EDIT 2013: Excellence in Detectors and Instrumentation Technologies

KEK, March 12 - 22, 2013

Detectors for luminosity frontier collider experiments

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Belle II

Contents

- Highlights from B factories (+ a little bit of history)
- Physics case for a super B factory
- Accellerator
- Detector upgrade
- Status and outlook

… Unfortunately, not enough time to cover LHCb

A little bit of history...

CP violation: difference in the properties of particles and their anti-particles – first observed in 1964 in the decays of neutral kaons.

M. Kobayashi and T. Maskawa (1973): CP violation in the Standard model – related to the weak interaction quark transition matrix

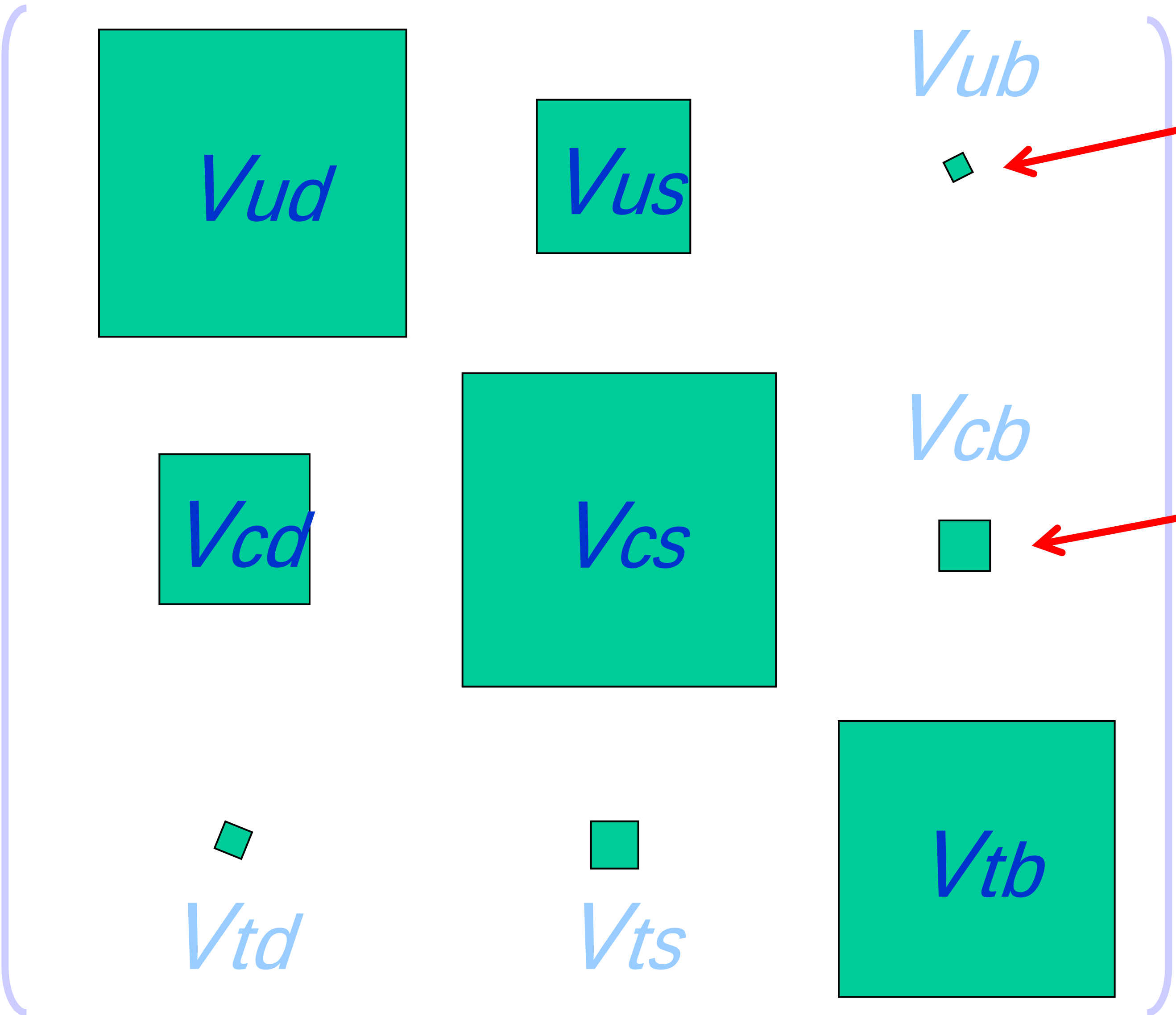
Their theory was formulated at a time when three quarks were known – and they requested the existence of three more!

The last missing quark was found in 1994.

... and in 2001 two experiments – Belle and BaBar at two powerfull accelerators (B factories) - have further investigated CP violation and have indeed proven that it is tightly connected to the quark transition matrix

CKM - Cabibbo-Kobayashi-Maskawa (quark transition) matrix:

almost real and diagonal, but not completely!



Amplitude for the b → u transition

Amplitude for the b → c transition

CKM: unitary matrix

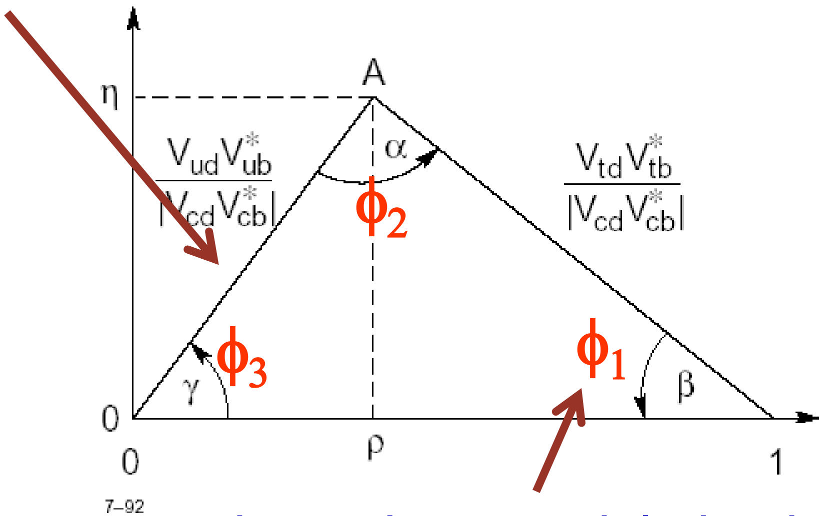
CKM matrix: determines charged weak interaction of quarks

Wolfenstein parametrisation: expand the CKM matrix in the parameter λ (=sinθ_c=0.22)

A, ρ and η: all of order one

$$V = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

determines probability of b→u transitions



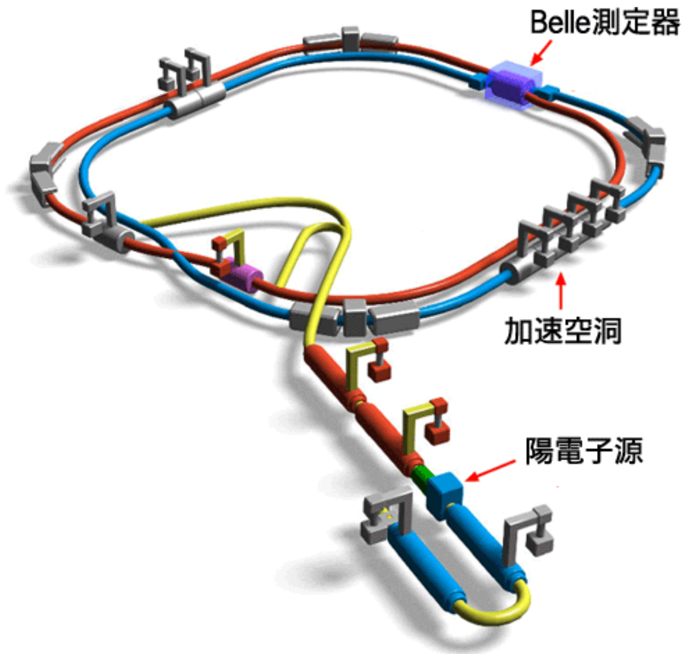
determines CP violation in $B \to J/\psi\ K_S$ decays

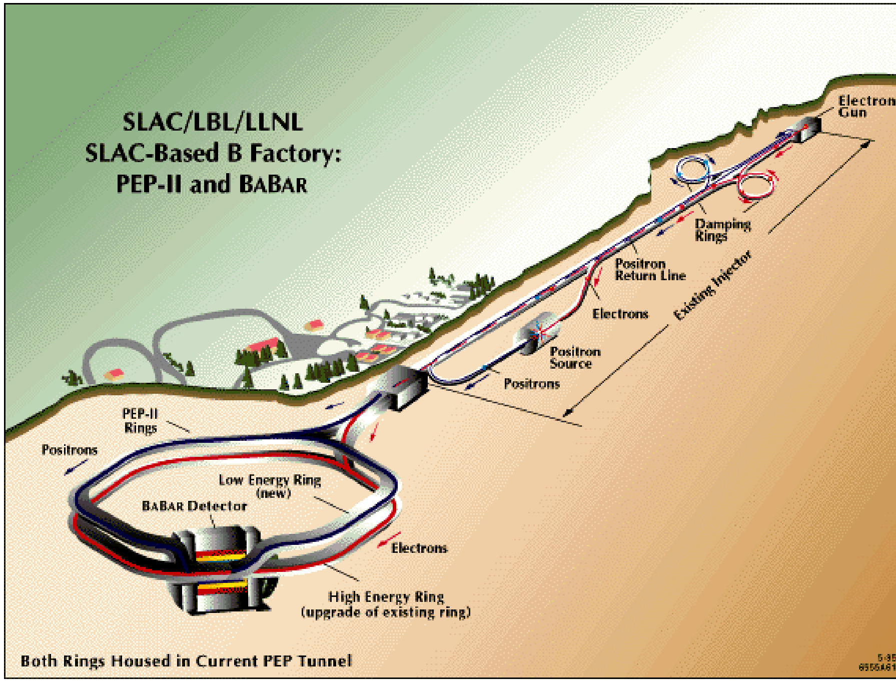
Unitarity condition:

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

Goal: measure sides and angles in several different ways, check consistency →

Asymmetric B factories





$\sqrt{s}$=10.58 GeV

e^+ → $\Upsilon(4s)$ ← e^-

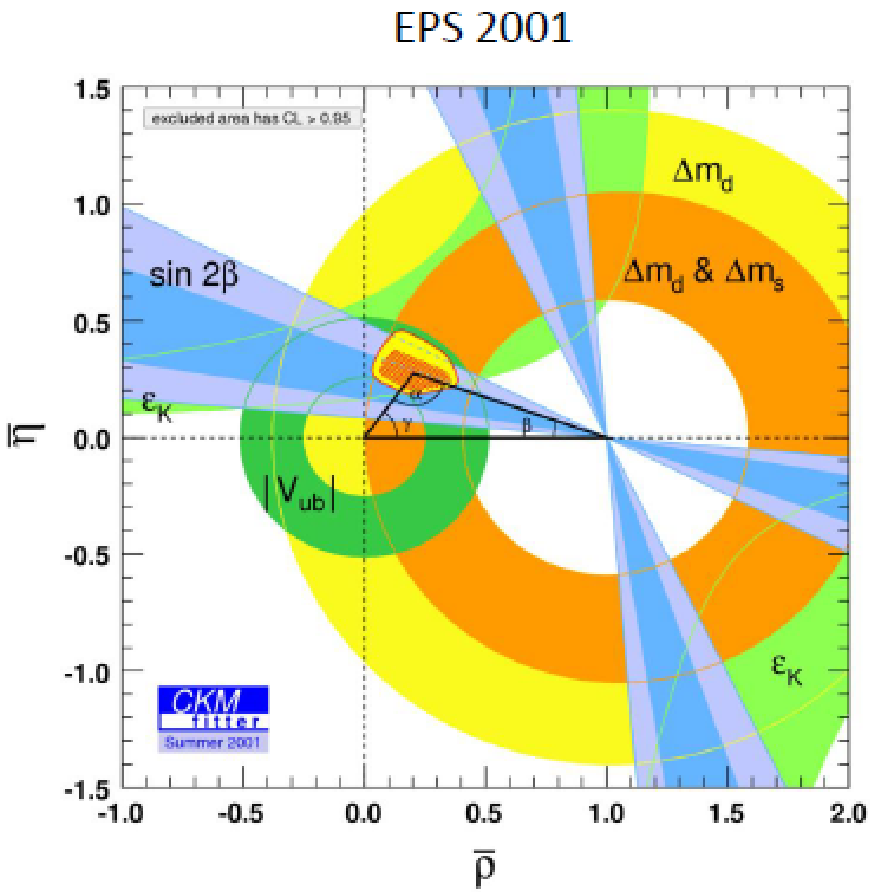
$\Upsilon(4s)$ → B, $\bar{B}$

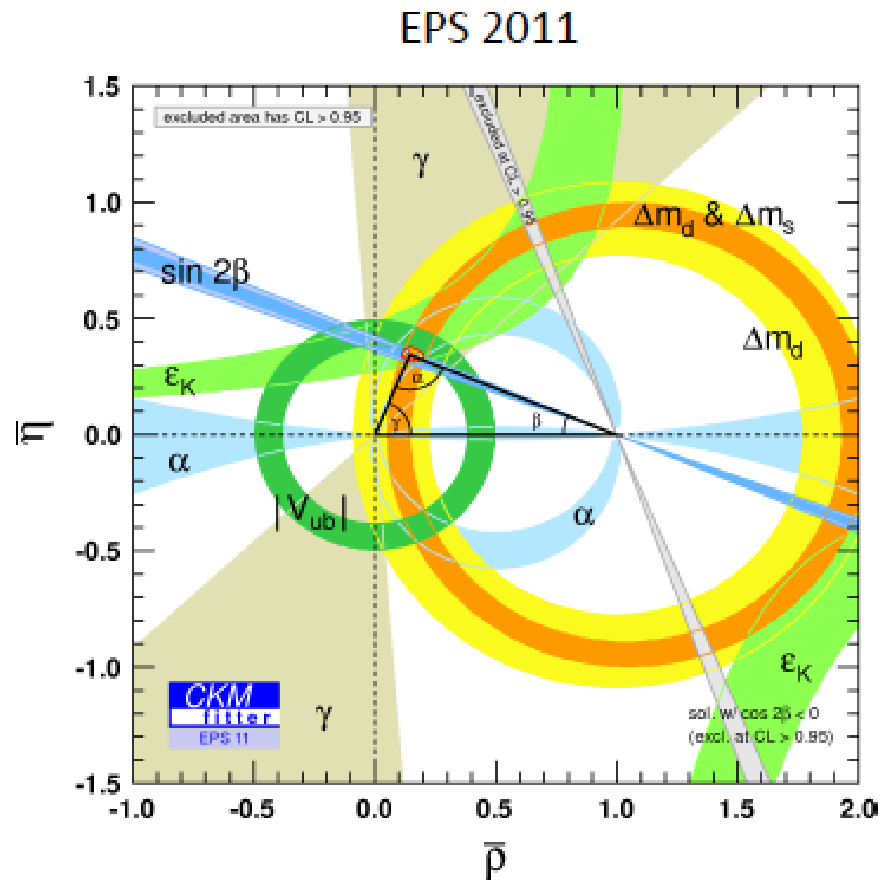
$\Delta z \sim c\beta\gamma\tau_B$
$\sim 200\mu m$

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

Unitarity triangle – 2011 vs 2001

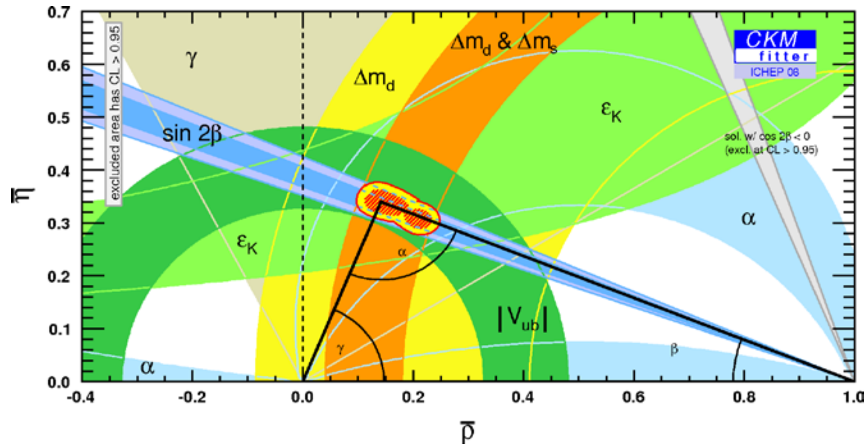
CP violation in the B system: from the discovery (2001) to a precision measurement (2011).





KM's bold idea verified by experiment

Relations between parameters as expected in the Standard model →



→ Nobel prize 2008!

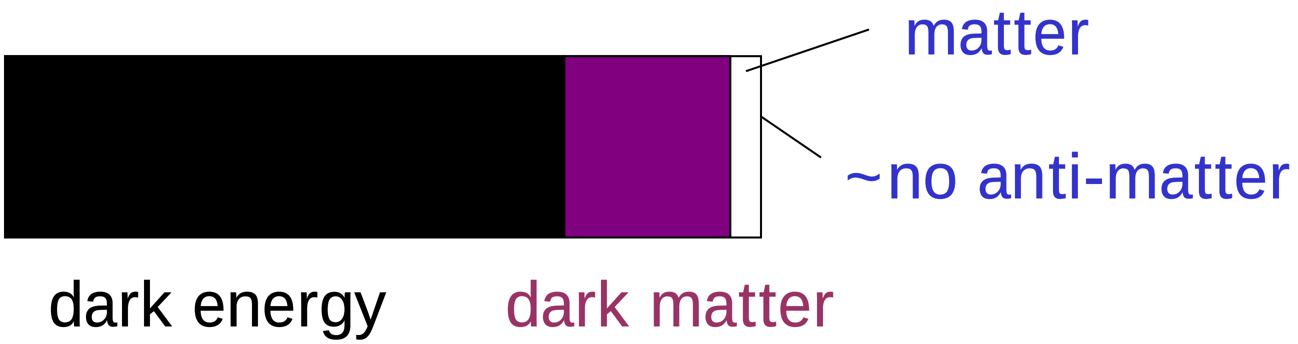
→ With essential experimental confirmations by BaBar and Belle! (explicitly noted in the Nobel Prize citation)

The KM scheme is now part of the Standard Model of Particle Physics

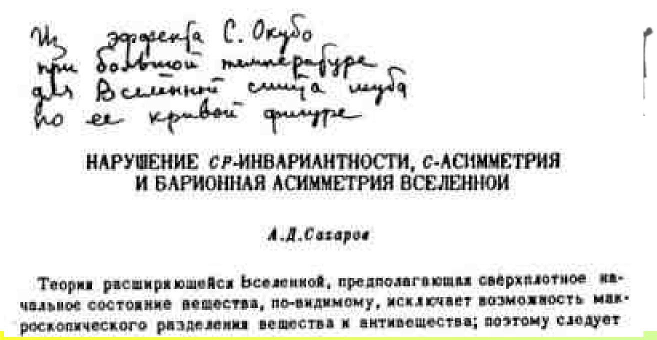
•However, the CP violation of the KM mechanism is too small to account for the asymmetry between matter and anti-matter in the Universe (falls short by 10 orders of magnitude !)

•SM does not contain the fourth fundamental interaction, gravitation

•Most of the Universe is made of stuff we do not understand...



Are we done ? (Didn’t the B factories accomplish their mission, recognized by the 2008 Nobel Prize in Physics ?)



Из эффекта С. Окубо
при большой температуре
для Вселенной сшита шуба
по ее кривой фигуре

НАРУШЕНИЕ CP-ИНВАРИАНТНОСТИ, C-АСИММЕТРИЯ И БАРИОННАЯ АСИММЕТРИЯ ВСЕЛЕННОЙ

А.Д.Сахаров

Теория расширяющейся Вселенной, предполагающая сверхплотное начальное состояние вещества, по-видимому, исключает возможность макроскопического разделения вещества и антивещества; поэтому следует

Matter - anti-matter asymmetry of the Universe: KM (Kobayashi-Maskawa) mechanism still short by 10 orders of magnitude !!!

Two frontiers

Two complementary approaches to study shortcomings of the Standard Model and to search for the so far unobserved processes and particles (so called New Physics, NP). These are the **energy frontier** and the **intensity frontier** .

Energy frontier : direct search for production of unknown particles at the highest achievable energies.

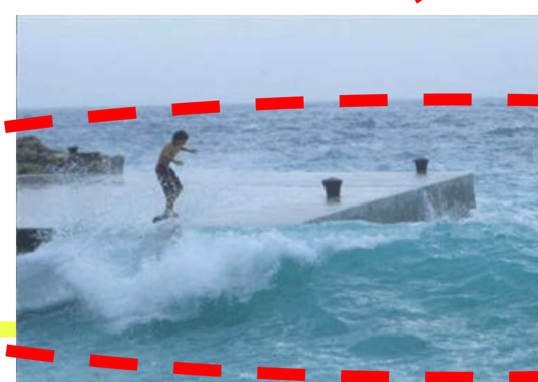
Intensity frontier : search for rare processes, deviations between theory predictions and experiments with the ultimate precision.

→for this kind of studies, one has to investigate a very large number of reactions events → need accelerators with ultimate **intensity** (= luminosity)

Comparison of **energy** /**intensity** frontiers

To observe a large ship far away one can either use **strong binoculars** or observe **carefully the direction and the speed of waves** produced by the vessel.

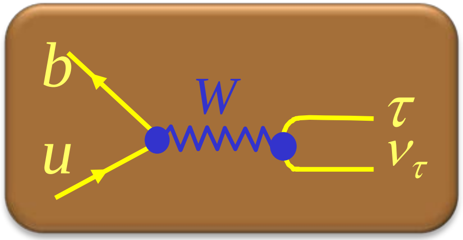
Energy frontier (LHC)



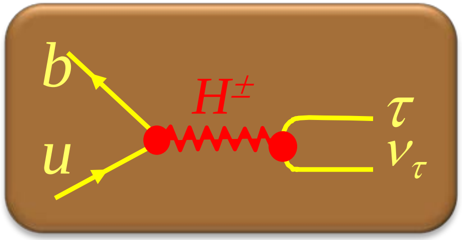
Luminosity frontier (Belle and Belle II)

An example: Hunting the charged Higgs in the decay $B^- \rightarrow \tau^- \nu_\tau$

In addition to the Standard Model Higgs – most probably just discovered at the LHC - in New Physics (e.g., in supersymmetric theories) there could also be a charged Higgs.



The rare decay $B^- \rightarrow \tau^- \nu_\tau$ is in SM mediated by the W boson

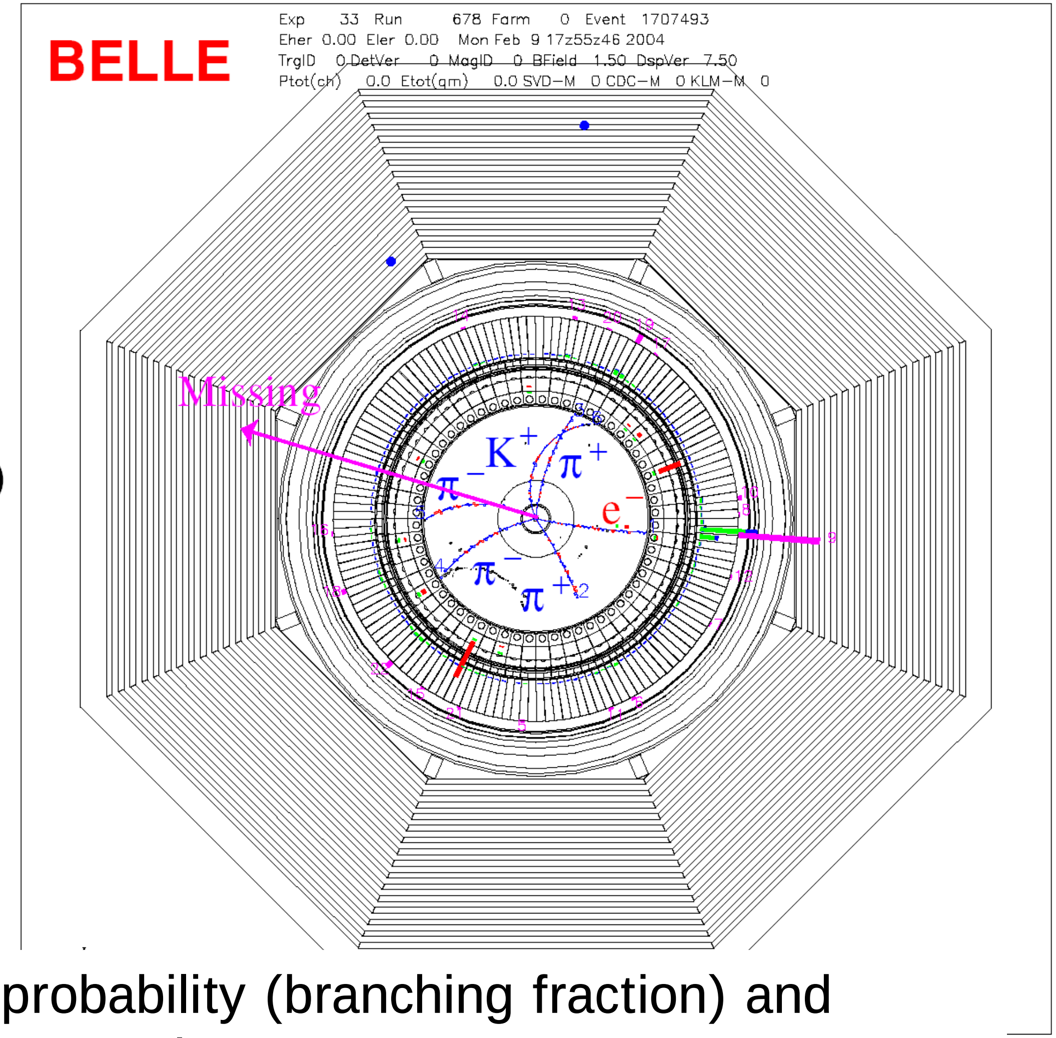


In some supersymmetric extensions it can also proceed via a charged Higgs

The charged Higgs would influence the decay of a B meson to a tau lepton and its neutrino, and modify the probability for this decay.

Missing Energy Decays: $B^- \to \tau^- \nu_\tau$

$$B^+ \to D^0 \pi^+$$
$$(\to K \pi^- \pi^+ \pi^-)$$
$$B^- \to \tau (\to e \nu \bar{\nu}) \nu$$



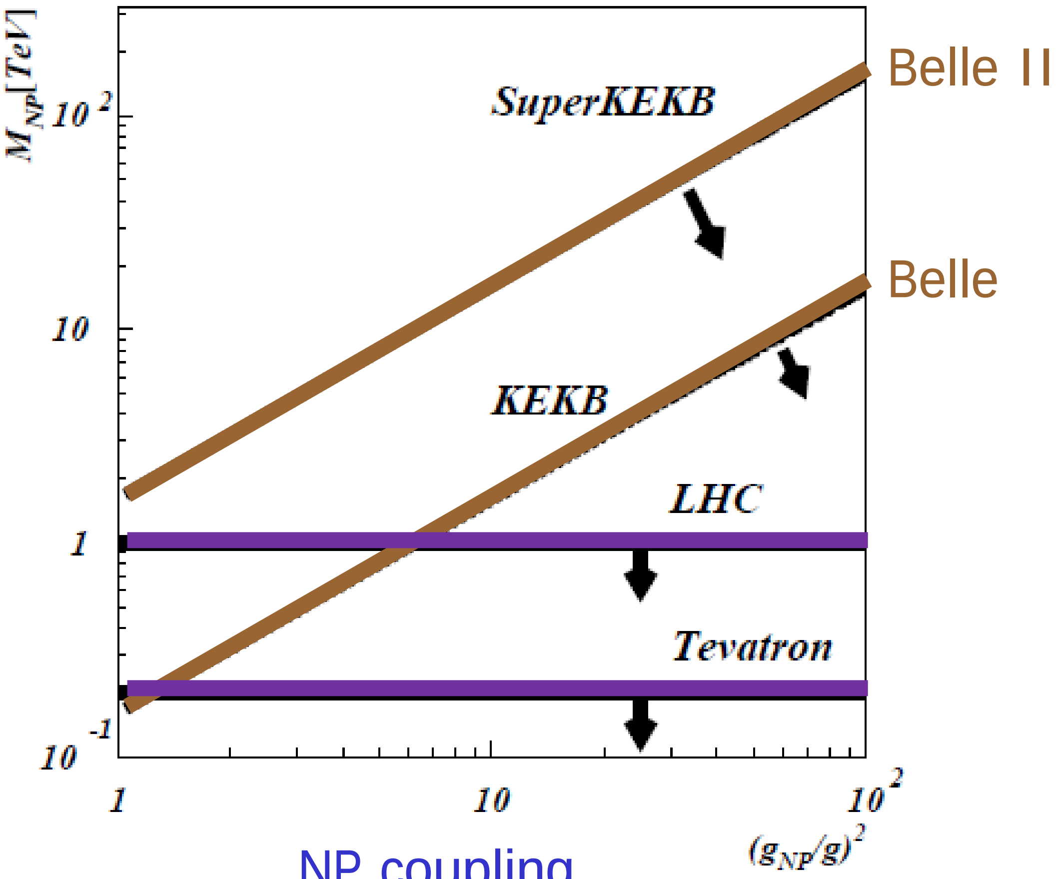
By measuring the decay probability (branching fraction) and comparing it to the SM expectation:

→ Properties of the charged Higgs (e.g. its mass)

New Physics reach

energy frontier vs. **intensity frontier**

NP mass scale (TeV)

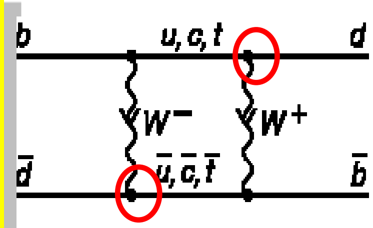


NP coupling

Super B Factory Motivation 2

- Lessons from history: the top quark

<u>Physics of top quark</u>
First estimate of mass: BB mixing → ARGUS
Direct production, Mass, width etc. → CDF/D0
Off-diagonal couplings, phase → BaBar/Belle



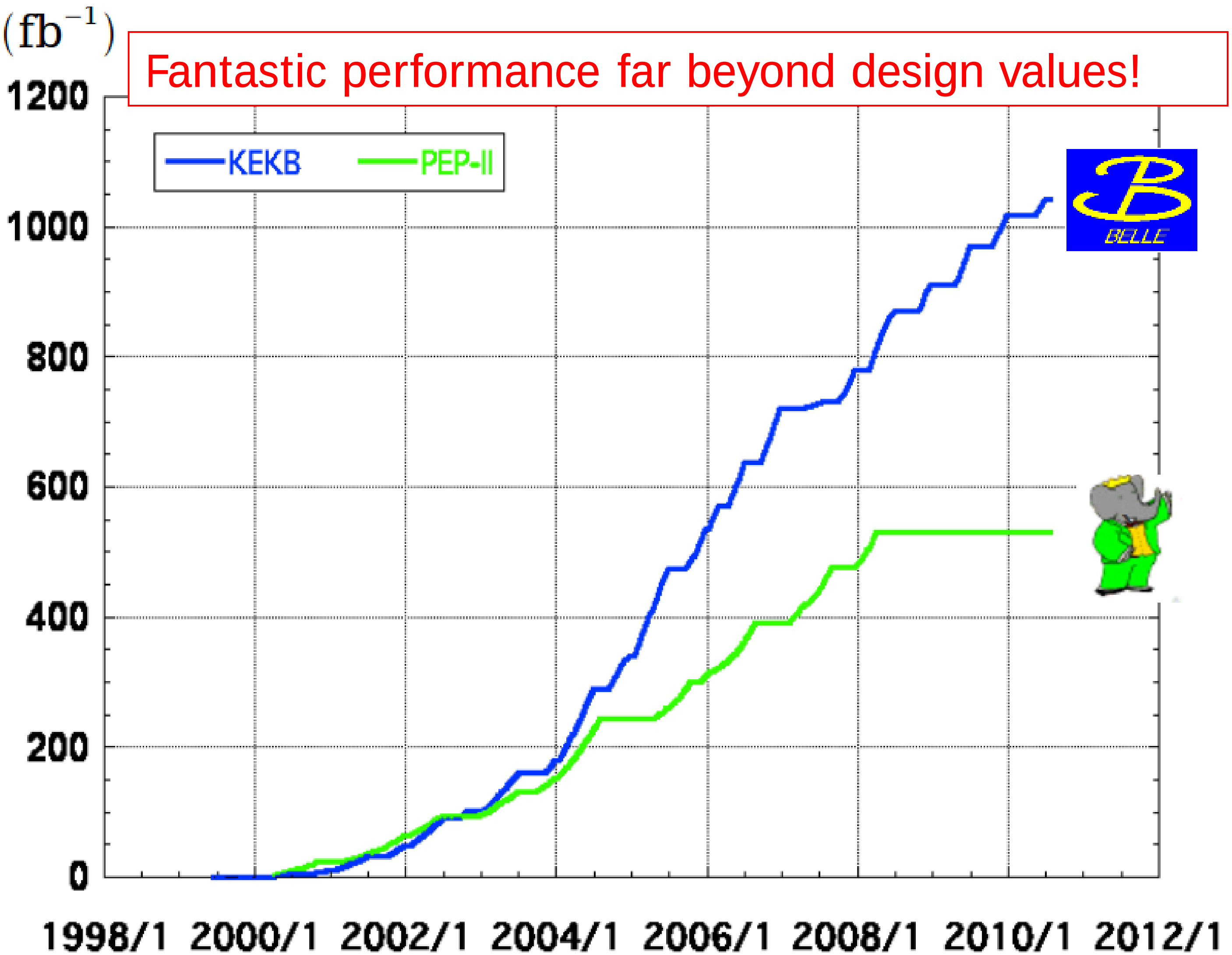
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- Even before that: prediction of charm quark from the GIM mechanism, and its mass from K^0 mixing

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 $b \to s l^+ l^-$ has become a powerfull tool to search for physics beyond SM.
- Observation of D mixing
- Searches for rare τ decays
- Observation of new hadrons

Integrated luminosity at B factories



> 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:

~ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

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

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

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

Off resonance:

~ 54 fb^{-1}

What next?

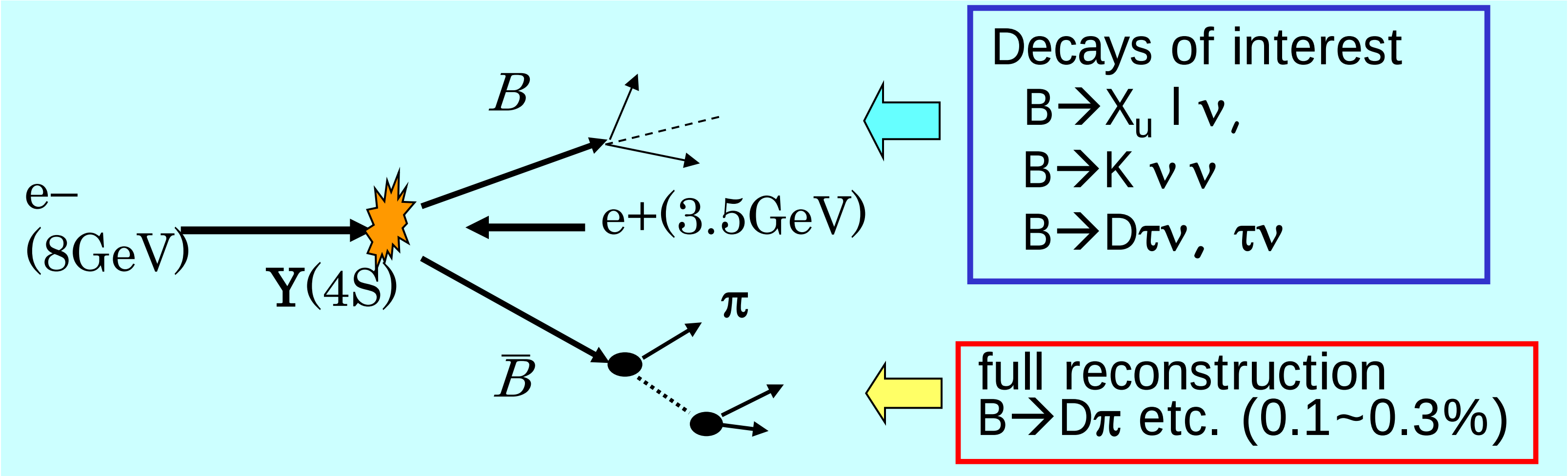
To search for NP effects, need much more data (two orders!) → Luminosity frontier experiment → Super B factory

However: it will be a different world in four years, there will be serious competition from LHCb and BESIII

Still, e^+e^- machines running at (or near) Υ(4s) will have considerable advantages in several classes of measurements, and will be complementary in many more

Full Reconstruction Method

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

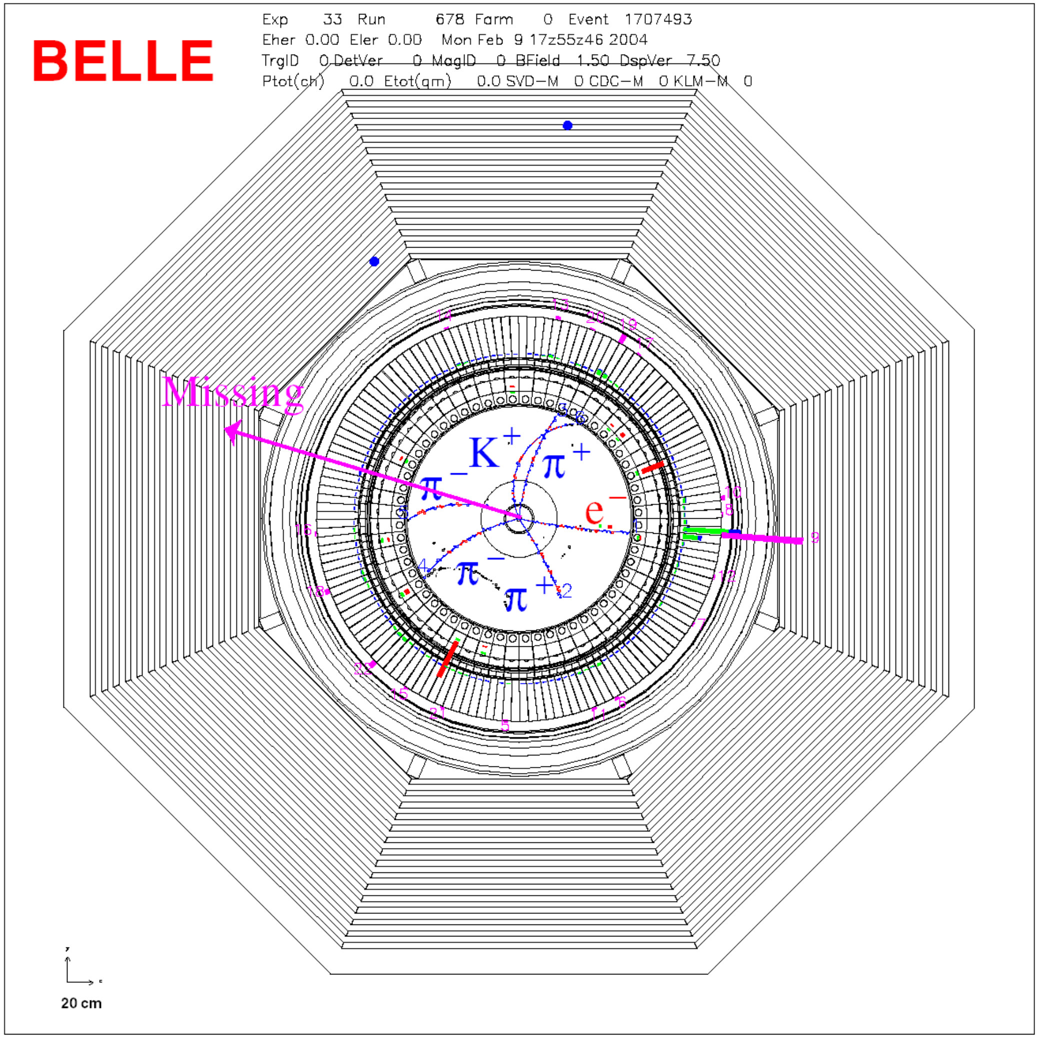


→ Offline B meson beam!

Powerful tool for B decays with neutrinos

Missing Energy Decays: $B^- \rightarrow \tau^- \nu_\tau$

$$B^+ \to D^0\pi^+$$
$$(\to K\pi^-\pi^+\pi^-)$$
$$B^- \to \tau(\to e\nu\bar{\nu})\nu$$



$B \to \nu\,\nu$ decay

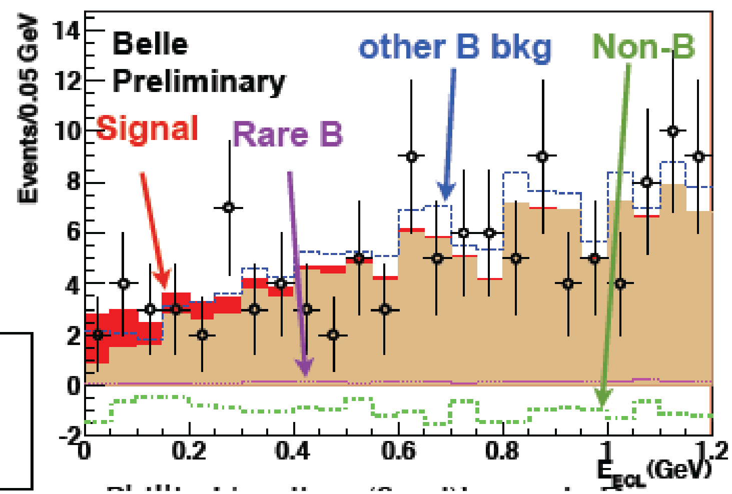
$B \to \nu\,\nu$ similar as $B \to \mu\,\mu$ a very sensitive channel to NP contributions

Even more strongly helicity suppressed by $\sim(m_\nu/m_B)^2$

$\to$ Any signal = NP

Unique feature at B factories: use tagged sample with fully reconstructed B decays on one side, require no signal from the other B.

Use rest energy in the calorimeter and angular distribution as the fit variables.



BELLE

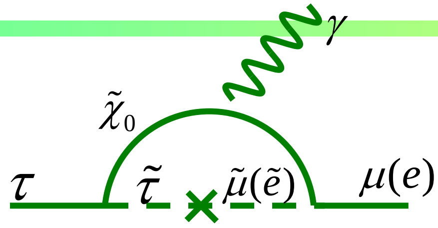
90% C.L. BR < 1.3 x 10^{-4}

Belle Preliminary 657M BBbar

c.f. (Babar) BR < 2.2 x 10^{-4}

LFV and New Physics

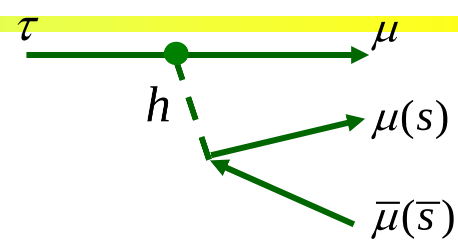
τ→lγ



- SUSY + Seasaw $(m^2_{\tilde{l}})_{23(13)}$
- Large LFV Br(τ→μγ)=O($10^{-7\sim9}$)

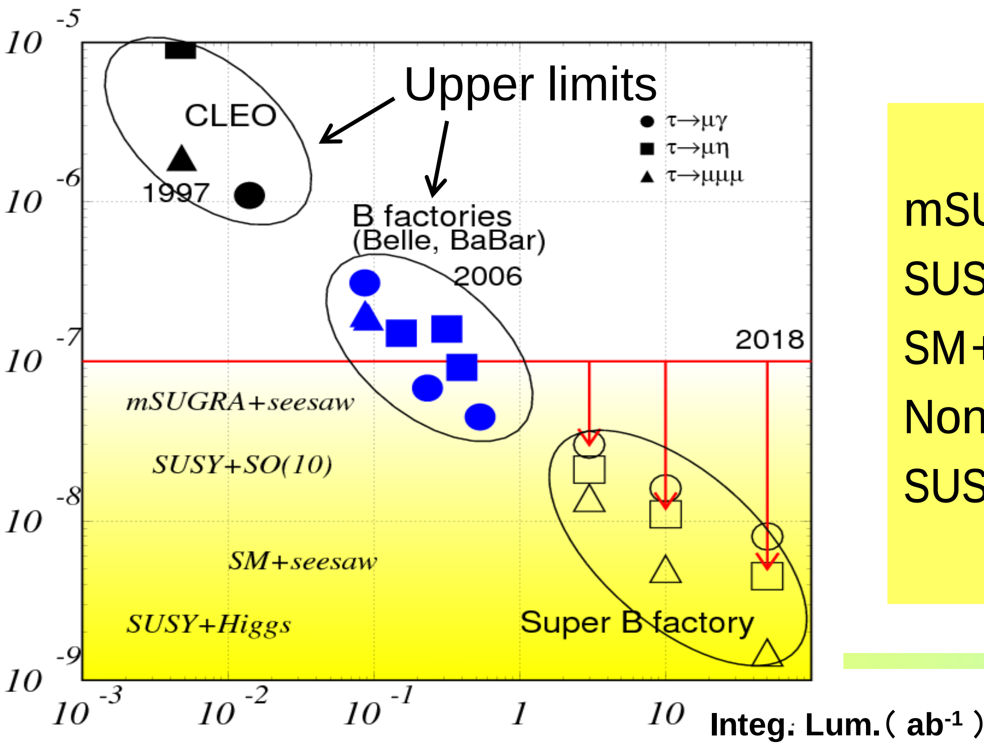
$$Br(\tau \to \mu\gamma) \simeq 10^{-6} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}} \right) \left(\frac{1\,TeV}{m_{SUSY}} \right)^4 \tan^2 \beta$$

τ→3l,lη



- Neutral Higgs mediated decay.
- Important when MSUSY >> EW scale.

$$Br(\tau \to 3\mu) = 4\times10^{-7} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}} \right) \left(\frac{\tan\beta}{60} \right)^6 \left(\frac{100GeV}{m_A} \right)^4$$



model	Br(τ→μγ)	Br(τ→lll)
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}

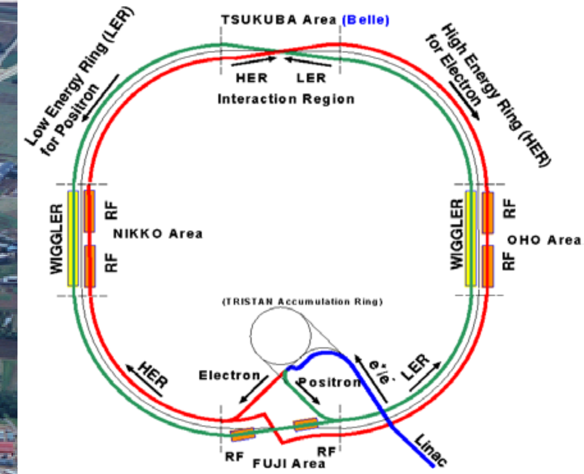
Physics at a Super B Factory

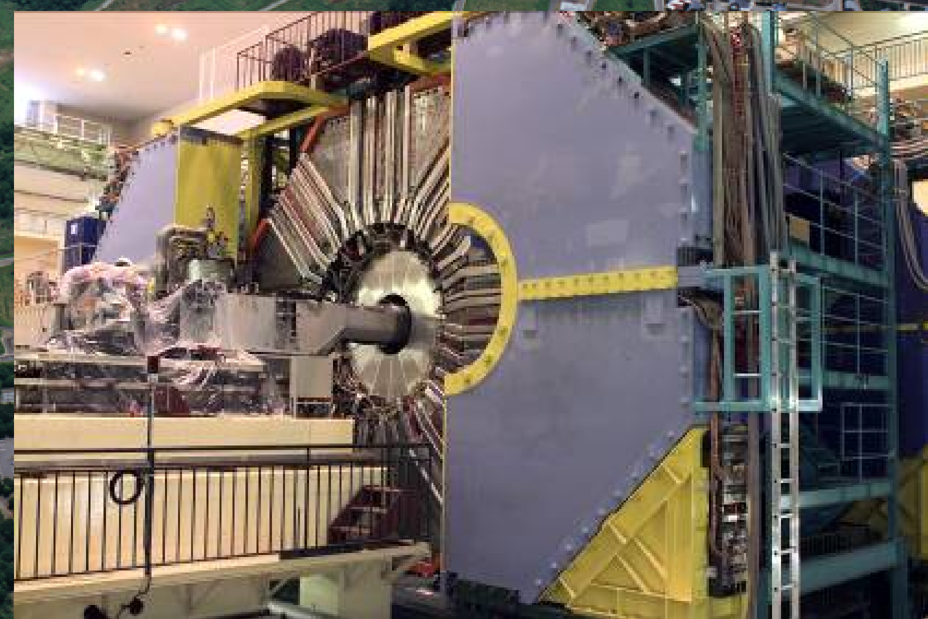
- There is a good chance to see new phenomena;
  - **CPV in B decays from the new physics (non KM).**
  - **Lepton flavor violations in τ decays.**
- They will help to diagnose (if found) or constrain (if not found) new physics models.
- $B \rightarrow \tau\nu$, $D\tau\nu$ can probe the charged Higgs in large $\tan\beta$ region.
- **Physics motivation is independent of LHC.**
  - If LHC finds NP, precision flavour physics is compulsory.
  - If LHC finds no NP, high statistics B/τ decays would be a unique way to search for the >TeV scale physics (=TeV scale in case of MFV).

Physics reach with 50 ab^{-1}:

- Physics at Super B Factory (Belle II authors + guests) hep-ex arXiv:1002.5012

How to do it?
→ upgrade KEKB and Belle

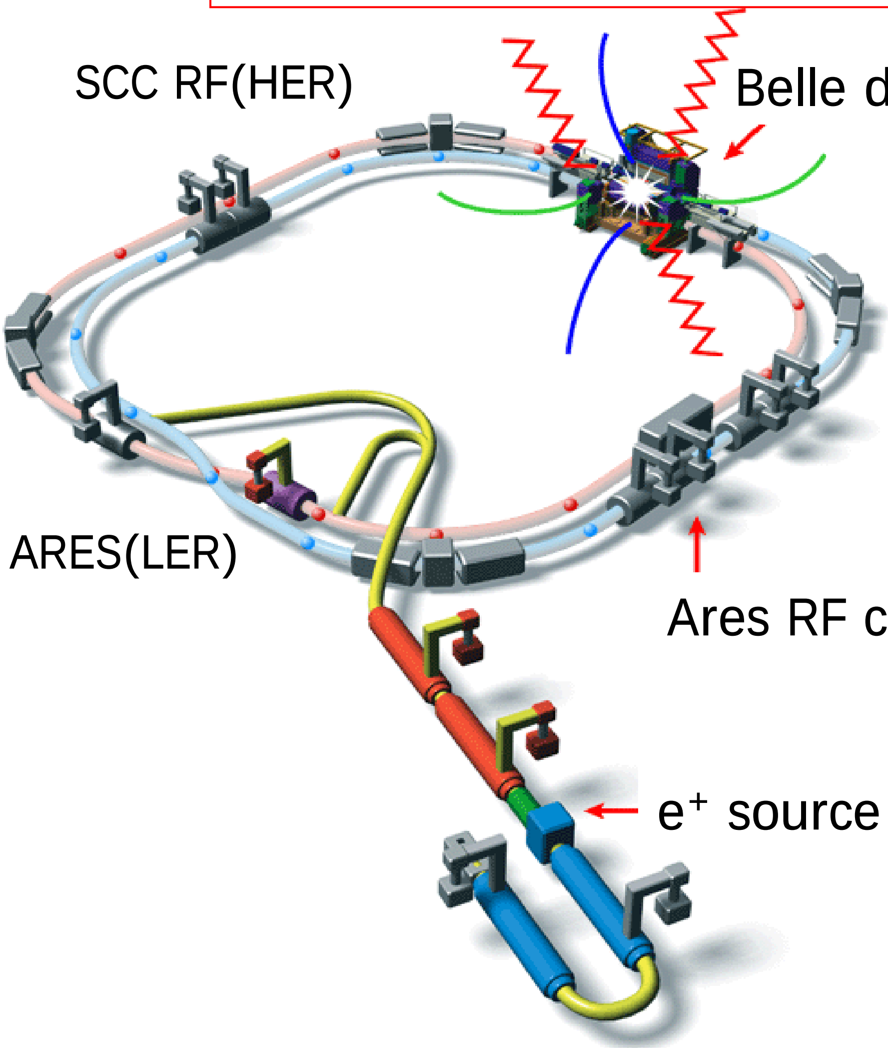




Accelerator

The KEKB Collider

Fantastic performance far beyond design values!



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

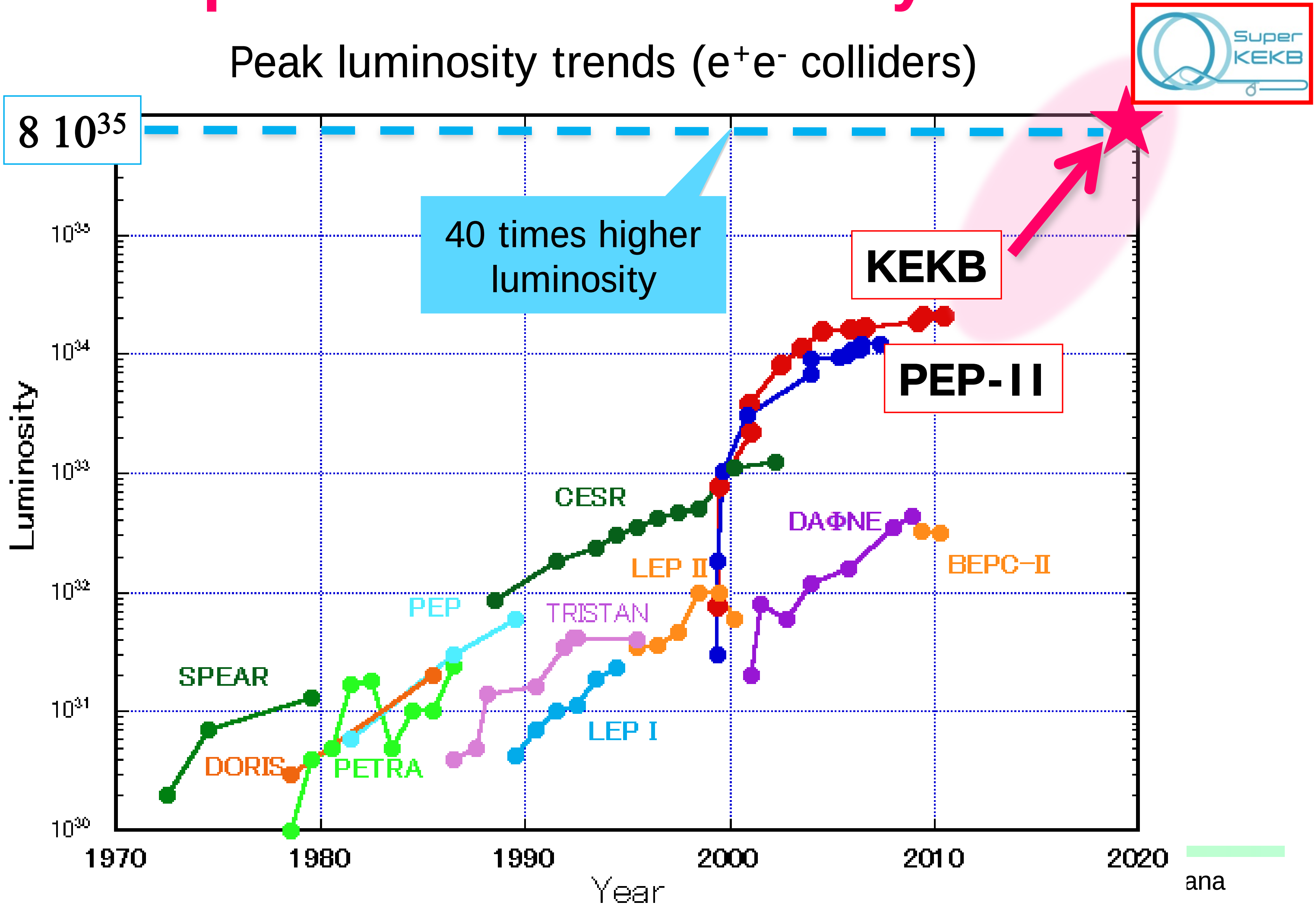
Peak luminosity (WR!) :

2.1×10^{34} cm^{-2}s^{-1}

=2x design value

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

SuperKEKB is the intensity frontier



ana

How to increase the luminosity?

Lorentz factor

Beam current

Beam-beam parameter

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

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

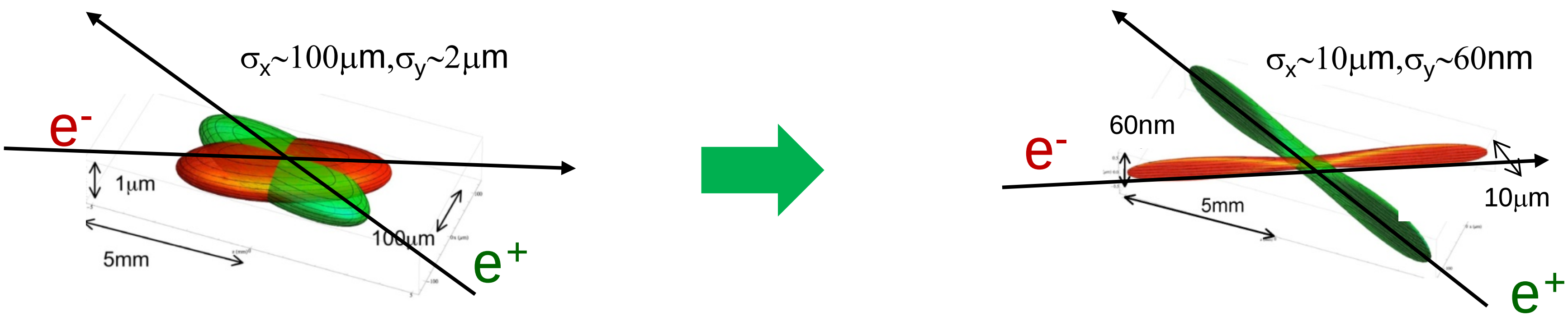
Collision with very small spot-size beams

Invented by Pantaleo Raimondi for SuperB – ‘spin-off‘ of linear collider studies

How big is a nano-beam ?

How to go from an excellent accelerator with world record performance – KEKB – to a 40x times better, more intense facility?

In KEKB, colliding electron and positron beams are much thinner than the human hair...



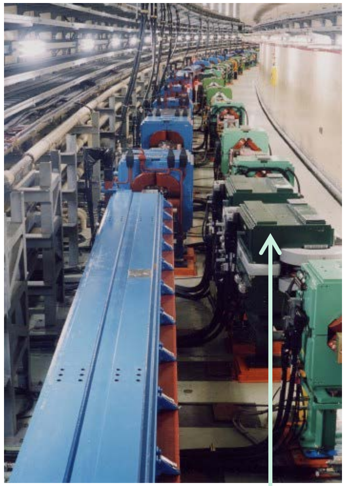
... For a 40x increase in intensity you have to make the beam as thin as a few 100 atomic layers!

Machine design parameters

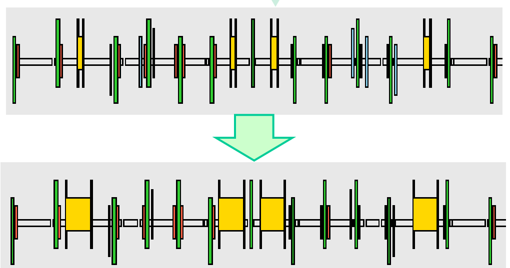
parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	φ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.37	0.40	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam currents	I_b	1.64	1.19	3.60	2.60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

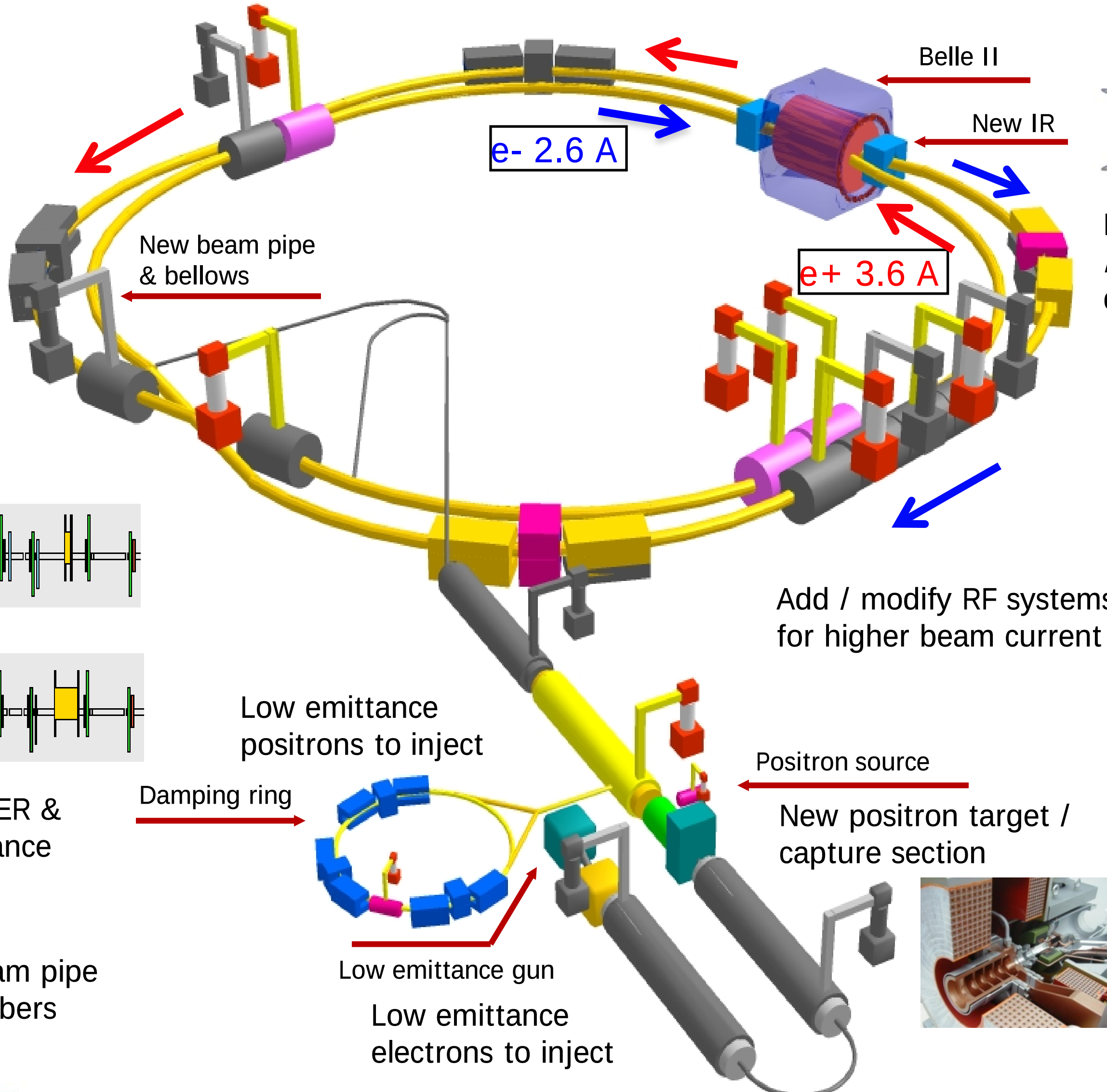
KEKB to SuperKEKB



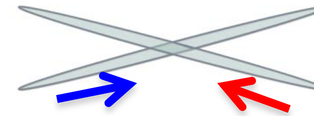
Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance



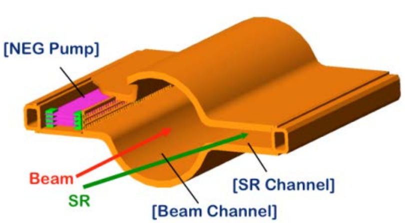
Colliding bunches



New superconducting /permanent final focusing quads near the IP

Add / modify RF systems for higher beam current

TiN-coated beam pipe with antechambers



To obtain x40 higher luminosity

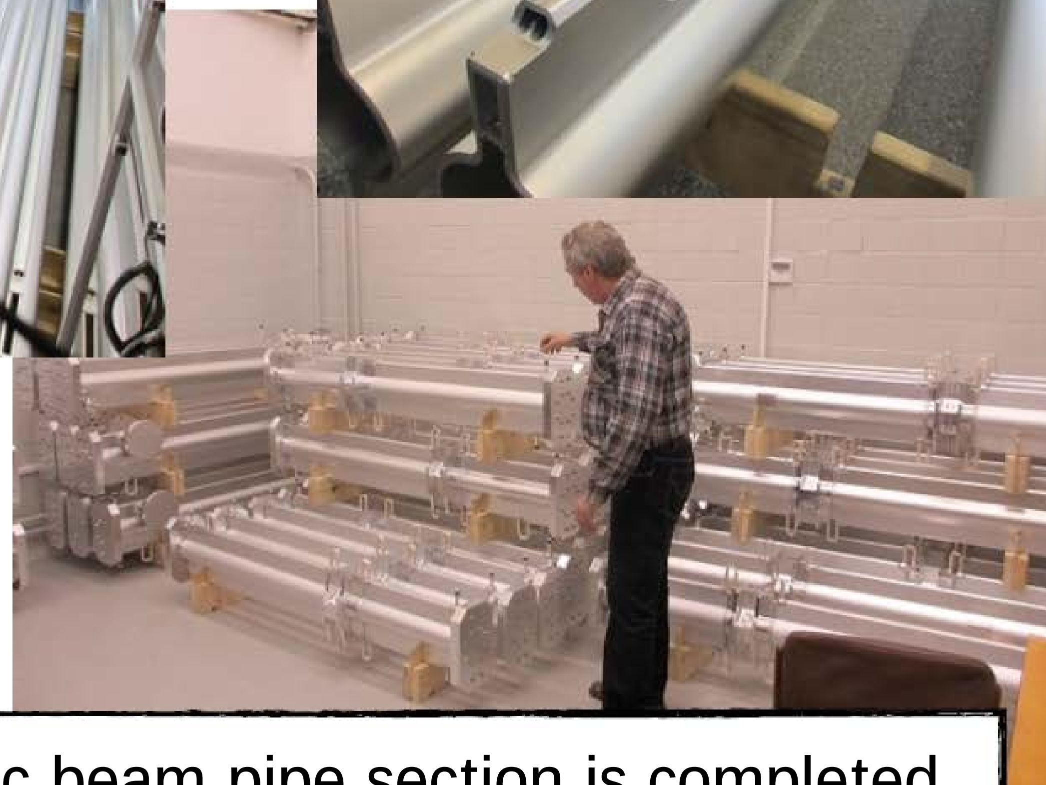
1/3 of new dipole magnets have been installed in LER. (July 9, 2012)

Three magnets per day !
Total ~100

- Installing the 4 m LER dipole over the 6 m HER dipole (remains in place).
- All LER dipoles are scheduled to be installed this year.

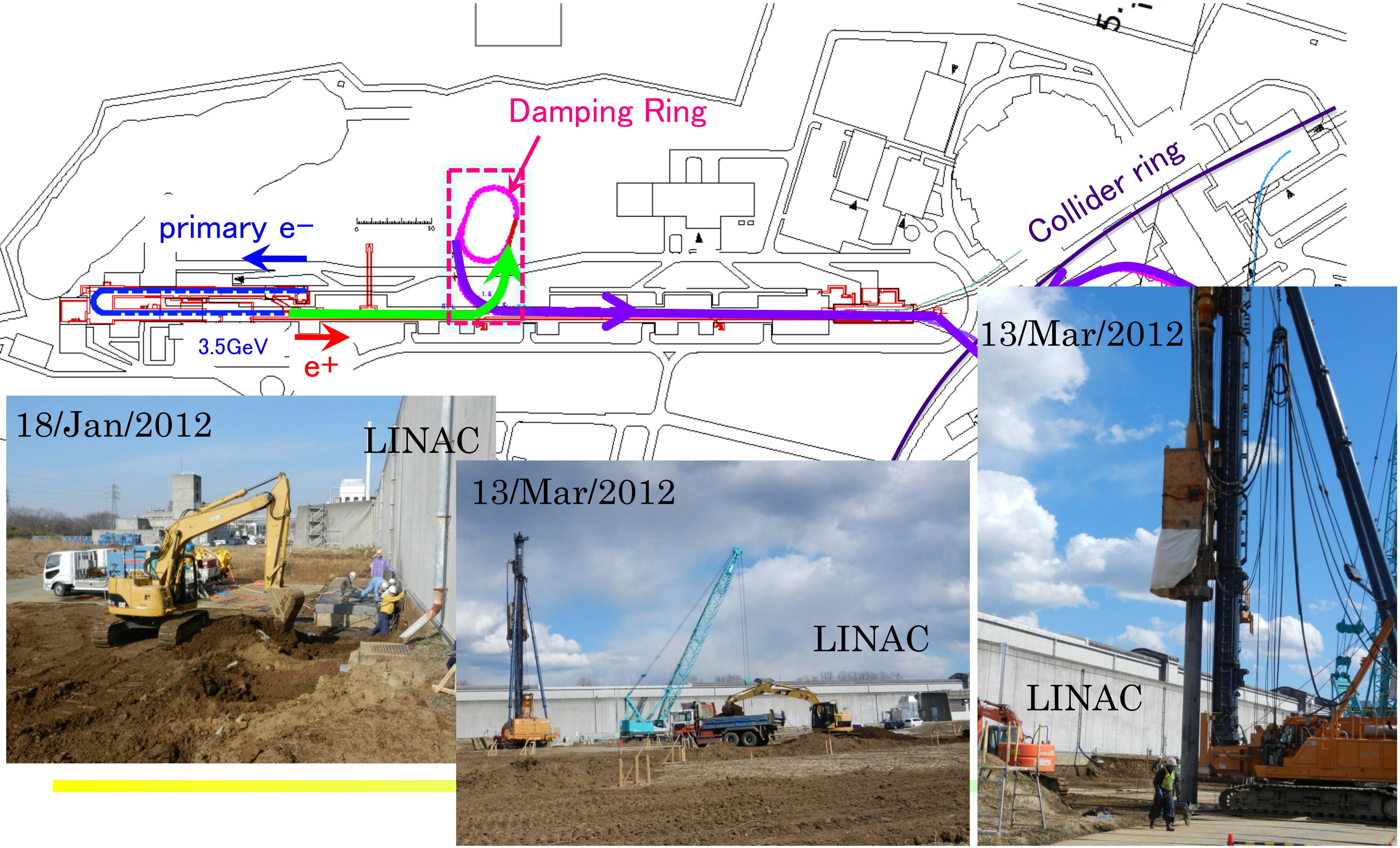
Entirely new LER beam pipe with ante-chamber and Ti-N coating

Beam pipe is made of aluminum.



Fabrication of the LER arc beam pipe section is completed

Damping ring construction started in Jan 2012



TiN Coating Machine

Beam pipe with TiN coating reduces emission of secondary photoelectrons.

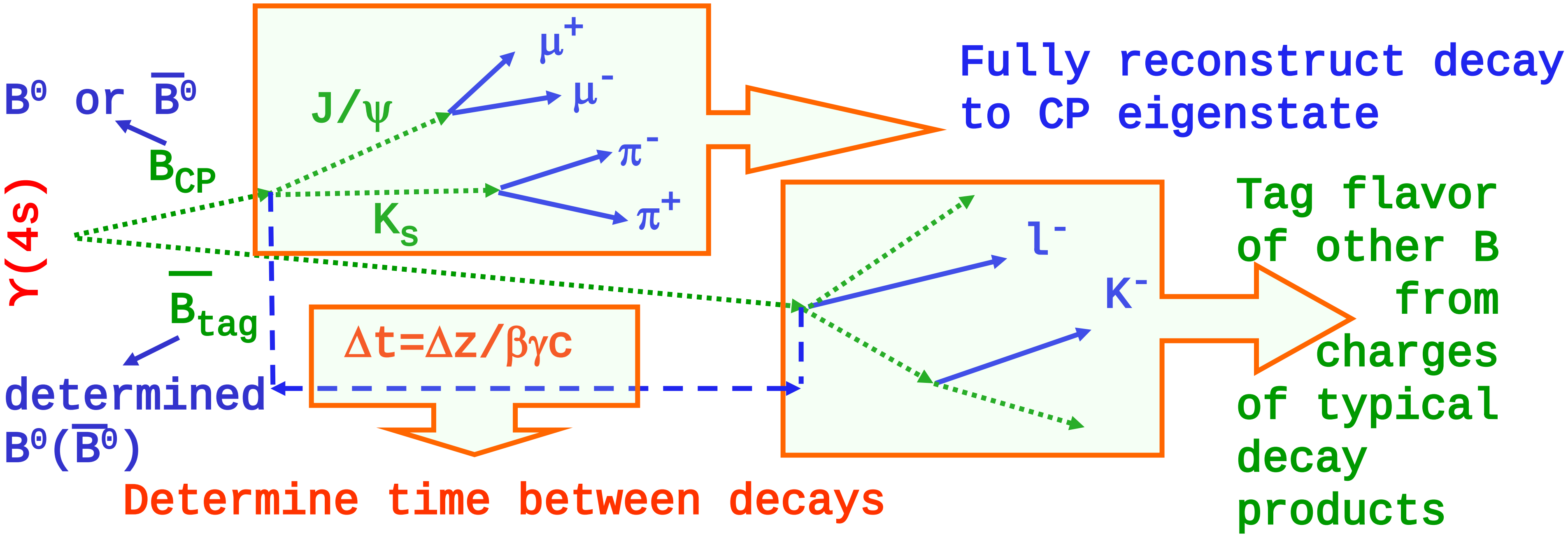
TiN coating machine (1st vertical type) in Oho experimental hall

Now we have two coating machines.

TiN coating has started – in a good shape

Experimental apparatus

Typical measurement



Components of an experimental apparatus ('spectrometer')

- Tracking and vertexing systems
- Particle identification devices
- Calorimeters (measurement of energy)

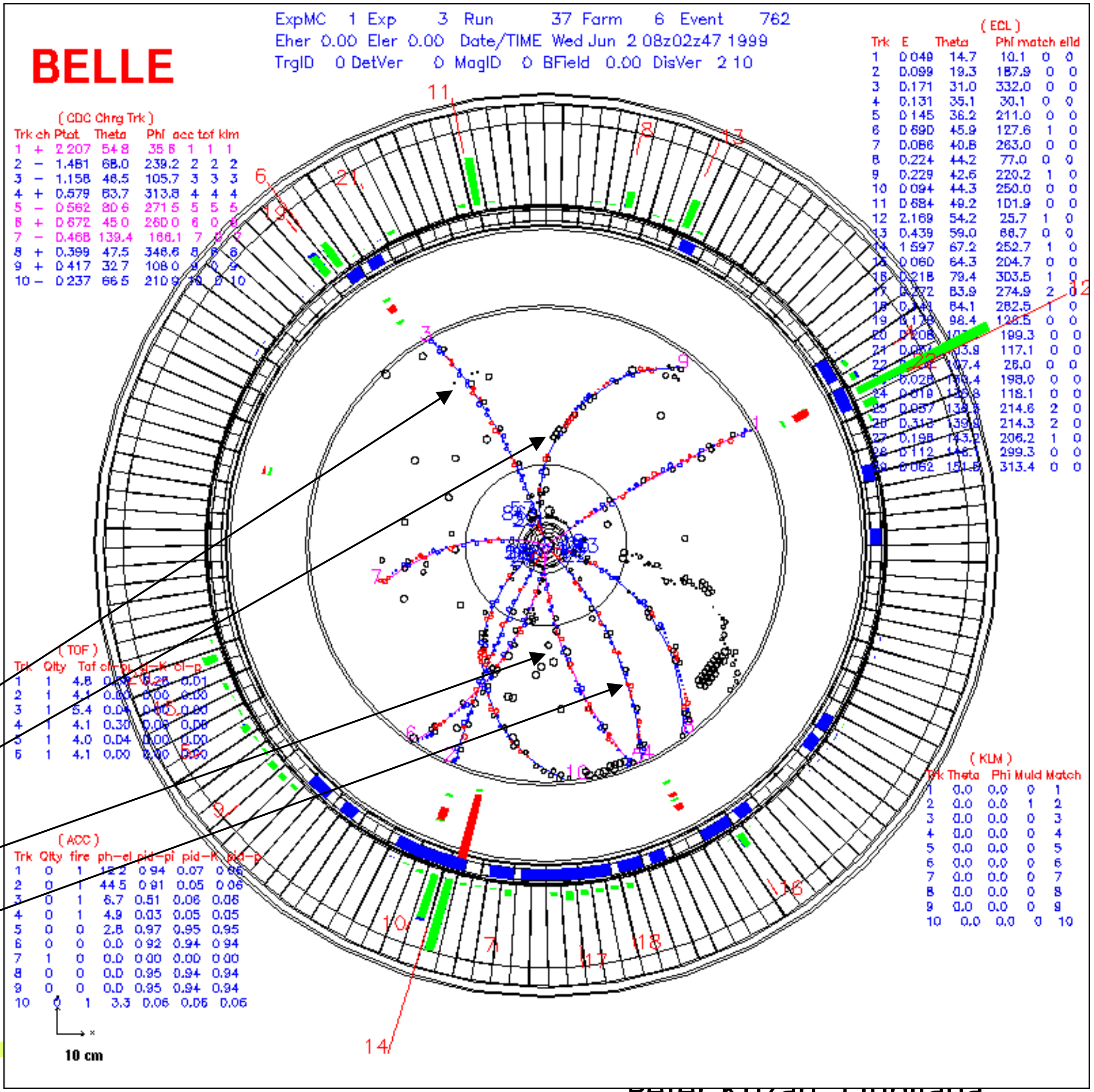
How to understand what happened in a collision?

Illustration on an example:

$B^0 \rightarrow K^0_S J/\psi$

$K^0_S \rightarrow \pi^- \pi^+$

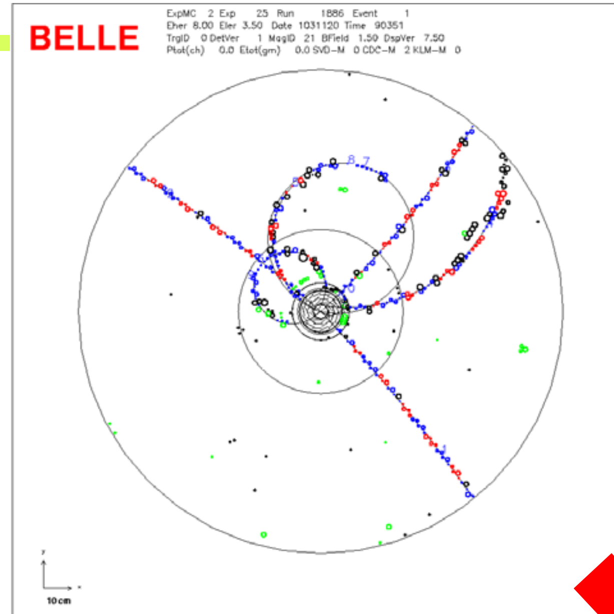
$J/\psi \rightarrow \mu^- \mu^+$

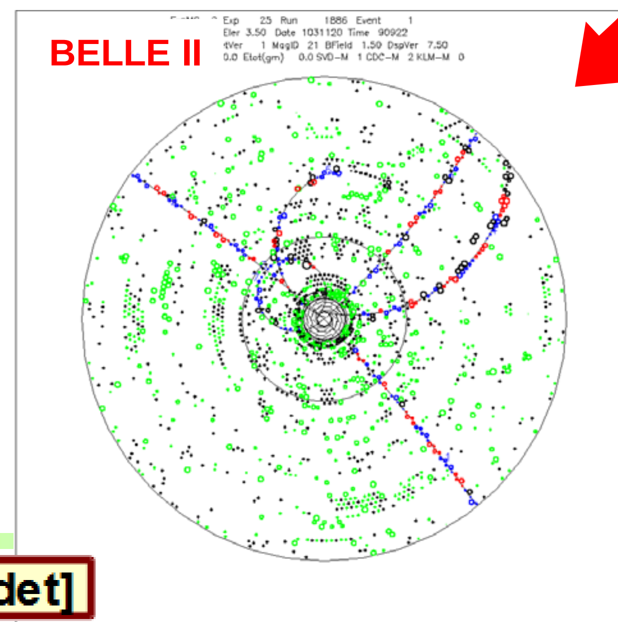


Need to build a new detector to handle higher backgrounds

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"

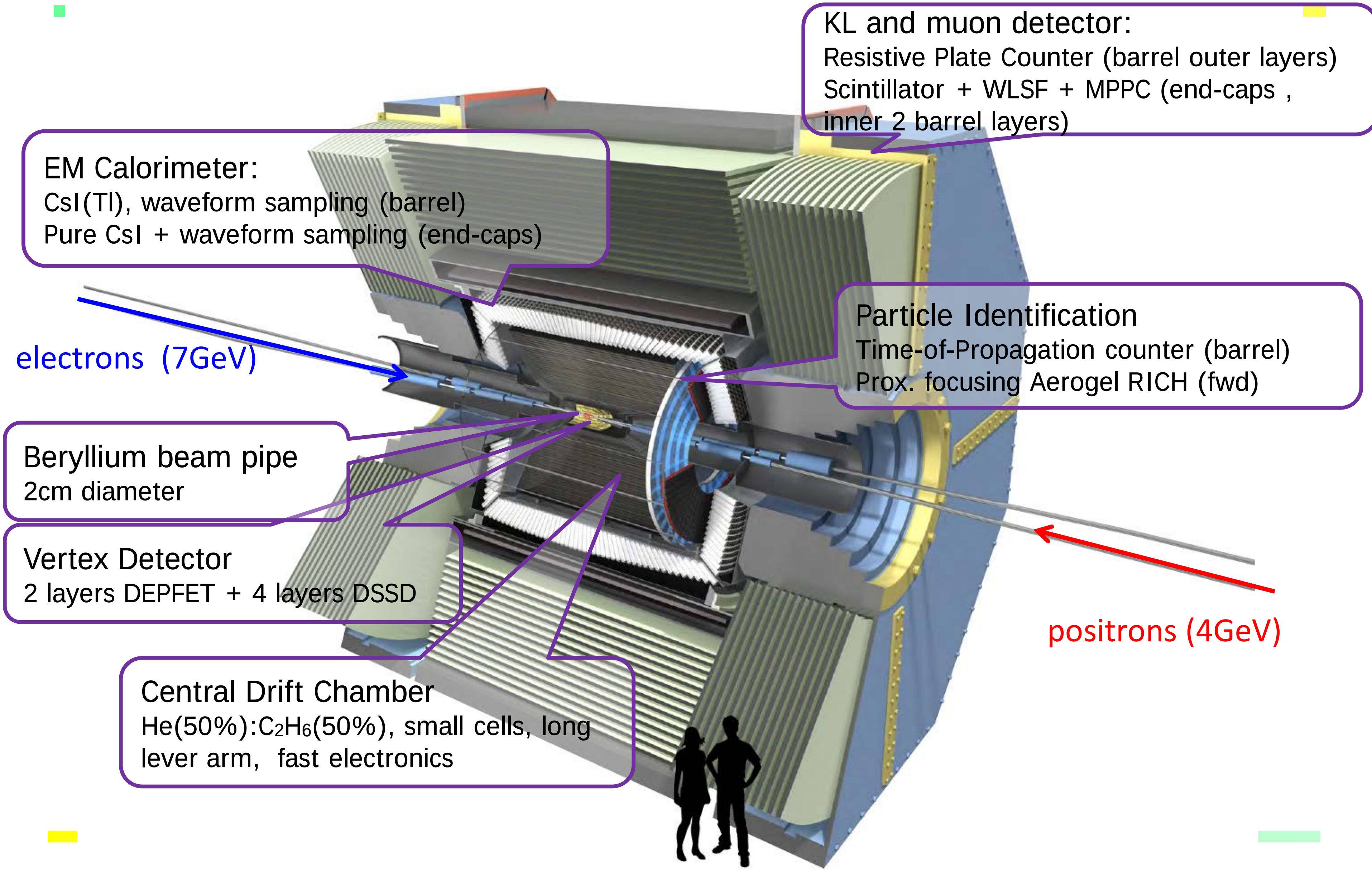




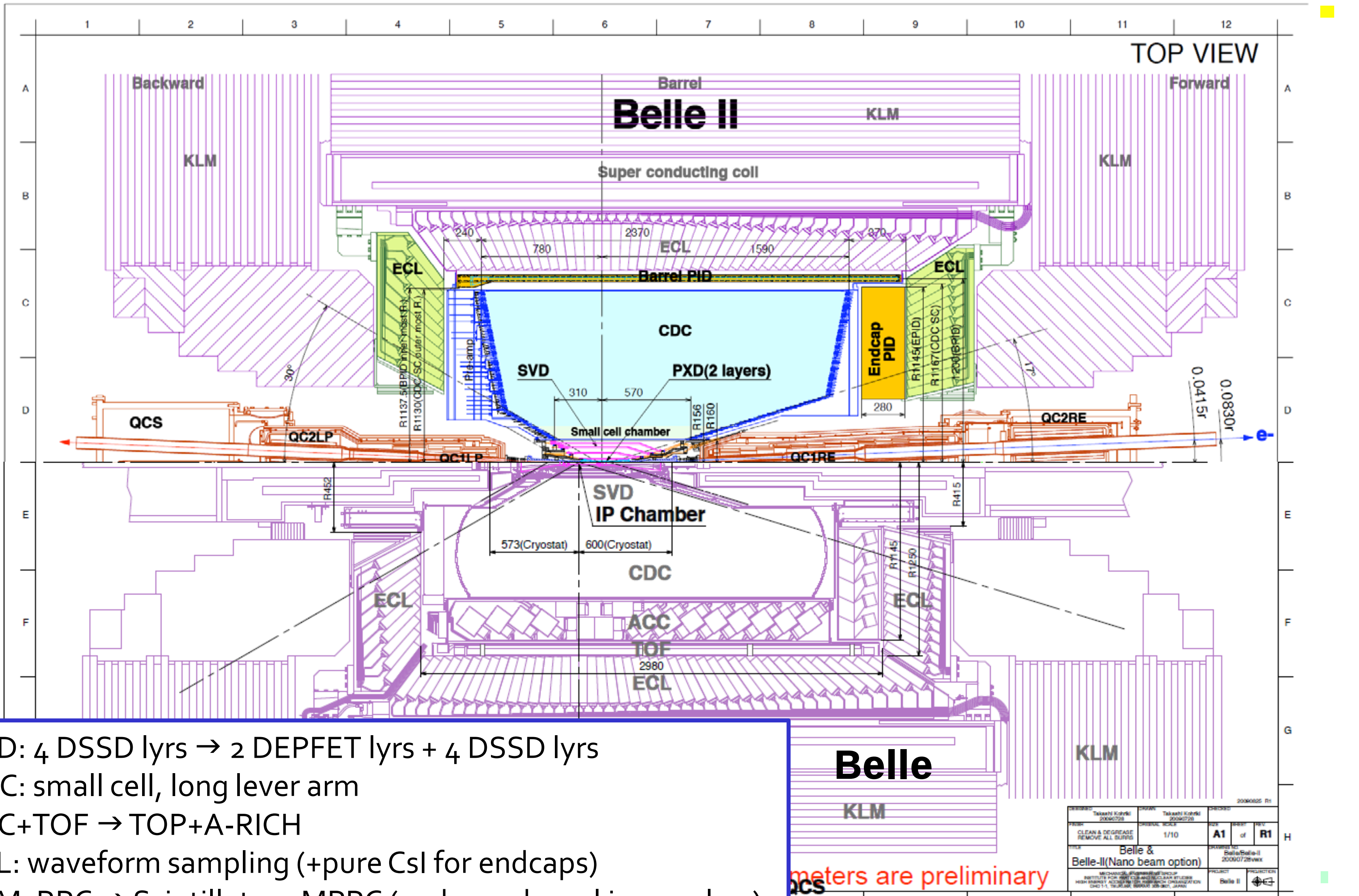
Have to employ and develop new technologies to make such an apparatus work! →

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

Belle II Detector



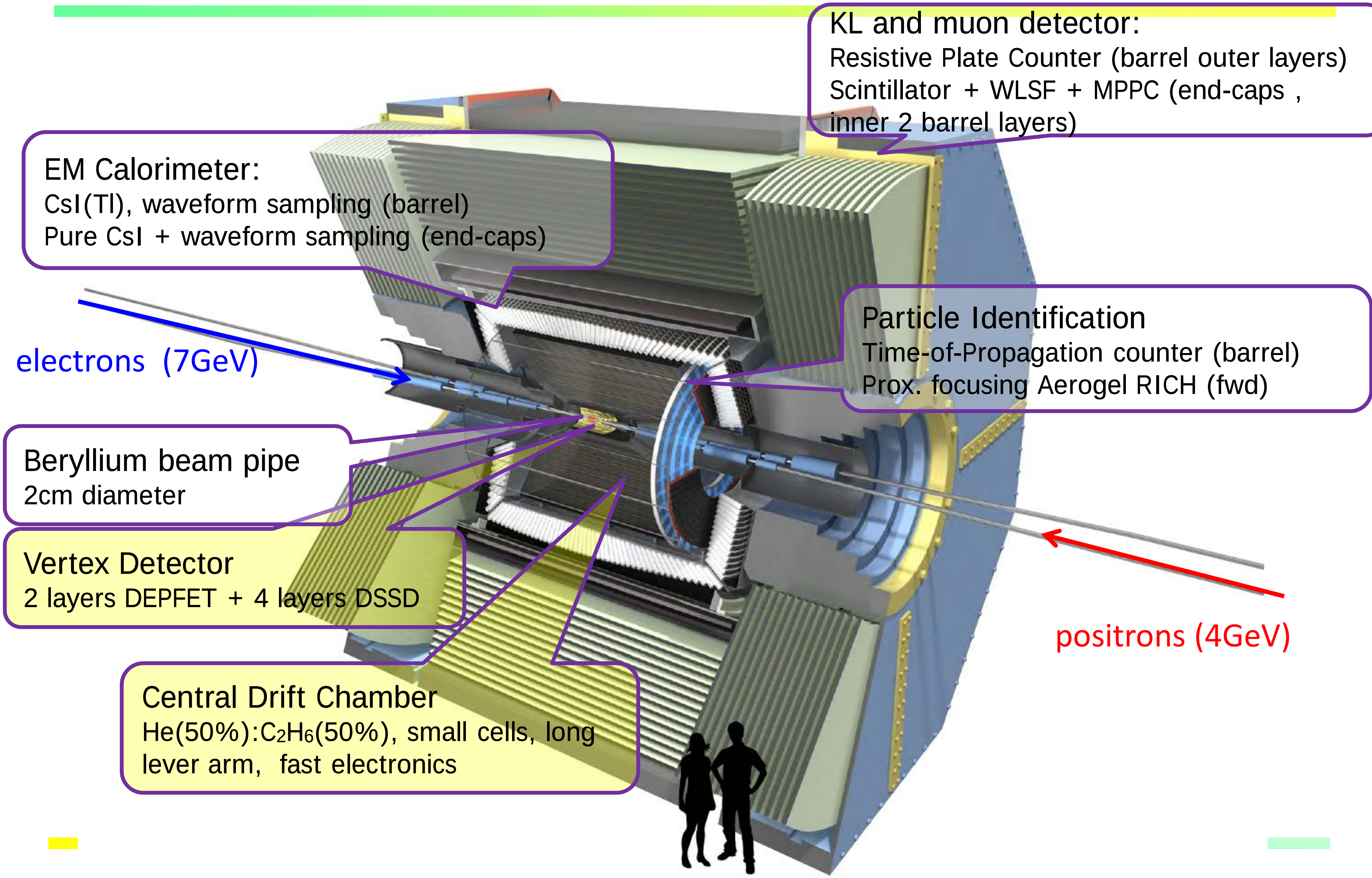
Belle II Detector (in comparison with Belle)



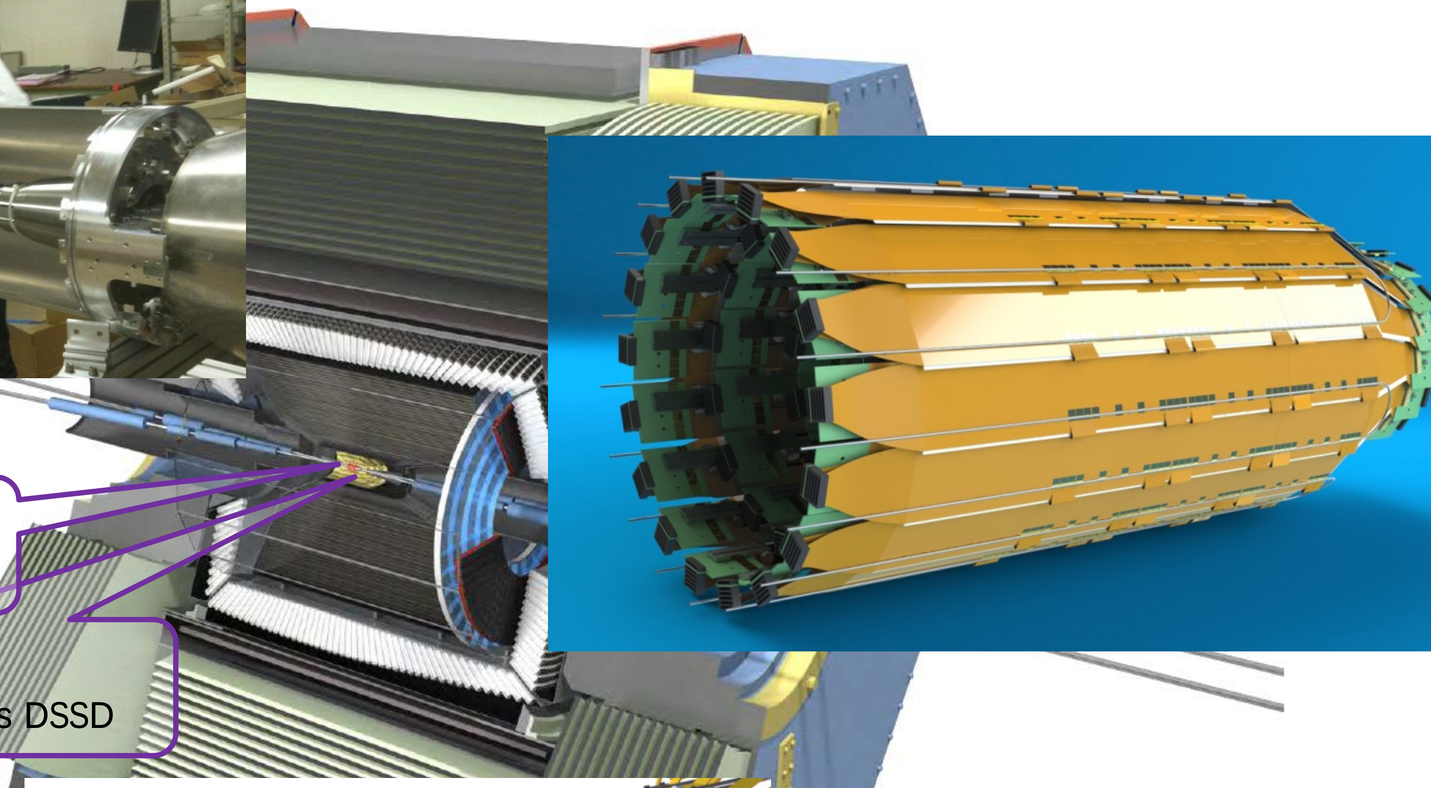
SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI for endcaps)
KLM: RPC → Scintillator +MPPC (endcaps, barrel inner 2 lyrs)

meters are preliminary

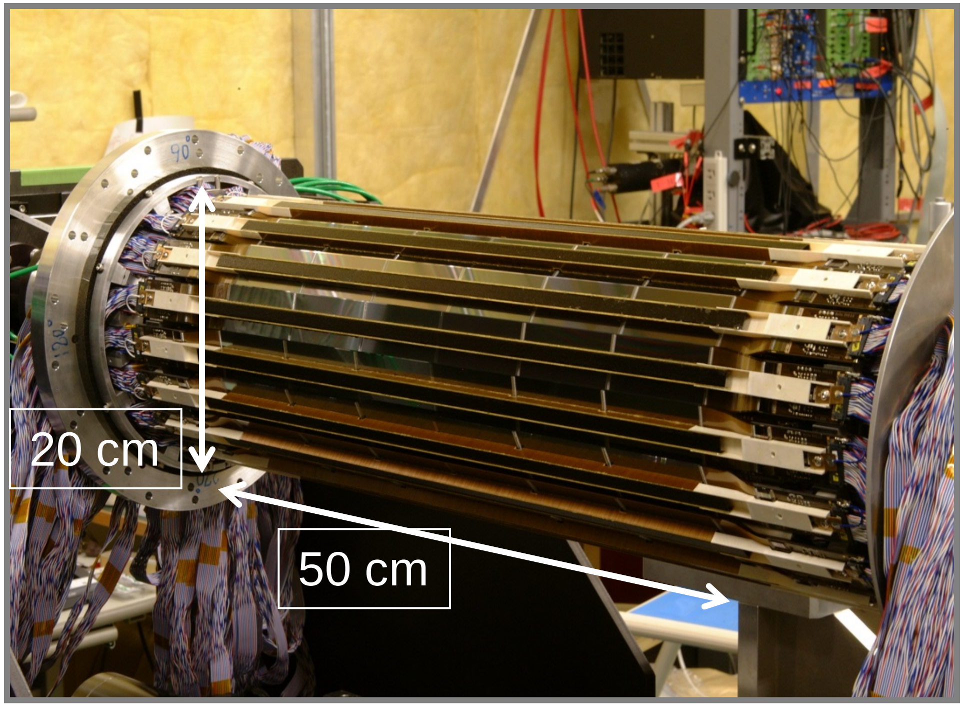
Tracking and vertex systems in Belle II

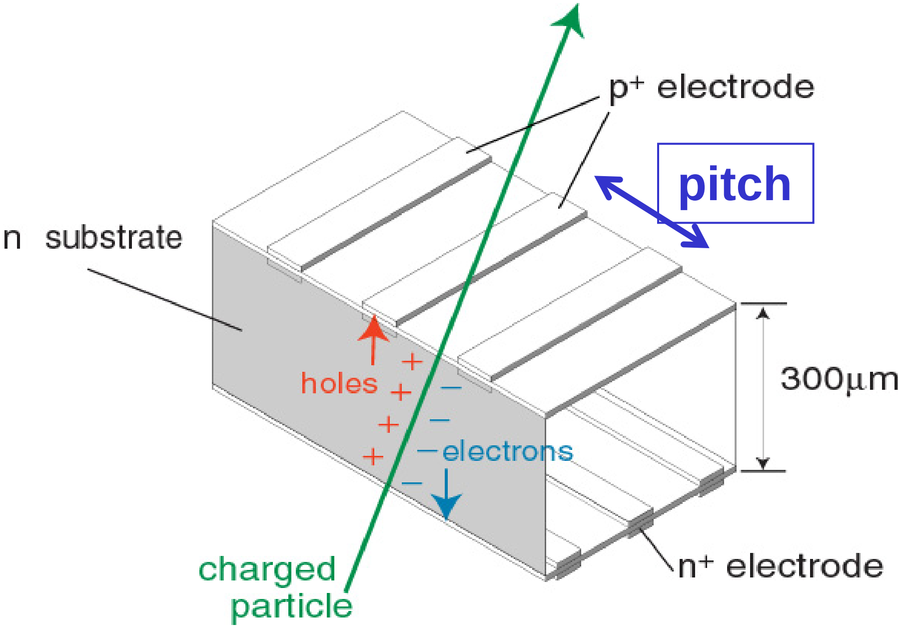


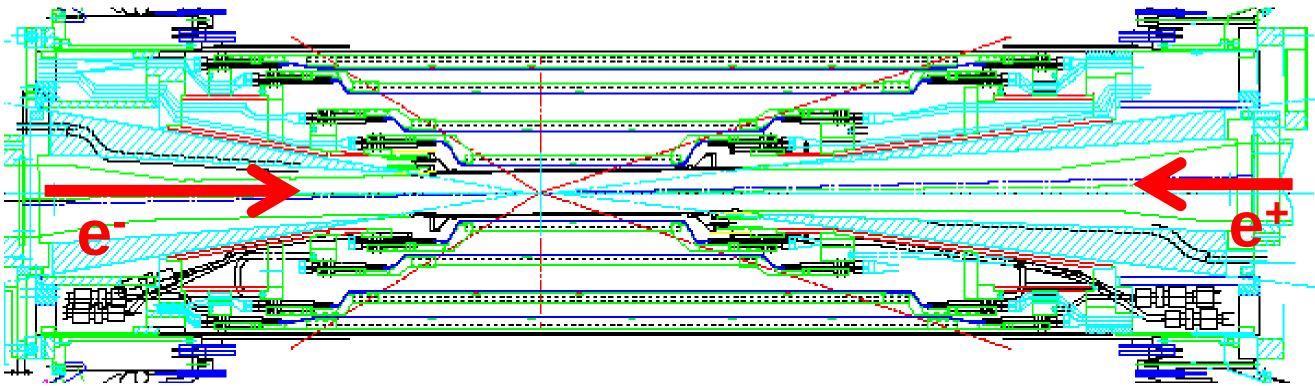
Belle II Detector – vertex region



Silicon vertex detector (SVD)







Two coordinates measured at the same time;

strip pitch: 50μm (75μm);

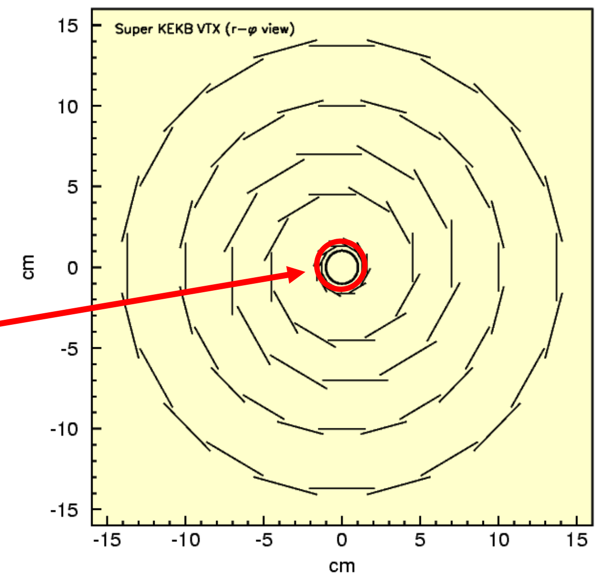
resolution 15μm (20μm).

Belle II Vertex detector SVD+PXD

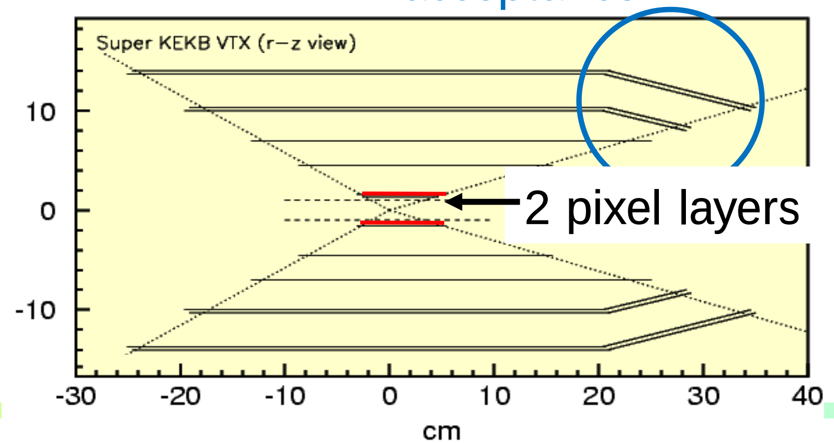
- Sensors of the innermost layers:

  Normal double sided Si detector (DSSD) → DEPFET Pixel sensors

- Configuration: 4 layers → 6 layers (outer radius = 8cm→14cm)
  - More robust tracking
  - Higher Ks vertex reconstruction efficiency
- Inner radius: 1.5cm → 1.3cm
  - Better vertex resolution
- Strip Readout chip: VA1TA → APV25
  - Reduction of occupancy coming from beam background.
  - Pipeline readout to reduce dead time.



Slant layer to keep the acceptance



Pixel vertex detector PXD principle: DEPFET

p-channel FET on a completely depleted bulk

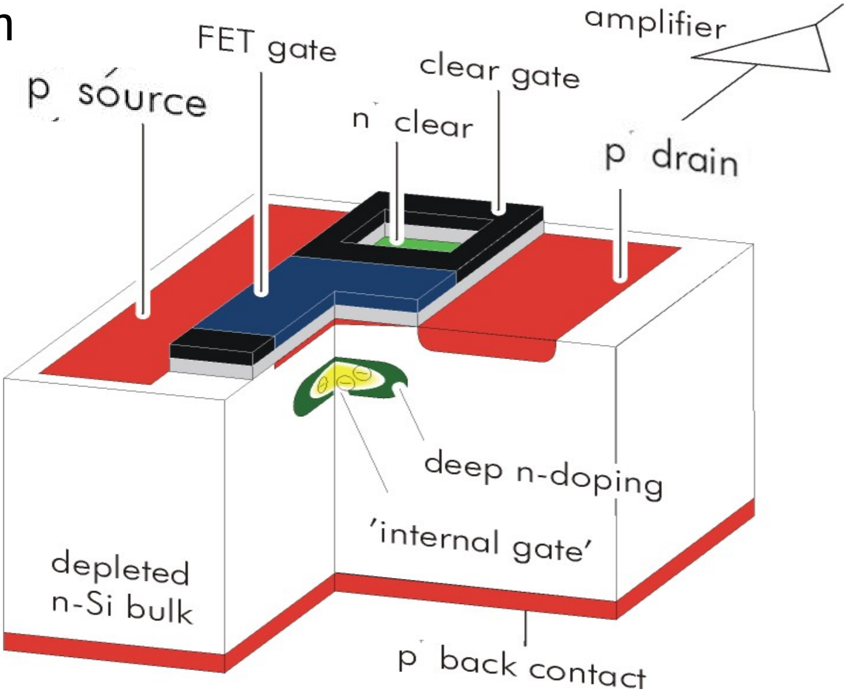
A deep n-implant creates a potential minimum for electrons under the gate ("internal gate")

Signal electrons accumulate in the internal gate and modulate the transistor current (g_q ~ 400 pA/e^-)

Accumulated charge can be removed by a clear contact ("reset")

Invented in MPI Munich

Depleted p-channel FET



Fully depleted:
→ large signal, fast signal collection

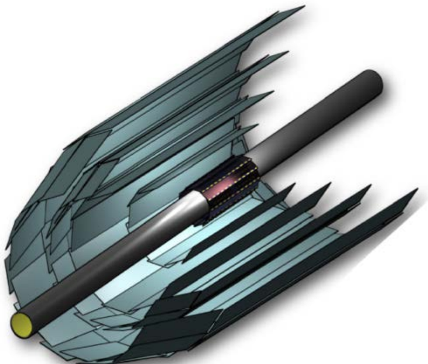
Low capacitance, internal amplification → low noise

Transistor on only during readout: low power

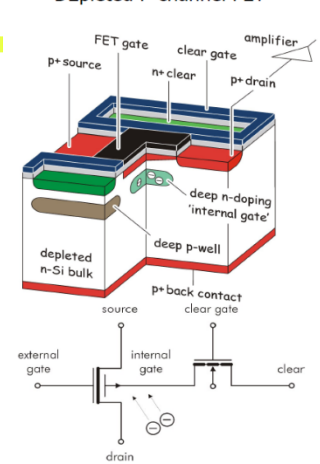
Complete clear → no reset noise

Vertex Detector

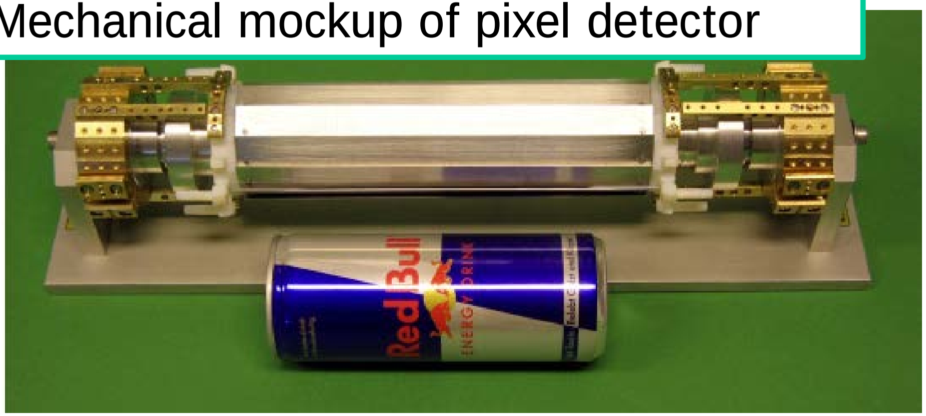
DEPFET:
http://aldebaran.hll.mpg.de/twiki/bin/view/DEPFET/WebHome

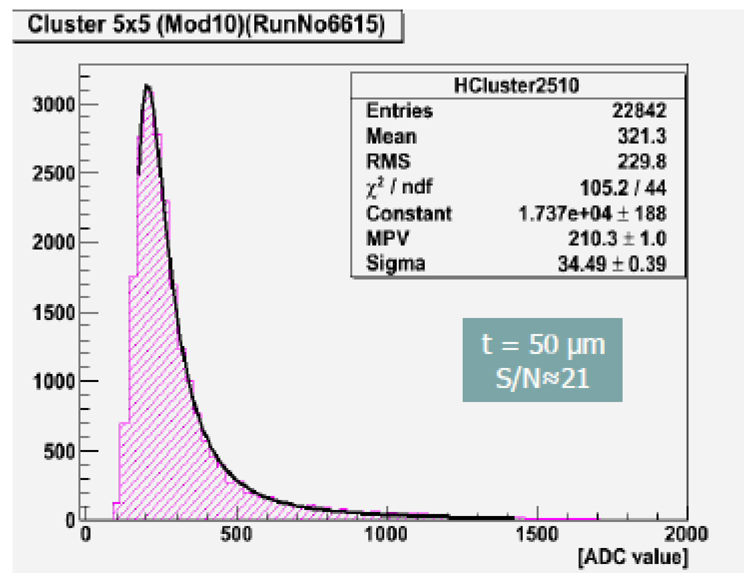


Beam Pipe		**r = 10mm**
DEPFET		
	Layer 1	**r = 14mm**
	Layer 2	**r = 22mm**
DSSD		
	Layer 3	**r = 38mm**
	Layer 4	**r = 80mm**
	Layer 5	**r = 115mm**
	Layer 6	**r = 140mm**



Mechanical mockup of pixel detector





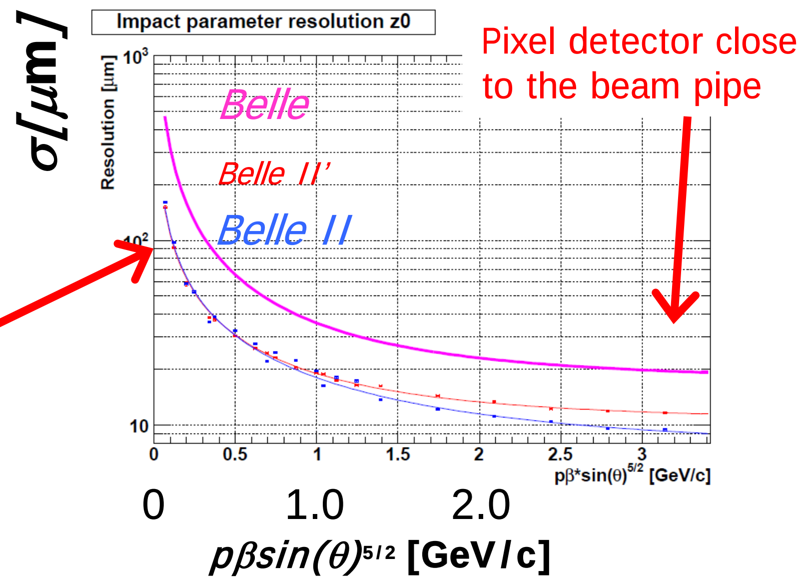
DEPFET pixel sensor

DEPFET sensor: very good S/N

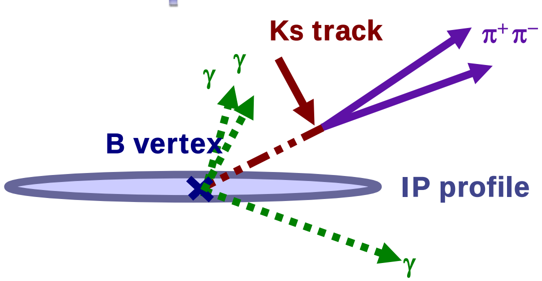
Expected performance

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

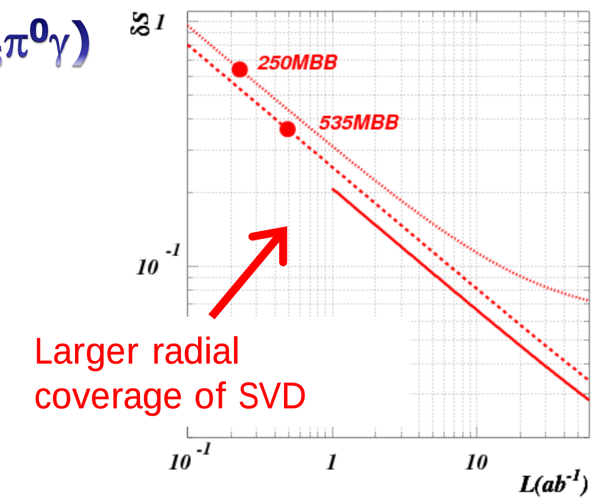
Significant improvement in vertex resolution!



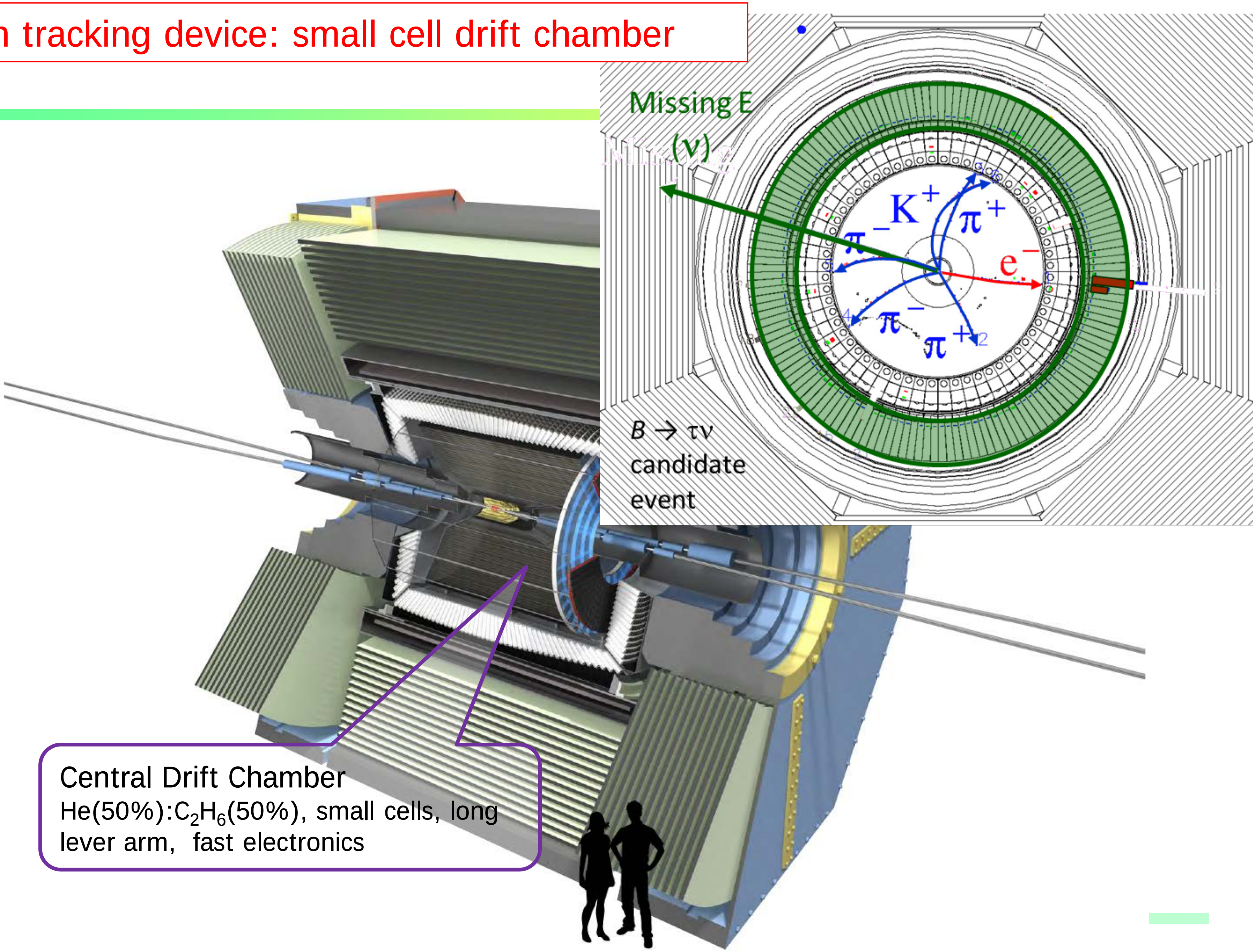
Significant improvement in $\delta S(K_S\pi^0\gamma)$



B decay point reconstruction with K_S trajectory



Main tracking device: small cell drift chamber

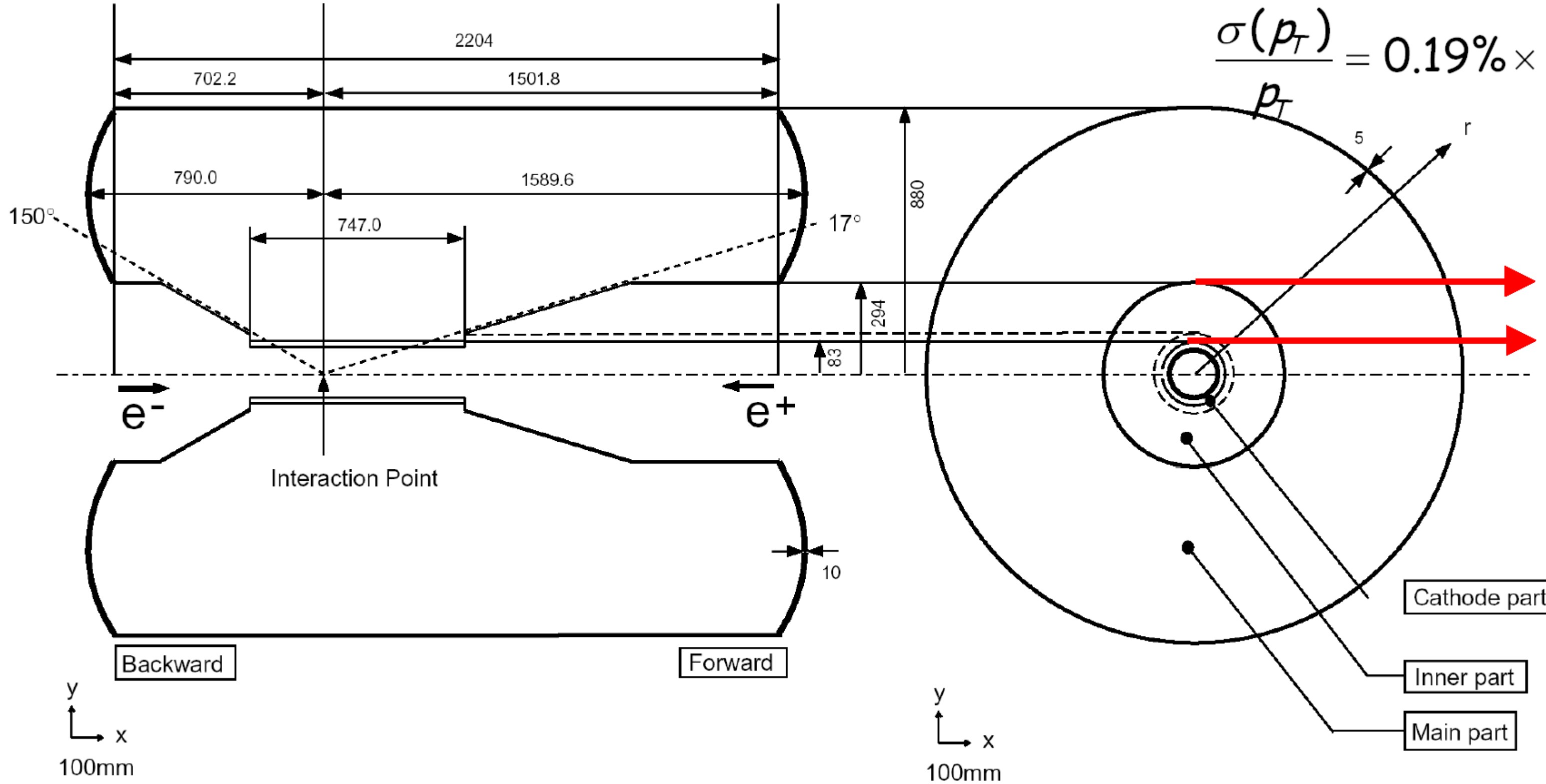


Central Drift Chamber
He(50%):C_2H_6(50%), small cells, long lever arm, fast electronics

Tracking: Belle central drift chamber

- 50 layers of wires (8400 cells) in 1.5 Tesla magnetic field
- Helium:Ethane 50:50 gas, W anode wires, Al field wires, CF inner wall with cathodes, and preamp only on endplates
- Particle identification from ionization loss (5.6-7% resolution)

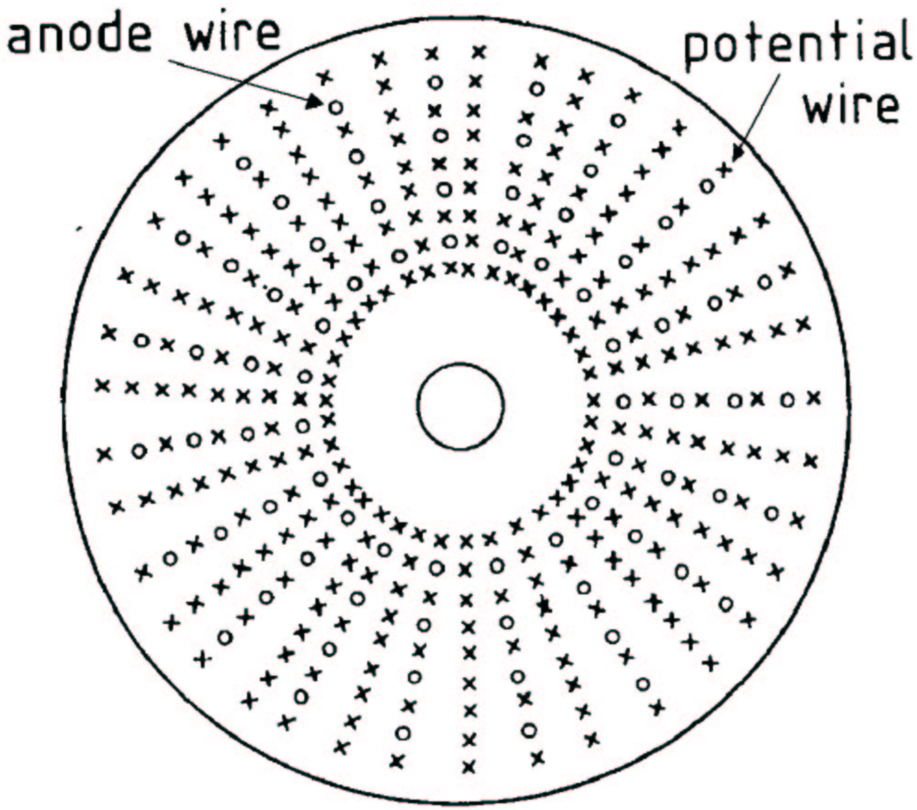
$$\frac{\sigma(p_T)}{p_T} = 0.19\% \times p_T \oplus \frac{0.30\%}{\beta}$$

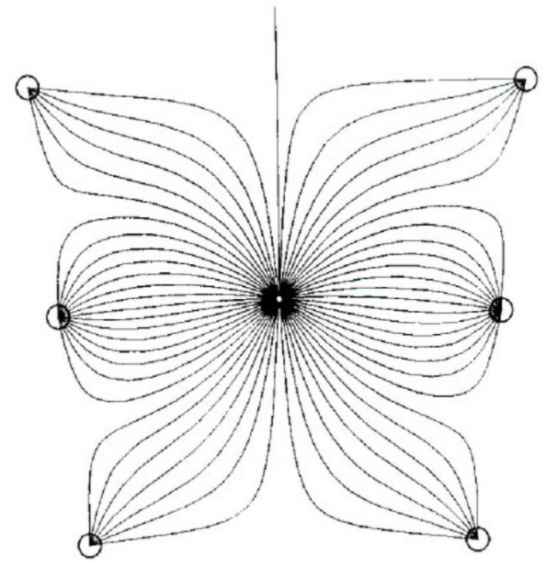


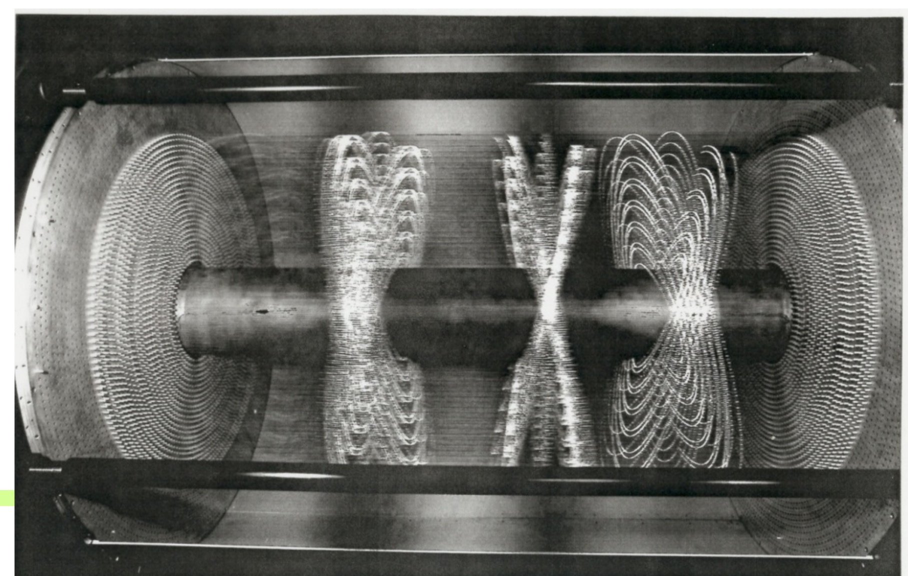
15 layers: 8.8-22.4 cm radius

Drift chamber with small cells

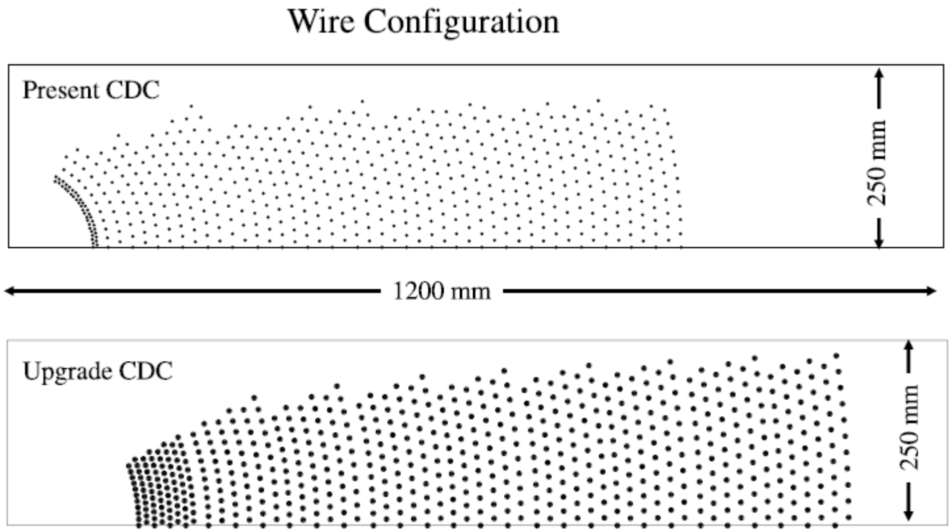
One big gas volume, small cells defined by the anode and field shaping (potential) wires

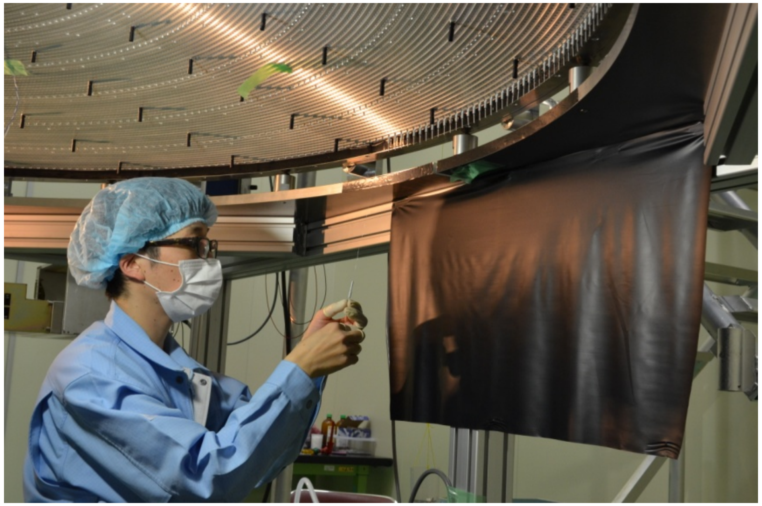






Belle II CDC

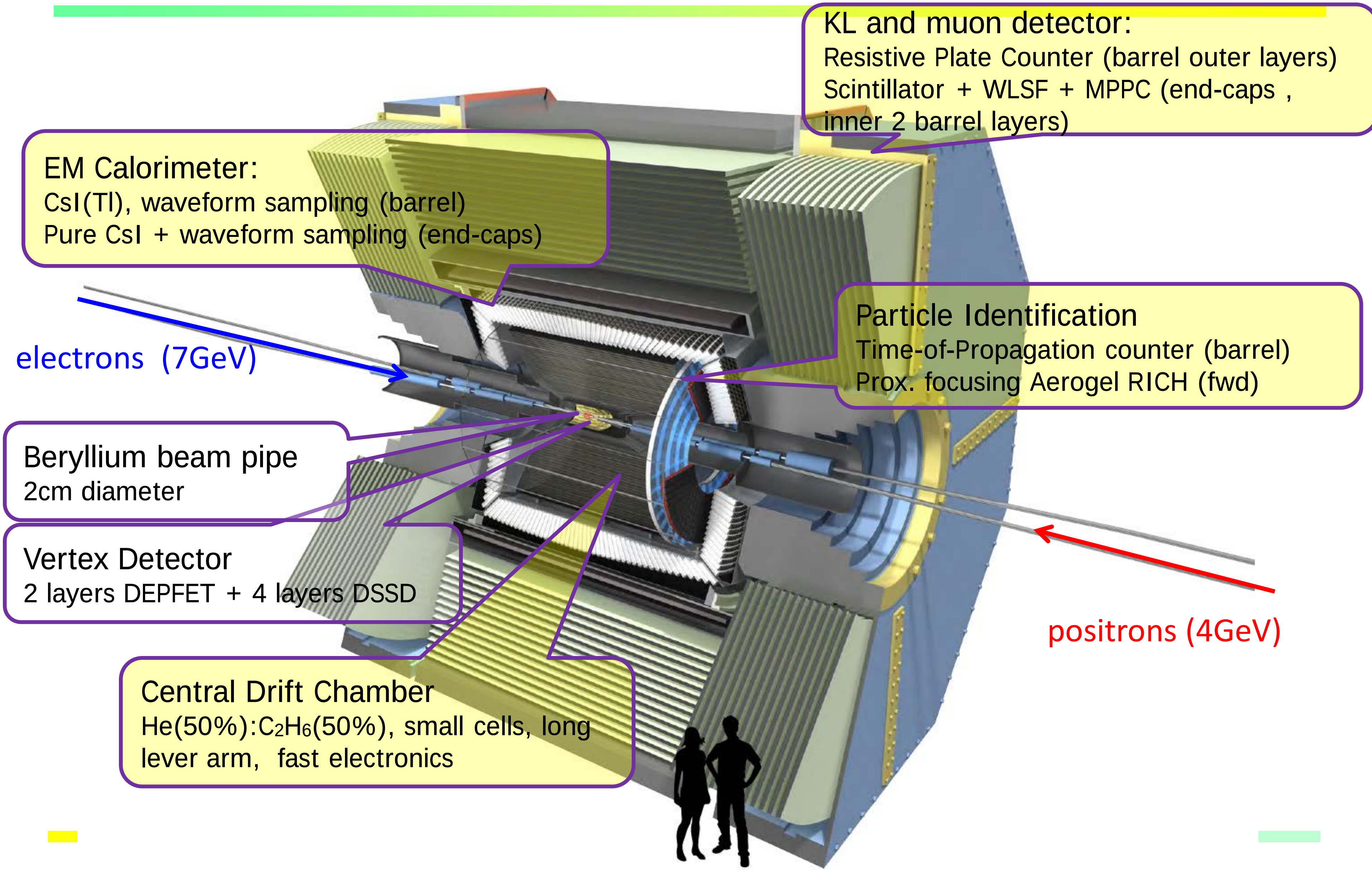




Wire stringing in a clean room

- thousands of wires,
- 1 year of work…

Particle identification systems in Belle II



Identification of charged particles

Particles are identified by their mass or by the way they interact.

Determination of mass: from the relation between momentum and velocity, $p=\gamma mv$.

Momentum known (radius of curvature in magnetic field)

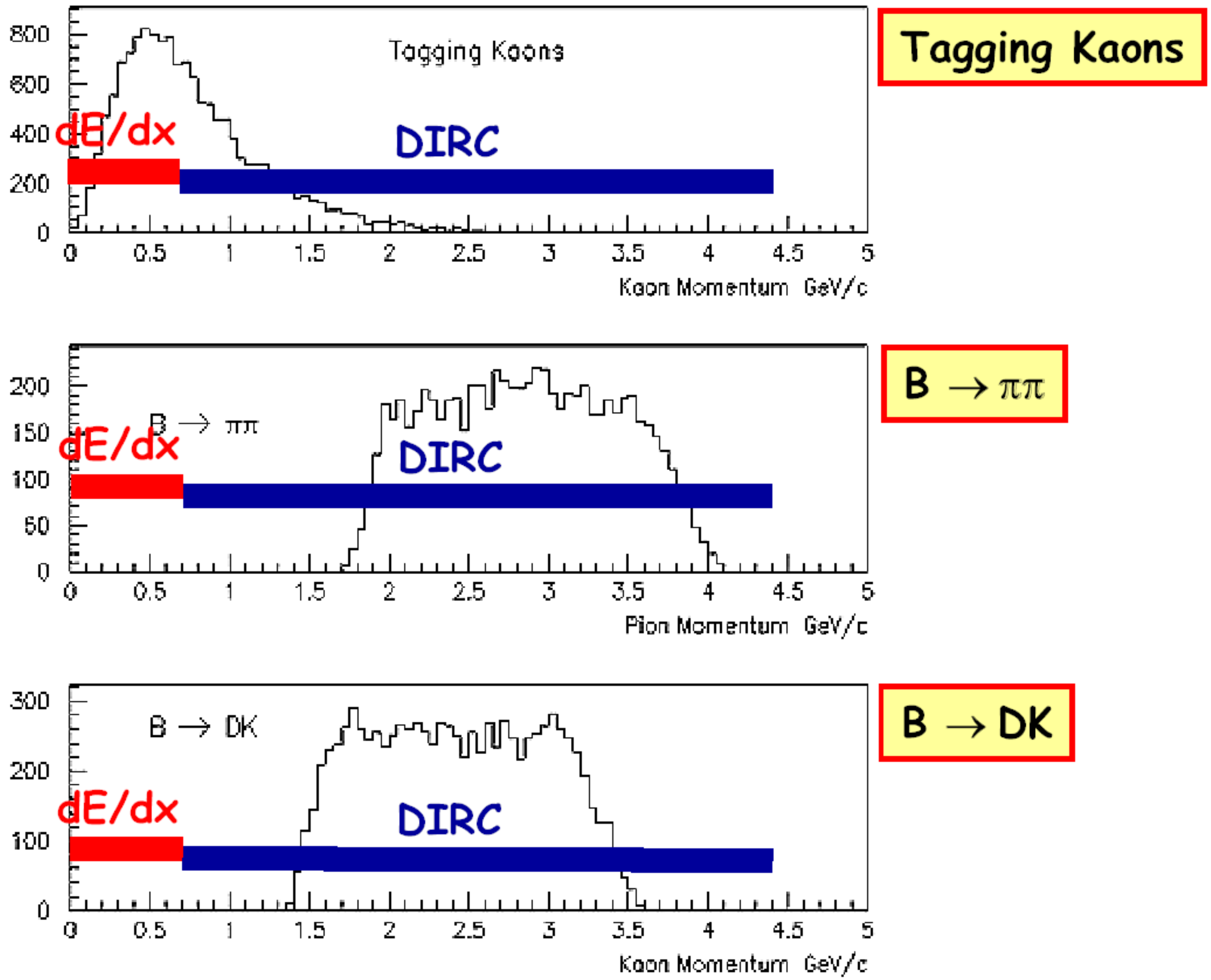
→Measure velocity:

- time of flight
- ionisation losses dE/dx
- Cherenkov angle
- transition radiation

Mainly used for the identification of hadrons.

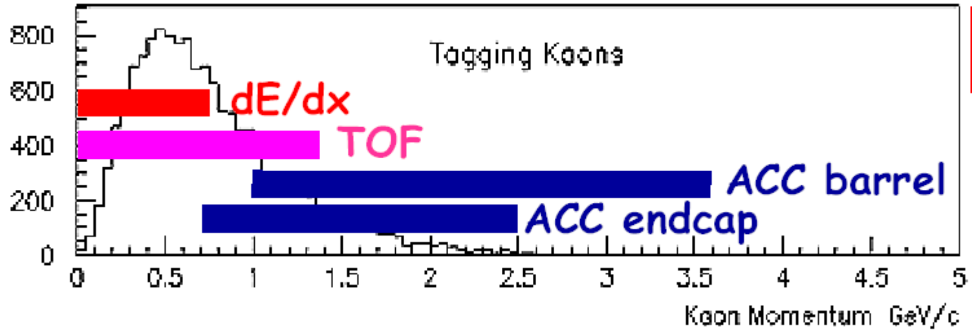
Identification through interaction: electrons and muons

PID coverage of kaon/pion spectra

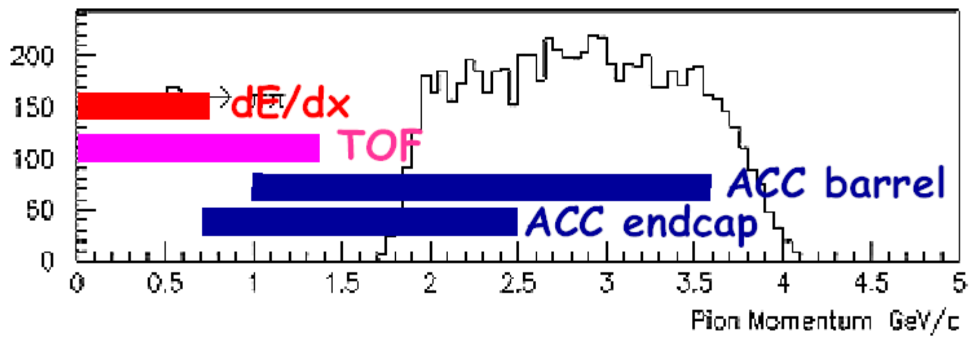


PID coverage of kaon/pion spectra

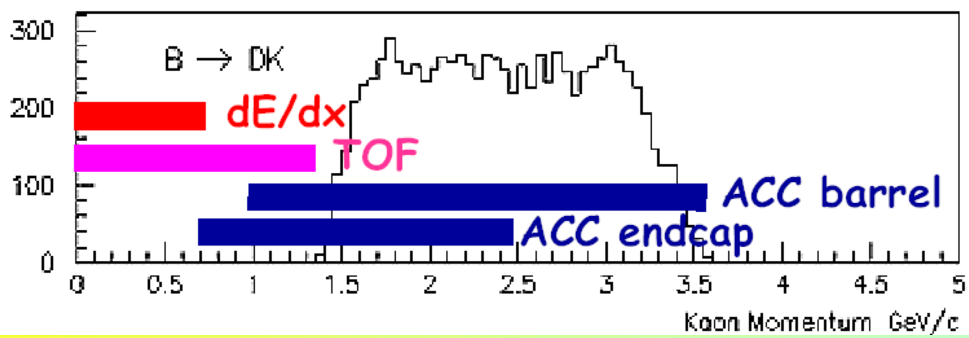
BELLE



Tagging Kaons

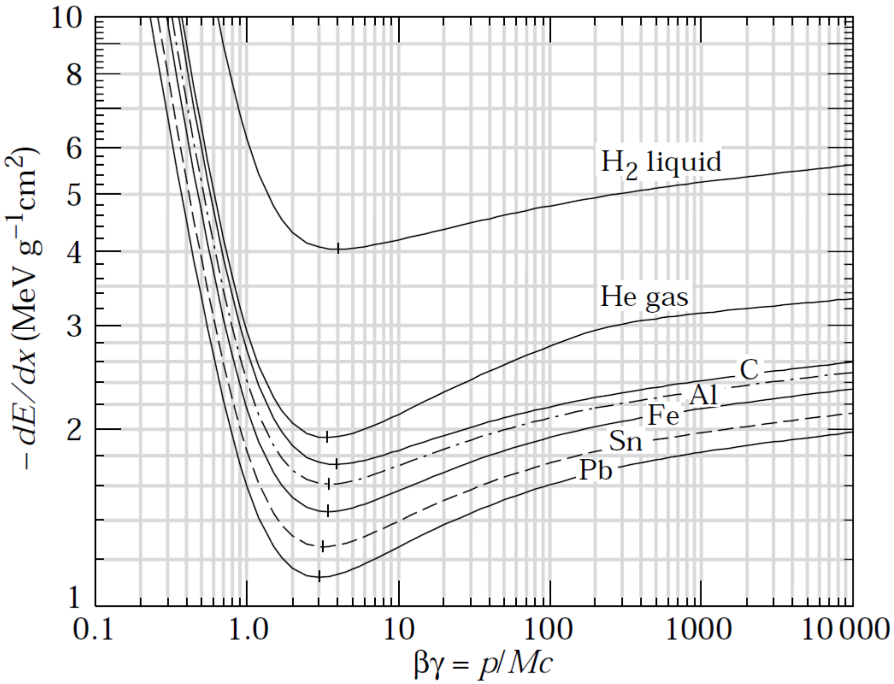


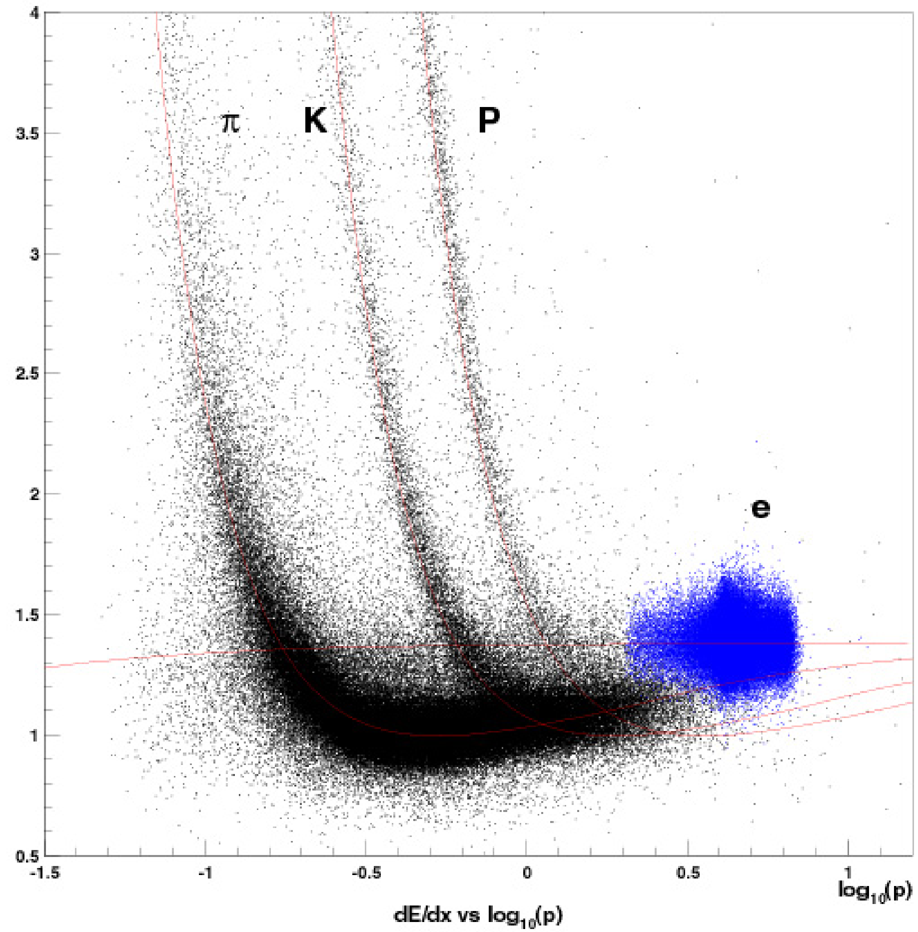
B $\rightarrow \pi\pi$



B $\rightarrow$ DK

Identification with the dE/dx measurement



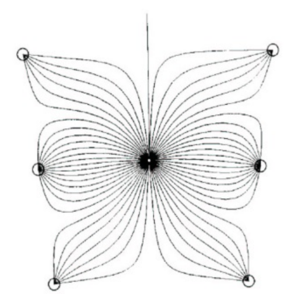


dE/dx is a function of velocity β

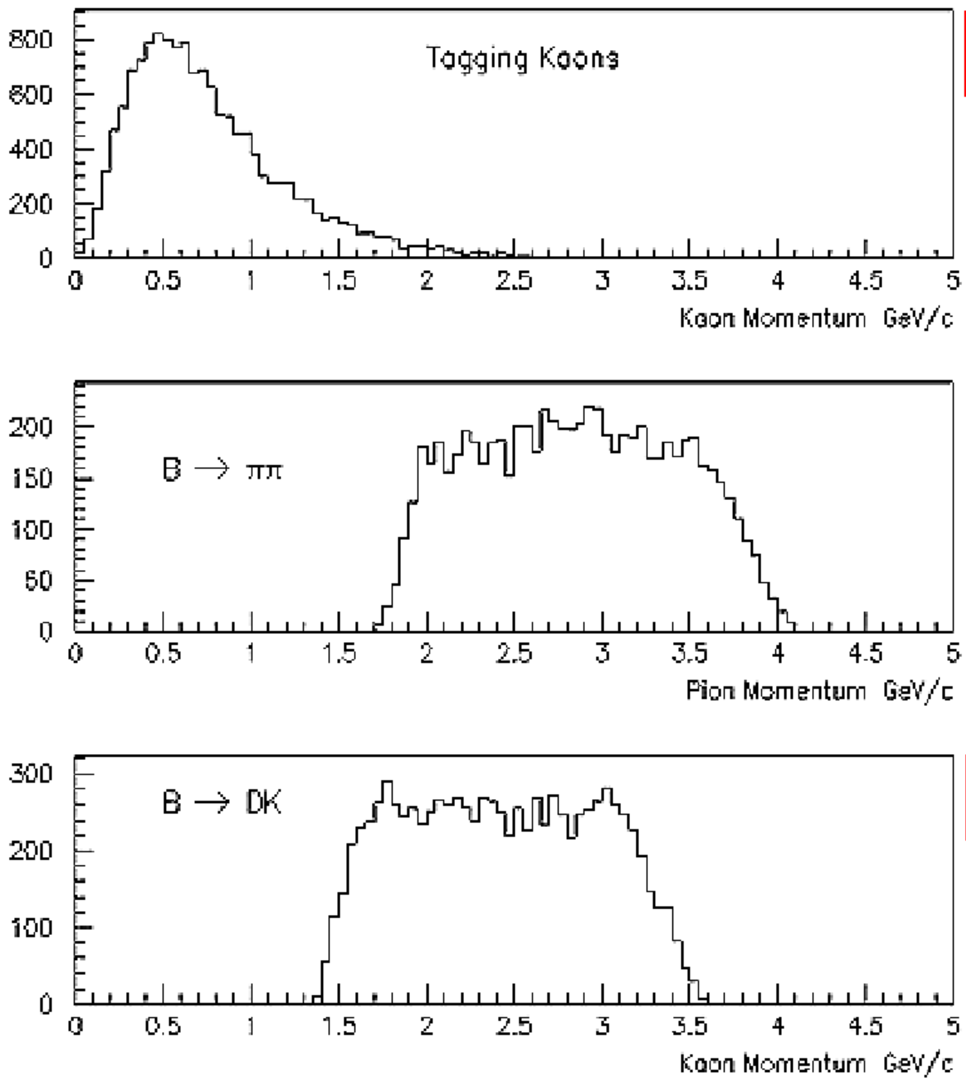
For particles with different mass the
Bethe-Bloch curve gets displaced
if plotted as a function of p

For good separation: resolution should be ~5%

Measure in each drift chamber layer – use truncated mean



Requirements: Particle Identification



Tagging Kaons

Relatively soft, ms dominated for tracking

B → ππ

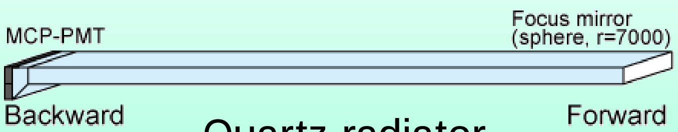
Requires dedicated PID

B → DK

Requires dedicated PID

Cherenkov detectors

Barrel PID: Time of Propagation Counter (TOP)



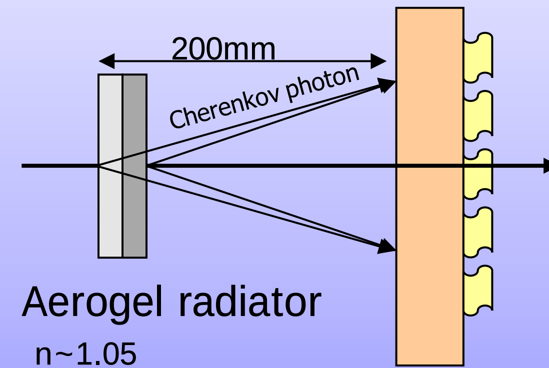
Quartz radiator

Focusing mirror

Small expansion block

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

Endcap PID: Aerogel RICH (ARICH)

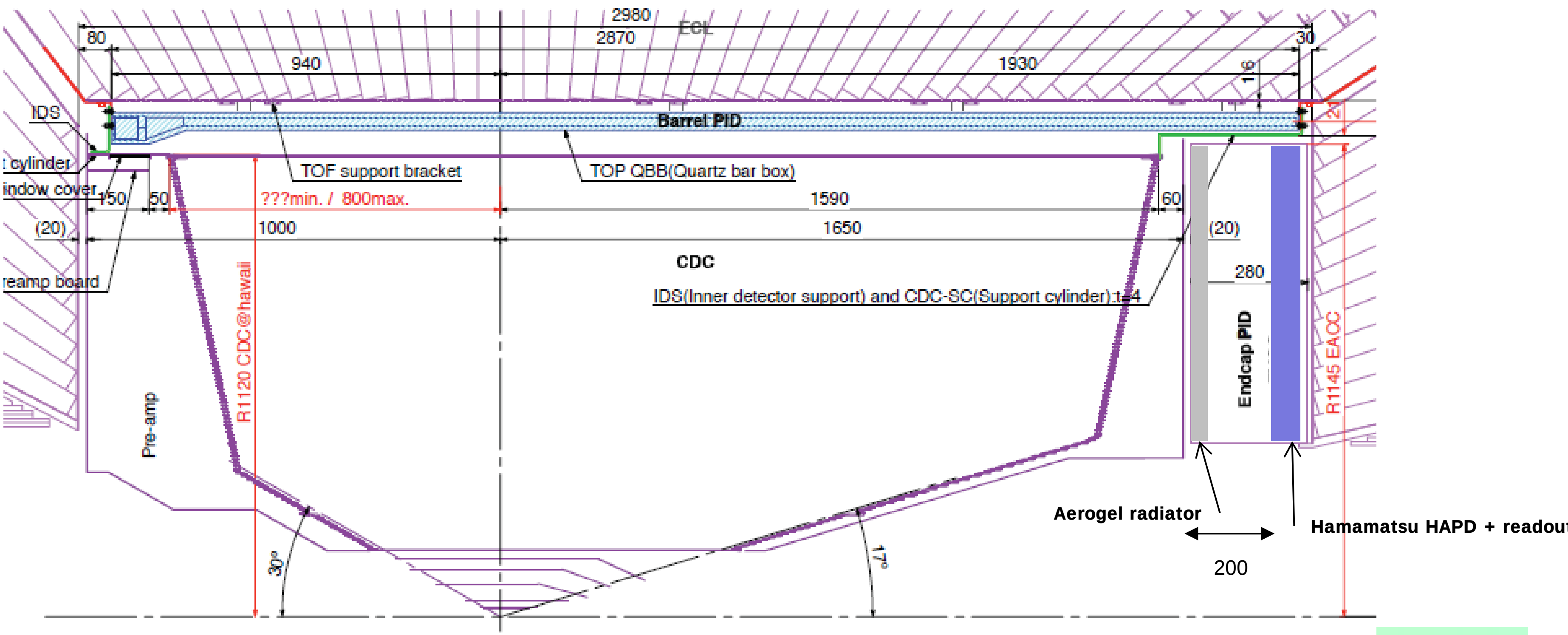


Aerogel radiator

n~1.05

Hamamatsu HAPD

+ new ASIC

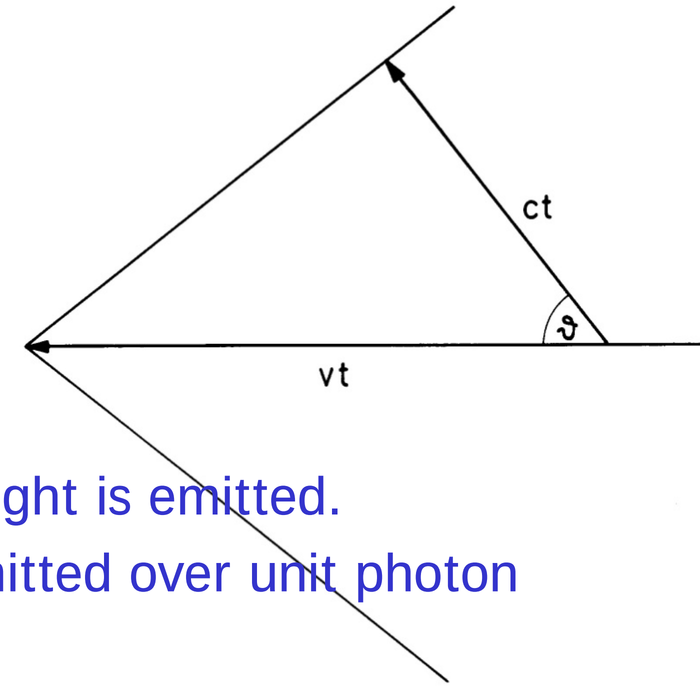


Peter Križan, Ljubljana

Cherenkov radiation

A charged track with velocity $v = \beta c$ exceeding the speed of light c/n in a medium with refractive index n emits polarized light at a characteristic (Cherenkov) angle,

$\cos\theta = c / nv = 1/\beta n$



Two cases:

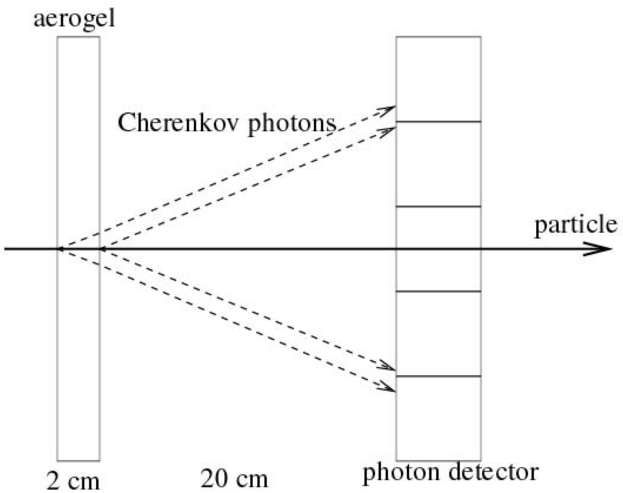
→ $\beta < \beta_t = 1/n$: below threshold no Cherenkov light is emitted.

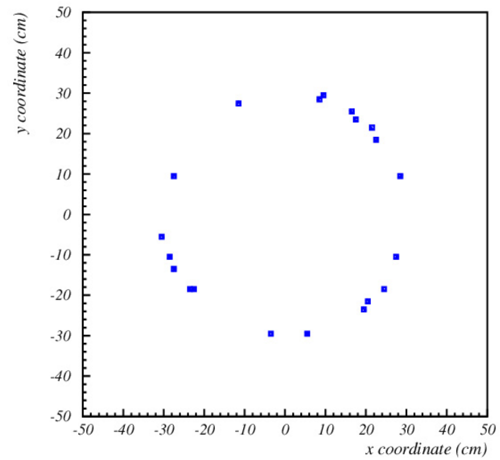
→ $\beta > \beta_t$: the number of Cherenkov photons emitted over unit photon energy $E = h\nu$ in a radiator of length L:

$$\frac{dN}{dE} = \frac{\alpha}{\hbar c} L \sin^2\theta = 370 (cm)^{-1} (eV)^{-1} L \sin^2\theta$$

→Few detected photons

Measuring the Cherenkov angle



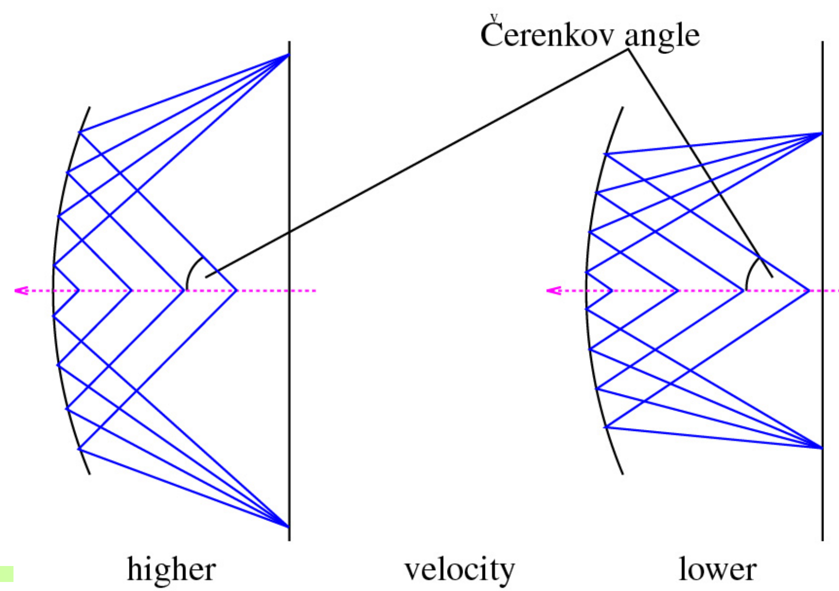


Idea: transform the direction into a coordinate → ring on the detection plane

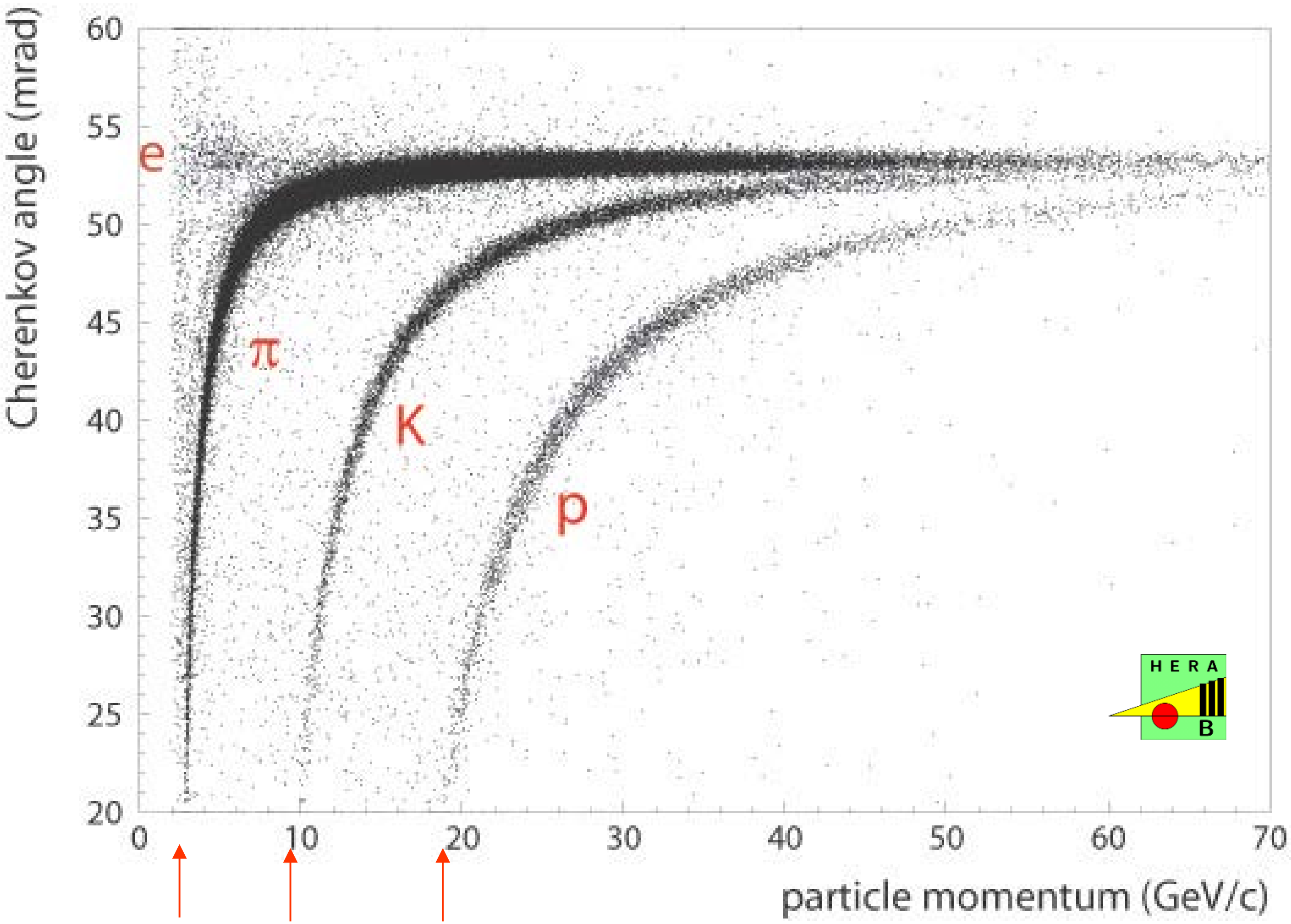
→ Ring Imaging Cherenkov (RICH) counter

Proximity focusing RICH

RICH with a focusing mirror



Measuring Cherenkov angle

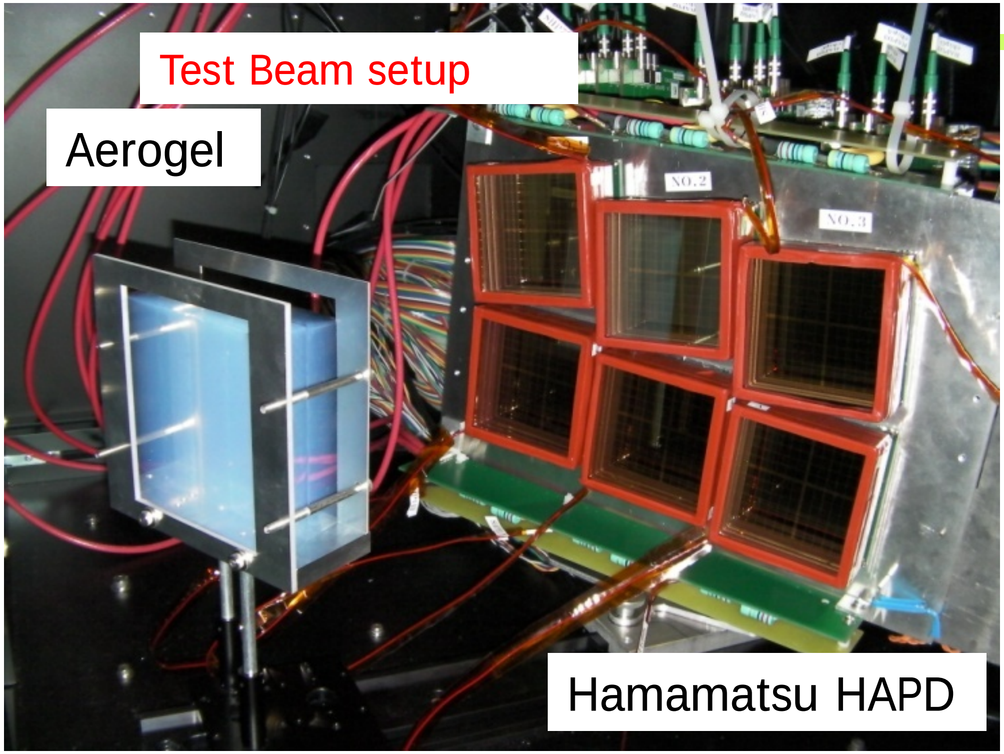


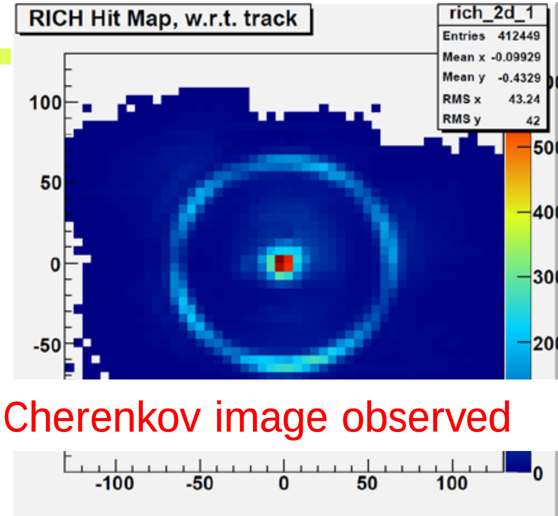
Radiator:
C_4F_{10} gas

π K p

thresholds

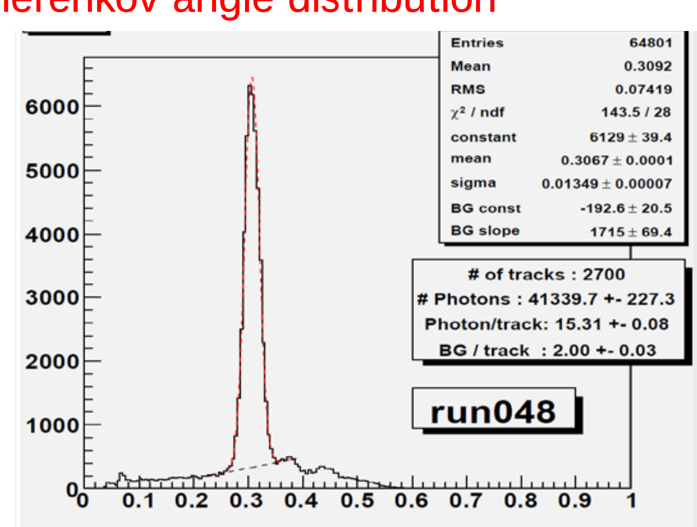
Aerogel RICH (endcap PID)



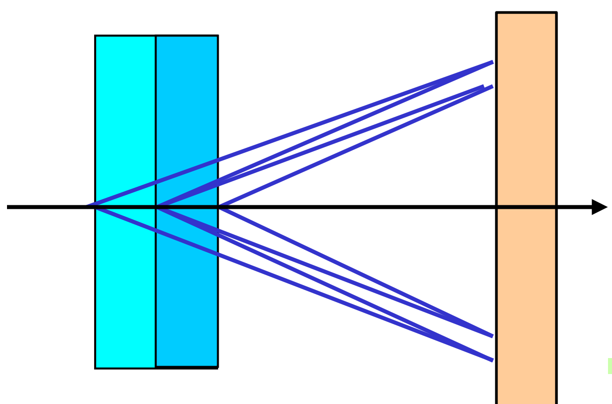


Clear Cherenkov image observed

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 !

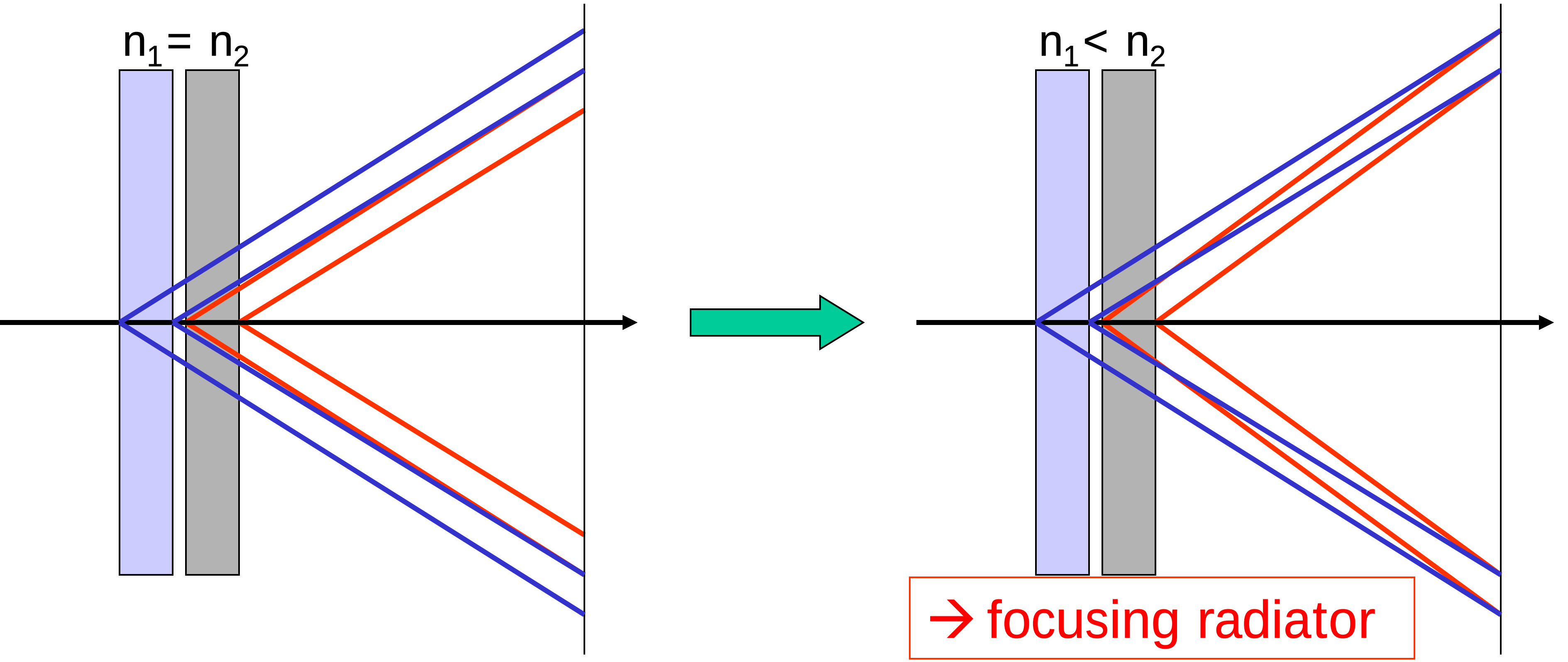
Peter Križan, Ljubljana

Radiator with multiple refractive indices

How to increase the number of photons without degrading the resolution?

→ stack two tiles with different refractive indices: “focusing” configuration

normal

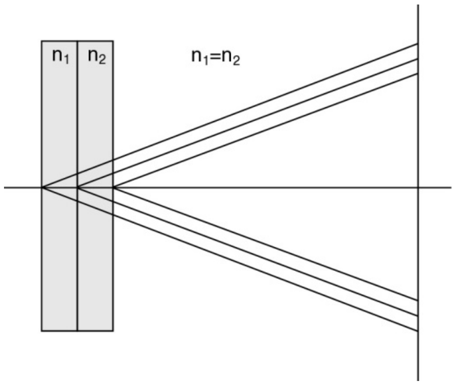


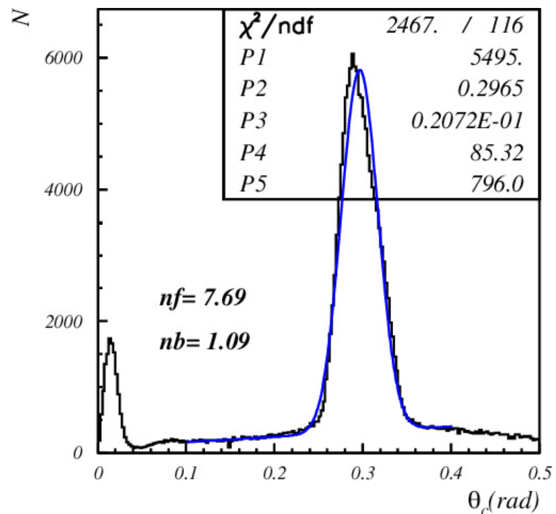
Such a configuration is only possible with aerogel (a form of Si_xO_y) – material with a tunable refractive index between 1.01 and 1.13.

Focusing configuration – data

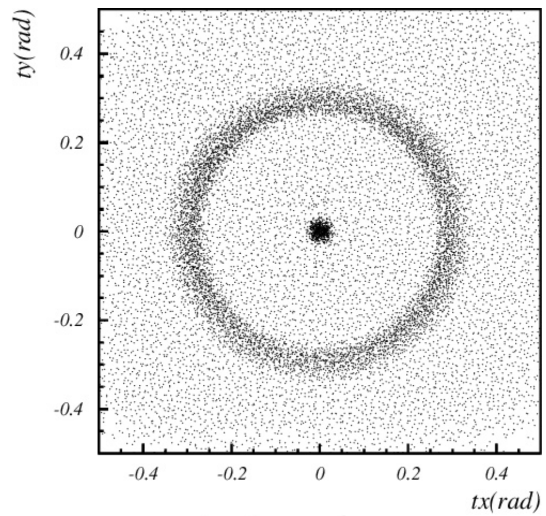
Increases the number of photons without degrading the resolution

4cm aerogel single index



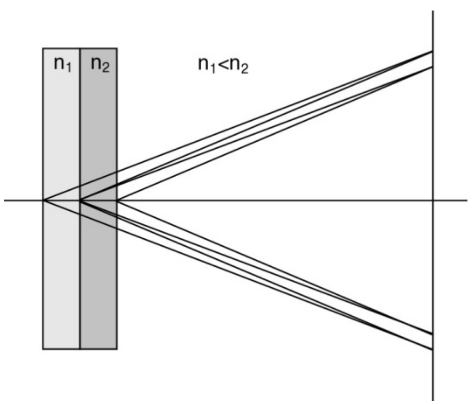


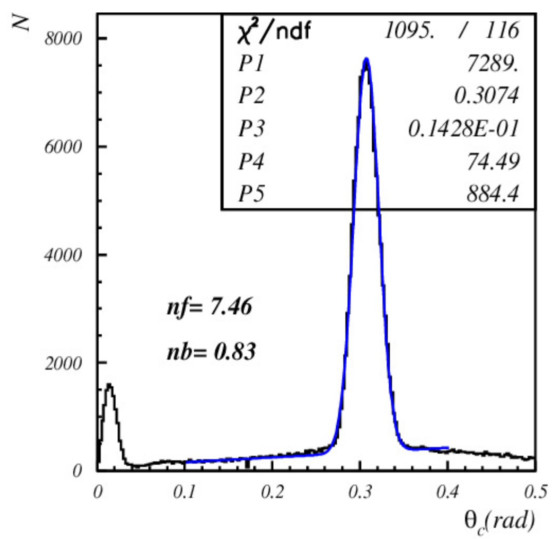
theta cerenkov

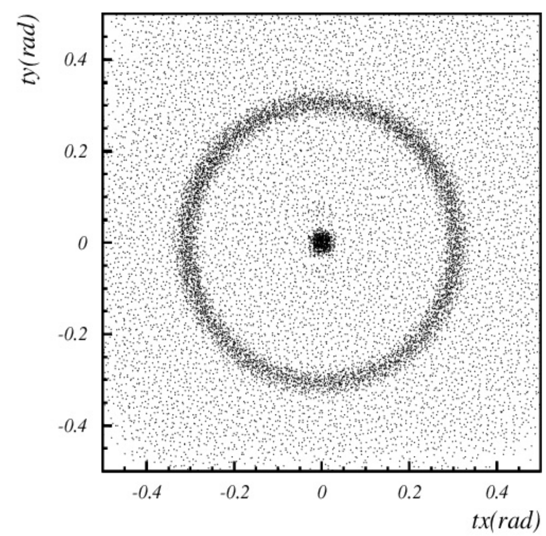


ring in cerenkov space

2+2cm aerogel

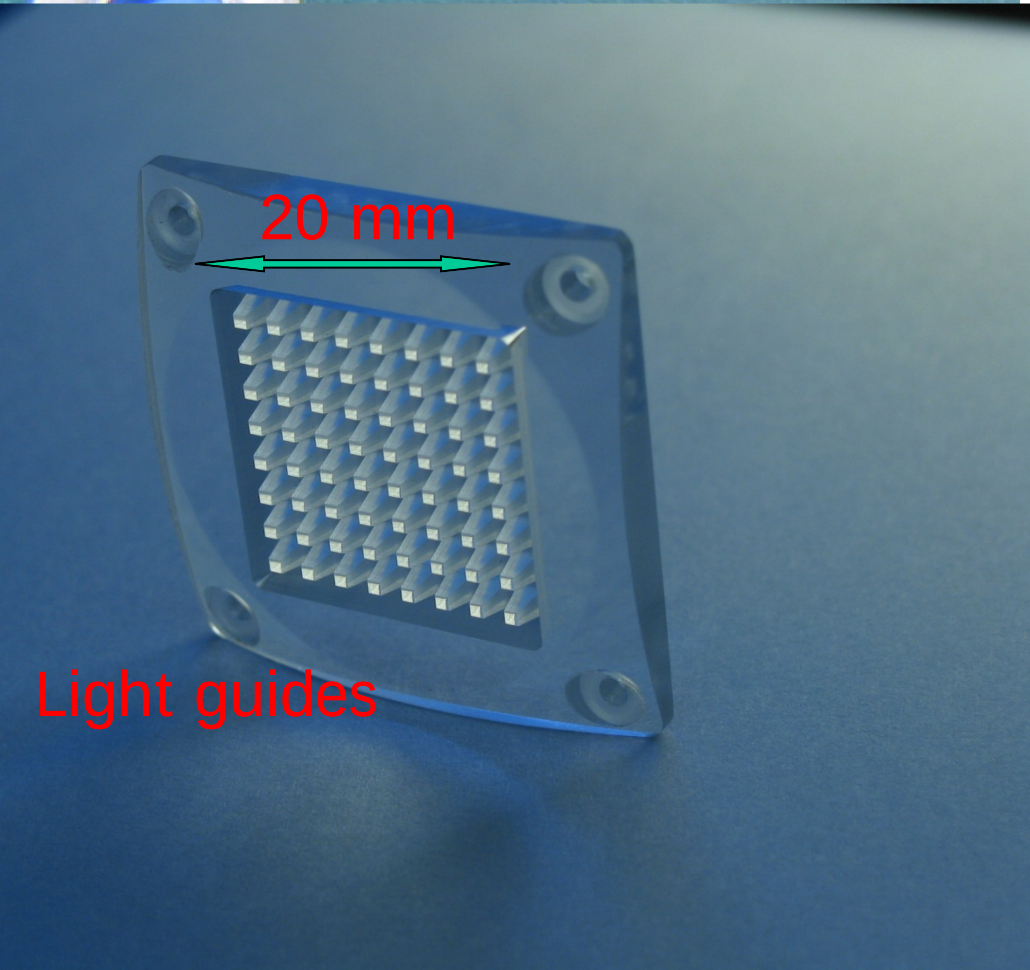


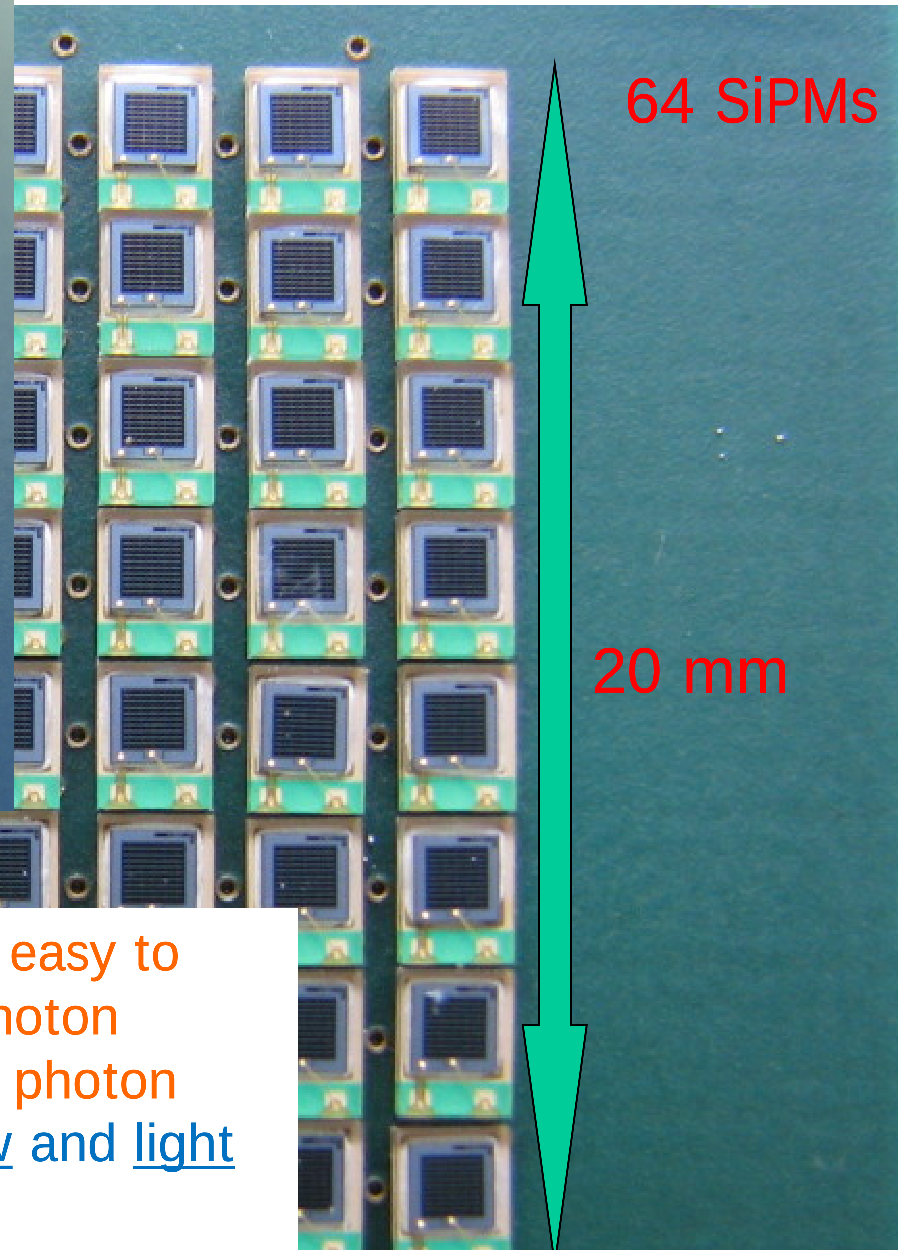




→NIM A548 (2005) 383

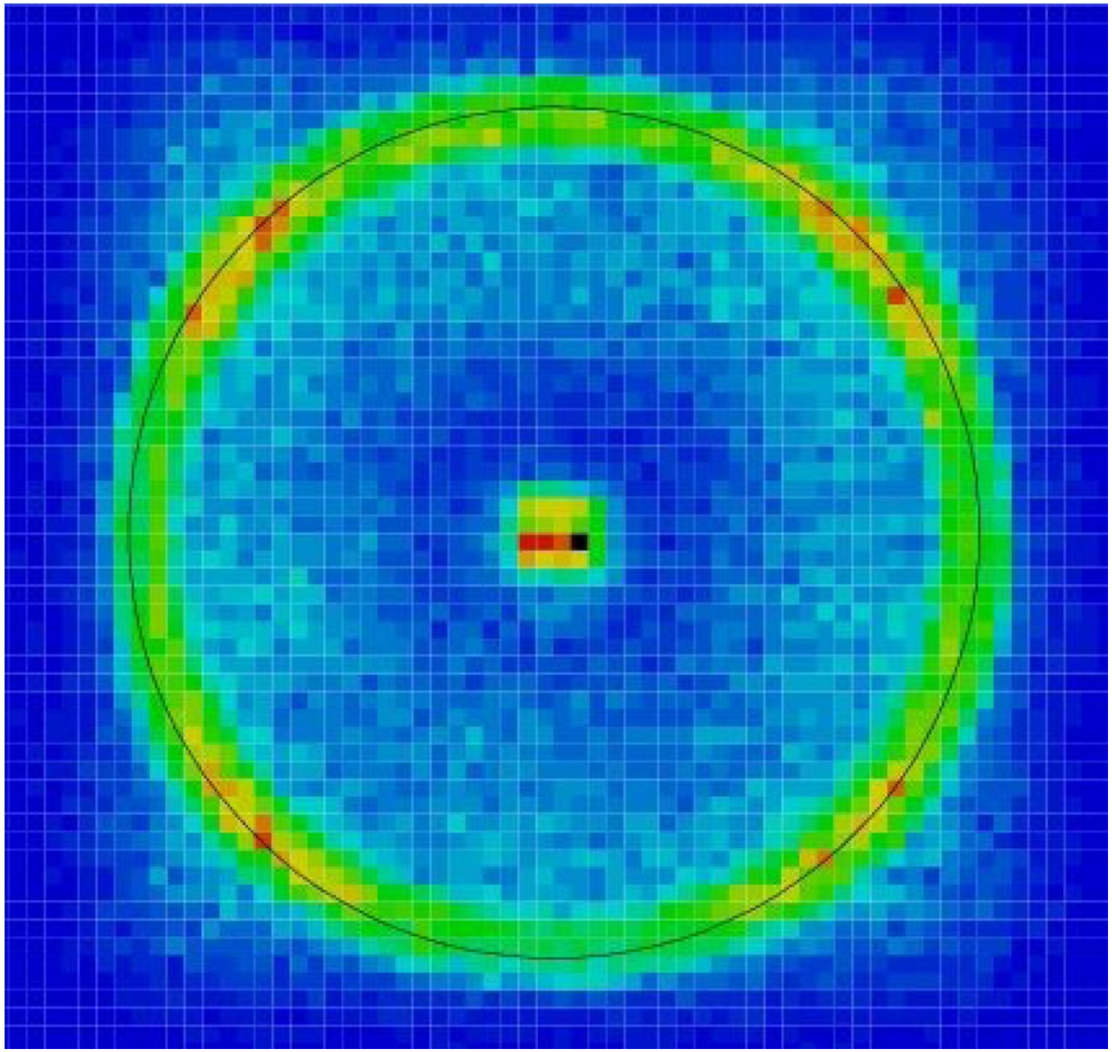
Another candidate: SiPM





Another sensor candidate: SiPMs (G-PAD), easy to handle, but never before used for single photon detection (high dark count rate with single photon pulse height) → use a narrow time window and light concentrators

Cherenkov ring with SiPMs

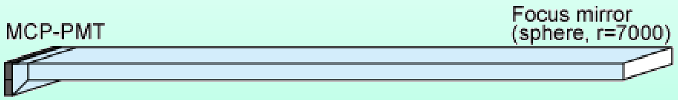


First successful use of SiPMs as single photon detectors in a RICH counter!

NIM A594 (2008) 13

Cherenkov detectors

Barrel PID: Time of Propagation Counter (TOP)



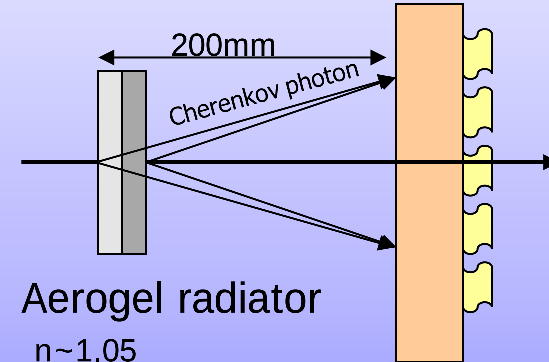
Quartz radiator

Focusing mirror

Small expansion block

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

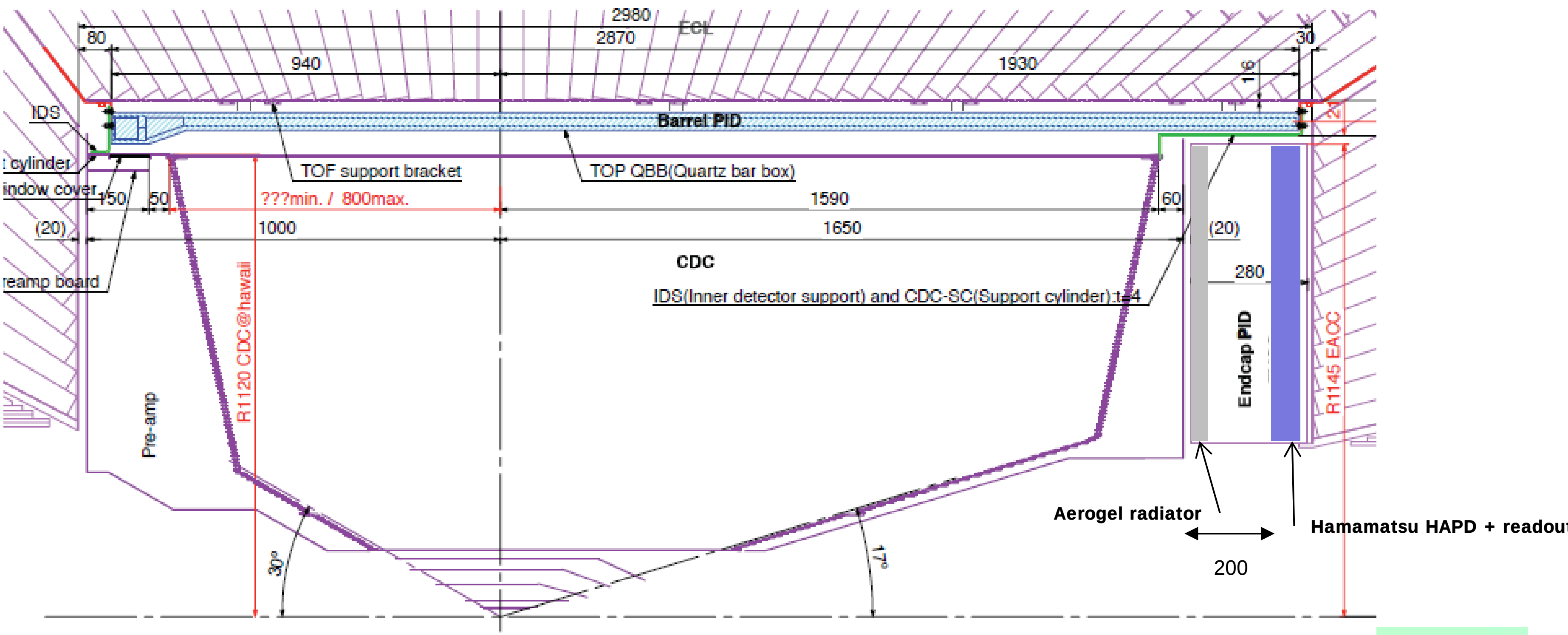
Endcap PID: Aerogel RICH (ARICH)



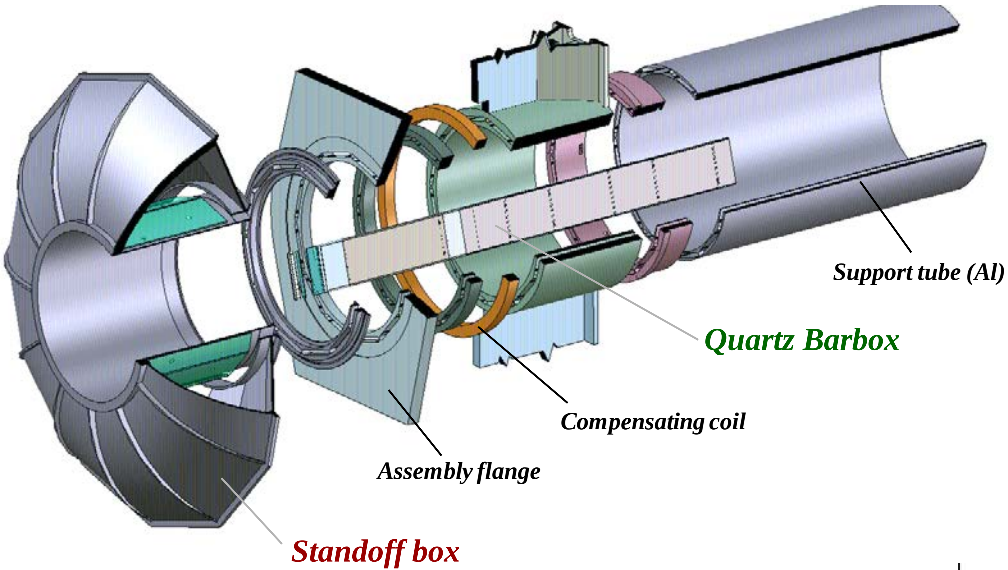
Aerogel radiator

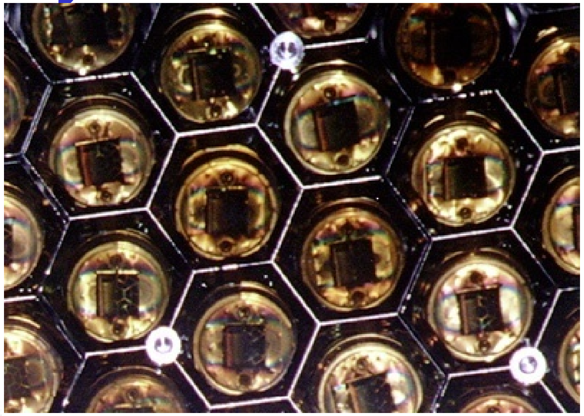
n~1.05

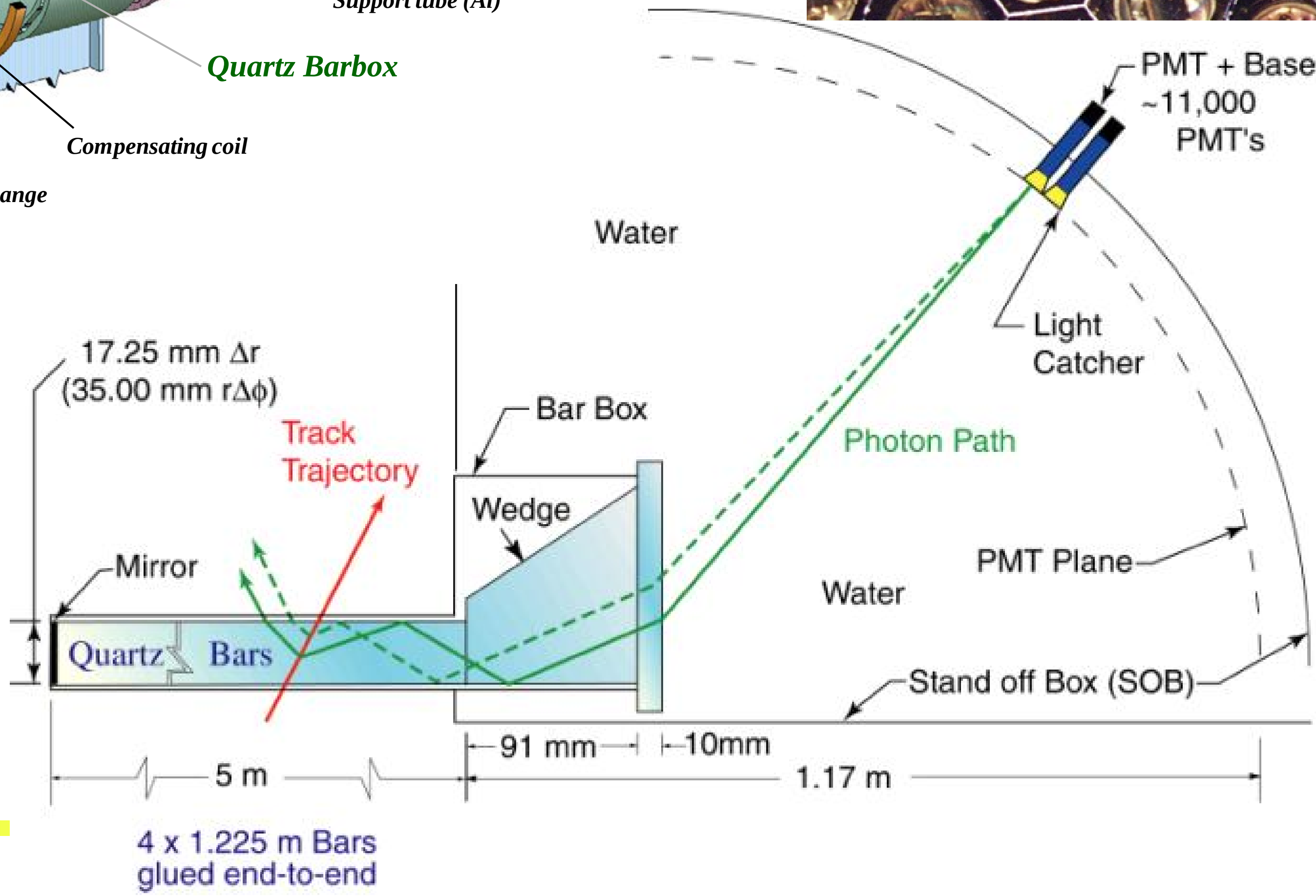
Hamamatsu HAPD
+ new ASIC

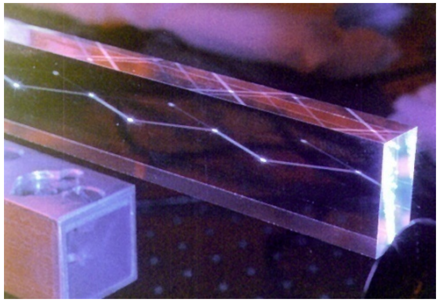


DIRC (@BaBar) - detector of internally reflected Cherenkov light

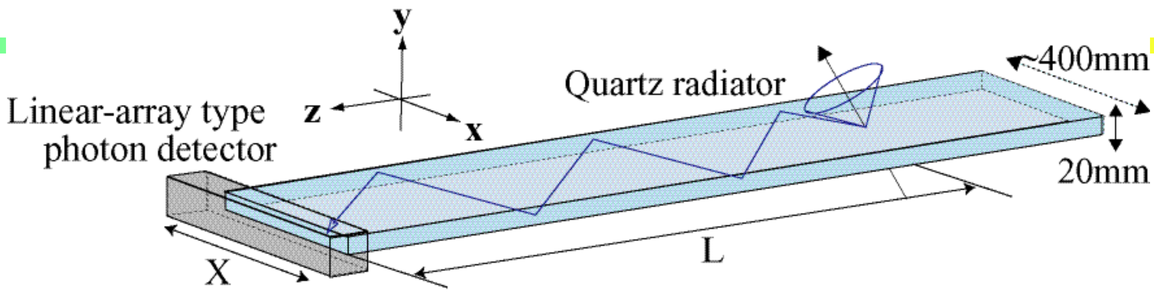


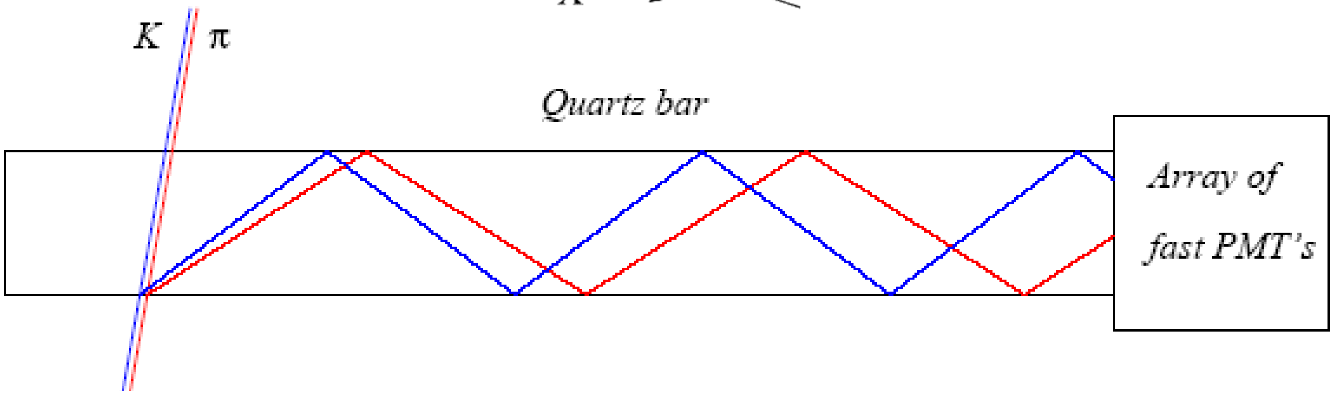


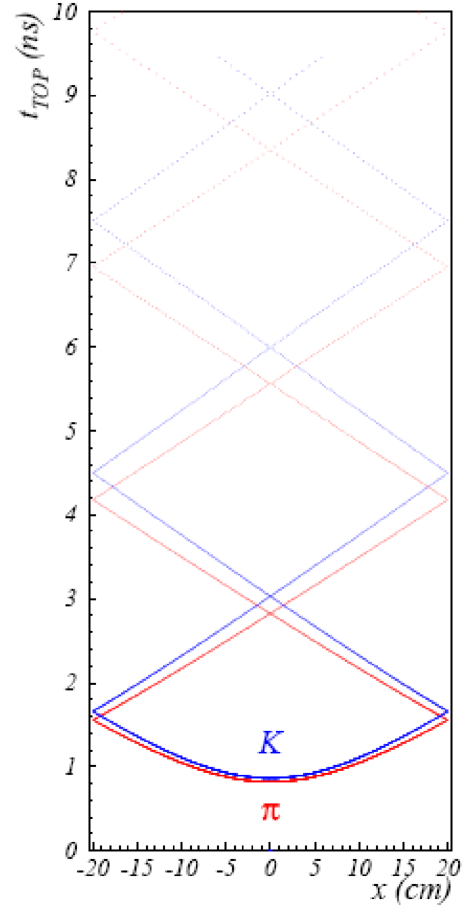




Belle II Barrel PID: Time of propagation (TOP) counter







- 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

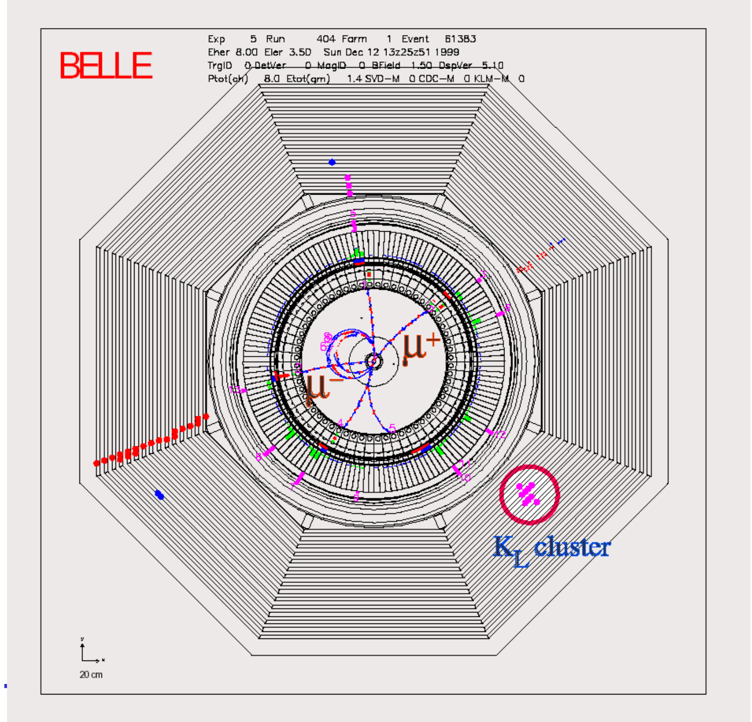
the time of propagation of the photon

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

Muon (and K_L) detector

Separate muons from hadrons (pions and kaons): exploit the fact that muons interact only e.m., while hadrons interact strongly → need a few interaction lengths (about 10x radiation length in iron, 20x in CsI)

Detect K_L interaction (cluster): again need a few interaction lengths.



→ Put the detector outside the magnet coil, and integrate into the return yoke

Some numbers: 3.9 interaction lengths (iron)

Interaction length: iron 132 g/cm^2, CsI 167 g/cm^2

$(dE/dx)_{min}$: iron 1.45 MeV/(g/cm^2), CsI 1.24 MeV/(g/cm^2) → ΔE_{min} = (0.36+0.11) GeV = 0.47 GeV → identification of muons above ~600 MeV

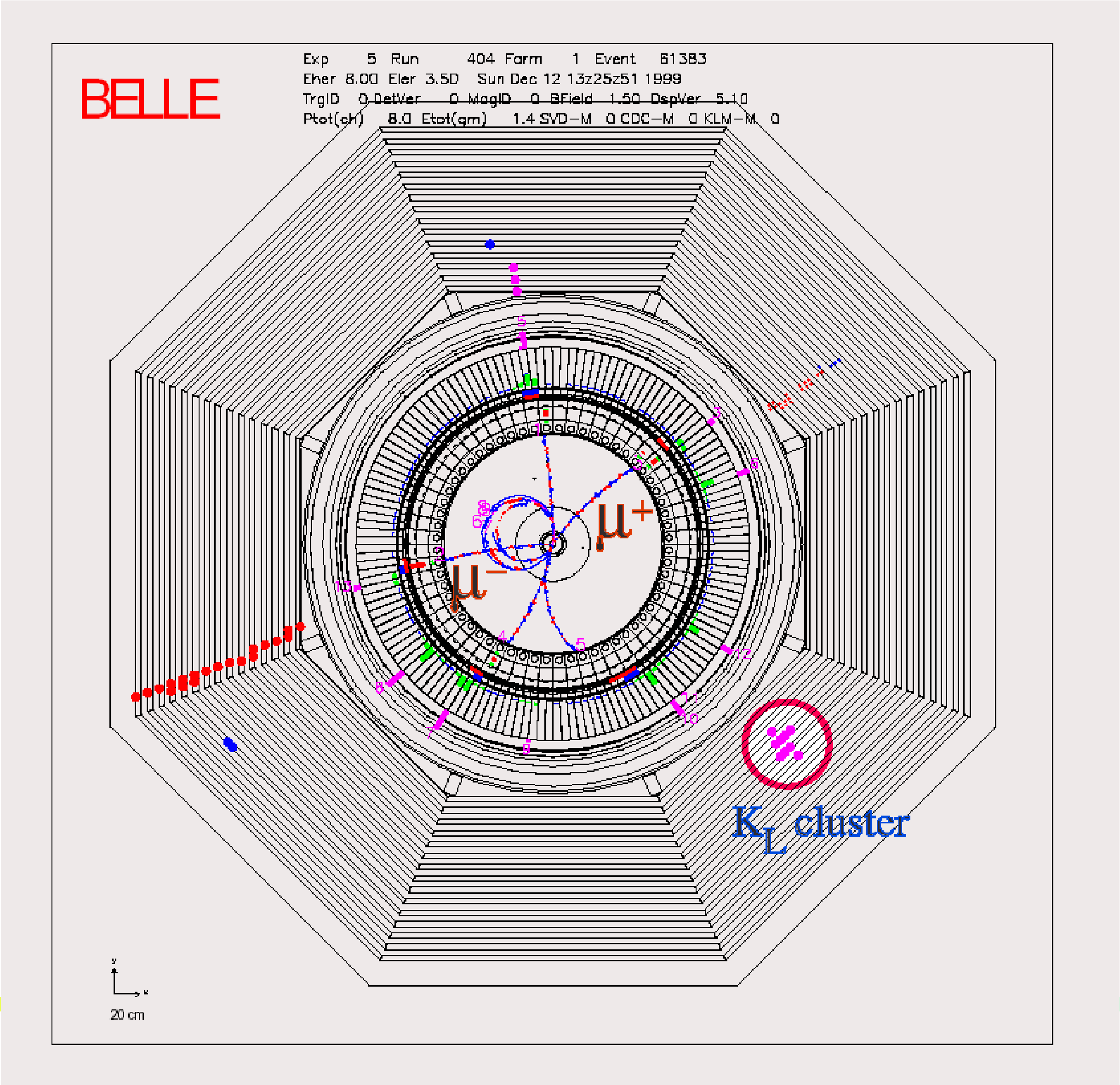
Muon and K_L detector

Example:

event with

- **two muons and a**
- **K_L**

and a pion that partly penetrated



Muon and K_L detector performance

Muon identification >800 MeV/c

efficiency

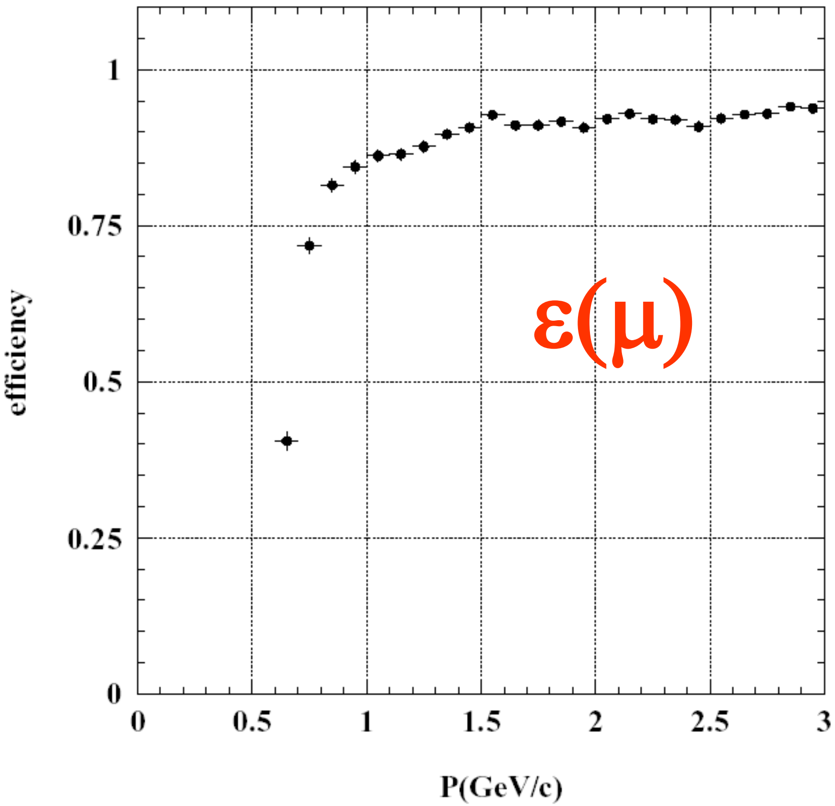


Fig. 109. Muon detection efficiency vs. momentum in KLM.

fake probability

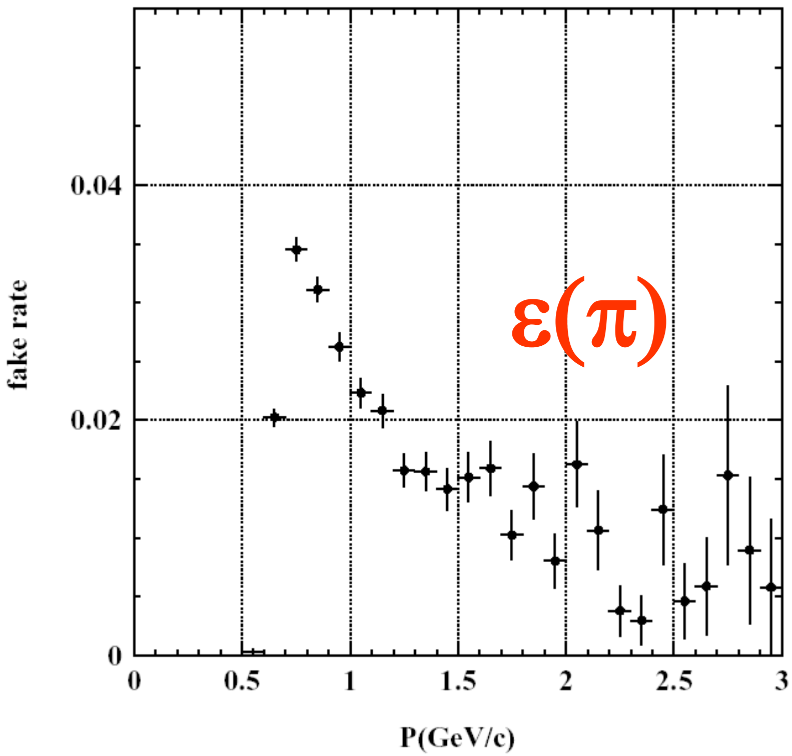


Fig. 110. Fake rate vs. momentum in KLM.

Muon and K_L detector performance

K_L detection: resolution in direction →

K_L detection: also with poss
with electromagnetic calori
(0.8 interactin lengths)

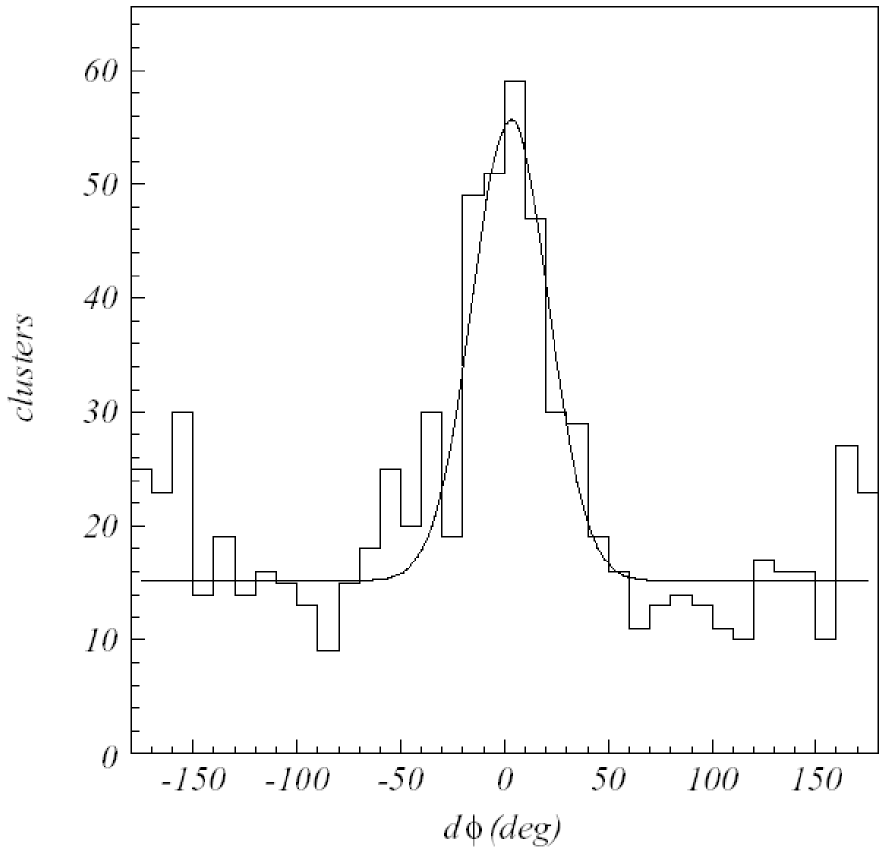


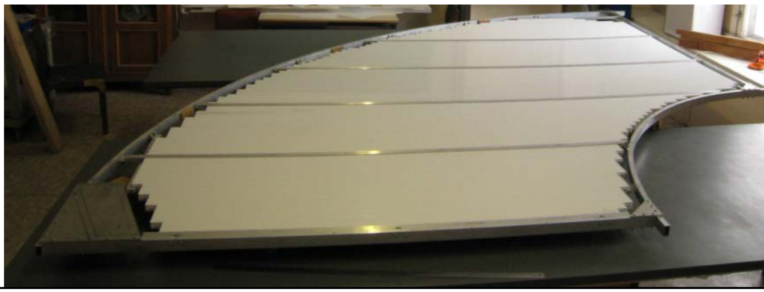
Fig. 107. Difference between the neutral cluster and the direction of missing momentum in KLM.

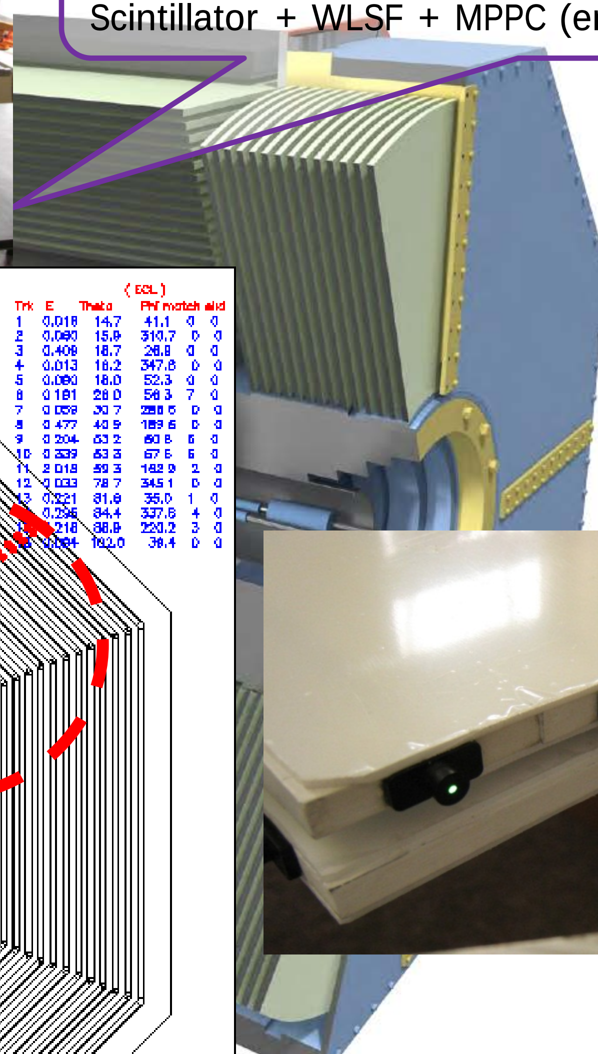
Belle II, detection of muons and K_Ls: Parts of the present RPC system have to be replaced to handle higher backgrounds (mainly from neutrons).

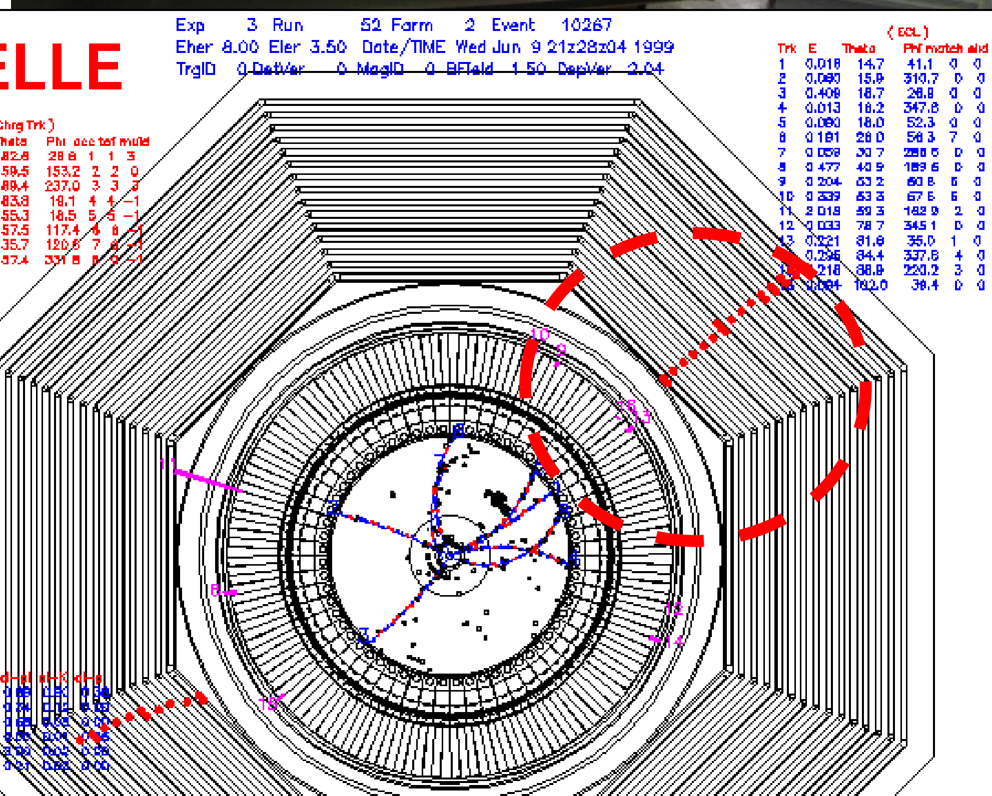
K_L and muon detector:

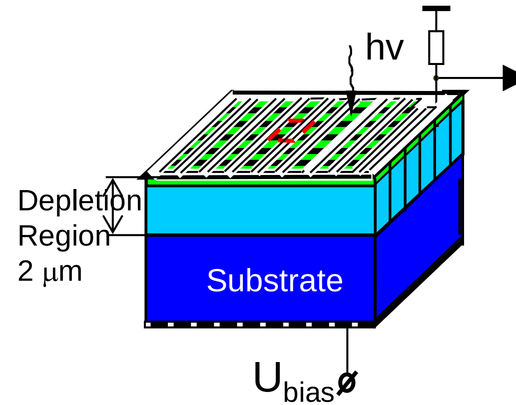
Resistive Plate Counter (barrel)

Scintillator + WLSF + MPPC (end-caps + barrel 2 inner layers)







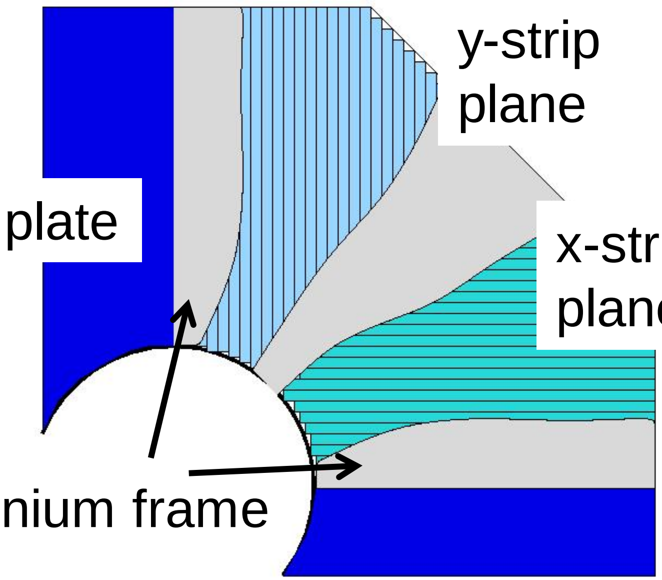


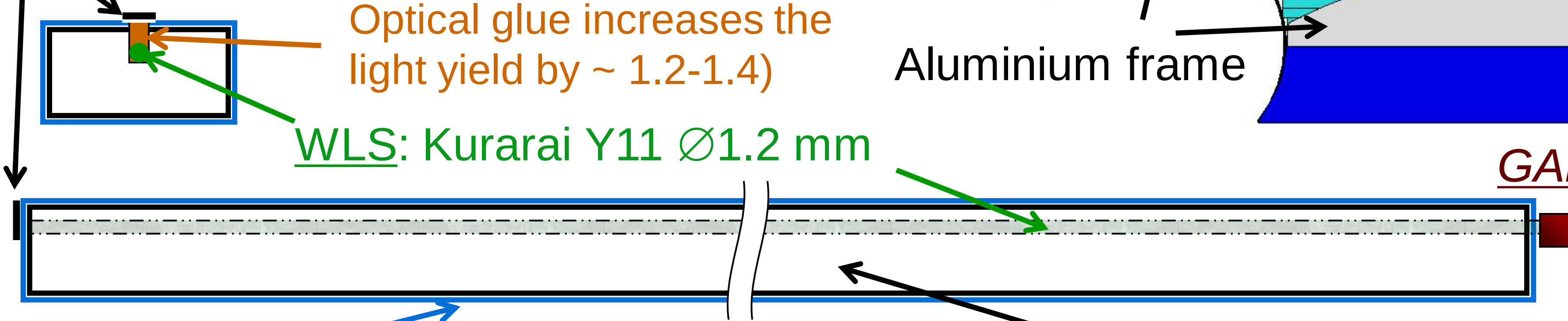
ljana

Muon detection system upgrade in the endcaps

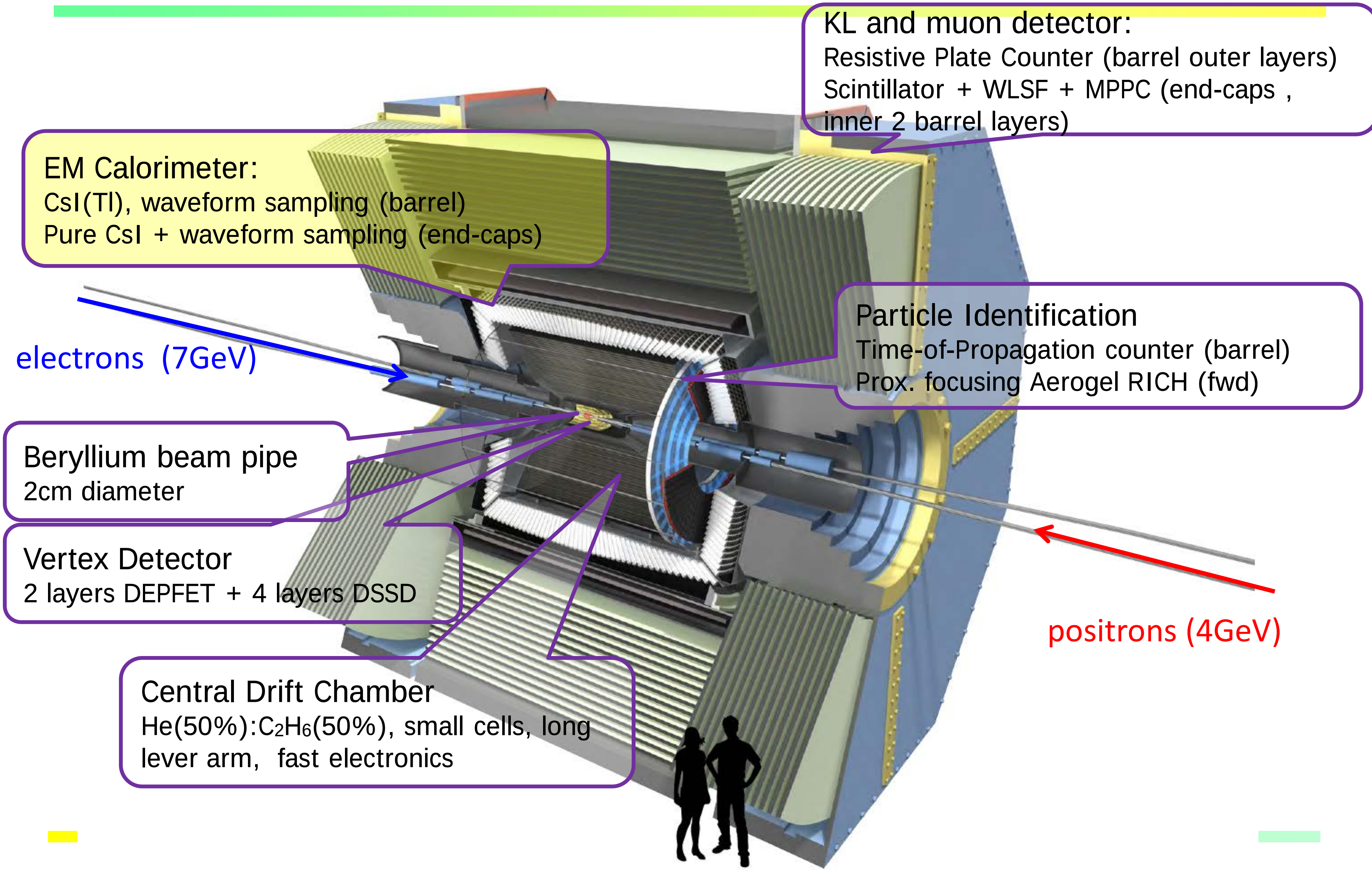
Scintillator-based KLM (endcap and two layers in the barrel part)

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

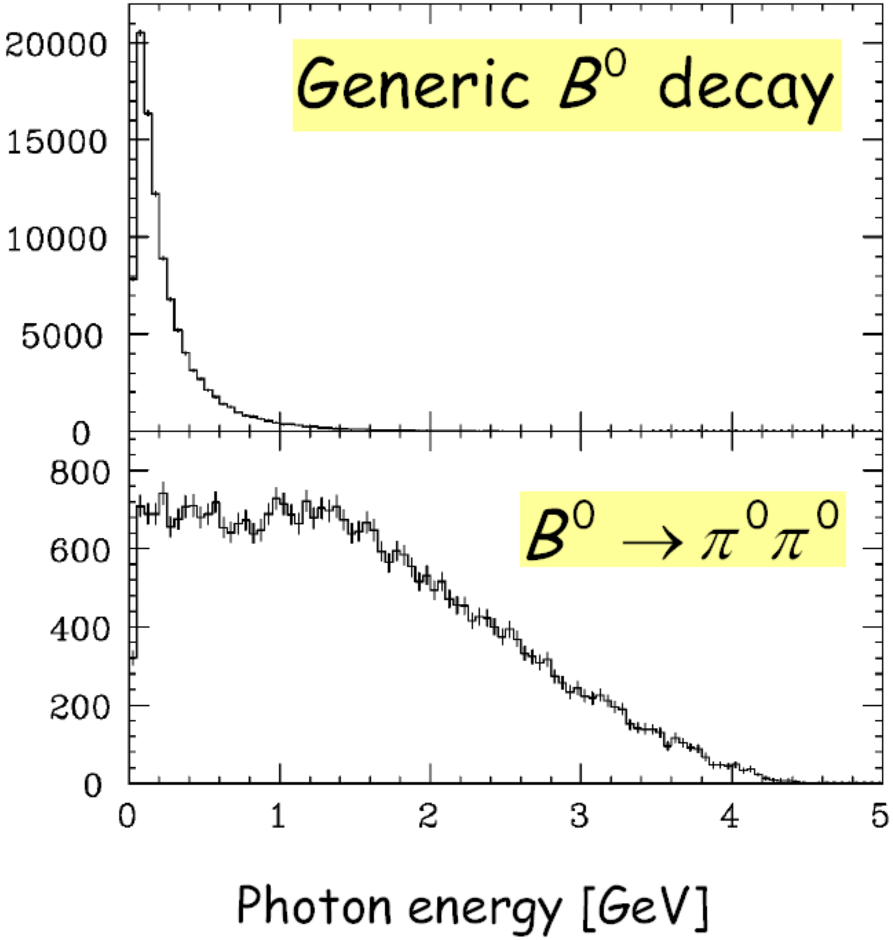


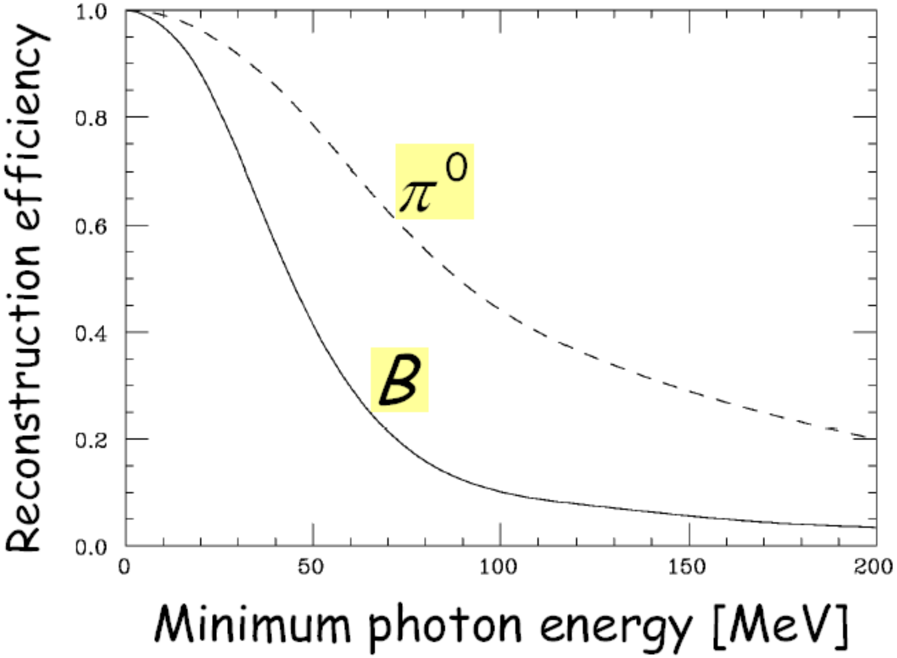


Calorimetry in Belle II

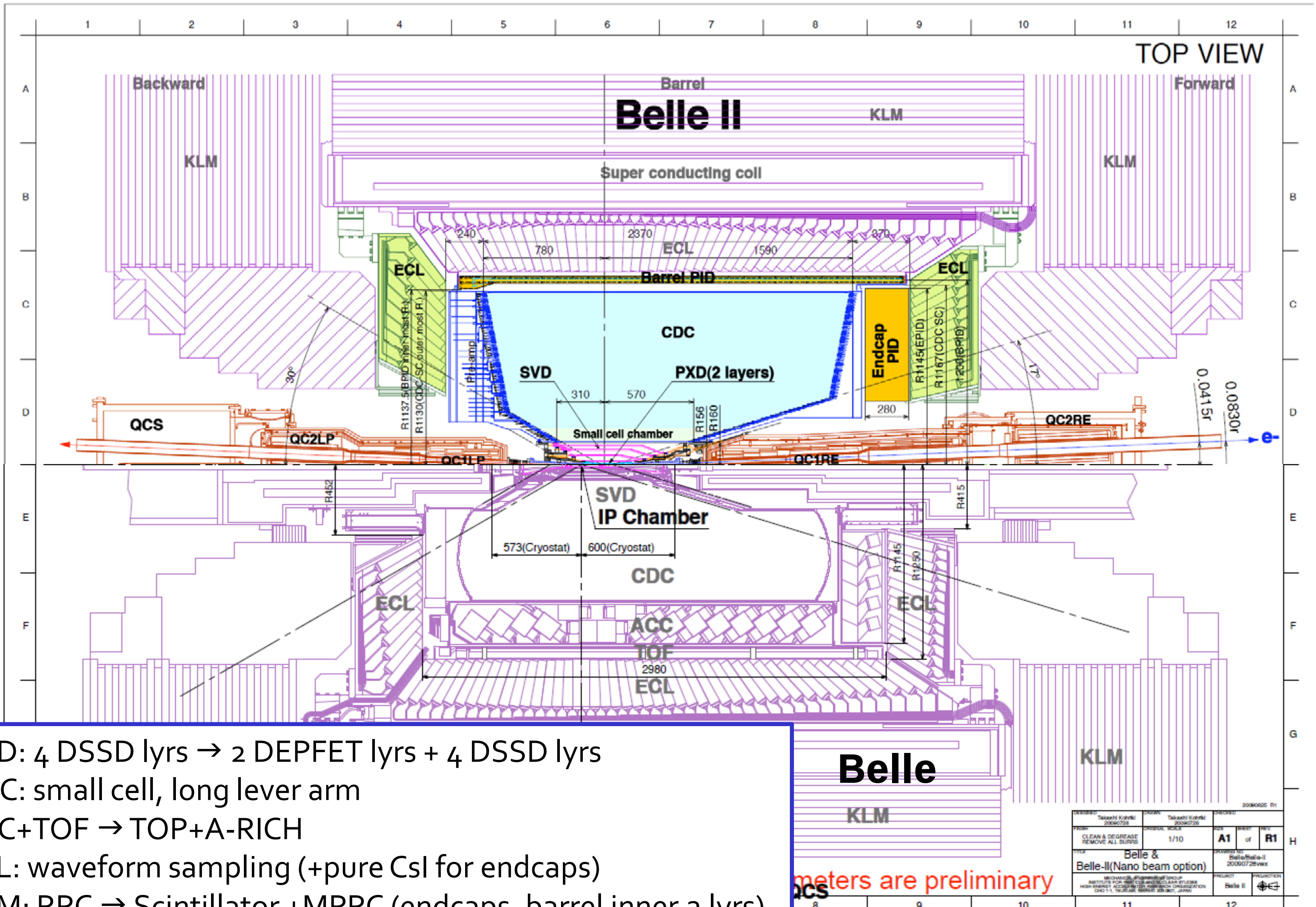


Requirements: Photons





Belle II Detector (in comparison with Belle)



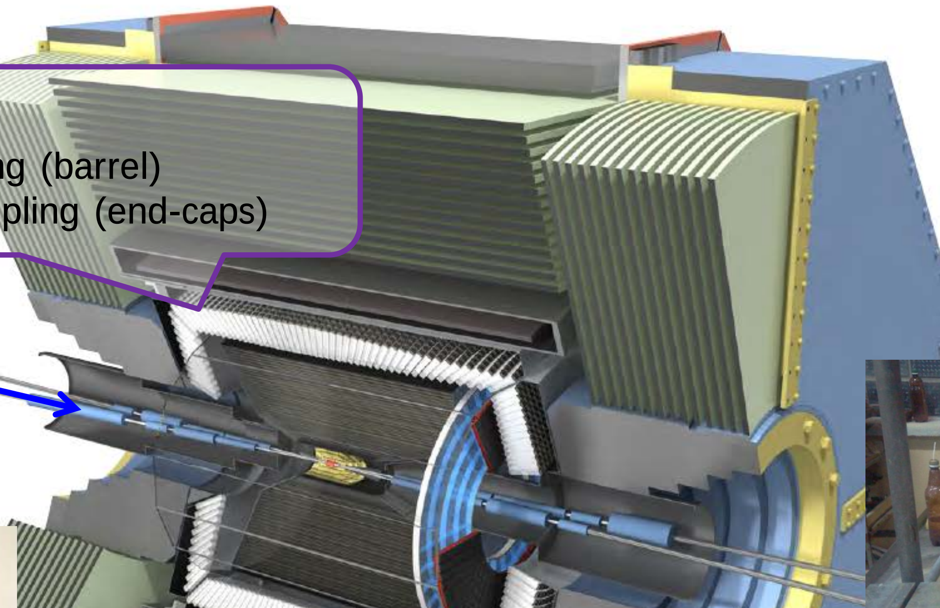
SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI for endcaps)
KLM: RPC → Scintillator +MPPC (endcaps, barrel inner 2 lyrs)

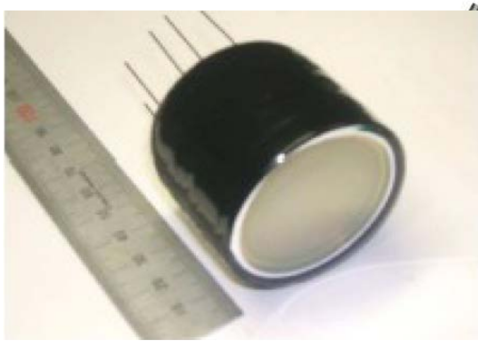
Comparison of Inorganic Scintillators

Scintillator material		Density (g/cm³)	Radiation length	Refractive index	Wavelength at peak	Decay time	Light yield (Y/MeV)
NaI (Tl)		3.67	2.59 cm	1.78	410 nm	230 ns	4.1 x10^4
CsI (Tl)		4.51	1.86 cm	1.85	550 nm	800–6000 ns	6.6 x10^4
CsI (Na)		4.51	1.86 cm	1.80	420 nm	630 ns	4.0 x10^4
$LaBr_3$ (Ce)		5.3	1.88 cm	1.9	358 nm	35 ns	6.1 x10^4
$Bi_4Si_3O_{12}$	BSO	6.8	1.15 cm	2.06	480 nm	100 ns	0.2 x10^4
$Bi_4Ge_3O_{12}$	BGO	7.1	1.12 cm	2.15	480 nm	300 ns	0.9 x10^4
$CdWO_4$		7.9	1.1 cm	2.25	495 nm	5000 ns	2.0 x10^4
$YAlO_3$ (Ce)	YAP	5.5	2.9 cm	1.94	350 nm	30 ns	2.1 x10^4
$Lu_3Al_5O_7$ (Ce)	LuAG	7.4	1.4 cm	1.84	420 nm	40 ns	2.6 x10^4
Gd_2SiO_5 (Ce)	GSO	6.7	1.4 cm	1.87	440 nm	60 ns	0.8 x10^4
$PbWO_4$		8.3	0.89 cm	1.82	425 nm	25 ns	0.05 x10^4

EM calorimeter: upgrade needed 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)

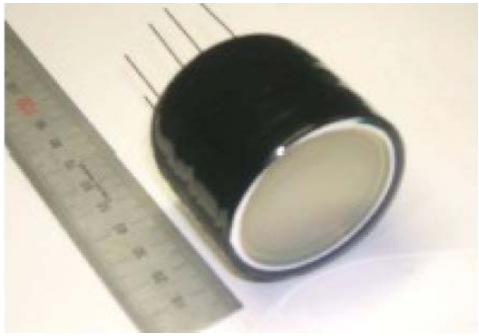




EM calorimeter: upgrade needed because of

- higher rates (barrel: electronics, endcap: electronics and CsI(Tl) → pure CsI), and
- radiation load (endcap: CsI(Tl) → pure CsI)

Pure CsI is faster, but has a smaller light yield…
→replace photodiodes with a special kind of PMT (photopentode) that can be operated in magnetic field

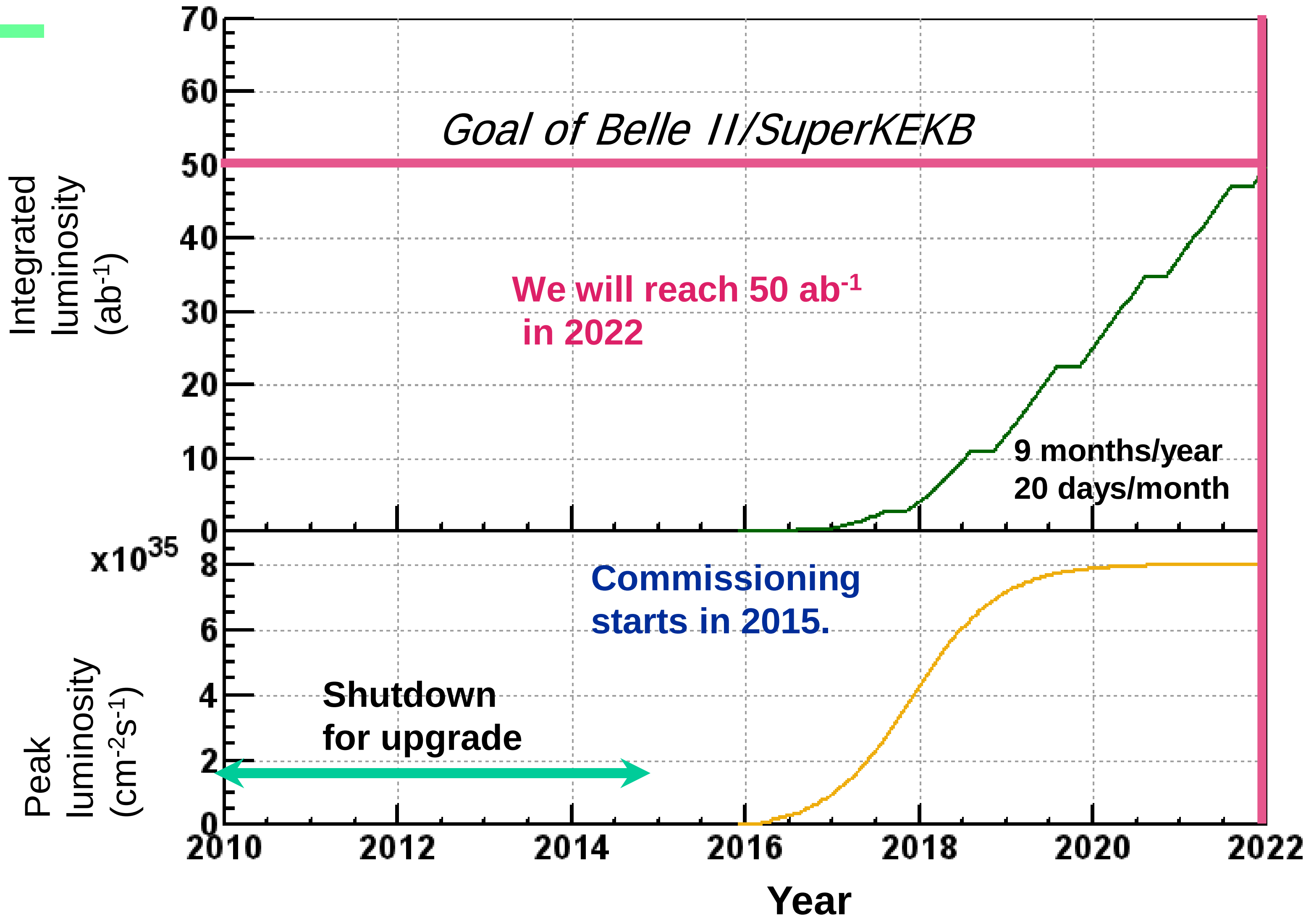


Status of the project

The Belle II Collaboration

A very strong group of ~480 highly motivated scientists!

Schedule



The schedule is likely to shift by a few months because of a new construction/commissioning strategy for the final quads.

Conclusion

- KEKB has proven to be an excellent tool for flavour physics, with reliable long term operation, breaking world records, and surpassing its design perfomance by a factor of two.
- Major upgrade at KEK in 2010-15 → SuperKEKB+Belle II, with 40x larger event rates, construction well under way
- Expect a new, exciting era of discoveries, complementary to the LHC

- There is a lot of work to be done – if you are interested, join us!

More slides…

Search for particles which decayed close to the production point

How do we reconstruct final states which decayed to several stable particles (e.g., 1,2,3)?
From the measured tracks calculate the invariant mass of the system (i= 1,2,3):

$$Mc^2 = \sqrt{(\sum E_i)^2 - (\sum \vec{p}_i)^2 c^2}$$

The candidates for the X→123 decay show up as a peak in the distribution on (mostly combinatorial) background.
The name of the game: have as little background under the peak as possible without loosing the events in the peak (=reduce background and have a small peak width).

How do we know it was precisely this reaction?

$B^0 \rightarrow K^0_S\, J/\psi$

$K^0_S \rightarrow \pi^- \pi^+$

$J/\psi \rightarrow \mu^- \mu^+$

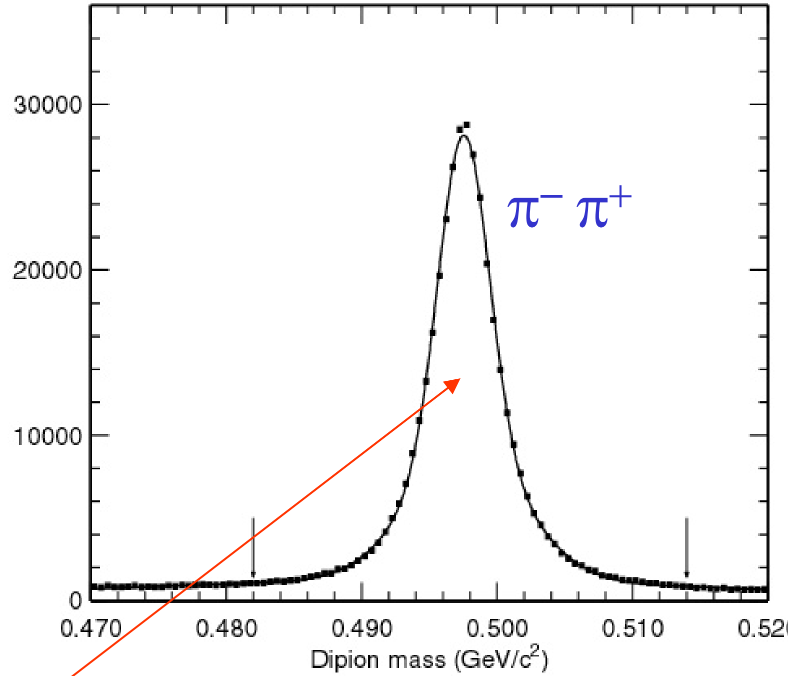
← detect

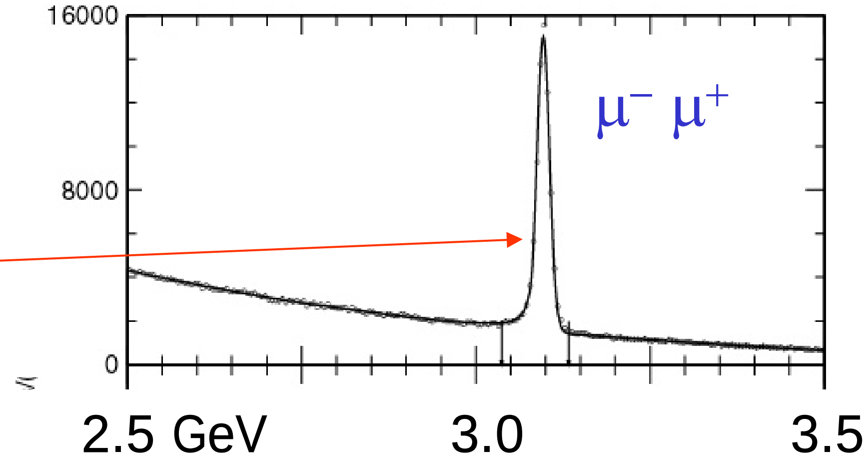
For $\pi^- \pi^+$ in $\mu^- \mu^+$ pairs we calculate the invariant mass:

$M^2c^4 = (E_1 + E_2)^2 - (p_1 + p_2)^2$

Mc^2 must be for K^0_S close to 0.5 GeV,

for J/ψ close to 3.1 GeV.

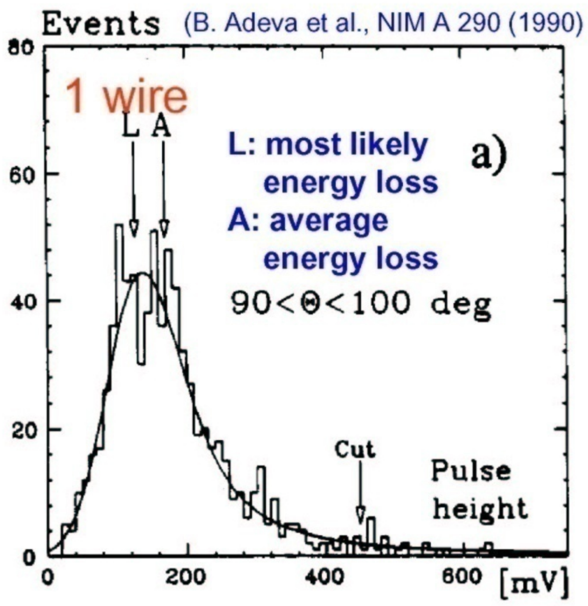


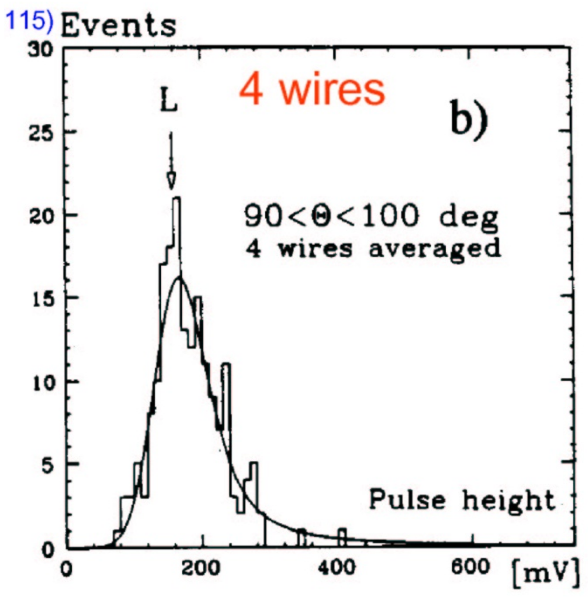


Rest in the histrogram: random coincidences (‘combinatorial background’)

Identification with dE/dx measurement 2

Problem: long tails (Landau distribution, not Gaussian)





Identification with dE/dx measurement 3

Optimisation of the counter: length L, number of samples N, resolution (FWHM)

If the distribution of individual measurements were Gaussian, only the total sample thickness would be relevant.

Tails: eliminate the largest 30% values → the optimumm depends also on the number of samples.