Belle and Belle II at TIFR

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DHEP Annual Meeting @ TIFR
April 7-8, 2016

Going from one to other frontier

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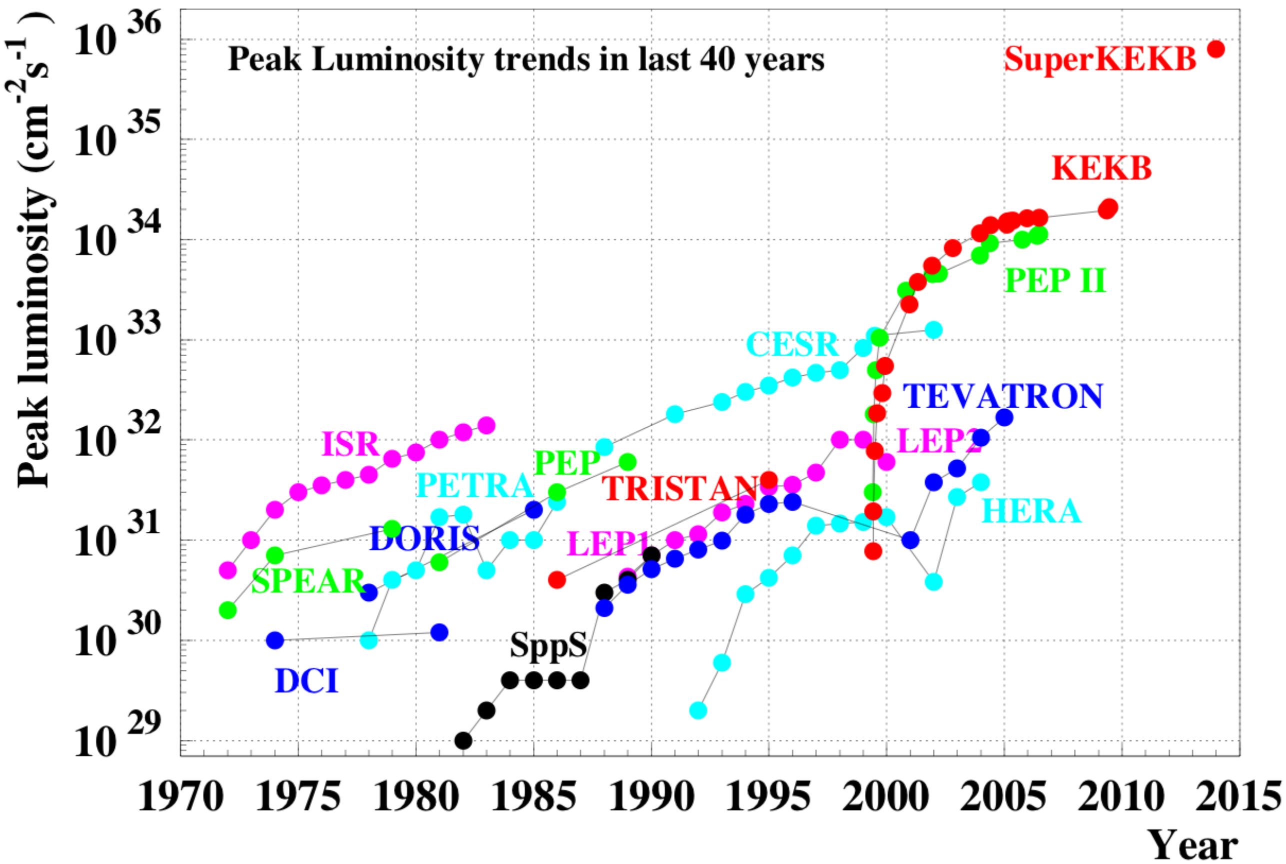


Group activities in one slide

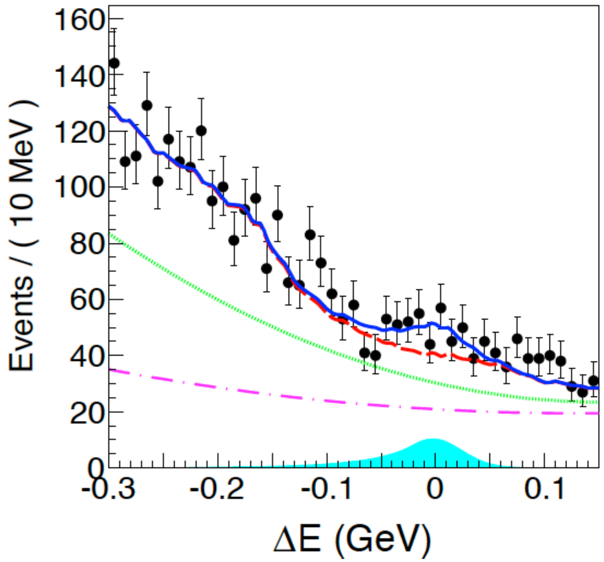
- CPV and rare B-meson decays
- CPV and rare charm decays
- Bottomonium spectroscopy

TIFR-Belle group

- Physics sensitivity studies
- Silicon Vertex Detector (L4)
- Continuum suppression

➢ A small group, having high visibility in terms of contribution and established leadership within the collaboration(s)

CP violation and rare B-meson decays



Evidence for the decay $B^0 \to K^+K^-\pi^0$

PRD 87, 091101(R) (2013)

- A challenging analysis challenged by huge continuum and peaking BB background
- Established a signal for the first time (3.5σ evidence)
- Will be a key analysis for Belle II

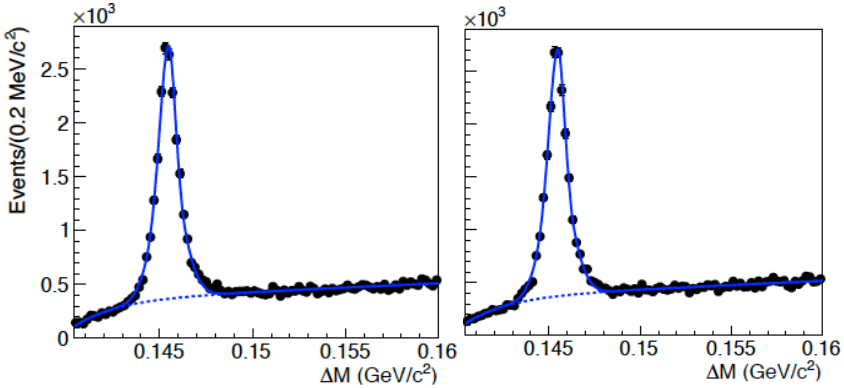
Measurements of Branching Fractions and Direct CP Asymmetries for $B \to K\pi$, $B \to \pi\pi$ and $B \to KK$ Decays

PRD 87, 031103(R) (2013)

We report measurements of the branching fractions and direct CP asymmetries ($\mathcal{A}_{CP}$) for $B \to K\pi, \pi\pi$ and KK decays (but not $\pi^0\pi^0$) based on the final data sample of 772×10^6 $B\overline{B}$ pairs collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. We set a 90% confidence-level upper limit for K^+K^- at 2.0×10^{-7}; all other decays are observed with branching fractions ranging from 10^{-6} to 10^{-5}. In the $B^0/\overline{B}^0 \to K^\pm\pi^\mp$ mode, we confirm Belle's previously reported large $\mathcal{A}_{CP}$ with a value of $-0.069 \pm 0.014 \pm 0.007$ and a significance of 4.4σ. For all other flavor-specific modes, we find $\mathcal{A}_{CP}$ values consistent with zero, including $\mathcal{A}_{CP}(K^+\pi^0) = +0.043 \pm 0.024 \pm 0.007$ with 1.8σ significance. The difference of CP asymmetry between $B^\pm \to K^\pm\pi^0$ and $B^0/\overline{B}^0 \to K^\pm\pi^\mp$ is found to be $\Delta\mathcal{A}_{K\pi} \equiv \mathcal{A}_{CP}(K^+\pi^0) - \mathcal{A}_{CP}(K^+\pi^-) = +0.112 \pm 0.027 \pm 0.007$ with 4.0σ significance. We also calculate the ratios of partial widths for the $B \to K\pi$ decays. Using our results, we test the validity of the sum rule $\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+)\frac{\Gamma(K^0\pi^+)}{\Gamma(K^+\pi^-)} - \mathcal{A}_{CP}(K^+\pi^0)\frac{2\Gamma(K^+\pi^0)}{\Gamma(K^+\pi^-)} - \mathcal{A}_{CP}(K^0\pi^0)\frac{2\Gamma(K^0\pi^0)}{\Gamma(K^+\pi^-)} = 0$ and obtain a sum of $-0.270 \pm 0.132 \pm 0.060$ with 1.9σ significance.

CP violation and rare charm decays

Search for CP violation in $D^0 \to \pi^0\pi^0$ decays



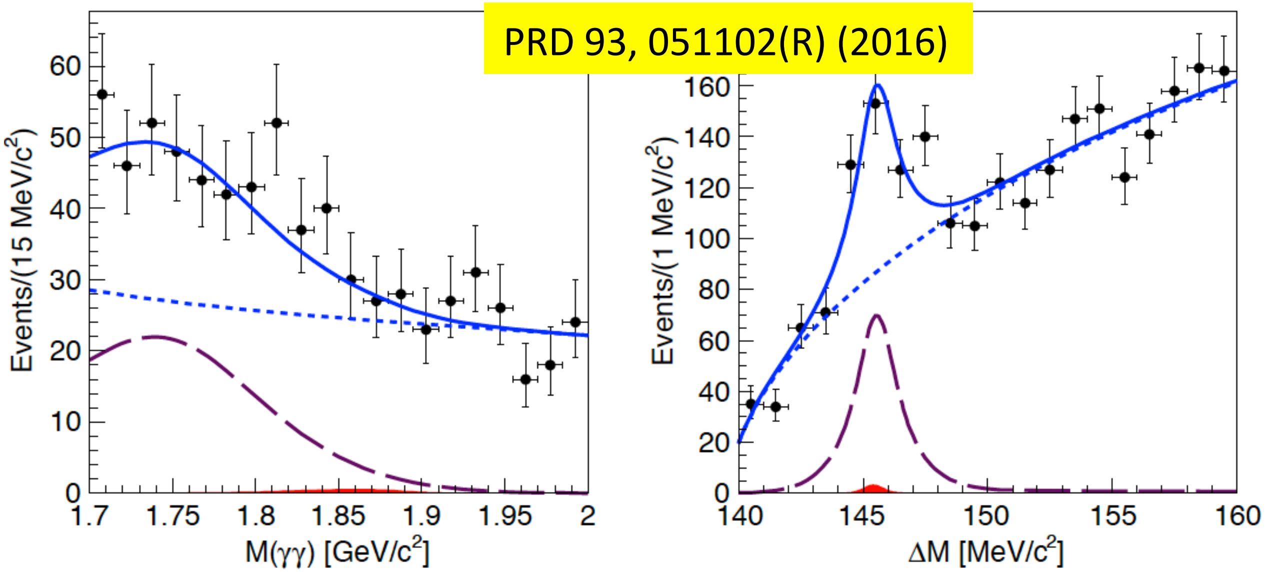
$$A_{CP}(D^0 \to \pi^0\pi^0) = (-0.03 \pm 0.64 \pm 0.10)\%$$

- ❑ Results consistent with no CP violation
- ❑ An order of magnitude improvement over the existing result

PRL 112, 211601 (2014)

Search for the rare decay $D^0 \to \gamma\gamma$

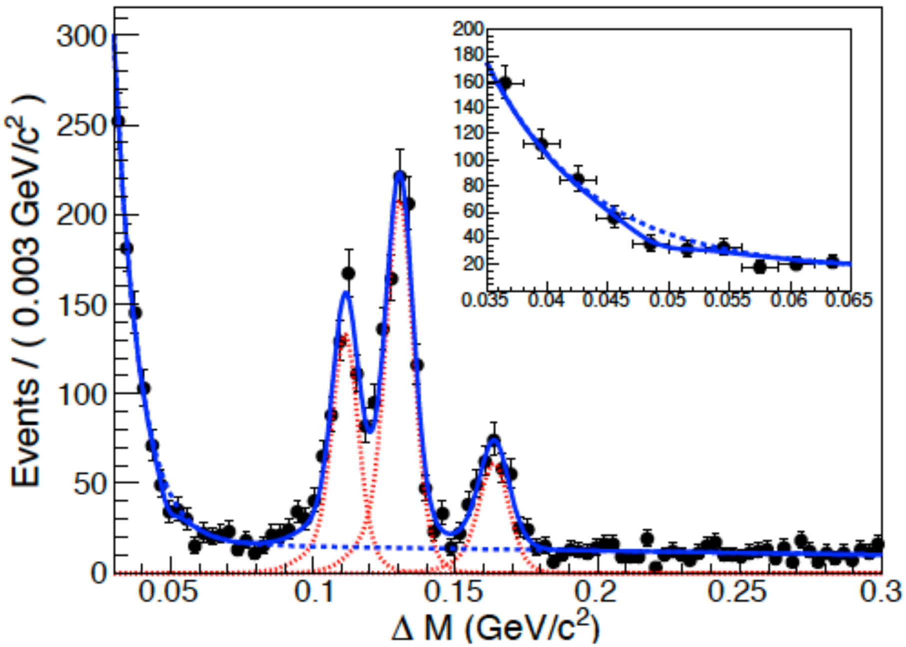
PRD 93, 051102(R) (2016)



- ❑ A nice channel for NP, which can only be studied at e^+e^- flavor factories
- ❑ Set world's best limit (8.5×10^{-7}) in absence of a signal

Bottomonium spectroscopy

Search for Bottomonium States in Exclusive Radiative $\Upsilon(2S)$ Decays

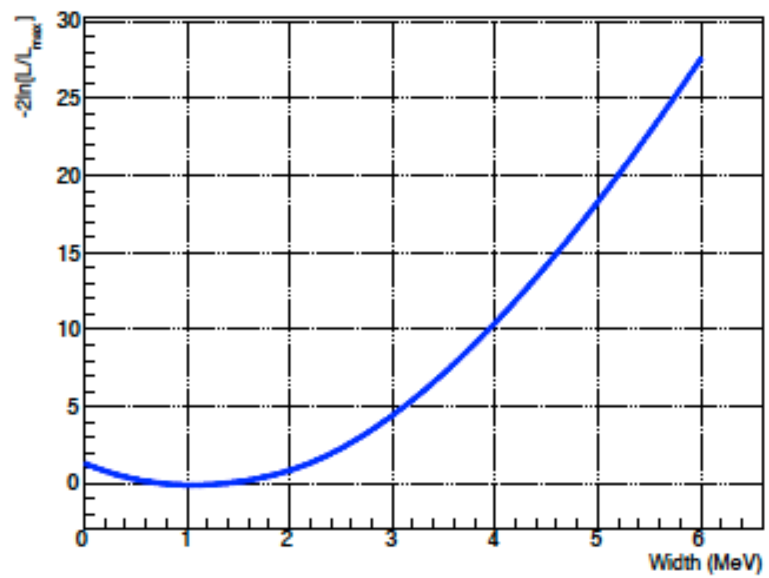


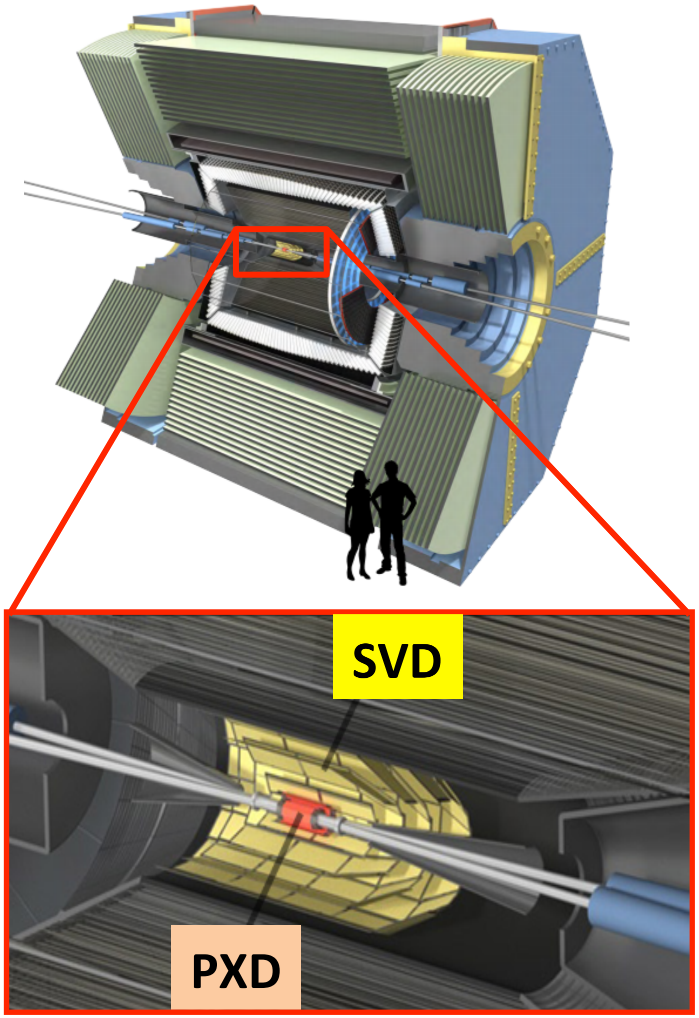
Paper in preparation

PRL 111, 112001 (2013)

- Unambiguously refuted the claim of dubious Xbb(9975) state, which was claimed by a study based on CLEO's data
- Paved way for further study on $\chi_{bJ}(1P)$ states – see below

- 85 new decay channels of $\chi_{bJ}(1P)$ are discovered
- First upper limit on the natural width of of $\chi_{b0}(1P)$





- Determine the vertex position of the weakly decaying particles
- Measure the two-dimensional track position and momentum for charged particles

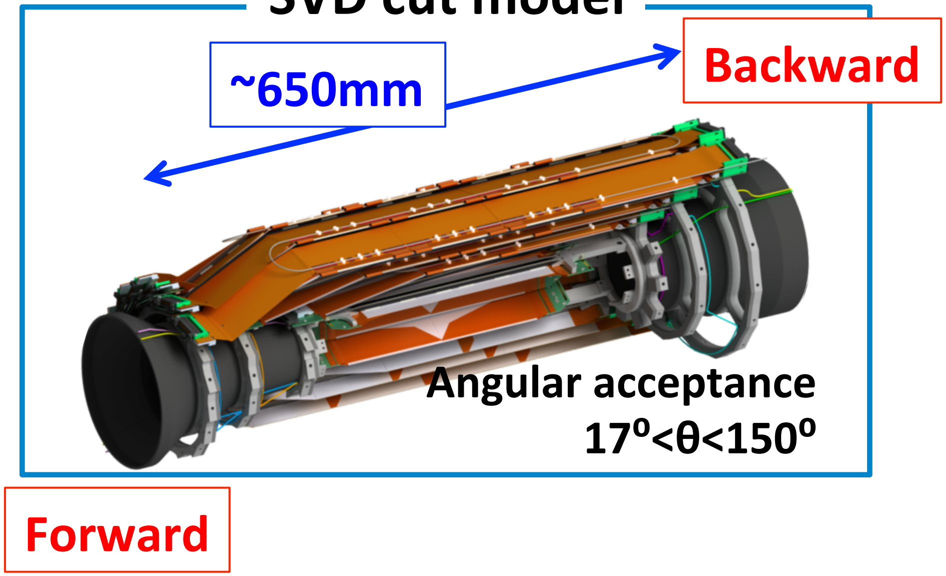
- PiXel Detector (PXD)
- Silicon Vertex Detector (SVD)
  - Double-sided silicon strip detectors (DSSDs)

VXD requirements

- Fast – to operate in high rate environment
- Excellent spatial resolution
- Radiation hard (up to 100 kGray)
- Good tracking capability – to track particles down to 50 MeV in p_T

SVD Structure Overview

SVD cut model

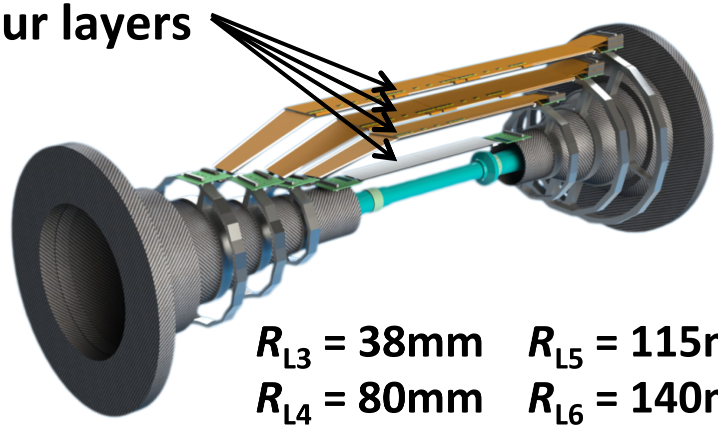


Layer	Institute
3	University of Melbourne
4	TIFR Mumbai
5	HEPHY Vienna
6	IPMU University of Tokyo
FW & BW	INFN Pisa

- **4 SVD layers (L3 to L6) composed of ladders arranged in a windmill structure**
- **Improved resolution at IP w.r.t Belle I**
- **Very lightweight – only 0.58%X_0 per layer**

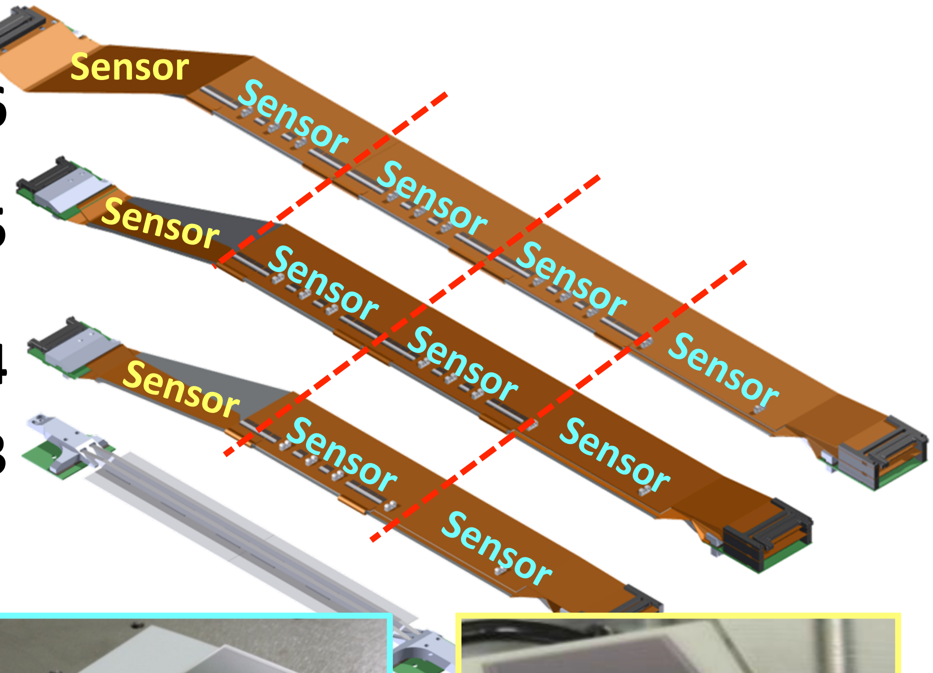
SVD Ladder Layout

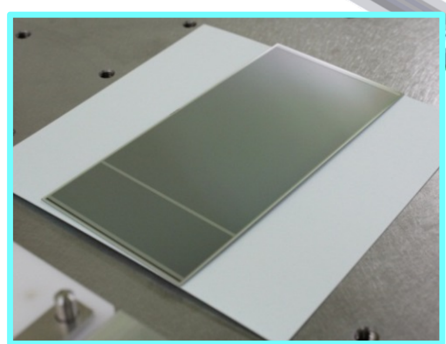
Four layers



R_{L3} = 38mm R_{L5} = 115mm
R_{L4} = 80mm R_{L6} = 140mm

Layer	Ladders	Sensors / Ladder	APVs
6	16	5	800
5	12	4	480
4	10	3	300
3	7	2	168



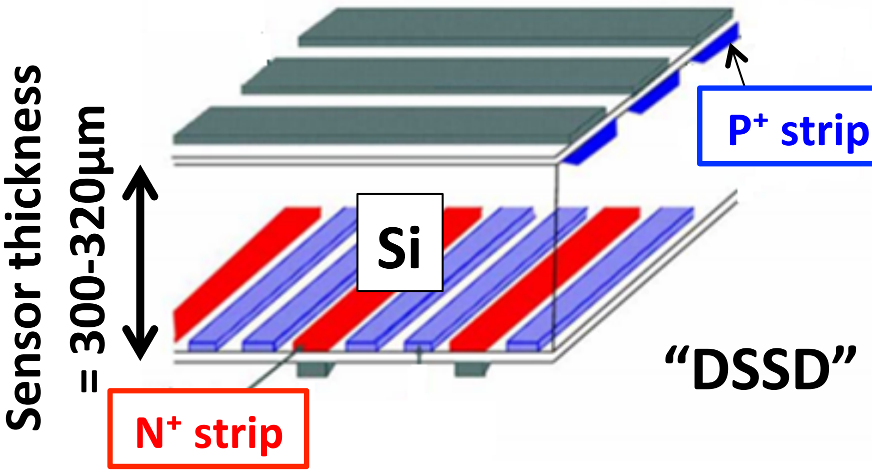


Rectangular sensor

Trapezoidal sensor

SVD Sensors and Readout ASIC

Double-sided Si strip detector

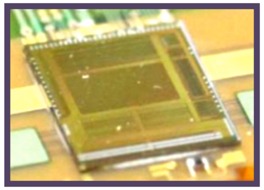


	Rectangular	Trapezoidal
# of *p*-strips	768	768
p-strip pitch	75μm	50…75μm
# of *n*-strips	512	512
n-strip pitch	240μm	240μm
Active area	57.72x122.9 mm²	5890mm²

Readout ASIC (APV25)

- As high hit rate is anticipated at Belle II, the readout chip should have a short signal shaping time for low noise and a good radiation hardness.

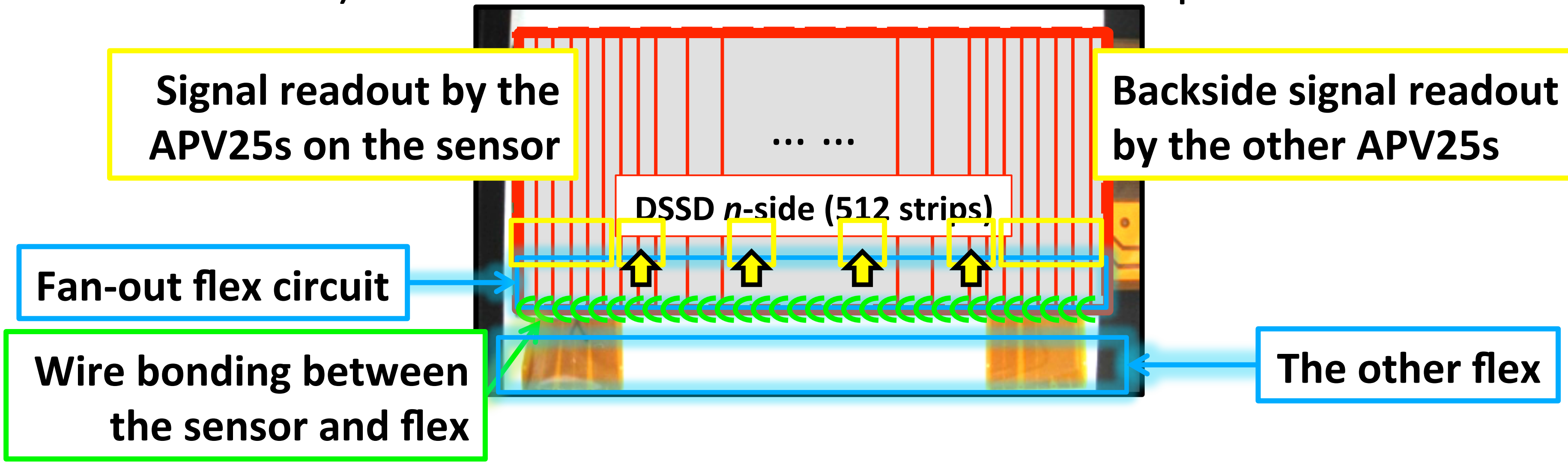
We adopted the APV25



- The APV25 was originally developed for the CMS.
  - Shaping time = 50ns.
  - Radiation hardness > 1MGray.
- Other characteristics
  - # of input channels = 128 / chip.
  - 192-deep analog pipeline for the dead-time reduction.
  - Thinned down to 100μm for the material budget reduction.

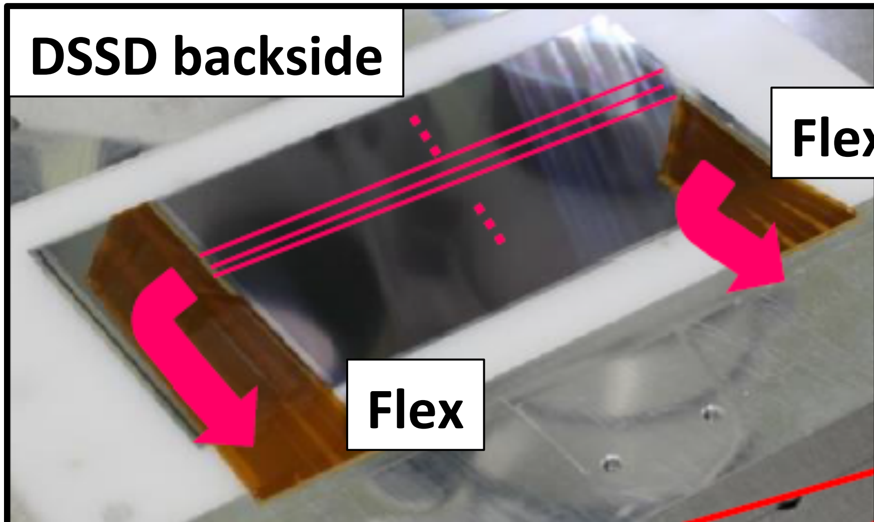
Chip-on-Sensor and “Origami” Concepts

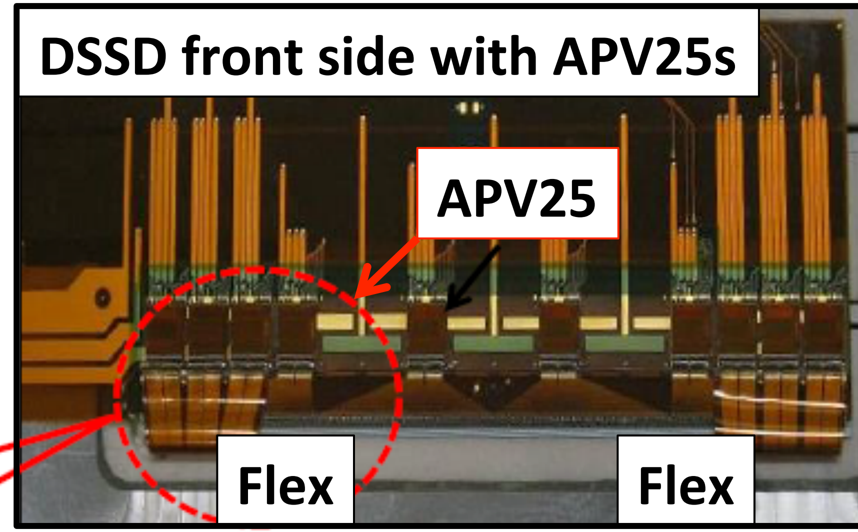
- APV25 on sensor
  - The APVs for the inner sensors are placed directly on the DSSDs to minimize the analog path length (capacitive noise)
- P-side readout
  - Signals on the sensor backside are brought to the upper side by other flex circuits and readout by APV25 chips mounted on the top

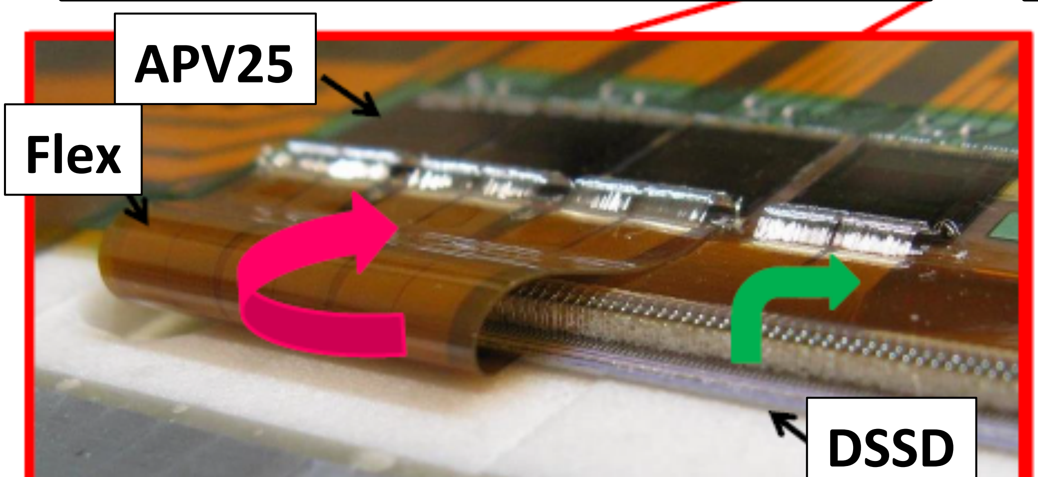


Readout ASICs on the same side & line → easier chilling by a single cooling pipe.

Snapshot – the "Origami" Concept

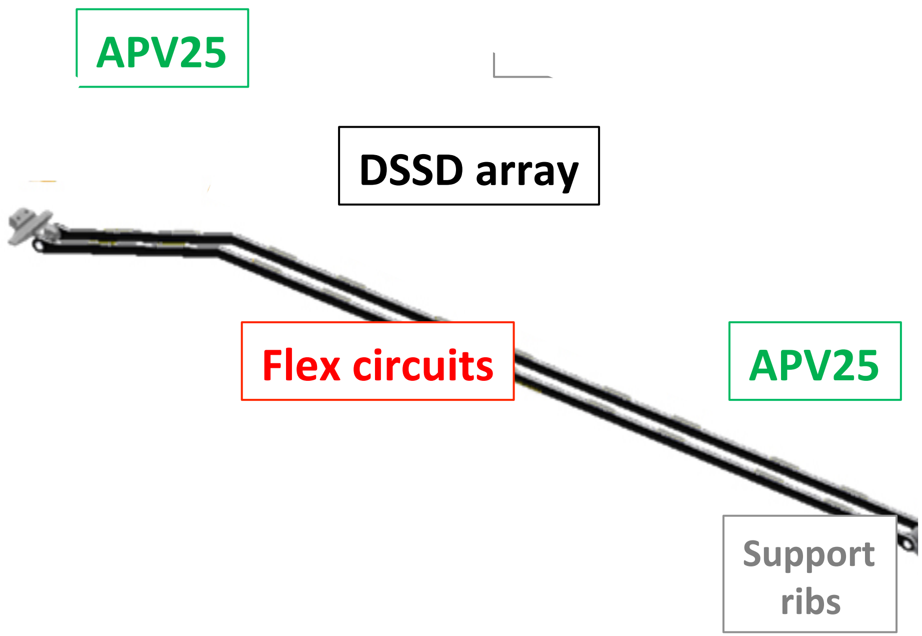






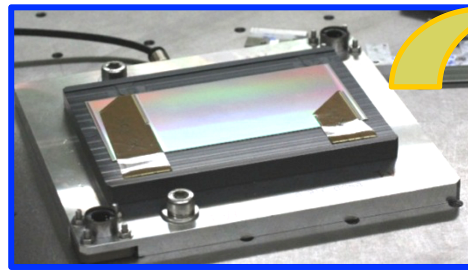
The backside signals are transmitted to the APV25 via *bent* (and glued) flex circuits.

SVD Ladder Assembly

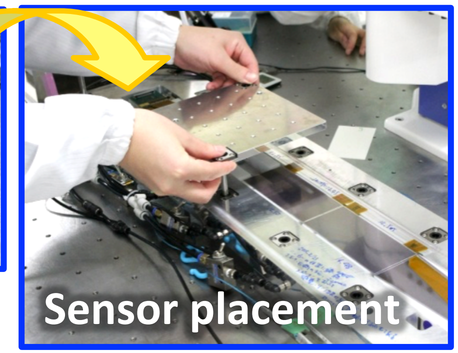


Precision DSSD alignment

DSSDs are handled with precision assembly jigs (O(50μm)), on which the sensors are fixed by vacuum chucking.

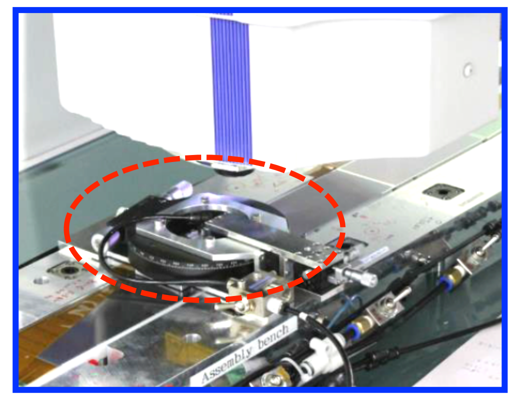


Sensor fixed on a jig



Sensor placement

Sensors are aligned with a Precision of 10μm by a position tuning jig with monitoring through a CMM.

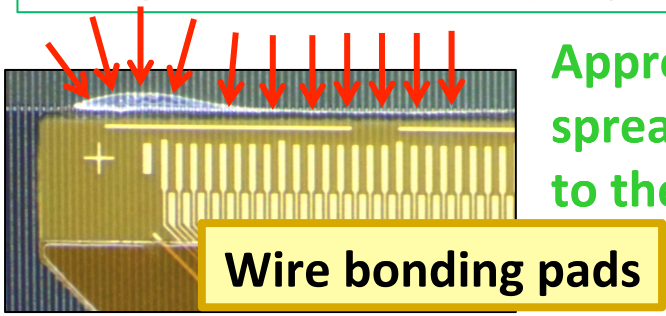


SVD Ladder Assembly

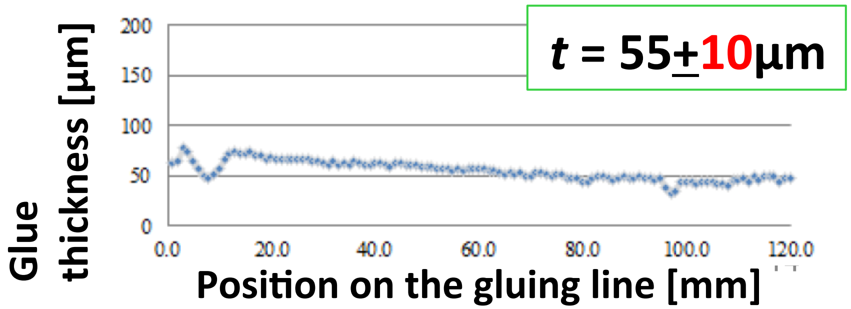
Ladder fabrication: gluing

Ladders are fabricated by gluing the components by Araldite®2011

Glue spread below bonding pads can affect the bonding yield and pull strength → glue amount and glue lining are controlled by a gluing robot.



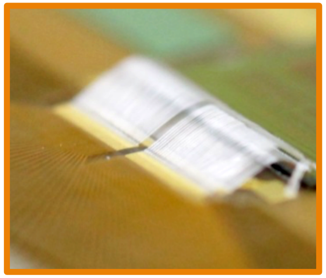
Appropriate spread of glue to the flex edge



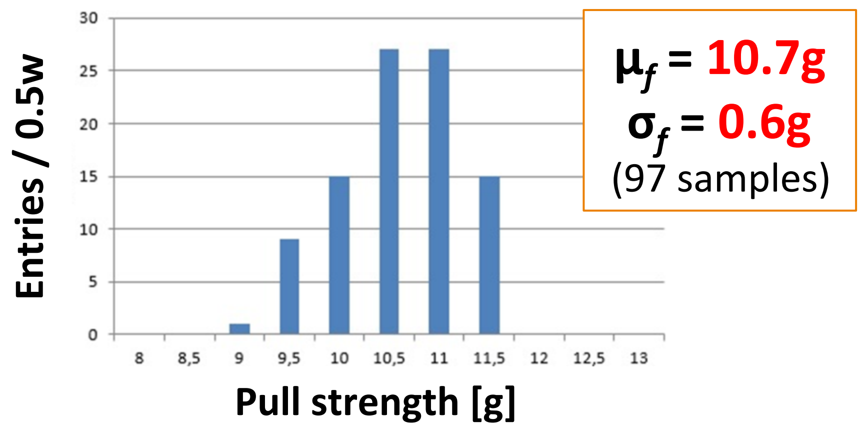
Electrical connection: wire bonding

The flex↔DSSD strips and flex↔APV25s are electrically connected by the wire bonding with Aℓ(99%) wire(ϕ=25µm).

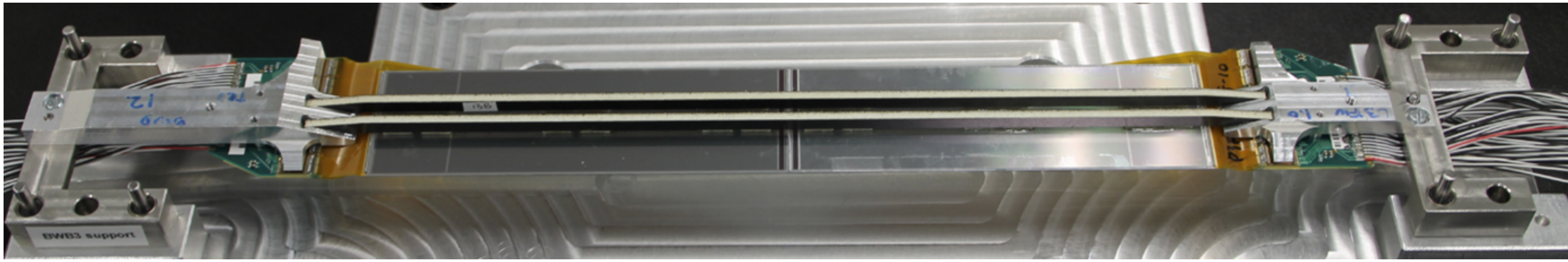
Number of total bonds = **450k**.



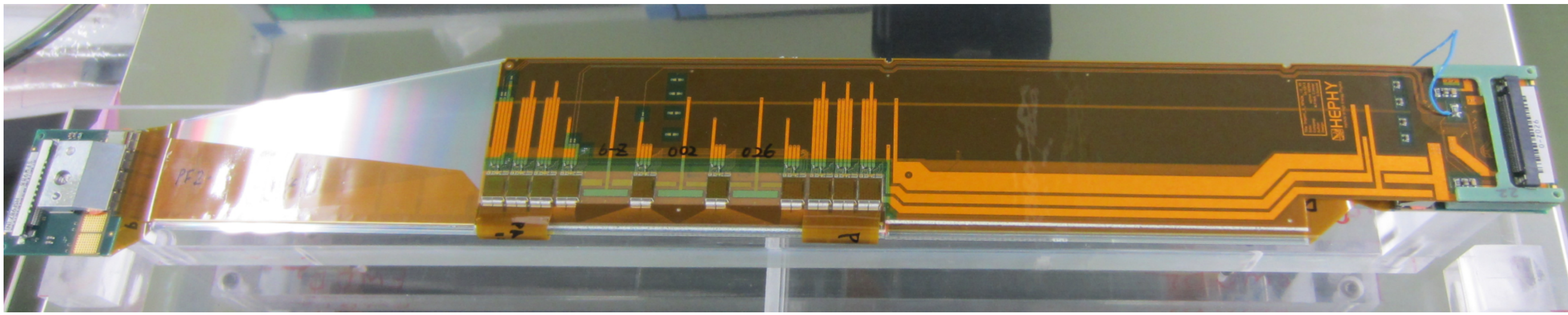
Bonding machine parameters are fine tuned to realize yield>99% and pull strength f:μ_f>5g, σ_f/f<20%.



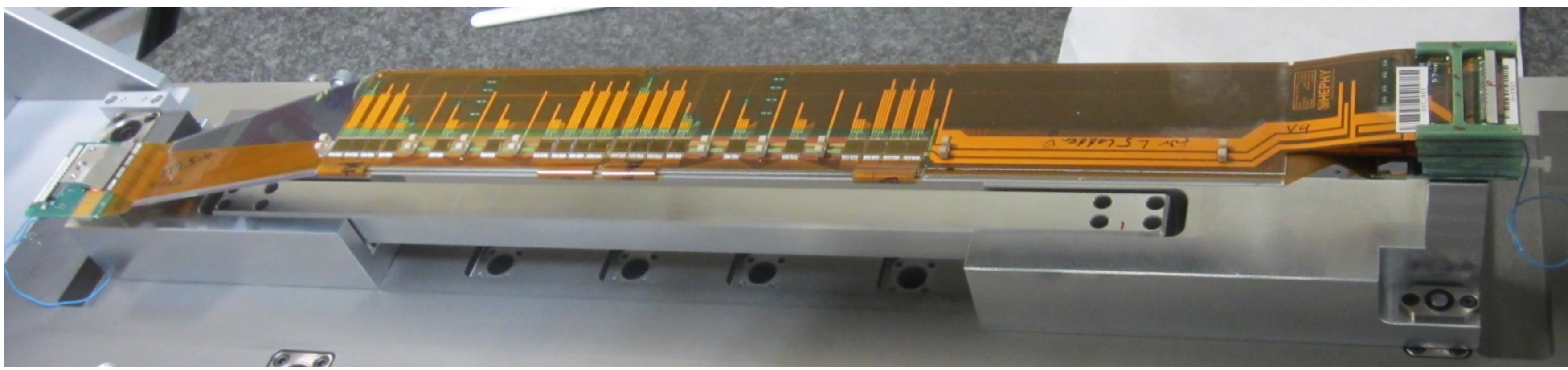
Assembled ladders



L3



L4

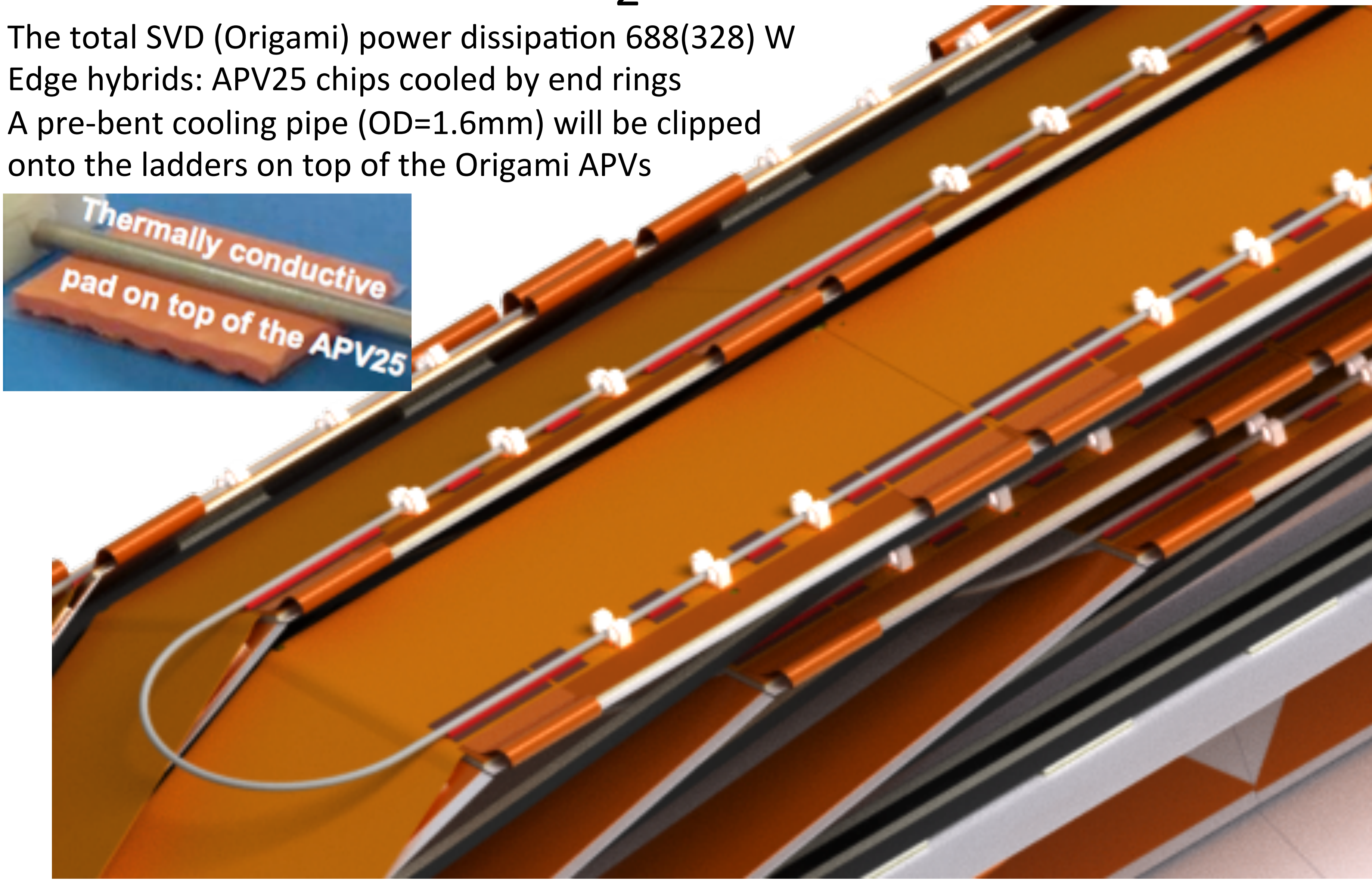


L5

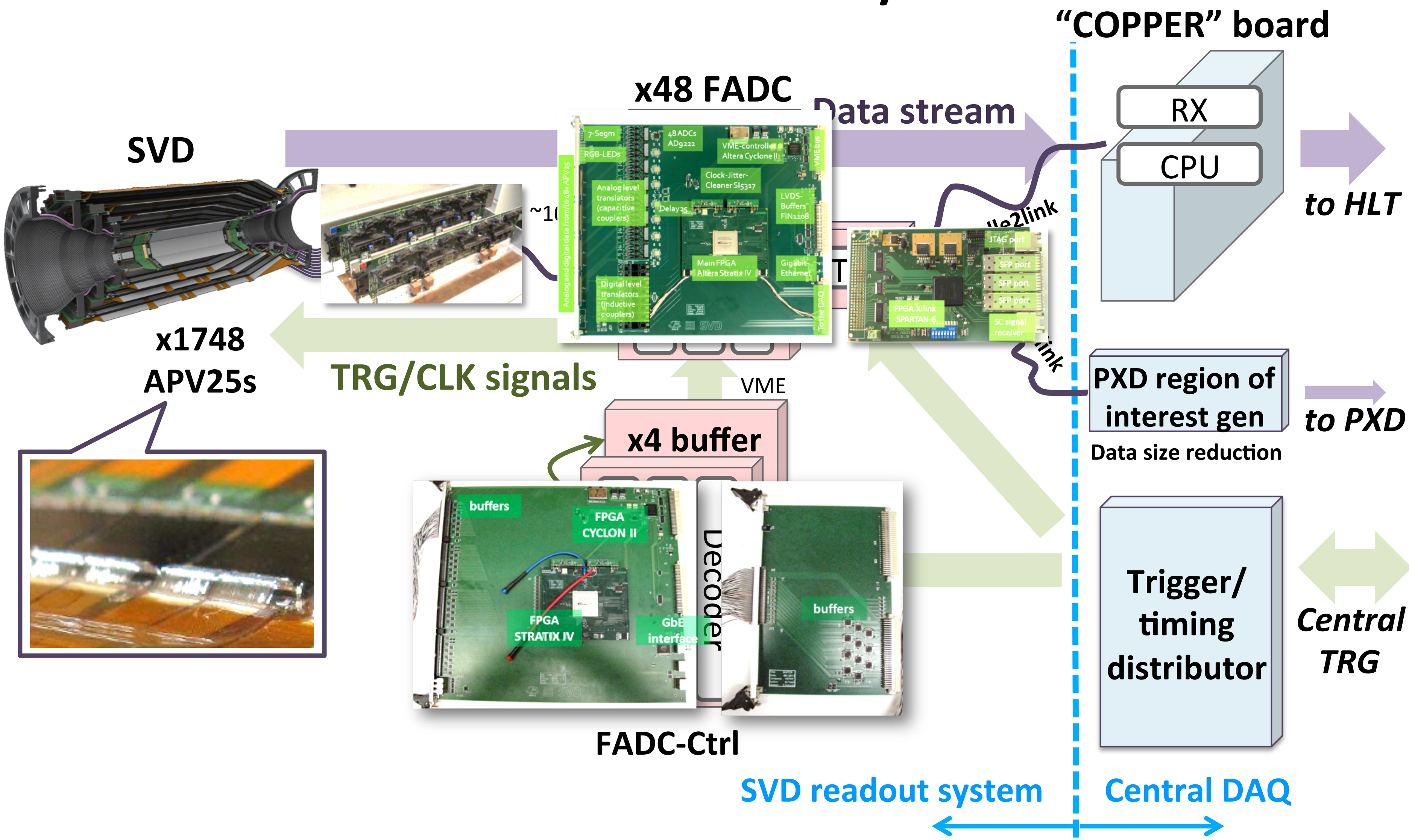
L6

CO_2 Cooling

The total SVD (Origami) power dissipation 688(328) W
Edge hybrids: APV25 chips cooled by end rings
A pre-bent cooling pipe (OD=1.6mm) will be clipped onto the ladders on top of the Origami APVs



FADC Readout System



Prototypes of all components have been developed.

Past Reviews

- Class C1 - Onsite review on 5th February 2015
- Class C2 - Onsite review on 27th June 2015
- Class B- (L4.905) - Electrically working but mechanically not
- Class C3 (L4.906) - Mechanically good but one corner of the FW sensor lifted up to 400microns
- L4.905 and L4.906 (remote) - 6th January 2016
- L4.001 (Class B) - 25th February 2016

Summary

- Taking a lead role in the Belle and Belle II experiments in probing NP in the luminosity frontier

- Both physics and detector (Belle II SVD)