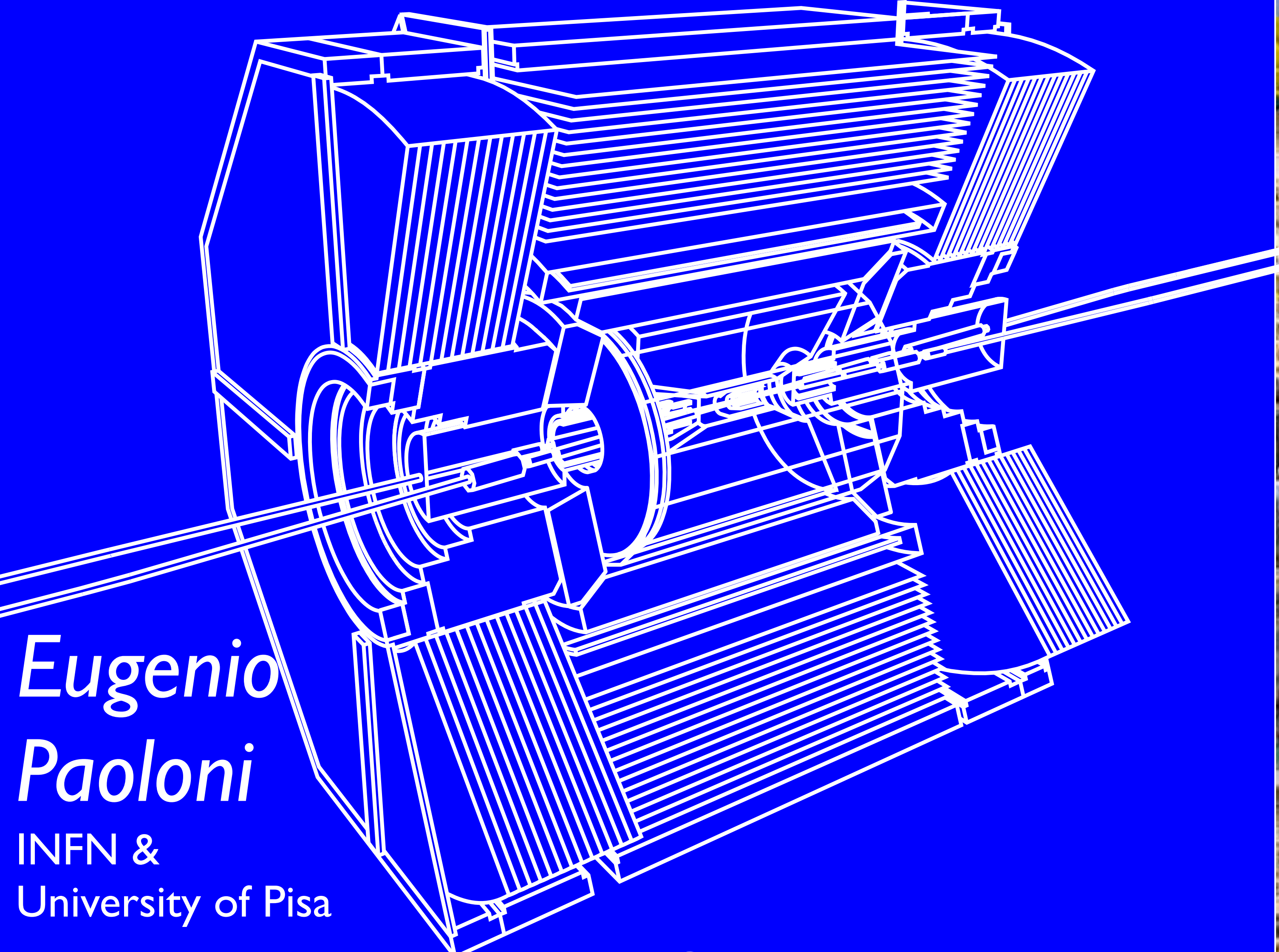
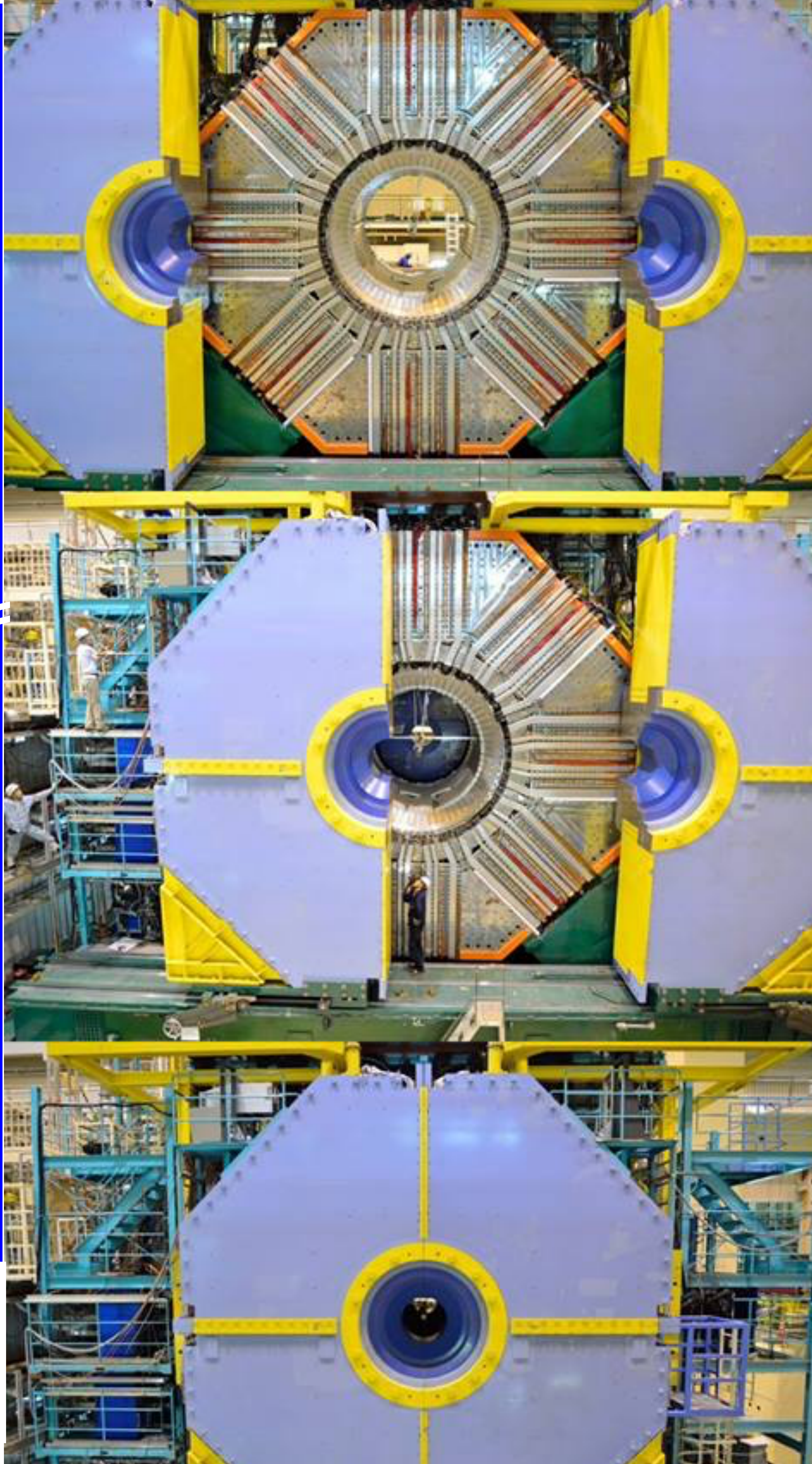
SuperKEKB and Belle II Status



Eugenio Paoloni
INFN &
University of Pisa

on behalf of the Belle2 Collaboration



Flavor Physics and *CP* Violation
FP*CP* 2016

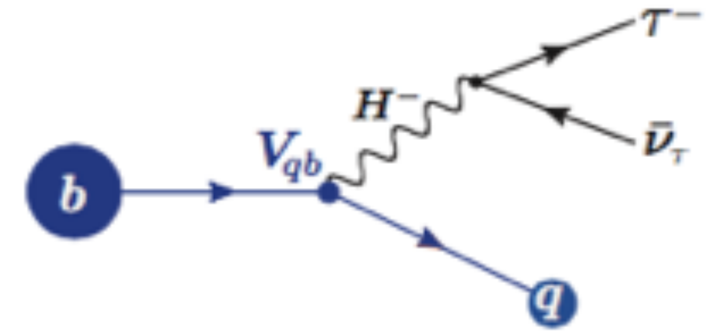
Caltech PMA

e^+e^-@ Υ(4S) is Still a Profitable Ore

- Many of the B-factories measurements are statistically limited.
- Some of them can provide precious informations:
  - if the New Physics is discovered at high Pt what is its model?
  - if not :'-(provide hints of New Physics
- Some of them are hard / impossible for LHCb (even though, guys! you are very clever! i.e. V_{ub})

Tantalizing Discrepancies With the SM

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\,\tau\,\bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\,\ell\,\bar{\nu}_\ell)}$$

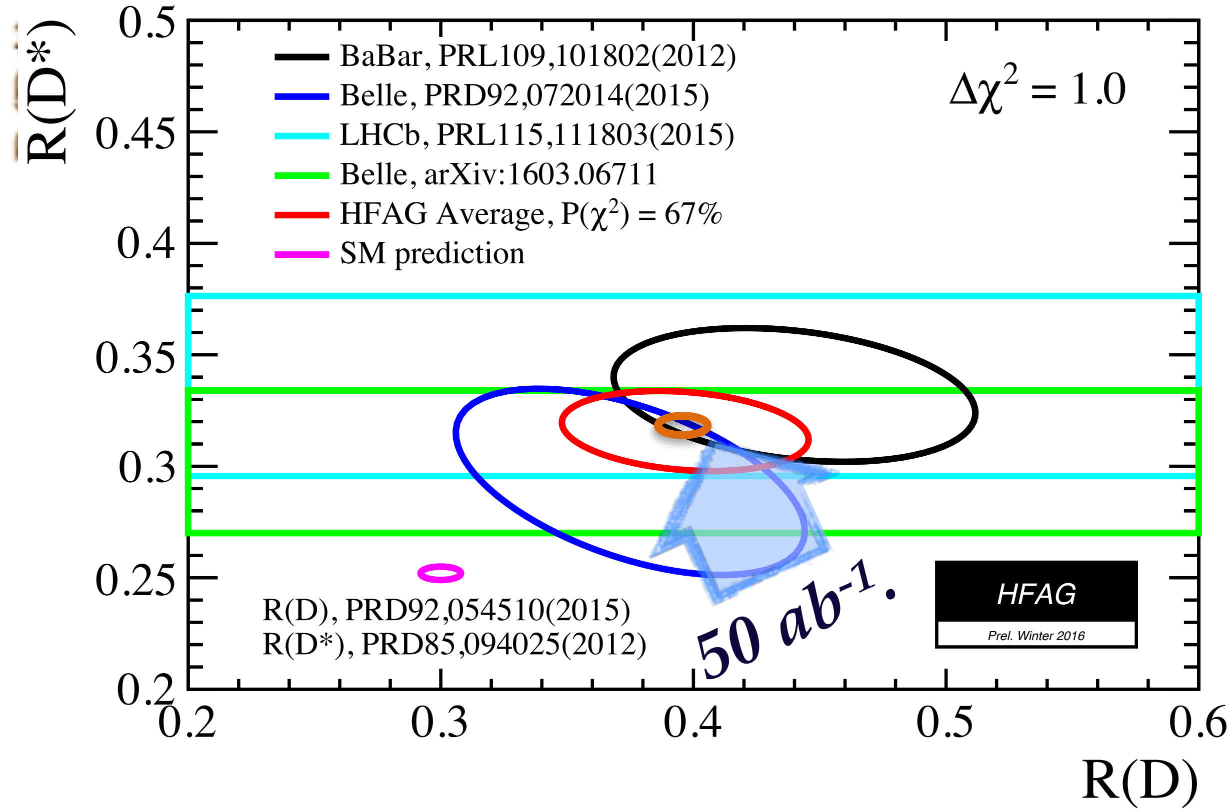


$R(D)$

Error	stat.	tot.
B-Factories	13%	16.2%
Belle II 5/ab	3.8%	5.6%
Belle II 50/ab	1.2%	**3.4%**

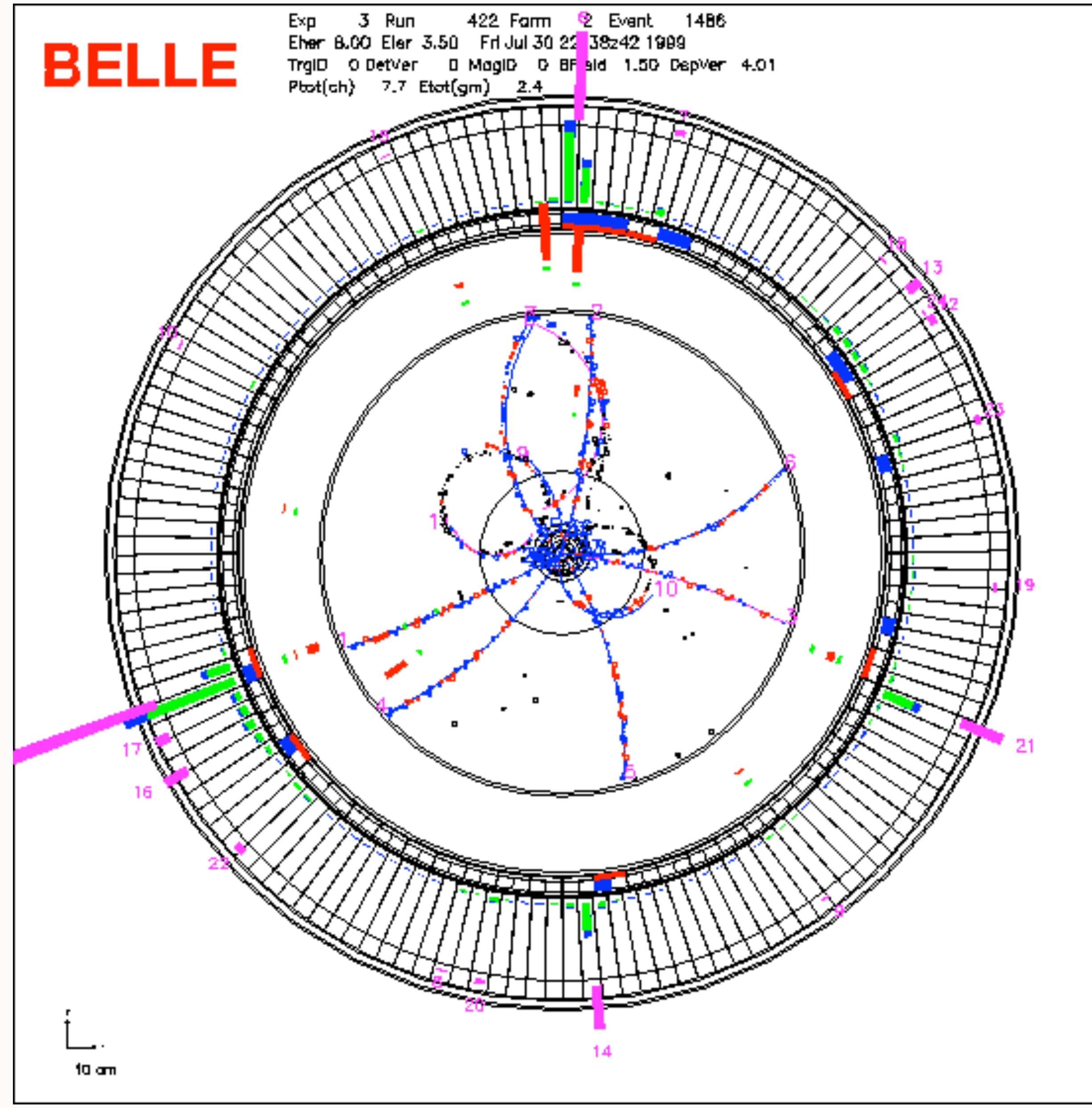
$R(D^*)$

Error	stat.	tot.
B-Factories	7.1%	9.0%
Belle II 5/ab	2.1%	3.2%
Belle II 50/ab	0.7%	**2.1%**

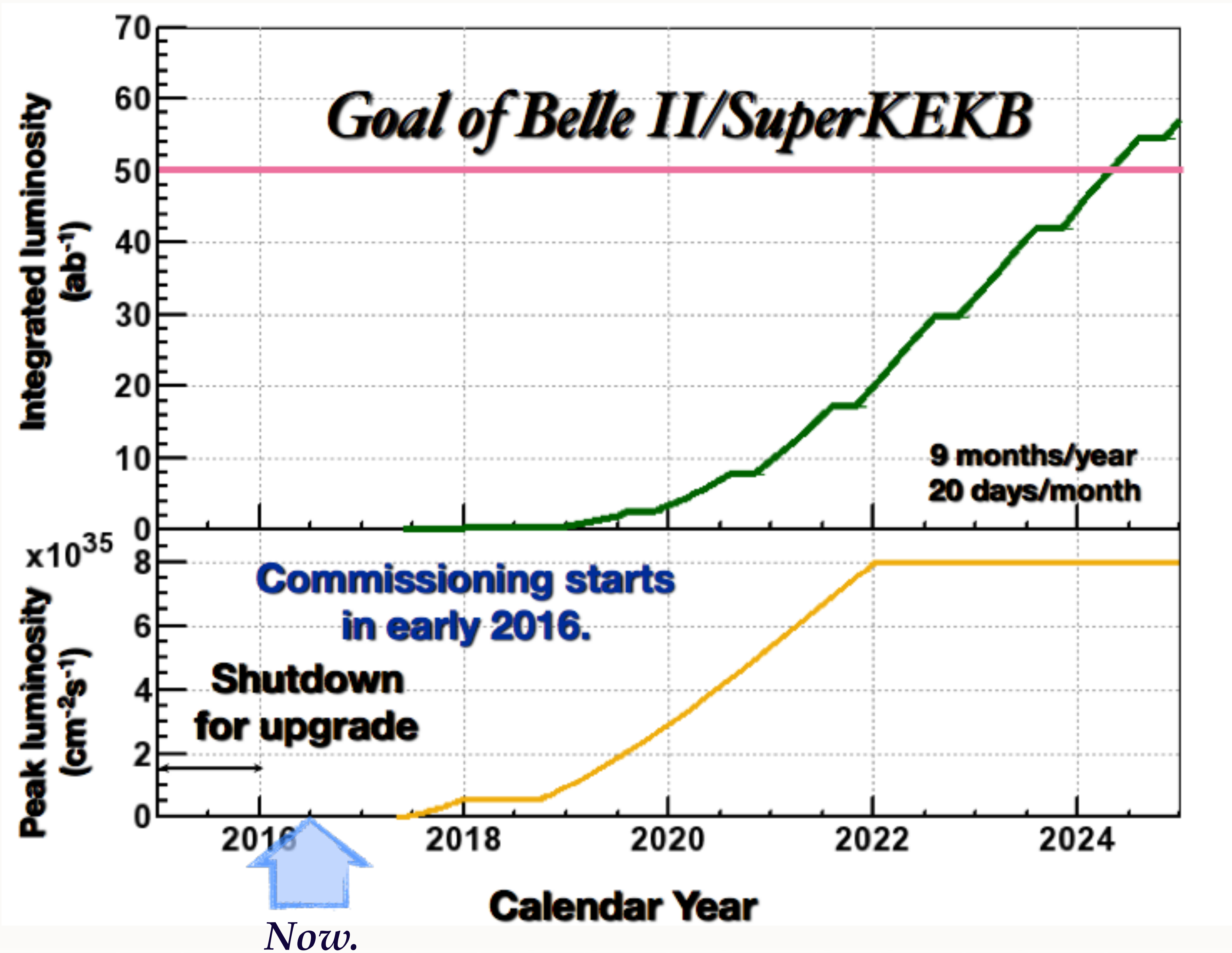


A Typical Υ(4s) Event

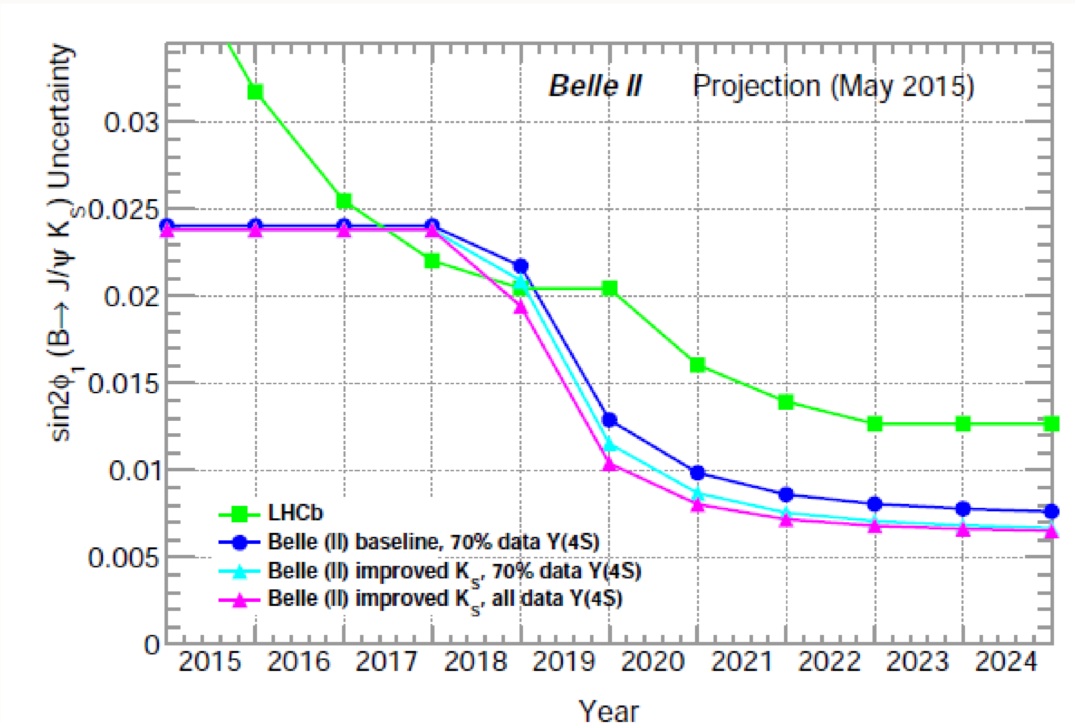
- 1nb production cross section.
  (~ for τ pairs and c cbar events)
- Average multiplicities
  - ~ 11 charged tracks
  - ~5 neutral pions
  - ~1 neutral kaon
- The center of mass Lorentz boost will be smaller than in Belle 1
  - 7 GeV e^- on 4 GeV e^+: $\beta\gamma \sim 0.28$
- The charged track momentum spectrum is soft
  - From pt ~ tens of MeV/c (soft pion from the D*) up to a few GeV/c (2 body B decay, tau pairs, muon pairs, Bhabha)

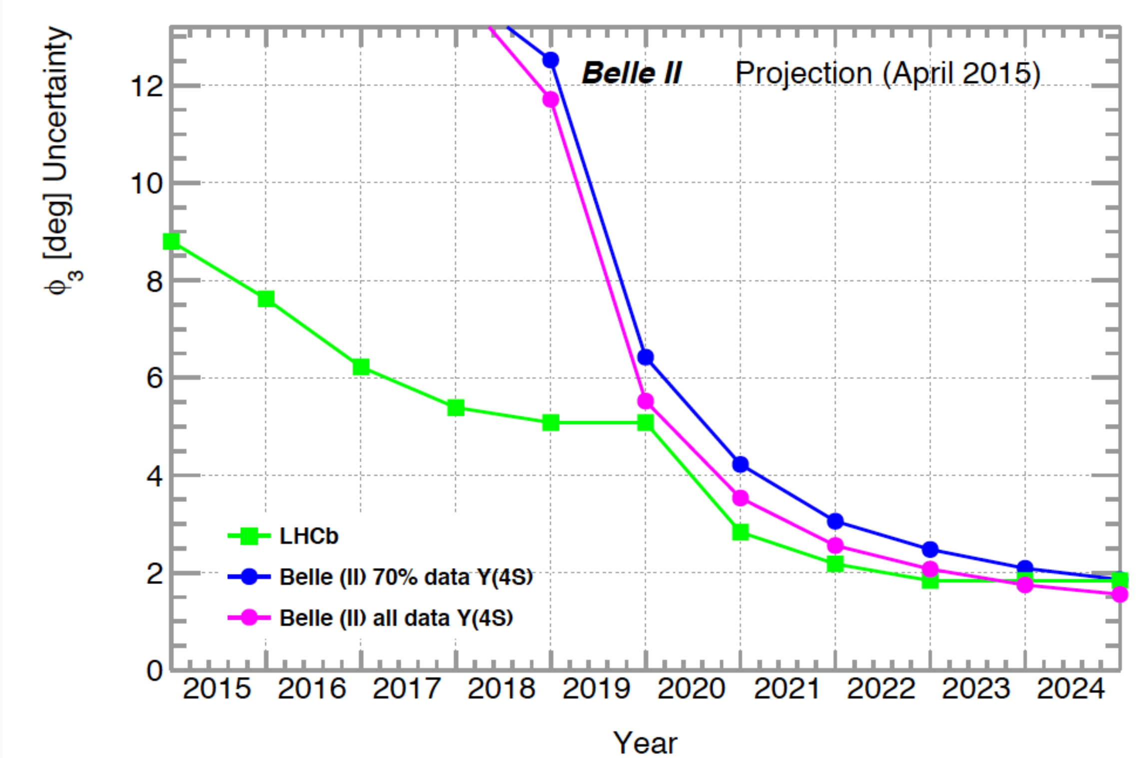


SuperKEKB: The 2nd generation B-factory



Nice complementarity with LHCb





Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\lvert V_{us}\rvert$ $[K \to \pi\ell\nu]$	**	0.1%	K-factory
$\lvert V_{cb}\rvert$ $[B \to X_c\ell\nu]$	**	1%	Belle II
$\lvert V_{ub}\rvert$ $[B_d \to \pi\ell\nu]$	*	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^d_{SL}	***	0.001	LHCb
A^s_{SL}	***	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
$\lvert q/p\rvert_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II

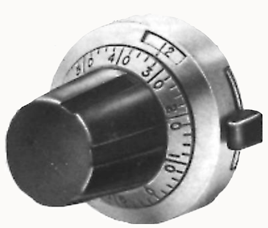
The SuperKEKB collider

Highest luminosity Collider x 40

$$\mathcal{L} \sim f_{\mathrm{coll}} \frac{N^+ N^-}{4\pi \sigma_x \sigma_y} = 8 \cdot 10^{35}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$$

A. Numerator ⤴ (Currents) 1.6A/1.2 A ⤴3.6/2.6 A

- ✦ Fundamental limit: the wall plug power ~ proportional to current + Longitudinal Fast Instability

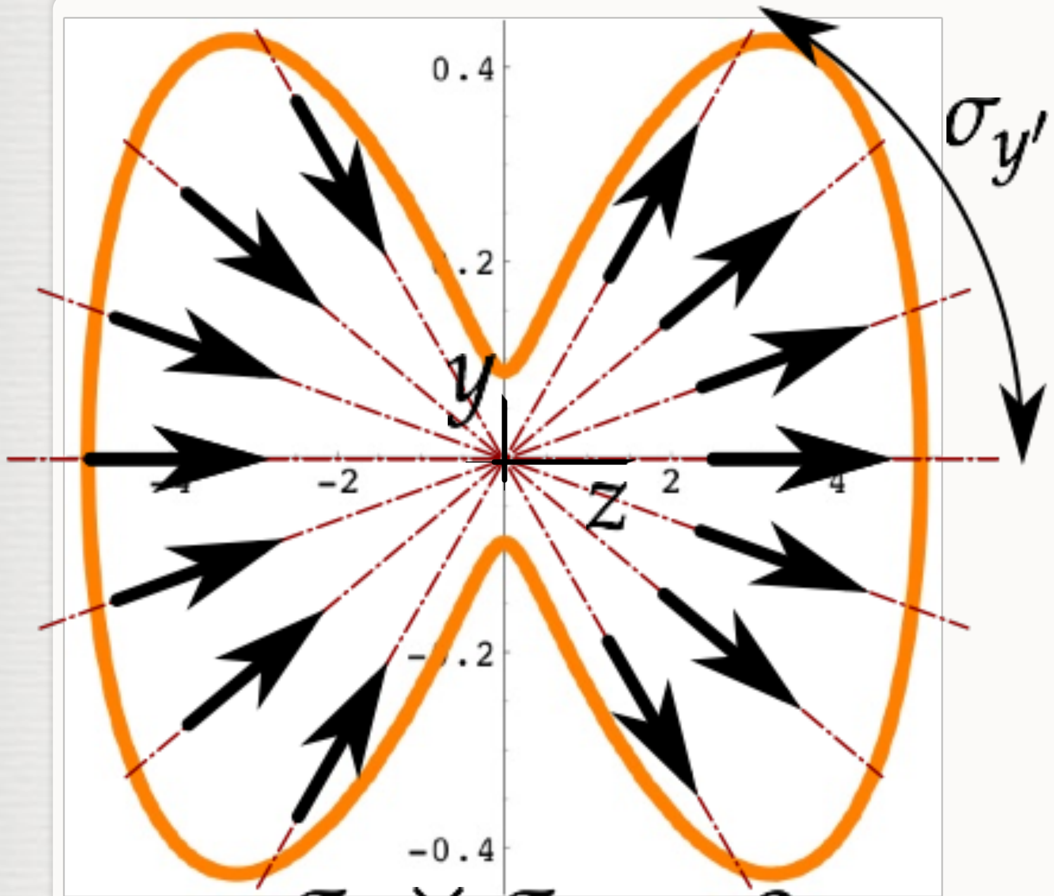


B. Denominator ⤵ (bunch cross section)

KEKB vertical size ~1.1 µm ⤵ SuperKEKB ~50 nm

How to squeeze down the bunch to 50 nm?

Down To 50 nm: Hour Glass Effect



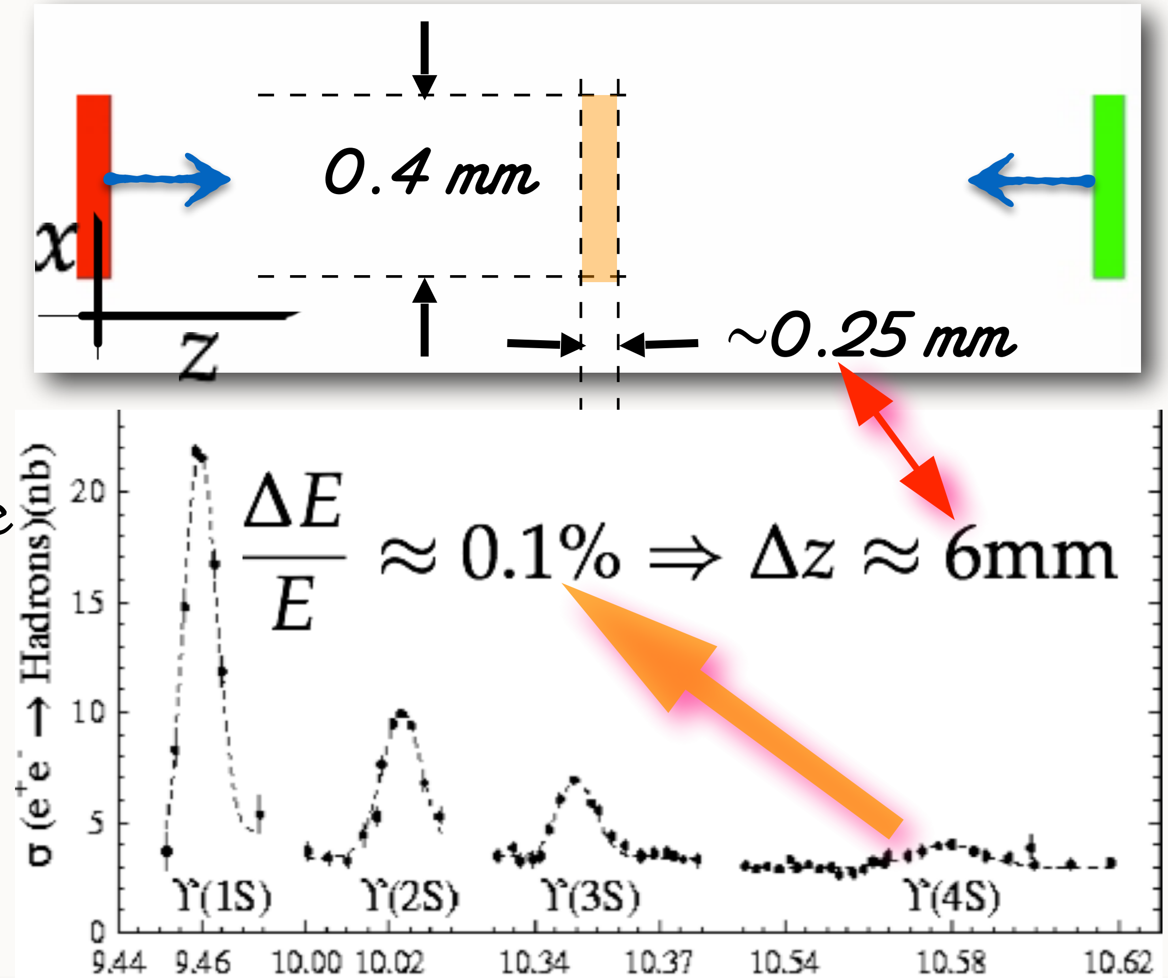
$\sigma_y \times \sigma_{y'} = \epsilon_y$

ANGULAR DIVERGENCE
X
CROSS SECTION SIZE @ IP
=
EMITTANCE (CHARACTERISTIC OF THE RING)

- KEKB emittance ~ 0.2nm x radiant
  Angular divergence ~ 4 mradiant = 4000 nm / mm
- SuperKEKB emittance ~ 0.010nm x radiant
  Angular divergence ~ 0.2 mradiant = 200 nm / mm = 50 nm / 0.25mm
  How to preparare an ultra short bunch: L ~ 0.25 mm??

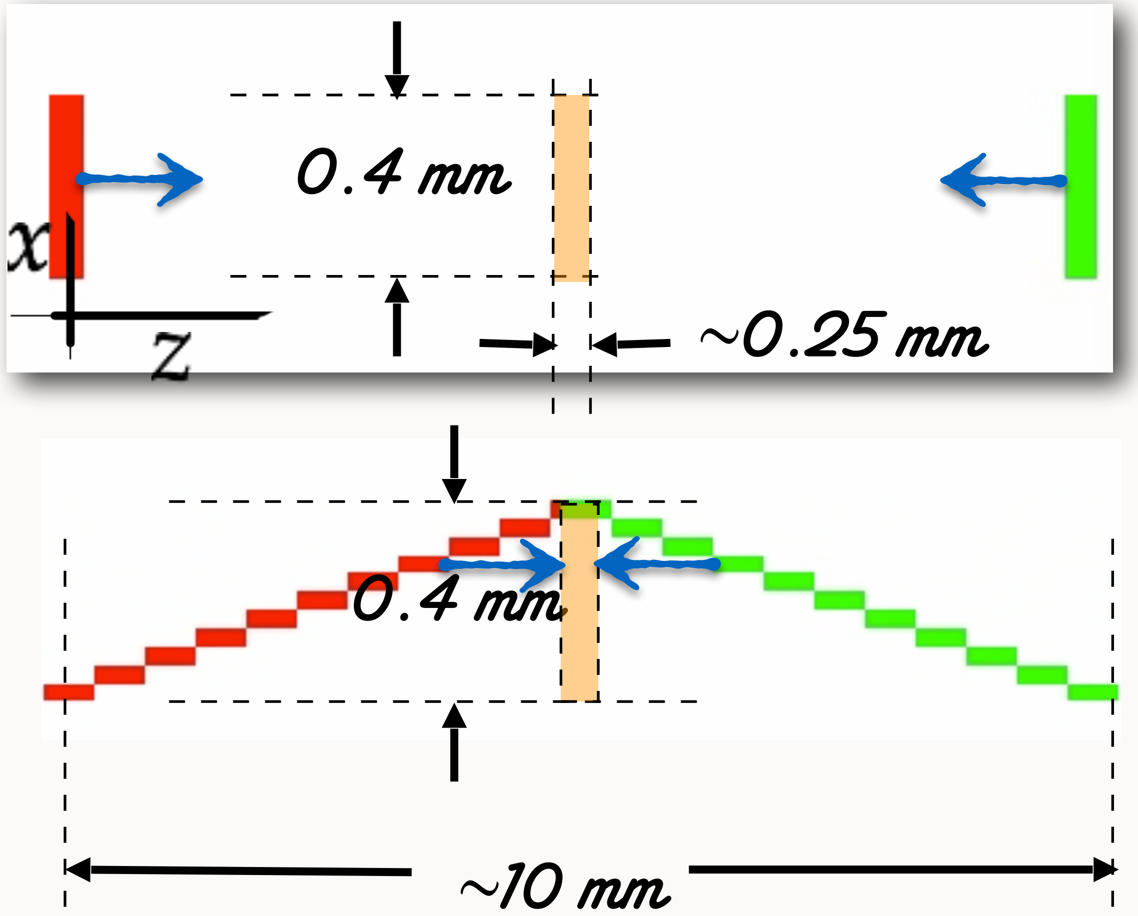
The Nano Beam Collision Scheme

Pantaleo Raimondi idea as he explained it to me ten years ago.



Bunch Length
x
Energy Spread
=
Characteristic Constant of The Ring

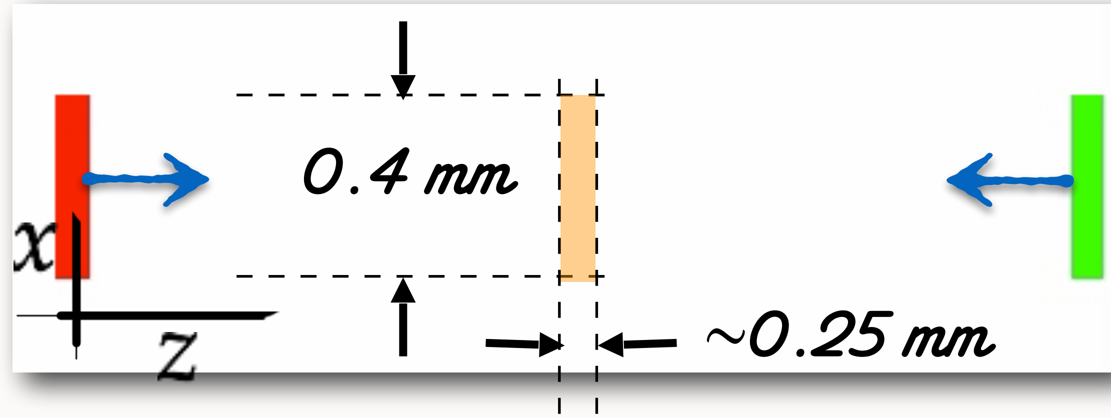
The Nano Beam Collision Scheme



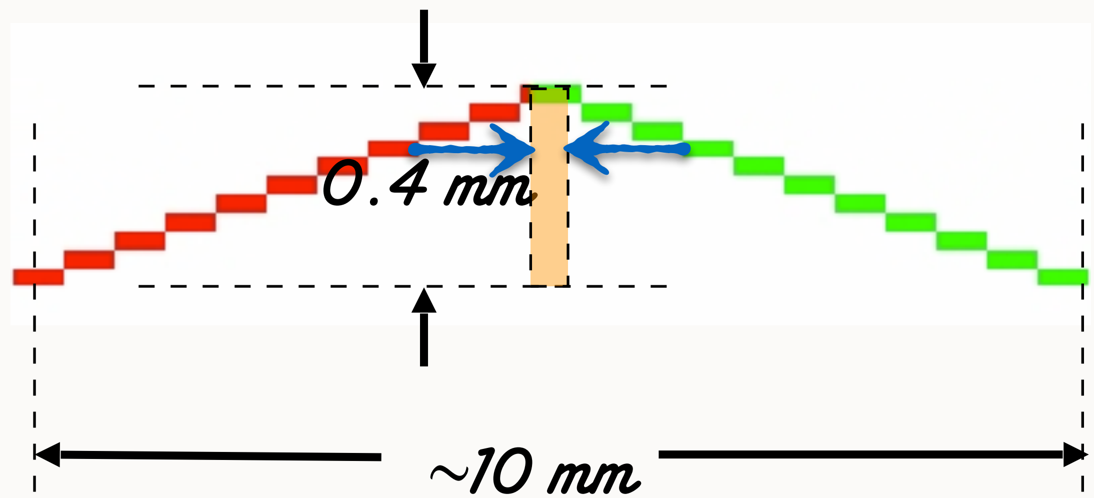
Pantaleo Raimondi idea
as he explained it to me
ten years ago.

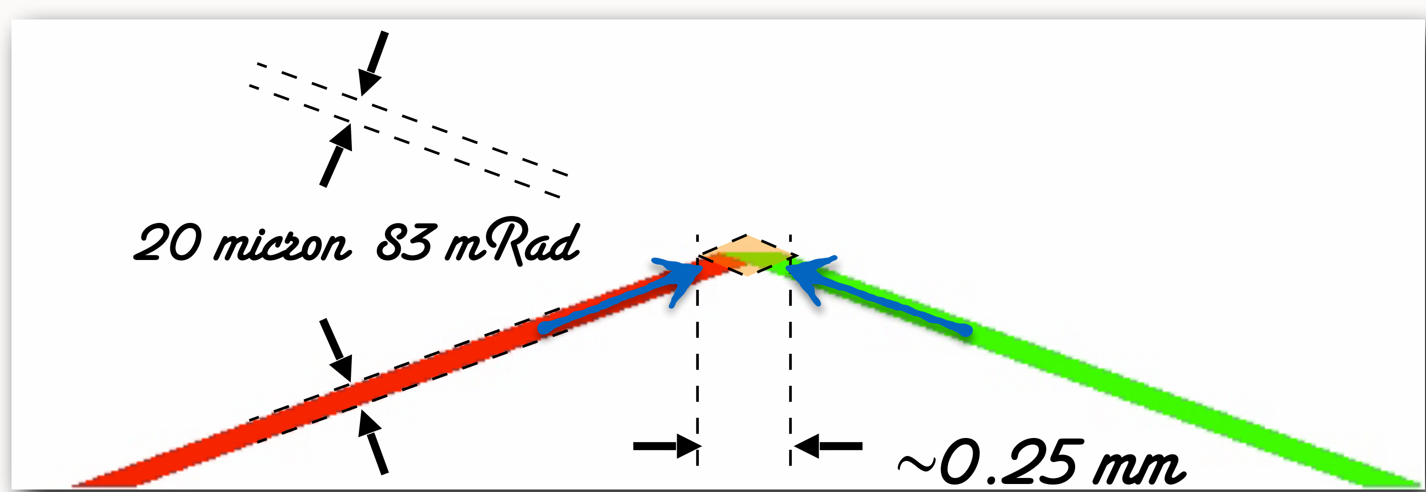
Bunch Length
x
Energy Spread
=
Characteristic Constant of The Ring

The Nano Beam Collision Scheme

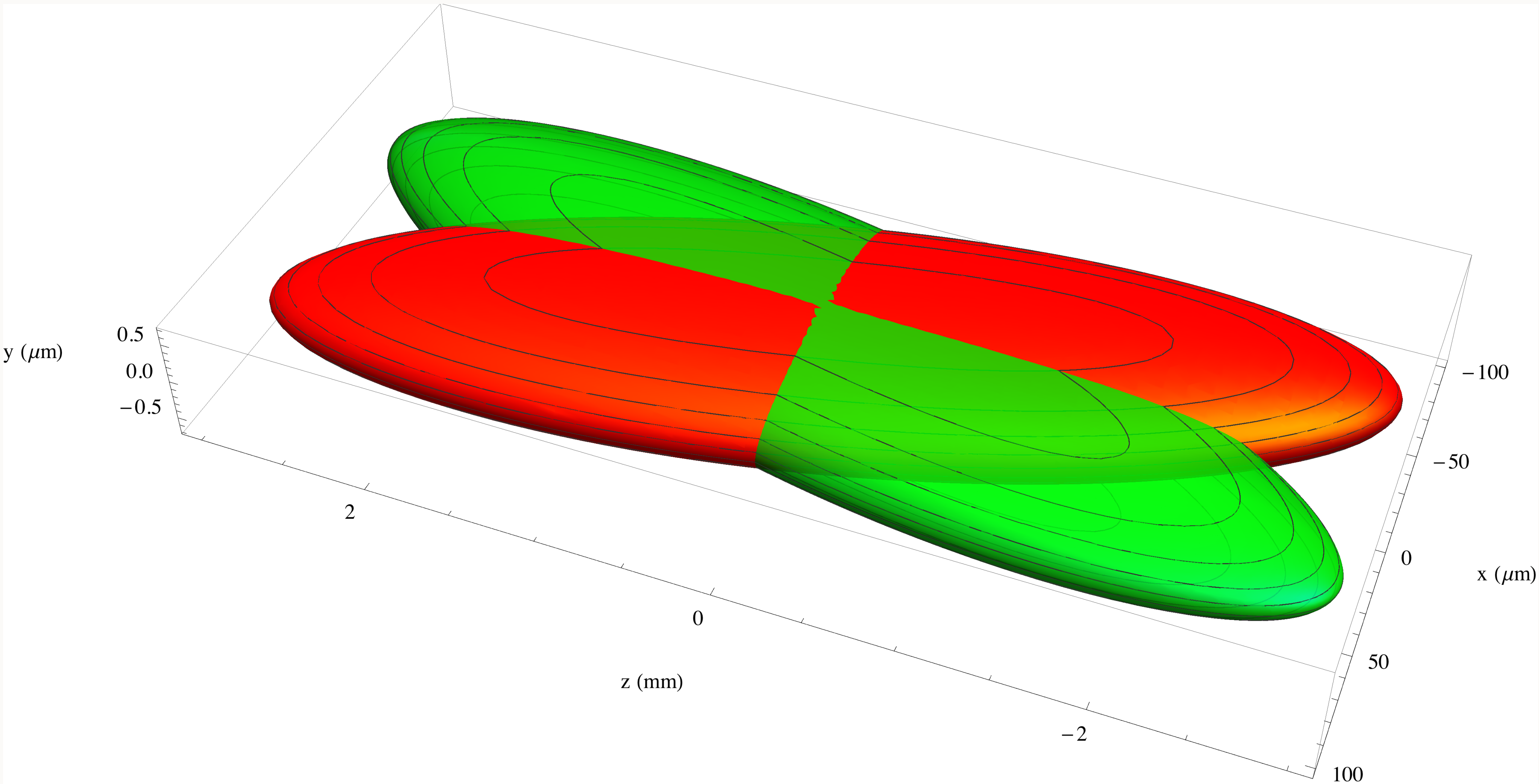


Pantaleo Raimondi idea as he explained it to me ten years ago.

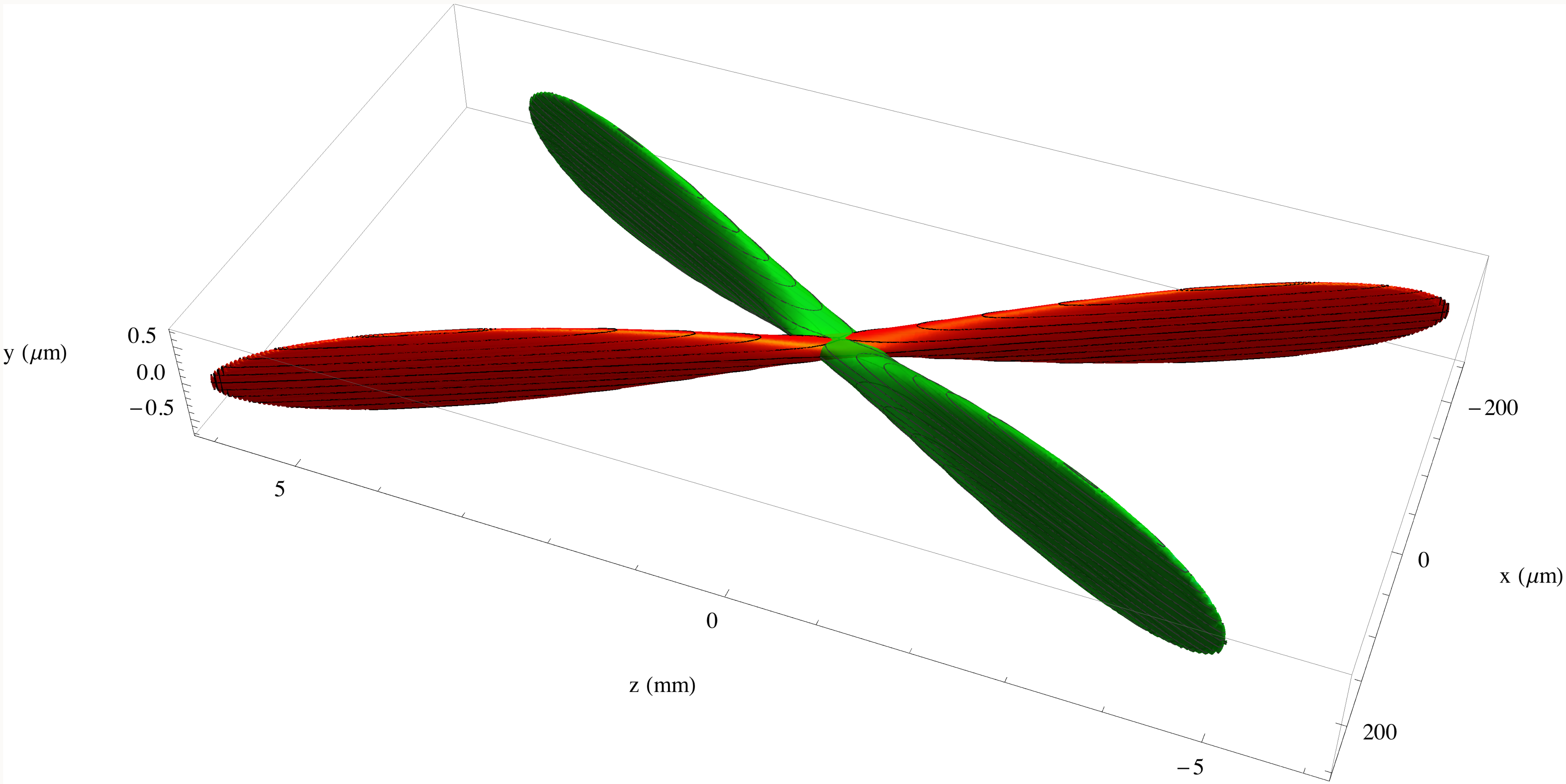




From KEKB



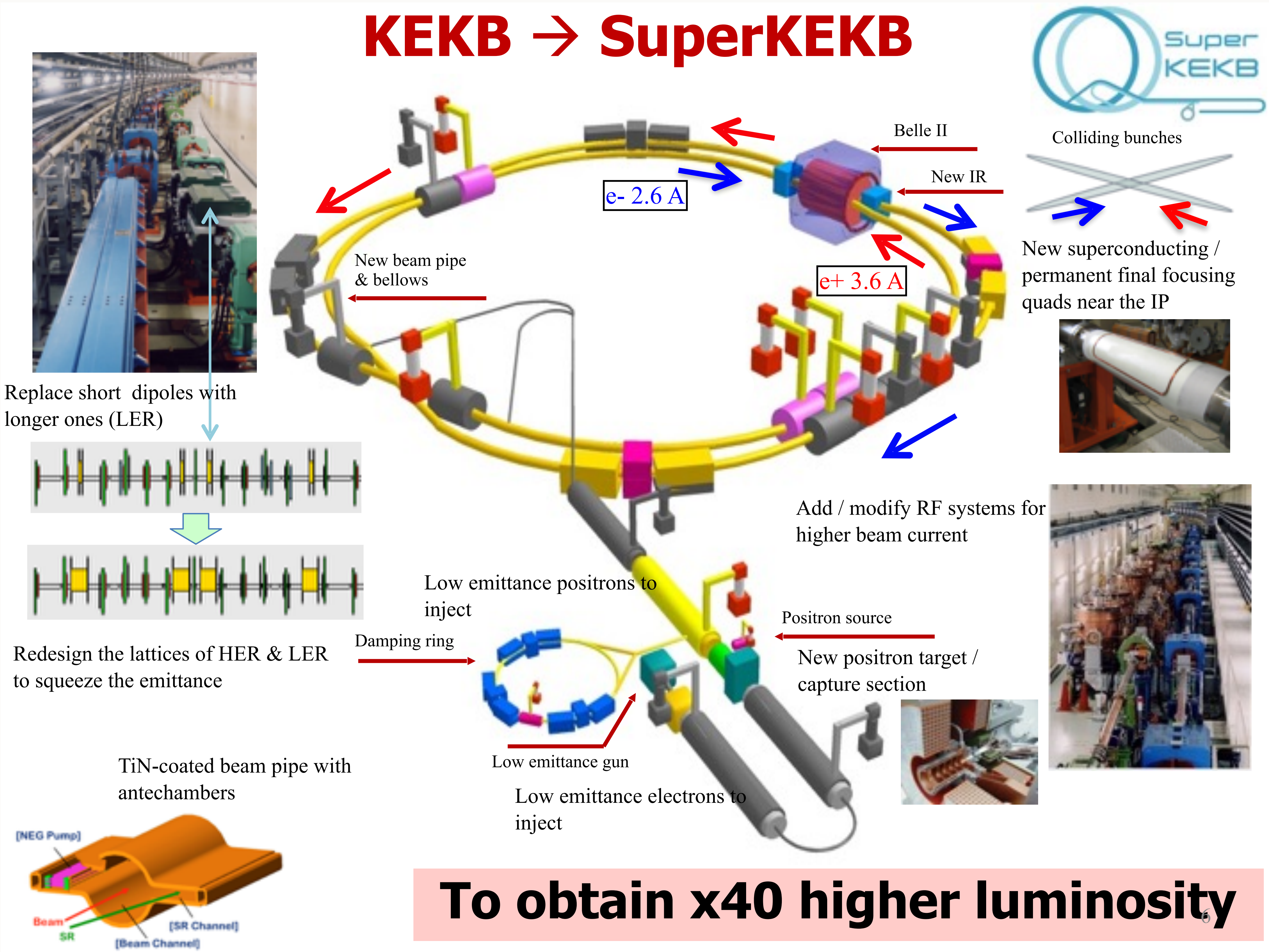
From KEKB to SuperKEKB



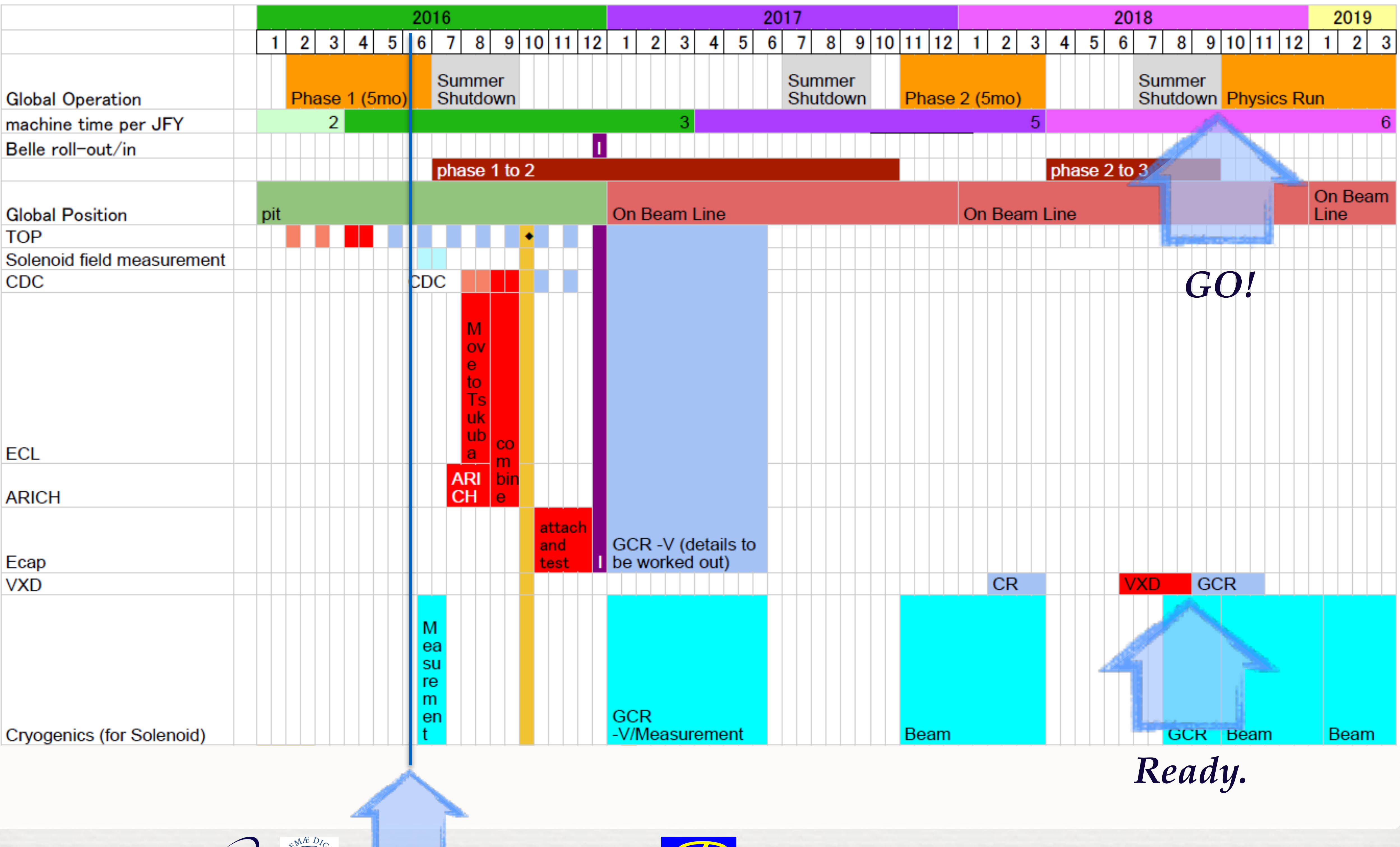
Machine Parameters

2013/July/29	LER	HER	unit	
E	4.000	7.007	GeV	
I	3.6	2.6	A	
Number of bunches	2,500			
Bunch Current	1.44	1.04	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/12.9(1.5)	nm/pm	():zero current
Coupling	0.27	0.28	%	includes beam-beam
β_x^*/β_y^*	32/0.27	25/0.30	mm	
Crossing angle	83		mrad	
α_p	3.18×10^{-4}	4.53×10^{-4}		
σ_δ	$8.10(7.73)\times10^{-4}$	$6.37(6.30)\times10^{-4}$		():zero current
V_c	9.4	15.0	MV	
σ_z	6.0(5.0)	5(4.9)	mm	():zero current
ν_s	-0.0244	-0.0280		
ν_x/ν_y	44.53/46.57	45.53/43.57		
U_0	1.86	2.43	MeV	
$\tau_{x,y}/\tau_s$	43.2/21.6	58.0/29.0	msec	
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807		
Luminosity	8×10^{35}		$cm^{-2}s^{-1}$	

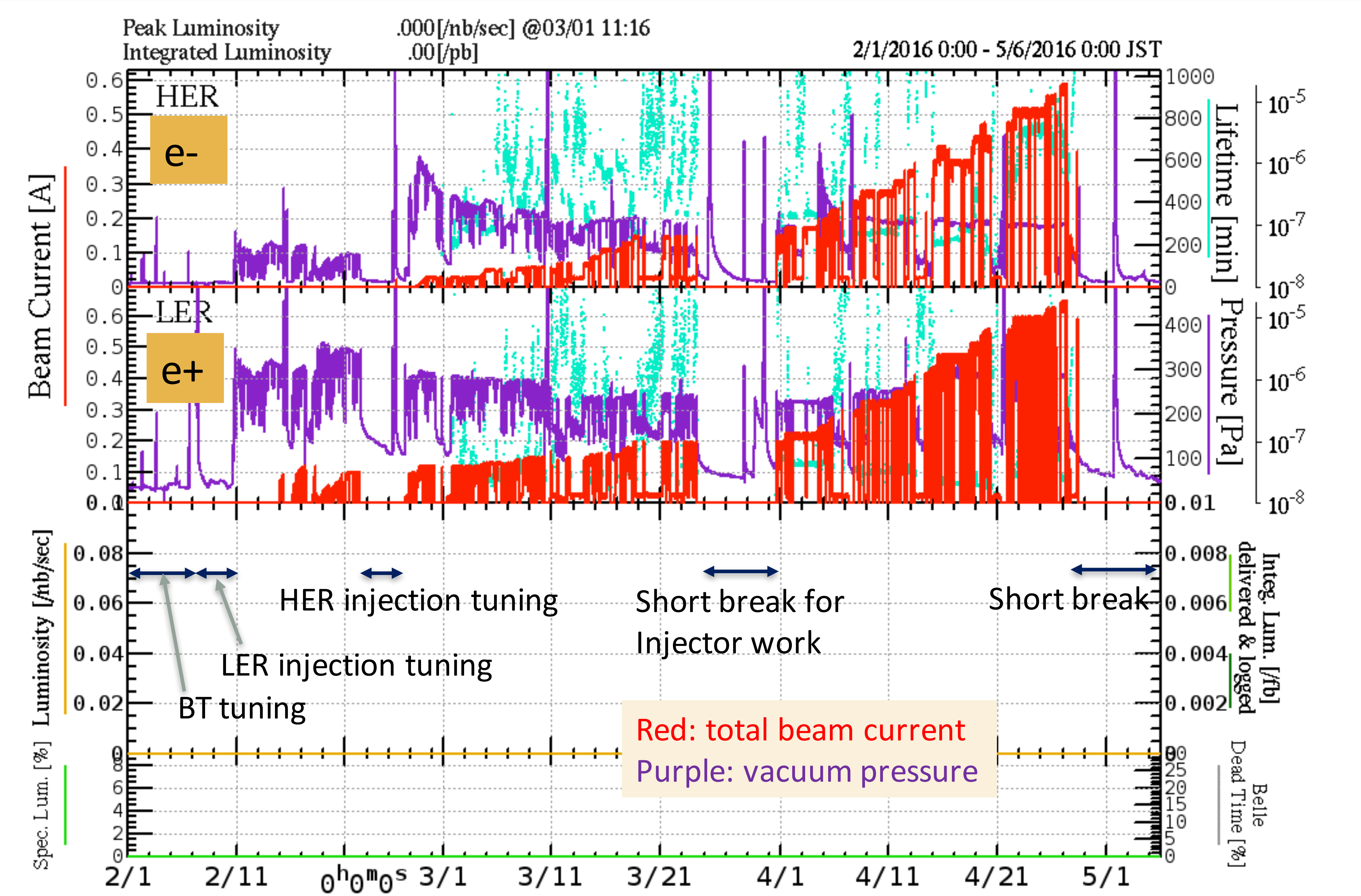
From KEKB to SuperKEKB



SuperKEKB Master Schedule



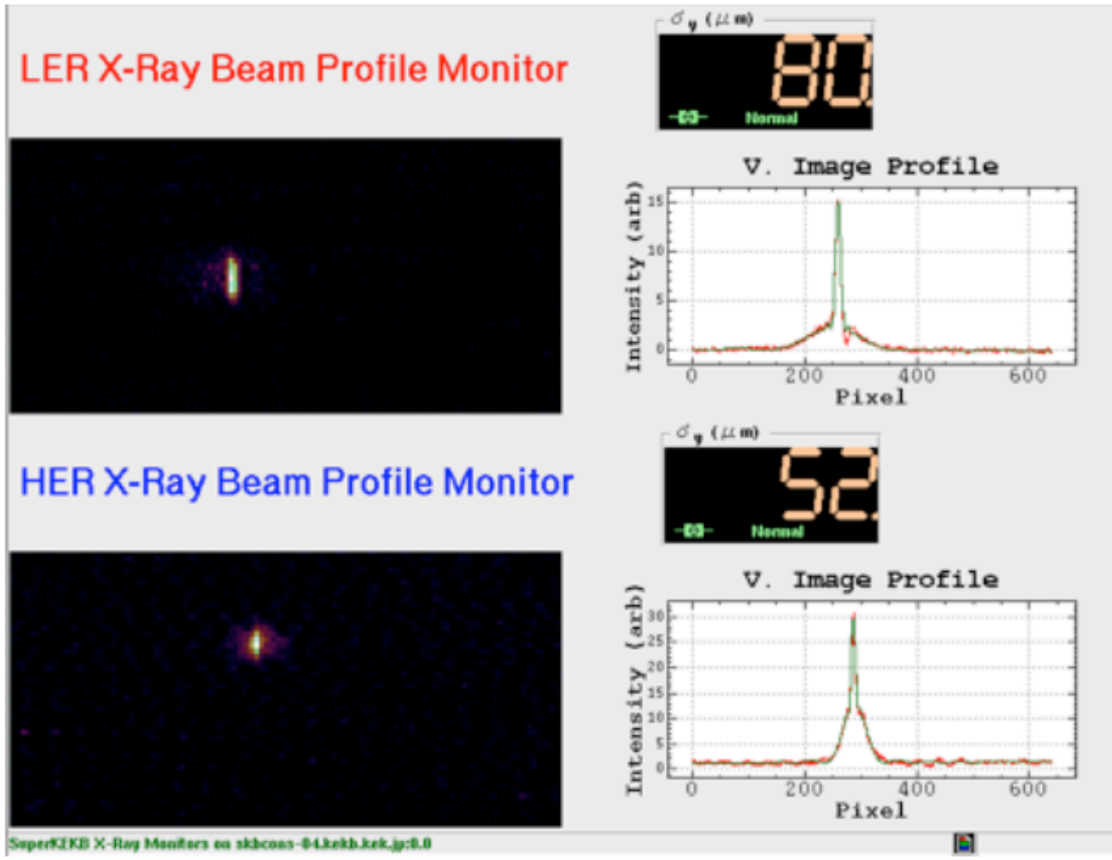
Phase1 Commissioning History



Funakoshi-san Report @ IPAC

- Much faster startup than KEKB
  - KEKB beam currents achieved after first 3 months
    LER: ~300mA, HER: ~200mA
  - SuperKEKB beam currents achieved after first 3 months
    LER: ~650mA, HER: ~590mA
- Compared with KEKB...
  - Each hardware component has been upgraded with experiences at KEK and has worked fine (RF, Magnet, Vacuum...)
  - The bunch-by-bunch feedback system has more effectively suppressed instabilities.
  - Operational tools (such as closed orbit correction system) has worked fine based on experiences at KEKB.
  - Less machine troubles than KEKB so far

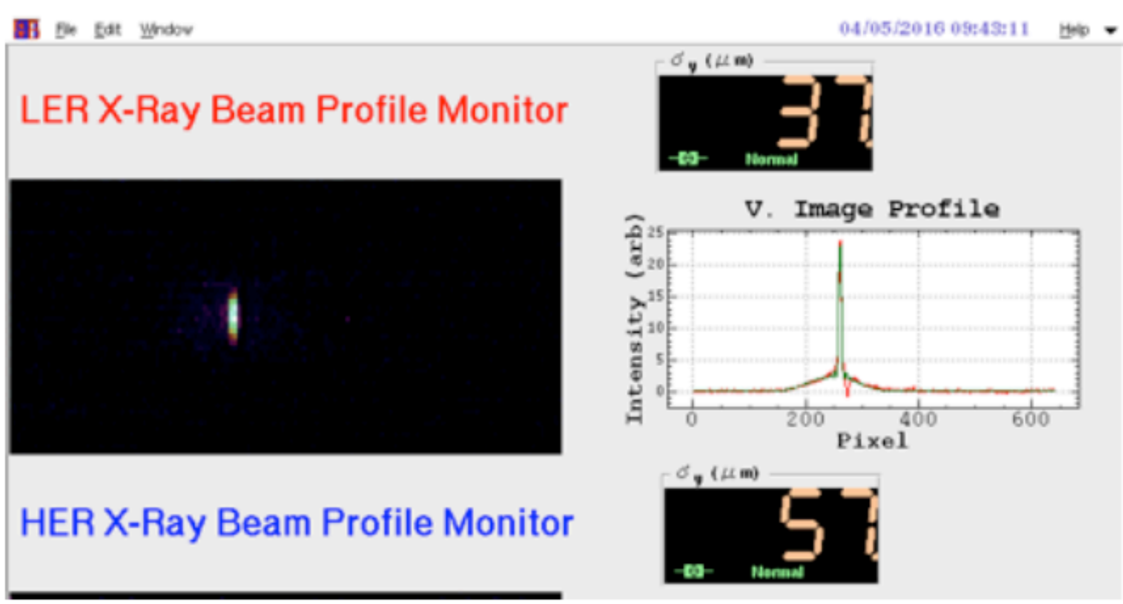
Beam size measurement by using X-ray monitor



ε_y = 96 pm (β_y = 67 m@source)
$\varepsilon_y / \varepsilon_x$ = 5.3 % (ε_x = 1.8 nm)

March 23, 2016

ε_y = 280 pm (β_y = 9.7 m@source)
$\varepsilon_y / \varepsilon_x$ = 5.3 % (ε_x = 5.3 nm)



April 5, 2016

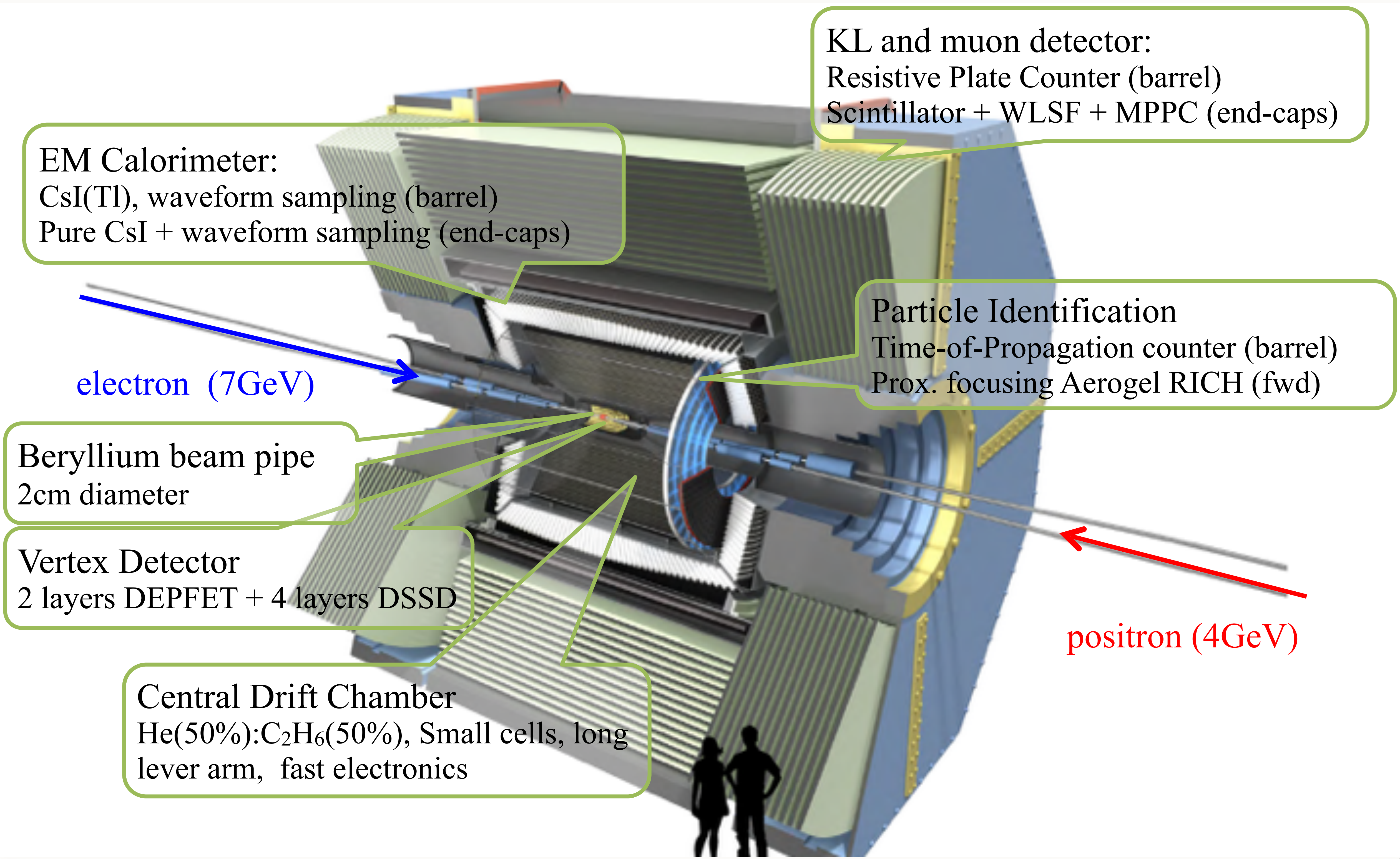
ε_y = 20 pm (β_y = 67 m@source)
$\varepsilon_y / \varepsilon_x$ = 1.1 % (ε_x = 1.8 nm)

Target vertical emittance in Phase 1 is 10pm.

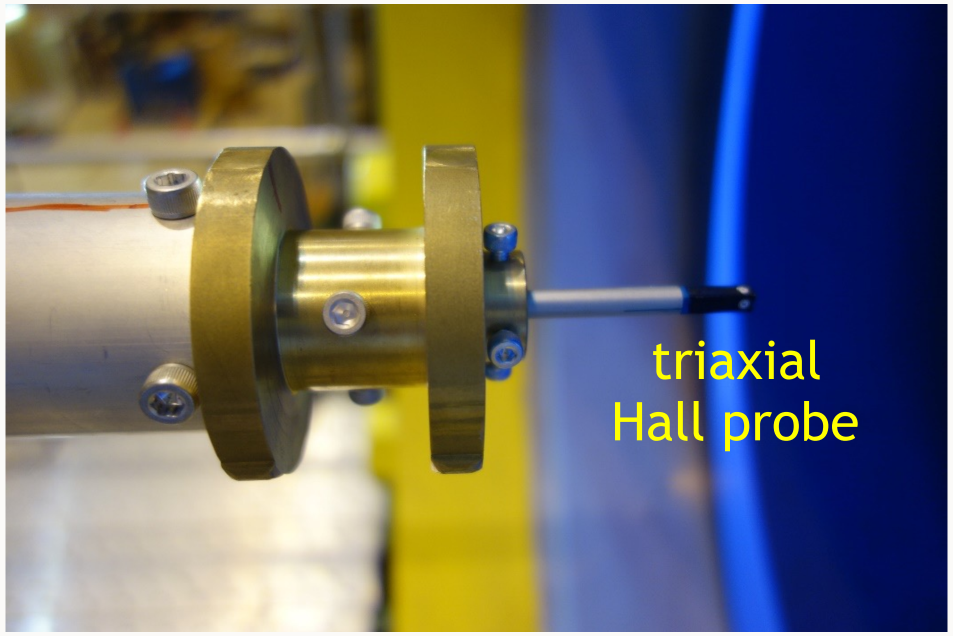
Work for calibration of X-ray monitor beam size monitor is on the way.

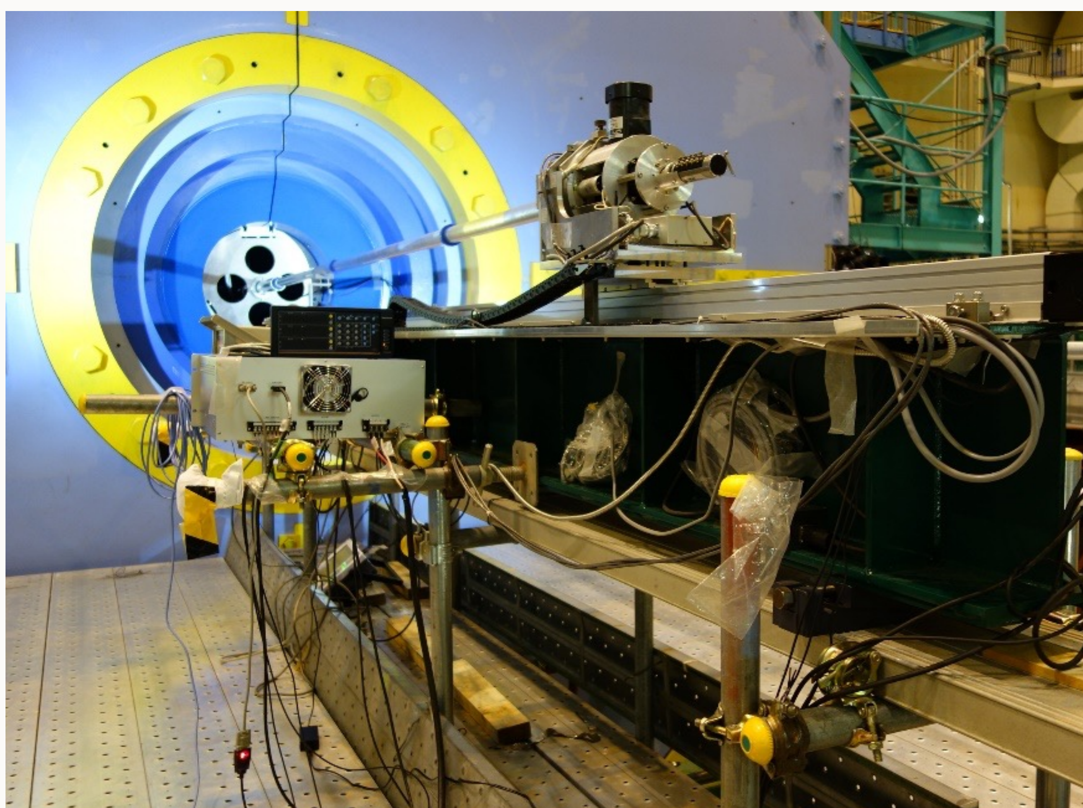
The Belle2 Detector

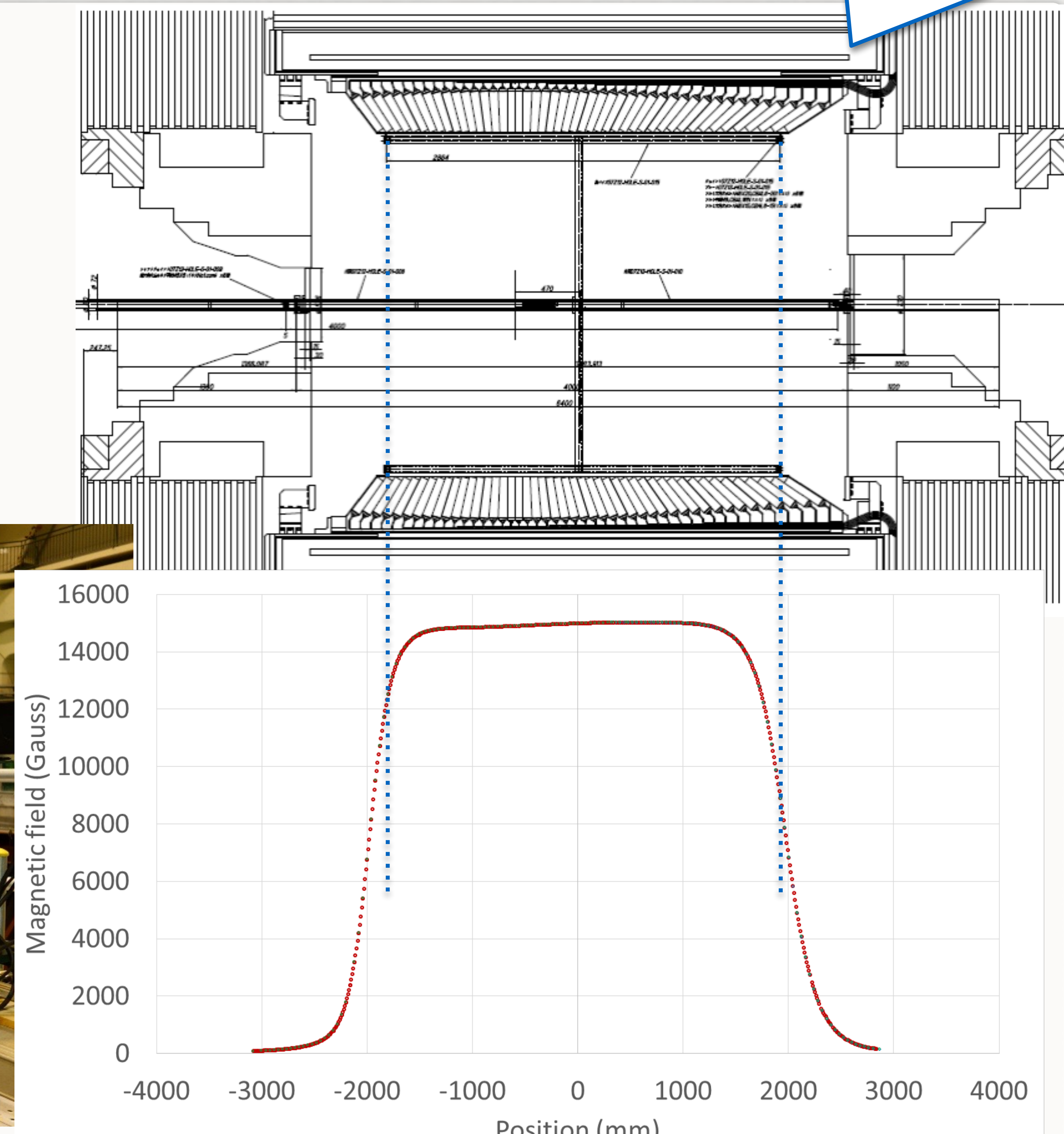
Belle2 in a nutshell



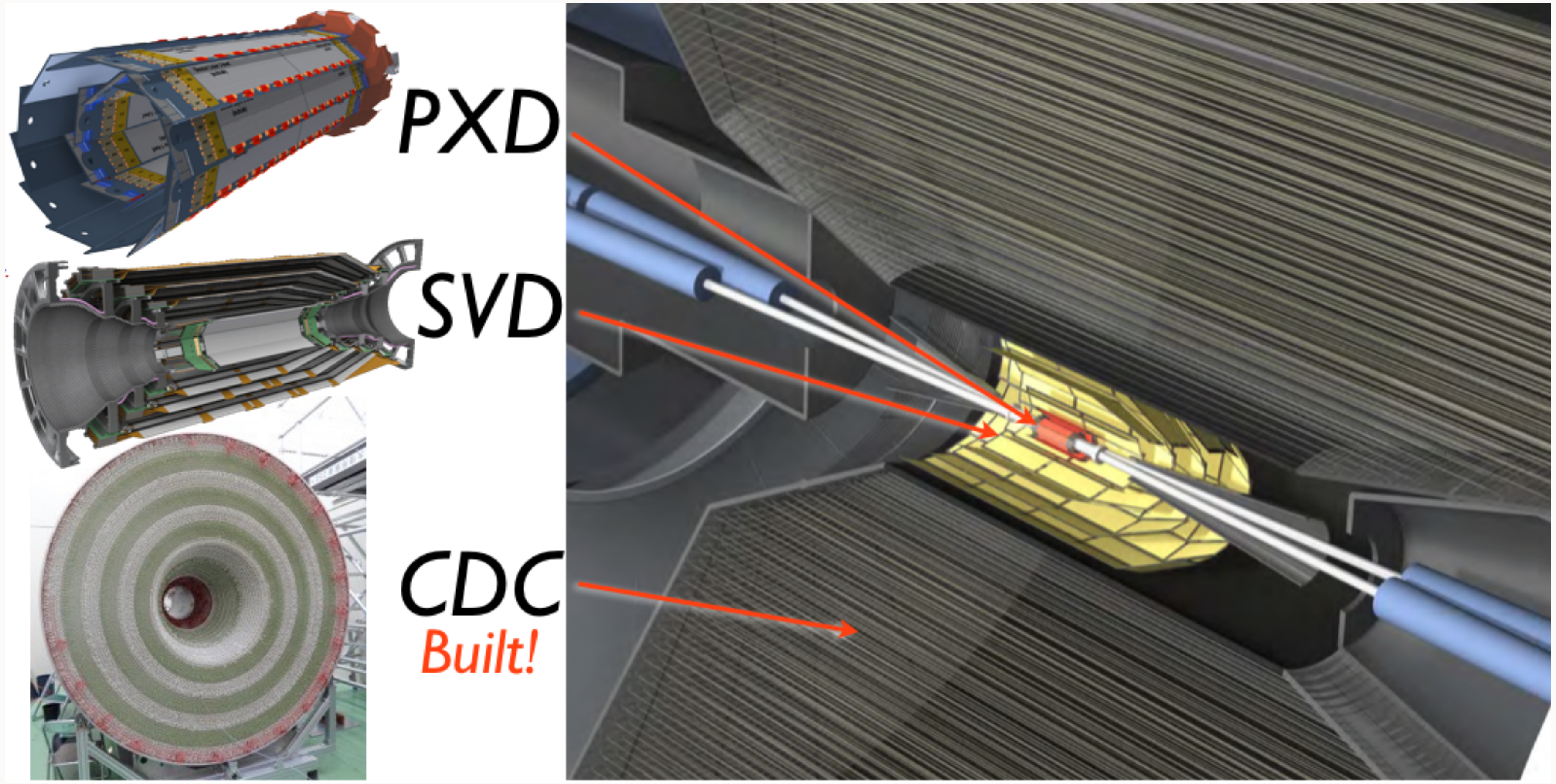
Superconducting Solenoid





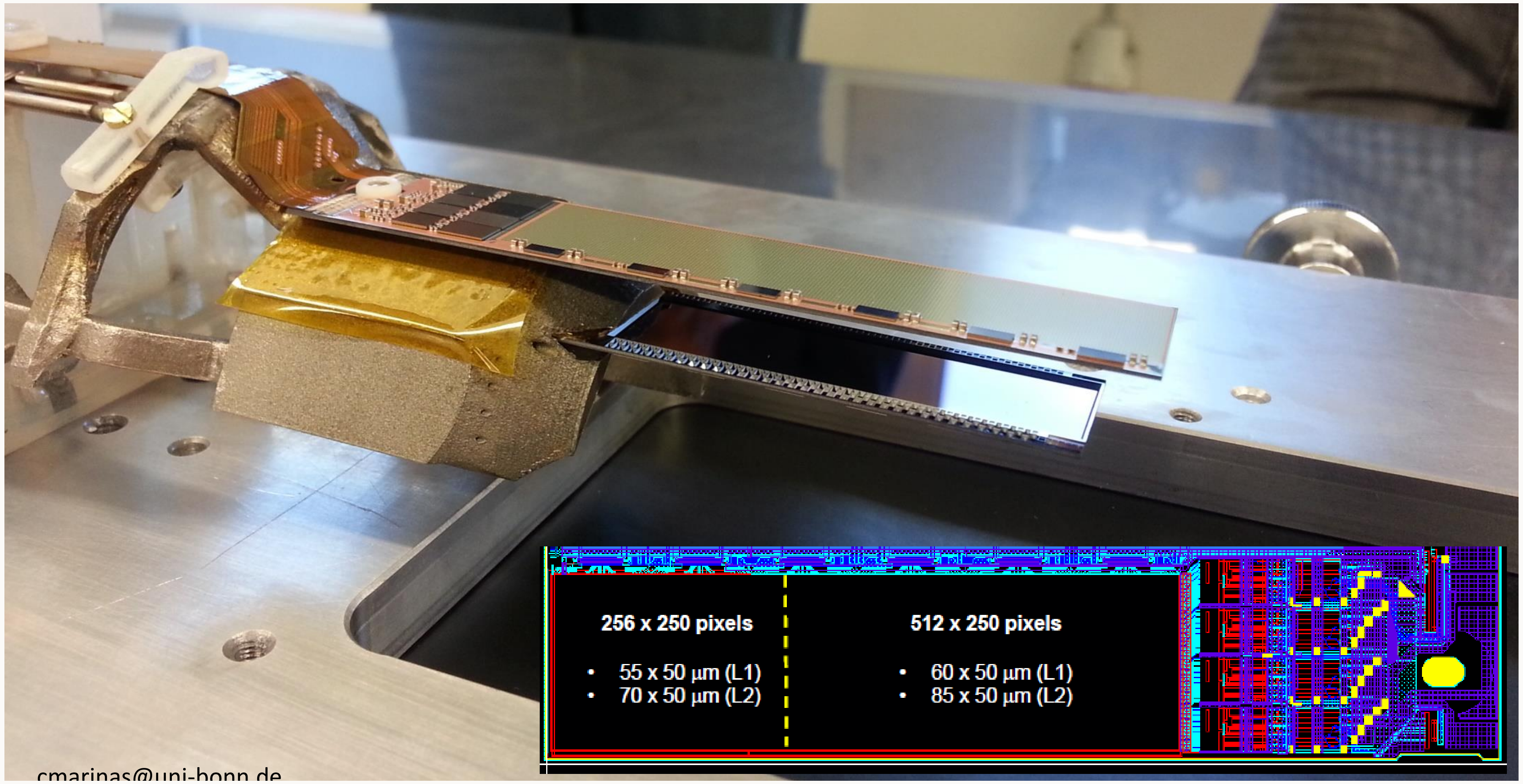


Tracking Detectors



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		impact parameter resolution $\sigma_{z_0} \sim 20\ \mu$m (PXD and SVD)
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	
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)

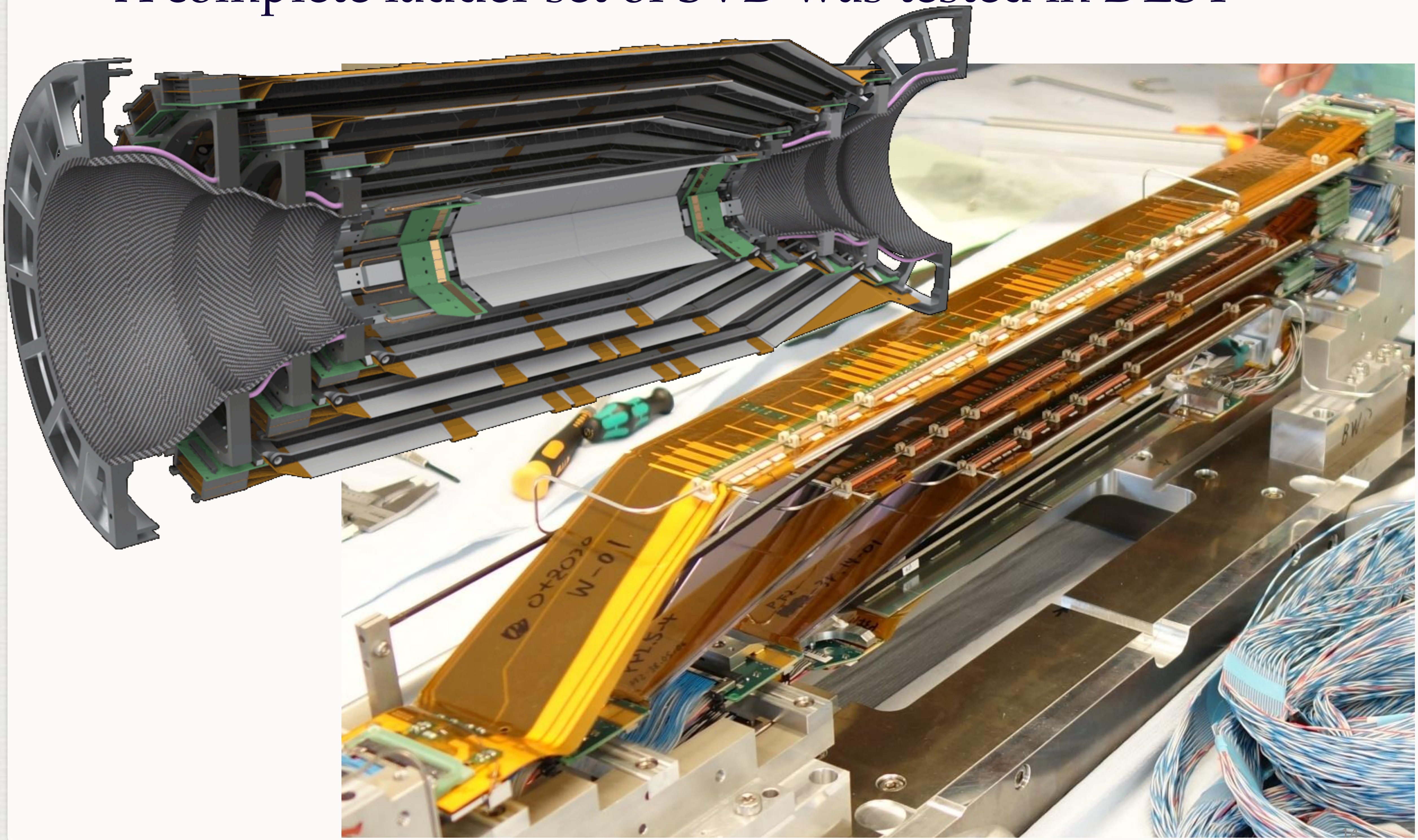
PXD (The Pixel Silicon Detector)



- Final devices extensively tested in DESY in April 2016
  - DAQ chain for PXD + SVD + High Level Trigger (HLT) + Event builder (PXD & SVD data merger)
  - Selection of hits on the Region Of Interest determined from the HLT
  - Analysis of the data (efficiency and resolution) are ongoing

SVD The Silicon Vertex Detector

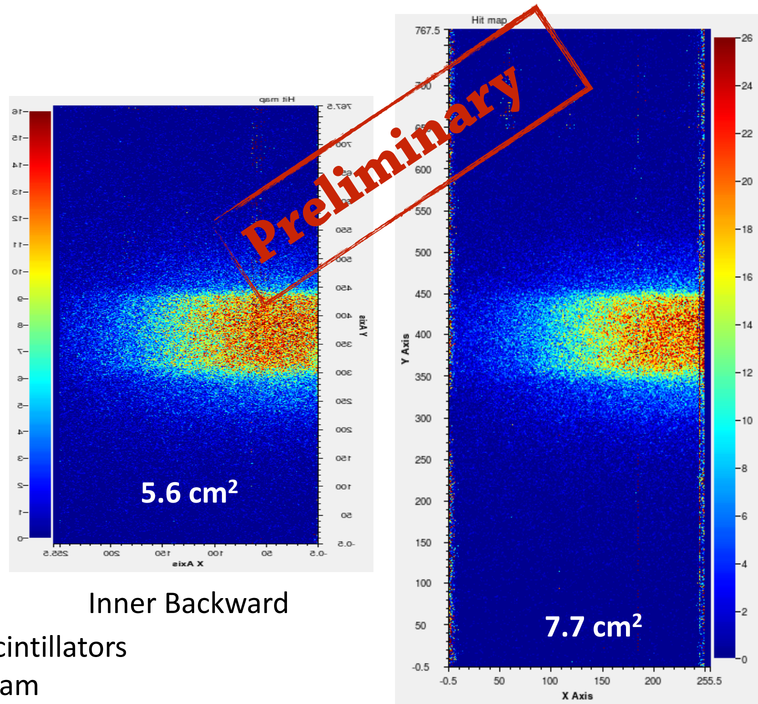
- A complete ladder set of SVD was tested in DESY



First Preliminary Results

PXD Hit Maps

Threshold = 5 (~ 1200 electrons)



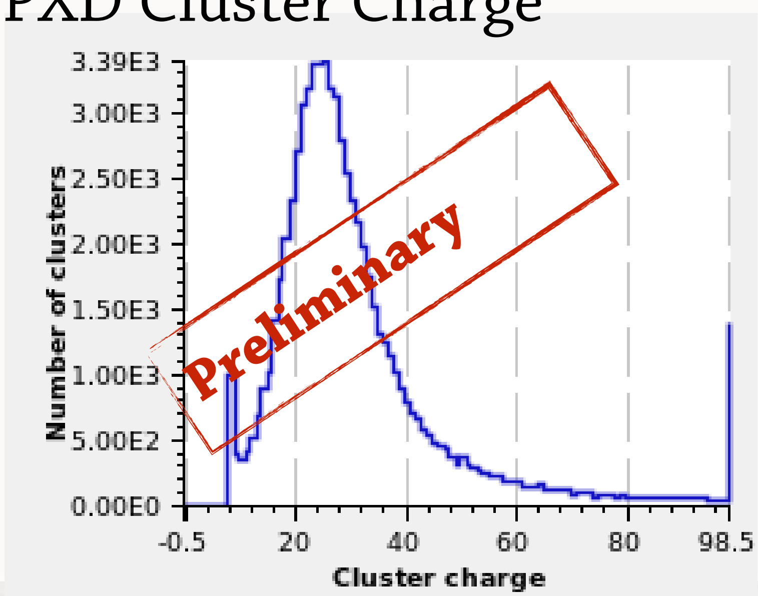
Inner Backward

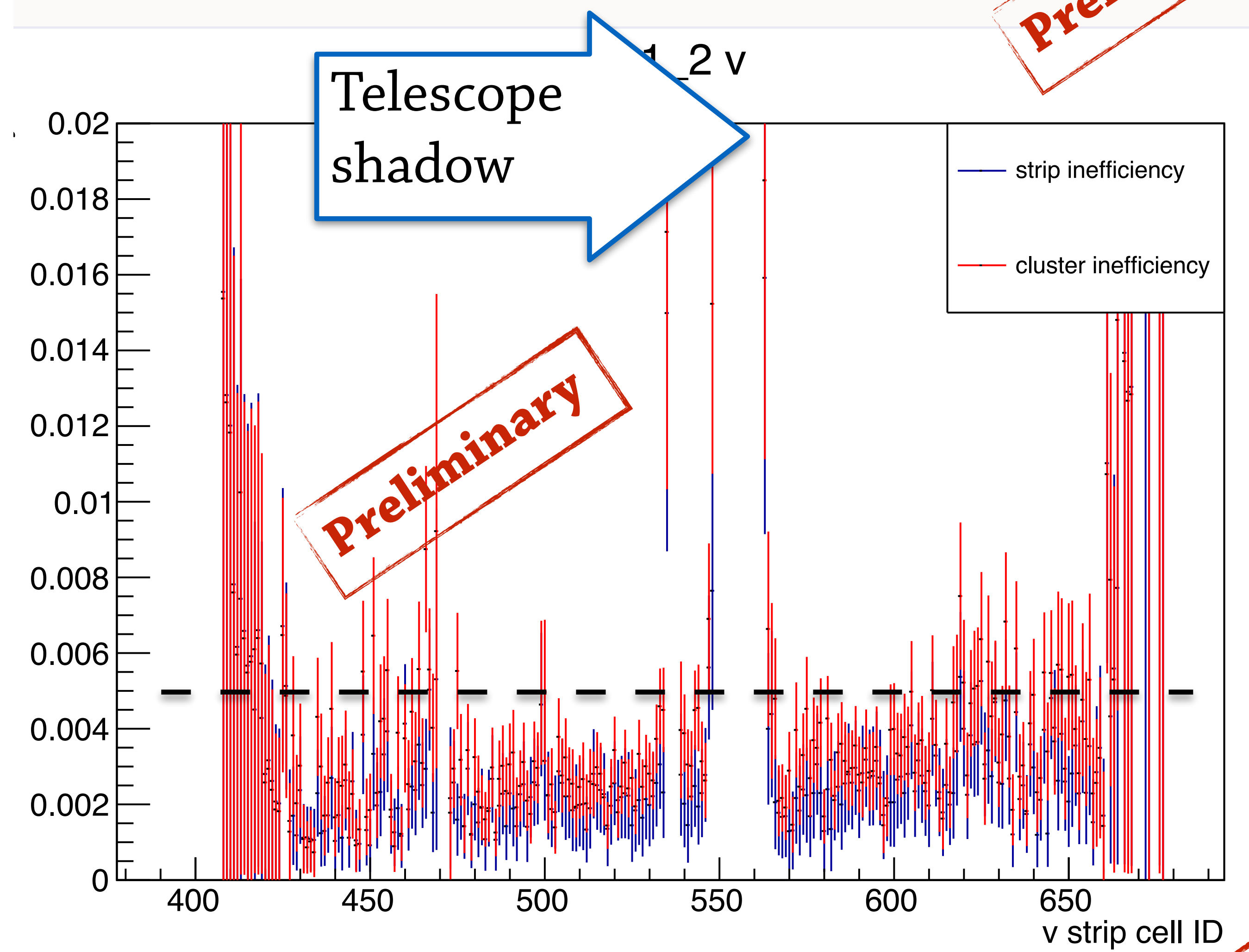
Outer Backward

Trigger on 4 scintillators
Collimated beam
No magnetic field

cmarinas@uni-bonn.de

PXD Cluster Charge

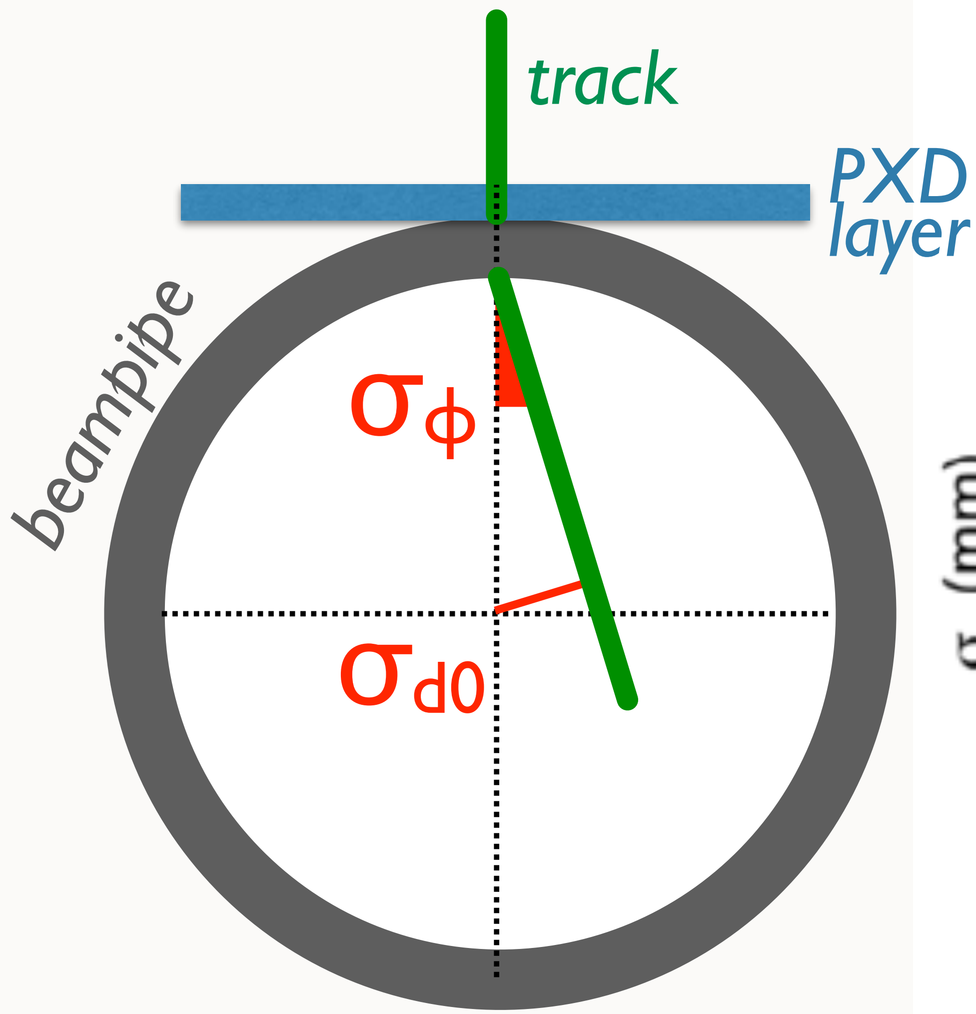




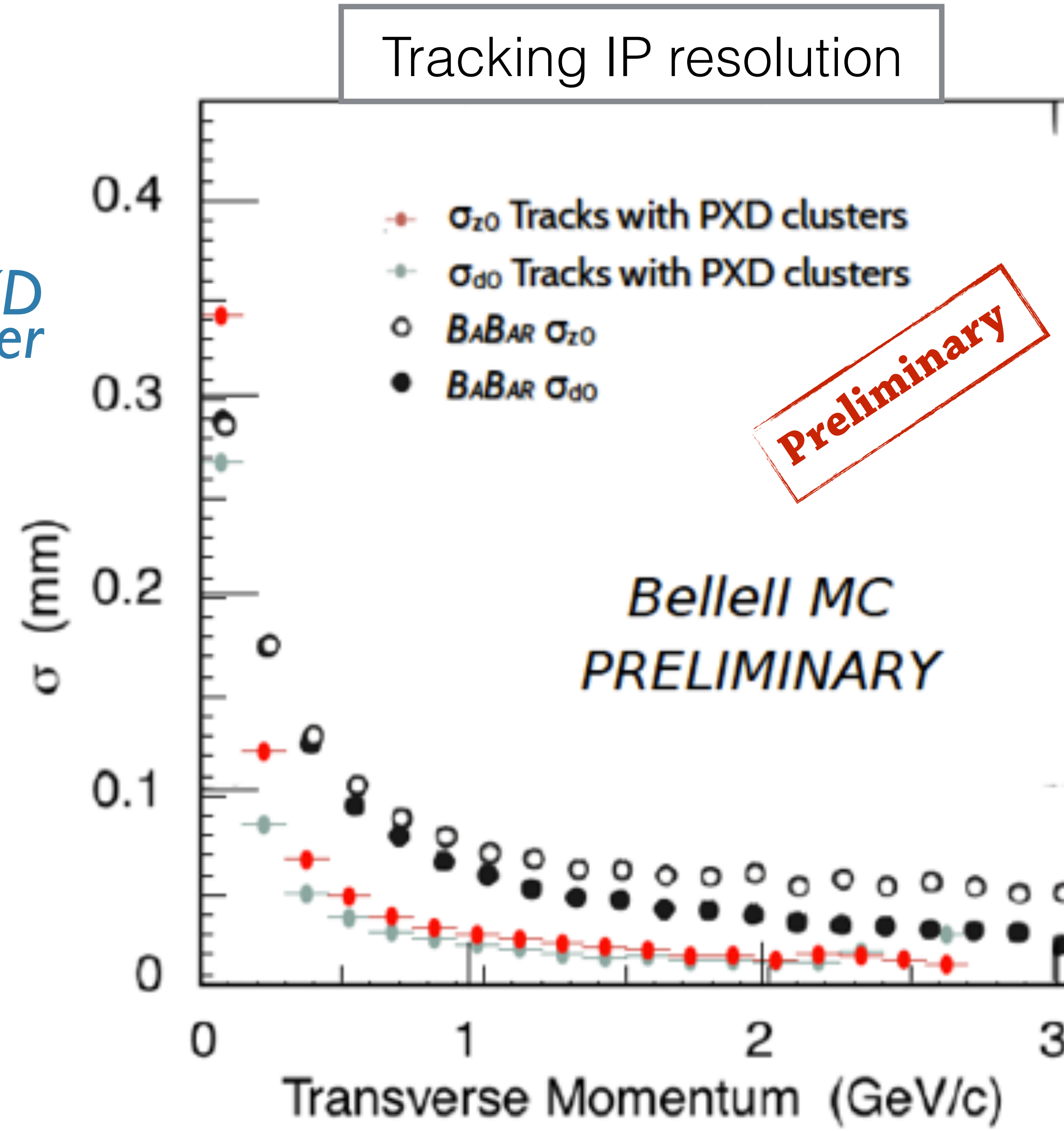
SVD typical strip inefficiency < 0.5%

Preliminary

Impact Parameter Resolution



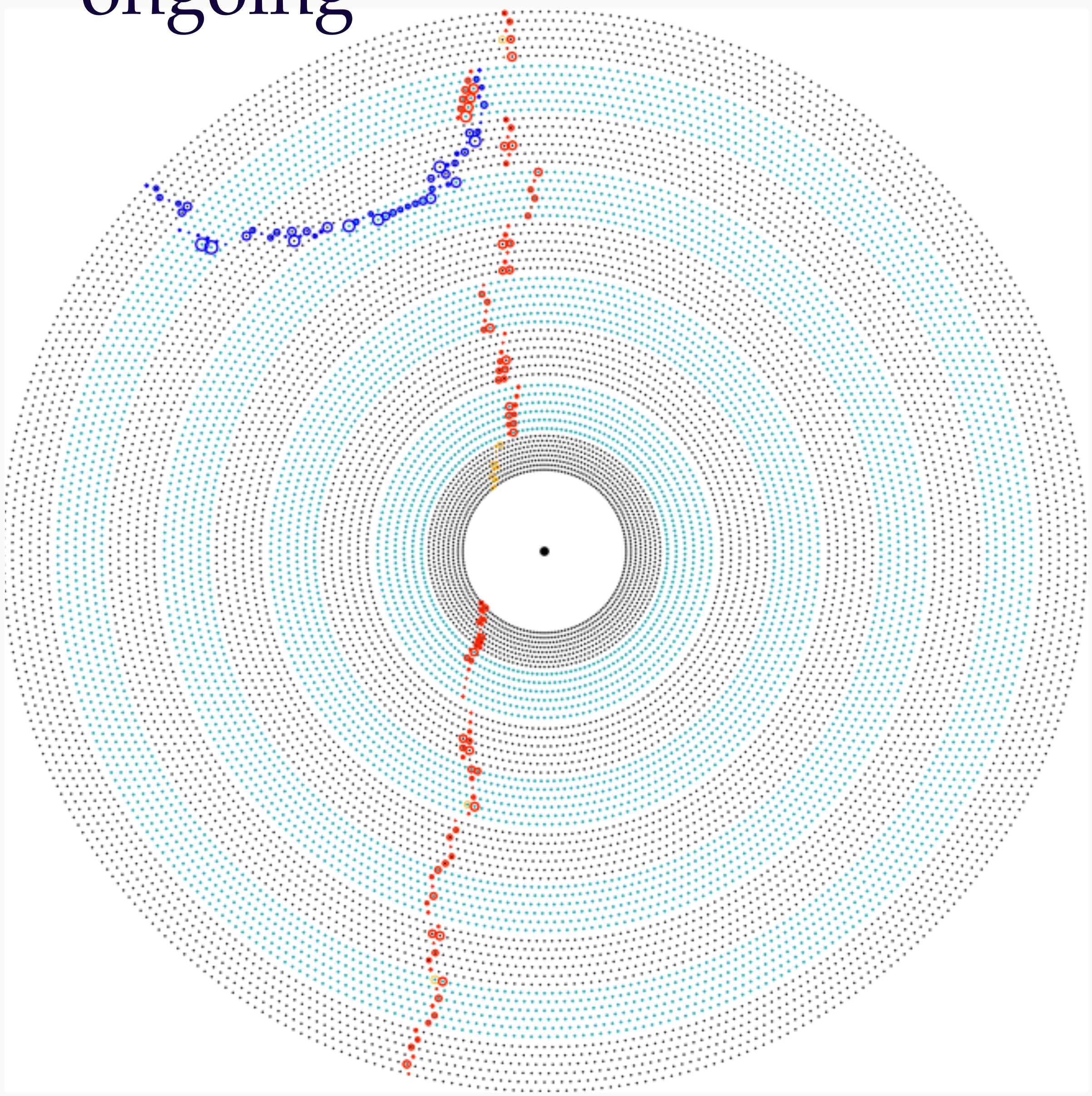
$\sigma_{d0} \simeq r_t \cdot \sigma_\phi$



Factor 2 improvement over BaBar!

CDC the Central Drift Chamber

- CDC stringing completed
- Commissioning using cosmic rays is ongoing



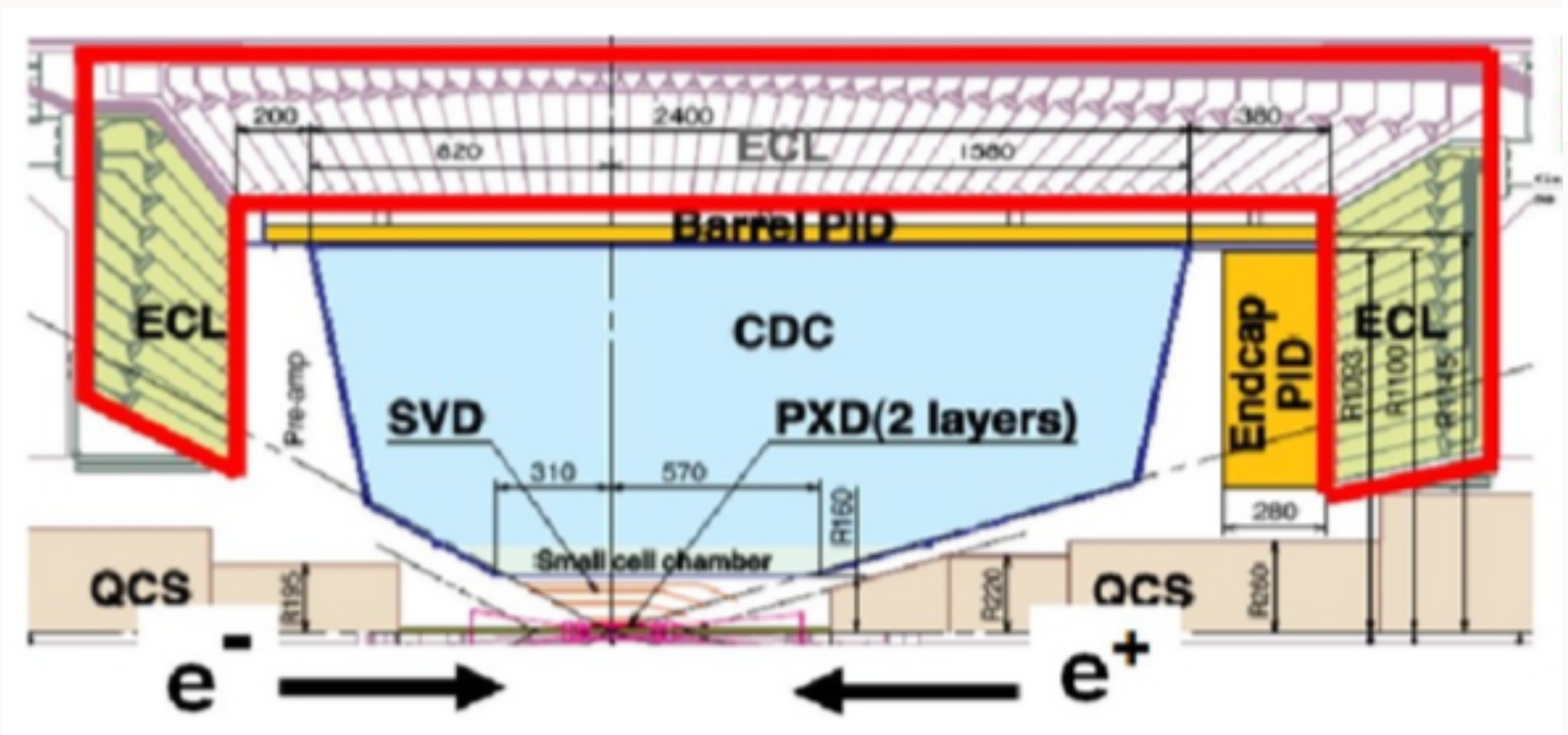
ECL: The Electromagnetic Calorimeter

- Higher backgrounds (Machine + Physics)
  - Electronic upgrade: improved waveform features extraction (ADC & fitting)
  - Cosmic rays commissioning ongoing

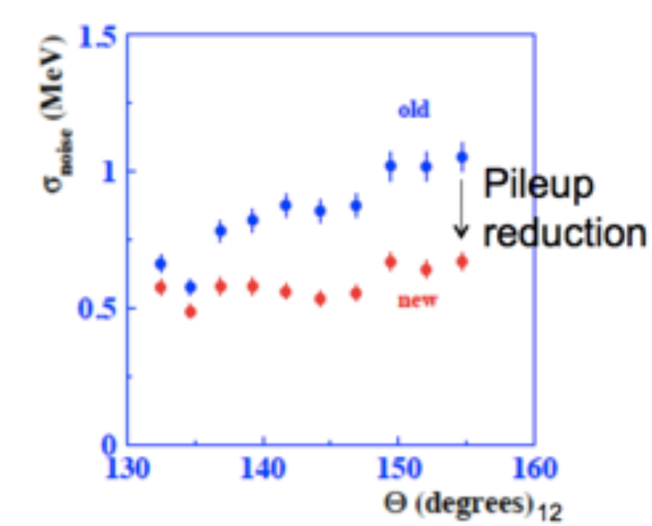
Belle II ECL trigger efficiency (simulation) compared to Belle ECL efficiency

Physics trigger: $E_{tot} > 1$ GeV

	ε_{phys} (total)	ε_{signal}	ε_{bkg}
Belle	99.42 %	88.70 %	10.72 %
Belle II	99.90 %	99.12 %	0.78 %



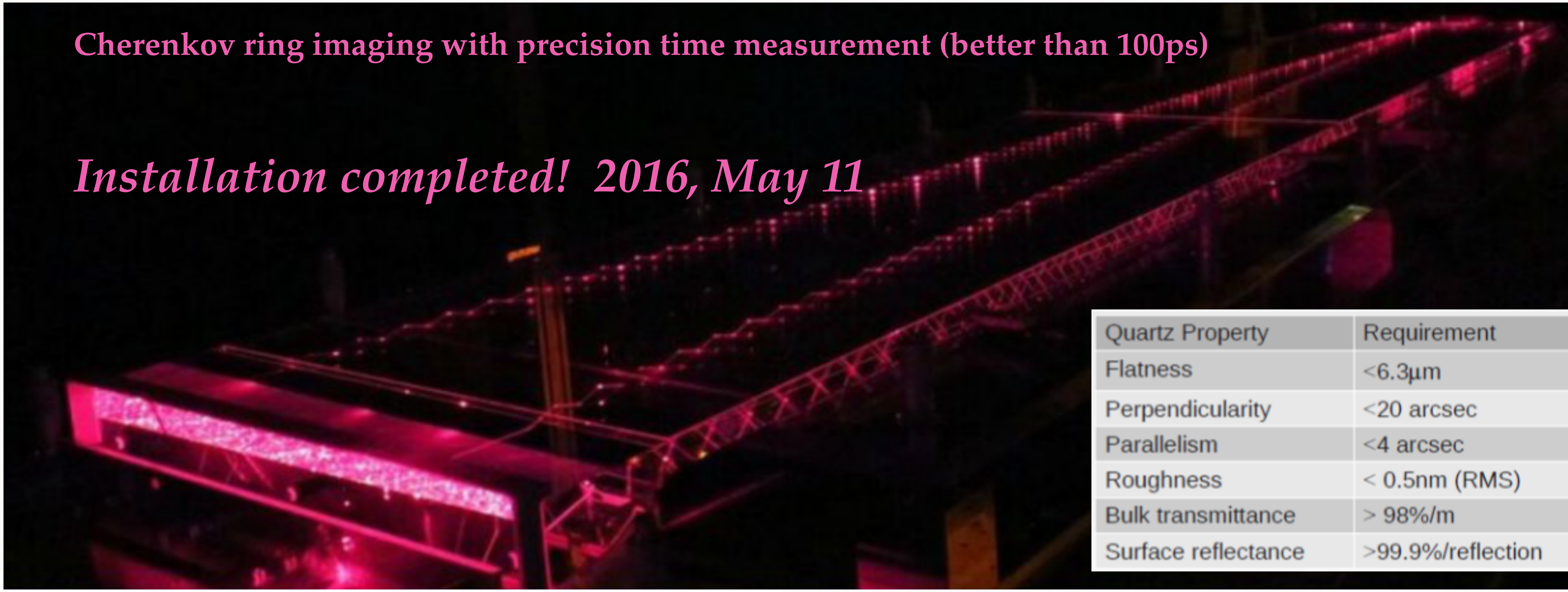
Early prototype tested at Belle



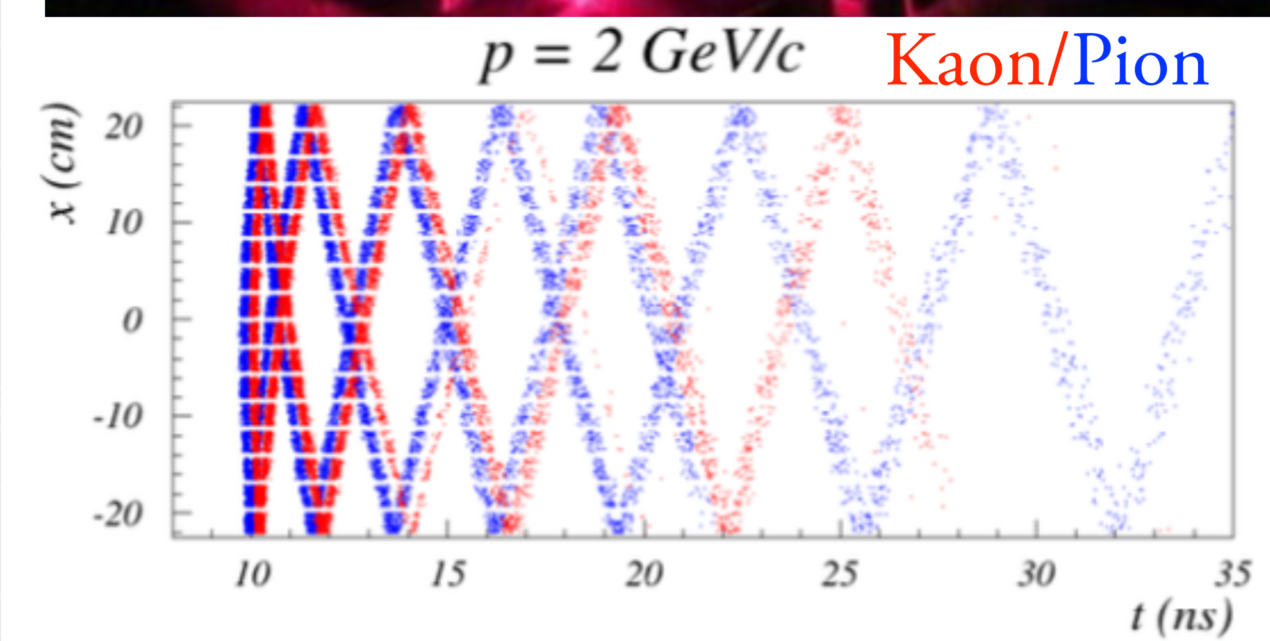
Barrel PID: TOP (Time Of Propagation)

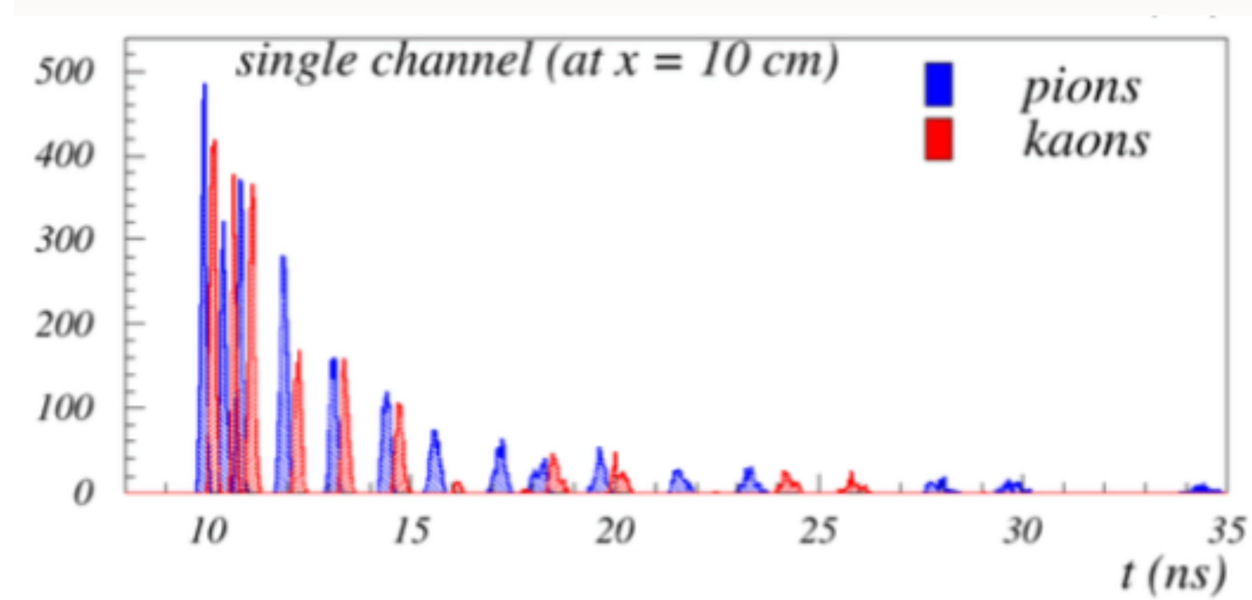
Cherenkov ring imaging with precision time measurement (better than 100ps)

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

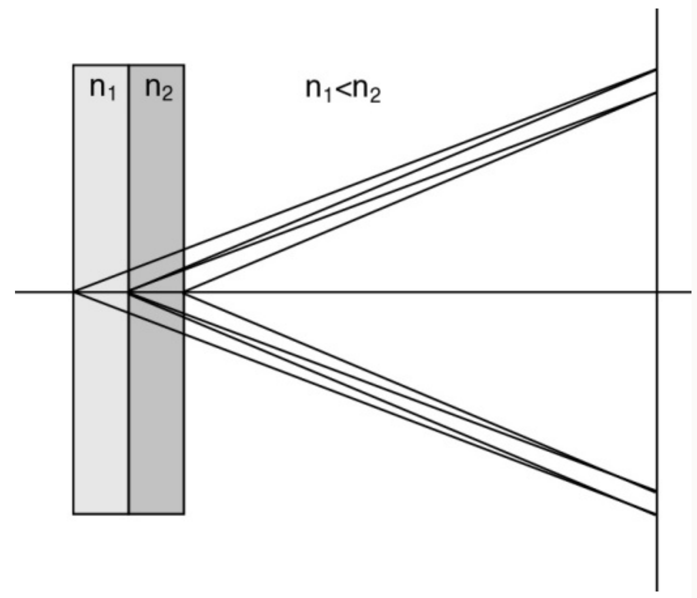


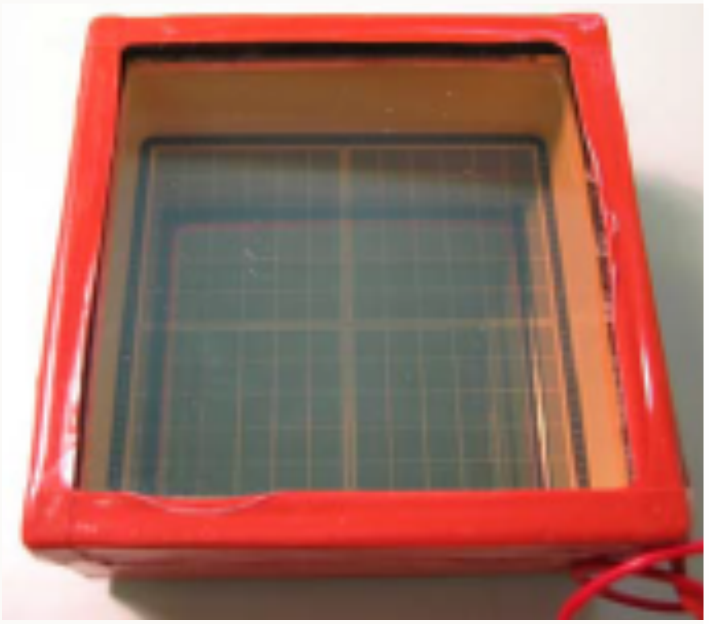


Forward PID:ARICH (Aerogel RICH)

- Focusing by refractive index grading. Readout by 144 channels HAPD
- Kaon / Pion separation: 6 sigma @ 4 GeV/c
- Successful test in magnetic field
- Installation in Autumn

2+2cm aerogel

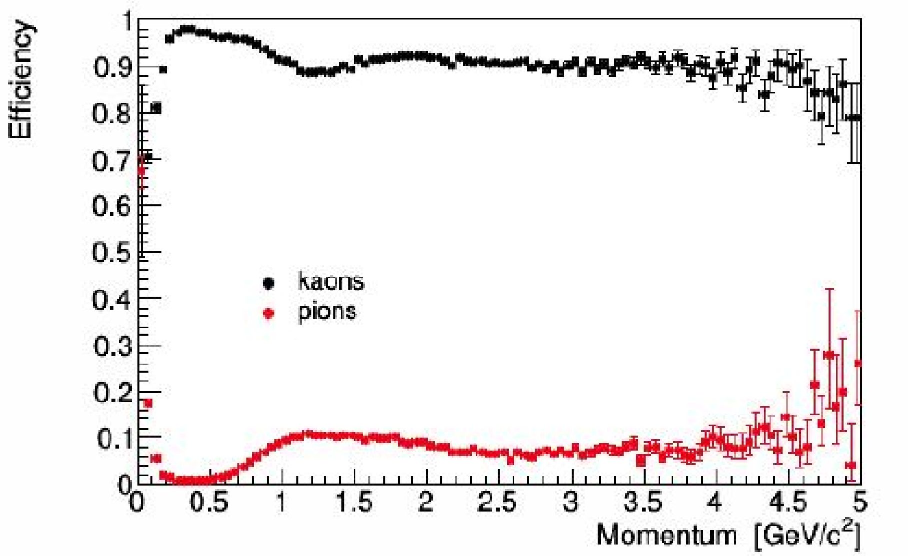




144 channels HAPD

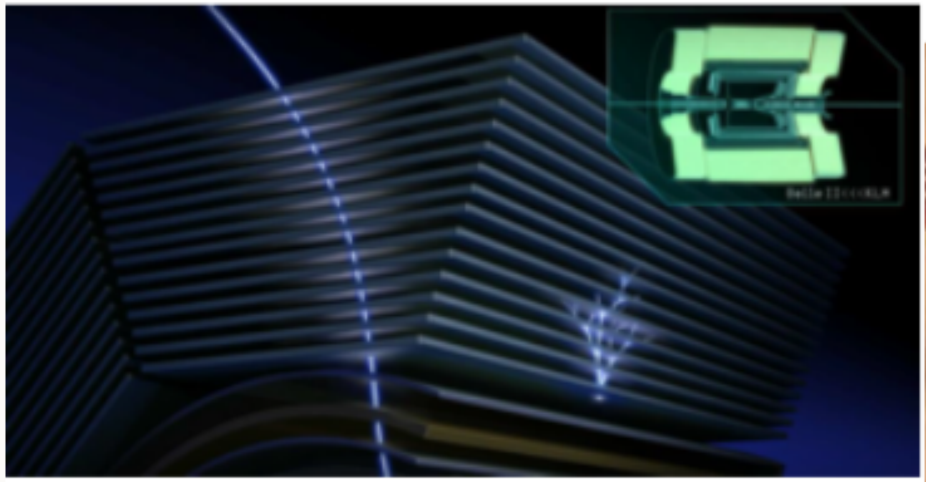
K/π separation

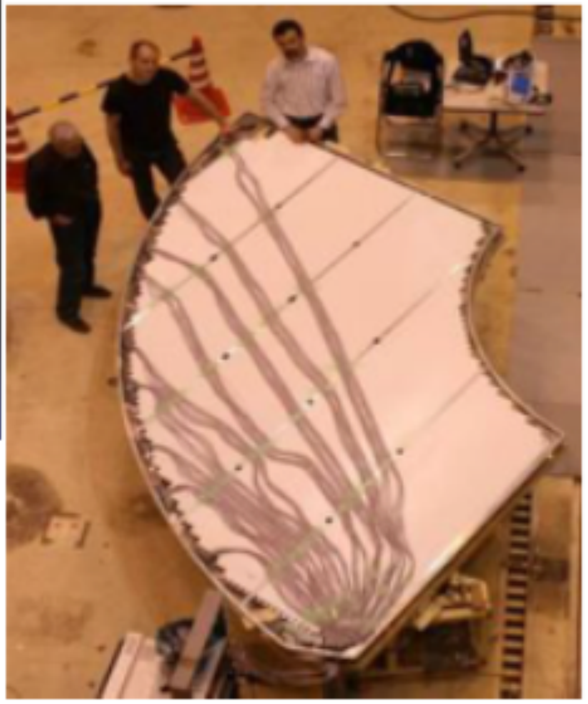
TOP+ARICH+dE/dx



KLM: K Long and Muon system

- The end-caps and the two innermost layers of the barrel were replaced with scintillators to cope with increased backgrounds
- Installation completed
- Commissioning in progress with cosmic rays data

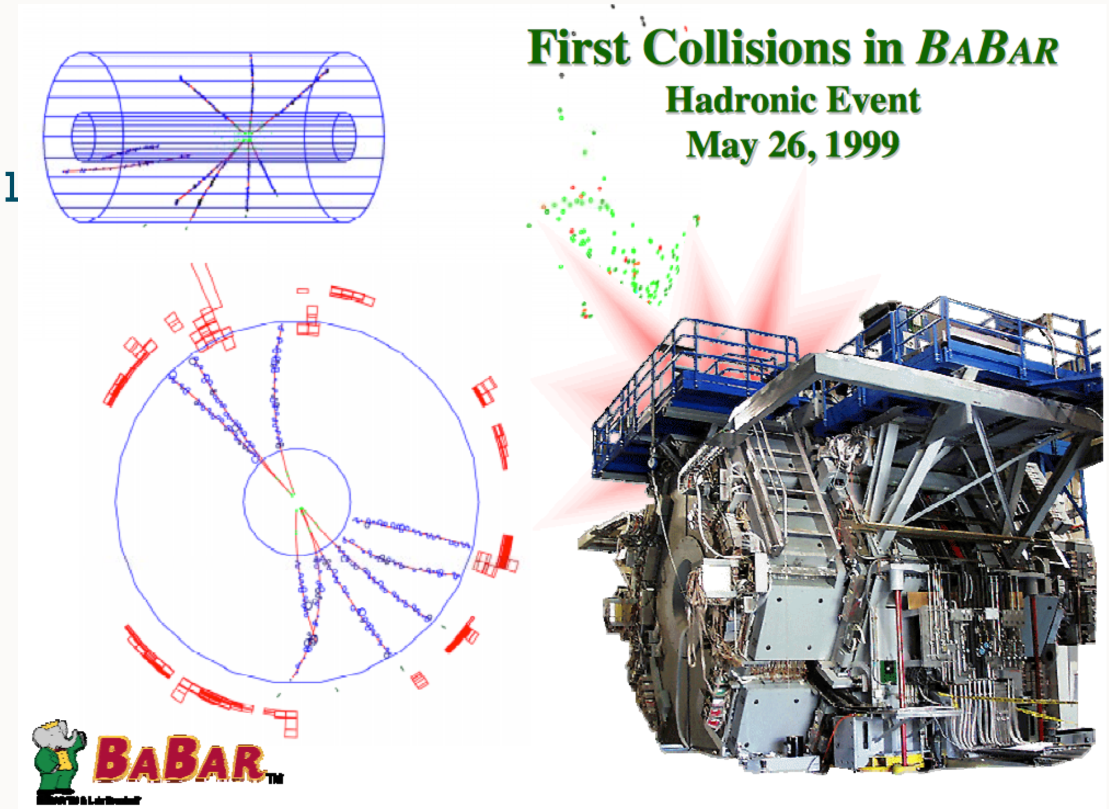




The Belle2 Software

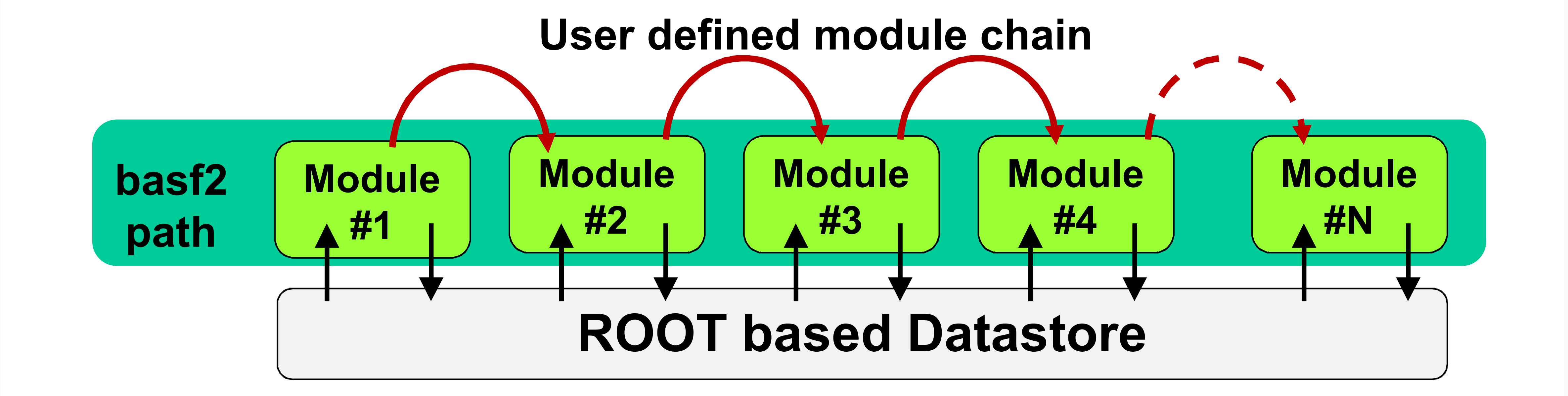
BaBar TrkRecoTrk CVS log

- 1.1 (Aug 30, 1996) [XXX, Undisclosed author]
  - A few scattered pieces of newly designed tracking code.Nothing worth looking at yet.
- 1.2 (Oct 10, 1996)
  - More bits and pieces. Someday it will compil
- 1.3 (Oct 24, 1996)
  - A couple of files compile now. Whoopee.
- 1.4 (Oct 30, 1996)
  - First set of files that will compile.
- 1.5 (Oct 30, 1996)
  - Untimely commit so I can move development to
- 1.6 (Nov 5, 1996)
  - Added a version of the helix fitter (currently implemented with unmodernized HOTs). Compiles.

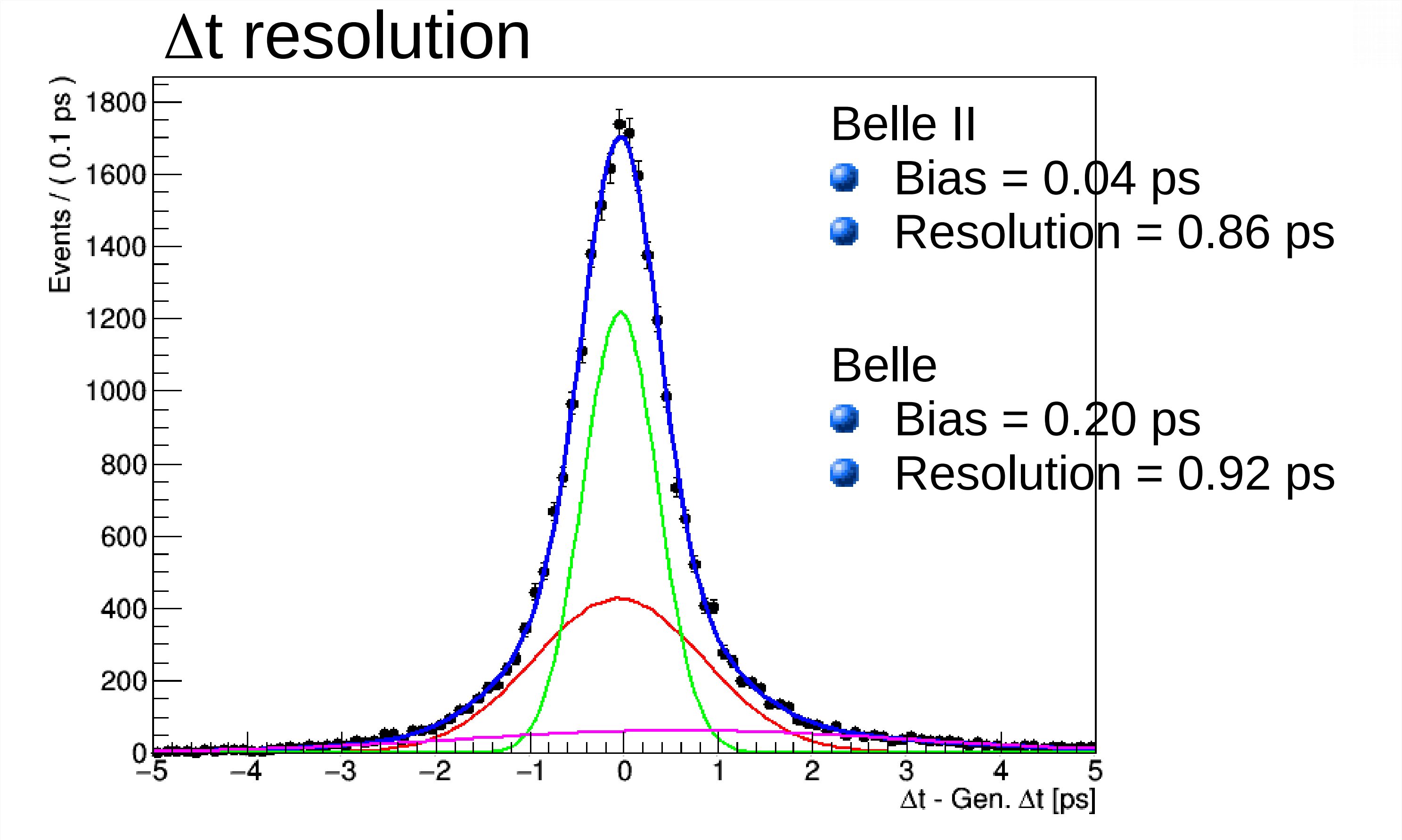


- April 1998: I joined the experiment. The track reconstruction was (painfully) working. There were no vertexing tools nor composition tools neither the map from reco objects to true MC particles on official MC production was available (because we were short on disk space).
  - May 26, 1999: first hadronic event. [XXX left the HEP business]
  - Aug 9, 1999: Lepton Photon talk: 2 (slowly spell it out: two) B to $J/\psi\ K_s$ events (~150 pb^{-1})

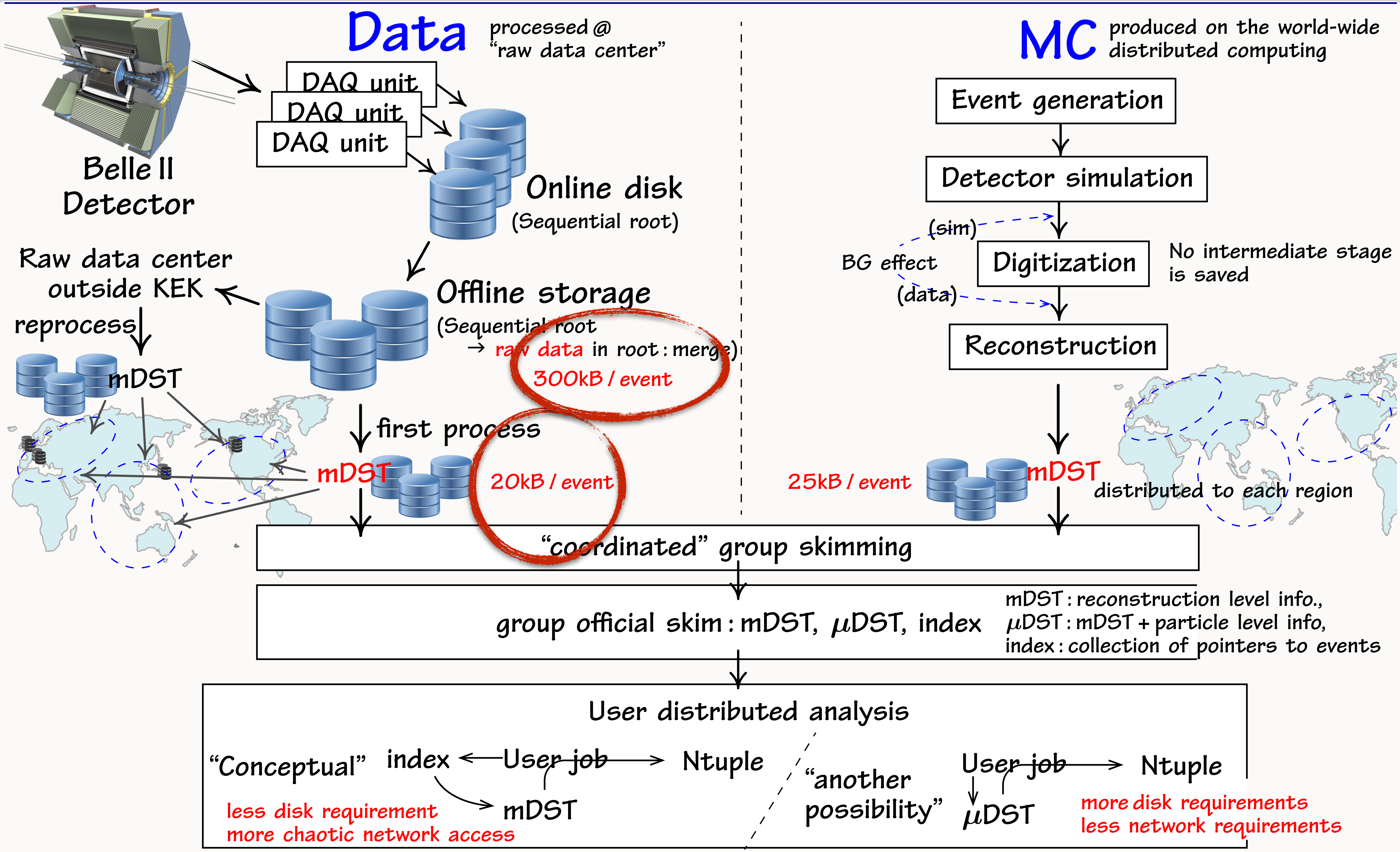
Reconstruction Software: BASF2



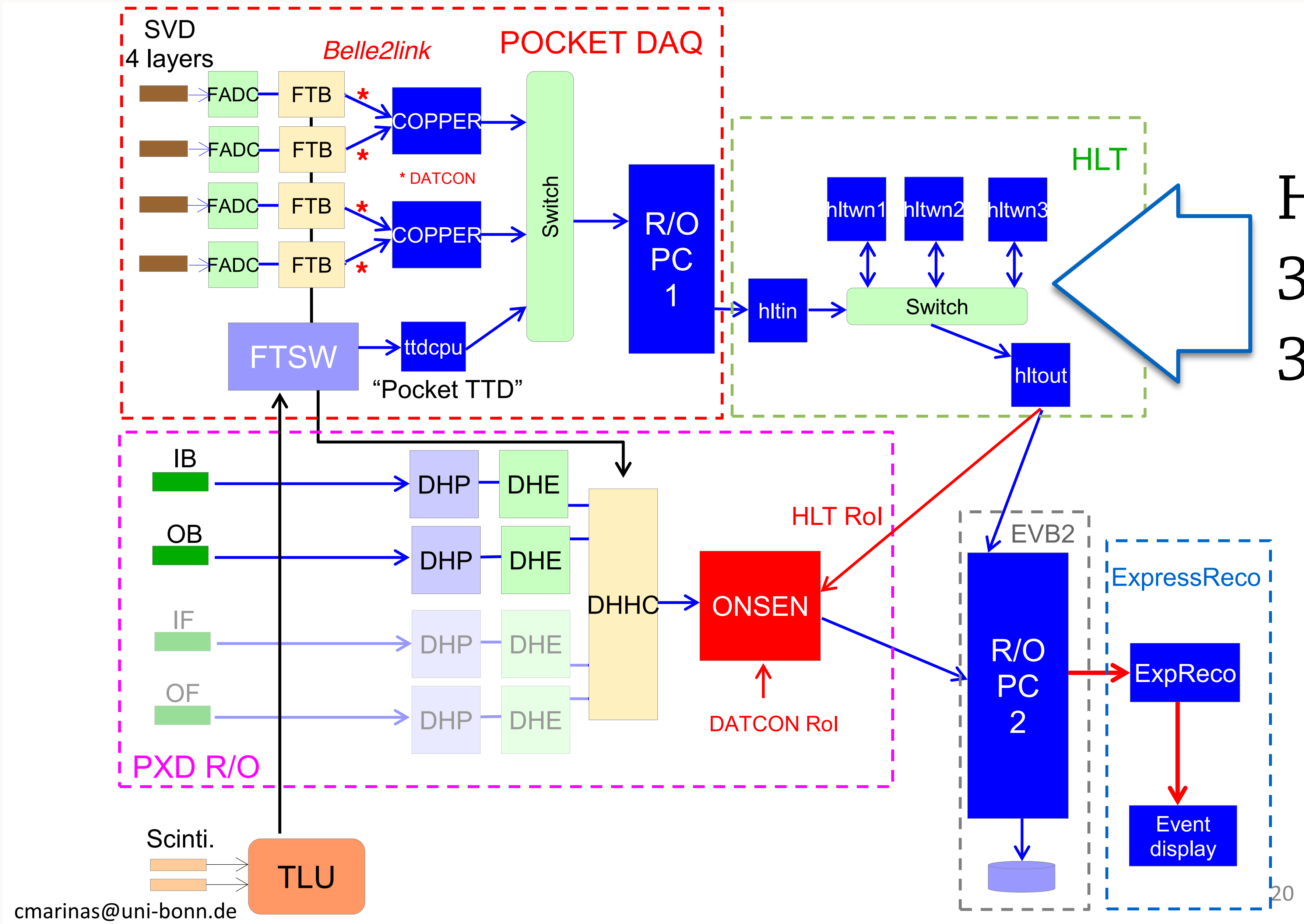
- BASF2: Belle2 AnalysiS Framework 2 +
  - ~ 650k C++ lines (excl. comments) + python steering files + external libraries and tools (Root, Geant, g++, python + …)
- Track reconstruction, kalman filtering, vertexing, neutral reconstruction, PID, vertexing, analysis



Computing Model



Scaled Version of the Full Belle2 DAQ

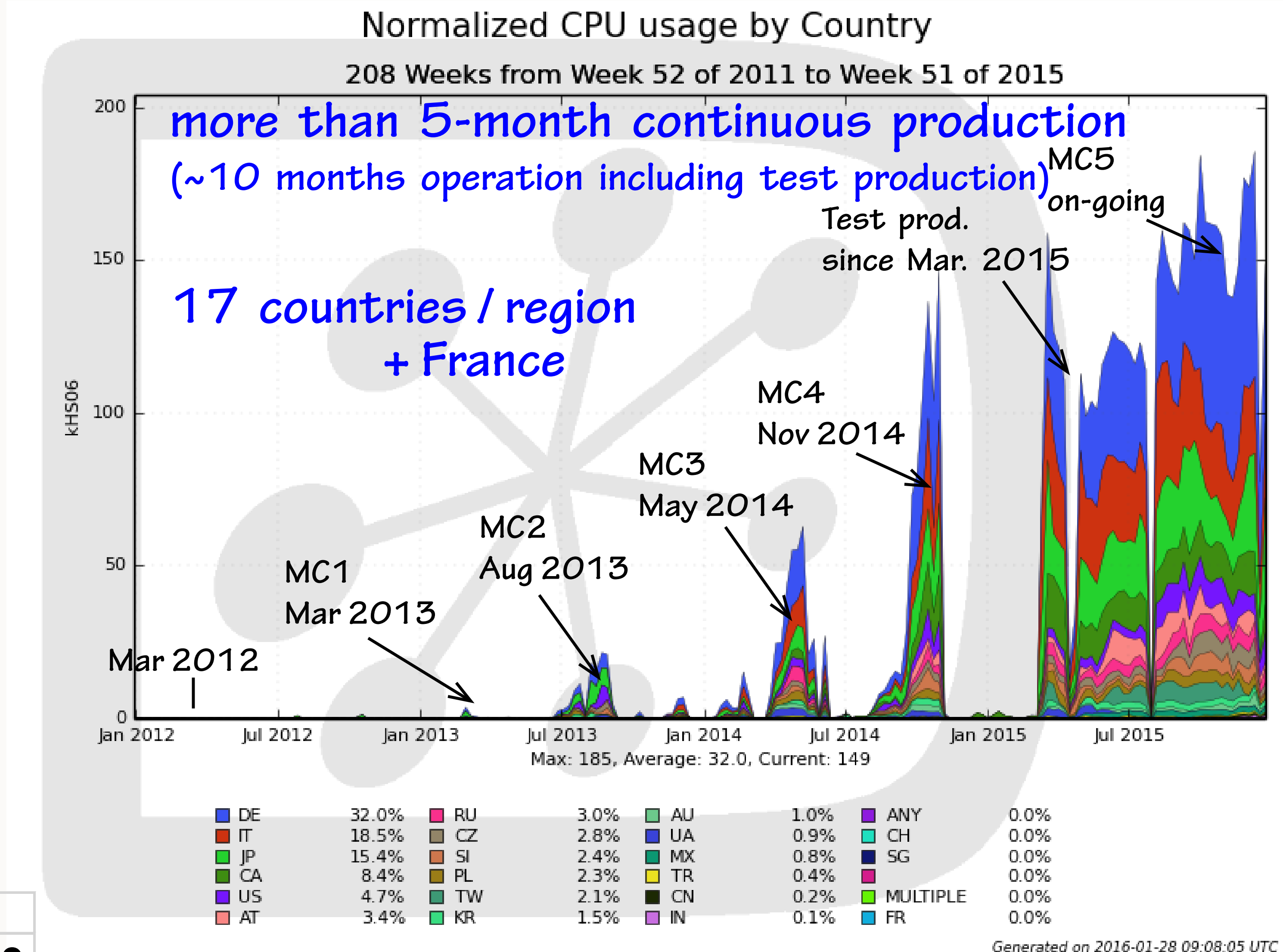


High Level Trigger
3 nodes, trigger rate 3KHz

- Scaled version of the DAQ system and of the High Level Trigger dataflow tested in DESY (April 2016)

Grid MC production

34.1 billion events
simulated and reconstructed
all around the world
24.1 billion of Υ(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.

Conclusions

- The present status of superKEKB and of the Belle2 Hardware and Software had been sketched
- The whole system will gradually be ready for the big Physics run starting end of 2017, beginning of 2018
- Join us now! Enjoy the heavy flavor in the cleanest environment ;) avoid the line.