The silicon strip vertex detector of the Belle II experiment

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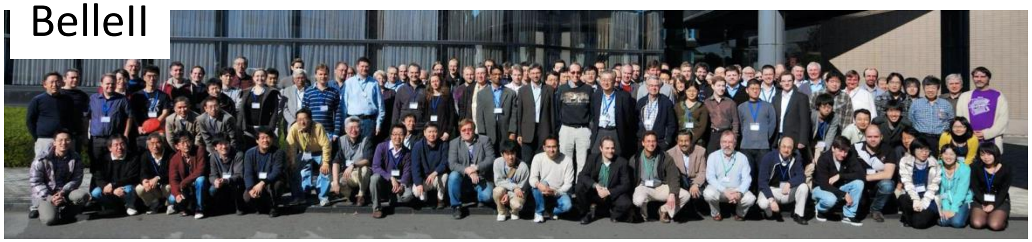
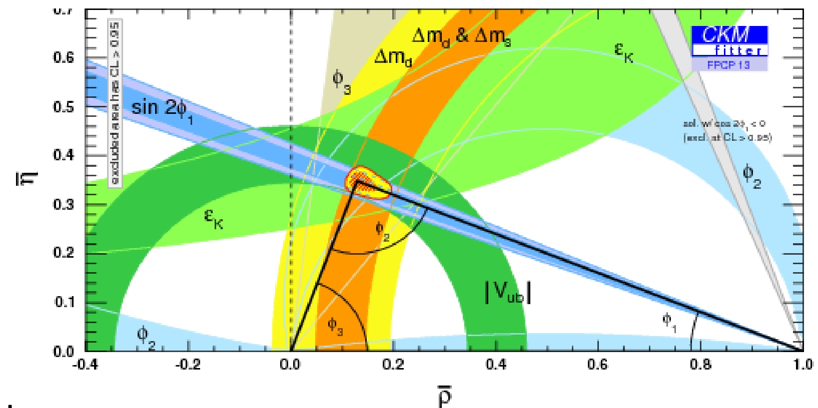
on the Development and Application of
Semiconductor Tracking Detectors,
Hiroshima, Japan

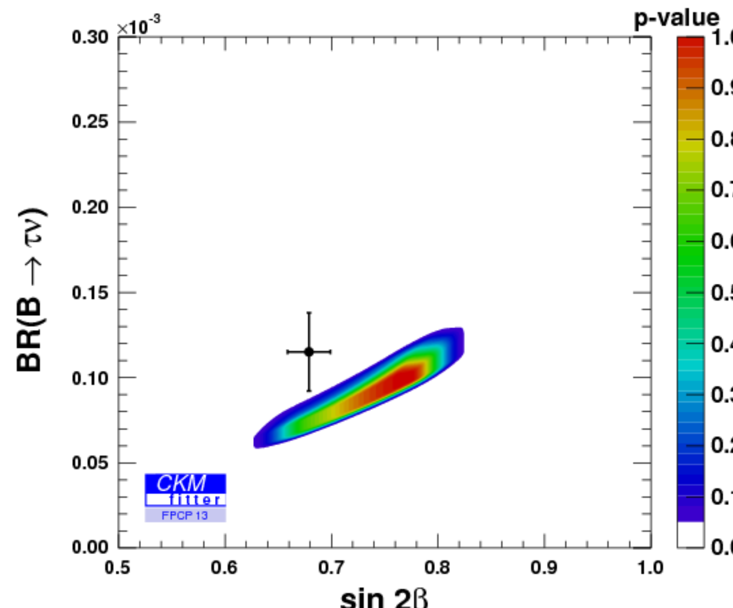
BelleII experiment

BelleII experiment is super B-factory with asymmetric energy of e+e- collider



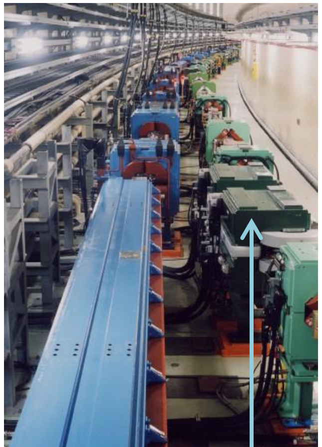


- Measurements of CKM matrix elements and angles of the unitary triangle
- CP & T & CPT test
- Observation of direct CP violation in B decays
- Measurements of rare decays (e.g., $B \to \tau\nu$, $D\tau\nu$) and the tension vs $\sin 2\phi_1$
- $b \to s$ transitions: probe for new sources of CPV and constraints from the $b \to s\gamma$ branching fraction
- Forward-backward asymmetry (A_{FB}) in $b \to sll$
- Observation of D mixing and charm-meson physics
- Searches for rare τ decays
- Observation of new hadrons and resonances

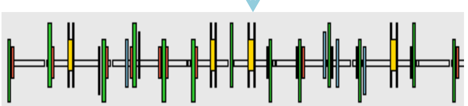


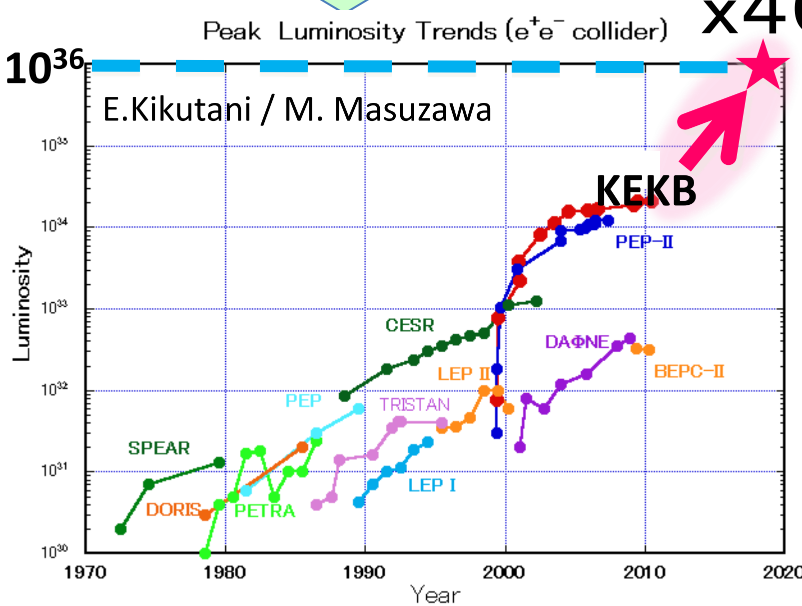
Precise tests of the phenomena which expected to be contributed from beyond SM with enormous B-meson and τ lepton data

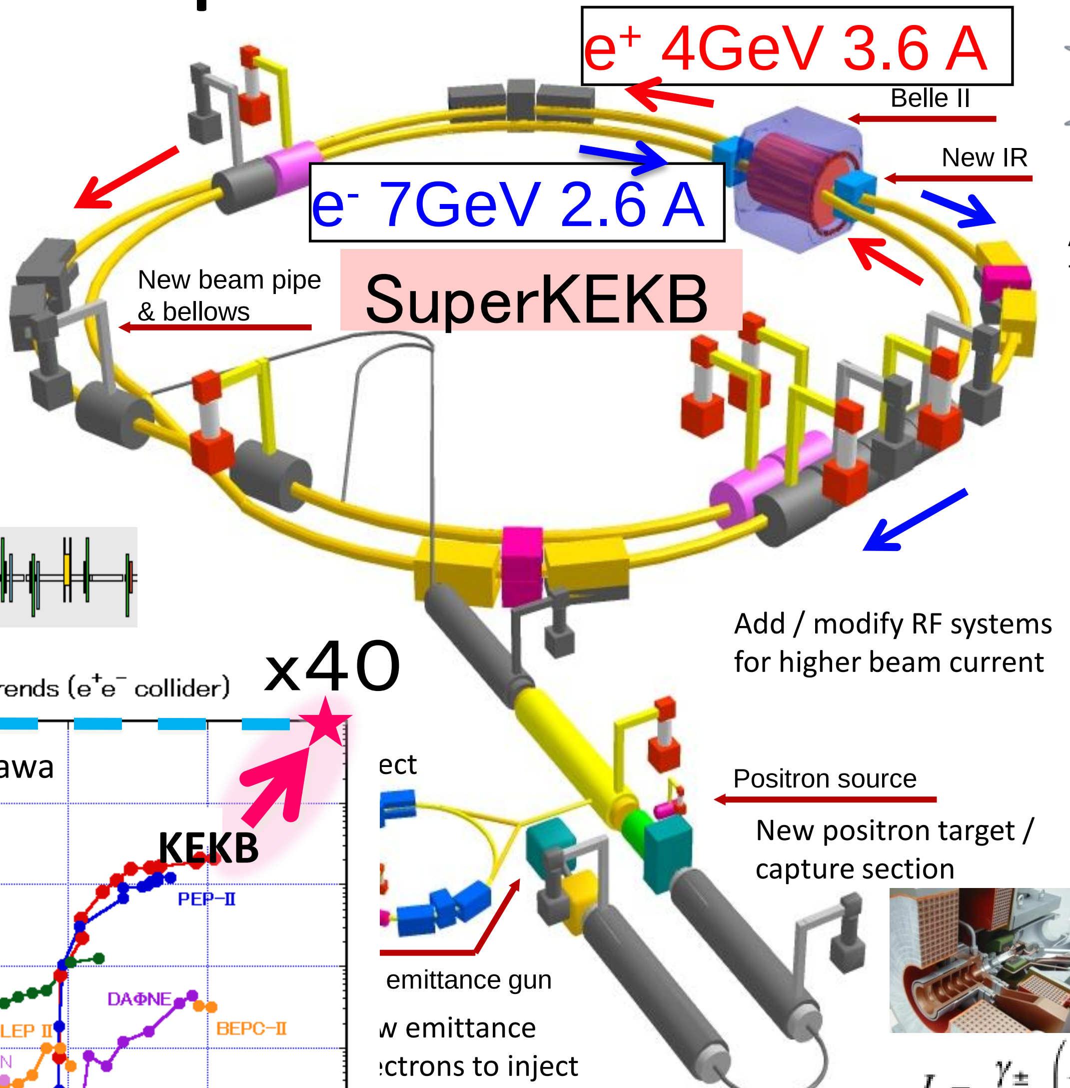
SuperKEKB collider

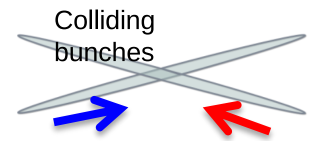


Replace short dipoles with longer ones (LER)

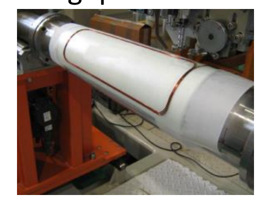


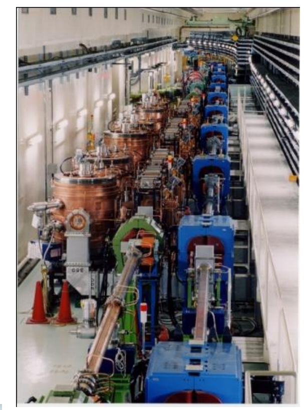






New superconducting /permanent final focusing quads near the IP

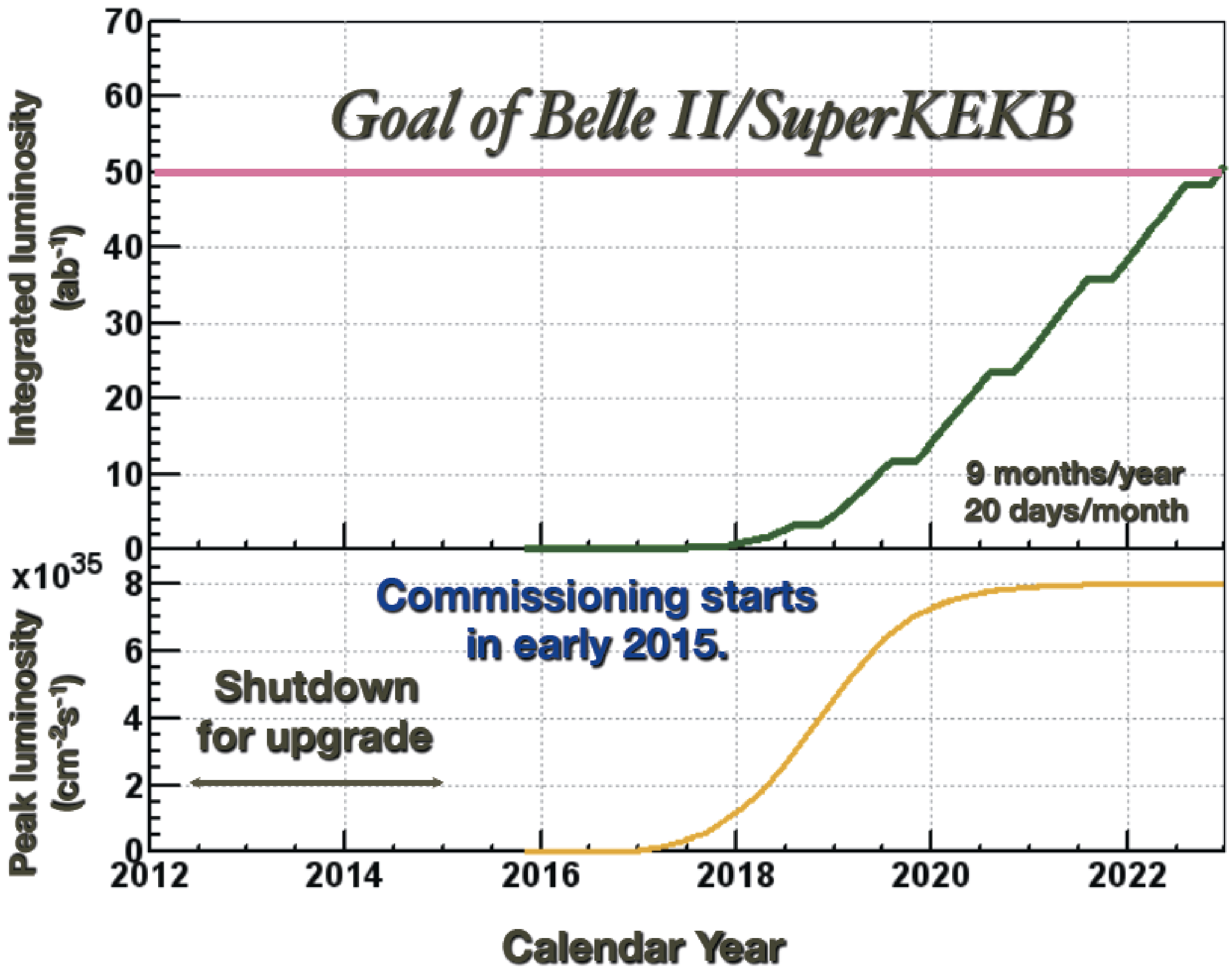




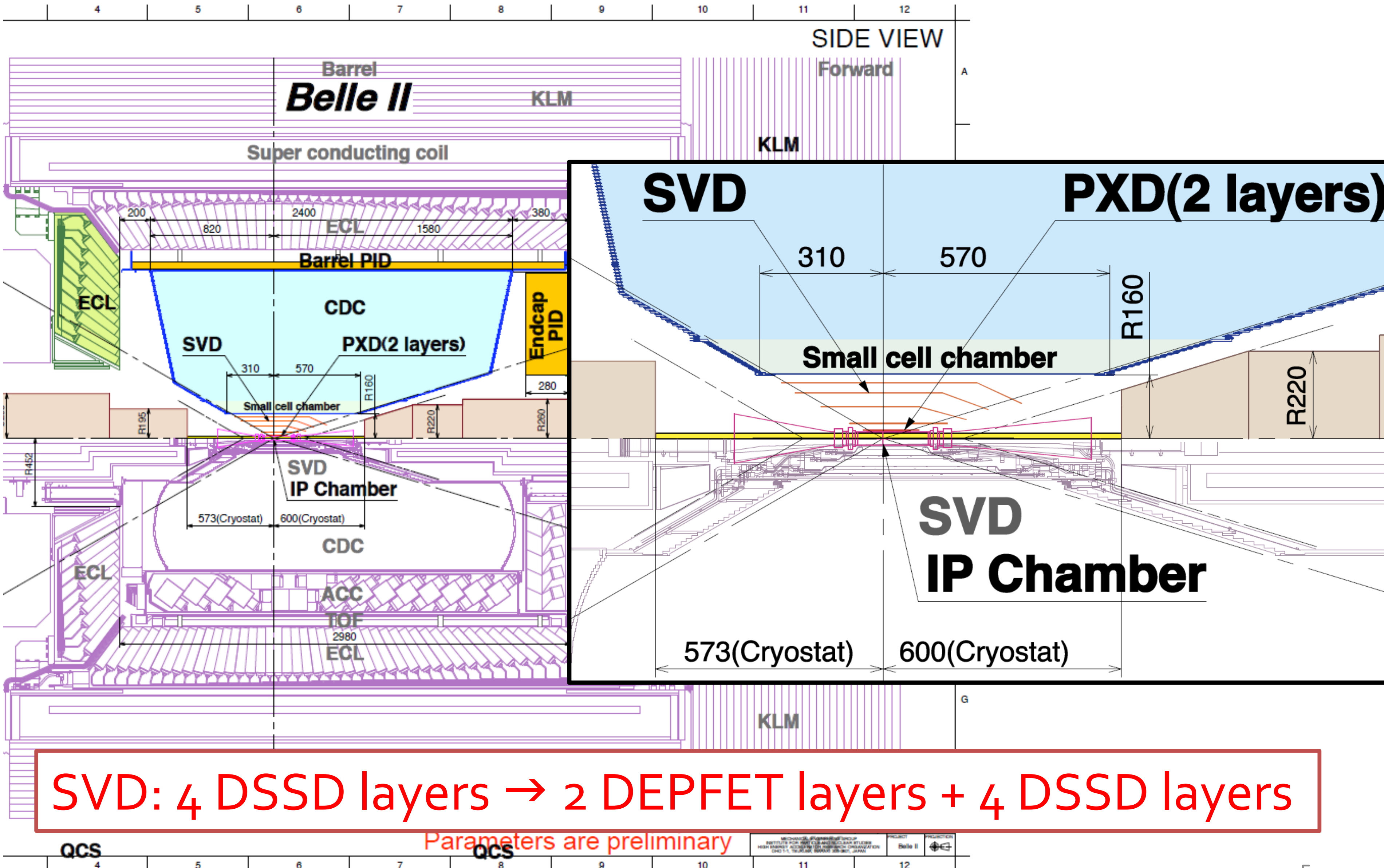
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

Target: L = $8\times10^{35}/cm^2/s$

Luminosity projection

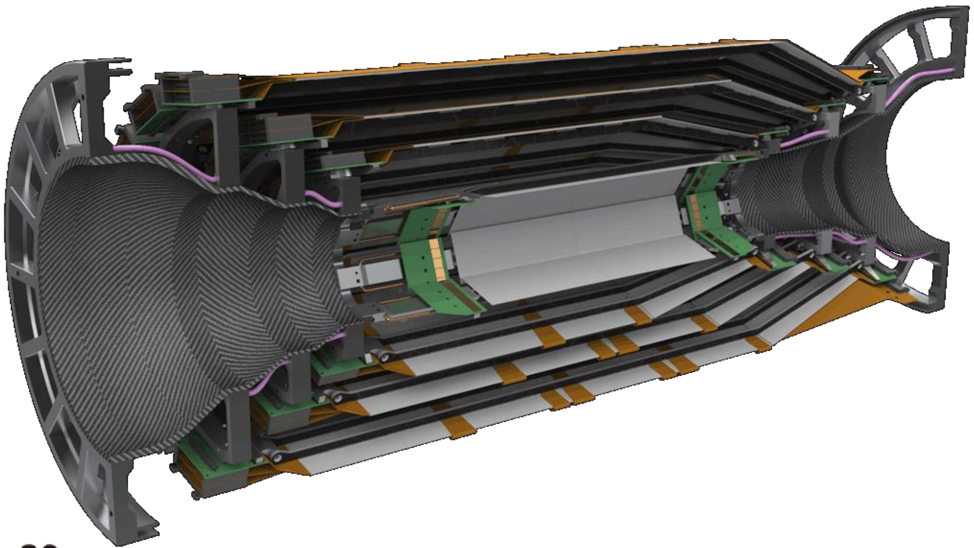


Detector upgrade



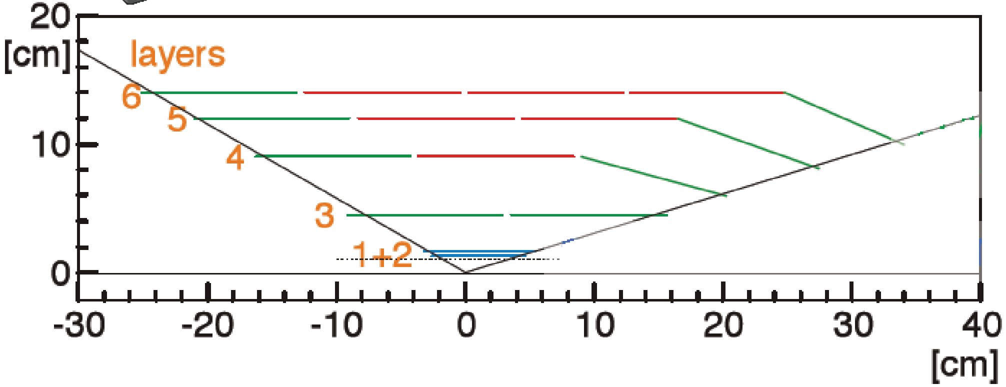
SVD: 4 DSSD layers → 2 DEPFET layers + 4 DSSD layers

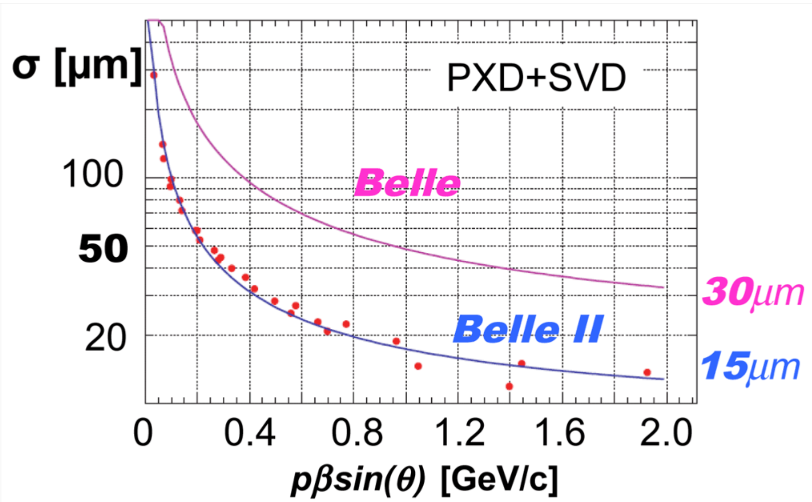
Strip Vertex Detector(SVD)



BelleII vertex detector(PXD+SVD)
@Low energy high luminosity machine

- Good vertex resolution(incl. $K_S \rightarrow \pi\pi$)
- Low pT tracking ($D^* \rightarrow D\pi_{slow}$)
- Low material budget
- Fast readout(trig. max~30kHz)
- CO_2 cooling pipe along with APV chips

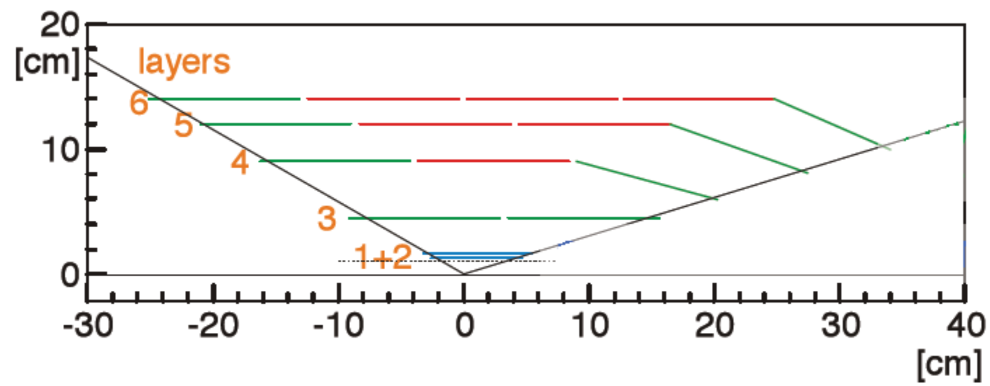


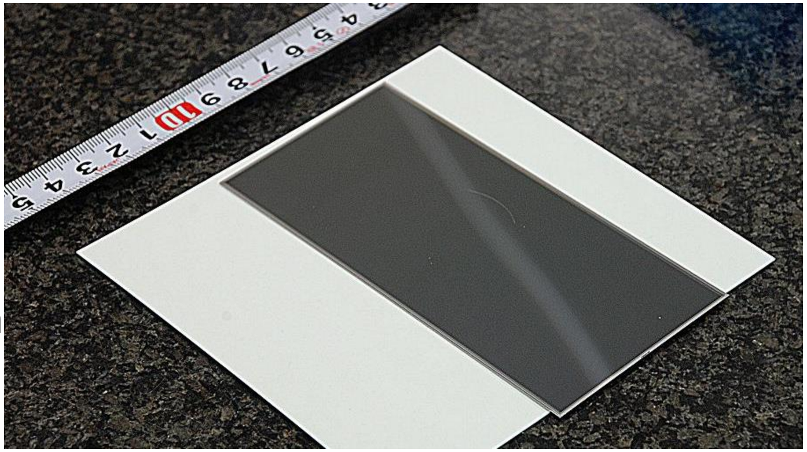


Layer	Sensor/ladder	Origami	Ladder	Length	Radius	Slant angle	Occupancy
3	2	0	7	262	38	0	6.7%
4	3	1	10	390	80	11.9	2.7%
5	4	2	12	515	104	17.2	1.3%
6	5	3	16	645	135	21.1	0.9%

Double-sided Silicon Strip Detector(DSSD)

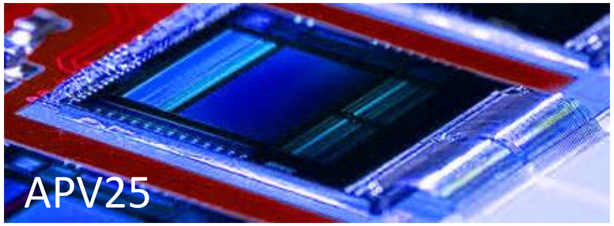
- Layer3: Small DSSD
  - Manufacturer: HPK
  - Chip size: 124.88 mm ×40.43 mm
  - Thickness: 320μm
  - P-stop layout: Atoll p-stop
- Layer4,5,6: Large DSSD
  - Manufacturer: HPK
  - Chip size: 124.88 mm ×59.60 mm
  - Thickness: 320μm
  - P-stop layout: Atoll p-stop
- Layer4,5,6: Trapezoidal DSSD
  - Manufacturer: Micron
  - Chip size: 125.58 mm ×60.63(41.02) mm
  - Thickness: 300μm
  - P-stop layout: Atoll p-stop



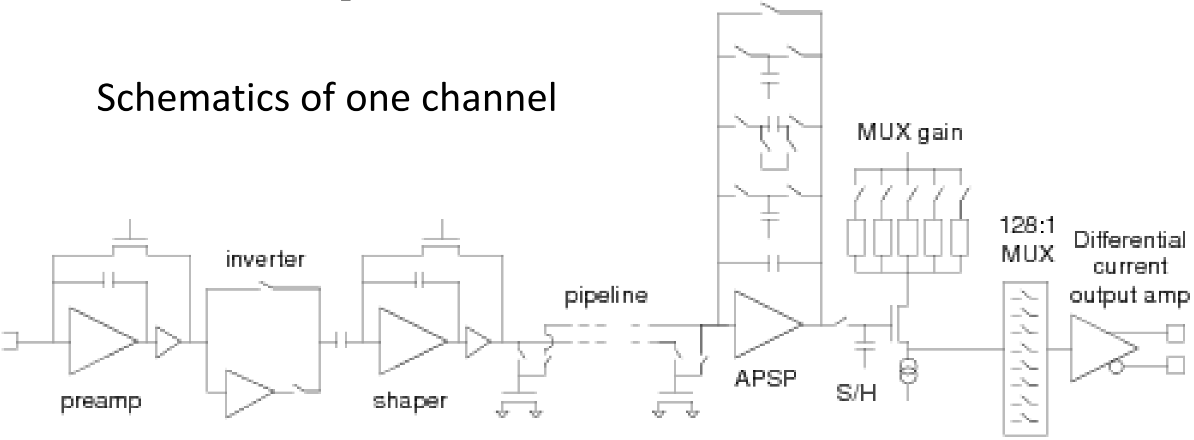


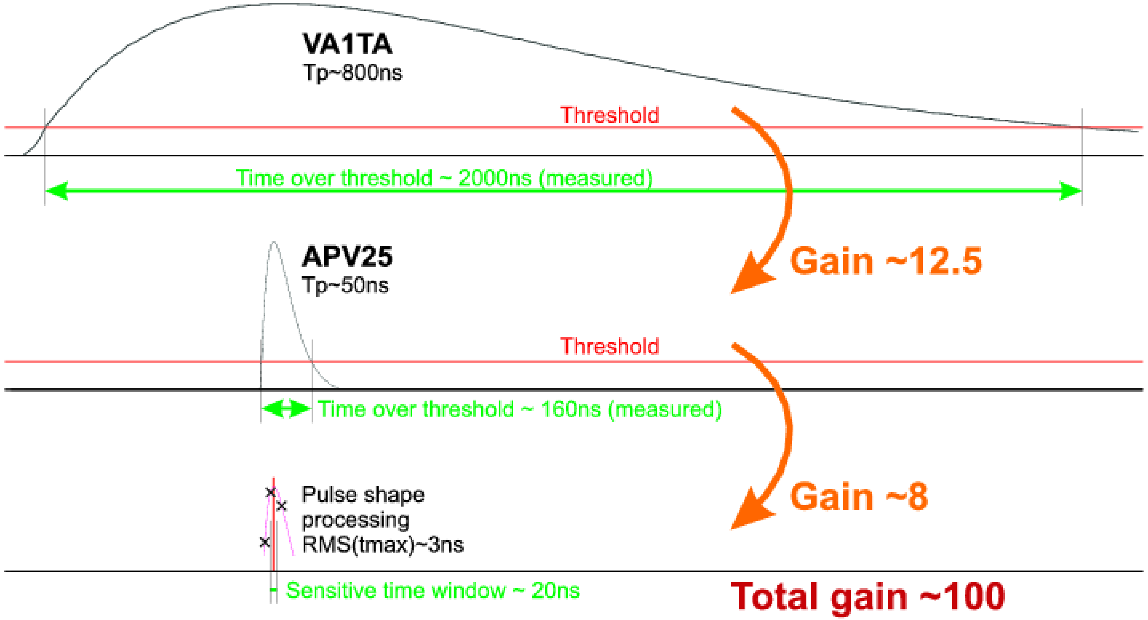
	Readout strip(p/Rϕ)	Readout strip(n/z)	Readout pitch(p/Rϕ)	Readout pitch(n/z)	Chip size (mm^2)	Active area (mm^2)
Large	768	512	75 μm	240 μm	124.88x 59.60 =7442.85	122.90x57.72 =7029.88
Trapezoidal	768	512	50-75 μm	240 μm	125.58x(60.63+41.02)/2=6382.60	122.76x(57.59+38.42)/2=5893.09
Small	768	768	50 μm	160 μm	124.88x40.43 =5048.90	122.90x38.55 =4737.80

Readout Chip APV25



Schematics of one channel

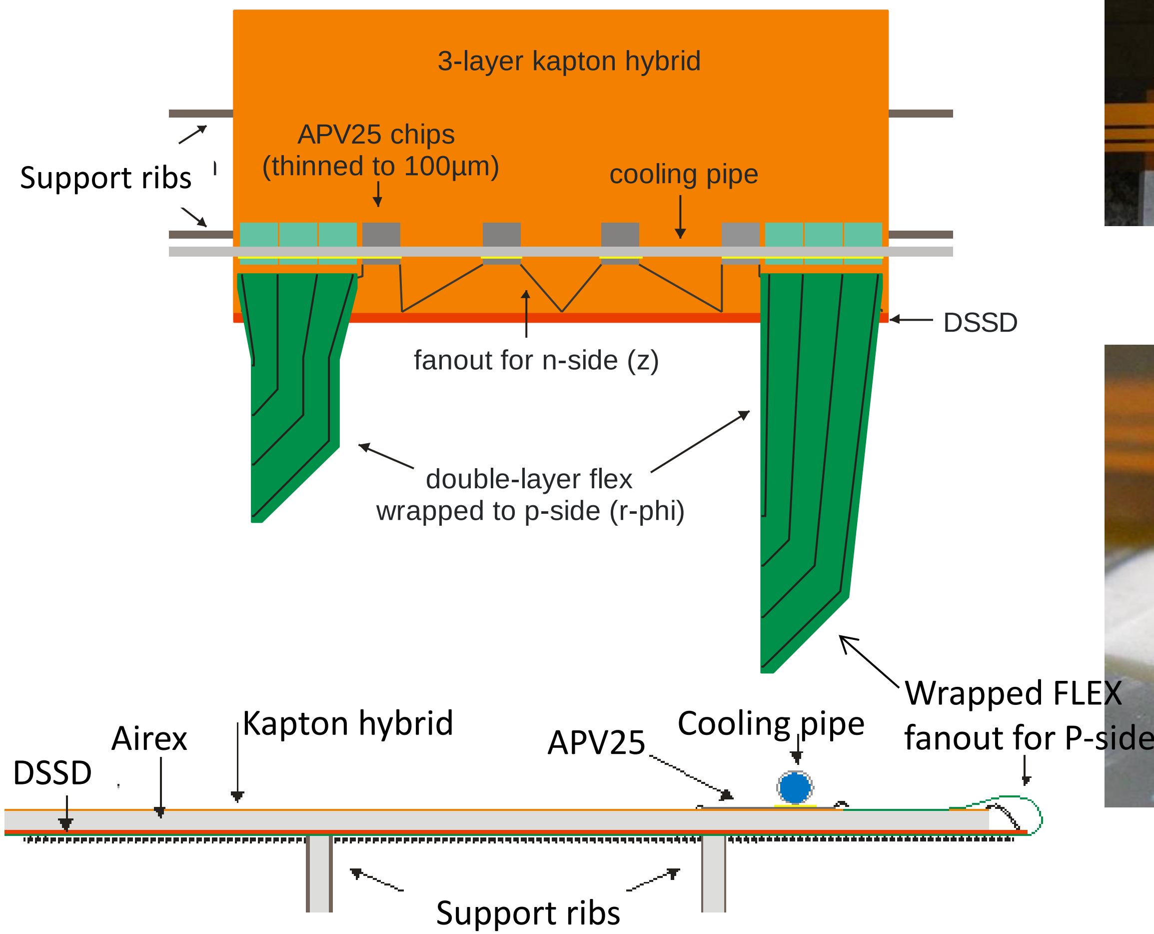


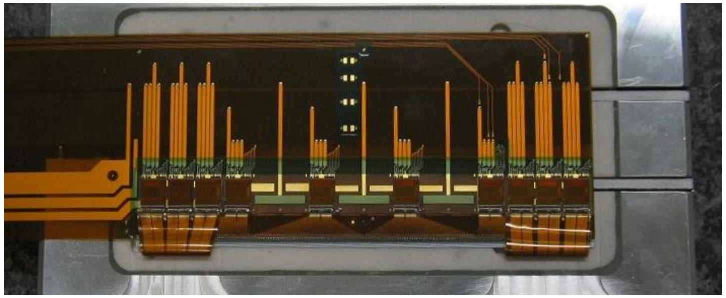


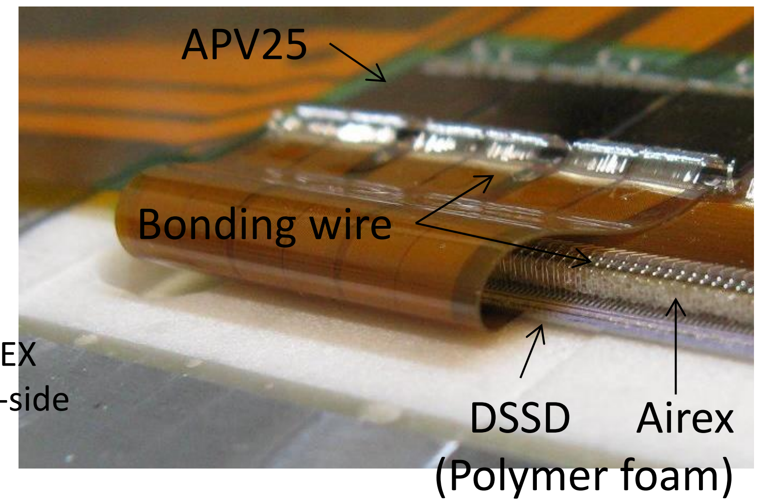
- Developed for CMS (LHC)
- 0.25 µm CMOS process
- Shaping time 50ns
- Input ch. 128ch
- Power consumption 350mW
- Thickness 100µm(thinned)
- Radiation tolerance >30Mrad
- ENC_C [e] 250e+36e × C[pF]
- Multi-peak mode (read out several samples along shaping curve)

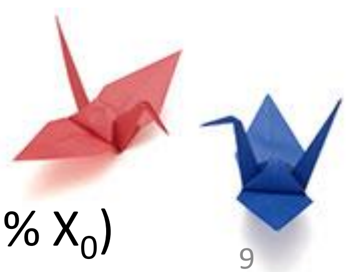
40x luminosity with harsh environment from beam background is expected.
We need fast shaping.

Chip-on-sensor method, Origami



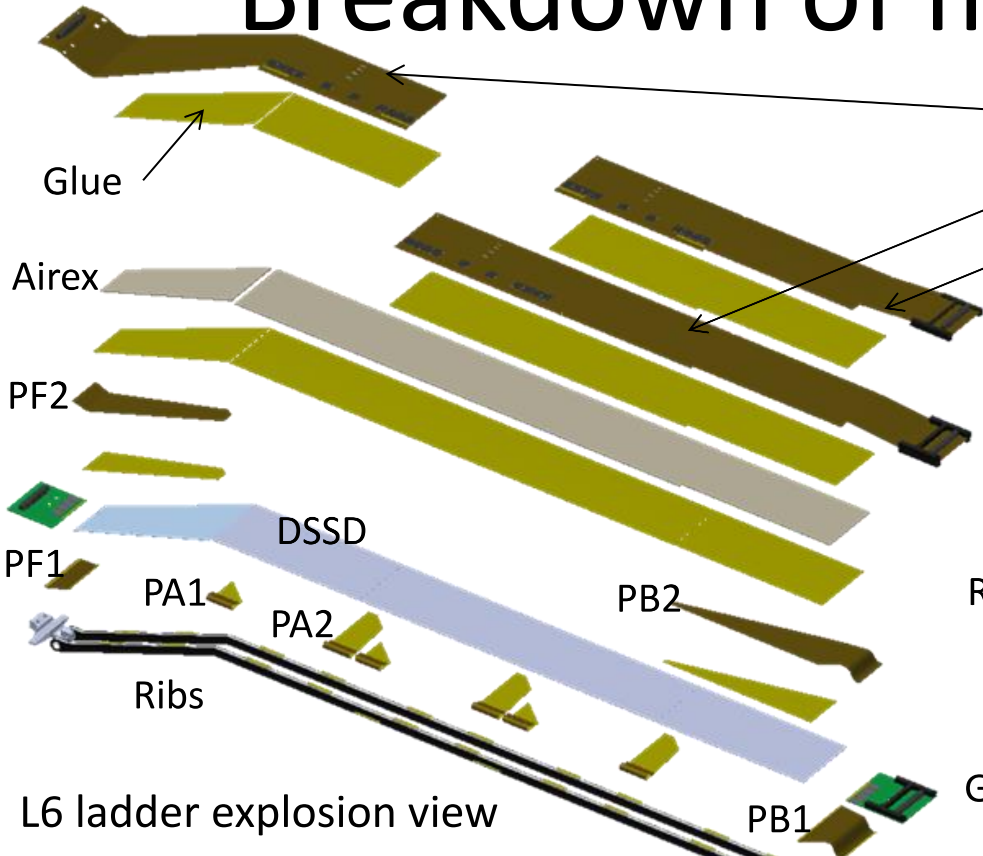




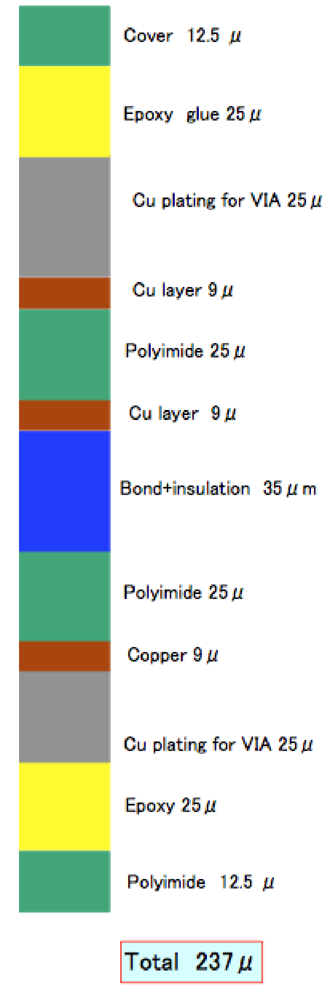


- Chip-on-sensor for double-sided readout, named “Origami”
- All chips aligned on one side → single cooling pipe (Ave. 0.59% X_0)

Breakdown of material budget

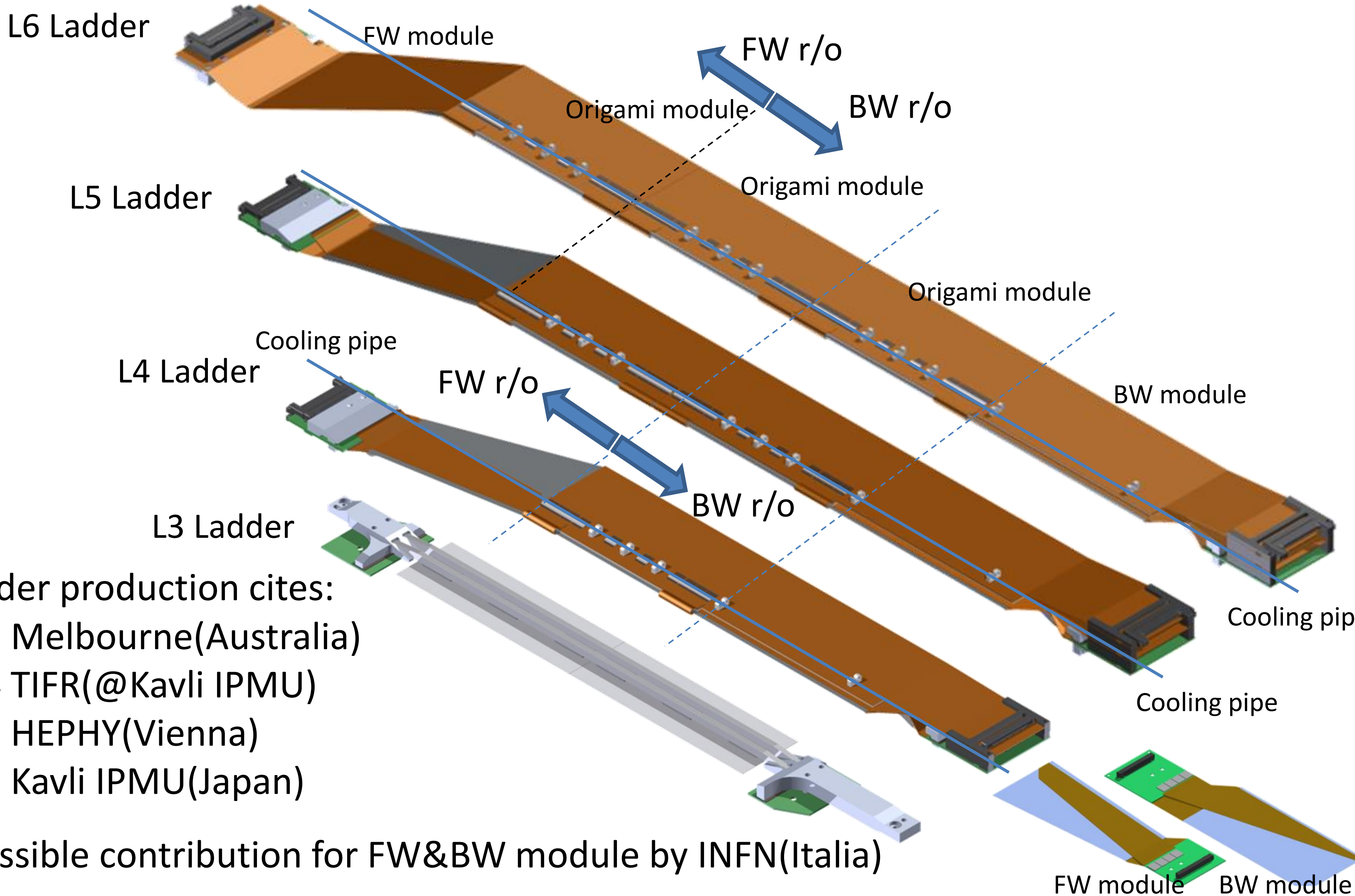


L6 ladder explosion view



DSSD+ Origami	Rib	DSSD	Airex	Origami	CO_2 Cooling	100μm Glue	Total % X_0
HPK+1Origami	0.035	0.340	0.055	0.133	0.037	0.033	0.593
HPK+2Origami	0.035	0.340	0.055	0.266	0.037	0.033	0.733
Micron	0.035	0.320	0.055	0	0	0.011	0.421
Micron+Origami	0.035	0.320	0.000	0.133	0	0.033	0.576

SVD Ladders



Ladder production cites:

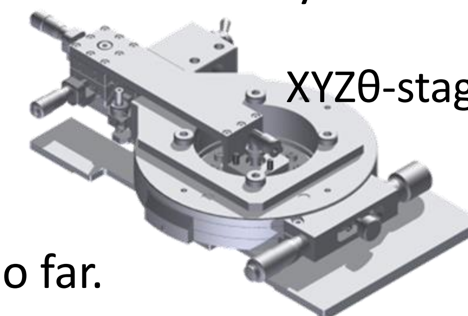
- L3 Melbourne(Australia)
- L4 TIFR(@Kavli IPMU)
- L5 HEPHY(Vienna)
- L6 Kavli IPMU(Japan)

Possible contribution for FW&BW module by INFN(Italia)

World wide collaborated ladder production

Ladder assembly

- Strategy
  - Active alignment of DSSDs at < O(10μm) with DSSD moving stage.
  - Measurement of whole fiducial marks on DSSD by CMM after the assembly.
  - Porting L6 production jigs to the other layer
- Status
  - A full set of L6 ladder production jigs in Kavli IPMU
  - Working single and double Origami modules are produced so far.
  - Verification of technical milestone w/ assembly of mockup ladder is in progress
  - Collaborative research agreement was concluded btw TIFR and Kavli IPMU.
  - Commissioning of wire-bonders in each institute is done. Training for production.



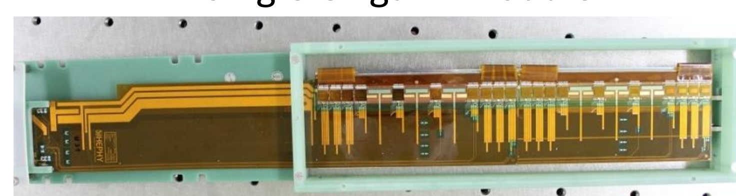
XYZθ-stage

Automatic wire bonder
Choonpa Co. REBO-7W
IPMU(borrowed KEK)

Automatic wire bonde
Delvotec 6400
HEPHY, TIFR(@Kavli IPMU)

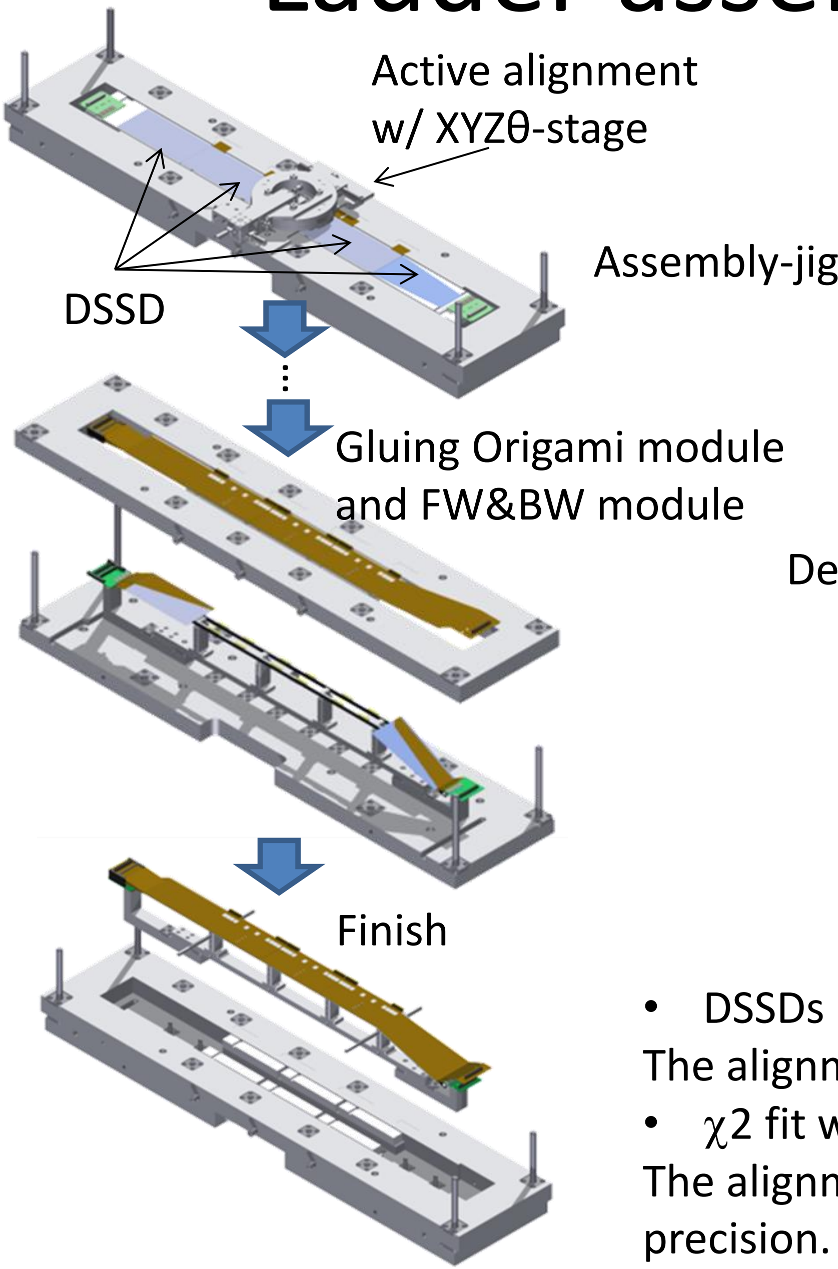
CMM
Mitsutoyo QV606
Kavli IPMU

Single Origami module

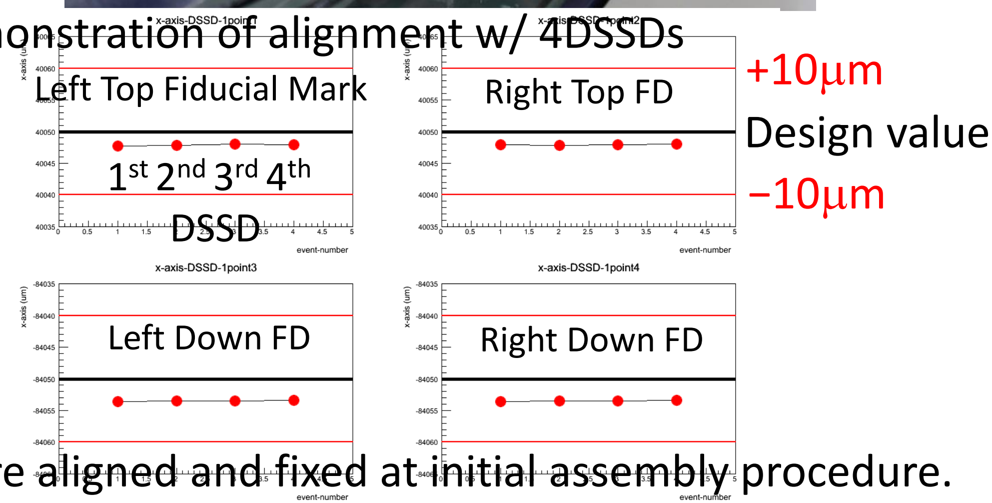


Double Origami module

Ladder assembly procedure

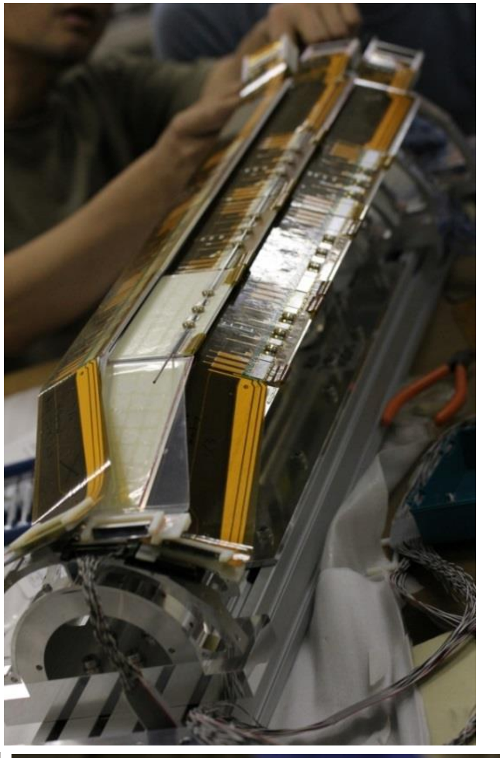


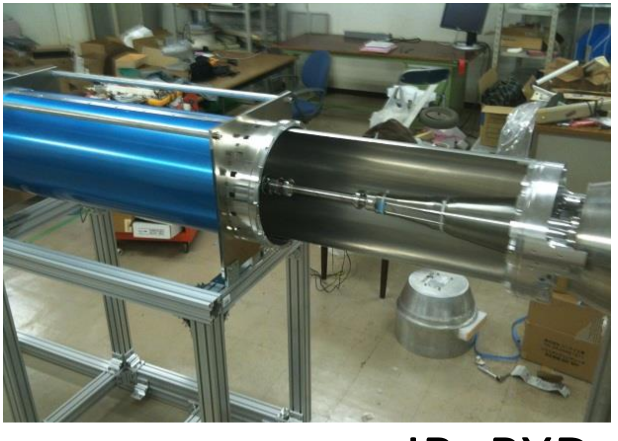
Demonstration of alignment w/ 4DSSDs

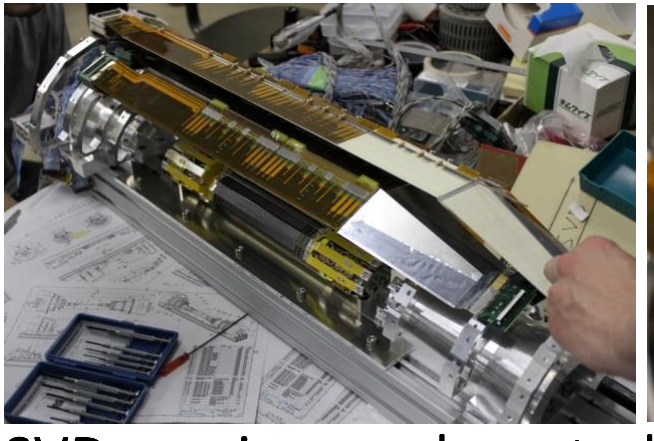


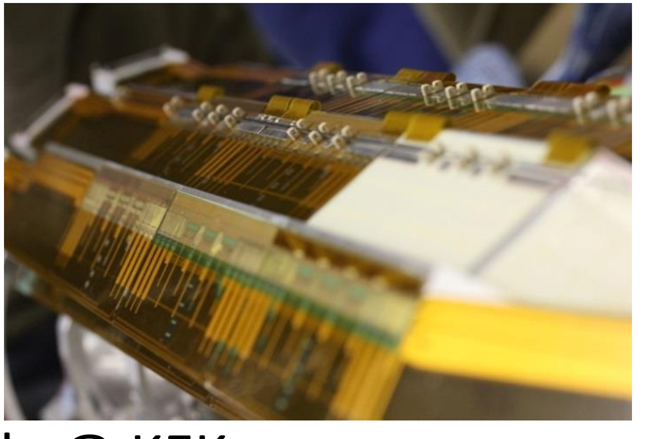
- DSSDs are aligned and fixed at initial assembly procedure. The alignment are kept till the end of the procedure.
- $\chi 2$ fit will be performed for the data after the assembly. The alignment correction parameters can be extracted at μm precision. → will be used for initial alignment constant.

Mockup IR-PXD-SVD



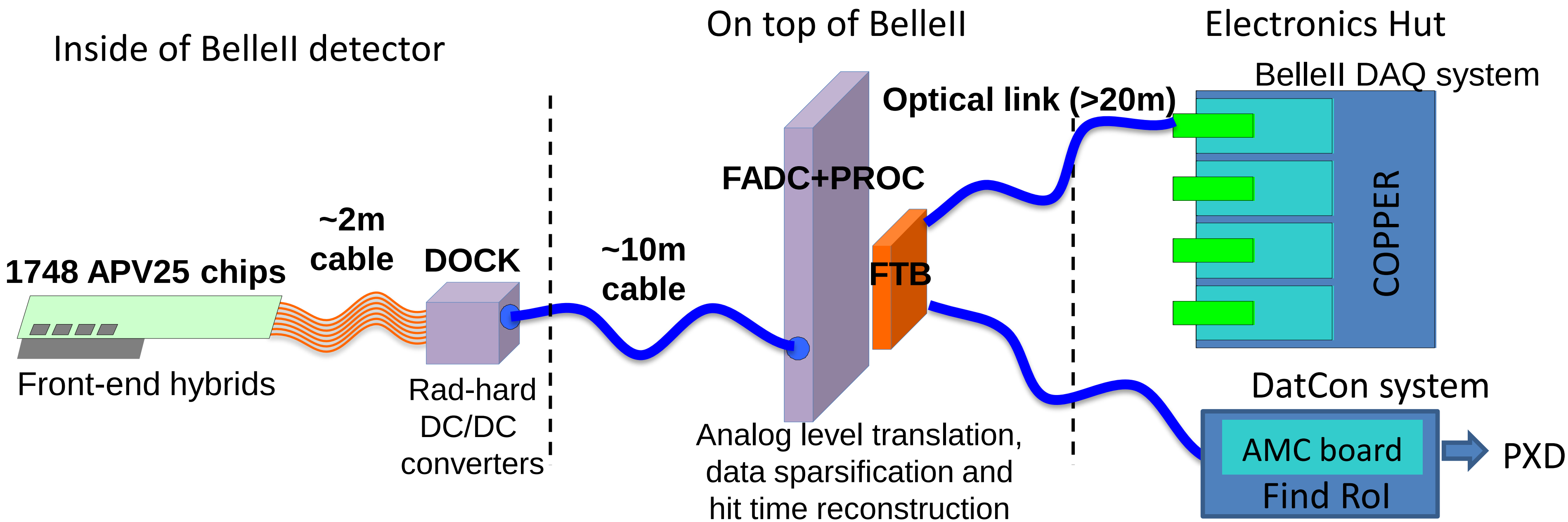


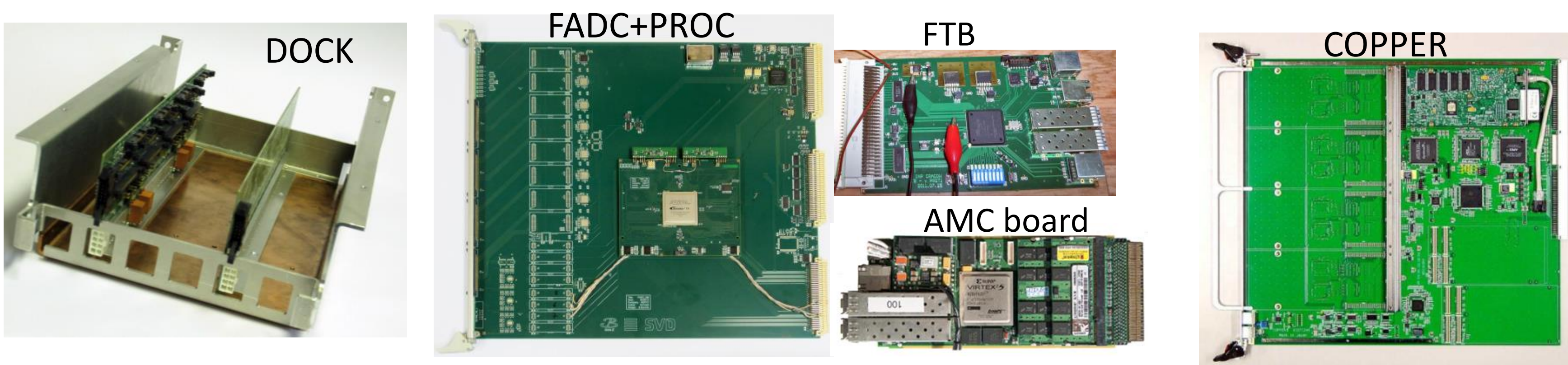




IR+PXD+SVD precise mockup study @ KEK

SVD DAQ system

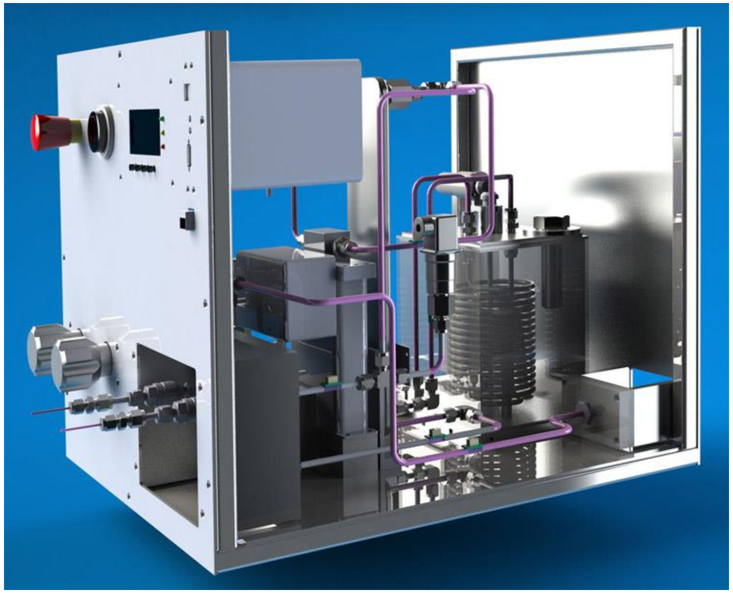


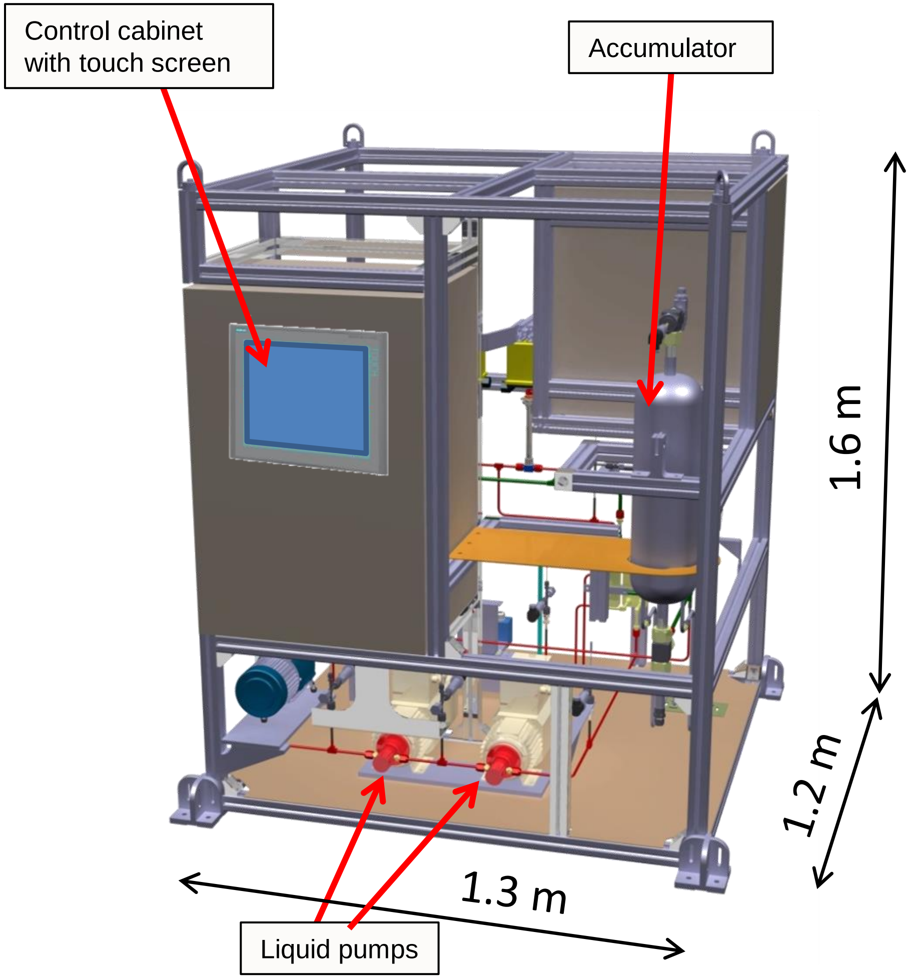


FADC-FTB-(COPPER+DatCon) chain test was succeeded on June 2013

CO_2 cooling

- Closed CO_2 cooling plant under development
- Collaboration with CERN
- First step is to gain experience with open (blow) system





Common CO_2 plant with PXD

SVD construction schedule

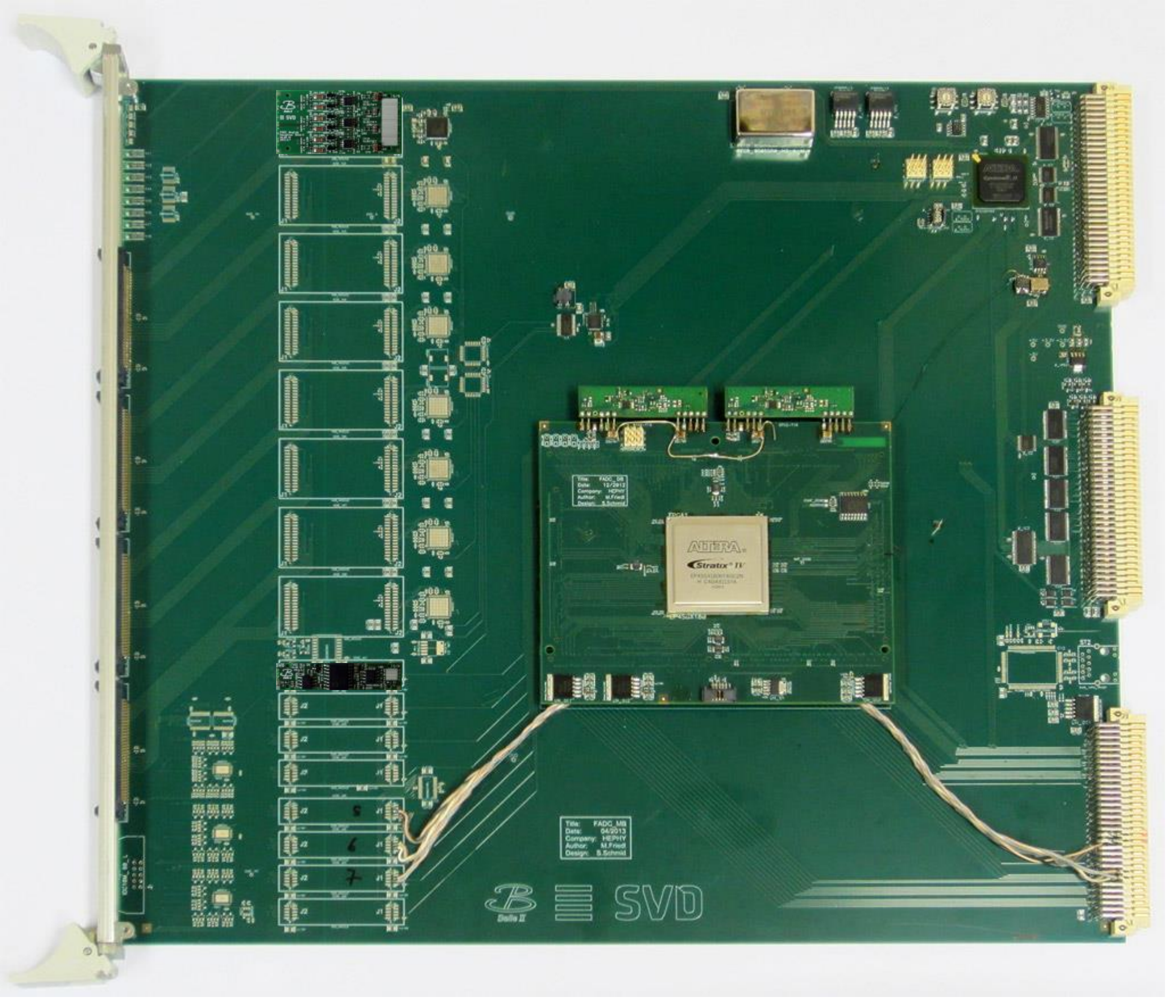
- Ladder production
  - L6 ladder production
    - 14 workdays per ladder
    - 13months for 19 ladders
  - L5 ladder production
    - 10months for 15 ladders
  - L4 Ladder production
    - 9months for 13 ladders
  - L3 Ladder production
    - 7months for 8 ladders
- L6 Ladder production will start Nov. 2013.
- Ladder mount on the SVD support structure will start Jan. 2015.
- L6 Ladder production will end Feb. 2015
- SVD ready Aug. 2015.
- Physics run Oct.2016

Summary

- SuperKEKB will be the highest luminosity machine
- Belle detector upgrade
  - Consists of 2 layers Pixel(PXD)+4 layers Strip(SVD) Vertex detector
- SVD
  - Layer3, 4, 5, 6 consist of 7, 10, 12, 16 ladders, respectively.
  - Chip on sensor readout scheme, named Origami, for outermost three layers for low material budget.
  - Active alignment will be applied in the ladder assembly.
  - Production of ladder will start Nov. 2013.

Backup slide

FADC



- Already partly equipped with components
- Used for connectivity test as shown
- Firmware development and testing of other parts has started

Material budget

- PA/PE/PB/SMD/ are neglected.
- Thickness of epoxy glue in ladder assembly is assumed to be 100 μm, or, 0.033 % X_0.

DSSD+ Origami	Rib	DSSD	Airex sheet	Origami	CO2 Cooling	100 μm Glue	Total
HPK+1ORIGAMI	0.035	0.340	0.055	0.133	0.037	0.033	0.593
HPK+2ORIGAMI	0.035	0.340	0.055	0.266	0.037	0.033	0.733
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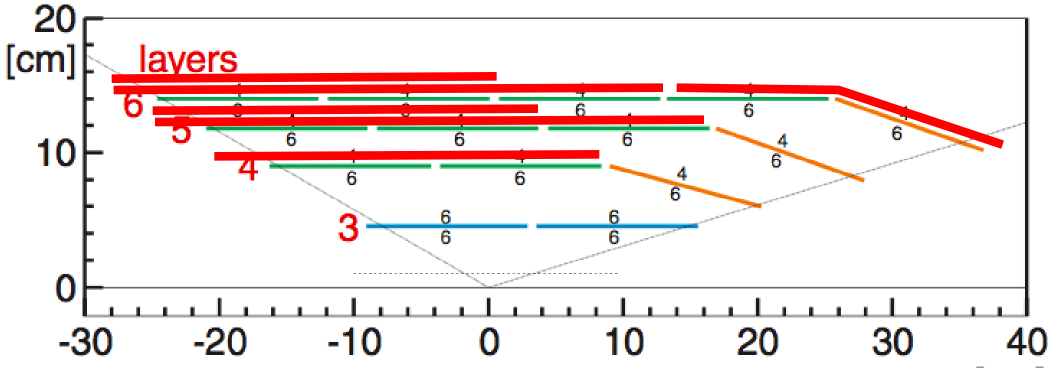
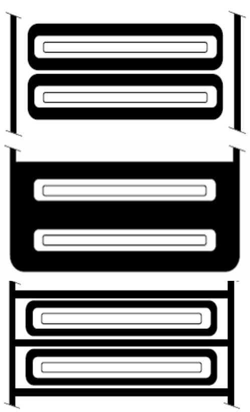


Trapezoidal DSSD

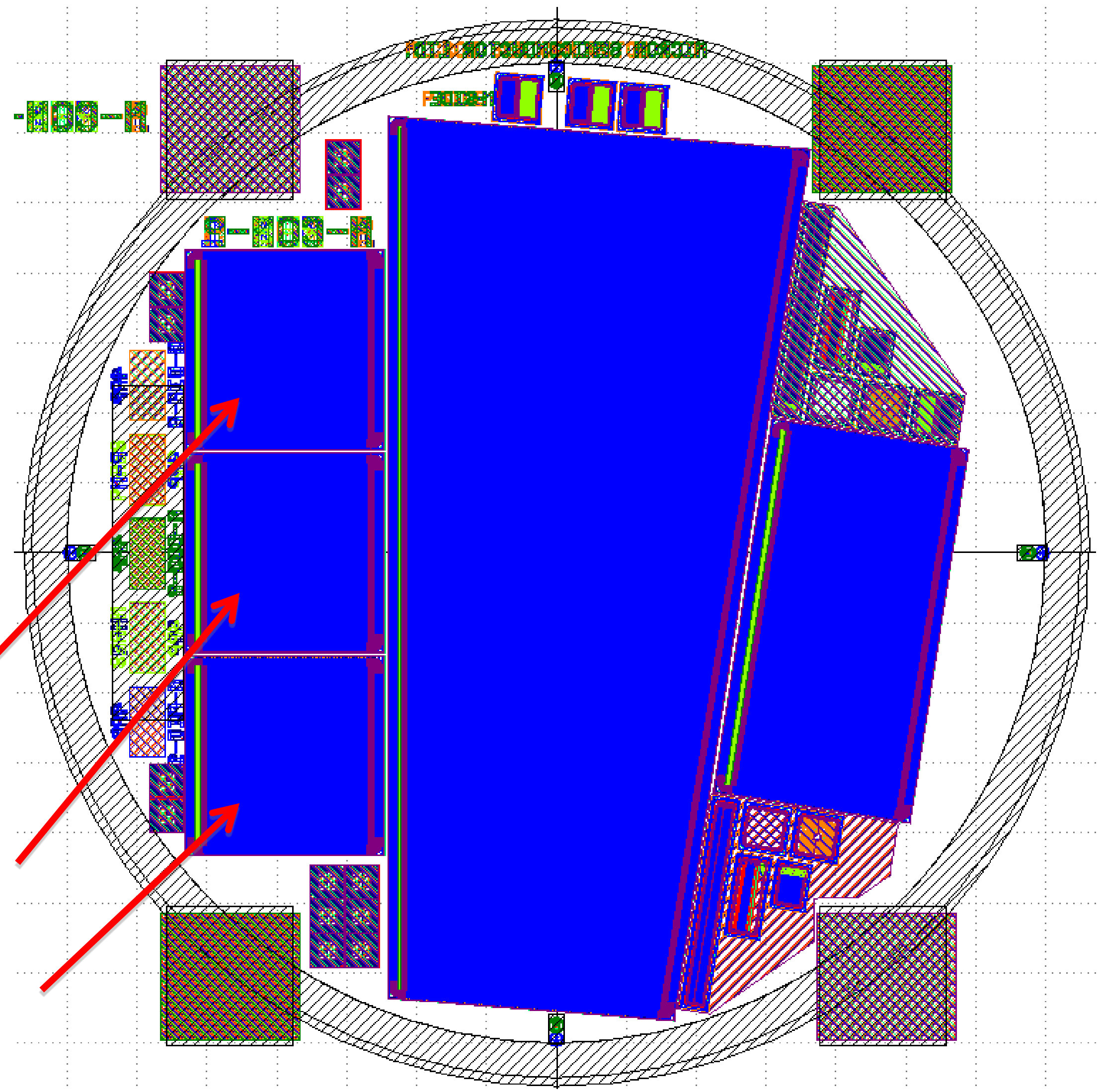
- Full wafer design by ourselves
- Main sensor (trapezoidal)
- Mini sensor (rect.)
- Test structures
- Baby sensors with various p-stop patterns



Atoll p-stop

Common p-stop

Combined p-stop



Comparison VA1TA – APV25

VA1TA (SVD)

- Commercial product (IDEAS)

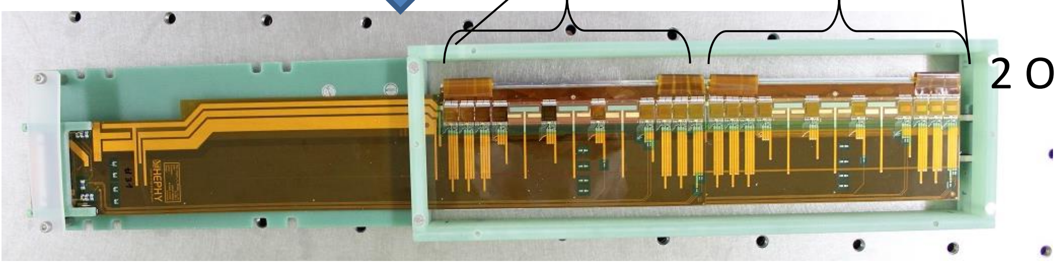
- Tp = 800ns (300 ns – 1000 ns)
- no pipeline
- <10 MHz readout
- 20 Mrad radiation tolerance
- noise: ENC = 180 e + 7.5 e/pF
- time over threshold: ~2000 ns
- single sample per trigger

APV25 (Belle-II SVD)

- Developed for CMS by IC London and RAL
- Tp = 50 ns (30 ns – 200 ns)
- 192 cells analog pipeline
- 40 MHz readout
- >100 Mrad radiation tolerance
- noise: ENC = 250 e + 36 e/pF
- time over threshold: ~160 ns
- multiple samples per trigger possible (Multi-Peak-Mode)

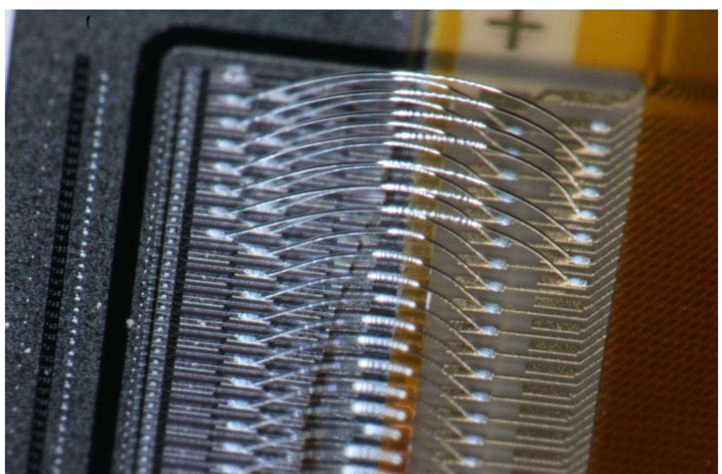
First 2 Origami module assembly@IPMU

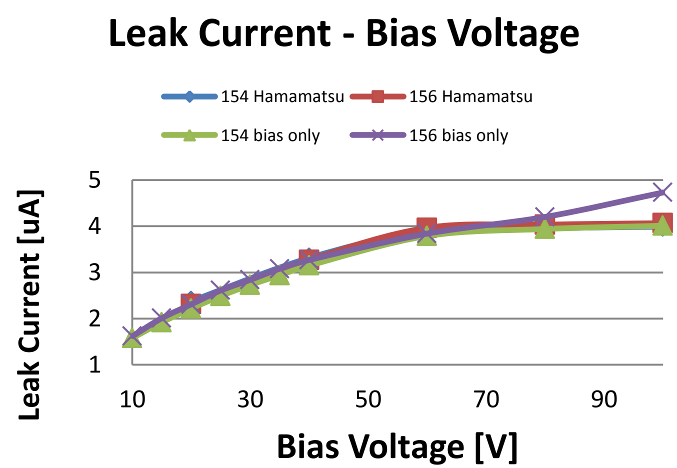
Single Origami module assembly@HEPHY



2 Origami module assembly(Jun. 2012)@IPMU

Automatic wire-bonder





First 2 Origami module@new clean room at IPMU

L6 Mockup ladder