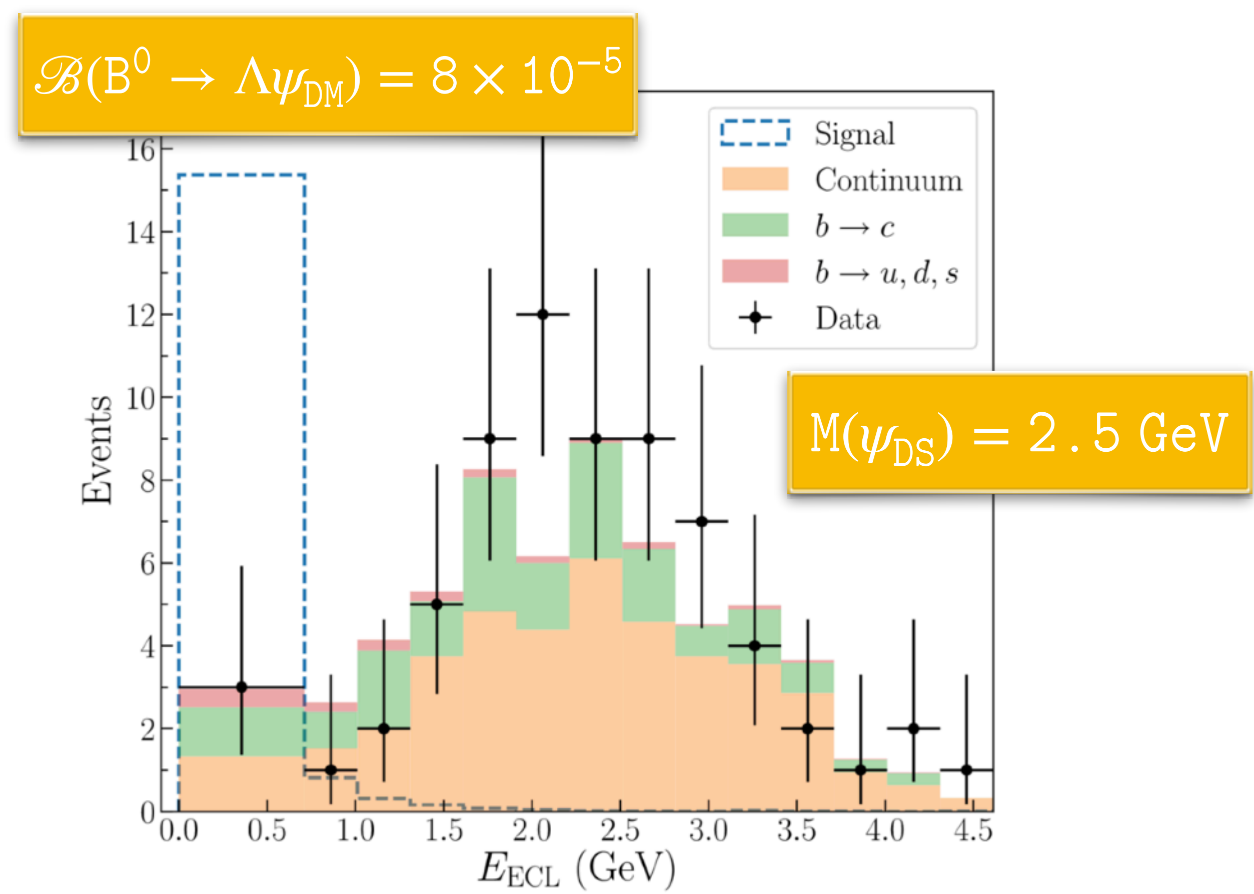
Baryonic B decays can be used to search for

1. Baryon Number Violation (BNV)
2. Dark Matter (DM)



- Current bound from ALEPH's input: $\mathscr{B}(B^0 \to \Lambda\psi_{DS}) \lesssim 2\times10^{-4}$ [Alvarez, Elor, Escudero PRD 104.035028]
- B_{tag} candidates are reconstructed in hadronic channels using the **F**ull **E**vent **I**nterpretation (Belle II tagging algorithm)





Sum of the energies of ECL clusters that are not associated with the reconstructed B_{tag} + Λ candidates

FEI: Comput Softw Big Sci 3, 6 (2019)

SUMMARY

Belle is still delivering physics results which are sensitive to BSM

- LFV in Υ, B

  First U.L.'s for $\Upsilon(1S) \to (\gamma)\ell\ell'$

  First Search for $B^0 \to \tau\ell$ @ Belle (U.L. $\mathcal{O}(10^{-5})$)

- Baryon sector: LFU, BNV

  $\Omega_c \to \Omega^- \ell^+ \nu_\ell$ First observation for $\ell = \mu$

  $B^0 \to \Lambda\psi_{DS}$ Best limits

Soon from Belle

- More LFV test in B decays
- Ω_c^0, Ξ_c^0 oscillations (BNV)

Belle II

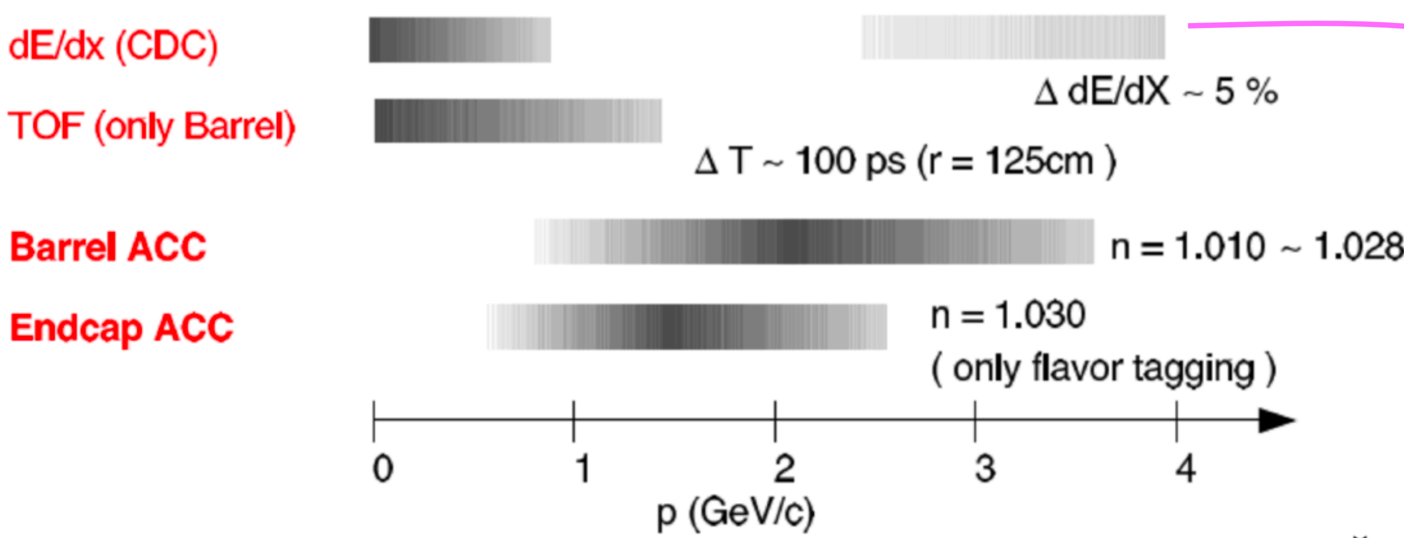
- Larger datasize (x50)
- Improved B-tagging

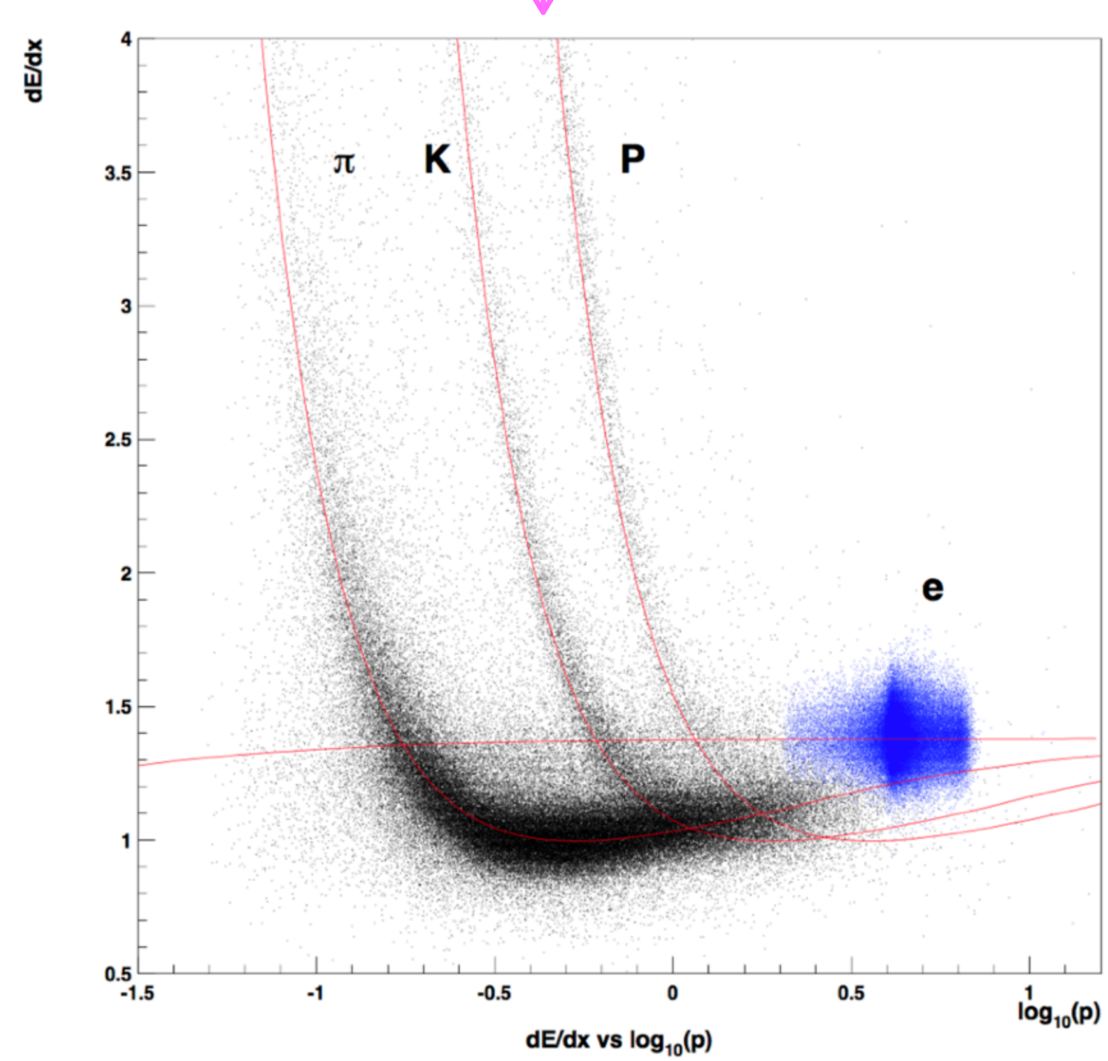
Thank you for your attention!

Grazie ☺️

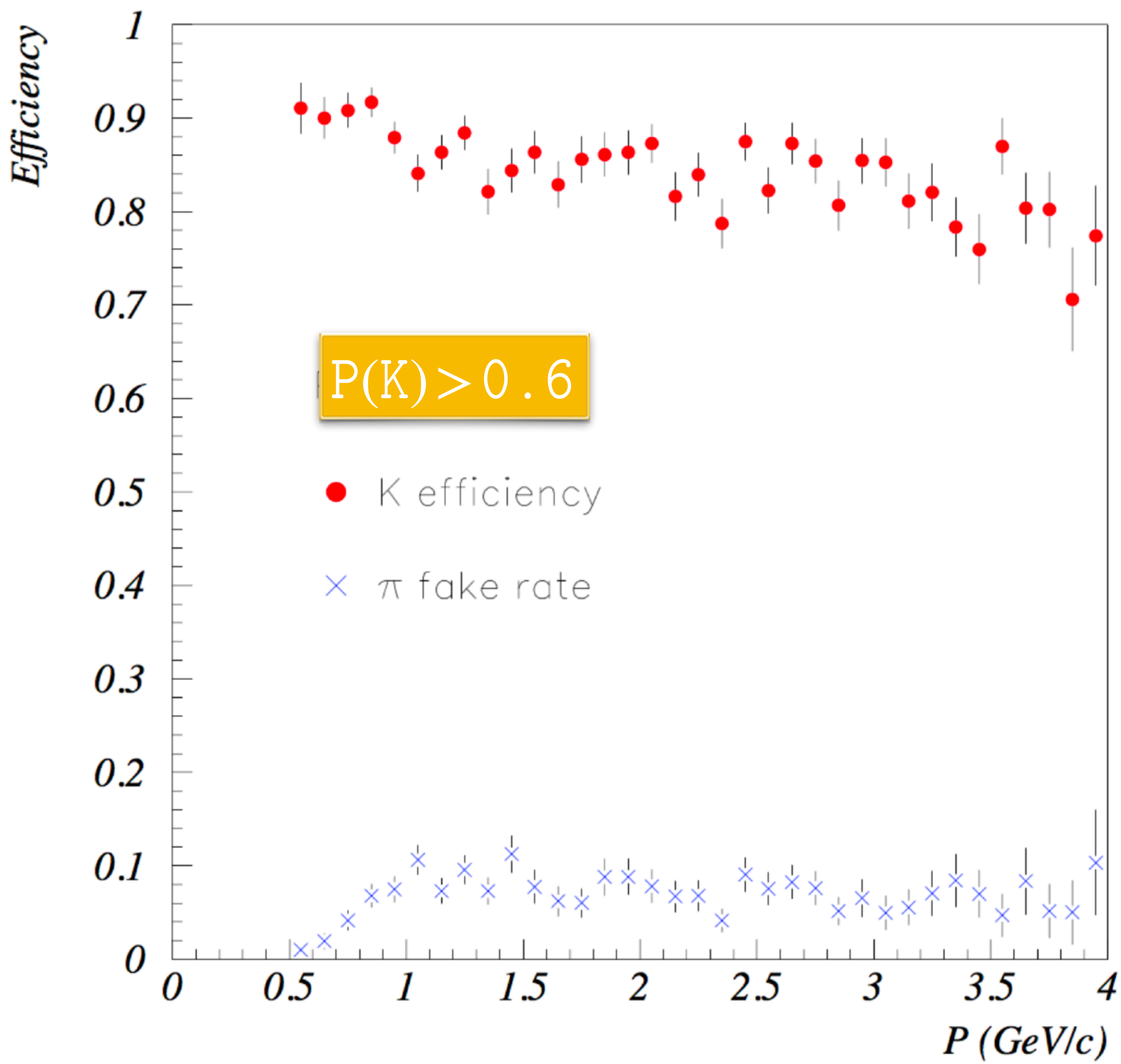
Additional Material

PID PERFORMANCE - I





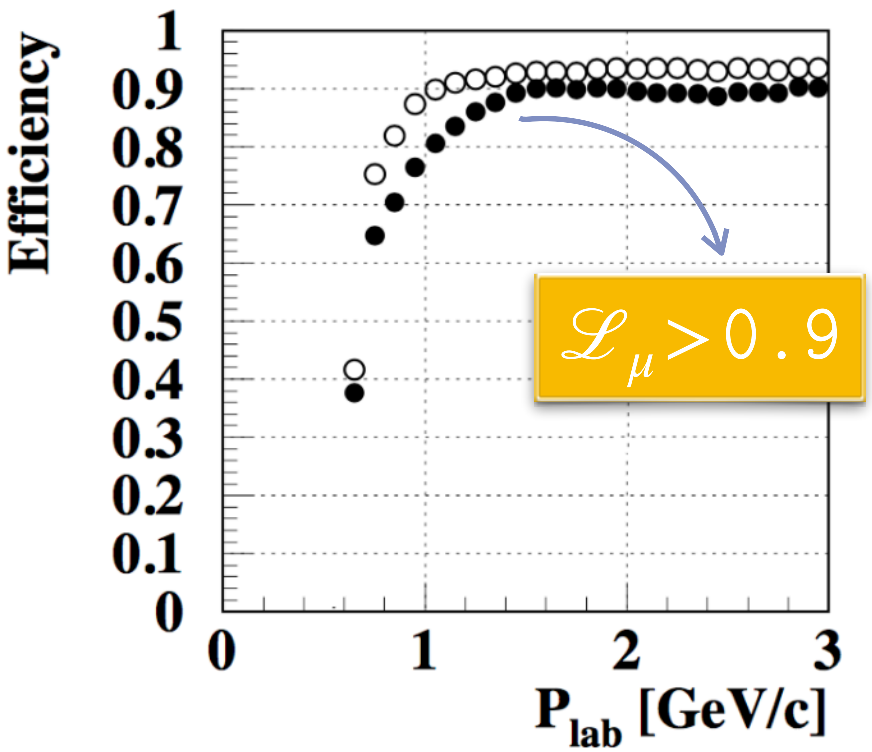
PID PERFORMANCE - II

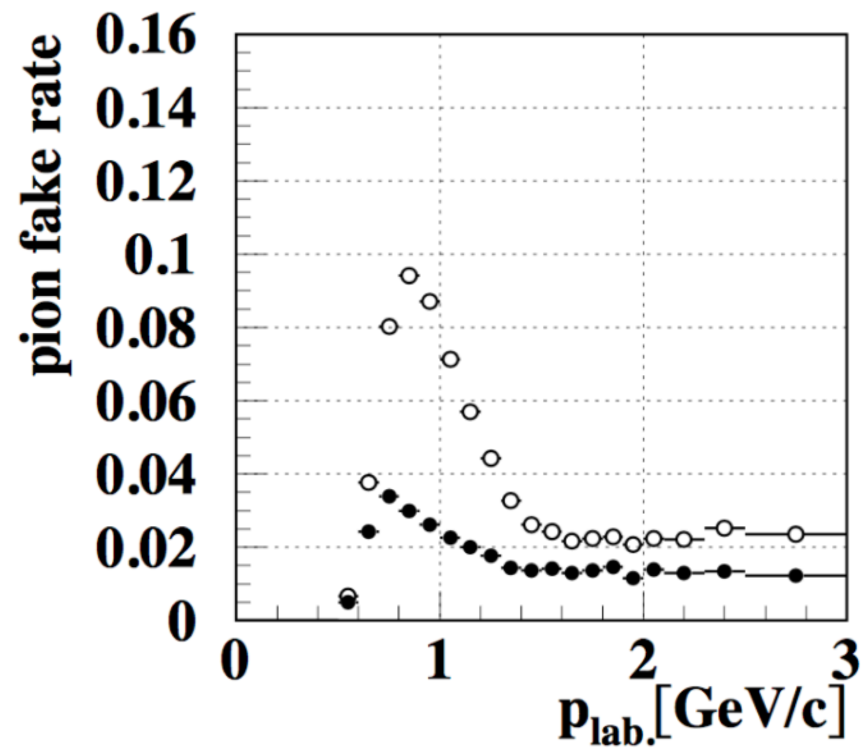


$\mathscr{R}(\mathrm{K}) > 0.6$:

- Efficiency: ~90%
- Pion fake rate: ~7%

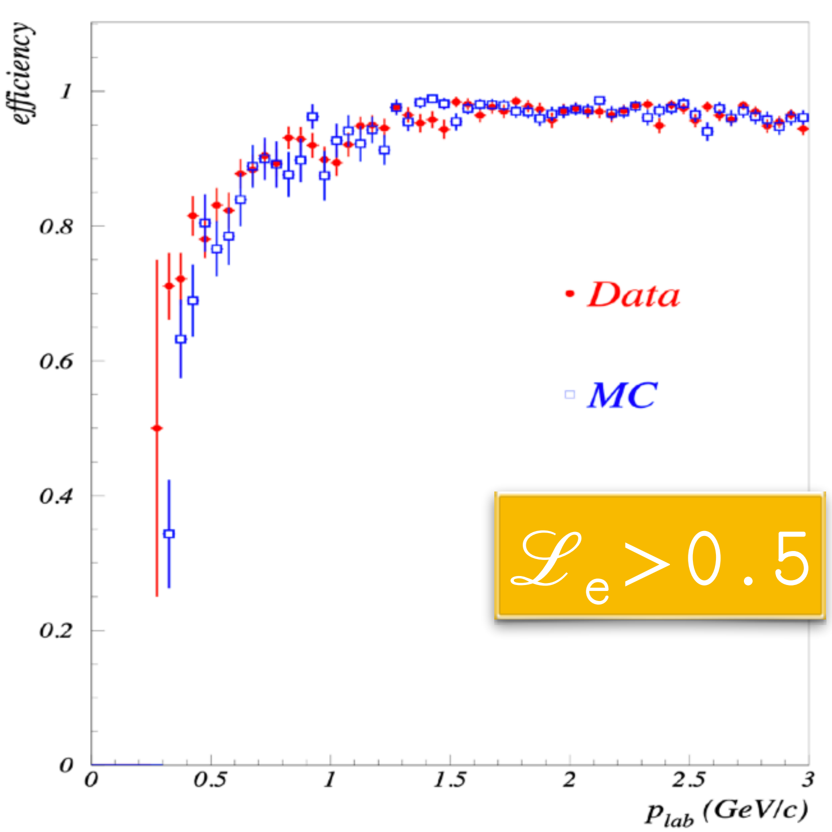
PID PERFORMANCE - III

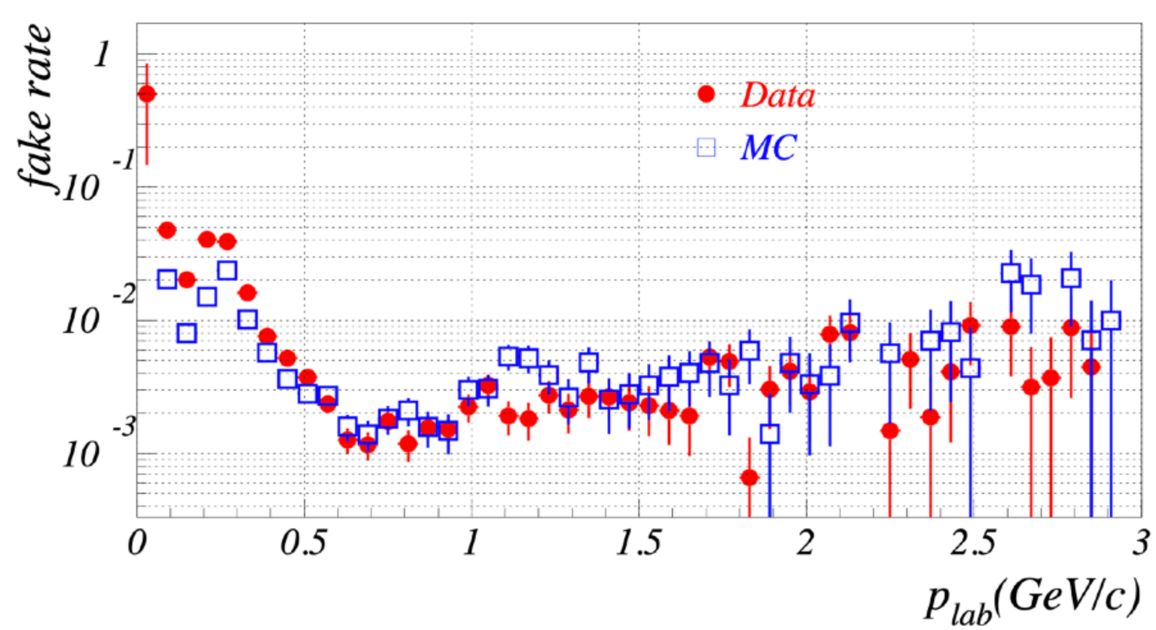




$\mathscr{L}_\mu > 0.9$:

- Efficiency: ~89%
- Pion fake rate: ~2%



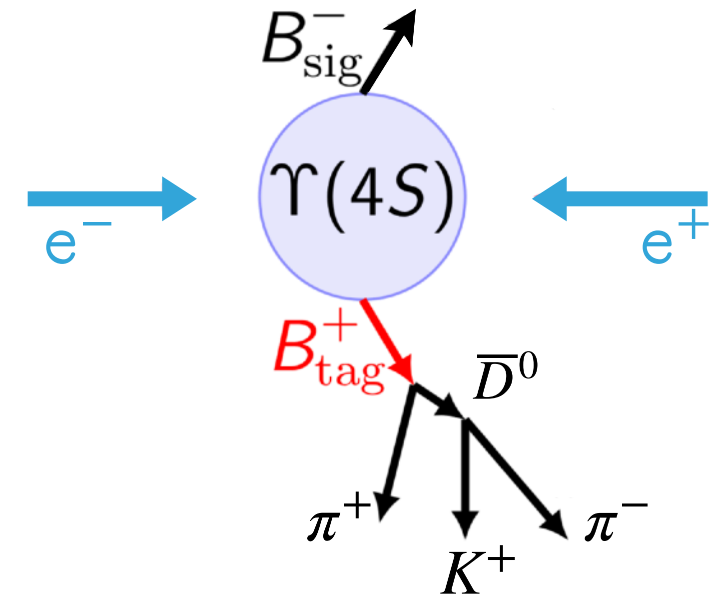


$\mathscr{L}_e > 0.9$:

- Efficiency: ~93%
- Pion fake rate: ~0.3%

FEI PERFORMANCE

Tagging efficiency: the fraction of Υ(4S) events which can be tagged)
Tag-side efficiency: the fraction of Υ(4S) events with a correct tag
Tag-side purity: the fraction of the tagged Υ(4S) events with a correct tag

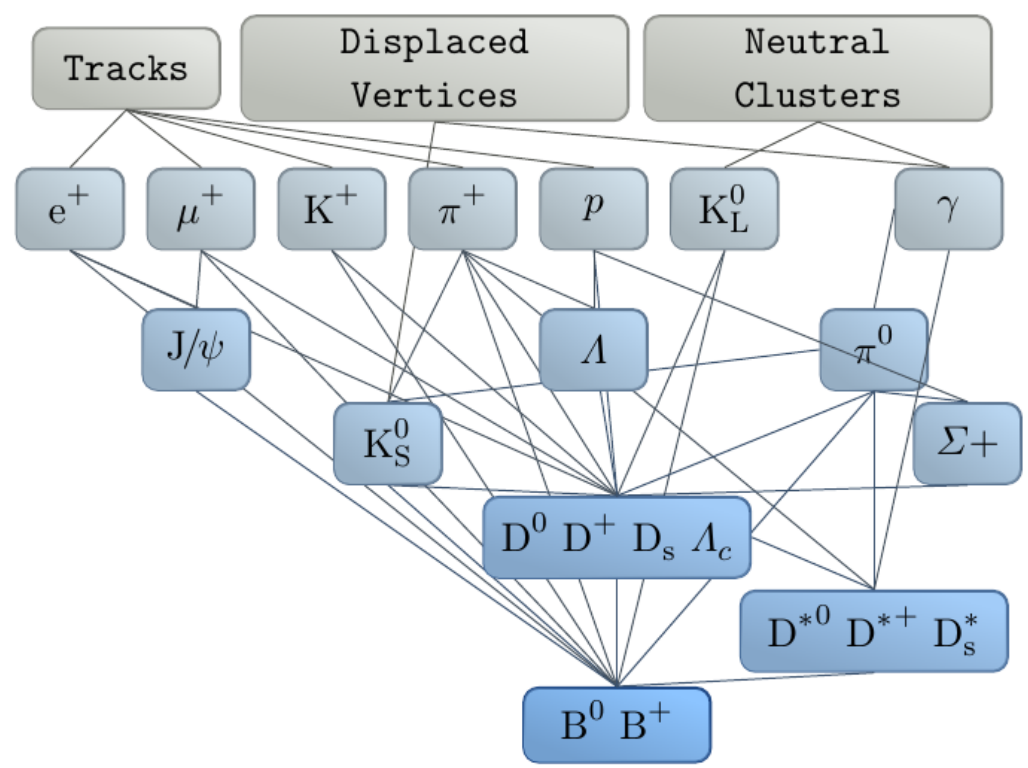


	$B^{\pm}$	B^0
Hadronic		
FEI with FR channels	0.53 %	0.33 %
FEI	0.76 %	0.46 %
FR	0.28 %	0.18 %
SER	0.4 %	0.2 %
Semileptonic		
FEI	1.80 %	2.04 %
FR	0.31 %	0.34 %
SER	0.3 %	0.6 %

~10% purity (Hadronic)

~5% purity (Semileptonic)

arXiv:hep-ex/1807.08680v4



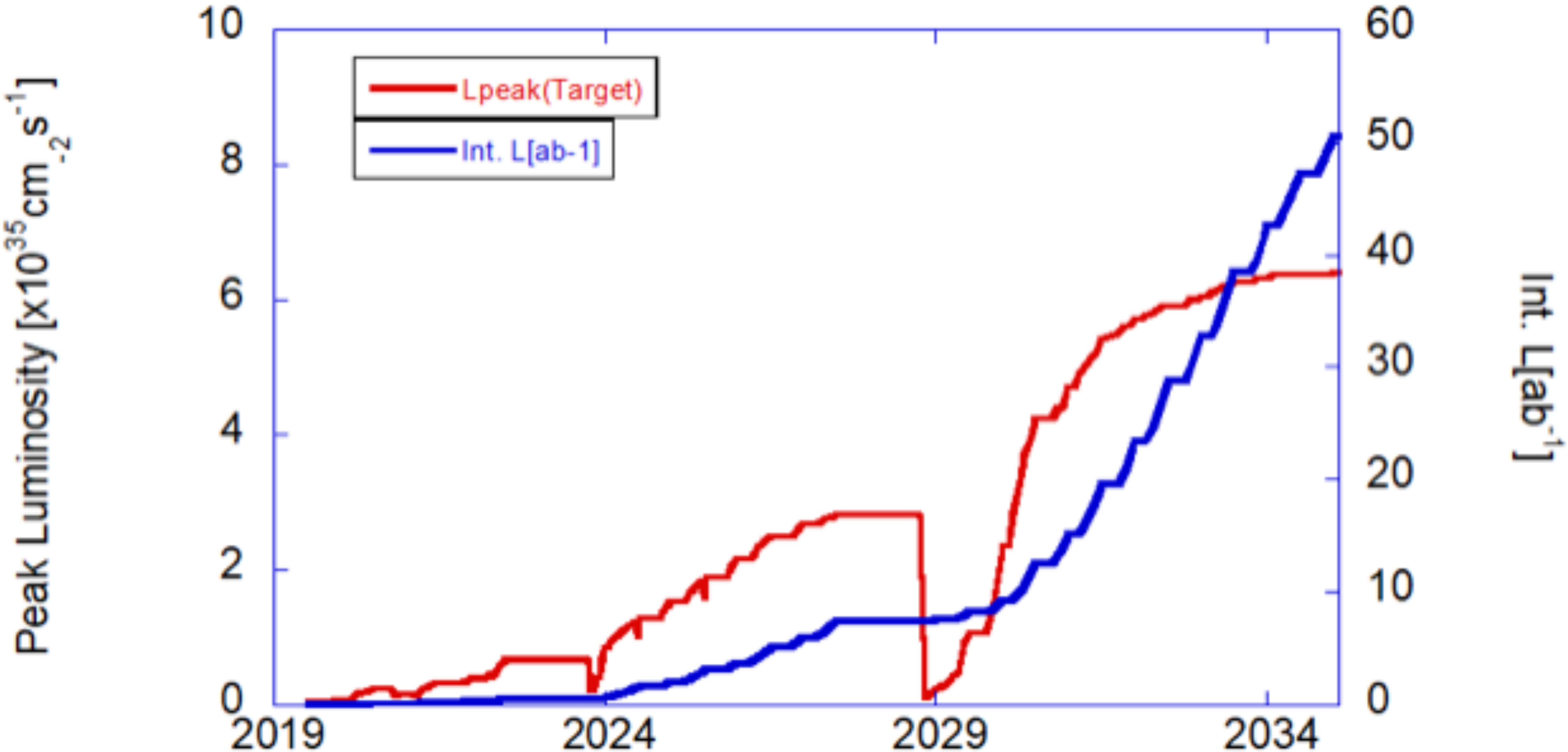
PhysRevD.91.113013

$V \to \ell\ell'$ PREDICTIONS

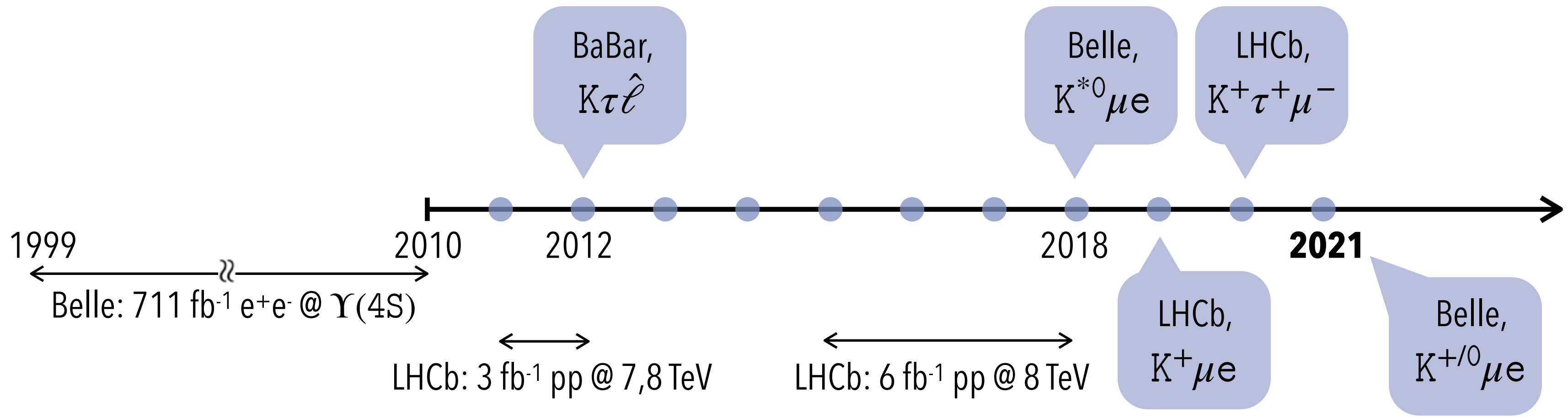
V	$\ell_\alpha\ell_\beta$	$m_4 = 1$ TeV	10 TeV	100 TeV	$m_5 = 1$ TeV	10 TeV	100 TeV
ϕ	$e\mu$	1×10^{-24}	5×10^{-24}	3×10^{-24}	1×10^{-23}	6×10^{-23}	5×10^{-23}
J/ψ	$e\mu$	2×10^{-21}	3×10^{-20}	6×10^{-21}	2×10^{-20}	9×10^{-20}	7×10^{-20}
	$e\tau$	5×10^{-18}	8×10^{-17}	2×10^{-19}	1×10^{-19}	3×10^{-18}	1×10^{-19}
	$\mu\tau$	8×10^{-18}	6×10^{-16}	3×10^{-20}	4×10^{-19}	4×10^{-18}	8×10^{-19}
$\psi(2S)$	$e\mu$	9×10^{-22}	1.5×10^{-20}	3×10^{-21}	4×10^{-21}	3×10^{-20}	2×10^{-20}
	$e\tau$	5×10^{-18}	2×10^{-17}	9×10^{-21}	4×10^{-20}	1×10^{-18}	4×10^{-20}
	$\mu\tau$	8×10^{-18}	3×10^{-17}	1.2×10^{-20}	1×10^{-19}	1×10^{-18}	2×10^{-19}
Υ	$e\mu$	7×10^{-18}	2×10^{-17}	6×10^{-18}	2×10^{-19}	2×10^{-17}	2×10^{-17}
	$e\tau$	5×10^{-14}	2×10^{-13}	9×10^{-17}	6×10^{-18}	4×10^{-16}	5×10^{-17}
	$\mu\tau$	5×10^{-16}	2.5×10^{-13}	1.2×10^{-16}	1×10^{-17}	8×10^{-16}	3×10^{-16}
$\Upsilon(2S)$	$e\mu$	5×10^{-18}	5×10^{-18}	1.5×10^{-18}	2×10^{-19}	2×10^{-17}	2×10^{-17}
	$e\tau$	1.8×10^{-14}	3×10^{-14}	3×10^{-18}	8×10^{-18}	5×10^{-16}	5×10^{-17}
	$\mu\tau$	2×10^{-16}	2×10^{-13}	2×10^{-17}	2×10^{-17}	8×10^{-16}	3×10^{-16}
$\Upsilon(3S)$	$e\mu$	1.5×10^{-17}	3×10^{-17}	1.5×10^{-17}	5×10^{-19}	5×10^{-17}	4×10^{-17}
	$e\tau$	5.5×10^{-14}	3×10^{-14}	4×10^{-17}	2×10^{-17}	1×10^{-15}	1×10^{-16}
	$\mu\tau$	2×10^{-15}	2×10^{-12}	4×10^{-17}	3×10^{-17}	2×10^{-15}	6×10^{-16}
Z	$e\mu$	1.2×10^{-14}	7×10^{-13}	4×10^{-13}	9×10^{-14}	8×10^{-13}	6×10^{-13}
	$e\tau$	2×10^{-10}	9×10^{-9}	4×10^{-13}	7×10^{-13}	4×10^{-11}	2×10^{-12}
	$\mu\tau$	5.5×10^{-10}	3.5×10^{-8}	1.6×10^{-12}	3×10^{-12}	6×10^{-11}	1×10^{-11}

Table 1: Upper bound on $B(V \to \ell_\alpha\ell_\beta)$ for three values of the mass $m_{4,5}$. The numbers in three column referring to m_4 are obtained by using the effective model discussed in the text, while the other three, referring to m_5, are results of the (2,3)-ISS model (also discussed in the text).

BELLE II LUMINOSITY PLAN



EXPERIMENTAL STATUS



	Mode	U.L. (90% CL)	Exp.	
	$B^+ \to K^+\mu^-e^+$	7.0×10^{-9}	LHCb	$3\,\mathrm{fb}^{-1}$
		3.0×10^{-8}	Belle	
	$B^+ \to K^+\mu^+e^-$	6.4×10^{-9}	LHCb	
		8.5×10^{-8}	Belle	
μ/e	$B^0 \to K^0\mu e$	3.8×10^{-8}	Belle	$711\,\mathrm{fb}^{-1}$
	$B^0 \to K^{*0}\mu^+e^-$	1.2×10^{-7}	Belle	
	$B^0 \to K^{*0}\mu^-e^+$	1.6×10^{-7}	Belle	
	$B^0 \to K^{*0}\mu e$	1.8×10^{-7}	Belle	
	$B^+ \to K^+\tau\mu$	4.8×10^{-5}	BaBar	$433\,\mathrm{fb}^{-1}$
τ/ℓ	$B^+ \to K^+\tau e$	3.0×10^{-5}	BaBar	
	$B^+ \to K^+\tau^+\mu^-$	3.9×10^{-5}	LHCb	$9\,\mathrm{fb}^{-1}$

- LFV searches containing 1st and 2nd generation leptons are often performed as ``incidental" studies along with related non-LFV modes
- Experimental limits on μ/e LFV modes ($\mathcal{O}(10^{-7})$) are more stringent than $\tau/\hat{\ell}$ ($\mathcal{O}(10^{-5})$)
- Models of LFV can produce signatures with different charge configurations ($\ell^+\ell'^-$, $\ell^-\ell'^+$) $\Rightarrow$ both limits are provided, in addition to the sum

$K^{+}\tau^{-}\ell^{+}$: **Same Sign**
$K^{+}\tau^{+}\ell^{-}$: **Opposite Sign**

$B^0 \to K^{*0} e\mu$ AT BELLE

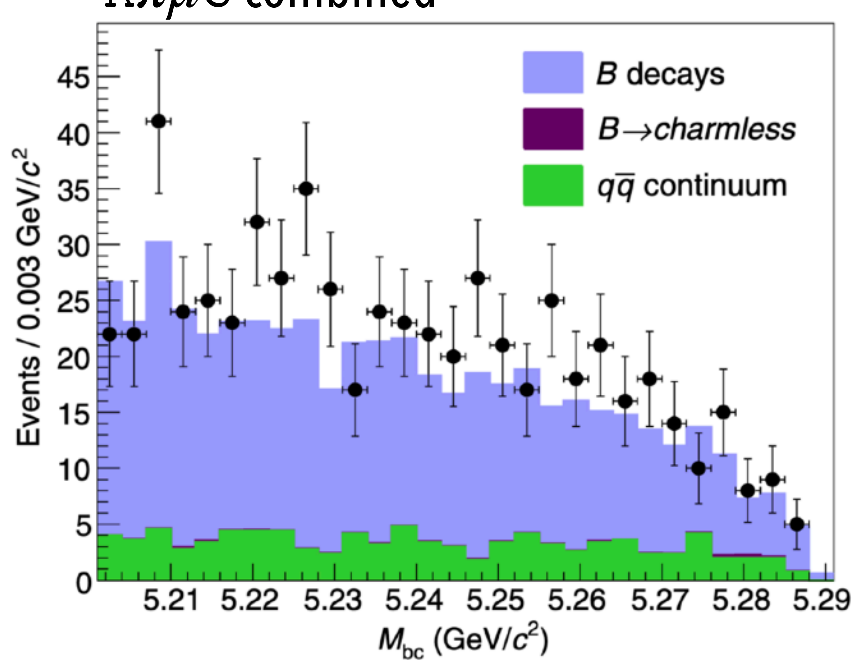
[Belle, PRD98, 0711001]

- Updated the BaBar result with ~3x larger statistics and provides the most stringent limits to date
- Vertex information of the four tracks $K\pi\mu e$
- 2 Multivariate analyzers constructed from NN
  1. Distinguish BB events from qq using event topology and flavor-tagging information of the non-signal B
  2. Reduce BB background
     - Both B's decay SL $B \to D^{(*)}(\to X\ell\nu)X\ell\nu$
     - Hadronic decay with mis-ID
- Peaking background $B^0 \to K^{*0}(\to K^+\pi^-)J/\psi(\to \ell^+\ell^-)$ (reduced with vetoes)
- **1-D** ML fit to the M_{bc} distribution

$$M_{bc} = \sqrt{(E_{beam}/c^2)^2 - (p_B^*/c)^2}$$
$$E_{beam} = \sqrt{s}/2$$

Mode	U.L. (90% CL)
$B^0 \to K^{*0}\mu^+e^-$	1.2×10^{-7}
$B^0 \to K^{*0}\mu^-e^+$	1.6×10^{-7}
$B^0 \to K^{*0}\mu e$	1.8×10^{-7}

$K\pi\mu e$ combined



$B \to K e \mu$ AT BELLE

Mode	U.L. (90% CL)
$B^+ \to K^+ \mu^+ e^-$	8.5×10^{-8}
$B^+ \to K^+ \mu^- e^+$	3.0×10^{-8}
$B^0 \to K^0 \mu e$	3.8×10^{-8}

[Belle, 1908.01848]

- Come as a by-product of LFU tests and benefit from $R_{K^{(*)}}$ measurements updates/improvements
- Both neutral and charged B's $\Rightarrow K = K^+, K^0_S$
- Similar background as for $B \to K^* \mu e$, suppressed via a single NN with output $\mathcal{O}$
- D^0 and J/ψ vetoes applied
- **3-D** ML fit to the M_{bc}, ΔE, and $\mathcal{O}'$ distributions
- Use 89 fb^{-1} off-resonance data (60 MeV below $\Upsilon(4S)$) to constrain yields from continuum processes ($q\bar{q}, \tau^+\tau^-$)

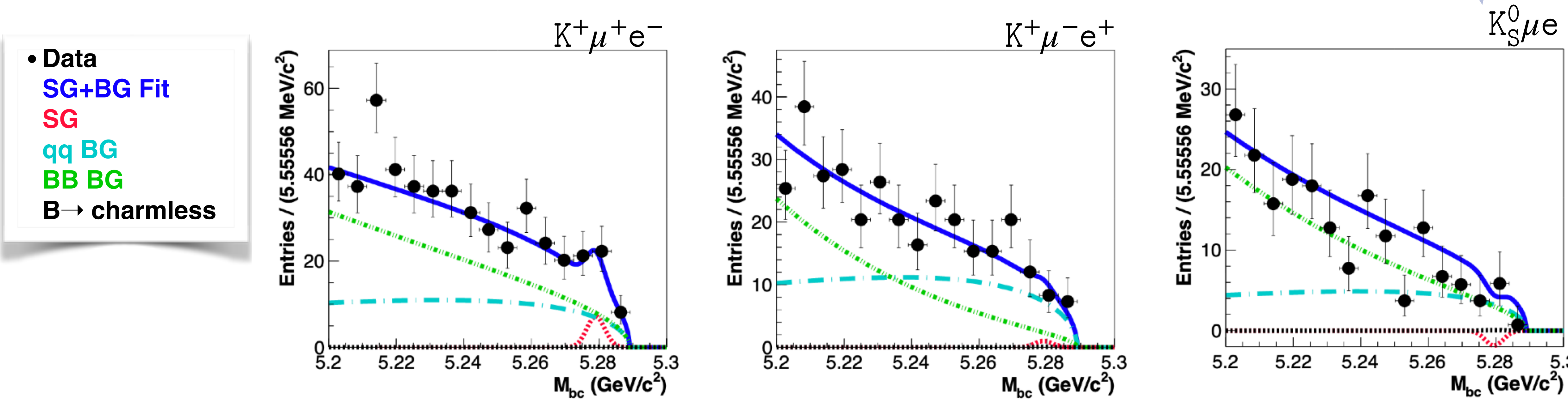
$$M_{bc} = \sqrt{(E_{beam}/c^2)^2 - (p^*_B/c)^2}$$

$$\Delta E = E^* - E_{beam}$$

$$E_{beam} = \sqrt{s}/2$$

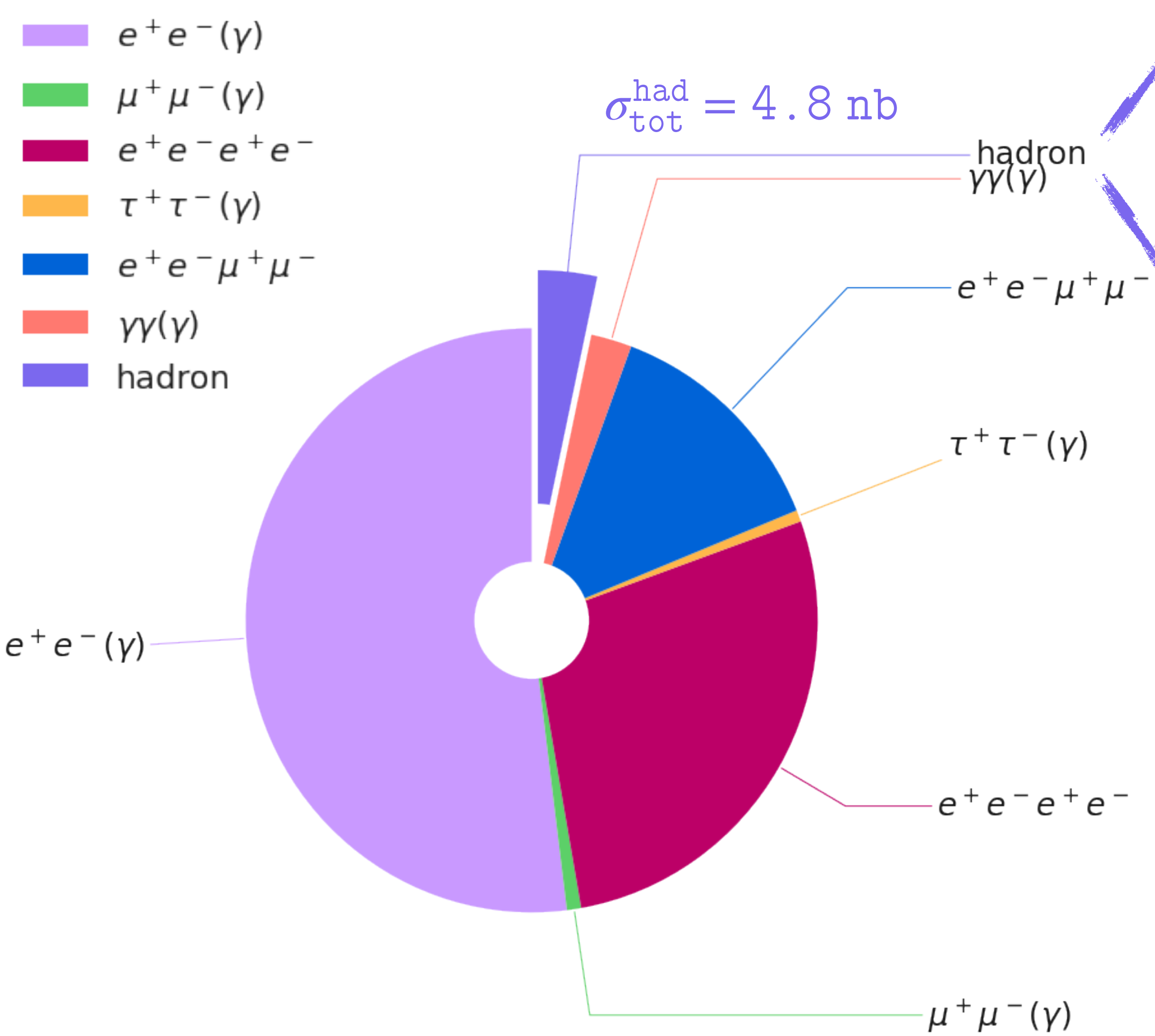
$$\mathcal{O}' = \log\left[\frac{\mathcal{O} - \mathcal{O}_{min}}{\mathcal{O}_{max} - \mathcal{O}}\right]$$

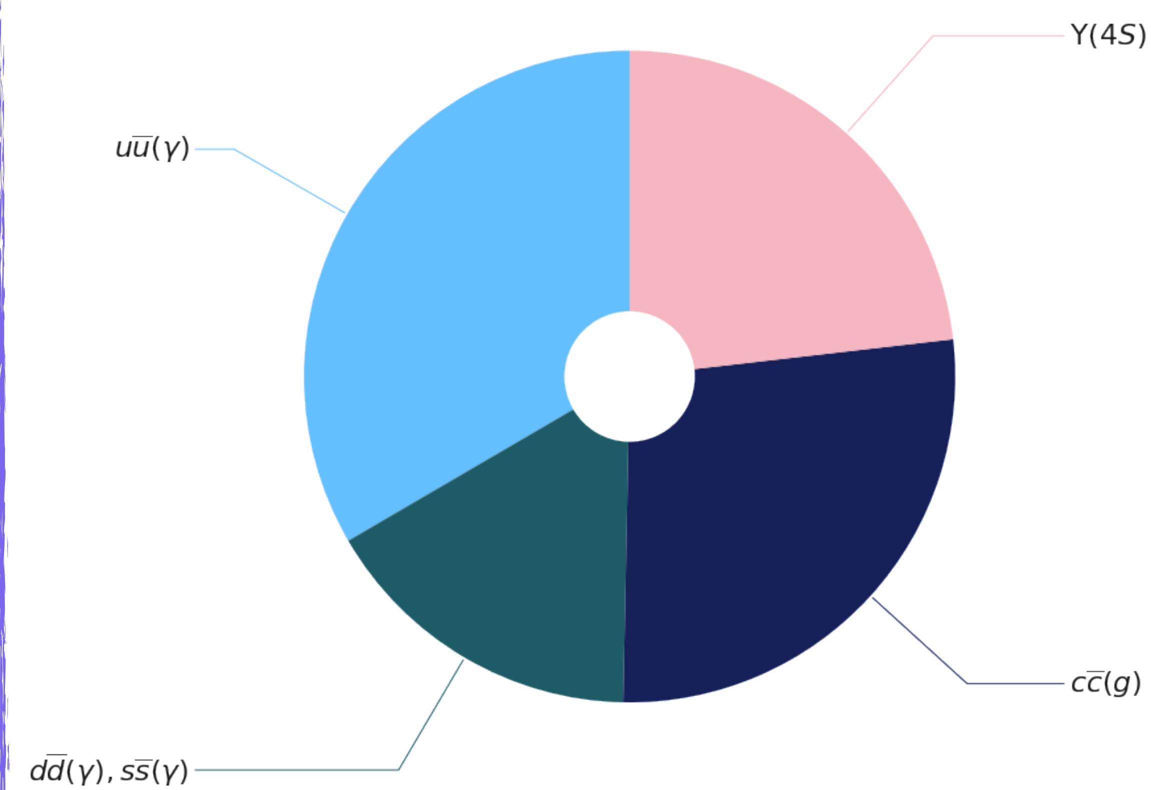
Potential of neutral modes with K^0_S - clean and strength of B-factories

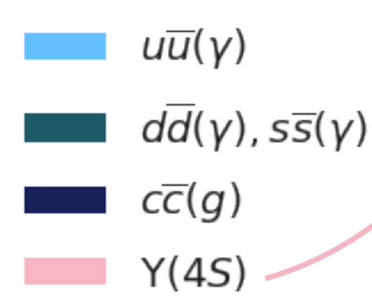


e^+e^- PRODUCTS *at $\sqrt{s}$ = 10.58 GeV*

$\sigma_{\mathrm{tot}}^{\mathrm{had}} = 4.8$ nb



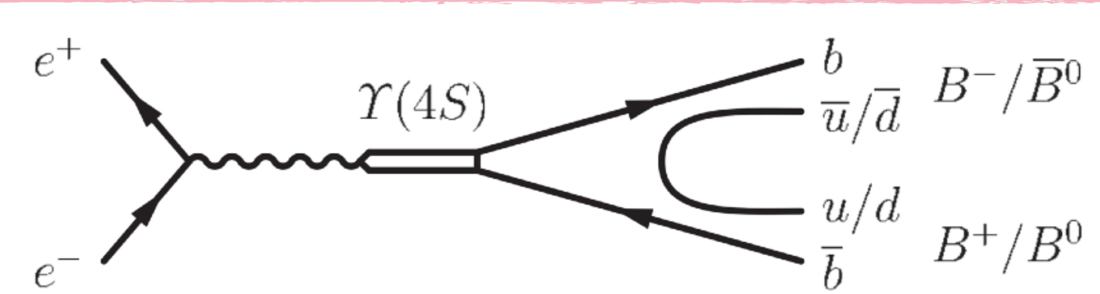


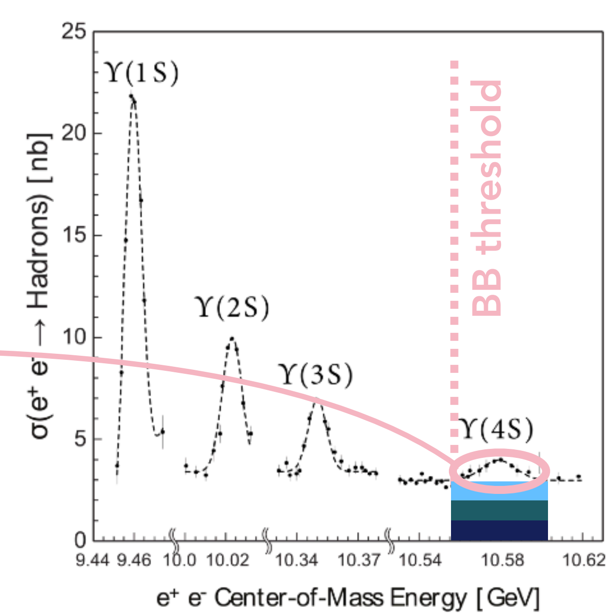


$\mathscr{B}(\Upsilon(4S) \to B\bar{B}) > 96\,\%$

$(\sigma = 1.1$ nb$)$

$\sigma_{b\bar{b}}/\sigma_{\mathrm{had}} \sim 1/4$

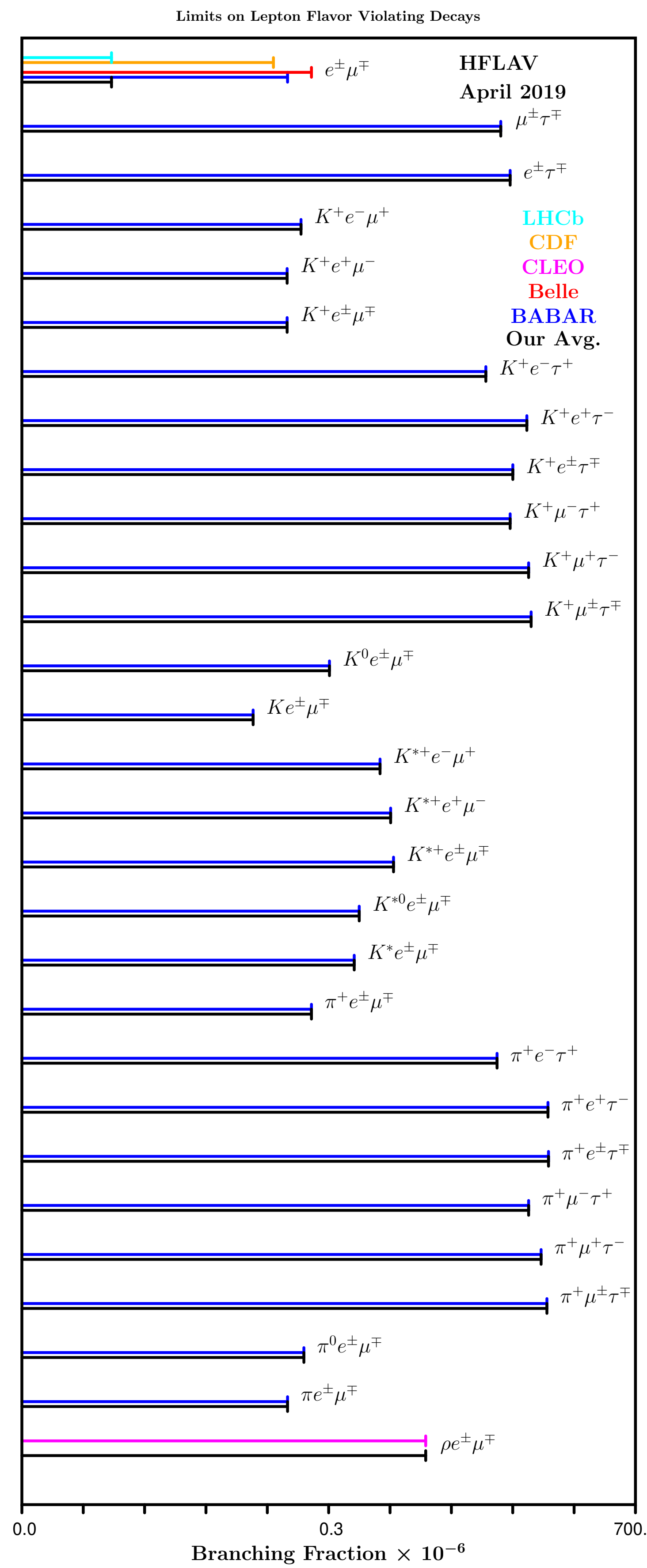




TABLES

Decay Mode	$N_{B\overline{B}}$ (10^6)	$\mathcal{B}$ upper limit (90% C.L.)
Lepton flavor violating modes (light flavors):		
$B^0 \to \mu^\pm e^\mp$	85	17×10^{-8}
$B^0 \to \mu^\pm e^\mp$	384	9.2×10^{-8}
$B^+ \to \pi^+\mu^\pm e^\mp$	230	17×10^{-8}
$B^0 \to \pi^0\mu^\pm e^\mp$		14×10^{-8}
$B \to \pi\mu^\pm e^\mp$		9.2×10^{-8}
$B^+ \to K^+\mu^- e^+$	229	9.1×10^{-8}
$B^+ \to K^+\mu^+ e^-$		13×10^{-8}
$B^+ \to K^+\mu^\mp e^\pm$		9.1×10^{-8}
$B^0 \to K^0\mu^\mp e^\pm$		27×10^{-8}
$B \to K\mu^\mp e^\pm$		3.8×10^{-8}
$B^+ \to K^{*0}\mu^- e^+$		53×10^{-8}
$B^+ \to K^{*0}\mu^+ e^-$		34×10^{-8}
$B^+ \to K^{*0}\mu^\mp e^\pm$		58×10^{-8}
$B^+ \to K^{*+}\mu^- e^+$		130×10^{-8}
$B^+ \to K^{*+}\mu^+ e^-$		99×10^{-8}
$B^+ \to K^{*+}\mu^\mp e^\pm$		140×10^{-8}
$B \to K^*\mu^\mp e^\pm$		51×10^{-8}

Decay Mode	$N_{B\overline{B}}$ (10^6)	$\mathcal{B}$ upper limit (90% C.L.)
Lepton flavor violating modes (including τ):		
$B^0 \to \tau^\pm e^\mp$	378	2.8×10^{-5}
$B^0 \to \tau^\pm \mu^\mp$		2.2×10^{-5}
$B^+ \to K^+\tau^-\mu^+$	472	4.5×10^{-5}
$B^+ \to K^+\tau^+\mu^-$		2.8×10^{-5}
$B^+ \to K^+\tau^\mp\mu^\pm$		4.8×10^{-5}
$B^+ \to K^+\tau^- e^+$		4.3×10^{-5}
$B^+ \to K^+\tau^+ e^-$		1.5×10^{-5}
$B^+ \to K^+\tau^\mp e^\pm$		3.0×10^{-5}
$B^+ \to \pi^+\tau^-\mu^+$		6.2×10^{-5}
$B^+ \to \pi^+\tau^+\mu^-$		4.5×10^{-5}
$B^+ \to \pi^+\tau^\mp\mu^\pm$		7.2×10^{-5}
$B^+ \to \pi^+\tau^- e^+$		7.4×10^{-5}
$B^+ \to \pi^+\tau^+ e^-$		2.0×10^{-5}
$B^+ \to \pi^+\tau^\mp e^\pm$		7.5×10^{-5}



LHC*b* MEASUREMENT

$B^+ \to K^+\mu^-\tau^+$ *(using* B^{*0}_{s2}*)*

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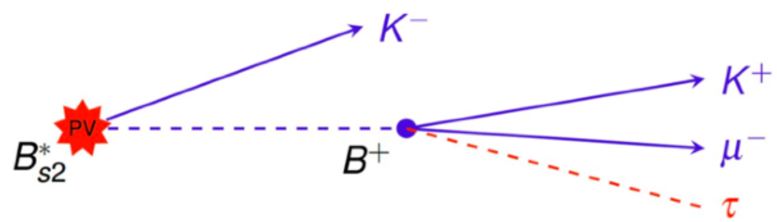
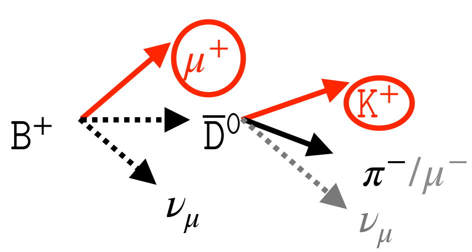
S. Weber - ICHEP 2020

- 9 fb[-1] @ 7, 8 and 13 TeV (Run1 & Run2)
- Use $B^{*0}_{s2} \to B^+K^-$ decay: about 1% of B^+ production
- $K^+\mu^-$ pair from secondary vertex plus additional track t^+

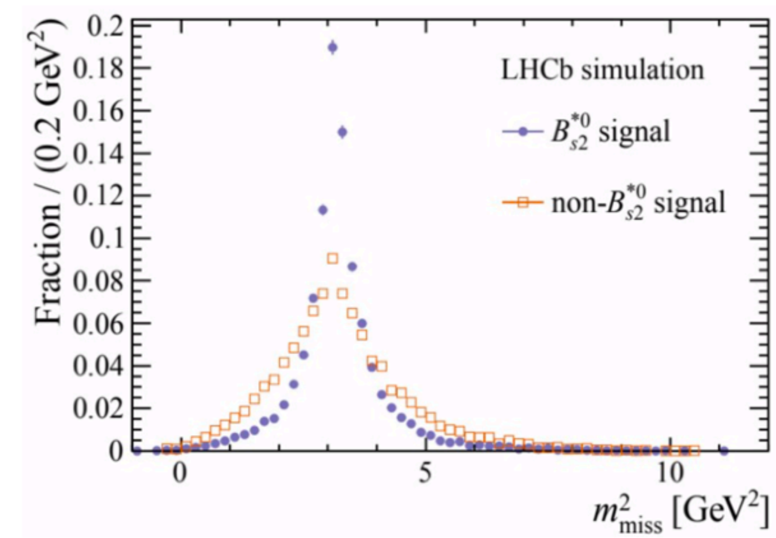


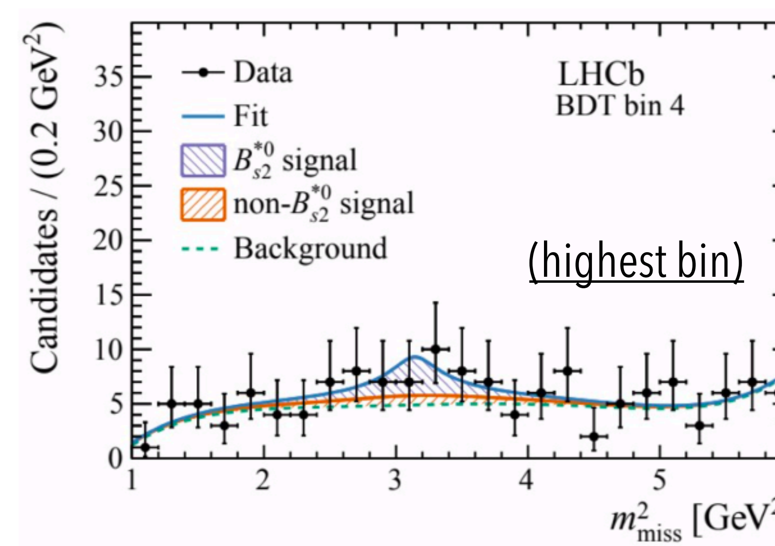
- Expect peak at τ mass also for B not from B^{*0}_{s2} decay, but wider distribution
- $K^+\mu^-\tau^+$ experimentally preferred over $K^+\mu^+\tau^-$ as it has a lower background from sSL B decays, because CF decays of the D mesons are likely to lead to K's of the same charge as the muon



- Remaining backgrounds produce smooth $m^2_{\rm miss}$ distributions
- Search performed in bins of final BDT output with increasing signal sensitivity

Mode	U.L. (90% CL)	Exp.
$B^+\to K^+\tau\mu$	4.8 x 10[-5]	BaBar
$B^+\to K^+\tau e$	3.0 x 10[-5]	BaBar
$B^+\to K^+\tau^+\mu^-$	3.9 x 10[-5]	LHCb





SHAPE VARIABLES FOR CONTINUUM SUPPRESSION

Variables related to the B meson direction: the spin-1 $\Upsilon(4S)$ decaying into two spin-0 B mesons results in a $\sin^2\theta_B$ angular distribution with respect to the beam axis; in contrast for $e^+e^- \to f\bar{f}$ events, the spin-1/2 fermions f, and its two resulting jets, are distributed following a $1 + \cos^2\theta_B$ distribution. Using the angle θ_B between the reconstructed momentum of the B candidate (computed in the $\Upsilon(4S)$ reference frame) and the beam axis, the variable **$|\cos\theta_B|$** allows one to discriminate between signal B decays and the B candidates from continuum background.

The **Fox-Wolfram moments**: for a collection of N particles with momenta p_i, the k-th order Fox-Wolfram moment H_k is defined as

$$H_k = \sum_{i,j}^{n} |\vec{p}_i||\vec{p}_j| P_k(\cos\theta_{ij})$$

where θ_{ij} is the angle between p_i and p_j, and P_k is the k-th order Legendre polynomial. Notice that in the limit of vanishing particle masses, $H_0 = 1$; that is why the normalized ratio $R_k = H_k/H_0$ is often used, so that for events with two strongly collimated jets, R_k takes values close to zero (one) for odd (even) values of k. These sharp signatures provide a convenient discrimination between events with different topologies.

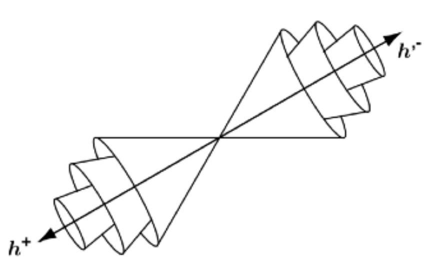
$$R_n = \frac{H_n}{H_0}$$

Thrust: for a collection of N momenta p_i ($i = 1,\cdots N$), the thrust axis T is defined as the unit vector along which their total projection is maximal; the thrust scalar T (or thrust) is a derived quantity defined as

$$T = \frac{\sum_{i=1}^{N} |\vec{T}\cdot\vec{p}_i|}{\sum_{i=1}^{N} |\vec{p}_i|}$$

For a BB event, both B mesons are produced almost at rest in the $\Upsilon(4S)$ rest frame, so their decay particles are isotropically distributed, their thrust axes are randomly distributed, and thus $|\cos\theta_T|$ follows a uniform distribution in the range [0,1]. In contrast for $q\bar{q}$ events, the momenta of particles follow the direction of the jets in the event, and as a consequence the thrusts of both the B candidate and the ROE are strongly directional and collimated, yielding a $|\cos\theta_T|$ distribution strongly peaked at large values.

Cleo Cones: Set of nine variables corresponding to the momentum flow around the thrust axis of the B candidate, binned in nine cones of 10° around the thrust axis as illustrated



SUPERKEKB ACCELERATOR

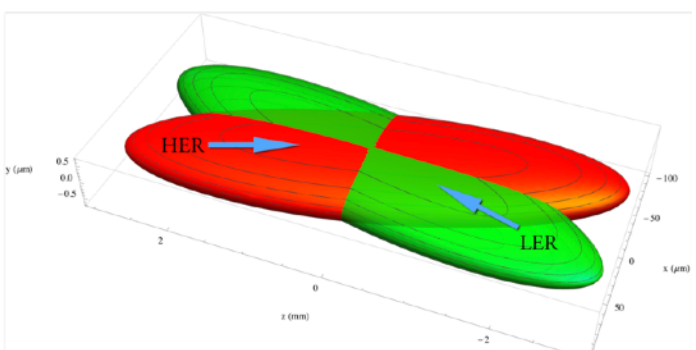
$$\mathscr{L} = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm\,\xi_{y\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_{y\pm}}}\right)$$

- **"Nano-beam"** scheme and higher currents
- Larger crossing angle Φ
- Lower βy by 40%

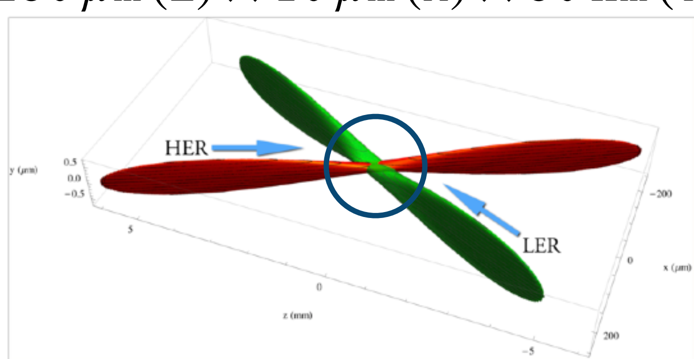
Wrt to 1st generation B factories

Beamspot

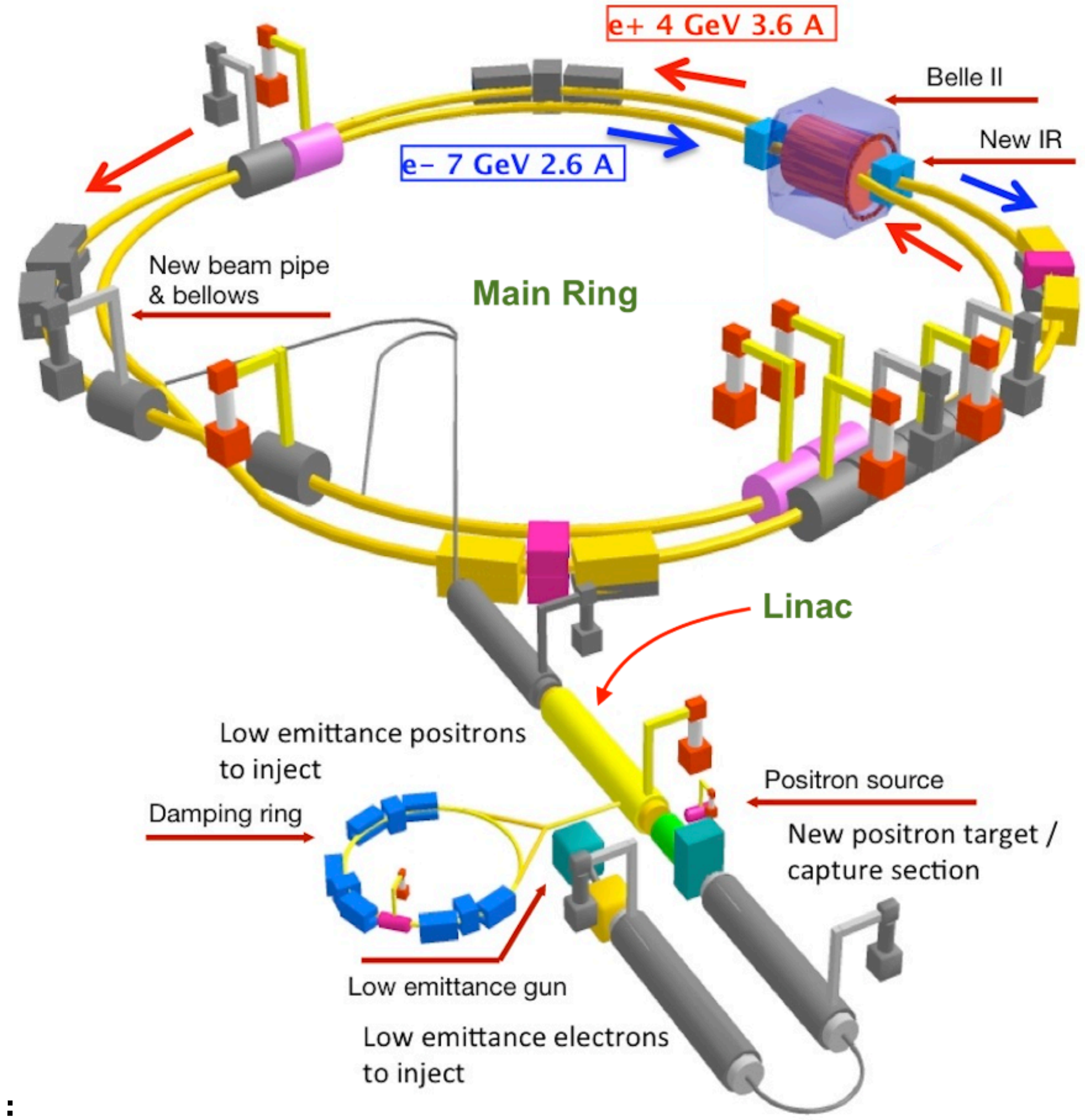
$250\,\mu\mathrm{m}\,(Z) \times 10\,\mu\mathrm{m}\,(X) \times 50\,\mathrm{nm}\,(Y)$



KEKB



SuperKEKB

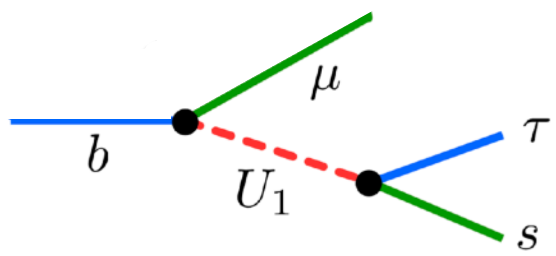


	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (mm) LER/HER	Φ (mrad)	I (A)	L ($cm^{-2}s^{-1}$) x10^{35}
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	0.2
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	8

Factor 20 Factor 2-3

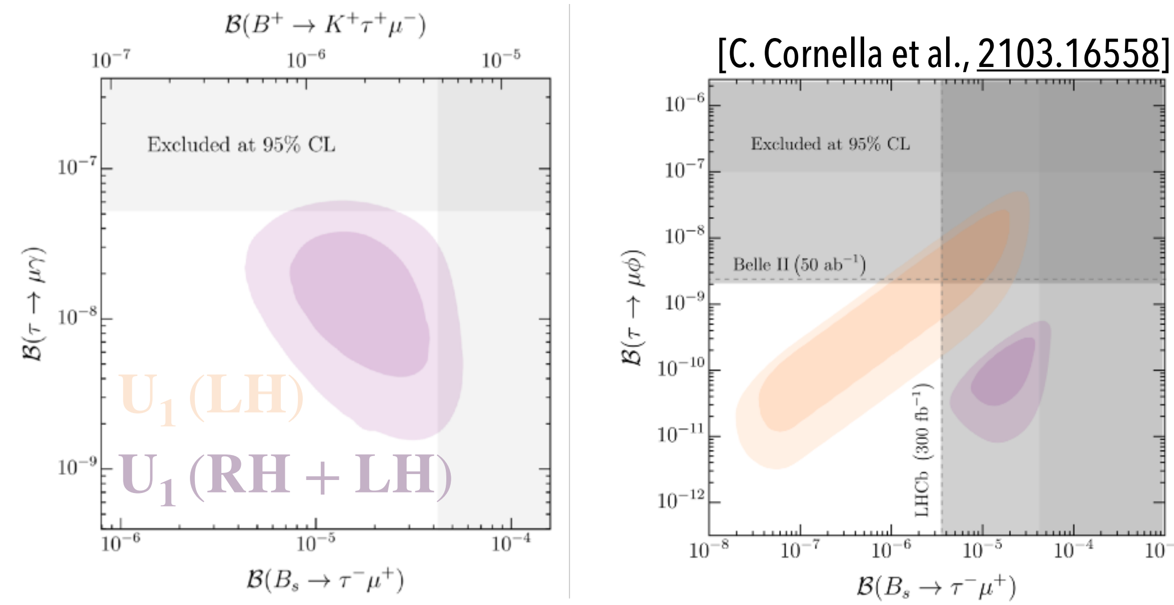
μ/τ LFV AND LEPTOQUARKS

A single LQ with $\mathrm{m_{LQ}} \sim \mathcal{O}$(1 TeV) can satisfy both $\mathrm{R_{K^{(*)}}} < \mathrm{R^{SM}_{K^{(*)}}}$ and $\mathrm{R_{D^{(*)}}} > \mathrm{R^{SM}_{D^{(*)}}}$ and could enhance the rate of $\mathrm{b} \to \mathrm{s}\mu\tau$ processes



$\mathrm{U_1} \sim (\mathbf{3}, \mathbf{1})_{2/3}$

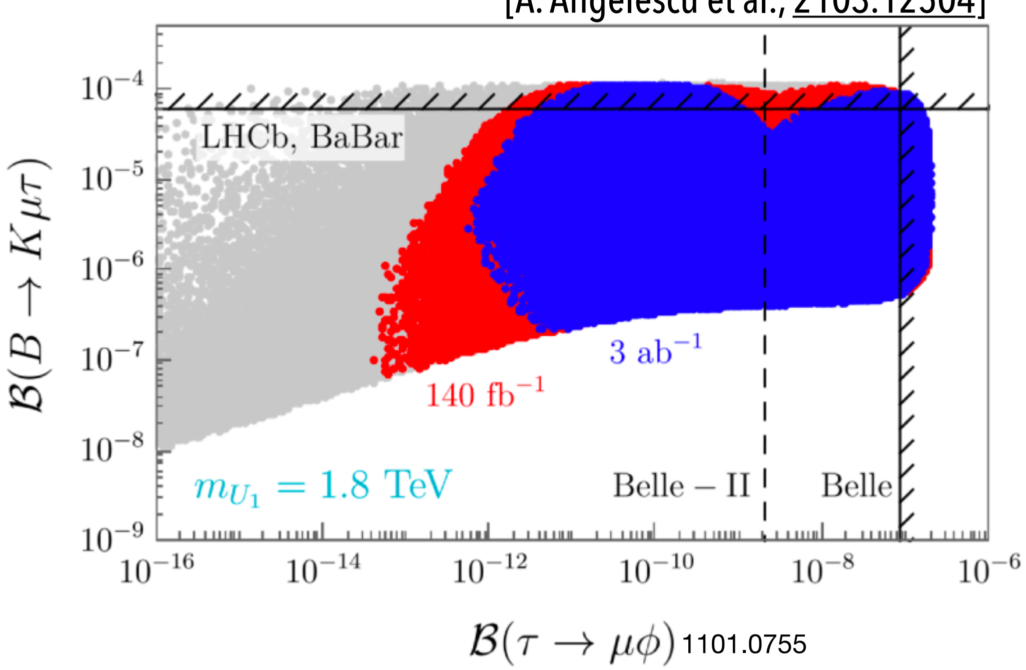
[C. Cornella et al., 2103.16558]



Predictions on several b.r.'s using the results of a $\mathrm{U_1}$ simplified model fit.

The most interesting ones are the LFV decays [$\mathrm{B} \to \mathrm{K}\tau\mu, \tau \to \phi\mu$, $\mathrm{B_s} \to \tau\mu, \tau \to \mu\gamma$]

[A. Angelescu et al., 2103.12504]



- Lower and upper bounds on the exclusive $\mathrm{b} \to \mathrm{s}\mu\tau$ processes as obtained from the **constraints** arising both **from the low-energy observables** and those coming from **the current direct searches at the LHC**