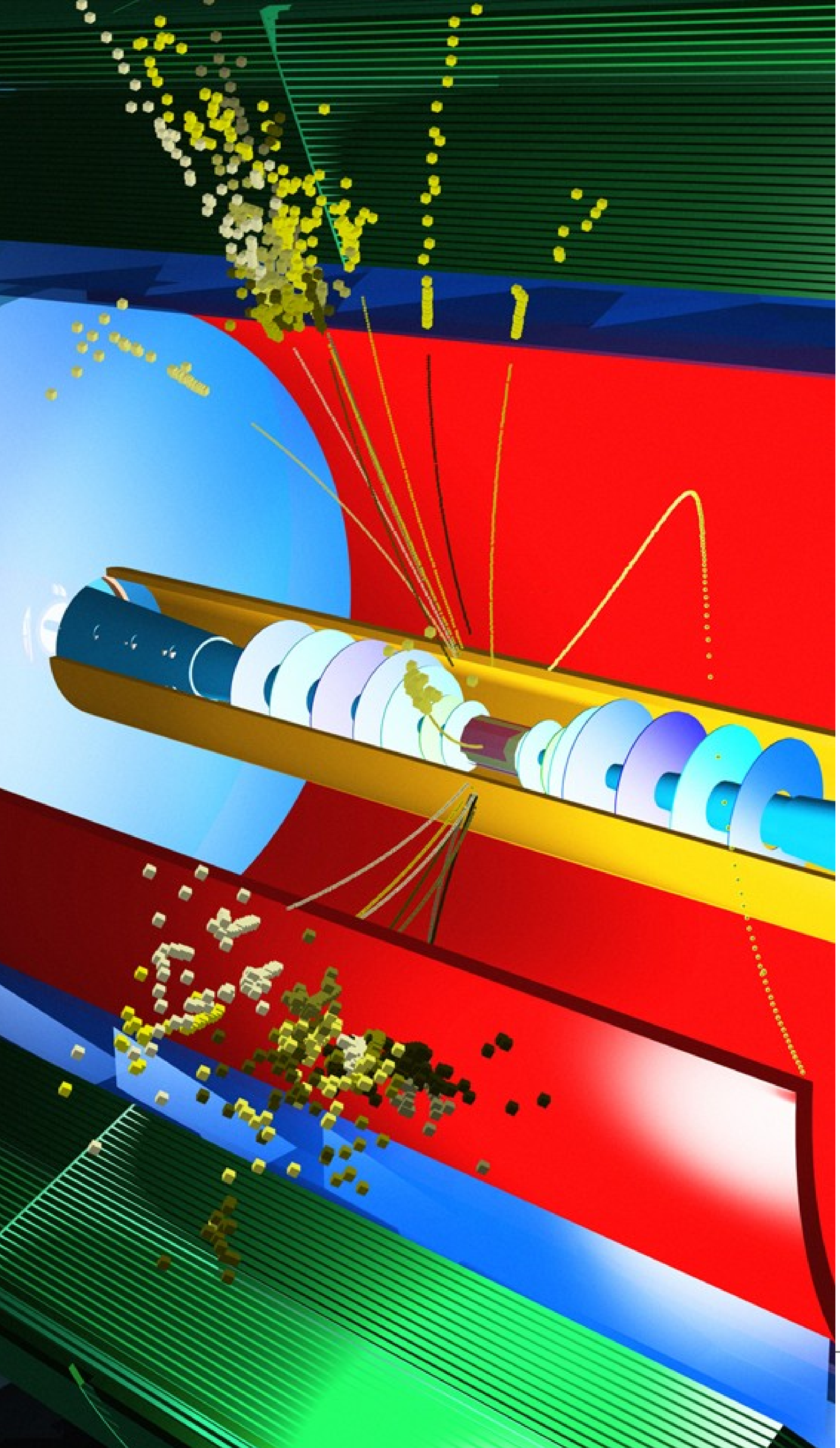


The ILD vertex detector and its relation to the inner tracker

ILD integration meeting

LAL, 2 february 2018

Marcel Vos IFIC (U. Valencia/CSIC), Spain

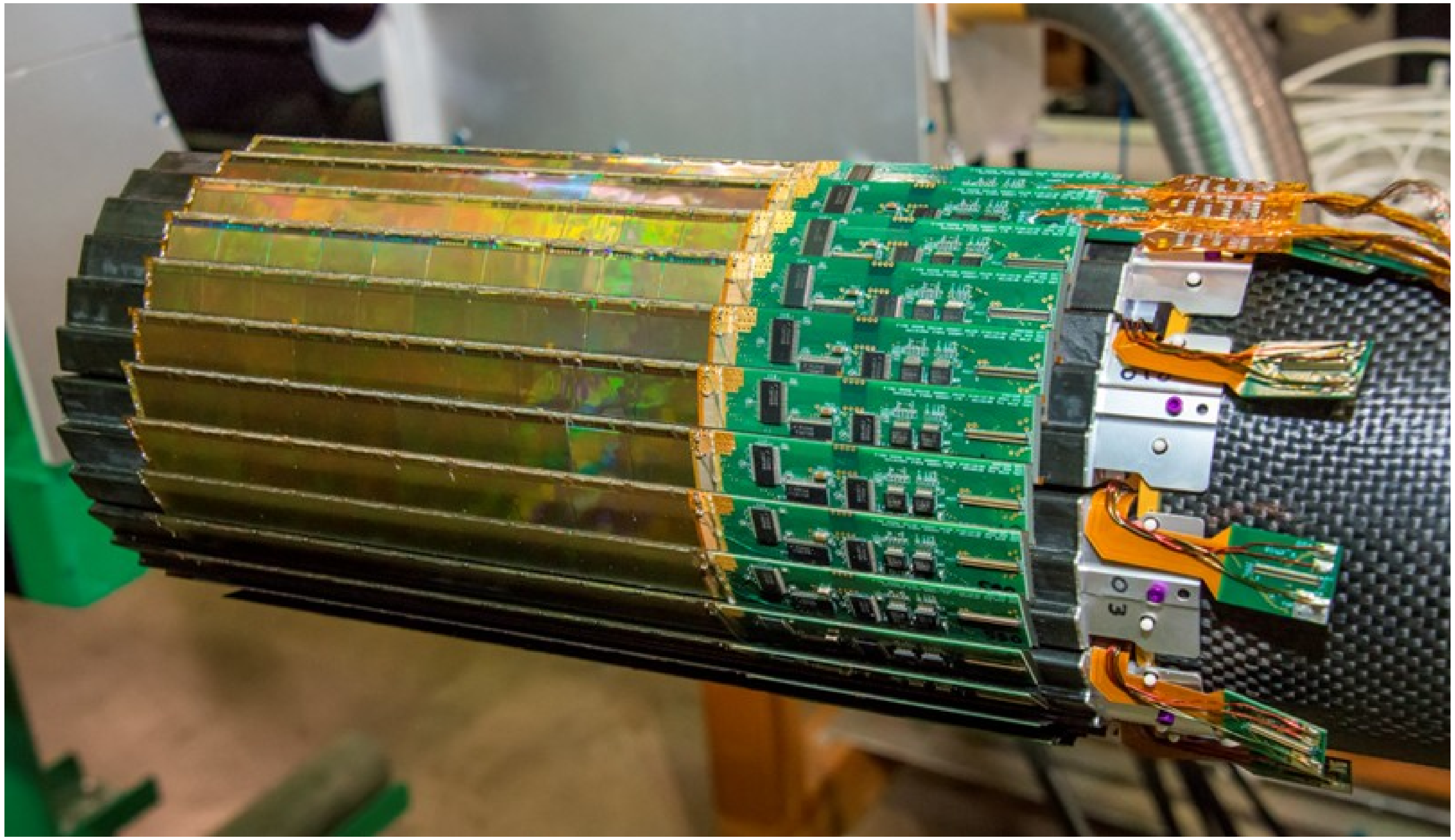
With inputs from Auguste Besson, Akimasa Ishikawa, Miguel Angel Villarejo, Ivan Vila

DEPFET

Active Pixel Detector

CMOS proof-of-principle

STAR Heavy Flavour Tagger
Based on MIMOSA CMOS sensor
Operated successfully 2014-2016
Multiple detectors built!



Air cooled!!

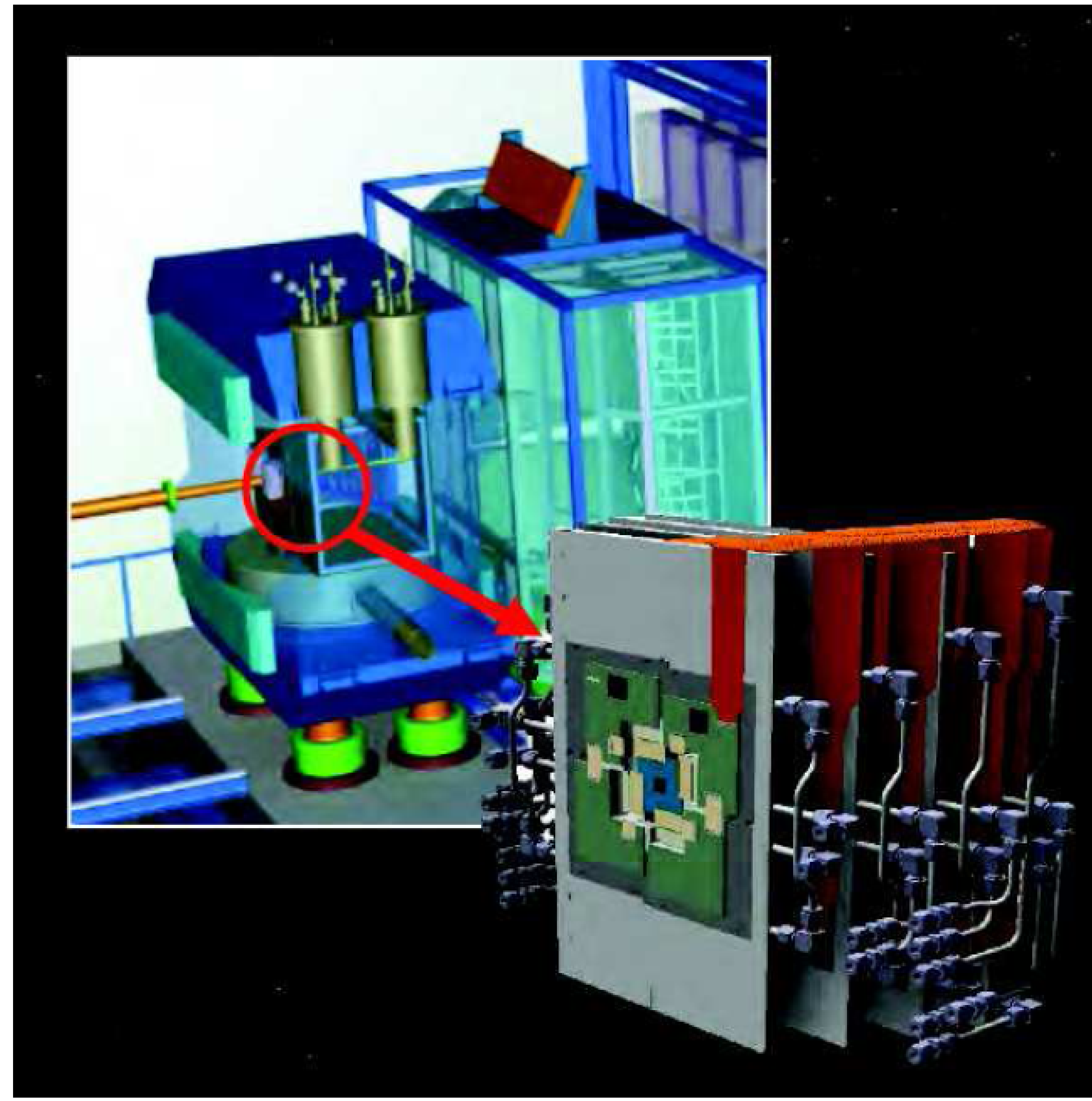
Note: positive experience with air cooling in STAR and Belle II; AIDA2020 air cooling setup at Oxford

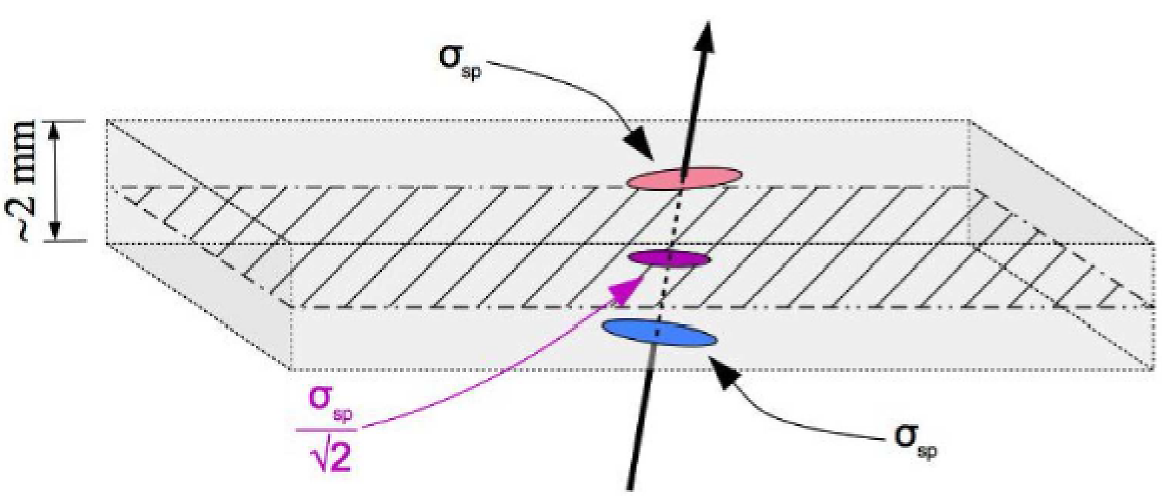
CMOS MAPs future

Starting point: CPS for ALICE
In-pixel ampl. ⊕ shaping ⊕ discr.
ALPIDE: 5 µm, 5 µs

MAPS for CBM-MVD
MIMOSIS hit rate 10^8 hits/cm^2
Prototype to be tested
Production in 2020/21

MAPS for ILC
PSIRA
VXD: 4 µm, 2/4 µs
SIT: 5 µm, 1 µs



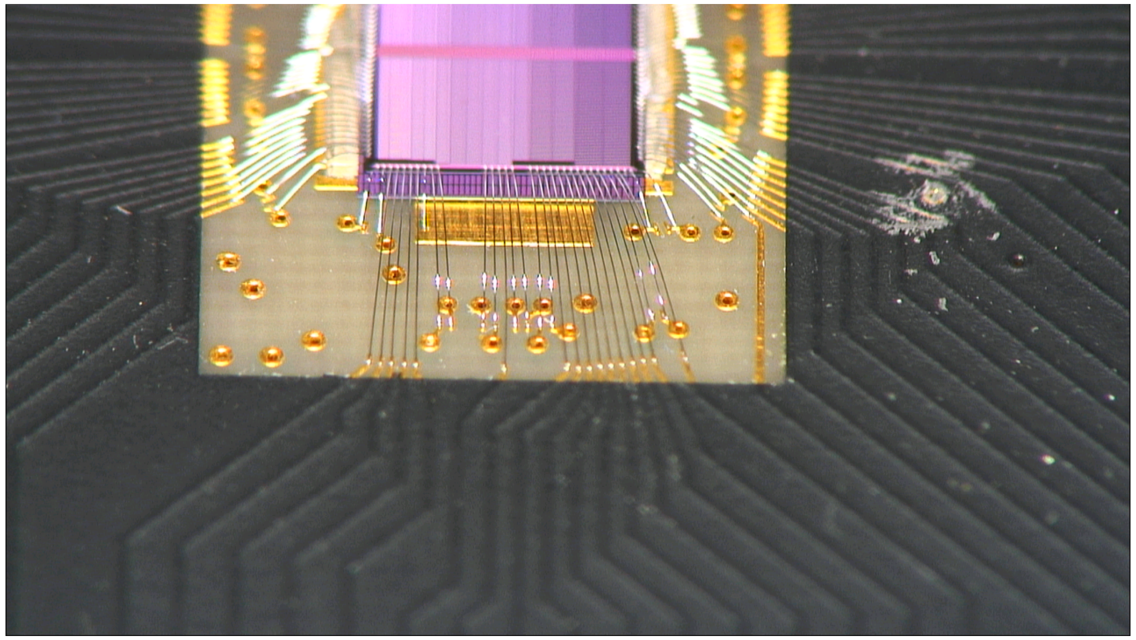


HVCMOS/HRCMOS

High Voltage or High Resisitivity CMOS process adopted by HEP
→ allows for a sizeable depleted region
→ contained signal, fast collection
→ multiple wells allow for in-pixel functionality

Fashionable at the LHC:
→ ALICE ITS upgrade
→ part of ATLAS upgrade plan

ILC/CLIC tracking
Strasbourg CMOS MAPs suited for silicon inner tracker SIT
CLICdp positively evaluated the possibility of all-pixel CMOS tracker (ALPIDE-based design)



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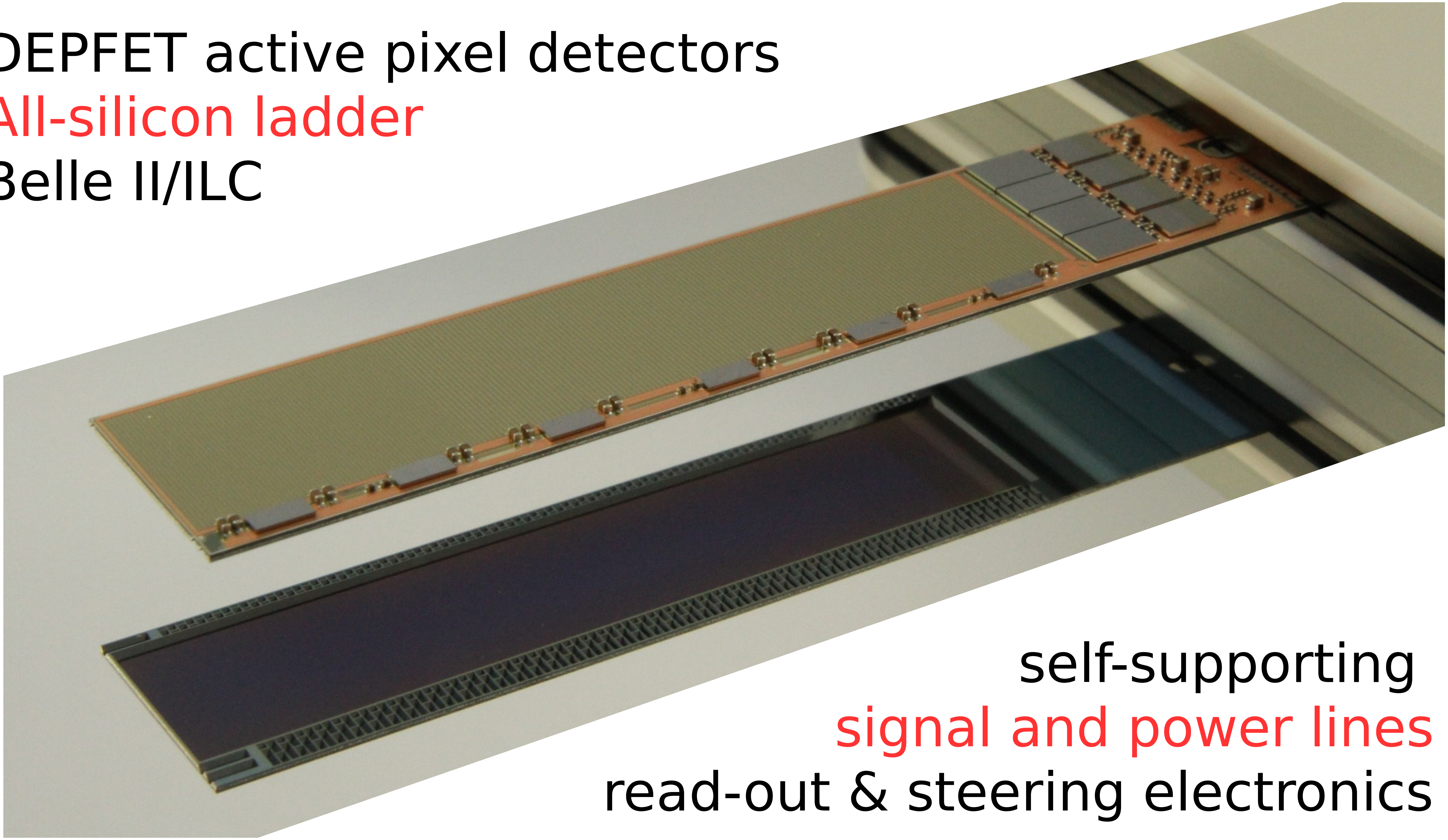
DEPFET active pixel detectors

All-silicon ladder

Belle II/ILC



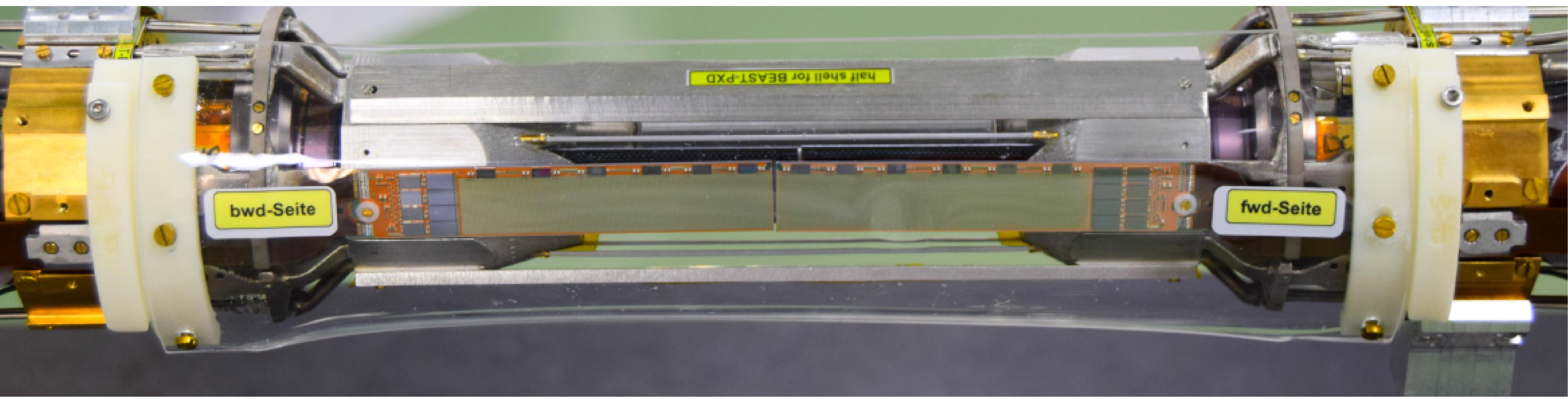
self-supporting

signal and power lines

read-out & steering electronics

The next generation is ready to take the stage

DEPFET vertex detector



One more milestone:
installation of DEPFET PXD + SVD ladders in Belle II commissioning detector

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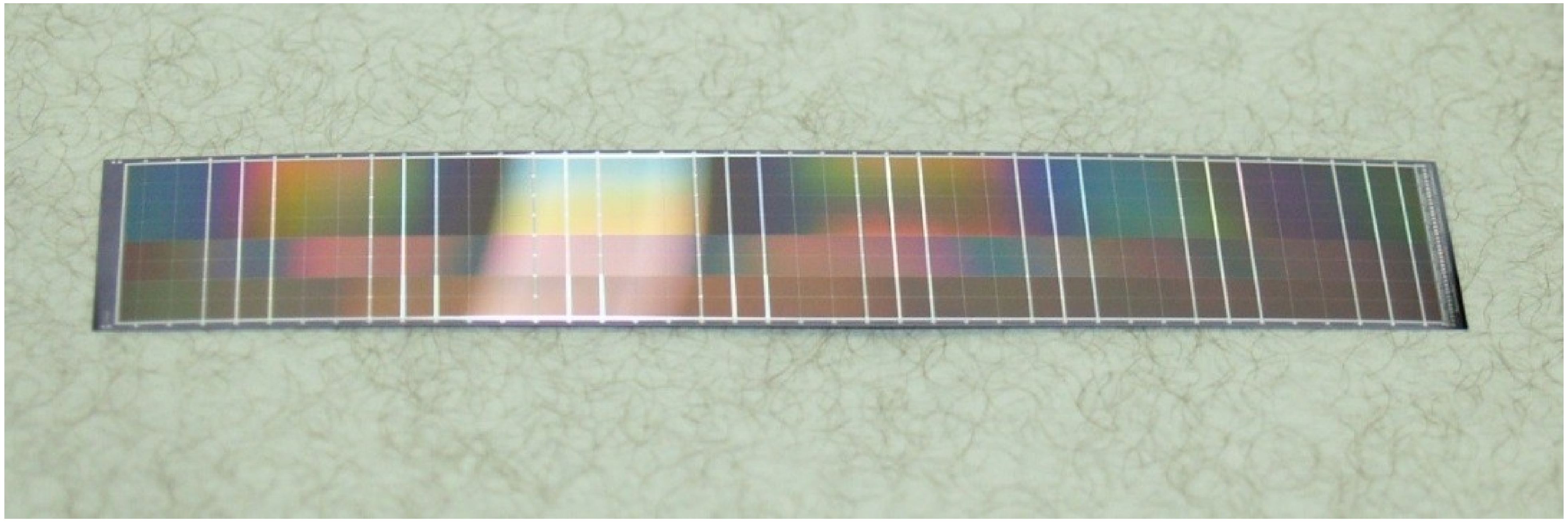
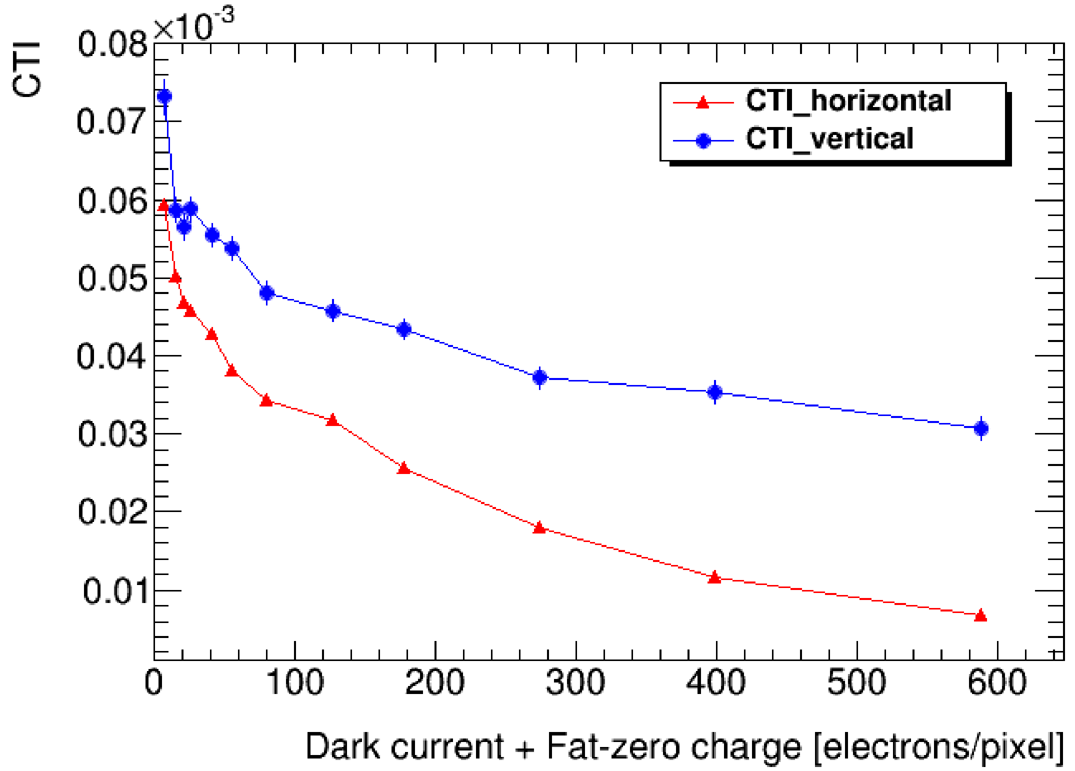
Come-back of a golden oldie



FPCCD: inspired by SLD vertex detector

Pixel size down to 5 x 5 μm^2

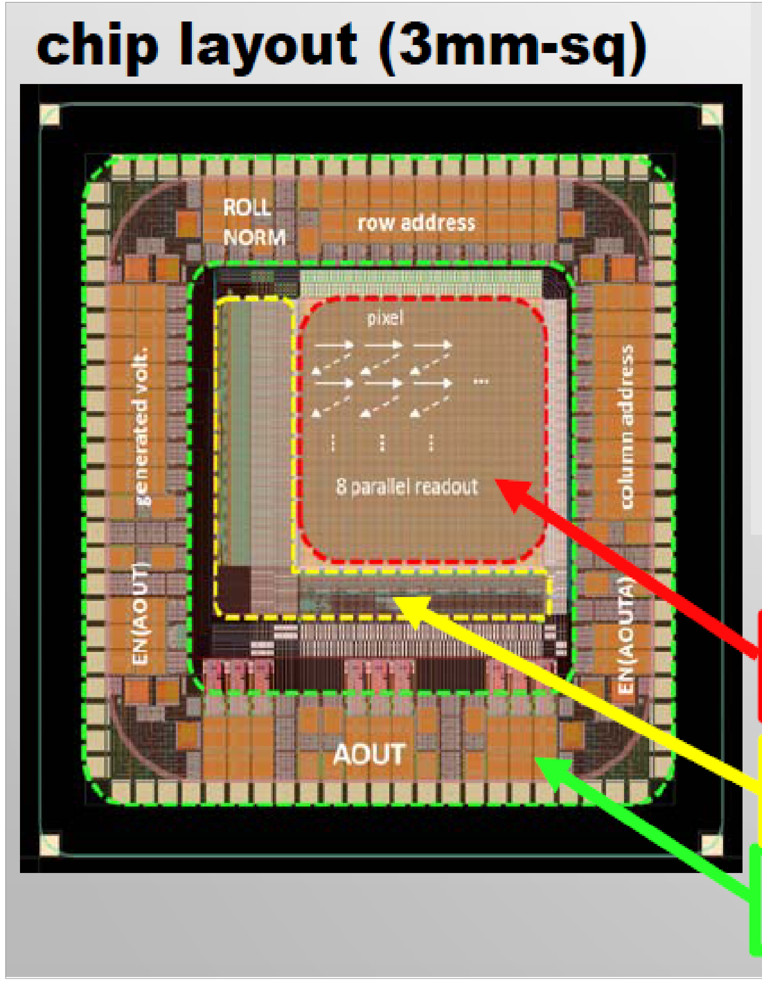
Radiation hardness (= charge transfer efficiency) significantly improved by charge injection



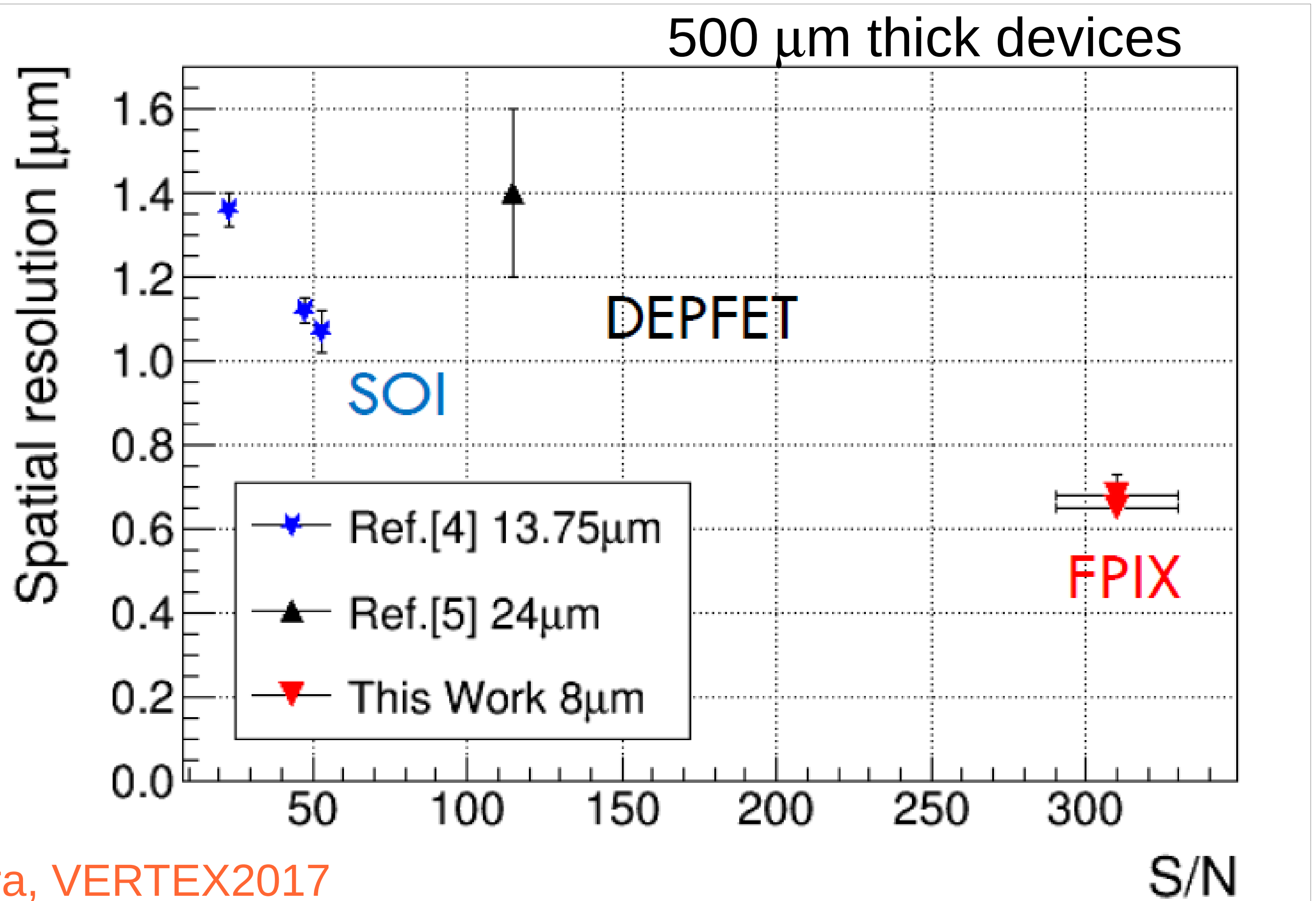
The next-to-next generation...

Double silicon-on-insulator (DSOI) solves main SOI problems:

back-gating, trapping and cross talk



FPIX2
resolution
demonstrator
8 x 8 μm^2

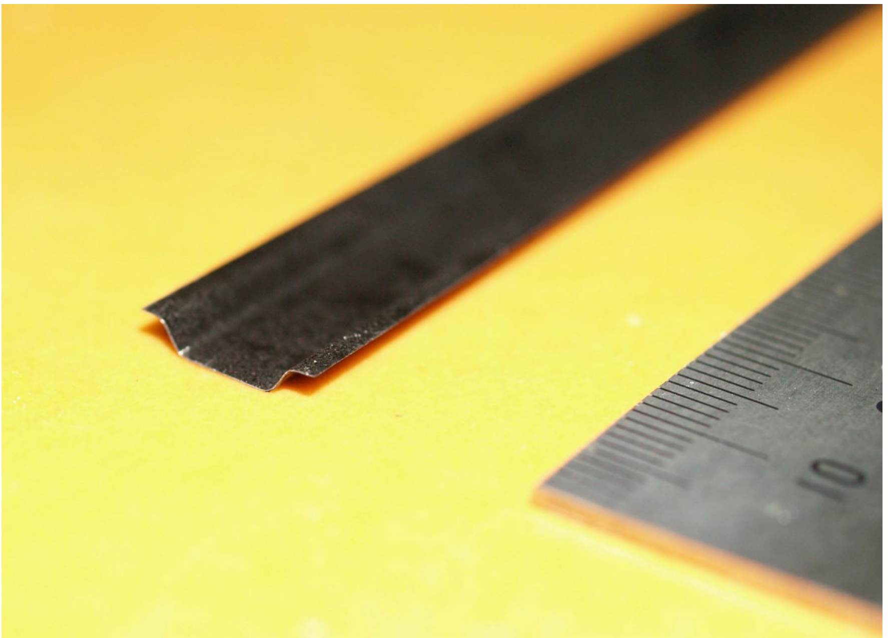


Hara, VERTEX2017

SOFIST: in-pixel time-stamping with 25 x 25 μm^2 pixels

...is anxious to take over

Mechanics – ladder design



CF frame for FPCCD

Aim for double ladders with very low material budget: 0.35 % X_0

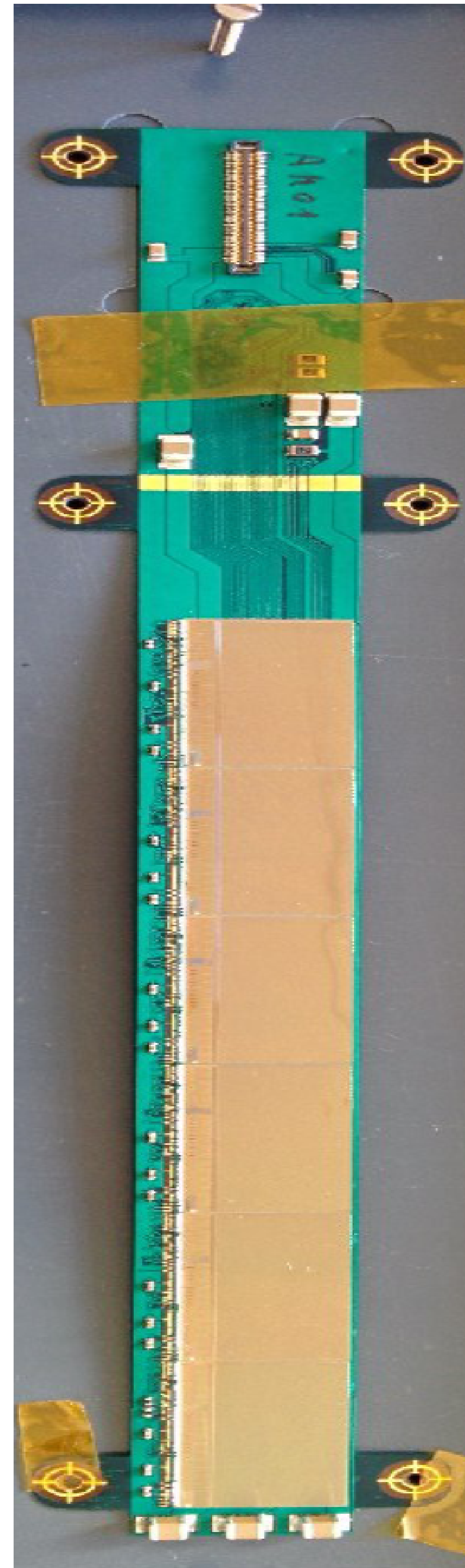
Alternative: single ladders

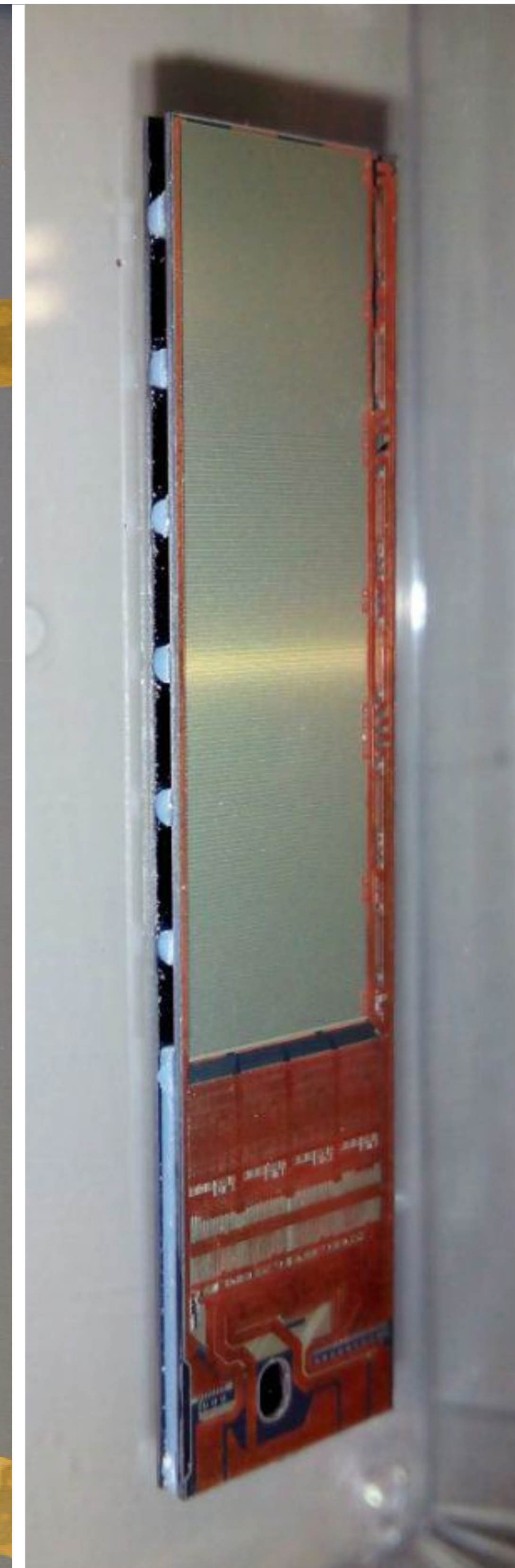
Si – Carbon fiber

Si - 4% SiC foam kapton – Si

Si – plastic + air – Si

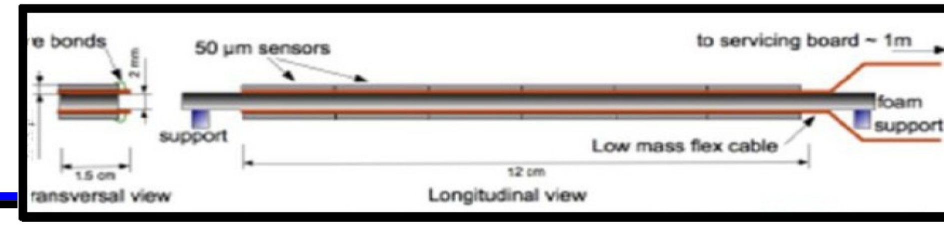
PLUME double-side ladder



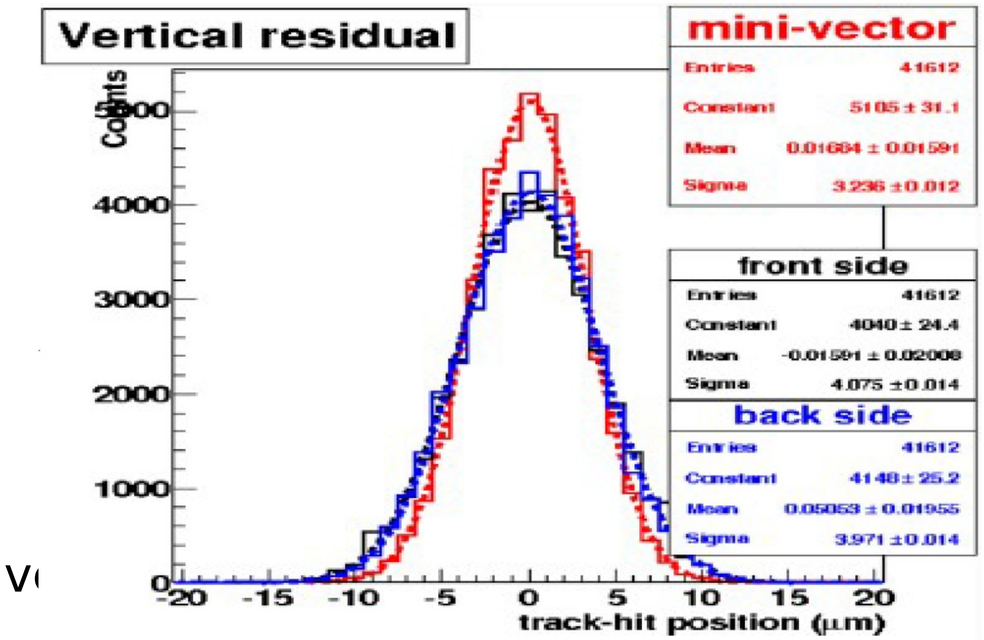


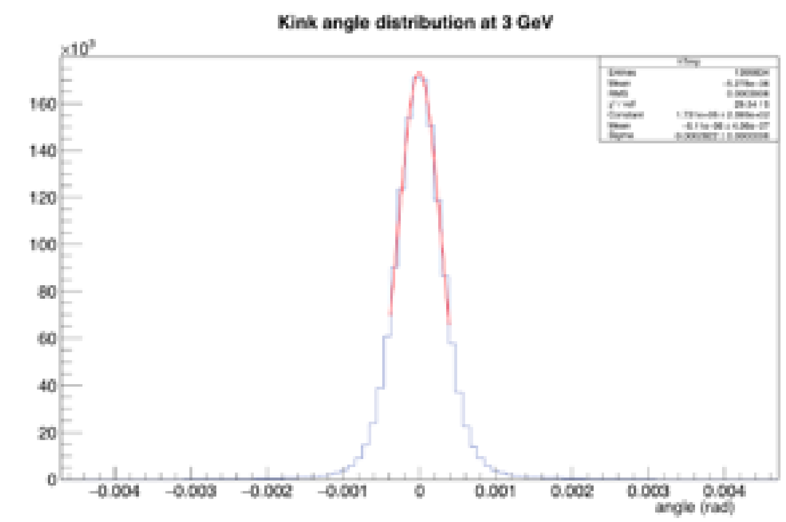
DEPFET all-silicon double-ladder

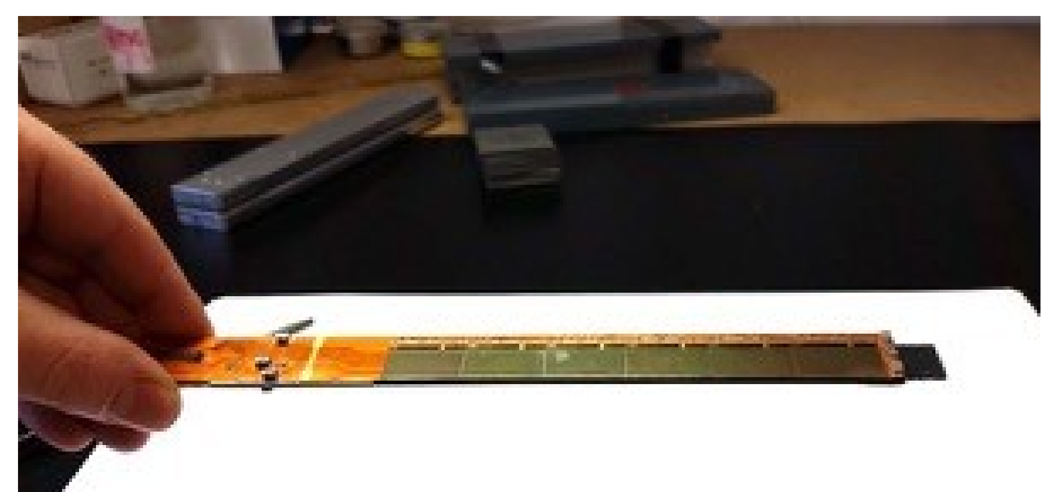
Integration: PLUME collaboration



- Plume collaboration (Bristol, DESY, IPHC)
  - Double sided ladders with minimized material budget
- Plume 01 prototype (fab. 2012)
  - 2x6 Mimosa-26 on 2 mm foam SiC
    - <mat.budget> ~ 0.6 % X_0 + Air cooling
  - Successfully validated in test beam
    - Mat. budget checked in test beam with kink angle in sensitiv area: 0.47±0.02 % X_0 (0.45 expected) (B.Boitrelle PhD)
- Plume 02 prototype → Reduced mat. Budget
  - Cu flex cable (0.42 % X_0)
    - 2 modules functional, 2 more expected
  - Al flex cable (0.35 % X_0)
    - 4 modules. Connectors issue □ fix in 2017
  - 6 ladders expected (2 fabricated)
    - Modules functional. Tests ongoing in 2016
-







Ladders close to ILC mat.budget specifications

Air cooling

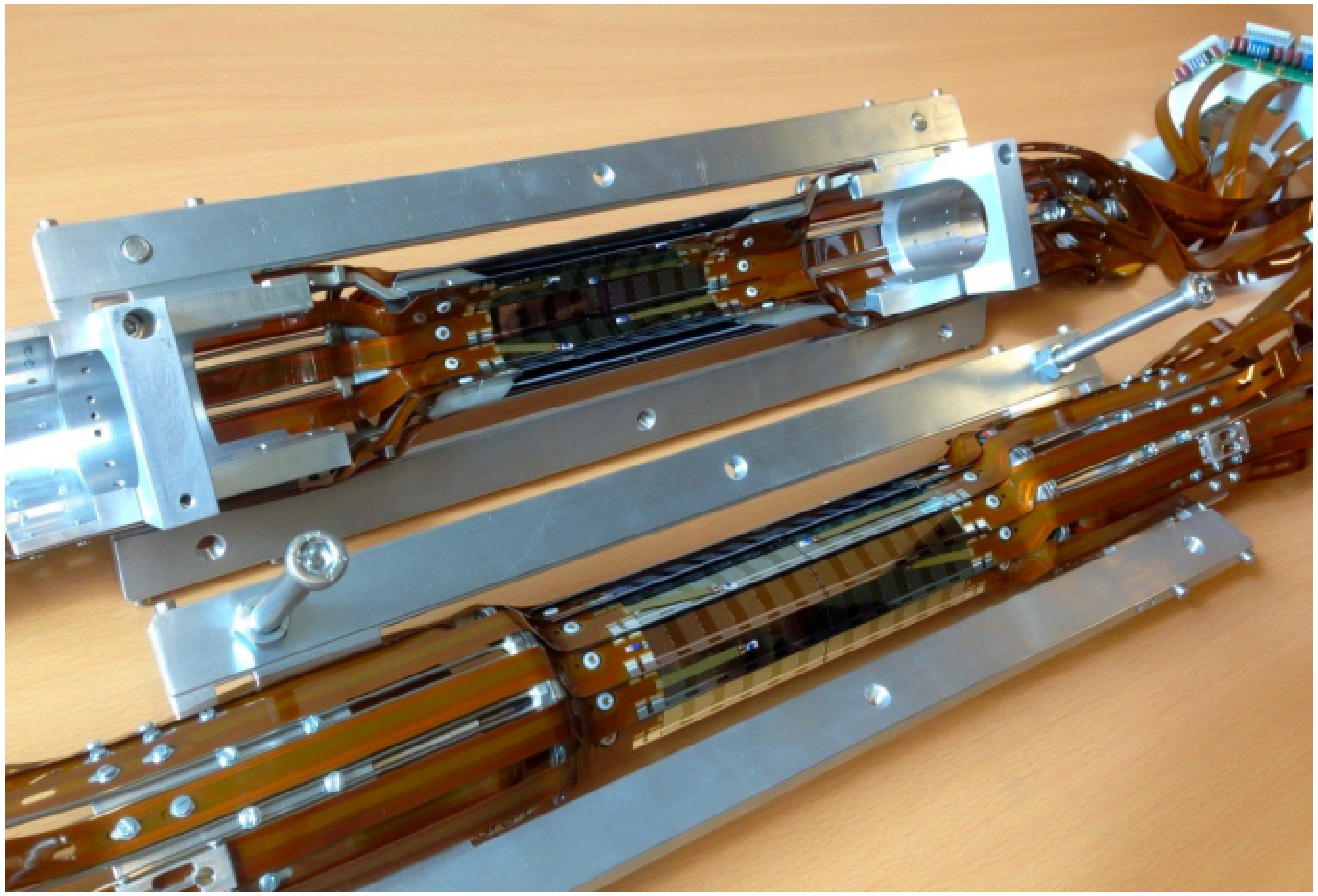
Ultra-thin silicon, power pulsing and air cooling?

Keep the silicon cool without affecting the stability or compromising the integrity!

Experience with air cooling in STAR
arXiv:1710.02176

Extensive studies in Belle II mock-up,
arXiv:1607.00663

Aggressive plans for Mu3e!
arXiv:1610.02021



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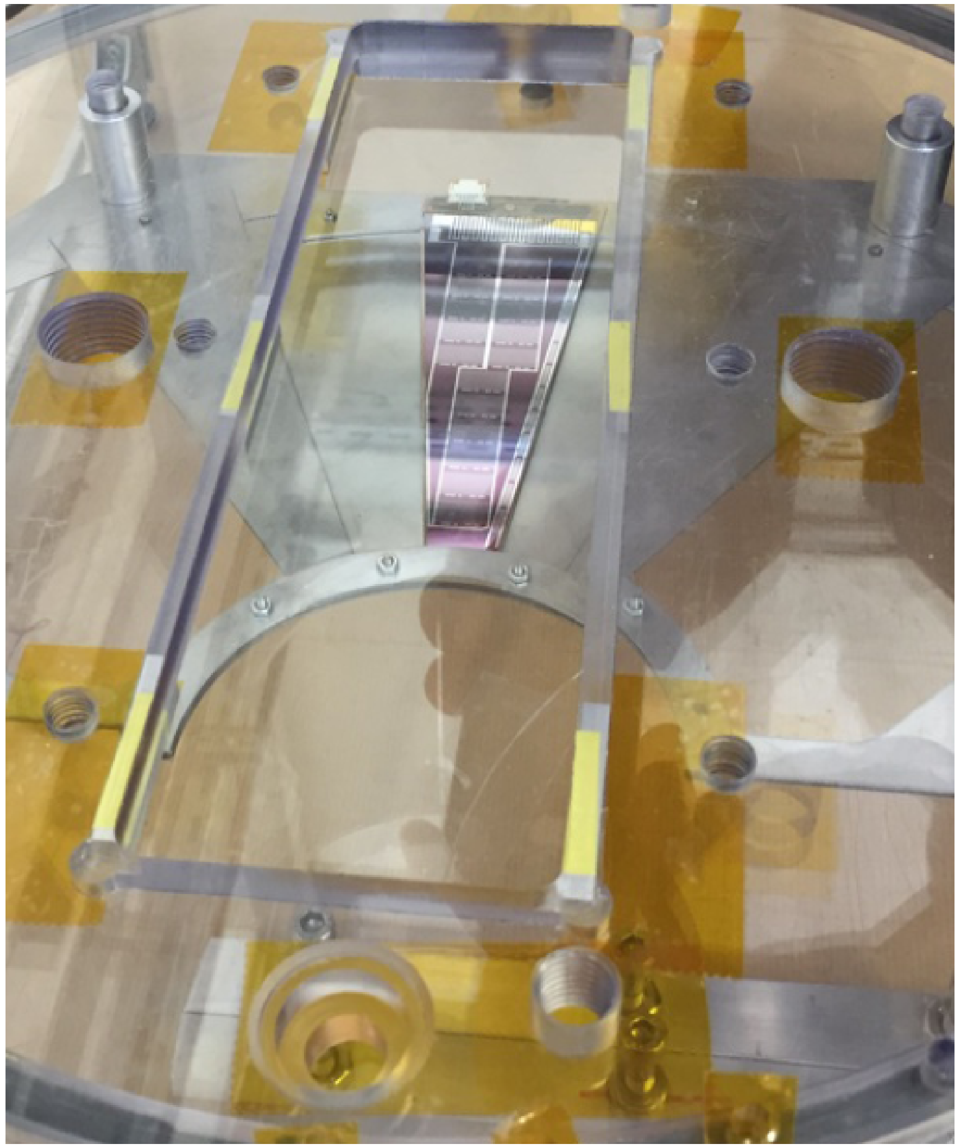
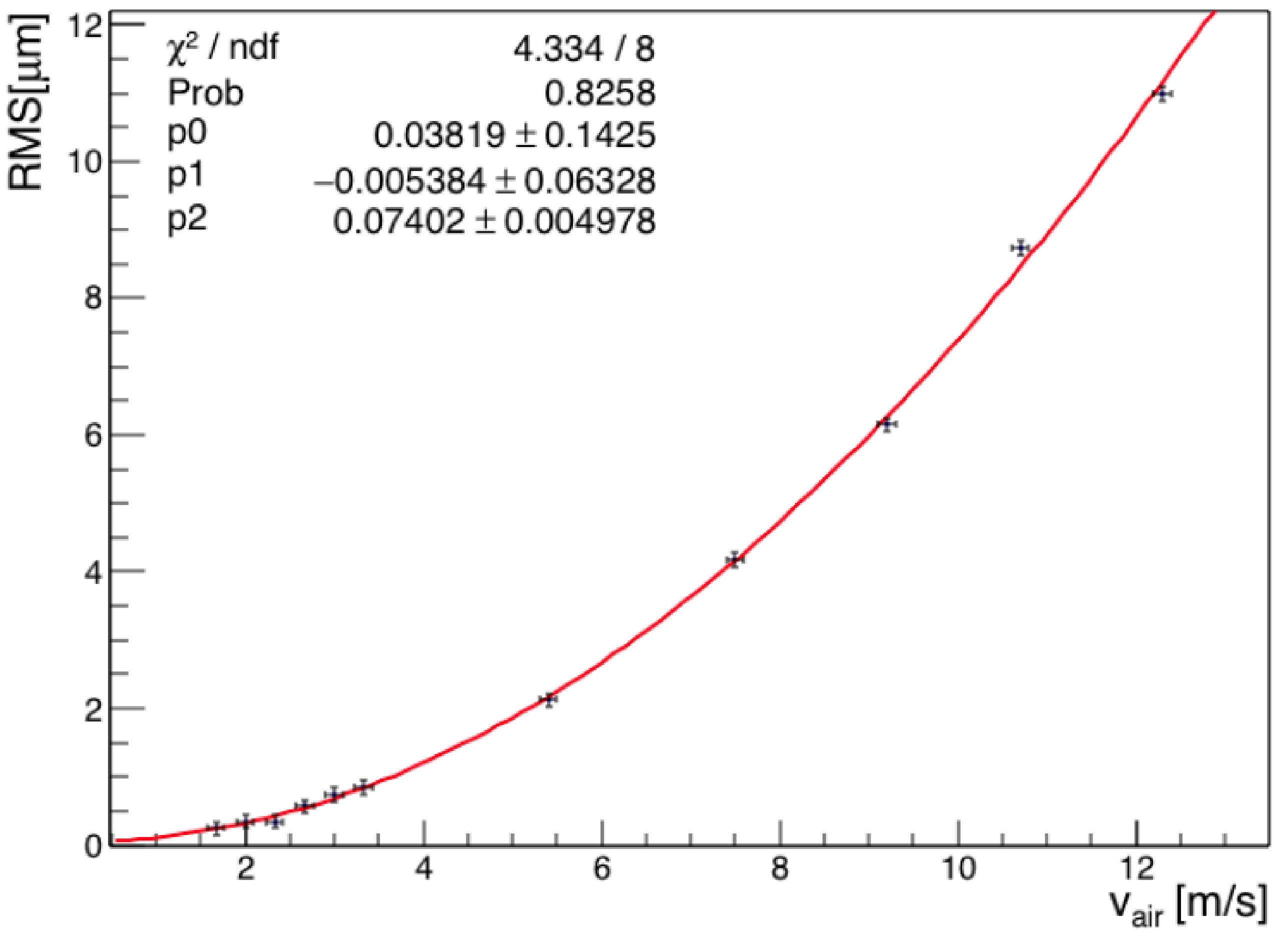
Air cooling & mechanical stability



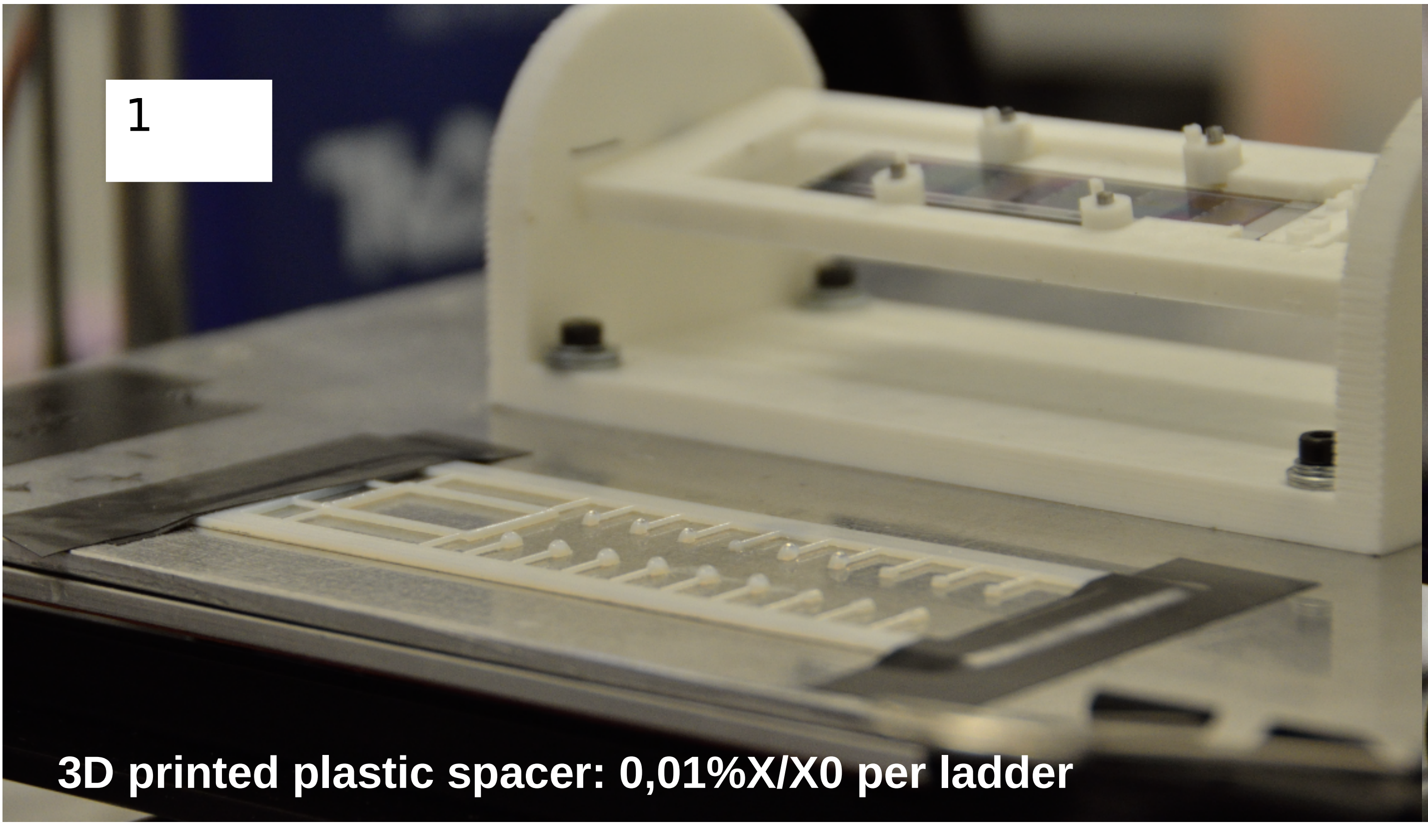
Dummy petal in CERN wind tunnel

Vibrations remain acceptable for air speed up to several m/s

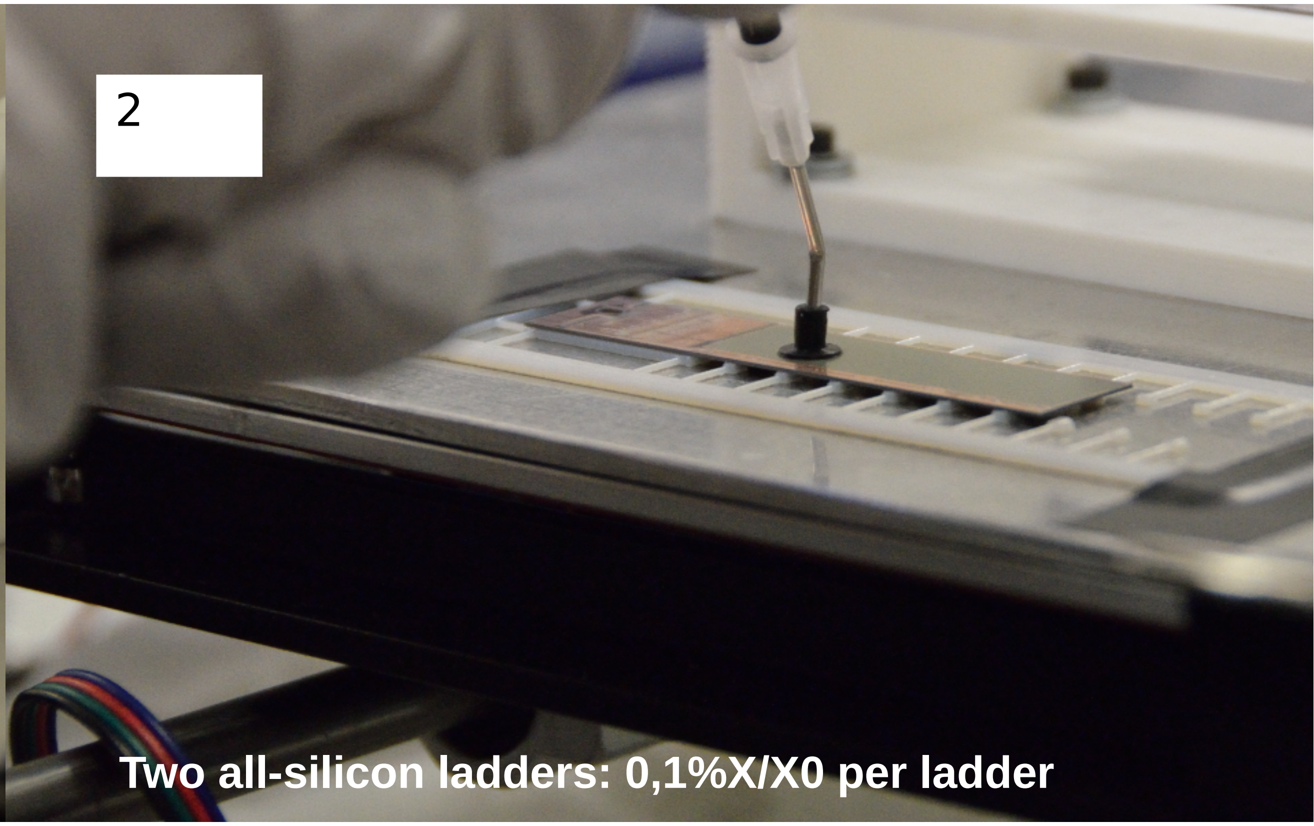


Ph.D. thesis Nacho Garcia,
U. Valencia, 2016

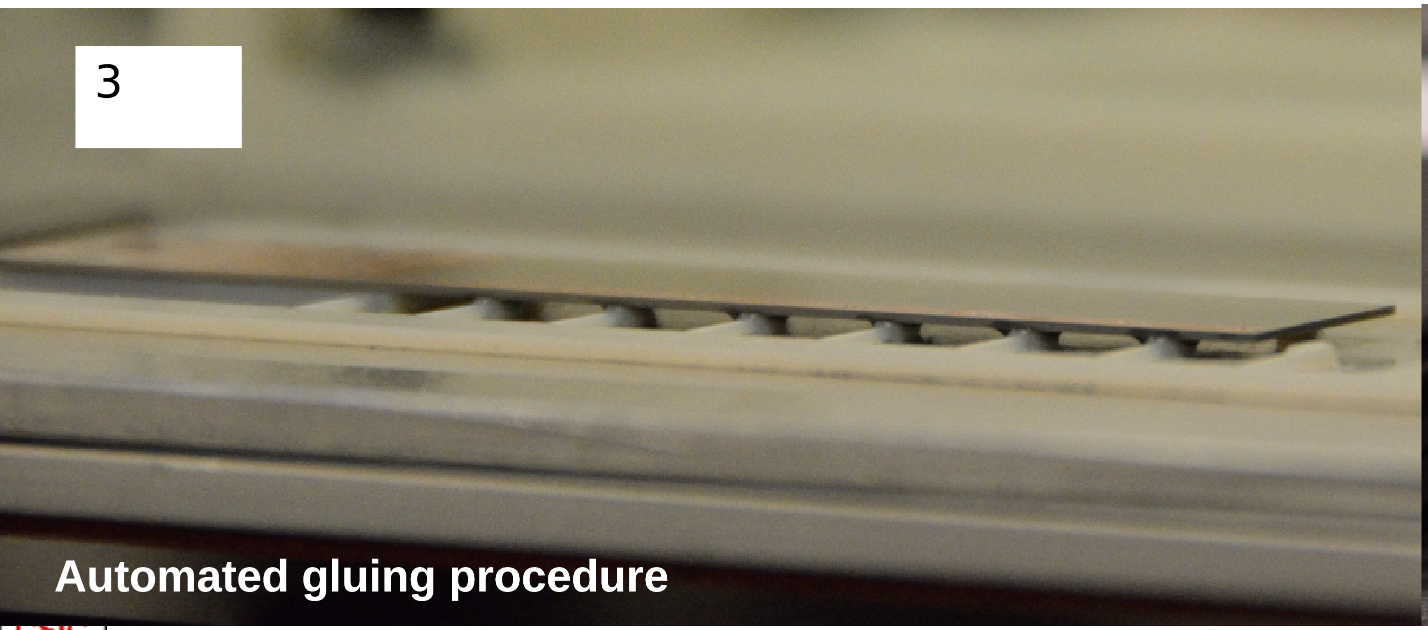
Double-sided structures



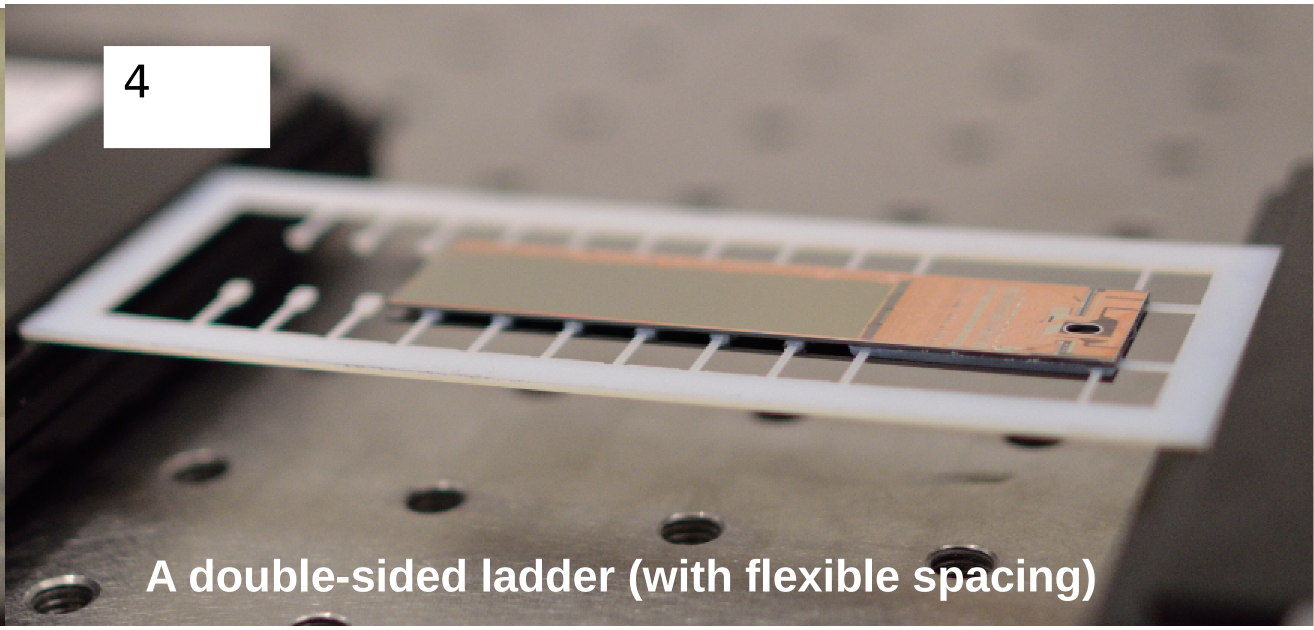
3D printed plastic spacer: 0,01%X/X0 per ladder



Two all-silicon ladders: 0,1%X/X0 per ladder



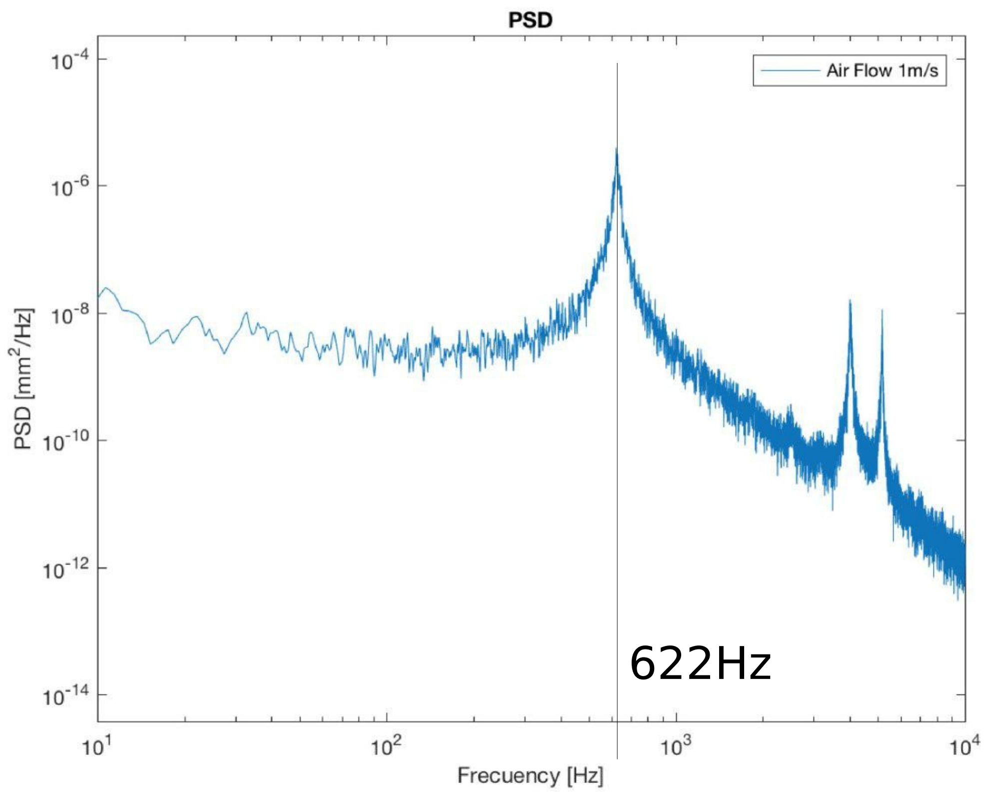
Automated gluing procedure

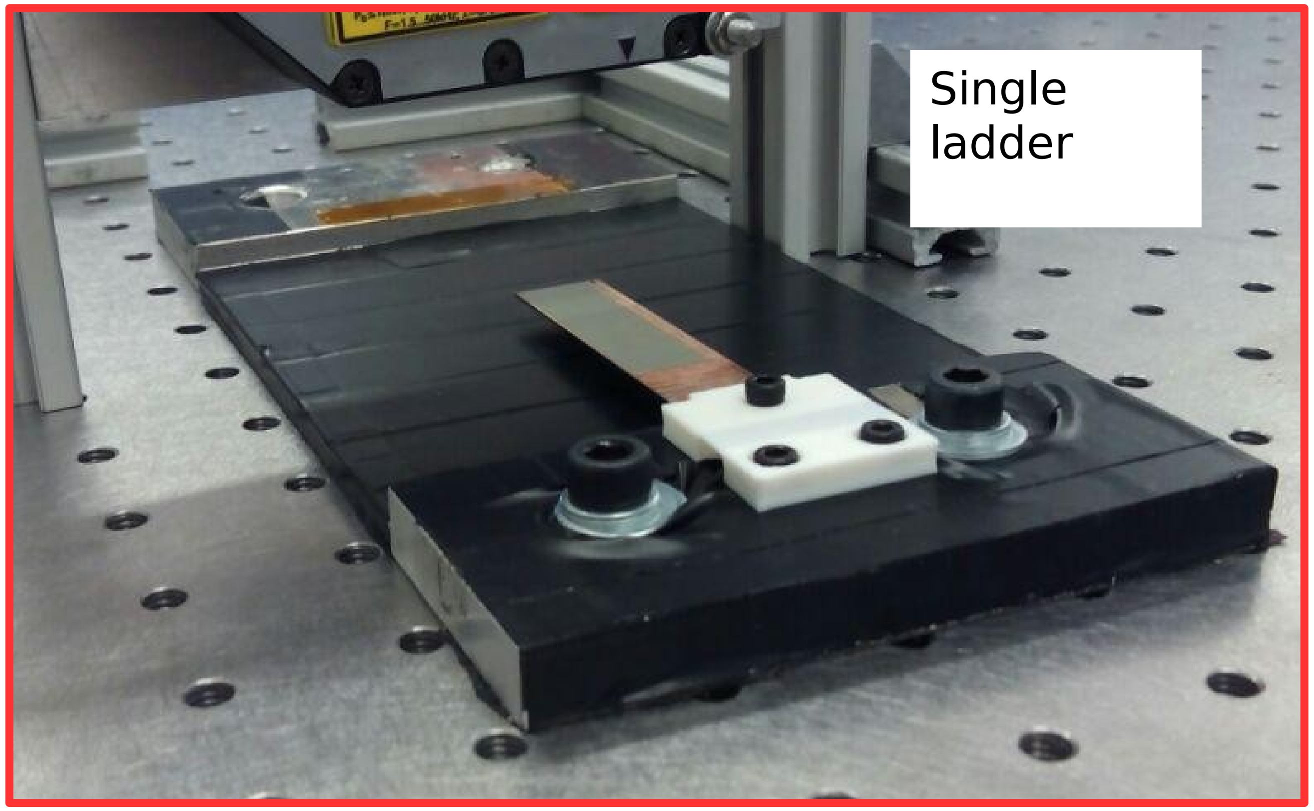


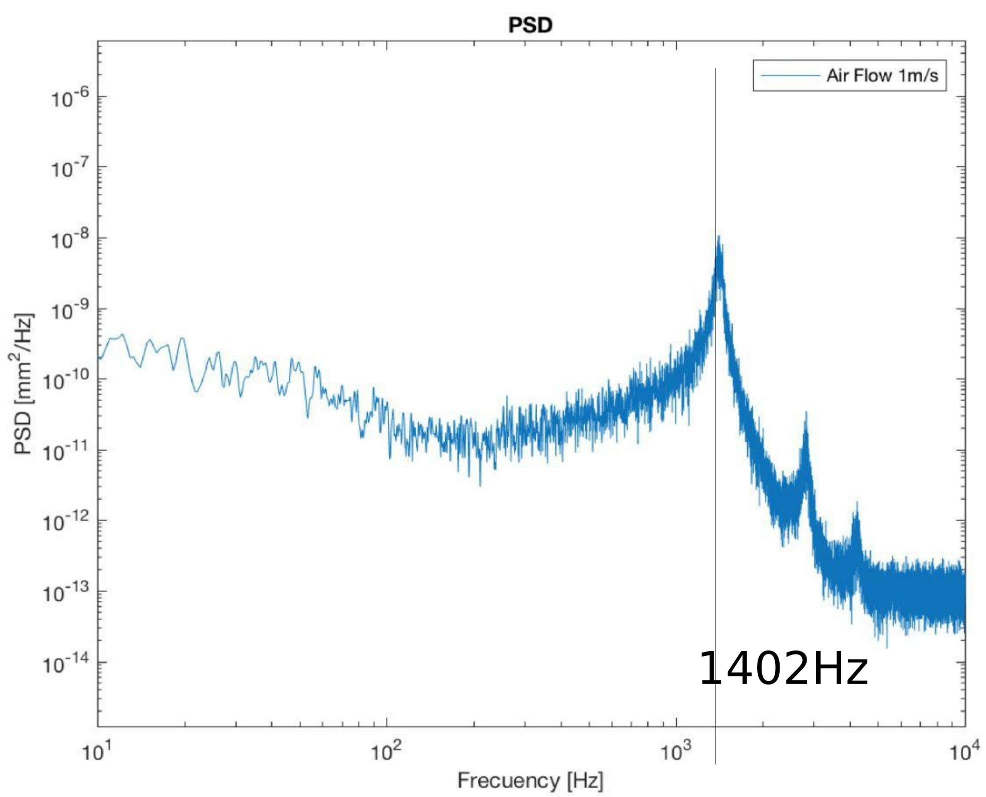
A double-sided ladder (with flexible spacing)

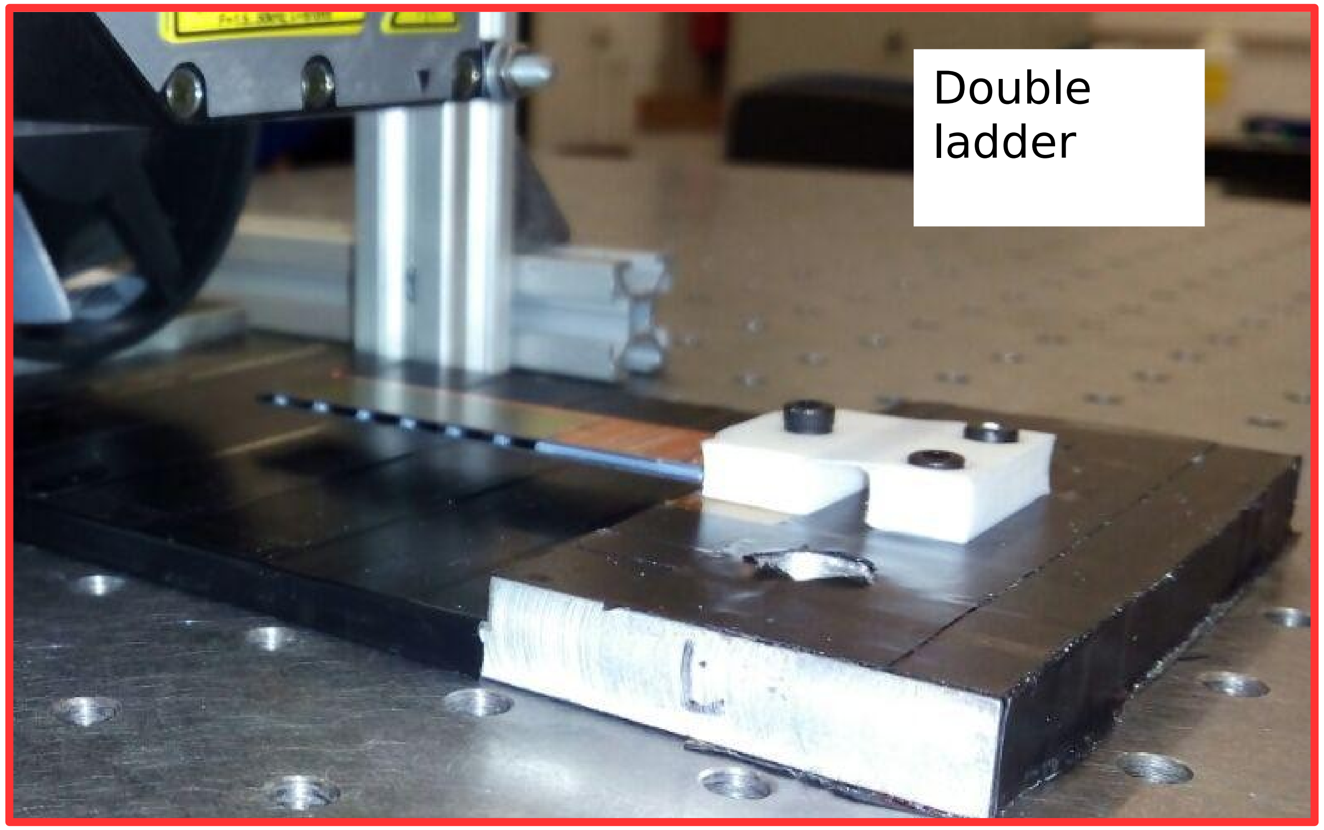
Double-sided structures based on all-silicon ladders

Air cooling









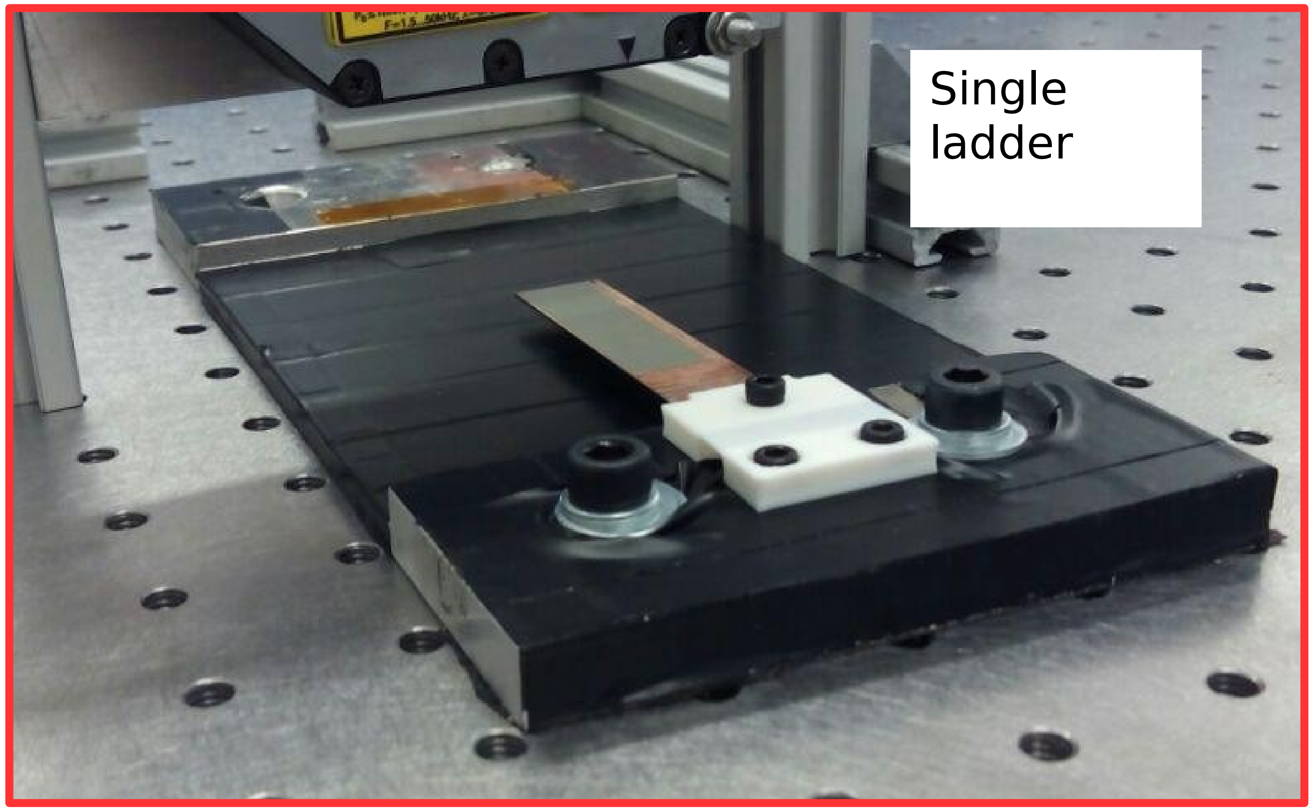
sided structures have considerably higher eigenfrequency

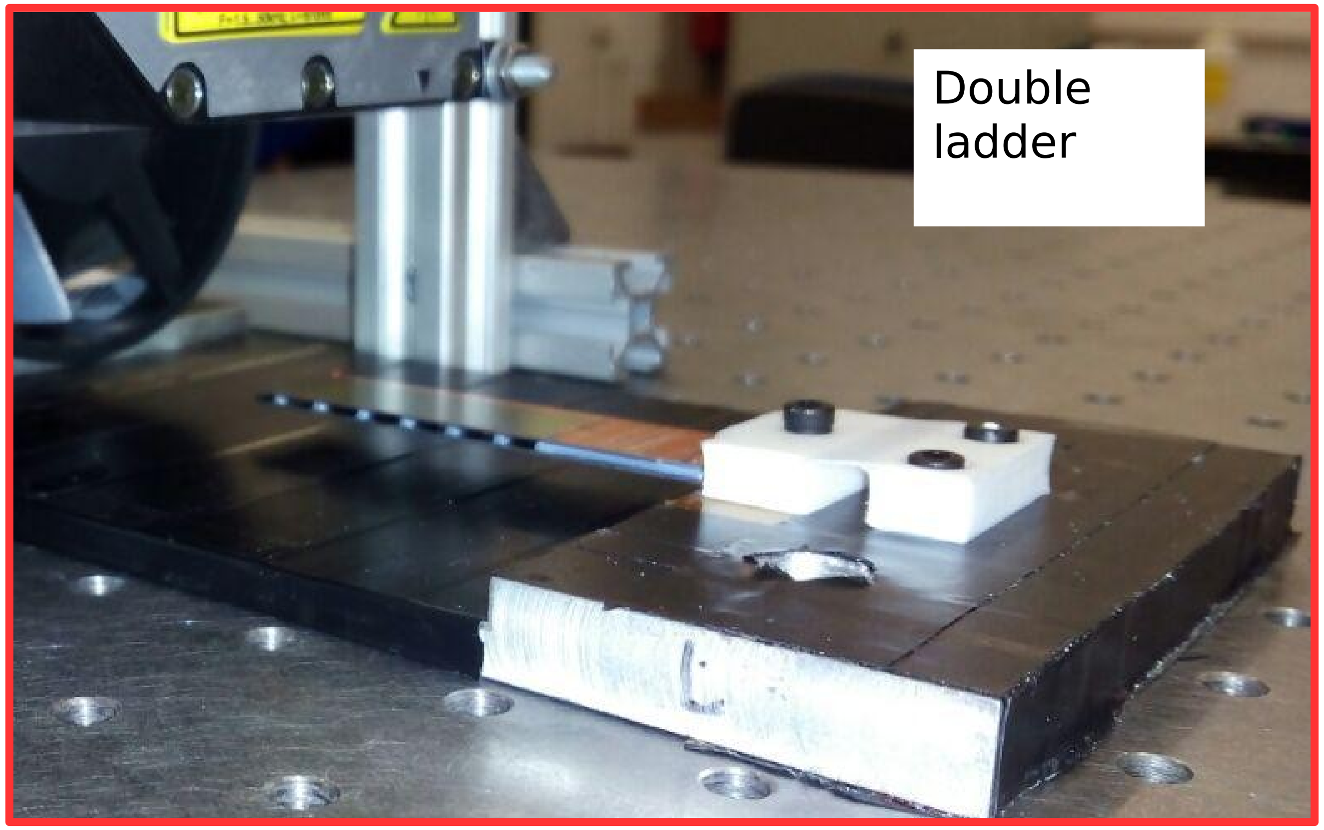
Air cooling

Double-sided structures improve resilience against air-induced vibrations

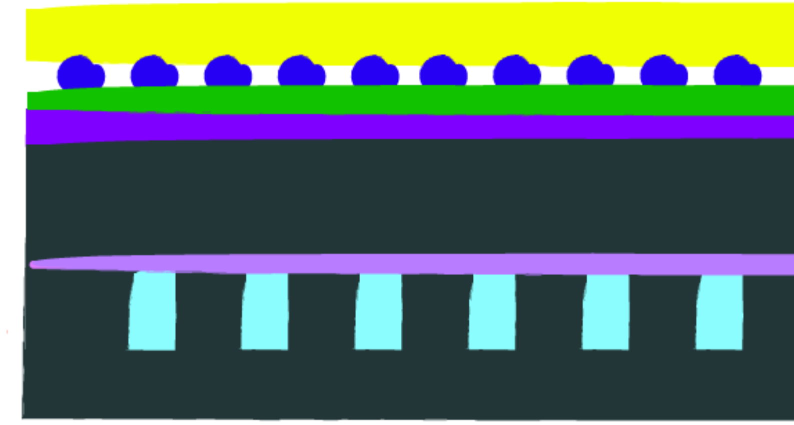
v=1m/s	Peak2Peak	RMS
Single ladder	68um	7,2um
Double ladder	8,1um	2,2um

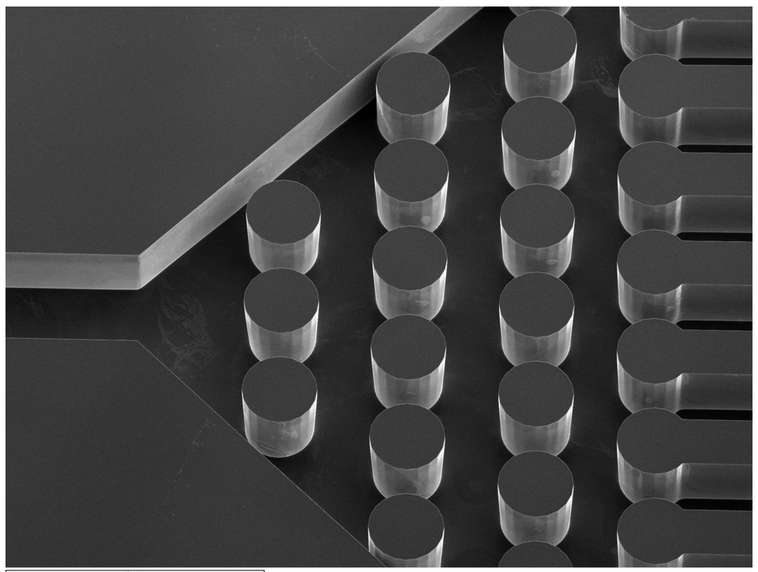
Note: ladders supported on one side only to amplify effects
Note: thick silicon (thinned assembly soon)
Note: petal-shaped structure to follow later

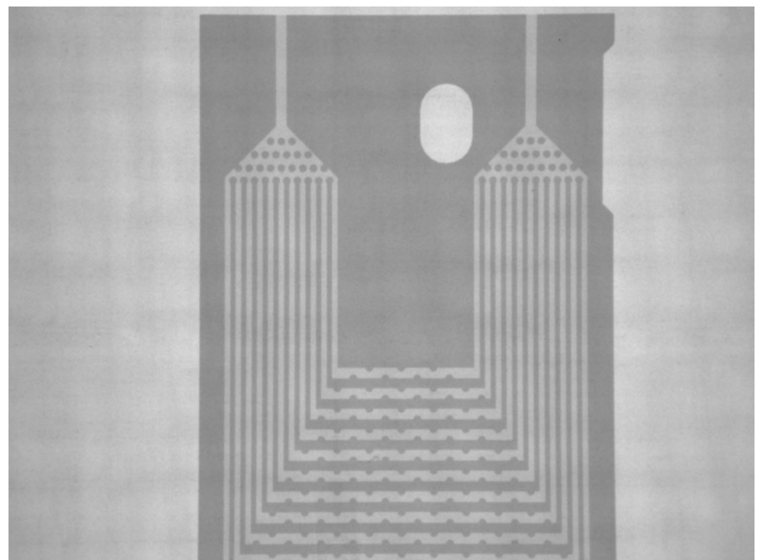




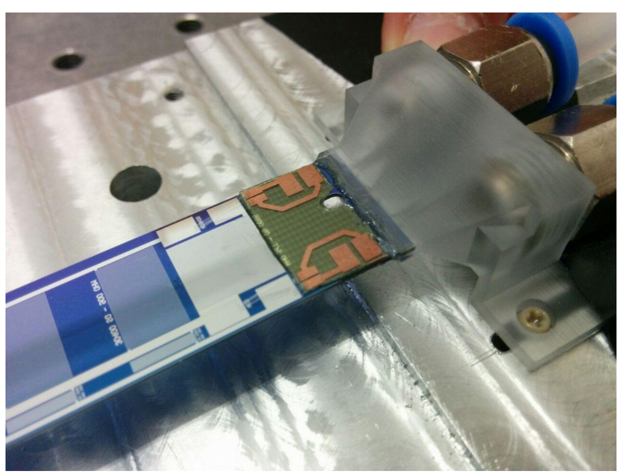
MCC

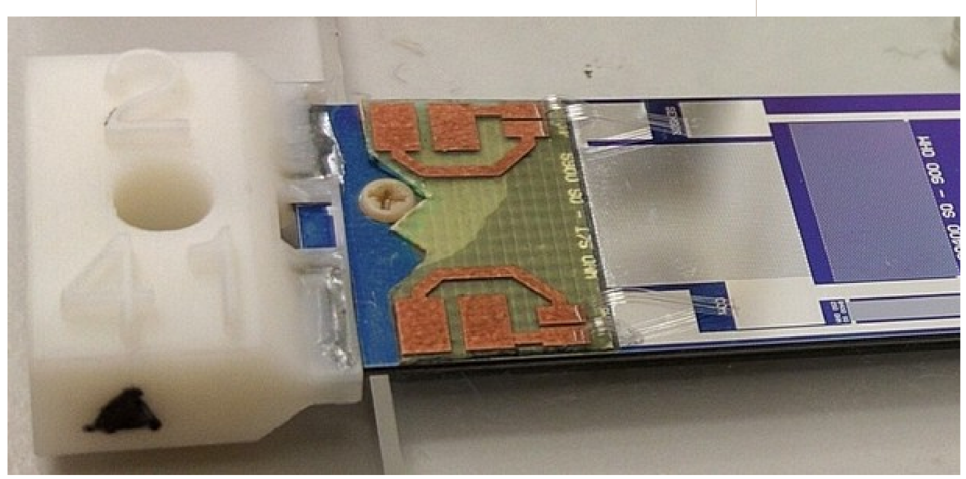


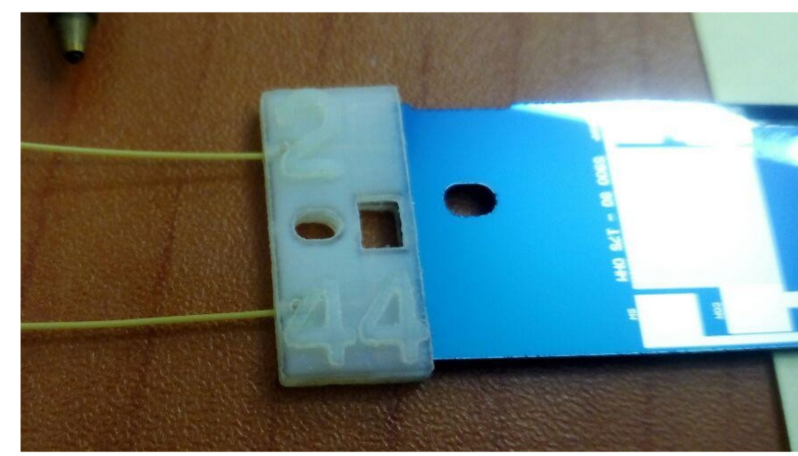




Micro-manifold before (photograph) and After wafer bonding (X-ray image) Samples produced at HLL.







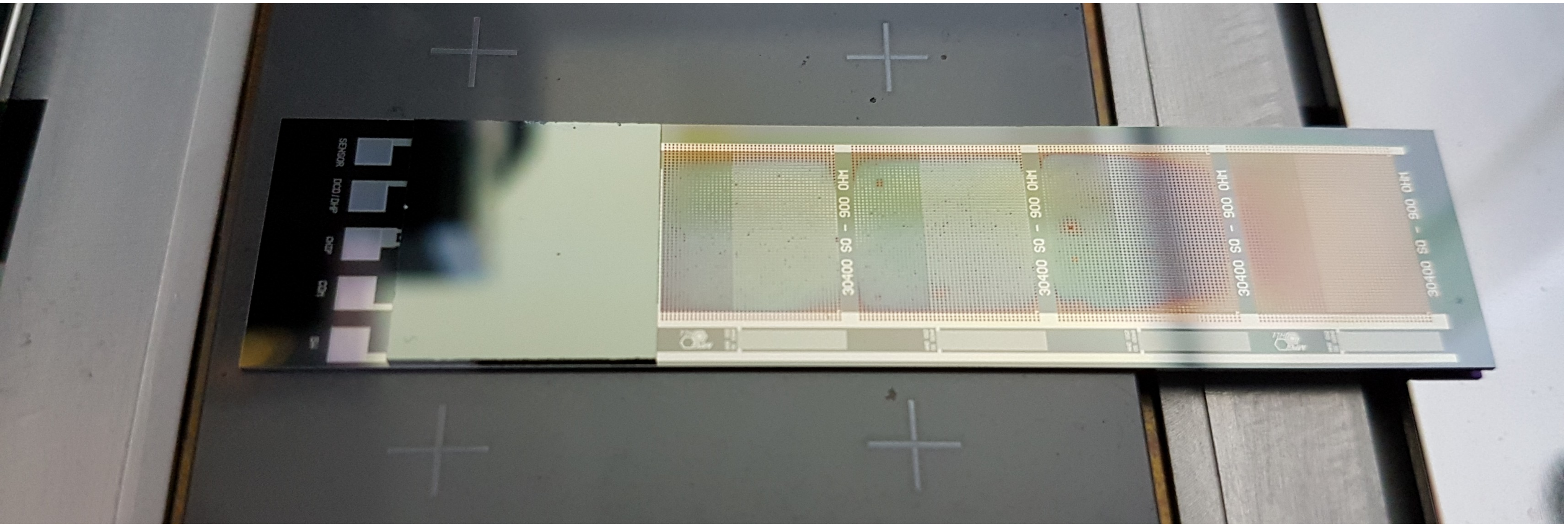
High-tech plumbing: custom, 3D-printed interfaces to commercial piping

First encouraging results: “cool 40 W with 3 l/h and ΔT = 10 K”
Published in JINST (arXiv:1604.0877)

New structures

AIDA2020 production: three wafers with 3x2 “sensors” each

First “sensor” sample bump-bonded to “chip” at NTC-UPV



Interface document

Sections divided among editors:

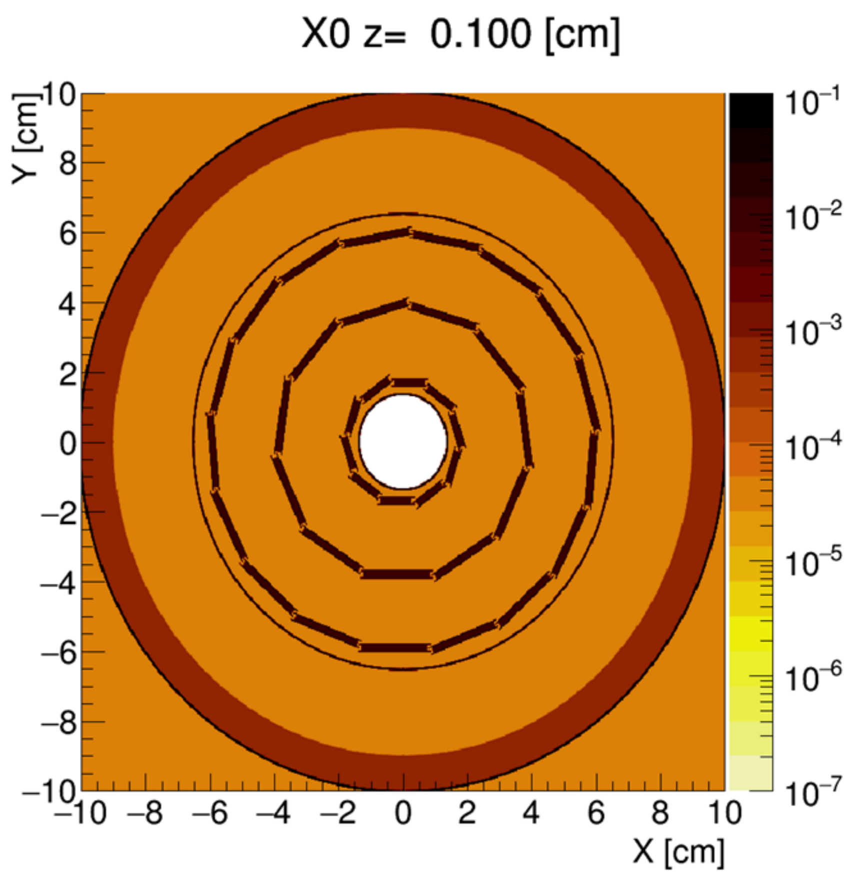
- Auguste Besson (electronics + dimensions + CMOS)
- M. V. (alignment + cooling + DEPFET)
- Akimasa Ishikawa (FPCCD)

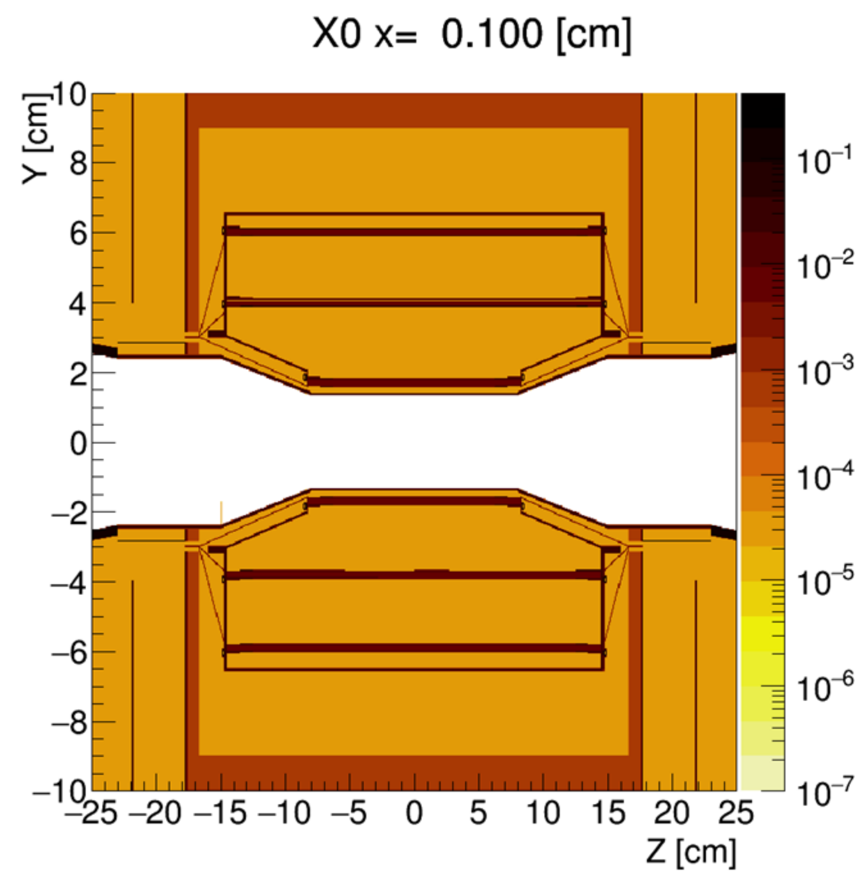
Most sections have text, but none are final.

Interface document: references

Reference Documents (RD)			
RD	**Title**	**Reference**	**Version**
VXD	A.Besson **The ILC Vertex Detector requirements**, Proceedings, to be published in Proceedings of Science ; The 25th International workshop on vertex detectors, September 26-30, 2016, La Biodola, Isola d´Elba, Italy.		
PLUME ladders	**Ultra-light ladders for linear collider vertex detector**, NUCLEAR INSTRUMENTS AND METHODS IN PHYSICS RESEARCH A 650 (2011) 208-212		
CMOS	*A. Besson, A. Pérez Pérez, E. Spiriti, J. Baudot, G. Claus, M. Goffe, M. Winter*. **From vertex detectors to inner trackers with CMOS pixel sensors** Nucl.Instr.Meht A 845 (2017) 33-37		
DEPFET	*O. Alonso et al., the DEPFET Collaboration*, **DEPFET active pixel detectors for a future linear e^+e^- collider**, IEEE Trans. Nucl. Sci. **60**, 1457 (2013), doi:10.1109/TNS.2013.2245680 [arXiv:1212.2160 [physics.ins-det]].		
DEPFET ancillary electronics	*M. Lemarenko, T. Hemperek, H. Krüger, M. Koch, F. Lütticke, C. Marinas and N. Wermes*, **Test results of the data handling processor for the DEPFET pixel vertex detector**, JINST 8, C01032 (2013). doi:10.1088/1748-0221/8/01/C01032		
DEPFET power supplies	*S. Rummel, the DEPFET Collaboration*, The power supply system for the DEPFET pixel detector at BELLE II, Nucl. Instrum. Meth. **A 699**, 51 (2013). doi:10.1016/j.nima.2012.04.041		
DEPFET cooling (Belle II)	*P. Ruiz-Valls et al., the DEPFET Collaboration*, **The ultra low mass cooling system of the Belle II DEPFET detector**, Nucl. Instrum. Meth. **A 731**, 280 (2013). doi:10.1016/j.nima.2013.03.054		
DEPFET thermo-mechanical	*H. Ye et al., the DEPFET Collaboration*, **Thermal mock-up studies of the DEPFET pixel vertex detector for Belle II**, arXiv:1607.00663 [physics.ins-det].		
Micro-channel cooling	*L. Andricek et al.*, **Integrated cooling channels in position-sensitive silicon detectors**, JINST **11**, no. 06, P06018 (2016), doi:10.1088/1748-0221/11/06/P06018,		

Interface document: figures





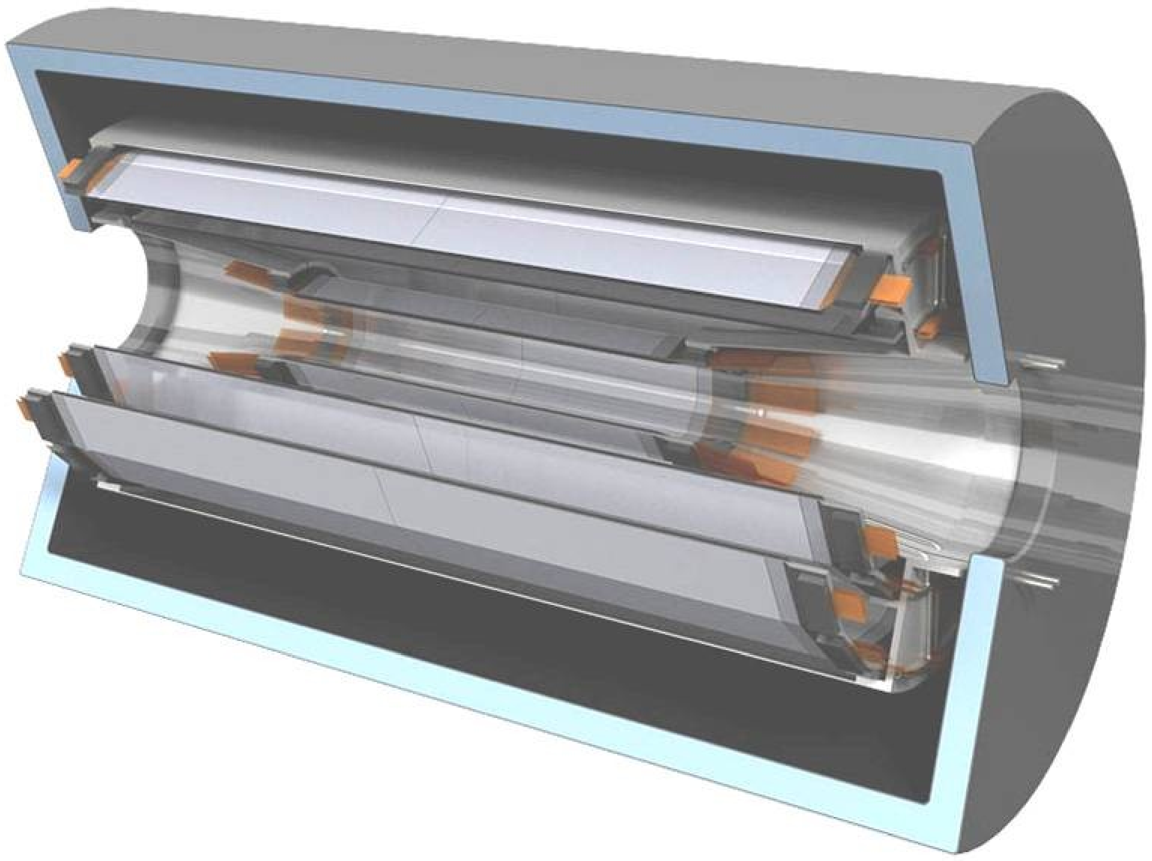
A few figures and tables indicating (critical) dimensions are included in the interface document

Detailed, realistic design, VXD

Vertex detector design still very “generic”

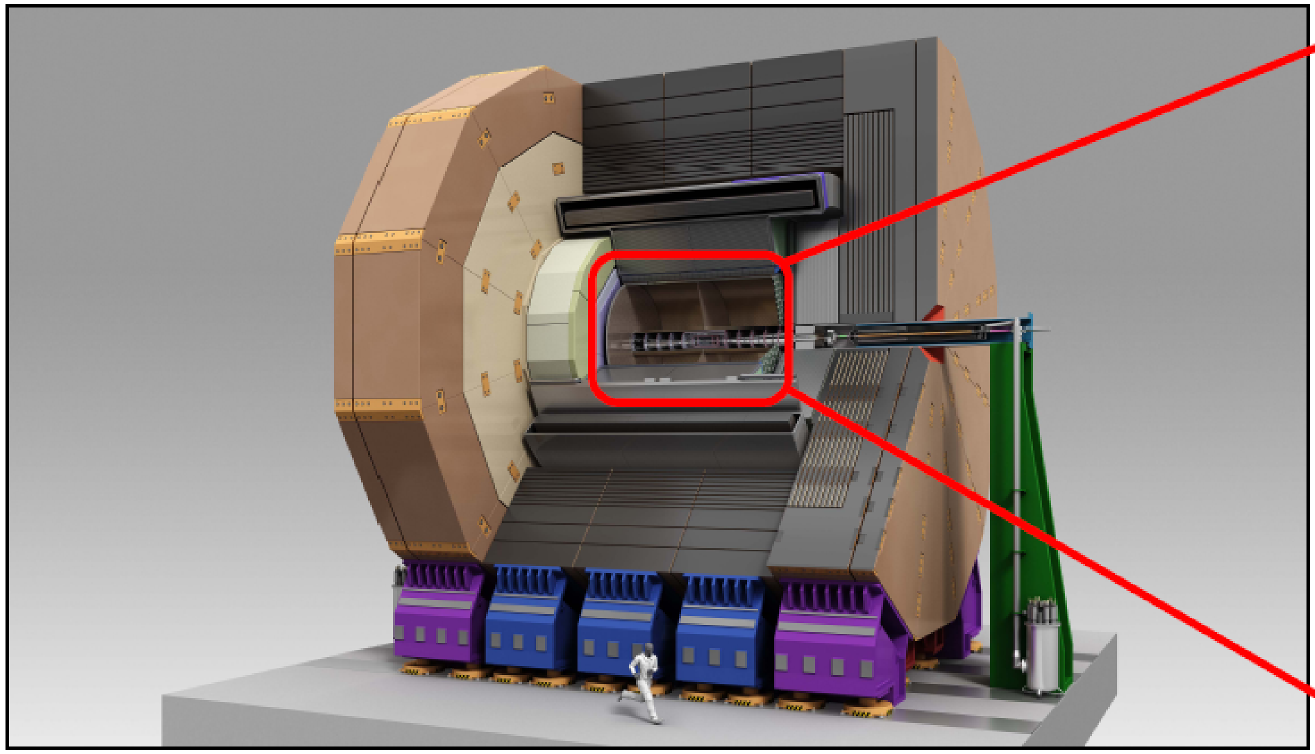
Estimate technology-dependent performance

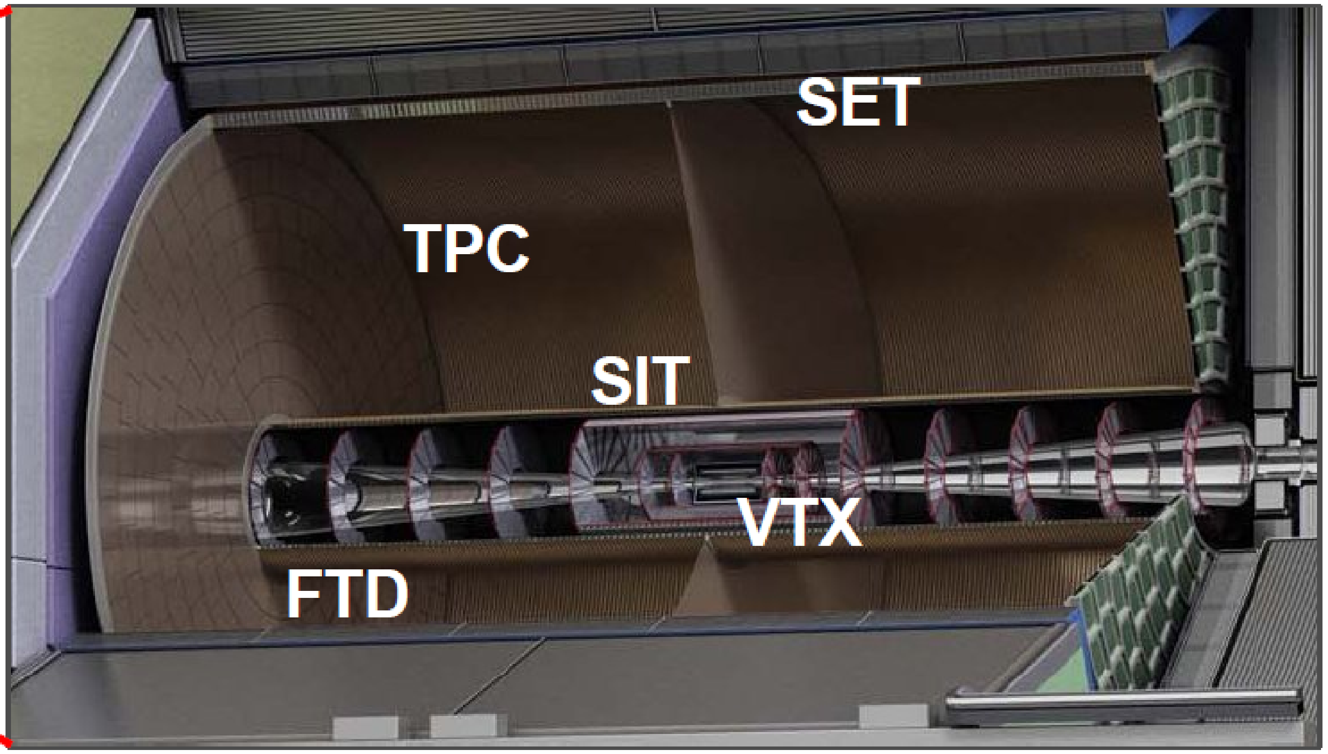
- detailed DEPFET/FPCCD/MAPs digitizers
  - Software exists, needs some effort
- realistic support structures
  - Double vs. Single layer
  - Refine as mock-ups evolve
- realistic end-of-ladder material for CLIC
  - M.A. Villarejo (now IFIC)
- realistic routing of services



Person-power: ?

ILD inner tracker engineering design





Sub-systems

Beam pipe

Vertex Detector

Silicon Intermediate Tracker

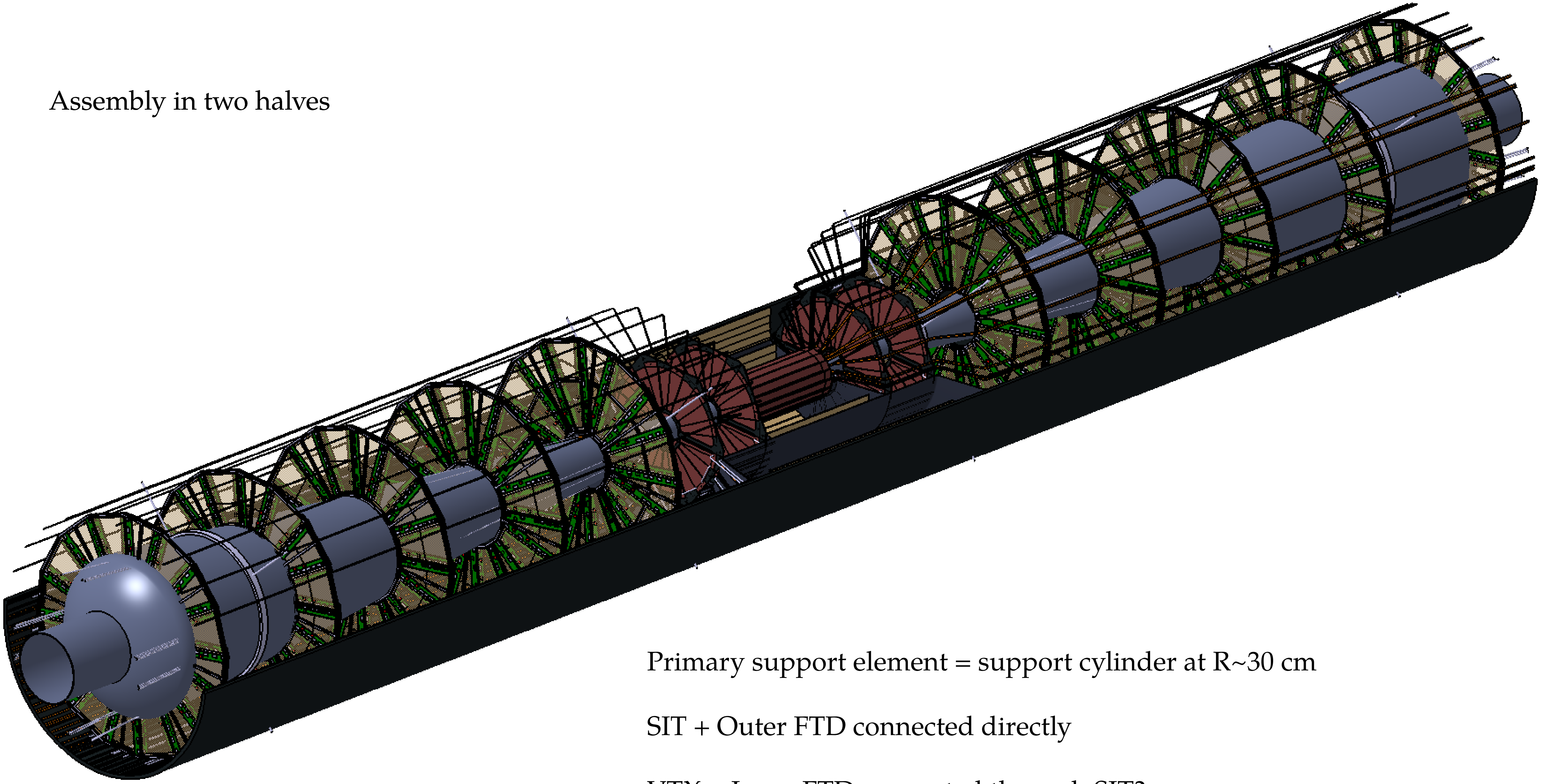
Forward Tracking Disks

Requires an integrated design of support and services

DEPFET Active Pixel Detector

Mechanics + integration

Assembly in two halves



Primary support element = support cylinder at R~30 cm

SIT + Outer FTD connected directly

VTX + Inner FTD connected through SIT?

Beam pipe connected too (where?)

ILD vertex detector alignment

Positioning and alignment constraints

Marcel

The alignment of the vertex detector is critical to achieve the challenging requirements for the precision of the position measurements. The specifications on impact parameters resolution of the vertex detector require a spatial resolution of approximately 3 μm. Some solutions can achieve even better resolution. This leads to a requirement that the position of the vertex detector elements must be known to approximately 1 μm.

The alignment of the vertex detector will be determined using track-based techniques. A relatively modest data sample is sufficient to determine the six alignment parameters of the vertex detector as a whole. The internal alignment of the detector forms a hierarchy : double layers, ladders and sensors each have six degrees of freedom. Determination of all parameters at the lowest level of the alignment hierarchy represents a much more complex problem. Determination of all individual degrees of freedom requires a very large data set. The internal alignment at the lowest level of the hierarchy (i.e. individual sensors) can only be repeated on the time scale of weeks or months. Distortion of these internal degrees of freedom on shorter time scales must be avoided.

Monitoring of the alignment with hardware systems is complementary to the track-based alignment. Hardware systems can be useful to provide information on time scales inaccessible to track-based alignment and can monitor distortions that are not easily spotted with the track-based alignments (so-called weak modes that leave the residuals unchanged). Previous experiments have used laser alignment systems (AMS, CMS) and frequency scanning interferometry (ATLAS). Strain measurements using Bragg optical fibers can provide an interesting addition.

While the position of all detector elements must be known to the 1 μm level, the actual position of the vertex detector at the time of installation and during operation is much less constrained. To avoid clashes between adjacent detector elements, a positioning tolerance of 100 μm is typically sufficient. Movements during operation of the same order are readily corrected, as long as the distortions act on relatively long time scale and affect the highest-level structure of the detector (i.e. the detector must move as one rigid entity). Experience from previous experiments shows that these requirements are met by modern silicon-based detector systems, at least to the at the level of 5-10 μm required by these detectors. A detailed mock-up of the vertex detector in realistic conditions is needed to demonstrate that a much lighter detector can robustly maintain its internal alignment to the 1 μm.

Forces acting on the vertex detector, from its own cables and services, from the beam pipe, transmitted by the service cylinder…. The system must be designed in such a way that the vertex detector will move under such forces, but that its internal structure will not be distorted.

Questions to overall ILD design and/or the machine interface:
How stable is the beam pipe?
How is it supported in the vicinity of the vertex detector?
How will it deform in response to the passage of the beam?
What beam pipe currents are induced in each bunch train?

Cooling, liquid requirements

Air cooling remains the baseline

- Present detailed numbers on gas flow rate
- Control of inner tracker gas conditions
  (temperature stability to 1 degree C, humidity well below dew point)

MCC cooling may be an interesting alternative

FPCCD requires CO2 cooling + cryostat

Cryostat and Liquid CO_2 (and gas N_2) cooling system

Should be cool down to -40degree

Inter-train readout Larger power consumption than CMOS/DEPFET

About 50W inside the cryostat, about 200W junction box

FPCCD 10mW/channel (heating is larger for readout side)

ASIC 5mW/channel

ASIC and FPCCD readout side can be directly cooled down via CFRP for doublet ladder

CO_2 : 1g/sec per side (note. cooling power 300J/g)

1 x 2mm cable per side in total 2 cables

CO2 cable is attached to endcap and cool down the air inside

N_2 : 6litter/min (or less)

If air flow is further needed to cool down the FPCCD for not-readout side, N_2 cooled down by CO_2 is flowed to cryostat.

outer wall : 0.2mm^t CFRP + 1cm^t Styrofoam + 0.2mm

Inner wall : similar one but styrofoam thinner

Conclusions

Vertex detector R&D is progressing mostly outside the LC, but with clear benefits for ILD

The integration document is being filled
(primary responsibles: Auguste Besson, Akimasa Ishikawa, Marcel Vos)

Expect:
- detailed descriptions of technologies, ladder design
- discussion of alignment & testing requirements & strategy
- less detail on inner tracker integration
  (unless progress is made on global issues)
- very little on technology-dependent detail
  (cables, connectors etc.)