

Lepton flavour universality and lepton flavour violation tests at Belle II

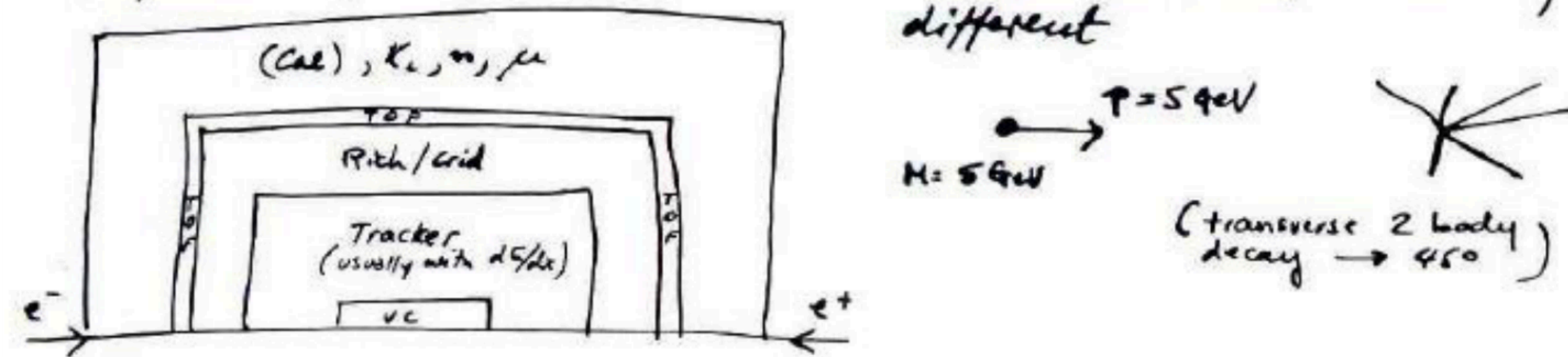
Elisa Manoni

Istituto Nazionale di Fisica Nucleare, Sezione di Perugia

“Interplay of quark and lepton flavour at Belle II and the LHC”
 Institute of the Physics of the Universe, Aix-Marseille Université
 July 3rd, 2021

S. Tanaka

Detectors across the range of machines look remarkably similar (important differences in detail)



Paraphrasing: boosted ($\Upsilon(4S)$) detector does not look very different

(transverse 2 body decay $\rightarrow 450$)

Figure 2: First presentation [17] of the boosted- $\Upsilon(4S)$ idea in 1987.

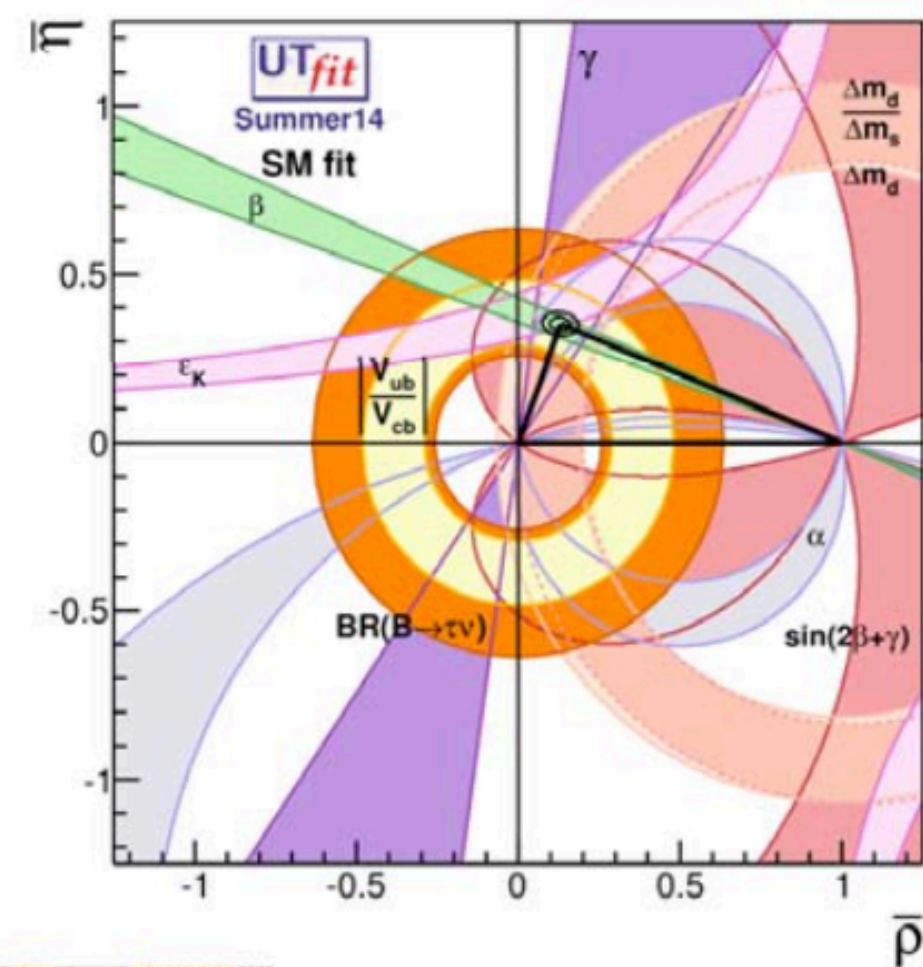
Standard Model is a working theory..

- Two examples:

a nobel from flavour experiments



2008 Nobel Prize



a nobel from hadronic machines

We have observed a new boson with a mass of **125.3 ± 0.6 GeV** at **4.9 sigma** significance



..but not the ultimate one

- What's the origin of lepton and quark particle mass and mixing angle pattern?
- Why matter dominates over anti-matter?
- What's the origin of dark matter?
-

..but not the ultimate one

- What's the pattern?
- Why matter?
- What's the point?
-


What's beyond?

- Theorists at work




- Experimentalist at work

The role of indirect searches

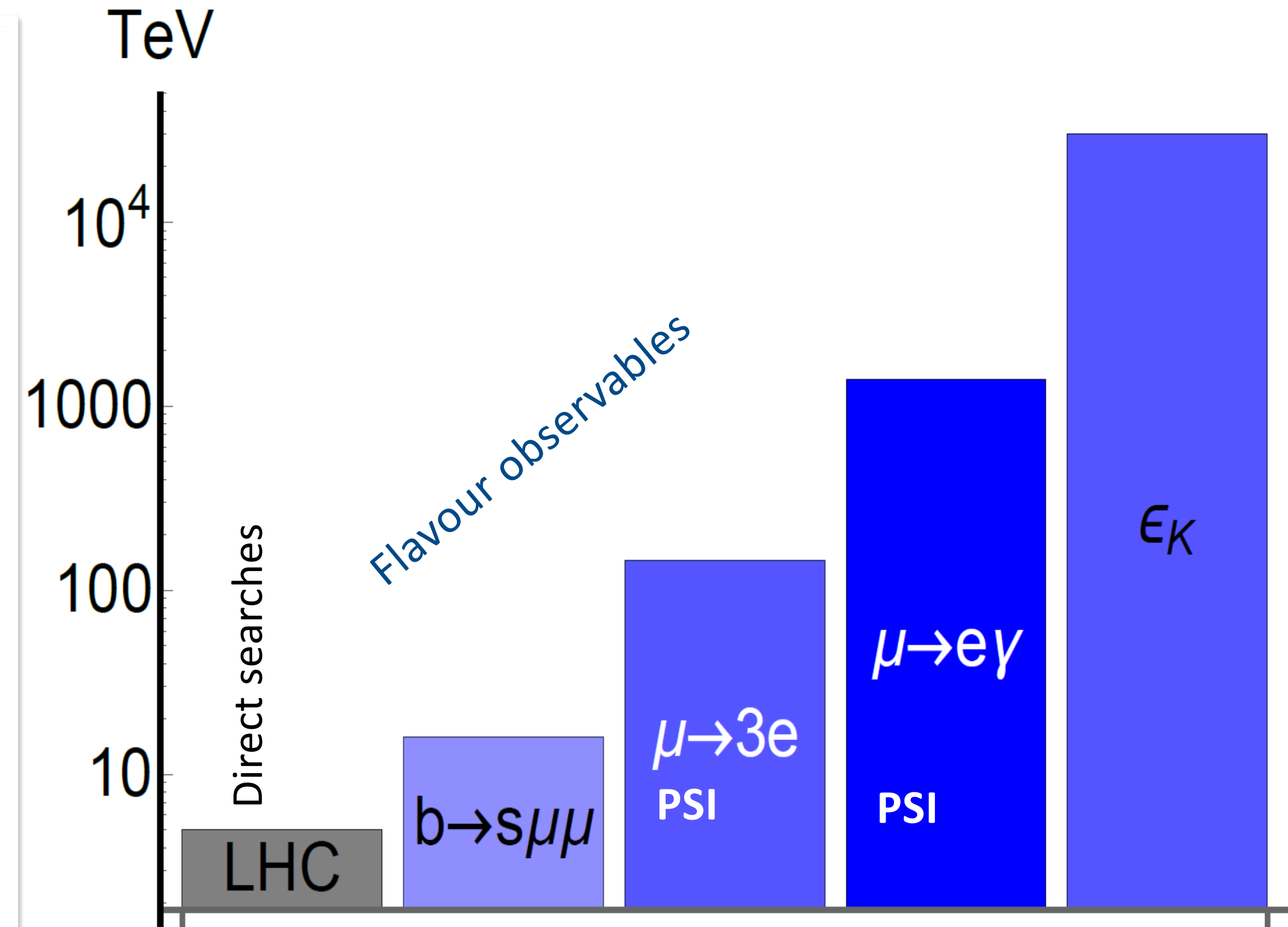
 **B physics:** shake the Box, listen

Some pieces might be heard without being seen.

LHC: open the Box

 Some goodies may remain hidden, obscured.

Clip from R. N. Cahn

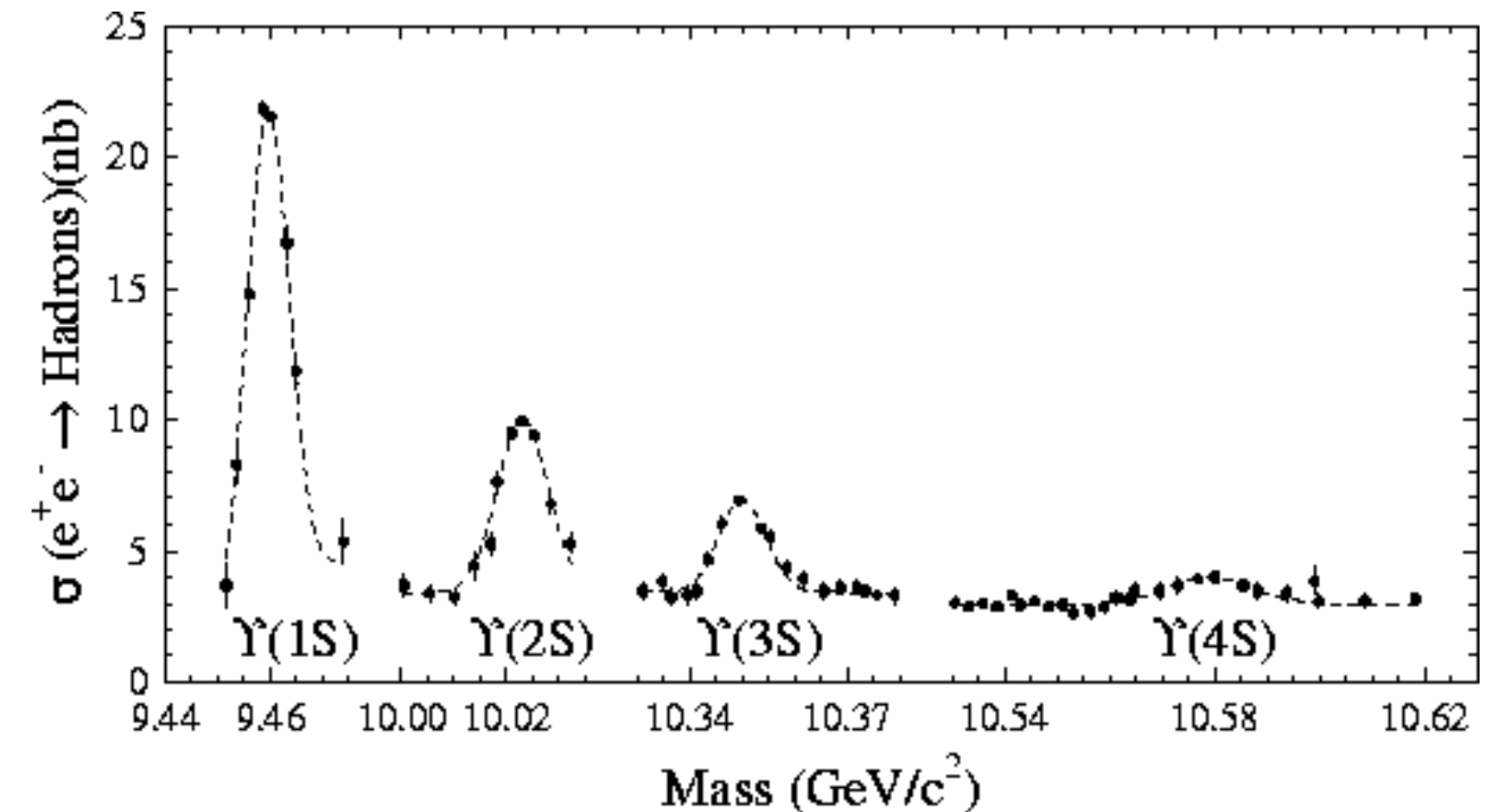
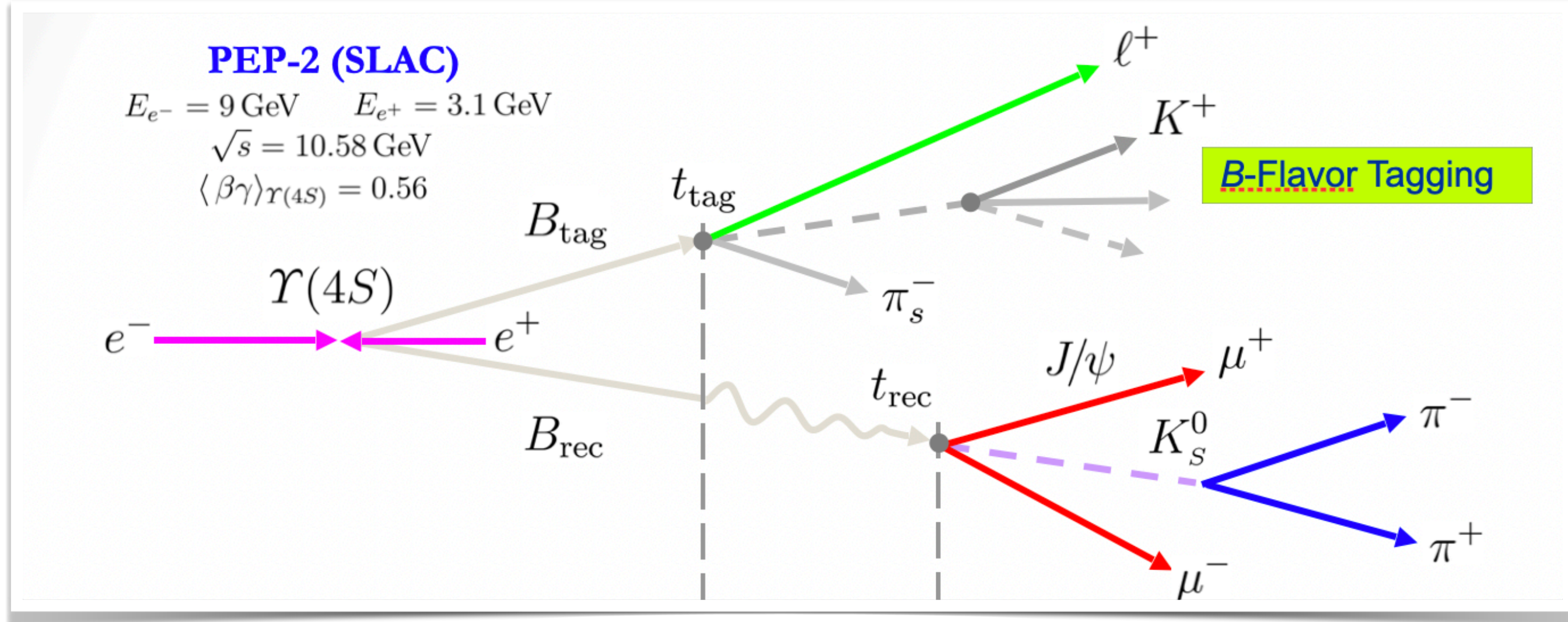
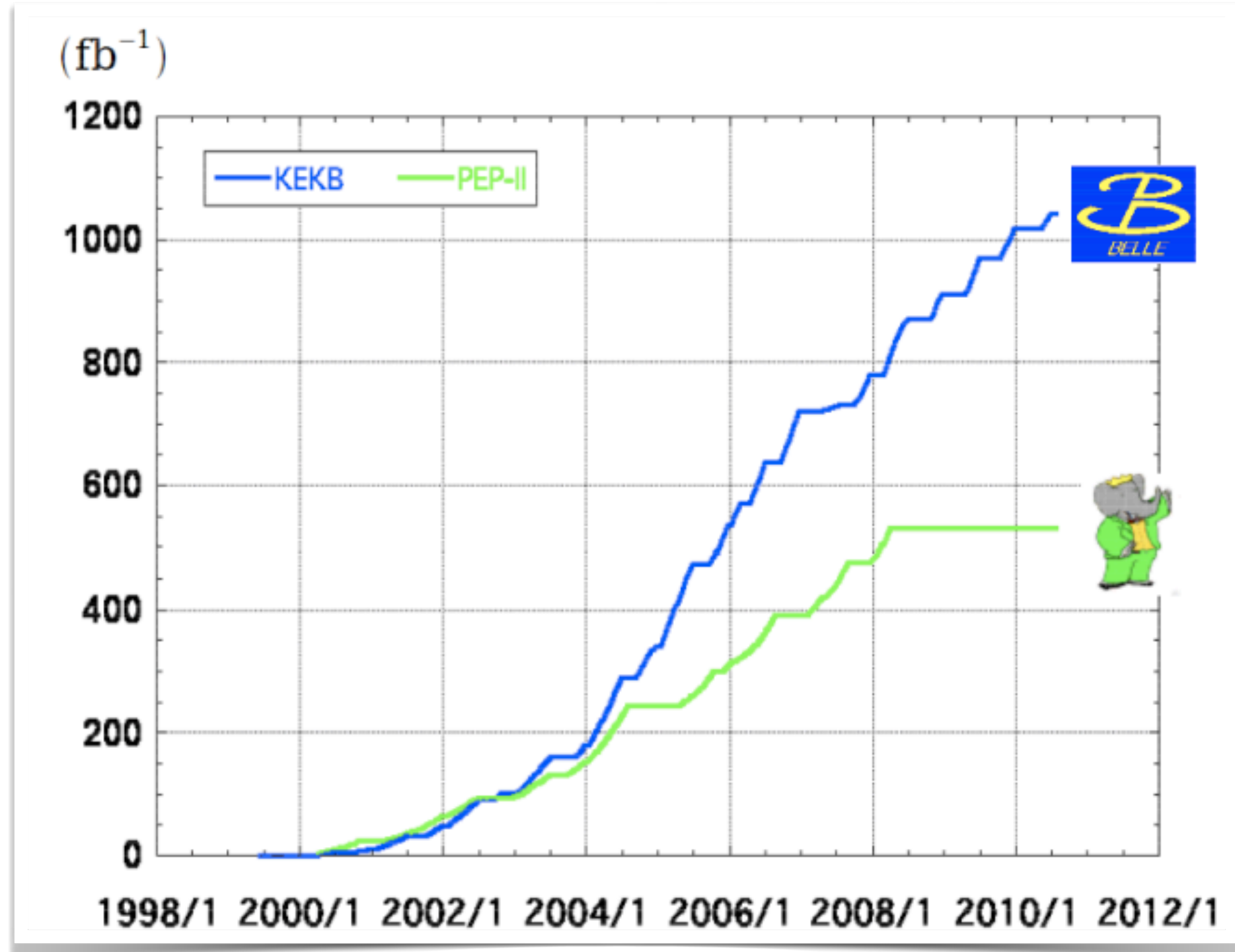


- Indirect searches allow to test higher NP energy scale, complementary to direct searches

The long way to indirect
searches @ at SuperB factory

First generation B factories: where and why

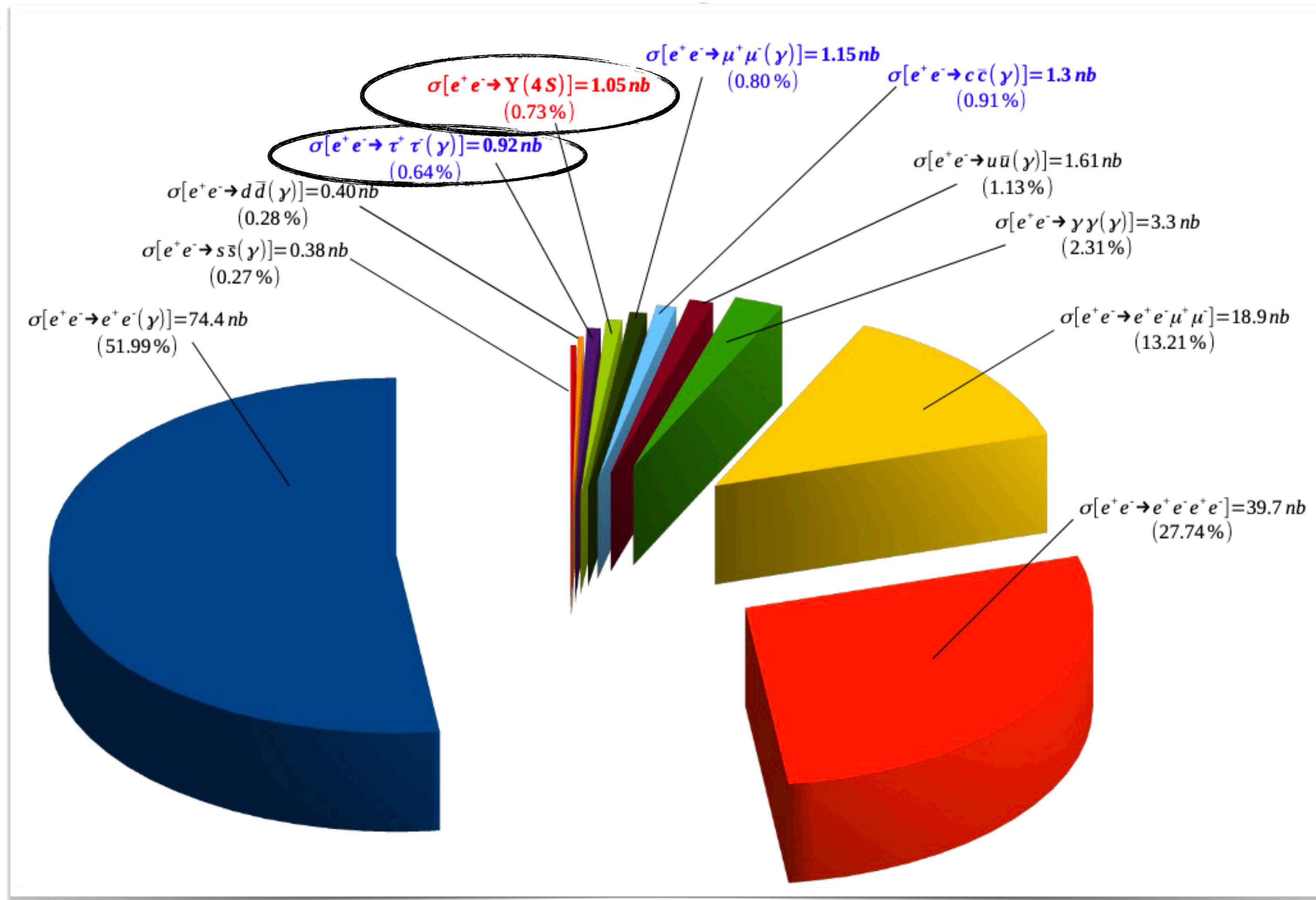
- Experiment @ first generation B factories: **BaBar** (USA) and **Belle** (JAPAN)
- took data for about 10 years , collecting ~ 480 and 780×10^6 BB pairs, respectively
- Experiment goal: measurement of **CP violation in B meson system**



Fantastic performances of the accelerators, well beyond design values, e.g. KEKB peak luminosity (WR!): **$2.1 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$**

Much more than just CPV in B system (I)

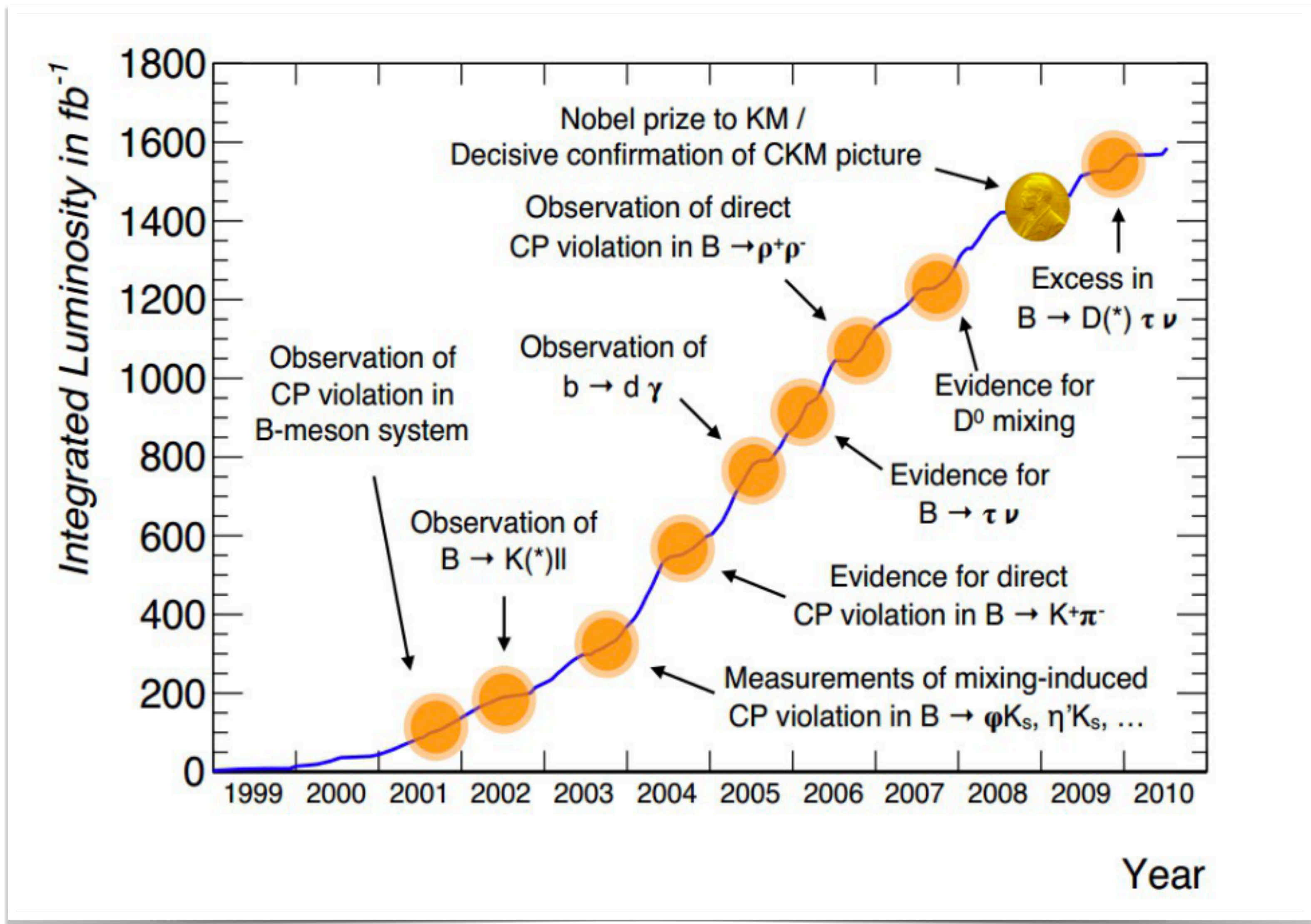
The BelleII Physics Book, PETP 2019, 123C01 (2019)



Physics process	Cross section [nb]
$\Upsilon(4S)$	1.110 ± 0.008
$u\bar{u}(\gamma)$	1.61
$d\bar{d}(\gamma)$	0.40
$s\bar{s}(\gamma)$	0.38
$c\bar{c}(\gamma)$	1.30
$e^+e^-(\gamma)$	300 ± 3 (MC stat.)
$e^+e^-(\gamma)$	74.4
$\gamma\gamma(\gamma)$	4.99 ± 0.05 (MC stat.)
$\gamma\gamma(\gamma)$	3.30
$\mu^+\mu^-(\gamma)$	1.148
$\mu^+\mu^-(\gamma)$	0.831
$\mu^+\mu^-\gamma(\gamma)$	0.242
$\tau^+\tau^-(\gamma)$	0.919
$\nu\bar{\nu}(\gamma)$	0.25×10^{-3}
$e^+e^-e^+e^-$	39.7 ± 0.1 (MC stat.)
$e^+e^-\mu^+\mu^-$	18.9 ± 0.1 (MC stat.)

Much more than just CPV in B system (II)

- They did much more than just measuring CP violation



To: PEP-II/BaBar
and KEKB/Belle

小林 尚
若川 敏英

2008.10.25



- The great success of BaBar and Belle led to the BelleII experiment



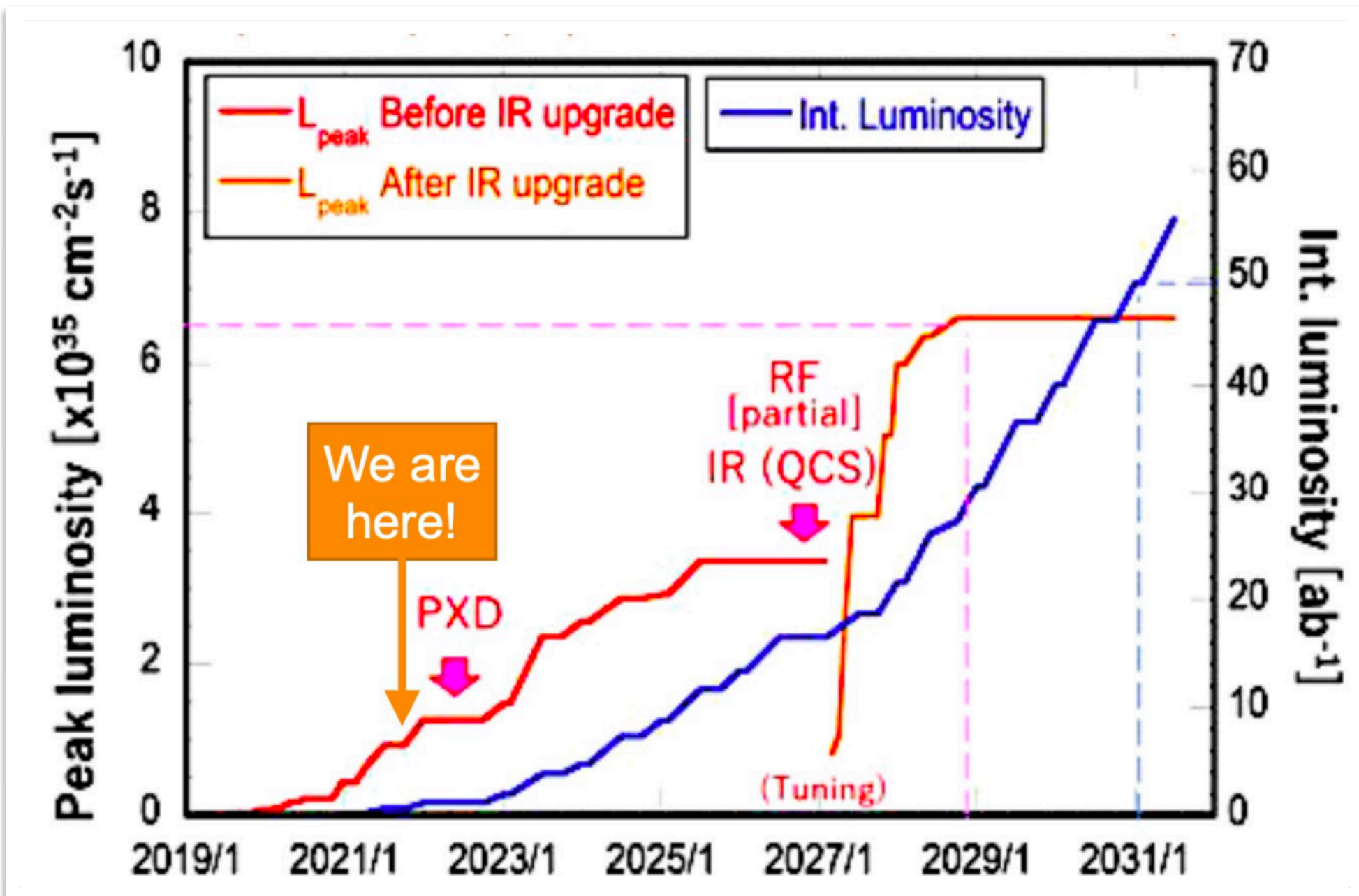
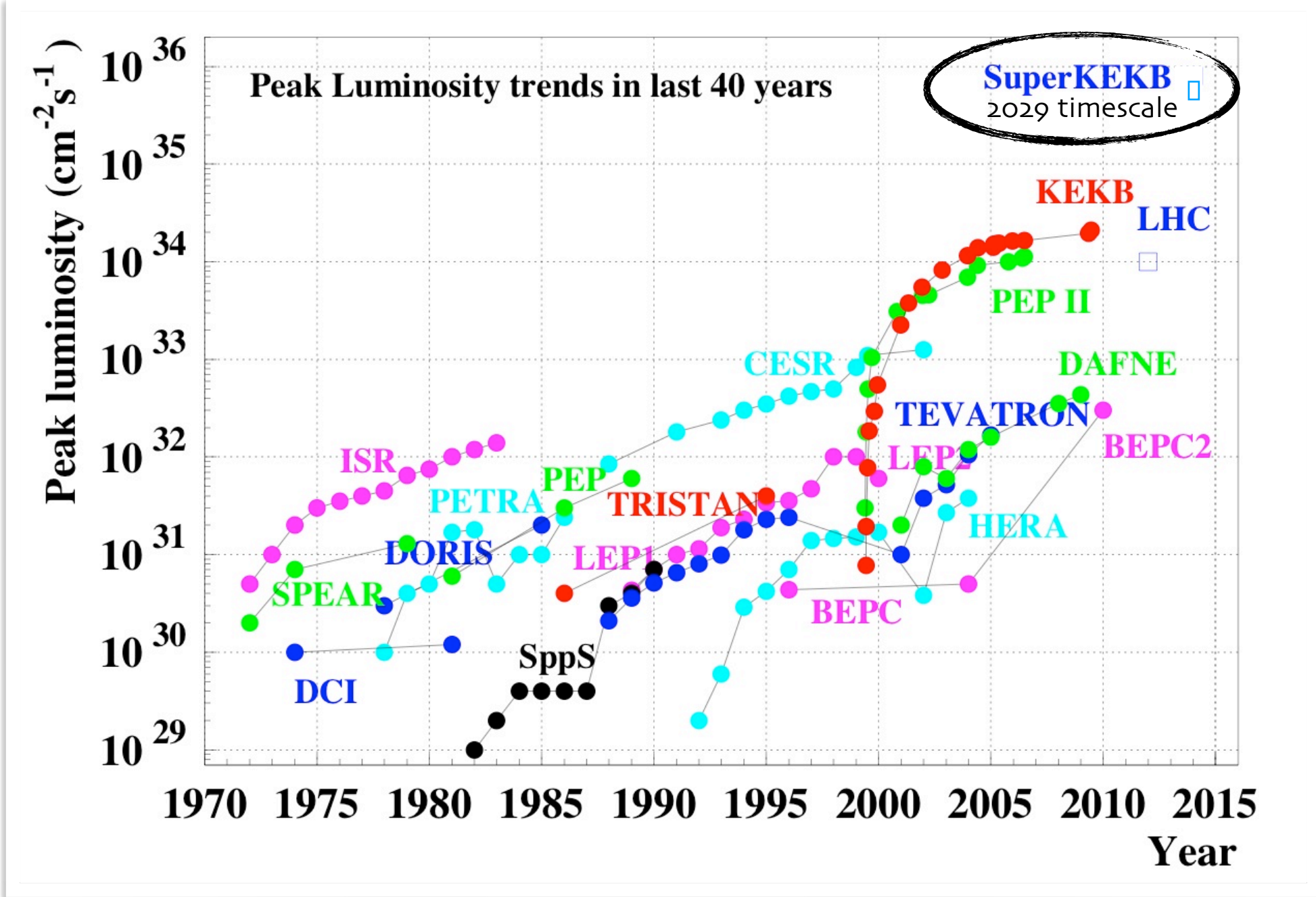
From B factories to SuperB factories: KEKB \Rightarrow SuperKEKB

- Aim to collect **50ab⁻¹** ($\sim 50\times$ Belle) by 2031 reaching **$\sim 60 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$** ($\sim 30\times$ KEKB)
- Can do this without using brute-force! Nano-beam scheme:

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

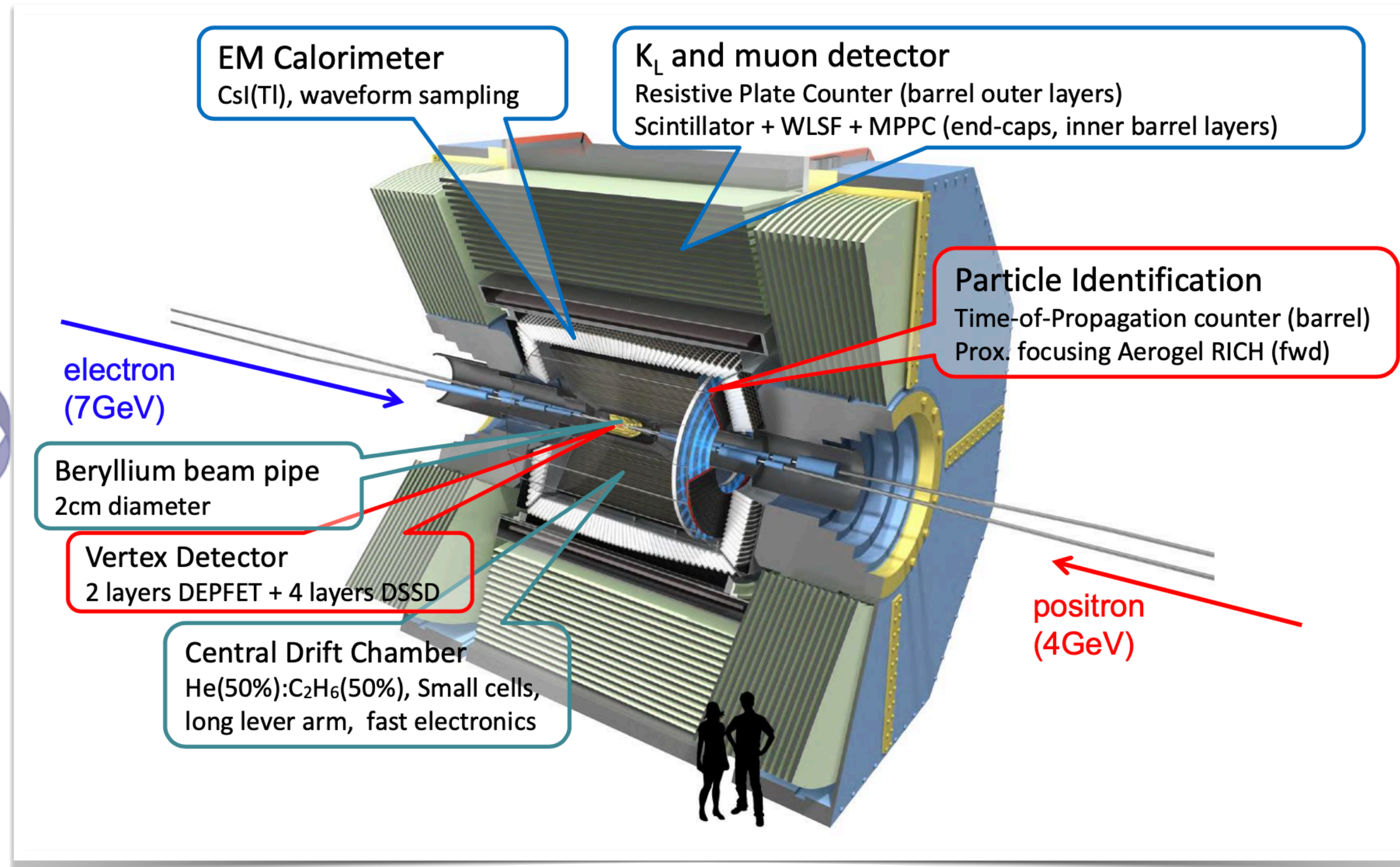
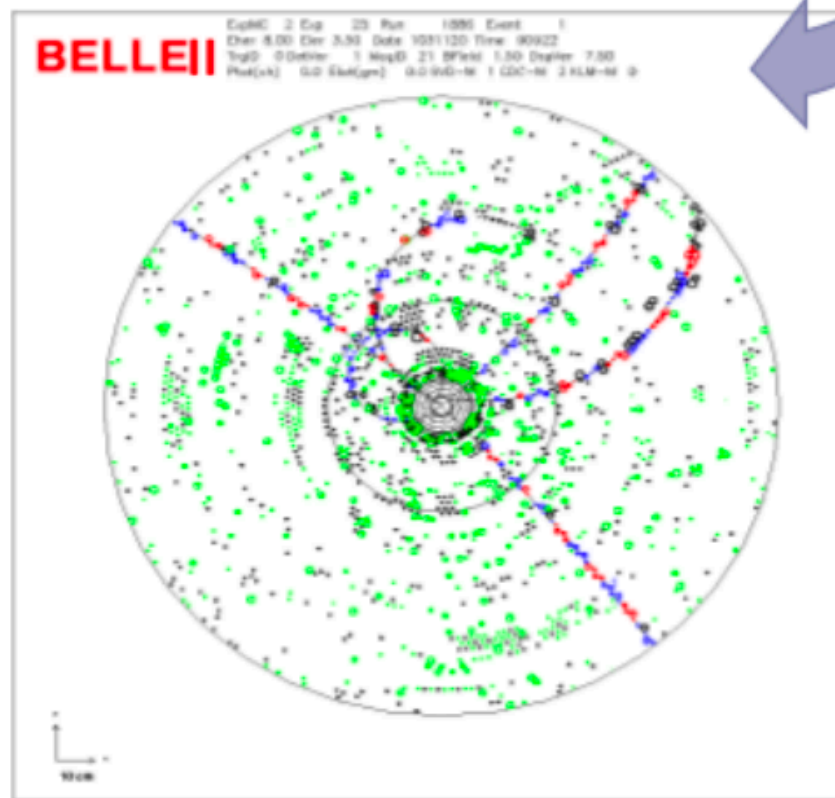
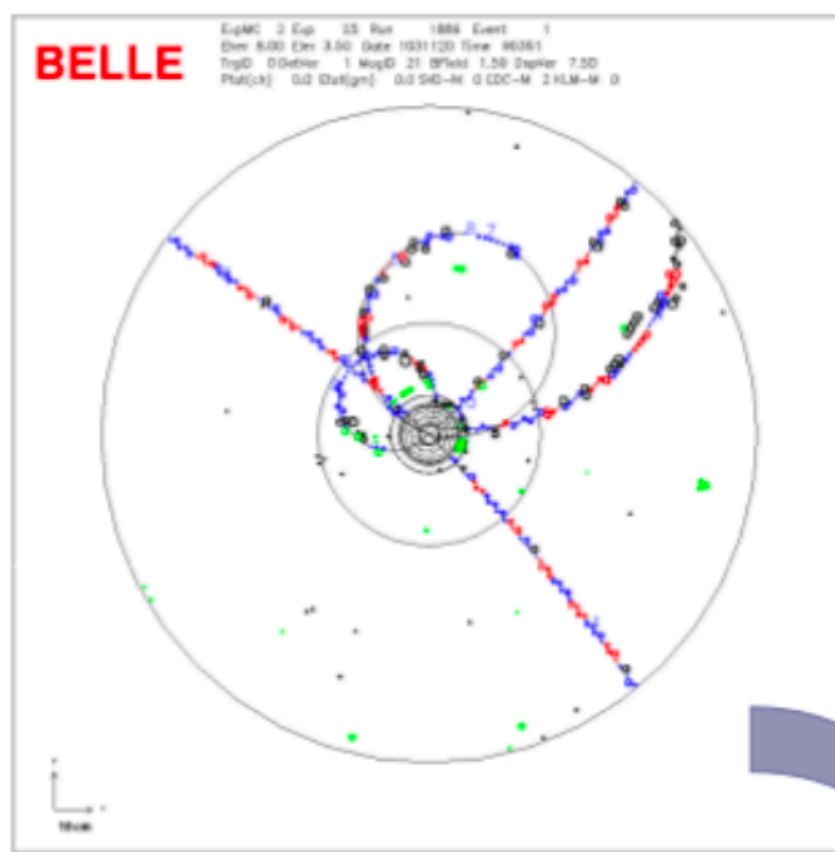
beam current
vertical beta function at IP

- 20x smaller β^*_y
- 1.5x higher currents
- price to be paid: higher “machine background”



From Belle to BelleII

- Higher luminosity mean higher machine background: from Belle to BelleII detector to **maintain or improve detector performances**
- “Faster” and more rad hard sub-detectors



- To realise nano-beam scheme:
 1. Lorentz boost factor reduced wrt Belle → higher detector **hermiticity**, important for searches with missing particles;
 2. smaller beam pipe → vertex detector closer to IP, better **vertex resolution**

Belle II/SuperKEKB @ work

- Belle II is taking data since 2019, data taking continued amid COVID-19 pandemic

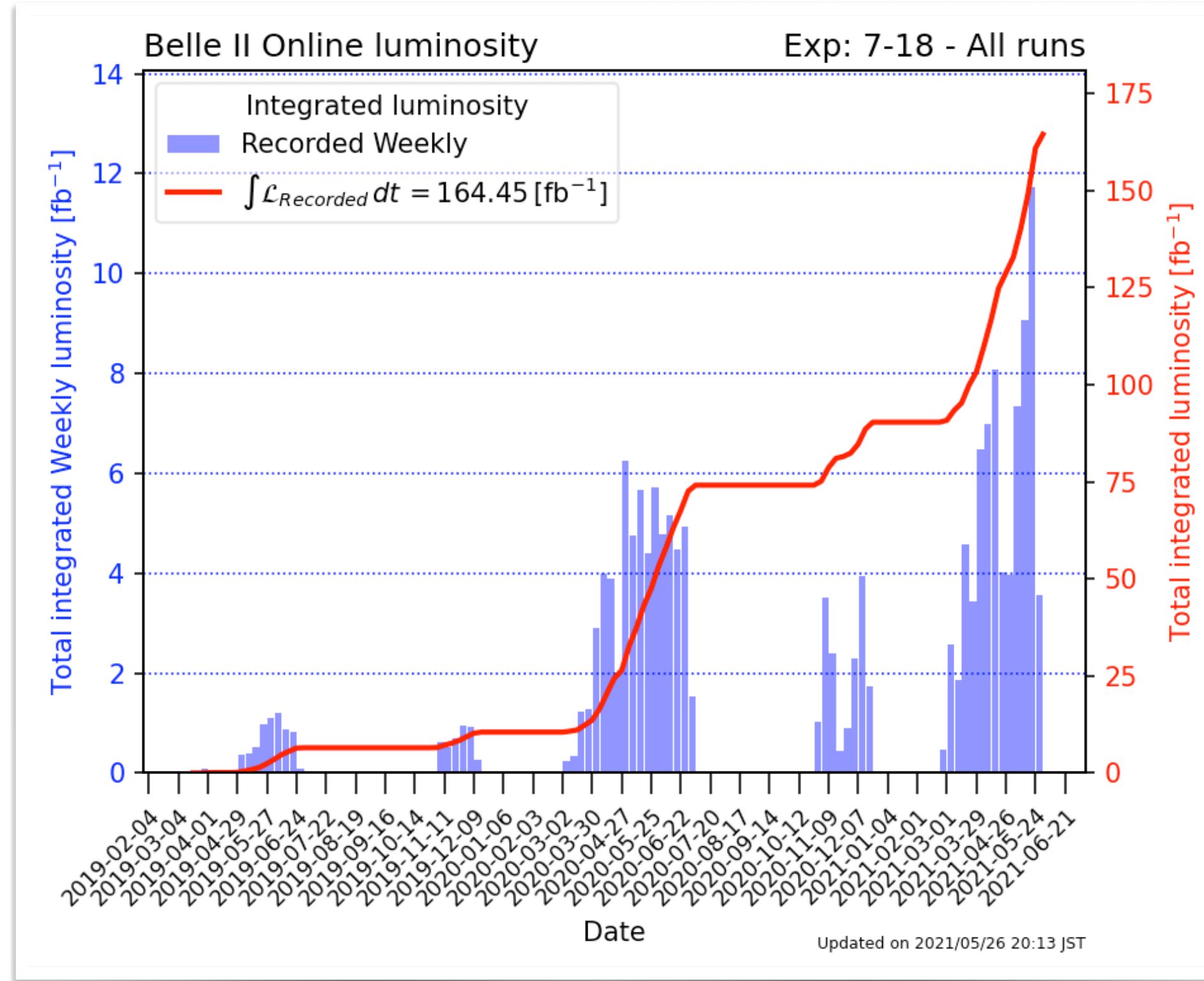
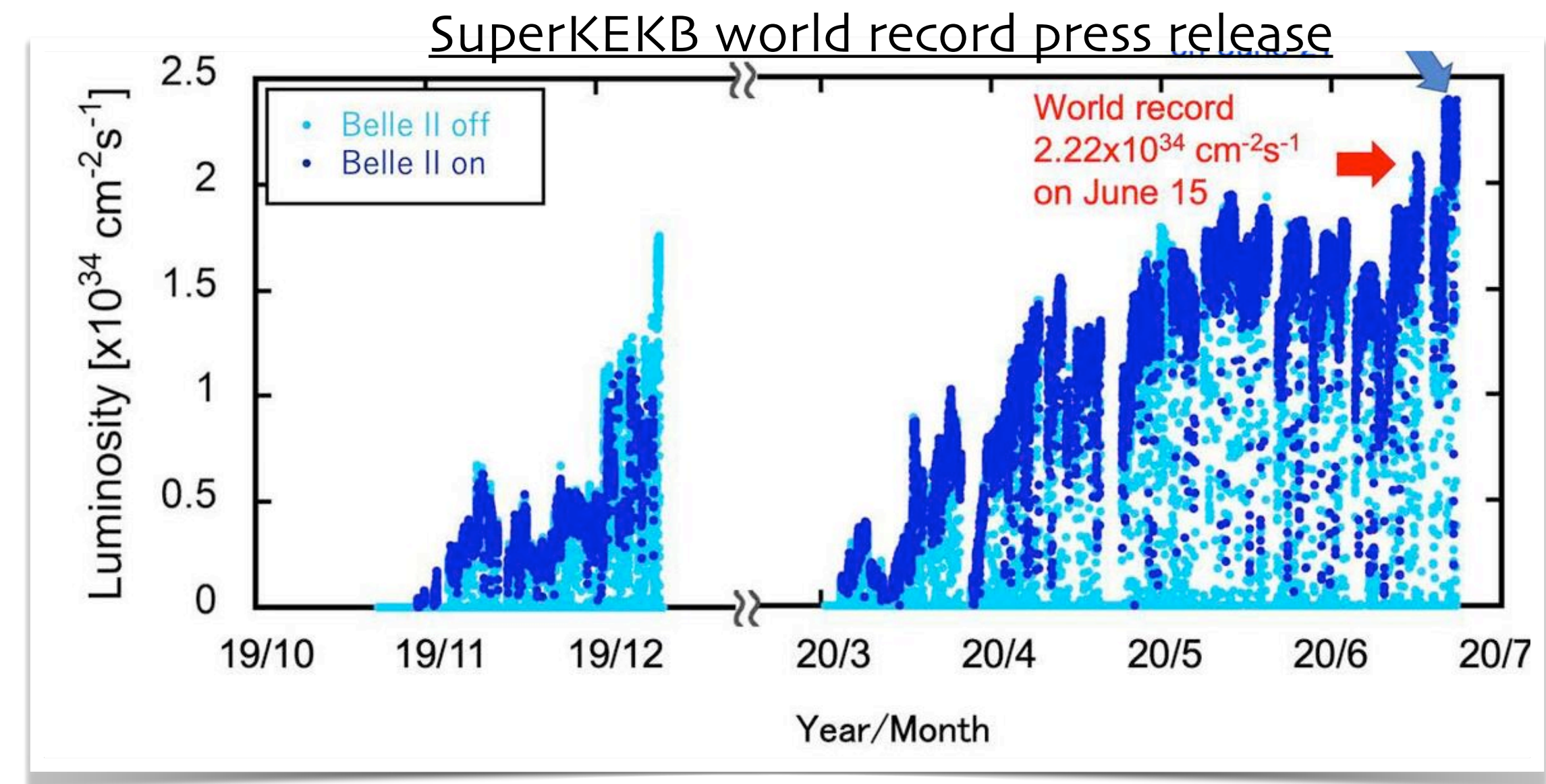
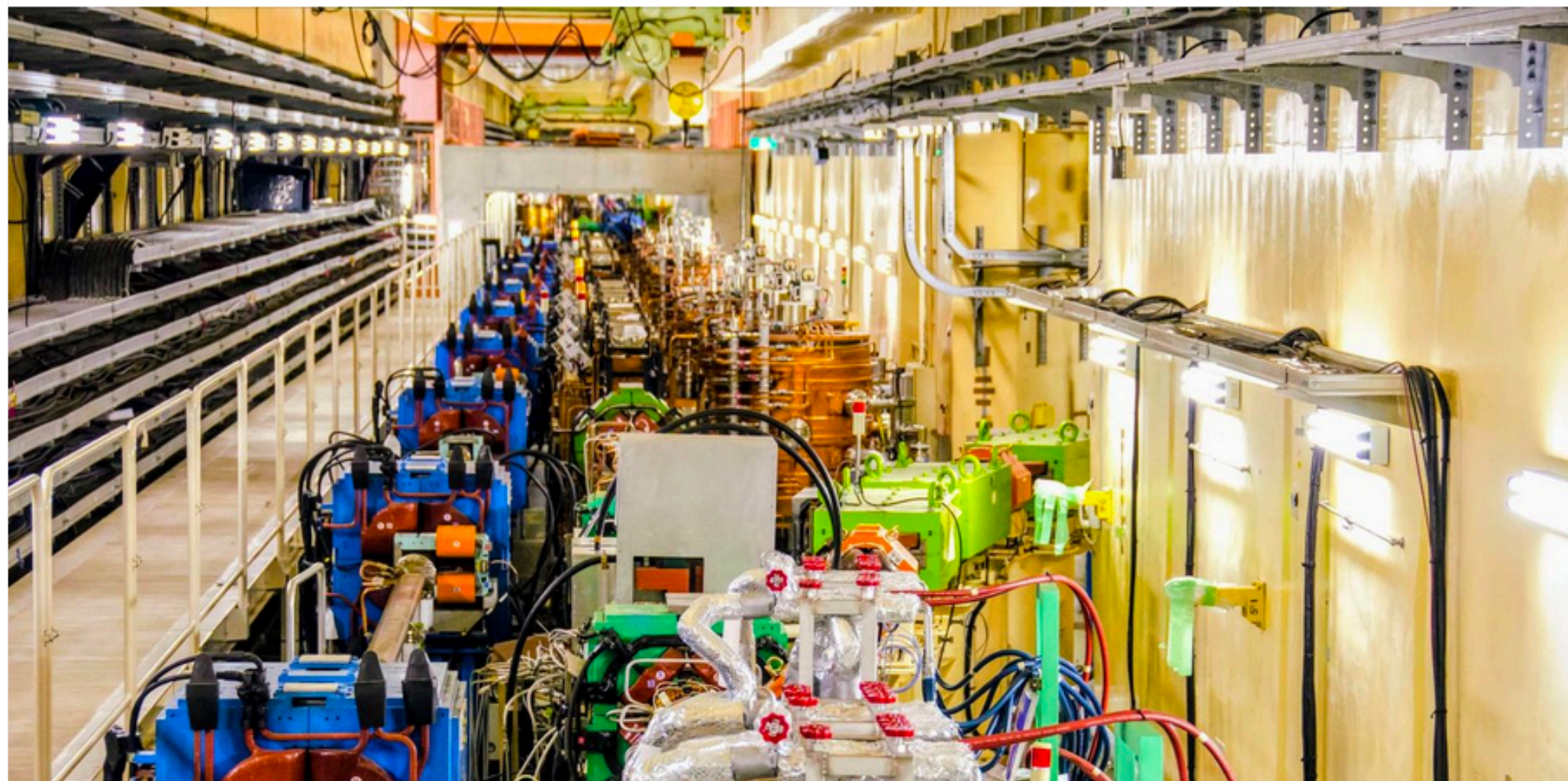


Belle II Collaboration

Ieri alle 09:15 · 🌐

SuperKEKB reaches Super-B factory class performance levels!

Belle II@SuperKEKB has integrated 12 fb^{-1} of data in a week - a new world record! By comparison, during the best week at KEKB more than a decade ago, Belle integrated 8 fb^{-1} , while PEP-II Integrated 5 fb^{-1} for BaBar during its best week. Stay tuned as [#Belle2@SuperKEKB](#) aims for the long-standing world record of integrated luminosity per month while it accumulates a large data sample to hunt for New Physics in the flavor sector.



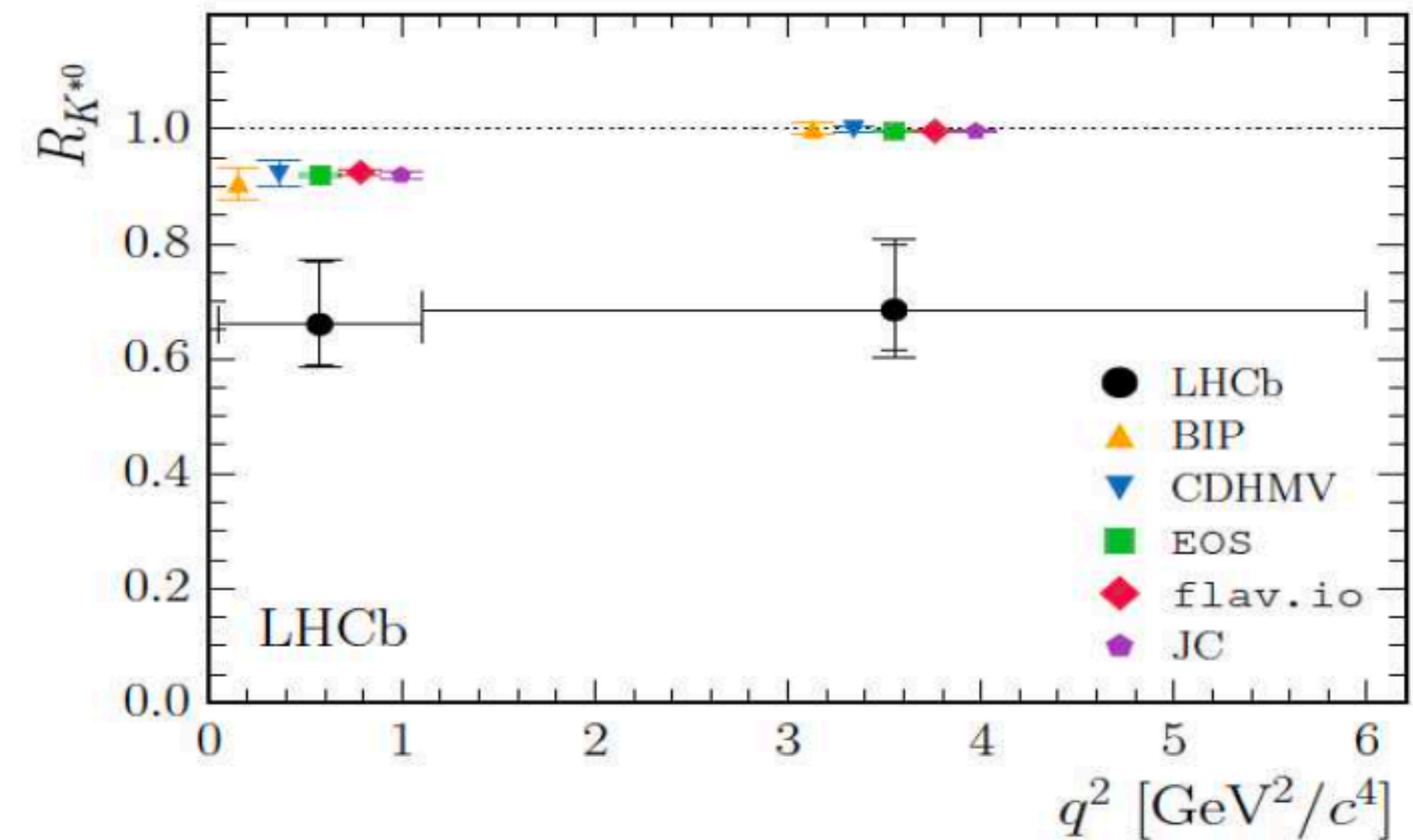
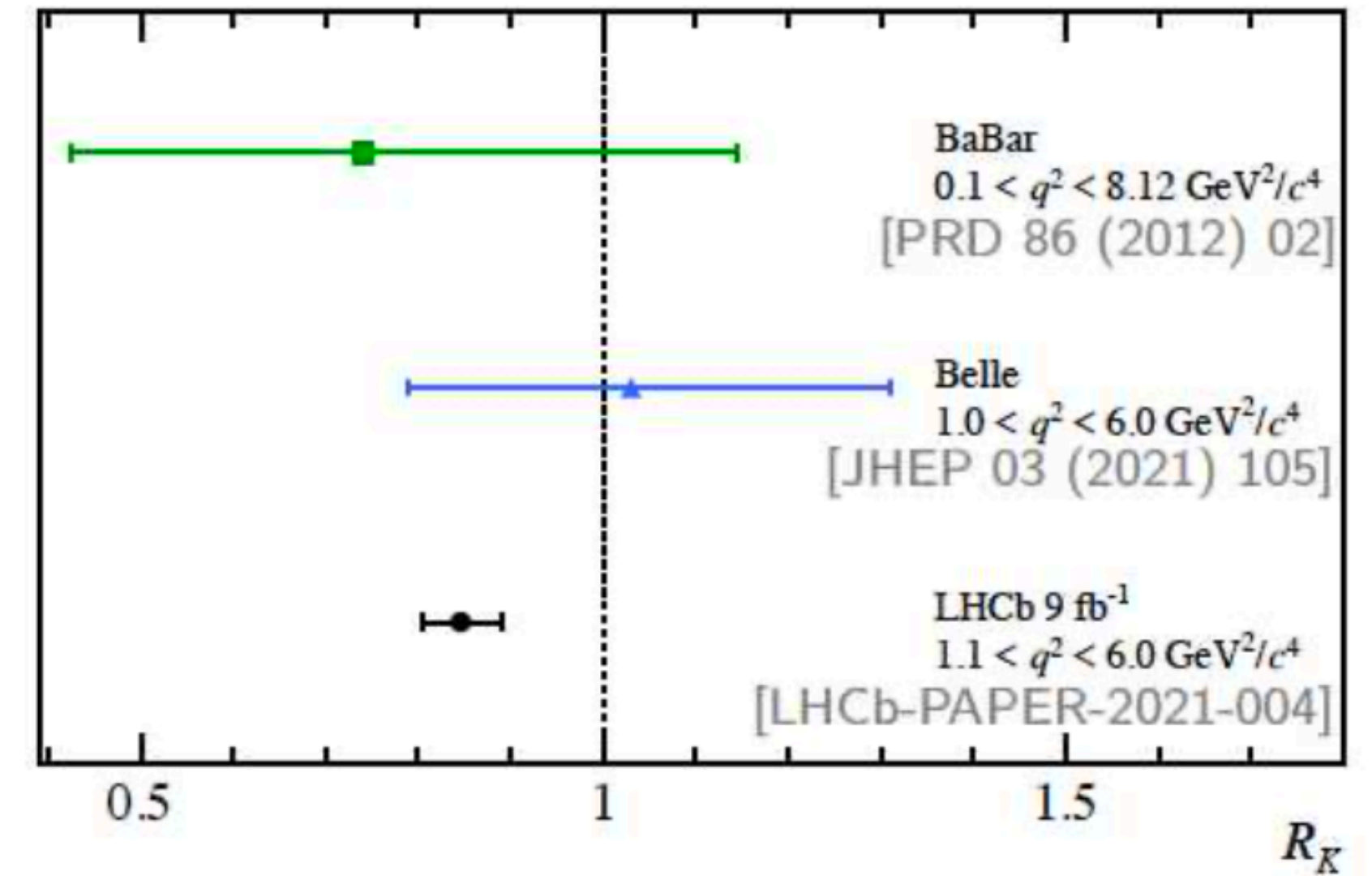
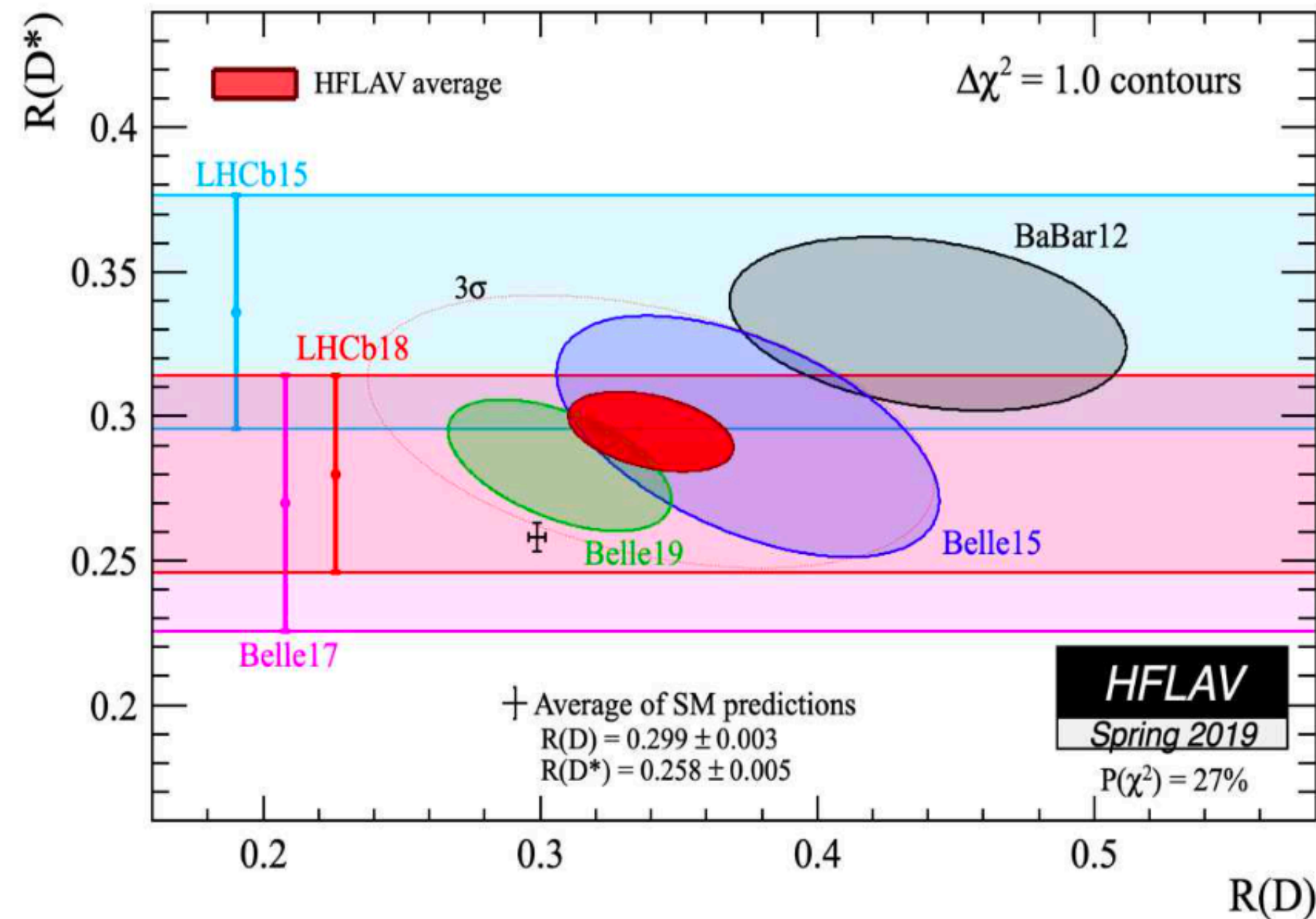
- Increasing peak luminosity: in spring 2021, exceeded $2.8 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

Flavour anomalies in a nutshell

- Tension between experimental measurement and SM predictions in

- $b \rightarrow c | \nu$

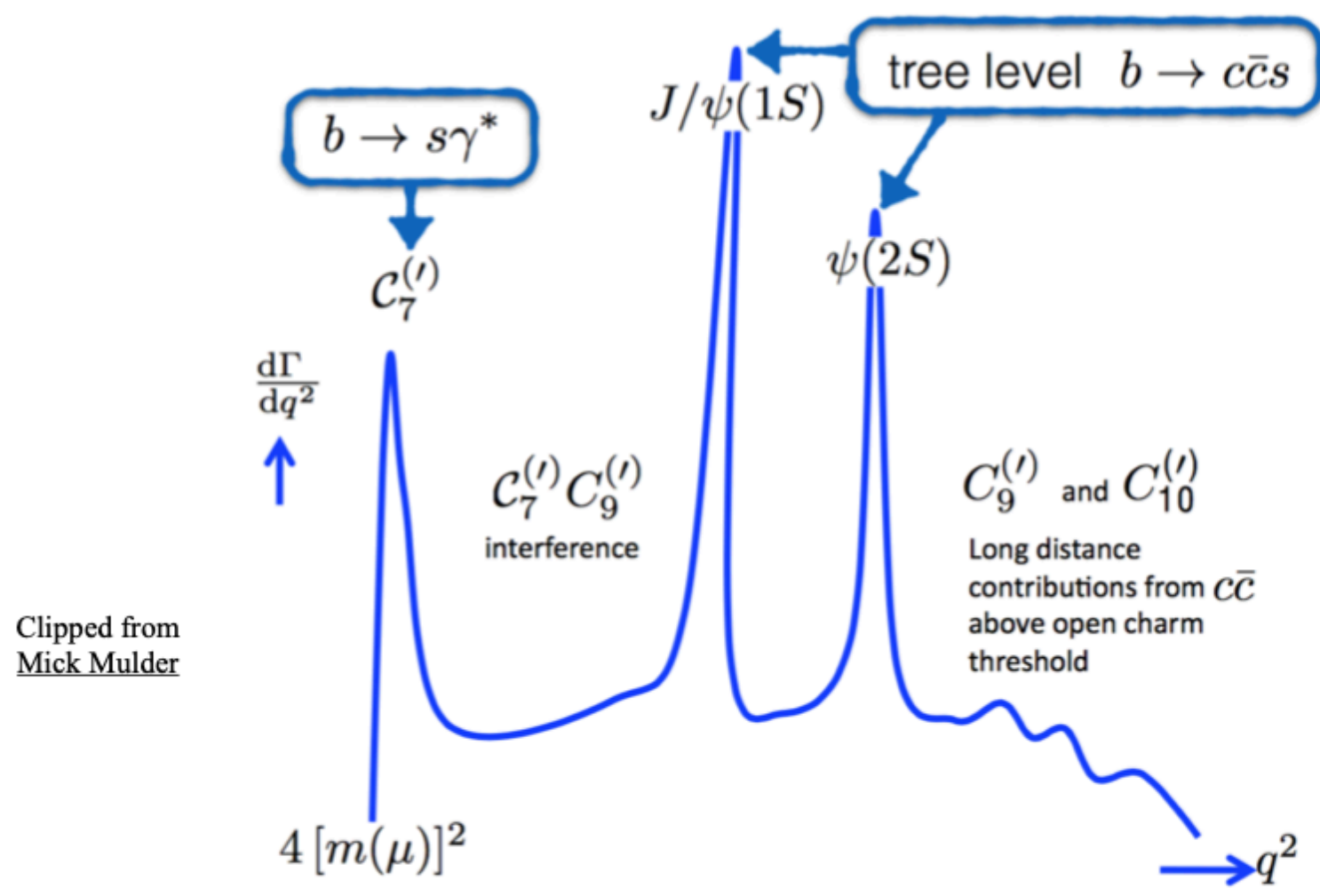
- $b \rightarrow s | \ell$



• What can BelleII say on these and other related modes?

b → sll

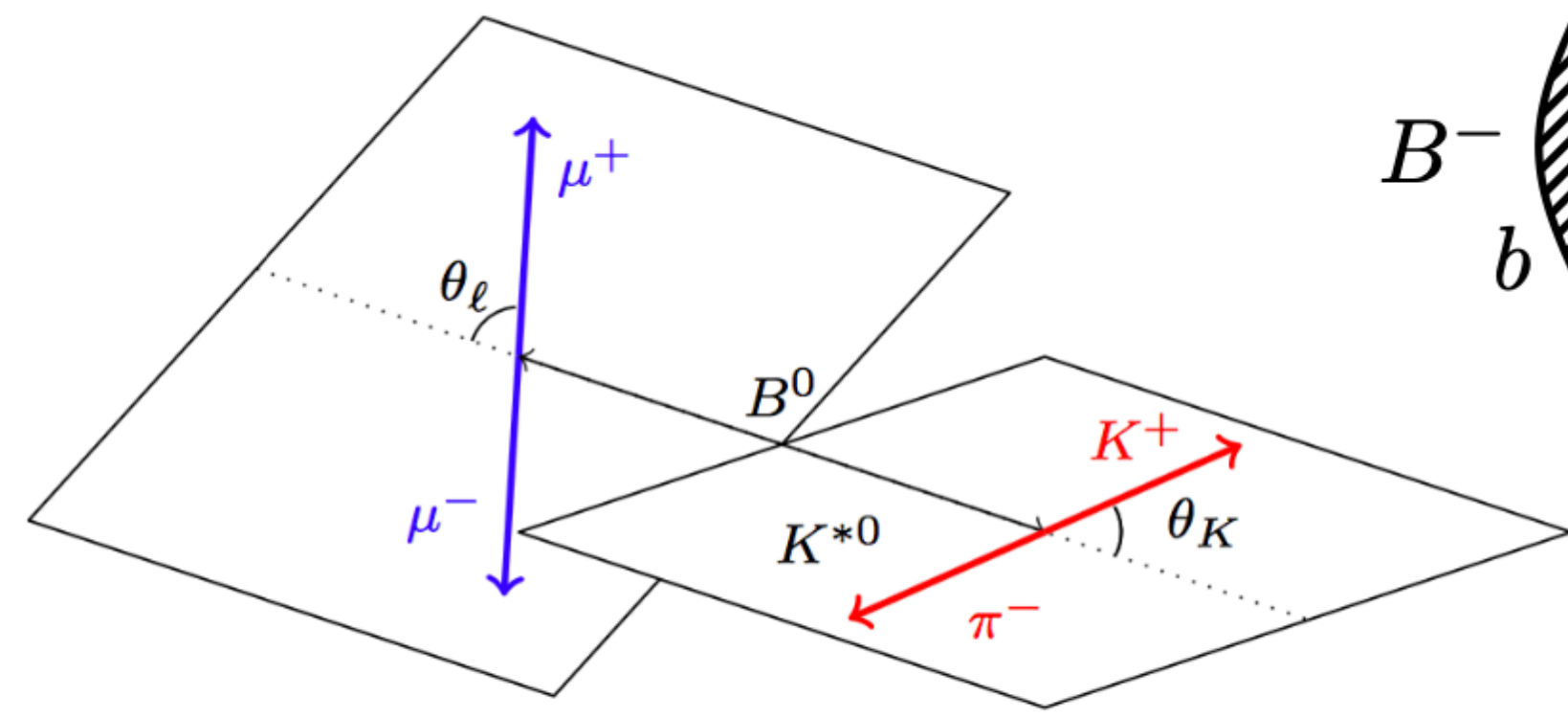
b → sll observables



Clipped from Mick Mulder

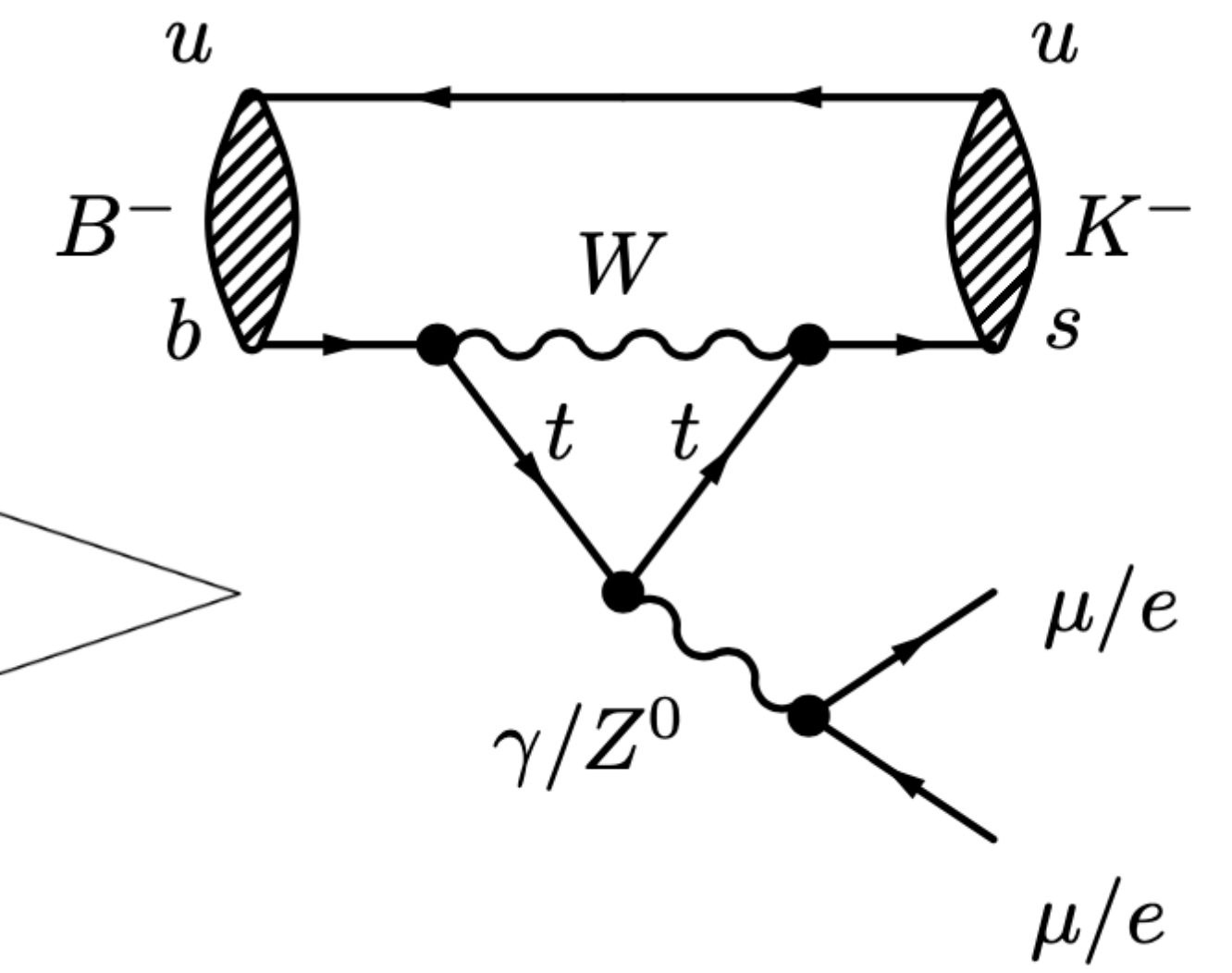
Branching fractions

large theory uncertainties



Angular observables

Minimal FF uncertainties, though sensitive to charm loops



LFU ratios $\mathcal{R}_{H_s} = \frac{H_b \rightarrow H_s \mu \mu}{H_b \rightarrow H_s e e}$

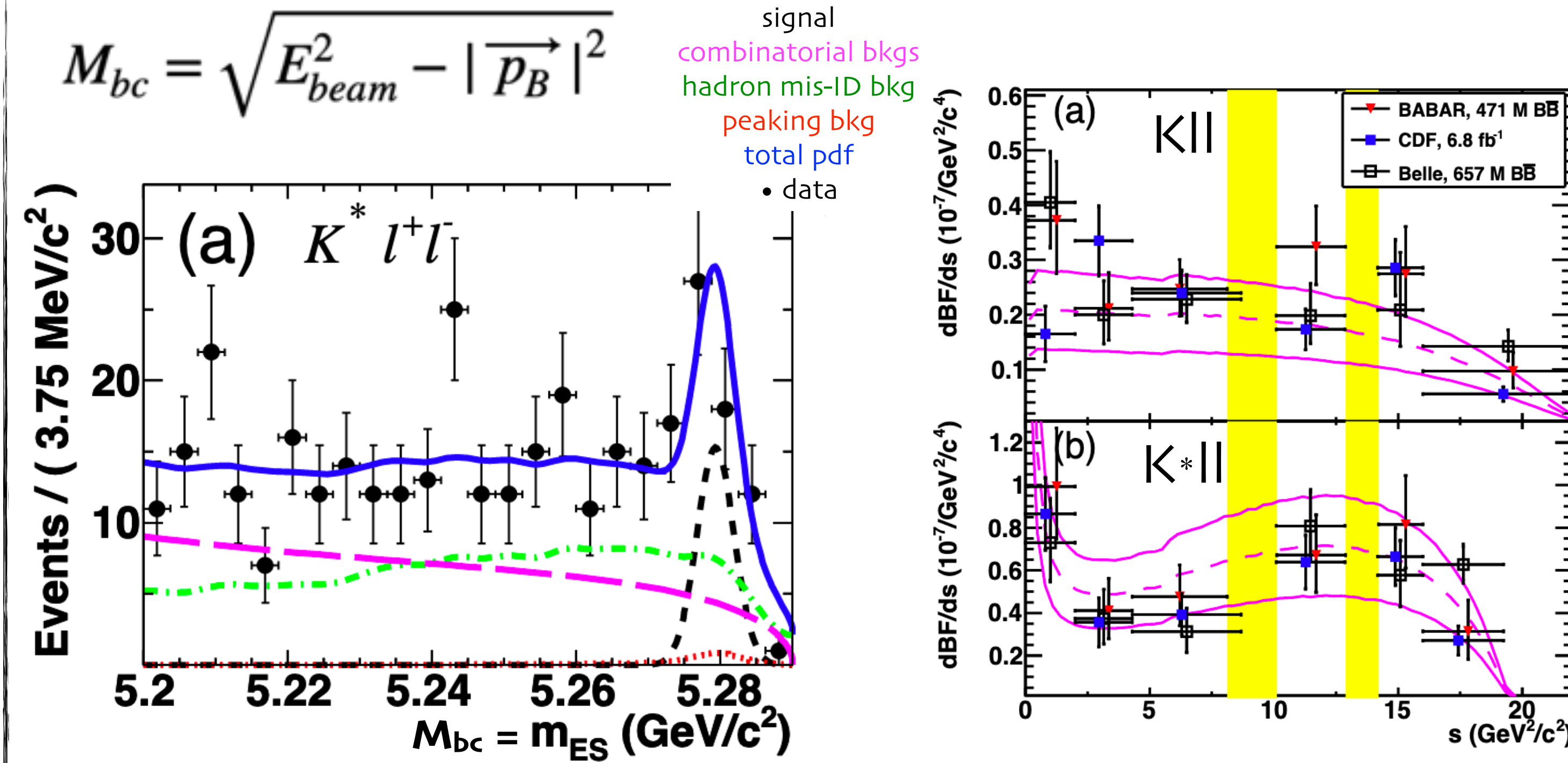
Theory uncertainty of ~1%

Clip from [M.F. Sevilla@ APS2021](#)

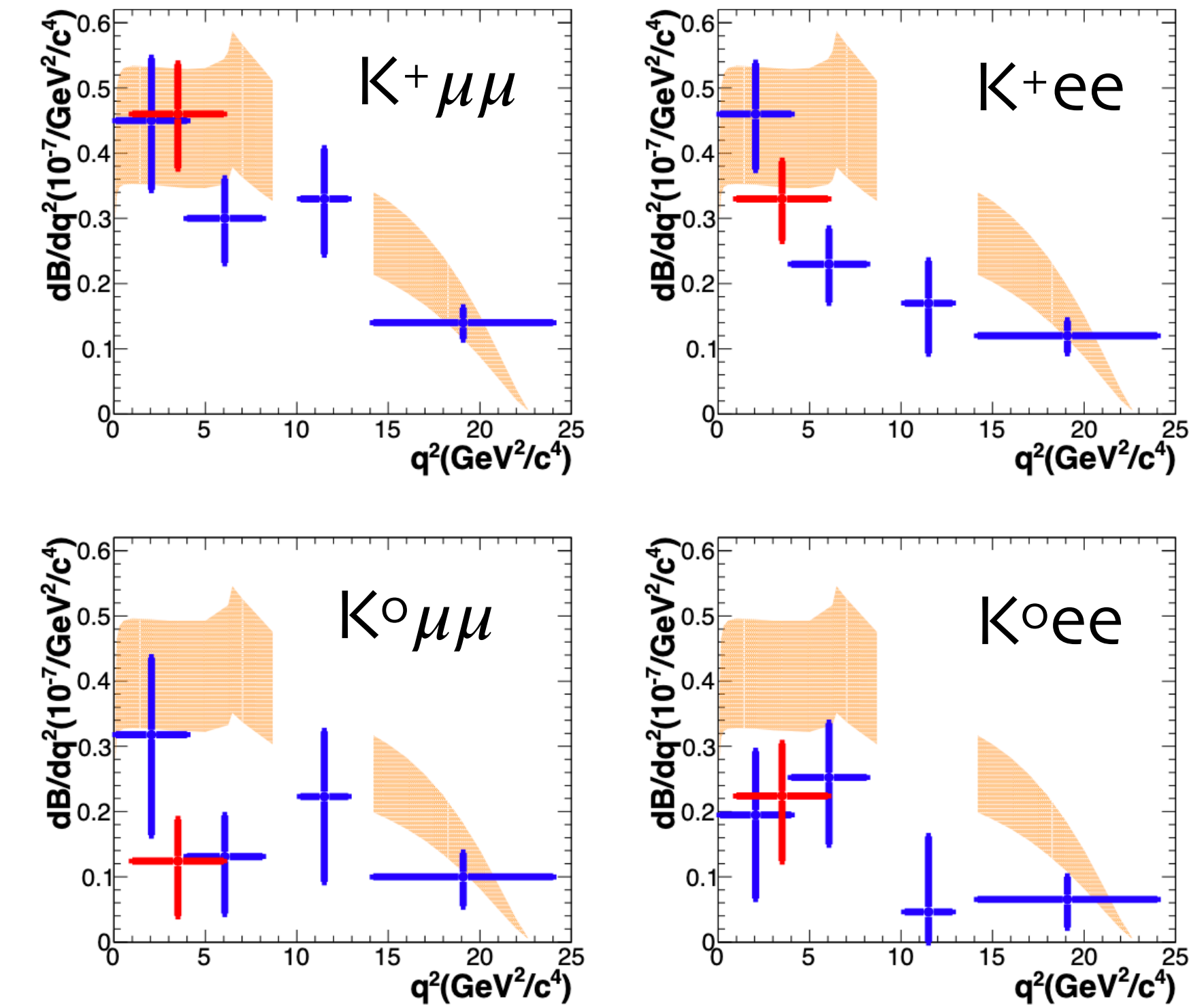
- Fully reconstructed final states, untagged analysis
- @ (super)B-factories, both charged and neutral K(*) modes are reconstructed
- Key ingredients: Lepton identification, hadron mis-identification (in particular μ-π)

Partial branching fractions from B factories

BaBar coll., *PhysRevD.86.032012* (prior latest Belle measurement)



Belle coll., *JHEP03(2021) 105* (latest Belle measurement)



- Partial branching fractions measured by BaBar, Belle, and CDF
 - latest Belle measurement, performed separately for electron and muons
 - in agreement with SM expectations, large experimental errors, **statistically limited**

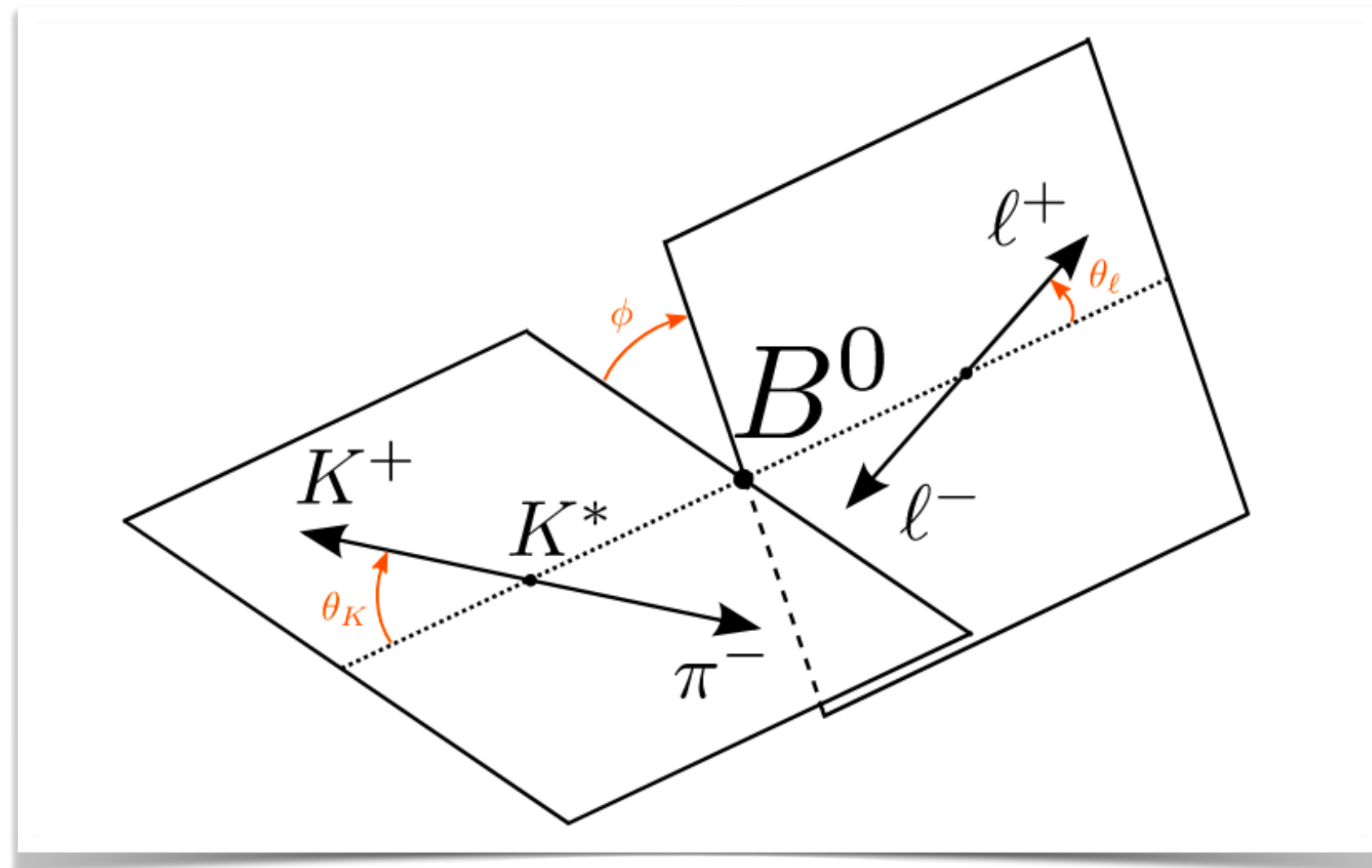
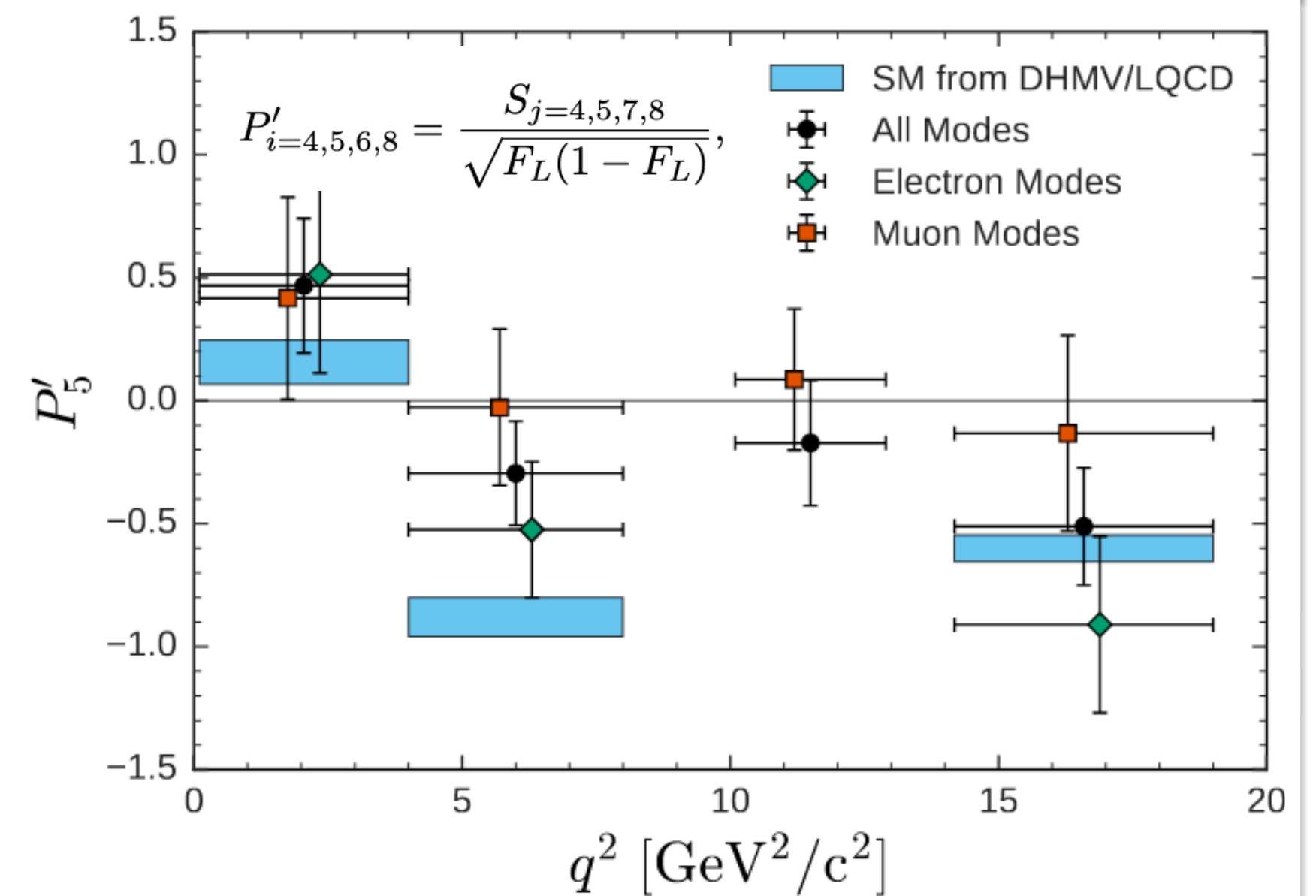
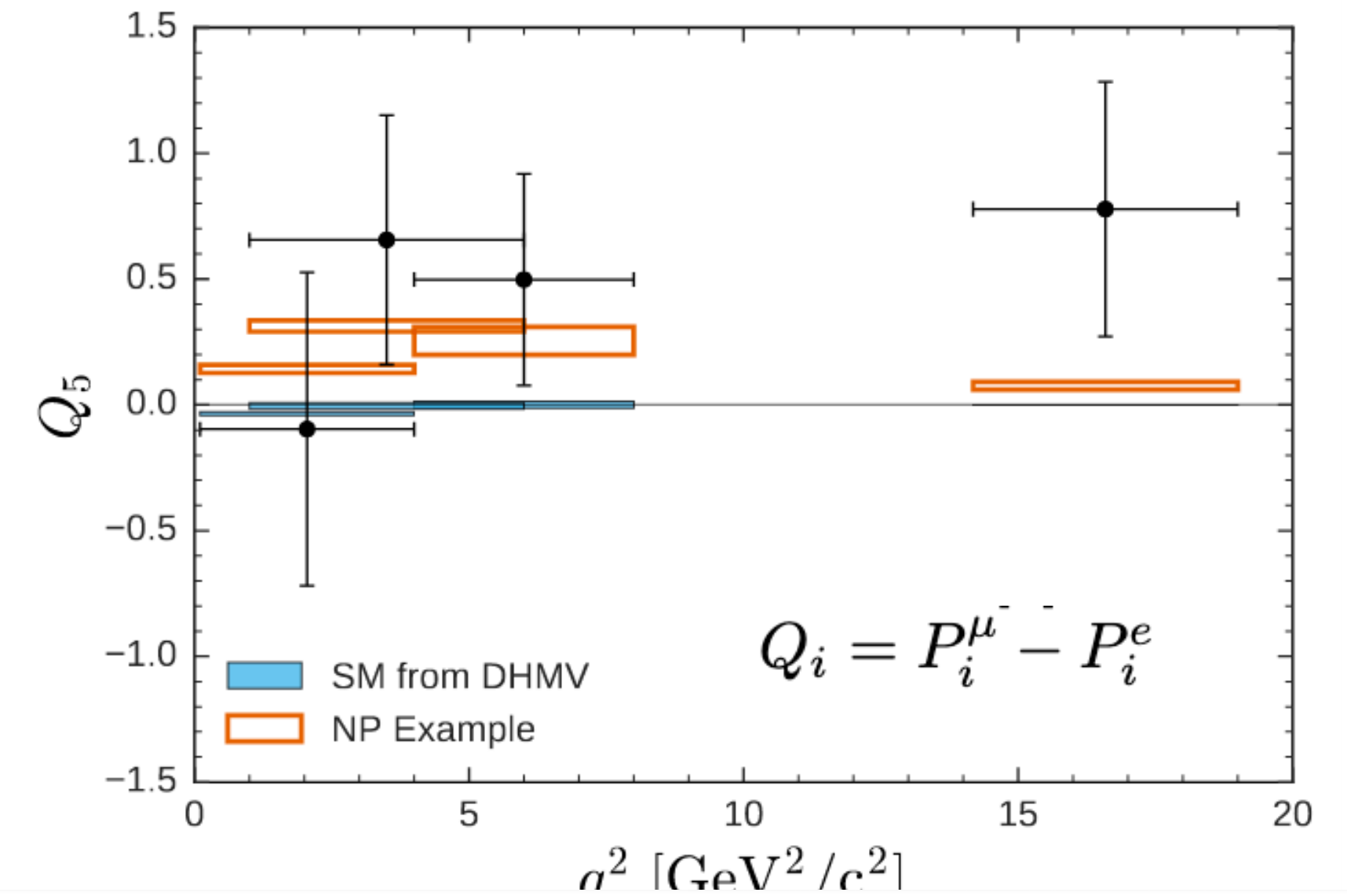
B → K* l angular analysis from B factories

- Differential decay rate as a function of 3 angles:

$$\frac{1}{d\Gamma/dq^2 d\cos\theta_L d\cos\theta_K d\phi dq^2} \frac{d^4\Gamma}{dq^2} = \frac{9}{32\pi} \left[\frac{3}{4}(1 - F_L) \sin^2 \theta_K + F_L \cos^2 \theta_K \right. \\ \left. + \frac{1}{4}(1 - F_L) \sin^2 \theta_K \cos 2\theta_L \right. \\ \left. - F_L \cos^2 \theta_K \cos 2\theta_L + S_3 \sin^2 \theta_K \sin^2 \theta_L \cos 2\phi \right. \\ \left. + S_4 \sin 2\theta_K \sin 2\theta_L \cos \phi + S_5 \sin 2\theta_K \sin \theta_L \cos \phi \right. \\ \left. + S_6 \sin^2 \theta_K \cos \theta_L + S_7 \sin 2\theta_K \sin \theta_L \sin \phi \right. \\ \left. + S_8 \sin 2\theta_K \sin 2\theta_L \sin \phi + S_9 \sin^2 \theta_K \sin^2 \theta_L \sin 2\phi \right]$$

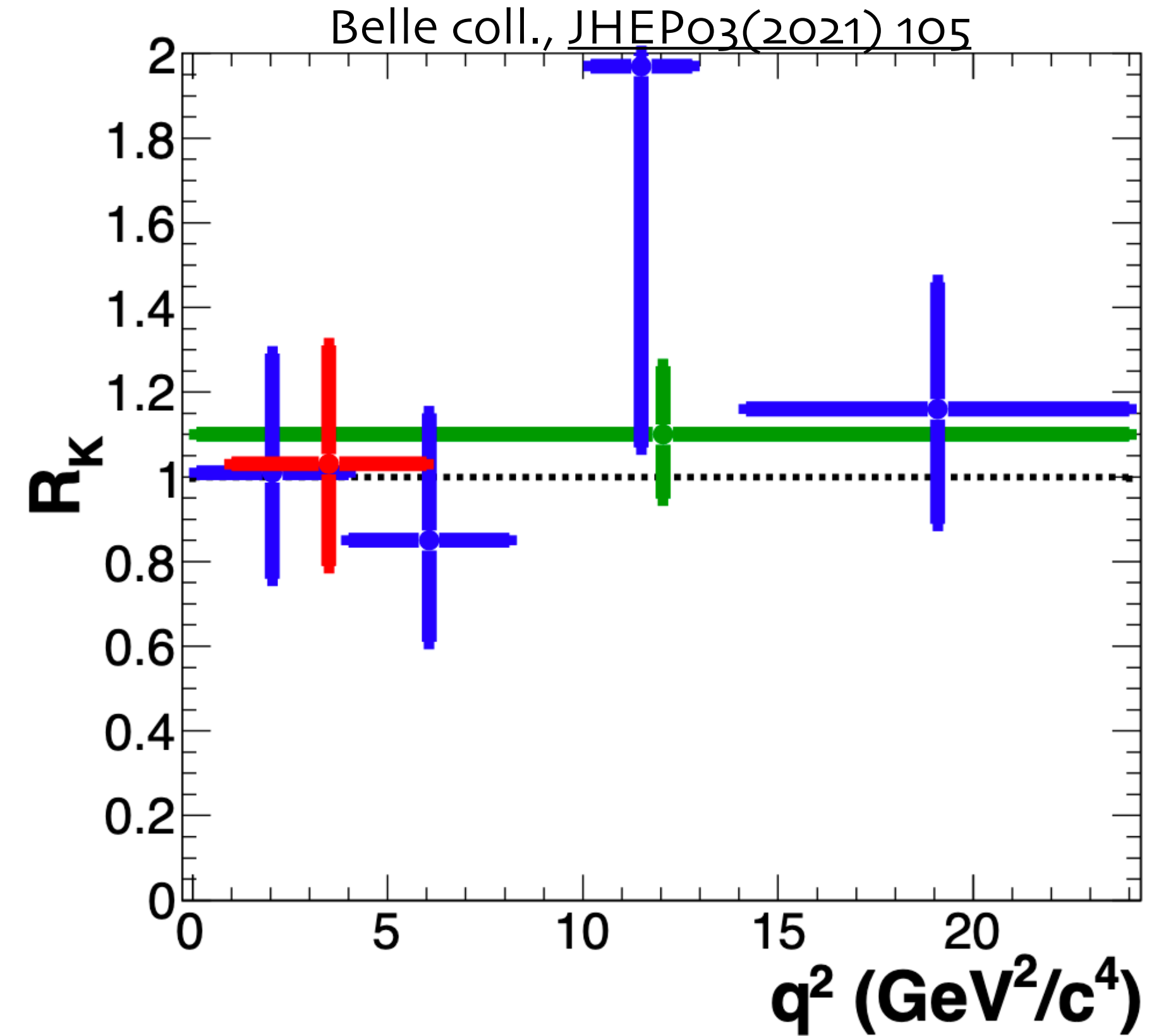
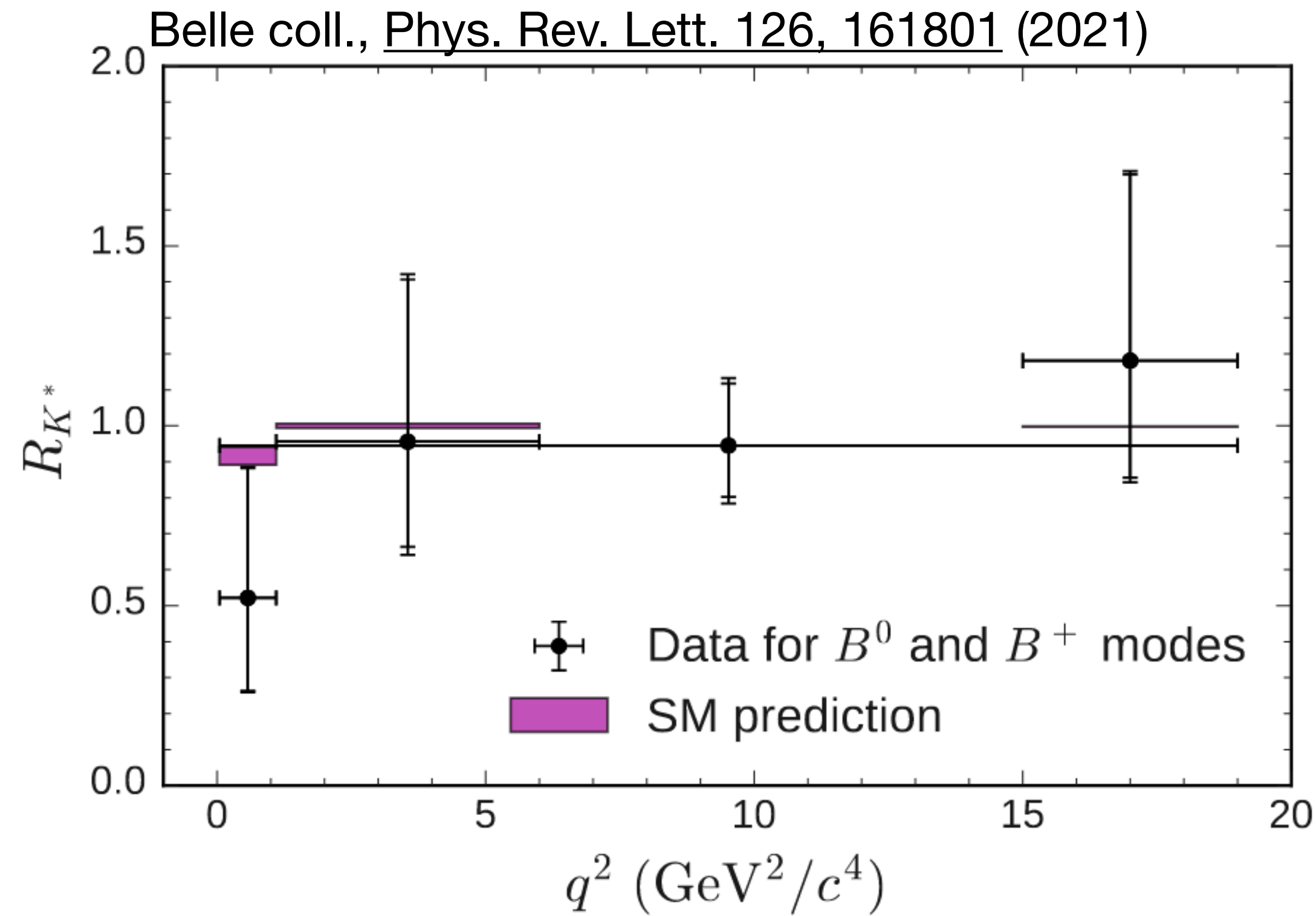
With a data transformation technique the dimension of the free parameters can be reduced to 4

Belle coll., Phys.Rev.Lett. 118 (2017) 11, 111801



- 2.6 σ discrepancy in muon channel for P_5' (uncertainty at the **50% level**, dominated by statistics)

$R(K^{(*)})$: latest measurement from Belle



q^2 in GeV ² /c ⁴	All modes
[0.045, 1.1]	$0.52^{+0.36}_{-0.26} \pm 0.06$
[1.1, 6]	$0.96^{+0.45}_{-0.29} \pm 0.11$
[0.1, 8]	$0.90^{+0.27}_{-0.21} \pm 0.10$
[15, 19]	$1.18^{+0.52}_{-0.32} \pm 0.11$
[0.045,]	$0.94^{+0.17}_{-0.14} \pm 0.08$

- In agreement with SM expectations within errors
- Measurement **statistically** limited
- Main systematics from lepton ID efficiency and knowledge of peaking background

Toward BelleII measurements (I)

- BelleII performances, some examples: Hadron ID, Lepton ID, neutral reconstruction
 - good understanding of the detector
 - performances comparable to Belle/BaBar in higher machine background environment
 - improvements in algorithms and understanding of the detectors foreseen

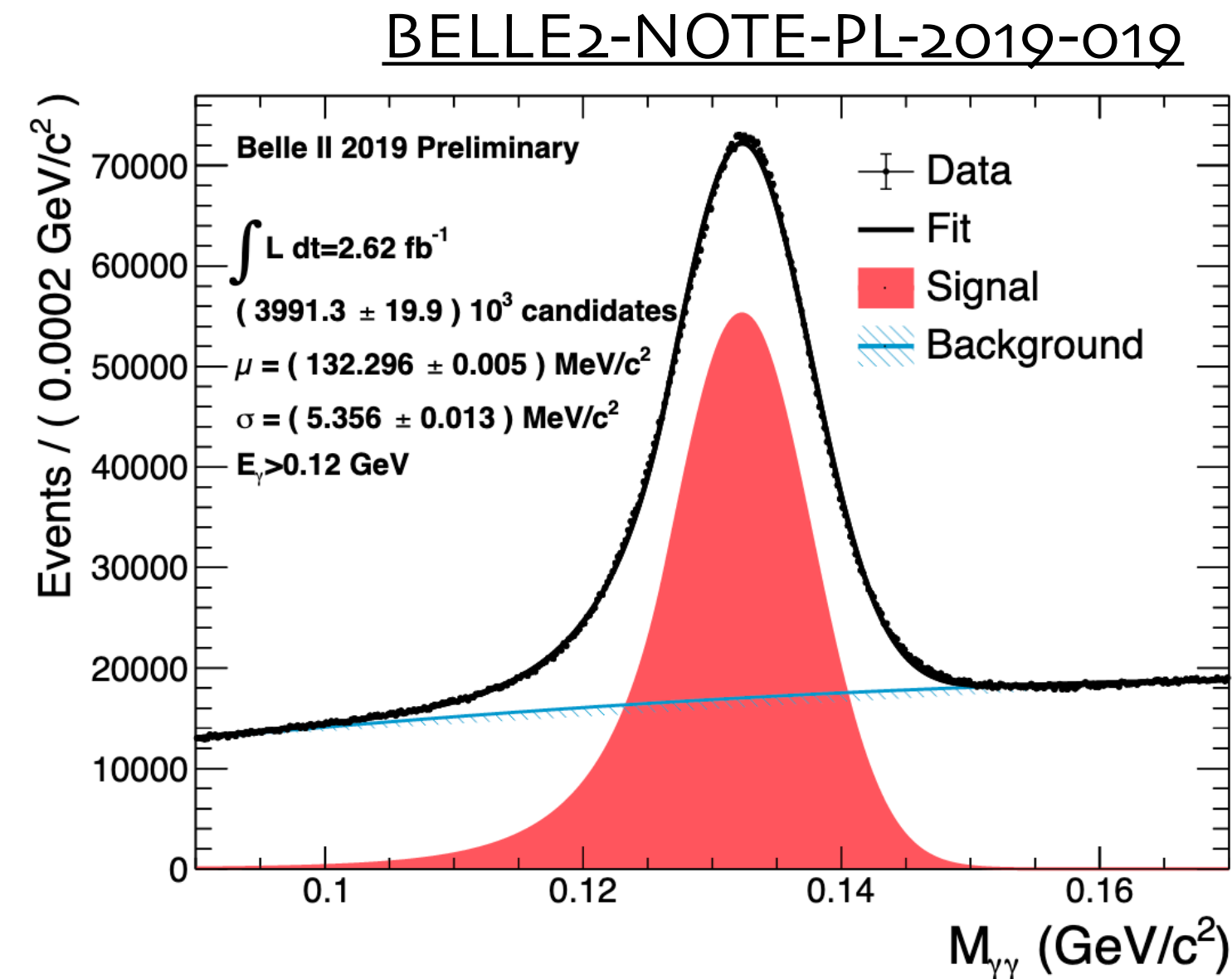
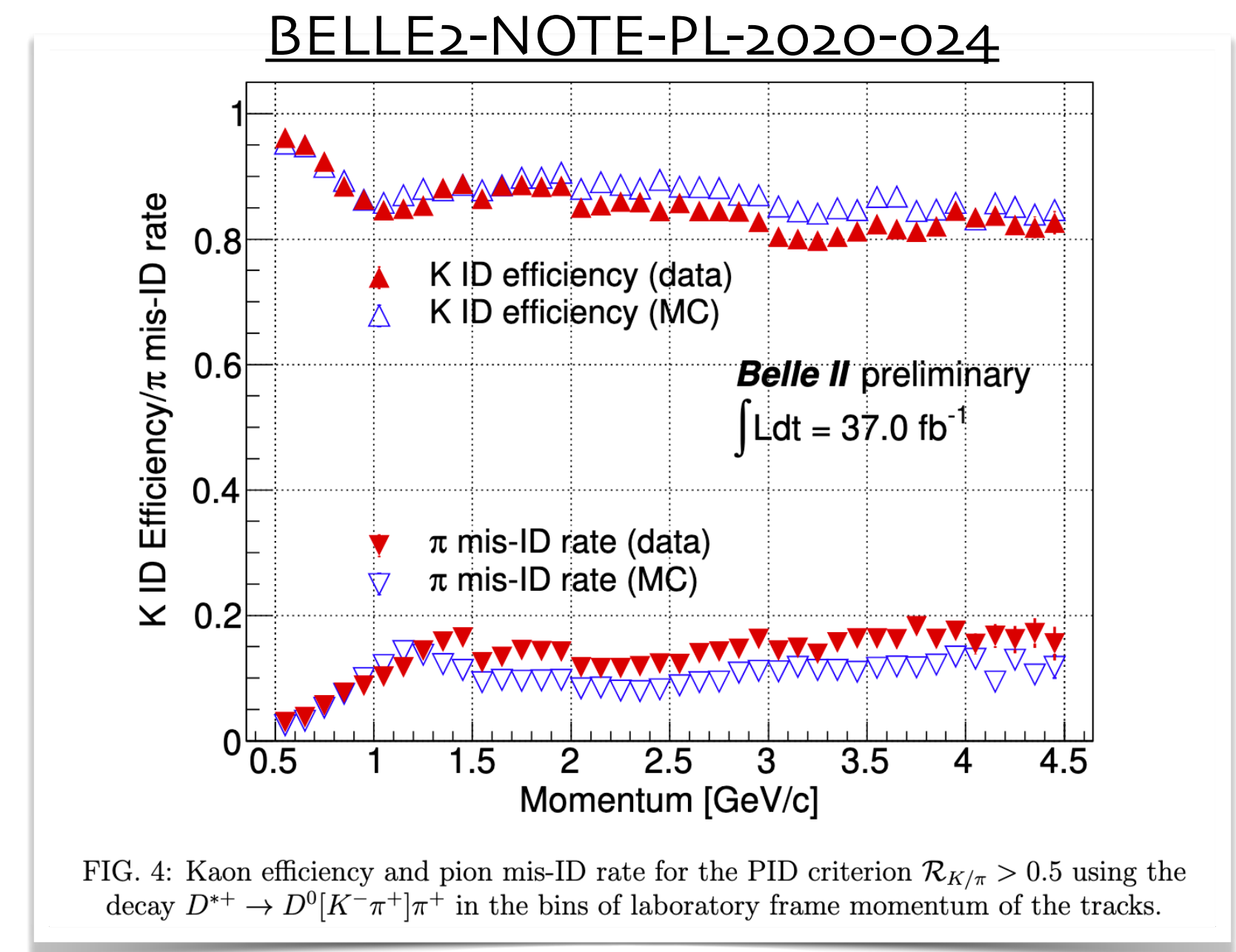
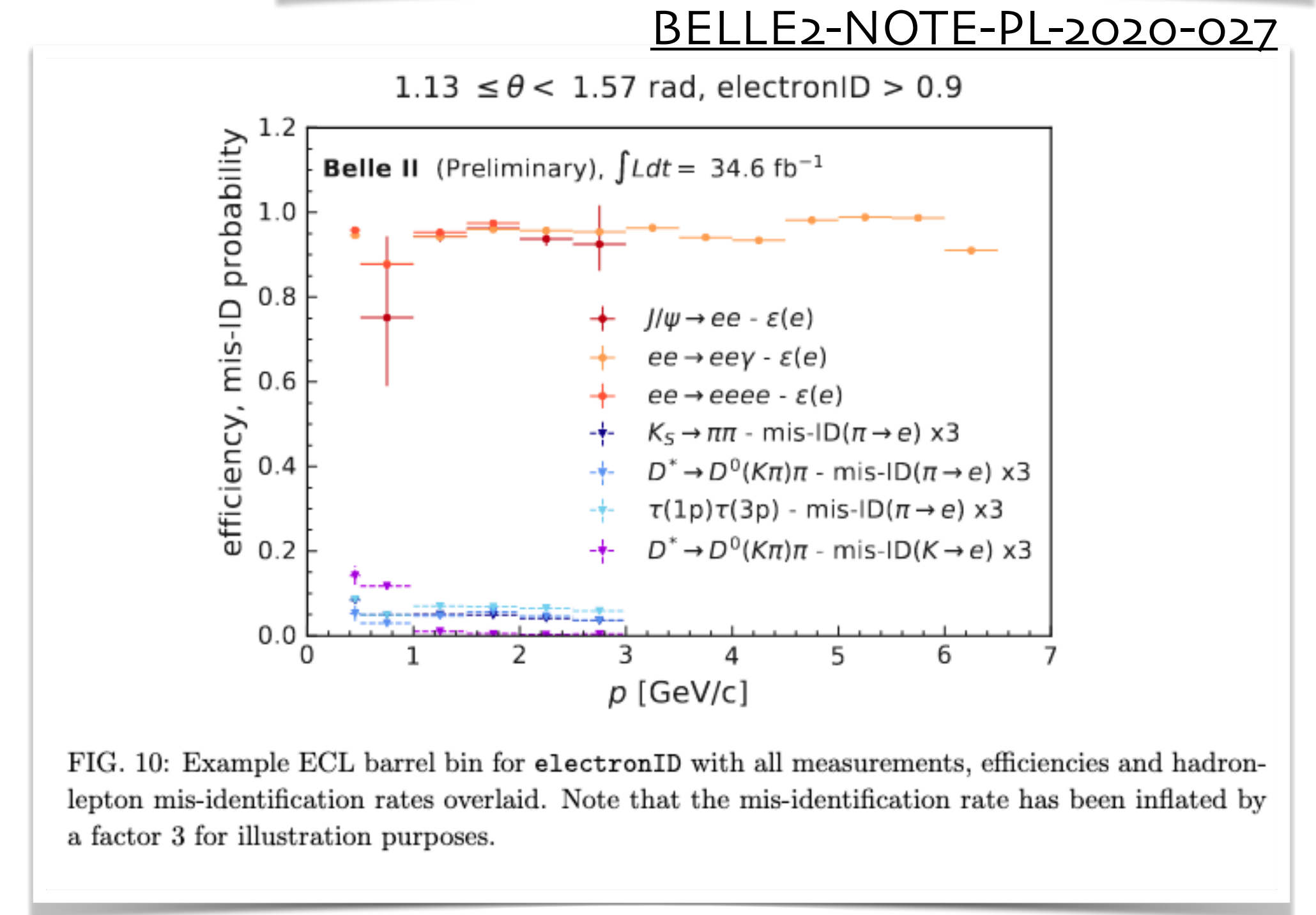


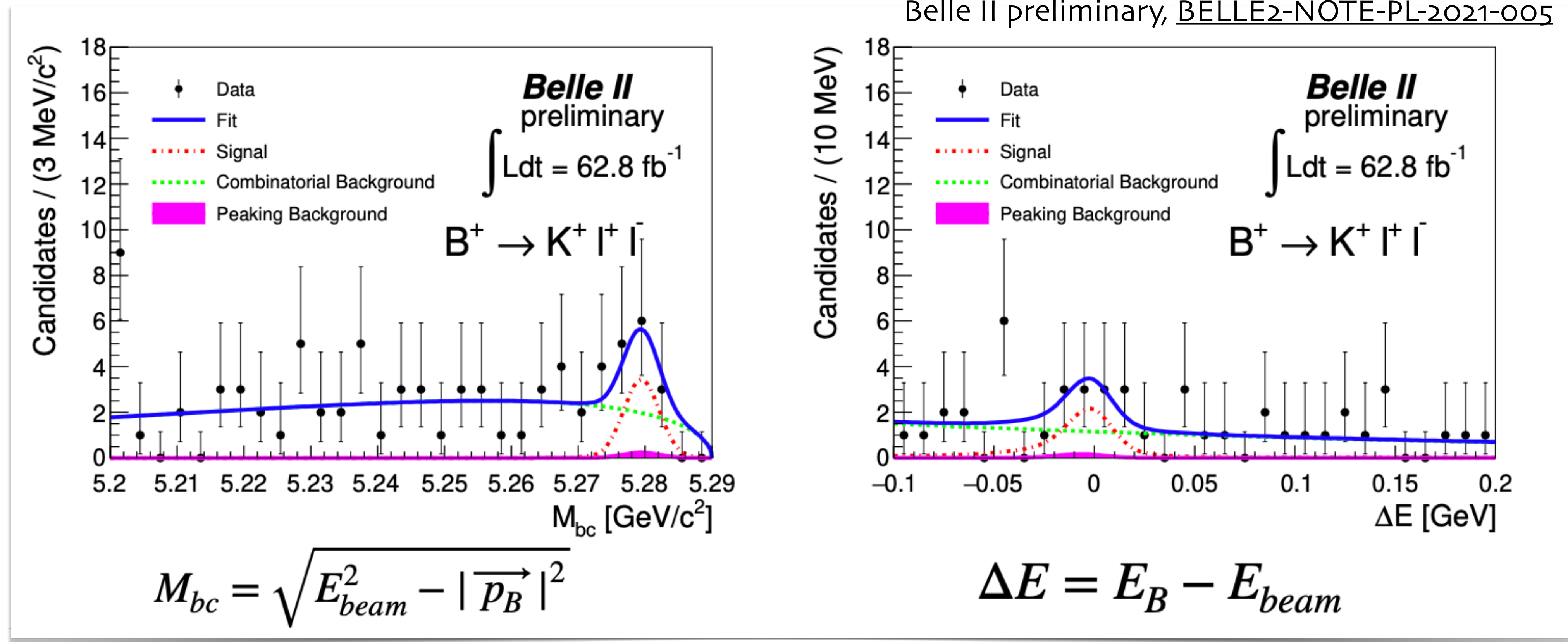
FIG. 1: Invariant mass of $\gamma\gamma$ for data phase III. The functions superimposed are the result of a binned ML fit to the data using as signal a Crystal Ball plus a Gauss (with the same mean) and a first order polynomial for background. A clear peak for the decay $\pi^0 \rightarrow \gamma\gamma$ is visible. Data corresponds to an integrated luminosity of 2.62 fb^{-1} (proc9 hadron skim). The selection criteria are $E_\gamma > 120 \text{ MeV}$, $E_9/E_{21} > 0.9$, $N_{hits} > 1.5$.



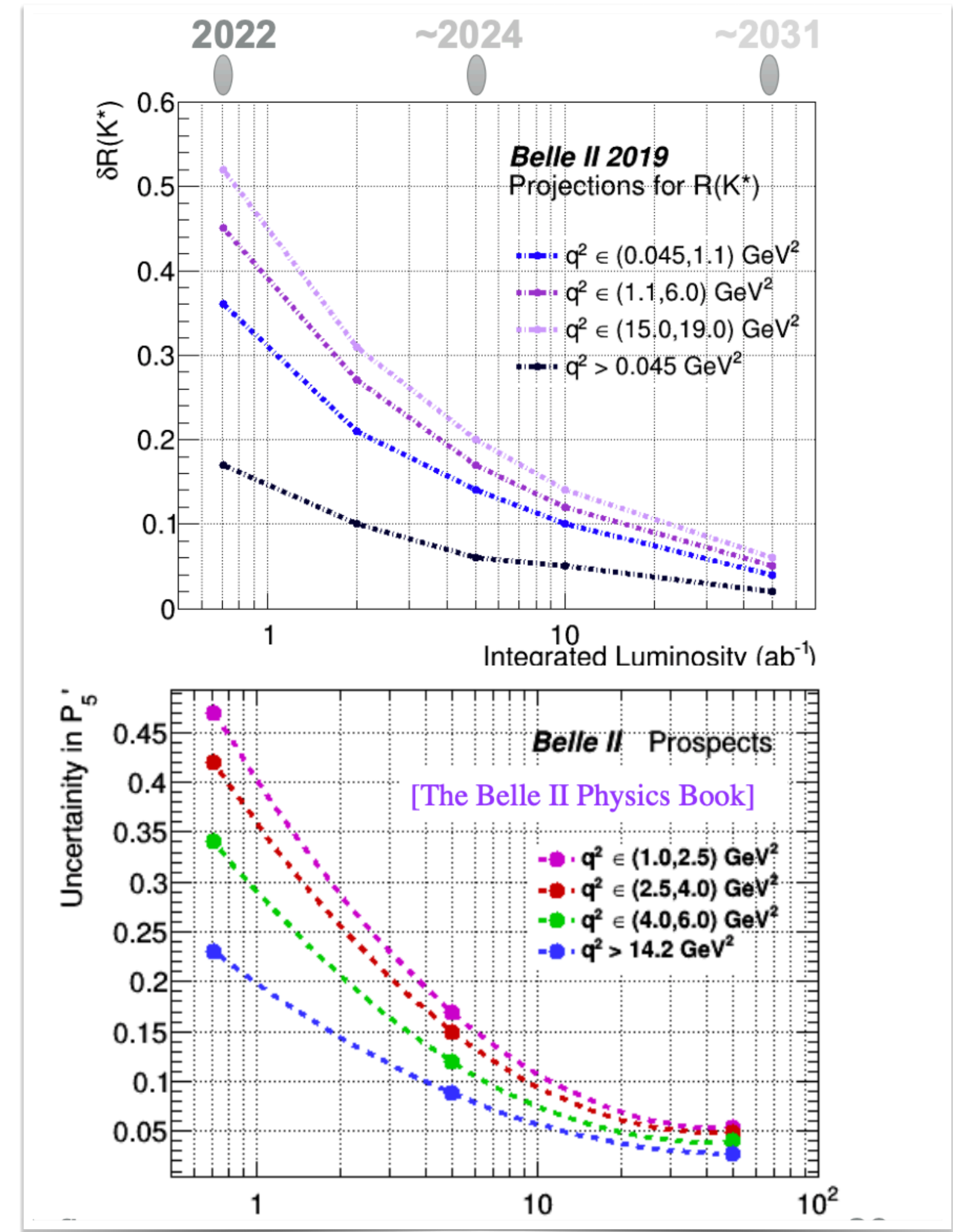
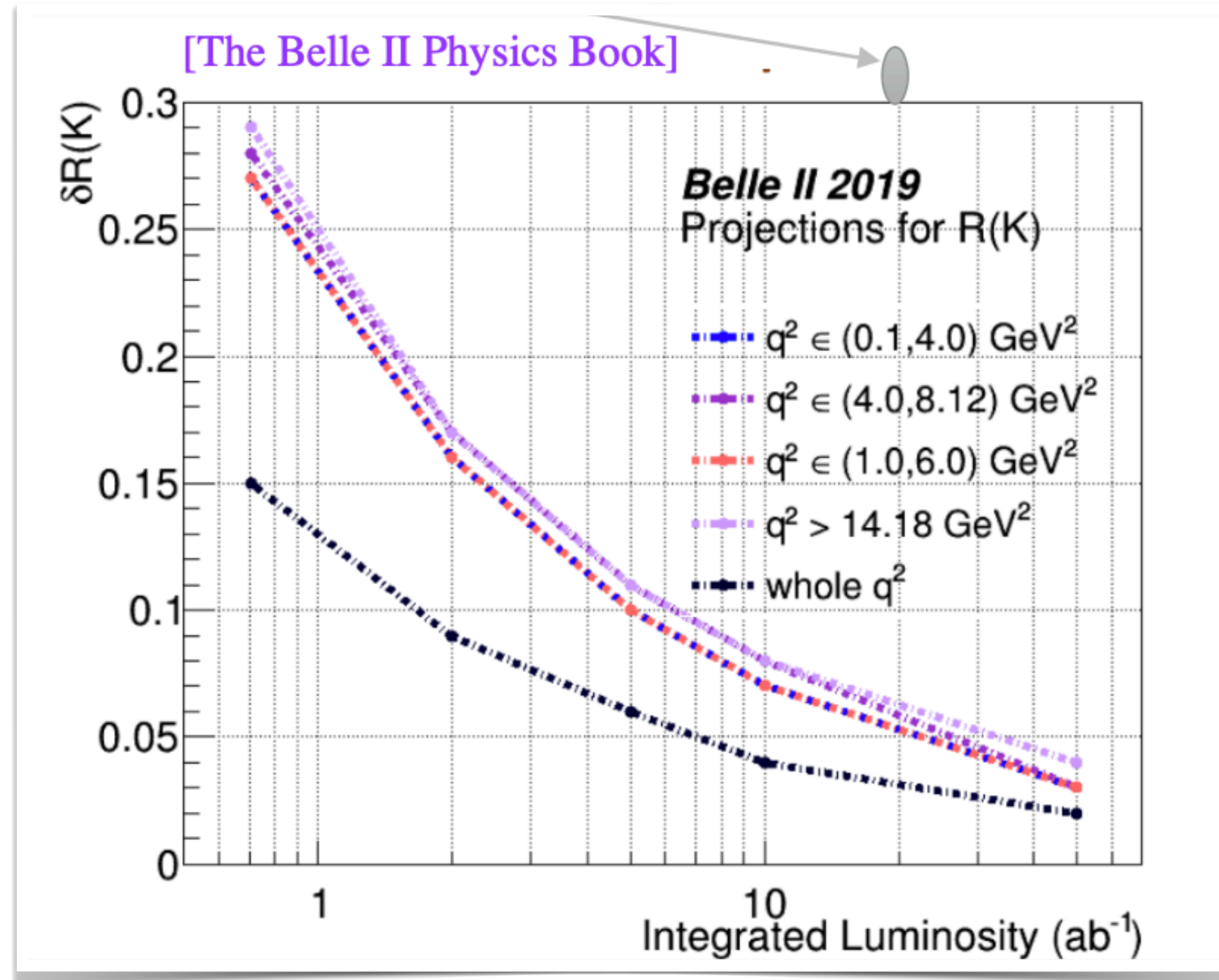
Toward BelleII measurements (II)

- Rediscovery of $\mathbf{B}^+ \rightarrow \mathbf{K}^+ \mathbf{l}^+ \mathbf{l}^-$, more on $b \rightarrow s \mathbf{l} \mathbf{l}$ to come in the next months
- Signal yield extracted from 2D fit to M_{bc} and ΔE , 2.7σ significance

- $N_{sig} = 8.6_{-3.9}^{+4.3}(\text{stat}) \pm 0.4(\text{syst})$



BelleII perspectives



- $R(K^{(*)})$: LHCb with full luminosity ($\sim 2035, 300fb^{-1}$) will have better precision in the low q^2 wrt to full BelleII data sample, in the high q^2 BelleII precision at **few %** level
- P_5' : will be studied in both e and μ channel at BelleII, **few %** level precision expected with full BelleII statistics

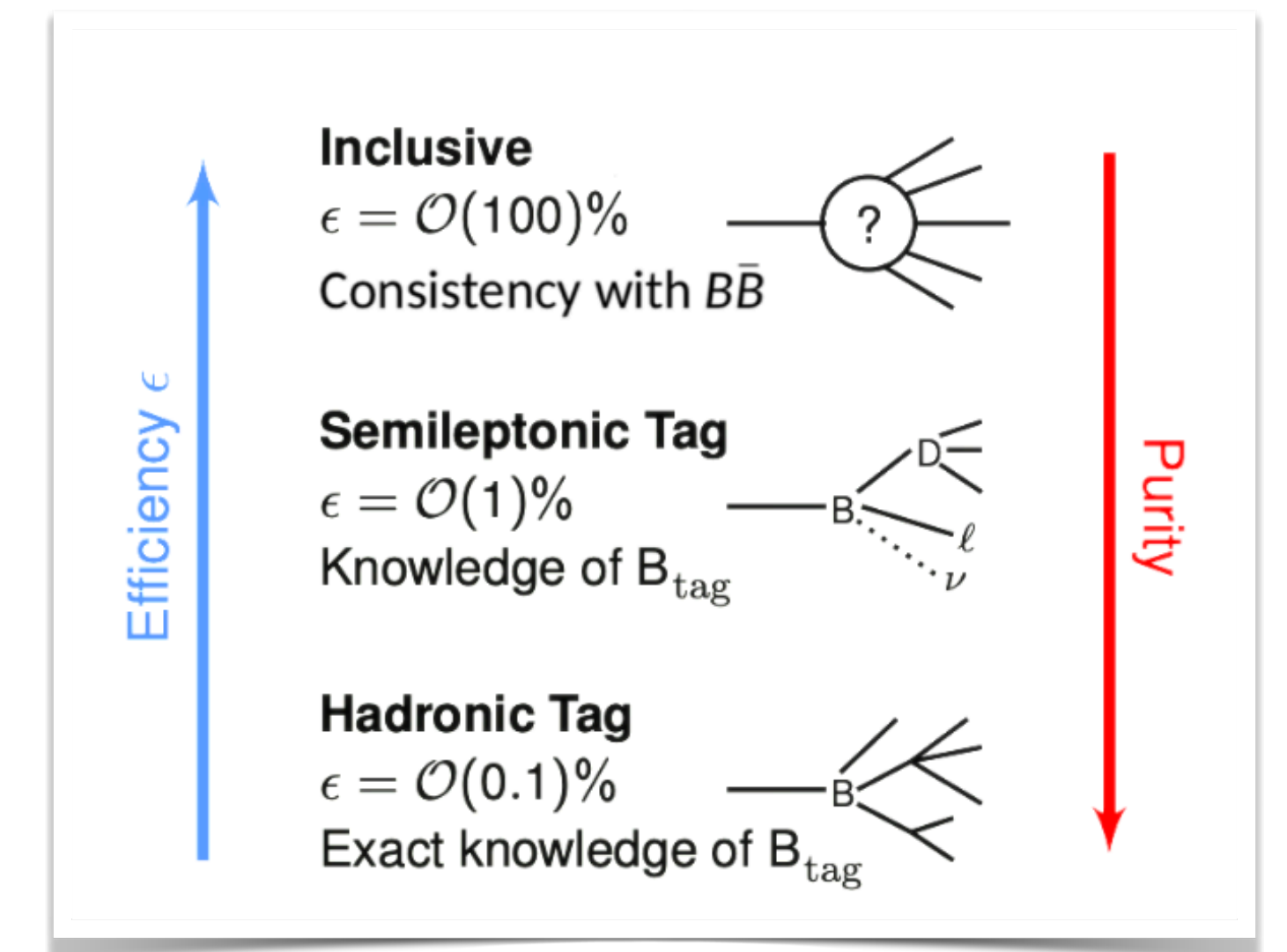
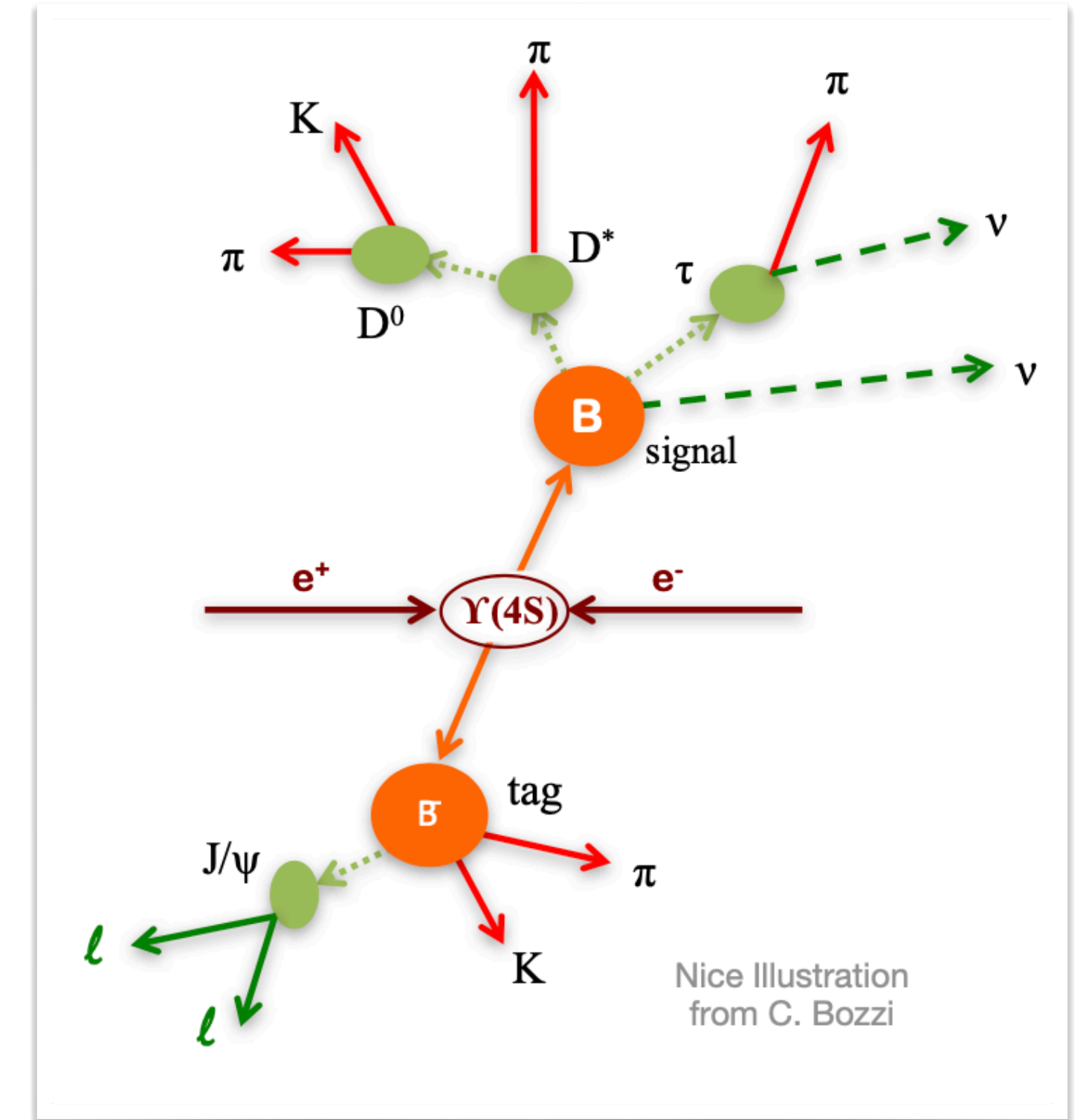
$b \rightarrow clv$

$\mathcal{R}(D^{(*)})$: analysis strategy

- Measurable:

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \rightarrow D^{(*)} \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \rightarrow D^{(*)} \ell^- \bar{\nu}_\ell)}$$

- Search for final states involving neutrinos, two key elements
- One of the KEYS of measurement @ B-factories:
 - beam energy completely transferred to BB pair:
 $e^+e^- \rightarrow Y(4S) \rightarrow B\bar{B}$
 - exploit (almost) **full reconstruction of one of the B** and look for signal or normalisation signature in the rest of the event
 - can compute momentum associated to **missing** particles, e.g. $p_{\text{miss}} = p_{e^+e^-} - p_{B_{\text{tag}}} - p_{D^*} - p_\pi$



$\mathcal{R}(D^{(*)})$: latest Belle measurement

- Tag side reconstructed in semileptonic final state
- τ reconstructed in purely leptonic modes
- Signal extracted from 2D fit to BDT and E_{ECL} :
- E_{ECL} = neutral energy deposited in the calorimeter not associated to signal nor to tag side, key ingredient in analysis with missing energy

$$\mathcal{R}(D) = 0.307 \pm 0.037 \pm 0.016$$

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

Most precise measurement to date

Belle coll., Phys.Rev.Lett. 124 (2020)

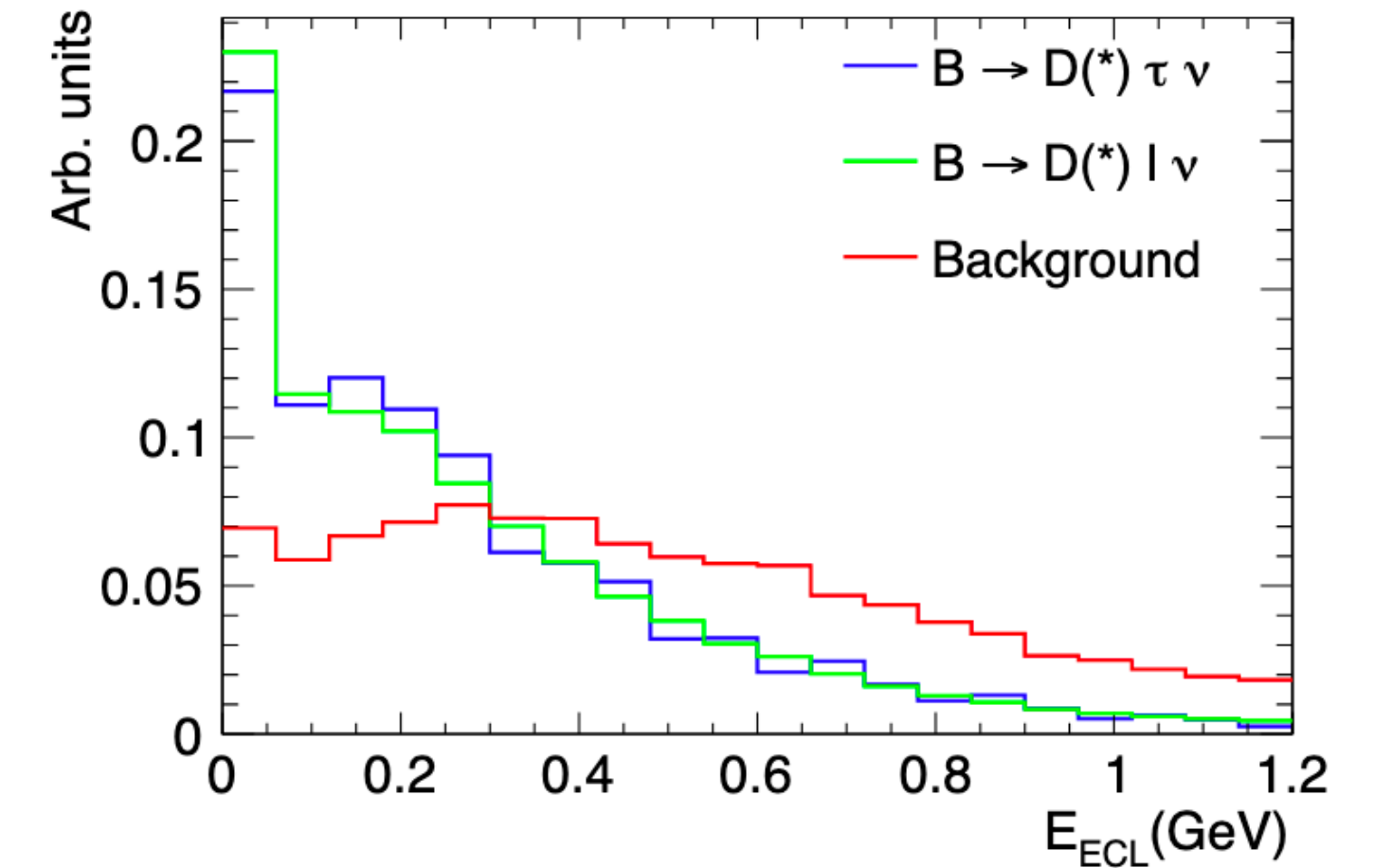
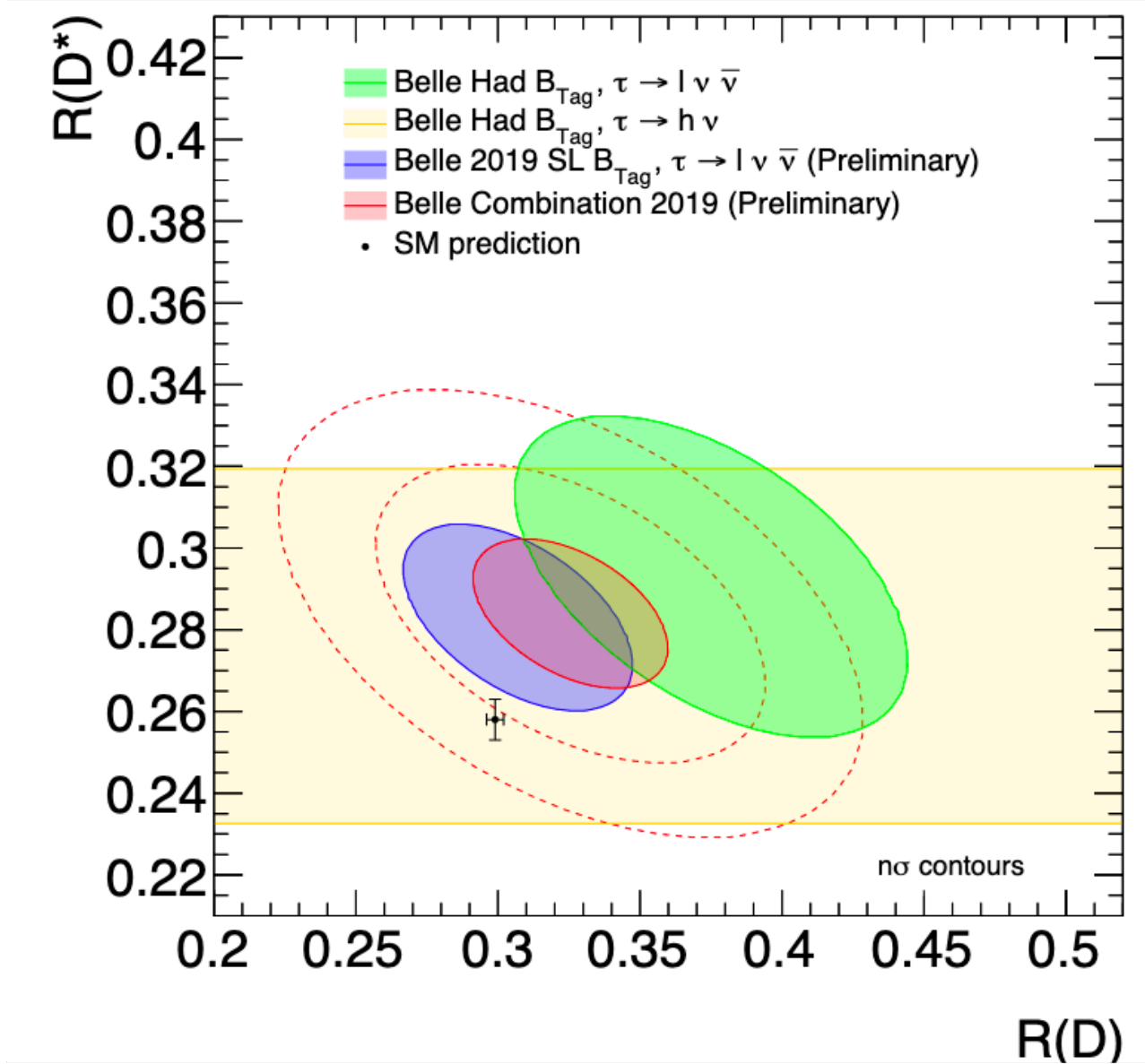


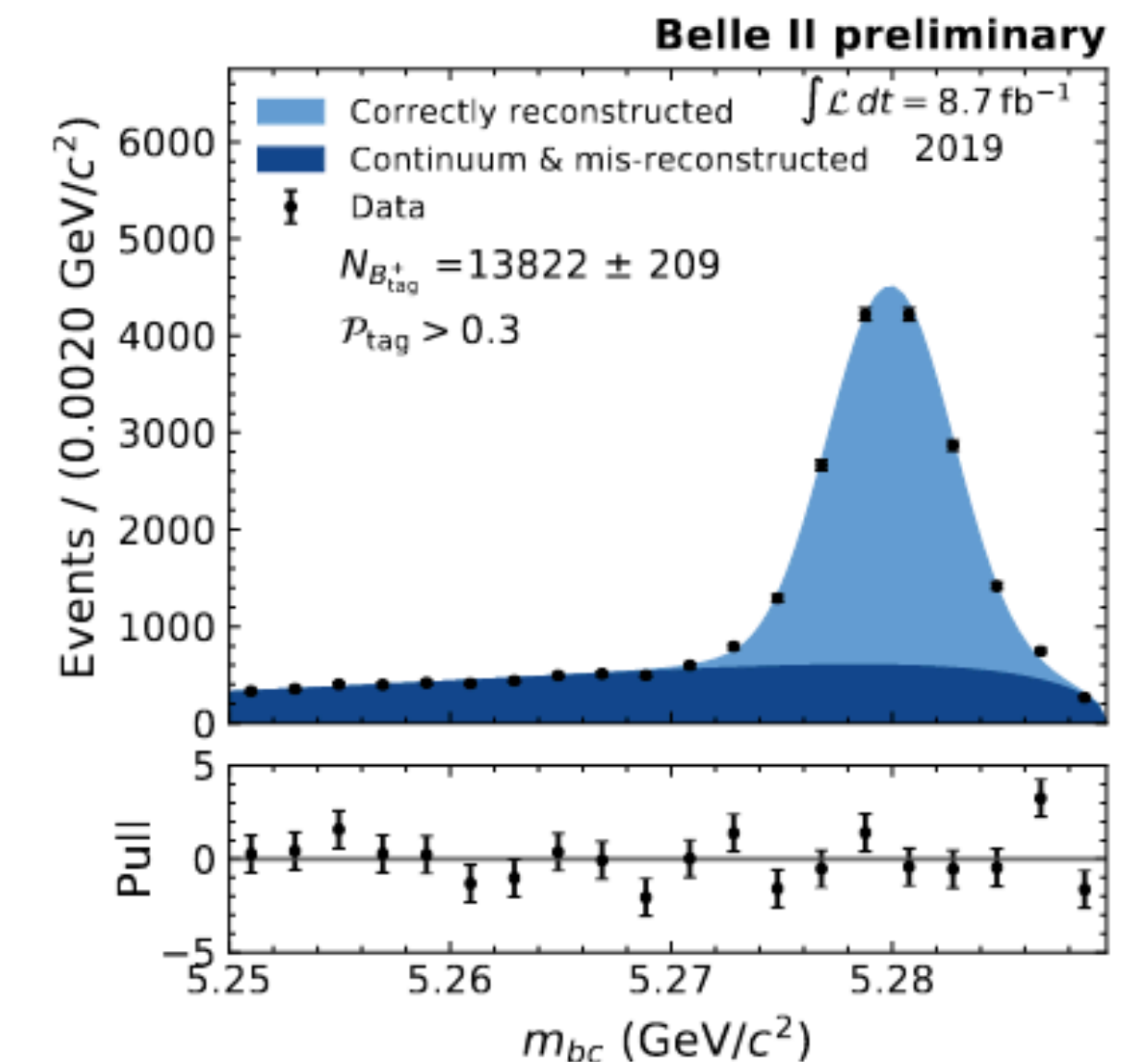
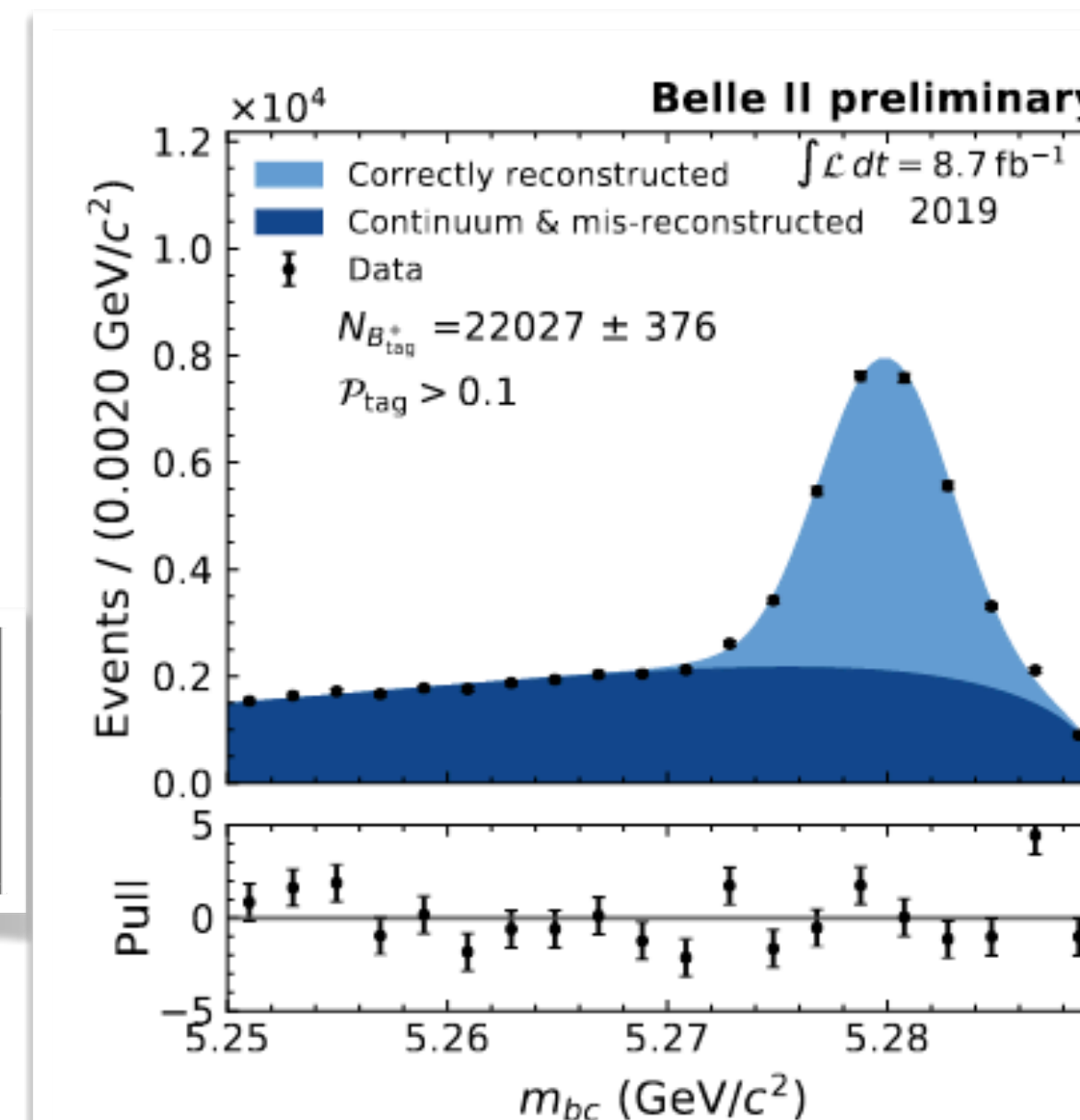
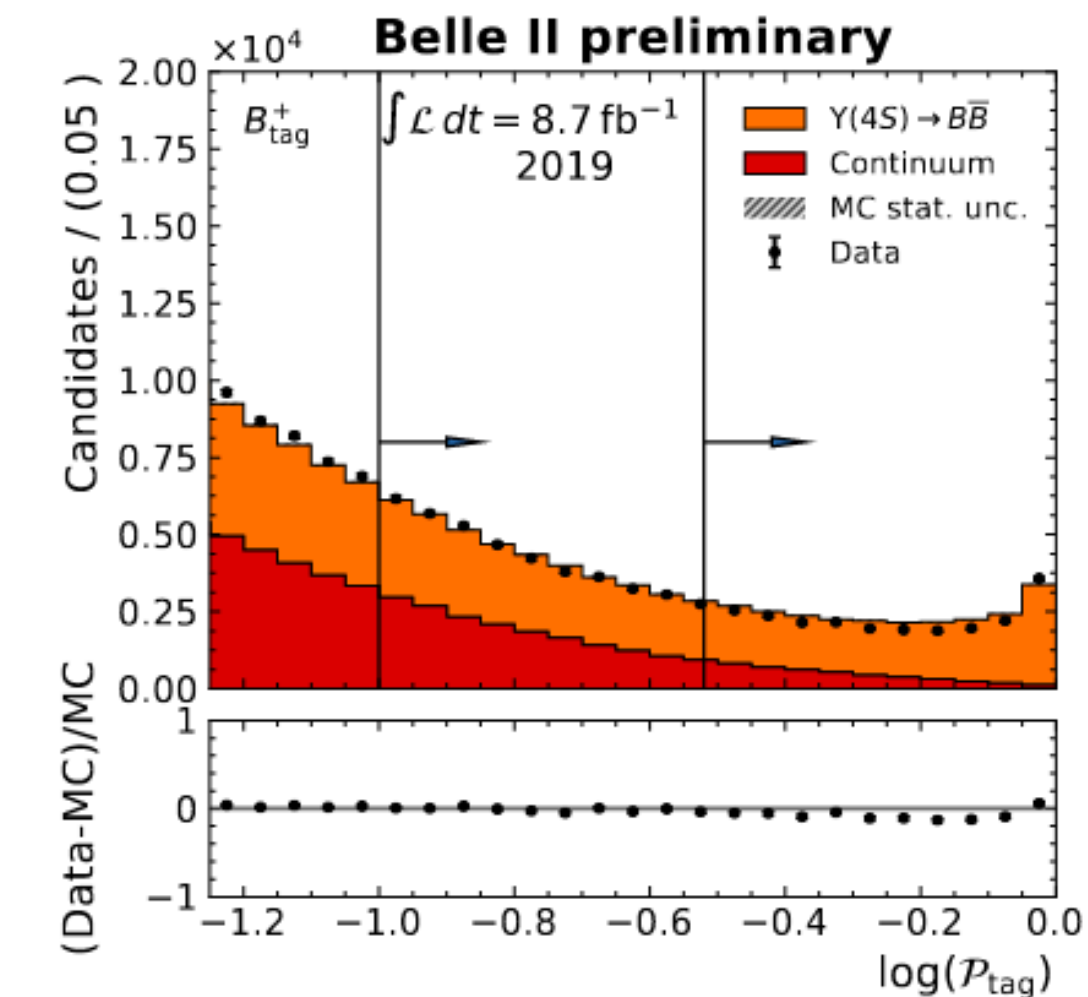
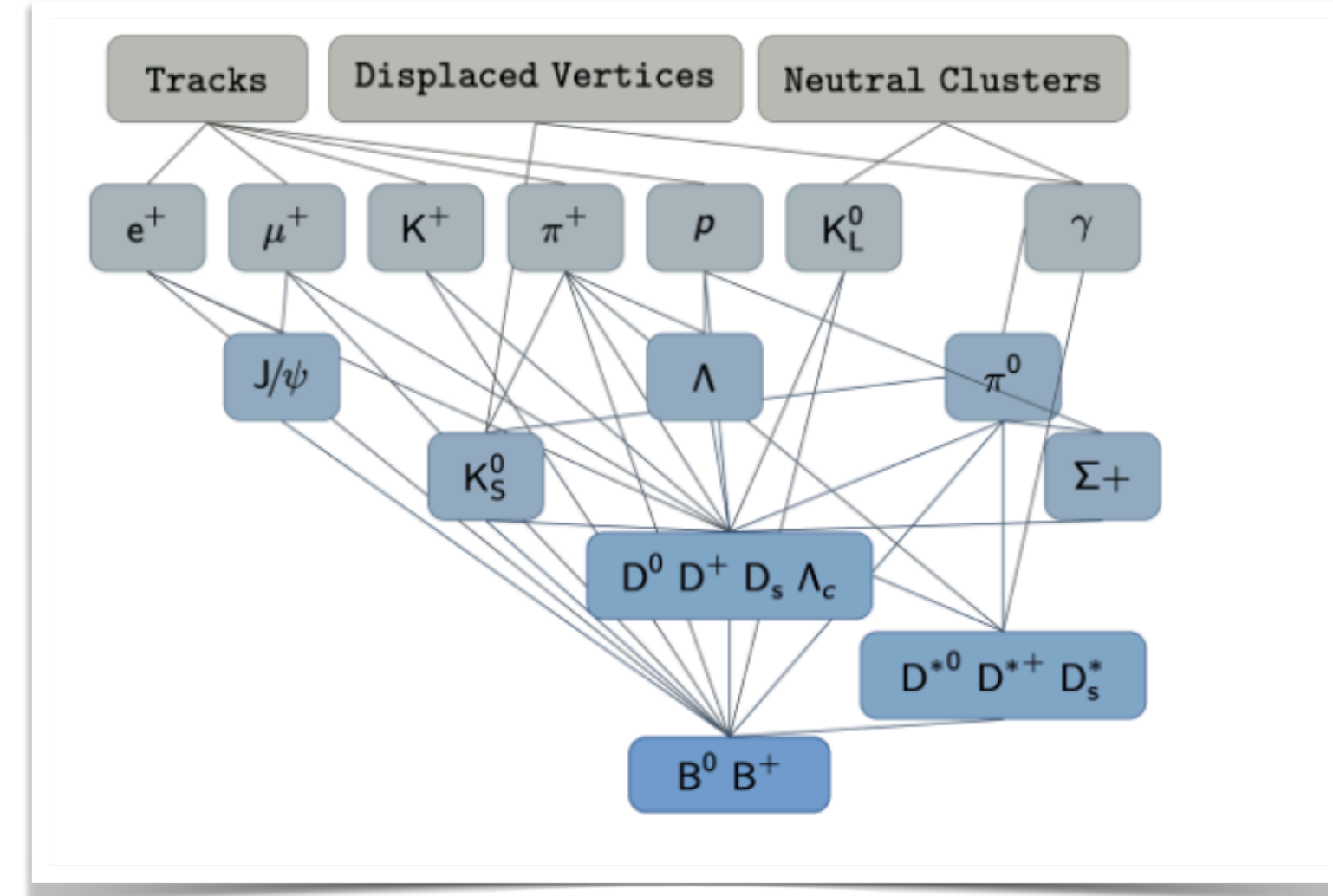
FIG. 1. E_{ECL} distributions for the signal, normalization, and background taken from MC simulation. The distributions for all decay modes are summed together and normalized to unity.



R(D^(*)): toward Belle II measurement (I)

BELLE2-NOTE-PL-2020-002

- Tag side reconstruction with **Full Event Interpretation (FEI)** (Keck et al., *Comp. Soft. Big Sci.* (2019) 3:6)
- Multivariate tagging algorithm optimised for BelleII, successor of Belle Full Reconstruction (Feindt et al. *Nucl.Instrum.Meth.A* 654 (2011) 432-440), can be applied to Belle data
- hierarchical approach to reconstruct O(200) decay channels via O(10⁴) decay chains



MC tag-side efficiency @10% purity	Had. B ⁺ /B ⁰ [%]	SL. B ⁺ /B ⁰ [%]
Full Reconstruction Belle	0.28/0.18	0.67/0.63
FEI Belle	0.76/0.46	1.80/2.04

P. Urquijo (BelleII), FPCP2020

R(D^(*)): toward Belle II measurement (II)

- Rediscovery of **normalisation channel** using hadronic **FEI**

Belle coll., BELLE2-CONF-PH-2020-009

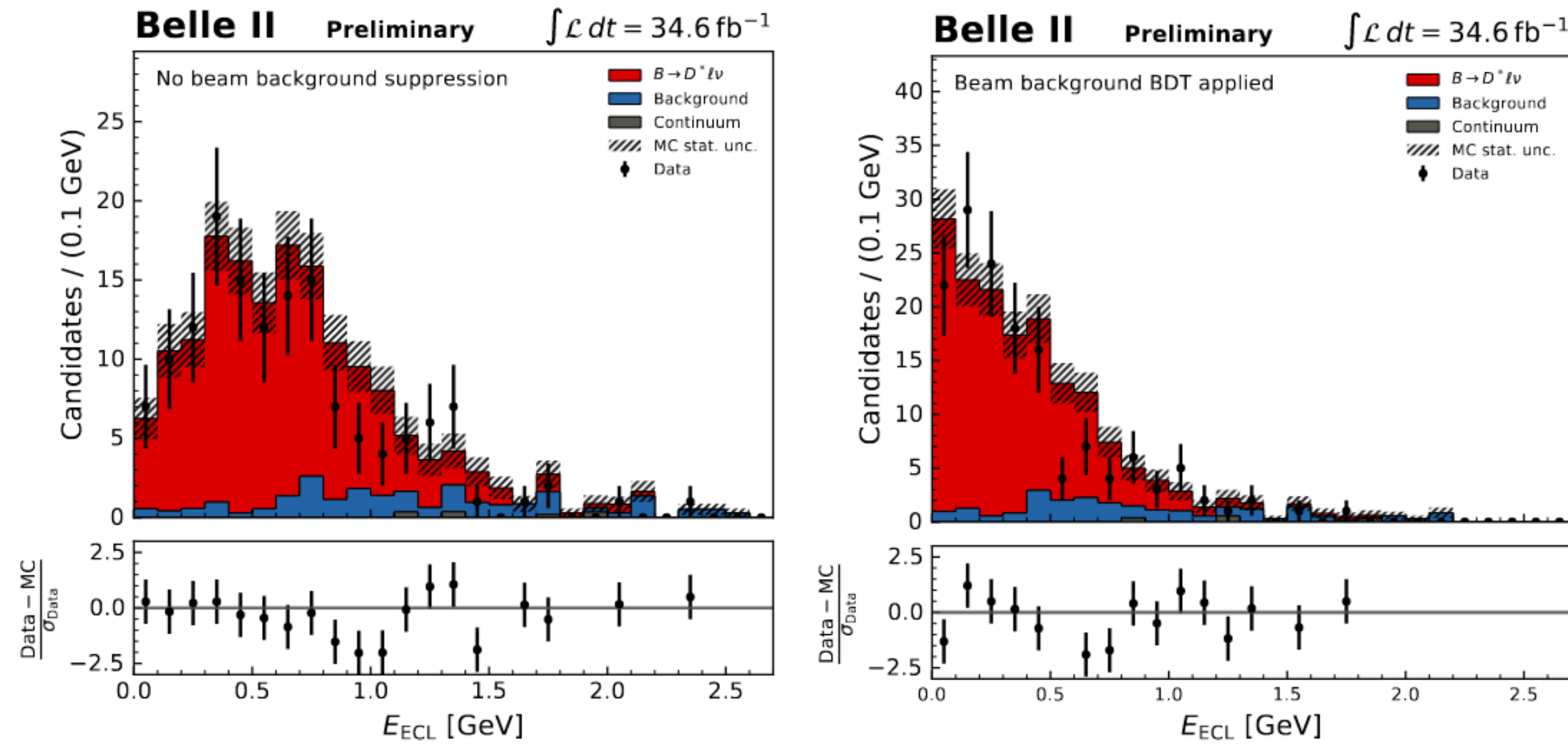


FIG. 3. Two versions of E_{ECL} are shown: (left) is the version applying detector region dependent energy selection criteria, (right) shows the impact of using a BDT to identify neutral energy depositions from beam background processes. It is based on shower shape variables and the detector region of the reconstructed neutral cluster.

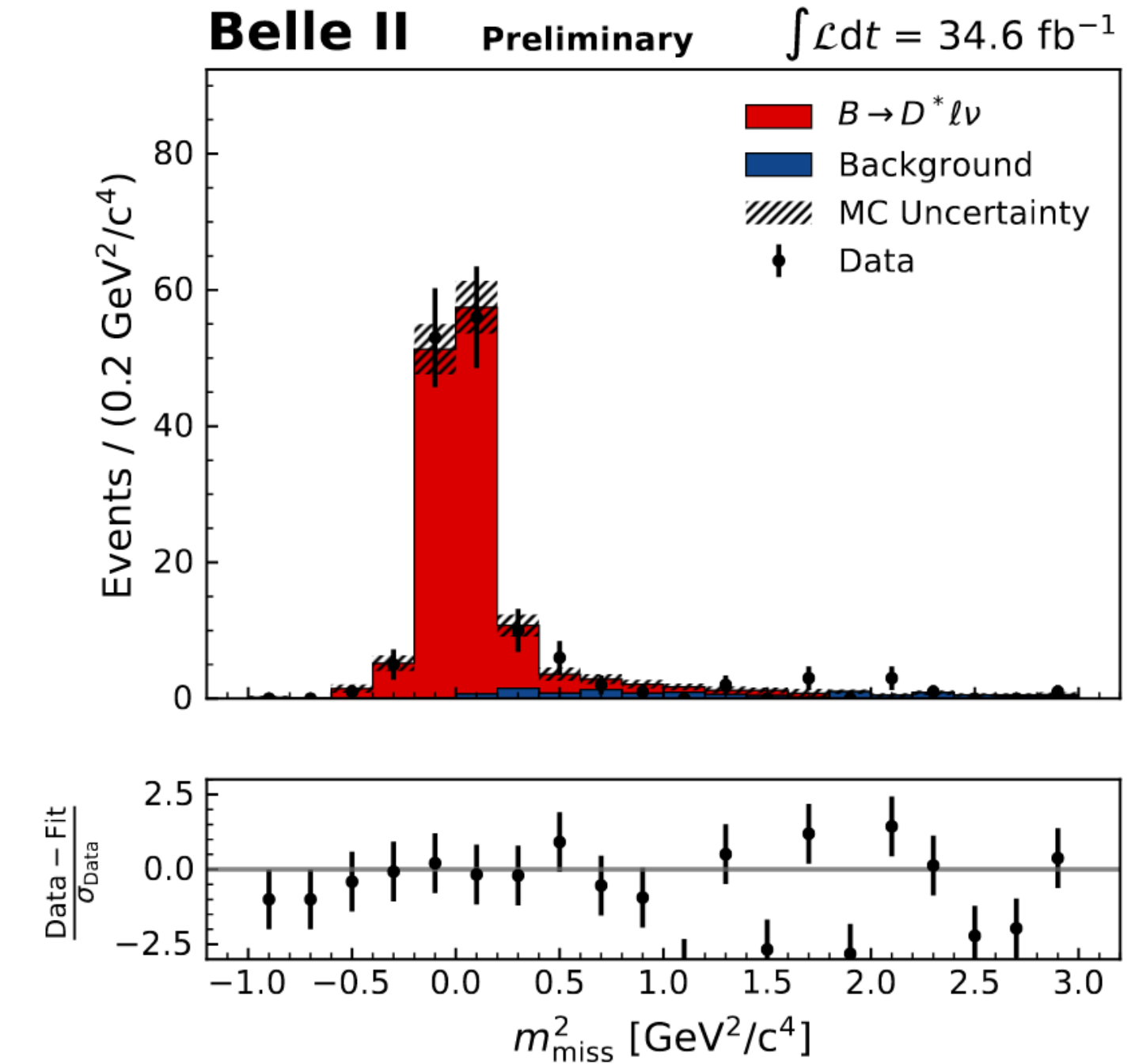
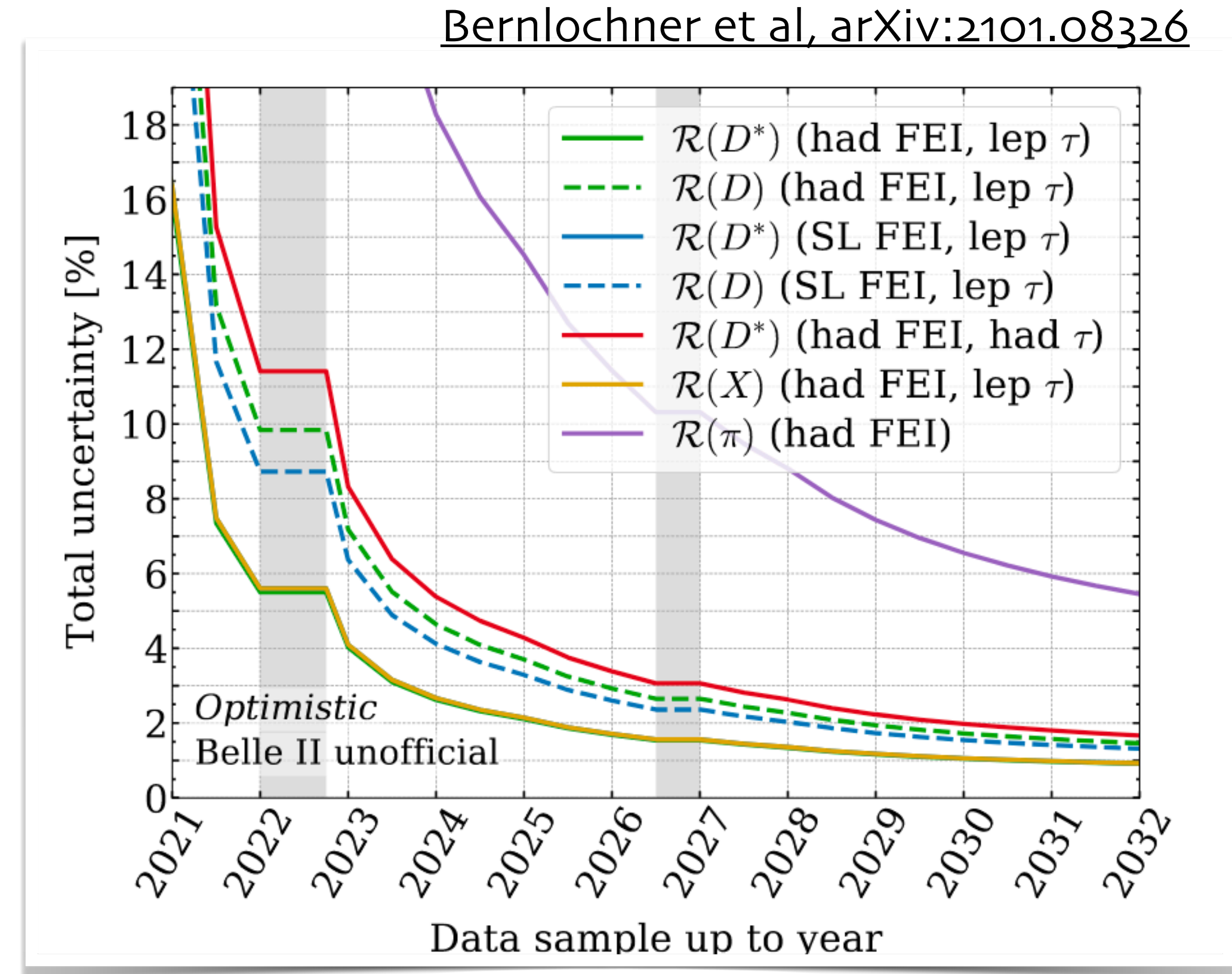
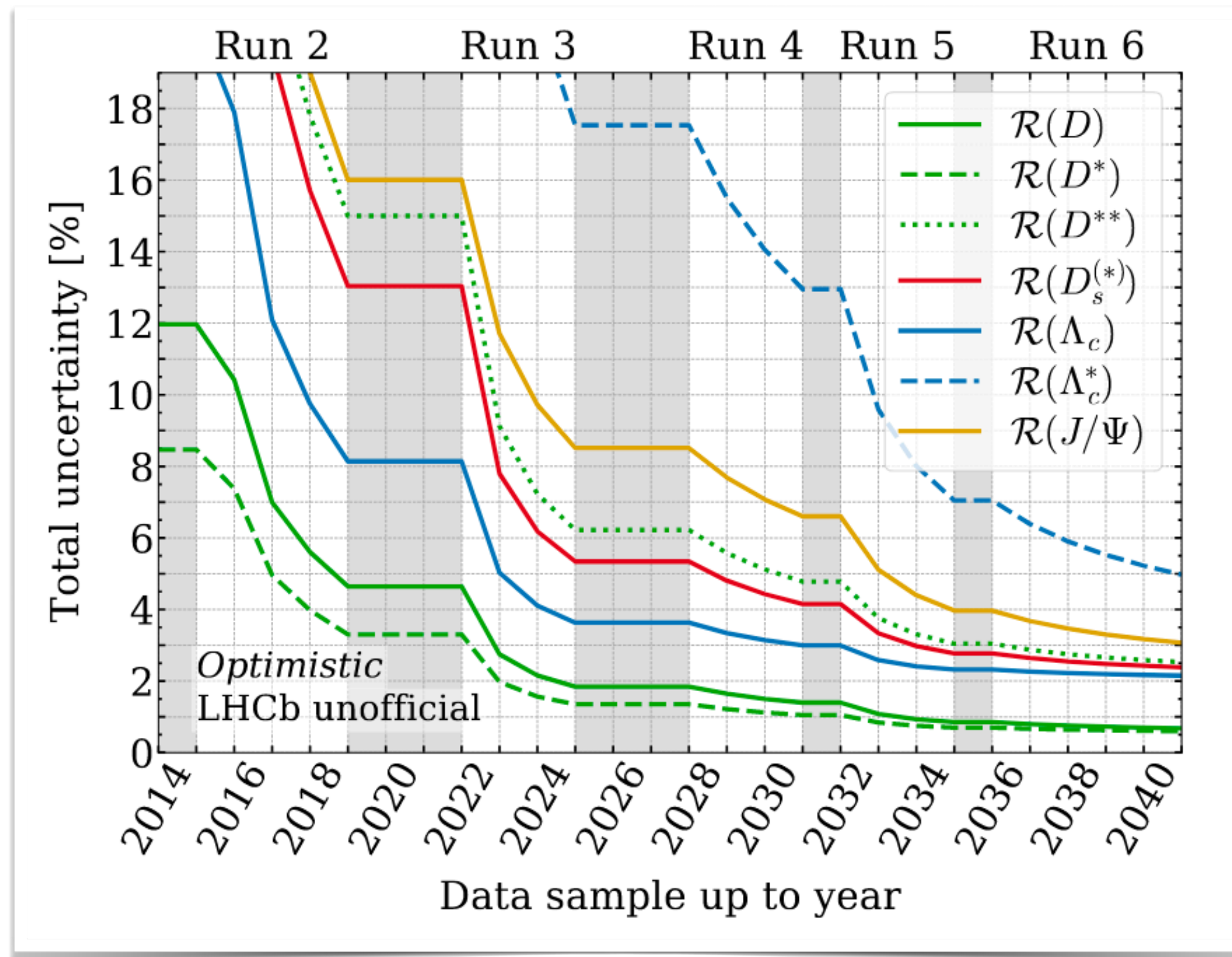


FIG. 2. The post-fit m_{miss}^2 distribution is shown.

$$\mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell) = (4.51 \pm 0.41_{\text{stat}} \pm 0.27_{\text{syst}} \pm 0.45_{\pi_s}) \%$$

$\mathcal{R}(D^{(*)})$: perspectives at BelleII



- Pletora of τ/l ratio measurements from LHCb and Belle
- On $\mathcal{R}(D^{(*)})$, (sub)-% level precision can be reached
- @ Belle, one of the dominant systematics from D^{**} background, can be studied in more detail with BelleII data

Table 49: Composition of the systematic uncertainty in each Belle analysis. Relative uncertainties in percent are shown. The analysis method and the τ decay mode are indicated in the parentheses; their meaning is explained in the caption of Table 48.

Source	Belle (Had, ℓ^-) R_D	Belle (Had, ℓ^-) R_{D^*}	Belle (SL, ℓ^-) R_{D^*}	Belle (Had, h^-) R_{D^*}
MC statistics	4.4%	3.6%	2.5%	+4.0% -2.9%
$B \rightarrow D^{**} \ell \nu_\ell$	4.4%	3.4%	+1.0% -1.7%	2.3%
Hadronic B	0.1%	0.1%	1.1%	+7.3% -6.5%
Other sources	3.4%	1.6%	+1.8% -1.4%	5.0%
Total	7.1%	5.2%	+3.4% -3.5%	+10.0% -9.0%

Looking for other NP
hints in B and τ decays

NP models explaining LFU violation

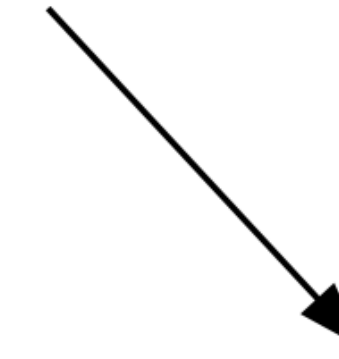
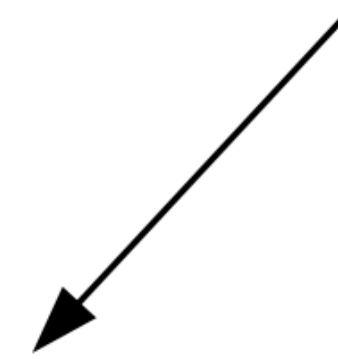


- G. Isidori @ Beyond the anomalies II

► From EFT to simplified models

Beside direct searches, an essential role is still played by low-energy observables → many visible BSM effects expected, by consistency, virtually in all models addressing the anomalies

Main message: “**super-reach**” program for **LHCb** & **Belle-II** and other low-energy facilities. This program is essential to confirm/disproof the picture and, if confirmed..., to determine the flavor structure of the new sector.



I. EFT-based (model-independent) correlations on a large class of semi-leptonic processes

[$b \rightarrow d \mu\mu$, $b \rightarrow s \tau\tau$, $b \rightarrow s \tau\mu$,
 $b \rightarrow u \tau\nu$, ...]

II. Model-dependent correlations for UV-sensitive observables

[$\Delta F=2$, $b \rightarrow s \nu\nu$, $\tau \rightarrow \mu\gamma$,
 $\tau \rightarrow 3\mu$, $\mu N \rightarrow eN$, ...]

$B \rightarrow K^{(*)} \nu \nu$: state of the art Moriond2021

- $b \rightarrow s$ transition with neutral leptons in the final state
- SM predictions:

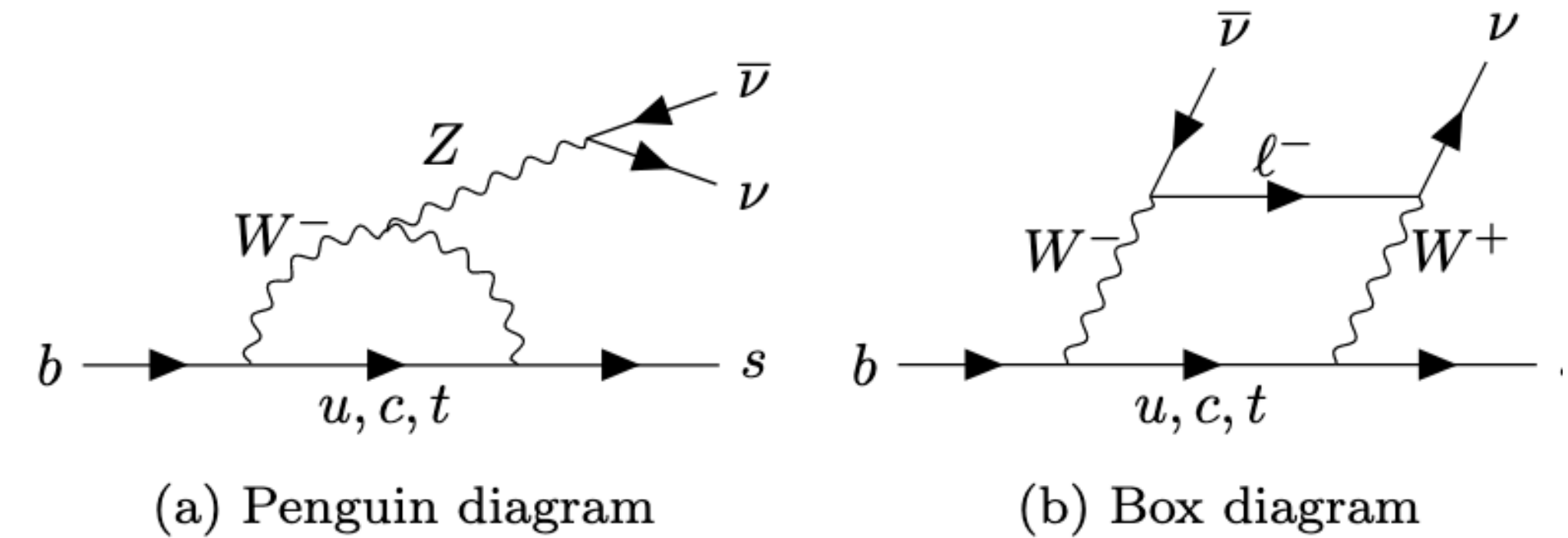
T. Blake, et al, Prog. Part.Nucl. Phys.92, 50 (2017)

$$\text{BR}(B^+ \rightarrow K^+ \nu \bar{\nu})_{\text{SM}} = (4.6 \pm 0.5) \times 10^{-6},$$

$$\text{BR}(B^+ \rightarrow K^{*+} \nu \bar{\nu})_{\text{SM}} = (8.4 \pm 1.5) \times 10^{-6},$$

$$F_L^{\text{SM}} = 0.47 \pm 0.03, \text{ Buras et al, JHEP 02 184 (2015)}$$

- BaBar and Belle key ingredients: **tag side** reconstruction in hadronic and semi-leptonic modes, usage of **event shape** variables to reduce contributions from $e^+e^- \rightarrow qq$ events and **extra neutral energy** deposited in the calorimeter



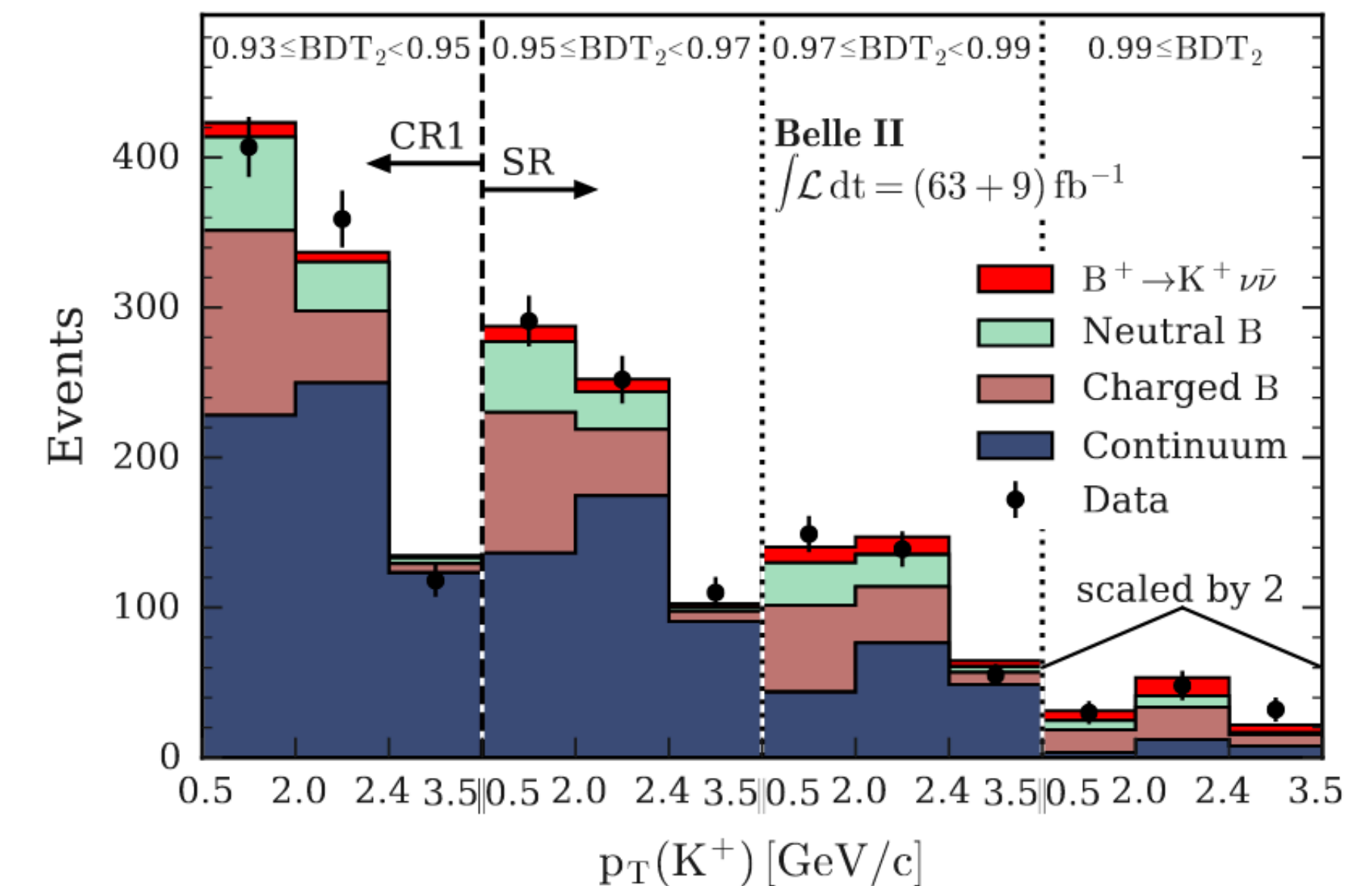
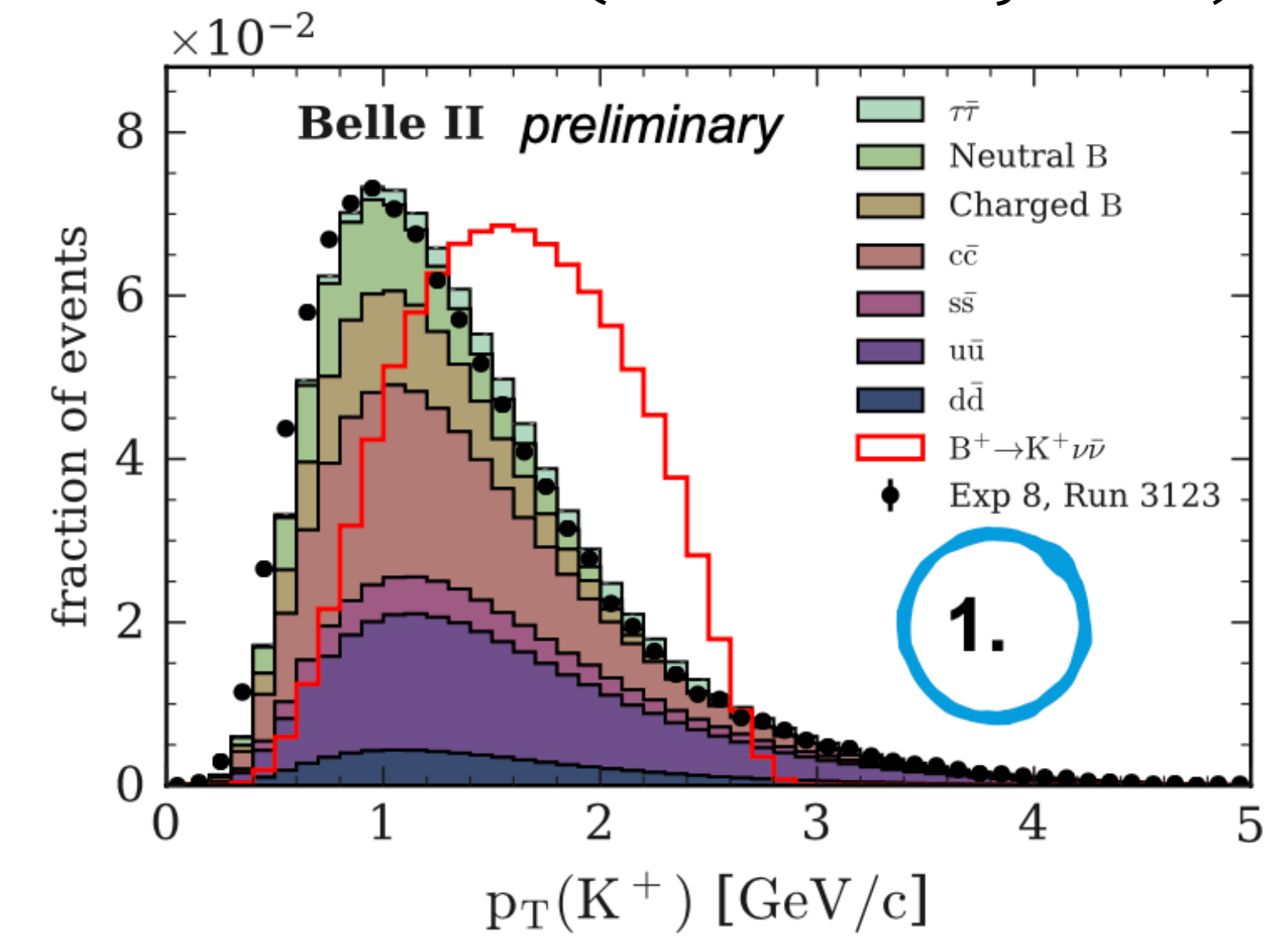
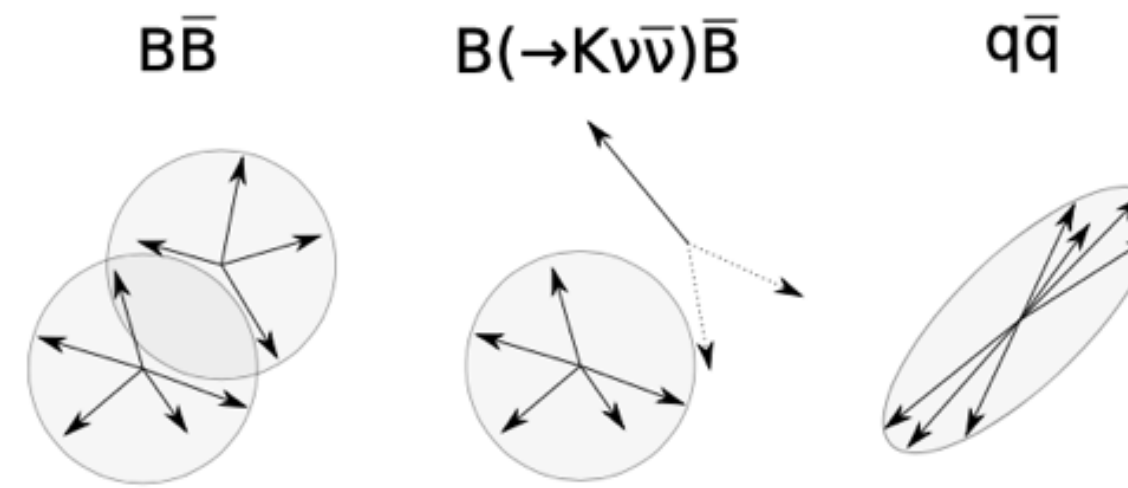
	UL @ 90% CL (10^{-5})	Ref
$B^+ \rightarrow K^+ \nu \nu$	1.6	BaBar, HAD+SL TAG, 429 fb ⁻¹
$B^+ \rightarrow K^{*+} \nu \nu$	4.0	Belle, HAD TAG, 711 fb ⁻¹
$B^0 \rightarrow K^0 \nu \nu$	2.6	Belle, SL TAG, 711 fb ⁻¹
$B^0 \rightarrow K^{*0} \nu \nu$	1.8	Belle, SL TAG, 711 fb ⁻¹

$B^+ \rightarrow K^+ \nu \bar{\nu}$ measurement @ Belle II (I)

BelleII coll., arXiv:2104.12624
(submitted to journal)

• NOVEL INCLUSIVE APPROACH:

- signal kaon = highest p_T track
- associate all other tracks and clusters to rest of the event
- use multivariate approach based on kinematics, event shape and vertexing variables to suppress background
- extract signal from binned simultaneous ML fit to on-resonance + off-resonance data



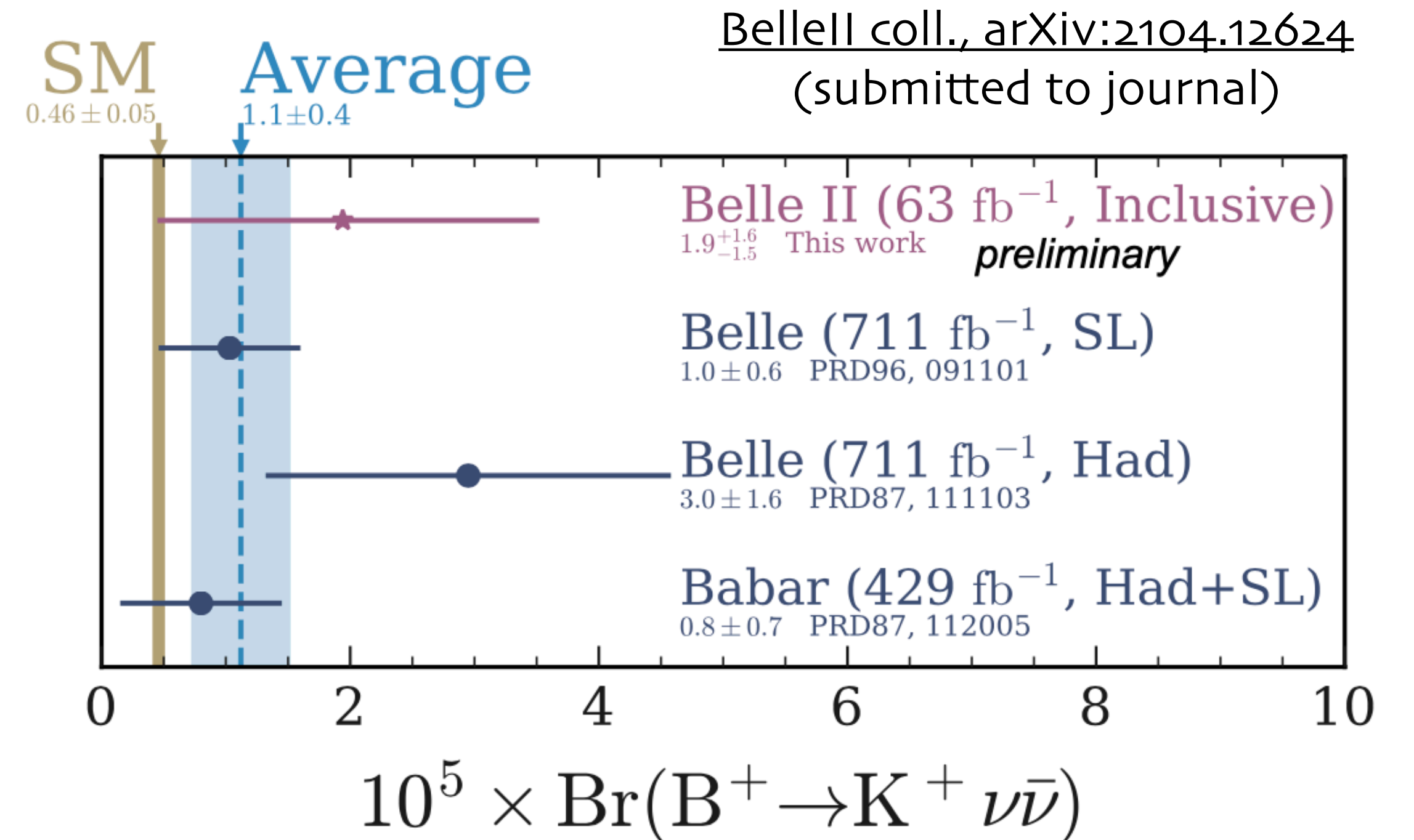
Measured signal strength $\mu = 4.2_{-2.8}^{+2.9}(\text{stat})_{-1.6}^{+1.8}(\text{syst})$

$$\mathcal{B}(B^+ \rightarrow K^+ \nu \bar{\nu}) = 1.9_{-1.5}^{+1.6} \times 10^{-5}$$

$B^+ \rightarrow K^+ \nu \bar{\nu}$ measurement @ BelleII (II)

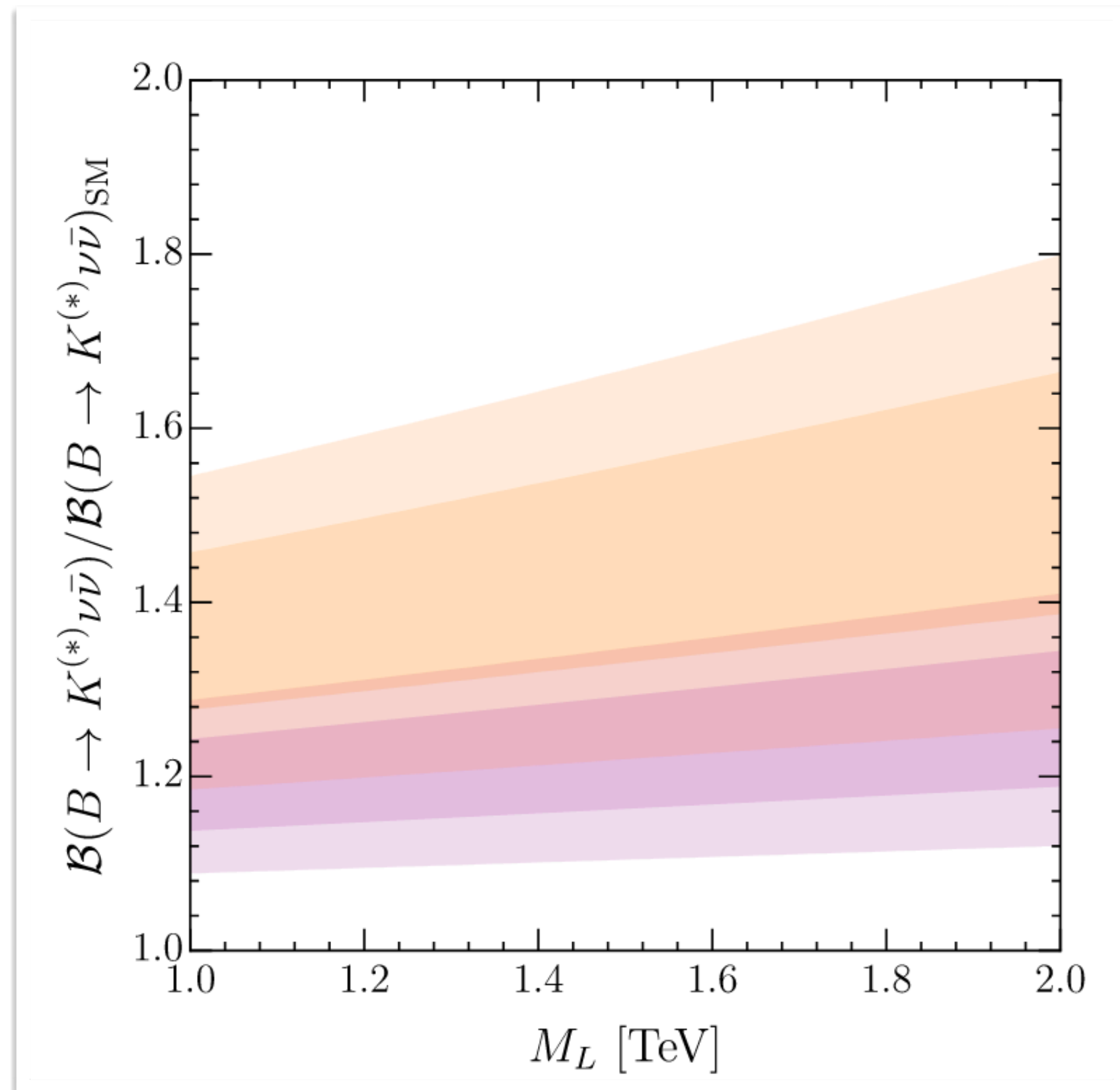
- Leading systematics: background normalisation uncertainty can be also reduced with increasing statistics
- Room for **improvement** in K^+ channel
- Application of inclusive method to **other channels** under study

Experiment	Year	Observed limit on $BR(B^+ \rightarrow K^+ \nu \bar{\nu})$	Approach	Data [fb ⁻¹]
BABAR	2013	$< 1.6 \times 10^{-5}$ [Phys.Rev.D87,112005]	SL + Had tag	429
Belle	2013	$< 5.5 \times 10^{-5}$ [Phys.Rev.D87,111103(R)]	Had tag	711
Belle	2017	$< 1.9 \times 10^{-5}$ [Phys.Rev.D96,091101(R)]	SL tag	711
Belle II preliminary	2021	$< 4.1 \times 10^{-5}$	Inclusive tag	63



$B \rightarrow K^{(*)} \nu \bar{\nu}$ @ Belle II perspectives

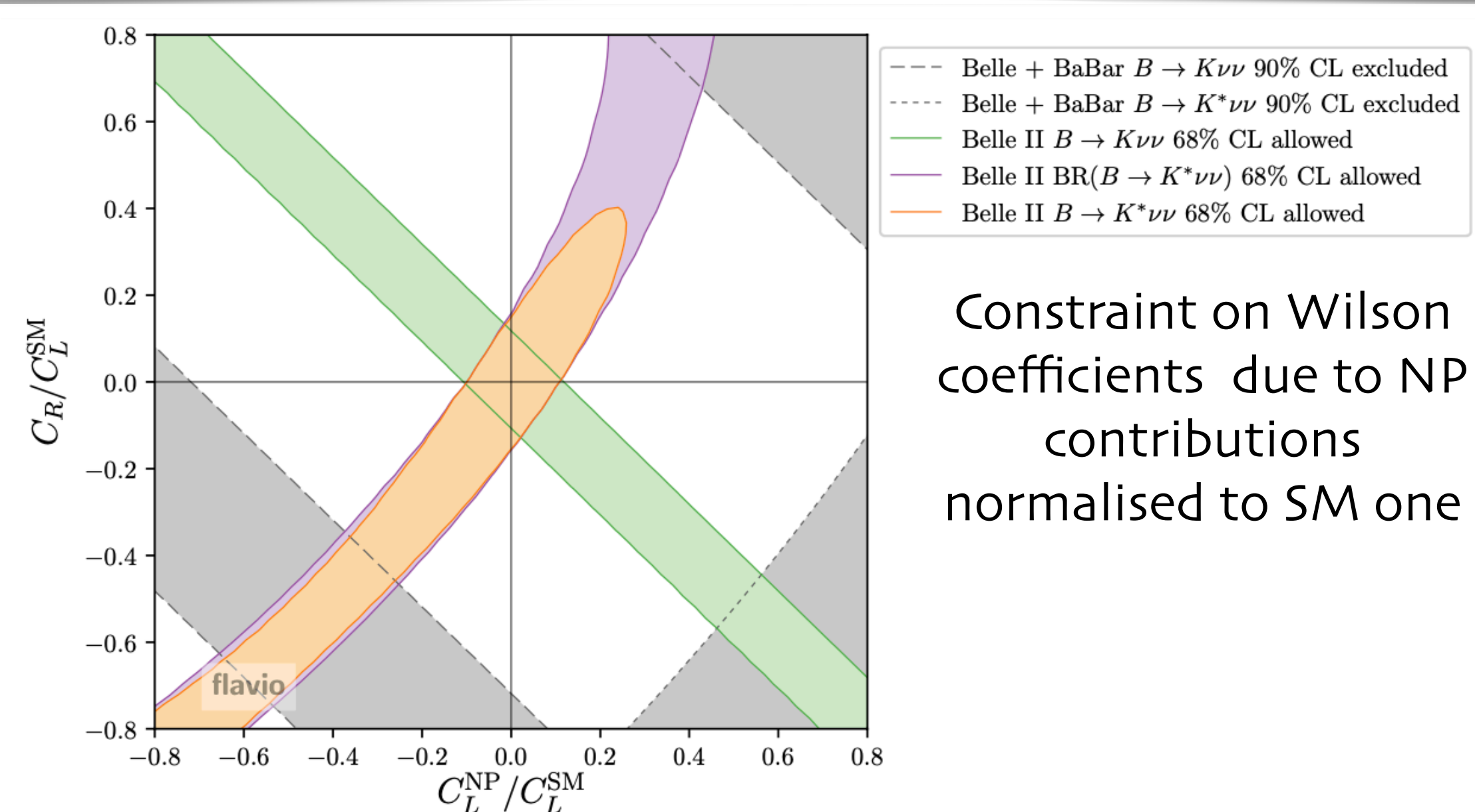
- Extrapolation done on **tagged analysis** only
- To be updated with most recent simulations and adding inclusive analysis



Cornella et al, arXiv:2103.16558

The BelleII Physics Book, PETP 2019, 123C01 (2019)

Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\text{Br}(B^+ \rightarrow K^+ \nu \bar{\nu})$	$< 450\%$	30%	11%
$\text{Br}(B^0 \rightarrow K^{*0} \nu \bar{\nu})$	$< 180\%$	26%	9.6%
$\text{Br}(B^+ \rightarrow K^{*+} \nu \bar{\nu})$	$< 420\%$	25%	9.3%
$F_L(B^0 \rightarrow K^{*0} \nu \bar{\nu})$	—	—	0.079
$F_L(B^+ \rightarrow K^{*+} \nu \bar{\nu})$	—	—	0.077



Constraint on Wilson coefficients due to NP contributions normalised to SM one

$B \rightarrow K(^*)\tau\tau/\tau$

- $b \rightarrow s\tau\tau/\tau$ can be **enhanced** in NP models explains B-anomalies

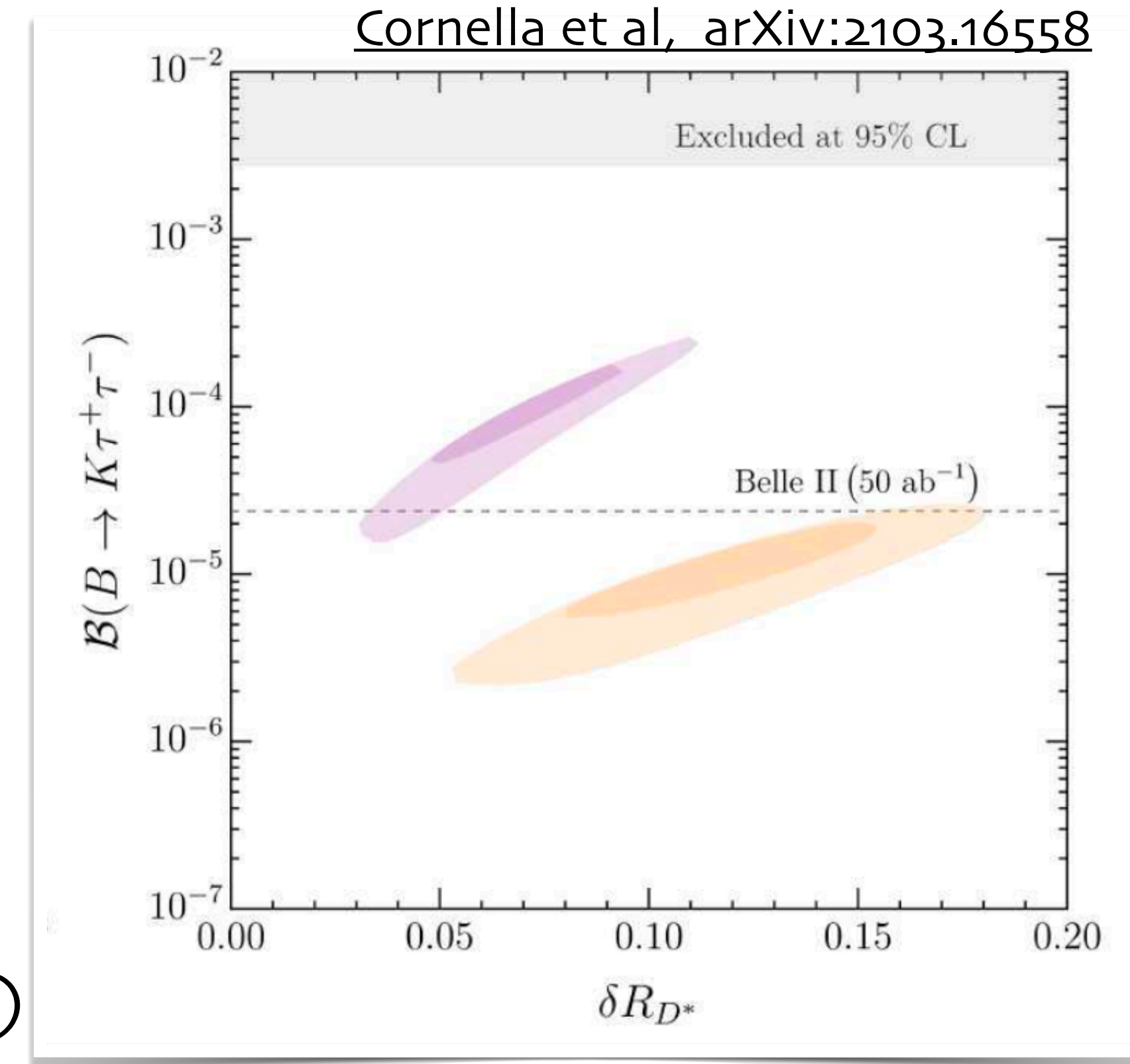
- **LFV** decay prohibited in the SM, expectation for $s\tau\tau$ final

state:

$$\begin{aligned} \mathcal{B}(B^+ \rightarrow K^+ \tau^+ \tau^-)_{SM} &= (1.22 \pm 0.10) 10^{-7} \\ \mathcal{B}(B^0 \rightarrow K^0 \tau^+ \tau^-)_{SM} &= (1.13 \pm 0.09) 10^{-7} \\ \mathcal{B}(B^+ \rightarrow K^{*+} \tau^+ \tau^-)_{SM} &= (0.99 \pm 0.12) 10^{-7} \\ \mathcal{B}(B^0 \rightarrow K^{*0} \tau^+ \tau^-)_{SM} &= (0.91 \pm 0.11) 10^{-7} \end{aligned}$$

- Usually searched for with **HAD** or **SL tagging** method

- State of the art and Belle II projections (K^* modes also feasible)



LHCb: [JHEP 06 (2020) 129]

$$\mathcal{B}(B^+ \rightarrow K^+ \tau \mu) < 3.9 \times 10^{-5}$$

BaBar: [Phys.Rev.D 86 (2012) 012004]

$$\mathcal{B}(B \rightarrow h\tau\ell)(\times 10^{-5})$$

Mode	Central value	90% C.L. UL
$B^+ \rightarrow K^+ \tau \mu$	$0.0_{-1.4}^{+2.7}$	<4.8
$B^+ \rightarrow K^+ \tau e$	$-0.6_{-1.4}^{+1.7}$	<3.0
$B^+ \rightarrow \pi^+ \tau \mu$	$0.5_{-3.2}^{+3.8}$	<7.2
$B^+ \rightarrow \pi^+ \tau e$	$2.3_{-1.7}^{+2.8}$	<7.5

Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\text{Br}(B^+ \rightarrow K^+ \tau^+ \tau^-) \cdot 10^5$	< 32	< 6.5	< 2.0
$\text{Br}(B^0 \rightarrow \tau^+ \tau^-) \cdot 10^5$	< 140	< 30	< 9.6
$\text{Br}(B_s^0 \rightarrow \tau^+ \tau^-) \cdot 10^4$	< 70	< 8.1	–
$\text{Br}(B^+ \rightarrow K^+ \tau^\pm e^\mp) \cdot 10^6$	–	–	< 2.1
$\text{Br}(B^+ \rightarrow K^+ \tau^\pm \mu^\mp) \cdot 10^6$	–	–	< 3.3
$\text{Br}(B^0 \rightarrow \tau^\pm e^\mp) \cdot 10^5$	–	–	< 1.6
$\text{Br}(B^0 \rightarrow \tau^\pm \mu^\mp) \cdot 10^5$	–	–	< 1.3

$$B \rightarrow K^{(*)} \tau \tau / \tau l$$

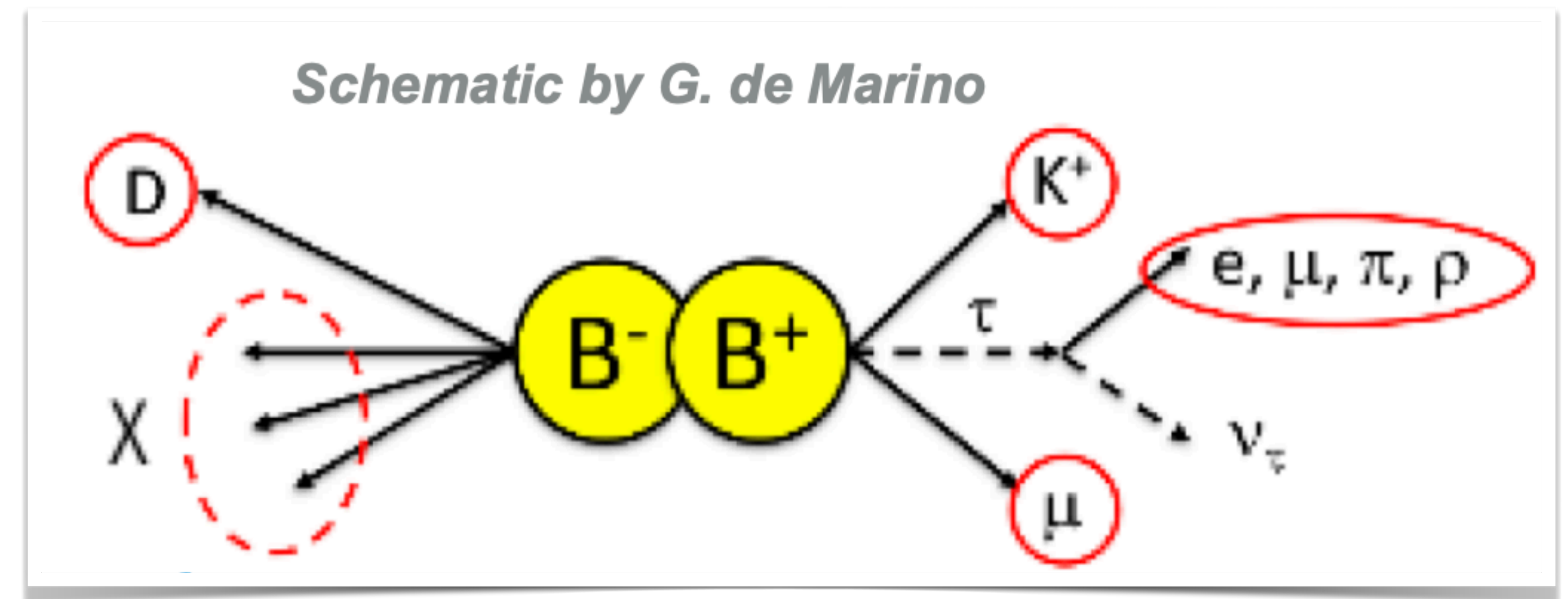
- New idea to measure $B(B^+ \rightarrow K^+ \tau l)$: **semi-inclusive tagging**
- Exploit high BF of $B^- \rightarrow D^0 X$: $79 \pm 4\%$
- Reconstruct tag D^0 and signal's K and l , and τ
- $D^0 X$ provides the tag-side

• Fit

$$m_\tau^2 = m_B^2 + m_{Kl}^2 - 2(E_B^* E_{Kl}^* - |\vec{p}_{B_{\text{sig}}}^*| |\vec{p}_{Kl}^*| \cos \theta)$$

E_{beam}^* $\sqrt{(E_{\text{beam}}^*)^2 - m_B^2}$

θ angle between $\vec{p}_{B_{\text{sig}}}^*$ ($= -\vec{p}_{B_{\text{tag}}}^*$) and \vec{p}_K^*

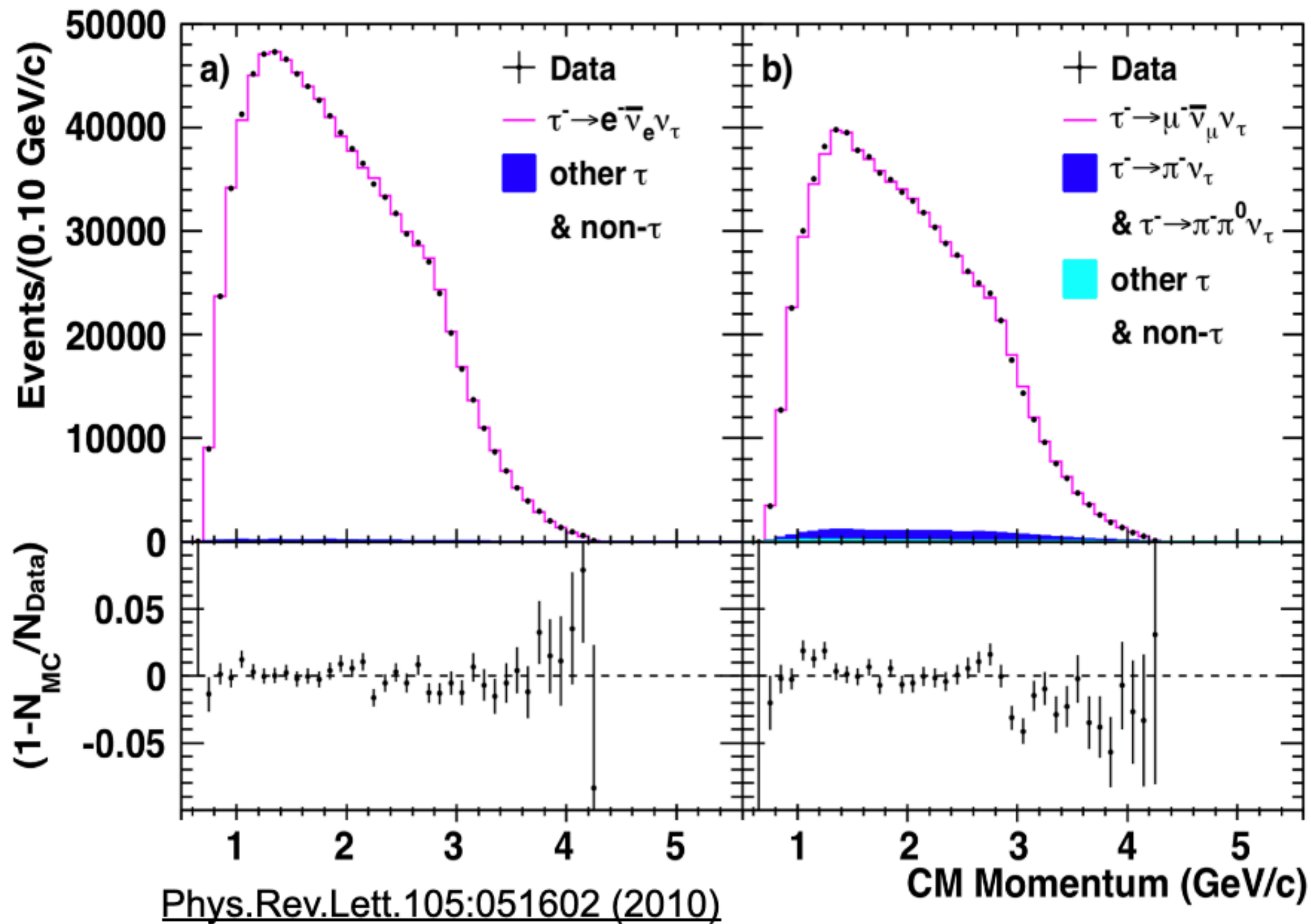


- Work in progress, can be also applied to other missing energy modes.

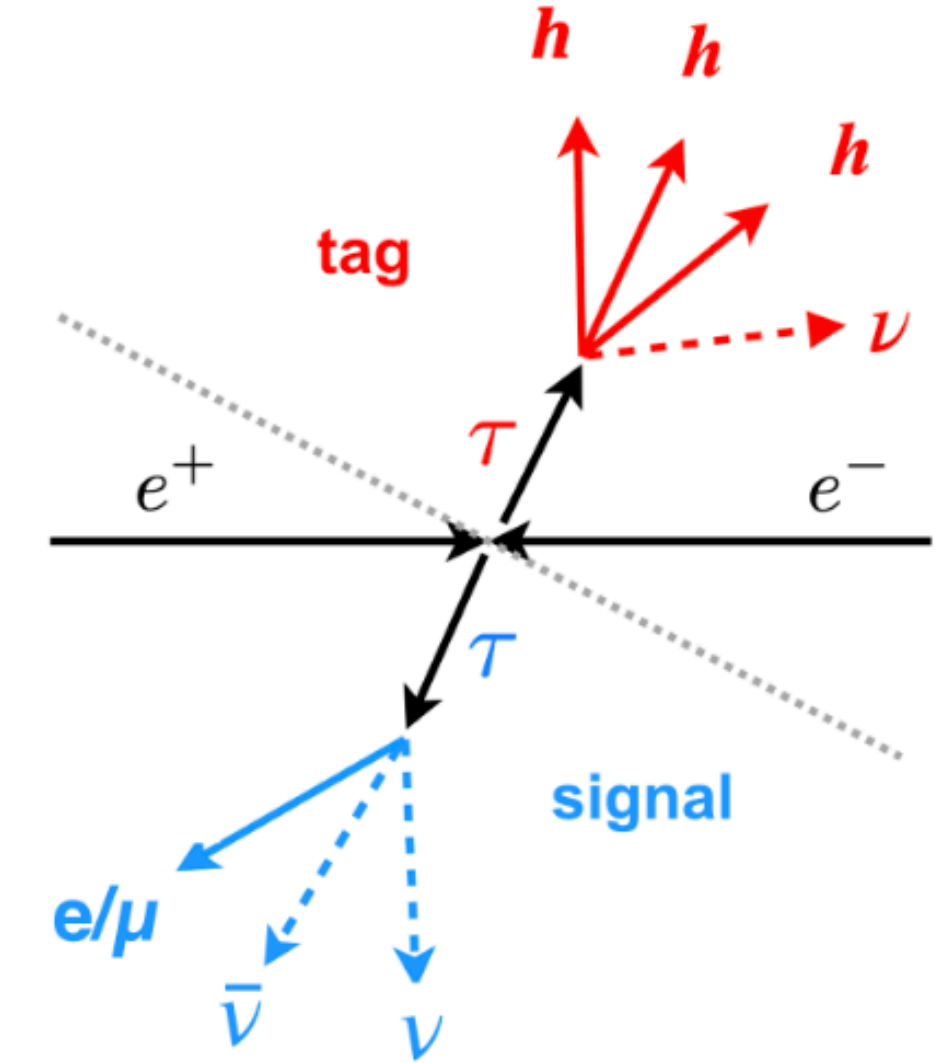
LFUV in tau decays

- LFU can be tested also in τ system

$$R_\mu \equiv \frac{\mathcal{B}(\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau)}{\mathcal{B}(\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau)} = 0.9796 \pm 0.0016 \text{ (stat)} \pm 0.0036 \text{ (sys)}$$



	μ
N^D	731102
Purity	97.3%
Total Efficiency	0.485%
Particle ID Efficiency	74.5%
Systematic uncertainties:	
Particle ID	0.32
Detector response	0.08
Backgrounds	0.08
Trigger	0.10
$\pi^- \pi^- \pi^+$ modelling	0.01
Radiation	0.04
$\mathcal{B}(\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau)$	0.05
$\mathcal{L}\sigma_{e^+e^- \rightarrow \tau^+\tau^-}$	0.02
Total [%]	0.36

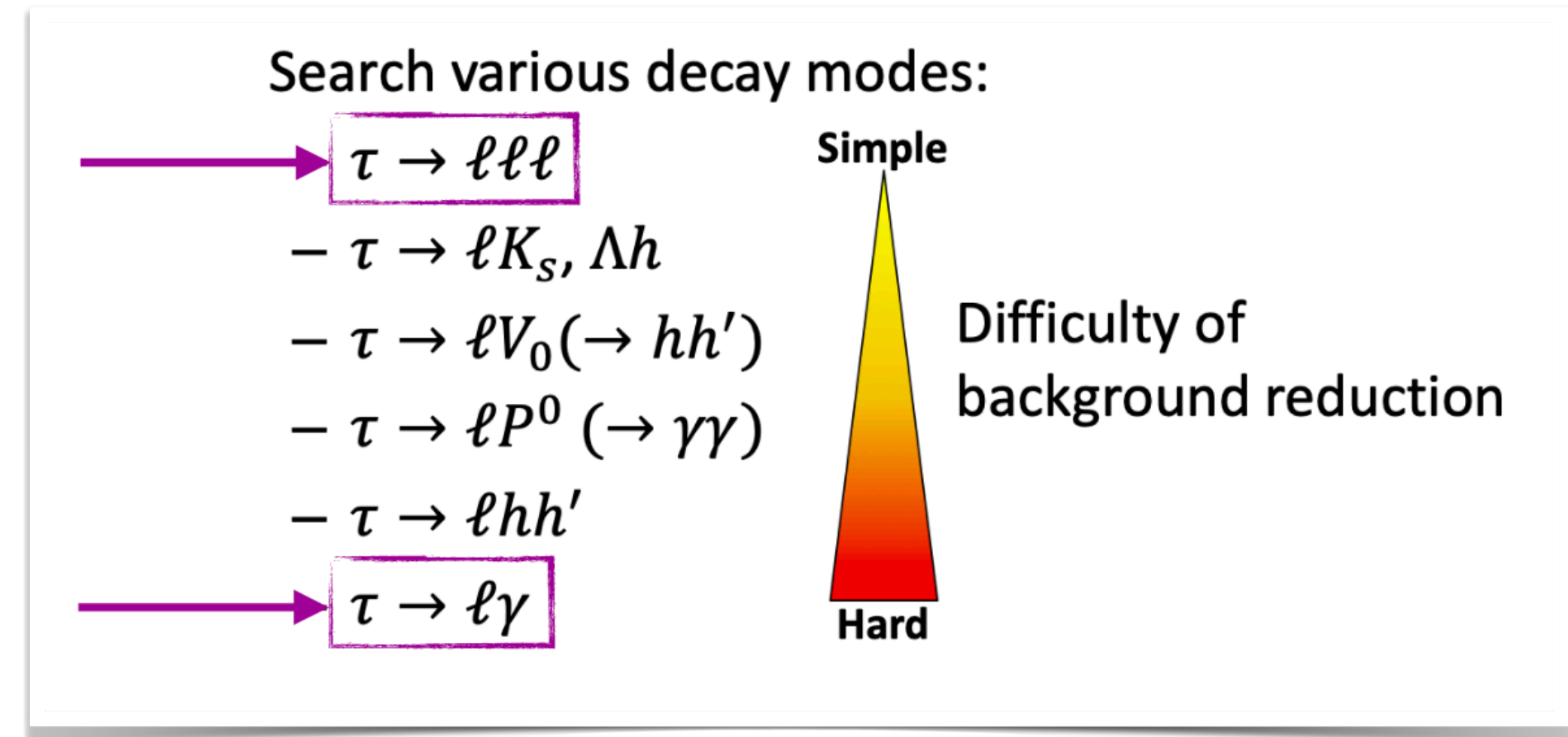


@ BelleII:

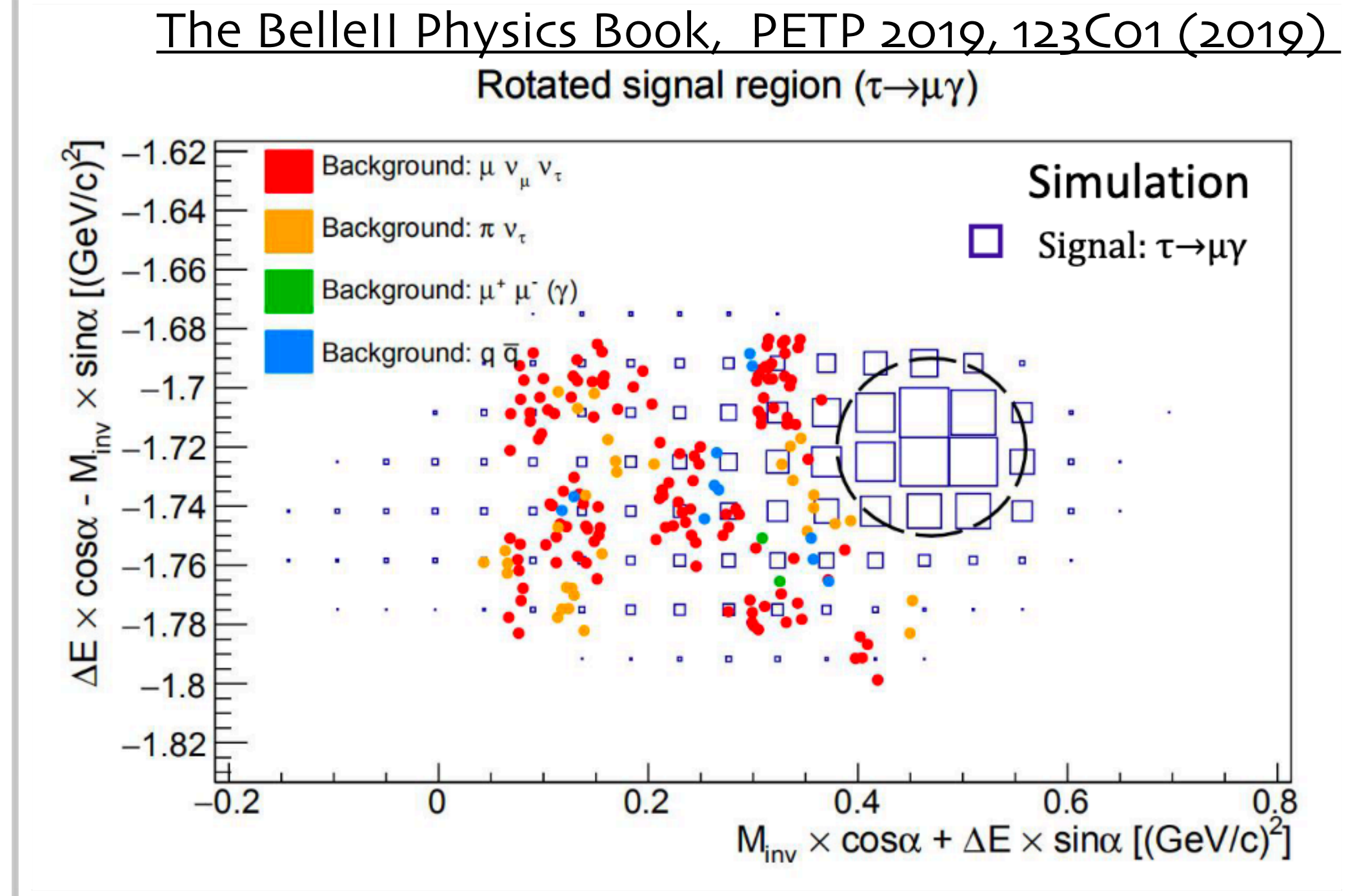
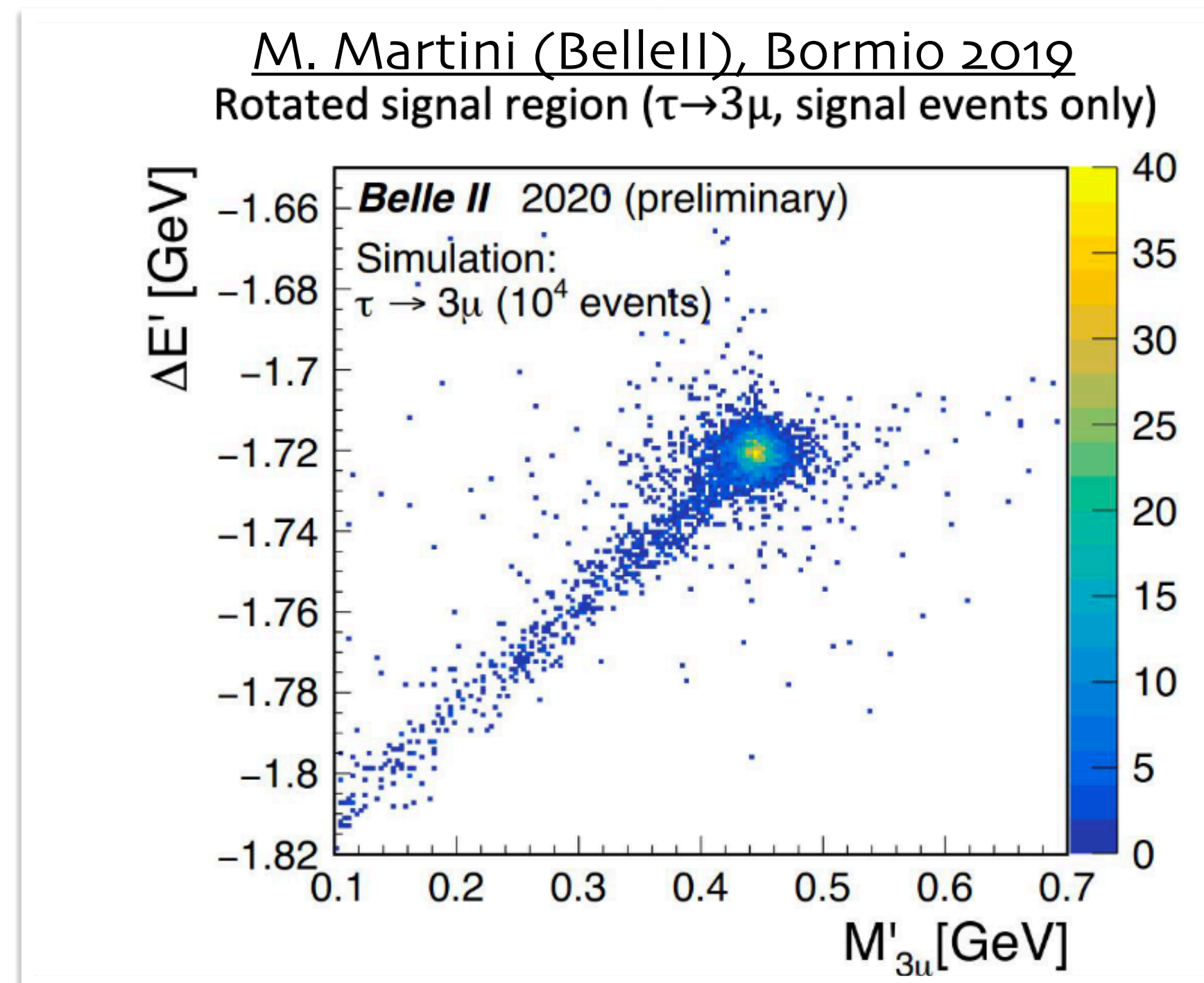
- syst due to PID correction is partially statistical in origin
- trigger studies ongoing
- preliminary sensitivity studies indicate a higher efficiency can be obtained wrt BaBar
- Work hard to **improve systematics** and add **tagging** modes to have a competitive measurement with stat < BaBar

LFV in τ decays (I)

- τ system is also ideal to search for LFV processes where NP can enter at tree or loop level
- Many modes to be studied \longrightarrow
- Fully reconstructed final states, extract signal using 2 main variables: \mathbf{M}_τ and $\Delta\mathbf{E} = E_\tau - E_{\text{beam}}$ (primed quantities: rotation to reduce correlation among the two variables)

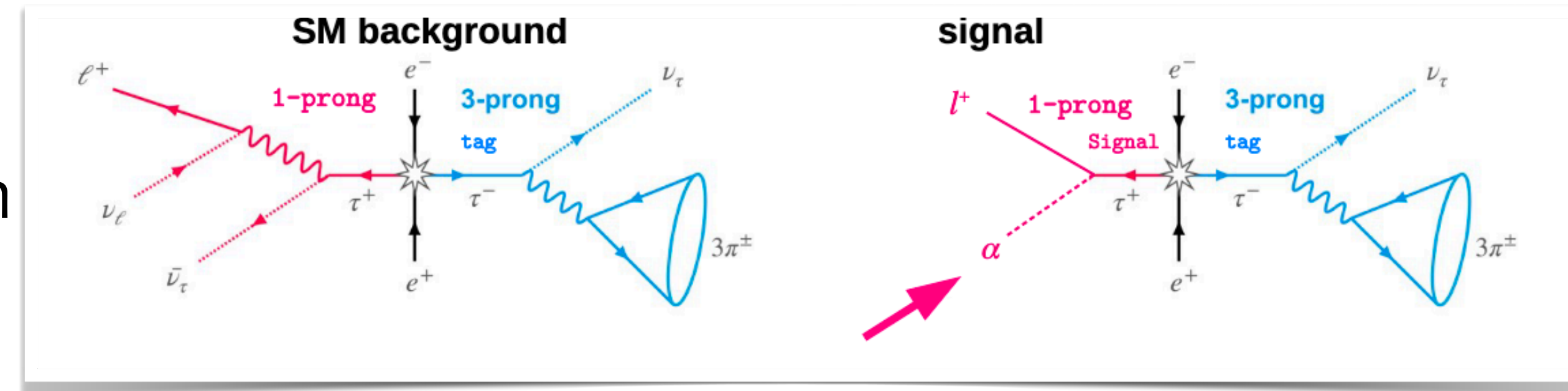


- 3μ final state, almost background free
- irreducible background in $\mu\gamma$



LFV in τ decays (II)

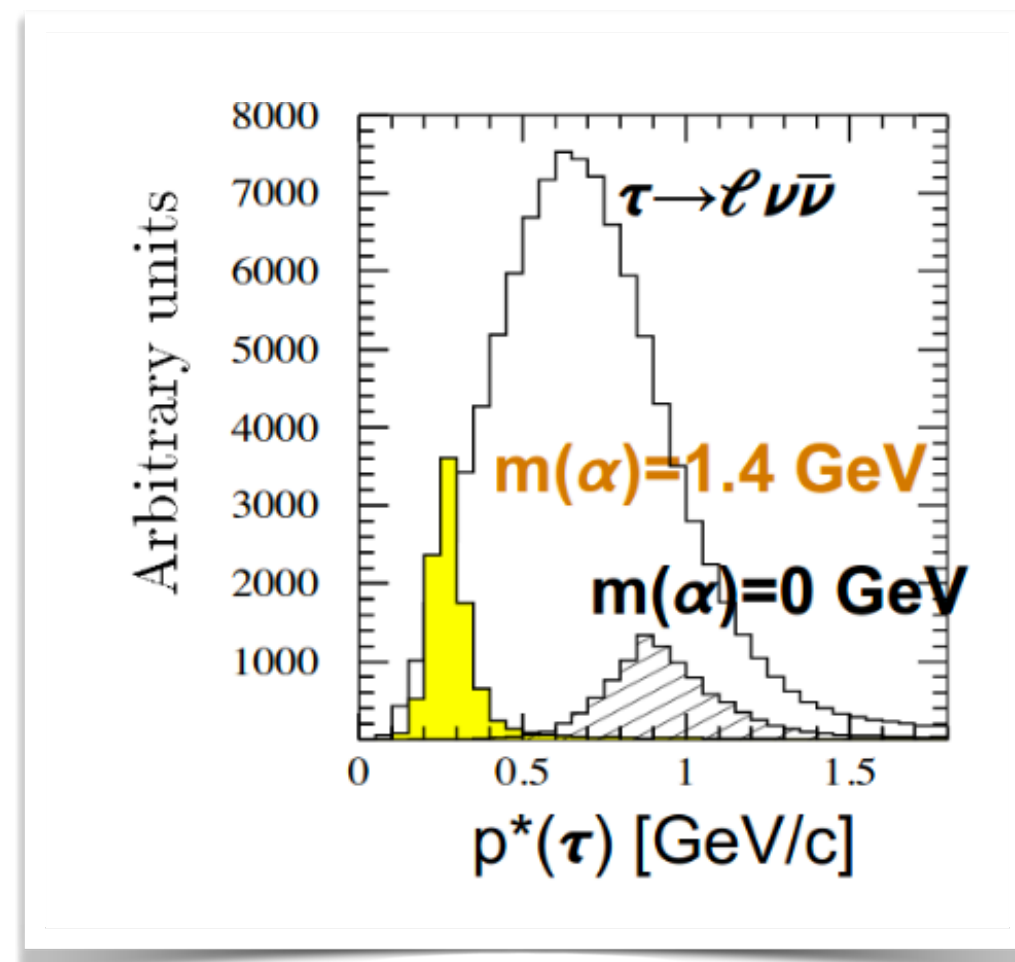
- Search for $\tau \rightarrow l\alpha$, α being an invisible particle
- Signal manifests as a peak in the τ momentum in pseudo-rest frame:



- τ boost not known, approximate it using 3-prong momentum (ARGUS method) or thrust direction

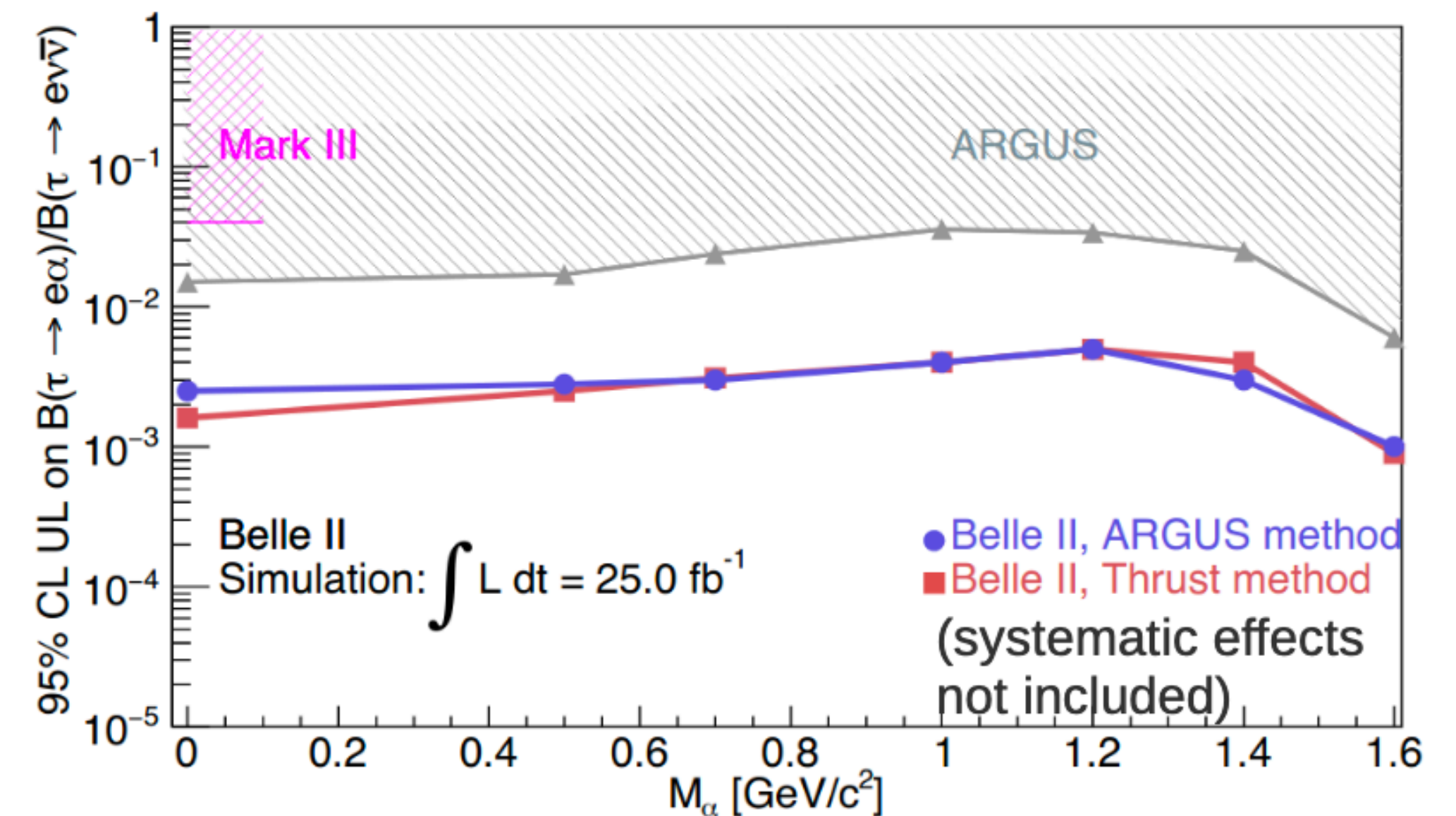
$$\vec{T} = \max \left(\frac{\sum_i \vec{p}_i \hat{T}}{|p_i|} \right)$$

- $\tau \rightarrow e\nu\nu$ irreducible background.



Argus coll., Z.Phys.
C68 (1995) 25-2

- UL is provided for the ratio $Br(\tau \rightarrow e\alpha)/Br(\tau \rightarrow e\nu\nu)$



BELLE2-NOTE-PL-2020-018

Summary and conclusions

- **LFU anomalies growing** since 2012: exciting times to explore flavour physics as playground for beyond standard model searches
- **Belle II** has started taking data in 2019 and foresees to collect **50ab^{-1}** by **2031**
- **Accelerators** and **detector** are performing well, improvements foreseen in reconstruction performances thanks to what we are learning while the experiment is running
- **Will play a major role in the flavour sector with strong interplay with LHCb**

Belle II

Higher sensitivity to decays with photons and neutrinos (e.g. $B \rightarrow K\nu\nu, \mu\nu$), inclusive decays, time dependent CPV in B_d, τ physics.

LHCb

Higher production rates for ultra rare B, D, & K decays, access to all b-hadron flavours (e.g. Λ_b), high boost for fast B_s oscillations.

Overlap in various key areas to verify discoveries.

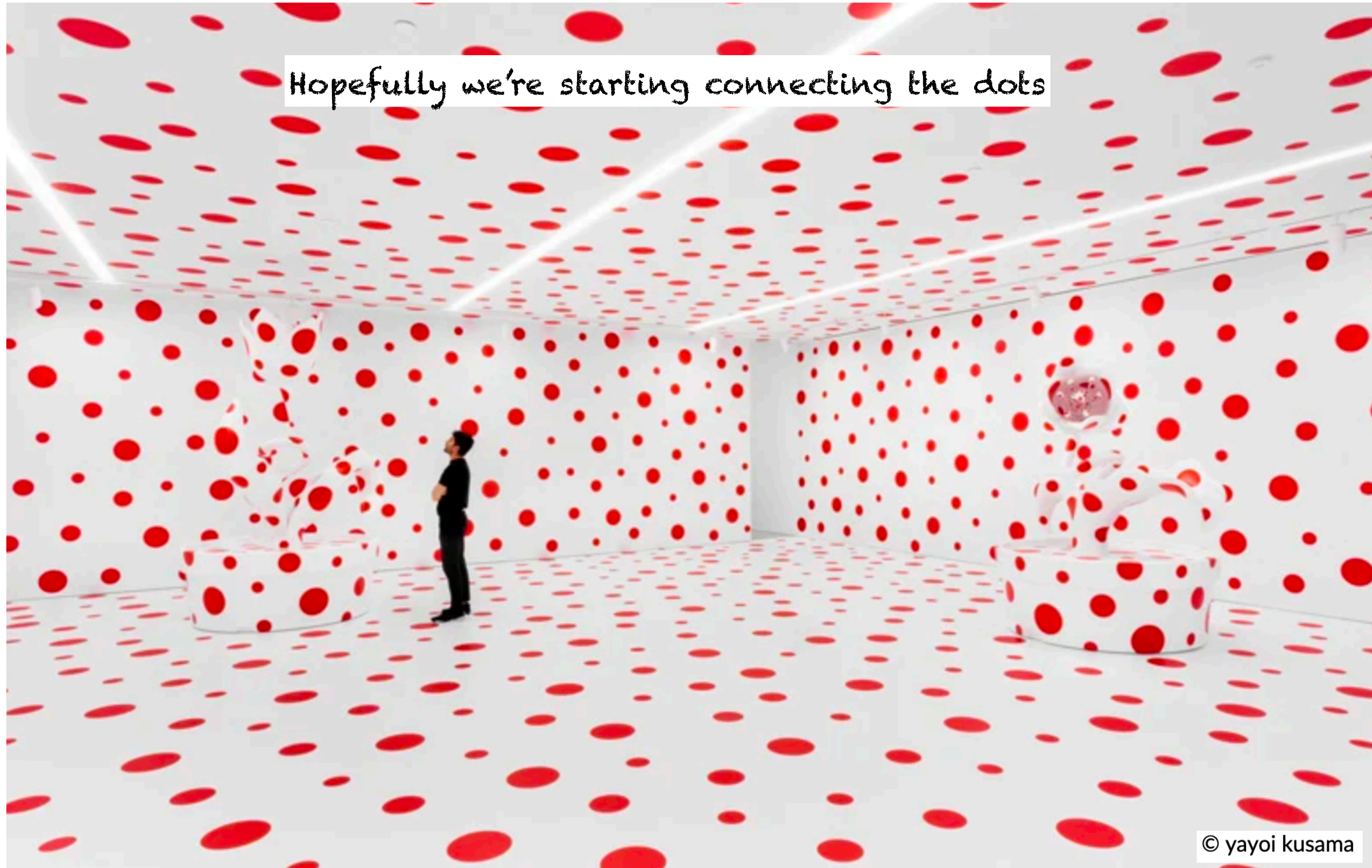
Upgrades

Most key channels will be stats. limited (not theory or syst.).

LHCb scheduled major upgrades during LS3 and LS4.

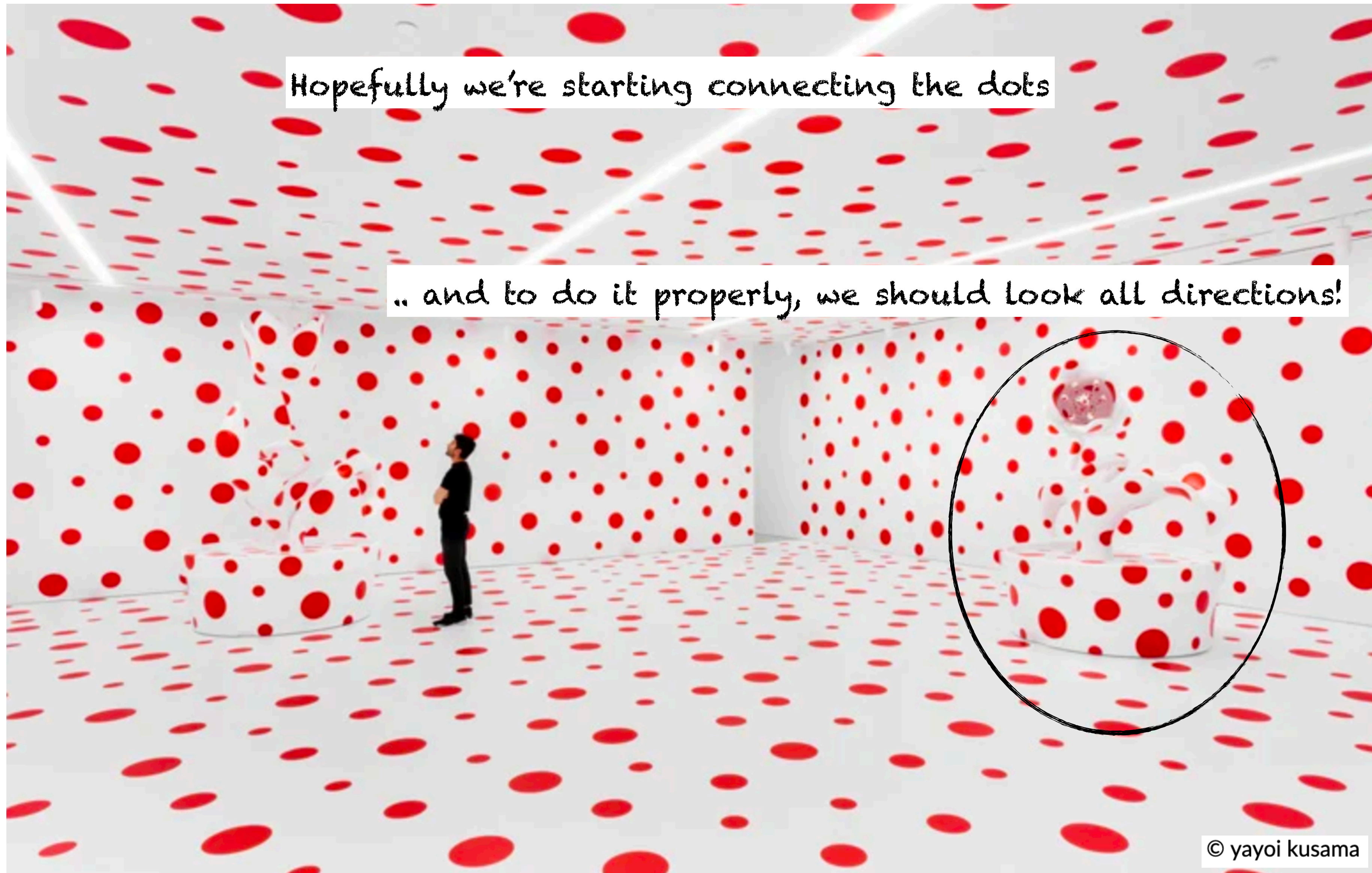
Belle II formulating a 250ab^{-1} upgrade program post 2028.

Summary and conclusions



© yayoi kusama

Summary and conclusions



extra slides

Belle II

Higher sensitivity to decays with photons and neutrinos (e.g. $B \rightarrow K\nu\nu, \mu\nu$), inclusive decays, time dependent CPV in B_d, τ physics.

LHCb

Higher production rates for ultra rare B, D, & K decays, access to all b-hadron flavours (e.g. Λ_b), high boost for fast B_s oscillations.

Overlap in various key areas to verify discoveries.

Upgrades

Most key channels will be stats. limited (not theory or syst.).

LHCb scheduled major upgrades during LS3 and LS4.

Belle II formulating a 250 ab^{-1} upgrade program post 2028.

Observable	Current Belle/Babar	2019 LHCb	Belle II (5 ab^{-1})	Belle II (50 ab^{-1})	LHCb (23 fb^{-1})	Belle II Upgrade (250 ab^{-1})	LHCb upgrade II (300 fb^{-1})
CKM precision, new physics in CP Violation							
★ $\sin 2\beta/\varphi_1$ ($B \rightarrow J/\psi K_S$)	0.03	0.04	0.012	0.005	0.011	0.002	0.003
★ γ/φ_3	13°	5.4°	4.7°	1.5°	1.5°	0.4°	0.4°
★ α/φ_2	4°	–	2	0.6°	–	0.3°	–
★ $ V_{ub} $ (Belle) or $ V_{ub} / V_{cb} $ (LHCb)	4.5%	6%	2%	1%	3%	<1%	1%
φ_s	–	49 mrad	–	–	14 mrad	–	4 mrad
★ $S_{CP}(B \rightarrow \eta' K_S, \text{gluonic penguin})$	0.08	○	0.03	0.015	○	0.007	○
★ $A_{CP}(B \rightarrow K_S \pi^0)$	0.15	–	0.07	0.04	–	0.02	–
New physics in radiative & EW Penguins, LFUV							
★ $S_{CP}(B_d \rightarrow K^* \gamma)$	0.32	○	0.11	0.035	○	0.015	○
★ $R(B \rightarrow K^* l^+ l^-)$ ($1 < q^2 < 6 \text{ GeV}^2/c^2$)	0.24	0.1	0.09	0.03	0.03	0.01	0.01
★ $R(B \rightarrow D^* \tau \nu)$	6%	10%	3%	1.5%	3%	<1%	1%
$Br(B \rightarrow \tau \nu), Br(B \rightarrow K^* \nu \nu)$	24%, –	–	9%, 25%	4%, 9%	–	1.7%, 4%	–
$Br(B_d \rightarrow \mu \mu)$	–	90%	–	–	34%	–	10%
Charm and τ							
★ $\Delta A_{CP}(KK-\pi\pi)$	–	8.5×10^{-4}	–	5.4×10^{-4}	1.7×10^{-4}	2×10^{-4}	0.3×10^{-4}
★ $A_{CP}(D \rightarrow \pi^+ \pi^0)$	1.2%	–	0.5%	0.2%	–	0.1%	–
$Br(\tau \rightarrow e \gamma)$	< 120×10^{-9}	–	< 40×10^{-9}	< 12×10^{-9}	–	< 5×10^{-9}	–
$Br(\tau \rightarrow \mu \mu \mu)$	< 21×10^{-9}	< 46×10^{-9}	< 3×10^{-9}	< 3×10^{-9}	< 16×10^{-9}	< 0.3×10^{-9}	< 5×10^{-9}

Results on other D & τ modes expected

○ Possible in similar channels, lower precision
– Not competitive.

Indirect searches: ATLAS

- <https://twiki.cern.ch/twiki/bin/view/AtlasPublic>
- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-009/fig_01.png
- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2020-020/fig_23.png

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: March 2021

Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference
Extra dimensions	ADD $G_{KK} + g/q$	$0 e, \mu, \tau, \gamma$	$1-4 j$	Yes	139	M_D 11.2 TeV $n=2$
	ADD non-resonant $\gamma\gamma$	2γ	-	-	36.7	M_S 8.6 TeV $n=3$ HLZ NLO
	ADD QBH	-	$2j$	-	37.0	M_{th} 8.9 TeV $n=6$
	ADD BH multijet	-	$\geq 3j$	-	3.6	M_{th} 9.55 TeV $n=6, M_D = 3 \text{ TeV, rot BH}$
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	-	-	139	G_{KK} mass $k/\overline{M}_{pl} = 0.1$
	Bulk RS $G_{KK} \rightarrow WW/ZZ$	multi-channel	-	-	36.1	G_{KK} mass $k/\overline{M}_{pl} = 1.0$
	Bulk RS $G_{KK} \rightarrow WV \rightarrow \ell\nu qq$	$1 e, \mu$	$2j/1J$	Yes	139	G_{KK} mass $k/\overline{M}_{pl} = 1.0$
	Bulk RS $G_{KK} \rightarrow tt$	$1 e, \mu$	$\geq 1 b, \geq 1J/2J$	Yes	36.1	G_{KK} mass $\Gamma/m = 15\%$
	2UED / RPP	$1 e, \mu$	$\geq 2 b, \geq 3j$	Yes	36.1	KK mass 1.8 TeV Tier (1,1), $\mathcal{B}(A^{(1,1)} \rightarrow tt) = 1$
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	-	-	139	Z' mass 5.1 TeV
	SSM $Z' \rightarrow \tau\tau$	2τ	-	-	36.1	Z' mass 2.42 TeV
	Leptophobic $Z' \rightarrow bb$	-	$2b$	-	36.1	Z' mass 2.1 TeV
	Leptophobic $Z' \rightarrow tt$	$0 e, \mu$	$\geq 1 b, \geq 2J$	Yes	139	Z' mass 4.1 TeV
	SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	-	Yes	139	W' mass 6.0 TeV
	SSM $W' \rightarrow \tau\nu$	1τ	-	Yes	36.1	W' mass 3.7 TeV
	HVT $W' \rightarrow WZ \rightarrow \ell\nu qq$ model B	$1 e, \mu$	$2j/1J$	Yes	139	W' mass 4.3 TeV
	HVT $Z' \rightarrow ZH$ model B	$0-2 e, \mu$	$1-2 b$	Yes	139	Z' mass 3.2 TeV
	HVT $W' \rightarrow WH$ model B	$0 e, \mu$	$\geq 1 b, \geq 2J$	Yes	139	W' mass 3.2 TeV
	LRSM $W_R \rightarrow tb$	multi-channel	-	-	36.1	W_R mass 3.25 TeV
	LRSM $W_R \rightarrow \mu N_R$	2μ	$1J$	-	80	W_R mass 5.0 TeV $m(N_R) = 0.5 \text{ TeV, } g_L = g_R$
CI	CI $qqqq$	-	$2j$	-	37.0	Λ 21.8 TeV η_{LL}
	CI $\ell\ell qq$	$2 e, \mu$	-	-	139	Λ 35.8 TeV η_{LL}
	CI $e e b s$	$2 e$	$1 b$	-	139	Λ 1.8 TeV
	CI $\mu\mu b s$	2μ	$1 b$	-	139	Λ 2.0 TeV
	CI $tttt$	$\geq 1 e, \mu$	$\geq 1 b, \geq 1j$	Yes	36.1	Λ 2.57 TeV
DM	Axial-vector med. (Dirac DM)	$0 e, \mu, \tau, \gamma$	$1-4 j$	Yes	139	m_{med} 2.1 TeV $g_a=0.25, g_s=1, m(\chi)=1 \text{ GeV}$
	Pseudo-scalar med. (Dirac DM)	$0 e, \mu, \tau, \gamma$	$1-4 j$	Yes	139	m_{med} 376 GeV $g_a=1, g_s=1, m(\chi)=1 \text{ GeV}$
	Vector med. Z' -2HDM (Dirac DM)	$0 e, \mu$	$2b$	Yes	139	m_{med} 3.1 TeV $\tan\beta=1, g_z=0.8, m(\chi)=100 \text{ GeV}$
	Pseudo-scalar med. 2HDM+a	$0 e, \mu$	$2b$	Yes	139	m_{med} 520 GeV $\tan\beta=1, g_s=1, m(\chi)=10 \text{ GeV}$
	Scalar reson. $\phi \rightarrow \chi\chi$ (Dirac DM)	$0-1 e, \mu$	$1 b, 0-1 J$	Yes	36.1	m_ϕ 3.4 TeV $y=0.4, a=0.2, m(\chi)=10 \text{ GeV}$
LQ	Scalar LQ 1 st gen	$2 e$	$\geq 2j$	Yes	139	LO mass 1.8 TeV $\beta=1$
	Scalar LQ 2 nd gen	2μ	$\geq 2j$	Yes	139	LO mass 1.7 TeV $\beta=1$
	Scalar LQ 3 rd gen	1τ	$\geq 2j$	Yes	139	LO mass 1.2 TeV $\mathcal{B}(LQ_S^0 \rightarrow b\tau) = 1$
	Scalar LQ 3 rd gen	$0 e, \mu$	$\geq 2j, \geq 2b$	Yes	139	LO mass 1.24 TeV $\mathcal{B}(LQ_S^0 \rightarrow t\nu) = 1$
	Scalar LQ 3 rd gen	$\geq 2e, \mu, \geq 1\tau, \geq 1j, \geq 1b$	-	-	139	LO mass 1.43 TeV $\mathcal{B}(LQ_S^0 \rightarrow t\tau) = 1$
	Scalar LQ 3 rd gen	$0 e, \mu, \geq 1\tau, 0-2j, 2b$	-	-	139	LO mass 1.26 TeV $\mathcal{B}(LQ_S^0 \rightarrow b\nu) = 1$
Heavy quarks	VLO $TT \rightarrow Ht/Zt/Wb + X$	multi-channel	-	-	36.1	T mass 1.37 TeV SU(2) doublet
	VLO $BB \rightarrow Wt/Zb + X$	multi-channel	-	-	36.1	B mass 1.34 TeV SU(2) doublet
	VLO $T_{5/3} T_{5/3} T_{5/3} \rightarrow Wt + X$	$2(SS) \geq 3 e, \mu \geq 1 b, \geq 1j$	Yes	36.1	$T_{5/3}$ mass 1.64 TeV $\mathcal{B}(T_{5/3} \rightarrow Wt) = 1, c(T_{5/3} Wt) = 1$	
	VLO $Y \rightarrow Wb + X$	$1 e, \mu \geq 1 b, \geq 1j$	Yes	36.1	Y mass 1.85 TeV $\mathcal{B}(Y \rightarrow Wb) = 1, c_R(Wb) = 1$	
	VLO $B \rightarrow Hb + X$	$0 e, \mu \geq 2 b, \geq 1j$	Yes	79.8	B mass 1.21 TeV singlet, $\kappa_B = 0.5$	
	VLO $QQ \rightarrow WqWq$	$1 e, \mu \geq 4j$	Yes	20.3	Q mass 690 GeV	
Excited fermions	Excited quark $q^* \rightarrow qg$	-	$2j$	-	139	q^* mass 6.7 TeV only u^* and d^* , $\Lambda = m(q^*)$
	Excited quark $q^* \rightarrow q\gamma$	1γ	$1j$	-	36.7	q^* mass 5.3 TeV only u^* and d^* , $\Lambda = m(q^*)$
	Excited quark $b^* \rightarrow b\gamma$	-	$1 b, 1j$	-	36.1	b^* mass 2.6 TeV
	Excited lepton ℓ^*	$3 e, \mu$	-	-	20.3	ℓ^* mass 3.0 TeV $\Lambda = 3.0 \text{ TeV}$
	Excited lepton ν^*	$3 e, \mu, \tau$	-	-	20.3	ν^* mass 1.6 TeV $\Lambda = 1.6 \text{ TeV}$
Other	Type III Seesaw	$1 e, \mu$	$\geq 2j$	Yes	139	N^0 mass 790 GeV
	LRSM Majorana ν	2μ	$2j$	-	36.1	N_R mass 3.2 TeV $m(N_R) = 4.1 \text{ TeV, } g_L = g_R$
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	$2, 3, 4 e, \mu$ (SS)	-	-	36.1	$H^{\pm\pm}$ mass 870 GeV DY production
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3 e, \mu, \tau$	-	-	20.3	$H^{\pm\pm}$ mass 400 GeV DY production, $\mathcal{B}(H^{\pm\pm} \rightarrow \ell\tau) = 1$
	Multi-charged particles	-	-	-	36.1	multi-charged particle mass 1.22 TeV DY production, $ q = 5e$
	Magnetic monopoles	-	-	-	34.4	monopole mass 2.37 TeV DY production, $ g = 1g_D, \text{ spin } 1/2$

$\sqrt{s} = 8 \text{ TeV}$ $\sqrt{s} = 13 \text{ TeV}$ partial data $\sqrt{s} = 13 \text{ TeV}$ full data

*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).

ATLAS Preliminary

$\int \mathcal{L} dt = (3.6 - 139) \text{ fb}^{-1}$ $\sqrt{s} = 8, 13 \text{ TeV}$

ATLAS SUSY Searches* - 95% CL Lower Limits

July 2020

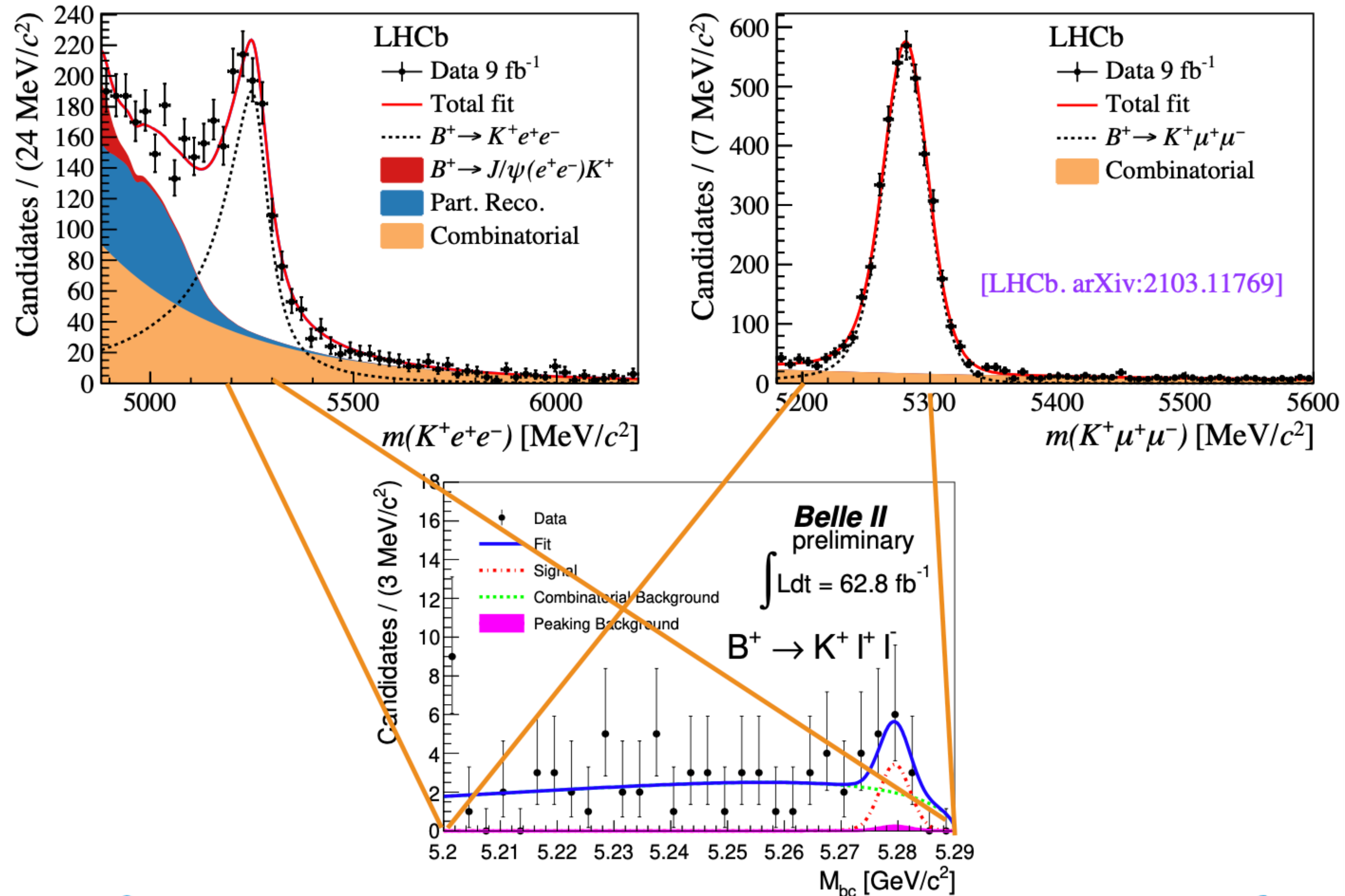
Model	Signature	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	Reference
Inclusive Searches	$q\bar{q}, \bar{q} \rightarrow q\bar{\chi}_1^0$	$0 e, \mu$ mono-jet	E_T^{miss} 139	\tilde{q} [10x Degen.] $m(\tilde{q}) - m(\tilde{\chi}_1^0) = 5 \text{ GeV}$
	$g\bar{g}, \bar{g} \rightarrow q\bar{q}\chi_1^0$	$0 e, \mu$ 2-6 jets	E_T^{miss} 36.1	\tilde{g} [1x, 8x Degen.] 0.43 0.71 1.9
	$g\bar{g}, \bar{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$	$0 e, \mu$ 2-6 jets	E_T^{miss} 139	\tilde{g} 2.35
	$g\bar{g}, \bar{g} \rightarrow q\bar{q}W\tilde{\chi}_1^0$	$1 e, \mu$ 2-6 jets	E_T^{miss} 139	\tilde{g} 2.2
	$g\bar{g}, \bar{g} \rightarrow q\bar{q}(L)\tilde{\chi}_1^0$	$ee, \mu\mu$ 2 jets	E_T^{miss} 36.1	\tilde{g} 1.2
	$g\bar{g}, \bar{g} \rightarrow q\bar{q}WZ\tilde{\chi}_1^0$	$0 e, \mu$ 7-11 jets	E_T^{miss} 139	\tilde{g} 1.97
	$g\bar{g}, \bar{g} \rightarrow q\bar{q}WZ\tilde{\nu}_1^0$	$SS e, \mu$ 6 jets	E_T^{miss} 139	\tilde{g} 1.15
	$g\bar{g}, \bar{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$	$0-1 e, \mu$ 3 b	E_T^{miss} 79.8	\tilde{g} 2.25
		$SS e, \mu$ 6 jets	E_T^{miss} 139	\tilde{g} 1.25
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\bar{\chi}_1^0/\bar{b}\chi_1^0$	Multiple Multiple	E_T^{miss} 36.1	\tilde{b}_1 0.9
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\bar{\chi}_2^0 \rightarrow b\tilde{h}\tilde{\chi}_1^0$	$0 e, \mu$ 6 b	E_T^{miss} 139	\tilde{b}_1 0.74
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\bar{\chi}_1^0$	2τ 2 b	E_T^{miss} 139	\tilde{b}_1 0.13-0.85 0.23-1.35
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$	$0-1 e, \mu$ ≥ 1 jet	E_T^{miss} 139	\tilde{t}_1 1.25
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$	$1 e, \mu$ 3 jets/1 b	E_T^{miss} 139	\tilde{t}_1 0.44-0.59
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \bar{\tau}b\nu, \bar{\tau}_1 \rightarrow \tau\bar{G}$	$1\tau + 1 e, \mu, \tau$ 2 jets/1 b	E_T^{miss} 36.1	\tilde{t}_1 1.16
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\bar{\chi}_1^0/\bar{c}\chi_1^0$	$0 e, \mu$ 2 c	E_T^{miss} 36.1	\tilde{t}_1 0.85
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Z/h\tilde{\chi}_1^0$	$0 e, \mu$ mono-jet	E_T^{miss} 36.1	\tilde{t}_1 0.46 0.43
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	$1-2 e, \mu$ 1-4 b	E_T^{miss} 139	\tilde{t}_1 0.067-1.18
		$3 e, \mu$ 1 b	E_T^{miss} 139	\tilde{t}_2 0.86
EW direct	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via WZ	$3 e, \mu$ $ee, \mu\mu$	E_T^{miss} 139	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ 0.205 0.64
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via WW	$2 e, \mu$	E_T^{miss} 139	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ 0.42
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via $\tilde{\ell}_L/\tilde{\nu}$	$0-1 e, \mu$ 2 b/2 γ	E_T^{miss} 139	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ 0.74
	$\tilde{\tau}\tilde{\tau}, \tilde{\tau} \rightarrow \tau\tilde{\chi}_1^0$	2τ	E_T^{miss} 139	$\tilde{\tau}$ 1.0
	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0$	$2 e, \mu$ 0 jets	E_T^{miss} 139	$\tilde{\tau}$ [F.L., $\tilde{\tau}$ R.L.] 0.16-0.3 0.12-0.39
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow H\tilde{G}/Z\tilde{G}$	$ee, \mu\mu$ ≥ 1 jet	E_T^{miss} 139	$\tilde{\tau}$ 0.7
		$0 e, \mu$ $\geq 3 b$	E_T^{miss} 36.1	\tilde{H} 0.256
		$4 e, \mu$ 0 jets	E_T^{miss} 139	\tilde{H} 0.13-0.23 0.29-0.88
Long-lived particles	Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	E_T^{miss} 36.1	$\tilde{\chi}_1^{\pm}$ 0.46
	Stable \tilde{g} R-hadron	Multiple	E_T^{miss} 36.1	\tilde{g} 2.0
	Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow qq\tilde{\chi}_1^0$	Multiple	E_T^{miss} 36.1	\tilde{g} [r(g)=10 ns, 0.2 ns] 2.05 2.4
RPV	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}, \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow Z\ell\ell$	$3 e, \mu$	E_T^{miss} 139	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ [BR(Z τ)=1, BR(Ze)=1] 0.625 1.05
	LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e\mu/\tau\mu$	$ee, ee, \mu\tau$	E_T^{miss} 3.2	$\tilde{\nu}_\tau$ 1.9
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp} \rightarrow WZ\ell\ell\nu\nu$	$4 e, \mu$ 0 jets	E_T^{miss} 36.1	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ [$\lambda_{133} \neq 0, \lambda_{123} \neq 0$] 0.82 1.33
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qq\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow qq$	4-5 large-R jets	E_T^{miss} 36.1	\tilde{g} [m($\tilde{\chi}_1^0$)=200 GeV, 1100 GeV] 1.3 1.9
		Multiple	E_T^{miss} 36.1	\tilde{g} [$\lambda'_{112} = 2e-4, 2e-5$] 1.05 2.0
	$\tilde{t}, \tilde{t} \rightarrow t\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow tbs$	Multiple	E_T^{miss} 36.1	\tilde{t} [m($\tilde{\chi}_1^0$)=200 GeV, bino-like] 0.55 1.05
	$\tilde{t}, \tilde{t} \rightarrow b\tilde{\chi}_1^+, \tilde{\chi}_1^+ \rightarrow bbs$	$\geq 4b$	E_T^{miss} 139	\tilde{t} [m($\tilde{\chi}_1^+$)=200 GeV, bino-like] 0.95
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow bs$	2 jets + 2 b	E_T^{miss} 36.7	\tilde{t}_1 [qq, bb] 0.42 0.61
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow q\ell$	$2 e, \mu$ 2 b	E_T^{miss} 36.1	\tilde{t}_1 0.4-1.45
		1μ DV	E_T^{miss} 136	\tilde{t}_1 [1e-10 < λ'_{233} < 1e-8, 3e-10 < λ'_{233} < 3e-9] 1.0 1.6

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

ATLAS Preliminary

$\sqrt{s} = 13 \text{ TeV}$

R(K)



Electrons (and muons) in Belle II have better resolution thanks to M_{bc}