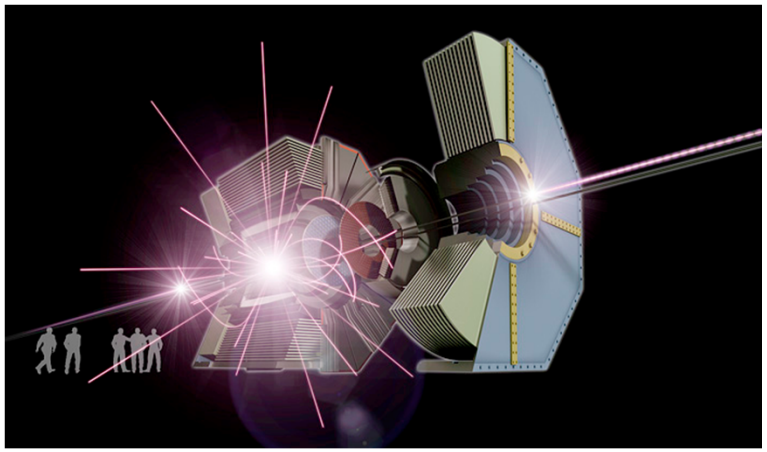


Belle II status and potential

Peter Križan

University of Ljubljana and J. Stefan Institute

University of Ljubljana

Jožef Stefan Institute

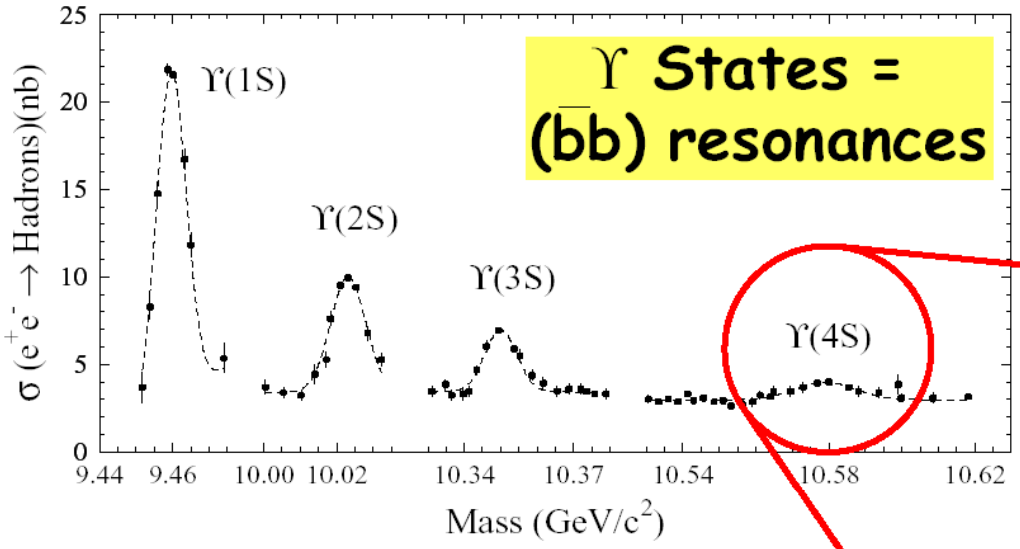
Contents

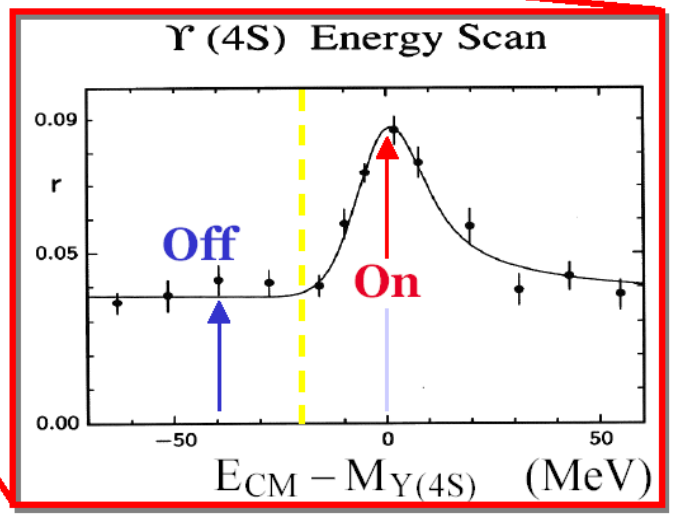
- Introduction
- SuperKEKB and Belle II: status and outlook
- Belle II physics

More on Belle II physics prospects: four talks at this workshop

- Prospects for semileptonic B decays - Guglielmo De Nardo
- Dark sector physics with Belle II - Seokhee Park
- Prospects for CP violation in inclusive and exclusive B decays - Olga Grzymkowska
- Search for BSM with radiative B decays in Belle II - Sviatoslav Bilokin

B meson production at Y(4S)





Cross Sections at Υ(4S):

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

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

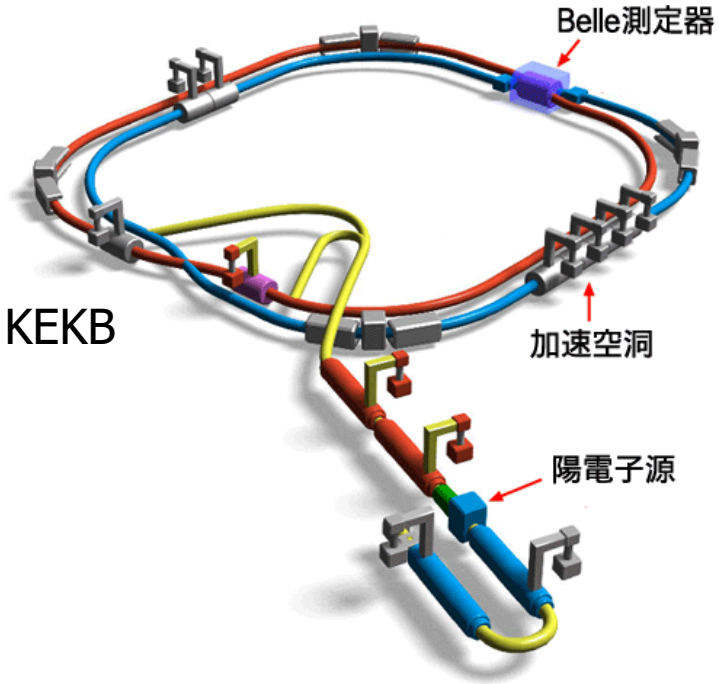
$d\bar{d}, s\bar{s} \sim 0.3$ nb

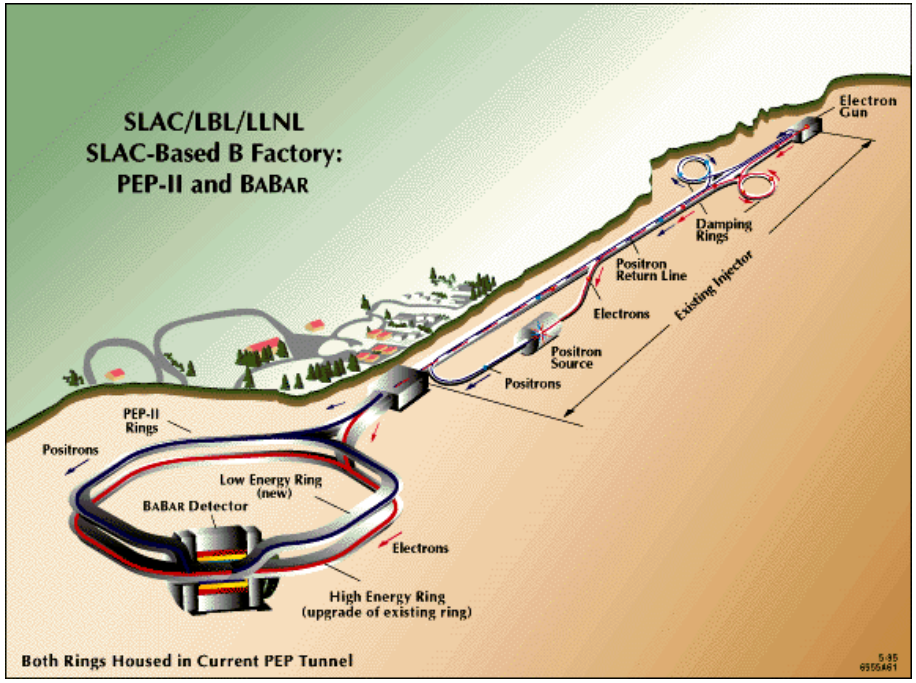
$u\bar{u} \sim 1.4$ nb

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

$L = 1$ state

Flavour physics at the luminosity frontier with asymmetric B factories





$\sqrt{s}$=10.58 GeV

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

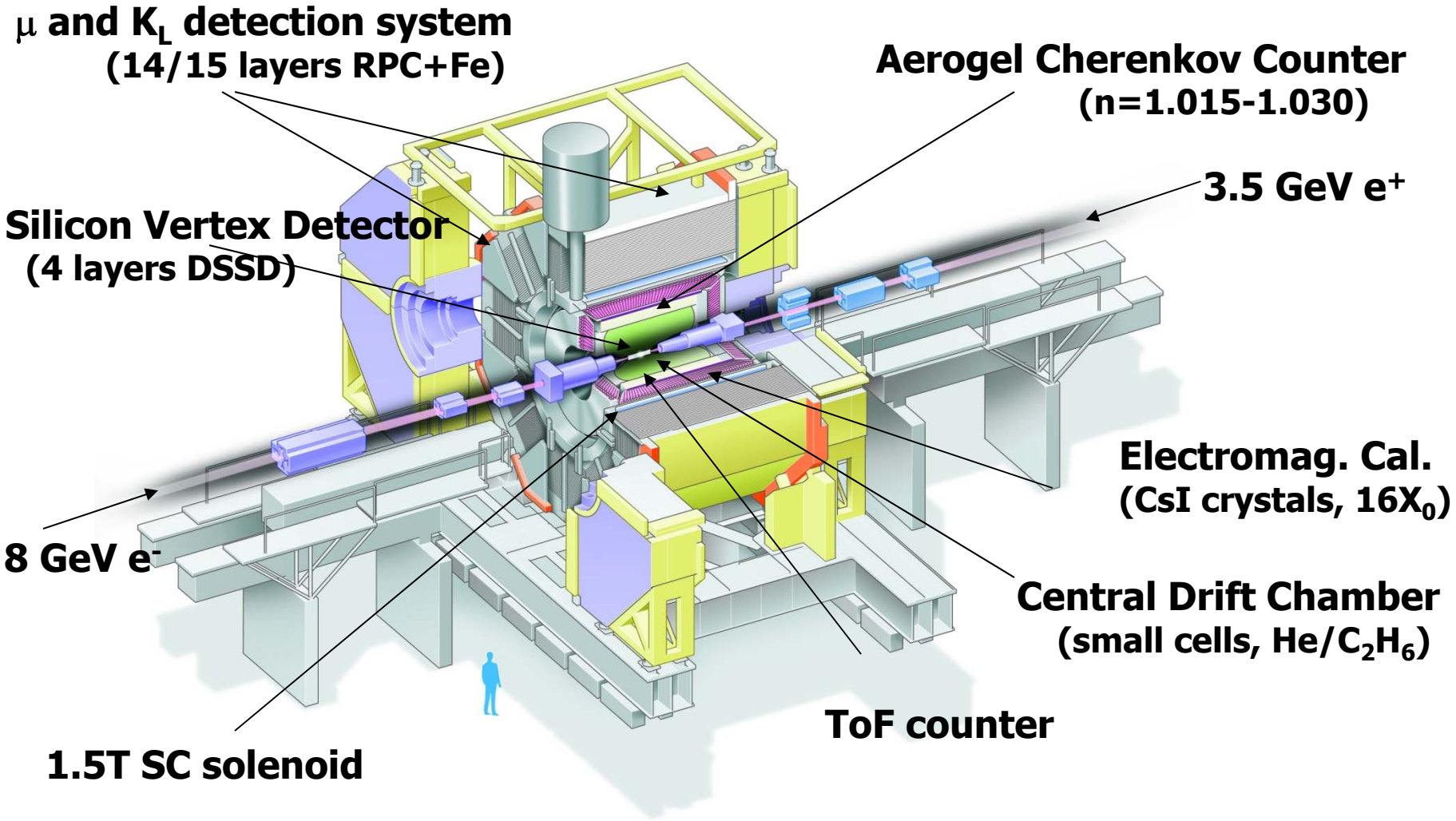
$\Upsilon(4S) \rightarrow B\bar{B}$

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

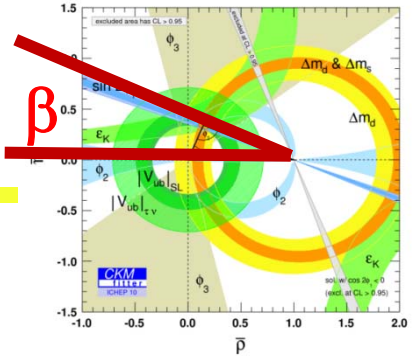
BaBar	$p(e^-)$=9 GeV $p(e^+)$=3.1 GeV	$\beta\gamma$=0.56
Belle	$p(e^-)$=8 GeV $p(e^+)$=3.5 GeV	$\beta\gamma$=0.42

To a large degree shaped flavour physics in the previous decade

Belle spectrometer at KEK-B

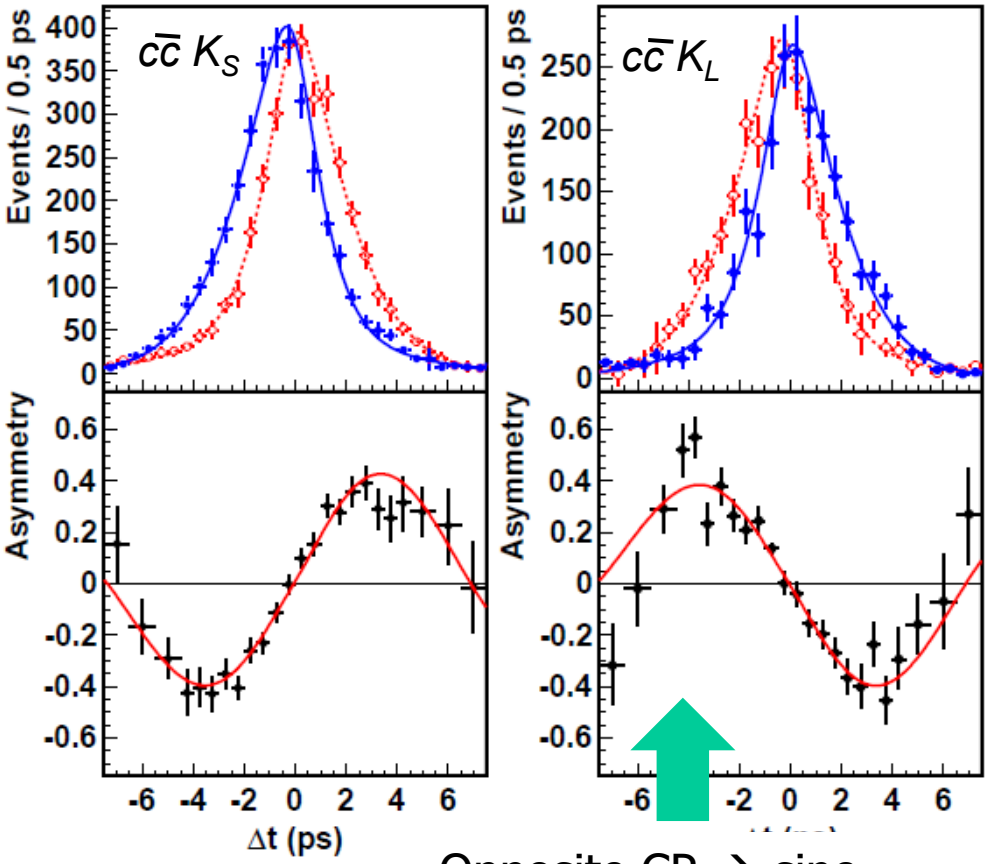


CP violation in the B meson system: measurement of the CKM phase



ϕ_1 from CP violation measurements in $B^0 \to J/\psi K^0$

$$a_{f_{CP}} = -\mathrm{Im}(\lambda_{f_{CP}})\sin(\Delta m t) = \sin 2\phi_1 \sin(\Delta m t)$$



Opposite CP → sine wave with a flipped sign

$\sin 2\phi_1$ (=$\sin 2\beta$)

Belle: 0.668 ± 0.023 ± 0.012
BaBar: 0.687 ± 0.028 ± 0.012

Belle, PRL 108, 171802 (2012)

BaBar, PRD 79, 072009 (2009)

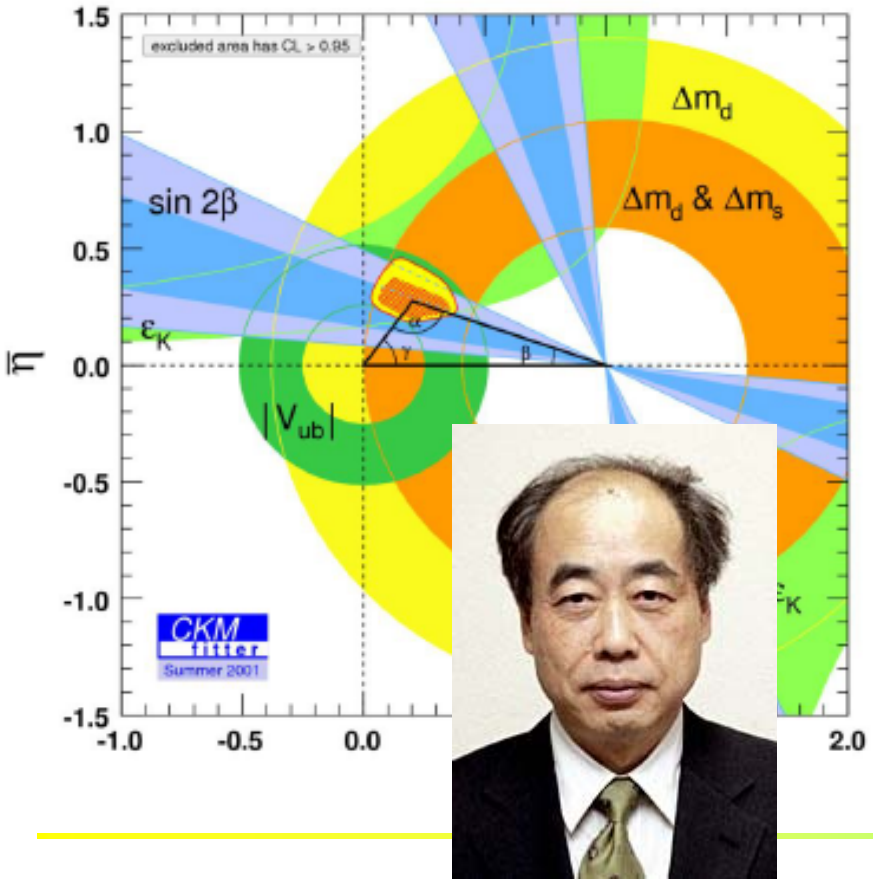
with a single experiment precision of ~4%!

$\phi_1 = \beta = (21.4 \pm 0.8)^0$

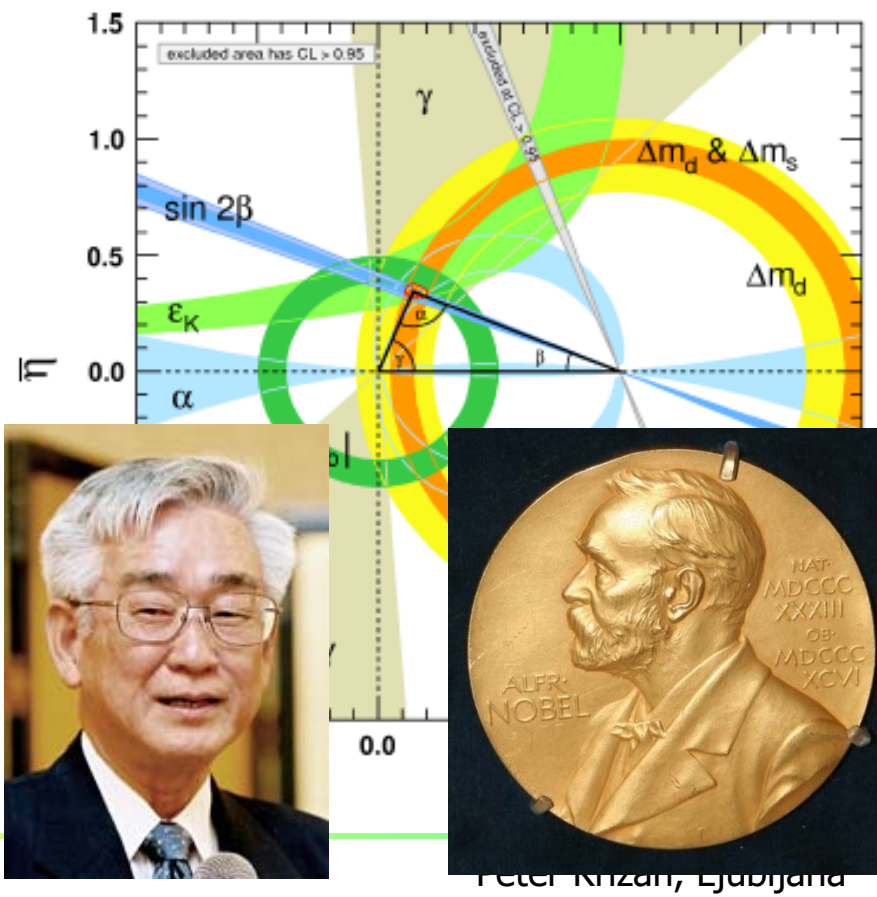
CP violation in the B system

B factories: CP violation in the B system: from the discovery (2001) to a precision measurement (2011) → remarkable agreement with the Kobayashi-Maskawa prediction!

EPS 2001



EPS 2011



What next?

Next generation: Super B factories → Looking for NP

→ Need much more data (almost two orders!)

However: a hard competition from LHCb and BESIII

Still, an e^+e^- machine running at (or near) Y(4s) will have considerable advantages in several classes of measurements, and will be complementary in many more

→ Physics at Super B Factory, arXiv:1002.5012 (Belle II)

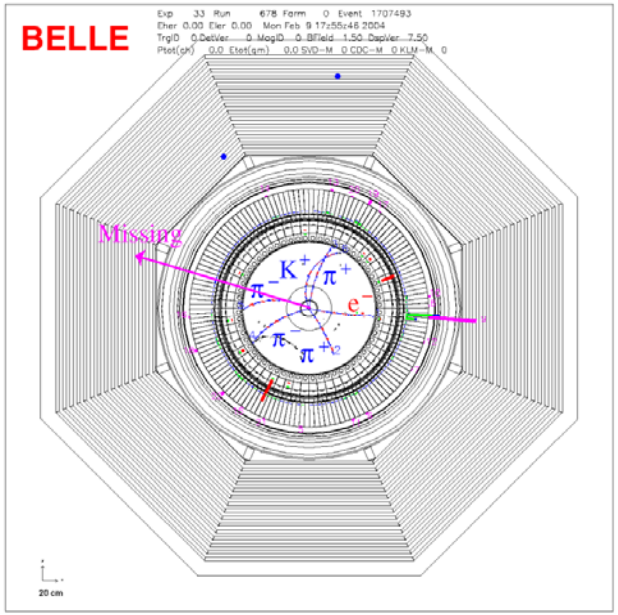
→ SuperB Progress Reports: Physics, arXiv:1008.1541 (SuperB)

→ Physics at B Factories, Eur. Phys. J. C74 (2014) 3026

→ Belle II Theory Interface Platform (B2TiP), to be published in PTEP New!

Advantages of B factories in the LHC era

$$B^+ \to D^0\pi^+$$
$$(\to K\pi^-\pi^+\pi^-)$$
$$B^- \to \tau(\to e\nu\bar{\nu})\nu$$



Unique capabilities of B factories:

→ Exactly two B mesons produced (at $\Upsilon(4S)$)

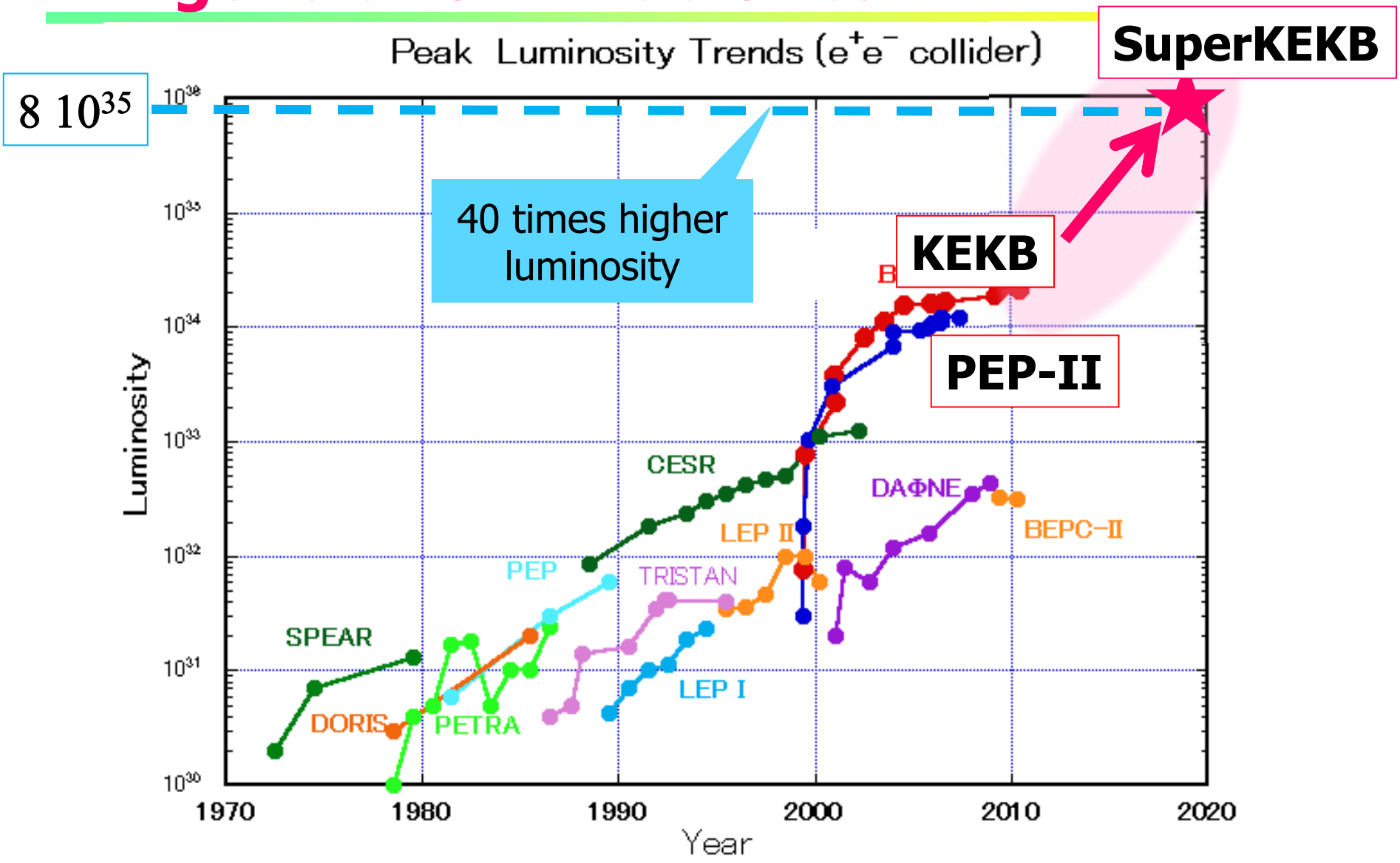
→ High flavour tagging efficiency

→ Detection of gammas, π^0s, K_Ls

→ Very clean detector environment (can observe decays with several neutrinos in the final state!)

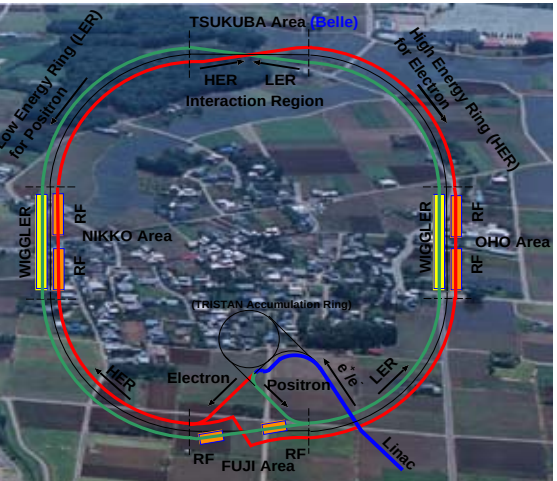
However, need a two-orders-of-magnitude larger data sample!

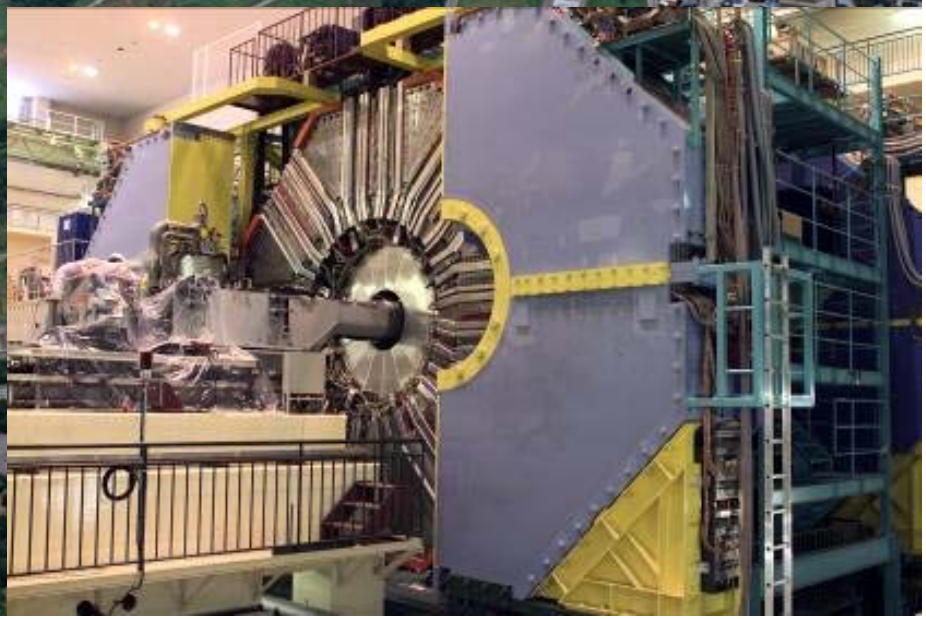
Need O(100x) more data →Next generation B-factories



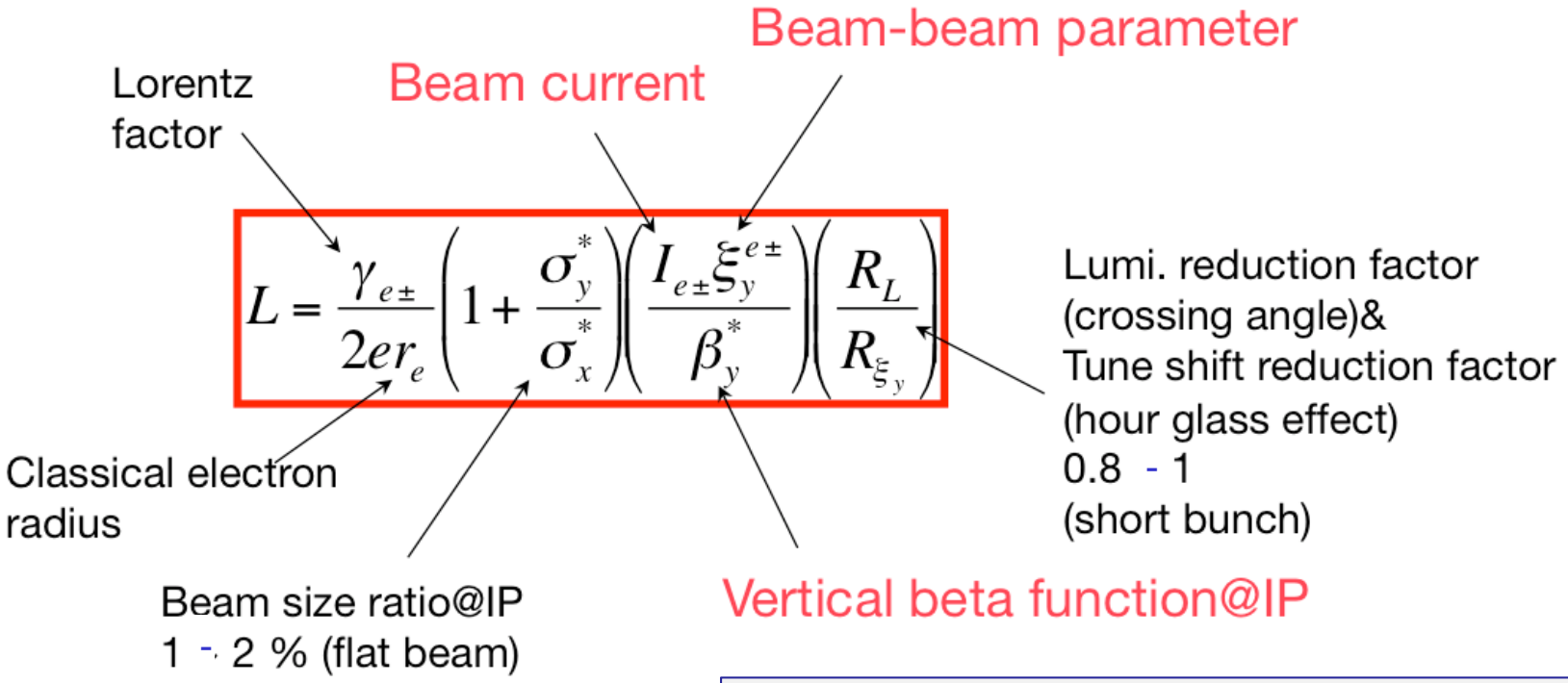
N.B. KEKB peak L: 2.11 10^{34} cm^{-2} s^{-1} , LHC peak L: 2.06 10^{34} cm^{-2} s^{-1}

How to do it?
→upgrade the existing KEKB and Belle facility





How to increase the luminosity?



(1) Smaller β_y^*

(2) Increase beam currents

(3) Increase ξ_y

"Nano-Beam" scheme

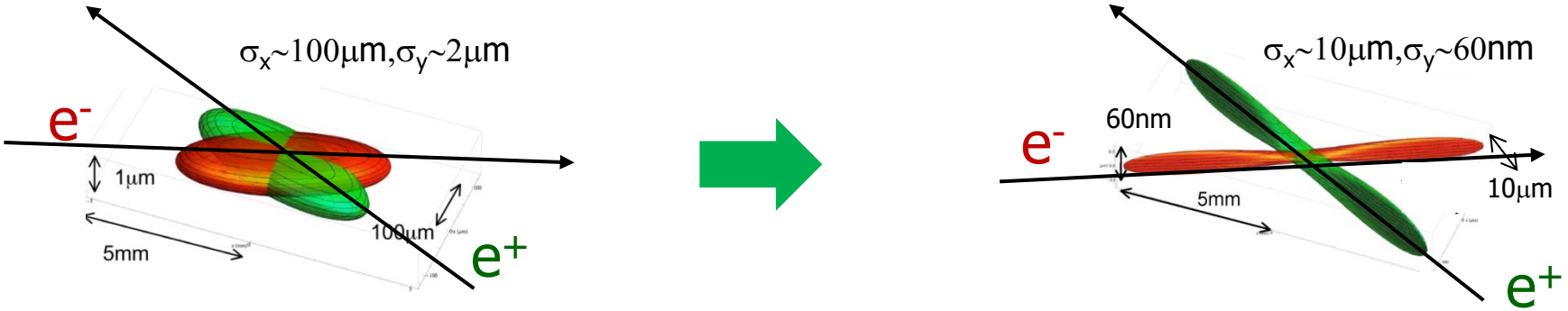
Collision with very small spot-size beams

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 40x times better, more intense facility?

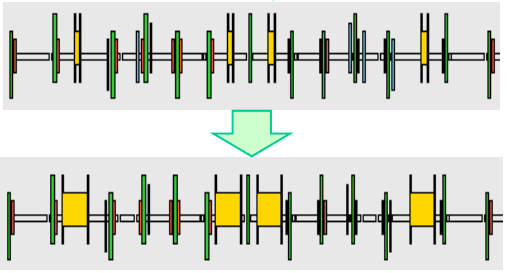
In KEKB, colliding electron and positron beams were already much thinner than a human hair...



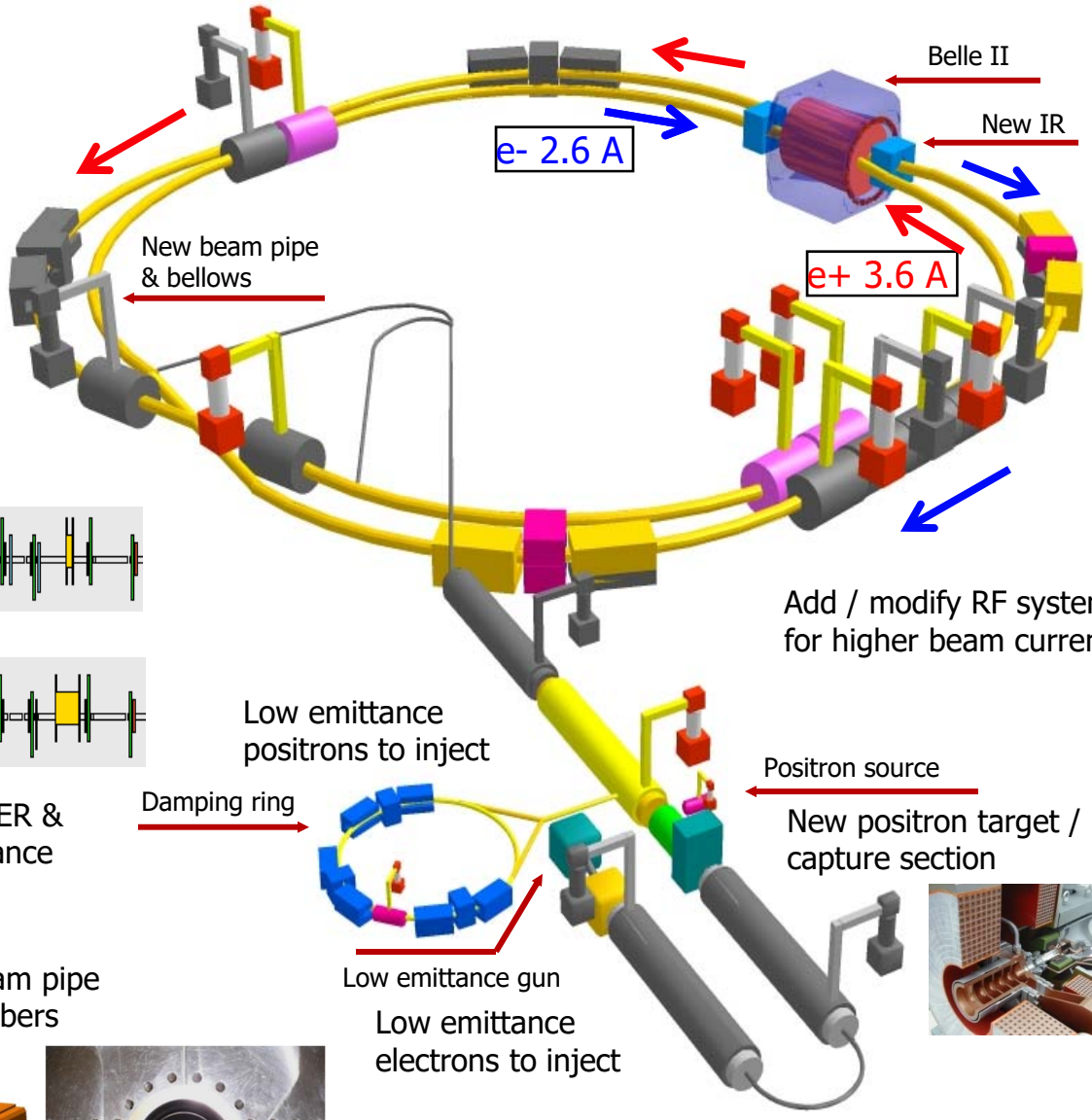
... For a 40x increase in intensity you have to make the beam as thin as a few x100 atomic layers!

KEKB → SuperKEKB

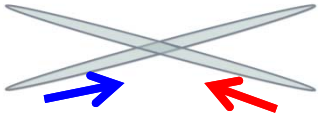
Replace short dipoles with longer ones (LER)



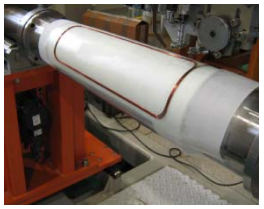
Redesign the lattices of HER & LER to squeeze the emittance



Colliding bunches

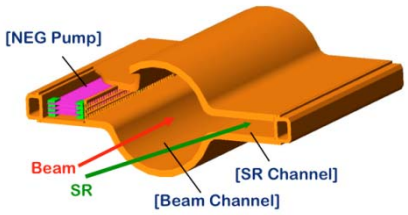


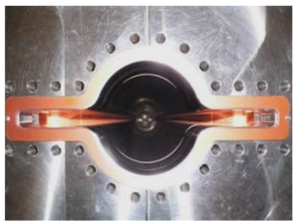
New superconducting /permanent final focusing quads near the IP



Add / modify RF systems for higher beam current

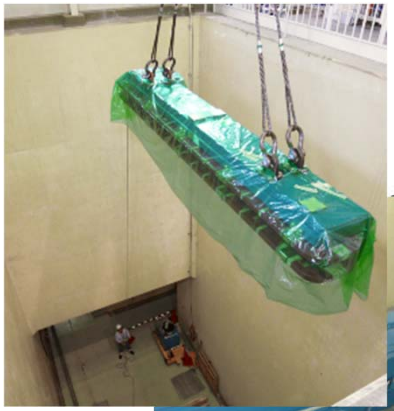
TiN-coated beam pipe with antechambers



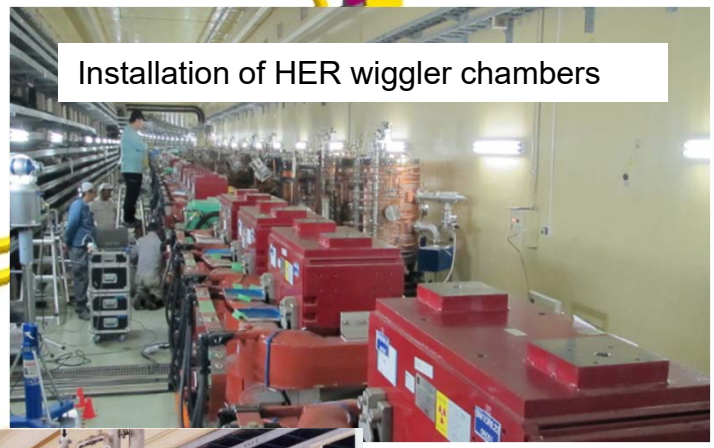


To get x40 higher luminosity

Installation of 100 new long
LER bending magnets



New superconducting
final quadrupoles

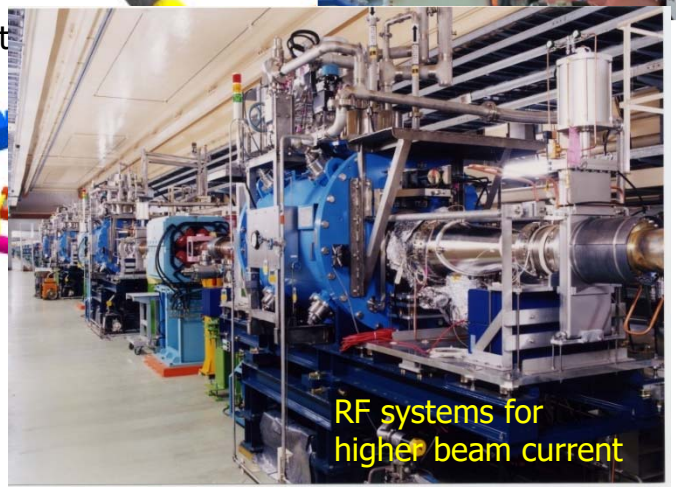


Installation of HER wiggler chambers

Damping ring tunnel

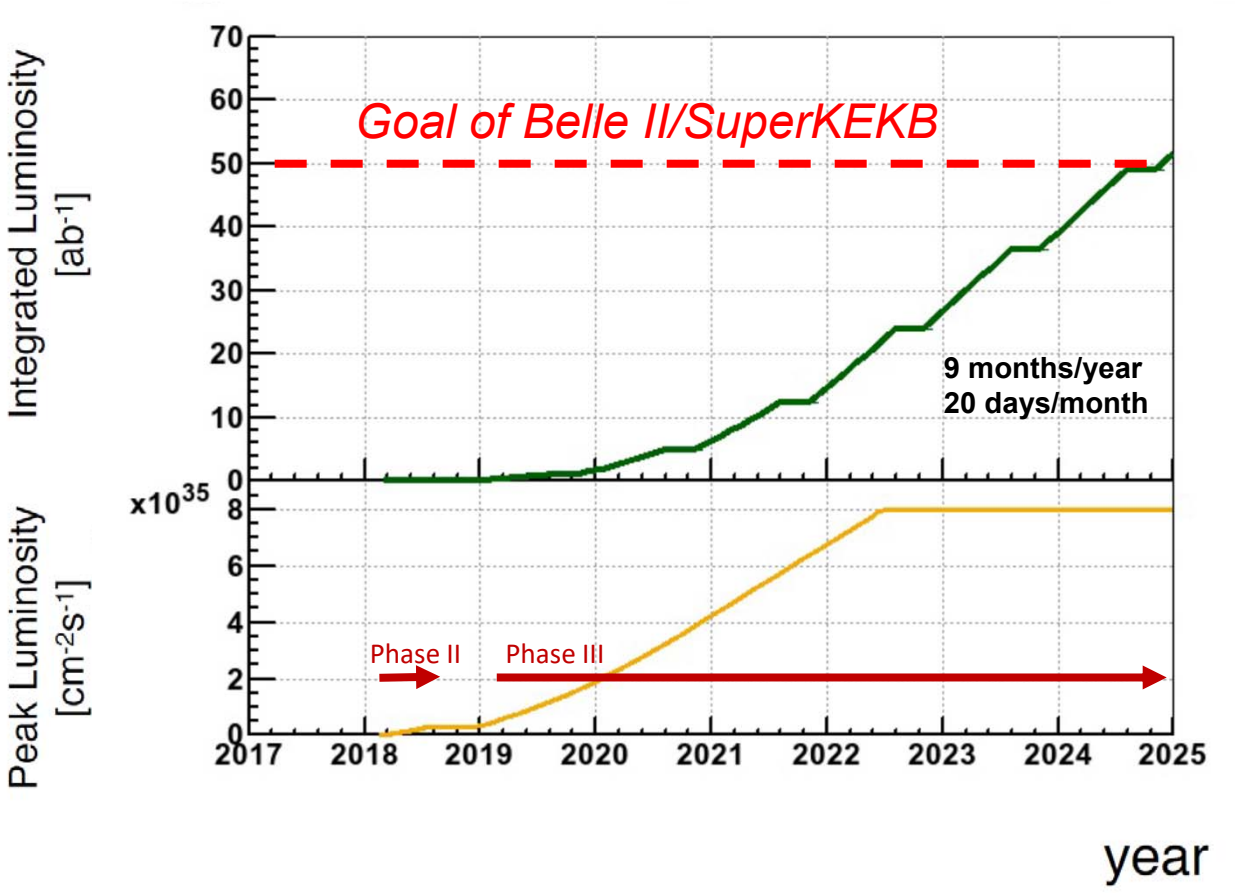
Low emitt
positrons

Damping ring



RF systems for
higher beam current

SuperKEKB phases and luminosity projection



Phase I (2016)

- NO final focus; NO damping ring
- Circulated both beams but no collisions;
- Tune accelerator optics, etc.; vacuum scrubbing
- Beam Background studies with dedicated BEAST II/1 detector

Phase II (2018)

- First collisions
- Beam Commissioning
- Background measurements with BEAST II/2
- Physics run with Belle II without Vertex Detector

Phase III (2019→)

- Physics run

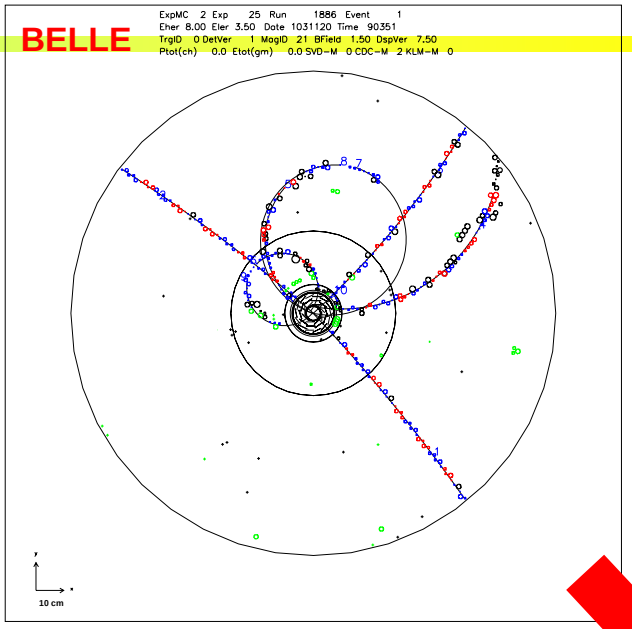
Requirements for the Belle II detector

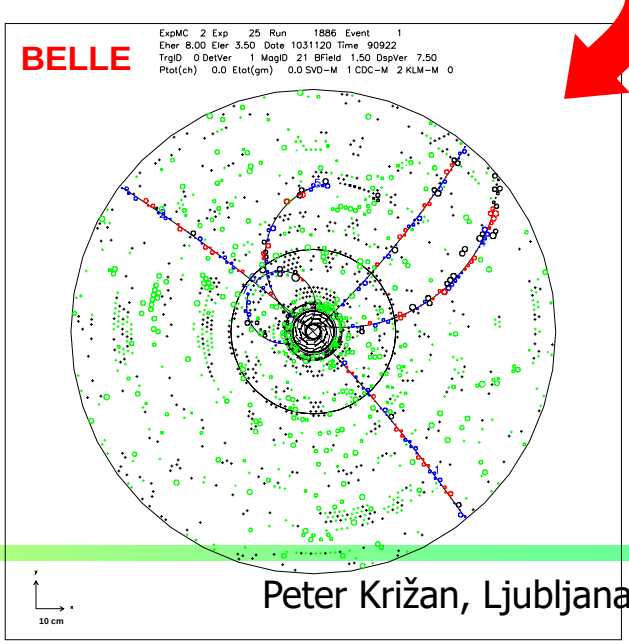
Critical issues at L= 8 x 10^{35}/cm^2/sec

- **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:

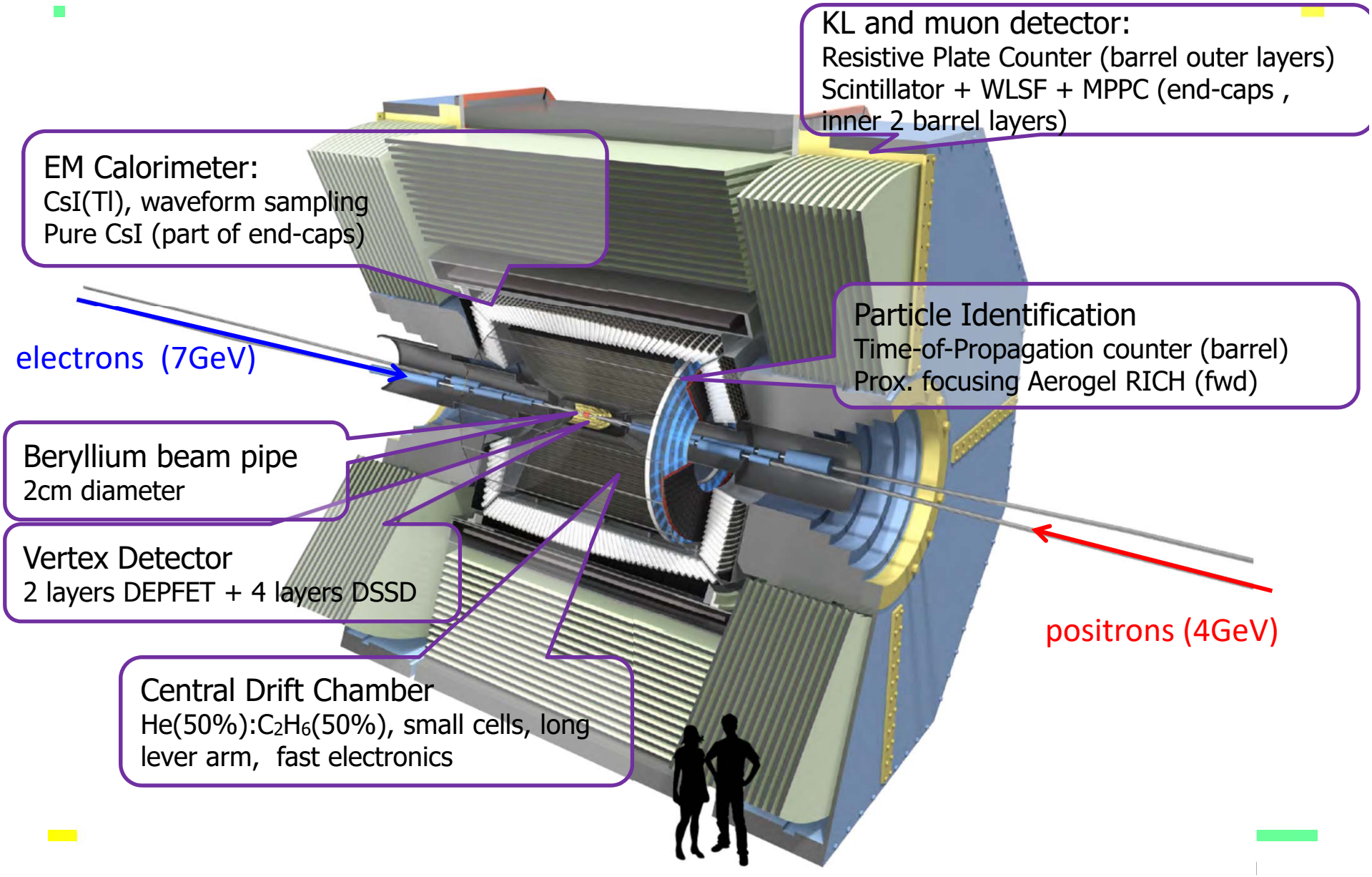
- Replace inner layers of the vertex detector with a pixel detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace part of endcap calorimeter crystals
- Faster readout electronics and computing system.



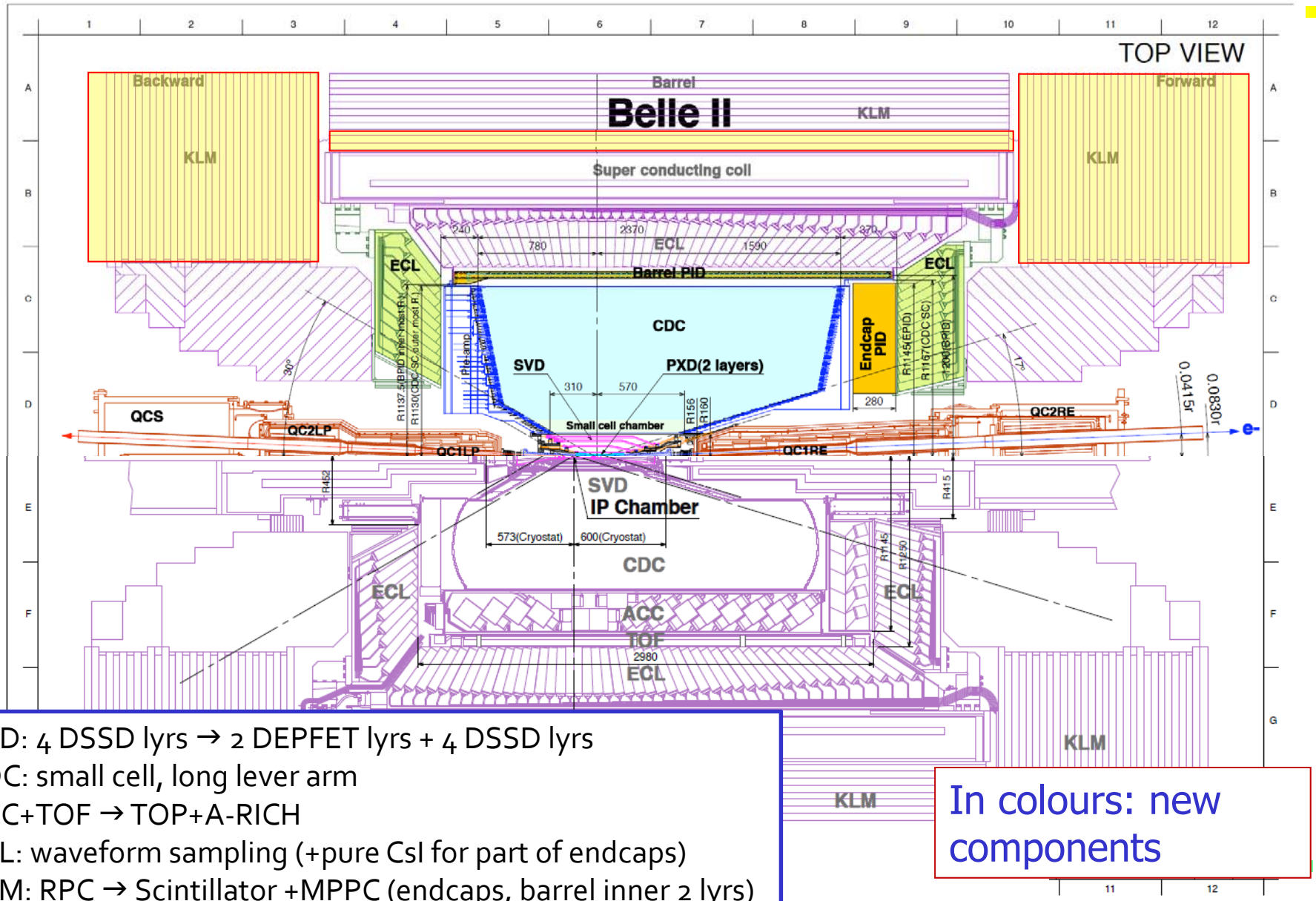


Belle II TDR, arxiv:1011.0352v1[physics.ins-det]

Belle II Detector



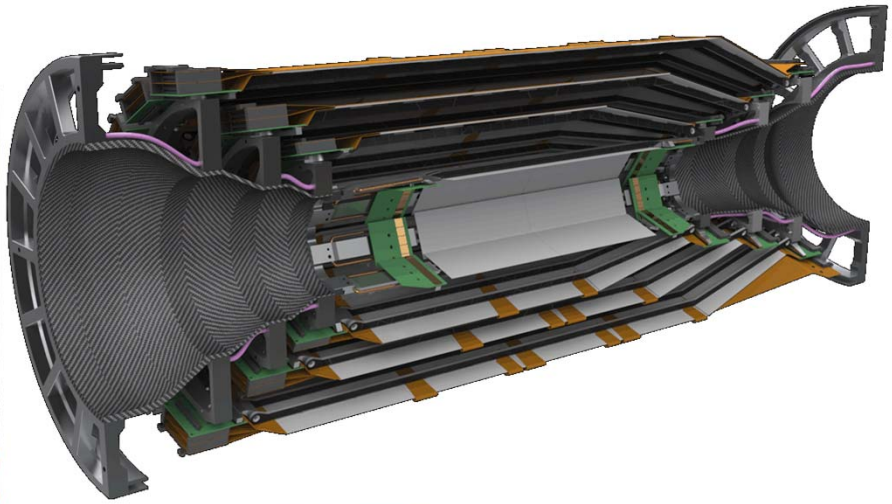
Belle II Detector (in comparison with Belle)



SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI for part of endcaps)
KLM: RPC → Scintillator +MPPC (endcaps, barrel inner 2 lyrs)

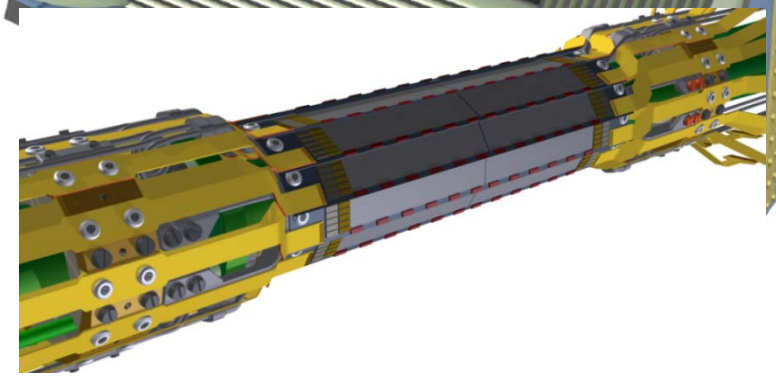
In colours: new components

Belle II Detector – vertex region



Beryllium beam pipe
2cm diameter

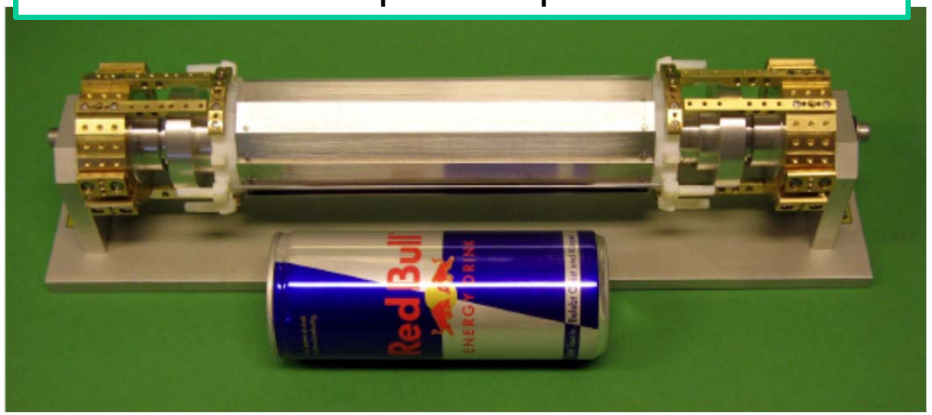
Vertex Detector
2 layers pixels + 4 layers strips

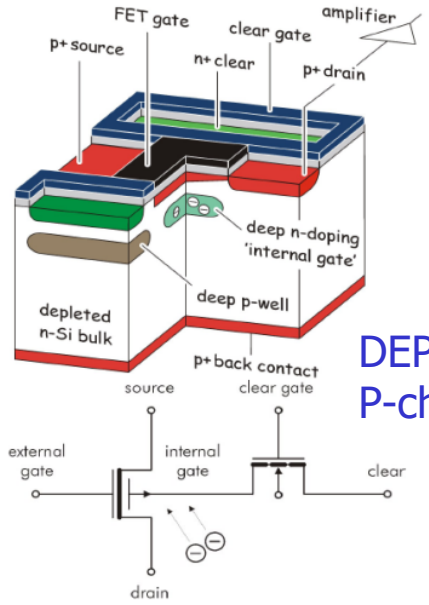


Beam Pipe	**r = 10mm**
DEPFET pixels	
Layer 1	**r = 14mm**
Layer 2	**r = 22mm**
DSSD silicon strips	
Layer 3	**r = 39mm**
Layer 4	**r = 80mm**
Layer 5	**r = 104mm**
Layer 6	**r = 135mm**

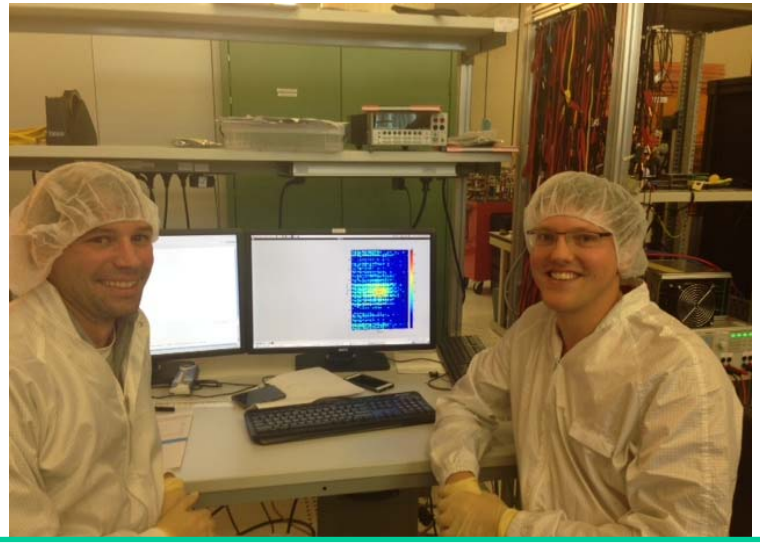
Pixel detector: 2 layers of DEPFET sensors

Mechanical mockup of the pixel detector



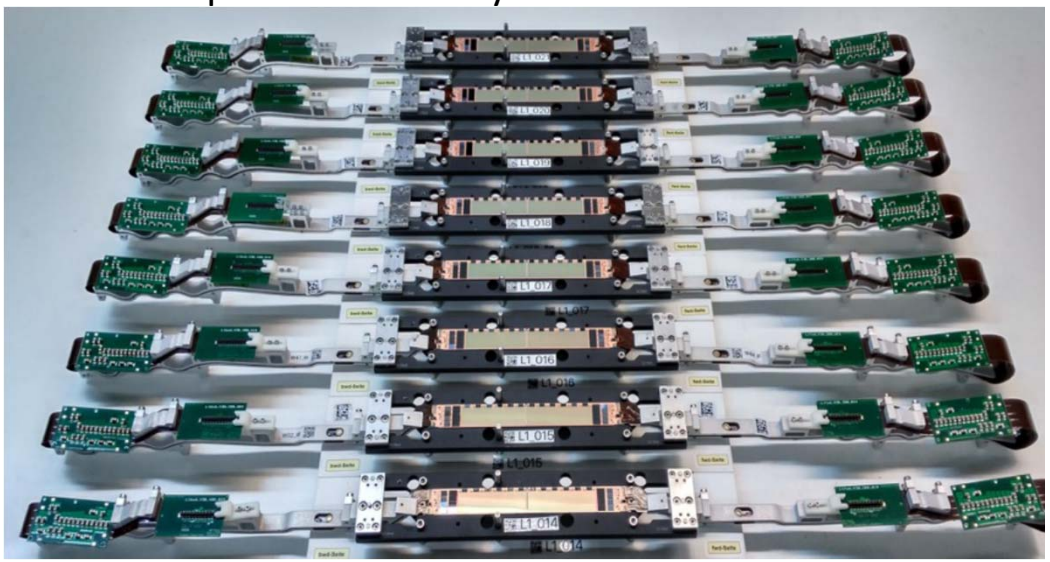


DEPFET sensor (Depleted P-channel FET)



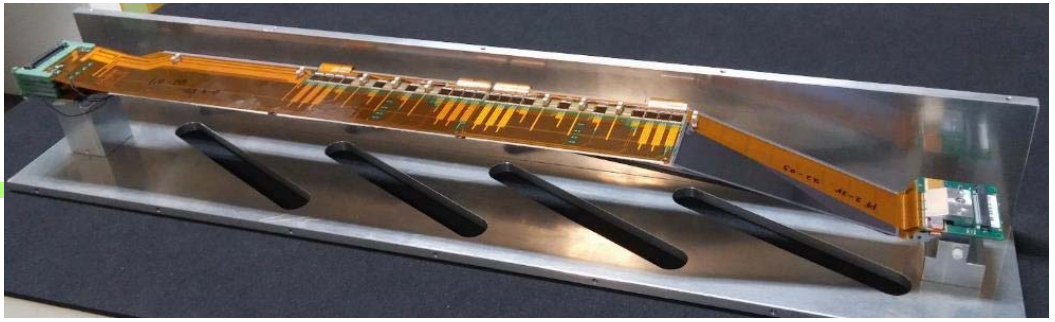
First laser light observed with the full size sensor

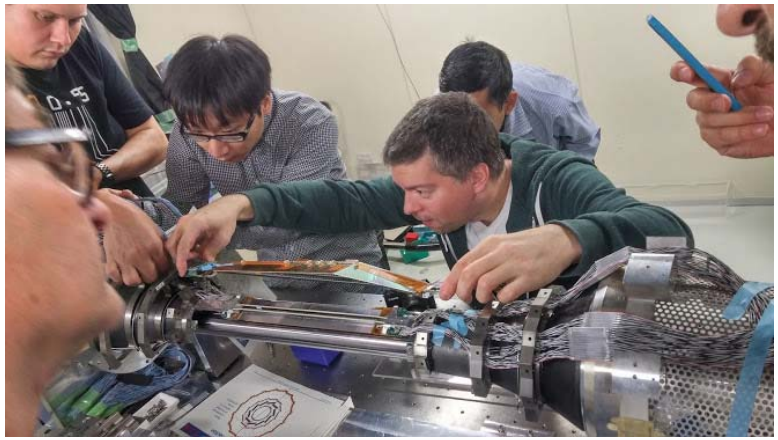
Completion of the Layer1 ladders for PXD

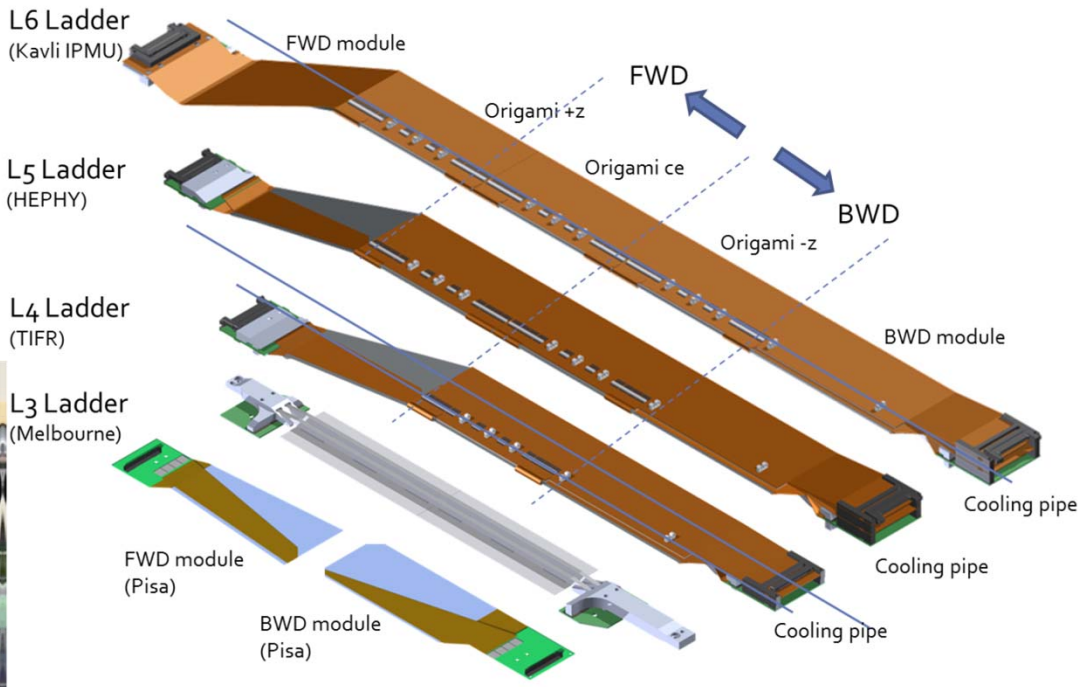


http://aldebaran.hll.mpg.de/twiki/bin/view/DEPFET/WebHome

SVD (Silicon Vertex Detector): four layers of double-sided silicon microstrip detectors.







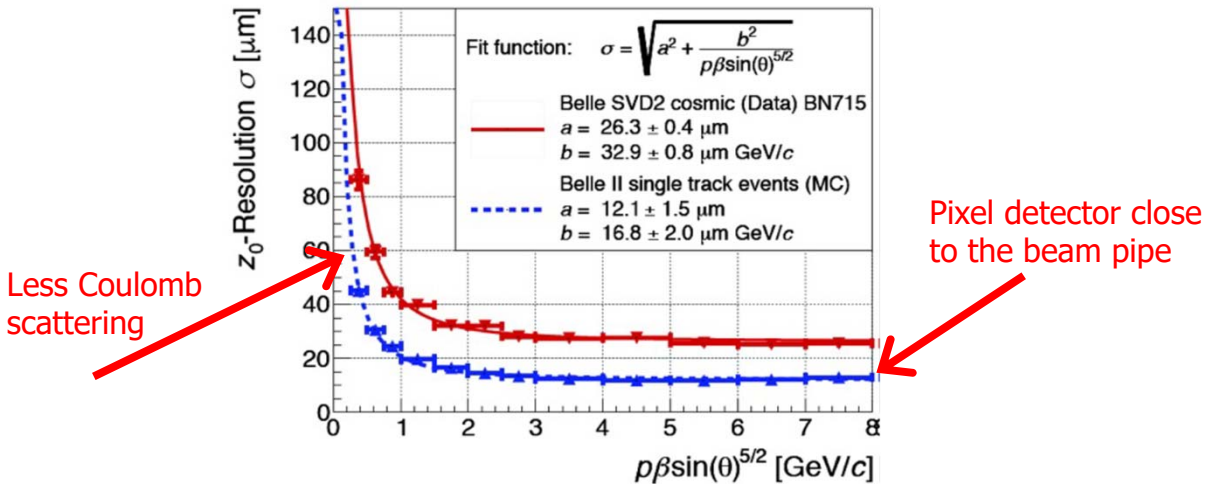
Completion of the first half of SVD on Jan 18, 2018

Preparation well under way!

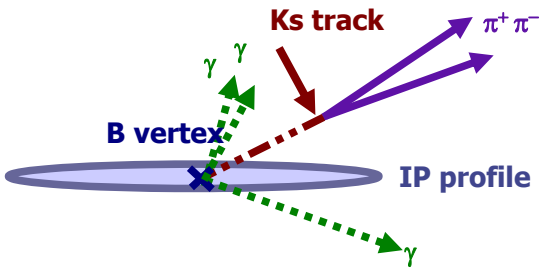
Peter Križan, Ljubljana

Expected performance

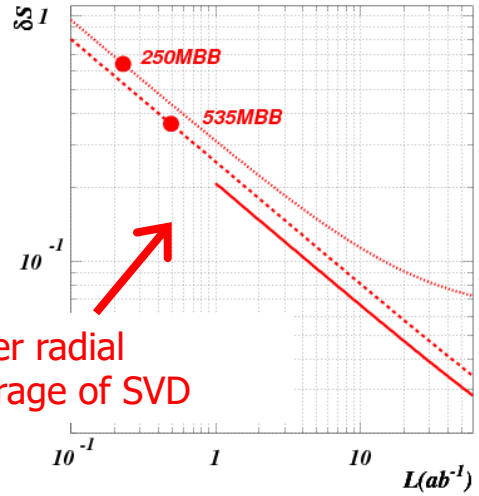
Significant improvement in vertex resolution vs Belle!



Significant improvement in $\delta S(K_S\pi^0\gamma)$



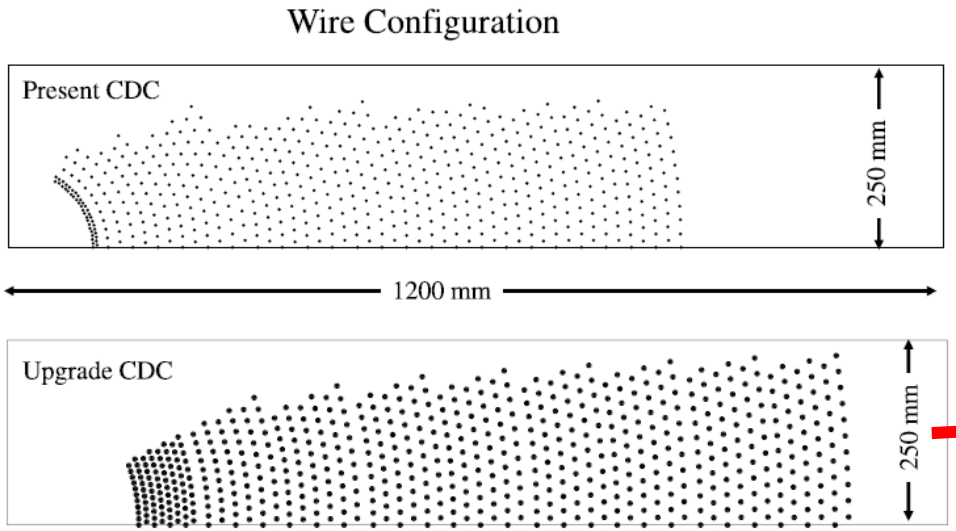
B decay point reconstruction with K_S trajectory

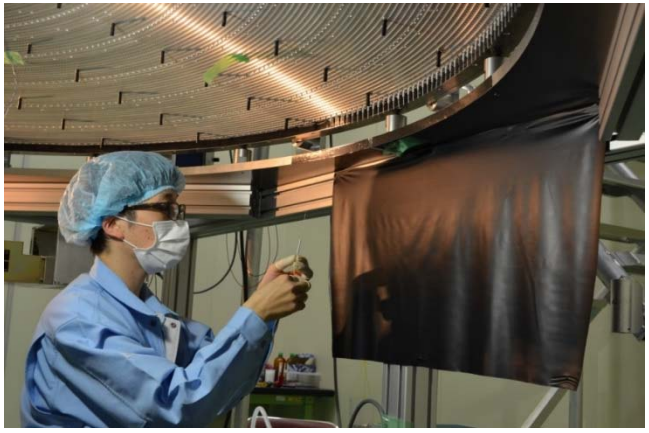


Belle II CDC

$$\frac{\sigma_{p_t}}{p_t} \sim 0.3\%/\beta \oplus 0.1\% \cdot p_t[GeV/c]$$

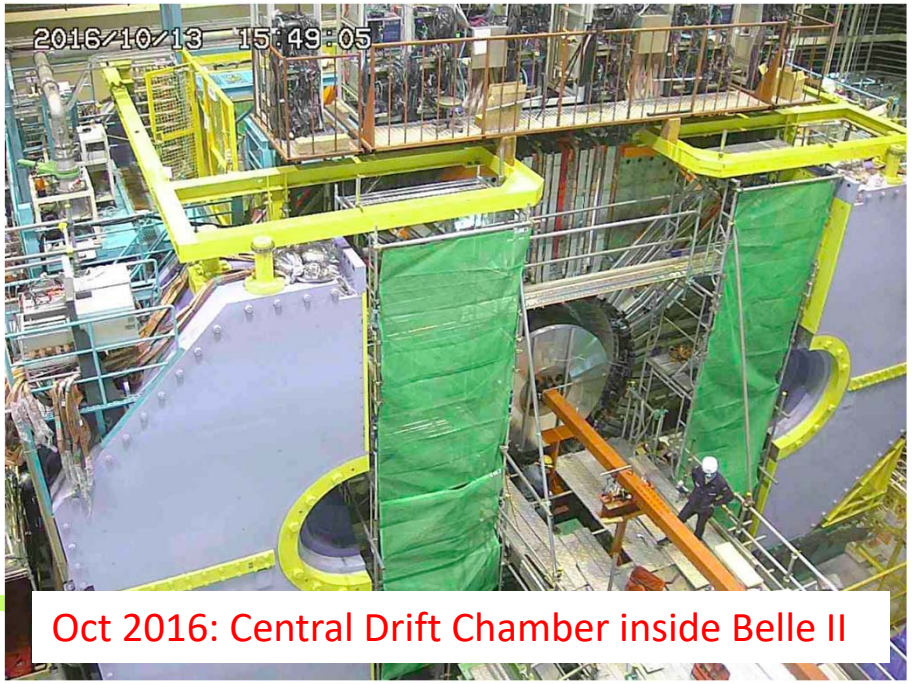
$$\sigma\left(\frac{dE}{dx}\right)\Big|_{MIP} \sim 5\%$$



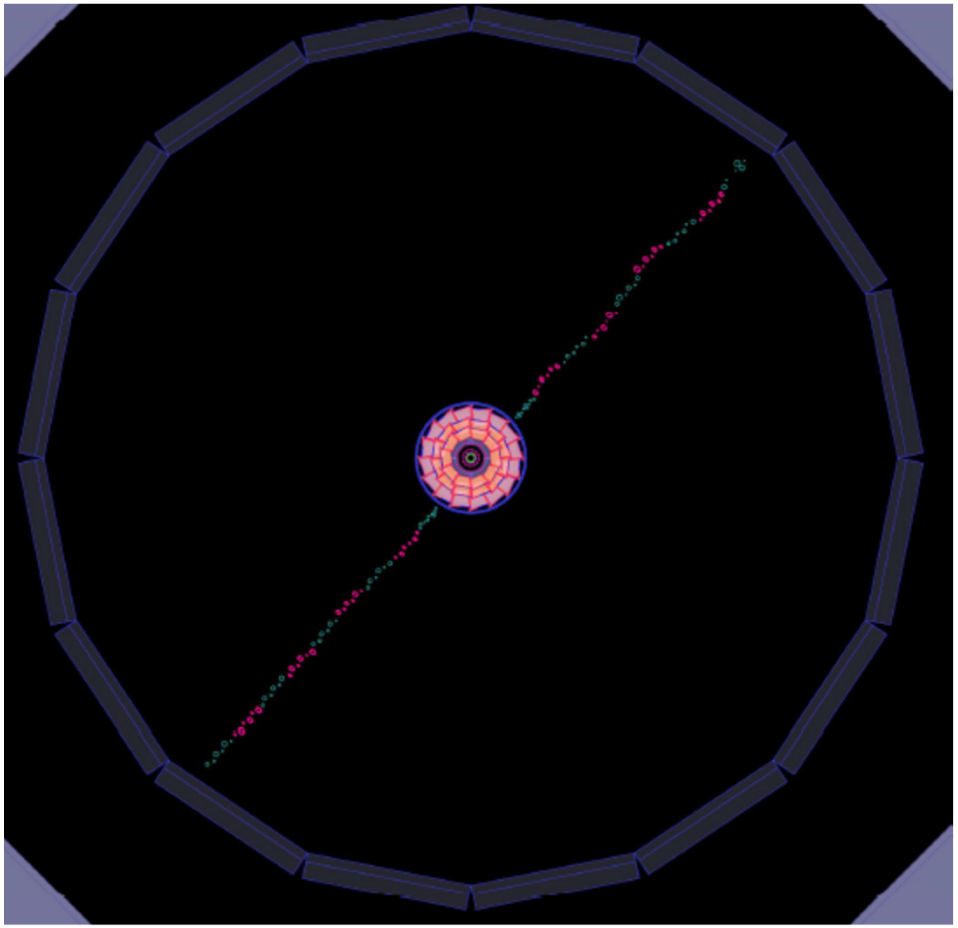


Wire stringing in a clean room

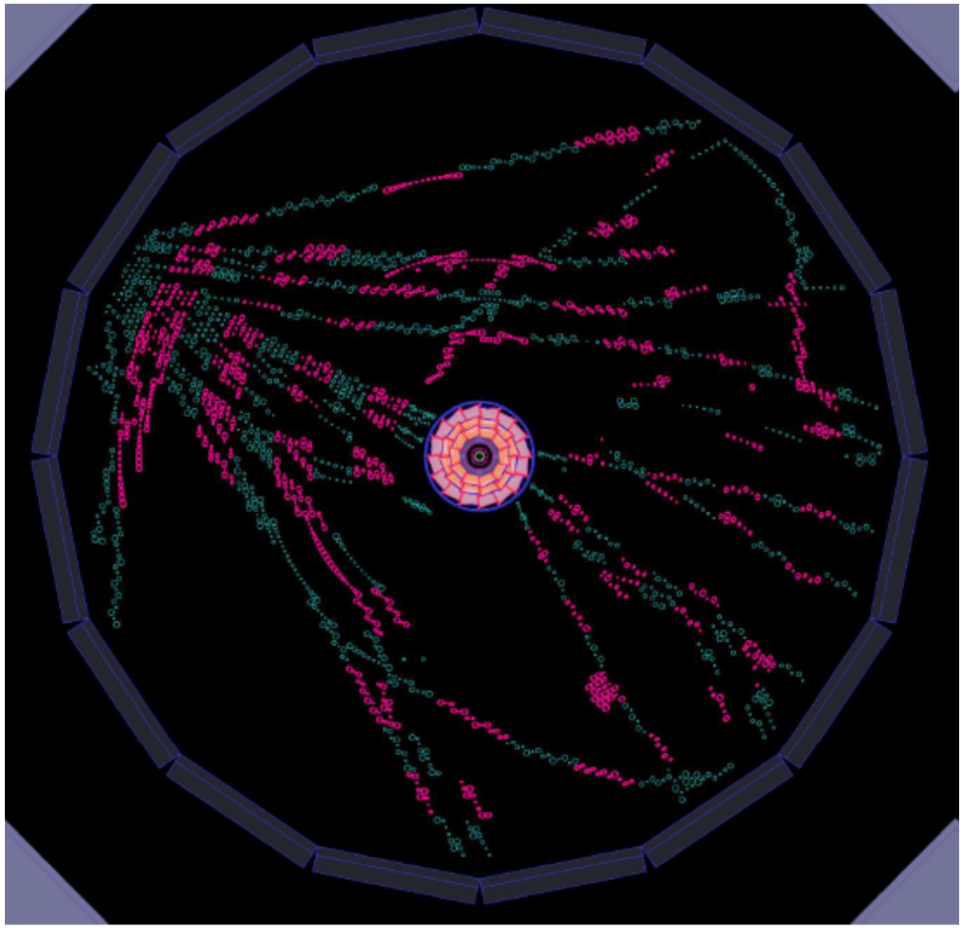
- thousands of wires,
- 1 year of work...



CDC event displays



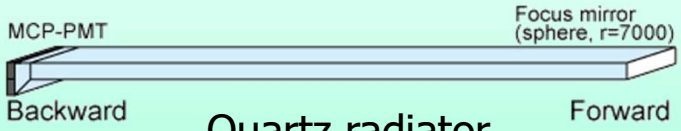
Single cosmic ray track



Multiple tracks
(showering cosmic ray event)

Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



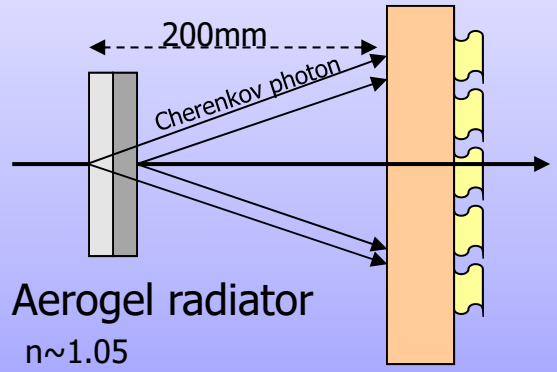
Quartz radiator

Focusing mirror

Small expansion block

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

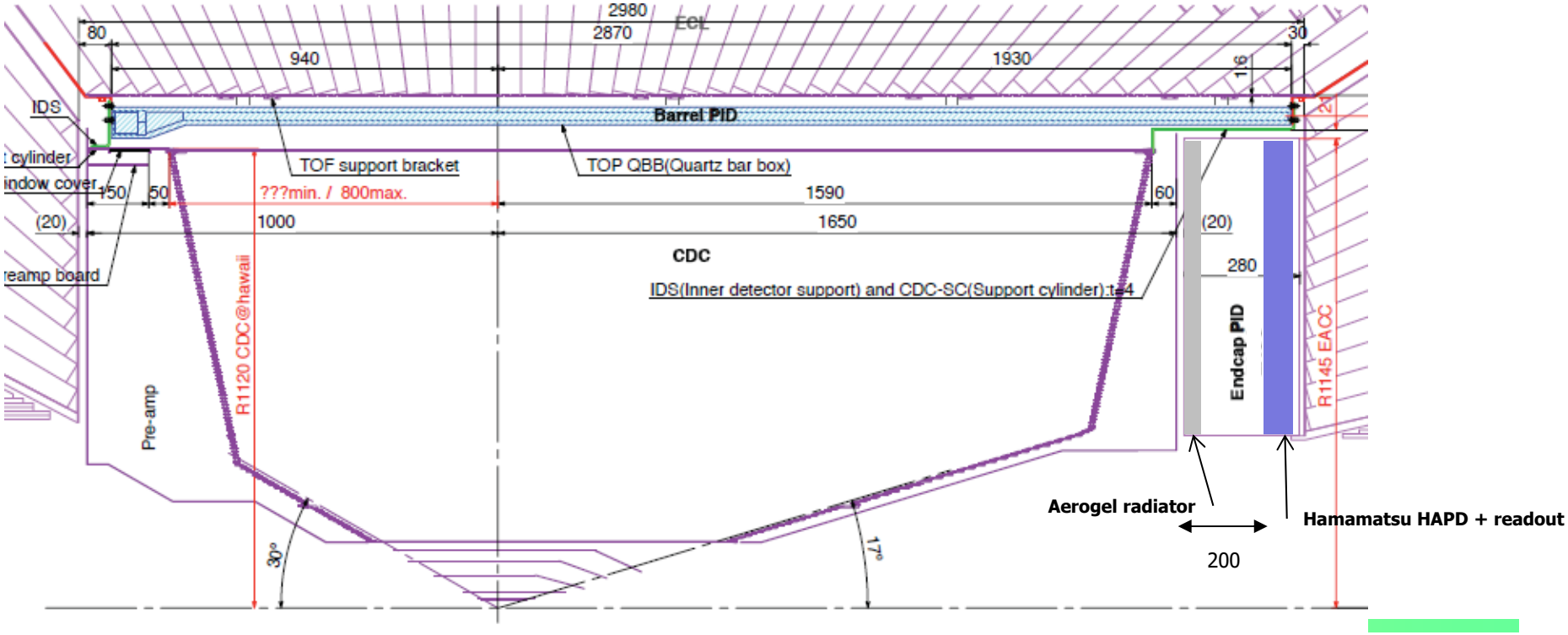
Endcap PID: Aerogel RICH (ARICH)



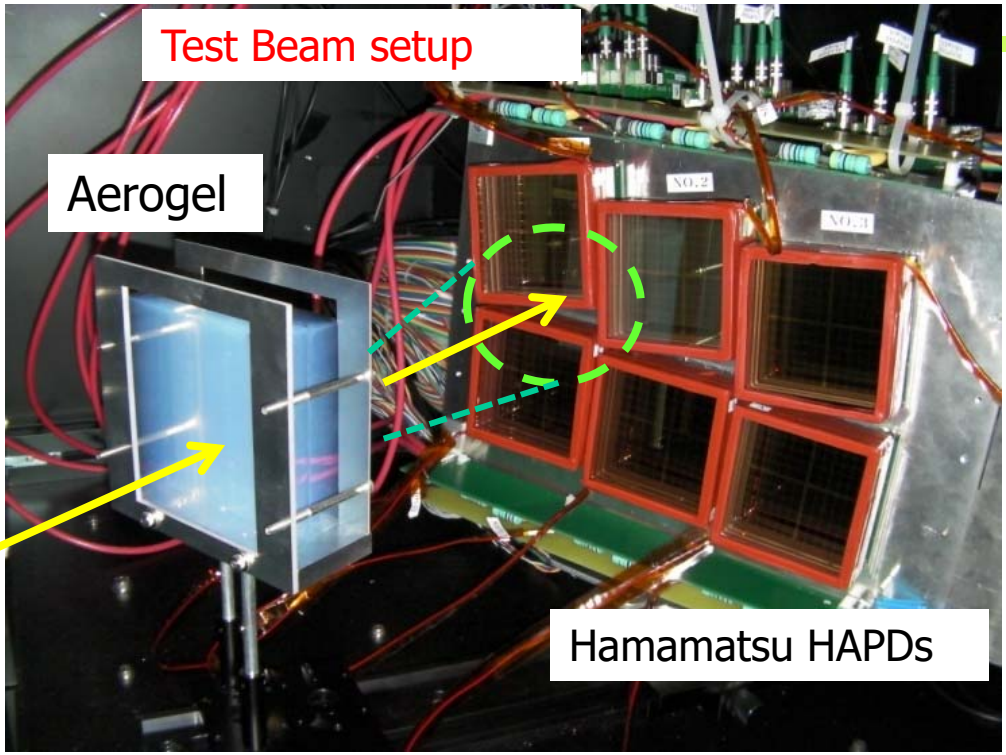
Aerogel radiator

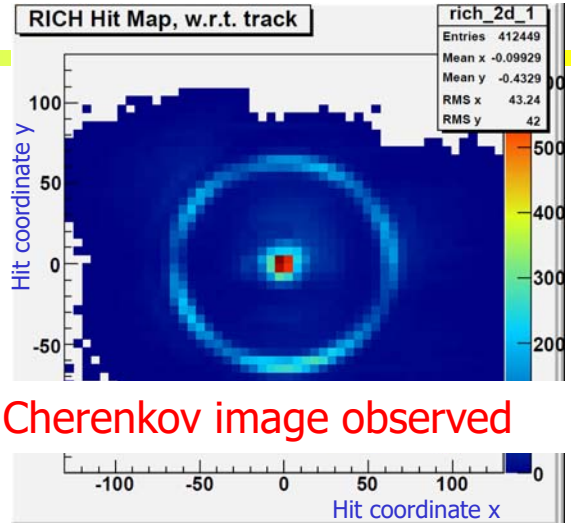
n~1.05

Hamamatsu HAPD



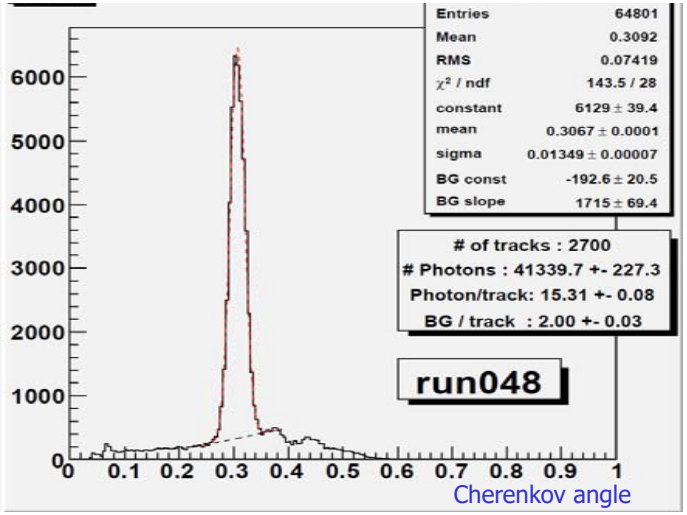
Aerogel RICH (endcap PID)





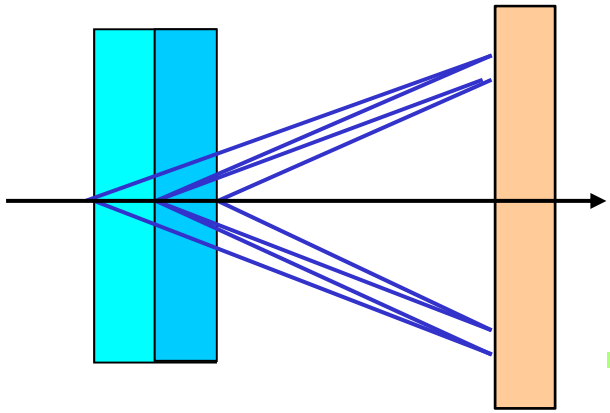
Clear Cherenkov image observed

Cherenkov angle distribution



RICH with a novel "focusing" radiator – a two layer radiator

Employ multiple layers with different refractive indices→ Cherenkov images from individual layers overlap on the photon detector.



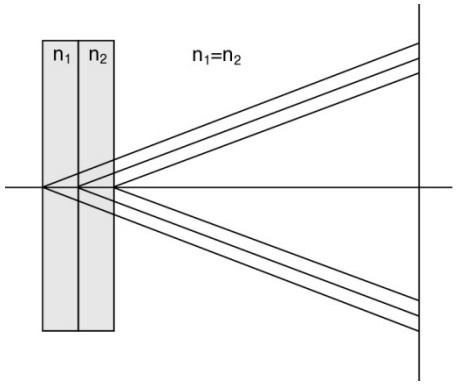
6.6 σ π/K at 4GeV/c !

Peter Križan, Ljubljana

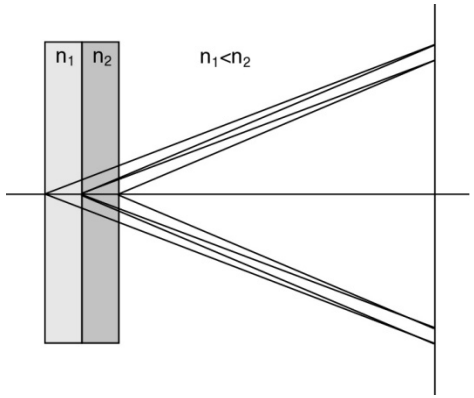
Focusing configuration – data

Increases the number of photons without degrading the resolution

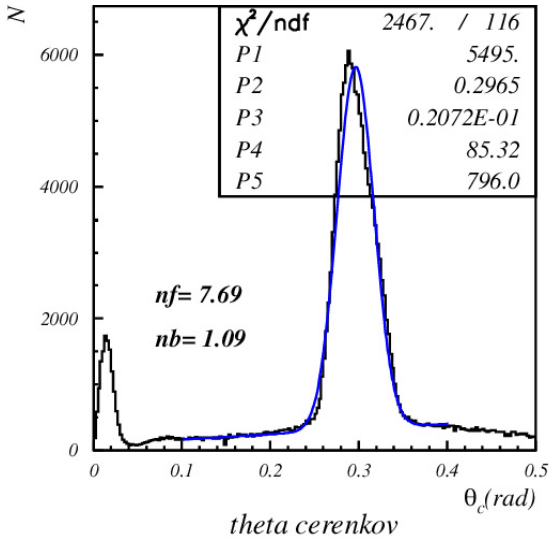
4cm aerogel single index



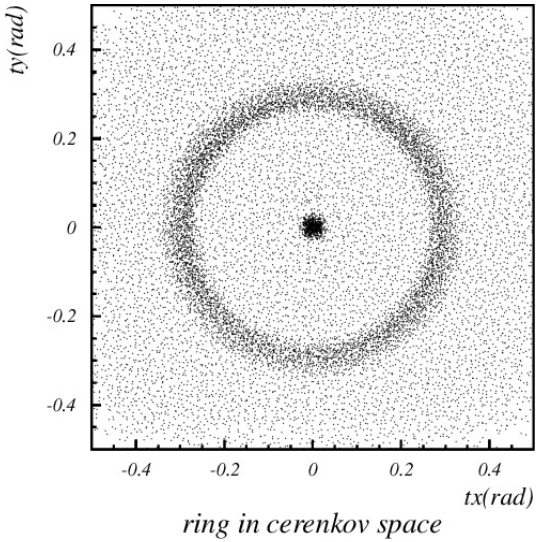
2+2cm aerogel



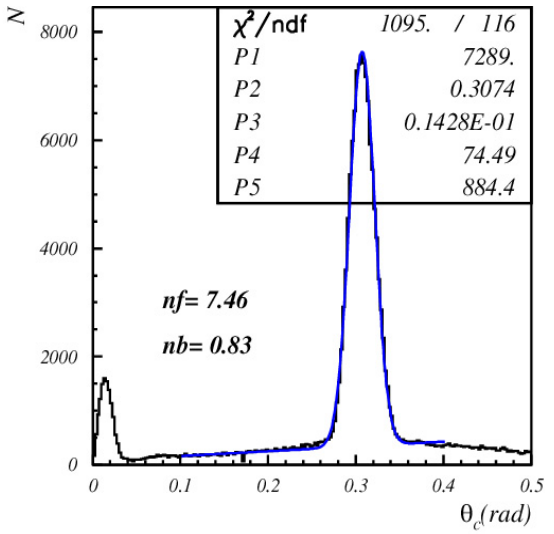
→NIM A548 (2005) 383

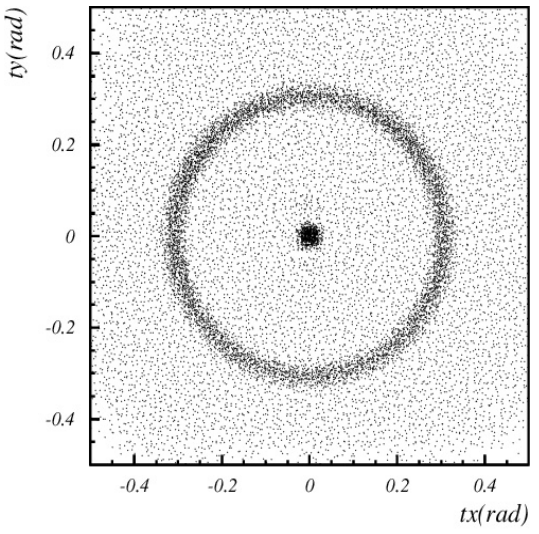


theta cerenkov

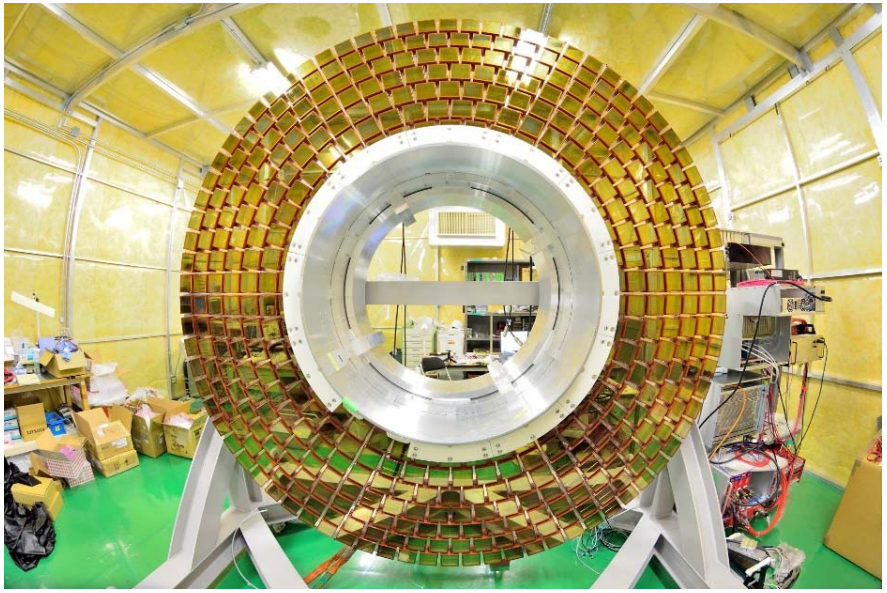


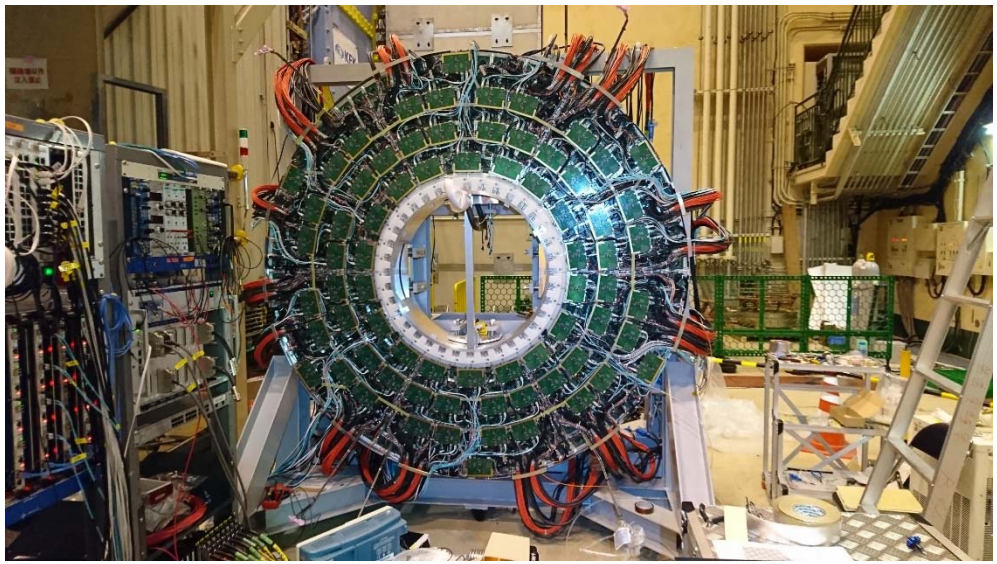
ring in cerenkov space

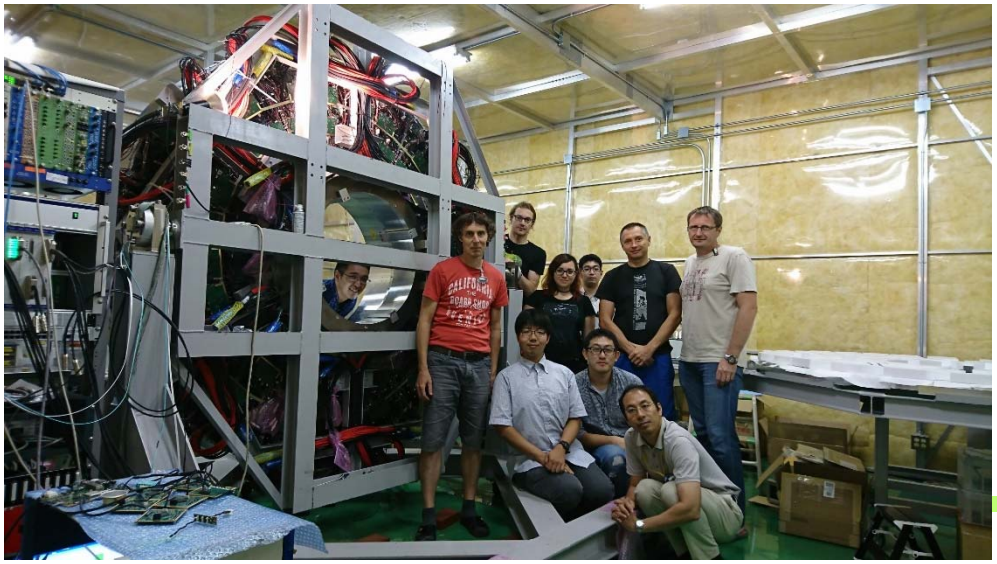


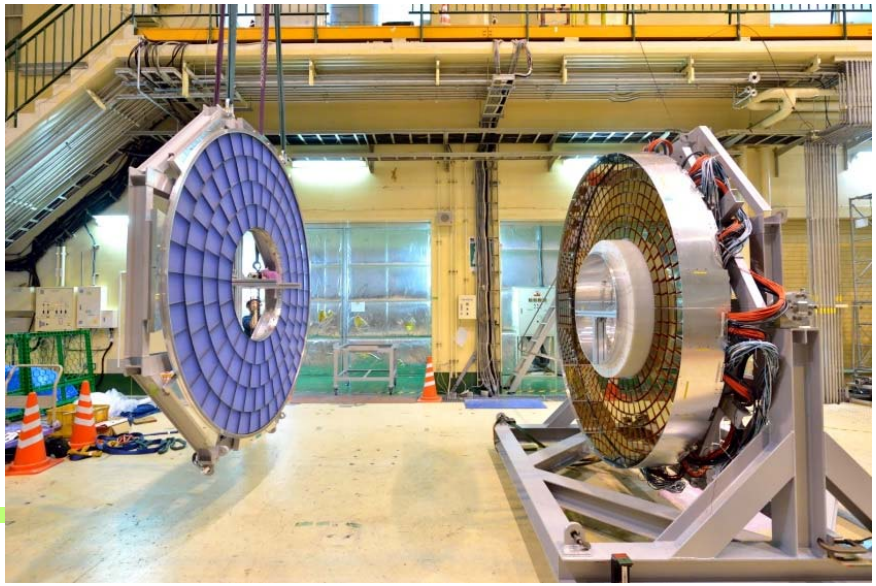


The big eye of ARICH



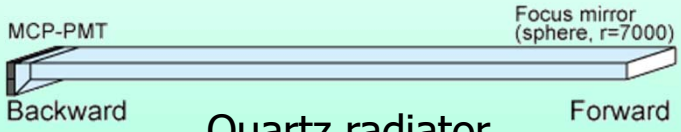






Cherenkov detectors

Barrel PID: Time of Propagation Counter (TOP)



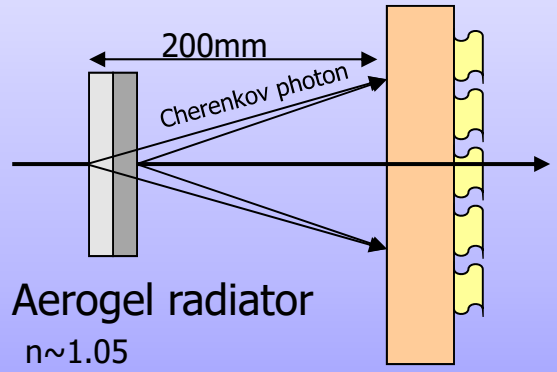
Quartz radiator

Focusing mirror

Small expansion block

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

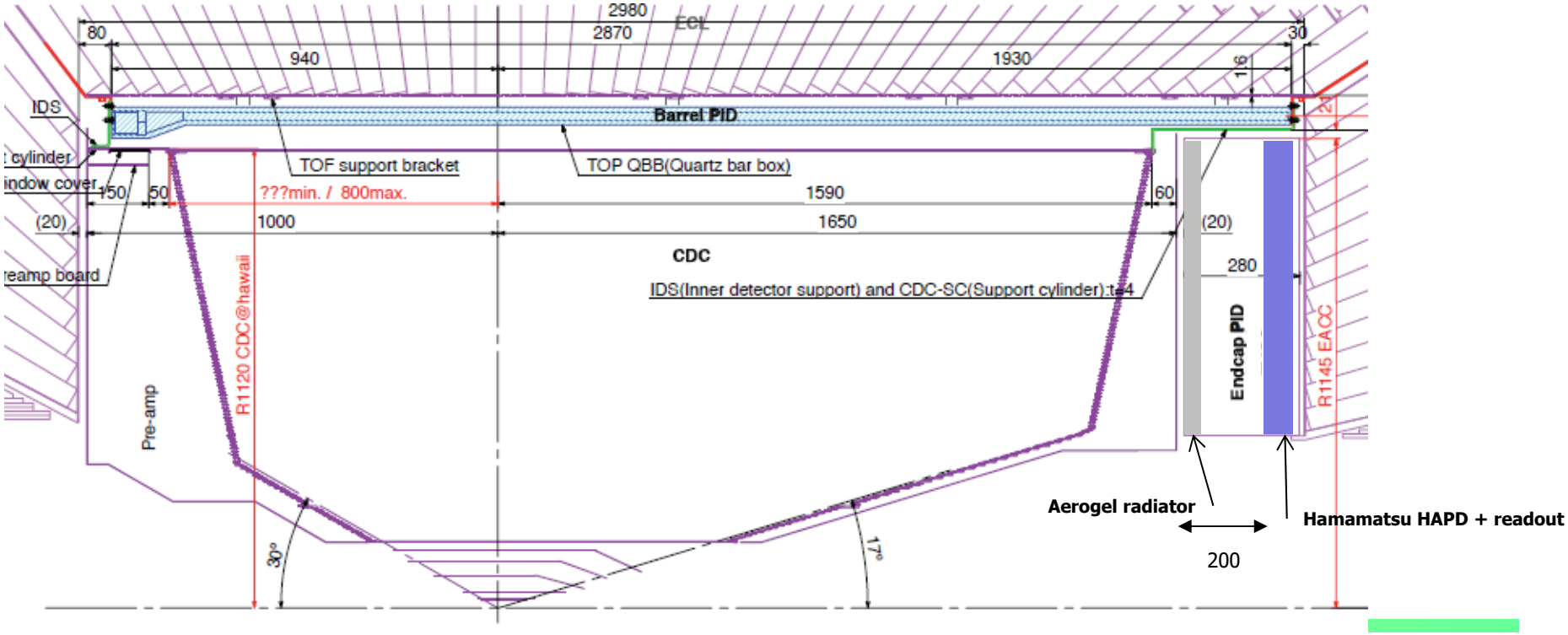
Endcap PID: Aerogel RICH (ARICH)



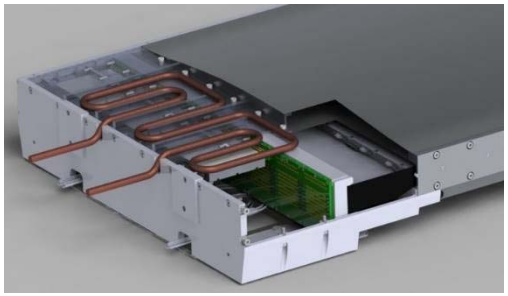
Aerogel radiator

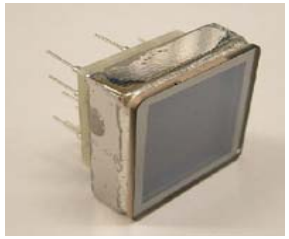
n~1.05

Hamamatsu HAPD
+ new ASIC

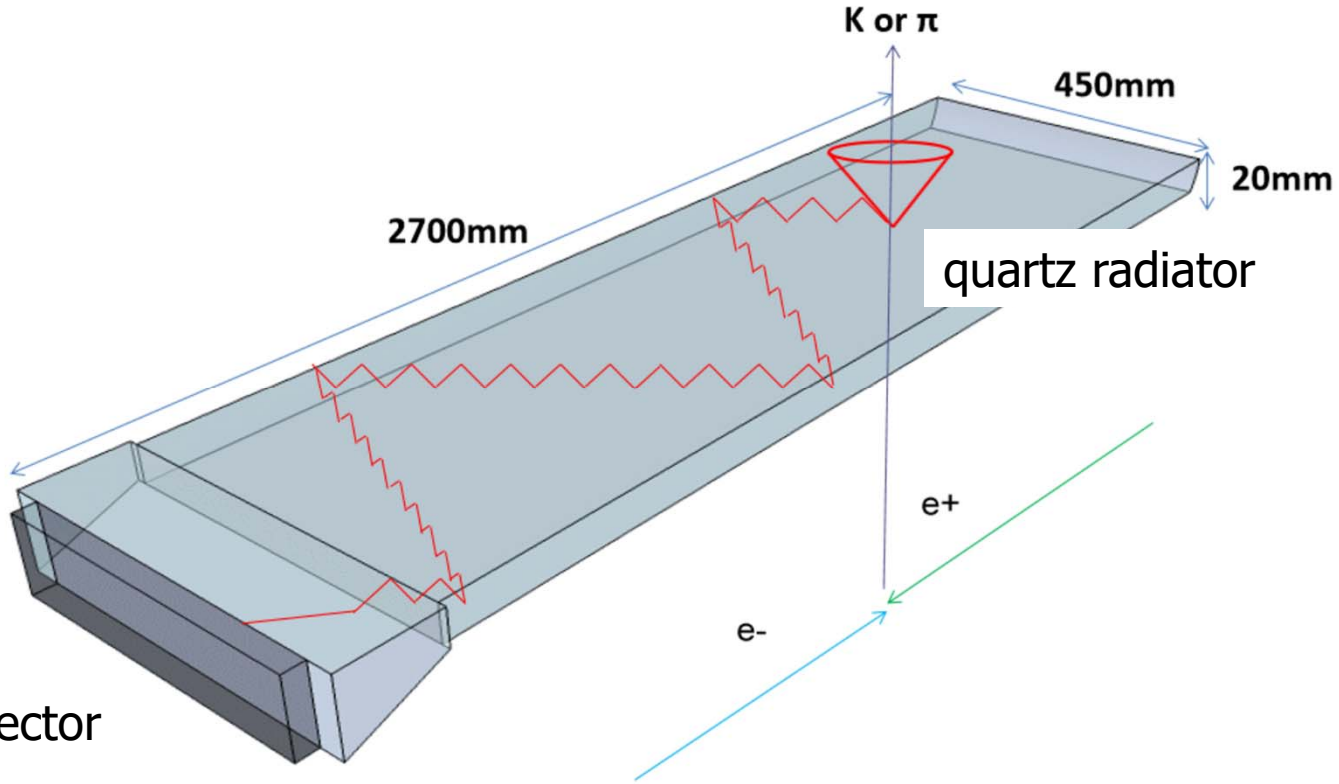


Barrel PID: Time of propagation (TOP) counter



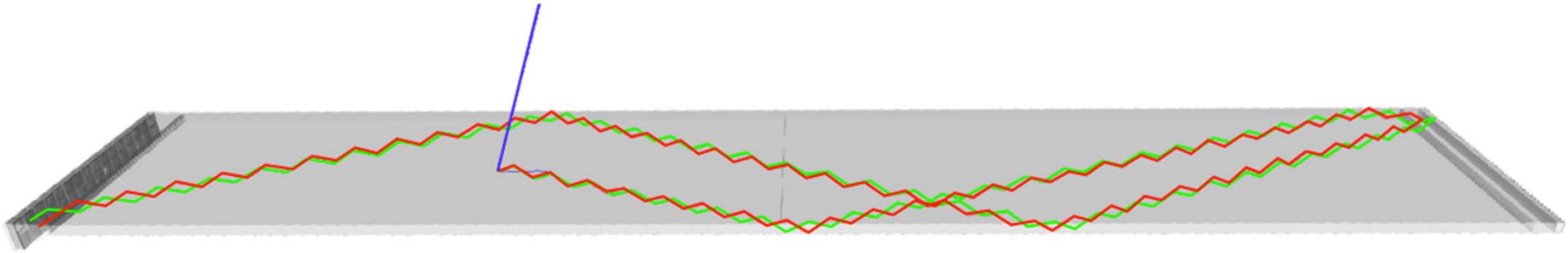


Photon detector

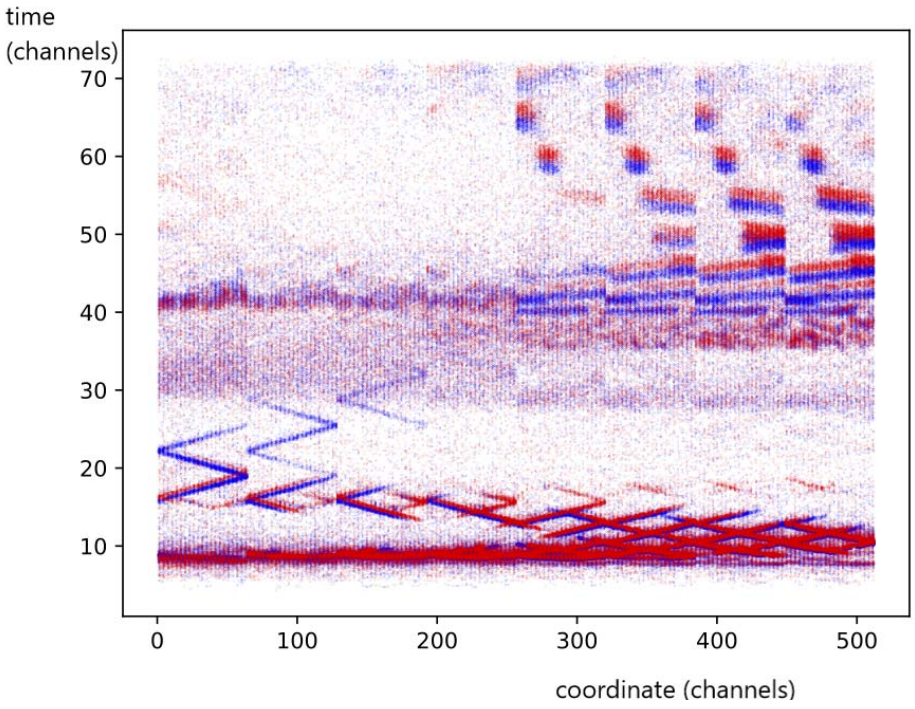


- Cherenkov ring imaging with precise time measurement.
- Reconstruct Cherenkov angle from two hit coordinates and the time of propagation of the photon
  - Quartz radiator (2cm thick)
  - Photon detector (MCP-PMT)
    - Excellent time resolution ~ 40 ps
    - Single photon sensitivity in 1.5 T

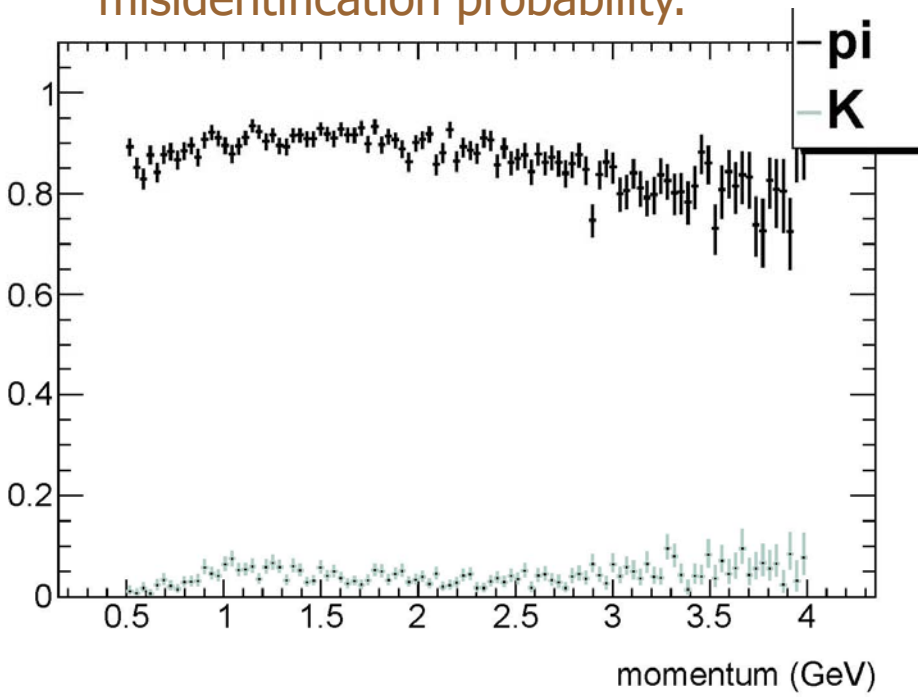
Separation of kaons and pions



Pions vs kaons in TOP:
different patterns in the time vs PMT impact point coordinate

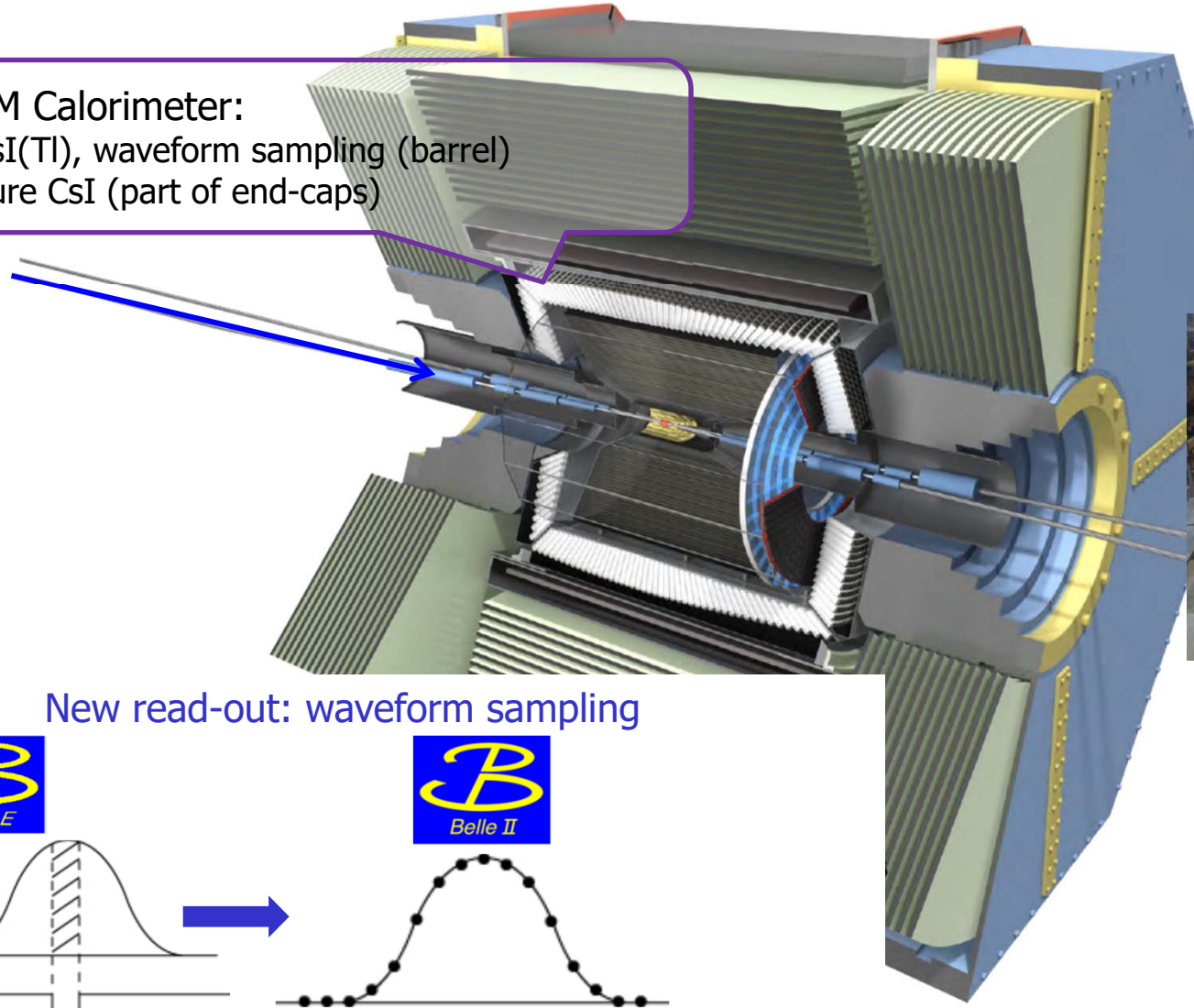


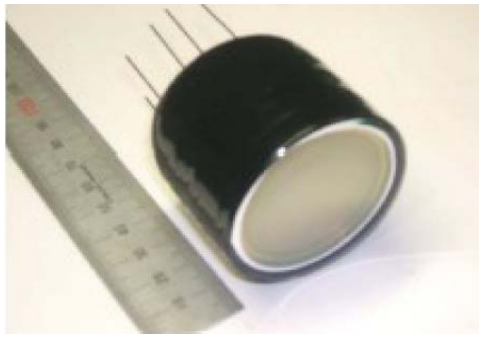
Pions vs kaons:
Expected PID efficiency and misidentification probability.



EM calorimeter: upgrade needed because of higher rates (electronics → waveform sampling) and radiation load (endcap, replace some fraction of crystals, CsI(Tl) → pure CsI)

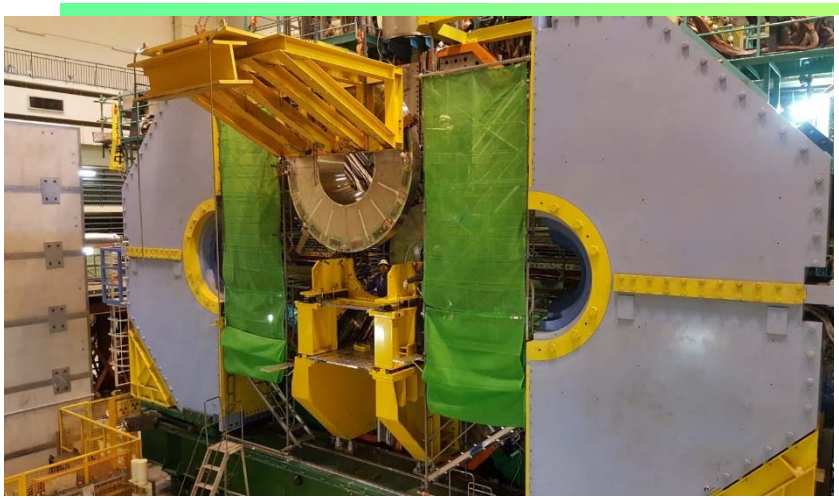
EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI (part of end-caps)

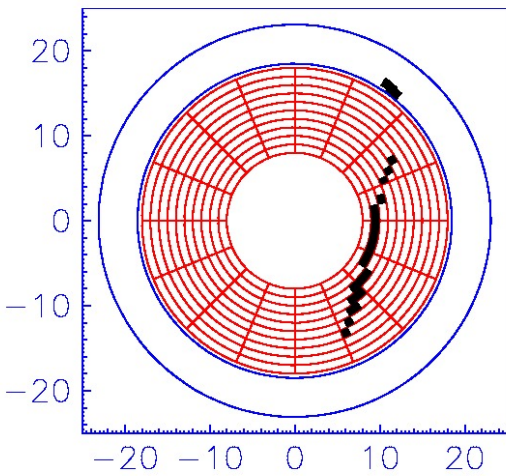


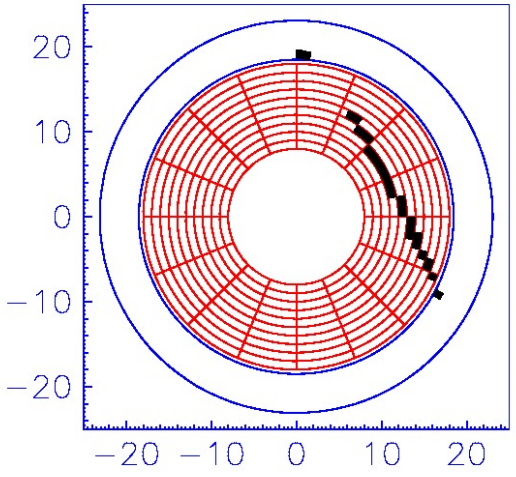


New read-out: waveform sampling

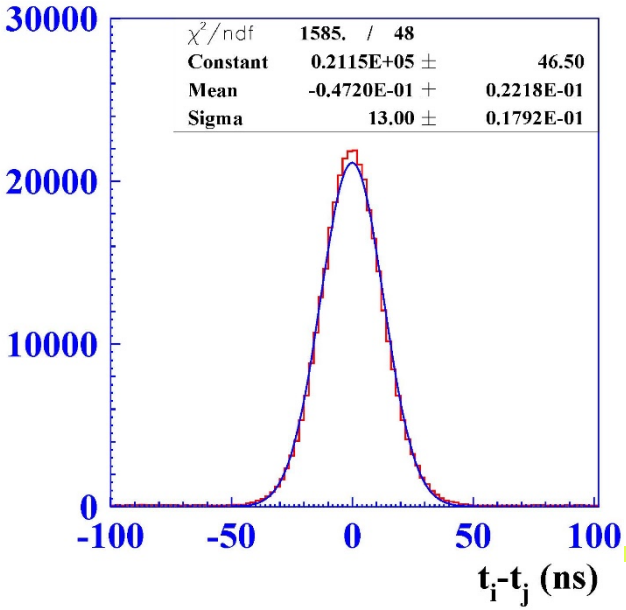
ECL: endcap installation, testing with cosmic ray tracks, expected performance



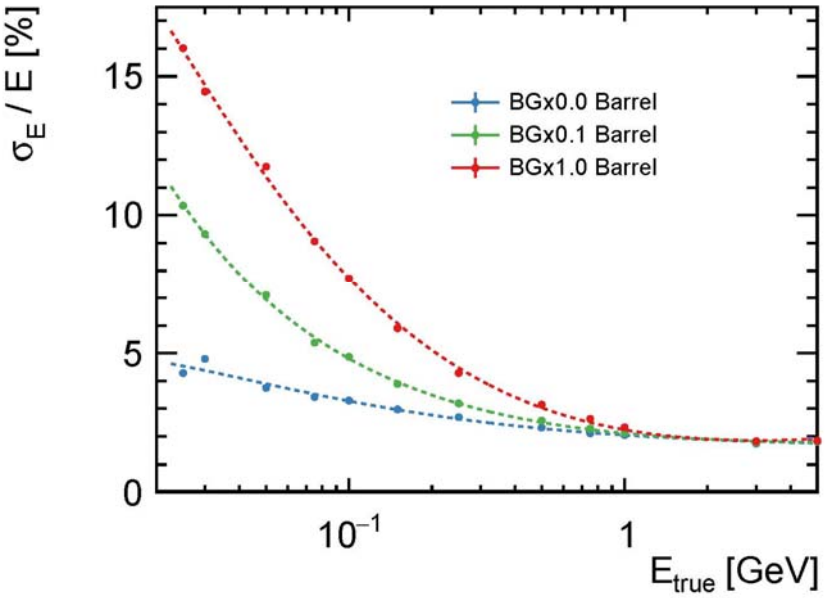




Measured time resolution

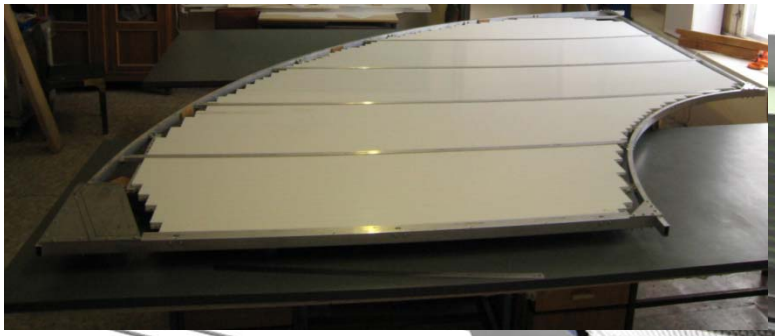


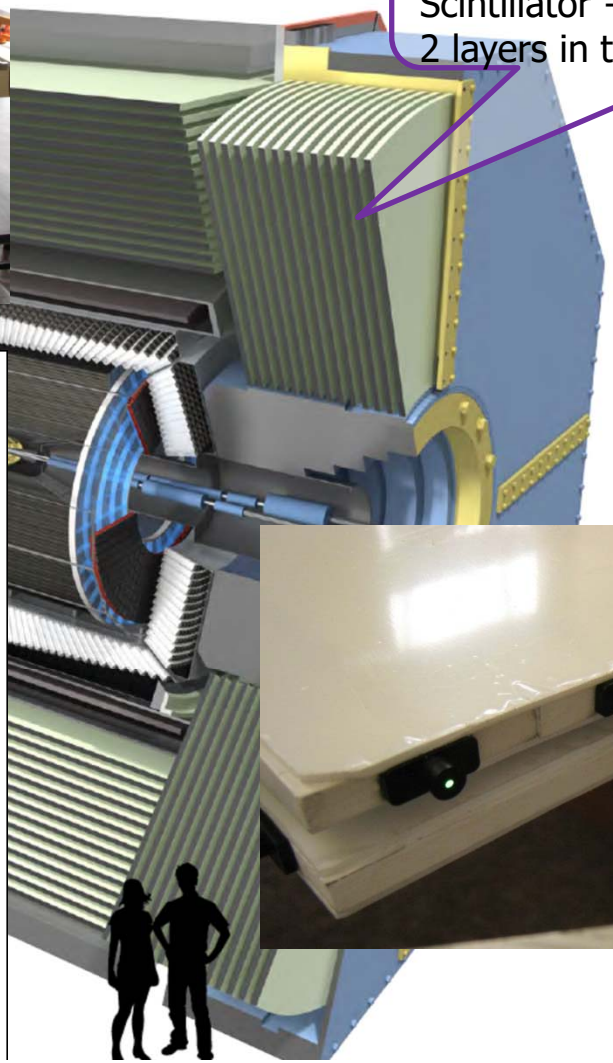
Expected energy resolution

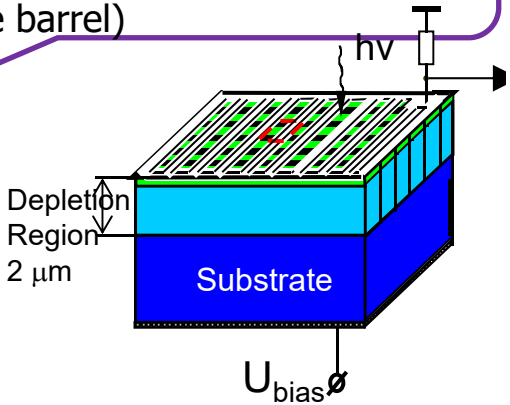


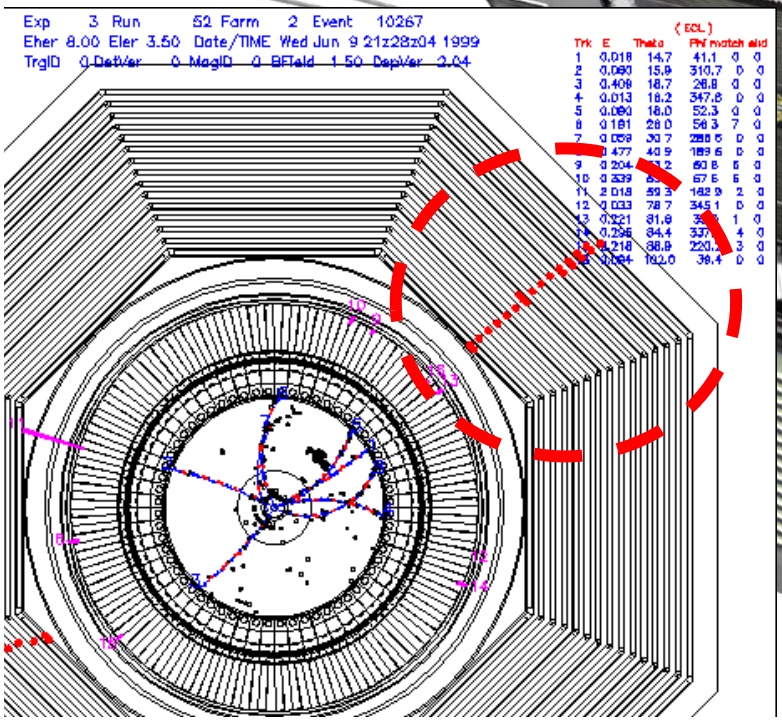
Detection of muons and K_Ls: mainly RPCs; parts of the original RPC system had to be replaced because they could not handle the high background rates (mainly neutrons)

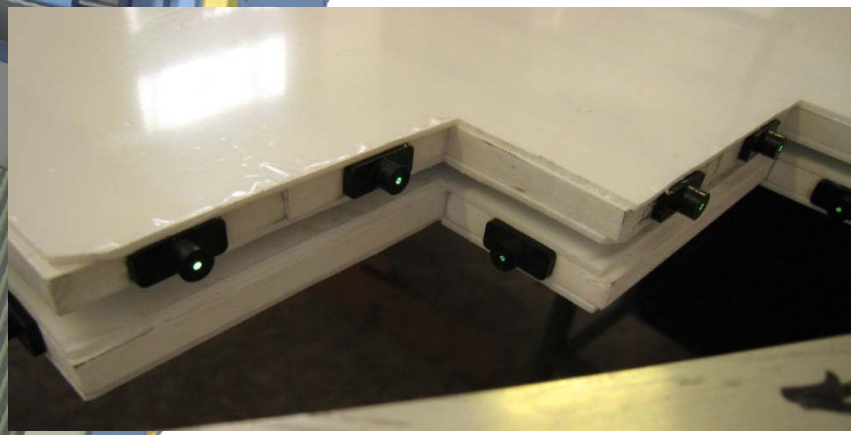
K_L and muon detector:
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps + 2 layers in the barrel)









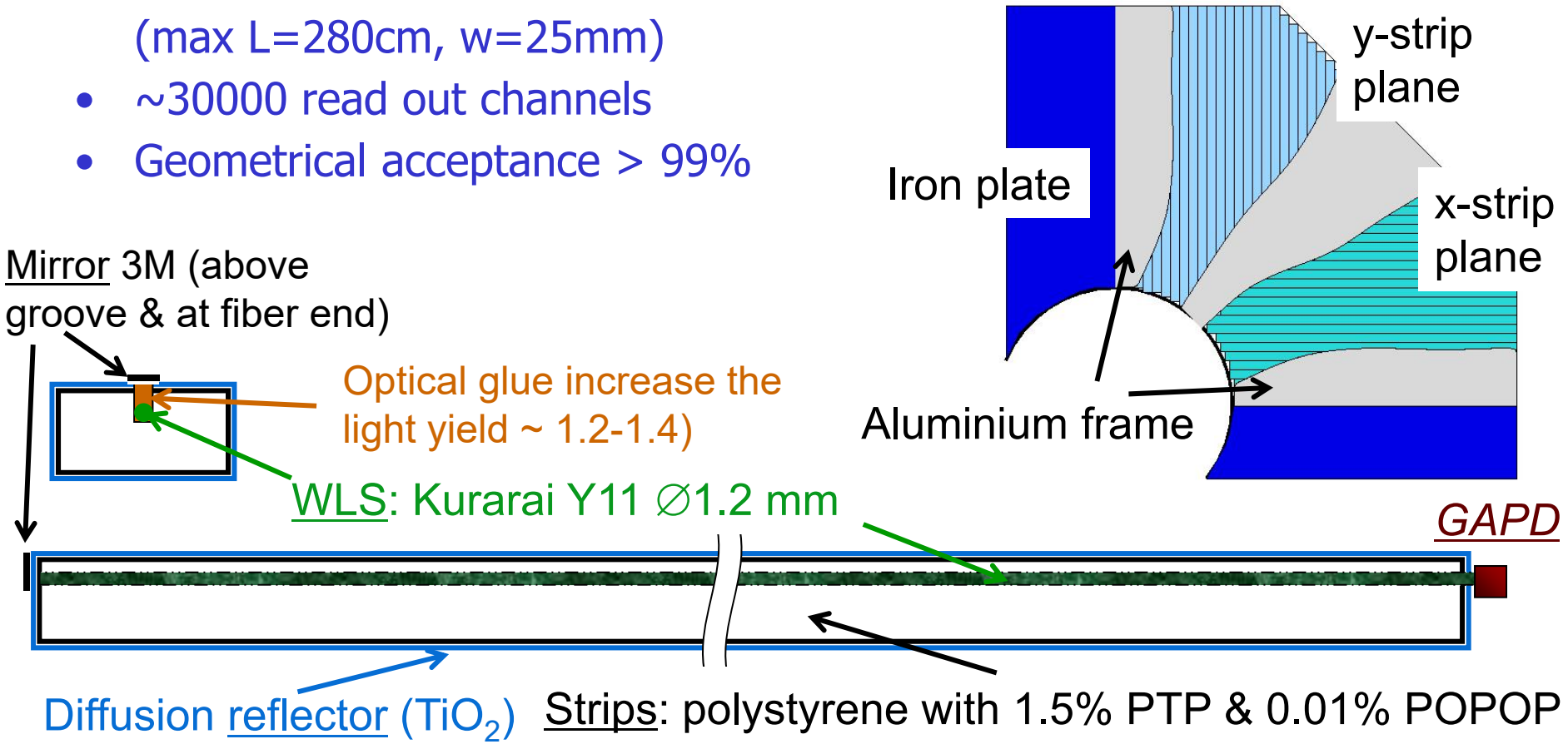


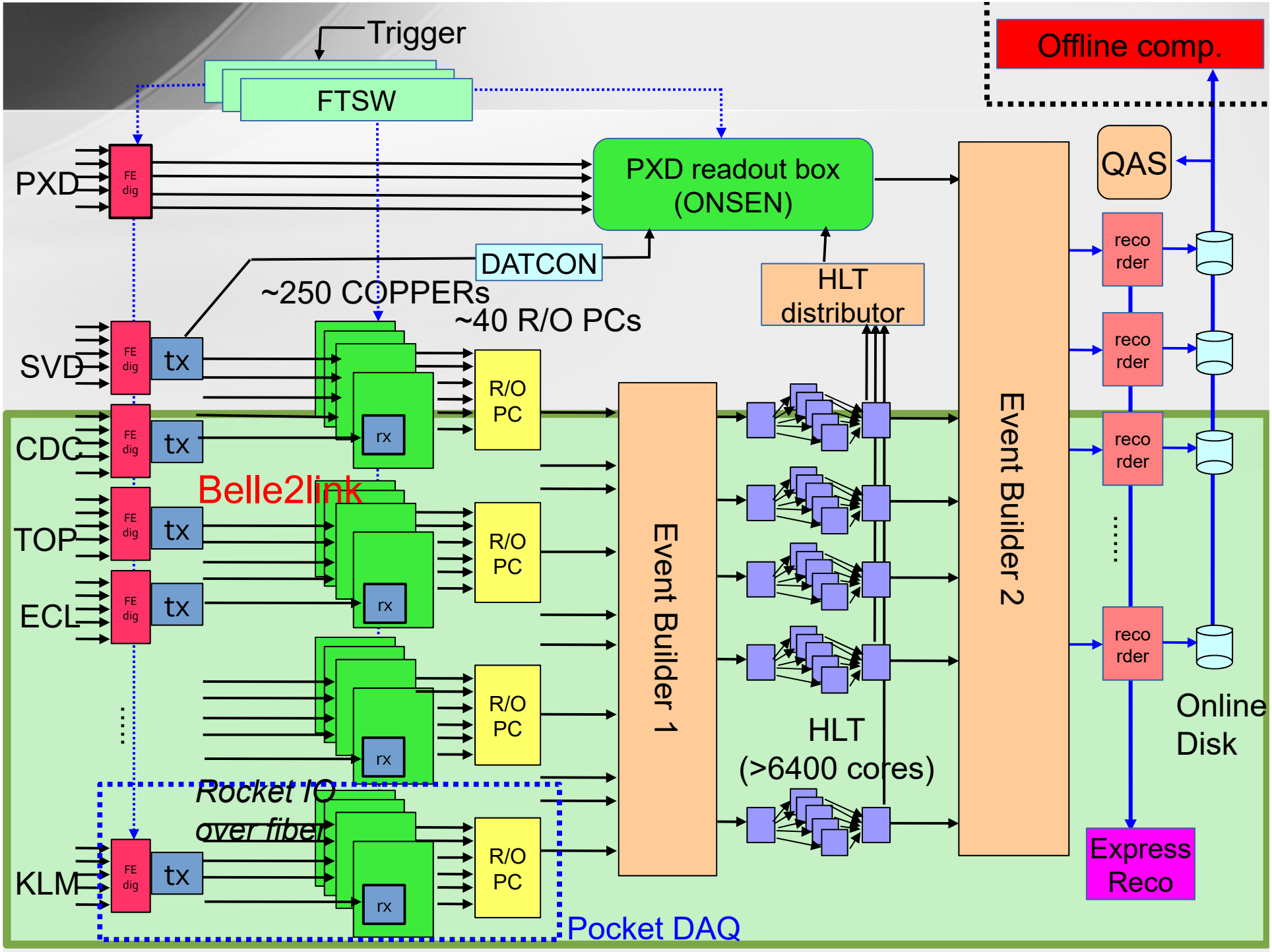
ljana

Muon detection system upgrade

Scintillator-based KLM (endcap in inner layers of the barrell part)

- Two independent (x and y) layers in one superlayer made of orthogonal strips with WLS read out
- Photo-detector = avalanche photodiode in Geiger mode (SiPM)
- ~120 strips in one 90º sector (max L=280cm, w=25mm)
- ~30000 read out channels
- Geometrical acceptance > 99%



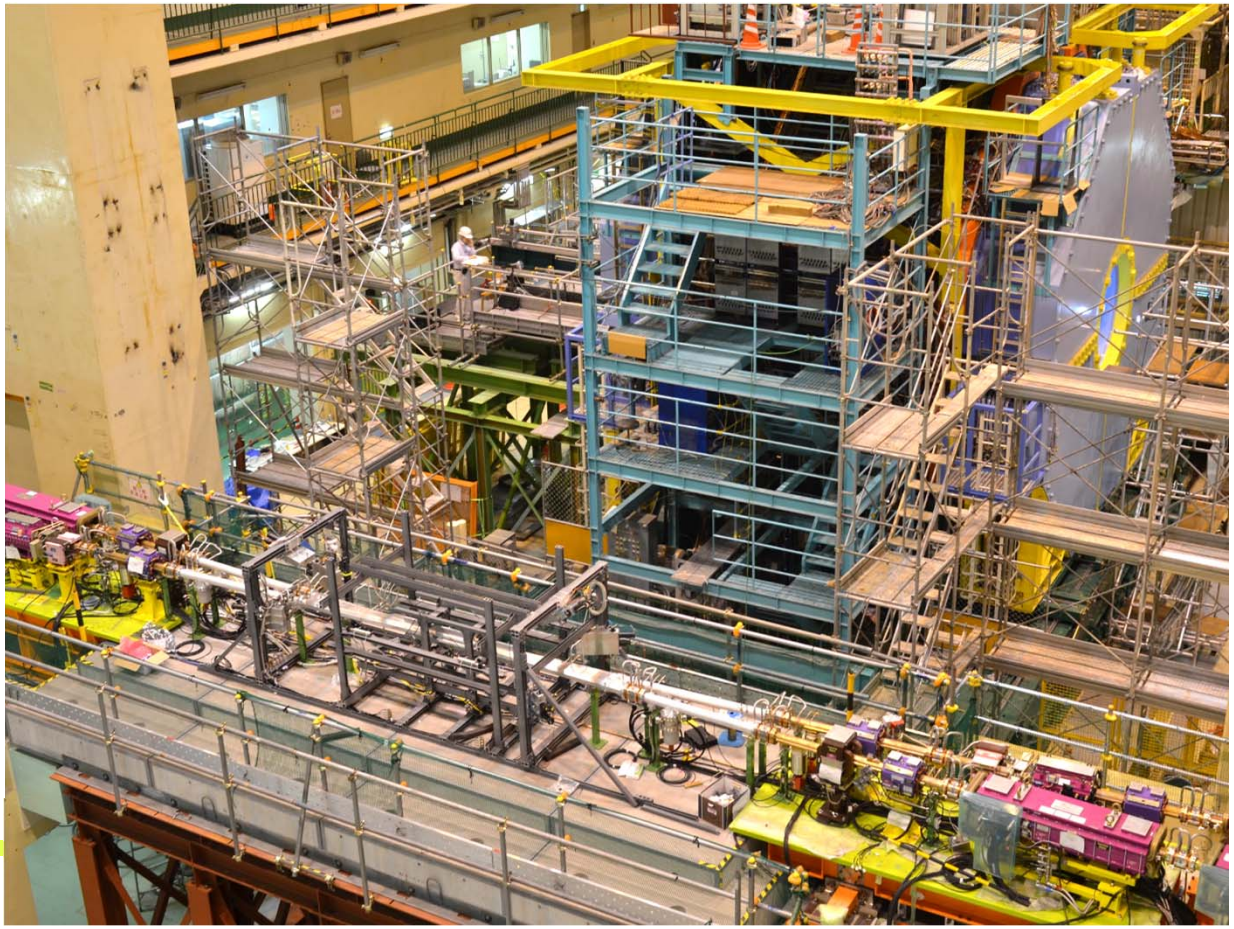

Trigger
FTSW
Offline comp.
PXD
FE dig
PXD readout box (ONSEN)
QAS
DATCON
HLT distributor
~250 COPPERs
~40 R/O PCs
SVD
tx
rx
R/O PC
reco rder
CDC
Belle2link
TOP
ECL
Event Builder 1
Event Builder 2
HLT (>6400 cores)
Online Disk
Express Reco
Rocket IO over fiber
KLM
Pocket DAQ

Getting ready…

SuperKEKB commissioning phase 1: BEAST II commissioning detector

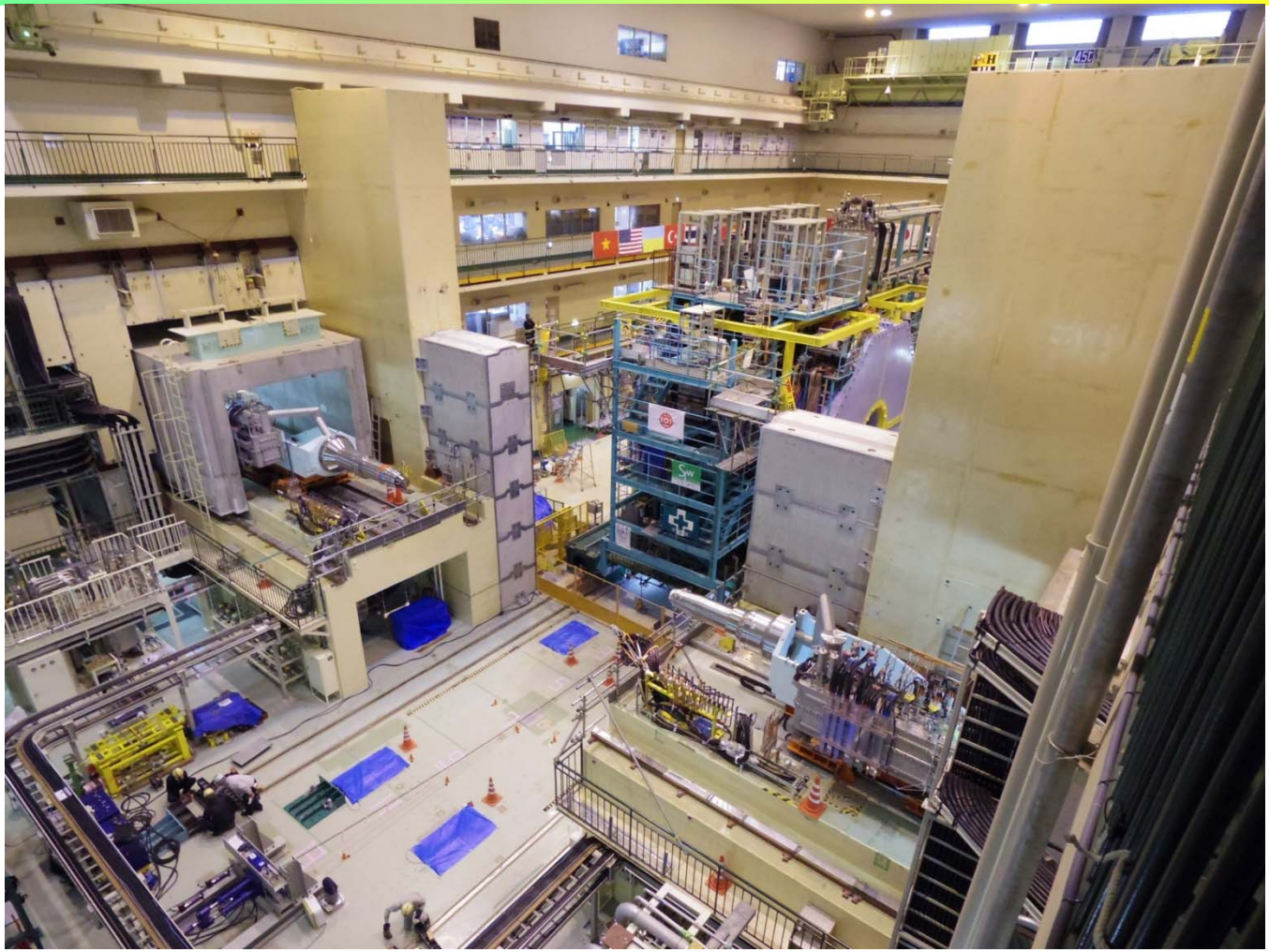
Commisioning (Phase 1) of the main ring (without final quads) successfully carried out from Feb 1, 2016 – end of June 2016!

Interaction point detector: instead of Belle II, a commissioning detector – BEAST II.



→a 100 page report to be published in NIMA

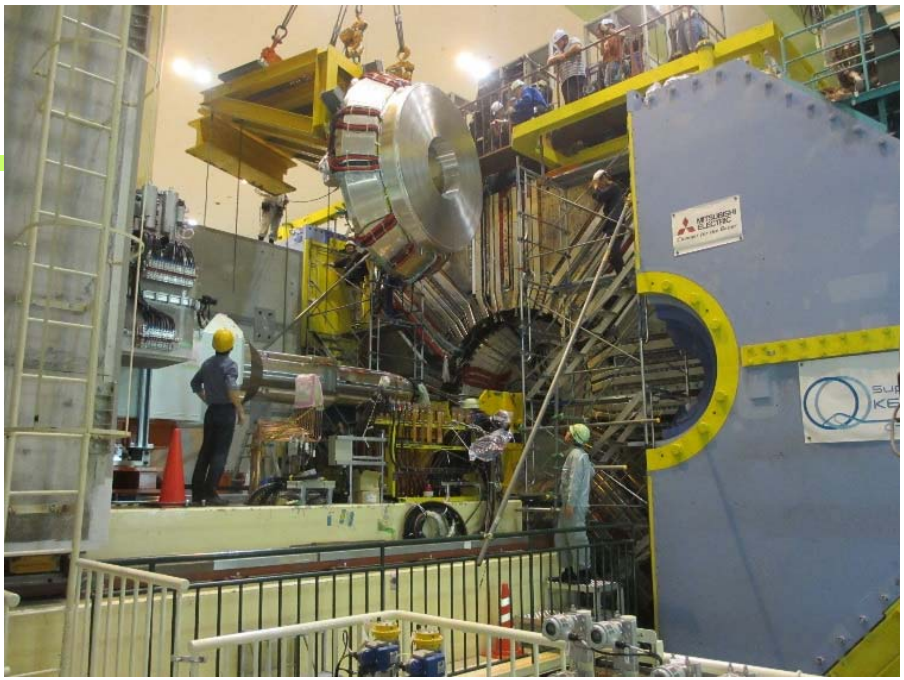
Belle II Roll-in

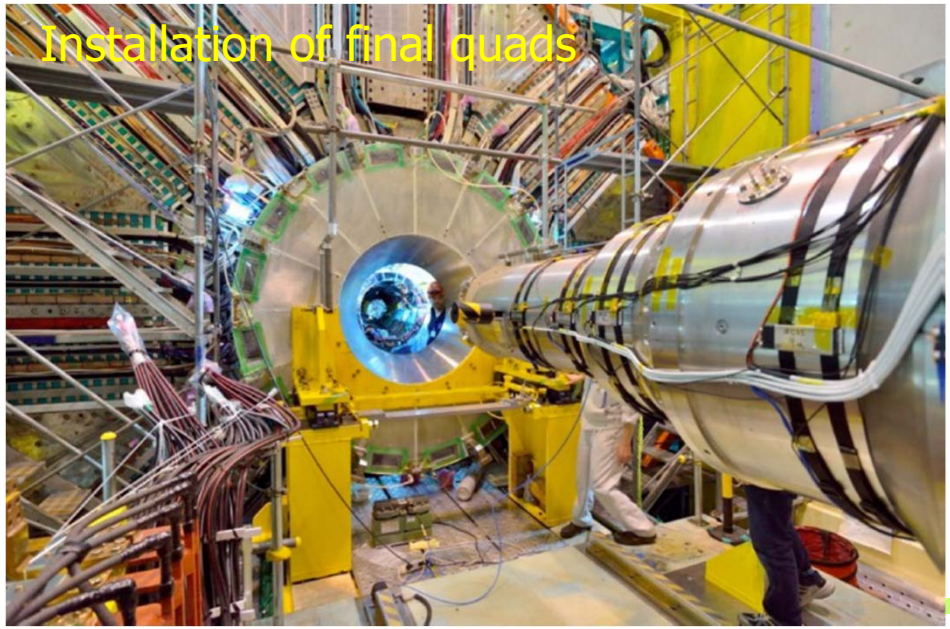


Belle II rolled-in to the beam line on April 11th, 2017
One of the most significant milestones in the construction phase
Live broadcasted by a video sharing website

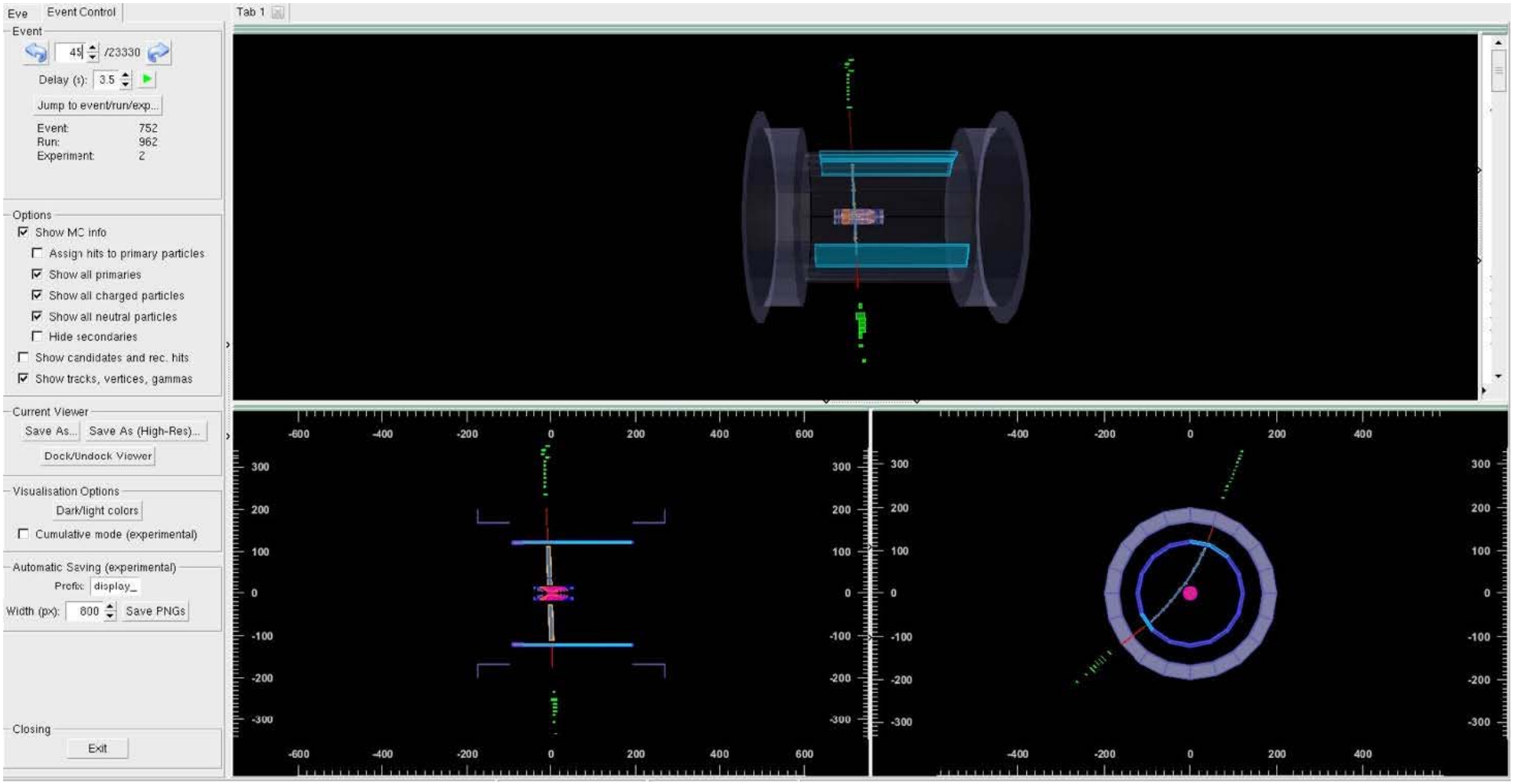
KEK × niconico


ARICH and forward endcap
calorimeter transport and installation

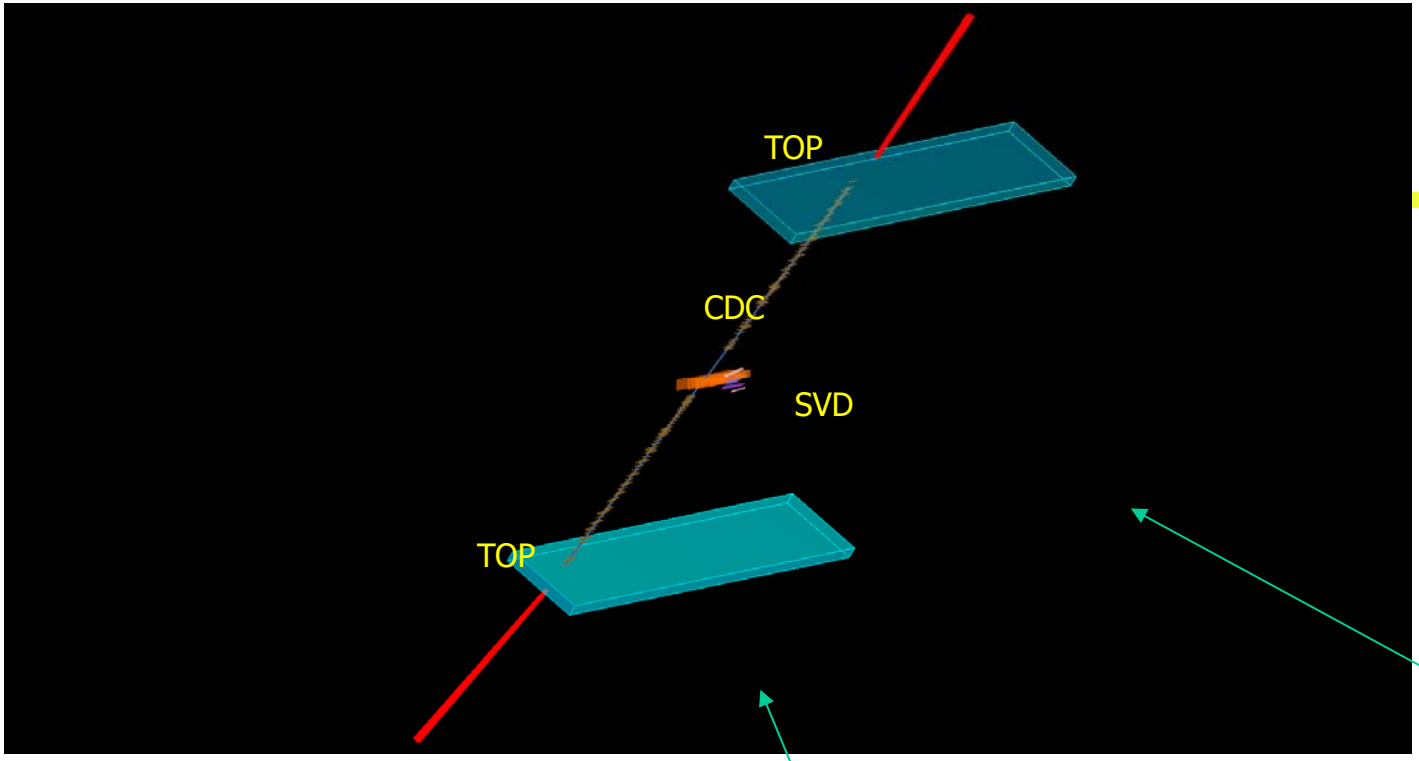


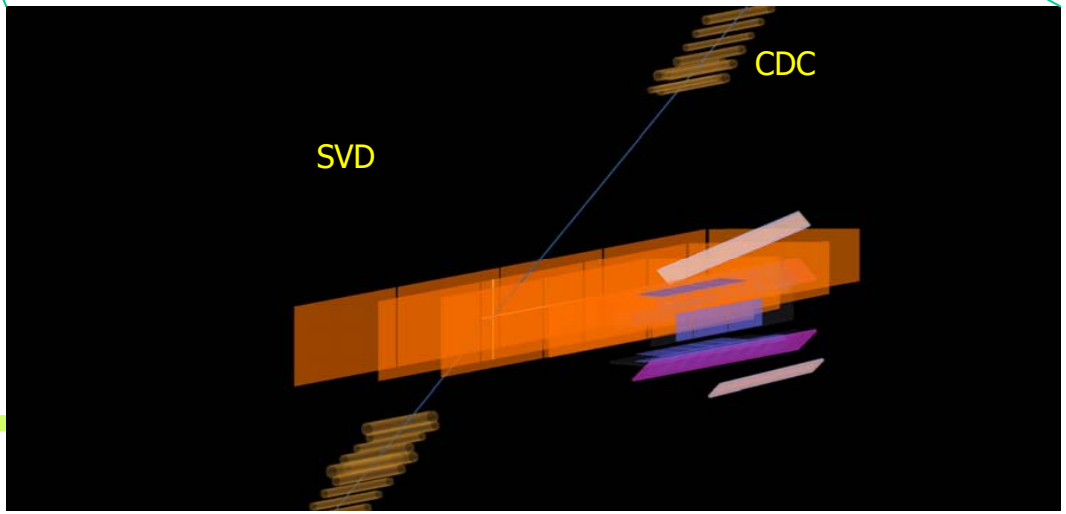

Installation of final quads


Installation of the commissioning
vertex detector



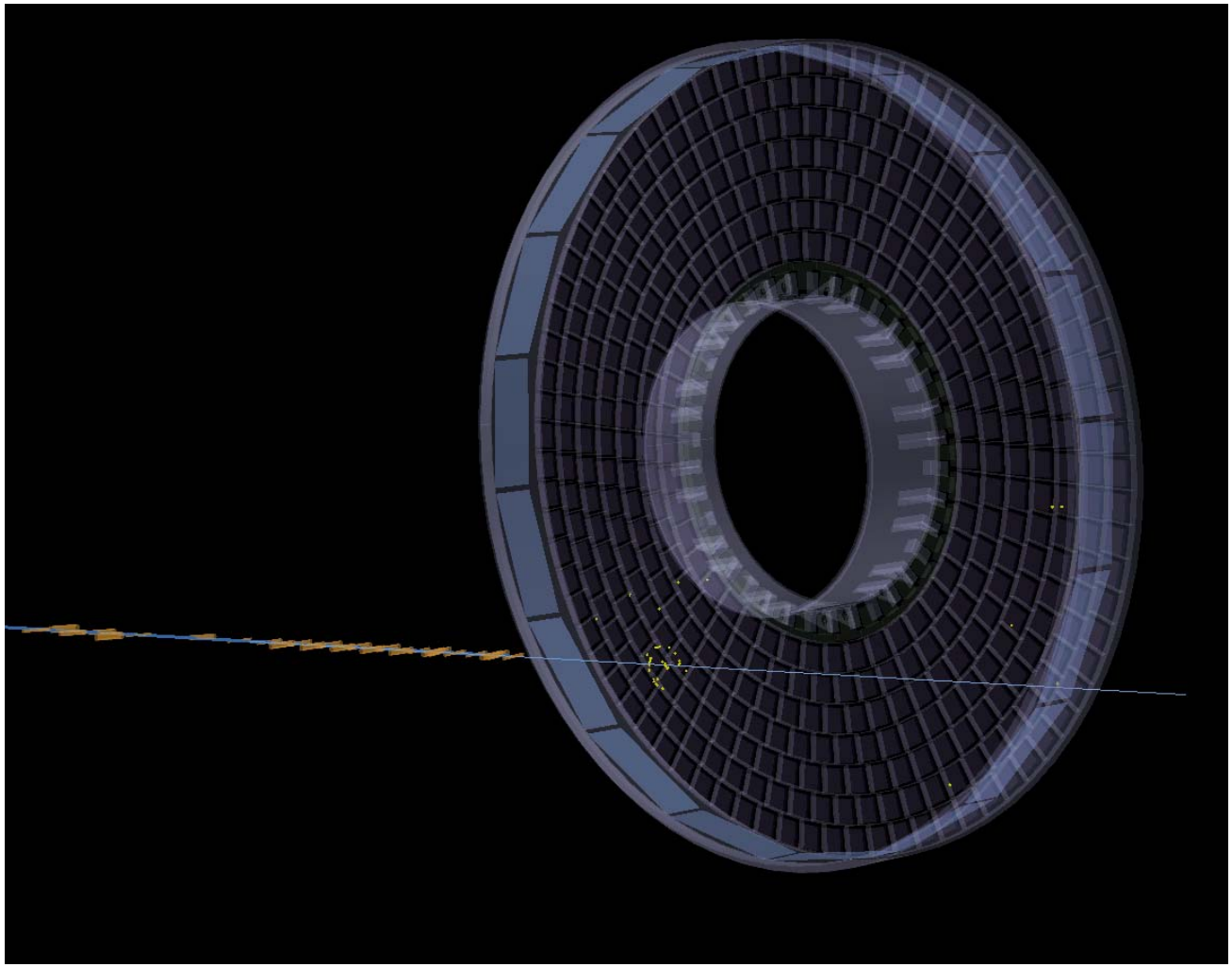
Four outer detector subsystems CDC, TOP, ECL, BKLM read out simultaneously





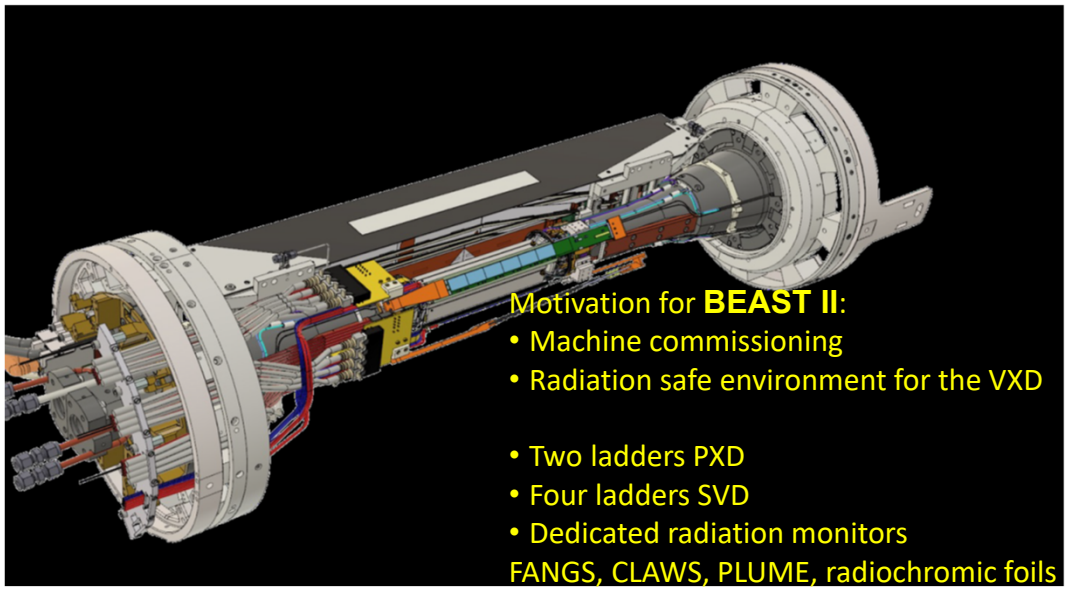
+ vertex detector hits!

ARICH: Rings from cosmic ray muons



First events recorded in the fully instrumented ARICH.

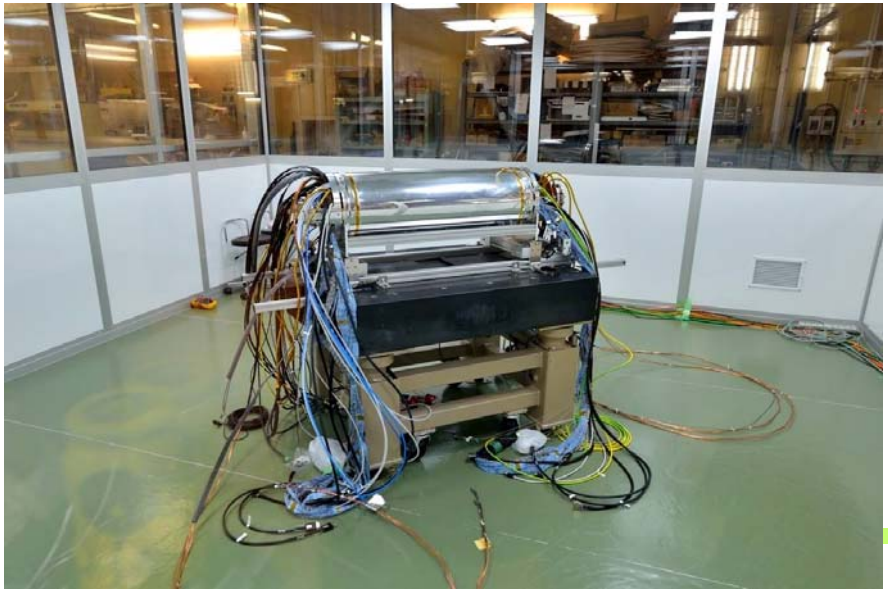
Phase 2 vertex detector (BEAST II): installed in Belle II

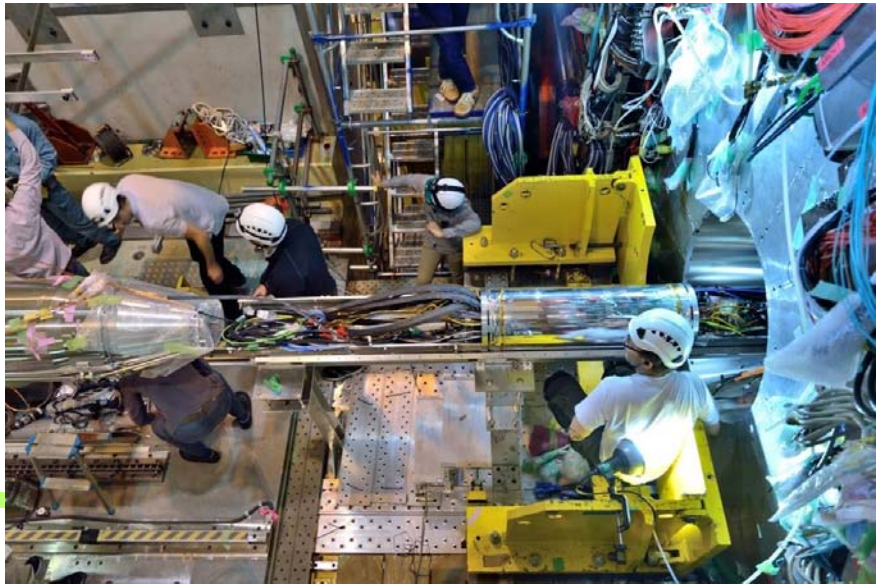


Motivation for **BEAST II**:
- Machine commissioning
- Radiation safe environment for the VXD

- Two ladders PXD
- Four ladders SVD
- Dedicated radiation monitors

FANGS, CLAWS, PLUME, radiochromic foils





Belle II Status Summary

The Belle II detector is on the beam line and taking cosmics

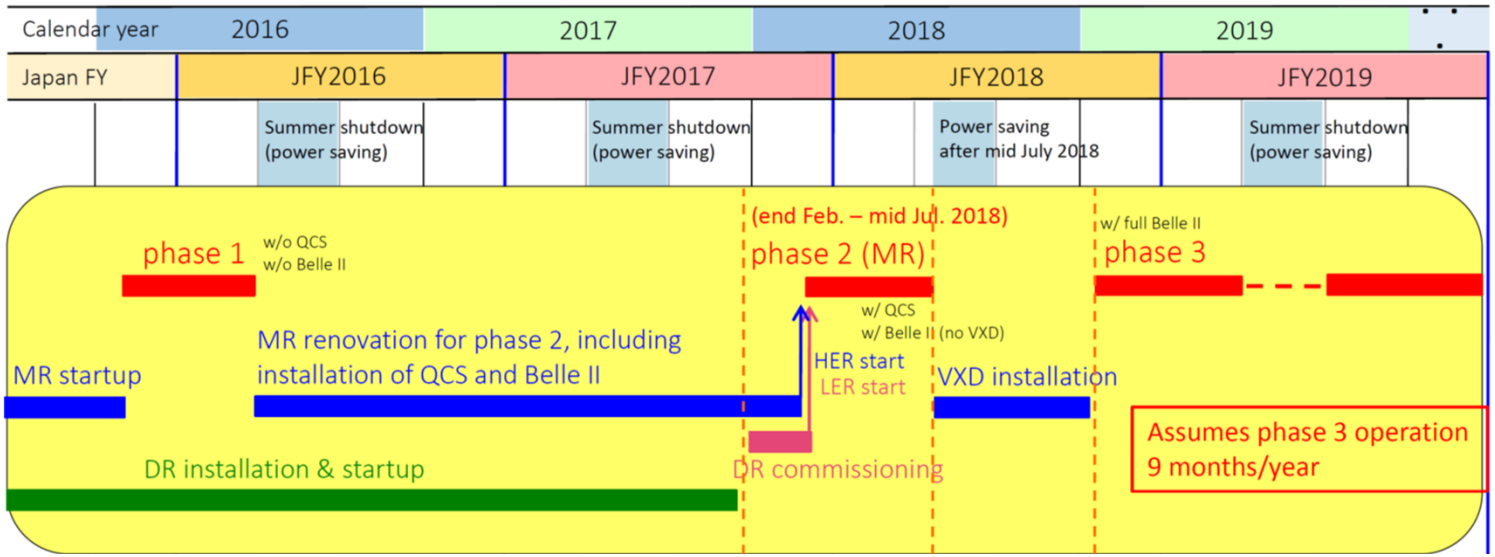
- Beast II installed in the VXD volume to monitor backgrounds
- All systems are working, some checkout, debugging and optimization is still ongoing.

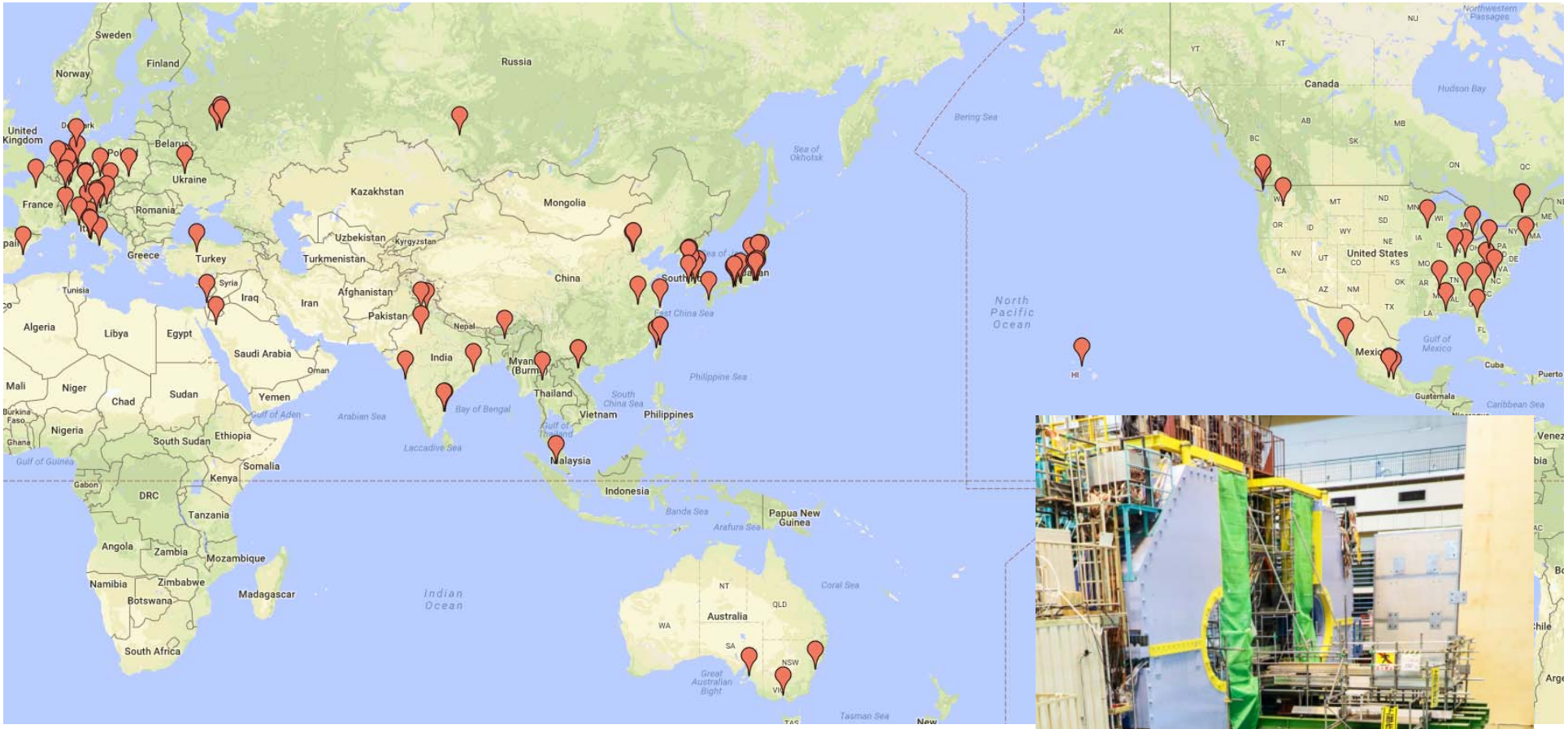
First beam injection on March 21 (e^-), March 31 (e^+), collisions expected end of April.

Phase 2 running will continue until July 17.

VXD installation: second half of 2018, physics running expected starting in Feb 2019.

The baseline plan: run for 9 months/year, with a target integrated luminosity of 50/ab.

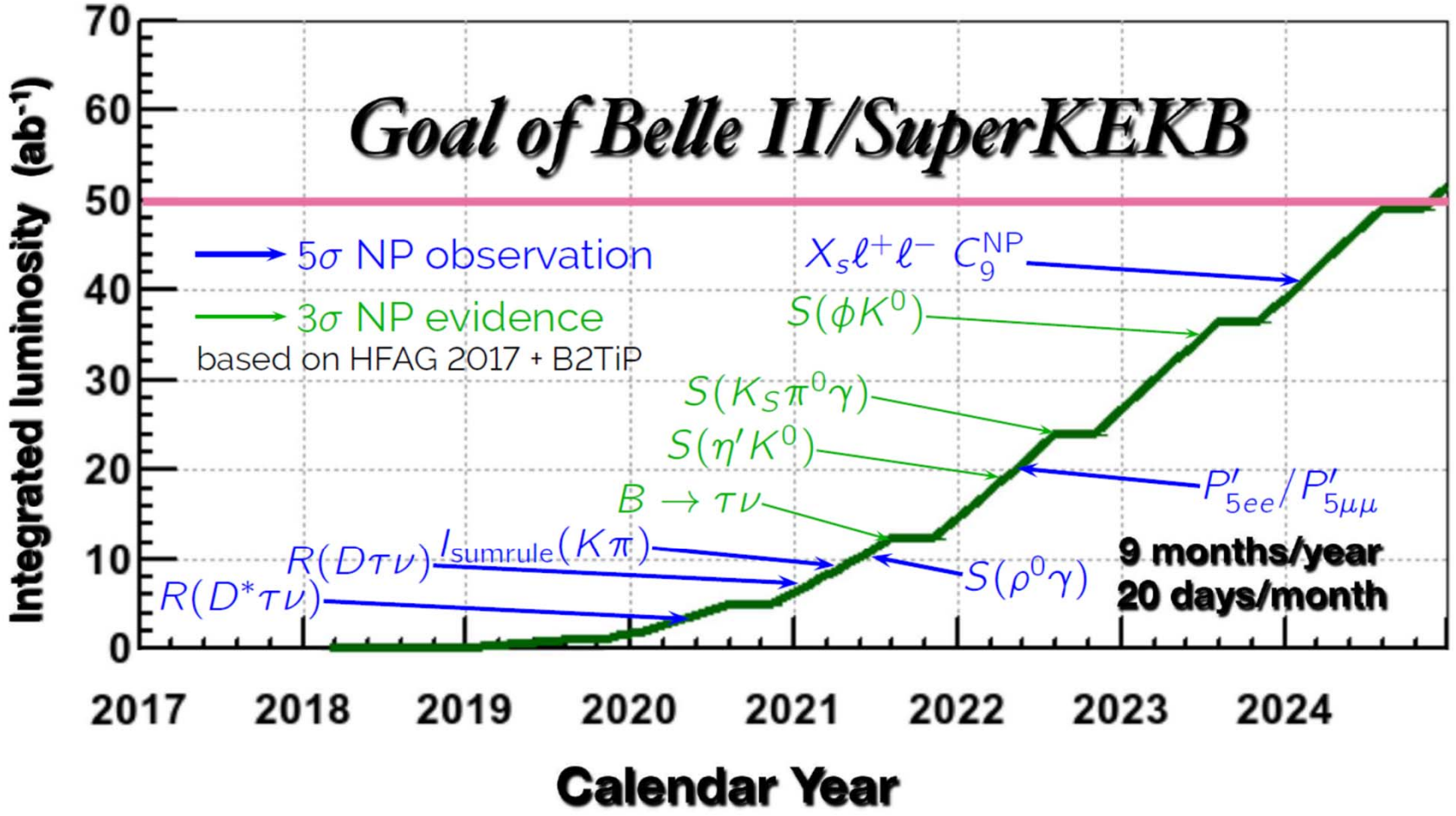




A very strong group of ~750 highly motivated scientists!

Physics prospects @ Belle II

B2TIP: Belle2 Theory Interface Platform
- A series of joint workshops with theorists
- Belle II Physics book in the final editing stage, to be submitted to PTEP



Physics prospects

Belle II strategy for New Physics searches:

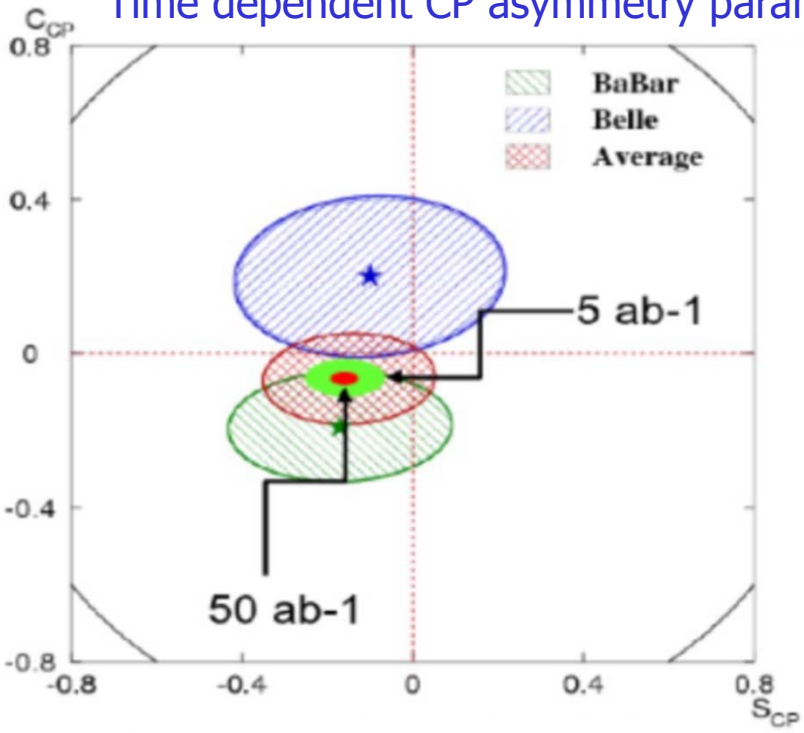
- Statistics 1 ab^{-1} (Belle) → 50 ab^{-1} (Belle II)
- Predictions of SM with small theoretical uncertainties
- Precise measurements with small systematic errors

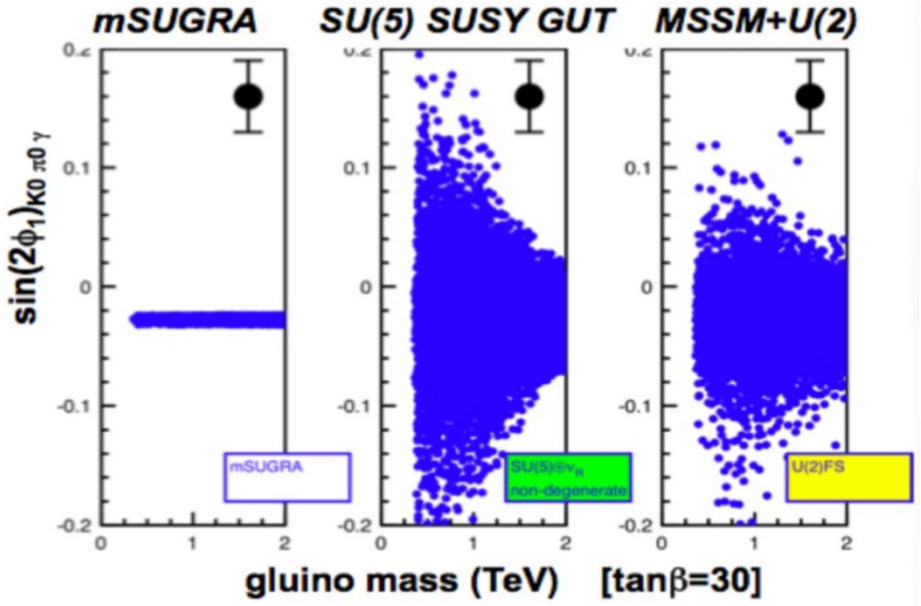
Belle II reach - a few examples

- lepton flavor universality checks
- B → K$\nu\nu$
- CPV in B → $K_S\pi^0\gamma$
- CPV in B → Kπ
- Dark sector studies in Phase 2

Measure TDCP asymmetry in $K_S \pi^0 \gamma$

Time dependent CP asymmetry parameters





The value of S can discriminate among SUSY-breaking mechanisms

S = -016 +- 0.22, C = -0.04 +- 0.14

Mostly statistic limited, expected uncertainties

$\sigma(S) \sim 0.09$ at 5 ab^{-1}

~ 0.03 at 50 ab^{-1}

G. Buchalla et al., EPJC 57 (2008) 309

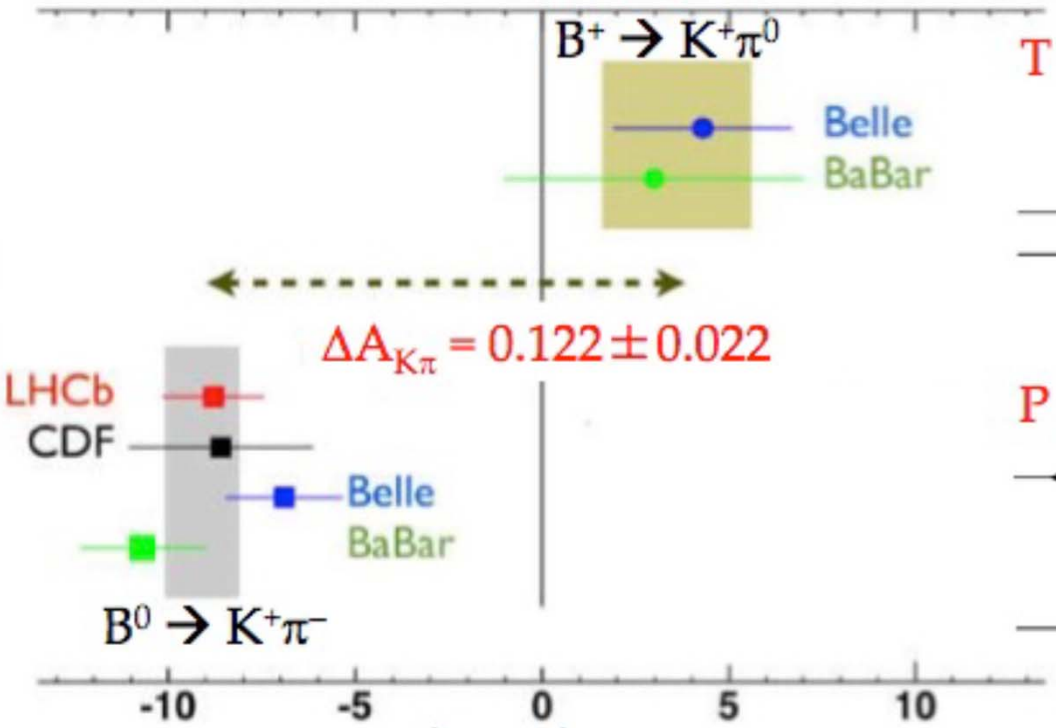
Kπ puzzle: Need to measure all the asymmetries

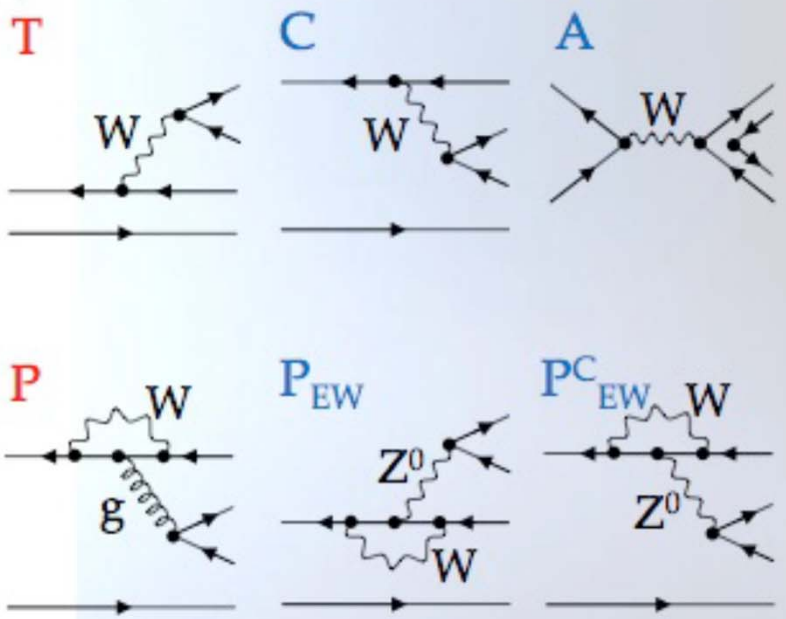
- Difference of CP asymmetry between B^0 and B^+
  - Enhanced C?
  - QCD?
  - New Physics in P_{EW}?

$B^+ \to K^+\pi^0$: $T + P + C + P_{EW} + P^C_{EW} + A$

$B^0 \to K^+\pi^-$: $T + P + P^C_{EW}$

Dominant Sub-dominant





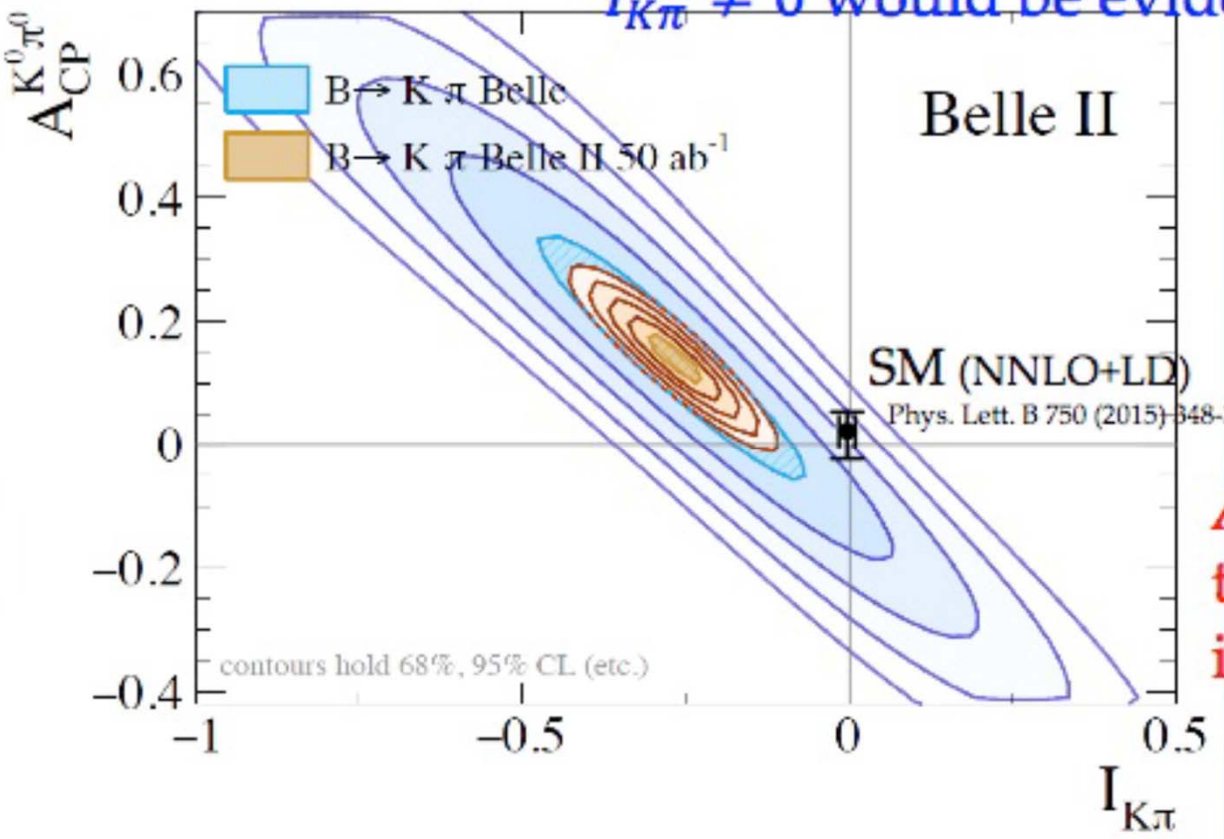
$$A_{CP}(B \to f) = \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)} \quad (\%)$$

Direct CP asymmetries in neutral states

- Sum rule of A_{CP} was proposed: [Phys. Lett. B 627 (2005) 82-88]

$$I_{K\pi} \equiv A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{B(K^0\pi^+)}{B(K^+\pi^-)}\frac{\tau_0}{\tau_+} - 2A_{CP}(K^+\pi^0)\frac{B(K^+\pi^0)}{B(K^+\pi^-)}\frac{\tau_0}{\tau_+} - 2A_{CP}(K^0\pi^0)\frac{B(K^0\pi^0)}{B(K^+\pi^-)} \approx 0$$

$I_{K\pi} \neq 0$ would be evidence for New Physics



$A_{CP}(K^0\pi^0)$ is one of the key measurements in Belle II

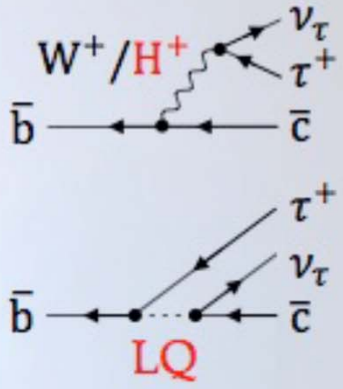
Lepton universality in $B \to D^{(*)}\tau\nu$

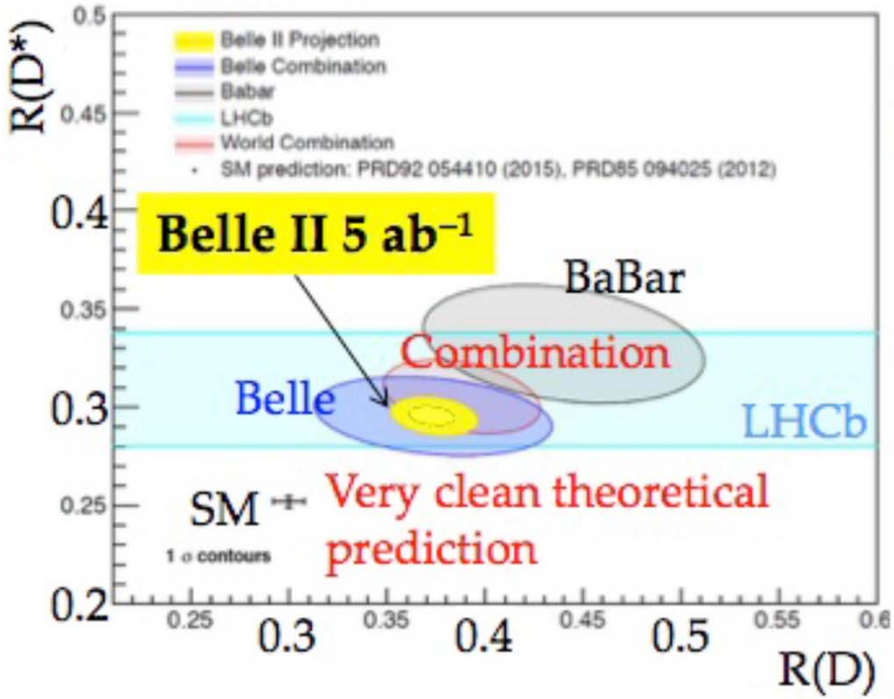
$$R(D^{(*)}) = \frac{\Gamma(B \to D^{(*)}\tau\nu)}{\Gamma(B \to D^{(*)}\ell\nu)} \quad (\ell = \text{e or } \mu)$$

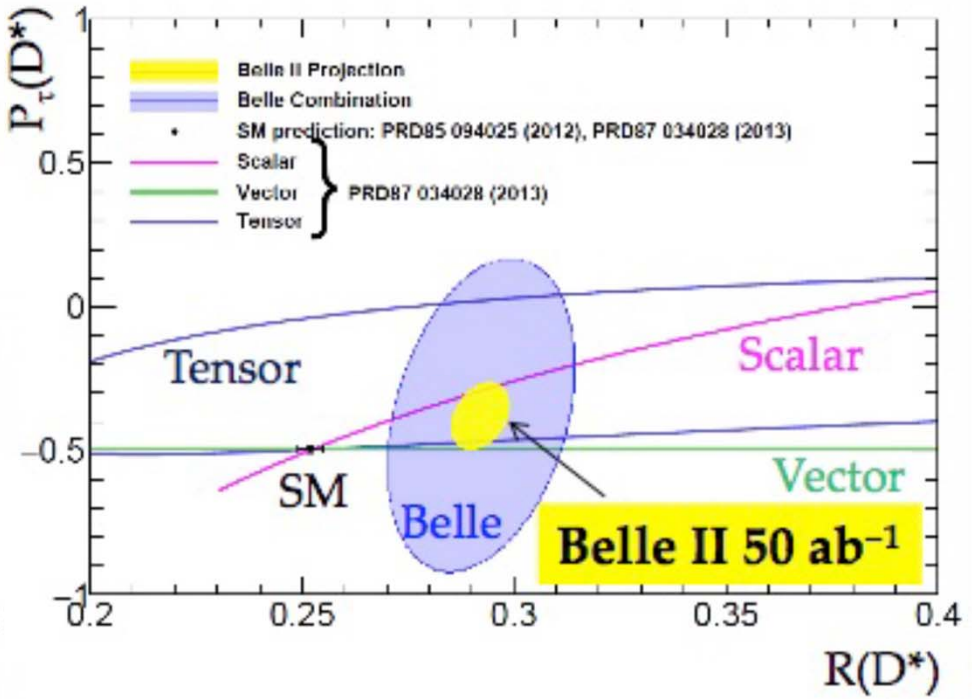
- Partial cancellation of theoretical uncertainties related to hadronic effects and measurement systematics.

$$P_\tau(D^*) = \frac{\Gamma^+ - \Gamma^-}{\Gamma^+ + \Gamma^-} \quad (\Gamma^\pm\text{: decay rate of } \pm\,\tau\text{-helicity})$$

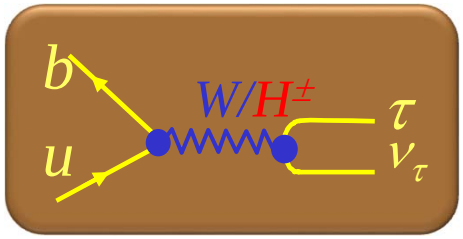
- Another probe of New Physics





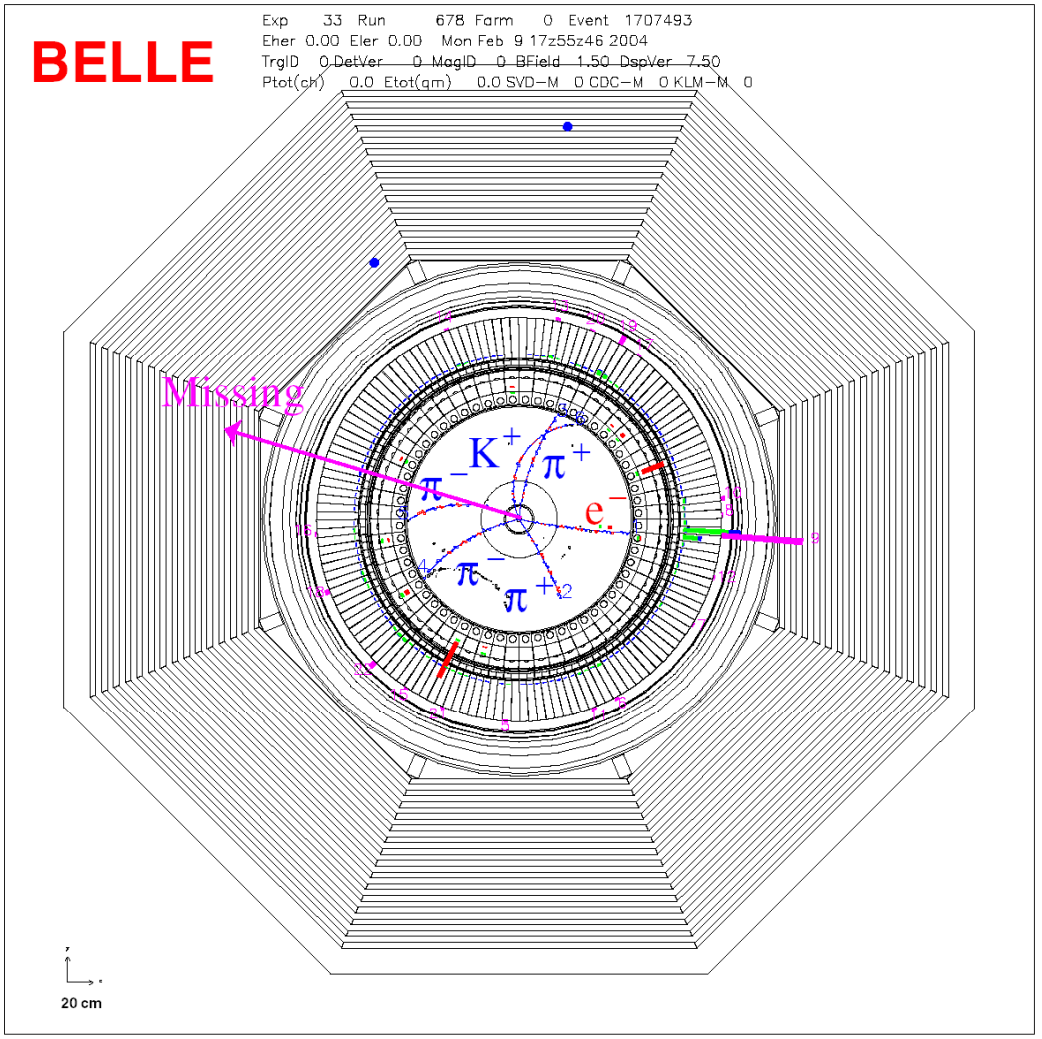


$B^- \rightarrow \tau^- \nu_\tau$



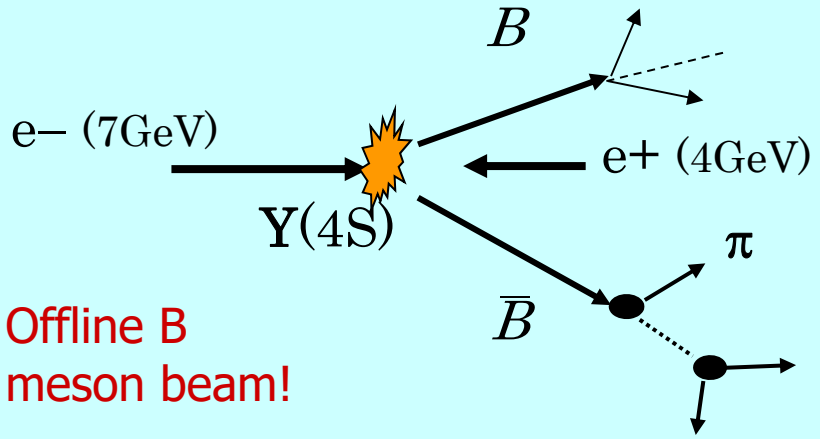
$$B^+ \rightarrow D^0 \pi^+$$
$$(\rightarrow K\pi^-\pi^+\pi^-)$$
$$B^- \rightarrow \tau(\rightarrow e\nu\bar{\nu})\nu$$

Example of a challenging rare decay



Full reconstruction tagging

Idea: fully (or partially) 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 $\Upsilon(4S)$ decays)



Offline B meson beam!

Decays of interest
- $B \to X_u l \nu$,
- $B \to K \nu \nu$
- $B \to D\tau\nu$, $\tau\nu$

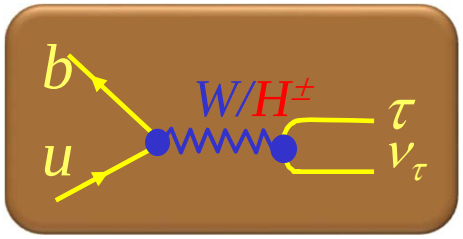
full reconstruction (0.5%):
- hadronic tagging, $B \to D\pi$ etc.

partial reconstruction (1%):
- semileptonic tagging

Powerful tool for B decays with neutrinos

→unique feature at B factories

Example for the impact of $B \to \tau^- \nu_\tau$: charged Higgs limits

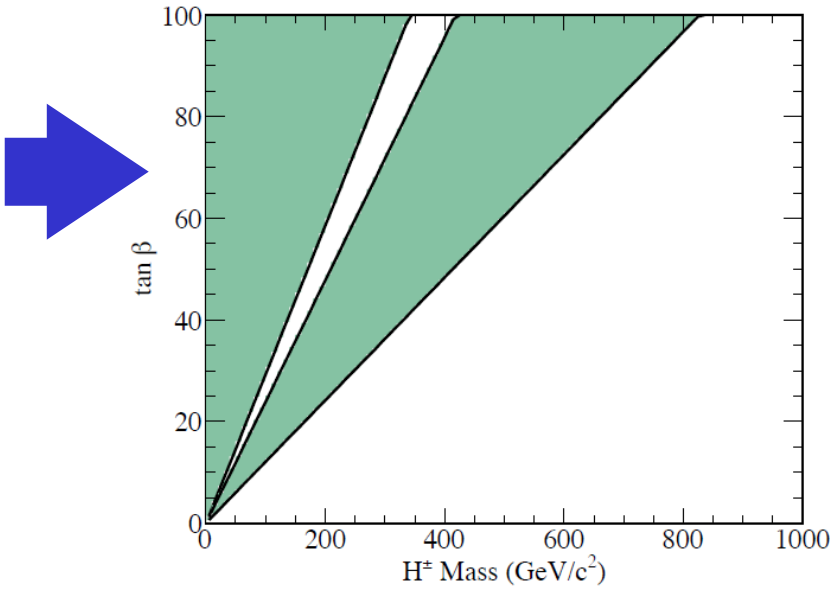


Measured value

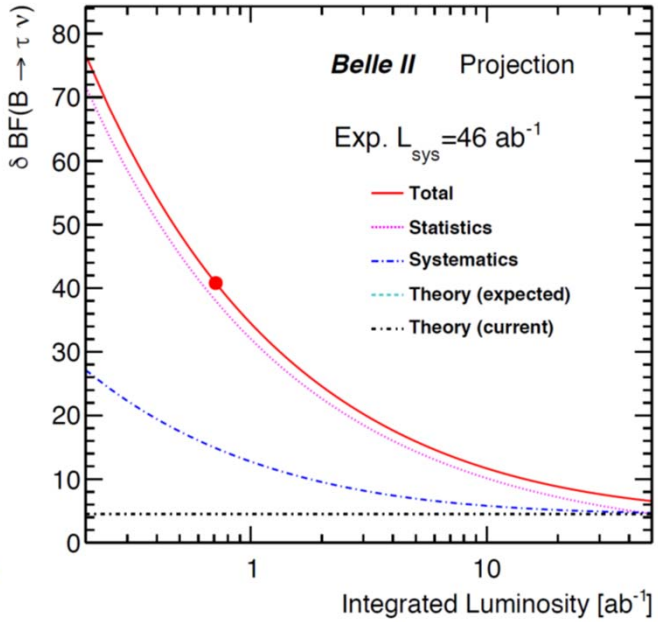
$$r_H = \frac{BF(B \to \tau\nu)}{BF(B \to \tau\nu)_{SM}} = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

can be – for example - turned into a limit on charged Higgs parameters (in case of the type II 2HDM)

B factories: Exclusion plot

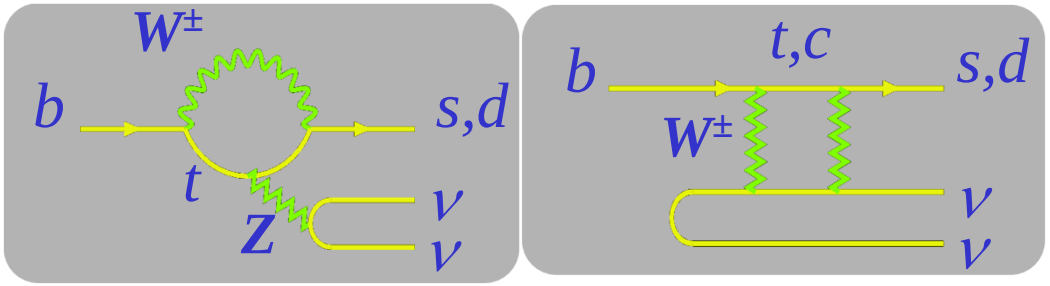


Belle II: in excellent competition with LHC!



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

SM: penguin + box diagrams



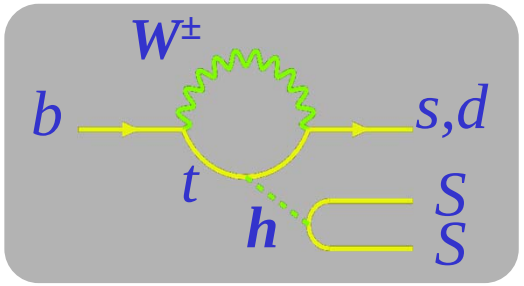
$B \to K\nu\nu$, $\mathcal{B} \sim 4 \cdot 10^{-6}$

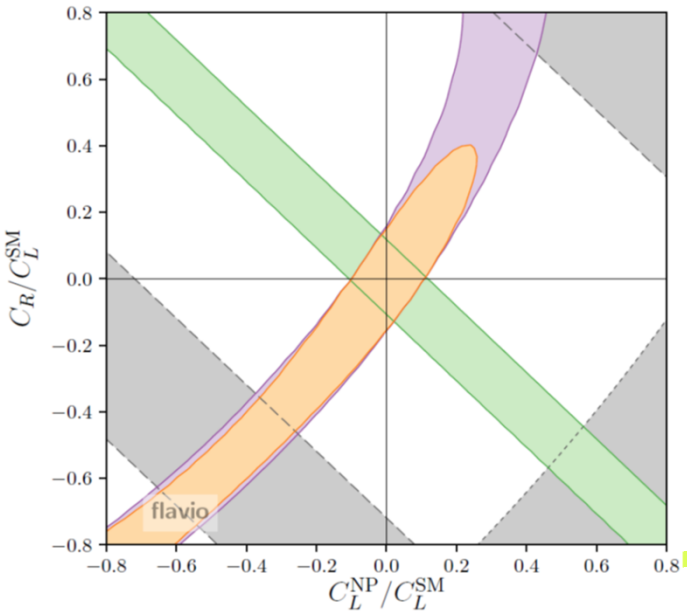
$B \to K^*\nu\nu$, $\mathcal{B} \sim 6.8 \cdot 10^{-6}$

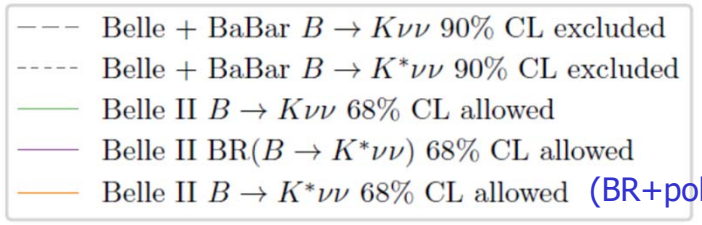
Look for deviations from the expected values → information on anomalous couplings

C^{ν}_{R} and C^{ν}_{L}

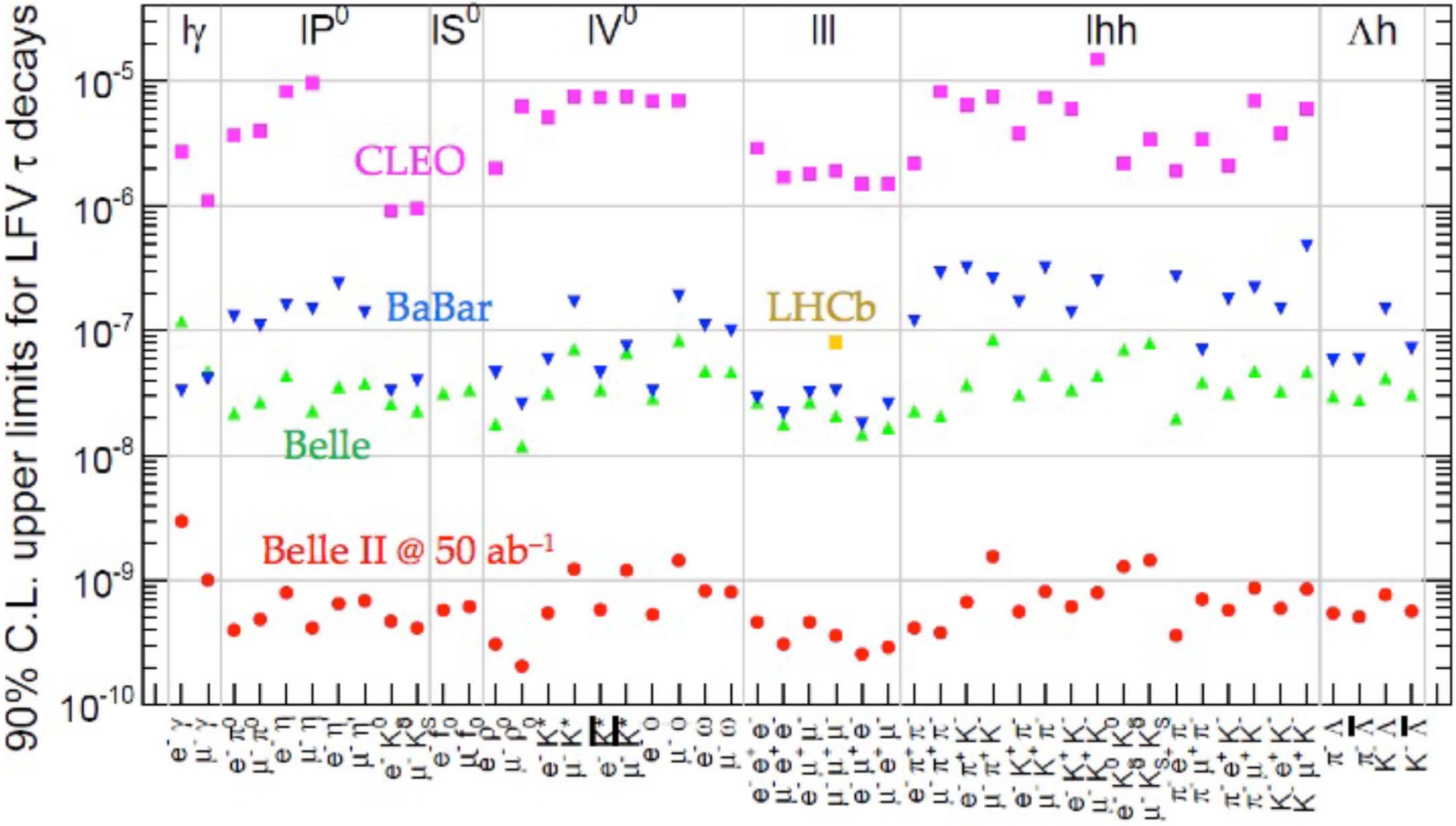
compared to the CM value $(C^{\nu}_{L})^{SM}$, coming from, e.g., processes like







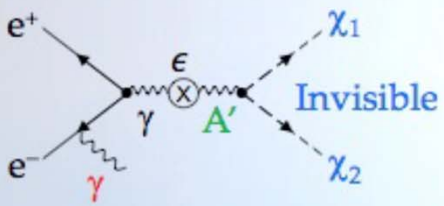
Lepton flavor violating τ decays



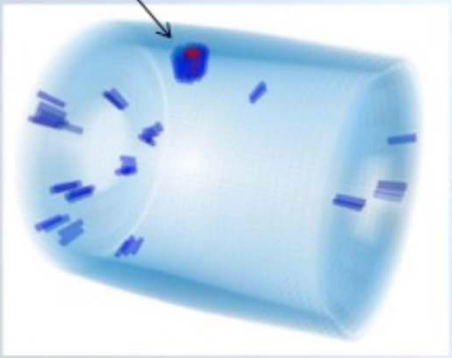
Dark sector

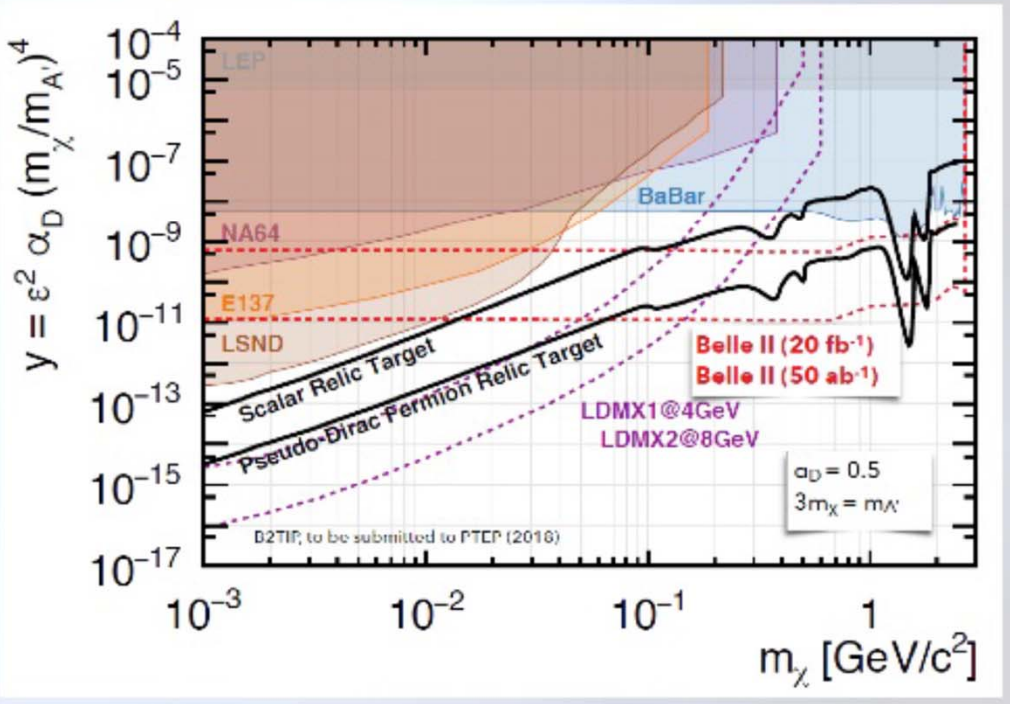
Possible to provide results even with the very limited statistics of Phase 2 running.

- New triggers will be used in Belle II to search for dark matter and dark photons.
  - Single photon trigger with ~1 GeV threshold to search for dark photon decaying into light dark matter



$$E_\gamma = \frac{E_{CM}^2 - M_{A'}^2}{2E_{CM}}$$





Summary

- Physics of B mesons has contributed substantially to our present understanding of elementary particles and their interactions
- B factories have proven to be an excellent tool for flavour physics as well for searches for new hadronic states, with reliable long term operation, constant improvement of the performance, achieving and surpassing design performance
- Super B factory at KEK, SuperKEKB+Belle II with L x40, in the final preparation phase
- In the time when LHCb is exploring anomalies in B decays, a new player is getting ready
- Expect a new, exciting era of discoveries, and a friendly competition and complementarity of Belle II, LHCb and BESIII