Belle II Experiment

Yutaka USHIRODA (IPNS, KEK)

KEKB Review Meeting

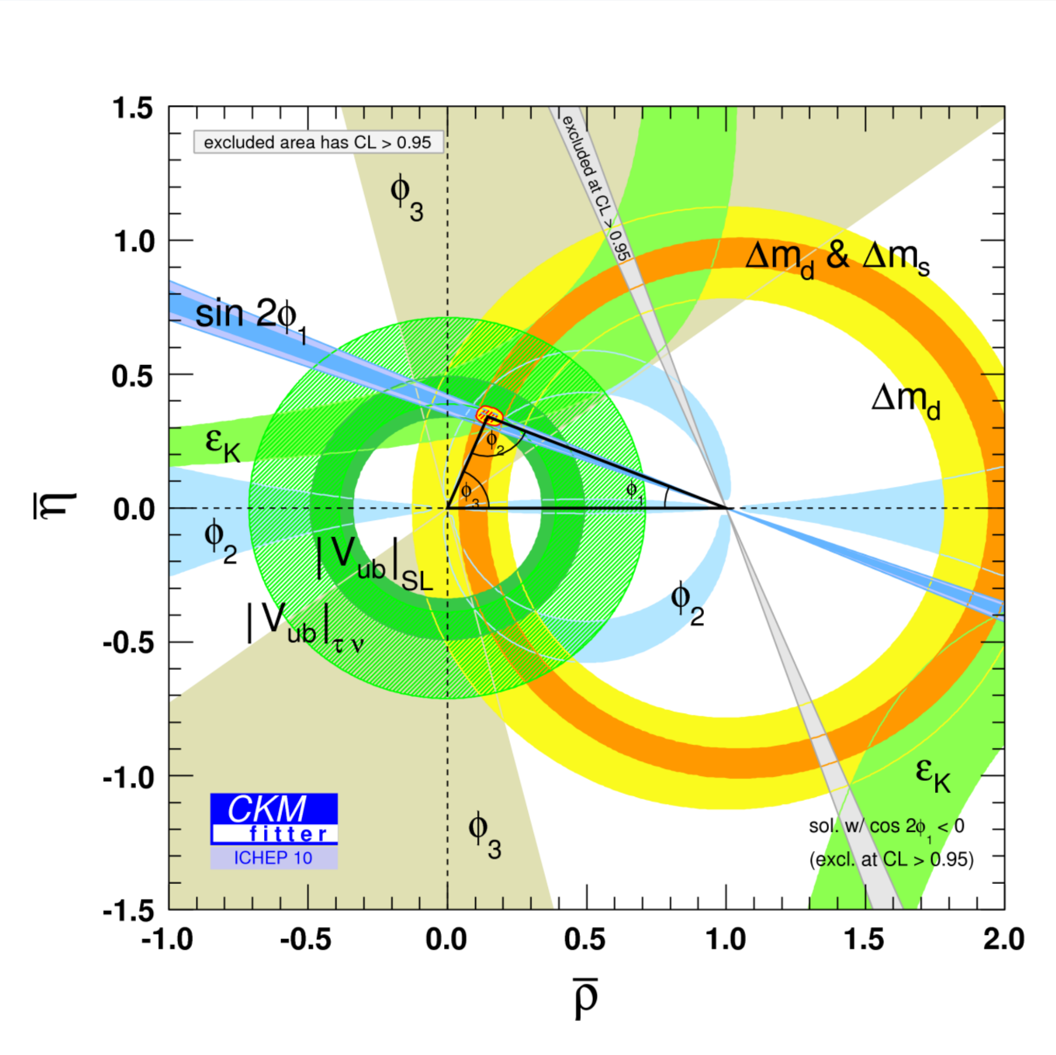
Feb. 7, 2011

Outline

- Introduction
- Detector Design
- Machine-Detector issues
- Construction Cost and Schedule
- Summary

Primary Target of KEKB/Belle

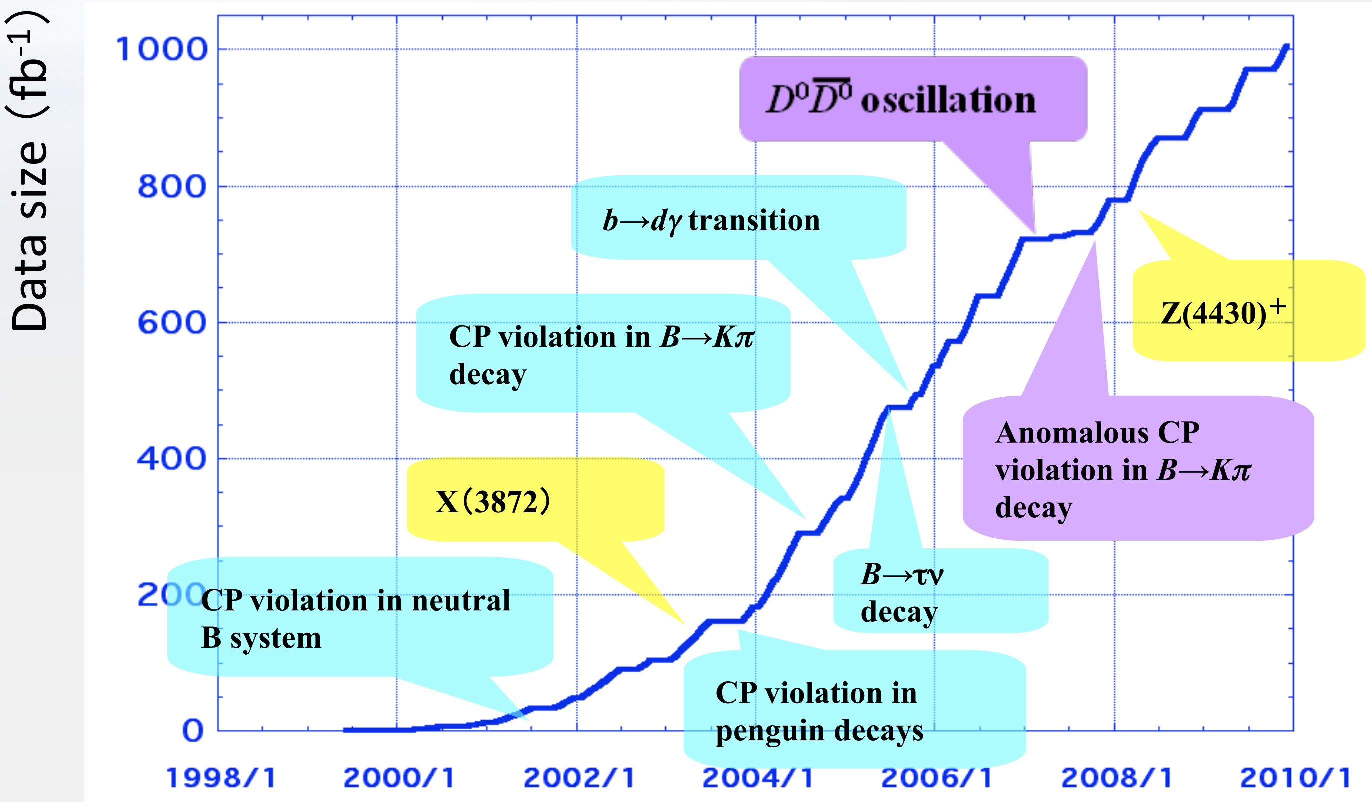
... was to confirm Kobayashi-Maskawa mechanism.



... and was so successful.

Hot news from Belle in the past

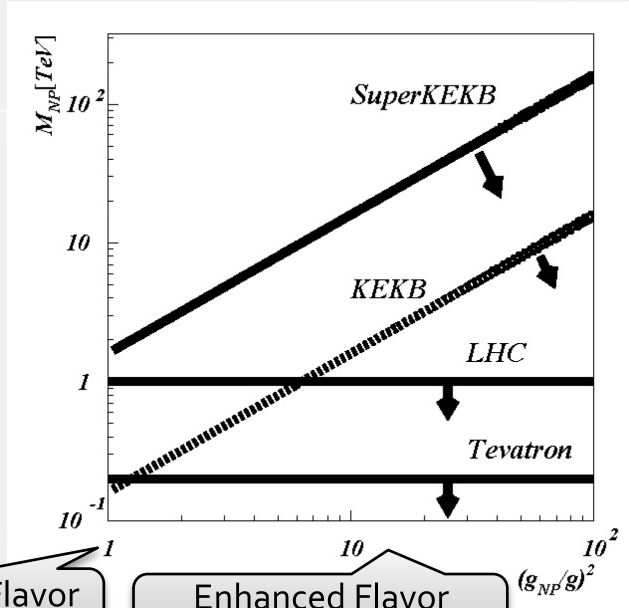
333 physics publications



1. Precise determination of SM (CKM)
2. Some unexpected observations such as new hadronic resonances (possible, but omitted in SM)
3. (Yet unclear) hints of new physics (impossible in SM, possible in NP)

Goal of Super B-factory

... is to search for NP,
discover it,
and determine model and parameters.
Or, to search for NP,
and constrain model and parameters.



Minimal Flavor Violation

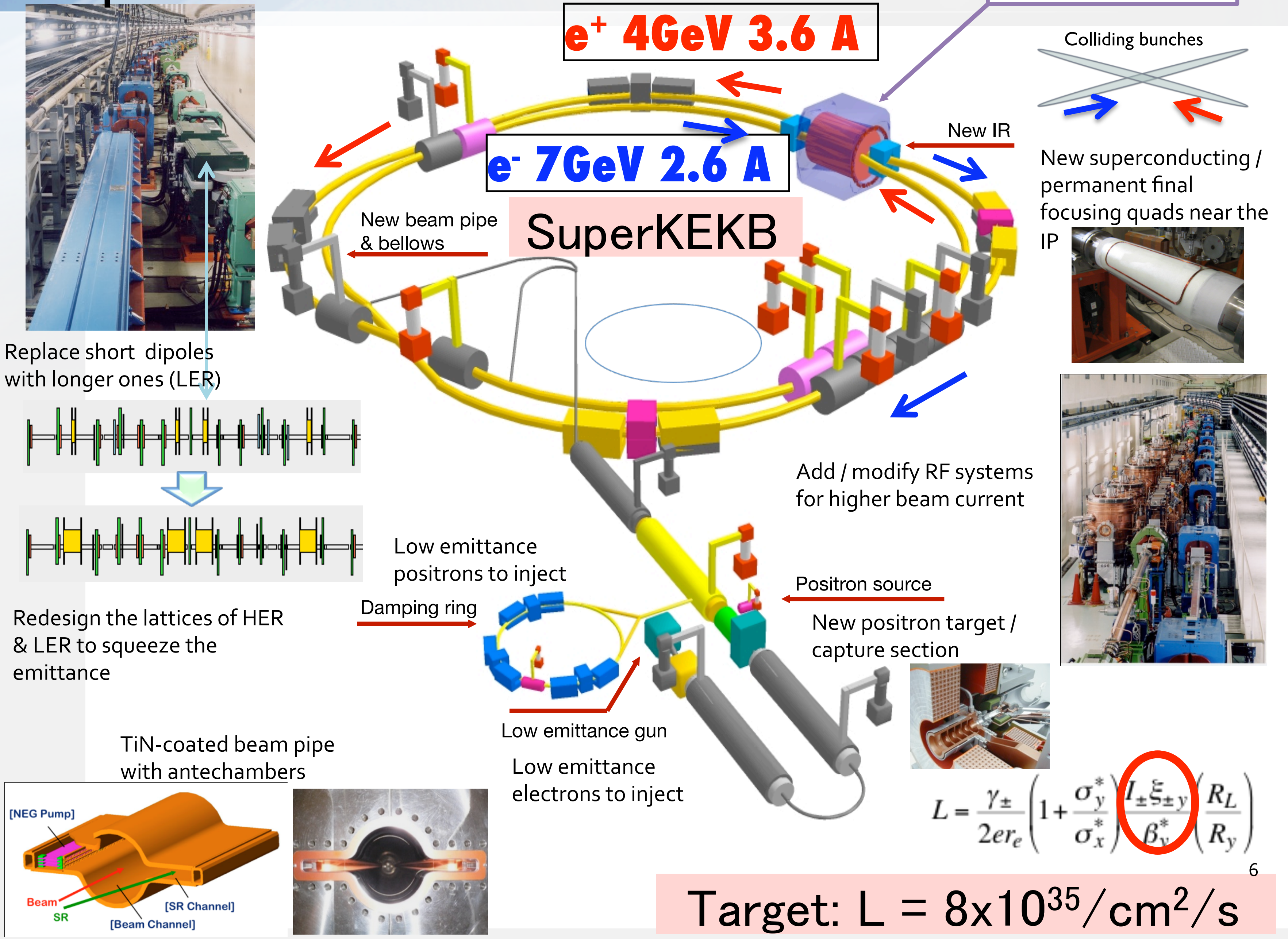
Enhanced Flavor Violating Couplings

ATLAS/CMS may discover it.
Yes, but they cannot measure flavor couplings and not good at determining models.

LHCb started in good shape.
Yes, but they are not good at measuring neutral particles involved in many important decay modes (BF($B \to \tau\nu$), S($K_S\pi^0\gamma$), $K^0\pi^0$, ...).

Next-generation flavor factory in clean environment of e^+e^- collisions is important.
→ **SuperKEKB/Belle II**

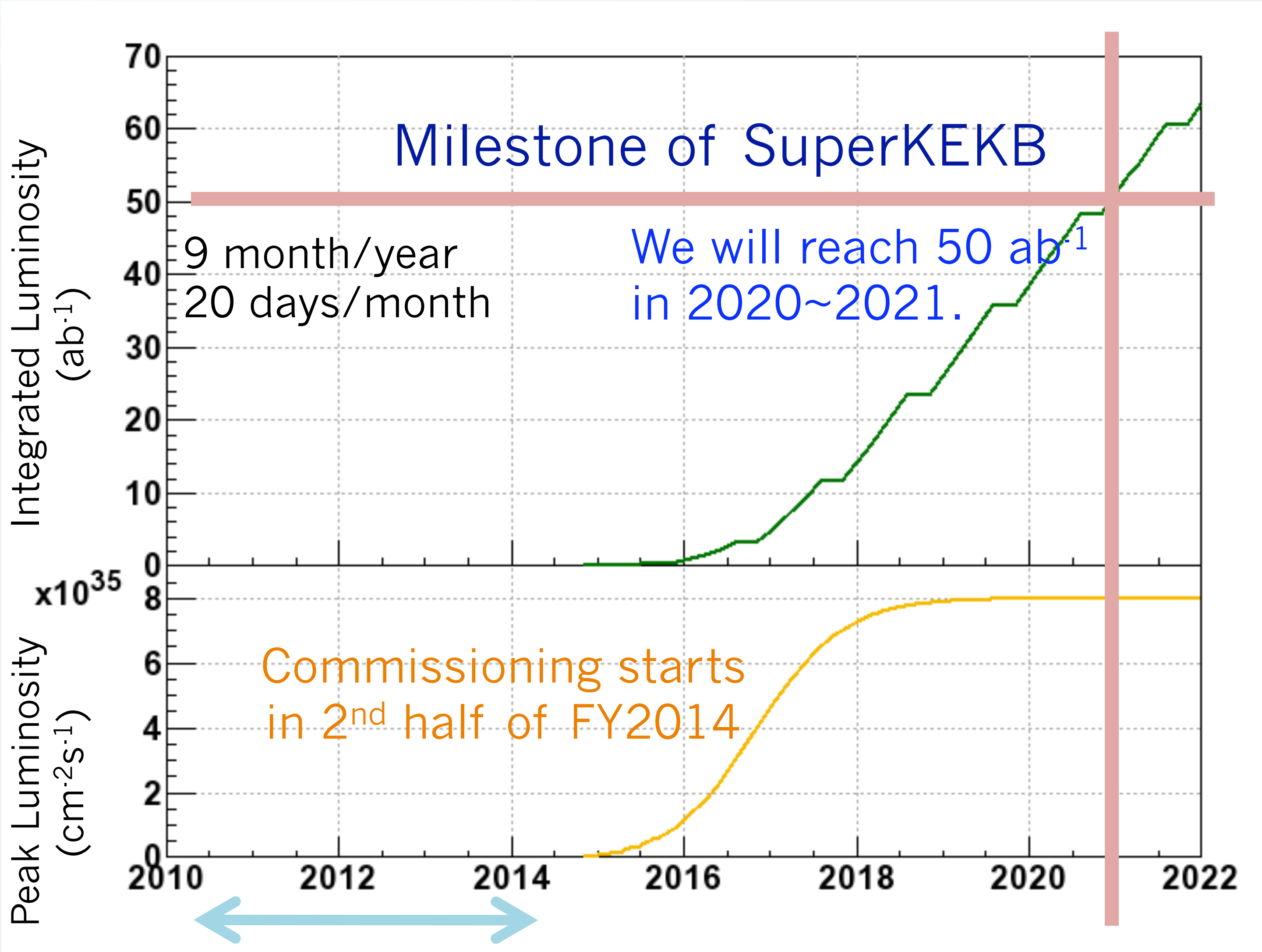
SuperKEKB and Belle II



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

Target: L = $8 \times 10^{35}/cm^2/s$

Luminosity prospect



Shutdown
for upgrade

M. Yamauchi

ORGANIZATION IN KEK

KEK-DG

KEKB ARC

BPAC

Acc. grou

p. group

- KEK's execu
- KEK's board
- Administrat
- Facility dep
- Public relat

earch center
ter
gineering center
y office

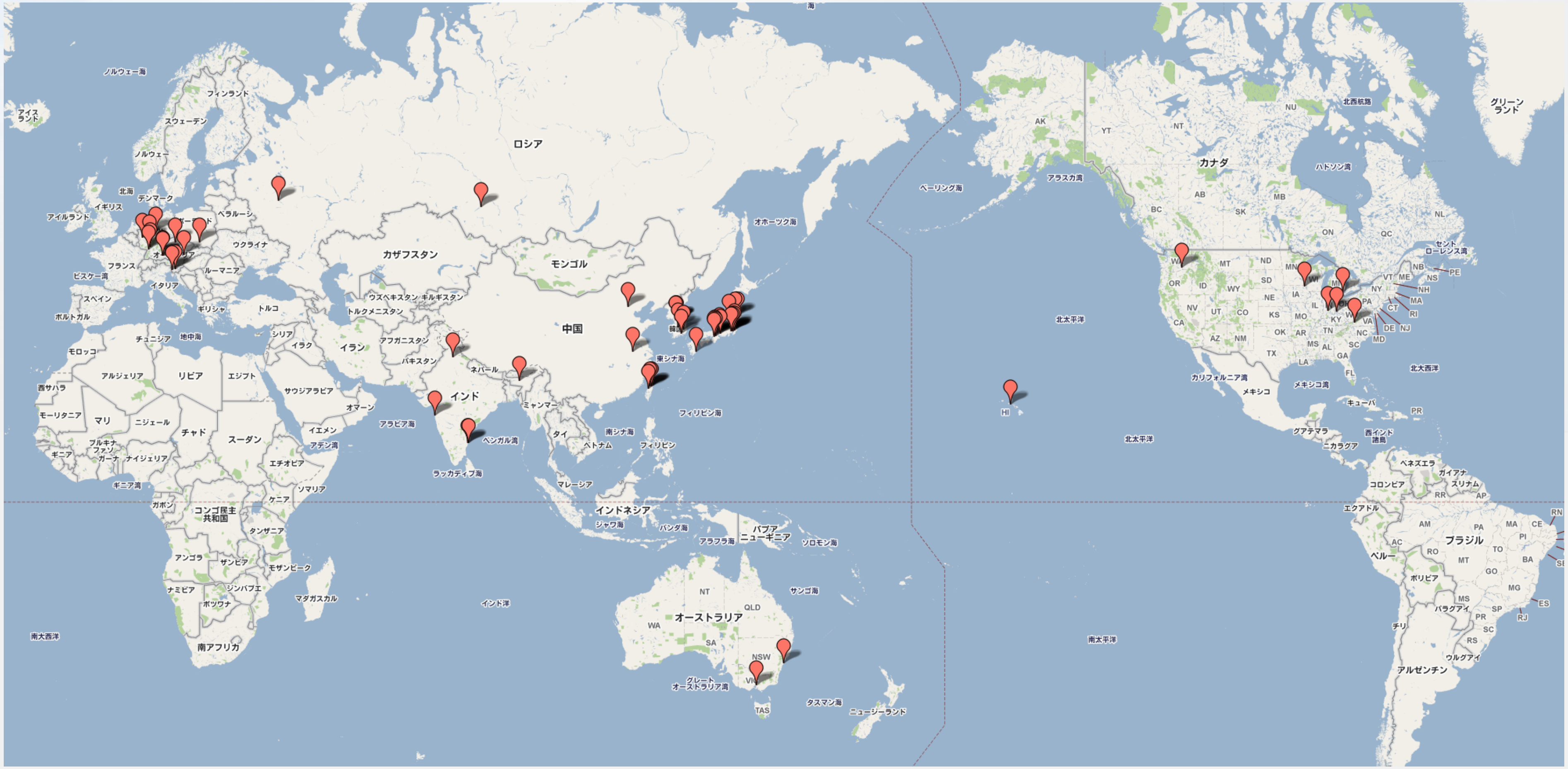
and many other field-level barrier-free interactions between machine and detector groups:

- SuperKEKB kentoukai,
- Belle II Executive Board meeting,
- Belle II General Meeting
- SuperKEKB Optics meeting,
- IR technical meeting,
- IR assembly meeting,
- Belle II SVD mechanical meeting

...

(addition by YU)

Belle II Collaboration

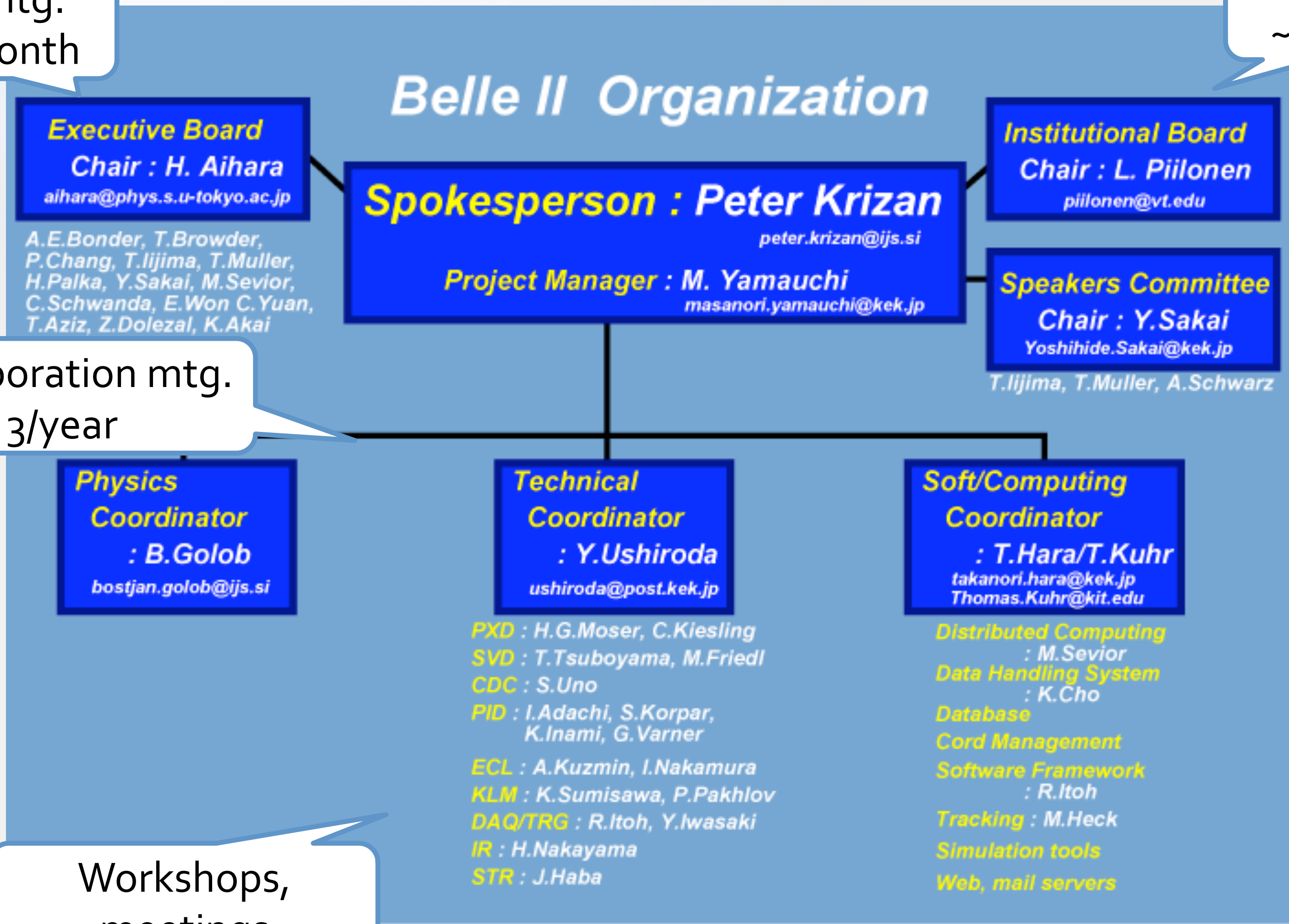


13 countries/regions, 57 institutes, 384 collaborators (Jan. 2011)

Belle II Organization

EB mtg.
~1/month

IB mtg.
~3/year

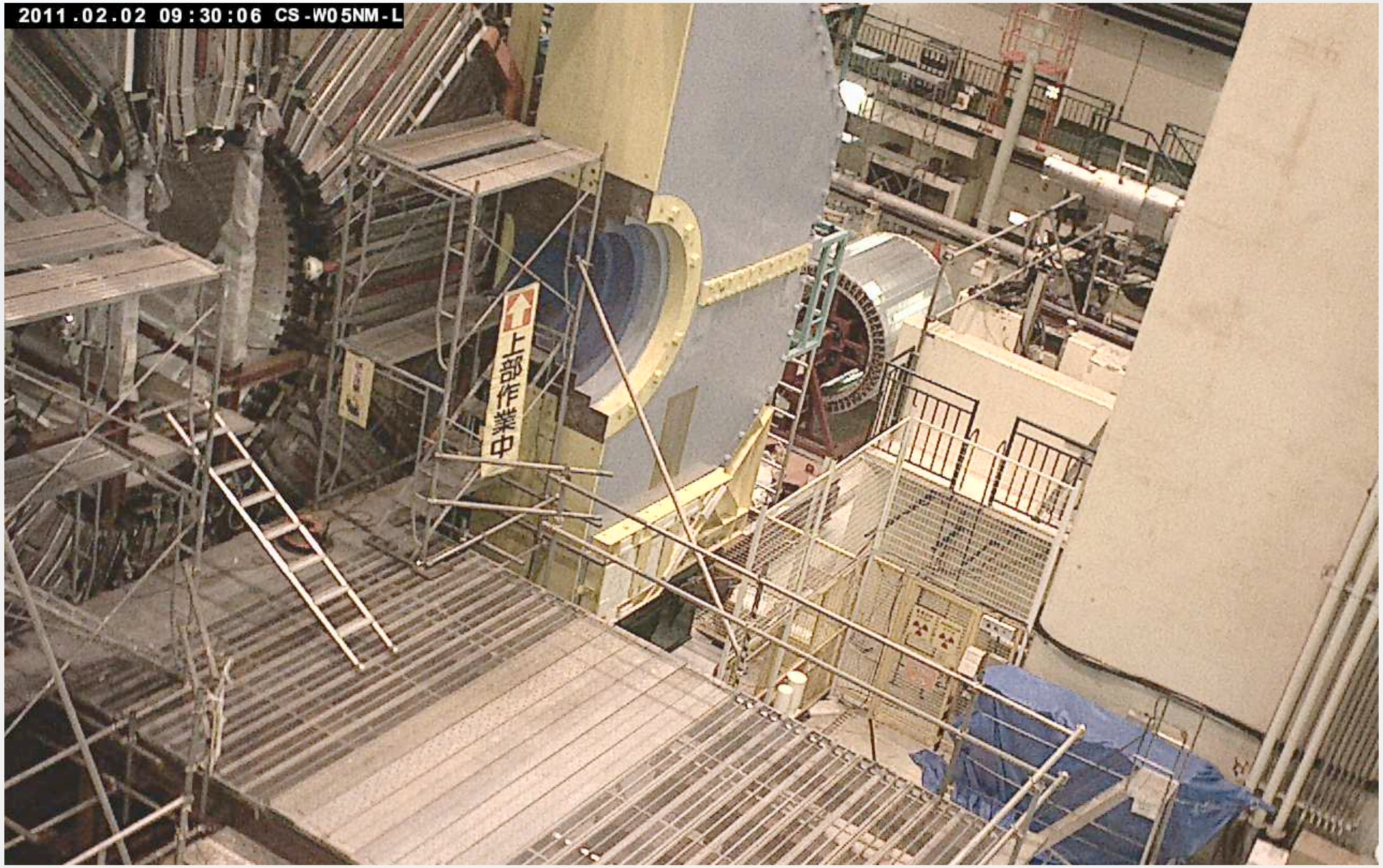


Collaboration mtg.
3/year

Workshops,
meetings

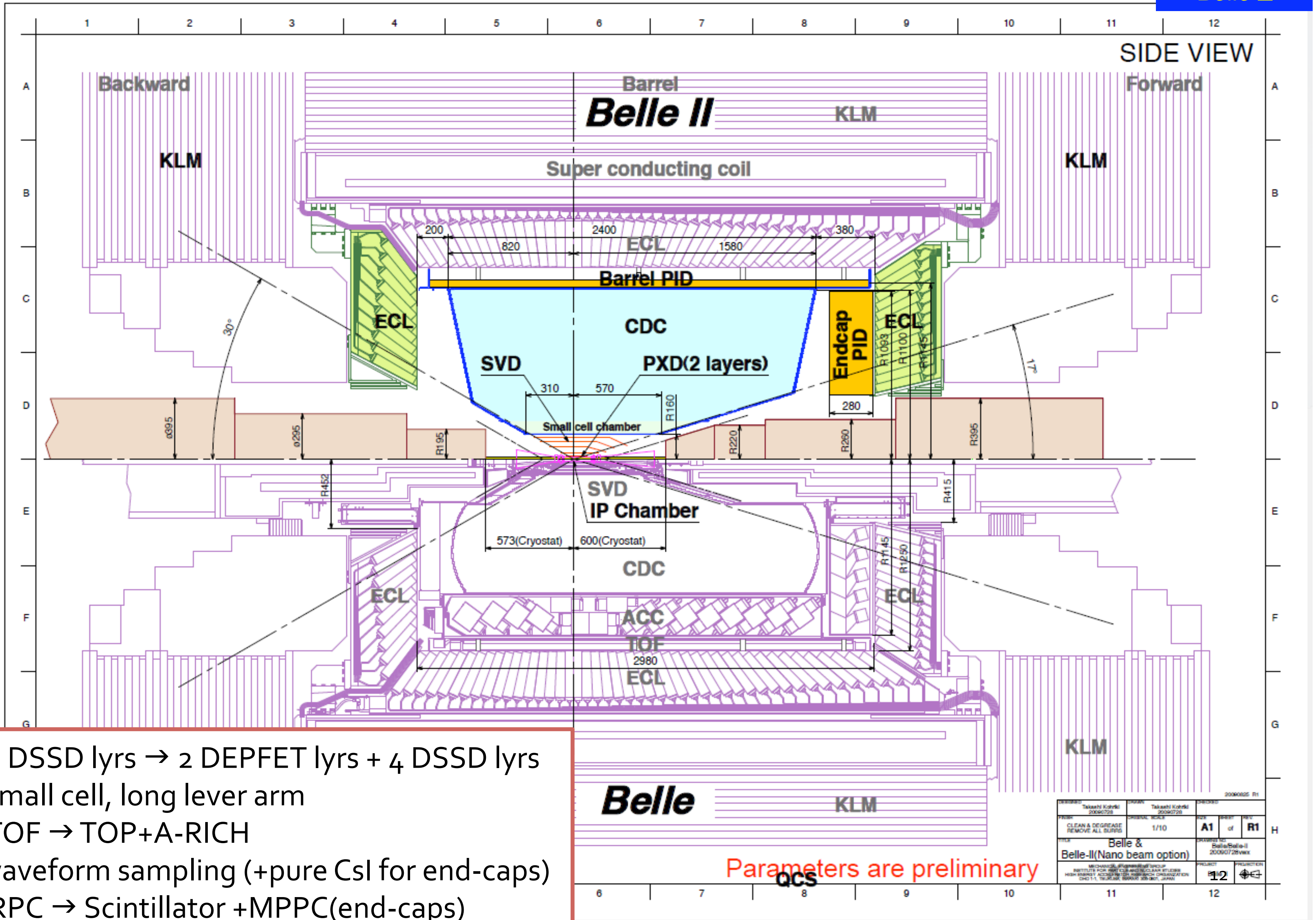
+Task forces

Tsukuba-hall webcam



Beam Pipe and Vertex Detector extraction: on Nov. 10, 2010
Belle Detector Roll-out: Dec. 9, 2010
End-caps, CDC, B-ACC, TOF extraction: in Jan. 2011

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 end-caps)

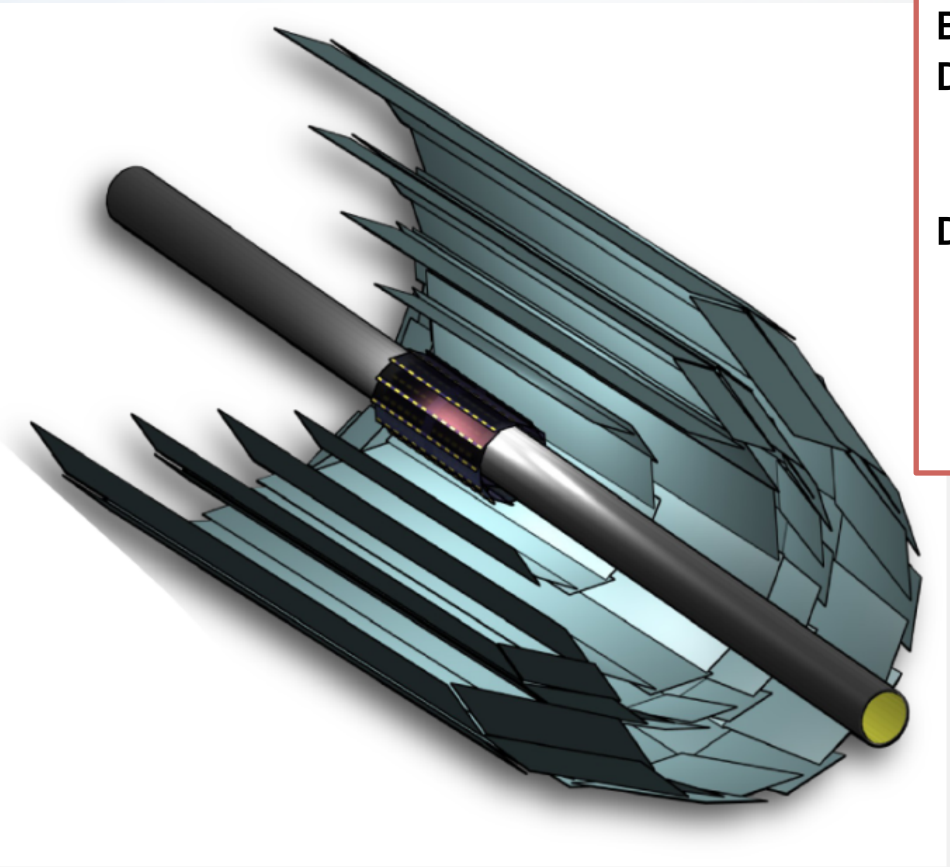
KLM: RPC → Scintillator +MPPC(end-caps)

Technical Design Report

- arXiv:1011.0352: http://arxiv.org/abs/1011.0352
- KEK Report 2010-1: http://www-lib.kek.jp/cgi-bin/kiss_prepri.v8?KN=201024001&OF=8.
- Belle II web page: http://b2comp.kek.jp/~twiki/pub/Organization/B2TDR/B2TDR.pdf

Reviewed by BPAC members + external experts in May and in Nov.
Printed in Nov.

Vertex Detector



		Belle II	Belle
Beam Pipe		r = 10mm	15mm
DEPFET			
	Layer 1	r = 14mm	
	Layer 2	r = 22mm	
DSSD			
	Layer 3	r = 38mm	20mm
	Layer 4	r = 80mm	43.5mm
	Layer 5	r = 115mm	70mm
	Layer 6	r = 140mm	88mm

PXD (DEPFET)

Each pixel is a 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$^-$)

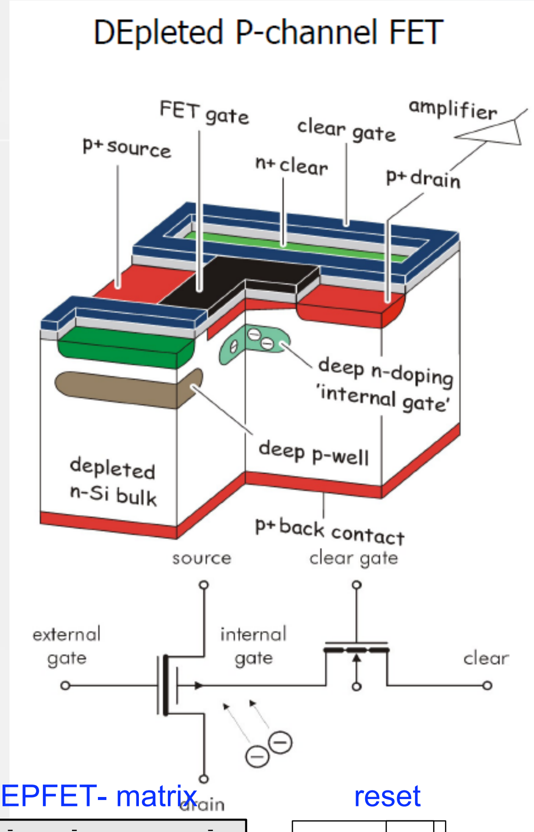
Accumulated charge can be removed by a clear contact (“reset”)

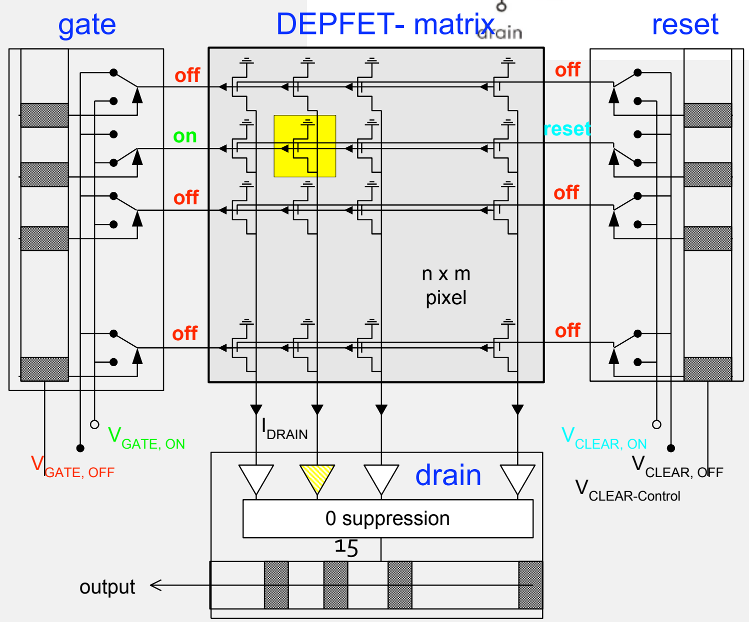
Fully depleted: => large signal, fast signal collection

Low capacitance, internal amplification: => low noise

High S/N even for thin sensors (50µm)

Rolling shutter mode (column parallel) for matrix operation
=> 20 µs frame readout time
=> Low power (only few lines powered)

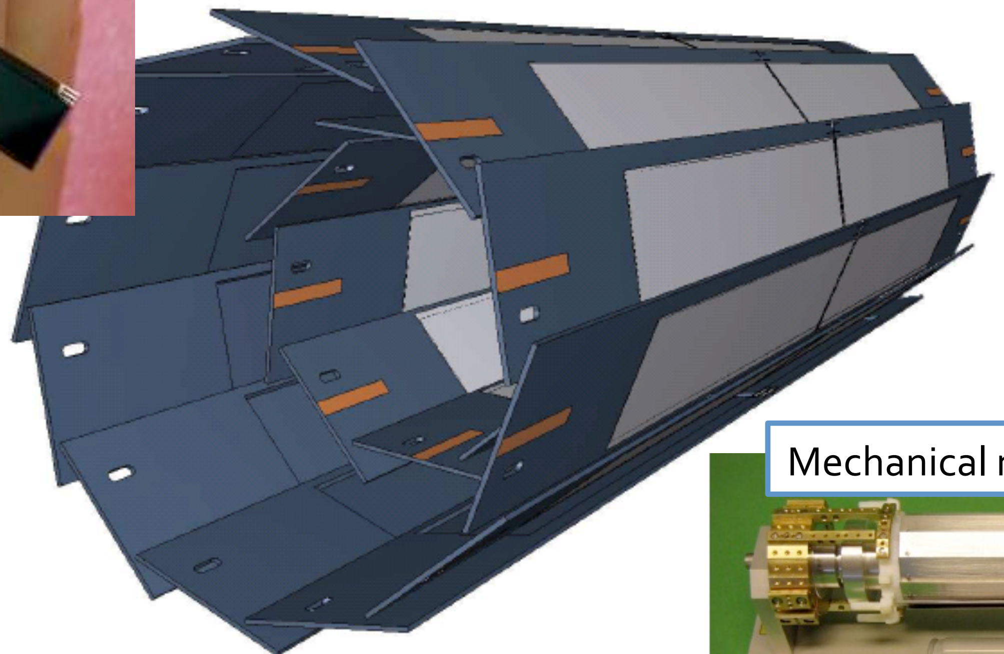




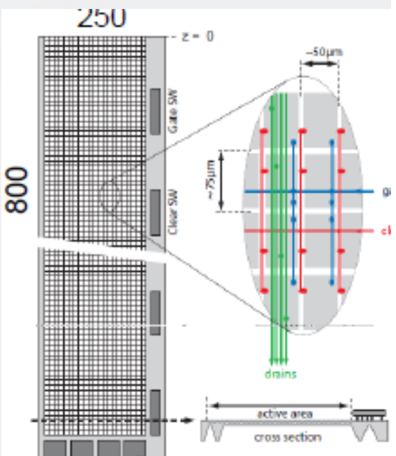
DEPFET:
http://aldebaran.hll.mpg.de/twiki/bin/view/DEPFET/WebHome

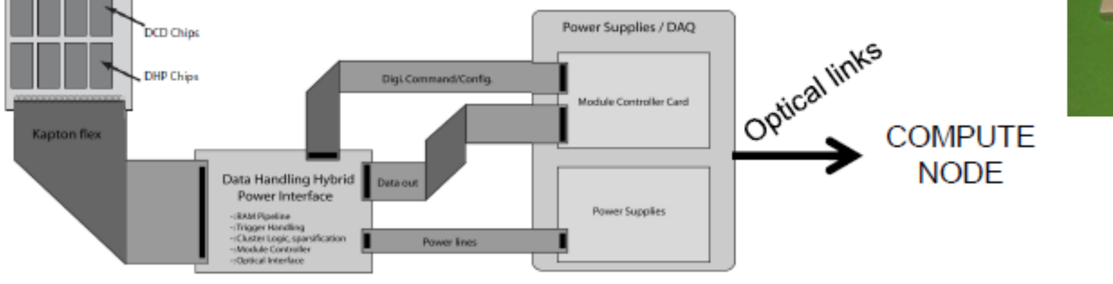
DEPFET for Belle II

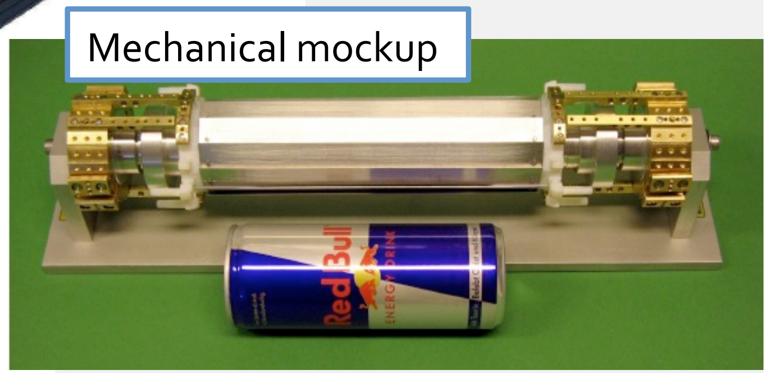
	radius	pixel	thickness
Layer 1	r = 14mm	50x50μm²	75μm(0.18%X0)
Layer 2	r = 22mm	50x75μm²	75μm



total of 8 Mpx

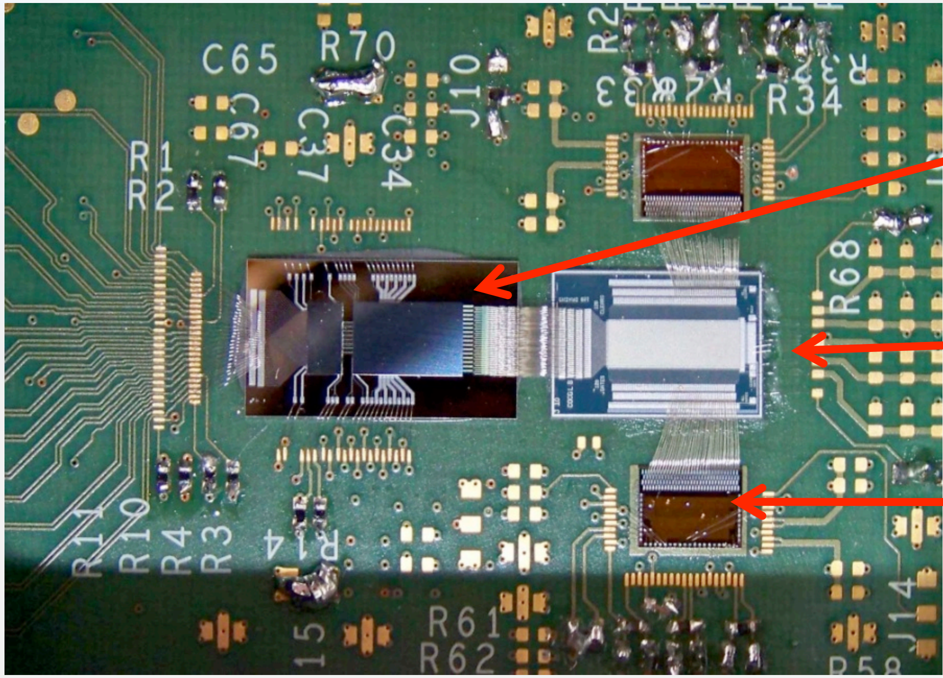






Power consumption in sensitive area: 0.1W/cm² => air-cooling sufficient

Test System



DCDB readout chip,
Bump bonded on interface board

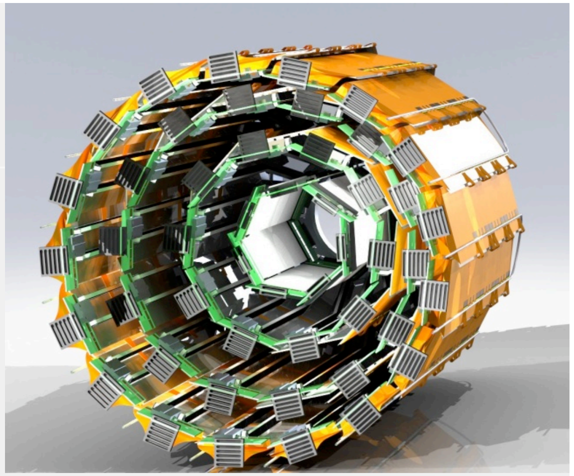
PXD5 DEPFET matrix

Switcher control chip

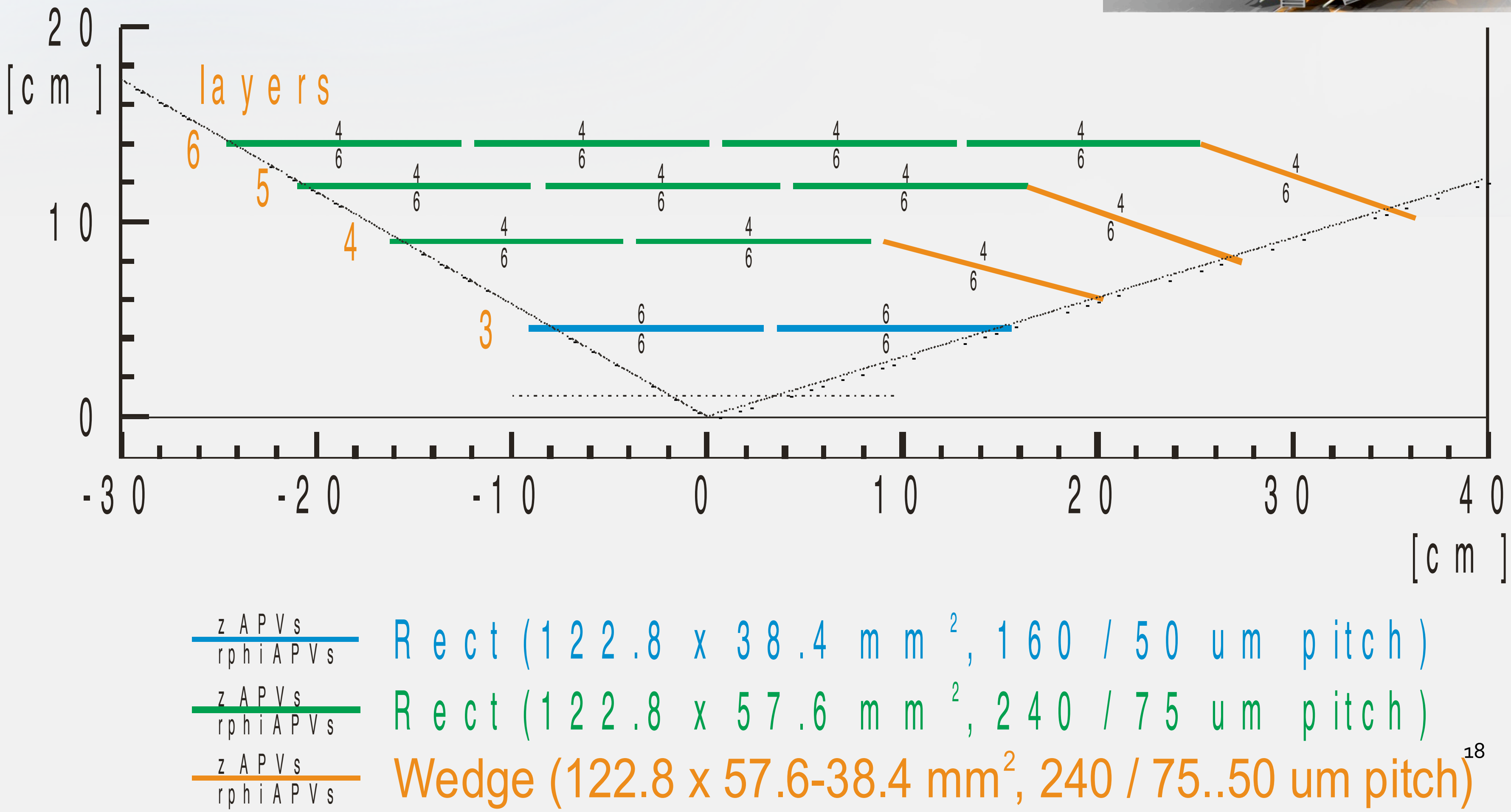
New switcher and DCD is tested with a DEPFET PXD5 matrix
So far the system reaches 120ns sampling time with 40nA (~ 100 electrons) noise
Some fine tuning needed to reach full speed (<100ns) (tests started 2 weeks ago)

Side remark: flipping and bump bonding of DCDB in adapter board worked without problems

SVD (DSSD)

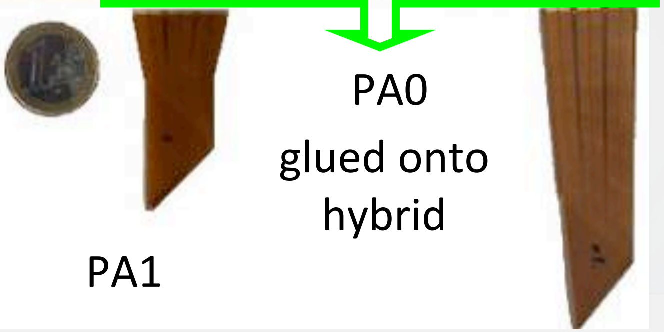


HPK resumed DSSD production with 6” wafers
Two types of rectangular sensors and
Trapezoidal sensors for slanted part (still under discussion)



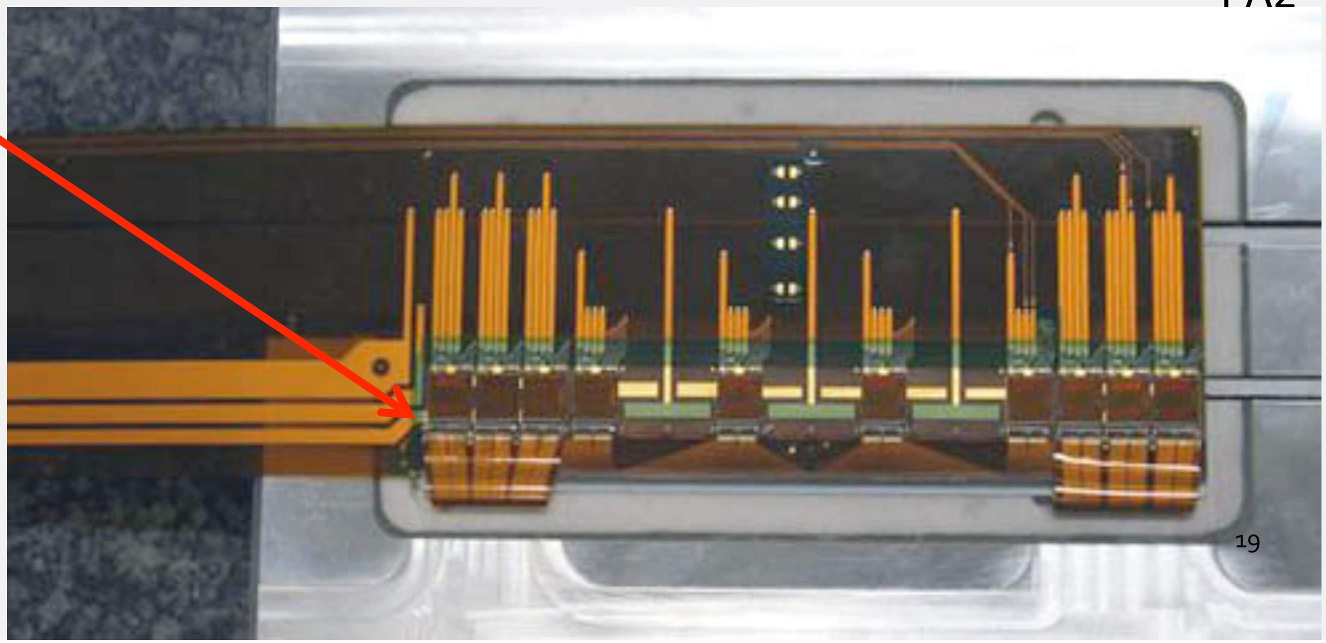
Flex PCBs and APV25

- Origami PCB
  - 3-layer design
  - 237μm thick (nominal)
- PA0, PA1 and PA2
  - 2-layer design
  - 145μm thick (nominal)

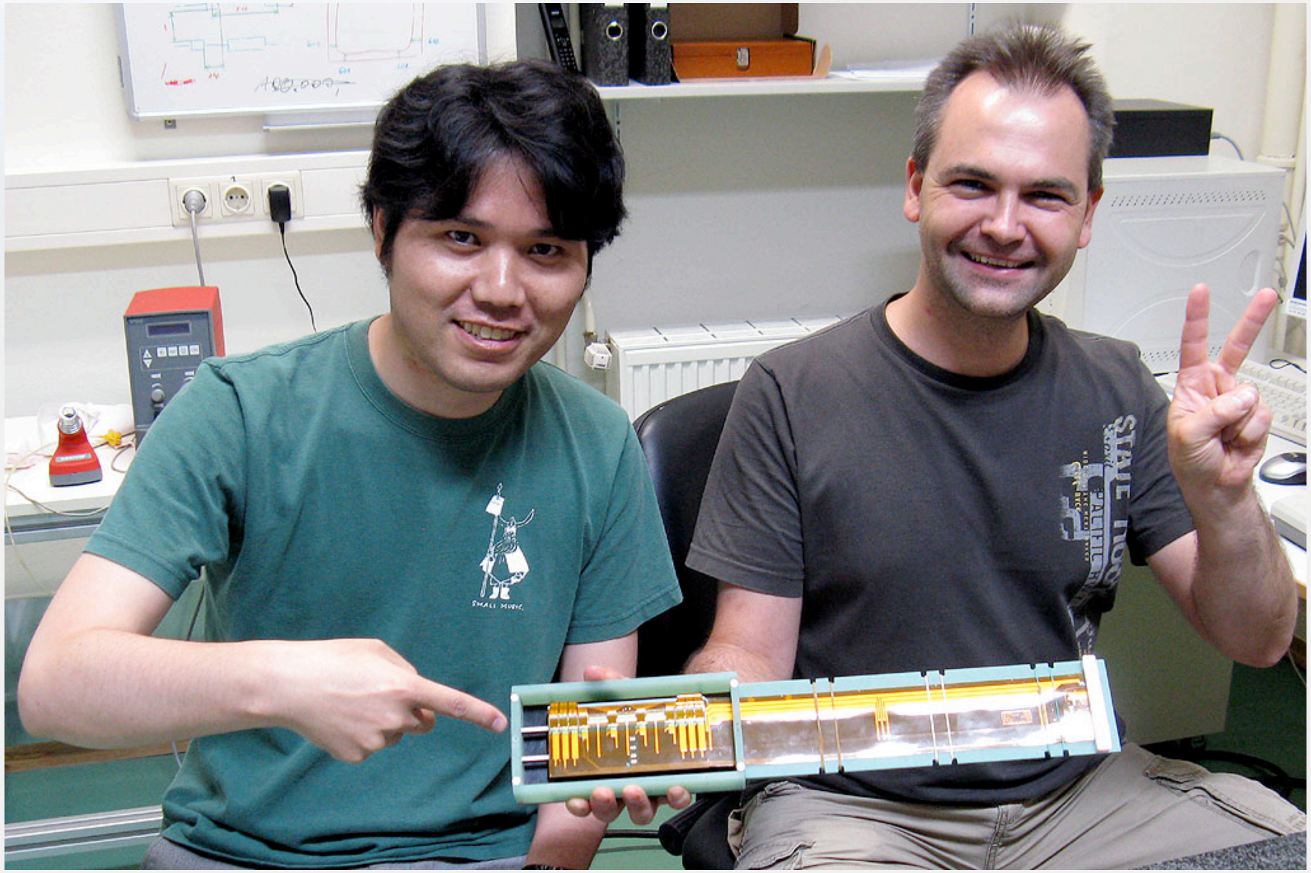


Thinned APV25
(300μm→~100μm)

~0.55%X_0/layer



First prototype ladder

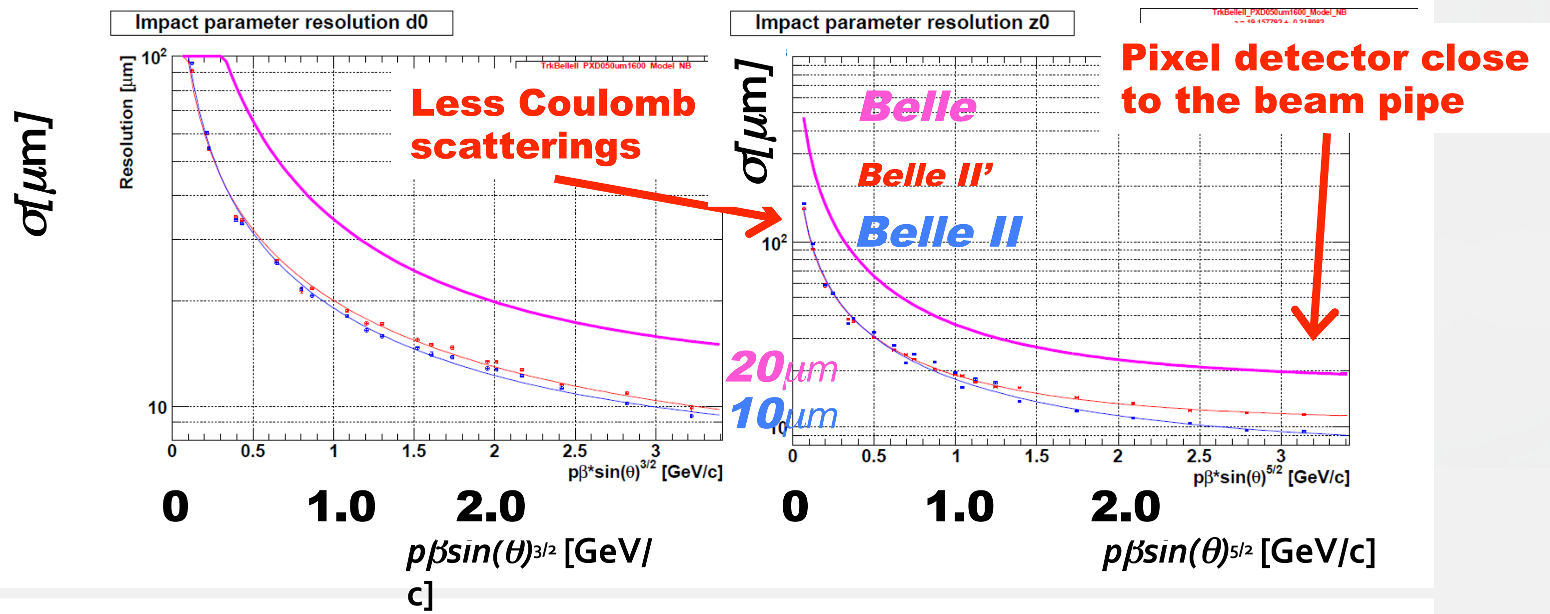


A prototype ladder using the first 6 inch DSSD from HPK has been assembled and tested.

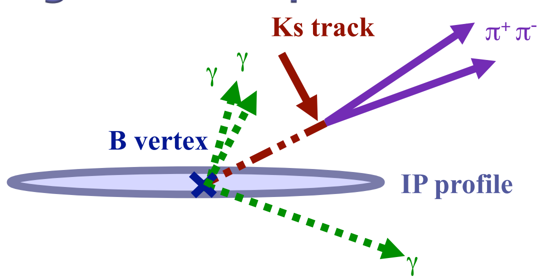
Expected performance

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

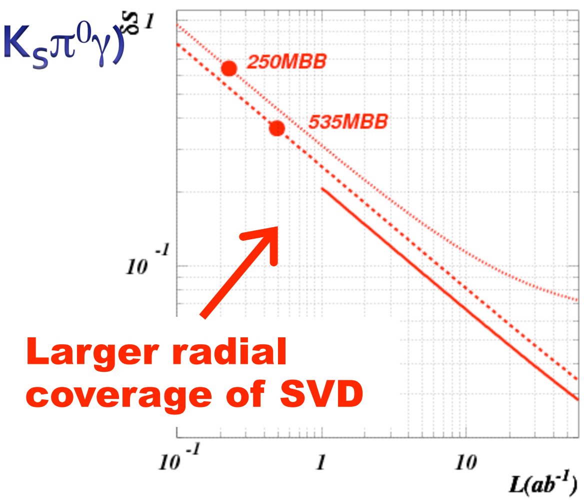
Significant improvement in IP resolution!



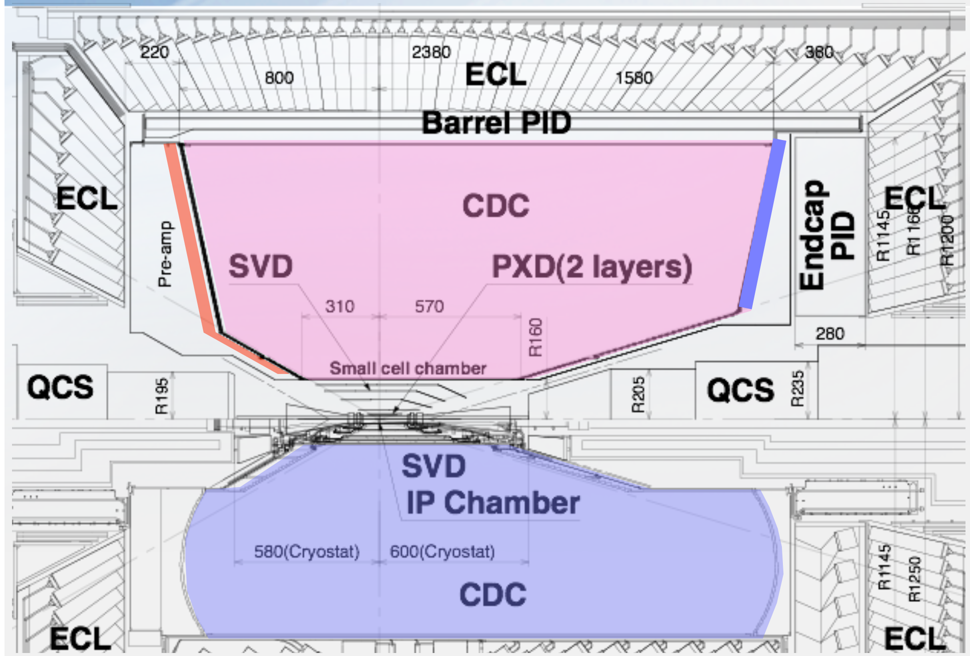
Significant improvement in $\delta S(K_S\pi^0\gamma)$



B decay point reconstruction with K_S trajectory



Central Drift Chamber



	Belle	Belle II
inner most sense wire	r=88mm	r=168mm
outer most sense wire	r=863mm	r=1111.4mm
Number of layers	50	56
Total sense wires	8400	14336
Gas	He:C_2H_6	He:C_2H_6
sense wire	W(Φ30μm)	W(Φ30μm)
field wire	Al(Φ120μm)	Al(Φ120μm)

longer lever arm

improve resolution of momentum and dE/dx

$$\sigma_{P_t}/P_t = 0.19 P_t \oplus 0.30/\beta$$

$$\sigma_{P_t}/P_t = 0.11 P_t \oplus 0.30/\beta$$

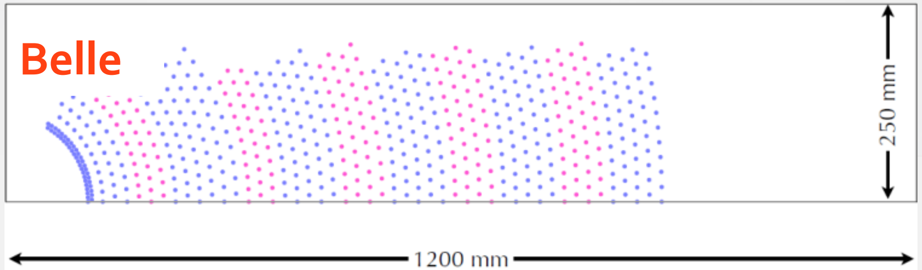
new readout system

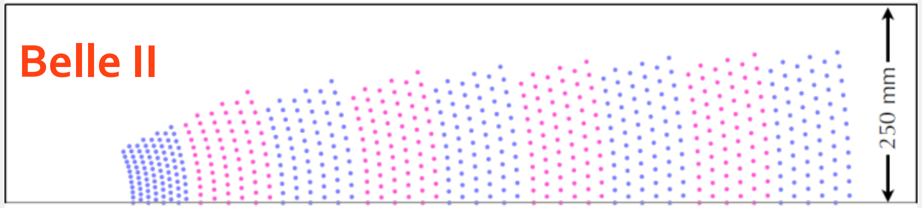
dead time 1-2μs → 200ns

small cell

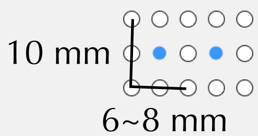
smaller hit rate for each wire

shorter maximum drift time

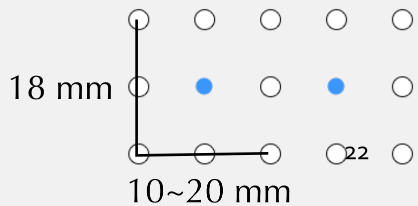




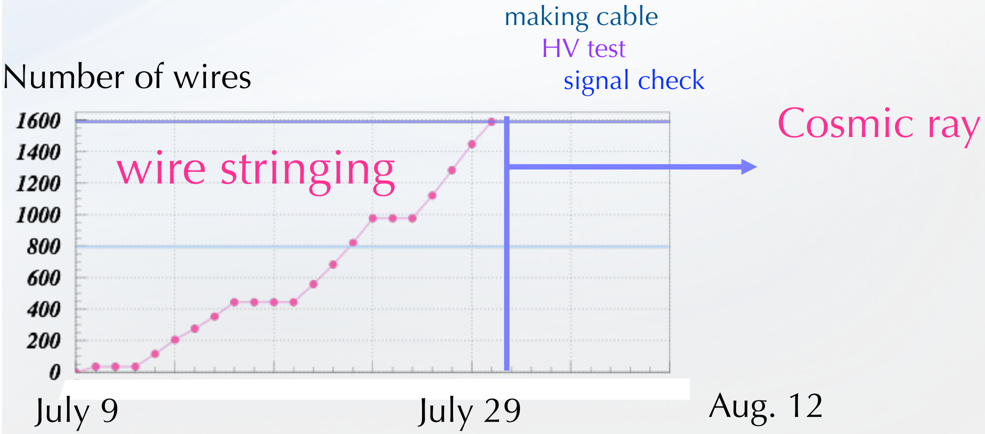
small cell



normal cell

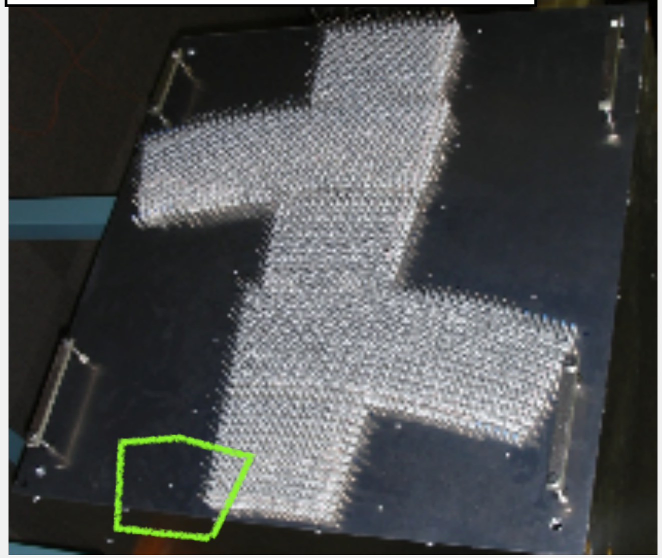


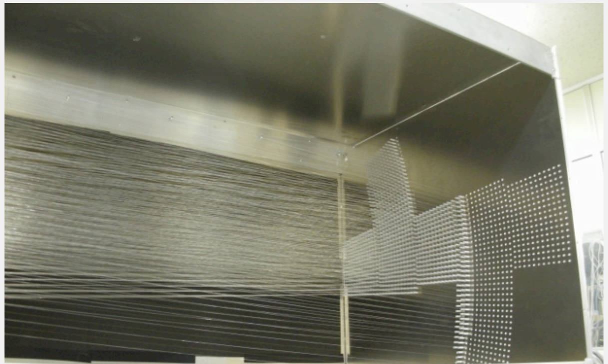
Test chamber fabrication for 3D TRG study



Analog signal of β-ray
with current Belle AMP

1205 field wires
384 sense wires

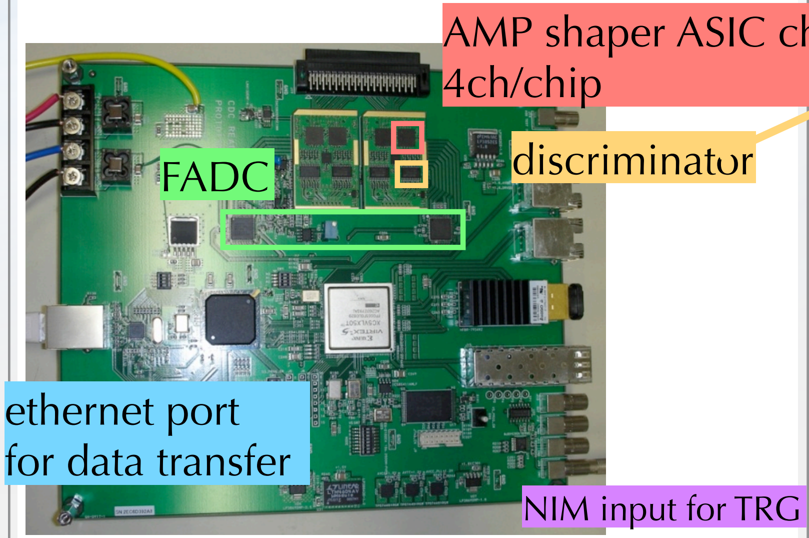




Full-length (540x570x2200) test chamber has also been made

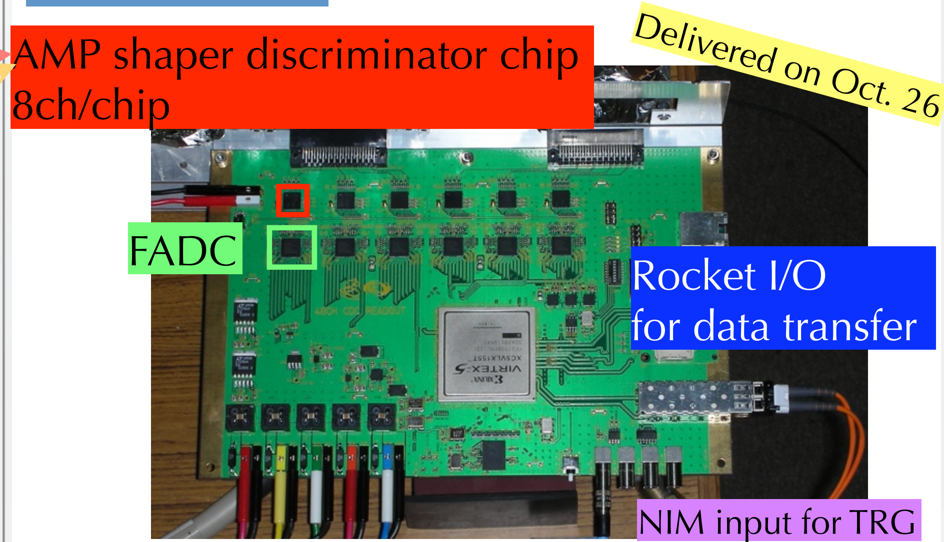
Status of new 48ch board for CDC

16ch board

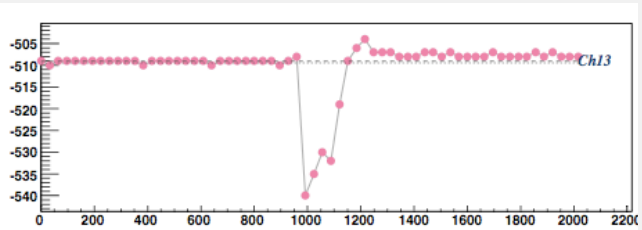


200mm x 175mm

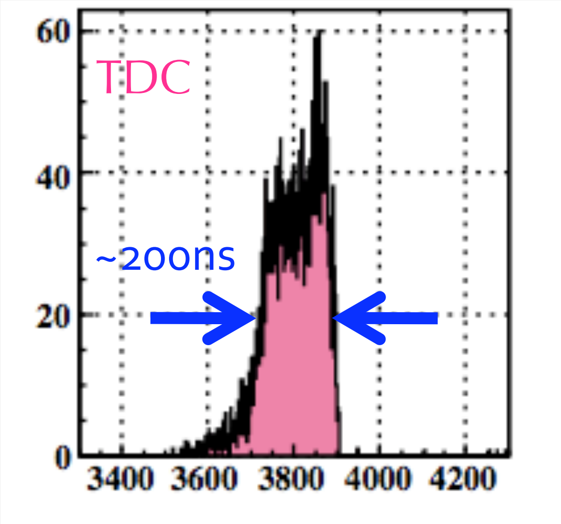
48ch board

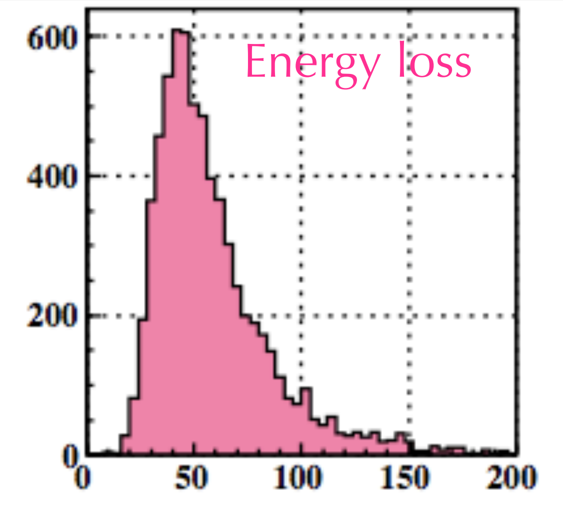


230mm x 150mm



waveform sampling with
32MHz FADC





Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)

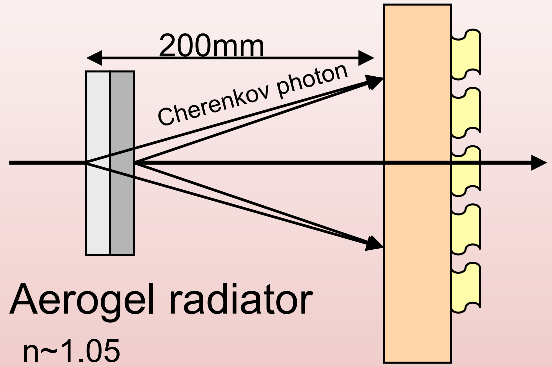
Quartz radiator

Focusing mirror

Small expansion block

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

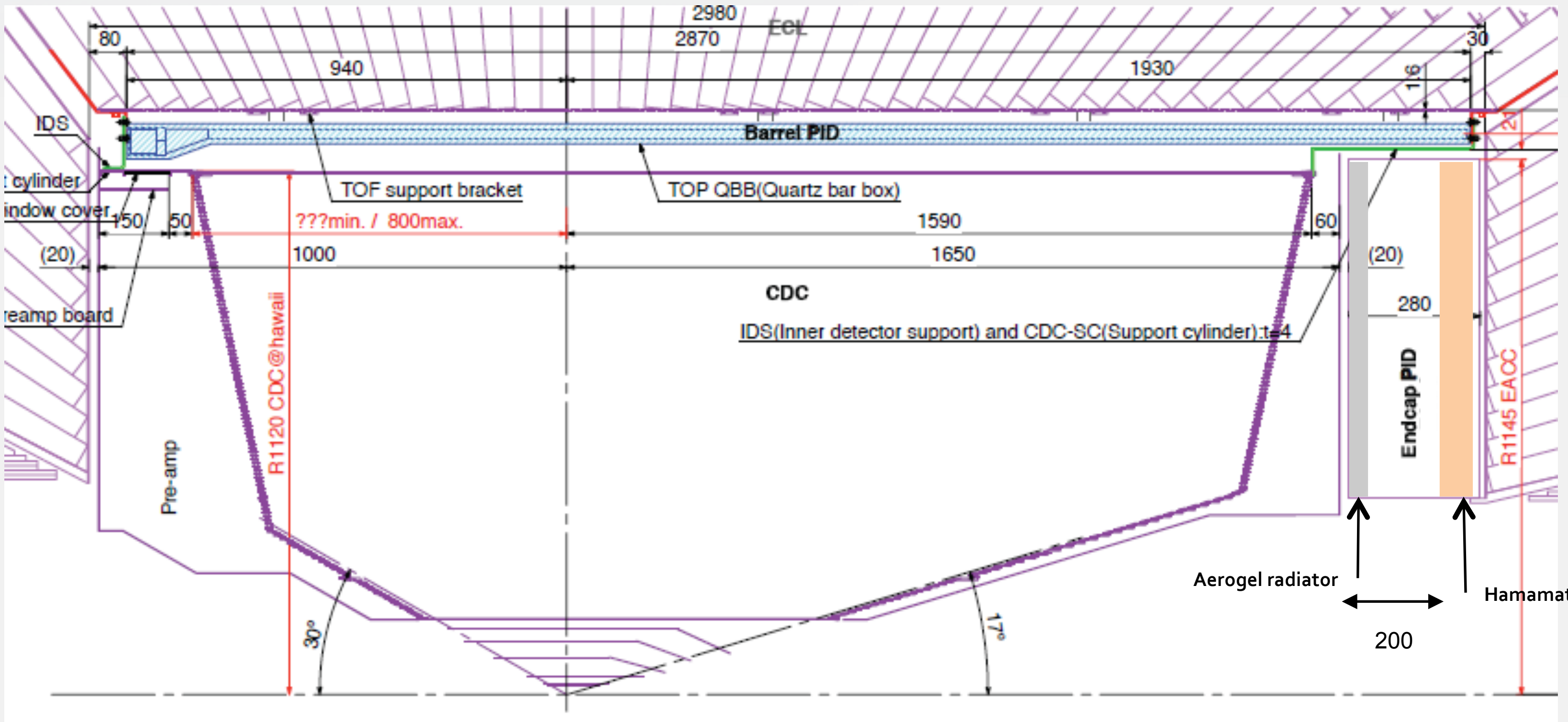
Endcap PID: Aerogel RICH (ARICH)



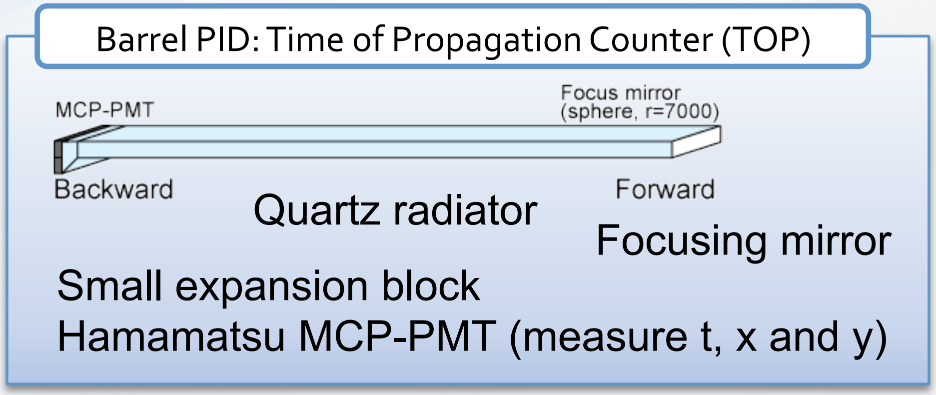
Aerogel radiator

n~1.05

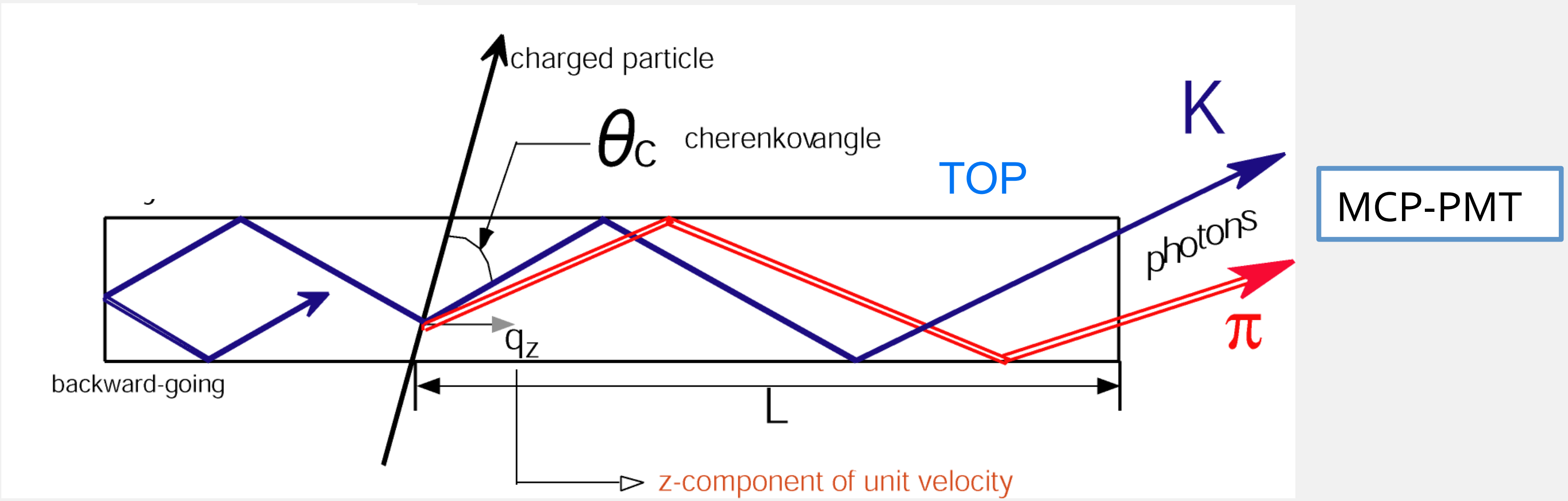
Hamamatsu HAPD
+ new ASIC



Time of Propagation Counter (TOP)



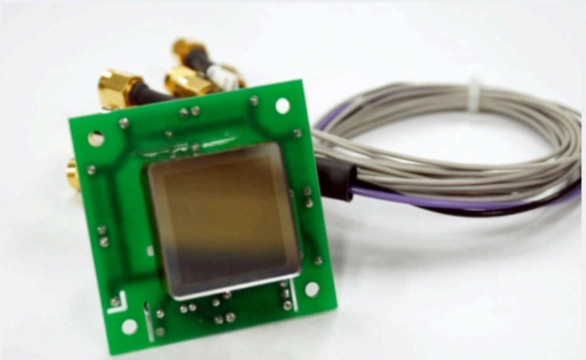
- Quartz radiator
  - 2.6m^{L} x 45cm^{W} x 2cm^{T}
  - Excellent surface accuracy
- MCP-PMT
  - Hamamatsu 16ch MCP-PMT
    - Good TTS (<35ps) & enough lifetime
    - Multialkali photo-cathode → SBA



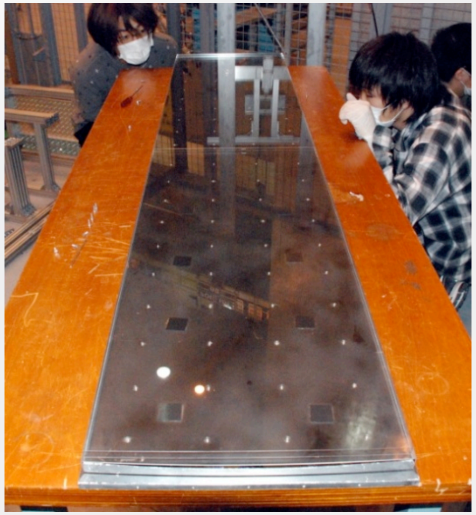
～1.2m
TOF

TOP (Barrel PID)

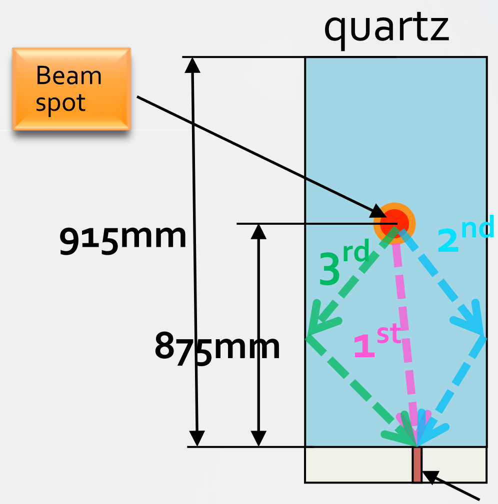
- Beam test done in 2009
  - # of photons consistent
  - Time resolution OK

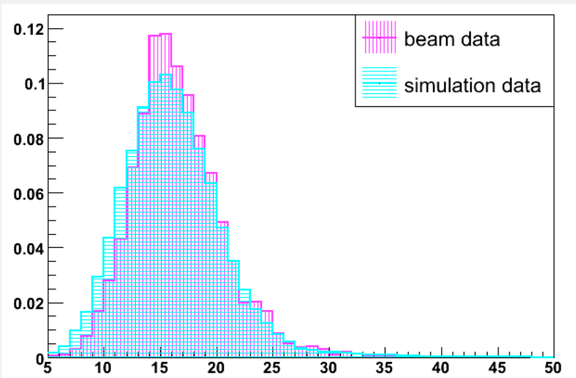


Hamamatsu MCP-PMT

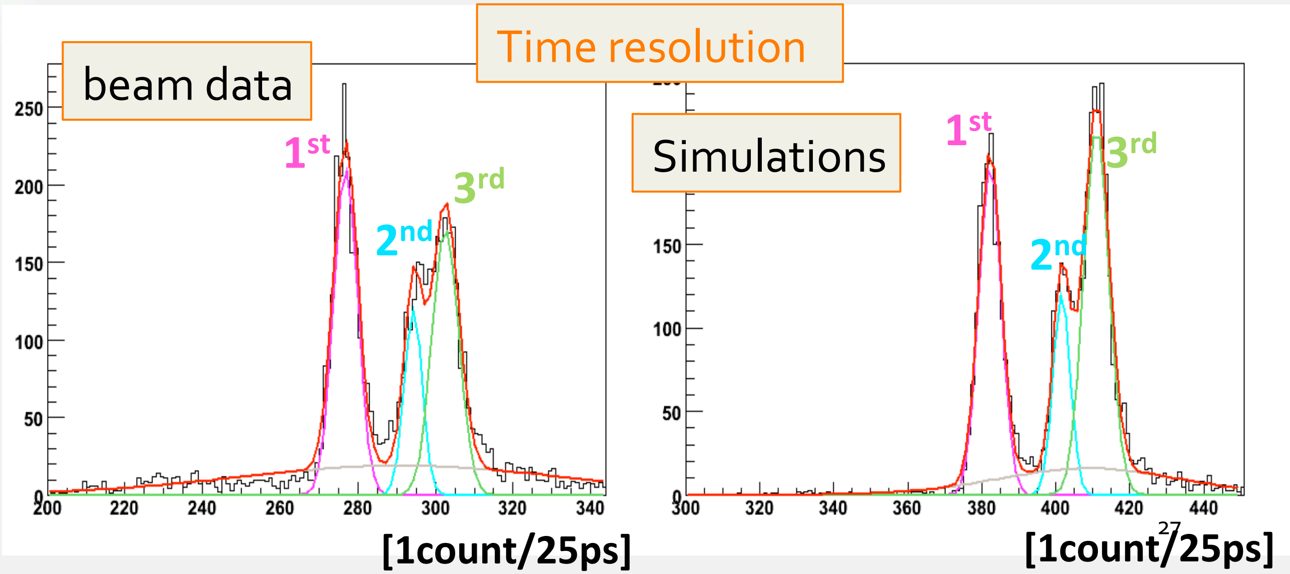


Quartz Radiator

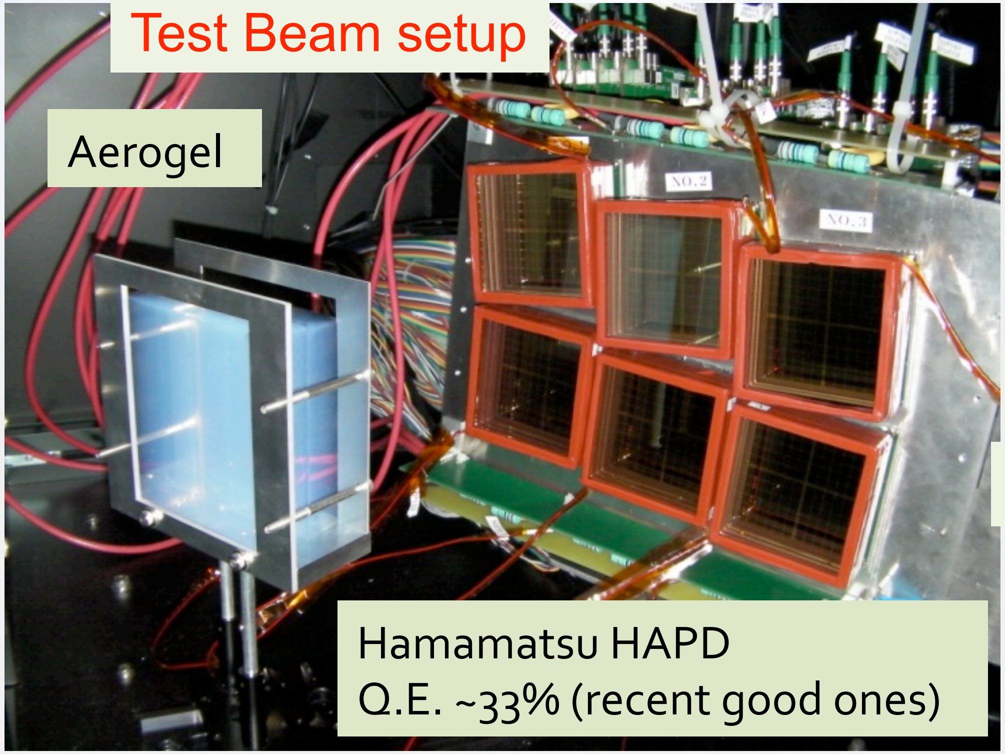


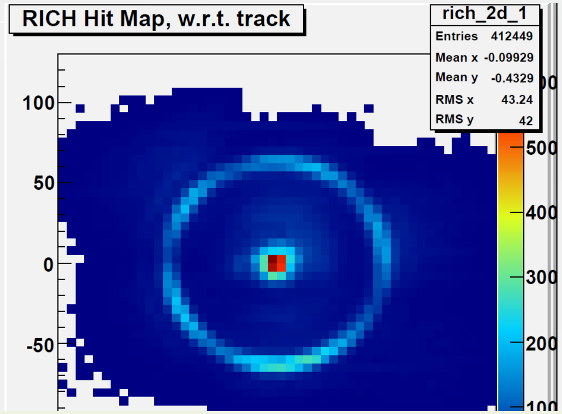


# of photons



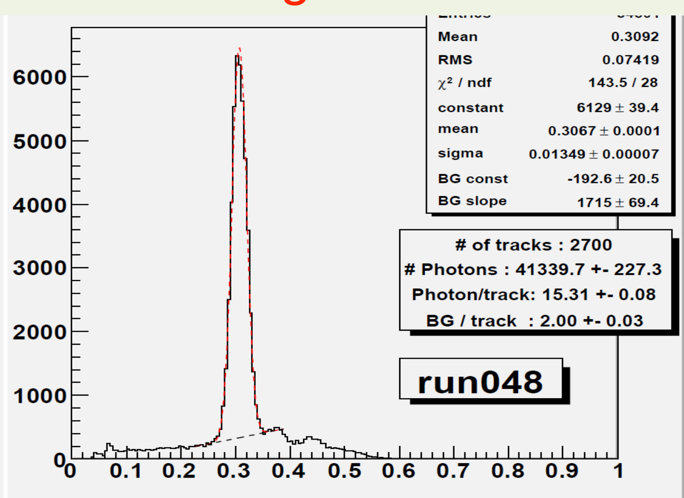
Test beam result





Clear Cherenkov image observed

Cherenkov angle distribution



Single photon angle resolution σ_0 = 13.5mrad
# of photoelectrons Npe = 15.3

6.6 σ π/K at 4GeV/c !

Expected Performance (Luminosity gain)

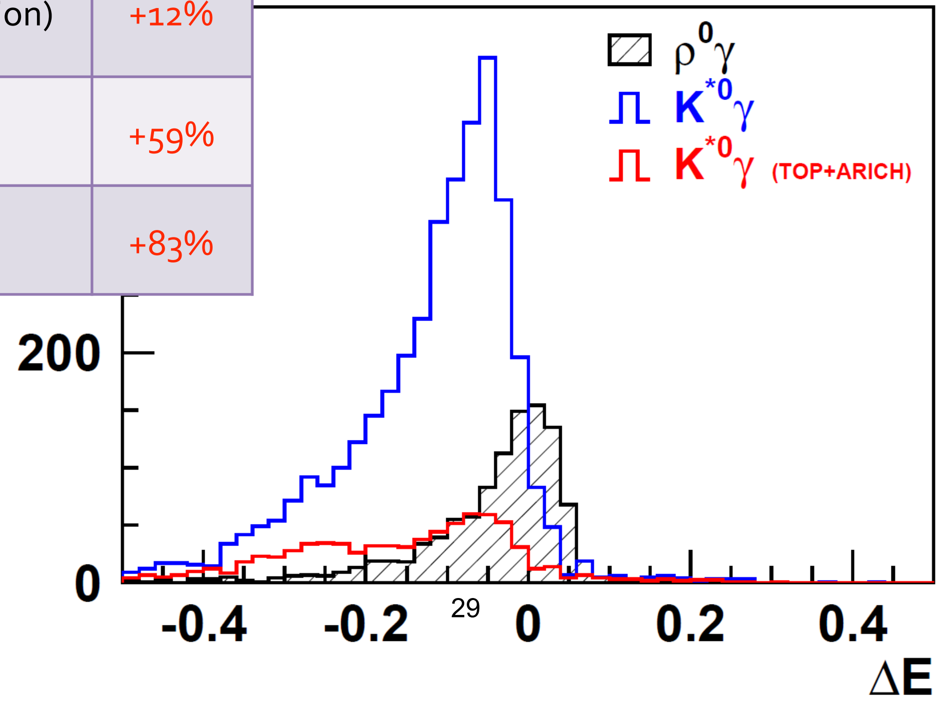
No upgrade BAD ← → Upgrade GOOD

$B^0 \to \rho^0 \gamma$

FWD / BRL	ACC only	dE/dx only	As good as Belle	A-RICH
TOF, dE/dx NA	−74%	−69%	−68%	−62%
TOF NA	−41%	−35%	−32%	−22%
As good as Belle	−10%	−4%	0% (definition)	+12%
TOP opt.0	+27%	+33%	+40%	+59%
TOP opt.2	+45%	+51%	+60%	+83%

(Rows: No upgrade BAD ↑ / ↓ Upgrade GOOD)

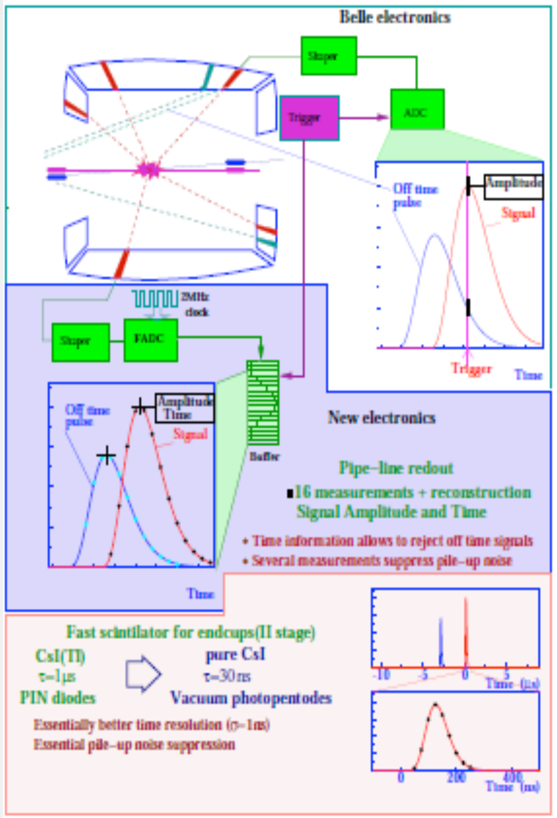
Completely different world with excellent PID detectors!



Upgrade of ECL

For Day 1

1. Upgrade electronics to do waveform sampling & fitting
2. Upgrade crystals for end caps (pure CsI + photomultiplier as the baseline)



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

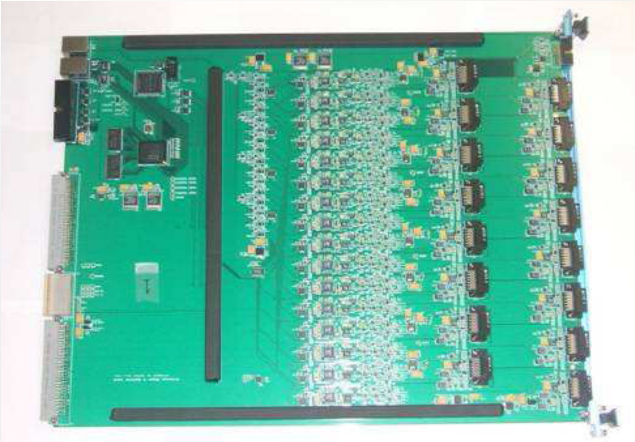
$$F(t) = A\ f(t - t_0)$$

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

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

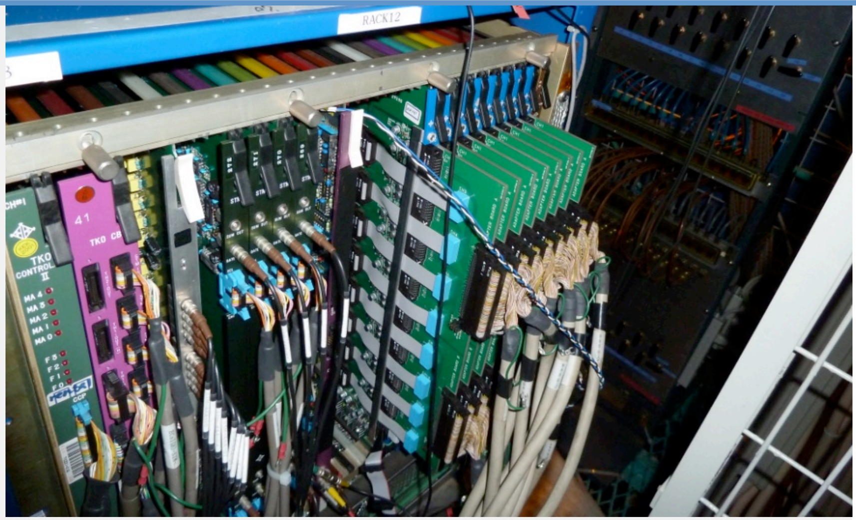
- Both amplitude and time information are reconstructed:
- Next stage: Replace the CsI(Tl) by the pure CsI crystals in endcaps.

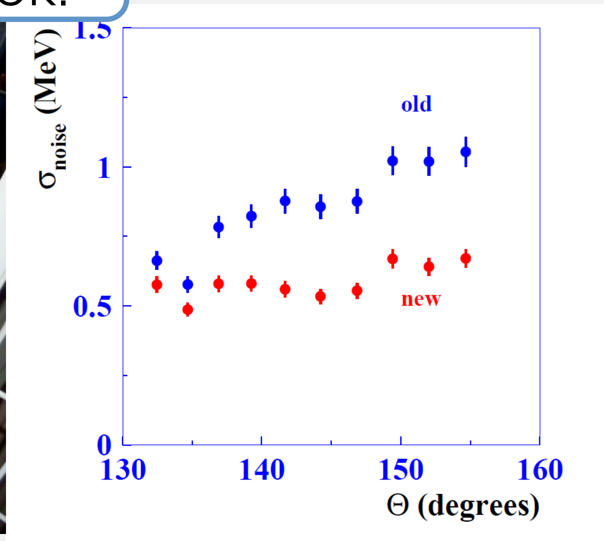
New shaper/readout boards



Basically ready for mass production
(minor revisions because we still have time.)

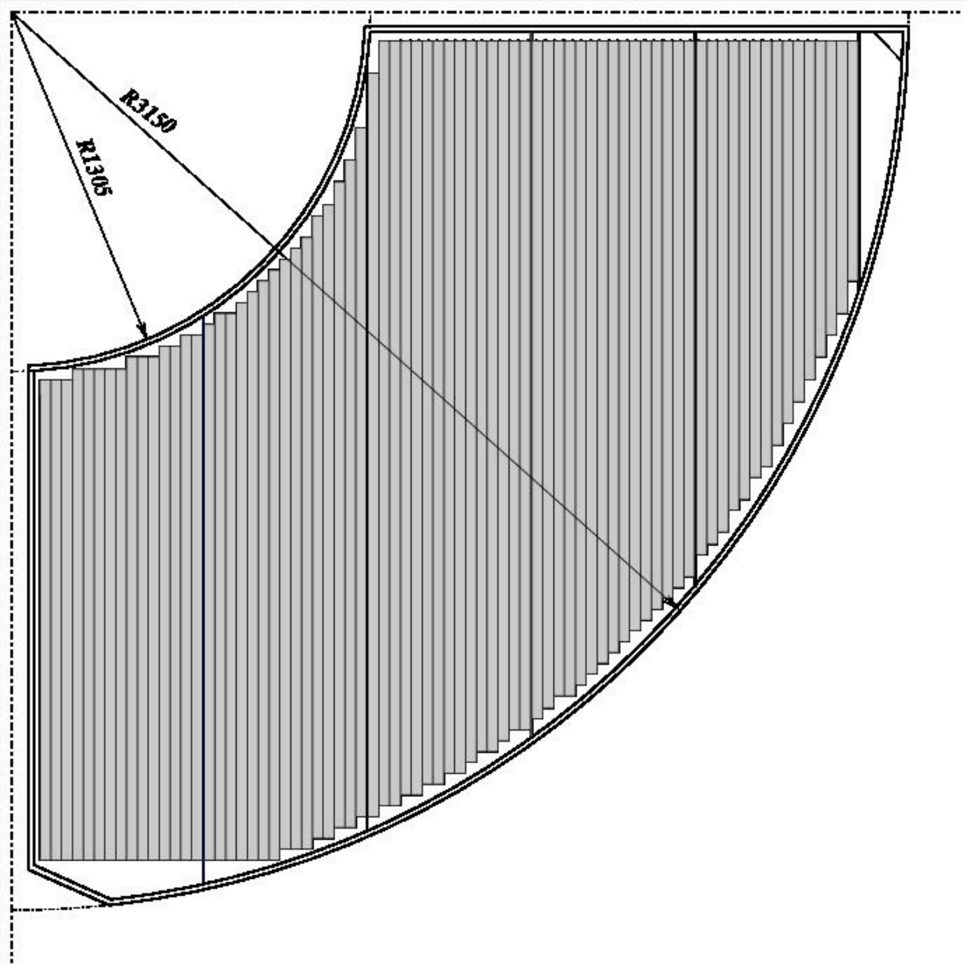
One of older versions has been installed in Belle to readout part of the end cap in 2008. Tested OK.





KLM: K_L&Muon detector

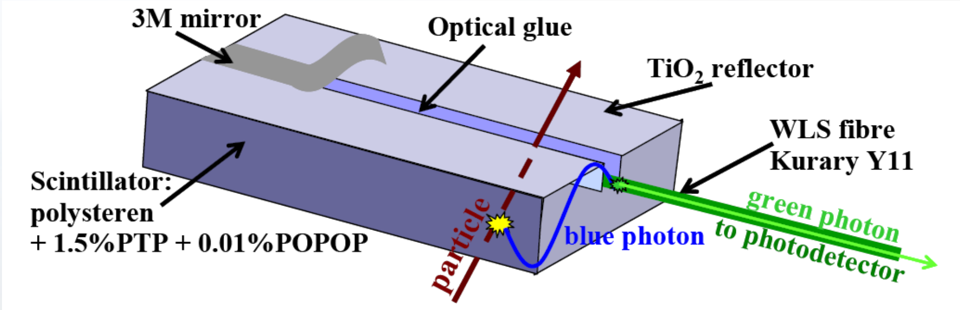
RPC → Scintillator (End cap)
also inner 1,2, or 3 layers of Barrel(?)

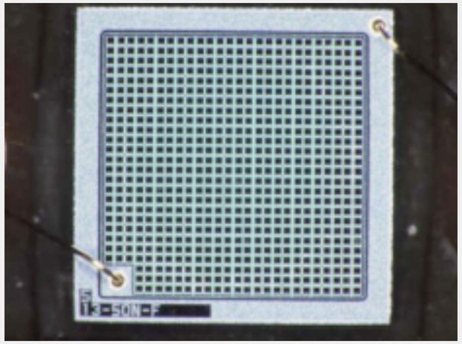


GENERAL LAYOUT

- One layer: 75 strips (4 cm width)/sector
- 5 segments
  1 segment = 15strips
- Two orthogonal layer = superlayer
- F&B endcap KLM:
  - Total area ~1400 m^2
  - 16800 strips
  - the longest strip 2.8 m; the shortest 0.6 m
- WLS fiber in each strip
- Hamamatsu MPPC at one fiber end
- mirrored far fiber end

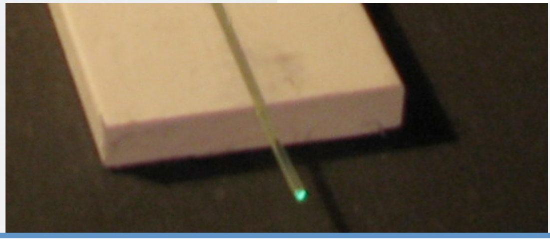
One strip



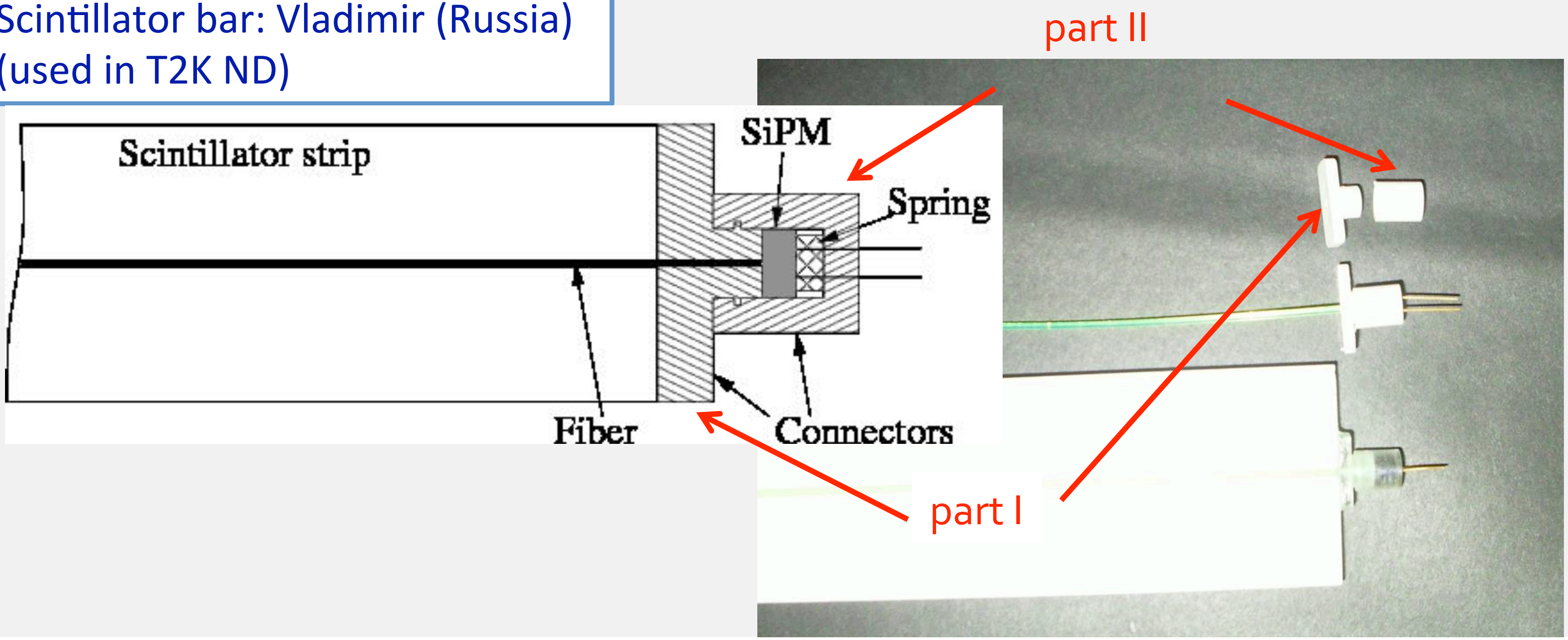


MPPC: Hamamatsu
1.3×1.3 mm 667 pixels
(used in T2K ND)

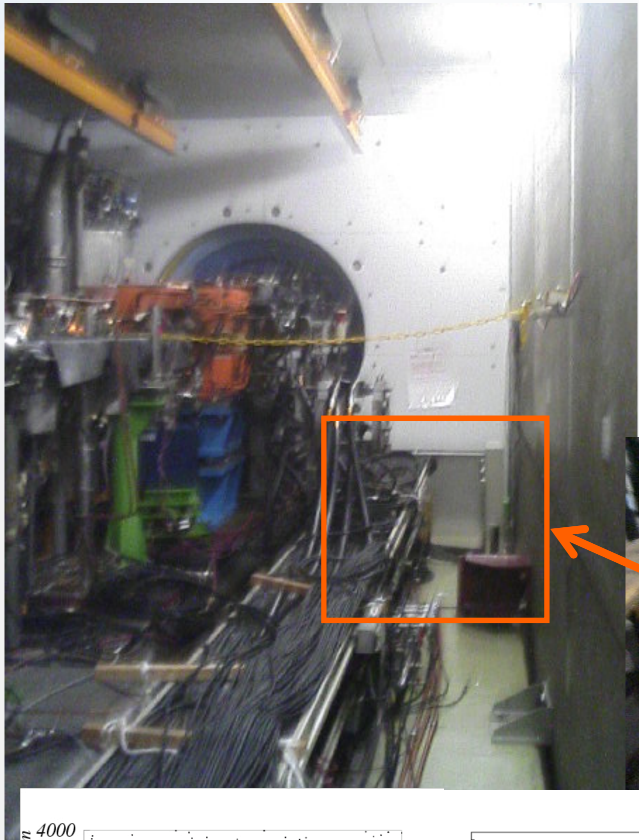
fiber: Kuraray Y11 MC

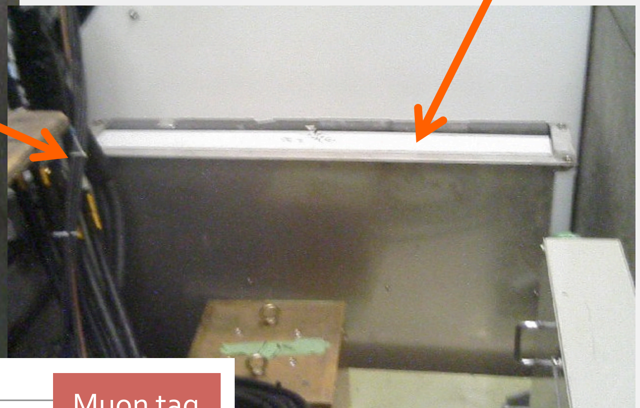


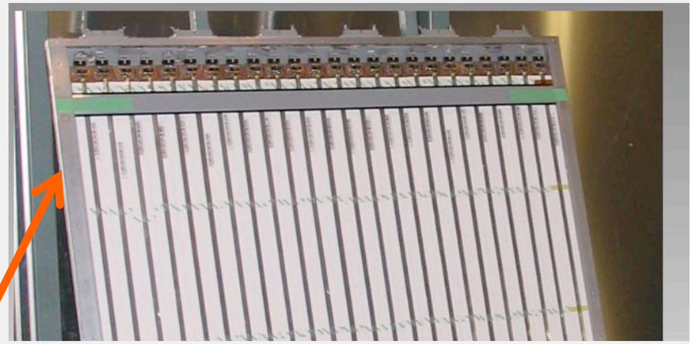
Scintillator bar: Vladimir (Russia)
(used in T2K ND)

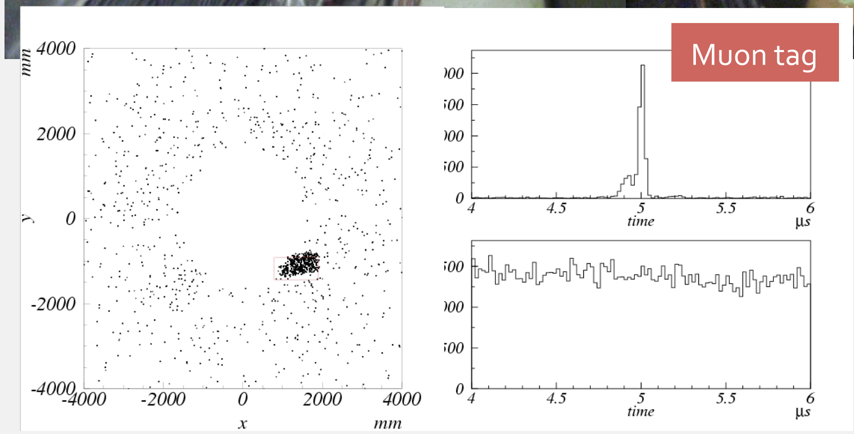


Test modules adjacent to Belle KLM (2008)



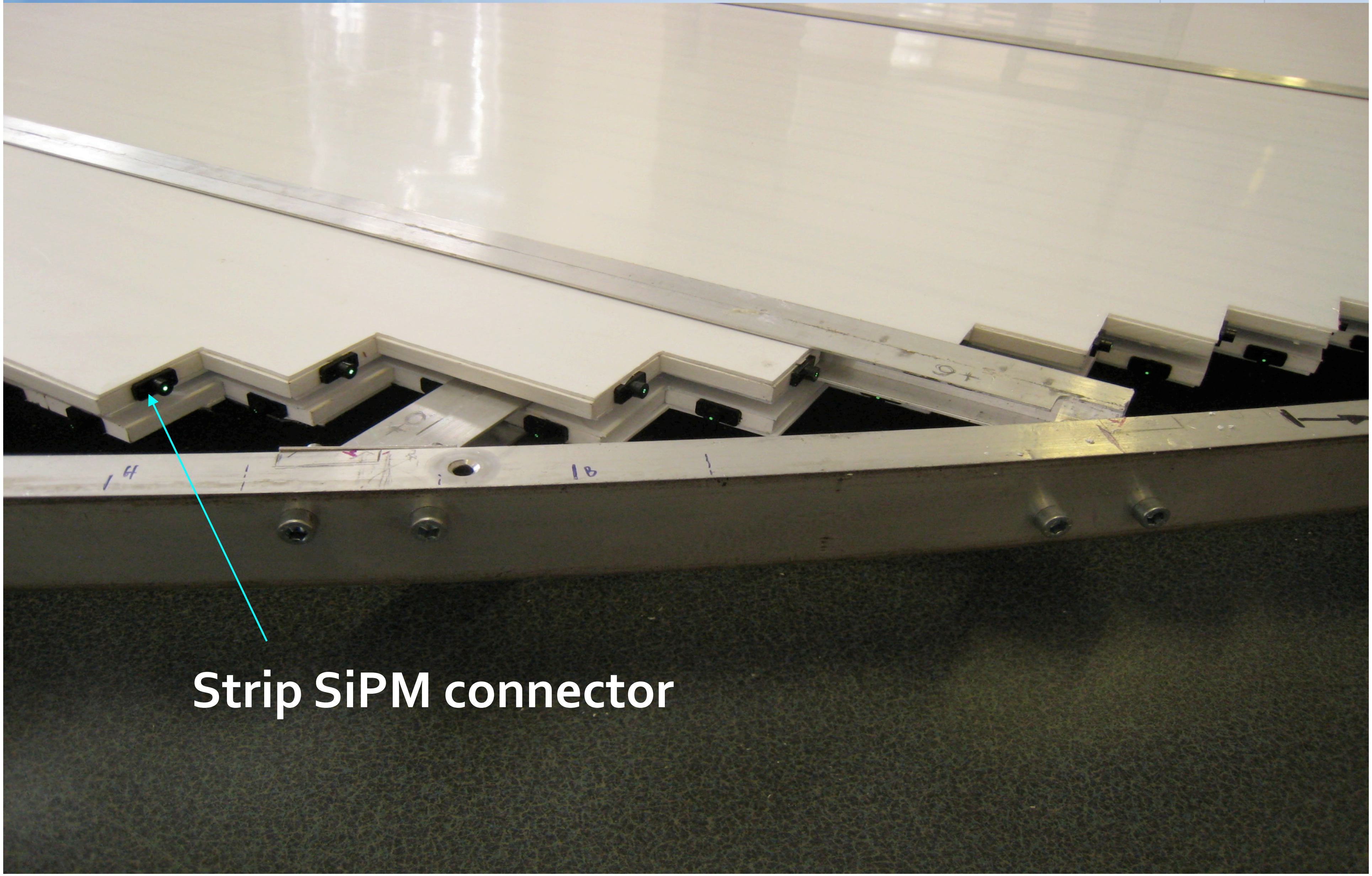




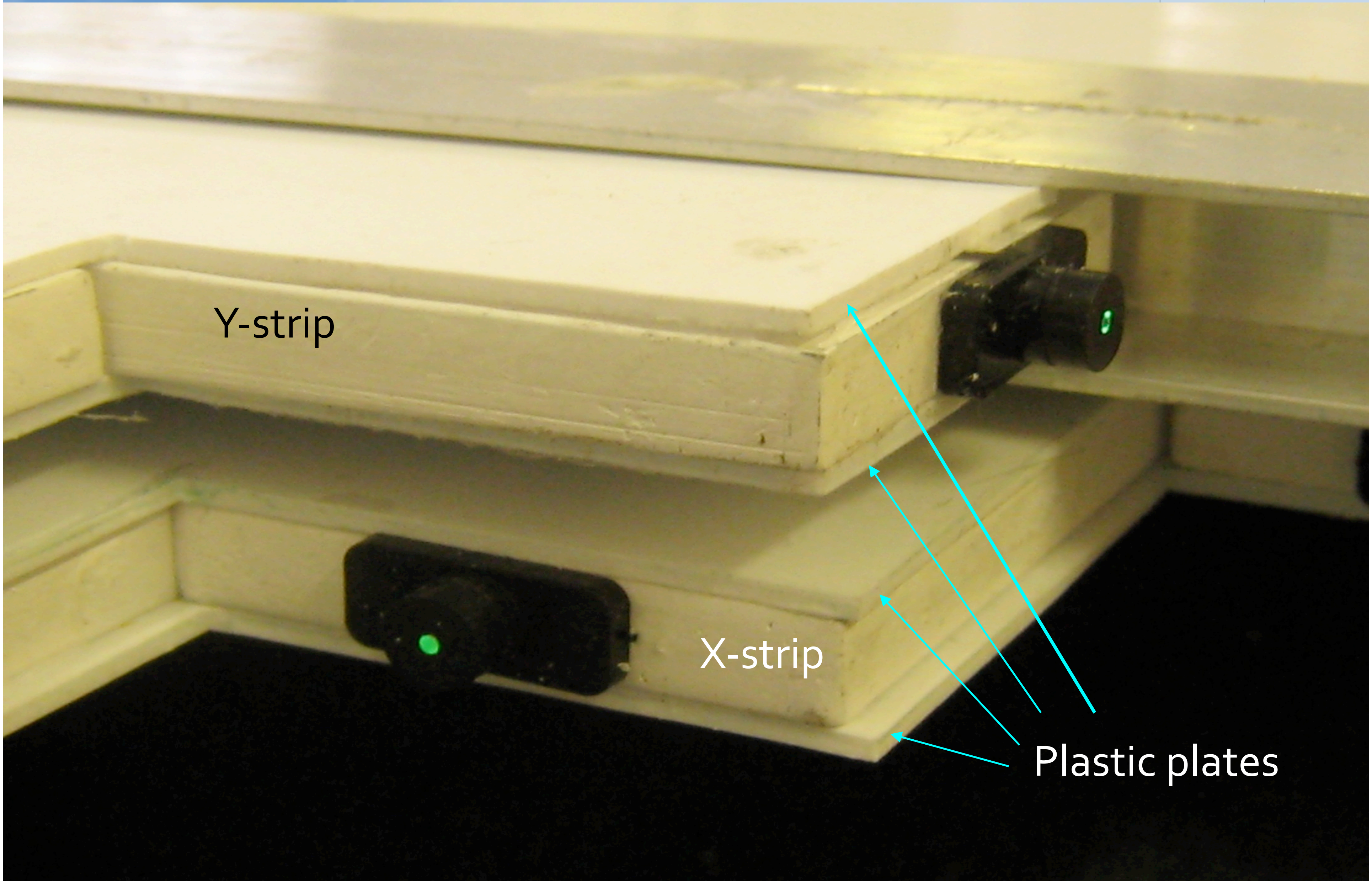


EKLM Module-0 assembled in ITEP into the frame mock-up

Close view of frame support structure and strips with SiPM connectors



Close view of strips.
Segment's plastic plates are easily seen



Machine-Detector issues

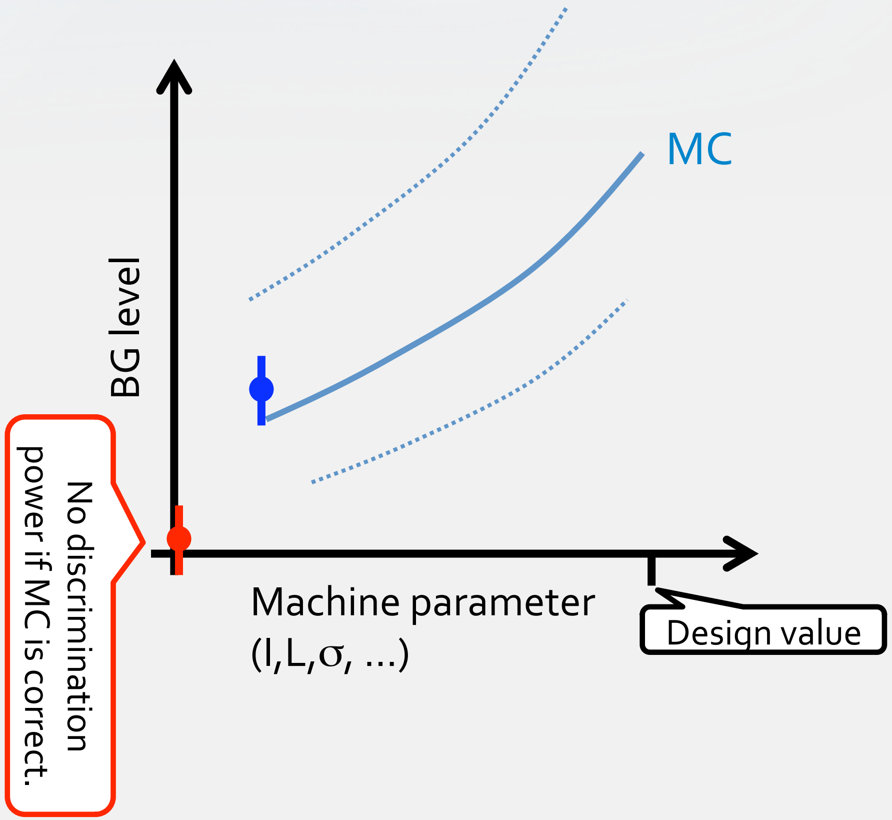
- ✓ IR design → Tuesday morning
- ✓ Beam Background → Tuesday morning

- ✓ Machine commissioning strategy
- ✓ Injection veto and PXD
- ✓ Beam energy asymmetry (settled)
- ✓ Detector rotation

Machine commissioning strategy

1. Our BG estimation (MC/extrapolation) has large uncertainty.
2. We don't like to burn our precious detectors before taking data.
3. We won't roll-in Belle II until we are confident about the BG level.

We will prepare dedicated detector (BEAST II) for machine commissioning to monitor the BG level and compare with our estimation.

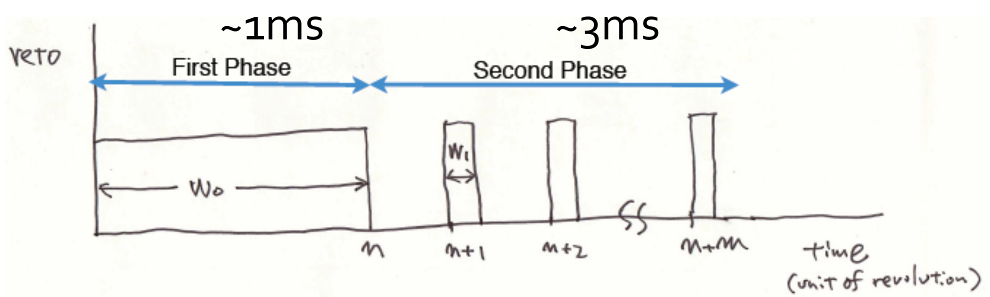


Machine parameters for BEAST II must be *close* enough to the design values so that natural extrapolation would work. Unpredictable jump should be avoided. (somewhat small beam size, some beam current and some luminosity needed)

BEAST II with Solenoid magnet (?)

Discussion started

Injection veto



- **Two phases**
  - **First phase : veto n turns completely**
    W0 = n * 10 usec
    n = 10～100
  - **Second phase : veto periodically**
    W1 = ～1 usec
    m ～ 300
  - **Three parameters (n, m, W1) : SKEKB depen**

Level 1 trigger is blocked after injection because BG is too high.
→ dead-time
Suppose n = 100, W1=1μs and m=300,
6.5% dead-time @ 50Hz injection.

DEPFET pixel detector integrates data for 20μs.
= 2 revolutions of noisy bunches.
Pixels are all exposed till the end of 2nd phase (4ms)
20% dead-time @ 50Hz injection.

Trying to increase the frame rate (20μs → 5μs), but still 10% dead-time @ 50Hz injection.

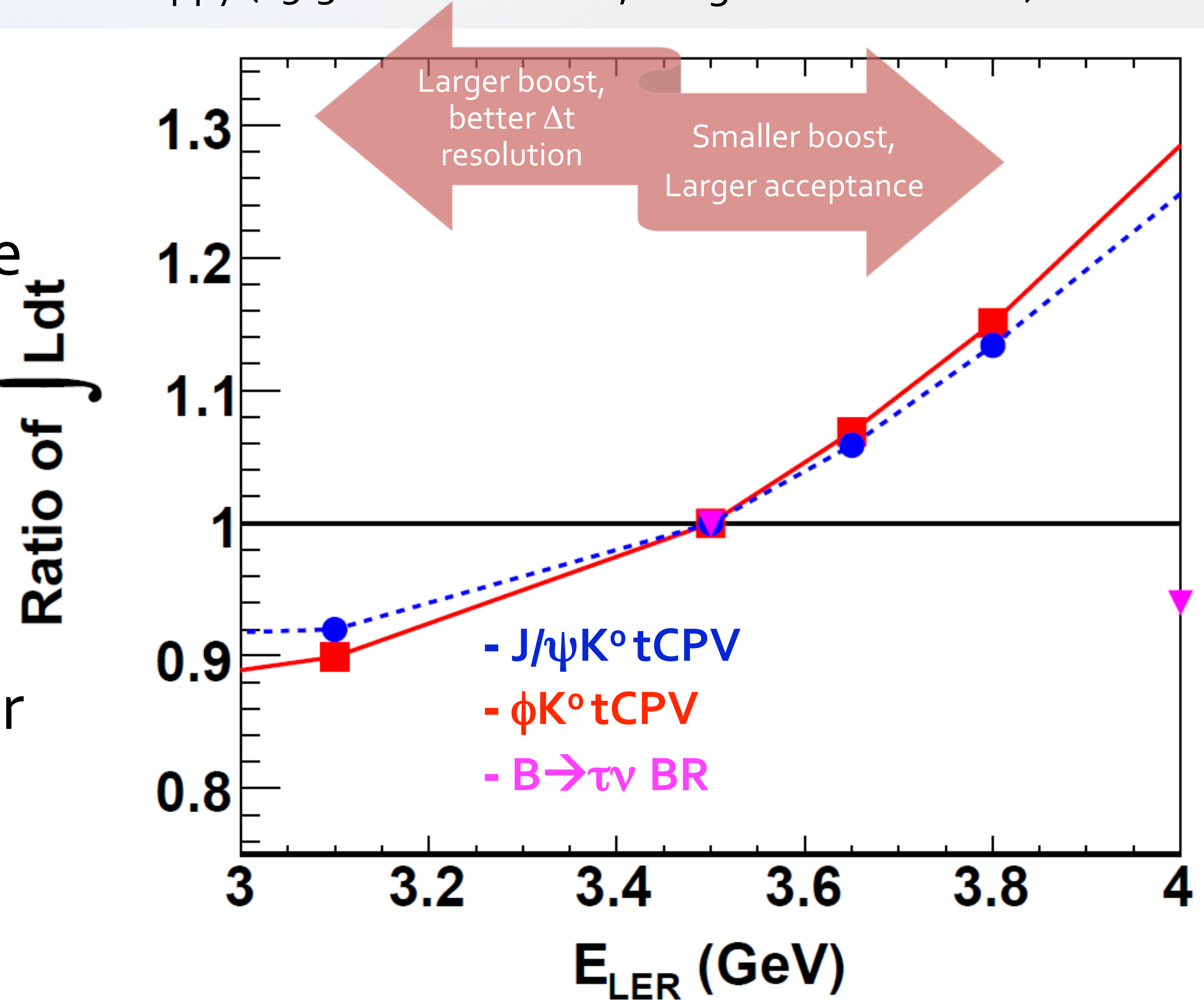
Any ideas
to reduce injection repetition rate (by reinforcing injectors?)
to achieve quiet injection, fast background dumping
are welcome.

LER Beam Energy (settled)

3.5GeV → 4GeV to mitigate Touschek lifetime.
We are not so happy (25-30% loss in TCPV, 6% gain in full-recon.).

worse

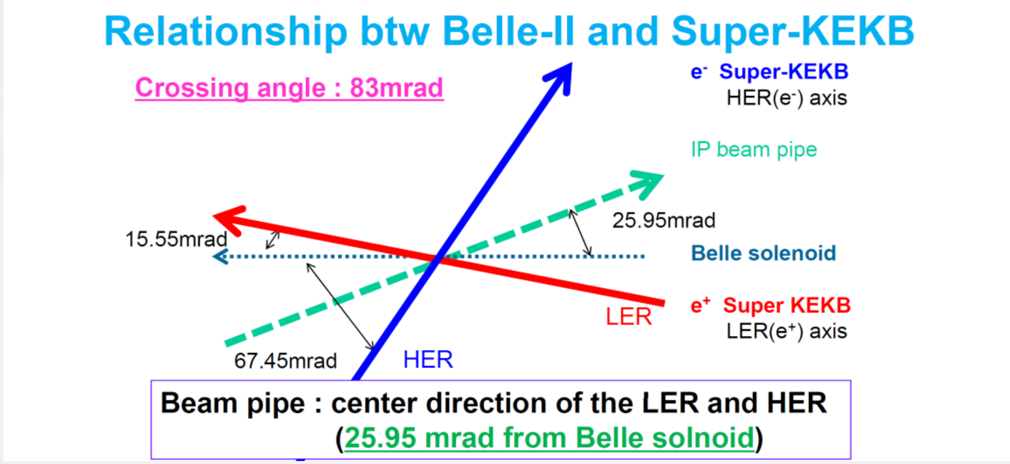
better



Detector Rotation

Two beams have finite crossing angle (83mrad).
Belle solenoid axis must be bisector of the angle, but now it is not.
Either Belle or two rings must be rotated.

Parameters are OLD

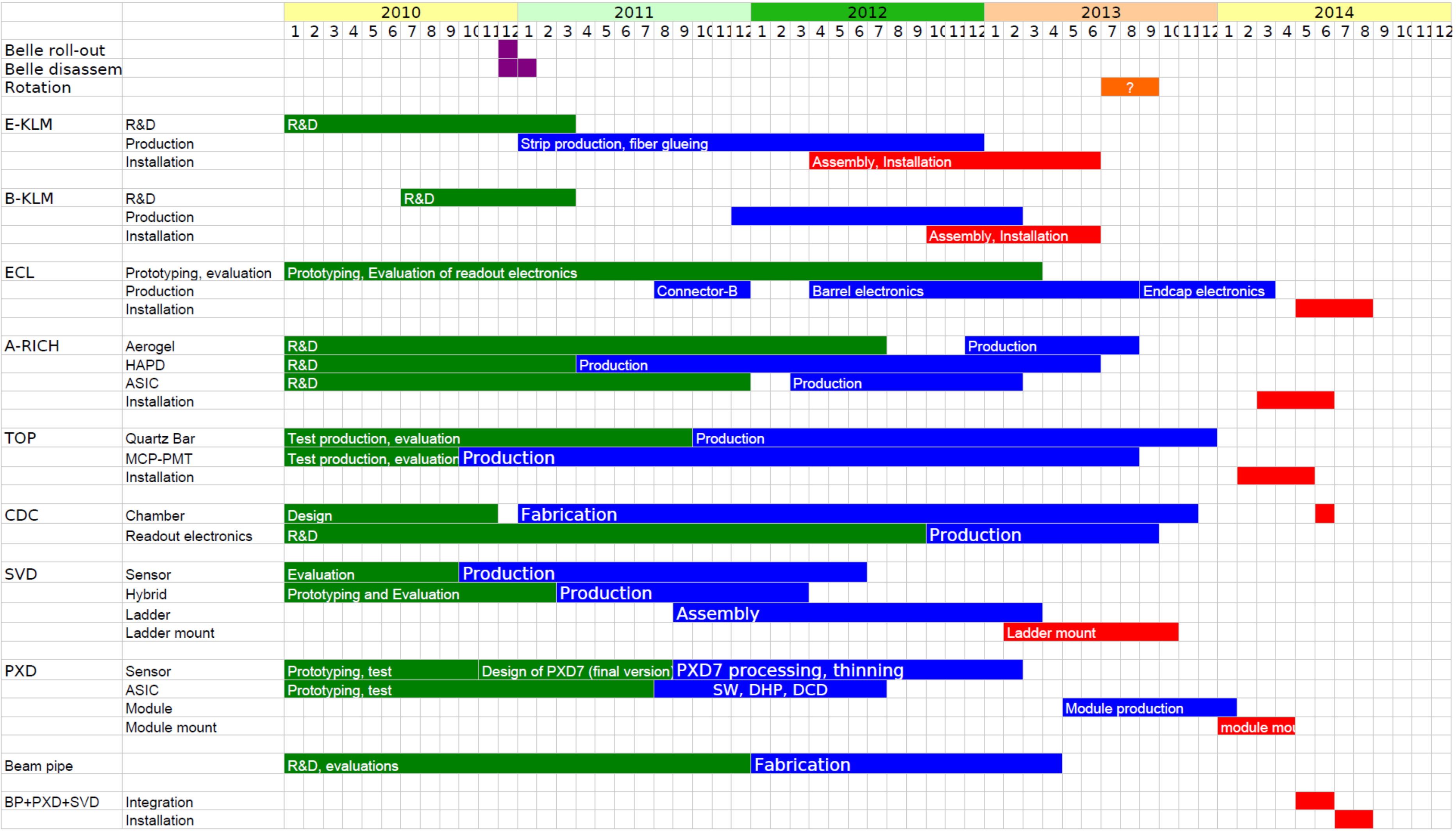


Rotation is technically possible.
Additional cost (very preliminary estimate: 3 oku yen)
Possible damage in detectors (?)

Concern from bad experience of buckled CsI container when constructing Belle.

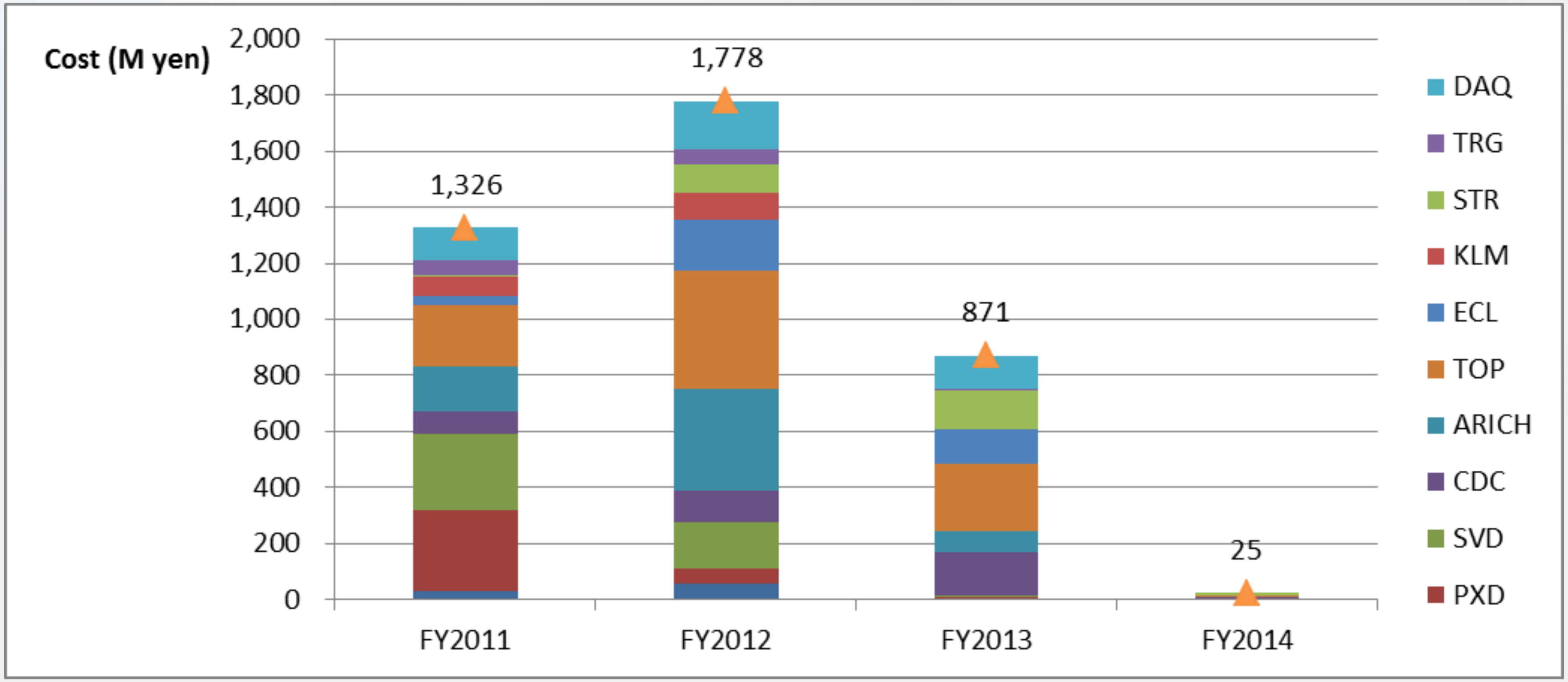
We will rotate Belle IF two rings cannot be rotated after all.
Cost to be covered by machine group.

Belle II Construction Schedule



Construction Cost

Cost profile in FY2011-2014



~40 Oku yen in three-four years (w/o comp.)

½ covered by KEK, ½ by collaborating institutes

Summary

- SuperKEKB/Belle II with $L=8\times10^{35}\ cm^{-2}s^{-1}$ is can explore many fruitful flavor physics in coming 10-15 years.
- Belle detector disassembly by end of Jan. as scheduled.
- Detector R&D, part of construction going on. On schedule so far.
- Several machine-detector issues to be cleared. Close cooperation of two groups is necessary.

Backup

Super B Factories

- Although there exist interesting possible hints for the NP at the present B factories, all the results are consistent with the SM.
- NP should exist at the higher energy scale, possibly in TeV region considering the hierarchy problem → LHC will discover it.
- Super B factories can help the identification of the NP, i.e. whether it is SUSY or others, or how SUSY breaking occurs.

SUSY scenario →

Observables @ Super B factories or other experiments ↓

	mSUGRA	MSSM+ν_R		SU(5)+ν_R		U(2) FS
		degenerate	non-degenerate	degenerate	non-degenerate	
$A_{CP}(s\gamma)$						✓
$S(K^*\gamma)$				✓	✓	✓
$S(\rho\gamma)$				✓	✓	✓
$S(\phi K_S)$				✓	✓	✓
$S(B_s \to J/\psi\ \phi)$				✓	✓	✓
$\mu \to e\gamma$		✓		✓	✓	?
$\tau \to \mu\gamma$		✓	✓	✓	✓	?
$\tau \to e\gamma$			✓		✓	?

[based on T.Goto et.al. PRD77, 095010(2008)]

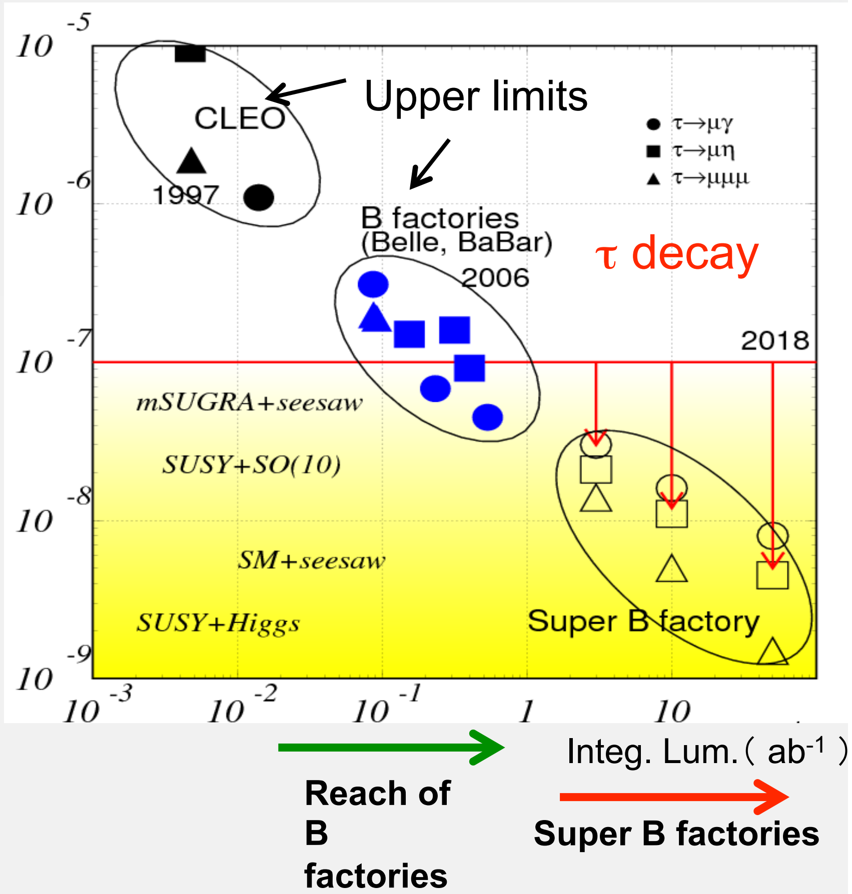
Physics with 50(75) ab^{-1}

Two recent publications:

- Physics at Super B Factory (Belle II) arXiv:1002.5012
- SuperB Progress Reports: Physics (SuperB) arXiv:1008.1541

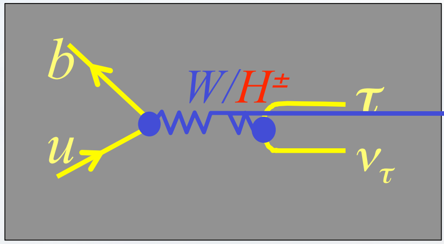
In addition to the topics in this talk,

- Photon polarization of $B \to K^* \gamma$.
- $B \to K^{(*)} \nu\nu$.
- CPV in D.
- LFV in τ decay.
- …

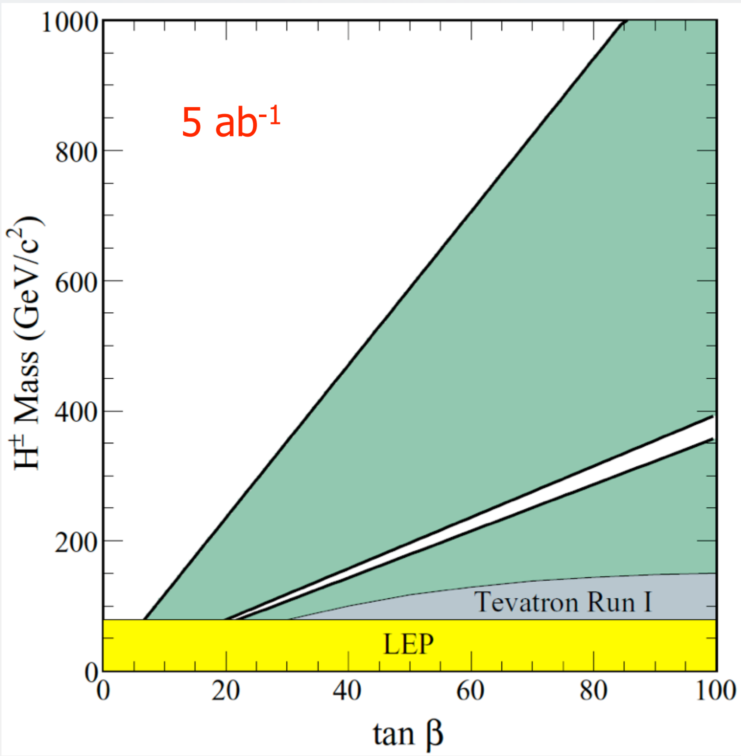


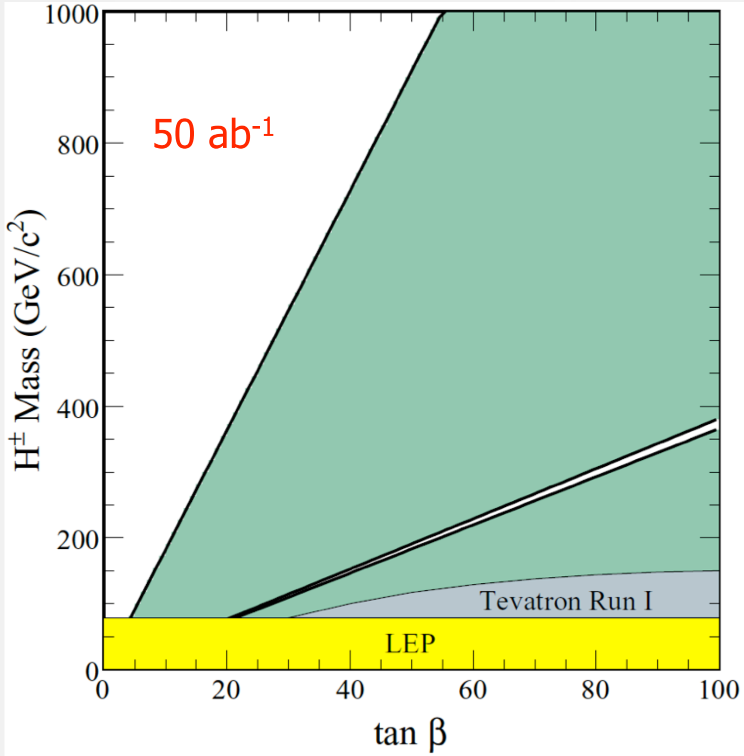
$B^- \to \tau^-\nu$ – charged higgs limits

$$r_H = Br(B\to\tau\nu)/Br(B\to\tau\nu)_{SM} = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)$$



→ limit on charged Higgs mass vs. tanβ





B → K*γ t-dependent CPV

$$P(B^0 \to f; \Delta t) = e^{-|\Delta t|/\tau}/4\tau \, [1 + S_{CP}^f \sin(\Delta m \Delta t) + A_{CP}^f \cos(\Delta m \Delta t)]$$

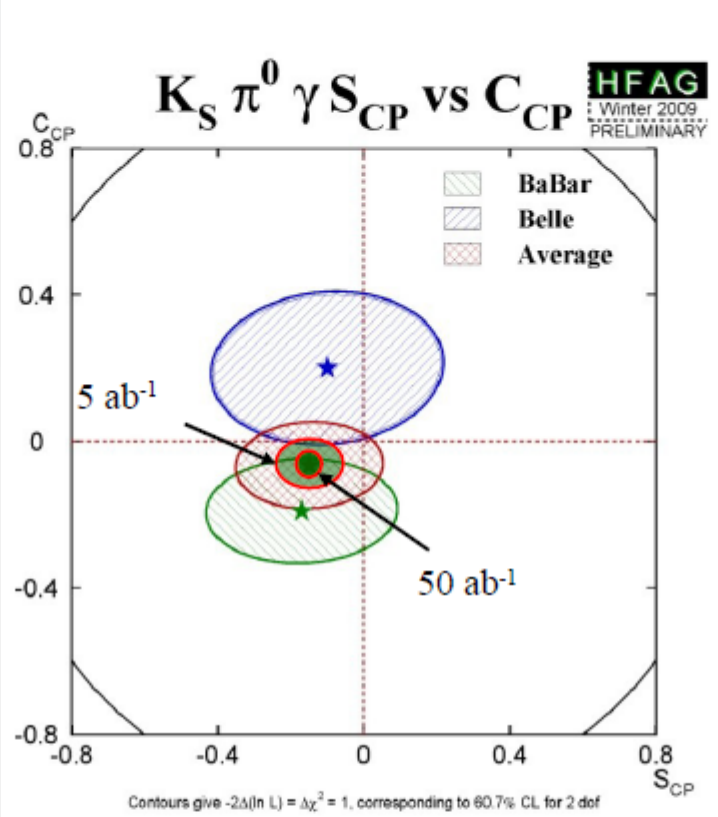
SM:

$|S_{CP}^{K_S \pi^0 \gamma}| \approx (2 m_s / m_b) \sin 2\Phi_1 \approx 0.04$

Left-Right Symmetric Models:

$|S_{CP}^{K_S \pi^0 \gamma}| \approx 0.67 \cos 2\Phi_1 \approx 0.5$

D. Atwood et al., PRL79, 185 (1997)



$S_{CP}^{K_S \pi^0 \gamma} = -0.15 \pm 0.20$

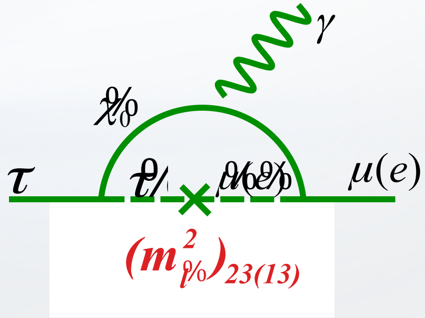
$A_{CP}^{K_S \pi^0 \gamma} = -0.07 \pm 0.12$

HFAG, Winter'09

$\sigma(S_{CP}^{K_S \pi^0 \gamma}) = 0.09 @ 5\,ab^{-1}$ $\quad 0.03 @ 50\,ab^{-1}$ (~SM prediction)

LFV and New Physics

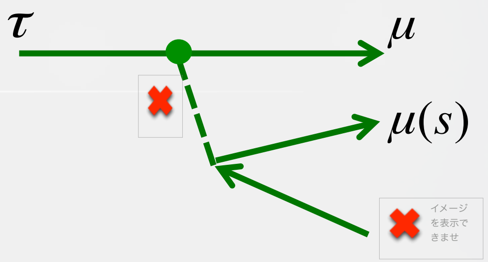
τ→ℓγ



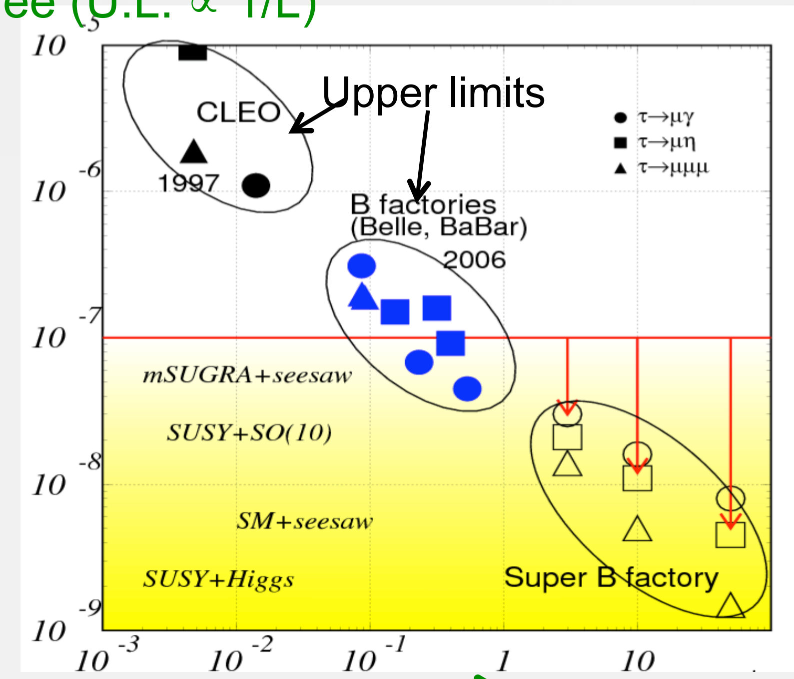
- SUSY + Seasaw
- Large LFV
- bkg. from ee→ ττγ (U.L. ∝ 1/√L)

model	Br(τ→ℓℓℓ)	Br(τ→μγ)
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}

τ→3ℓ,ℓη



- Neutral Higgs mediated decay.
- Important when MSUSY >> EW scale
- bkg. free (U.L. ∝ 1/L)



Integ. Lum. (ab⁻¹)

Reach of B factories

Super B factories

Comparison with LHCb

	Belle	Belle II	Belle II	LHCb
	~ 0.5 ab^{-1}	5 ab^{-1}	50 ab^{-1}	10 fb^{-1} [5yrs]
$\Delta S(\phi K_S)$	0.22	0.073	0.029	0.14
$\Delta S(\eta' K_S)$	0.11	0.038	0.020	---
ϕ_s from $S(J/\psi\phi)$	---	---	---	0.01
$S(K^*\gamma)$	0.36	0.12	0.03	---
$S(\rho\gamma)$	0.68	0.22	0.08	---
$\Delta B/B(B \to \tau\nu)$	3.5σ	10%	3%	---
$B_s \to \mu\mu$	•	•	•	5σ @ 6 fb^{-1}
$\tau \to \mu\gamma$ [$\times 10^{-9}$]	<45	<30	<8	---
$\tau \to \mu\mu\mu$ [$\times 10^{-9}$]	<209	<10	<1	---
ϕ_2	11^0	2^0	1^0	4.5^0
ϕ_3	16^0	6^0	2^0	2.4^0

Advantage:

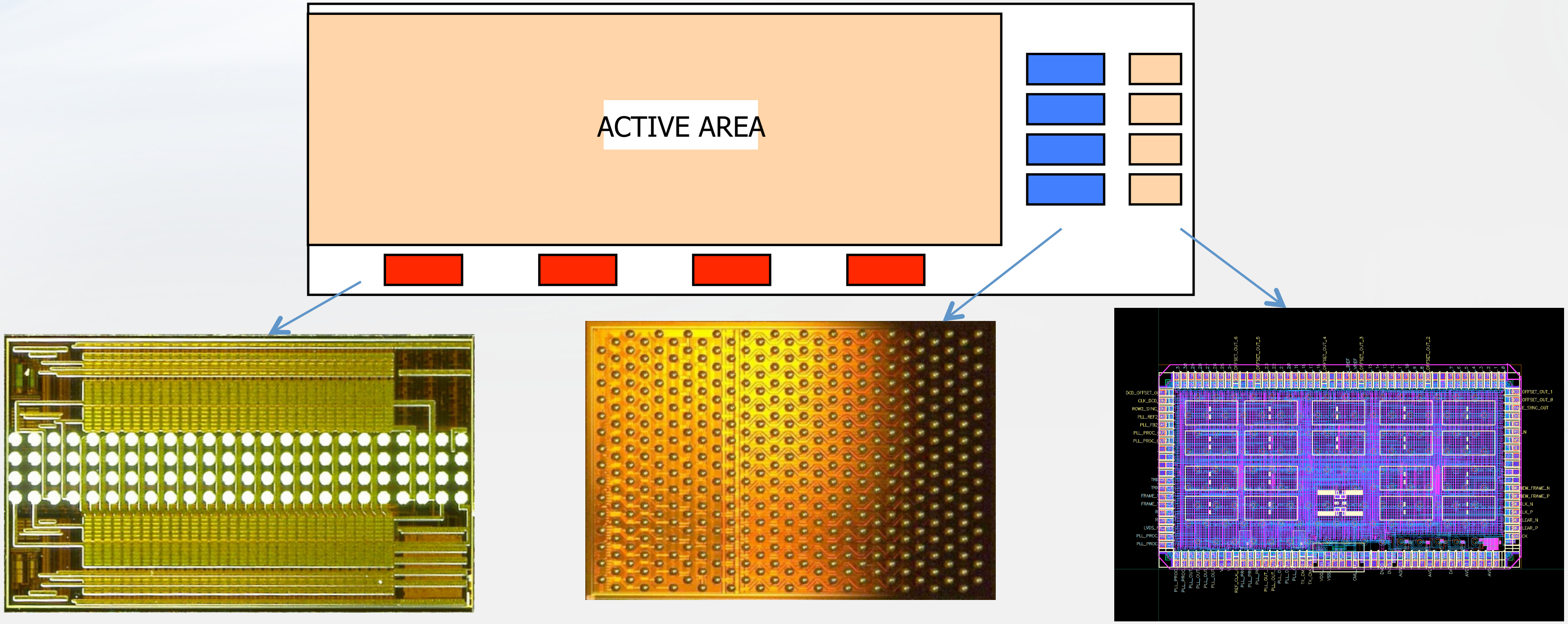
LHCb

- Modes where the final states are charged only.
- B_s
- B_c, Λ_b
- .....

B factories

- Modes with γ, π^0 .
- Modes with ν .
- τ decays.
- K_S vertex.

ASICs for control and readout



Switcher
Control of gate and clear
32 x 2 channels
Switches up to 30V
AMS 0.35 µm HV technology
Tested up to 36 Mrad

DCDB
Amplification and digitization of DEPFET signals
256 input channels
8-bit ADC per channel
92 ns sampling time
UMC 189nm
Rad hard design

DHP
Signal processor
Common mode correction
Pedestal subtraction
0-supression
Timing and trigger control
IBM 90 nm
Rad hard design
½ size (32 channel) test chip

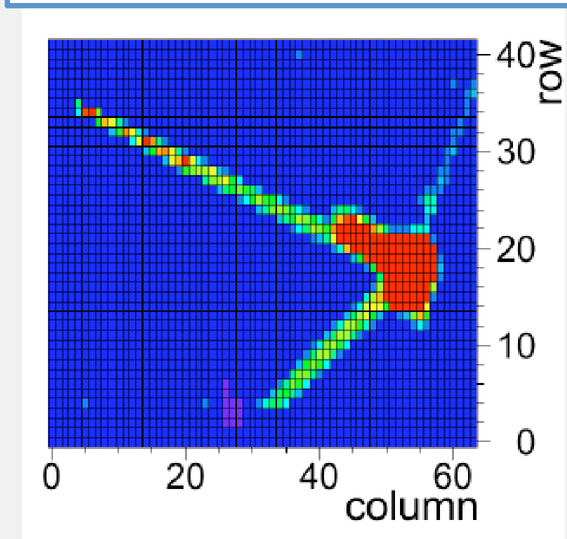
All three chips fabricated and successfully tested

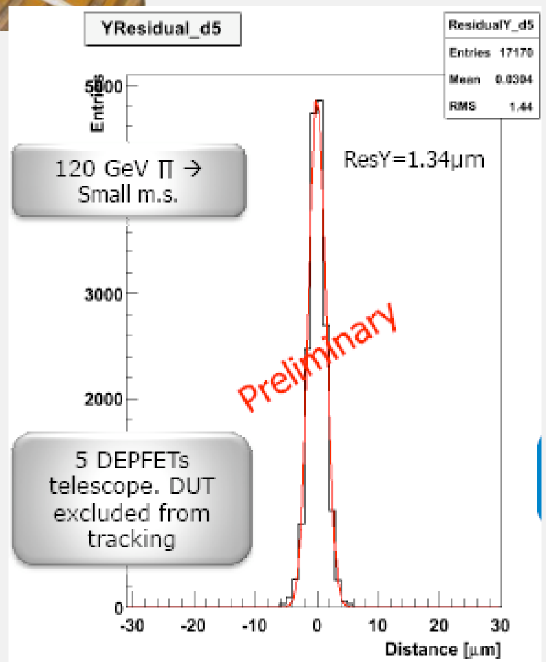
Test Beam in 2009 (ILC version)

Array of 6 DEPFET modules

120GeV π

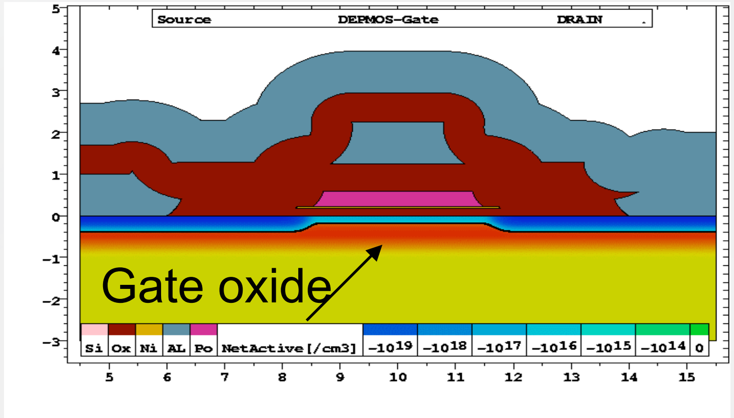
(Not a typical) event display

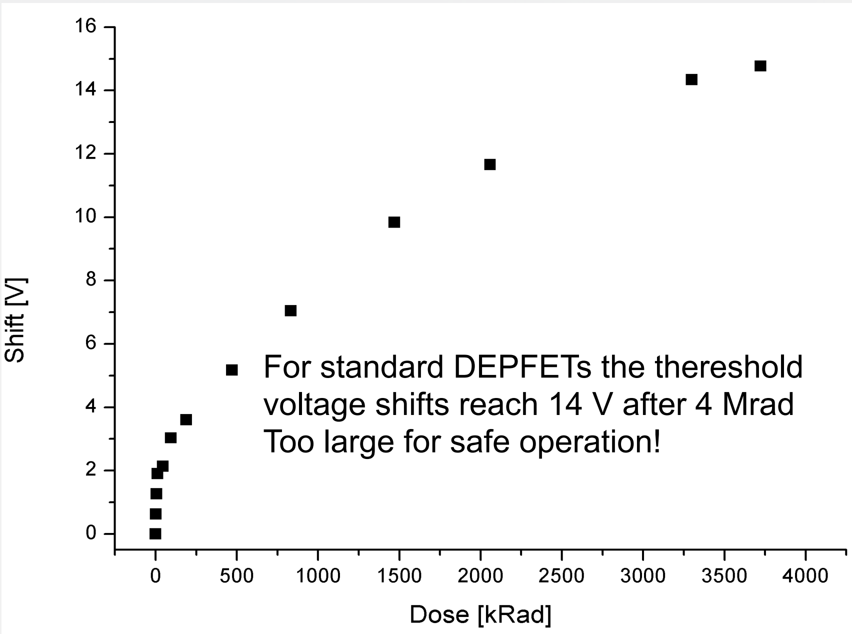


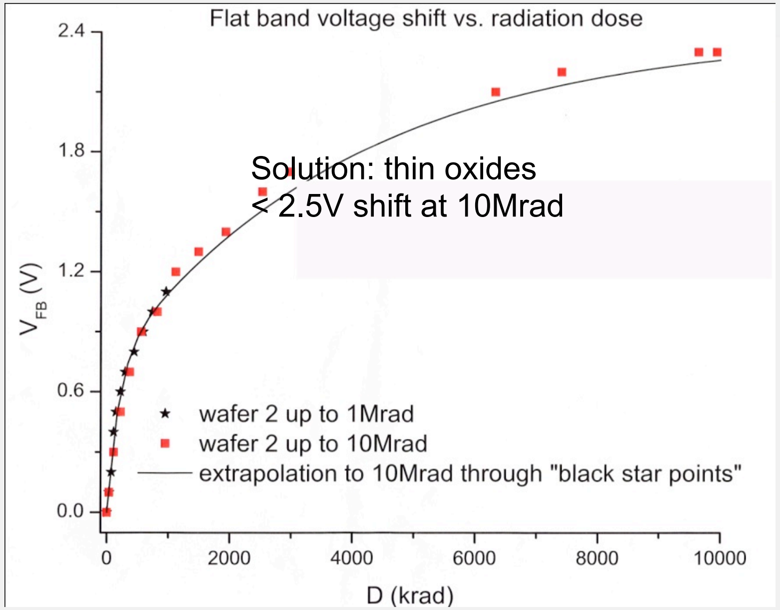


Radiation Damage

DEPFET based on a MOS structure
problem with ionising radiation:
Creation of fixed (positive) charges in the oxide layer and at the interface
Attracts electrons at the Si/SiO_2 interface
Need more negative gate voltages to compensate
=> Shift of transistor threshold

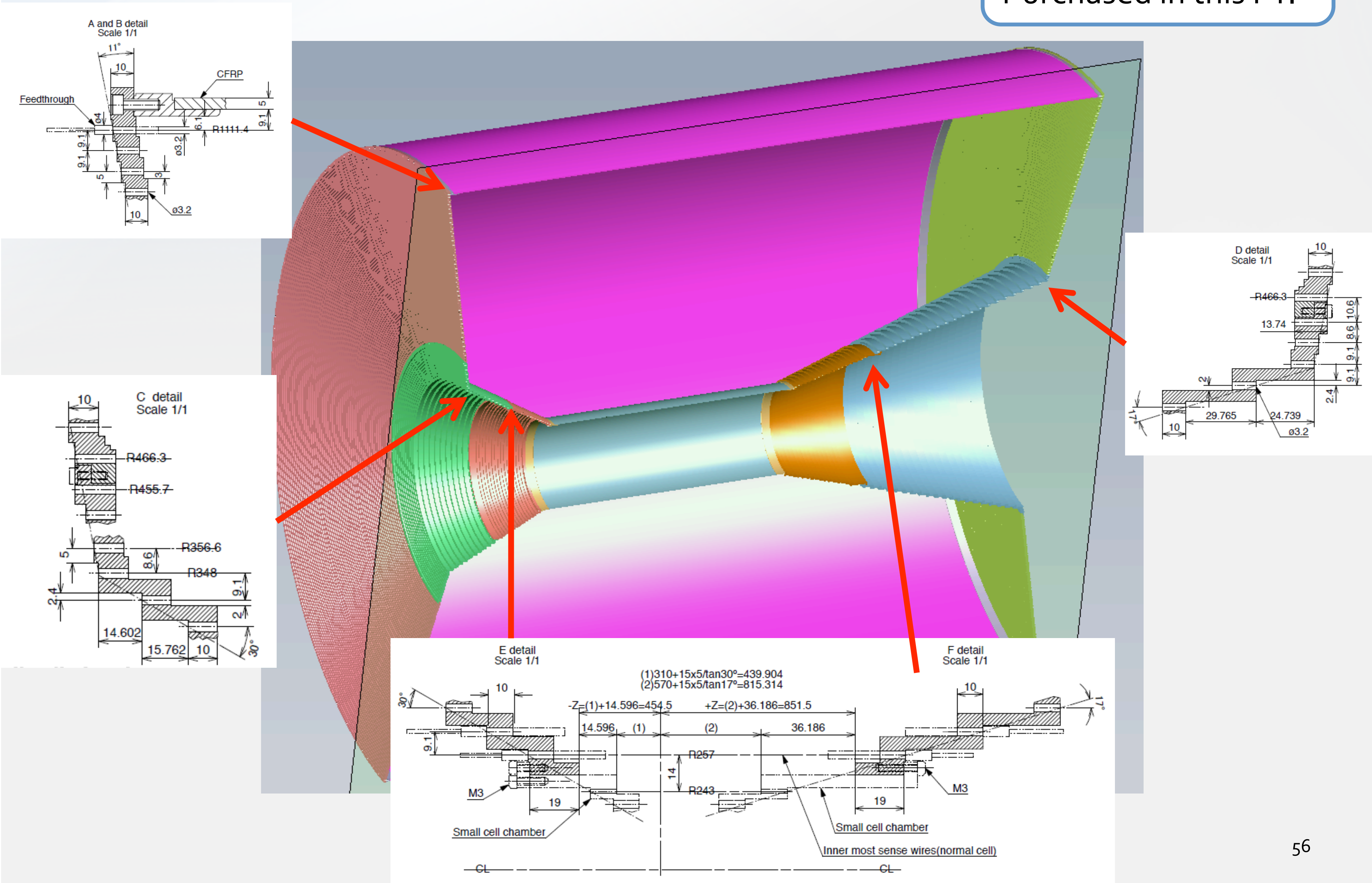






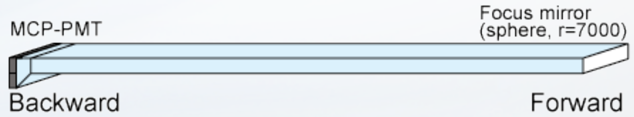
CDC: End-plate

Design finalized.
Purchased in this FY.

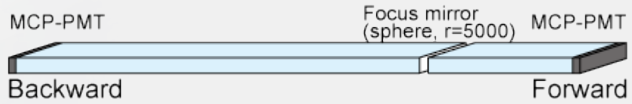


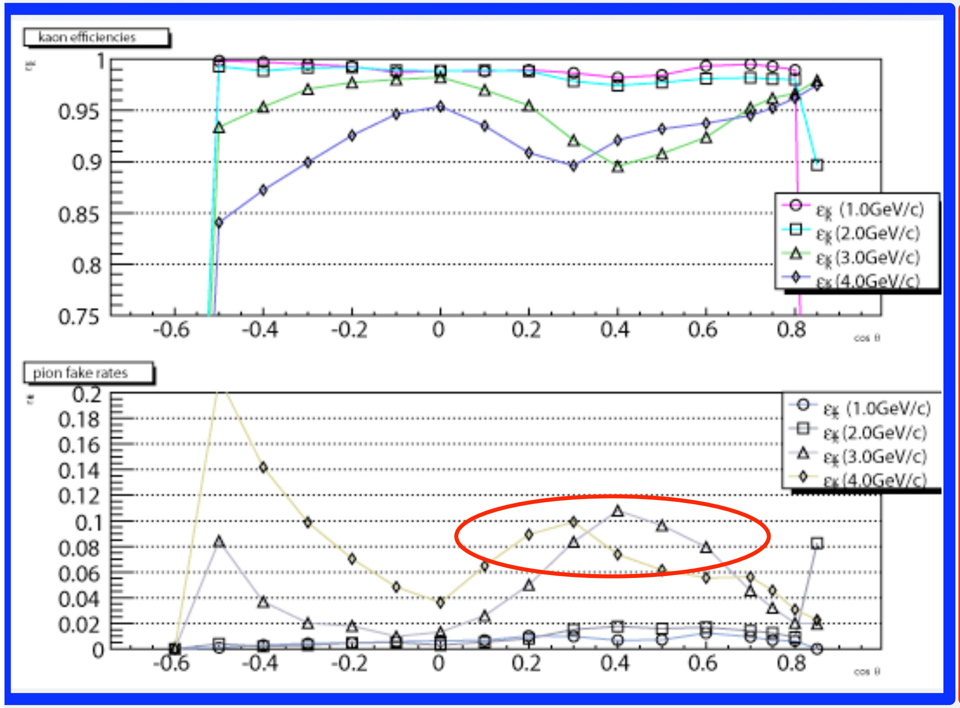
Performance of 1-bar/2-bar TOP

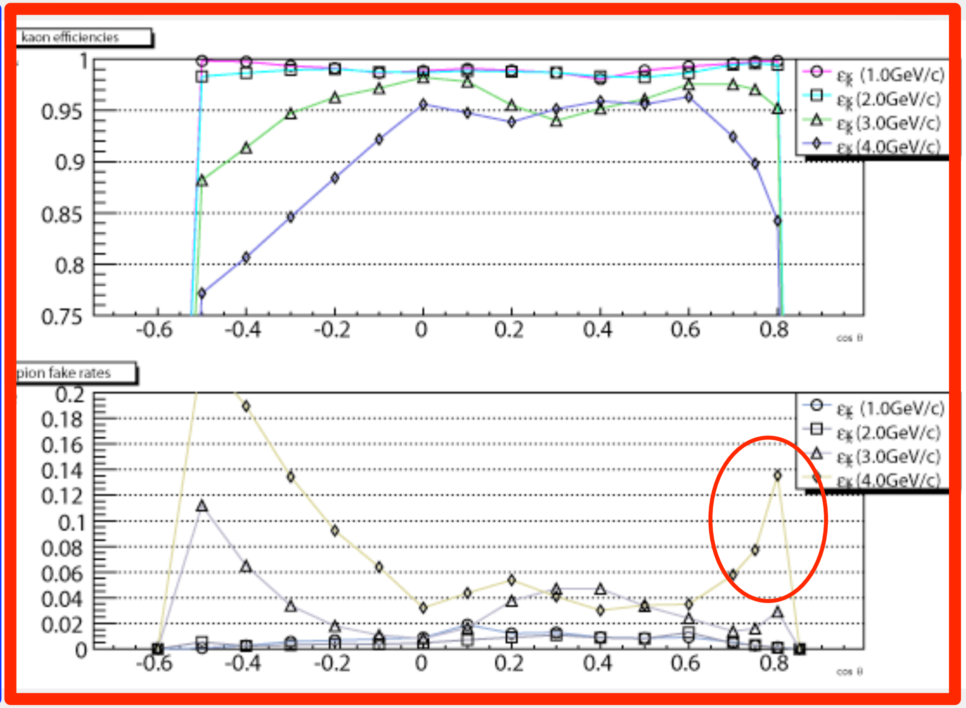
1-bar



2-bar







Incident angle fluctuation (1mrad)

Timing fluctuation (25ps)

Performance similar (weighted) for physics case studies

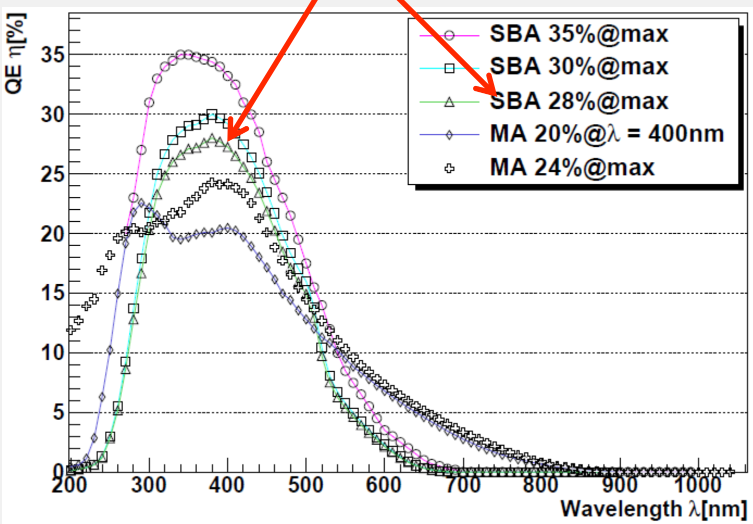
3% fake~4σ

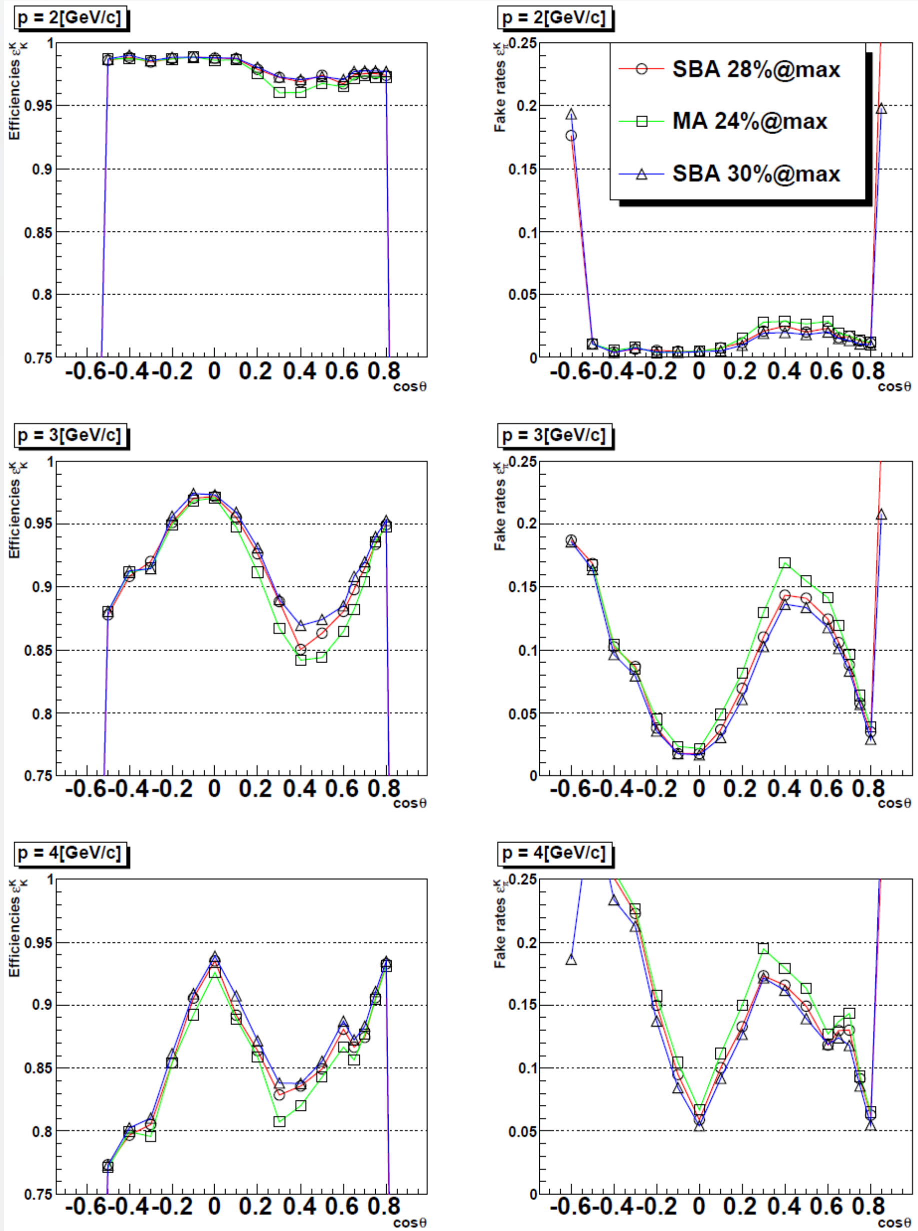
Configuration choice (May, 2010)

- Two configurations show similar performance
- 1-bar configuration shows stable performance as a function of increased timing jitter. 2-bar need precise, continual timing calibration during experiment operation.
- 1-bar case has larger forward acceptance and requires readout only in the backward direction. (forward cable routing is very crowded)
- We chose the 1-bar configuration as baseline, with 2-bar as a backup option, due to these practical considerations.

MCP-PMT photocathode

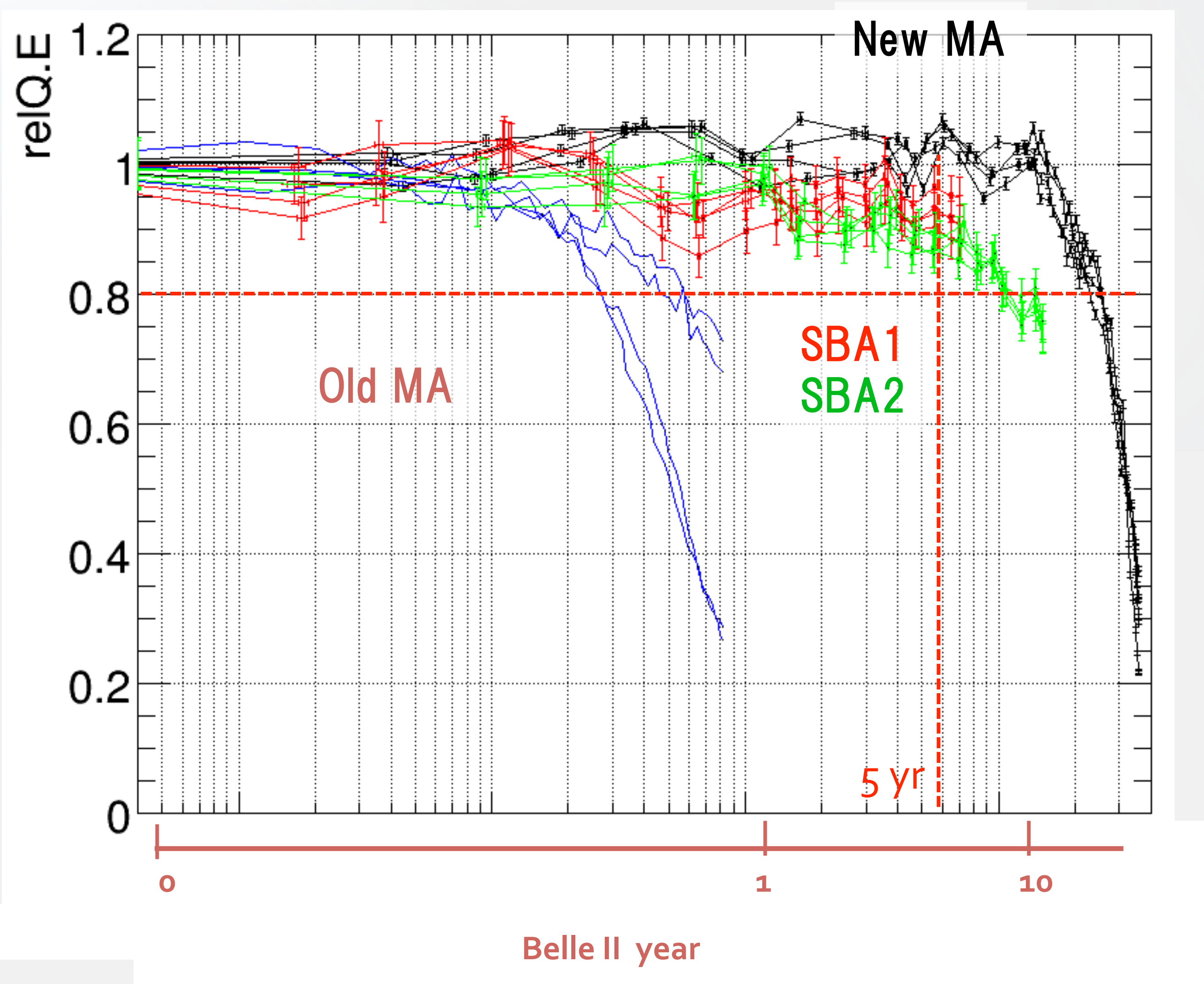
- Typical QE at max.
  - Bialkali (SBA); 28%
  - Multialkali (MA); 24%
- Performance check by simulation
  - Difference QE distribution makes different chromaticity effect.
- SBA shows better performance.
  → Chose SBA.
  - We push HPK to improve QE during production.





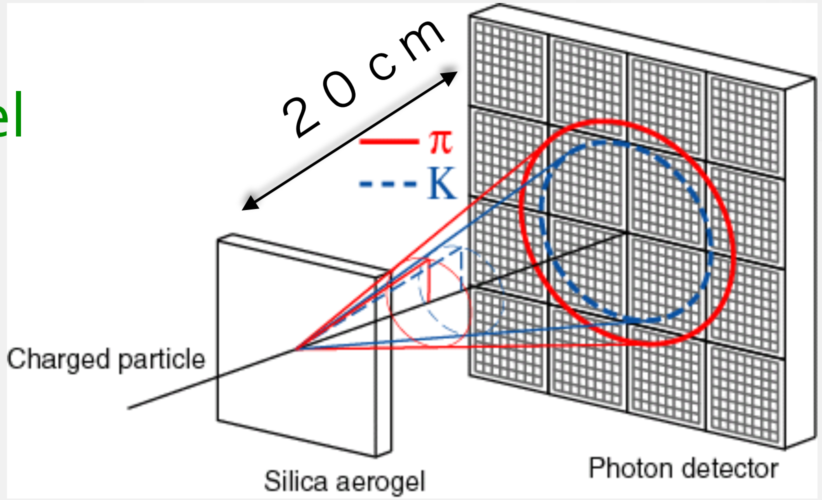
MCP-PMT: improvement in lifetime

Protections against
-Ion feedback
-Neutral gas
were effective.



End-cap Particle Identification

- Ring imaging Cherenkov counter based on silica aerogel radiator
  - Space limited -> proximity focusing with expansion distance of 20 cm
  - Requirements
    - Transparent silica aerogel
    - Photo-detector
      - Single-photon sensitivity
      - Pixel 5x5mm^2
      - Operational in 1.5T
      - Compact
    - Readout electronics
      - ~70K channels



n=1.05 aerogel
$|\sigma_c(\pi)-\sigma_c(K)|$ = 23 mrad at P=4GeV/c

Target: More than 4 σ π/K separation at 4 GeV/c

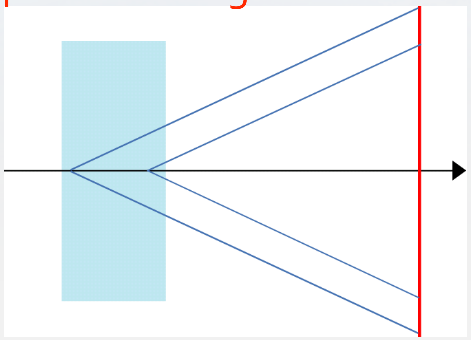
Novel "focusing" radiator

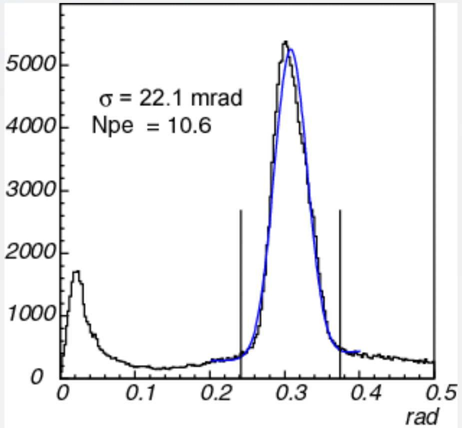
Possible only with aerogel !

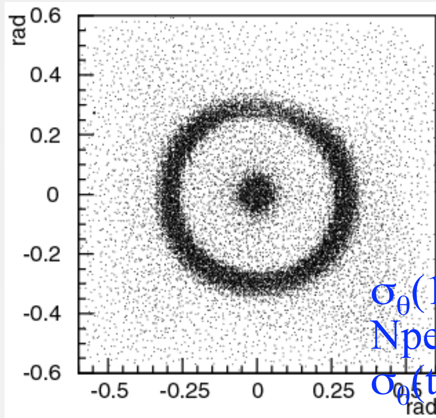
Simple accumulation of radiator layer gives more photons, but degrades PID performance

➔ Multiple aerogel layers with different indices

4cm-thick single index aerogel

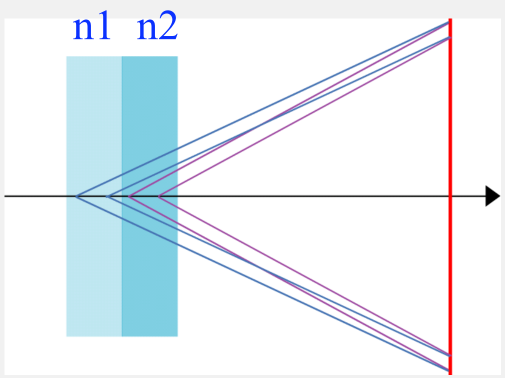


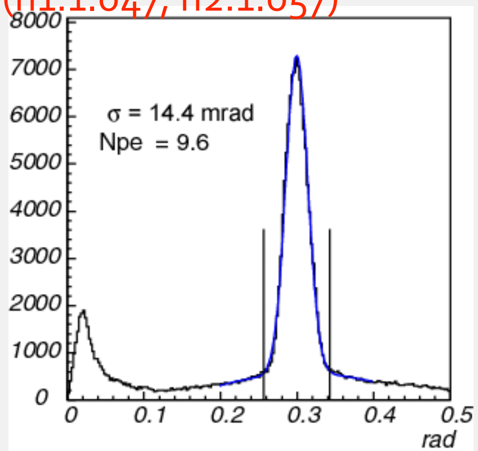


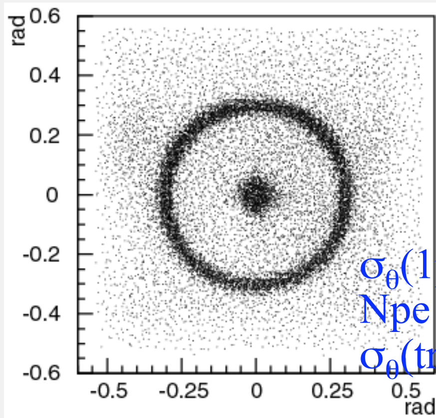


σ_θ(1p.e.) = 22 mrad
Npe ~ 10.6
σ_θ(track) = 6.9 mrad

Focusing by 2cm+2cm aerogel (n1:1.047, n2:1.057)





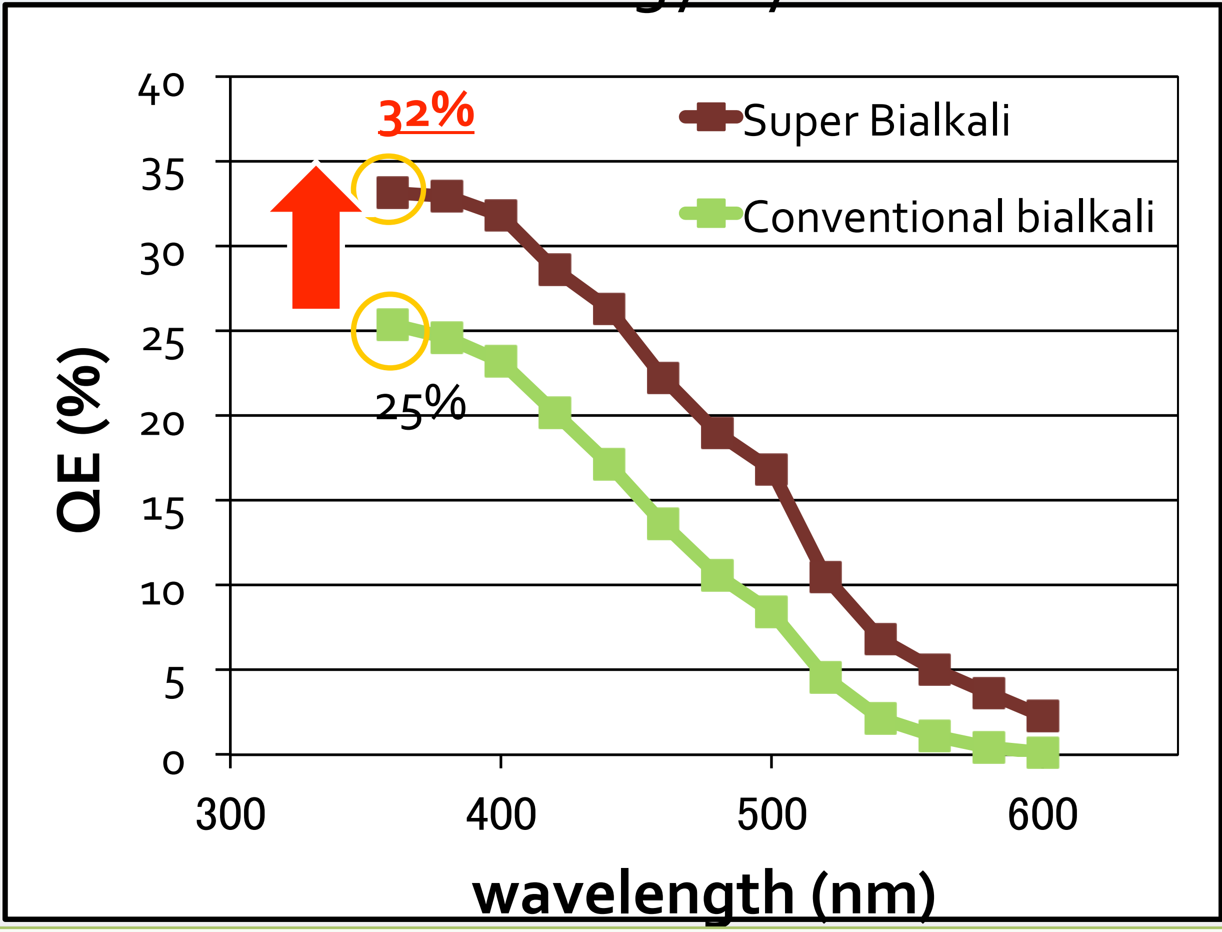


σ_θ(1p.e.) = 14.4 mrad
Npe ~ 9.6
σ_θ(track) = 4.8 mrad

NIM A548(2005)383

HAPD QE Improvement

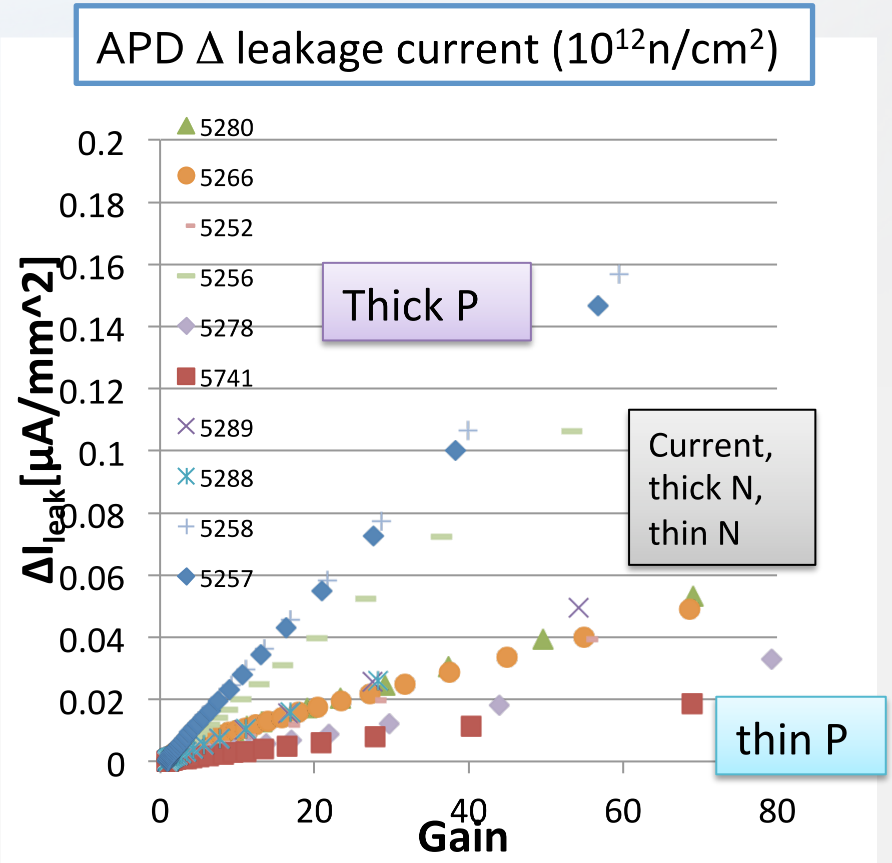
HAPD QE has been greatly improved with "super bialkali" technology by Hamamatsu.

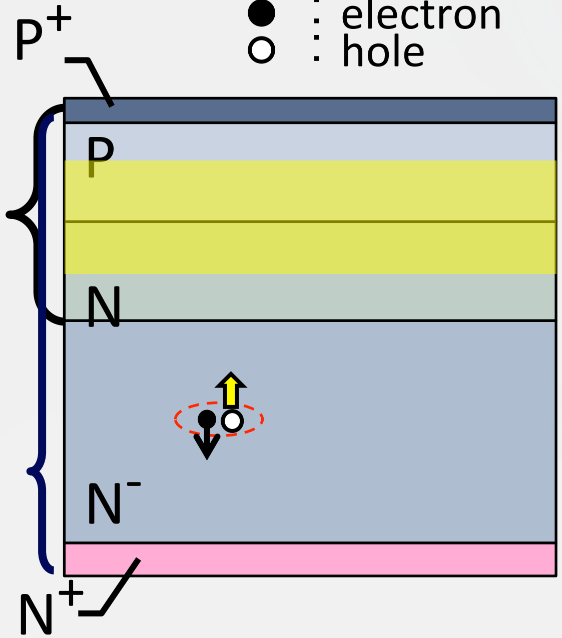


Peak QE > 30% has been achieved

Studies to Reduce Neutron Damage

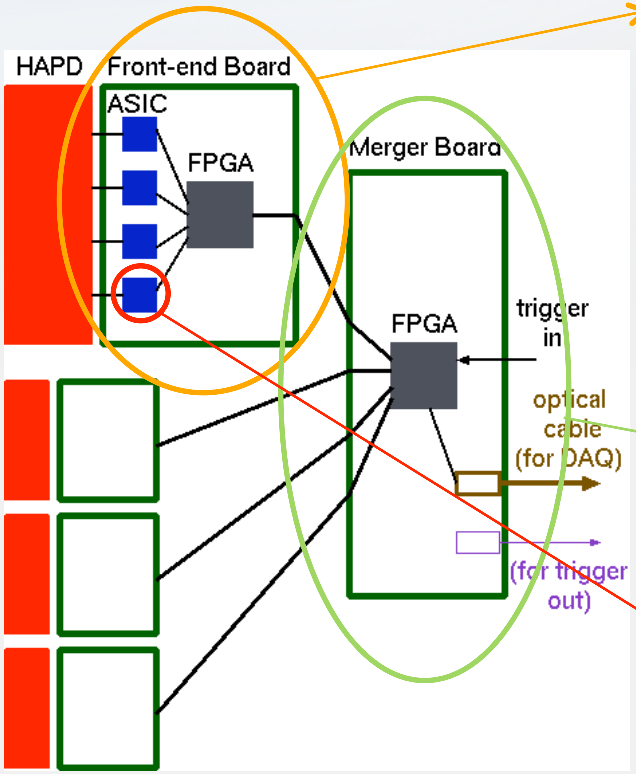
Thinner APD to reduce neutron induced lattice deficits

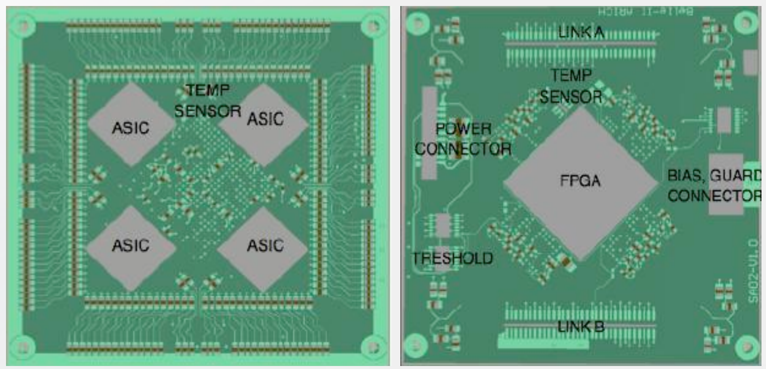




- Contribution of N-layer (hole) is about 1/100 of that of P-layer (e).
  → Thinner P layer
- Improvement confirmed with APD irradiation tests
  → presumably this improves HAPD tolerance, too
  → HAPD irradiation test is under way.

Status of Readout Electronics for Aerogel RICH





~74mm
(~final size)

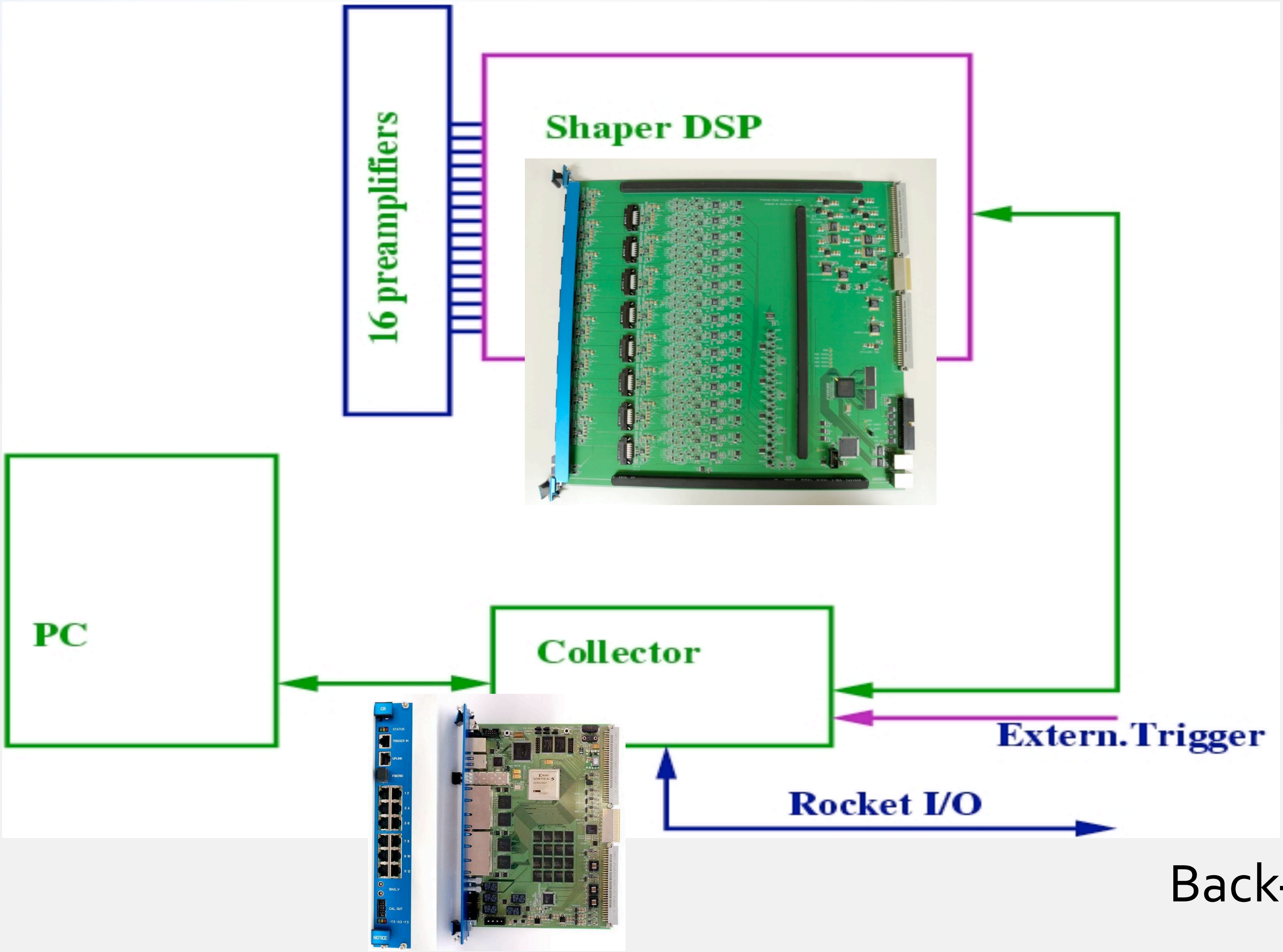
Trial production of the front end board in progress (Ljubljana).

Prototype Merger board will be designed in this fiscal year.

The design of the next version of the ASIC (S03) has just started.

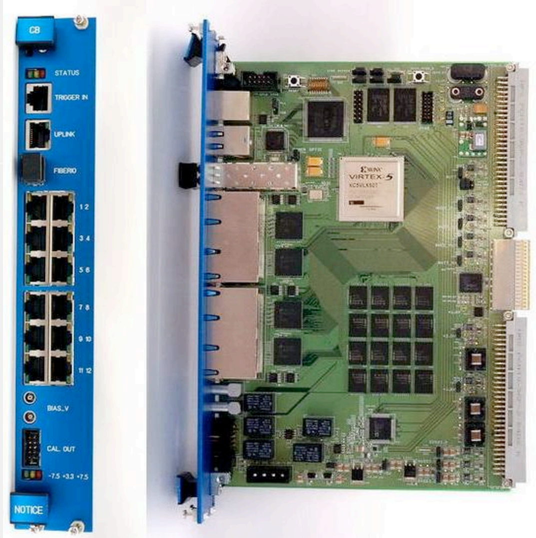
- Shorter shaping time.
- Production schedule depends on HAPD & front-end board development

Front-end electronics of ECL



Back-end DAQ

ECL Collector module

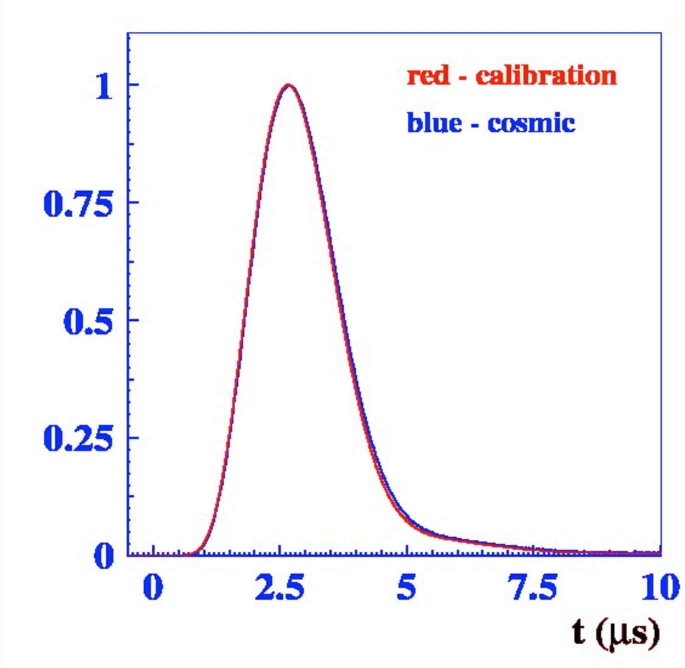


Role of the module:

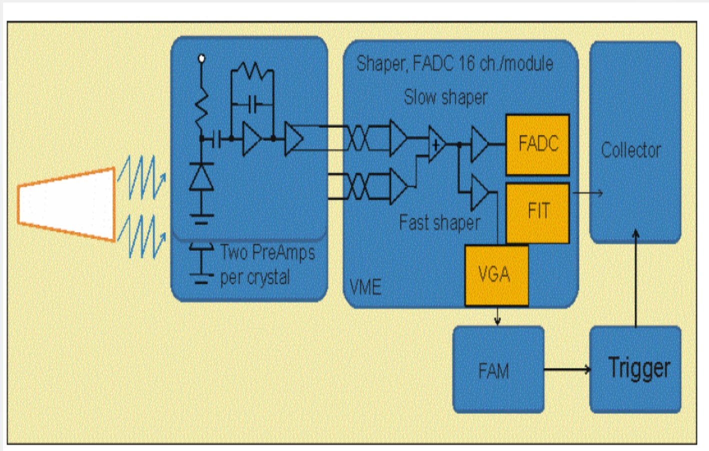
- Configure Xilinx FPGA on ShaperDSP modules
- Synchronize sampling process on all 12 ShaperDSP modules
- Collect data from 12 connected ShaperDSP modules
- Calibration signal generation
- Interface with remote PC for stand-alone operation
- Provide interface with Belle II TTD and DAQ

Status:

- Prototype module … produced
- Remote firmware configuration on ShaperDSP … established
- Interface with remote PC …established
- Calibration signal generation … established
- Rocket-I/O … to be tested soon



Shaper DSP module

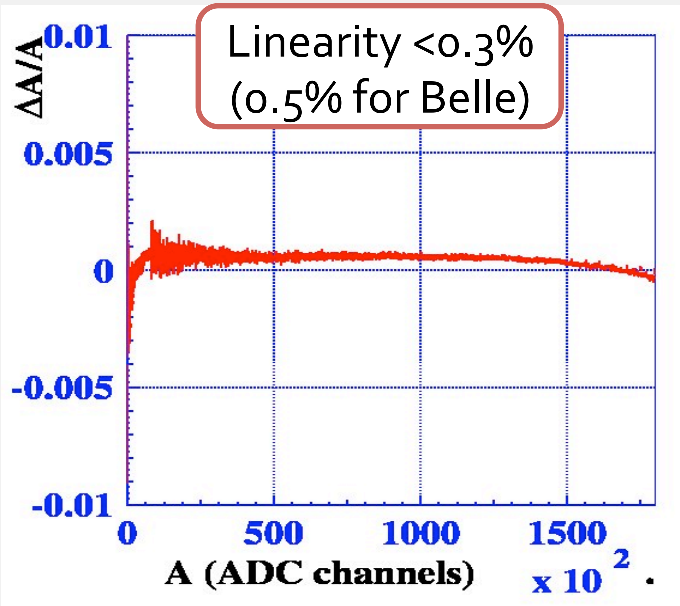


Key features:

- 16 channels per module
- τ=0.5μs shaper
- FADC
- Waveform fitting

  Output pulse height, timing, and quality of fit

- Fast shaper + Variable gain amp. for trigger output.



Status:

- Prototype module … produced
- New revision … to be submitted in this FY

	Belle	Belle II
Linearity	<0.5%	<0.3%
Shaping time	1μs	0.5μs
ENE	~200keV	~300keV
ENE (w/ pile-up noise)	500-1000keV	400-600keV

Most critical path of each subsystem

	Most crucial item	Necessary time
BP	Design study, Beryllium pipe production	1-1.5 years, 1 year
PXD	Sensor production	1.5 years
SVD	Sensor production	2 years
CDC	Drilling small cell end-plate	9 months after getting skilled
TOP	Quartz bar production	2.3 years
A-RICH	HAPD production	1.3 years
ECL	(To exchange pre-amps If we do so)	
KLM	Scintillator bar production	1.5 years,

Simpler Be pipe by new companies (→ 4 months)

New companies (in US) → 1 year

Commissioning procedure