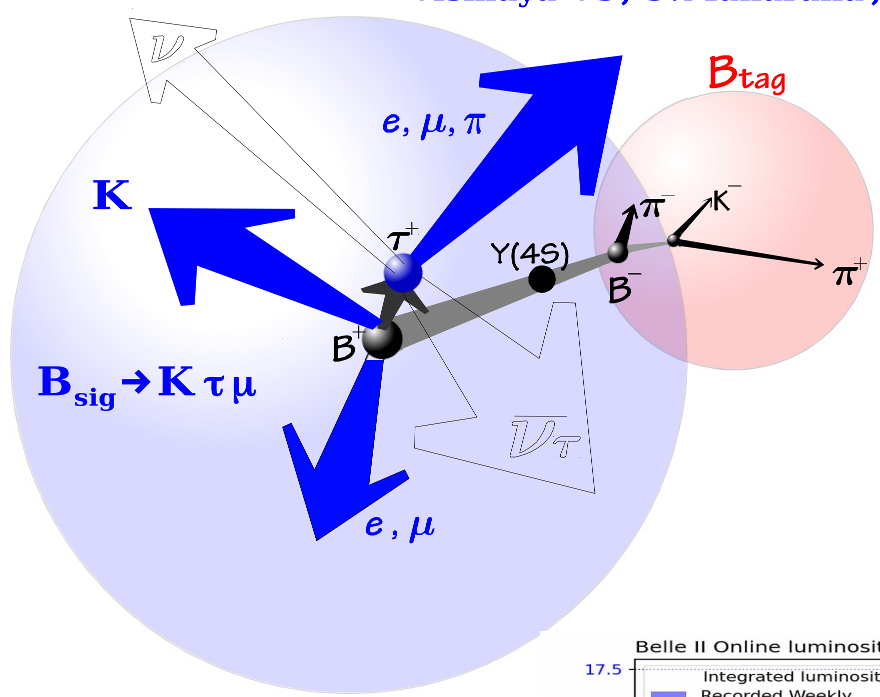
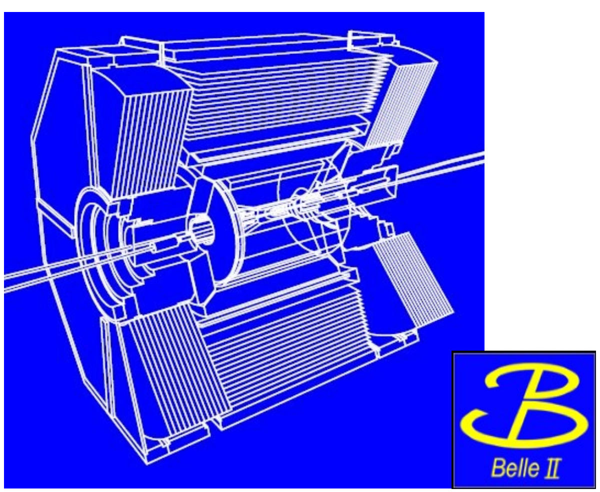
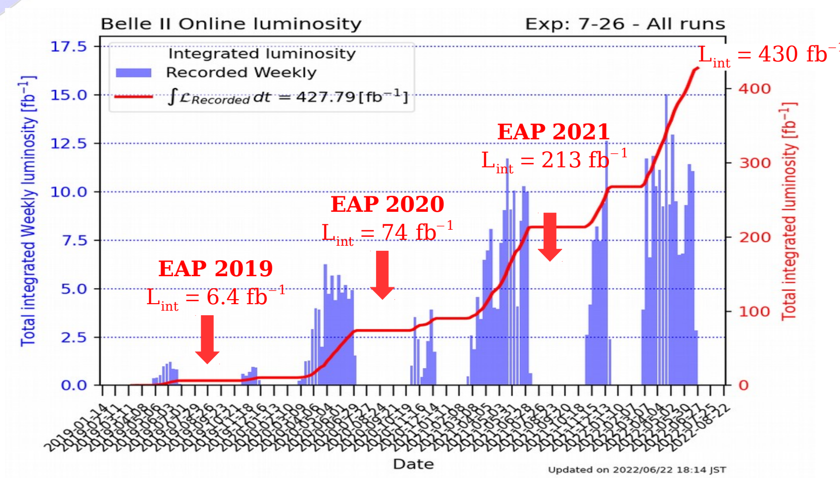
Save the B's

K.Trabelsi (IJCLab)
karim.trabelsi@in2p3.fr

G. de Marino, V. Vobbilisetti, M.Liu (IJCLab)
Vismaya VS, S.Maharana, S.Sandilya (IIT Hyderabad)
N.Rout (Trieste)
V. Bertacchi (CPPM)







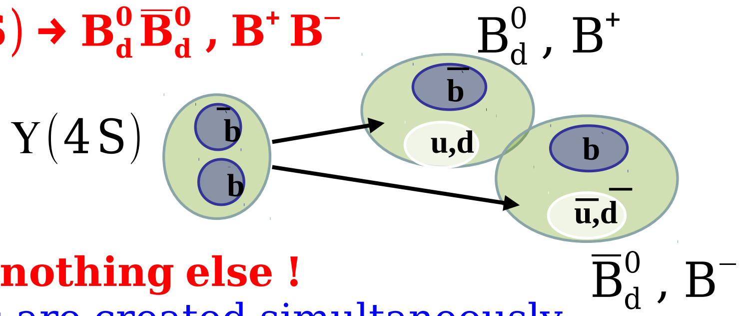
Belle II, a flavour-factory,

(Belle ~ 1 ab^{-1}) **a rich physics program...**

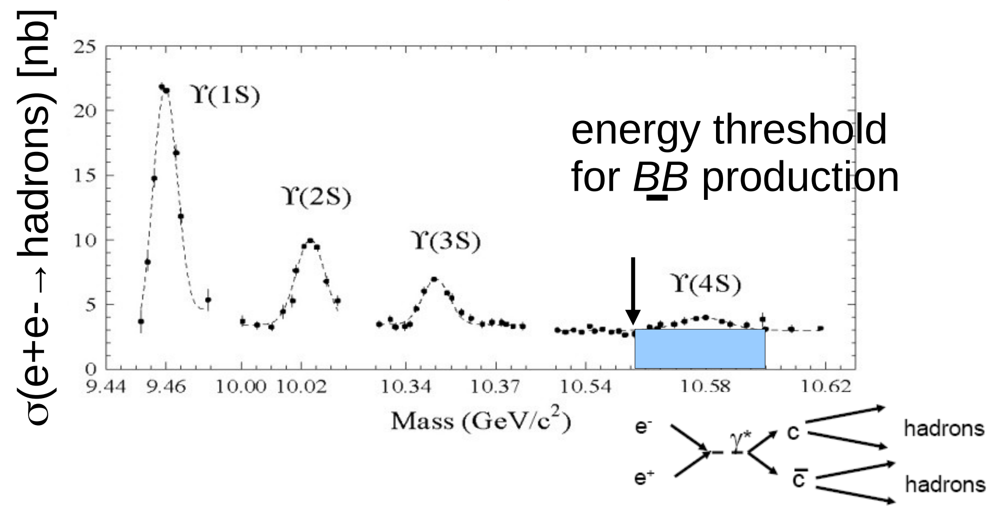
- We plan to collect (**at least**) 50 ab^{-1} of e^+e^- collisions at (or close to) the $\Upsilon(4S)$ resonance, so that we have:
  - **a (Super) B-factory ($\sim 1.1 \times 10^9$ $B\bar{B}$ pairs per ab^{-1})**

"on resonance" production

$e^+e^- \to \Upsilon(4S) \to B_d^0\bar{B}_d^0$, B^+B^-



- **2 B's and nothing else !**
- 2 B mesons are created simultaneously in a L=1 coherent state



  - a (Super) charm factory ($\sim 1.3 \times 10^9$ $c\bar{c}$ pairs per ab^{-1})
    (but also charmonium, X, Y, Z, pentaquarks, tetraquarks, bottomonium...)
  - **a (Super) τ factory ($\sim 0.9 \times 10^9$ $\tau^+\tau^-$ pairs per ab^{-1})**
  - exploit the clean e^+e^- environment to probe the existence of exotic hadrons, dark photons/Higgs, light Dark Matter particles, ALPs, LLPs ...

$\Rightarrow$ to reach 6×10^{35} $cm^{-2}s^{-1}$

$\Rightarrow$ cumulate 50 ab^{-1} by ~2035

Belle(II), LHCb side by side

Belle (II)

$e^+e^- \to \Upsilon(4S) \to b\bar{b}$

at $\Upsilon(4S)$: 2 B's (B^0 or B^+) and nothing else ⇒ clean events

(flavour tagging, B tagging, missing energy)

⇒ initial conditions are precisely known

$\sigma_{b\bar{b}} \sim 1\,\mathrm{nb} \Rightarrow 1\ \mathrm{fb}^{-1}$ produces $10^6\ B\bar{B}$

$\sigma_{b\bar{b}}/\sigma_{total} \sim 1/4$

LHCb

$pp \to b\bar{b}X$

production of B^+, B^0, B_s, B_c, Λ_b...

but also a lot of other particles in the event

⇒ lower reconstruction efficiencies

$\sigma_{b\bar{b}}$ much higher than at the $\Upsilon(4S)$

	$\sqrt{s}$ [GeV]	$\sigma_{b\bar{b}}$ [nb]	$\sigma_{b\bar{b}}/\sigma_{tot}$
HERA pA	42 GeV	~30	~10^{-6}
Tevatron	2 TeV	5000	~10^{-3}
LHC	8 TeV	~3×10^5	~ 5×10^{-3}
	14 TeV	~6×10^5	~10^{-2}

$b\bar{b}$ production cross-section at LHCb ~ 500,000 × BaBar/Belle !!

higher luminosity

$\sigma_{b\bar{b}}/\sigma_{total}$ much lower than at the $\Upsilon(4S)$

⇒ lower trigger efficiencies

B mesons live relativey long

mean decay length $\beta\gamma c\tau \sim 200\ \mu m$

mean decay length $\beta\gamma c\tau \sim 7$ mm

(displaced vertices)

data taking period(s)

[1999-2010] = 1 ab^{-1}

[2019-...] = ...

[run I: 2010-2012] = 3 fb^{-1}

[run II: 2015-2018] = 6 fb^{-1}

(near) future

[Belle II from 2019] → 50 ab^{-1}

[LHCb upgrade from 2022]

Test of lepton universality using $B^+ \to K^{(*)} l^+ l^-$ decays

Model candidates

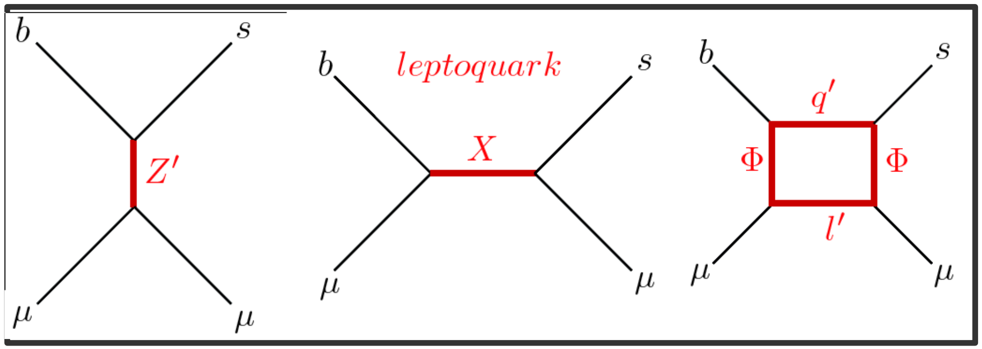
- ✓ Effective operator from Z' exchange
- ✓ Extra U(1) symmetry with flavor dependent charge

✧ **Models with leptoquarks**

- ✓ Effective operator from LQ exchange
- ✓ Yukawa interaction with LQs provide flavor violation

✧ **Models with loop induced effective operator**

- ✓ With extended Higgs sector and/or vector like quarks/leptons
- ✓ Flavor violation from new Yukawa interactions



Leptoquarks are color-triplet bosons that carry both lepton and baryon numbers

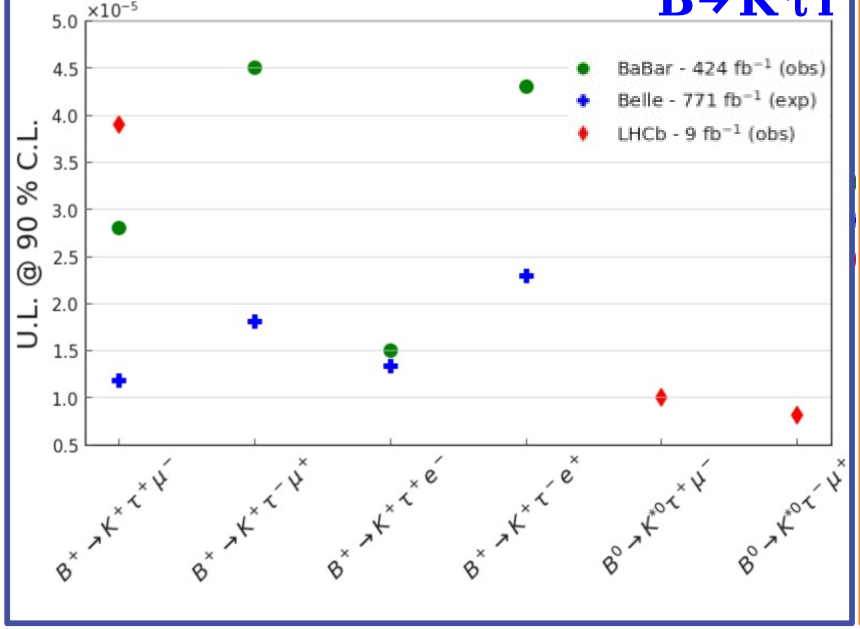
Lot of those models predict also LFV $b \to s e\mu, b \to s e\tau, \ldots$

G.Isidori, FPCP 2020: correlations among $b \to s(d) l l'$ within the (2)-based EFT

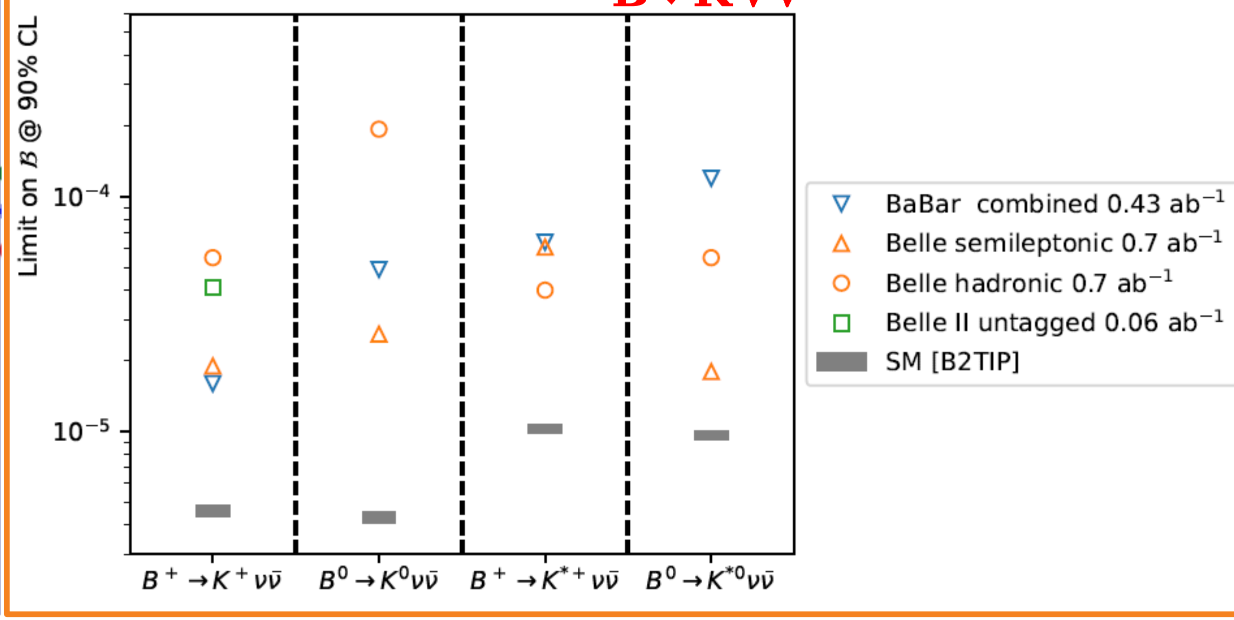
	μμ (ee)	ττ	νν	τμ	μe
$b \to s$	R_K, R_{K^*} O(20%)	$B \to K^{(*)} \tau\tau$ $\to$ 100×SM	$B \to K^{(*)} \nu\nu$ O(1)	$B \to K \tau\mu$ $\to 10^{-6}$	$B \to K \mu e$???
$b \to d$	$B_d \to \mu\mu$ $B \to \pi \mu\mu$ $B_s \to K^{(*)} \mu\mu$ O(20%) $[R_K=R_\pi]$	$B \to \pi \tau\tau$ $\to$ 100×SM	$B \to \pi \nu\nu$ O(1)	$B \to \pi \tau\mu$ $\to 10^{-7}$	$B \to \pi \mu e$???

Missing energy analyses (so efficient ….)

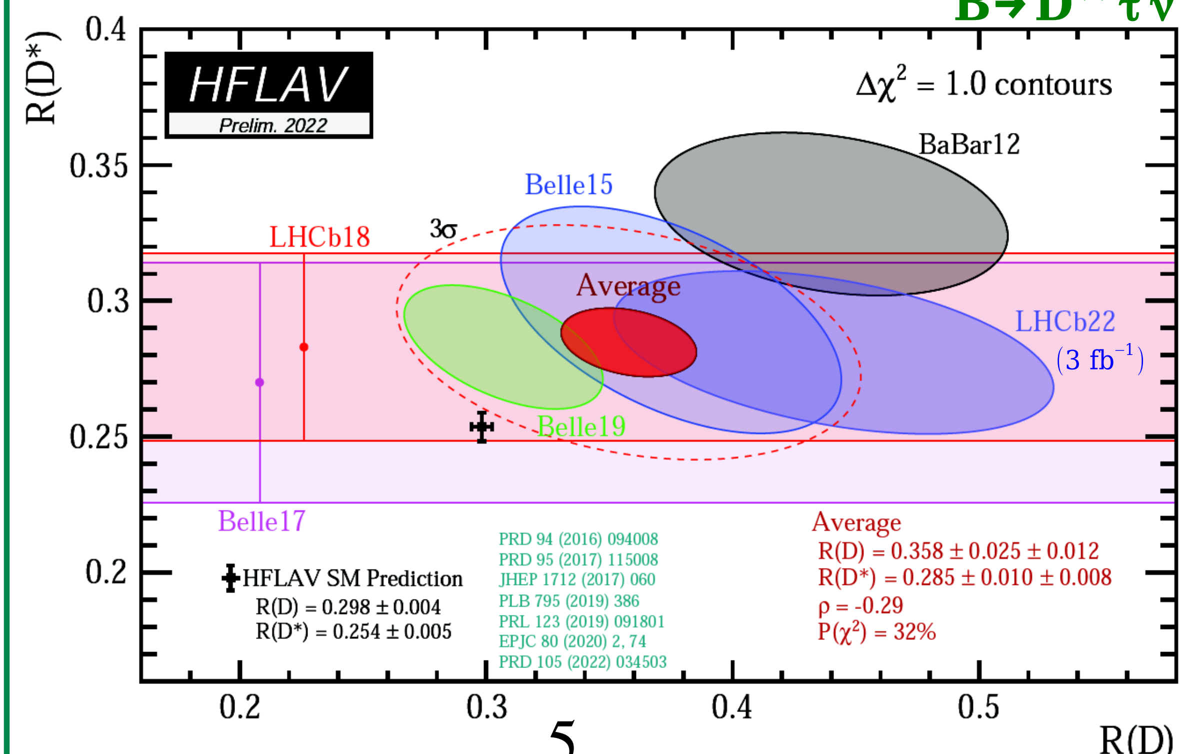
$B \to K\tau l$



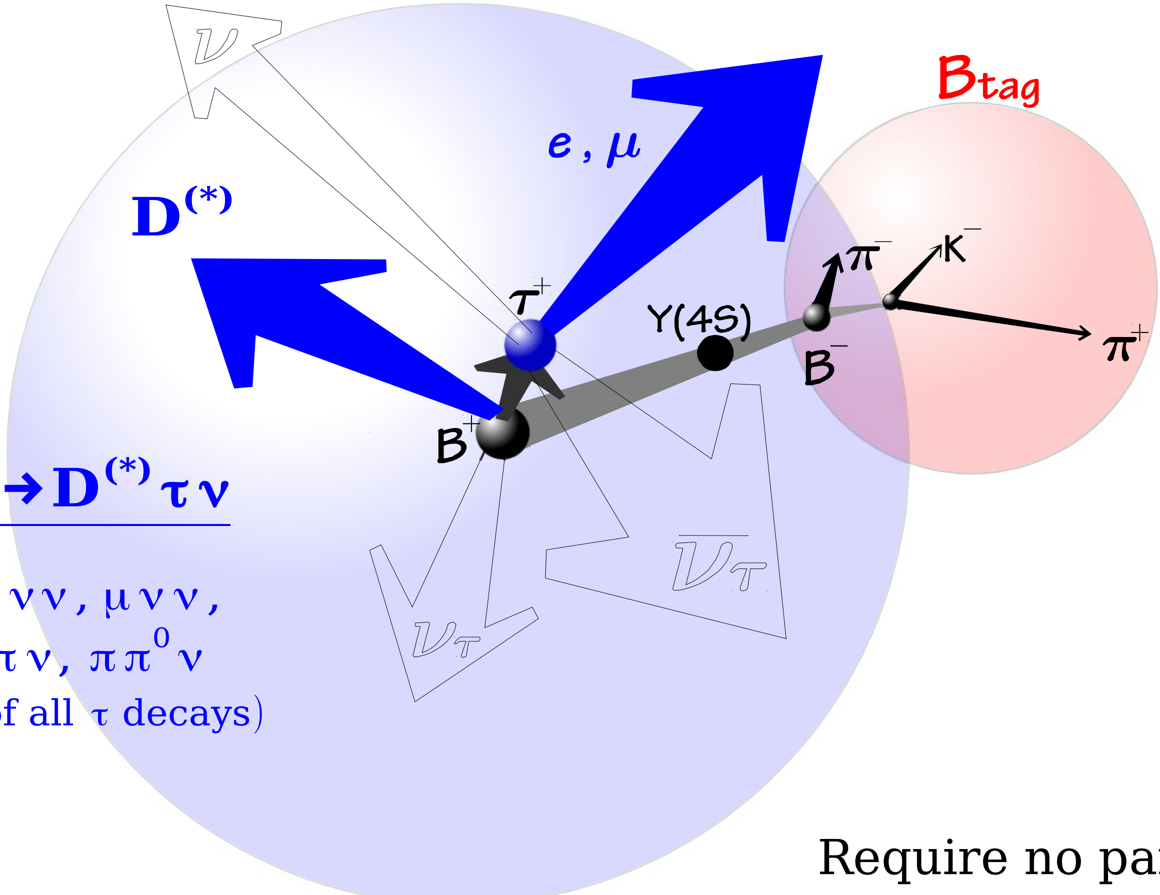
$B \to K\nu\bar{\nu}$



$B \to D^{(*)}\tau\bar{\nu}$



Event reconstruction in $B \to D^{(*)} \tau \nu$ at B factories



$B_{sig} \to D^{(*)} \tau \nu$

$\tau \to e \nu \nu$, $\mu \nu \nu$,
$\tau \to \pi \nu$, $\pi \pi^0 \nu$
(70 % of all τ decays)

B_{tag}

hadronic tag
$B \to D^{(*)} \pi$, $D^{(*)} \rho$...
$\epsilon \sim 0.5\,\%$

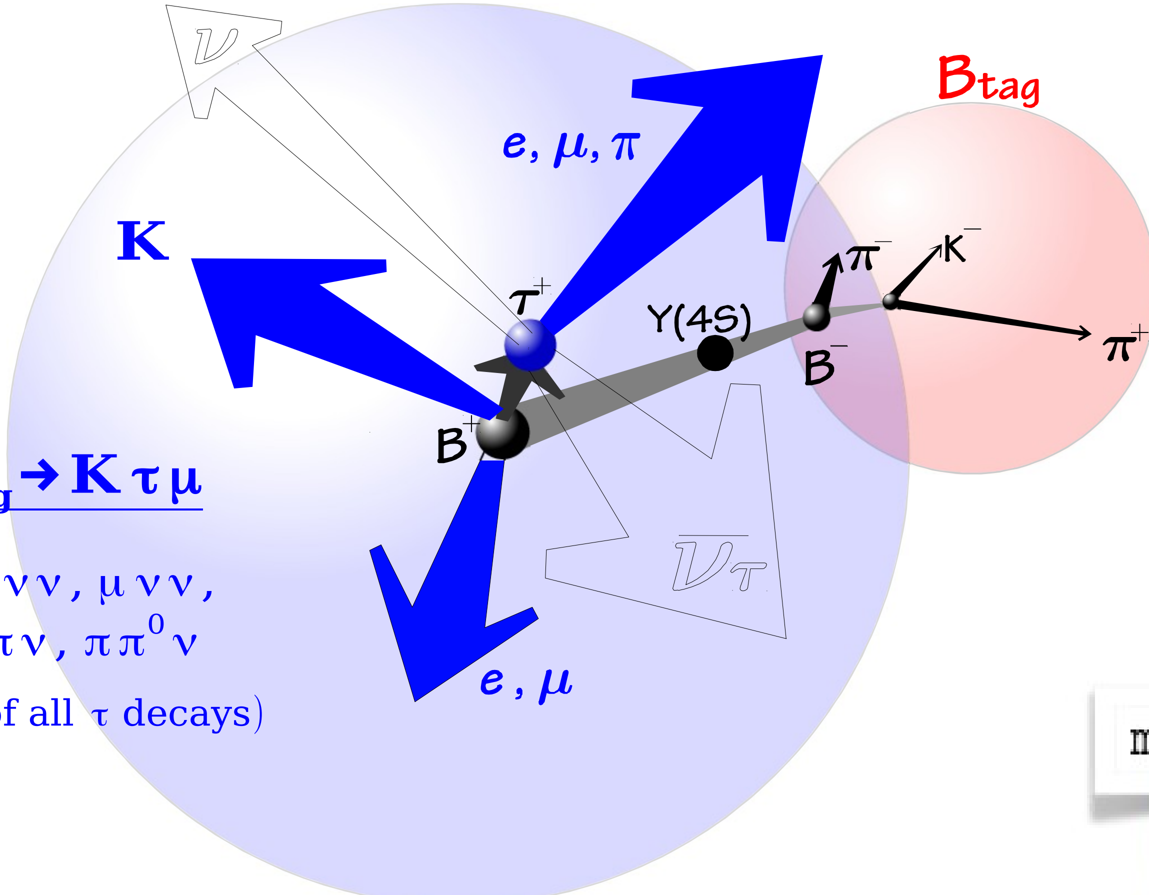
semileptonic tag
$B \to D^{(*)} l \nu X$

Require no particle and no energy left after removing B_{tag} and visible particles of B_{sig}

main signal - background discriminator

$$m^2_{miss} = (p_{ee} - p_{tag} - p_{D^{(*)}} - p_l)^2$$

Event reconstruction in B→K τ μ at B factories



$B_{sig} \rightarrow K \tau \mu$

$\tau \rightarrow e \nu \nu$, $\mu \nu \nu$,
$\tau \rightarrow \pi \nu$, $\pi \pi^0 \nu$
(70 % of all τ decays)

neutrinos are <u>all</u> coming from the tau here !

B_{tag}

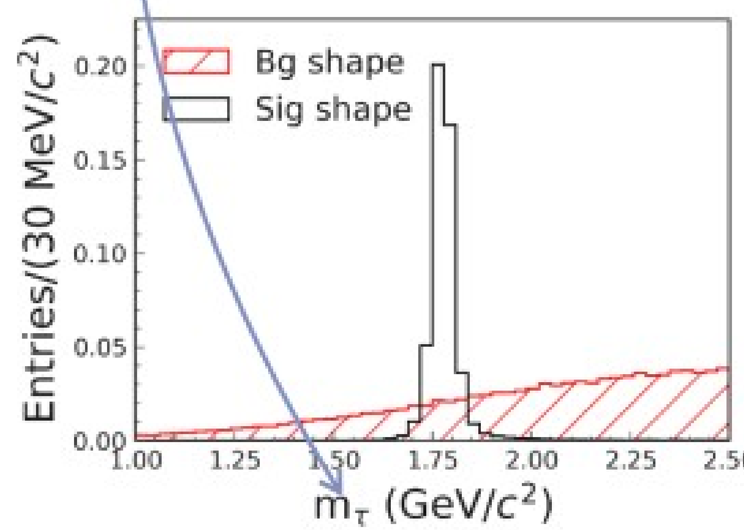
hadronic tag

$B \rightarrow D^{(*)} \pi$, $D^{(*)} \rho$ ...
$\epsilon \sim 0.5\,\%$

semileptonic tag

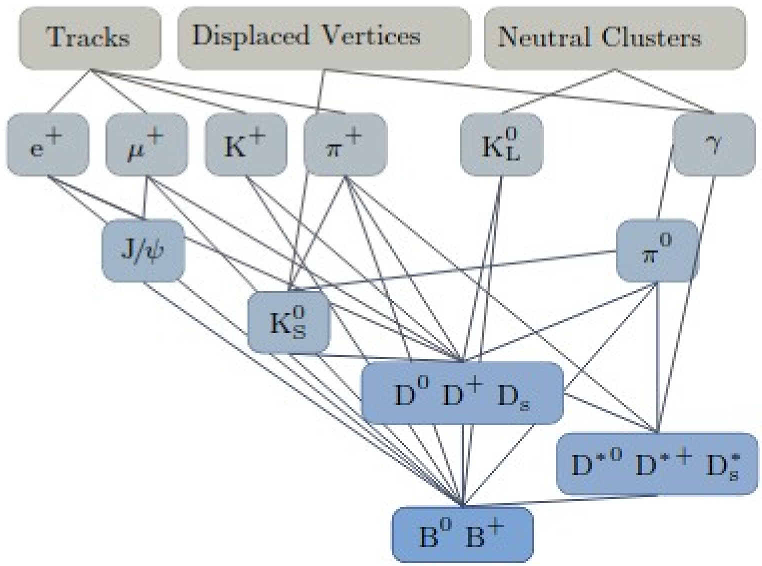
$B \rightarrow D^{(*)} l \nu\ X$

$$m_\tau^2 = (p_{e^+e^-} - p_K - p_\ell - p_{B_{tag}})^2$$



Hadronic B-tagging at Belle/Belle II

''Full Event Interpretation'' package:

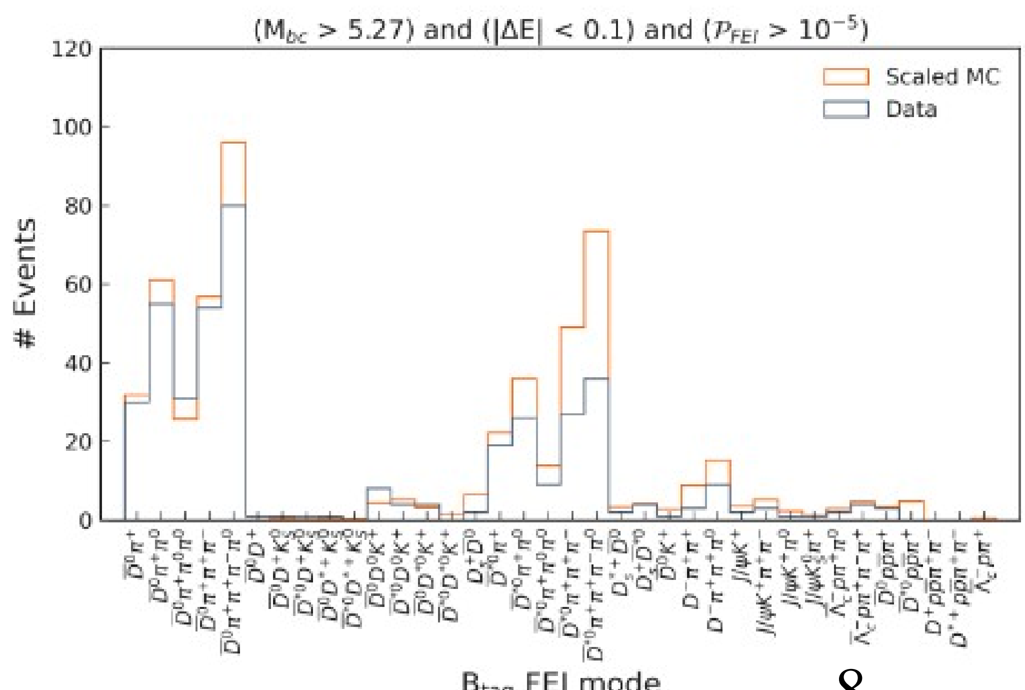


[T.Keck et. al, Comput Softw Big Sci (2019) 3: 6]

In FEI, Belle II's B-tagging algorithm: BDTs are trained on MC for some final states in a hierarchical structure starting from tracks and clusters.

⇒ any ML strategy will train on MC… assuming it is reproducing properly data

The hadronic FEI algorithm reconstructs B in 36 different B decays.



But 12 B decays among them account for >90% of the efficiency, so let's focus on them

Tagging efficiency in data
($_{tag}$= BF x $_{reco}$)
is one of the limiting factors

B^+ tagging: Effectively 12 final states !

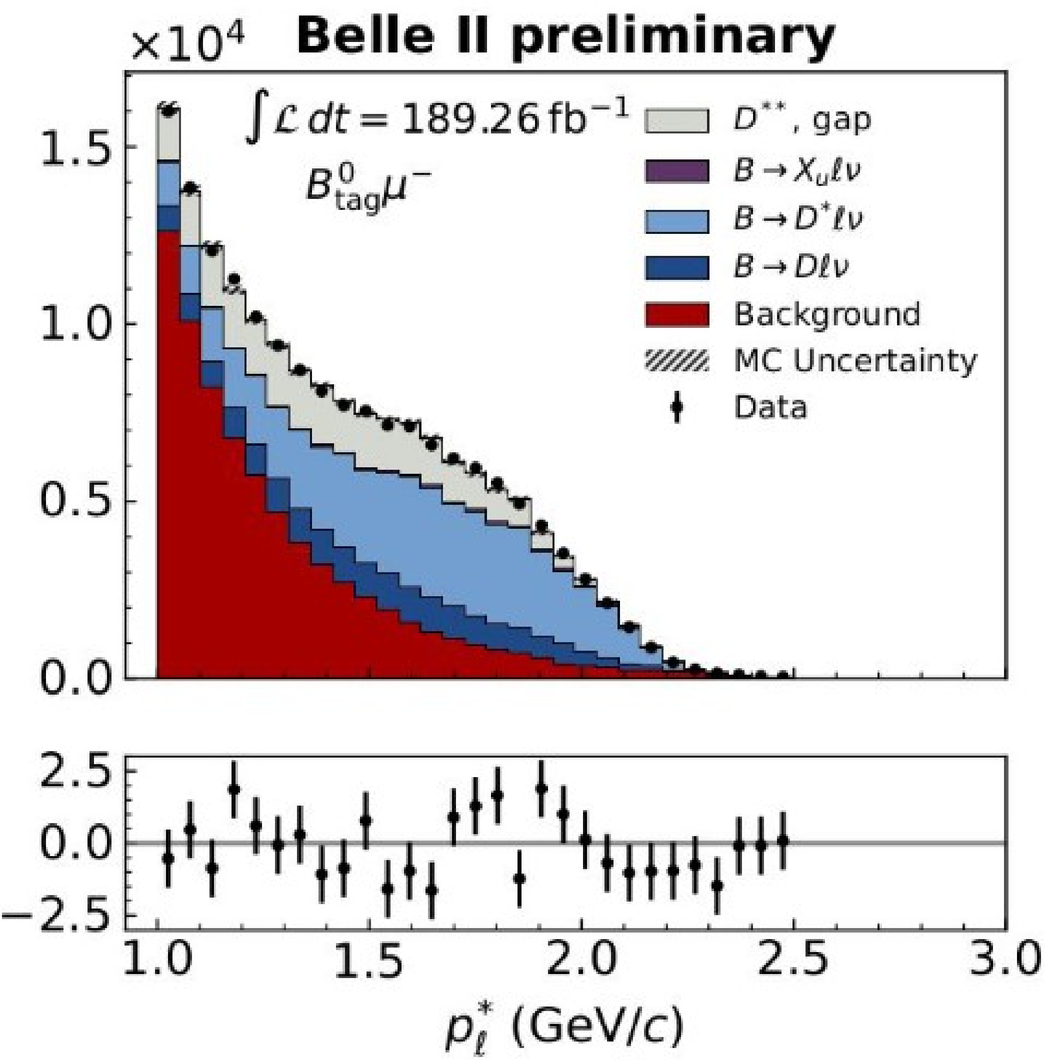
In Hadronic tagging, we essentially reconstruct (12 decays) **$B \rightarrow D^{(*)}$ $(n\pi^+)$ $(m\pi^0)$** final states:

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

More π ⇒ More complex, but "high" Branching Fraction

B^+ tagging: Traditional calibration sample

BDTs are trained on MC
⇒ The performance has to be calibrated with data.



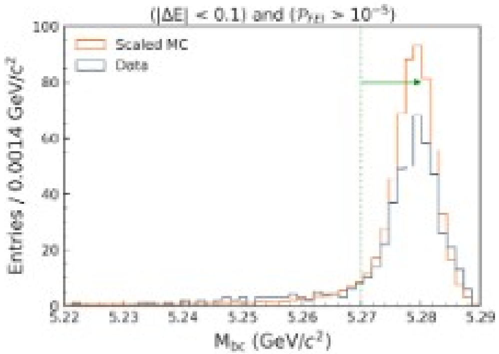
Traditionally, this calibration is done with semi-leptonic B on the signal side because it has large branching fraction.

But, if MC is not optimal, the BDT selection will not be optimal.

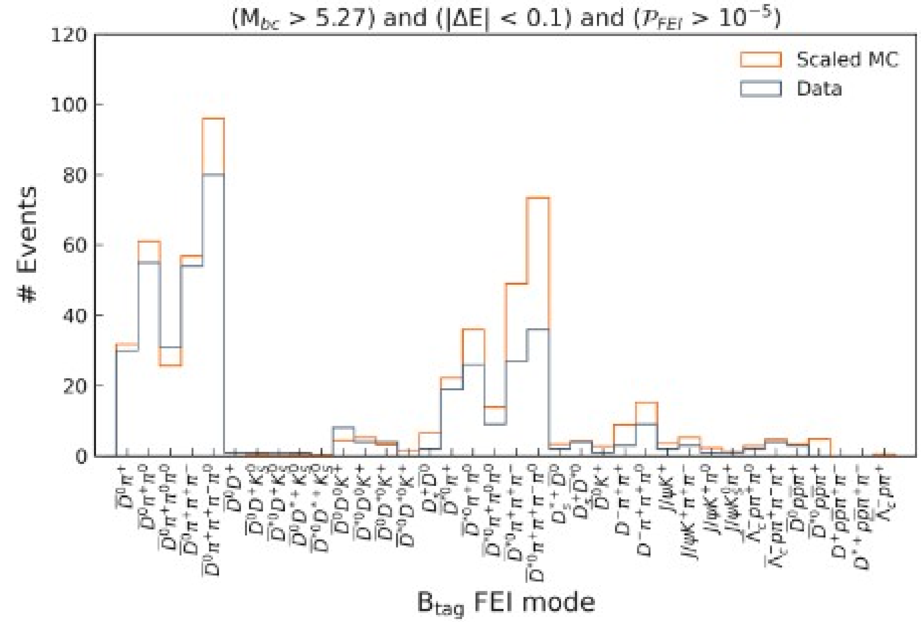
This cannot be easily studied with semi-leptonic B because there are no peaking structures.

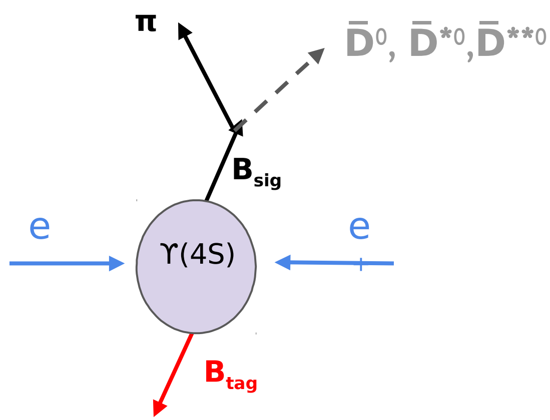
Ideal control sample to study B-tagging

First idea, use $B \to J/\psi K$:



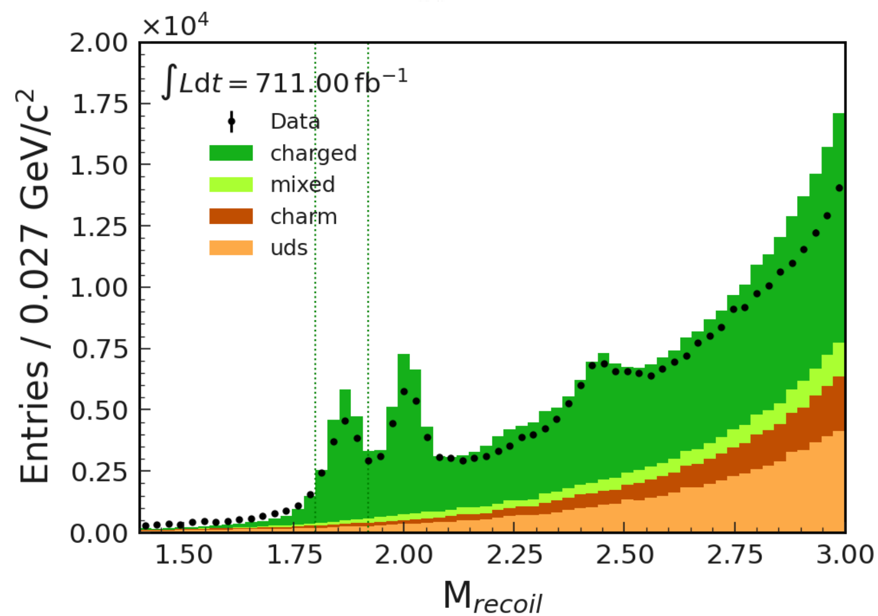
clean, allow first estimation (large MC/data differences)
⇒ but too limited stat (~ 400 evts after B-tagging)





We can look for D^0, D^{*0} and even D^{**0} in the recoil mass of a fully reconstructed B and a π±

Within a narrow region around the peak, we know that one B decays to $D^0\pi^+$ and we can study the other B (decaying hadronically)



~16k events in a 3σ window around each peak in data.

Need to calibrate the algorithm, but more importantly, need to improve MC for training.

Improving MC model: An example

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

Decay	Belle	Belle II
$B^+ \to \overline{D}^0 \pi^- \pi^+ \pi^+$	0.46	0.51
$B^+ \to \overline{D}^0 \rho(770)^0 \pi^+; \rho(770)^0 \to \pi^+ \pi^-$	0.39	0.42
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to \rho(770)^0 \pi^+; \rho(770)^0 \to \pi^+ \pi^-$	0.13	0.14
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to f_0(600) \pi^+; f_0(600) \to \pi^+ \pi^-$	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
$B^+ \to \overline{D}_1(2430)^0 \pi^+; \overline{D}_1(2430)^0 \to D^*(2010)^- \pi^+; D^*(2010)^- \to \overline{D}^0 \pi^-$	0.03	0.02
$B^+ \to \overline{D}_2^*(2460)^0 \pi^+; \overline{D}_2^*(2460)^0 \to D^*(2010)^- \pi^+; D^*(2010)^- \to \overline{D}^0 \pi^-$	0.01	0.01
$B^+ \to D^*(2010)^- \pi^+ \pi^+; D^*(2010)^- \to \overline{D}^0 \pi^-$	-	0.09
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to \pi^+ \pi^+ \pi^-$	-	0.07
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to f_0(500) \pi^+; f_0(500) \to \pi^+ \pi^-$	-	0.05
$B^+ \to \overline{D}_1(2420)^0 \pi^+; \overline{D}_1(2420)^0 \to \overline{D}^0 \pi^- \pi^+$	-	0.02
$B^+ \to \overline{D}^0 K^*(892)^+; K^*(892)^+ \to K^0 \pi^+; K^0 \to K_S^0; K_S^0 \to \pi^+ \pi^-$	-	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

The $\pi^+ \pi^+ \pi^-$ could be directly generated, could come through $\rho^0 \pi^+$ or through an intermediate $a_1{}^+$ resonance.

Improving MC model: An example

[Phys.Rev.D 45 (1992) 21-35]

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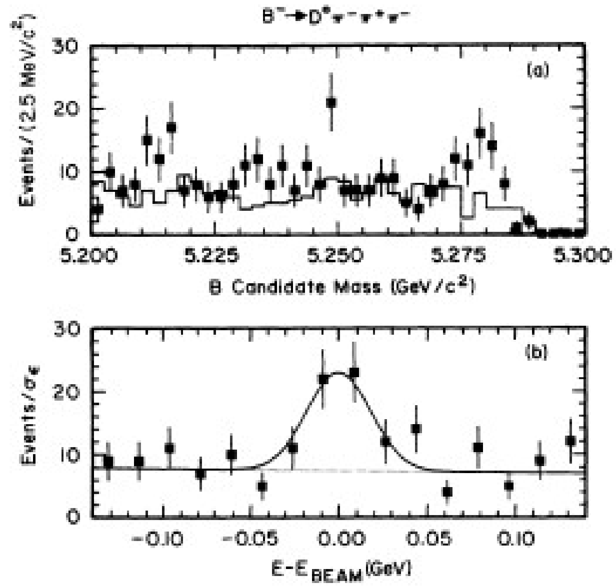
(0.51 ± 0.41)%
(0.42 ± 0.30)%
(0.14 ± 0.11)%



In 1992, CLEO experiment measured these 3 values but with ~75% uncertainty!

Improving MC model: An example

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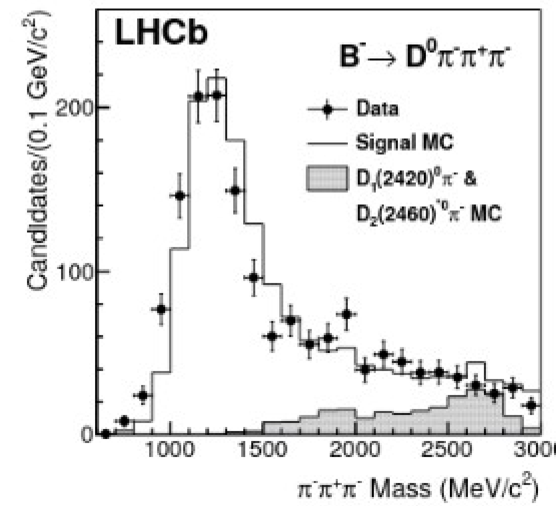
Phys.Rev.D 84 (2011) 092001



In 2011 (~20 years later), LHCb looked at this final state, but did not provide individual measurements.

So we are still suck with a 30 year old CLEO measurement in PDG.

Improving MC model: An example

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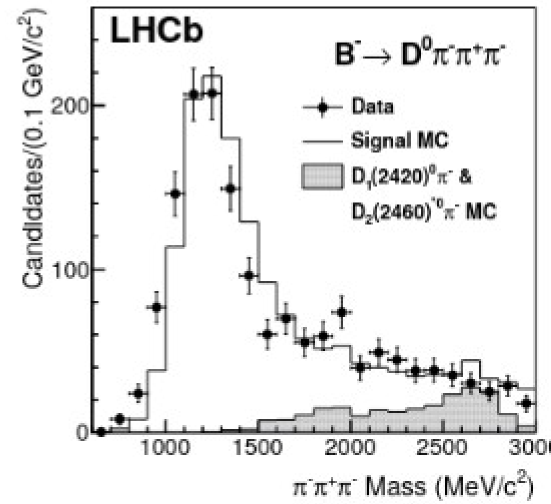
Phys.Rev.D 84 (2011) 092001



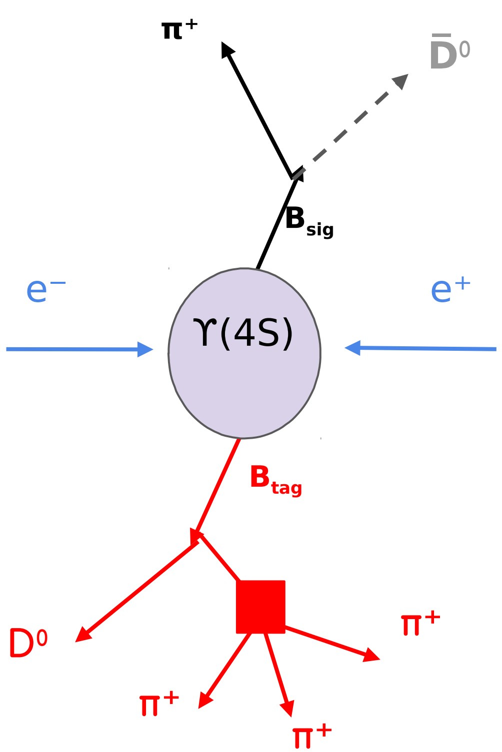
But looking at this plot, it looks like most contribution comes through a_1^+ resonance (mass 1400 MeV/c²).

Improving MC model: An example

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

Decay	Belle	Belle II
$B^+ \to \overline{D}^0 \pi^- \pi^+ \pi^+$	0.46	0.51
$B^+ \to \overline{D}^0 \rho(770)^0 \pi^+; \rho(770)^0 \to \pi^+ \pi^-$	0.39	0.42
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to \rho(770)^0 \pi^+; \rho(770)^0 \to \pi^+ \pi^-$	0.13	0.14
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to f_0(600) \pi^+; f_0(600) \to \pi^+ \pi^-$	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
$B^+ \to \overline{D}_1(2430)^0 \pi^+; \overline{D}_1(2430)^0 \to D^*(2010)^- \pi^+; D^*(2010)^- \to \overline{D}^0 \pi^-$	0.03	0.02
$B^+ \to \overline{D}_2^*(2460)^0 \pi^+; \overline{D}_2^*(2460)^0 \to D^*(2010)^- \pi^+; D^*(2010)^- \to \overline{D}^0 \pi^-$	0.01	0.01
$B^+ \to D^*(2010)^- \pi^+ \pi^+; D^*(2010)^- \to \overline{D}^0 \pi^-$	-	0.09
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to \pi^+ \pi^+ \pi^-$	-	0.07
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to f_0(500) \pi^+; f_0(500) \to \pi^+ \pi^-$	-	0.05
$B^+ \to \overline{D}_1(2420)^0 \pi^+; \overline{D}_1(2420)^0 \to \overline{D}^0 \pi^- \pi^+$	-	0.02
$B^+ \to \overline{D}^0 K^*(892)^+; K^*(892)^+ \to K^0 \pi^+; K^0 \to K_S^0; K_S^0 \to \pi^+ \pi^-$	-	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

Can be compared with data at Belle, if we reconstruct one B as $B^+ \to \bar{D}^0 \pi^+$ and other B as $B^- \to D^0 \pi^+ \pi^+ \pi^-$



Improving MC model: An example

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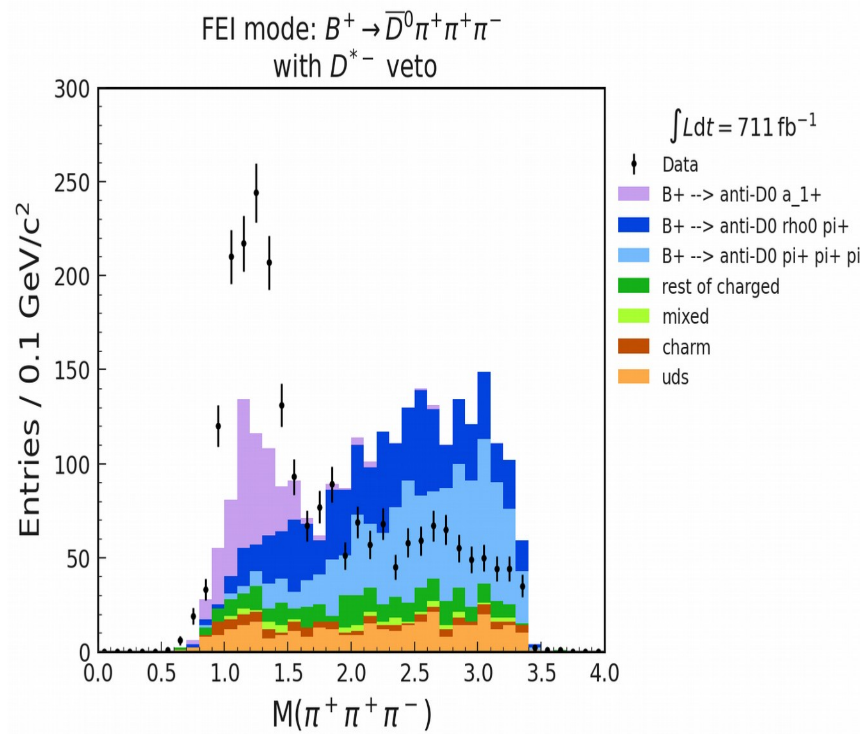
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to \rho(770)^0 \pi^+; \rho(770)^0 \to \pi^+ \pi^-$	0.13	0.14
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to f_0(600) \pi^+; f_0(600) \to \pi^+ \pi^-$	0.05	-
$B^+ \to \overline{D}_1(2420)^0 \pi^+; \overline{D}_1(2420)^0 \to D^*(2010)^- \pi^+; D^*(2010)^- \to \overline{D}^0 \pi^-$	0.04	0.02
$B^+ \to \overline{D}_1(2430)^0 \pi^+; \overline{D}_1(2430)^0 \to D^*(2010)^- \pi^+; D^*(2010)^- \to \overline{D}^0 \pi^-$	0.03	0.02
$B^+ \to \overline{D}_2^*(2460)^0 \pi^+; \overline{D}_2^*(2460)^0 \to D^*(2010)^- \pi^+; D^*(2010)^- \to \overline{D}^0 \pi^-$	0.01	0.01
$B^+ \to D^*(2010)^- \pi^+ \pi^+; D^*(2010)^- \to \overline{D}^0 \pi^-$	-	0.09
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to \pi^+ \pi^+ \pi^-$	-	0.07
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to f_0(500) \pi^+; f_0(500) \to \pi^+ \pi^-$	-	0.05
$B^+ \to \overline{D}_1(2420)^0 \pi^+; \overline{D}_1(2420)^0 \to \overline{D}^0 \pi^- \pi^+$	-	0.02
$B^+ \to \overline{D}^0 K^*(892)^+; K^*(892)^+ \to K^0 \pi^+; K^0 \to K_S^0; K_S^0 \to \pi^+ \pi^-$	-	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



Comparing with data clearly shows that a_1^+ component is underestimated, and the $\rho^0\pi^+$ and direct $\pi^+ \pi^+ \pi^-$ components are overestimated.

Similarly, for other final states

BELLE2-NOTE-PH-2022-002

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

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

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	3.90	3.03

blue means generated by PYTHIA

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

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.

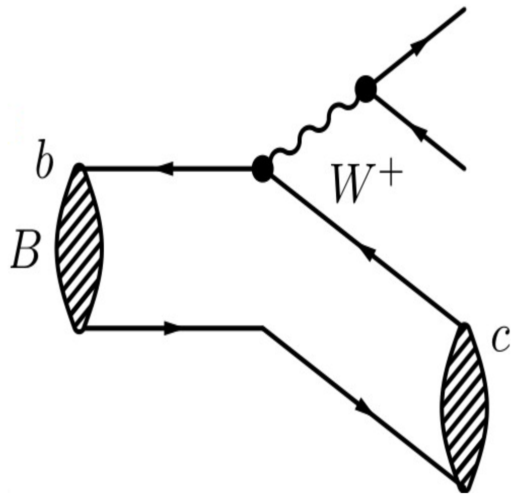
Decay	Belle	Belle II	Marker	Ref
$B^+ \to \overline{D}^*(2007)^0\pi^-\pi^+\pi^+$	1.03	-	■	[2], [7]
$B^+ \to \overline{D}^*(2007)^0 a_1(1260)^+;\ a_1(1260)^+ \to \rho(770)^0\pi^+;\ \rho(770)^0 \to \pi^+\pi^-$	0.66	0.58	★	
$B^+ \to \overline{D}^*(2007)^0 a_1(1260)^+;\ a_1(1260)^+ \to f_0(600)\pi^+;\ f_0(600) \to \pi^+\pi^-$	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		

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

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	★	

Model for B → $D^{(*,**)}$ $n\pi$ $m\pi^0$ decays



X = π, ρ, a_1, ωπ, ρππ, ηπ

Y = D, D*, D**

Happens through 2 channels, one with spectator quarks (call Y) and one from the W (call X).

We want to modify the DECAY table to latest PDG/paper interpretations and this model to see the impact.

Essentially validation, we do not want to fine-tune (except set 0 there is no signal*).

2 primary rules:

- D^0 X: D^{*0} X : D^{**0} X ~= 1 : 1 : 1
  (based on observation from D π^- : D* π^- : D** π^- and D ρ^- : D* ρ^-)
- Y π^- : Y ρ^- : Y a_1^- ~= 1 : 2.5 : 2.5
  (based on predictions and confirmed with τ → h ν decays)

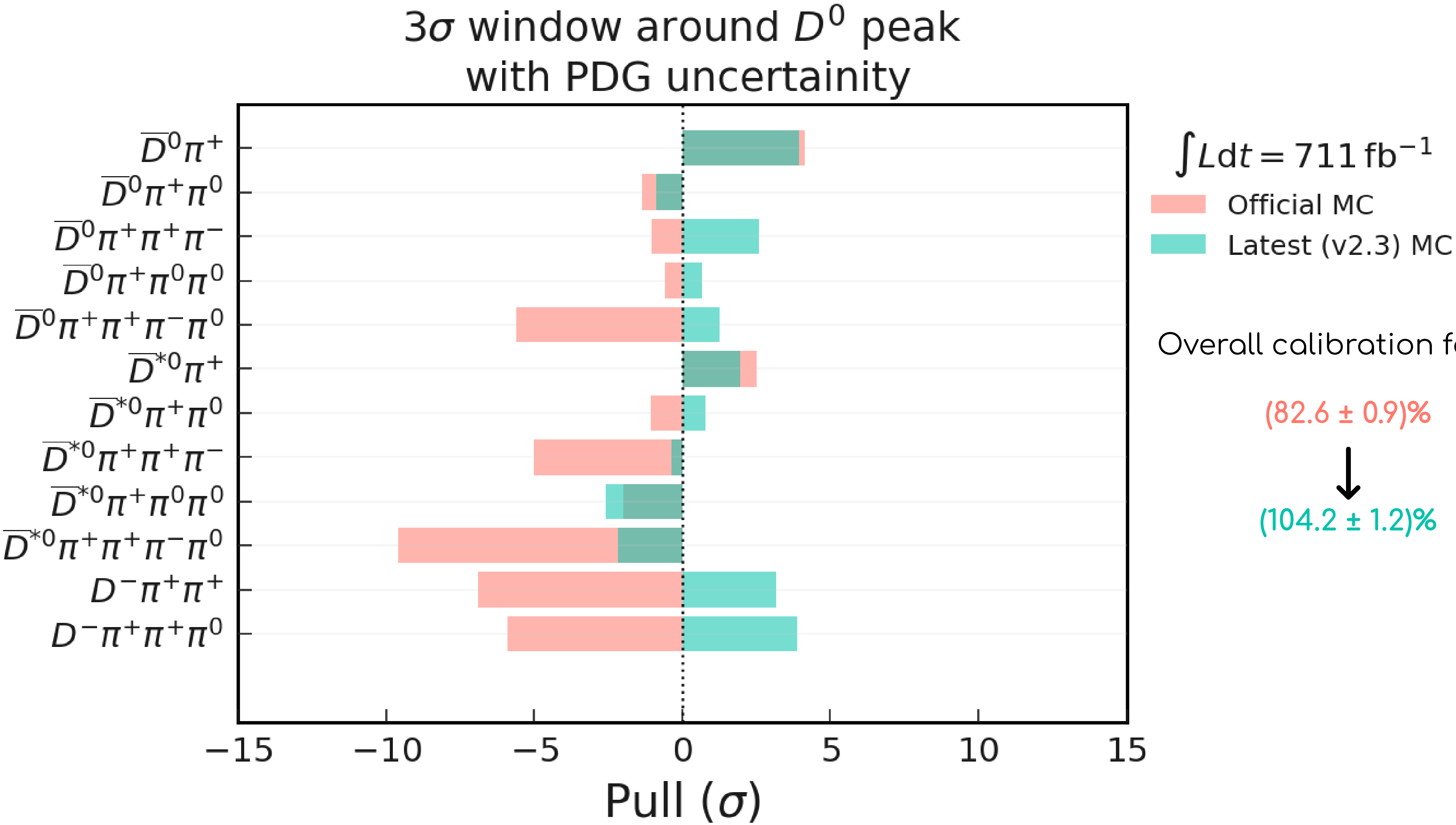
Additional information:

- 3π π^0 is hard to model without some sort of ρ' resonance
  - For **ωπ** we fix from measurements.
  - For **ρππ** and **ηπ**, we let PYTHIA generate it.
- Decays of D** particles is synchronized with Belle II
- The fraction of 4 different D** is fixed based on observations.

*See backup

Pulls of calibration factors

Another way to visualize the improvement in the calibration factors:



Overall calibration factor

(82.6 ± 0.9)%

↓

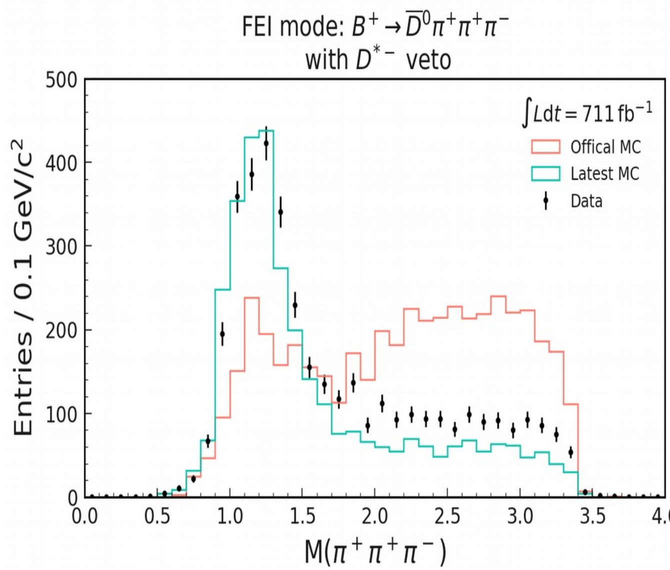
(104.2 ± 1.2)%

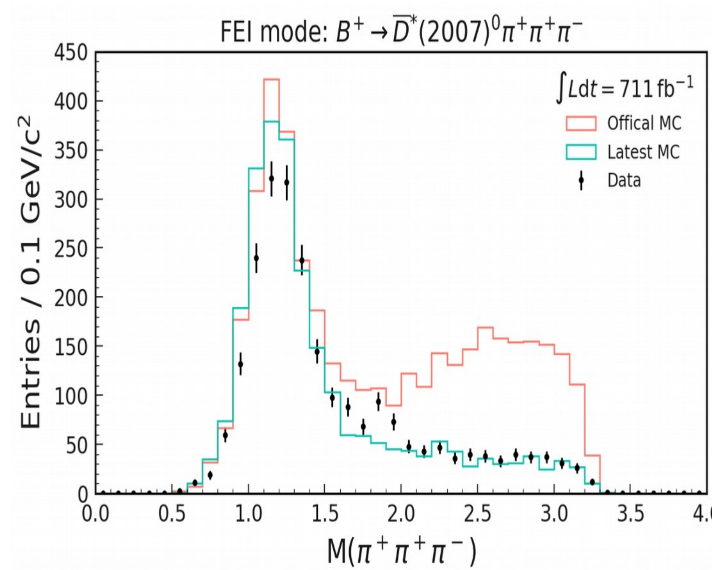
improving description of hadronic B decays ⇒ improve B− tagging efficiency

Decay description is improved !

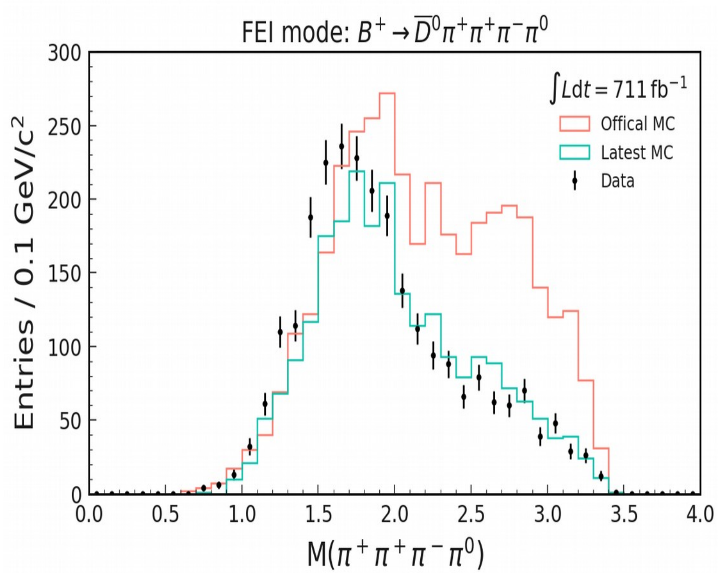
The improvement is not limited to calibration factors, but more importantly in the invariant masses (of intermediate particles), which are used as training variables in FEI

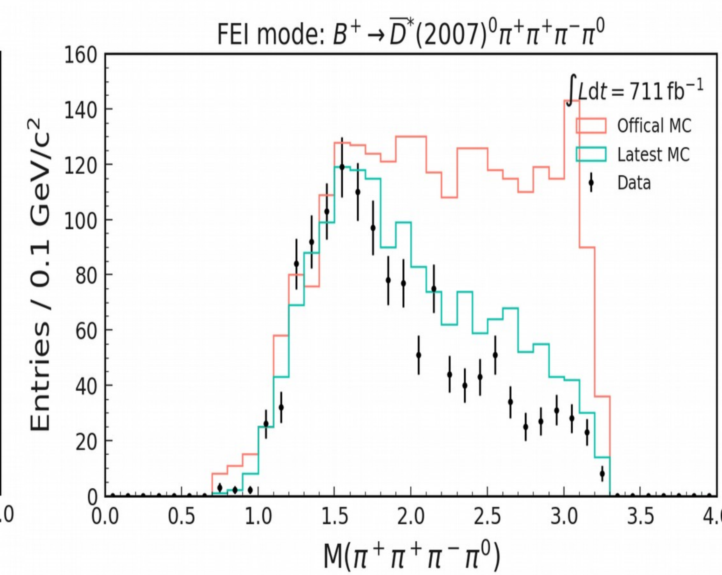
3π± case:





3π± π⁰ case:

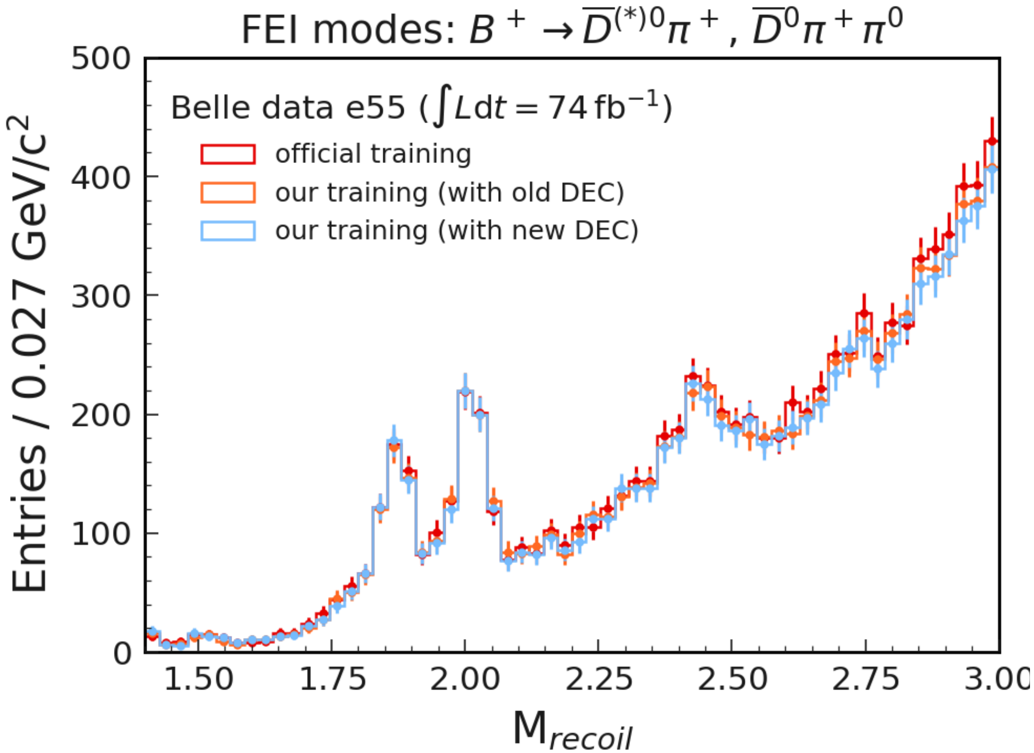




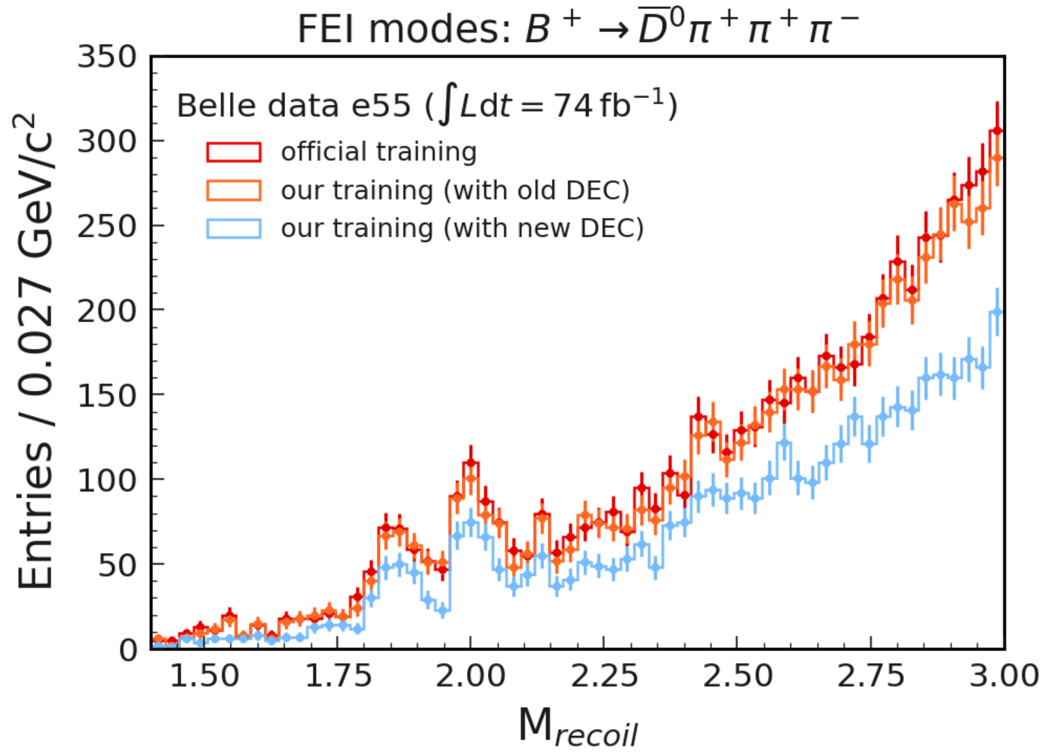
improving description of hadronic B decays ⇒ improve B−tagging efficiency

Retraining FEI: Validation

Once we have a new model for how the **$B \to D^{(*)}$ ($n\pi^+$) ($m\pi^0$)** decays, we can train BDTs again with it and see performance:

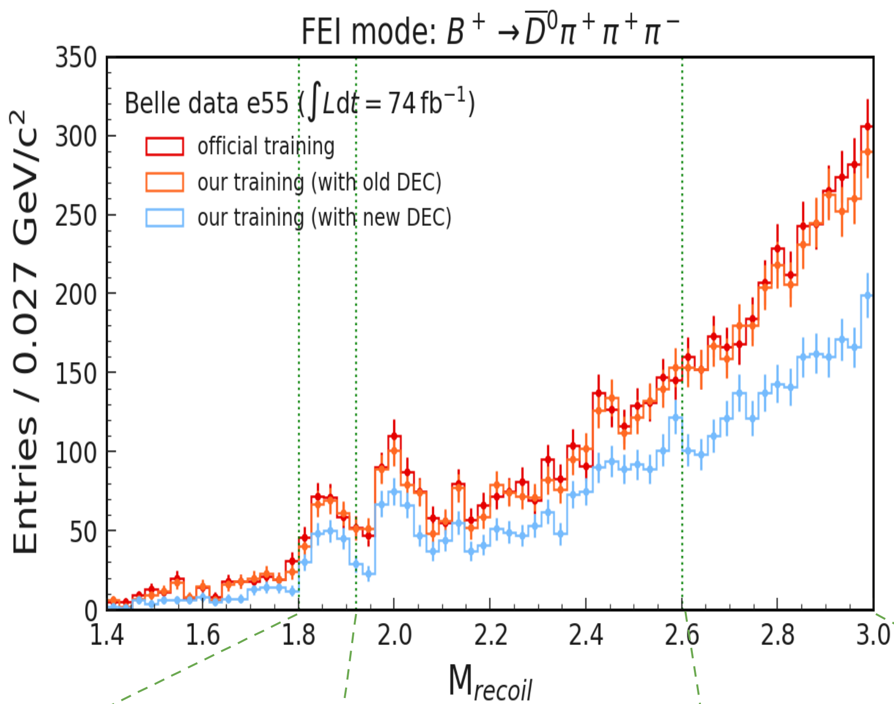


Nothing changes in the FEI modes where we did not change anything.



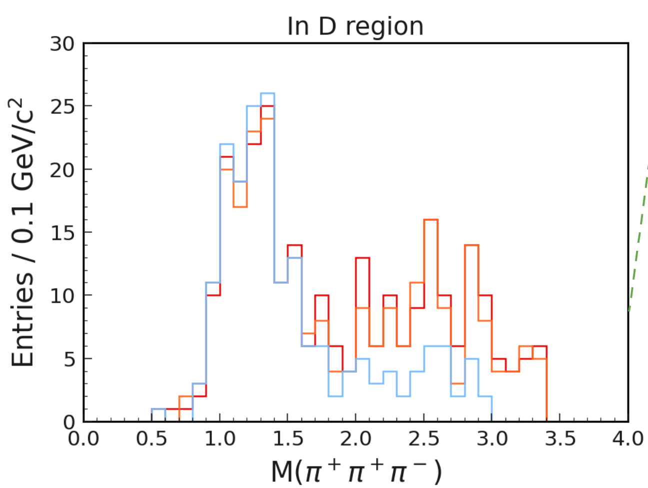
There is a significant background reduction in FEI modes where MC model is improved.

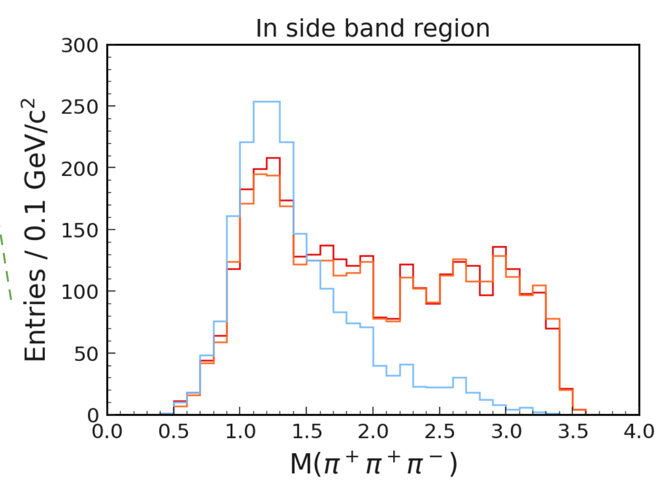
Retraining FEI: Effective cuts



The new training is learning the a_1+ cut from the MC we give it!

Can we apply this cut manually instead?



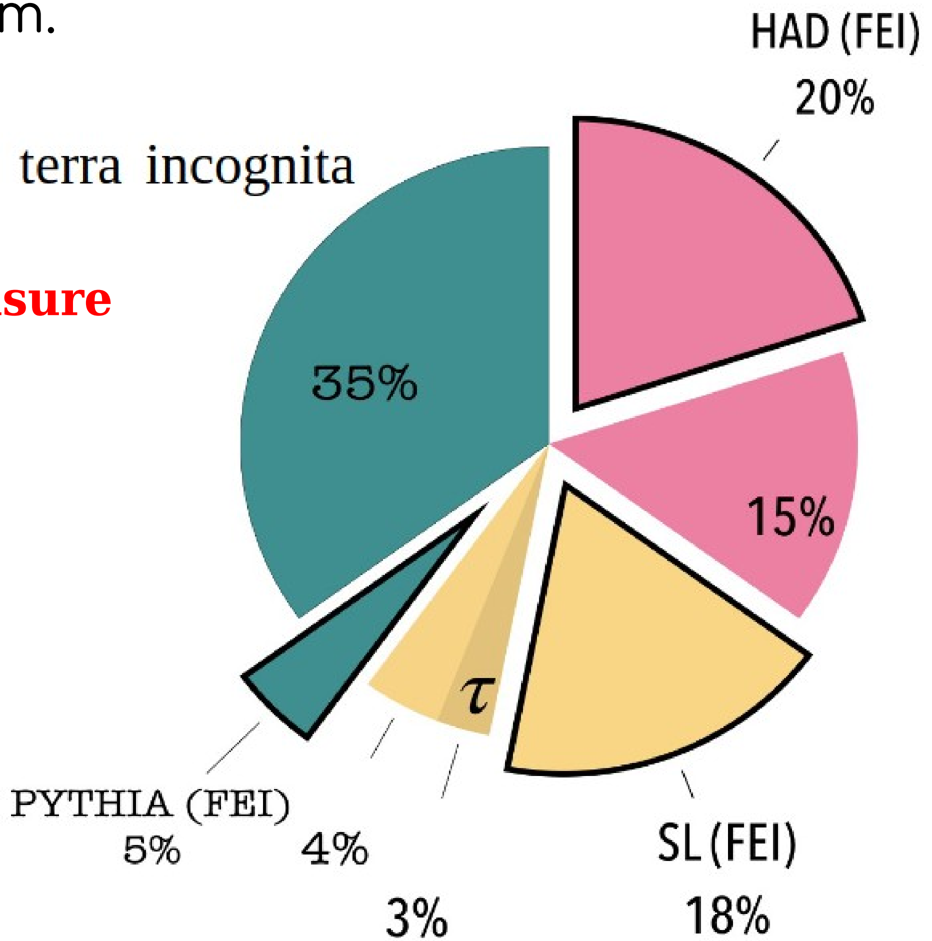


Why is B-decay modeling so hard ?

We already saw that we (and PDG) uses a 30-year-old measurement with ~75% uncertainty for one of the largest hadronic B-decays..

But on top of that, we don't know how B decays ~**40%** of the time !
We ask **PYTHIA** to (poorly) generate them.

lot of hadronic B decays to understand/measure
⇒ new contributions to B-tagging ??



$B \to K\tau\ell$ WITH SEMILEPTONIC B-TAGGING

At Belle the semileptonic tagging is also tried.

The main differences wrt the hadronic approach are:

1. Higher efficiency efficiency BUT
2. Different background nature
3. Worse resolution on M_{recoil}

$$M_{recoil} = [m_B^2 + m_{K\ell}^2 - 2(E_B^* E_{K\ell}^* + |\vec{p}_B^*||\vec{p}_{K\ell}^*|\cos\theta)]^{\frac{1}{2}}$$

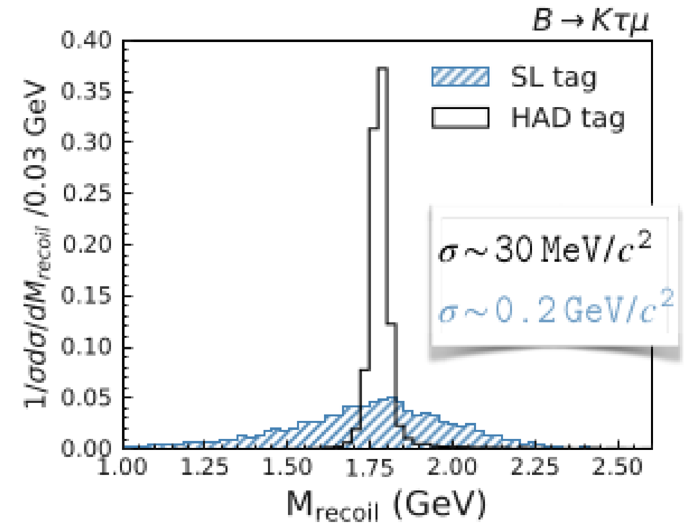
E_B^*: E^*_{beam}

$|\vec{p}_B^*|$: $p^*_{B_{tag}}$, $\sqrt{(E^*_{beam})^2 - m_B^2}$

θ: $\angle(\vec{p}^*_{B_{tag}}, \vec{p}^*_{K\mu})$

Random $\cos\theta$

The direction of the B_{tag} is lost!



Despite the degraded resolution, the background level is under control, which combined to the higher signal efficiency, provide a sensitivity in the same ballpark of the hadronic tag analysis

Can we do better?

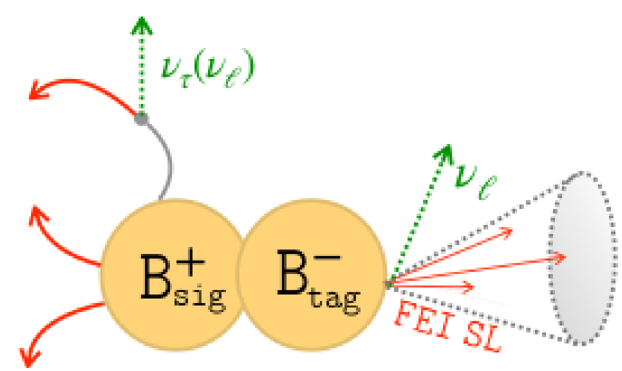
MC study presented in arXiv:2209.03387 (de Marino, Guadagnoli, Park, Trabelsi)

Obtain M_{recoil} as a solution of a constrained minimisation, the constraints being:

- Kinematic information → Initial state knowledge + 2-body τ (hadronic) decays
- Vertexing information → Not very constraining at B-factories

This information only can bring significant improvement in resolution

The semileptonic tagged-sample is orthogonal to the hadronic one; reaching a similar sensitivity is crucial to confirm an observation at any level of significance



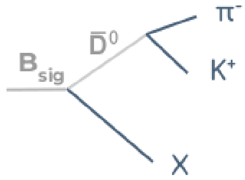
Visible products

$$e^+e^- \to B_1 B_2 \to V_1(p_1)\chi_1(k_1) + V_2(p_2)\chi_2(k_2)$$

Invisible products

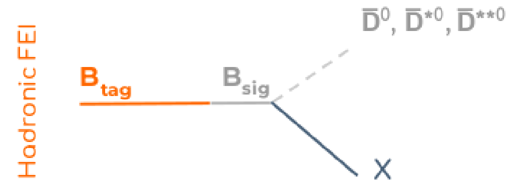
More with recoil mass and Hadronic B-tagging at Belle/Belle II

Exclusive vs Partial reconstruction



To extend on this idea, we are not limited to π and ρ here.

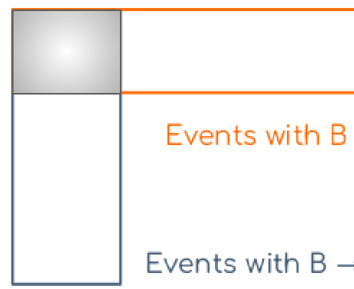
X can be anything like ηπ, ηρ, ωπ, KK_S, KK*.....?!



Here, D* has lower efficiency than D.

Here D* and D have same efficiency!

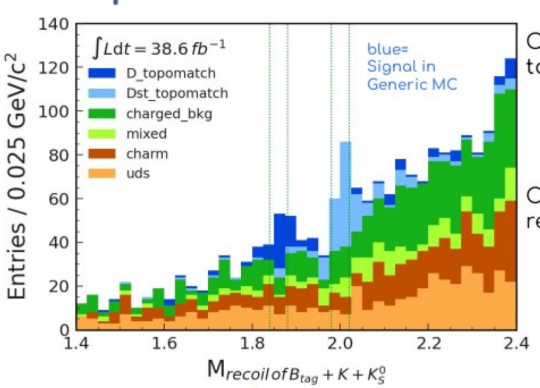
Both procedure look at different events:



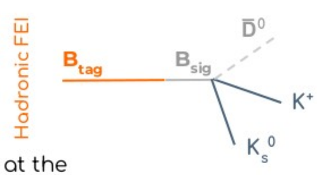
Events with $B \to D^{(*(*))}X$ where the other B → Had B-tag

Events with B → DX where D → Kπ

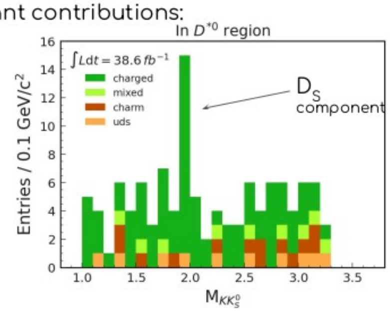
DKK partial reconstruction performance



One can fit to get the BR



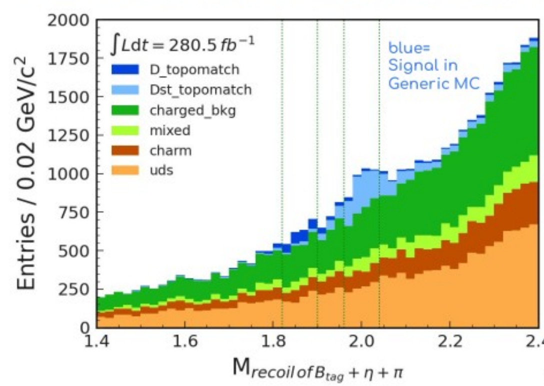
Can also look at the resonant contributions:

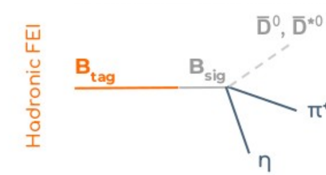


Efficiency (%)	Exclusive* (hep-ex/0207041)	Partial
D	~0.3	~0.3
D*	~0.1	~0.3

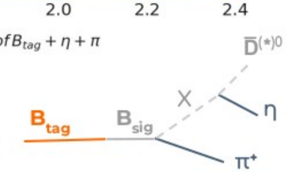
Same efficiency!

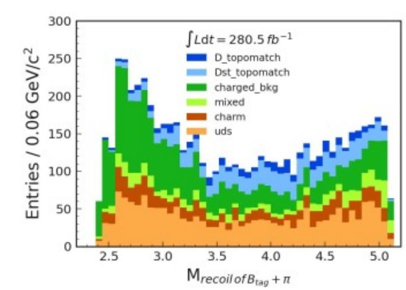
Partial reconstruction of Dηπ?



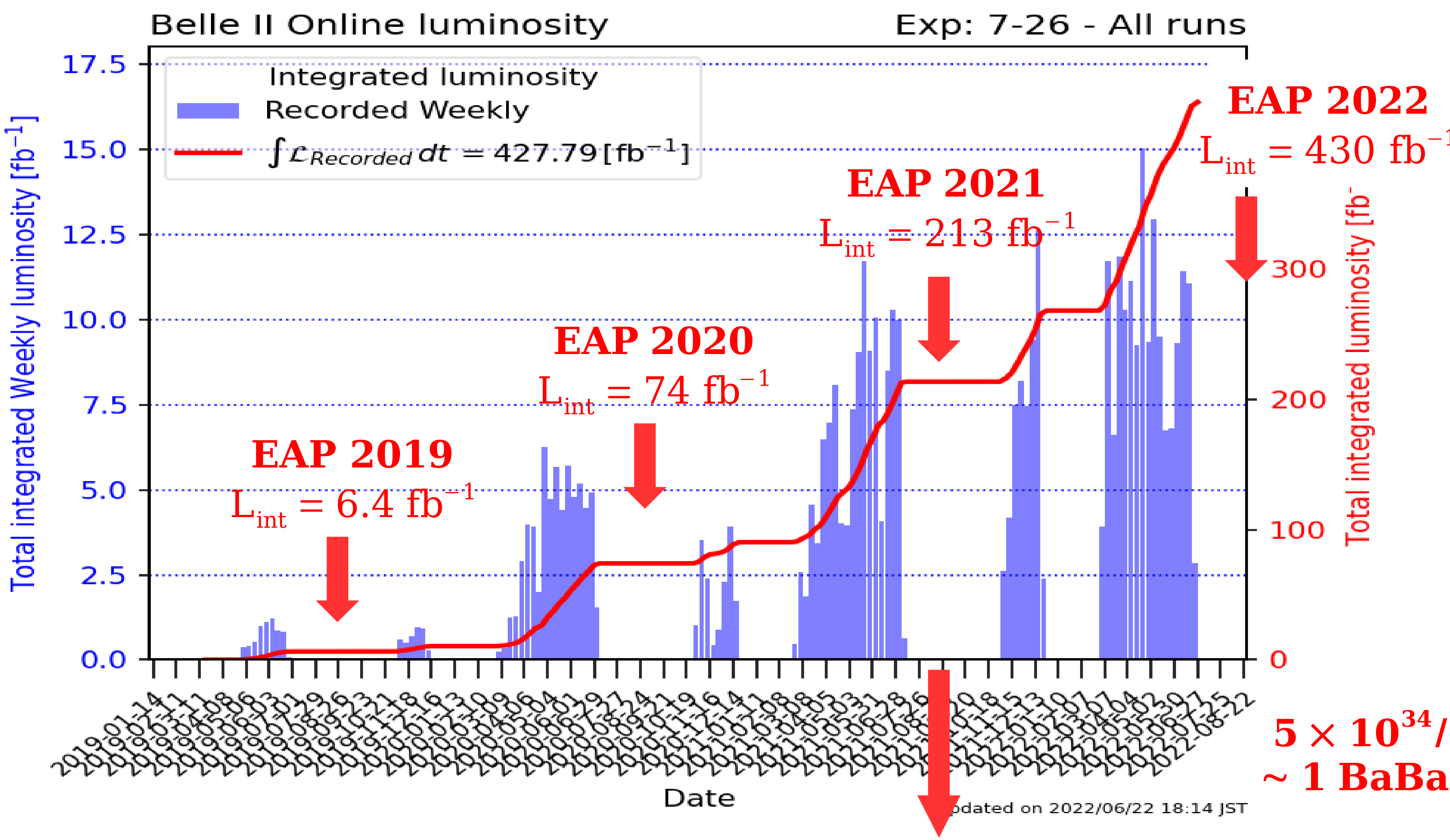


Within the selected region, we can see if there is a resonance like:





Belle II run I (2019 - 2022)



$5 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$
$\sim$ 1 BaBar/year

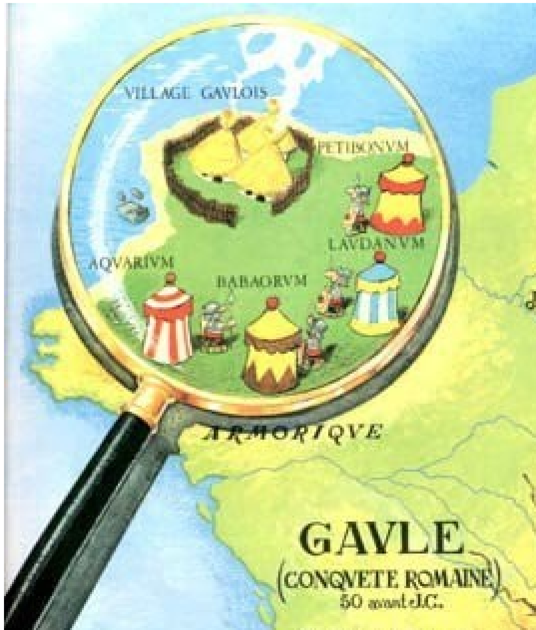
ICHEP 2022 results

Summary

- Belle (II) is a unique environment to study modes with missing energy
  $B \rightarrow K\nu\bar{\nu}$, $K\tau\tau$, $K\tau l$, $\tau\tau$, τl, $D^{(*)}\tau\nu$, $\tau\nu$, $\mu\nu$...
- Improvements of B-tagging requires a much better understanding of
  B hadronic decays ($\Rightarrow$ measurements)
- along with other venues: Semi-leptonic B-tagging, inclusive B-tagging...

Belle II calendar

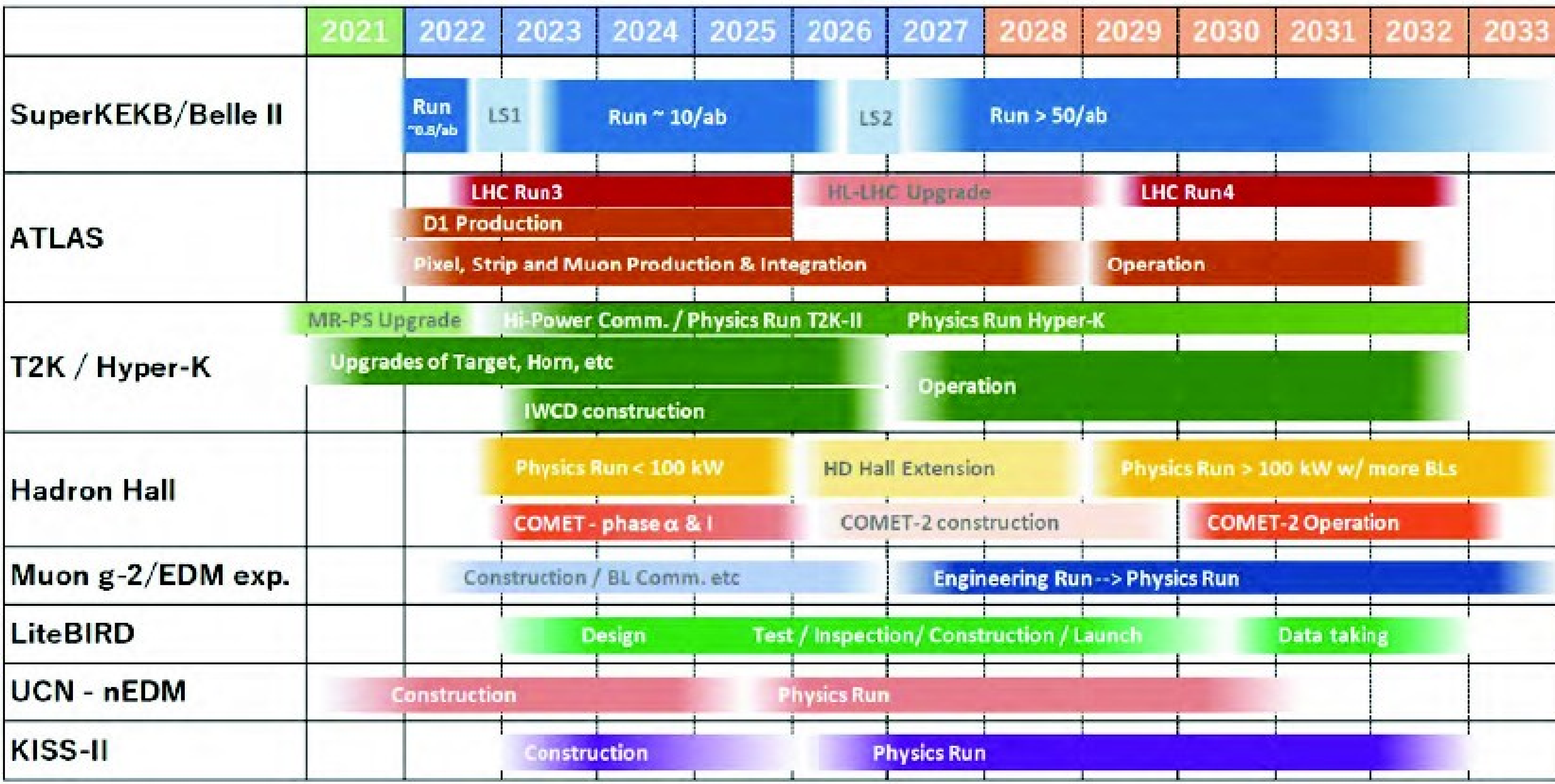
- the stat of a B-factory by summer of 2022... (Run 1, $> 400\,\mathrm{fb}^{-1}$)
- PXD2 installation during LS1 (until end of 2023)
- Run 2: until $\sim 7\ \mathrm{ab}^{-1}$
- ~ 2027: upgrade QCS/VXD (LS2)
- Run 3: until $50\ \mathrm{ab}^{-1}$ by 2035



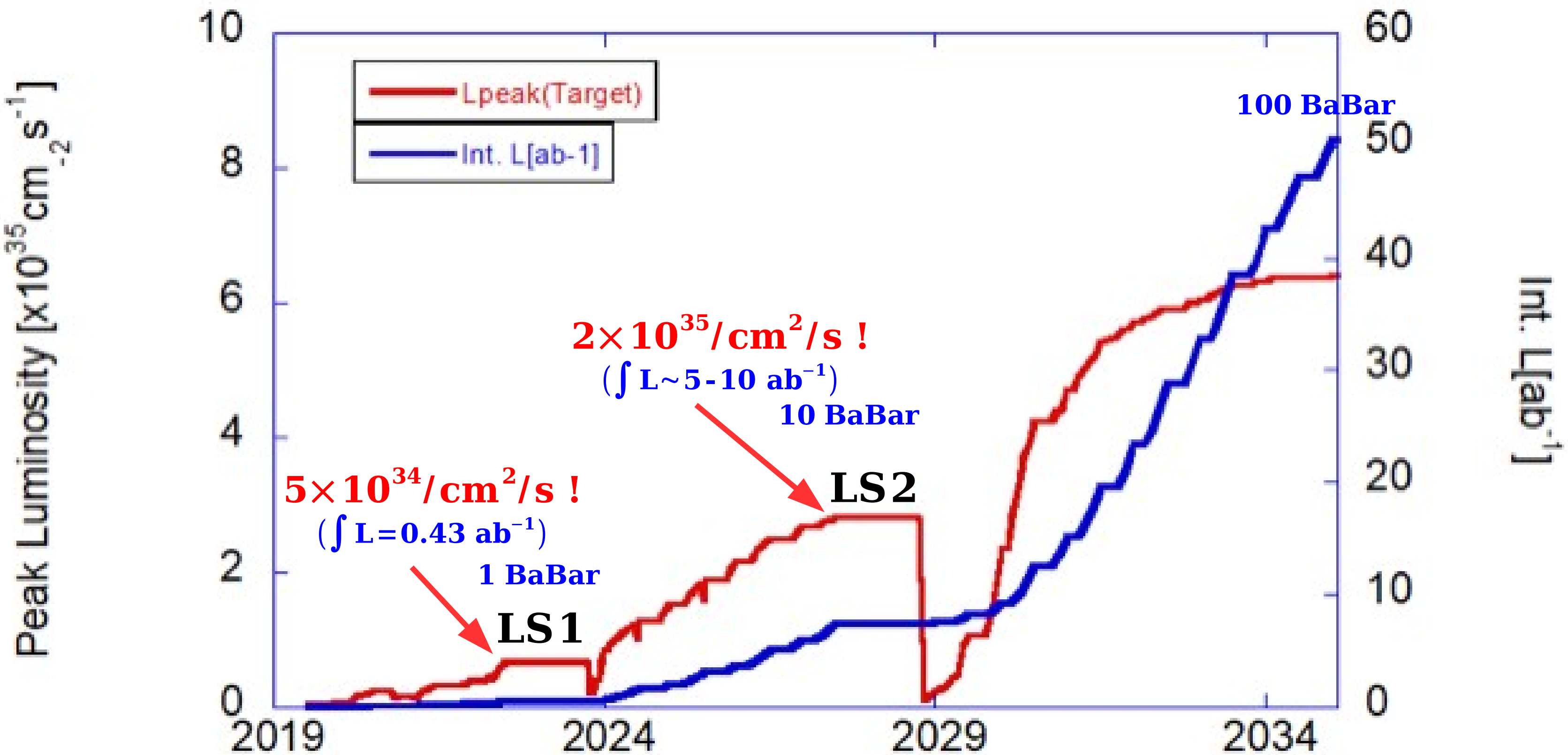
Backup

The Timeline (ver 2022.01.26)

- Intended schedule by IPNS, so far
- ILC will be mentioned after the conclusion by an external panel under MEXT, then follow-up discussion by community



Calendrier de Belle II



run 1 (➔ juin 2022): luminosite integre ~0.43 ab^{-1}, $4-5\times10^{34}/cm^2/s$

PXD complet (2 couches) a installe durant LS1 (2022-2023)

(+ beampipe + TOP PMTs)

run 2 (➔ 2027): luminosite integre 5-10 ab^{-1}, $2\times10^{35}/cm^2/s$

2027 : collider upgrade (QCS+RF) ➔ installation upgraded detector

run 3 (➔ > 2030): 50 ab^{-1}

➔ SuperKEKB with polarized beams, White Paper (arXiv:2205.12847)

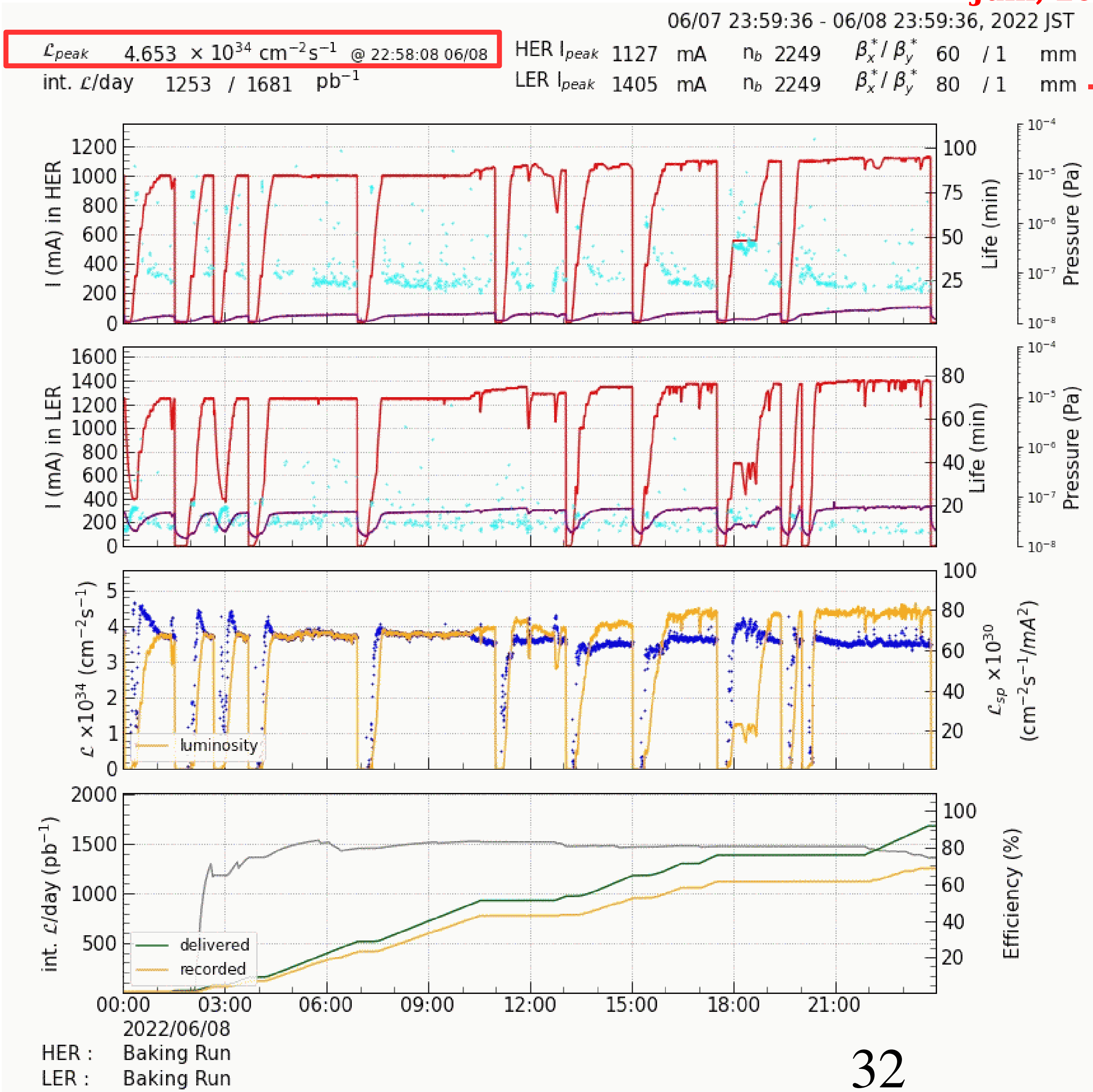
Belle II run I (2019 - 2022)

prise de donnees de mars 2019 a juin 2022

→ malgre des conditions difficiles depuis mars 2020 (Covid, guerre en Ukraine, cout de l'energie...)

luminosity : $4.7 \times 10^{34}/cm^2/s$! > 2 fb^{-1} per day !

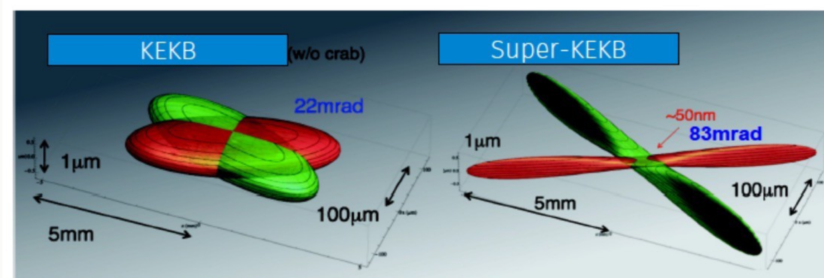
Juin, 2022



→ **$\beta_y^* = 1$ mm, $I_{LER/HER} = 1.4/1.2$ A**

record de KEKB/Belle
$2 \times 10^{34}/cm^2/s$ currents > 1 A

record de PEPII/BaBar
$1 \times 10^{34}/cm^2/s$ currents > 2 A



	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10^{34}

factor 20

factor 2-3

squeezing further β_y^* (→ 0.6 mm)
doubling (or more) the currents
⇒ L > $10^{35}/cm^2/s$ after LS1

SuperKEKB, the first new collider in particle physics since the LHC in 2008 (electron-positron $(e^+ e^-)$ rather than proton-proton (p-p))

Phase 1

Background, Optics commissioning

Feb - June **2016**

Brand new 3km positron ring

Phase 2: Pilot run

Superconducting Final Focus

add positron damping ring

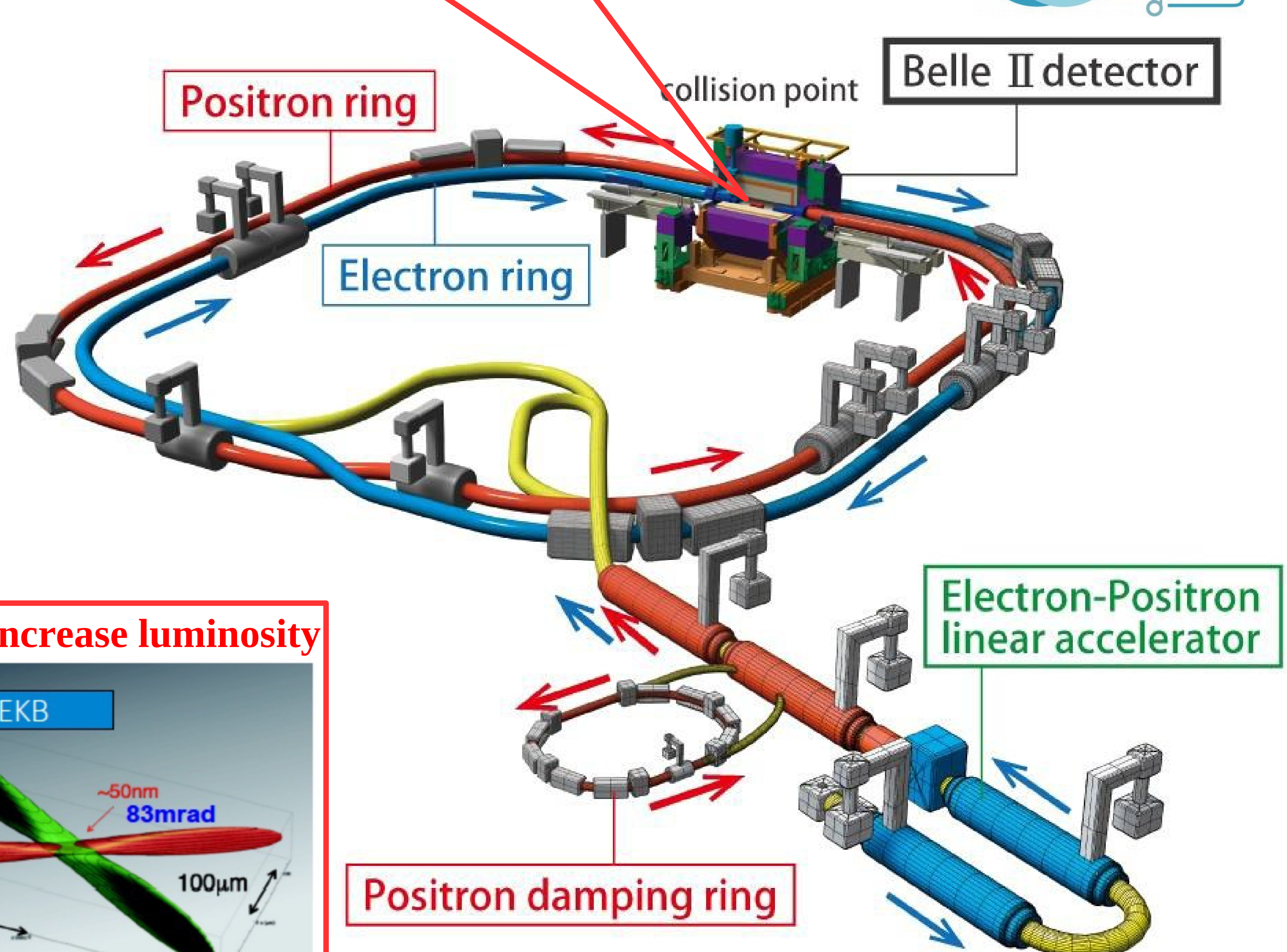
First Collisions $(0.5\ fb^{-1})$

April 27 - July 17, **2018**

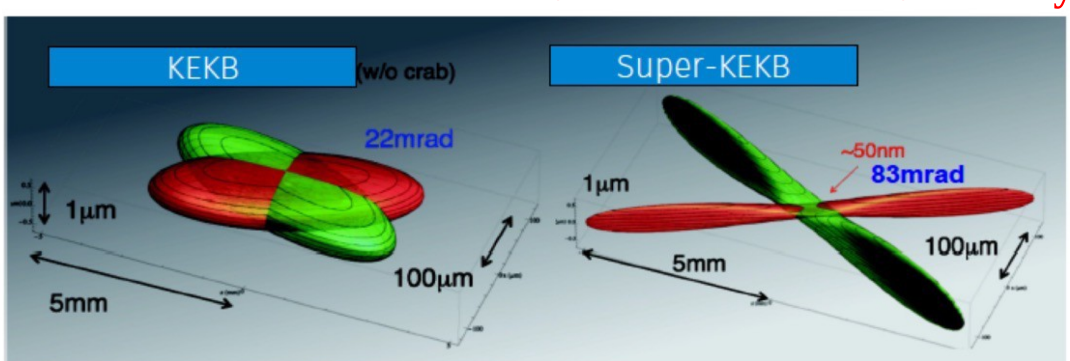
Phase 3: Physics run

Since April, **2019**

Squeeze strongly at IP



Nano-beams and more beam current to increase luminosity



	E (GeV) LER/HER	β*y (mm) LER/HER	β*x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L (cm-2s-1)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10^{34}

factor 20 | factor 2-3

⇒ to reach ~ $6 \times 10^{35}\ cm^{-2} s^{-1}$

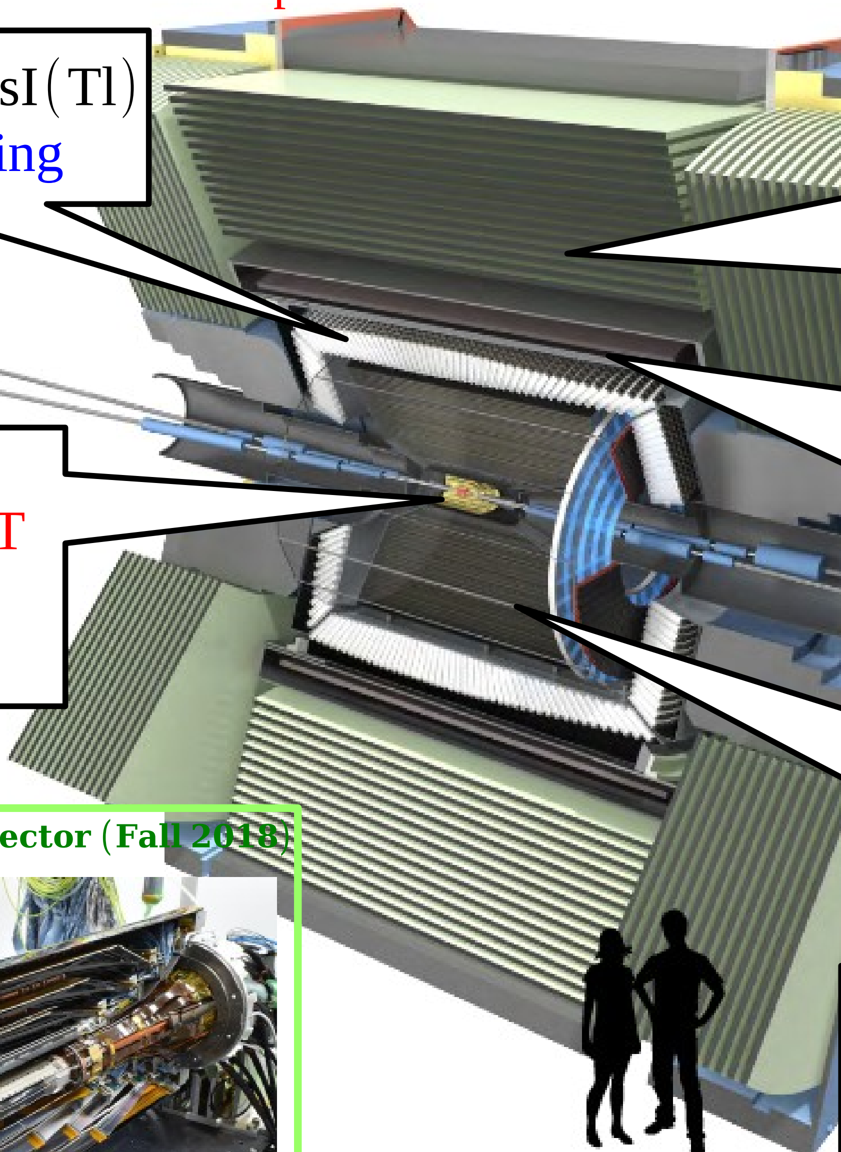
⇒ cumulate 50 ab^{-1} by ~2035

Belle II detector

Main challenge: Preserve detector performances while luminosity (so beam background) increases

EM Calorimeter: CsI(Tl)
waveform sampling

K_L and muon detector
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC
(endcaps)

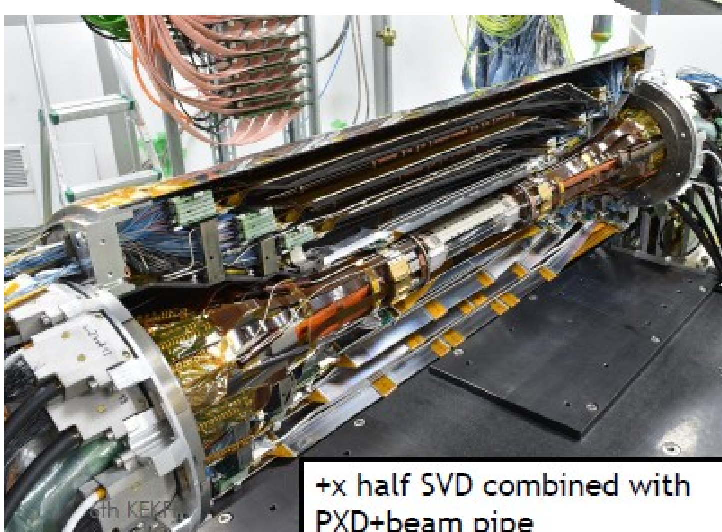


Particle Identification
Time-Of-Propagation counter (barrel)
Prox. focusing Aerogel RICH

Vertex Detector
1/2 layers DEPFET
+
4 layers DSSD

Central Drift Chamber
He (50%):C_2H_6 (50%)
small cells, long level arm, fast electronics

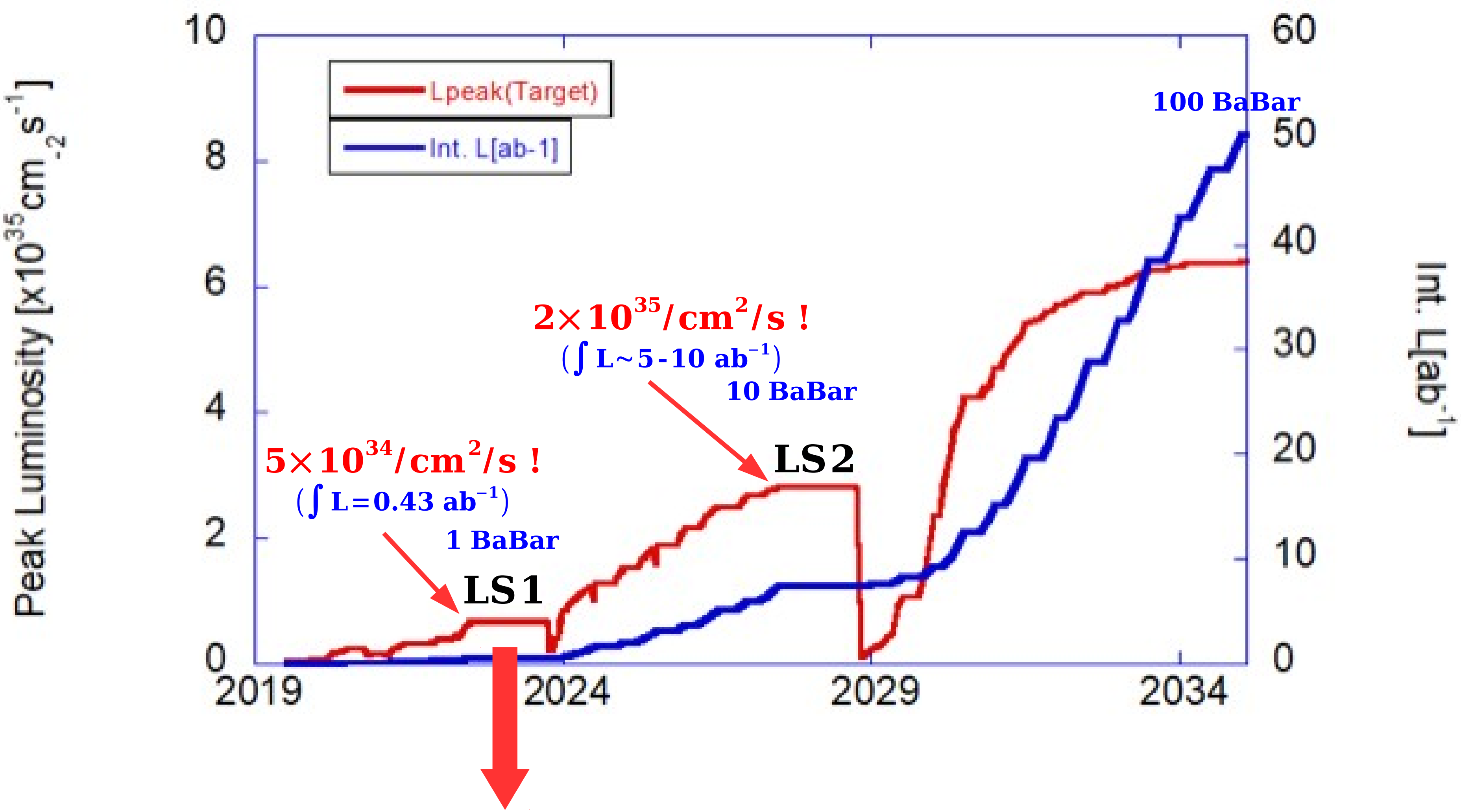
Installation of Vertex Detector (Fall 2018)



on-going DAQ upgrade
(installed in 2021-2023)
PCIe40 board, capable of reading via high speed optical links and to write to computer at rate of 100 Gb/s:
limited number of boards (20) enough **to read entire Belle II detector**

considering now VTX upgrade (2027 or later)

LS1 work for SuperKEKB



first long shutdown :

- accelerator : Linac upgrade + main ring improvements
- Belle II detector : PXD2 and few PMTs/boards replacements (TOP/CDC) + beam background shielding

Fast beam loss abort is a serious problem (BCS quench and collimator damages)

cause not fully understood (improve simulation and prepare additional monitors)

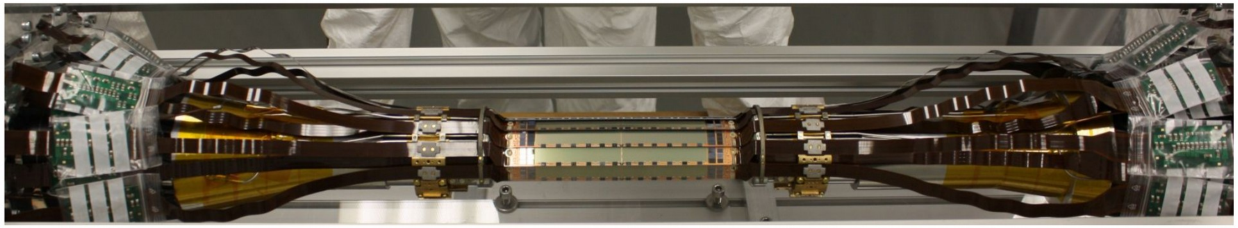
Linac + BT upgrade items during LS1:

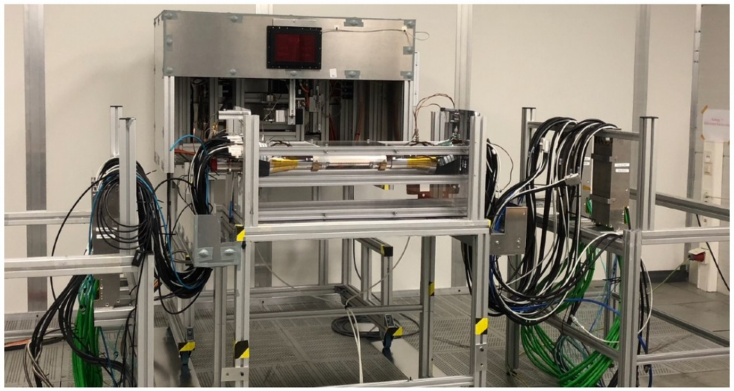
- electron two-bunch injection suffered from vertical orbit shift and emittance growth of the 2^{nd} bunch

  ➜ Linac fast kicker to solve the orbit shift
- Installation of 8 pulsed quads at J-arc matching section
- Installation of 4 pulsed quads at e+/e- compatible optics region

LS1 work for Belle II

Status of Half Shell Testing





- Cooling
  - CO_2 lines connected
  - pressure test pending
- Services
  - patch panels connected
  - two HS links need to be investigated (badly plugged, dirty or broken fibres?)
- HS1 Tests
  - warm module tests have started
  - cold tests will start next week

PXD 2 (+new beampipe)

⇒ news about PXD 2

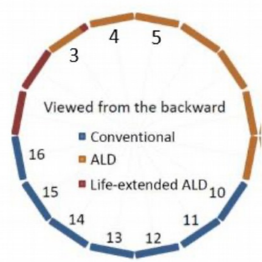
all ladders for L 1 and L 2 ready
half – shelves mounted
need to understand glue issues with 2 ladders
→ expect no significant impact on schedule

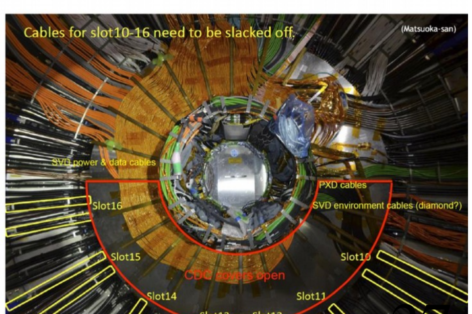
MCP-PMT access during LS1

5

TOP

- Want to take out PMTs and confirm QE by measurement system at Nagoya
  - Modify the system to attach PMT module directly
- Take out some conventional PMTs at around Sep.-Oct.
  - Current candidate is slot16.
    - Also get PMTs with low output charge.
- Take out some ALD PMTs
  - Need VXD cable works. Then take out some PMTs in slot3,4 or 5.
    - Then check at Nagoya
- Want to replace bad electronics in slot4*, 6*, 8*, 16, 13, 5*, 10, (7*, 14)
  - *; Accessible only during VXD work



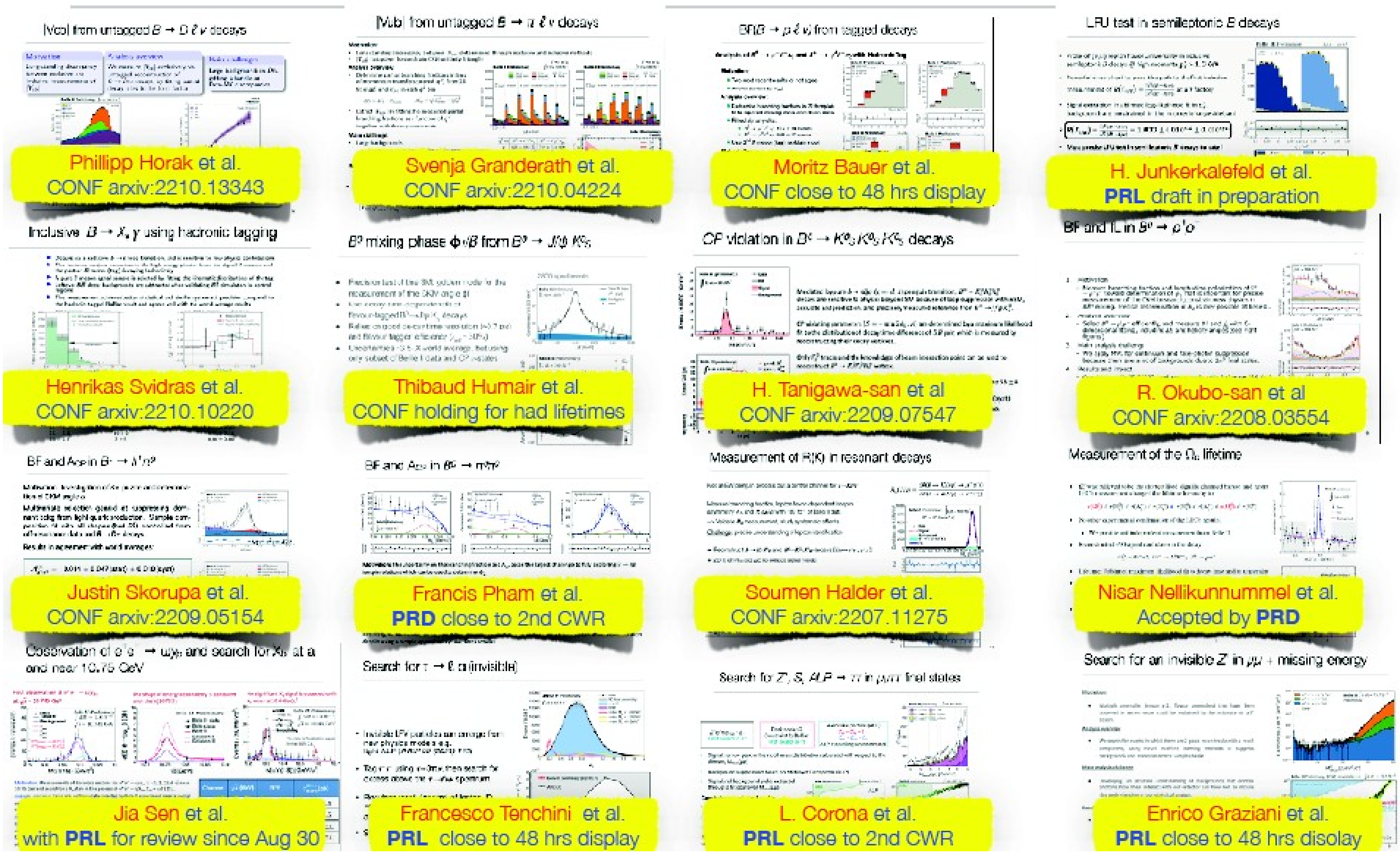


and also CDC: HV resistor replacement, FE repair..

⇒ reprise prevue pour fin 2023

Physique en une page

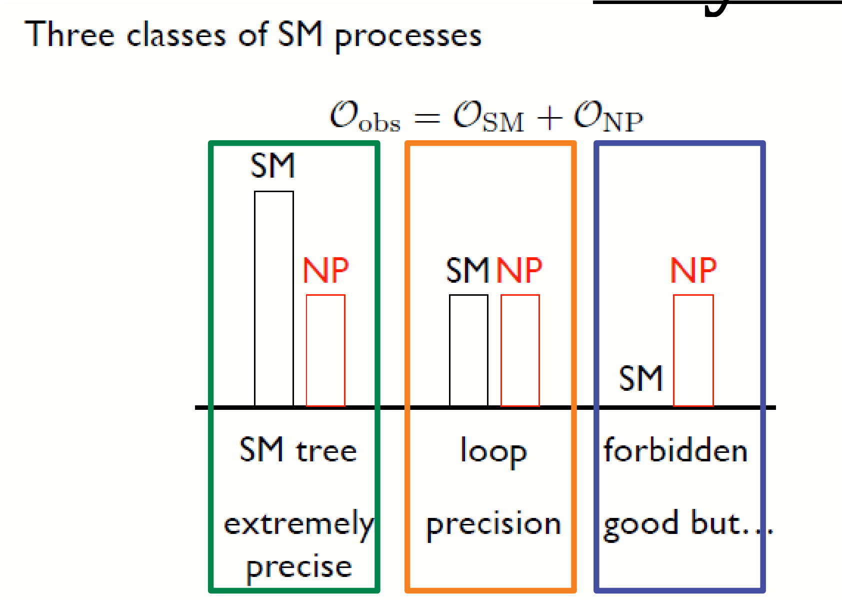
⇒ detecteur entierement fonctionnel



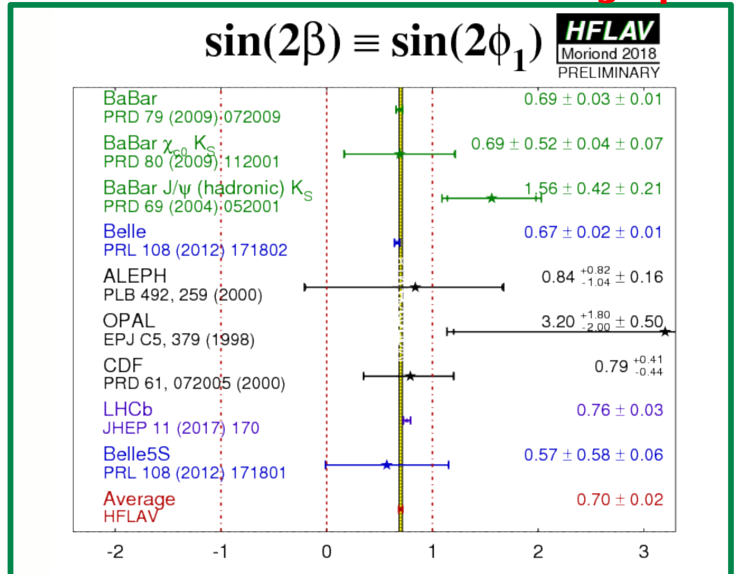
programme de physique avec 0.5 ab^{-1} deja pertinent (Belle peut encore publier 30 articles/an et rester competitif face a LHCb dans de nombreux secteurs (TCPV, τ et energie manquante))

et l'ensemble des donnees pretes (et le MC !) pour l'analyse des 430 fb^{-1} pour 2023

Physics at Belle II

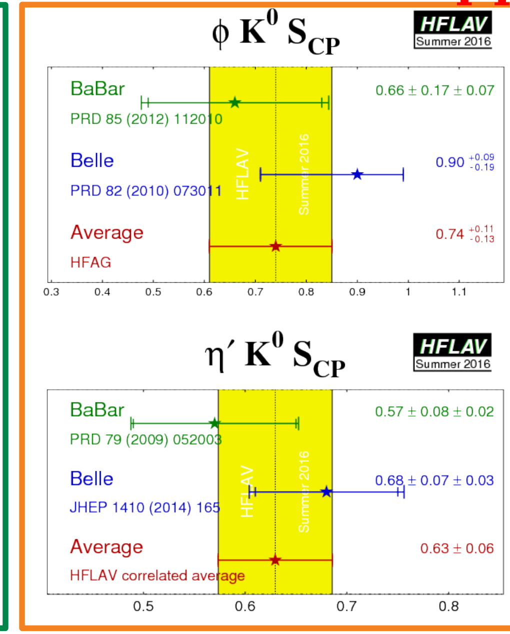


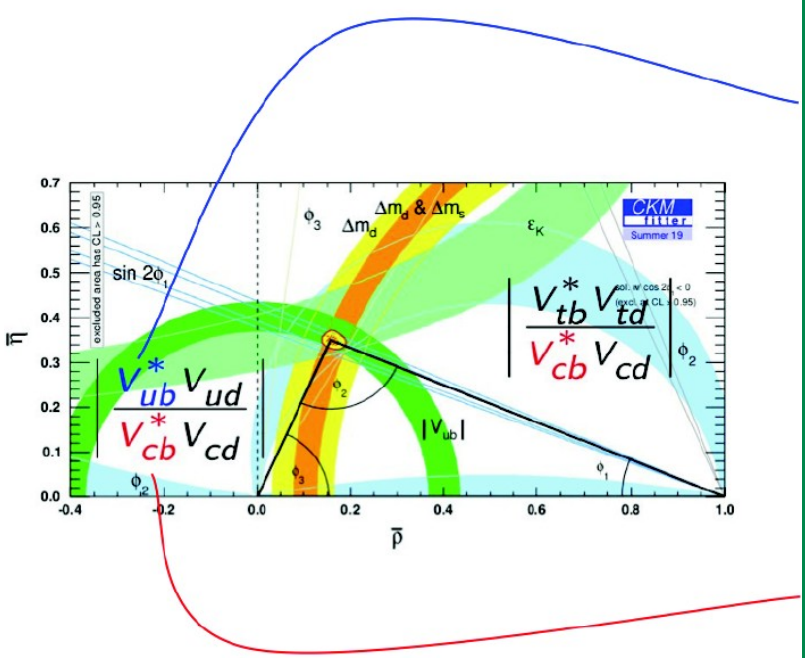
$B \to J/\psi K^0$



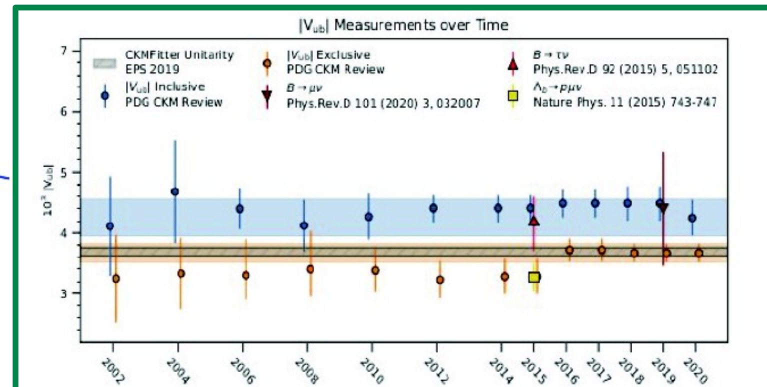
$\sin 2\beta = 0.72 \pm 0.06 \pm 0.02$ w/ 190 fb^{-1} only !

$b \to s q \bar{q}$

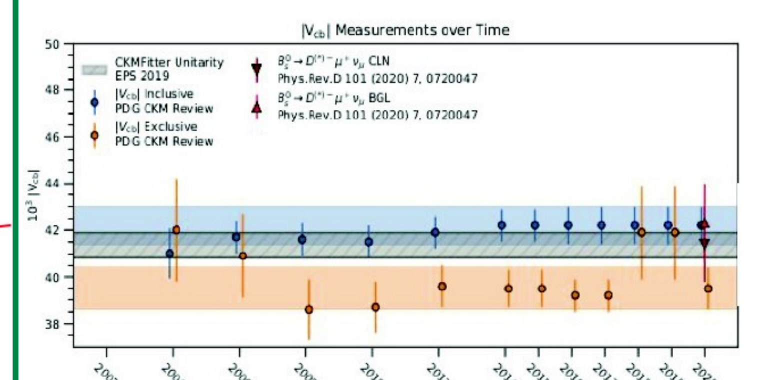




$\left|\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}\right|$ $\left|\frac{V_{tb}^* V_{td}}{V_{cb}^* V_{cd}}\right|$



V_{ub}



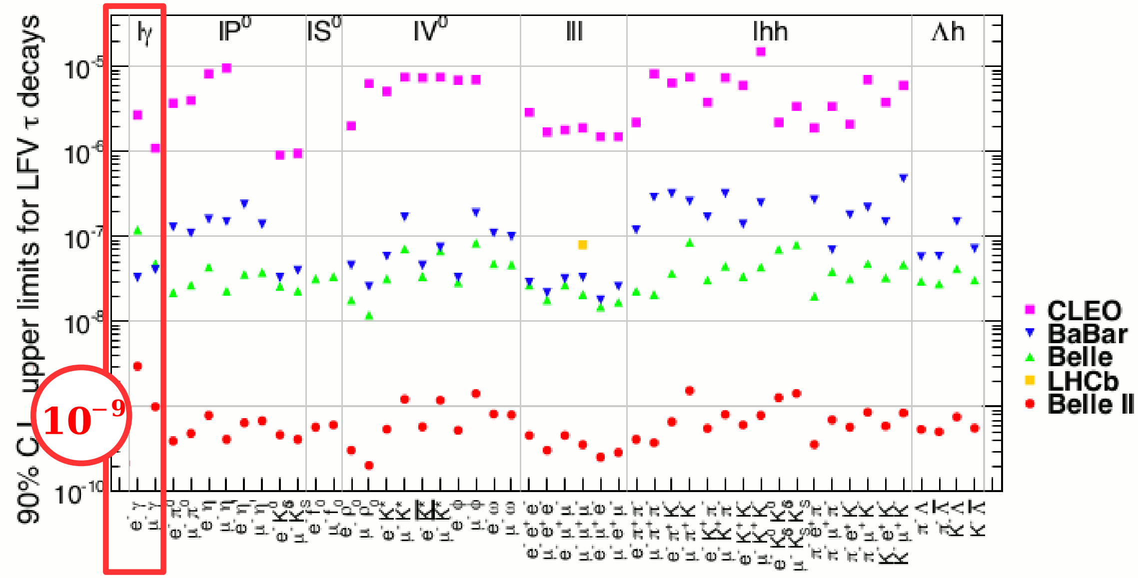
V_{cb}

"τ center"

- **B-factory is also a τ-factory!**
- **lepton flavour violating decays of the τ as NP probe**

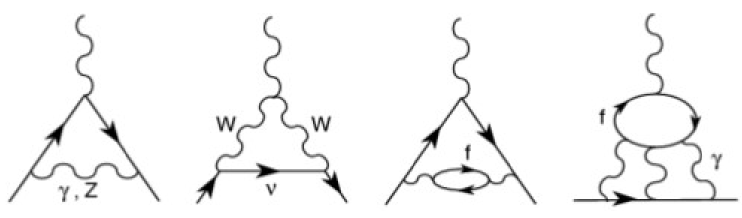
⇒ LFV accidental symmetry of SM, many NP models can naturally break this symmetry

Model	Reference	τ→μγ	τ→μμμ
SM+ ν oscillations	EPJ C8 (1999) 513	10^{-40}	10^{-40}
SM+ heavy Maj ν_R	PRD 66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66 (2002) 115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566 (2003) 217	10^{-10}	10^{-7}



◦ Search of $\tau \to p\mu\mu$ ($\tau \to p l^+ l'^-$) decays with Belle [with D.Sahoo (TIFR)]
⇒ results summarized in PRD 102 (2020) 111101

τ Anomalous Magnetic Moment (A.Martens, F.Zomer)



$$a_\mu^{exp} - a_\mu^{th} \sim 4\sigma$$

S.Eidelman, M.Passera

$$10^8 \cdot a_\tau^{th} = 117\,324 \pm 2 \quad \text{QED}$$
$$+ \; 47.4 \pm 0.5 \quad \text{EW}$$
$$+ \; 337.5 \pm 3.7 \quad \text{hvp}$$
$$+ \; 7.6 \pm 0.2 \quad \text{hvp NLO}$$
$$+ \; 5 \pm 3 \quad \text{light-by-light}$$
$$= \mathbf{117\,721 \pm 5}$$

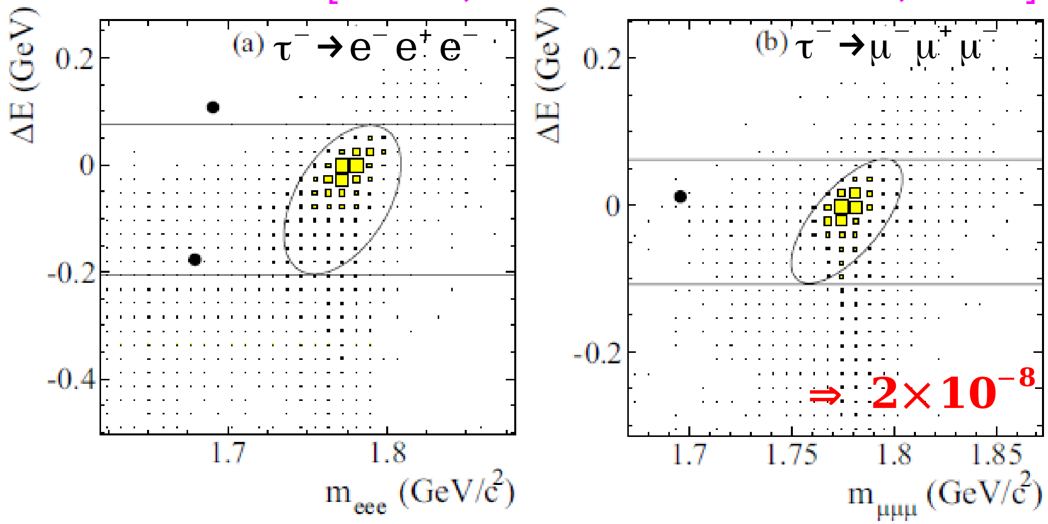
Enhanced sensitivity to new physics: $(m_\tau/m_\mu)^2 = 283$

◦ difficult to measure, $a_\tau^{exp} = (-0.018 \pm 0.017)$, DELPHI, EPJC 35 (2004) 159

cLFV : beyond the Standard Model

τ LFV searches at Belle II will be extremely clean with very little background (if any), thanks to pair production and double-tag analysis technique.

[Belle, PLB 687:139–143,2010]



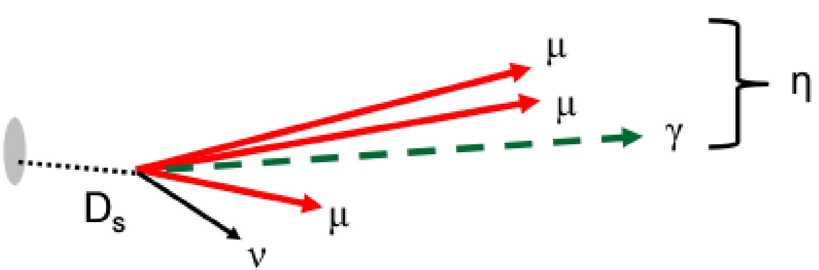
$\Rightarrow$ 2×10^{-8} at 90%CL

how to improve further ?

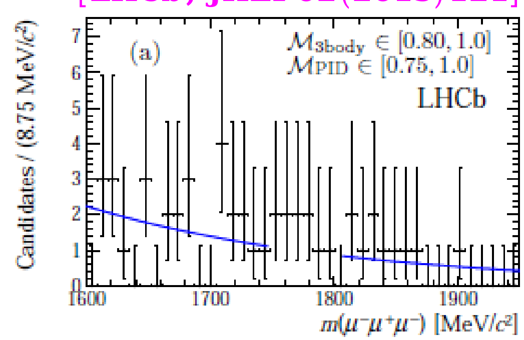
…considering $\tau \to \mu/e\, h^+ h^-$ in function of one prong tag categories

…for $\tau \to 3$ muons, improve μ-ID at low mom (ECL info)

In contrast, hadron collider experiments must contend with larger combinatorial and specific backgrounds



[LHCb, JHEP02(2015)121]



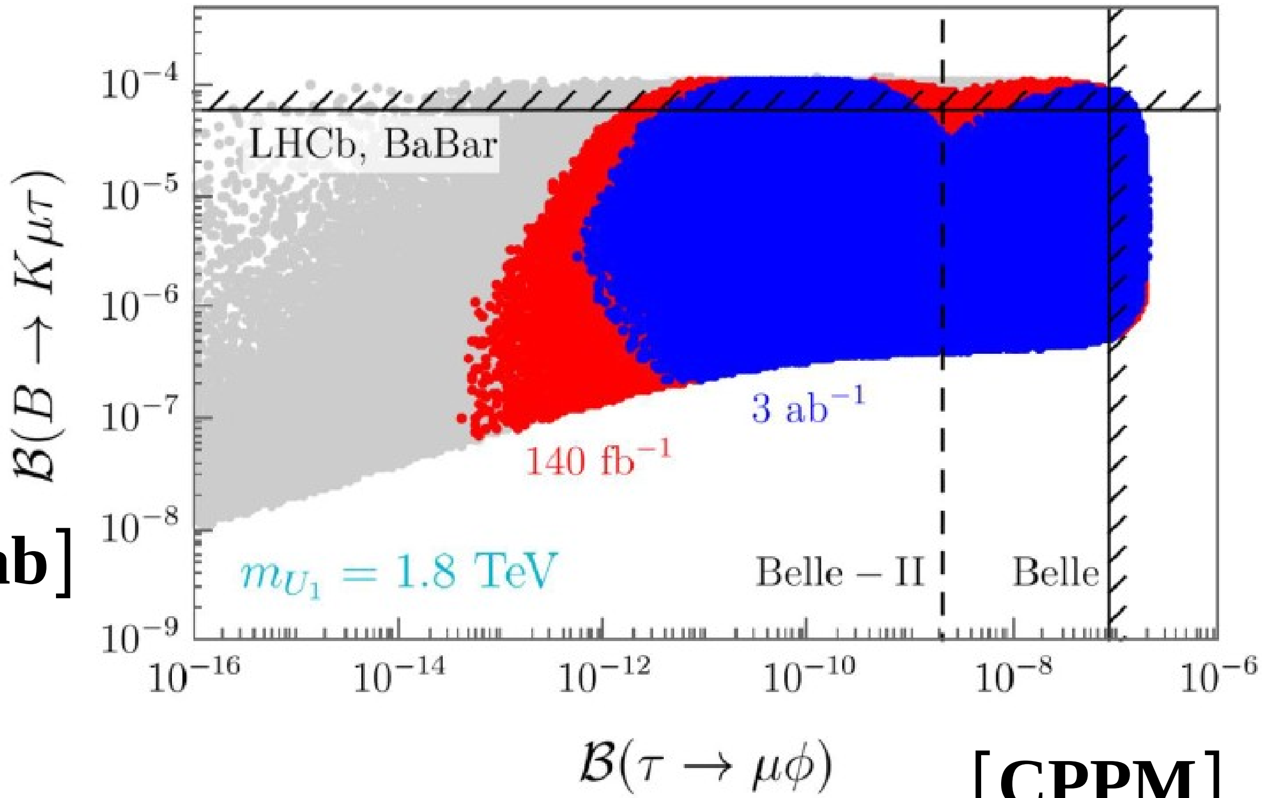
$\Rightarrow$ 5×10^{-8} at 90%CL

Background modes normalised to $D_s \to \eta(\mu\mu\gamma)\mu\nu$ (BR ~ 10^{-5})

Decay channel	Relative abundance
$D_s \to \eta(\mu\mu\gamma)\mu\nu$	1
$D_s \to \varphi(\mu\mu)\mu\nu$	0.87
$D_s \to \eta'(\mu\mu\gamma)\mu\nu$	0.13
$D \to \eta(\mu\mu\gamma)\mu\nu$	0.13
$D \to \omega(\mu\mu)\mu\nu$	0.06
$D \to \rho(\mu\mu)\mu\nu$	0.05

Most improvement in coming decade is expected from Belle II, which can reach 1×10^{-9} [arXiv:1011.0352] and will do even better if can achieve ~ zero bckgd

Nice complementarity



[IJCLab]

[CPPM]

A. Angelescu et al., arXiv:2103.12504v2 (21 Apr 2021)

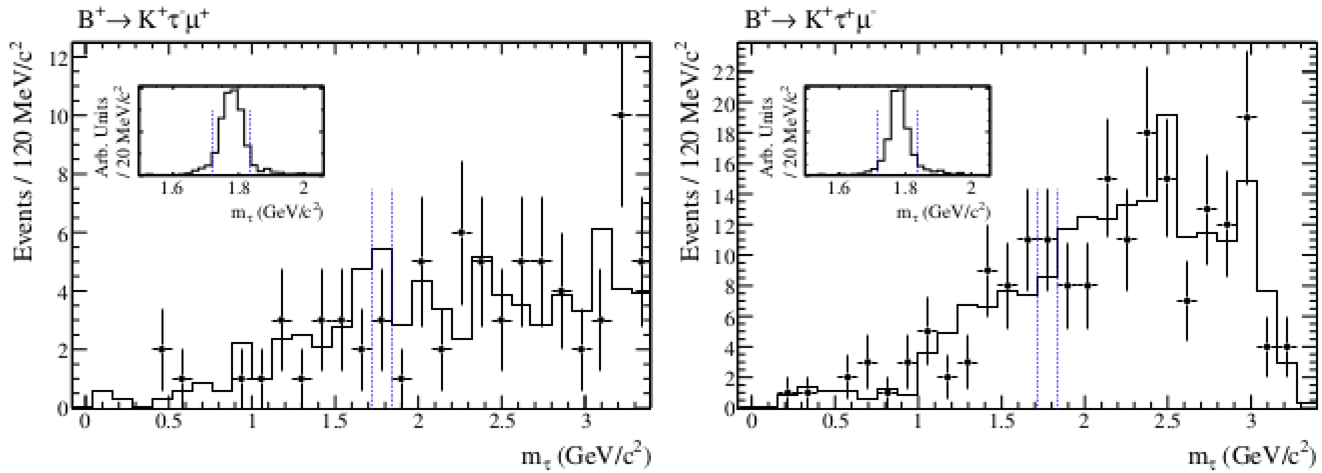
LFV $B \to K \tau l$ ($l = e, \mu$) decays

[BaBar, arXiv:1204.2852]

strategy used: B fully reconstructed (had tag), $\tau^+ \to l^+ \nu_l \nu_\tau$, $(n\pi^0)\pi\nu$, with $n \geq 0$

using momenta of K, l and B, **can fully determine the τ four-momentum**

unique system: no other neutrino than the ones from one tau ($\neq B \to \tau\nu$, $D^{(*)}\tau\nu$...)



$B(B^+ \to K^+ \tau^- \mu^+) < 4.5 \times 10^{-5}$ at 90%CL, $B(B^+ \to K^+ \tau^+ \mu^-) < 2.8 \times 10^{-5}$ at 90%CL

(also results for $B \to K^+ \tau^\pm e^\mp$, $B \to \pi^+ \tau^\pm \mu^\mp$, $B \to \pi^+ \tau^\pm e^\mp$ modes)

[Belle II, arXiv:1808.10567]

Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B^+ \to K^+\tau^\pm e^\mp) \cdot 10^6$	–	–	< 2.1
$\mathrm{Br}(B^+ \to K^+\tau^\pm \mu^\mp) \cdot 10^6$	–	–	< 3.3
$\mathrm{Br}(B^0 \to \tau^\pm e^\mp) \cdot 10^5$	–	–	< 1.6
$\mathrm{Br}(B^0 \to \tau^\pm \mu^\mp) \cdot 10^5$	–	–	< 1.3

⇒ **can we do better ? combining hadronic tag with an more inclusive tag...**

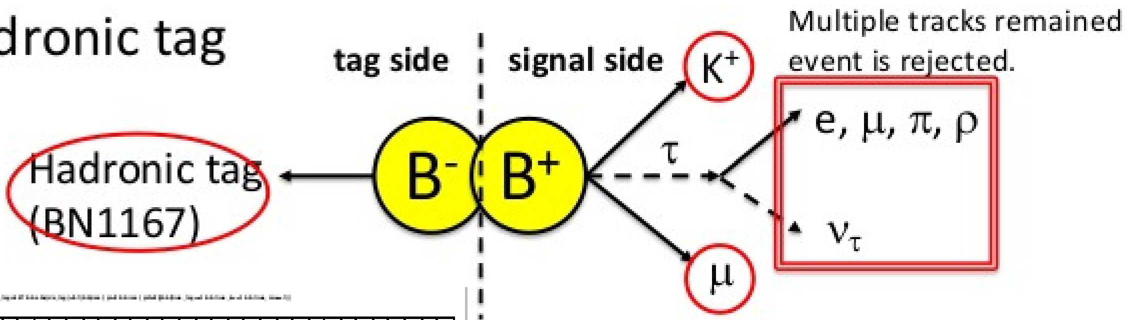
⇒ **can do $K^*\tau e$, $K^*\tau\mu$ with similar sensitivity...**

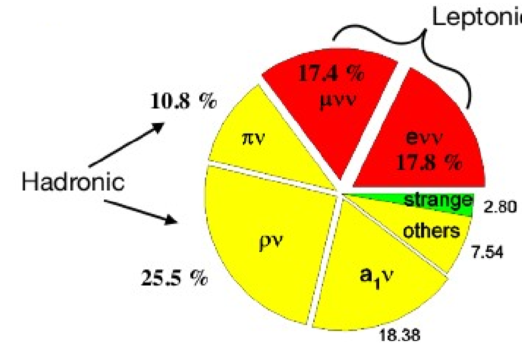
LFV $B \to K \tau l$ ($l = e, \mu$) decays

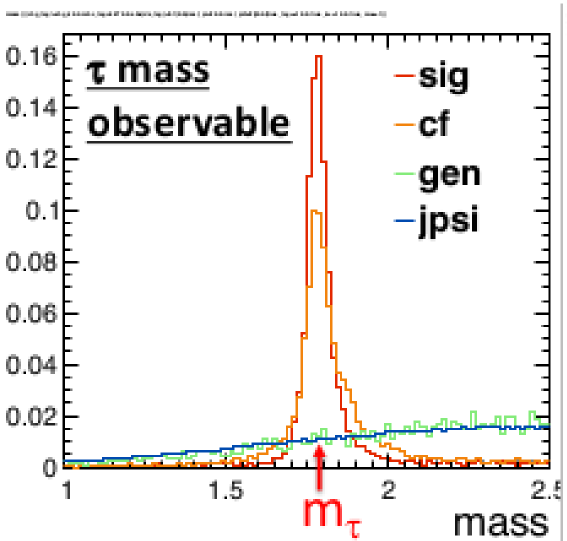
[Belle & Belle II]

focus on K (K^+ or K^0_S), $\tau \to e\nu\nu, \mu\nu\nu, \pi\nu, \rho\nu$

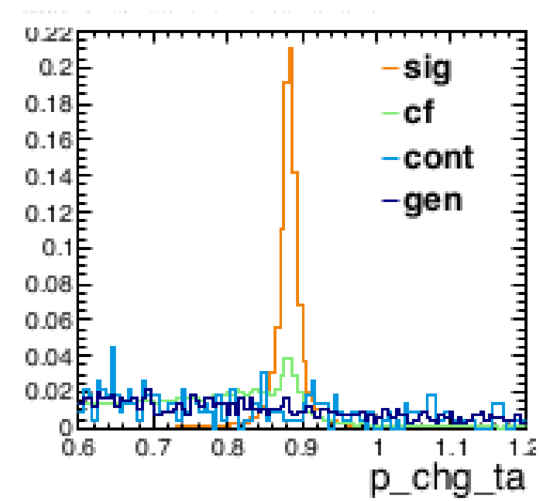
- Hadronic tag



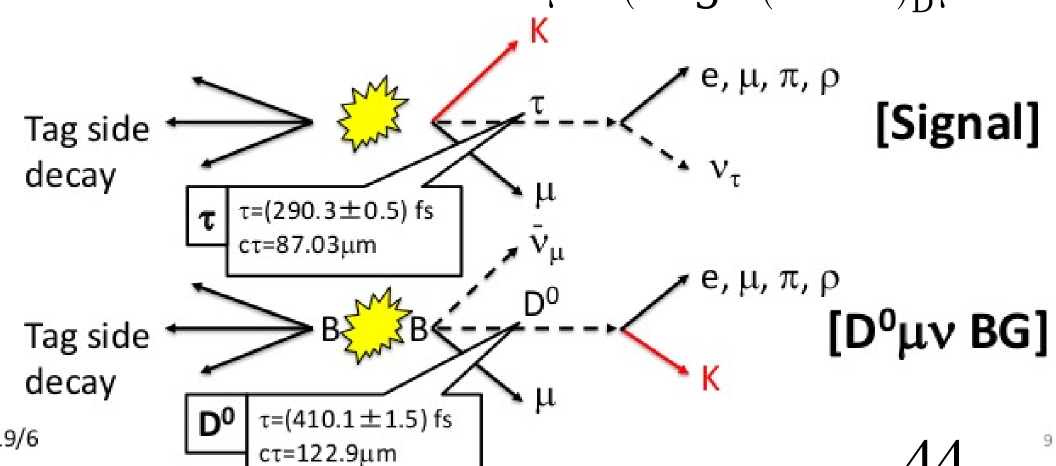


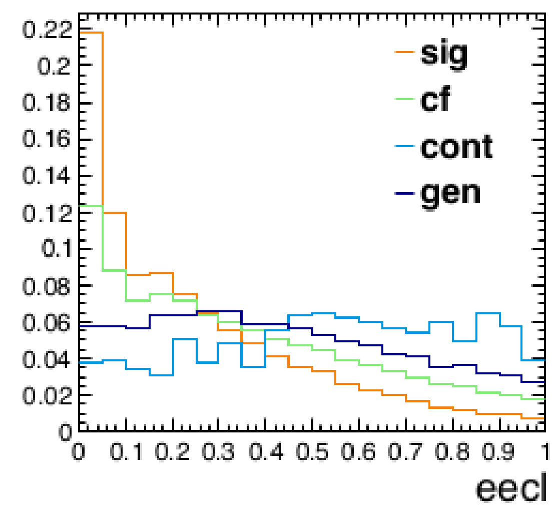


- For $\tau \to \pi\nu$, $\rho\nu$ channel, kinematic cut is useful to suppress BG.
- $\tau \to \pi\nu$
  - Monochromatic momentum of π in τ rest frame
- $\tau \to \rho\nu \to \pi\pi^0\nu$
  - Monochromatic momentum of ρ in τ rest frame
  - Invariant mass of $\pi\pi^0$



dominant BG is $B^+ \to D^{(*)0}\mu\nu$ (e.g. $(K\pi X)_D\mu\nu$ in $\tau \to \pi\nu$ case)





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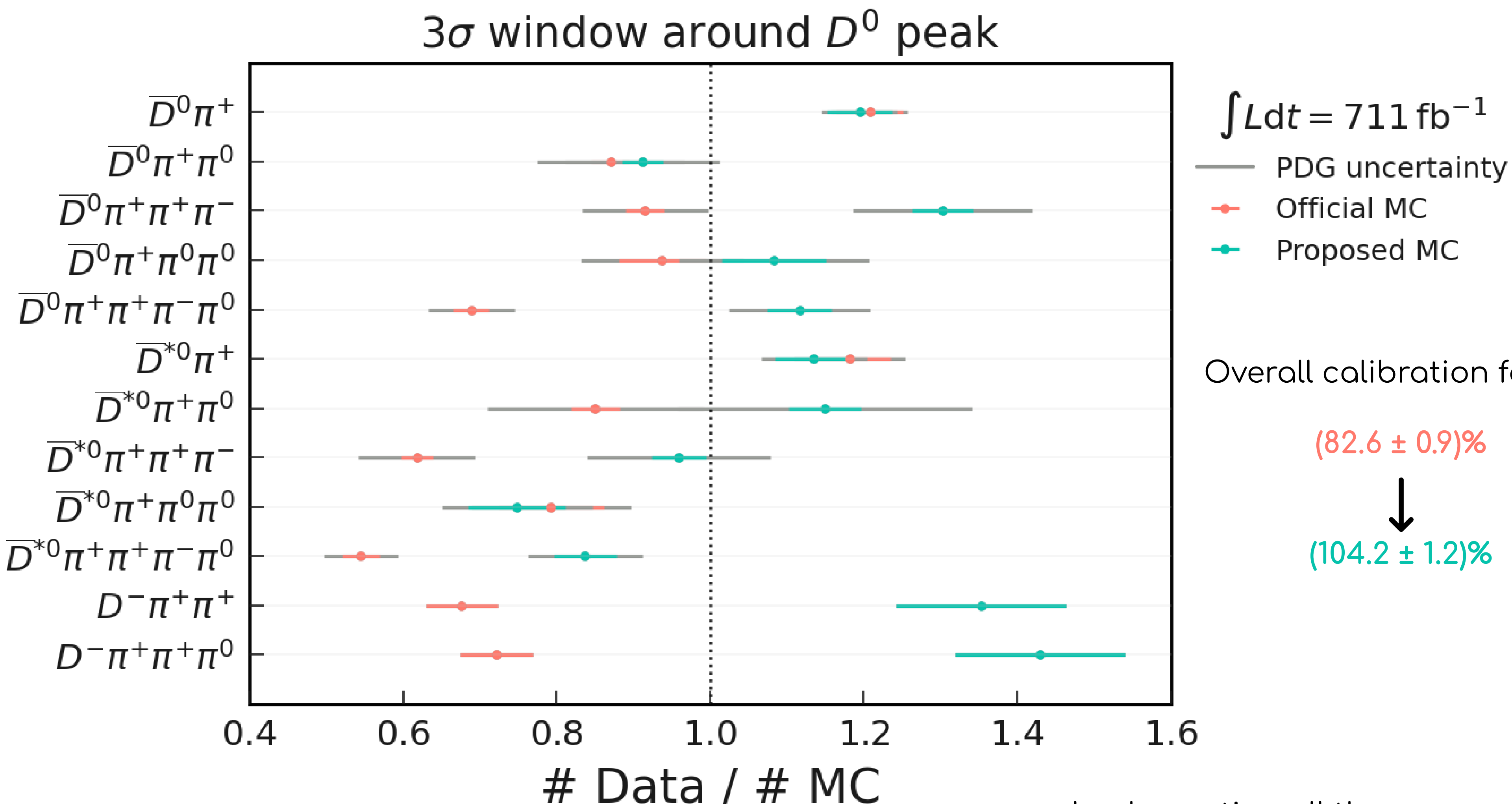
Improving MC model ⇒ B^+ tagging



Overall calibration factor

(82.6 ± 0.9)%

↓

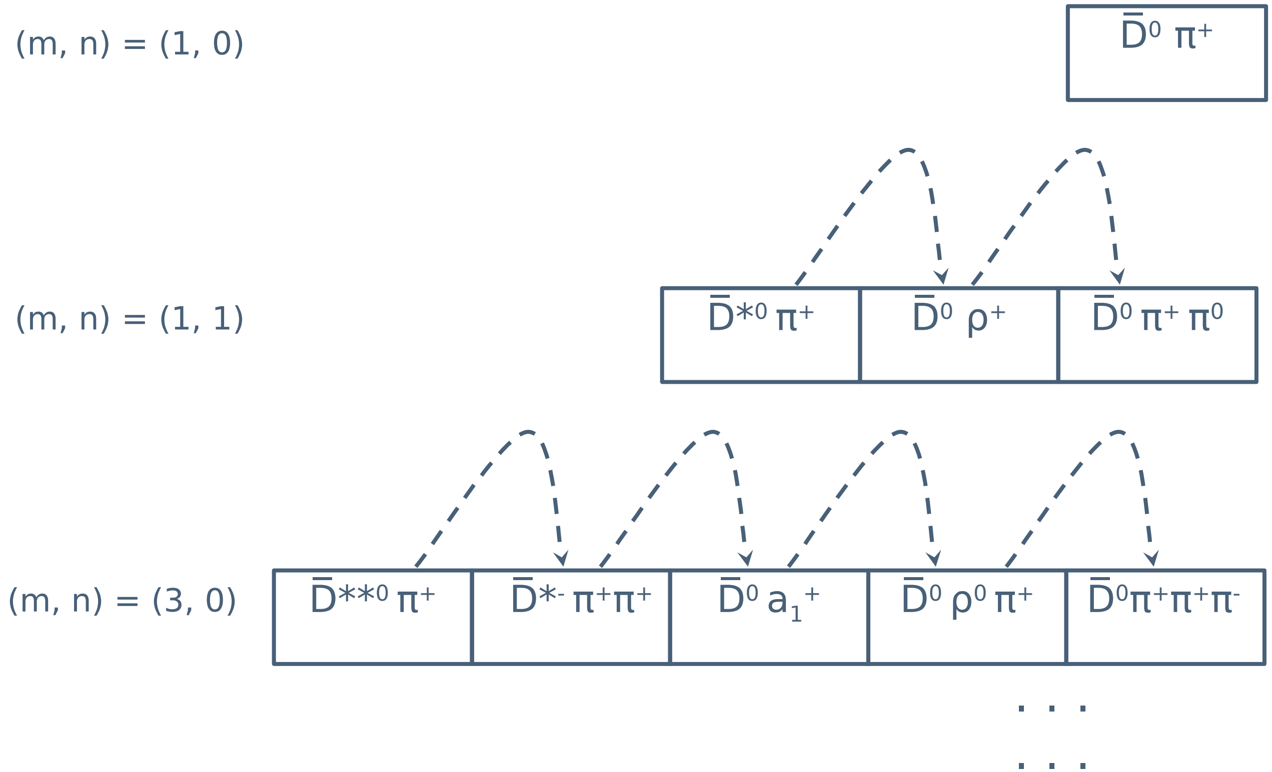
(104.2 ± 1.2)%

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

Alternative FEI algorithm

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

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

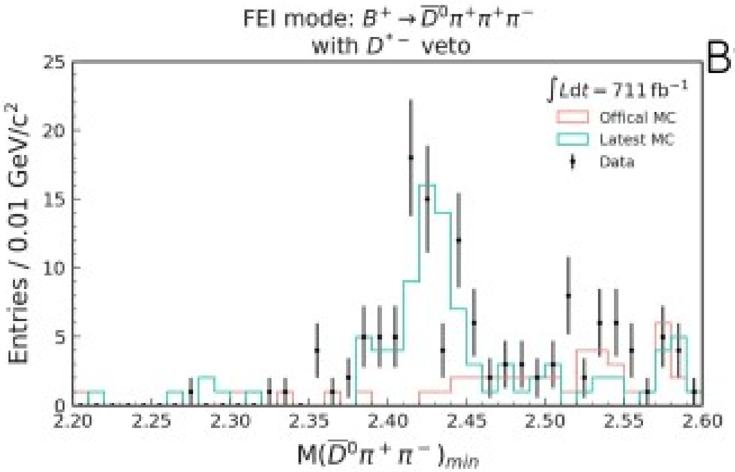


Reconstructing in this order,
going to the next step only if it fails, ⇒ Simpler best candidate selection
using the constraints of intermediate resonances when possible ⇒ Higher purity

Let’s call this algorithm “ FREE ”

Decay description is also improving!

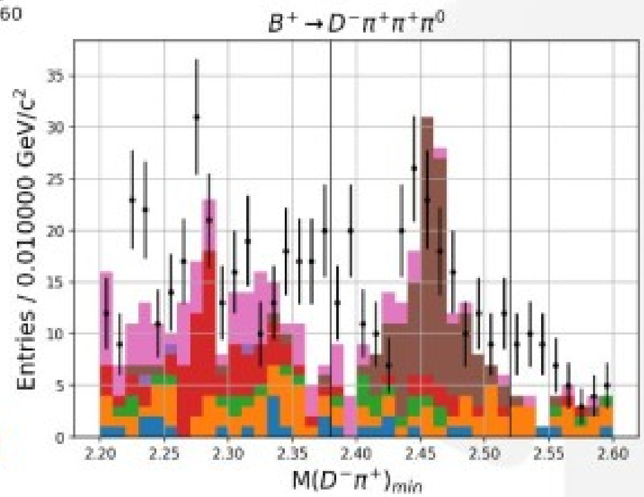
The improvement is not limited to calibration factors, but even more importantly the invariant masses (of intermediate particles), which are used as training variables in FEI.

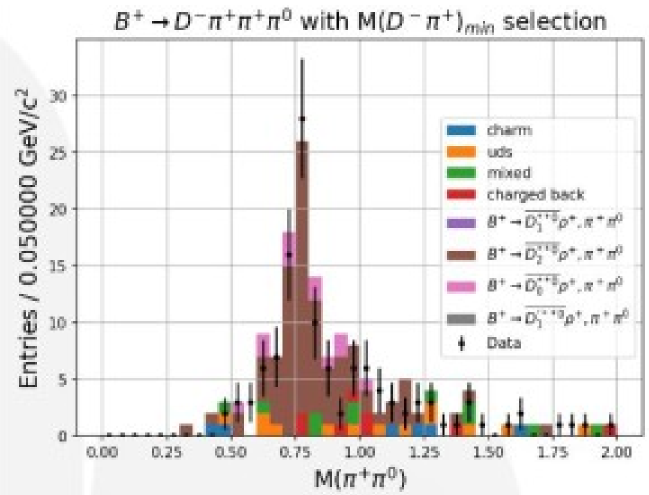


$B^+ \to \overline{D}_1 [\to \overline{D}^0 \pi^+ \pi^-] \pi^+$

We saw some new channels along the way too :)

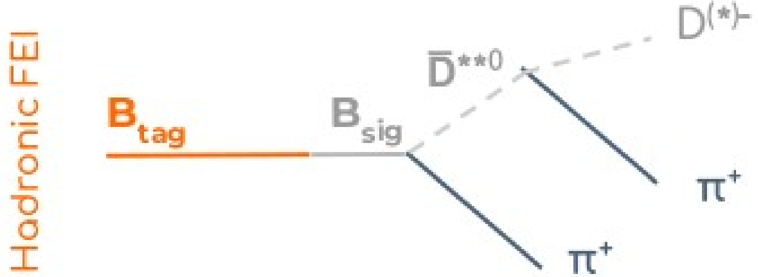
Like $B^+ \to \overline{D}_2 [\to D^- \pi^+] \rho^+ [\to \pi^+ \pi^0]$:





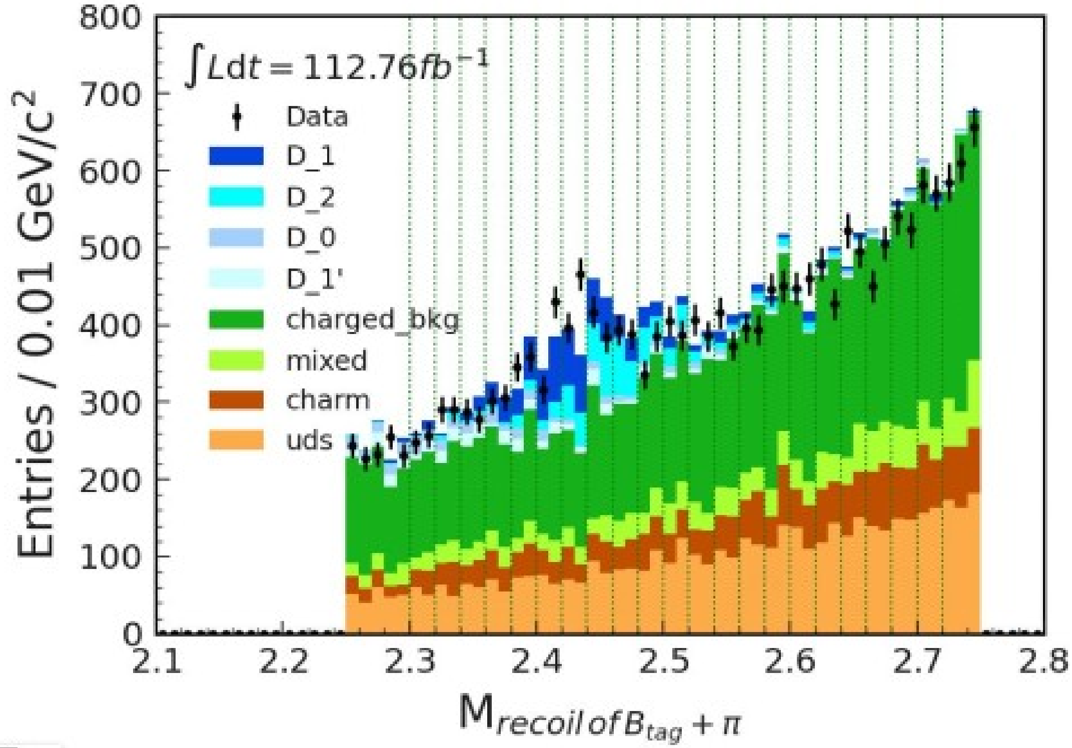
Master project of
Salah El Dine Hammoud

Double-recoil with D** sample



In these events, we can do a "double-recoil" by adding another π^+

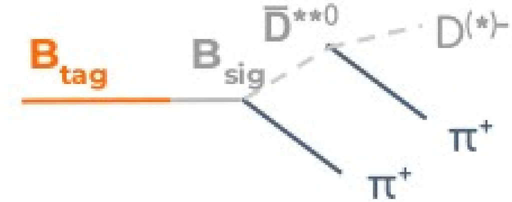
D_1 can only decay to $D^{*-}\pi^+$, but
D_2 can decay to both $D^-\pi^+$ and $D^{*-}\pi^+$



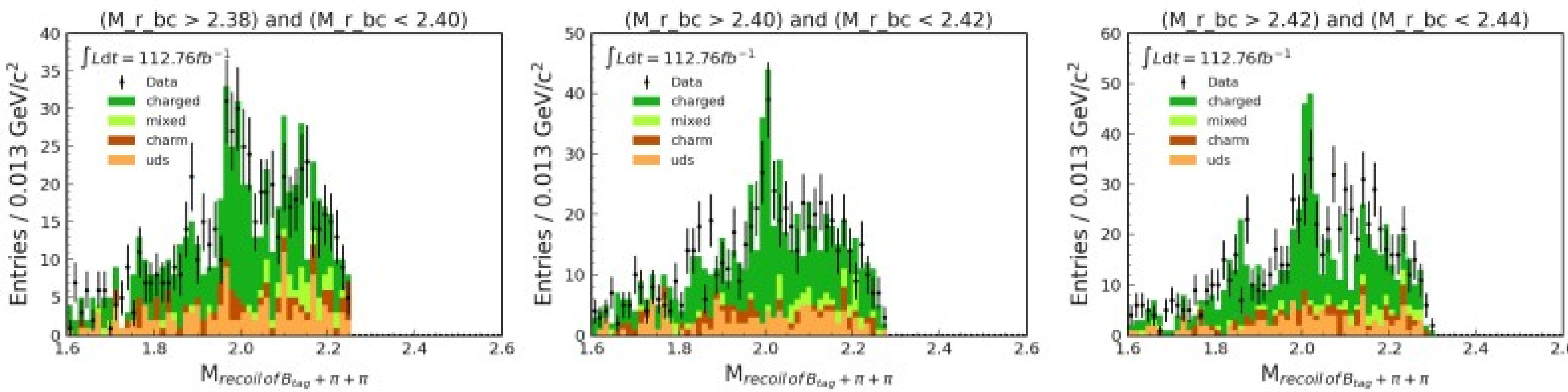
$D_1(2420)^0$	$D^{*0}\pi^0$	0.1997
	$D^{*+}\pi^-$	0.3994
	$D^0\pi^+\pi^-$	0.1719
	$D^0\pi^0\pi^0$	0.1145
	$D^+\pi^-\pi^0$	0.1145

$D_2^*(2460)^0$	$D^{*0}\pi^0$	0.1334
	$D^{*+}\pi^-$	0.2669
	$D^0\pi^0$	0.1999
	$D^+\pi^-$	0.3998

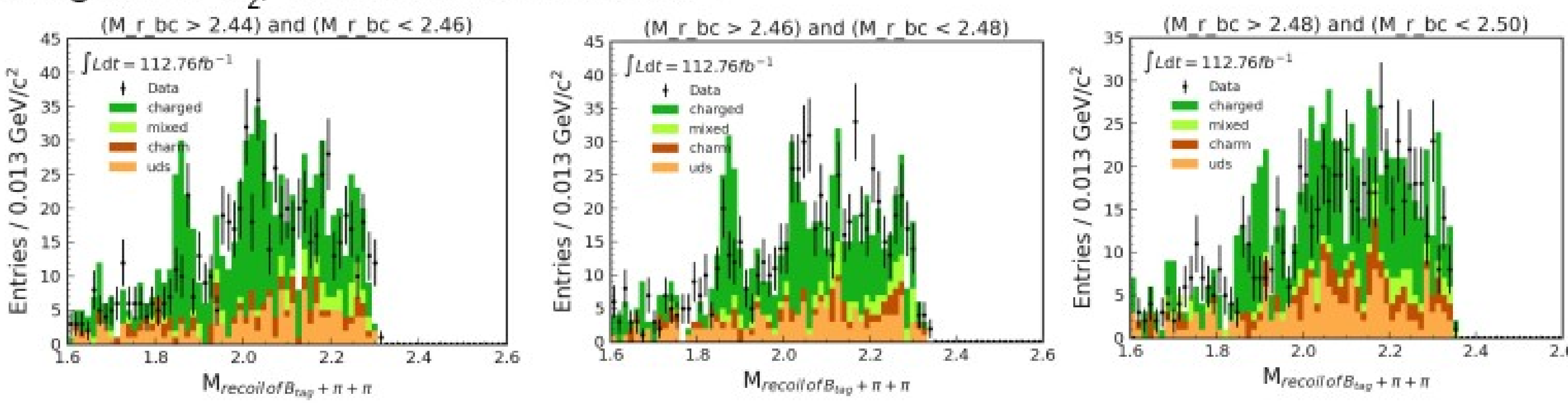
Double-recoil with D** sample



As expected, in the region of D_1, we see mostly D^{*-}:



And in the region of D_2, we see both D^- and D^{*-}:

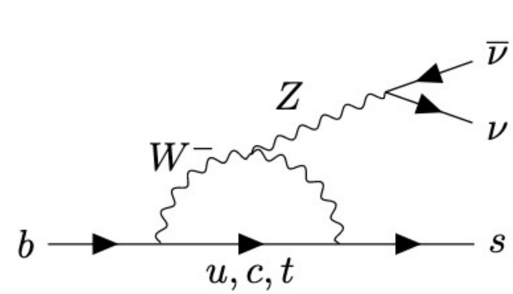


$B^+ \to K^+ \nu \bar{\nu}$

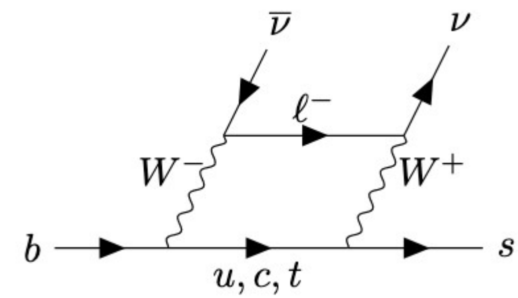
- SM predictions:

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

$$\mathrm{BR}(B^+ \to K^+ \nu\bar{\nu})_{\mathrm{SM}} = (4.6 \pm 0.5) \times 10^{-6}\,,$$
$$\mathrm{BR}(B^+ \to K^{*+} \nu\bar{\nu})_{\mathrm{SM}} = (8.4 \pm 1.5) \times 10^{-6}\,,$$



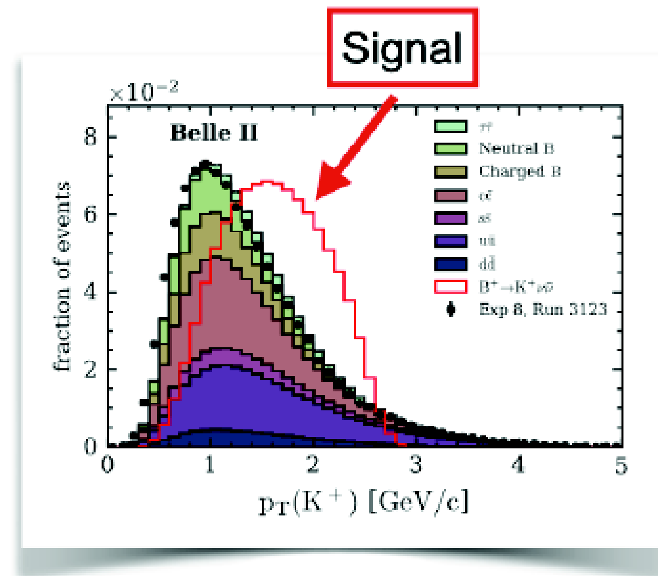
(a) Penguin diagram



(b) Box diagram

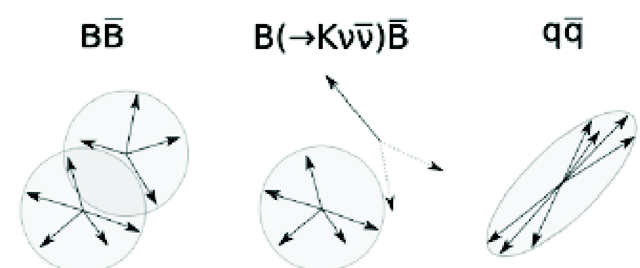
NOVEL <u>INCLUSIVE</u> APPROACH on <u>63 fb^{-1}</u> of Belle II data:

- Signal kaon = highest p_T track →



- Associate all other tracks and clusters to other B in the event

- Use multivariate approach (2 BDTs in cascade) based on kinematics, event shape and vertexing variables to suppress background

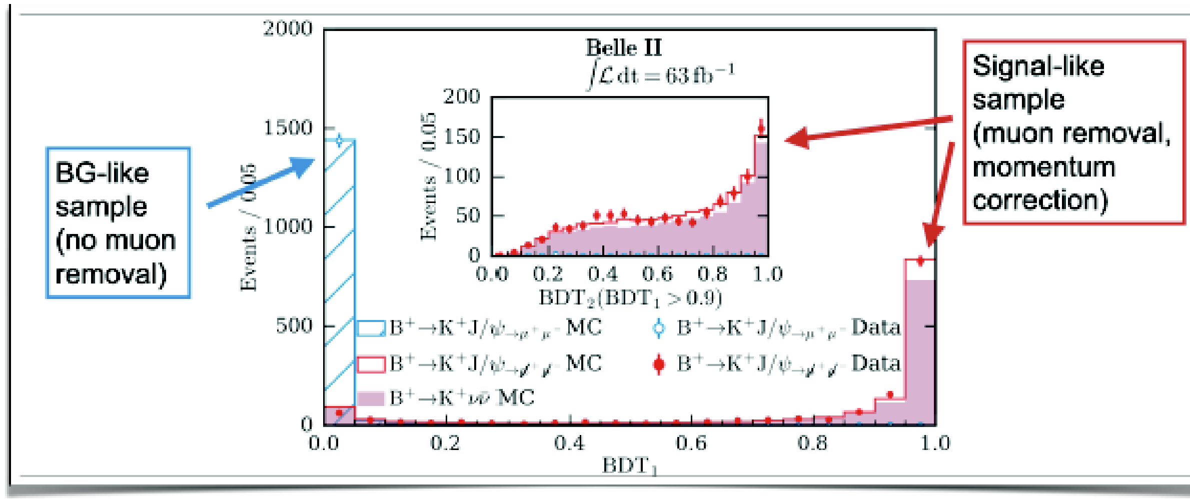


- **Signal efficiency ~ 4.3 %** (SM signal)

$B^+ \to K^+ \nu \bar{\nu}$ measurement at Belle II

[arXiv:2104.12624] accepted by PRL

- Check data-simulation agreement in BDTs output using $B^+ \to J/\psi(\mu^+\mu^-)K^+$ control sample
- **Data/MC ratio in fit region**: 1.06 ± 0.10

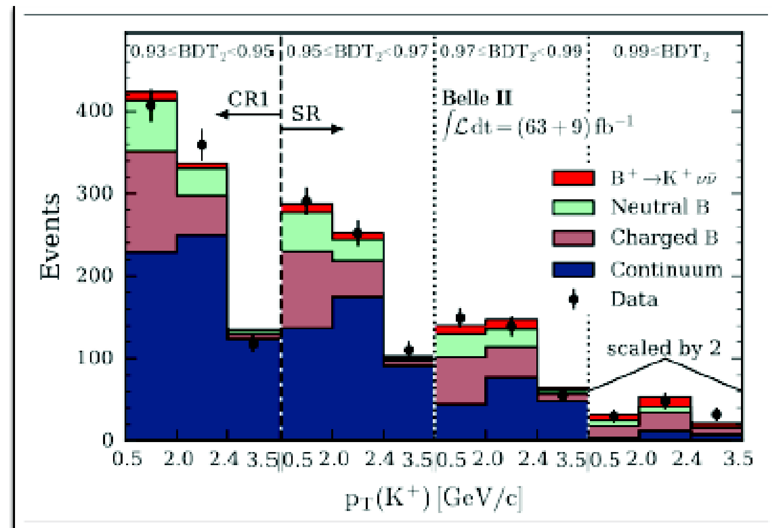


- Extract signal from simultaneous maximum likelihood fit to on-resonance + off- resonance data (taken 60MeV below $\Upsilon(4S)$ resonance) in bins of $p_T(K^+)$ and second BDT (BDT$_2$):

Signal strength:

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

- consistent with SM exp (μ=1) at 1 σ
- consistent with background-only hypothesis at 1.3 σ



- Leading systematics: **background normalisation** uncertainty can be also reduced with increasing statistics

$B^+ \to K^+ \nu \bar{\nu}$ measurement at Belle II

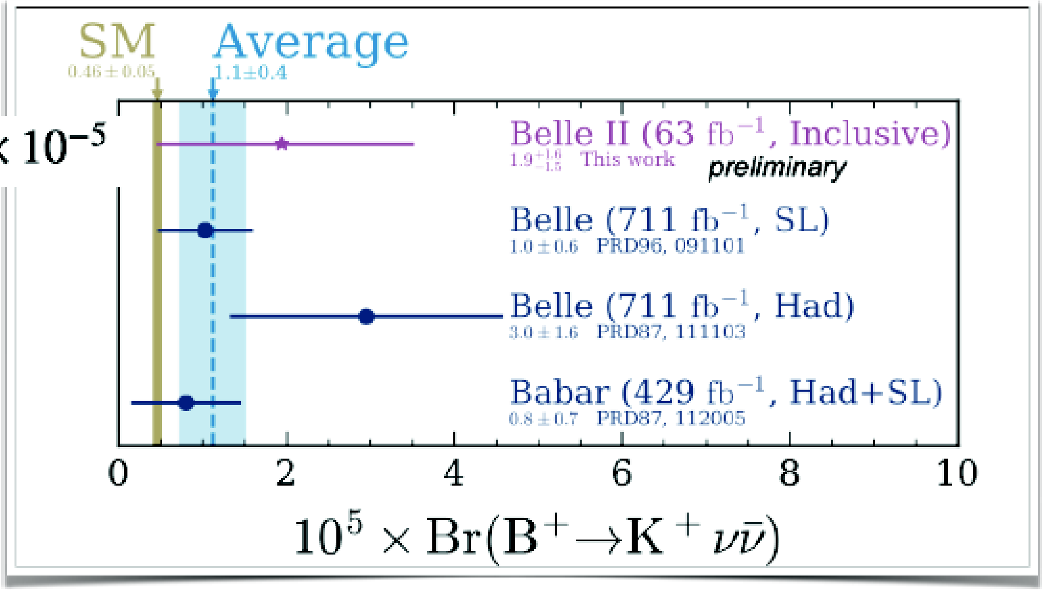
[arXiv:2104.12624]
accepted by PRL

- No evidence for signal, upper limit on BR using CLs method (assuming SM signal)

$$\mathscr{B}(B^\pm \to K^\pm \nu\bar{\nu}) < (4.1 \pm 0.5) \times 10^{-5} \, @ 90\,\%\,\mathrm{CL}$$

- Comparing theory and experiments:

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



- When converted to the same luminosity, **our measurement is better*) than semi-leptonic tagging by 10-20%**
- … **and than hadronic tagging by a factor 3.5!**

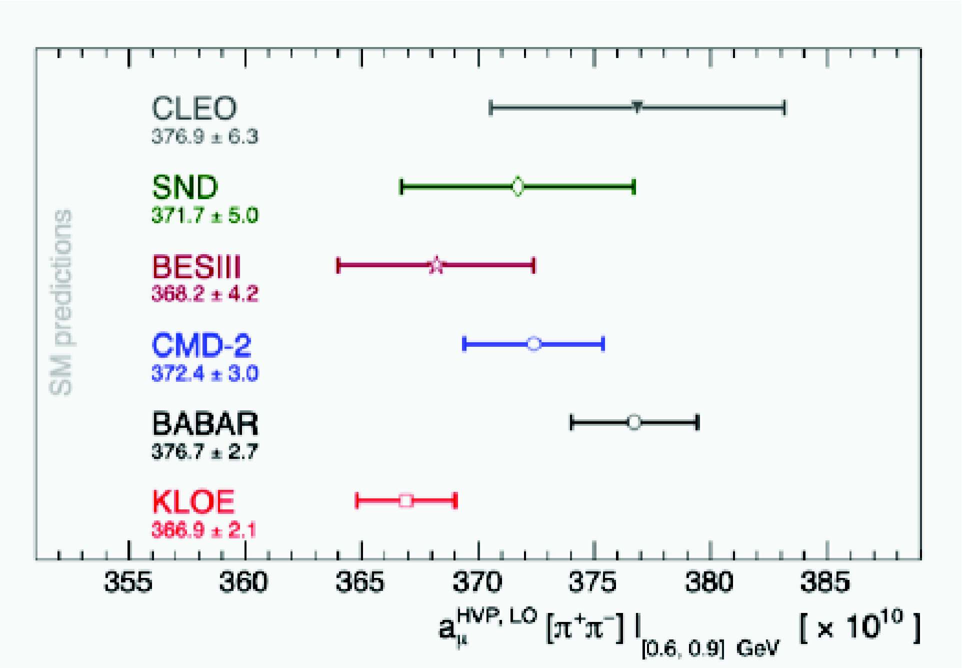
*) assuming the total uncertainty on the branching-fraction scales with $1/\sqrt{L}$

- Room for **improvement** in K^+ channel, application of inclusive method to **other channels** in progress

Dominated by Belle I
competitive with current dat

Cross-section for $e^+e^- \to \pi^+\pi^-(\gamma)$

Uncertainty in $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))$ at ω–ρ interference dominates leading-order hadronic contribution to predictions of $(g\text{-}2)_\mu$ based on dispersion relations



Boils down to a permille measurement of $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))/\,\sigma(e^+e^- \to \mu^+\mu^-(\gamma))$ *vs* two-body mass.

Dominated by PID systematic uncert.

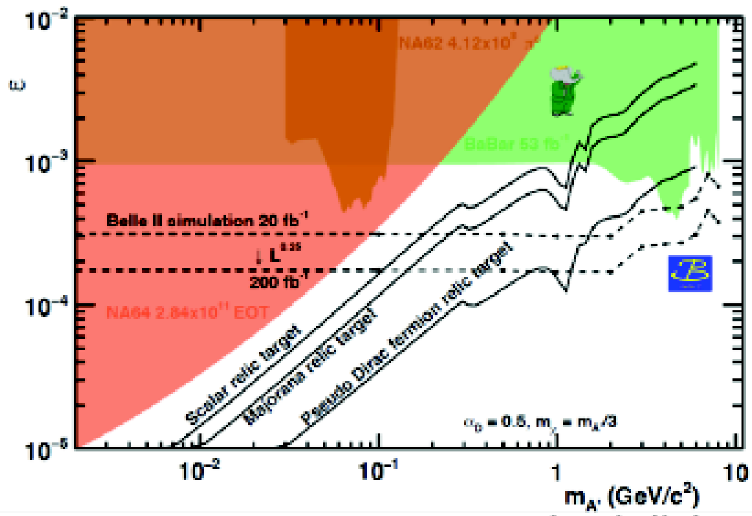
Projections are hard: no Belle measurement, no preliminary Belle II result.

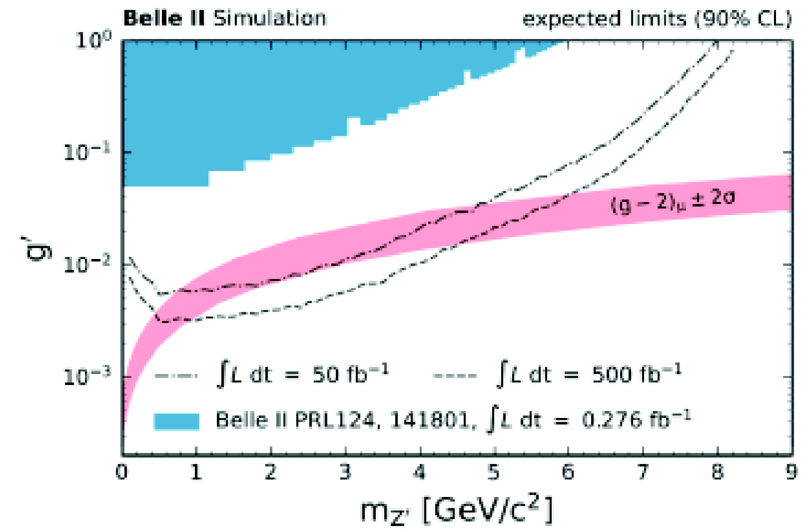
Safe to assume a measurement at least as precise as Babar's.

Unique to Belle II
competitive with current dat

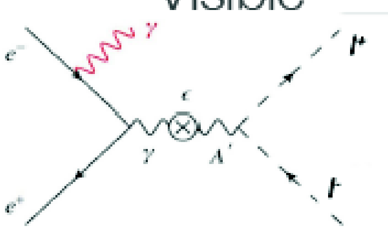
Low-mass dark sector

- Triggering on low-multiplicity without clogging DAQ with ee → ℓℓ, ℓℓℓℓ, γγ
- Understand collision backrgounds (SM simulations, beam bckg), cosmics and detector hermeticity to achieve > ppm rejections

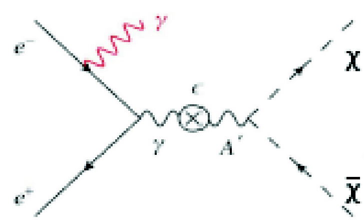


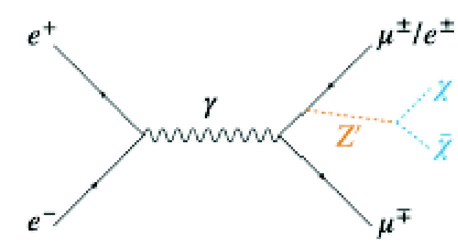


Visible



Invisible





"Easier," but less generic
Challenge: can extend to electrons?

Harder, truly generic
Challenge: understanding of material/hermeticity: KLM vetoes crucial. Trigger.

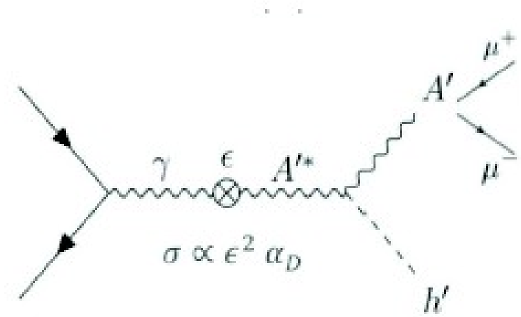
Probes plausible explanation for muon g-2

Also ALP → γγ (PRL 125 (2020) 161806)

Unique to Belle II

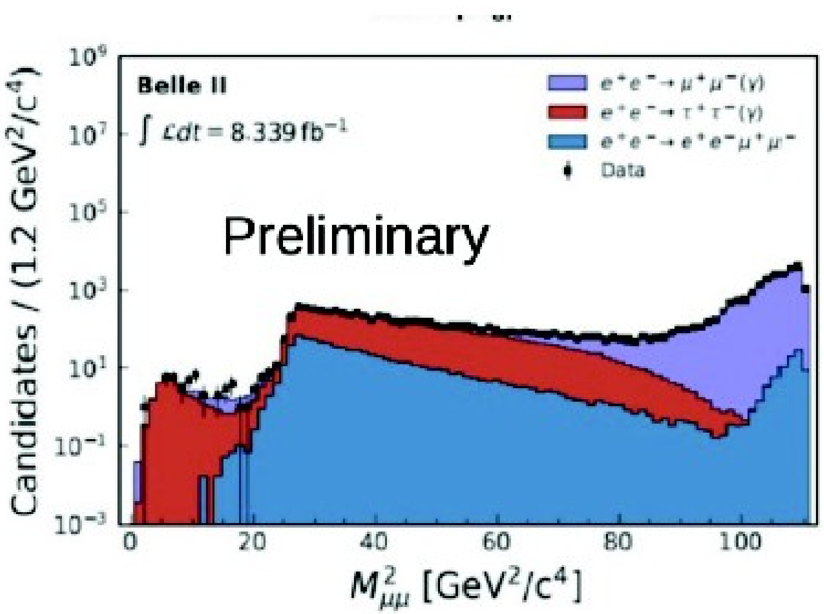
Recent example - Darkhiggstrahlung

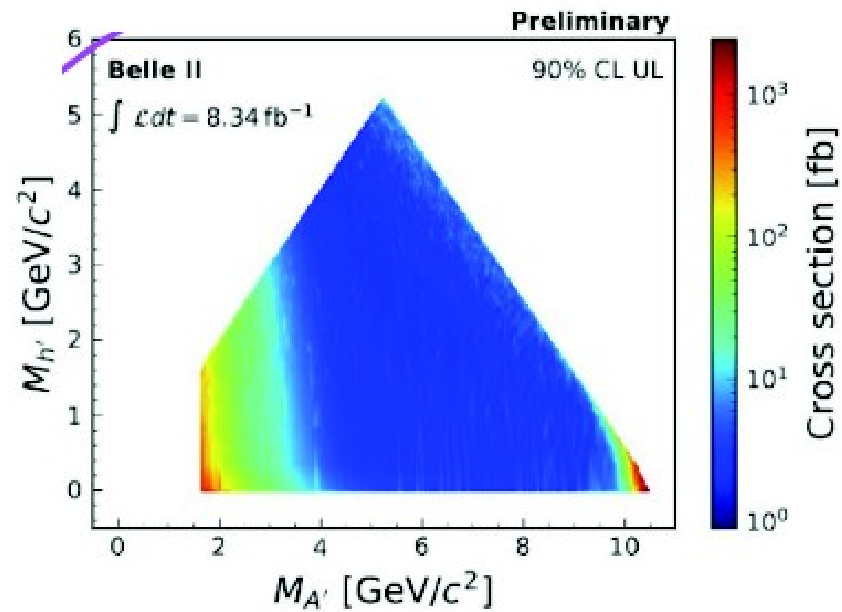
If dark photon A' exists, its mass can be generated by Higgs-like mechanism mediated by a dark higgs (h') field.



Bump hunt for a peak in the two-dimensional plane of mumu and recoil masses with very early data

Belle II has unique capability to probe the ***invisible h' decay ($m_{h'} < m_{A'}$)*** with A' decaying to a muon pair





World best results in 2-10 GeV range