New approaches for missing energy modes

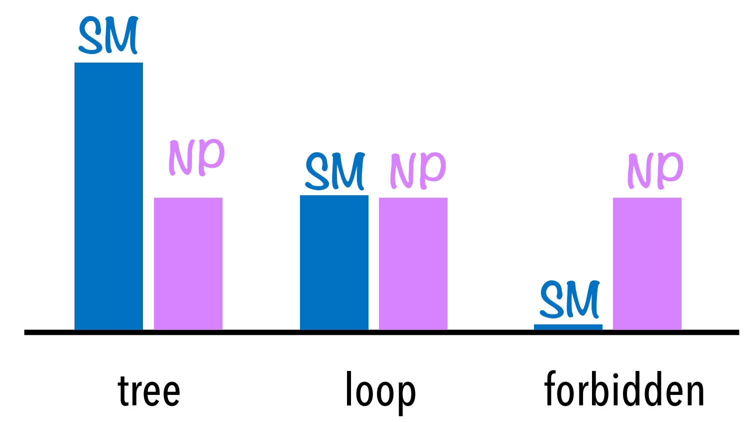
Search for LFV $B \to K\tau\ell$

G. de Marino, K. Trabelsi

2021.05.17 - SÉMINAIRES DOCTORANTS

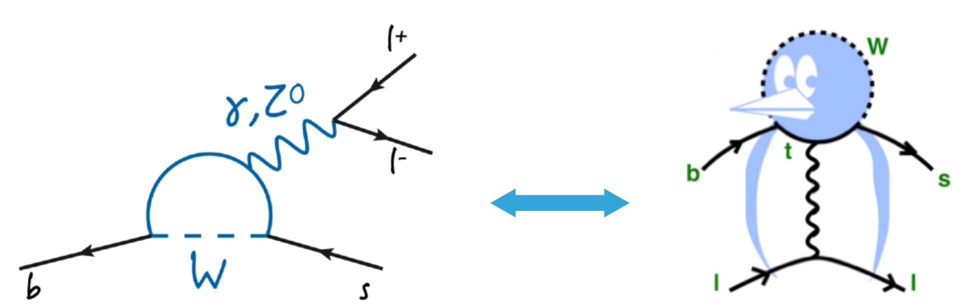
FLAVOR PHYSICS AND EW PENGUINS

- Goals of **flavor physics**:
  - Precisely measure parameters of the standard model (e.g. CKM quark mixing matrix) — tree
  - Search for the effects of physics beyond the standard model in precision measurements — loop
  - Discover processes that are forbidden (or highly suppressed) by SM — forbidden

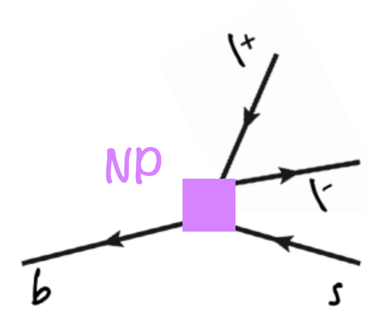


- **Flavour-changing neutral current** (FCNC) $b \to s(d)$ are of great importance to precision flavor physics. The FCNC processes proceed at lowest order via one-loop diagrams in the SM.

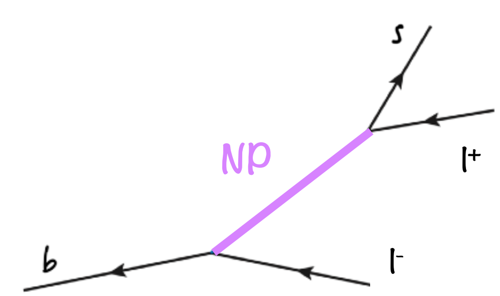
Electro-weak penguins



- Since **new-physics** particles may enter the loop diagrams or even mediate FCNCs at tree level, the $b \to s(d)$ are sensitive to physics beyond the SM. Moreover, final states involving lepton pairs are theoretically and experimentally clean.



Tree:



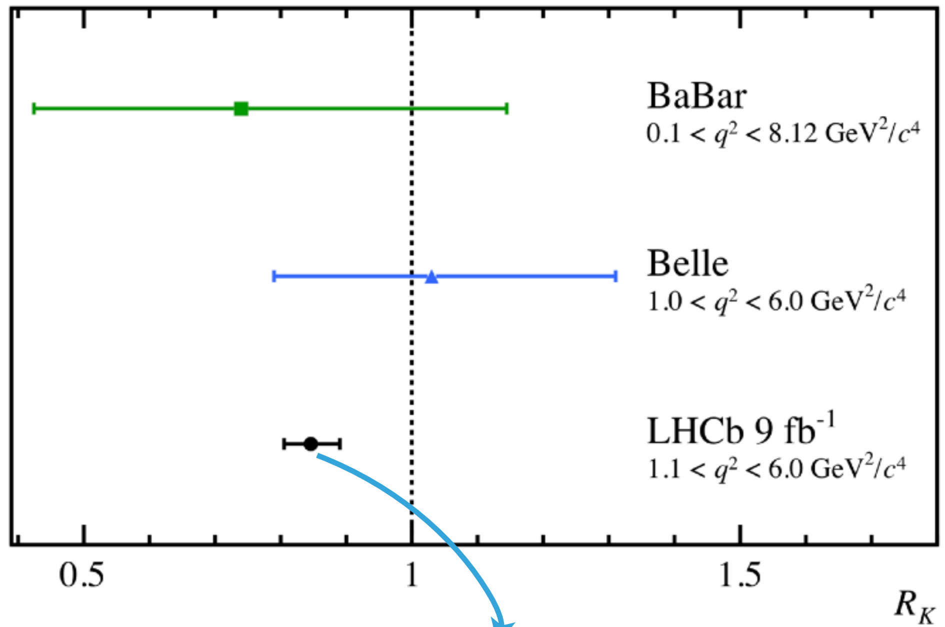
STATUS OF R_K AND PROSPECTS

Semi-leptonic B decays are showing tensions with the SM predictions that are connected to a possible violation of the Lepton Flavor Universality (LFU). Different behaviour of lepton generations in the process:

$b \to s l^+ l^-$ (neutral currents): **μ vs. e**

$$R_K = \left.\frac{\Gamma\left(B \to K\mu^+\mu^-\right)}{\Gamma\left(B \to Ke^+e^-\right)}\right|_{q^2 \in (q^2_{min}, q^2_{max})}$$

$$R_K^{exp} < R_K^{SM}$$



3.1 σ deviation

Belle 2021

$$R_K = 1.03^{+0.28}_{-0.24} \pm 0.01$$
$q^2 \in (1.0, 6.0)$ GeV$^2/c^4$ (0.7 ab^{-1})

[JHEP 03 (2021) 105]

LHCb 2021

$$R_K = 0.846^{+0.042+0.013}_{-0.039-0.012}$$
for $q^2 \in [1.1, 6.0]$ GeV$^2/c^4$ (9 fb^{-1})

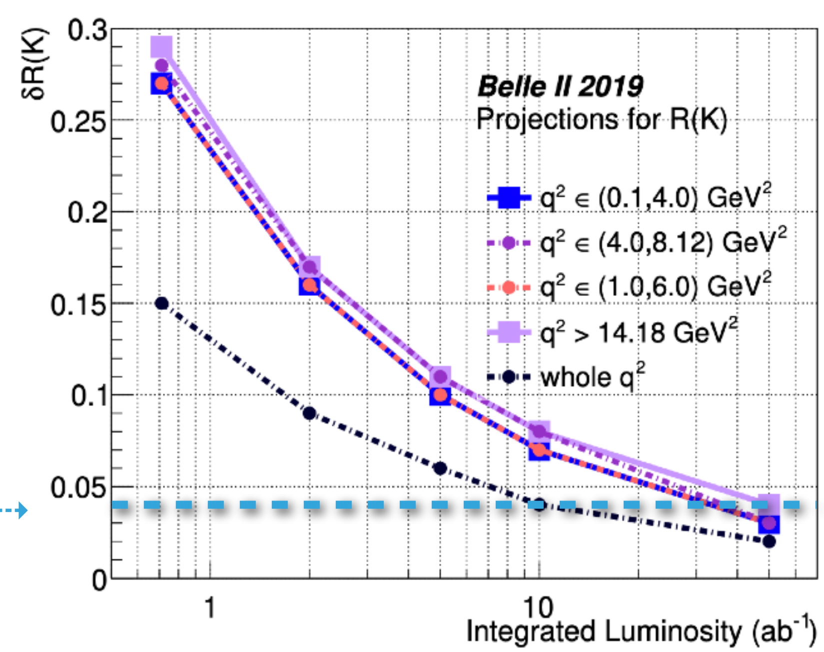
[arXiv:2103.11769v1]

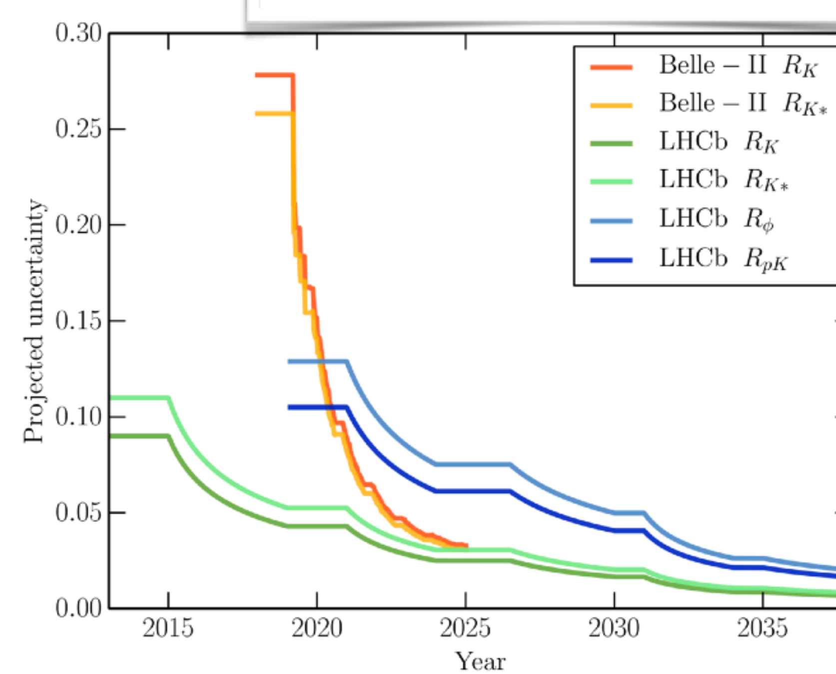
Rules of 👍

- ab^{-1}@ Belle II ~1 fb^{-1} @ LHCb
- Belle II: 1 fb^{-1} ⇔ 10⁶ $B\bar{B}$

Belle II will provide new, independent tests of the anomalies in the $B \to s l^+ l^-$ family!

Current LHCb precision ⇢





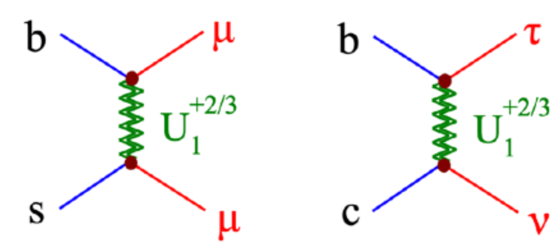
PHYSICS IMPLICATIONS

1. Lepton-flavor violating (LFV) decays are strongly suppressed in SM. However, their rates could be enhanced if LFU is violated
2. Many NP scenarios can explain the $b \to s$ anomalies
   - If we restrict the attention to tree-level mediators: W', Z', Leptoquarks (LQ)
   - LQ -both scalar and vectors- are usually preferred over other mediators
3. LQ models predict sizeable LFV rates for leptonic and semileptonic B-decays [Hiller et al.,1609.08895]

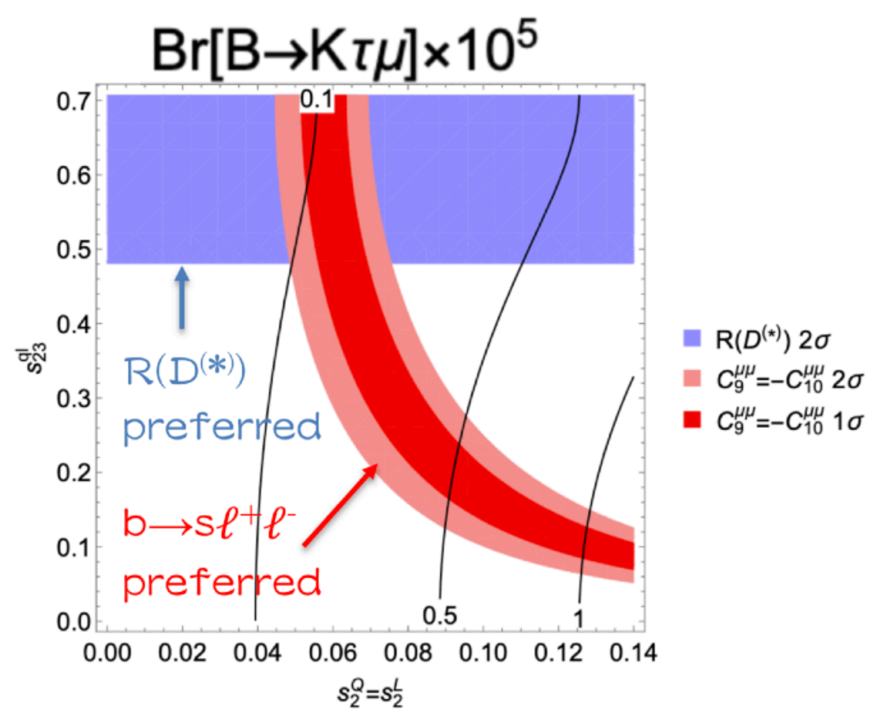
$$\mathcal{B}(B \to K(e^{\pm}, \mu^{\pm})\tau^{\mp}) \sim 2 \cdot 10^{-8} \left(\frac{1 - R_K}{0.23}\right)^2$$

4. The $U_1 \sim (\mathbf{3}, \mathbf{1})_{2/3}$ vector leptoquark is an excellent mediator to explain charged and neutral anomalies at same time [Angelescu et al., 1808.08179]

G. Isidori, Beyond the Flavor Anomalies 2021



5. 3rd generation might receive larger effect of NP

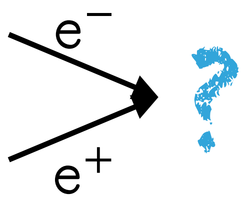


L. Calibbi [arXiv:1709.00692]

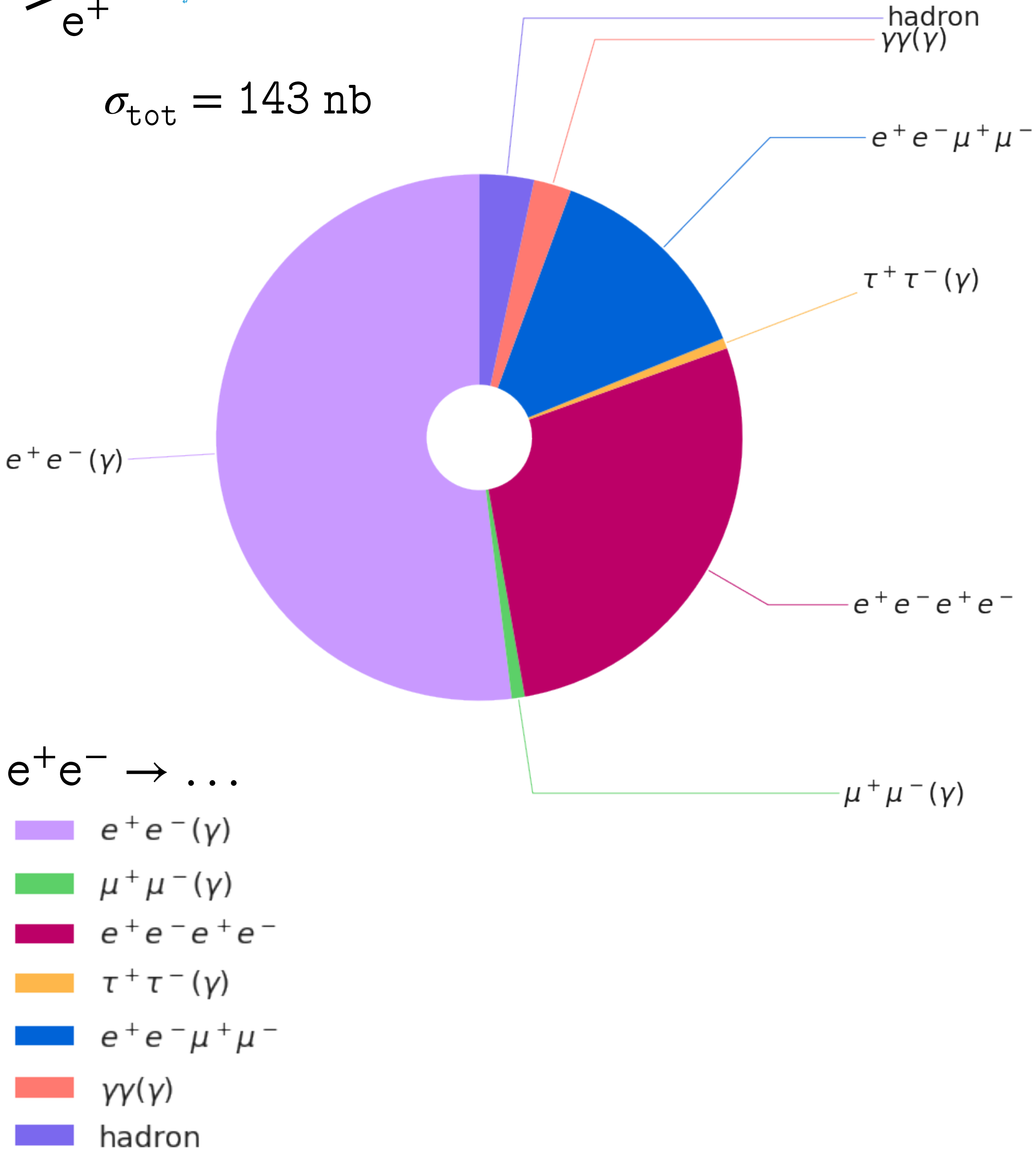
Observation of a charged LFV decay would be a striking sign of new physics!

SEARCH FOR THE DECAY $B^+ \to K^+\tau l$ AT B-FACTORIES

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



$\sigma_{\mathrm{tot}} = 143\ \mathrm{nb}$



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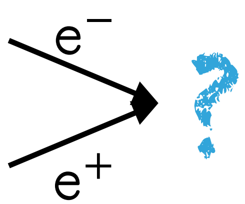
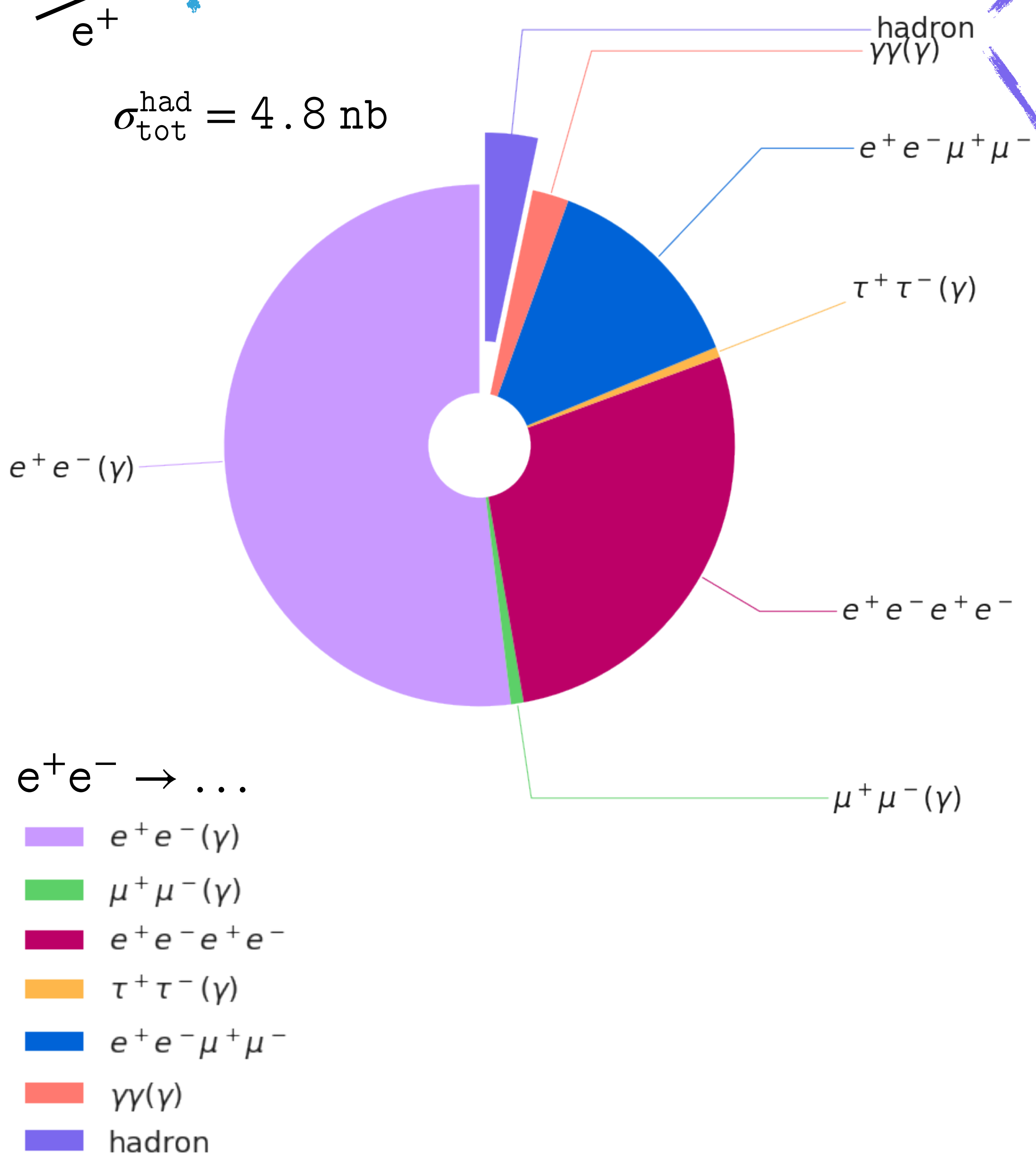
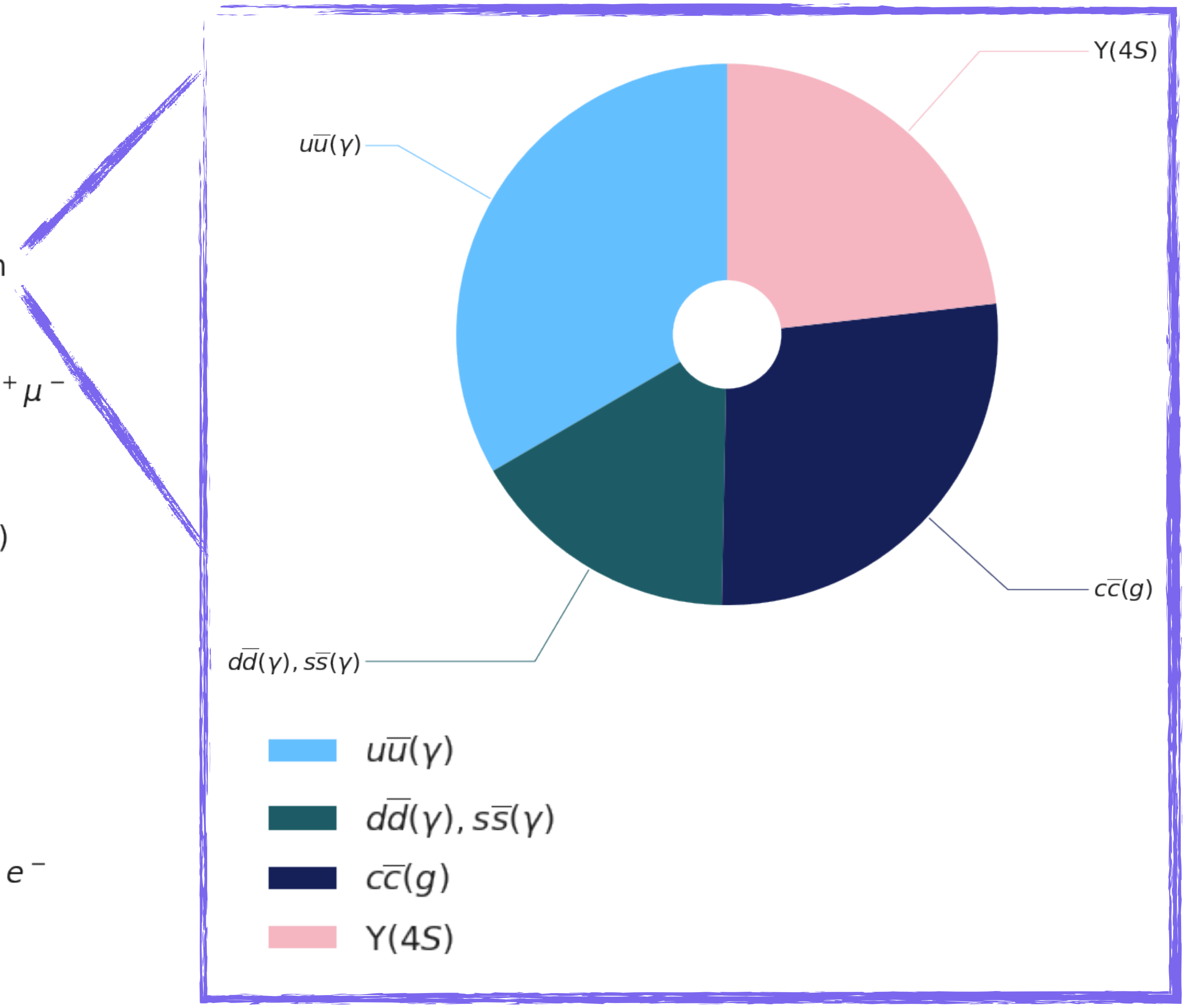


$\sigma_{tot}^{had} = 4.8$ nb





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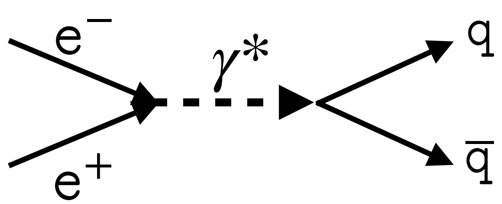

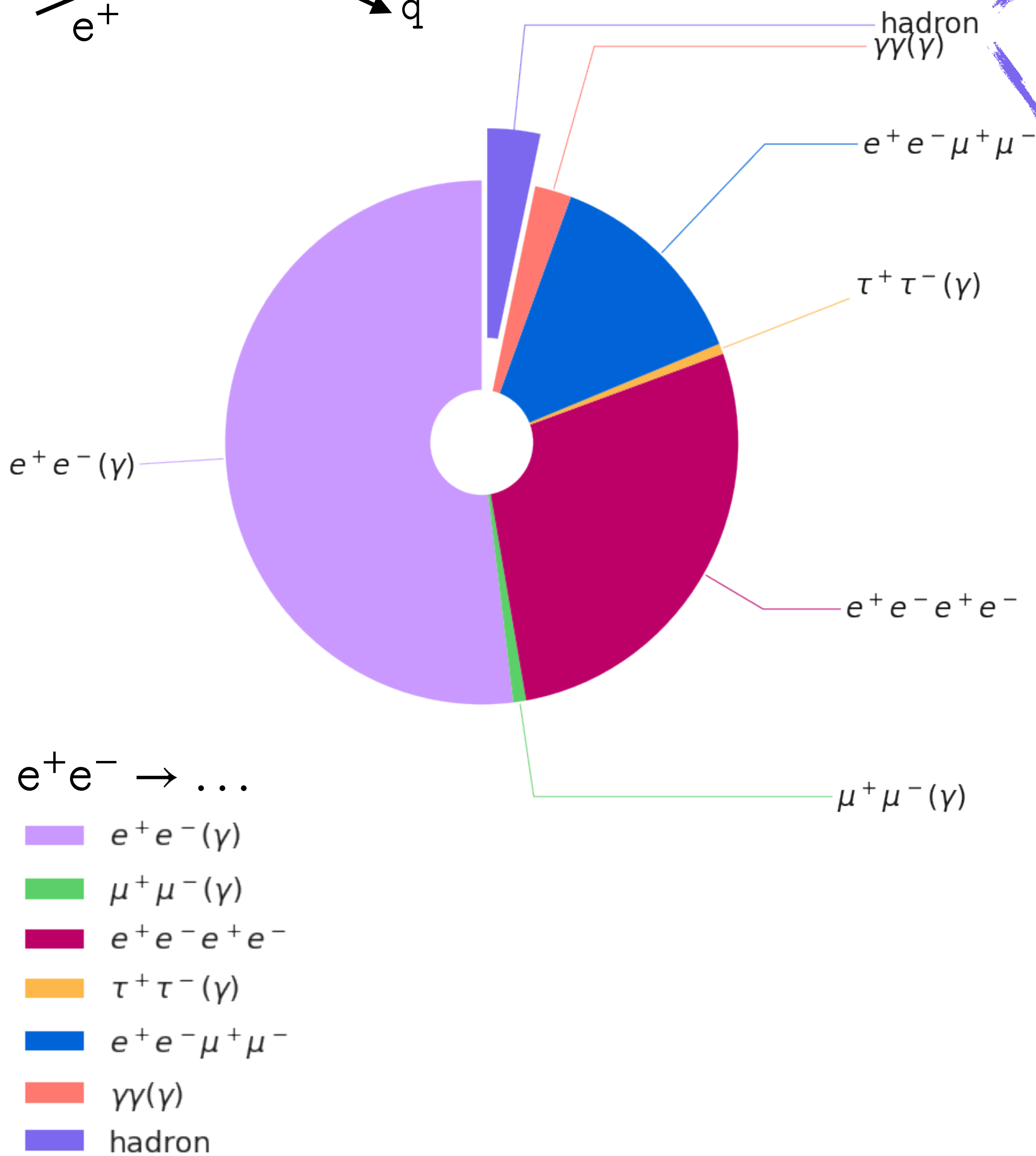

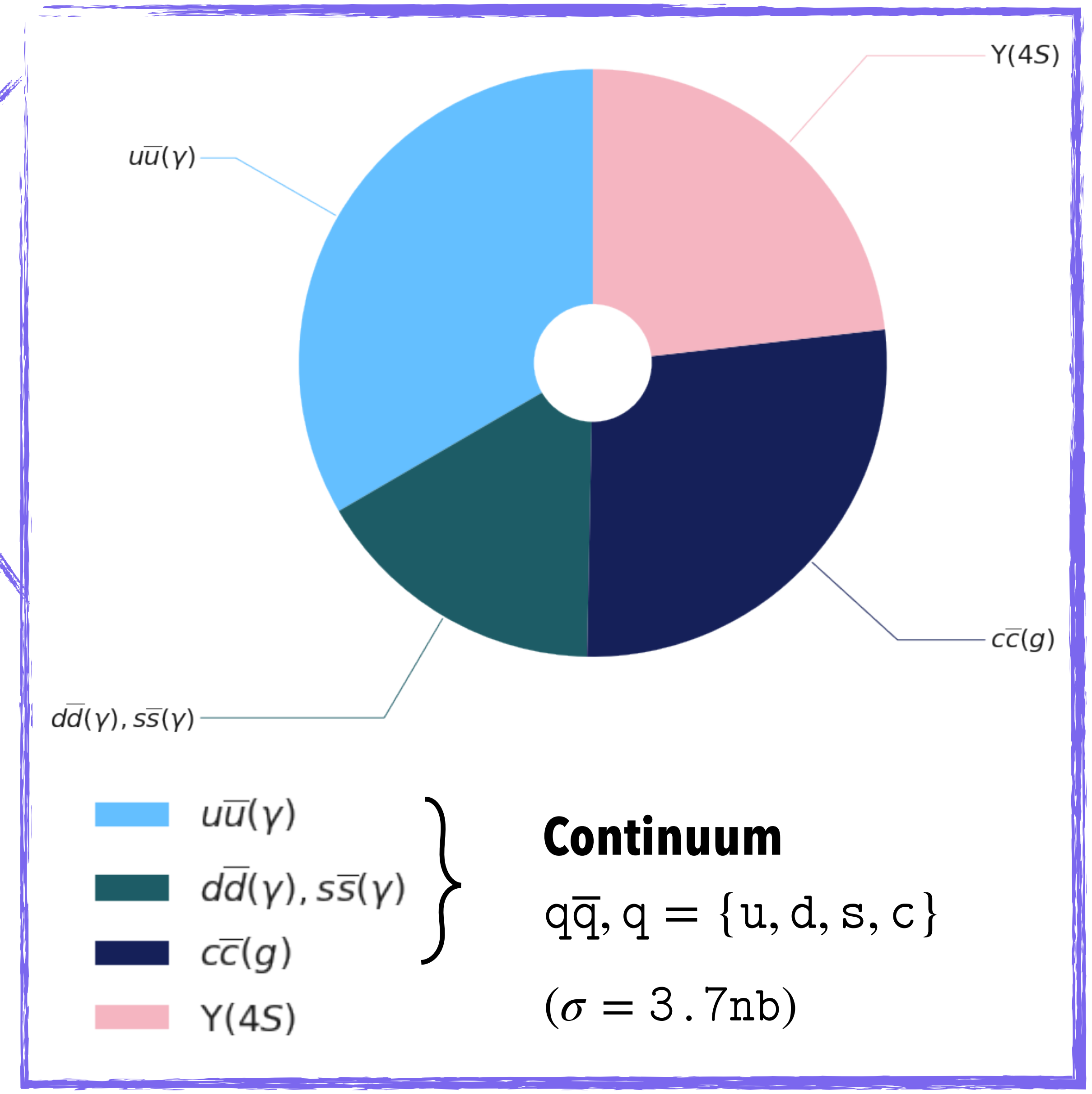

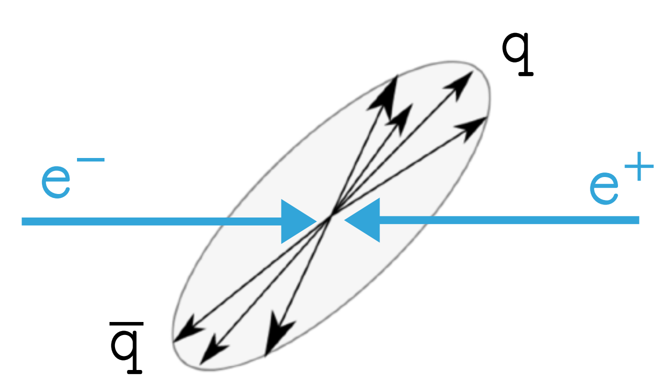

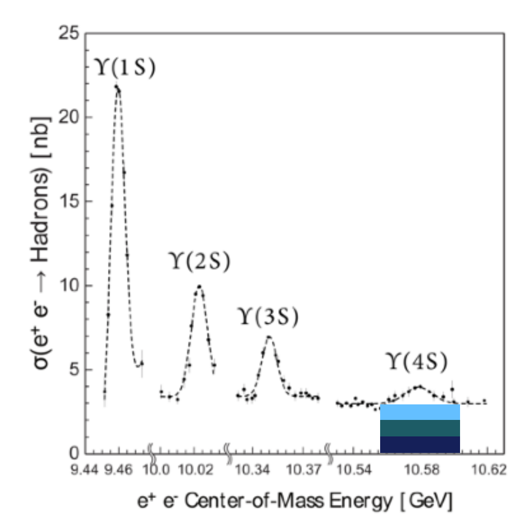

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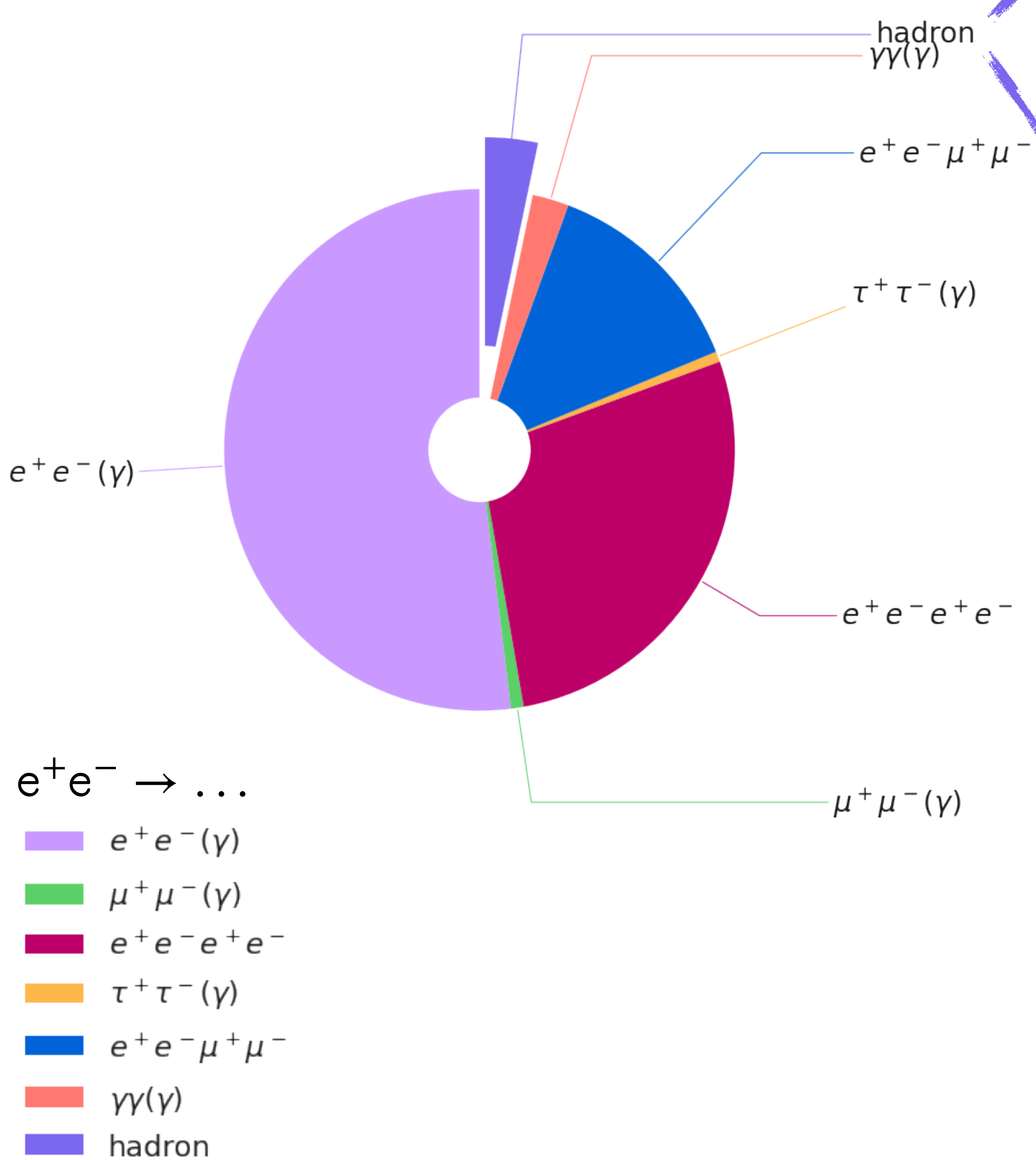
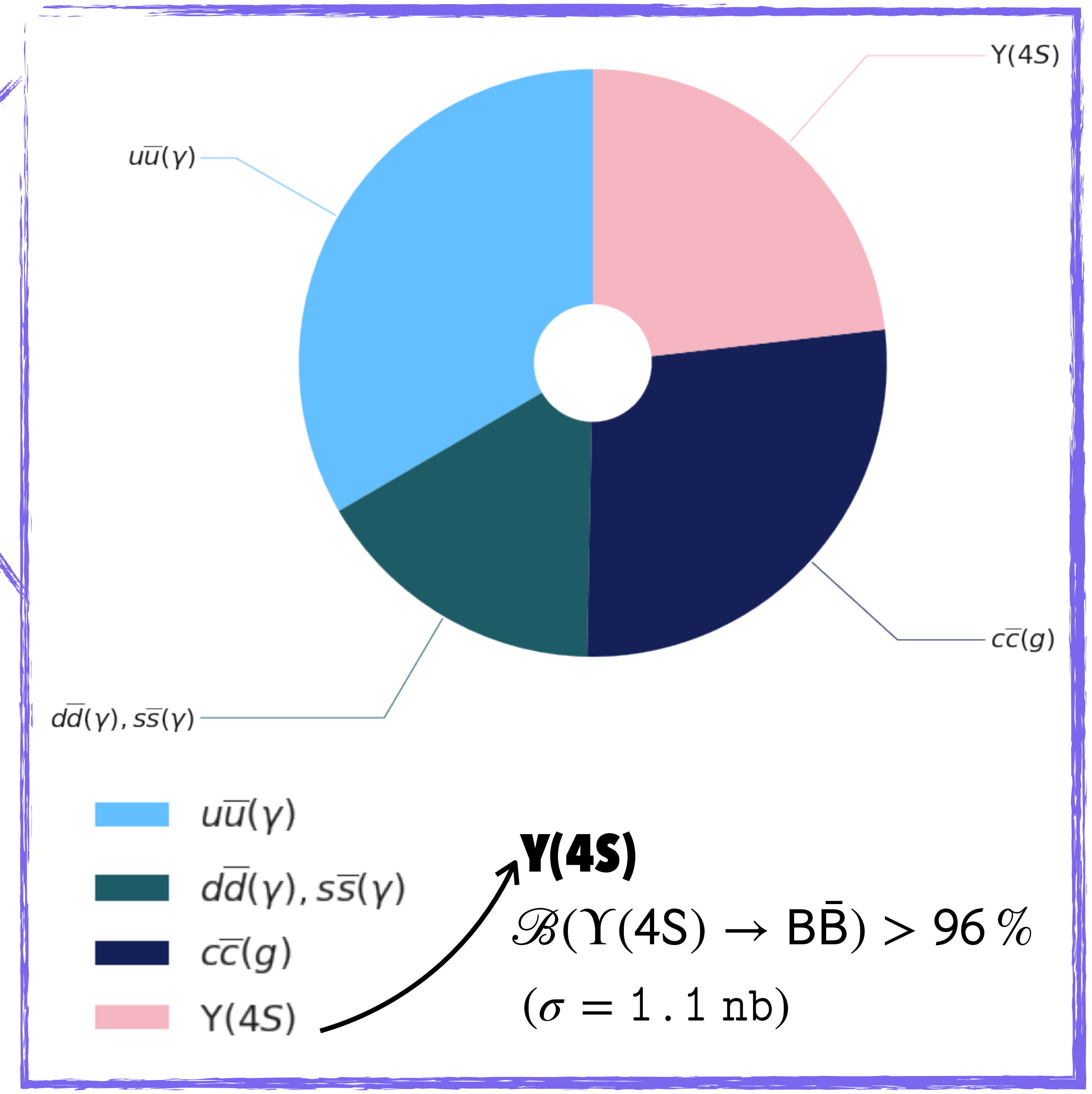
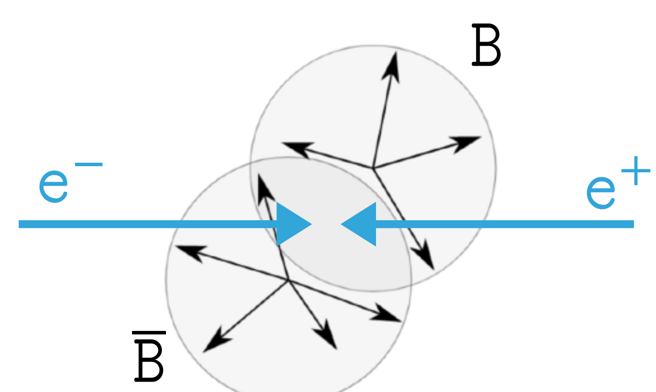


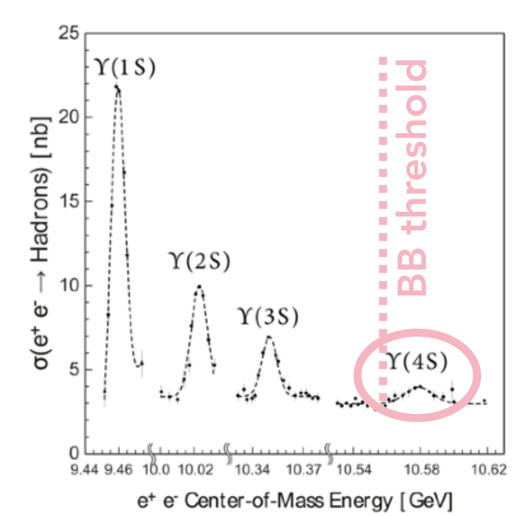


Υ(4S)

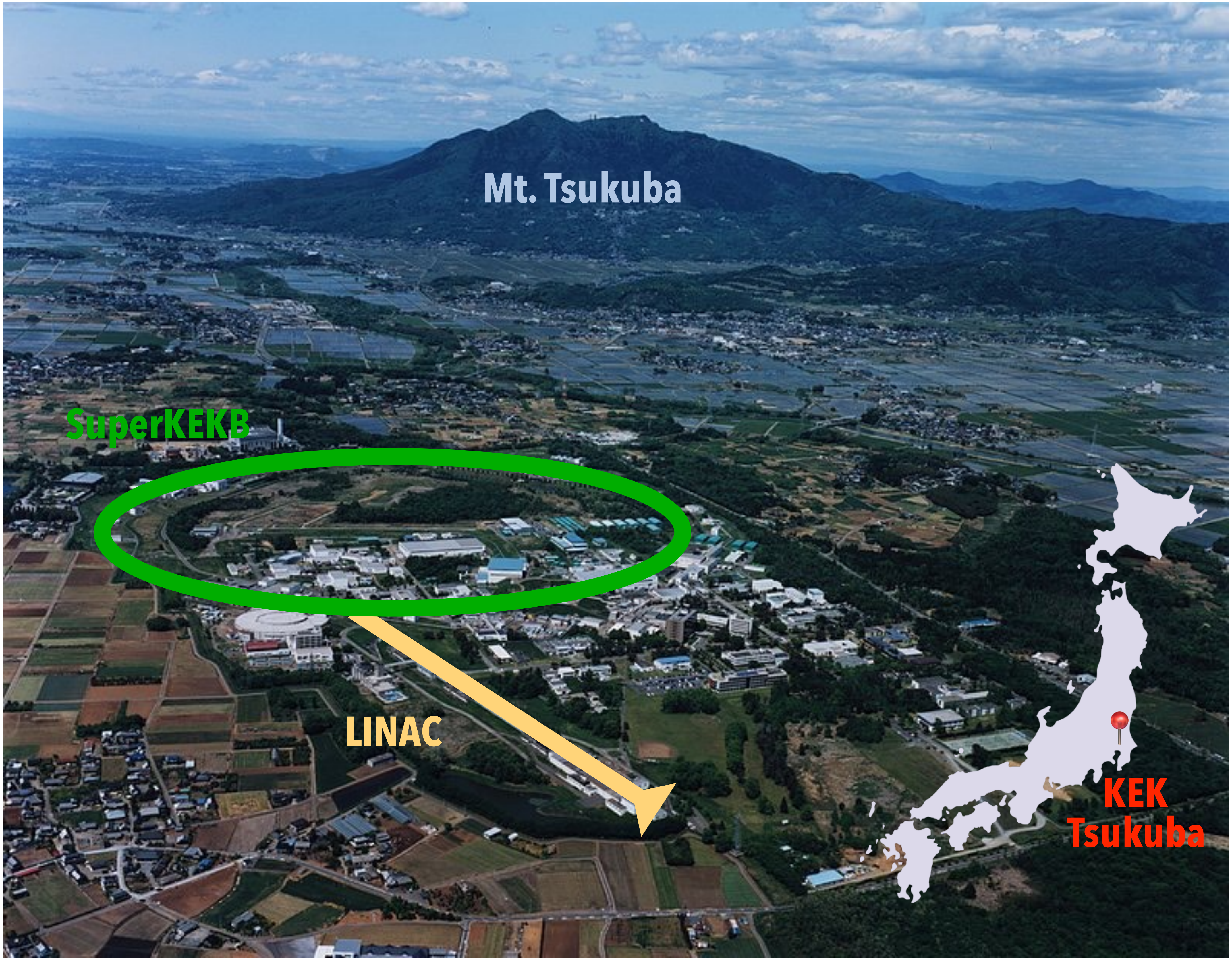
$\mathscr{B}(\Upsilon(4S) \to B\bar{B}) > 96\,\%$

$(\sigma = 1.1\ \text{nb})$





(SUPER)KEKB ACCELERATOR

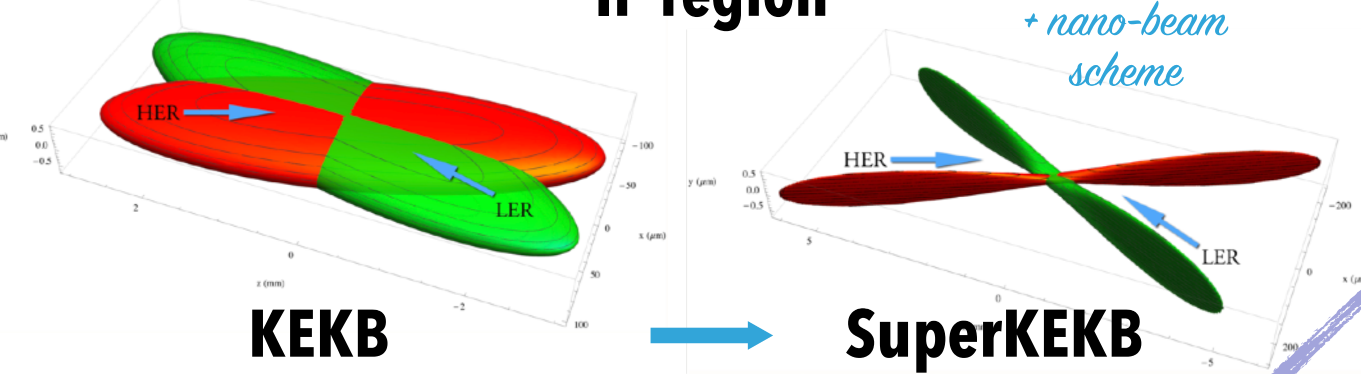


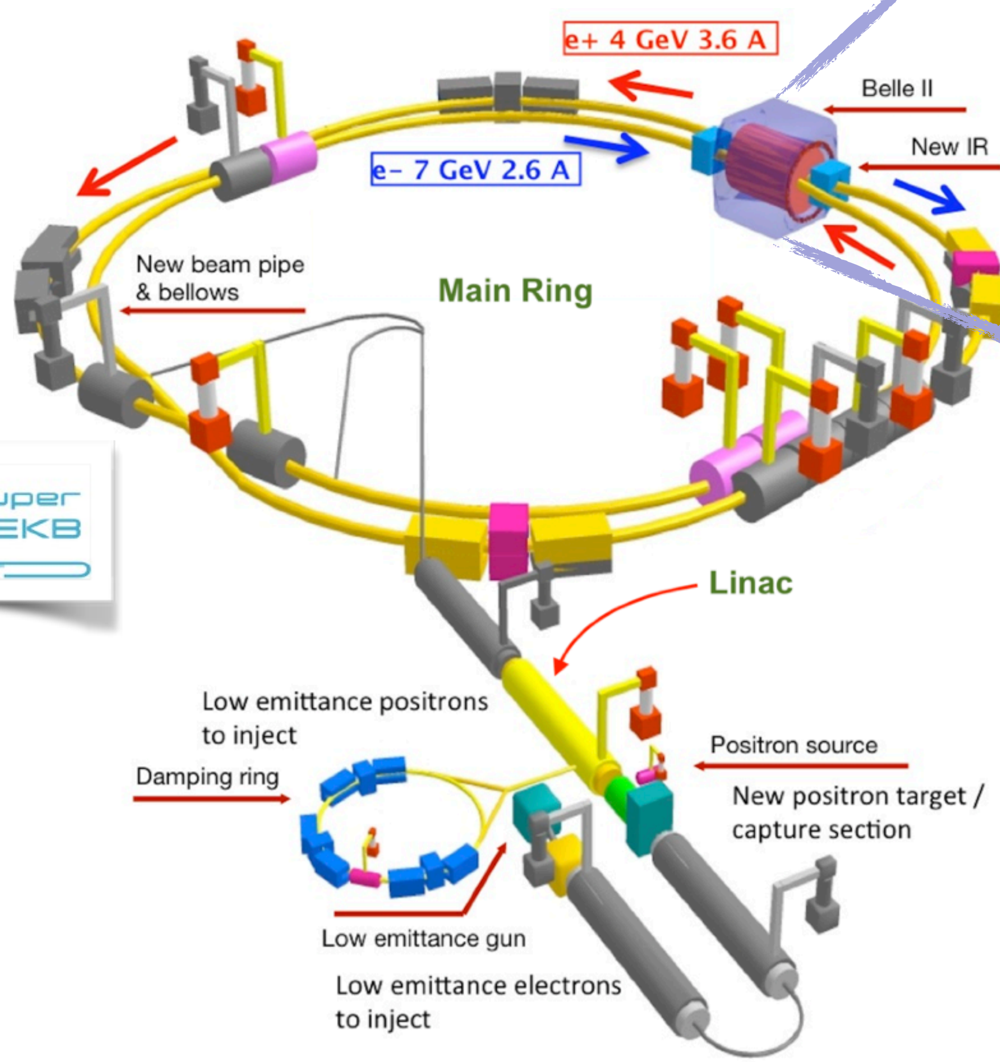
BELLE II EXPERIMENT

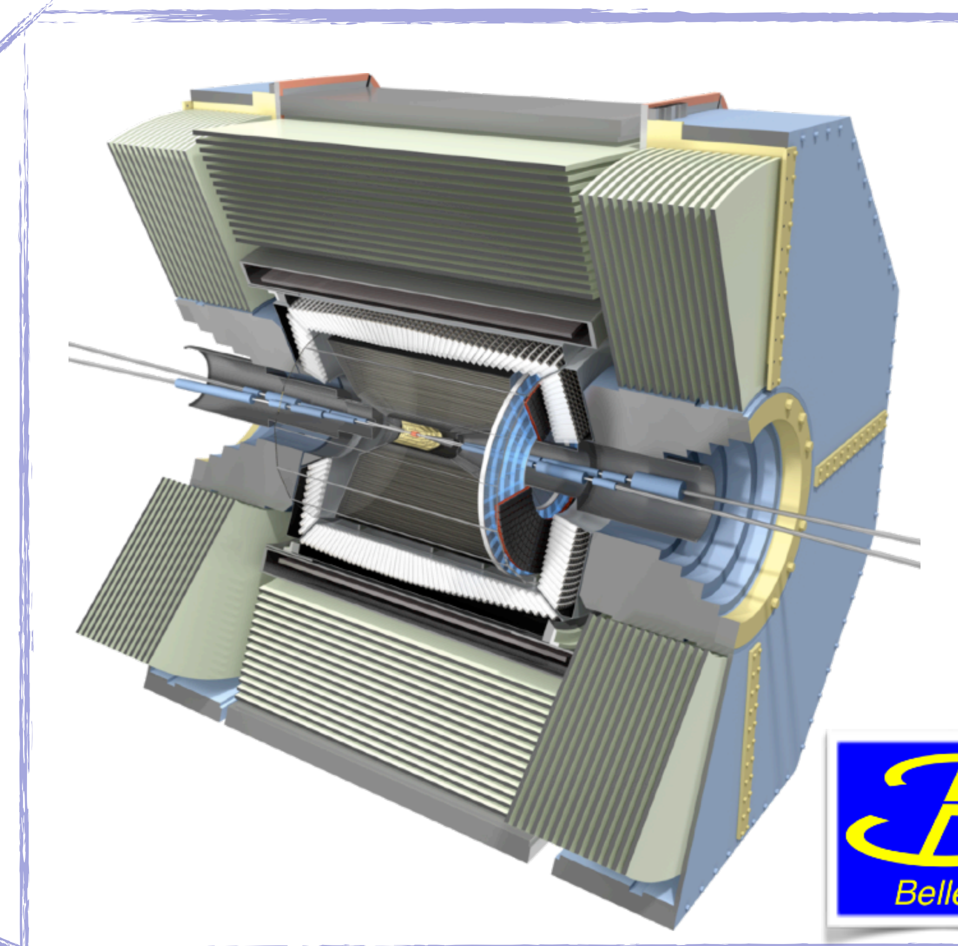
Goal: $\mathscr{L}_{\text{int}} = 50\ \text{ab}^{-1}$ **(2019 - 2031)**

(Belle @ KEKB: $\mathscr{L}_{\text{int}} = 1.05\ \text{ab}^{-1}$ *[1999-2010])*

IP region



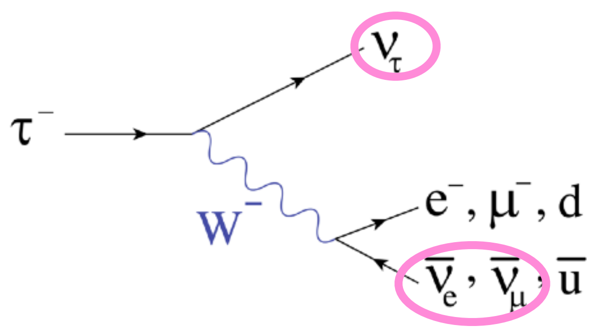


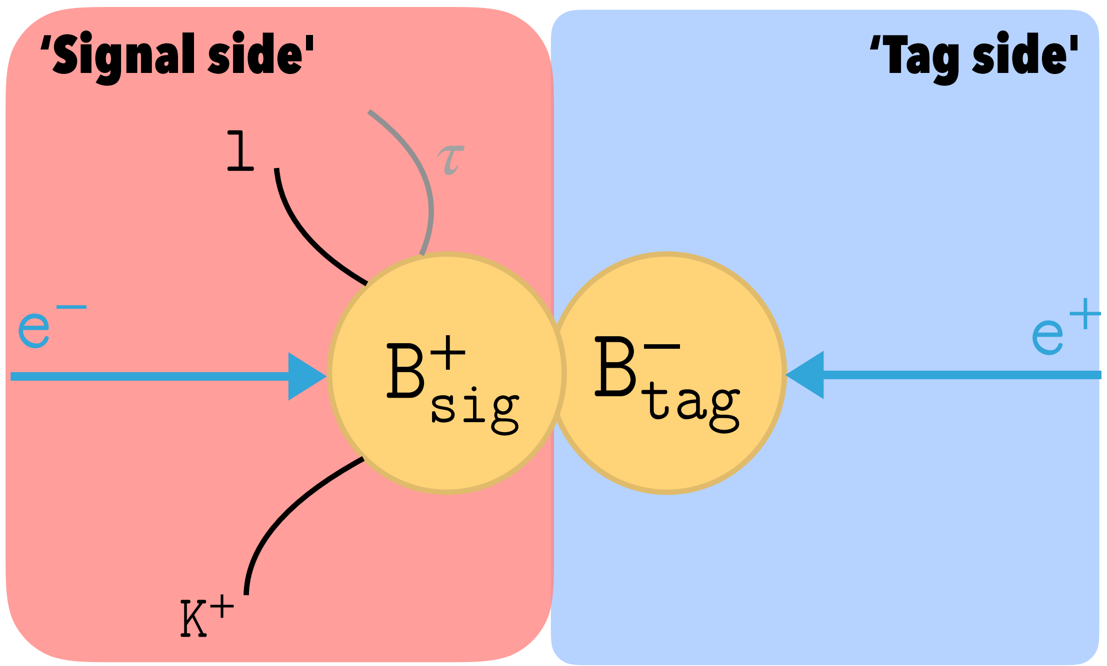


The upgrade **KEKB⇢SuperKEKB** has required a substantial **redesign of Belle II detector**, whose performance are challenged by radiation damage and higher background (design luminosity is **x40** higher). The aim is to guarantee in the new environment equal or better performance than Belle with KEKB.

STRATEGY FOR $B^+ \to K^+ \tau l$

- Processes involving τ's are experimentally challenging because of **missing energy**

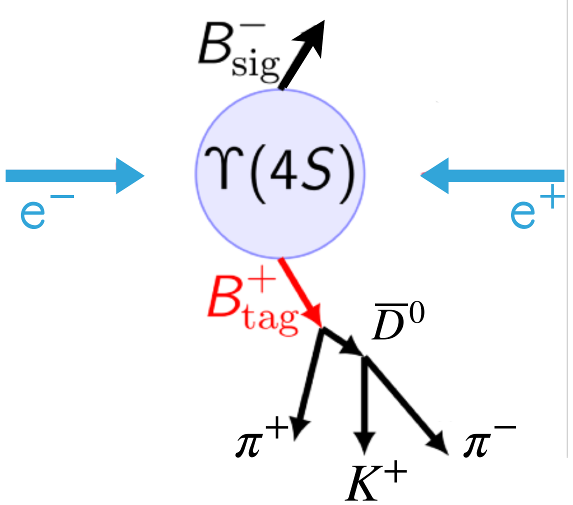




- Once the B_{tag} is fully reconstructed, the only source of missing energy is the the τ itself:
  - The recoil mass $m_\tau = [m_B^2 + m_{Kl}^2 - 2(E_B^* E_{Kl}^* + |\vec{p}_B^{\,*}||\vec{p}_{Kl}^{\,*}|\cos\theta)]^{\frac{1}{2}}$ can be used to extract the signal from the background

How to reconstruct the tag side

THE PRINCIPLE OF TAGGING



- $\mathrm{B\overline{B}}$ events must be *tagged* to distinguish them from other $\mathrm{q\bar{q}}$ processes
- The B *tag* candidate is reconstructed by choosing a tagging algorithm
- The remaining reconstructed particles in the event make up the target (*signal*) B

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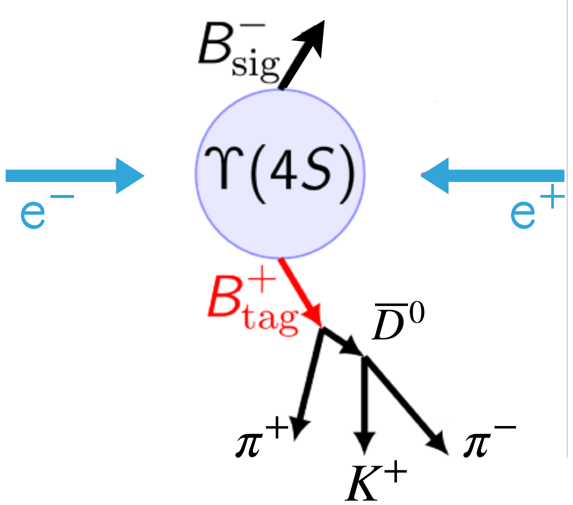

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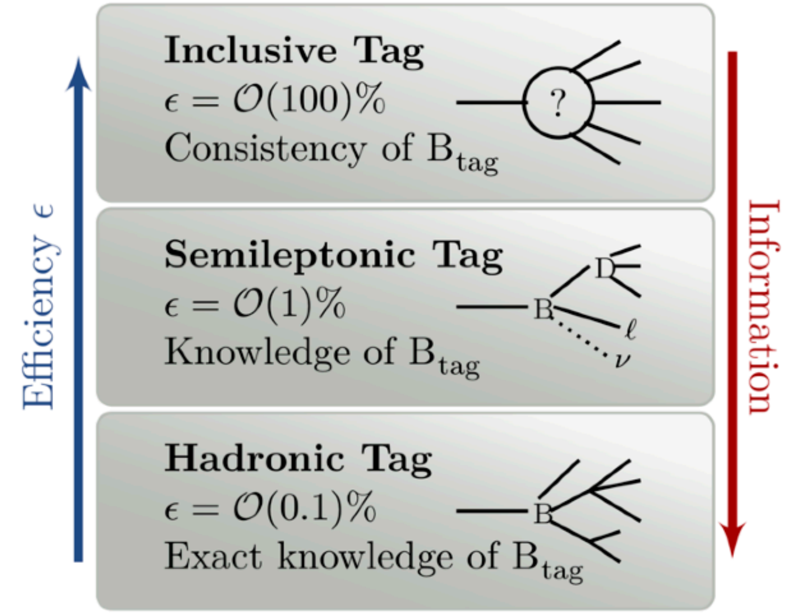

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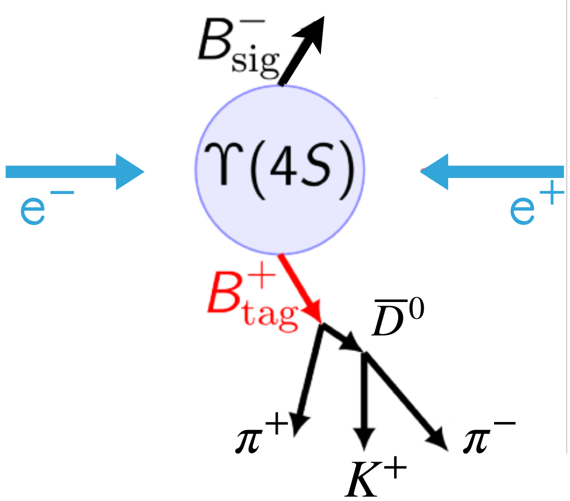

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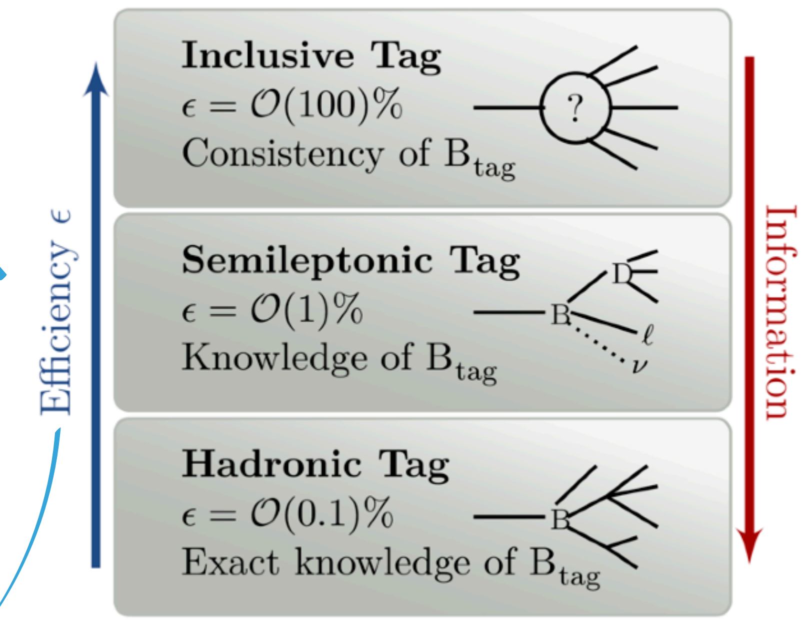
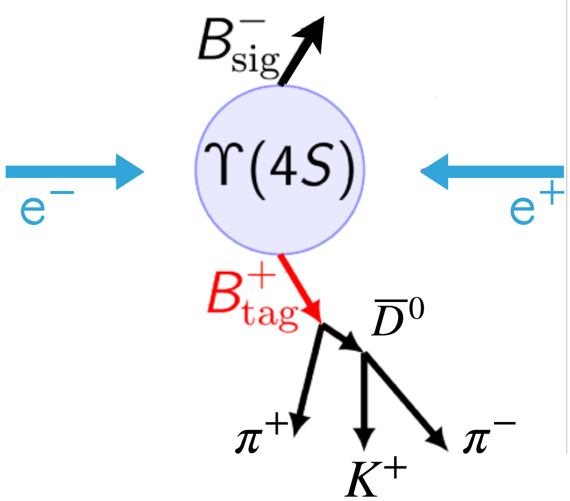


$$\varepsilon_{\text{tag}} = \sum_i \varepsilon_i \, \mathcal{B}_i$$

THE PRINCIPLE OF TAGGING



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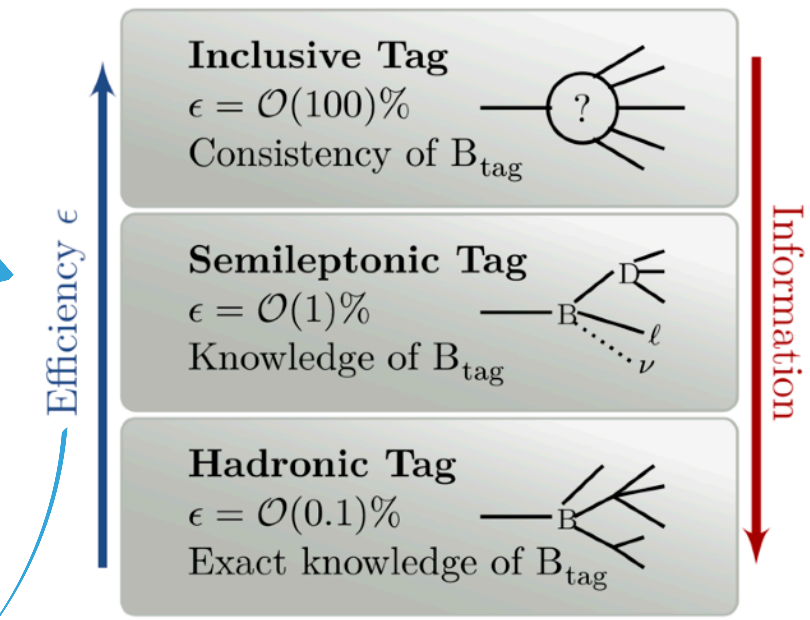

$$\varepsilon_{tag} = \sum_i \varepsilon_i \mathscr{B}_i$$

Reconstruction efficiency depends on:

- Acceptance
- Tracking eff.
- Particle identification

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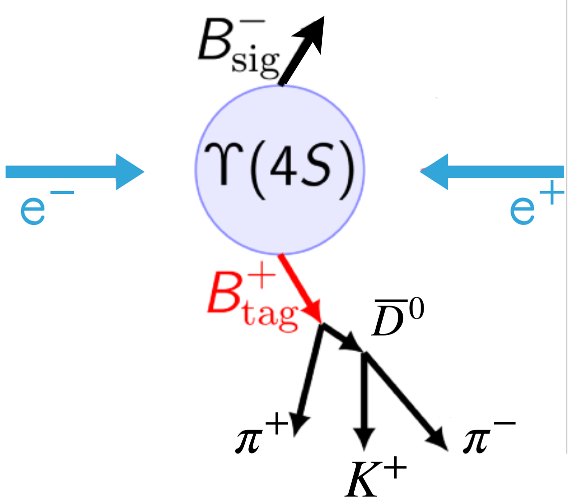

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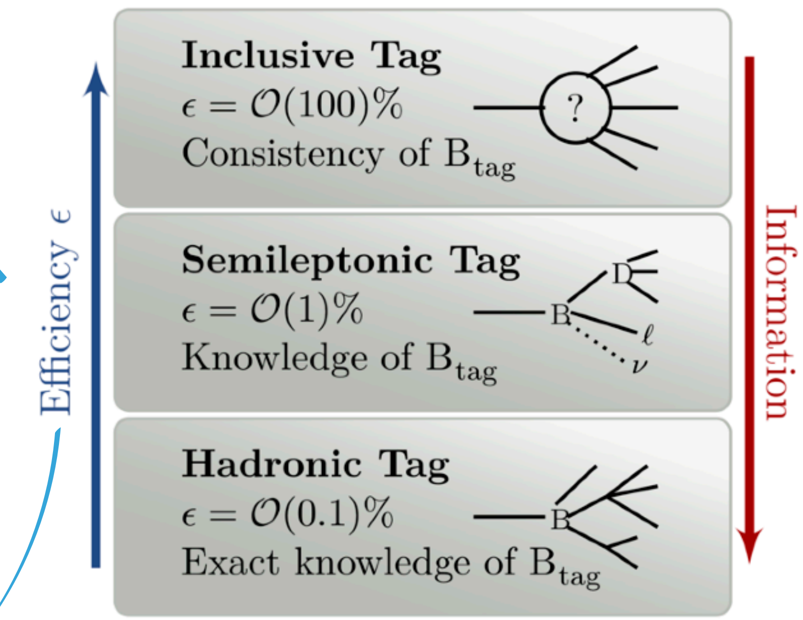

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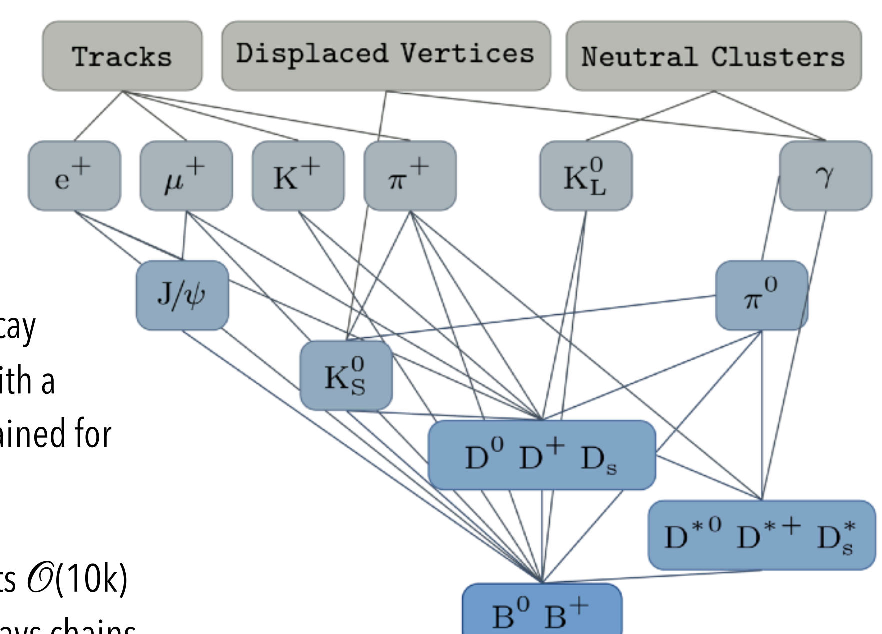
Branching ratio

- $B^- \to X_c l^- \nu$: 22% (Semileptonic B decays)
- Hadronic decays

FEI algorithm



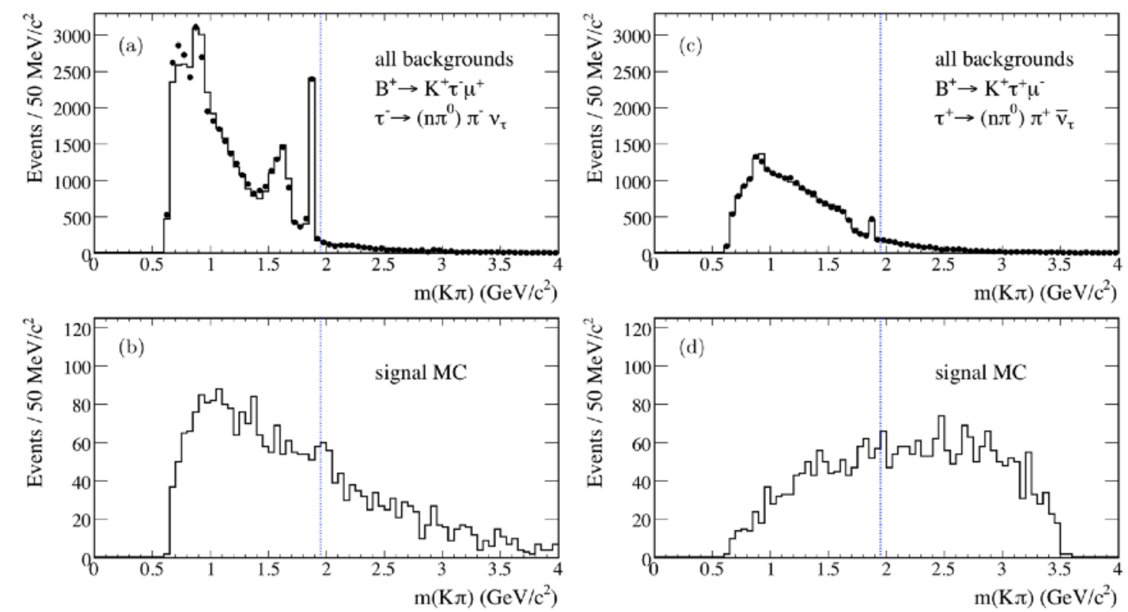
- $\mathcal{O}(200)$ decay channels with a classifier trained for each
- Reconstructs $\mathcal{O}(10k)$ unique decays chains in 6 stages

FEI : arXiv:1807.086880v4 [hep-ex]

BABAR MEASUREMENT
with hadronic tagging

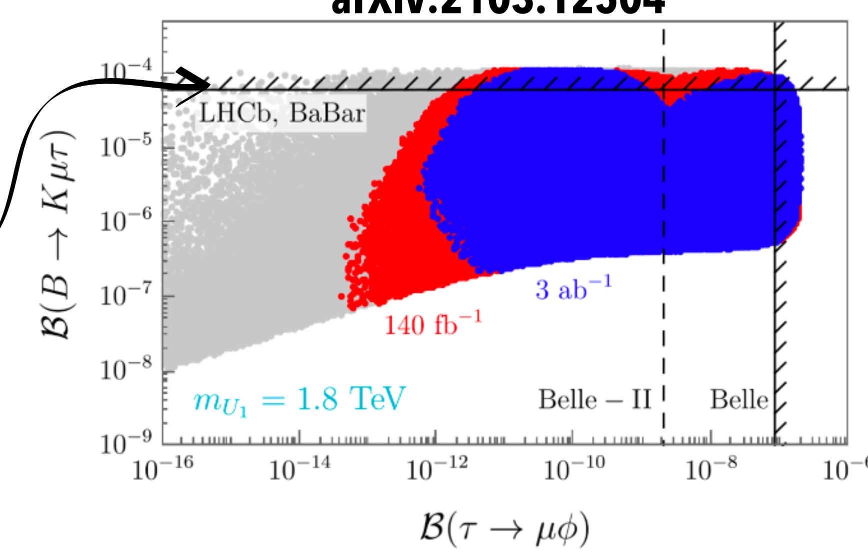
A search for the decay modes $B^{\pm} \to h^{\pm}\tau l$: arXiv:1204.2852v2 [hep-ex]

- The Btag is fully reconstructed in one of many final states of the form $B^- \to D^{(*)0}X^-$ (hadronic B decays - Semi-Exclusive Reconstruction) $\varepsilon_{SER} \sim 0.4\,\%$
- One-prong τ decays are selected $\mathscr{B}(\tau \to 1\ \mathrm{prong}) \simeq 81\,\%$
- τ candidate mass is the main discriminant against background
- .After the $m(K\pi) > 1.95\ \mathrm{GeV}/c^2$ requirement, the BB background is highly suppressed. The remaining background is dominated by continuum quark-pair production ($e^+e^- \to q\bar{q}$; $q = \{u, d, s, c\}$), which is suppressed by a likelihood ratio.



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

arXiv:2103.12504

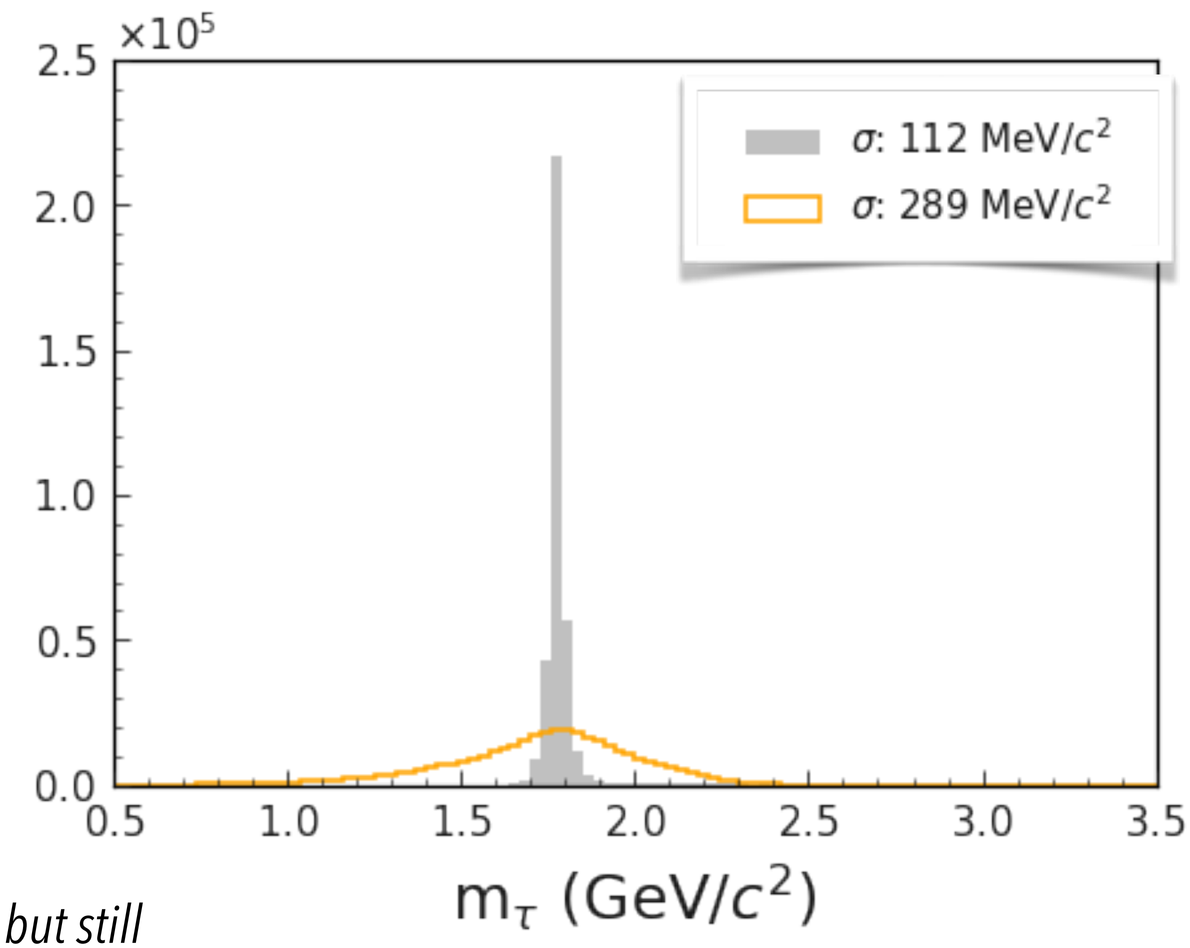


Exp.	Scans / Off-res. fb^{-1}	$\Upsilon(4S)$ 10580 MeV fb^{-1}	10^6
CLEO	17.1	16	17.1
BaBar	54	433	471
Belle	100	711	772

Millions of BB pairs

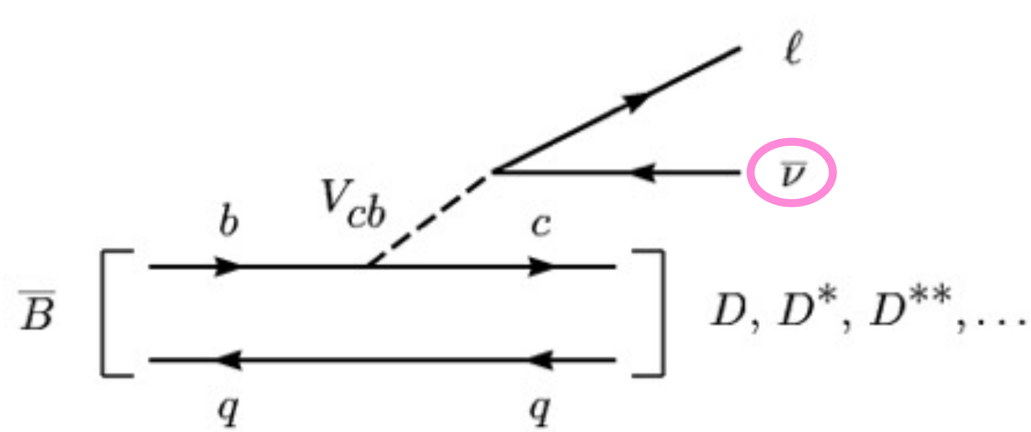
Analysis with hadronic FEI and Belle dataset is ongoing !

TAGGING METHOD AND RECOIL MASS



- Hadronic tag provides the highest purity in $\mathtt{B}_{\mathtt{tag}}$:
  - Best knowledge of the $\vec{\mathtt{p}}_{\mathtt{B}_{\mathtt{tag}}}$ ⇢ *highest resolution on* $\mathtt{m}_\tau$
  - Very costful in terms of efficiency ($\varepsilon^{\mathtt{FEI}}_{\mathtt{had}} \lesssim 1\,\%$)

- Semileptonic tag:
  - $\vec{\mathtt{p}}_{\mathtt{B}_{\mathtt{tag}}}$ is unknown due to **neutrino** ⇢ *worse resolution on* $\mathtt{m}_\tau$ *but still usable as long as signal side is well reconstructed*
  - Higher tagging efficiency ($\varepsilon^{\mathtt{FEI}}_{\mathtt{sl}} \sim 2\,\%$)

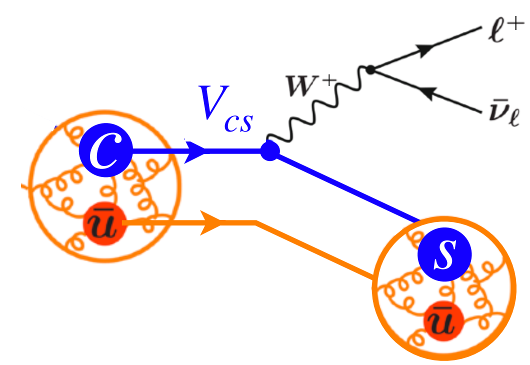


Which method to choose ?

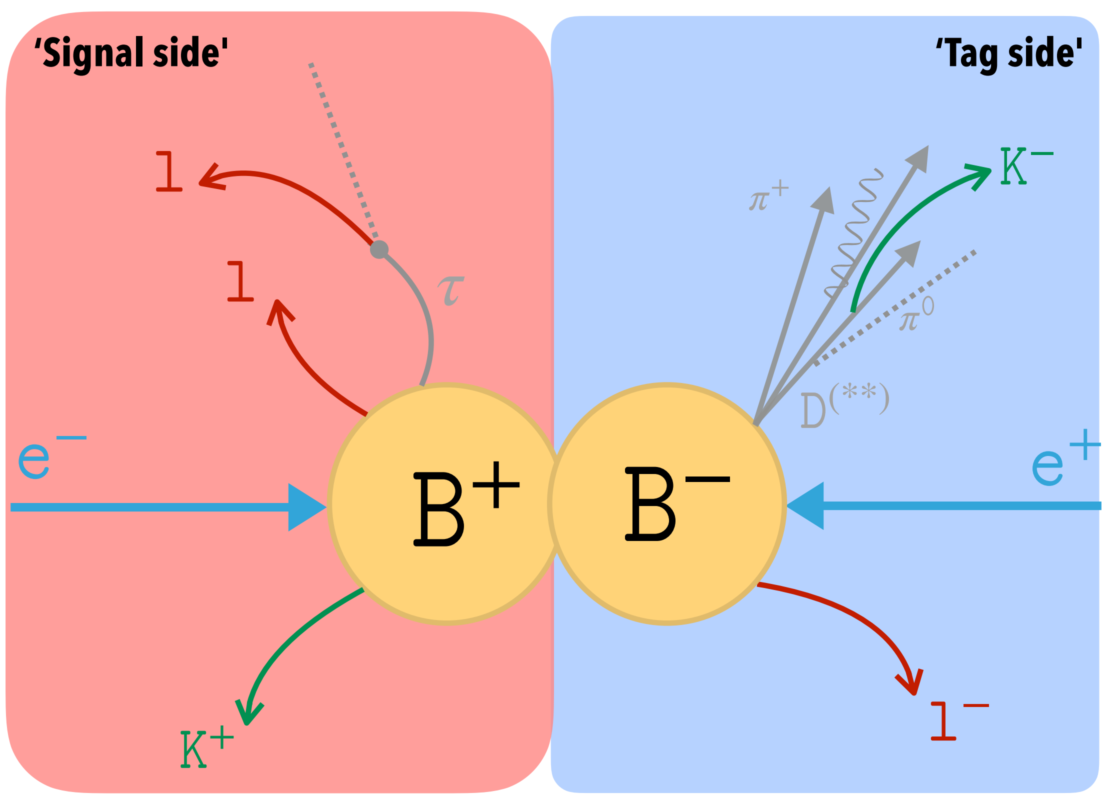
$B^+ \to K^+\tau l$: AN 'INCLUSIVE' TAGGING APPROACH

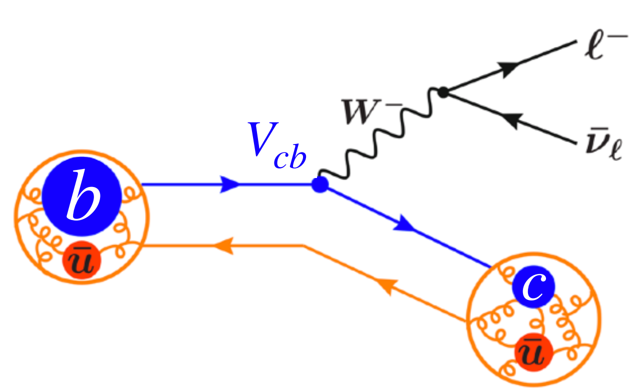
Develop a new algorithm using Belle dataset

- *Charged Kaon*
  - Reveals the presence of D^0
  - $c \to s + W^{*+}$
  - $\mathscr{B}(D^0 \to K^- X) \simeq 55\,\%$



- *Choose leptonic tau decays*
  - Only one *track (lower multiplicity)* $\mathscr{B}(\tau^+ \to l^+\nu\nu) \simeq 35\,\%$
  - **+1 lepton**





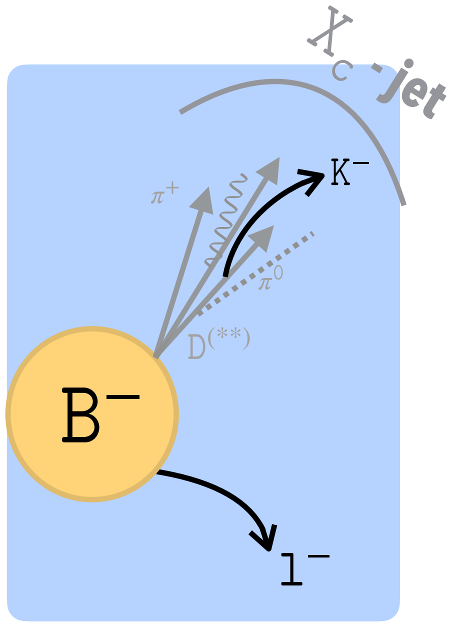
- *Choose 'inclusive' SL B tagging*
  - High b.r.
  - $b \to c + W^{*-}$
  - **+1 (high momentum) lepton**
  - Intermediate D resonances are not reconstructed

The K2l3 way…

CONCLUSION

Ongoing

- **Multi-variate analysis to suppress background**
  - *Kinematic*
  - *Jet characterisation*
  - *Event-based/Continuum suppression*
- **Thorough study of background composition via MC**



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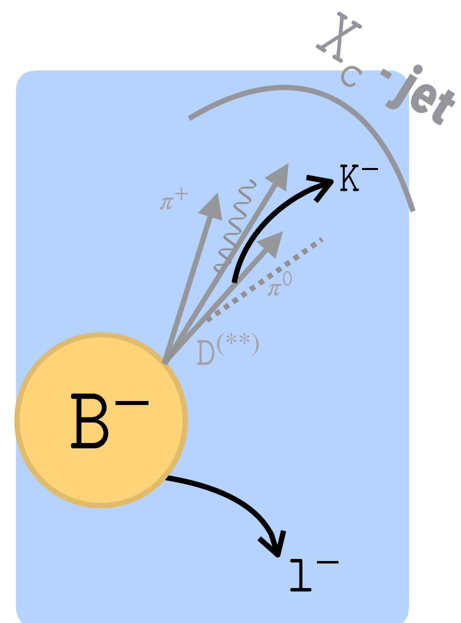


Summary

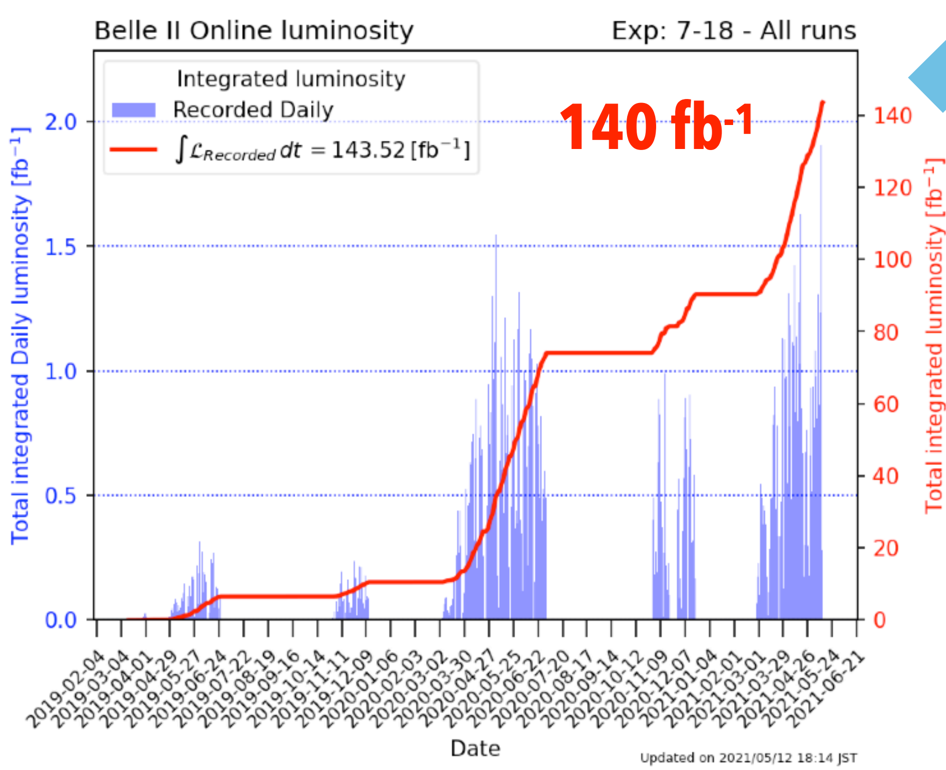
- $b \to s$ **anomalies: Hints of LFU**
- **LFV processes enhanced for NP scenarios** ⇢ $B \to K\tau l$ **(LQ?)**
- **Search of** $B \to K\tau l$ **at B-factories**
  - **BaBar:** $\mathcal{O}(10^{-5})$
  - **Belle:** FEI (ongoing)
  - **Belle:** Alternative, inclusive SL approach (me!), hopefully usable for more analyses (@ Belle II)

CONCLUSION

To do

- **Validation through MC/Data comparison**
  - Jet characterisation through $B^+ \to J\psi K^+$ method
  - Background check in data
- **Study of a specific LQ model**
- **U.L. extraction (to be compared to the more 'conservative' - but never applied yet! - FEI semileptonic)**

BELLE II IS TAKING DATA NOW!



$50\ ab^{-1}$ by ~2031

In order to shed further light on the possible origin of the existing flavour anomalies, additional independent measurements are needed!

Observables	Belle $0.71\,ab^{-1}$	Belle II $50\,ab^{-1}$
$Br(B^+ \to K^+\tau^\pm e^\mp)\cdot 10^6$	< 10	< 1
$Br(B^+ \to K^+\tau^\pm \mu^\mp)\cdot 10^6$	< 10	< 1

THANK YOU FOR
YOUR ATTENTION

BACKUP

SHAPE VARIABLES FOR CONTINUUM SUPPRESSION

Variables related to the B meson direction: the spin-1 ϒ(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 ϒ (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.

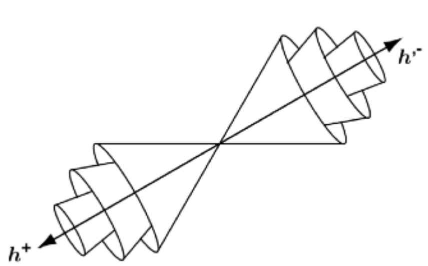
$$R_n = \frac{H_n}{H_0}$$

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 ϒ(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

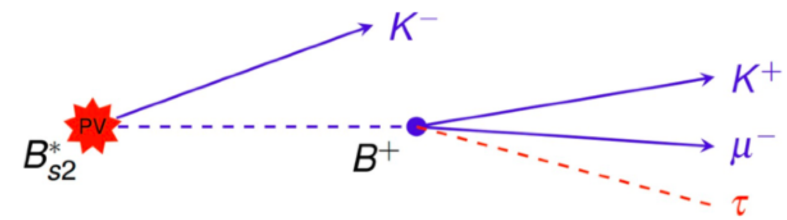


LHC*b* MEASUREMENT

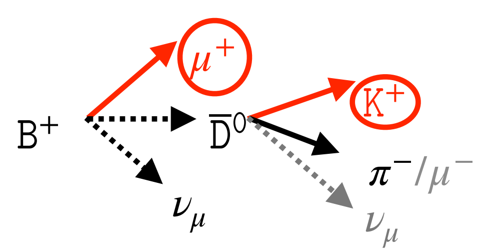
JHEP 06 (2020) 129

S. Weber - ICHEP 2020

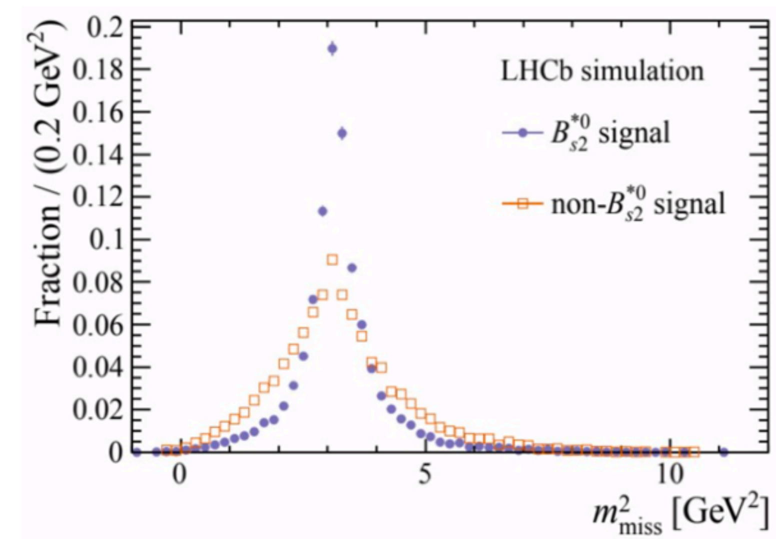
$B^+ \to K^+\mu^-\tau^+$ *(using B_{s2}^{*0})*



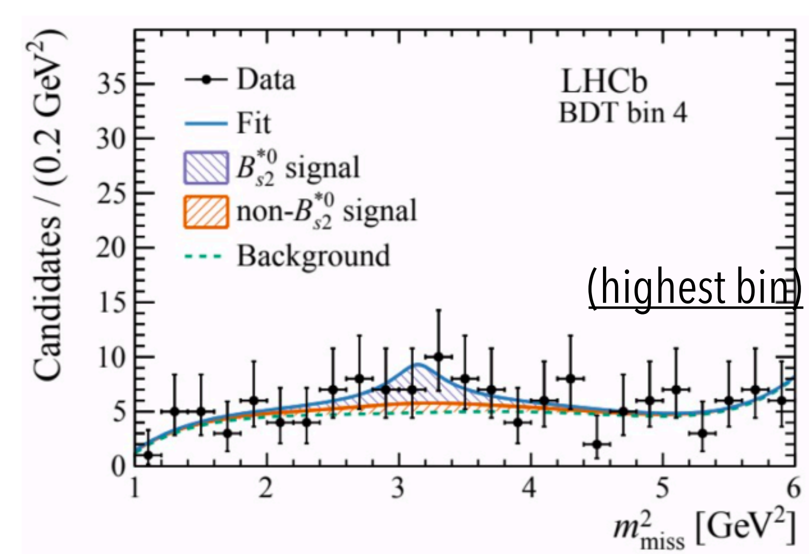
- 9 fb^{-1} @ 7, 8 and 13 TeV (Run1 & Run2)
- Use $B_{s2}^{*0} \to B^+K^-$ decay: about 1% of B^+ production
- $K^+\mu^-$ pair from secondary vertex plus additional track t^+
- Expect peak at τ mass also for B not from B_{s2}^{*0} decay, but wider distribution
- $K^+\mu^-\tau^+$ has lower backgrounds than $K^+\mu^+\tau^-$



- Remaining backgrounds produce smooth m^2_{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



BACKUP NUMBERS

Th Belle II Physics Book, **[arXiv:1808.10567]**

Belle II sensitivities

Observables	Belle $0.71\,\mathrm{ab}^{-1}$	Belle II $5\,\mathrm{ab}^{-1}$	Belle II $50\,\mathrm{ab}^{-1}$
R_K ($[1.0, 6.0]\,\mathrm{GeV}^2$)	28%	11%	3.6%
R_K ($> 14.4\,\mathrm{GeV}^2$)	30%	12%	3.6%
R_{K^*} ($[1.0, 6.0]\,\mathrm{GeV}^2$)	26%	10%	3.2%
R_{K^*} ($> 14.4\,\mathrm{GeV}^2$)	24%	9.2%	2.8%
R_{X_s} ($[1.0, 6.0]\,\mathrm{GeV}^2$)	32%	12%	4.0%
R_{X_s} ($> 14.4\,\mathrm{GeV}^2$)	28%	11%	3.4%

2019

$\mathrm{Exp:}\quad R_D = 0.340 \pm 0.030\,,\quad R_{D^*} = 0.295 \pm 0.014$

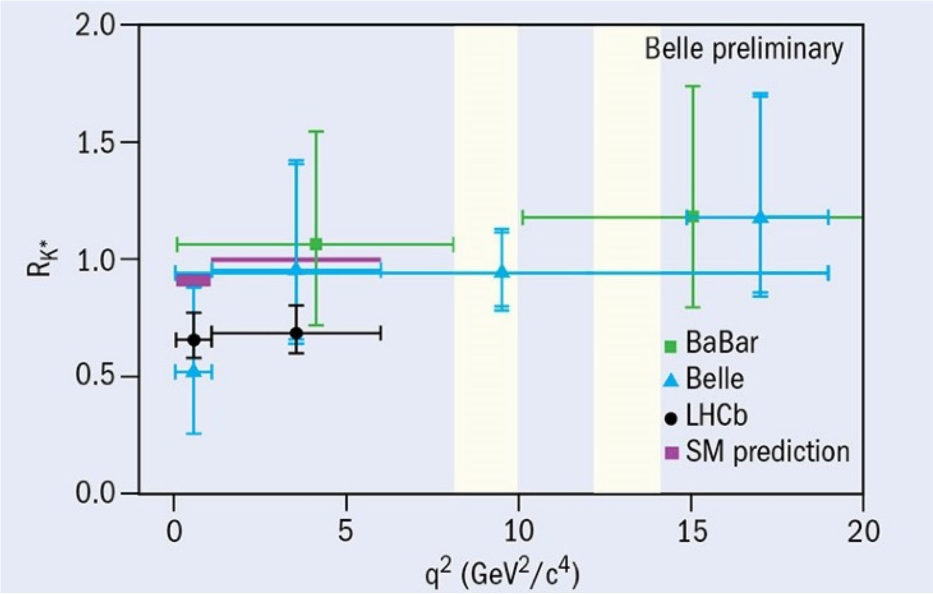
$\mathrm{SM:}\quad R_D^{\mathrm{SM}} = 0.293 \pm 0.008\,,\quad R_{D^*}^{\mathrm{SM}} = 0.257 \pm 0.003$

Moriond 2021

$R_K^{[1.1,6]} = 0.847(42)^{\mathrm{LHCb}} \quad \mathrm{vs} \quad R_K^{[1,6]} = 1.00(1)^{\mathrm{SM}}$

LHCb 2017

$R_{K^*}^{[1.1,6]} = 0.71(10)^{\mathrm{LHCb}} \quad \mathrm{vs} \quad R_{K^*}^{[1,6]} = 1.00(1)^{\mathrm{SM}}$



LUMINOSITY

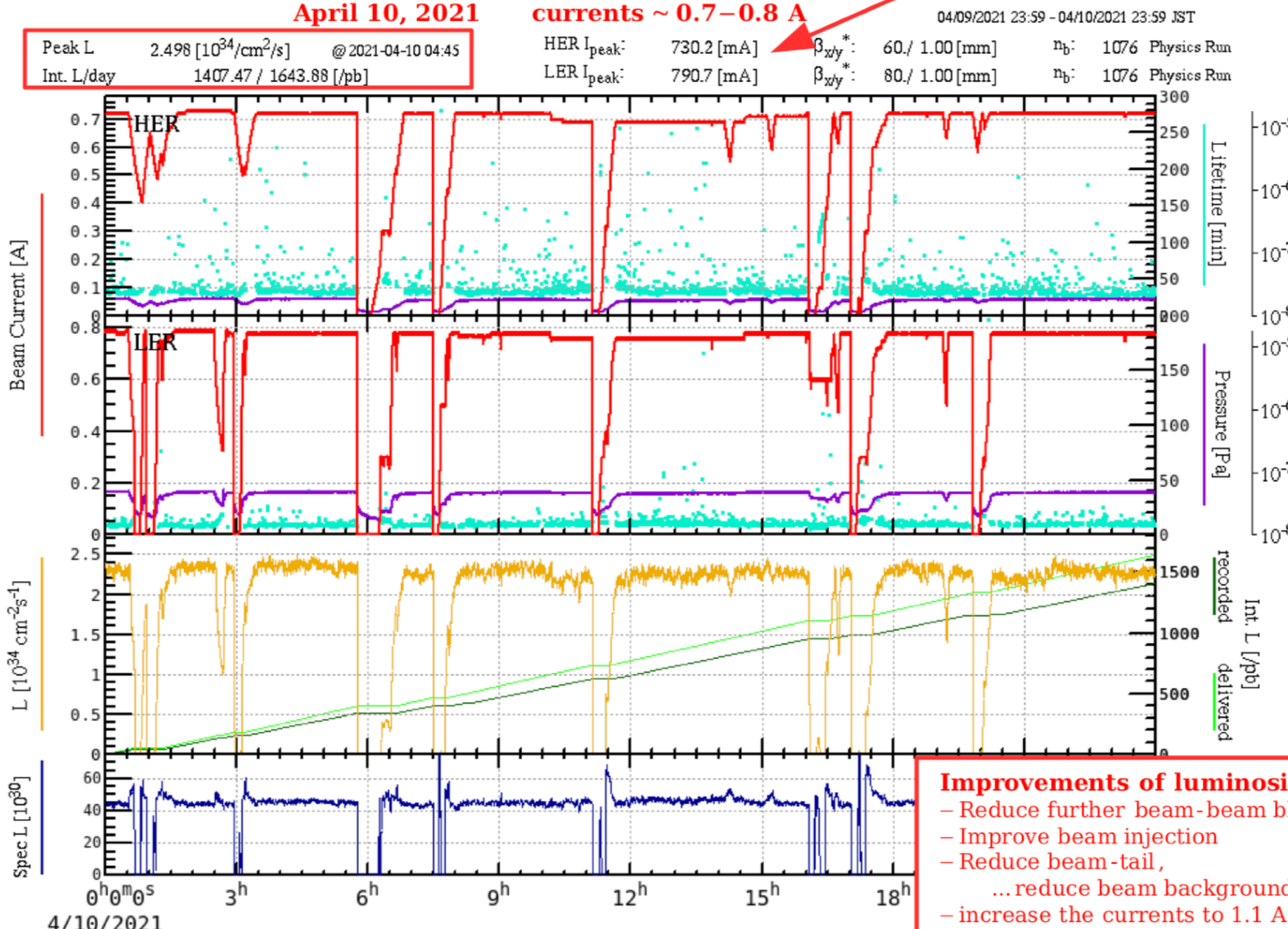
News about Belle II

- successfully introduced last year, crab waist for LER/HER
- despite difficult conditions, continued to take data since March 2020

$\sim 2.5\times10^{34}/cm^2/s$! $\sim 1.5\,fb^{-1}$ per day

record of KEKB/Belle
$2.1\times10^{34}/cm^2/s$ currents $>1\,A$
record of PEPII/BaBar
$1.2\times10^{34}/cm^2/s$ currents $>2\,A$

April 10, 2021 **currents $\sim 0.7-0.8$ A**

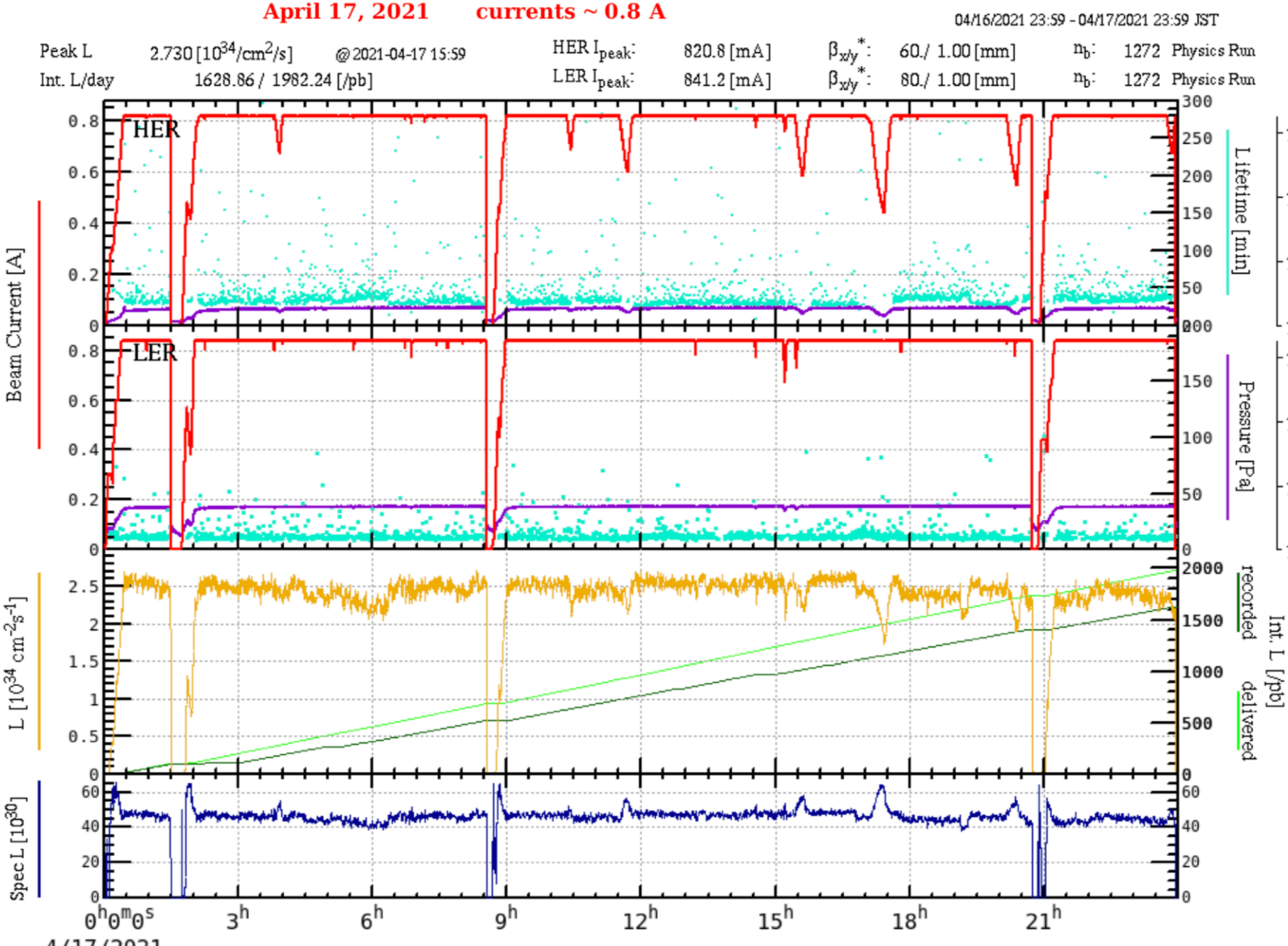


Improvements of luminosity performance
- Reduce further beam-beam blowup
- Improve beam injection
- Reduce beam-tail,
  ... reduce beam background
- increase the currents to 1.1 A
- then keep squeezing: $\beta_y^* \rightarrow 0.3$ mm

LUMINOSITY

$\sim 2.7\times10^{34}/cm^2/s$! $\sim 1.6\,fb^{-1}$ per day

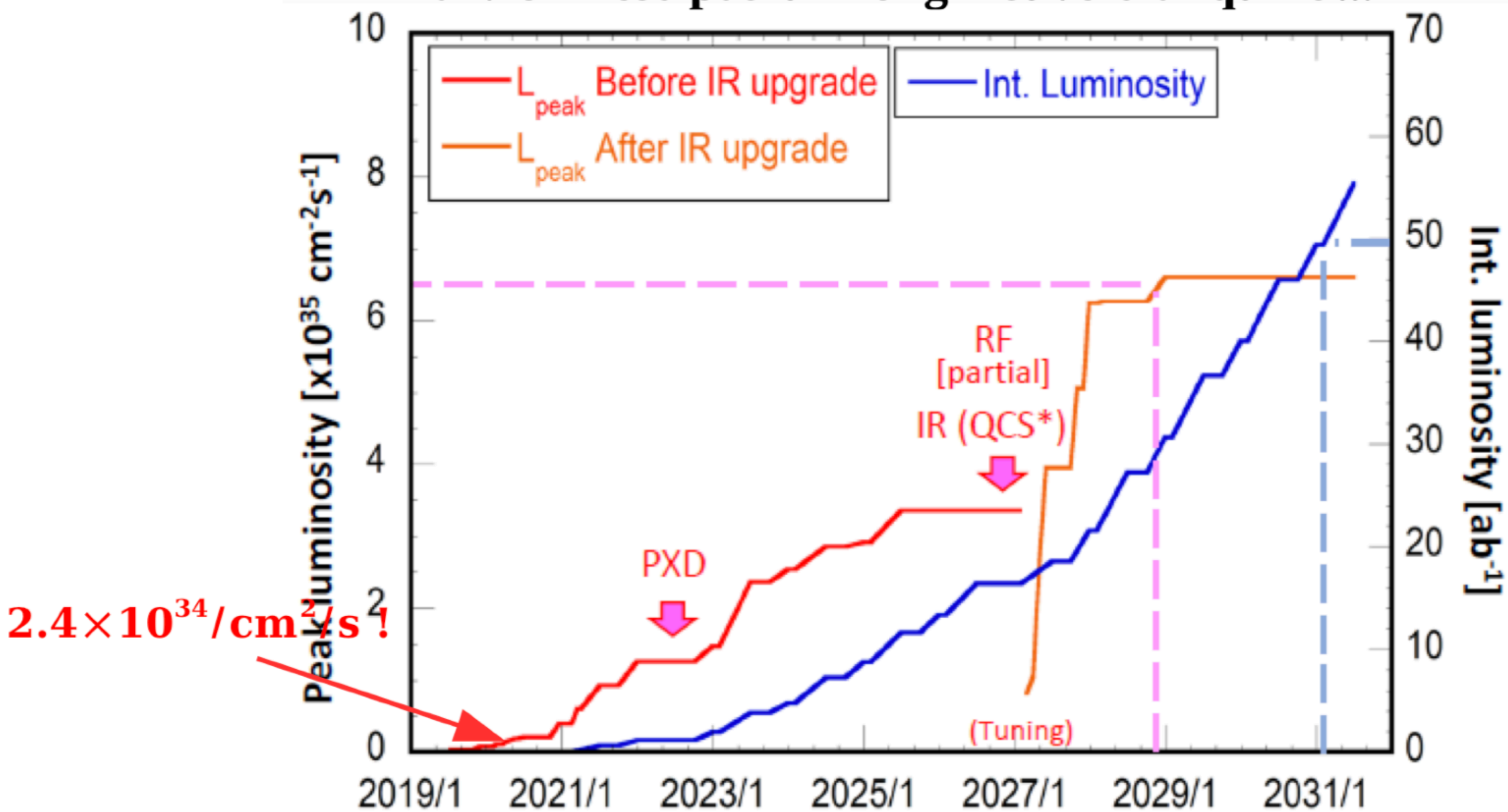
April 17, 2021 currents ~ 0.8 A



PLAN

Belle II/SuperKEKB calendar

la vie n'est pas un long fleuve tranquille...



By summer 2022: ~1 ab^{-1}

complete PXD (2 layers) installed in 2022

(replace some TOP PMT)

➔ **...et d'opportunites**

2026: collider upgrade (QCS+RF) ➔ installation upgraded detector

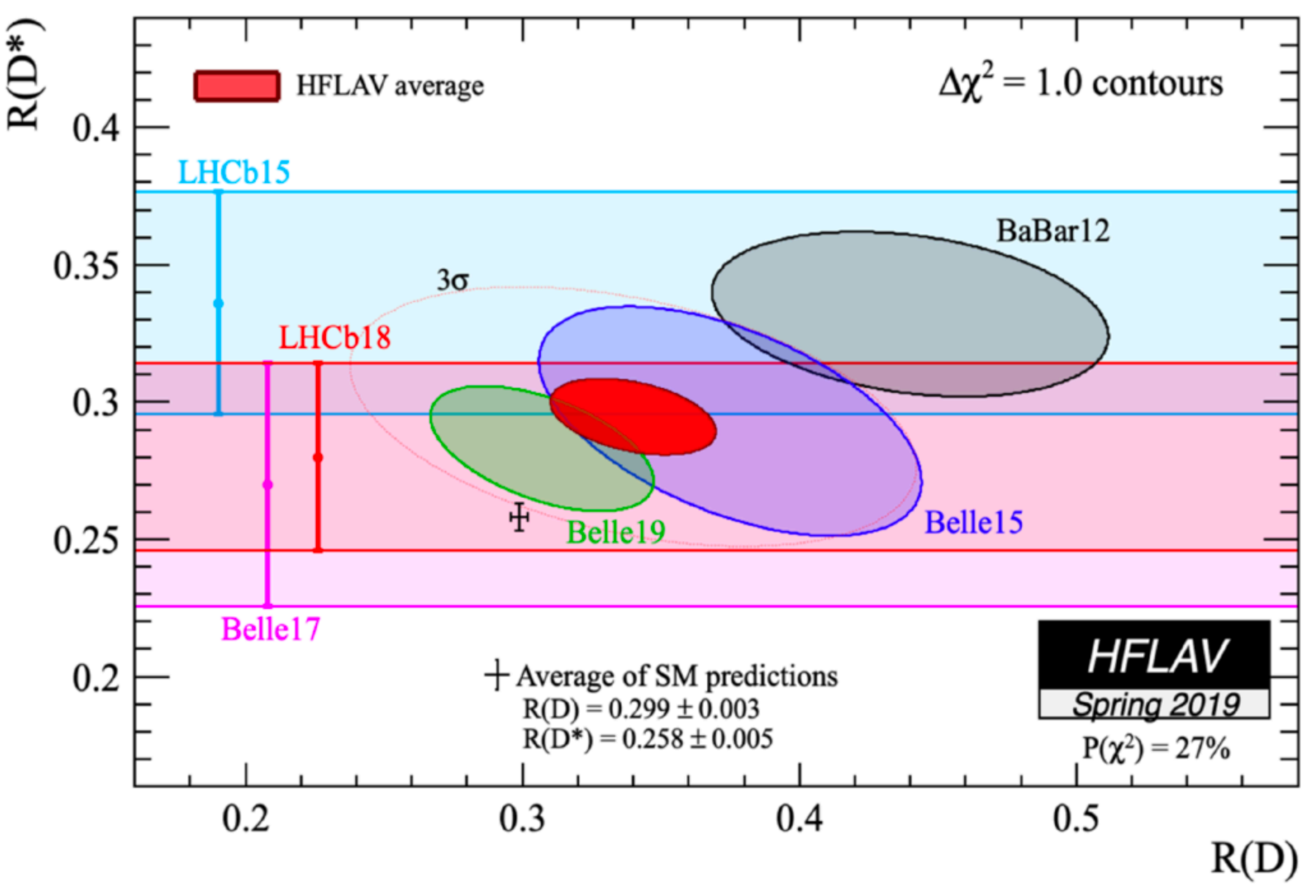
2031: 50 ab^{-1}

➔ SuperKEKB with polarized beams

writing White Paper (A.Martens for polarimety part)

CURRENT STATUS OF R(D$^{(*)}$)

$$R_{D^{(*)}} = \frac{\Gamma\left(B \to D^{(*)}\tau\nu_\tau\right)}{\Gamma\left(B \to D^{(*)}l\nu_l\right)} \qquad l \in \{e, \mu\}$$



Belle15

(Had tag)

$R(D) = 0.375 \pm 0.064 \pm 0.026$

$R(D^*) = 0.293 \pm 0.038 \pm 0.015$

Belle19

(SL tag)

$R(D) = 0.307 \pm 0.037 \pm 0.016$

$R(D^*) = 0.283 \pm 0.018 \pm 0.014$

LHCb

$R(D) = 0.336 \pm 0.027 \pm 0.030$ 2015

$R(D) = 0.280 \pm 0.018 \pm 0.029$ 2018

BaBar12

$R(D) = 0.440 \pm 0.058 \pm 0.042$

$R(D^*) = 0.332 \pm 0.024 \pm 0.018$

Average

$R(D) = 0.340 \pm 0.027 \pm 0.013$

$R(D^*) = 0.295 \pm 0.011 \pm 0.008$

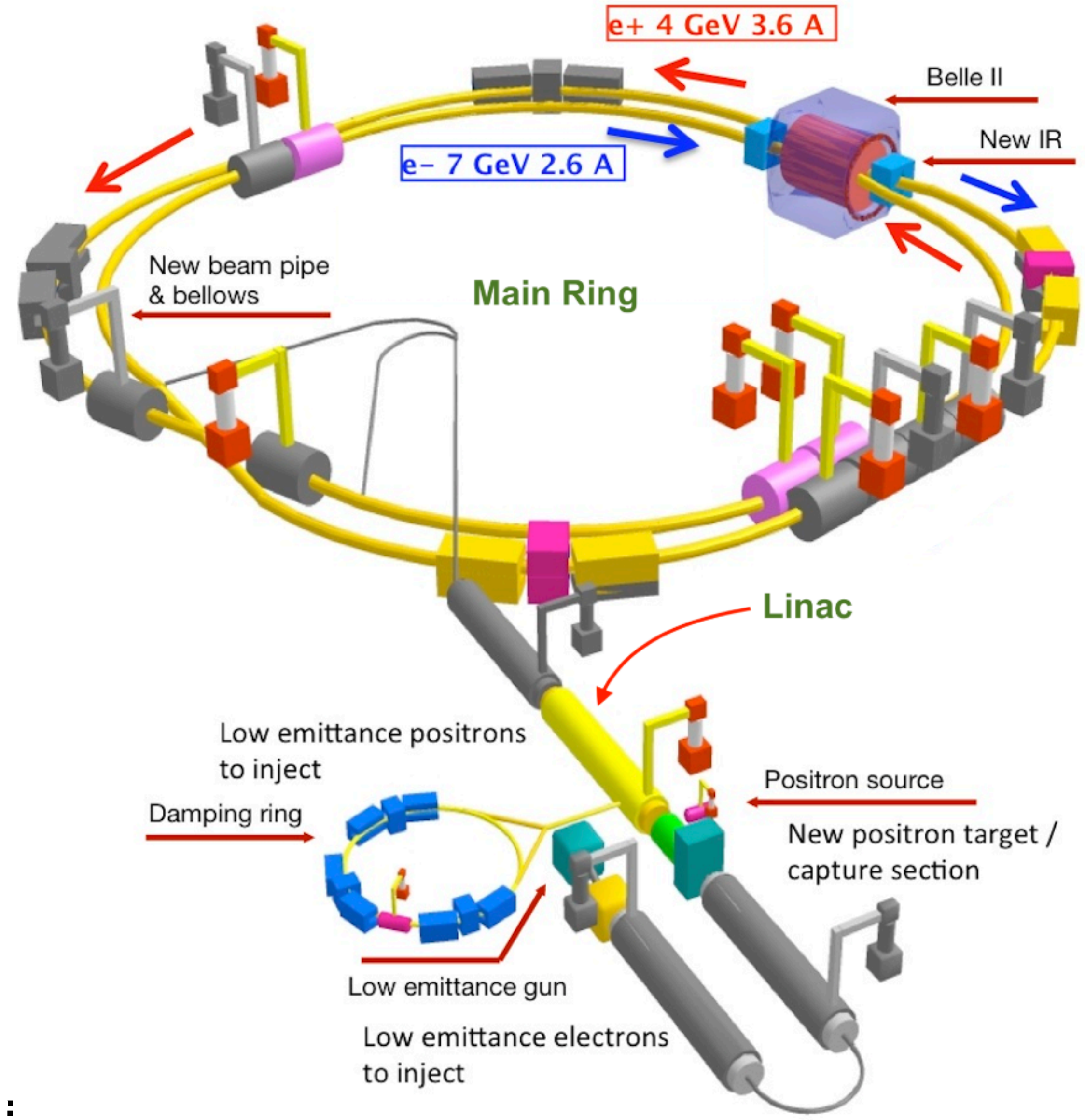
R(D) and R(D*) exceed the SM predictions given in the last row of the table above, by 1.4σ and 2.5σ respectively. Considering the R(D)-R(D*)) correlation of -0.38, the resulting combined χ^2 is 12.33 for 2 degree of freedom, corresponding to a p-value of 2.07 x 10^{-3}. The difference with the SM predictions reported above, corresponds to about 3.08σ **HFLAV**

SUPERKEKB ACCELERATOR

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

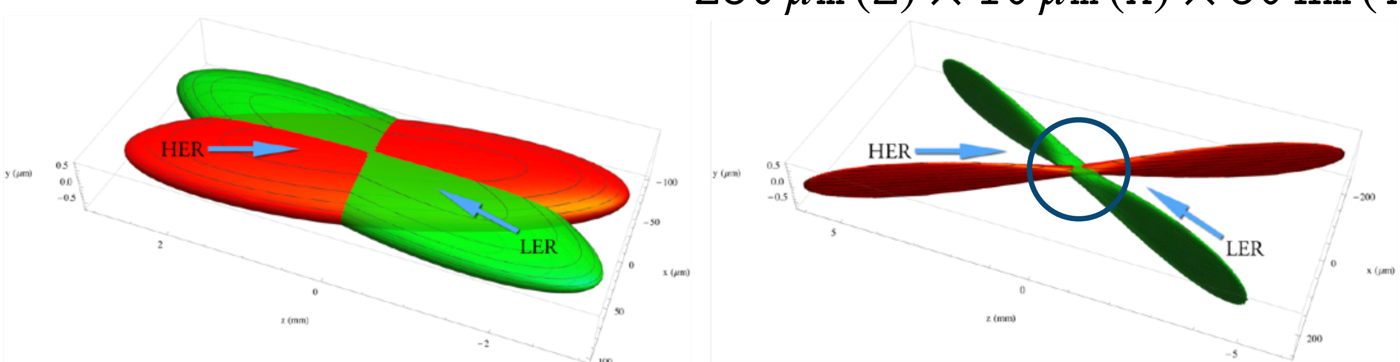
- **"Nano-beam"** scheme and higher currents
- Larger crossing angle Φ
- Lower βY by 40%

} Wrt to 1st generation B factories



Beamspot

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



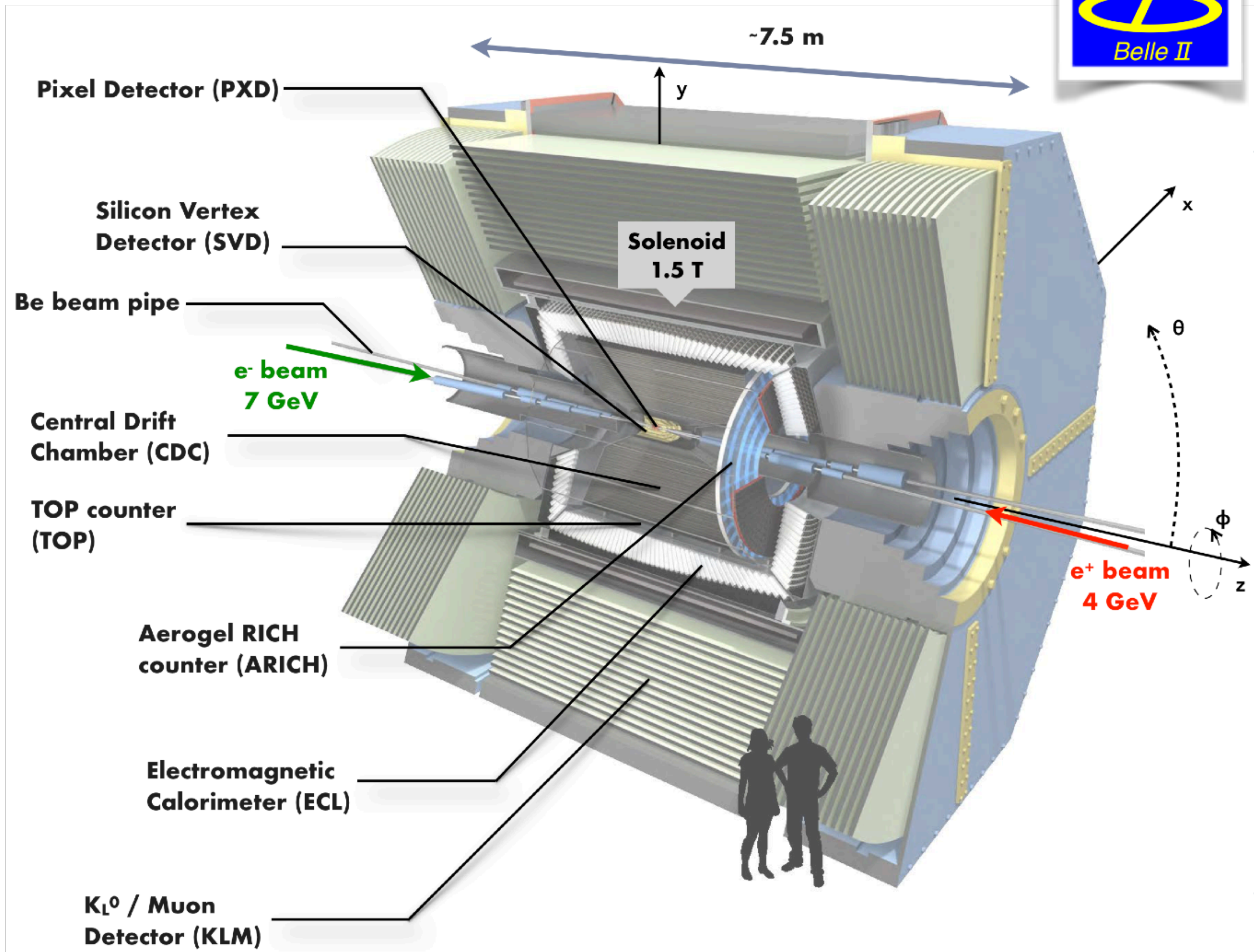
KEKB **SuperKEKB**

	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

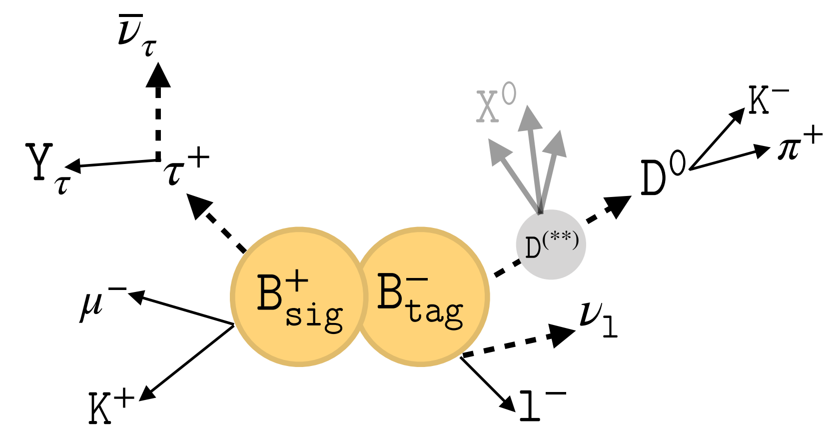
Factor 20 Factor 2-3

BELLE II EXPERIMENT

- Acceptance ~4π and extended in the FWD region.
- Vertex resolution (<100 μm), both along the beam direction and in the transverse plane.
- Very high reconstruction efficiencies for charged particles and photons, down to momenta of ~10 MeV/c.
- Very good momentum resolution for a wide range of momenta.
- Precise measurements of γ energy and position, from 20 MeV to 8 GeV in order to reconstruct π^0 mesons.
- Highly efficient particle identification for electrons and muons, as well as a π/K separation over from ~0.6 GeV/c to ~4 GeV/c.



STUDY ON TAG EFFICIENCY



The main differences of this approach with respect to SL FEI are:

- Give up the reconstruction of the intermediate $D^{*(*)0}$ resonances (**efficiency**)
- Use only the $D^0 \to K\pi$ mode (**purity**)

$$\frac{\varepsilon_{SL}}{\varepsilon_{D^0 l}} = \frac{\mathscr{B}(B^+ \to \overline{D}^0 X l \nu_l)\, \varepsilon_{D^0}\, \varepsilon_X\, \varepsilon_l}{\mathscr{B}(B^+ \to \overline{D}^0 X l \nu_l)\, \varepsilon'_{D^0}\, \varepsilon_l} = \frac{\varepsilon_{D^0}\, \varepsilon_X}{\varepsilon'_{D^0}}$$

$$\sim \frac{0.12}{0.03} \times [0.30 + 0.63(0.65\, \varepsilon_{\pi^0} + 0.35\, \varepsilon_\gamma) + 0.07\, \varepsilon_t^2] \sim 2.6$$

$$\varepsilon_{D^0} = \sum_{i \in FEI} \varepsilon_i \mathscr{B}_i \sim 0.12$$

$$\varepsilon'_{D^0} = \varepsilon_{K\pi} \mathscr{B}_{K\pi} \sim 0.03$$

$$\frac{\varepsilon_{SL}}{\varepsilon_{Kl}} = \frac{\mathscr{B}(B^+ \to \overline{D}^0 X l \nu_l)\, \varepsilon_{D^0}\, \varepsilon_X\, \varepsilon_l}{\mathscr{B}(B^+ \to \overline{D}^0 X l \nu_l)\, \mathscr{B}(\overline{D}^0 \to K^+ X)\, \varepsilon_t\, \varepsilon_l} = \frac{\varepsilon_{D^0}\, \varepsilon_X}{\mathscr{B}(\overline{D}^0 \to K^+ X)\, \varepsilon_t}$$

$$\sim \frac{0.12}{0.4} \times [0.30 + 0.63(0.65\, \varepsilon_{\pi^0} + 0.35\, \varepsilon_\gamma) + 0.07\, \varepsilon_t^2] \sim 0.2$$

Eff. - Assumed (%)

- π^0: 40
- γ: 60

Eff. - Measured (%)

- Track: ~70
- μ_τ: ~40

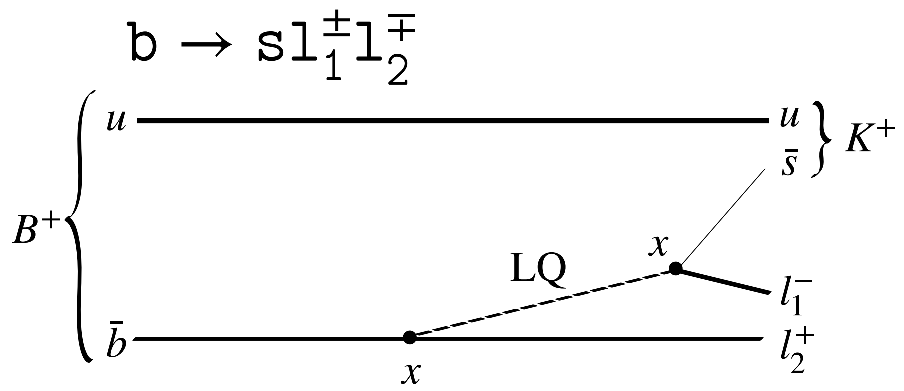
B.R.'s (%)

- $B^- \to X_c l^- \nu$: 11
- $B^- \to D^0 X l^- \nu$: 10
- $\tau \to 3\pi$: 9
- $\tau \to l$: 18
- $\tau \to$ 1-pr: 72
- $B^- \to D^0 X$: 79
- $D^0 \to K^- X$: 55
- $D^0 \to K^- \pi^+$: 4

- *An l indicates an e or a μ mode, not a sum over these modes {PDG}*
- *1-pr: π, e, μ, ρ*

Tag	Tag. eff.	Y_τ	τ ch. eff.	ε_{TOT}
HAD fei	0.50%	1-prong	34%	0.08%
SL fei	1.00%	lept	20%	0.09%
$D^0(K\pi)$+l	0.38%	lept	20%	0.03%
$D^0(K\pi)$+l	0.38%	1-prong	34%	0.06%
K+l	5.20%	lept	20%	0.48%
K+l	5.20%	1-prong	34%	0.83%

THEORY - U_1 MODEL



Weak singlet vector LQ that can simultaneously explain R_K and R_D - Absence of the tree level constraint coming from $\mathscr{B}(B \to K^{(*)}\nu\bar{\nu})$. Such NP extension is non-renormalizable at loop level: additional assumptions must be specified (e.g. completions involving Z′ and a color-octet of vector bosons).

$$U_1 = (\mathbf{3}, \mathbf{1}, 2/3)$$
$$Q = Y + T_3 = 0 + 2/3 = 2/3$$

"Simplified models with LQ states seem to be favored. Among them, the U_1 case stands for simplicity & phenomenological success." G. Isidori (FCPC)

$$\mathcal{L} \supset + x_{1\,ij}^{LL} \bar{Q}_L^{i,a} \gamma^\mu U_{1,\mu} L_L^{j,a} + x_{1\,ij}^{RR} \bar{d}_R^i \gamma^\mu U_{1,\mu} e_R^j + x_{1\,ij}^{\overline{RR}} \bar{u}_R^i \gamma^\mu U_{1,\mu} \nu_R^j + \text{h.c.}.$$

'Genuine' LQ: does not possess "diquark" couplings due to the SM quantum number assignment.

x denotes the coupling matrices of scalar (vector) leptoquarks with the quark–lepton pairs **arXiv:1603.04993v3 [hep-ph]**

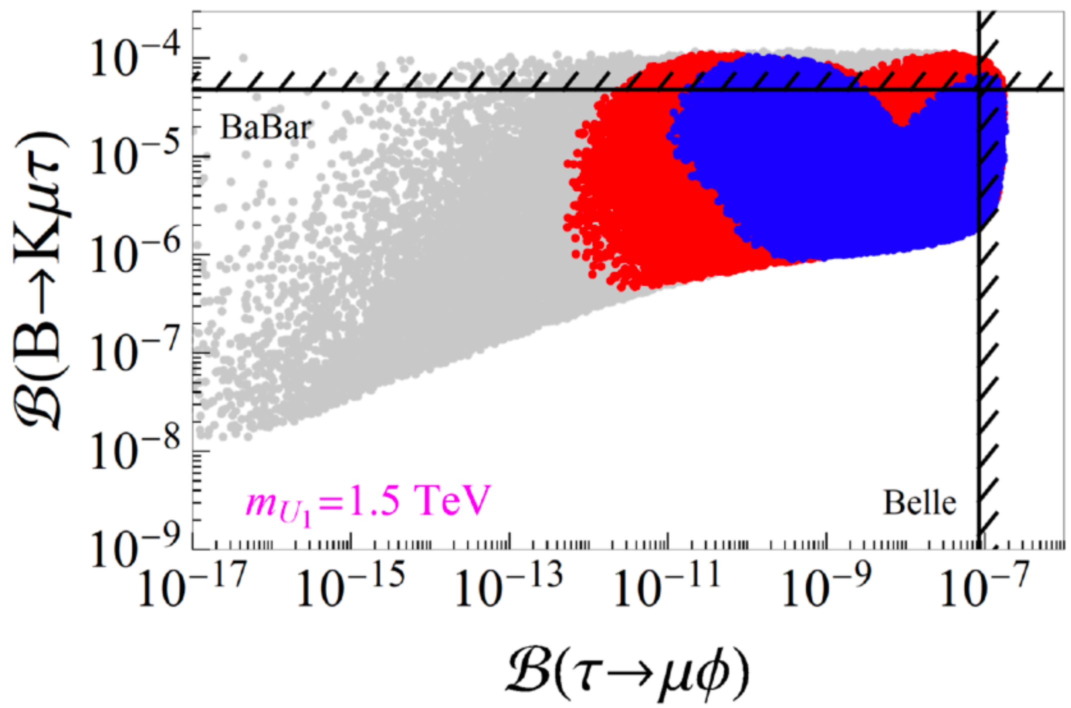
arXiv:2103.12504v1 [hep-ph]

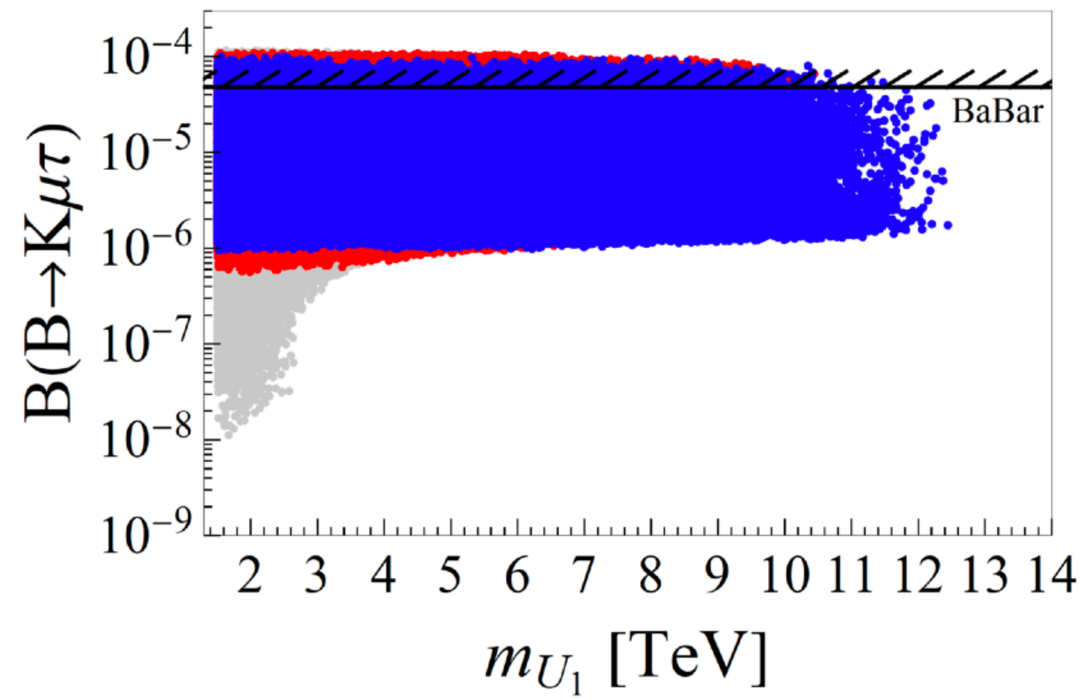
Model	$R_{K^{(*)}}$	$R_{D^{(*)}}$	$R_{K^{(*)}}$ & $R_{D^{(*)}}$
S_3 $(\bar{\mathbf{3}}, \mathbf{3}, 1/3)$	✓	✗	✗
S_1 $(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$	✗	✓	✗
R_2 $(\mathbf{3}, \mathbf{2}, 7/6)$	✗	✓	✗
U_1 $(\mathbf{3}, \mathbf{1}, 2/3)$	✓	✓	✓
U_3 $(\mathbf{3}, \mathbf{3}, 2/3)$	✓	✗	✗

TABLE III. *Summary of the LQ models which can accommodate $R_{K^{(*)}}$ (first column), $R_{D^{(*)}}$ (second column), and both $R_{K^{(*)}}$ and $R_{D^{(*)}}$ (third column), without being in conflict with existing constraints. See text for details.*

THEORY - PREDICTION ON BR

arXiv:1808.08179v3 [hep-ph]

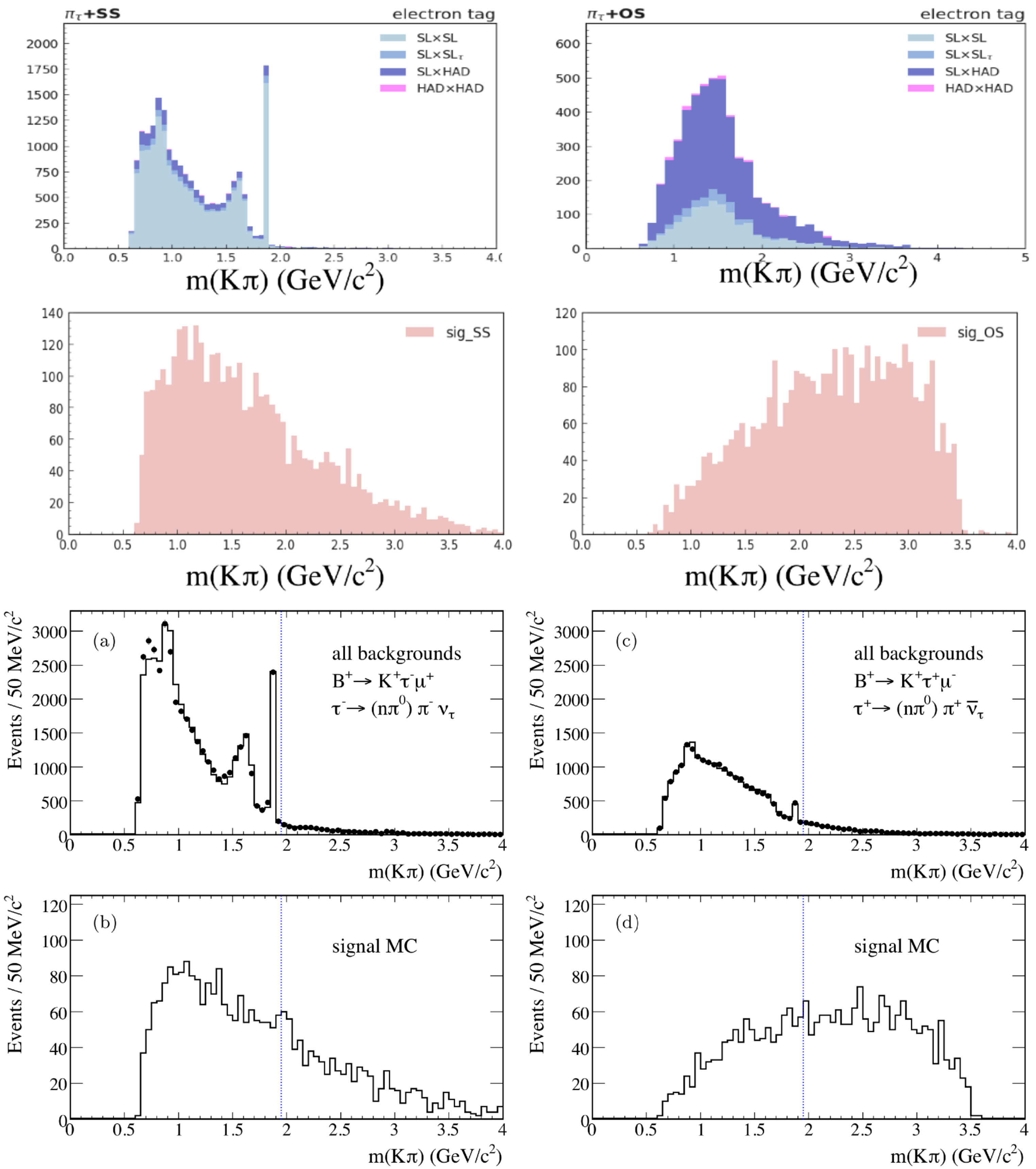




Gray points are excluded by current LHC data (36 fb^{-1}) on pp → ll (l = μ,τ). The future LHC sensitivity is depicted by the red points, which were obtained by extrapolating current data to 300 fb^{-1}, as discussed in Sec. 4.2. Blue points are allowed by all constraints, including the extrapolated LHC results to 300 fb^{-1}.

[…] In particular we find the lower bound on the LFV mode B(B → Kμτ) few×10^{-7} for any mass of m_{U1} in which Yukawa couplings are kept within the perturbativity limits and in the minimal U1 scenario in which only left-handed couplings are allowed to take values different from zero. The upper bound is superseded by the current experimental bound $B(B \to K\mu\tau)^{exp} < 4.8\times10^{-5}$, which can be improved both at LHCb and Belle II. Improving that bound by two orders of magnitude can therefore either exclude or, if observed, corroborate the validity of the minimal U1 scenario.

$m(K\pi)$ - COMPARISON WITH BABAR



FEI PERFORMANCE

	$B^{\pm}$	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 %

arXiv:hep-ex/1807.08680v4

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

HADRONIC

~10% purity

	B^+	B^0
FEI efficiency (%) Belle II	0.7	0.5
Full Reconstruction (%) Belle	0.45	0.29

SEMILEPTONIC

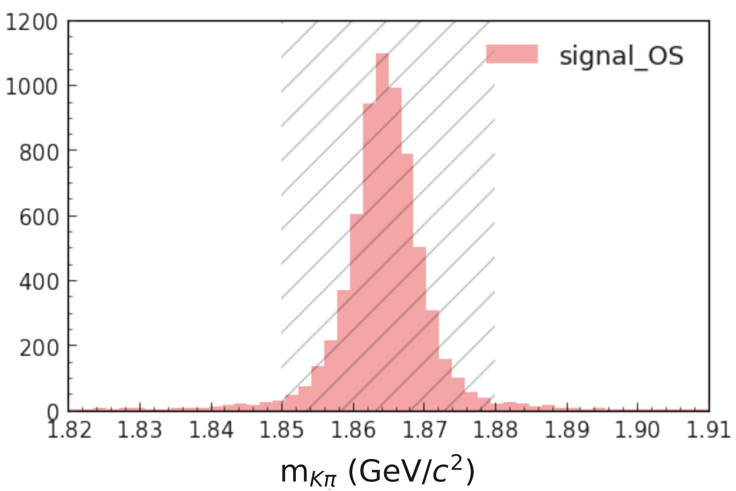
~5% purity

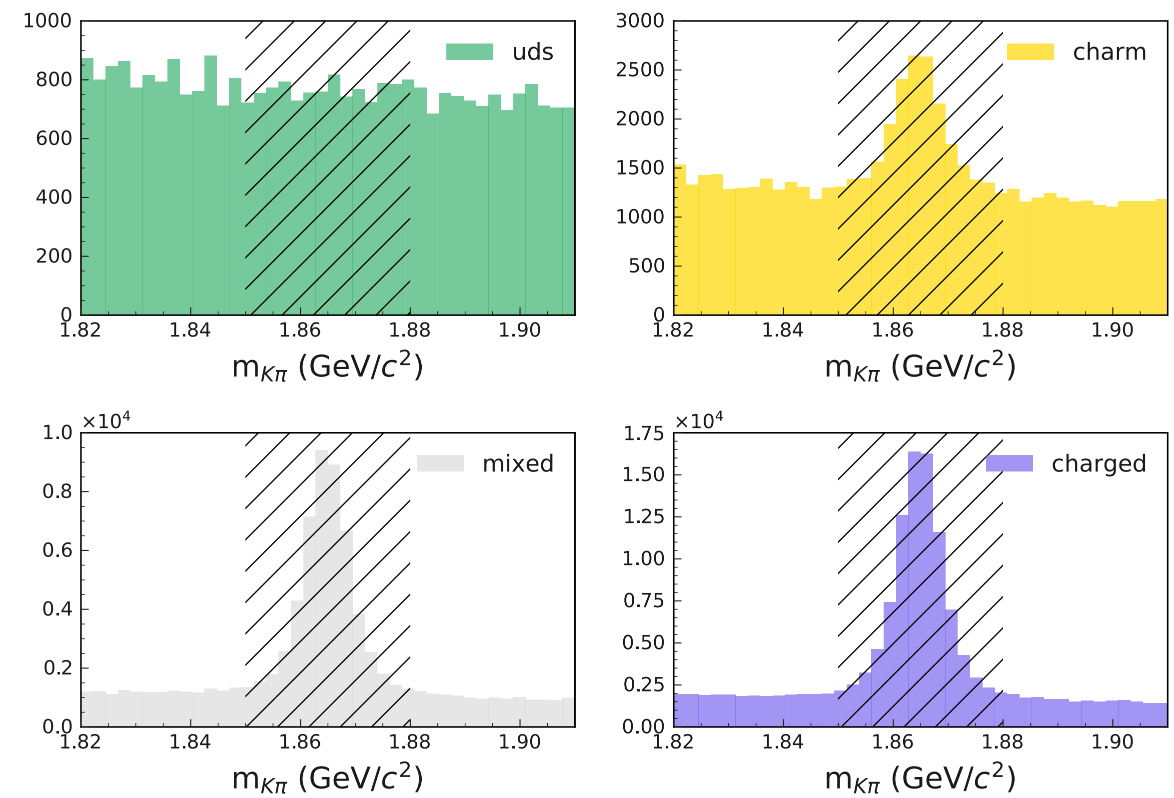
	B^+	B^0
FEI efficiency (%) Belle II	2.04	1.80
Full Reconstruction (%) Belle	0.34	0.31

Swapped?

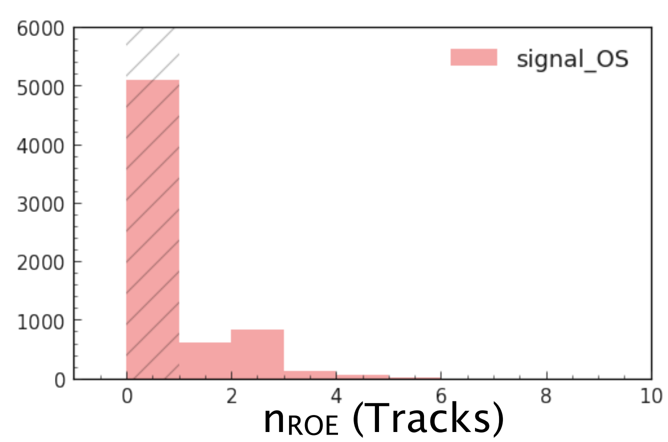
OS MODE - $m(K\pi)$ AND ROE

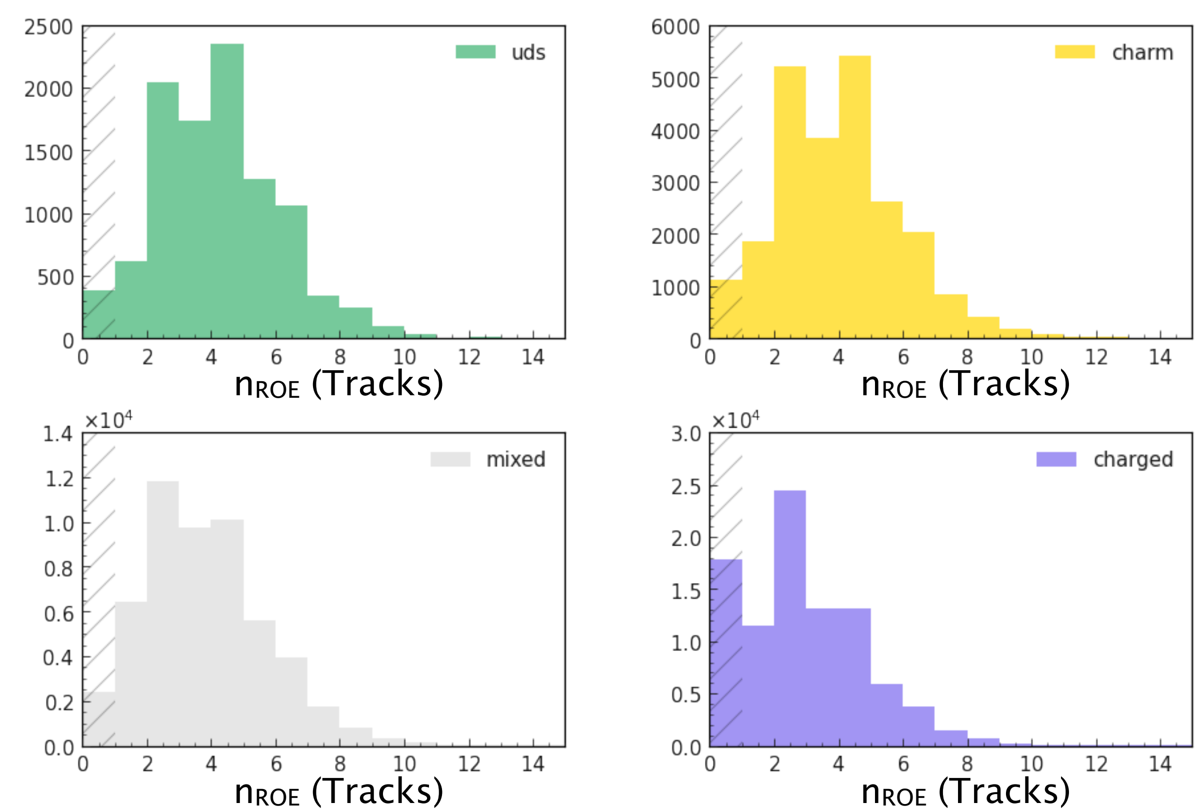
- **1st cut:** 3-σ $m(K\pi)$ interval → effective on `uds` and `charm` background



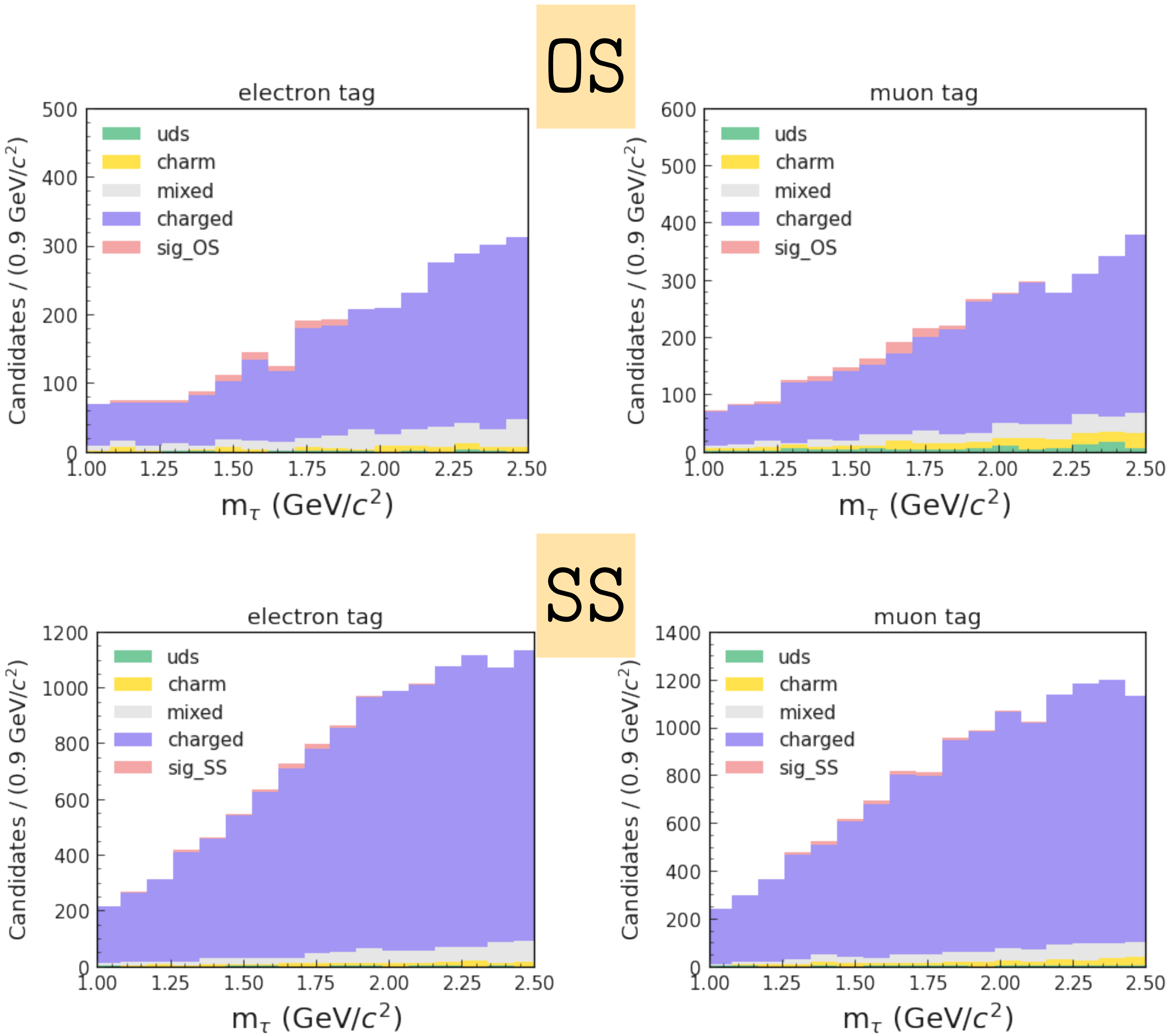


- **2nd cut:** The ROE, **deprived of the 1-prong τ daughter** candidate, has mostly zero tracks



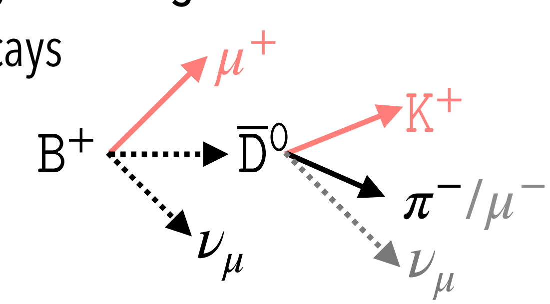


RECOIL m_τ - OS AND SS MODE



- Similar level of background for the two tag modes
- B^+B^- main source of background

- Main differences wrt OS case
  - *For the signal:* **No swaps between $\mu_{\mathtt{tag}}$ and $\mu_{\mathtt{sig}}$**
  - **Higher background** from CF decays



Signal b.r. ~2.5x10^{-4}. Still long way to go!

BABAR RESULTS

TABLE IV: Results for the observed sideband events $N_{sb,i}$, signal-to-sideband ratio $R_{b,i}$, expected background events b_i, number of observed events n_i, signal efficiency $\epsilon_{h\tau\ell,i}$ (assuming uniform three-body phase space decays) for each τ channel i and $B \to h\tau\ell$ [9] branching fraction central value and 90% C.L. upper limits (UL). All uncertainties include statistical and systematic sources.

Mode	τ channel	$N_{sb,i}$	$R_{b,i}$	b_i	n_i	$\epsilon_{h\tau\ell,i}$	$\mathcal{B}(B \to h\tau\ell)$ ($\times 10^{-5}$) central value	$\mathcal{B}(B \to h\tau\ell)$ ($\times 10^{-5}$) 90% C.L. UL
$B^+ \to K^+\tau^-\mu^+$	e	22	0.02 ± 0.01	0.4 ± 0.2	2	$(2.6 \pm 0.2)\%$	$0.8\,^{+1.9}_{-1.4}$	< 4.5
	μ	4	0.08 ± 0.05	0.3 ± 0.2	0	$(3.2 \pm 0.4)\%$		
	π	39	0.045 ± 0.020	1.8 ± 0.8	1	$(4.1 \pm 0.4)\%$		
$B^+ \to K^+\tau^+\mu^-$	e	5	0.03 ± 0.01	0.2 ± 0.1	0	$(3.7 \pm 0.3)\%$	$-0.4\,^{+1.4}_{-0.9}$	< 2.8
	μ	3	0.06 ± 0.03	0.2 ± 0.1	0	$(3.6 \pm 0.7)\%$		
	π	153	0.045 ± 0.010	6.9 ± 1.5	11	$(9.1 \pm 0.5)\%$		
$B^+ \to K^+\tau^-e^+$	e	6	0.095 ± 0.020	0.6 ± 0.1	2	$(2.2 \pm 0.2)\%$	$0.2\,^{+2.1}_{-1.0}$	< 4.3
	μ	4	0.025 ± 0.010	0.1 ± 0.1	0	$(2.7 \pm 0.6)\%$		
	π	33	0.045 ± 0.015	1.5 ± 0.5	1	$(4.8 \pm 0.6)\%$		
$B^+ \to K^+\tau^+e^-$	e	8	0.10 ± 0.06	0.8 ± 0.5	0	$(2.8 \pm 1.1)\%$	$-1.3\,^{+1.5}_{-1.8}$	< 1.5
	μ	3	0.045 ± 0.020	0.1 ± 0.1	0	$(3.2 \pm 0.7)\%$		
	π	132	0.035 ± 0.010	4.6 ± 1.3	4	$(8.7 \pm 1.2)\%$		
$B^+ \to \pi^+\tau^-\mu^+$	e	55	0.017 ± 0.010	0.9 ± 0.6	0	$(2.3 \pm 0.2)\%$	$0.4\,^{+3.1}_{-2.2}$	< 6.2
	μ	10	0.11 ± 0.04	1.1 ± 0.4	2	$(2.9 \pm 0.4)\%$		
	π	93	0.035 ± 0.010	3.3 ± 0.9	4	$(2.8 \pm 0.2)\%$		
$B^+ \to \pi^+\tau^+\mu^-$	e	171	0.012 ± 0.003	2.1 ± 0.5	2	$(3.8 \pm 0.3)\%$	$0.0\,^{+2.6}_{-2.0}$	< 4.5
	μ	89	0.04 ± 0.01	3.6 ± 0.9	4	$(4.8 \pm 0.3)\%$		
	π	512	0.050 ± 0.005	25 ± 3	23	$(9.1 \pm 0.6)\%$		
$B^+ \to \pi^+\tau^-e^+$	e	1	0.050 ± 0.025	0.1 ± 0.1	1	$(2.0 \pm 0.8)\%$	$2.8\,^{+2.4}_{-1.9}$	< 7.4
	μ	16	0.025 ± 0.010	0.4 ± 0.2	1	$(2.8 \pm 0.3)\%$		
	π	172	0.035 ± 0.008	6.0 ± 1.4	7	$(5.8 \pm 0.3)\%$		
$B^+ \to \pi^+\tau^+e^-$	e	31	0.033 ± 0.013	1.0 ± 0.4	0	$(2.9 \pm 0.3)\%$	$-3.1\,^{+2.4}_{-2.1}$	< 2.0
	μ	247	0.012 ± 0.005	3.0 ± 1.2	2	$(4.6 \pm 0.4)\%$		
	π	82	0.07 ± 0.03	5.7 ± 2.5	3	$(3.7 \pm 1.0)\%$		

SEMILEPTONIC B DECAYS

SEMILEPTONIC B DECAYS - Belle 2

B.R.	Channel	B.R.(CAT)	B.R.(CAT)/TOT	B+ --> D0 X l v		
0,05490	anti-D*0 e+ nu_e	0,08528	0,79	0,098	0,31	direct
0,00050	anti-D*0 pi0 e+ nu_e				0,64	from D*0
0,00113	anti-D*0 pi+ pi- e+ nu_e					
0,00075	anti-D*0 pi0 pi0 e+ nu_e					
0,00201	anti-D*0 eta e+ nu_e					
0,00050	anti-D0 pi0 e+ nu_e					
0,00023	anti-D0 pi+ pi- e+ nu_e					
0,02310	anti-D0 e+ nu_e					
0,00015	anti-D0 pi0 pi0 e+ nu_e					
0,00201	anti-D0 eta e+ nu_e					
0,00100	D*- pi+ e+ nu_e	0,00215	0,02			
0,00100	D- pi+ e+ nu_e					
0,00015	D- pi+ pi0 e+ nu_e					
0,00030	D_s*- K+ e+ nu_e	0,00060	0,01			
0,00030	D_s- K+ e+ nu_e			Of which going to anti-D0		
0,00757	anti-D_10 e+ nu_e	0,01950	0,18	0,11		
0,00389	anti-D_0*0 e+ nu_e					
0,00431	anti-D'_10 e+ nu_e					
0,00373	anti-D_2*0 e+ nu_e					
		0,10753	1,00			

SEMILEPTONIC B DECAYS - Belle

B.R.	Channel	B.R.(CAT)	B.R.(CAT)/TOT	B+ --> D0 X l v		
0,05790	anti-D*0 e+ nu_e	0,08180	0,72	0,100	0,30	direct
0,00030	anti-D*0 pi0 e+ nu_e				0,63	from D*0
0,00000	anti-D*0 pi+ pi- e+ nu_e					
0,00000	anti-D*0 pi0 pi0 e+ nu_e					
0,00000	anti-D*0 eta e+ nu_e					
0,00050	anti-D0 pi0 e+ nu_e					
0,00000	anti-D0 pi+ pi- e+ nu_e					
0,02310	anti-D0 e+ nu_e					
0,00000	anti-D0 pi0 pi0 e+ nu_e					
0,00000	anti-D0 eta e+ nu_e					
0,00070	D*- pi+ e+ nu_e	0,00180	0,02			
0,00110	D- pi+ e+ nu_e					
0,00000	D- pi+ pi0 e+ nu_e			Of which going to anti-D0		
0,00020	anti-D(2S)0 e+ nu_e	0,02990	0,26	0,16		
0,00050	anti-D*(2S)0 e+ nu_e					
0,00810	anti-D_10 e+ nu_e					
0,00910	anti-D_0*0 e+ nu_e					
0,00810	anti-D'_10 e+ nu_e					
0,00390	anti-D_2*0 e+ nu_e					
		0,11350	1,00			