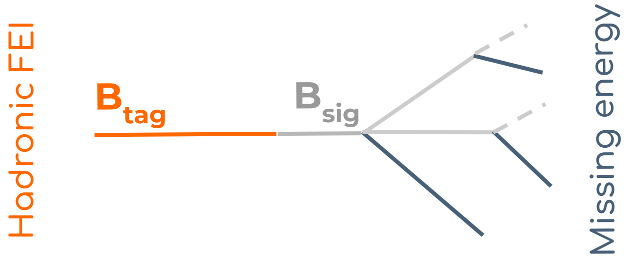
Search for $B^+ \rightarrow K^+ \tau^+ \tau^-$ at Belle II

CAT Séminaires Doctorants 2022



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07 May 2022

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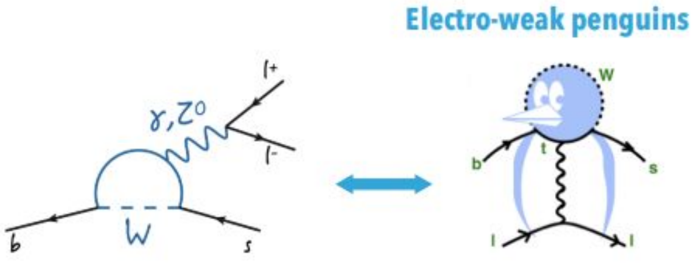
Flavor physics and EW penguins

By precisely measuring the parameters of Standard Model (SM), we might find signatures of New Physics (NP) beyond the SM.
Or even discover processes that are forbidden in SM.

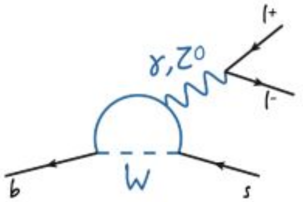
Flavour Changing Neutral Currents (FCNC) **b → s(d)** are one such precision measurements in flavor physics.

The FCNC processes proceed via one-loop diagrams in the SM at lowest order.

Since NP particles may enter the loop diagrams or even mediate FCNCs at tree level, the **b → s(d)** are sensitive to physics beyond the SM.



Current anomalies in B-physics



Semi-leptonic B decays are showing tensions with the SM predictions
⇒ a possible violation of the Lepton Flavor Universality (LFU).

Different behaviour for different lepton generations:

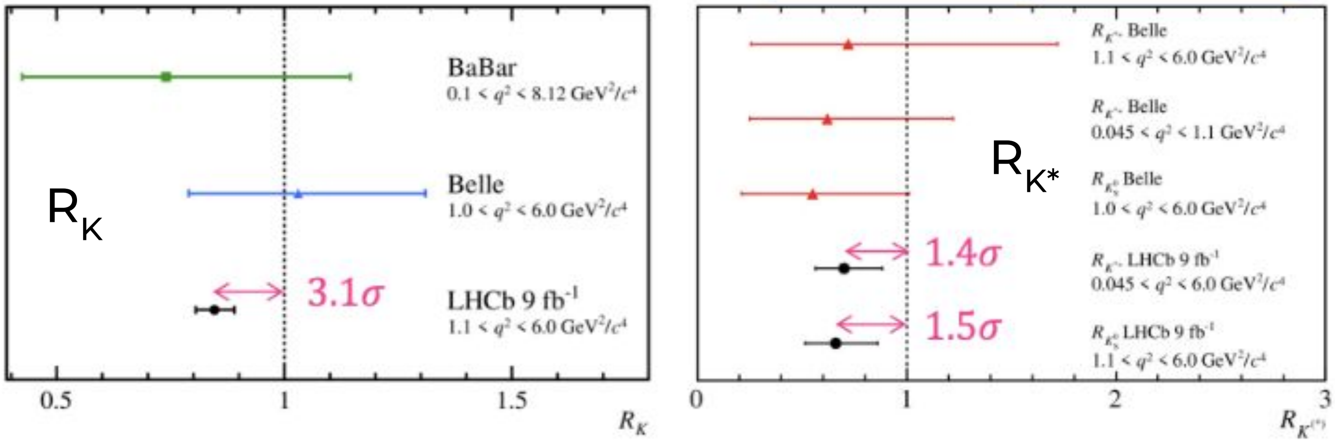
SM

$$R(K^{(*)}) = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)} = 1 \pm \mathcal{O}(10^{-2})$$

$q^2 \in [1(1.1), 6]$ for $R(K^{(*)})$

JHEP 2018, 93 (2018)

arXiv:2103.11769, arXiv:2110.09501



$$R_{K^{(*)}}^{\text{exp}} < R_{K^{(*)}}^{\text{SM}}$$

Current anomalies in B-physics (cont.)

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

Semi-leptonic B decays are showing tensions with the SM predictions ⇒ a possible violation of the Lepton Flavor Universality (LFU).

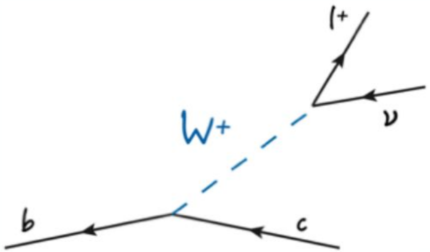
$$R_{K(*)}^{exp} < R_{K(*)}^{SM}$$

SM

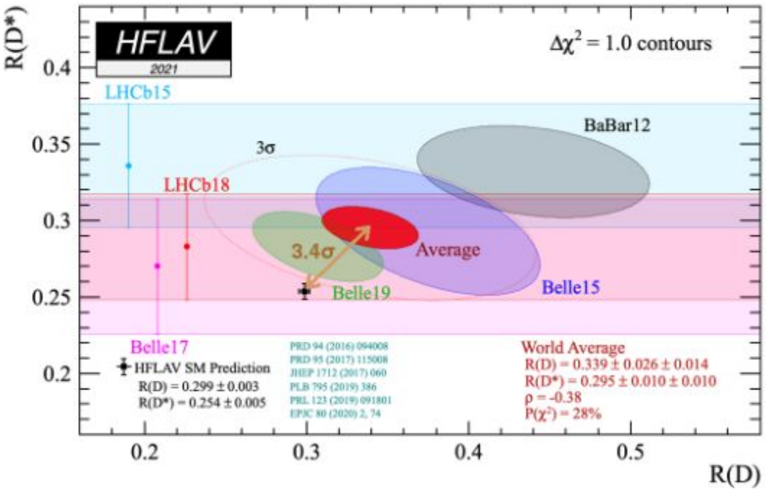
$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\nu_\ell)}$$

$$= 0.300(0.252) \pm \mathcal{O}(10^{-3})$$

$$\ell = e, \mu$$



[HFLAV average]



$$R(D^{(*)})^{exp} > R(D^{(*)})^{SM}$$

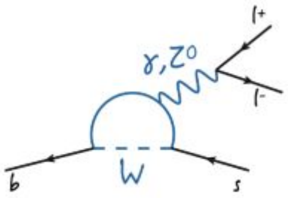
NP coupling:
3rd gen > 2nd gen > 1st gen

Discrepancy w.r.t. combined average (BaBar, Belle, LHCb):

- R(D): 1.4σ
- R(D*): 2.9σ
- Combined: 3.4σ

Impact on $B^+ \to K^+ \tau^+ \tau^-$ decays

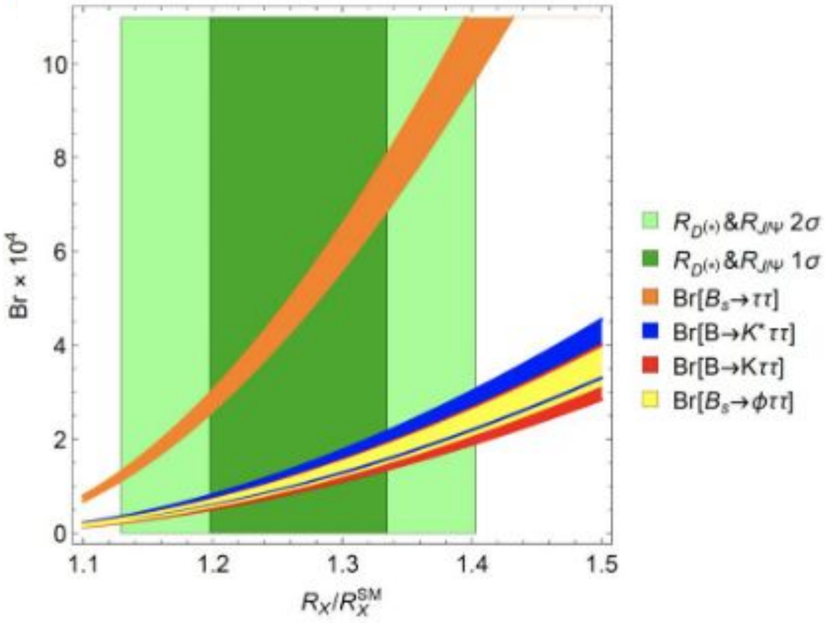
$B^+ \to K^+ \tau^+ \tau^-$ is a FCNC process
⇒ highly suppressed in SM,
⇒ happens through penguin loops
predicted BF: **O(10^{-7})**



τ is 3rd generation and higher mass
⇒ stronger coupling to NP,
like U(1) leptoquark predicts BF: **O(10^{-5})**

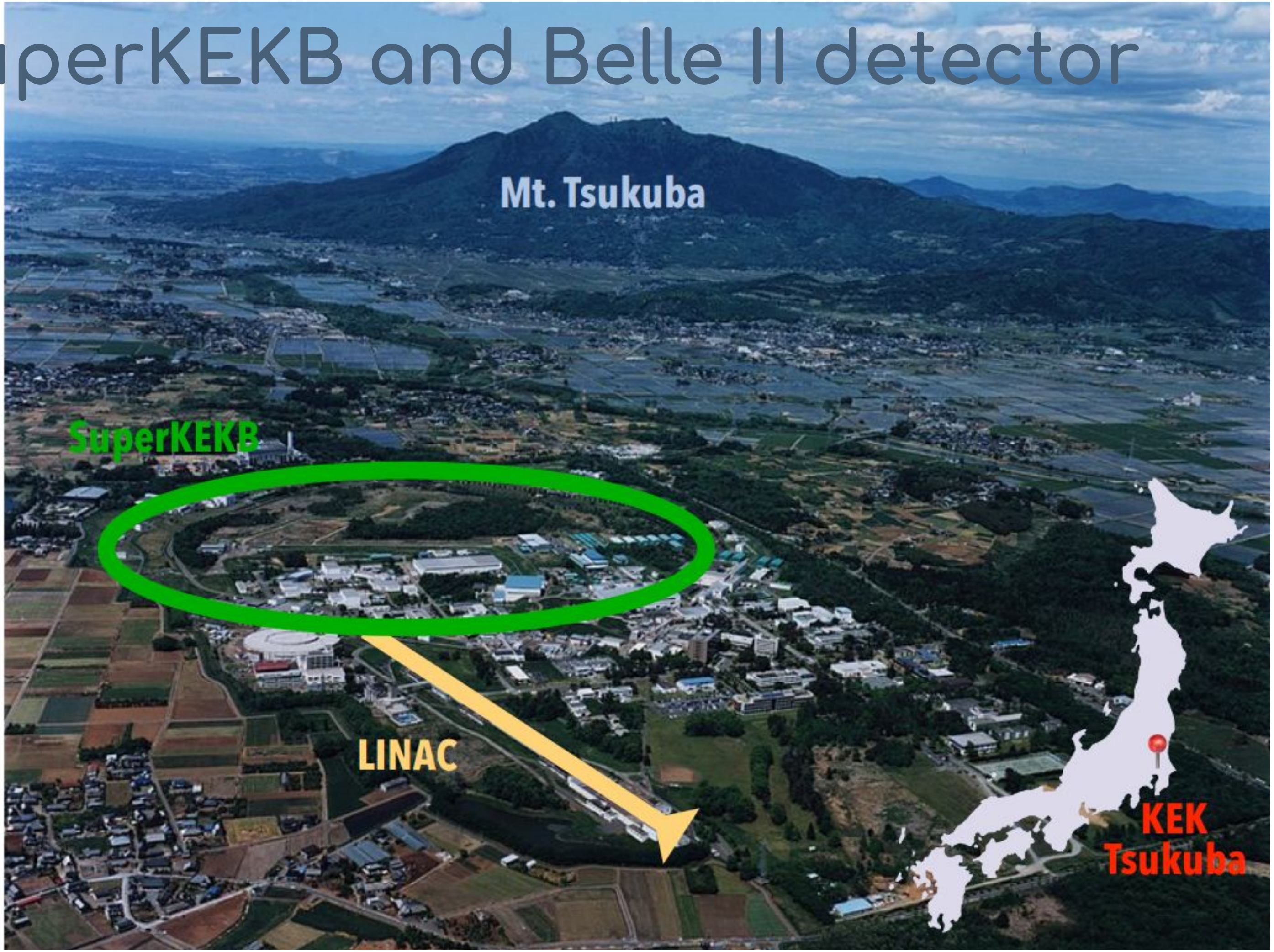
Current limits:
BaBar: BF $\boxed{< 2.25 \times 10^{-3}}$ @ 90% CL [1605.09637]

NP coupling: 3rd gen > 2nd gen > 1st gen



B. Capdevila, A. Crivellin, S. Descotes-Genon, L. Hofer, et J. Matias, *arXiv:1712.01919, PRL 120, 181802*

SuperKEKB and Belle II detector

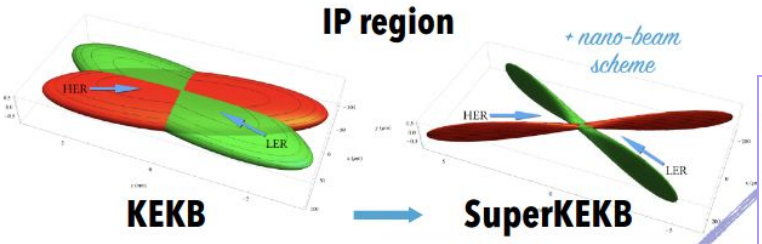


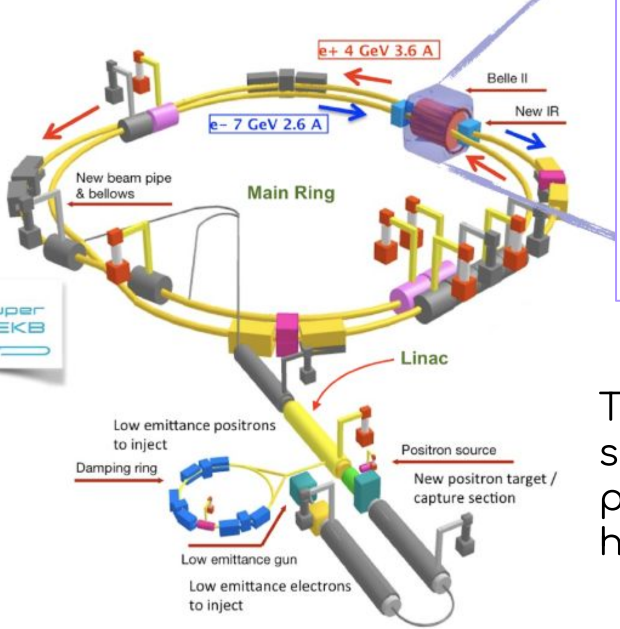
KEKB+Belle collected ~1ab^{-1} in ~10 years.

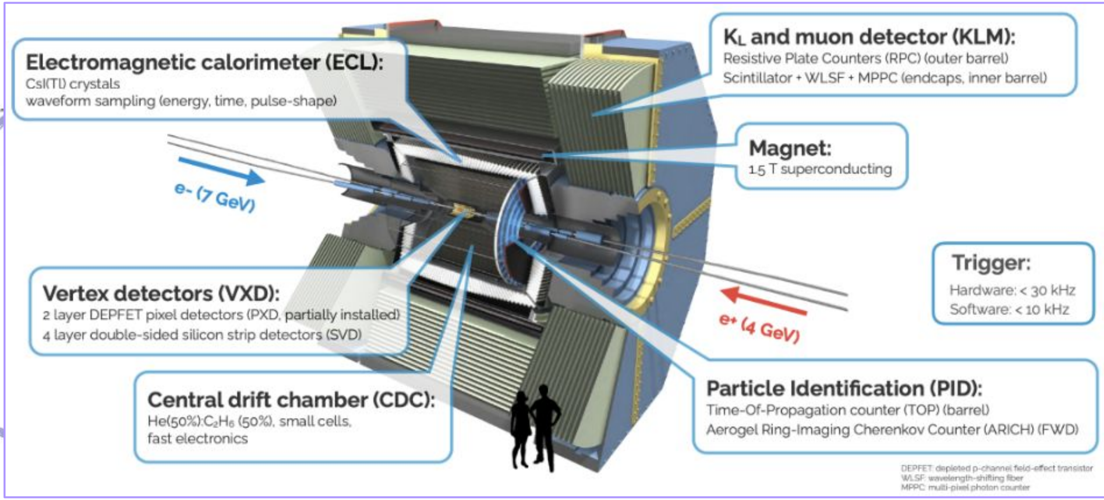
SuperKEKB+ Belle II plans to collect ~50ab^{-1} in ~10 years.

Need to increase instantaneous luminosity substantially!

SuperKEKB and Belle II detector

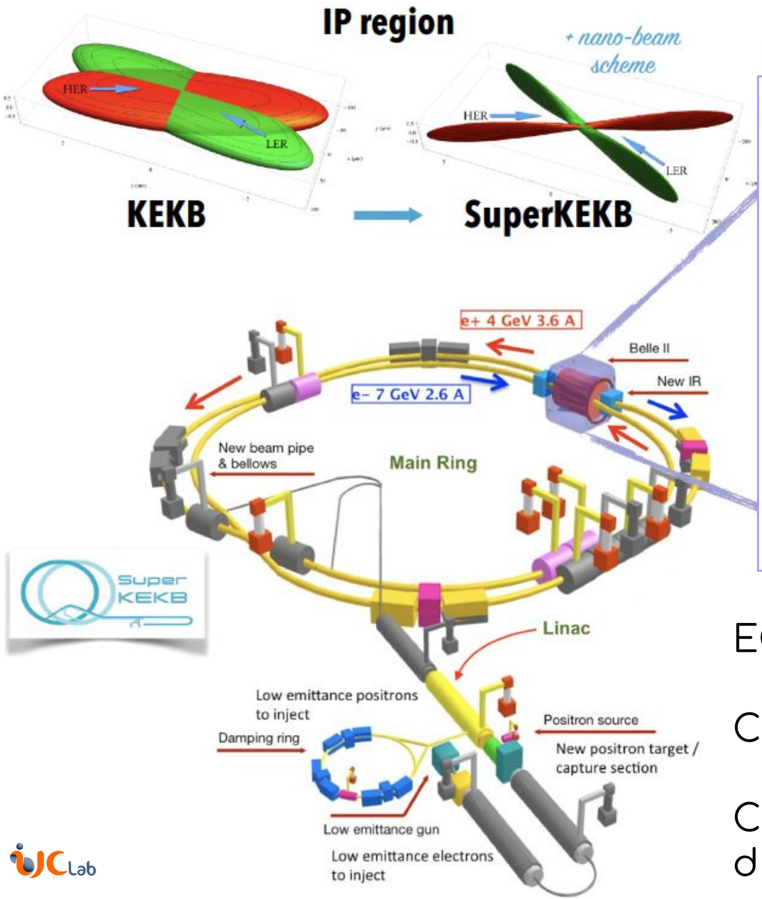


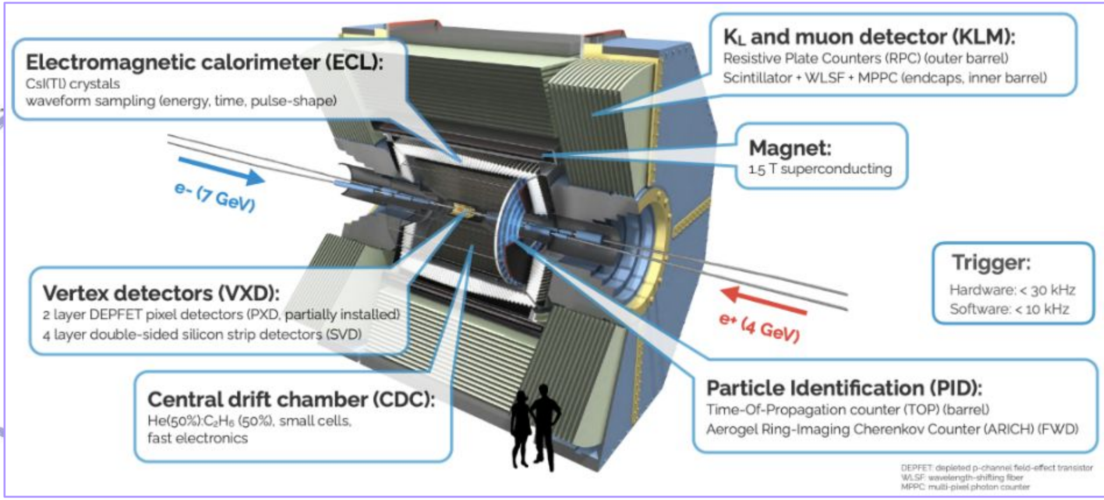




The upgrade KEKB → SuperKEKB has required a substantial redesign of Belle II detector, whose performance are challenged by radiation damage and higher background (design luminosity is x40 higher).

SuperKEKB and Belle II detector



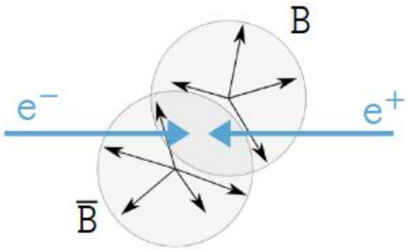


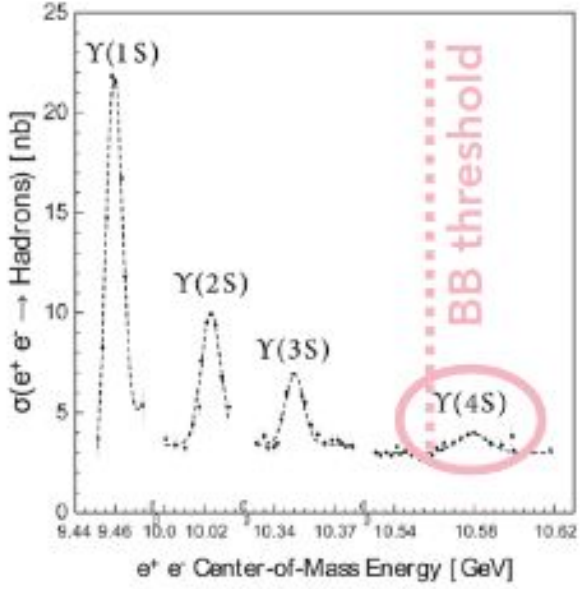
ECL provides information about the energy deposited.

CDC provides information on tracks.

CDC along with other dedicated detectors help identify different particles (PID): e vs μ vs π vs K

Principle of B-factories





e^+e^- collisions at Υ(4S) @ 10.58 GeV
(above the threshold to produce BB pairs)

$e^+ e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$

happens along with:

$$e^+e^- \rightarrow \begin{array}{l} e^+e^-(\gamma) \\ \mu^+\mu^-(\gamma) \\ e^+e^-e^+e^- \\ \tau^+\tau^-(\gamma) \\ e^+e^-\mu^+\mu^- \\ \gamma\gamma(\gamma) \\ u\overline{u}(\gamma) \\ d\overline{d}(\gamma), s\overline{s}(\gamma) \\ c\overline{c}(g) \end{array}$$

Here, the initial state is well know
⇒ If we know the kinematics of one B,
we can find the kinematics of another B.

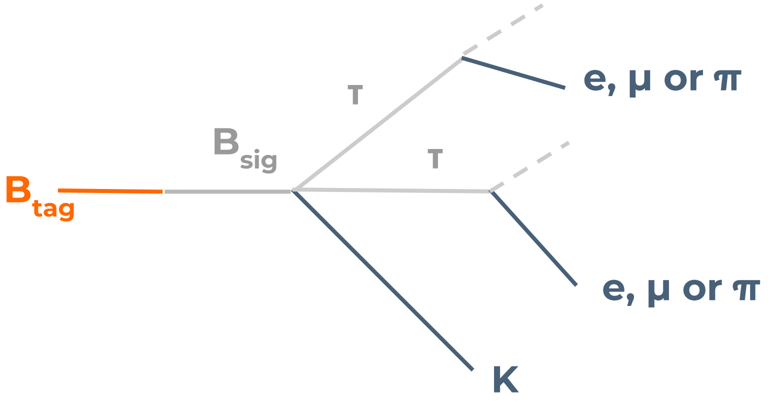
Use of B-tagging!

Analysis procedure

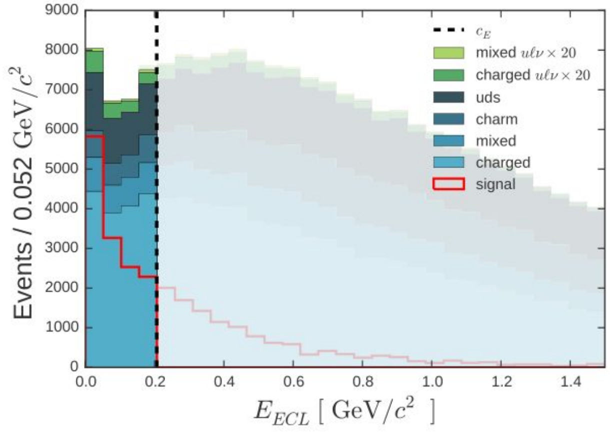
- We start by reconstructing one B (tag-side) completely.
- And look for a K and a combination pair of e, μ or π in the rest of the event.

- i.e., we reconstruct everything in the event except for the 2-4 neutrinos in the final state.

- The extra energy in calorimeter (E_{ECL}) should peak at 0.*



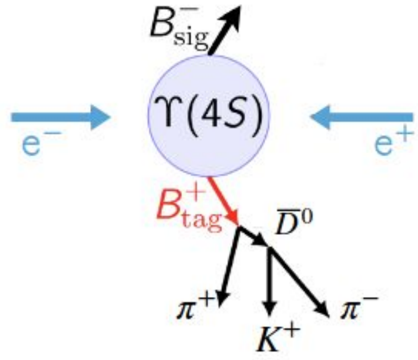
BF($\tau^+ \to e^+ \bar{\nu} \nu$) = 17%
BF($\tau^+ \to \mu^+ \bar{\nu} \nu$) = 17%
BF($\tau^+ \to \pi^+ \bar{\nu}$) = 10%



Just for illustration
(based on Simon Wehle's note)

*If we do π^0 veto

B^+ tagging



$B\overline{B}$ events must be tagged to distinguish them from other $q\overline{q}$ processes

In Hadronic tagging, we essentially reconstruct $B \to D^{(*)}\,(n\pi^+)\,(m\pi^0)$ final states:

$\overline{D}^0\pi^+$
$\overline{D}^{*0}\pi^+$
$\overline{D}^0\pi^+\pi^0$
$\overline{D}^{*0}\pi^+\pi^0$
$\overline{D}^0\pi^+\pi^+\pi^-$
$\overline{D}^{*0}\pi^+\pi^+\pi^-$
$\overline{D}^0\pi^+\pi^0\pi^0$
$\overline{D}^{*0}\pi^+\pi^0\pi^0$
$\overline{D}^0\pi^+\pi^+\pi^-\pi^0$
$\overline{D}^{*0}\pi^+\pi^+\pi^-\pi^0$
$D^-\pi^+\pi^+$
$D^-\pi^+\pi^+\pi^0$

More $\pi \Rightarrow$ More complex, but higher Branching Fraction

Tagging efficiency in data (ϵ_{tag}) is one of the limiting factor.

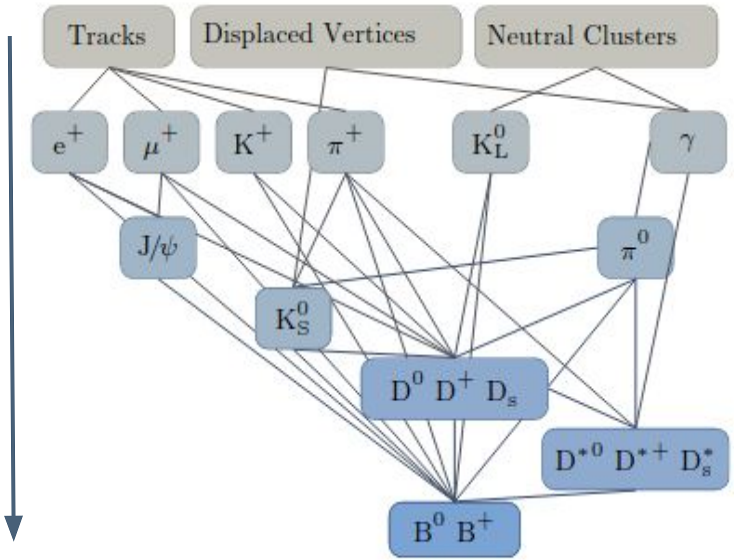
B^+ tagging: FEI algorithm

In Hadronic tagging, we essentially reconstruct
$B \rightarrow D^{(*)}\ (n\pi^+)\ (m\pi^0)$ final states:

$\bar{D}^0\pi^+$
$\bar{D}^{*0}\pi^+$
$\bar{D}^0\pi^+\pi^0$
$\bar{D}^{*0}\pi^+\pi^0$
$\bar{D}^0\pi^+\pi^+\pi^-$
$\bar{D}^{*0}\pi^+\pi^+\pi^-$
$\bar{D}^0\pi^+\pi^0\pi^0$
$\bar{D}^{*0}\pi^+\pi^0\pi^0$
$\bar{D}^0\pi^+\pi^+\pi^-\pi^0$
$\bar{D}^{*0}\pi^+\pi^+\pi^-\pi^0$
$D^-\pi^+\pi^+$
$D^-\pi^+\pi^+\pi^0$

BDTs are trained on MC for these final states in a hierarchical structure starting from tracks and clusters.

If MC is not optimal, the BDT selection will not be optimal.



Improving MC model: An example

Let's take one final state for example: $B^- \to D^{(*)0}\,\pi^+\,\pi^+\,\pi^-\,\pi^0$.
It can be produced through many intermediate states:

Decay	Belle	Belle II
$B^+ \to \overline{D}^{*0}\pi^-\pi^+\pi^+\pi^0$	1.80	1.80
$B^+ \to \overline{D}^{*0}\omega(782)\pi^+;\ \omega(782) \to \pi^-\pi^+\pi^0$	0.40	0.41
Rest of Exclusive	0.02	0.05
Sum of Exclusive	2.22	2.25
$B^+ \to \overline{D}^{*0}\rho(770)^0\rho(770)^+;\ \rho(770)^0 \to \pi^+\pi^-;\ \rho(770)^+ \to \pi^+\pi^0$	0.49	0.20
$B^+ \to \overline{D}^{*0}\rho(770)^+\pi^+\pi^-;\ \rho(770)^+ \to \pi^+\pi^0$	0.40	0.20
$B^+ \to \overline{D}^{*0}\rho(770)^0\pi^+\pi^0;\ \rho(770)^0 \to \pi^+\pi^-$	0.40	0.20
$B^+ \to \overline{D}^{*0}\rho(770)^-\pi^+\pi^+;\ \rho(770)^- \to \pi^-\pi^0$	0.20	0.10
$B^+ \to \overline{D}^{*0}\eta\pi^+;\ \eta \to \pi^-\pi^+\pi^0$	0.14	0.07
$B^+ \to \overline{D}_1(2430)^0\rho(770)^0\pi^+;\ \overline{D}_1(2430)^0 \to \overline{D}^{*0}\pi^0;\ \rho(770)^0 \to \pi^+\pi^-$	0.03	-
Rest of PYTHIA	0.02	0.01
Sum of PYTHIA	1.68	0.77
Total Sum	$\boxed{3.90}$	$\boxed{3.03}$

This is wrong!
The measurement is (1.80 ± 0.24 ± 0.27)%

Improving MC model: An example

Let's take one final state for example: **$B^- \rightarrow D^{(*)0}\,\pi^+\,\pi^+\,\pi^-\,\pi^0$**.
It can be produced through many intermediate states:

Decay	Belle	Belle II
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$B^+ \to \overline{D}^{*0}\omega(782)\pi^+;\ \omega(782) \to \pi^-\pi^+\pi^0$	0.40	0.41
Rest of Exclusive	0.02	0.05
Sum of Exclusive	2.22	2.25
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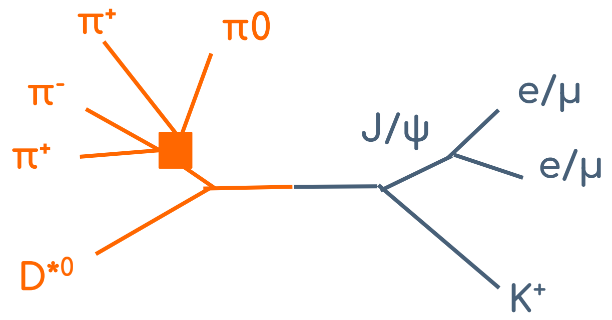
$B^+ \to \overline{D}^{*0}\rho(770)^+\pi^+\pi^-;\ \rho(770)^+ \to \pi^+\pi^0$	0.40	0.20
$B^+ \to \overline{D}^{*0}\rho(770)^0\pi^+\pi^0;\ \rho(770)^0 \to \pi^+\pi^-$	0.40	0.20
$B^+ \to \overline{D}^{*0}\rho(770)^-\pi^+\pi^+;\ \rho(770)^- \to \pi^-\pi^0$	0.20	0.10
$B^+ \to \overline{D}^{*0}\eta\pi^+;\ \eta \to \pi^-\pi^+\pi^0$	0.14	0.07
$B^+ \to \overline{D}_1(2430)^0\rho(770)^0\pi^+;\ \overline{D}_1(2430)^0 \to \overline{D}^{*0}\pi^0;\ \rho(770)^0 \to \pi^+\pi^-$	0.03	-
Rest of PYTHIA	0.02	0.01
Sum of PYTHIA	1.68	0.77
Total Sum	$\boxed{3.90}$	$\boxed{3.03}$

Can be compared with Data,
if we reconstruct one B as **$B^+ \rightarrow J/\psi\,K^+$**
and other B as **$B^- \rightarrow D^{(*)0}\,\pi^+\,\pi^+\,\pi^-\,\pi^0$**



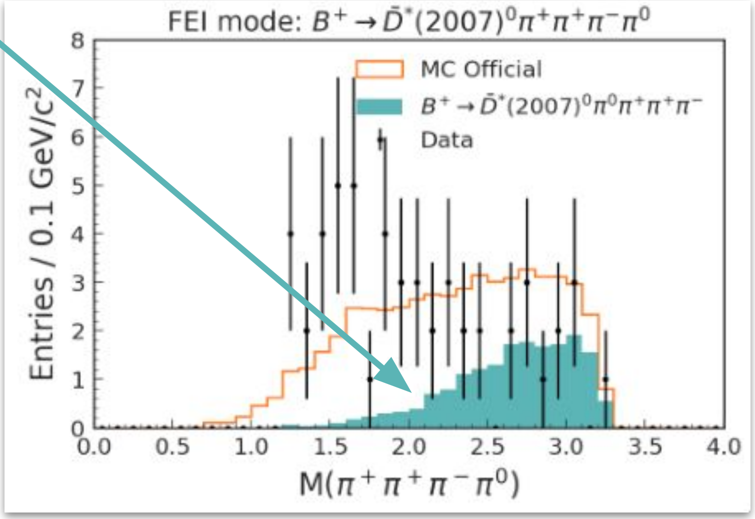
The measurement is 1.80%

Improving MC model: An example

Let's take one final state for example: $B^- \to D^{(*)0}\, \pi^+\, \pi^+\, \pi^-\, \pi^0$.
It can be produced through many intermediate states:

Decay	Belle	Belle II
$B^+ \to \overline{D}^{*0}\pi^-\pi^+\pi^+\pi^0$	1.80	1.80
$B^+ \to \overline{D}^{*0}\omega(782)\pi^+;\ \omega(782) \to \pi^-\pi^+\pi^0$	0.40	0.41
Rest of Exclusive	0.02	0.05
Sum of Exclusive	2.22	2.25
$B^+ \to \overline{D}^{*0}\rho(770)^0\rho(770)^+;\ \rho(770)^0 \to \pi^+\pi^-;\ \rho(770)^+ \to \pi^+\pi^0$	0.49	0.20
$B^+ \to \overline{D}^{*0}\rho(770)^+\pi^+\pi^-;\ \rho(770)^+ \to \pi^+\pi^0$	0.40	0.20
$B^+ \to \overline{D}^{*0}\rho(770)^0\pi^+\pi^0;\ \rho(770)^0 \to \pi^+\pi^-$	0.40	0.20
$B^+ \to \overline{D}^{*0}\rho(770)^-\pi^+\pi^+;\ \rho(770)^- \to \pi^-\pi^0$	0.20	0.10
$B^+ \to \overline{D}^{*0}\eta\pi^+;\ \eta \to \pi^-\pi^+\pi^0$	0.14	0.07
$B^+ \to \overline{D}_1(2430)^0\rho(770)^0\pi^+;\ \overline{D}_1(2430)^0 \to \overline{D}^{*0}\pi^0;\ \rho(770)^0 \to \pi^+\pi^-$	0.03	-
Rest of PYTHIA	0.02	0.01
Sum of PYTHIA	1.68	0.77
Total Sum	$\boxed{3.90}$	$\boxed{3.03}$

This component is extra!



The measurement is 1.80%

Similarly for other final states

BELLE2-NOTE-PH-2022-002

Marker convention:
★ : Old/No measurement
■ : Double counting

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

TABLE V: Contents of the DECAY file concerning the $B^+ \to \overline{D}^0\pi^+\pi^+\pi^-$ final state and corresponding measurements in PDG [in %].

Decay	Belle	Belle II	Marker	Ref
$B^+ \to \overline{D}^0\pi^-\pi^+\pi^+$	0.46	0.51	■	[4]
$B^+ \to \overline{D}^0\rho(770)^0\pi^+; \rho(770)^0 \to \pi^+\pi^-$	0.39	0.42	★	[4]
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to \rho(770)^0\pi^+; \rho(770)^0 \to \pi^+\pi^-$	0.13	0.14	★	[4]
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to f_0(600)\pi^+; f_0(600) \to \pi^+\pi^-$	0.05	-	★	
$B^+ \to \overline{D}_1(2420)^0\pi^+; \overline{D}_1(2420)^0 \to D^*(2010)^-\pi^+; D^*(2010)^- \to \overline{D}^0\pi^-$	0.04	0.02		[6], [5]
$B^+ \to \overline{D}_1(2430)^0\pi^+; \overline{D}_1(2430)^0 \to D^*(2010)^-\pi^+; D^*(2010)^- \to \overline{D}^0\pi^-$	0.03	0.02		[6], [5]
$B^+ \to \overline{D}_2^*(2460)^0\pi^+; \overline{D}_2^*(2460)^0 \to D^*(2010)^-\pi^+; D^*(2010)^- \to \overline{D}^0\pi^-$	0.01	0.01		[6], [5]
$B^+ \to D^*(2010)^-\pi^+\pi^+; D^*(2010)^- \to \overline{D}^0\pi^-$	-	0.09	■	[6]
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to \pi^+\pi^+\pi^-$	-	0.07	★	[4]
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to f_0(500)\pi^+; f_0(500) \to \pi^+\pi^-$	-	0.05	★	[4]
$B^+ \to \overline{D}_1(2420)^0\pi^+; \overline{D}_1(2420)^0 \to \overline{D}^0\pi^-\pi^+$	-	0.02		[6], [5]
$B^+ \to \overline{D}^0 K^*(892)^+; K^*(892)^+ \to K^0\pi^+; K^0 \to K_S^0; K_S^0 \to \pi^+\pi^-$	-	0.01		
Rest of Exclusive	0.03	0.03		
Sum of Exclusive	1.12	1.38		
Sum of Pythia	0	0		
Total Sum	1.12	1.38		

$\overline{D}^{*0} \pi^+ \pi^+ \pi^-$

TABLE VI: Contents of the DECAY file concerning the $B^+ \to \overline{D}^{*0}\pi^+\pi^+\pi^-$ final state and corresponding measurements in PDG [in %]. The rows in blue correspond to decays produced by Pythia.

Decay	Belle	Belle II	Marker	Ref
$B^+ \to \overline{D}^*(2007)^0\pi^-\pi^+\pi^+$	1.03	-	■	[2], [7]
$B^+ \to \overline{D}^*(2007)^0 a_1(1260)^+; a_1(1260)^+ \to \rho(770)^0\pi^+; \rho(770)^0 \to \pi^+\pi^-$	0.66	0.58	★	
$B^+ \to \overline{D}^*(2007)^0 a_1(1260)^+; a_1(1260)^+ \to f_0(600)\pi^+; f_0(600) \to \pi^+\pi^-$	0.25	-	★	
$B^+ \to \overline{D}^*(2007)^0 a_1(1260)^+; a_1(1260)^+ \to \pi^+\pi^+\pi^-$	-	0.28	★	
$B^+ \to \overline{D}^*(2007)^0 a_1(1260)^+; a_1(1260)^+ \to f_0(500)\pi^+; f_0(500) \to \pi^+\pi^-$	-	0.20	★	
$B^+ \to \overline{D}^*(2007)^0\rho(770)^0\pi^+; \rho(770)^0 \to \pi^+\pi^-$	-	0.04	★	
Rest of Exclusive	0.02	0.05		
Sum of Exclusive	1.96	1.15		
$B^+ \to \overline{D}^*(2007)^0 f_0(980)\pi^+; f_0(980) \to \pi^+\pi^-$	0.05	-	★	
$B^+ \to \overline{D}^*(2007)^0\pi^+\pi^+\pi^-$	-	0.20	■	
Rest of Pythia	0.00	0.00		
Sum of Pythia	0.05	0.20		
Total Sum	2.01	1.35		

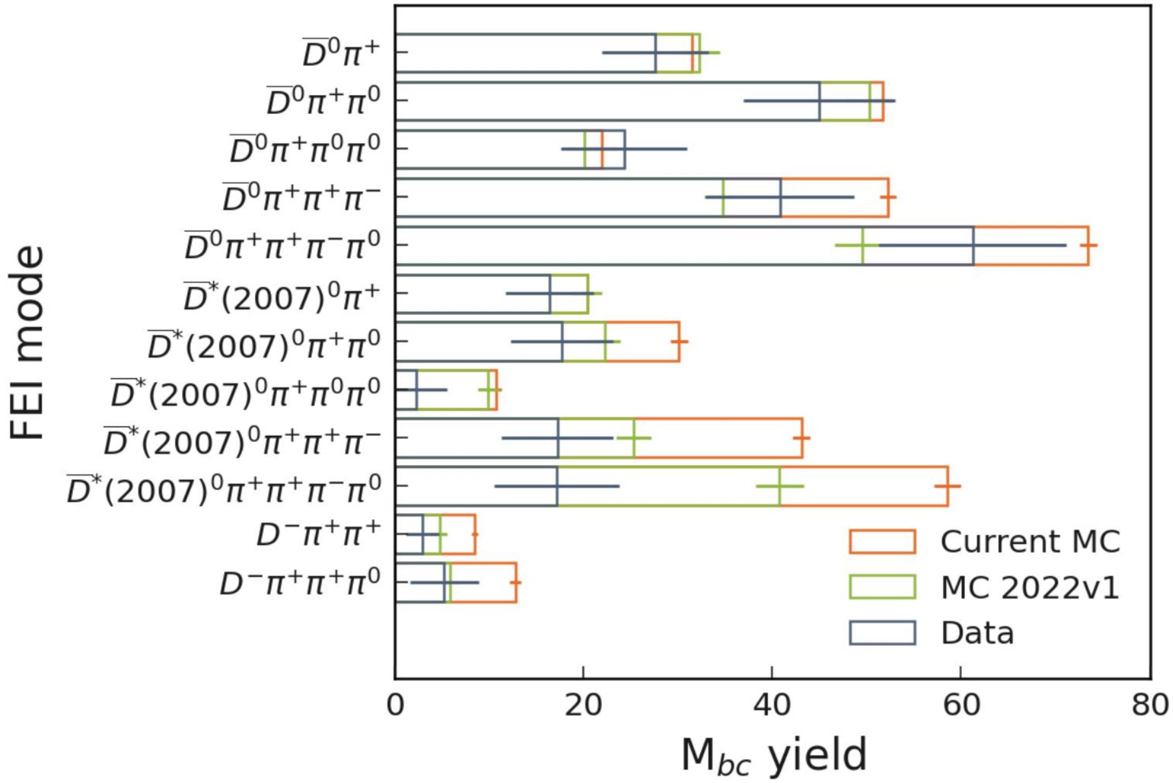
$B^+ \to \overline{D}^0 \pi^+ \pi^+ \pi^- \pi^0$

TABLE IX: Contents of the DECAY file concerning the $B^+ \to \overline{D}^0\pi^+\pi^+\pi^-\pi^0$ final state and corresponding measurements in PDG [in %]. The rows in blue correspond to decays produced by Pythia.

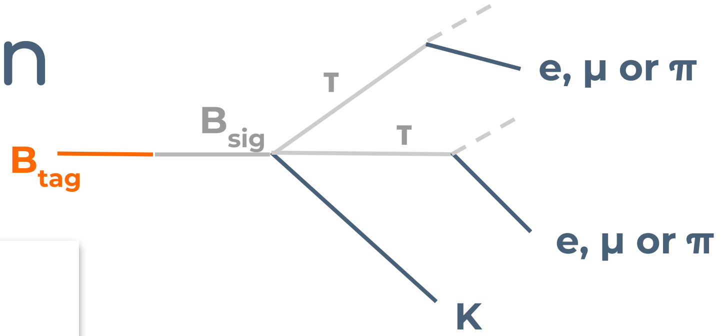
Decay	Belle	Belle II	Markers	Ref
$B^+ \to D^*(2010)^-\pi^0\pi^+\pi^+; D^*(2010)^- \to \overline{D}^0\pi^-$	1.02	1.03	★	[8]
$B^+ \to \overline{D}^*(2007)^0\pi^-\pi^+\pi^+; \overline{D}^*(2007)^0 \to \overline{D}^0\pi^0$	0.64	-	■	
$B^+ \to \overline{D}^*(2007)^0 a_1(1260)^+; \overline{D}^*(2007)^0 \to \overline{D}^0\pi^0; a_1(1260)^+ \to \rho(770)^0\pi^+; \rho(770)^0 \to \pi^+\pi^-$	0.41	0.38	★	
$B^+ \to \overline{D}^0\omega(782)\pi^+; \omega(782) \to \pi^-\pi^+\pi^0$	0.37	0.37	★	[9]
$B^+ \to \overline{D}^*(2007)^0 a_1(1260)^+; \overline{D}^*(2007)^0 \to \overline{D}^0\pi^0; a_1(1260)^+ \to f_0(600)\pi^+; f_0(600) \to \pi^+\pi^-$	0.16	-	★	
$B^+ \to D^*(2010)^-\rho(770)^+\pi^+; D^*(2010)^- \to \overline{D}^0\pi^-; \rho(770)^+ \to \pi^+\pi^0$	0.14	0.14	★	
$B^+ \to \overline{D}^*(2007)^0 a_1(1260)^+; \overline{D}^*(2007)^0 \to \overline{D}^0\pi^0; a_1(1260)^+ \to \pi^+\pi^+\pi^-$	-	0.18	★	
$B^+ \to \overline{D}^*(2007)^0 a_1(1260)^+; \overline{D}^*(2007)^0 \to \overline{D}^0\pi^0; a_1(1260)^+ \to f_0(500)\pi^+; f_0(500) \to \pi^+\pi^-$	-	0.13	★	
Rest of Exclusive	0.03	0.10		
Sum of Exclusive	2.75	2.32		
$B^+ \to \overline{D}^0\rho(770)^+\pi^+\pi^-; \rho(770)^+ \to \pi^+\pi^0$	0.20	0.30		
$B^+ \to \overline{D}^0\rho(770)^0\rho(770)^+; \rho(770)^0 \to \pi^+\pi^-; \rho(770)^+ \to \pi^+\pi^0$	0.20	0.20		
$B^+ \to \overline{D}^0\rho(770)^-\pi^+\pi^+; \rho(770)^- \to \pi^-\pi^0$	0.10	0.10		
$B^+ \to \overline{D}^0\rho(770)^0\pi^+\pi^0; \rho(770)^0 \to \pi^+\pi^-$	0.10	0.20		
$B^+ \to \overline{D}^0\eta\pi^+; \eta \to \pi^-\pi^+\pi^0$	0.05	0.07	★	
$B^+ \to \overline{D}_1(2430)^0\pi^+\pi^0; \overline{D}_1(2430)^0 \to D^*(2010)^-\pi^+; D^*(2010)^- \to \overline{D}^0\pi^-$	0.05	-		
$B^+ \to \overline{D}_0^*(2300)^0\rho(770)^0\pi^+; \overline{D}_0^*(2300)^0 \to \overline{D}^0\pi^0; \rho(770)^0 \to \pi^+\pi^-$	0.03	-		
$B^+ \to \overline{D}^*(2007)^0 f_0(980)\pi^+; \overline{D}^*(2007)^0 \to \overline{D}^0\pi^0; f_0(980) \to \pi^+\pi^-$	0.03	-	■	
$B^+ \to \overline{D}_2^*(2460)^0\rho(770)^0\pi^+; \overline{D}_2^*(2460)^0 \to \overline{D}^0\pi^0; \rho(770)^0 \to \pi^+\pi^-$	0.02	-		
$B^+ \to \overline{D}_2^*(2460)^0\pi^+\pi^0; \overline{D}_2^*(2460)^0 \to D^*(2010)^-\pi^+; D^*(2010)^- \to \overline{D}^0\pi^-$	0.01	-		
$B^+ \to \overline{D}^*(2007)^0\pi^+\pi^+\pi^-; \overline{D}^*(2007)^0 \to \overline{D}^0\pi^0$	-	0.13	■	
$B^+ \to \overline{D}^0\pi^+\pi^+\pi^-\pi^0$	-	0.10		
Rest of Pythia	0.01	0.01		
Sum of Pythia	0.79	1.10		
Total Sum	3.54	3.42	★	

Improving MC model ⇒ B⁺ tagging

Implementing all the identified issues already improves the Data-MC agreement!



Signal-side reconstruction



Once we have a B_{tag} + K + 2<e, μ or π> candidate,
to suppress background, we train BDT using variables:

- B_{tag}: FEI Signal Probability of the B_{tag} candidate.
- $M_{K^+\tau^-}$: Invariant mass of K^+ and charged daughter of the τ^-
- $\hat{p}_{\tau^+}$: The momentum of the charged daughter of τ^+ in the rest frame of the signal-B candidate.
- $decaychannel$: Decay hash value corresponding to the six possibilities of the mass hypotherses of the charged children of the τ pair (ee, $e\mu$, $e\pi$, $\mu\mu$, $\mu\pi$, $\pi\pi$).
- ΔE_{tag}: The beam constrained energy of the B_{tag} candidate
- q^2: The constrained invariant mass of τ pair.
- $M_{\tau^+\tau^-}$: The reconstructed invariant mass of τ pair.
- M_{bc}^{tag}: The beam constrained mass of B_{tag} candidate.
- $\theta_{\tau^-}^{hel}$: The pseudo helicity angle of the τ^-
- $\sigma(d_{B_{tag}})$: The significance of the distance to the B_{tag} candidate, derived from the error of the vertex fit.
- χ^2: χ^2 value of the vertex fit of the candidate.
- d_{IP} : Distance of the candidate to the interaction point.
- Q : Defined as the reconstructed mass of the B candidate subtracted by the reconstructed mass of the children: $Q = M_B - M_{K^+} - M_{\tau^+} - M_{\tau^-}$.

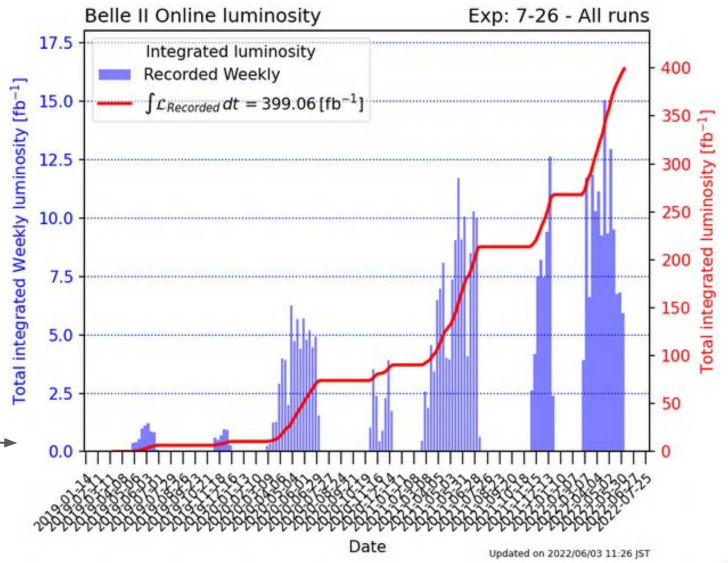
In our group, similar efforts have been made for $B^+ \to K^+ \tau^+ l^-$ reconstruction.

Estimated sensitivity:
BF $\boxed{< 3.2 \times 10^{-4}}$ at 90% CL
(based on Simon Wehle's study)

Summary

- $B^+ \to K^+ \tau^+ \tau^-$ has two 3rd gen. leptons
  ⇒ Good probe for New Physics

- Search at B-factories:
  - Only 1 result (from BaBar) so far.
  - Working on Belle data with hadronic-tagging
  - Belle II is taking data now!



Better MC modeling of hadronic B decays can improve B-tagging performance

Collected : ~400 fb^{-1}
10 year goal : 50 ab^{-1}

Analysis procedure

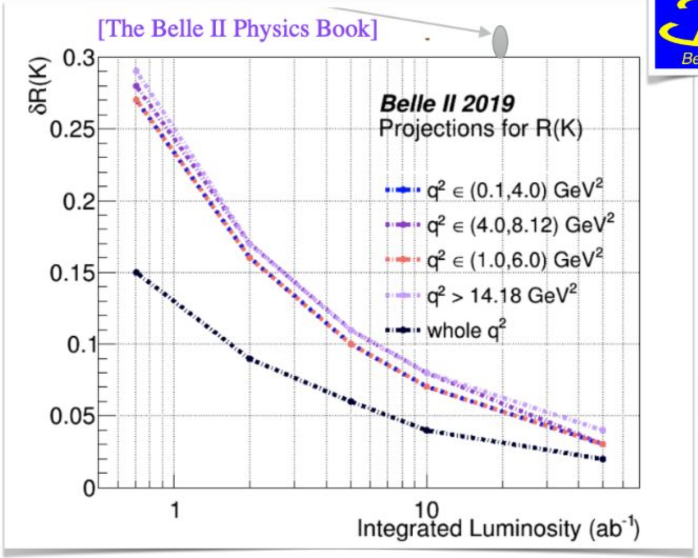
1. There are two B in one event
2. One B is fully reconstructed
3. Many B modes, and as soon as more than two π in $B \to D^{(*)}X$, it is complex but high BF.
4. In other B you can probe modes with neutrinos (even 4!)
5. Competitive with LHCb already with Belle sample (different situation than $B^+ \to K^+ l^+ l^-$)

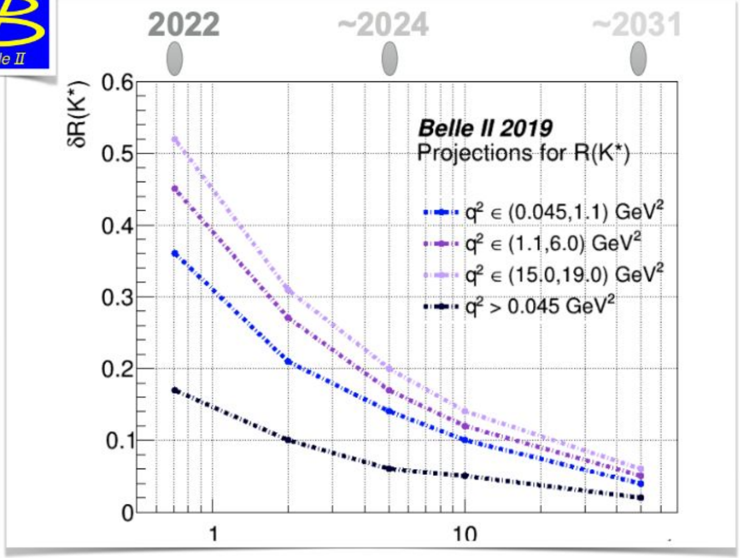
Backup

LFU violation in $b \to s\, l^+ l^-$: Projection

- Belle II, enjoys nearly symmetric electron/muon reconstruction performance, and can:
  - provide independent check of $R(K^{(*)})$ anomalies with > 5-10 ab^{-1}

The Belle II Physics Book, PETP 2019, 123C01 (2019)

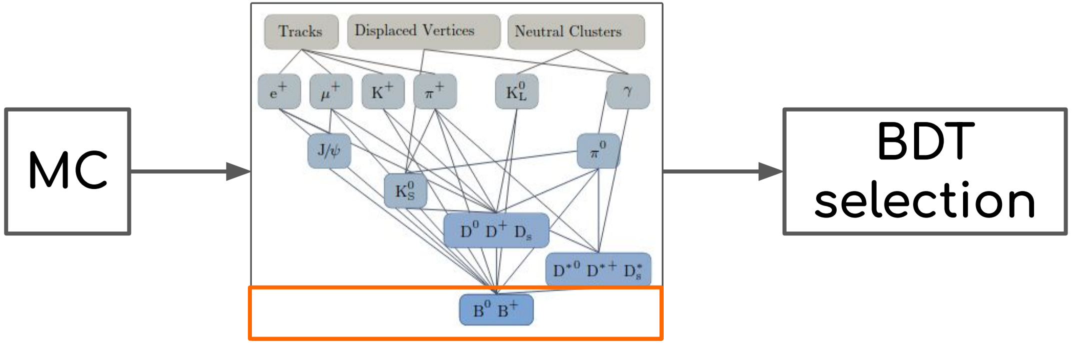




Improving B^+ tagging

- Training is done on MC. If MC does not resemble data:
  - Biases enter in selection conditions.
  - The efficiency looks different in MC and data.

We are studying the main modes of hadronic tag and improving their MC model to look closer to data.



- Can we replace the last stage (B^+ reconstruction) BDT → cut-based
  to avoid (re)training-time and be more robust?

MC - Data comparison

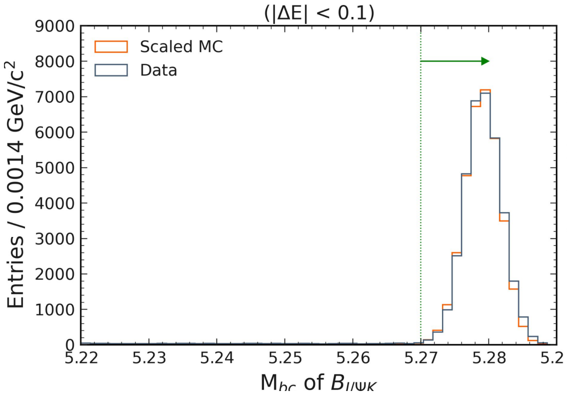
BELLE2-NOTE-PH-2022-002

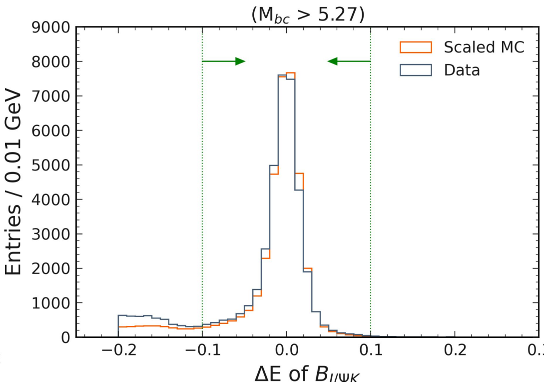
To verify this, we reconstruct the pure $B^+ \rightarrow J/\psi\, K^+$ on one side and hadronic FEI on the other side, in Belle Data and MC (100x Belle statistics).

$B_{J/\psi\ K}$

Selection adapted from Seema et al. [Belle Note 1599].

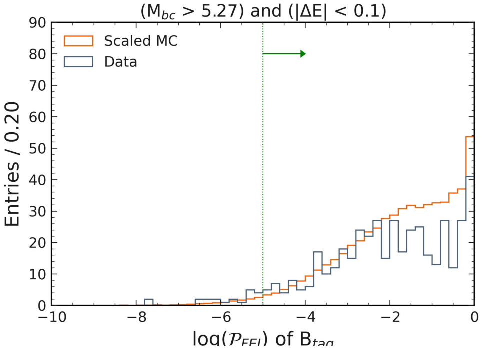
~35k events with high purity after these cuts

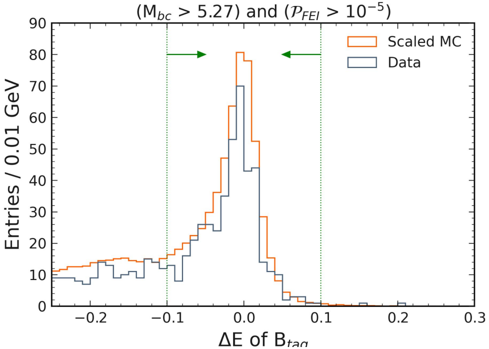


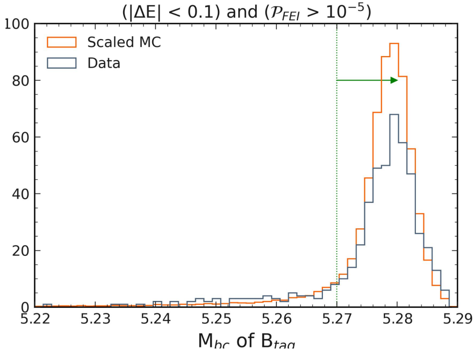


B_{FEI}

~420 events after these cuts





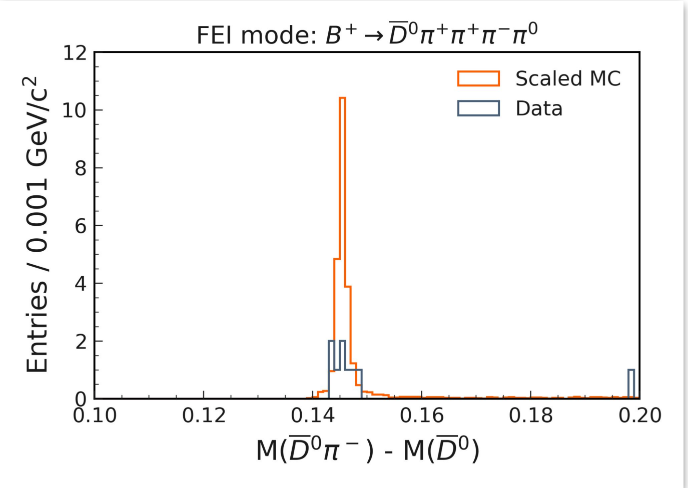


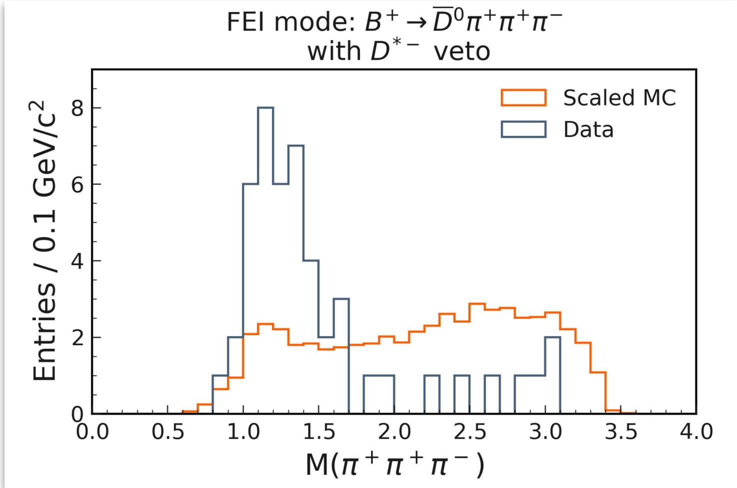
MC is scaled by Luminosity

Disagreement in intermediate resonances

BELLE2-NOTE-PH-2022-002

The difference is not just in the total branching fractions, but also in **intermediate resonances**:





Like, we have too much $D^{*-}\pi^+\pi^+\pi^0$
(Based on ARGUS 1990 result)

It has to be mostly a_1^+

So, it is not just about **simply scaling** the total BF, but also tuning the **intermediate resonances**.

Better MC modeling is necessary for optimization (including Machine Learning performance)

Alternative FEI algorithm

Alternatively, using FEI particle list of $\bar{D}^0$, we want to reconstruct B^+ particle list manually

in orders of $\bar{D}^0$ **($m\ \pi^+$) ($n\ \pi^0$)**:

(m, n) = (1, 0)

$\bar{D}^0\ \pi^+$

(m, n) = (1, 1)

$\bar{D}^{*0}\ \pi^+$	$\bar{D}^0\ \rho^+$	$\bar{D}^0\ \pi^+\ \pi^0$

(m, n) = (3, 0)

$\bar{D}^{**0}\ \pi^+$	$\bar{D}^{*-}\ \pi^+\pi^+$	$\bar{D}^0\ a_1^+$	$\bar{D}^0\ \rho^0\ \pi^+$	$\bar{D}^0\pi^+\pi^+\pi^-$

. . .

. . .

Reconstructing in this order,
going to the next step only if it fails, ⇒ Simpler best candidate selection
using the constraints of intermediate resonances when possible ⇒ Higher purity

Let's call this algorithm " FREE "

More Statistics

[Salah El Dine Hammoud]

To further validate the impact of MC modeling and the new tagging algorithm (FREE), we need larger statistics.
One approach we are considering is partially reconstructing $\bar{D}^{(*)0}\pi^+$ similar to the control sample of the Belle $B^0 \to \tau l$ analysis:

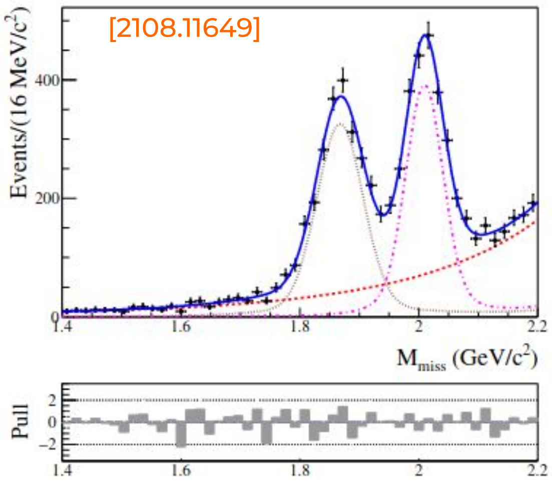


FIG. 1. The $M_{\rm miss}$ distribution of $B^0 \to D^{(*)-}\pi^+$ candidates observed in data (black dots) along with projections of the fit result: the overall fit result (solid blue curve), the background component (dashed red curve), the $B^0 \to D^-\pi^+$ component (dotted brown curve) and the $B^0 \to D^{*-}\pi^+$ component (dash-dotted magenta curve). The plot below the distribution shows the residuals divided by the errors (pulls).

dom ($n_{\rm dof}$) gives $\chi^2/n_{\rm dof} = 0.89$. The fitted yields are 2136 ± 71 and 2071 ± 74, and the resulting branching fractions are $\mathcal{B}(B^0 \to D^-\pi^+) = (2.54 \pm 0.11) \times 10^{-3}$ and $\mathcal{B}(B^0 \to D^{*-}\pi^+) = (2.67 \pm 0.12) \times 10^{-3}$, where the uncertainties listed are statistical only. These val-

In B^+, with Belle data we should have ~**35000 FEI events** of $\bar{D}^0\pi^+$ and $\bar{D}^{*0}\pi^+$ each. (c.f. ~400 with $J/\psi K^+$).

More Statistics

[Salah El Dine Hammoud]

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