SuperKEKB & Belle II Status

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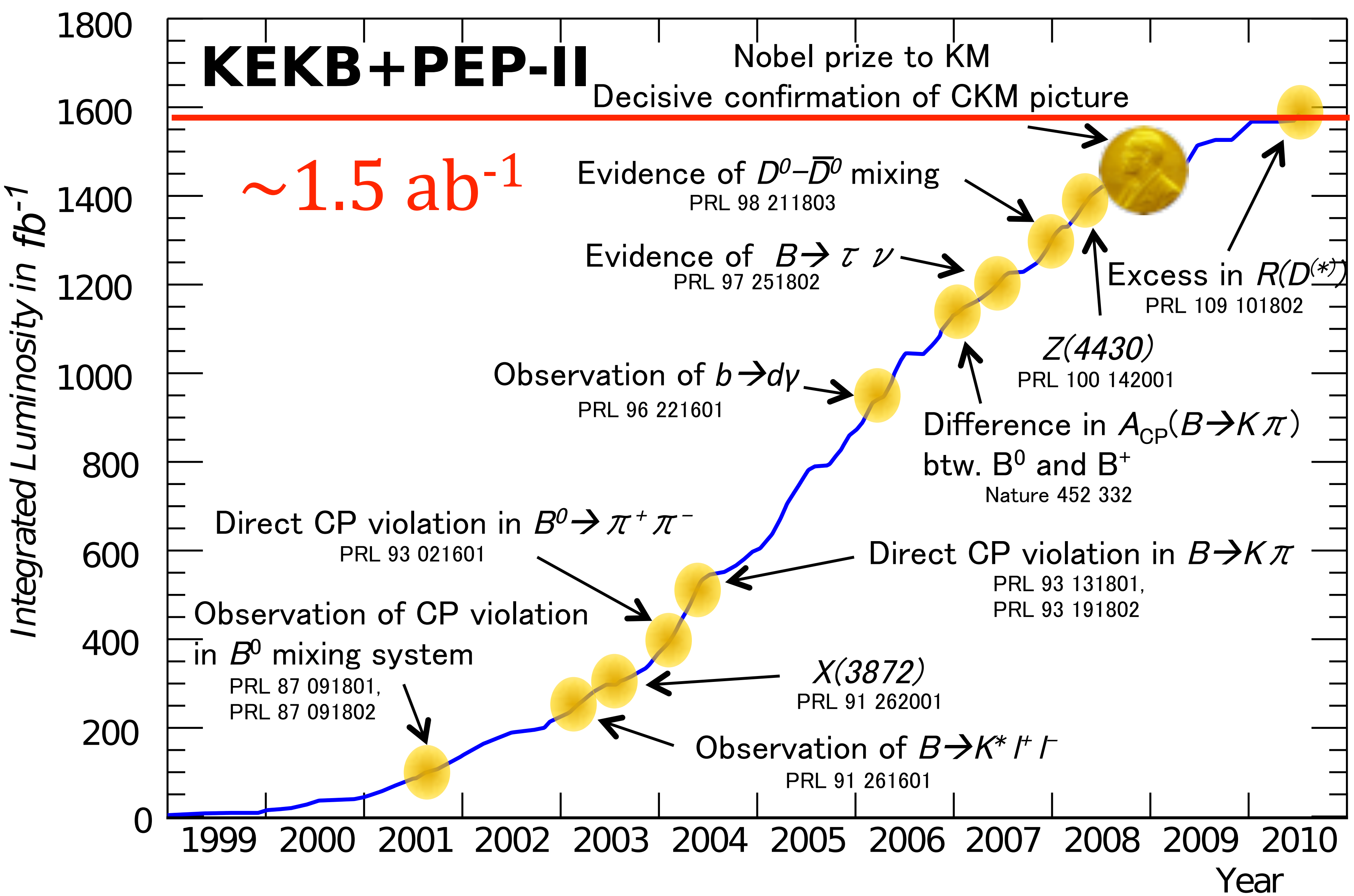
FPCP 2017 - Prague, 4-9 June 2017

Outline

- Introduction
- Commissioning status and plans
  - SuperKEKB accelerator
  - Belle II detector
- Outlook

The B Factory Legacy



Next Generation SuperKEKB+ Belle II with 50 ab^{-1}

→ Discover new physics!

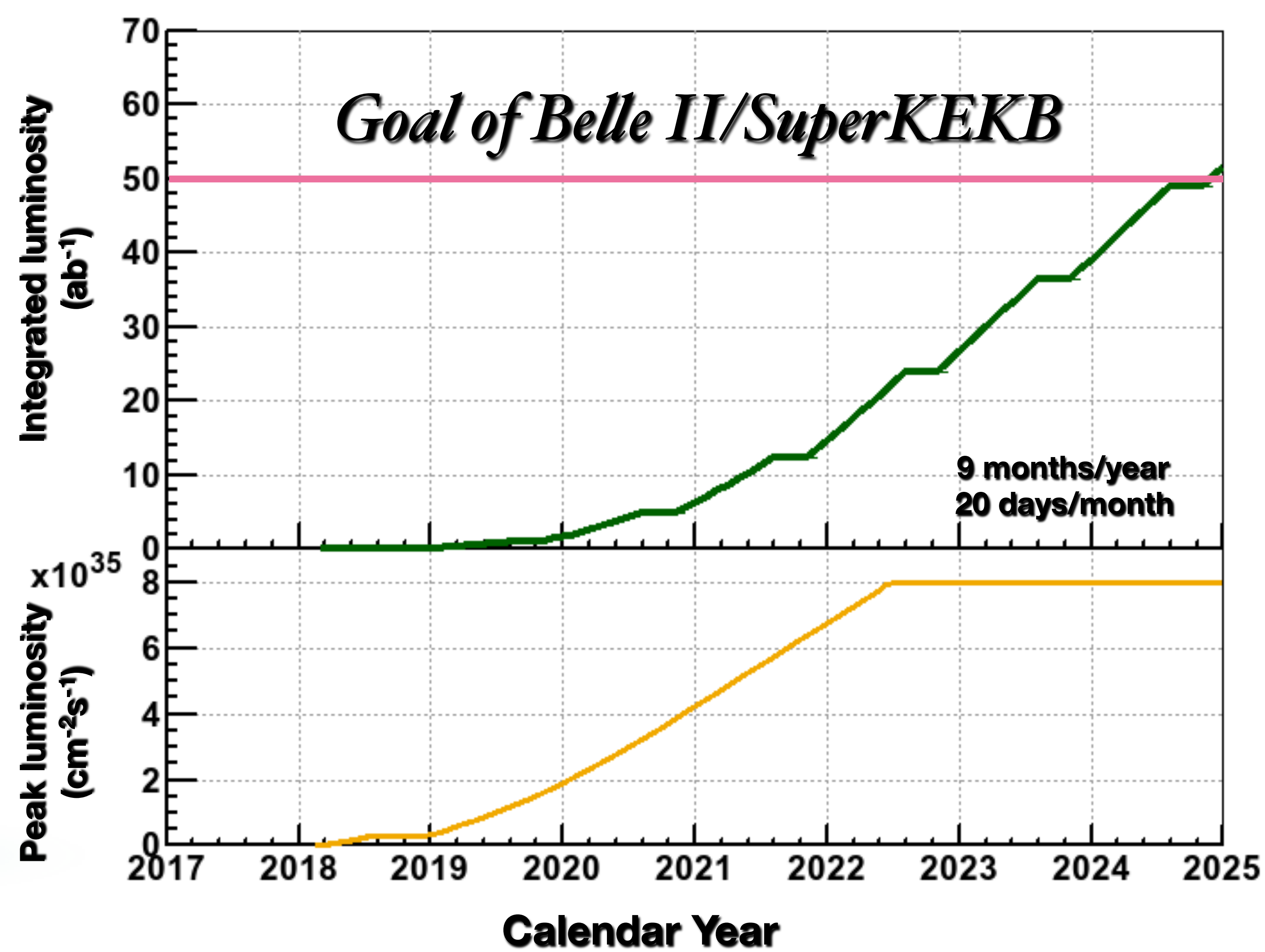
See talk by E. Guido

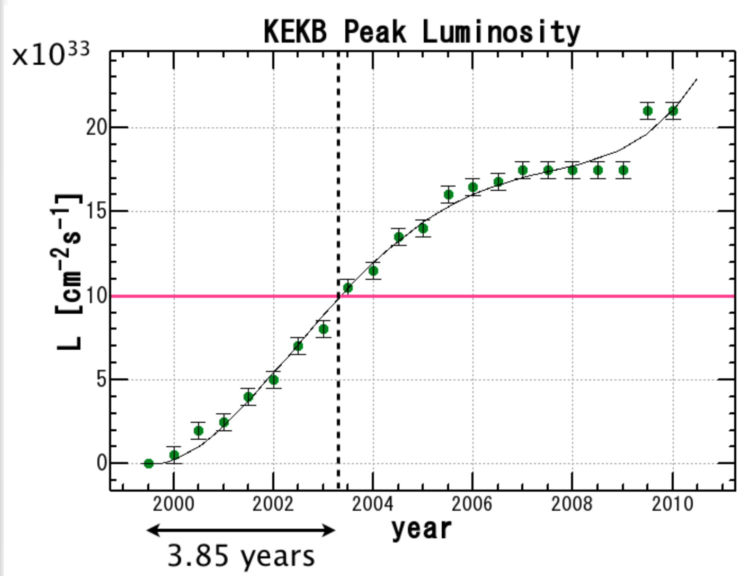
Luminosity profile of the next generation B factory @ KEK

Expected data sample @ full luminosity

Channel	Belle	BaBar	Belle II (per year)*
$B\bar{B}$	7.7×10^8	4.8×10^8	1.1×10^{10}
$B_s^{(*)}\bar{B}_s^{(*)}$	7.0×10^6	–	6.0×10^8
$\Upsilon(1S)$	1.0×10^8		1.8×10^{11}
$\Upsilon(2S)$	1.7×10^8	0.9×10^7	7.0×10^{10}
$\Upsilon(3S)$	1.0×10^7	1.0×10^8	3.7×10^{10}
$\Upsilon(5S)$	3.6×10^7	–	3.0×10^9
$\tau\tau$	1.0×10^9	0.6×10^9	1.0×10^{10}

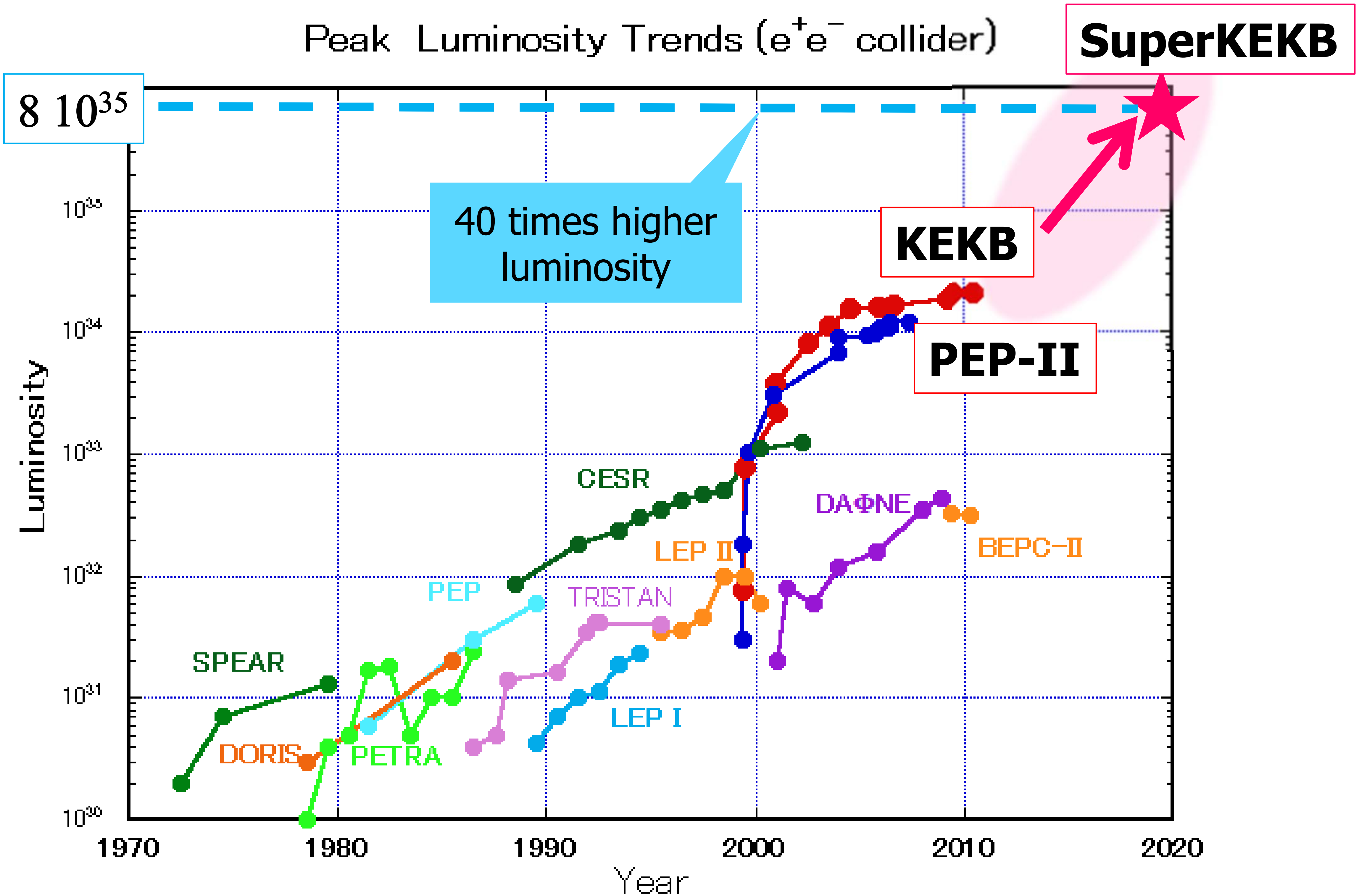
* assuming 100% running at each energy





- Assumptions:
  - same commissioning time to reach nominal luminosity as in KEKB
  - 9 months/year running
  - 20 days/month

$2 \cdot 10^{34} \rightarrow 8 \cdot 10^{35}$



The “nano-beam scheme”

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

Lorentz factor

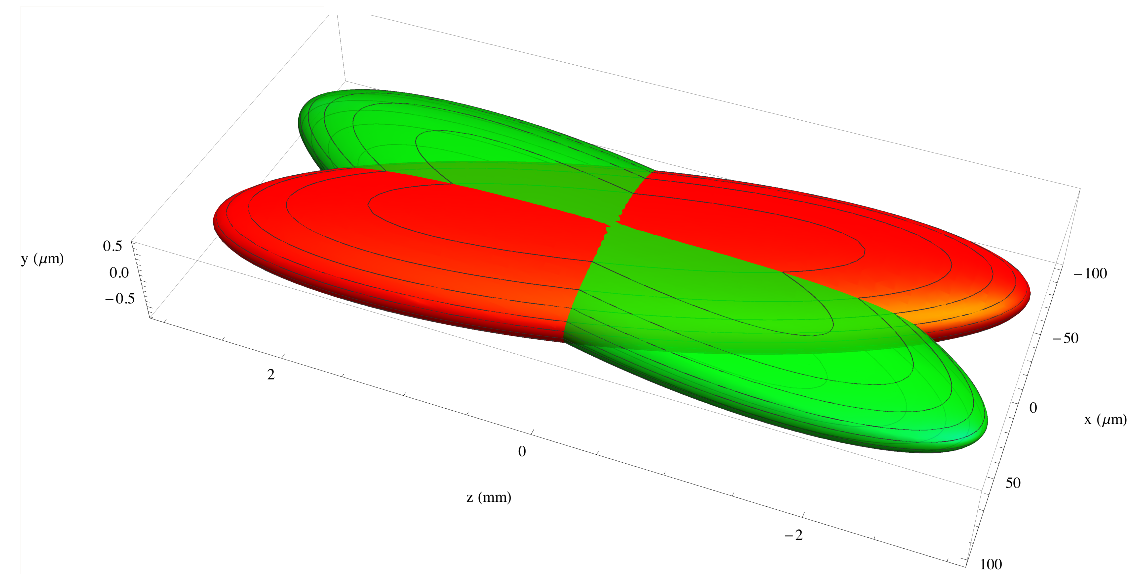
Beam current

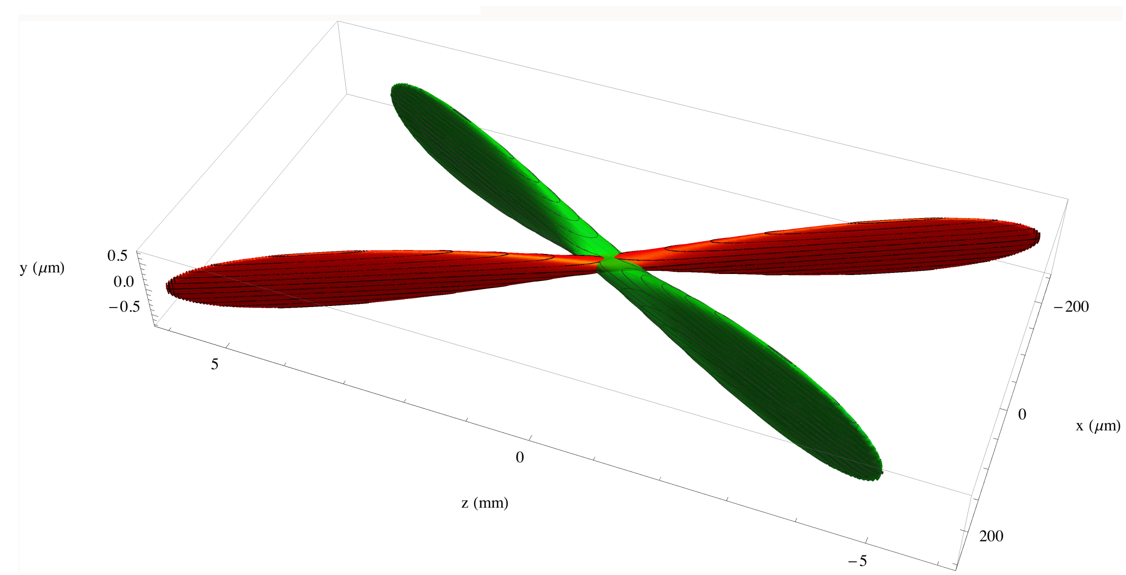
Beam-Beam parameter

Beam aspect ratio at IP
(0.01-0.02)

Vertical beta function at IP

I ↑ x 2
β^*_y ↓ x 1/20





Very focused beams, large crossing angle (83 mrad)

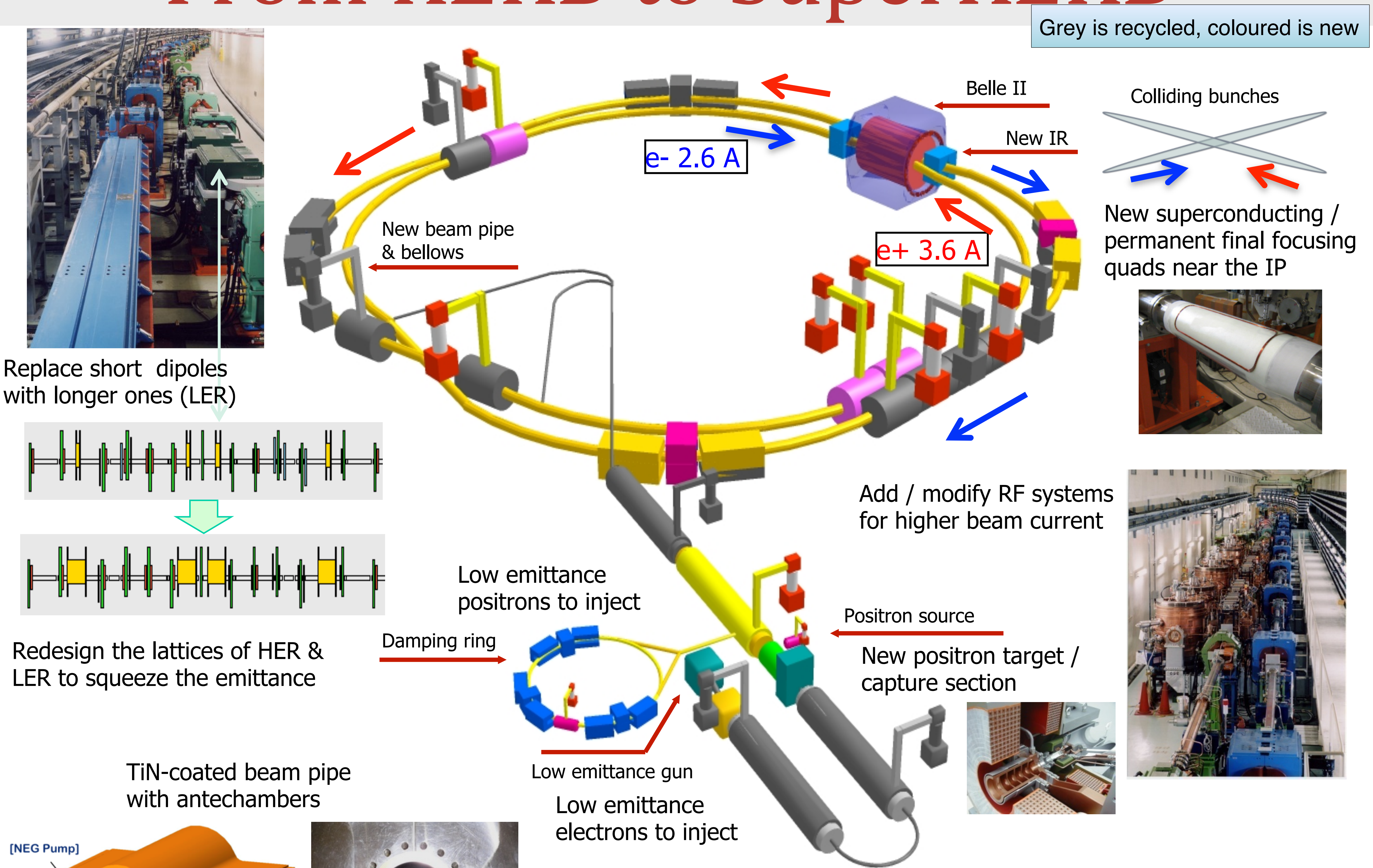
KEK & SuperKEKB parameters

	KEKB Design	KEKB Achieved : with crab	SuperKEKB Nano-Beam
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.0/7.0
β_y^* (mm)	10/10	5.9/5.9	0.27/0.30
β_x^* (mm)	330/330	1200/1200	32/25
ε_x (nm)	18/18	18/24	3.2/5.3
$\varepsilon_y/\varepsilon_x$ (%)	1	0.85/0.64	0.27/0.24
σ_y(μm)	1.9	0.94	0.048/0.062
ξ_y	0.052	0.129/0.090	0.09/0.081
σ_z (mm)	4	6 - 7	6/5
I_{beam} (A)	2.6/1.1	1.64/1.19	3.6/2.6
$N_{bunches}$	5000	1584	2500
Luminosity (10^{34} cm^{-2} s^{-1})	1	2.11	80

- Lower E_{HER} (RF power)
- Higher E_{LER} (Touschek lifetime)

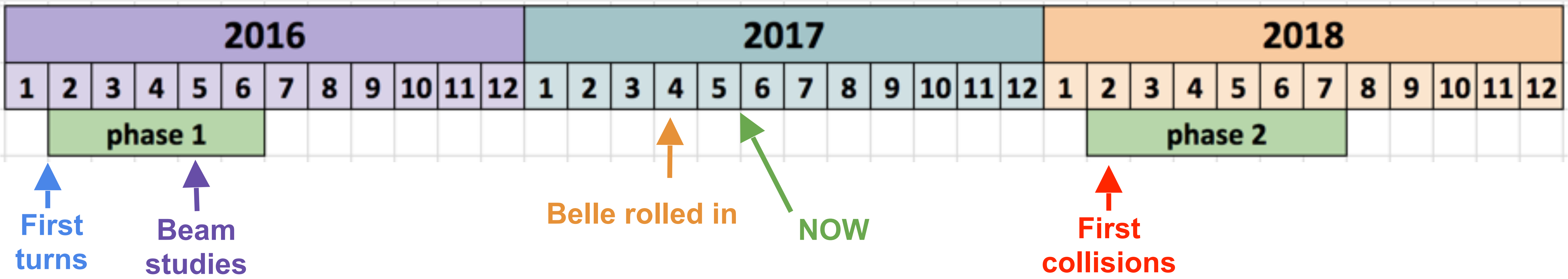
→ **Boost 0.42 → 0.28**

From KEKB to SuperKEKB



To get 40x higher luminosity

SuperKEKB Commissioning



Phase I (2016): No Belle II, circulate both beams without collisions

Phase II (2018): With Belle II without vertex detector, first collisions

Commissioning Goals

SuperKEKB

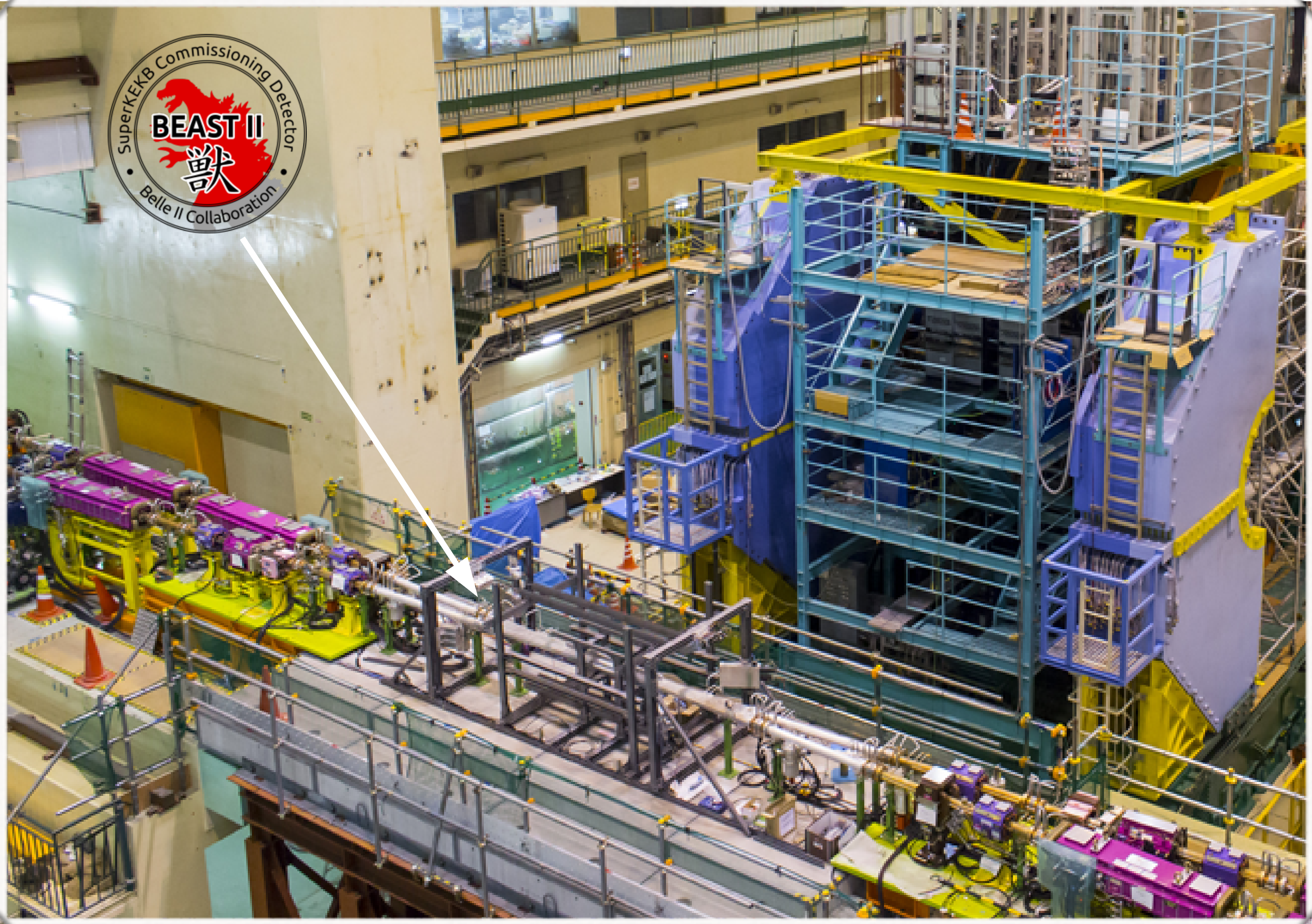
- Clean beam pipe (vacuum scrubbing)
- Real-time monitoring of beam conditions
- Tune accelerator optics, collimators etc.
- Isolate sources of beam loss and collect data for simulations used to improve performances

Belle II

- Guarantee a safe operating environment for Belle II
- Mitigate beam backgrounds around the IP
- Test beam abort system based on diamond sensors
- Collect beam background data to validate background simulations

BEAST II - phase 1

Beam **E**xorcisms for **A St**able Belle II Experiment



Goals

- Measure BG levels near IP
  - X-rays, charged tracks, neutrons
  - online feedback to SuperKEKB
  - offline for analysis
- Test and calibration of diamond sensor VXD beam abort
- First measurements of SuperKEKB injection backgrounds
- First comparison of SuperKEKB beam-loss simulation with experimental data

Expected SuperKEKB Backgrounds

Phase I (no collisions)

Touschek scattering:
- intra-bunch scattering process
- dominant with highly compressed beams
- 20 times higher

Beam-gas scattering:
- Bremsstrahlung (negligible) & Coulomb interactions (up to 100 times higher) with residual gas atoms & molecules

Synchrotron radiation:
- emission of photons by charged particles (e^+e^-) when deflected in *B*-field

Phase 2 (collisions)

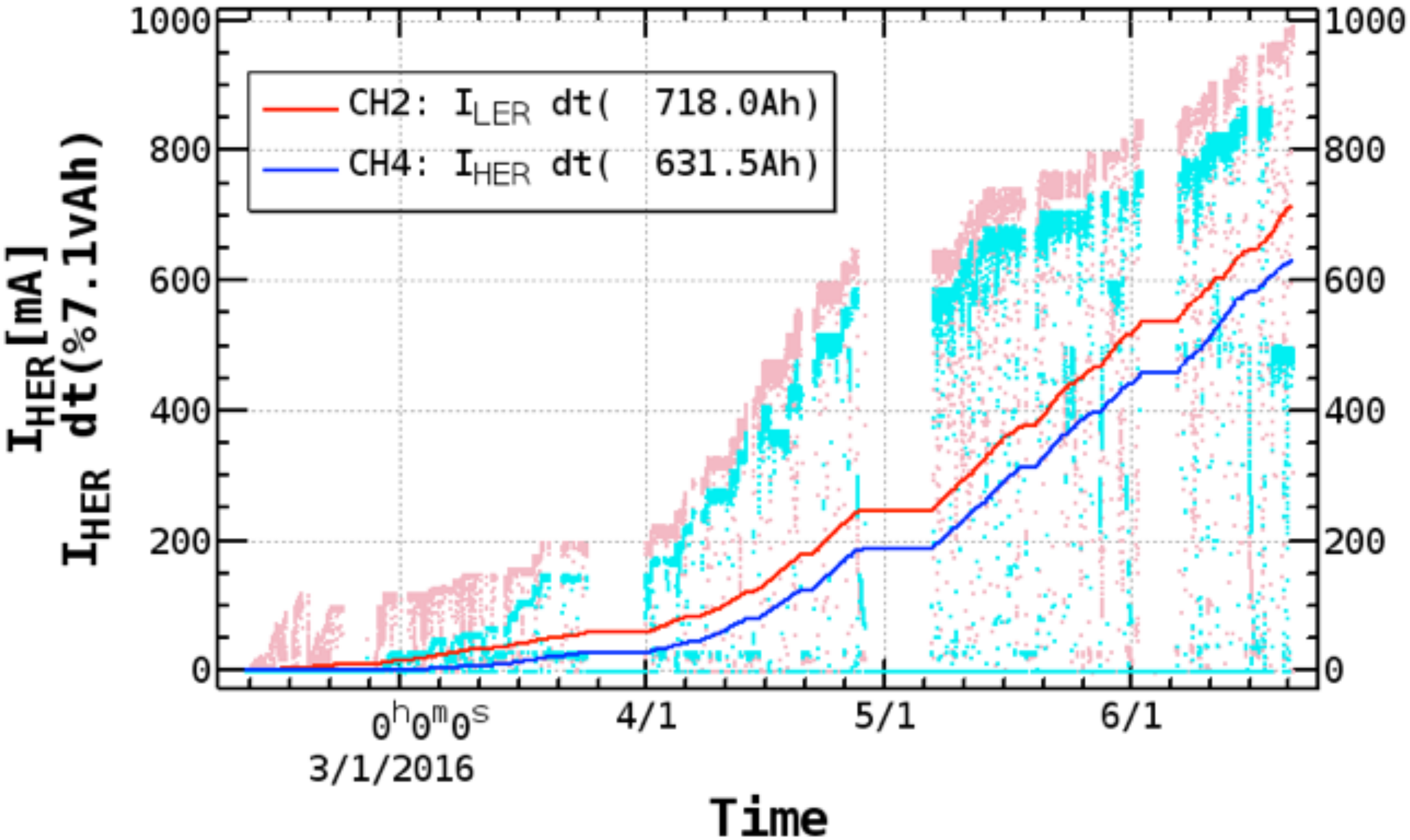
Radiative Bhabha process:
- photon emission prior or after *Bhabha* scattering
- interaction with iron in the magnets leads to neutron background

Two photon process:
- very low momentum e^+e^- pairs via $e^+e^- \rightarrow e^+e^-e^+e^-$
- increased hit occupancy in inner detectors

Injection Background:
- covered later in the talk

History of Phase 1 operation

June 21: LER beam current exceeded 1 Ampere



First 4 months of beam commissioning

KEKB

LER: 540 mA

HER: 300 mA

SuperKEKB

LER: 820 mA

HER: 740 mA

- SuperKEKB startup much faster than KEKB
- All upgraded components worked fine!
- KEKB experience was key

Y. Funakoshi, June '16 B2GM

Belle II

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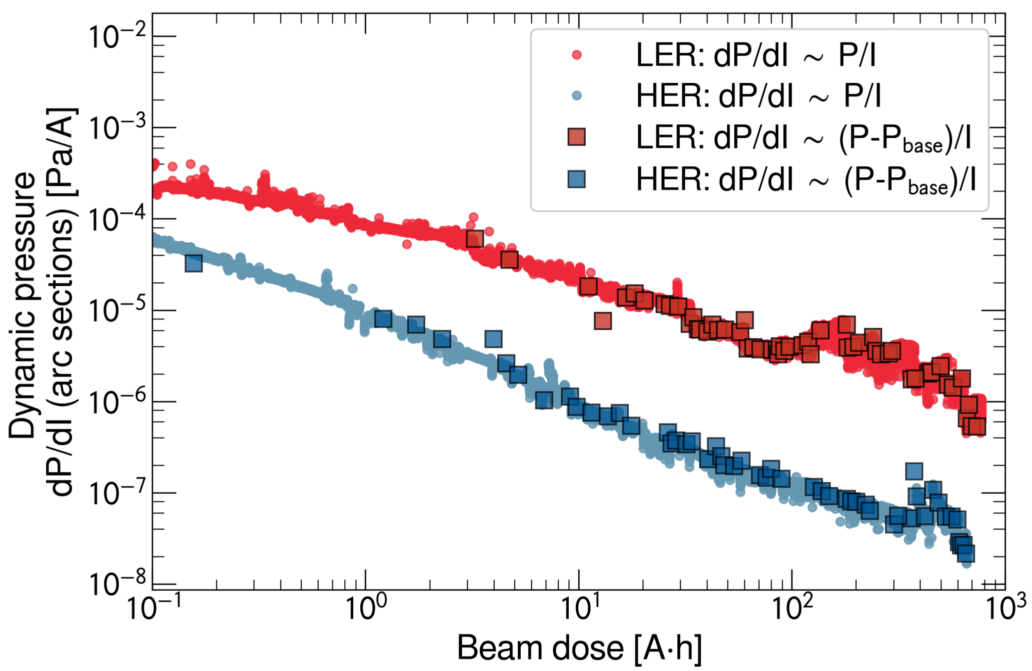
BEAST II - Phase 1

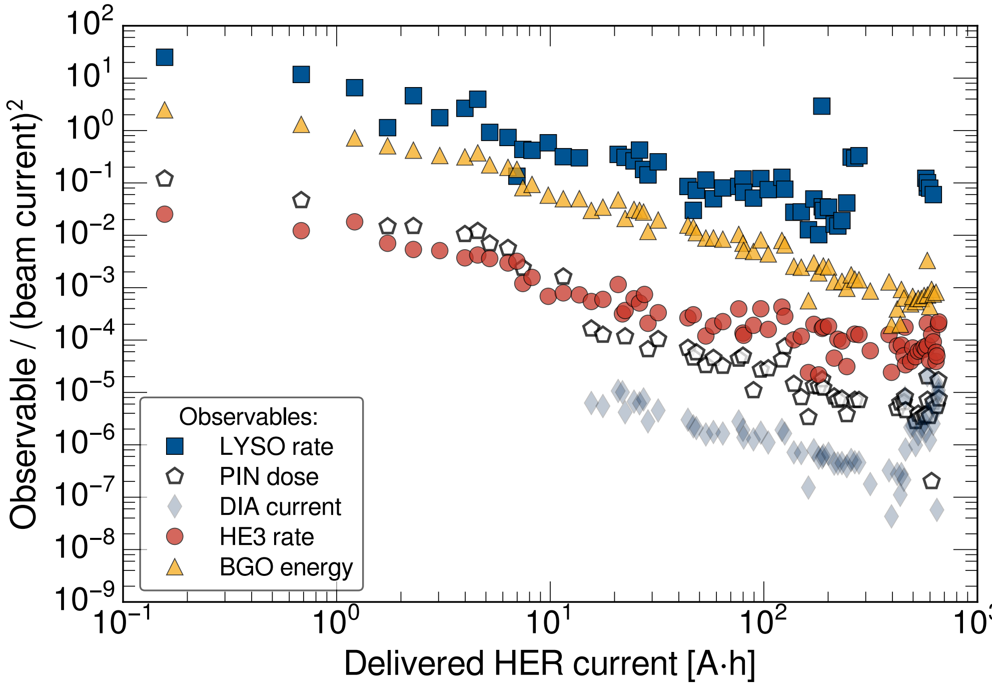
Cleaning a new beam pipe

- A key goal of phase 1 was to “scrub” the beam pipes
  - High currents stimulate desorption of impurities from beam pipe walls
  - Over time, **vacuum improves** lowering beam-gas backgrounds
- BEAST quantified distinct improvements in beam-gas in phase 1

SuperKEKB measurements of dP/dI vs integrated current



BEAST measurements of Rates/I^2 vs integrated current



Beam-Gas & Touschek

Describe data with heuristic model

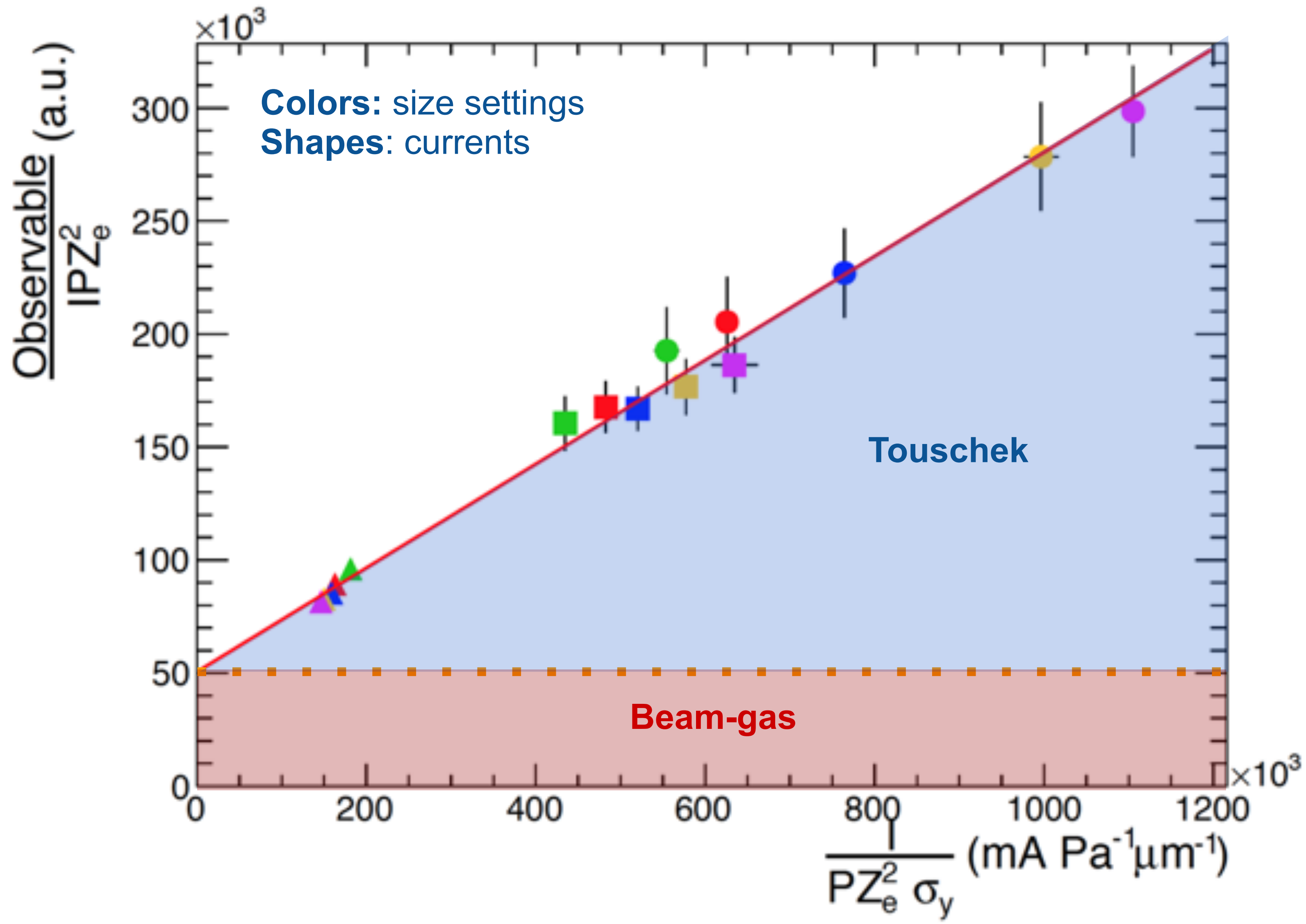
$$Observable = B \cdot IPZ_e^2 + T \cdot \frac{I^2}{\sigma_y}$$

- Size-sweep scans
- Run beam at 5 different beam sizes and at 3 currents (15 runs total)
- Observable comes from BGO crystals
- Rewrite so beam-gas is flat:

$$\frac{Observable}{IPZ_e^2} = B + T \cdot \frac{I}{PZ_e^2\sigma_y}$$

- Quality of linear fit validates model
- Fit measures sensitivities B (offset) and T (slope)

Z_e: An "effective" atomic number taking into account the gas mixture recorded by a residual gas analyzer

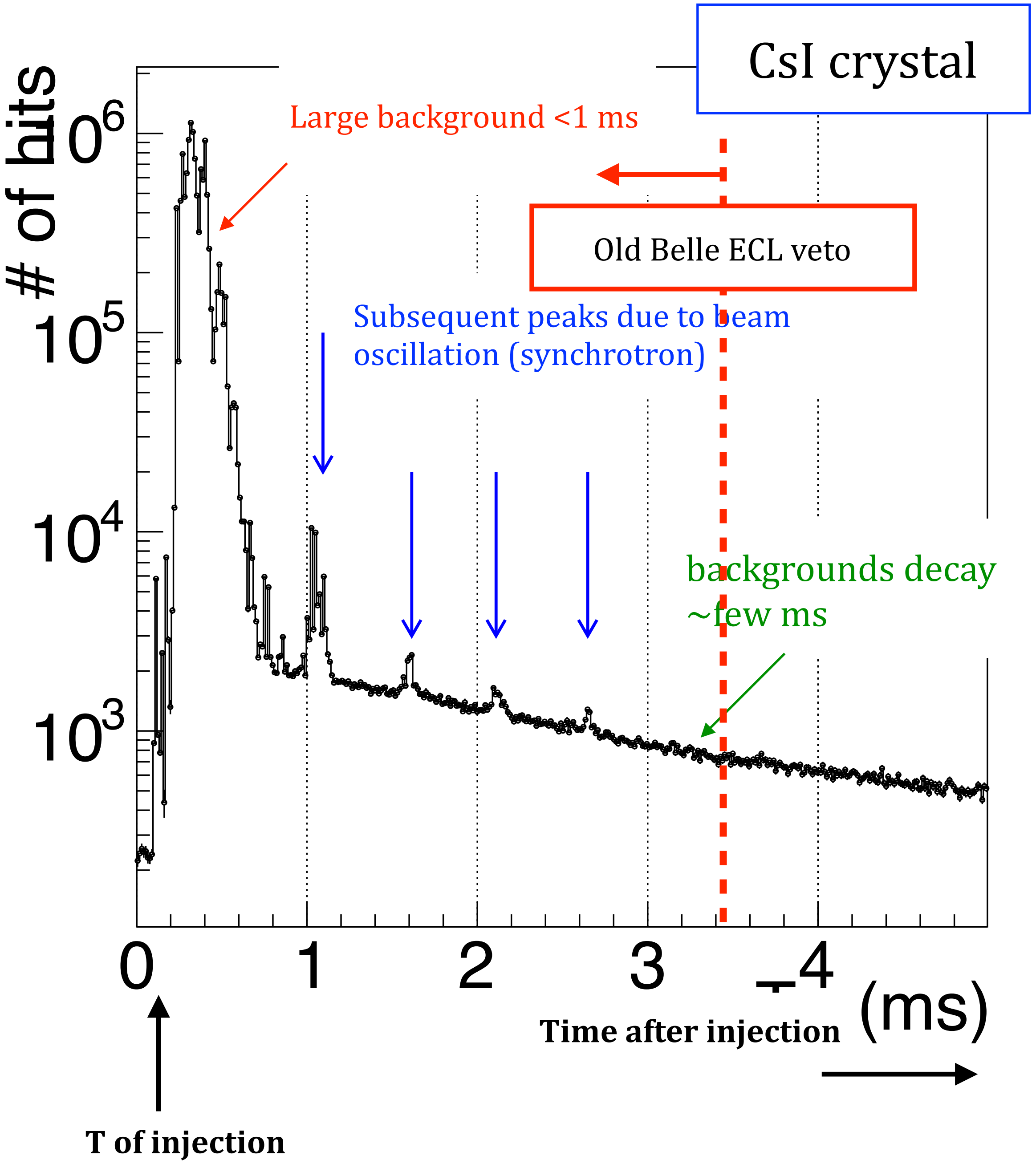


Good agreement with the model!

The comparison of data with MC is underway

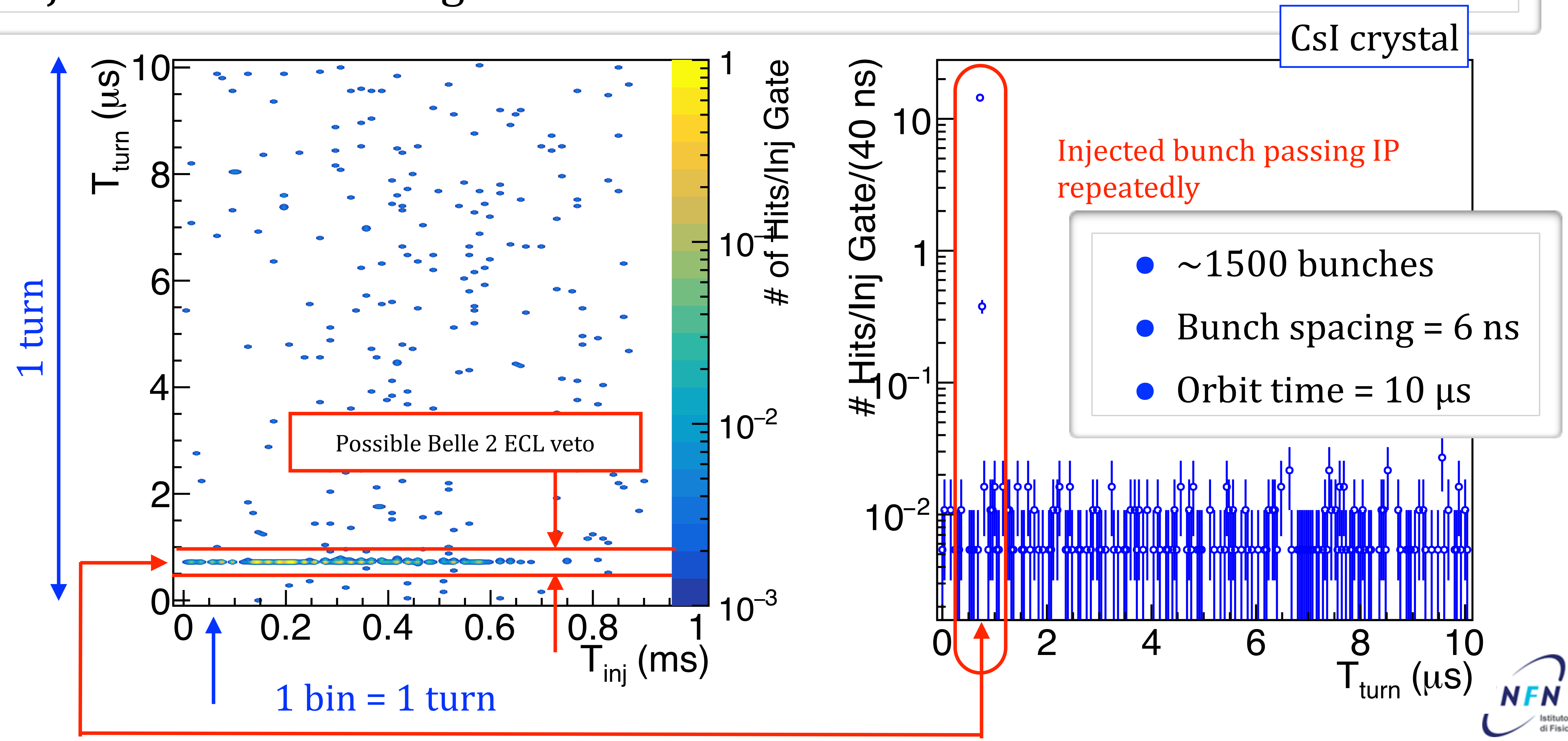
Injection Background BEAST II - Phase 1

- Injection produces high backgrounds
  - Factory mode: to compensate for shorter beam lifetime use continuous injection → DAQ Veto
- Continuos injection @ 100 Hz during SuperKEKB-factory operation
  - Belle injection ECL DAQ veto scheme would produce 35% dead time!
  - → Study injection background time structure with BEAST crystal, CLAWS and scintillators subsystems
- Background surge ~x100-x1000 in first ms after injection



Injection Background BEAST II - Phase 1

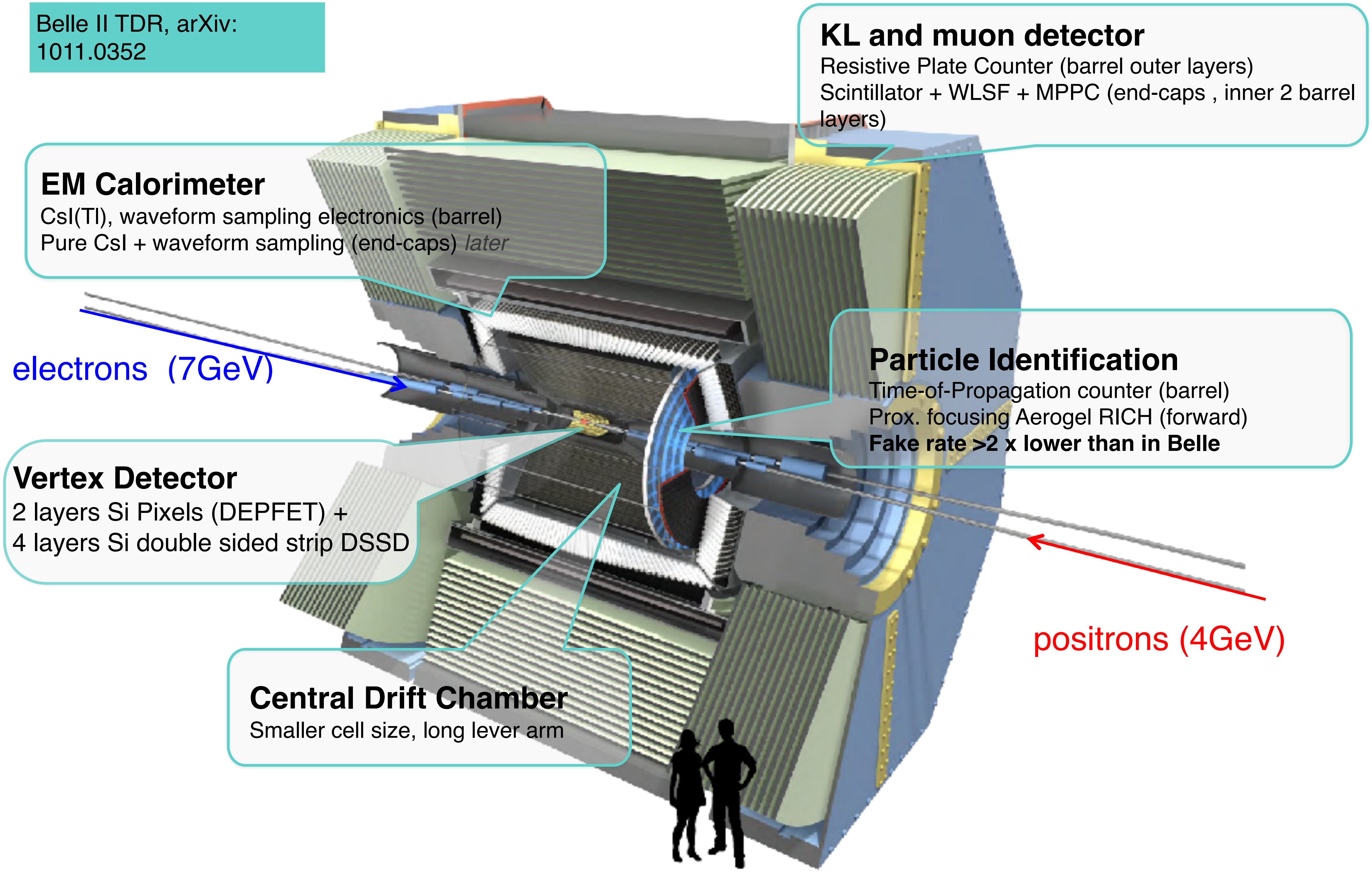
- Injection perturbs the orbit parameters of (almost) only the injected bunch
  - → High backgrounds lasting few ms after injection are highly correlated in time with the injected bunch
- Veto for ~1ms only for few 10s of ns around the time of passage of the injected bunch through the IP → dead time ok



Belle II Detector

Belle II Detector [735 collaborators, 101 institutes, 23 nations]

Belle II TDR, arXiv: 1011.0352



Belle II Detector

Factor x40 luminosity also brings in:

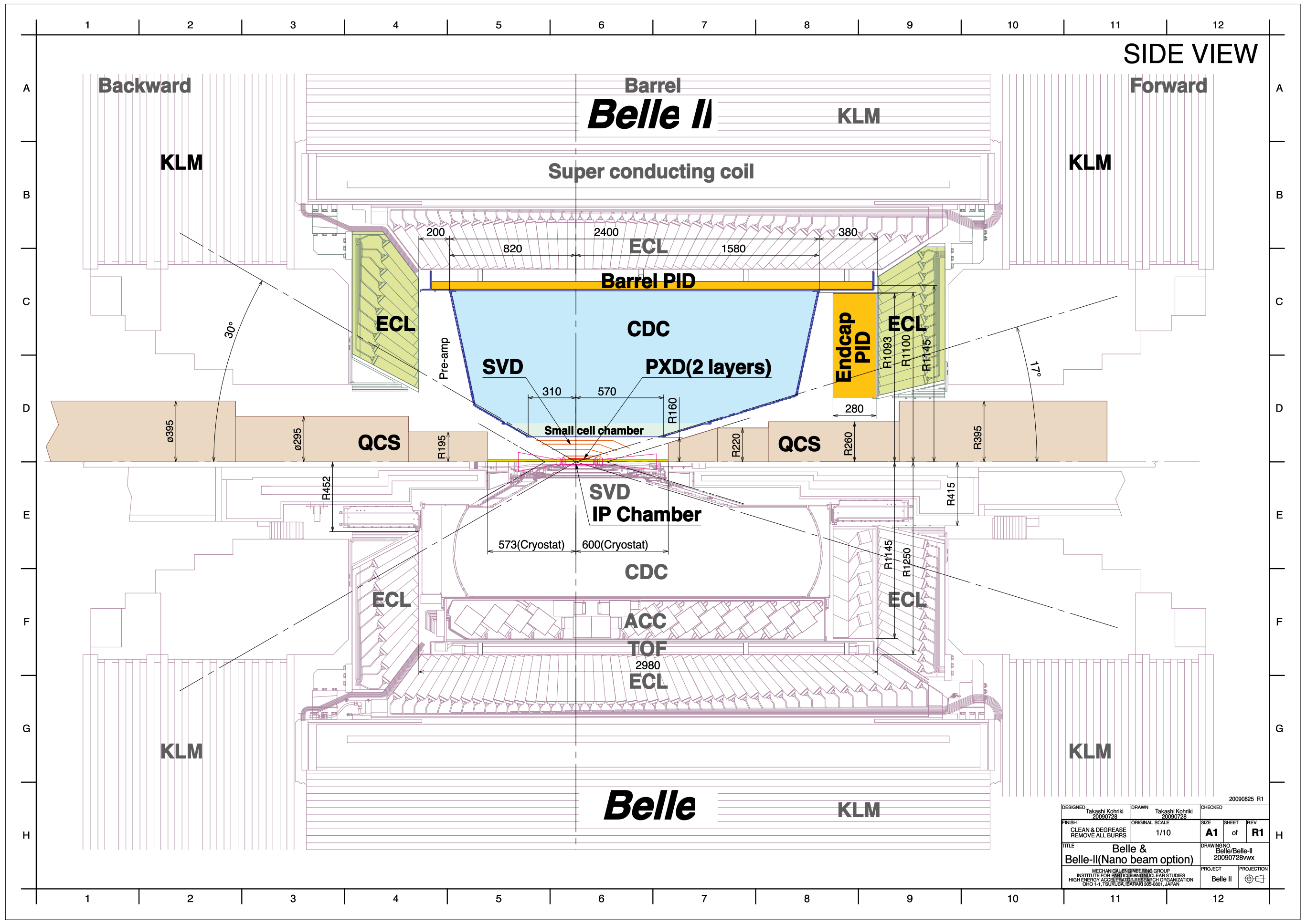
- Higher occupancy, pile-up, fake hits
- increased trigger and DAQ rates
- radiation damage

Upgrade the Belle detector

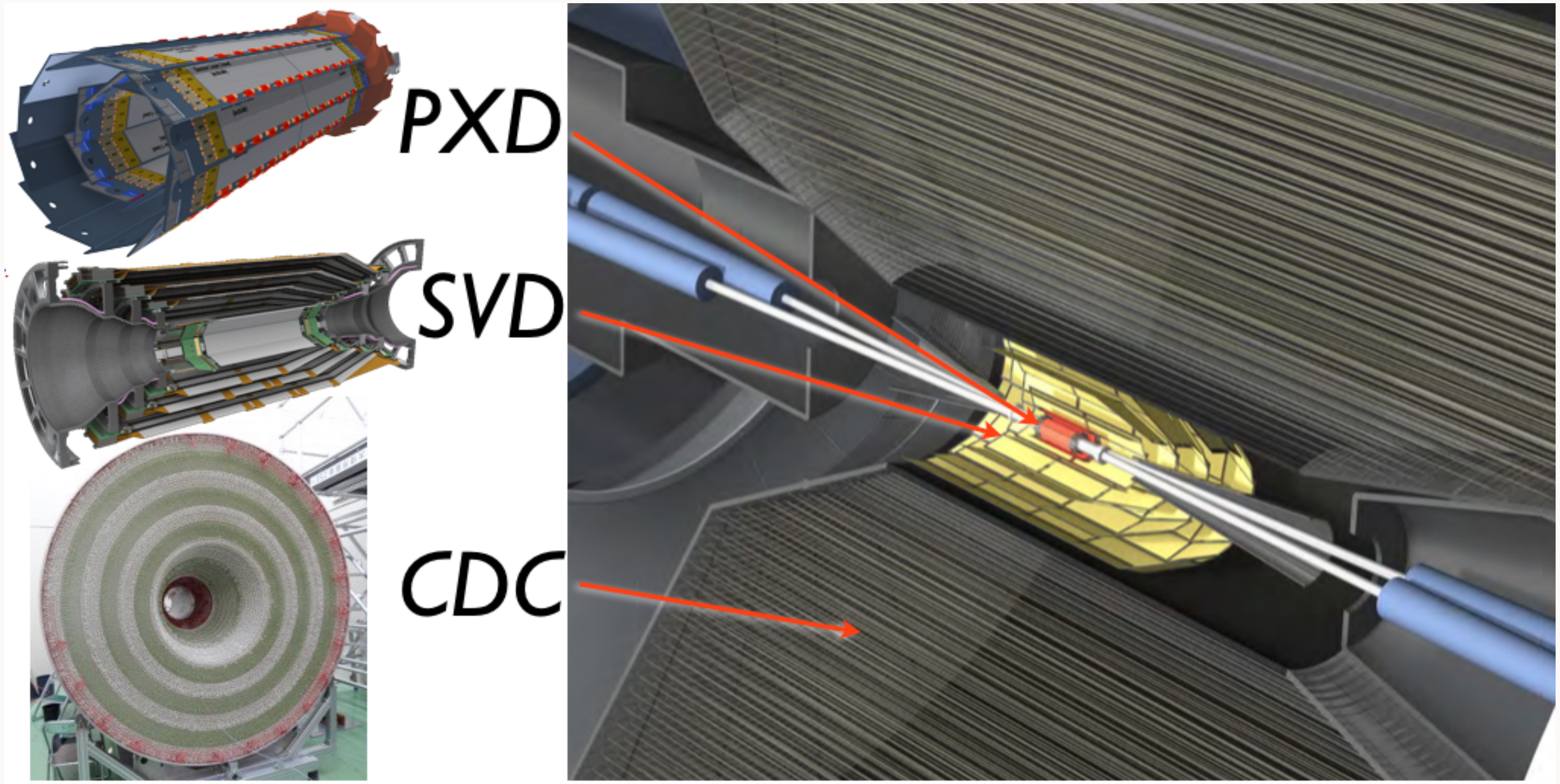
- starting point is the Belle detector
- in practice, reuse the crystal CsI(Tl) calorimeter, the solenoid, the KLM barrel detector

Improvements over Belle

- Fast signal shaping and waveform fit of e.m. calorimeter signals to preserve excellent energy resolution in high-pileup environment
- Increase K_S efficiency (by ~30%)
- Improve IP and secondary vertex resolution (~factor 2)
- Better K/π separation (π fake rate decreases by ~2.5)
- Improve π^0 reconstruction

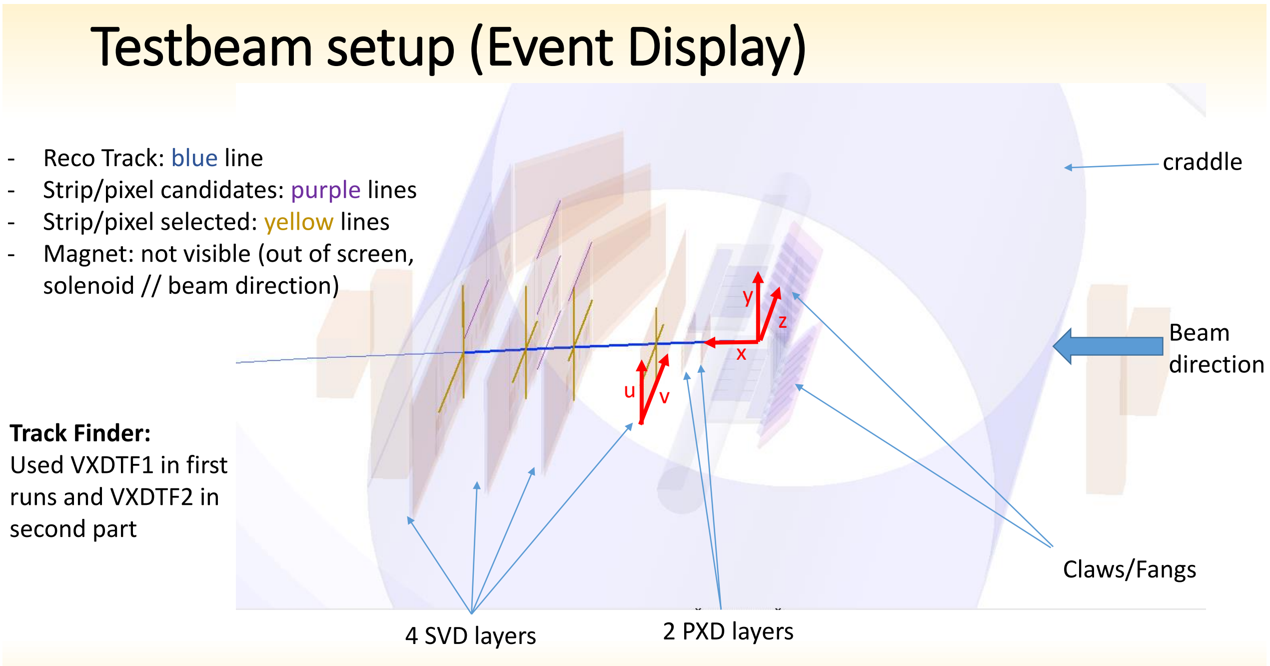


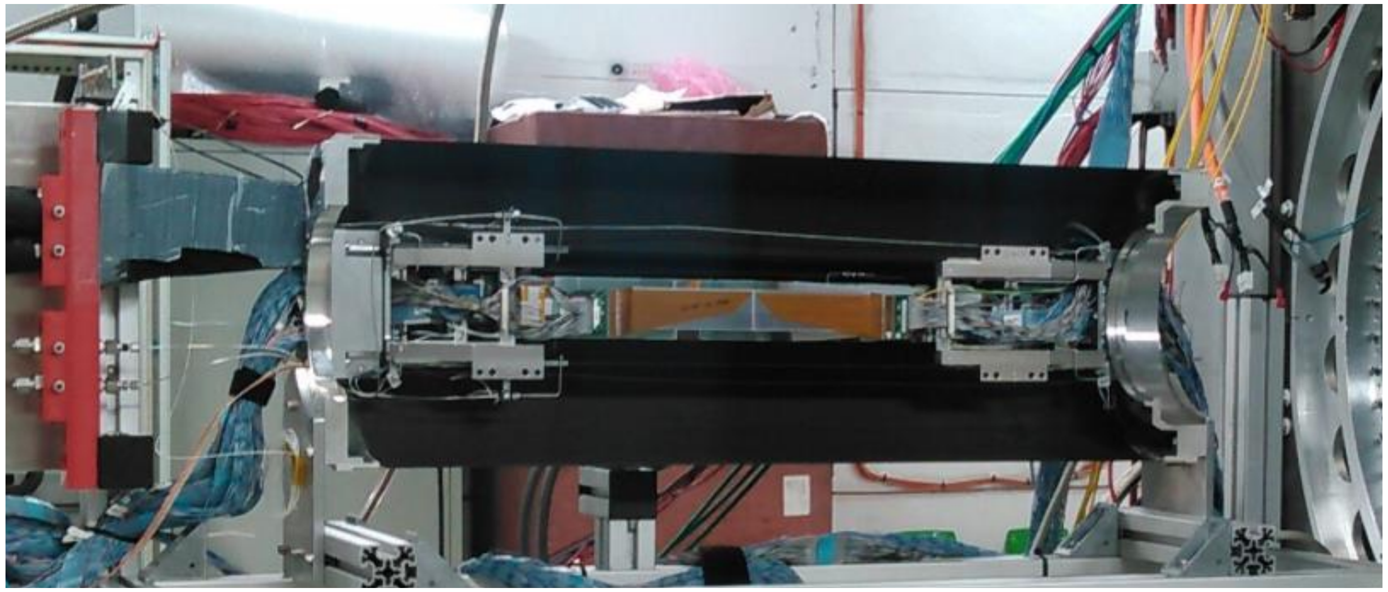
The tracking system

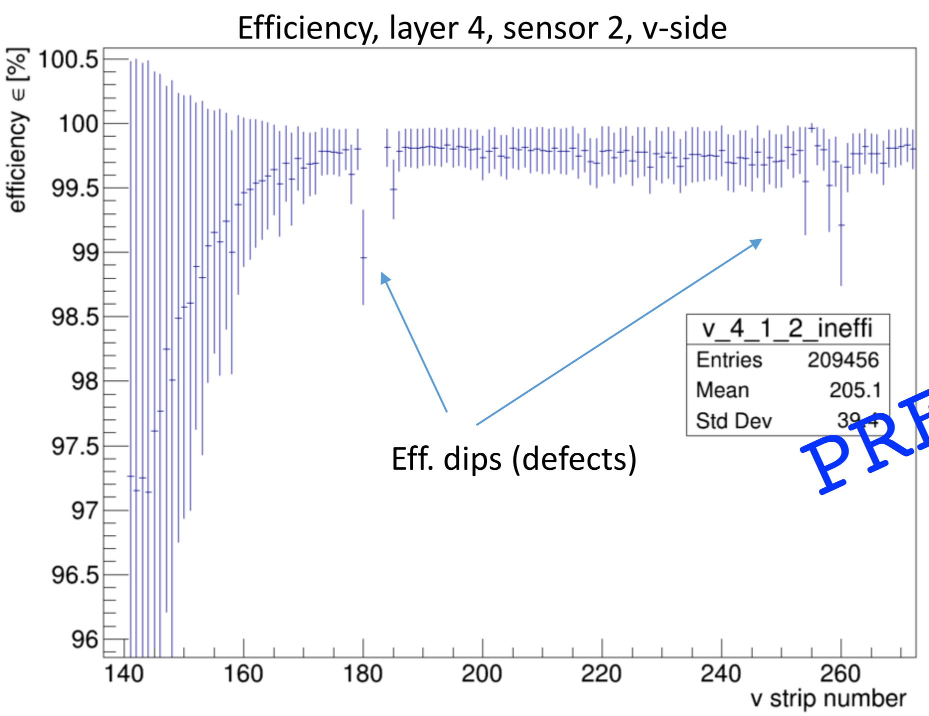


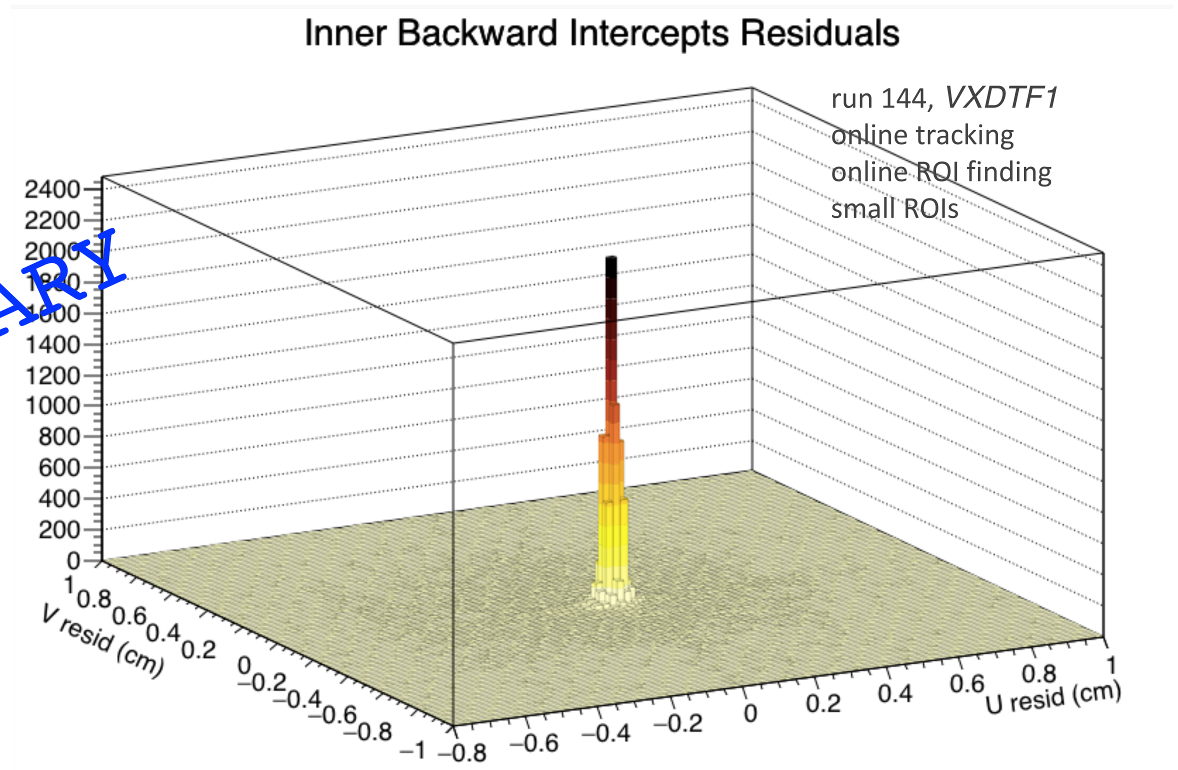
Component	Type	Configuration	Readout	Performance
Beam pipe	Beryllium double-wall	Cylindrical, inner radius 10 mm, 10 μm Au, 0.6 mm Be, 1 mm coolant (paraffin), 0.4 mm Be		
PXD	Silicon pixel (DEPFET)	Sensor size: 15×100 (120) mm^2 pixel size: 50×50 (75) μm^2 2 layers: 8 (12) sensors	10 M	impact parameter resolution $\sigma_{z_0} \sim 20\ \mu$m (PXD and SVD)
SVD	Double sided Silicon strip	Sensors: rectangular and trapezoidal Strip pitch: 50(p)/160(n) - 75(p)/240(n) μm 4 layers: 16/30/56/85 sensors	245 k	
CDC	Small cell drift chamber	56 layers, 32 axial, 24 stereo r = 16 - 112 cm - 83 $\leq z \leq$ 159 cm	14 k	$\sigma_{r\phi} = 100\ \mu$m, $\sigma_z = 2$ mm $\sigma_{p_t}/p_t = \sqrt{(0.2\% p_t)^2 + (0.3\%/\beta)^2}$ $\sigma_{p_t}/p_t = \sqrt{(0.1\% p_t)^2 + (0.3\%/\beta)^2}$ (with SVD)

Combined PXD+SVD beam test at DESY

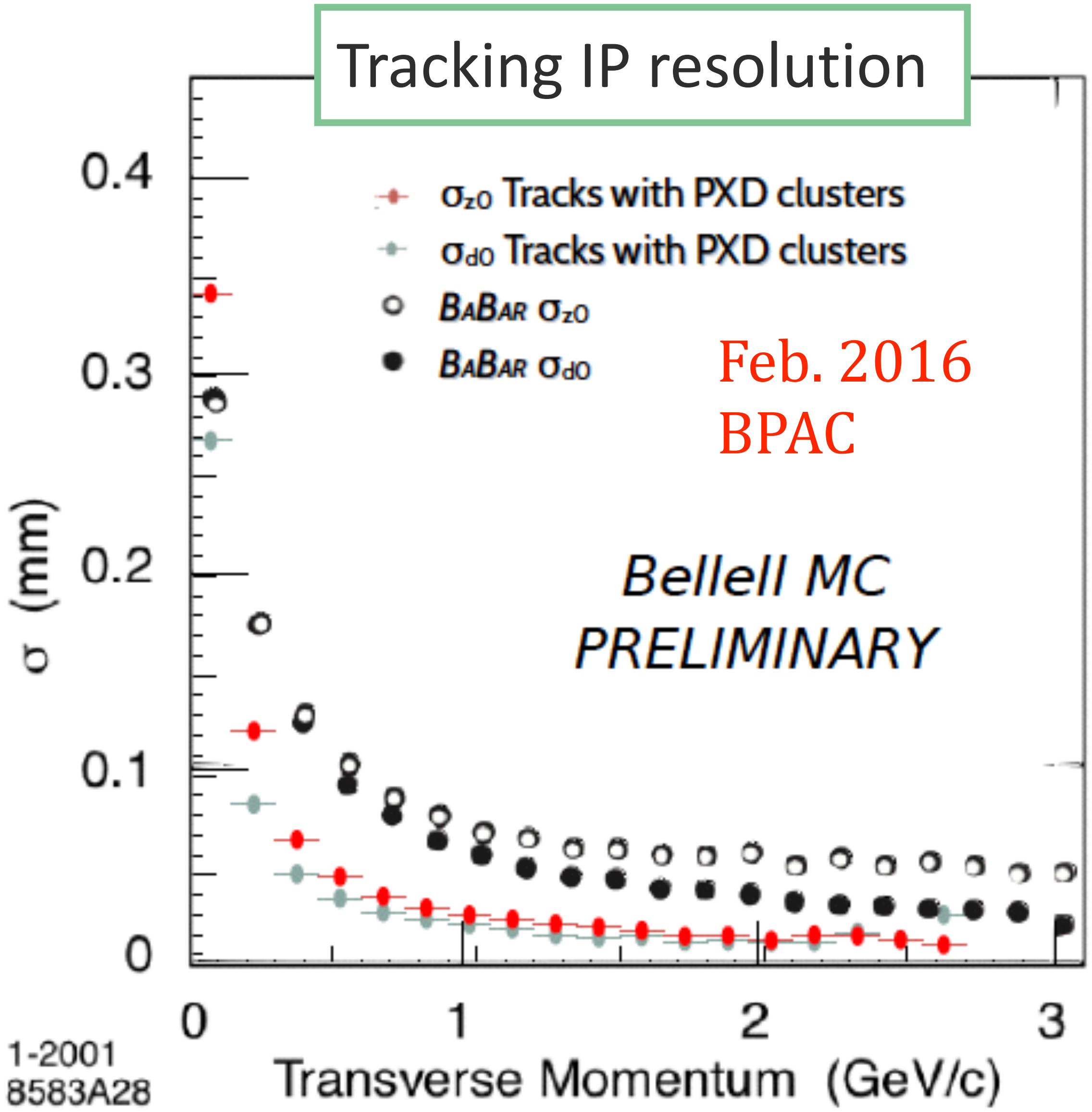








Improvements of vertex detector



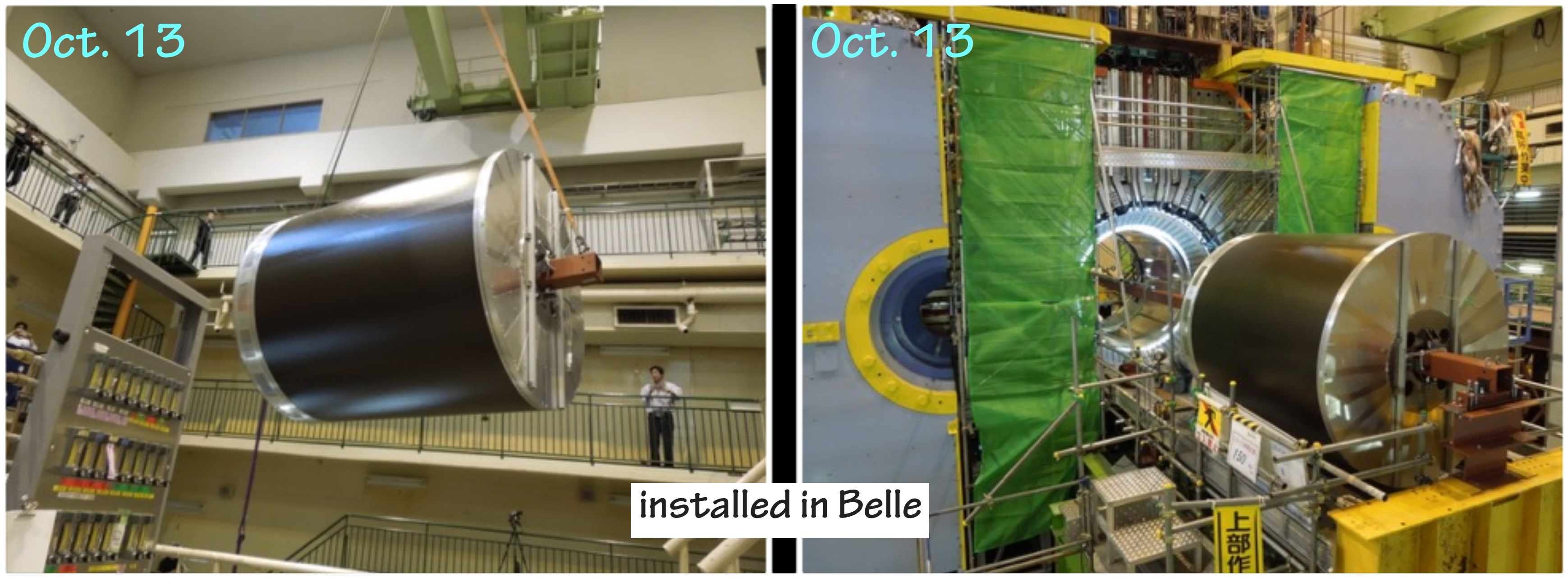
- Extrapolations of detector performance confirmed after beam-test results, and realistic software implementation
- Currently, in spite of

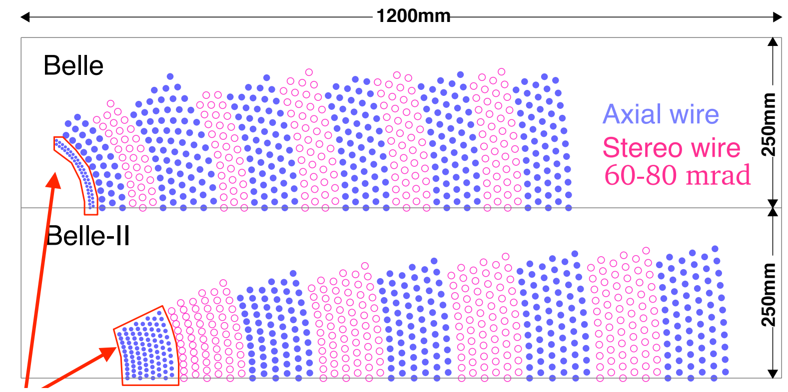
$$\langle\beta\gamma\rangle^{\text{Belle II}} = 28/44 \cdot \langle\beta\gamma\rangle^{\text{Belle}}$$

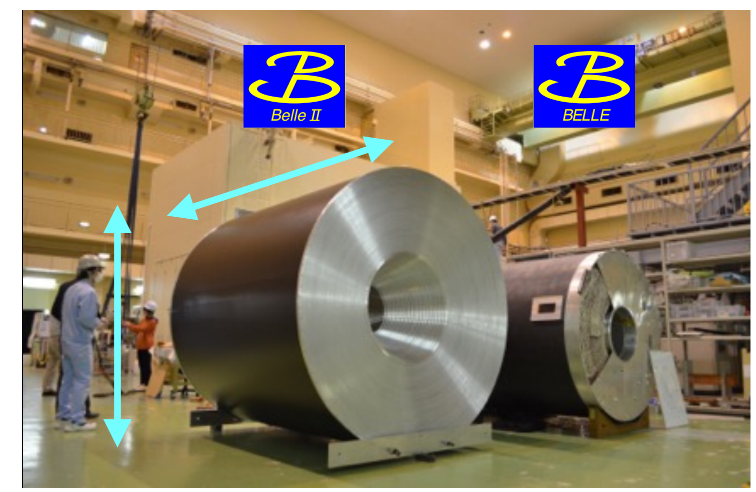
$$\sigma_{\Delta_t}^{\text{Belle II}} \sim \frac{3}{4}\sigma_{\Delta t}^{\text{Belle}}$$

See also Jakub Kandra poster on Belle II PXD+SVD alignment

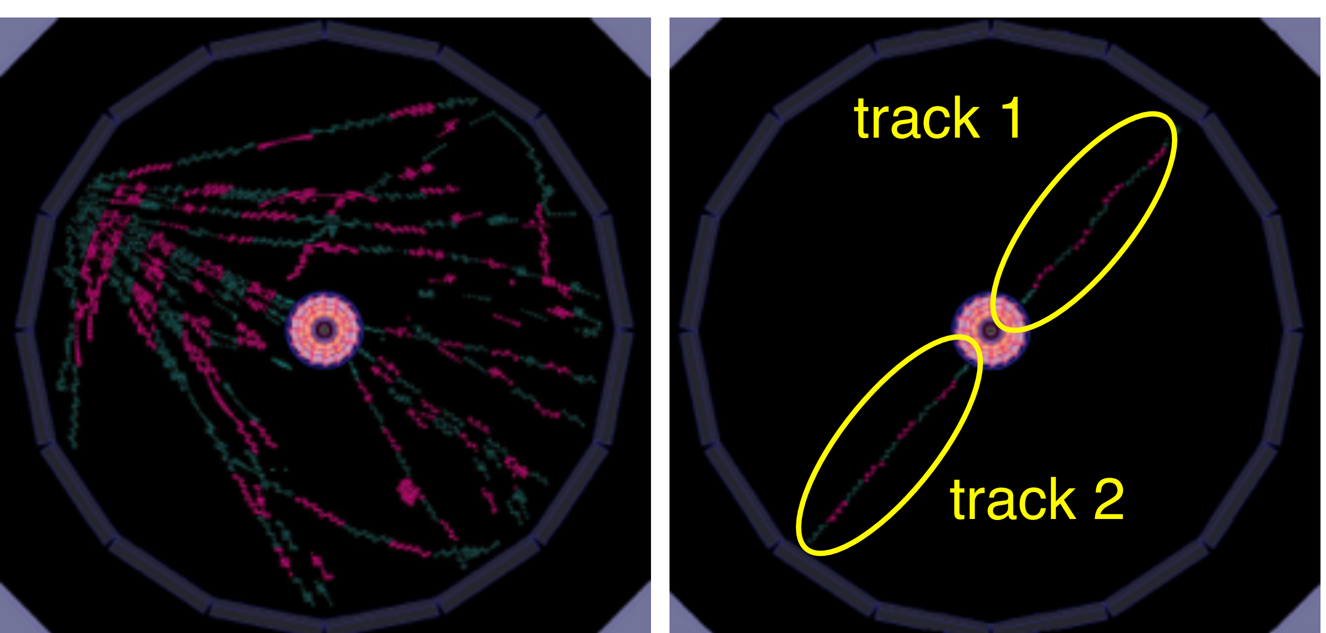
The Central Drift Chamber (CDC)

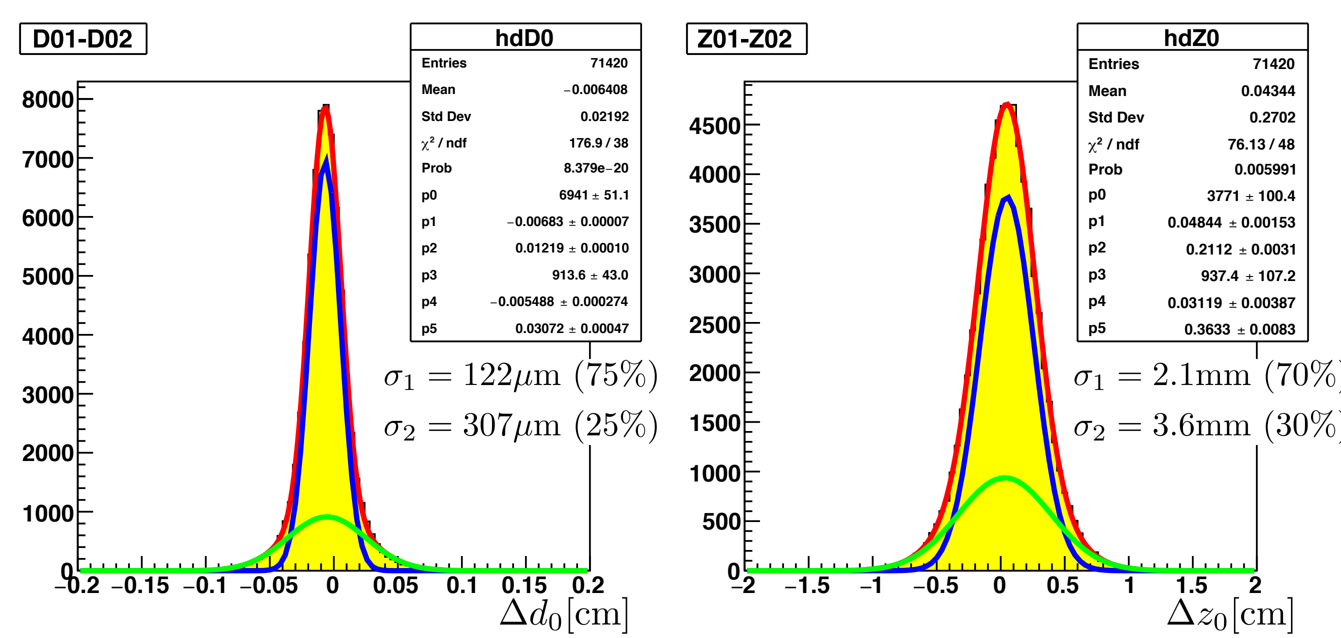






- Installed on Oct, 2016
- Commissioning with cosmic ray tracks is ongoing

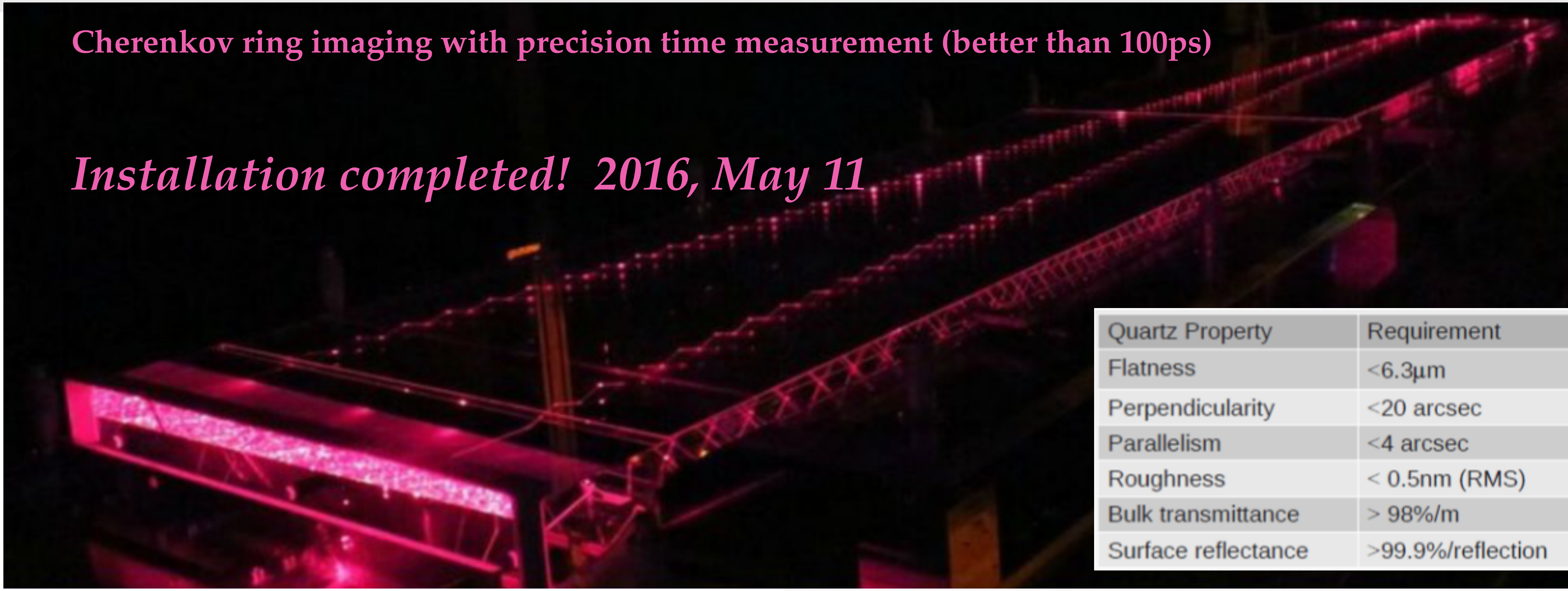




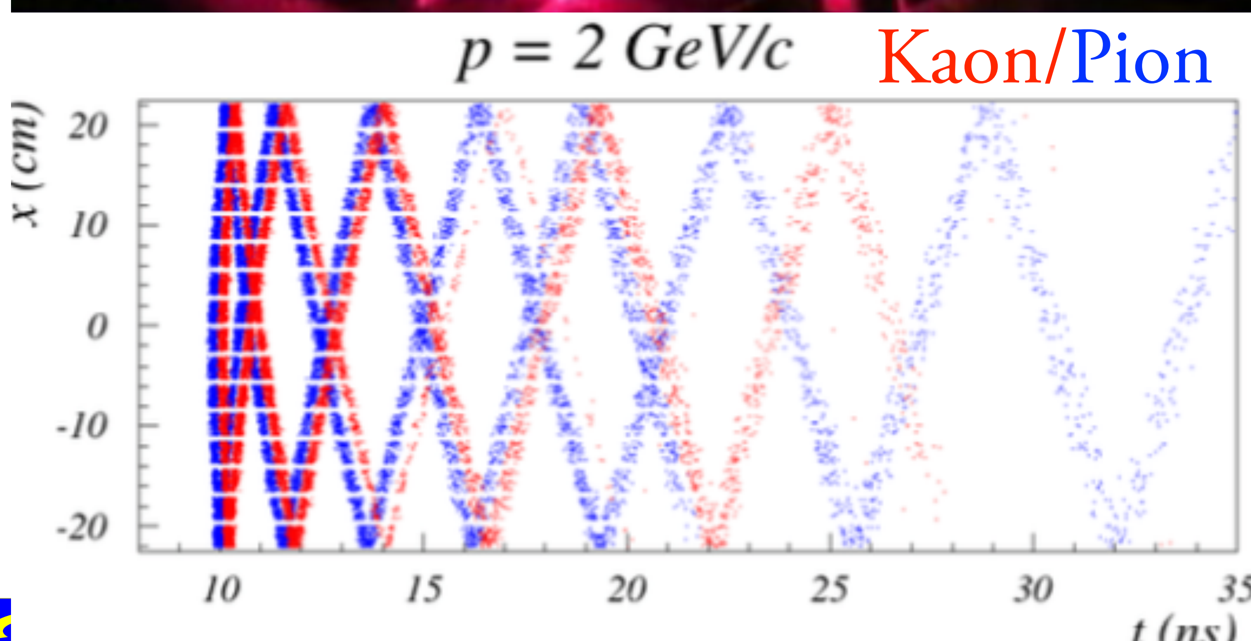
Barrel PID: Time Of Propagation

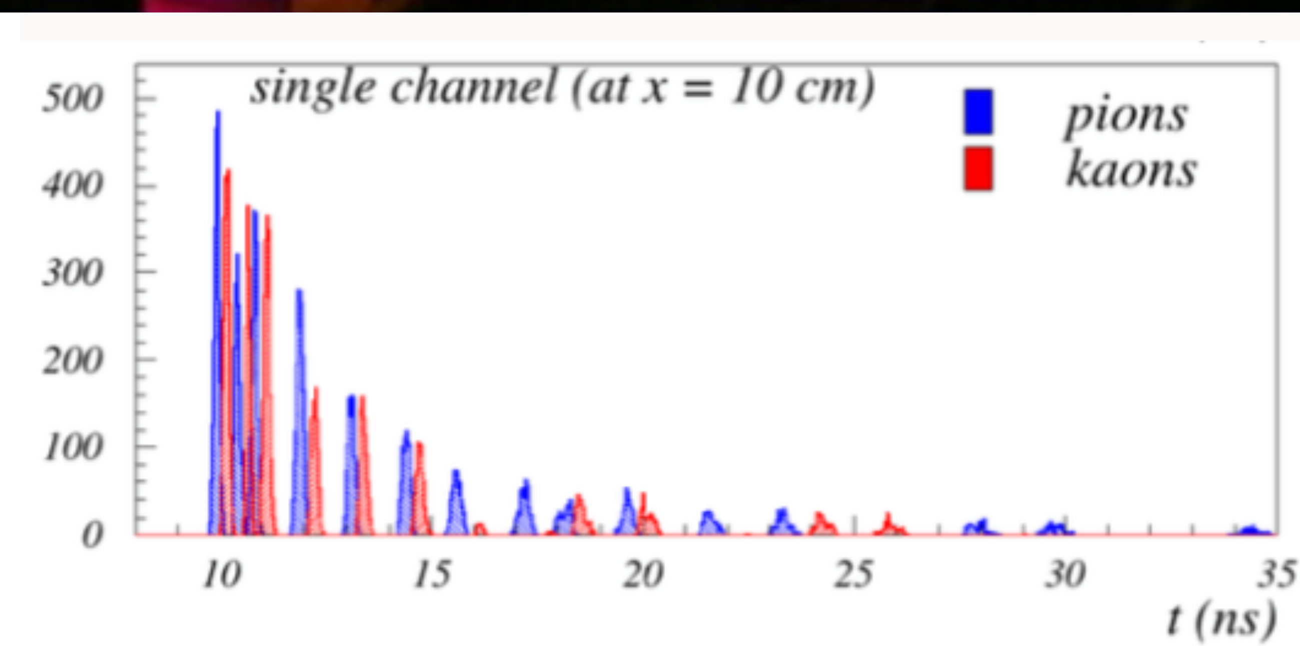
Cherenkov ring imaging with precision time measurement (better than 100ps)

Installation completed! 2016, May 11



Quartz Property	Requirement
Flatness	<6.3µm
Perpendicularity	<20 arcsec
Parallelism	<4 arcsec
Roughness	< 0.5nm (RMS)
Bulk transmittance	> 98%/m
Surface reflectance	>99.9%/reflection

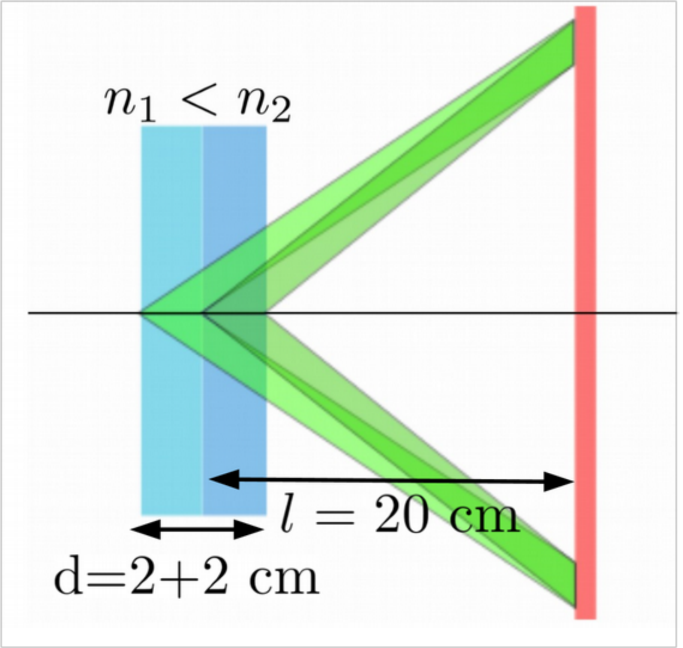




Forward PID: the Aerogel RICH

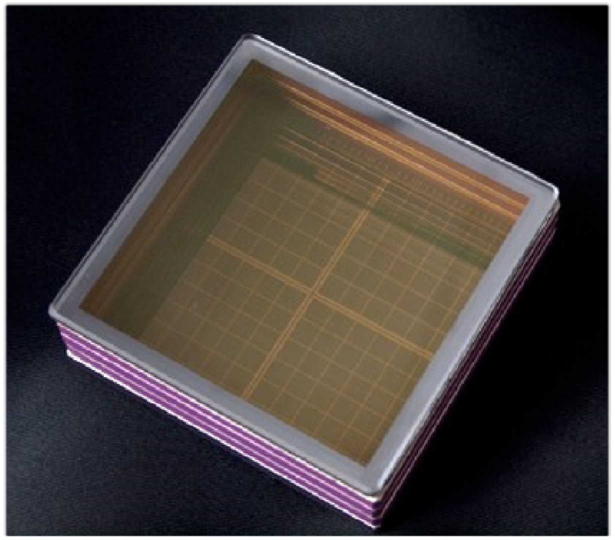
Use two aerogel layers in focusing configuration to increase n. of photons without resolution degradation

$n_1 = 1.045, \; n_2 = 1.055$



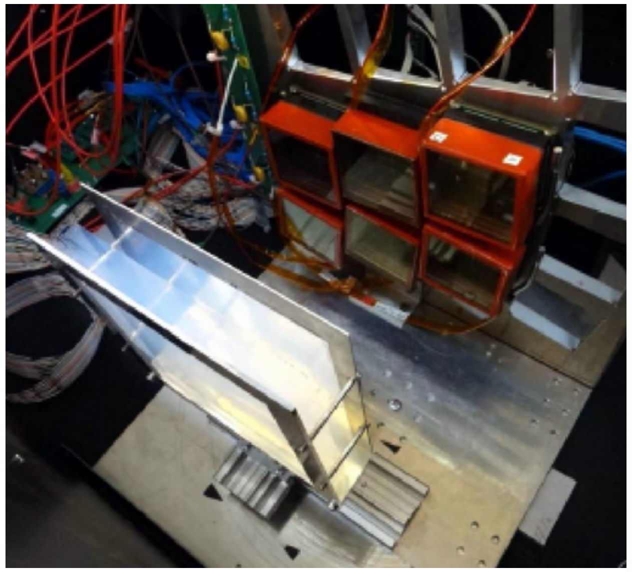
HAPD – Hybrid Avalanche Photo-Detector

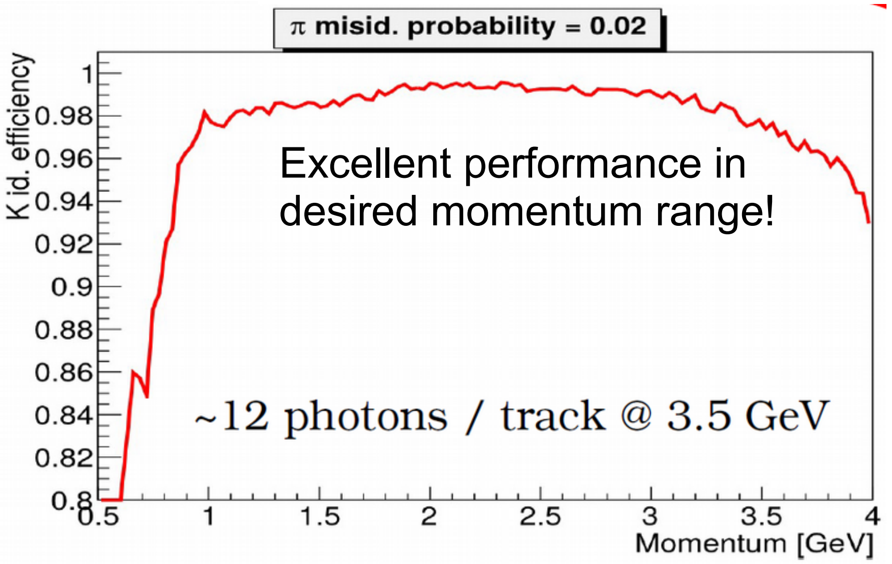
- Developed in collaboration with Hamamatsu photonics
- Basic requirements: - 1.5 T - n,γ tolerance ($10^{12}\ n/\mathrm{cm}^2$)



- position resolution
- large coverage (3.5 m^2)

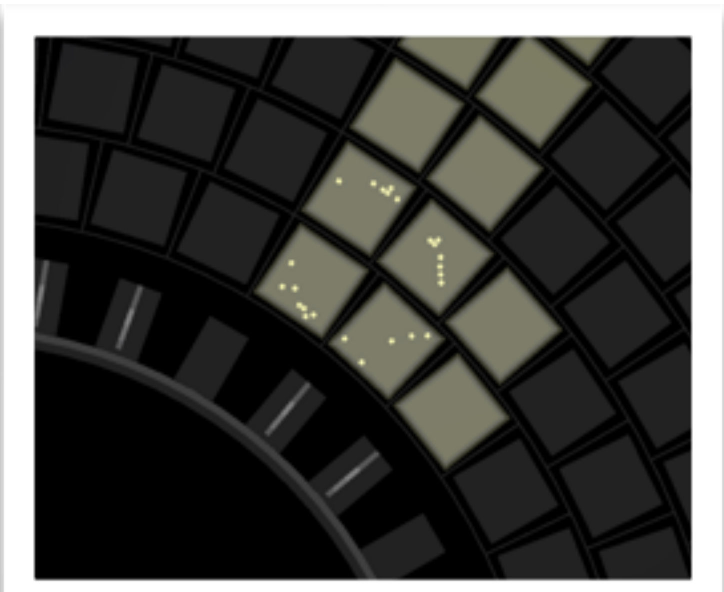
Beam test measurements

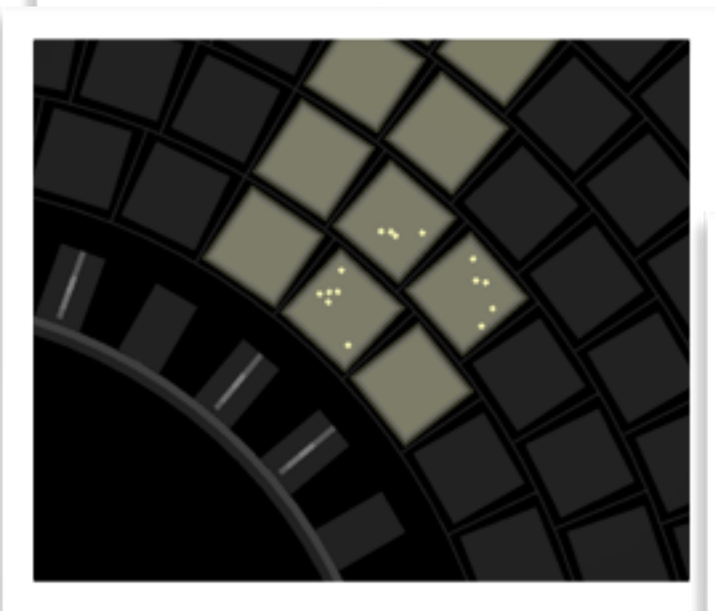




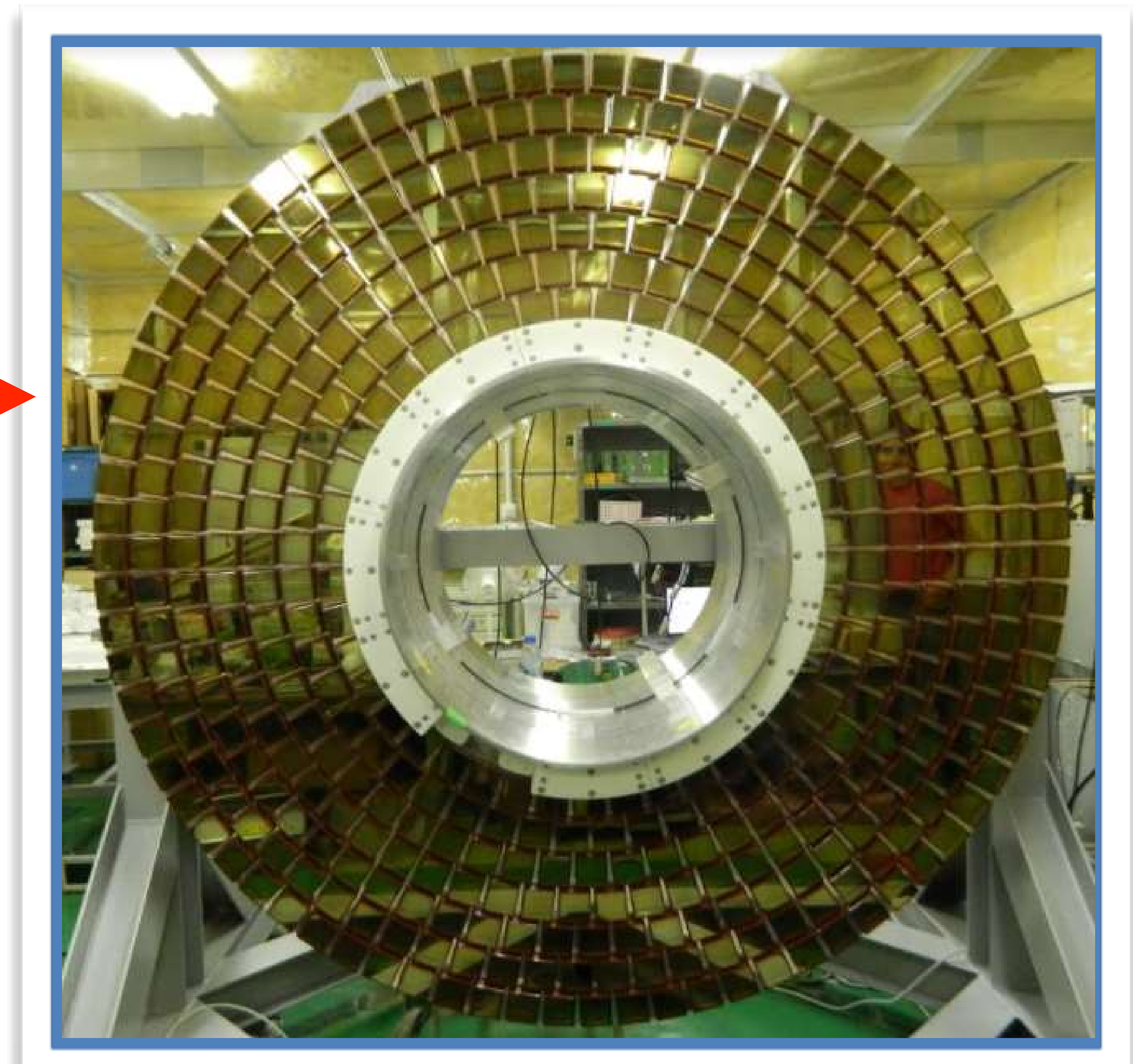
ARICH Rings from cosmic ray muons

- First events from CR tracks recorded in a partially instrumented sector of the ARICH





- Production of aerogel tiles and HAPDs is finished.
- Installation on the structure complete!
- Install in Belle II in September.



Belle II

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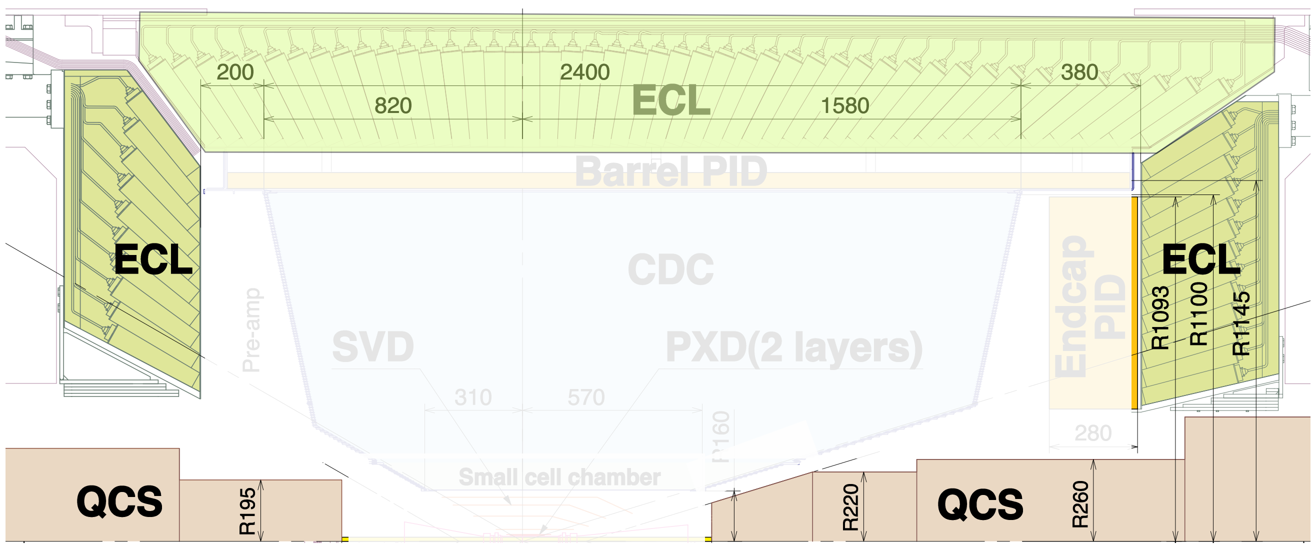
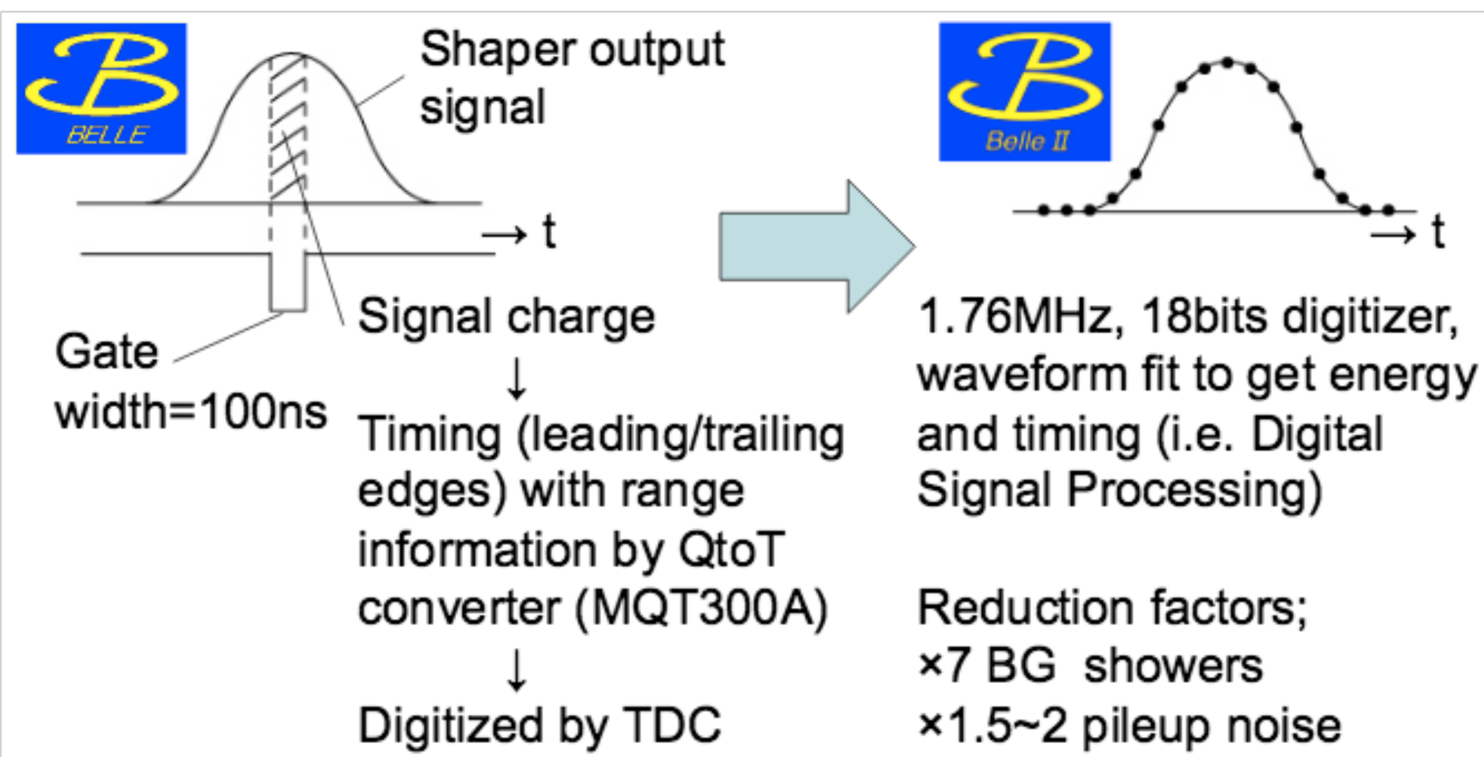
E.M. Calorimeter (ECL)



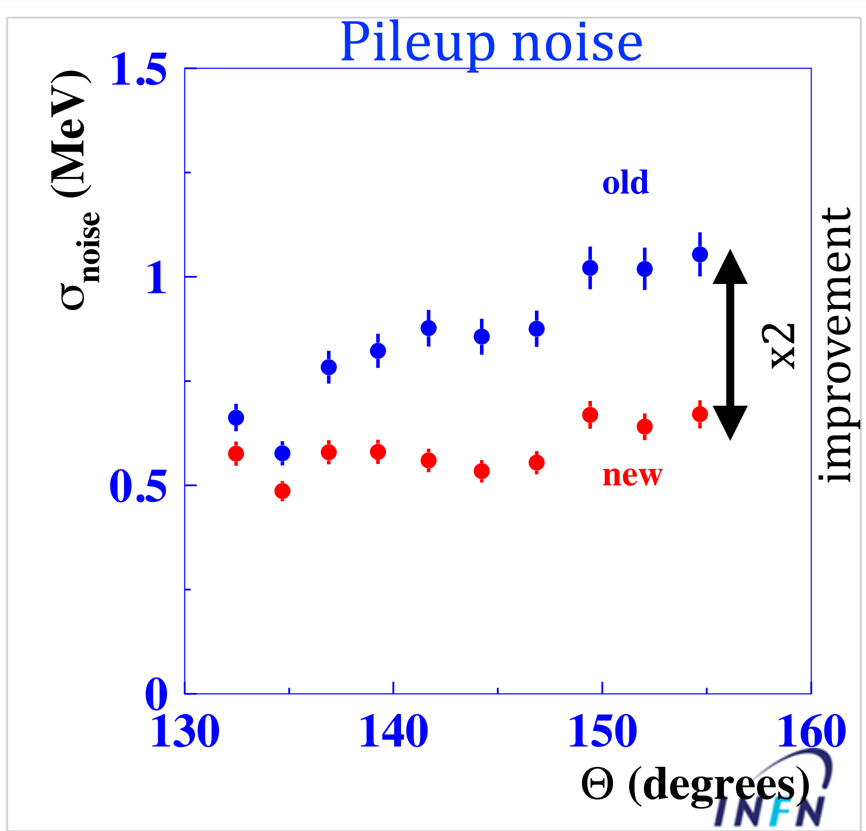
Belle calorimeter

- 8736 CsI(Tl) crystals
- 6624 Barrel
- 1152 Fwd Endcap
- 960 Bwd Endcap

- High rates (machine+physics) ⇒ upgrade of electronics
  - shorter signal shaping
  - waveform fit to extract signal time and amplitude



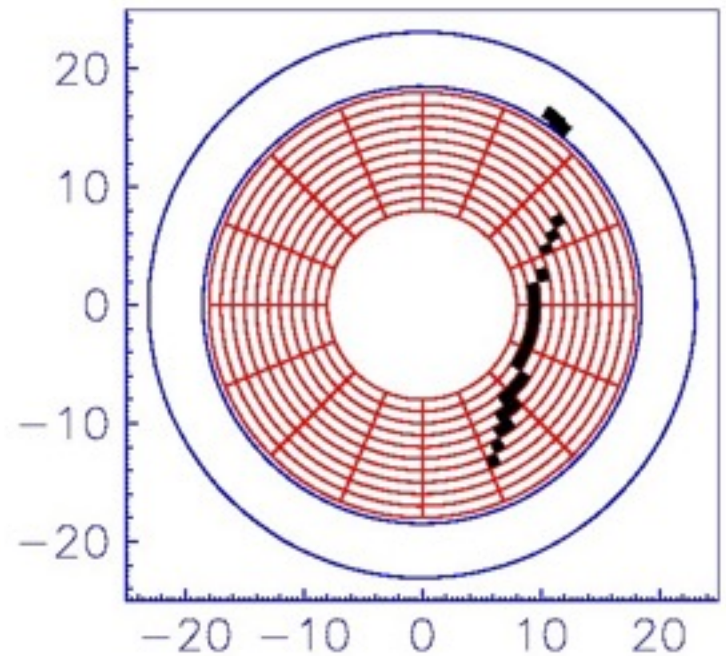
Early prototype tested at Belle

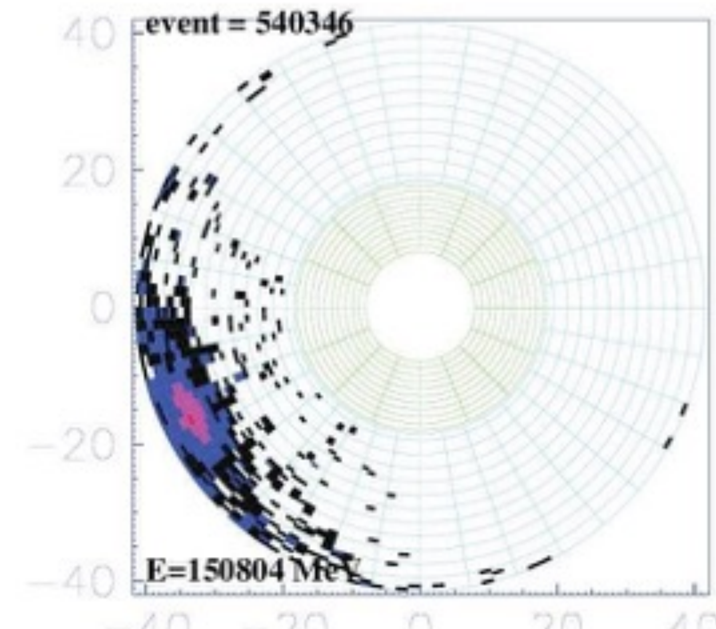


ECL commissioning

BWD endcap installation
January 2017

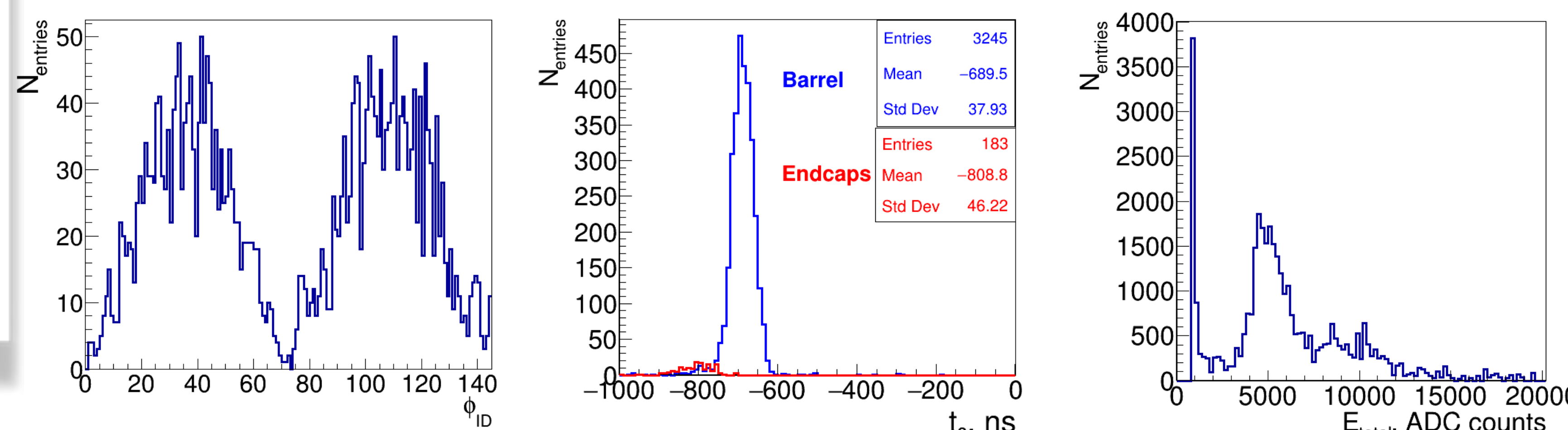
- Barrel ECL under CR test since 2015
- Endcap calorimeter CR test ongoing





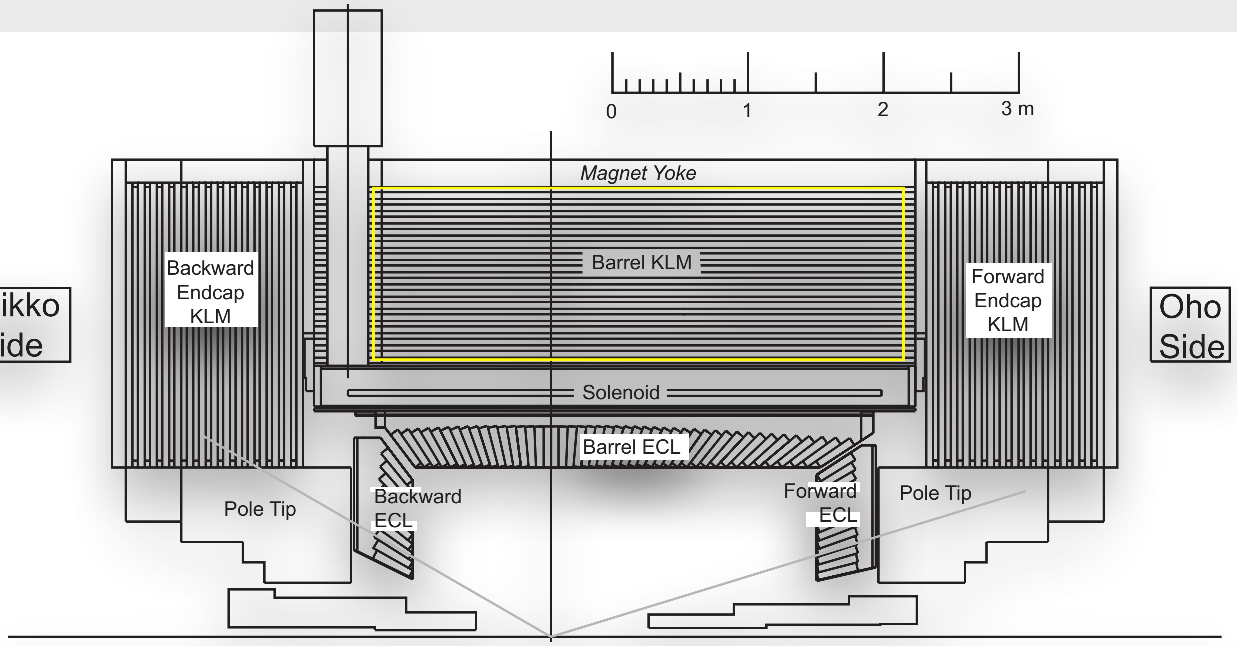
150GeV shower!

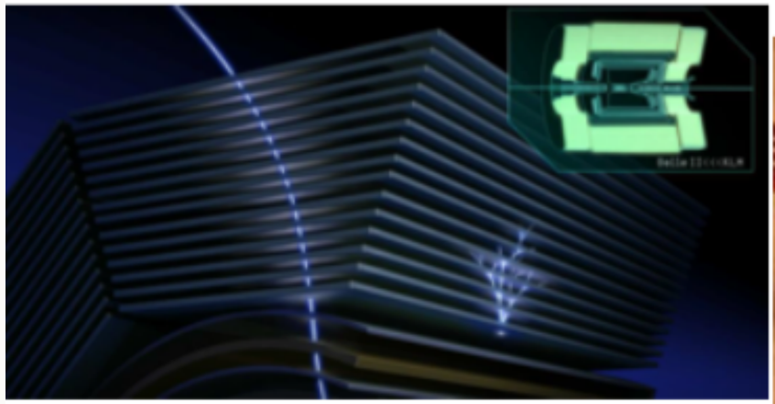
Combined CDC-ECL cosmic ray test

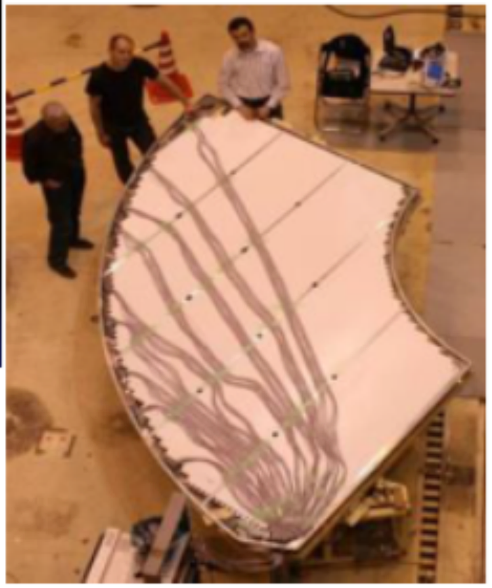


The KLong and Muon detector KLM

- 14 iron layers 4.7cm thick
- 15 barrel active layers
  - ✓ 2 x [scintillator strips + WLS + SiPM] ⇐ **NEW**
  - ✓ 13 x [double glass RPC + 5 cm orthogonal phi, z strips]
- 14 endcap active layers
  - ✓ 14 x [scintillator strips + WLS + SiPM] ⇐ **NEW**







- All endcap glass RPC + 2 in the innermost layers of the barrel replaced with scintillator strips to resist higher backgrounds
- Installation is complete
- Commissioning with cosmic rays ongoing

Belle II Roll In

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FACILITIES

Belle II rolls in

On 11 April, the Belle II detector at the KEK laboratory in Japan was successfully "rolled-in" to the collision point of the upgraded SuperKEKB accelerator, marking an important milestone for the international B-physics community. The Belle II experiment is an international collaboration hosted by KEK in Tsukuba, Japan, with related physics goals to those of the LHCb experiment at CERN but in the pristine environment of electron–positron collisions. It will analyse copious quantities of B mesons to study CP violation and signs of physics beyond the Standard Model (*CERN Courier* September 2016 p32).

"Roll-in" involves moving the entire 8 m-tall, 1400 tonne Belle II detector system from its assembly area to the beam-collision point 13 m away. The detector is now integrated with SuperKEKB and all its seven subdetectors, except for the innermost vertex detector, are in place. The next step is to

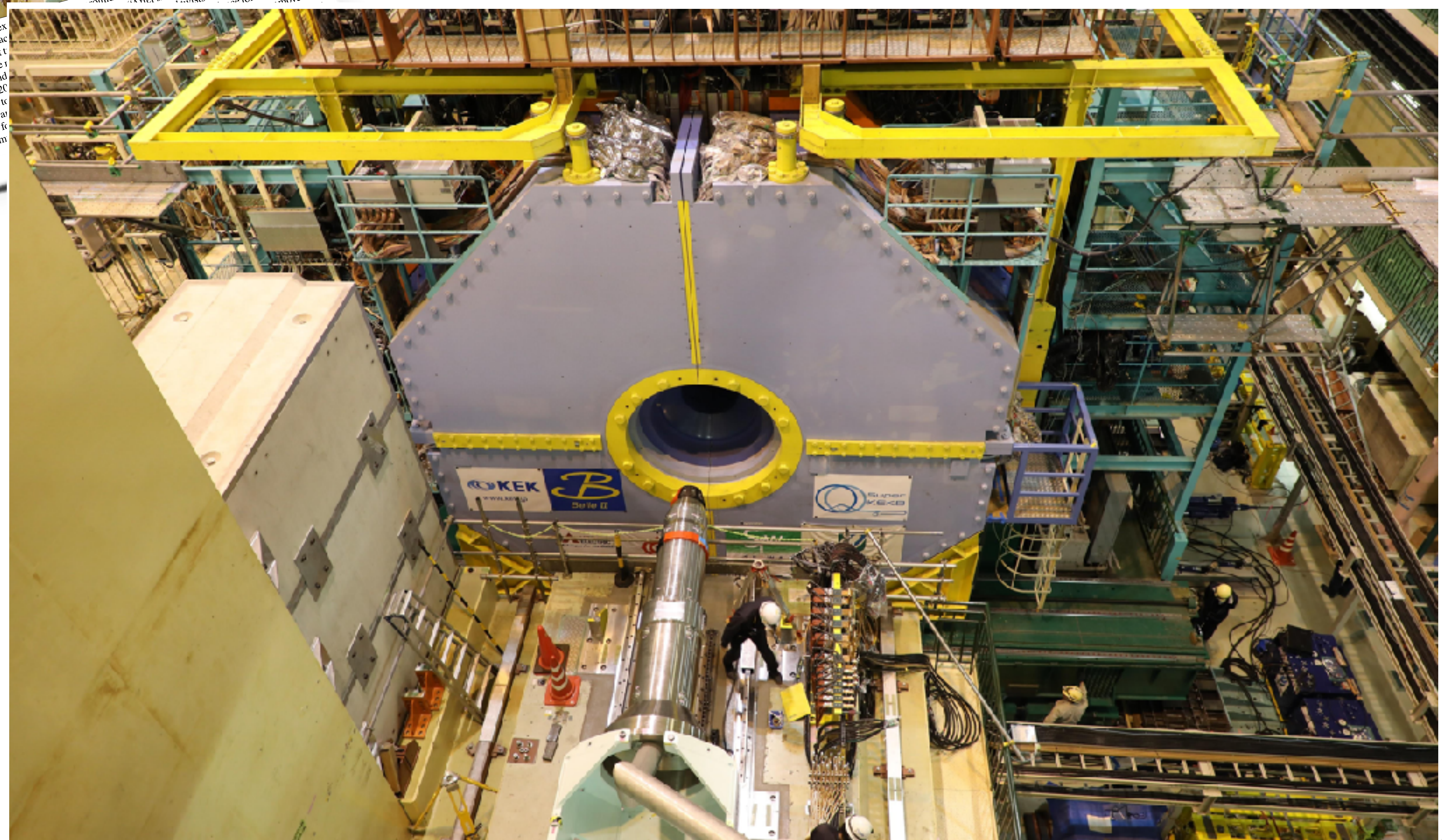
install the complex … the Belle II interac… achieved its first t… operation of the … early spring and … by the end of 20…

Compared to … experiment, a… made to the f… will allow m…

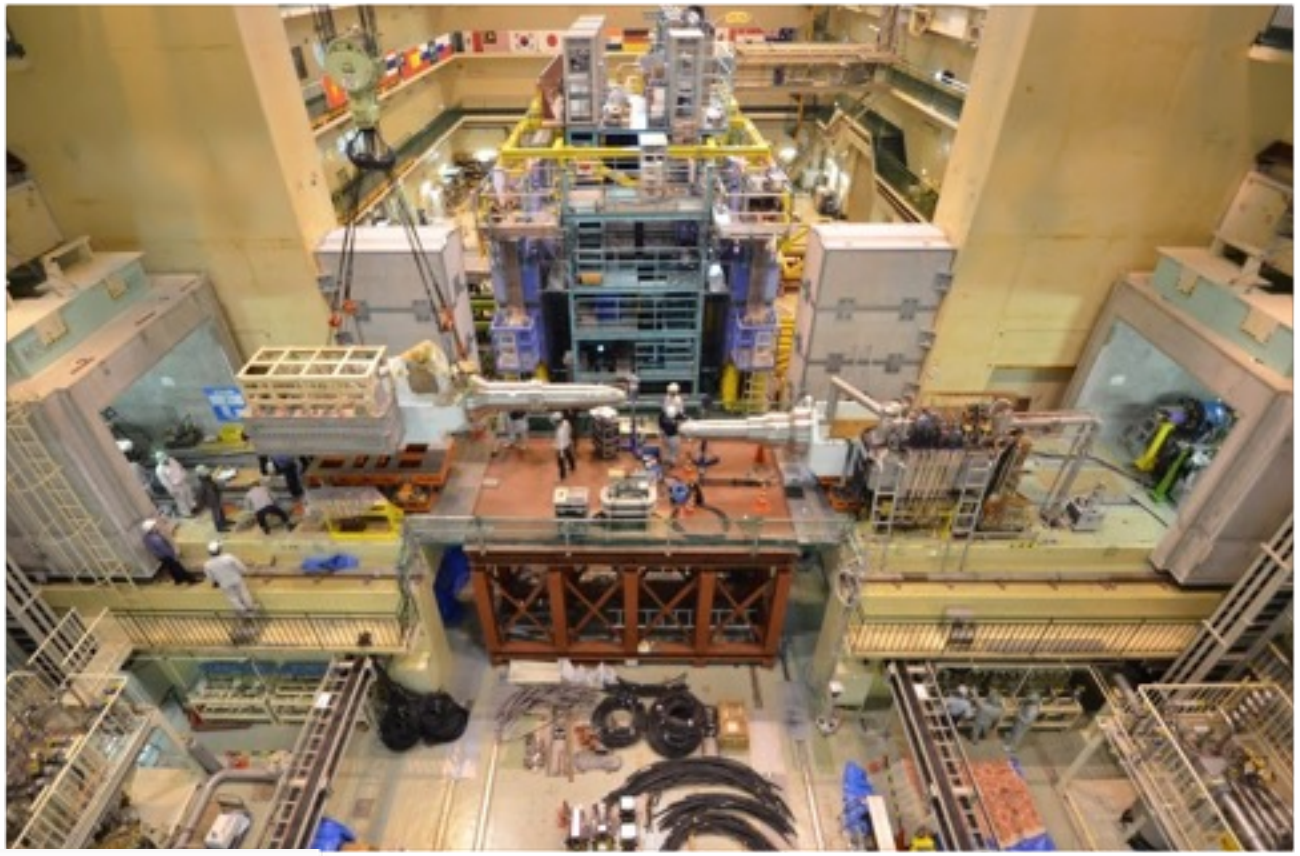
… collected with much improved precision. "After six years of gruelling work with many … twists and turns, it was a moving … for everyone on the … move to the …

The Belle II detector is now in place at the SuperKEKB facility in Japan.

April 11th Belle II Milestone!



Final focus magnets



Superconducting quadrupole magnets with 30+25 coils

The second one delivered on Feb 13

World's most complex SC final focus!

When do we start Belle II ?

- Phase II Operation: *Starts in Nov 2017*
  - Begin with damping ring commissioning
  - Main ring (Feb 2018): first collisions!
  - Two main goals:
    - SuperKEKB luminosity with nano-beams - reach KEKB maximum luminosity at the end of phase 2.
    - Ensure background levels are compatible with the operation of the vertex detector
  - Limited physics without vertex detectors

- Phase III: *Starts late 2018*
  - Belle II Physics Running (with vertex detectors in)

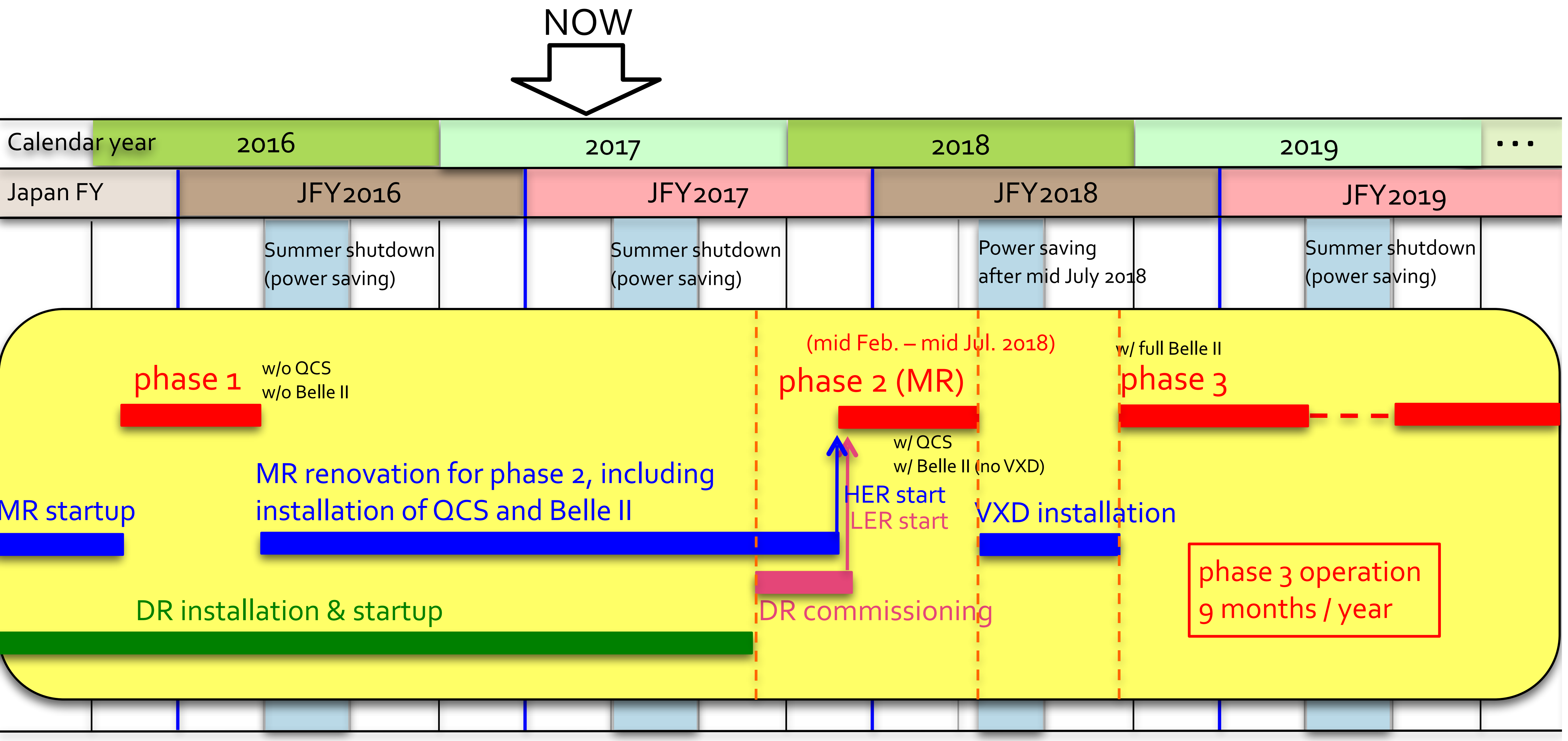
Outlook

- Phase 1 of the SuperKEKB commissioning successfully completed in 2016, with BEAST II commissioning detector on the beam line
  - Background characterisation, including during injection
- Belle II rolled in on April 11th !
- **June 2017** - B-field measurement, start global cosmic ray run
- **Sep 2017**- Installation of A-RICH and forward ECL
- **Nov 2017** - Spring 2018: Phase 2 commissioning (+ first Physics runs, without vertex detector)
- **Summer 2018** - Install vertex detectors
- **Late 2018** - full detector operation - Start of Physics runs

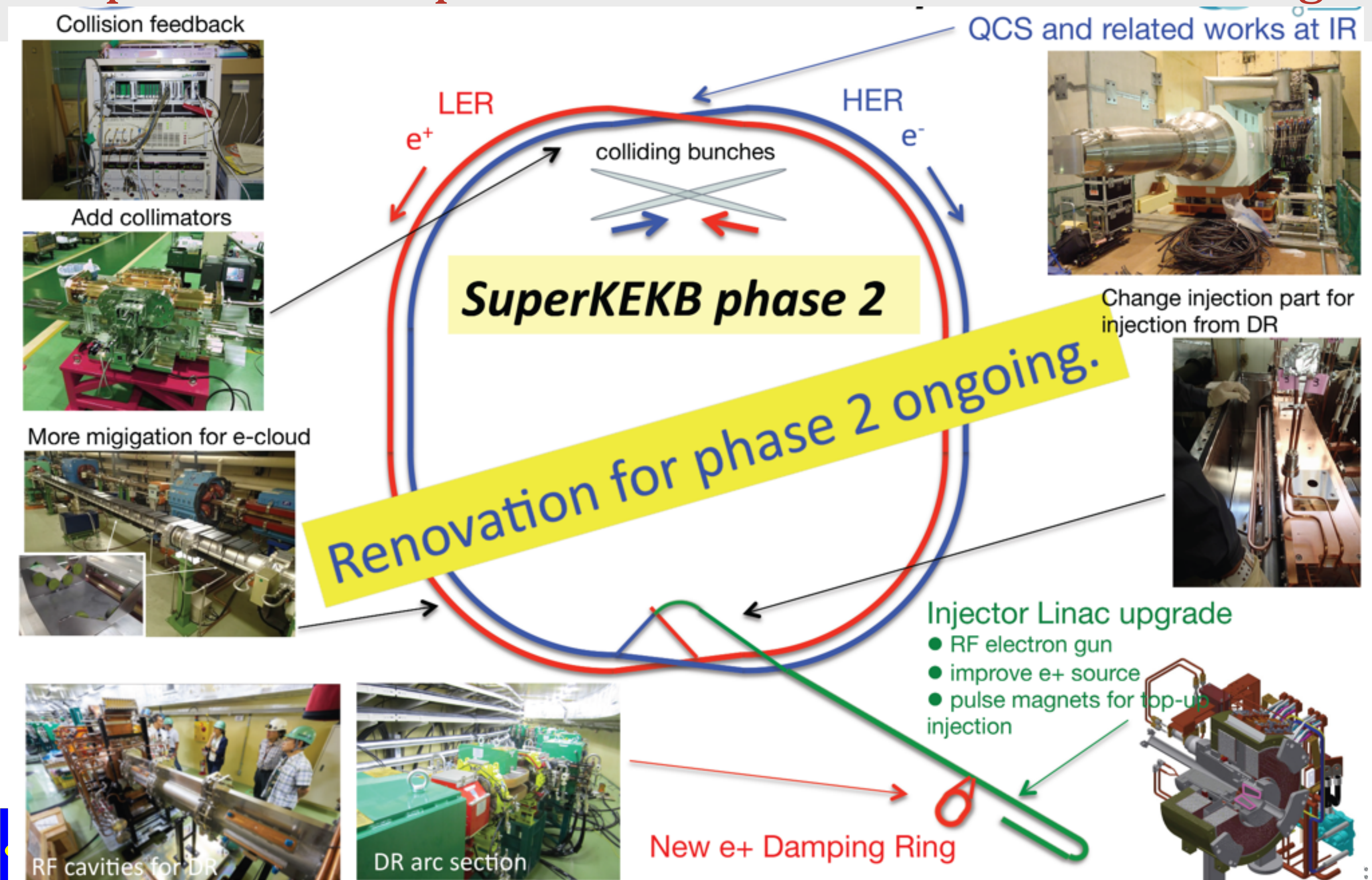
Thank you!

Backup

SuperKEKB/Belle II schedule

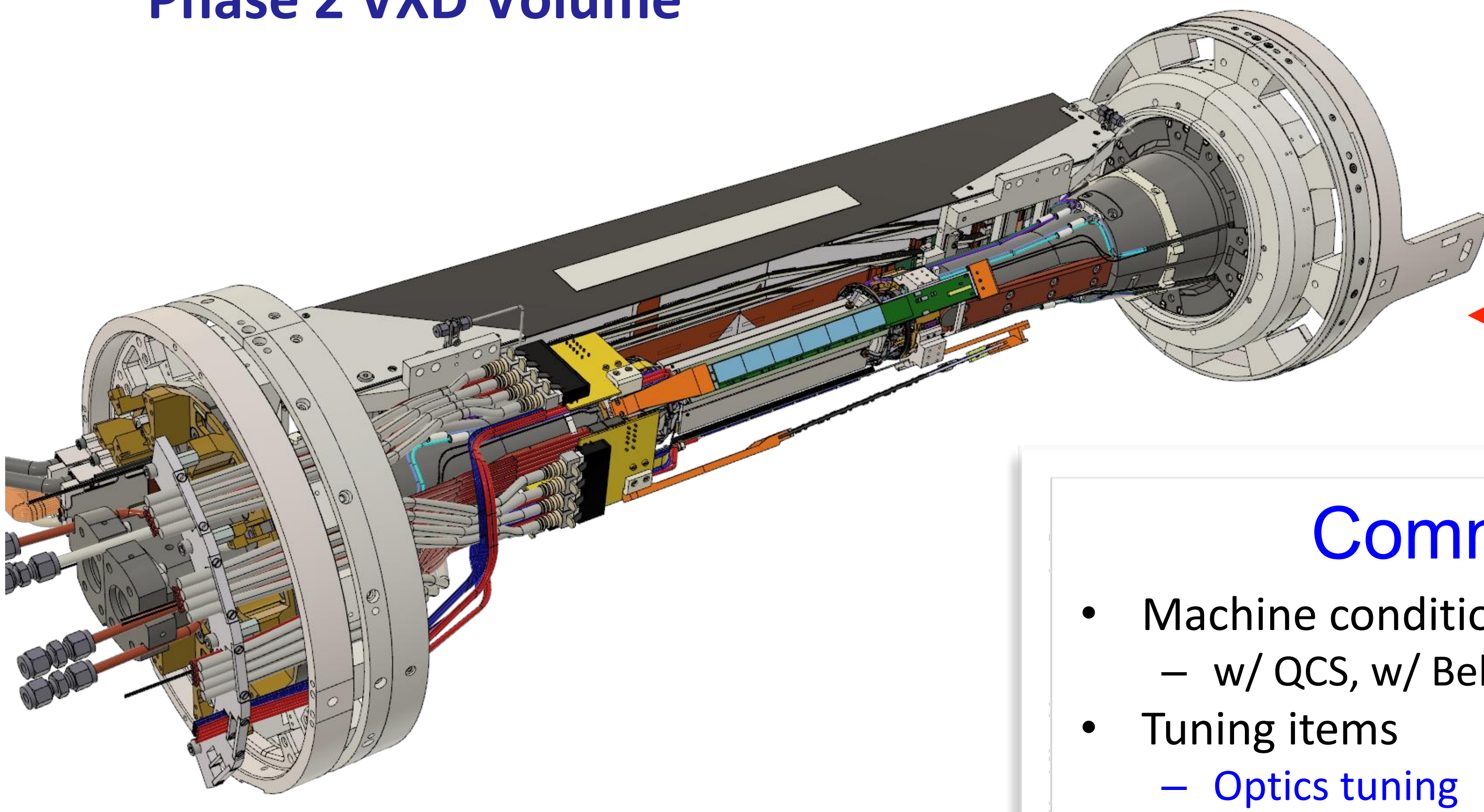


SuperKEKB: Preparations for Phase 2 Commissioning

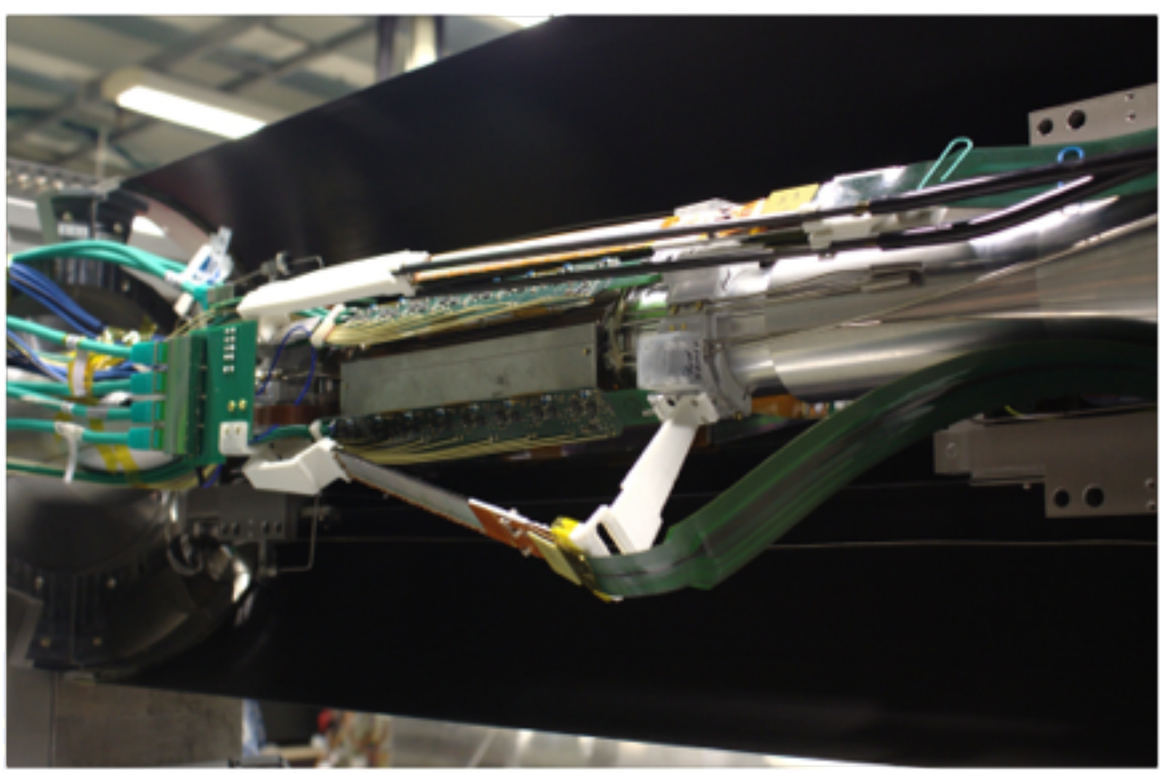


BEAST II - Phase 2

Phase 2 VXD Volume



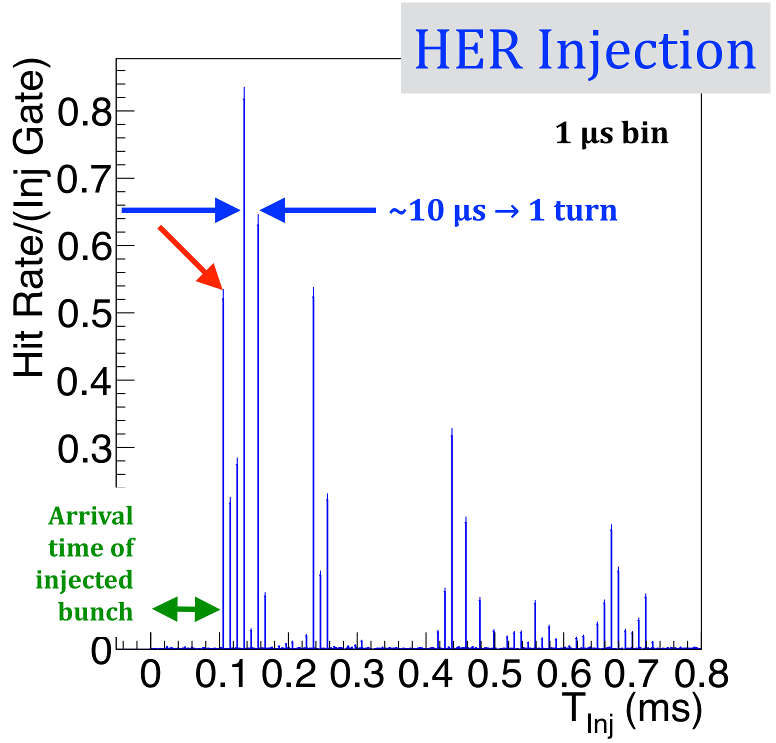
The volume left empty by the vertex detector will be filled by BEAST - Phase 2

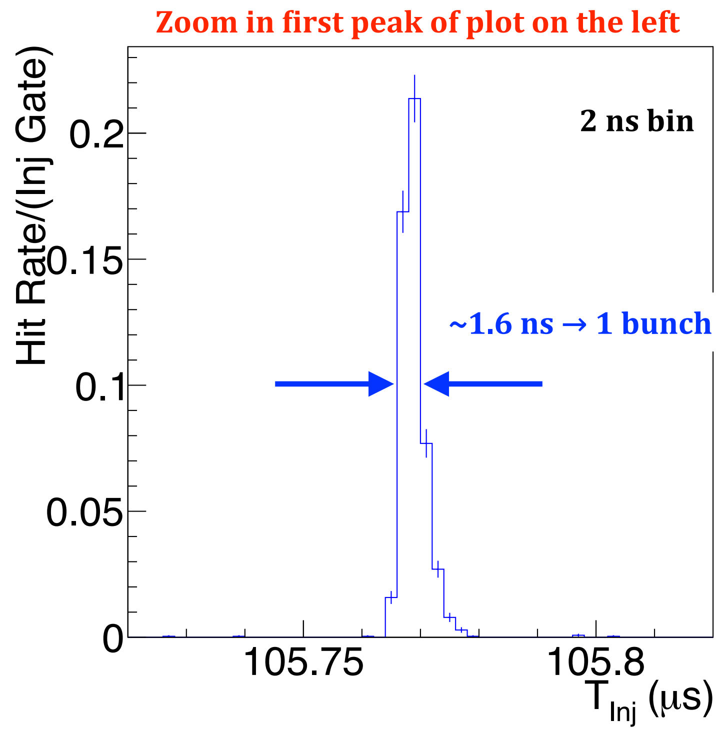


Commissioning phase 2 (~5 months)

- Machine condition
  - w/ QCS, w/ Belle II (w/o VXD), full accelerator tuning
- Tuning items
  - Optics tuning
    - Tentative target values of IP beta's: β_x^*: x4, β_y^*: x8
    - Optics tuning with QCS and Belle II solenoid
    - Low emittance tuning w/ Belle II solenoid
    - Optics tuning w/ beam collision
  - Detector beam background
    - Study with Belle II detector, test of continuous injection (BEAST)
  - Beam collision tuning
    - Orbit feedback (fast feedback, dithering system)
    - Collision tuning w/ "Nano-Beam" scheme
  - Luminosity tuning
    - Tuning knobs (x-y coupling at IP etc.)
    - Tentave target luminosity: 1 x 10^{34} cm^{-2} s^{-1} (design of KEKB)
  - Increase of beam currents (instability, RF power, vacuum issues)
    - Detector background may possibly give some restriction.
    - Continue upgrade for RF system (support ~70% of design beam currents)

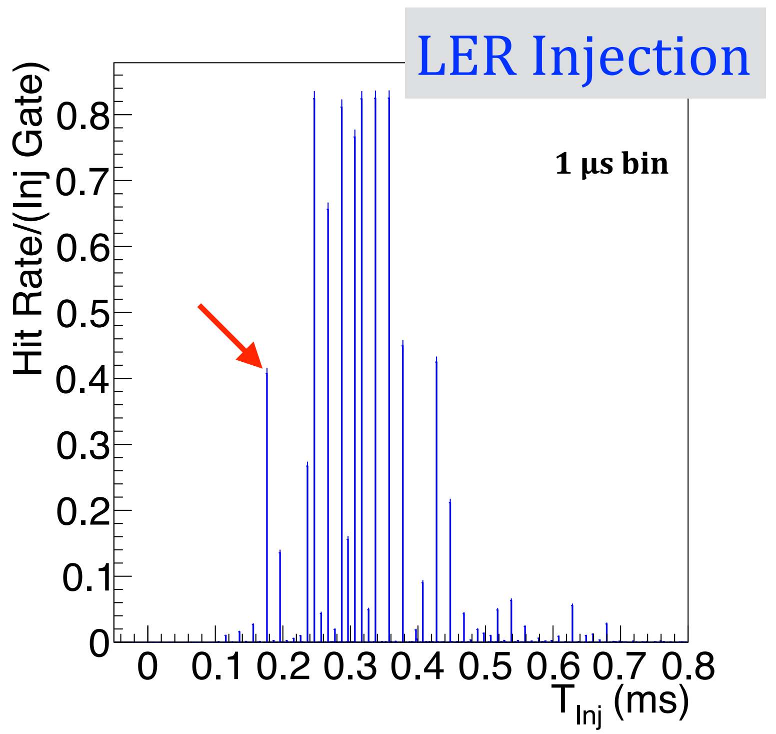
Injection Background BEAST II - Phase 1

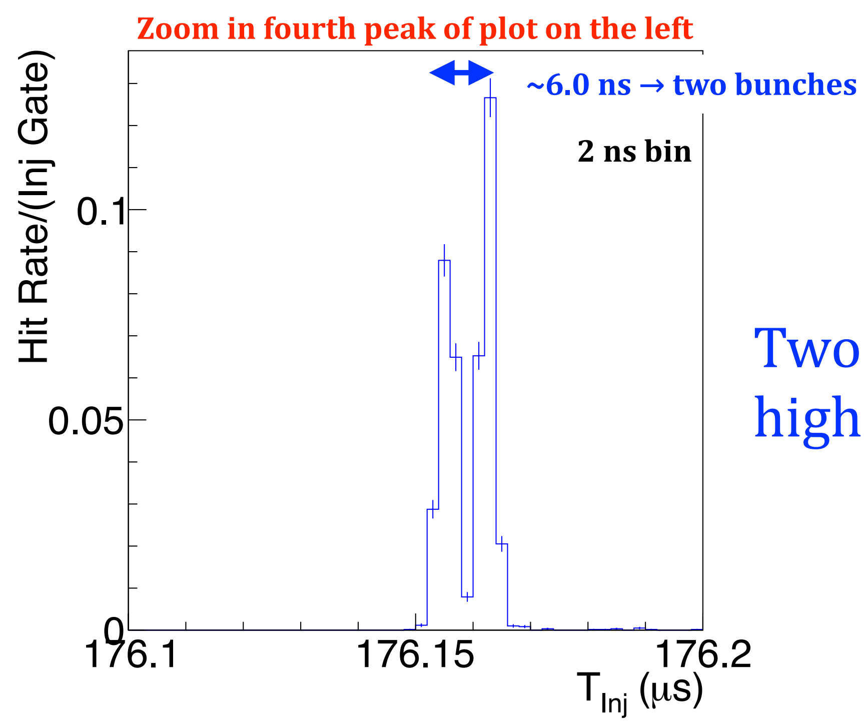




Pure CsI crystals

- Exploit time resolution to look at the single bunch level
  - Bunch spacing = 6 ns
  - Orbit time = 10 µs
- Looking more closely we observed also medium (~µs) and short (~ns) time structures in data



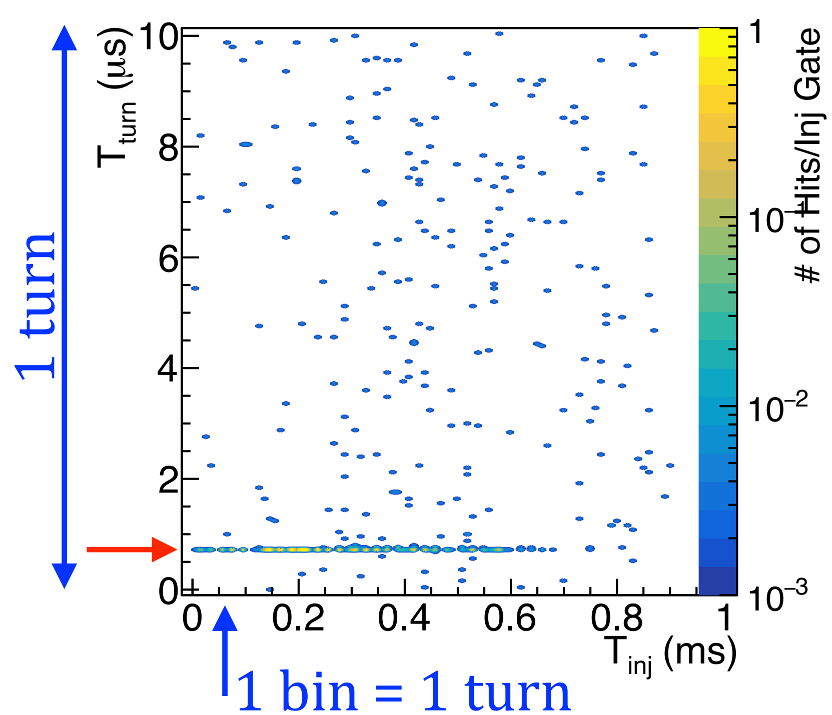


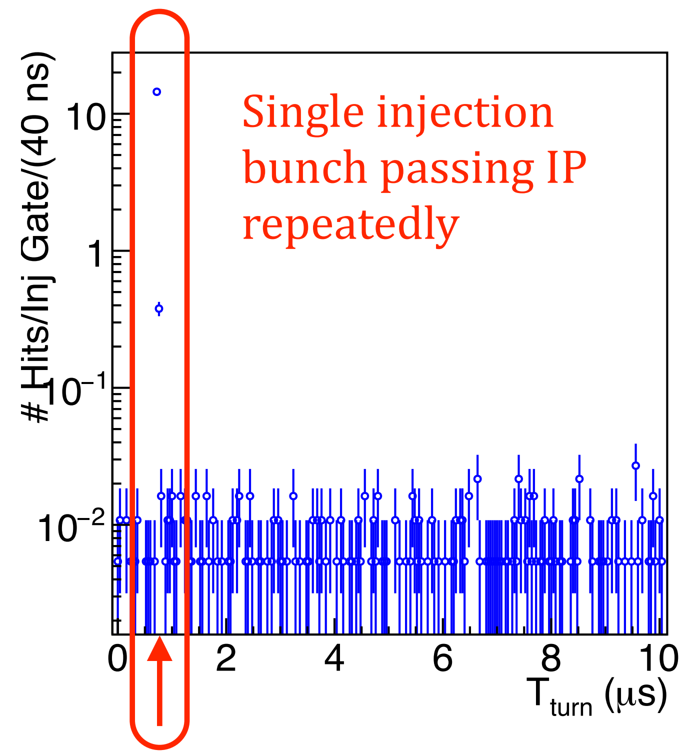
Two adjacent bunches exhibit high background in this case!

Similar data recorded with CLAWS and scintillators

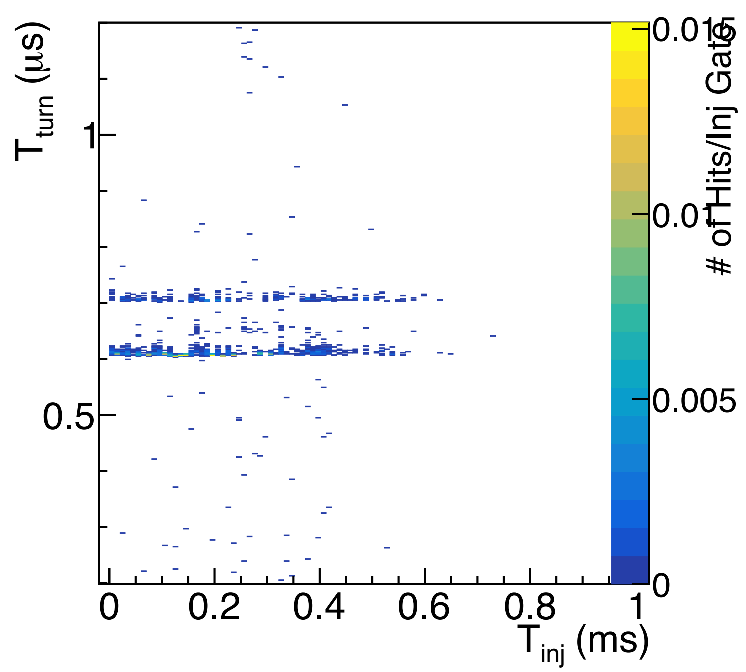
BEAST II - Phase 1

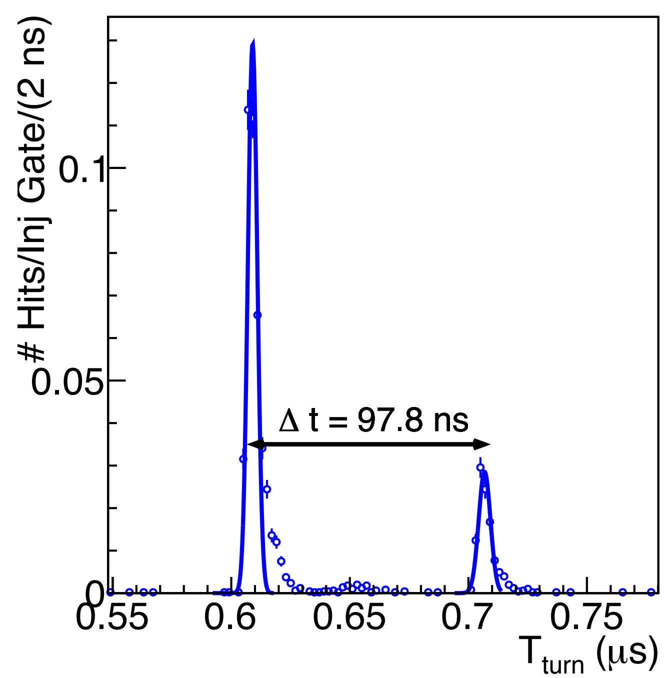
Injection Background





Single bunch injection
CsI crystals

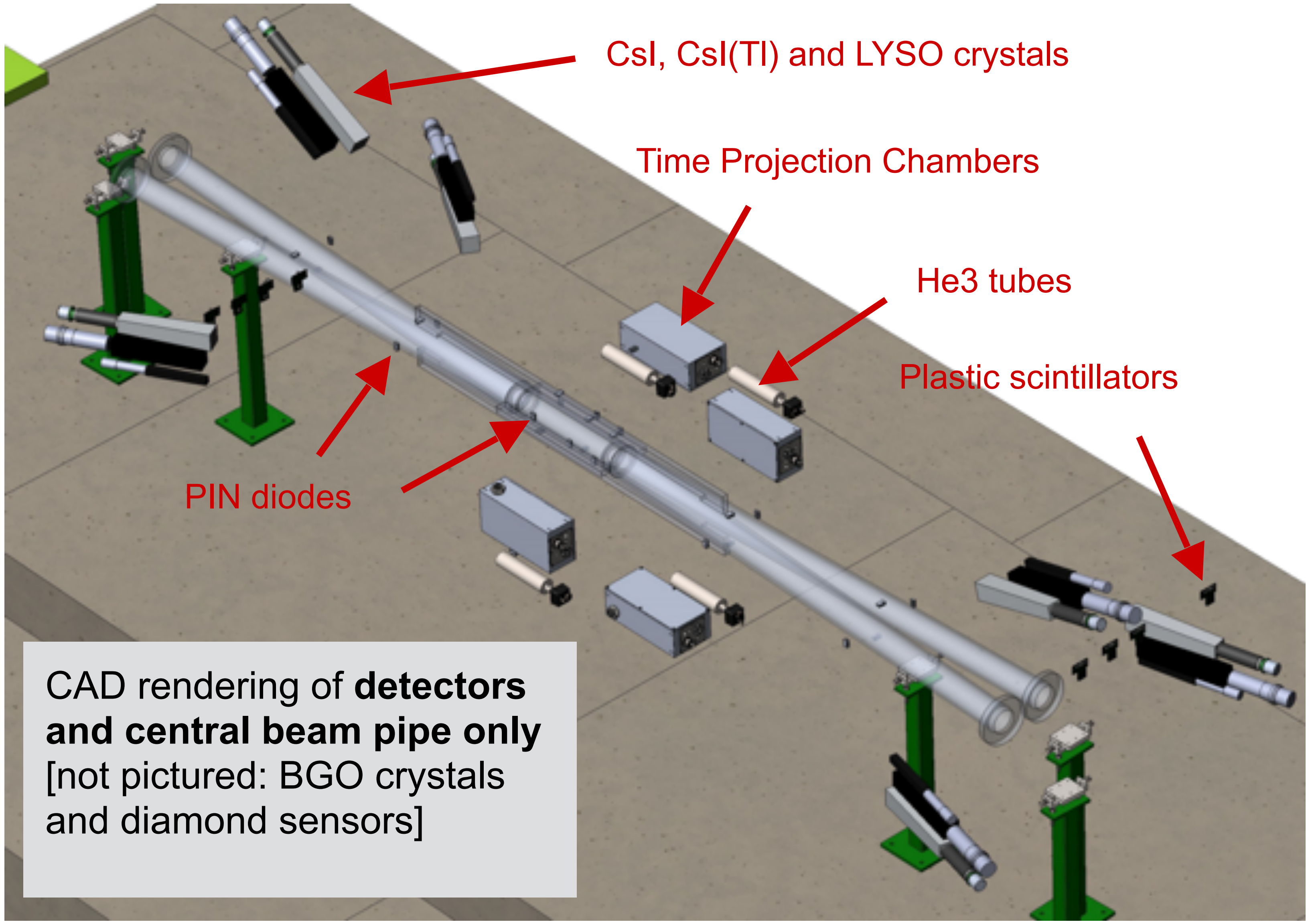




Double bunch injection
LYSO crystals

BEAST II - Phase 1

Detector Components



System	Detectors Installed	Unique Measurement
PIN Diodes	64/64	Neutral vs charged radiation dose
Diamonds	4/4	ionizing radiation dose
Micro-TPCs	2/2	fast neutron flux++
He-3 tubes	4/4	thermal neutron flux
Crystals	6/6 CsI(Tl) 6/6 CsI 6/6/ LYSO	EM energy spectrum
BGO	8/8	luminosity
"CLAWS" Scintillator	8/8	Injection backgrounds

Simulated Background Rates in Belle 2

Table 22: Beam background types (12th background campaign).

type	source	rate [MHz]
radiative Bhabha	HER	1320
radiative Bhabha	LER	1294
radiative Bhabha (wide angle)	HER	40
radiative Bhabha (wide angle)	LER	85
Touschek scattering	HER	31
Touschek scattering	LER	83
beam-gas interactions	HER	1
beam-gas interactions	LER	156
two-photon QED	-	206

← Total rates from simulation

Total number of hits per event in each sub-detector ↓

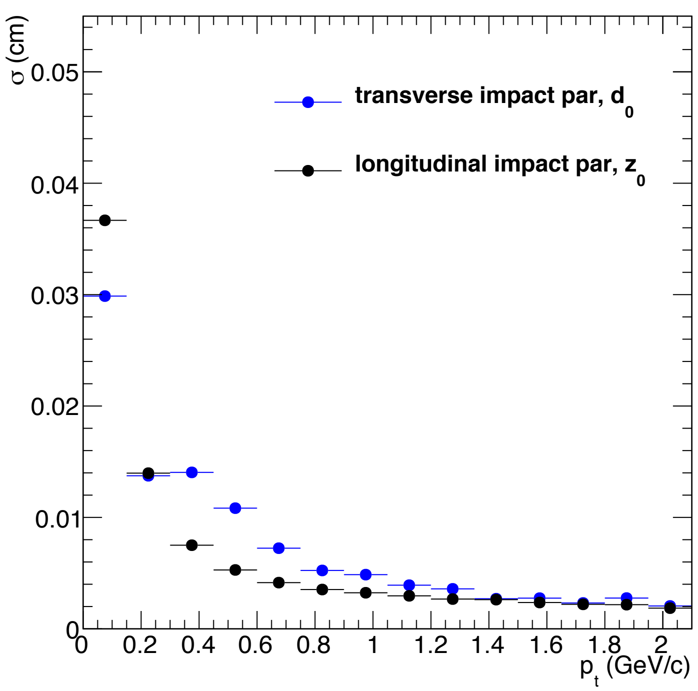
component	background	generic $B\overline{B}$
PXD	10000 (580)*	23
SVD	284 (134)	108
CDC	654	810
TOP	150	205
ARICH	191	188
ECL	3470	510
BKLM	484	33
EKLM	142	34

* in parentheses numbers without 2-γ QED

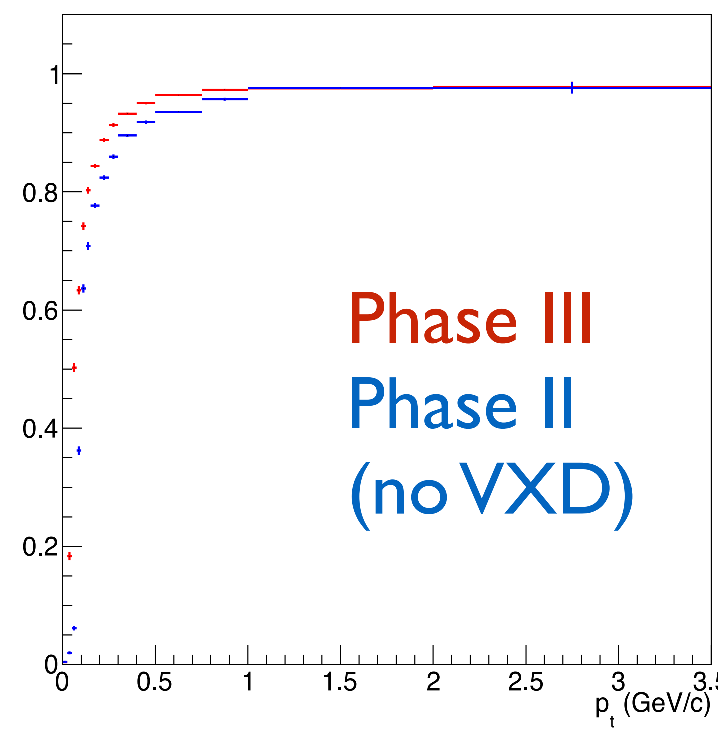
Backgrounds are ~ x20 Belle

Performance Snapshot: Reconstructed Particles

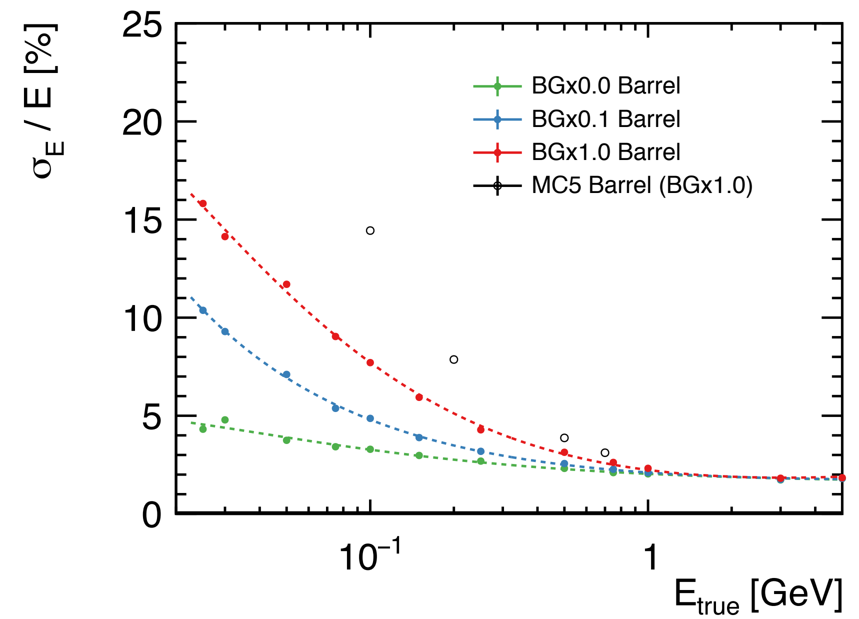
Tracking IP resolution, Rel7



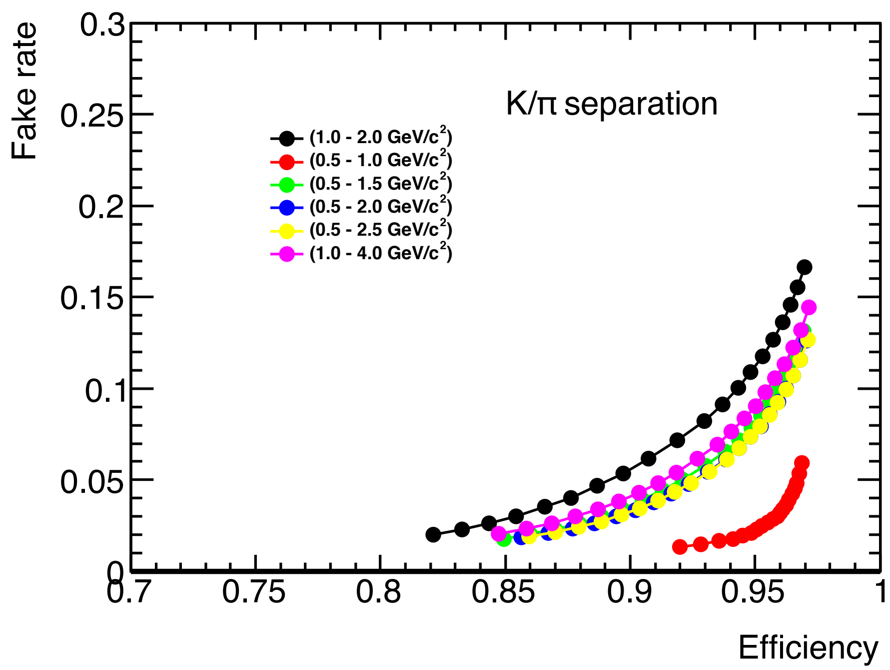
Tracking efficiency vs Pt, Rel7



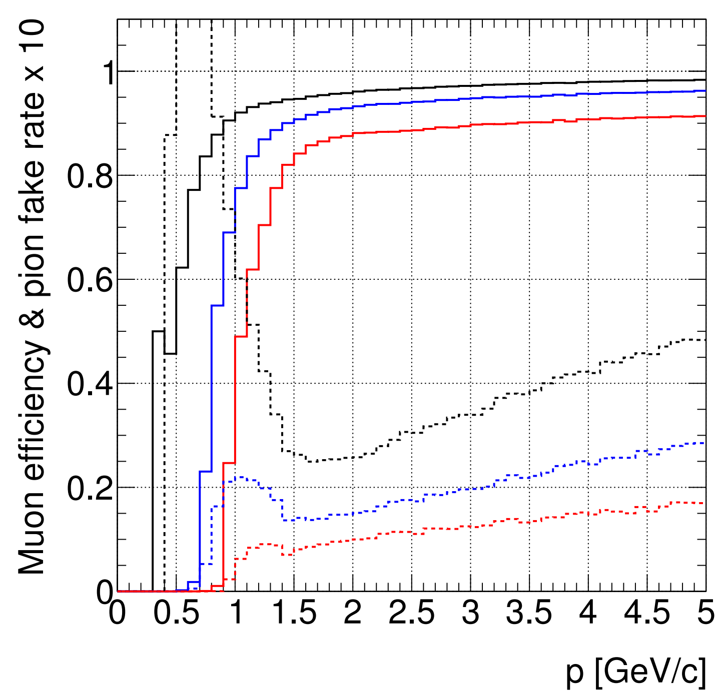
Photon energy resolution, Rel7



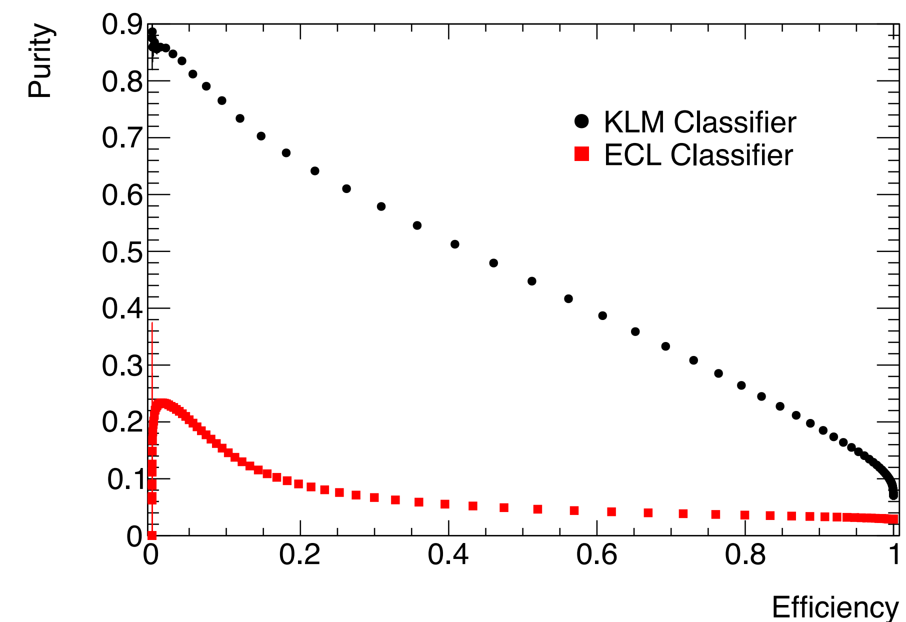
K/π separation ROC, Rel7



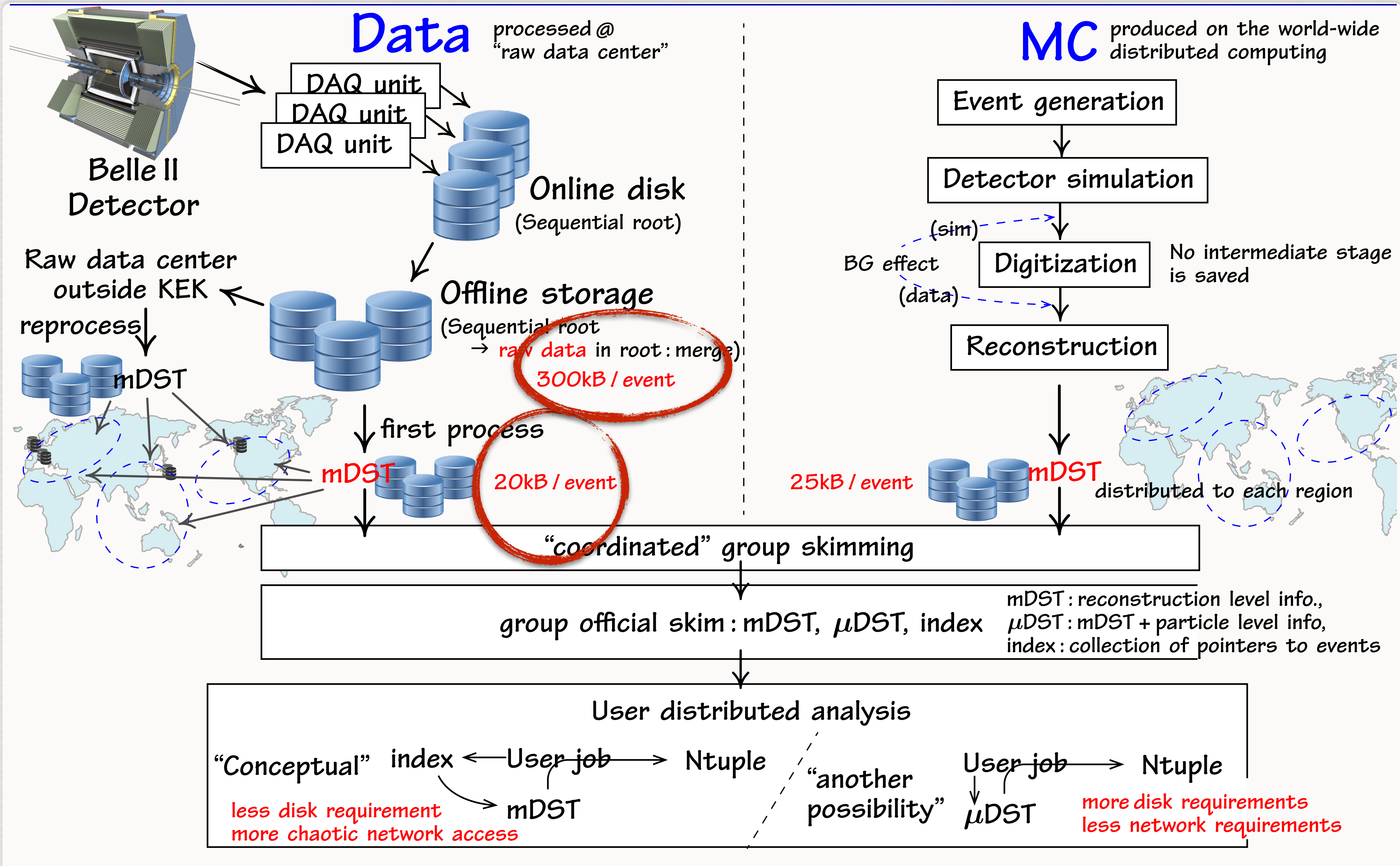
Muon ID efficiency, Rel7



K_L ID ROC, Rel7



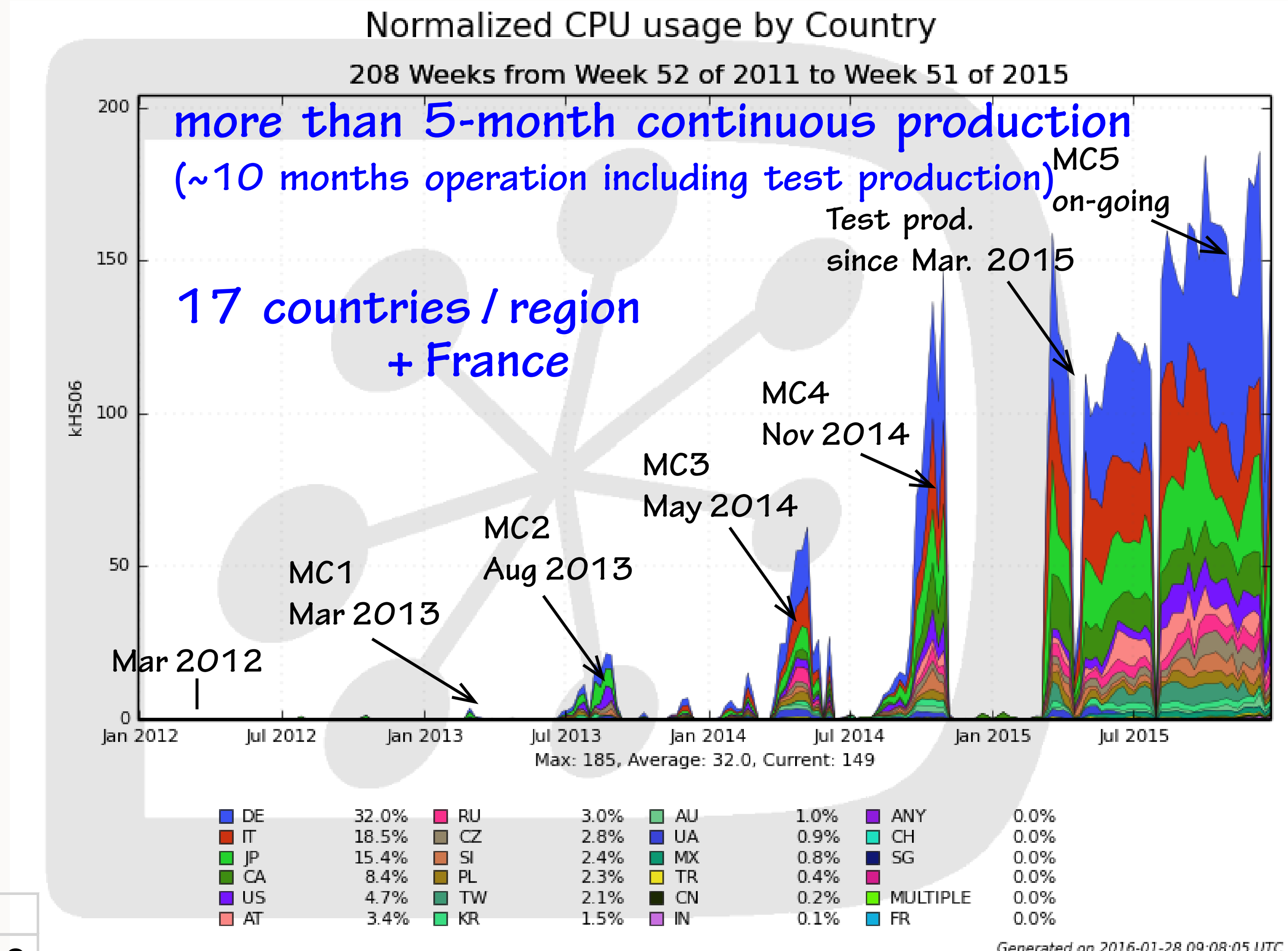
Computing Model



Grid MC production

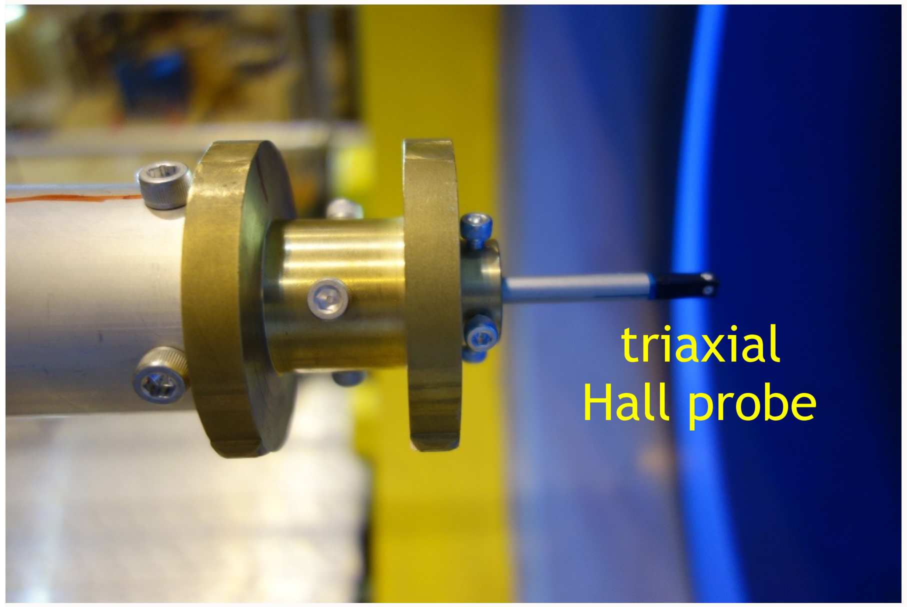
34.1 billion events
simulated and reconstructed
all around the world
24.1 billion of Y(4S)

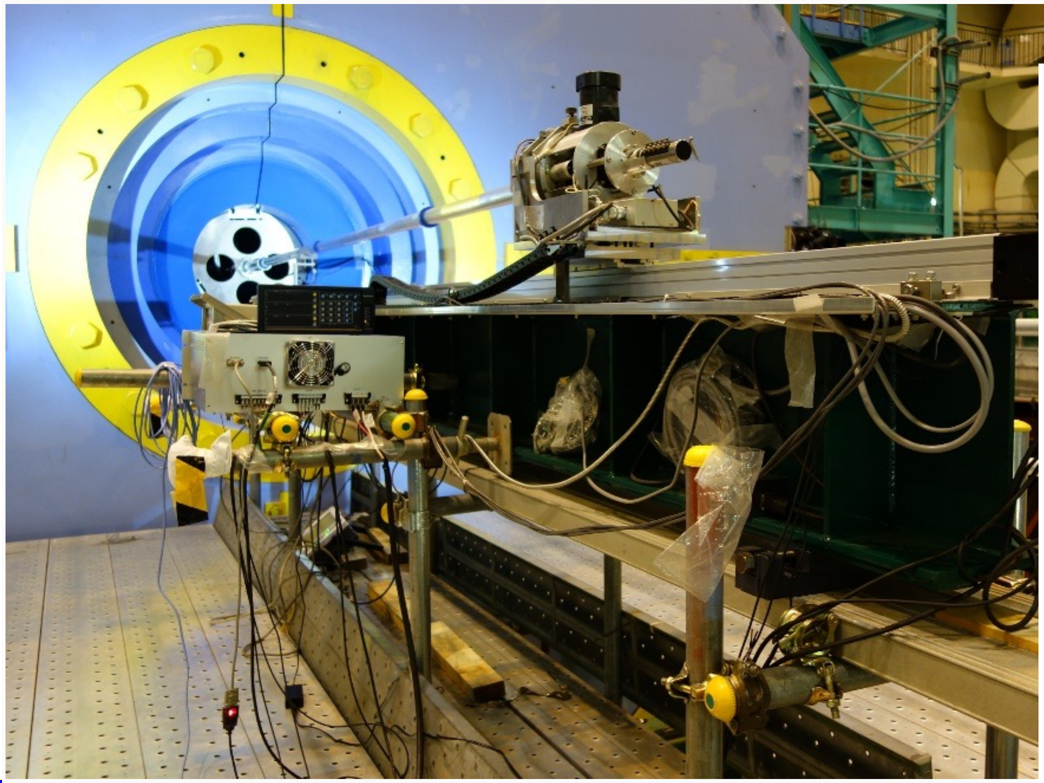
Totals			
	TOTAL		**3.41E+10**
	4S hadronic		2.41E+10
Subtotals	Rare 4S		8.25E+08
	Btag skim		2.75E+09
	3S		6.00E+08
	5S		0.00E+00
	Tau pairs		4.60E+09
	Low Multiplicity		1.21E+09

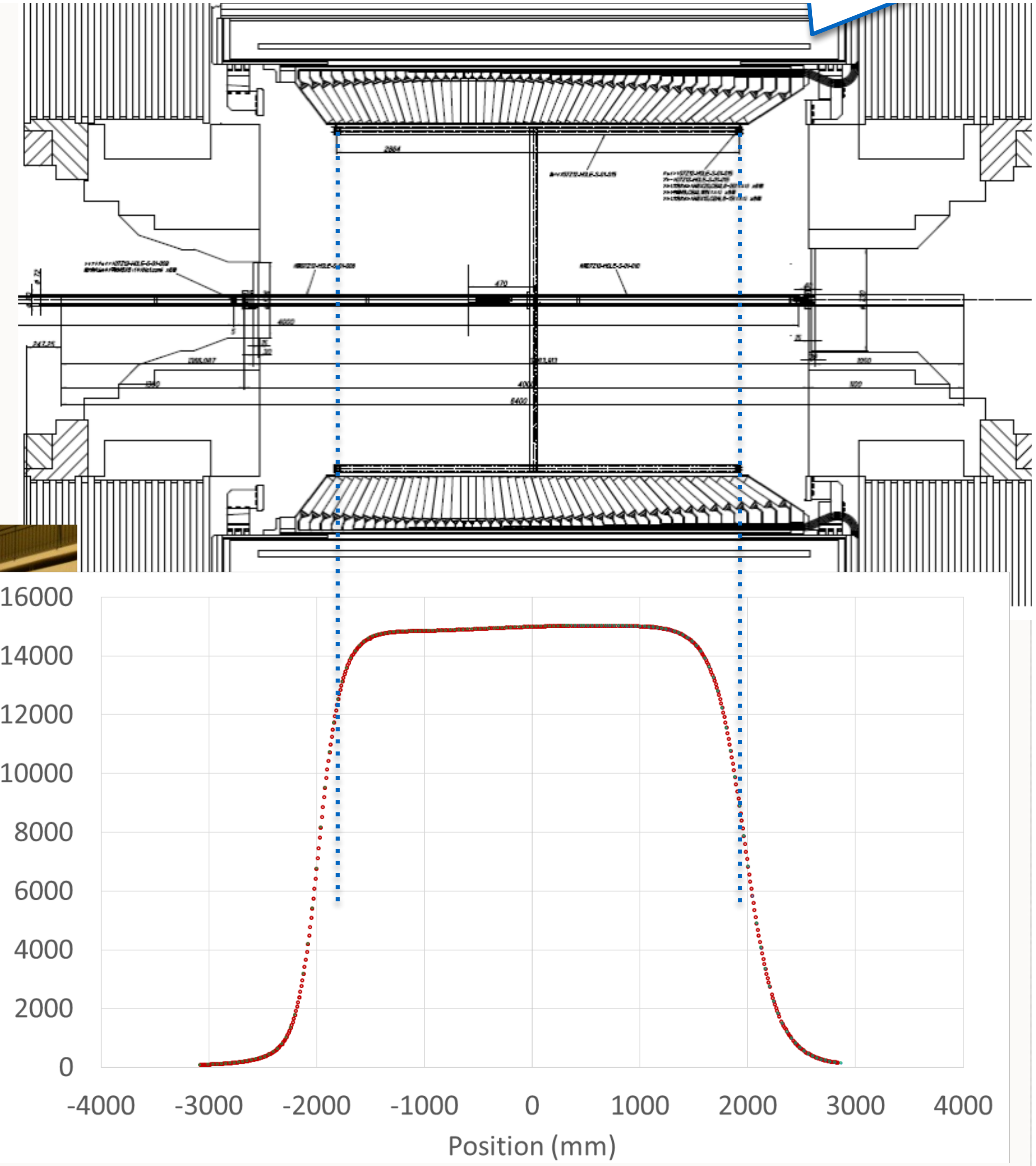


First attempts of distributed analysis on the Grid.

B-field measurement

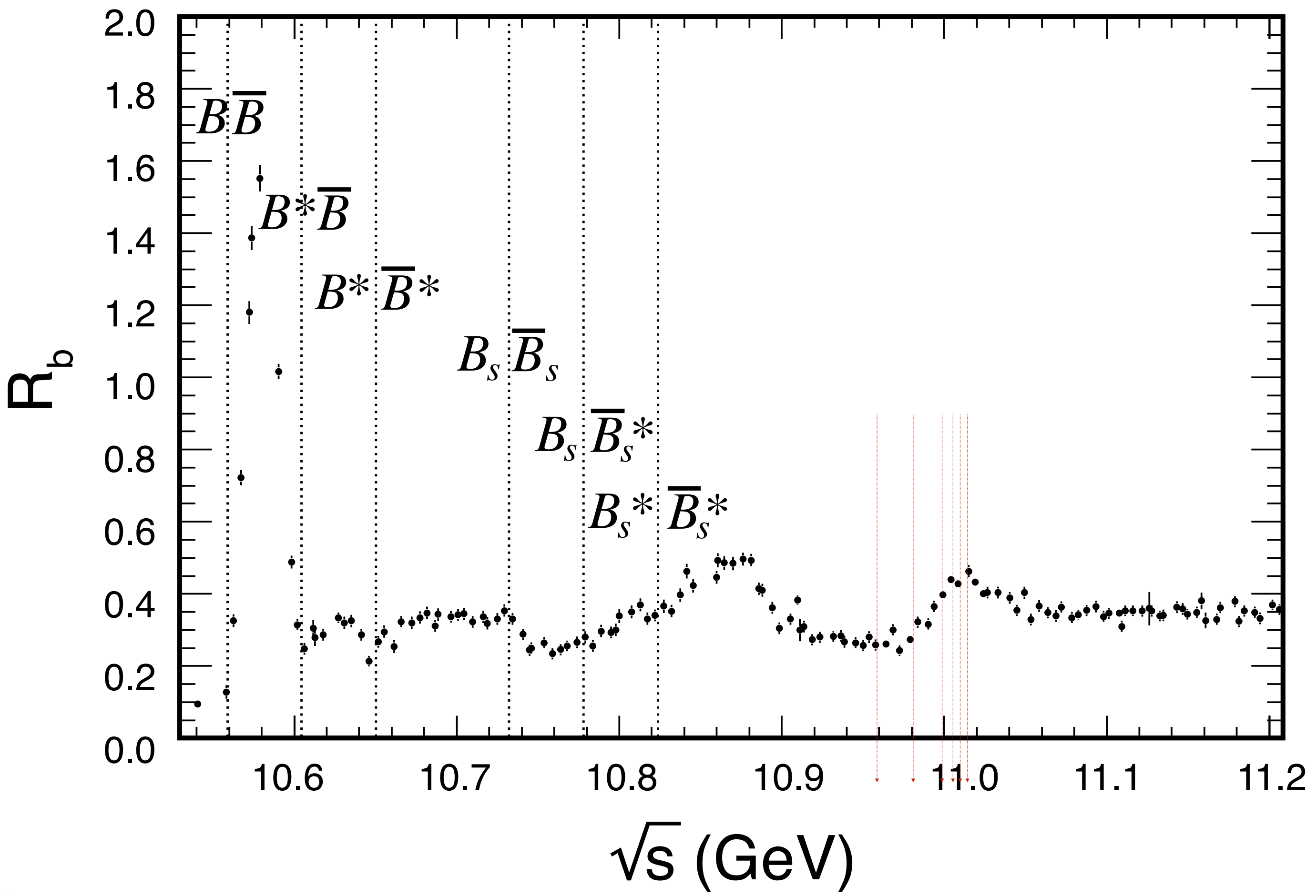






Phase II Unique data sets

- **Only ~20-40 fb^{-1} in Phase II**
  - Unique E_{CM}, e.g. Y(6S) for bottomonium - strong interaction studies
  - New trigger menu to greatly enhance low multiplicity & dark sector physics



Experiment	Scans Off. Res.	$\Upsilon(6S)$ fb^{-1}	$\Upsilon(5S)$ fb^{-1}	$\Upsilon(5S)$ 10^6	$\Upsilon(4S)$ fb^{-1}	$\Upsilon(4S)$ 10^6	$\Upsilon(3S)$ fb^{-1}	$\Upsilon(3S)$ 10^6	$\Upsilon(2S)$ fb^{-1}	$\Upsilon(2S)$ 10^6	$\Upsilon(1S)$ fb^{-1}	$\Upsilon(1S)$ 10^6
CLEO	17.1	-	0.1	0.4	16	17.1	1.2	5	1.2	10	1.2	21
BaBar	54	R_b scan			433	471	30	122	14	99	–	
Belle	100	~ 5.5	36	121	711	772	3	12	25	158	6	102

Triggering dark sector physics

- 2 stage trigger: **Hardware** (L1) then **Software**.

Physics process	Cross section (nb)	Rate (Hz)
$\Upsilon(4S) \to B\bar{B}$	1.2	960
$e^+e^- \to$ continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha ($\theta_{\rm lab} \geq 17^\circ$)	44	350 [a]
$\gamma\gamma$ ($\theta_{\rm lab} \geq 17^\circ$)	2.4	19 [a]
2γ processes [b]	~ 80	~ 15000
Total	~ 130	~ 20000

[a] The rate is pre-scaled by a factor of 1/100.
[b] $\theta_{\rm lab} \geq 17^\circ$, $p_t \geq 0.1{\rm GeV}/c$

	Hardware Trigger accept	Physics output rate	Raw event size
Belle	500 Hz	90 Hz	
Belle II	30 kHz	3-10kHz	~200 kB
ATLAS	100 kHz	1 kHz	1.6MB