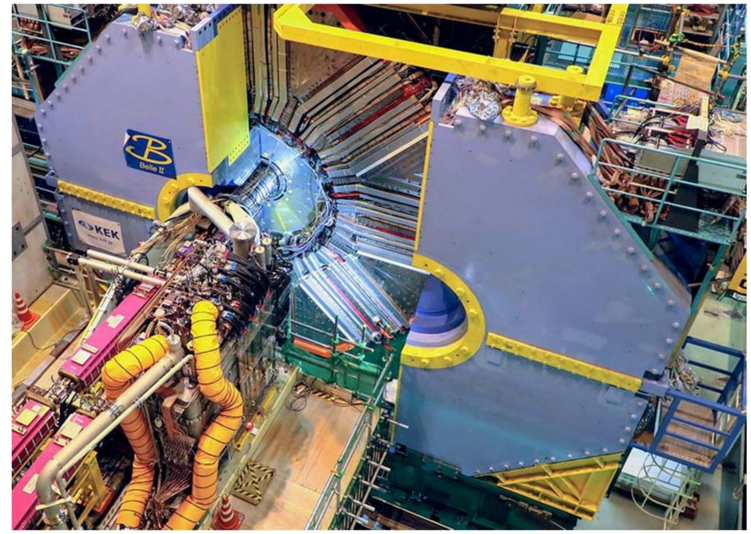
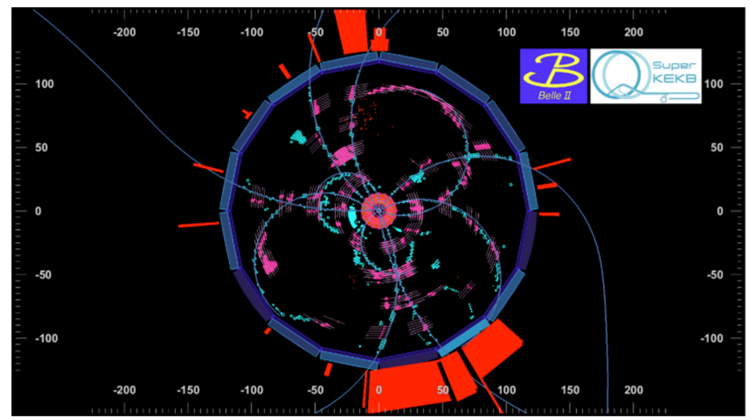
Seminar, Oxford, October 27, 2020





Belle II - first results from a new flavour physics experiment

Univerza *v Ljubljani*
Fakulteta za *matematiko in fiziko*

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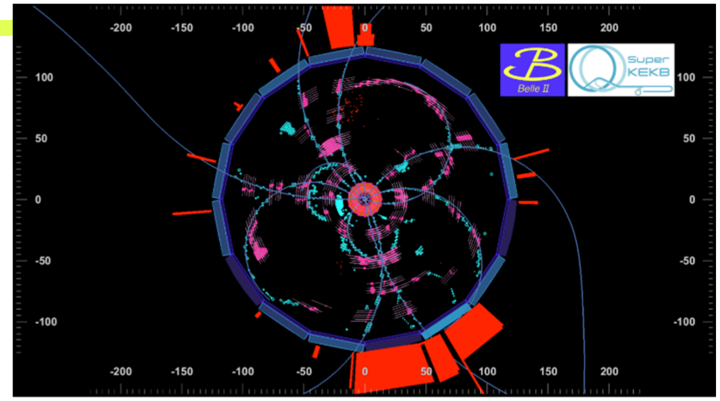
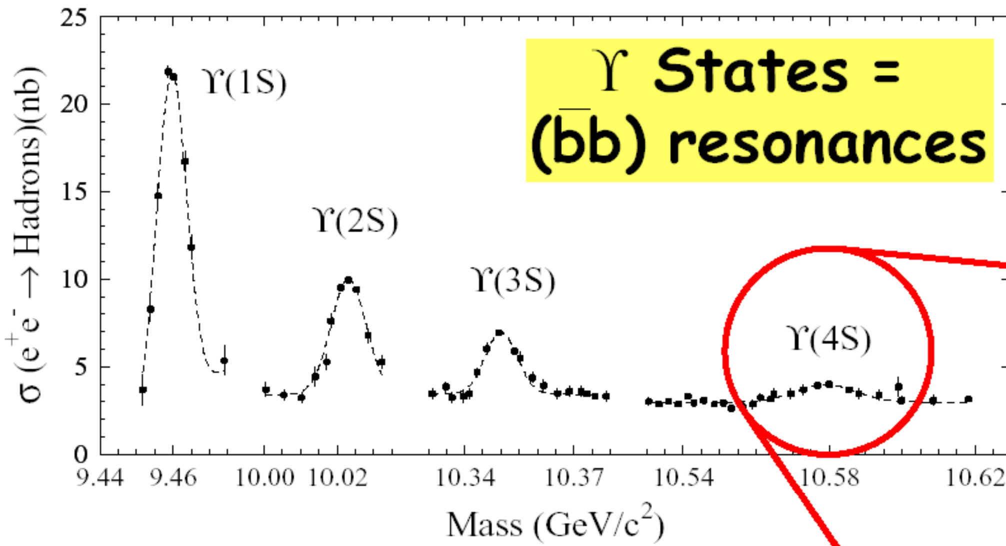
University of Ljubljana and J. Stefan Institute

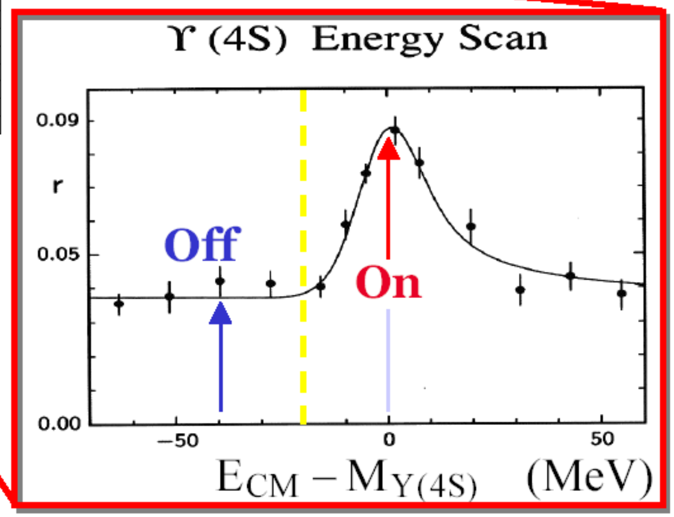
Contents

- Why a super B factory, and how?
- SuperKEKB and Belle II
- Belle II: first results
- Outlook

B meson production in $e^+e^- \rightarrow \Upsilon(4S) \rightarrow BB$







Cross Sections at Υ(4S):

$b\bar{b} \sim 1.1$ nb

$c\bar{c} \sim 1.3$ nb

$d\bar{d}, s\bar{s} \sim 0.3$ nb

$u\bar{u} \sim 1.4$ nb

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

$L = 1$ state

B factories

Systematic studies of B mesons at Υ(4S)

80s-90s: two very successful experiments:

- ARGUS at DORIS (DESY)
- CLEO at CESR (Cornell)

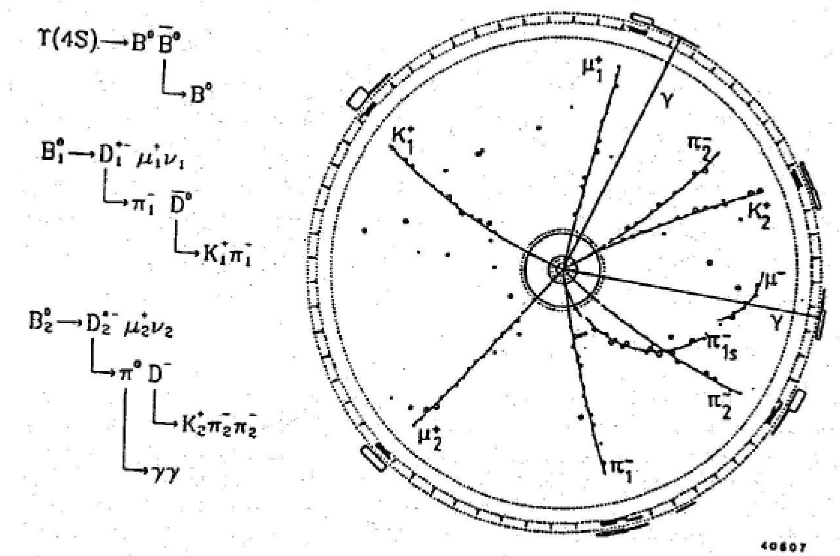
Magnetic spectrometers at e^+e^- colliders (5.3GeV+5.3GeV beams)

Large solid angle, excellent tracking and good particle identification (TOF, dE/dx, EM calorimeter, muon chambers).

1987, one of the highlights: ARGUS discovers large BB mixing: B^0 turns into anti-B^0

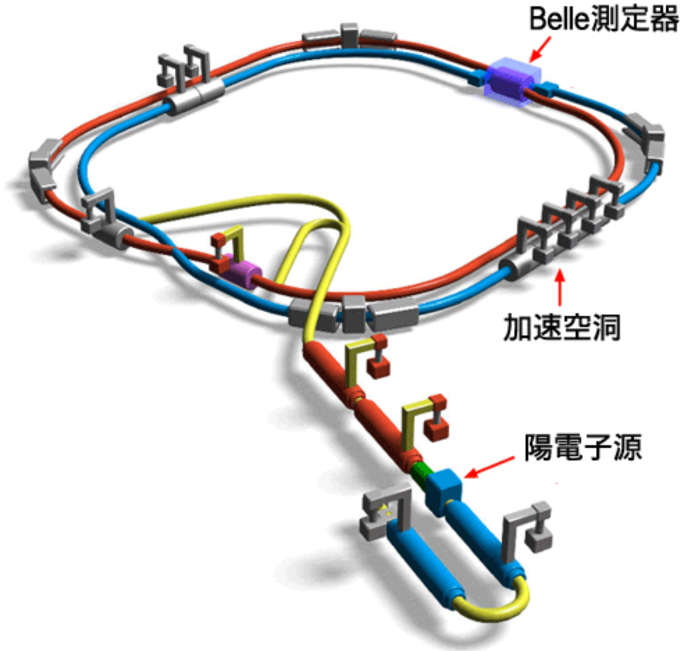
Large mixing rate → high top mass (in the Standard Model)

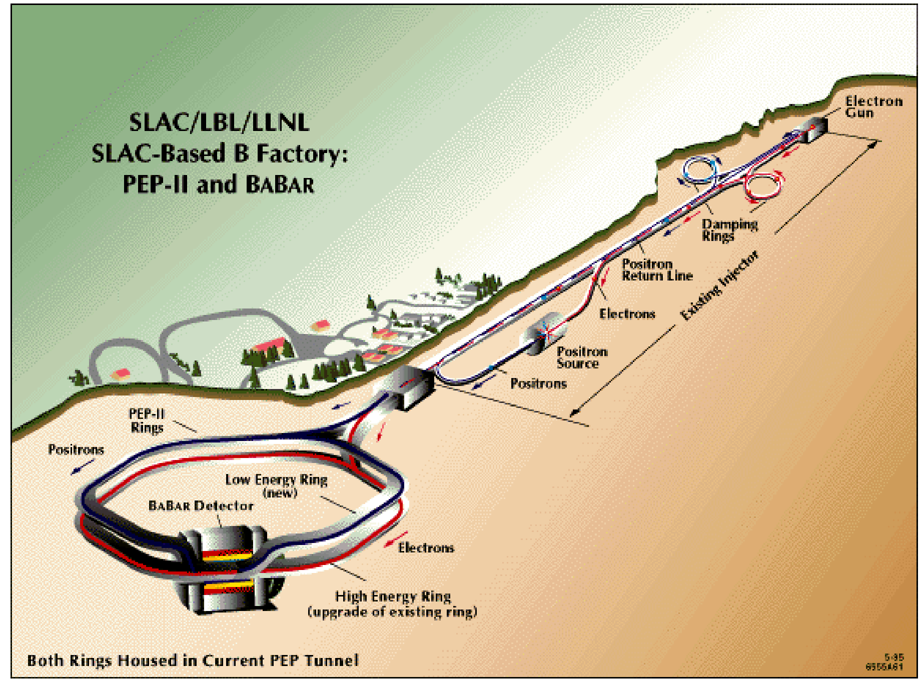
The top quark has only been discovered seven years later!



Reconstructed event where a B^0 turns into anti-B^0

Next generation: asymmetric B factories





$\sqrt{s}=10.58$ GeV

$e^+ \rightarrow \Upsilon(4S) \leftarrow e^-$

$\Upsilon(4S) \rightarrow B\,\bar{B}$

$\Delta z \sim c\beta\gamma\tau_B \sim 200\mu m$

BaBar	$p(e^-)=9$ GeV	$p(e^+)=3.1$ GeV	$\beta\gamma=0.56$
Belle	$p(e^-)=8$ GeV	$p(e^+)=3.5$ GeV	$\beta\gamma=0.42$

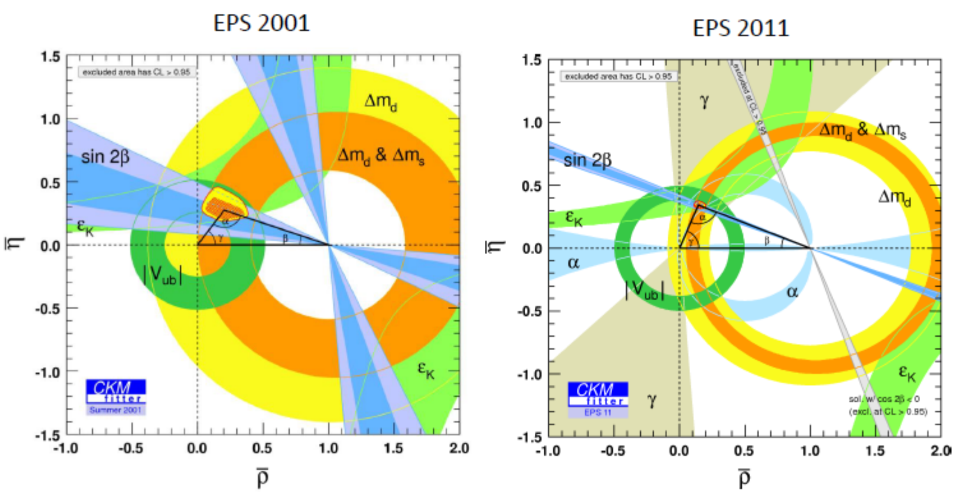
Asymmetric beam energies→B mesons are boosted, needed for studies of time evolution

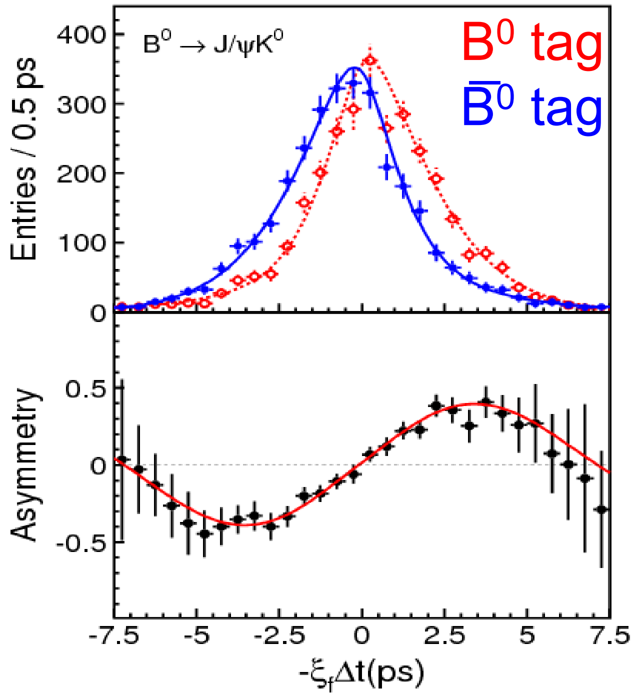
Physics of B mesons at asymmetric B factories

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

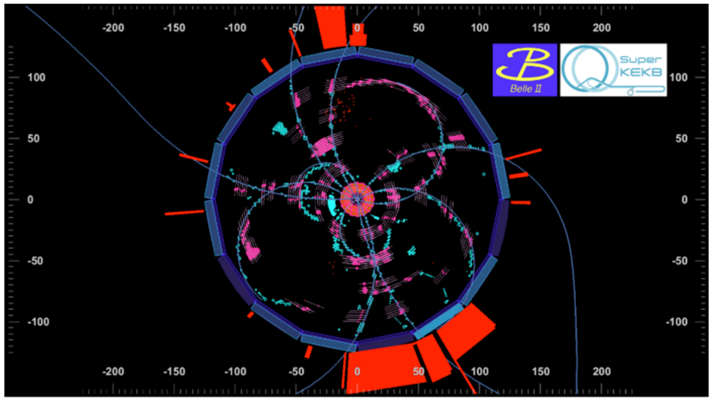
B factories: a success story

- 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

Advantages of a B factory in the LHC era

Fantastic performance of LHCb with many interesting results!

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



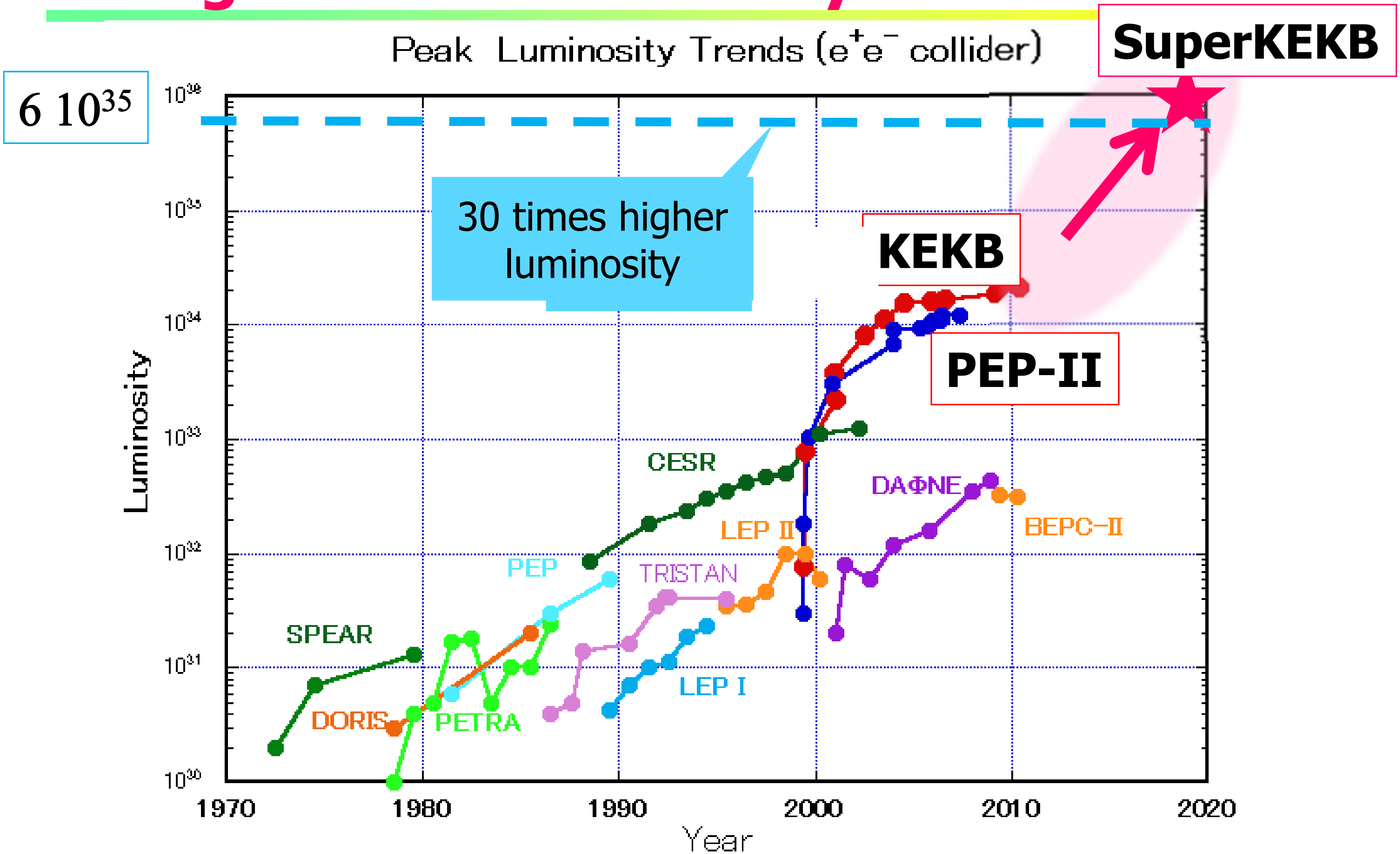
Unique capabilities of a B factory:

→ 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) 12, arXiv:1808.10567

However, need a two-orders-of-magnitude larger data sample!

Need O(100x) more data →Next generation B-factory



N.B. KEKB peak L: 2.11 10^{34} cm^{-2} s^{-1}

How to increase the luminosity?

Beam-beam parameter

Lorentz factor

Beam current

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

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

Classical electron radius

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

Vertical beta function@IP

(1) Smaller β_y^*
(2) Increase beam currents
(3) Increase ξ_y

"Nano-Beam" scheme

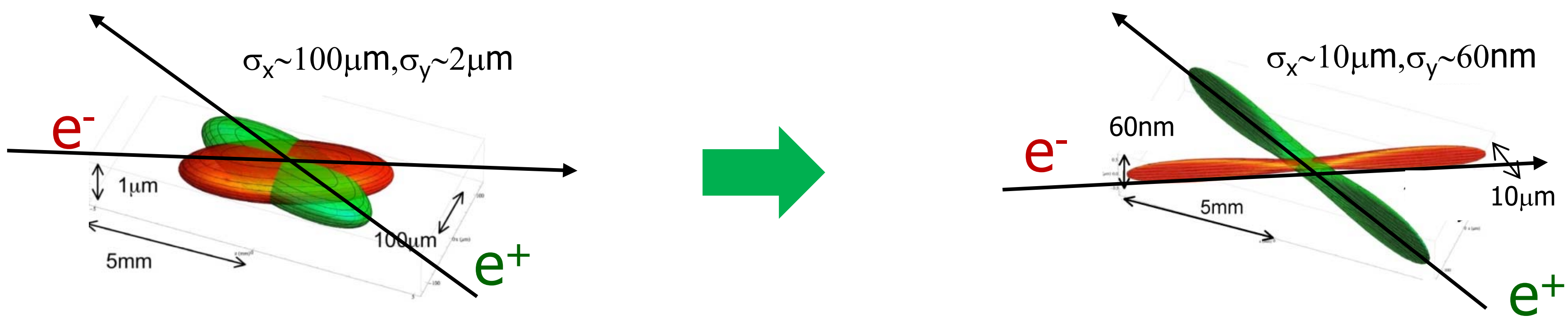
Collision with very small spot-size beams

Invented by Pantaleo Raimondi for SuperB

How big is a nano-beam ?

How to go from an excellent accelerator with world record performance – KEKB – to a 30x times better, more intense facility?

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

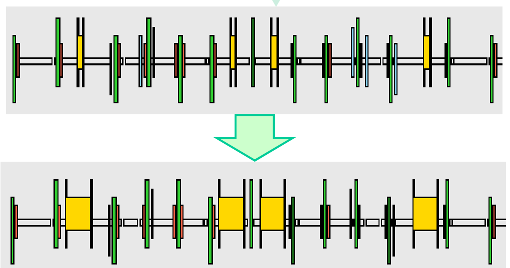


... For a 30x increase in intensity you have to make the beam as thin as a few x100 atomic layers!

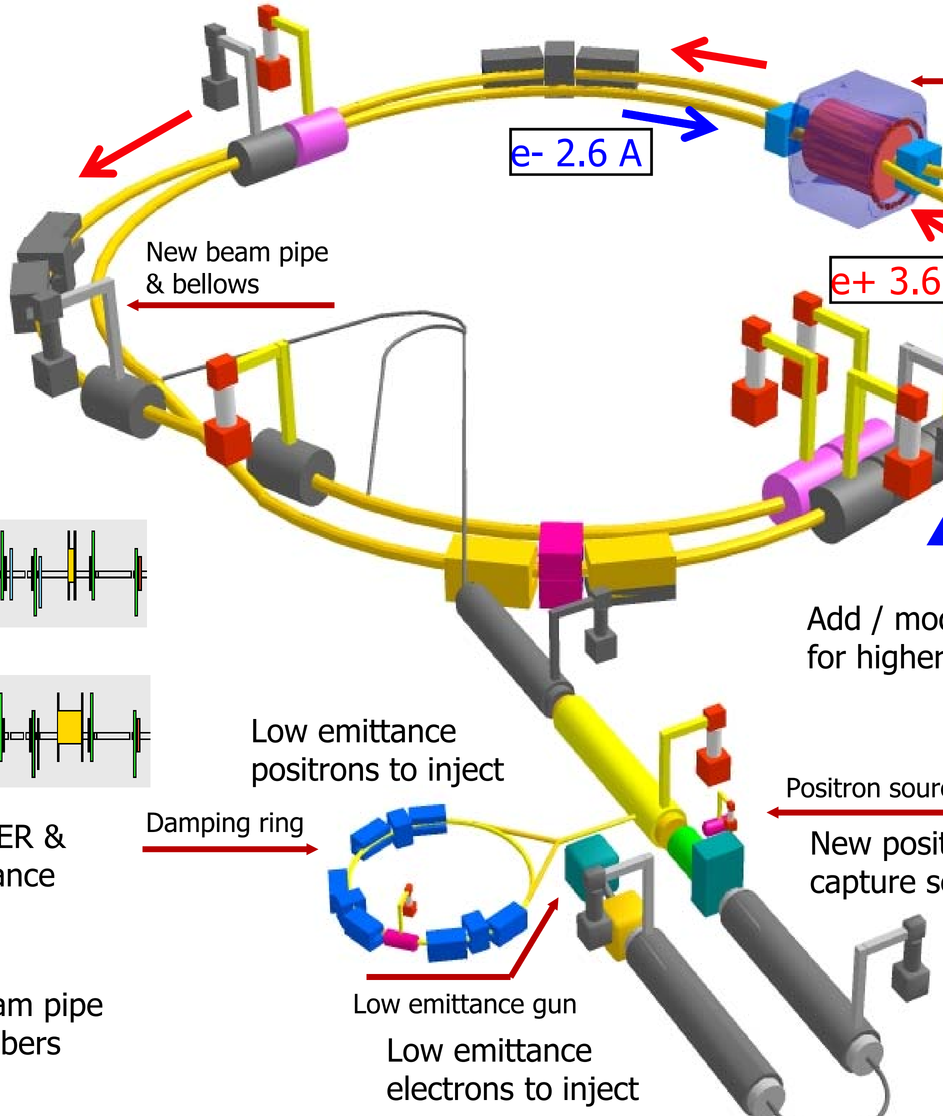
To get x40 higher luminosity

KEKB → SuperKEKB

Replace short dipoles with longer ones (LER)

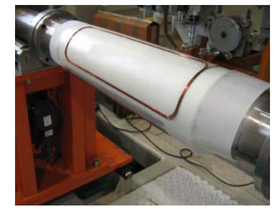


Redesign the lattices of HER & LER to squeeze the emittance



Colliding bunches

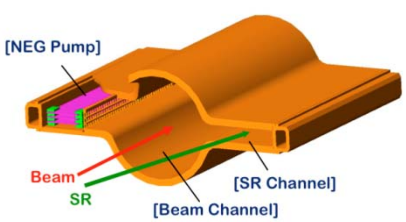
New superconducting /permanent final focusing quads near the IP



Add / modify RF systems for higher beam current

New positron target / capture section

TiN-coated beam pipe with antechambers



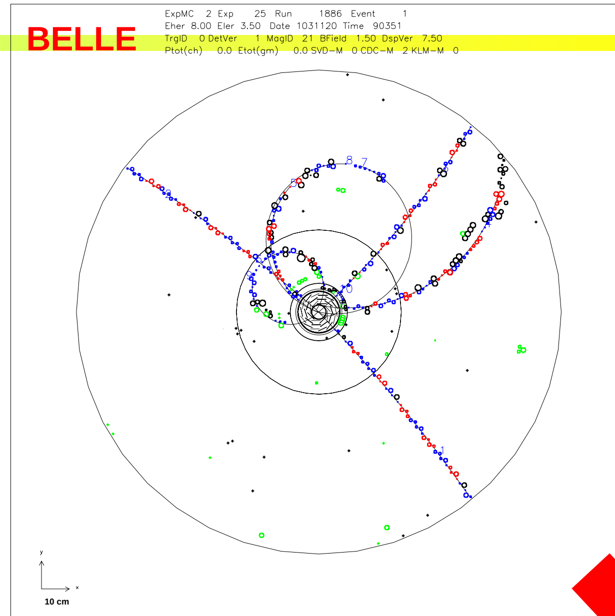
SuperKEKB, the first new collider in particle physics since the LHC

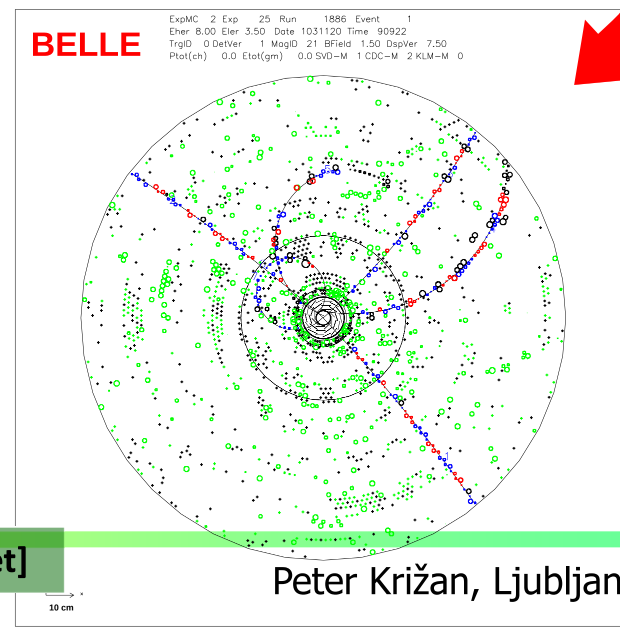
Super KEKB Quest for BSM

Requirements for the Belle II detector

Critical issues at L= 6 x 10^{35}/cm^2/sec

- **Higher background (×10-20)**
  - radiation damage and occupancy
  - fake hits and pile-up noise in the EM
- **Higher event rate (×10)**
  - higher rate trigger, DAQ and computing
- **Require special features**
  - low *p* μ identification ← sμμ recon. eff.
  - hermeticity ← ν “reconstruction”



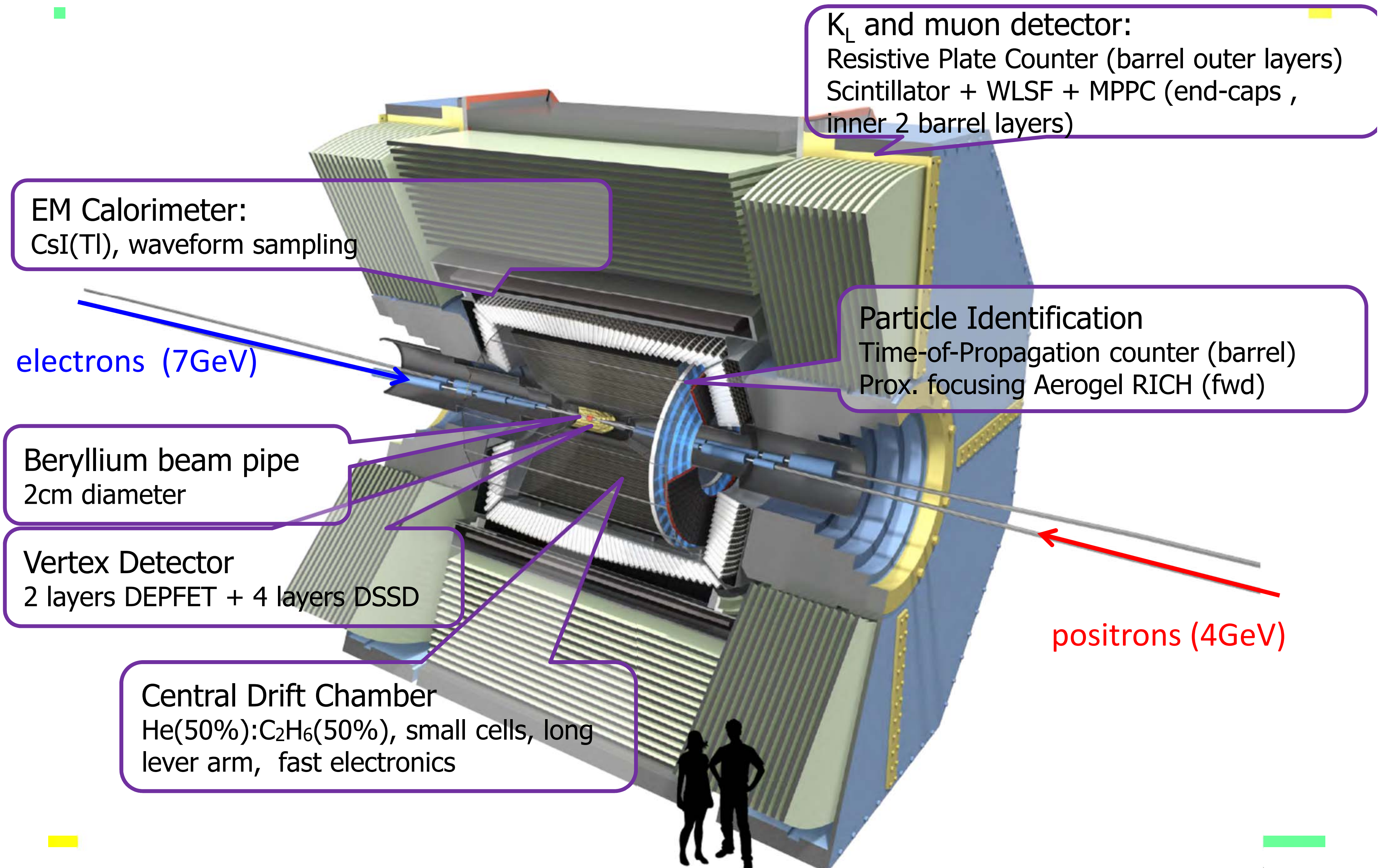


Solutions:

- Replace inner layers of the vertex detector with a pixel detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace part of endcap calorimeter crystals
- Faster readout electronics and computing system.

NIMA 907 (2018) 46-59; Belle II TDR, arxiv:1011.0352v1[physics.ins-det]

Belle II Detector



Advanced & Innovative Technologies used in Belle II

Pixelated sensors play a central role

MCP-PMTs in the TOP
HAPDs in the ARICH
SiPMs in the KLM

} photo-sensors

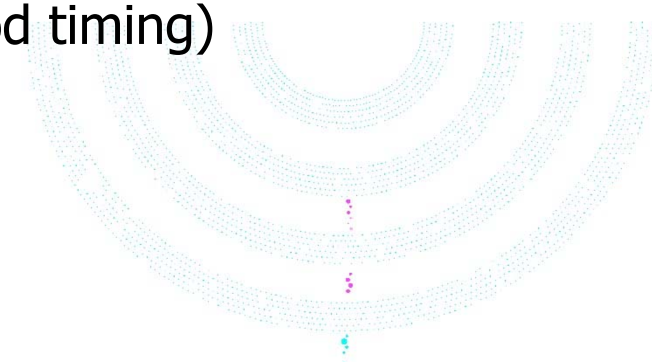
Collaboration with industry

DEPFET pixel sensors (vertexing)

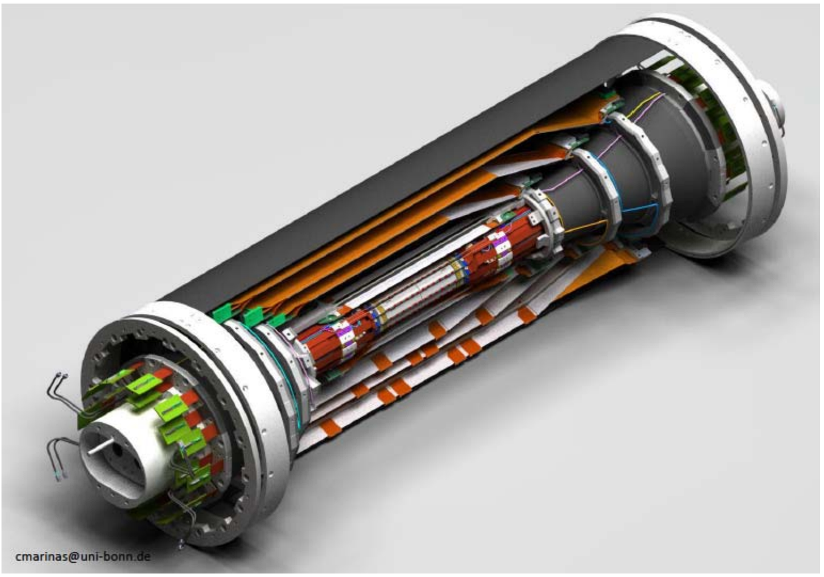
Essential: read-out with waveform sampling with precise timing

Front-end custom ASICs for most subsystems
DAQ with high performance network switches, large HLT software trigger farm

- KLM *(TARGETX* ASIC*)*
- ECL (New waveform sampling backend with good timing)
- TOP *(IRSX* ASIC*)*
- ARICH (KEK custom ASIC)
- CDC (KEK custom ASIC)
- SVD (APV25 readout chip adapted from CMS)
- PXD (3 Readout ASICs)



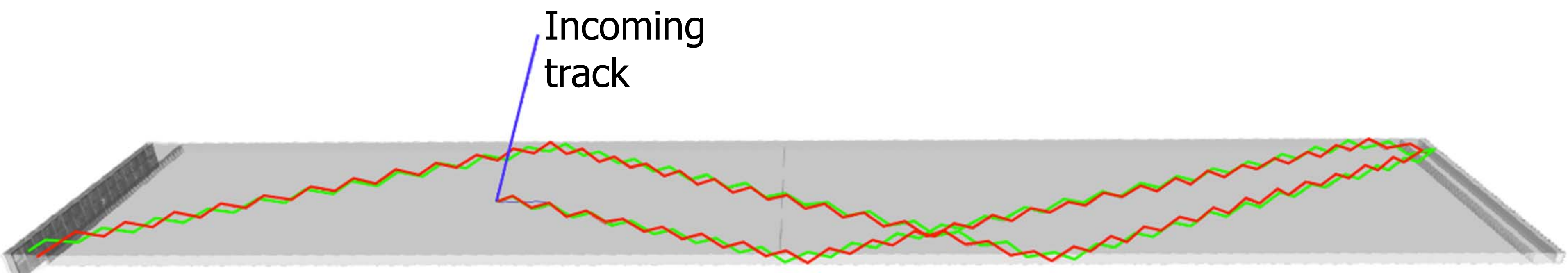
Vertexing/Inner Tracking



Beampipe r= 10 mm (Japan)
DEPFET pixels (Germany, Czech Republic, Spain, China, Poland)
Layer 1 r=14 mm
Layer 2 r= 22 mm
DSSD (double sided silicon detectors)
Layer 3 r=38 mm (Australia)
Layer 4 r=80 mm (India)
Layer 5 r=105 mm (Austria)
Layer 6 r=135 mm (Japan)
FWD/BWD (Italy)
+Poland, Korea

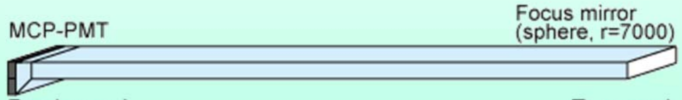
Barrel Particle Identification (uses Cherenkov radiation)

The paths of Cherenkov photons from a 2 GeV pion and kaon interacting in a TOP quartz bar. (Japan, US, Slovenia, Italy)



Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



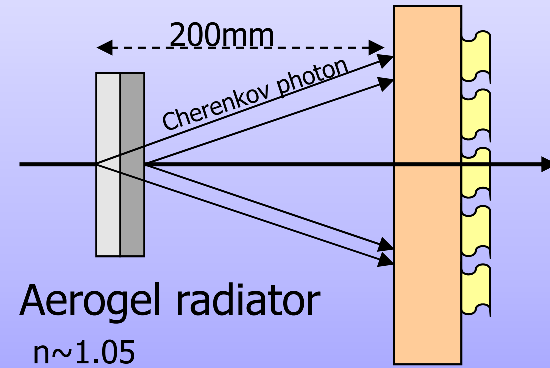
Quartz radiator

Focusing mirror

Small expansion block

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

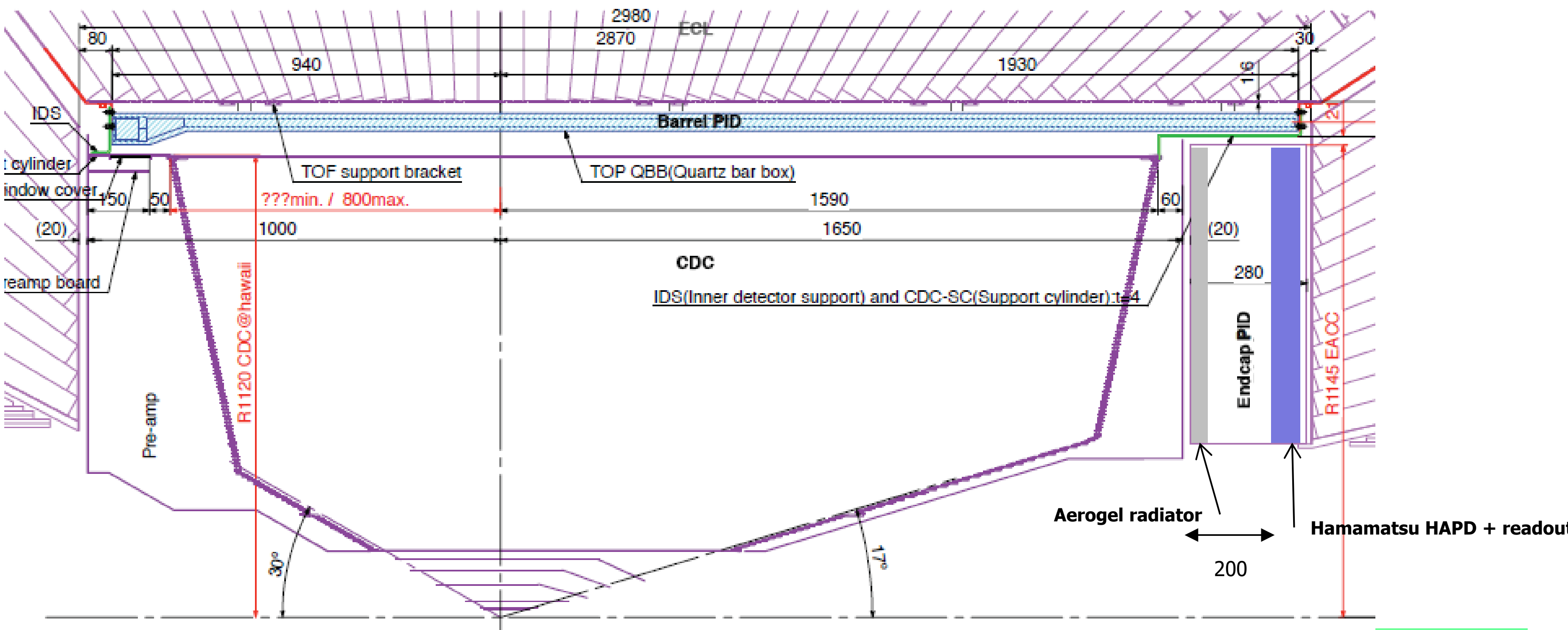
Endcap PID: Aerogel RICH (ARICH)



Aerogel radiator

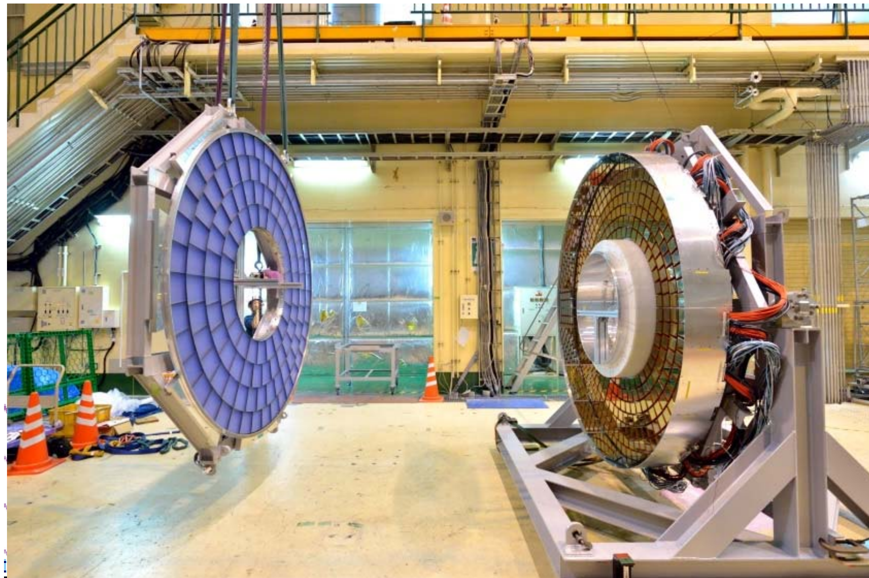
n~1.05

Hamamatsu HAPD

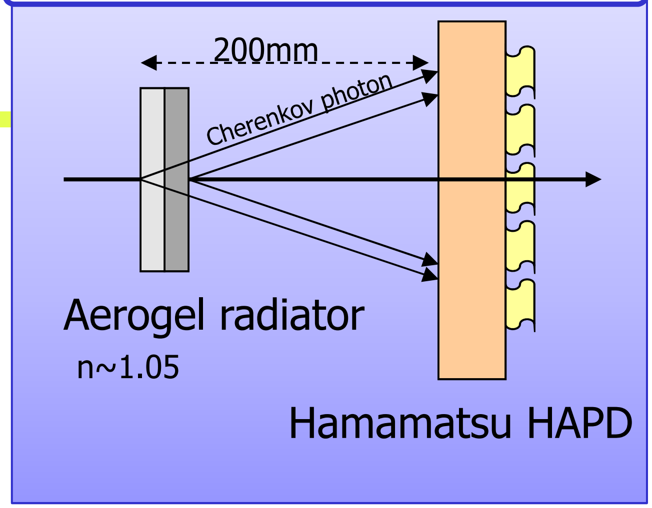


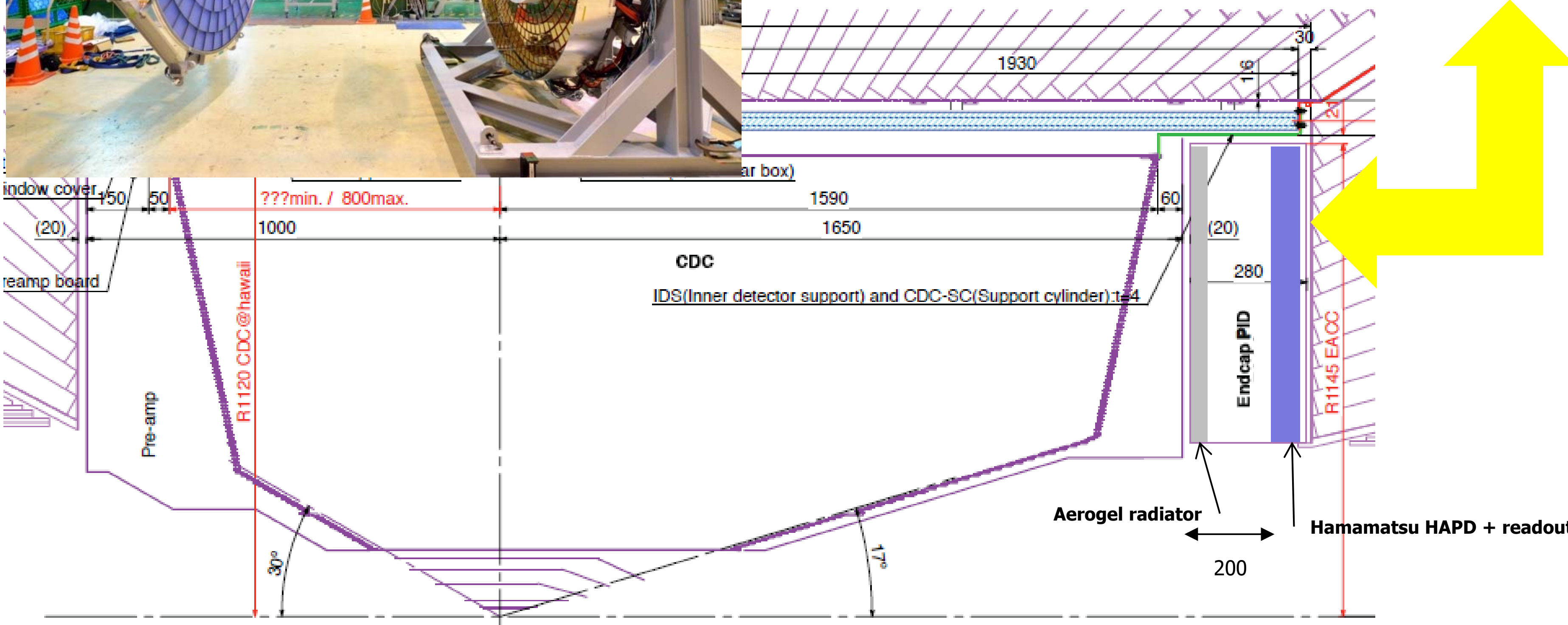
Peter Križan, Ljubljana

PID Devices: ARICH for endcap



Endcap PID: Aerogel RICH (ARICH)





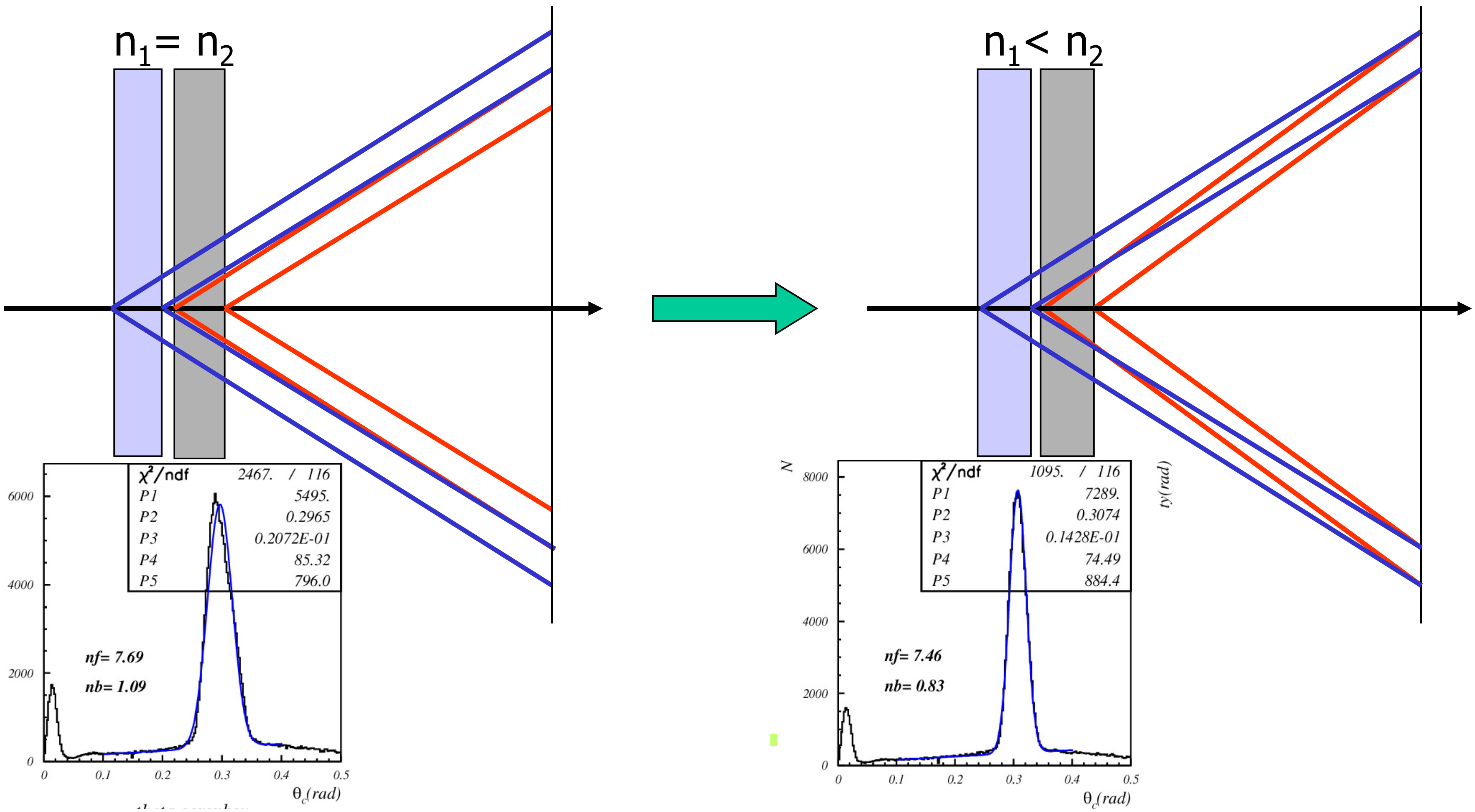
Radiator with multiple refractive indices

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

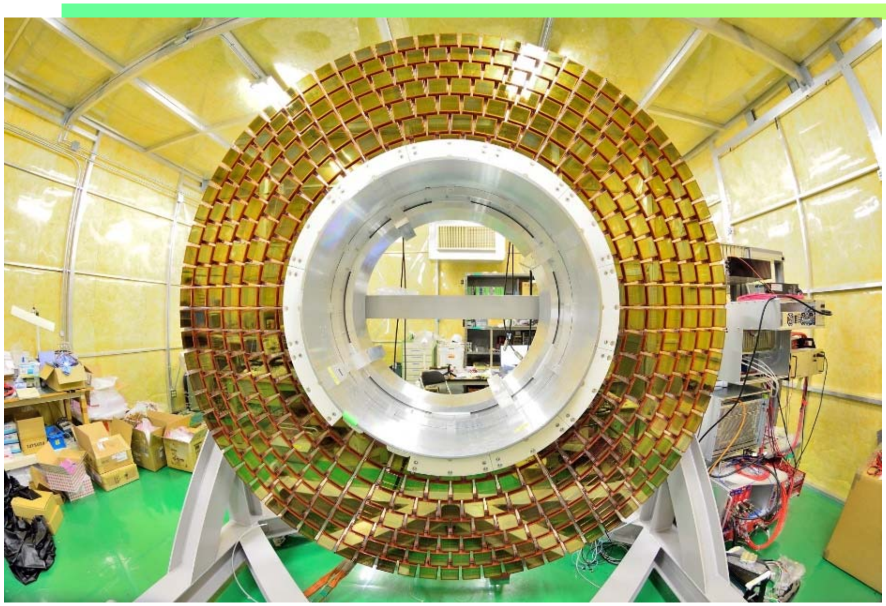
How to improve the resolution by keeping the same number of photons?

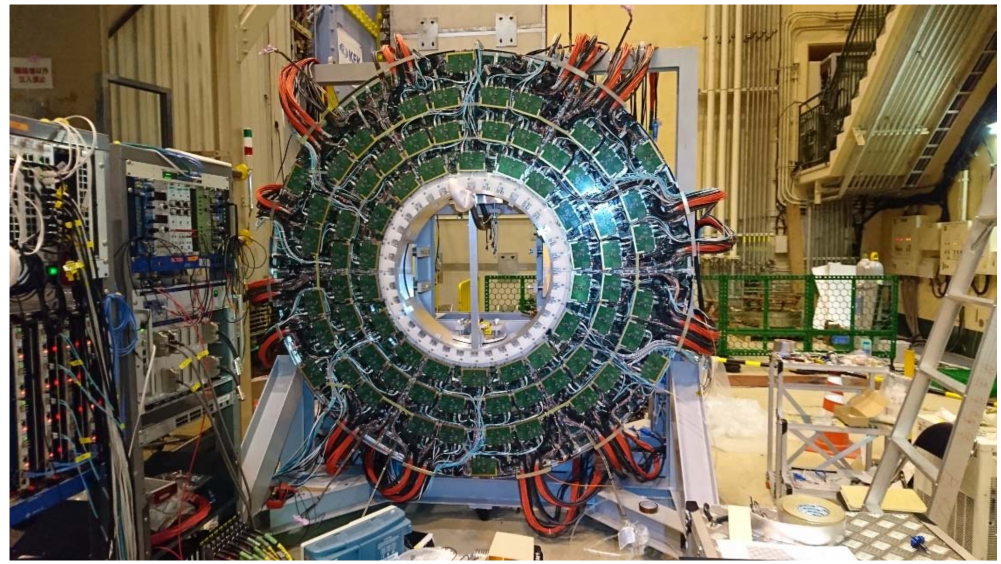
normal

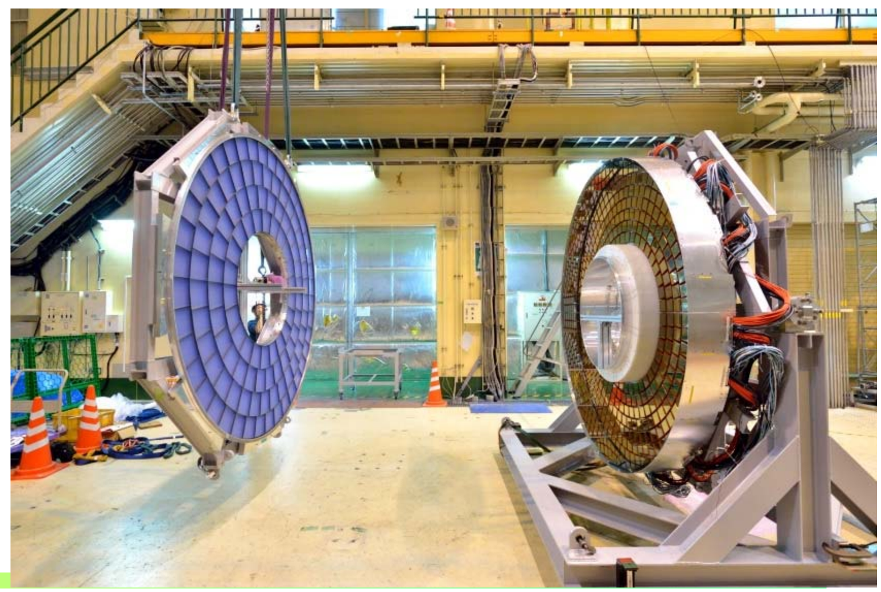
→ stack two tiles with different refractive indices:
"focusing" configuration → "focusing radiator"



The big eye of ARICH

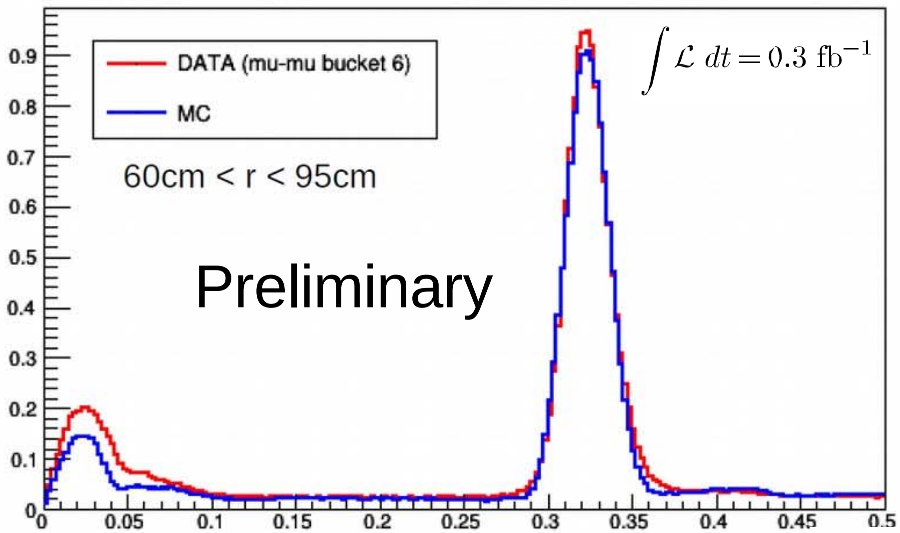






Performance in the early Belle II data

Cherenkov angle distribution in $e^+e^- \to \mu^+\mu^-$



DATA

$N_{sig} = 11.38/\text{track}$

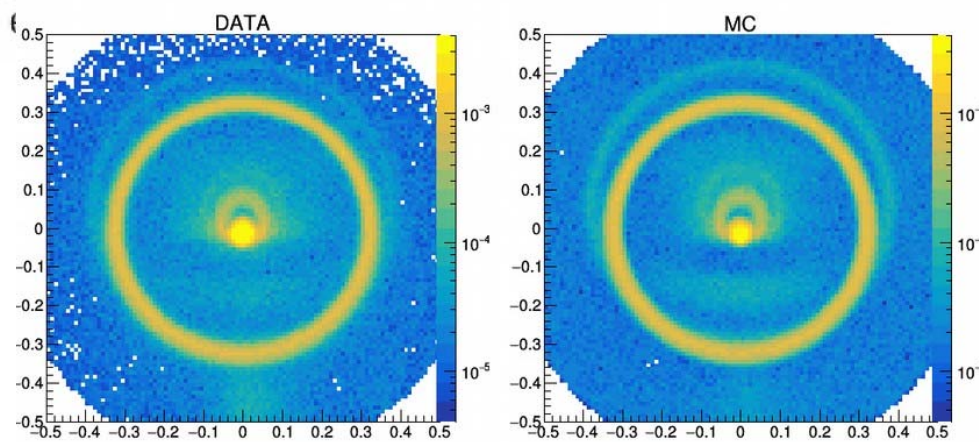
$\sigma_c = 12.7\ \text{mrad}$

MC

$N_{sig} = 11.27/\text{track}$

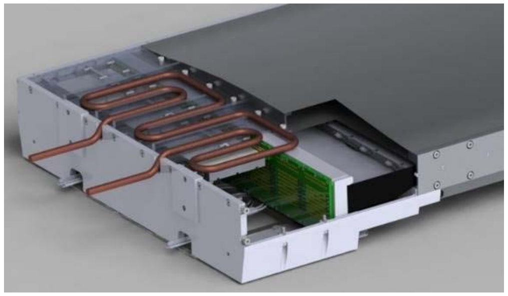
$\sigma_c = 12.75\ \text{mrad}$

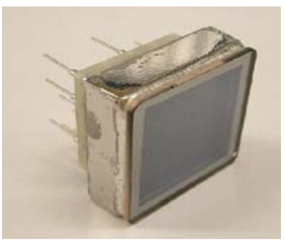
Overall a very good DATA/MC agreement !



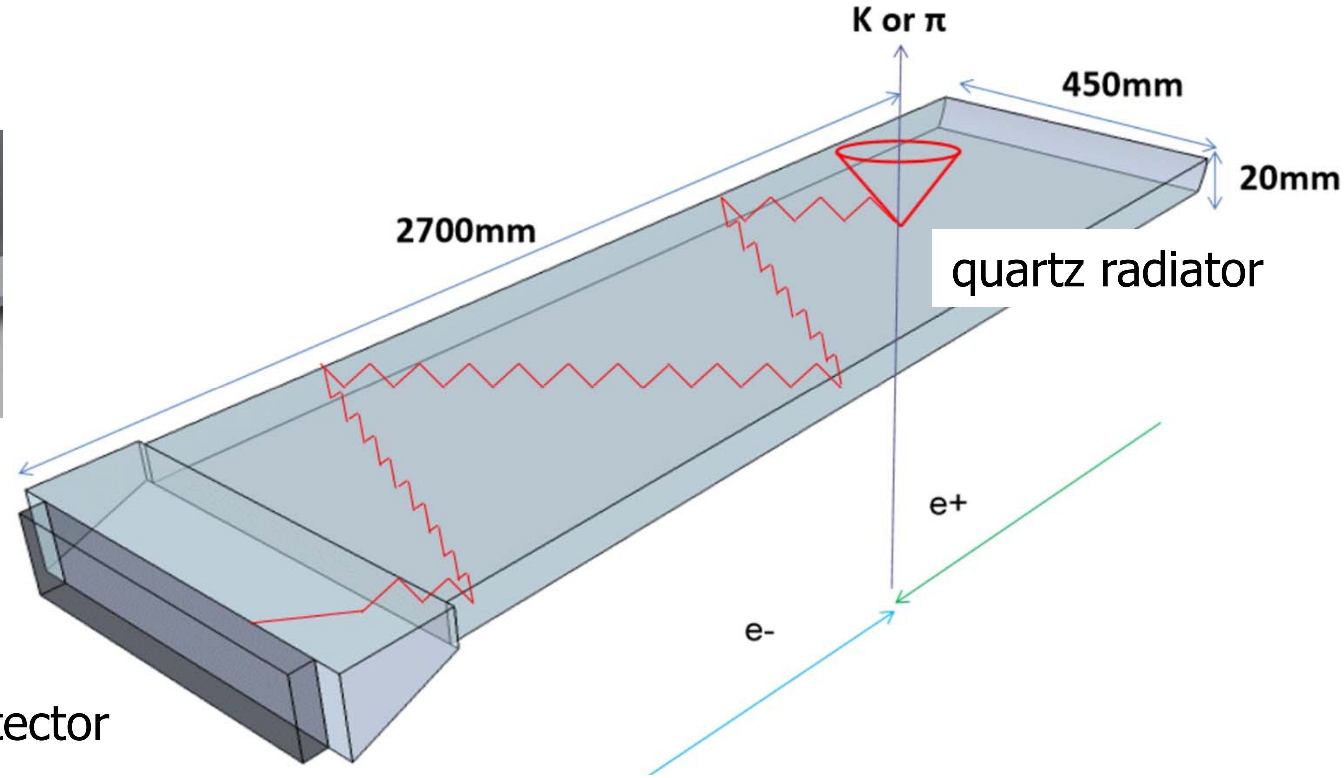
Chrenkov ring (accumulated)

Barrel PID: Time of propagation (TOP) counter





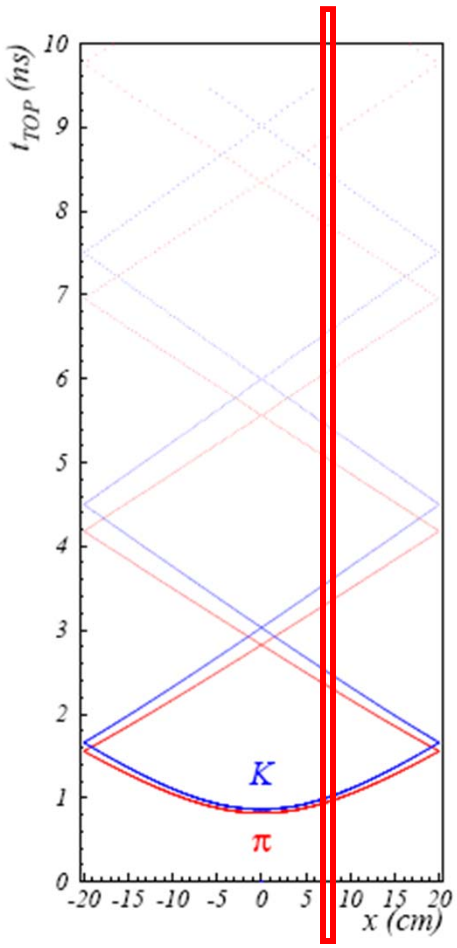
Photon detector



- 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

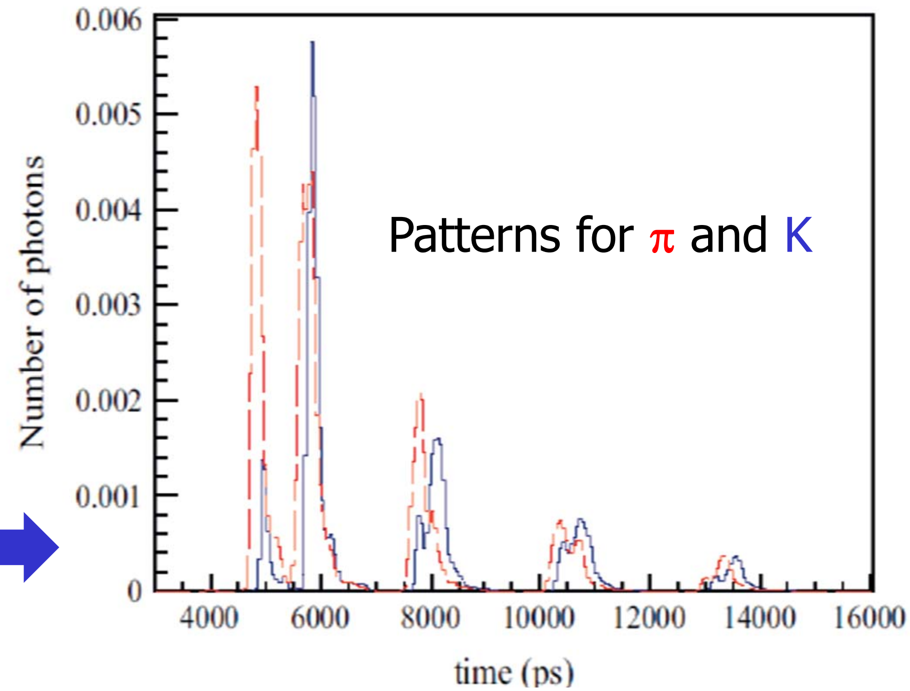
Inspired by the DIRC of the BaBar experiment, similar to the TORCH detector

TOP image reconstruction



Pattern in the coordinate-time space ('ring') of a pion and kaon hitting a quartz bar

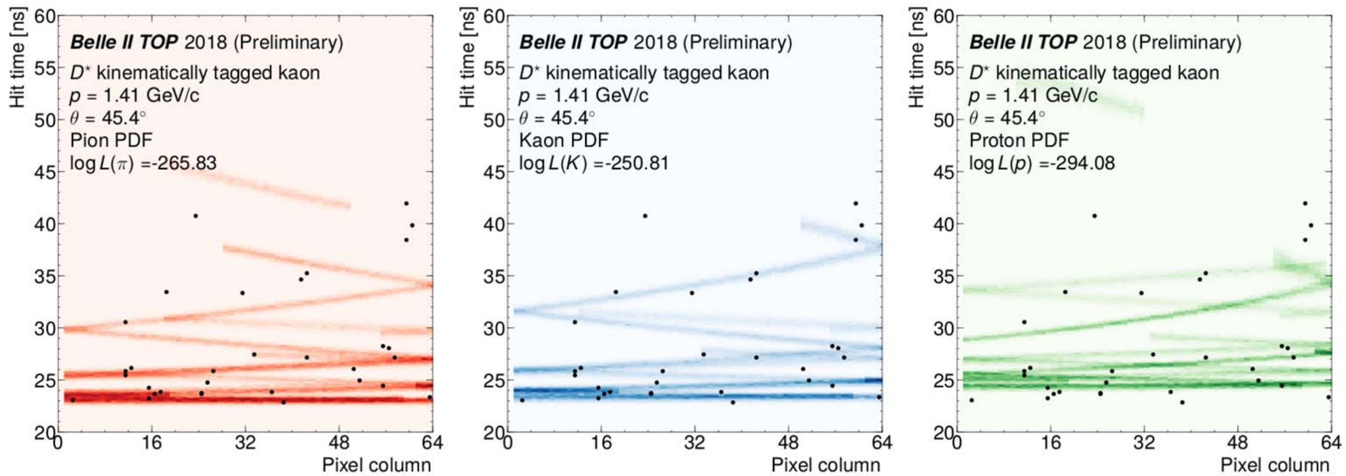
Time distribution of signals recorded by one of the PMT channels (slice in x): different for π and K (~shifted in time)



The name of the game: analytic expressions for the 2D likelihood functions →M. Starič et al., NIMA A595 (2008) 252-255

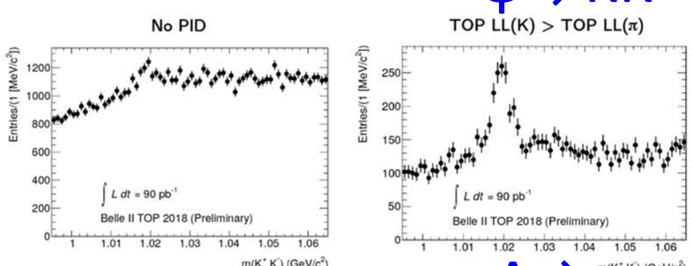
TOP first events

The early data demonstrated that the TOP principle is working



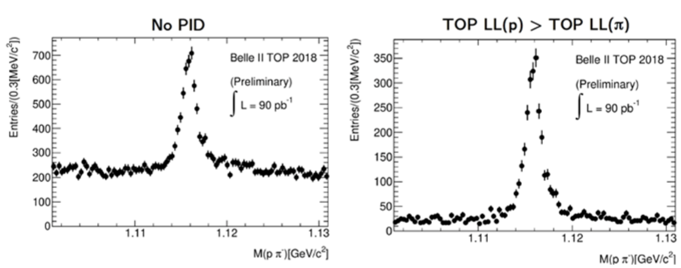
$\phi \to K^+K^-$ with both the tracks in the TOP acceptance

ϕ→KK

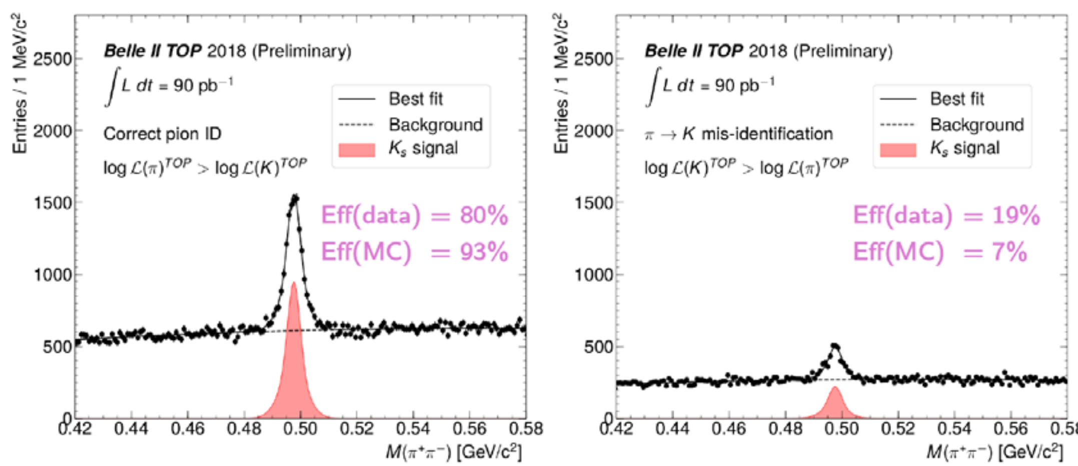


$\Lambda \to p\pi$ with the **proton candidate** in the TOP acceptance

Λ→pπ

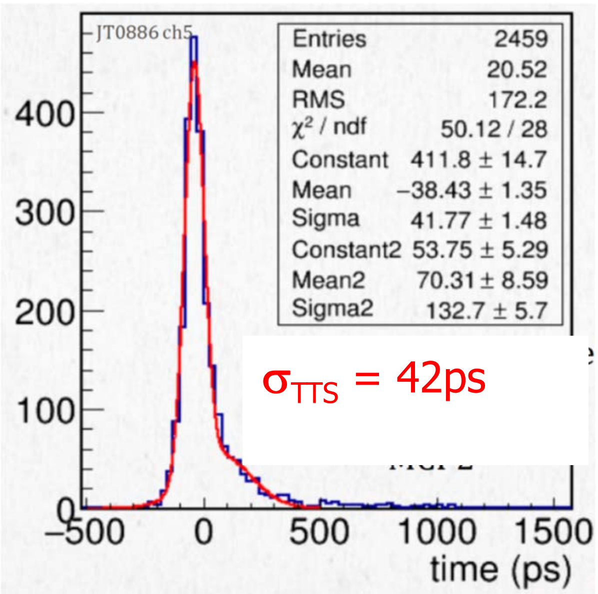


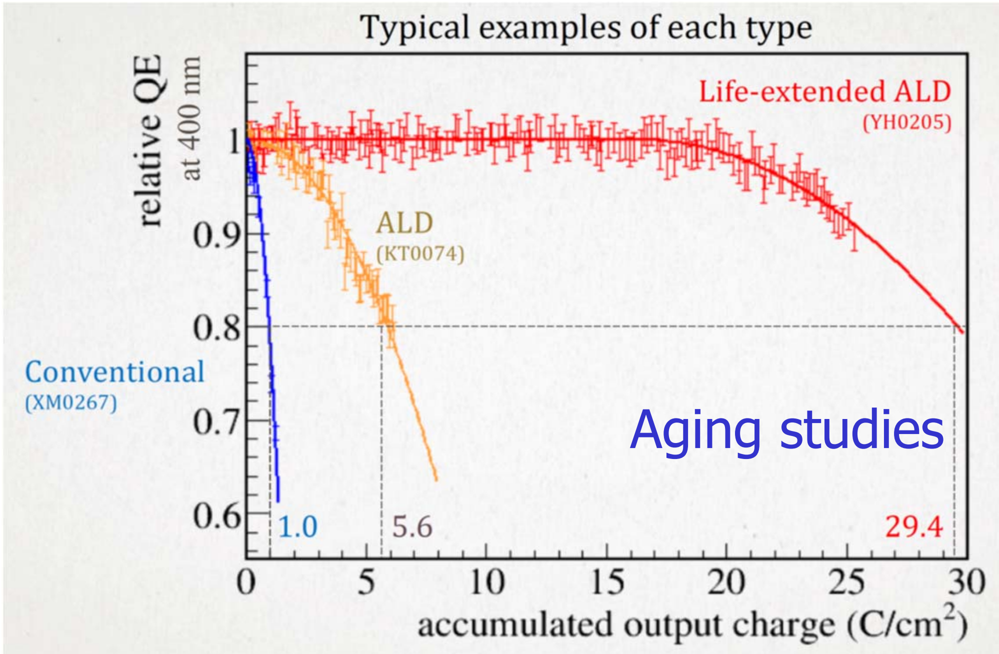
$K_s \to \pi\pi$



TOP R+D areas

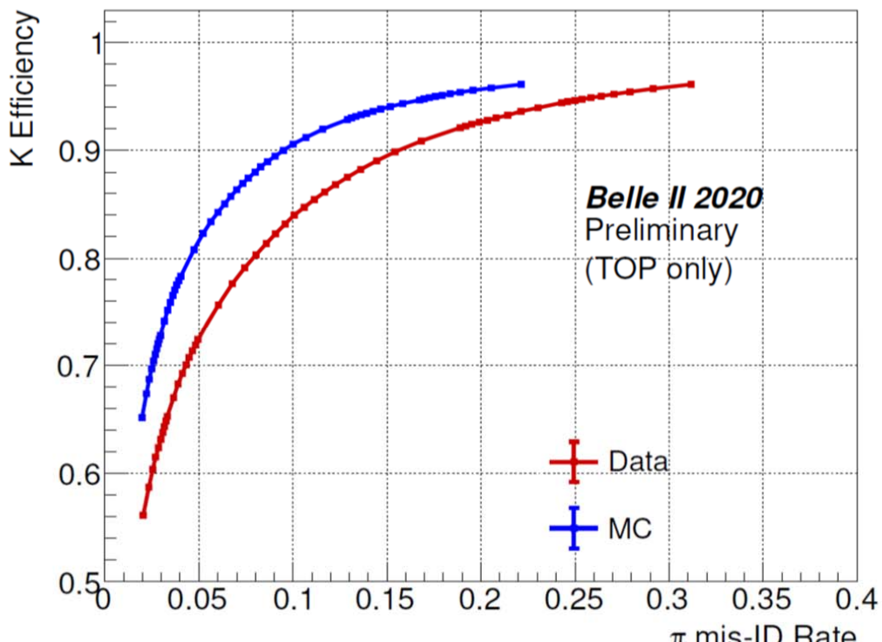
- Very fast photosensors for operation in 1.5 T field (MCP PMTs)
- R+D to mitigate aging of photocathodes in MCP PMTs (ALD)

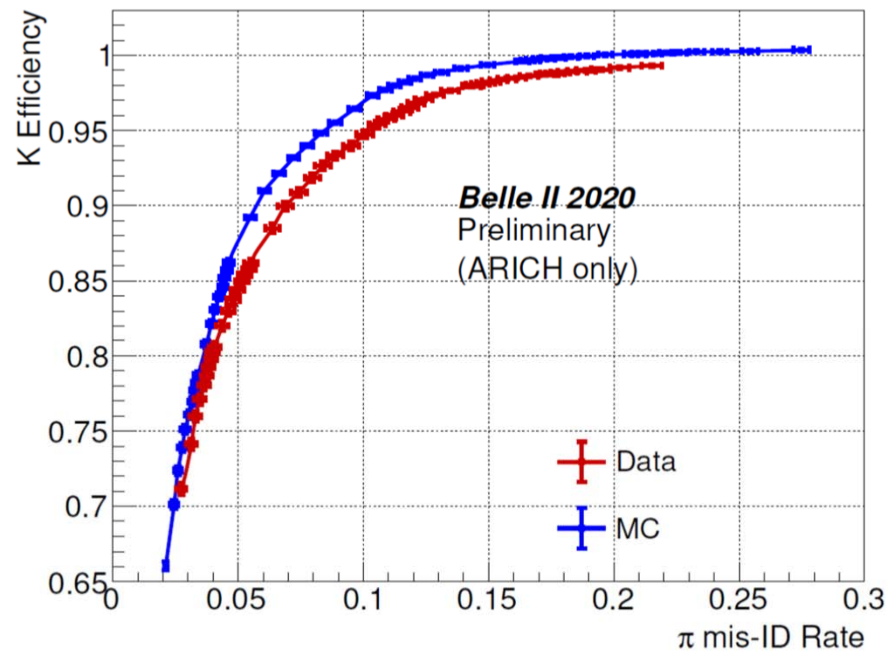




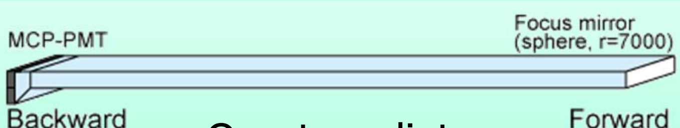
- Very fast and compact readout electronics with waveform sampling for a precise time measurement
- Production of large quartz pieces, construction of modules, mechanics and installation methods
- Analytic expressions for the very complex 2D likelihood functions.

Particle identification: performance on data





Barrel PID: Time of Propagation Counter (TOP)



Quartz radiator

Focusing mirror

Small expansion block

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

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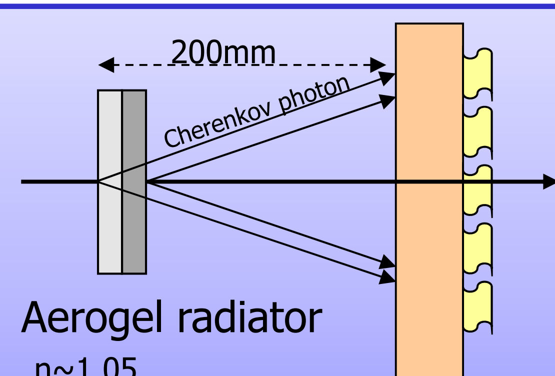


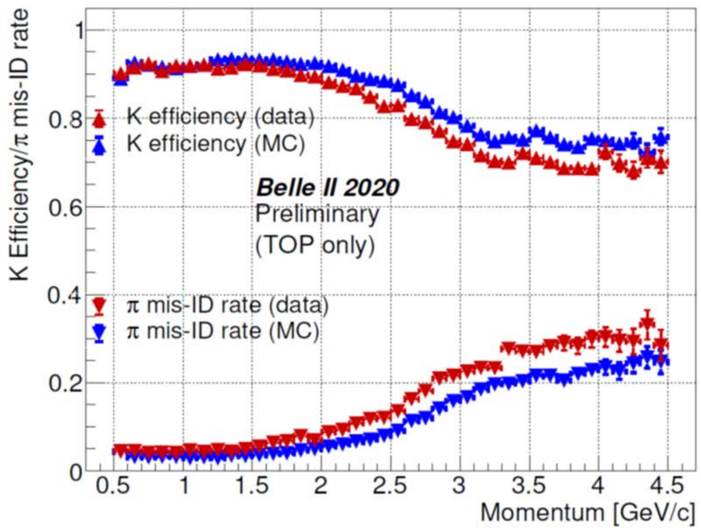
Aerogel radiator

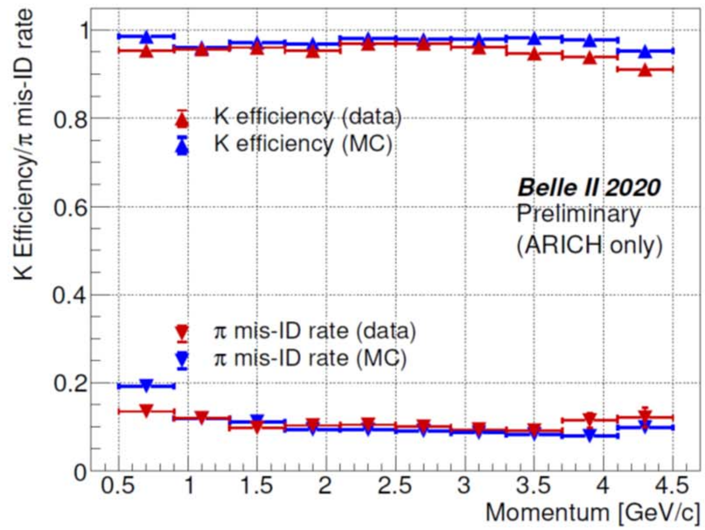
n~1.05

Hamamatsu HAPD

Refinements of PDFs of both detector are underway, further improvements of performance expected

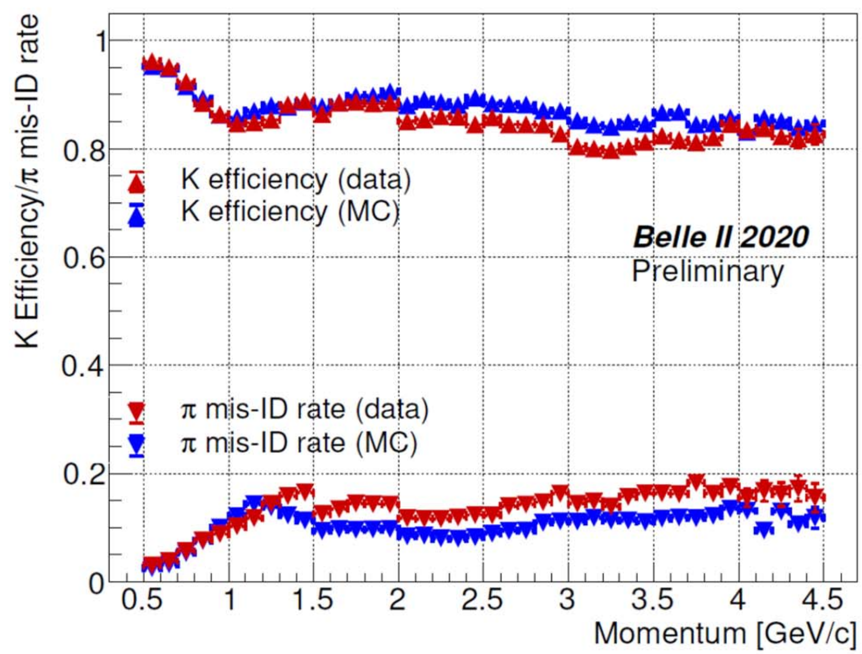
Kaon/pion identification: performance on data





TOP (left) and ARICH (right) performance vs momentum

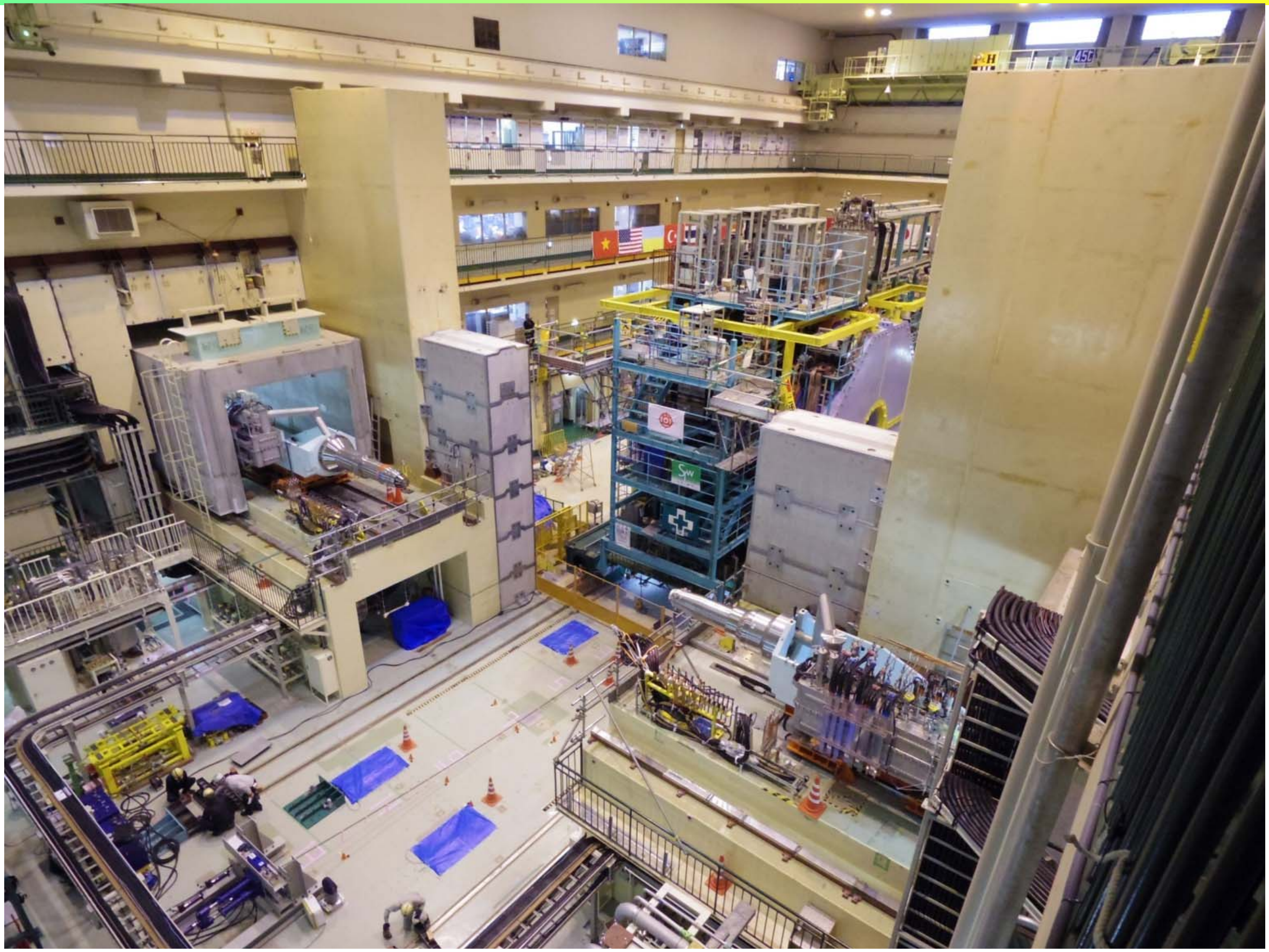
Combined PID performance of CDC (dE/dx), TOP and ARICH vs momentum



Refinements of PDFs of both detector are underway, further improvements of performance expected

Belle II data taking phases

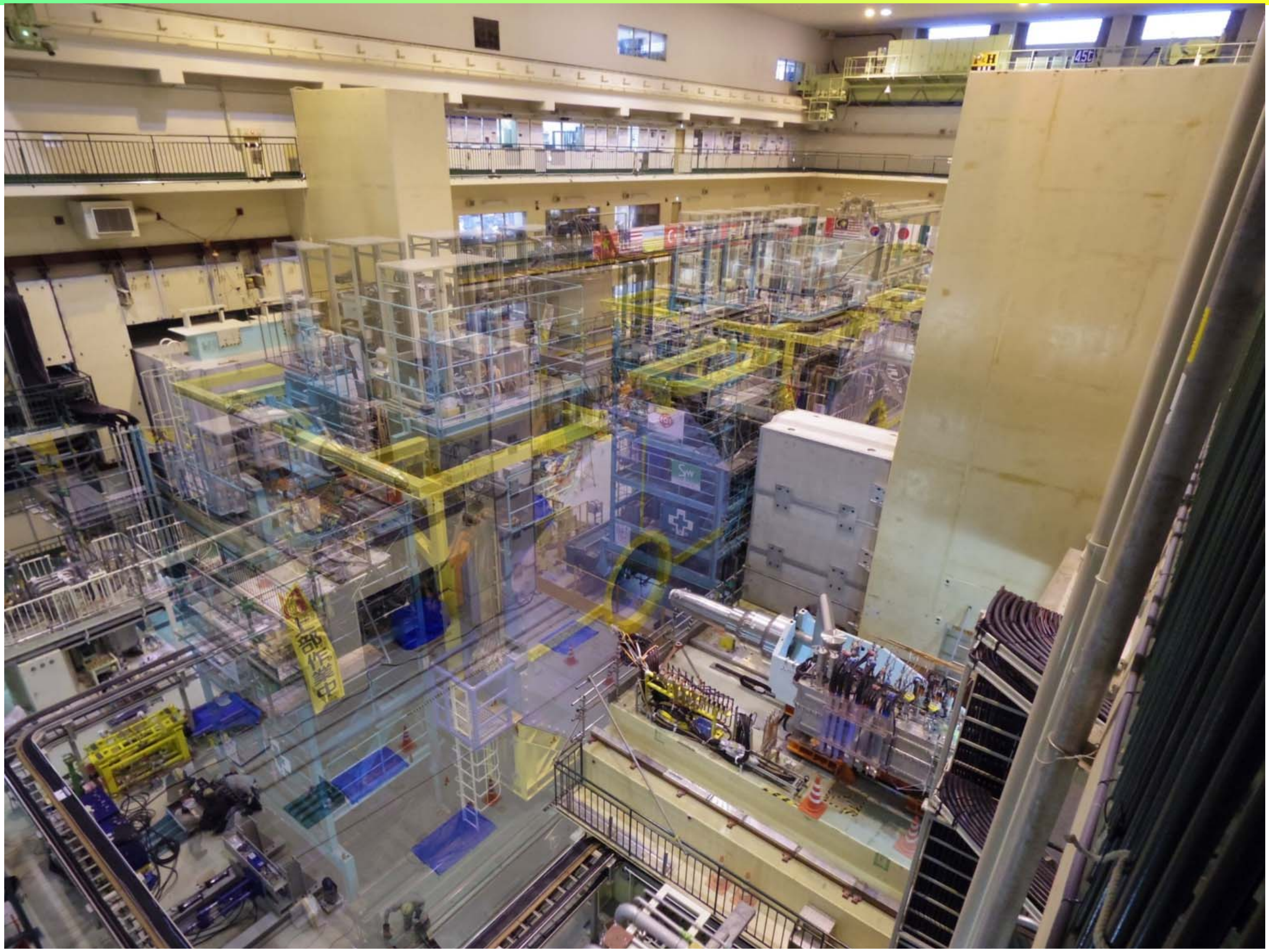
Belle II Roll-in



Belle II rolled-in to the beam line on April 11th, 2017

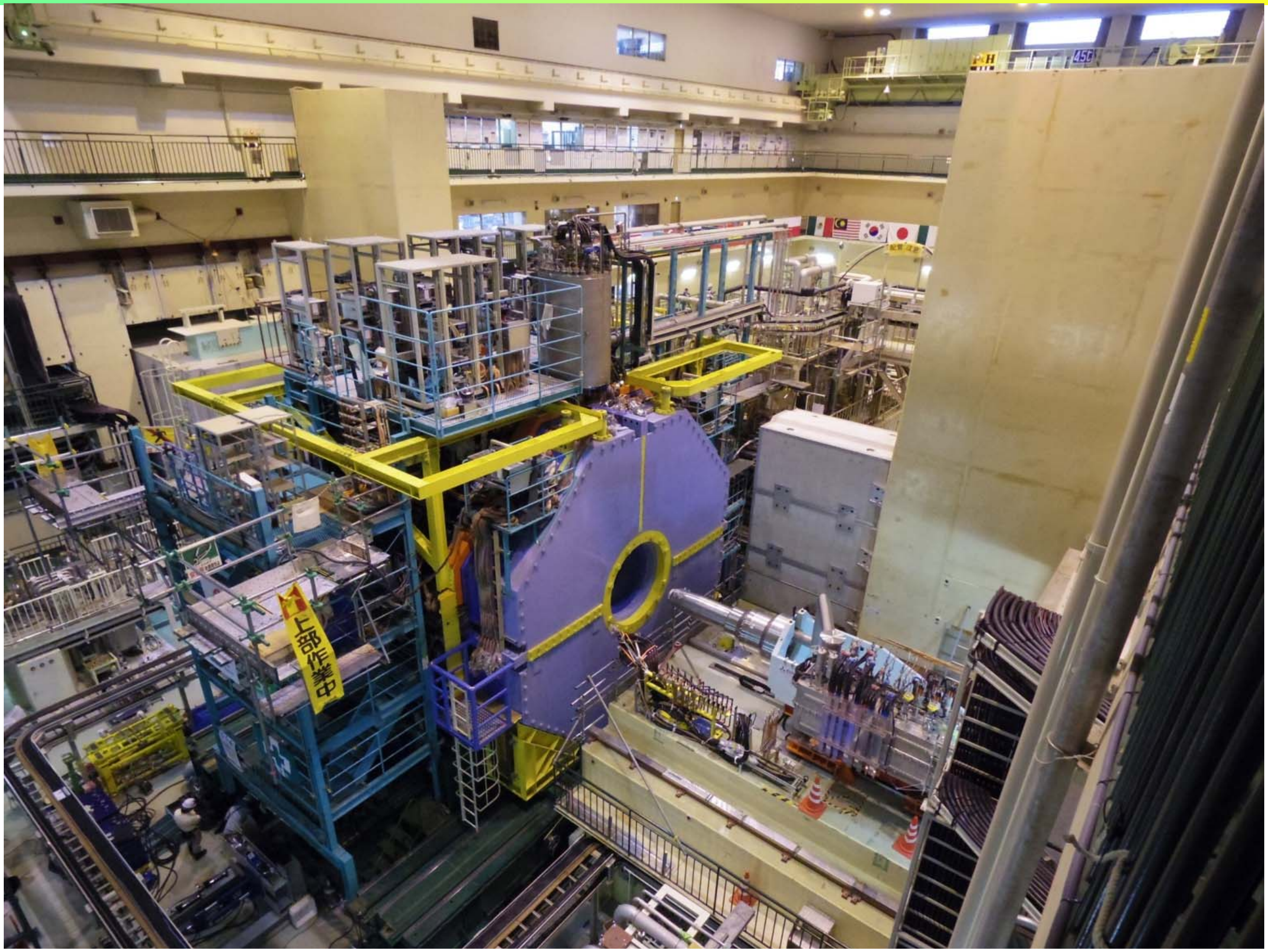
One of the most significant milestones in the construction phase

Belle II Roll-in



Belle II rolled-in to the beam line on April 11th, 2017
One of the most significant milestones in the construction phase

Belle II Roll-in



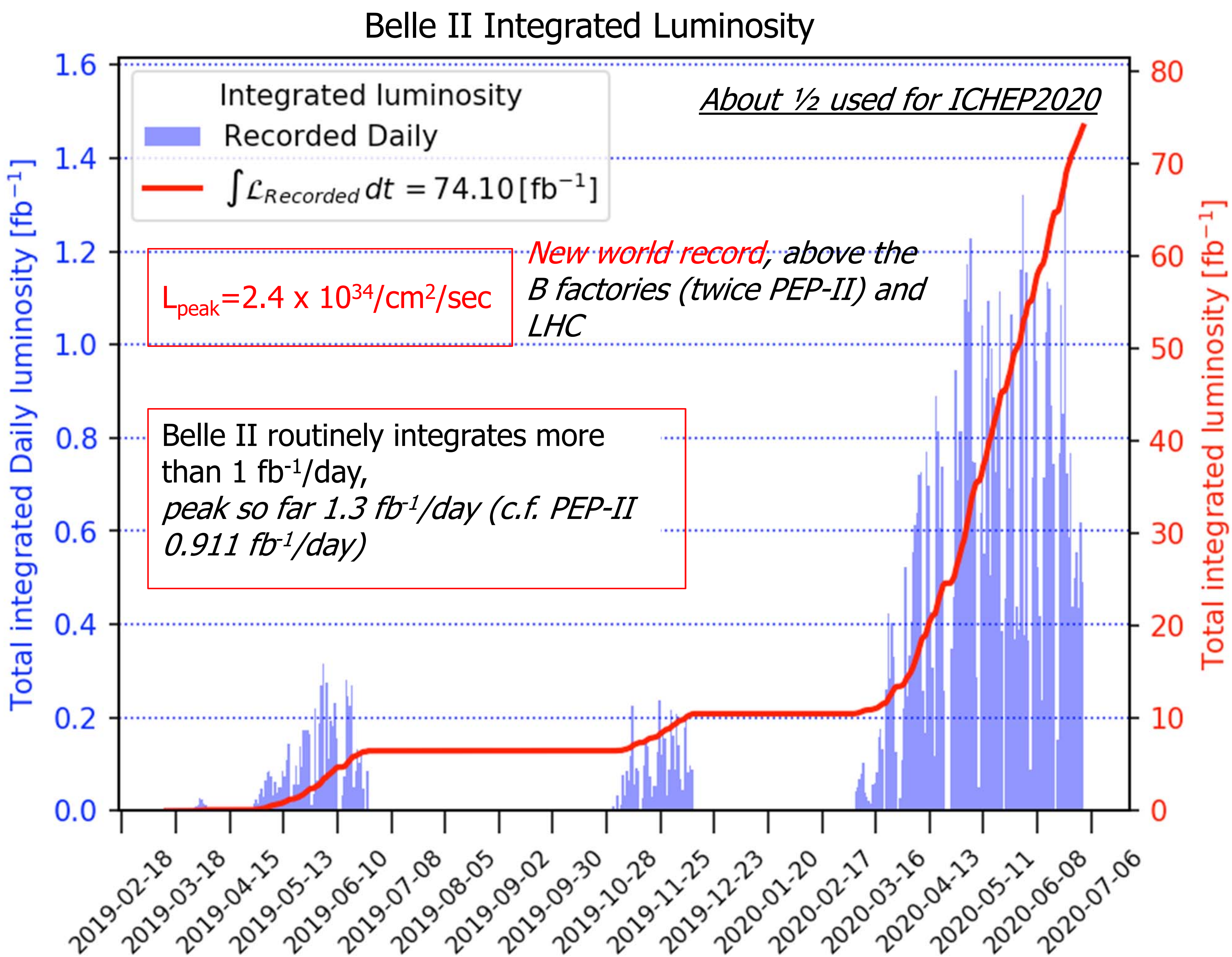
Belle II rolled-in to the beam line on April 11th, 2017
One of the most significant milestones in the construction phase

Belle II / SuperKEKB Operation phases

Phase 1:
Background, Vaccum Scrubbing, RF system
Feb-June 2016.
Brand new 3 km positron ring.

Phase 2: Pilot run without VXD
Superconducting Final Focus, add positron damping ring,
First Collisions on Apr. 26, 2018 (0.5 fb^{-1}).
Feb-July, 2018

Phase 3: → Physics running (spring 2019, fall 2019, spring 2020).
Have integrated 74 fb^{-1} so far.



Also see https://cerncourier.com/a/kek-reclaims-luminosity-record/

Major issue in the operation: fighting the backgrounds

Detector lifetime (in particular TOP counter)

• To keep the MCP-PMT QE within an acceptable level until 50 ab^{-1}, the Touschek and beam-gas backgrounds have to be kept constant by collimators, beam tuning, additional shielding, …

$\longrightarrow$ TOP PMT hit rate could limit the luminosity.

Permanent damage on PXD and SVD by accidental huge beam loss.

Synchrotron radiation from HER beam on PXD

$\longrightarrow$ Should be carefully monitored not to irradiate PXD unnecessarily.

Spring 2020: Running an international experiment and accelerator during a global pandemic

SuperKEKB/Belle II was/is operating during the COVID-19 pandemic with protocols in place to maximize safety and minimize the risk of infection. Somewhat difficult with travel restrictions and a heavy load on a skeleton crew at KEK (~40 people).

Developed a "social distancing" scheme for on-site shifts in the Belle II and SuperKEKB control rooms. Mobilized remote shifters around the world – depended heavily on internet chat utilities for communication and monitoring.

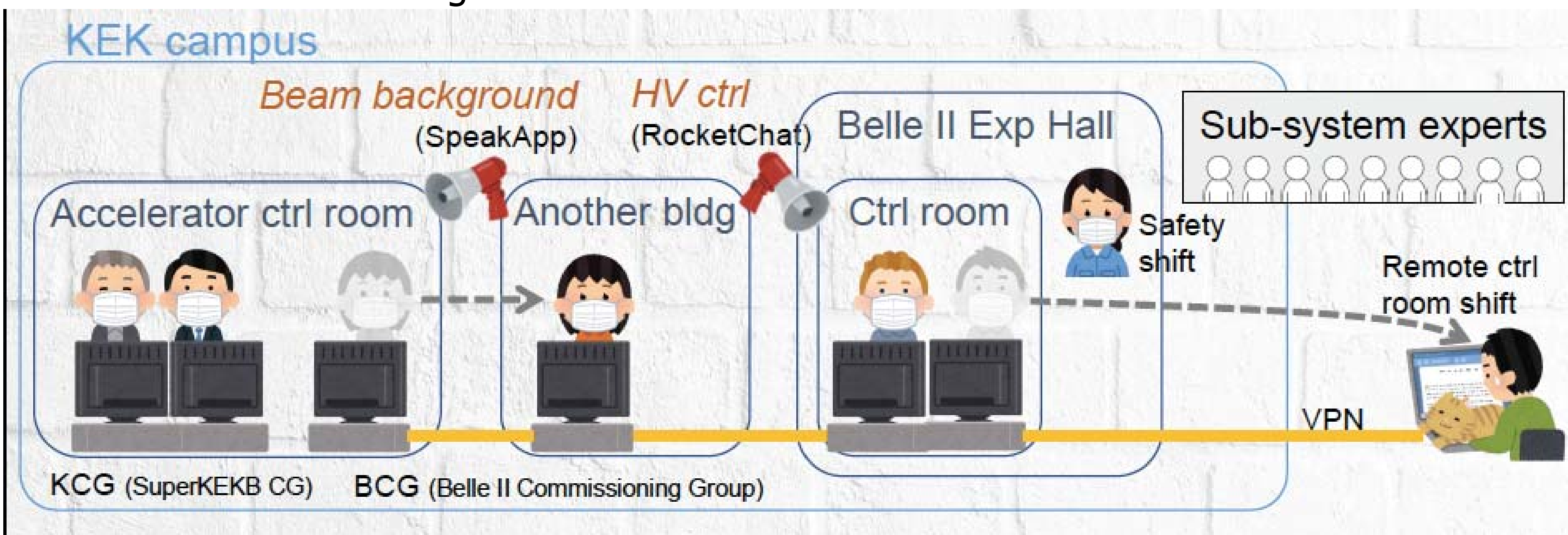
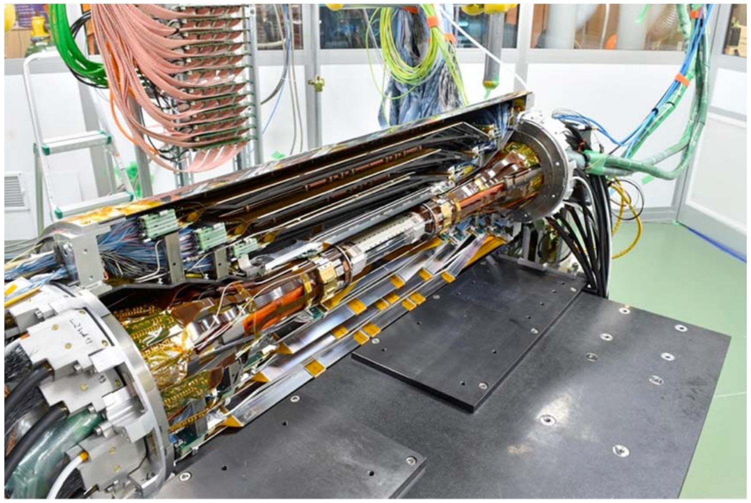


Figure credit: K. Matsuoka

Belle II/SuperKEKB Phase 3 (Physics Run) Goals

Early aims: Demonstrate SuperKEKB Physics running with acceptable backgrounds, and all the detector, readout, DAQ and trigger capabilities of Belle II including tracking, electron/muon id, high momentum PID, and especially the *ability to do time-dependent measurements needed for CP violation.*



Carry out innovative and world leading dark sector searches/measurements. Publish first papers.

Long term: Integrate the world's largest e^+e^- data samples and observe or constrain New Physics in B physics, charm physics and tau physics.

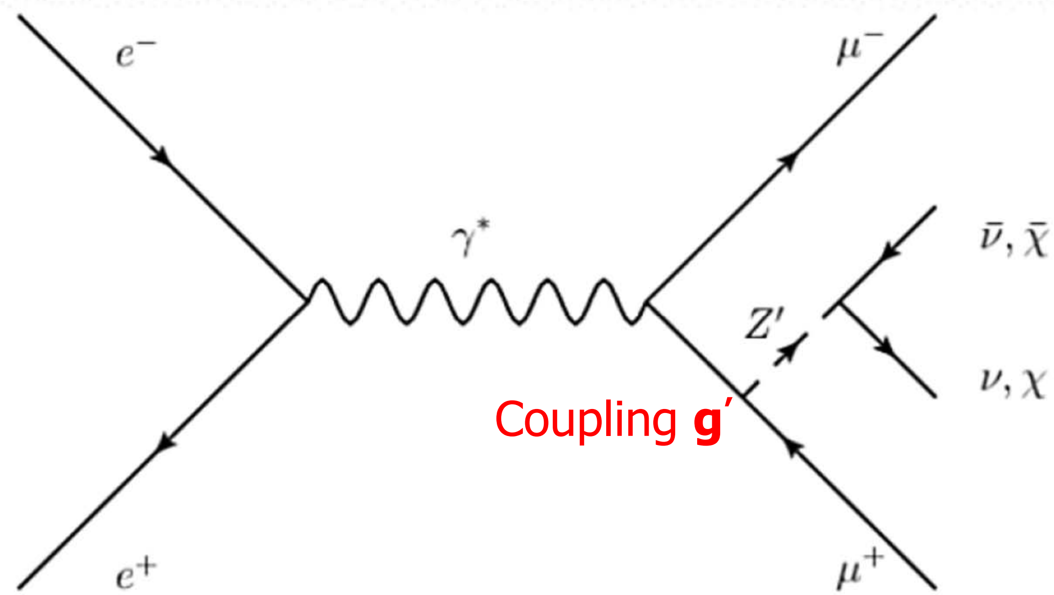
Dark Sector:

B factories: limited by triggering, QED backgrounds and theoretical imagination. *Now new possibilities of triggering, more bandwidth.*

There are a variety of possible dark sector portal particles: Vector, Scalar, Pseudo-scalars.

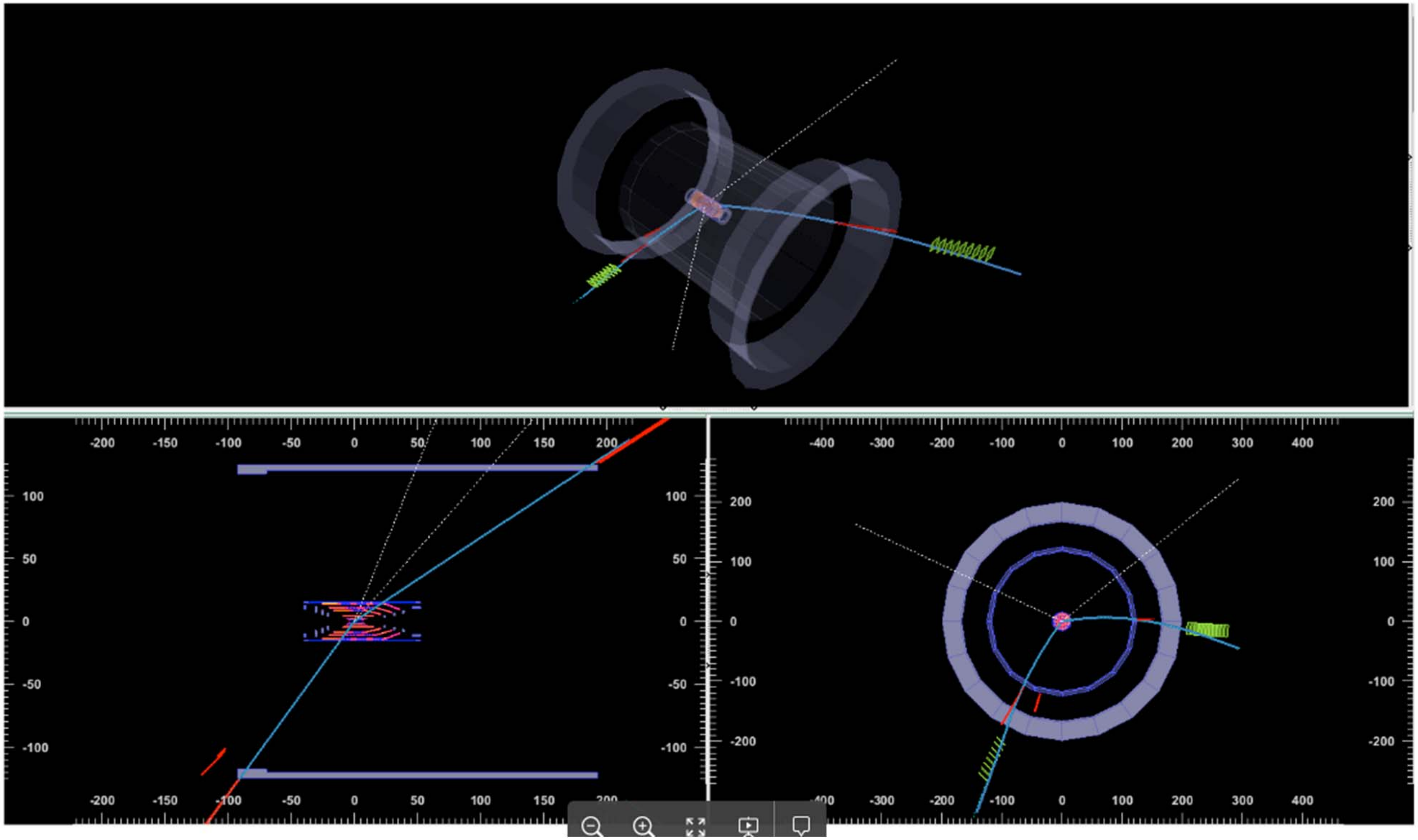
They may decay to lepton pairs, photon pairs, or Invisible particles

Belle II First Physics. A novel result on the dark sector (Z' →nothing) recoiling against di-muons *or* an electron-muon pair. *Both possibilities are poorly constrained at low Z' mass and in the first case, could explain the muon g-2 anomaly.*



Also examine a *lepton flavor violating* NP signature in the dark sector

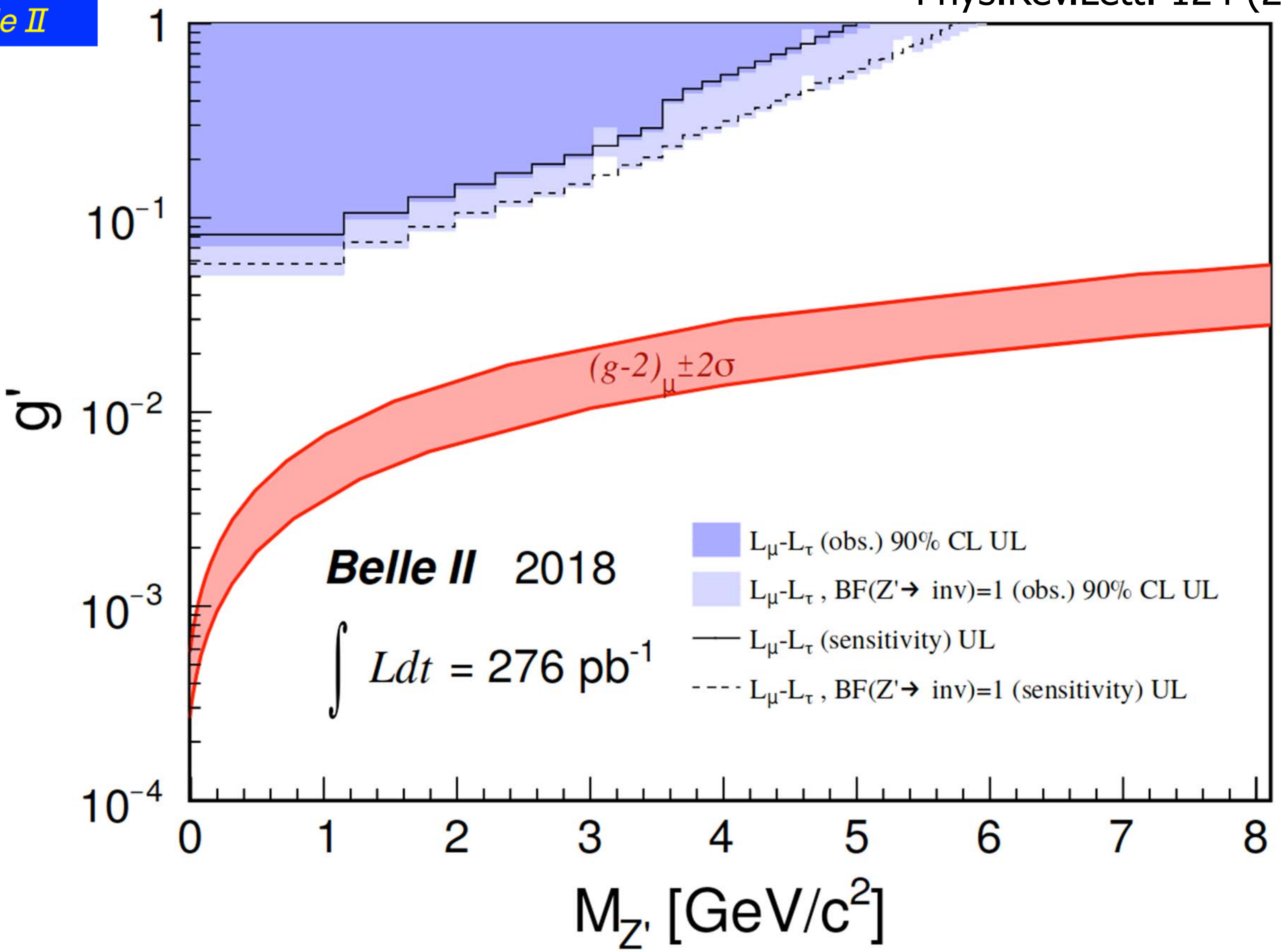
Monte Carlo simulation of a Z′ →invisible



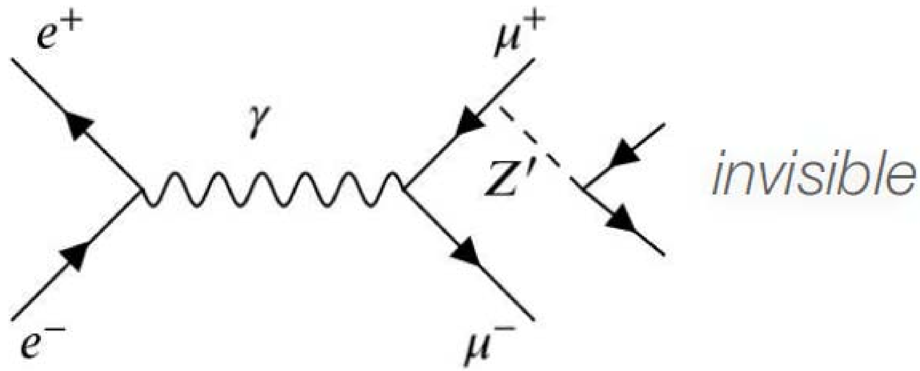
However, in data we do not find any significant excess in the recoil mass distribution.

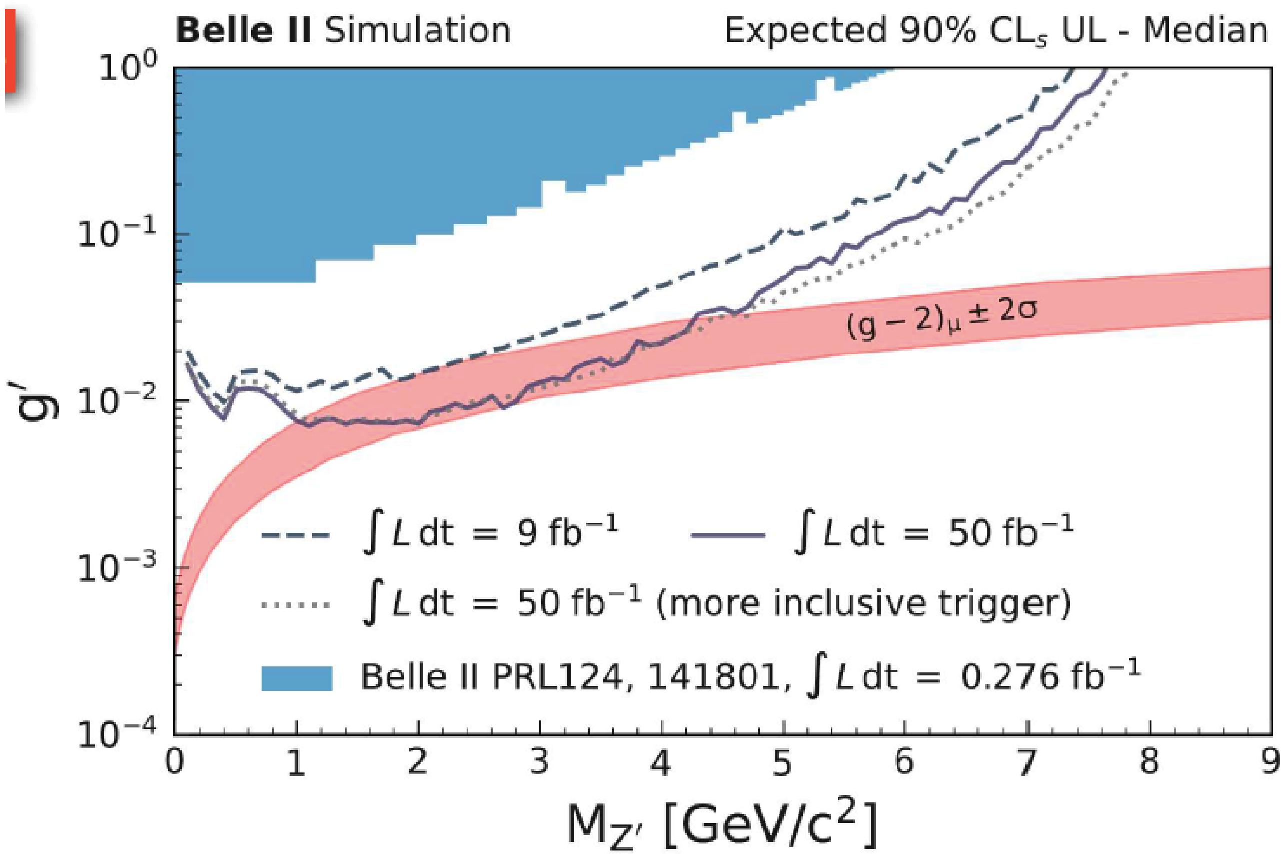
With 278 pb^{-1} from the Phase 2 pilot run

Phys.Rev.Lett. 124 (2020) 14



Near term prospects for Z′ →invisible

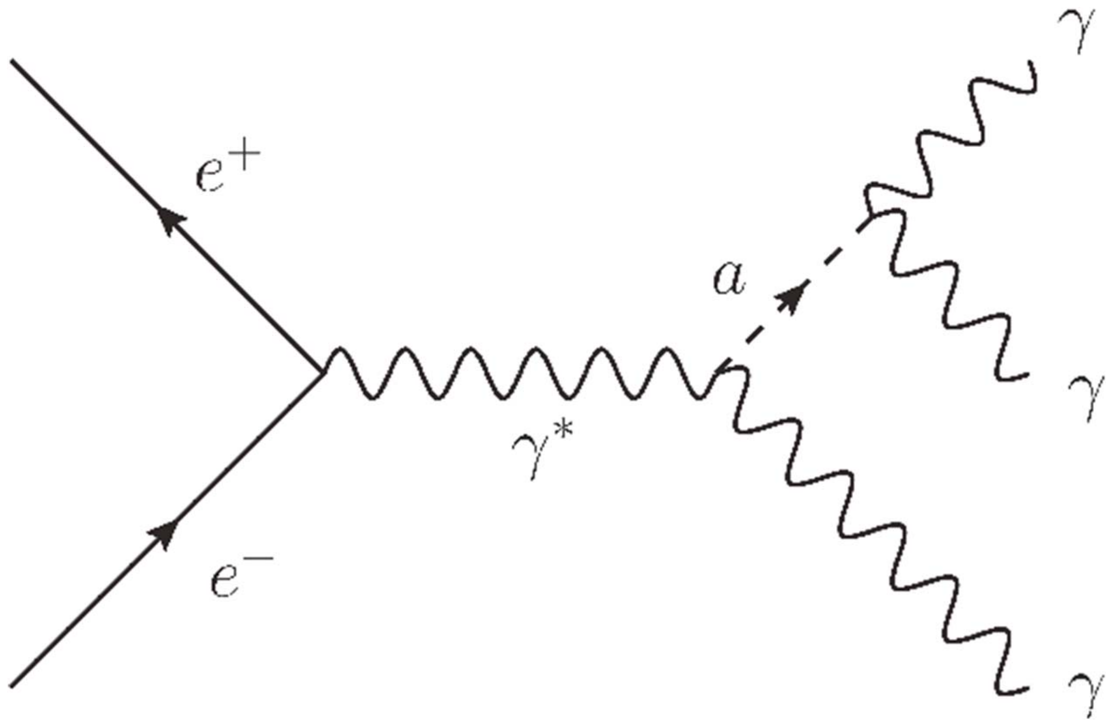




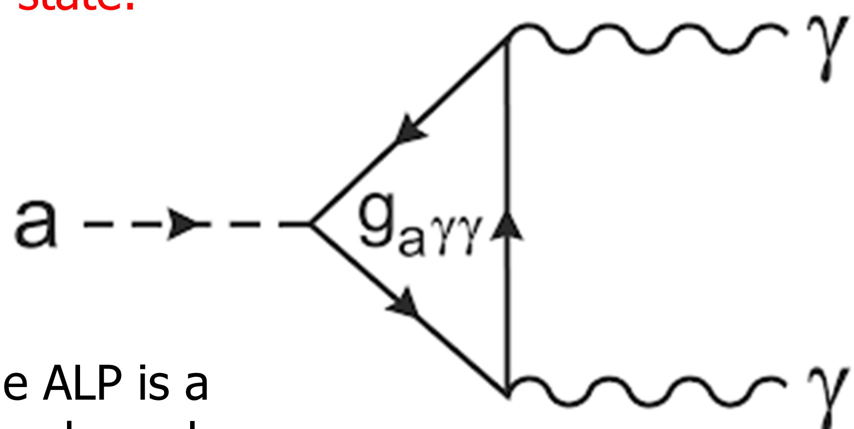
Uses Phase 3 data on tape. Adding in KLM triggers may allow us to "break through" the g-2 band.

Search for ALPs (Axion Like Particles) at Belle II

An extra term was introduced in the QCD Lagrangian by Peccei, Quinn to solve the strong CP problem in 1977. Wilczek introduced a particle interpretation called the Axion. Expected to be very light (microeV or millieV).



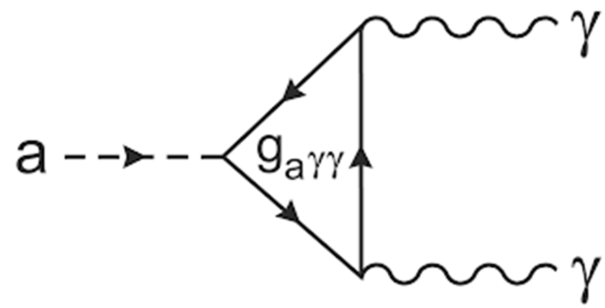
Examine the three photon final state:



The ALP is a pseudo-scalar

The Belle II mass range is *200 MeV to 9.7 GeV*, *far above* the keV mass range suggested by the Xenon1T excess.

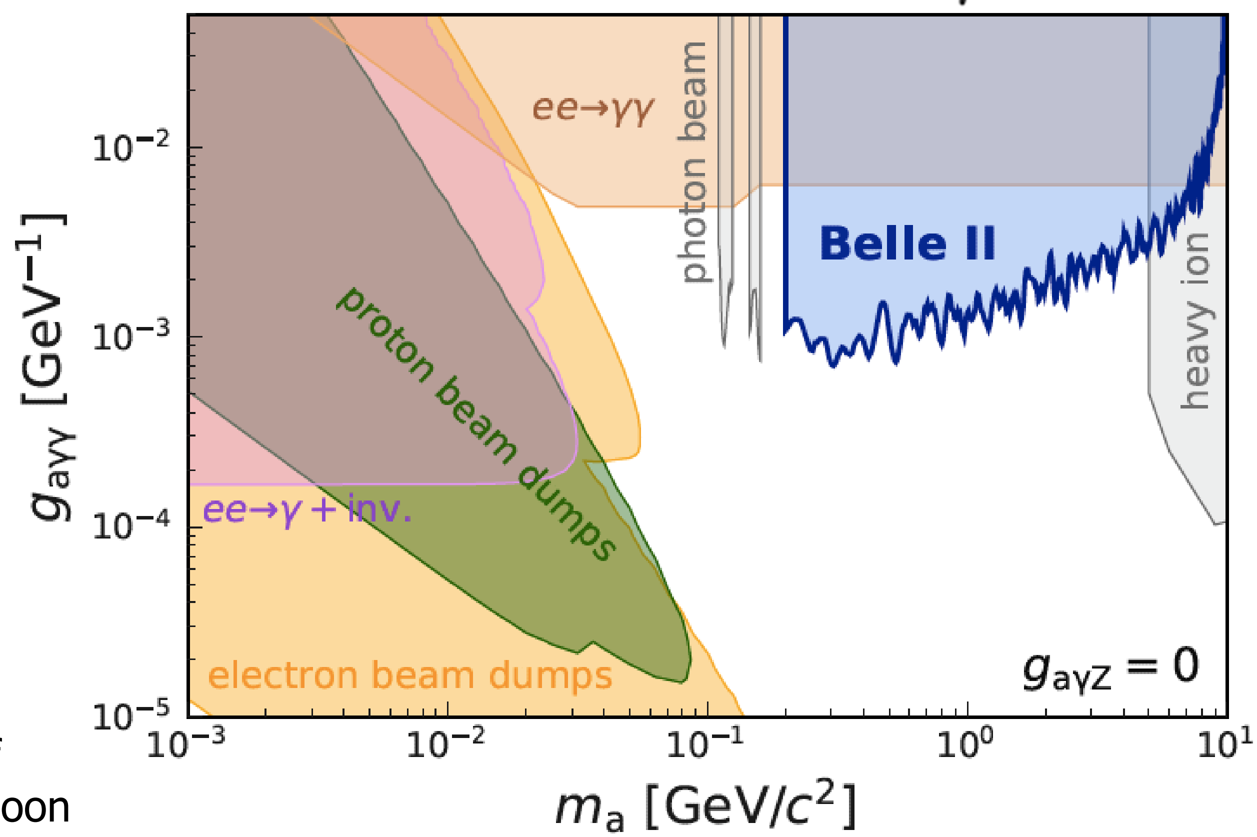
https://arxiv.org/abs/2006.09721



Final ALPs results with 445 pb^{-1} of pilot run (Phase 2) data

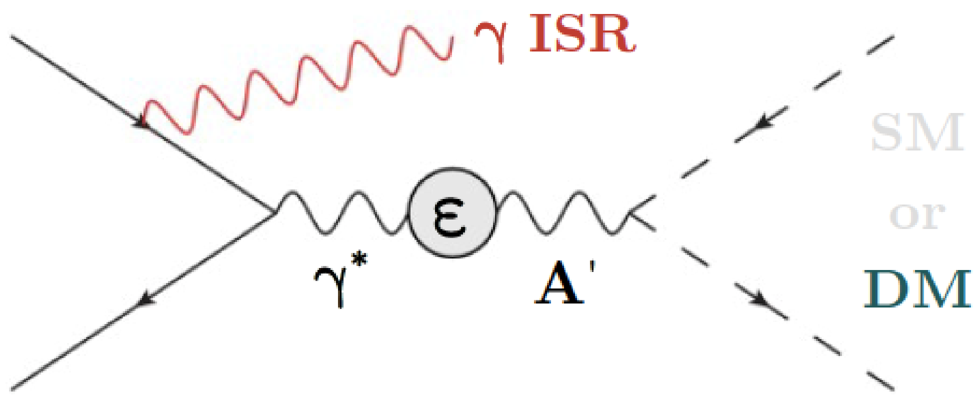
arxiv:2007.13071

Plan to update with two orders of magnitude more data.



* Missing in this plot: a recast of LEP results, plot to be updated soon

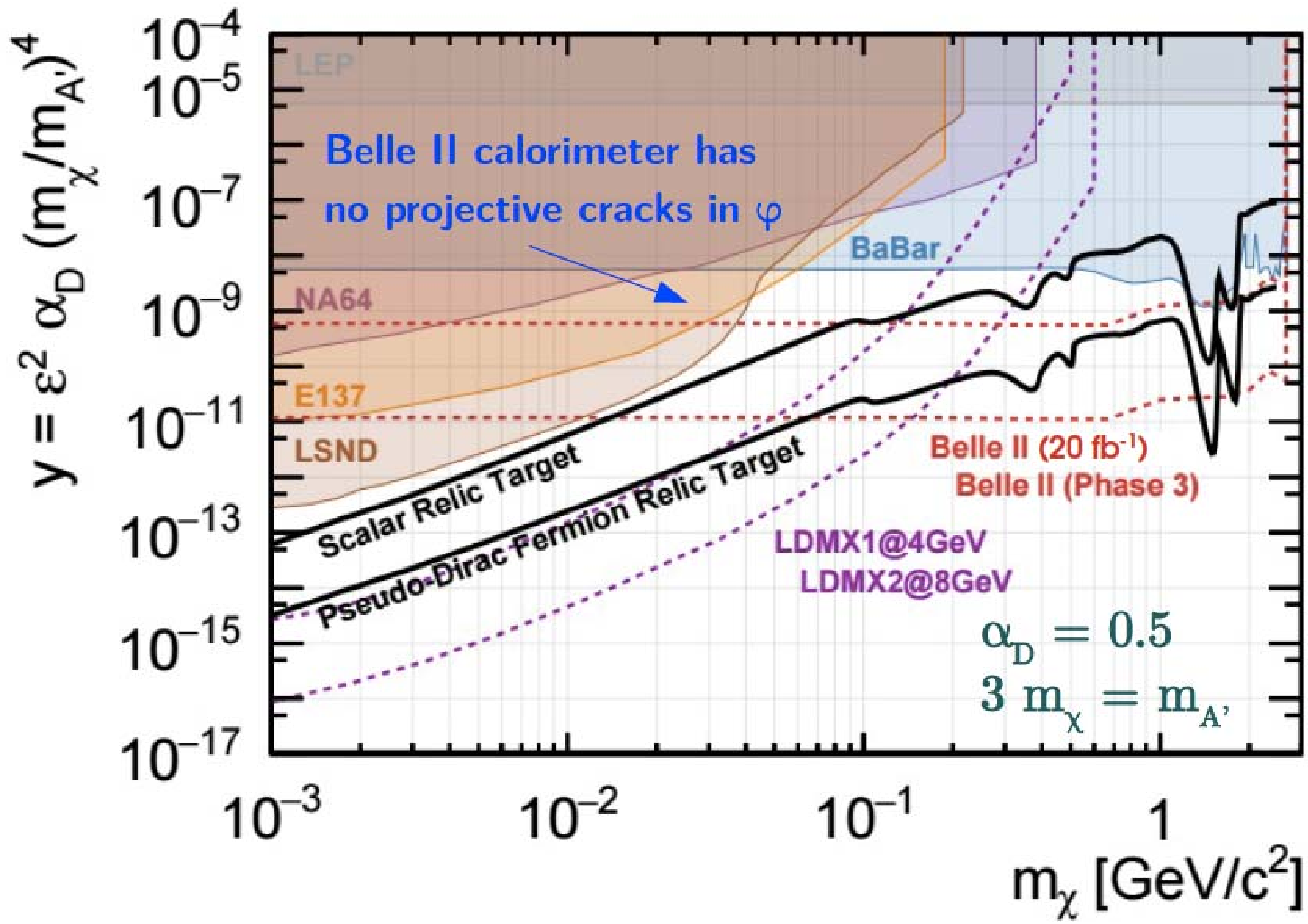
Belle II



Sensitivity for the "dark photon" with the signature: e+e- →γ + nothing

- a bump in the recoil mass:

$$E_\gamma = \frac{s - m_{A'}^2}{2\sqrt{s}}$$



Lower trigger threshold wrt BaBar

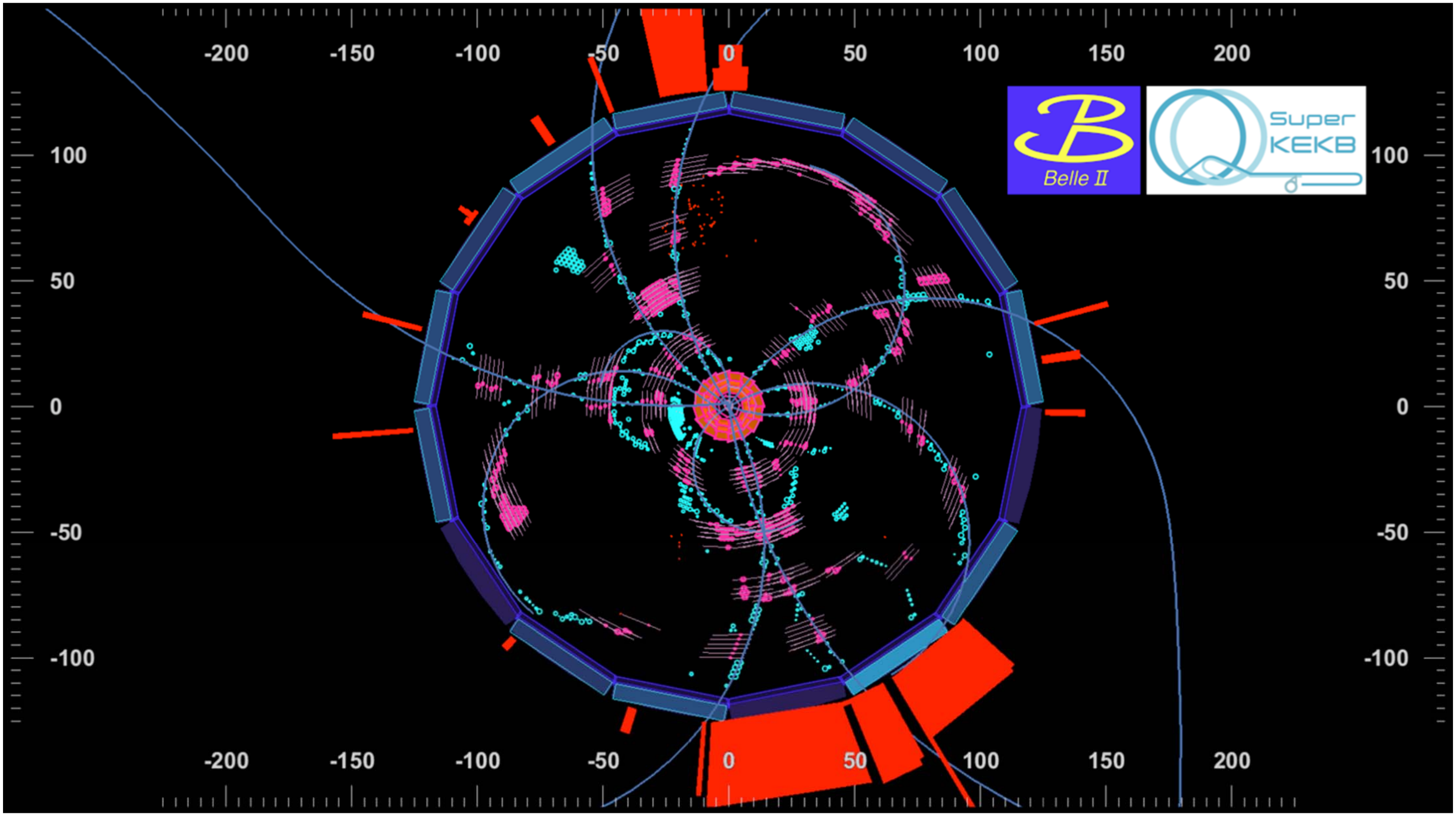
J. Alexander et al. (2016), *arXiv:1608.08632*

N. Toro, private communication (2017)

J. P. Lees et al., BaBar (2017), *arXiv:1702.0332*

The Belle II Physics Book, *arXiv:1808.10567*

Flavor Results from the Physics Run ("Phase 3")

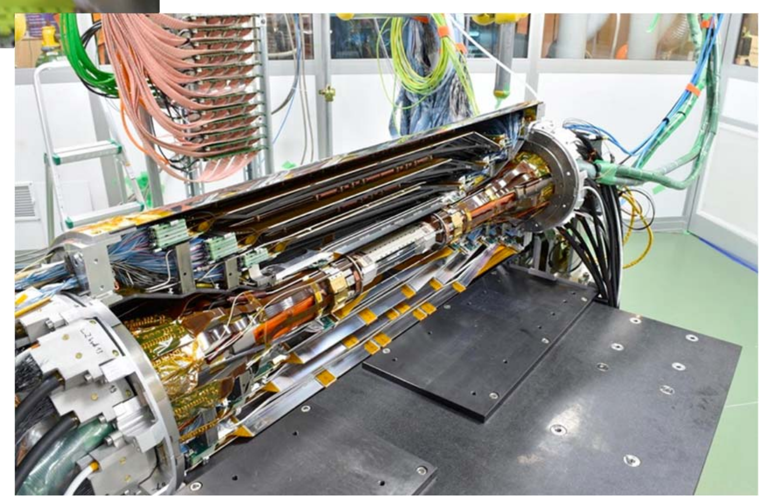


Time Dependent Measurements at Belle II

Belle II

Belle II VXD installed on Nov 21, 2018.

- PXD: L1 and two ladders of L2,
- SVD (4 layers)



Check time-dependent capabilities: Examples of D^0 lifetime results.

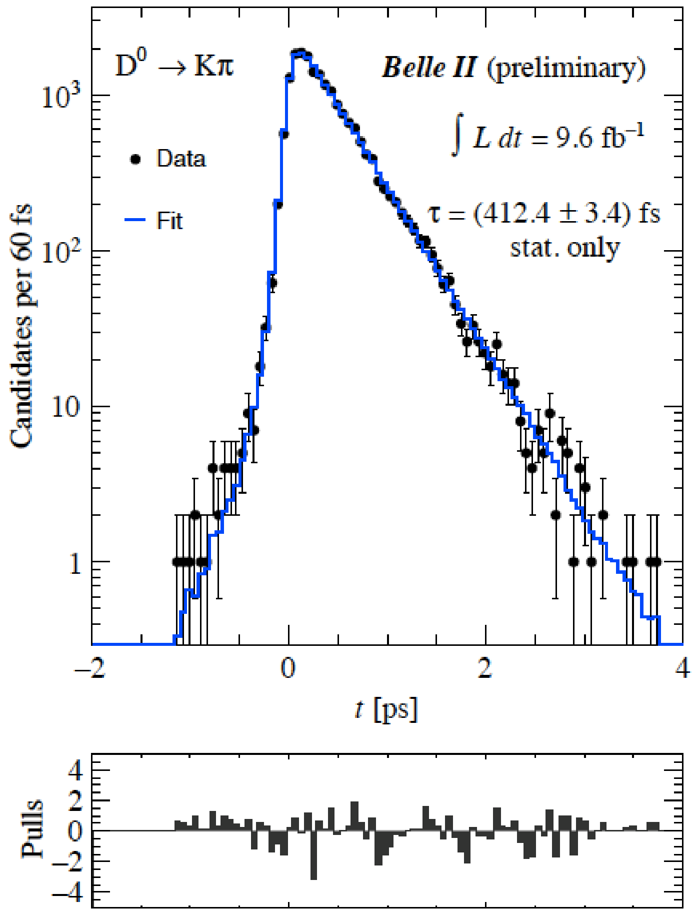


Figure 2: Fit to the proper-time distributions of D^*-tagged $D^0 \to K^-\pi^+$ candidates reconstructed with 2019 Belle II data. The extracted lifetime in this channel is (412.4 ± 3.4) fs, the estimated average proper time resolution is (97 ± 8) fs.

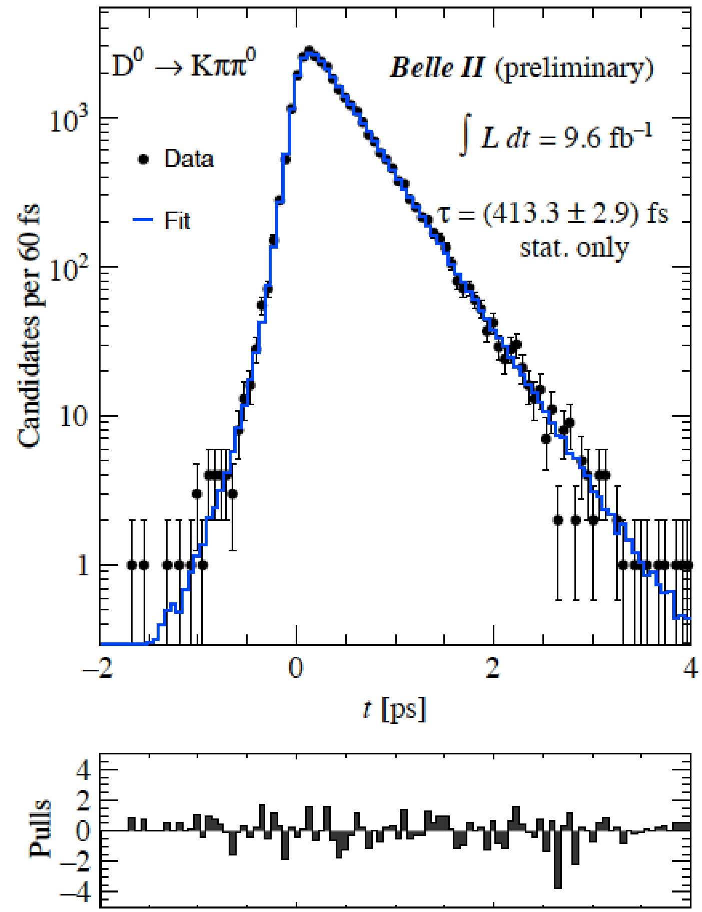
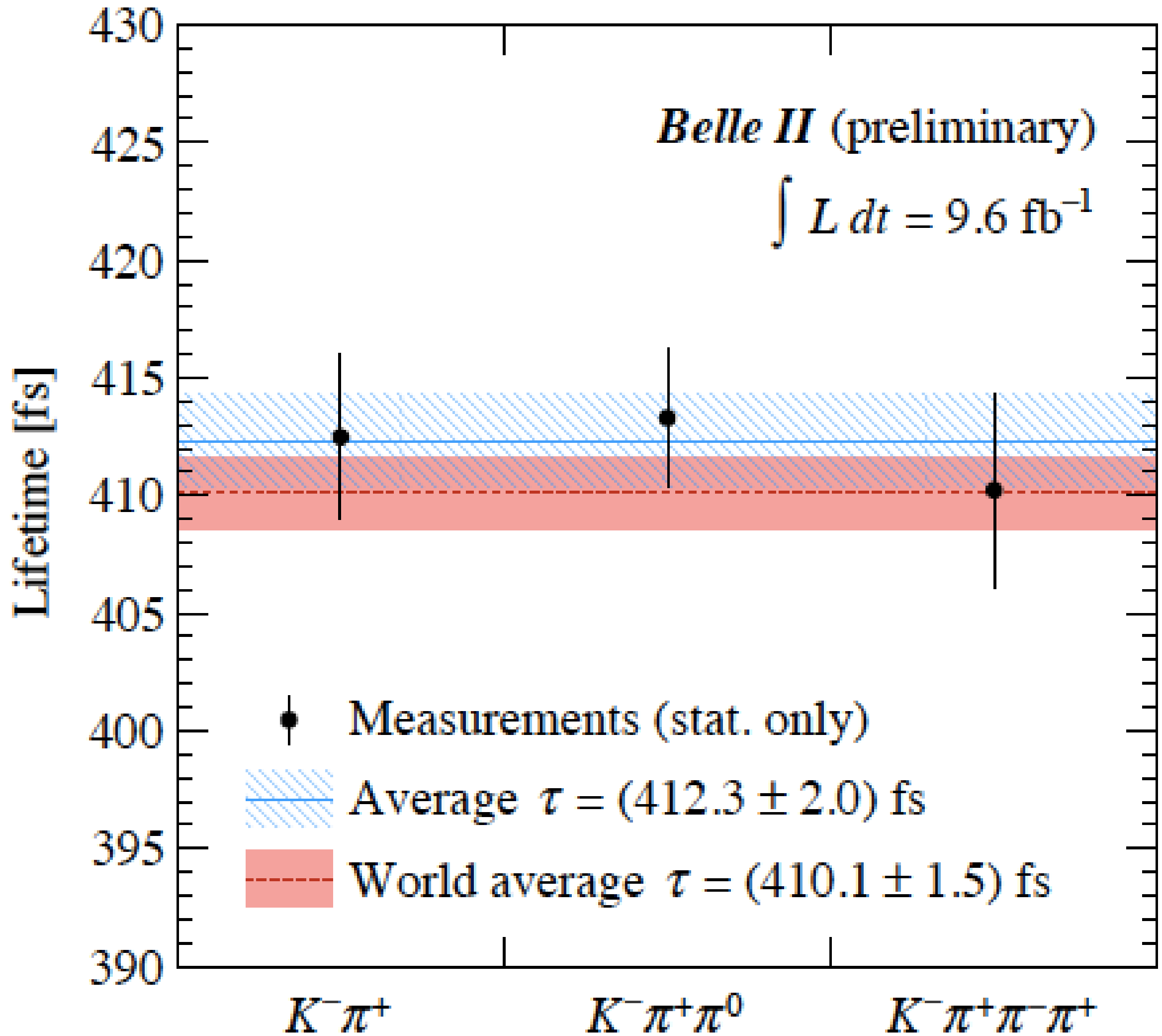


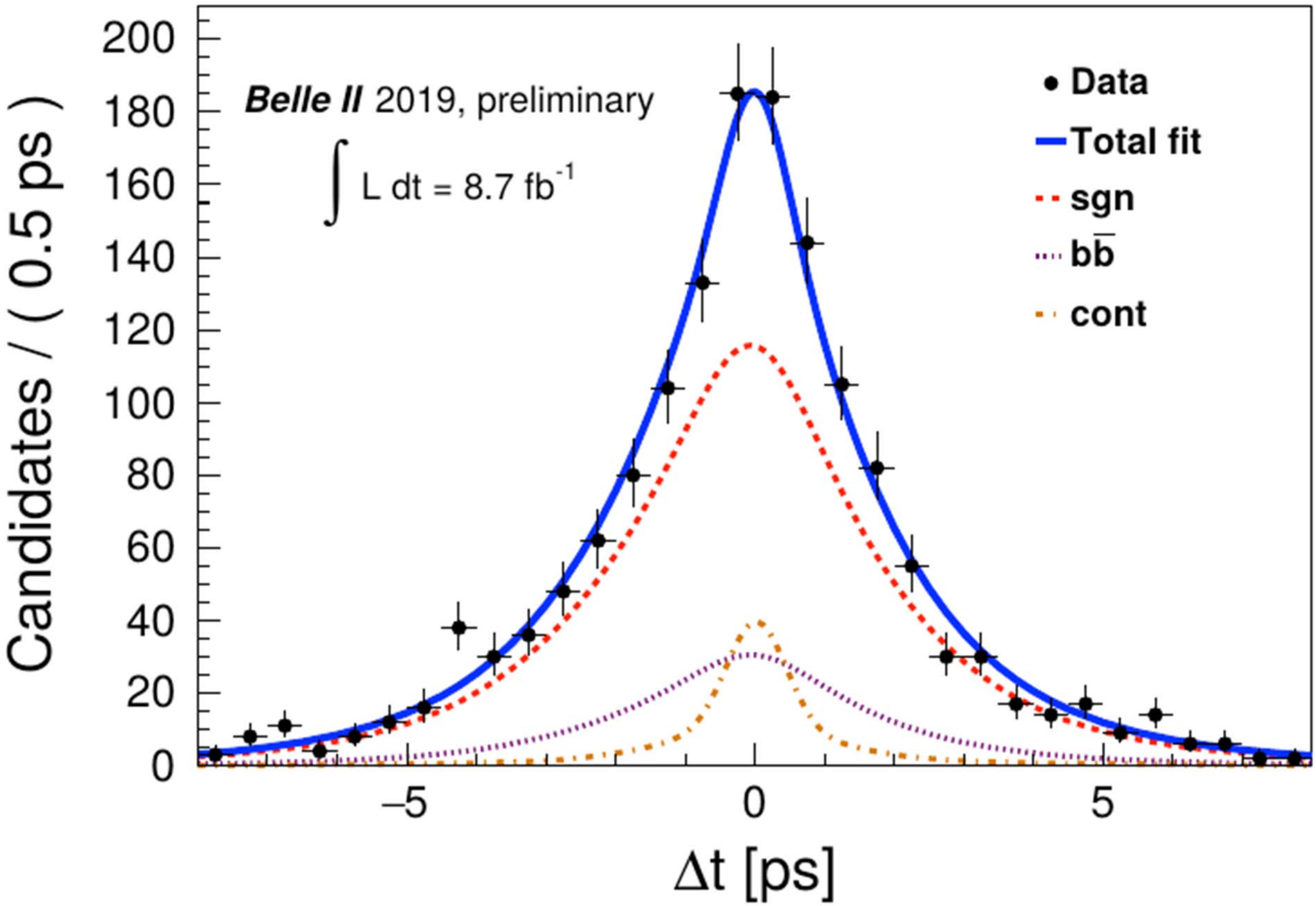
Figure 3: Fit to the proper-time distributions of D^*-tagged $D^0 \to K^-\pi^+\pi^0$ candidates reconstructed with 2019 Belle II data. The extracted lifetime in this channel is (413.3 ± 2.9) fs, the estimated average proper time resolution is (128 ± 9) fs.

Time resolution parameterization can be determined from data.



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

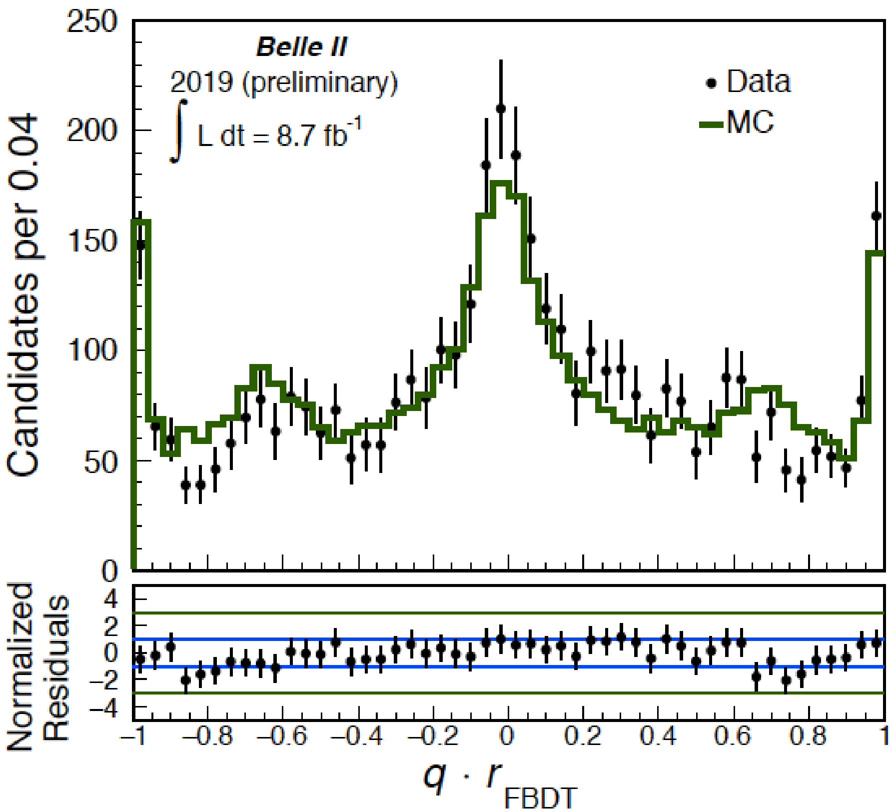
B^0 Lifetime measurement ($B \rightarrow D^{(*)} h$)



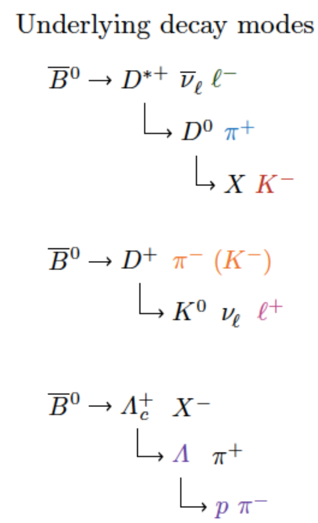
$\tau(B^0) = 1.48 \pm 0.28 \pm 0.06\, ps$

https://arxiv.org/pdf/2005.07507

Flavor Tagging (b quark or anti-b quark ?)



Categories	Targets for $\overline{B}^0$
Electron	e^-
Intermediate Electron	e^+
Muon	μ^-
Intermediate Muon	μ^+
Kinetic Lepton	l^-
Intermediate Kinetic Lepton	l^+
Kaon	K^-
Kaon-Pion	K^-, π^+
Slow Pion	π^+
Maximum P*	l^-, π^-
Fast-Slow-Correlated (FSC)	l^-, π^+
Fast Hadron	π^-, K^-
Lambda	Λ



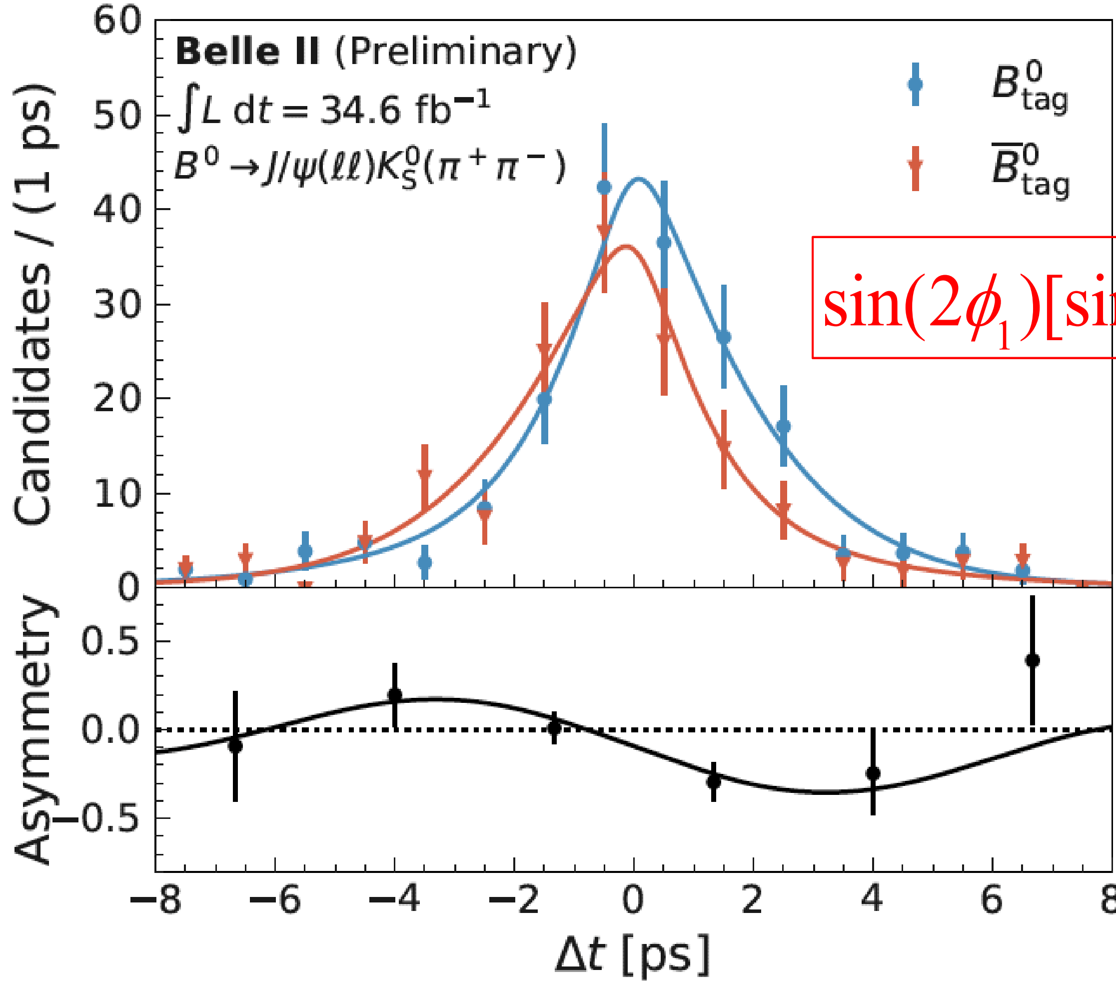
We obtain epsilon_eff = epsilon(1-2 w^2)= **33.8+-3.9%**, which is a slight improvement over the Belle result of 30.1+-0.4%

Agreement of Data and MC

arXiv:2008.02707 [hep-ex]

Hint of time-dependent CPV from Belle II (2.7σ significance)

BELLE2-NOTE-PL-2020-011



$$\sin(2\phi_1)[\sin(2\beta)] = 0.55 \pm 0.21 \pm 0.04$$

(WA=0.691±0.017)

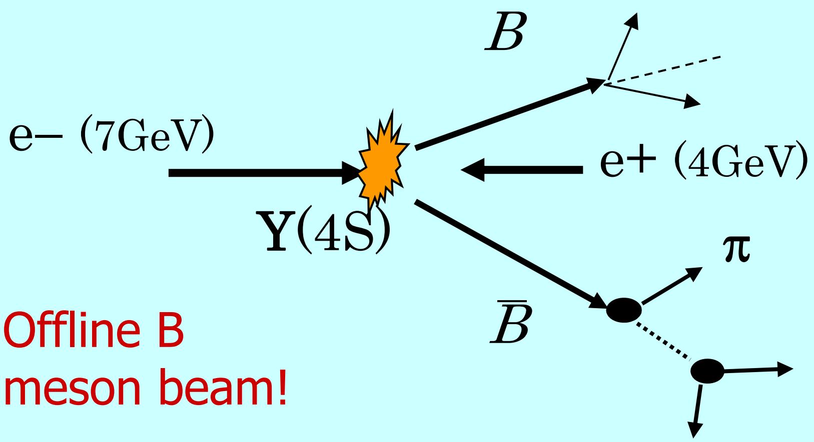
$$B^0 \to f \; ; B^0 \to \overline{B^0} \to f$$

$$N_{+/-} \quad \frac{\exp(-|\Delta t|/\tau)}{4\tau}\left\{1 \pm (1-2w)\sin(2\phi_1)\sin(\Delta m_d \Delta t)\right\} \otimes R(\Delta t)$$

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 → X_u l ν, π l ν
- B → K ν ν
- B → D$\tau\nu$, $\tau\nu$

full reconstruction(~0.5%):
- hadronic tagging, B→Dπ etc.

partial reconstruction (~2%):
- semileptonic tagging

Powerful tool for B decays with neutrinos

→unique feature at B factories

V_{ub}: Exclusive $B \rightarrow \pi^- l^+ \nu$ with FEI

Measurements of the BF at q^2(max) combined with lattice QCD gives $|V_{ub}|$

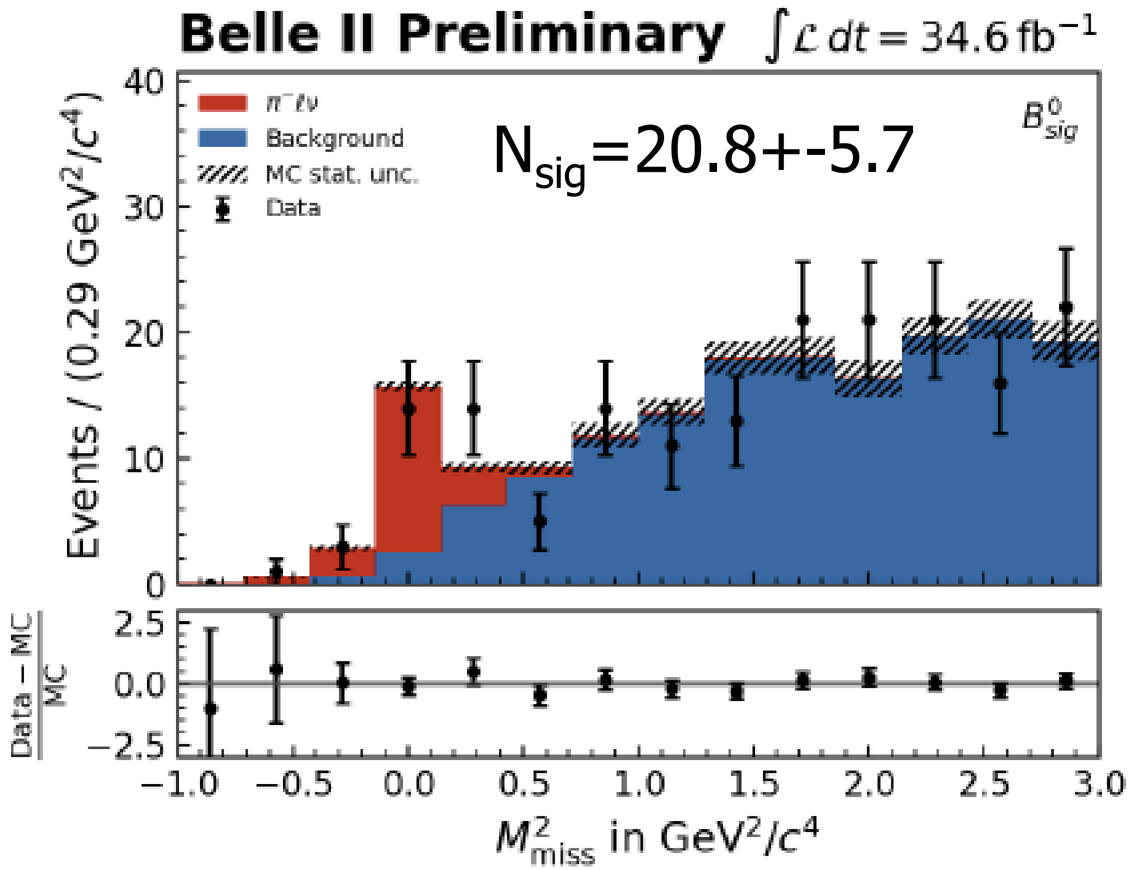


FIG. 4: Post-fit M^2_{miss} distribution in 34.6 fb^{-1} of data.

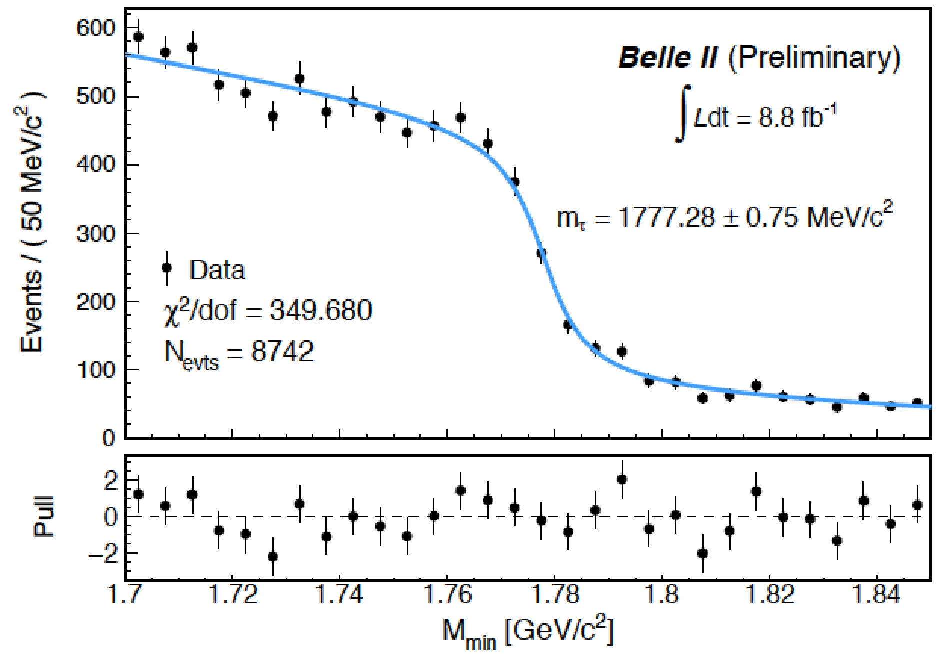
$$BF(B^0 \rightarrow \pi^- l^+ \nu) = [1.58 \pm 0.43(stat) \pm 0.07(sys)] \times 10^{-4}$$

arXiv:2008.08819 [hep-ex]

Tau Mass Measurement

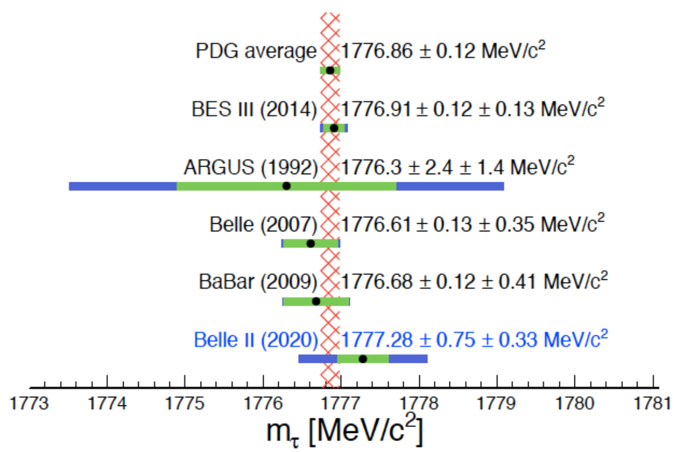
Use 1 prong vs 3-prong tau pair events from e+e- $\rightarrow \tau^+ \tau^-$

$$M_{\min} = \sqrt{M_{3\pi}^2 + 2(E_{\text{beam}} - E_{3\pi})(E_{3\pi} - P_{3\pi})} \leq m_\tau$$

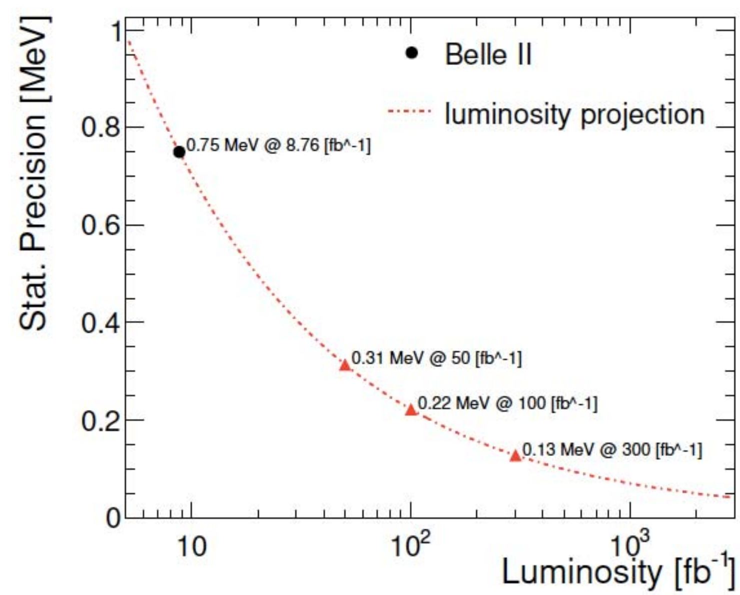


$$m(\tau) = 1777.28 \pm 0.75(stat) \pm 0.33(sys)\,\text{MeV/c}^2$$

arXiv:2008.04665 [hep-ex]

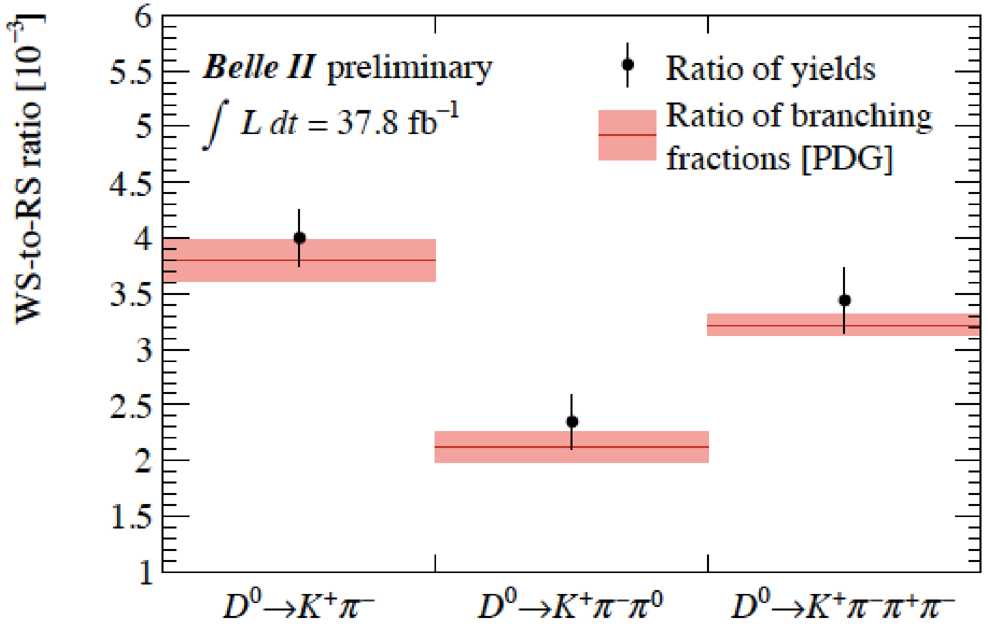


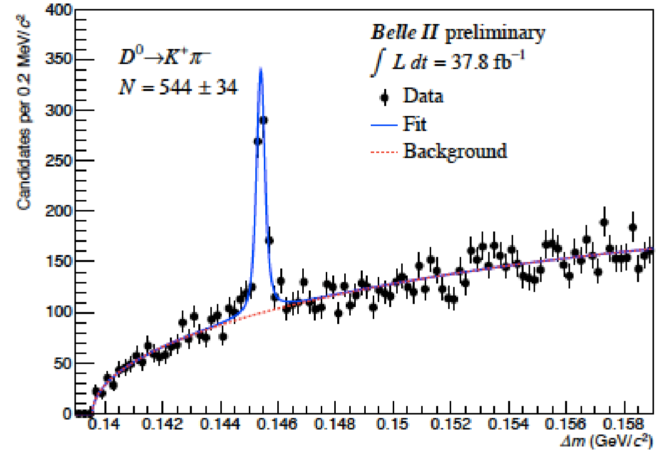
Currently BESIII dominates the world average.

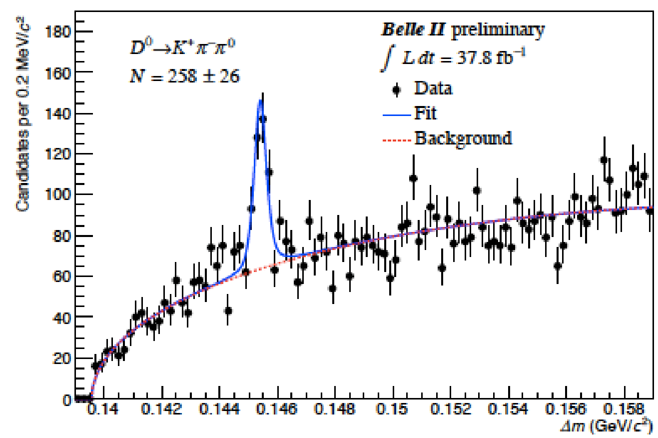


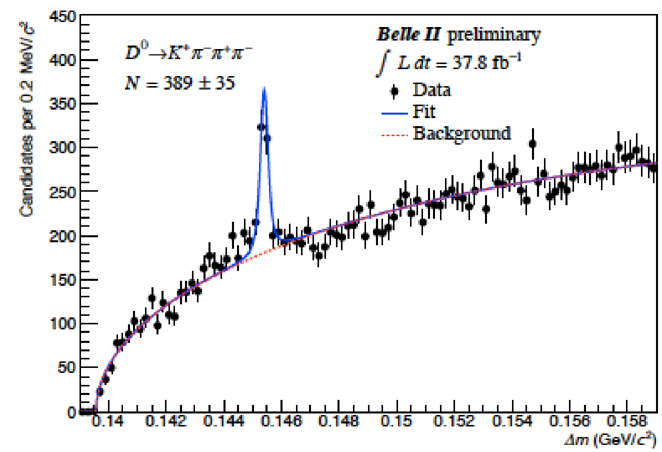
Charm physics, example

Three wrong-sign D decay modes clearly observed, including modes with π^0. These can be used for D-Dbar mixing measurements in the future.

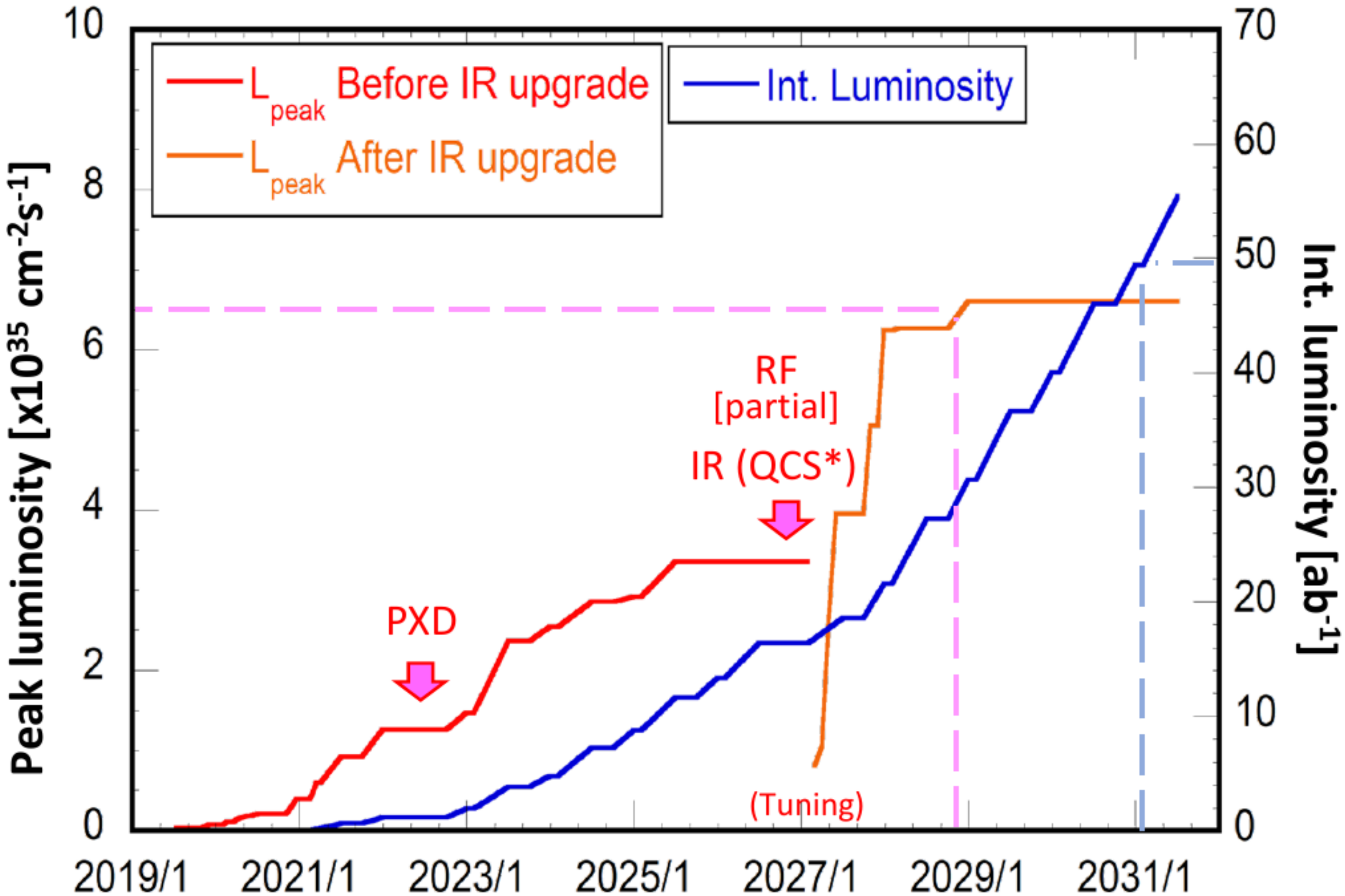




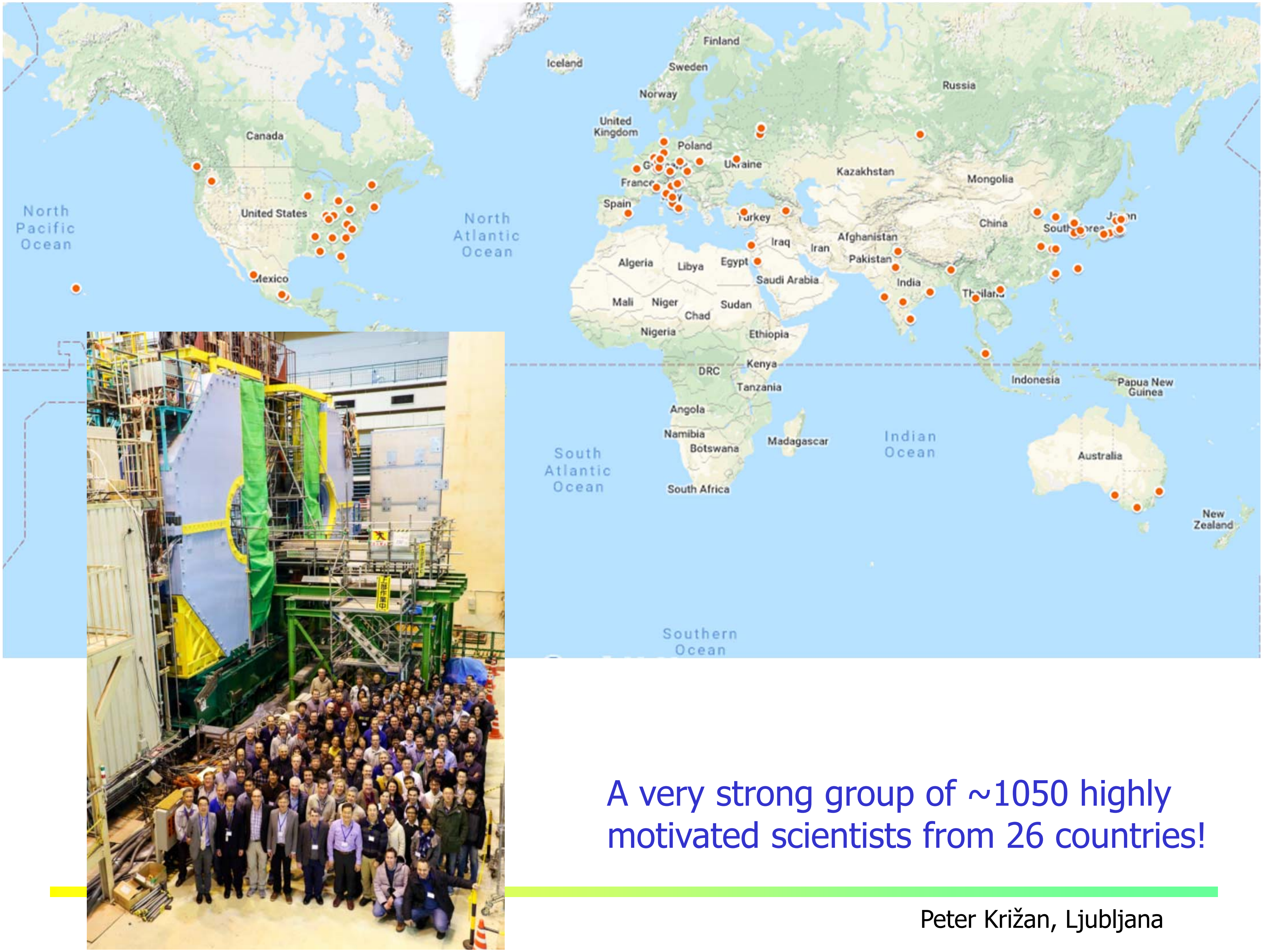




Updated plan for SuperKEKB submitted to the MEXT Roadmap Committee



Two steps:
Intermediate luminosity (1 x 10^{35} /cm^2/sec, 5ab^{-1});
High Luminosity (6 x 10^{35}/cm^2/sec, 50 ab^{-1}) with a detector upgrade



A very strong group of ~1050 highly motivated scientists from 26 countries!

https://arxiv.org/abs/1808.10567

Outcome of the B2TIP (Belle II Theory Interface) Workshops
Emphasis is on New Physics (NP) reach.

Strong participation from theory community,
lattice QCD community and Belle II experimenters.
689 pages, published by Oxford University Press

KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047
UWThPh 2018-26

The Belle II Physics Book

E. Kou[74,¶,†], P. Urquijo[143,§,†], W. Altmannshofer[133,¶], F. Beaujean[78,¶], G. Bell[120,¶], M. Beneke[112,¶], I. I. Bigi[146,¶], F. Bishara[148,16,¶], M. Blanke[49,50,¶], C. Bobeth[111,112,¶], M. Bona[150,¶], N. Brambilla[112,¶], V. M. Braun[43,¶], J. Brod[110,133,¶], A. J. Buras[113,¶], H. Y. Cheng[44,¶], C. W. Chiang[91,¶], M. Ciuchini[58,¶], G. Colangelo[126,¶], H. Czyz[154,29,¶], A. Datta[144,¶], F. De Fazio[52,¶], T. Deppisch[50,¶], M. J. Dolan[143,¶], J. Evans[133,¶], S. Fajfer[107,139,¶], T. Feldmann[120,¶], S. Godfrey[7,¶], M. Gronau[61,¶], Y. Grossman[15,¶], F. K. Guo[41,132,¶], U. Haisch[148,11,¶], C. Hanhart[21,¶], S. Hashimoto[30,26,¶], S. Hirose[88,¶], J. Hisano[88,89,¶], L. Hofer[125,¶], M. Hoferichter[166,¶], W. S. Hou[91,¶], T. Huber[120,¶], S. Jaeger[157,¶], S. Jahn[82,¶], M. Jamin[124,¶], J. Jones[102,¶], M. Jung[111,¶], A. L. Kagan[133,¶], F. Kahlhoefer[1,¶], J. F. Kamenik[107,139,¶], T. Kaneko[30,26,¶], Y. Kiyo[63,¶], A. Kokulu[112,138,¶], N. Kosnik[107,139,¶], A. S. Kronfeld[20,¶], Z. Ligeti[19,¶], H. Logan[7,¶], C. D. Lu[41,¶], V. Lubicz[151,¶], F. Mahmoudi[140,¶], K. Maltman[171,¶], S. Mishima[30,¶], M. Misiak[164,¶],

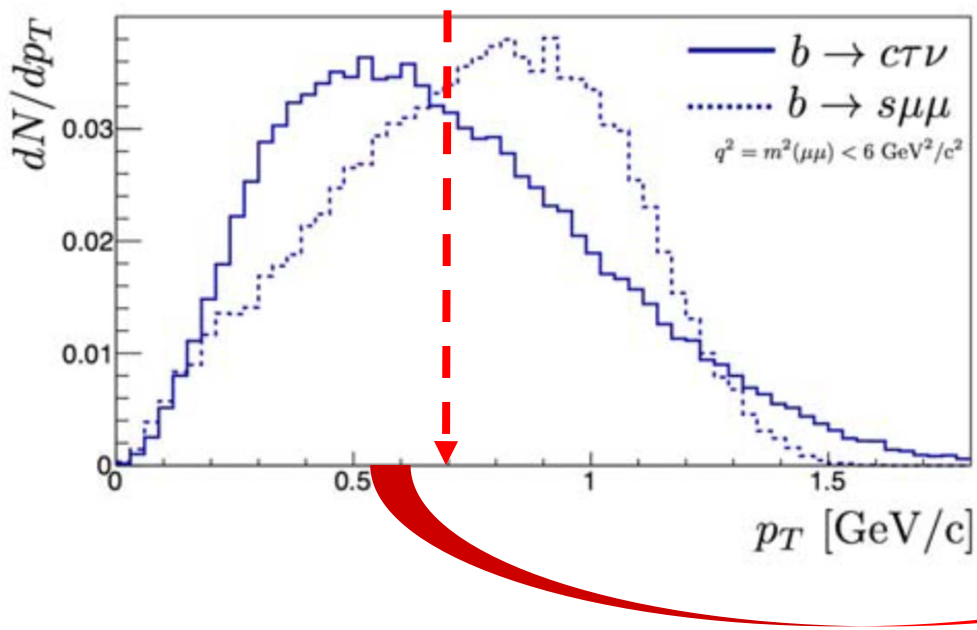
Summary

- Belle II is working well and is now producing physics.
- SuperKEKB has broken the world-luminosity record and is now entering the "Super B Factory" regime.
- World-leading results already on the dark sector (Search for $Z' \rightarrow$ invisible and ALPs publications)
- Rediscovering many of the signals seen at the B factories: semileptonic decays, improving FEI, establishing "missing energy" and time-dependent capabilities, and beginning to see hints of time-dependent CP violation. Need more data to make further progress
- Expect a new, exciting era of discoveries, and a friendly competition and complementarity of Belle II and LHCb

Additional slides

RICH for muon identification at low momenta at Belle II

Hot topic in flavour physics, lepton flavour universality tests: muon momentum spectra



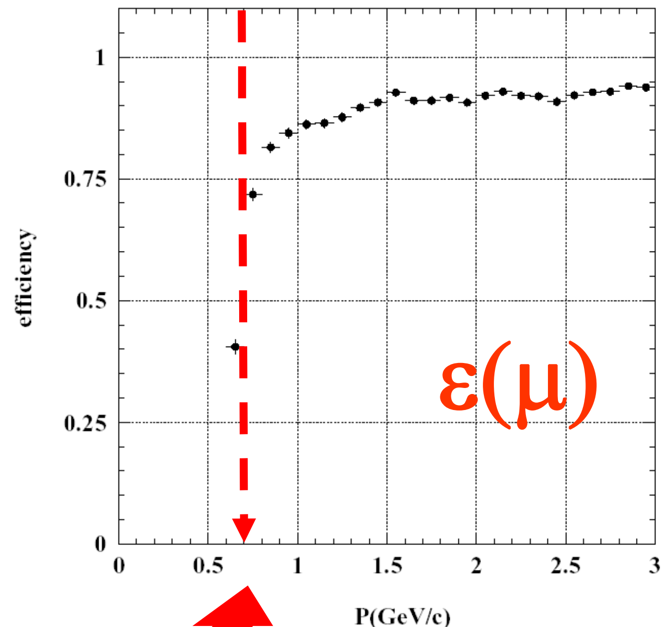
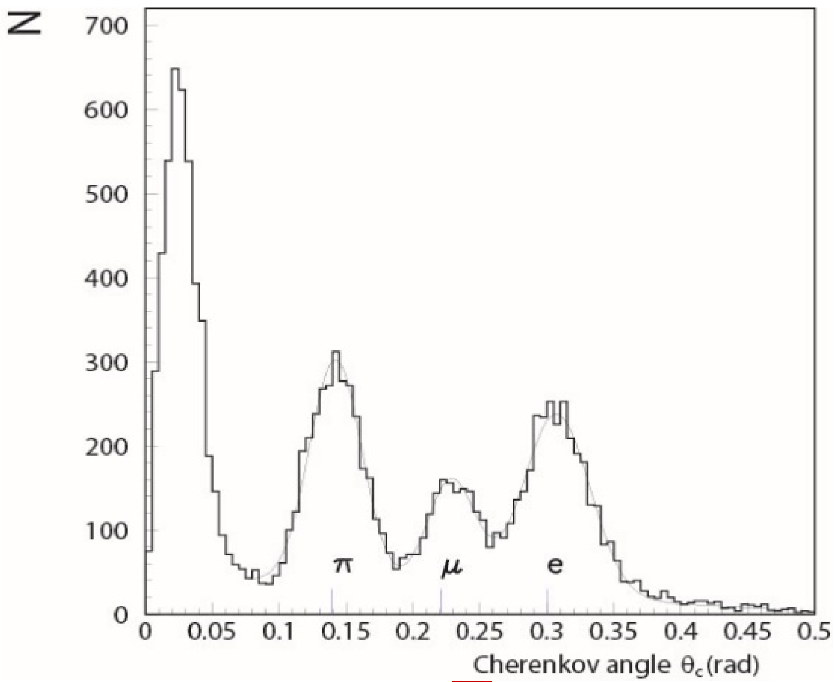


Fig. 109. Muon detection efficiency vs. momentum in KLM.

→ Muons cannot be efficiently separated from pions at low momenta – because they do not make it to the muon system

RICH for muon identification at low momenta at Belle II

Cherenkov angle for single Cherenkov photons from pions, muons, and electrons as measured in a 0.5 GeV/c test beam by a ring imaging Cherenkov detector prototype; with typically about 10 photons per muon as expected in such a counter, the muon and pion peaks would be well separated.



Single photon distribution

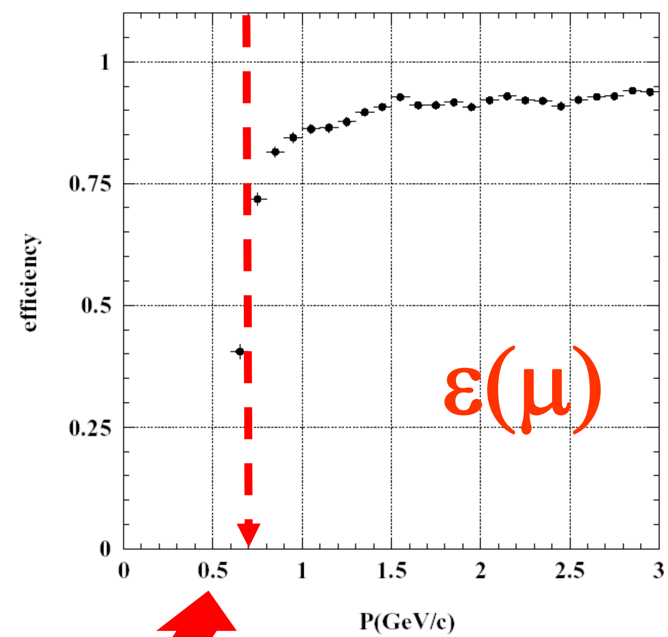


Fig. 109. Muon detection efficiency vs. momentum in KLM.