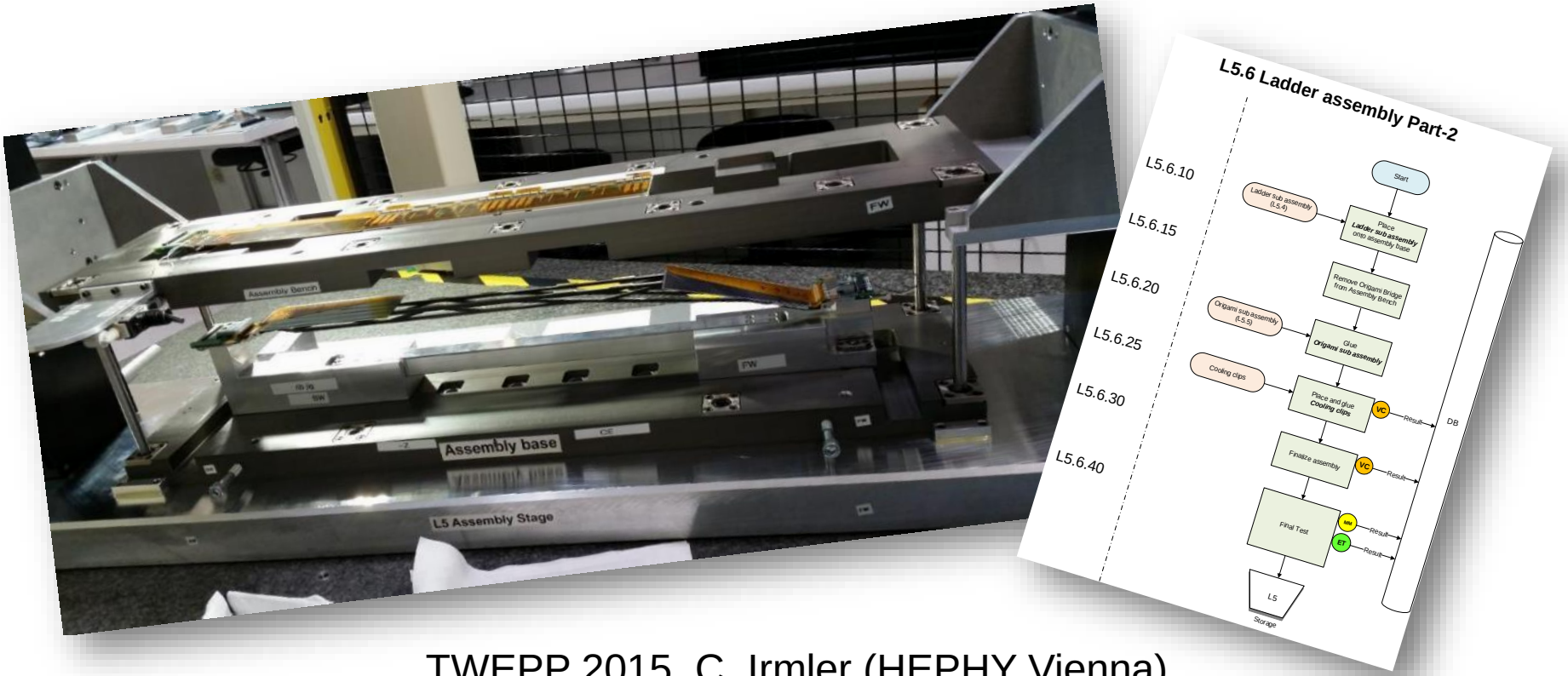
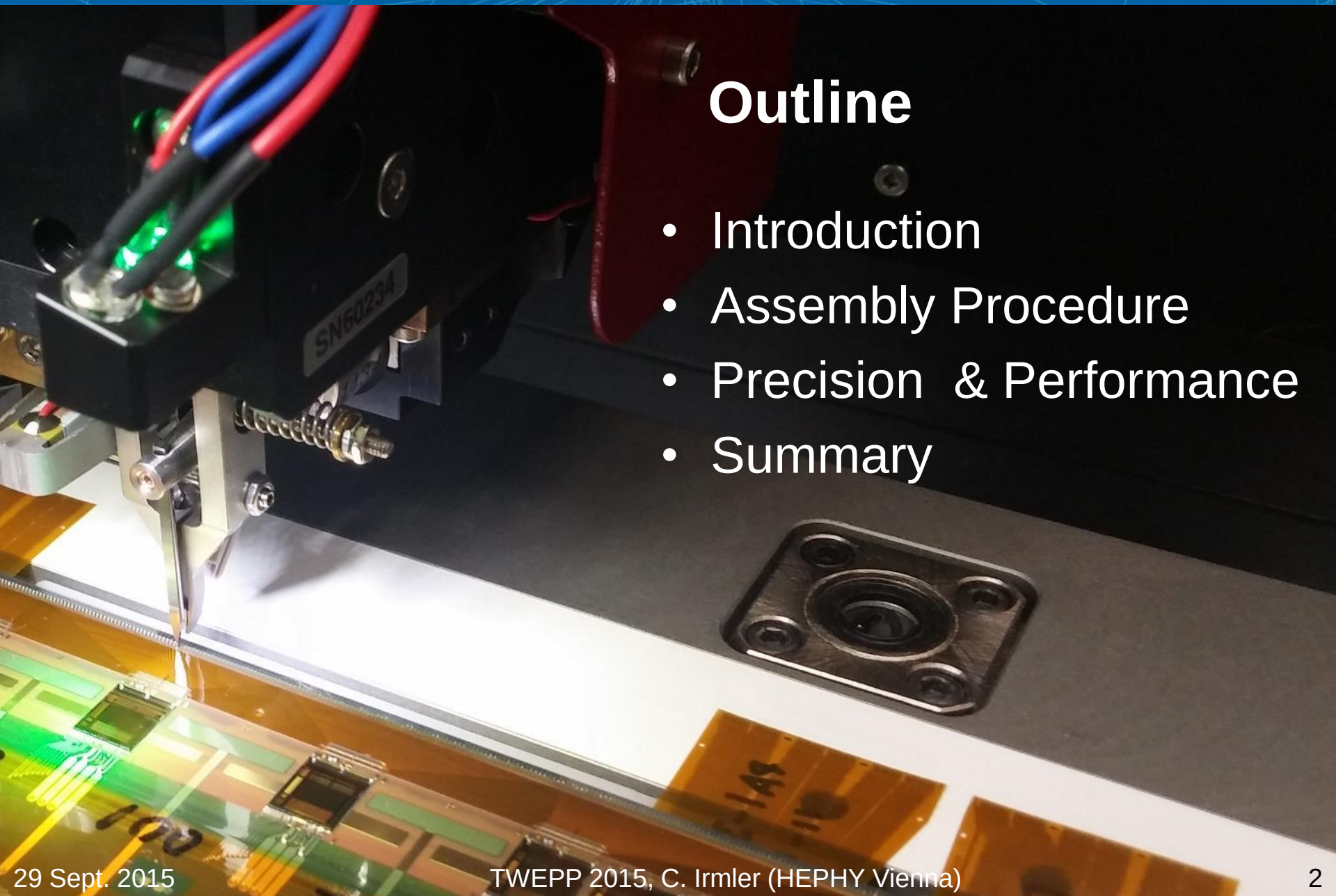
Construction and Test of the First Belle II SVD Ladder Implementing the Origami Chip-on-Sensor Design

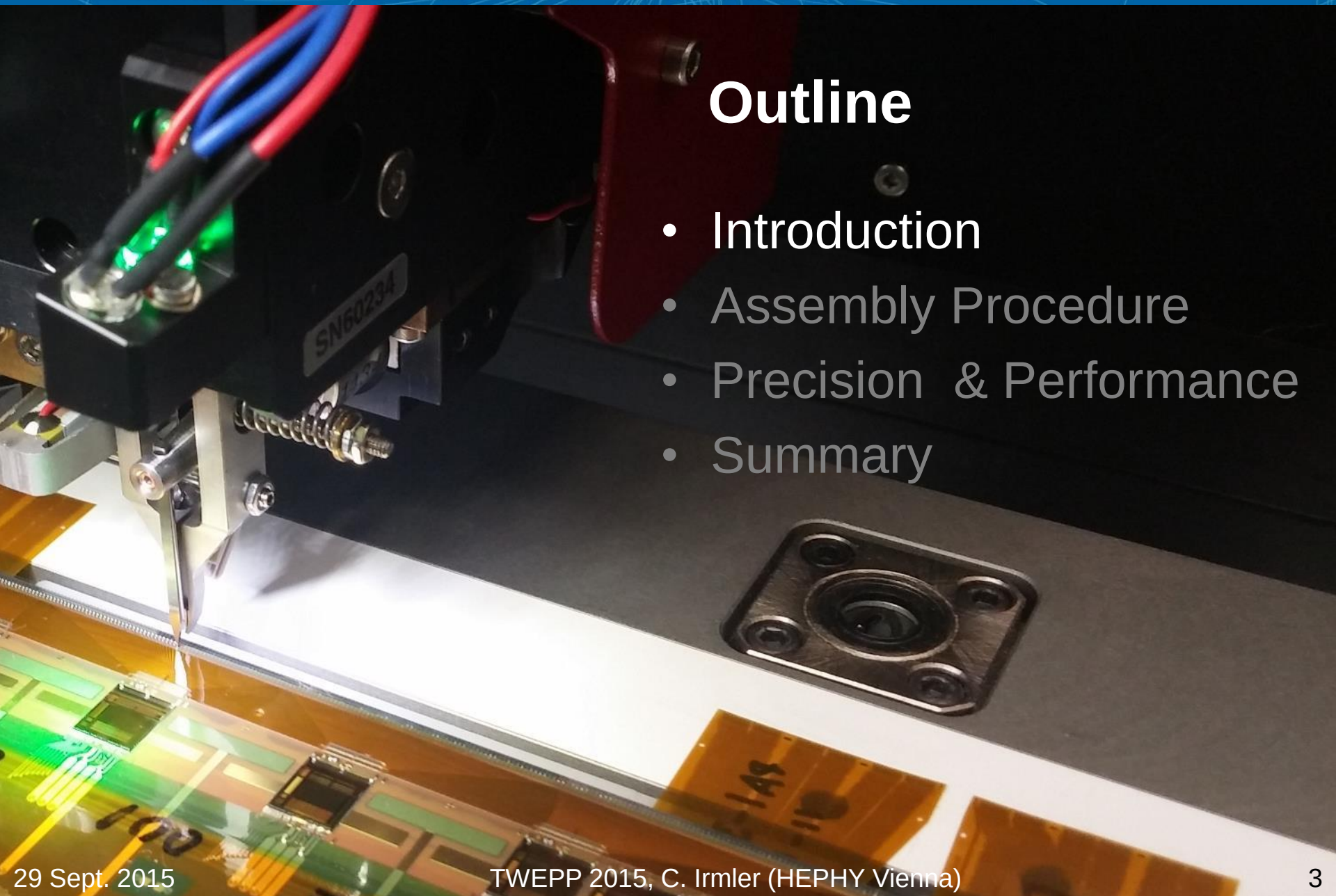


TWEPP 2015, C. Irmler (HEPHY Vienna)



Outline

- Introduction
- Assembly Procedure
- Precision & Performance
- Summary

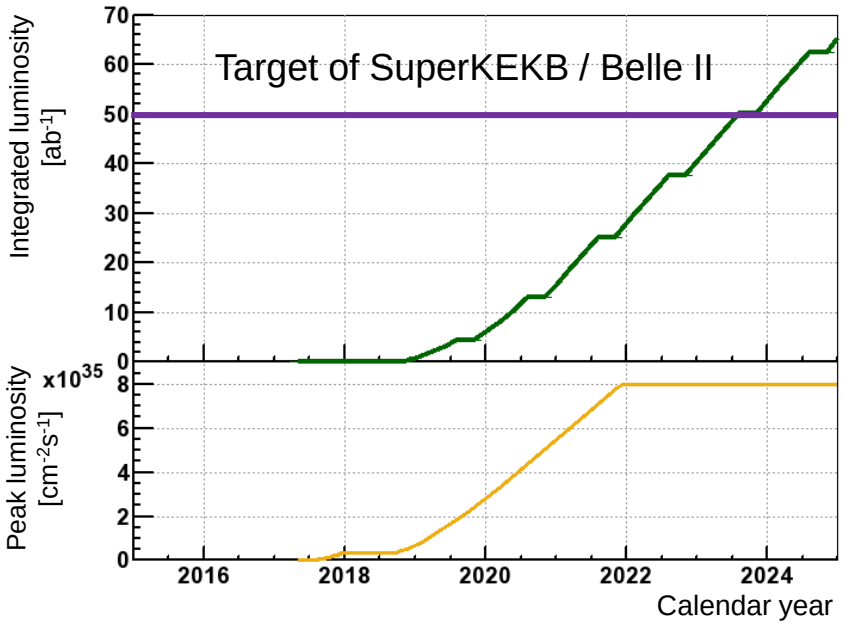


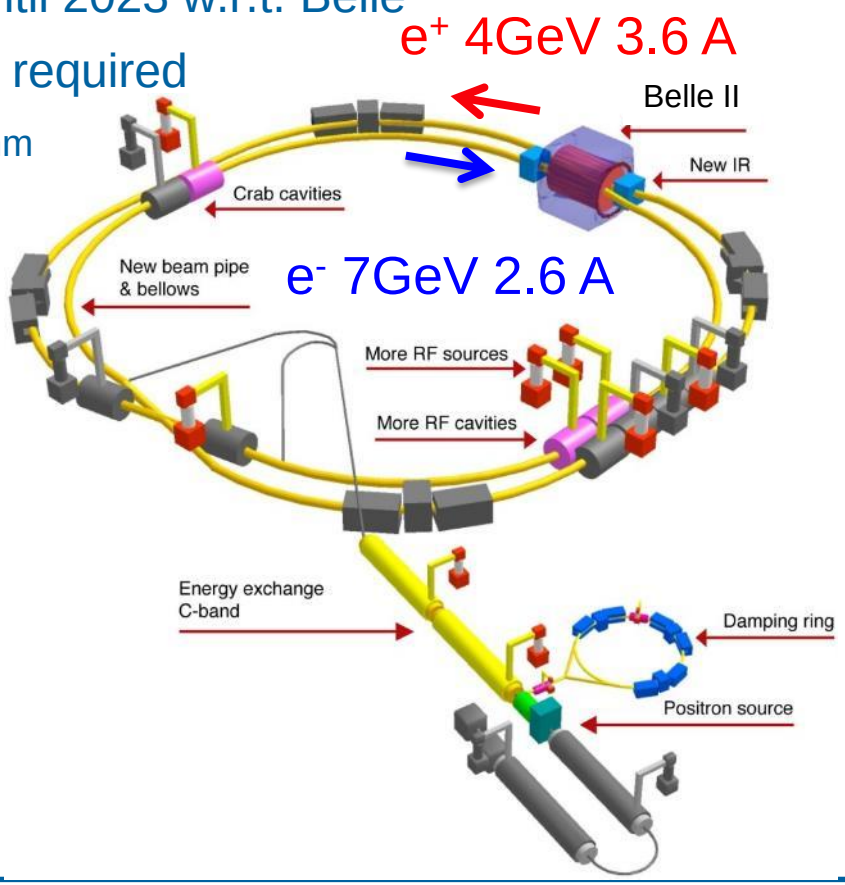
Outline

- Introduction
- Assembly Procedure
- Precision & Performance
- Summary

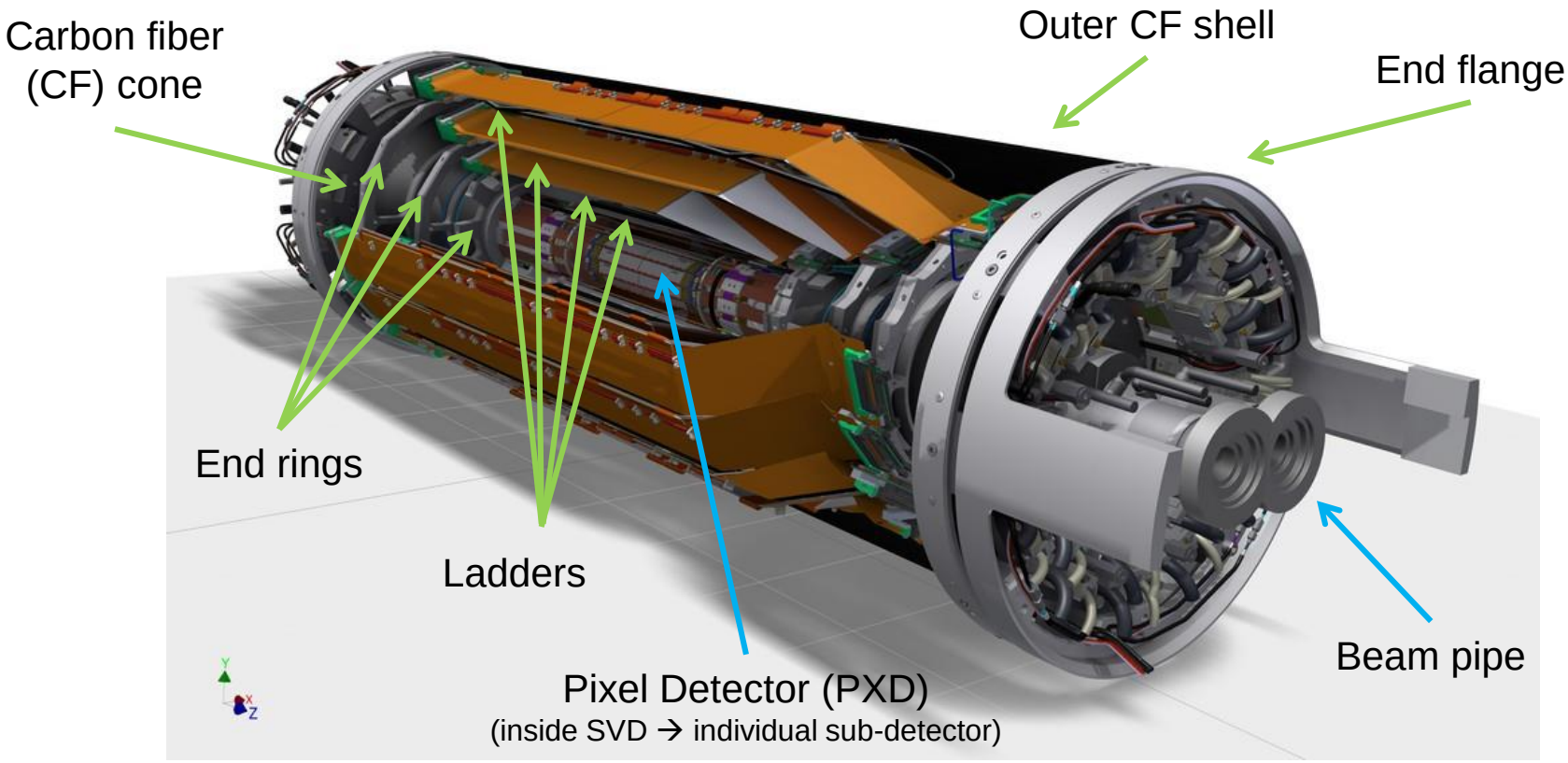
SuperKEKB / Belle II

- SuperKEKB: e^-/e^+ collider at KEK, Tsukuba, Japan → B factory
- 40-fold increase in peak luminosity to $8\times10^{35}\,cm^{-2}s^{-1} \rightarrow 1\times10^{10}$ BB / year
- 50-fold increase in integrated luminosity until 2023 w.r.t. Belle
- Refurbishment of accelerator and detector required
  - Nano-beams with cross-sections of ~10 µm x 60 nm
  - 10 mm radius beam pipe at interaction region



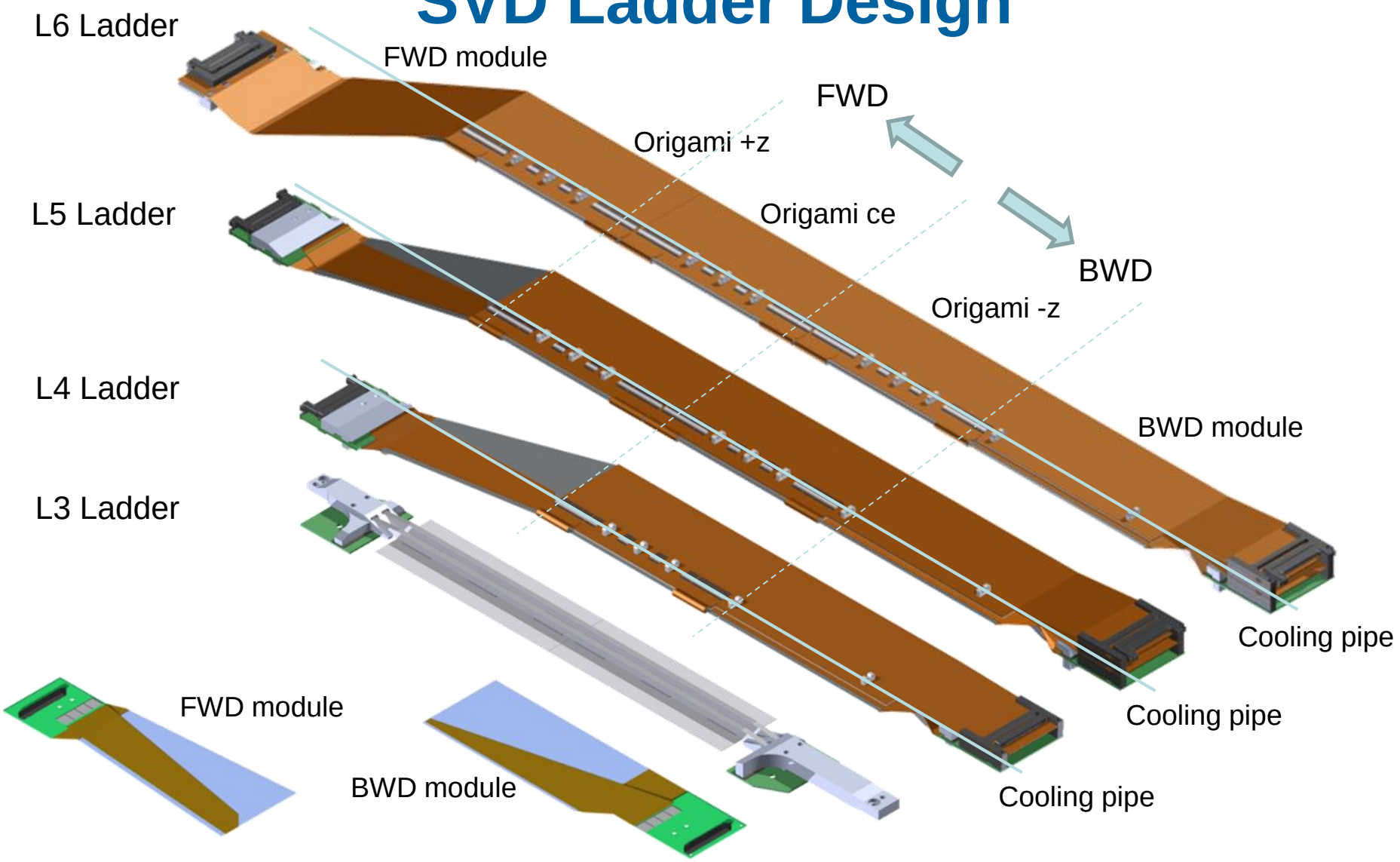


Belle II Silicon Vertex Detector

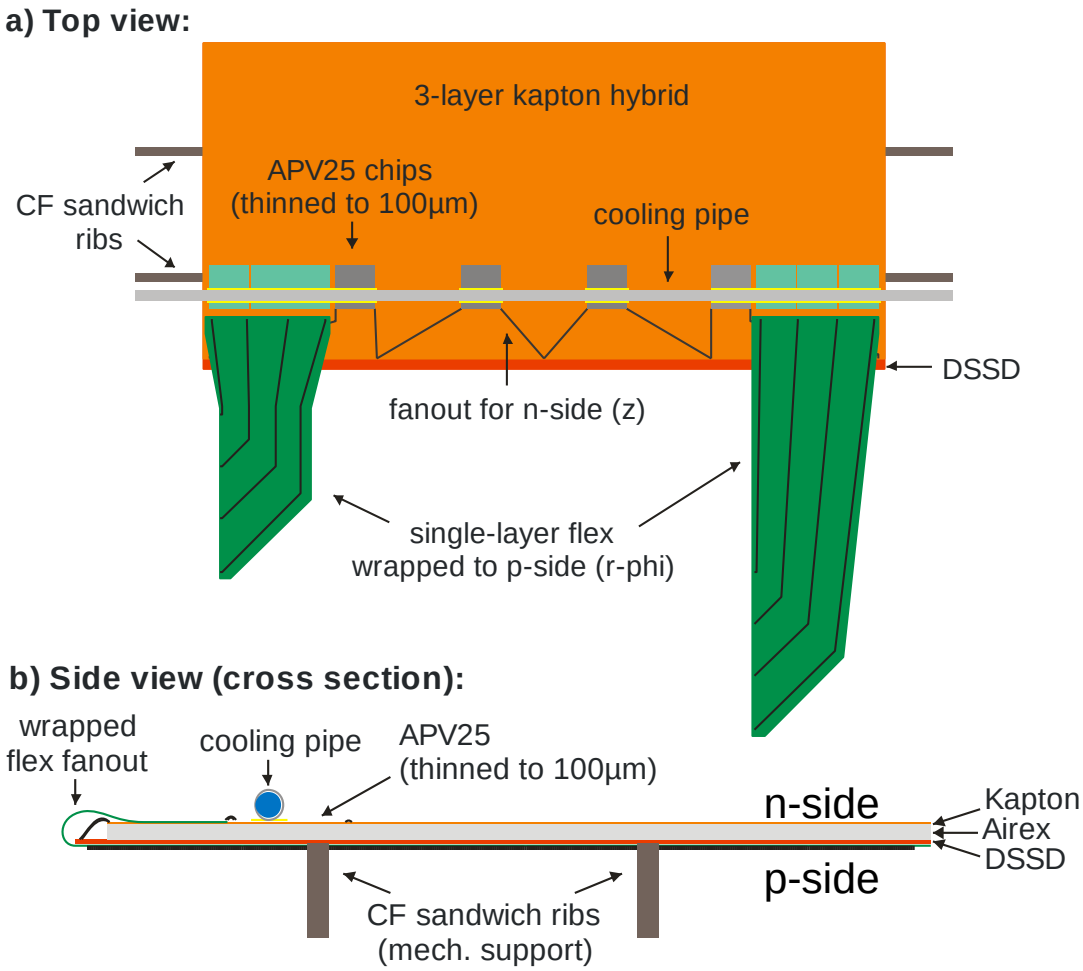


- Belle II Vertex Detector (VXD) = Silicon Vertex Detector (SVD) + Pixel Detector (PXD)
- Four layers of double sided silicon strip detectors (made from 6” wafers)
- Radii of SVD layers: 38 / 80 / 115 / 140 mm
- 2,3,4 or 5 sensors per ladder

SVD Ladder Design



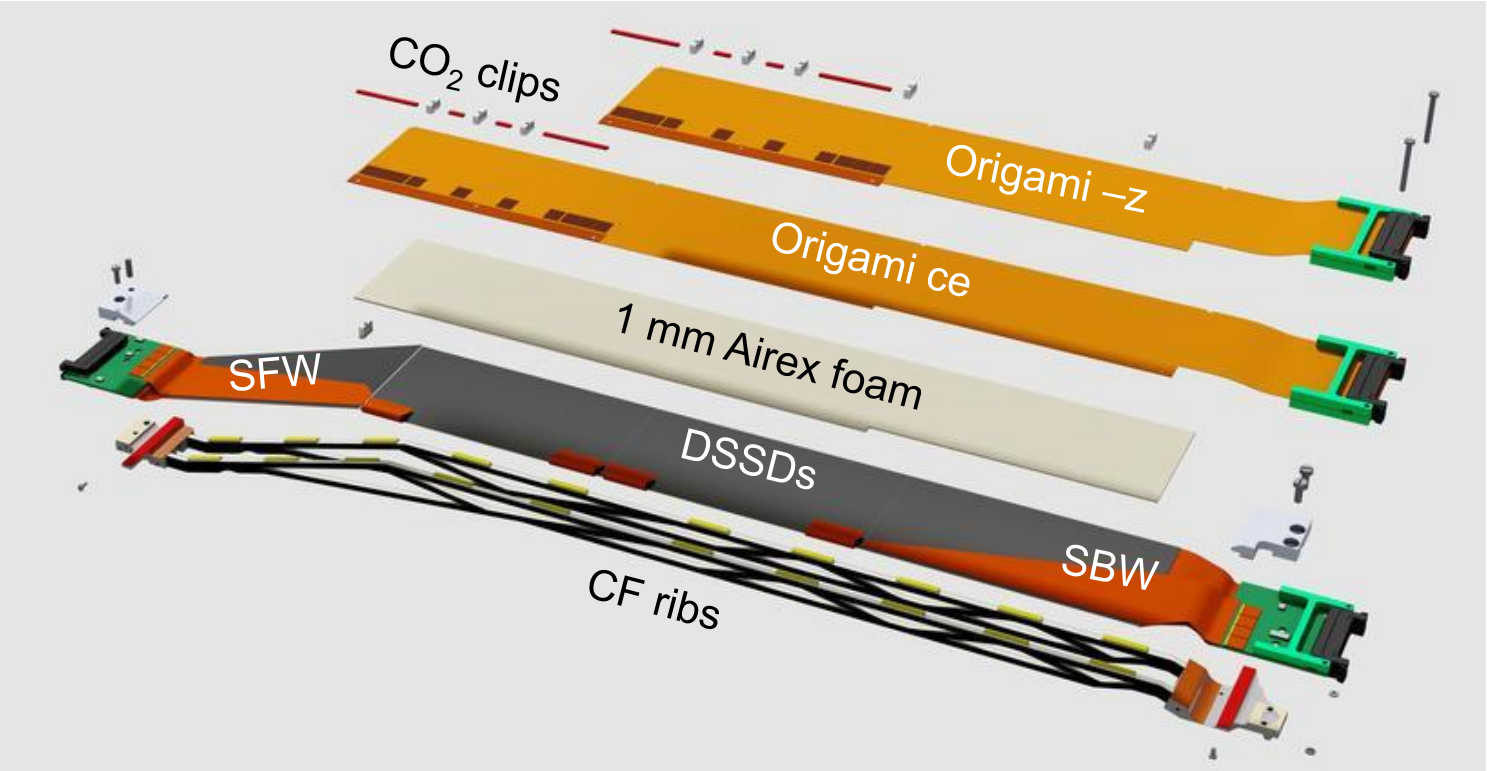
The Origami Chip-on-Sensor Concept



- CF reinforced ribs
- 6” DSSD
- 1 mm Airex® sheet as isolator
- 3-layer flex circuit
- Thinned APV25 chips (100µm)
- Connection to Strips:
  - Top side: pitch adapter (PA0)
  - Bottom side: wrapped pitch adapters (PA1, PA2)
- Cooling:
  - CO2 cooling
  - Single cooling pipe
- **Trade-off between material budget & SNR**
- 0.60% X_0 (averaged)

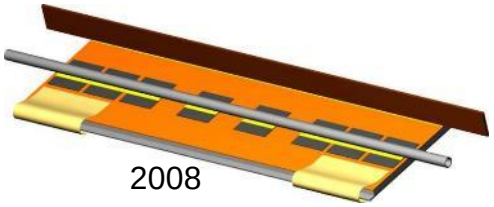
Tail part of Origami flex not shown in fig. a)

SVD Ladder Design (Layer 5)

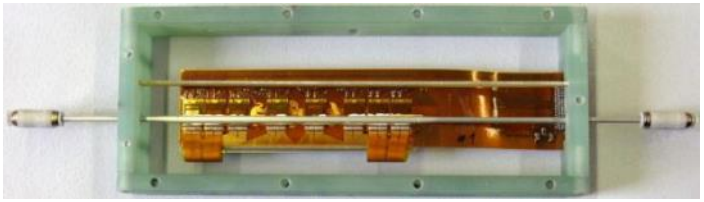


- 3 rectangular + 1 trapezoidal DSSDs
- SFW, SBW: forward, backward sub-assemblies (INFN Pisa)
- **Central sensors read out by Origami hybrids**

The Evolution of the Origami Design

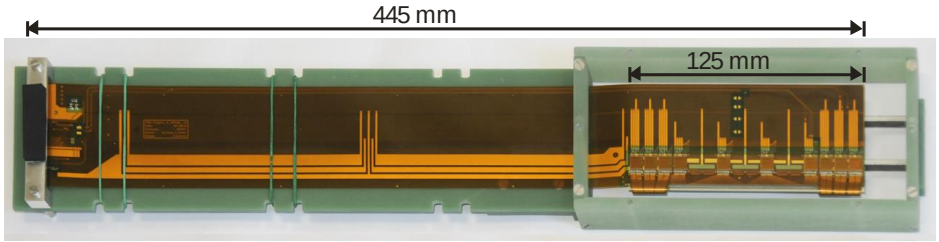


2008

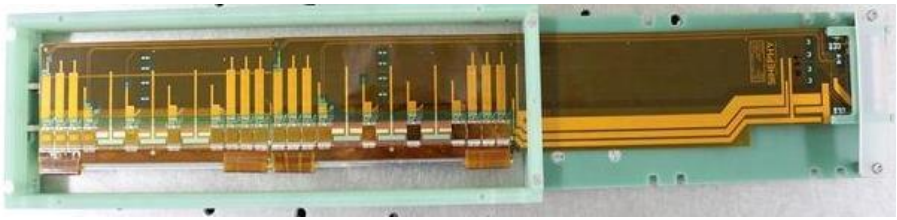


2009

- 2008: Introduction of concept
- 2009: Feasibility shown with 4” DSSD module
- 2010: First full-size module with 6” DSSD
- 2011: Re-design to fit mechanical requirements of Belle II SVD ladders
- 2012: Assembly of first 2-DSSD module



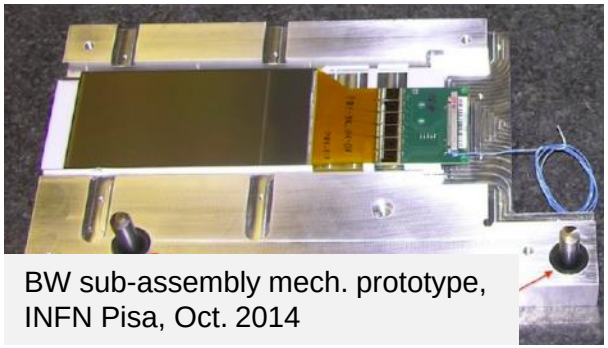
2010

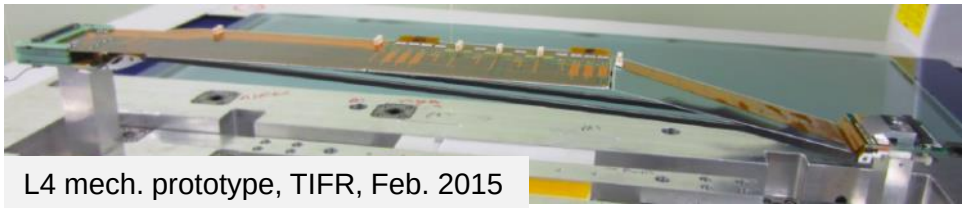


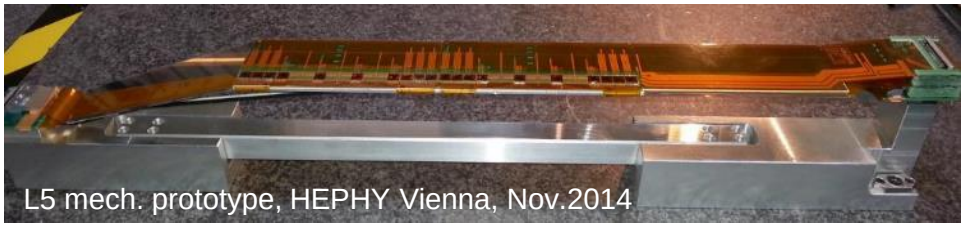
2012

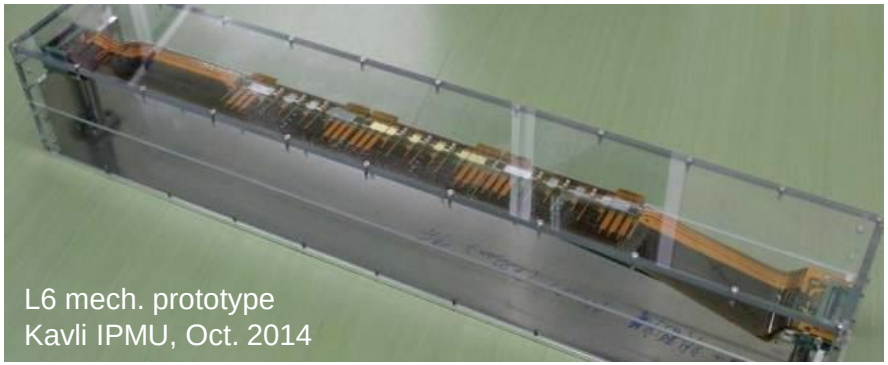
2013 - 2015

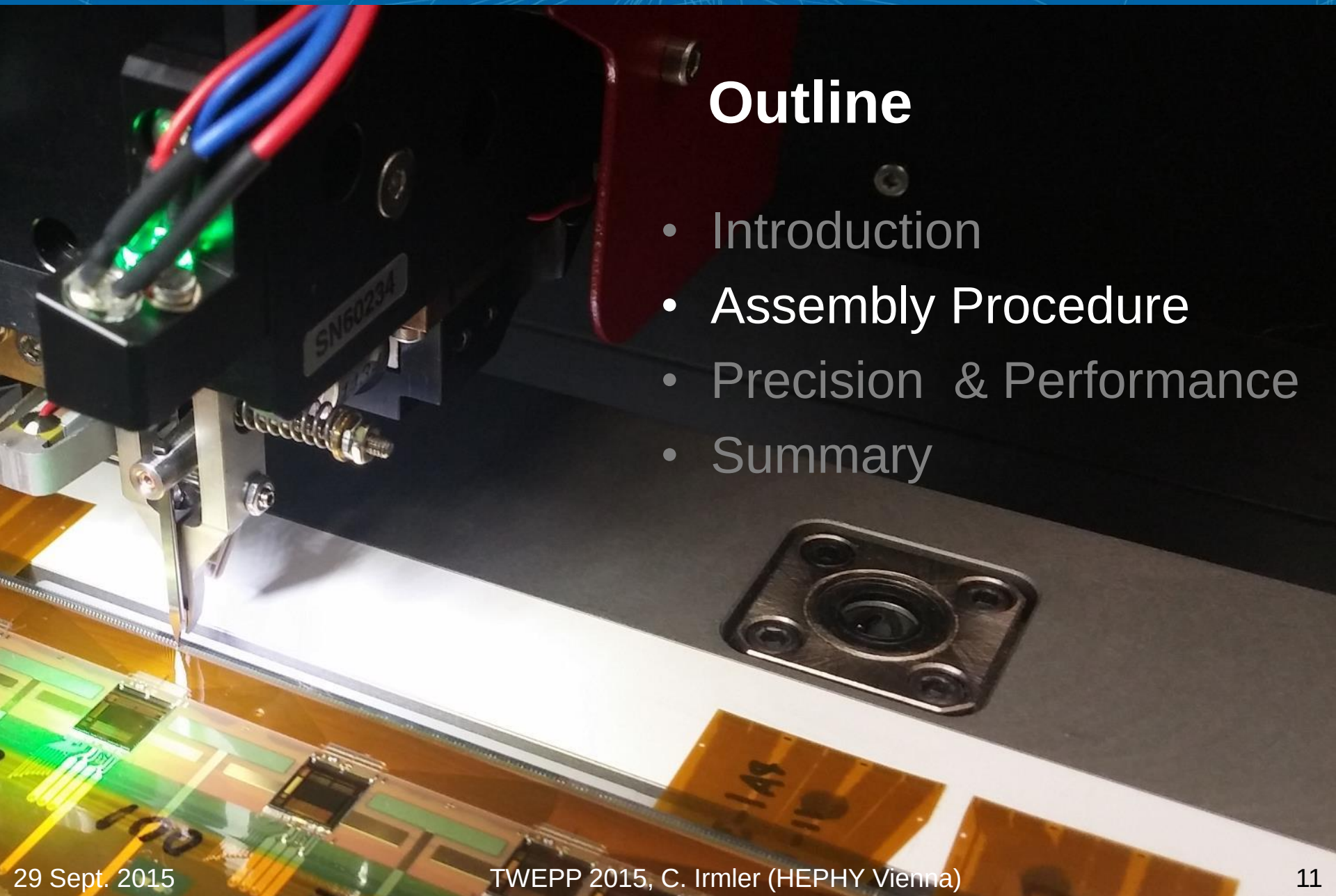
- 2013-2014:
  - Development of a reliable assembly procedure for full SVD ladders
  - Production of required jigs
  - Design production and tuning of ladder components
  - Gluing and wire bonding studies
  - Assembly of first mechanical prototype ladders
- 2015:
  - **Assembly and test of first electrically functional ladders**


BW sub-assembly mech. prototype, INFN Pisa, Oct. 2014


L4 mech. prototype, TIFR, Feb. 2015


L5 mech. prototype, HEPHY Vienna, Nov.2014


L6 mech. prototype
Kavli IPMU, Oct. 2014

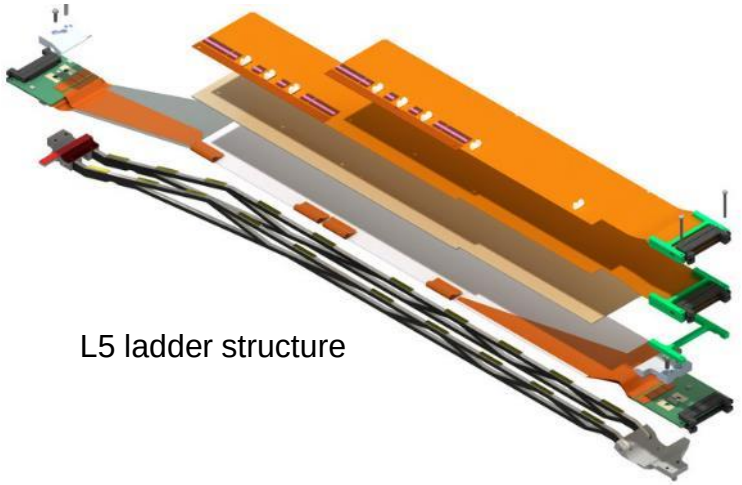


Outline

- Introduction
- Assembly Procedure
- Precision & Performance
- Summary

Layer 5 Ladder Assembly

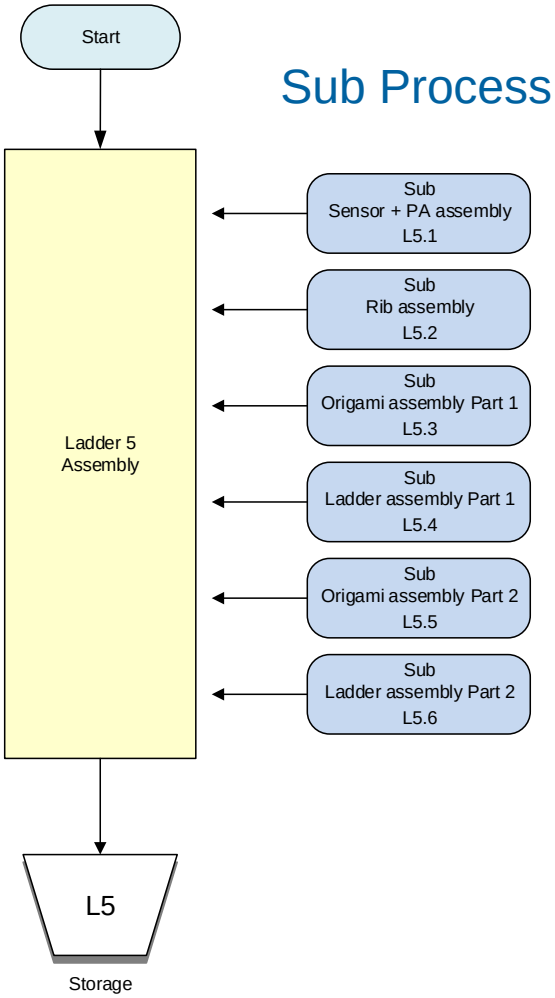
- Ladder assembly procedure shown by the example of a layer 5 ladder
- ~25 vacuum jigs required
- Complex procedure
  - Assembly of mechanical structure (ribs)
  - Precise pitch adapter gluing
  - Sensor alignment
  - Origami flex gluing
  - PA wrapping and gluing
  - Wire bonding (~3000 connections per sensor)
  - Attaching sub-assemblies to ribs
  - Electrical testing
- ~15 working days for one L5 ladder

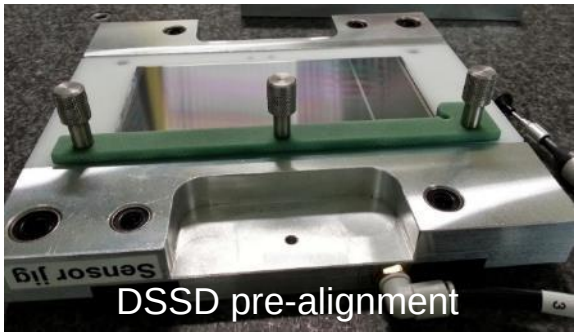


L5 ladder structure

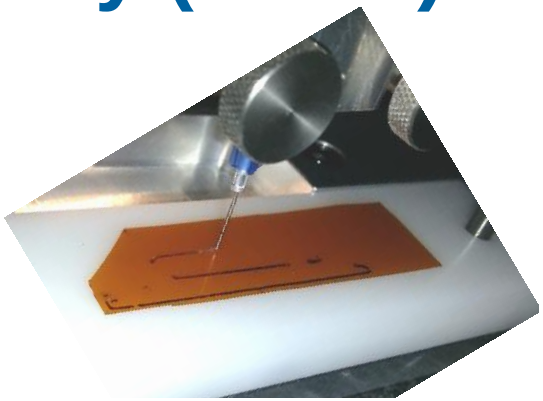
Selection of L5 assembly jigs

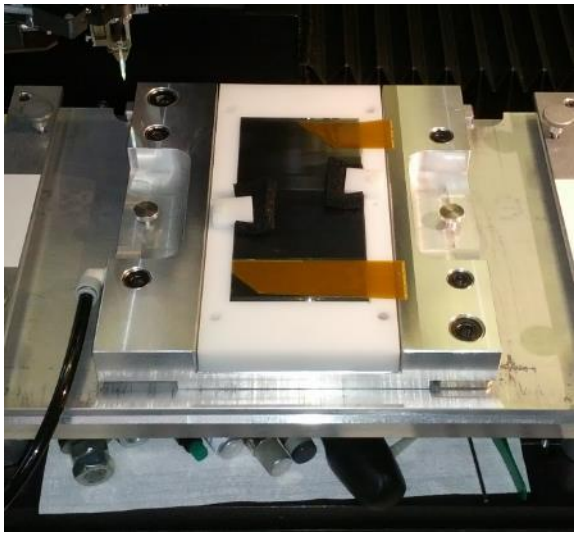
Sensor + Pitch Adapter Assembly (SPA5)





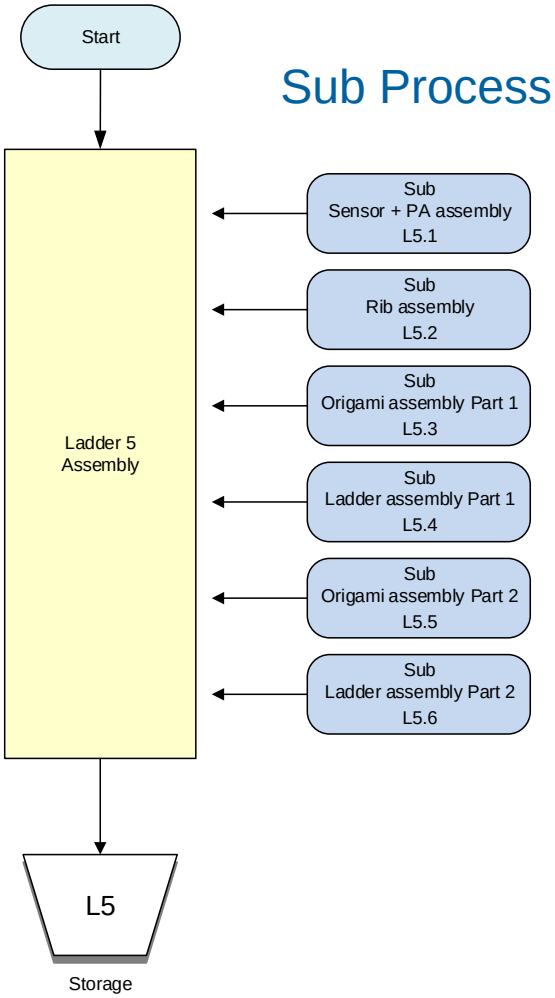
DSSD pre-alignment

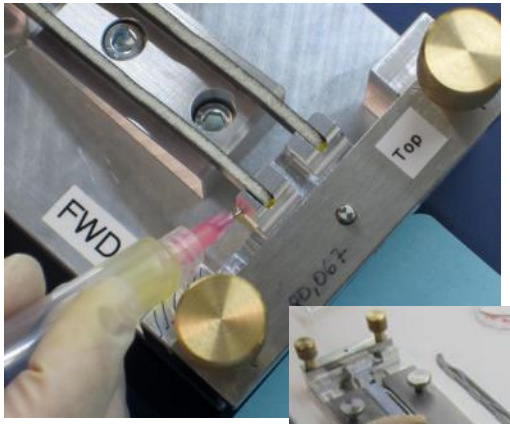

Applying glue onto pitch adapter

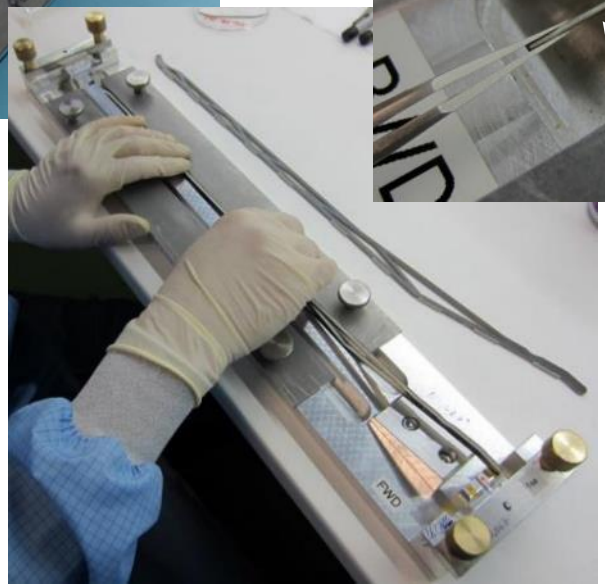

Wire bonding

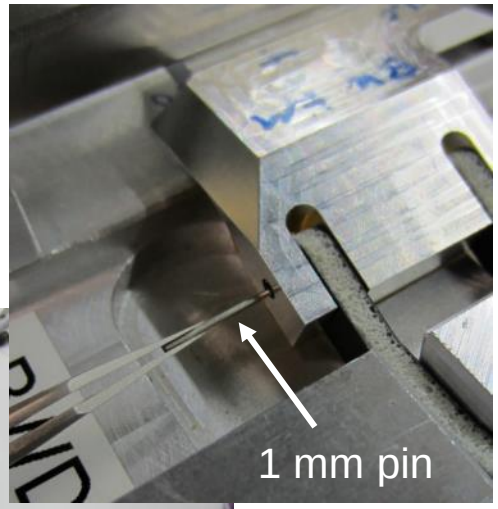

SPA5 stored on Gel-Pak®

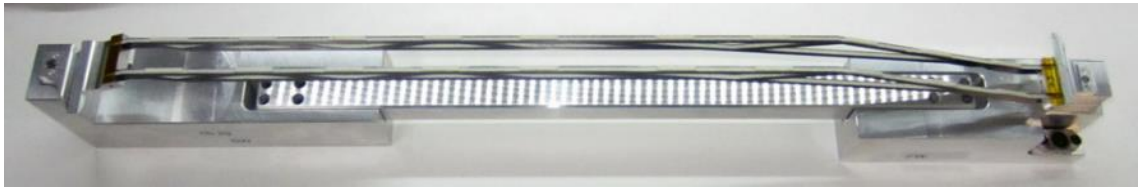
Rib-Assembly (RS5)



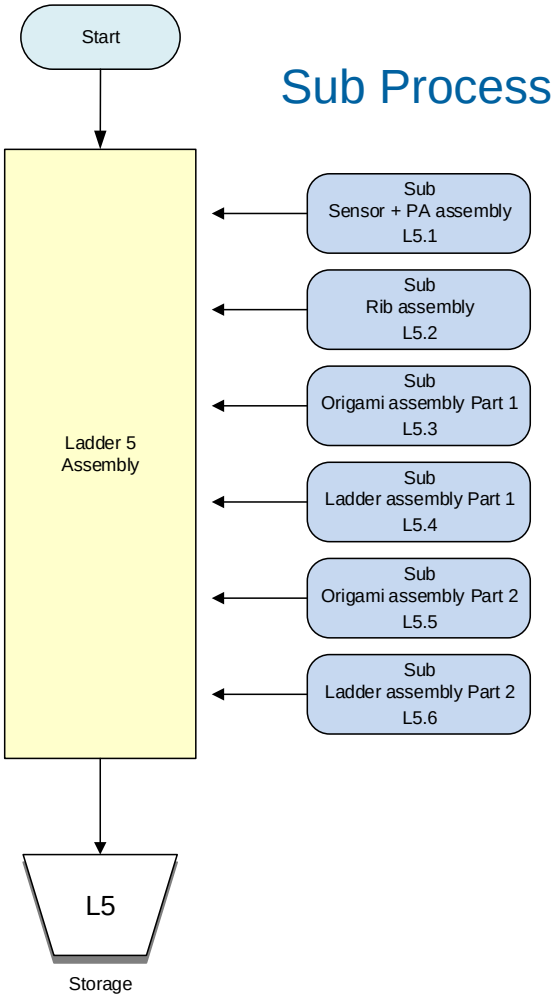






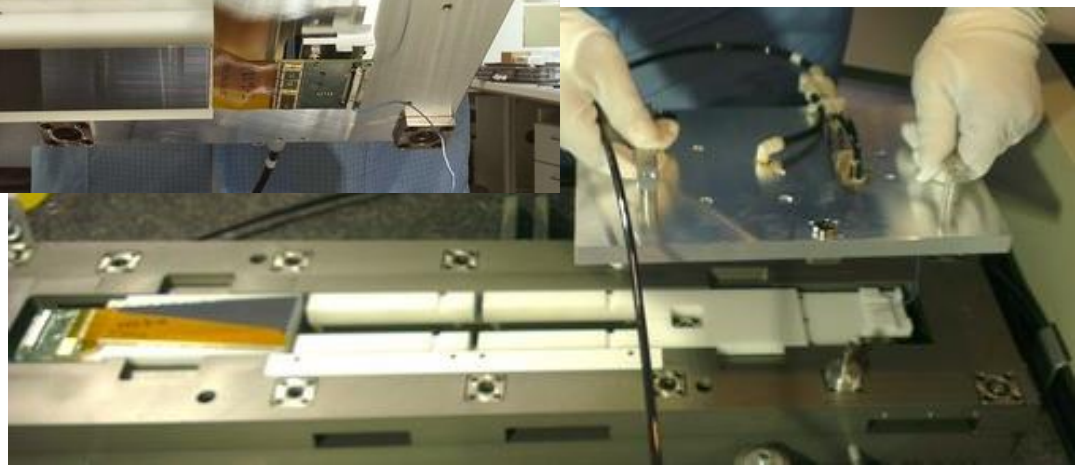


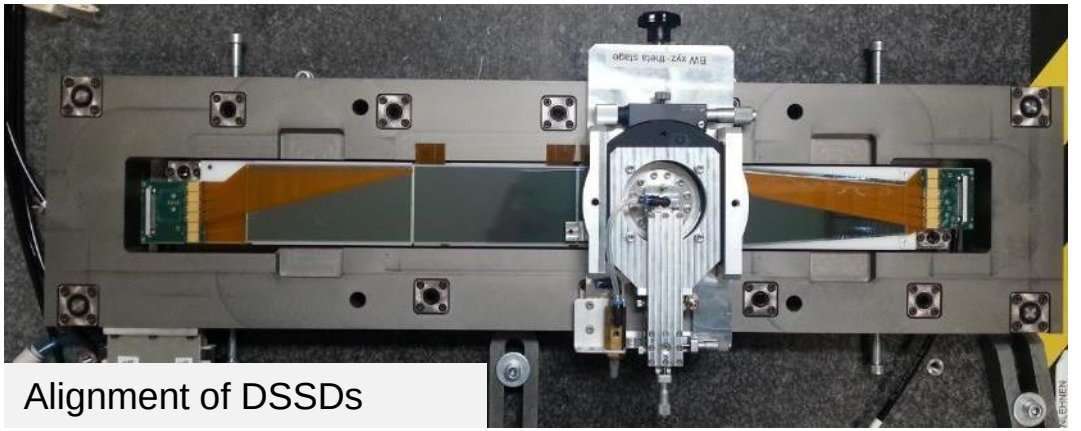
DSSD Alignment



Sub Process

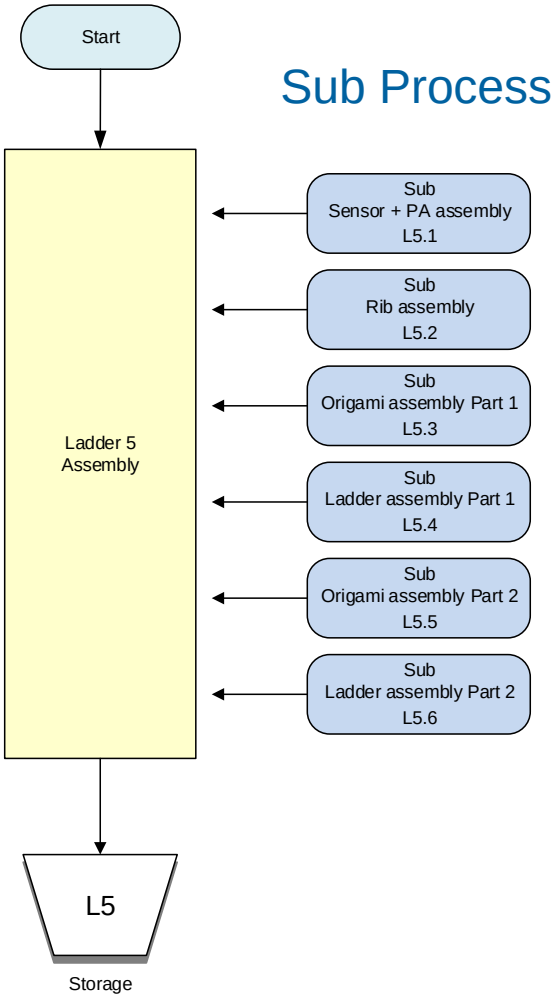
Placing DSSDs onto assembly bench

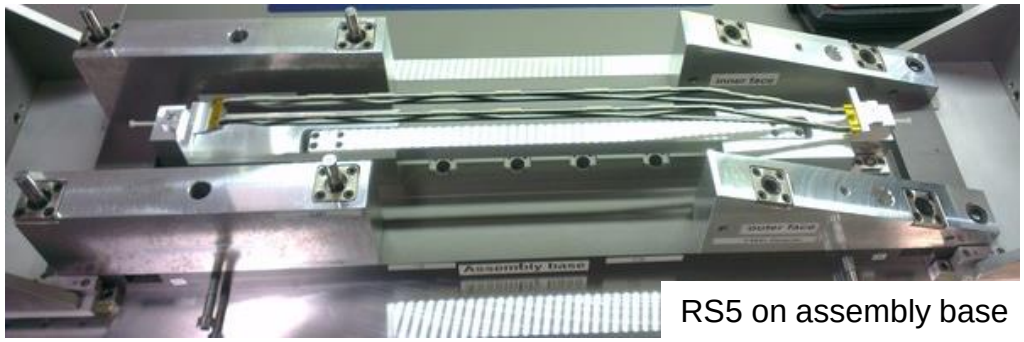




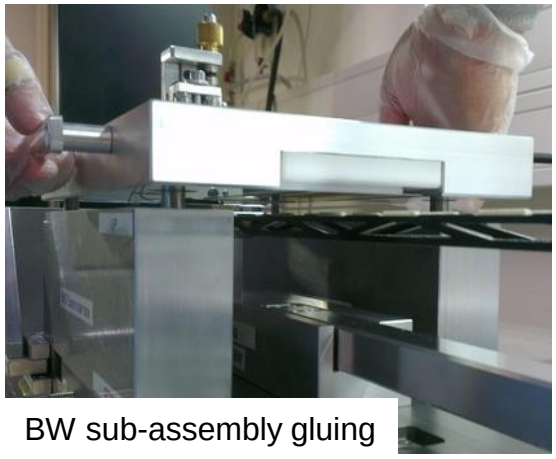
Alignment of DSSDs

Half-Ladder Assembly

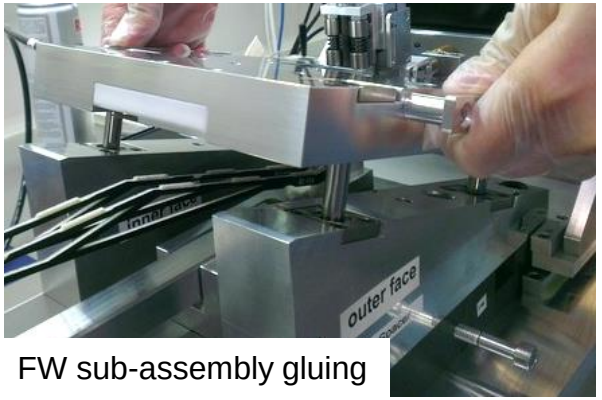




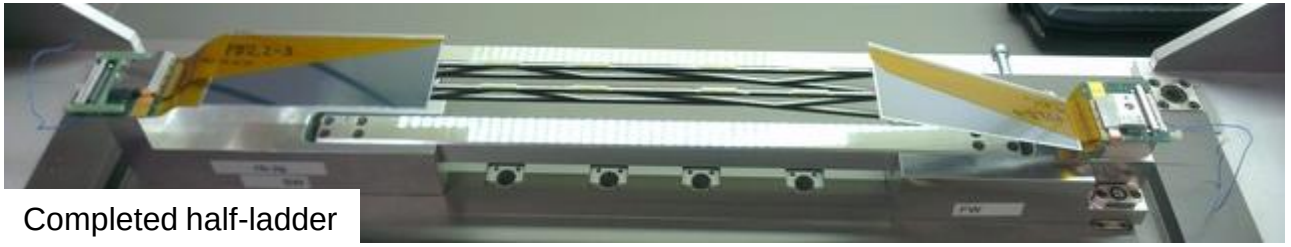
RS5 on assembly base



BW sub-assembly gluing

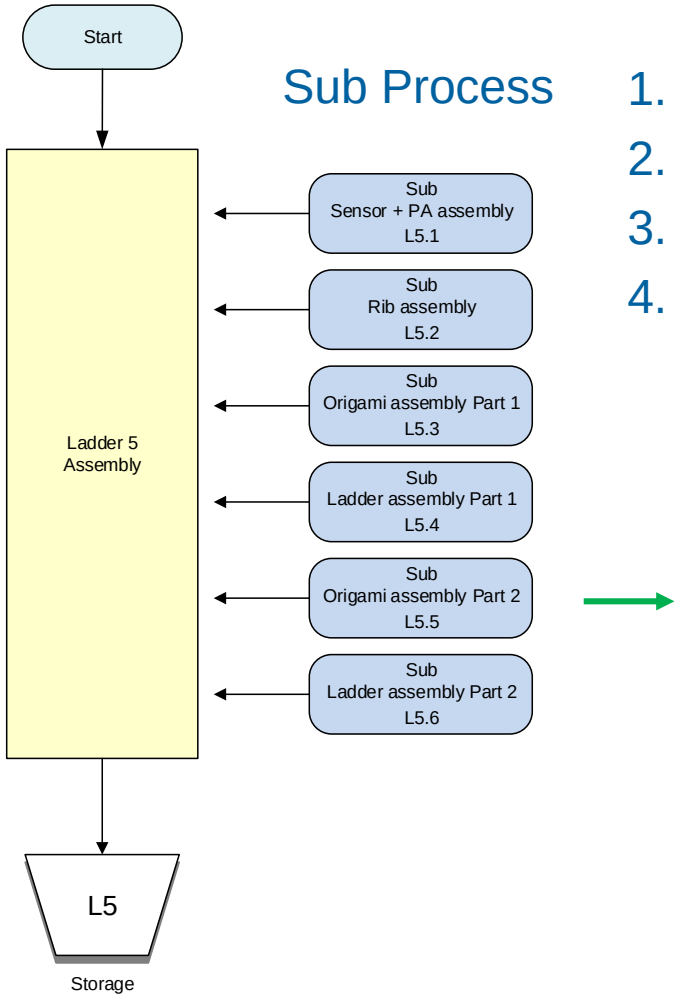


FW sub-assembly gluing



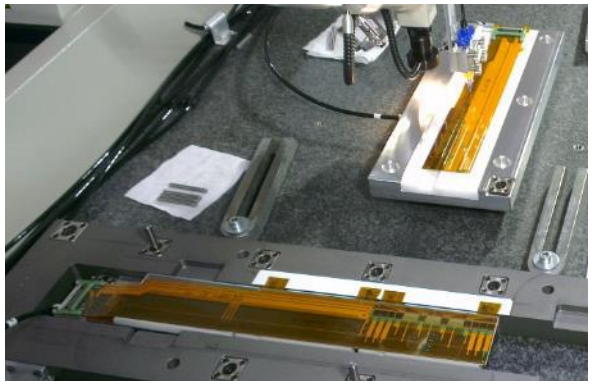
Completed half-ladder

Origami Sub-Assembly – Hybrids Gluing



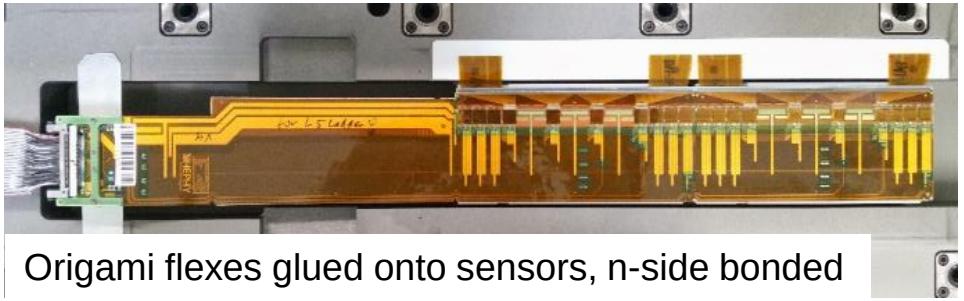
Sub Process

1. Airex gluing
2. Origami ce gluing
3. Origami –z gluing
4. Wire bonding n-side



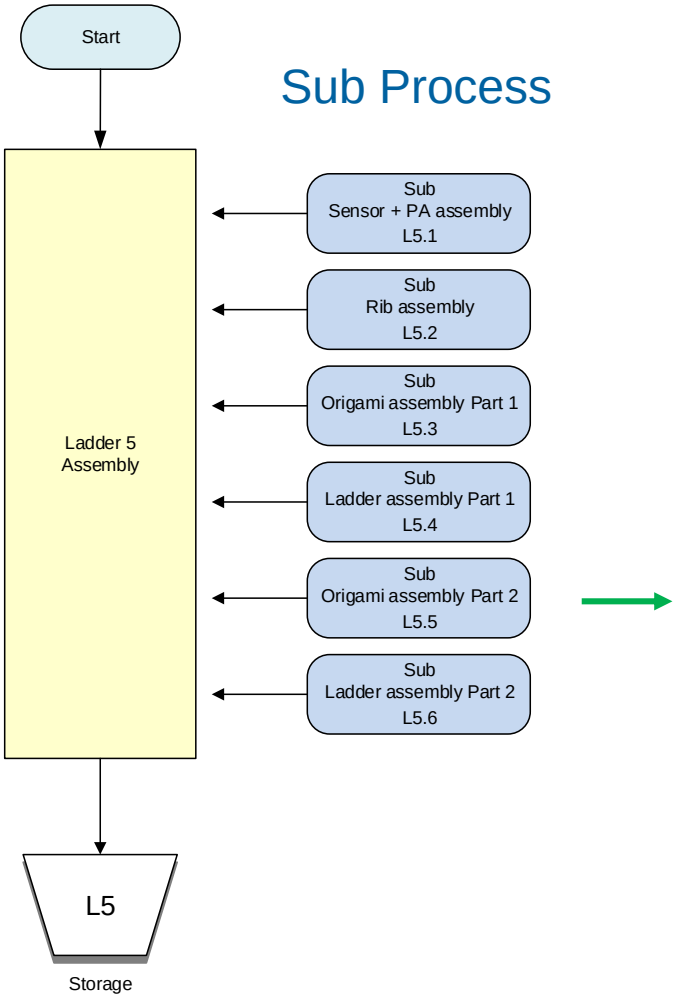
OCE already glued onto sensor, applying glue onto O-Z

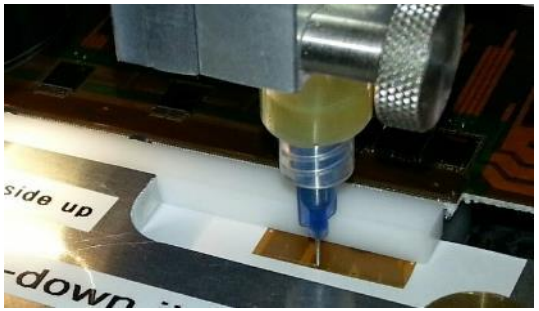
Attaching O-Z



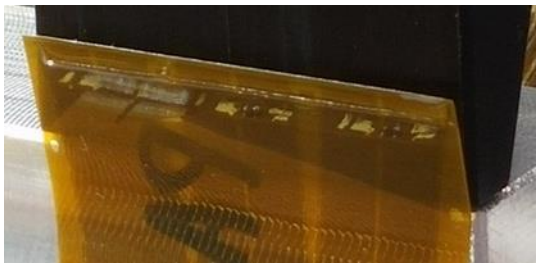
Origami flexes glued onto sensors, n-side bonded

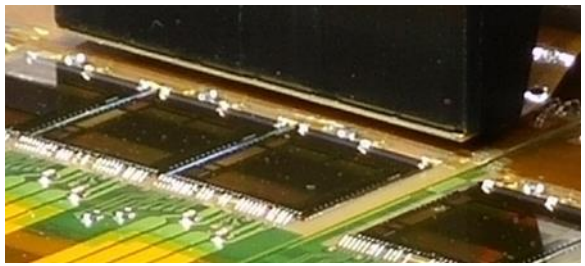
Origami Sub-Assembly – PA Wrapping

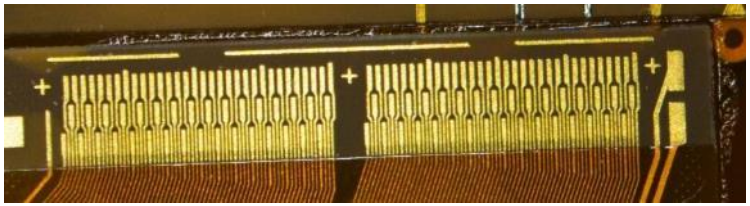


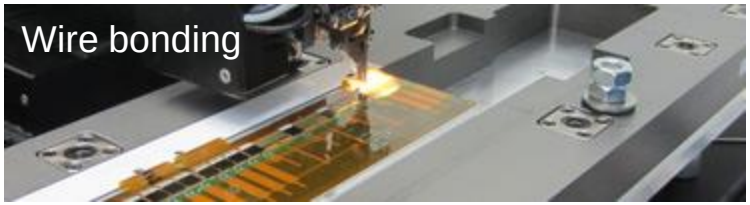


Glue applied to PA, micro positioner equipped with vacuum nozzles used to bend and glue pitch adapters



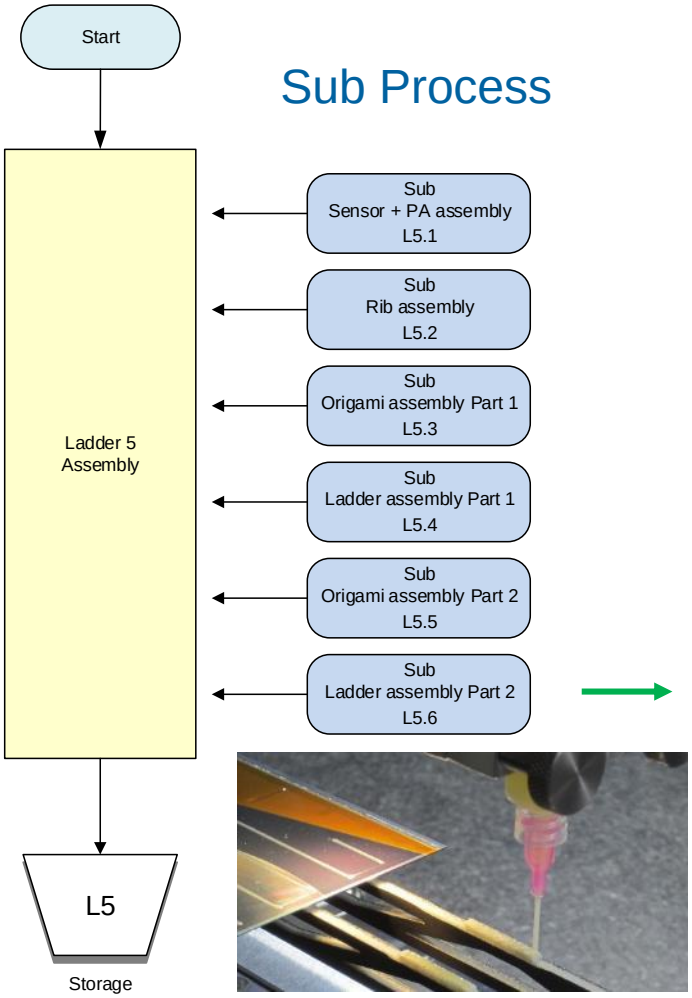


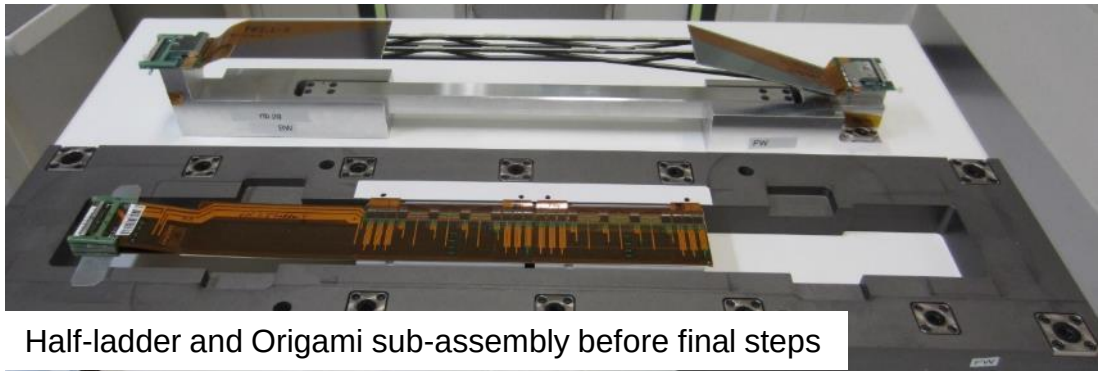




- Glued pitch adapter
- Uniform glue spread required for wire bonding

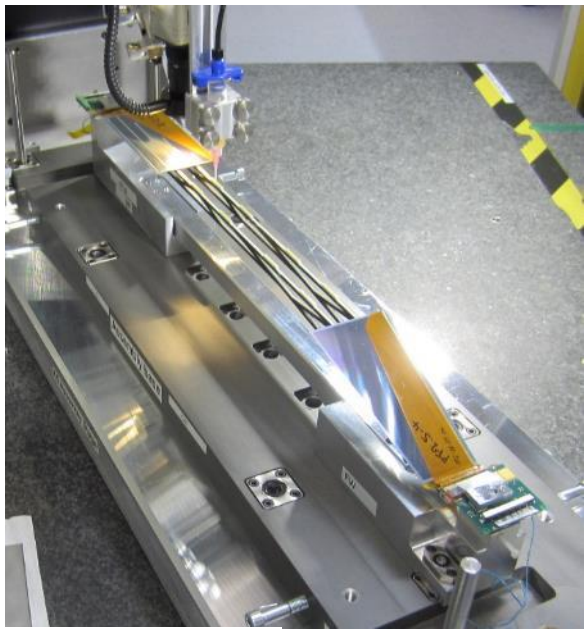
Ladder Assembly Part 2





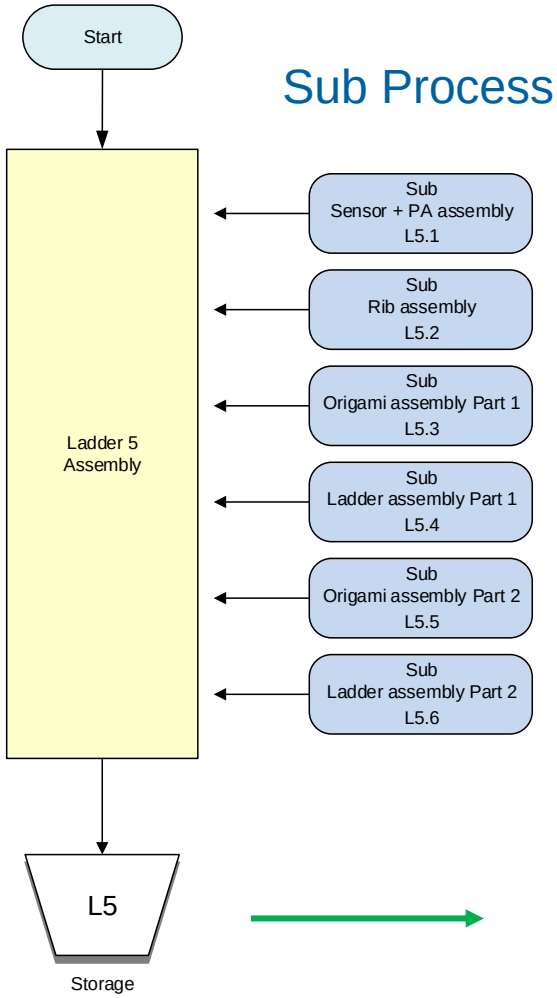
Half-ladder and Origami sub-assembly before final steps

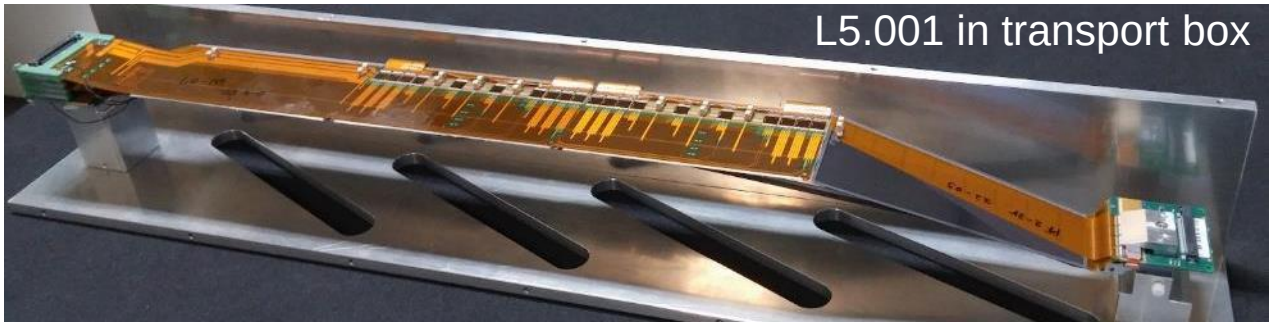
Applying glue onto BW sensor and ribs

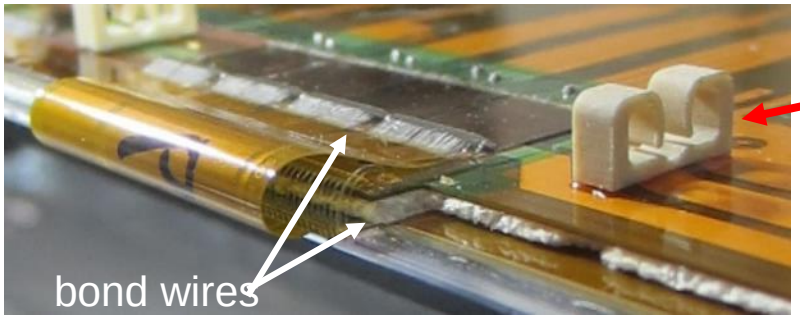


Attaching OS5 with vertical stages

Final L5 Ladder

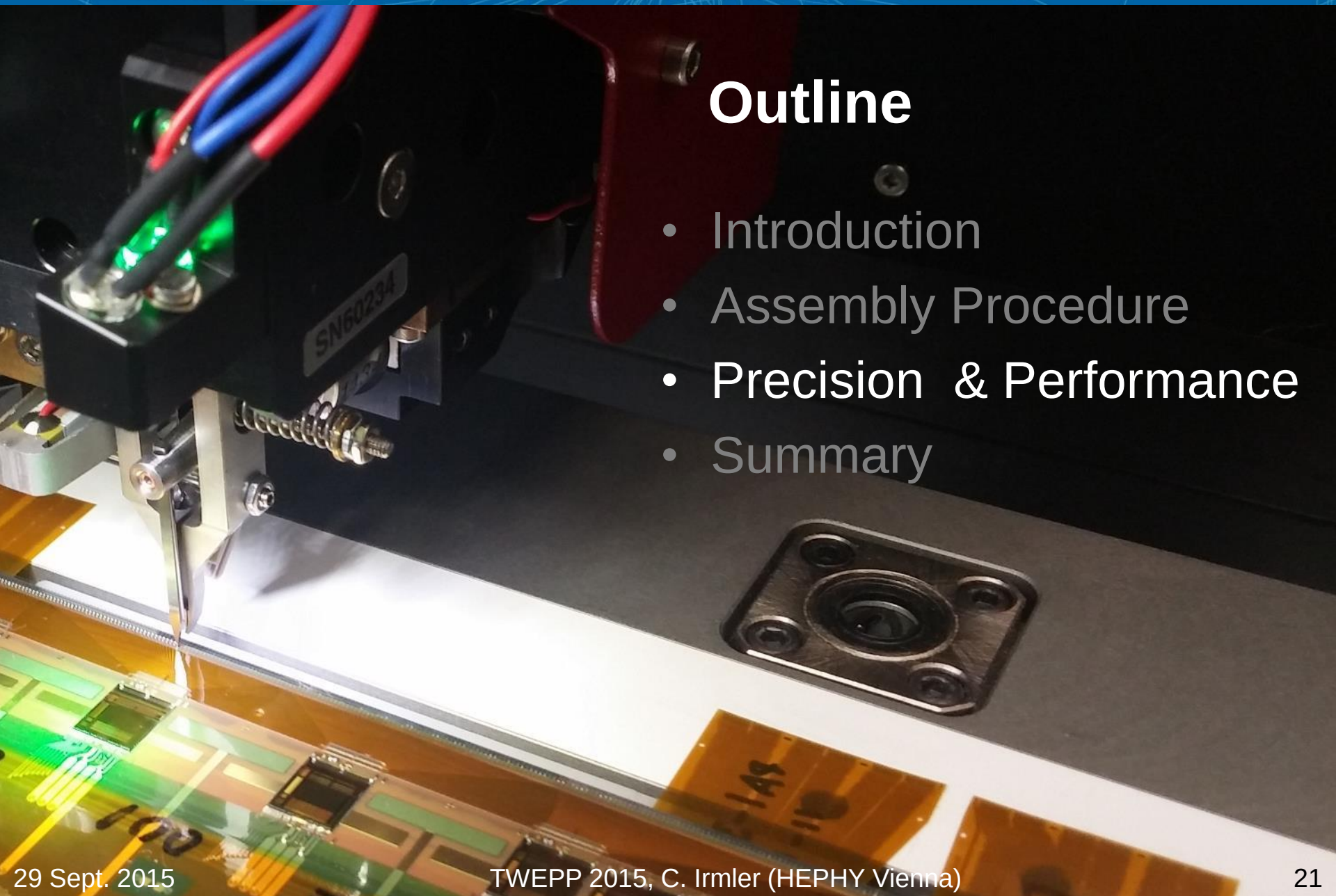






CO2 pipe clip

- So far completed L5 ladders:
  - Class C: L5.902, L5.904
    - Precise mechanical prototypes
  - Class B: L5.903, L5.001
    - Electrically functional, but DSSD with some defects used.

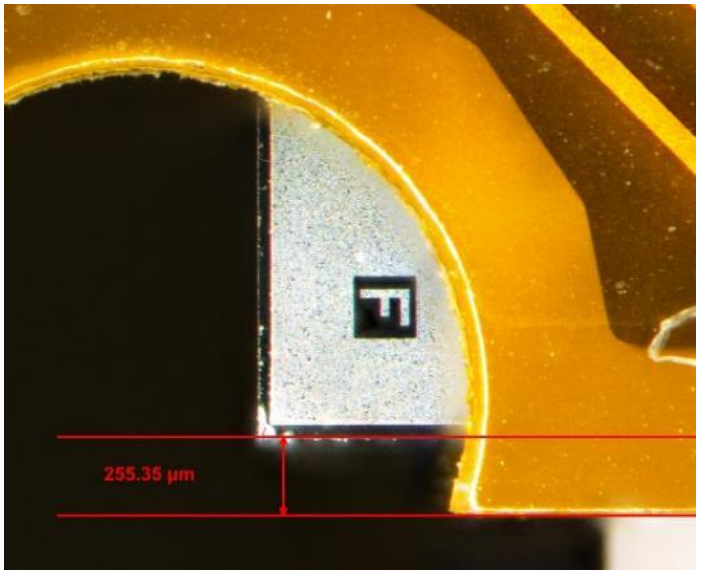


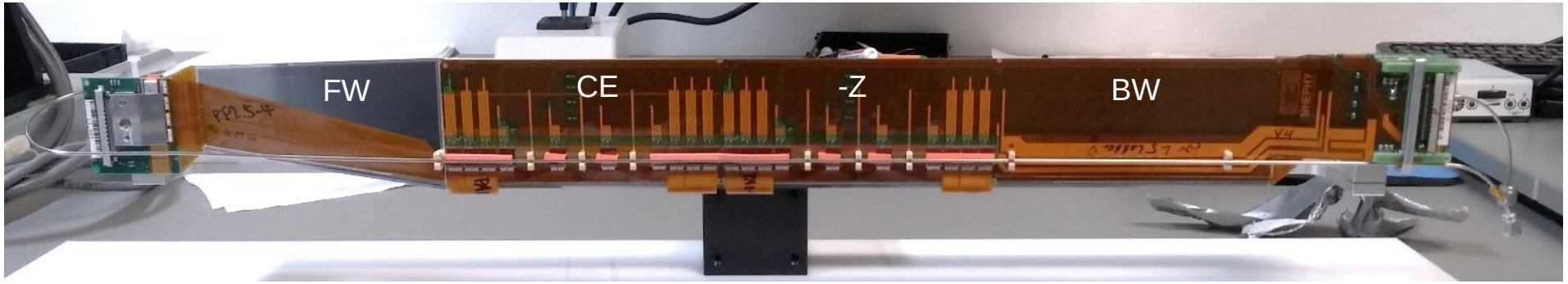
Outline

- Introduction
- Assembly Procedure
- Precision & Performance
- Summary

Mechanical Survey of Ladders

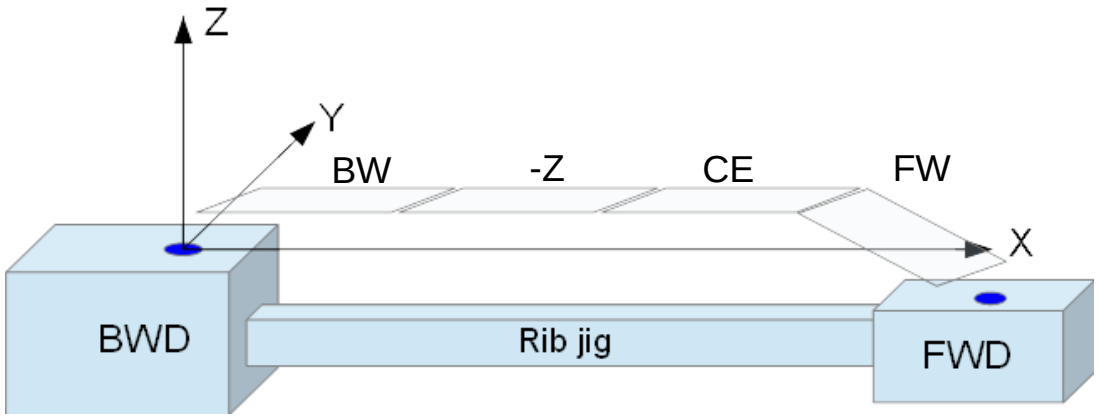
- F-marks at DSSD corners
  - Used for alignment
  - Measured on final ladder
- Aimed precision: 100µm
- Measurement done on CMM
- Optical measurement
- Sensor positions: BW, -Z, CE, FW

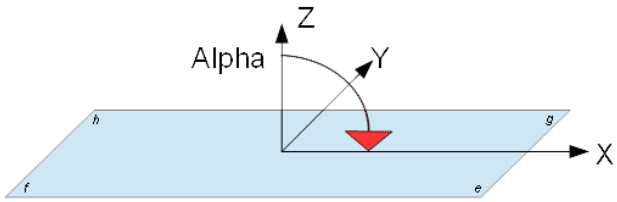


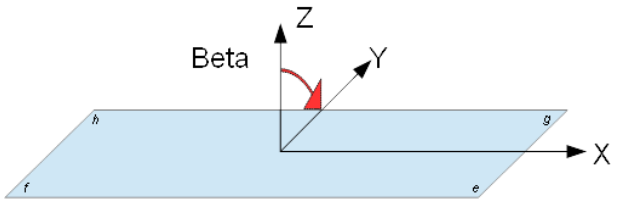


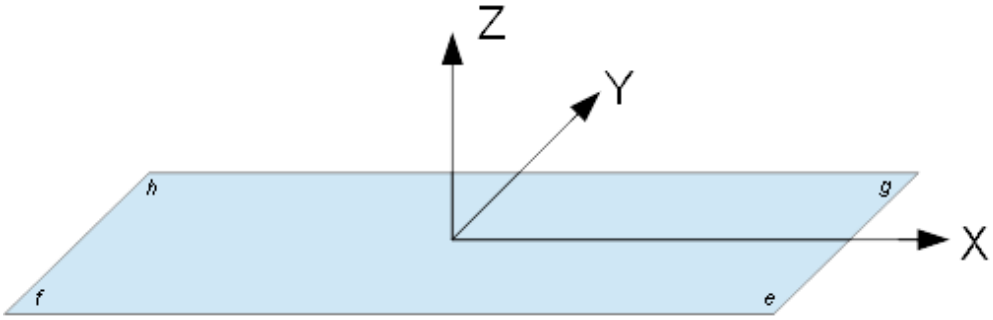
L5.903 mounted onto beam test support with cooling pipe attached

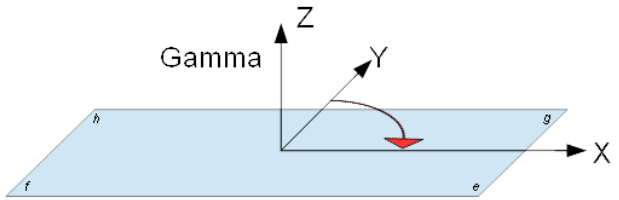
Coordinate System for Ladder Survey



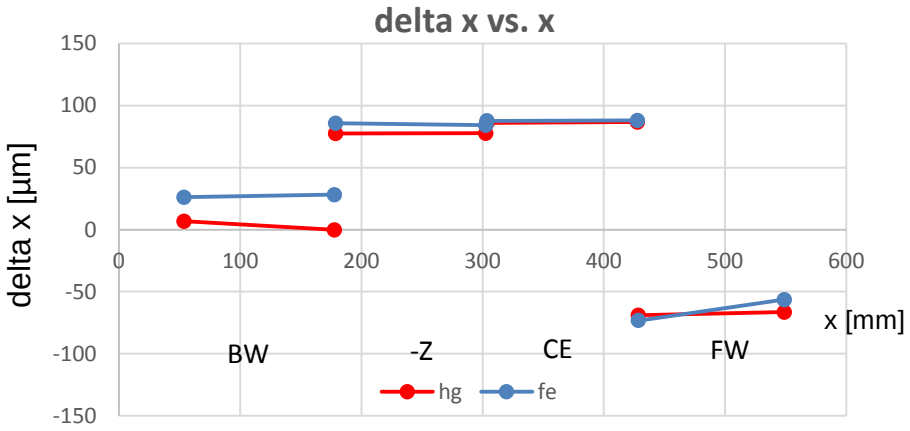


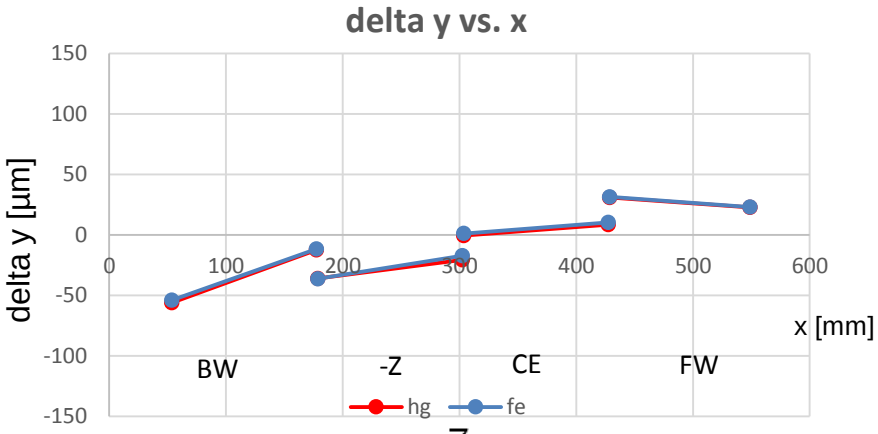


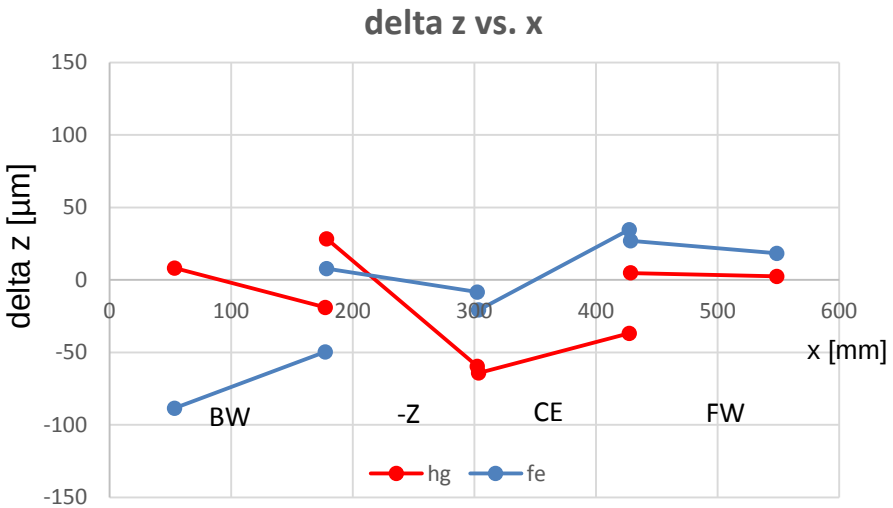


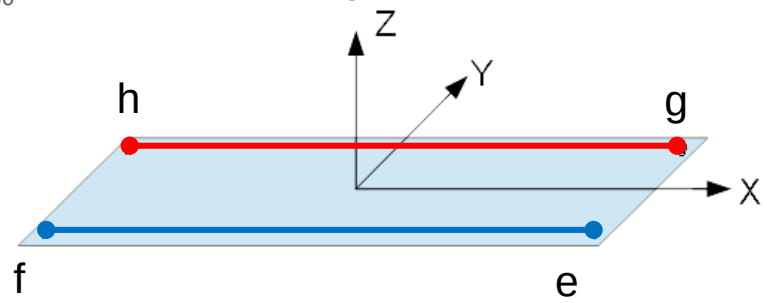


Mechanical Survey Results L5.904







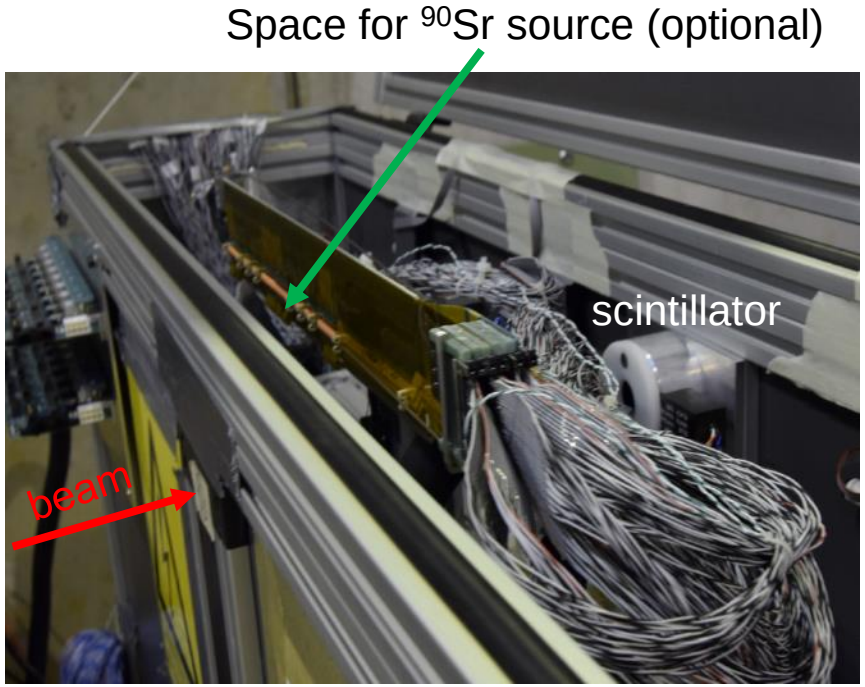


Average displacement:

- L5.904: Precise mech. prototype
- Average of 4 measurements
- **Better than ±100µm in all directions**

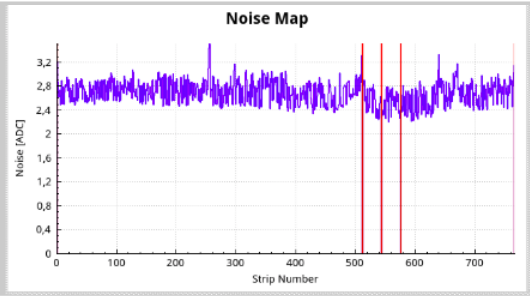
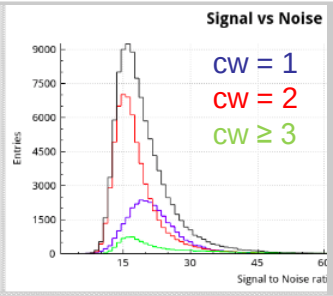
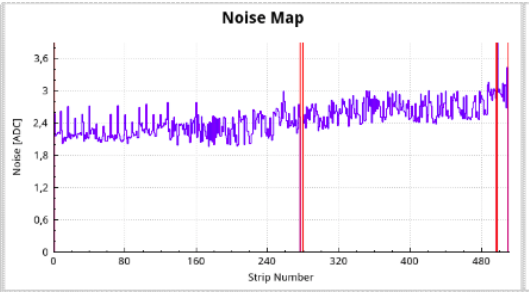
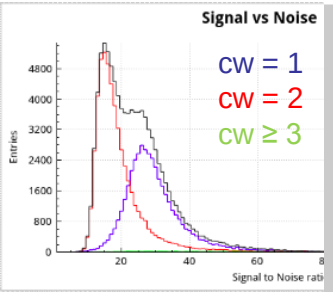
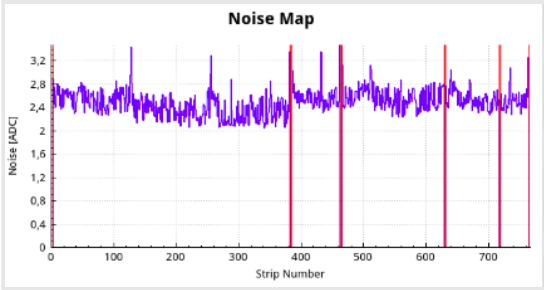
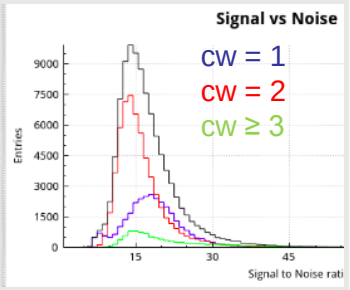
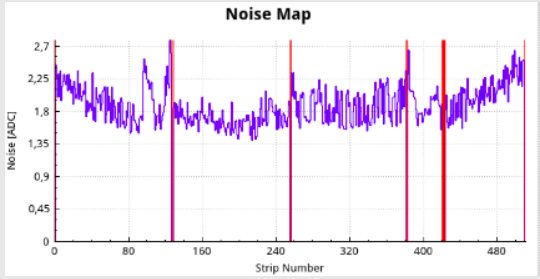
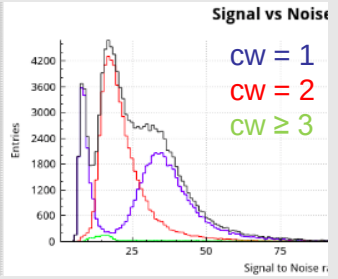
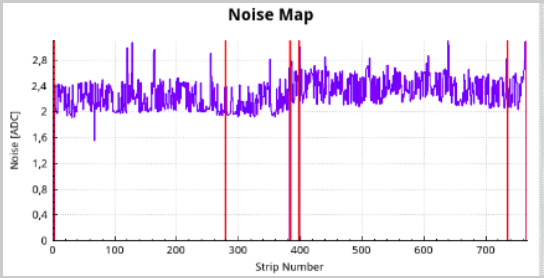
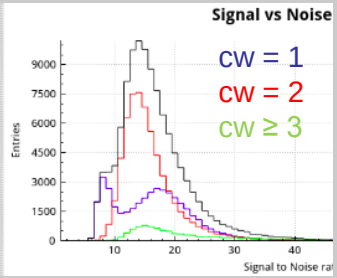
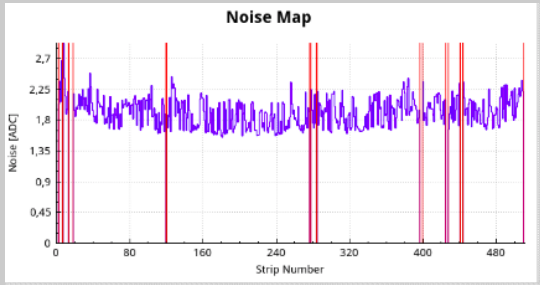
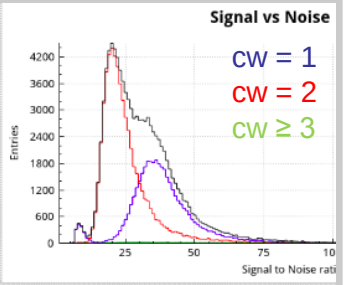
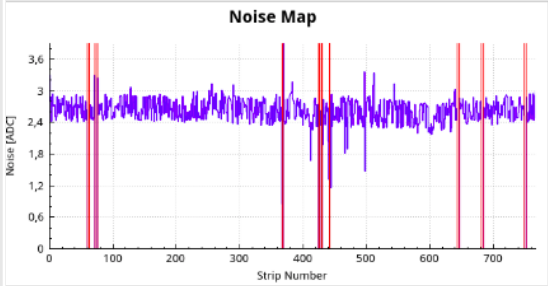
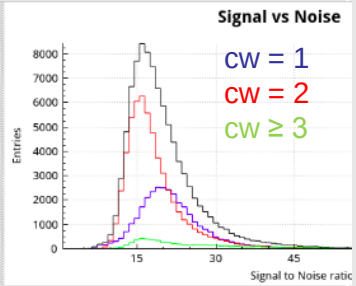
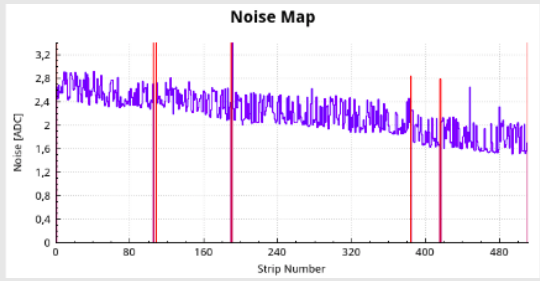
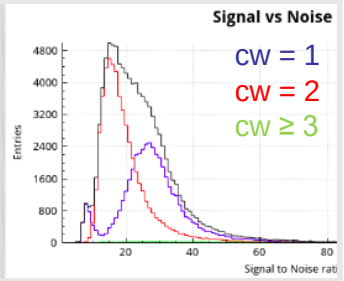
Electrical Performance of L5.903

- Electrical tests of L5.903
  - ^{90}Sr source test in lab
  - EMC measurements in Zaragoza, Spain → see R. Thalmeier
  - Beam test at CERN SPS
- Test setup
  - Ladder mounted on moveable stage of ladder test box
  - Test box is used for both source and beam tests



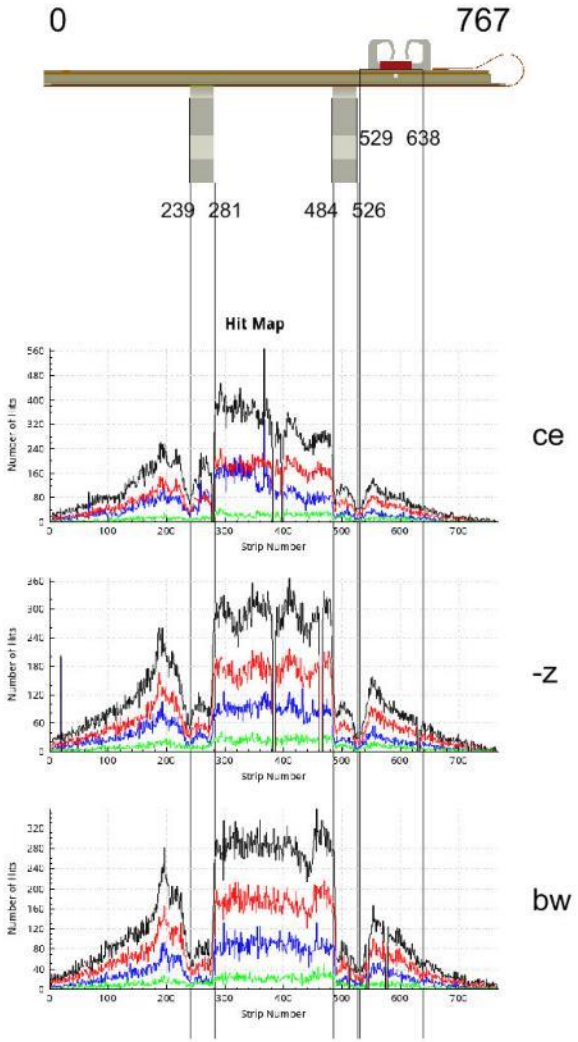
L5.903 mounted on moveable stage inside of ladder test box

L5.903 Source Test: Noise & SNR

	p-side		n-side	
BW				
-Z				
CE				
FW				

L5.903 Source Test: Conclusion

- All noise patterns look as expected
  - p-side: ~2.5 ADC
  - n-side: ~2.1 ADC
- SNR in the expected range
  - cluster width = 2:
    p-side = ~15
    n-side = ~18
- **Operating the full ladder simultaneously works as good as individual parts**

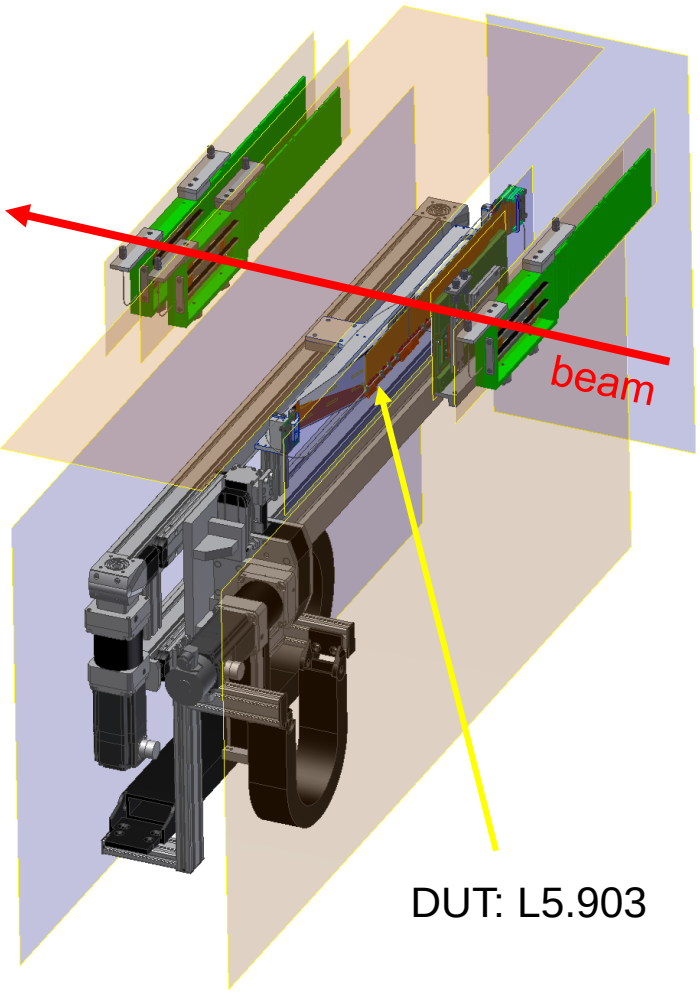


Ladder structure visible in hit maps

L5.903: Beam Test

- 3.-14.6.2015 @ CERN SPS
- Setup and device under test (DUT)
  - L5.903 mounted into test box
  - „Pseudo-telescope“ with single sensor modules in front and back
  - CO_2 cooling
- Beam: 120 GeV/c

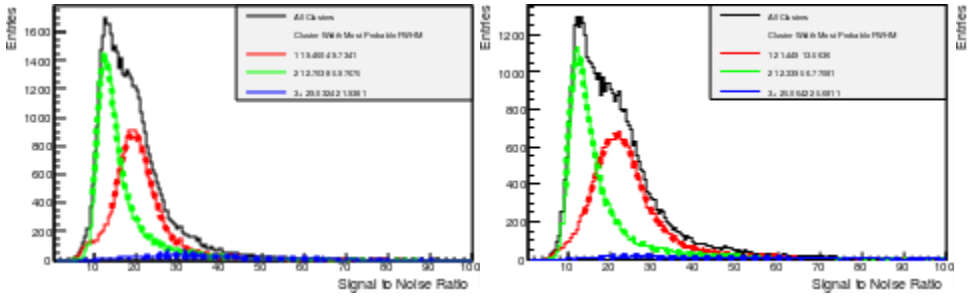

Modules at back side



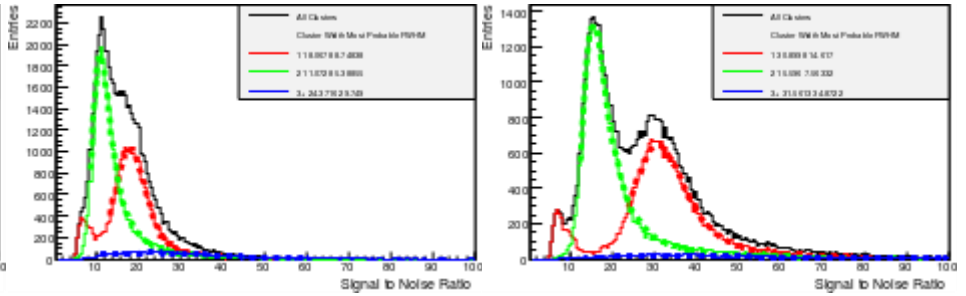
preliminary

L5.903 Beam Test SNR

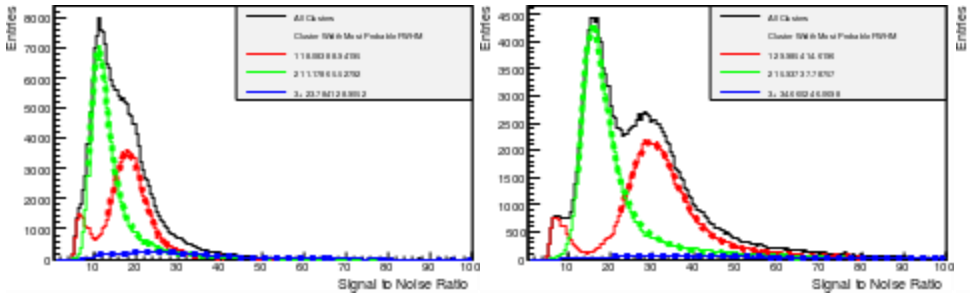
p-side FW n-side



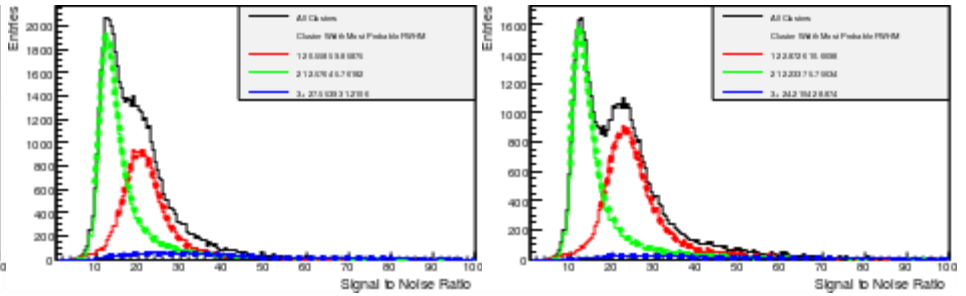
p-side -Z n-side



p-side CE n-side



p-side BW n-side



- Mean noise: 2.7 ADC on p-side and 2.5 ADC on n-side.
- All sensors performed as expected
- Analysis ongoing

L5.903 BeamTest: Conclusion

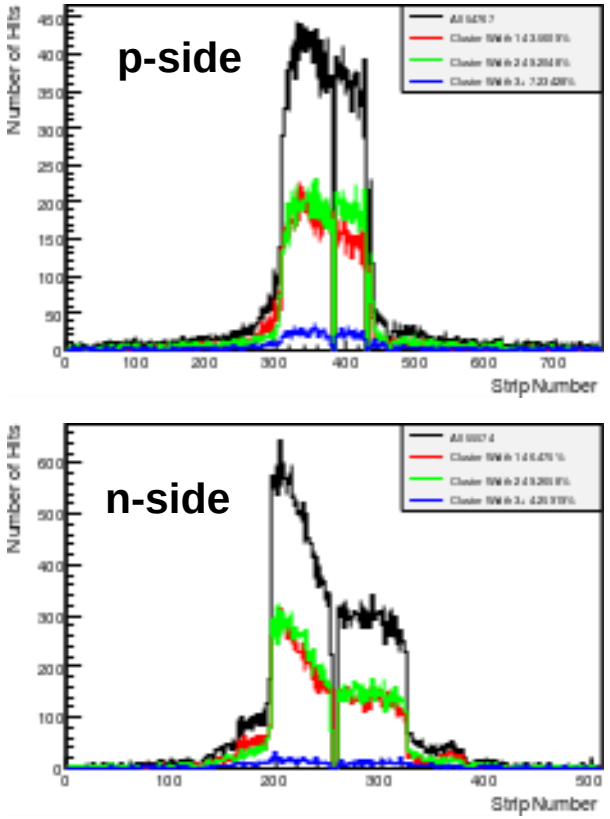
- All noise figures as expected
- SNR in the expected range

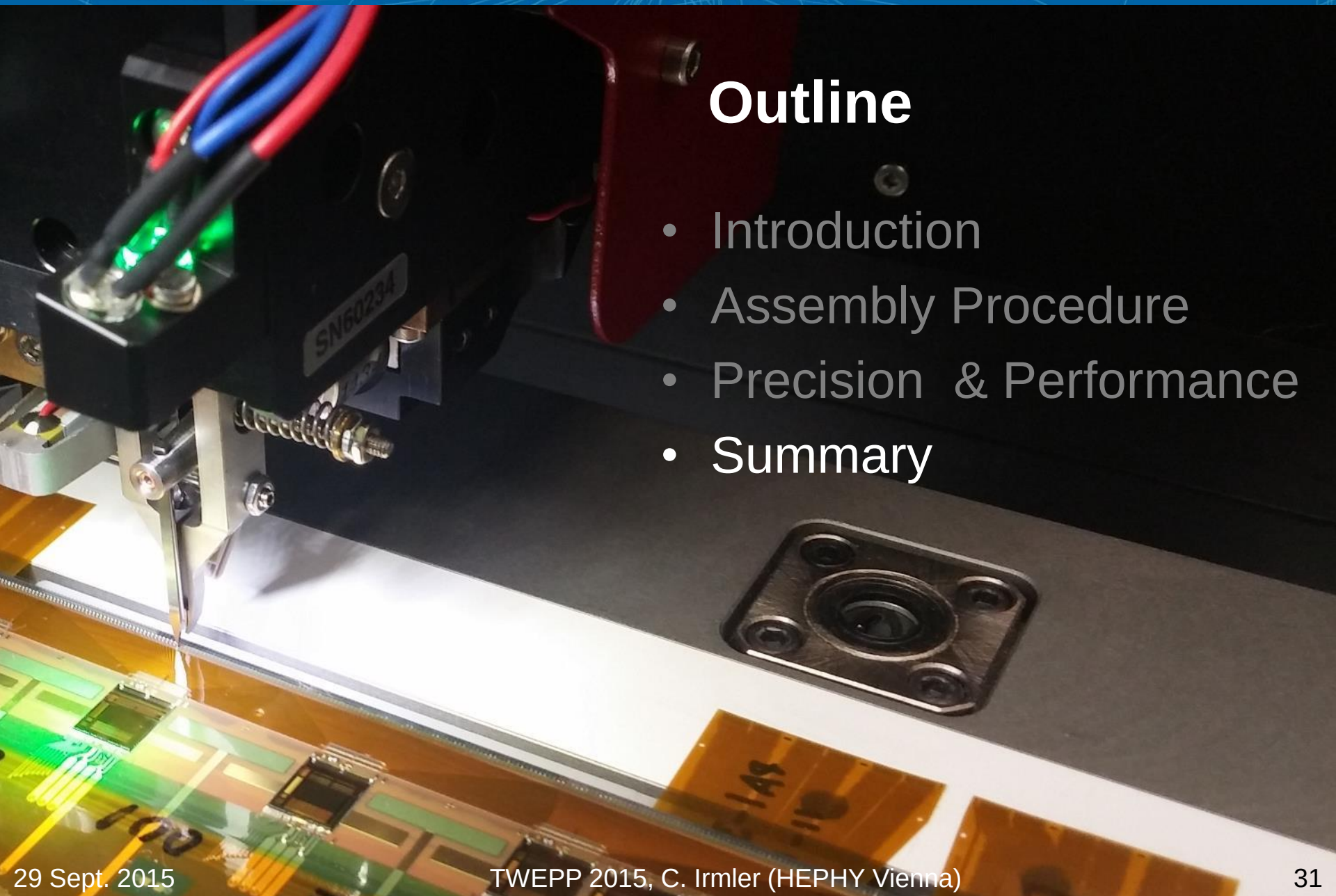
clw=2	w/o cooling	CO2 cooling -20°C
n-side	14	15
p-side	12	12,5

- Slightly better SNR with cooling
- Analysis of beam test data ongoing

- **Full L5.903 ladder works as good as single sensor modules**

Hit maps -Z





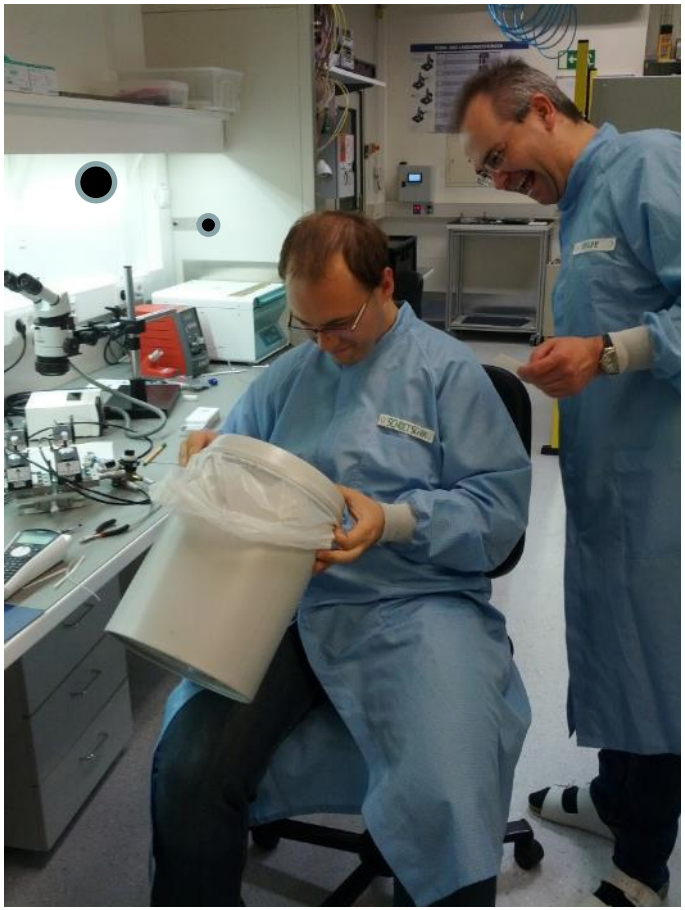
Outline

- Introduction
- Assembly Procedure
- Precision & Performance
- Summary

Summary

- Procedure to build Belle II SVD ladders by utilizing the Origami chip-on-sensor concept
- Mechanical precision proven by prototype ladders
- First electrically working L5 ladders assembled
- Good electrical performance confirmed with both source measurements and beam test

Have you seen our ladder?



Thank You for Your Attention!

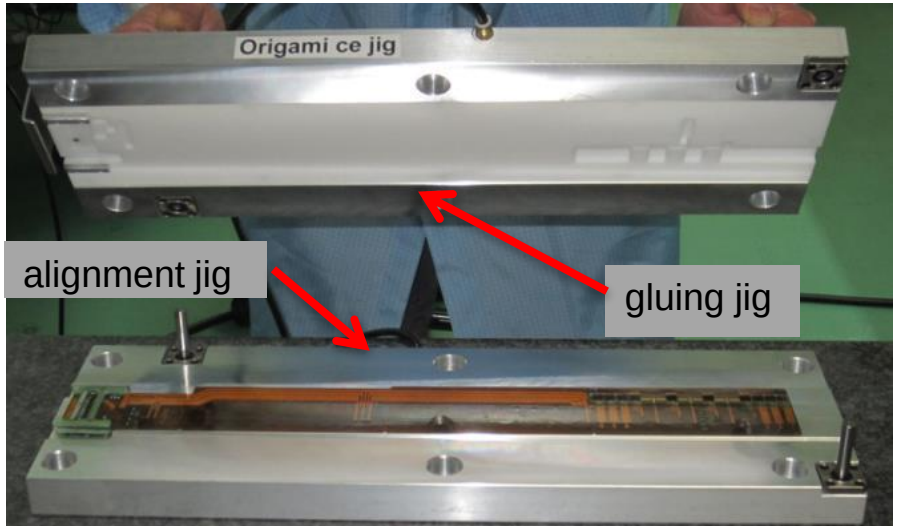
Backup Slides

Assembly Sites

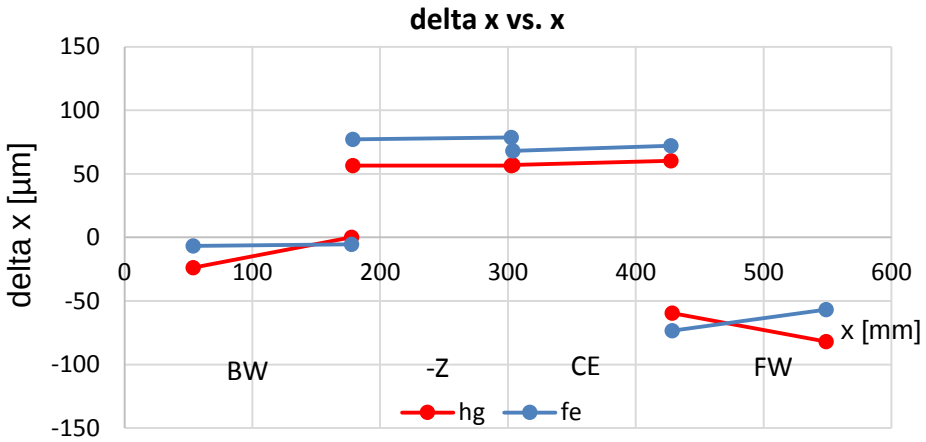
- L3 ladders: Univ. of Melbourne
- L4 ladders: TIFR (@ IPMU)
- L5 ladders: HEPHY Vienna
- L6 ladders: Kavli IPMU
- FWD/BWD modules: INFN Pisa

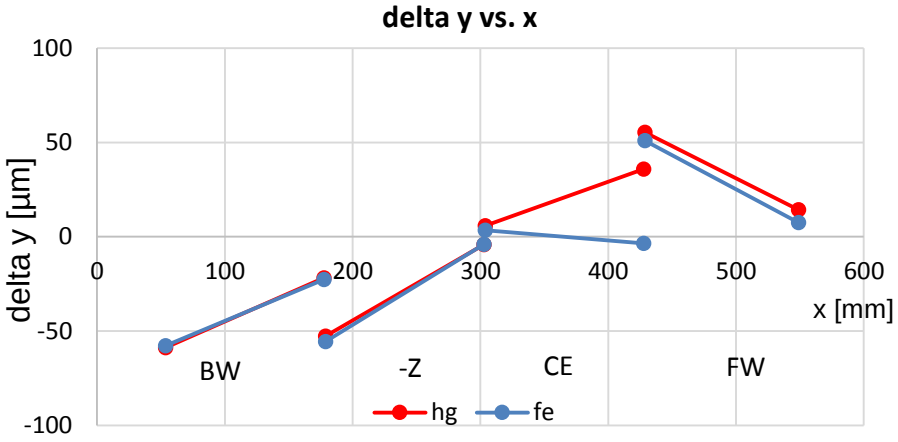
Origami Hybrid Gluing

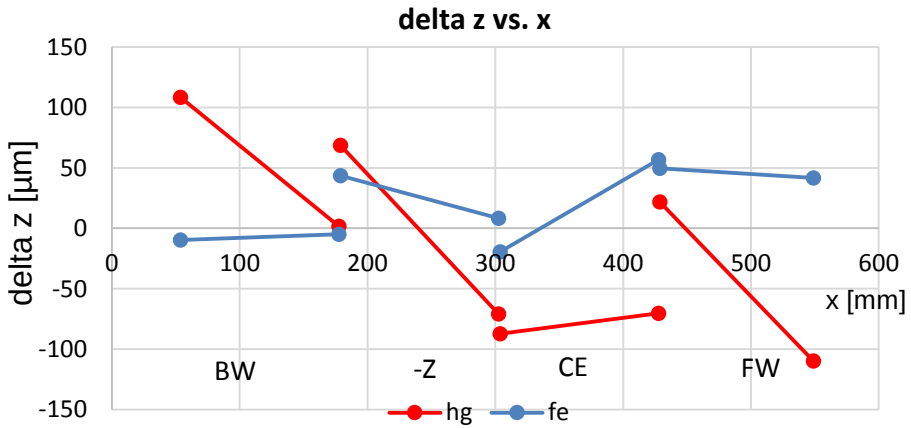
- Alignment of Origami flex by reference holes
- Origami hybrid is picked up with gluing jig
- Glue is applied onto Origami flex
- Origami flex is glued onto sensor by placing the Origami jig onto the assembly bench, guided by precision pins



Mechanical Survey Results L5.001





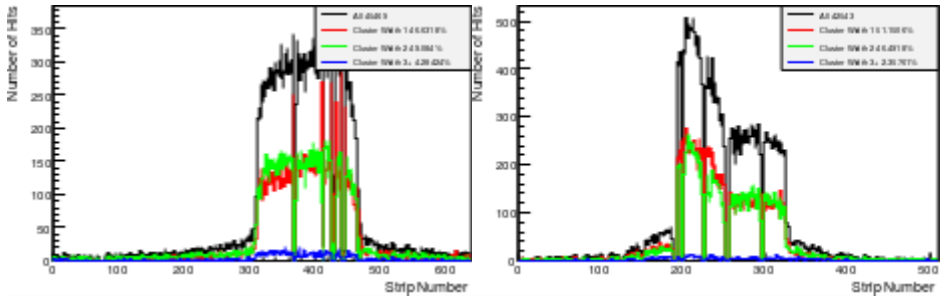


Average displacement:

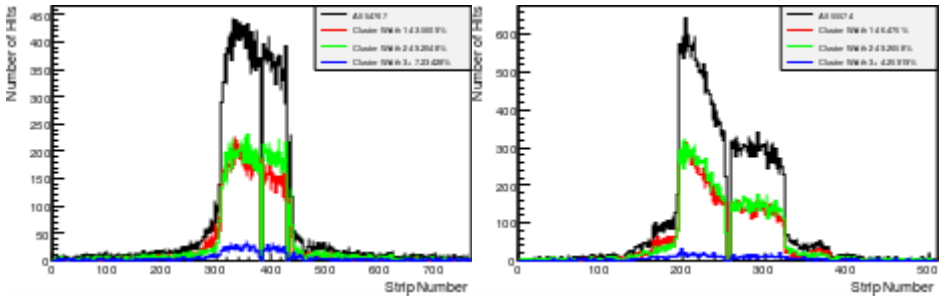
- L5.001: Latest, electrically functional ladder
- Average of 4 measurements
- **x, y: ±100µm, z: + ±100µm**
- Slightly worse, but same order of precision

L5.903: Beam Test Hit Maps

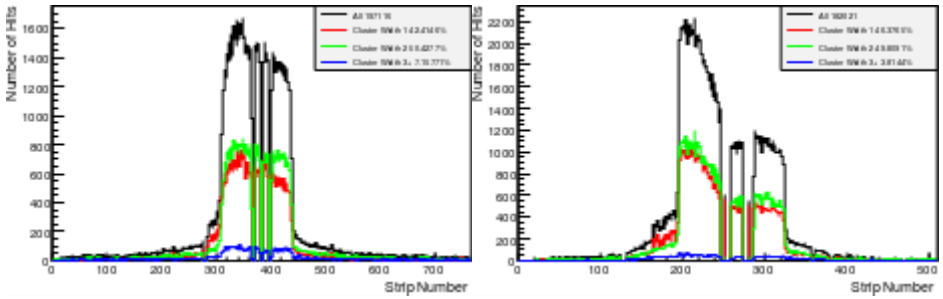
p-side FW n-side



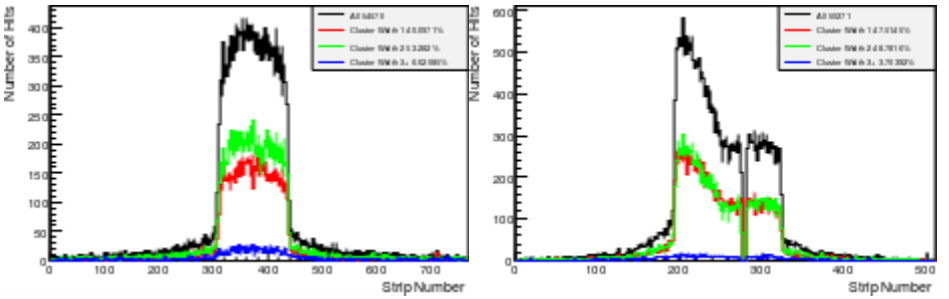
p-side -Z n-side



p-side CE n-side



p-side BW n-side



Data taken without cooling at room temperature.

preliminary