Belle II physics, schedule and construction status

ARC 2014.03.03
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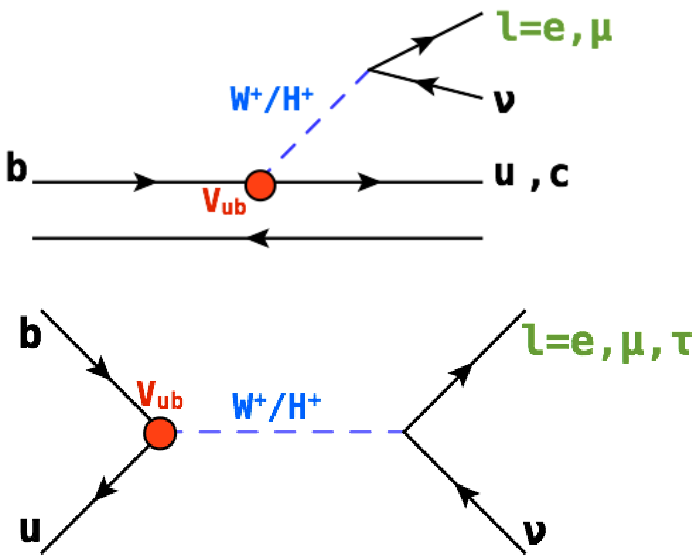
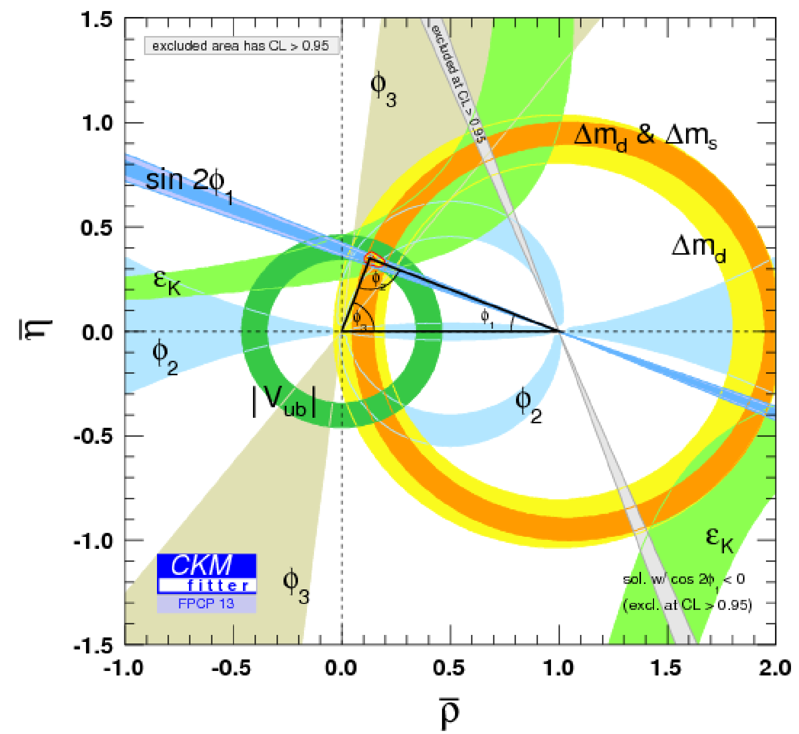
Slides based on 8th Belle PAC: Feb. 9-11 and 17th B2GM:Feb. 4-8

Physics motivation

- The Flavour Sector of the Standard Model is remarkably successful.
- Requires the knowledge of masses and of strength and type of the charged-current interactions.
- Most SM extensions contain new CP-violating phases and new quark-flavour changing interactions (but no evidence from B-factories & hadron machines!)





Searches for New Phenomena by flavor frontier

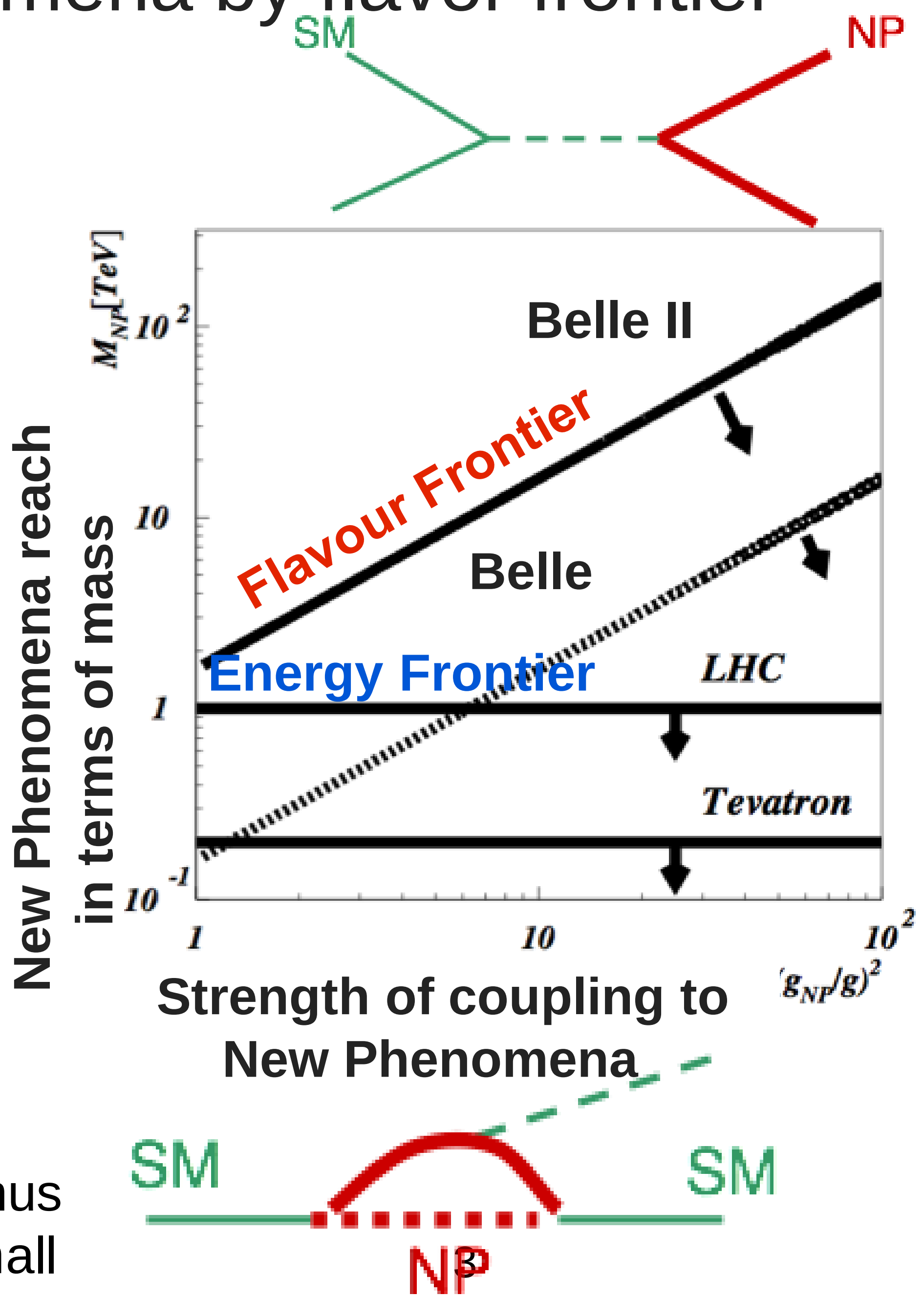
Energy Frontier: Production of **new particles** from *collisions* at high-***Energy*** (**LHC**)

- *Limited by Beam Energy*

Flavor Frontier: **virtual production of new particles** to probe energies beyond the energy frontier.

- Often **first clues** about new phenomena, e.g. **weak force**, **c, b, t** quarks, Higgs boson.
- High precision required: very tiny effects

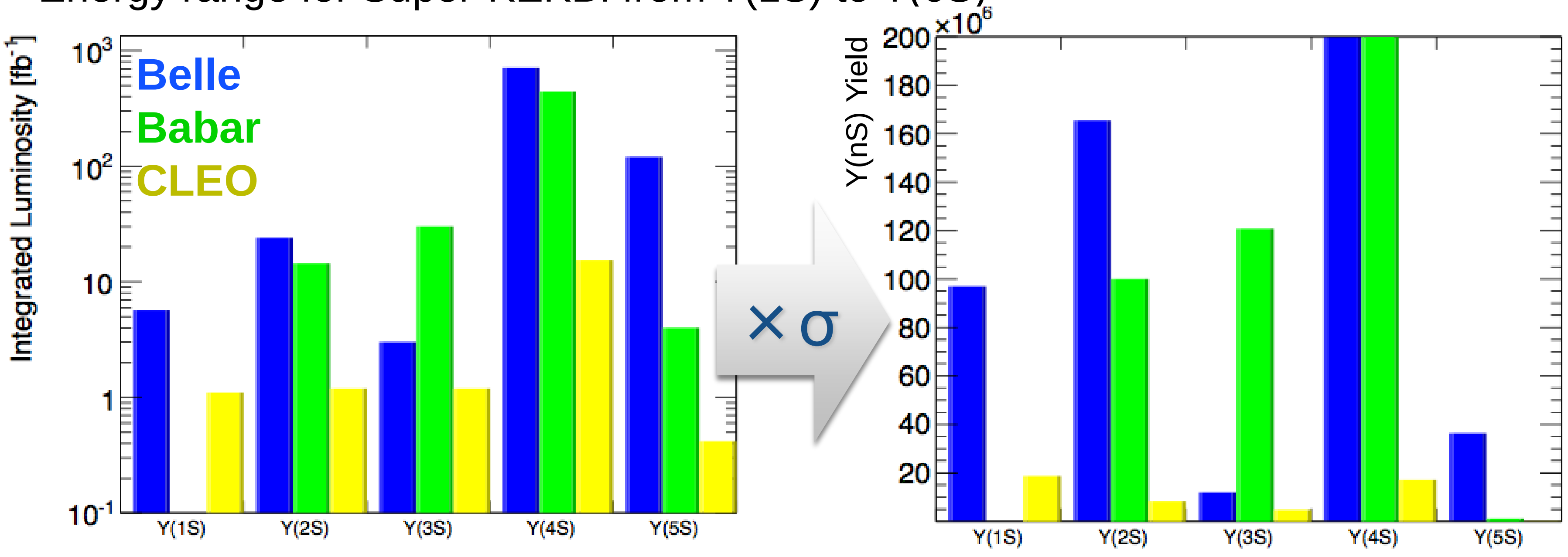
- Consistency between ATLAS/CMS and FF necessary to understand the NP flavour puzzles



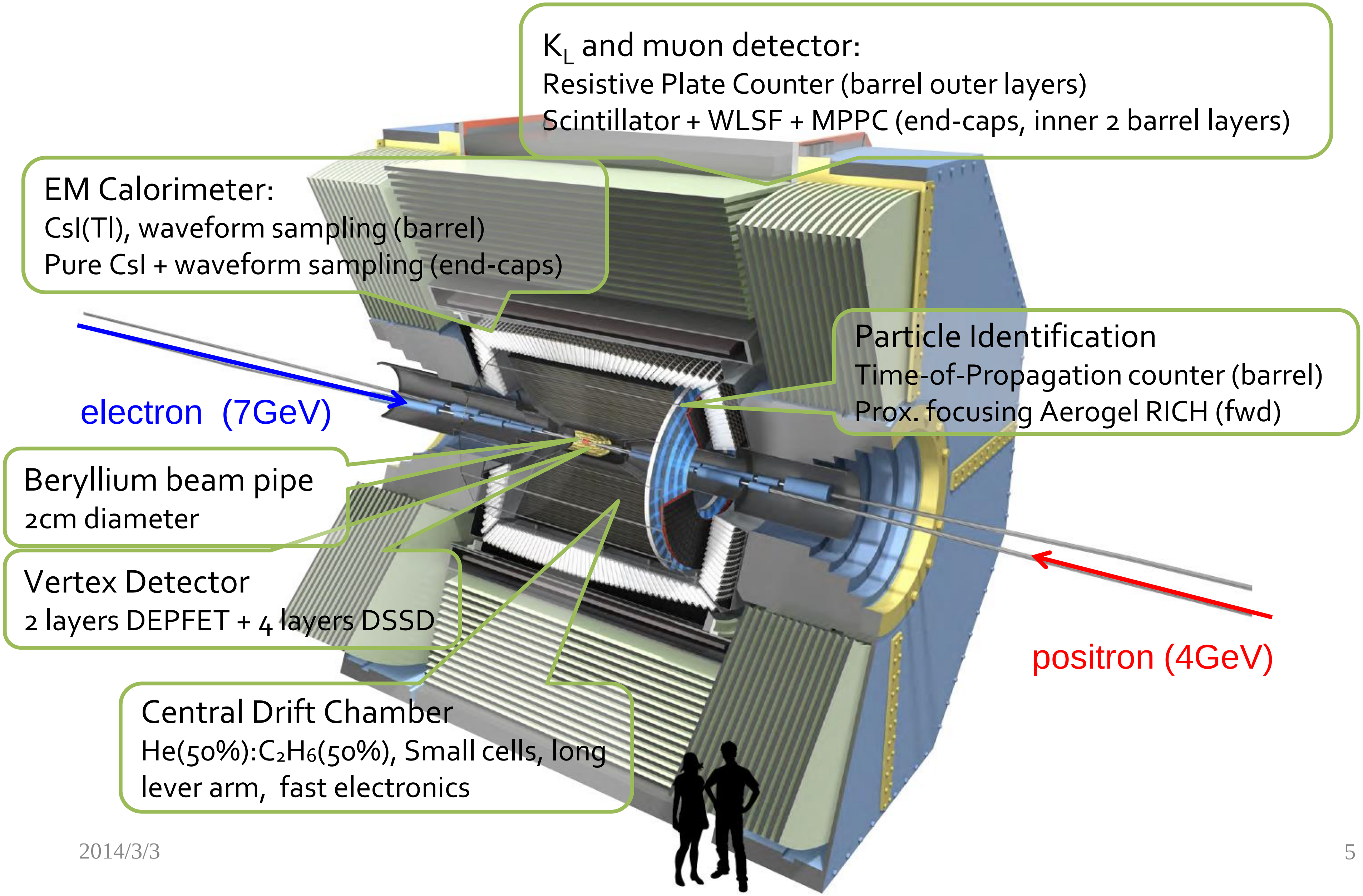
Highly virtual, thus probabilities small

Phase 1 Physics Program

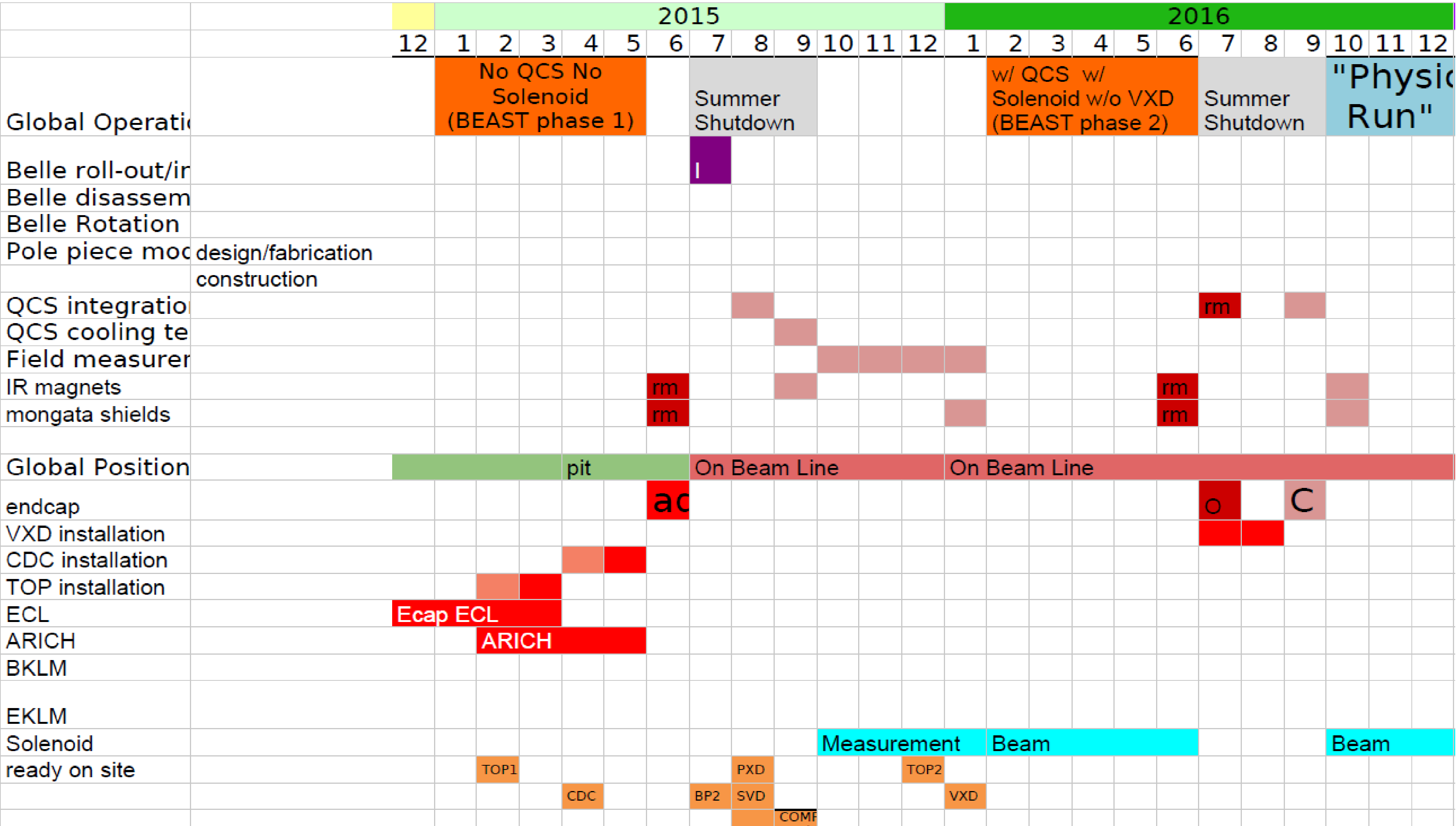
- First physics schedule (Partial TOP / 200-300 fb^{-1}):
- **Commissioning @ Y(4S) of course**
  - But physics is stat. limited (compared to Belle), high systematics on partial detector.
- Alternative: Large **Unique** e^+e^- data set studies @ Y(2, 3, or 5S)
  - K/π separation not as crucial in bottomonium studies (Y(2S), Y(3S), Y(5S))
  - Neither is vertexing
- Energy range for Super-KEKB: from Y(1S) to Y(6S)



Belle II Detector



Belle II Schedule



First new sub-detector installed (B-KLM)

Start "physics run" from Oct. 2016 even with partial TOP

Slowly shifting from construction phase to integration phase

Challenges on Belle II Upgrade

High Background (×10-20)

- Radiation Hardness
- Occupancy
- Pile-up Noise

High Event Rates

Improved Performance

- Vertex Reconstruction
- PID, Neutral particles
- Hermeticity

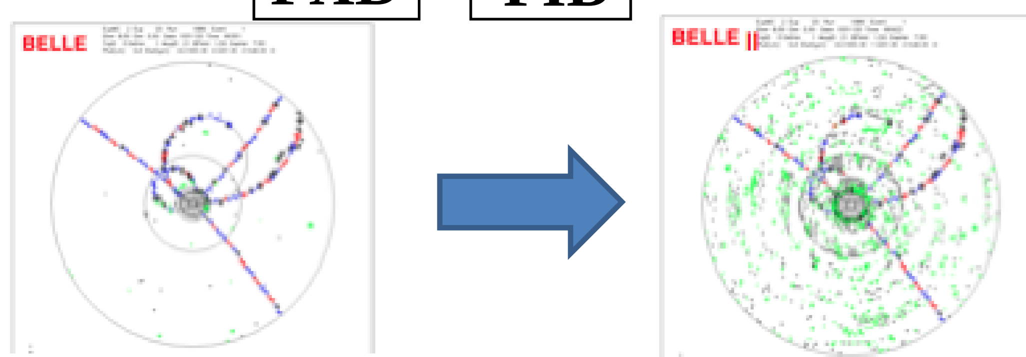
High Speed Readout

ECL SVD CDC

KLM endcap/barrel DAQ

New Technology

PXD PID

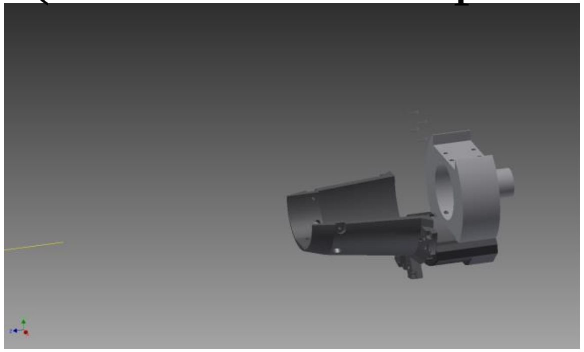


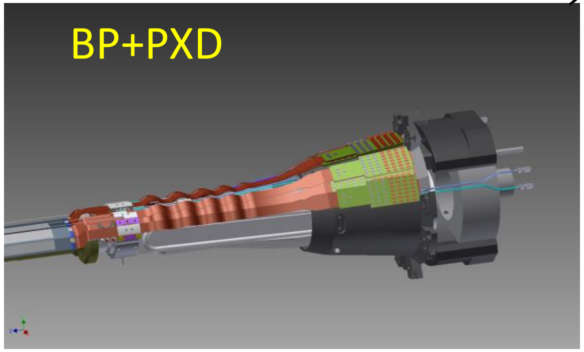
Smaller Lorenz boost factor
is requiring finer vertex resolution

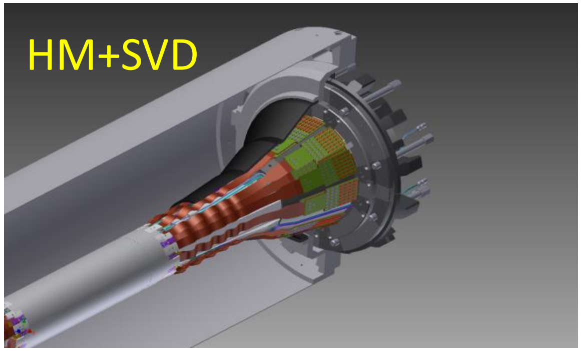
BaBar	$p(e^-)=9$ GeV	$p(e^+)=3.1$ GeV	$\beta\gamma=0.56$
Belle	$p(e^-)=8$ GeV	$p(e^+)=3.5$ GeV	$\beta\gamma=0.42$
Belle II	$p(e^-)=7$ GeV	$p(e^+)=4$ GeV	$\beta\gamma=0.28$

VXD assembly steps

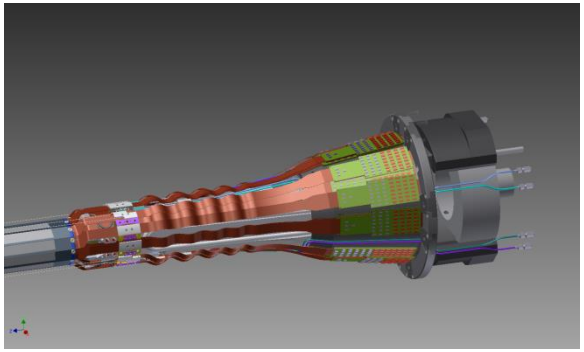
VXD design and assembly procedure (incl. BP) have agreed
1st set of mechanics parts will be delivered in March.
(There are two options of installation method)

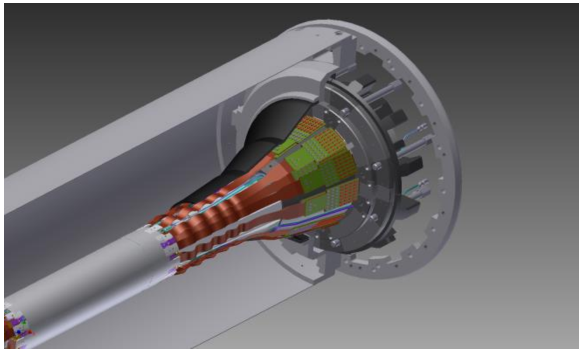


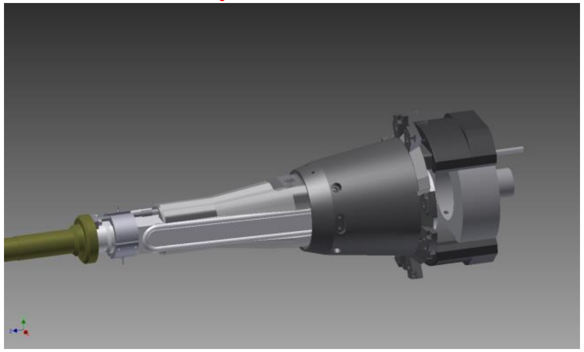


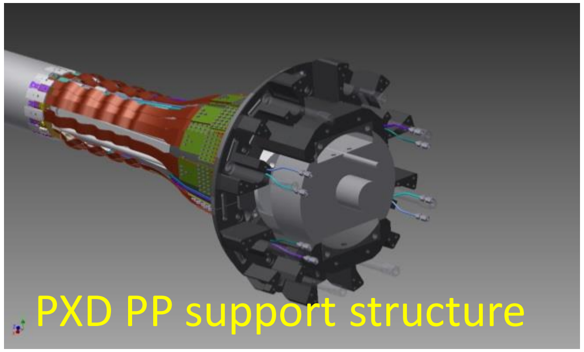


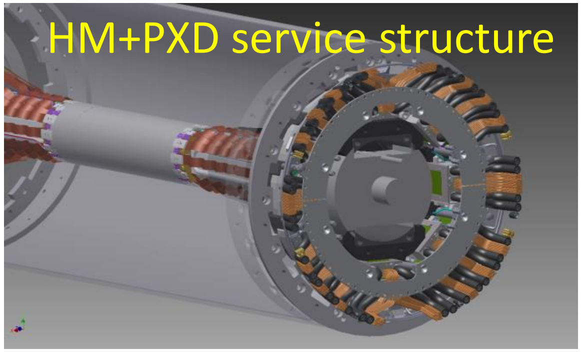
HM:
Heavy Metal shields



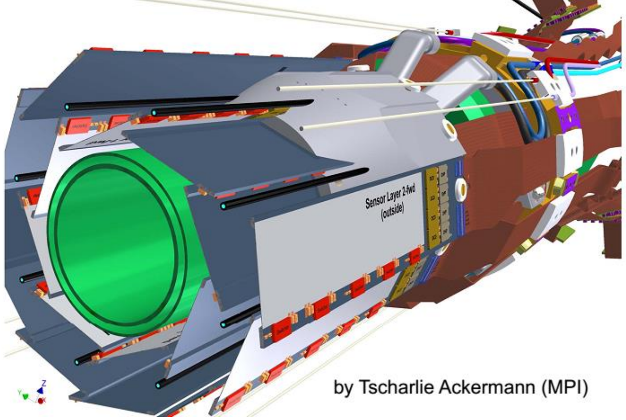


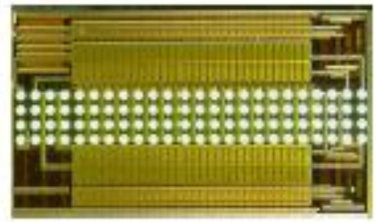






PXD ladder



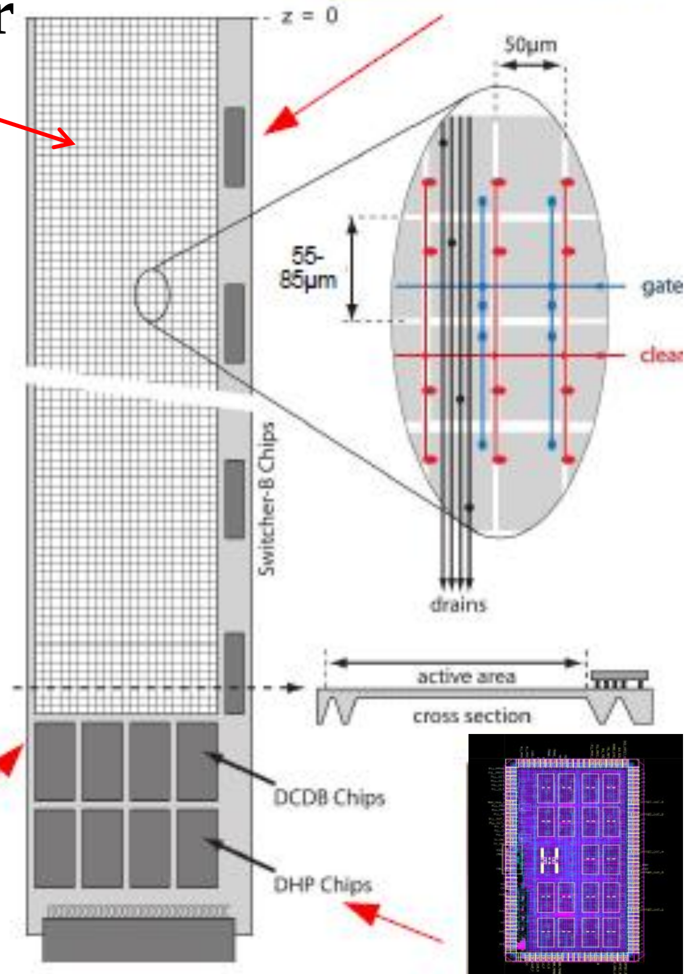


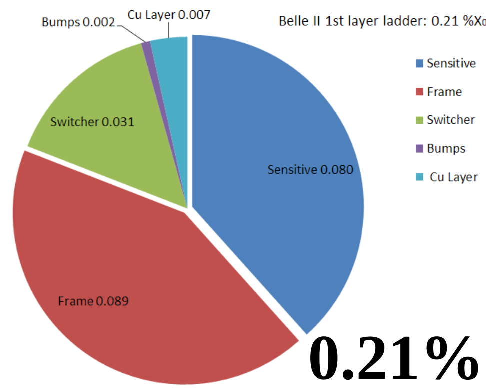
Switcher

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

DEPFET sensor

250 x 768 pixel
50µm x 55µm (min)
50µm x 80µm (max)
75µm thick

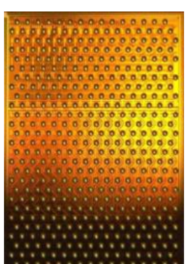




0.21% X_0

DCDB

Amplification and digitization of DEPFET signals
256 input channels
8-bit ADC per channel
92 ns sampling time
UMC 180 nm

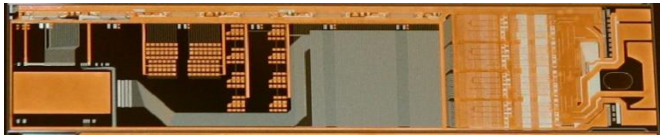


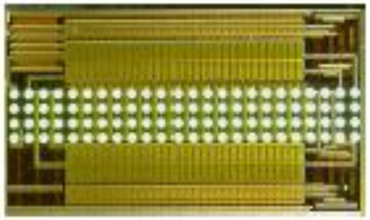
DHP

Signal processor
Common mode correction
Pedestal subtraction
0-supression
Timing and trigger control
TSMC 65nm (first version IBM 90nm)

PXD ladder

EMCM: Electrical Dummy to be equipped with ASICs and tested like a real module



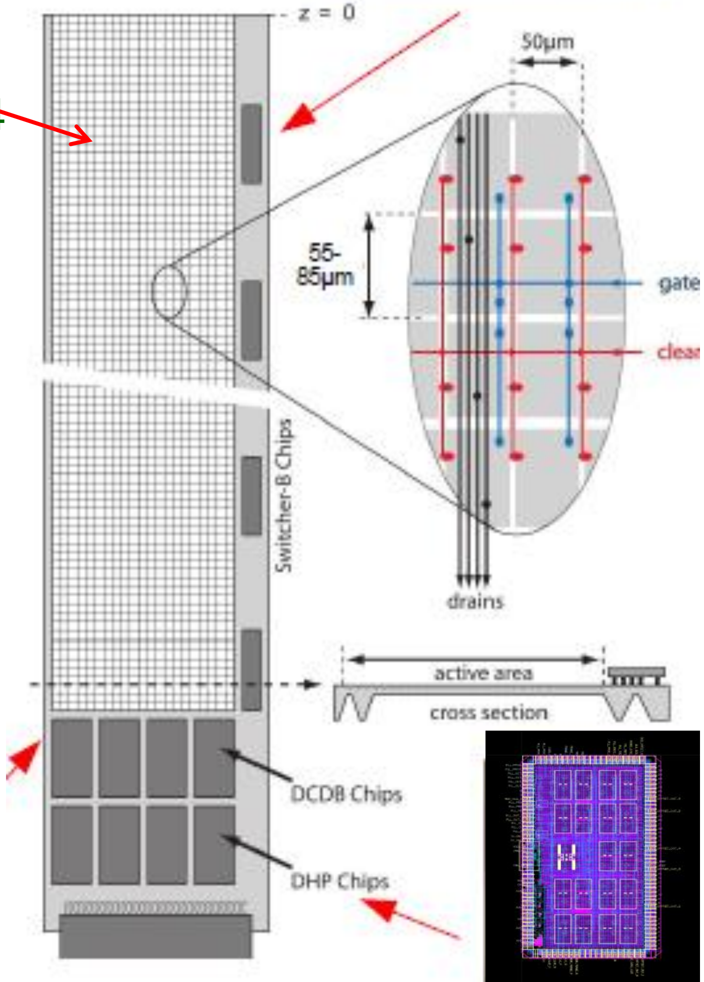


Switcher

Only minor modifications needed (E.g. resize of the output driver for faster clear signal)

DEPFET sensor

First sensors will be available in October 2014
Production finished in June 2015



DCDB

Noise at 320MHz higher than at 100MHz
Two types of chip have submitted

DCDBv4
DCDBPipeline

DHP

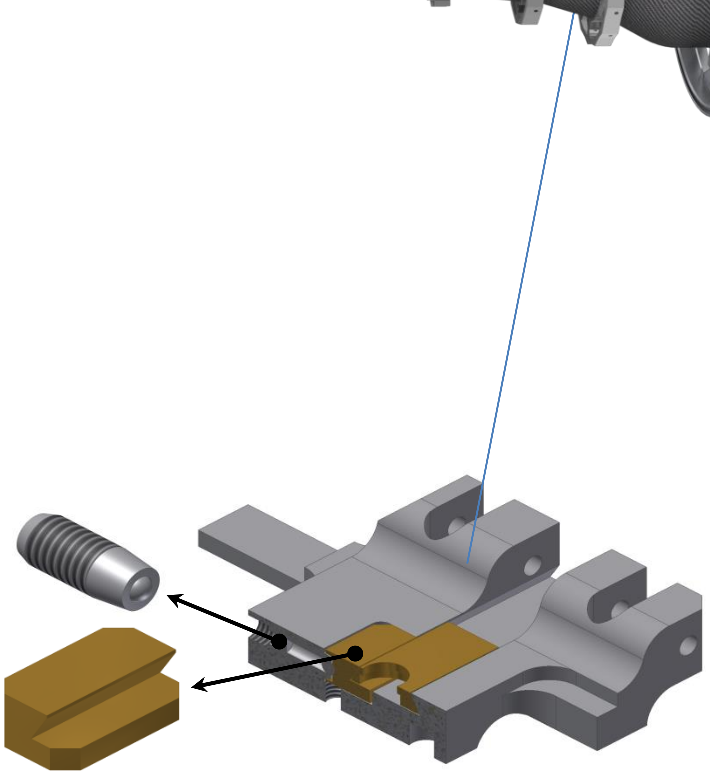
Conversion from IBM 90nm to TSMC 65nm completed
increased buffer size for higher rates

Serializer works, but Vcc has to be adjusted to get full speed

1.4 V (nominal) => 60 MHz
1.6 V => 80 MHz
(will be fixed by next submission)

Silicon Vertex Detector

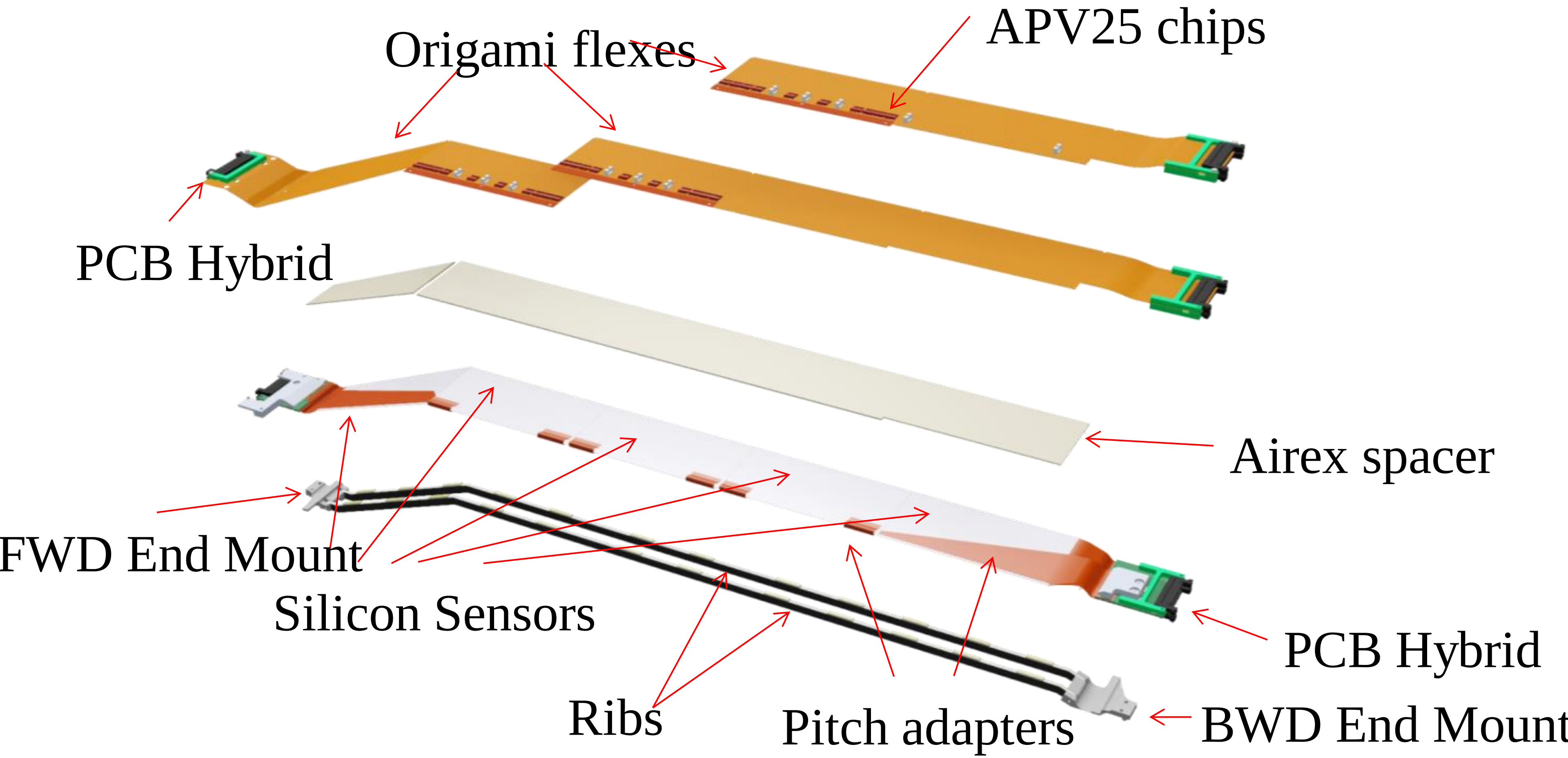
- Ladders
  - Latest version: Rev. 1.0
  - Ribs produced
  - BWD end mounts & L3 bridges in production
  - FWD sliding mech. under test
- End rings
  - Actual design to be used for thermal mockup
  - Some fine tuning required
- CF cones, end flanges, shell
  - First design exists
  - Production ongoing



Design will be finished in March.

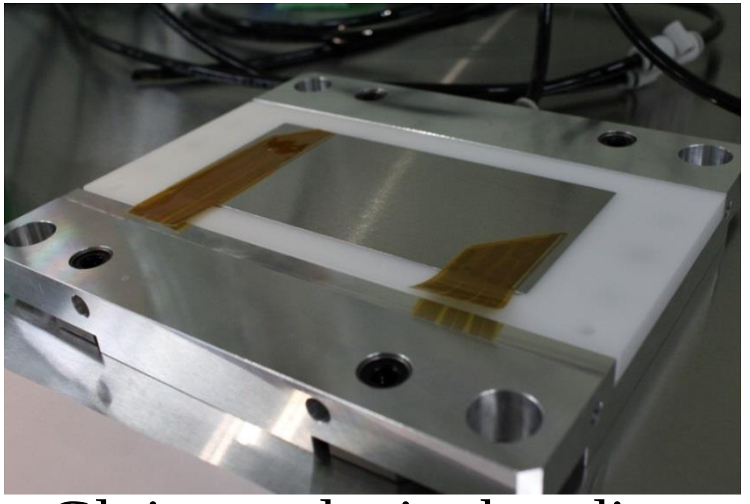
SVD ladder

- Longest ladder type (L6) shown here

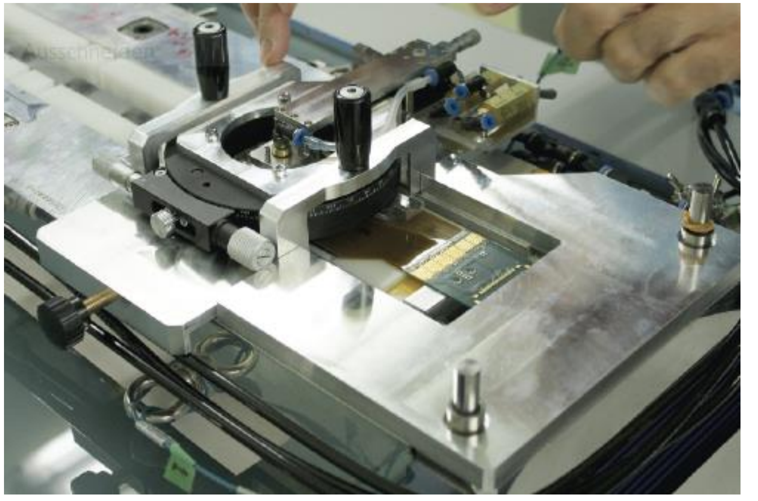


Ladder mass production is scheduled from July
Parts and jigs preparation is ongoing

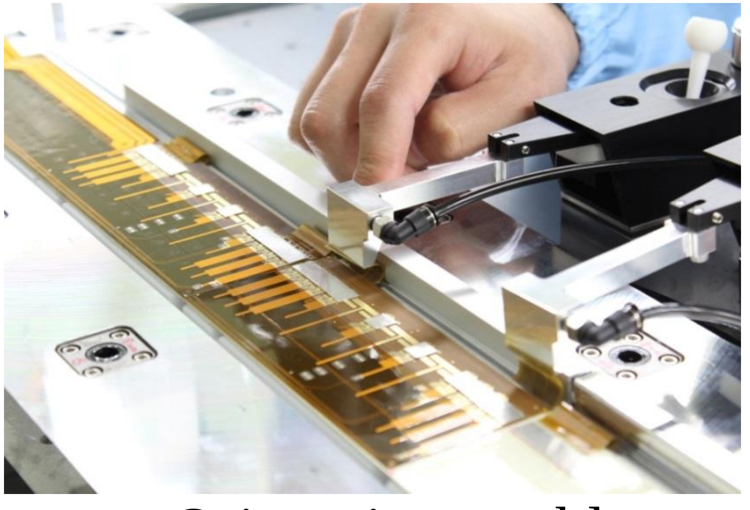
SVD ladder production



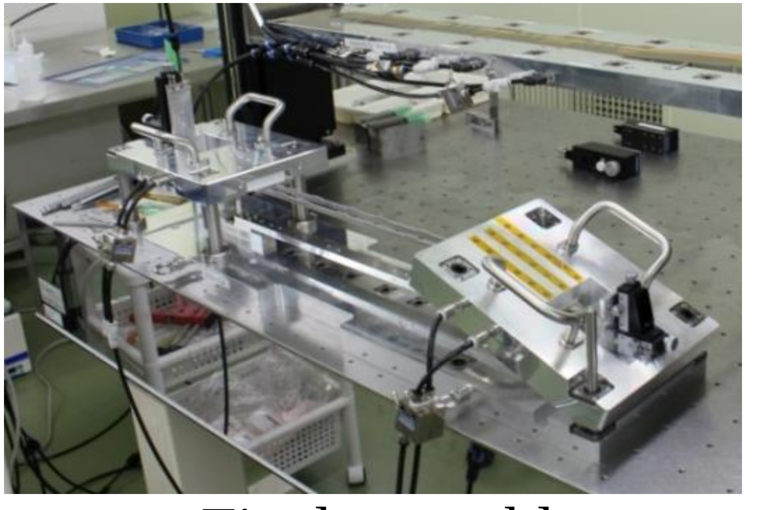
Gluing and wire bonding



Alignment



Origami assembly



Final assembly

VXD beam test (PXD,SVD,DAQ)

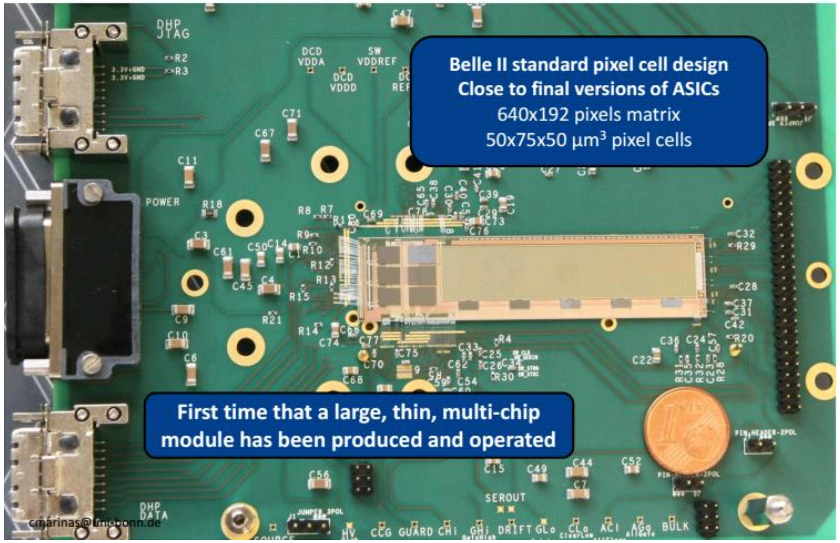
VXD common test beam in January 2014 (4 weeks)

- Small sector of the close to final prototype detectors and ASICs

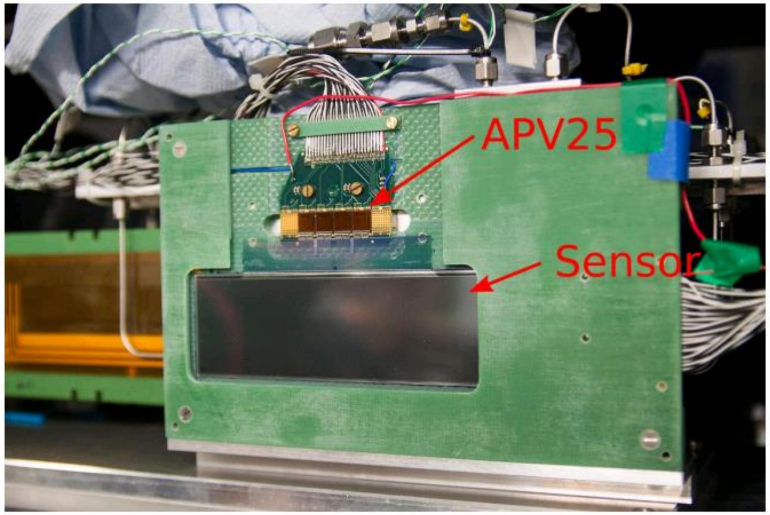
2 PXD half ladders + 4 SVD single module layers

- Complete VXD readout chain: HLT, monitoring, event building, PocketDAQ (Belle II DAQ downsized system)
- CO2cooling, slow control, environmental sensors
- Illumination with (up to) 6 GeV e under solenoid magnetic field
- Alignment, tracking algorithms, ROI for PXD readout

PXD6 on Hybrid 6



SVD Layer 3



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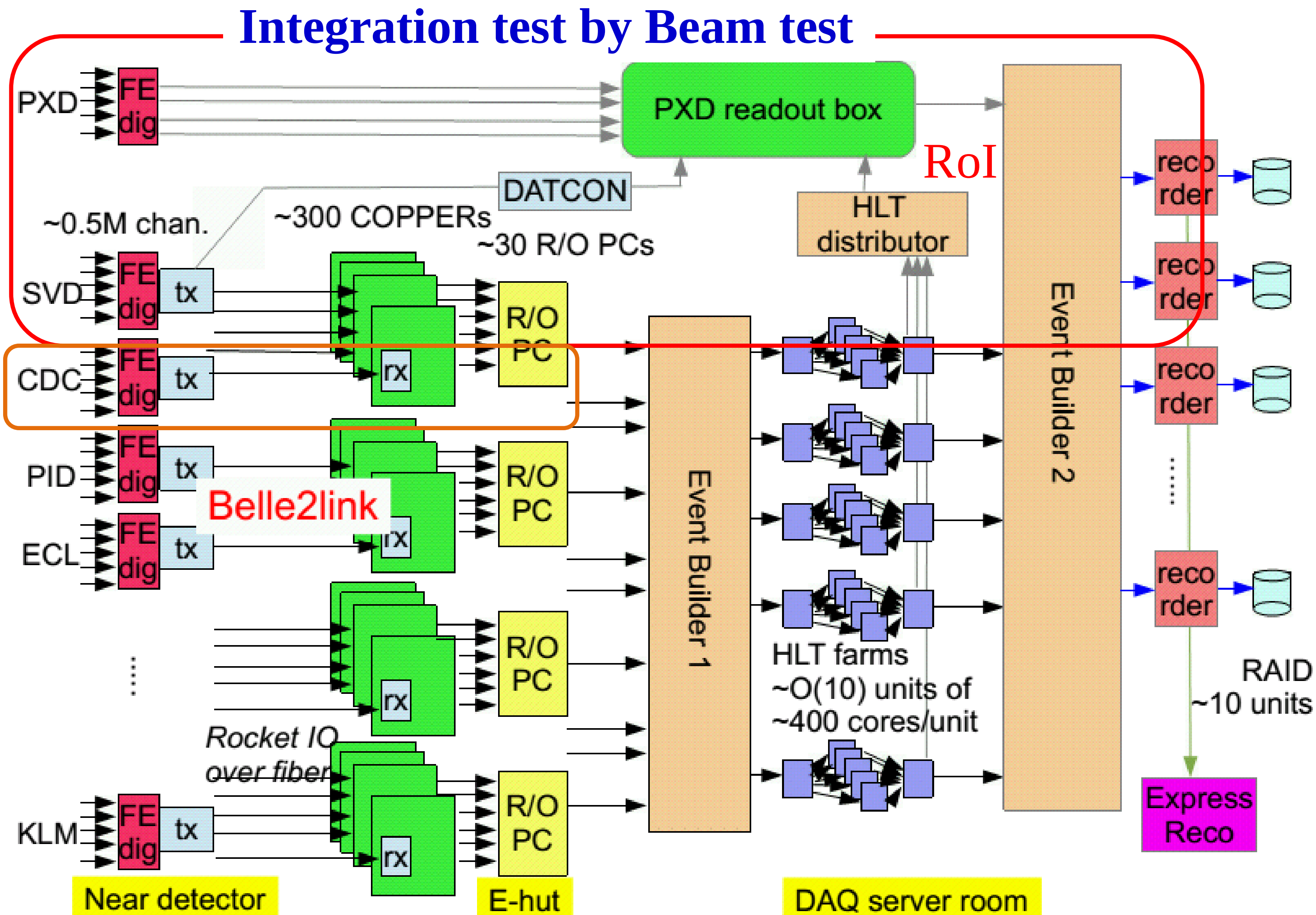
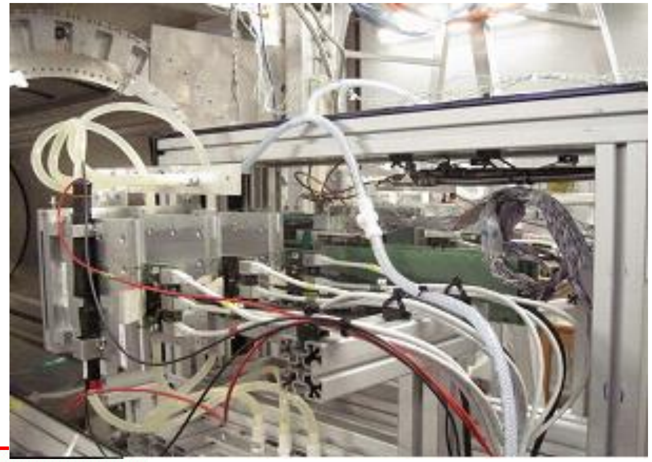
Belle II DAQ

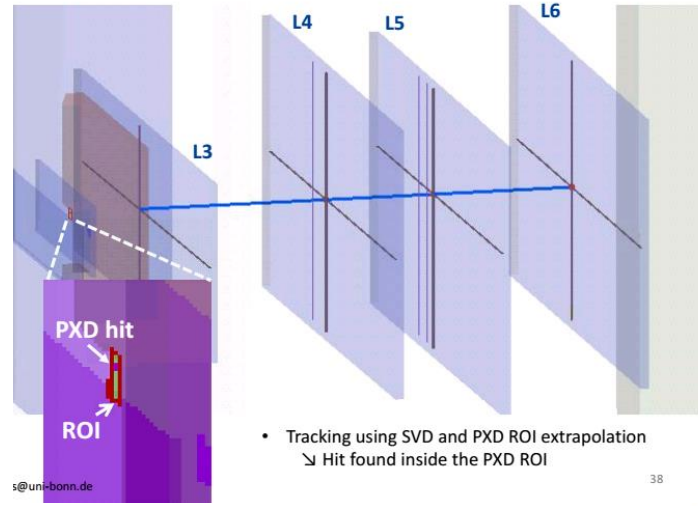


Integration test by Beam test
PXD
FE dig
PXD readout box
RoI
DATCON
HLT distributor
~0.5M chan.
~300 COPPERs
~30 R/O PCs
SVD
CDC
PID
ECL
KLM
tx
rx
R/O PC
Belle2link
Rocket IO over fiber
Event Builder 1
Event Builder 2
HLT farms
~O(10) units of
~400 cores/unit
reco rder
RAID
~10 units
Express Reco
Near detector
E-hut
DAQ server room

Test Beam VXD DAQ



Region Of Interest



- Tracking using SVD and PXD ROI extrapolation
  ↘ Hit found inside the PXD ROI

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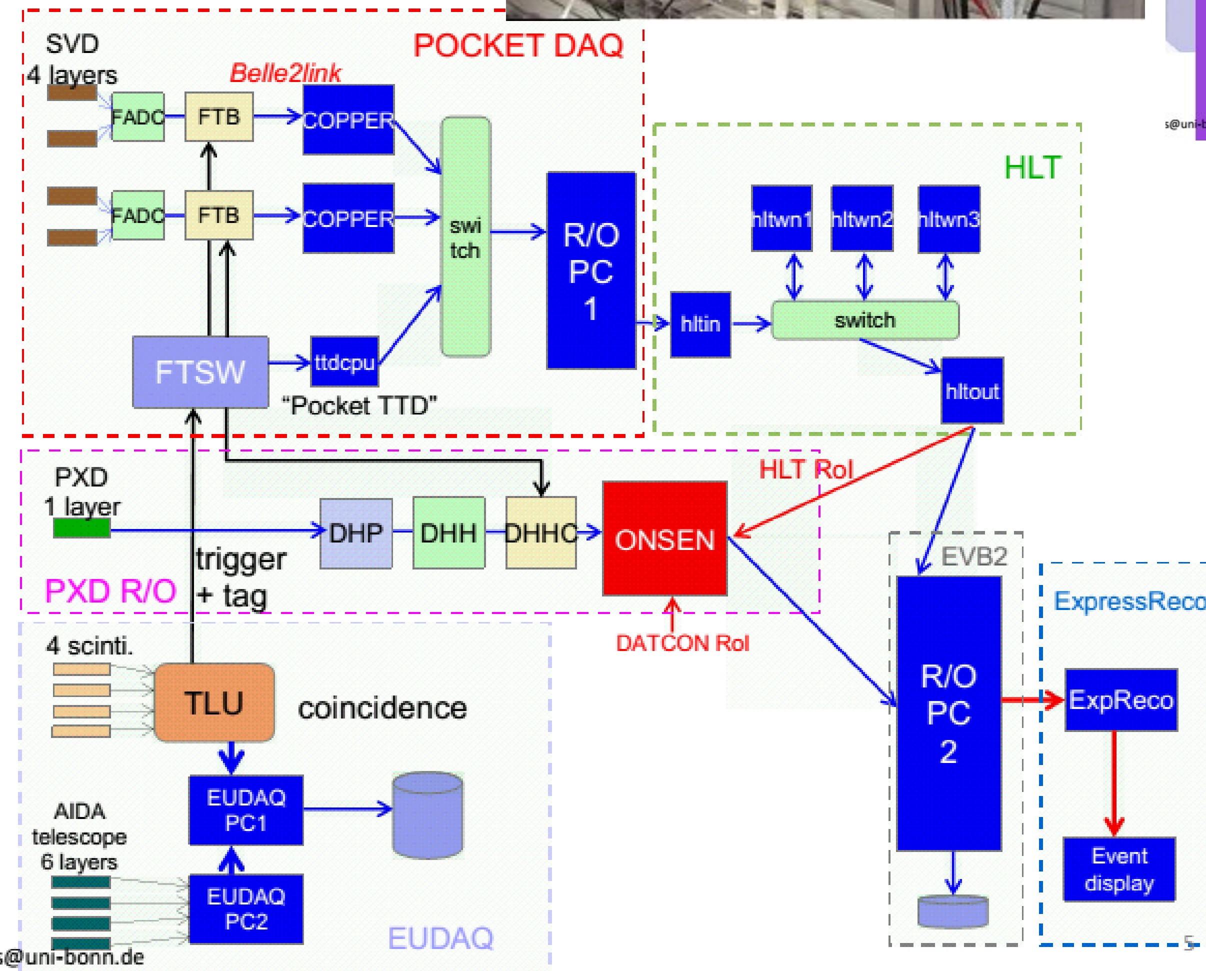
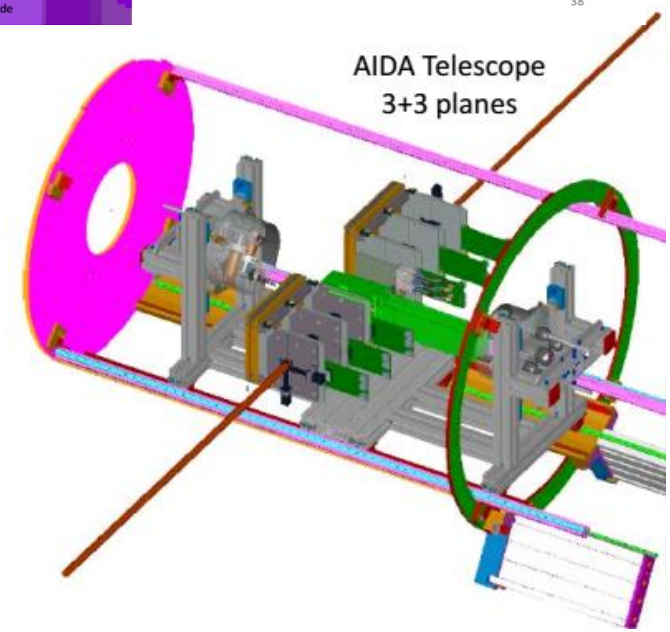
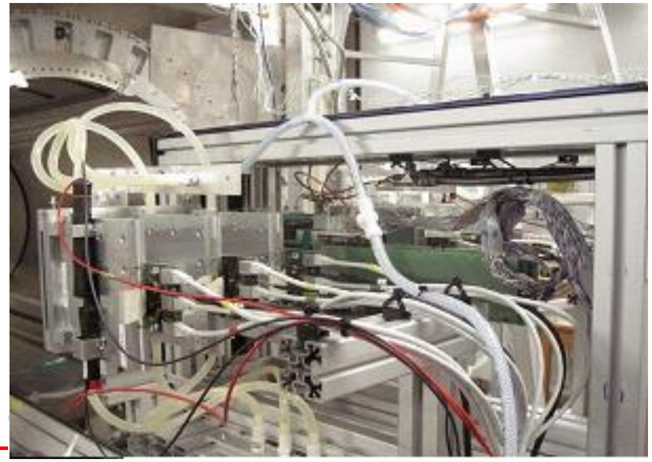
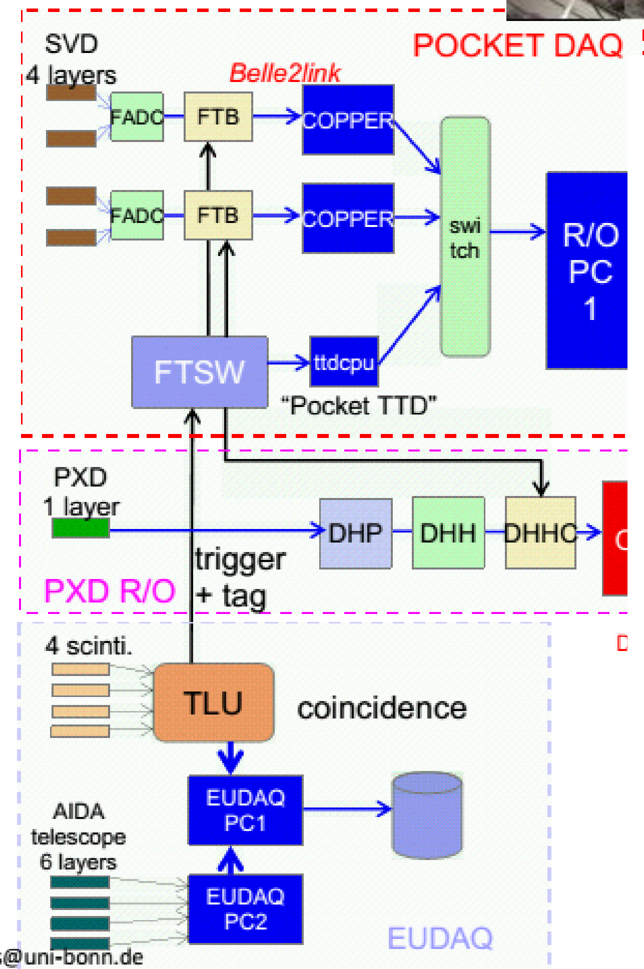




Test Beam VXD DAQ





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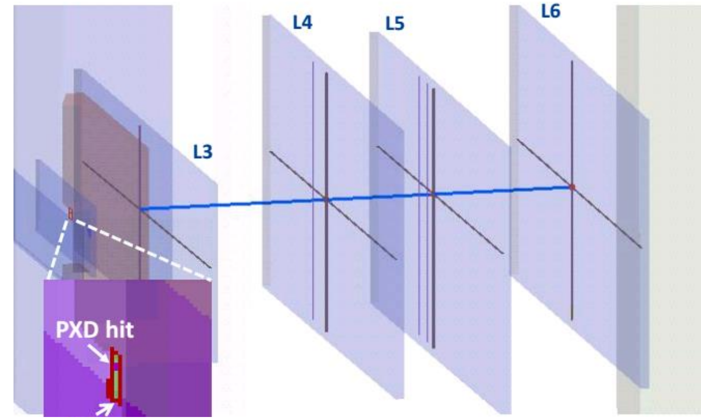
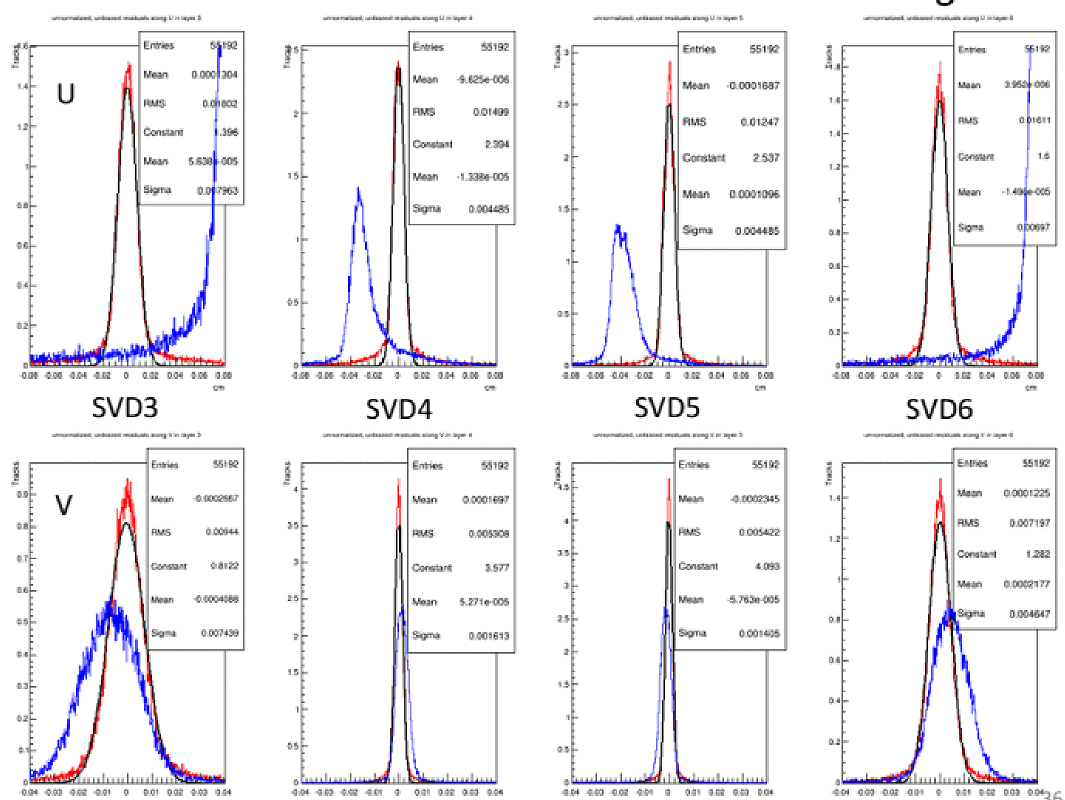
Region Of Interest



Alignment

Before and **After** alignment



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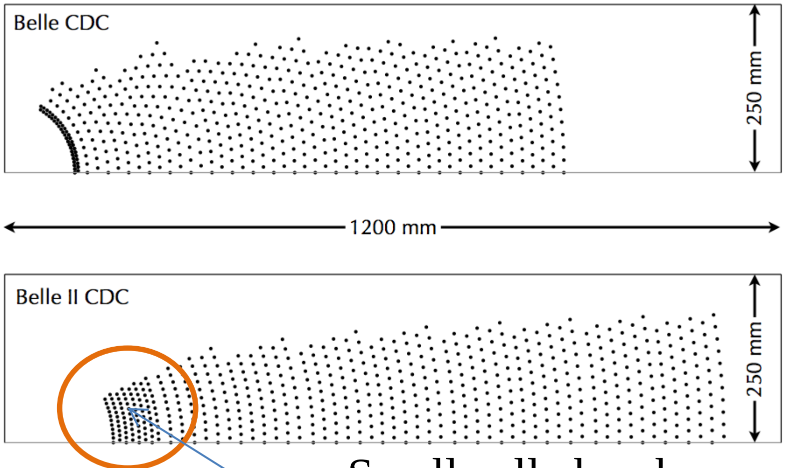
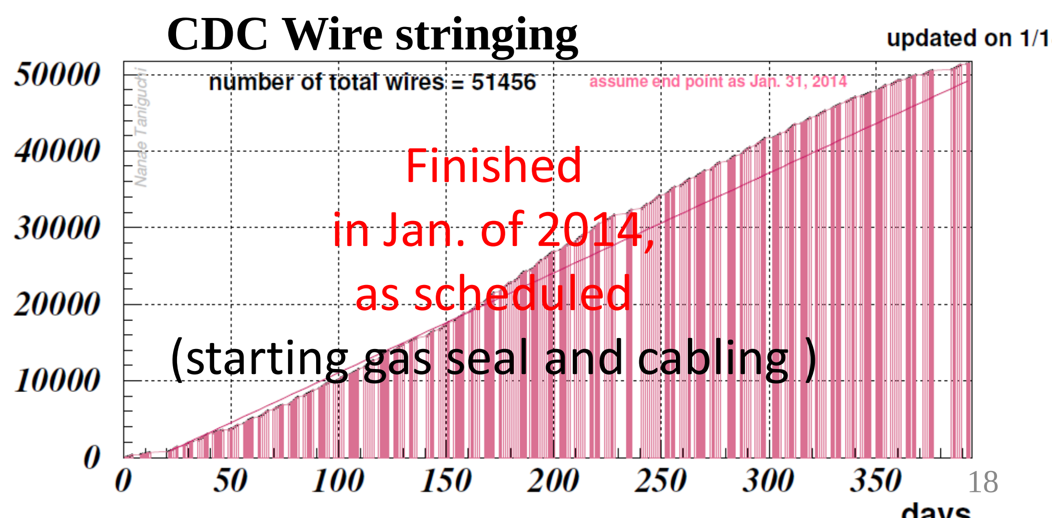
Central Drift Chamber



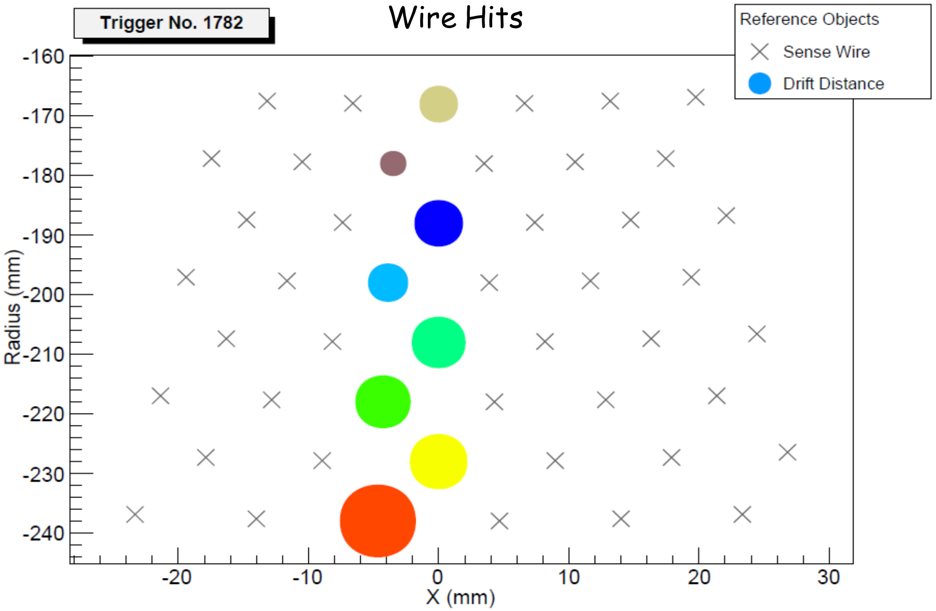
Small cell chamber
(short drift length for
high rate operation)

	Belle	Belle II
radius of inner most sense wire	88	168
radius of outer most sense wire	863	1111.4
Number of layers	50	56
Number of total sense wire	8400	14336
Gas	He:C_2H_6	He:C_2H_6
sense/field wire	W(Φ30μm)/Al(Φ120μm)	W(Φ30μm)/Al(Φ120μm)

new readout system
dead time 1-2μs → 200ns

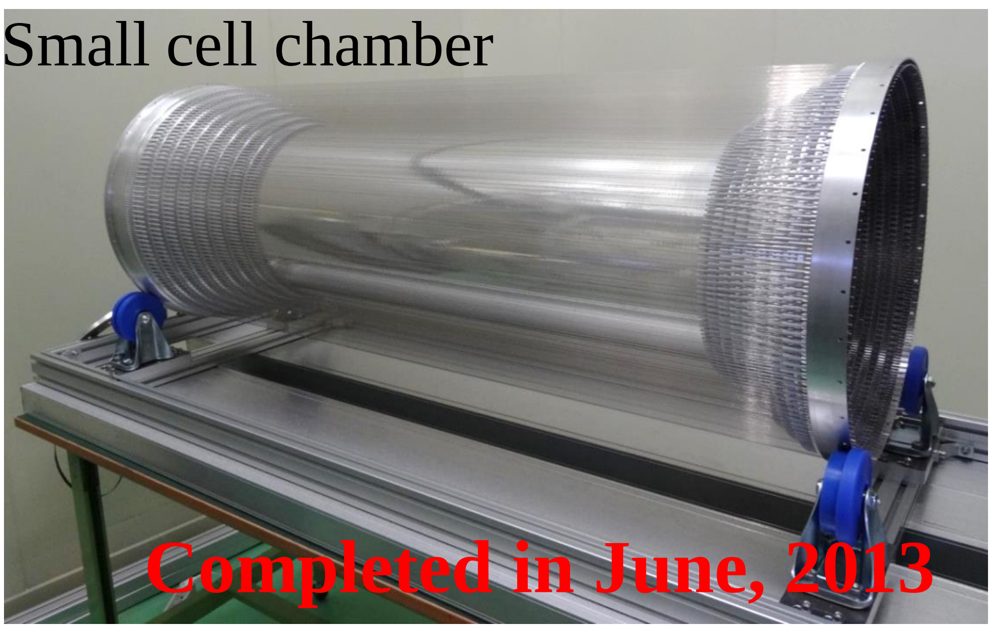


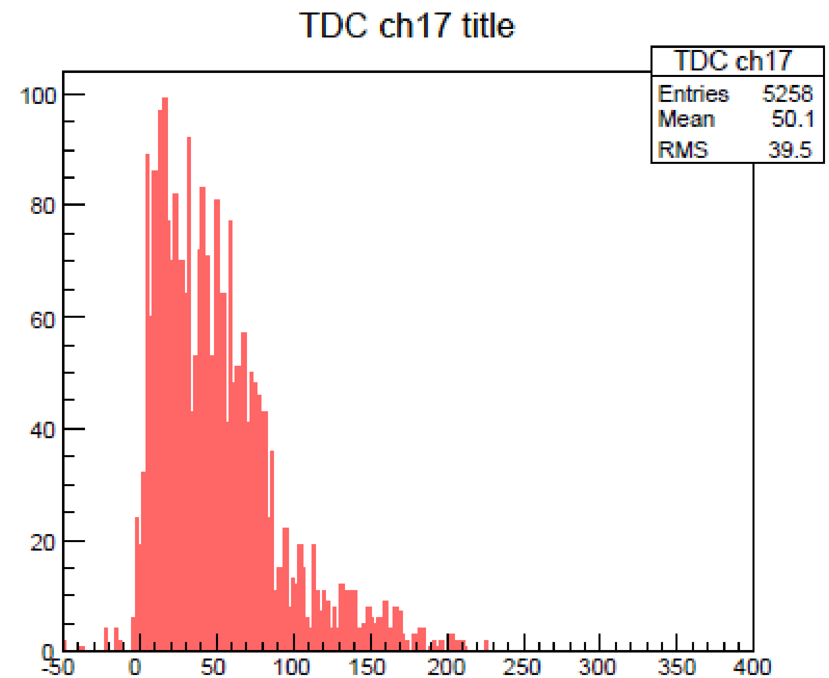
Cosmic ray test



- On the 1st of July, 2013,
  - He/C_2H_6 (50/50)
  - flow rate 40 cc/min
  - apply HV of 2.0kV

  we got the first signal!!



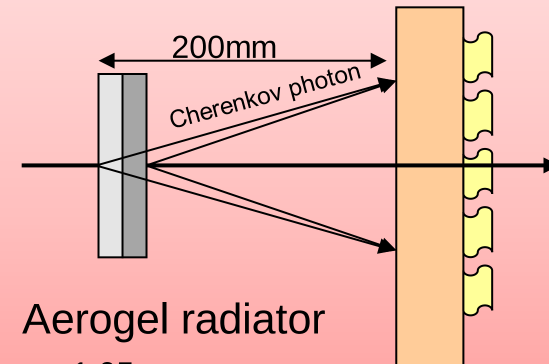


Particle ID

Barrel PID:
Time of Propagation Counter (TOP)

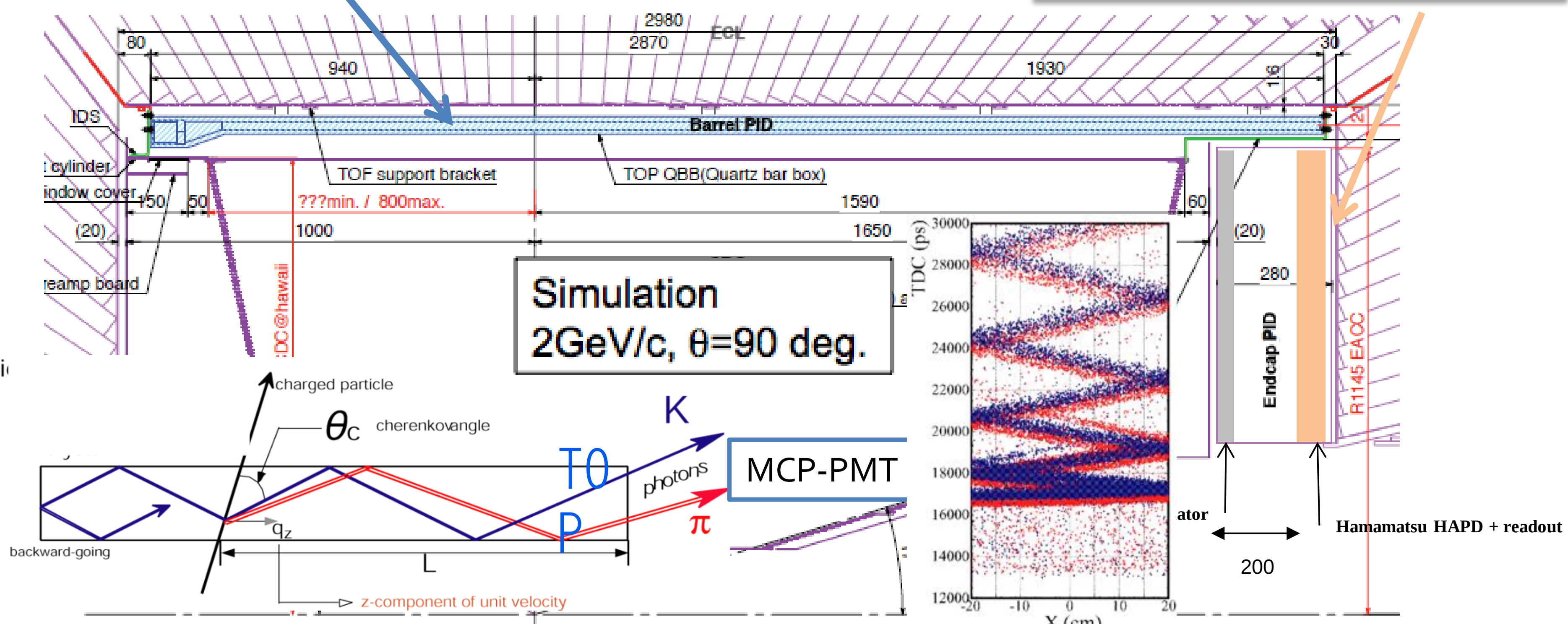
Quartz radiator

Endcap PID:
Aerogel RICH(ARICH)



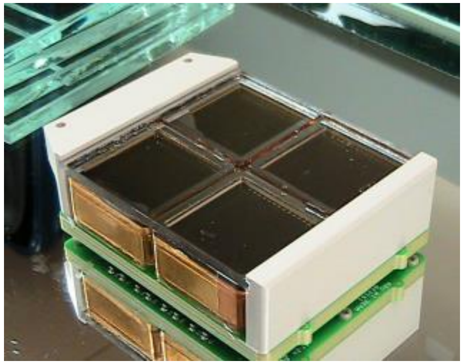
Aerogel radiator

n~1.05



Major Issues for the TOP System and milestones

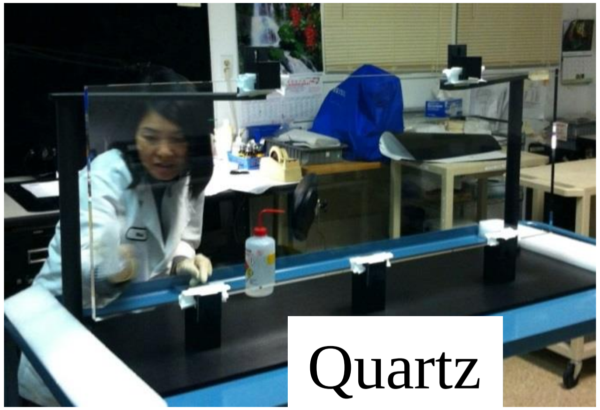
- Quartz Optics – production rate, quality
- MCPPMTs – production, lifetime
- GHz waveform digitizers (IRS ASIC) – timing, stability
- Mechanics – pristine environment for quartz, rigidity
- System performance – beam test results, physics performance



MCPPMT

DOE CD-2/3 review in March – final project review for production

ITT Mirror

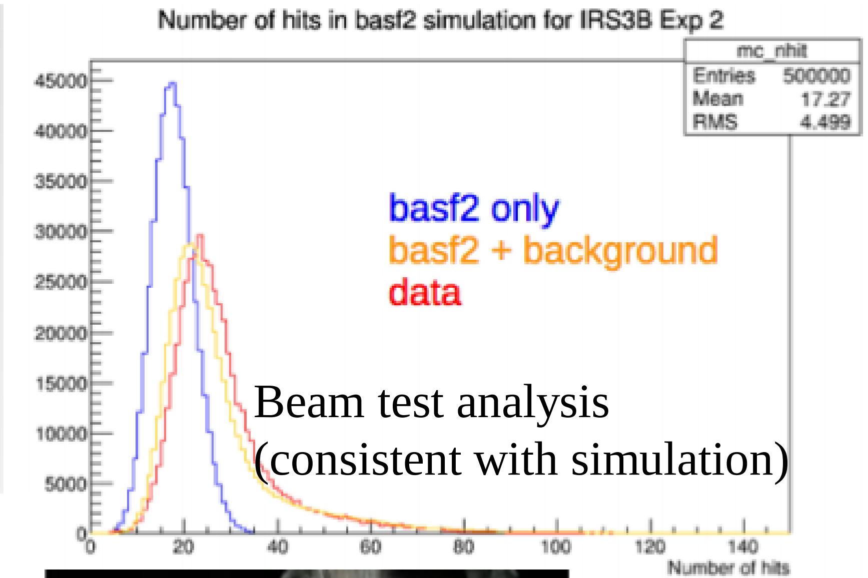


Quartz

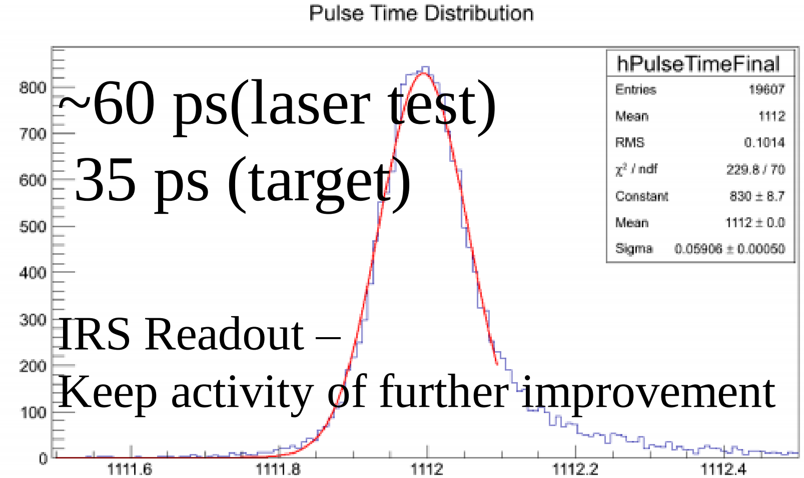
Milestones

Validation of quartz specifications – February BPAC
Validation of final board stack – End February 2014
CD-2/3 – IPR March 19/20; ESAAB in April
Module 1 assembly – April 2014
Production orders of quartz – April 2014
IRSX validated – May 2014
Beam test of Module 1 – July 2014
¼of modules completed – October 2014
½(+) of modules completed – March 2015
All modules completed – September 2015

TOP activities



Beam test analysis
(consistent with simulation)



~60 ps(laser test)
35 ps (target)

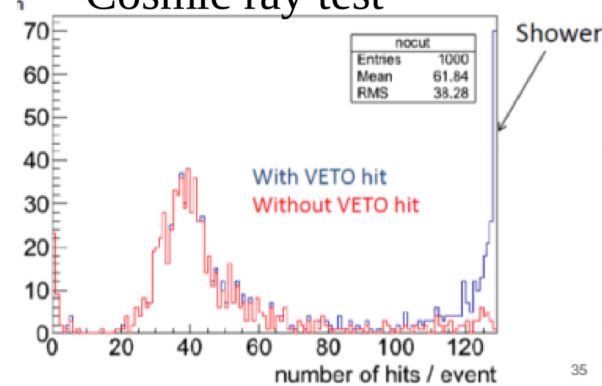
IRS Readout –
Keep activity of further improvement

Gluing test

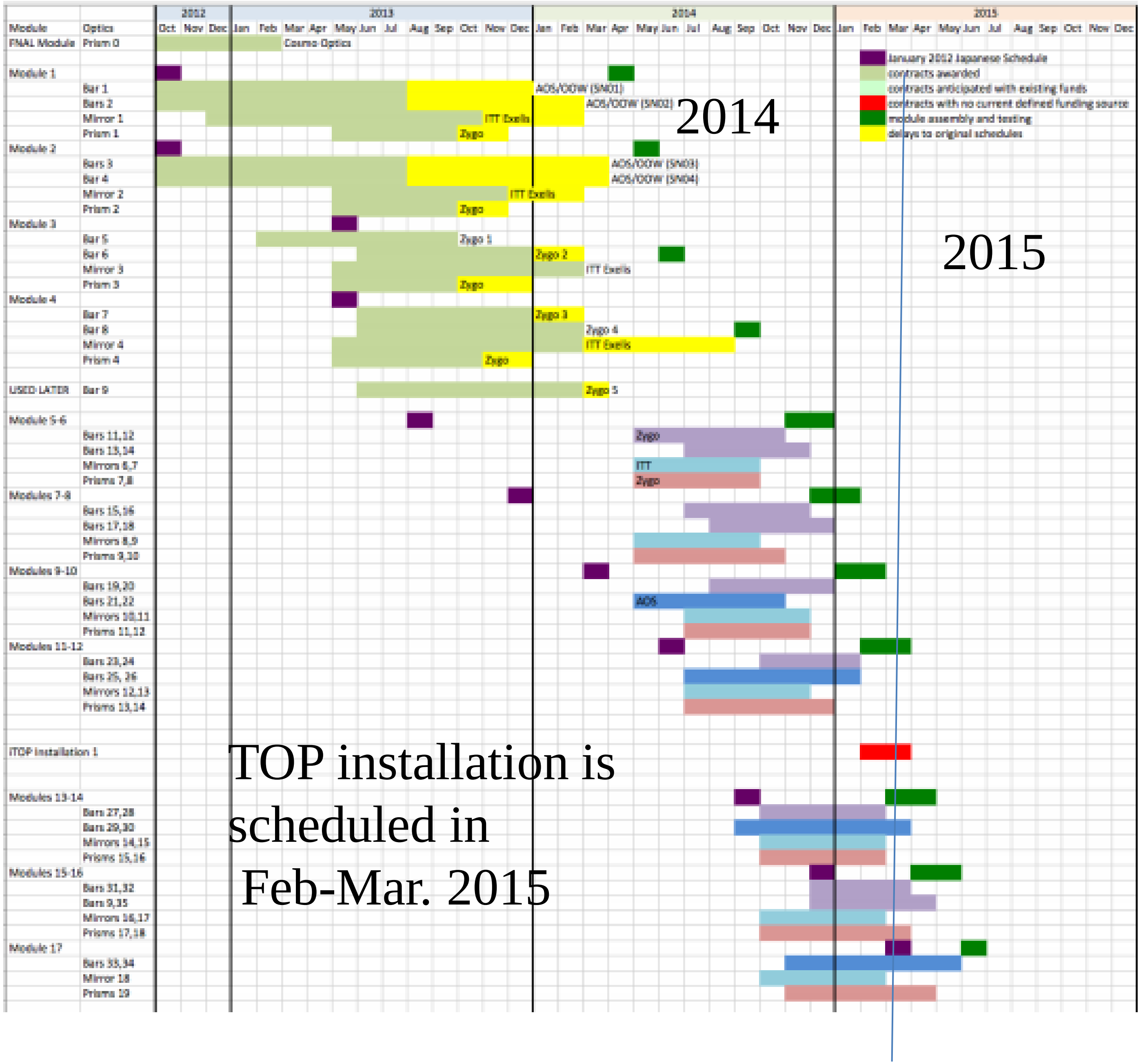
TOP mechanics for assembly

Installation test

Cosmic ray test



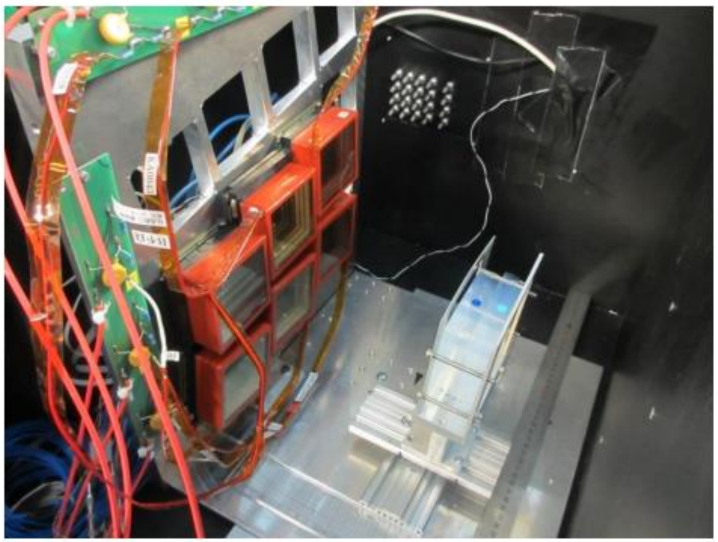
Monte Carlo expectation is 38 hits/event

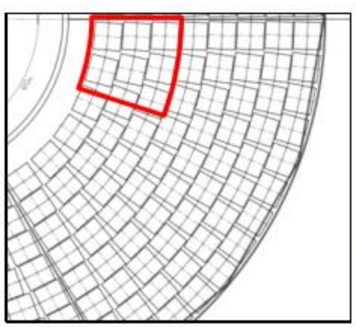


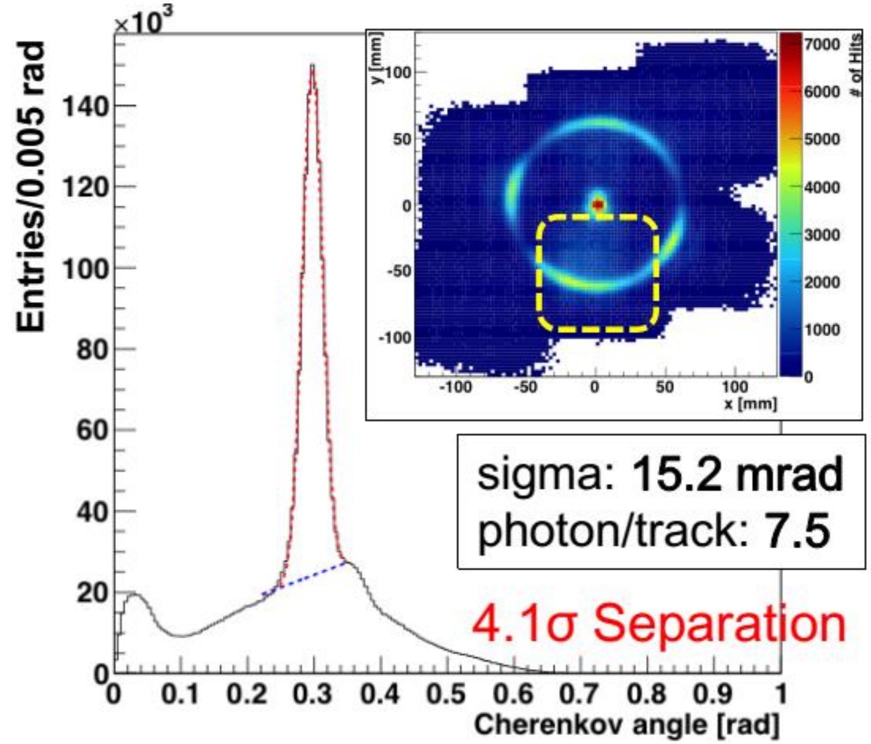
TOP installation is scheduled in Feb-Mar. 2015

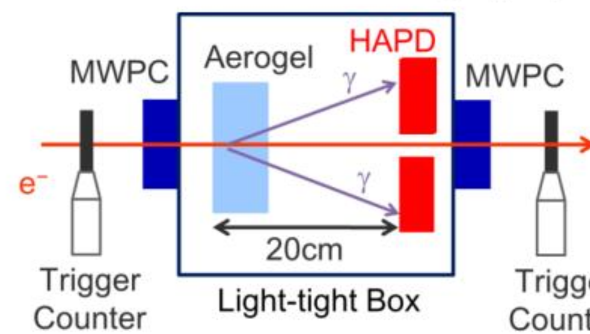
ARICH beam test @DESY

Beam test at DESY (May 2013)



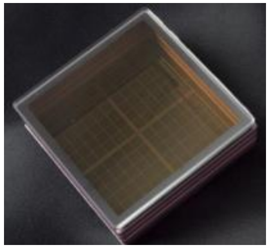




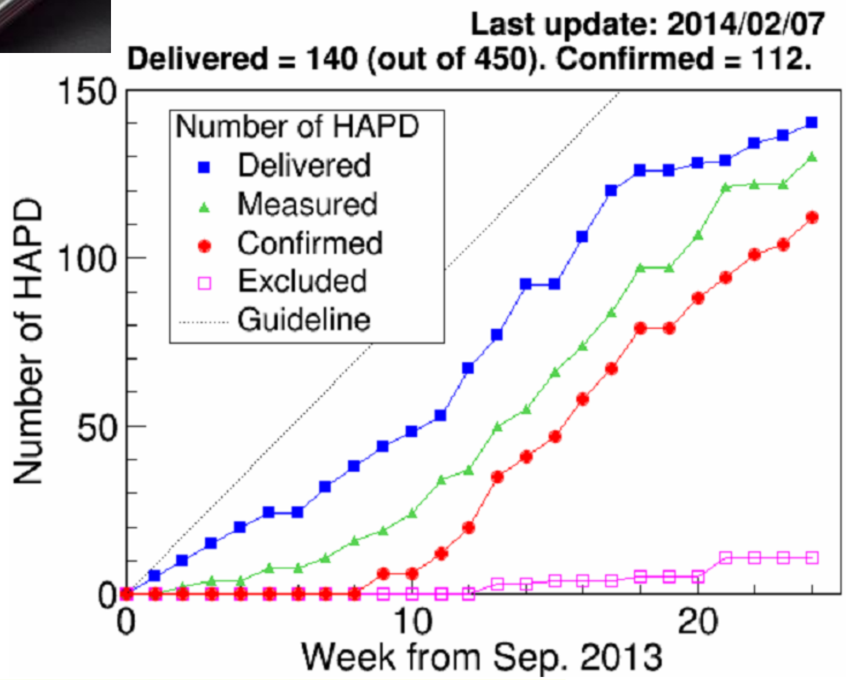


Also irradiated samples have tested

- Threshold level increased to the irradiated samples.
- No difference found in the detected number of photons.

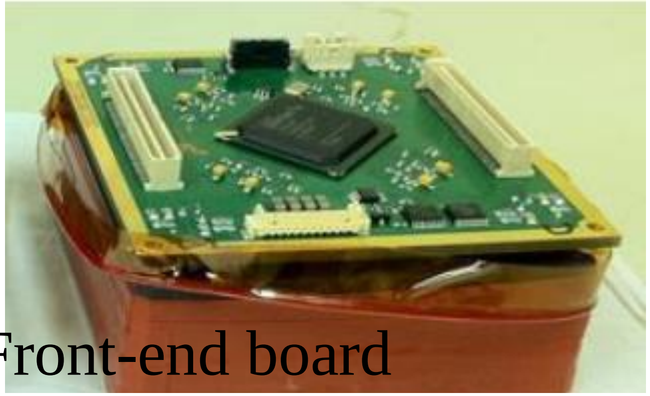


Mass production



2013 Sep-2014 Sep.

- 140 HAPDs were delivered.
- Delivery of all HAPDs before 2014 Sep. is possible (as far as the present problem is solved).



Front-end board

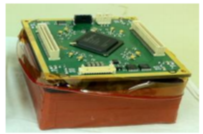
Mass production starts in June.

Design of the final version in Apr.

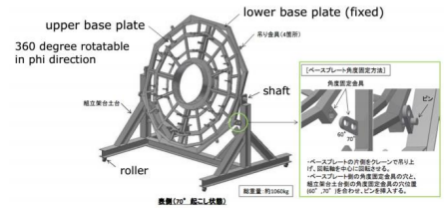
Merger board collects data from 5 or 6 FE boards, and send them to DAQ through Belle2Link.

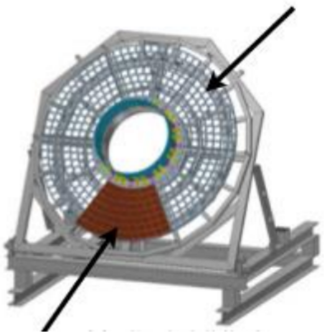
ARICH assembly and installation

Attach FE board to the HAPDs and then make a test [2014 Jul-Oct]



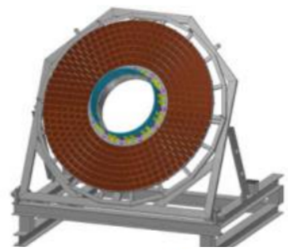
Mechanical structure (and supporting system) is now under construction and will be ready in Sep. 2014.



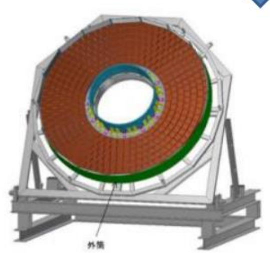


HAPD installation for one sector (sextant) [2014 Oct-].

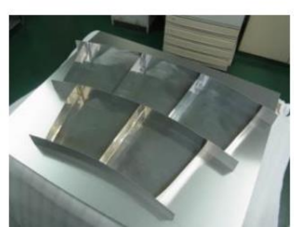
- Monitor system should be installed first.
- Apply HV and guard for all 70 HAPDs and make a test.



Repeat the procedure for all the sectors.

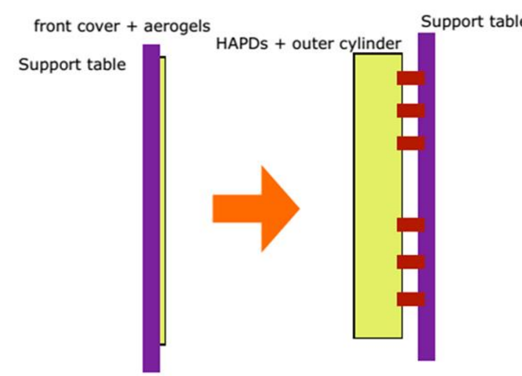


Install mirror and outer cover



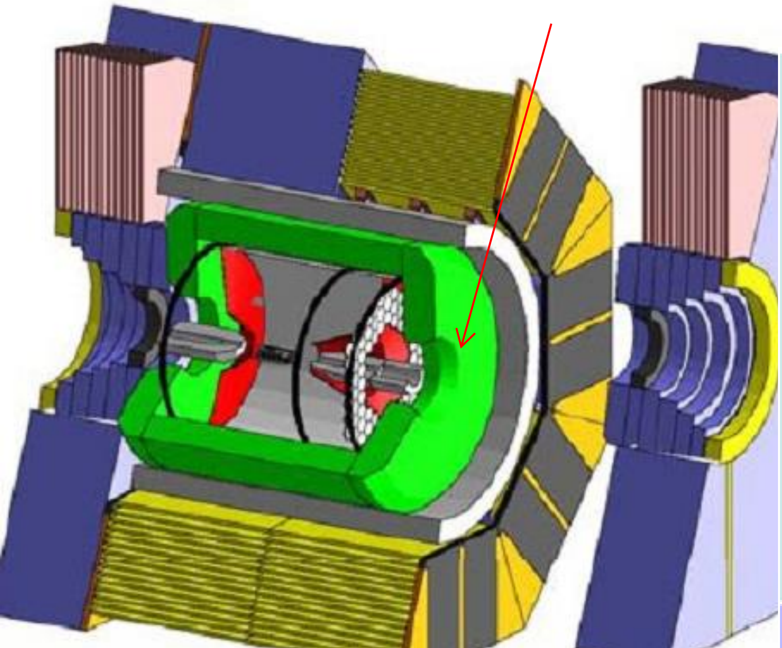
Install Aerogels to the front cover.

Assembly with front cover (aerogels), cabling, install mergers. [2014 Dec]

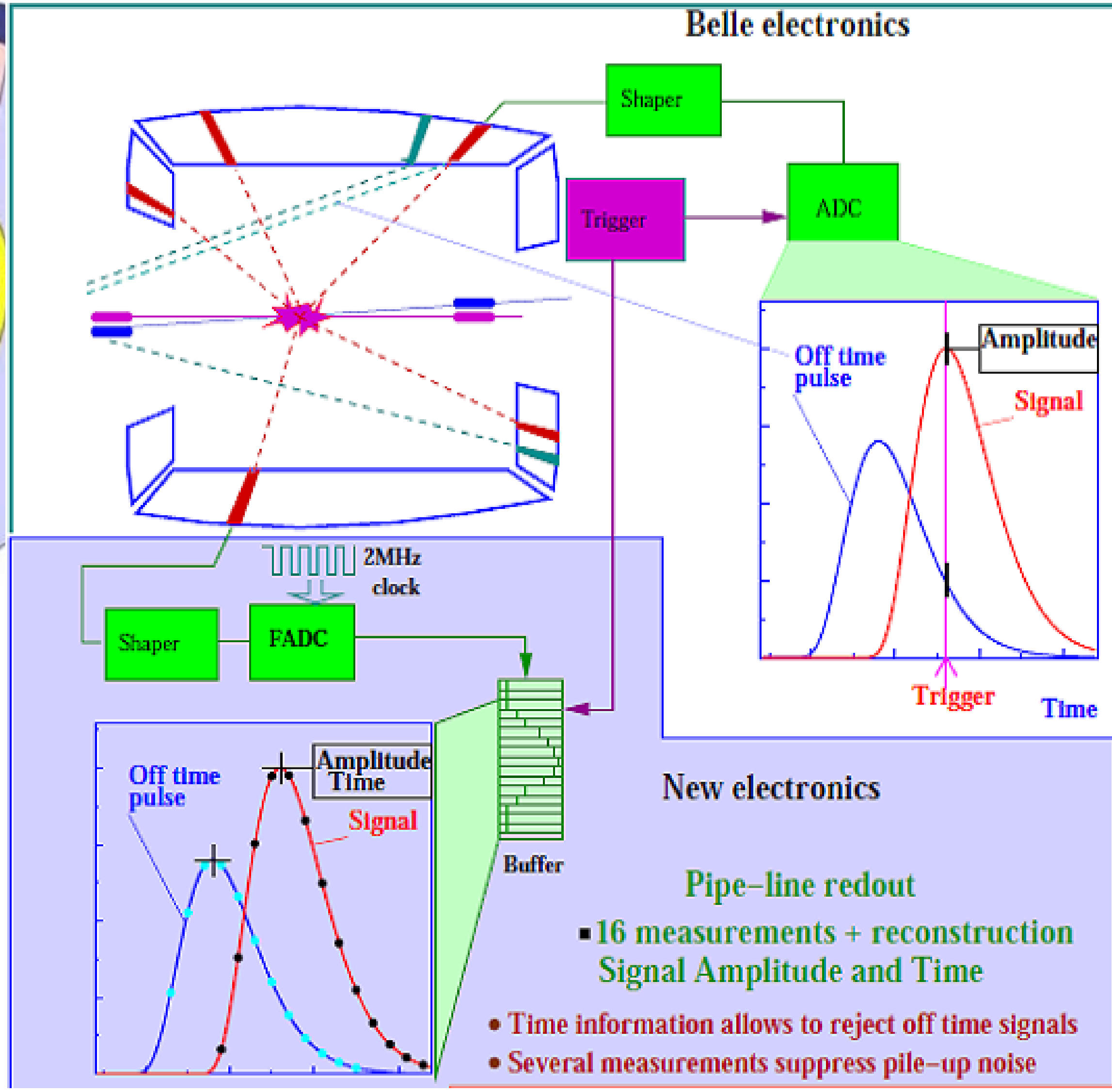


Full System Test (2015 Jan)

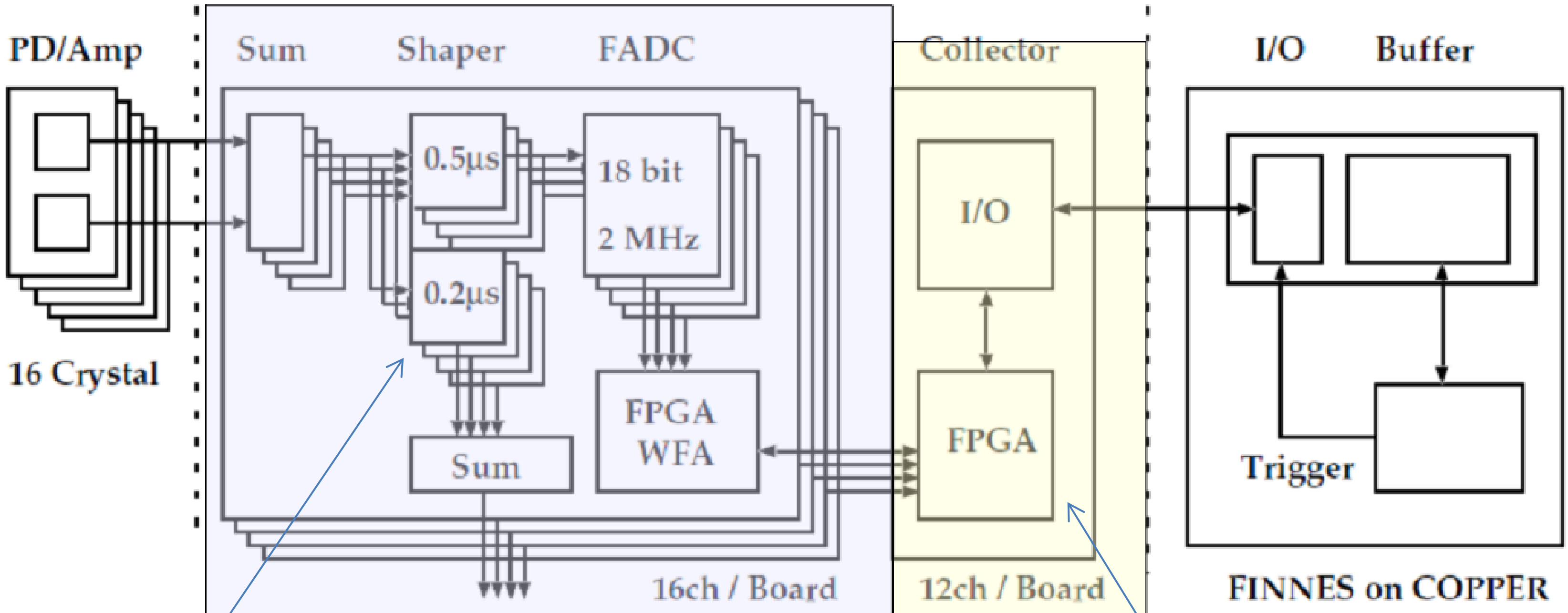
ECL



	PureCsI	CsI(Tl)
Density(g/cm3)	4.53	4.53
Radiation length(cm)	1.86	1.86
Wave length(nm)	300	560
# of photons(NaI(Tl)=100)	3.7	165
Attenuation time(ns)	～10	1300



Belle II ECL electronics

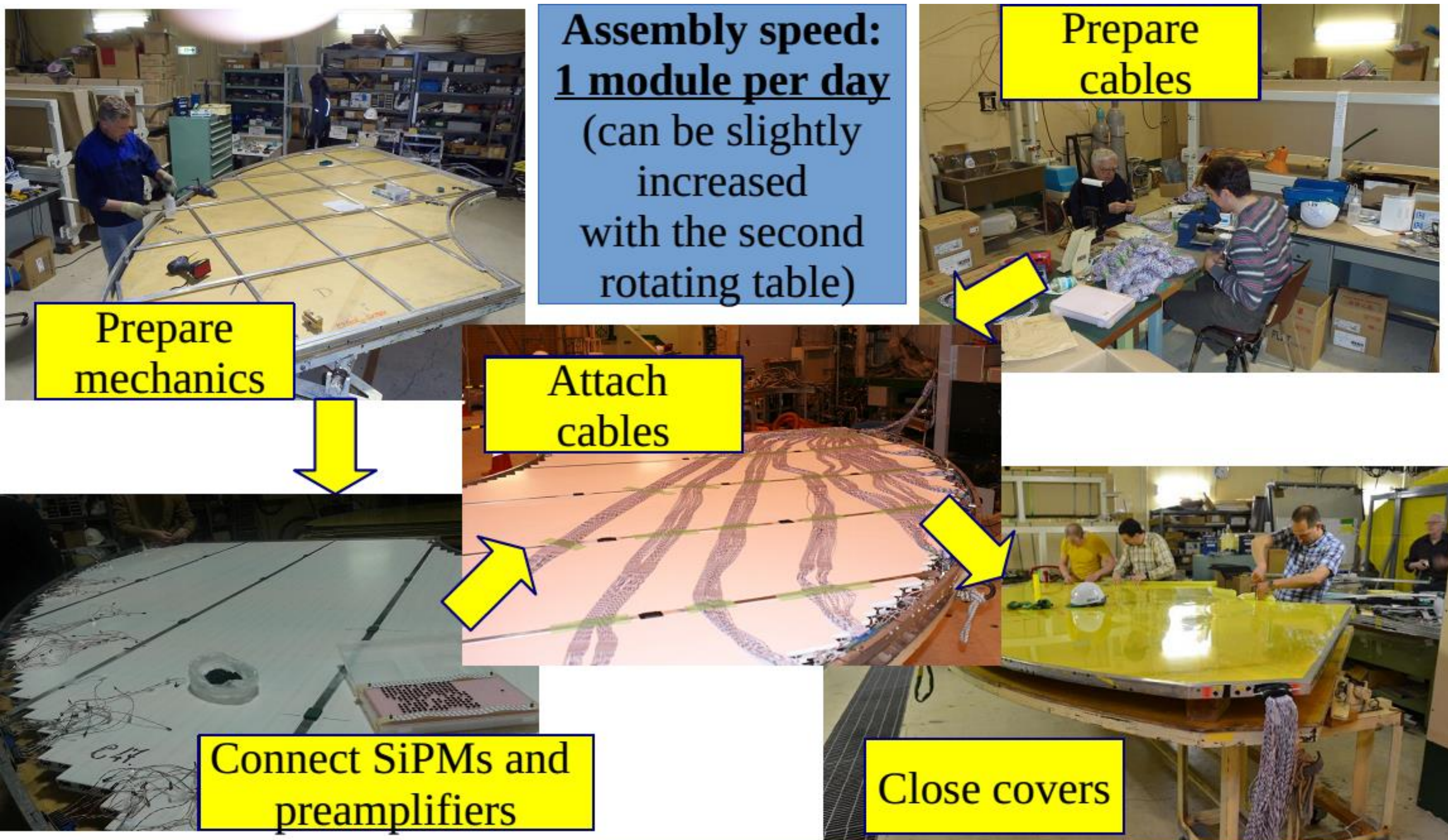


58 barrel modules+140 endcap modues will be produced in 2014

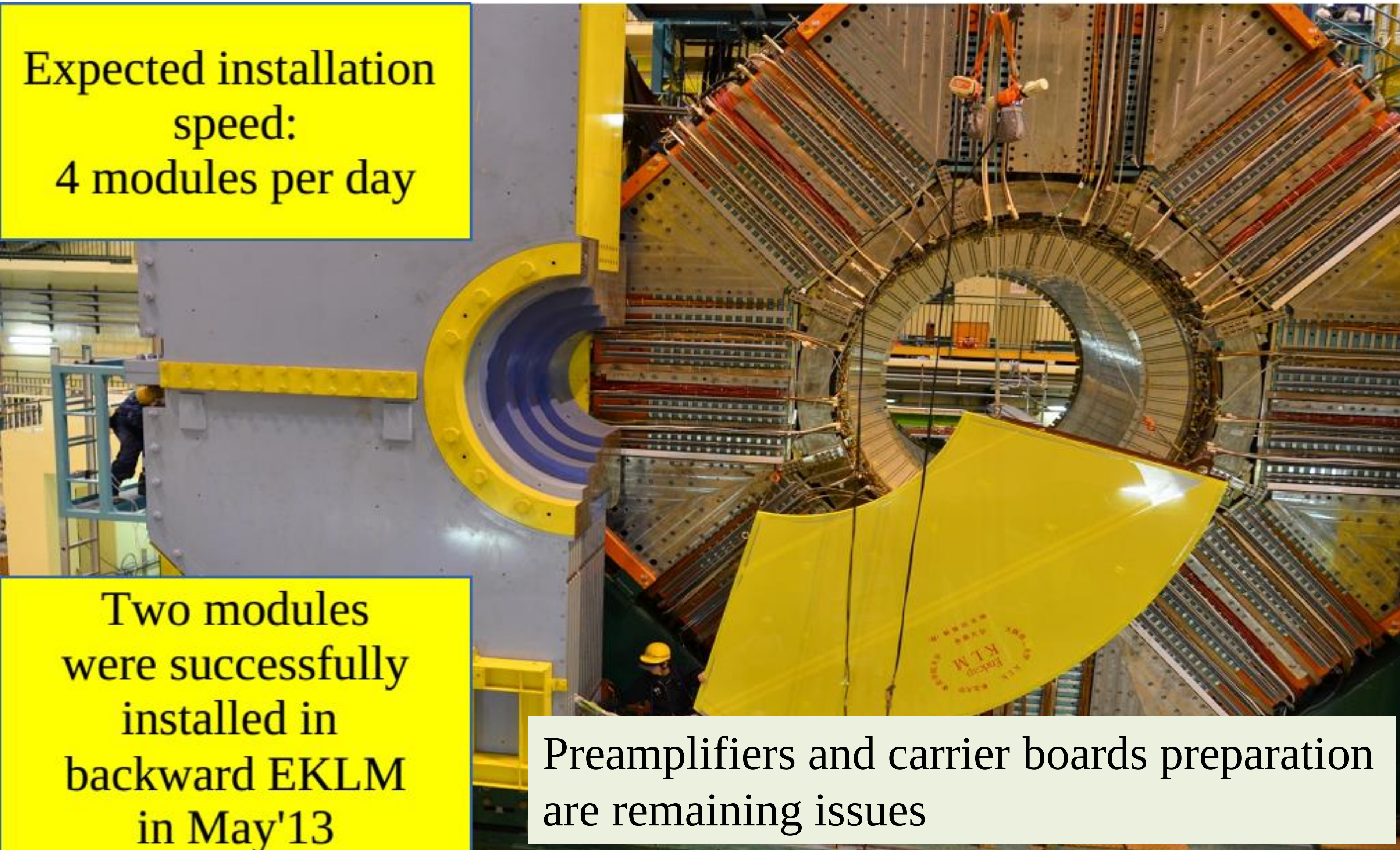
-All functions were tested last year

-belle2-link performance has been tested up to 30 kHz trigger rate last December

EKLM module assembly@ KEK



EKLM sensor replacement



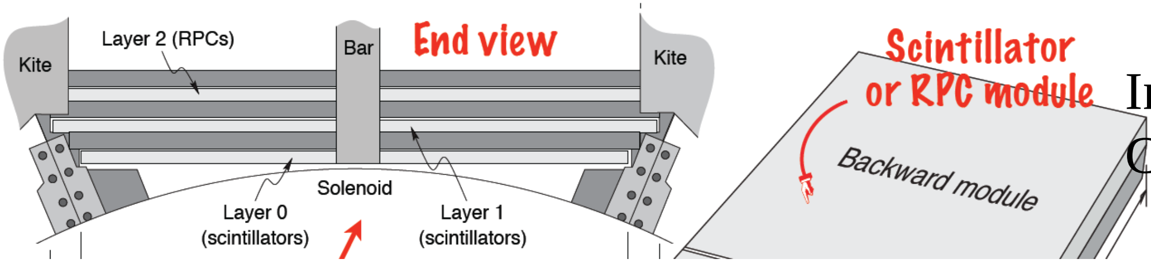
Expected installation speed:
4 modules per day

Two modules were successfully installed in backward EKLM in May'13

Preamplifiers and carrier boards preparation are remaining issues

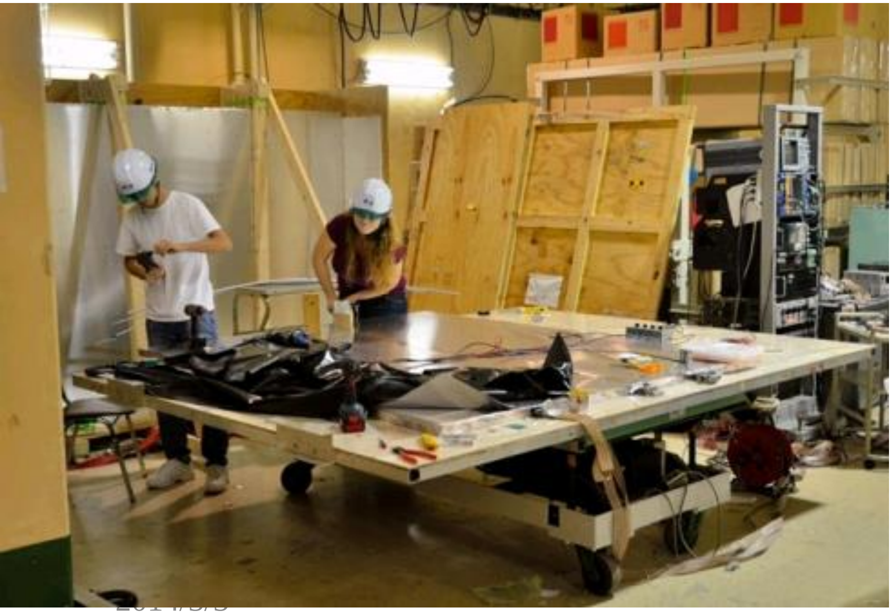
BKLM

Barrel KLM: Replace layer 0 and 1 RPCs with extruded-strip scintillator detectors within the same form-factor modules as the existing RPCs



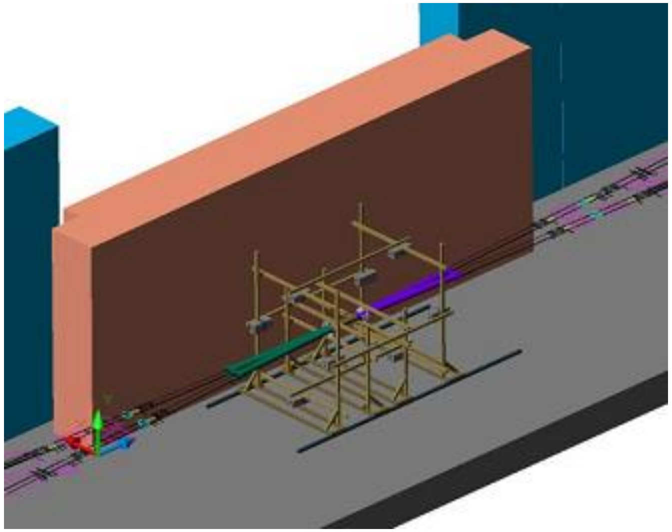
1 dead channel found by test after installation (3000 channels)

Integration test +
Cosmic ray test is ongoing



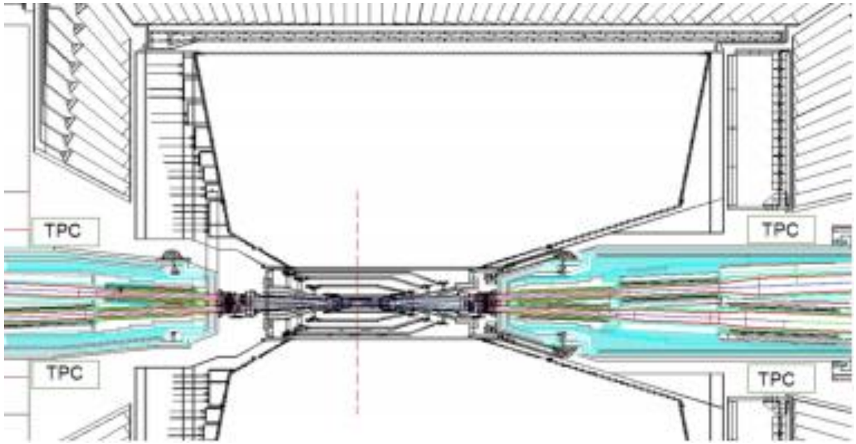
BEASTII

BEAST phase 1 ~2015 Jan.



BG monitoring on vacuum scrubbing
Belle is not installed

BEAST phase II ~2016 Feb.



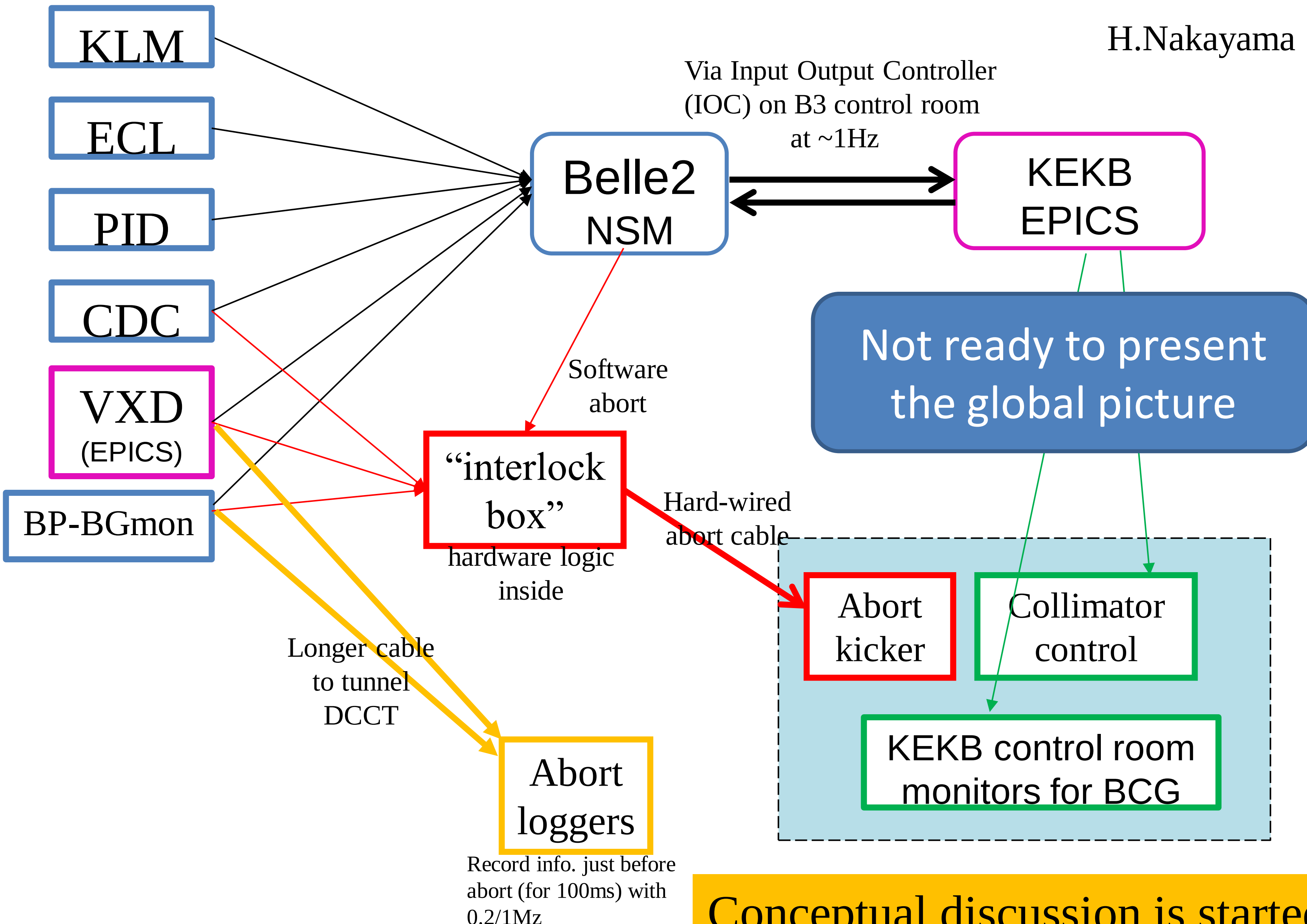
No VXD detector
BelleII DAQ test start without VXD
Beam abort setting optimization
BG study by BEAST sensors

BEAST systems: 8 BGO crystals, 2 TPCs, 1-2 He-3 tubes, BEAST DAQ, PIN diode

PIN diodes / loss monitors:
TPCs: fast neutrons
He-3 tubes: thermal neutrons
VXD test sensors
BGO for luminosity measurement
Diamond sensor for VXD abort settings

New activity

Data flow diagram(monitor)



Conceptual discussion is started

Summary

- Installation of sub-detectors started (KLM)
- Sub-detectors will be installed by June 2015; roll-in in July 2015
  - (other than VXD system, part of TOP)
- Schedule is tight for VXD (SVD ladder, PXD sensor) and TOP (quartz production)

Belle II Collaboration

23 countries, 95 institutes, 599 collaborators

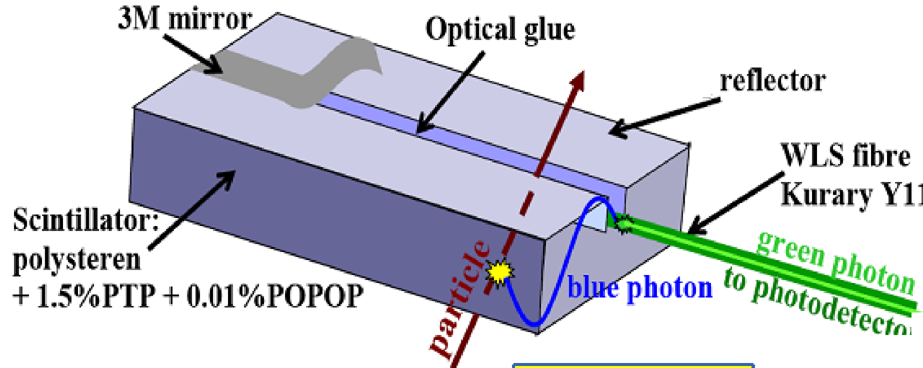
(as of 2014.01.24)

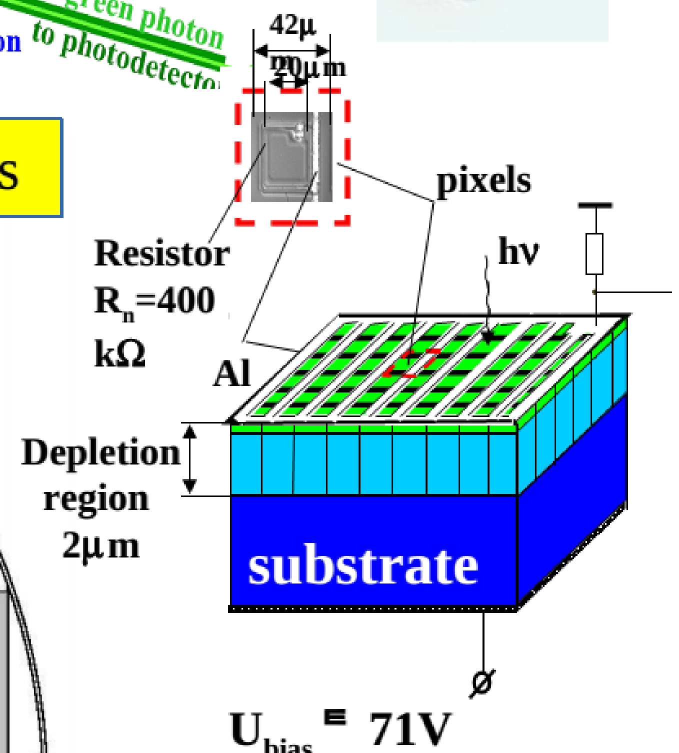
20 countries, 70 institutes, ~450 collaborators in 2013

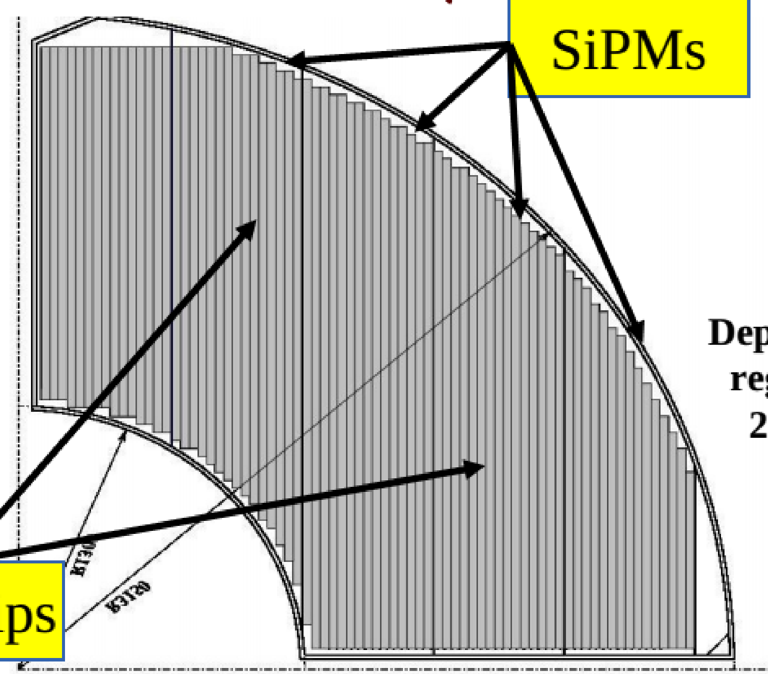
End-Cap KLM

TDR efficiencies for RPC

Layer	Endcap forward	
	KEKB	SuperKEKB
0	0.91	0.0
1	0.93	0.0
2	0.94	0.0
3	0.94	0.0
4	0.94	0.0
5	0.92	0.0
6	0.93	0.0
7	0.92	0.0
8	0.92	0.0
9	0.90	0.0
10	0.87	0.0
11	0.82	0.0
12	0.78	0.0
13	0.77	0.0
14	N/A	N/A



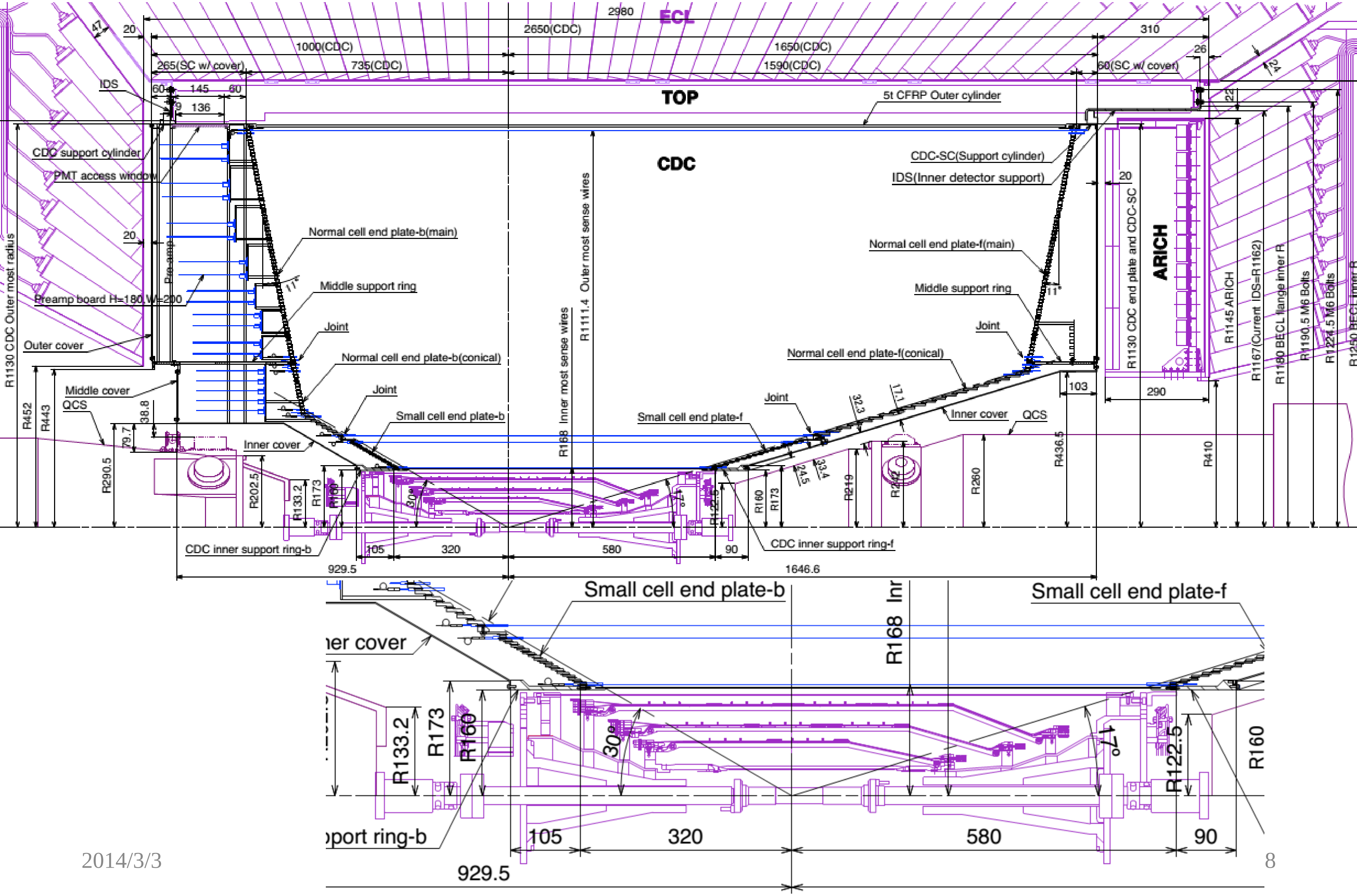




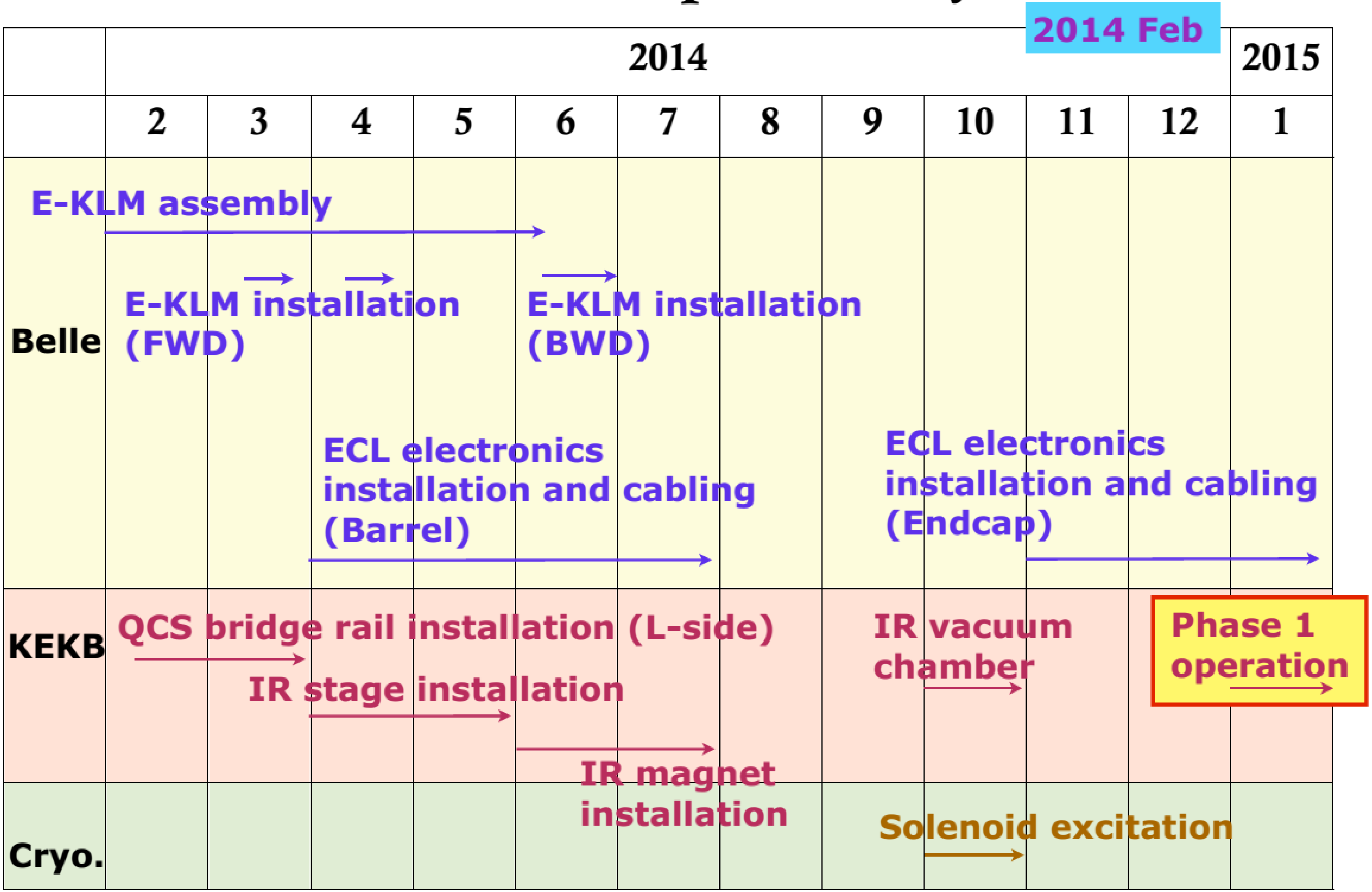
Highlights since last review

- Belle Rotation (Mar.)
- Belle roll-out (May)
- B-KLM module installation successfully completed (Nov.)
- CDC wire stringing completed (Jan.)
- VXD beam test at DESY (Jan.)

Belle II detector (inside of KLM)



Schedule in Tsukuba Exp. Hall : 1 year from now



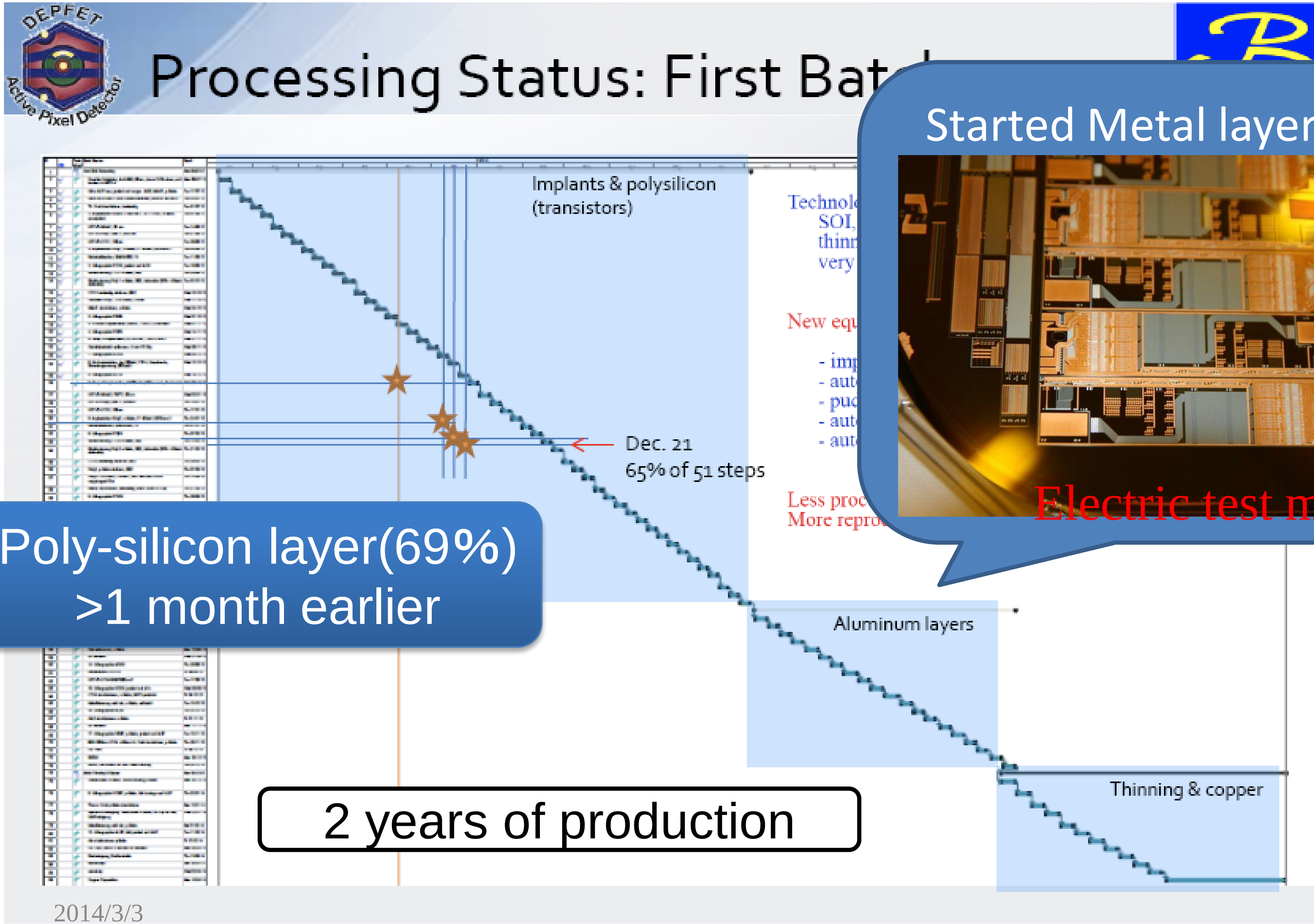
Construction Schedule

[2013]
- KLM installation: ~Jun. 2014

[2014]
- ECL barrel electronics installation: Apr.– Aug. 2014
- ECL endcap electronics installation: Dec. 2014– Mar. 2015

[2015]
- ARICH installation: Feb.–May 2015
- *Endcap ready for installation: summer 2015*
- TOP installation: Feb–Mar. 2015
- CDC installation: Apr–May. 2015
- SVD/PXD ready at KEK: Aug. 2015
- *VXD integration, ready for installation: autumn 2015*
- Belle II DAQ integration, commissioning, …

PXD: Production



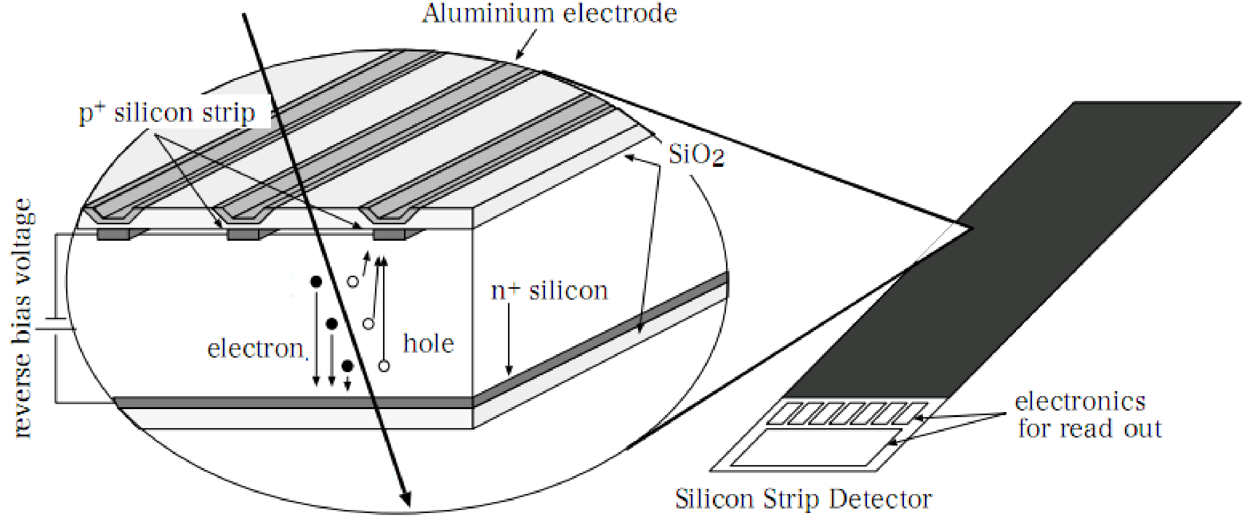
Poly-silicon layer(69%)
>1 month earlier

2 years of production

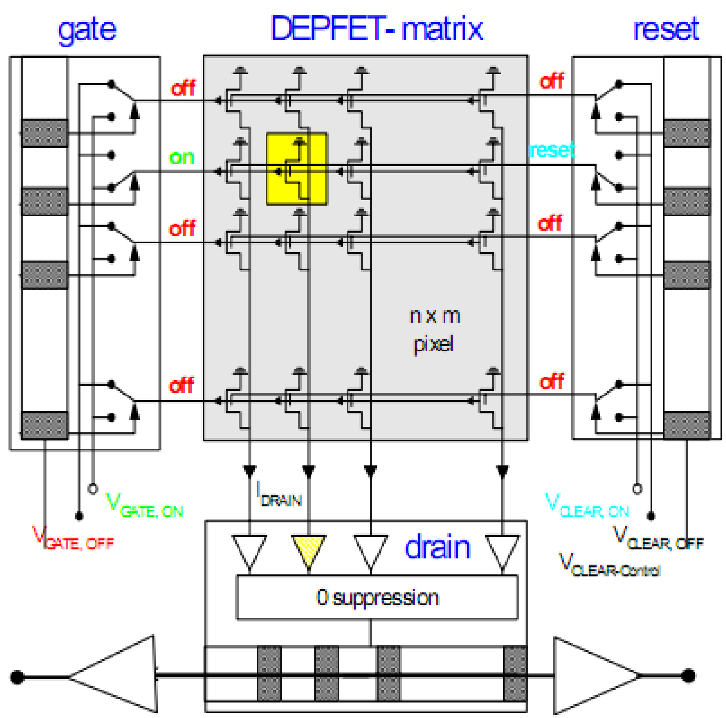
Started Metal layer test

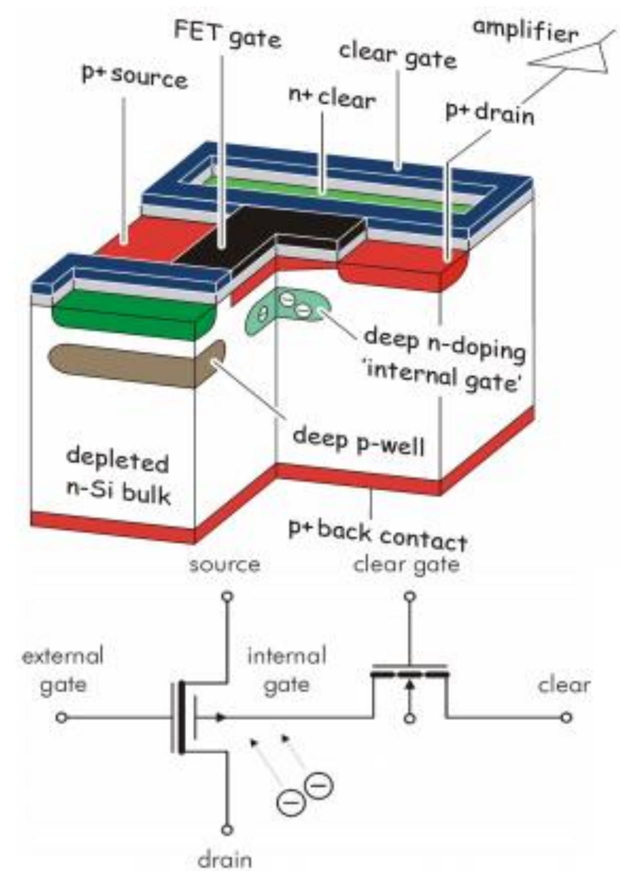
Electric test module

SVD

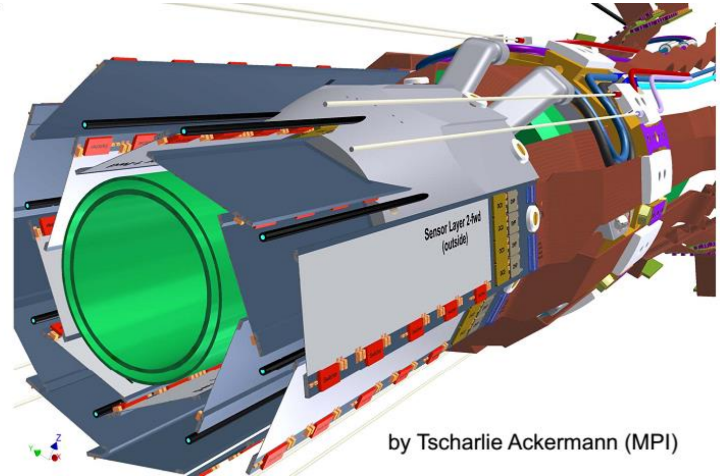

Aluminium electrode
p+ silicon strip
SiO2
reverse bias voltage
n+ silicon
electron
hole
electronics
for read out
Silicon Strip Detector

PXD


gate
DEPFET- matrix
reset
off
on
off
off
off
reset
off
off
n x m
pixel
$V_{GATE,\ ON}$
$V_{GATE,\ OFF}$
I_{DRAIN}
$V_{CLEAR,\ ON}$
$V_{CLEAR,\ OFF}$
$V_{CLEAR\text{-}Control}$
drain
0 suppression


FET gate
amplifier
p+ source
clear gate
n+ clear
p+ drain
deep n-doping
'internal gate'
deep p-well
depleted
n-Si bulk
p+ back contact
source
clear gate
external
gate
internal
gate
clear
drain

PXD sensor Production



Production phases

phase 1

- -implantations
- - oxide/nitride depositions
- - polysilicon deposition

phase 2

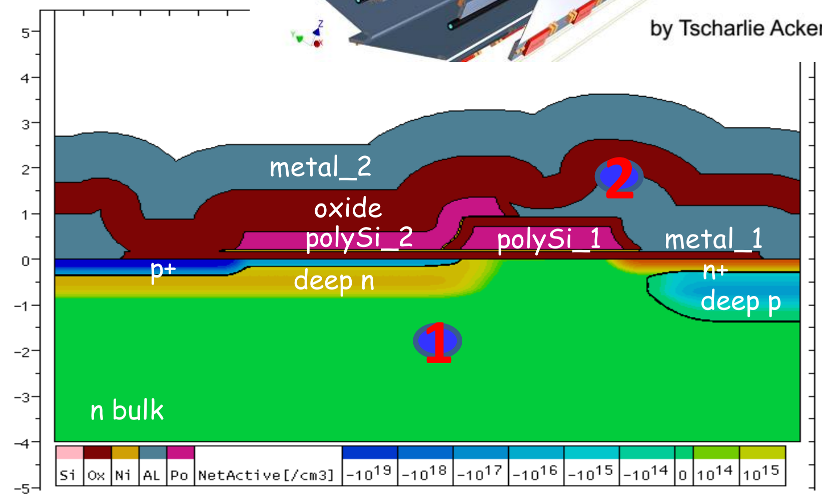
- - metal 1 (alu)
- - insulation oxide/contacts
- - metal 2 (alu)

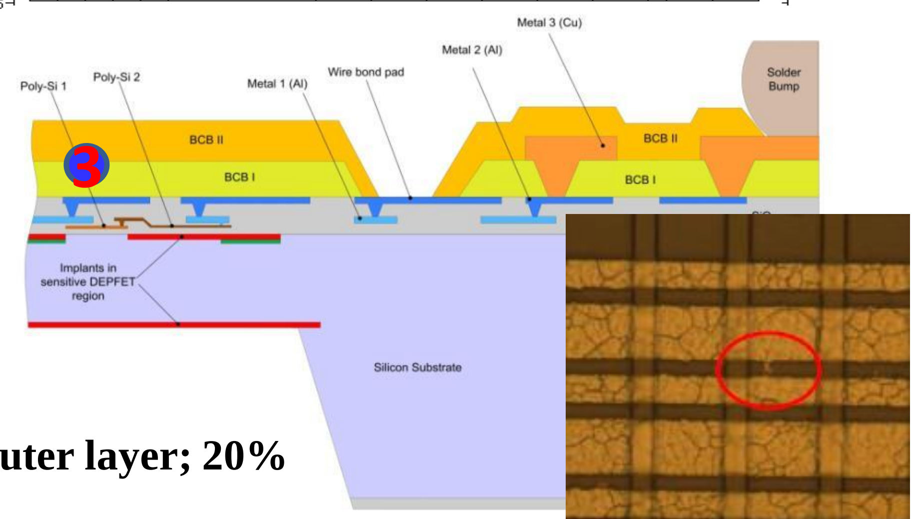
phase 3 (outside main cleanroom)

- - thinning
- - BCB insulation
- - copper
- - BCB passivation

p1 is the most time consuming ~250 days

p2 is the most critical in terms of yield





31 wafers are processed in 3 batches

Minimum yield needed: Inner layer: 26%; Outer layer; 20%

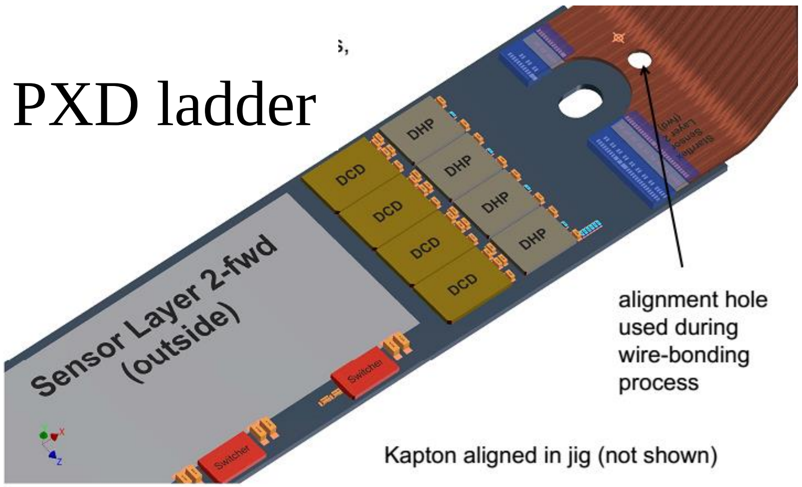
Test metal system with EMCM

EMCM: Electrical Dummy to be equipped with ASICs and tested like a real module

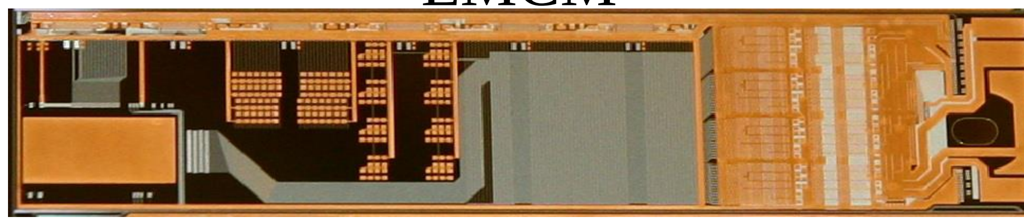
Allows tests of the electrical performance

- routing errors (despite automatic checking tools)
- cross talk, voltage drops, RC delays

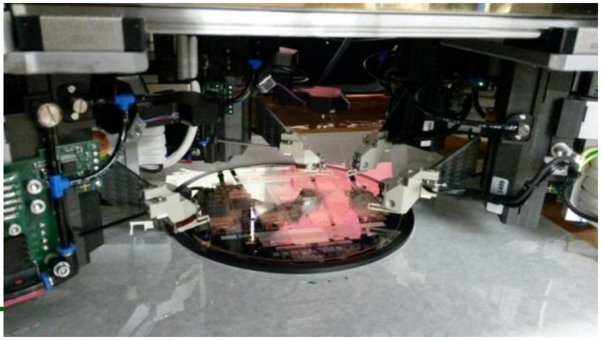
PXD ladder



EMCM



Test network before ASIC bonding:
4055 pads to test, 2149 independent electrical nets
>100 k individual tests to be made!

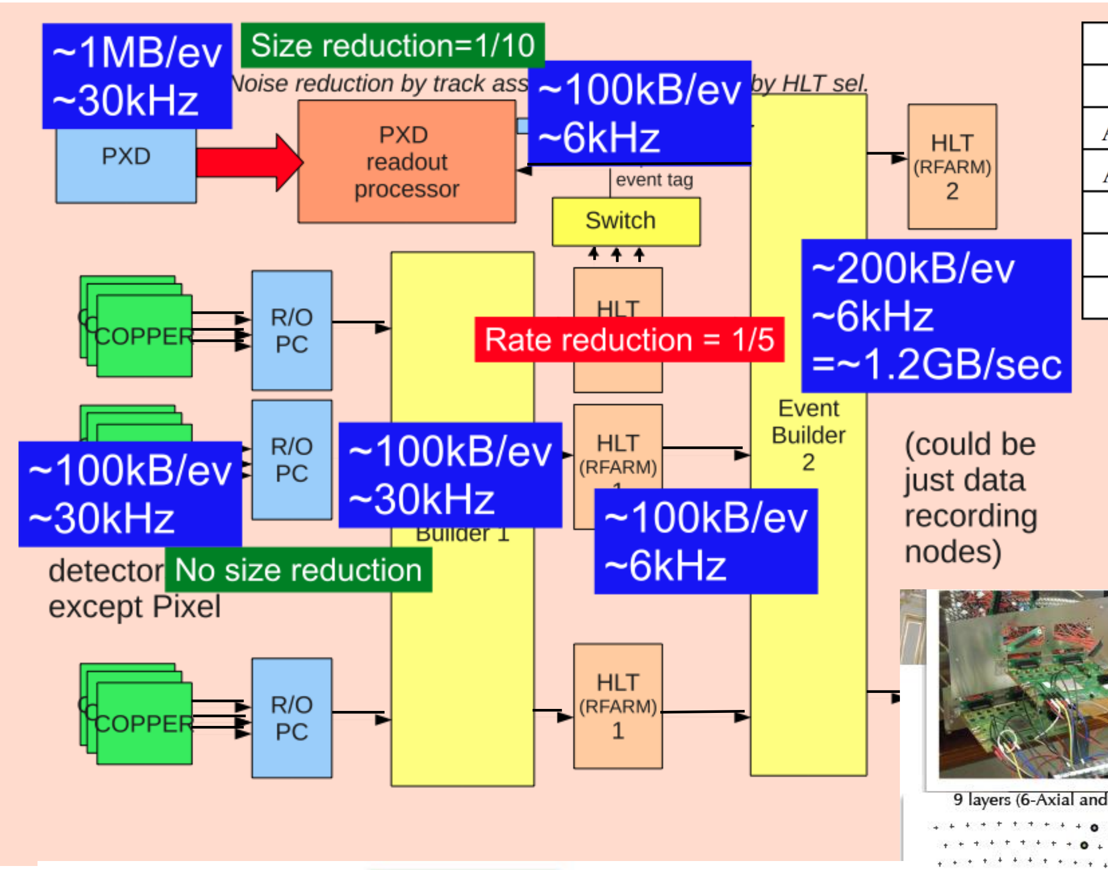


After EMCM study

First sensors will be available in October 2014

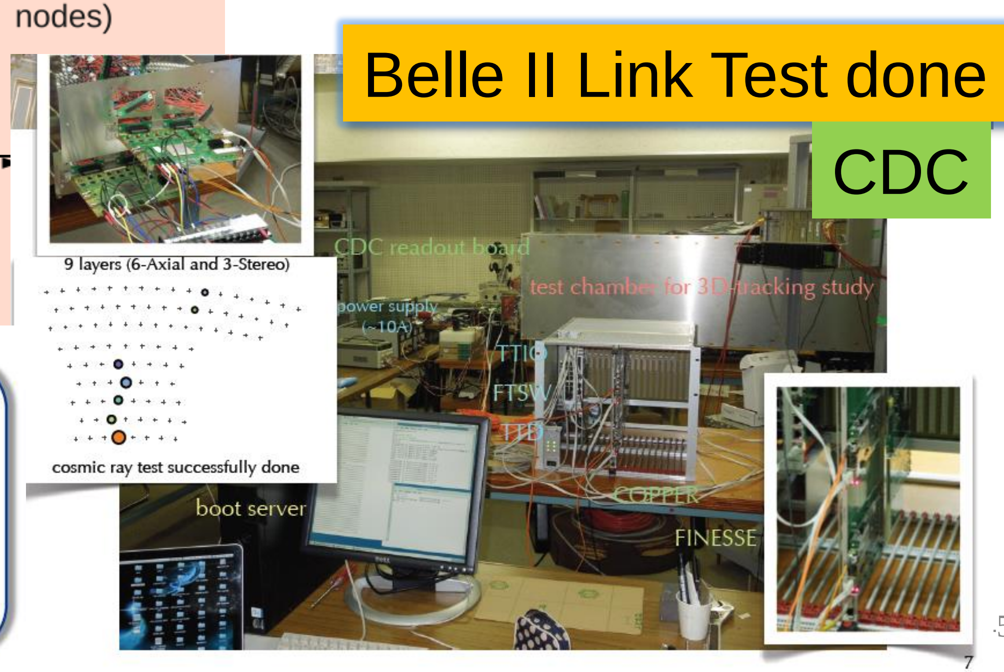
Production finished in June 2015

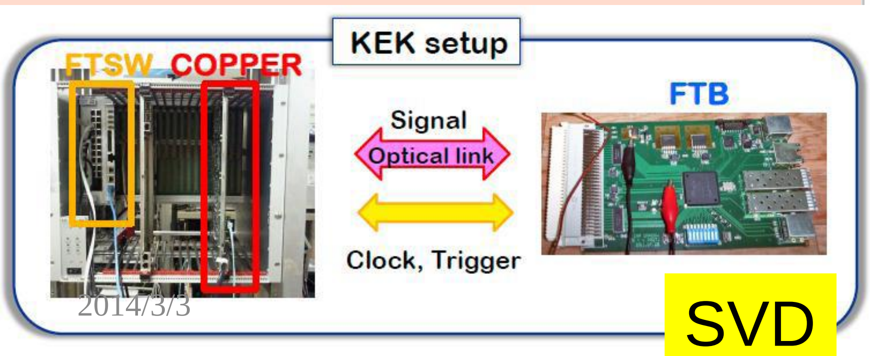
DAQ & Trigger



実験	Event Size [kB]	記録 rate [Hz]	記録 rate [MB/s]
Belle II	300	6,000	1,800
ALICE(HI)	12,500	100	1,250
ALICE(pp)	1,000	100	100
ATLAS	1,600	200	320
CMS	1,500	150	225
LHCb	25	2,000	50

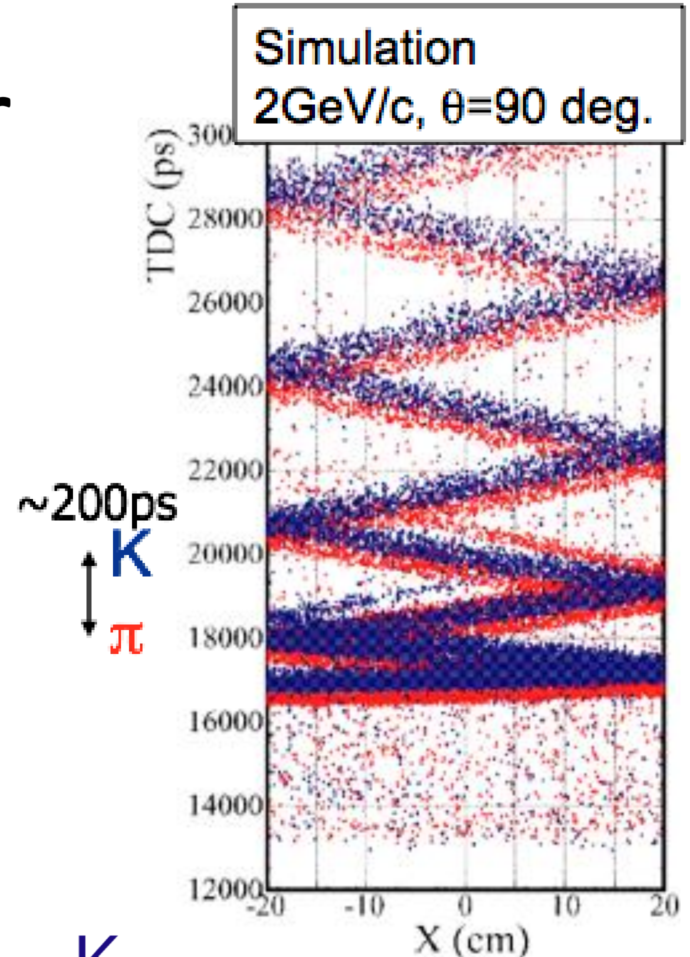
Larger data size than LHC !

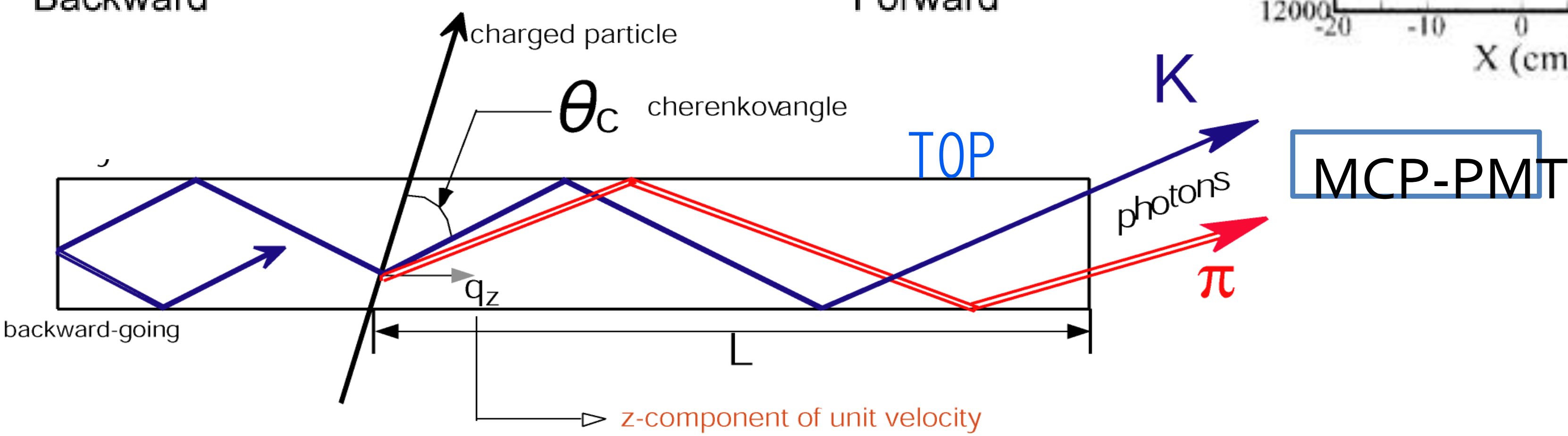




PID: TOP counter

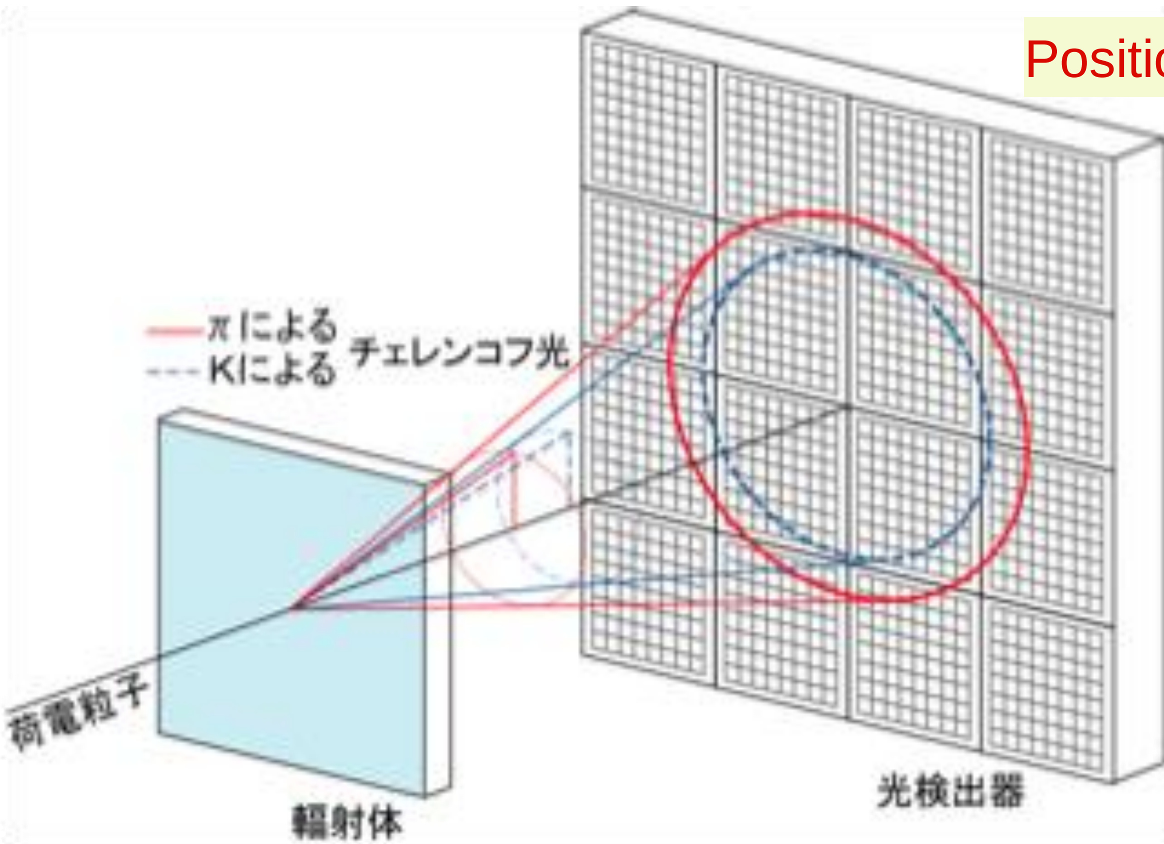
- Quartz radiator
  - 2.6m^{L} x 45cm^{W} x 2cm^{T}
  - Excellent surface accuracy
- MCP-PMT
  - Hamamatsu 16ch MCP-PMT
    - Good TTS (<35ps) & enough lifetime
    - Multialkali photo-cathode → SBA





TOF～1.2m

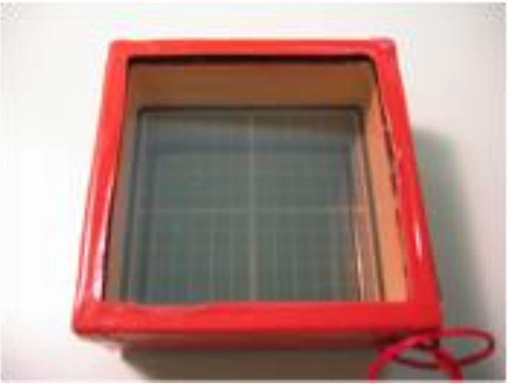
E-PID: Aerogel RICH



Position-sensitive photon sensor

+ Readout Electronics

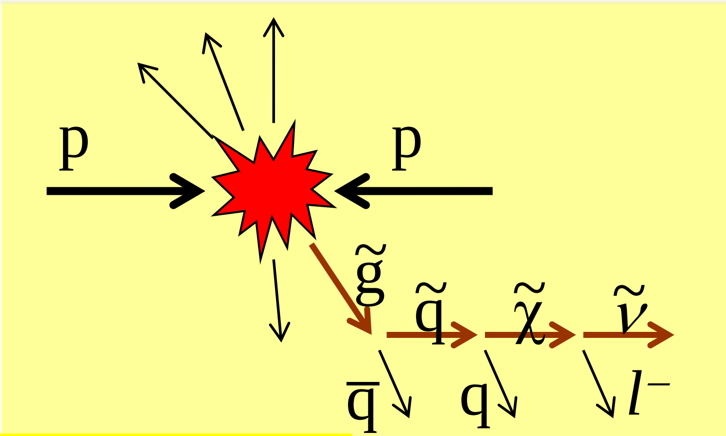
Hybrid Avalanche Photo-Detector (HAPD)



- Dveloped with Hamamatsu
  - 144 channel, 5mm×5mm/pixel

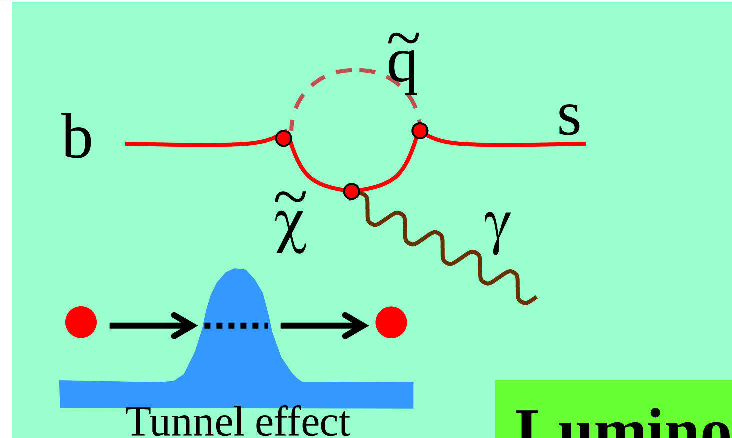
Energy Frontier vs Flavor Physics

Direct Production by High Energy Coll.



Energy Frontier

Virtual Production via Quantum Eff.



Luminosity Frontier

Diagonal terms

Off-diagonal terms

$$\left(m^2_{\tilde{q}}\right)_{ij} = \begin{pmatrix} m^2_{11} & m^2_{12} & m^2_{13} \\ m^2_{21} & m^2_{22} & m^2_{23} \\ m^2_{31} & m^2_{32} & m^2_{33} \end{pmatrix}$$

Higher Energy Scale
Can be searched
(even if LHC finds
no New Physics)

New Physics Prospects

Complemantarity

Super B factory

LHCb

K experiments

→ theory uncertainty matches the expected exp. precision

→ theory uncertainty will match the expected exp. precision with expected progress in LQCD

G. Isidori et al., Ann.Rev.Nucl.Part.Sci. 60, 355 (2010)

Observable	SM prediction	Theory error	Present result	Future error	Future Facility
$\|V_{us}\|$ $[K \to \pi \ell \nu]$	input	$0.5\% \to 0.1\%_{\rm Latt}$	0.2246 ± 0.0012	0.1%	K factory
$\|V_{cb}\|$ $[B \to X_c \ell \nu]$	input	1%	$(41.54 \pm 0.73) \times 10^{-3}$	1%	Super-B
$\|V_{ub}\|$ $[B \to \pi \ell \nu]$	input	$10\% \to 5\%_{\rm Latt}$	$(3.38 \pm 0.36) \times 10^{-3}$	4%	Super-B
γ $[B \to DK]$	input	$< 1^\circ$	$(70^{+27}_{-30})^\circ$	3°	LHCb
$S_{B_d \to \psi K}$	$\sin(2\beta)$	$\lesssim 0.01$	0.671 ± 0.023	0.01	LHCb
$S_{B_s \to \psi \phi}$	0.036	$\lesssim 0.01$	$0.81^{+0.12}_{-0.32}$	0.01	LHCb
$S_{B_d \to \phi K}$	$\sin(2\beta)$	$\lesssim 0.05$	0.44 ± 0.18	0.1	LHCb
$S_{B_s \to \phi \phi}$	0.036	$\lesssim 0.05$	—	0.05	LHCb
$S_{B_d \to K^* \gamma}$	few × 0.01	0.01	-0.16 ± 0.22	0.03	Super-B
$S_{B_s \to \phi \gamma}$	few × 0.01	0.01	—	0.05	LHCb
$A^d_{\rm SL}$	-5×10^{-4}	10^{-4}	$-(5.8 \pm 3.4) \times 10^{-3}$	10^{-3}	LHCb
$A^s_{\rm SL}$	2×10^{-5}	$< 10^{-5}$	$(1.6 \pm 8.5) \times 10^{-3}$	10^{-3}	LHCb
$A_{CP}(b \to s\gamma)$	< 0.01	< 0.01	-0.012 ± 0.028	0.005	Super-B
$\mathcal{B}(B \to \tau \nu)$	1×10^{-4}	$20\% \to 5\%_{\rm Latt}$	$(1.73 \pm 0.35) \times 10^{-4}$	5%	Super-B
$\mathcal{B}(B \to \mu \nu)$	4×10^{-7}	$20\% \to 5\%_{\rm Latt}$	$< 1.3 \times 10^{-6}$	6%	Super-B
$\mathcal{B}(B_s \to \mu^+ \mu^-)$	3×10^{-9}	$20\% \to 5\%_{\rm Latt}$	$< 5 \times 10^{-8}$	10%	LHCb
$\mathcal{B}(B_d \to \mu^+ \mu^-)$	1×10^{-10}	$20\% \to 5\%_{\rm Latt}$	$< 1.5 \times 10^{-8}$	[?]	LHCb
$A_{\rm FB}(B \to K^* \mu^+ \mu^-)_{q_0^2}$	0	0.05	(0.2 ± 0.2)	0.05	LHCb
$B \to K \nu \bar{\nu}$	4 × 10 [illegible]	$20\% \to 10\%_{\rm Latt}$	$< 1.4 \times 10^{-5}$	20%	Super-B
$\|q/p\|_{D-\rm mixing}$	1	$< 10^{-3}$	$(0.86^{+0.18}_{-0.15})$	0.03	Super-B
ϕ_D	0	$< 10^{-3}$	$(9.6^{+8.3}_{-9.5})^\circ$	2°	Super-B
$\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu})$	8.5×10^{-11}	8%	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$	10%	K factory
$\mathcal{B}(K_L \to \pi^0 \nu \bar{\nu})$	2.6×10^{-11}	10%	$< 2.6 \times 10^{-8}$	[?]	K factory
$R^{(e/\mu)}(K \to \pi \ell \nu)$	2.477×10^{-5}	0.04%	$(2.498 \pm 0.014) \times 10^{-5}$	0.1%	K factory
$\mathcal{B}(t \to c\,Z, \gamma)$	$\mathcal{O}(10^{-13})$	$\mathcal{O}(10^{-13})$	$< 0.6 \times 10^{-2}$	$\mathcal{O}(10^{-5})$	LHC (100 fb^{-1})

Observable	Future error	Future Facility
$B(B \to X_s \gamma)$	6%	Super-B
$B(B \to X_d \gamma)$	20%	Super-B
$S(B \to \rho \gamma)$	0.15	Super-B
$B(\tau \to \mu \gamma)$	$3 \cdot 10^{-9}$	Super-B (90% U.L.)
$B(B^+ \to D \tau \nu)$	3%	Super-B
$B(B_s \to \gamma \gamma)$	$0.25 \cdot 10^{-6}$	Super-B (5 ab^{-1})
$\sin^2\theta_W$ @ $\Upsilon(4S)$	$3 \cdot 10^{-4}$	Super-B