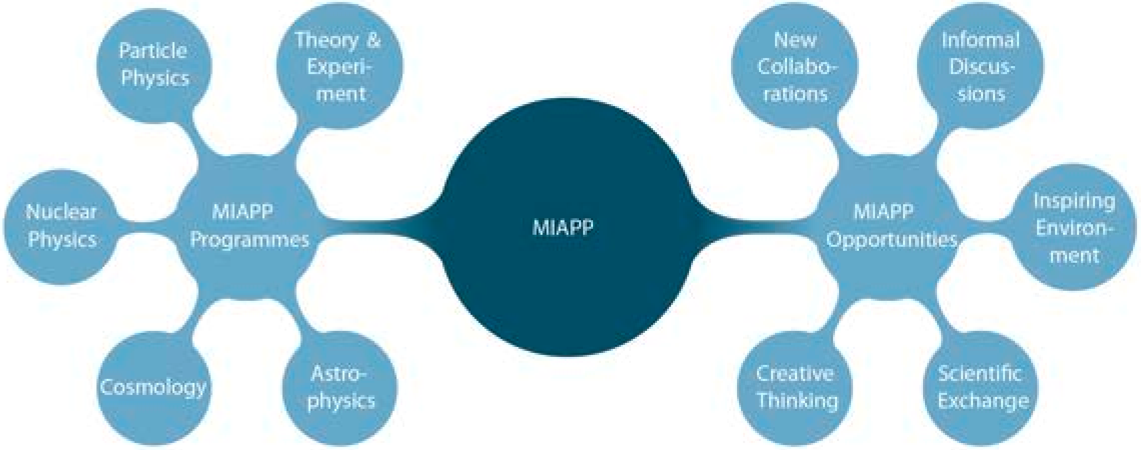
Flavour Physics with High-Luminosity Experiments



Belle II: status and plans

Peter Križan

University of Ljubljana and J. Stefan Institute

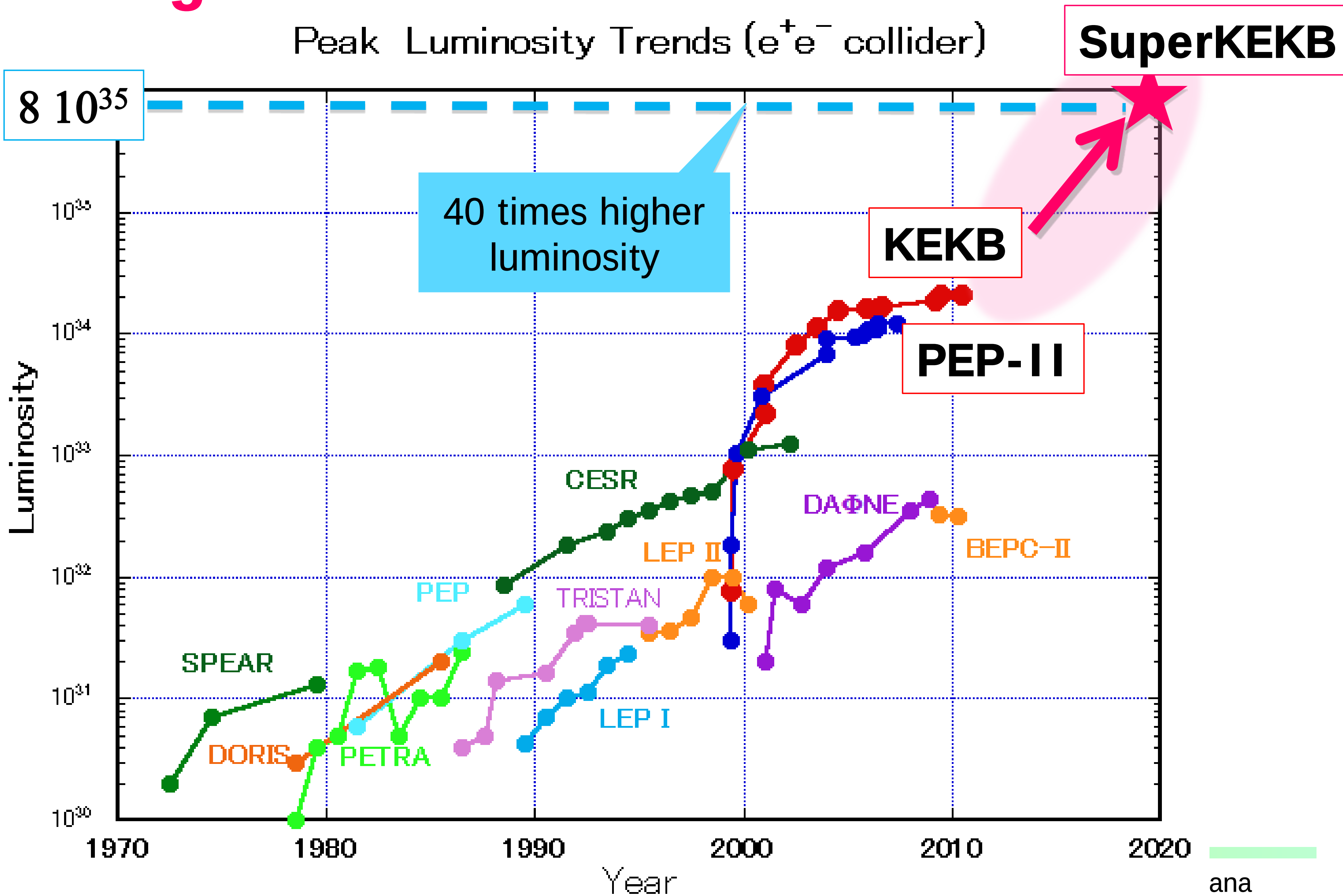
University of Ljubljana

"Jožef Stefan" Institute

Contents

- Accelerator status
- Detector construction: status and schedule
- Commissioning
- Outlook

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



ana

How to increase the luminosity?

Lorentz factor

Beam current

Beam-beam parameter

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

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 b_y^*

(2) Increase beam currents

(3) Increase x_y

"Nano-Beam" scheme

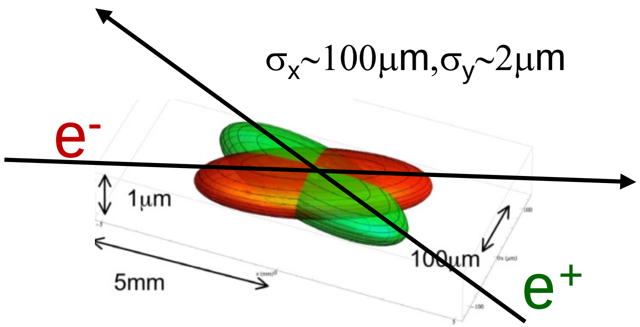
Collision with very small spot-size beams

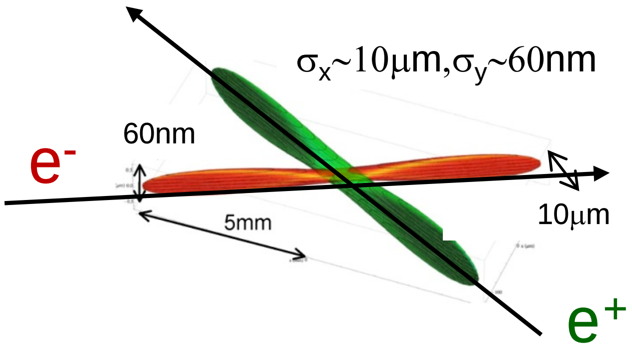
Invented by Pantaleo Raimondi for SuperB

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?

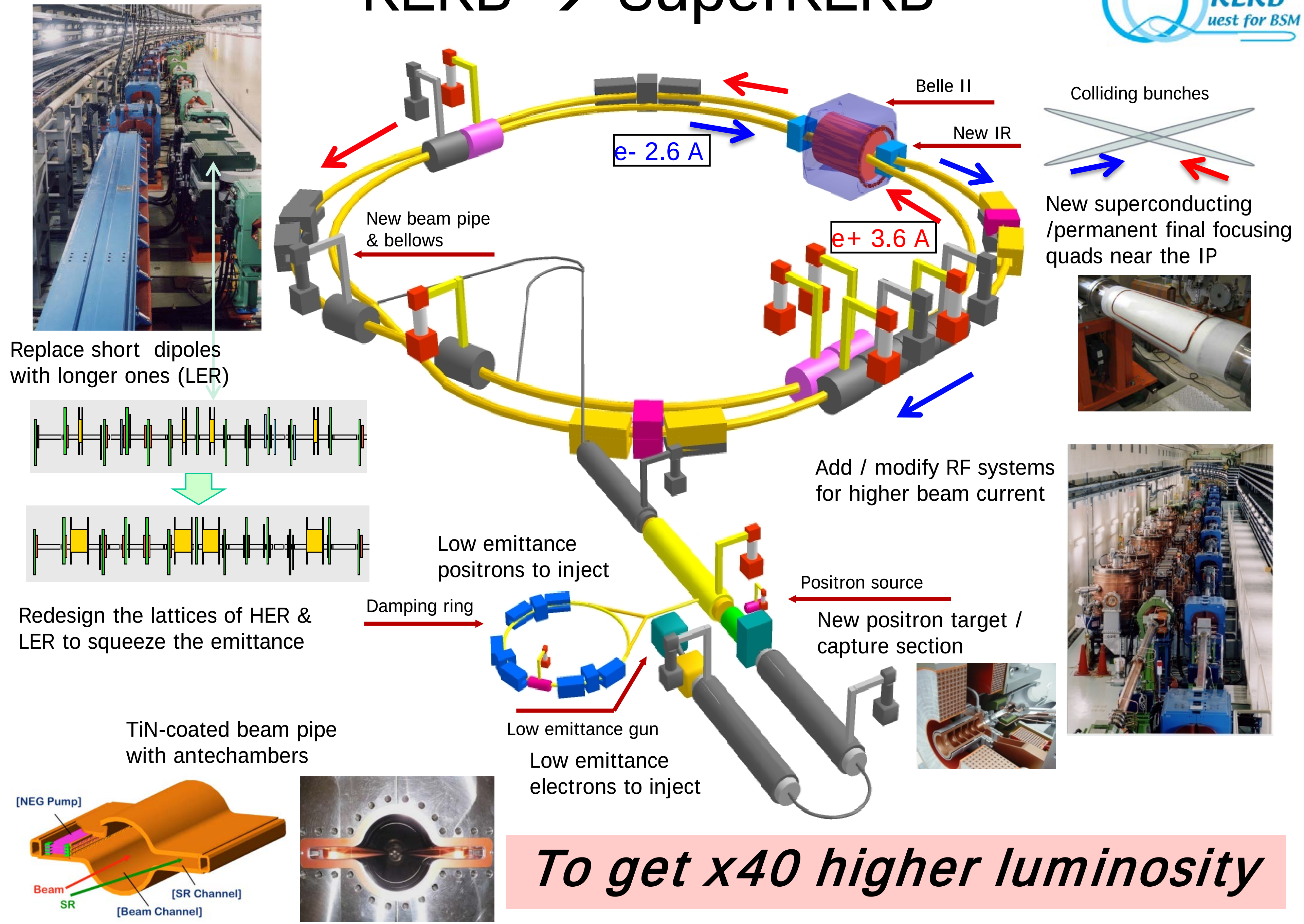
In KEKB, colliding electron and positron beams were already much thinner than a human hair...





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

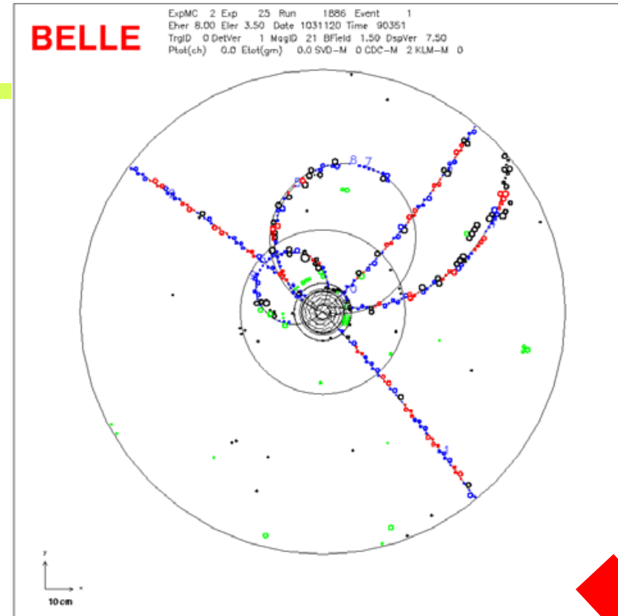
KEKB → SuperKEKB

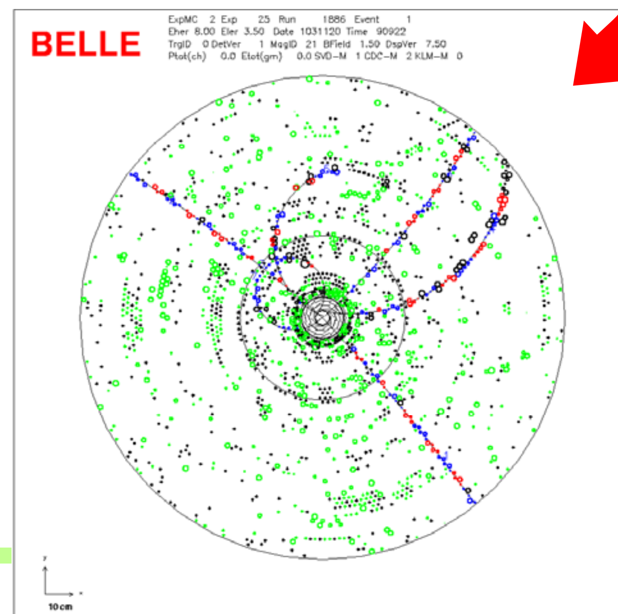


Requirements for the Belle II detector

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

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



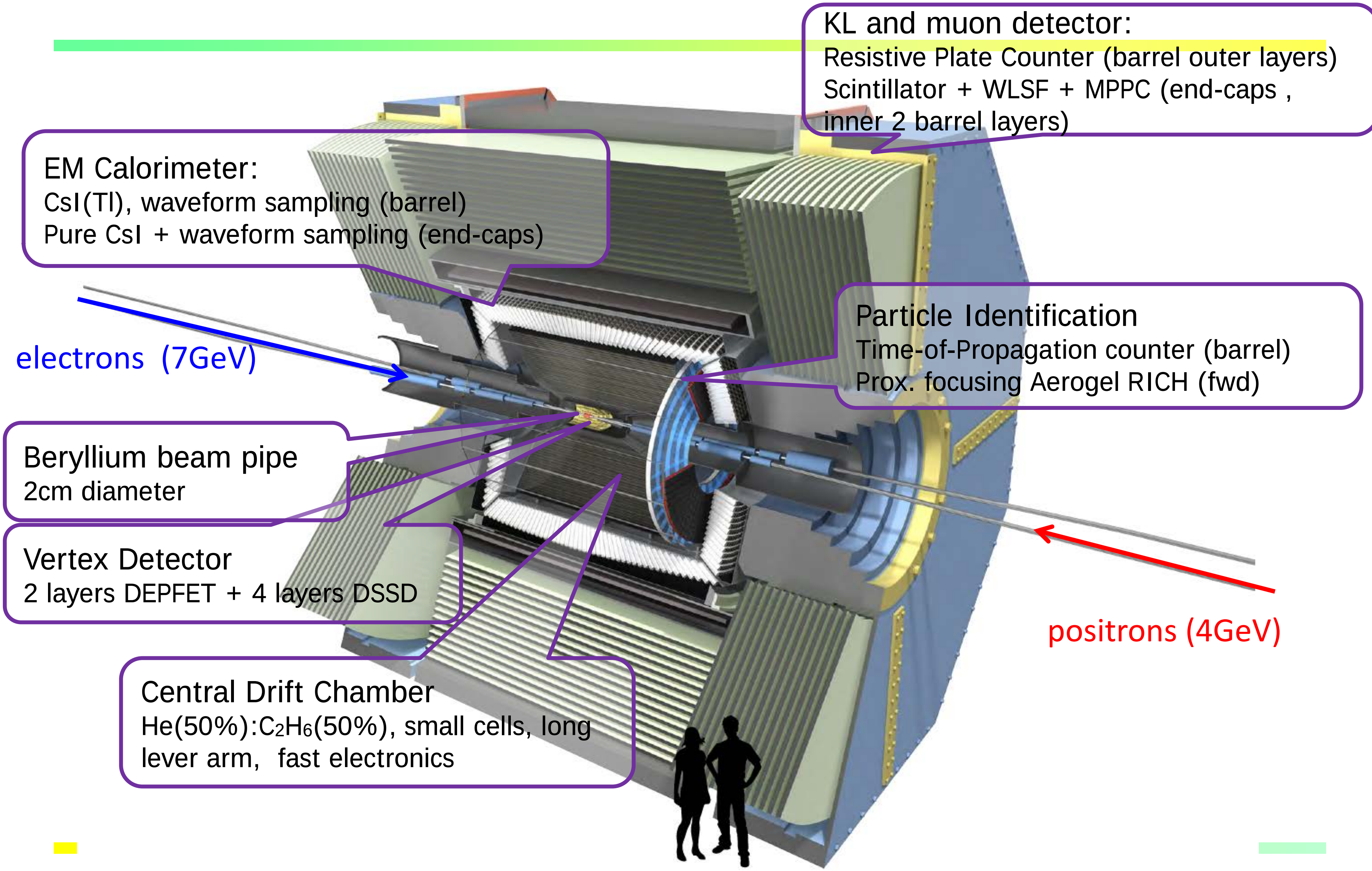


Solutions:

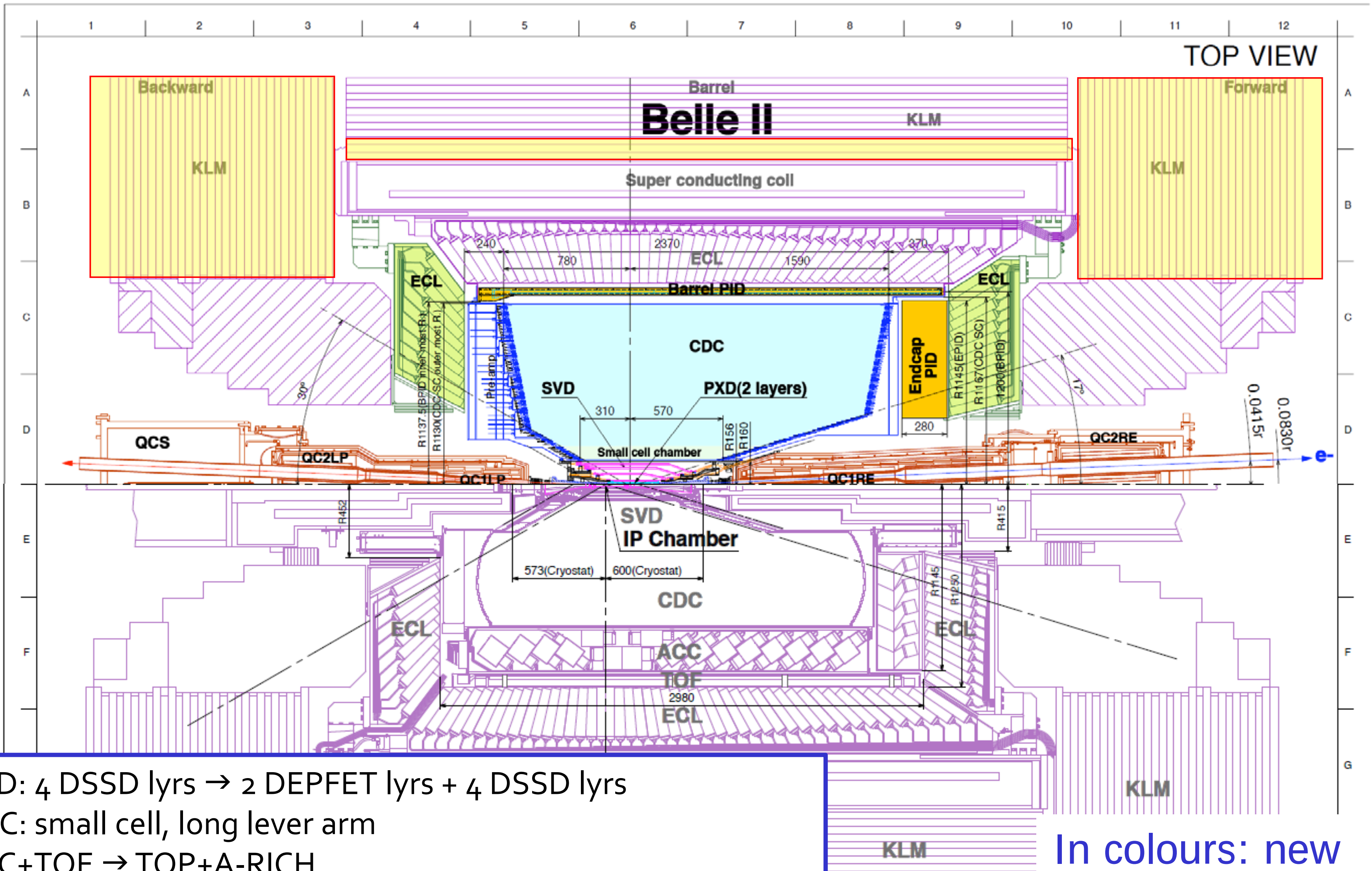
- Replace inner layers of the vertex detector with a pixel detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace endcap calorimeter crystals
- Faster readout electronics and computing system.

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

Belle II Detector



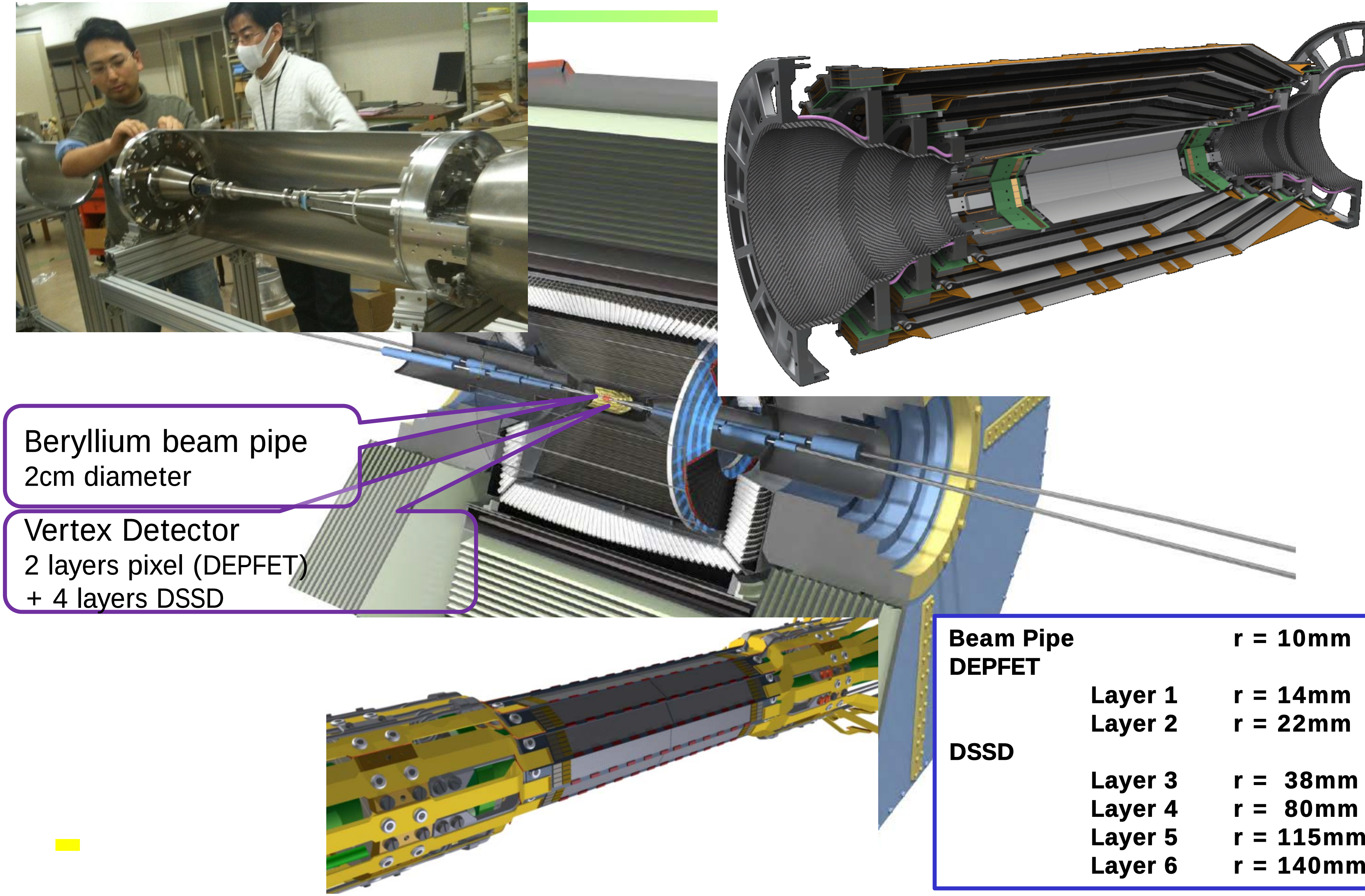
Belle II Detector (in comparison with Belle)



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 endcaps)
KLM: RPC → Scintillator +MPPC (endcaps, barrel inner 2 lyrs)

In colours: new components

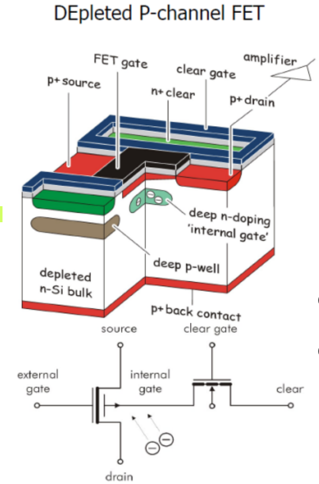
Belle II Detector – vertex region



Beam Pipe		**r = 10mm**
DEPFET		
	Layer 1	**r = 14mm**
	Layer 2	**r = 22mm**
DSSD		
	Layer 3	**r = 38mm**
	Layer 4	**r = 80mm**
	Layer 5	**r = 115mm**
	Layer 6	**r = 140mm**

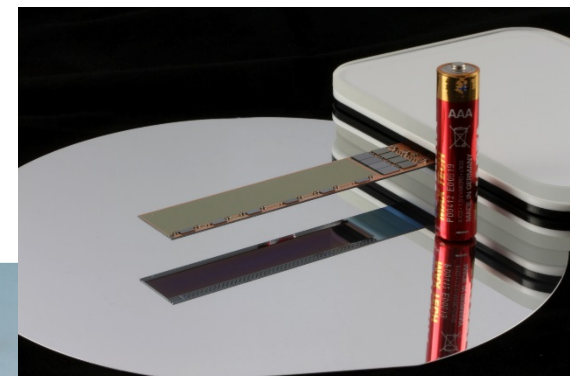
Pixel detector: 2 layers of DEPFET sensors

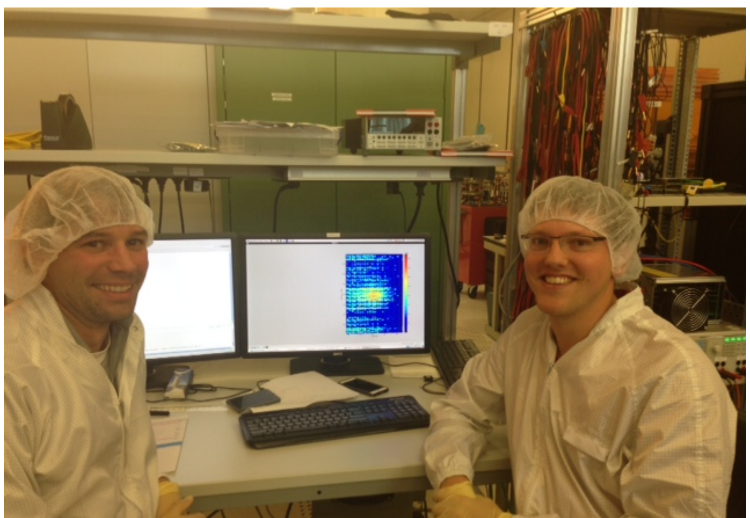
Mechanical mockup of the pixel detector



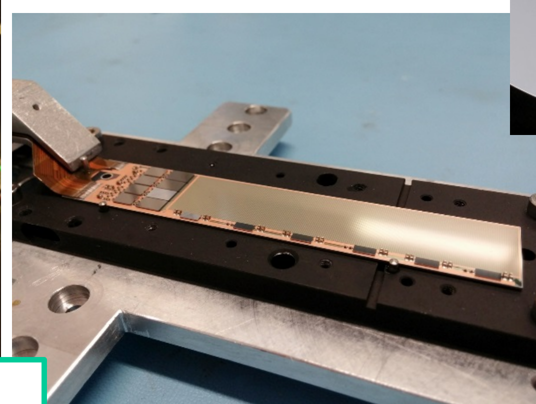
DEPFET sensor: developed at MPI Munich, produced at HLL

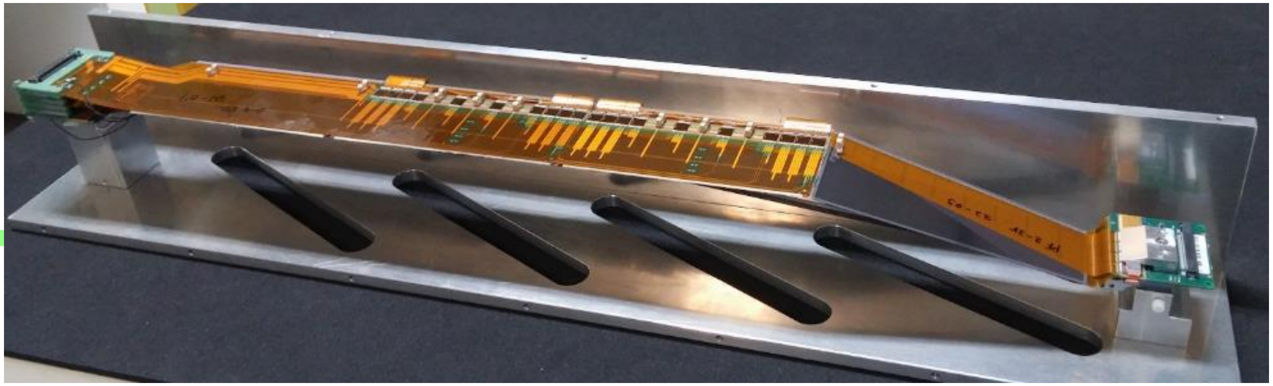
http://aldebaran.hll.mpg.de/twiki/bin/view/DEPFET/WebHome



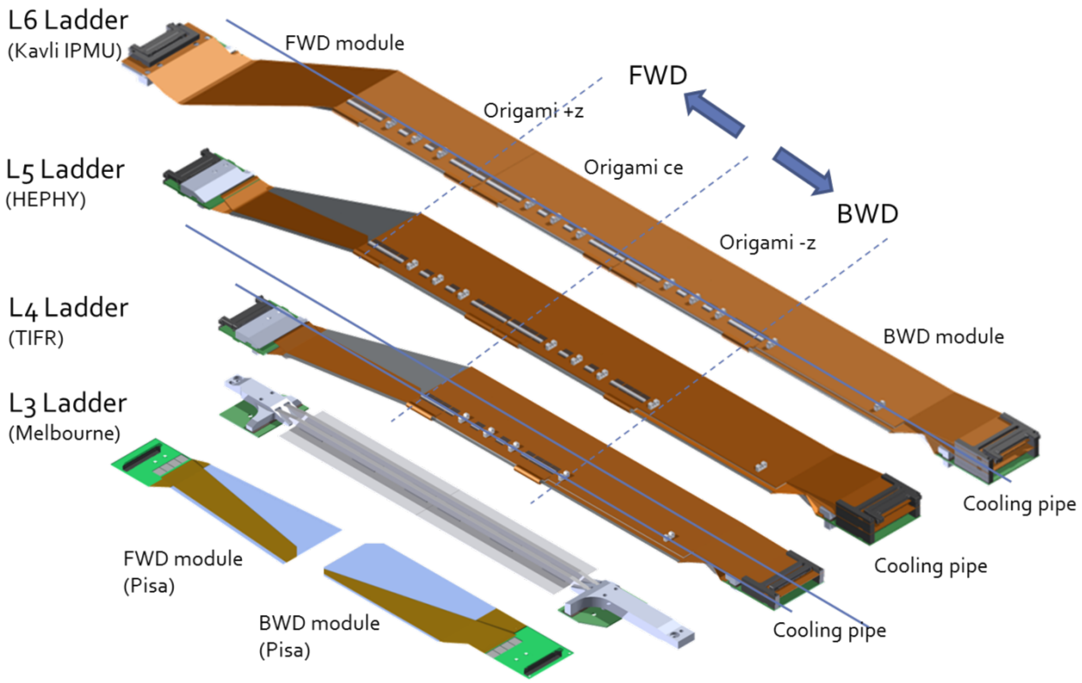


First laser light observed with the full size sensor

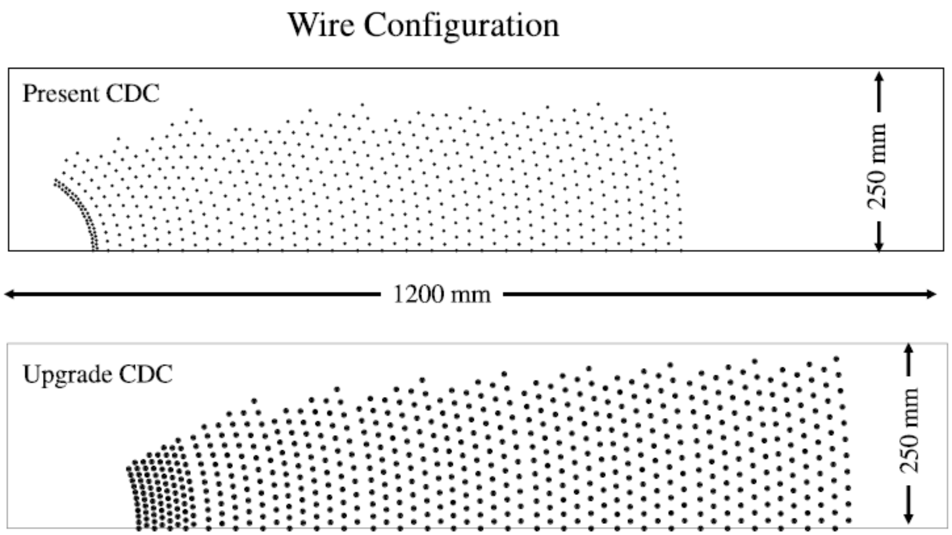




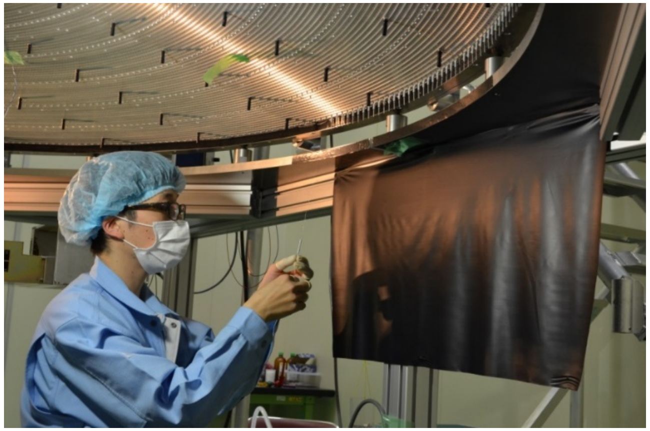
SVD: four layers of silicon microstrip detectors.



Belle II CDC

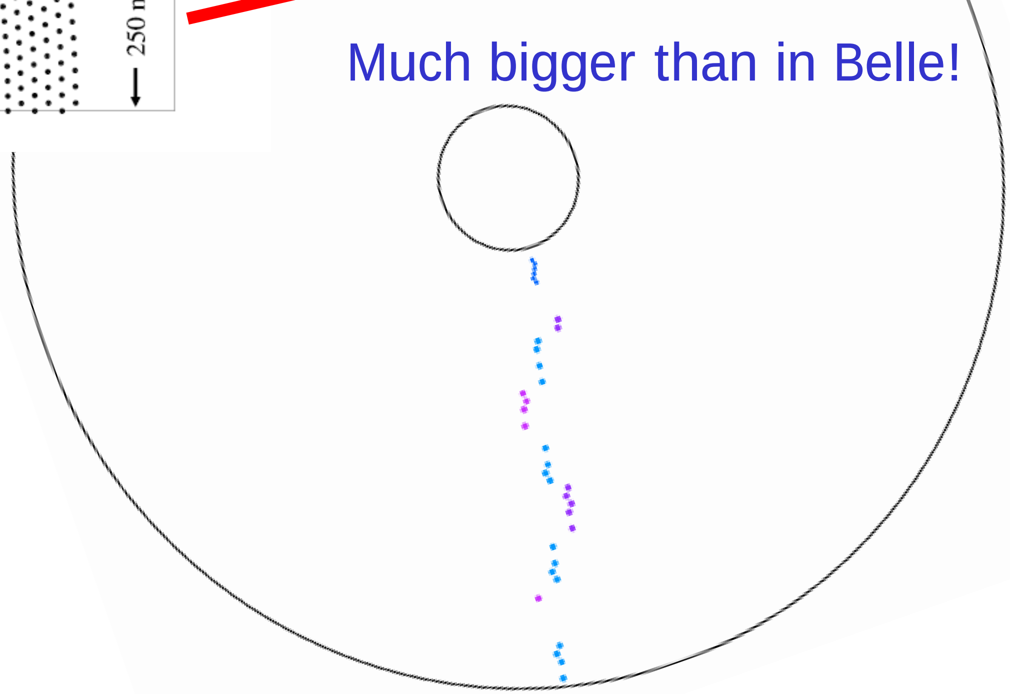


Much bigger than in Belle!



Wire stringing in a clean room

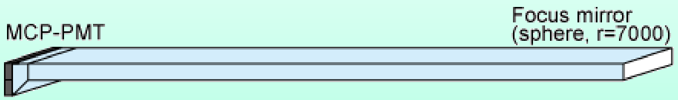
- thousands of wires,
- 1 year of work...



Being commissioned with cosmic rays.

Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



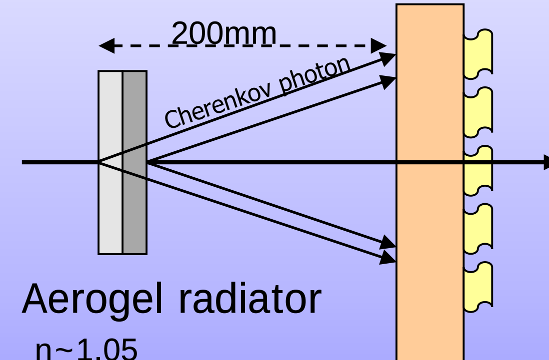
Quartz radiator

Focusing mirror

Small expansion block

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

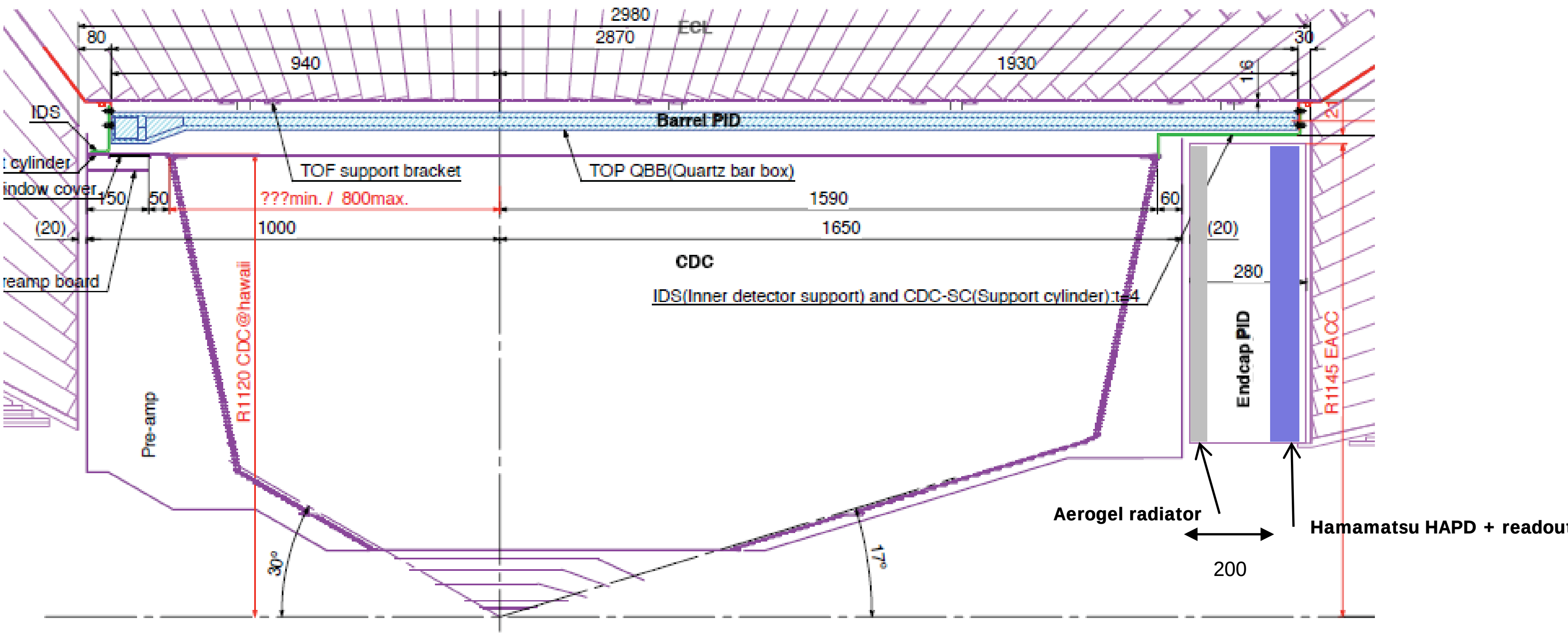
Endcap PID: Aerogel RICH (ARICH)



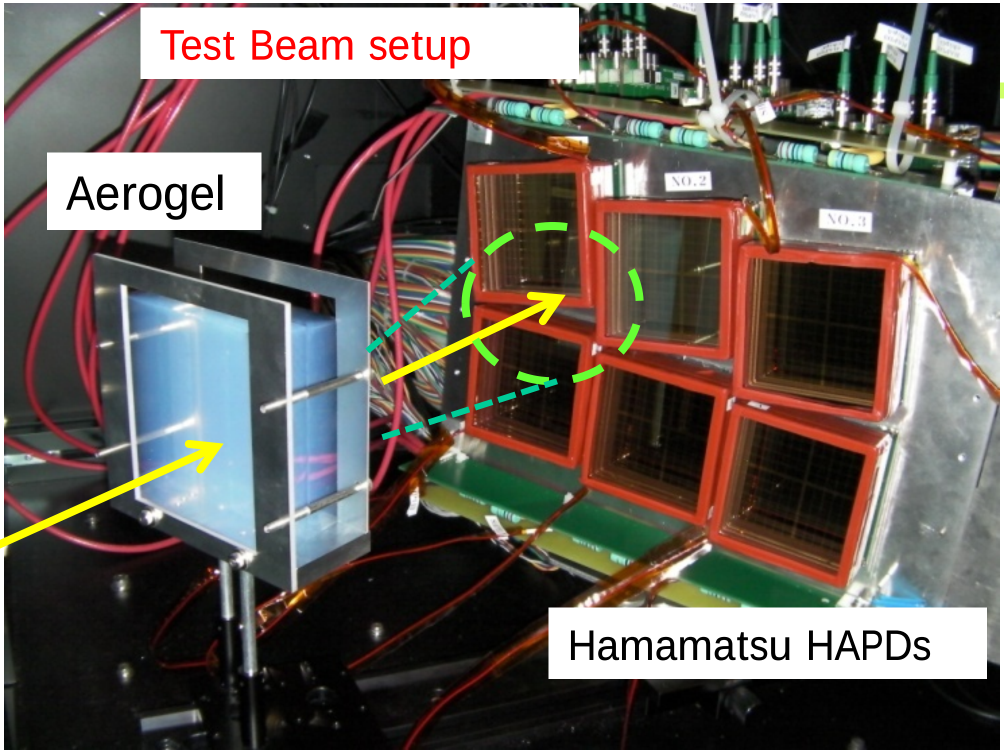
Aerogel radiator

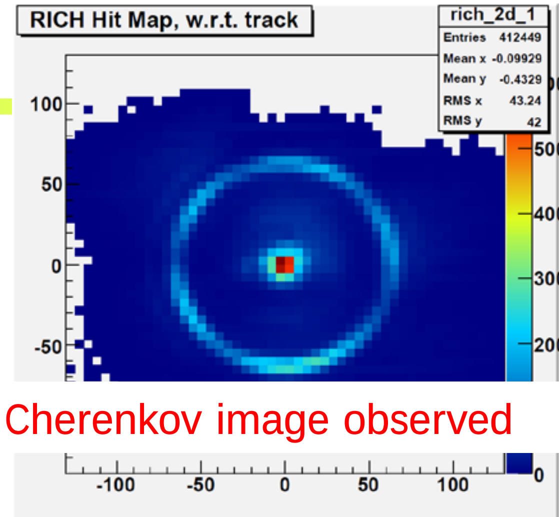
n~1.05

Hamamatsu HAPD



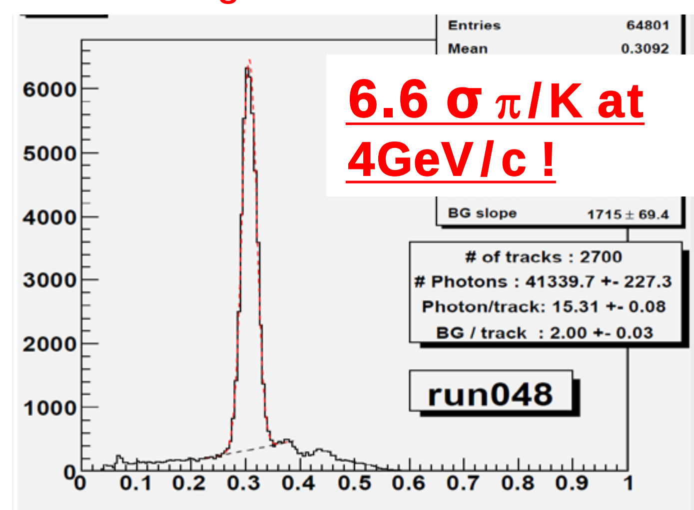
Aerogel RICH (endcap PID)





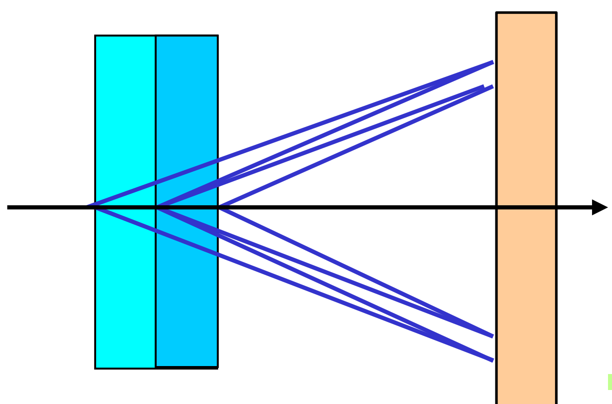
Clear Cherenkov image observed

Cherenkov angle distribution



6.6 σ π/K at 4GeV/c !

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



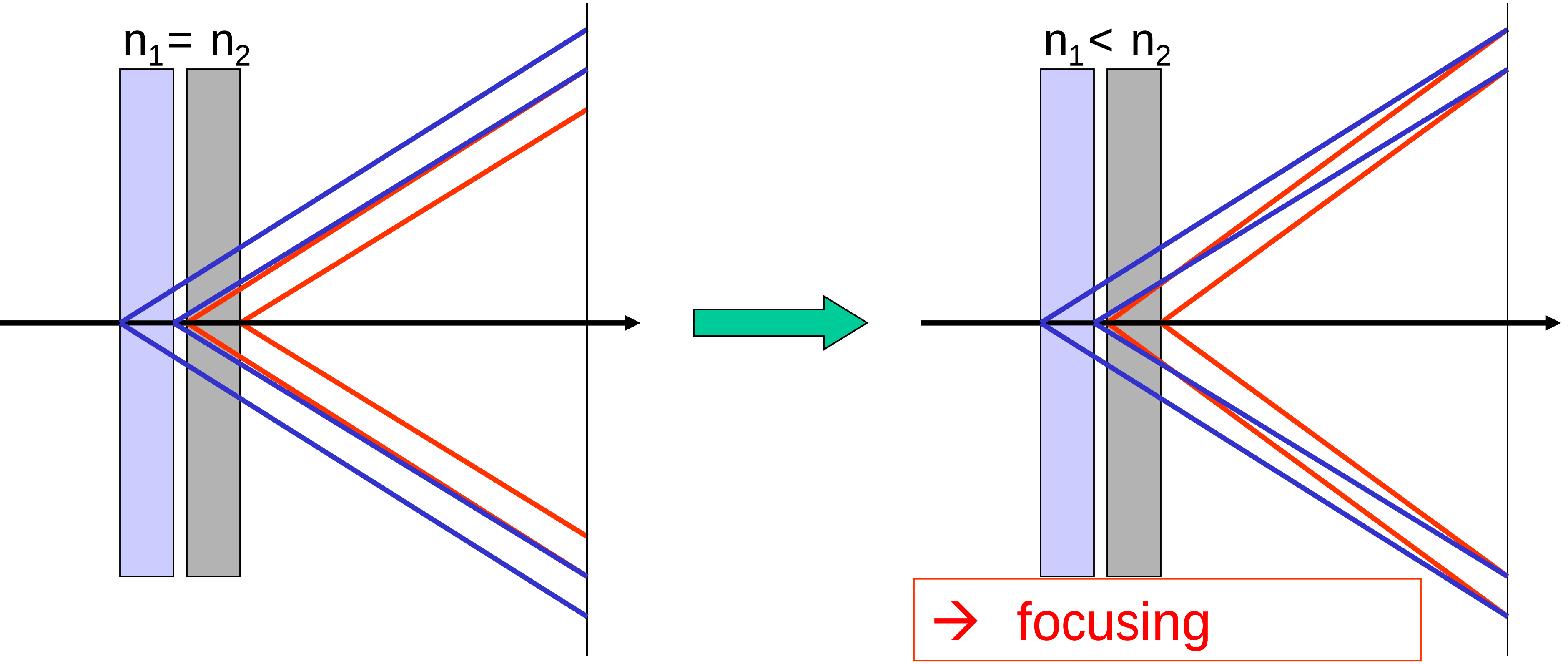
Employ multiple layers with different refractive indices→ Cherenkov images from individual layers overlap on the photon detector.

Radiator with multiple refractive indices

How to increase the number of photons without degrading the resolution?

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

normal



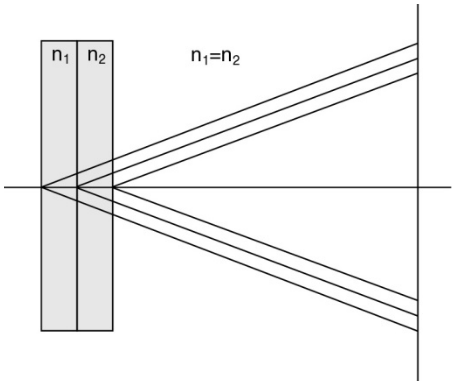
→ focusing

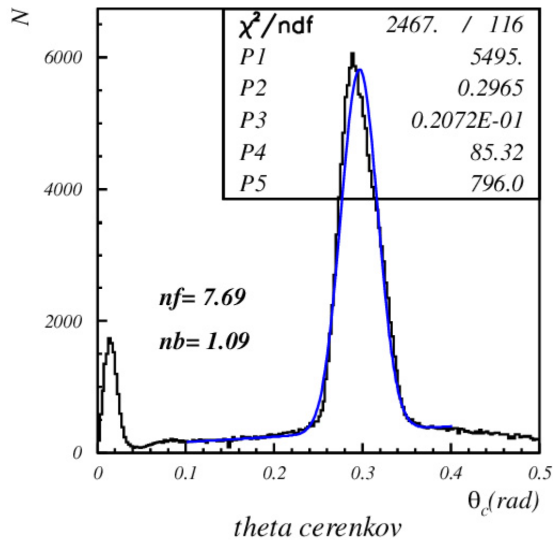
Such a configuration is only possible with aerogel (a form of Si_xO_y) – material with a tunable refractive index between 1.01 and 1.13.

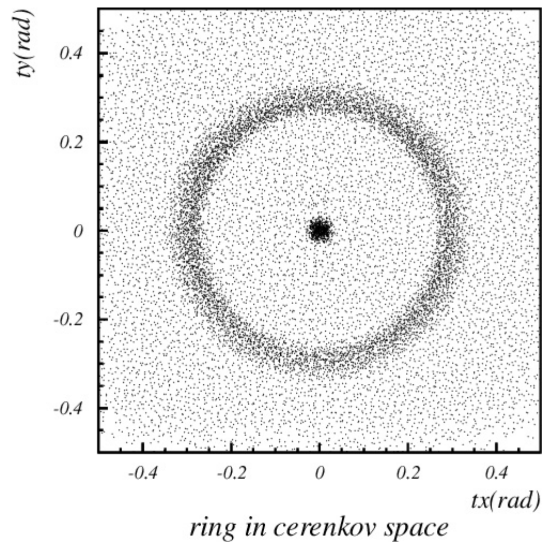
Focusing configuration – data

Increases the number of photons without degrading the resolution

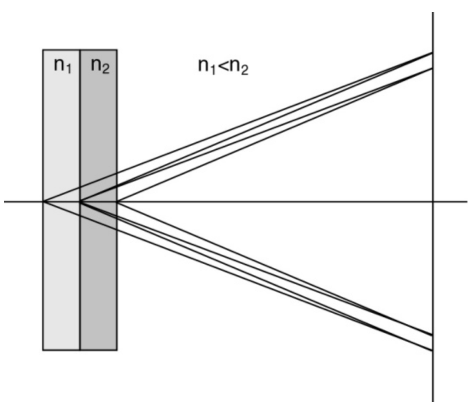
4cm aerogel single index

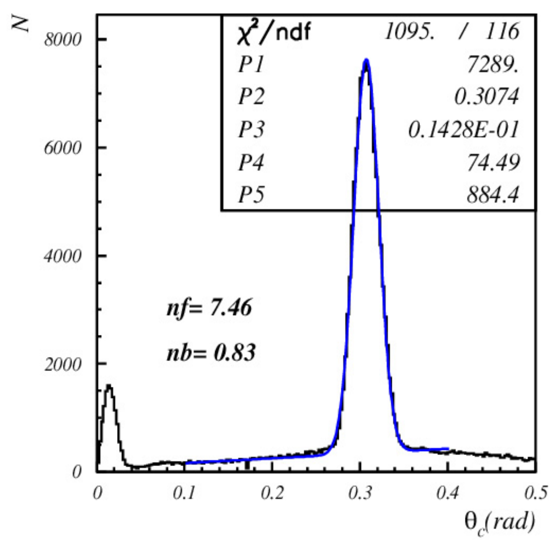


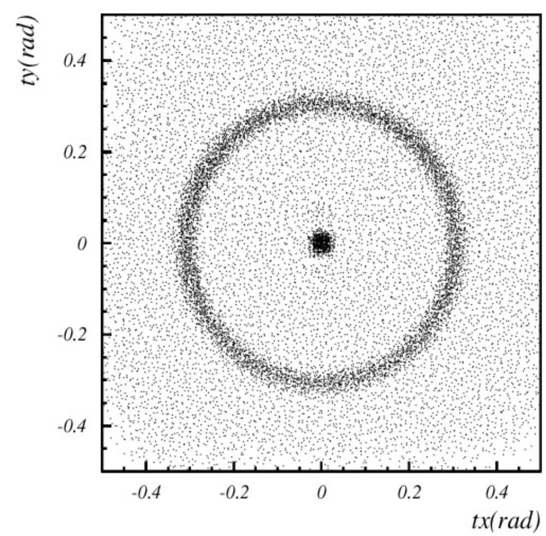




2+2cm aerogel







→NIM A548 (2005) 383

Cherenkov detectors

Barrel PID: Time of Propagation Counter (TOP)

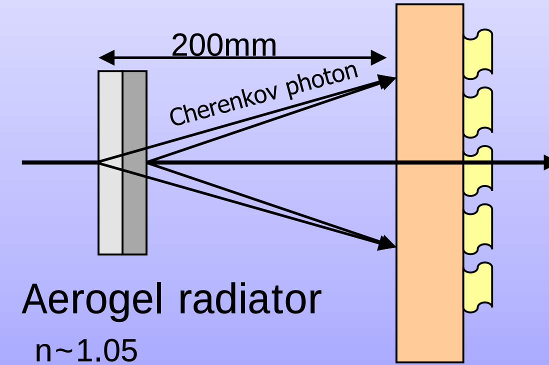
Quartz radiator

Focusing mirror

Small expansion block

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

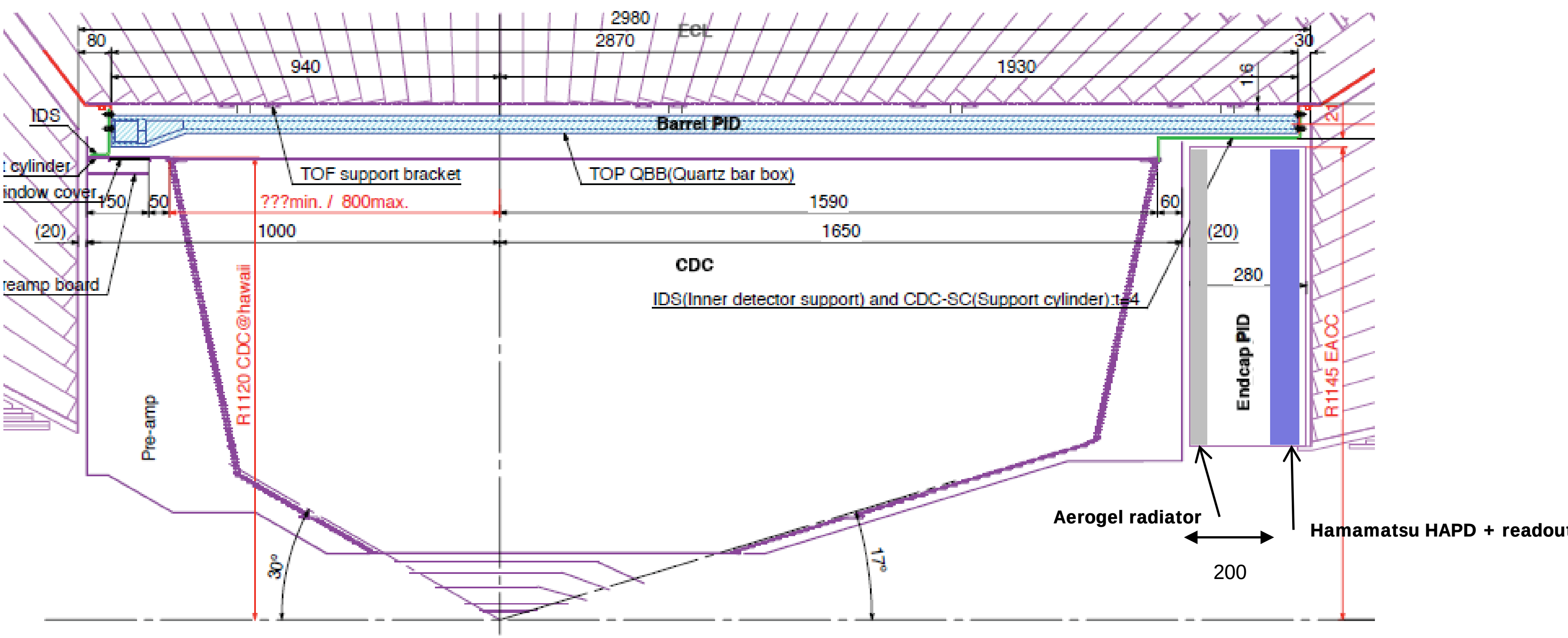
Endcap PID: Aerogel RICH (ARICH)



Aerogel radiator

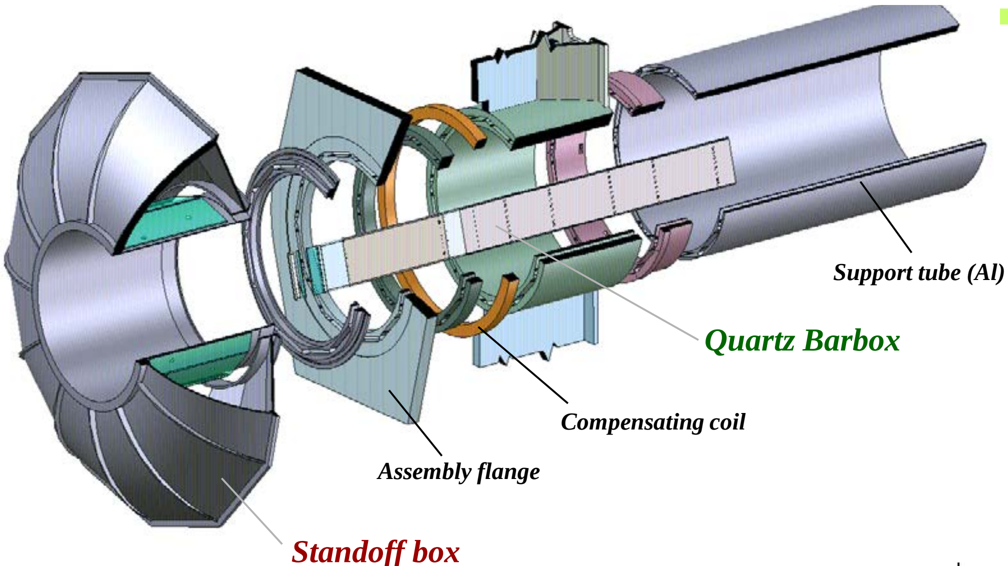
n~1.05

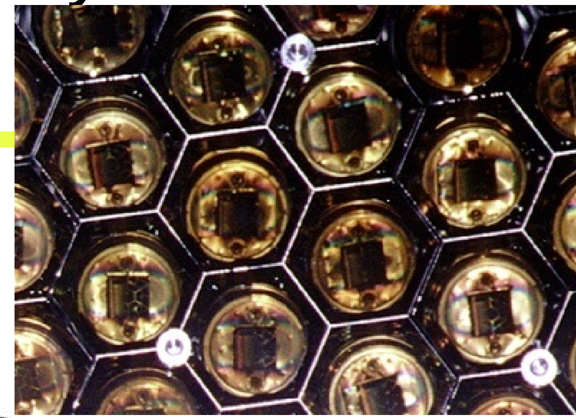
Hamamatsu HAPD
+ new ASIC

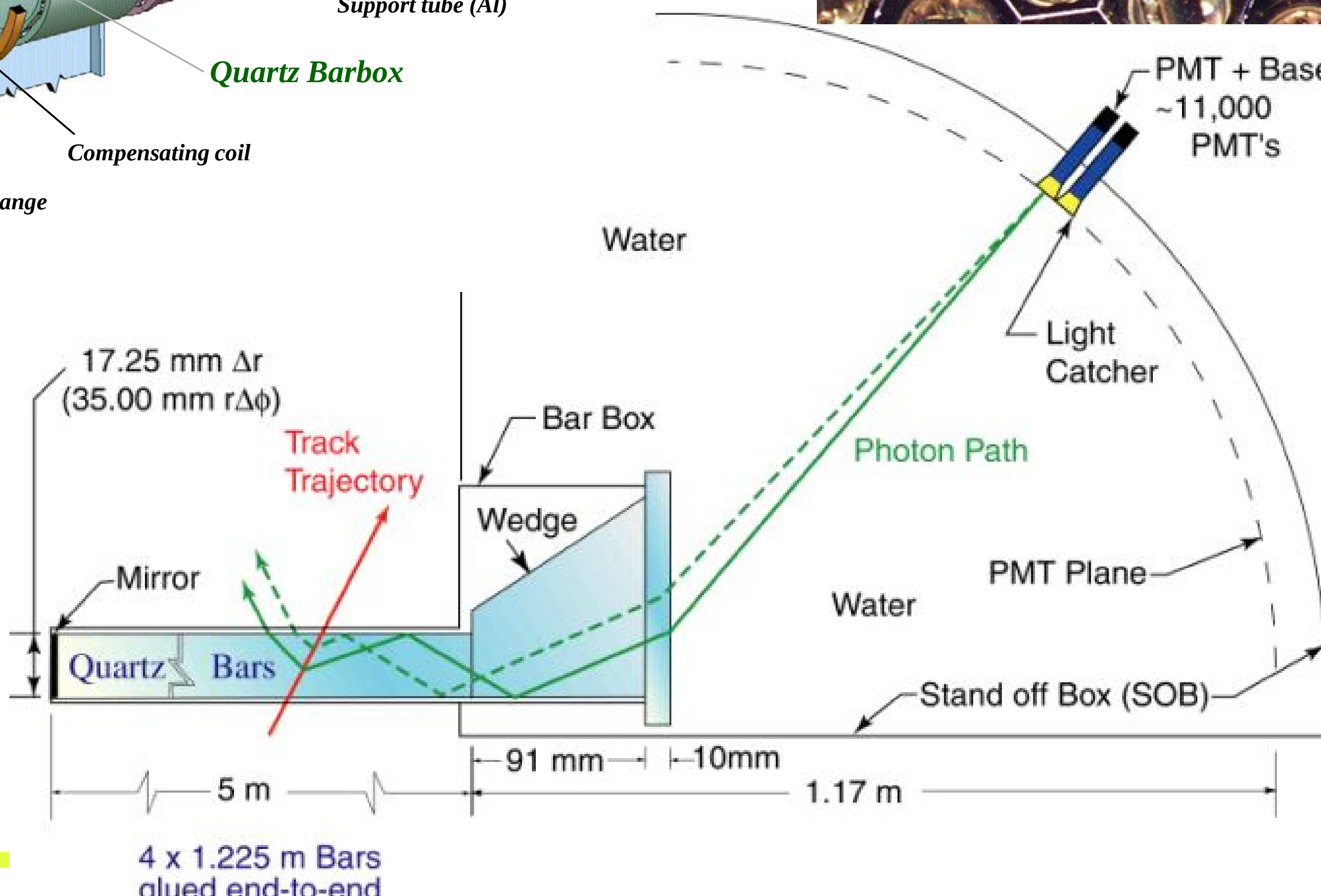


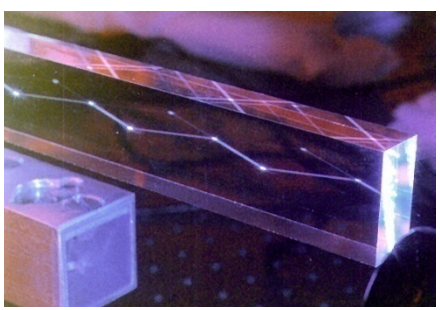
Peter Križan, Ljubljana

DIRC (@BaBar) - detector of internally reflected Cherenkov light

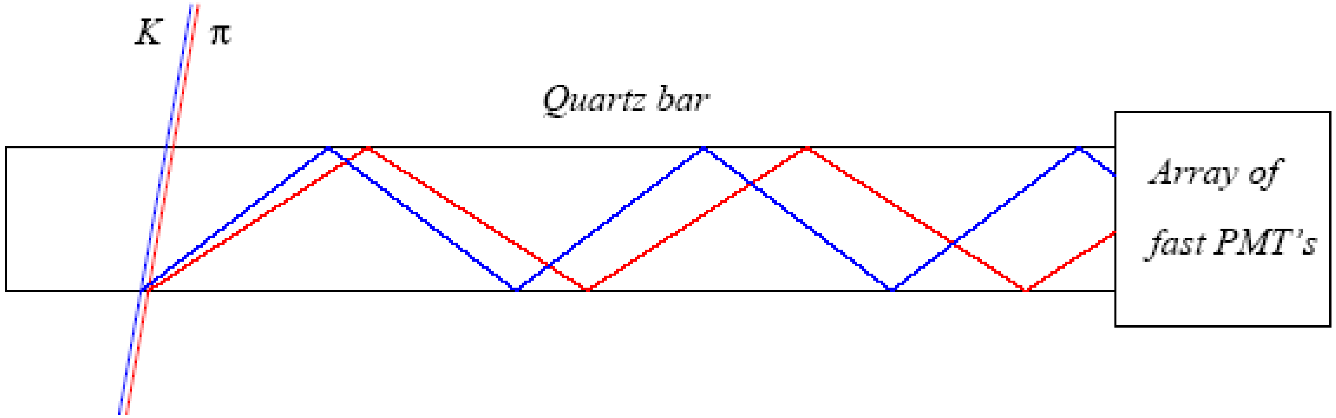


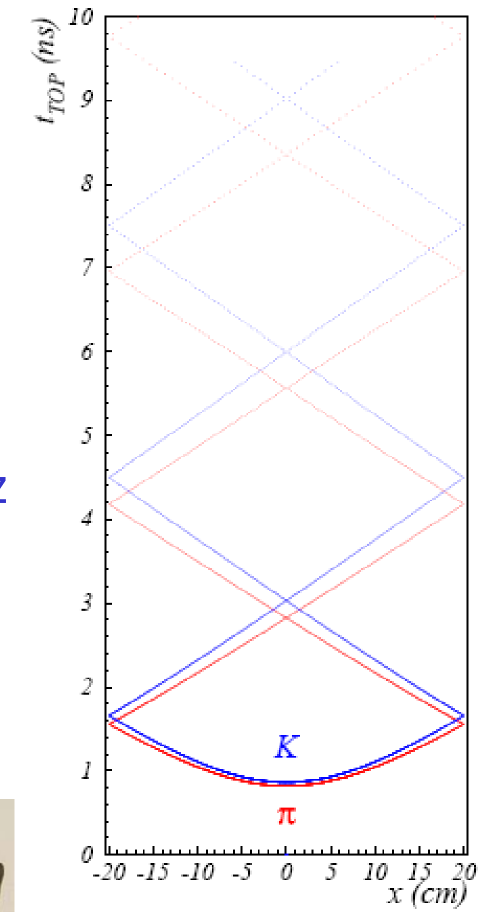






Belle II Barrel PID: Time of propagation (TOP) counter



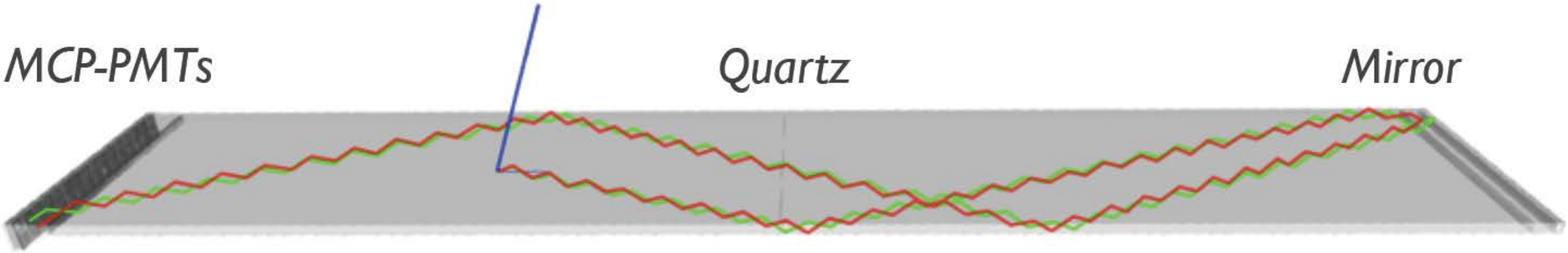


- Cherenkov ring imaging with precise time measurement.
- Uses internal reflection of Cherenkov ring images from quartz like the BaBar DIRC.
- Reconstruct Cherenkov angle from two hit coordinates and

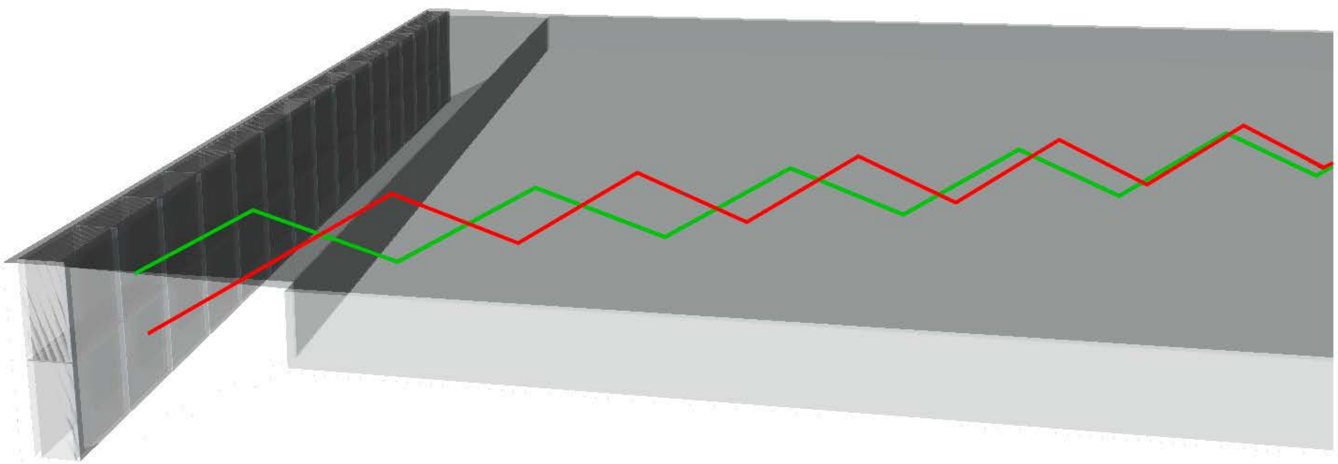
the time of propagation of the photon

  - Quartz radiator (2cm thick)
  - Photon detector (MCP-PMT)
    - Excellent time resolution ~ 40 ps
    - Single photon sensitivity in 1.5

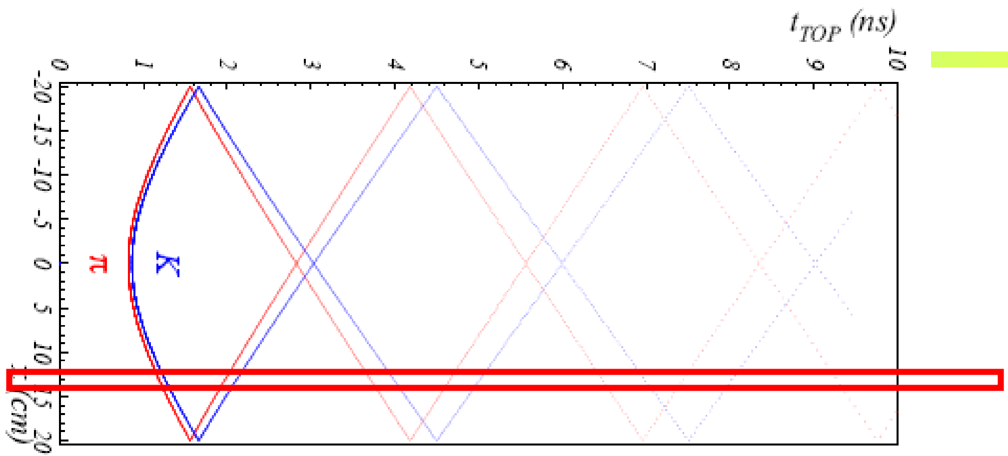
Barrel PID: Time of propagation (TOP) counter



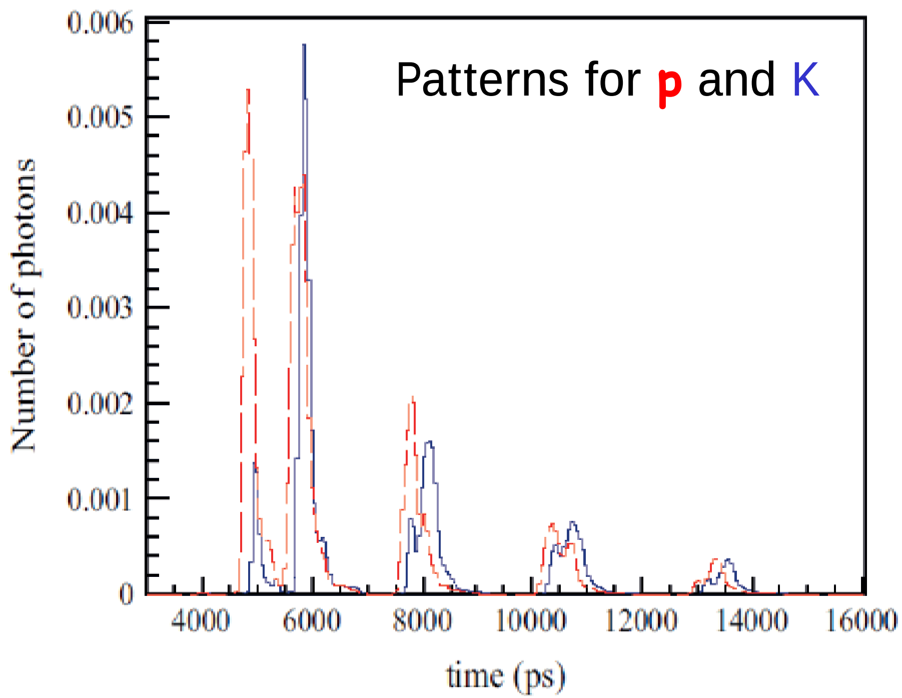
Example of Cherenkov-photon paths for 2 GeV/c $\pi^{\pm}$ and $K^{\pm}$.



TOP image

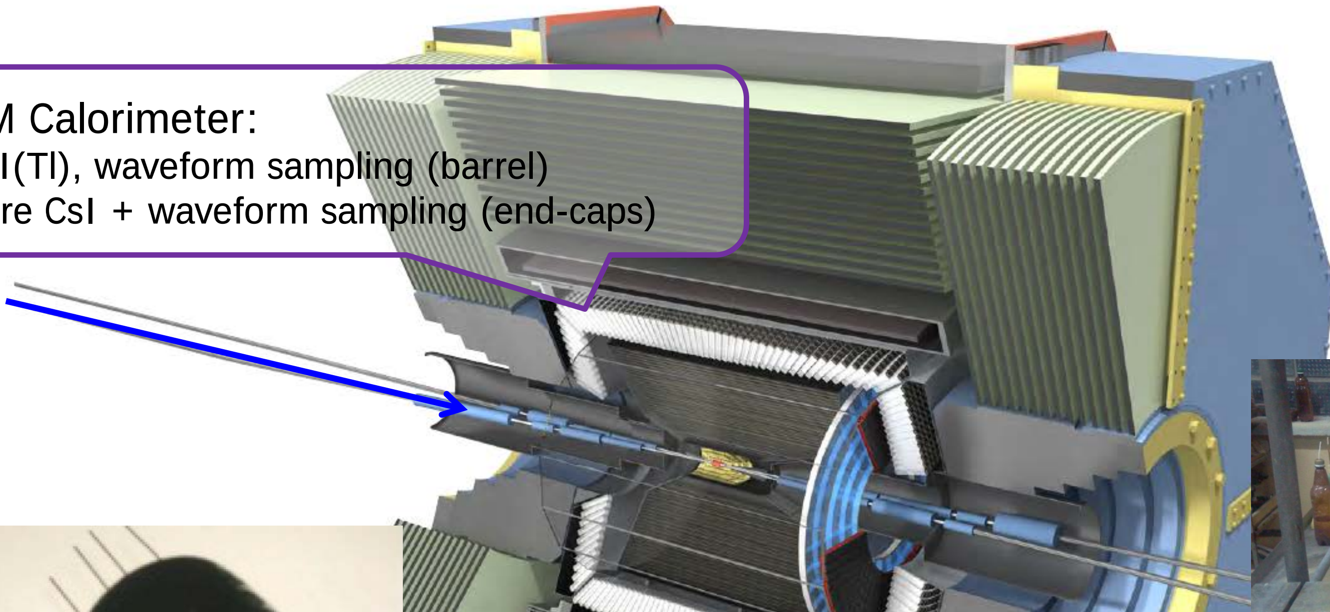


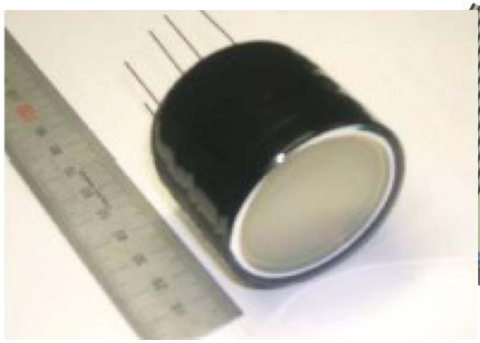
Pattern in the coordinate-time space ('ring') of a pion and kaon hitting a quartz bar



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

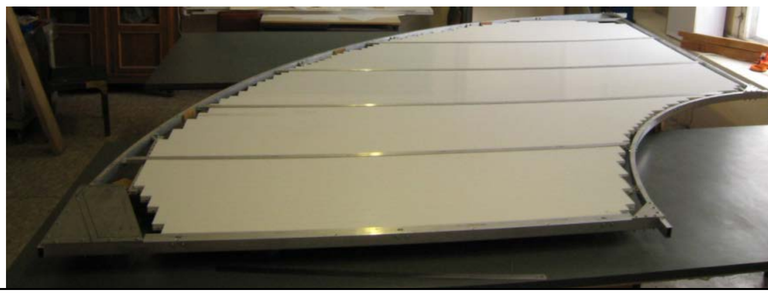
EM calorimeter: upgrade needed because of higher rates (electronics → waveform sampling) and radiation load (endcap, replace some fraction of crystals CsI(Tl) → pure CsI)

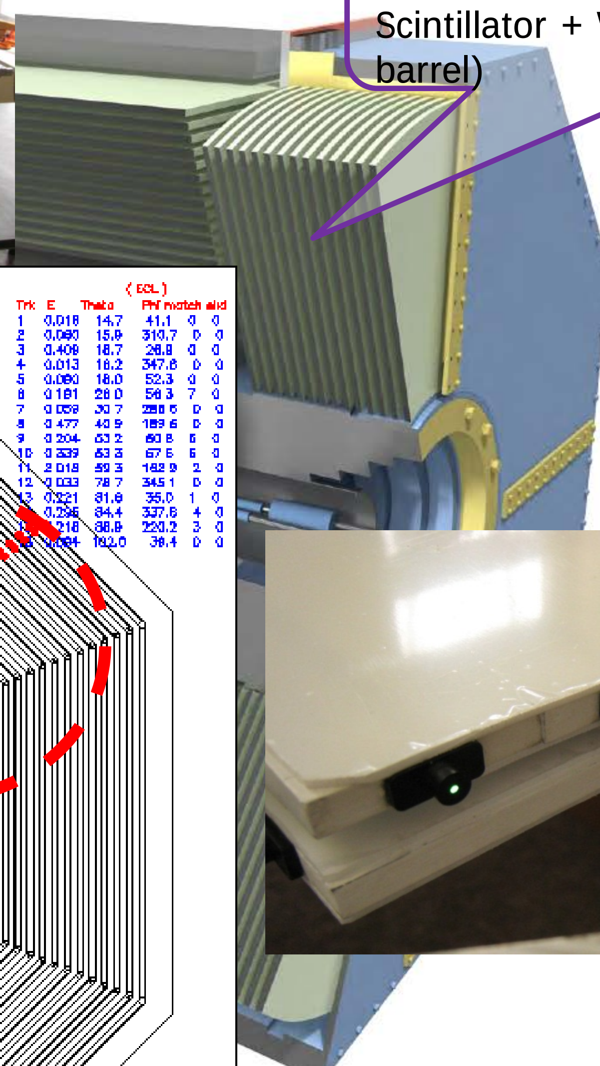


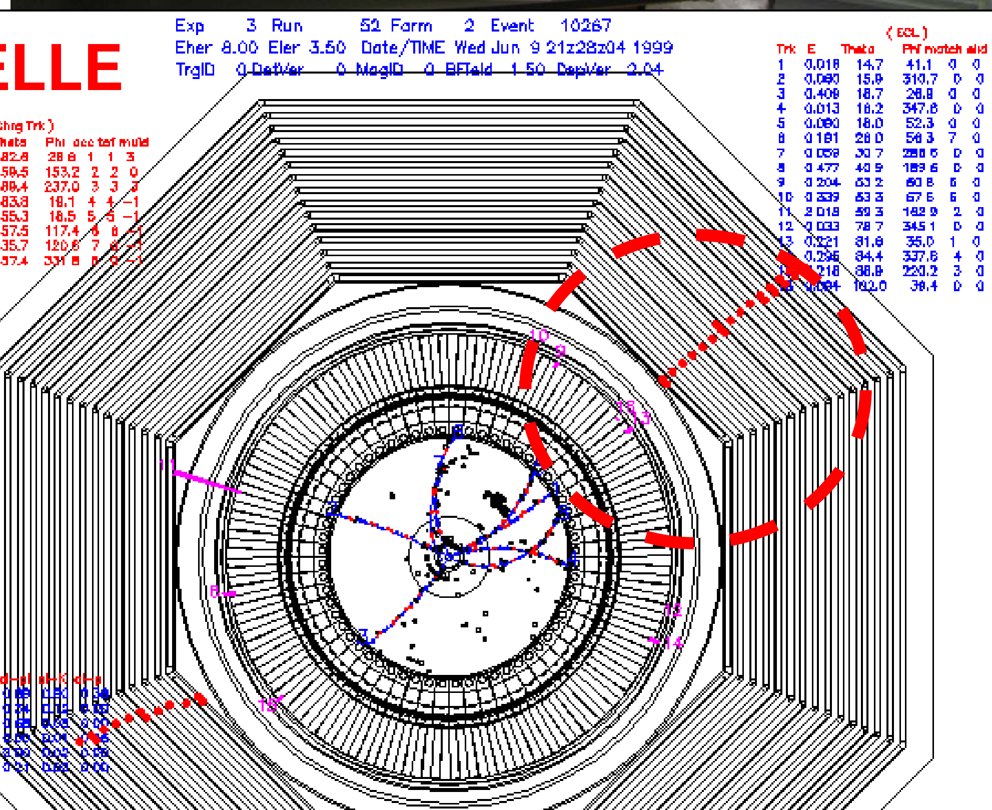


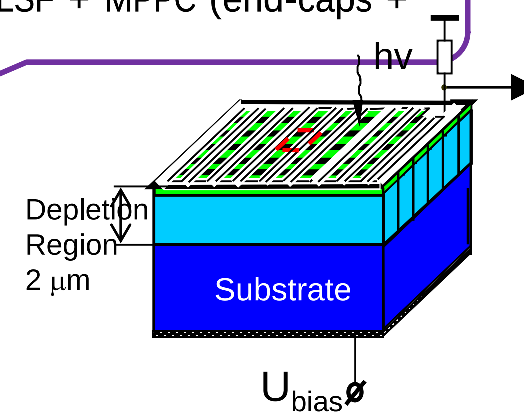
Detection of muons and K_Ls: parts of the original RPC system have to be replace because they could not handle the high background rates (mainly neutrons)

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







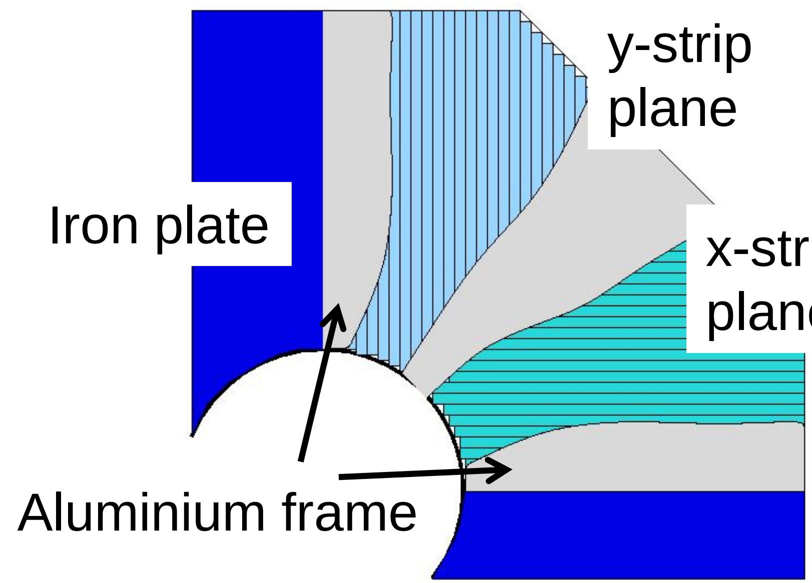


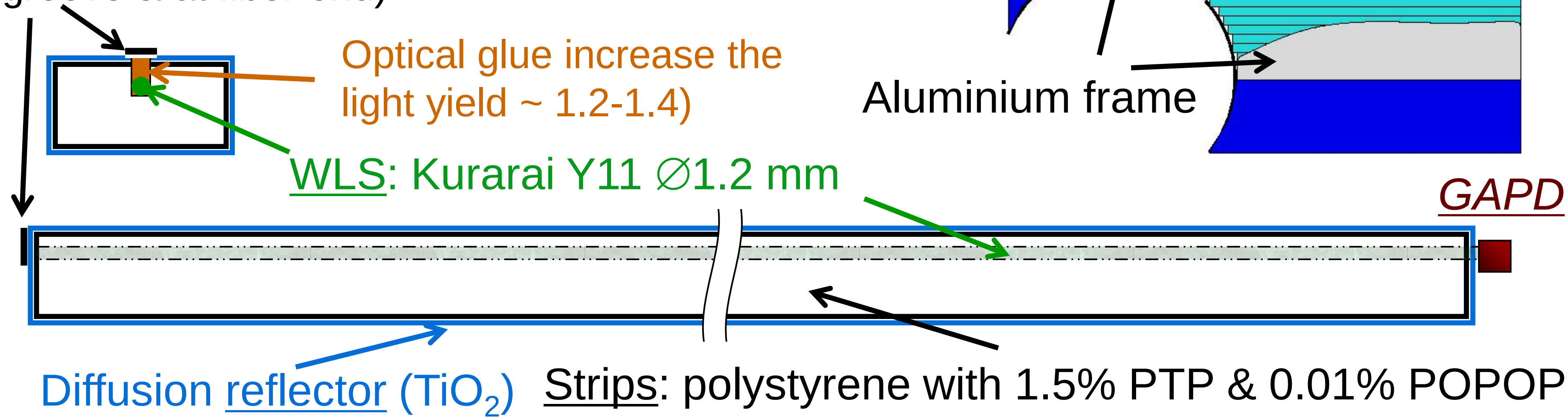
ljana

Muon detection system upgrade in the endcaps

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%

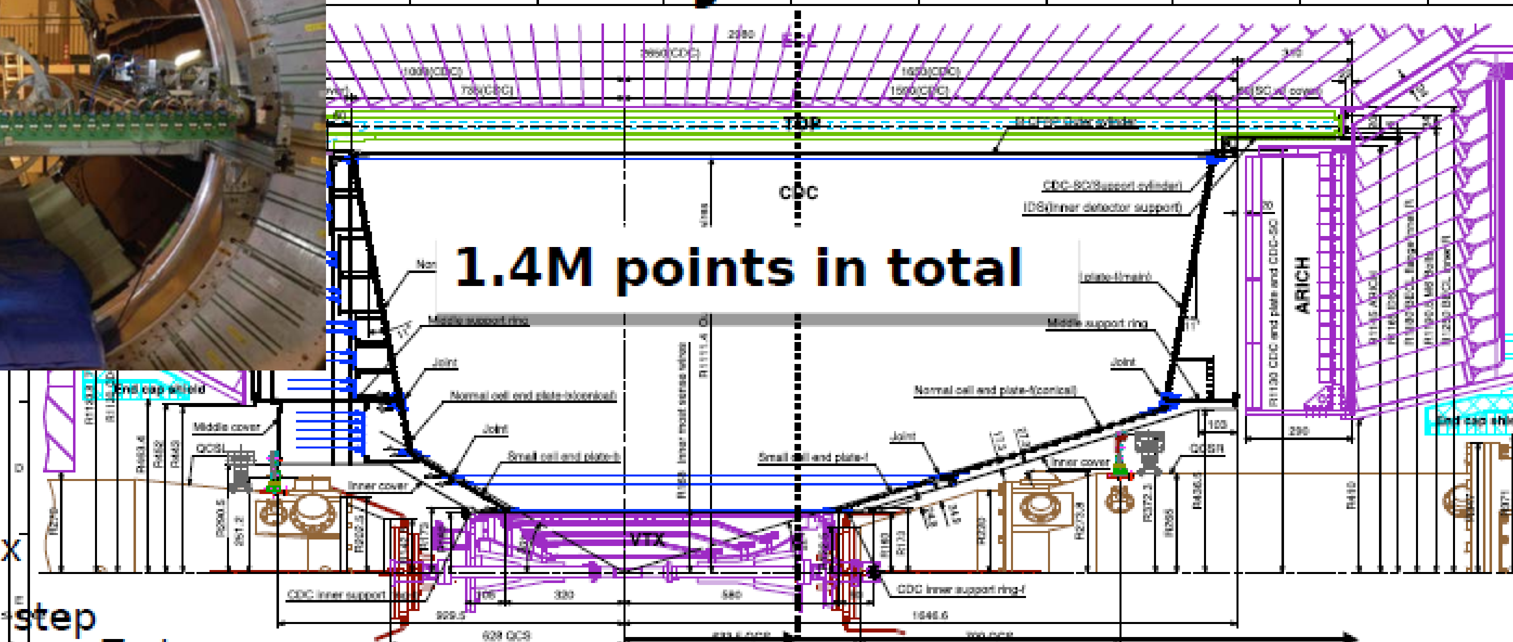




Outer Detector Highlights

Magnetic field survey

Summary of the data



1.4M points in total

File index

Phi step

Z step

10: 12; 22
11: 48; 16
12: 48; 46, 16
13: 48; 28, 16
14: 48; 79
15: 48; 38
16: 48; 38
17: 48; 92
18: 48; 46
19: 48; 46
20: 180; 8
21: 48; 91
22: 96; 40
23: 96; 40
24: 60; 67

27-28 June

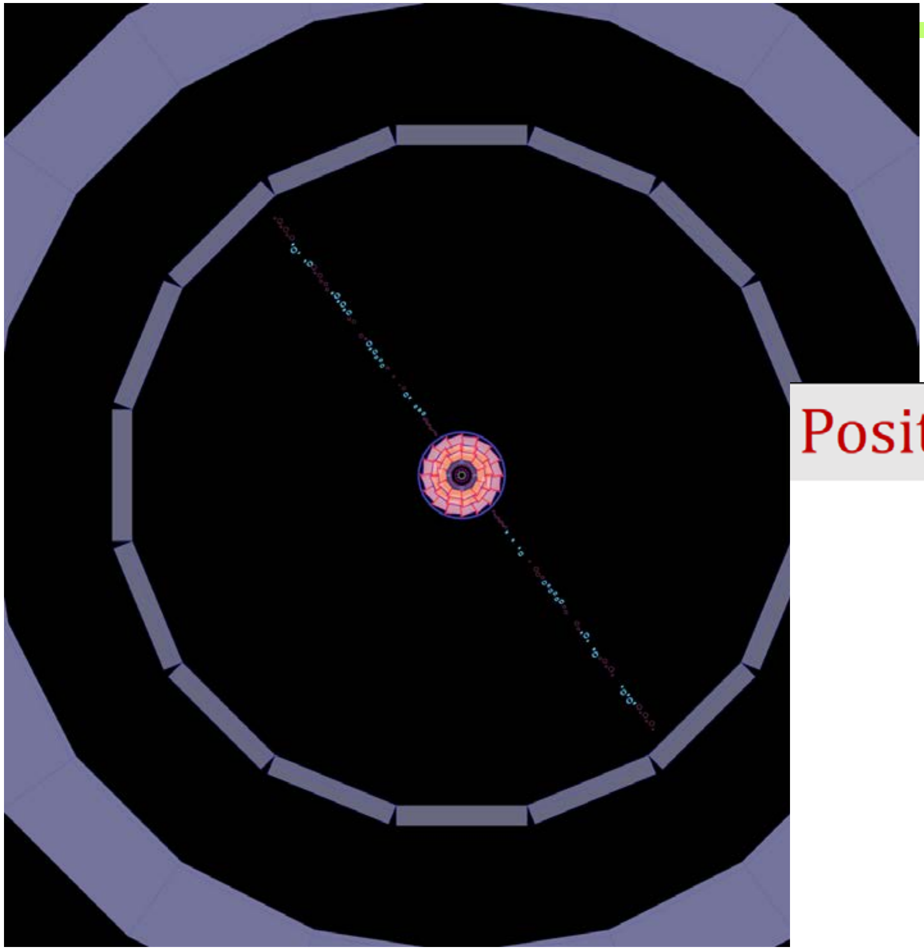
1-3 July

1.50 T

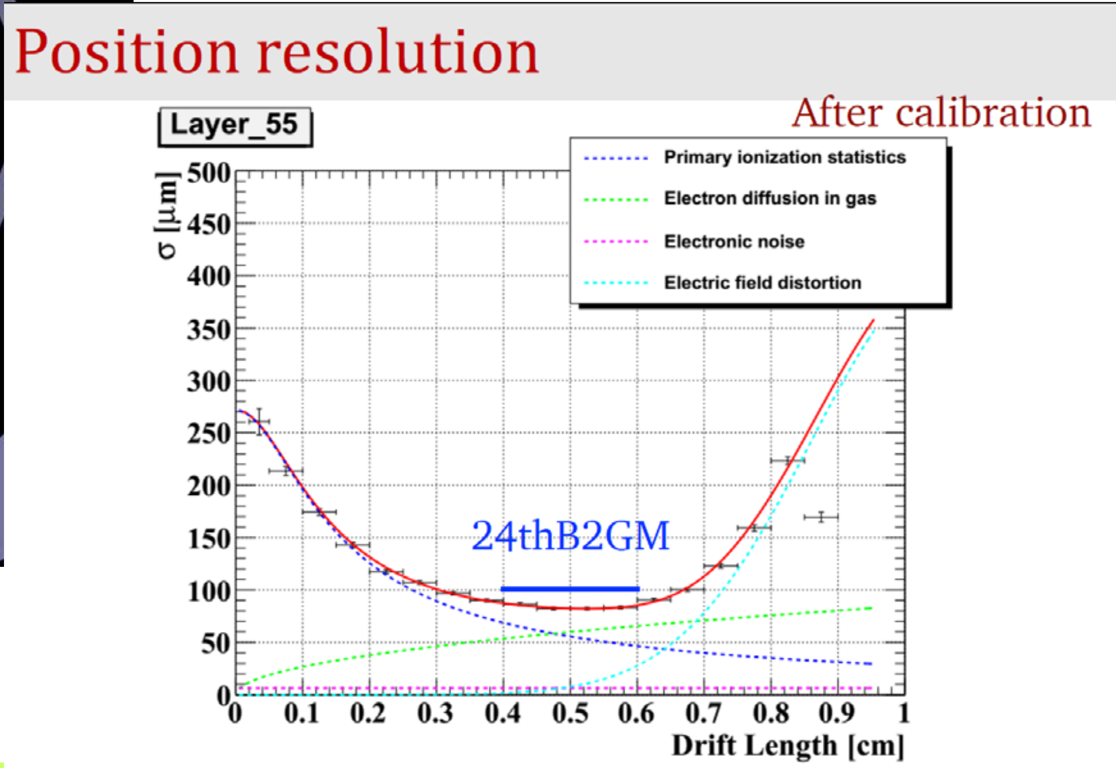
1.25 T

1.00 T

CDC, stand-alone cosmic test in spring



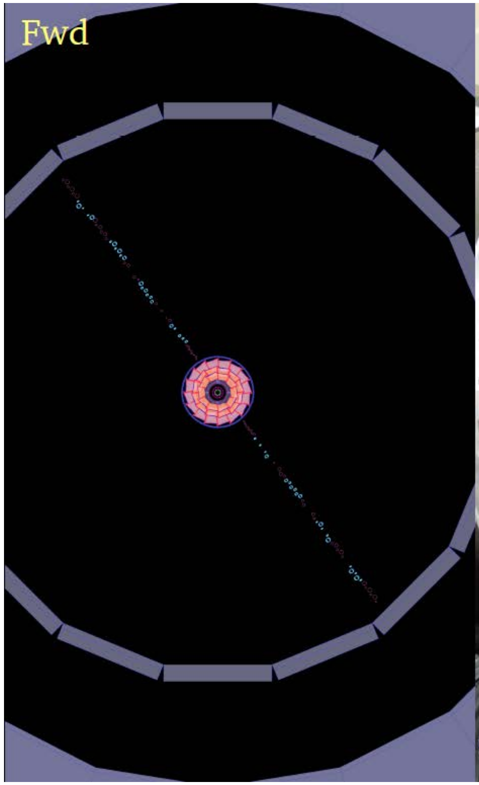
Excellent performance!



Position resolution at good region: 80-150μm, it depends on layer.

Before installation: CDC cosmic ray test

- A cosmic ray test was performed in the back-to-back configuration using 59(out of 299) FE boards.
- Clear tracks were observed using the real Belle-II central DAQ system.



Event display

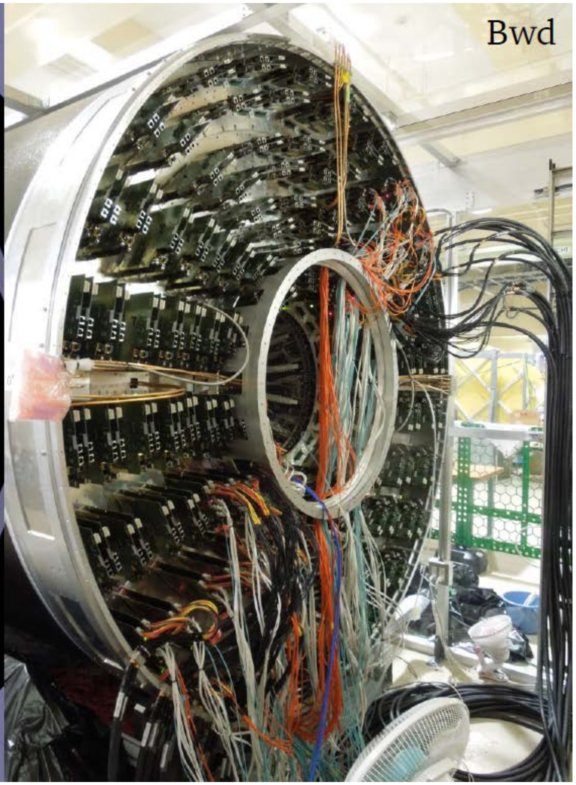
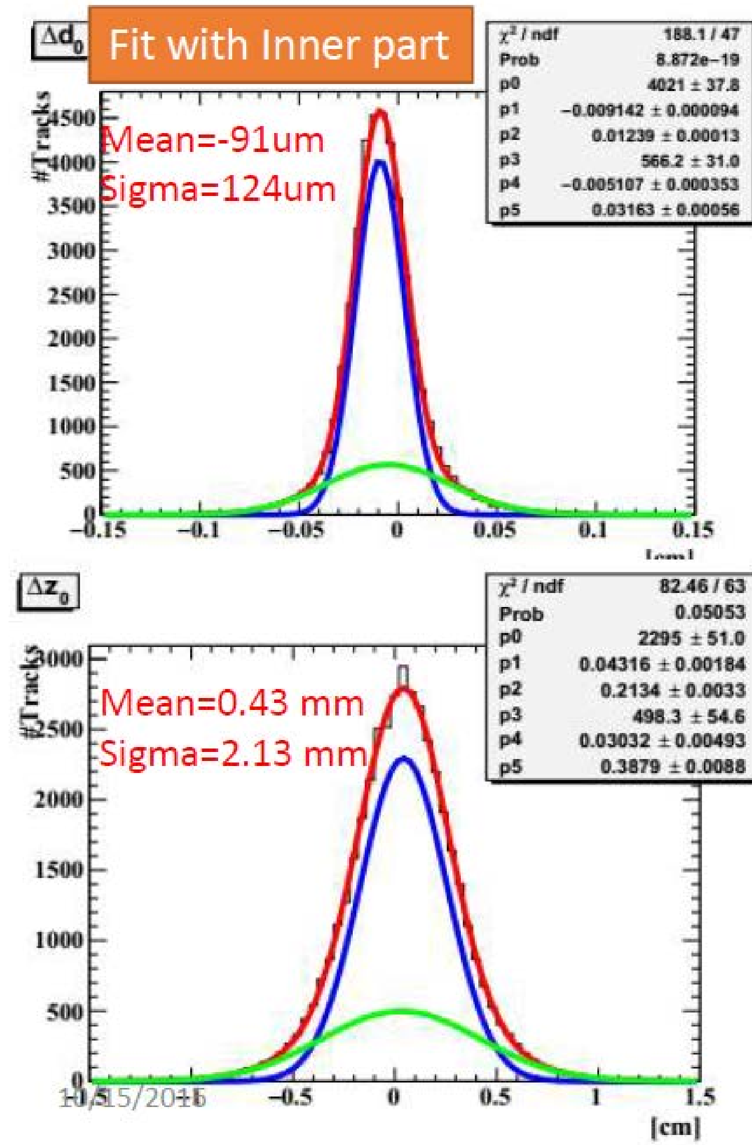


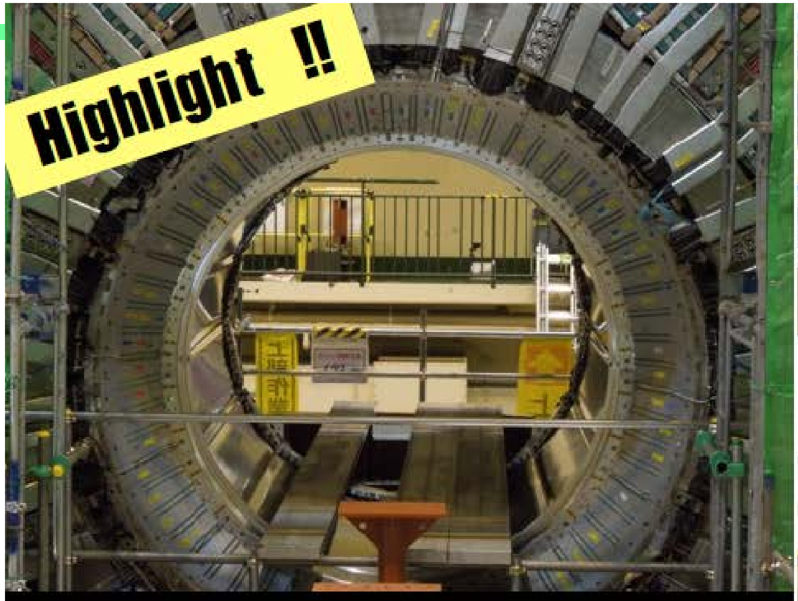
Photo in the side room with many cables

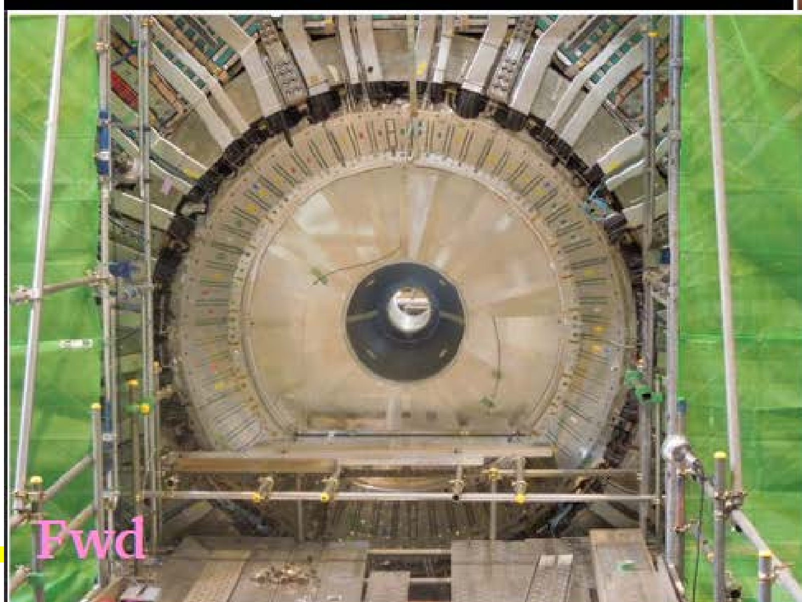
Analysis of CDC cosmic ray muons

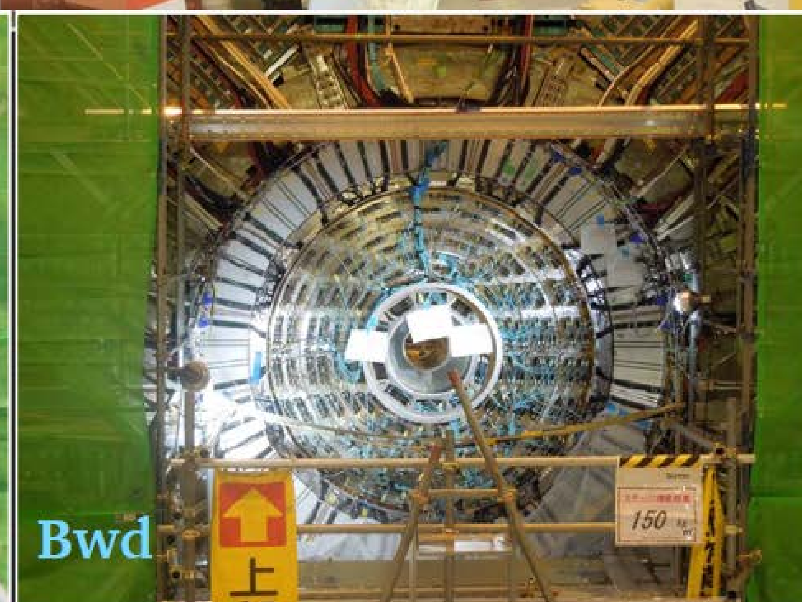
- Upper and lower track segments were analyzed separately.
- Reasonable matching resolutions were already obtained between two tracks in both r-φ and z directions even at this initial stage.
- A *small* systematic shift in r-ϕ is found due to a tiny rotation of the inner CDC with respect to main part of the chamber.



TOP and CDC: installed, cabling of CDC almost finished





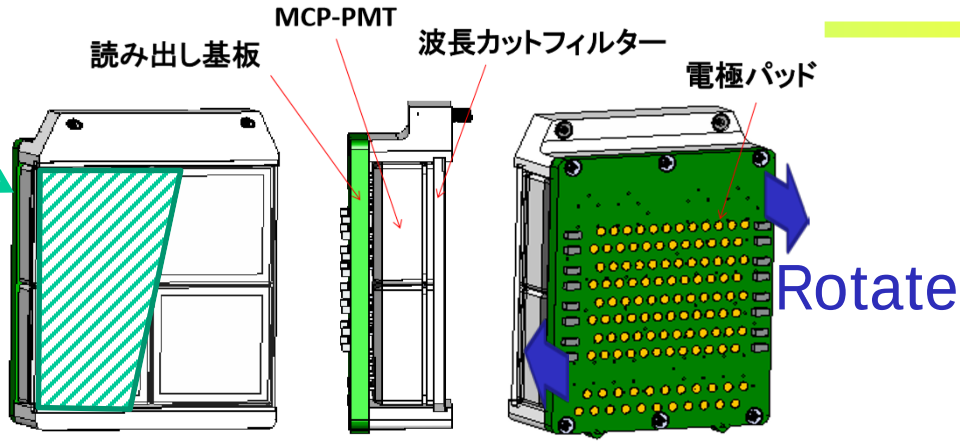


TOP: running the installed detector

- High statistics laser/cosmic running for all modules with stable ASIC configuration completed
  - Both with and without B-field to understand performance differences
- Significant progress on firmware, but <u>feature extraction</u> not yet implemented on installed modules due to urgent need for stable operation
- <u>Gain operational experience in 1.5 T B-field !</u>
  - Serious issue with PMTs discovered (“rotation issue”)
  - MCPs use Kovar (Cobalt-Nickel alloy) and are magnetic.
  - Repair to main issue completed

MCP-PMT Rotation Problem

Peeled off from here

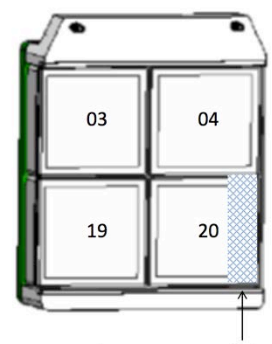


- <u>Repaired all 16 modules</u> and retested in B-field prior to CDC installation
  - Shim between PMT modules and aluminum enclosure on side that wants to move towards the prism to restrict rotation
- <u>New problem</u> of individual PMTs moving found in 2 MCPPMT modules
  - Fixed these and decided to install CDC and observe TOP until Phase II-III shutdown

Slot07 PMTmodule07

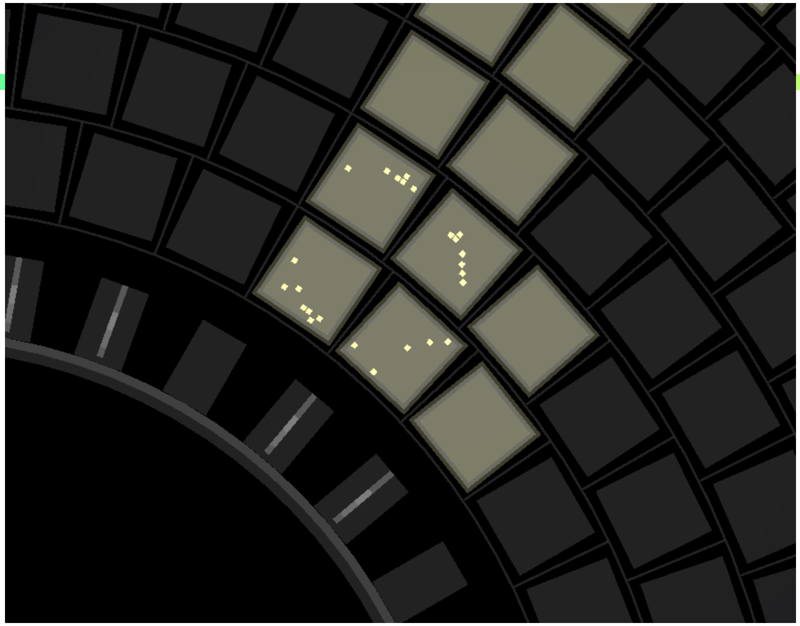
The bottom two PMTs rotated and came off the filter.

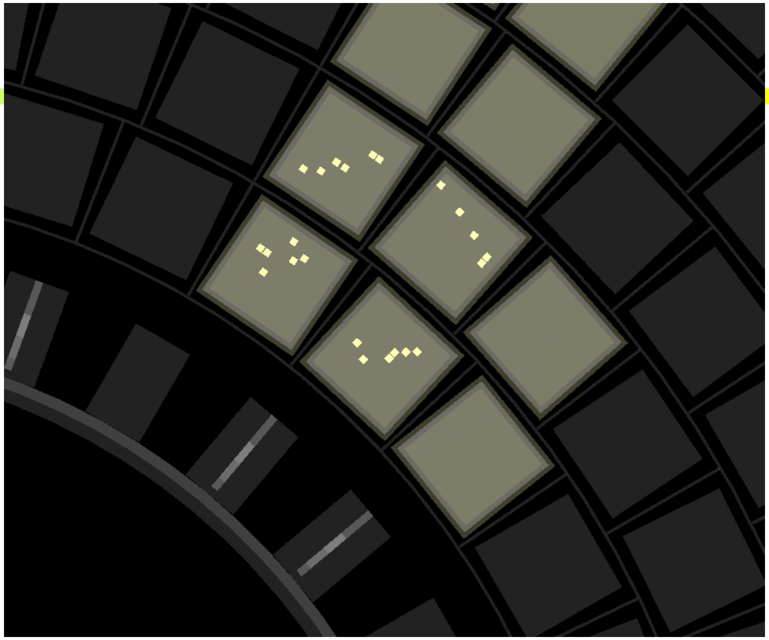
Slot11 PMTmodule02

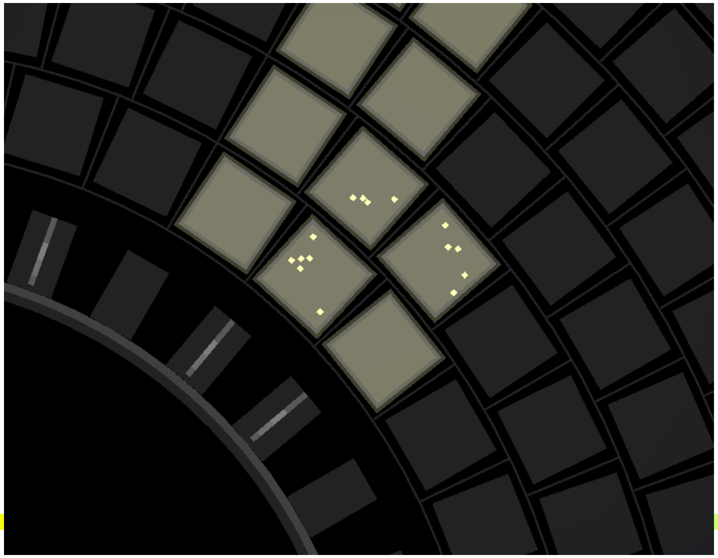


This part came off the filter.

ARICH: Rings from cosmic ray muons

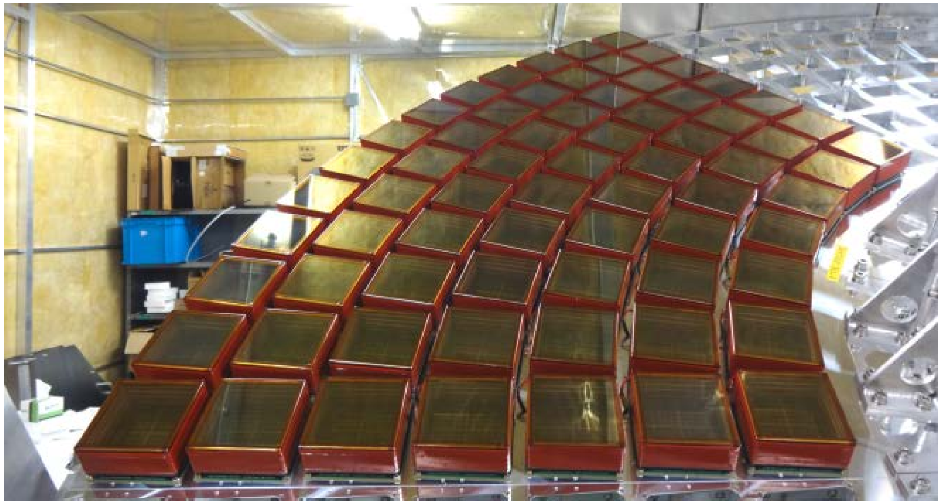






One sector of the ARICH has been instrumented.

ARICH Highlights

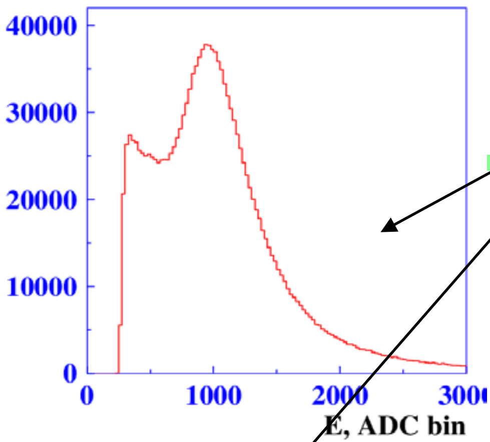


- First rings observed in August
- We are expanding our cosmic test setup for more HAPDs.
- We expect to complete the detector in Mar. 2017. After the system test, ARICH will be ready to connect with forward endcap in May 2017.

- Aerogel installation will be finished in Nov.
- Photosensor (HAPD) delivery will be completed by the end of the year.
- HV connectors and cables are critical for ARICH construction schedule.
  - ✓ We plan to finish the test with of cables HAPDs in Oct., and we want to move to mass production immediately after that.

The magnetic torque on HAPDs seems to have only a small impact. Probably this is not an issue, though additional test are planned. Measurements in excellent agreement with calculations.

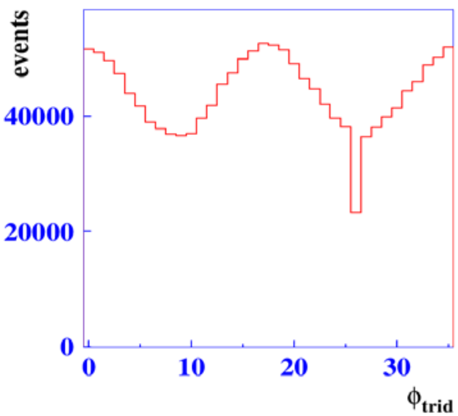
ECL Highlights

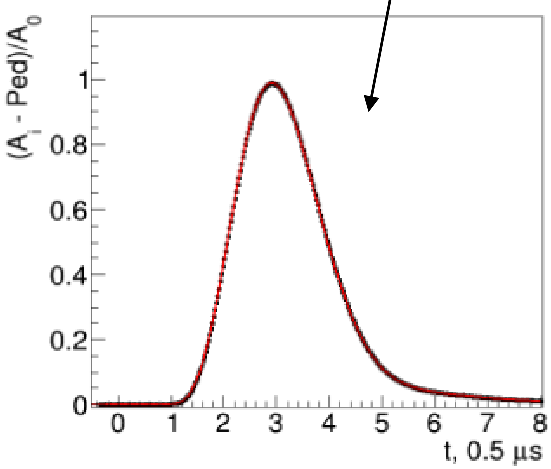


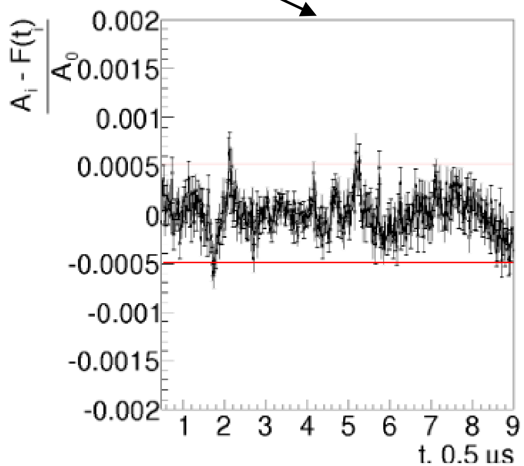
ECL Trigger is now available

Shape of the signal from each of 6624 barrel counter was calibrated

Accuracy of shape description is 10^{-3}







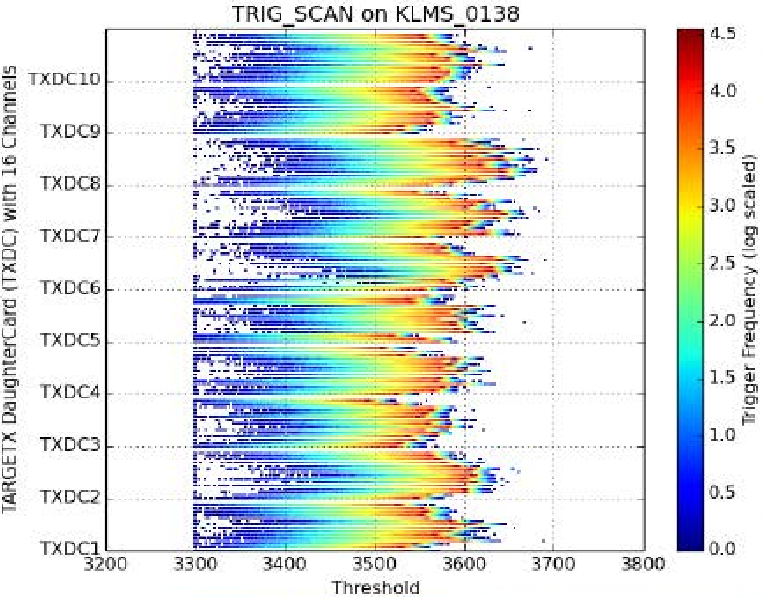
- **Firmware modifications for Shaper DSP were implemented:**

-test pulse time stability

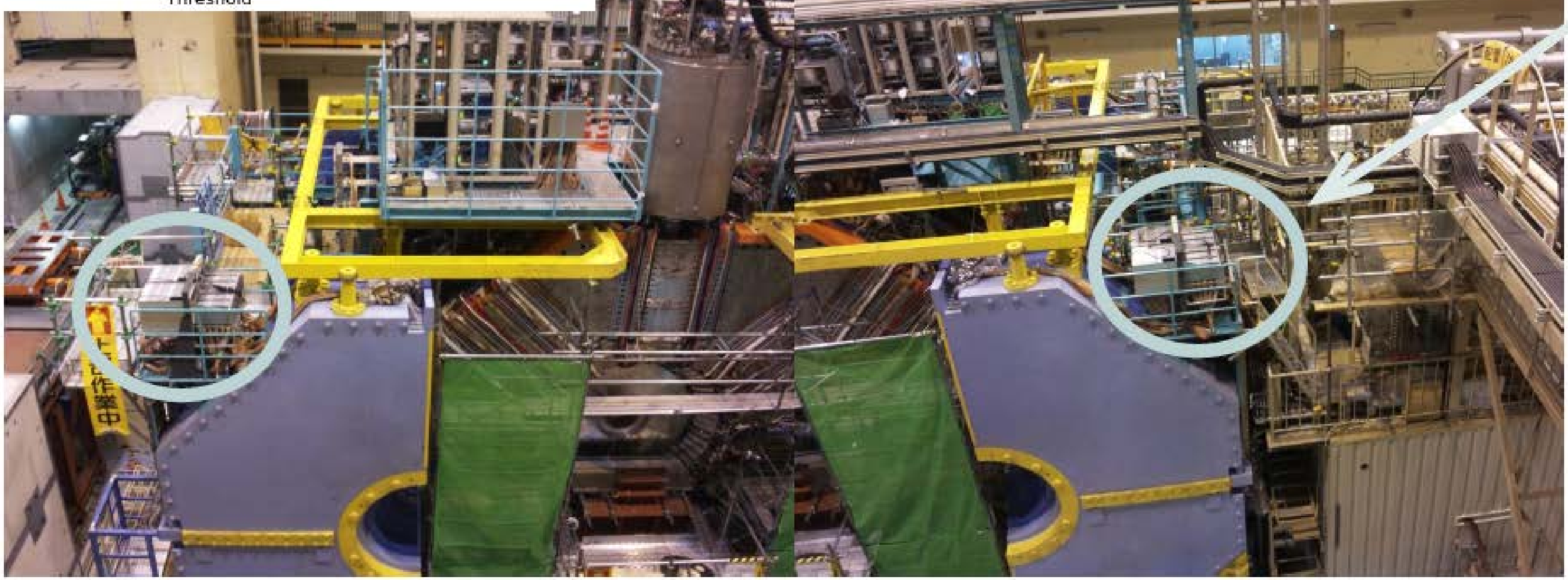
-uploading of shaperDSP from optical link

All Backward KLM sectors fully connected to DAQ boards and tested

EKLM



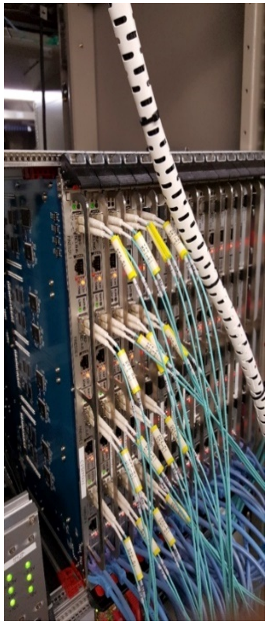
Test of one superlayer, 150 channels

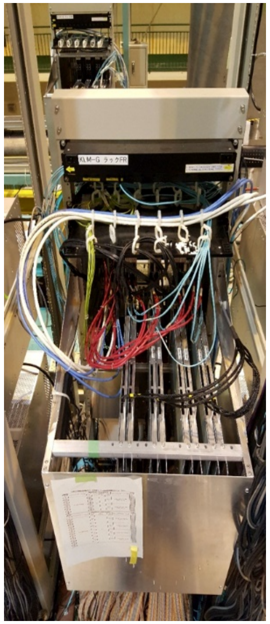


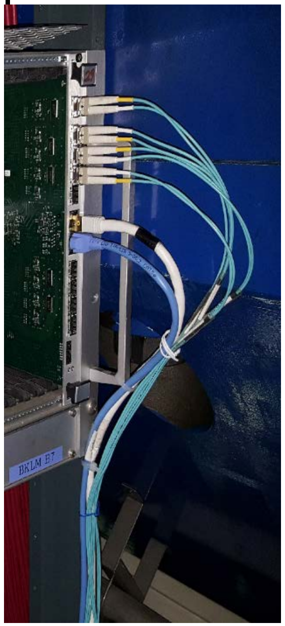
Forward KLM sectors: 30% done, complete connection by the end of this year

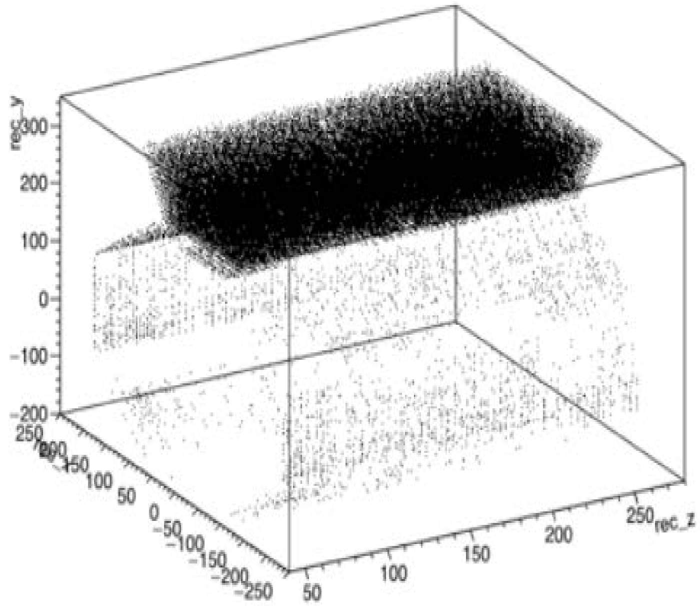
BKLM Highlights

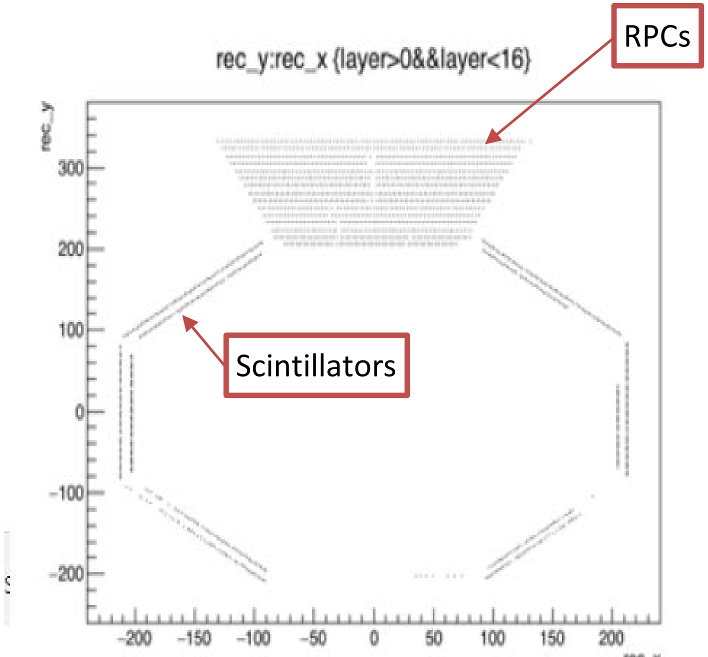
- ✓ All DAQ infrastructure (scintillator readout modules, data concentrators, cables/fibers, FTSWs, COPPERs, UT3 trigger) installed
- ✓ Forward octants BF0–BF7 operational *(taking data, sending to backend)* ➡
- ✓ UT3 trigger for KLM-TOP is operational
- ✓ INFN contracts awarded for production of 250 RPC readout boards: completion 7/17







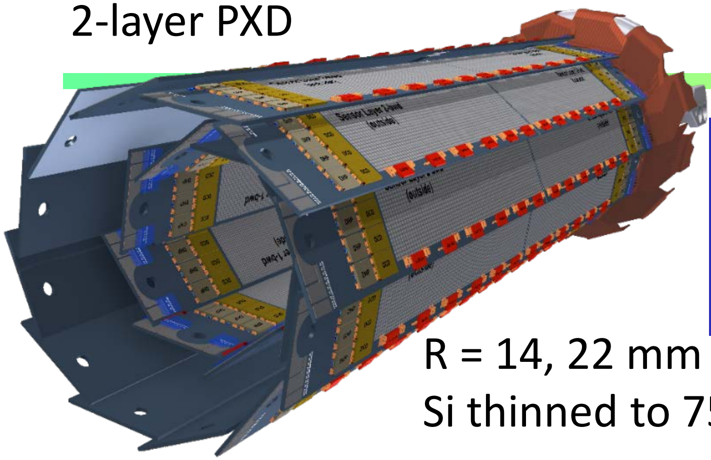




Global DAQ: 2D hits in BKLM Forward octants

PXD Ladder Production

2-layer PXD



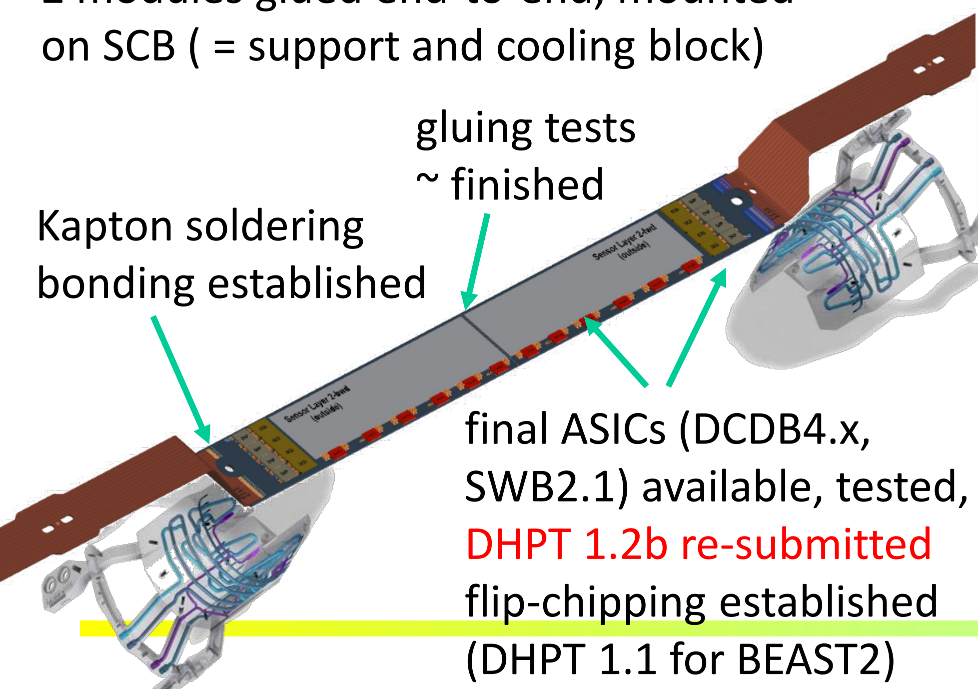
R = 14, 22 mm
Si thinned to 75 µm

Total of 29 wafers in process (172 sensors, 40 needed)
Combined yield Pilot (3) + PXD9-7 (4) + PXD9-8 (5 sensors):

- **74/96 (87.5%) working sensors (>97.5% pixels)**
- **64/96 (66.7%) prime grade sensors (>99% pixels)**
- **Production yield better than expected (> 50%)**

Main prod. 1 (PXD9-8): 9 wafers (5 ready)
Main prod. 2 (PXD9-9): 6 wafers (= metalliz.)
entire production finished by Dec. 2016
Contingency: 7 wafers (Phase II: metal 1)

8 (L1) / 12 (L2) self-supporting ladders:
2 modules glued end-to-end, mounted on SCB (= support and cooling block)



gluing tests
~ finished

Kapton soldering
bonding established

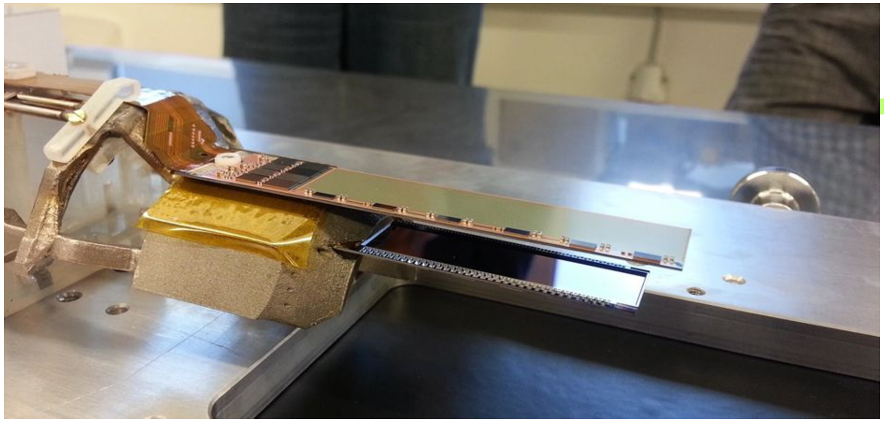
final ASICs (DCDB4.x, SWB2.1) available, tested,
DHPT 1.2b re-submitted
flip-chipping established
(DHPT 1.1 for BEAST2)

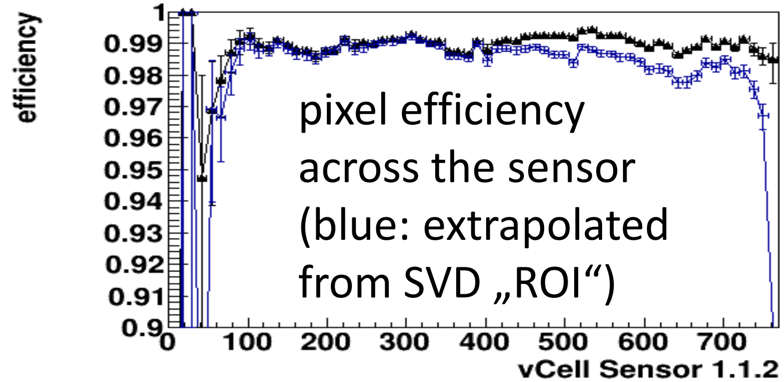
We have already now all PXD sensors needed for the Phases 2 and 3 PXD („contingency“ production continues)

Bottleneck right now: bumping of SWB2.1 (comes as single chip from MPW run), *develop new process* with IZM Berlin in (wafer) matrix, first results next month

Module production for BEAST2 started (flip-chipping at IZM, back in 3 weeks)

PERSY (Permanent System @ DESY) → BEAST2 → PXD





The start: 2 PXD modules with ASICs, SMDs and Kapton, fixed on and cooled by SCB (April ,16)

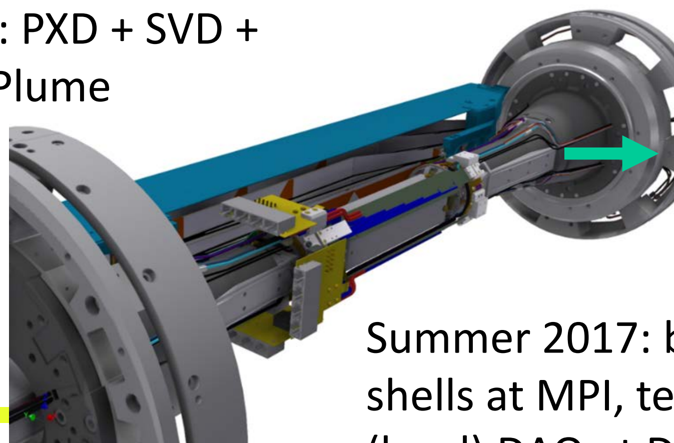
Aim: stepwise system integration including DHH / Onsen /pocket DAQ

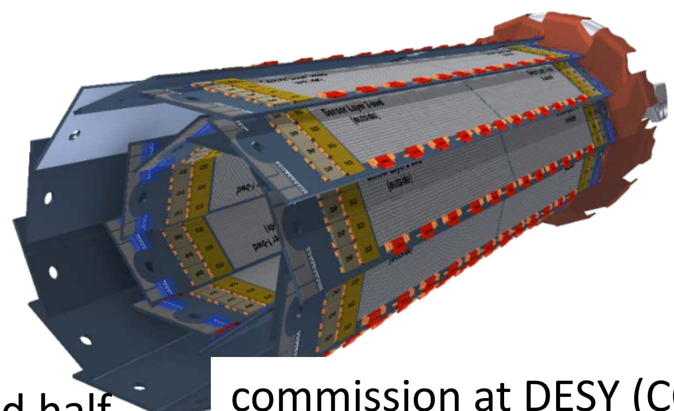
Present status (fall 2016): Problems during DESY test beam (April 2016) solved (ROI crisis, event number mismatch)

Next step (Dec `16 – Feb `17). Build Phase 2 detector system: PXD + SVD + FANGS/CLAWS/Plume

full DAQ:
- Dec. `16

final beam test:
- Feb `17





Summer 2017: build half shells at MPI, test with (local) DAQ at DESY

commission at DESY (CO2 / cosmics), transport to KEK by early spring `18

VXD (= PXD + SVD) Interaction Region Components

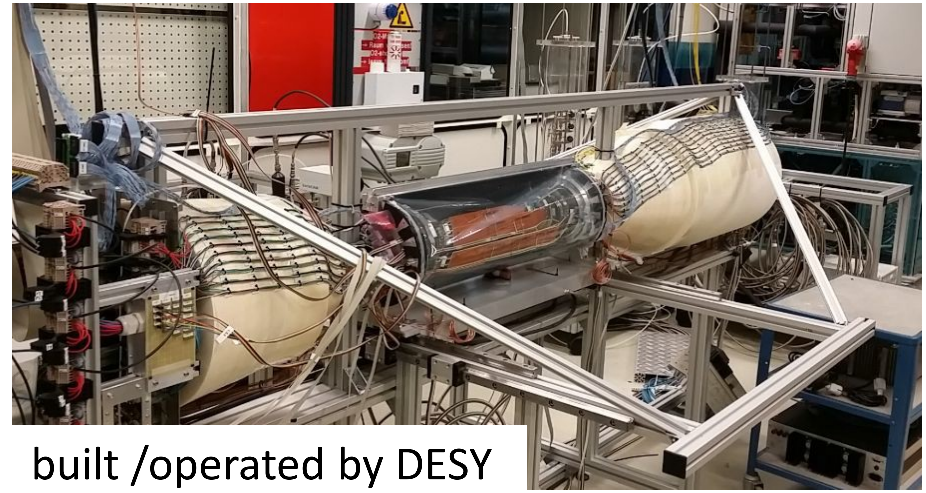
2-phase CO_2 cooling unit („IBBelle“)

built at MPI in collaboration with CERN / Nikhef (~same as ATLAS unit)

Cooling power > 2 kW fully comissioned at MPI (needed for PXD/SVD : 360/750 W)

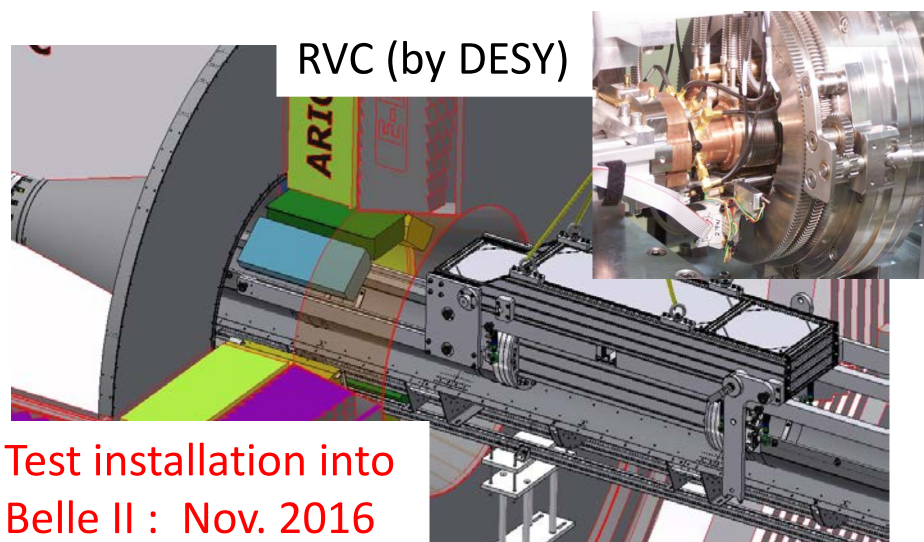
IBBelle has arrived at KEK on Oct. 20

VXD thermal management mockup for CO2 cooling studies: original sizes and materials



built /operated by DESY

VXD installation into Belle (design by MPI)



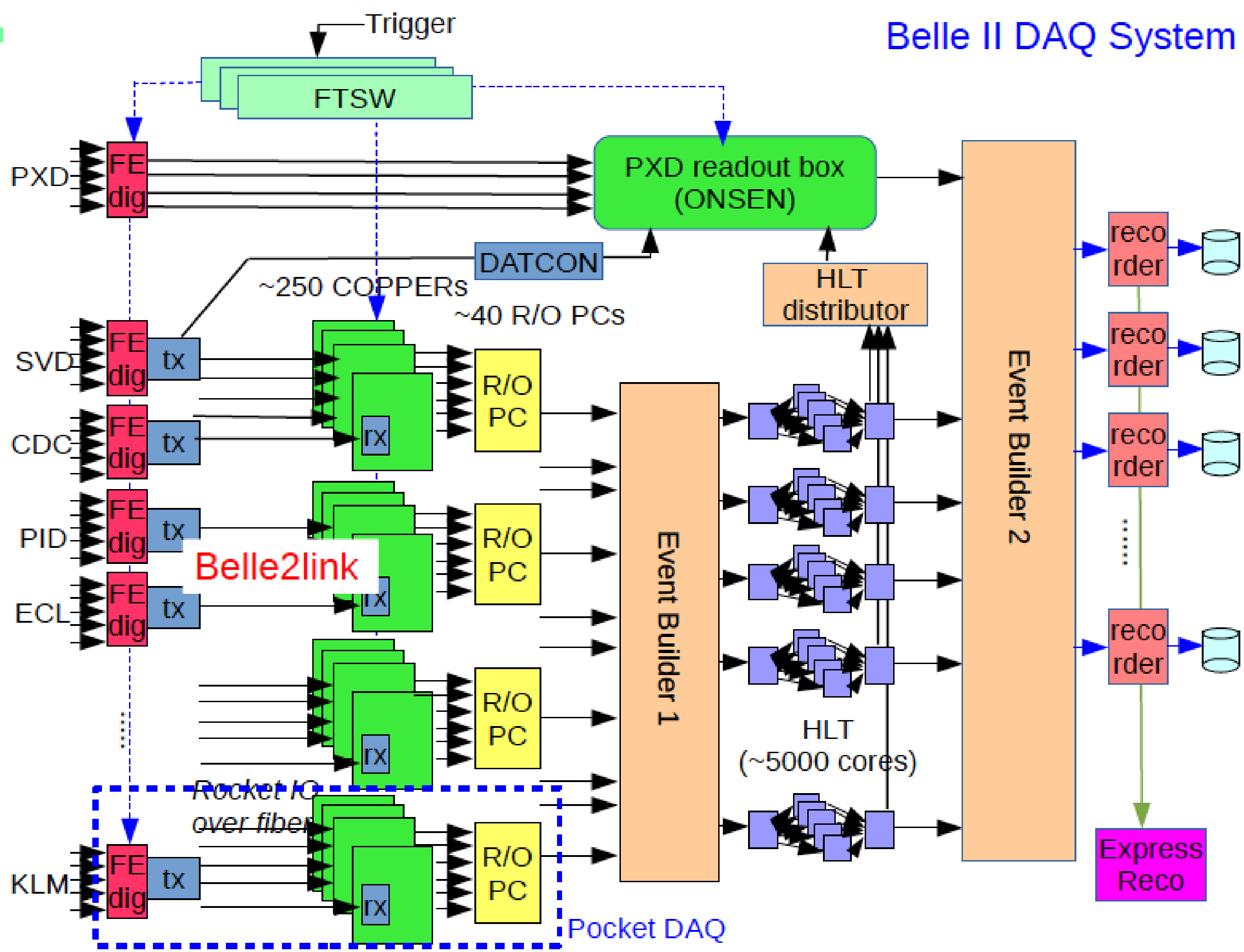
RVC (by DESY)

Test installation into Belle II : Nov. 2016

SVD ladder production status

- Pisa (FW/BW) Production of the nominal 47 forward and backward sub-assemblies completed by October 7, 2016
- Melbourne (L3) 9 out of 7+2 ladders completed by October 11, 2016
- TIFR (L4) 4 out of 10+2 ladders completed, assembly of the 5th class A ladder ongoing
- HEPHY (L5) 4 out of 12+3 ladders completed, assembly of the 5th class A ladder ongoing
- Kavli IPMU (L6) 3 out of 16+4 ladders completed, assembly of the 4th class A ladder ongoing; 7 working day/week assembly shift system is being set up, which will allow L6 to meet the global schedule.

Trigger, DAQ and readout integration



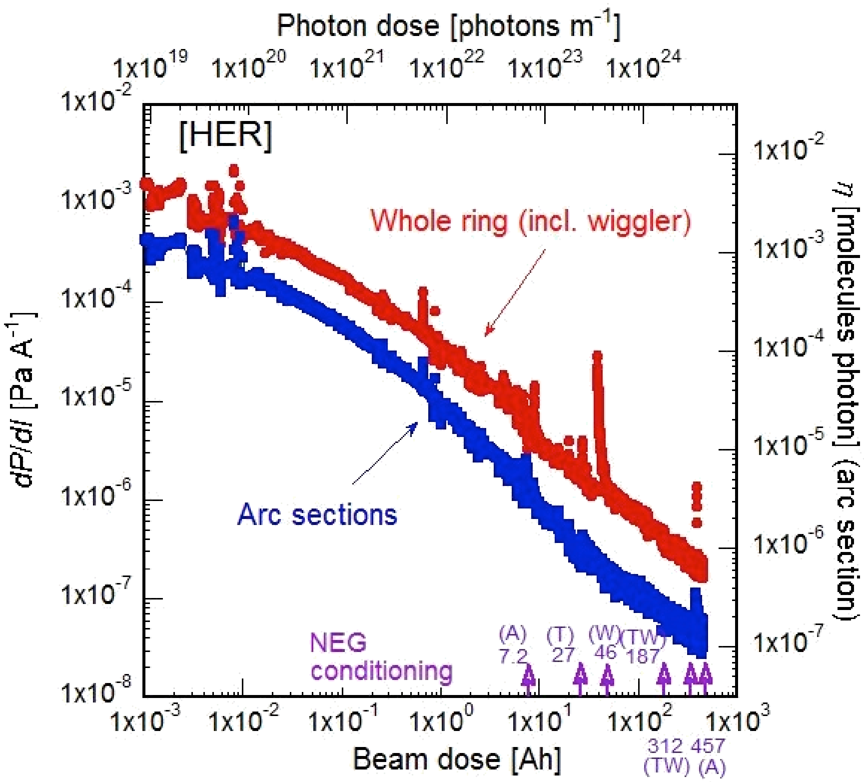
Readout Readiness Review by the BPAC on the weekend

SuperKEKB/Belle II Status

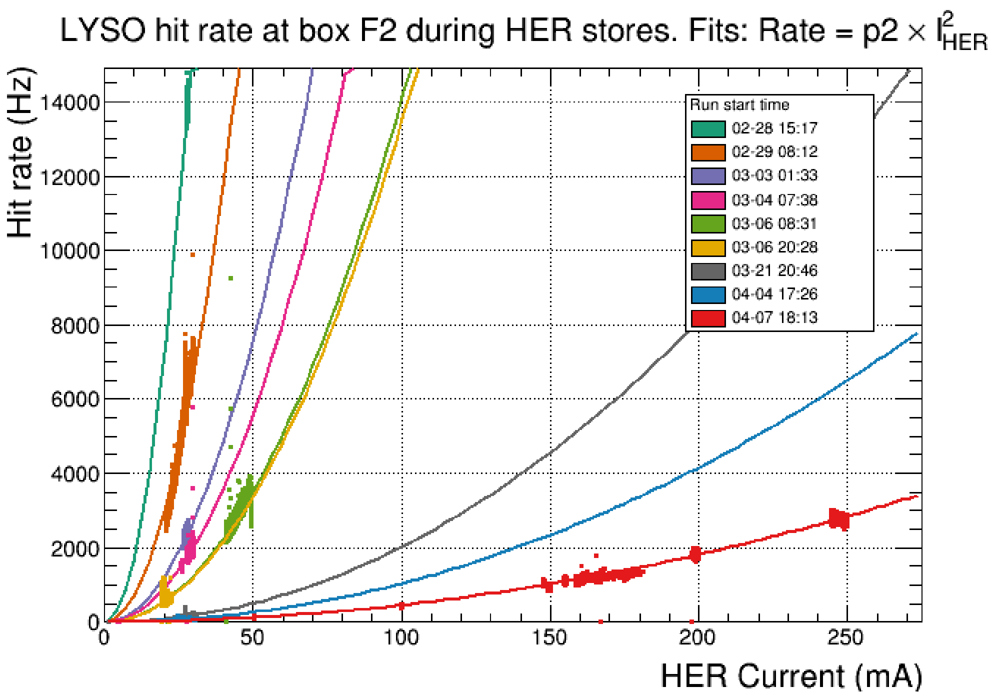
- Commisioning (Phase 1) of the main ring (without final quads) successfully carried out from Feb 1, 2016 – end of June! Interaction point detector: instead of Belle II, a commissioning detector – Beast II.

BEAST II: First experience with the new accelerator complex (no QCS)

HER integrated beam dose 662 Ah (LER 776 Ah)

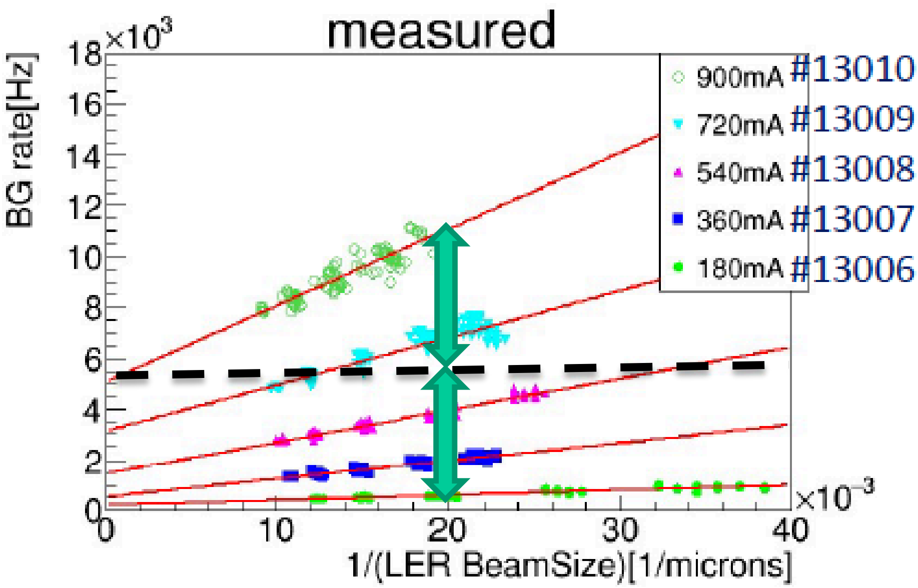


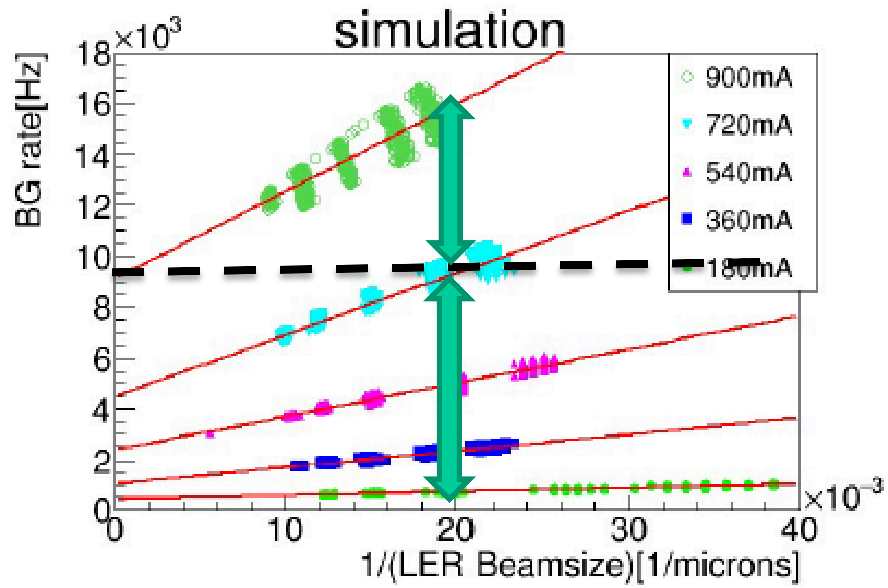
BEAST background in the HER vs time



BEAST II, Phase 1: Many New Results

Example: Touschek LER study





- At 900 mA
  - LER beam gas rate: MC / data ~ 1.8
  - LER Touschek rate: MC / data ~ 1.2
- But
  - BeamSize from x-ray monitor still needs to be corrected
  - Sensor position in MC not fully accurate

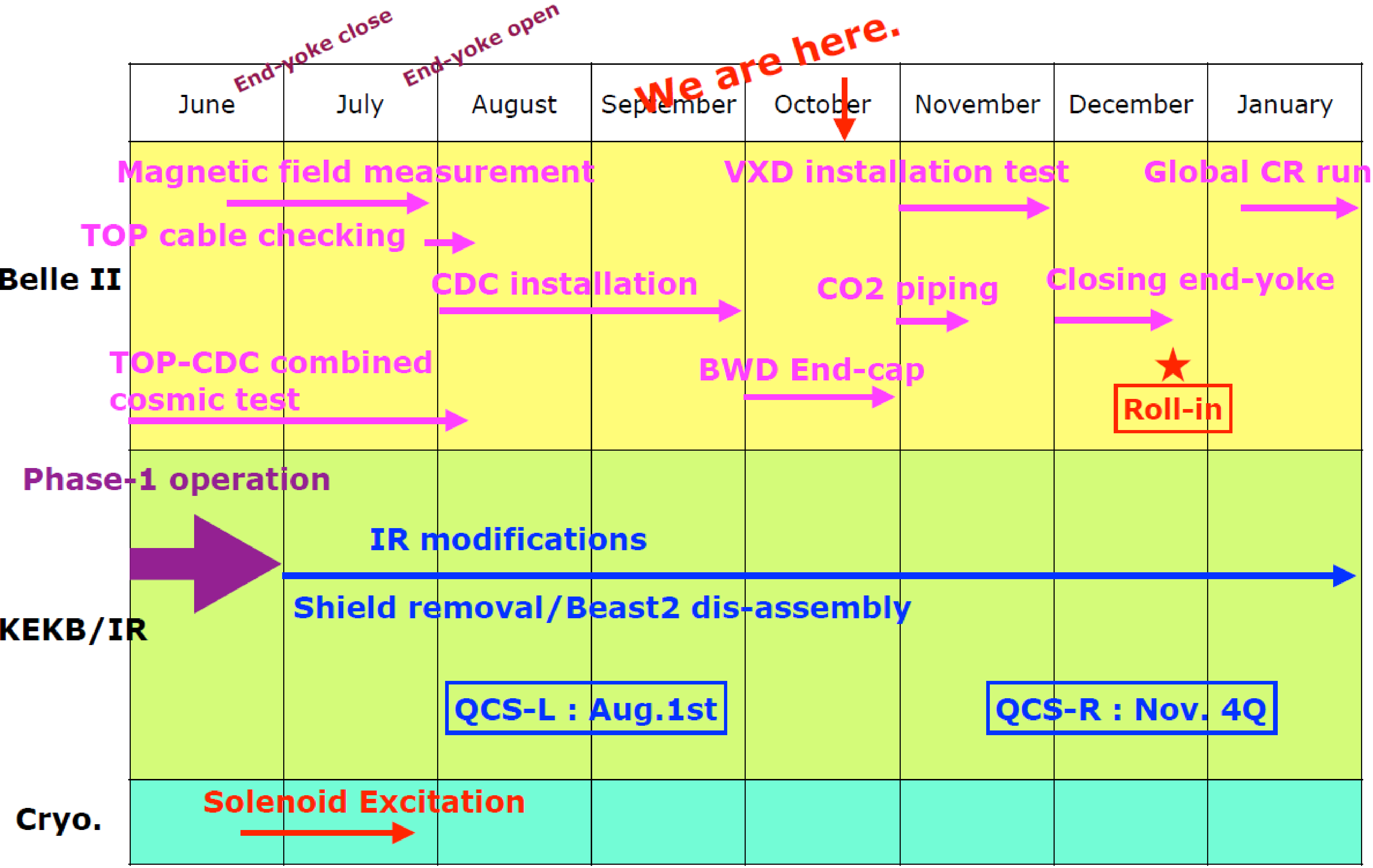
Precision MC/data comparison still ongoing. Aiming to have publication ready for collaboration review in spring 2017.

BEAST Phase 1: Lessons Learned

- Vacuum scrubbing successful, but not complete
  - Dynamic pressure low, but not at design value
- Safe to install Belle II + BEAST phase 2
  - Total dose in phase 1: A few hundred krad near beampipe
  - ~1/r^2
  - No large dose from SR
- LER Beam gas and Touschek BG agree roughly with predictions
- HER Touschek BG does not agree with predictions
  - More work needed to understand
- SAD modifications resulting from phase 1 validation led to increase in predicted HER Touschek BG for phase 3
  - may still be mitigated by collimators

Shown in June B2GM

2016-2017 Schedule

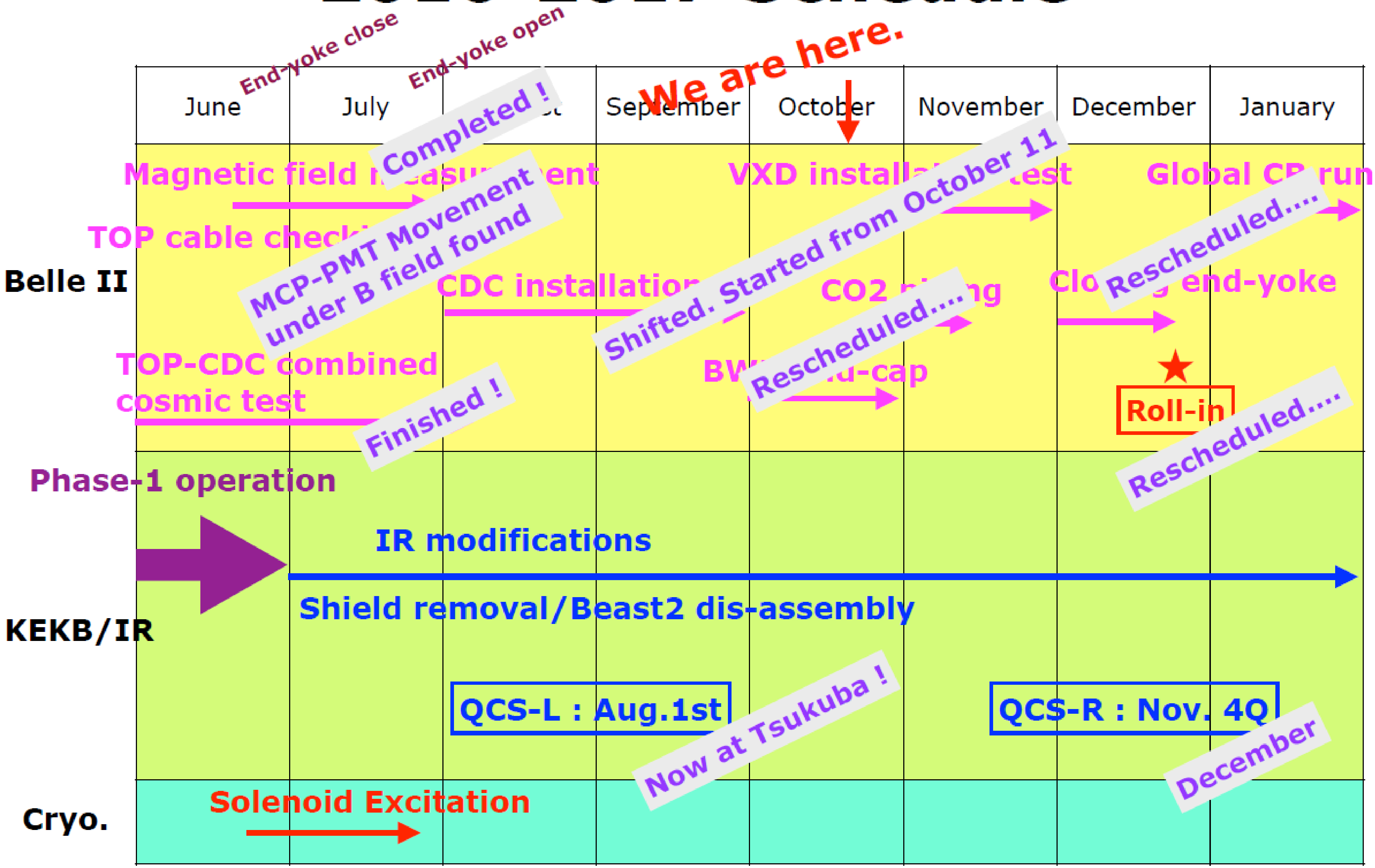


B2GM(6.20-24)

B2GM(10.17-21)

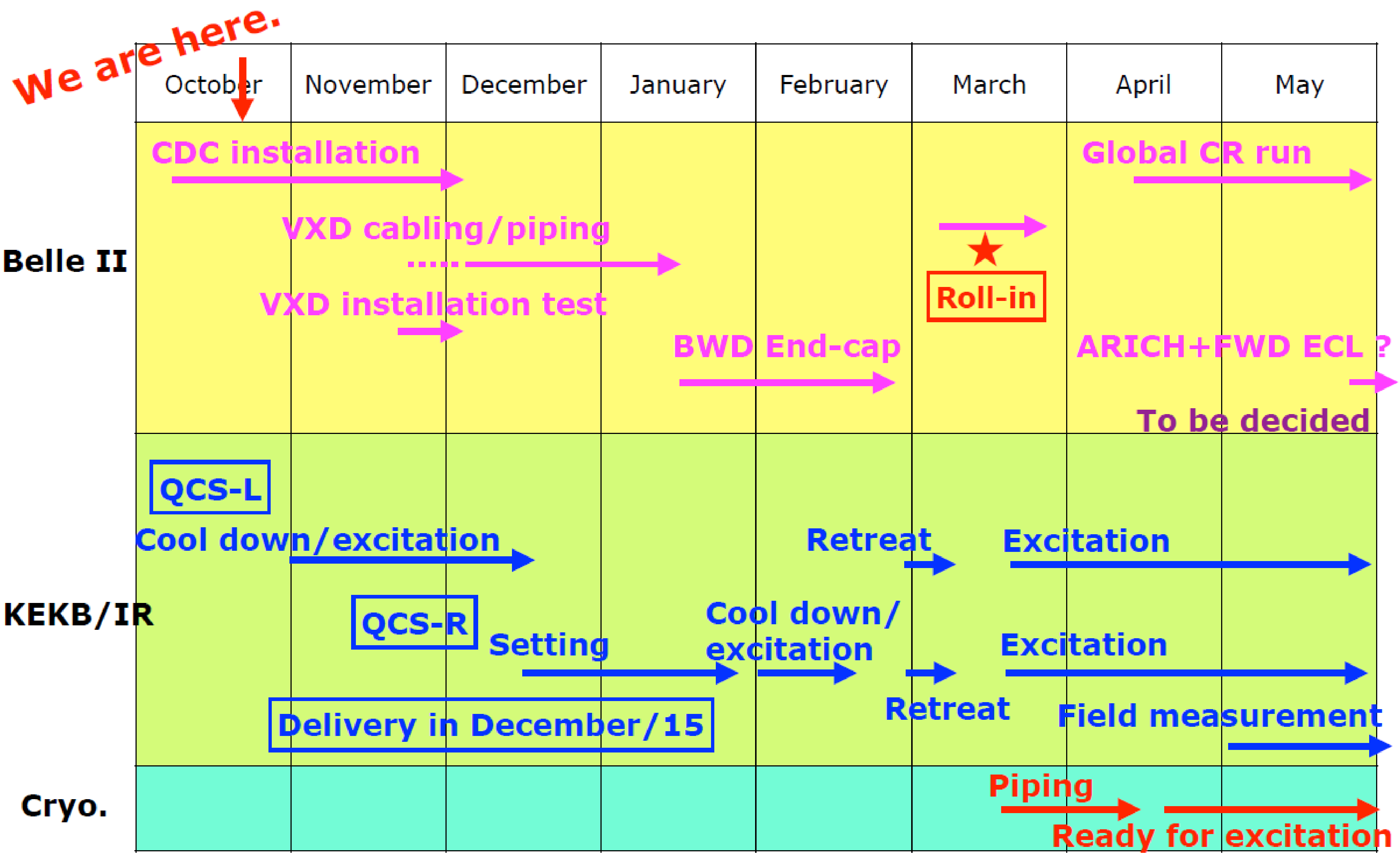
Shown in June B2GM

2016-2017 Schedule



October B2GM

2016-2017 Schedule



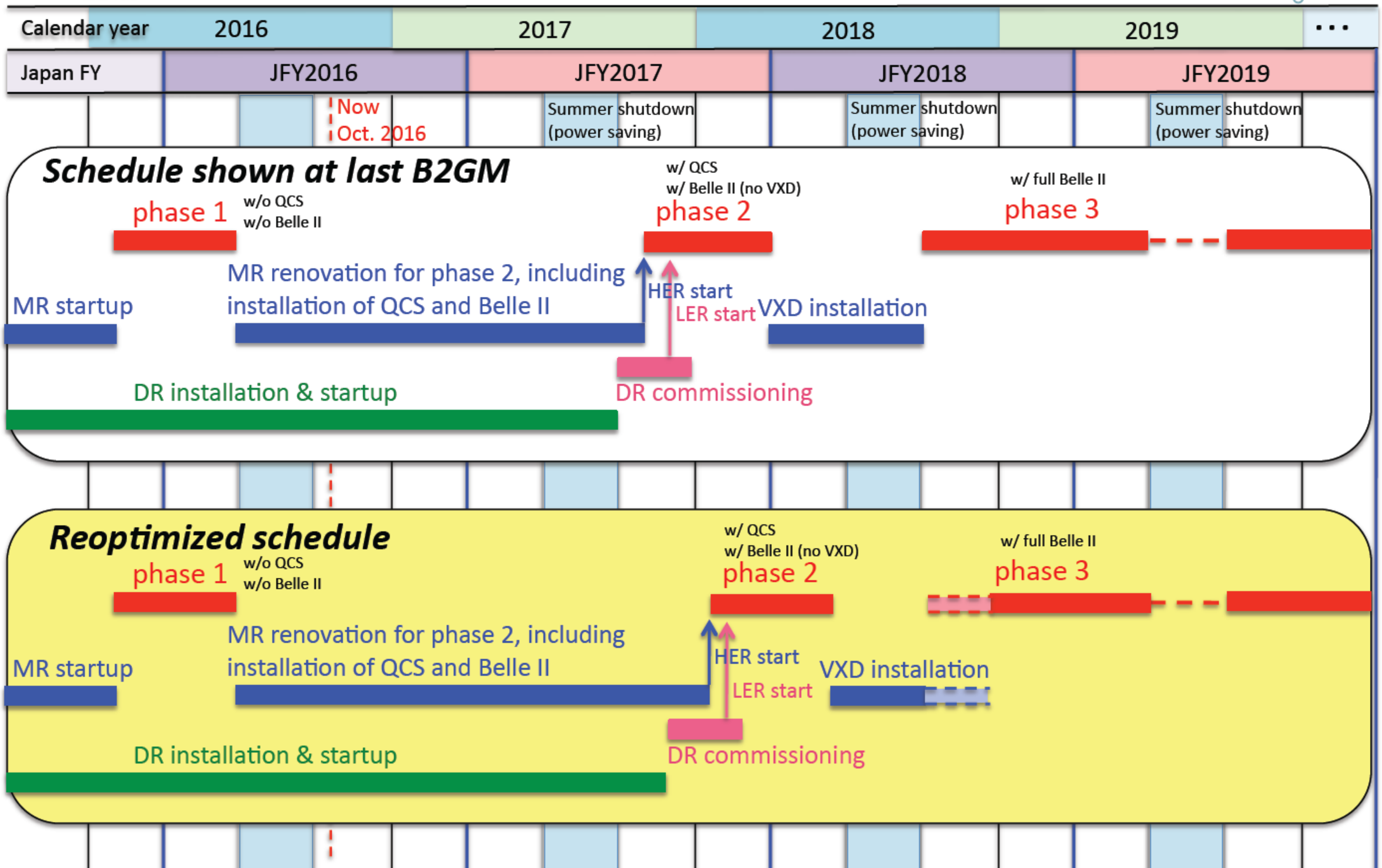
B2GM(6.20-24) B2GM(10.17-21)

SuperKEKB/Belle II Status

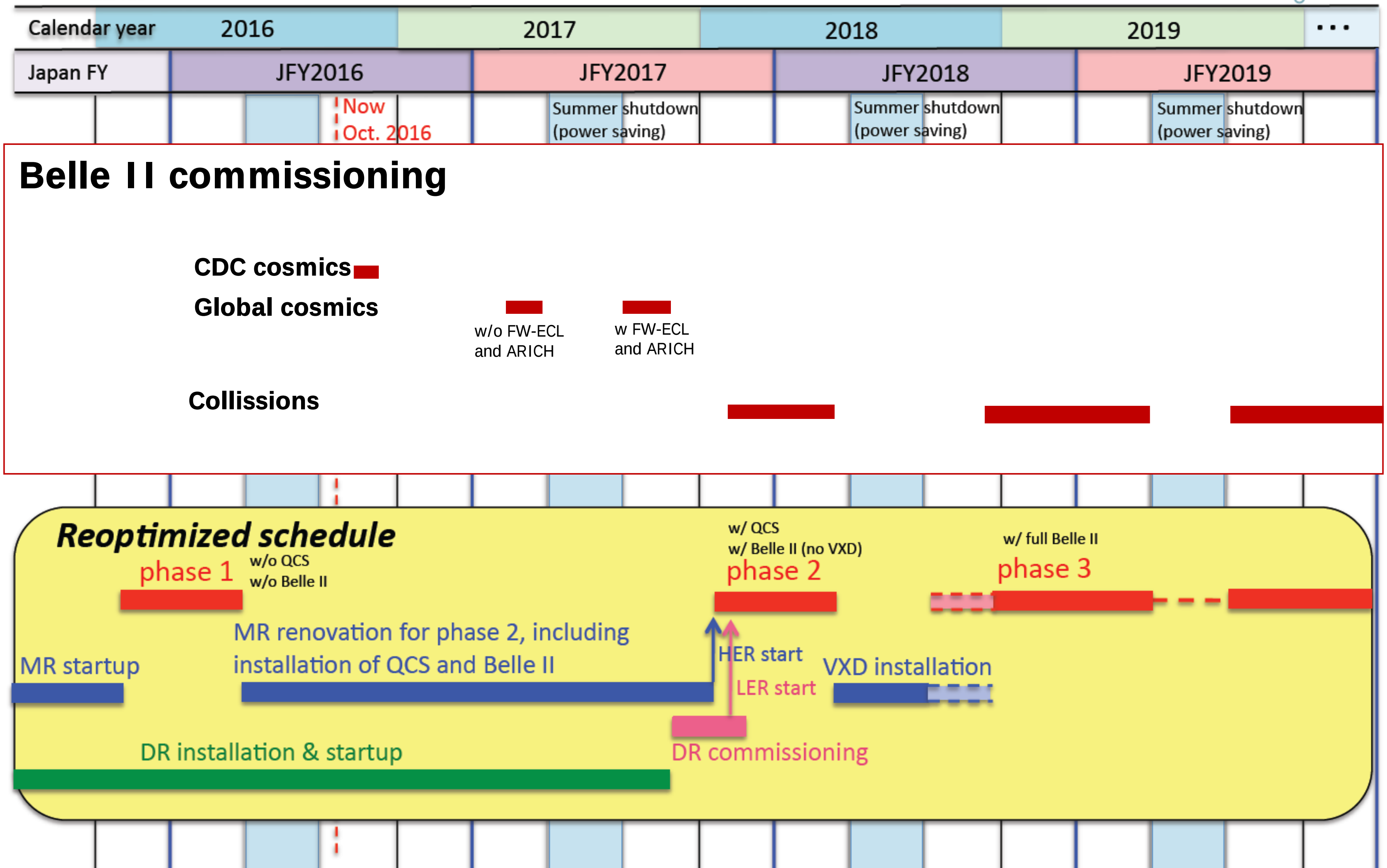
- Commisioning (Phase 1) of the main ring (without final quads) successfully carried out from Feb 1, 2016 – end of June! Interaction point detector: instead of Belle II, a commissioning detector – Beast II.

- Add final quads in until end of 2016
- Belle II: installation of outer detectors: spring – december 2016
- Belle II (without the vertex detector) roll in March 2017, cosmic rays
- Phase 2 commissioning Nov 2017 – spring 2018 (+ first physics runs)
- Install vertex detector summer 2018
- Full detector operation by the end 2018 (Phase 3)

SuperKEKB Schedule



SuperKEKB + Belle II Schedule

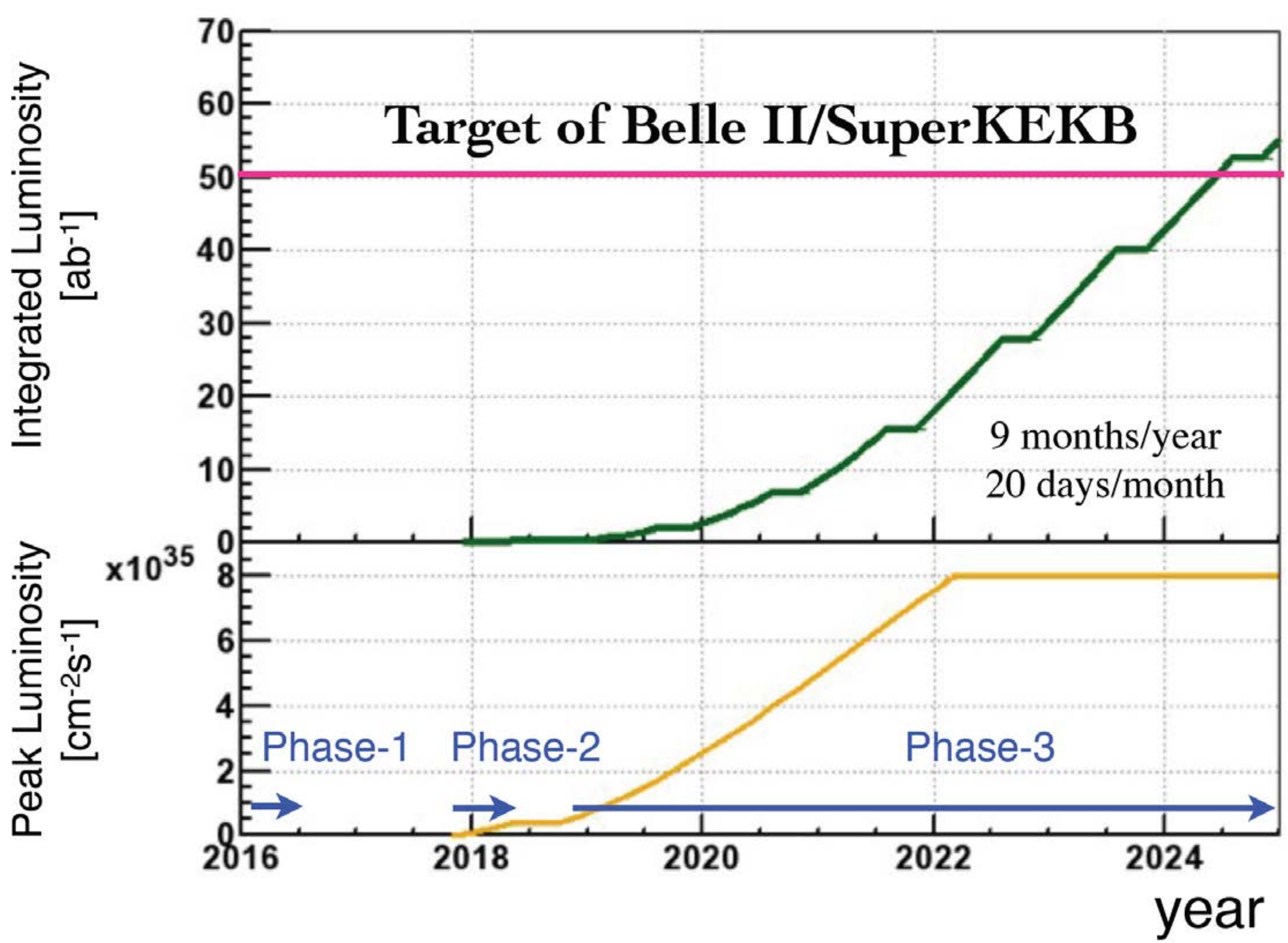


SuperKEKB/Belle II Status

- Commisioning (Phase 1) of the main ring (without final quads) successfully carried out from Feb 1, 2016 – end of June! Interaction point detector: instead of Belle II, a commissioning detector – Beast II.

- Add final quads in until end of 2016
- Belle II: installation of outer detectors: spring – december 2016
- Belle II (without the vertex detector) roll in March 2017, cosmic rays
- Phase 2 commissioning Nov 2017 – spring 2018 (+ first physics runs)
- Install vertex detector summer 2018
- Full detector operation by the end 2018 (Phase 3)

SuperKEKB luminosity projection



Summary

Detector construction well underway

Accelerator: in December expect delivery of the one missing piece, one of the two final quads.

First data taking in spring 2018

Main physics run starts end of 2018.

Will do our best to provide you with data asap!

More slides