KEK FF workshop, March 14, 2013

Belle II status

Peter Križan

University of Ljubljana and J. Stefan Institute

University of Ljubljana

“Jožef Stefan” Institute

Contents

- Physics case for Belle II →talks of this workshop
- Accellerator – SuperKEKB
- Detector – Belle II
- Status and prospects

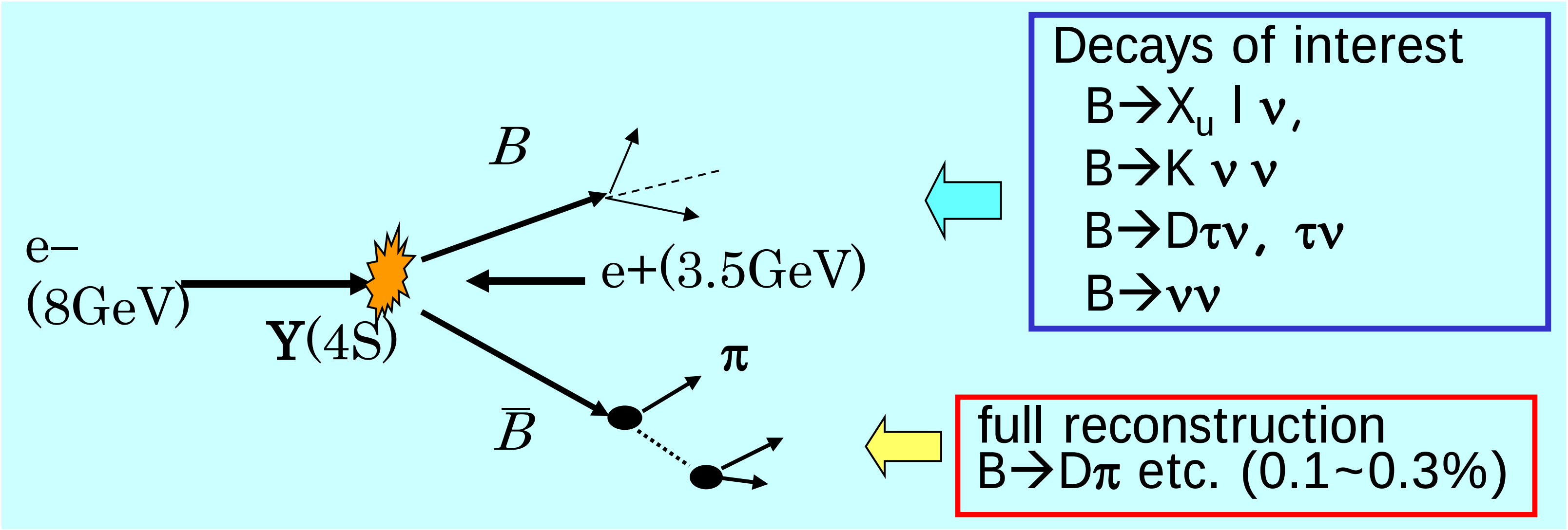
B factories: a success story

- Measurements of CKM matrix elements and angles of the unitarity triangle
- Observation of direct CP violation in B decays
- Measurements of rare decay modes (e.g., $B \to \tau\nu$, $D\tau\nu$)
- $b \to s$ transitions: probe for new sources of CPV and constraints from the $b \to s\gamma$ branching fraction
- Forward-backward asymmetry (A_{FB}) in $b \to sl^+l^-$ has become a powerfull tool to search for physics beyond SM.
- Observation of D mixing
- Searches for rare τ decays
- Observation of new hadrons

Possible also because of unique capabilities of B factories: detection of neutrals, neutrinos, clean event environment.

Power of e^+e^-, example: Full Reconstruction Method

- Fully reconstruct one of the B mesons to
  - Tag B flavor/charge
  - Determine B momentum
  - Exclude decay products of one B from further analysis



→ Offline B meson beam!

Powerful tool for B decays with neutrinos

Complementary to LHCb

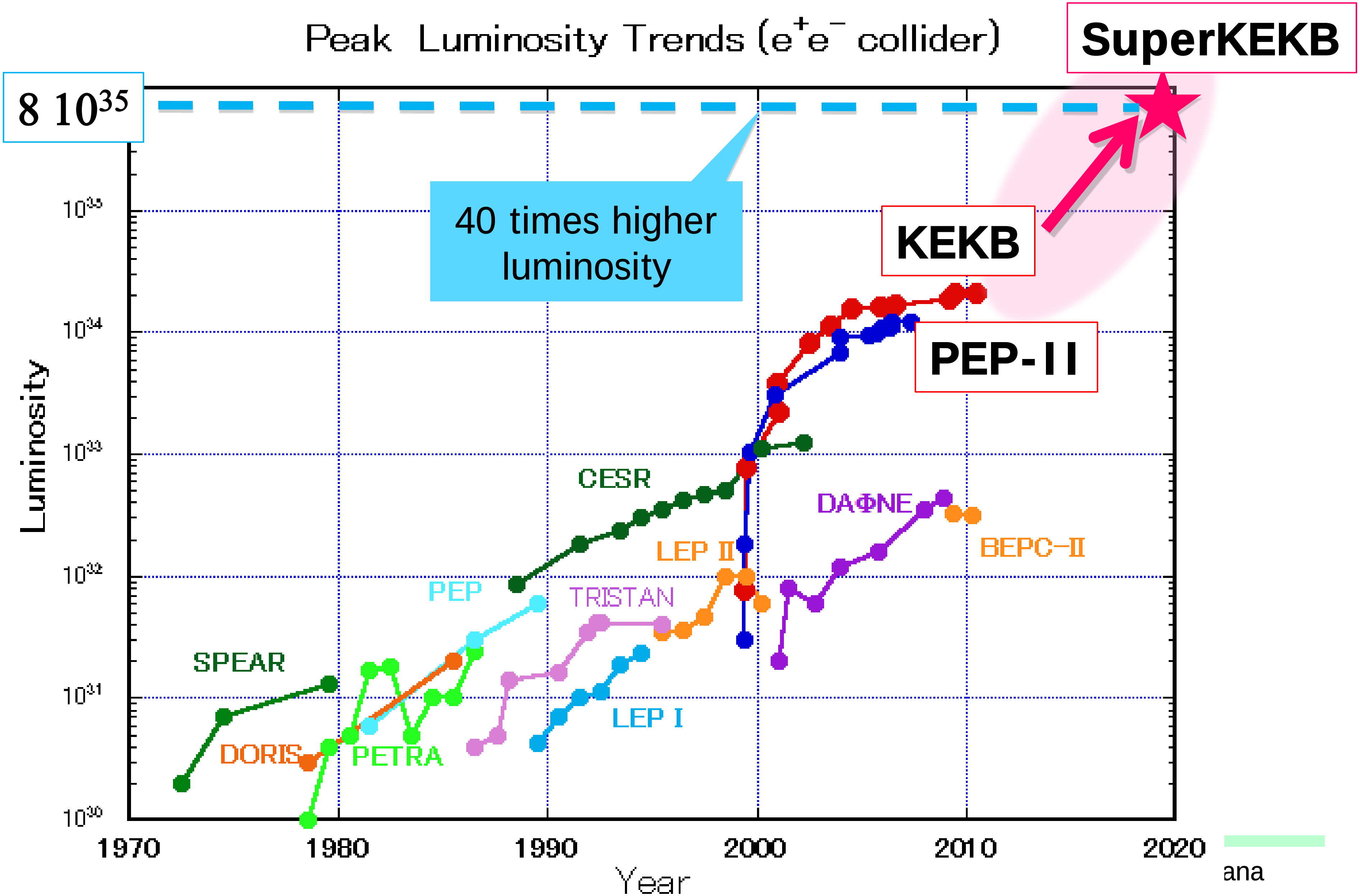
Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\|V_{us}\|$ $[K \to \pi \ell \nu]$	**	0.1%	K-factory
$\|V_{cb}\|$ $[B \to X_c \ell \nu]$	**	1%	Belle II
$\|V_{ub}\|$ $[B_d \to \pi \ell \nu]$	*	4%	Belle II
$\sin(2\phi_1)$ $[c\bar{c}K_S^0$	***	$8 \cdot 10^{-3}$	Belle II/LHCb
ϕ_2		1.5°	Belle II
ϕ_3	***	3°	LHCb
CPV			
$S(B_s \to \psi\phi)$	**	0.01	LHCb
$S(B_s \to \phi\phi)$	**	0.05	LHCb
$S(B_d \to \phi K)$	***	0.05	Belle II/LHCb
$S(B_d \to \eta' K)$	***	0.02	Belle II
$S(B_d \to K^*(\to K_S^0\pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A_{SL}^d	***	0.001	LHCb
A_{SL}^s	***	0.001	LHCb
$A_{CP}(B_d \to s\gamma)$	*	0.005	Belle II
rare decays			
$\mathcal{B}(B \to \tau\nu)$	**	3%	Belle II
$\mathcal{B}(B \to D\tau\nu)$		3%	Belle II
$\mathcal{B}(B_d \to \mu\nu)$	**	6%	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb
zero of $A_{FB}(B \to K^*\mu\mu)$	**	0.05	LHCb
$\mathcal{B}(B \to K^{(*)}\nu\nu)$	***	30%	Belle II
$\mathcal{B}(B \to s\gamma)$		4%	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$		$0.25 \cdot 10^{-6}$	Belle II (with 5 ab^{-1})
$\mathcal{B}(K \to \pi\nu\nu)$	**	10%	K-factory
$\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$	***	0.1%	K-factory
charm and τ			
$\mathcal{B}(\tau \to \mu\gamma)$	***	$3 \cdot 10^{-9}$	Belle II
$\|q/p\|_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II

→Need both LHCb and super B factories to cover all aspects of precision flavour physics

- B. Golob, KEK FF Workshop, Feb. 2012

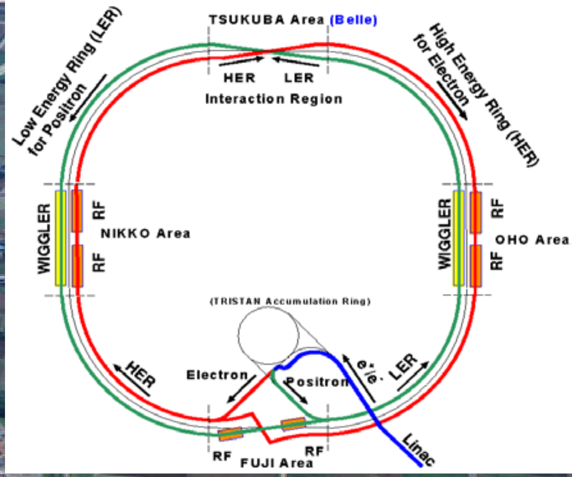
Accelerators

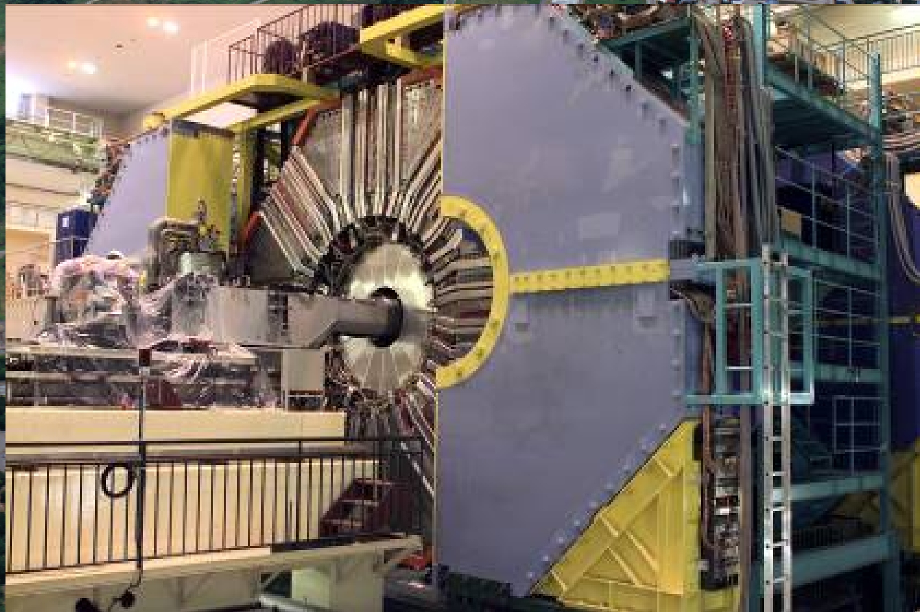
Need 50x more data → Next generation B-factories



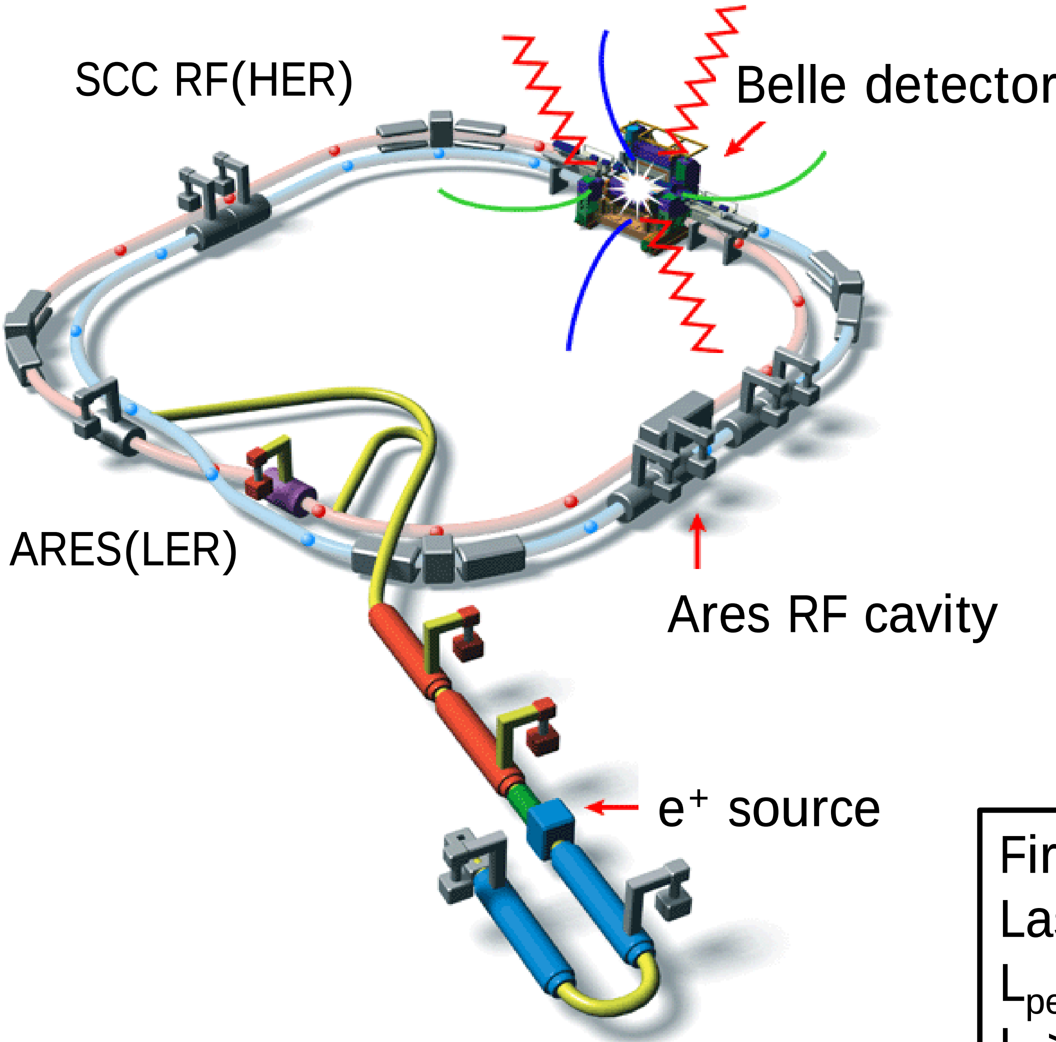
ana

How to do it?
→ upgrade KEKB and Belle





The KEKB Collider & Belle Detector



- e^- (8 GeV) on e^+(3.5 GeV)
  - $\sqrt{s} \approx m_{\Upsilon(4S)}$
  - Lorentz boost: $\beta\gamma$=0.425
- 22 mrad crossing angle
- Operating since 1999

Peak luminosity (WR!) :

$2.1 \times 10^{34}\ cm^{-2}s^{-1}$

=2x design value

First physics run on June 2, 1999
Last physics run on June 30, 2010
$L_{peak} = 2.1 \times 10^{34}/cm^2/s$
$L > 1 ab^{-1}$

Strategies for increasing luminosity

Beam-beam parameter

Lorentz factor

Beam current

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

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

Classical electron radius

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

Vertical beta function@IP

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

"Nano-Beam" scheme

Collision with very small spot-size beams

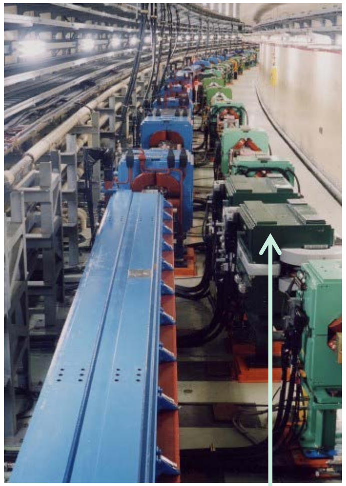
Invented by Pantaleo Raimondi for SuperB

Machine design parameters

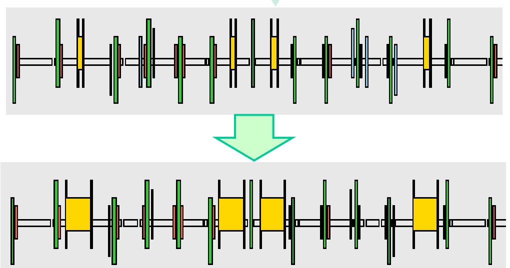
parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	φ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.37	0.40	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	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 to SuperKEKB

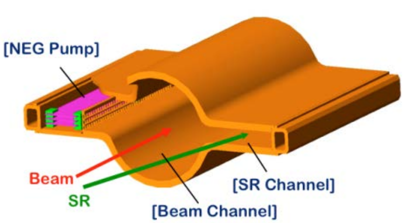


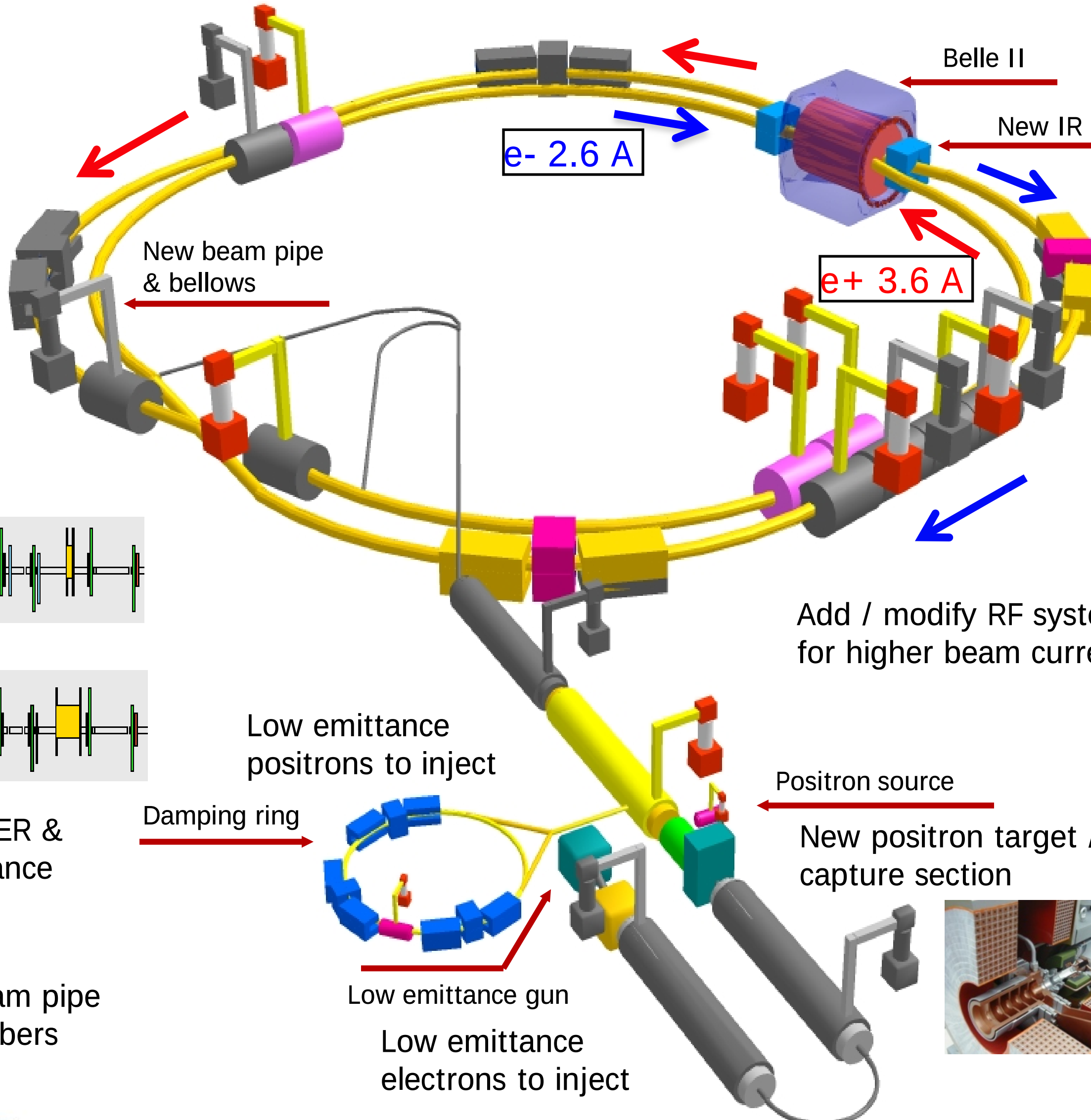
Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance

TiN-coated beam pipe with antechambers

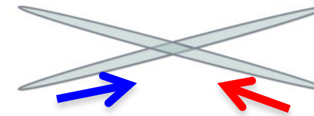




Low emittance positrons to inject

Low emittance electrons to inject

Colliding bunches



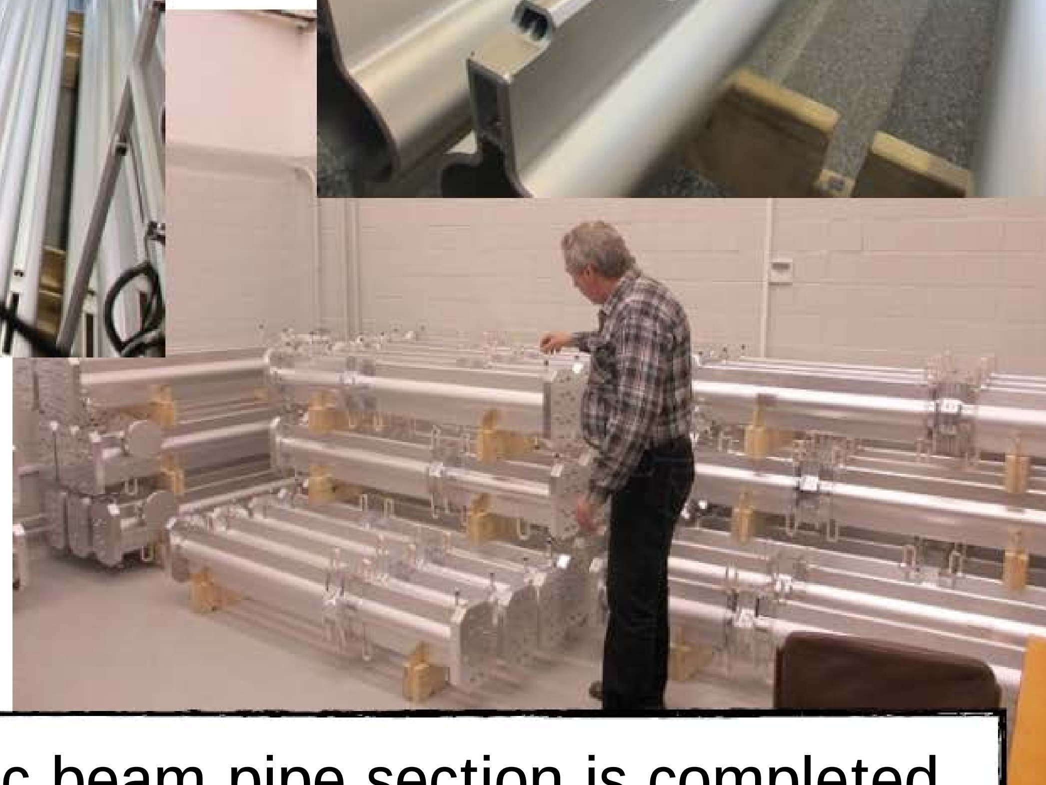
New superconducting /permanent final focusing quads near the IP

Add / modify RF systems for higher beam current

New positron target / capture section

To obtain x40 higher luminosity

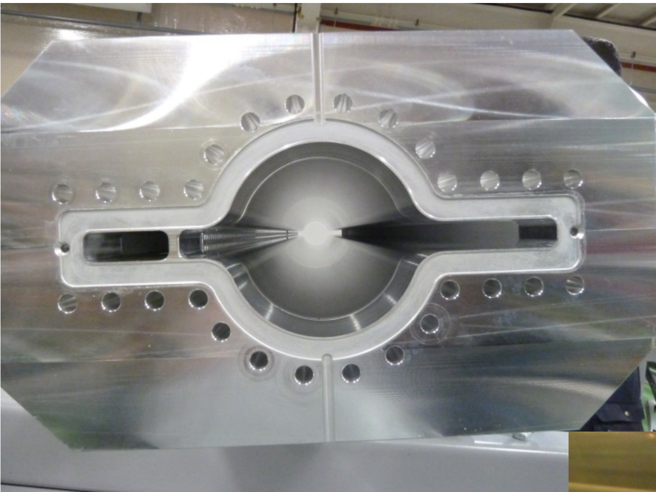
Entirely new LER beam pipe with ante-chamber and Ti-N coating

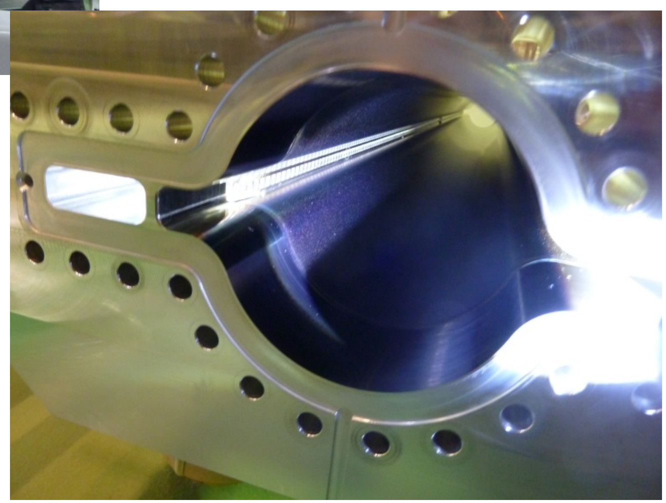


Beam pipe is made of aluminum.

Fabrication of the LER arc beam pipe section is completed

Al ante-chamber before coating





After TiN coating
before baking

After baking

All 100 4 m long dipole magnets have been successfully installed in the low energy ring (LER)!

Three magnets per day !

Installing the 4 m long LER dipole **over** the 6 m long HER dipole (remains in place).

Magnet installation

field measurement

move into tunnel

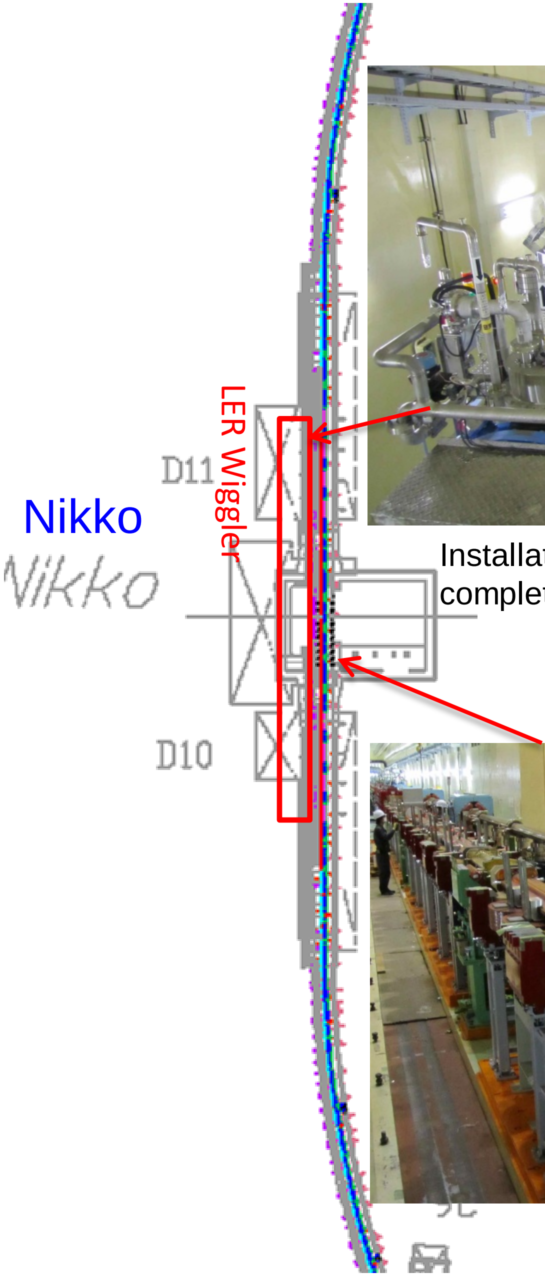
Installation of 100 new LER bending magnets done

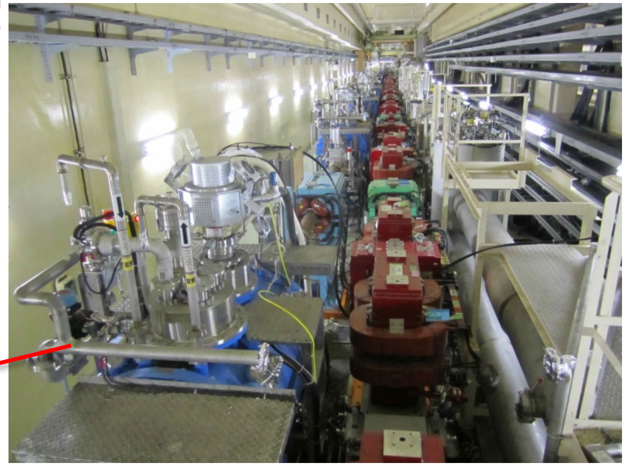
carry on an air-pallet

carry over existing HER dipole

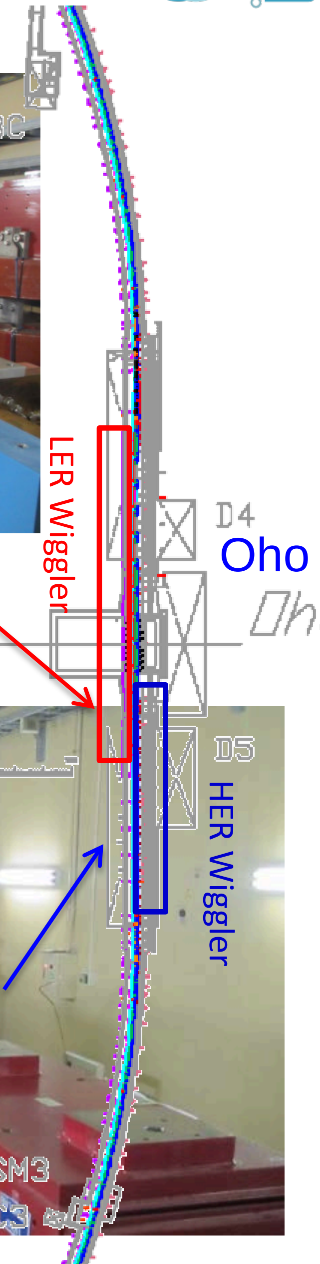
install done

Wiggler sections



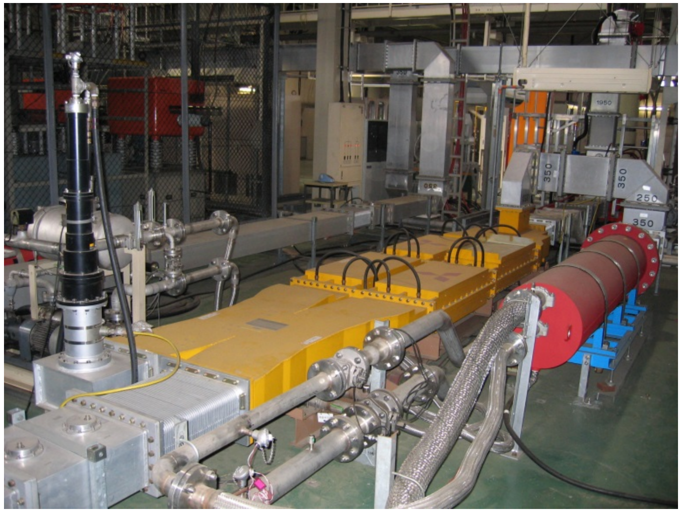


Installation of LER wiggler chambers in Nikko and Oho straight sections will be completed in March.



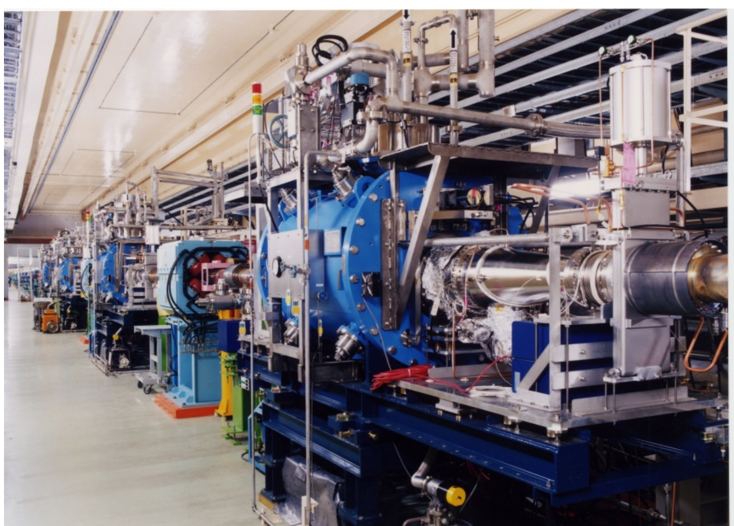
Installation of HER wiggler chambers in Oho straight section is done.

Upgrade of RF system to cope with twice beam currents and 2.5 times beam power

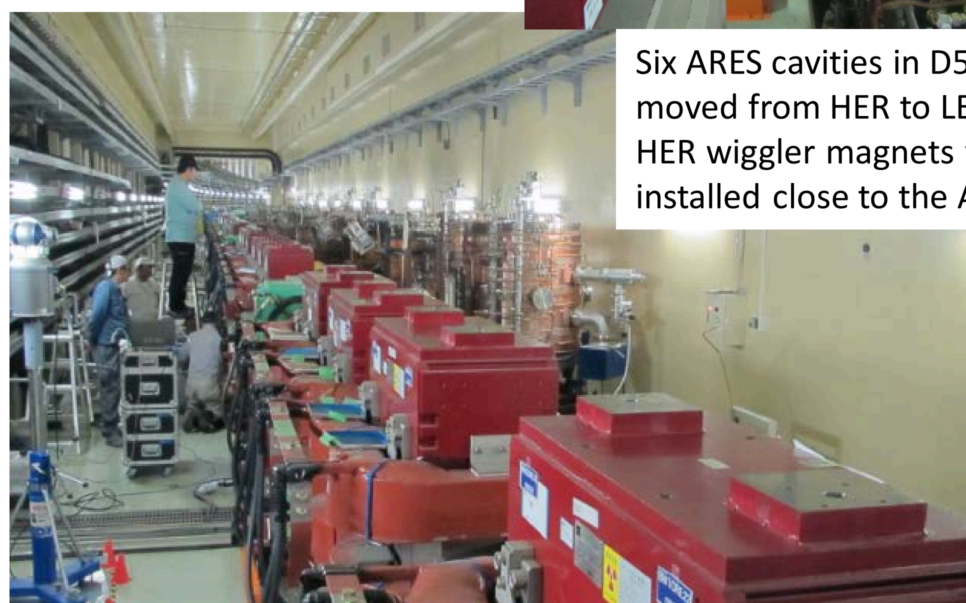


RF high power system

1.2MW CW kystron

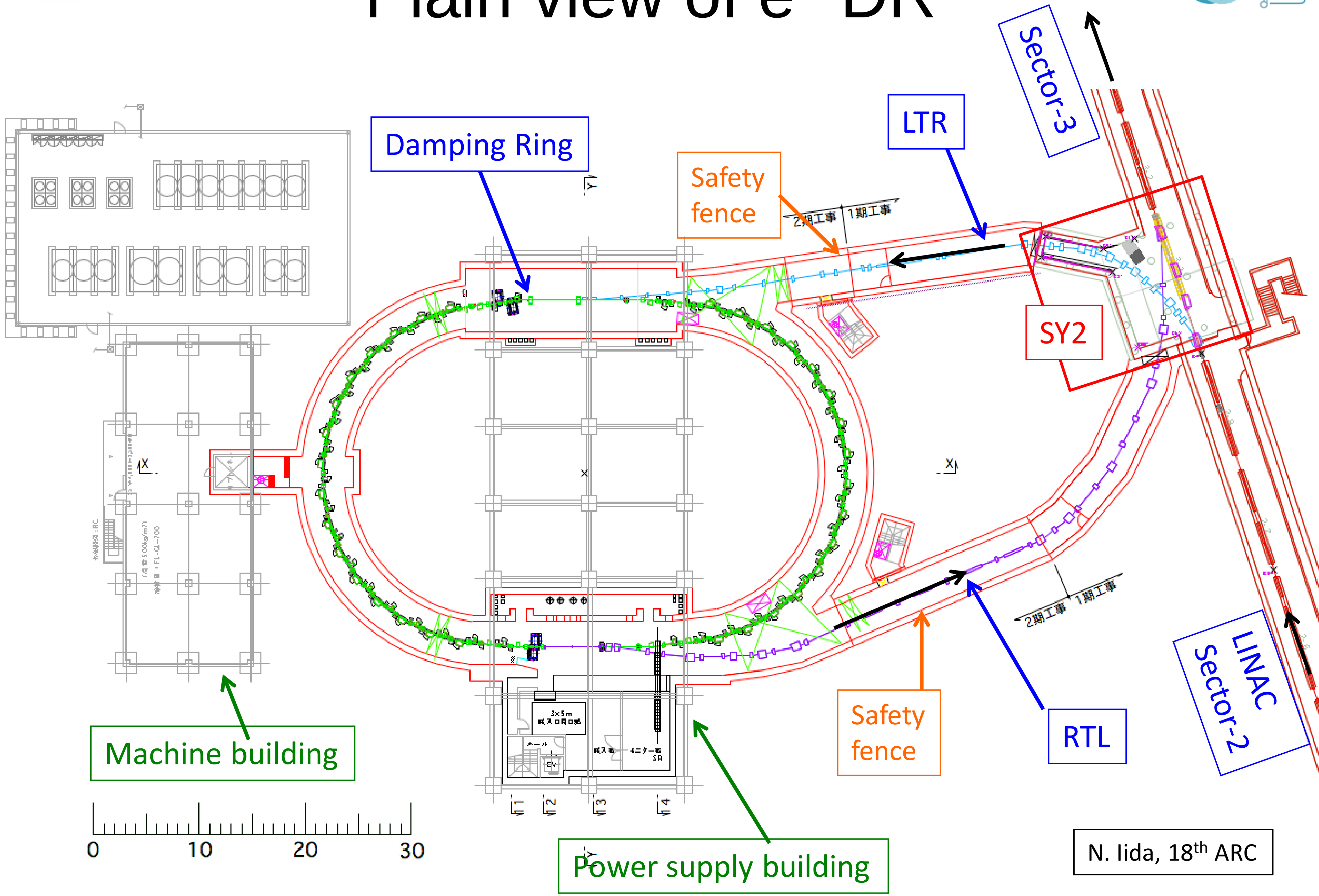


Superconducting cavities



Six ARES cavities in D5 moved from HER to LER. HER wiggler magnets were installed close to the ARES.

Plain view of e^+ DR



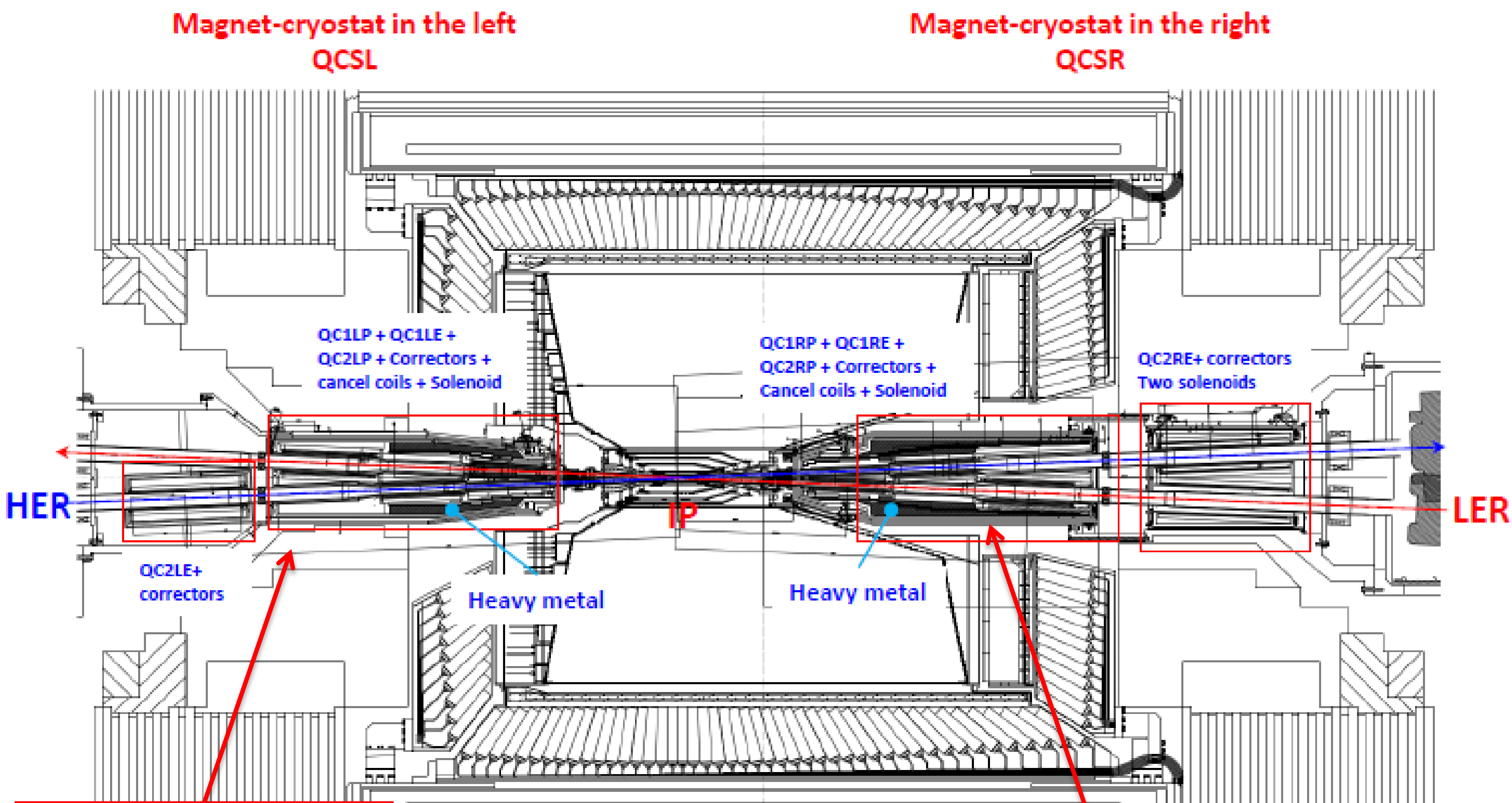
DR under construction on 18/Dec/2012

- Tunnel construction under way in 2012-13; half year delay due to budget suspend caused by the earthquake.
- Construction of buildings for DR will start in April this year.
- Fabrication of accelerator components ongoing. Installation starts in 2014.
- DR commissioning will start in 2015.

Inside DR tunnel

Now DR has been buried.

IR magnets overview



in production

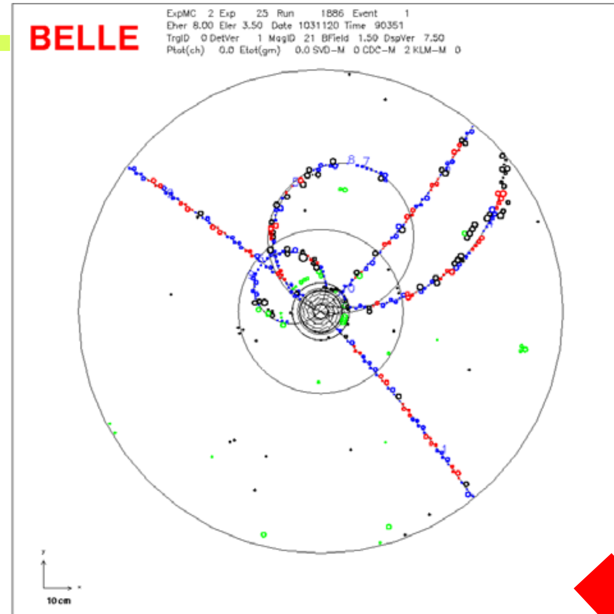
design being finalized
→in production from summer

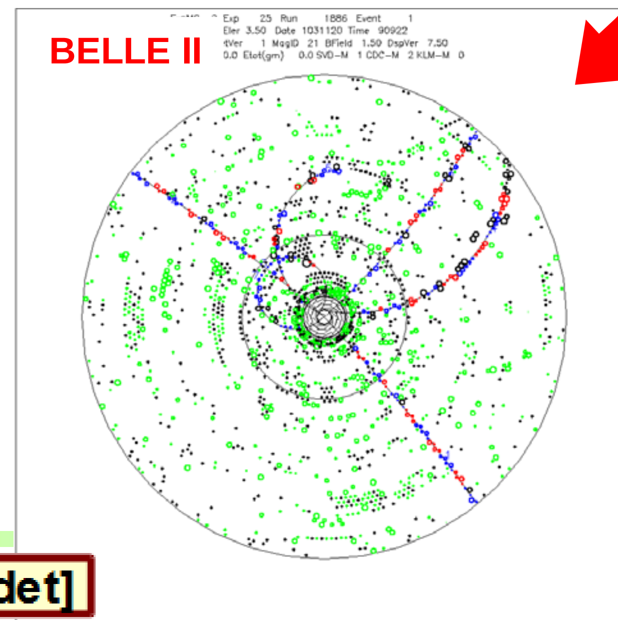
Detector

Need to build a new detector to handle higher backgrounds

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"

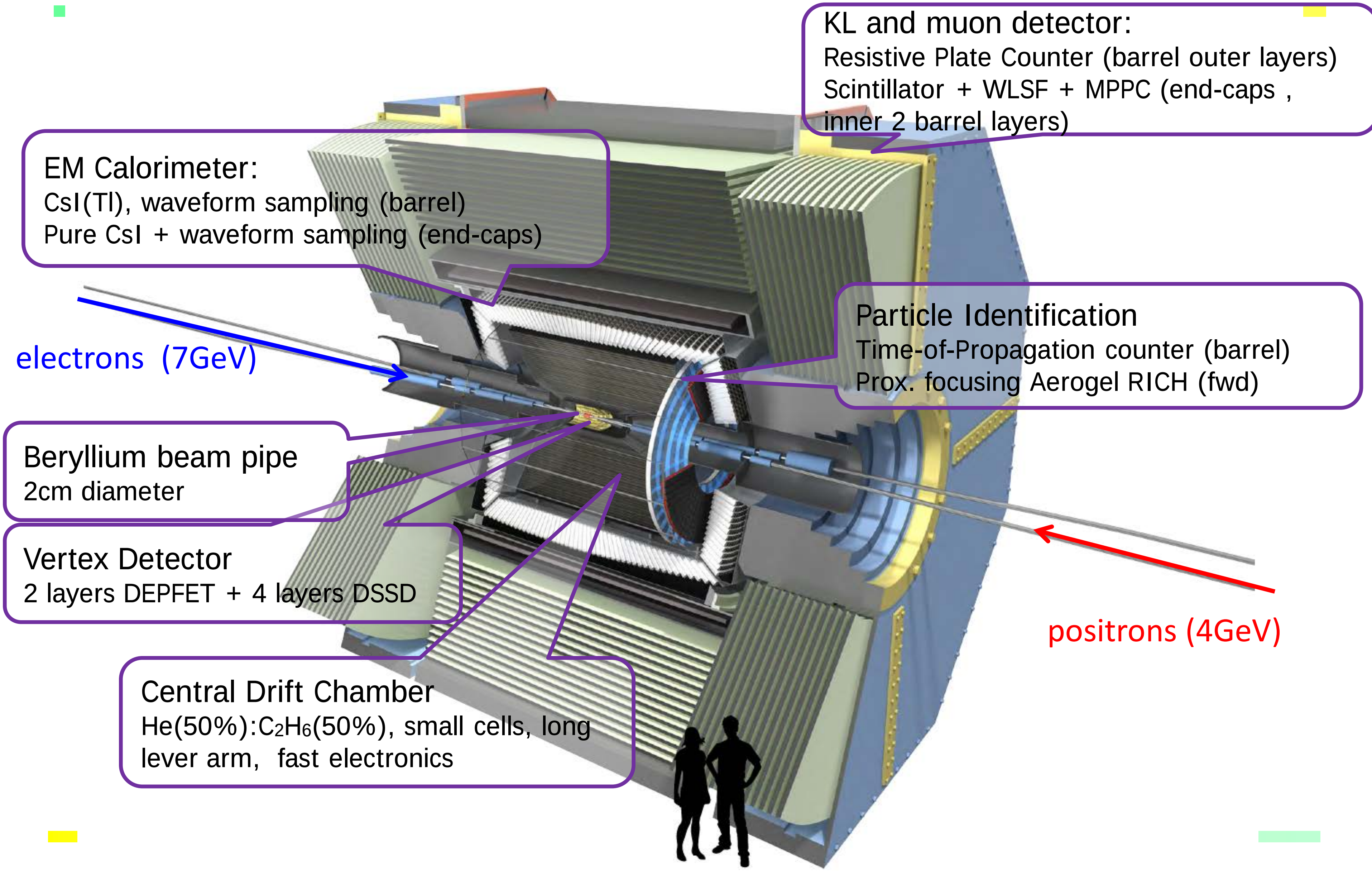




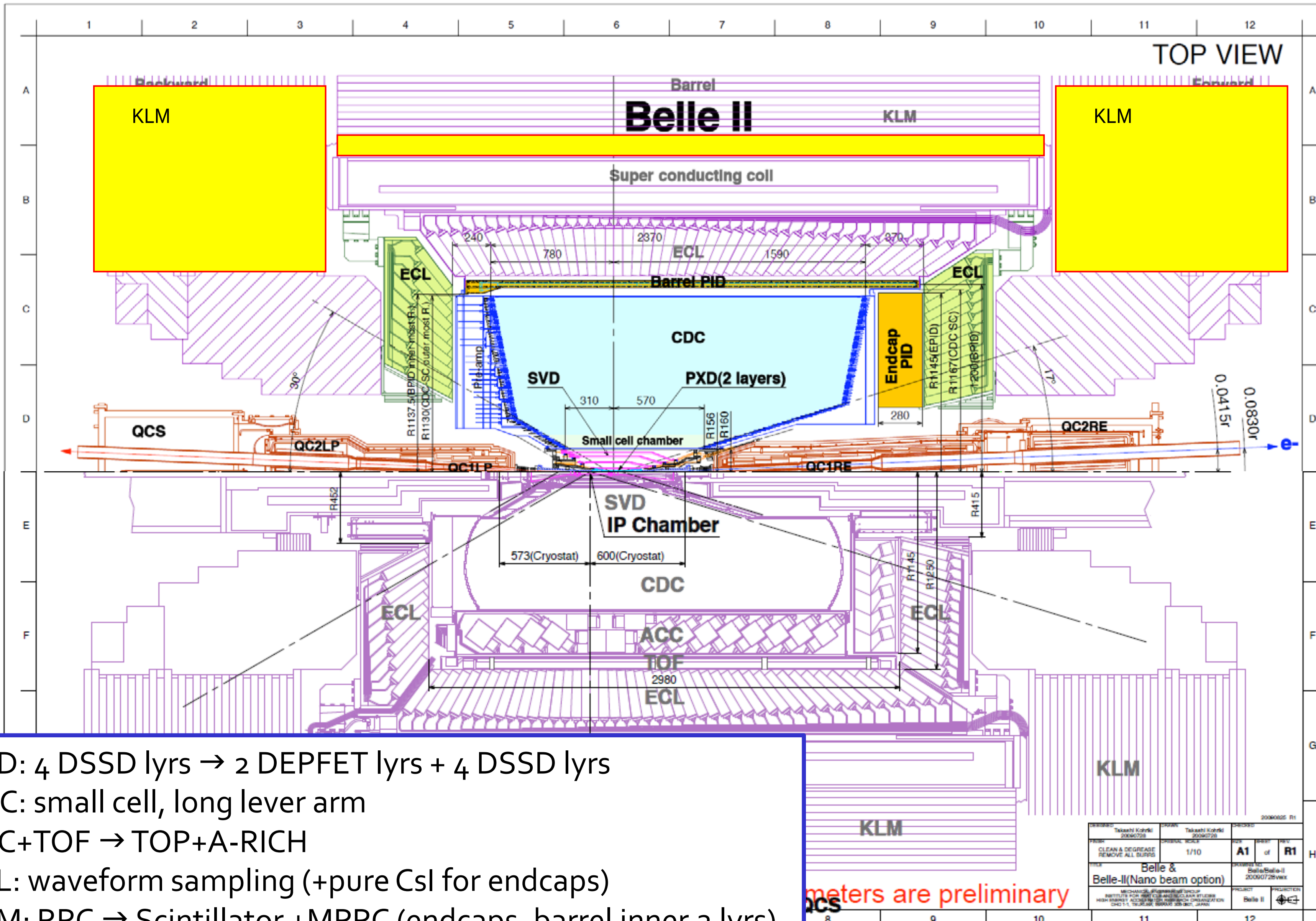
Have to employ and develop new technologies to make such an apparatus work! →

TDR published arXiv:1011.0352v1 [physics.ins-det]

Belle II Detector

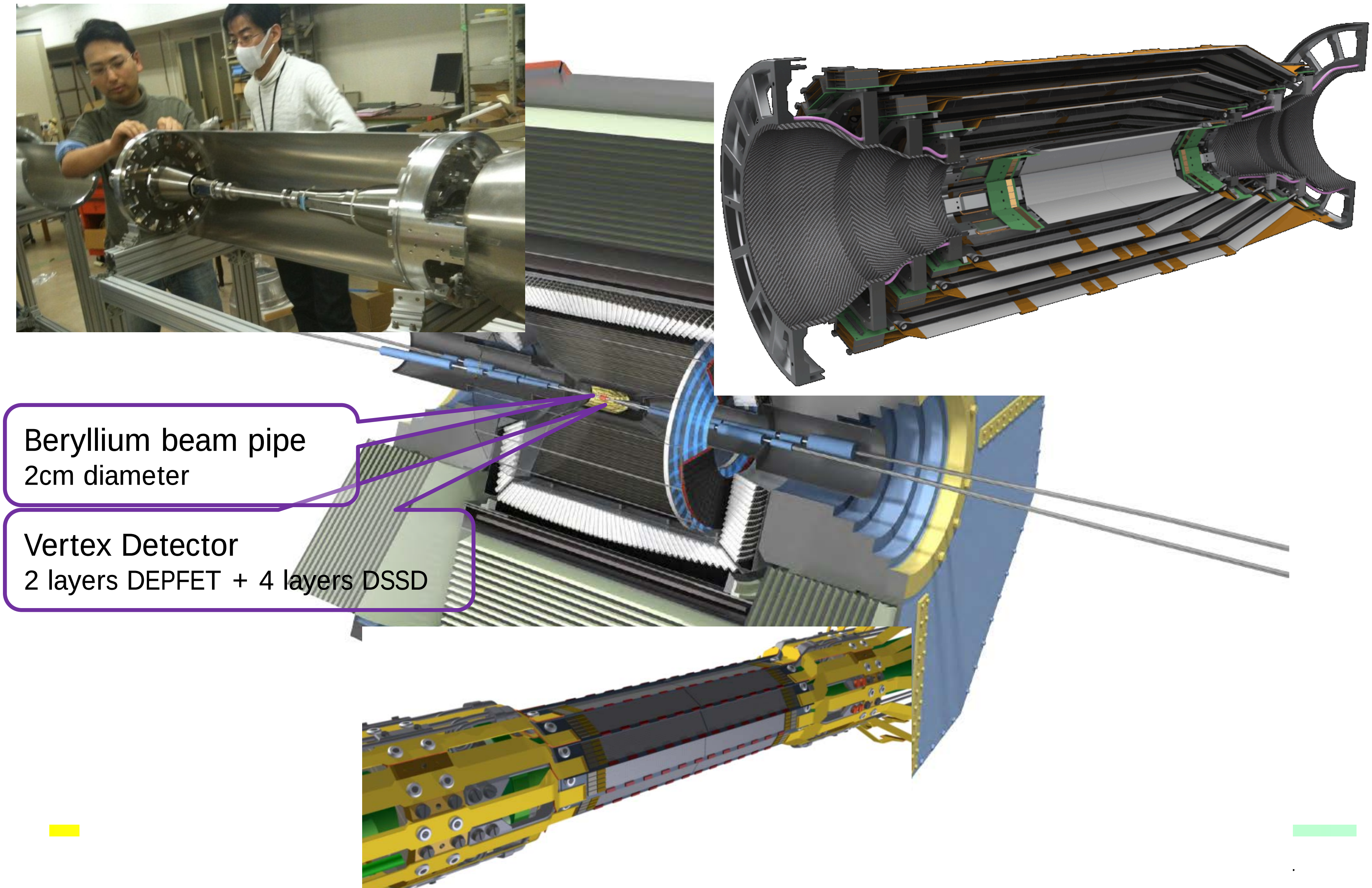


Belle II Detector (in comparison with Belle)



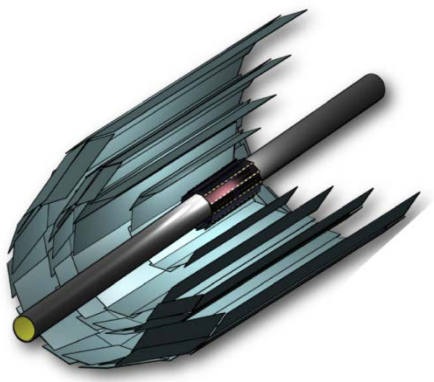
SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI for endcaps)
KLM: RPC → Scintillator +MPPC (endcaps, barrel inner 2 lyrs)

Belle II Detector – vertex region

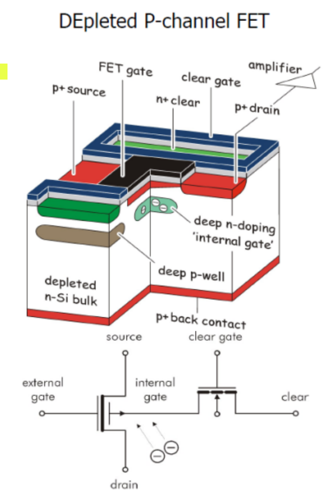


Vertex Detector

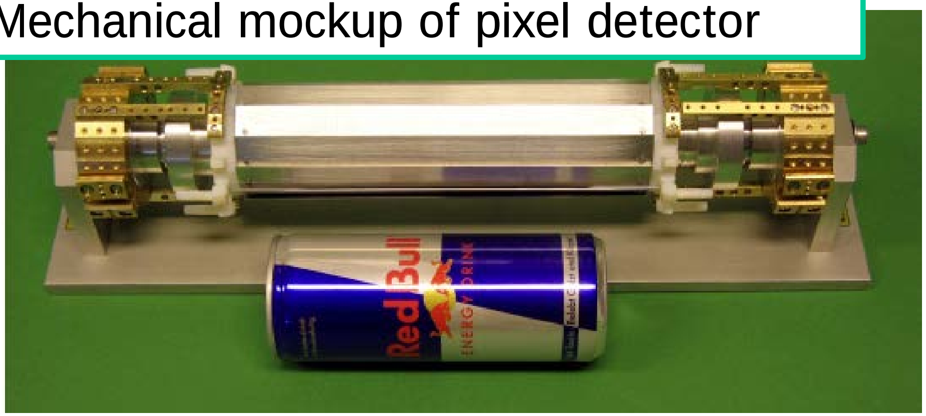
DEPFET:
http://aldebaran.hll.mpg.de/twiki/bin/view/DEPFET/WebHome

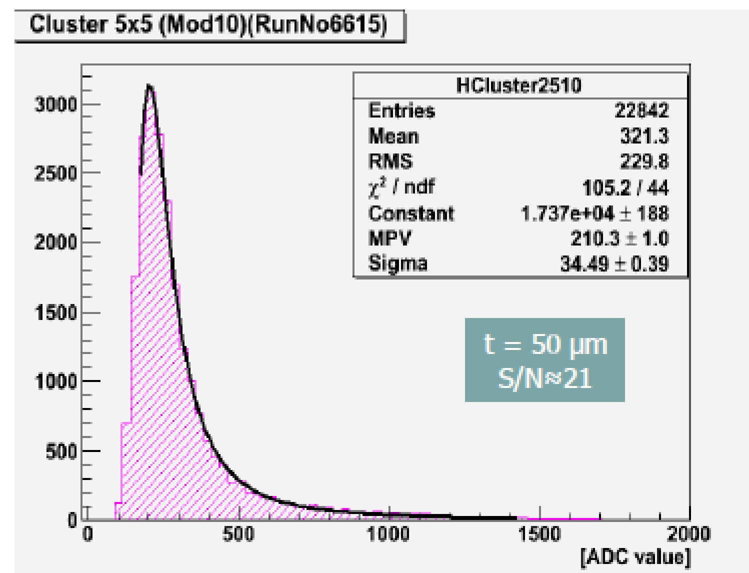


Beam Pipe		**r = 10mm**
DEPFET		
	Layer 1	**r = 14mm**
	Layer 2	**r = 22mm**
DSSD		
	Layer 3	**r = 38mm**
	Layer 4	**r = 80mm**
	Layer 5	**r = 115mm**
	Layer 6	**r = 140mm**



Mechanical mockup of pixel detector





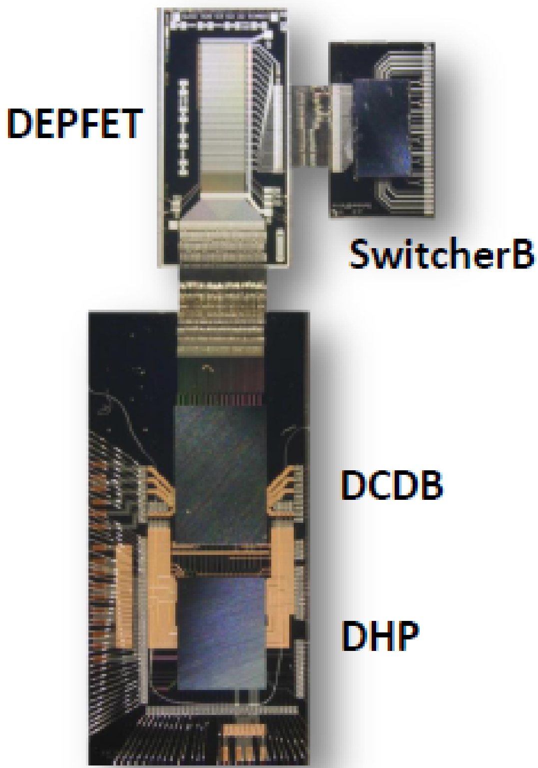
DEPFET pixel sensor

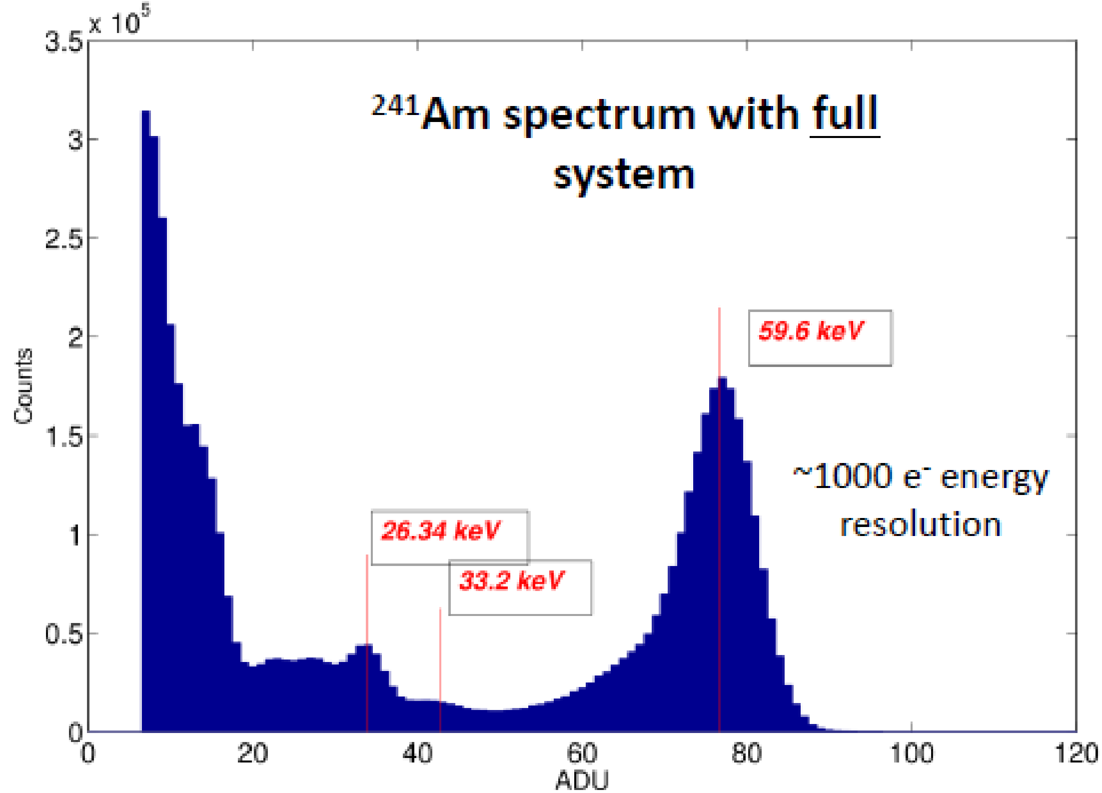
DEPFET sensor: very good S/N

PXD: test of the full read-out chain

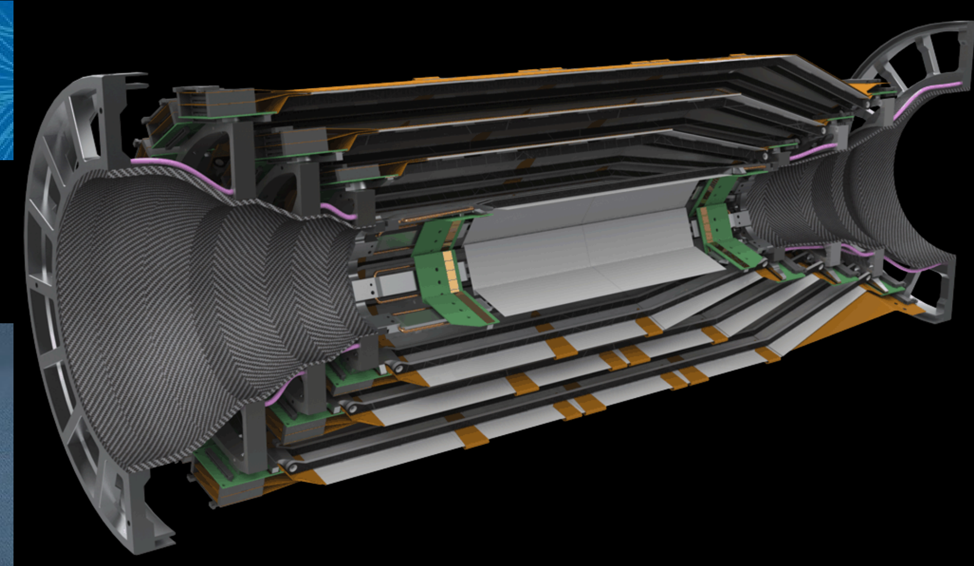
- All the ASICs + Belle II DEPFET working together
- Trigger-less zero suppression readout

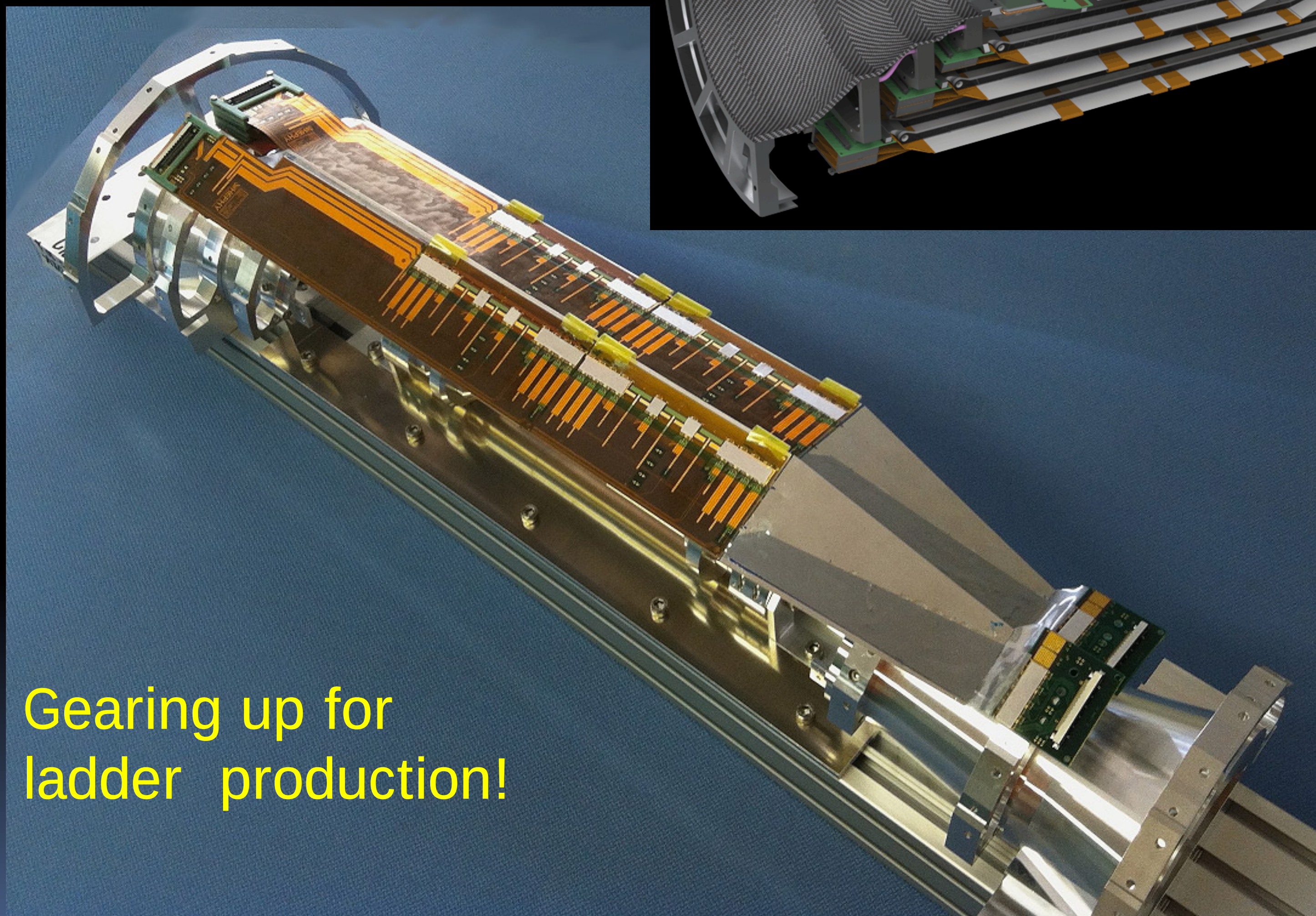
Carlos Marinas, Bonn





SVD Mechanical Mockup



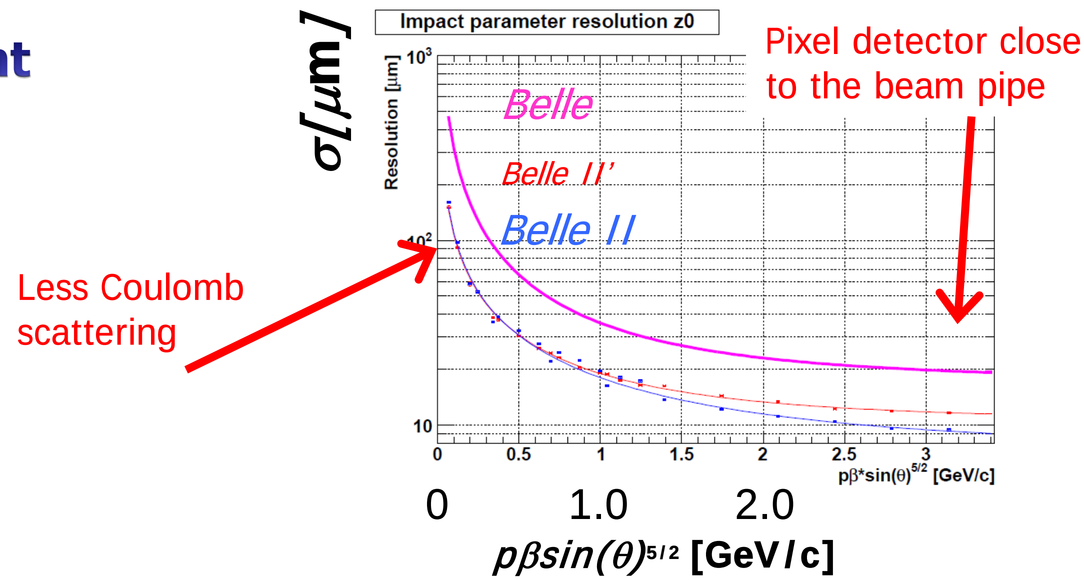


Gearing up for
ladder production!

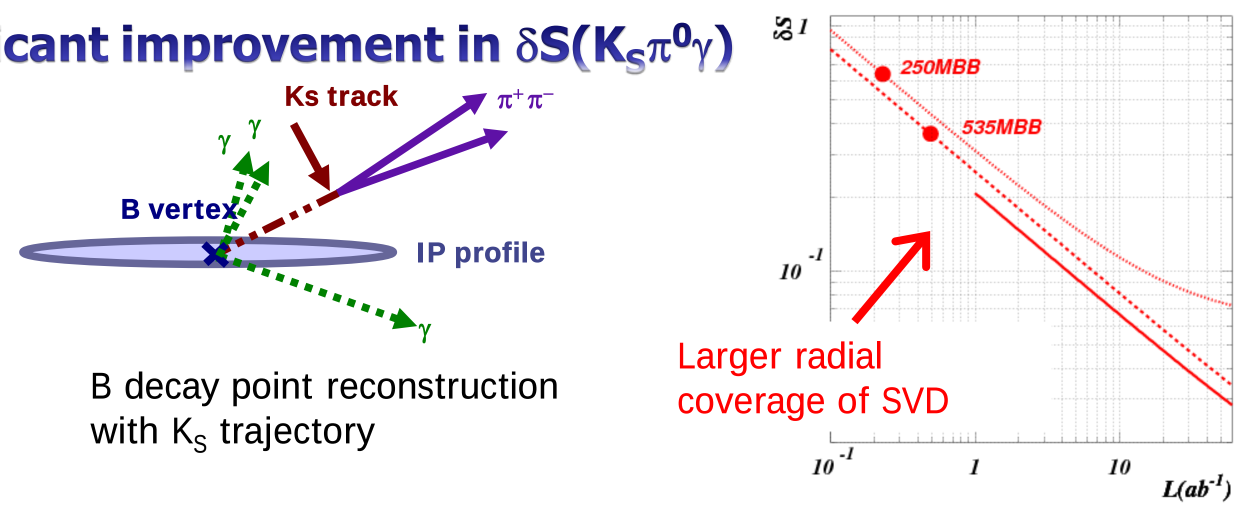
Expected performance

$$\sigma = a + \frac{b}{p\beta \sin^{\nu}\theta}$$

Significant improvement in vertex resolution!

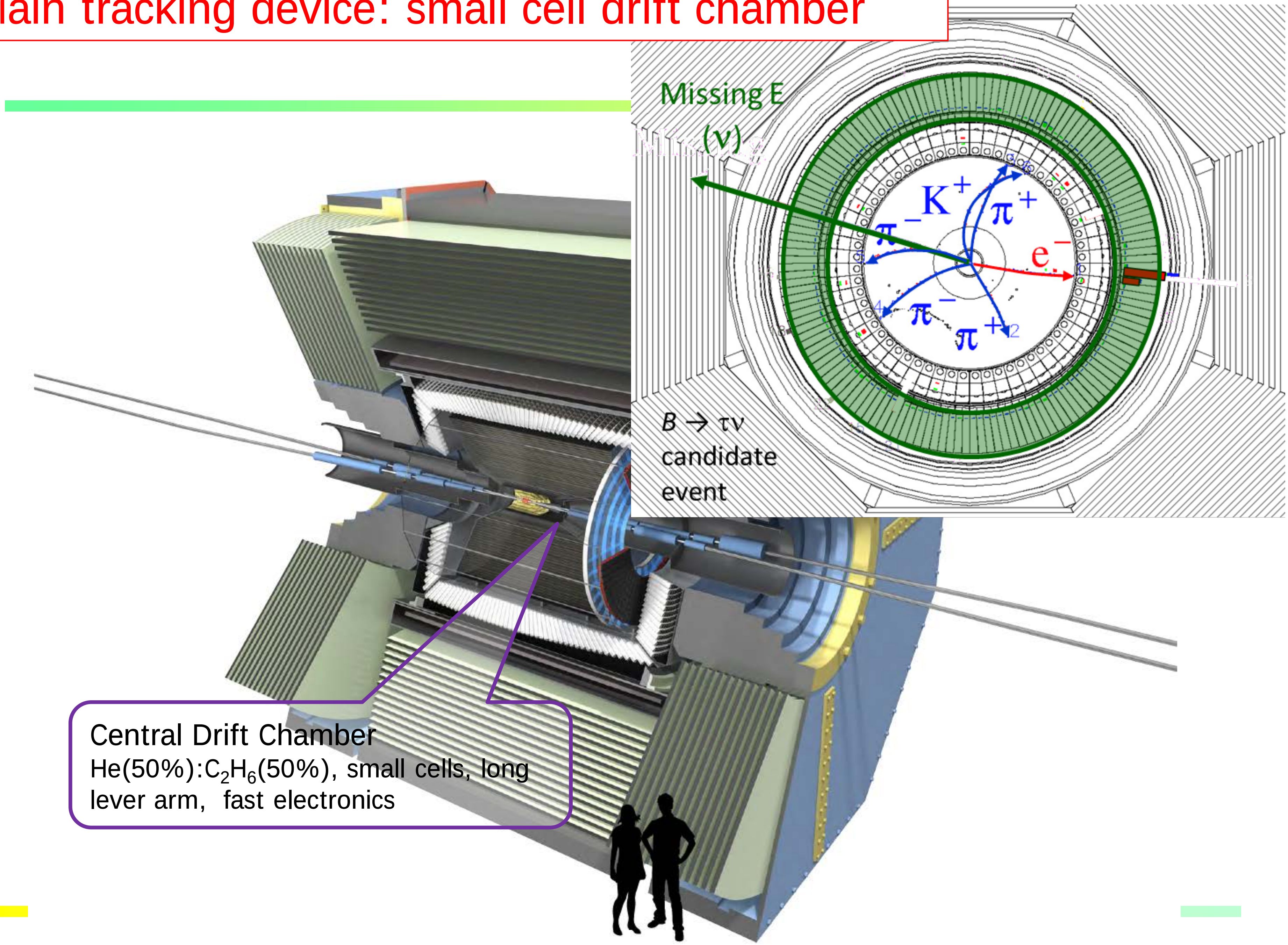


Significant improvement in $\delta S(K_S\pi^0\gamma)$

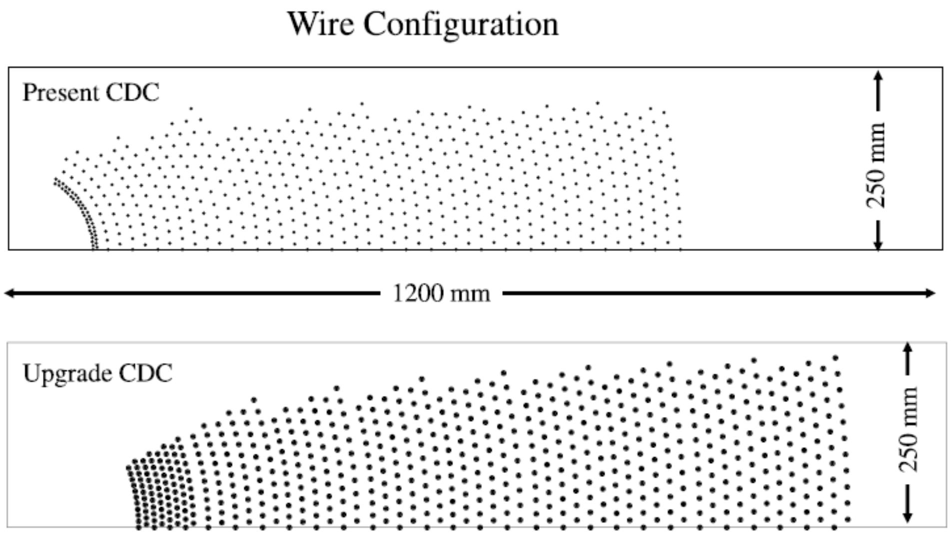


B decay point reconstruction with K_S trajectory

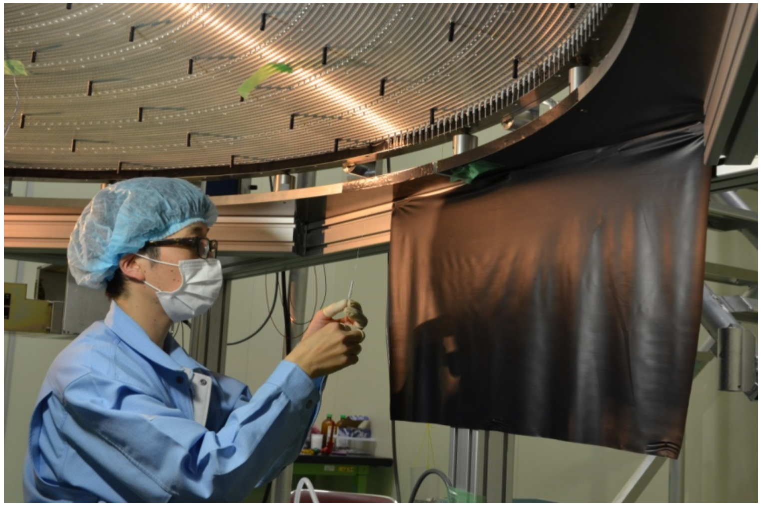
Main tracking device: small cell drift chamber



Belle II CDC



Much bigger than in Belle!

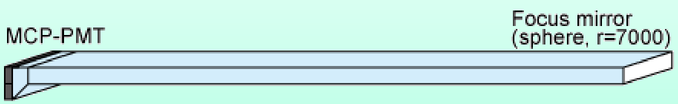


Wire stringing in a clean room

- thousands of wires,
- 1 year of work…

Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



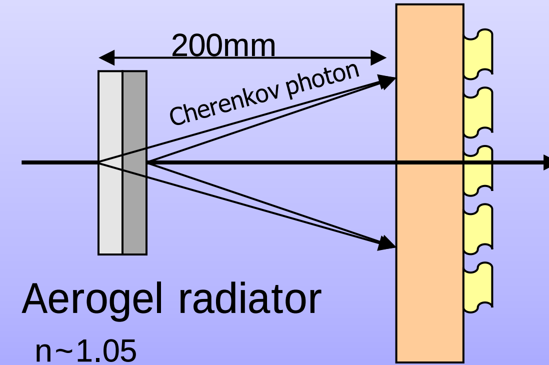
Quartz radiator

Focusing mirror

Small expansion block

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

Endcap PID: Aerogel RICH (ARICH)

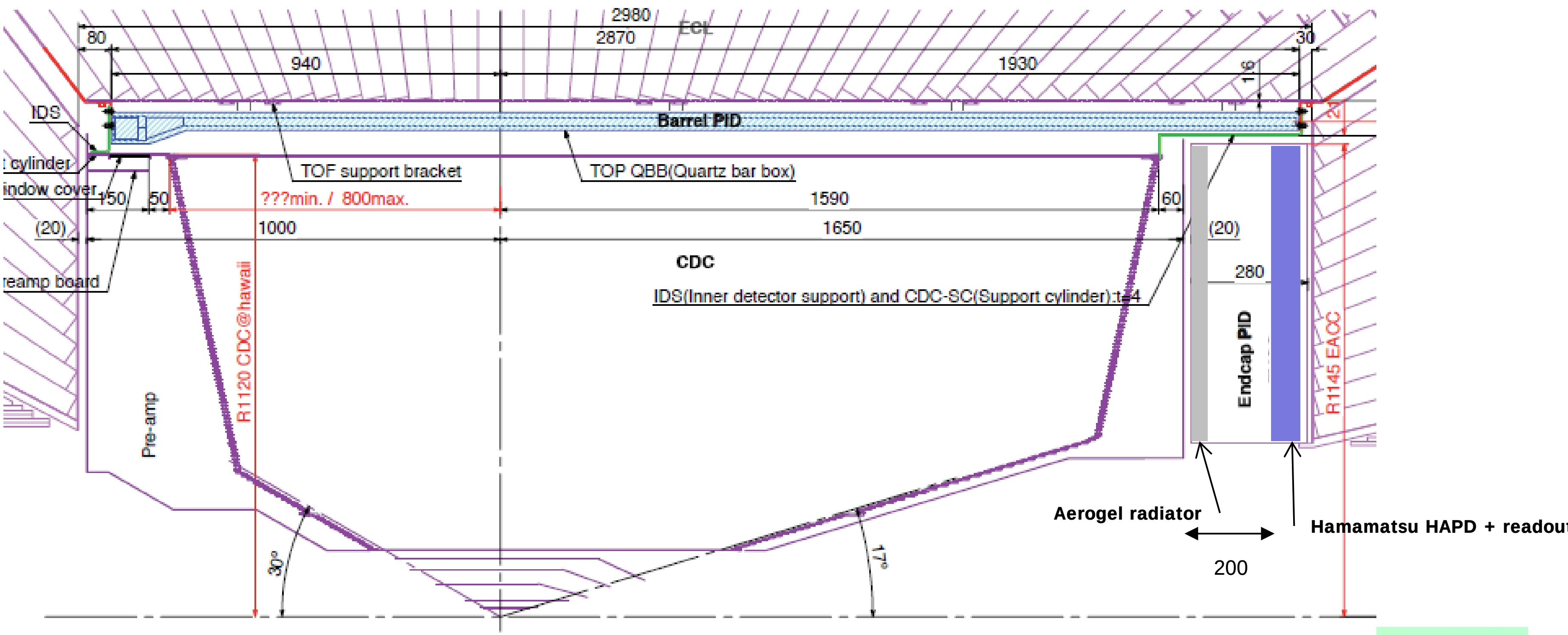


Aerogel radiator

n~1.05

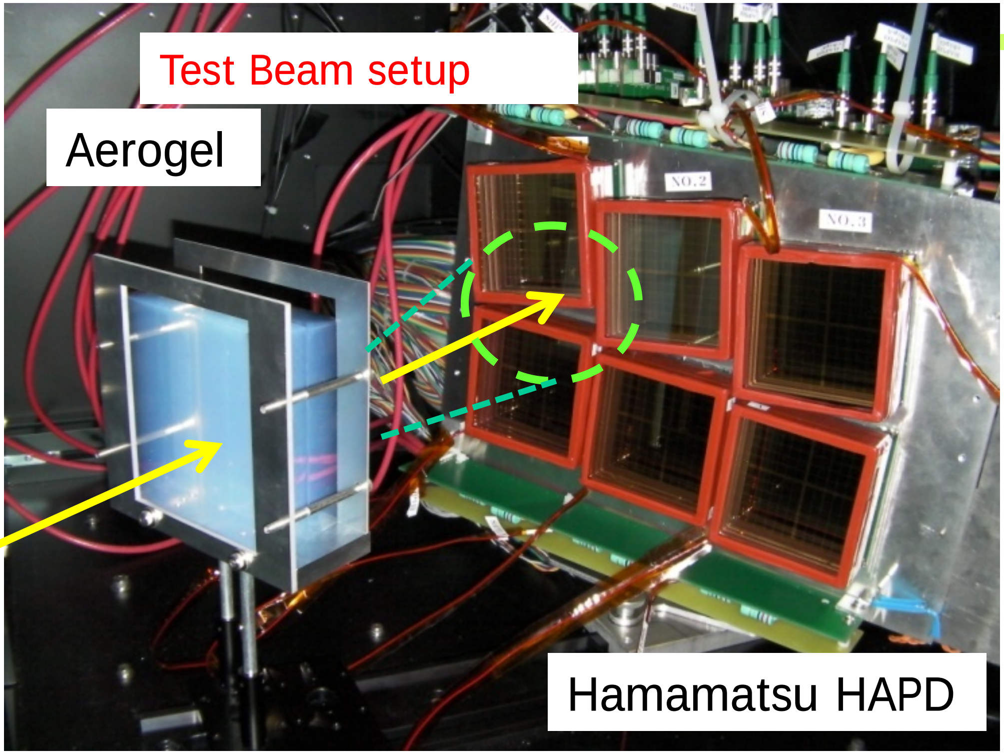
Hamamatsu HAPD

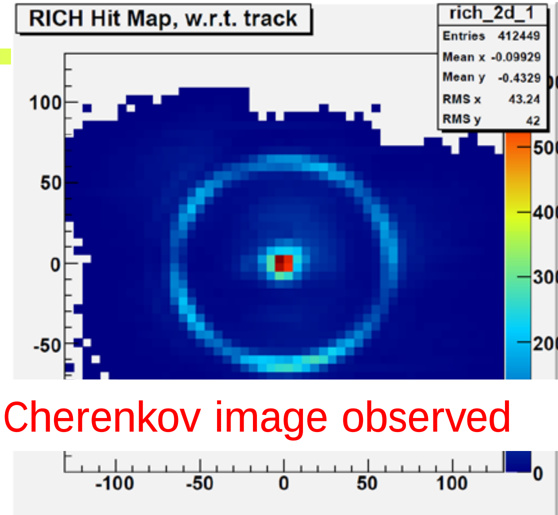
+ new ASIC



Peter Križan, Ljubljana

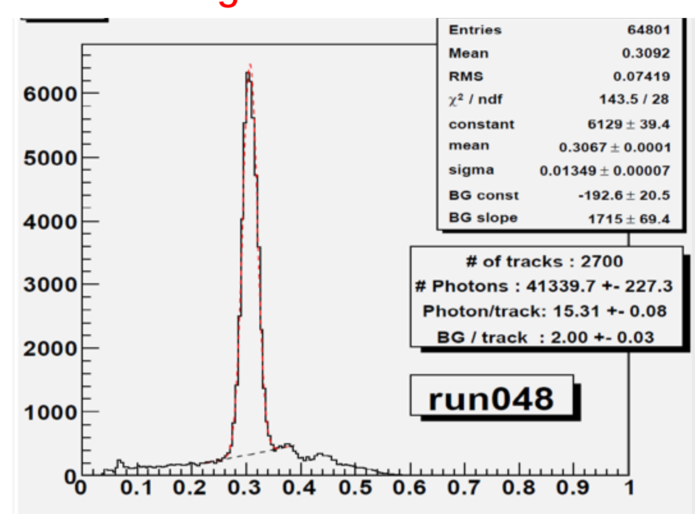
Aerogel RICH (endcap PID)



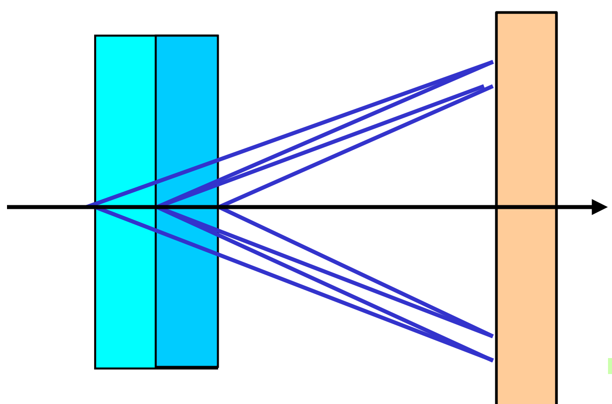


Clear Cherenkov image observed

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.

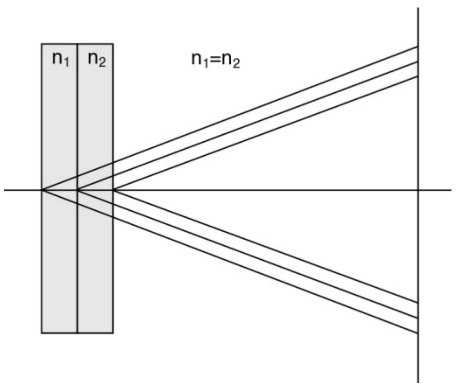
6.6 σ π / K at 4GeV / c !

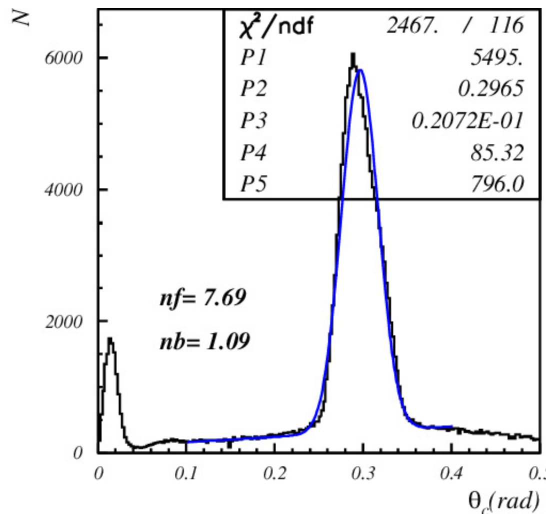
Peter Križan, Ljubljana

RICH with a focusing radiator

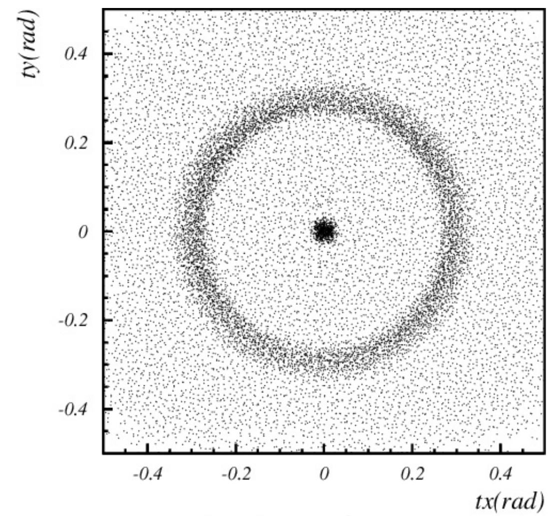
Increases the number of photons without degrading the resolution

4cm aerogel single index



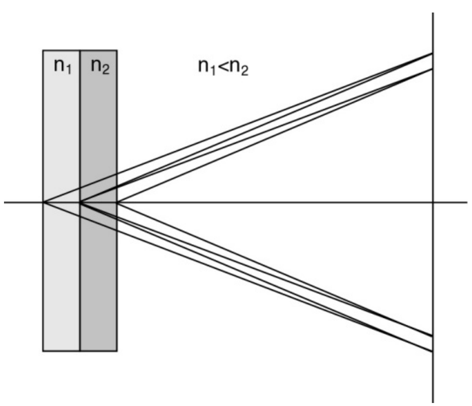


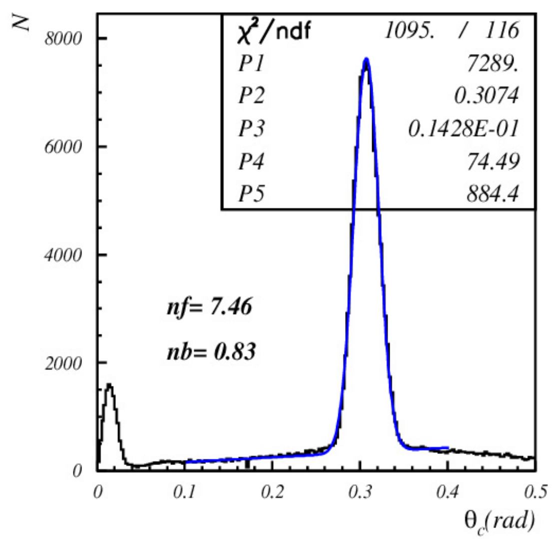
theta cerenkov

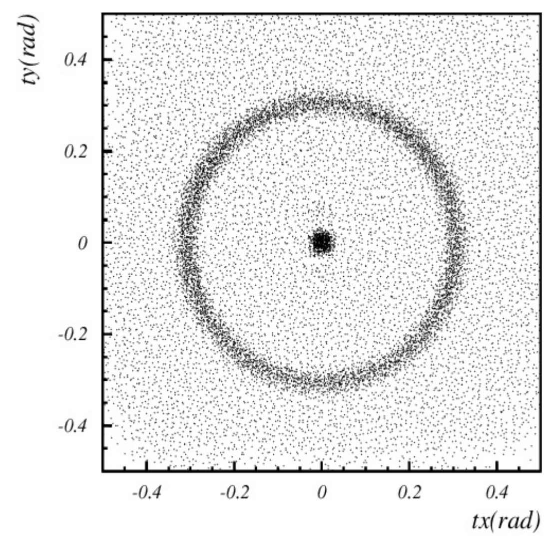


ring in cerenkov space

2+2cm aerogel



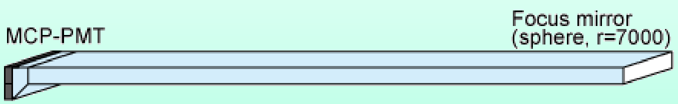




→NIM A548 (2005) 383

Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



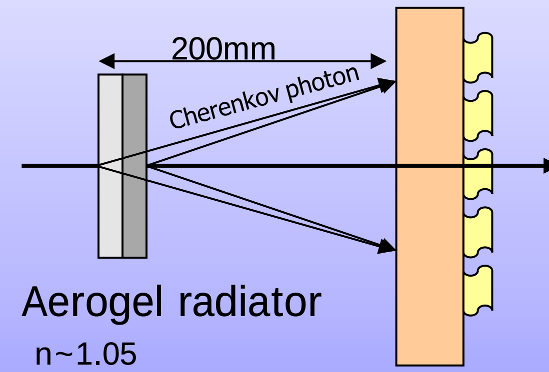
Quartz radiator

Focusing mirror

Small expansion block

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

Endcap PID: Aerogel RICH (ARICH)

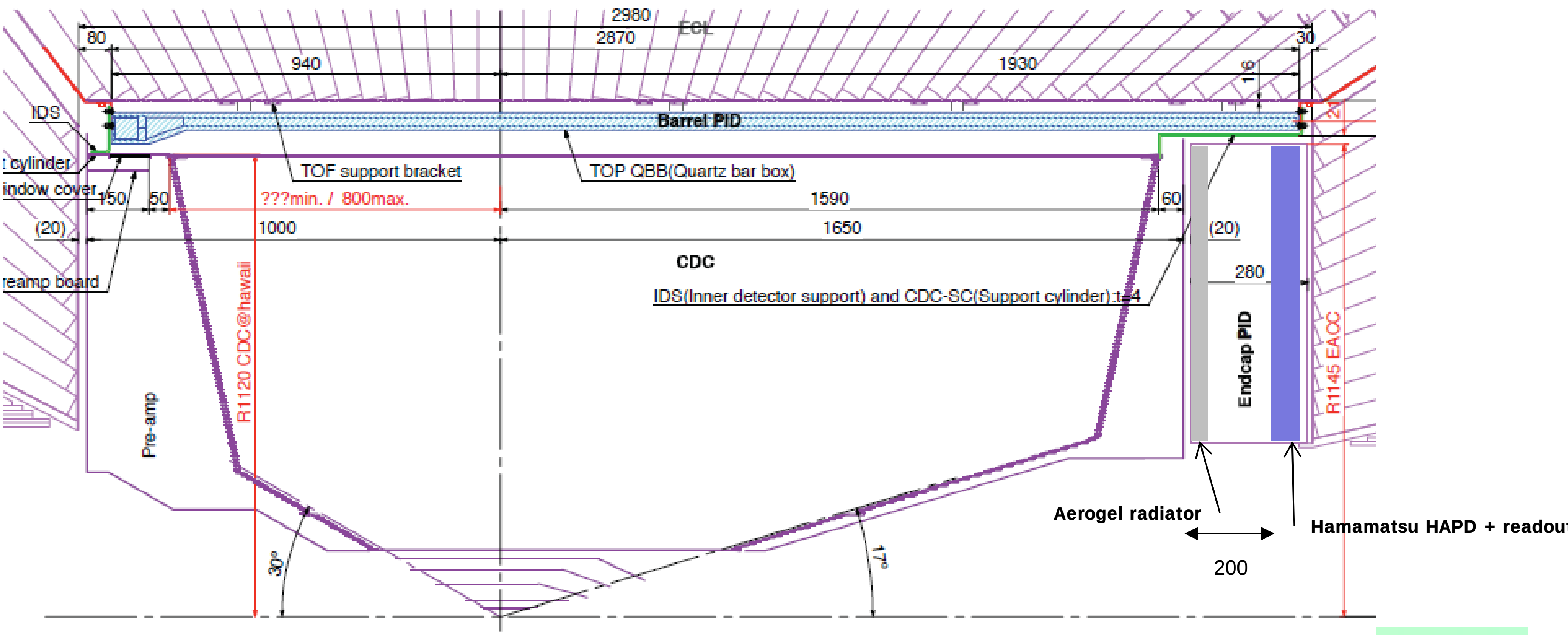


Aerogel radiator

n~1.05

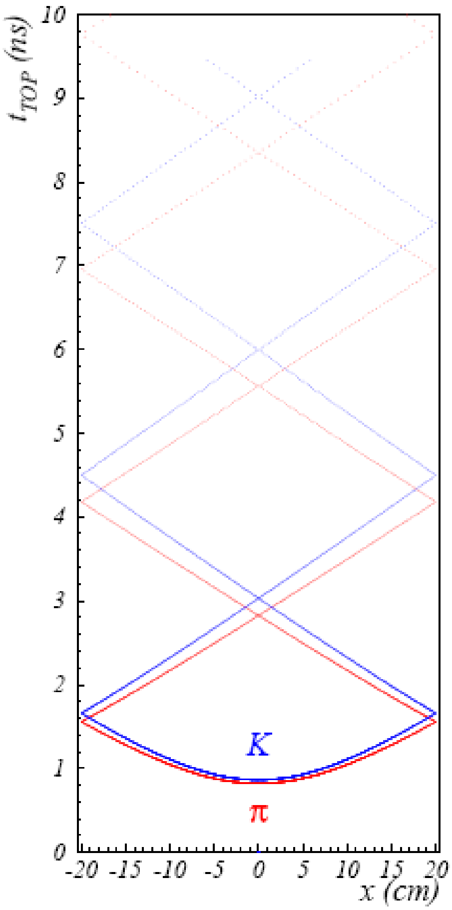
Hamamatsu HAPD

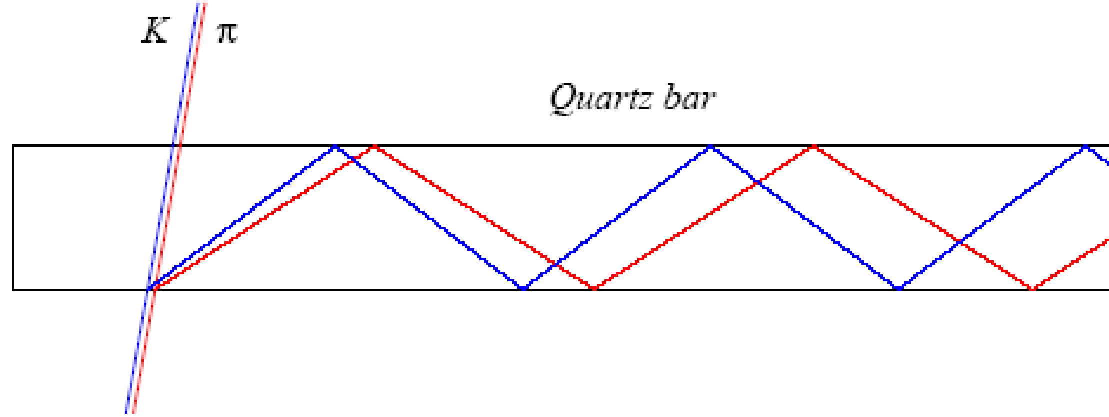
+ new ASIC



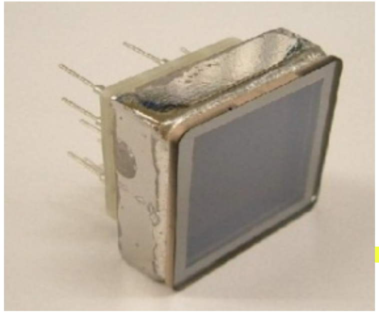
Peter Križan, Ljubljana

Barrel PID: Time of propagation (TOP) counter

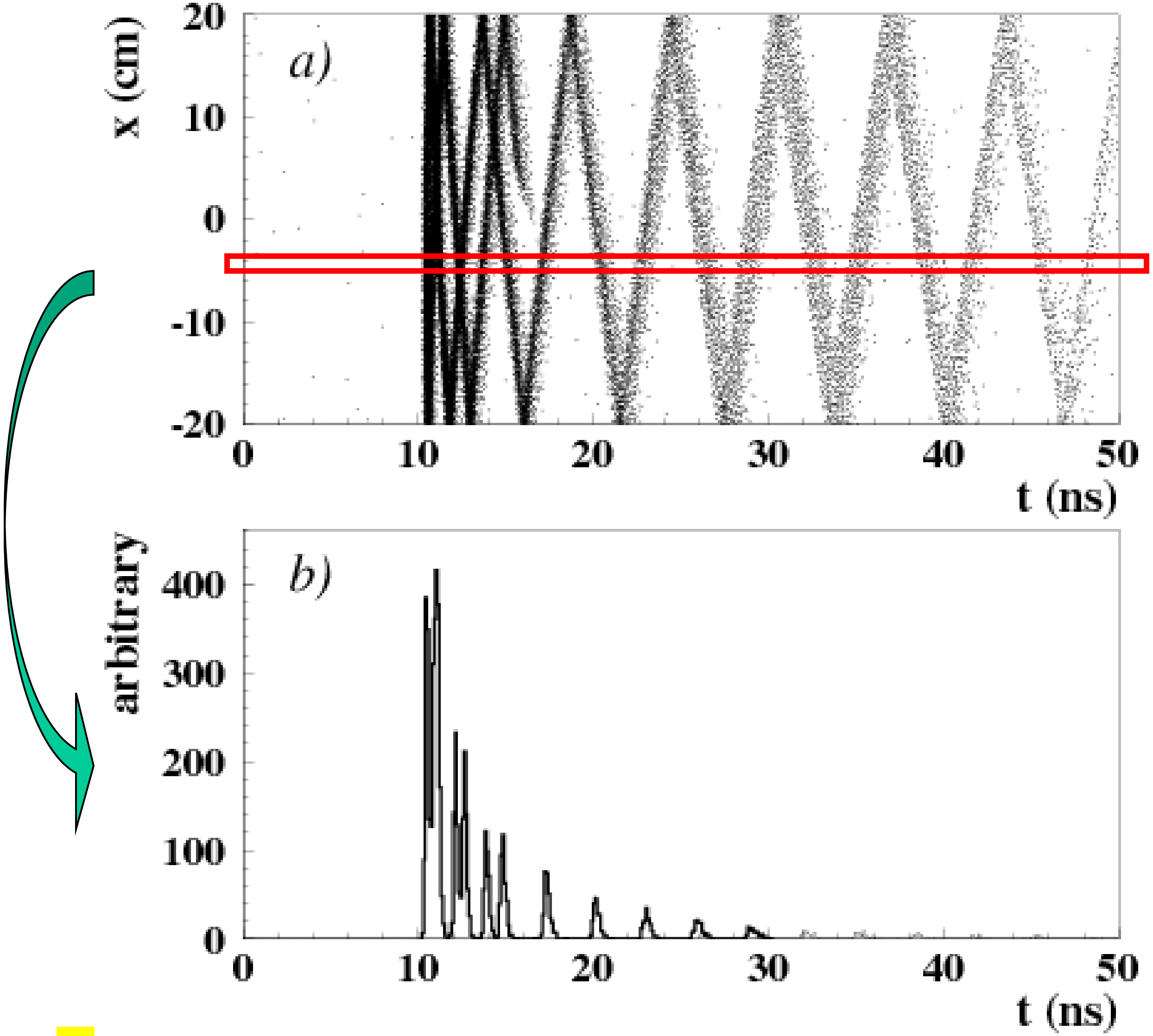




- Cherenkov ring imaging with precise time measurement.
- Device uses internal reflection of Cerenkov ring images from quartz like the BaBar DIRC
- Reconstruct Cherenkov angle from two hit coordinates and the time of propagation of the photon
  - Quartz radiator (2cm)
  - Photon detector (MCP-PMT)
    - Good time resolution ~ 40 ps
    - Single photon sensitivity in 1.5 T field
    - Hamamatsu SL10



TOP image

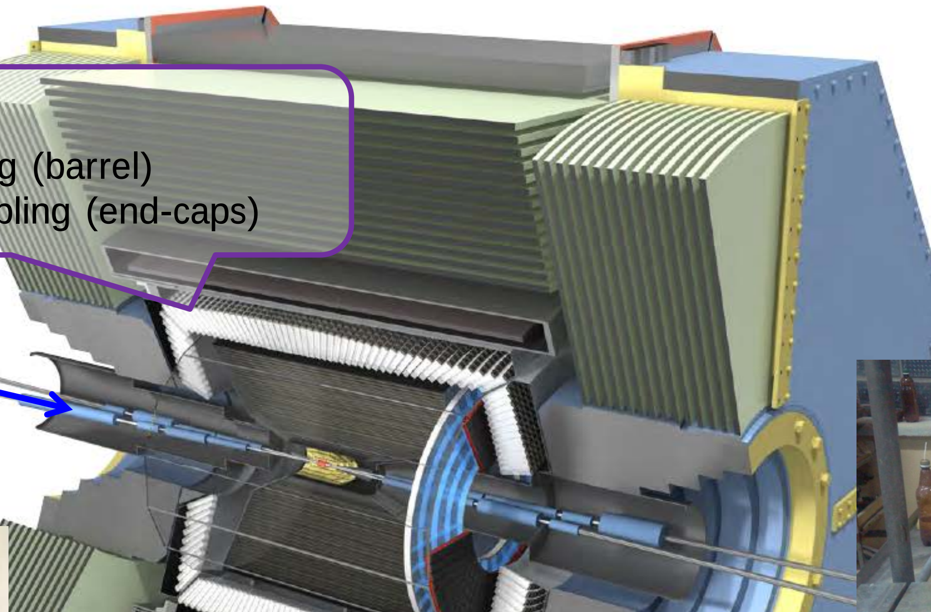


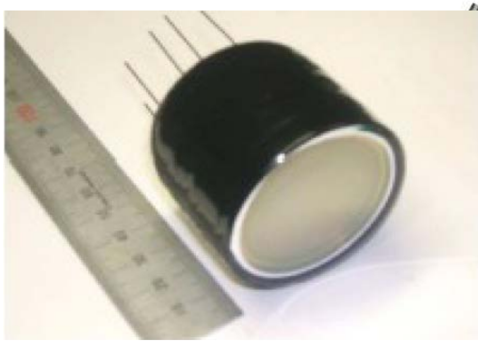
Pattern in the coordinate-time space ('ring') of a pion hitting a quartz bar with ~80 MAPMT channels

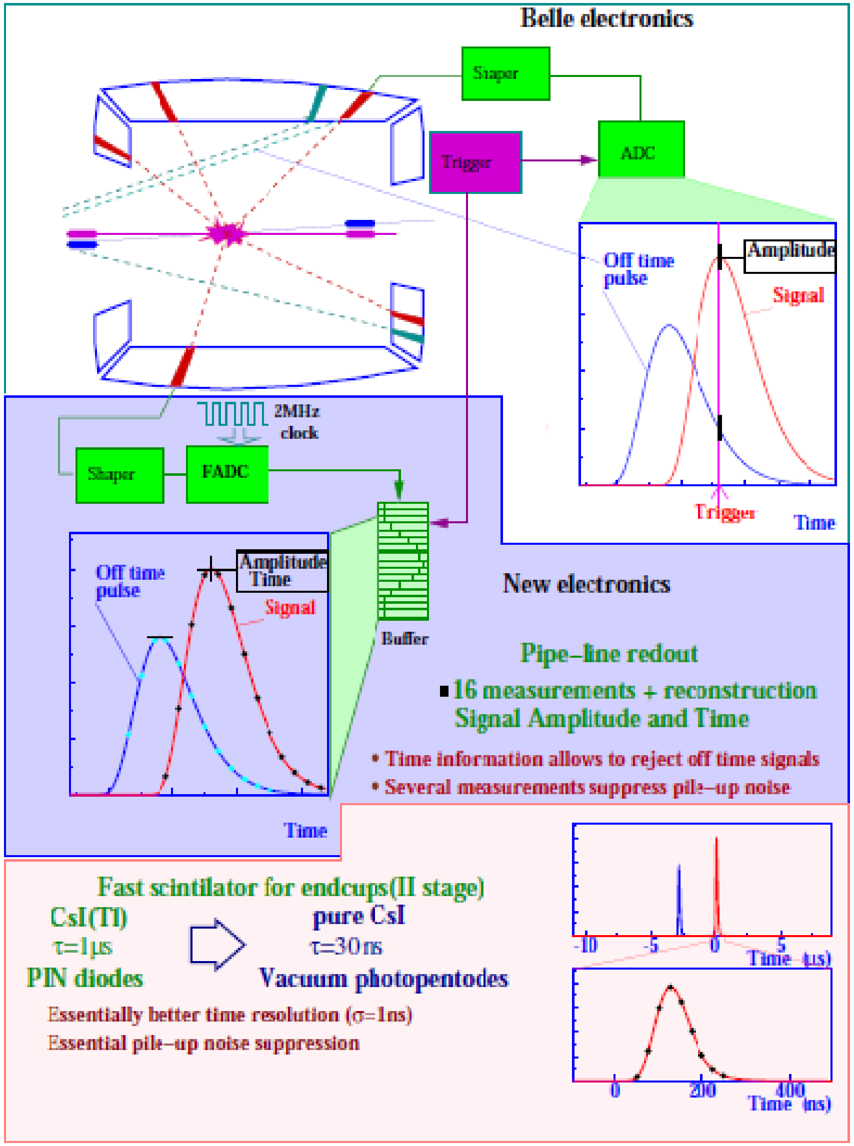
Time distribution of signals recorded by one of the PMT channels: different for π and K (~shifted in time)

EM calorimeter: upgrade needede because of higher rates (barrel: electronics, endcap: electronics and CsI(Tl) → pure CsI) and radiation load (endcap: CsI(Tl) → pure CsI)

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







- Belle II can get advantage in π^0 and soft photon-detection efficiency and resolution in comparision with LHCb experiment
- Modify electronics for the barrel.
- Pipe-line readout with waveform analysis:
- 16 points within the signal are fitted by the signal function $F(t)$:

$$F(t) = A\ f(t - t_0)$$

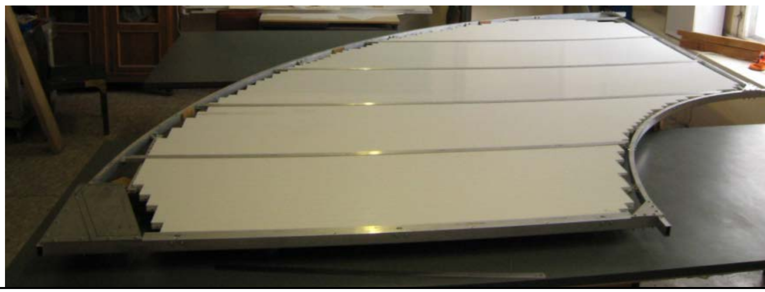
A - amplitude of the signal and
t_0 – time of the signal,

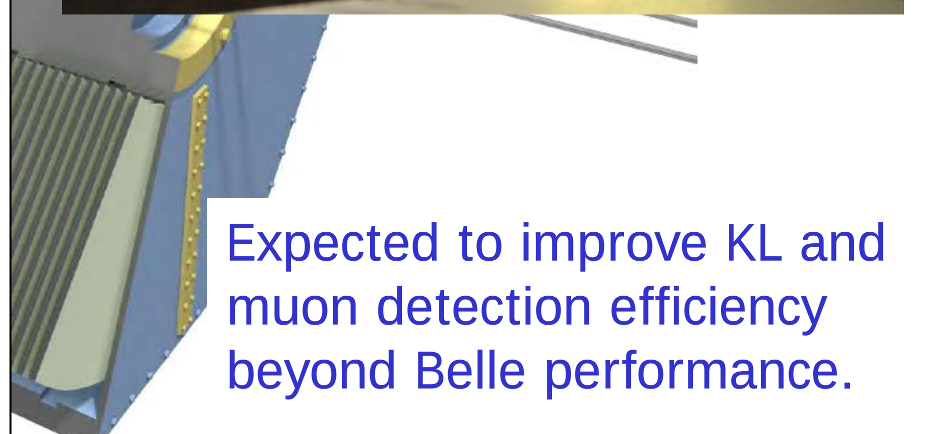
$$\chi^2 = \sum (y_i - A\ f(t_i - t_0)) S_{ij}^{-1} (y_i - A\ f(t_i - t_0))$$

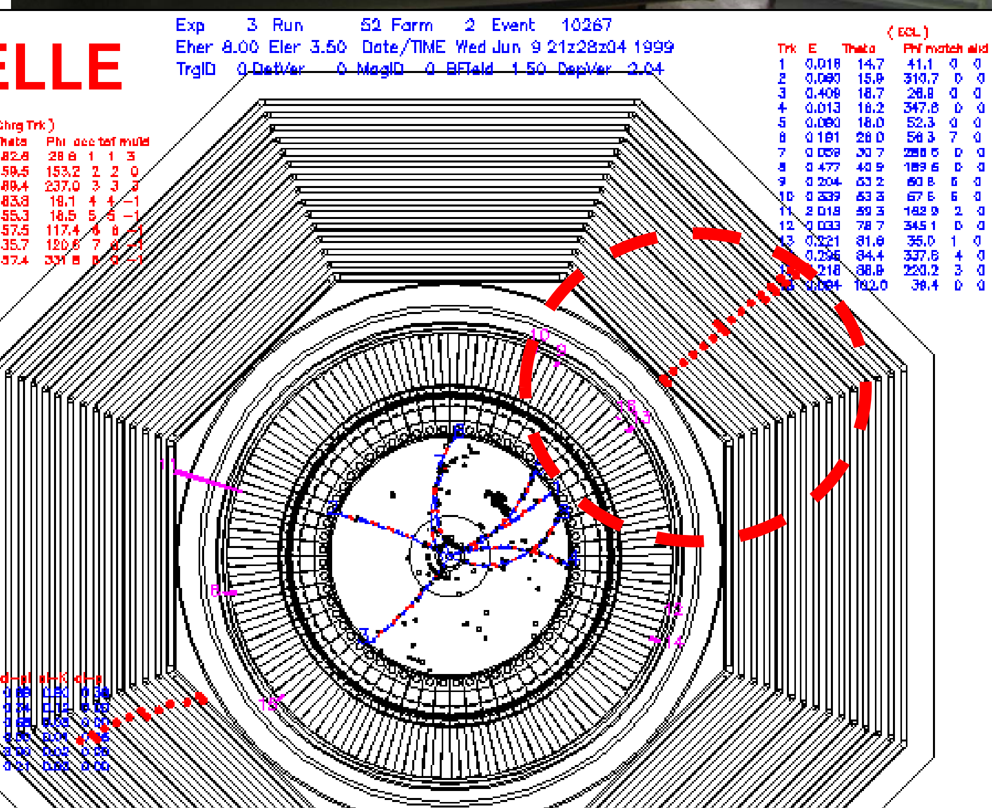
- Both amplitude and time information are reconstructed:
- Next stage: Replace the CsI(Tl) by the pure CsI crystals in endcaps.

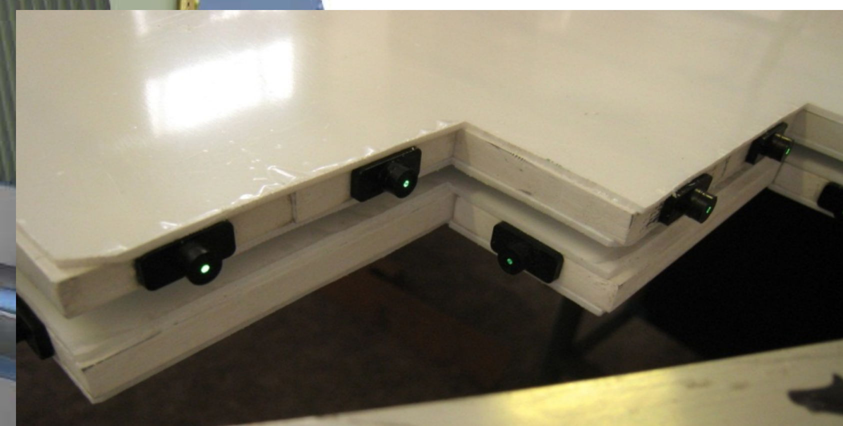
Detection of muons and KLs: Parts of the present RPC system have to be replaced to handle higher backgrounds (mainly from neutrons).

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



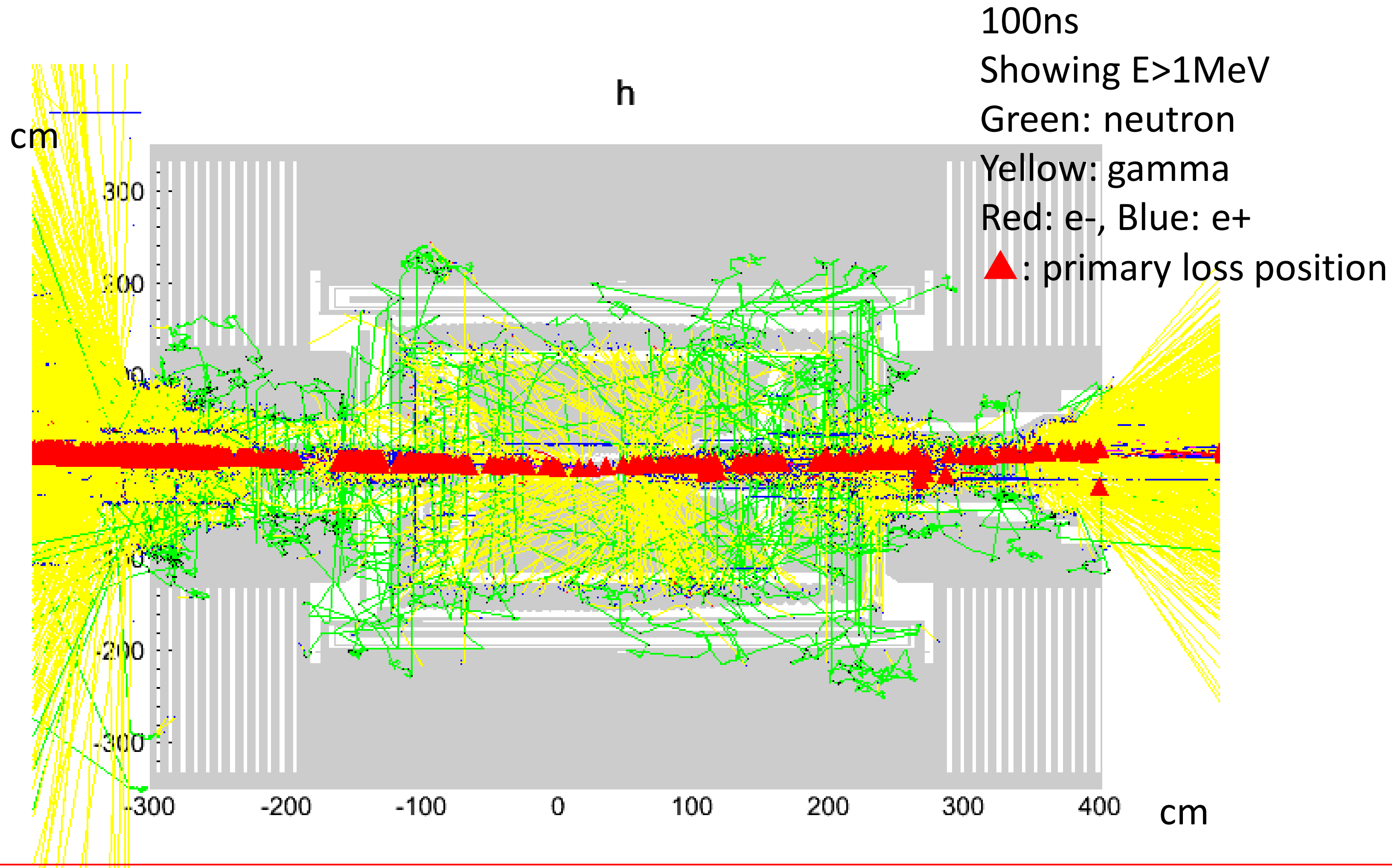






Expected to improve KL and muon detection efficiency beyond Belle performance.

Background event display

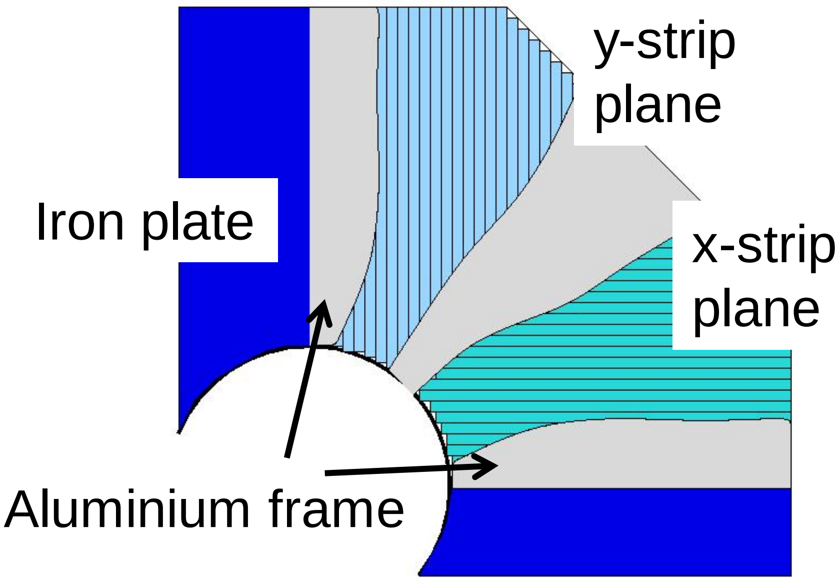


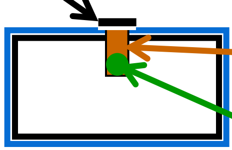
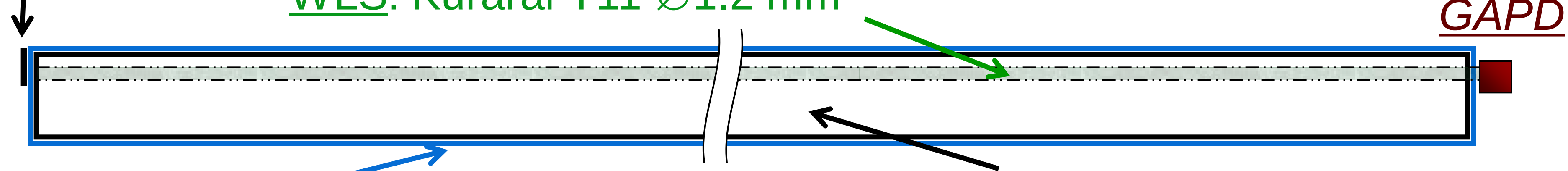
Neutrons: background hits in the muon and KL detection system (KLM) → reduce the efficiency of muon and KL detection → replace RPCs in the endcaps and 2 barrel layers.

Muon detection system upgrade

Scintillator-based KLM (endcap and 2 barrle layers)

- 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%



Status of the project

The Belle II Collaboration

A very strong group of ~480 highly motivated scientists!

SuperKEKB/Belle II Status

Funding

- ~100 MUS for machine approved in 2009 -- Very Advanced Research Support Program (FY2010-2012)
- Full approval by the Japanese government in December 2010; the project was finally in the JFY2011 budget as approved by the Japanese Diet end of March 2011
- Most of non-Japanese funding agencies have also already allocated sizable funds for the upgrade of the detector.

→construction started in 2010!

Fortunately little damage during the March 2011 earthquake → no delay

Ground breaking ceremony in November 2011

SuperKEKB and Belle II construction proceeds according to the schedule.

SuperKEKB/Belle II Status - 2

Bad news

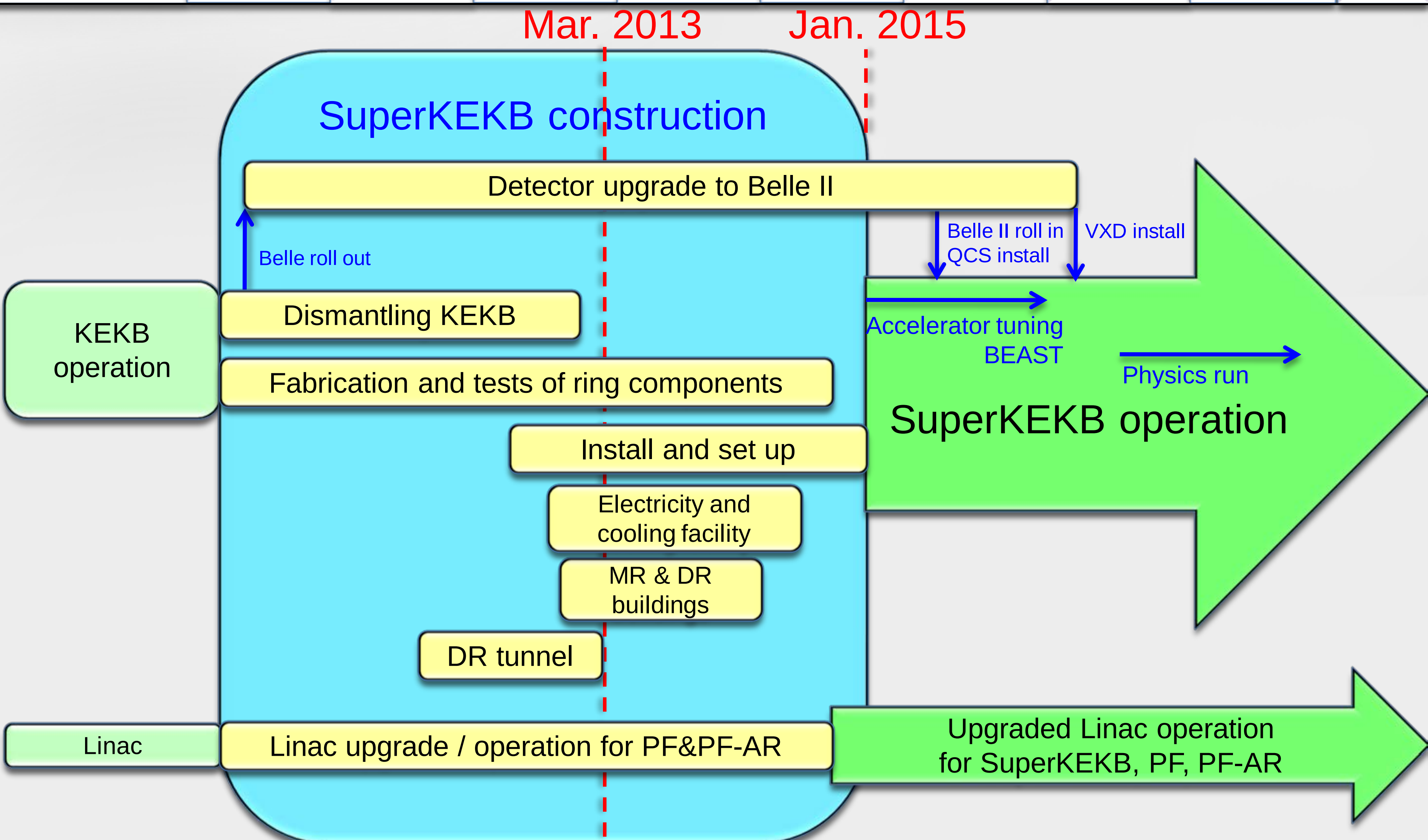
- SuperB was canceled – we are left without one of our competitors

Good news

- Some of the SuperB collaborators have decided to join (or are seriously considering to join)
- Canadian groups members since last week
- Discussions with Italian, French and Mexican institutions

SuperKEKB/Belle II schedule

Calendar	2010	2011	2012	2013	2014	2015	2016	2017	· · ·
Japan FY	2010	2011	2012	2013	2014	2015	2016	2017	· ·

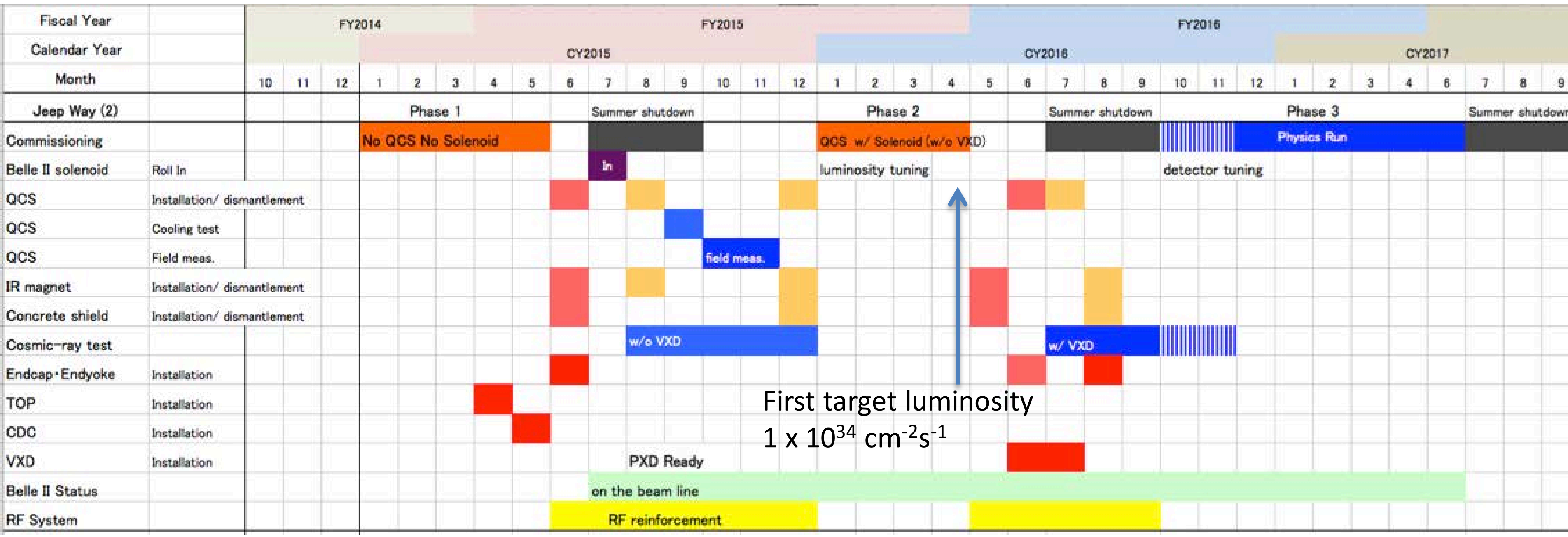


SuperKEKB Commissioning Scenario

Commissioning in three phases:

- Phase 1: w/o final quads, w/o Belle II
  - basic machine tuning
  - low emittance beam tuning
  - vacuum scrubbing
    - At least one month at beam currents of 0.5~1A.
  - Damping ring commissioning
- Phase 2: with final quads and Belle II, but no VXD
  - low beta* beam tuning
  - small x-y coupling tuning
  - collision tuning
  - study beam background
    - careful checks beam background before VXD installation.
- Phase 3: with QCS and full Belle II
  - physics run
  - luminosity increase

Commissioning schedule



SuperKEKB luminosity projection

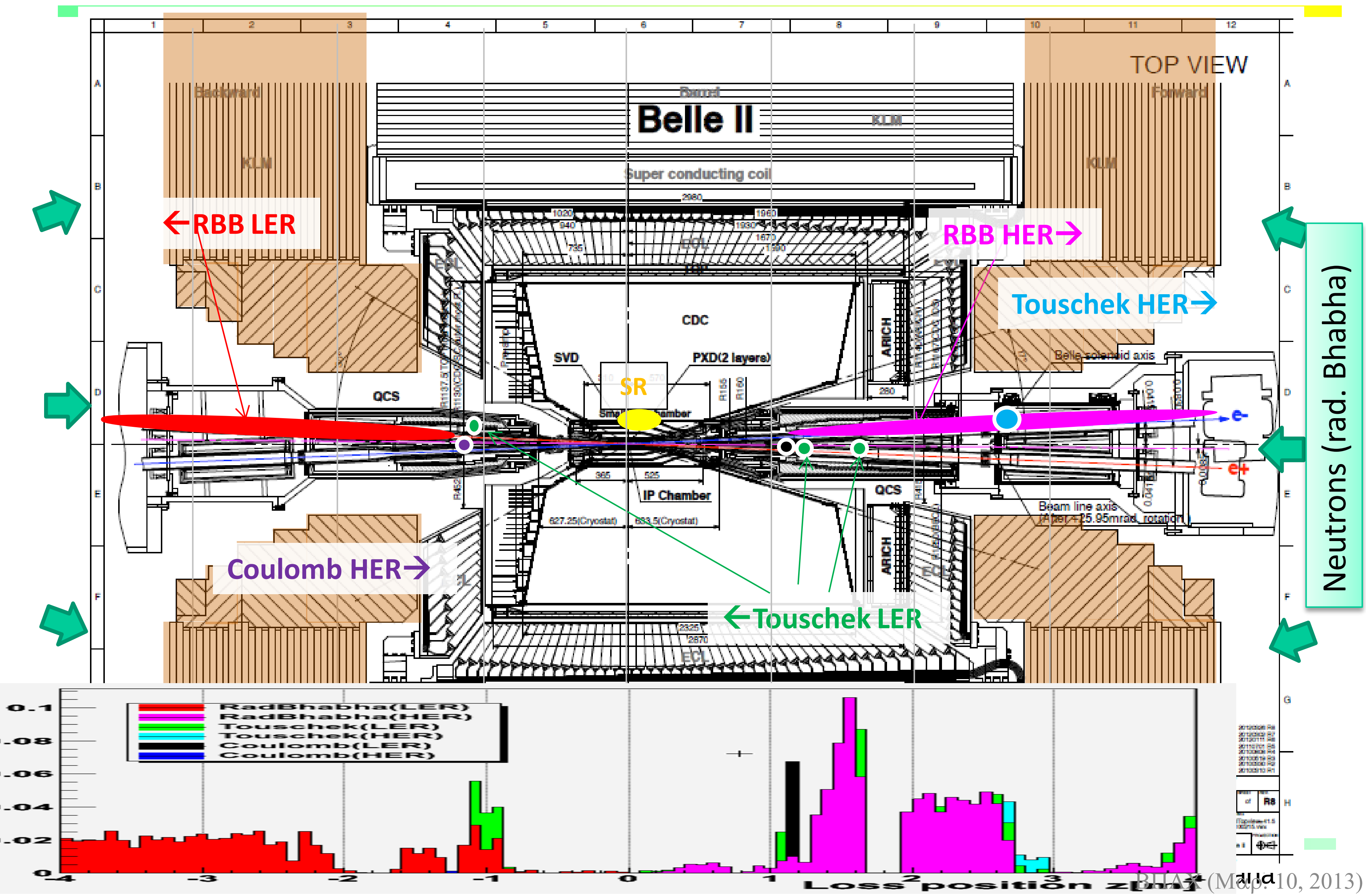
Summary

- B factories have proven to be an excellent tool for flavour physics, with reliable long term operation, constant improvement of the performance, achieving and surpasing design values
- Major upgrade at KEK in 2010-15 → SuperKEKB+Belle II, L x40, construction started, final approval by the Japanese government end of 2010
- Funding also secured by collaborating countries
- Physics reach updates available
- Expect a new, exciting era of discoveries, complementary to the LHC

Additional slides

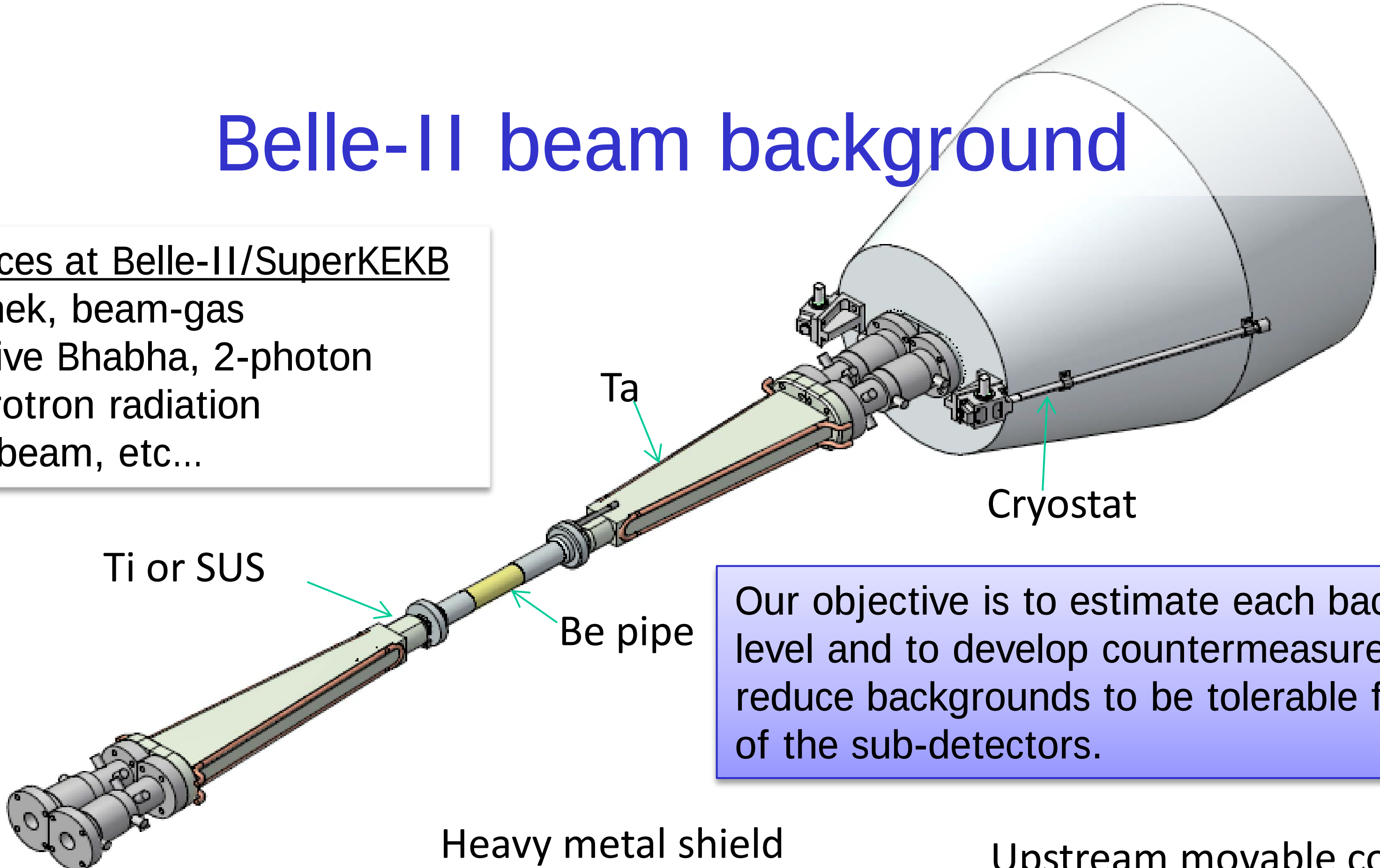
Backgrounds

Ver. 2013.3.4



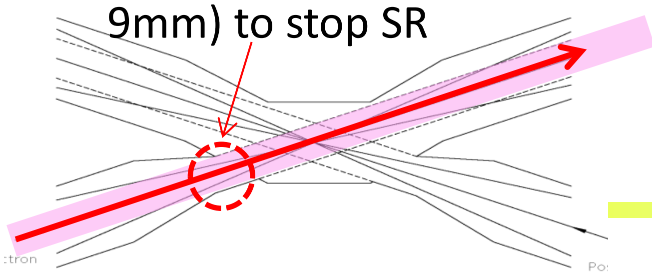
Belle-II beam background

<u>BG sources at Belle-II/SuperKEKB</u>
- Touschek, beam-gas
- Radiative Bhabha, 2-photon
- Synchrotron radiation
- beam-beam, etc…

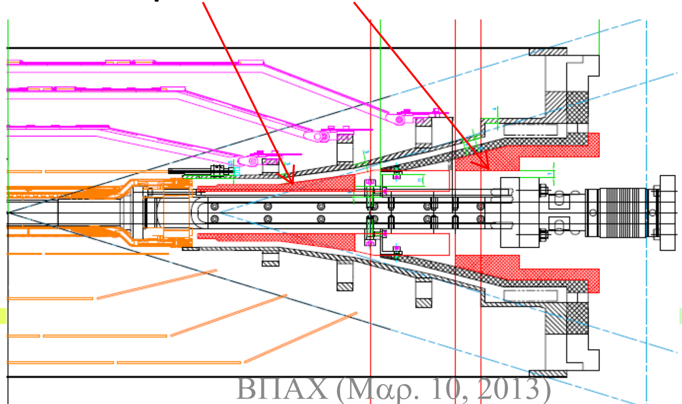


Our objective is to estimate each background level and to develop countermeasures which reduce backgrounds to be tolerable for each of the sub-detectors.

Collimation (20mm->9mm) to stop SR



Heavy metal shield to stop BG showers



Upstream movable collimators