Instrumentation for Colliding Beam Physics (INSTR-17)
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Budker Institute of Nuclear Physics

Status and Plans of the SuperKEKB and Belle II Project

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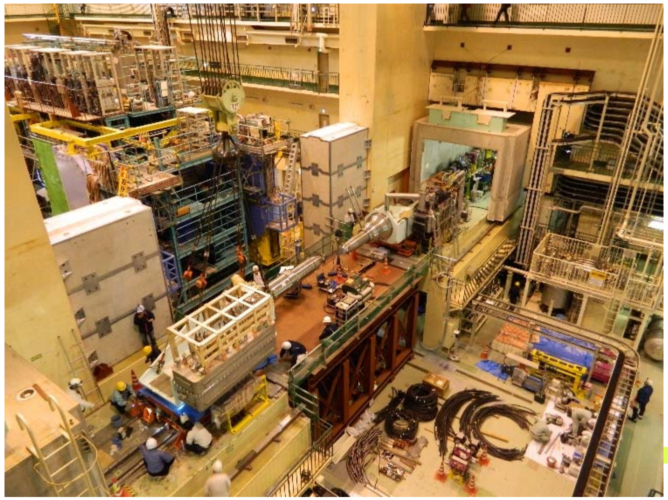
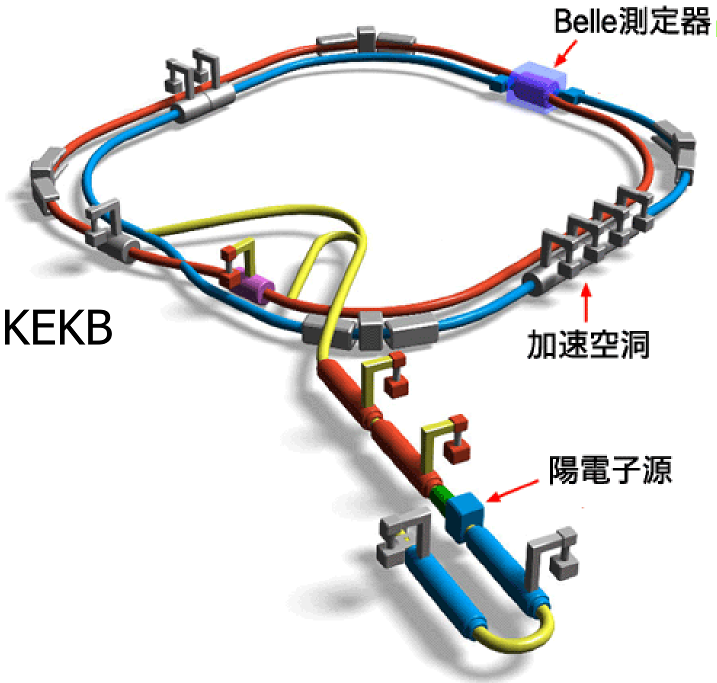
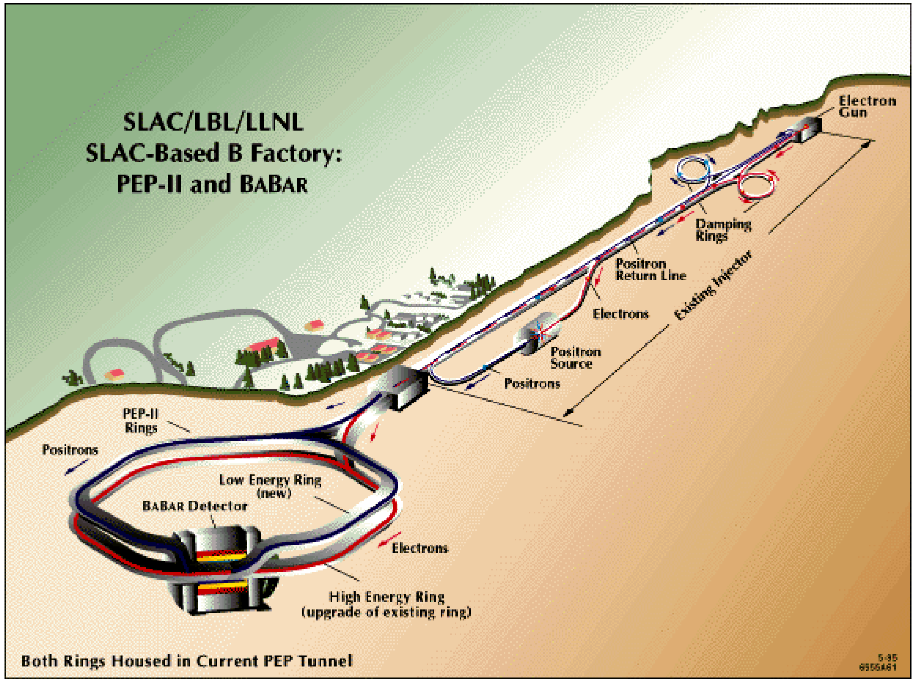


Asymmetric B factories: flavour physics at the luminosity frontier





$\sqrt{s}$=10.58 GeV

e^+ → $\Upsilon(4s)$ ← e^-

$\Upsilon(4s)$ → B, $\bar{B}$

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

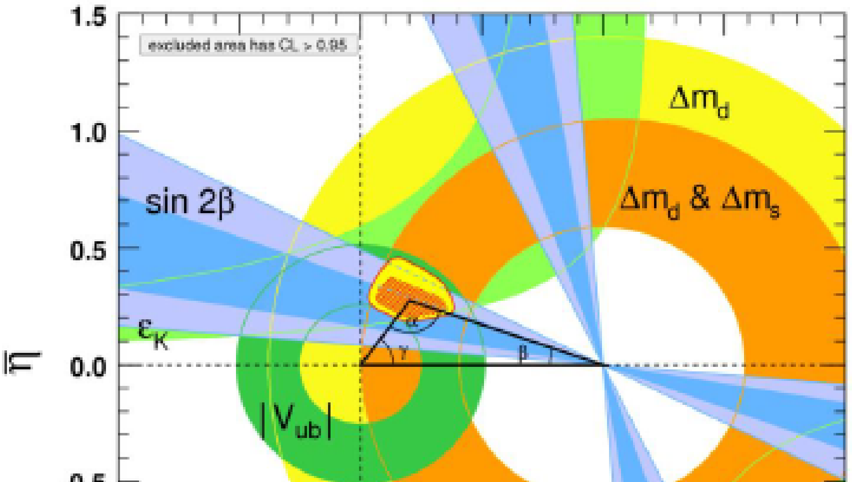
BaBar	$p(e^-)$=9 GeV	$p(e^+)$=3.1 GeV	$\beta\gamma$=0.56
Belle	$p(e^-)$=8 GeV	$p(e^+)$=3.5 GeV	$\beta\gamma$=0.42

To a large degree shaped flavour physics in the previous decade

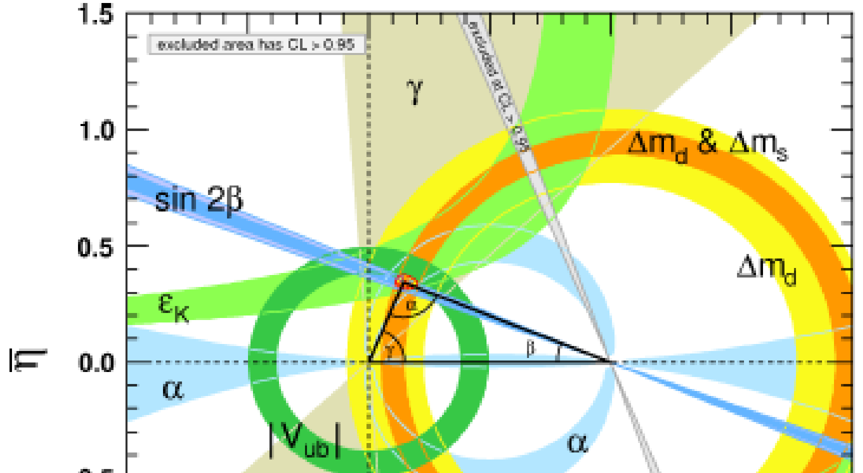
B factories: CP violation in the B system

CP violation in the B system: from the discovery (2001) to a precision measurement (2011).

EPS 2001



EPS 2011



A Super B factory

Motivation: search for physics phenomena beyond SM in B, D, and τ decays through precision studies.

Need: 50x larger data set

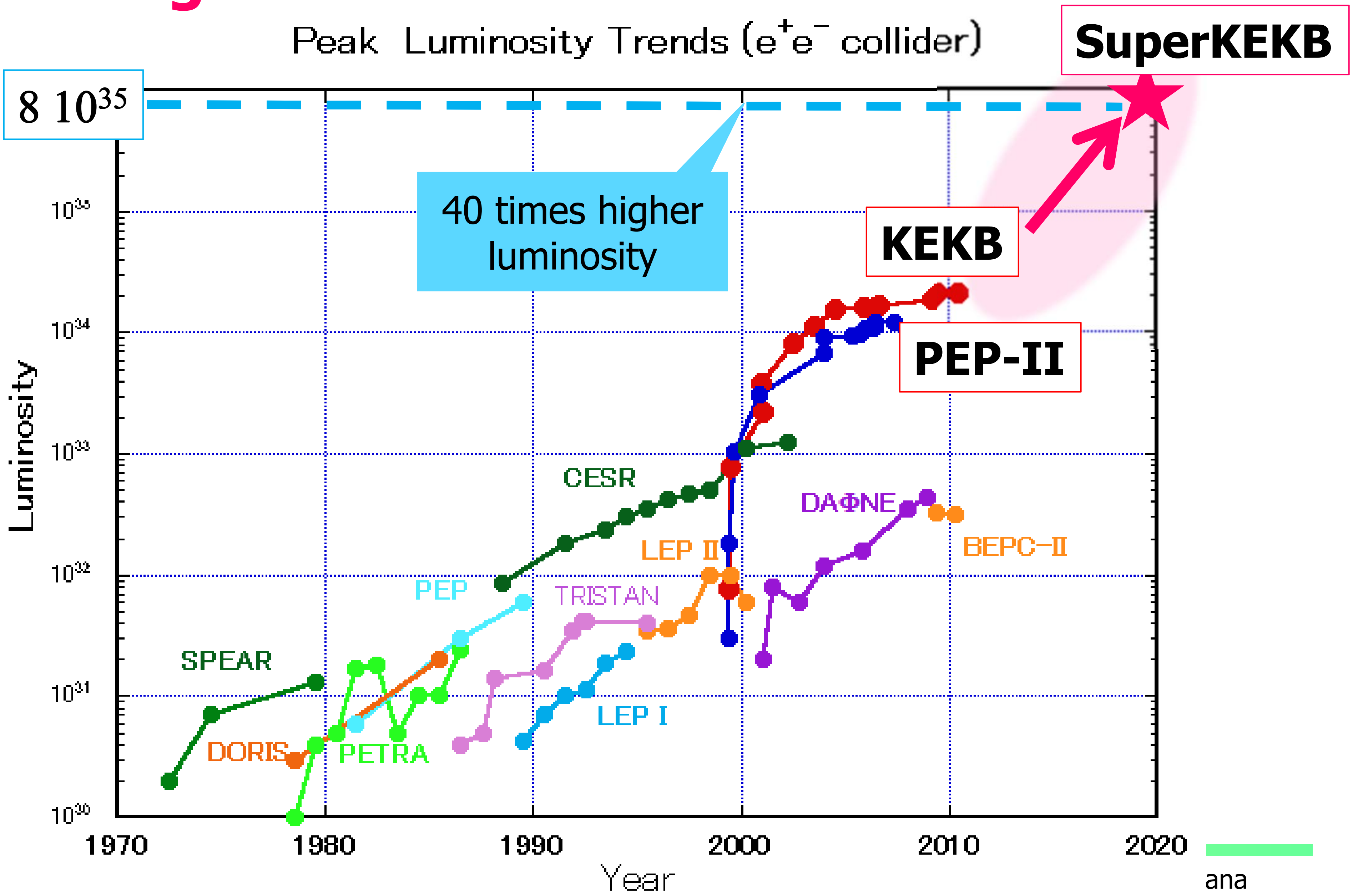
→ talk by T. Kuhr

Accelerator: asymmetric beams, ~50x higher luminosity

Detector: has to provide

- Excellent tracking (momentum) and vertexing (time evolution)
- Hadron, electron and muon identification
- Detection of high energy gamma rays
- Hermeticity (full B and D meson reconstruction)

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



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 b_y^*
(2) Increase beam currents
(3) Increase x_y

"Nano-Beam" scheme

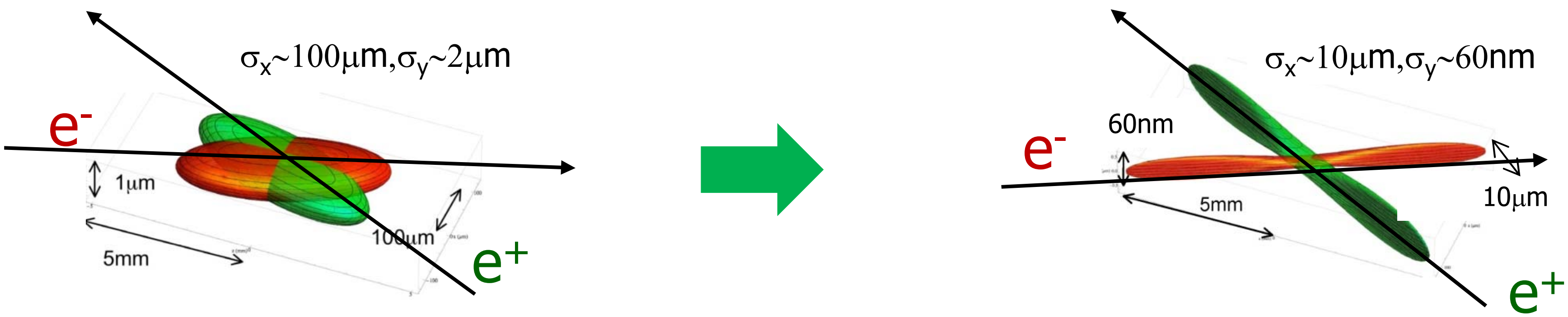
Collision with very small spot-size beams

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!

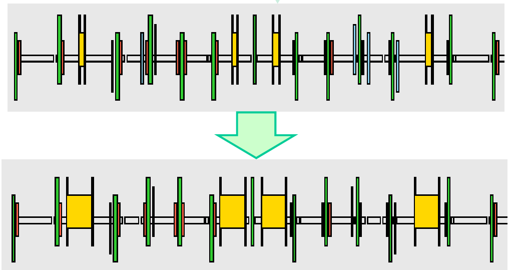
SuperKEKB design parameters

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	φ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.37	0.40	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	A
beam-beam parameter	ξ_y	0.129	0.090	0.0881	0.0807	
Luminosity	**L**	**2.1×10^{34}**		**8×10^{35}**		**$cm^{-2}s^{-1}$**

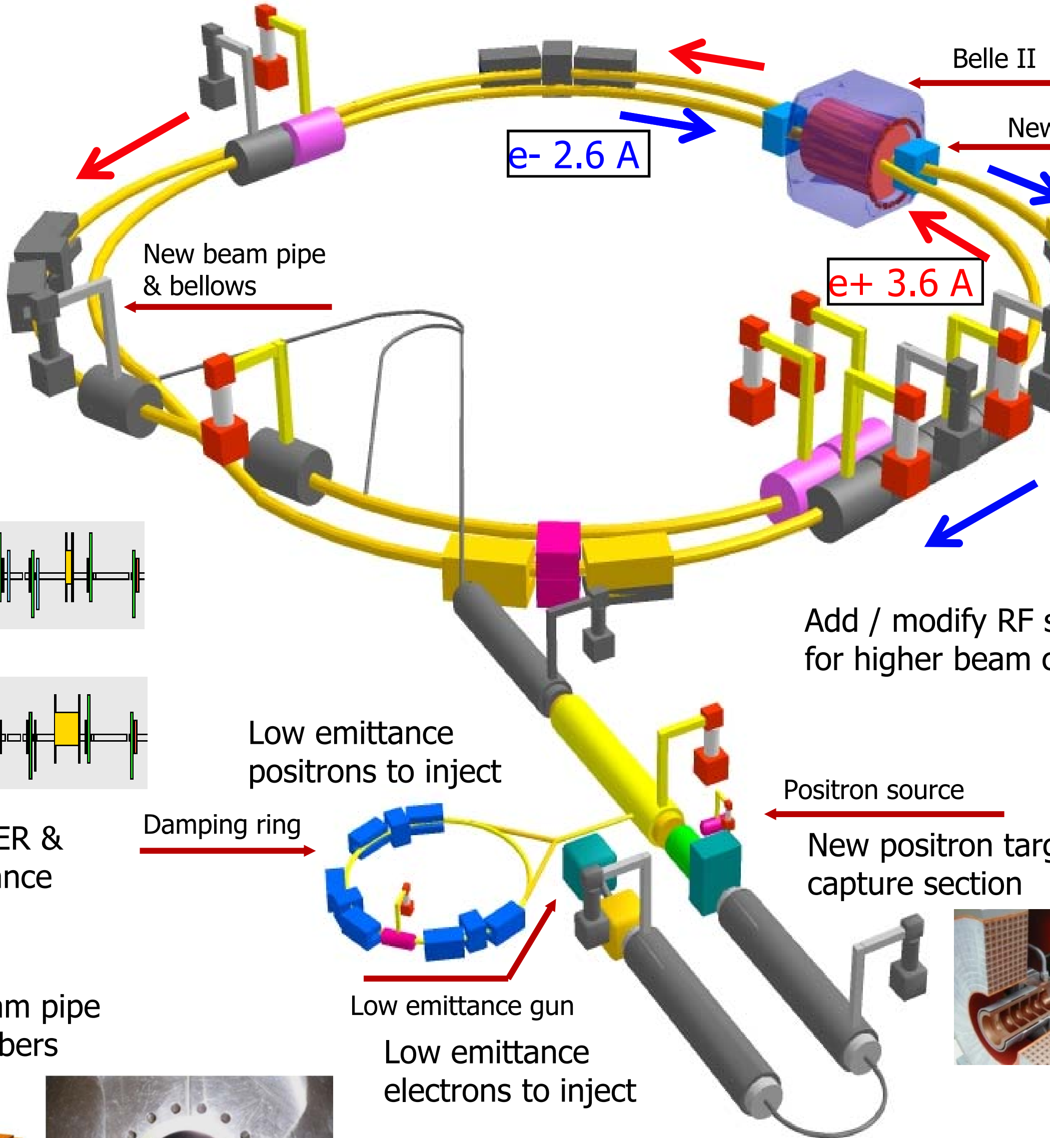
- **Nano-beams and a factor of two more beam current** to increase luminosity
- **Large crossing angle**
- **Change beam energies** to solve the problem of short lifetime for the LER

KEKB → SuperKEKB

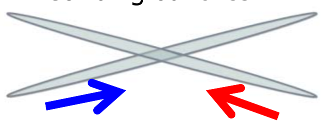
Replace short dipoles with longer ones (LER)



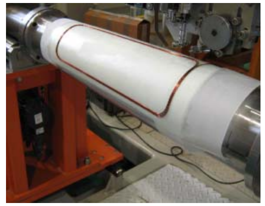
Redesign the lattices of HER & LER to squeeze the emittance



Colliding bunches

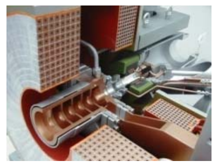


New superconducting /permanent final focusing quads near the IP

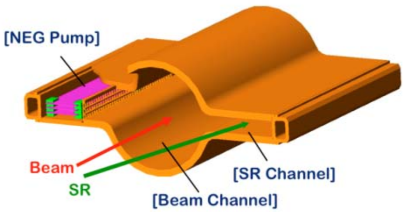


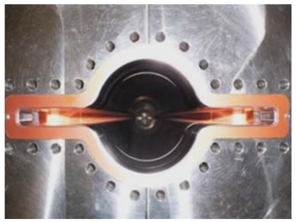
Add / modify RF systems for higher beam current

New positron target / capture section

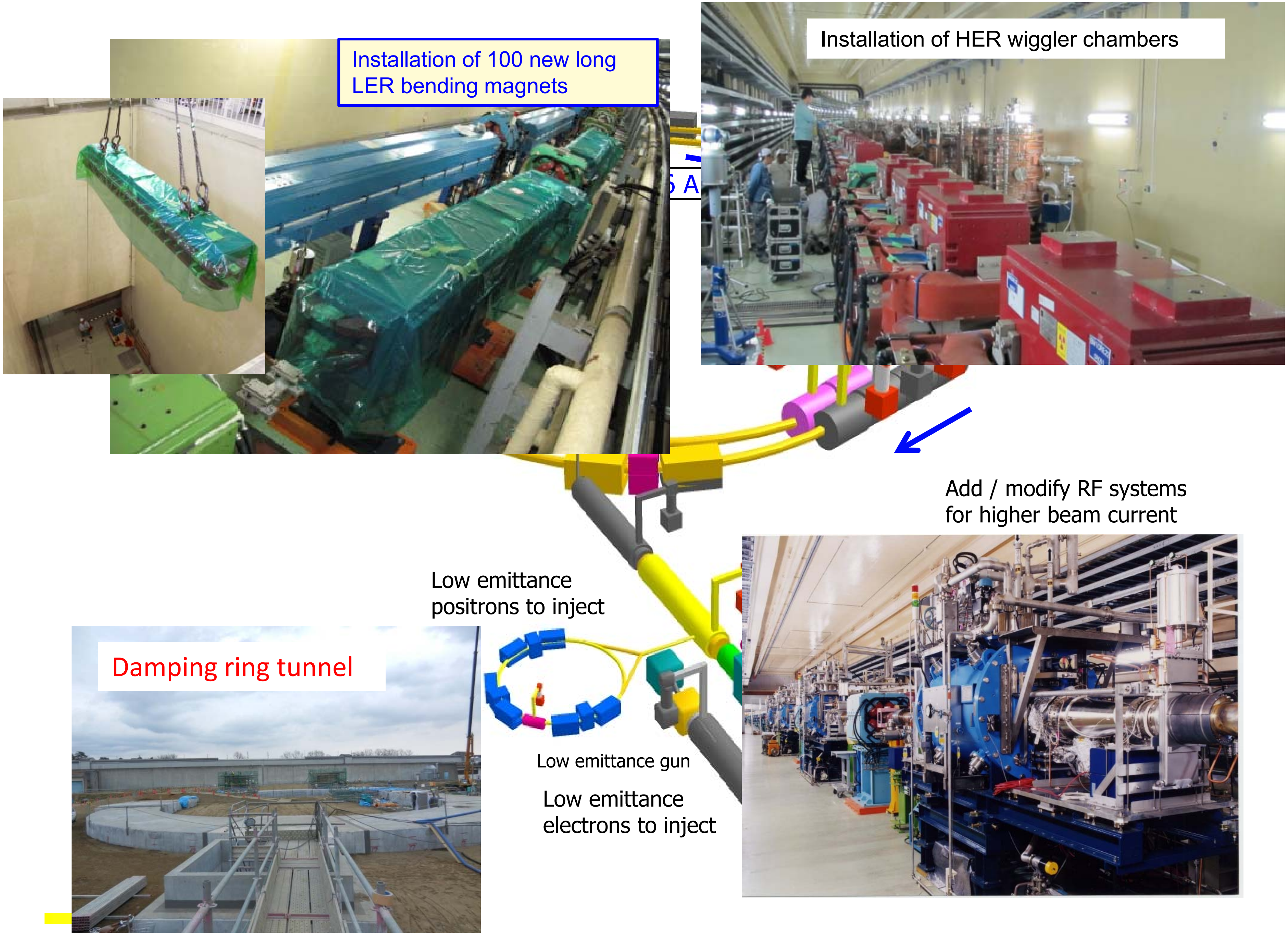


TiN-coated beam pipe with antechambers

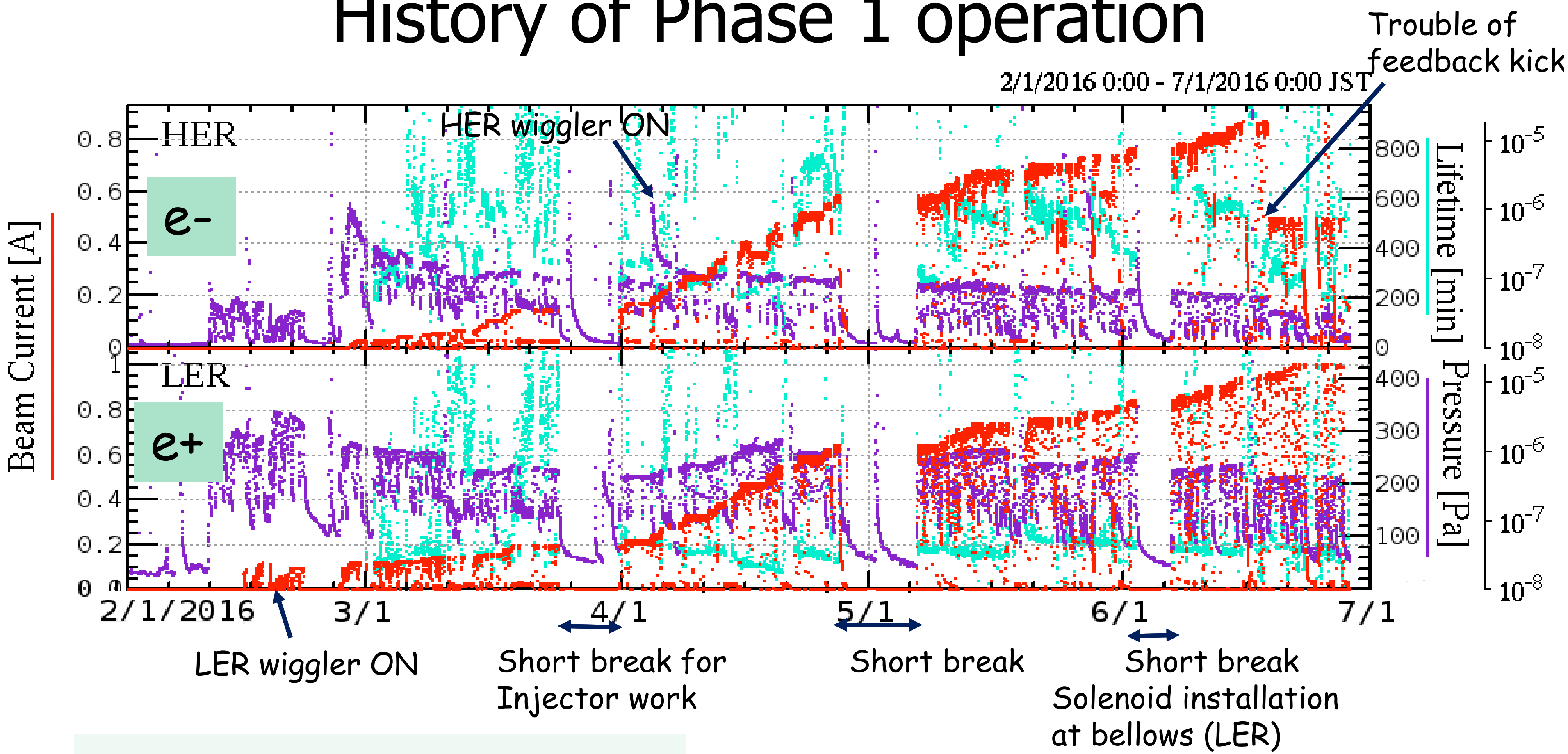




To get x40 higher luminosity


Installation of 100 new long LER bending magnets
Installation of HER wiggler chambers
Add / modify RF systems for higher beam current
Low emittance positrons to inject
Damping ring tunnel
Low emittance gun
Low emittance electrons to inject

History of Phase 1 operation

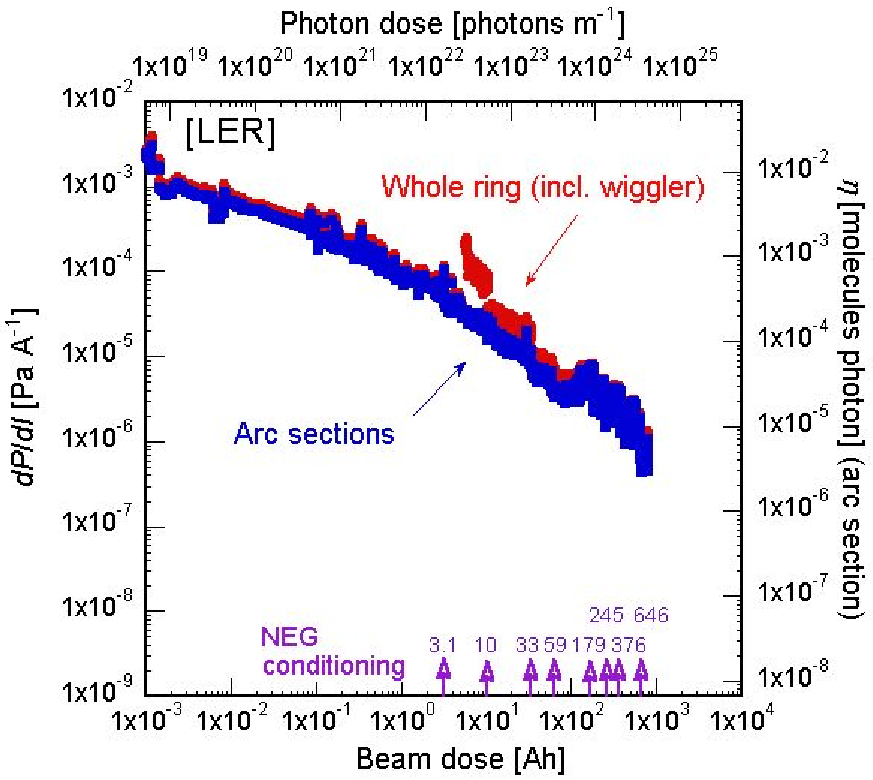


Red: total beam current
Purple: vacuum pressure
Cyan: beam lifetime

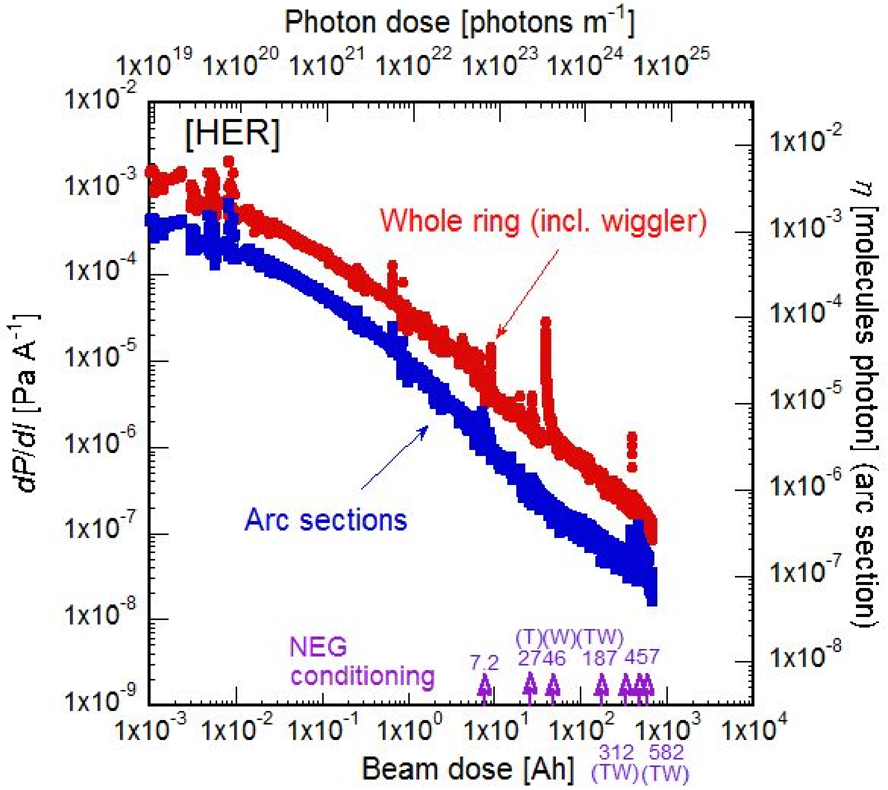
HER:
870 mA, 5.7×10^{-8} Pa, ~200 min. (6/17)
LER:
1010mA, 4.7×10^{-7} Pa, ~60 min. (6/22)

Vacuum scrubbing in Phase 1

4 GeV/c positron ring



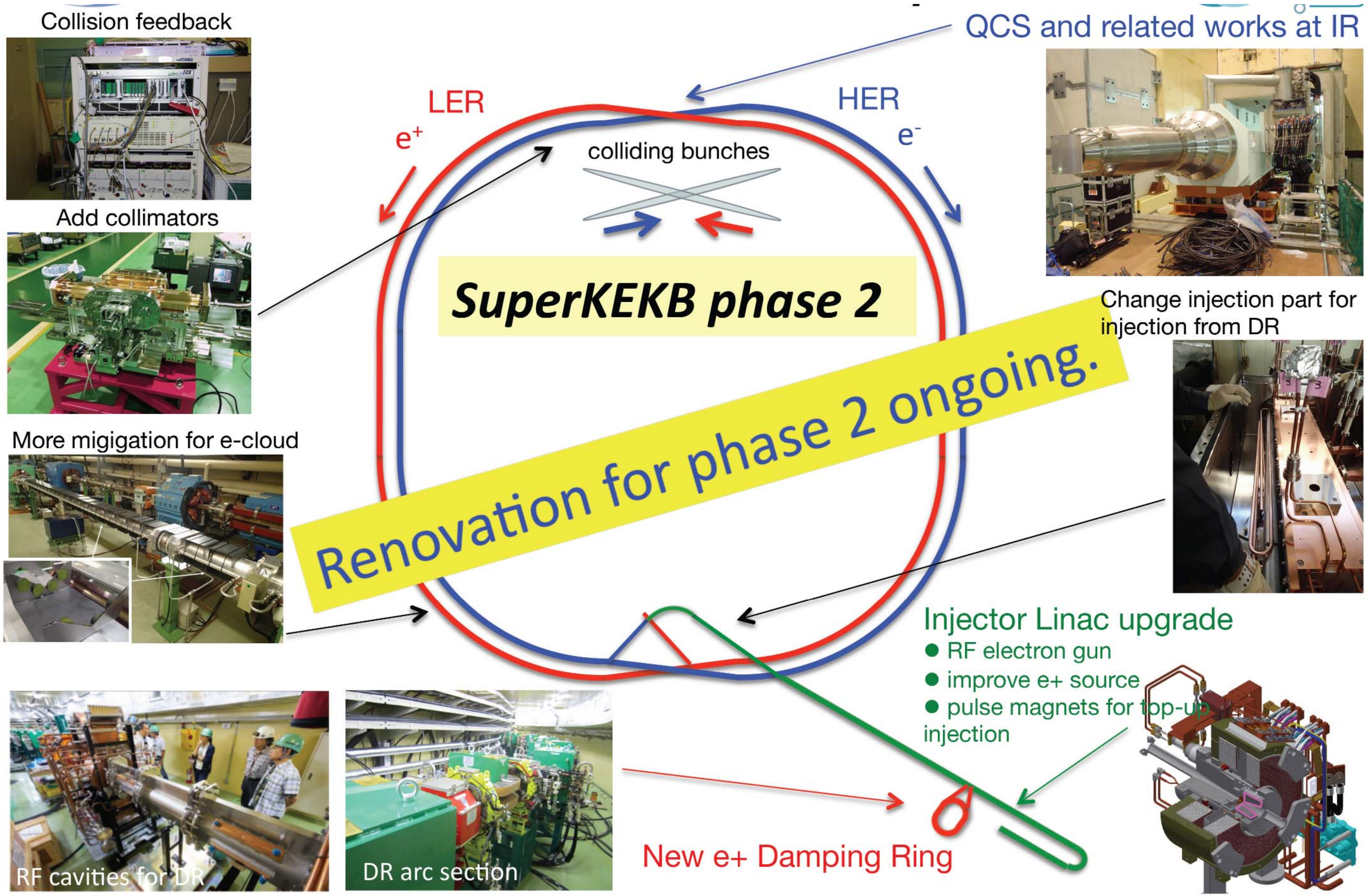
7 GeV/c electron ring



dP/dI~ 8×10^{-7} Pa A^{-1} @I_{doze} = 780 Ah
-> Photon stimulated desorption coefficient:
η ~ 6×10^{-6} molecules $photon^{-1}$ (Target $\eta = 1 \times 10^{-6}$)

dP/dI ~ 4×10^{-8} Pa A^{-1} @I_{doze} = 660 Ah
η ~ 1×10^{-7} molecules $photon^{-1}$ (Target $\eta = 1 \times 10^{-6}$)

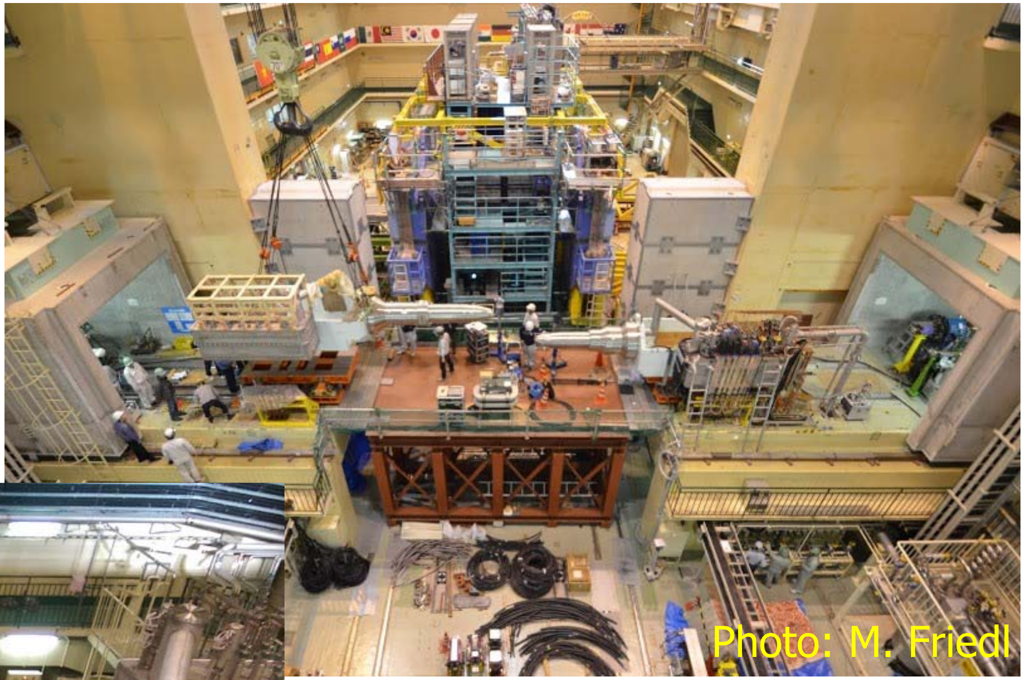
SuperKEKB: Preparations for Phase 2 Commissioning



Final focus magnets

Superconducting quadrupole magnets with 30+25 coils

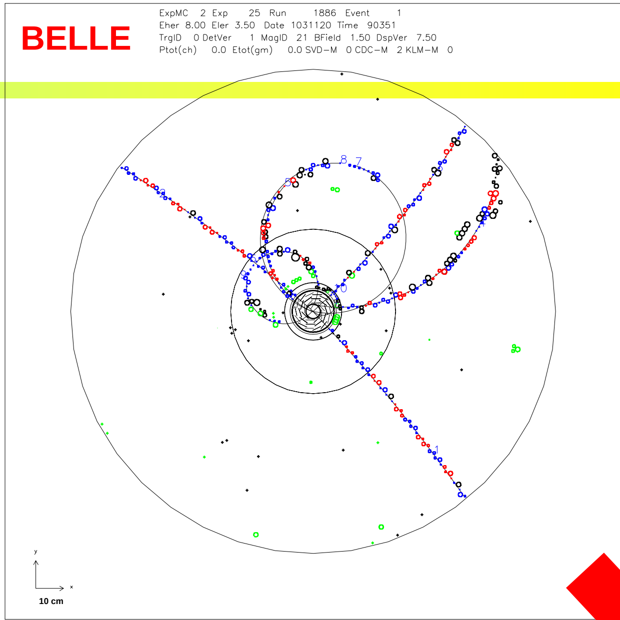
The final one delivered on Feb 13.

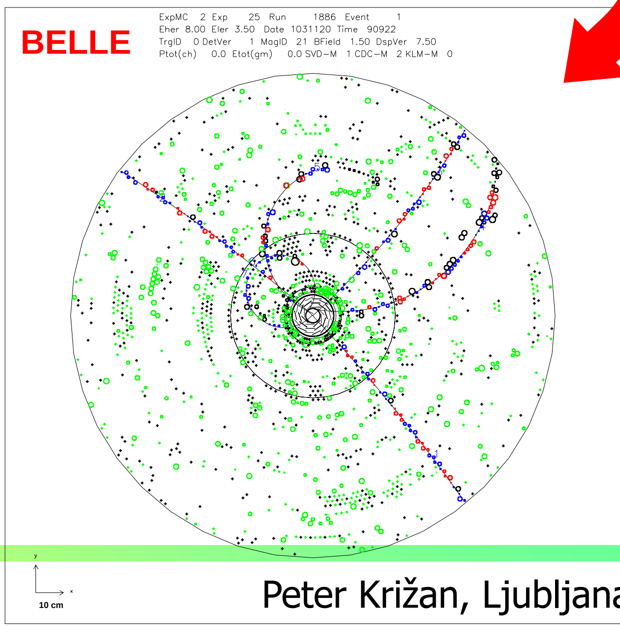


Requirements for the Belle II detector

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 ← s$\mu\mu$ recon. eff.
  - hermeticity ← ν “reconstruction”

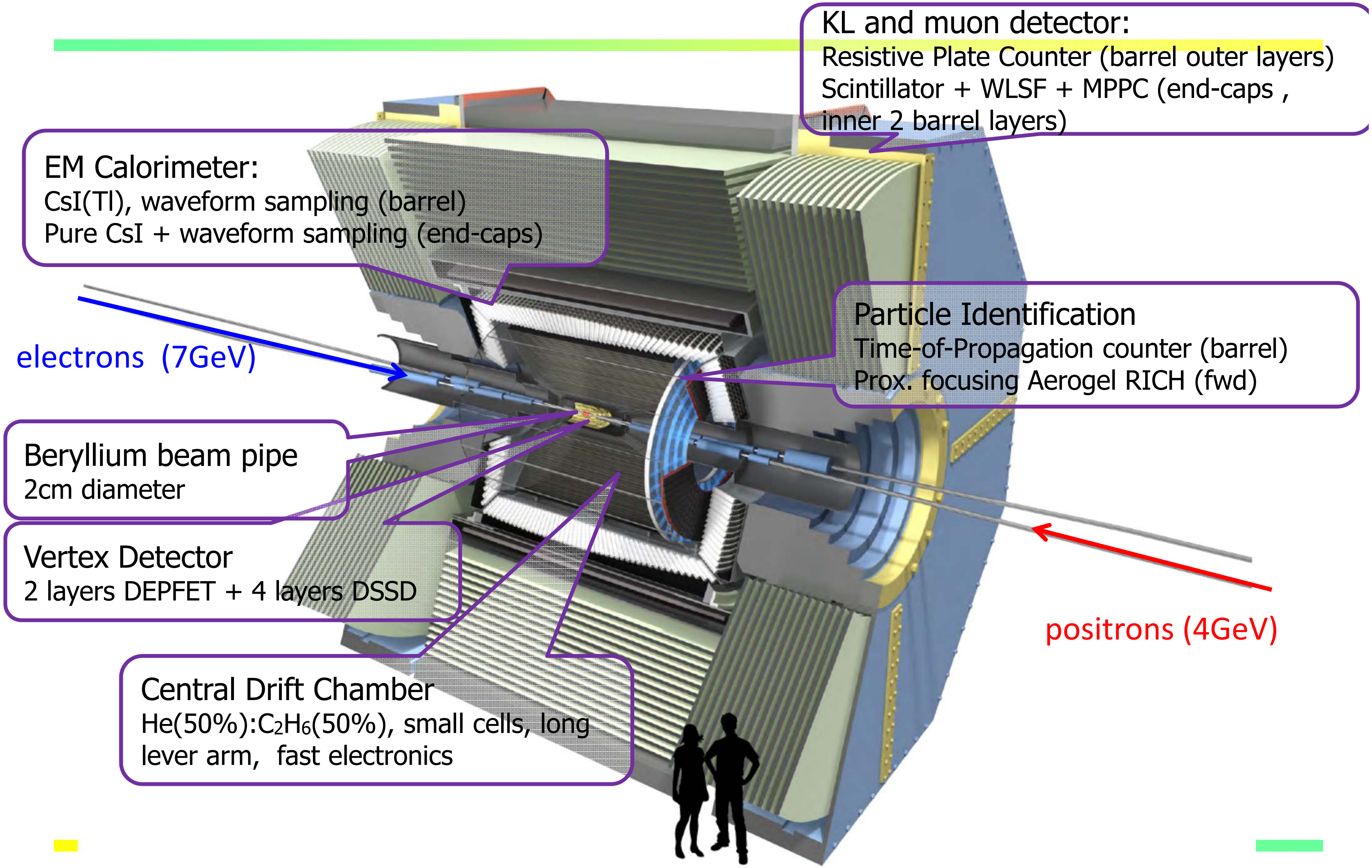




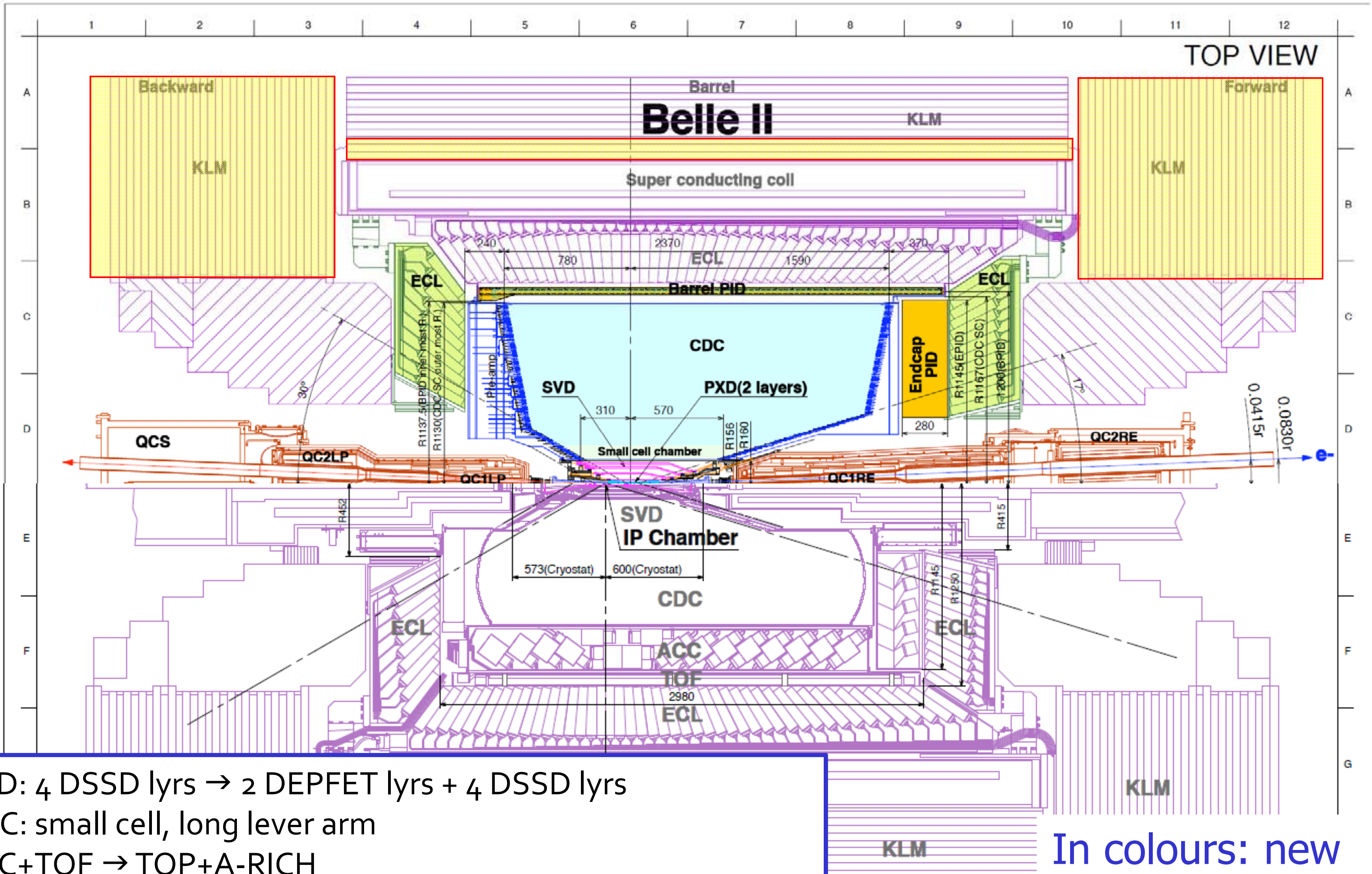
Solutions:
- Replace inner layers of the vertex detector with a pixel detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace endcap calorimeter crystals
- Faster readout electronics and computing system.

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

Belle II Detector



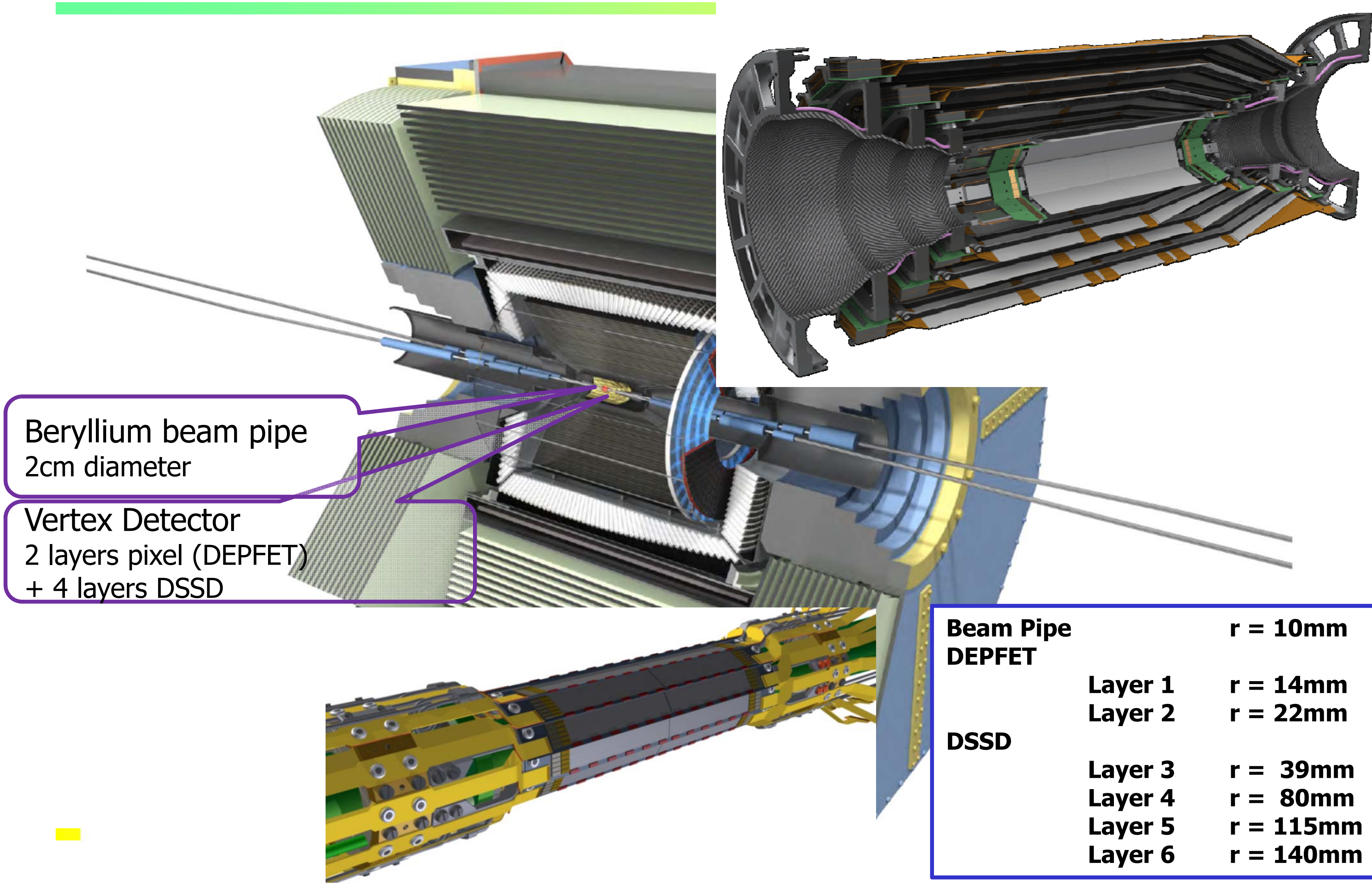
Belle II Detector (in comparison with Belle)



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

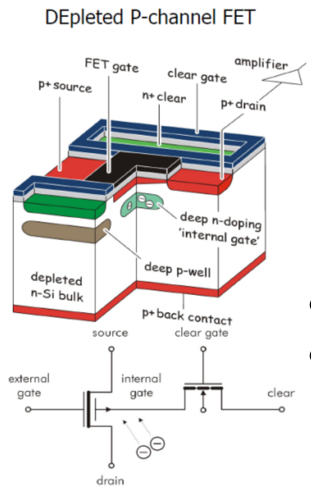
Belle II Detector – vertex region



Beam Pipe		**r = 10mm**
DEPFET		
	Layer 1	**r = 14mm**
	Layer 2	**r = 22mm**
DSSD		
	Layer 3	**r = 39mm**
	Layer 4	**r = 80mm**
	Layer 5	**r = 115mm**
	Layer 6	**r = 140mm**

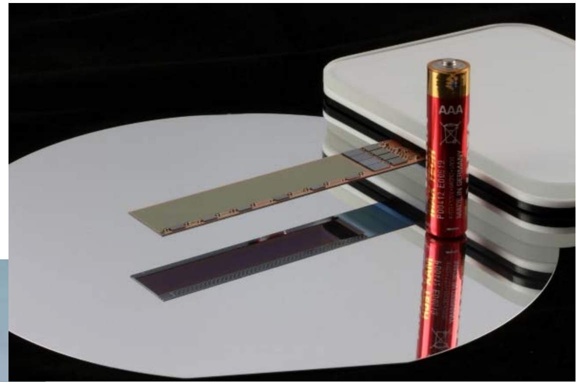
Pixel detector: 2 layers of DEPFET sensors

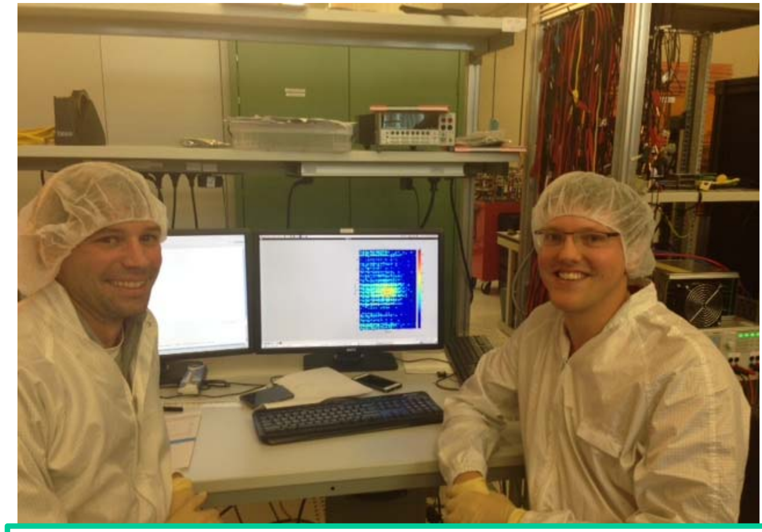
Mechanical mockup of the pixel detector

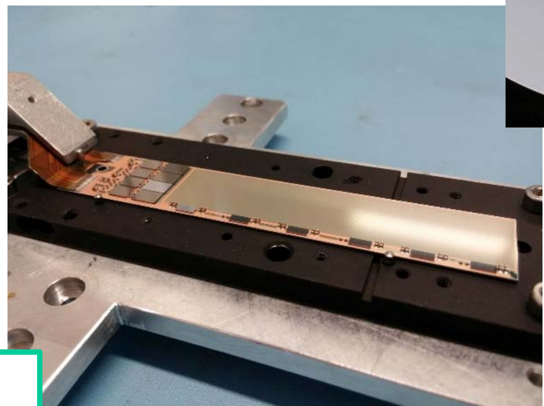


DEPFET sensor: developed at MPI Munich, produced at HLL

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

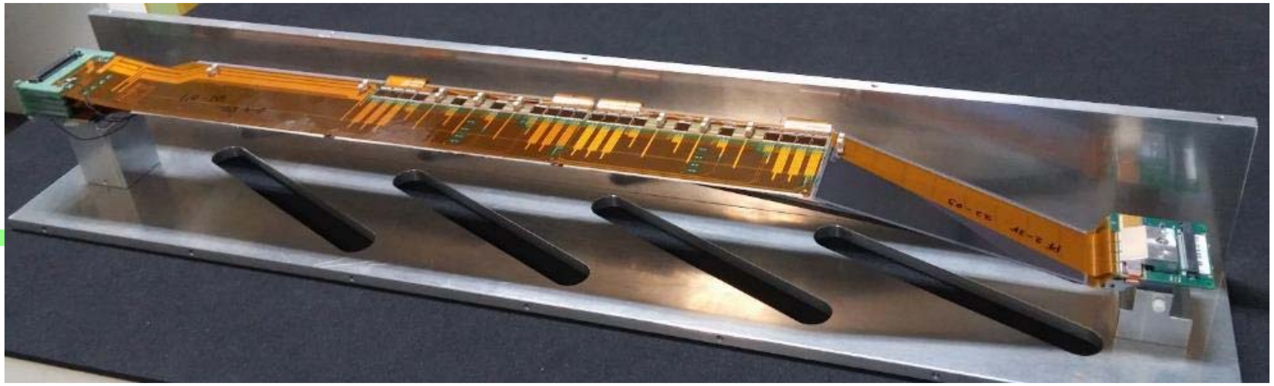




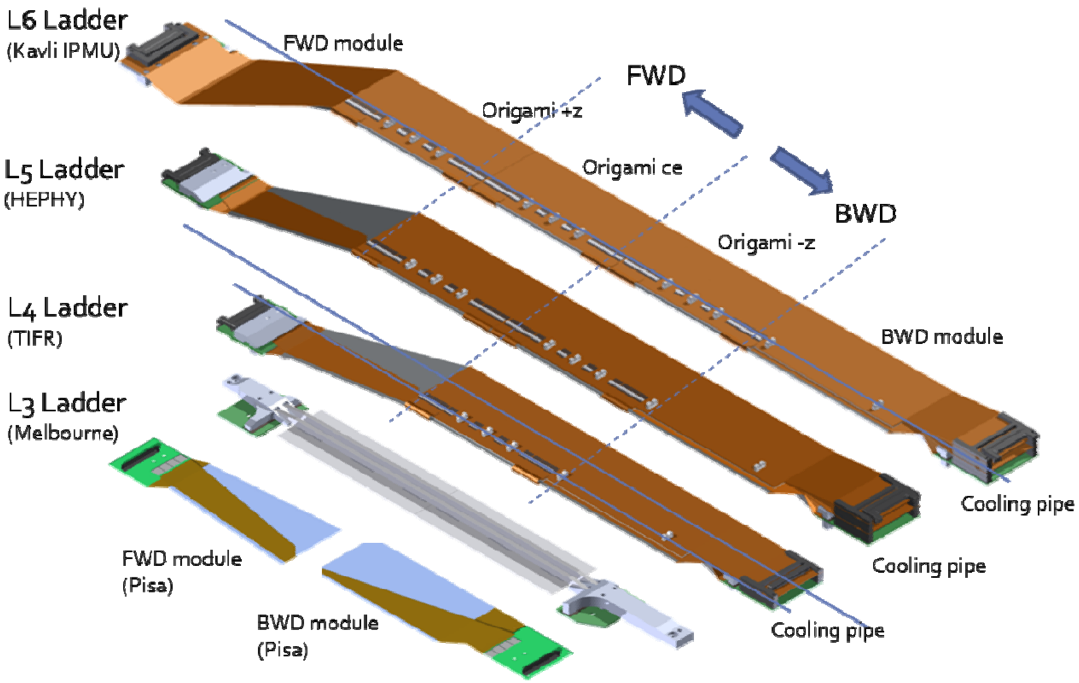


First laser light observed with the full size sensor

→ talk K. Lautenbach

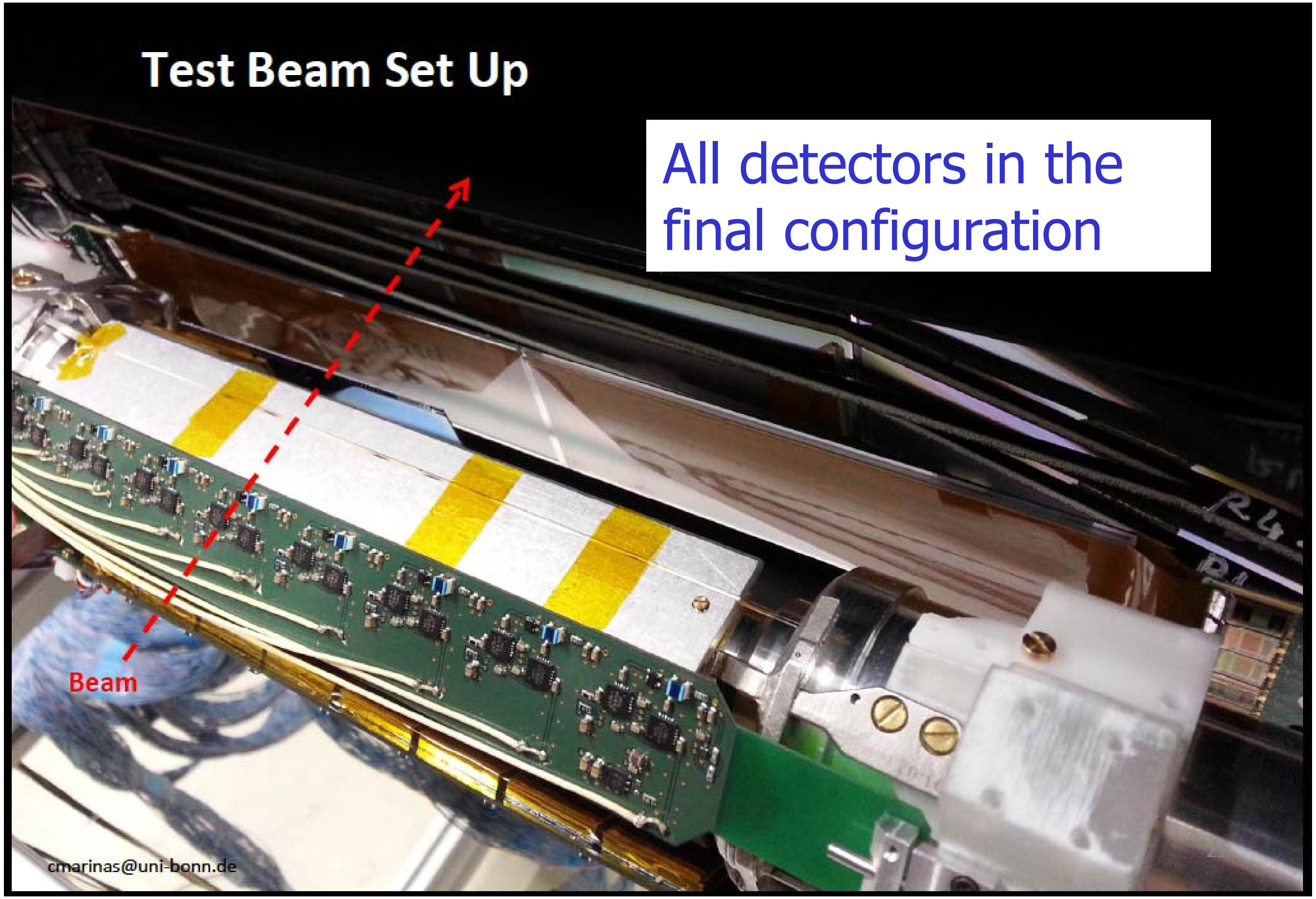


SVD: four layers of silicon microstrip detectors.



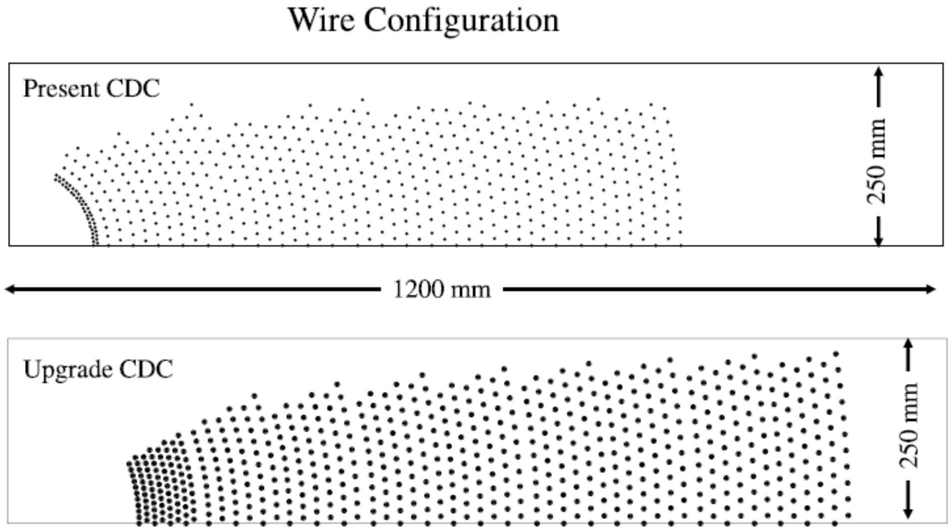
A truly worldwide effort…

DESY VXD beam test – currently running

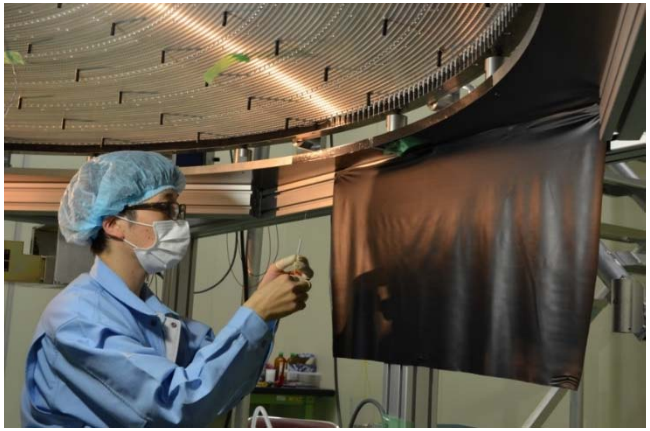


All detectors in the final configuration

Belle II CDC

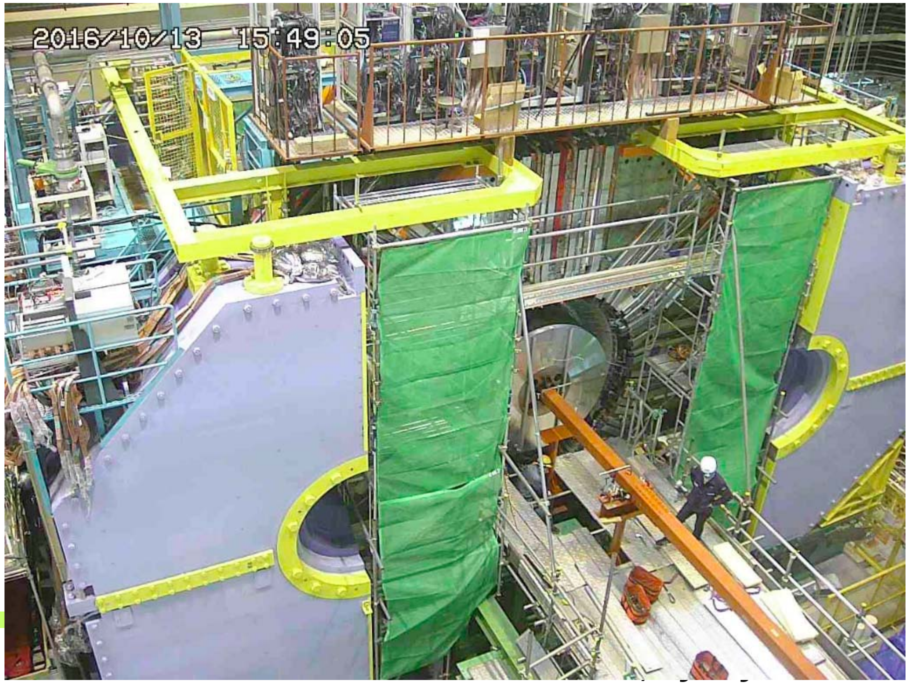


Much bigger than in Belle!

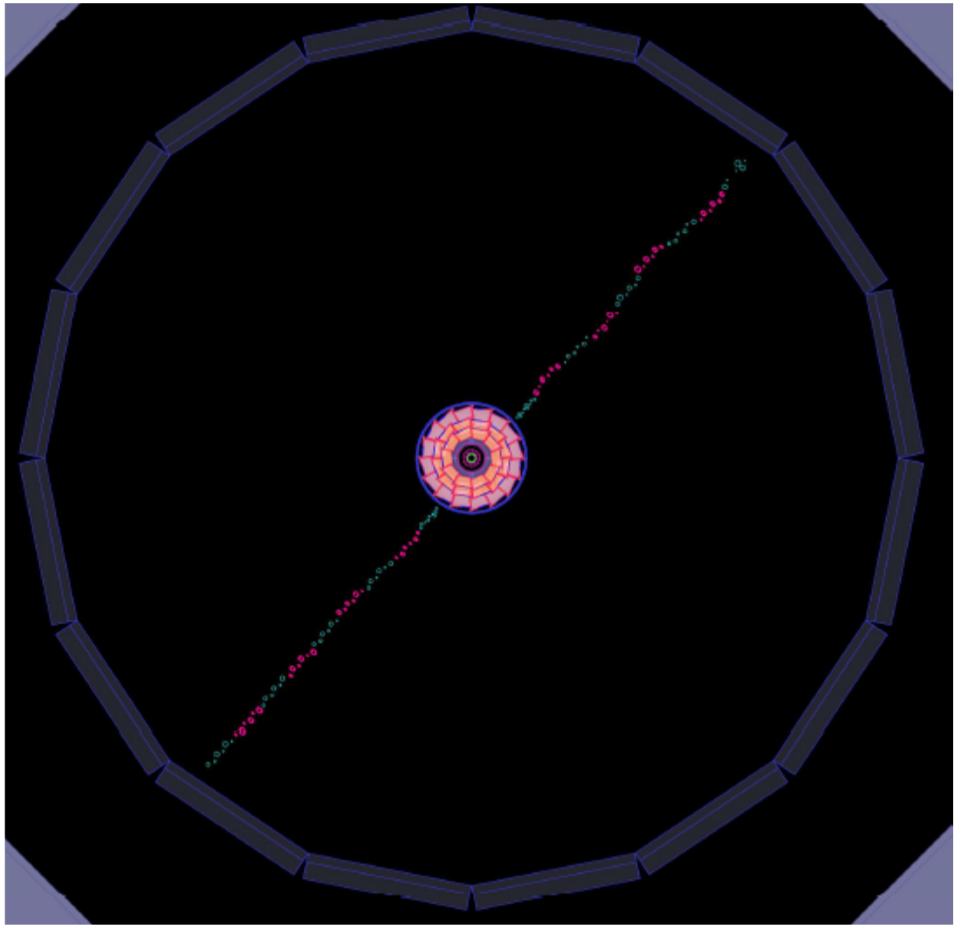


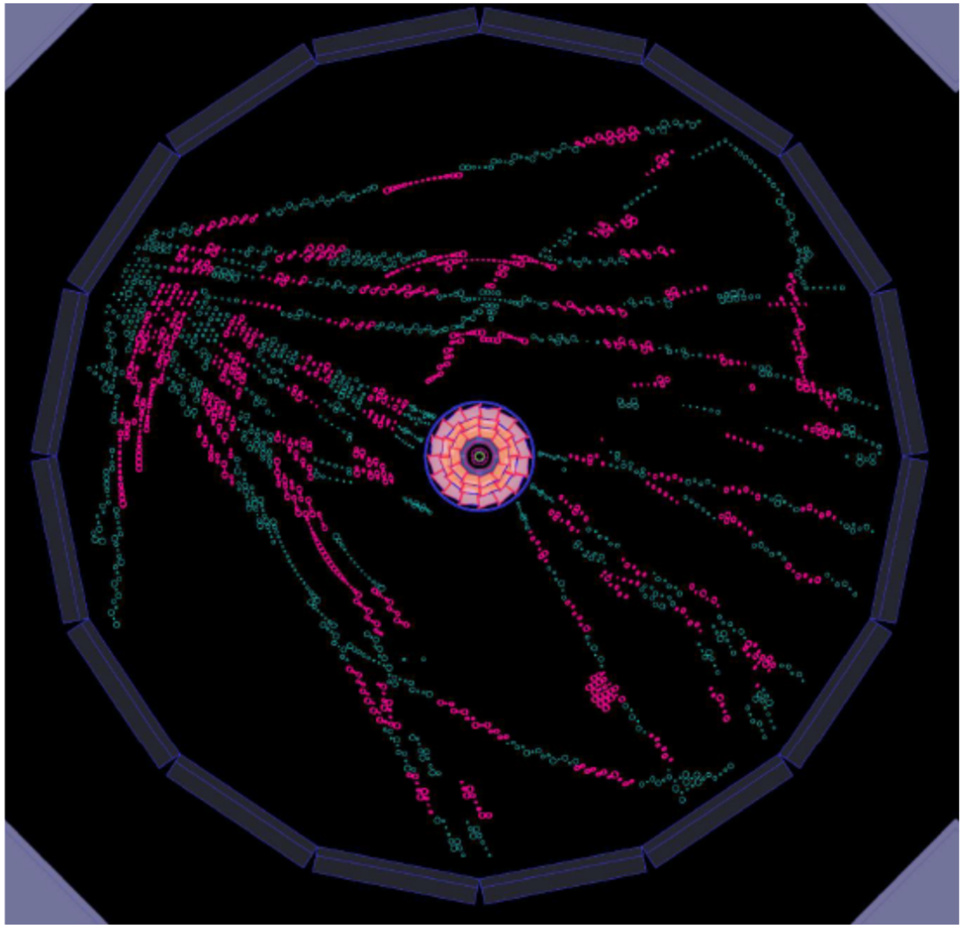
Wire stringing in a clean room

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



CDC Event displays (with fully instrumented readout)



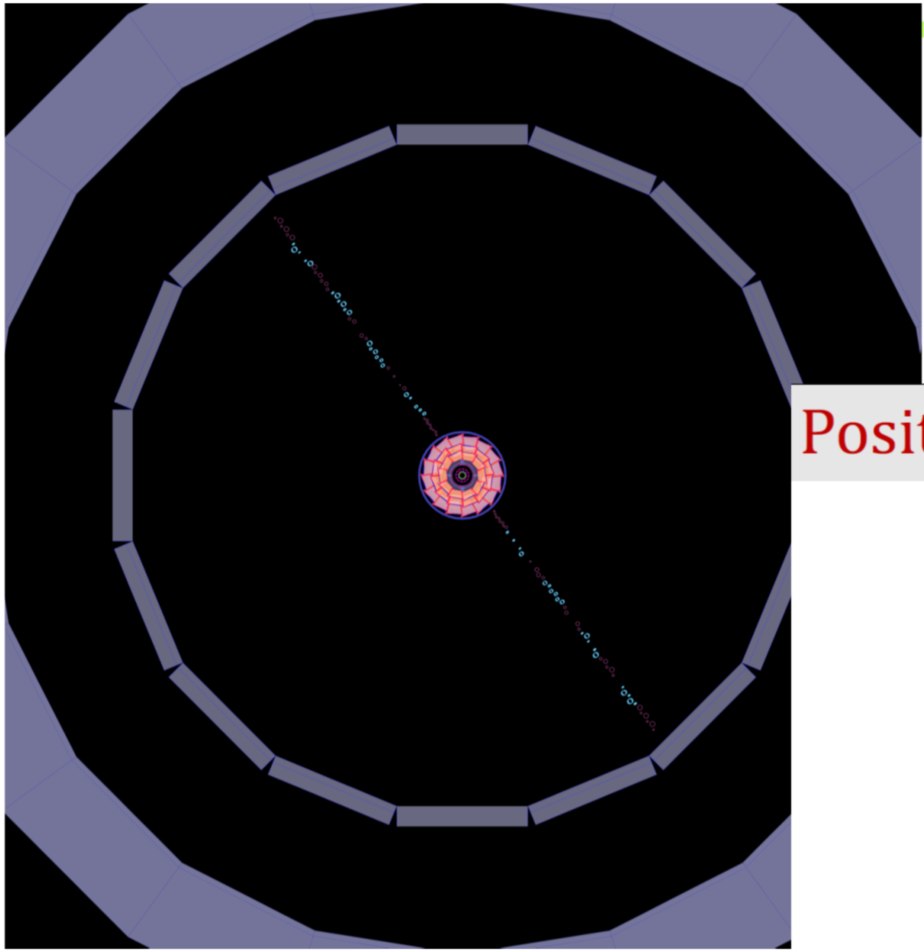


Single cosmic ray track

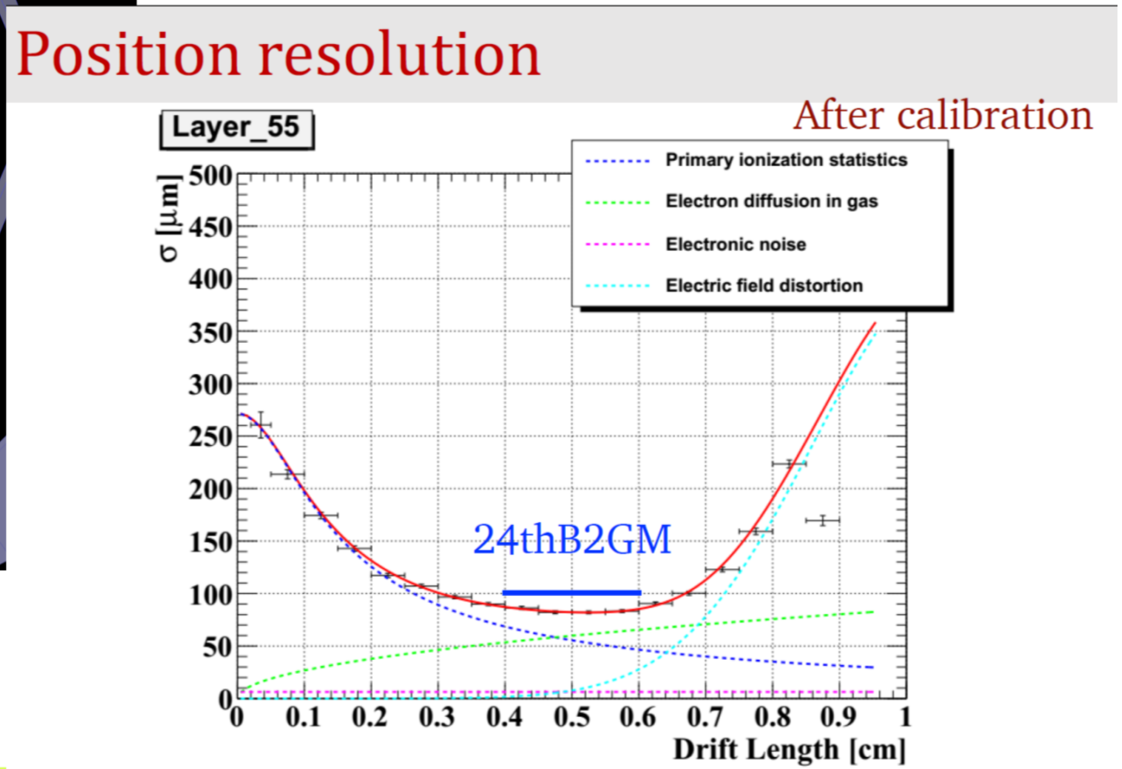
Multiple tracks (showering cosmic ray event)

→ talk by N. Taniguchi

CDC, stand-alone cosmic test in spring



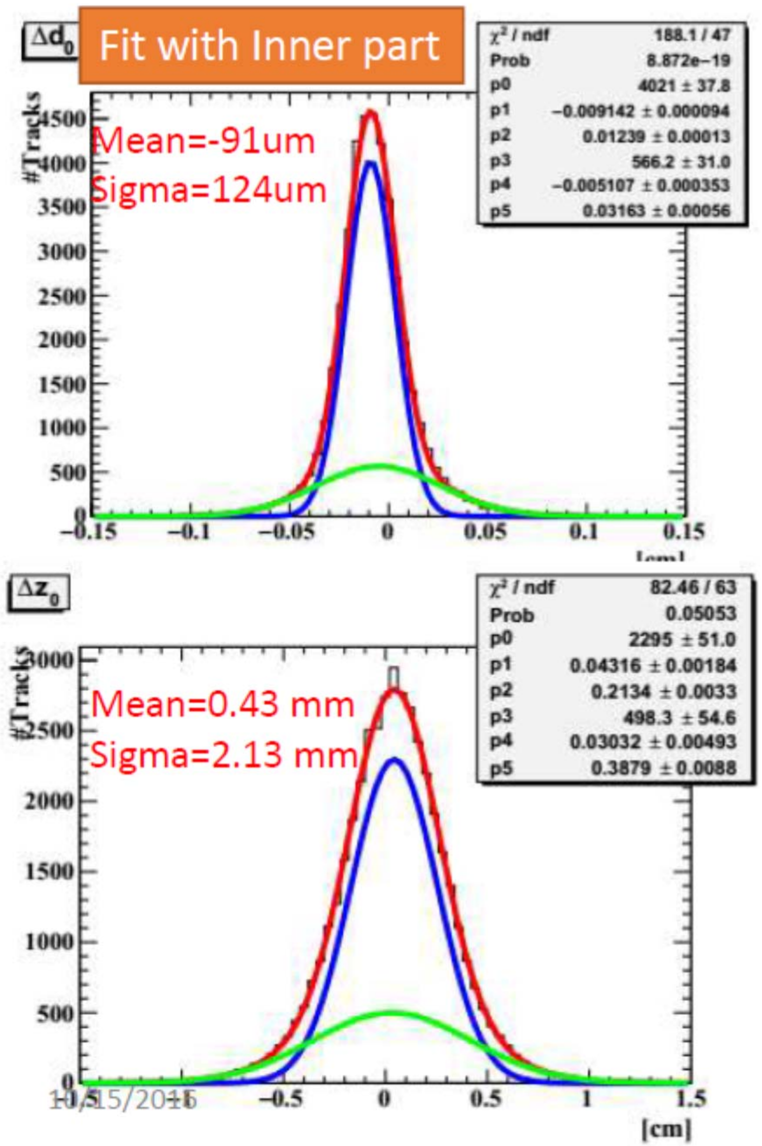
Excellent performance!



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

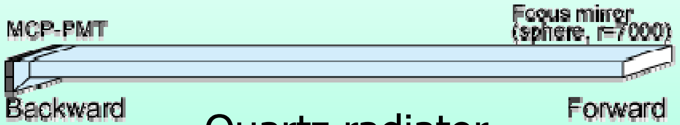
Analysis of CDC cosmic ray muons

- 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.



Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



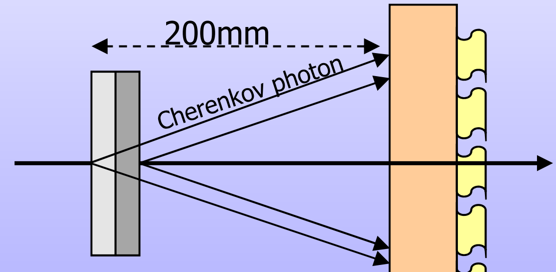
Quartz radiator

Focusing mirror

Small expansion block

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

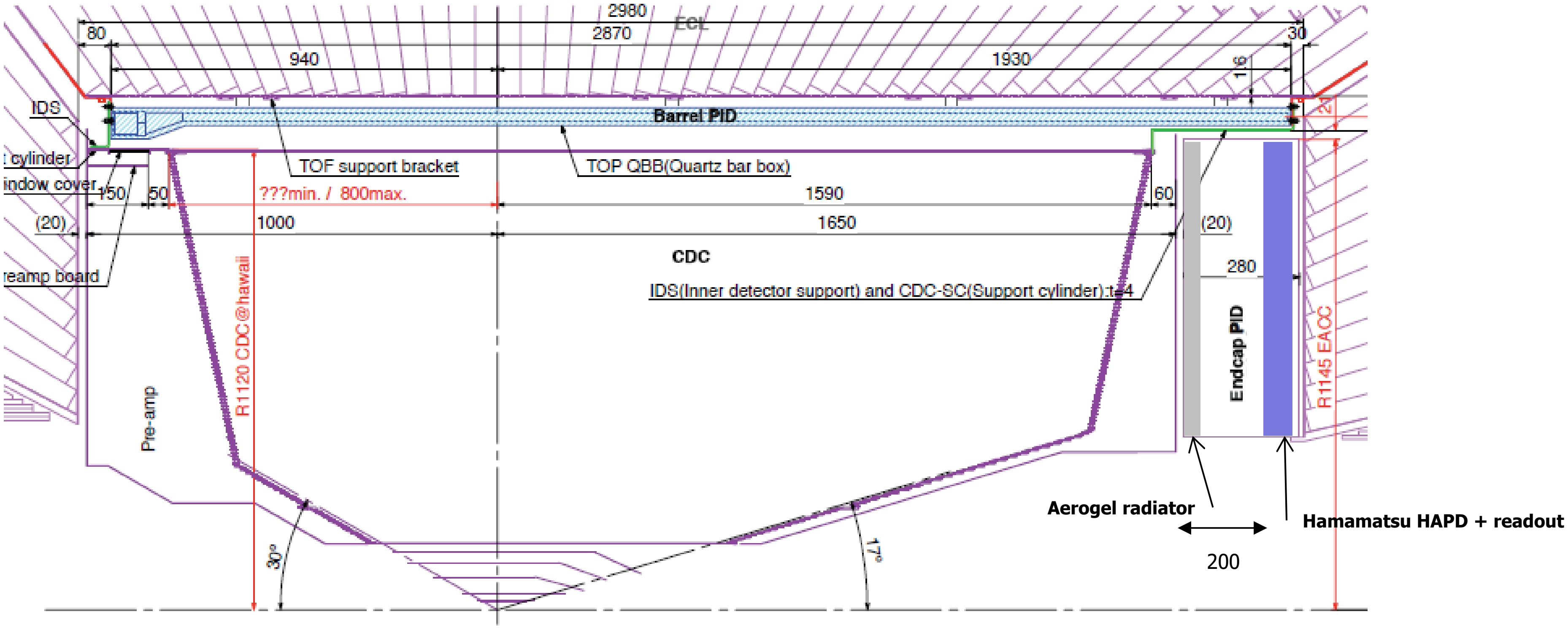
Endcap PID: Aerogel RICH (ARICH)



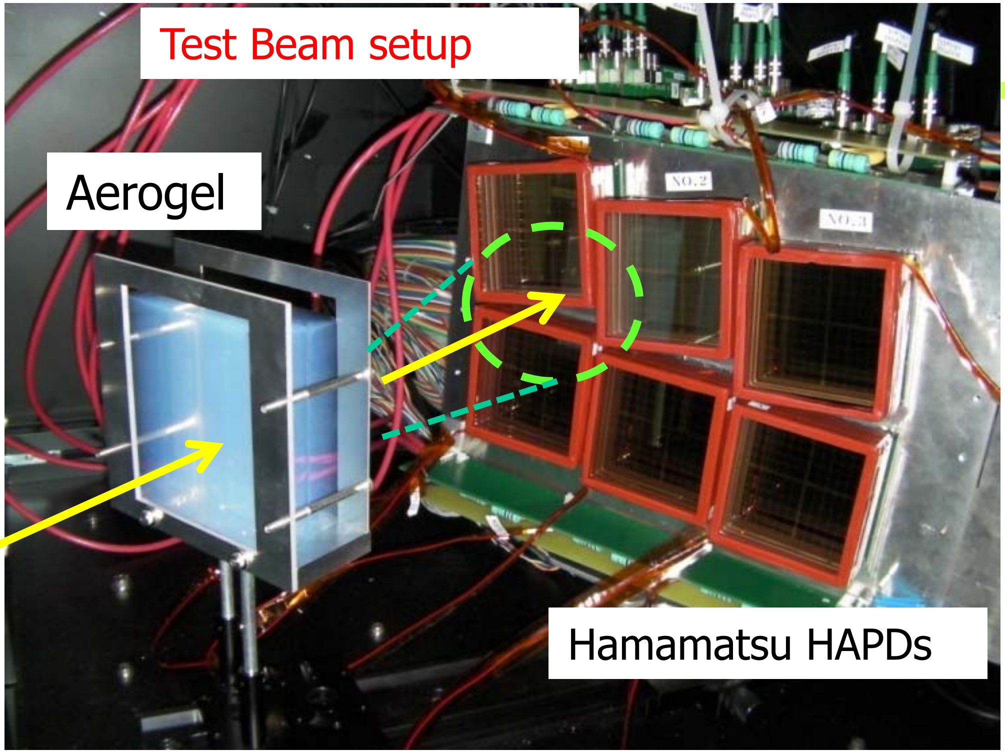
Aerogel radiator

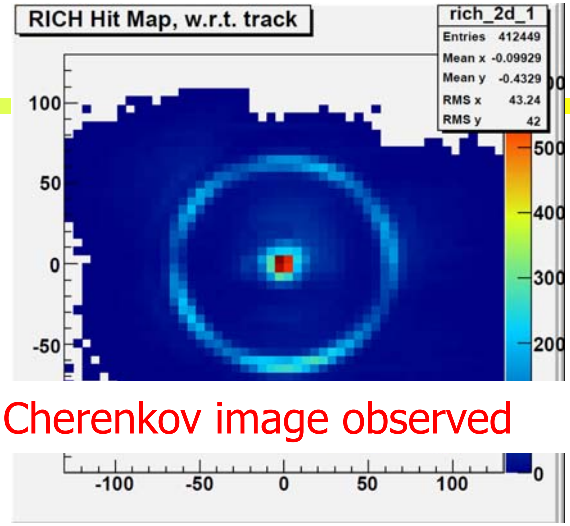
n~1.05

Hamamatsu HAPD



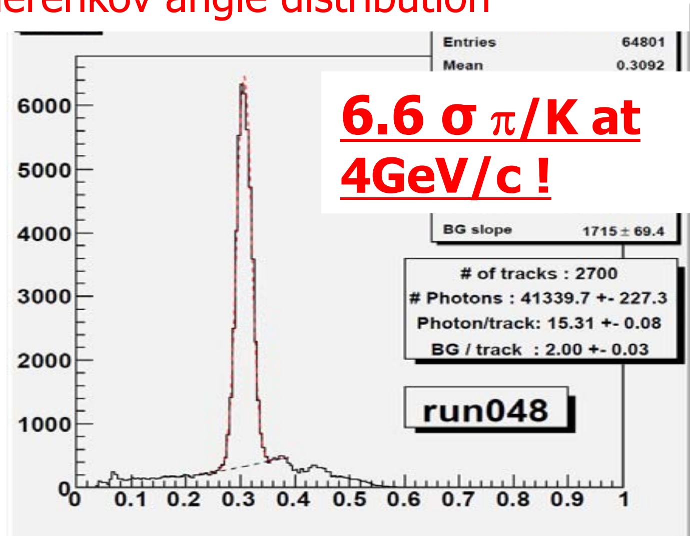
Aerogel RICH (endcap PID)





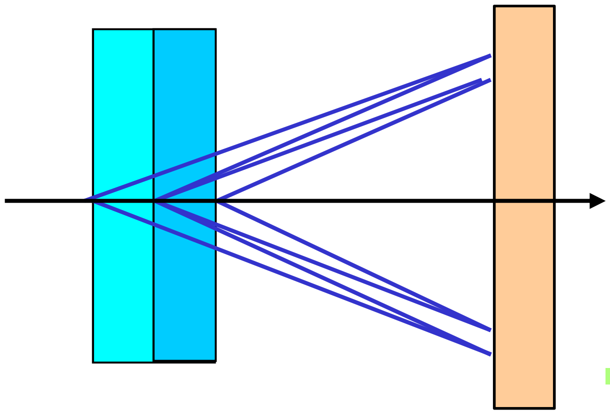
Clear Cherenkov image observed

Cherenkov angle distribution



6.6 σ π/K at 4GeV/c !

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



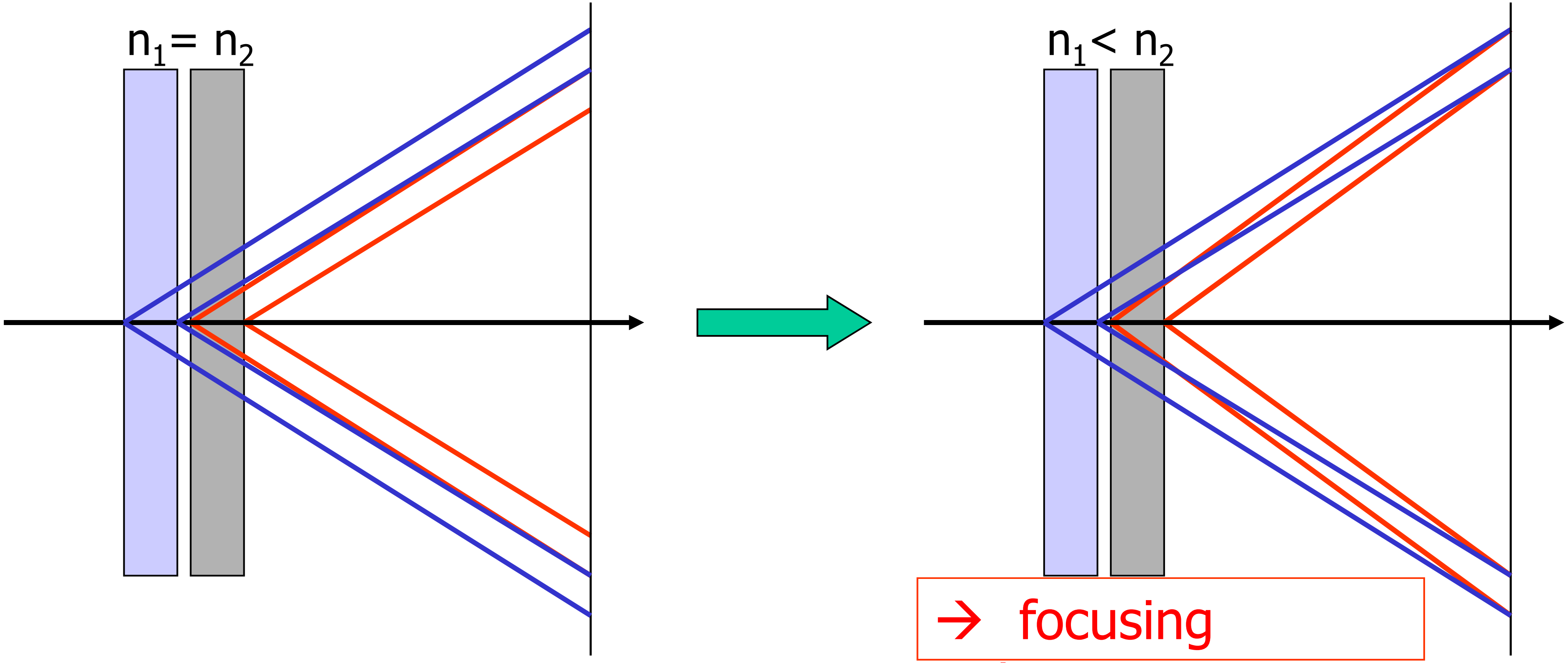
Employ multiple layers with different refractive indices→ Cherenkov images from individual layers overlap on the photon detector.

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

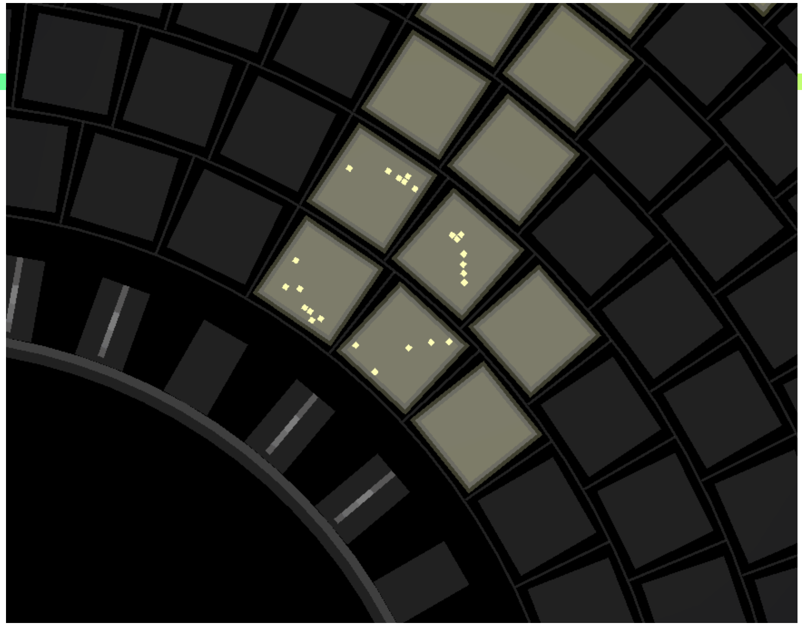
normal

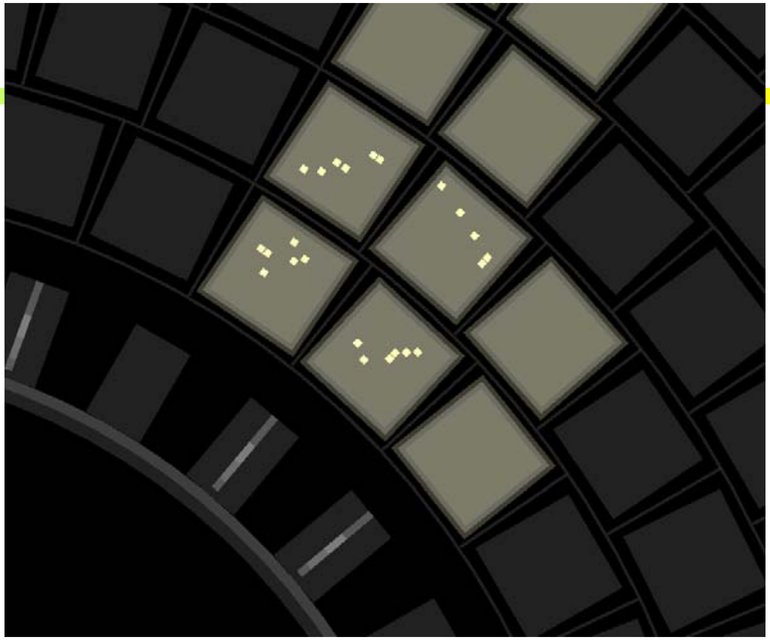


→ focusing

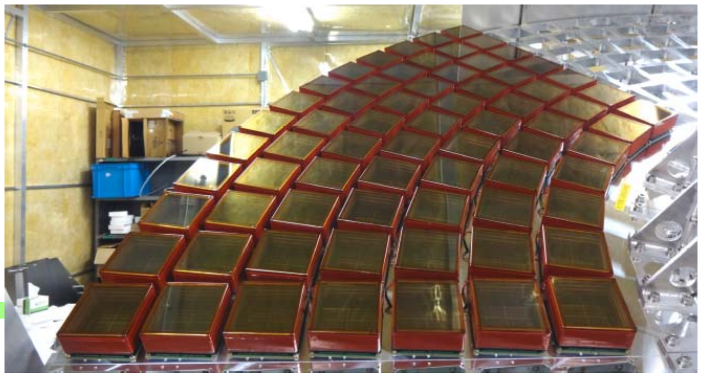
Such a configuration is only possible with aerogel (a form of Si_xO_y) – material with a tunable refractive index between 1.01 and 1.13.

ARICH: Rings from cosmic ray muons



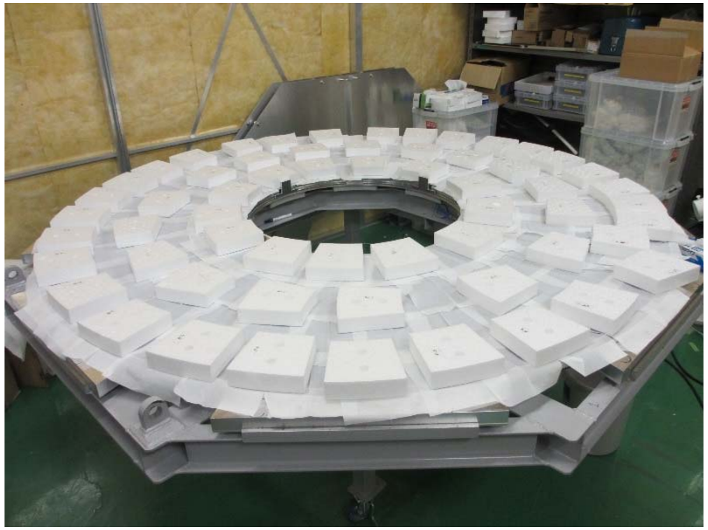


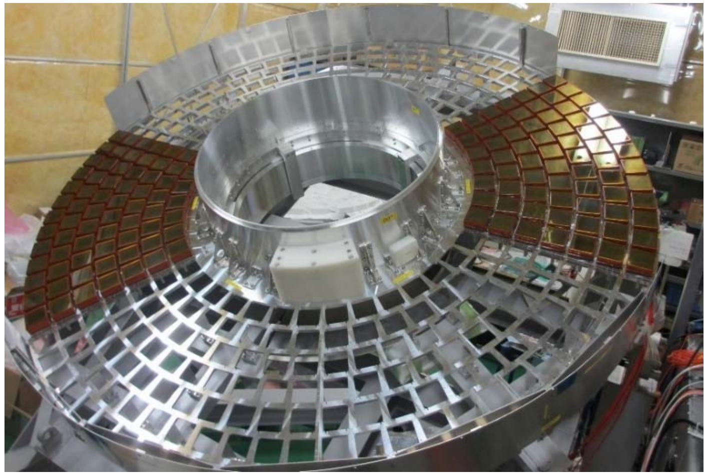
First events recorded in a partially instrumented sector of the ARICH.

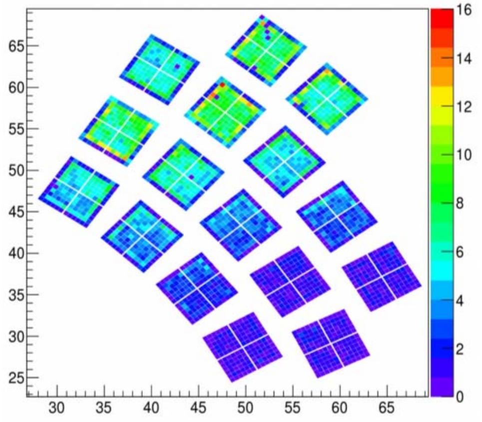


ARICH status

- Aerogel tile installation was completed in Dec. 2016!
- "Getter reactivation" of HAPDs was completed (cure for frequent large pulses in the magnetic field)
- HAPD module assembly and tests were finished (420 HAPD modules +spares).
- 140 HAPD modules (two sectors) are installed, ~1 day/sector
- Tests of DAQ under way
- Bottleneck: delivery of HV power supplies, modules for one sector expected in June





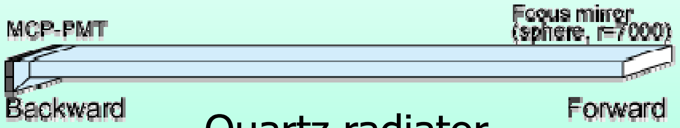


Response to the monitoring LED light source

→ talk by L. Šantelj

Cherenkov detectors

Barrel PID: Time of Propagation Counter (TOP)



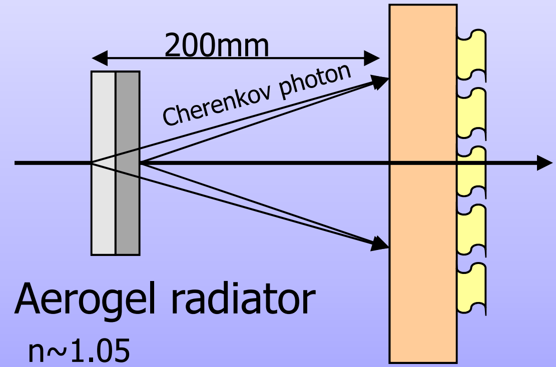
Quartz radiator

Focusing mirror

Small expansion block

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

Endcap PID: Aerogel RICH (ARICH)

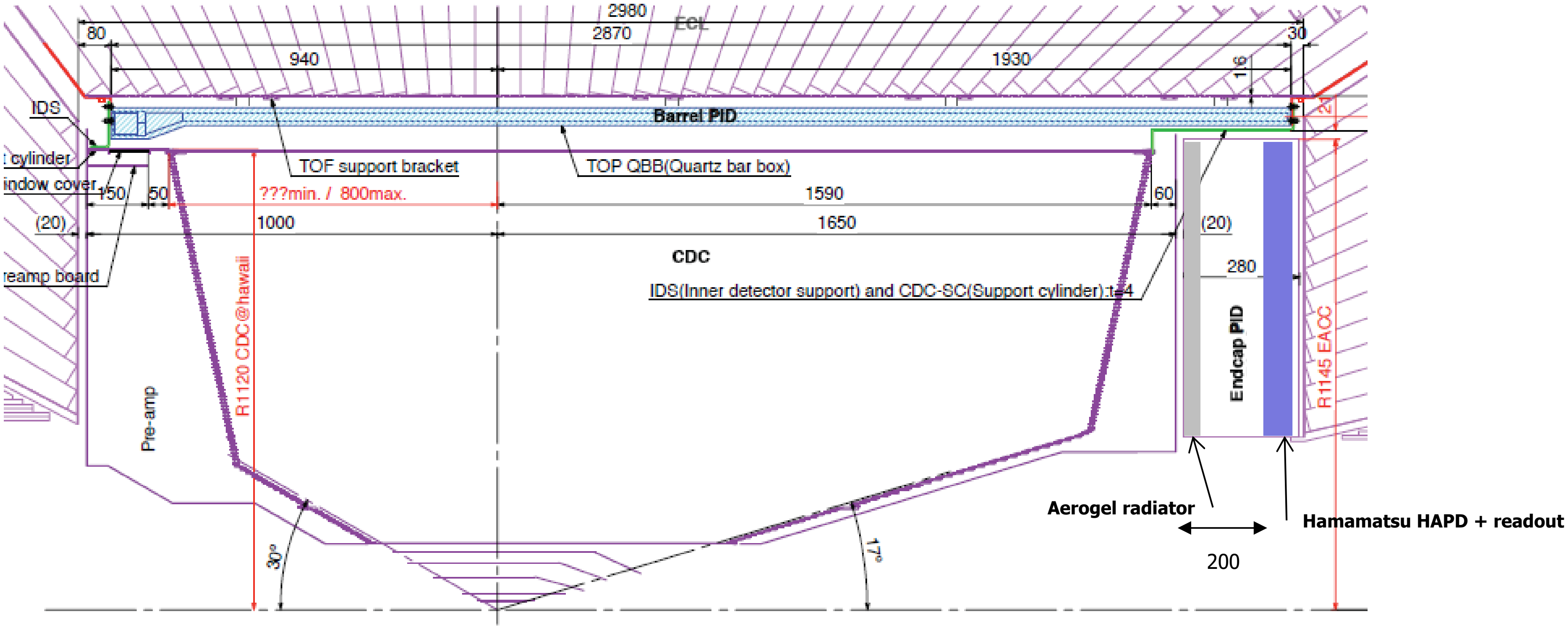


Aerogel radiator

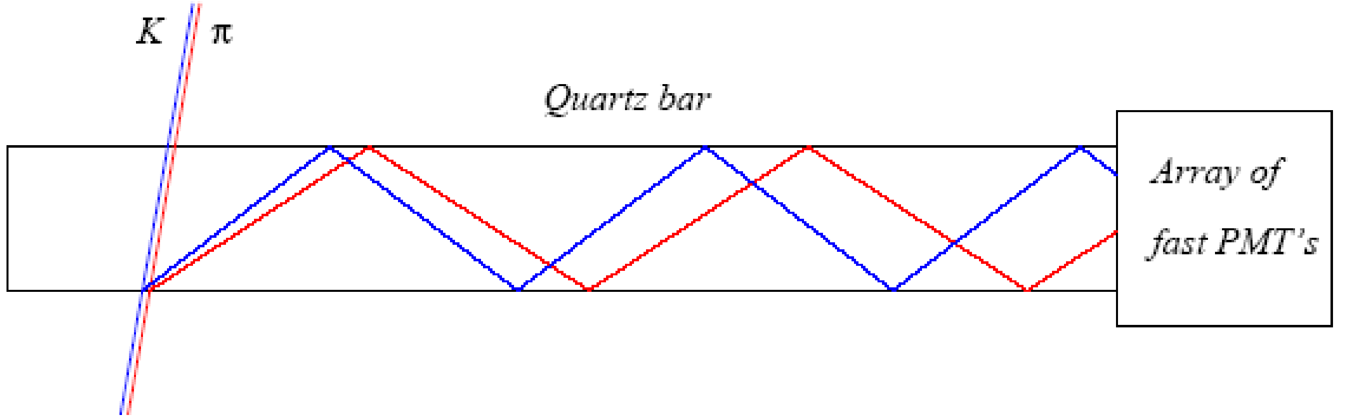
n~1.05

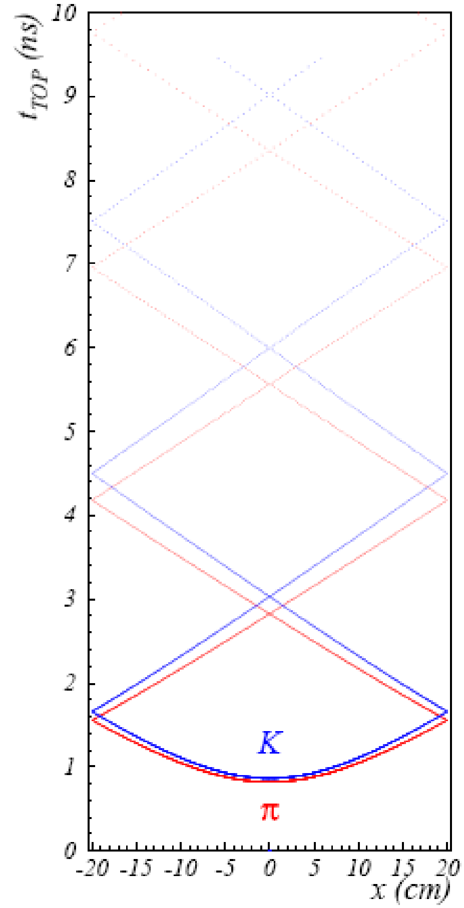
Hamamatsu HAPD

+ new ASIC



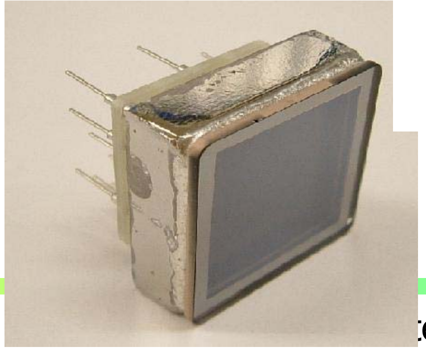
Belle II Barrel PID: Time of propagation (TOP) counter



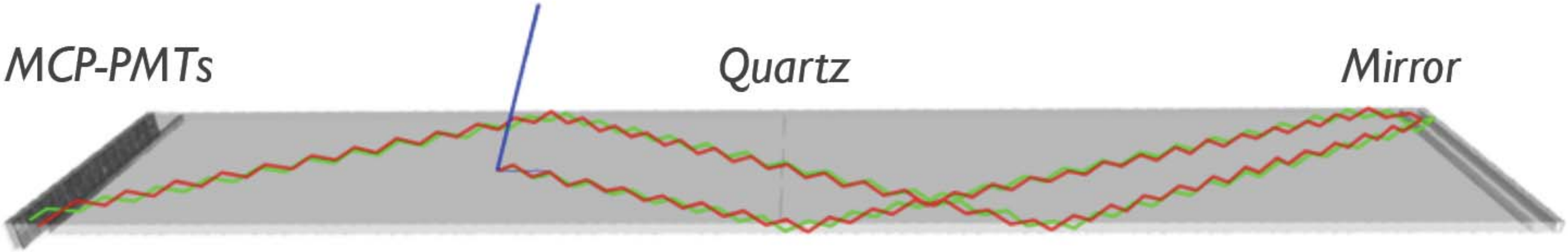


- Cherenkov ring imaging with precise time measurement.
- Uses internal reflection of Cherenkov ring images from quartz like the BaBar DIRC.
- Reconstruct Cherenkov angle from two hit coordinates and

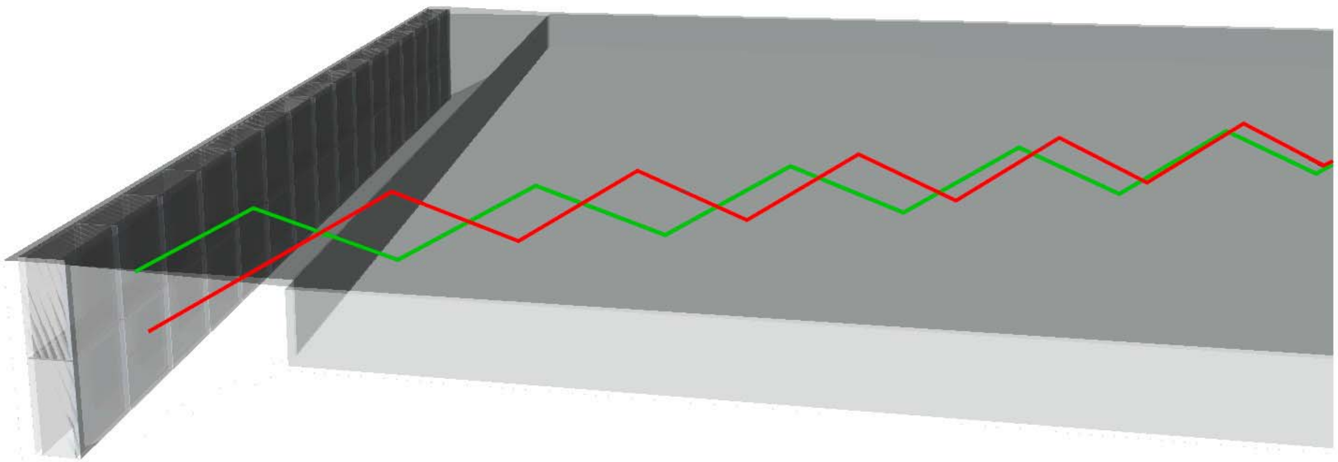
the time of propagation of the photon
  - Quartz radiator (2cm thick)
  - Photon detector (MCP-PMT)
    - Excellent time resolution ~ 40 ps
    - Single photon sensitivity in 1.5



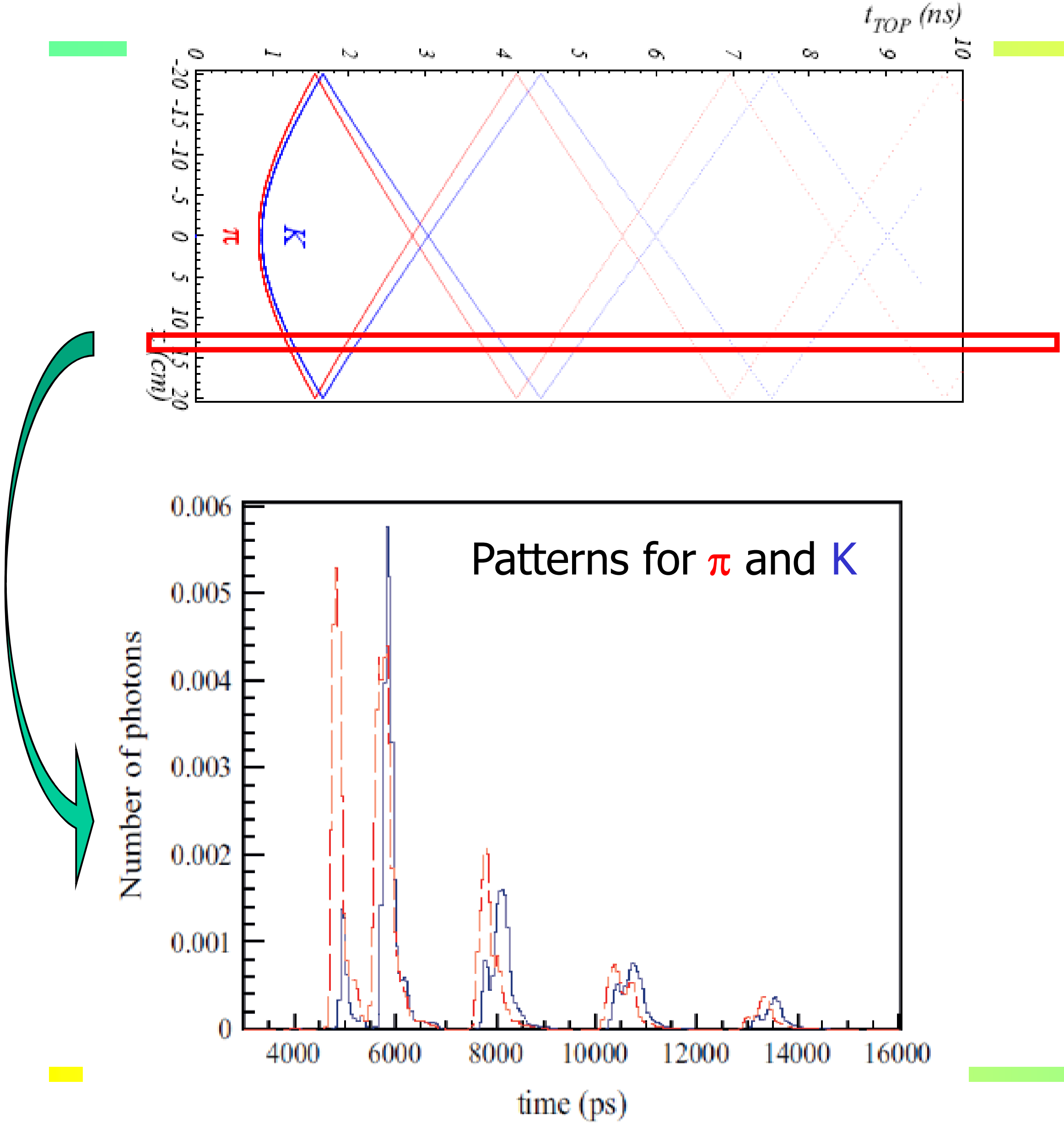
Barrel PID: Time of propagation (TOP) counter



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)

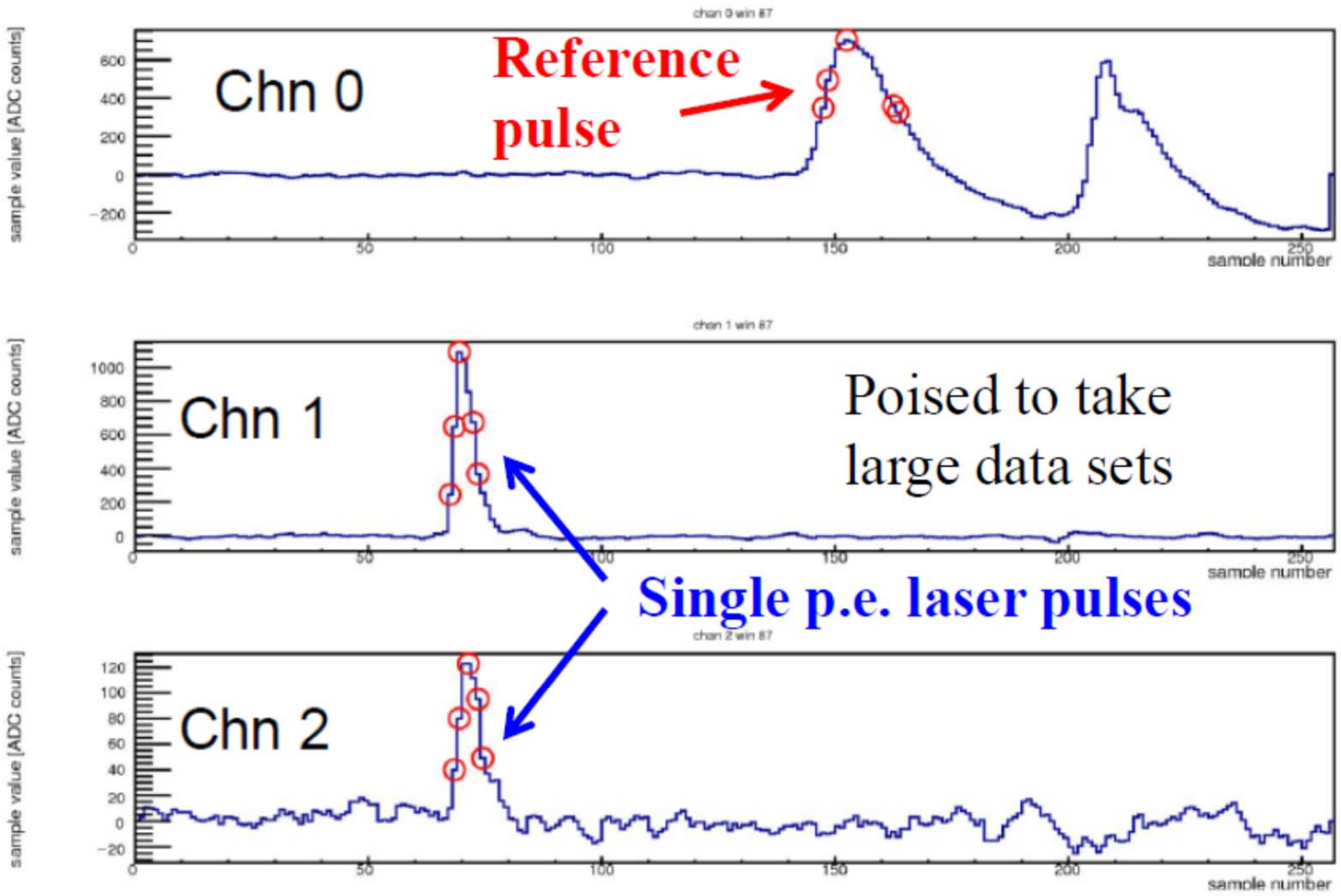
TOP: running the installed detector

- 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, including the crucial feature extraction
- Gain operational experience in 1.5 T B-field !
  - Serious issue with PMTs discovered ("rotation issue")
  - MCPs use Kovar (Cobalt-Nickel alloy) and are magnetic.
  - Repair to main issue completed

→ talk by Y. Maeda

TOP read-out status: a major step forward!

ROI & FE (laser data)

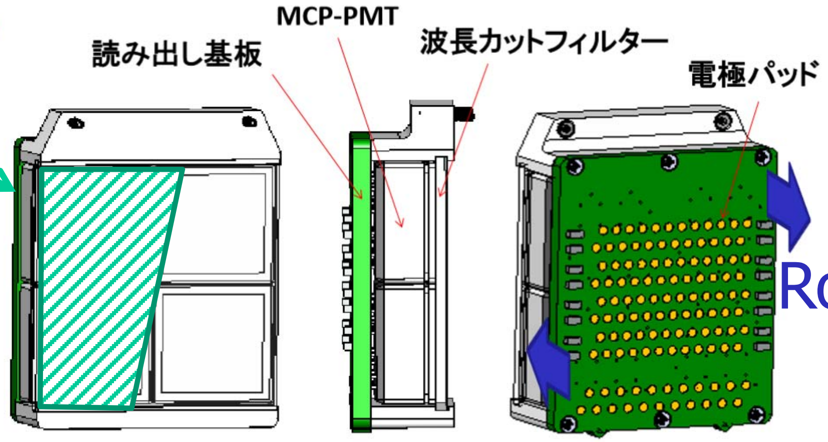


Region of Interest and Feature Extraction Firmware now running on installed modules

→ talk by D. Kolchetkov

MCP-PMT Rotation Problem

Peeled off from here



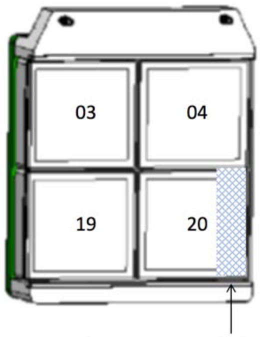
Rotate

- Repaired all 16 modules 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
- New problem 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.

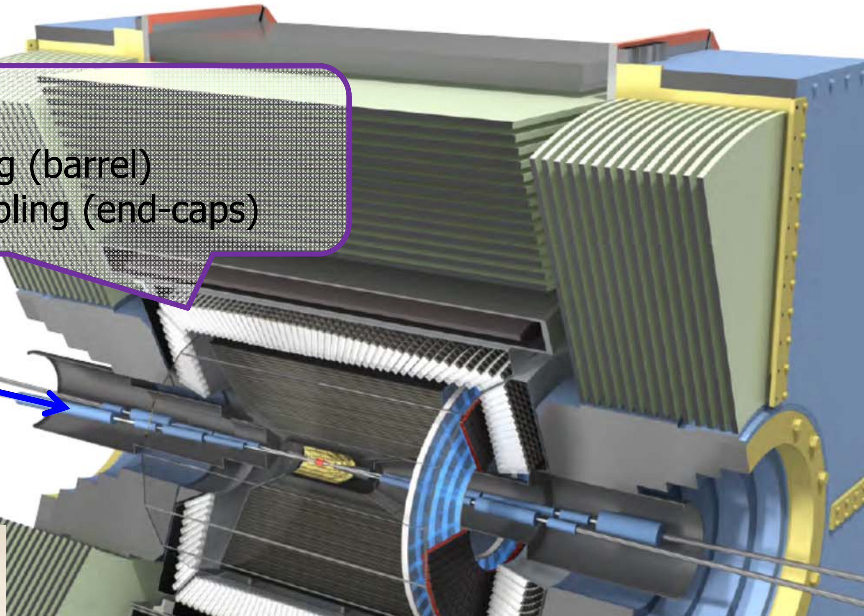
Slot11 PMTmodule02

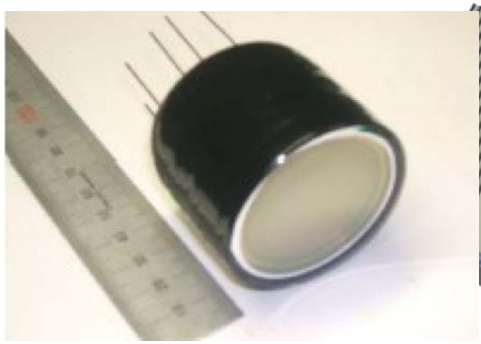


This part came off the filter.

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

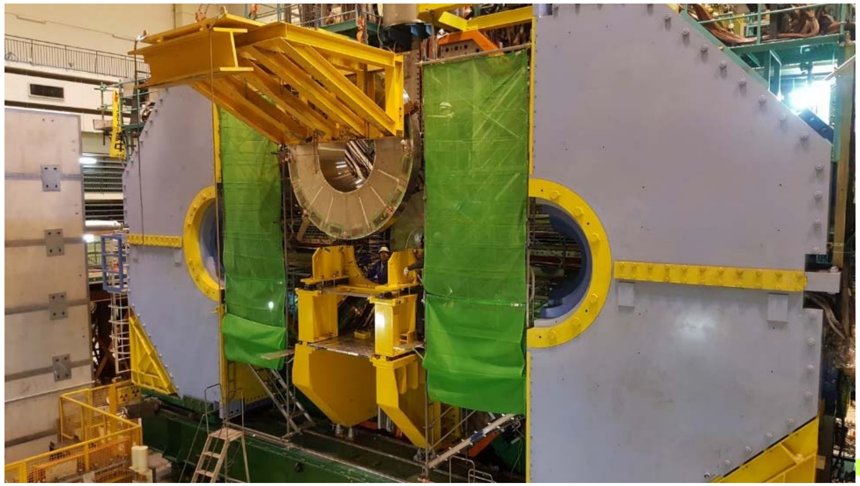
EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)

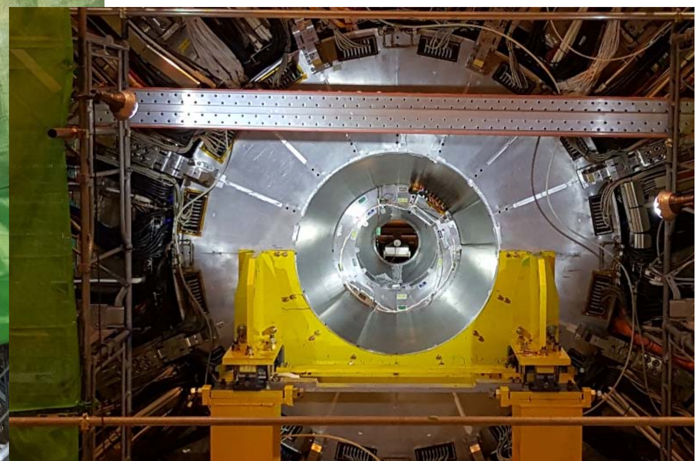




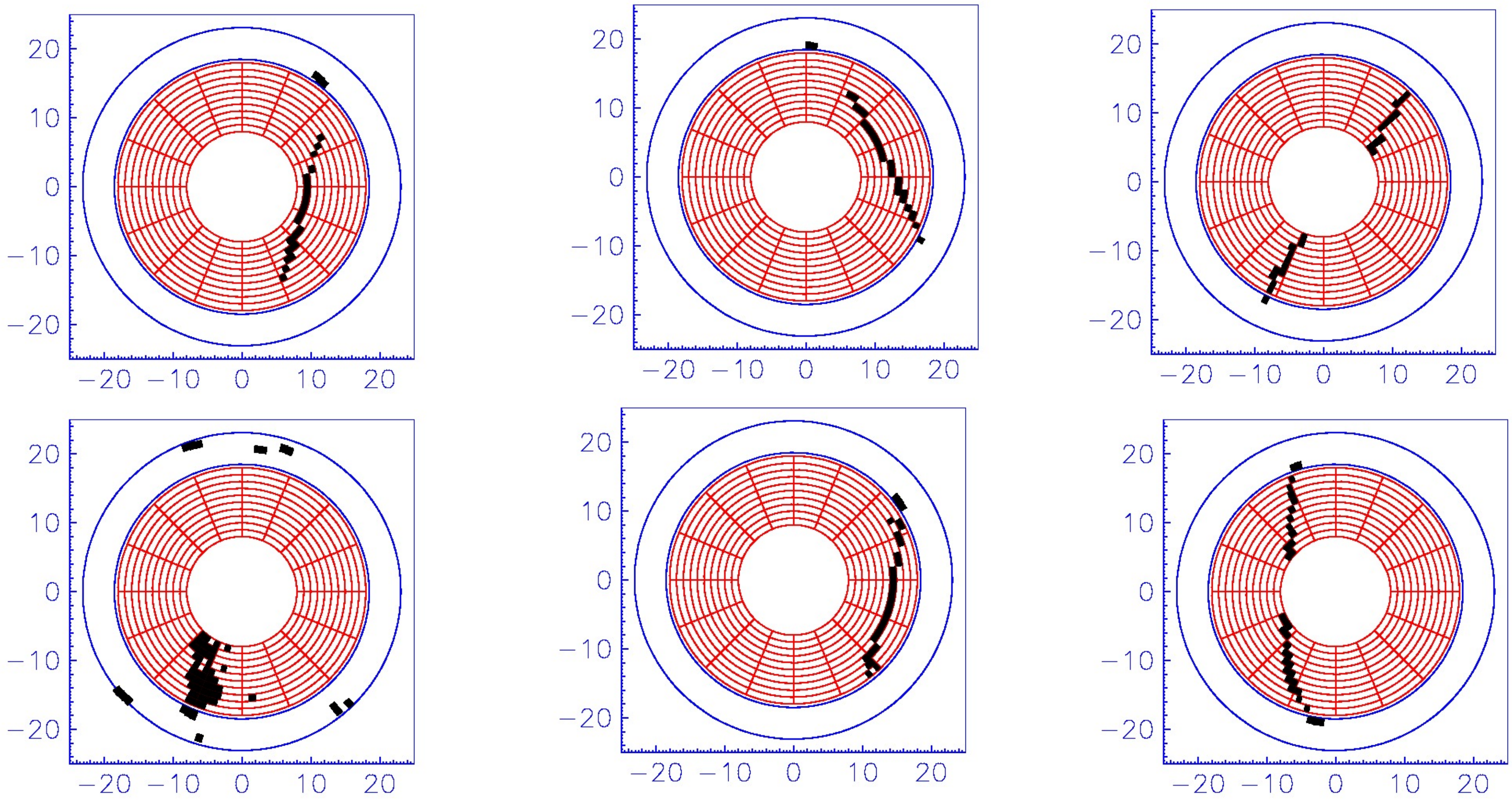
→ talk by C. Cecchi
→ talk by F. Di Capua
→ poster A. Bobrov
→ poster D. Matvienko
→ poster S.-H. Kim

ECL Endcap installation



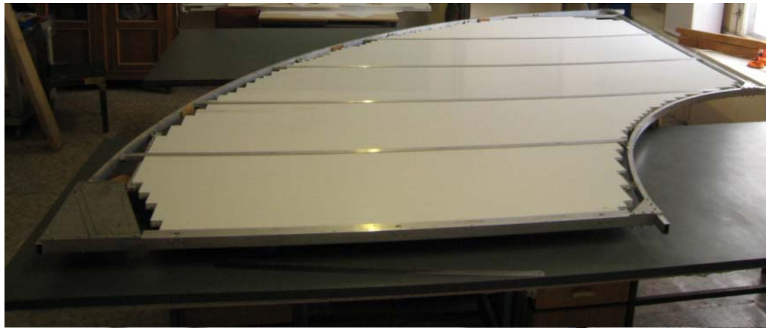


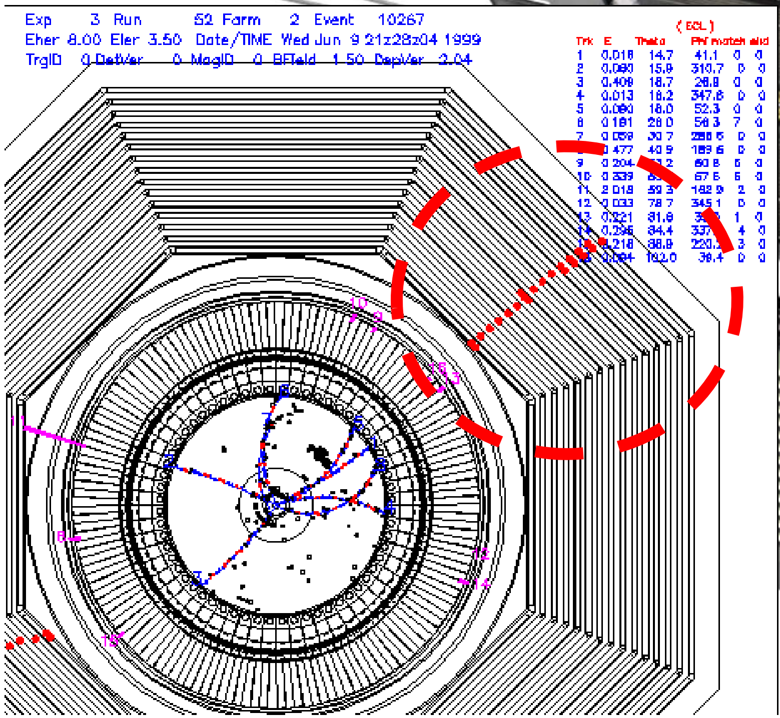
ECL: Cosmic ray tracks in the endcap calorimeter

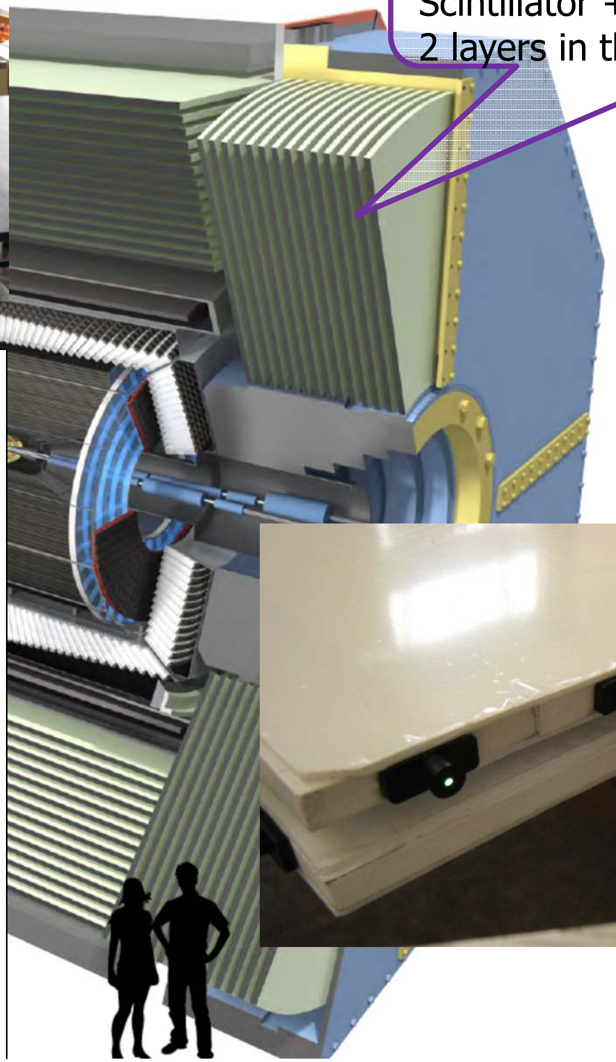


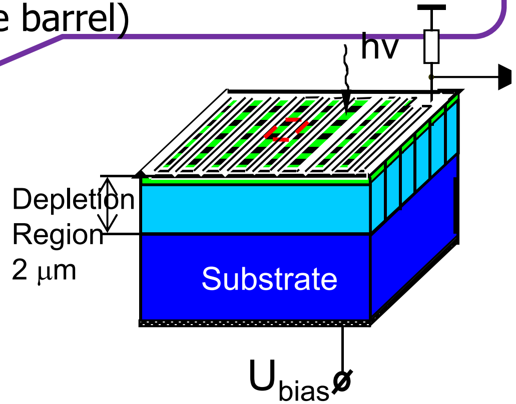
Detection of muons and K_Ls: parts of the original RPC system have to be replace because they could not handle the high background rates (mainly neutrons)

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







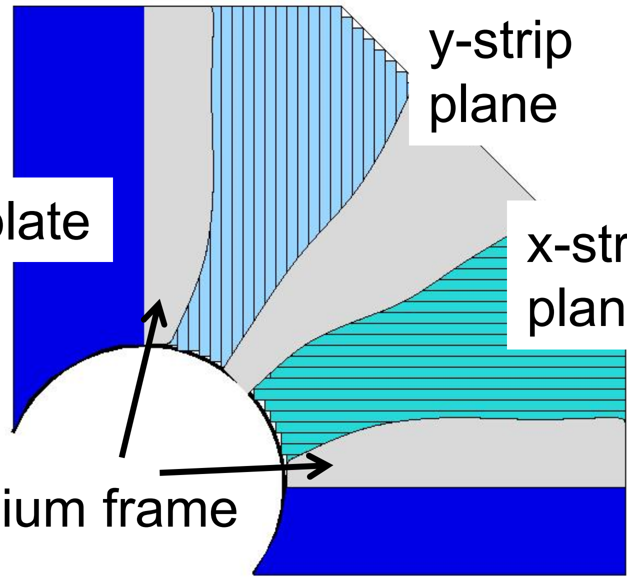


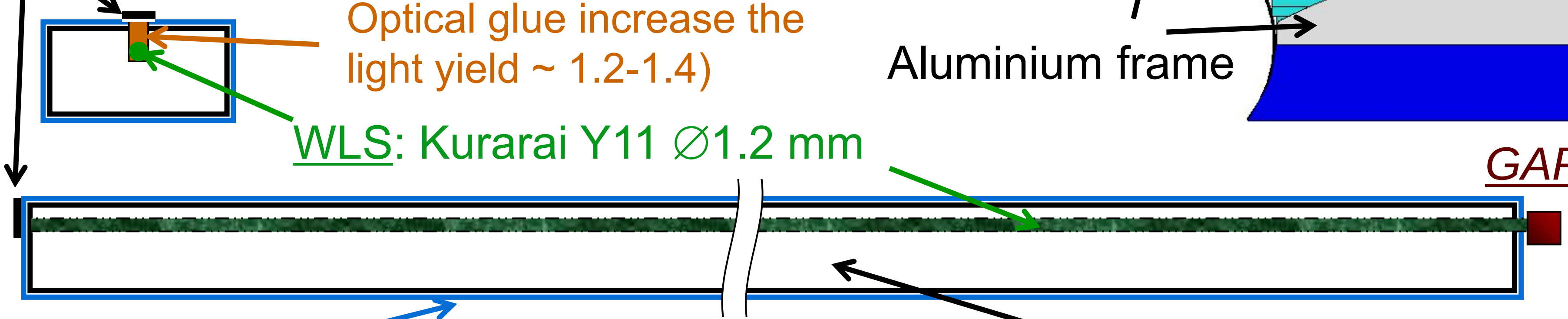
→ Talk T. Uglov

Muon detection system upgrade in the endcaps

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

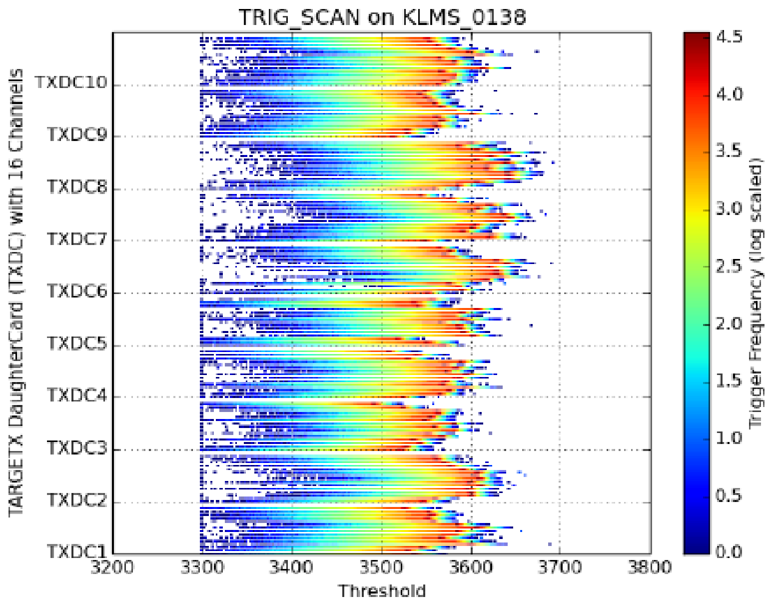
- Two independent (x and y) layers in one superlayer made of orthogonal strips with WLS read out
- Photo-detector = avalanche photodiode in Geiger mode (SiPM)
- ~120 strips in one 90º sector (max L=280cm, w=25mm)
- ~30000 read out channels
- Geometrical acceptance > 99%



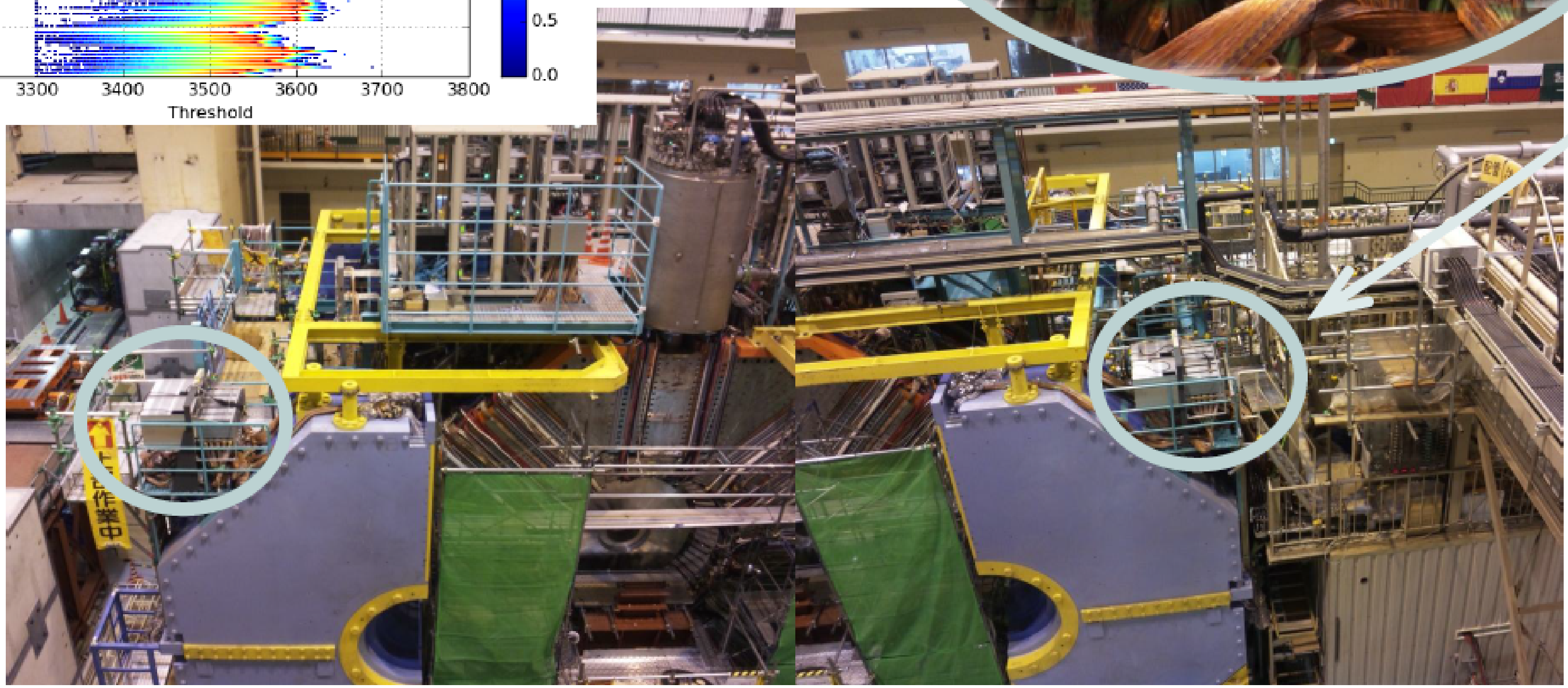


KLM - endcaps

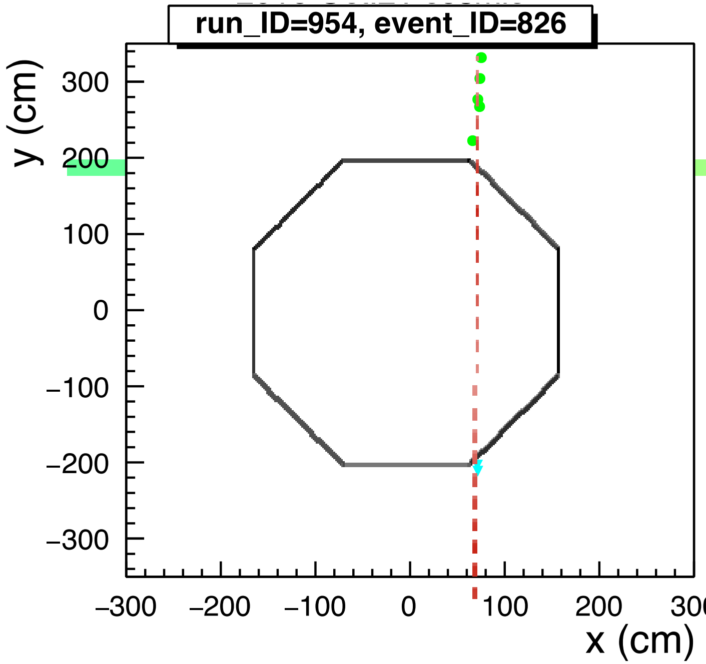
All Backward KLM sectors fully connected to DAQ boards and tested

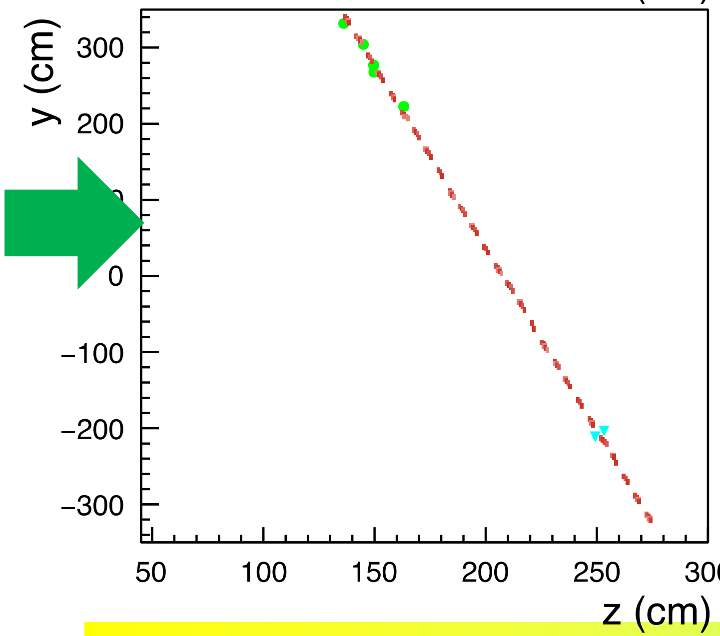


Test of one superlayer, 150 channels



KLM - barrel

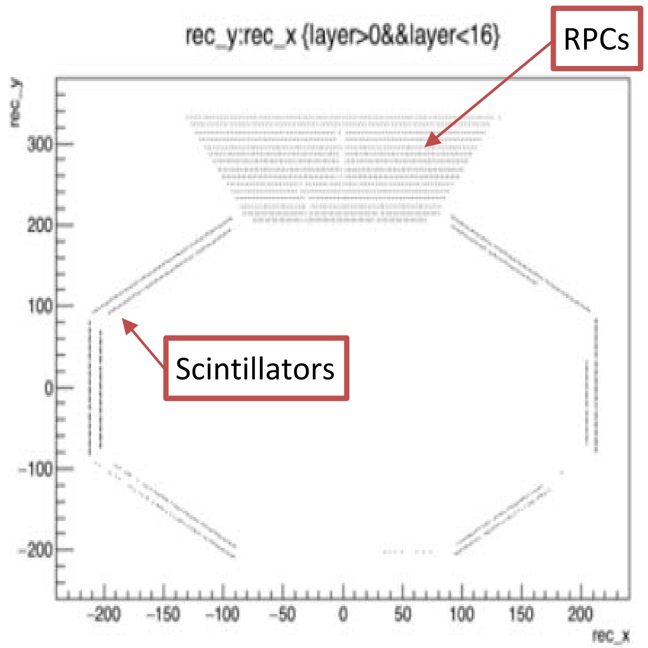




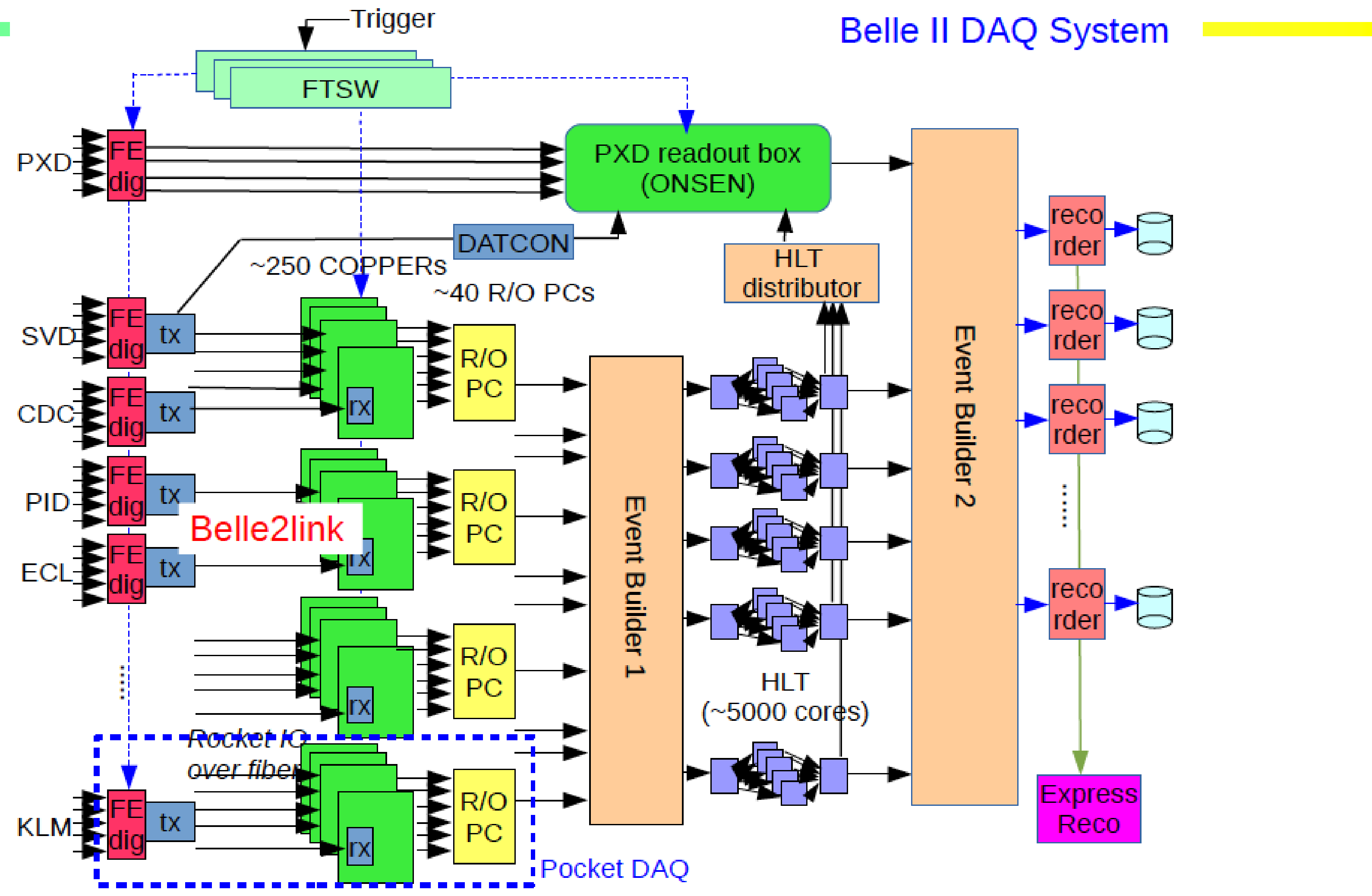
Barrel KLM: scintillators (2 layers) + RPCs

Missing: RPC read-out

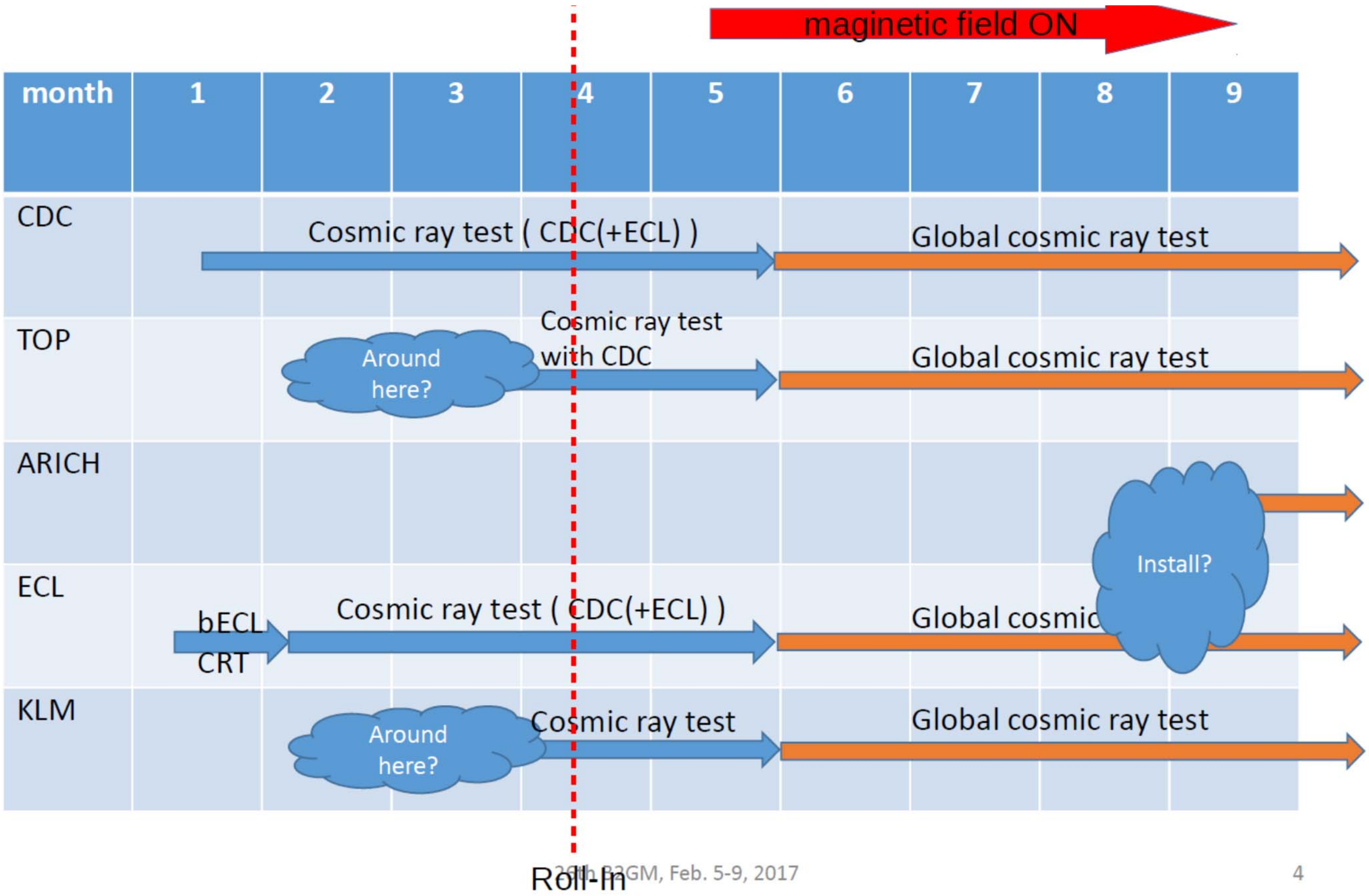
INFN pre-production RPC readout boards (14) arrived at KEK for final tests before green light to start full production



Trigger, DAQ and readout integration



DAQ commissioning

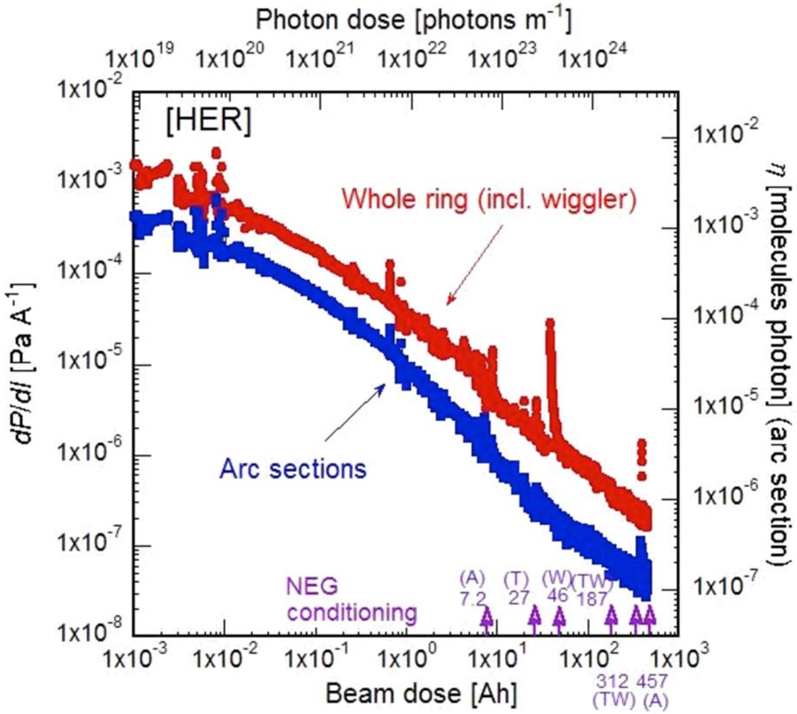


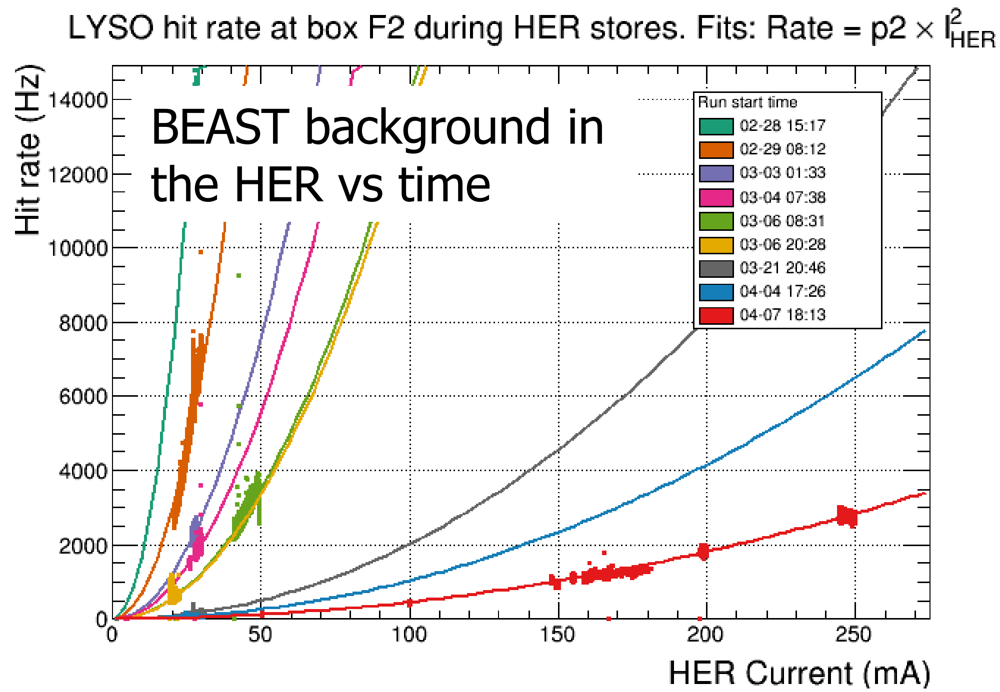
SuperKEKB commissioning phase 1: Beast II commissioning detector

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

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

HER integrated beam dose 662 Ah (LER 776 Ah)



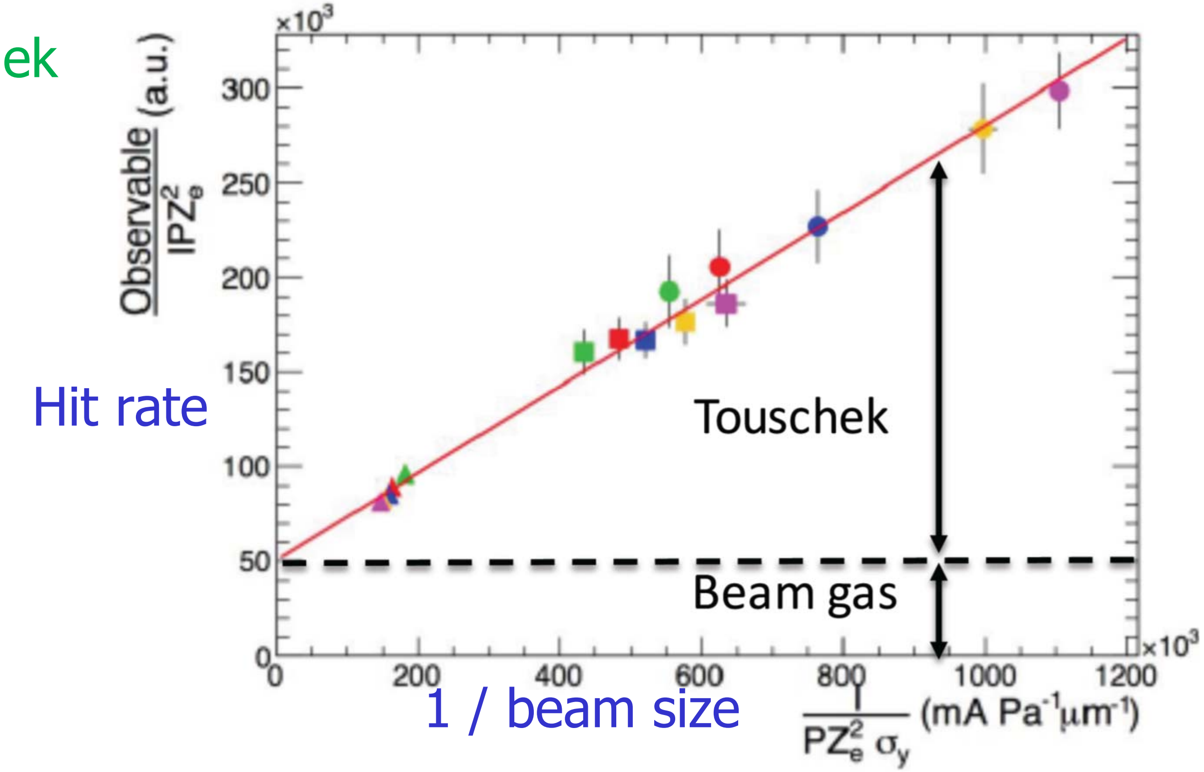


- Vacuum scrubbing successful, but not complete
  - Dynamic pressure low, but not at design value
- Safe to install Belle II + BEAST phase 2
  - Total dose in phase 1: A few hundred krad near beampipe
  - ~1/r^2, no large dose from SR

→ Talk P. Lewis

BEAST Phase 1: Lessons Learned

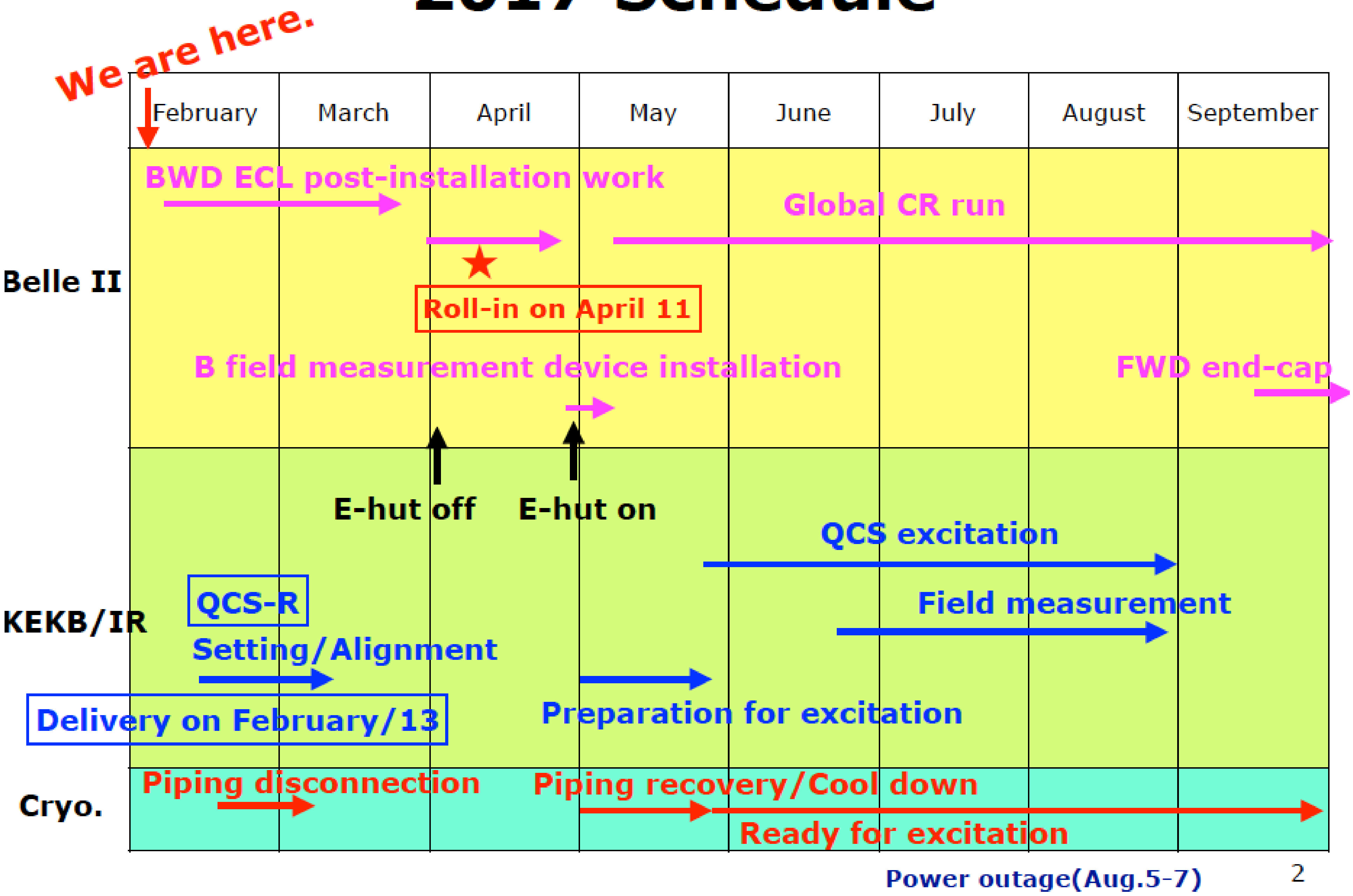
- LER Beam gas and Touschek BG agree roughly with predictions, MC/data comparison still ongoing



- Accelerator transport simulation (SAD): modifications resulting from phase 1 validation led to increase in predicted HER Touschek BG for phase 3
  - may still be mitigated by collimators

February B2GM

2017 Schedule



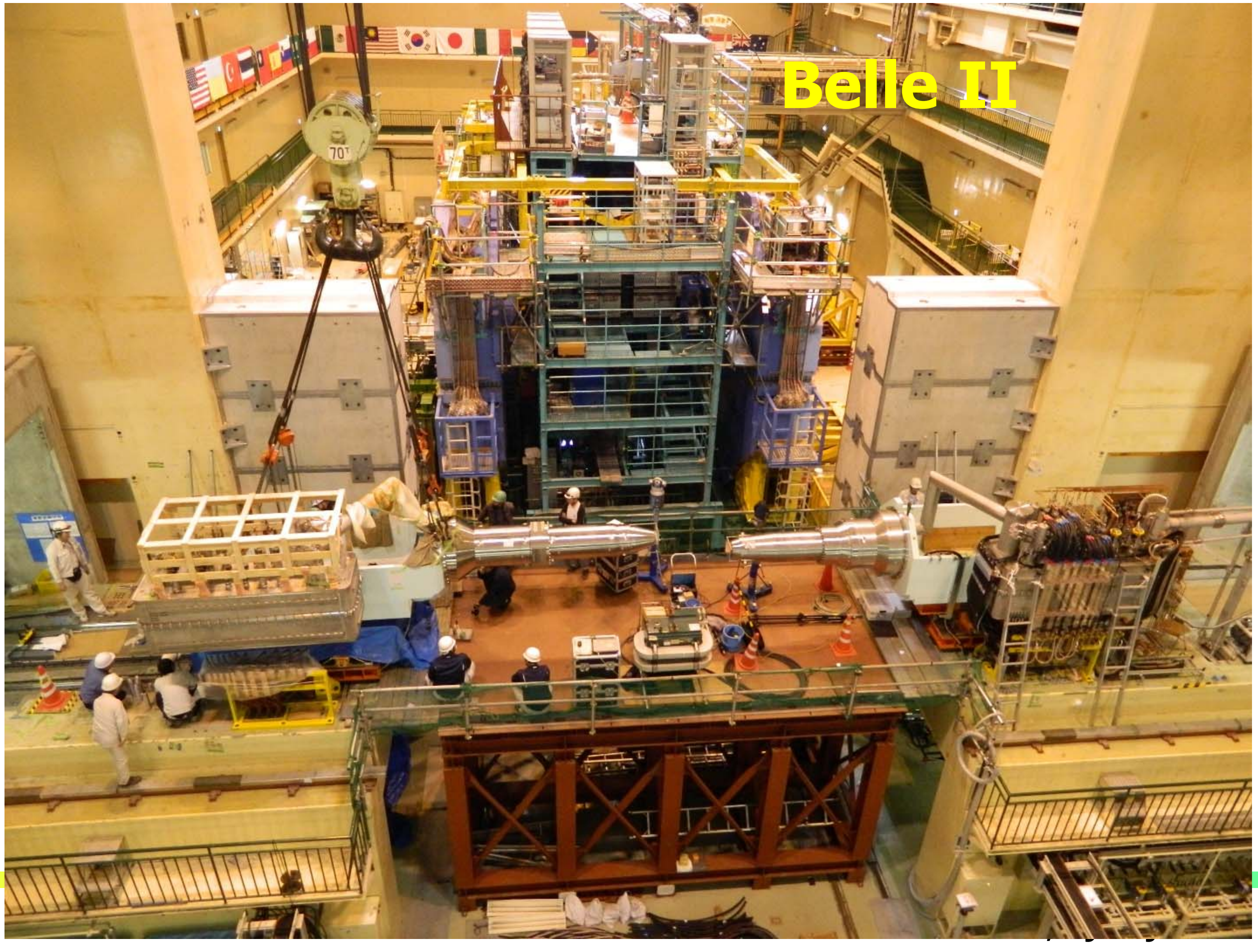
SuperKEKB/Belle II Status

- 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.

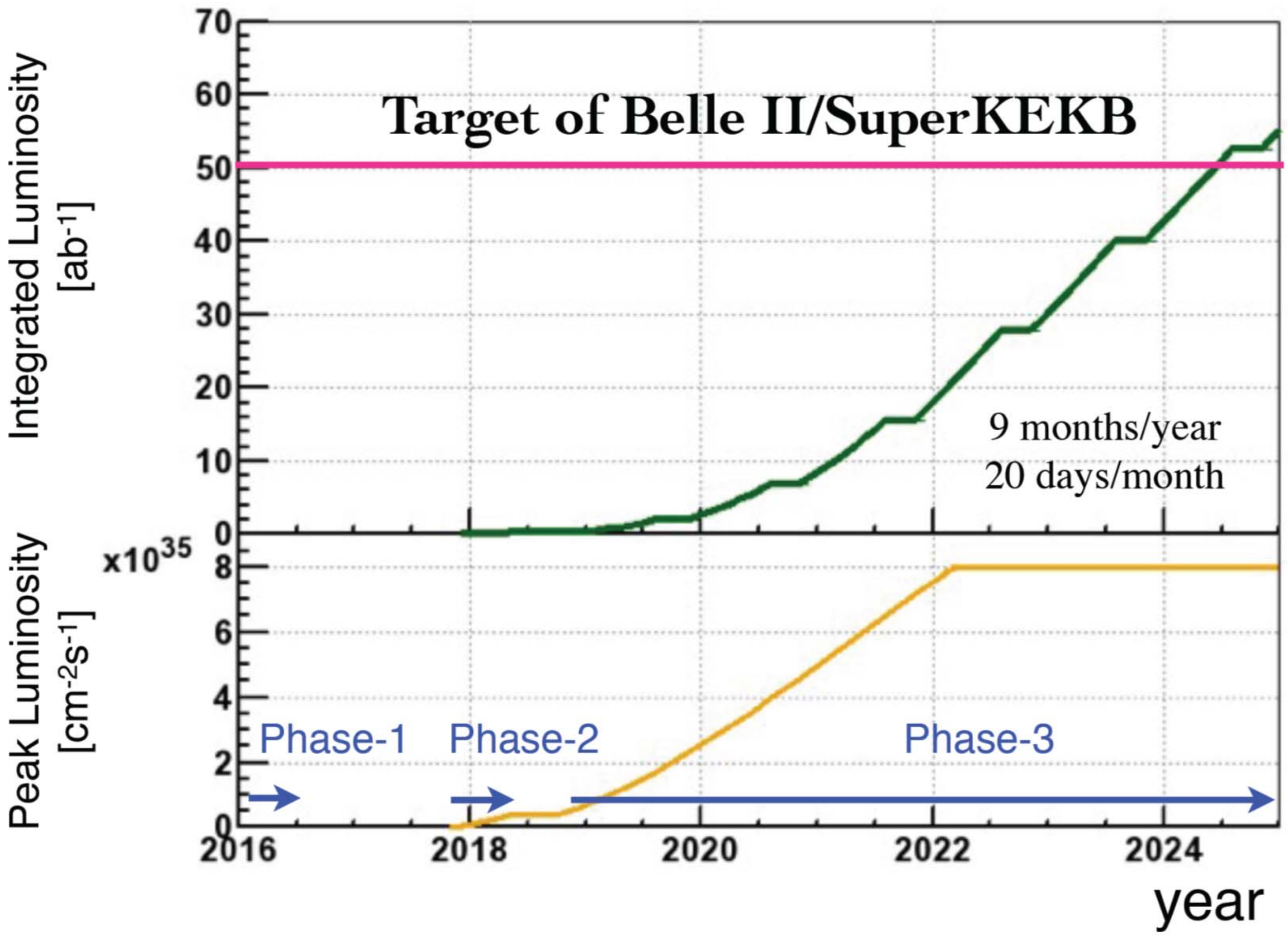
- Final quads in since Feb. 13
- Belle II: installation of outer detectors: spring – December 2016
- Belle II (without the vertex detector) roll in in April 2017, cosmic rays
- Phase 2 commissioning Nov 2017 – spring 2018 (+ first physics runs)
- Install vertex detector summer 2018
- Full detector operation by the end 2018 (Phase 3)

Next major event: roll-in

- Retract superconducting final focus magnets
- Roll in the Belle II detector and electronics trailer.
- Mid April



SuperKEKB luminosity projection



Summary

Detector construction well underway

Accelerator: the last missing piece, one of the two final quads, delivered.

First data taking in spring 2018

Main physics run starts end of 2018.

Belle II @ INSTR2017, talks

- Beam background detection at SuperKEKB/Belle II (P. Lewis)
- The Belle II Pixel Detector Data Acquisition and Background Suppression System (K. Lautenbach)
- Central Drift Chamber for Belle-II (N. Taniguchi)
- Aerogel RICH counter for the Belle II forward PID (L. Šantelj)
- Status of installation and commissioning for the Belle II time-of-propagation counter (Y. Maeda)
- Electronic readout system for Belle II imaging Time of Propagation detector (D. Kolchetkov)
- The Upgrade of the ECL forward calorimeter of the BelleII experiment at SuperKEKB (C. Cecchi)
- K long and muon system for the Belle II experiment (T. Uglov)
- Monitoring complex detectors: the uSOP approach in Belle II experiment (F. Di Capua)
- The Belle II Software - From Detector Signals to Physics Results (T. Kuhr)

Belle II @ INSTR2017, posters

- Energy and time reconstruction algorithm of Belle II electromagnetic calorimeter (Alexander Bobrov)
- Radiation hardness study of CsI(Tl) scintillation crystals for the Belle II calorimeter (Dmitry Matvienko)
- Status of the electromagnetic calorimeter trigger system at the Belle II (SungHyun Kim)