Belle II Status

Pedro Podesta

On behalf of the Belle II collaboration

Annual Meeting on particles and Fields 12 to 13 June 2023, CINVESTAV Mexico

Outline

1.-Introduction

2. Physics motivation

3.- SuperKEK

4.- Beam Monitoring

5.- Belle II

6.- D^0/D^+ Lifetime

7.- τ physics

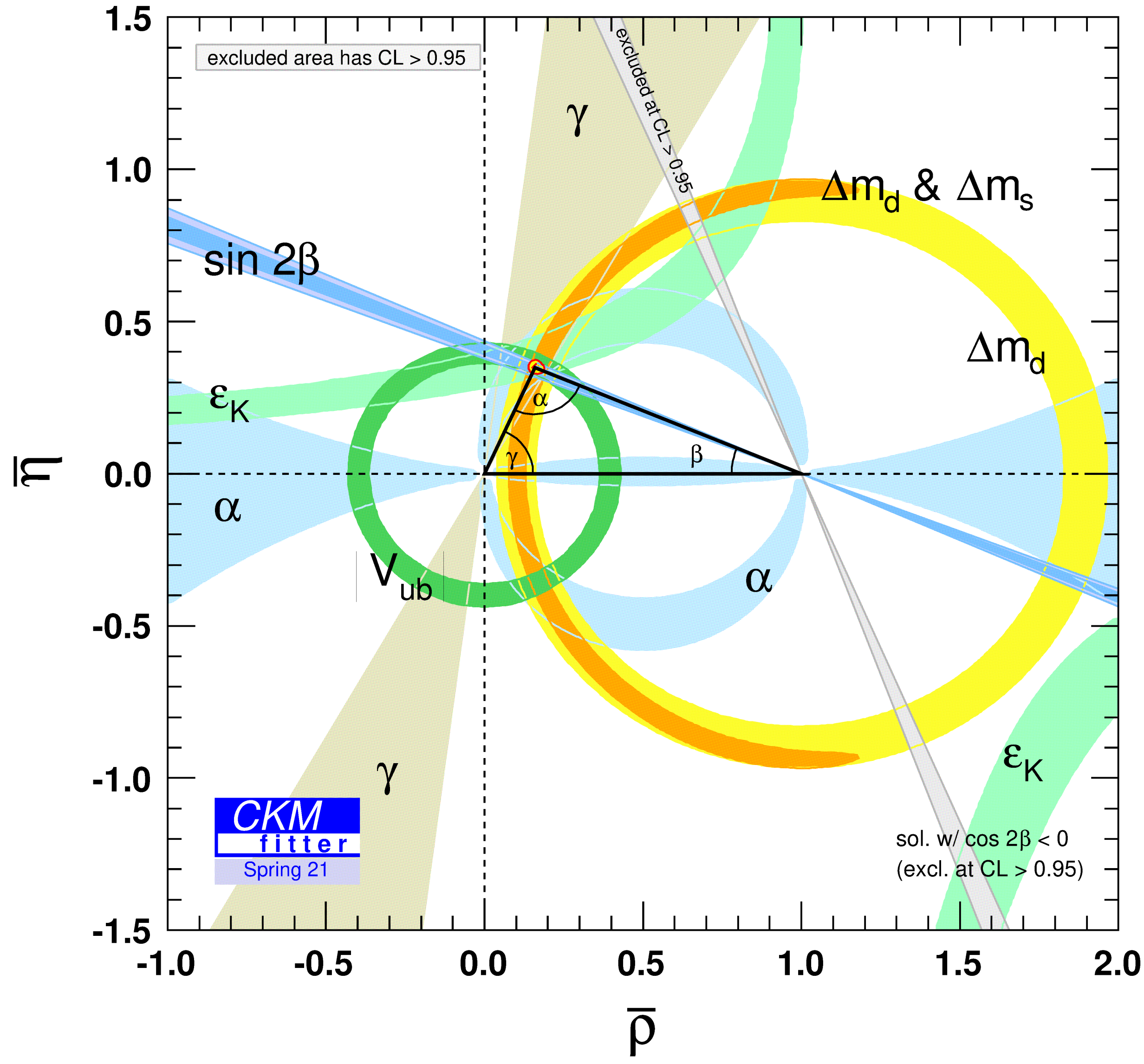
8.- $B^0 \rightarrow K^0_S \pi^0$

9.- Light lepton (μ/e) universality

10.- Conclusions

Why is matter so predominant in the universe ?

Why Matter so predominant in the universe ?



What is dark matter ?

Sterile neutrino ?

WIMP ?

Qball ?

Beyond the standard Model ?

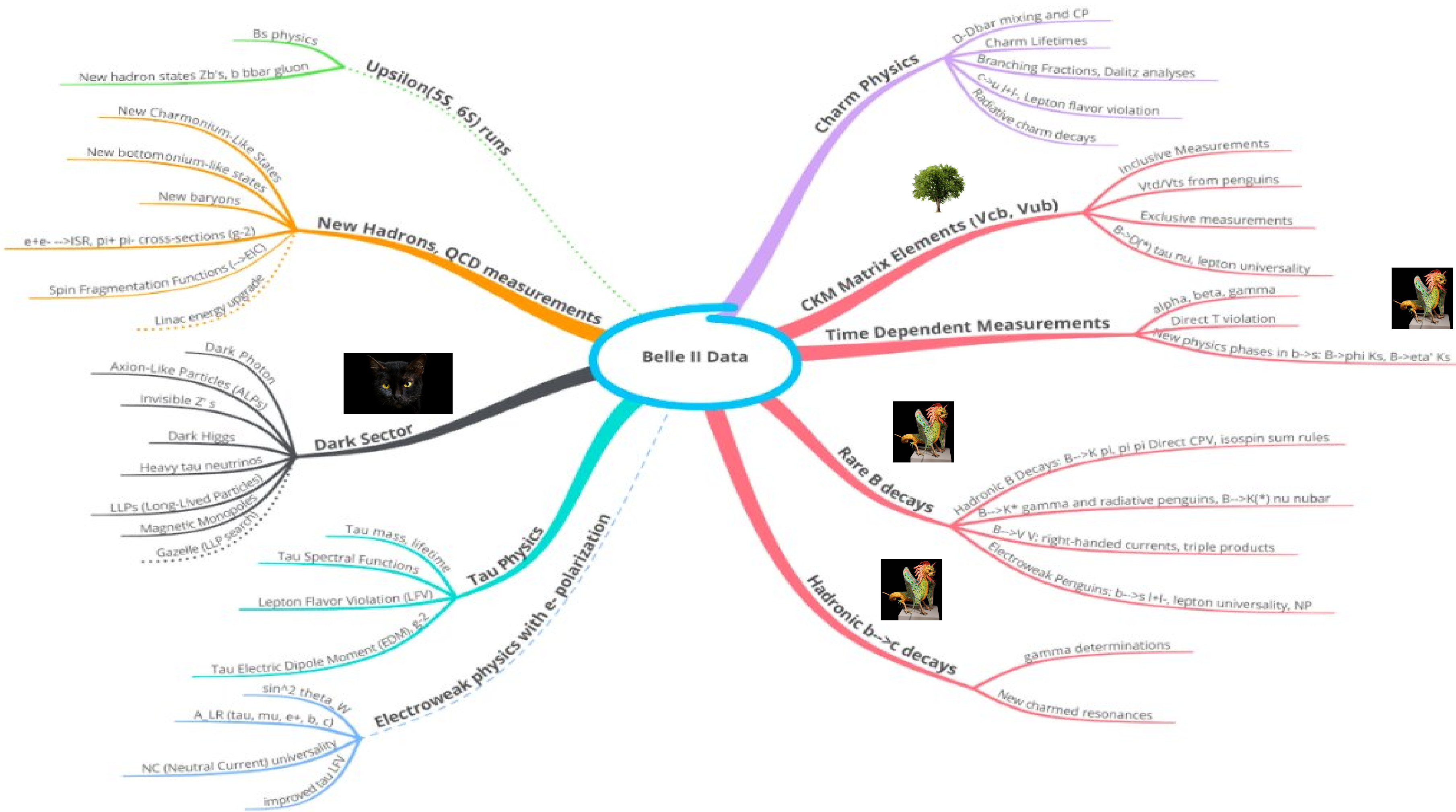
The SM describe very well the physics, but the whole picture seem…. Suspicious …

Belle II collaboration

26 countries and regions, 123 institutions, ~1100 collaborators

Armenia (1), Australia (3), Austria (1), Canada (5), China (12), Czechia (1), France (3), Germany (12), India (9), Israel (1), Italy (9), Japan (16),Malaysia (1), Mexico (3), Poland (1), Russia(6), Saudi Arabia(1), Slovenia(2), South Korea(9), Spain(1), Taiwan(3), Thailand(2), Turkey(1), USA (18), Ukraine (1), Viet Nam(1).

Belle II physics



40 new results past year, 20 accepted and submitted papers. More on the way

From KEKB to SuperKEKB

$$Instantaneous\ Target\ Luminosity:\ L = 6\,x\,10^{35}\,cm^{-2}s^{-1}$$

$$Achieved\ Luminosity\,(world\ record):L = 4.7\,x\,10^{34}\,cm^{-2}s^{-1}$$

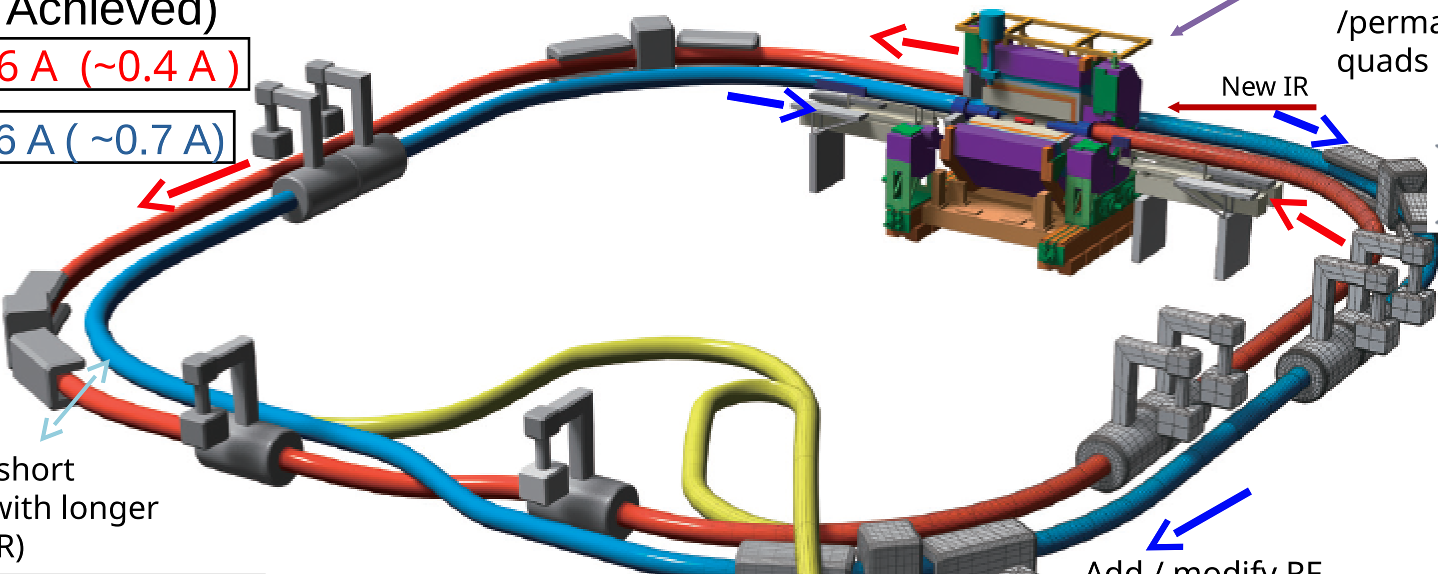
Target (Achieved)

e^+ 4GeV 3.6 A (~0.4 A)

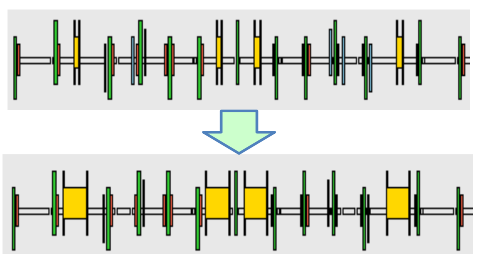
e^- 7GeV 2.6 A (~0.7 A)

Belle II

New superconducting /permanent final focusing quads near the IP

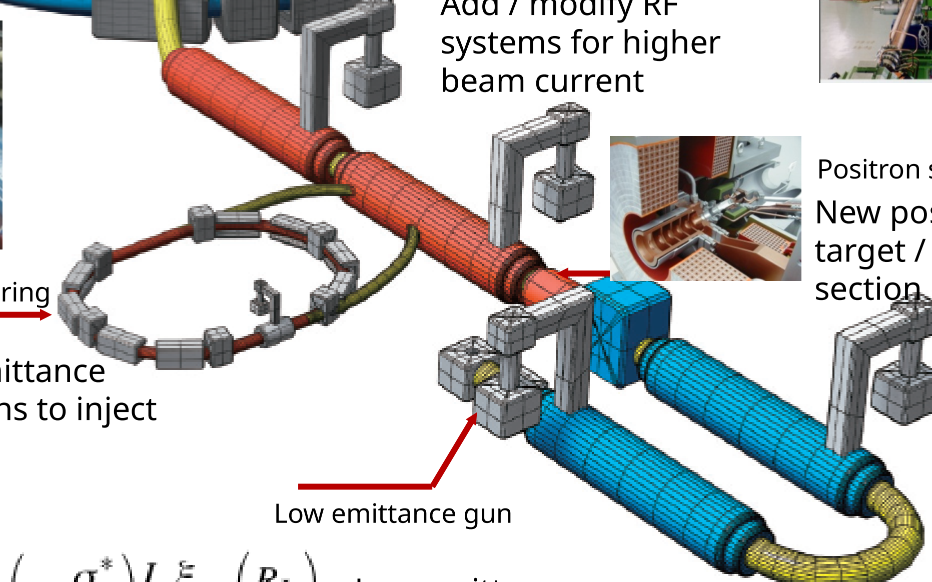


Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance

Add / modify RF systems for higher beam current

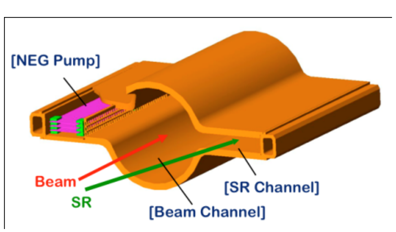


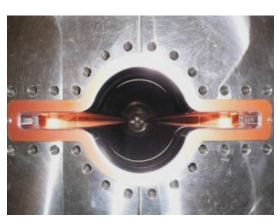
Positron source

New positron target / capture section

Low emittance positrons to inject

TiN-coated beam pipe with antechambers



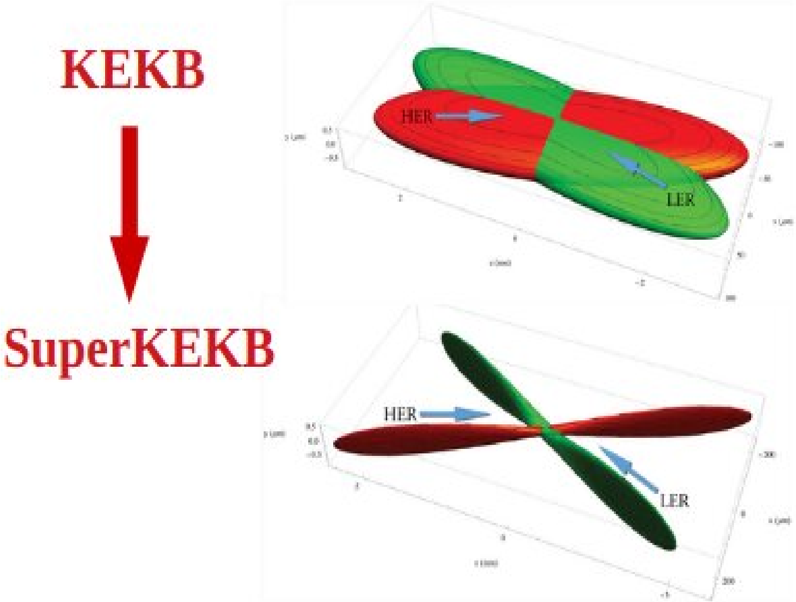


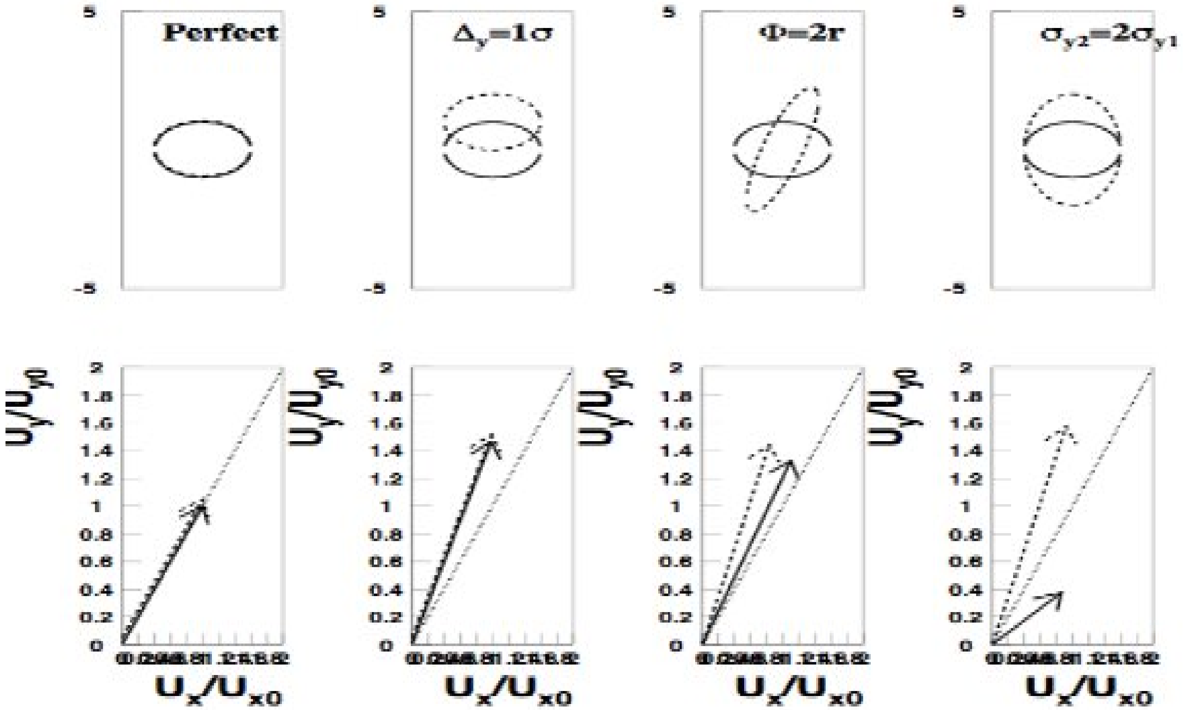
$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

Low emittance electrons to inject

Large Angle Beamstrahlung Monitor (LABM)

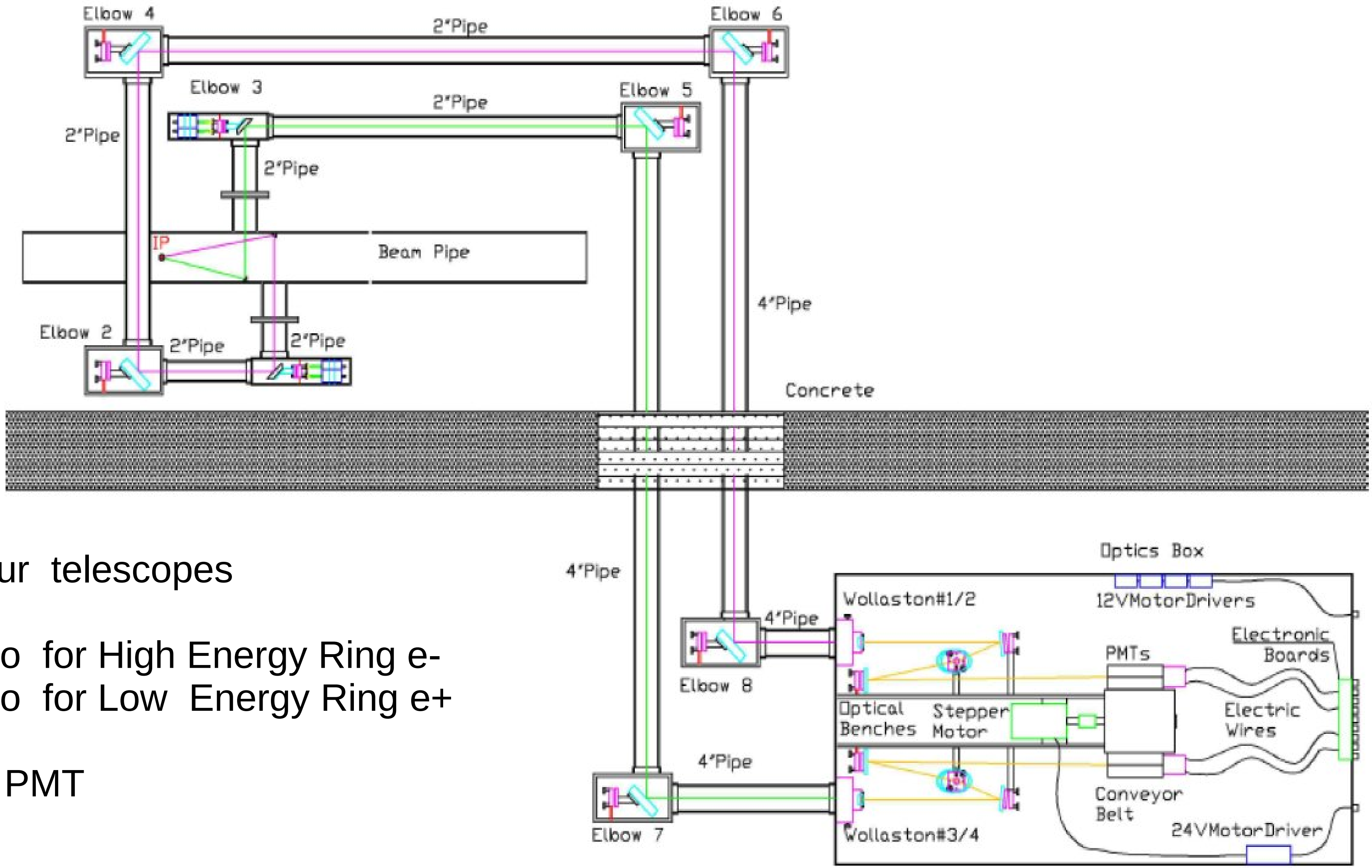
- Bremsstrahlung light produced by the interaction of one beam and the electromagnetic field of the other. Useful for **nanobeam**, Based in measurement of polarization.





Some examples of large angle BMST pattern recognition (collinear beams case)
3 asymmetries are defined (4 are possible)

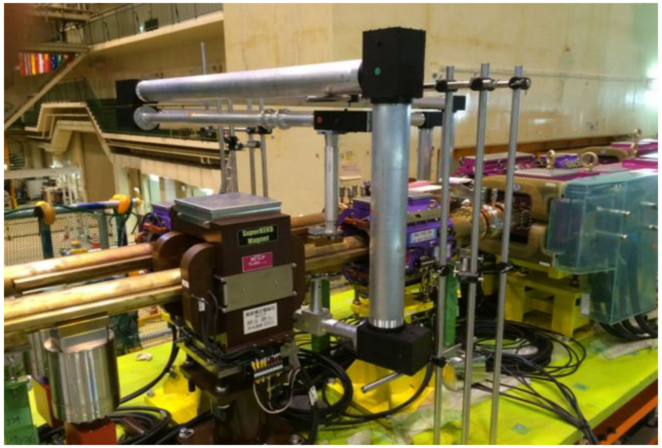
LABM diagram



Four telescopes

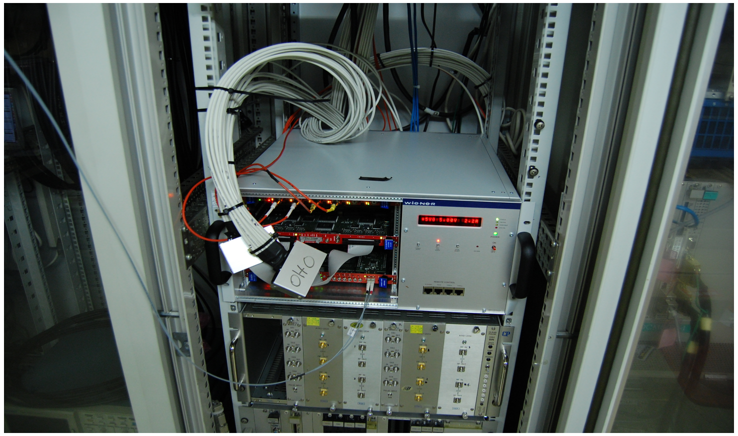
Two for High Energy Ring e-
Two for Low Energy Ring e+

32 PMT

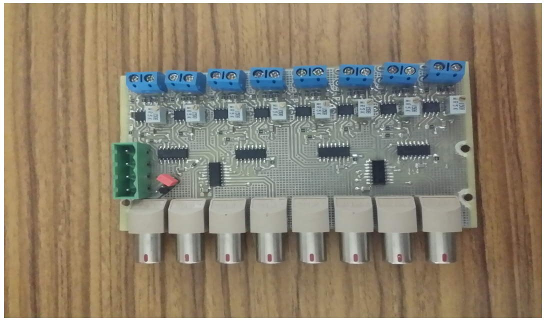


Connection to beam line

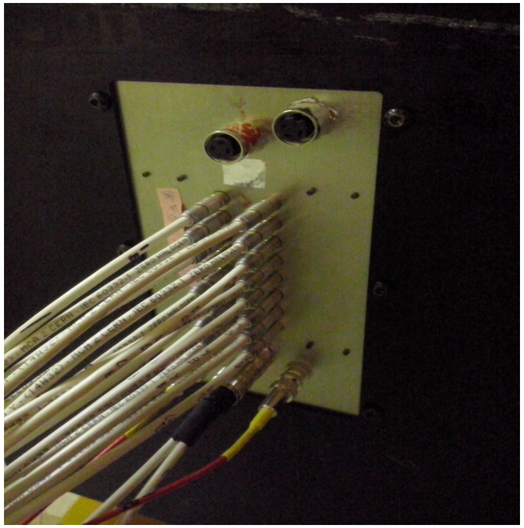
Optical line (4)

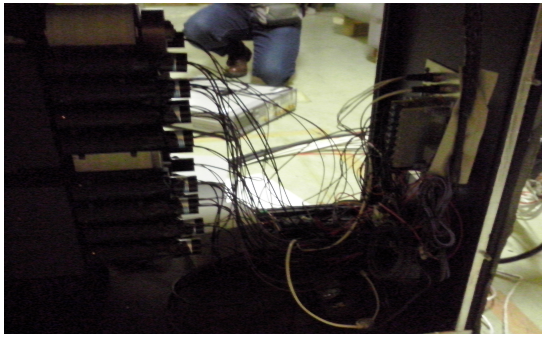


Scaler, power supply (16)



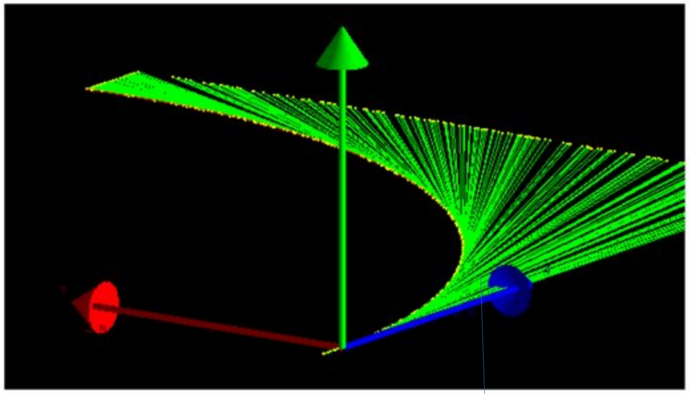
Digitization card (4)



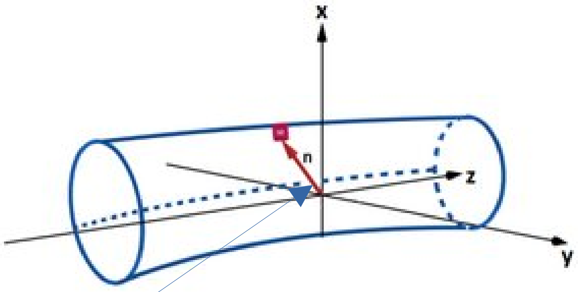


Photomultipliers (32)

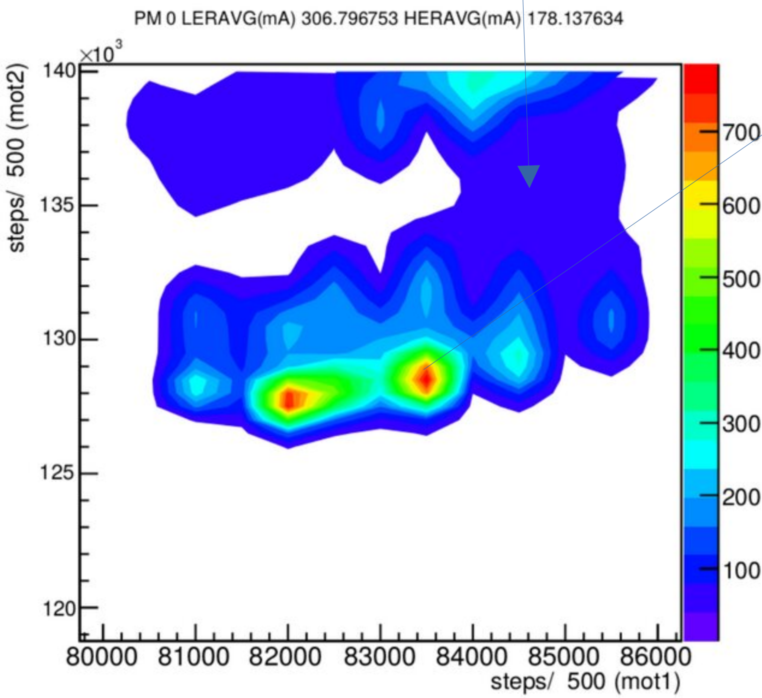
LABM scans

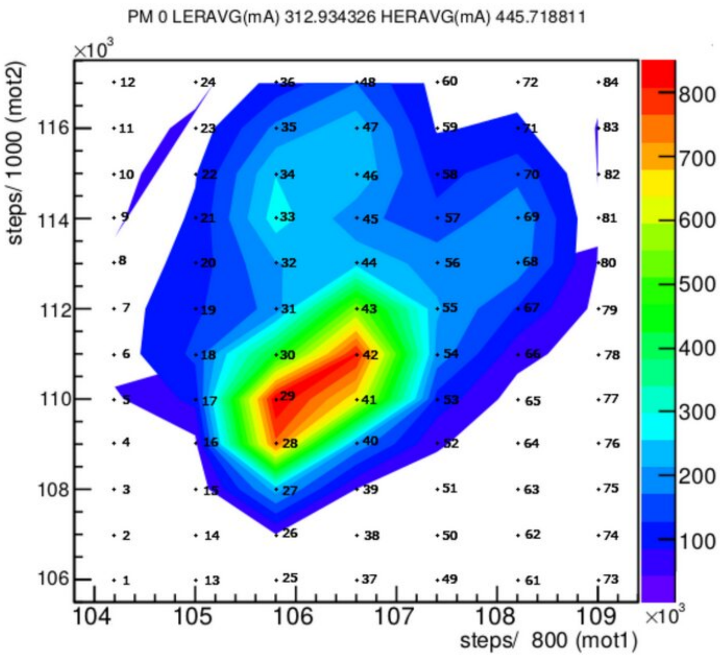


Synchrotron radiation (Geant4)



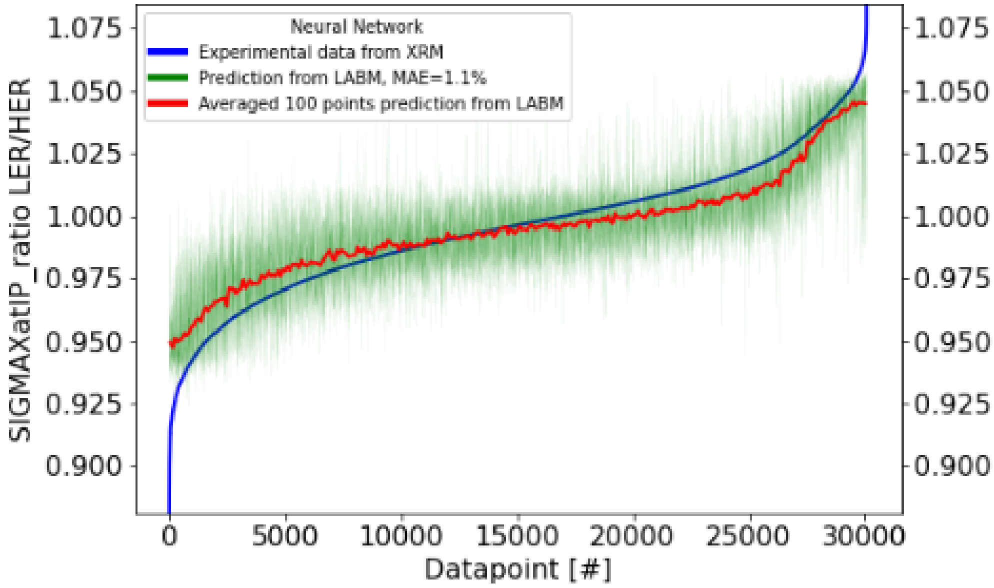
Beamstrahlung radiation (kind of a laser Beam)

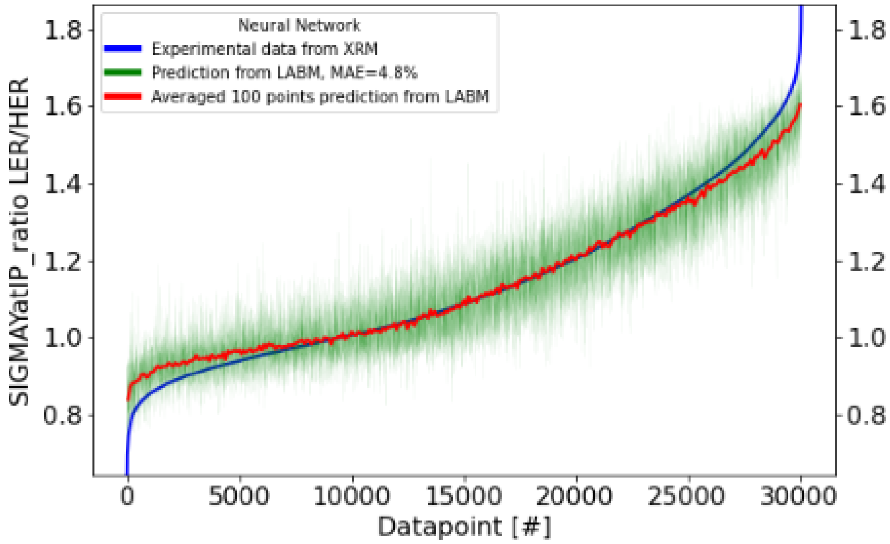




Heat map for signal (parallell vs vertical position of the primary mirror) Blue synchrotron radiation, Red Beamstrahlung radiation .

Analysis of data using a neural network





We had the first publication in 2022

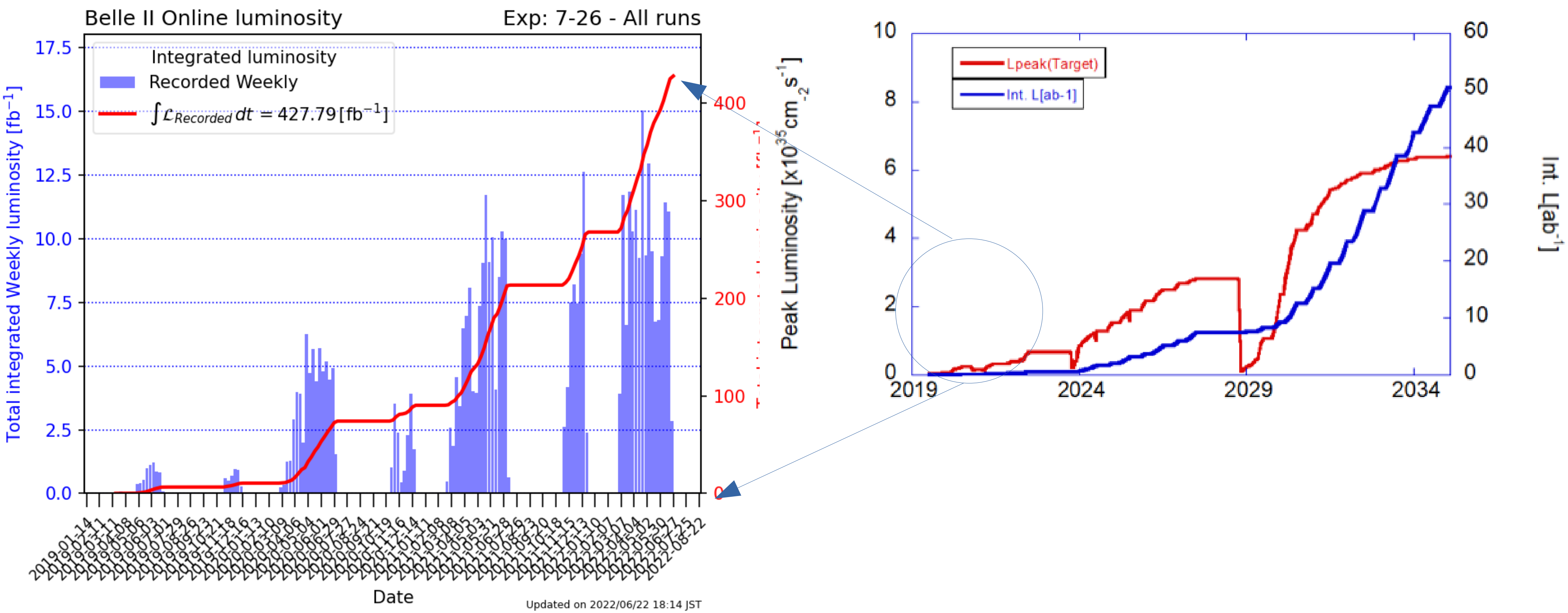
https://arxiv.org/abs/2206.11709

We can see Beamstrahlung Radiation !!!

Upgrade (November 2023)

- Replace PMT by cameras
- Fix motor issues and new control
- New DAQ and data

Luminosity status



- Record instantaneous luminosity: 4.7 x 10 ^{34} cm^{-2} s^{-1};

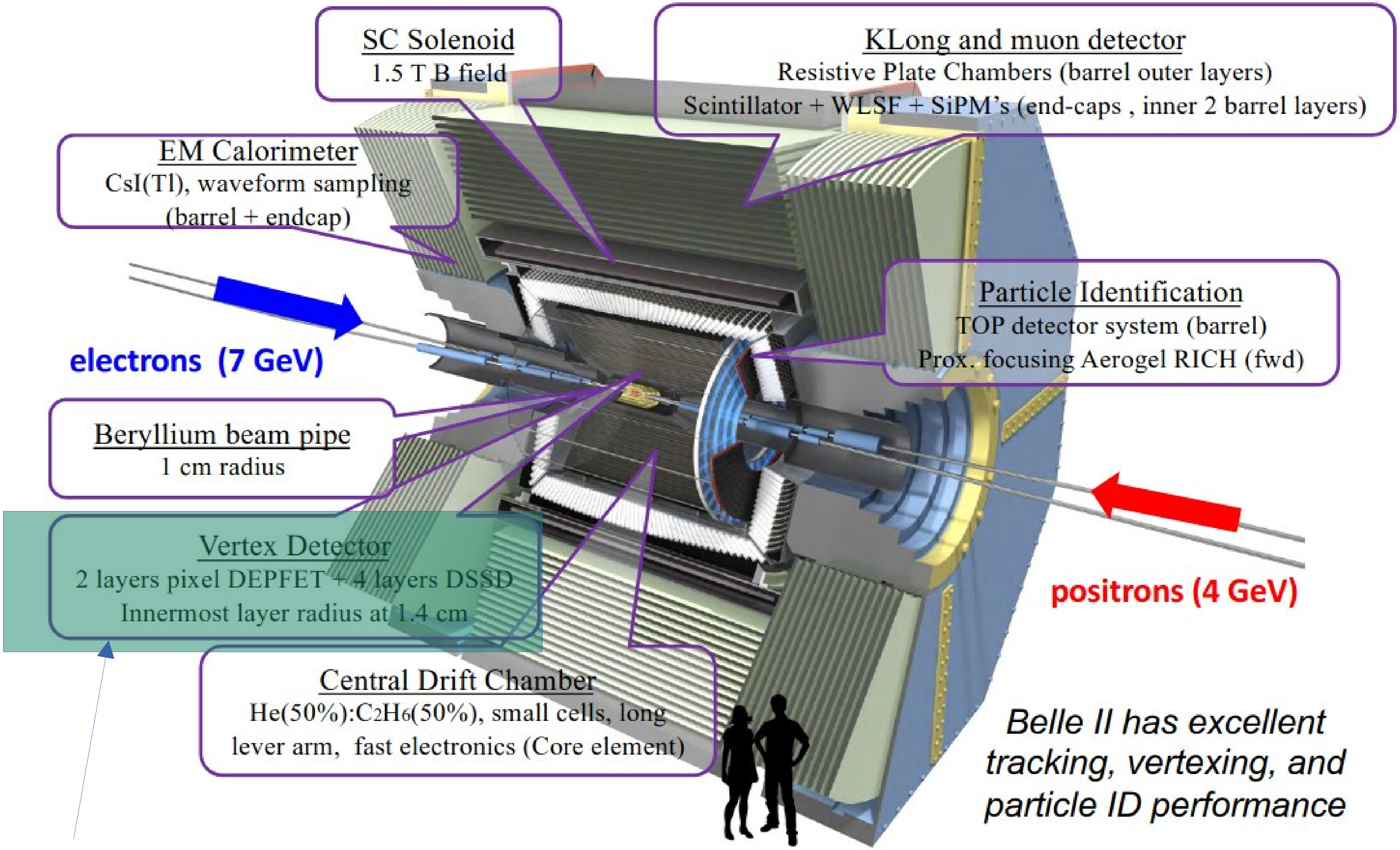
- 2023 we had nine month long shutdown to complete the vertex detector,

- Resume data taking in December 11, 2023.

Belle II Luminosity

https://confluence.desy.de/display/BI/Belle+II+Luminosity

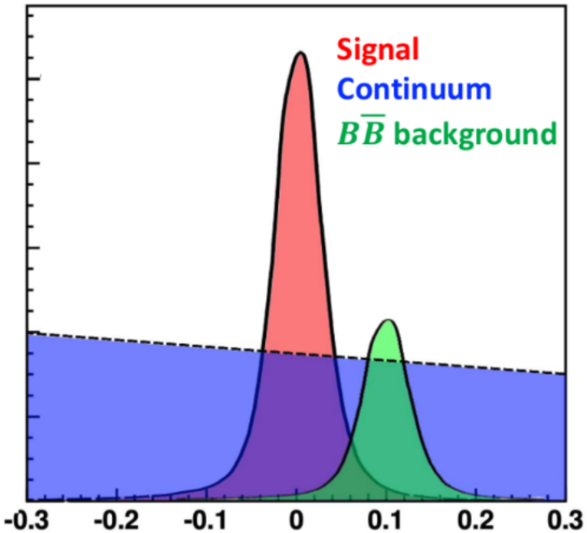
Belle II detector



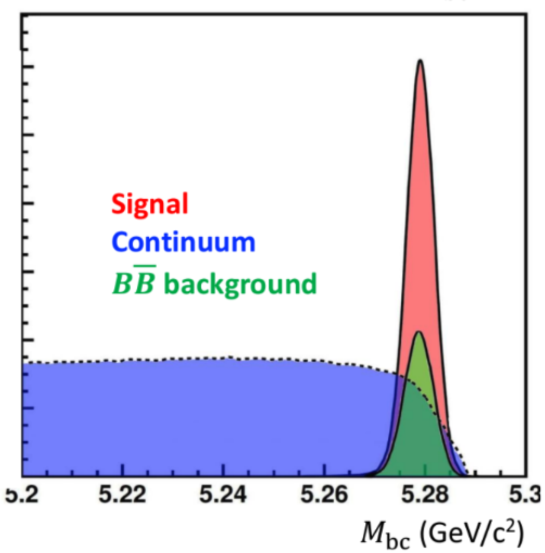
FULLY INSTRUMENTED, after shutdown

The Belle II workhorses

$$\Delta E = E_B^* - \sqrt{s}/2$$



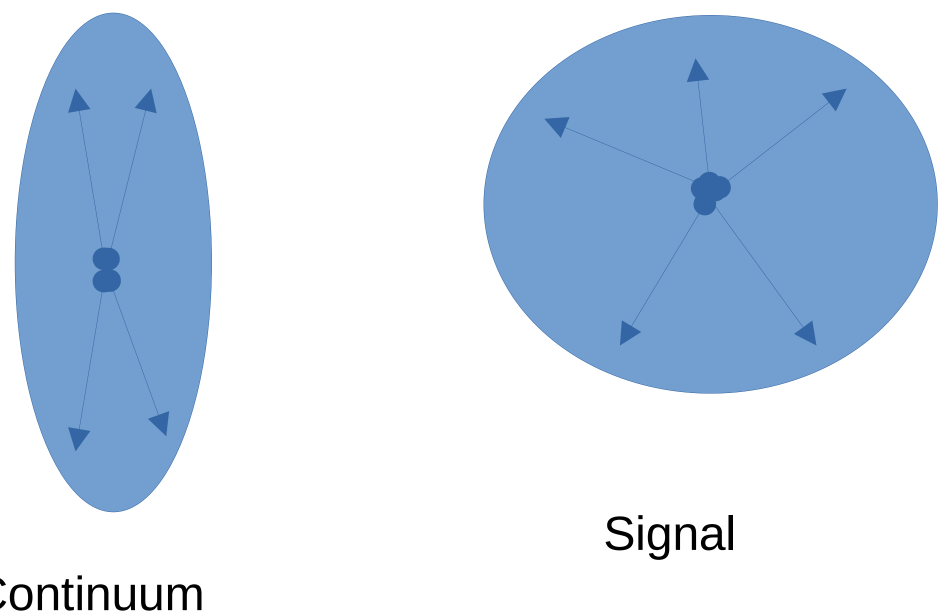
$$M_{bc} = \sqrt{(\sqrt{s}/2)^2 - \vec{p}_B^{*2}}$$



Kinematics:

- Invariant B mass replaced by half of the collision energy.
- Difference between expected and observed energy.

Event Shape

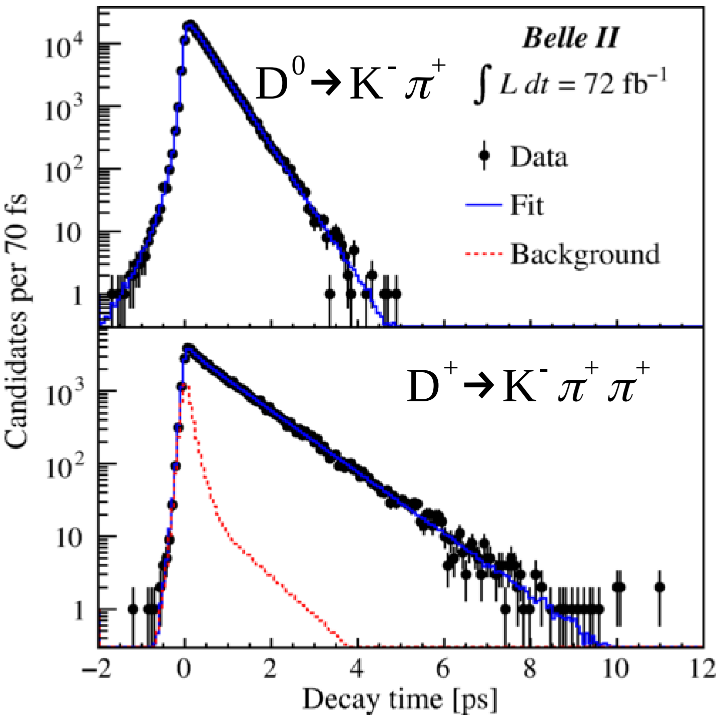


Belle II is much more than Belle with more data

- Is a new detector: Only magnet and calorimeter is reused, basically new detector
- Is new algorithms: Particle Identification, Full Event Interpretation, Charm tagger, Flavor tagger coming soon.
- Is a new accelerator with a novel strategy to increase luminosity.
- Let us see this over the following slides

D^0/D^+ Lifetime

- Main PDG result from FOCUS 20 years old
- Useful for LHCb in D_s^+
- No input from simulation
- Blind analysis
- 2D fit, mass and lifetime
- Mass signal: Two Gaussians + Crystal Ball
- Mass background: exponential
- Lifetime: convoluted exponential for signal



Results (Most Precise In the world)

$$\tau(D^0) = (410.0 \pm 1.1 \pm 0.8)\,fs$$

$$\tau(D^+) = (1030.4 \pm 4.7 \pm 3.1)\,fs$$

Phys, Rev. Lett. 127, 211801 (2021)

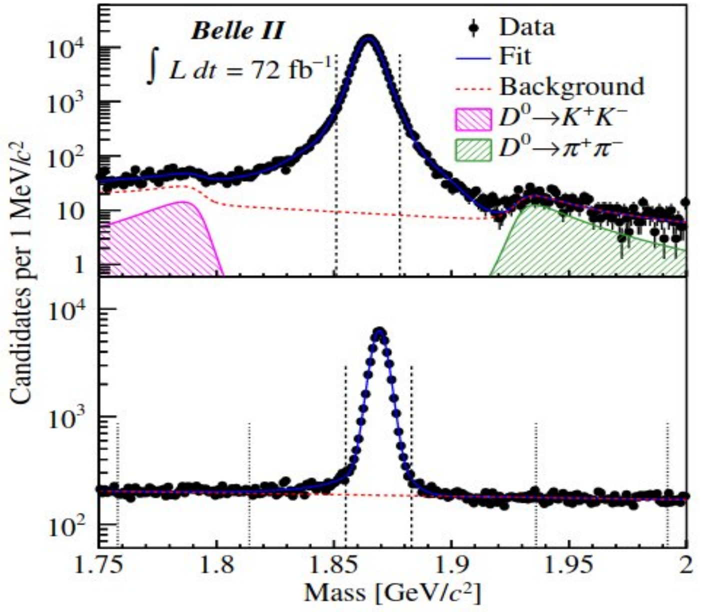
More Lifetime results (Most precise)

$$\tau(\Lambda_c^+) = (203.2 \pm 0.9 \pm 0.8)\,fs$$ Phys.Rev.Lett. 130 071802 (2023)

$$\tau(D_s^+) = (498.7 \pm 1.7 (+1.1/-0.8))\,fs$$ arXiv:2306.00365

Lifetime result (Highly competitive)

$$\tau(\Omega_c^0) = (243.0 \pm 48.0 \pm 11.0)\,fs$$ Phys. Rev. D 107 L031103 (2023)



τ physics

- Cross section similar to **b** so Belle II is a **τ factory** !!!
- Belle II will be leading **τ** Physics for the next decade
- Neutrino always involved full event never fully reconstructed.
- Not as thoroughly studied as the B sector.
- BSM physic in the **τ** sector ???
- Strong participation of the Mexican group.

τ Mass

The least precise measurement of the charged leptons

$$m_e = (.5109989461 \pm 0.0000000031)\, MeV/c^2$$
$$m_\mu = (105.6583745 \pm 0.0000024)\, MeV/c^2$$
$$m_\tau = (1776.86 \pm 0.12)\, MeV/c^2$$

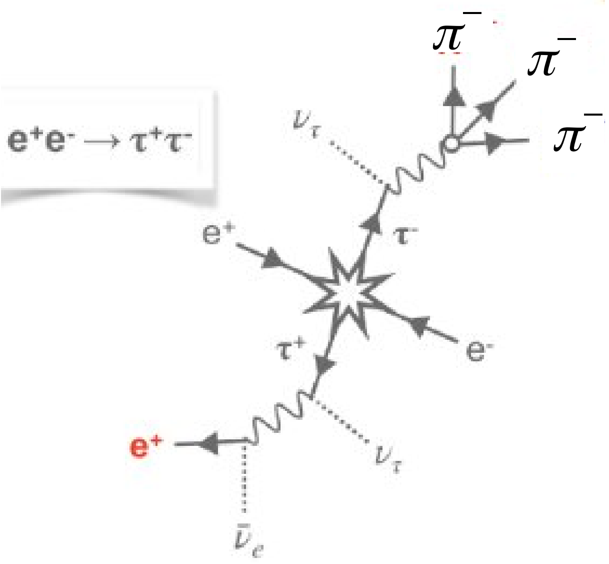
Measured in the decay mode $\tau \to 3\pi\nu$, using a pseudomass technique developed by the **ARGUS** collaboration.

The tau mass can be calculated as

$$m_\tau^2 = (p_h + p_\nu)^2$$
$$= 2E_h(E_\tau - E_h) + m_h^2 - 2|\vec{p}_h|(E_\tau - E_h)\ \cos(\vec{p}_h, \vec{p}_\nu)$$

As the direction of the neutrino is not known, the approximation $\cos(\vec{p}_\nu, \vec{p}_h) = 1$ is taken, resulting in

$$M_{\min}^2 = 2E_h(E_\tau - E_h) + m_h^2 - 2|\vec{p}_h|(E_\tau - E_h)\ < m_\tau^2$$

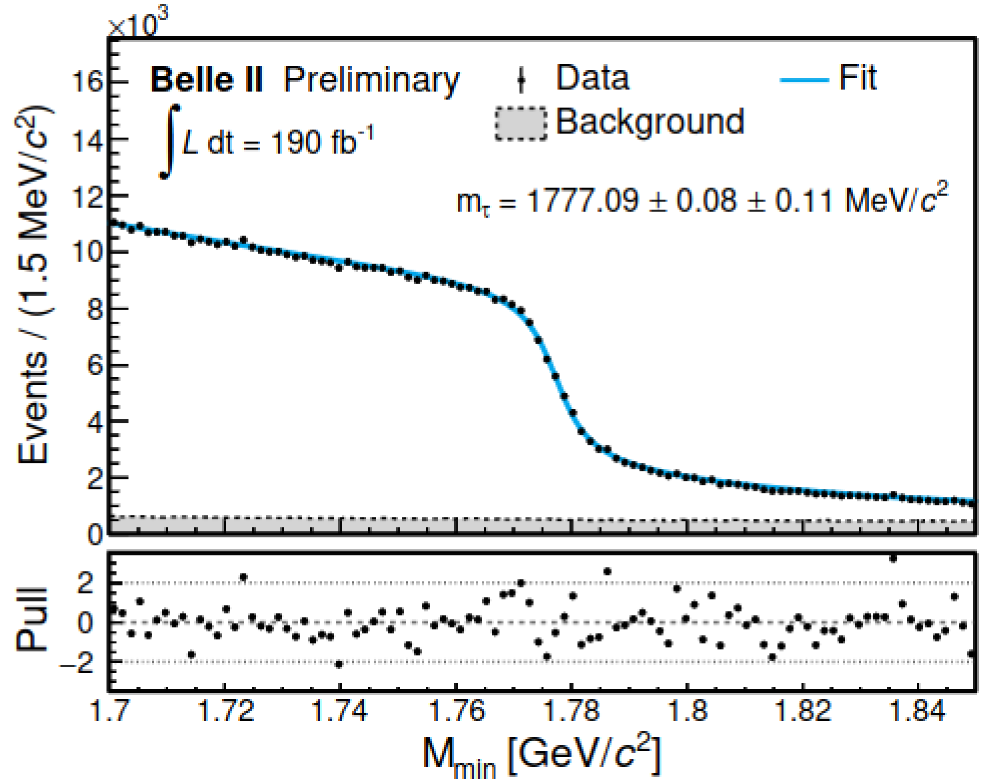


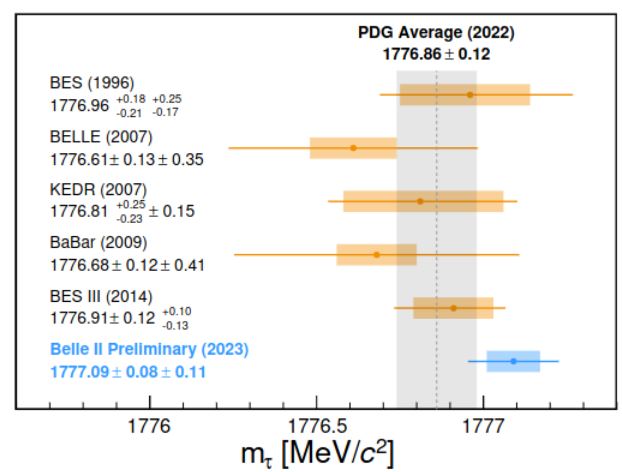
Then, the distribution of the pseudomass is fitted to an empirical edge function, and the position of the cutoff indicates the value of the mass.

Fit to edge in the p.d.f in the cutoff region

$$F(M_{\min}, \vec{P}) = (P_3 + P_4 M_{\min}) \cdot \tan^{-1}[(M_{\min} - P_1$$

Source	Uncertainty [MeV/c^2]
Knowledge of the colliding beams:	
Beam-energy correction	0.07
Boost vector	< 0.01
Reconstruction of charged particles:	
Charged-particle momentum correction	0.06
Detector misalignment	0.03
Fit model:	
Estimator bias	0.03
Choice of the fit function	0.02
Mass dependence of the bias	< 0.01
Imperfections of the simulation:	
Detector material density	0.03
Modeling of ISR, FSR and τ decay	0.02
Neutral particle reconstruction efficiency	≤ 0.01
Momentum resolution	< 0.01
Tracking efficiency correction	< 0.01
Trigger efficiency	< 0.01
Background processes	< 0.01
Total	0.11



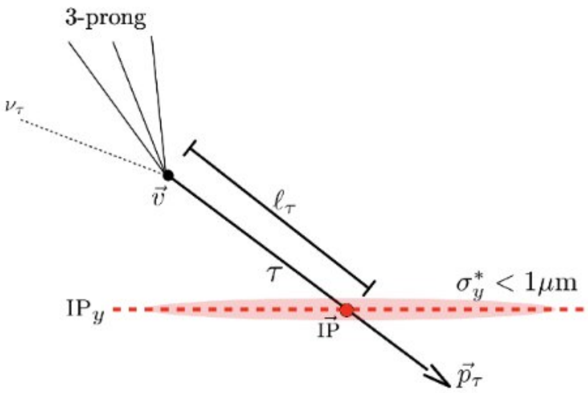


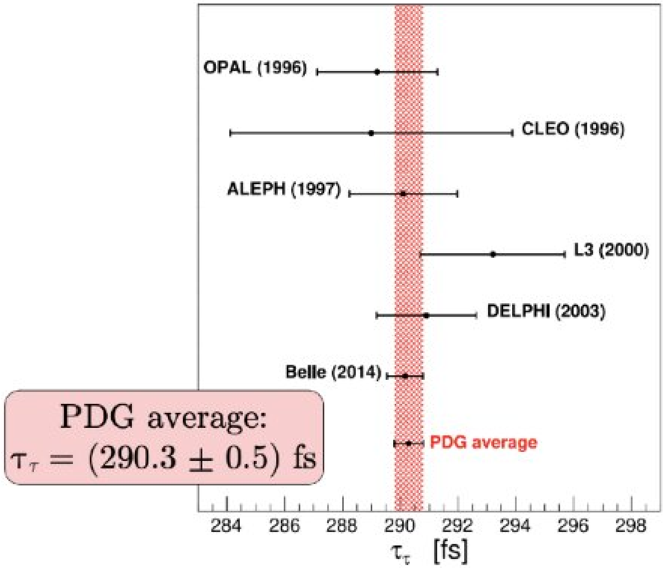
Submitted to PRD in **May 30 2023**
https://arxiv.org/abs/2305.19116

Best Result in the WORLD !!

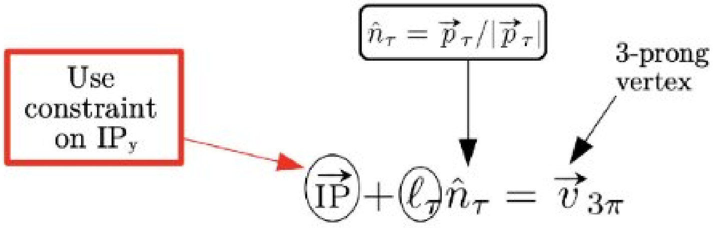
τ lifetime

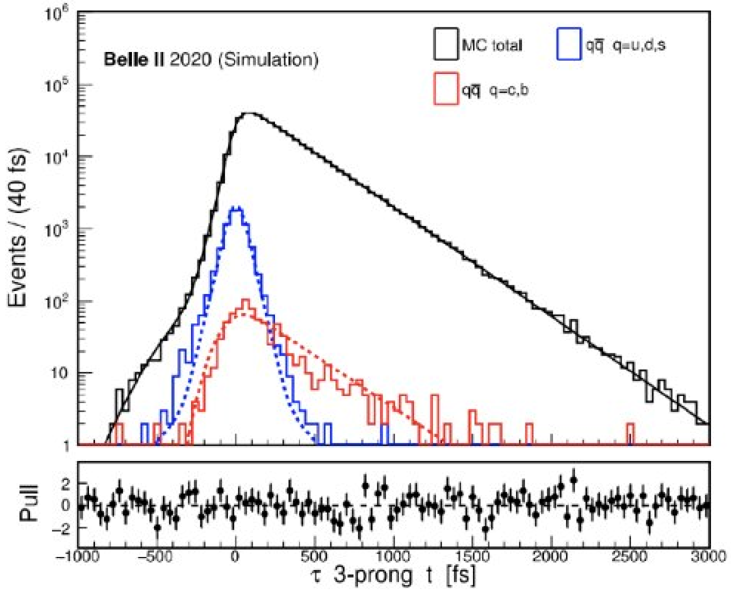
3 prong in one side for Belle II
 -Better statistics
3 prong in two sides for Belle





- ℓ_τ reconstruction and IP constrain:





- Lifetime extraction:
  - **$\tau_\tau = 287.2 \pm 0.5$ (stat) fs**
  - Same statistical uncertainty of Belle.
    (200 fb^{-1} vs 711 fb^{-1})

Isospin sum rule: $B \to K^+\pi^-, K^+\pi^0, K^0\pi^+$

- Isospin sum-rule relation for $B \to K\pi$ provides a stringent SM test

$$I_{K\pi} = \mathcal{A}_{K^+\pi^-} + \mathcal{A}_{K^0\pi^+}\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^+\pi^0}\frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^0\pi^0}\frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)} = 0$$

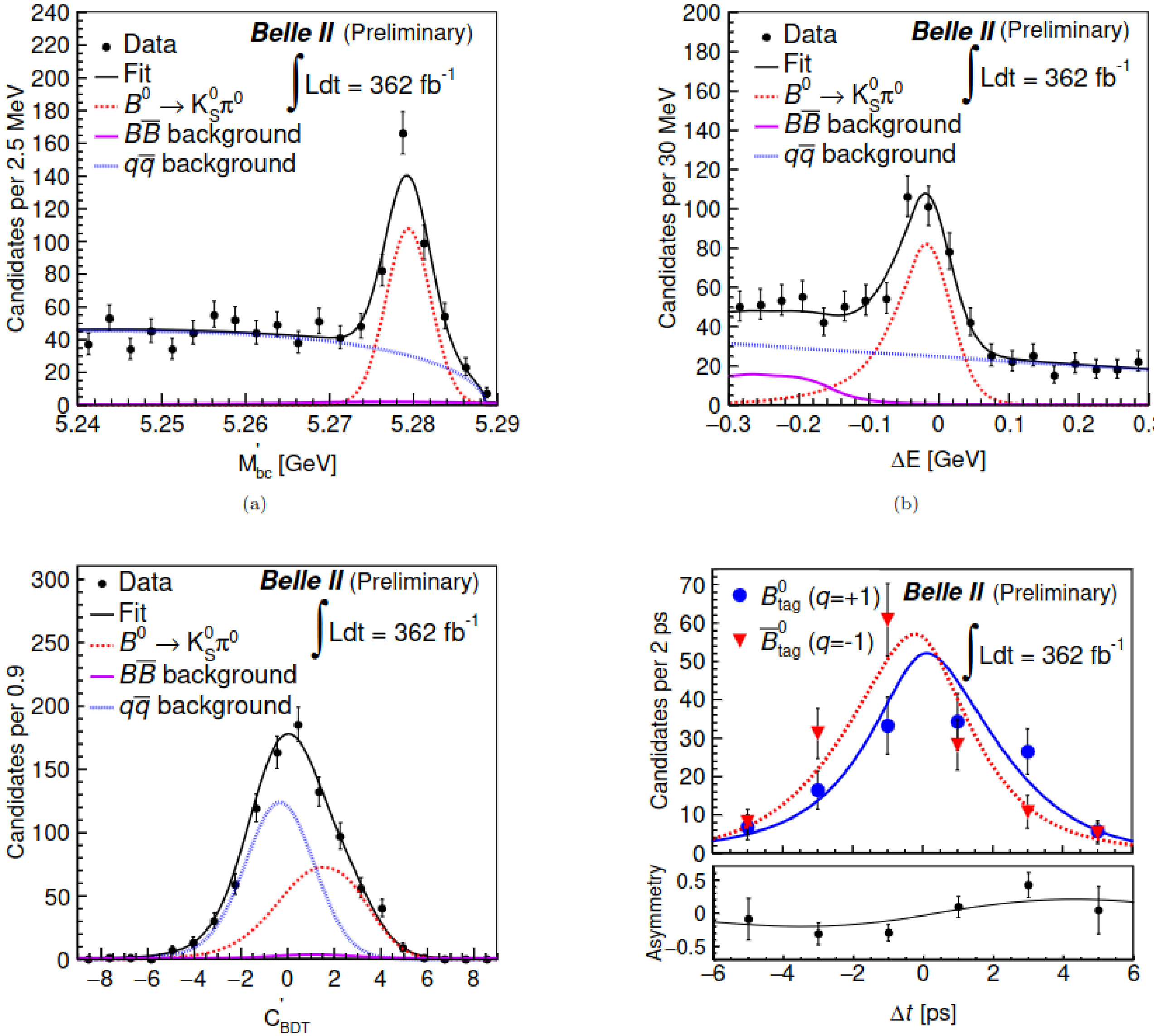
(Phys.Lett. B627 (2005) 82-8)

- 1% precision in the SM

- Experimental precision is 11% dominated by **$B^0 \to K^0\pi^0$**

- Unique to Belle II but hard: it's rare, it involves π^0 and K^0 also if B0 or B0 was produced.

$B^0 \rightarrow K^0_S \pi^0$



$$A = 0.04 \pm 0.15(stat) \pm 0.05(syst)$$

$$B = (10.5 \pm 0.6(stat) \pm 0.7(syst))\ x\ 10^{-0}$$

BSM in b → sqq

Isoespin sum rule

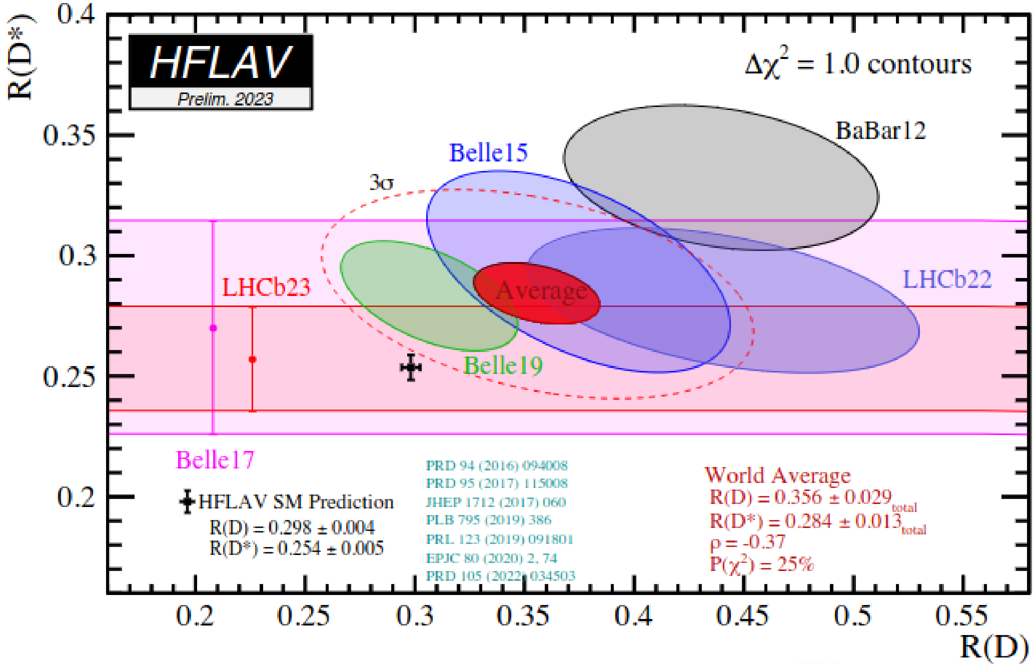
$I_{K\pi}$ = − 0.03 ± 0.13(stat) ± 0.05 (syst)

$I_{K\pi}$ (World average) = − 0.13 ± 0.11

$I_{K\pi}$ (SM) = 0

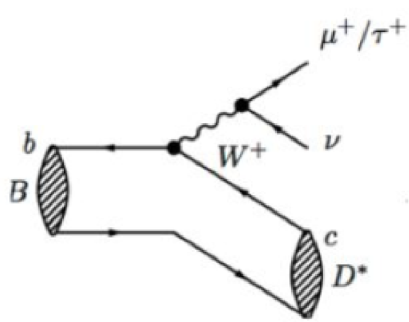
https://arxiv.org/abs/2305.07555

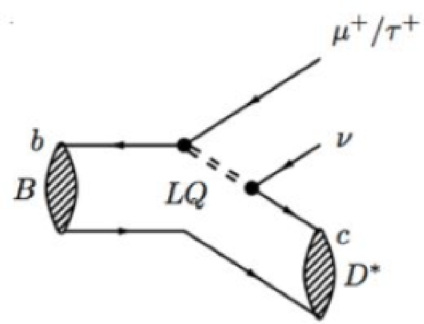
Hints of New Physics in semileptonic B decays



$$R(D^*) \equiv \frac{\mathcal{B}(\bar{B} \to D^{*+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{*+}\ell^-\bar{\nu}_\ell)}$$

$$R(D) \equiv \frac{\mathcal{B}(\bar{B} \to D^{+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{+}\ell^-\bar{\nu}_\ell)}$$



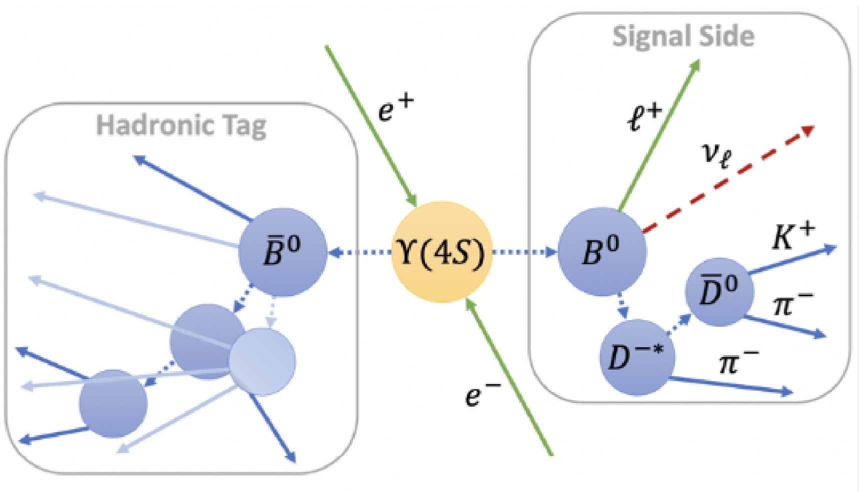


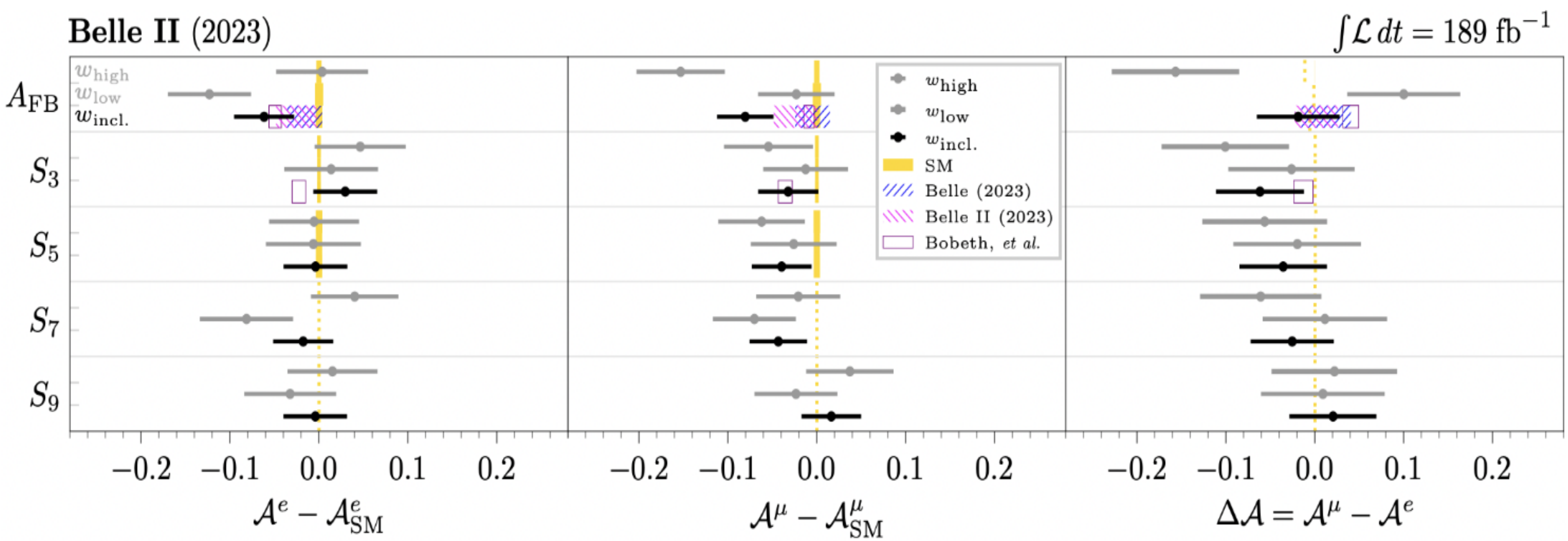
As a first step testing light lepton (μ/e) universality

$B^0 \to D^{*-}\mu^+ \nu$ and $B^0 \to D^{*-}e^+ \nu$

SM consistent within 10%

A_{FB} is an asymmetry that measure the likelihood of the lepton to travel in the same direction as the W

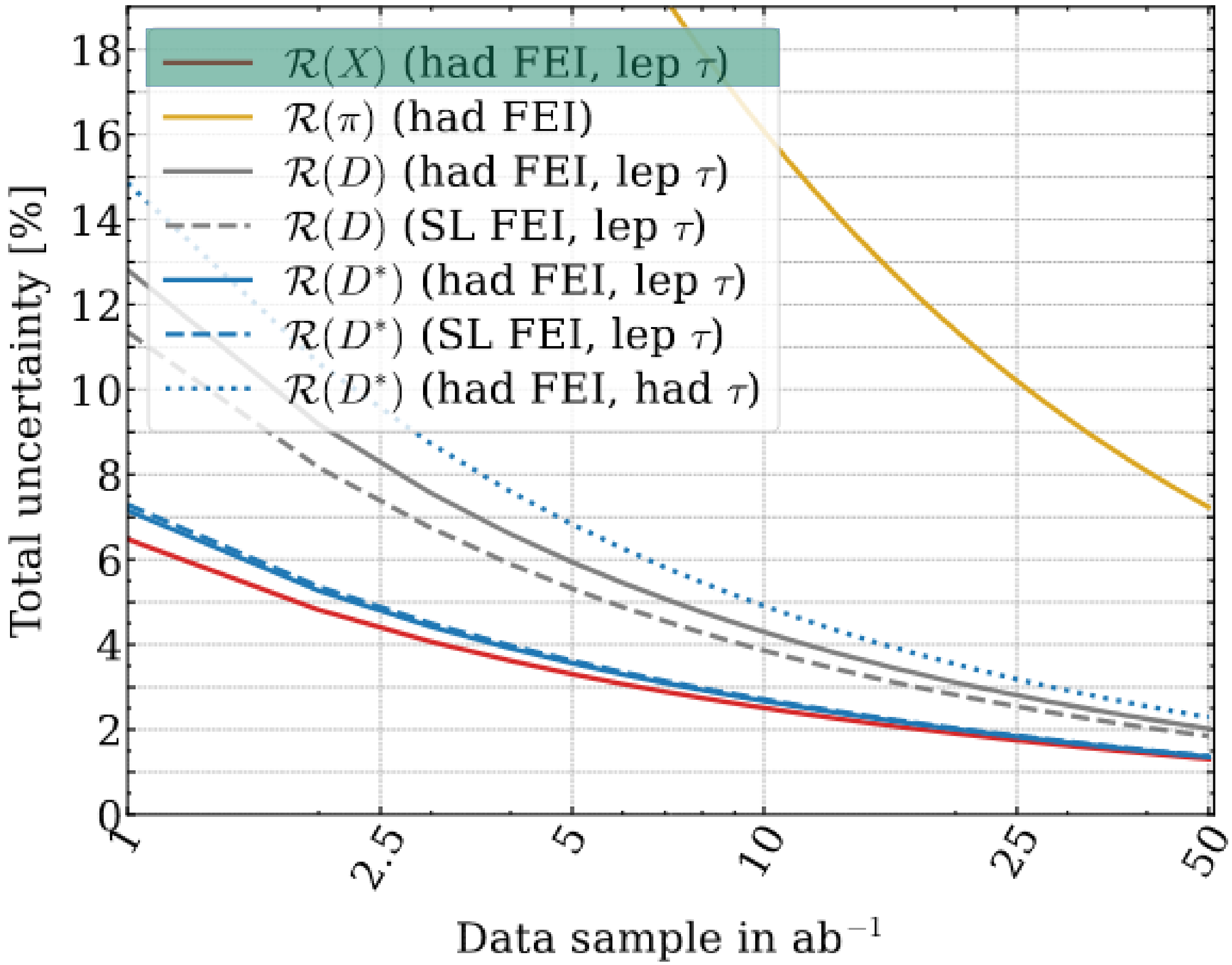




arXiv:2301.07529 [arXiv:2301.04716]

Muon – electron universality inclusive projection

arxiv:2207.06307

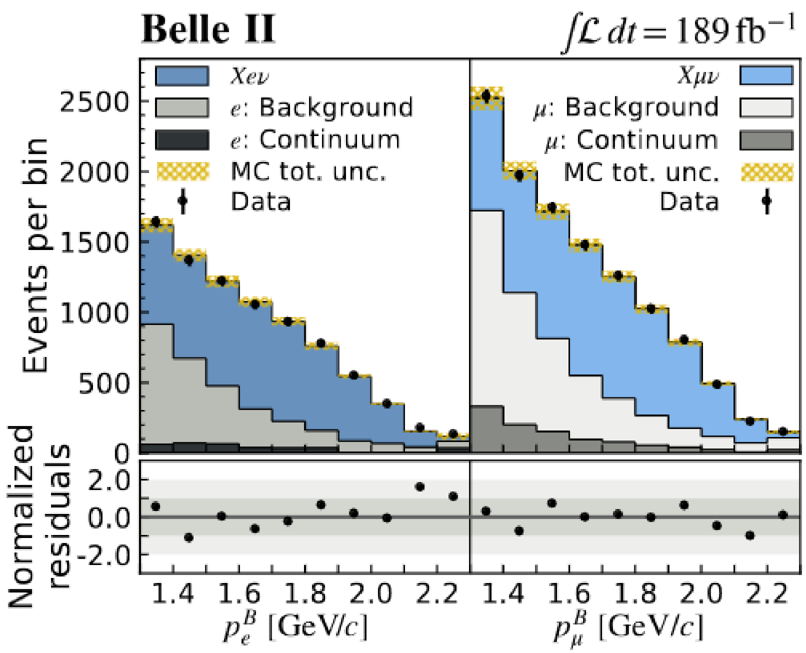


Semileptonic B decays

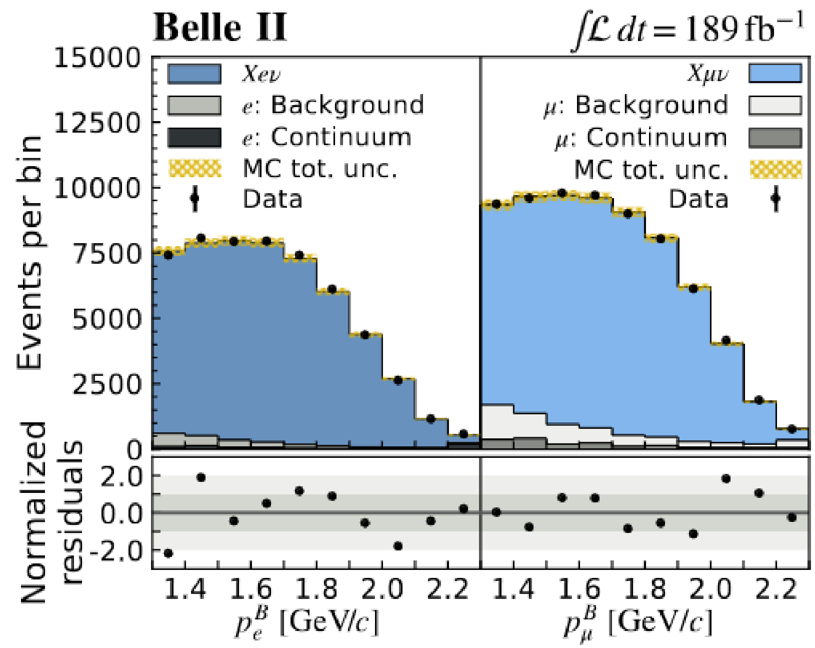
$R(X_{e/\mu}) = B(B \to X e \nu) / B(B \to X \mu \nu)$,

arxiv:2301.08266

Control channel (B^0 B^0) / (B^+ B^+)



Signal channel (B^{0+} $\overline{B}^0$/B^+ B^-)



$R(X_{e/\mu})$ = 1.007 ± 0.009 (stat) ± 0.019 (syst)	Belle II
$R(X_{e/\mu})$ = 1.006 ± 0.001	SM

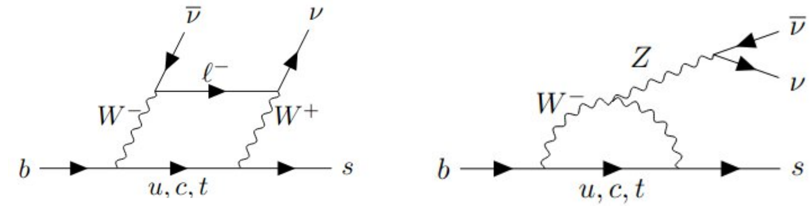
Consistent with SM $R(X_{e/\mu})$ {1} by 1.2 sigma and with the exclusive Belle $R(X_{e/\mu})$ {2, 3}

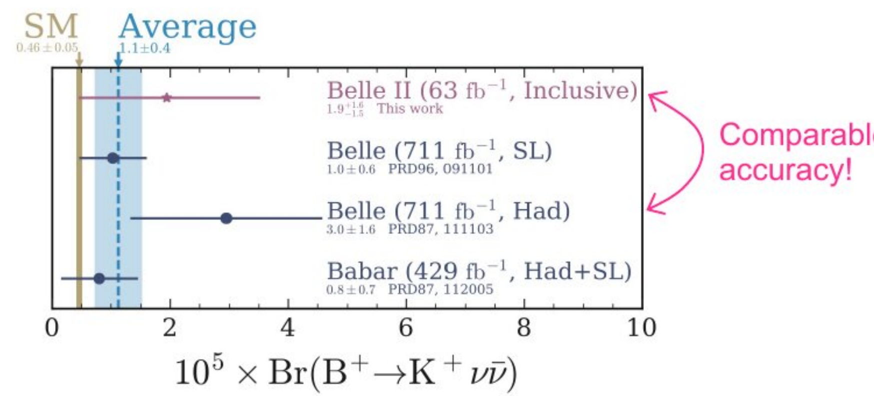
[1] J. High Energy Phys. 11, 007 (2022), [2] Phys. Rev. D 100, 052007 (2019) [3] arXiv:2301.07529

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

- Flavor changing neutral current
- SM prediction is 4.6 x 10^{-06}
- Enhancement means physics BSM
- Measuring a limit helps in constraining models for leptoquarks, axions, dark matter.

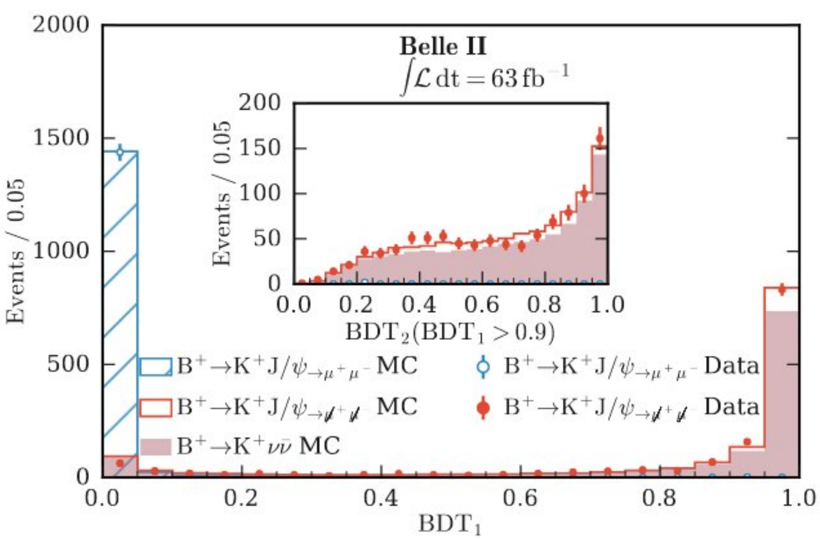
Analysis based in BDT, use well known $B^+ \rightarrow K^+ J/\Psi$ is used as validation.
Inclusive tagging: 4% Efficiency (Belle II)
Semileptonic: 0.2 % Efficiency (Belle)

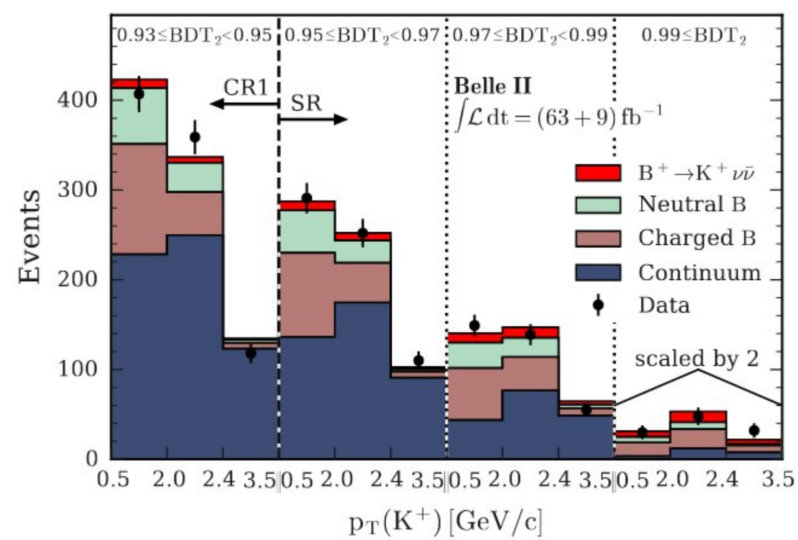




$$\textit{Observed}\,(\textit{Expected})$$

$$B^+ \rightarrow K^+ \; \nu\bar{\nu} \; < \; 4.1\,(1.9)\, x\, 10^{-5} @ 90\,\%\, CL$$





Phys. Rev. Lett. 127, 181802 (2021)

Conclusions

- SuperKEK has been increasing in delivering luminosity. It is hard but we are progressing to achieve this goal.
- Beamstrahlung radiation can be observed in superKEK.
- The upgraded detector is working smoothly and new tools in beam, software, tagging allowed us to get competitive results with less data than in Belle.
- First steps in τ physics program best world measurement of τ Mass. We expect exciting results over the next years in Belle II.
- Lifetimes in D, B are the best in the world, with fully vertex instrumented these will be even better.
- Lepton universality seems to hold for the light ones.
- We are working in multiple searches for New Physics, BUT so far none has been observed at least in FCNC In B+ and isosespin in $B \rightarrow K^{+}\pi$.
- Mexican participation in the collaboration is consolidated.

GRACIAS

BELLE II LEGO

75 bloques menos de 10 minutos

https://build-your-own-particle-detector.org/models/belle-2-micro-model/