Physics and Status of Belle II

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SAGA YONSEI
Workshop on High-Energy Physics

Contents

I. Challenges to the Standard Model

II. Why a Super B Factory?

III. The Super KEKB Project

IV. The Belle II Detector

V. Progress and Status

Part I

The Standard Model

The Age of Quantum Theory

- 1900 – 1964 A.D.
  - The start of the modern physics.
  - By 1930, quantum mechanics and special relativity are well established. Only three known fundamental particles :
    Proton, electron, photon.
  - However, they found new particles in cosmic rays.

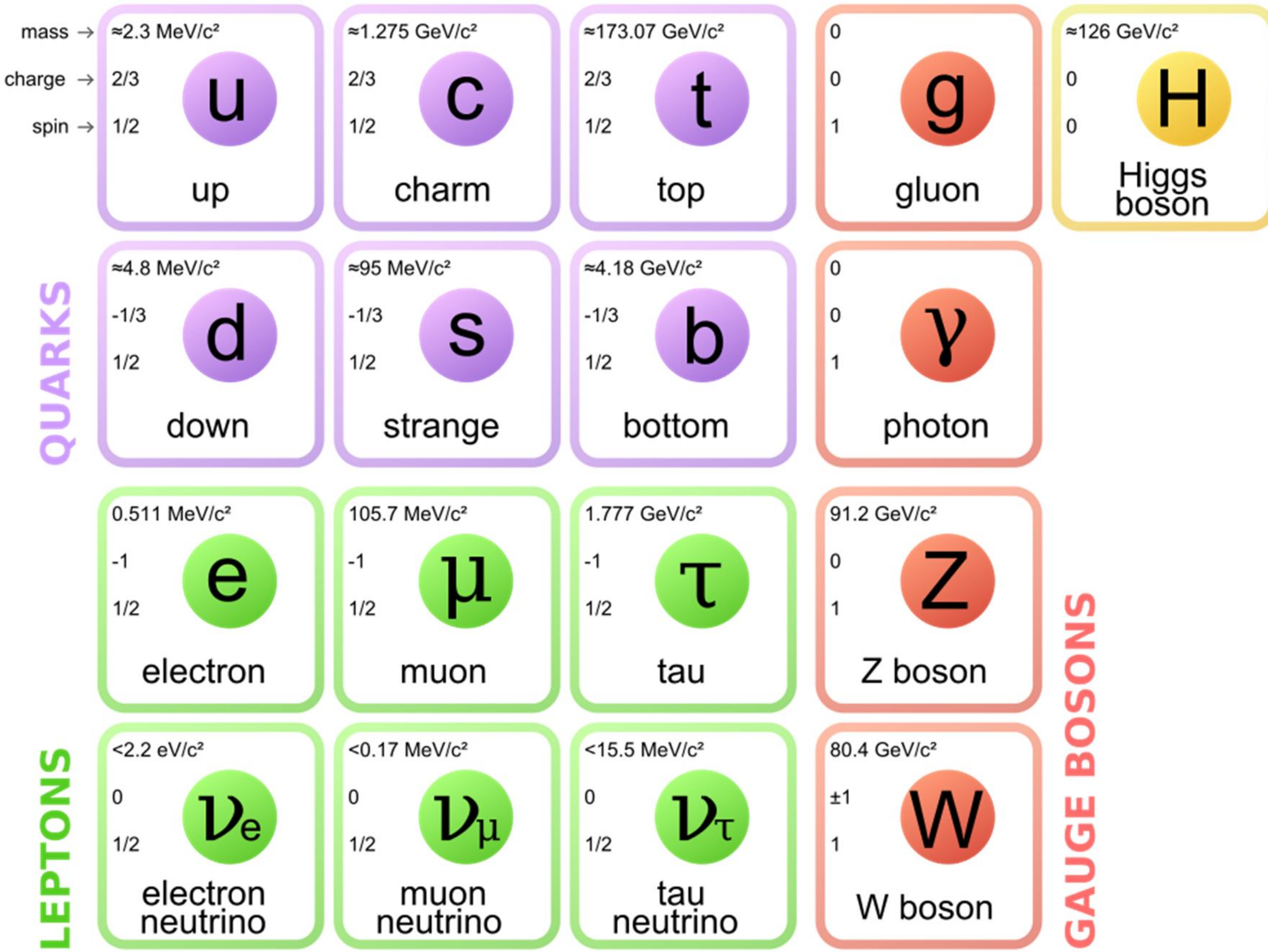
Niels Bohr, Werner Heisenberg, and Wolfgang Pauli

http://photos.aip.org/favorites.jsp

The Age of Standard Model

- 1964 A.D. – Present
  - Many efforts to understand why there are so many particles and try to unify the known physics forces into one.
  - Gell-Mann, Zweig, Glashow, Bjorken, Nambu, Weinberg, Salam, Feynman, Iliopoulos, Maiani, Perkins, Wilczek, Righter, Ting, Goldhaber, Perl, Lederman, Rubbia, …
  - In summer of 1974, John Iliopoulos collected all the views of physics in a single report. The name “Standard Model”.
  - November 1974 (the November Revolution) :
    The Ting group at Brookhaven and the Richter group at SLAC announced the discovery of charm-anticharm particle independently, called “J” or “psi”, on the same day.
  - July 2012, discovery of the “Higgs” particle announced.

The Standard Model

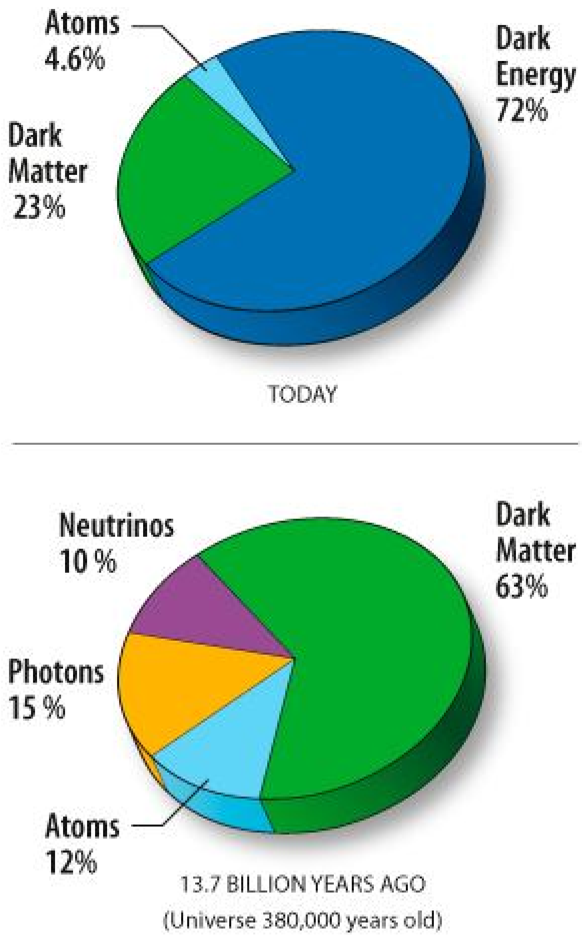


http://en.wikipedia.org/wiki/File:Standard_Model_of_Elementary_Particles.svg

What Now?

The Big Questions to the Standard Model

Challenges to the Standard Model



The Standard Model has been very successful. However,

- It can explain only the 4.6% of the matter and energy in the present Universe.
  - Dark Energy: 72%.
  - Dark Matter: 23%

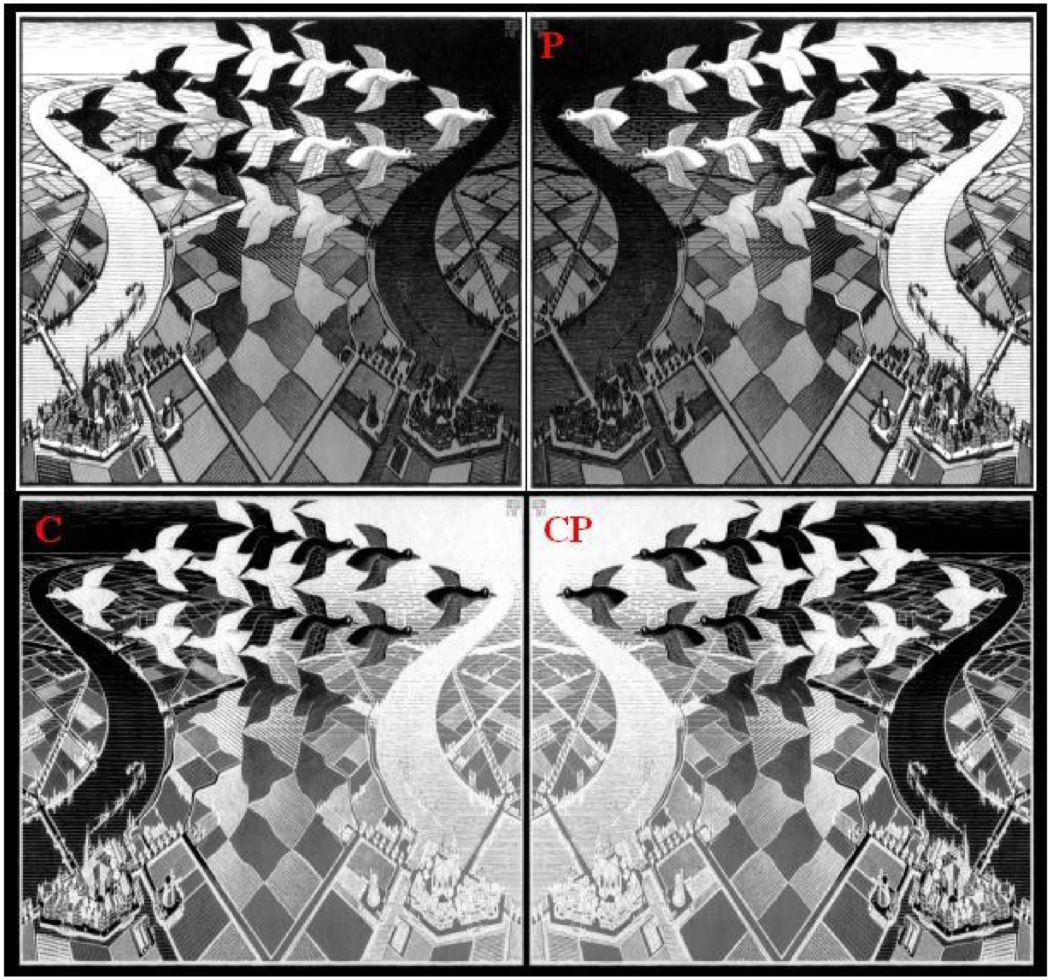
http://map.gsfc.nasa.gov/media/080998/index.htm

The Problem of CP Violation

Observed CPV in SM is not enough

to explain matter dominance over anti-matter

in the present Universe



Escher

And the Problems Goes On …

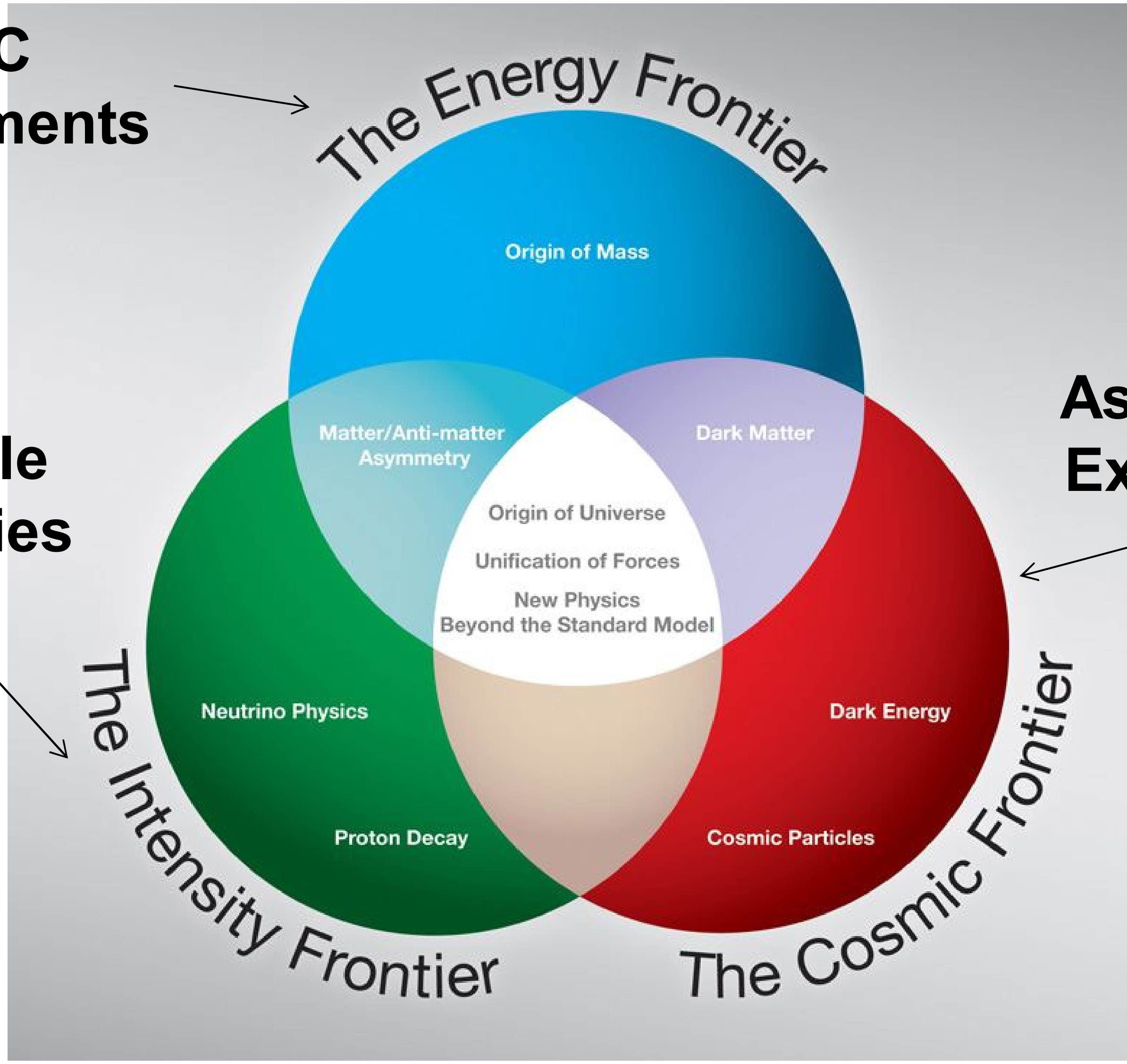
- Why there is no CP violation in the strong nuclear force processes?
- Why do the neutrinos have mass and oscillate among one another?
- Where does the gravity fit in with the other forces?
- Even though it explains only 4.6% of the matter and energy of the present Universe, the Standard Model has 19 parameters. A number too many.
- What happens if the energy of the physics processes goes higher?

Challenges to Experiments

LHC Experiments

Particle Factories

Astroparticle Experiments



http://www.fnal.gov/pub/science/frontiers/

Part II

The Belle II Experiment

– Why a Super B Factory?

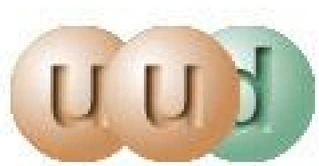
Advantages of an e+ e- B Factory

- Background is very low compared to a proton-proton collider machine such as LHC:
  $\rightarrow$ Signal signature is clean. Trigger efficiency is high. No multiple interactions per event.
- A B meson is a long lived particle with many interesting decay modes. Easy to identify and study the decay process.
- Precise detection/reconstruction of photon, pi0, kaons is possible.
- Because of the low background, the missing energy and momentum can be regarded as analysis variables.
  - For example, a neutrino does not react directly with the detector in general.
    $\rightarrow$ Will appear as a missing energy and momentum.
- Systematic uncertainties are different from the LHC experiments.
  - Detector response / systematics is well known.
  - Will be crucial to either confirm or refute the LHC results.

We Cannot See Quarks Directly inside the Detector.

- Leptons can exist by themselves
  - Electron, muon, tau, and their neutrinos
- Quarks "cannot" exist by themselves.
  They are only found as constituents for

  mesons (two quarks) and baryons (three quarks).
  - Baryon :Proton (uud), neutron(udd)



  - Meson: $\pi^0(u\bar{u} - d\bar{d}),\ \pi^+(u\bar{d}).$

$$K^+(u\bar{s}),\ K_S^0(d\bar{s} - s\bar{d}),\ K_L^0(d\bar{s} + s\bar{d}).$$

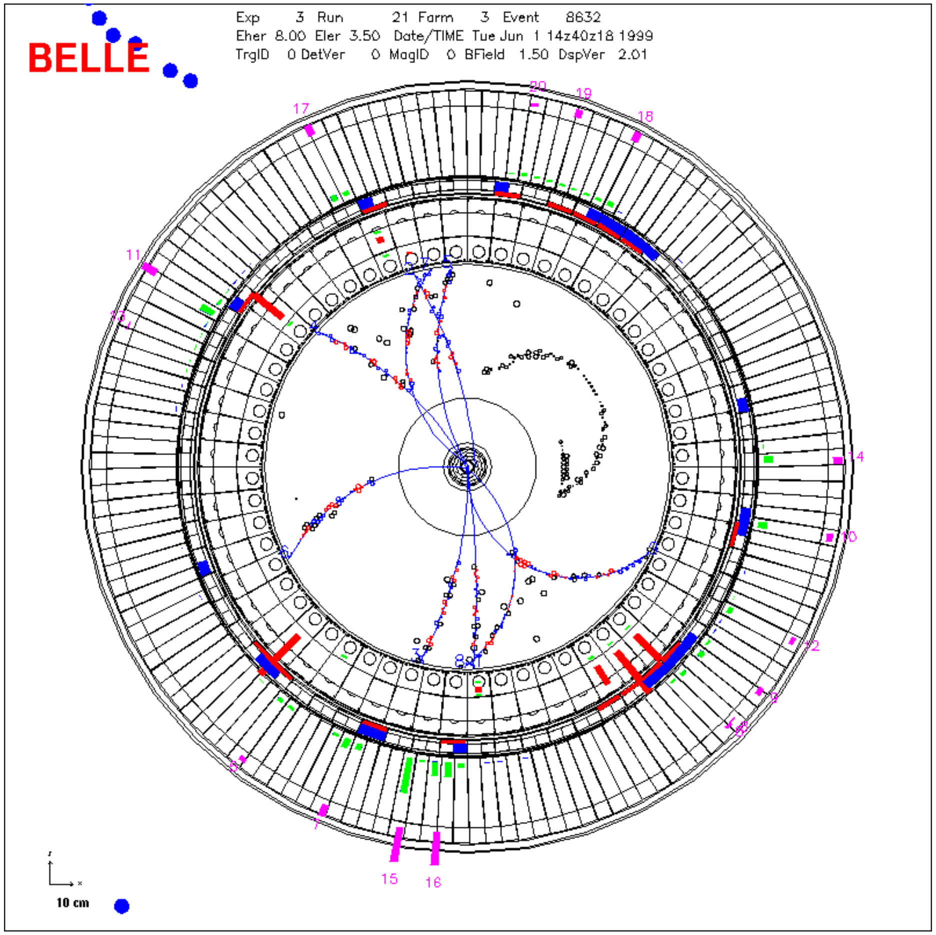
$$D^0(c\bar{u}),\ D^+(c\bar{d}),\ D_s^+(c\bar{s}).$$

$$B^0(d\bar{b}),\ B^+(u\bar{b}),\ B_s^0(s\bar{b}),\ B_c^+(c\bar{b}).$$

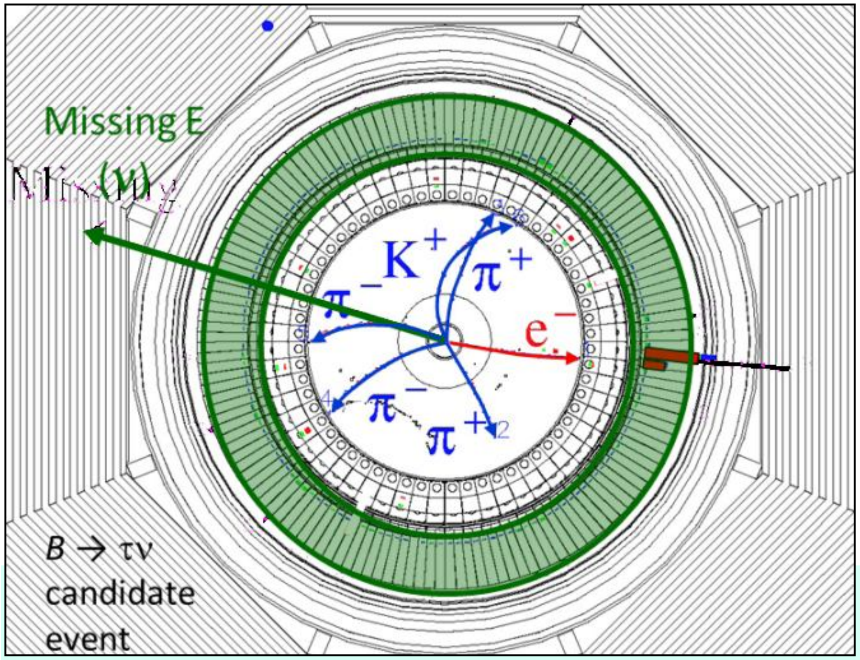
What We See Inside Detectors

- The detectors can see the trajectory of long lived particles such as
  - Photons
  - Electrons and muons.
  - Pions, kaons, and protons.

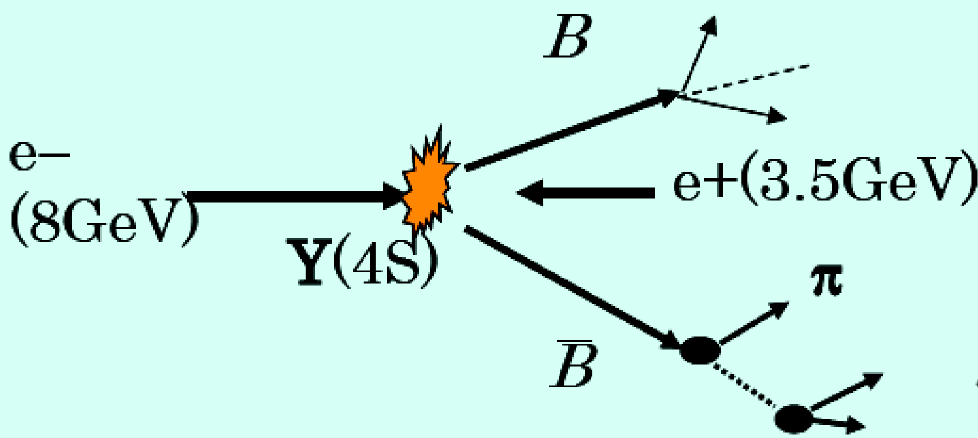
- The short lived particles decay promptly inside the detector. They are reconstructed from its long-lived children.
  - Tau
  - Most of mesons and baryons.



An e+ e- → B $\bar{B}$ Event Example



- Fully reconstructed event (tagged event):
  - One B is fully reconstructed.
  - The remaining tracks and/or missing energy is the decay of interest.
- Untagged reconstruction method is also available.

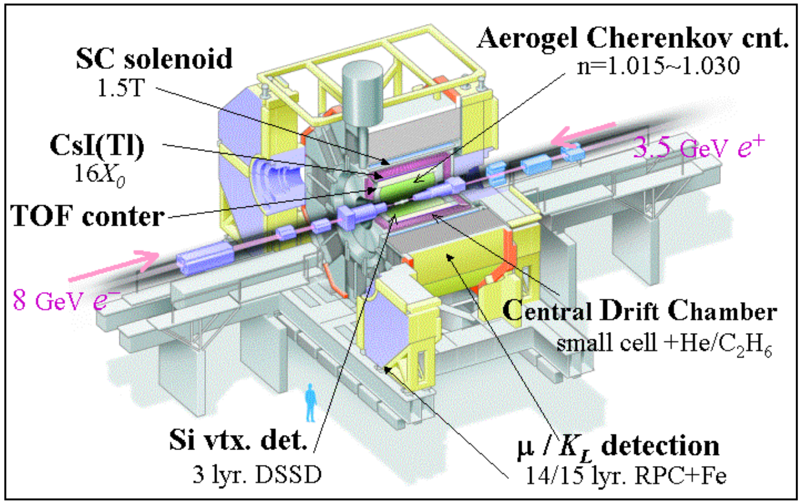


Decays of interest
$B \to X_u\, l\, \nu$,
$B \to K\, \nu\, \nu$
$B \to D\tau\nu$, $\tau\nu$
$B \to \nu\nu$

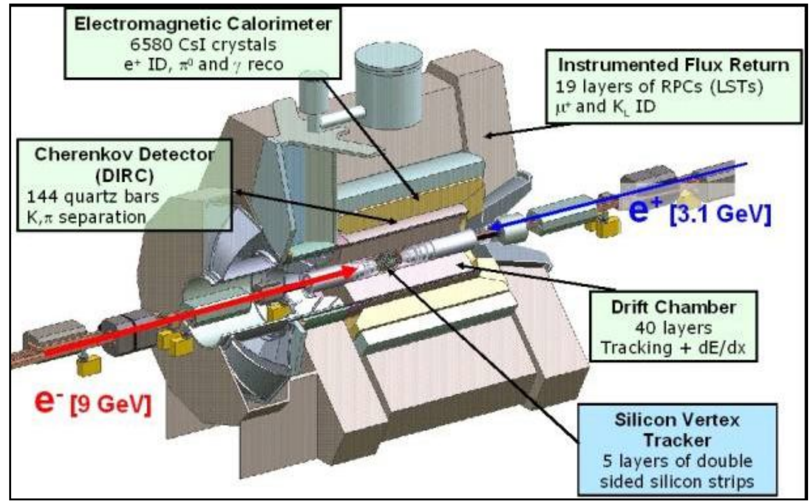
full reconstruction
$B \to D\pi$ etc. (0.1~0.3%)

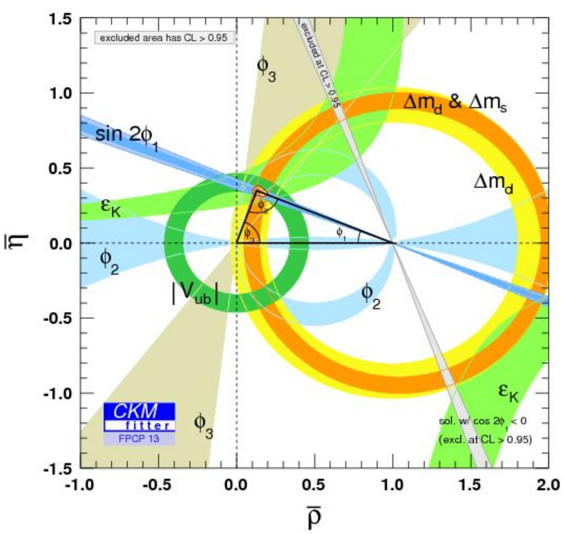
Tales of Two B Factories

Belle / KEKB



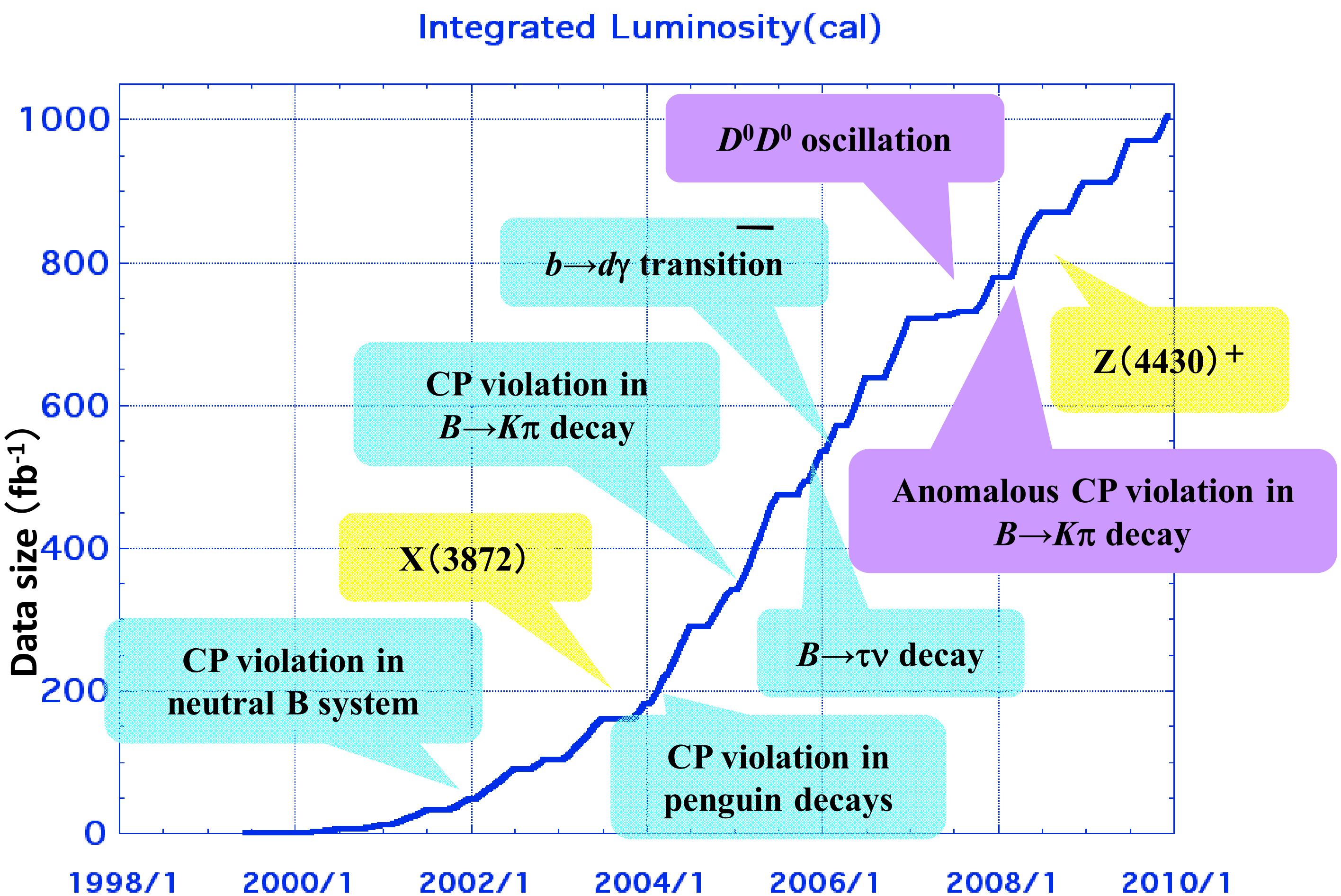
BABAR / PEP II





- Two e+ e- B factories at Υ(4s) resonance (10. 58 GeV) since the end of 1990's for a decade.
- Sum of data sets collected about 1.5 ab^{-1}
- Confirmation of CPV in the B sector and precision measurements of CKM matrix.
- 2008 Novel Prize

Example: Successful Run at KEKB/Belle

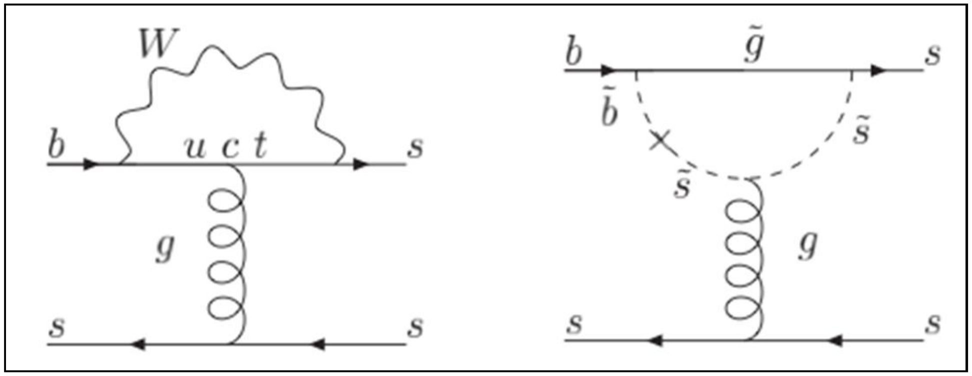


List of Important Results from B Factories

- Observation of direct CPV in B decays
- $b \rightarrow s$ transitions: CPV search and constraints from the $b \rightarrow s\,\gamma$ branching fraction
- Forward-backward asymmetry in $b \rightarrow s\, l+\, l-$: A new physics search
- Rare decays $B \rightarrow \tau\, \nu$, $D(*)\, \tau\, \nu$: Search for charged Higgs
- Search for heavy neutrinos in B decays
- Study of Bs decays
- Observation of new bottomonium-like states
- Observation of D^0- $\overline{D}^0$ mixing
- Search for CPV in D and D_s decays
- Observation of exotic charmonium states
- Search for lepton flavor violation (LFV) in τ decays
- Search for CPV and study of hadronic τ decays
- Search for CPTV in B and τ decays
- Precise measurement of the cross sections and dynamics of $\gamma\,\gamma$ -> hadrons and $e+\, e- \rightarrow$ hadrons γ_{ISR} processes

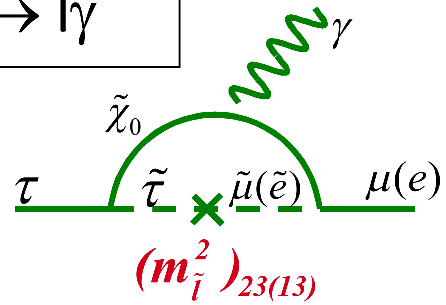
Physics at a Super B Factory

- Precision test of CKM unitarity matrix
  - More data → Overconstraining of unitarity triangle
  - Search for deviations from the Standard Model
- There is a good chance to see new phenomena:
  - CP Violation from the new physics .
  - Lepton flavor violations in τ decays.
  - Search for the charged Higgs boson in $B \rightarrow \tau\nu$, $D(*)\tau\nu$ decays.
  - New particles affecting the flavor changing neutral current.
  - More topics: CP Violation in charm mesons, new hadrons, …



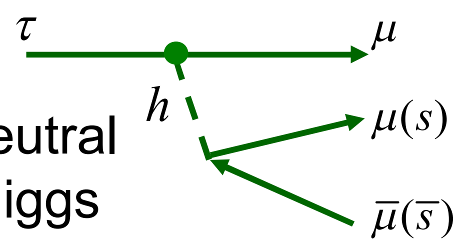
Example: τ Lepton Flavor Violation

$\tau \rightarrow l\gamma$



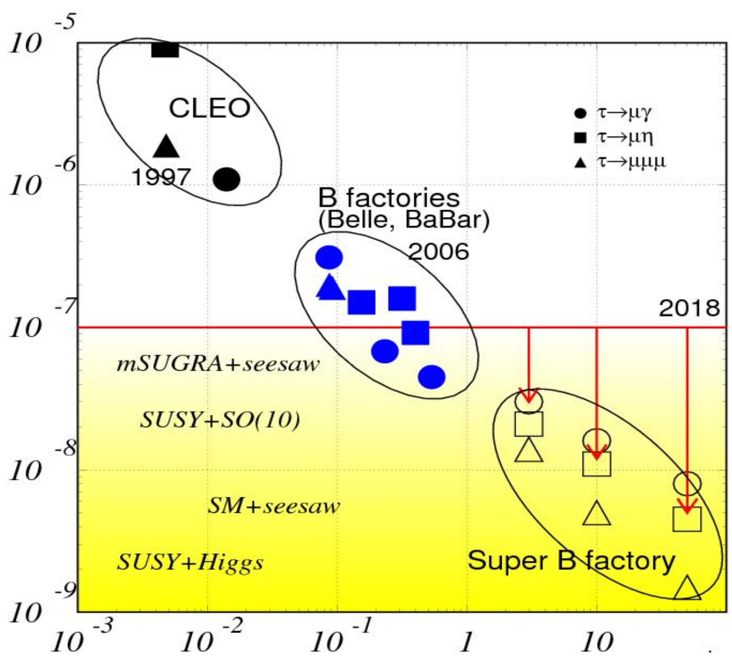
SUSY+
Seesaw

$\tau \rightarrow 3l,\ l\eta$



Neutral
Higgs

Experimental sensitivity



mode	Br(τ → μγ)	Br(τ → 3l)
mSUGRA + seesaw	10^{-7}	10^{-9}
SUSY + SO(10)	10^{-8}	10^{-10}
SM + seesaw	10^{-9}	10^{-10}
Non-universal Z'	10^{-9}	10^{-8}
SUSY + Higgs	10^{-10}	10^{-7}

Belle II Physics Sensitivity

[arXiv:1002.5012 [hep-ex]]

Observable	Belle 2006	SuperKEKB		†LHCb	
	(~0.5 ab^{-1})	(5 ab^{-1})	(50 ab^{-1})	(2 fb^{-1})	(10 fb^{-1})
Leptonic/semileptonic B decays					
$\mathcal{B}(B^+ \to \tau^+\nu)$	3.5σ	10%	3%	-	-
$\mathcal{B}(B^+ \to \mu^+\nu)$	†† $< 2.4\mathcal{B}_{SM}$	4.3 ab^{-1} for 5σ discovery		-	-
$\mathcal{B}(B^+ \to D\tau\nu)$	-	8%	3%	-	-
$\mathcal{B}(B^0 \to D\tau\nu)$	-	30%	10%	-	-
LFV in τ decays (U.L. at 90% C.L.)					
$\mathcal{B}(\tau \to \mu\gamma)$ $[10^{-9}]$	45	10	5	-	-
$\mathcal{B}(\tau \to \mu\eta)$ $[10^{-9}]$	65	5	2	-	-
$\mathcal{B}(\tau \to \mu\mu\mu)$ $[10^{-9}]$	21	3	1	-	-
Unitarity triangle parameters					
$\sin 2\phi_1$	0.026	0.016	0.012	~0.02	~0.01
ϕ_2 $(\pi\pi)$	11°	10°	3°	-	-
ϕ_2 $(\rho\pi)$	$68° < \phi_2 < 95°$	3°	1.5°	10°	4.5°
ϕ_2 $(\rho\rho)$	$62° < \phi_2 < 107°$	3°	1.5°	-	-
ϕ_2 (combined)		2°	$\lesssim 1°$	10°	4.5°
ϕ_3 $(D^{(*)}K^{(*)})$ (Dalitz mod. ind.)	20°	7°	2°	8°	
ϕ_3 $(DK^{(*)})$ (ADS+GLW)	-	16°	5°	5-15°	
ϕ_3 $(D^{(*)}\pi)$	-	18°	6°		
ϕ_3 (combined)		6°	1.5°	4.2°	2.4°
$\lvert V_{ub}\rvert$ (inclusive)	6%	5%	3%	-	-
$\lvert V_{ub}\rvert$ (exclusive)	15%	12% (LQCD)	5% (LQCD)	-	-
$\bar{\rho}$	20.0%		3.4%		
$\bar{\eta}$	15.7%		1.7%		

Part III

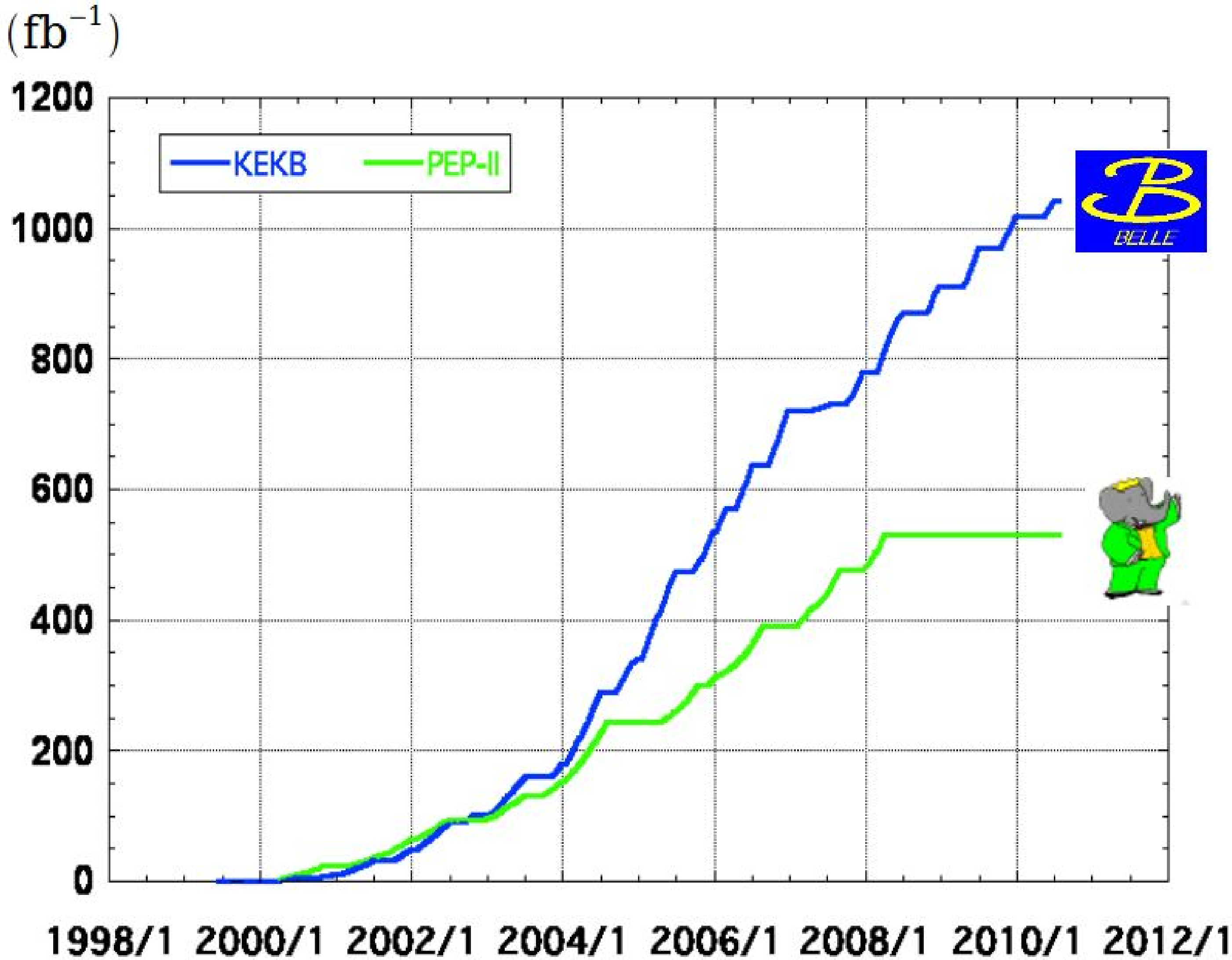
The Belle II Experiment

– Why a Super B Factory?

– The Super KEKB Project


KEK
High Energy Accelerator Reseach Organization

B Factories were Highly Successfull



$> 1\ ab^{-1}$

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

$\sim 100\ fb^{-1}$

$\sim 550\ fb^{-1}$

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

$\sim 54\ fb^{-1}$

The SuperKEKB Project

Upgrade of KEKB/Belle

	KEKB		SuperKEKB	
Luminosity:	2.1×10^{34}	$\rightarrow$	8×10^{35}	(x 40)
Total Data:	1 ab^{-1}	$\rightarrow$	50 ab^{-1} <	(x 50)
Detector :	Belle	$\rightarrow$	Belle II	

Luminosity Increase by a Factor 40

- “Nano-Beam” scheme of Pantaleo Raimondi for SuperB.

Lorentz factor

Beam current

Beam-beam parameter

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

Geometrical reduction factors (crossing angle, hourglass effect)

Classical electron radius

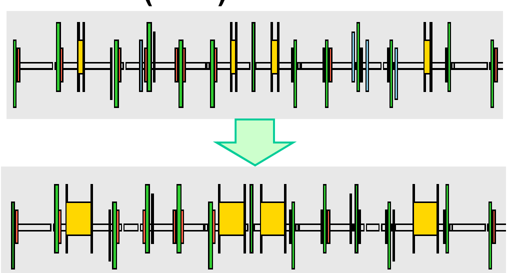
Beam size ratio at IP 1-2% (flat beam)

Vertical beta function at IP

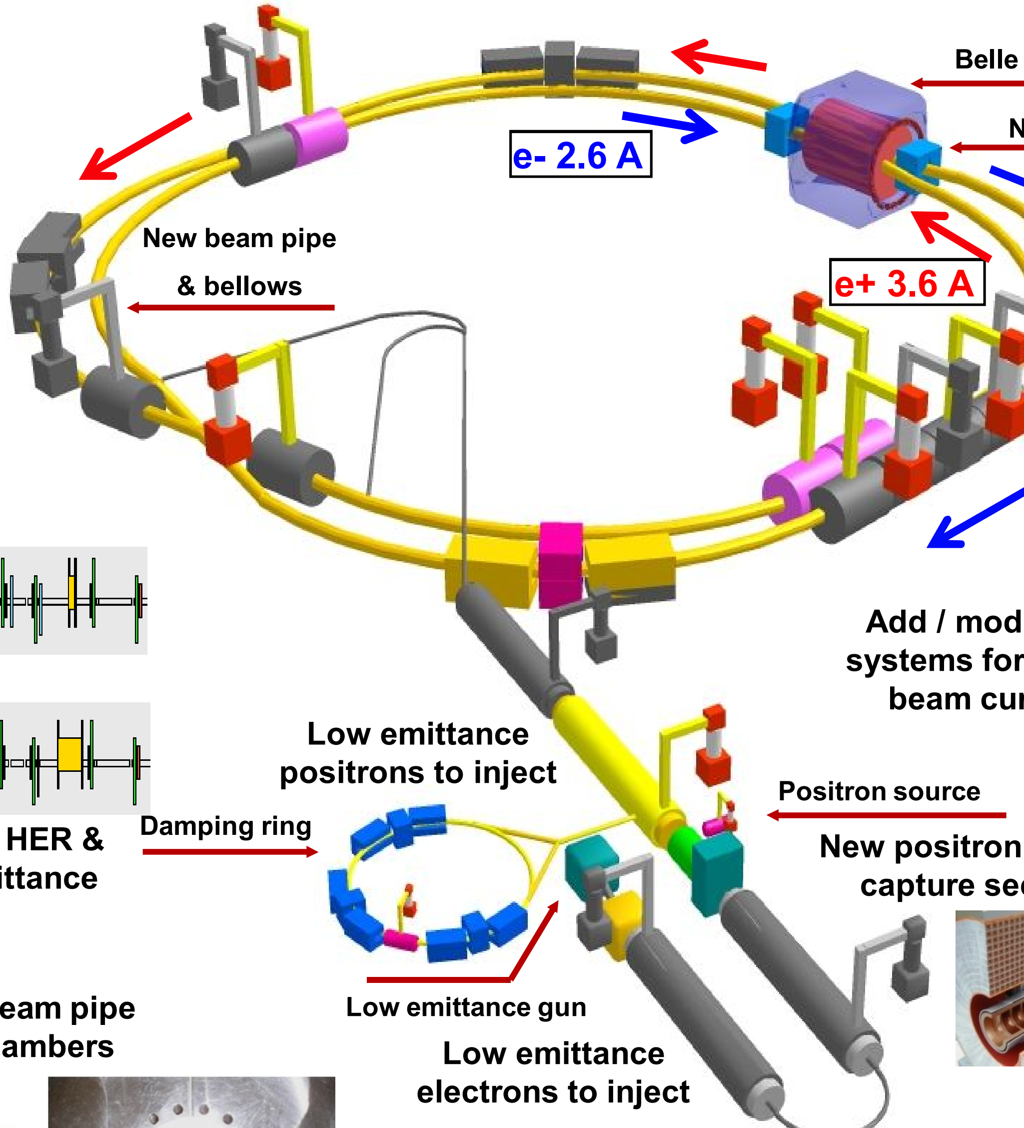
- Beam Energies 8.0/3.5 → 7.0/4.0 GeV.
  - Increase in LER energy improves lifetime.
  - Decrease in HER energy reduces Synchrotron power requirements

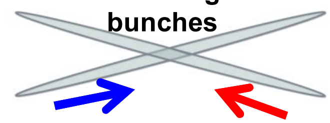
Upgrade Process to SuperKEKB

Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance



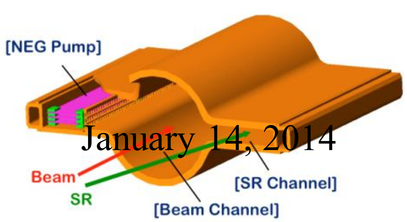


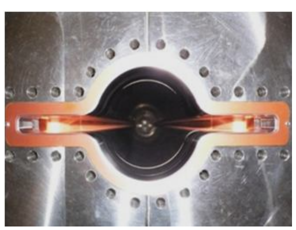
New superconducting /permanent final focusing quads near the IP

Add / modify RF systems for higher beam current

New positron target / capture section

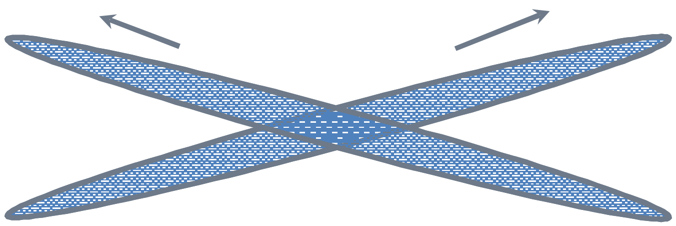
TiN-coated beam pipe with antechambers



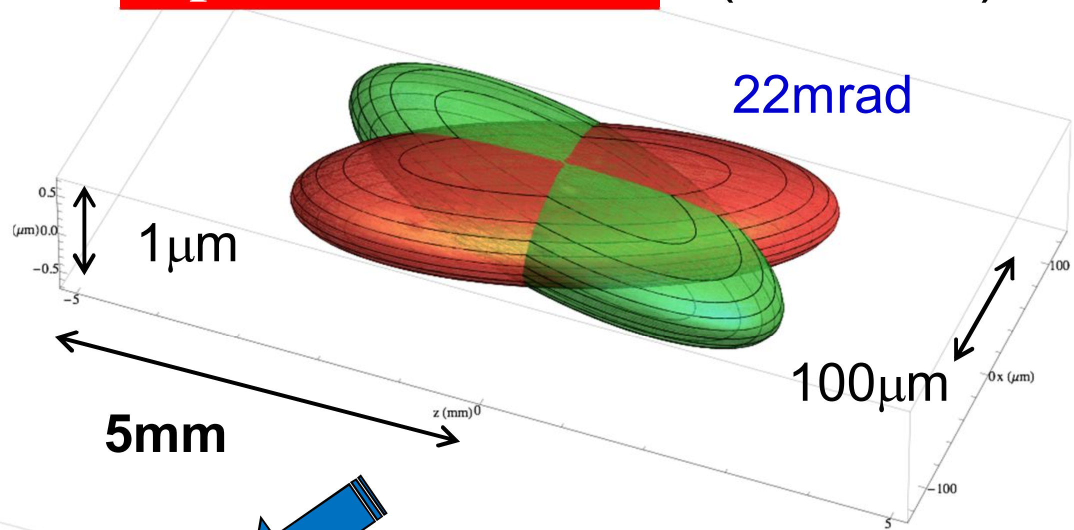


To get x40 higher luminosity

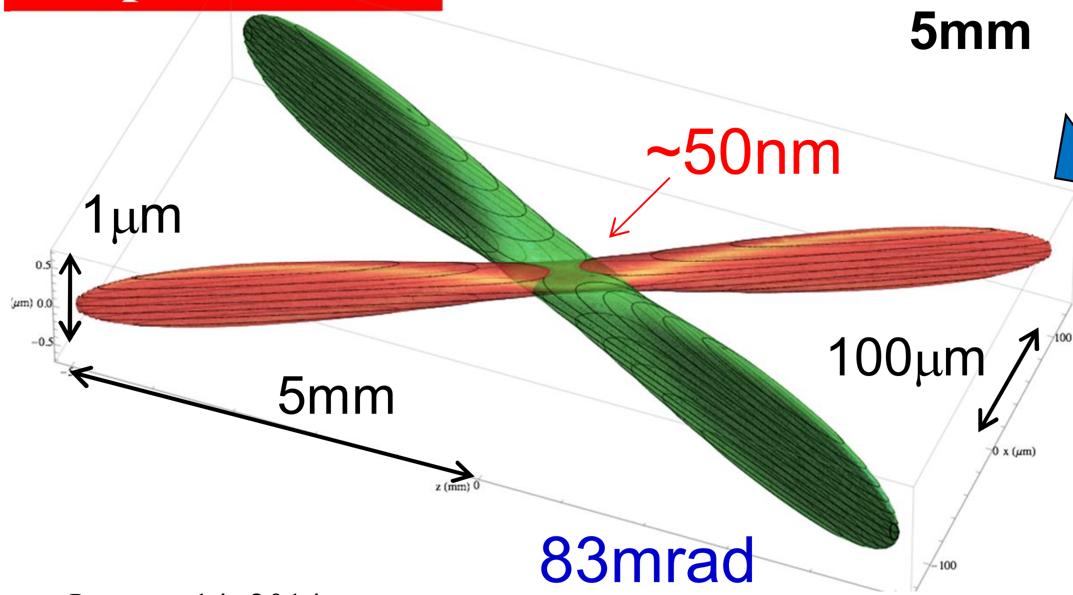
Nano-Beam Scheme



present KEKB (w/o crab)



SuperKEKB



SuperKEKB Machine 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	5.0	nm
Emittance ratio	κ	0.88	0.66	0.27	0.25	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.31	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	A
beam-beam parameter	ξ_y	0.129	0.090	0.0886	0.0830	
Luminosity	**L**	**2.1×10^{34}**		**8×10^{35}**		**$cm^{-2}s^{-1}$**

Part IV

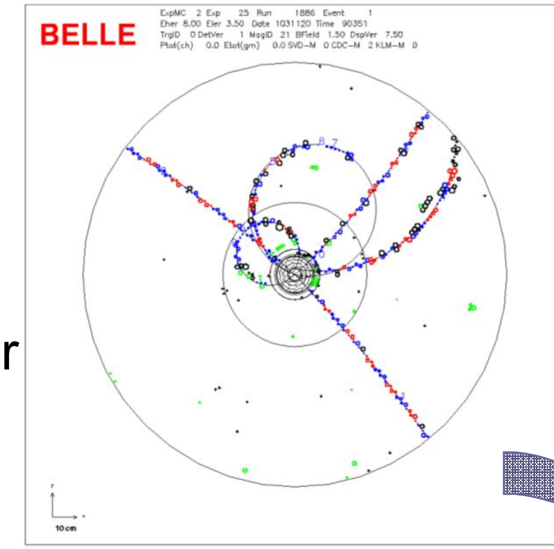
The Belle II Experiment

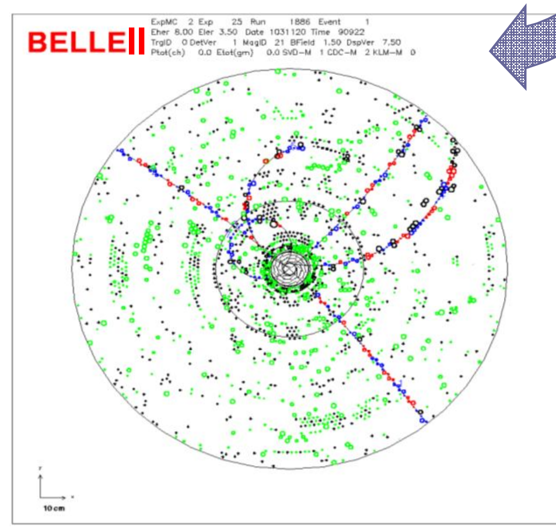
- Why a Super B Factory?
- The Super KEKB Project
- The BELLE II Detector

Detector Upgrade

Critical issues at L= 8×10^{35}/cm^2/s:

- Higher background ($\times$10 - 20)
  - Radiatve Bhaba events dominate
  - Radiation damage and higher occupancy
  - Fake hits and pile-up noise in EM calorimeter

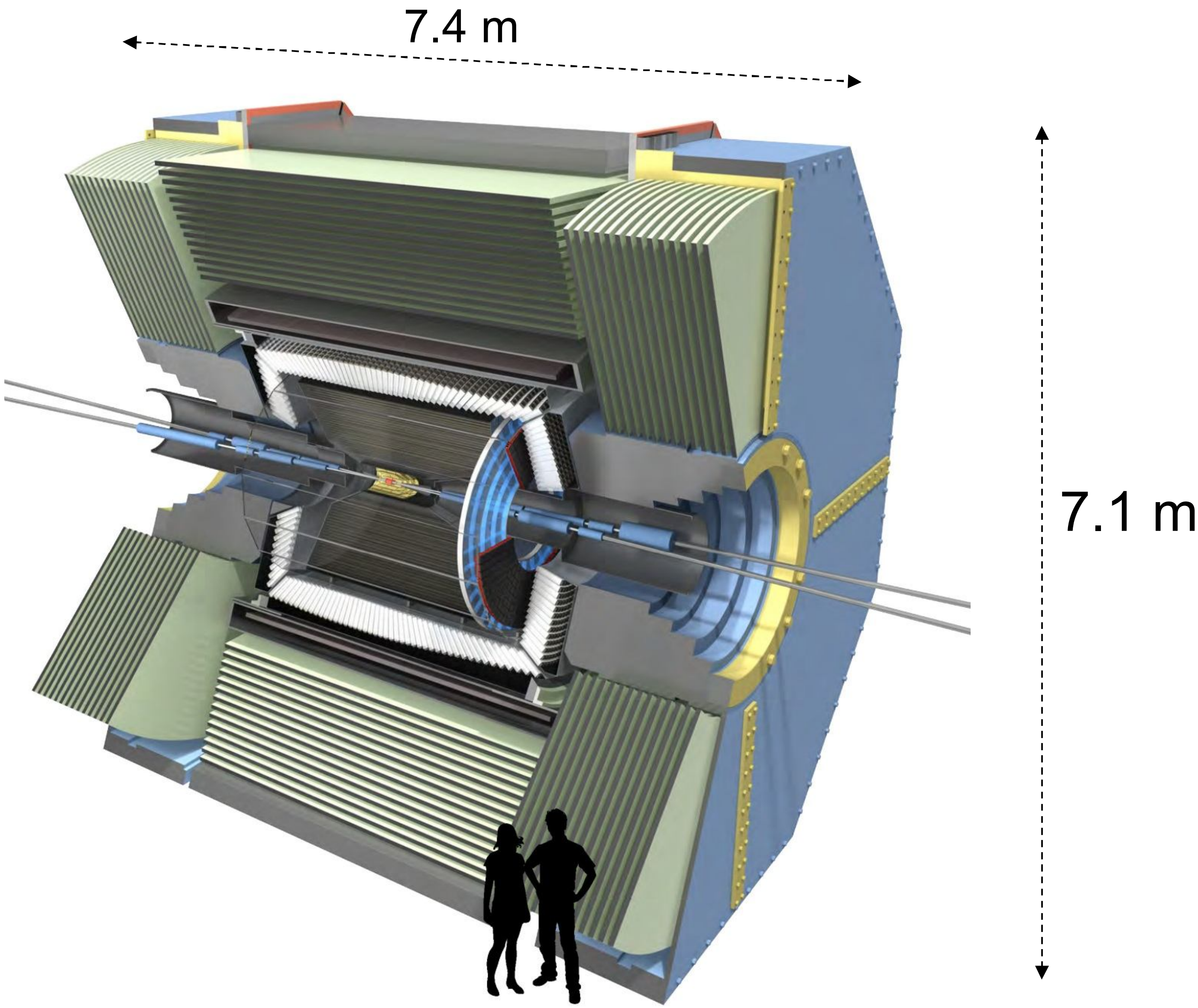




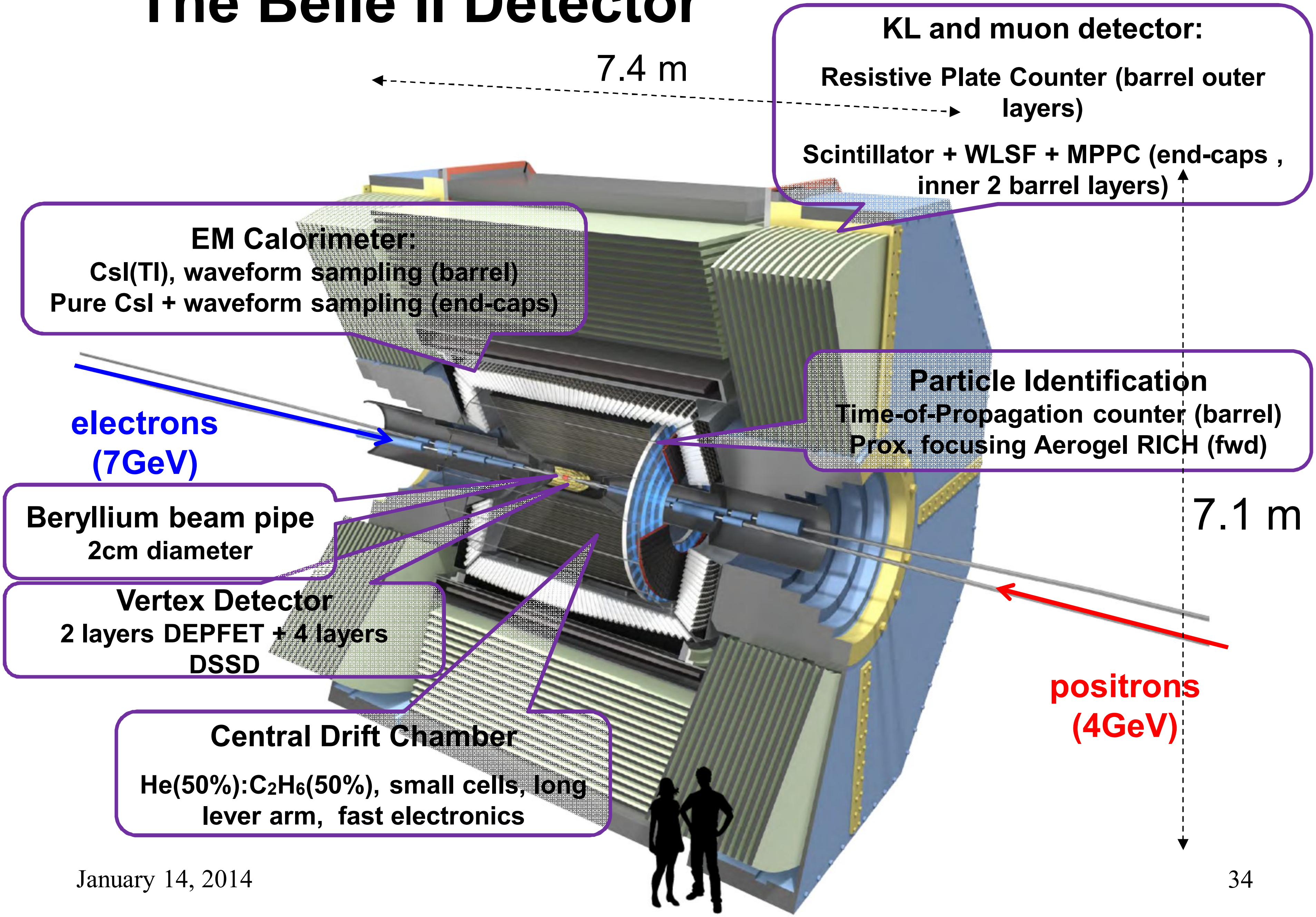
- Higher event rates ($\times$40)
  - Higher rate trigger (L1 trigg. 0.5→20 kHz)
  - DAQ, computing

- Target:
  - Maintain or improve over Belle I data quality in the high background/ high rate environment

Belle II Detector



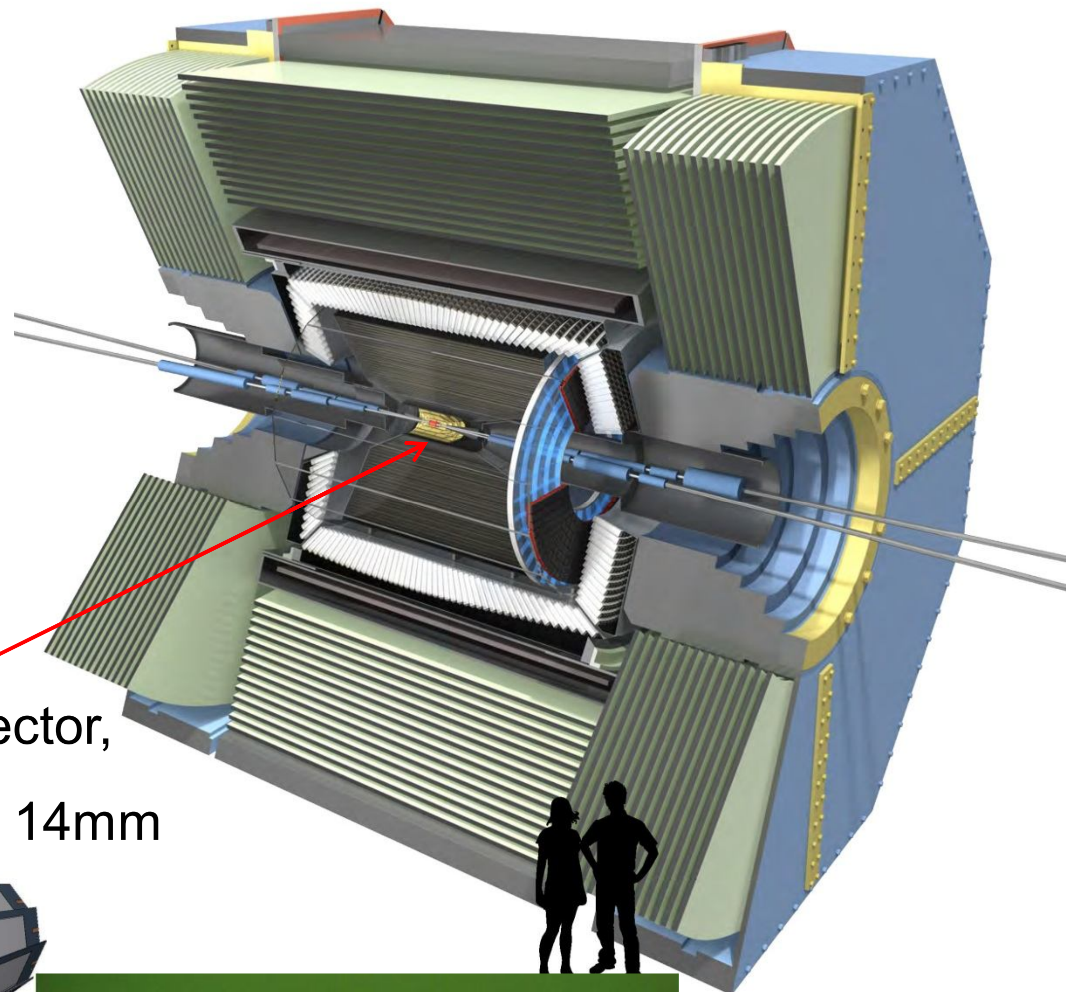
The Belle II Detector



Silicon Pixel Detector at the Innermost Center

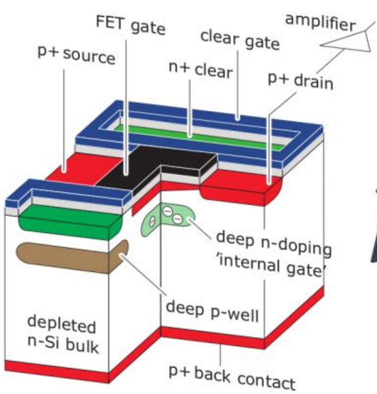
A charged particle leaves a path of ionization in the silicon.

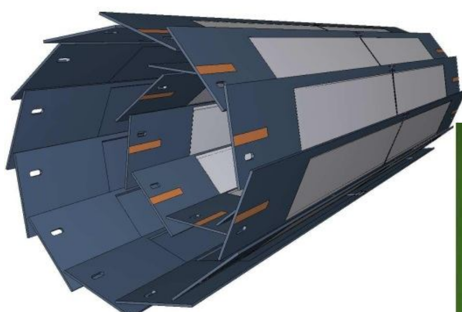
The path is used to reconstruct the production vertex and momentum of the particle.



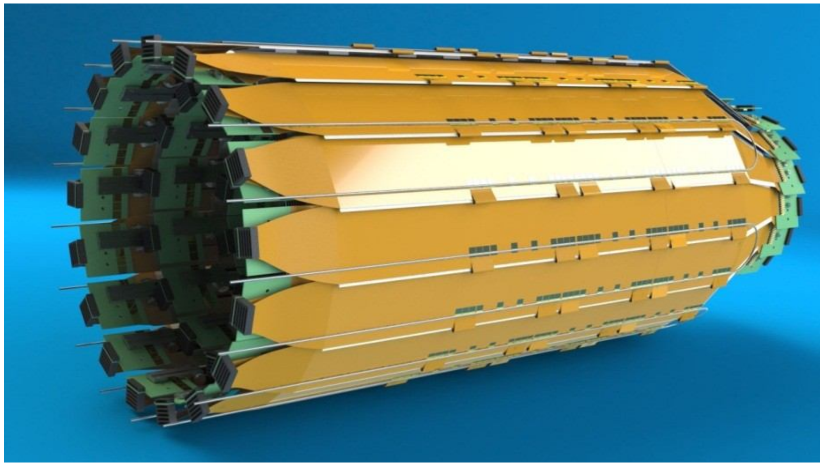
Pixel Detector,

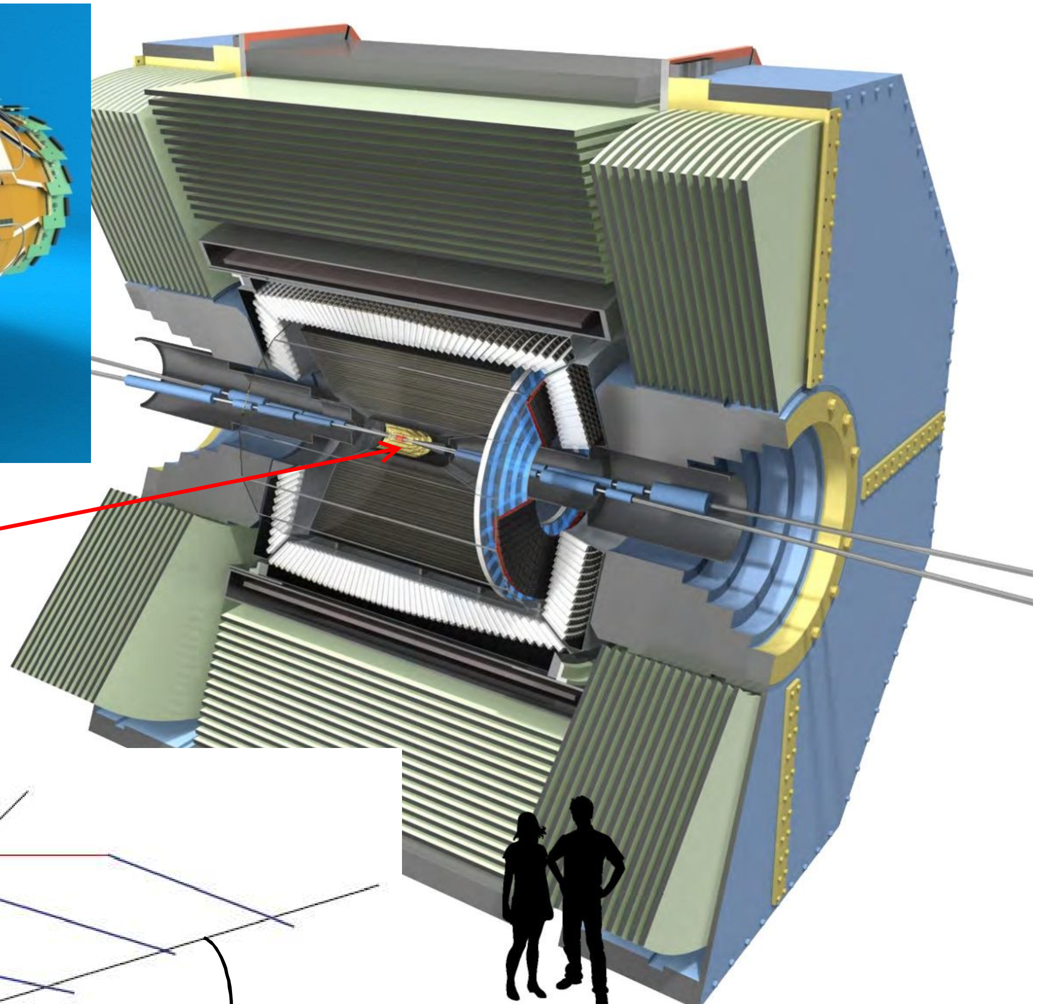
inner radius 14mm



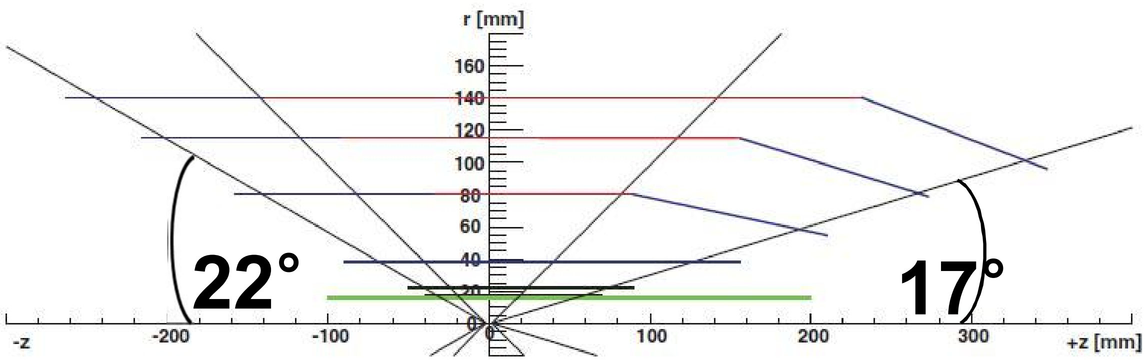


Silicon Strip Detector Outside the Pixel Detector



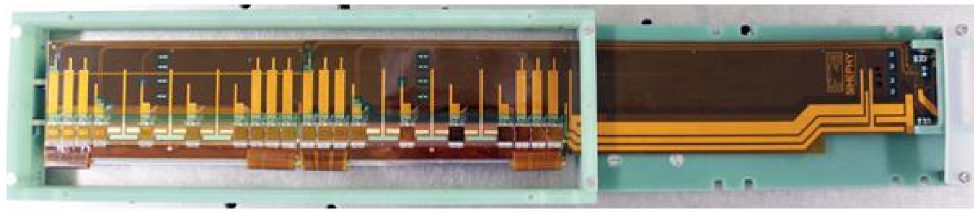


Silicon Vertex Detector 4 layers

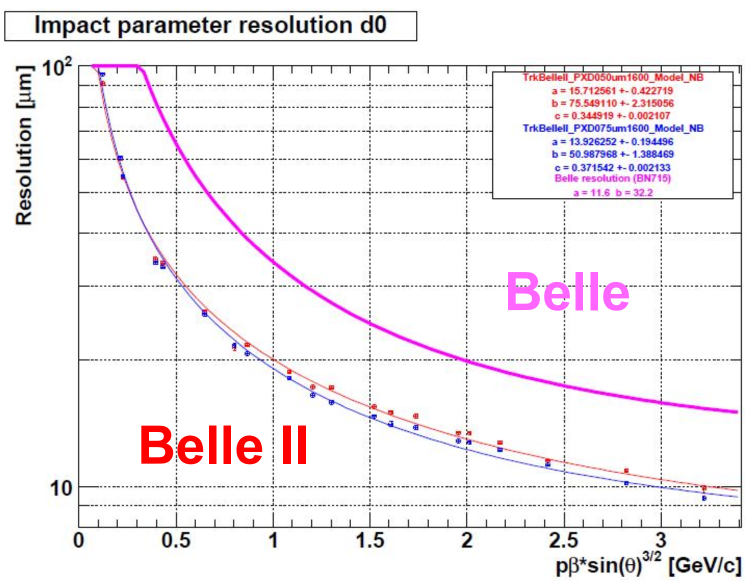


Silicon Strip Detector Outside the Pixel Detector

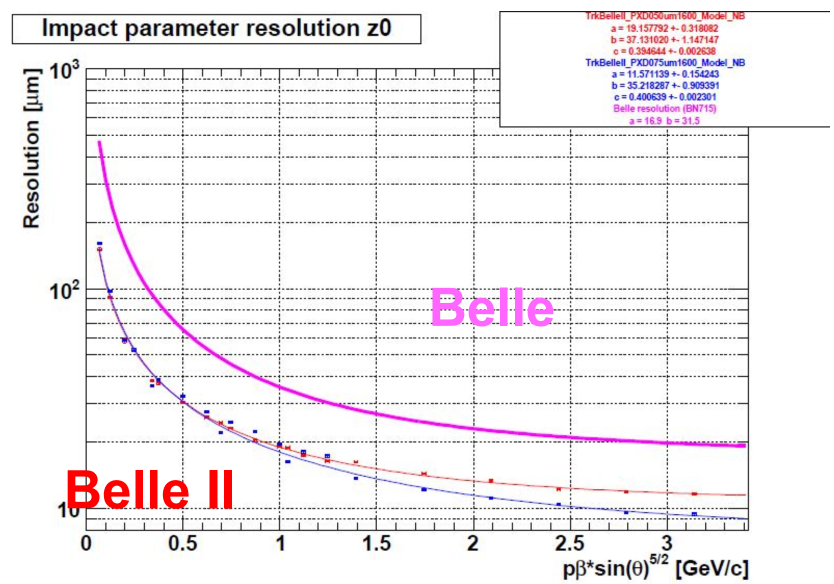
- A low-mass solution for double-sided readout
- Flex fan-out pieces wrapped to the opposite side



dr(R-φ) resolution



Z resolution



Central Drift Chamber

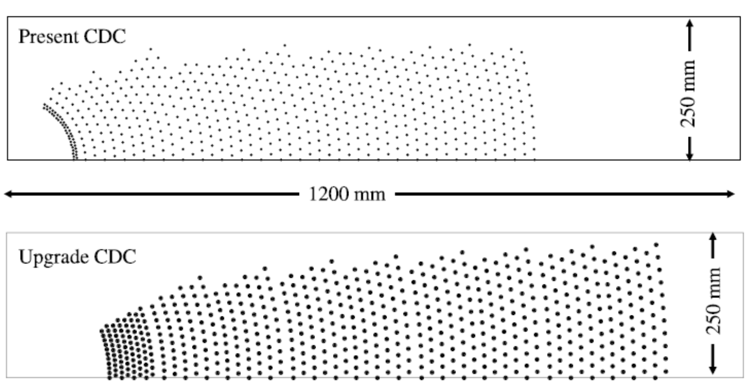
A charged particle leaves a path of ionization in the gas.

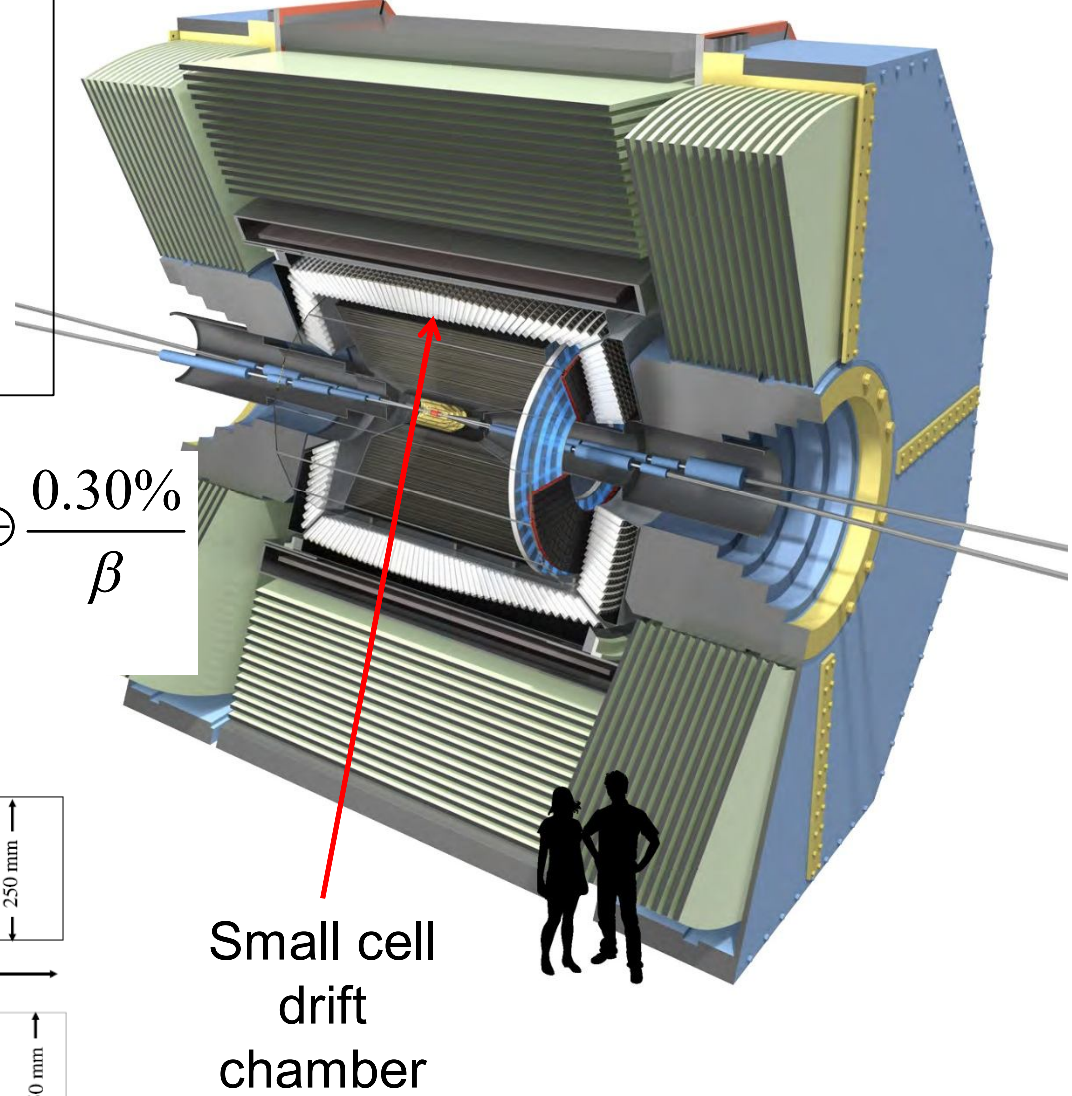
With the magnetic field bending, its momentum is measured and identity is checked.

$$\sigma_{pt} / P_t = 0.11\% \times P_t (GeV / c) \oplus \frac{0.30\%}{\beta}$$

$$\sigma(dE / dx) \approx 6\%$$

Wire Configuration

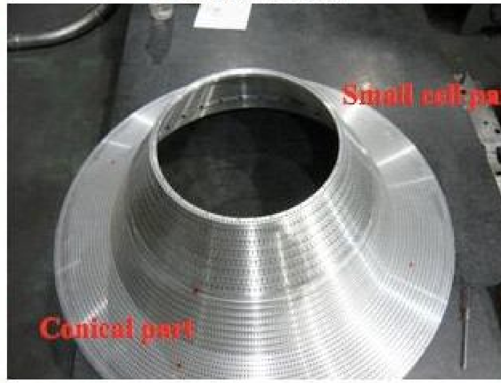


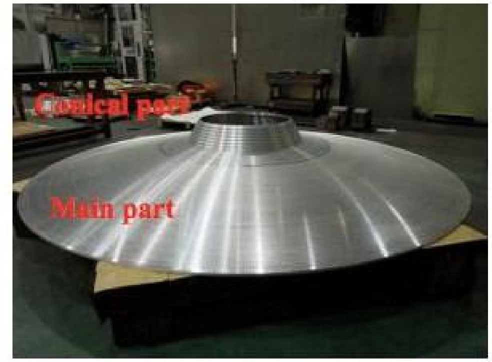


Central Drift Chamber

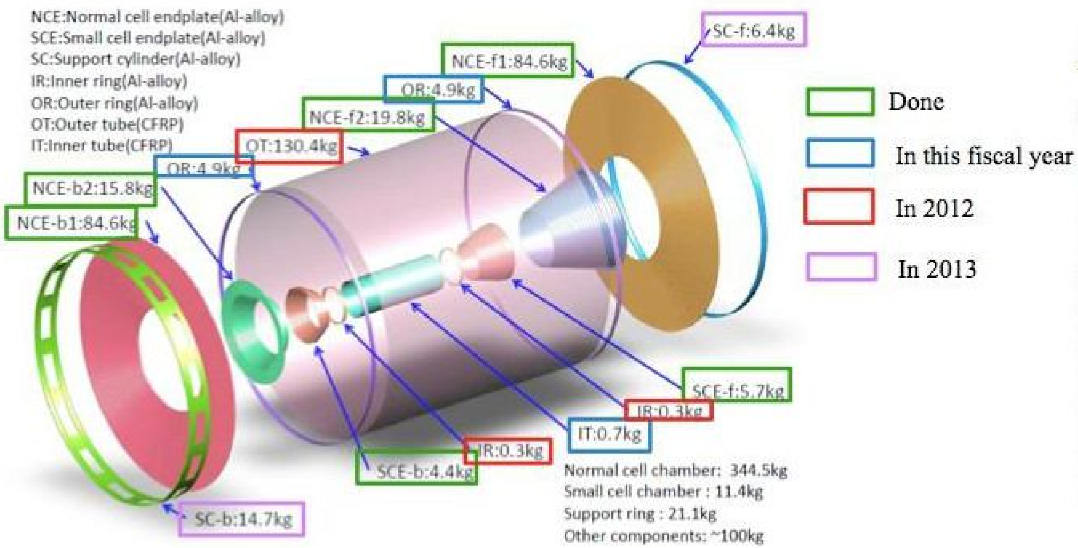
Forward

Backward





Connections are very smooth
Accuracy check will be performed in next fiscal year



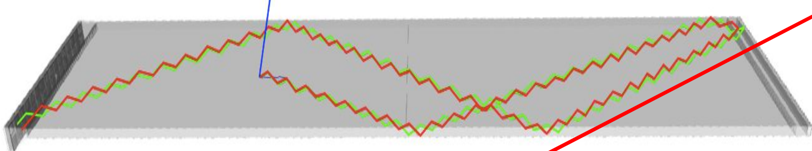
Wire stringing
Autumn, 2012 - Winter , 2013

Wire stringing place : Fuji B4

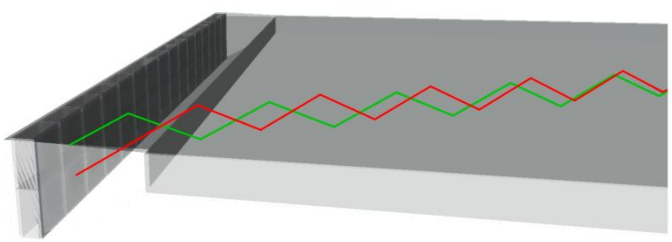
Time-Of-Propagation Detector (Barrel Particle Identification and Timing)

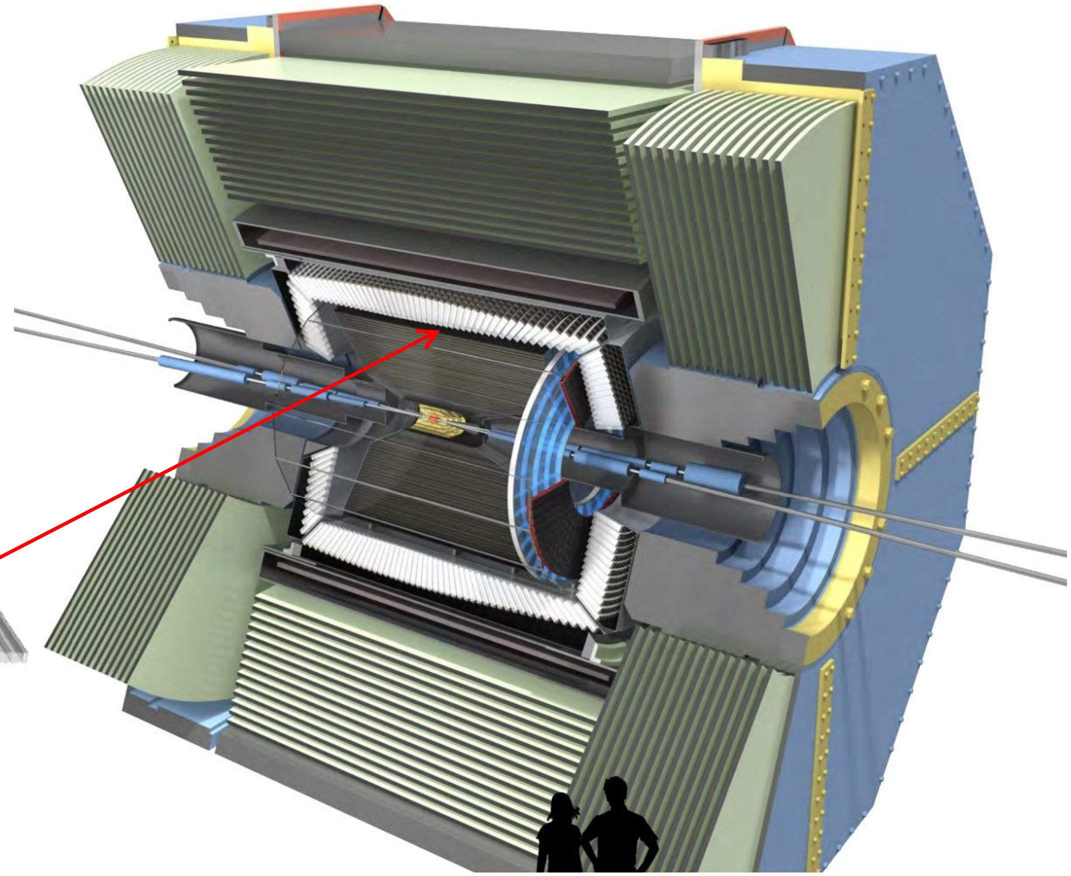
A Cherenkov detector:
A light particle can radiate inside but a heavy particle cannot. The radiation angle depends on the mass of the particle.

Used the information to identify particles..



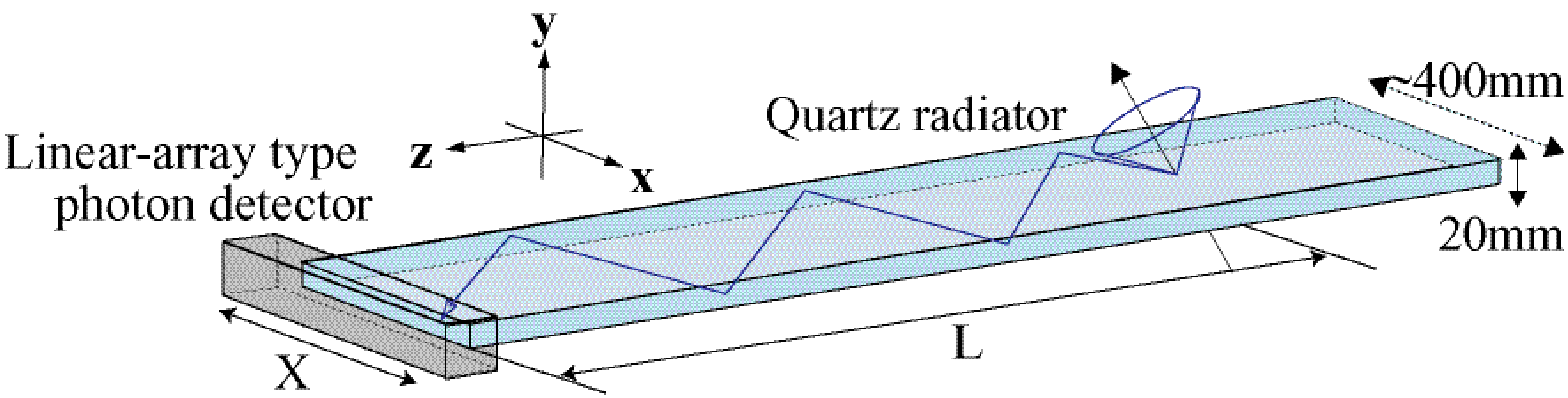
TOP Detector (Barrel PID)

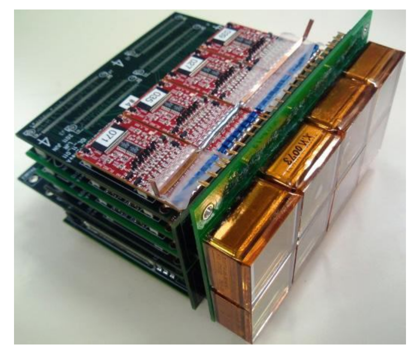




- Cerenkov ring imaging with precise time measurement
- Two hit coordinates (X and Y) and photon propagation time

Time-Of-Propagation Detector
(Barrel Particle Identification and Timing)

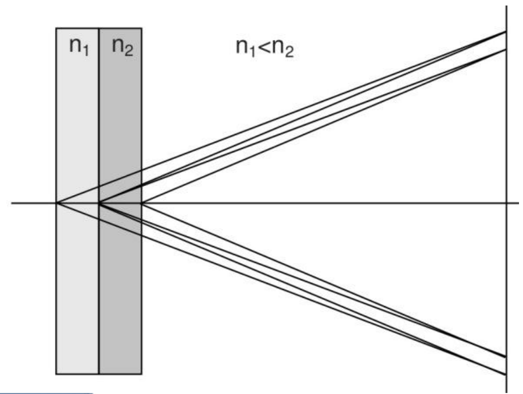


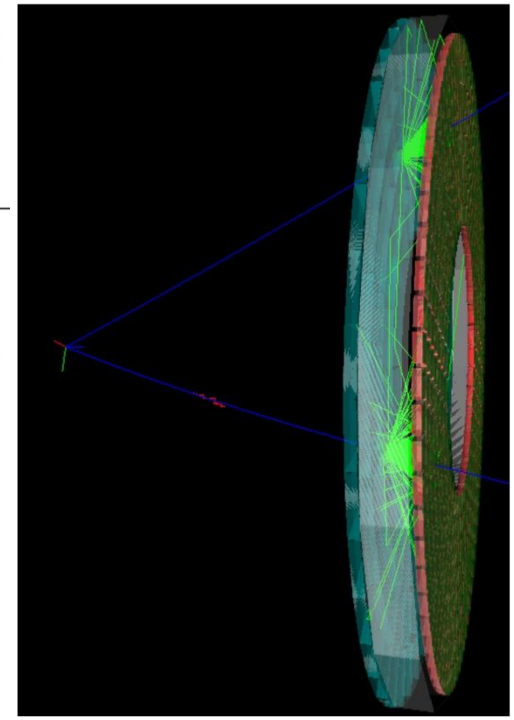


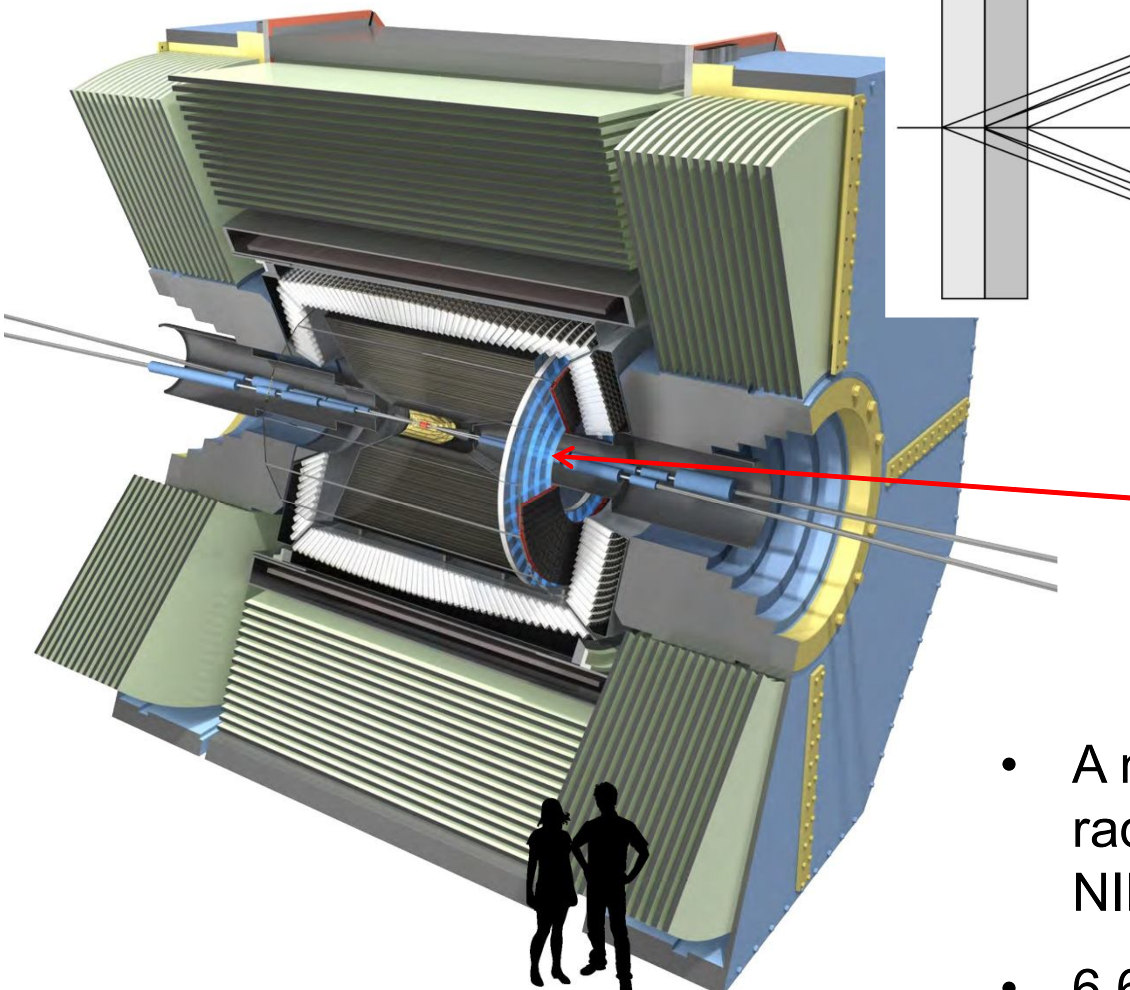
Prototype MCP-PMT

for beam test

Aerogel Cherenkov (endcap PID)

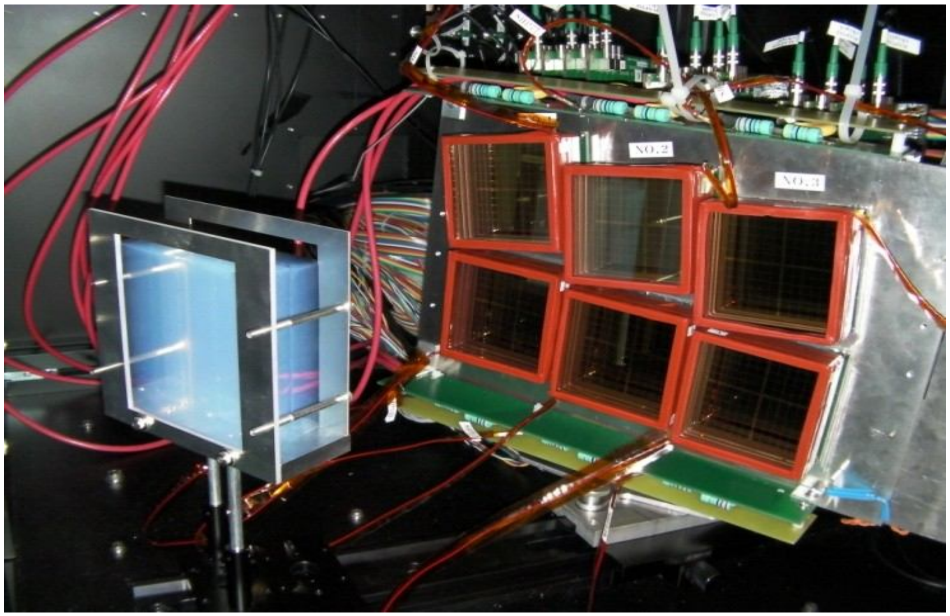




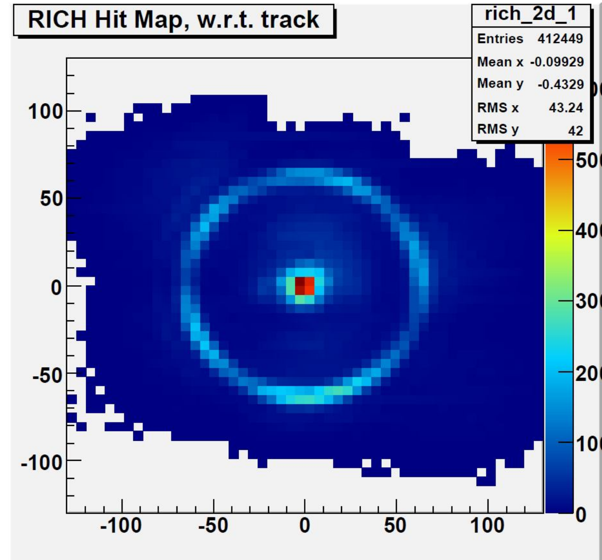


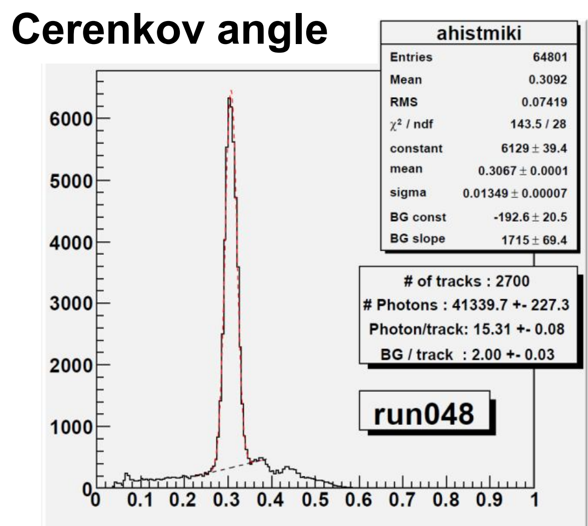
- A novel concept: Two layer radiator
  NIM A548 383 (2005)
- 6.6 σ K/pi separation at p = 4GeV.

Aerogel Cherenkov (endcap PID)



Beam Test





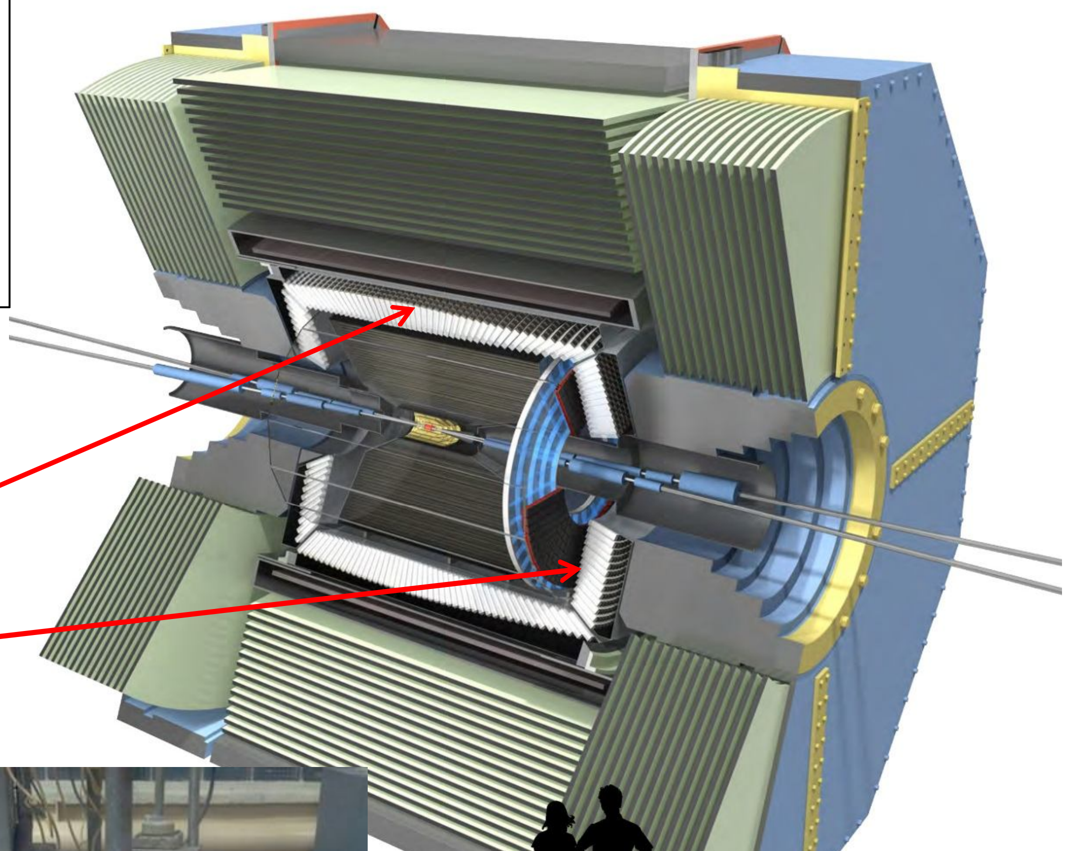
Electromagnetic Calorimeter

Photons and electrons leave large showers inside the calorimeter. Identify them by checking the shower pattern.

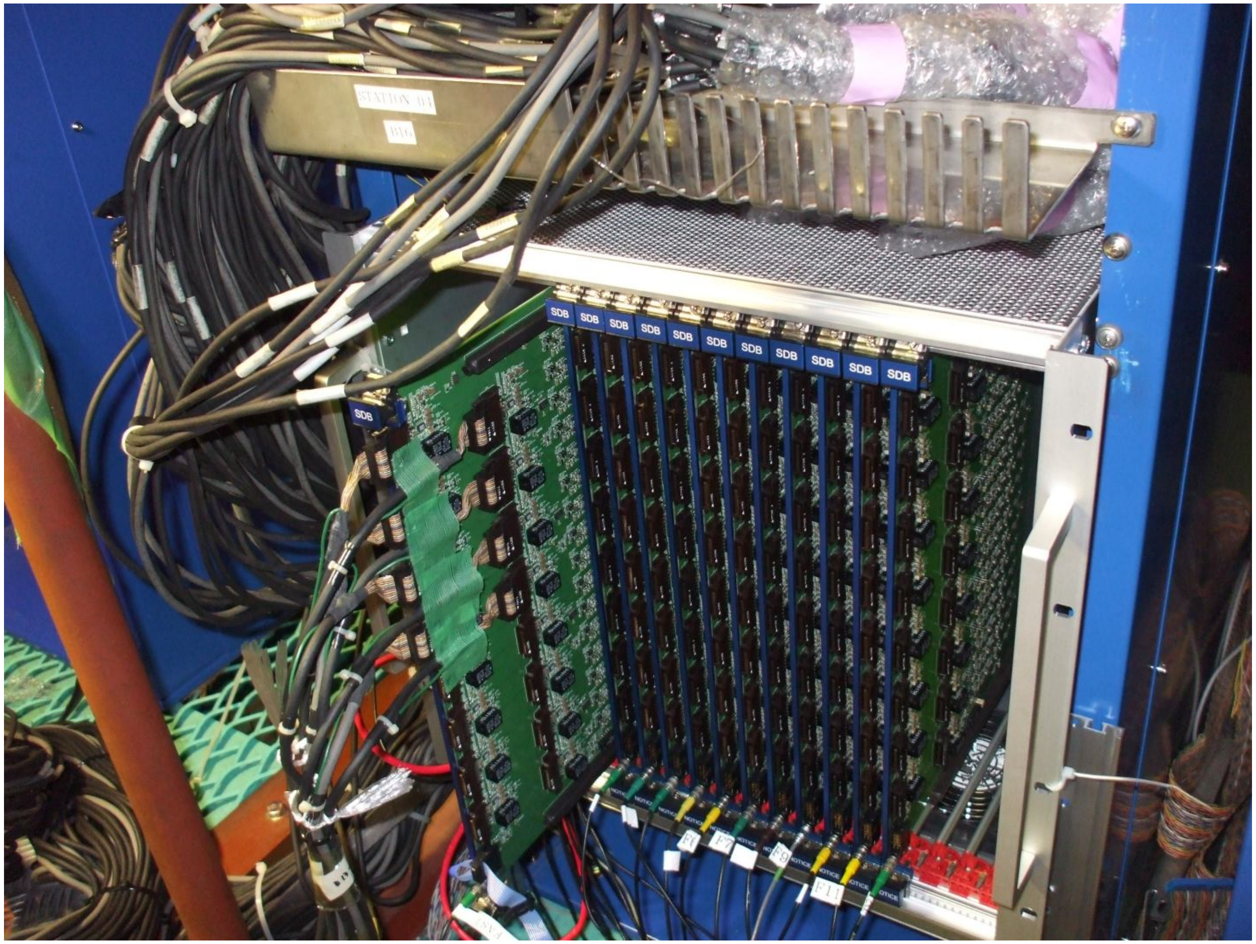
Electromagnetic Calorimeter:

Reuse: CsI(Tl) Barrel

Planned: Pure CsI Endcap



Electromagnetic Calorimeter

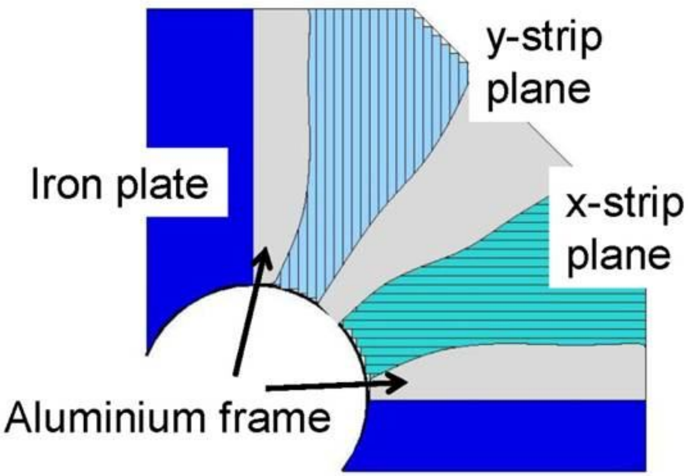


- Test of the new ECL electronics
- The electronics will be installed in 2014.

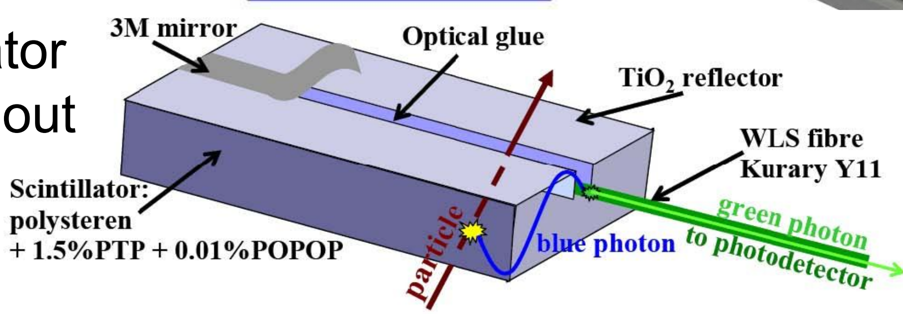
K_L – Muon Detector

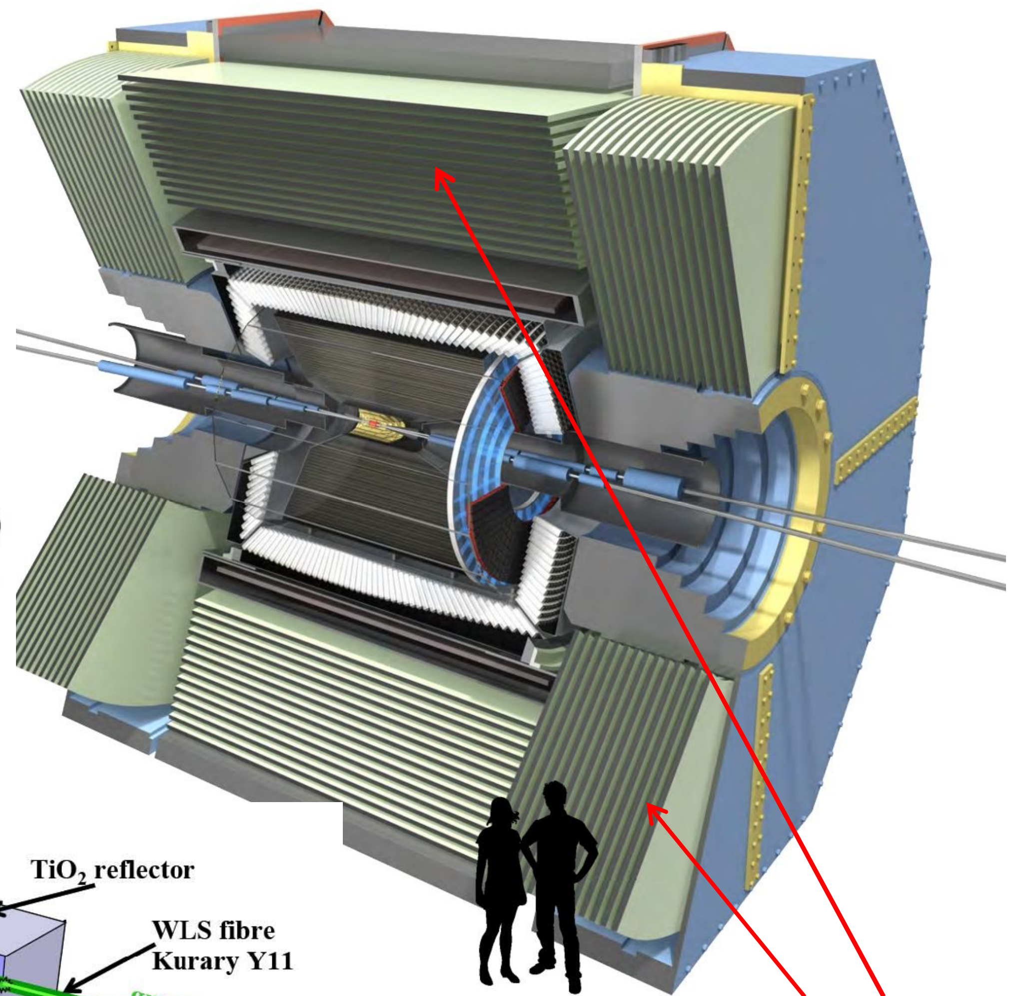
Only K_L and muon live long enough to reach the outermost detector.

Part of resistive plate chamber has been replaced by …

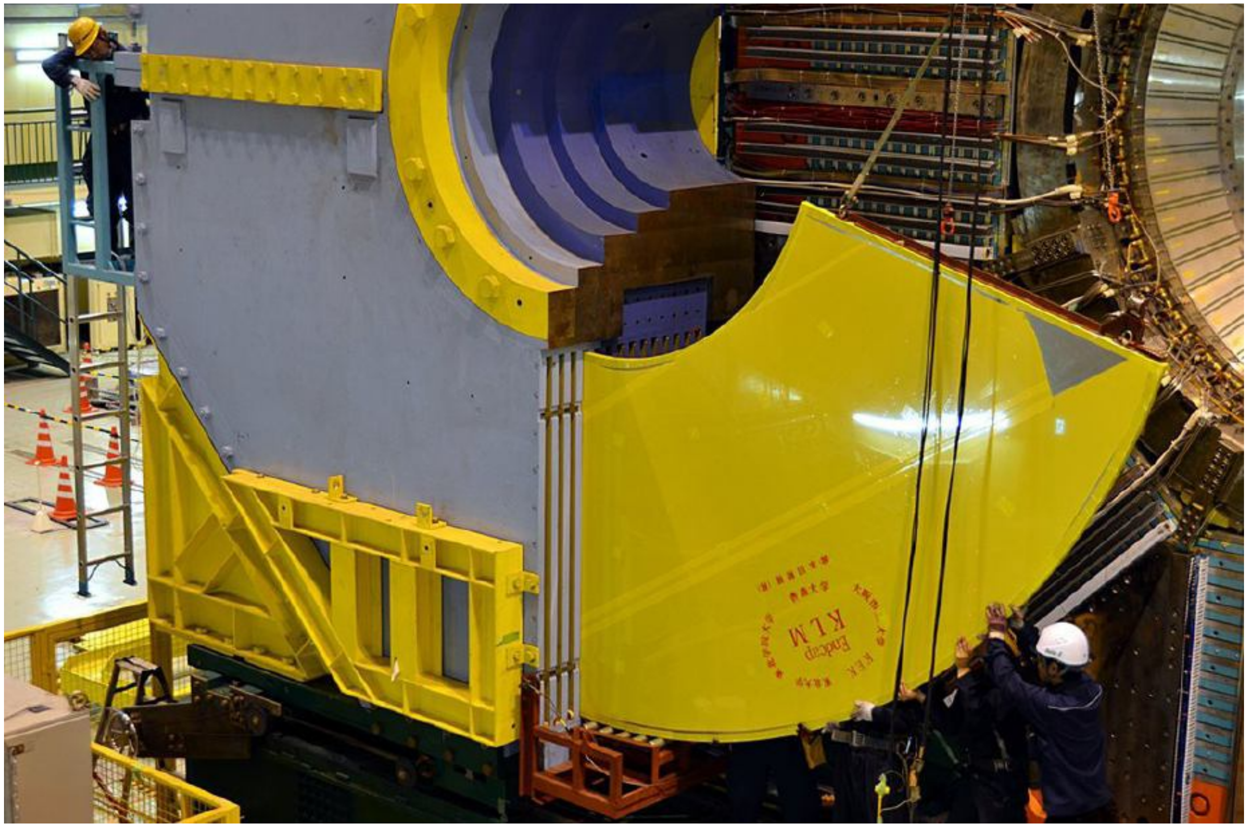


Scintillator
+ Readout





K_L – Muon Detector



- Barrel + Endcap KLMs: > 99% geometrical coverage

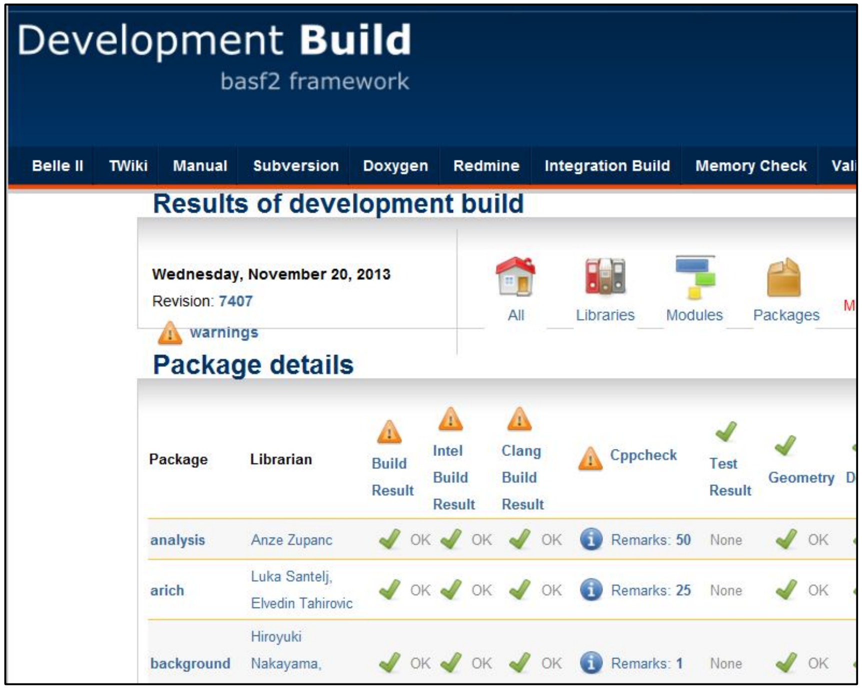
DAQ - Event Rate

Experiment	Event Size [kB]	Rate [Hz]	Rate [MB/s]
High rate scenario for Belle II DAQ			
Belle II	300	6,000	1,800
LCG TDR (2005)*			
ALICE (HI)	12,500	100	1,250
ALICE (pp)	1,000	100	100
ATLAS	1,600	200	320
CMS	1,500	150	225
LHCb	25	2,000	50

* The LHC experiments are running at a factor of two or higher event rates

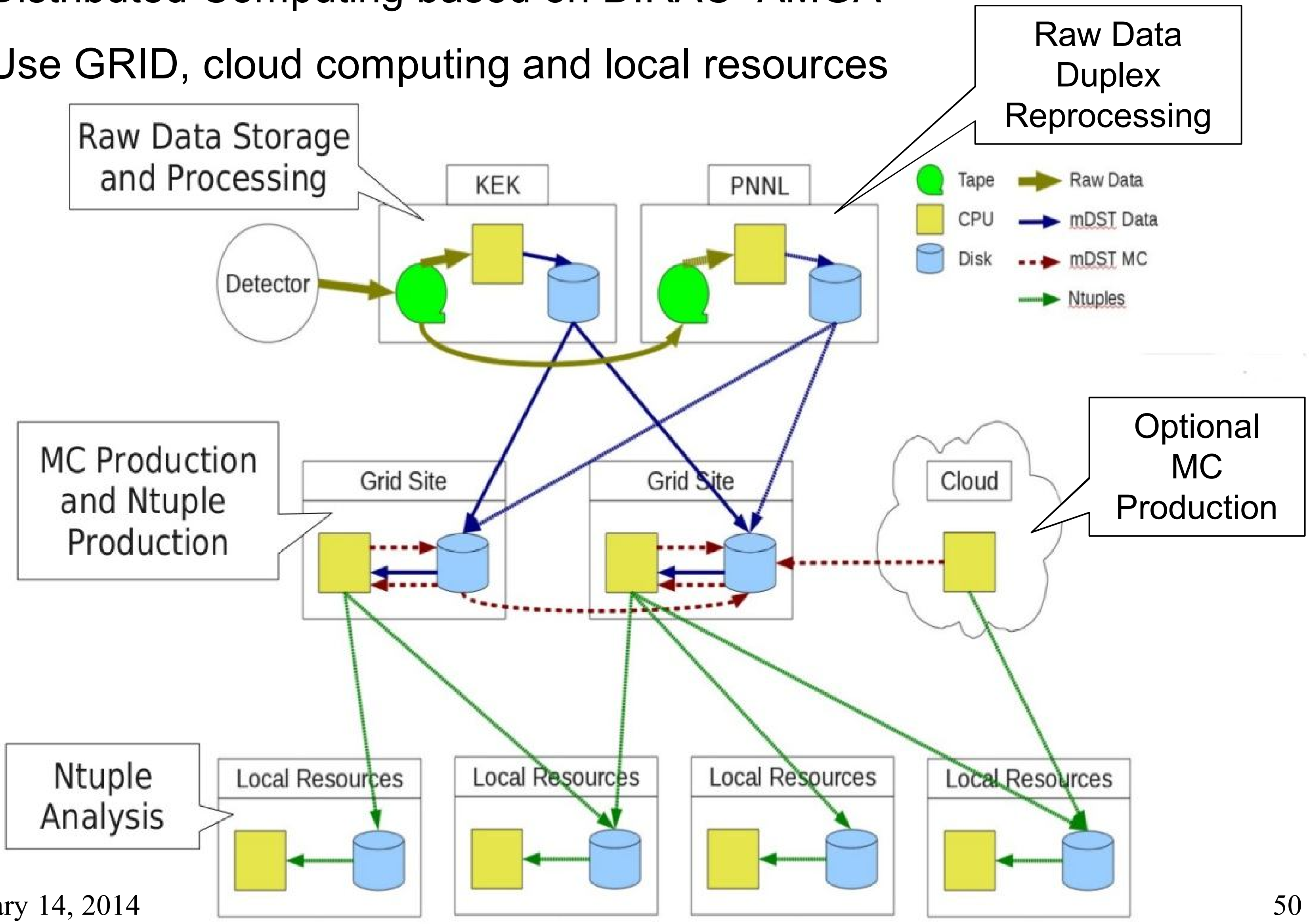
The Belle II Software System

- A "framework" system with dynamic module loading, parallel processing, Python steering, and ROOT I/O
- Full detector simulation with Geant4
- Code management systems at KEK: The Subversion software
- All common linux operating systems supported: SL, Fedora, Ubuntu, etc
- C++ 11 and gcc 4.7
- Formatting tool: astyle
- Building: scons and buildbot system
- Documentation: Doxygen, Twiki
- Issue tracking: Redmine

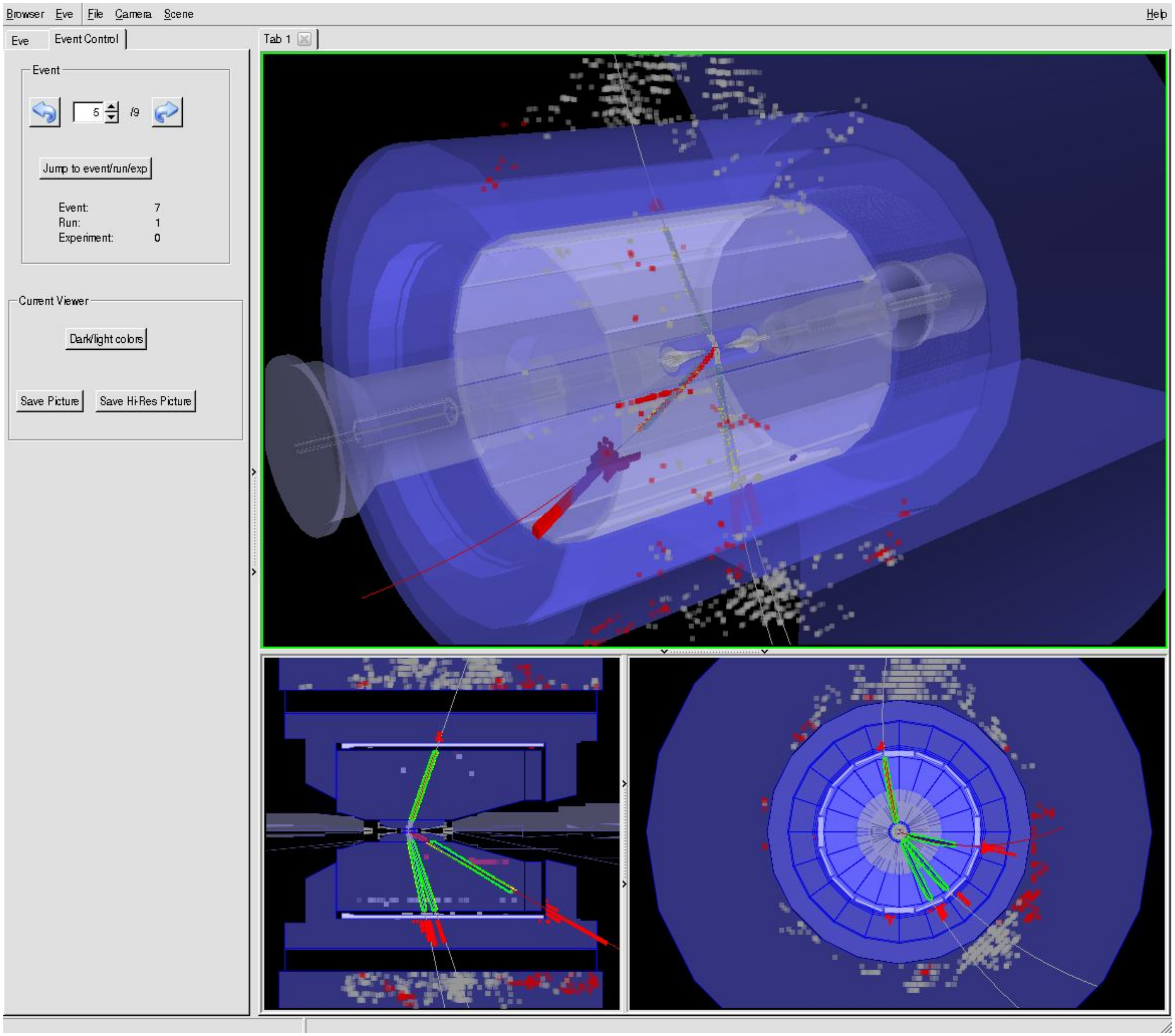


Distributed Computing System

- Distributed Computing based on DIRAC+AMGA
- Use GRID, cloud computing and local resources



Event Display



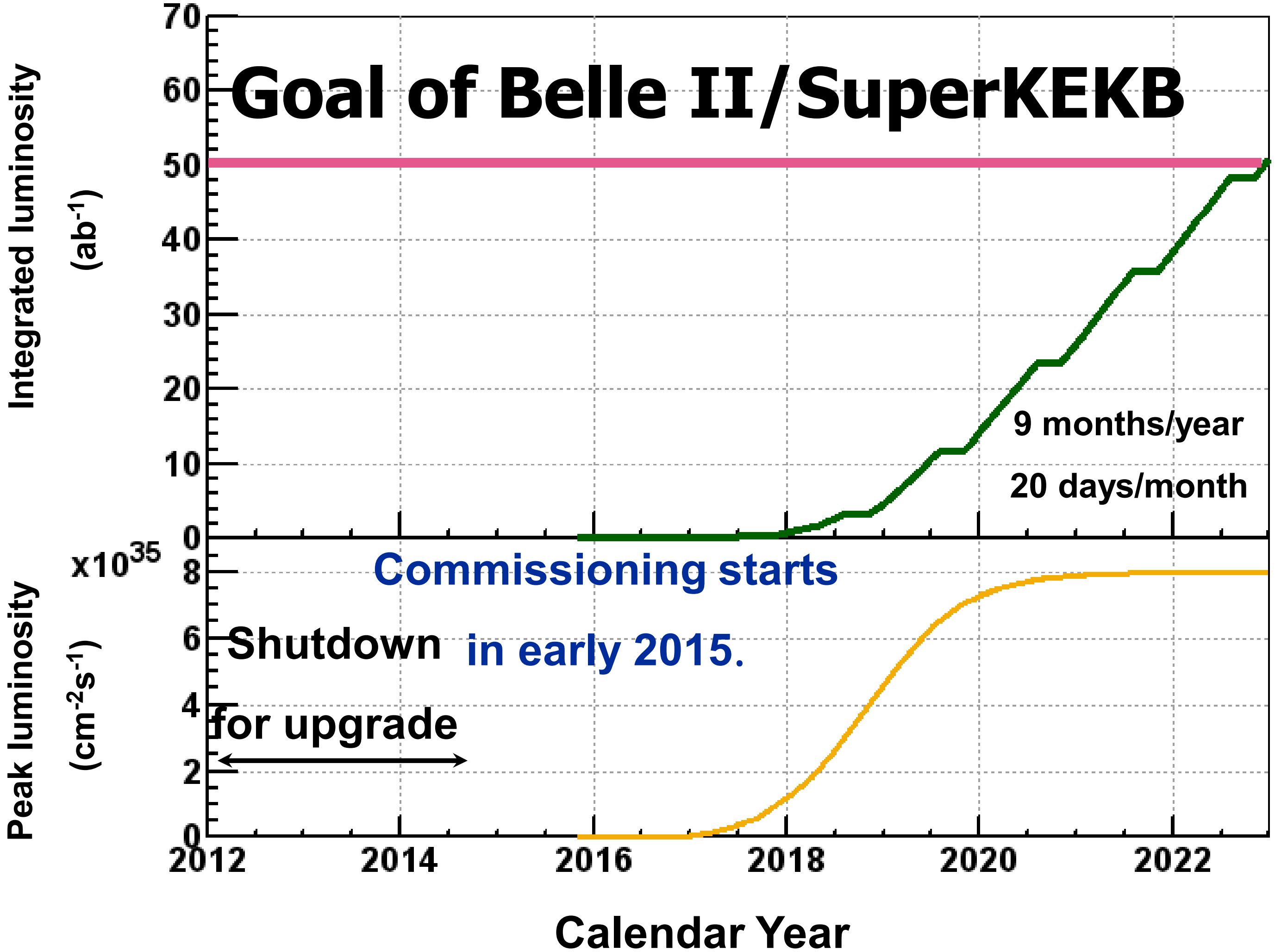
Basf2 + ROOT with OpenGL support

Part V

The Belle II Experiment

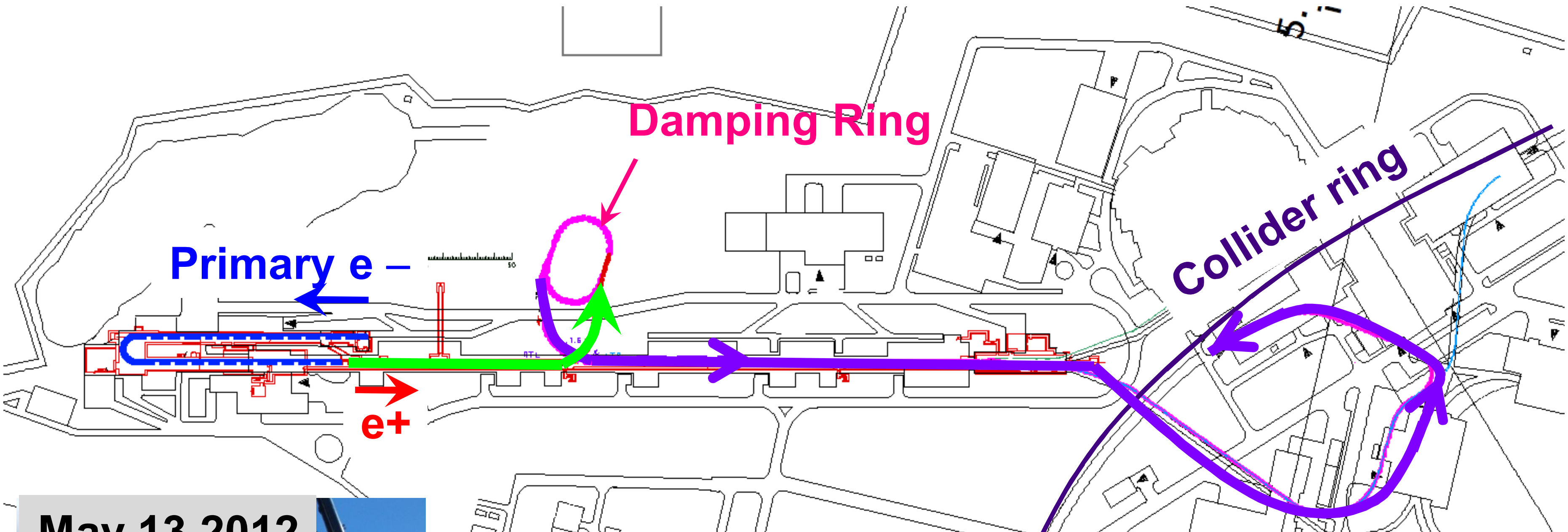
- Why a Super B Factory?
- The Super KEKB Project
- The BELLE II Detector
- Progress and Status

SuperKEKB Luminosity Projection



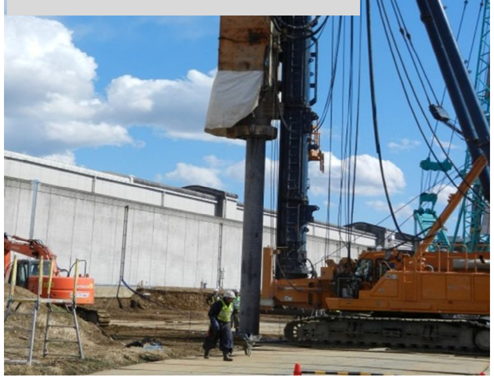
Nov 18, 2011 SuperKEKB Groundbreaking

Construction



May 13 2012

LINAC



Feb 7 2012 First Dipole

Quadrupole

July 2013Belle / Belle II Collaboration Meeting at Virginia Tech, US

~500 scientists
~100 institutes
from 23 countries/regions.

Summary

- A B factory to Super B factory transition:
  SuperKEKB and Belle II.
- Commissioning starts in 2015.
  First physics run expected in 2016.
- The luminosity goal is 50/ab by 2022, 50 times of the current Belle sample.
- New physics beyond the Standard Model will be explored:
  - In B and D meson and τ lepton decays.
  - Becomes an additional search route besides LHC.

References

- Belle II Technical Design Report
  [arXiv:1011.03252 [physics.ins-det]]

- Belle II Physics
  [arXiv:1002.5012 [hep-ex]]