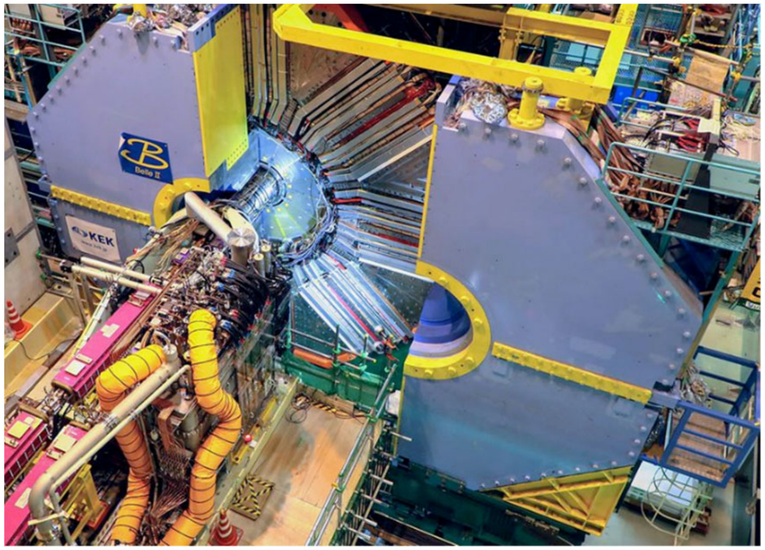

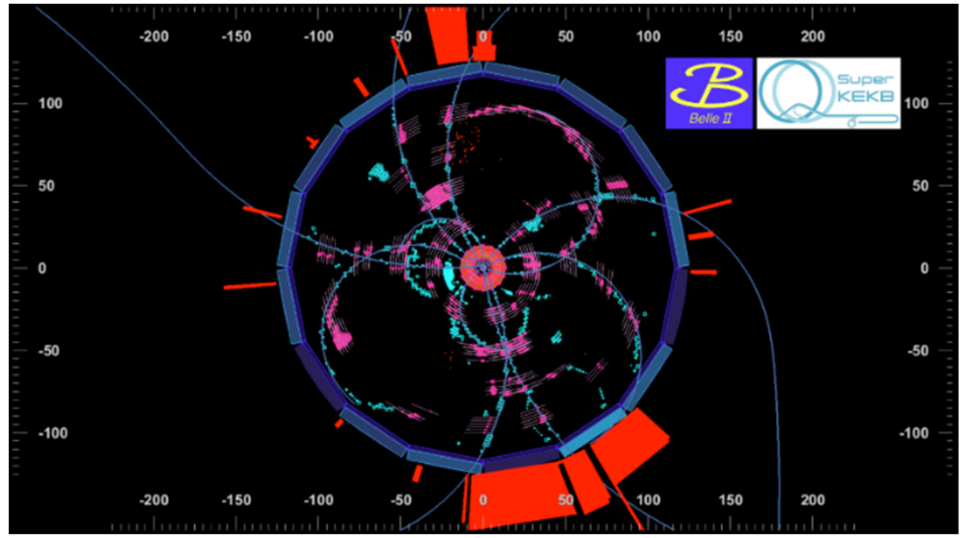

Seminar, U. Geneva, April 10, 2024

Belle II - selected results, status and plans

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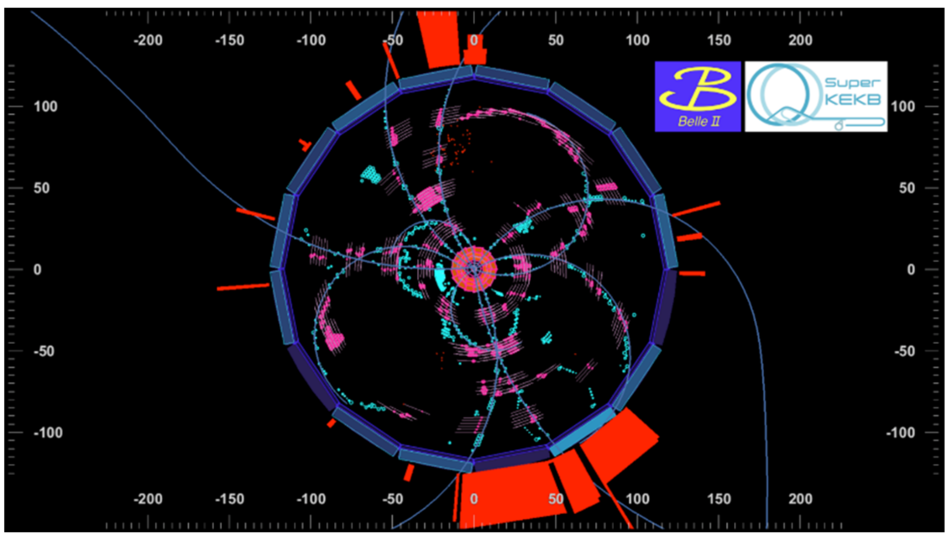
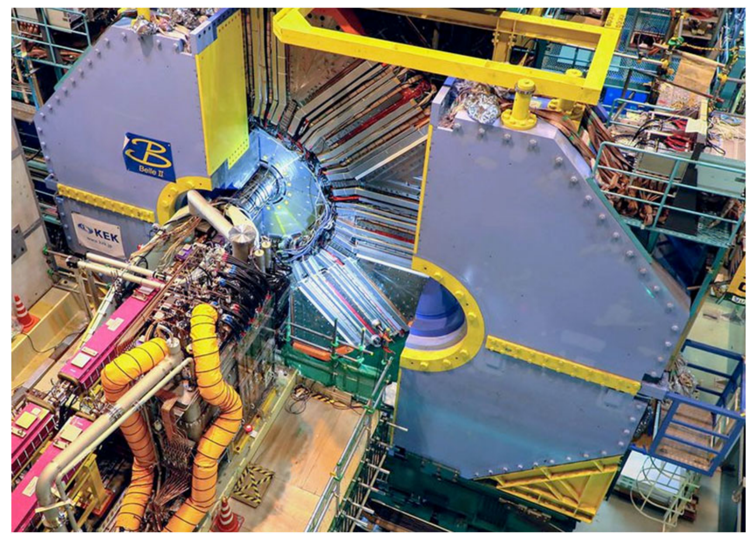
Contents

- Belle II at SuperKEKB
- Physics topics
- Recent results
- Outlook





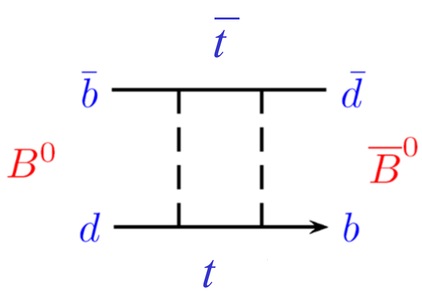
Flavour physics in searches for new particles – two historic examples

Possibly the most prominent example: the prediction of the charm quark based on the unexpectedly low rate of the rare kaon decay $K^0 \rightarrow \mu^+ \mu^-$

1987: ARGUS (and UA1) discovered a large BB mixing: B^0 turns into anti-B^0

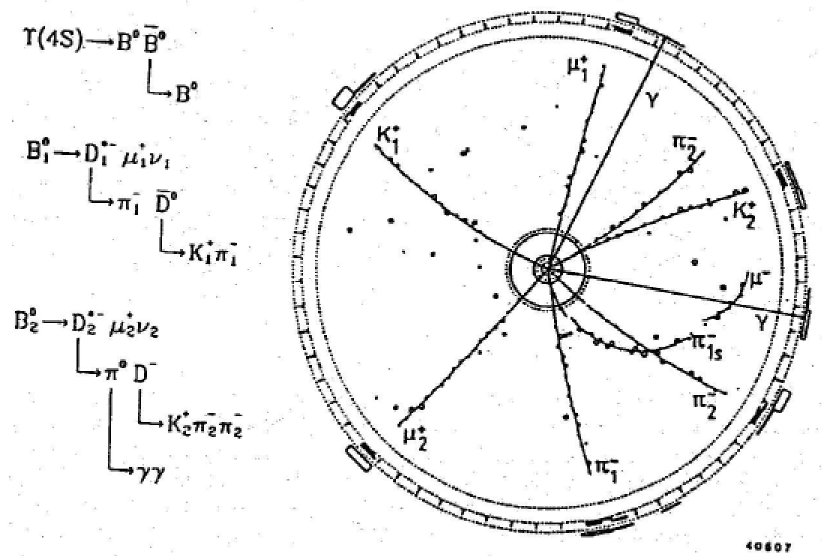
Large mixing rate → high top mass (in the Standard Model)

The top quark has only been discovered seven years later!



mixing frequency $\Delta m \propto$

$$|V_{tb}^* V_{td}|^2 m_t^2 \;\propto\; \lambda^6 m_t^2$$



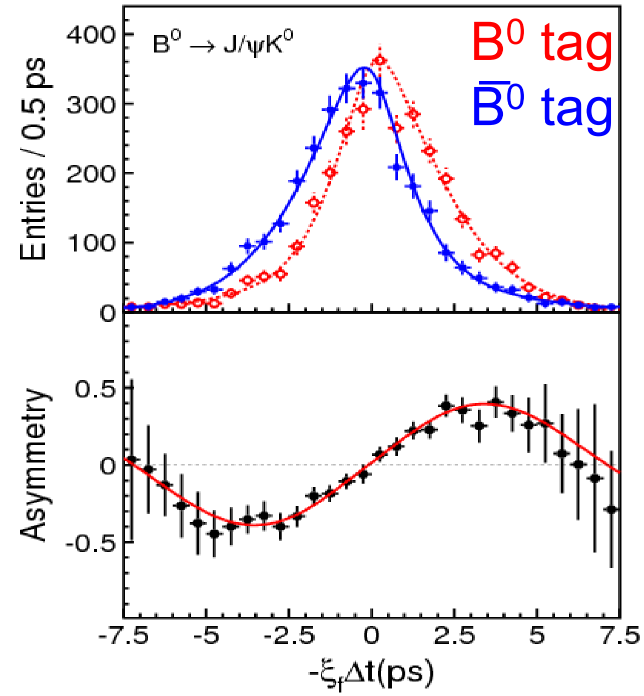
ARGUS: A fully reconstructed event where an anti-B^0 turns into a B^0

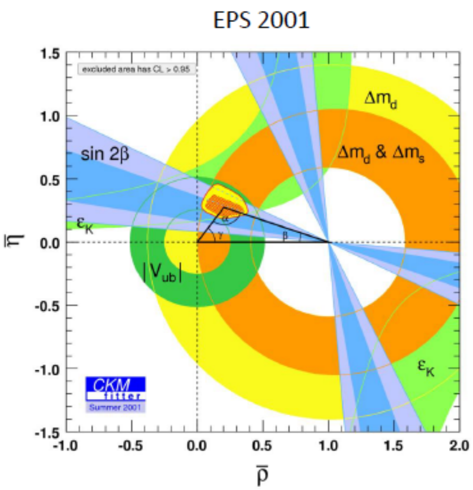
Physics of B mesons at asymmetric B factories

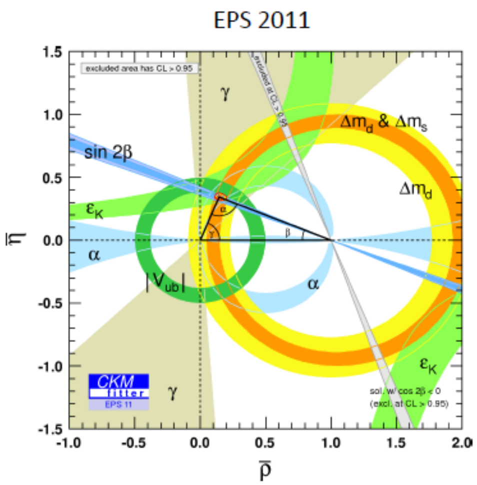
Played a central role in particle physics from 2001 to 2010

Established the complex unitary Cabbibo-Kobayashi-Maskawa quark transition matrix as the source of CP violation in SM

CP violation in B system: from the discovery (2001) to a precision measurement







Constraints from measurements of angles and sides of the unitarity triangle

→ Remarkable agreement

→ Nobel prize for Kobayashi and Maskawa

B factories: a success story

- Measurements of CKM matrix elements and angles of the unitarity triangle
- Observation of direct CP violation in B decays
- Measurements of rare decay modes (e.g., $B \to \tau\nu$, $D\tau\nu$)
- $b \to s$ transitions: probe for new sources of CPV and constraints from the $b \to s\gamma$ branching fraction
- Study forward-backward asymmetry (A_{FB}) in $b \to s l^+ l^-$
- First look at the possible violation of lepton flavour universality
- Observation of D mixing
- Searches for rare τ decays
- Observation of new hadrons

Flavour Physics in 2024

The standard model of particle physics is in a great shape, after decades of deep investigation and precision measurements, all phenomena happening at colliders are accounted for.

However, in the past years, interesting hints of departures from SM expectations have been accumulating:

➔ hints of violation of Lepton Flavor Universality;

➔ (partial) branching fractions and angular observables of B decays dominated by loop amplitudes;

➔ $(g\text{-}2)_\mu$

Taken one by one, these anomalies are not striking, but they seem to paint an interesting picture...

Flavor physics at an e^+e^- collider

• Clear disadvantage against the LHC in terms of cross sections, but:

• Many of the interesting modes (not only for flavor physics) are unique to B Factories:

➔ channels with π^0, K_L, η(‘), … ;

➔ final states with one or more ν’s;

➔ modes affected by “difficult” backgrounds, where the full knowledge of the kinematics in the event is the only way to control them;

➔ a variety of inclusive measurements can be performed.

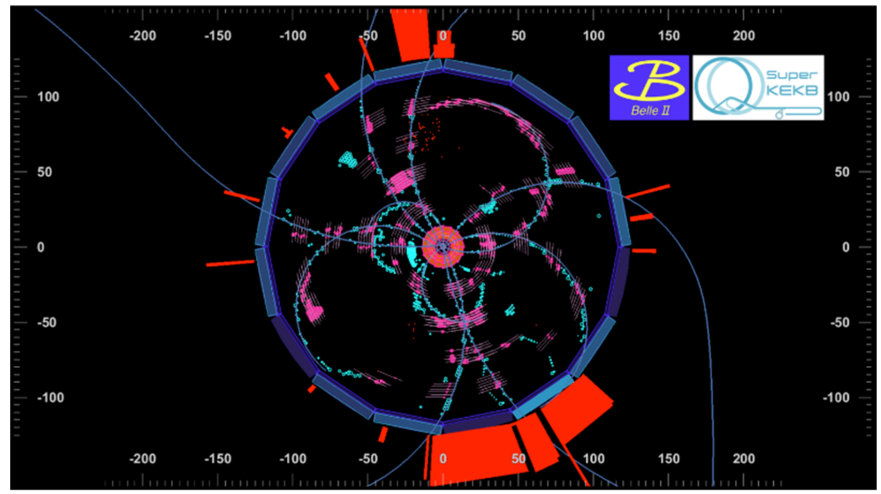
• In general: a wider spectrum of measurements allows for a better understanding (or highlights our lack of…).

• And extraordinary claims require extraordinary evidence: we need an independent confirmation for as many modes as possible.

A B factory in the LHC era

Fantastic performance of LHCb with many interesting results!

Still, an e^+e^- machine running at (or near) Y(4S) is complementary to LHCb in several aspects.



Unique capabilities of a B factory:

→ Exactly two B mesons produced
→ High flavour tagging efficiency
→ Detection of gammas, π^0s, K_Ls
→ Very clean detector environment (decays with several neutrinos in the final state, tau physics, dark sector)

Physics potential summarized in Belle II Theory Interface Platform (B2TiP) ‘physics book‘ PTEP 2019 (2019) 123C01, arXiv:1808.10567

<u>However, need a two-orders-of-magnitude larger data sample!</u>

<u>→ Increase by 30x the luminosity of a world record accelerator</u>

How to increase the luminosity?

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

Lorentz factor

Beam current

Beam-beam parameter

Classical electron radius

Beam size ratio@IP 1 ~ 2 % (flat beam)

Vertical beta function@IP

Lumi. reduction factor (crossing angle)& Tune shift reduction factor (hour glass effect) 0.8 ~ 1 (short bunch)

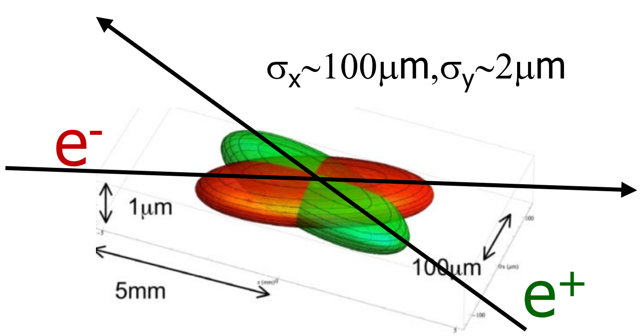
(1) Smaller β_y^*

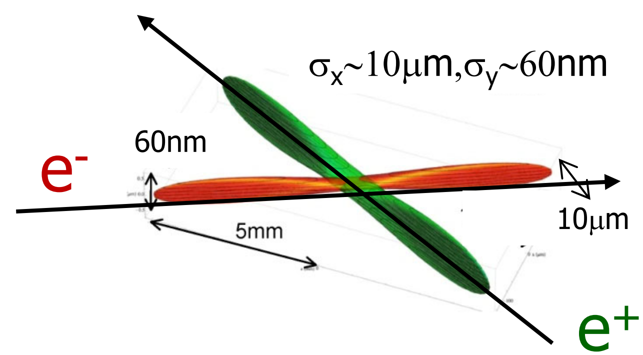
(2) Increase beam currents

(3) Increase ξ_y

"Nano-Beam" scheme

Invented by Pantaleo Raimondi for SuperB

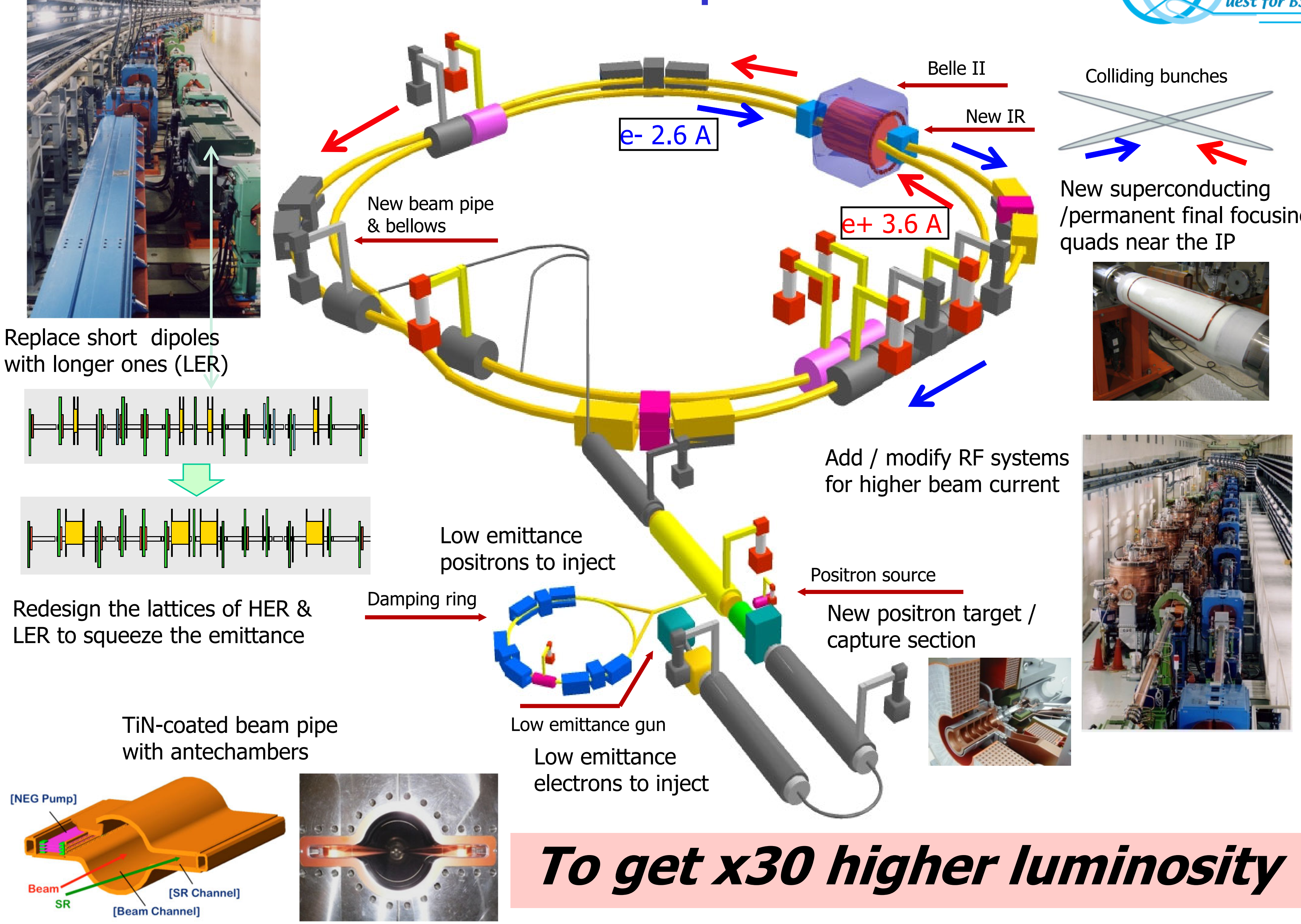




In KEKB, colliding electron and positron beams were already much thinner than a human hair...

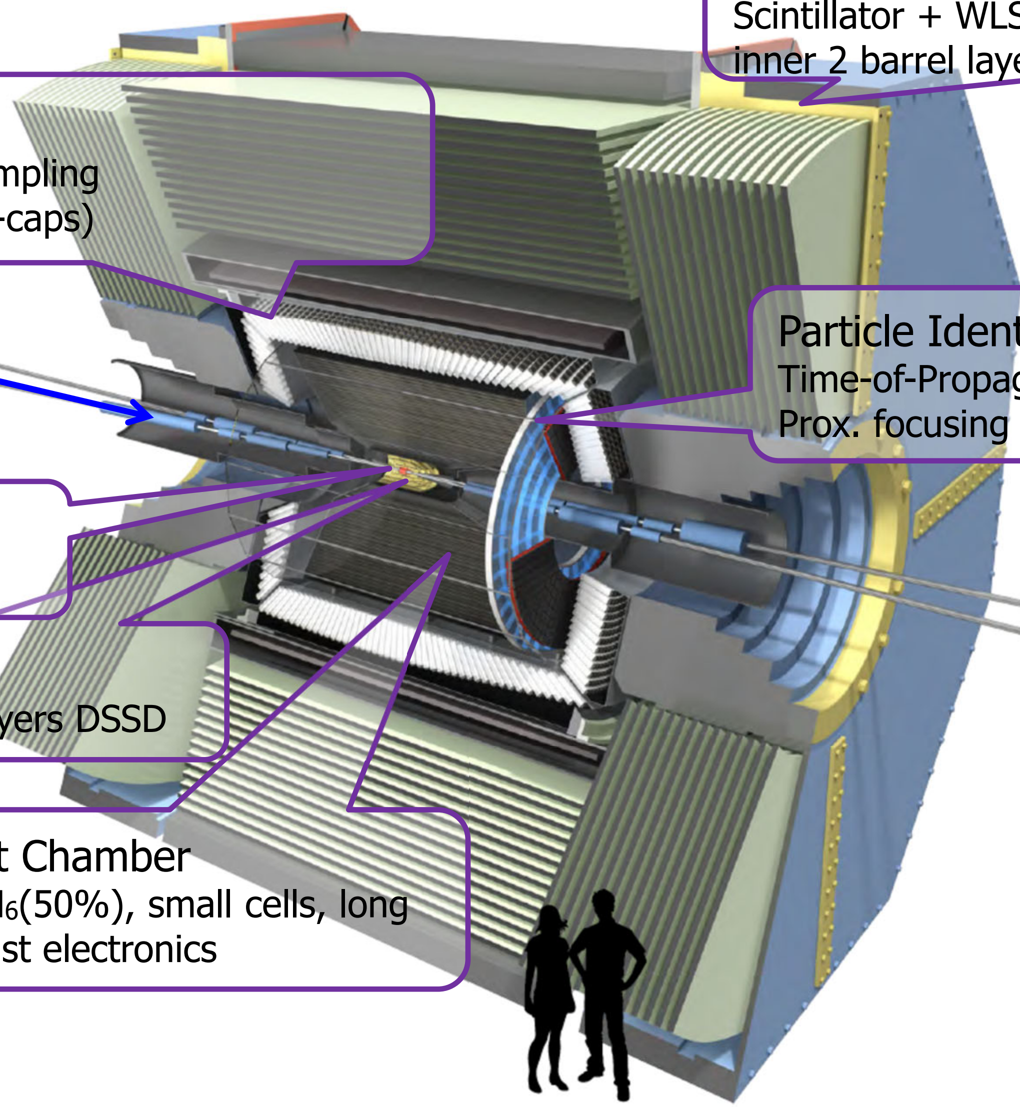
... For a 30x increase in intensity you have to make the beam as thin as a few x100 atomic layers!

KEKB → SuperKEKB

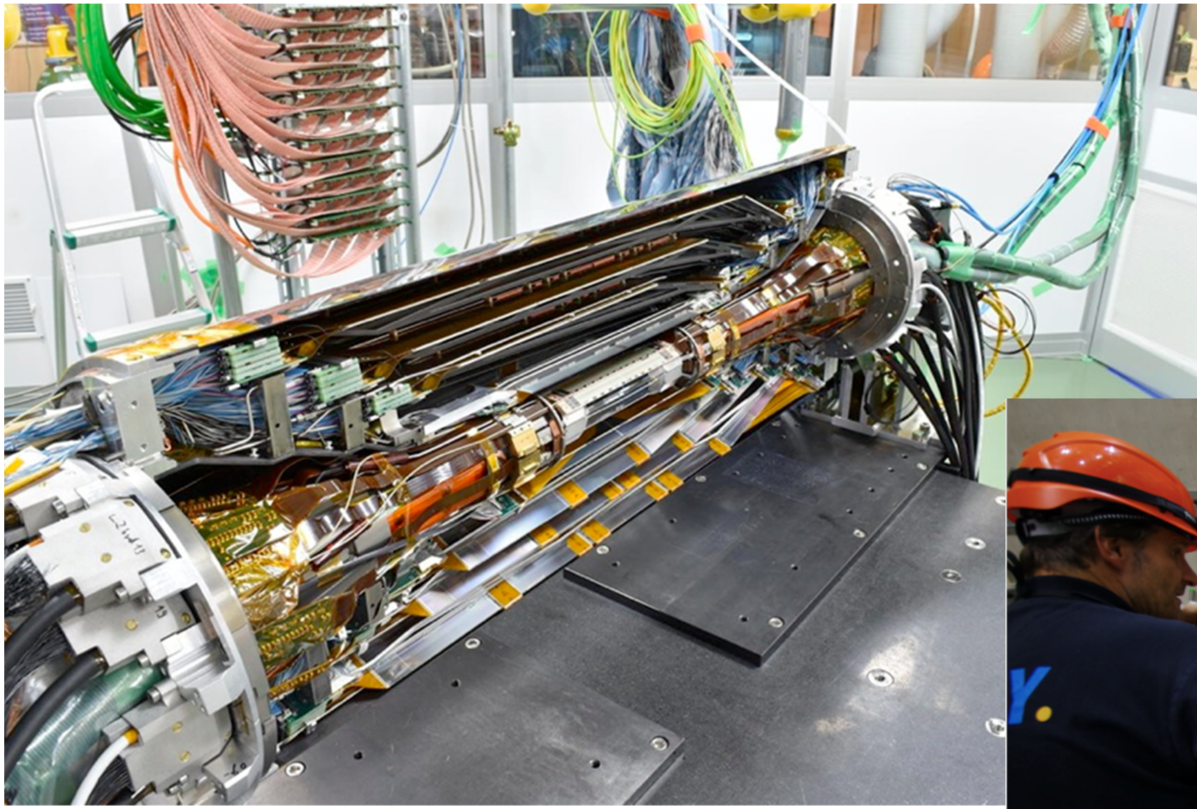


Detector: Belle → Belle II

It looks like Belle, but practically
it is a brand new detector!



Vertex detector of Belle II



Belle II VXD

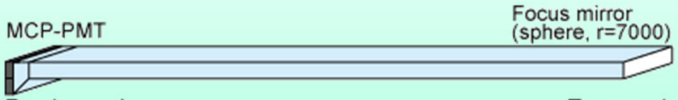
•PXD: DEPFET based pixel detector; layer 1 and a part (two ladders) of layer 2,

•SVD (4 layers): double-sided silicon strip detector →installed on Nov 21, 2018

LS1 (2022-2023): reinstall with a complete layer 2 of the PXD

Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



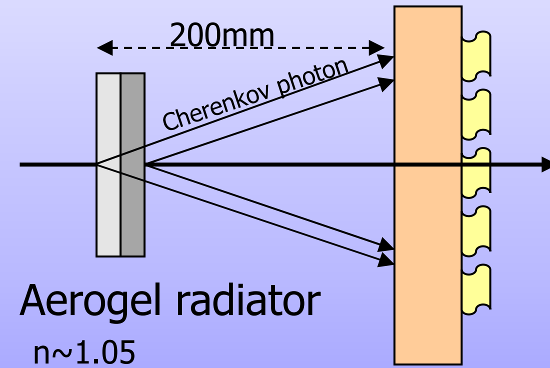
Quartz radiator

Focusing mirror

Small expansion block

Hamamatsu MCP-PMT (measure t, x and y)

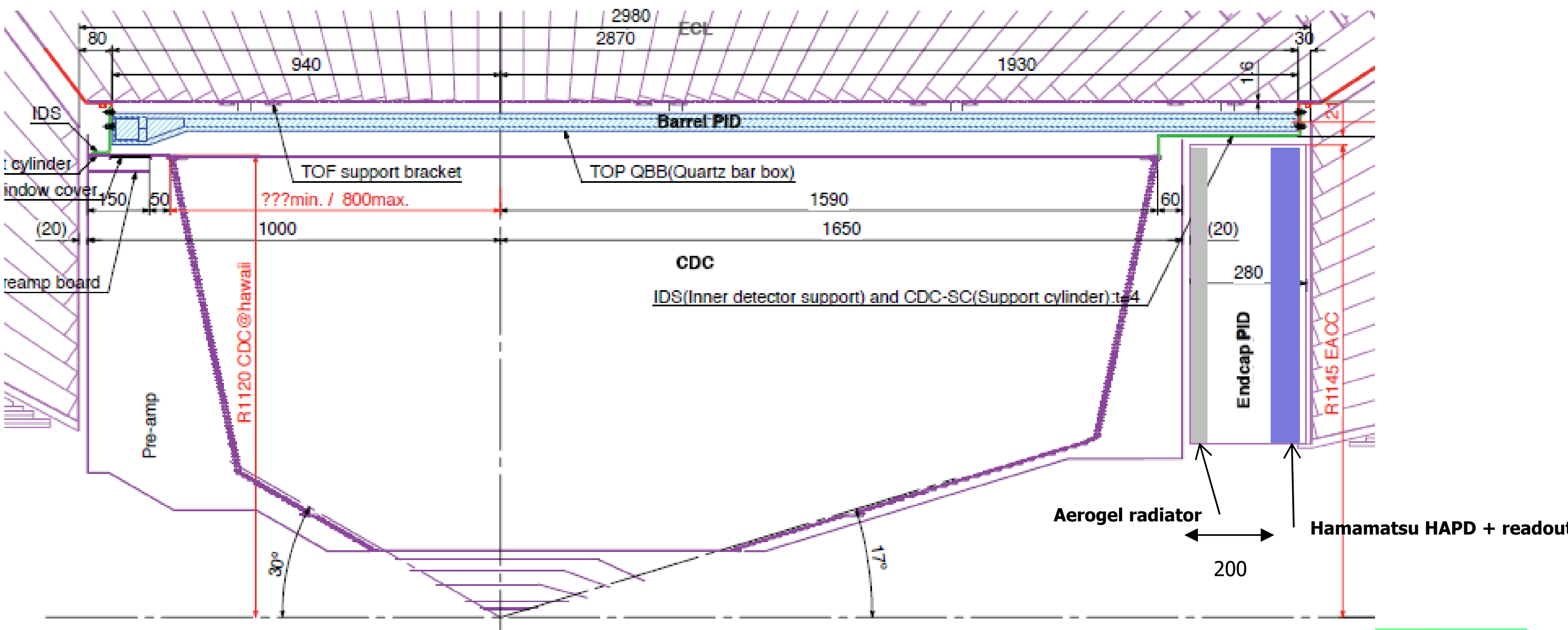
Endcap PID: Aerogel RICH (ARICH)



Aerogel radiator

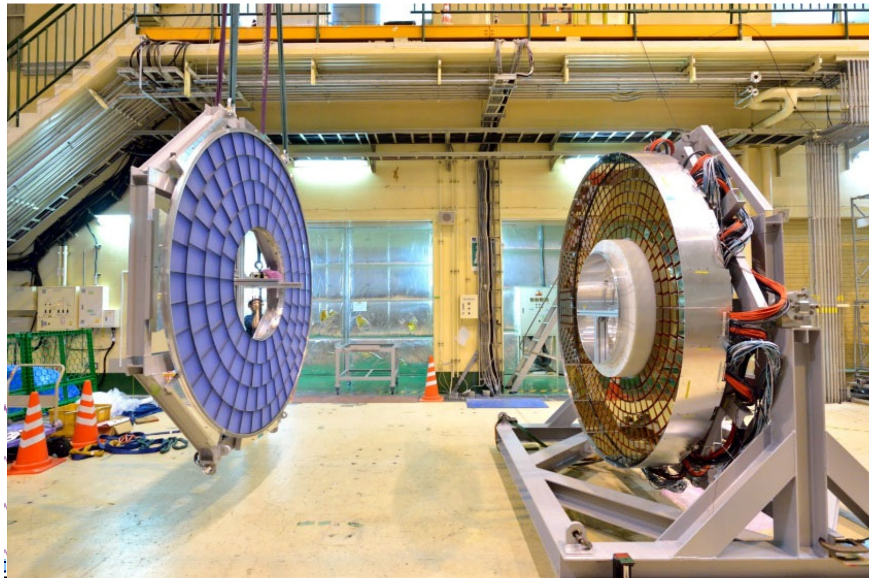
n~1.05

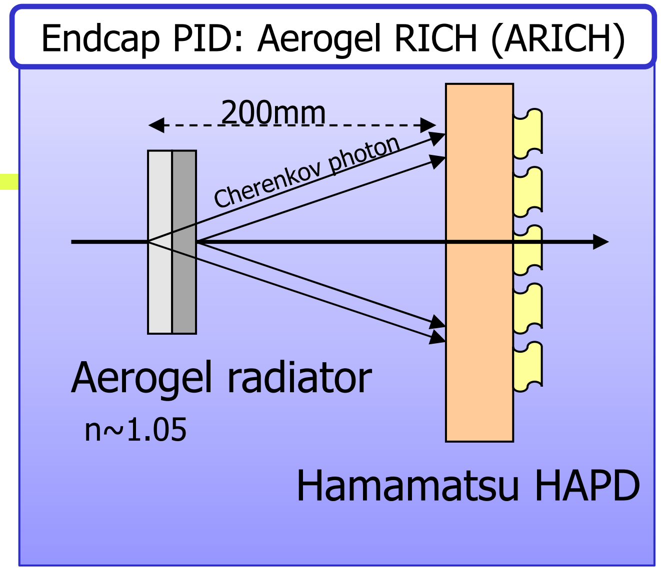
Hamamatsu HAPD

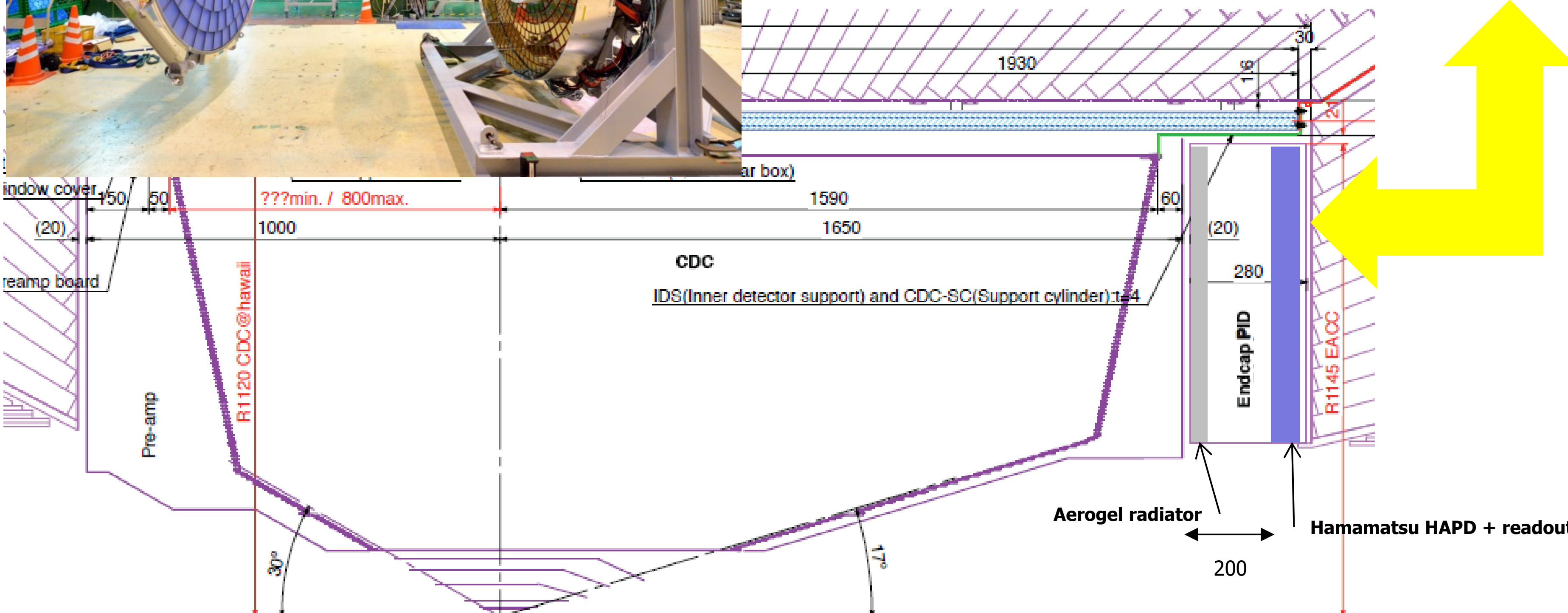


Peter Križan, Ljubljana

PID Devices: ARICH for endcap







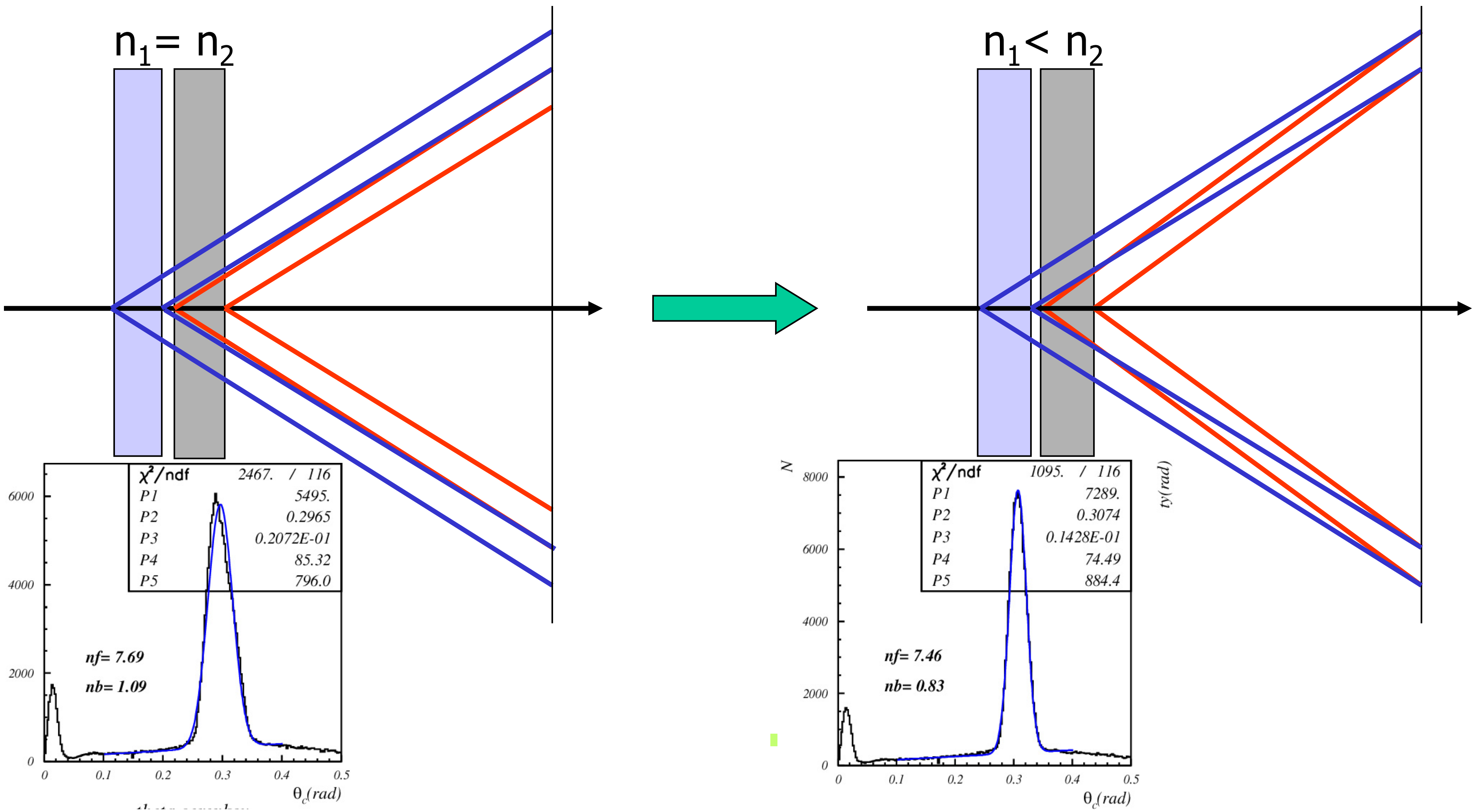
Radiator with multiple refractive indices

Small number of photons from aerogel → need a thick layer of aerogel.

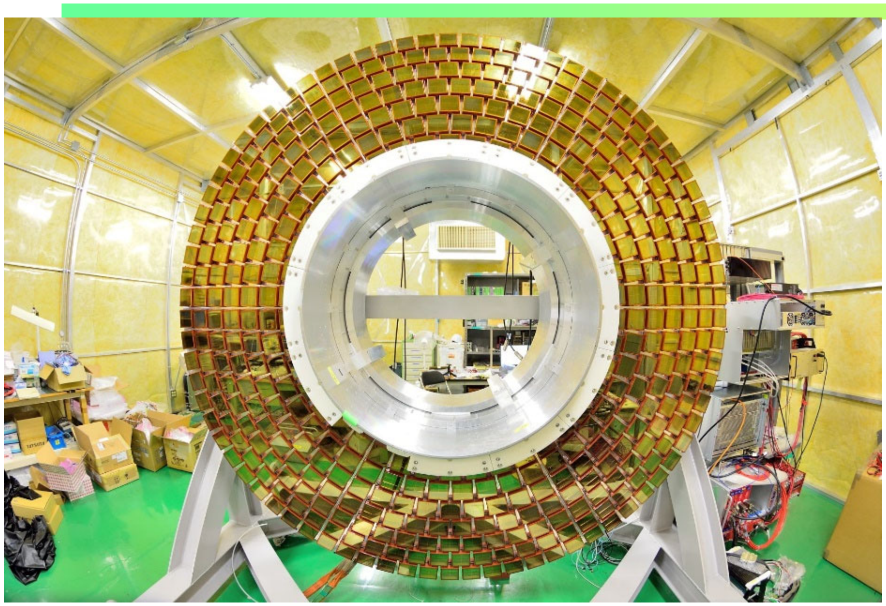
How to improve the resolution by keeping the same number of photons?

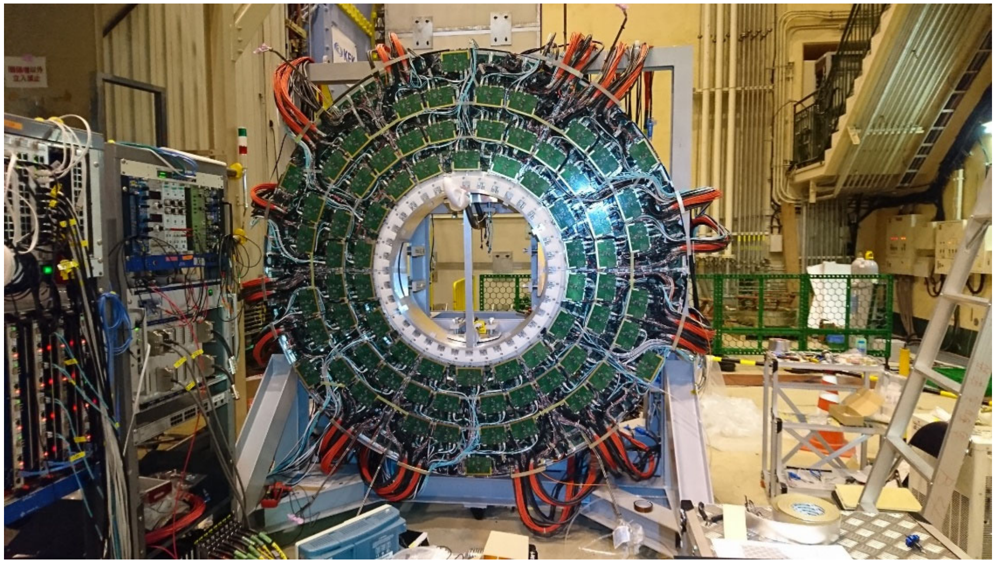
→ stack two tiles with different refractive indices:
"focusing" configuration → "focusing radiator"

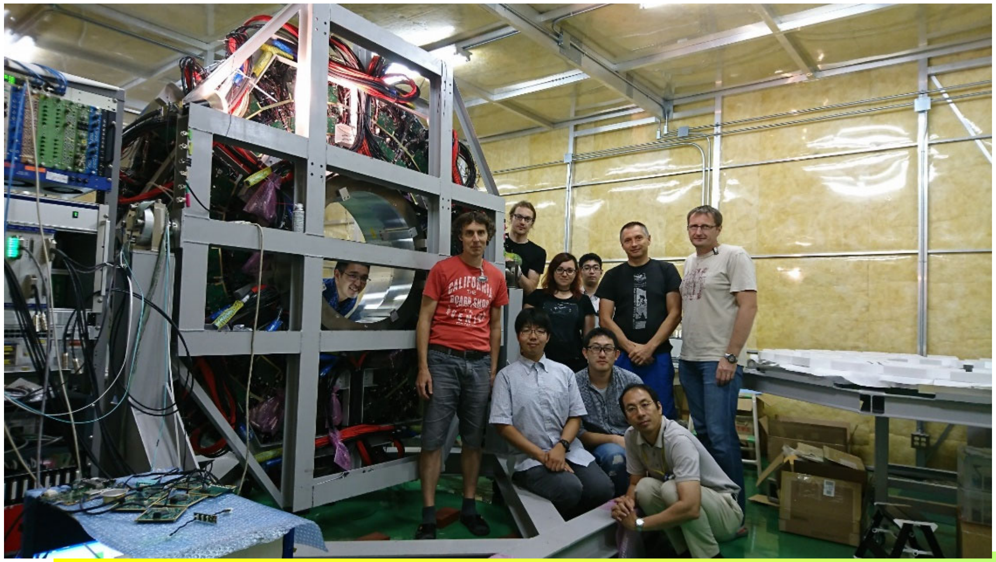
normal

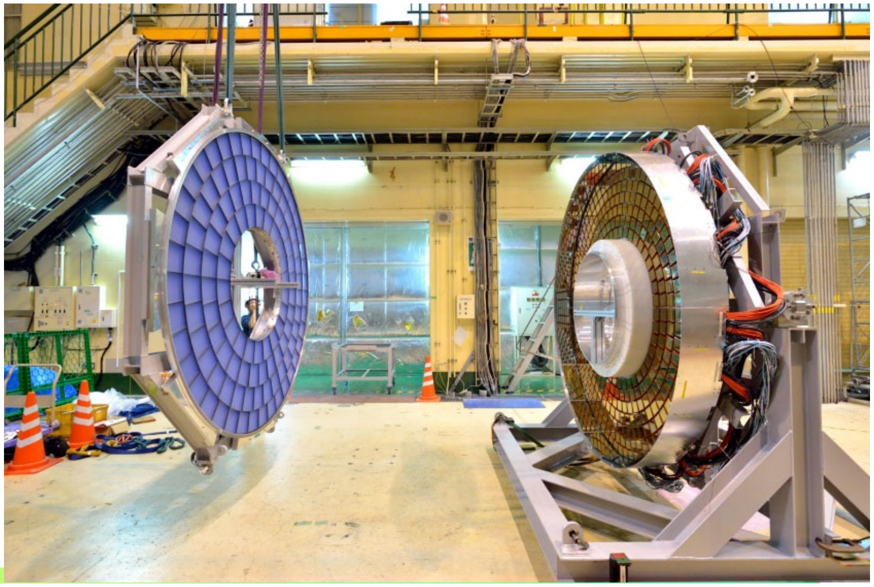


The big eye of ARICH

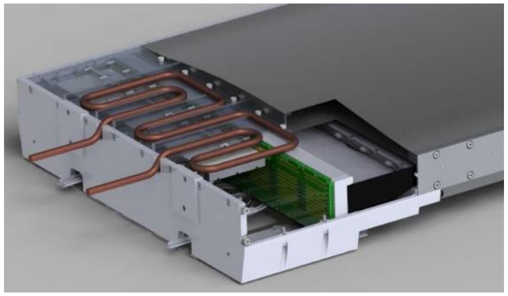


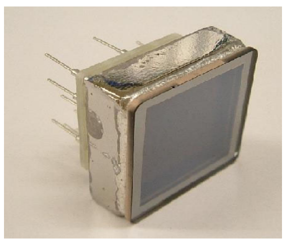




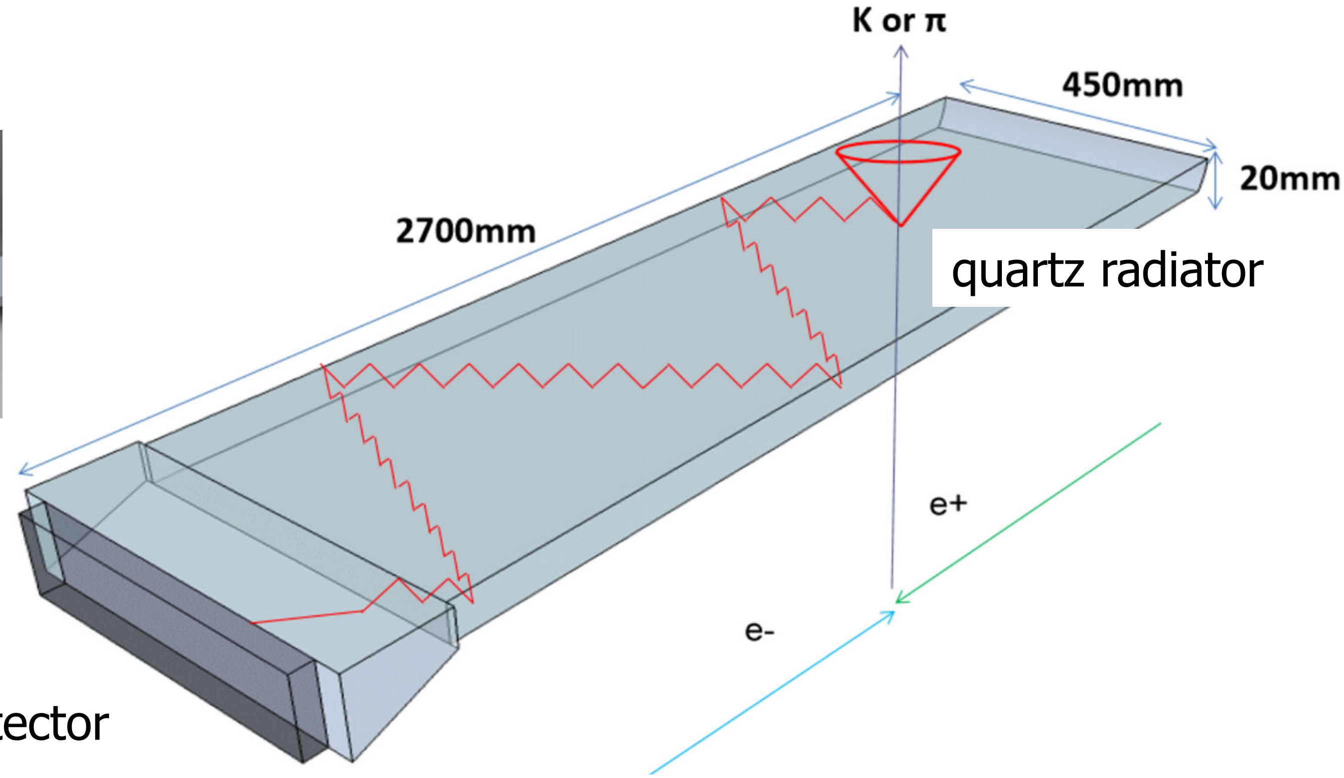


Barrel PID: Time of propagation (TOP) counter





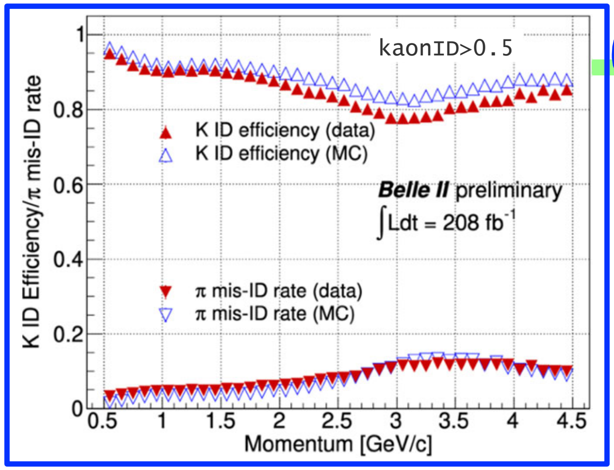
Photon detector



- Cherenkov ring imaging with precise time measurement.
- Reconstruct Cherenkov angle from two hit coordinates and the time of propagation of the photon
  - Quartz radiator (2cm thick)
  - Photon detector (MCP-PMT)
    - Excellent time resolution ~ 40 ps
    - Single photon sensitivity in 1.5 T

Inspired by the DIRC detector of the BaBar experiment, a similar device (TORCH) is planned for LHCb

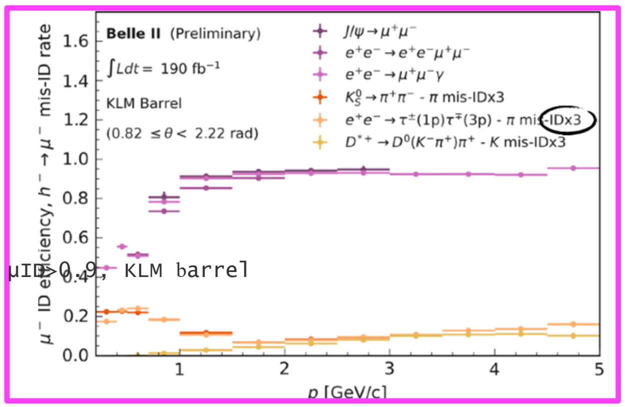
PID Performance



KID

ε

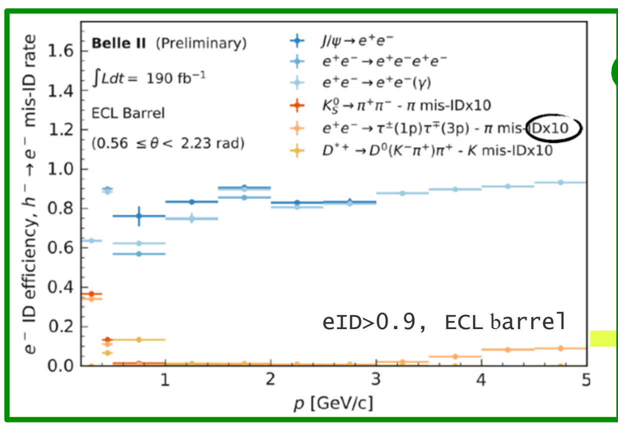
π



μID [1]

e

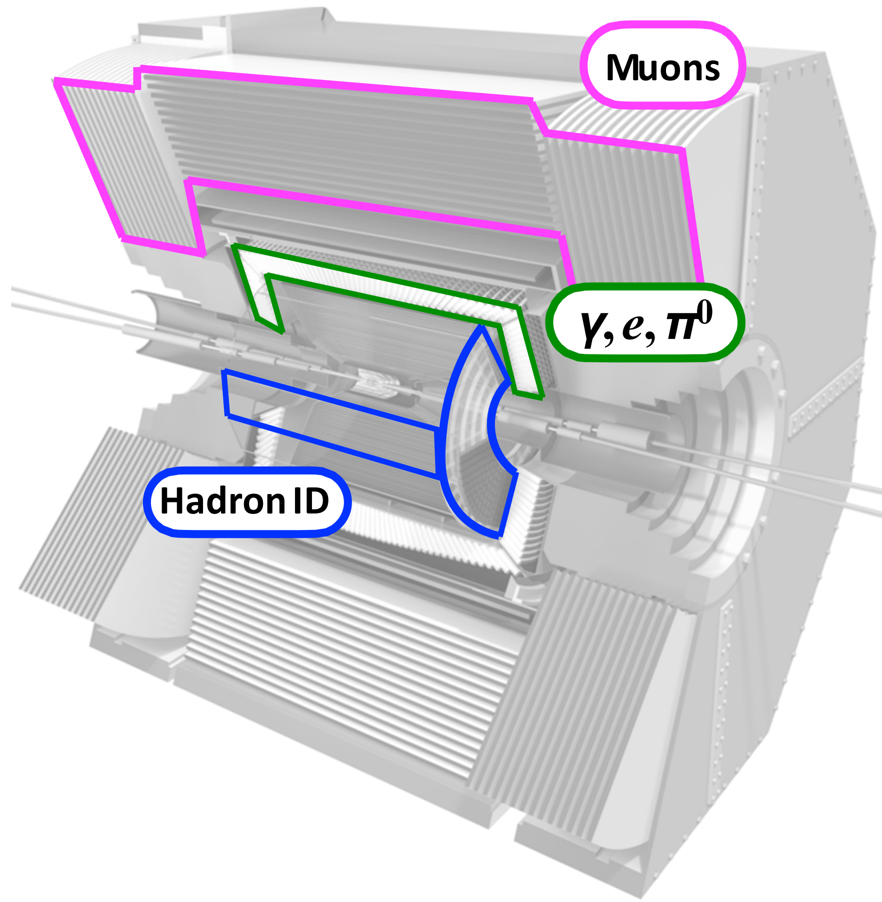
$\pi \rightarrow \mu \sim 5 - 10$ %



eID

e

π



More methods are in preparation like e/muon/pion separation at low momenta via an ML-based pattern analysis in the EM calorimeter

SuperKEKB/Belle II phases

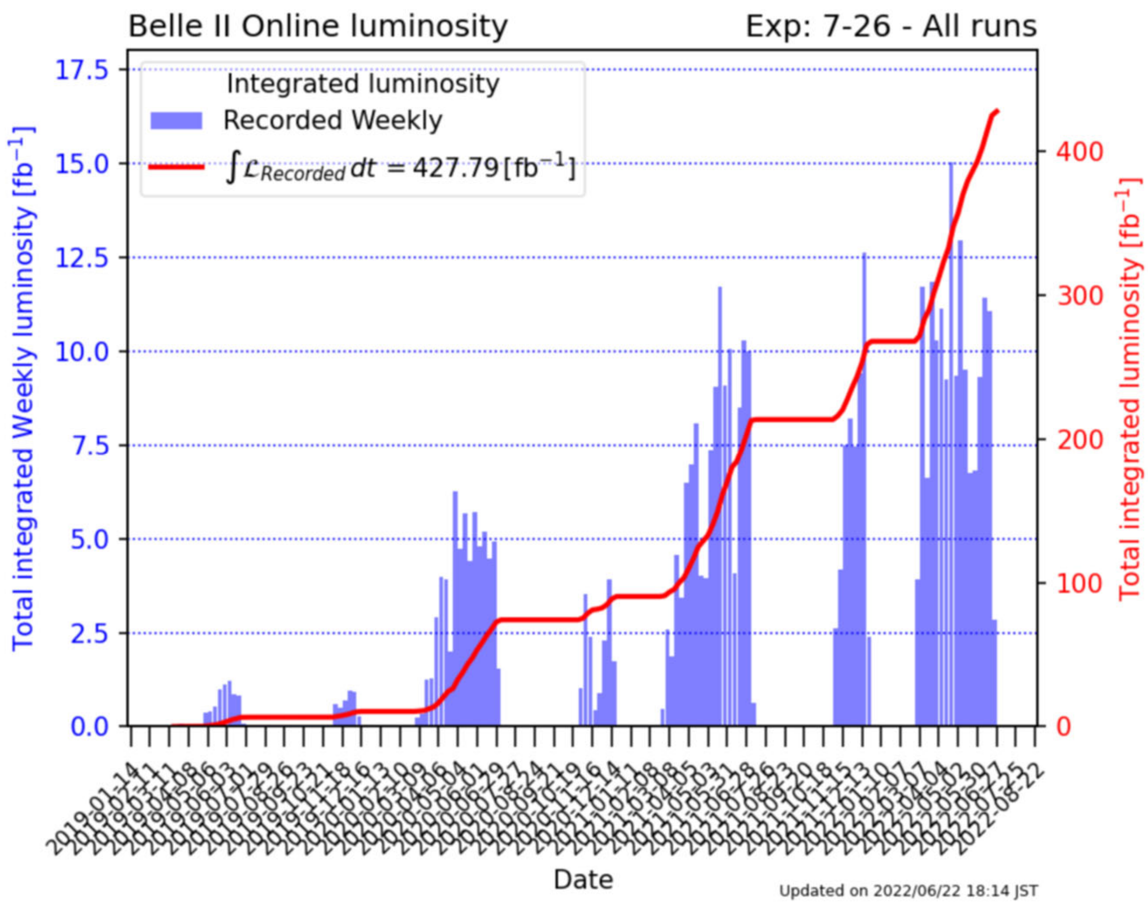
- Phase 1(2016): no detector, no collision, test the rings, baking the 3km of the accelerator vacuum chambers

- Phase 2 (2018): first collisions with complete accelerator
  - Incomplete detector: Vertex detector replaced by dedicated background detector (Beast 2)

- Phase 3 (2019-): luminosity run with complete detector
  - Pixel Detector (PXD): layer 1 + partly equipped layer 2
  - Full 4-layers strip detector (SVD)
  - First physics paper appeared in January 2020

- New and difficult accelerator. Additional operational complexity during the pandemic
- Record peak luminosity 4.7×10^{34} cm^{-2} s^{-1}
- Path to reach 2×10^{35} cm^{-2} s^{-1} identified.
- More effort needed to reach the target peak luminosity of 6×10^{35} cm^{-2} s^{-1}

Belle II and SuperKEKB



Very successful data taking throughout the pandemic

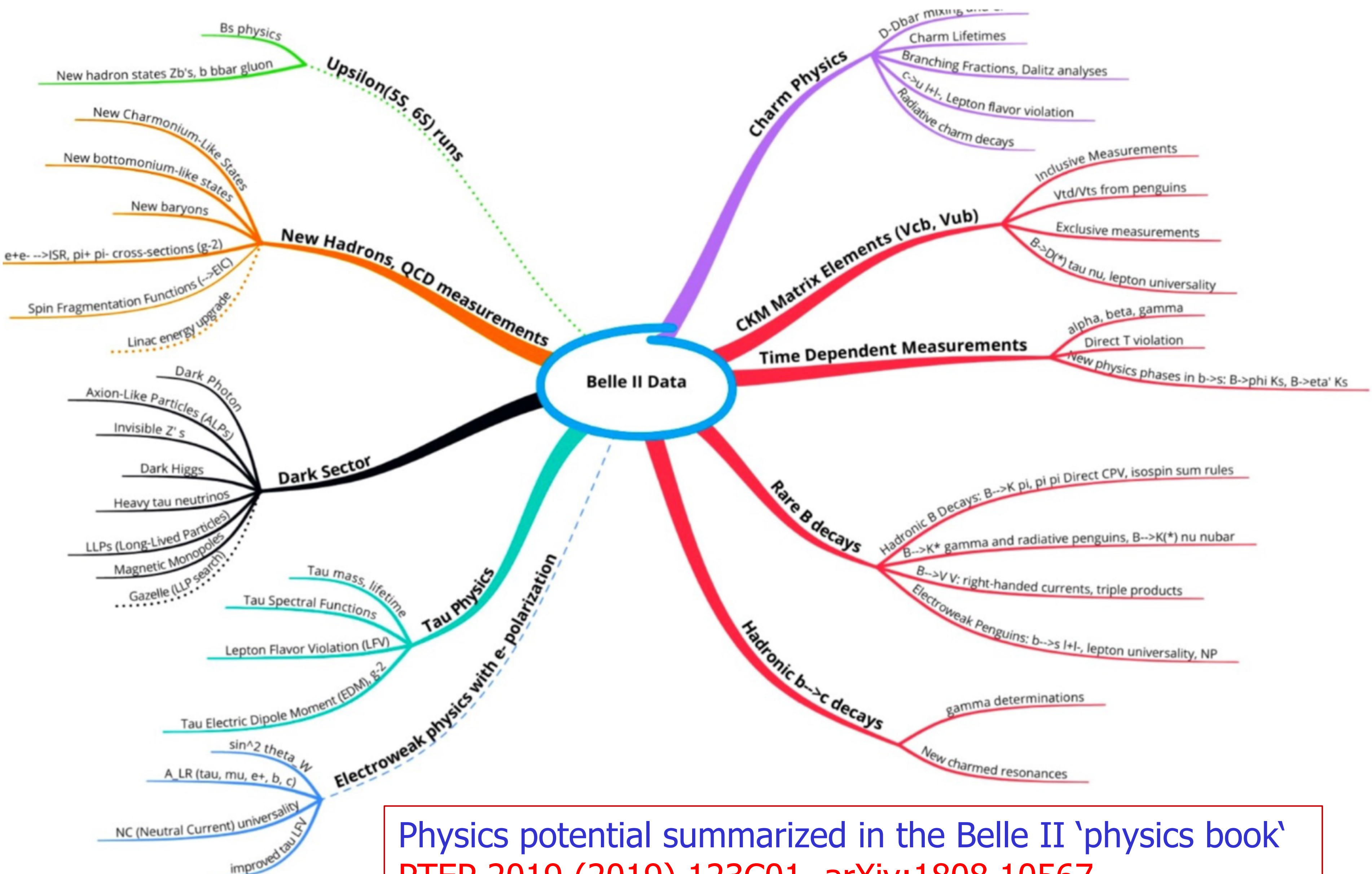
-overall data taking efficiency of 89.5%

-reached world record instantaneous luminosity: 4.7×10^{34} cm^{-2} s^{-1} , collected up to 15 fb^{-1} per week: Super-B factory mode

-recorded luminosity at Belle II: 428 fb^{-1} (Belle 988 fb^{-1}, BaBar 513 fb^{-1})

Ultimate goal: reach 50 ab^{-1} by operating at the instantaneous luminosity of 6×10^{35} cm^{-2} s^{-1}

Physics program



Physics potential summarized in the Belle II ‘physics book‘
PTEP 2019 (2019) 123C01, arXiv:1808.10567

Recent results – selected topics

This talk - a subselection of recent results:

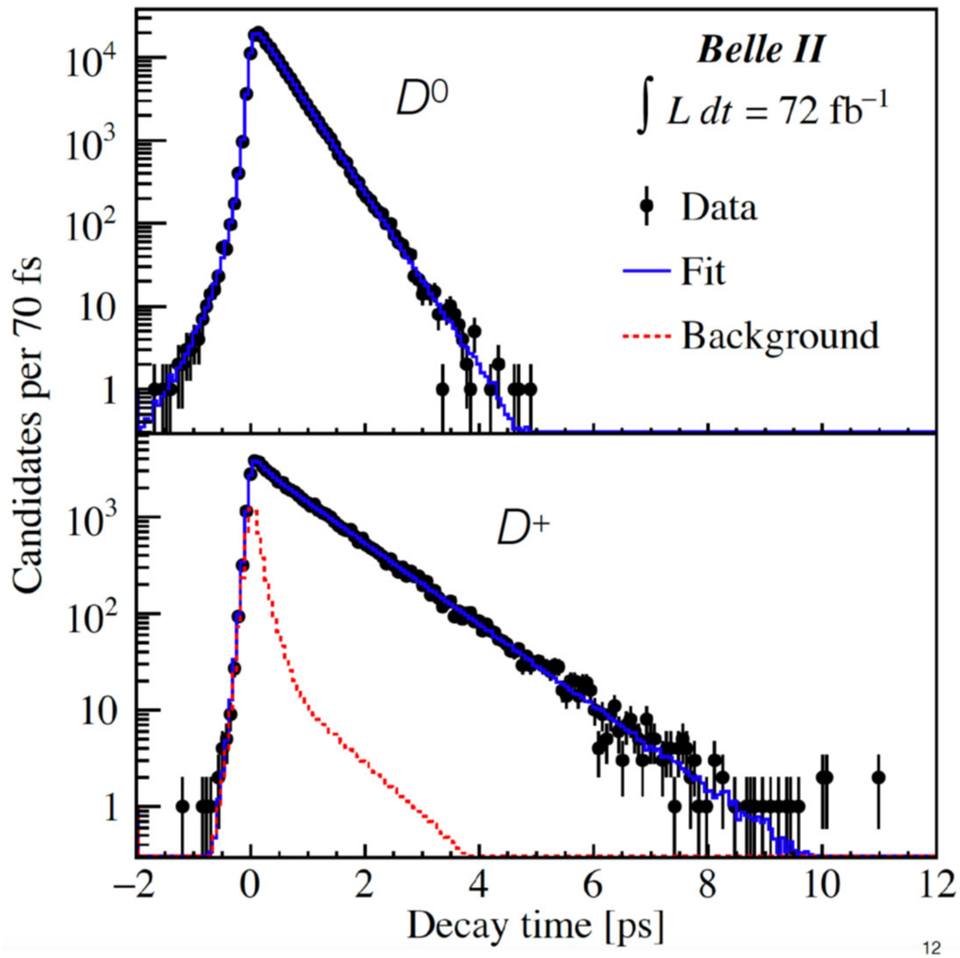
- Lifetimes of charmed hadrons
- Time dependent CP violation on $B^0 \to J/\psi\ K_S$ and $\eta'\ K_S$ decays
- Test of Lepton Flavour Universality: $R(D^*) = BR(B \to D^*\ \tau\ \nu)\ /\ BR(B \to D^*\ l\ \nu)$
- Searches for new physics in rare and forbidden decays in b → s transitions:
  $B^{\pm} \to K^{\pm}\ \nu\nu$, $B \to K^{(*)}\tau\tau$, $B \to K\ell'\ell$
- Tau lepton mass
- Dark sector searches

D^0 and D^+ lifetime measurements

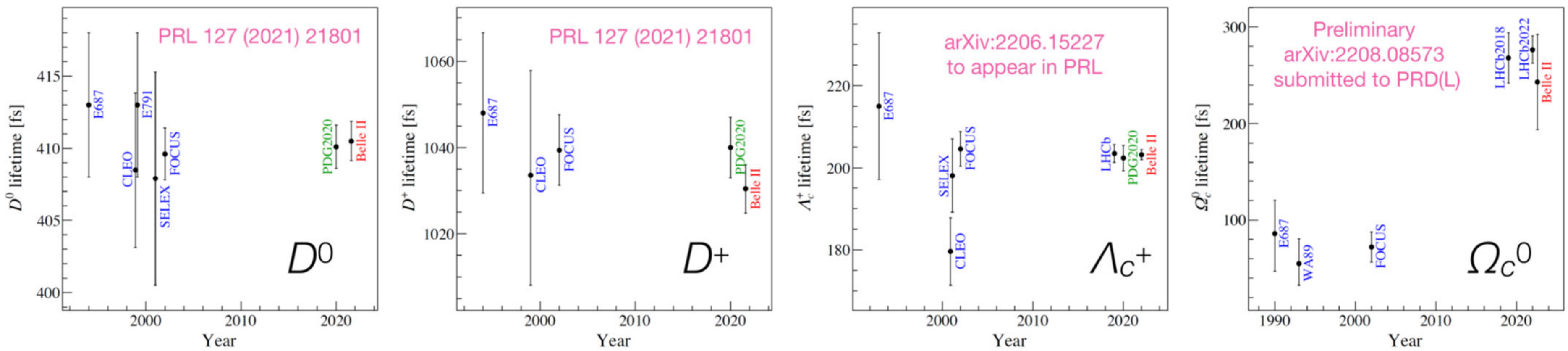
Example of improved performance of Belle II vs Belle: time-dependent capabilities in D lifetime measurements.

The addition of a pixel vertex detector (with a 1cm radius beam pipe) gives a *factor of two improvement* in proper time resolution for charm lifetime measurements compared to Belle. Alignment systematics are much improved.

PRL 127 (2021) 21801



Lifetimes of charmed hadrons

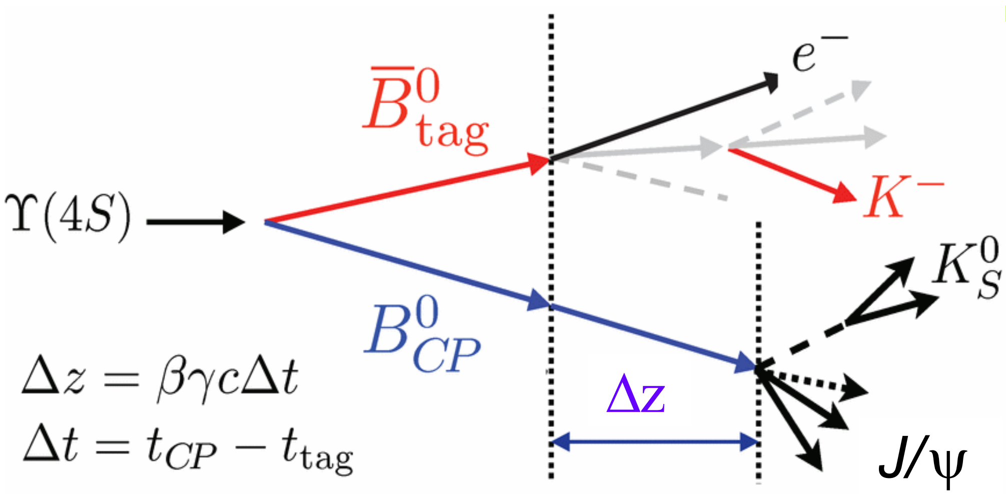


Used early Belle II data to measure lifetimes of charm hadrons

- World-best D^0, D^+ and Λ_c^+ lifetimes (first Belle II precision measurements)
- Confirmation of LHCb result indicating that the Ω_c^0 is not the shortest-lived weakly decaying charmed baryon

Tiny systematic uncertainties (e.g., 2‰ for D^0) demonstrate excellent performance and understanding of the Belle II detector, never achieved at previous B factories

Time dependent analyses



$\langle\Delta z\rangle \sim 130\ \mu m$ at Belle II

Flagship measurement of the B Factories, still very important at Belle II;

$$\mathcal{A}_f(\Delta t) = \frac{\Gamma(\overline{B}^0(\Delta t) \to f) - \Gamma(B^0(\Delta t) \to f)}{\Gamma(\overline{B}^0(\Delta t) \to f) + \Gamma(B^0(\Delta t) \to f)} = S_f \sin(\Delta m_B \Delta t) - C_f \cos(\Delta m_B \Delta t)$$

S_f : time dependent asymmetry
C_f : time integrated (or direct) asymmetry

Quite complicated analysis, several ingredients must be in place:

1) ability to identify the flavor (B^0 or $\overline{B}^0$) of the unreconstructed B (flavor tagging);
2) B-decay vertices resolution;
3) signal side efficiency, background modeling.

Fully exploiting the quantum entanglement of the two B mesons!

Progress in B flavor tagging

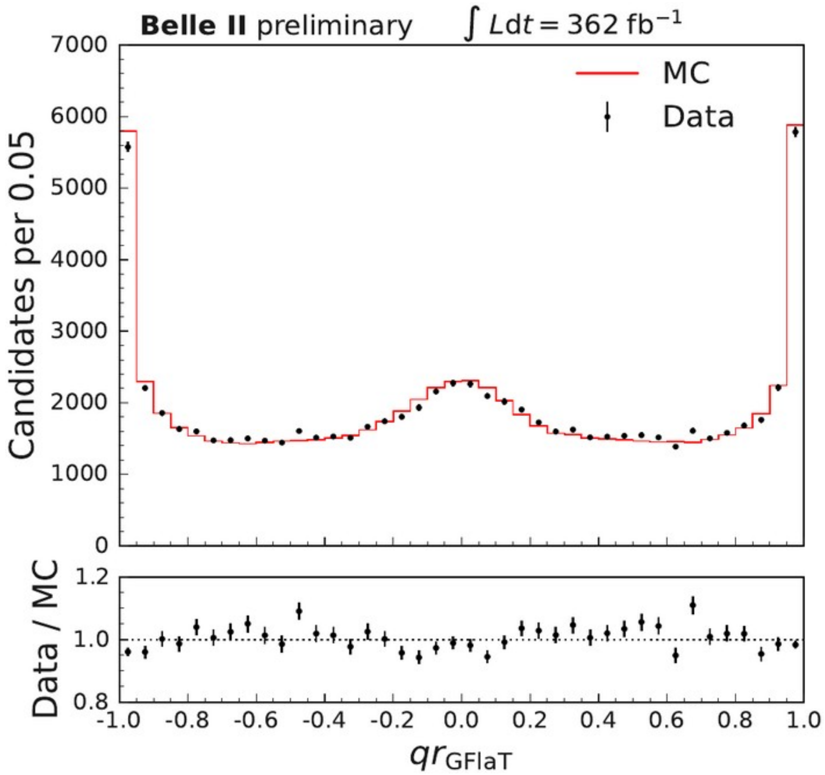
The first CP violation analyses in Belle II relied on a category-based (CB) algorithm [Eur. Phys. J 82, 283 (2022)];

Y. Uematsu, CKM 2023

We explored a more advanced algorithm, GFlaT, based on a graph convolutional neural network, exploiting 25 variables for each track from the unreconstructed B decay (for up to 16 tracks);

The performance is evaluated from a time dependent analysis of self-tagging $B^0 \rightarrow D^{(*)-}\pi^+$ decays;

We measure an impressive increase in the effective tagging efficiency, compared to the previous algorithm:



$$\varepsilon_{\mathrm{tag,CB}} = (31.7 \pm 0.5 \pm 0.4)\%$$

$$\varepsilon_{\mathrm{tag,GFlaT}} = (37.4 \pm 0.4 \pm 0.3)\%$$

This corresponds to ~18% more luminosity available for CP violation analyses!

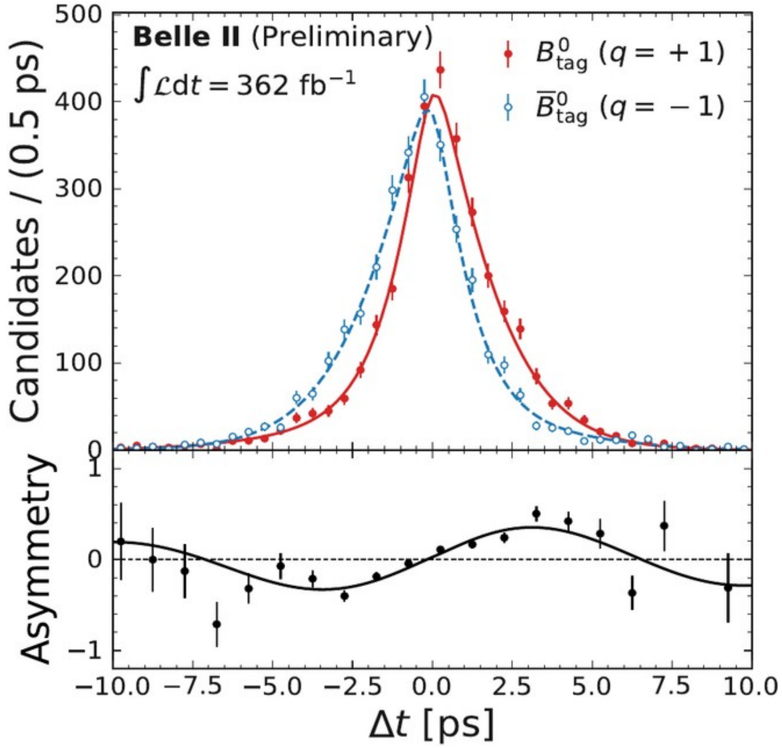
$\sin 2\phi_1$ / $\sin 2\beta$ from $B^0 \to J/\psi K_S$

- We update the flagship measurement of the B factories using the full Belle II data set and the GFlaT flavor tagger;
- We fit the ΔE distribution of the selected candidates in order to subtract the backgrounds;
- We then fit the background subtracted Δt distributions and measure the CP violating parameters:

$$S = 0.724 \pm 0.035 \pm 0.014$$
$$C = -0.035 \pm 0.026 \pm 0.013$$

- This is well compatible with the world averages and the latest LHCb result (which is a factor ~2 more precise).

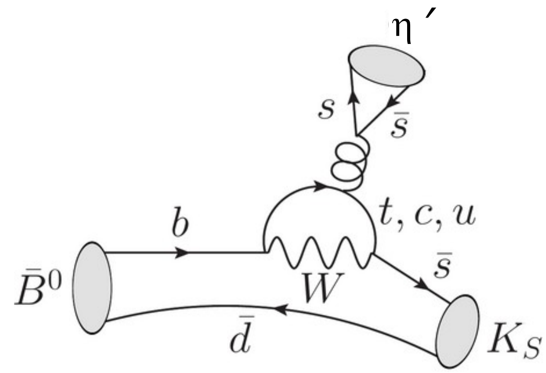
Y. Uematsu, CKM 2023



$\sin 2\phi_1$ / $\sin 2\beta$ from $B^0 \to \eta' K_S$

Motivations: the time dependent CP violation in $B^0 \to \eta' K_S$ (proceeding through loop diagrams) is expected to be the same observed in $B^0 \to J/\psi\, K_S$ (tree);

Any significant deviation would be an indication of new physics;

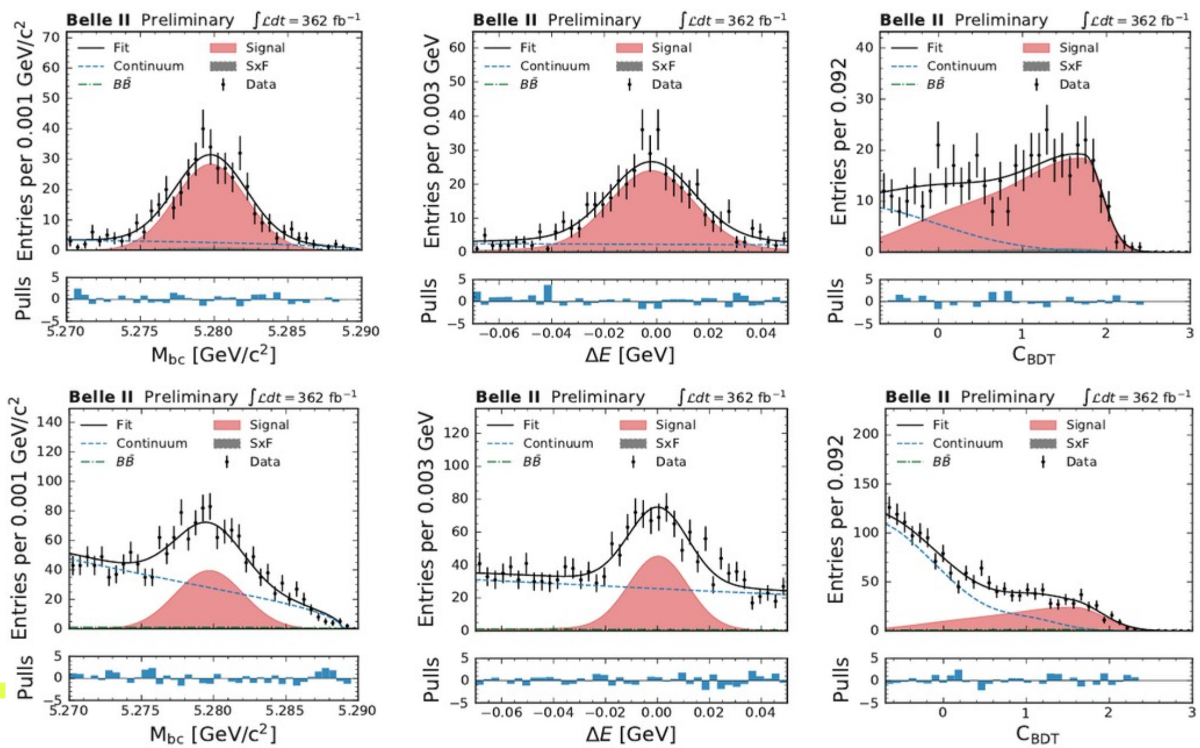


We reconstruct the sub-channels: $\eta' \to \eta(\to\gamma\gamma)\pi^+\pi^-$ and $\eta' \to \rho^0\gamma$, and determine their yields with a three dimensional fit:

$\eta' \to \eta(\to\gamma\gamma)\pi^+\pi^-$

$\eta' \to \rho^0\gamma$

Y. Uematsu, CKM 2023



$\sin 2\phi_1$ / $\sin 2\beta$ from $B^0 \to \eta' K_S$

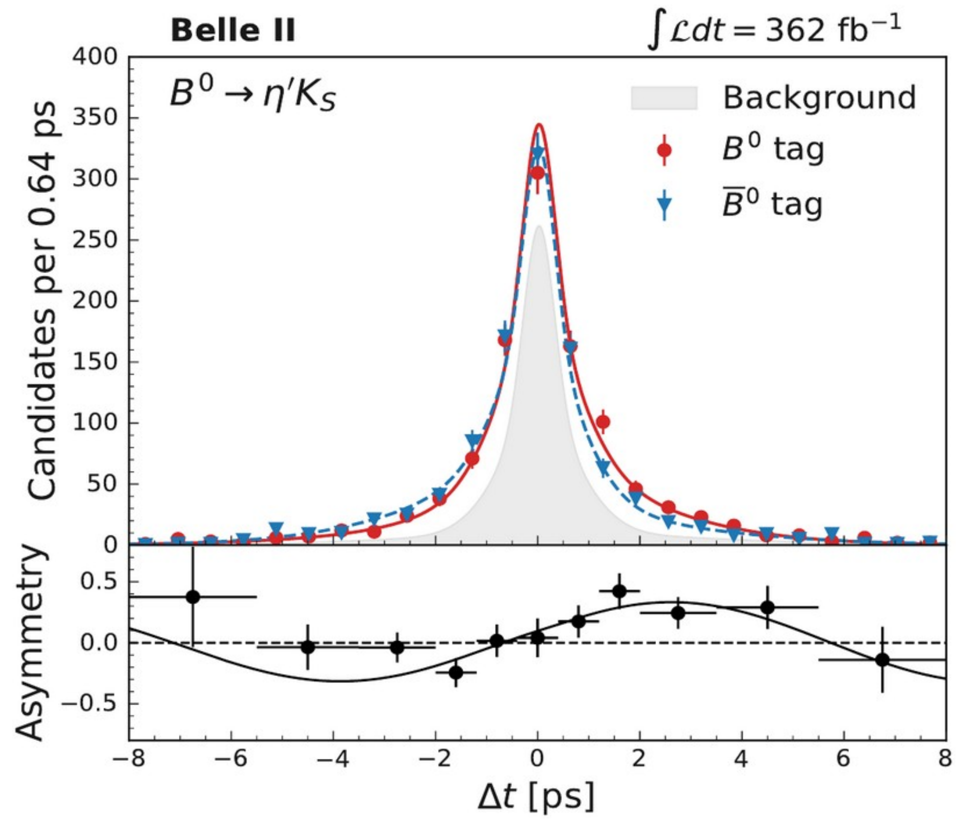
With the yields (~800 signal events in total) fixed from the previous step, we perform the time dependent fit:

Preliminary

We find:

$$C_{\eta' K_S^0} = -0.19 \pm 0.08 \pm 0.03$$
$$S_{\eta' K_S^0} = 0.67 \pm 0.10 \pm 0.04$$

which is in good agreement with both the world average and the $B^0 \to J/\psi\ K_S$ result.

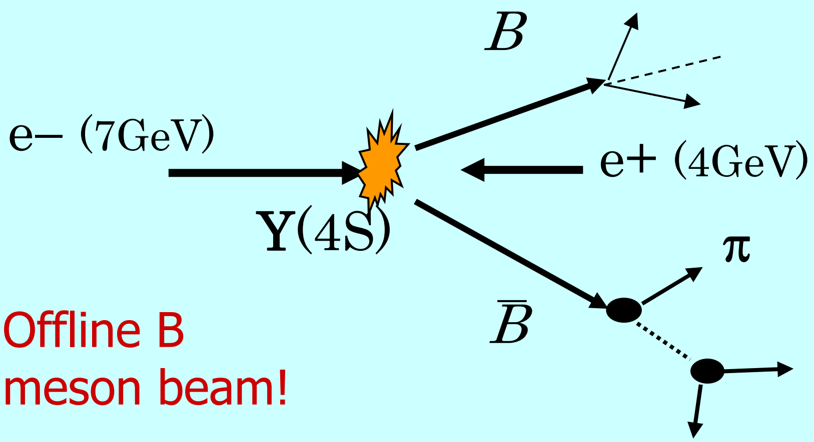


Y. Uematsu, CKM 2023

Full Event Interpretation (FEI)

Idea: reconstruct one of the B's to tag B flavor/charge, determine its momentum, and exclude decay products of this B from further analysis

(exactly two B's produced in Υ(4S) decays)



Offline B meson beam!

Decays of interest

- $B \to X_u\, l\, \nu,\ \pi\, l\, \nu$
- $B \to K\, \nu\, \nu$
- $B \to D\tau\nu,\ \tau\nu$

full reconstruction:

- hadronic tagging, $B \to D\pi$ etc. (1%/0.5%)

partial reconstruction:

- semileptonic tagging (2%/2%)

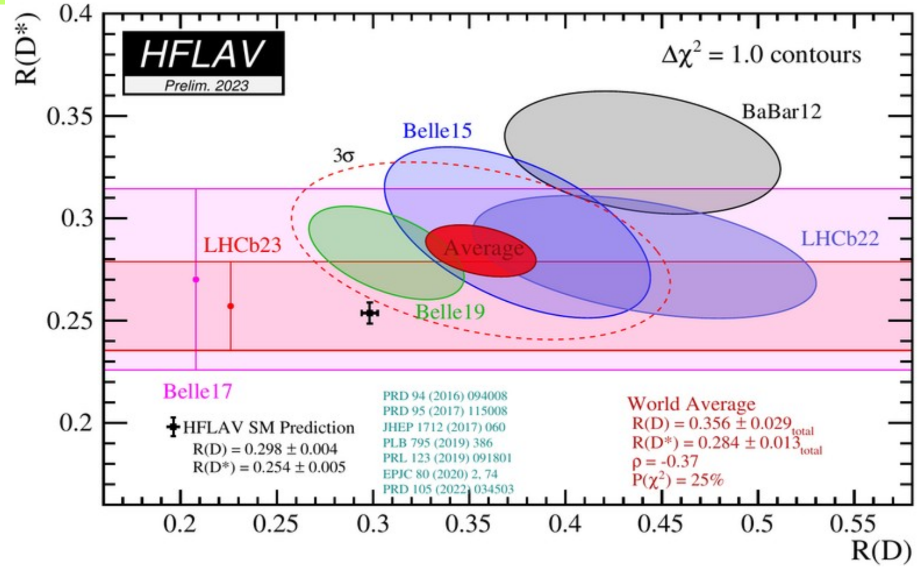
Powerful tool for B decays with neutrinos

→unique feature at B factories

Belle II on lepton flavour anomalies: the first R(D*) measurement

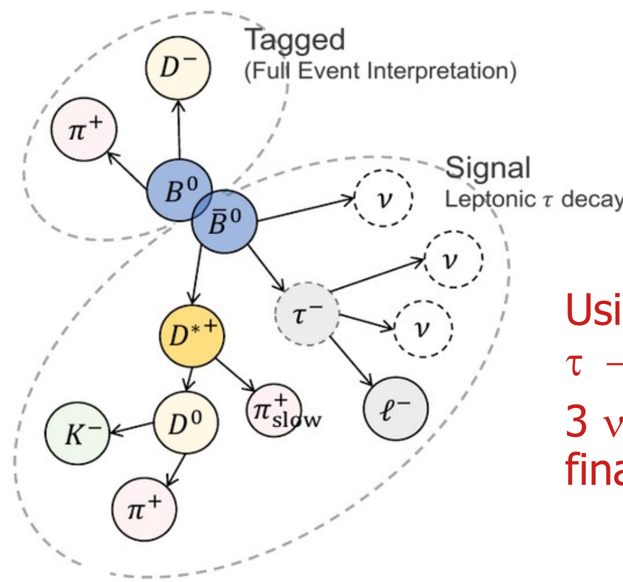
One of the outstanding anomalies, pointing towards a violation of the Lepton Flavor Universality:

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



Experimental challenges: backgrounds are difficult to control, due to at least two n's in the final state, no clear signal peak;

First Belle II measurement of R(D*): we use the Full Event Interpretation (same as B → Knn HTA), to have the strongest control of the backgrounds, at the price of reducing the statistics.



Using only $\tau \to l\nu\nu$,
3 ν's in the final state!

arXiv:2401.02840 [hep-ex]

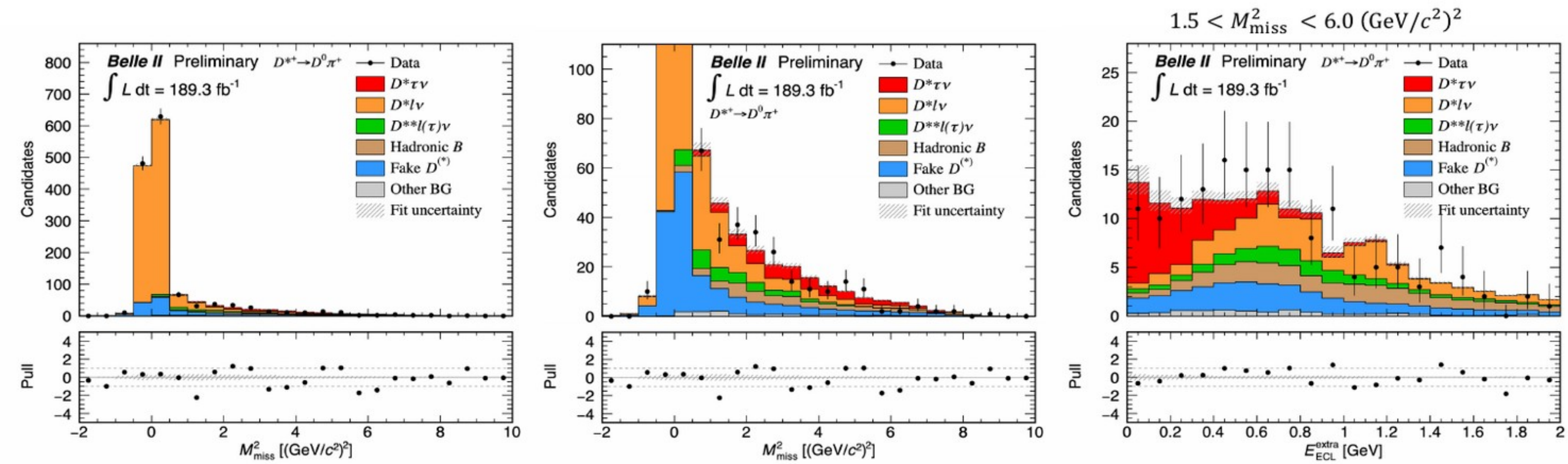
First R(D*) measurement at Belle II

Analysis strategy: we extract the signal from a 2D fit on the variables:

missing mass squared: $M^2_{\rm miss} = (p_{e^+e^-} - p_{B_{tag}} - p_{D^*} - p_\ell)^2$

extra energy on the calorimeter: $E^{\rm extra}_{\rm ECL}$

arXiv:2401.02840 [hep-ex]



The major backgrounds are validated on data sidebands:

low q^2 sideband (D* l n enhanced);
extra p^0 selection (D** l n enriched);
Δm = m(D*) - m(D) sideband (fake D*).

Using only ~50% of the statistics available at Belle II

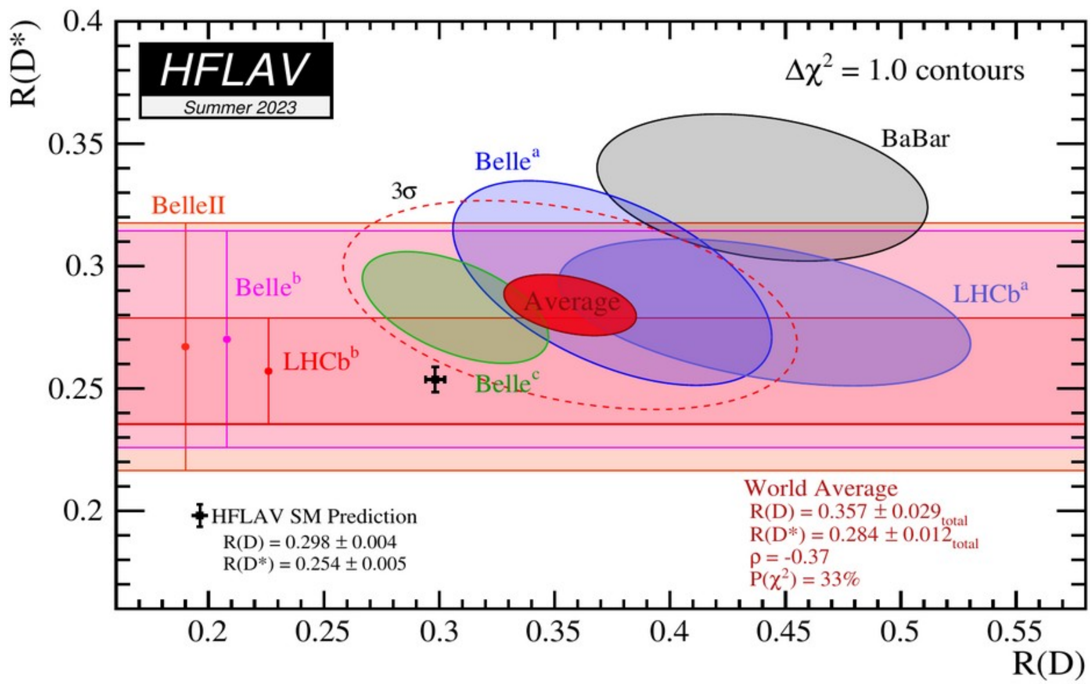
First R(D*) measurement at Belle II

Result:

$$R(D^*) = 0.262 \; ^{+0.041}_{-0.039}(\text{stat.}) \; ^{+0.035}_{-0.032}(\text{syst.})$$

arXiv:2401.02840 [hep-ex]

40% improvement in the statistical precision compared to Belle with the same luminosity



Performed also the first inclusive measurement of:

$$R(X) = \frac{BF(B \to X\tau\nu)}{BF(B \to Xl\nu)}$$

Results consistent with both SM and R(D*) world average

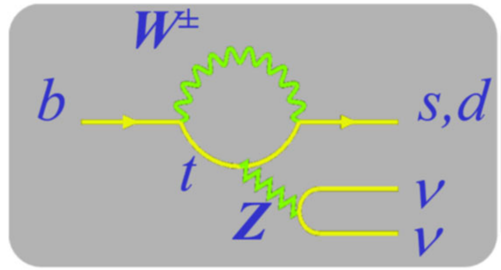
arXiv:2311.07248 [hep-ex]

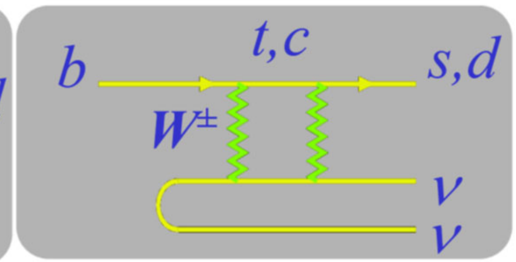
Compatible with both the SM predictions and the World average, we need more data, and also the measurement of R(D), to shed more light on this problem.

$B^+ \rightarrow K^+ \nu \nu$ – motivations

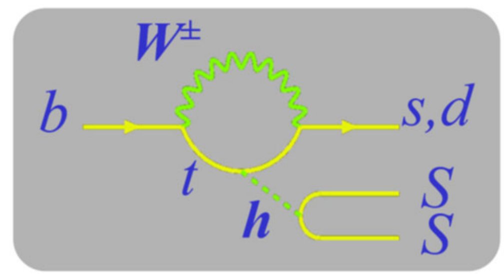
Very suppressed in the SM, proceeding only through box/loop diagrams;

Expected BR: (5.6 ± 0.4) x 10^{-6}
[Phys. Rev. D 107, 014511 (2023)];





It could be enhanced by new physics contributions, and be connected to other anomalies seen in $b \rightarrow s\, l^+ l^-$, $R(D^{(*)})$, $(g\text{-}2)_\mu$, … - or come from something even more exotic…

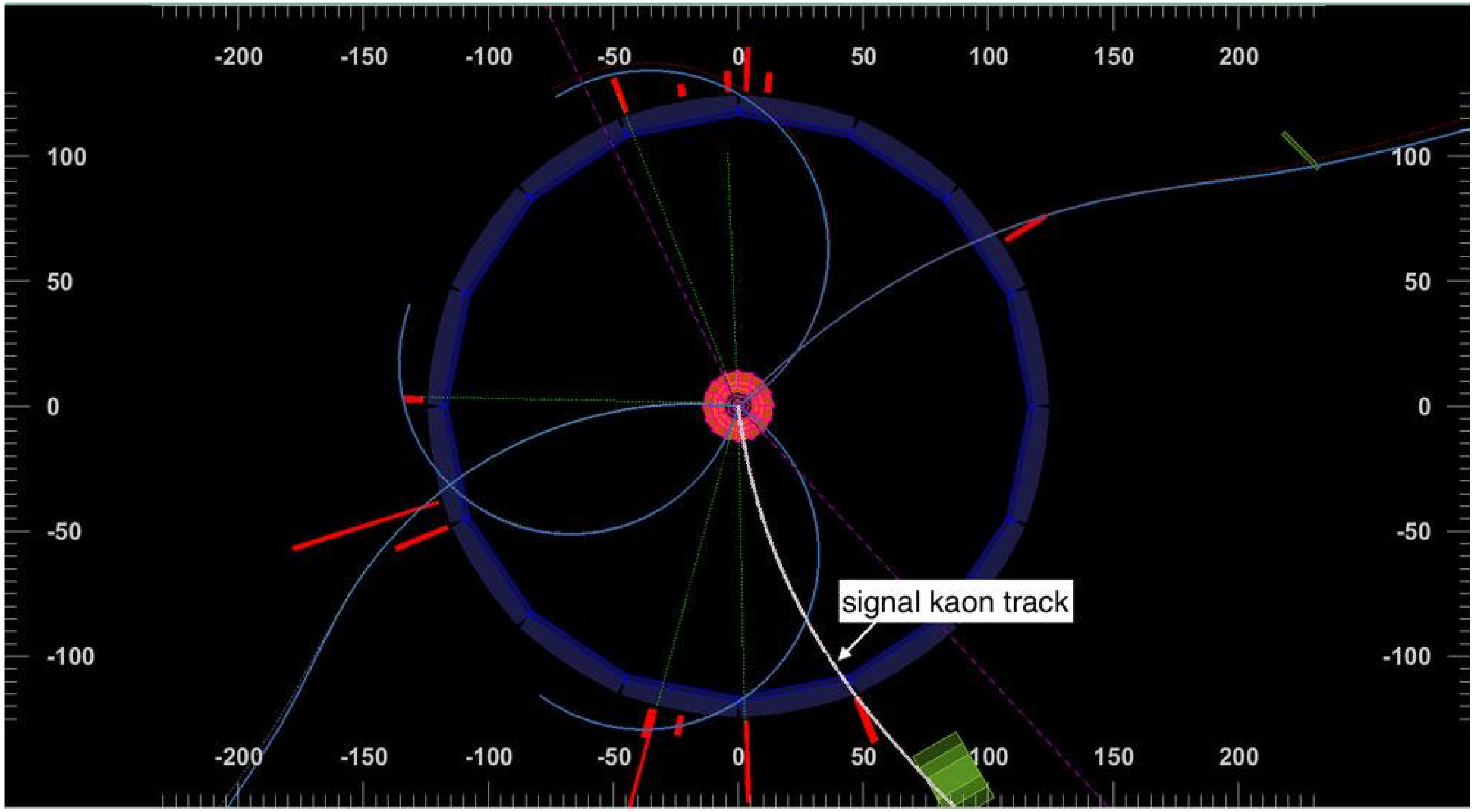


Very challenging from the experimental point of view: at least two ν's in the final state, controlling the backgrounds is crucial.

Upper limits provided by BaBar [HAD, SL] and Belle [HAD, SL], exploiting the reconstruction of the other B in the event in a hadronic or semileptonic final state.

$B^+ \rightarrow K^+ \nu \nu$ – event

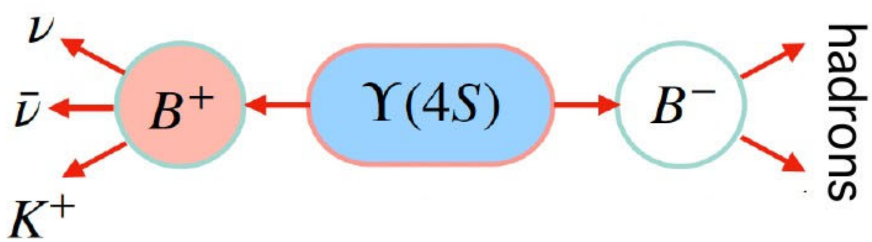
One B decaying to K^+ + nothing visible ($\nu \nu$)

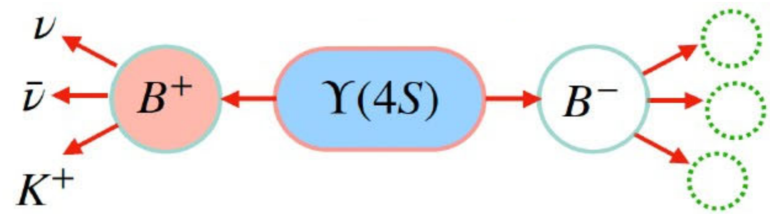


$B^+ \rightarrow K^+ \nu \nu$ – experimental approaches

Two techniques utilized in parallel at Belle II:

[arXiv:2311.14647 [hep-ex]]





More "conventional"

Efficiency →

← Purity

More sensitive

Hadronic Tag Analysis (HTA): stronger control of the backgrounds, but lower efficiency. Relying on the Full Event Interpretation (FEI) algorithm [Comput. Softw. Big Sci 3, 6 (2019)]

Inclusive Tag Analysis (ITA): first tried at Belle II, background suppression relies on the properties of the *Rest Of the Event (ROE)*, which should correspond to the other B in the event

The two analyses are (almost) statistically independent

$B^+ \rightarrow K^+ \nu \nu$ – selection

We select a kaon candidate track
(PID efficiency ~68%, p → K mis-ID rate 1.2%);

arXiv:2311.14647 [hep-ex]

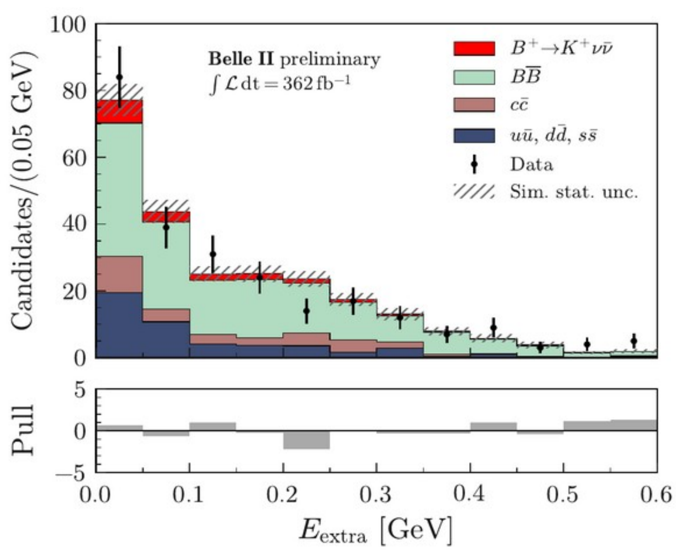
If two K candidates are present in the ITA, we select that with the lowest q^2:

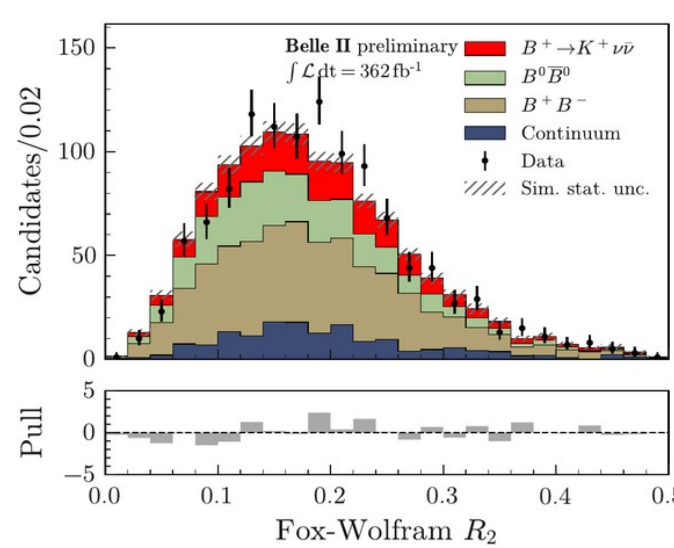
$$q^2_{\mathrm{rec}} = s/(4c^4) + M_K^2 - \sqrt{s}E_K^*/c^4$$

(the choice is correct in ~96% of the cases)

Variables sensitive to the signal properties, event shape, extra particles in the event, … , are combined in one (for HTA) or two successive (for ITA) BDT's;

HTA

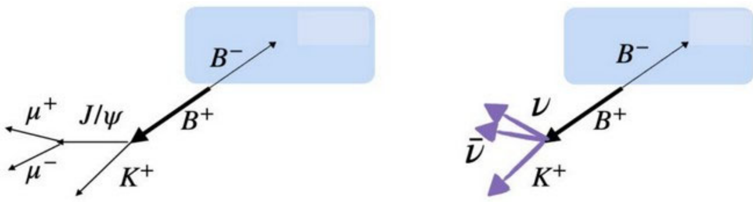


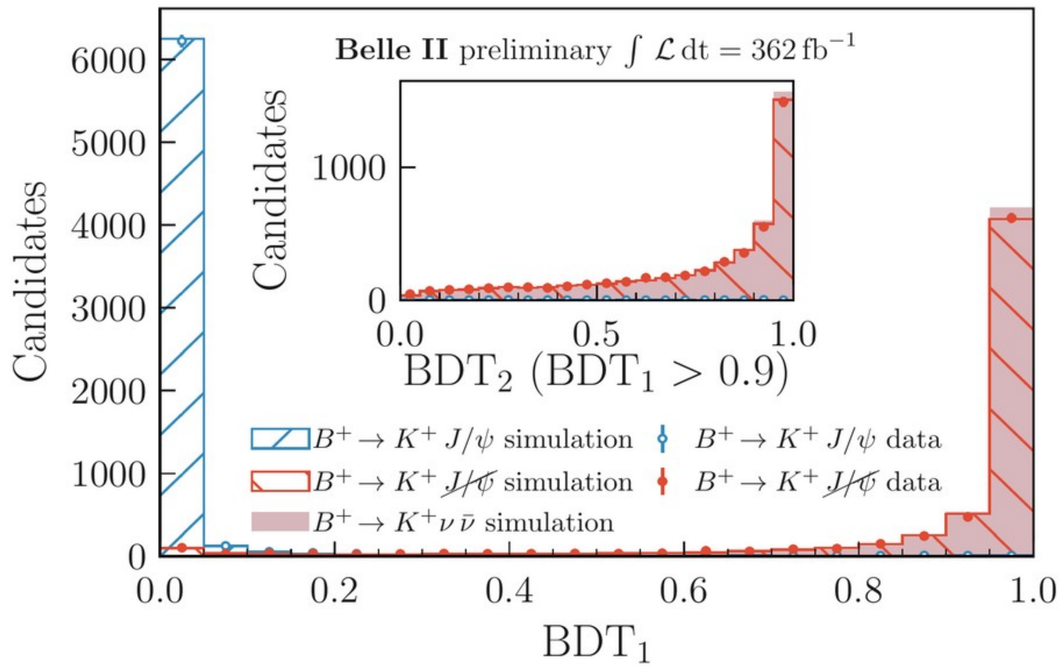


ITA

$B^+ \to K^+ \nu \nu$ – validation

We validate the ITA procedure and signal efficiency using $B^+ \to K^+ J/\psi(\to\mu^+\mu^-)$;





We see very good agreement in the BDT output between data and signal simulation;

Other checks from:

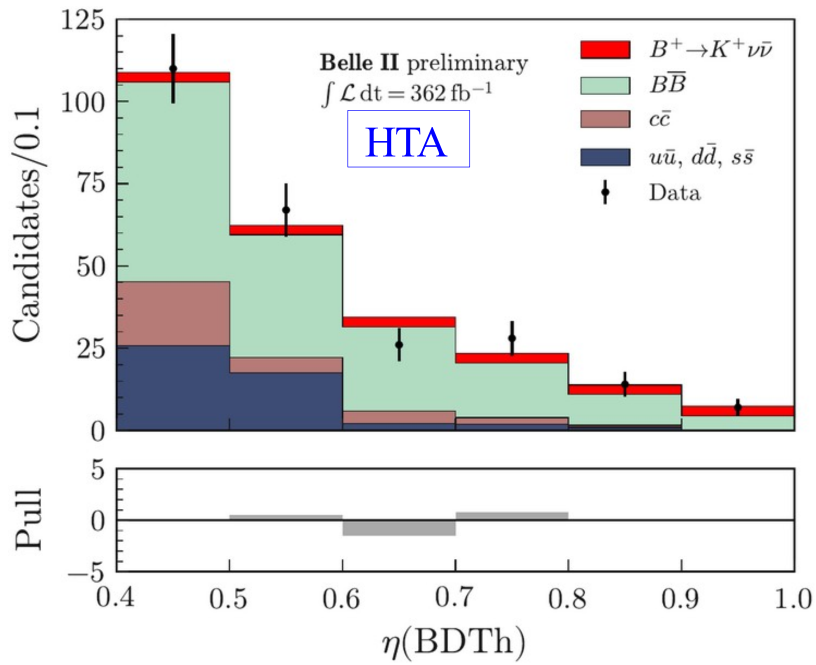
- study of off-resonance data;
- pion enriched control samples;
- measurement of $B^+ \to \pi^+ K^0$;
- … ;

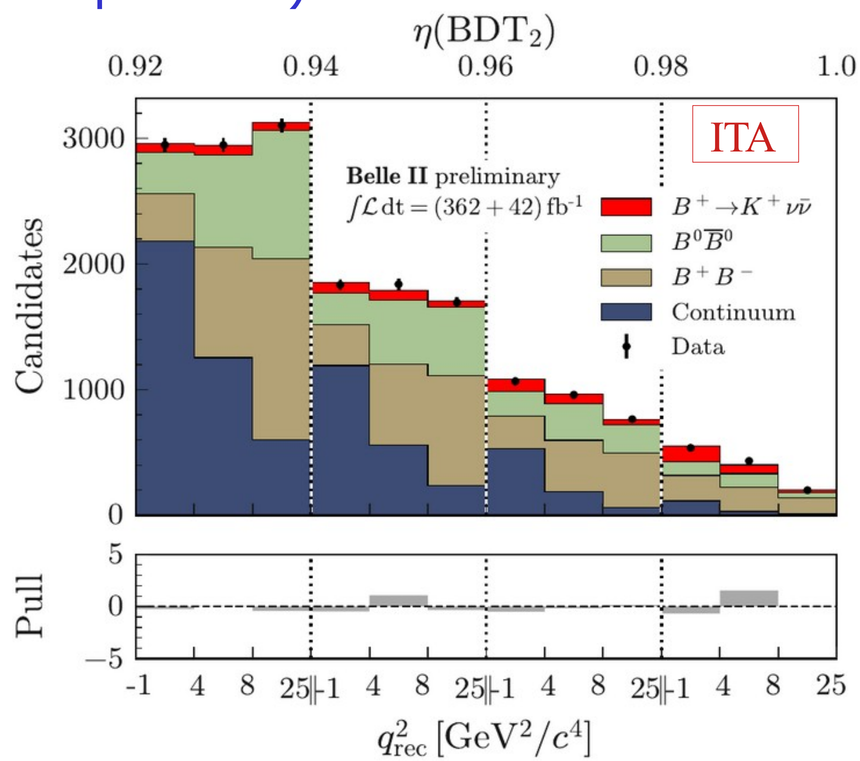
Data/MC differences observed in the normalization of the control samples contribute to the systematic uncertainties

arXiv:2311.14647 [hep-ex]

$B^+ \to K^+ \nu \nu$ – results

The signal is extracted in bins of the transformed (flat in efficiency) output η of the BDT (and q^2 for ITA):





$$\mu_{HTA} = 2.2^{+1.8}_{-1.7}(stat)^{+1.6}_{-1.1}(syst)$$

$$\mu_{ITA} = 5.4 \pm 1.0(stat) \pm 1.1(syst)$$

1.1σ above the background only hypothesis 0.6σ above the SM expectation

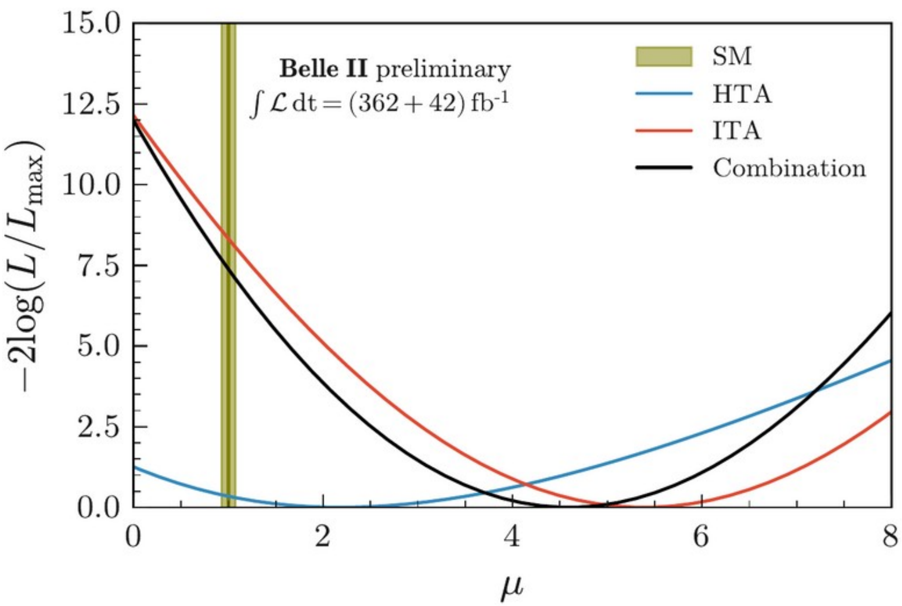
3.5σ above the background only hypothesis 2.9σ above the SM expectation

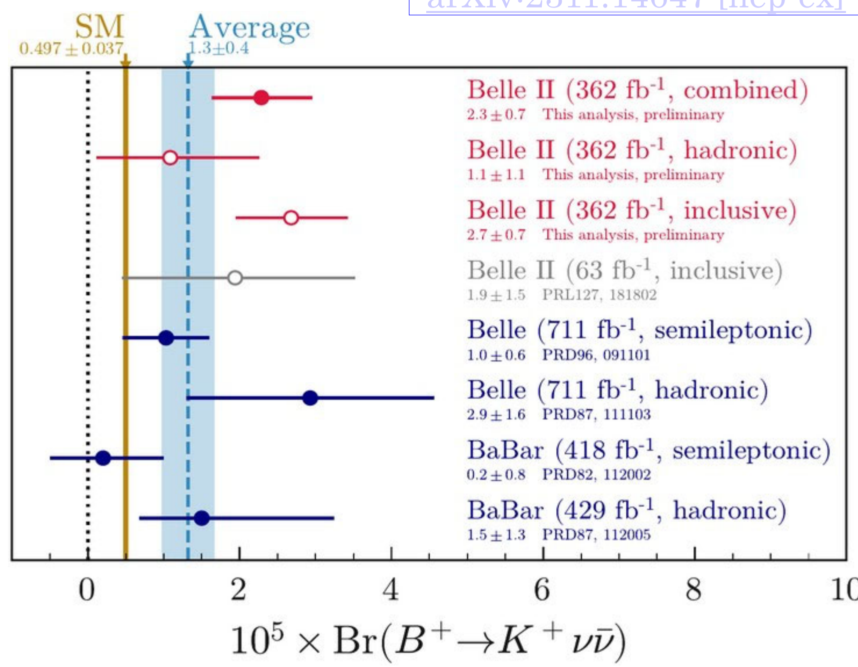
arXiv:2311.14647 [hep-ex]

$B^+ \to K^+ \nu \nu$ – results

Combining the results of ITA and HTA:

arXiv:2311.14647 [hep-ex]





$$\mu = 4.6 \pm 1.0(\text{stat}) \pm 0.9(\text{syst})$$

$$BR(B^+ \to K^+ \nu\nu) = [2.4 \pm 0.5(\text{stat})^{+0.5}_{-0.4}(\text{syst})] \times 10^{-5}$$

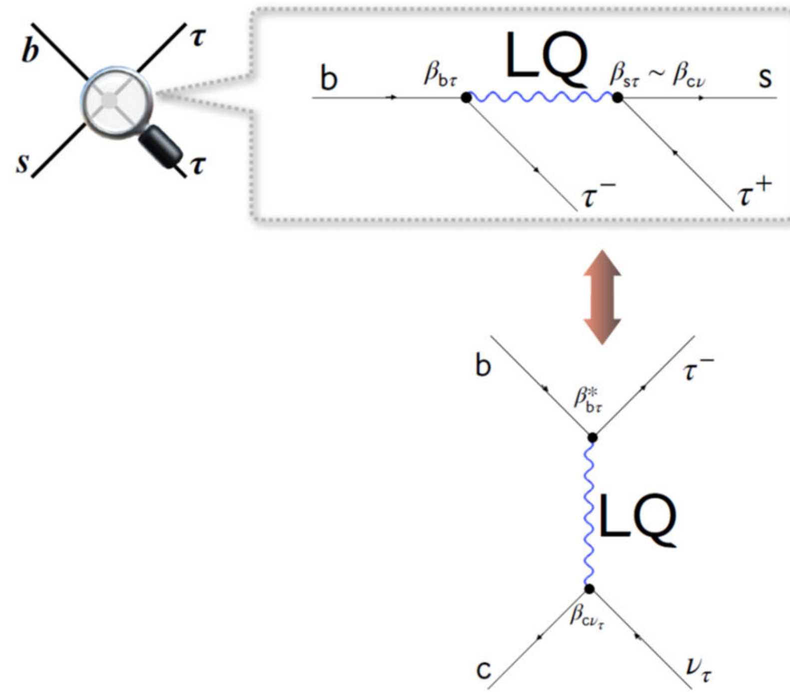
3.5σ above the background only hypothesis, 2.7σ above the SM expectation

Exciting result, to be confirmed with Belle ITA, semileptonic tagged analysis and the investigation of more $B \to K^{(*)} \nu \nu$ modes.

$B \to K^{(*)} \tau^+ \tau^-$

- SM Expected BF $\mathcal{O}(10^{-7})$ [1]
- Correlation with $R_{D^{(*)}}$ [2]
- Large enhancements to SM BF $\mathcal{O}(10^2 - 10^3)$

$$C_9^{\tau\tau} = C_{10}^{\tau\tau} \sim -\frac{2\pi}{\alpha} \frac{V_{cb}}{V_{tb} V_{ts}^*} \left(\sqrt{\frac{R_{D^{(*)}}}{R_{D^{(*)}}^{SM}}} - 1 \right) \quad [3]$$



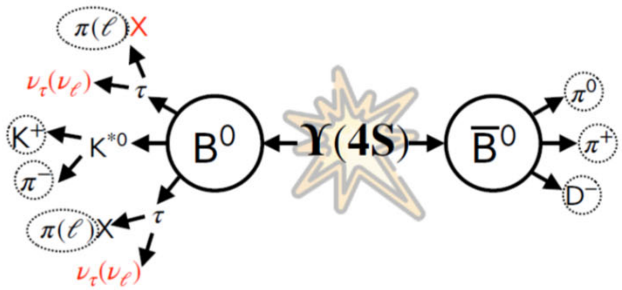
Decay	BF U.L. @ 90% CL		
$B_s \to \tau\tau$	5.2×10^{-3}	$3\ fb^{-1}$	PRL 118.251802 (2017)
$B^+ \to K^+\tau\tau$	2.3×10^{-3}	$424\ fb^{-1}$	PRL 118.031802 (2017)
$B^0 \to K^{*0}\tau\tau$	3.1×10^{-3}	$711\ fb^{-1}$	2110.03871

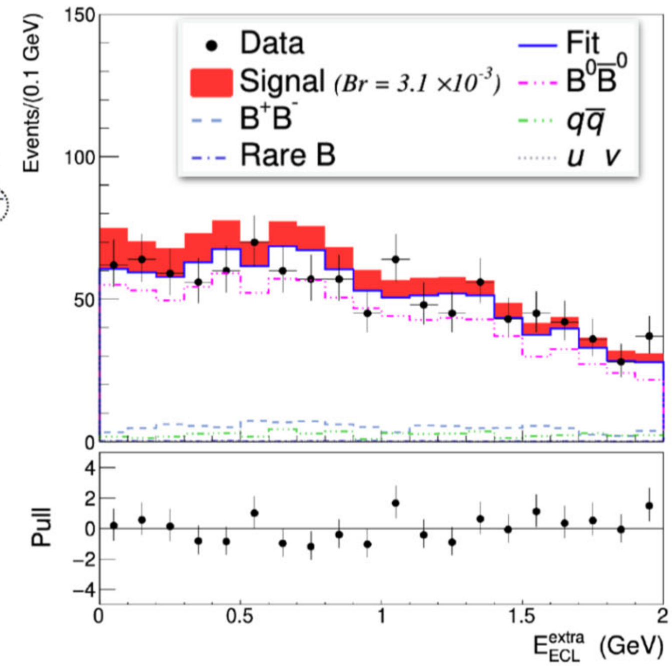
Current sensitivity far from $\mathscr{B}_{SM}$!

[1] PRL 120.181802 (2018) [2] PRL120.181802(2018) [3] PRD 105.113007 (2022)

B $\rightarrow K^{(*)} \tau^+ \tau^-$

2110.03871





Search at Belle (711 fb-1)

- Hadronic B-tagging Belle algorithm (Neurobayes FR)
- $\tau \rightarrow \ell \nu \bar{\nu}, \pi\nu$ modes considered
- Cut&count analysis
- $\mathscr{B}(B^0 \rightarrow K^{*0}\tau\tau) < 3.1 \times 10^{-3}$ (90 % CL)

Belle II projections 2207.06307

	$\mathcal{B}(B^0 \to K^{*0}\tau\tau)$ (had tag)	
ab^{-1}	"Baseline" scenario	"Improved" scenario
1	$< 3.2 \times 10^{-3}$	$< 1.2 \times 10^{-3}$
5	$< 2.0 \times 10^{-3}$	$< 6.8 \times 10^{-4}$
10	$< 1.8 \times 10^{-3}$	$< 6.5 \times 10^{-4}$
50	$< 1.6 \times 10^{-3}$	$< 5.3 \times 10^{-4}$

Increased signal efficiency while assuming same syst. unc. as Belle (Total 9%: MC sample size 4%, B_{tag} eff. correction 5%, track eff. 4%)

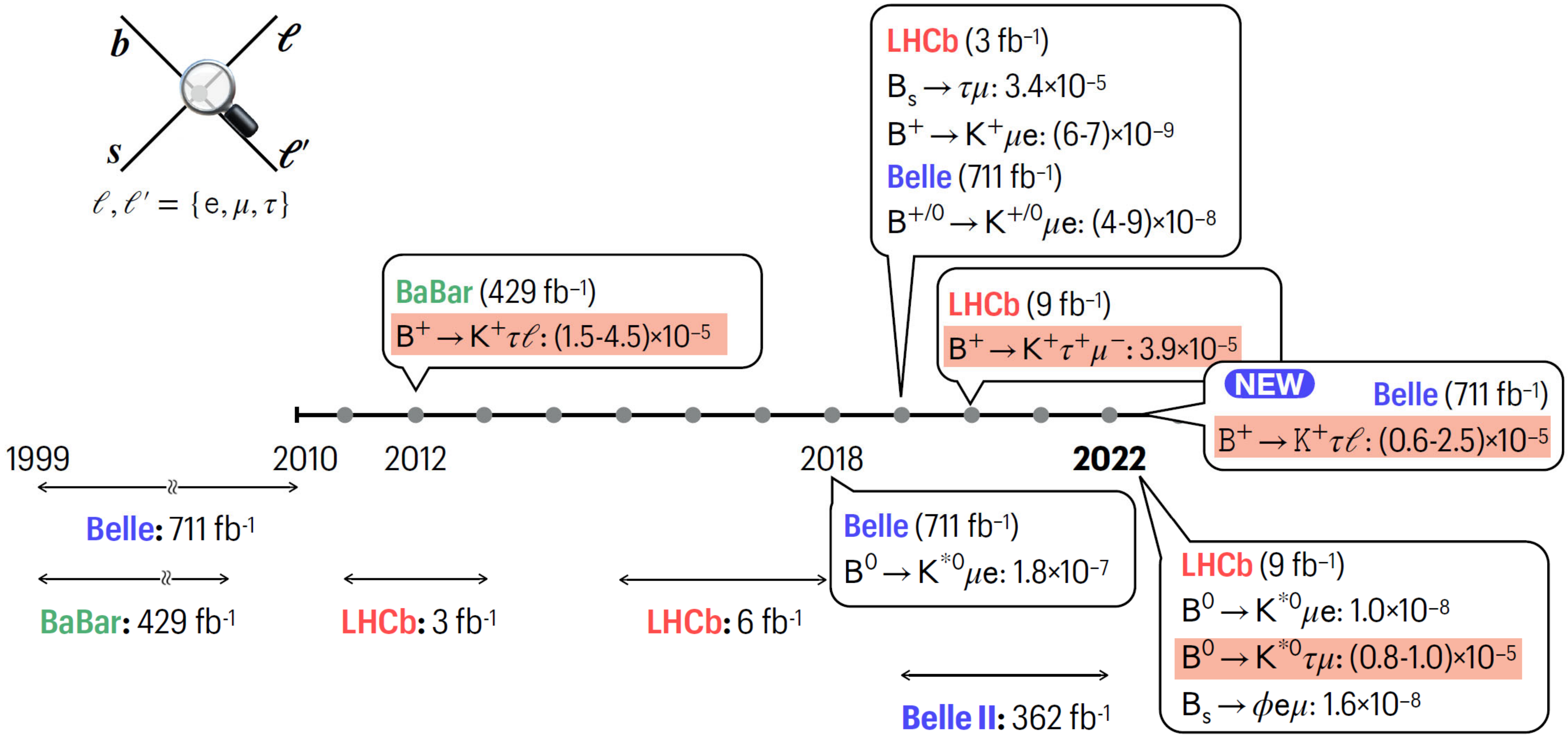
Improvement @ Belle II

- ~2x hadronic B-tagging efficiency: **FR → FEI**
- **Multivariate analysis**
- **Add $\tau \rightarrow \rho\nu$ modes**

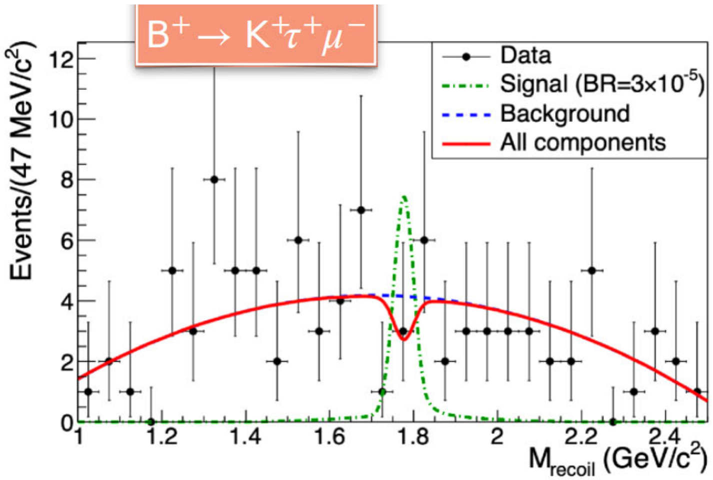
Will offer unprecedented sensitivity in $B \rightarrow K\tau\tau$ decays

Lepton flavour violating b→s: B →K$^{(*)}$ τ μ/e

- $b \to s\ell\ell'$ probed at B-factories and LHCb
- $B \to K\tau\ell$ more interesting ($R_{K^{(*)}}$ & $R_{D^{(*)}}$ anomalies) but experimentally more challenging
  - Sensitivity is entering now the 10^{-6} regime



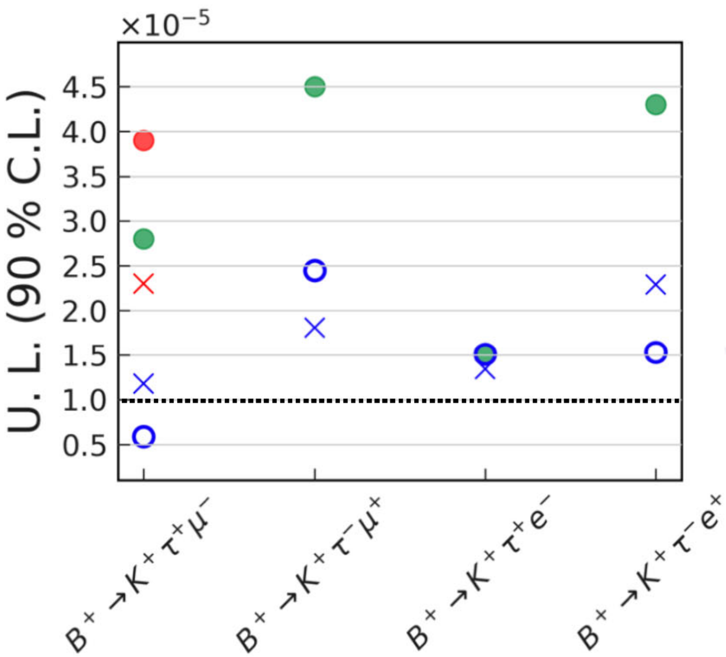
Status of B →K$^{(*)}$ τ μ/e



No significant signal is observed for any of the 4 modes

Mode	$\varepsilon(\%)$	N_{sig}	$\mathcal{B}^{UL}(10^{-5})$ @ 90 % CL
$B^+ \to K^+\tau^+\mu^-$	0.064	-2.1 ± 2.9	0.59
$B^+ \to K^+\tau^+e^-$	0.084	1.5 ± 5.5	1.51
$B^+ \to K^+\tau^-\mu^+$	0.046	2.3 ± 4.1	2.45
$B^+ \to K^+\tau^-e^+$	0.079	-1.1 ± 7.4	1.53

$$\mathscr{B}^{UL} = \frac{N^{UL}_{sig}}{\varepsilon \times 2N_{B\bar{B}} \times f^{+-}}$$



Best limits for the $B^+ \to K^+\tau\ell$ modes!

τ mass measurement

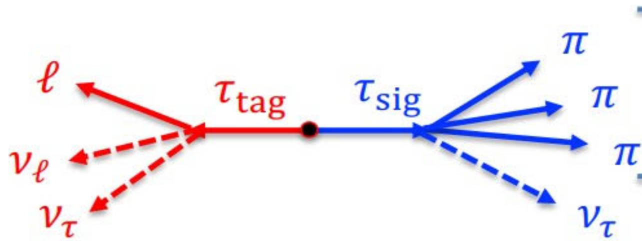
Fundamental parameter of the standard model

Important input to lepton-flavour universality tests

$$R_e = \frac{\mathcal{B}[\tau^- \to e^- \bar{\nu}_e \nu_\tau]}{\mathcal{B}[\mu^- \to e^- \bar{\nu}_e \nu_\mu]} \qquad \left(\frac{g_\tau}{g_\mu}\right)_e = \sqrt{R_e \frac{\tau_\mu}{\tau_\tau} \frac{m_\mu^3}{m_\tau^3} (1+\delta_W)(1+\delta_\gamma)}$$

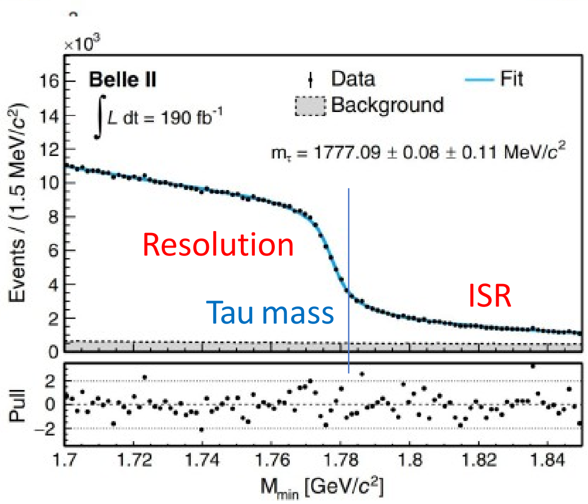
(δs are radiative corrections)

We use the pseudomass variable to determine the mass



$$M_{\min} = \sqrt{m_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi})(E_{3\pi} - |\vec{p}_{3\pi}|)} \le m_\tau$$

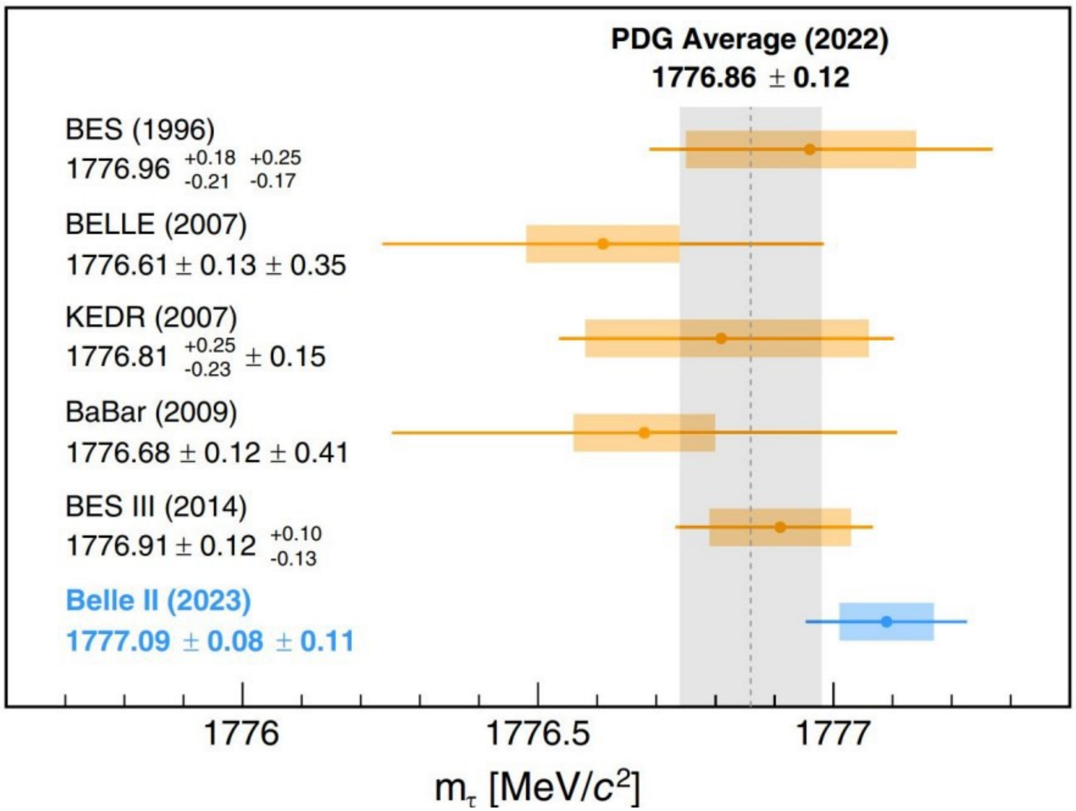
Fit to the endpoint with empirical function



- Fit to distribution with analytic form that accounts for ISR, FSR and resolution
- Knowing the scale key: beam energy (from E_B*) and momentum (from D mass)

Phys. Rev. D **108**, 032006 (2023)

τ mass measurement



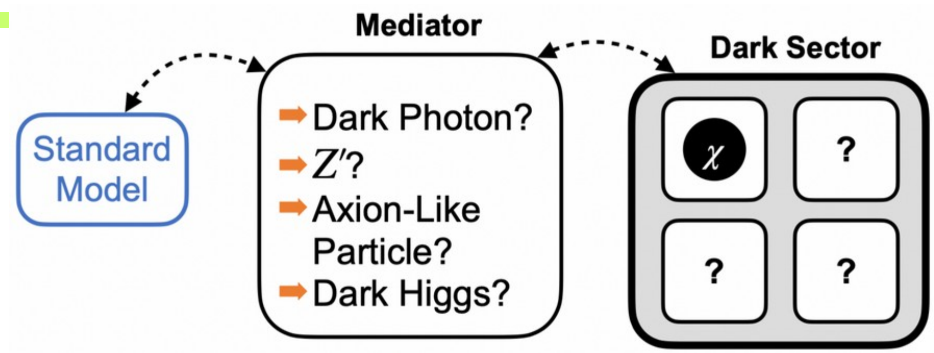
World's most precise measurement to date

Impact on other precision measurements

Dark sector searches

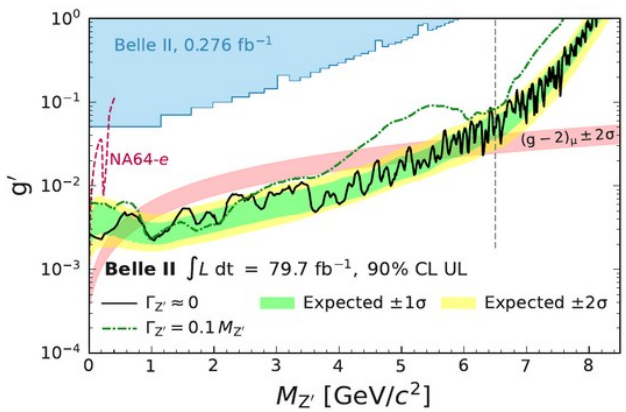
In many extensions of the SM, there exist a dark sector, that interacts with the SM particles via a weakly coupled mediator;

If the mass of the mediator is in the [0.01 – 10] GeV range, this could be accessible to Belle II;



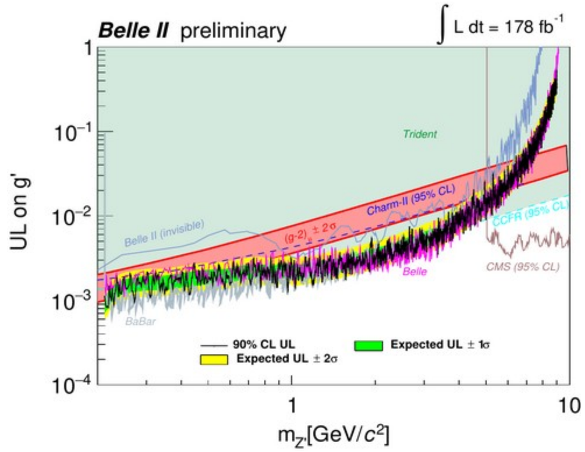
Belle II implements trigger strategies that were not available to Belle, thus opening new territories even with smaller luminosity:

Search for Z′ → invisible



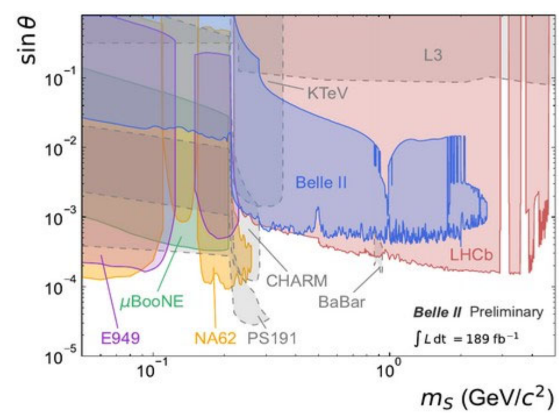
Phys. Rev. Lett. 130, 231801 (20

Search for Z′ → μμ



M. Laurenza, DMNET 2023

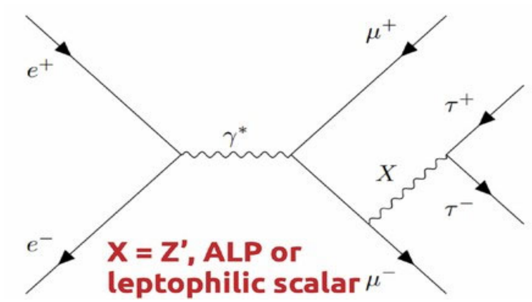
Search for Long Lived Particles



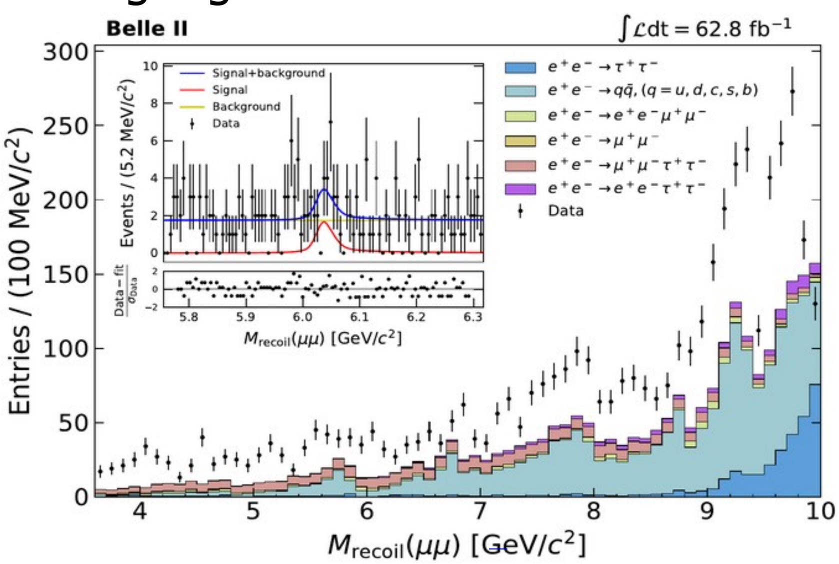
Phys. Rev. D 108, L111104 (2023)

Dark sector searches

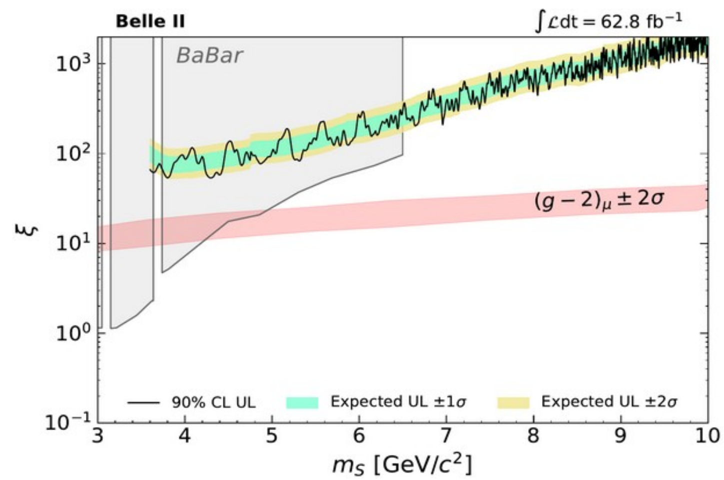
Search for a ττ resonance in $e^+e^- \to \mu^+\mu^- X$, $X \to \tau^+\tau^-$;

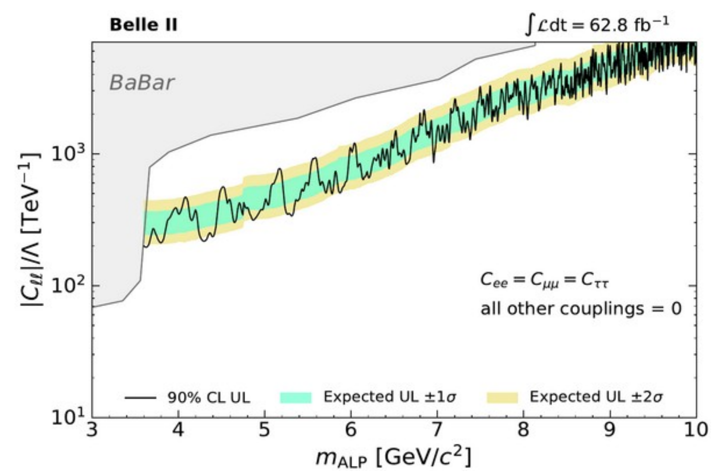


Looking for a narrow peak in the mass recoiling against the dimuons:



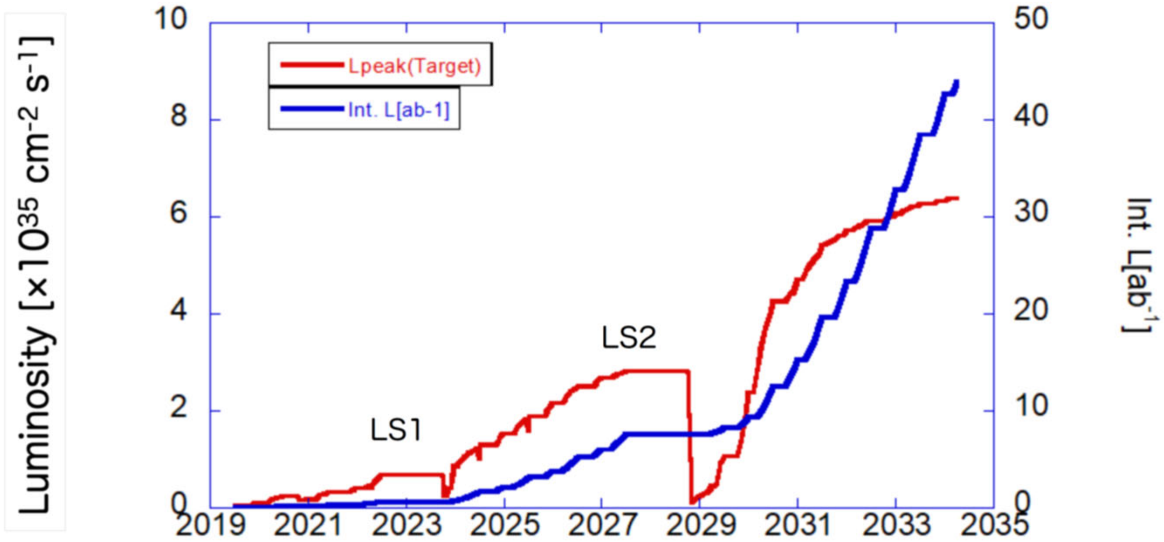
Part of the $\gamma\gamma \to qq$ backgrounds are not covered by the simulation





Phys. Rev. Lett. 131, 121802 (2023)

Outlook



Ultimate goal: reach 50/ab by operating at the design luminosity of 6 x 10^{35} cm^{-2} s^{-1}

Current working plan follows the KEK Roadmap2020
-LS1 in 2022-23 for the full pixel vertex detector (PXD) installation & partial replacement of MCP-PMTs in TOP – successfully completed
-an interaction region upgrade (LS2) ≳2027 under study
→https://arxiv.org/abs/2203.11349

Beyond: discussions of physics and detector options with an upgraded accelerator to reach an even larger data sample of ~250/ab

Summary

Physics of b and c hadrons and t leptons has contributed substantially to our present understanding of elementary particles and their interactions

B, D and τ decays have been and continue being a very hot topic in searches for new physics. Intriguing phenomena that have been seen in recent years make this research area one of the most interesting in particle physics.

Belle II has entered the super-B-factory regime.

Expect a new, exciting era of discoveries, and a friendly competition and complementarity of Belle II and LHCb, as well ATLAS and CMS