The International Conference on Instrumentation for Colliding Beam Physics **(INSTR 2014)**

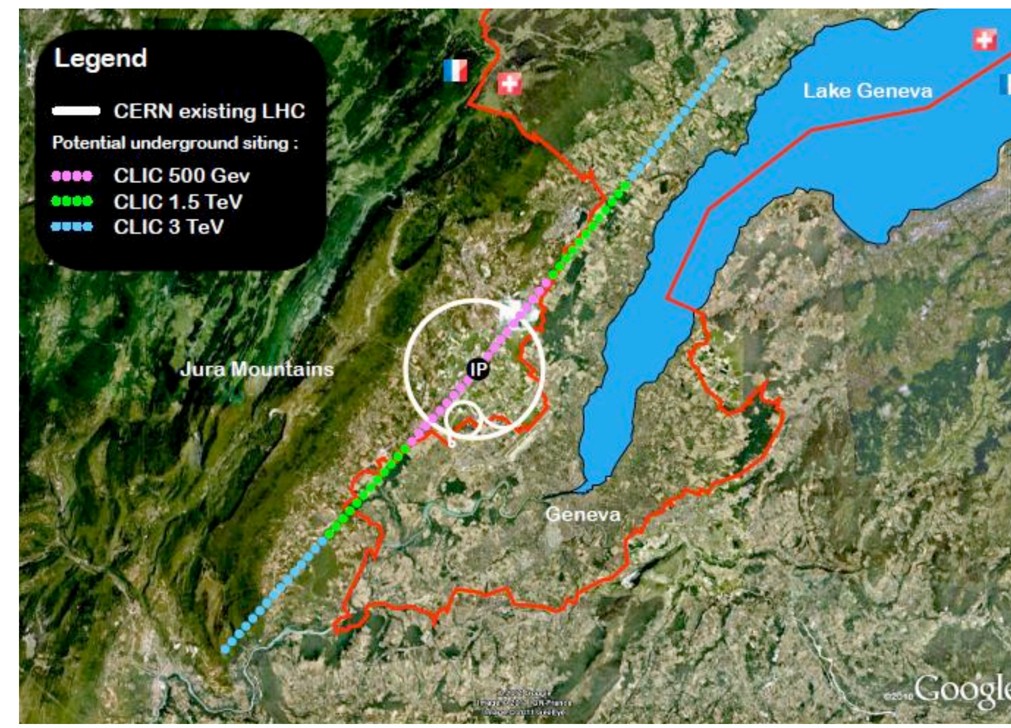
CLIC Vertex Detector R&D

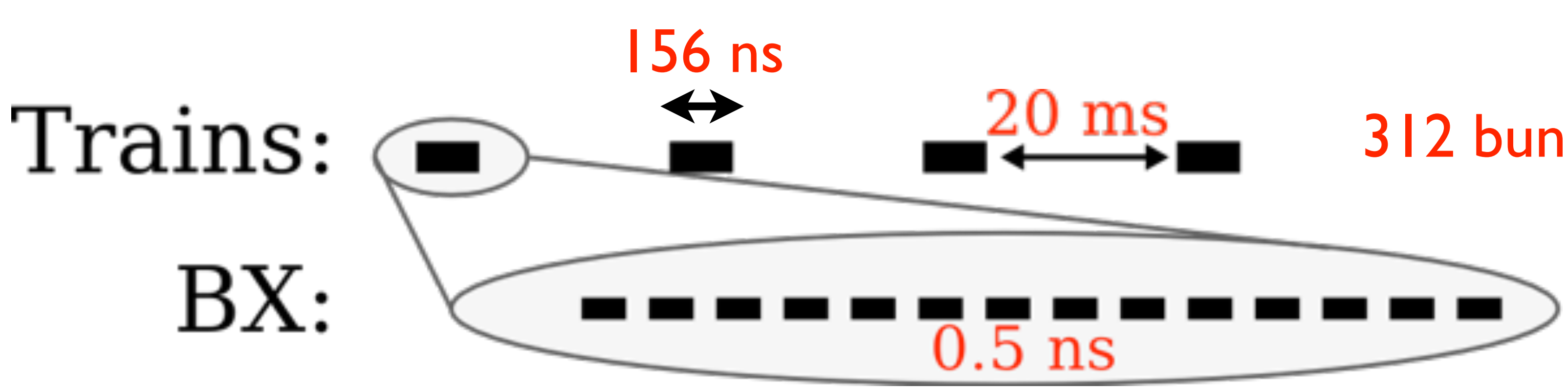
Sophie Redford

on behalf of the CLIC Detector and Physics Collaboration

CLIC - a collider for the future

- Linear electron-positron collider
- $\sqrt{s}$ = 3 TeV (staged construction)
- High luminosity: 10^{34} $cm^{-2}s^{-1}$
- Small bunch size: σ_{xyz}(40 nm, 1 nm, 44 μm)
- Beam structure:

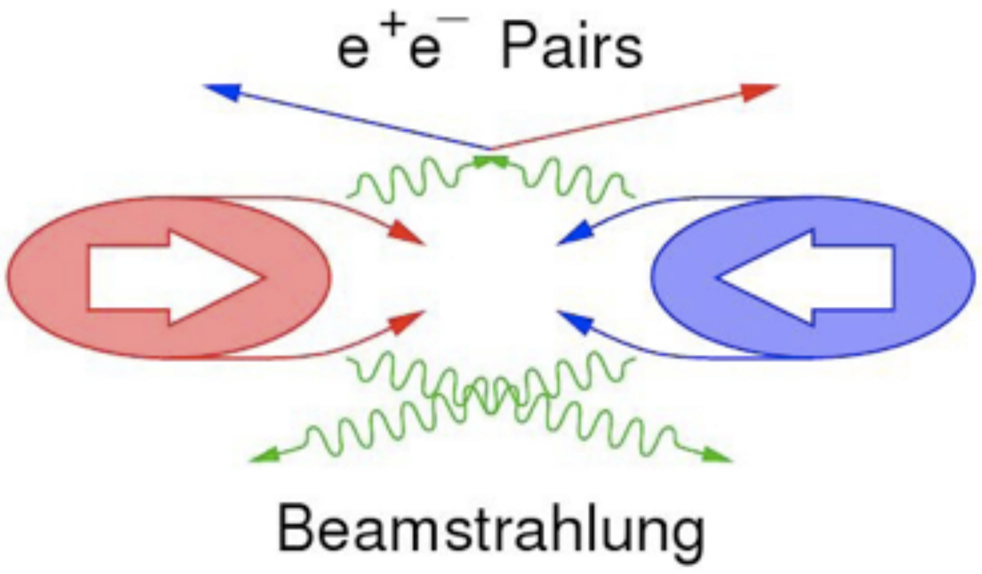


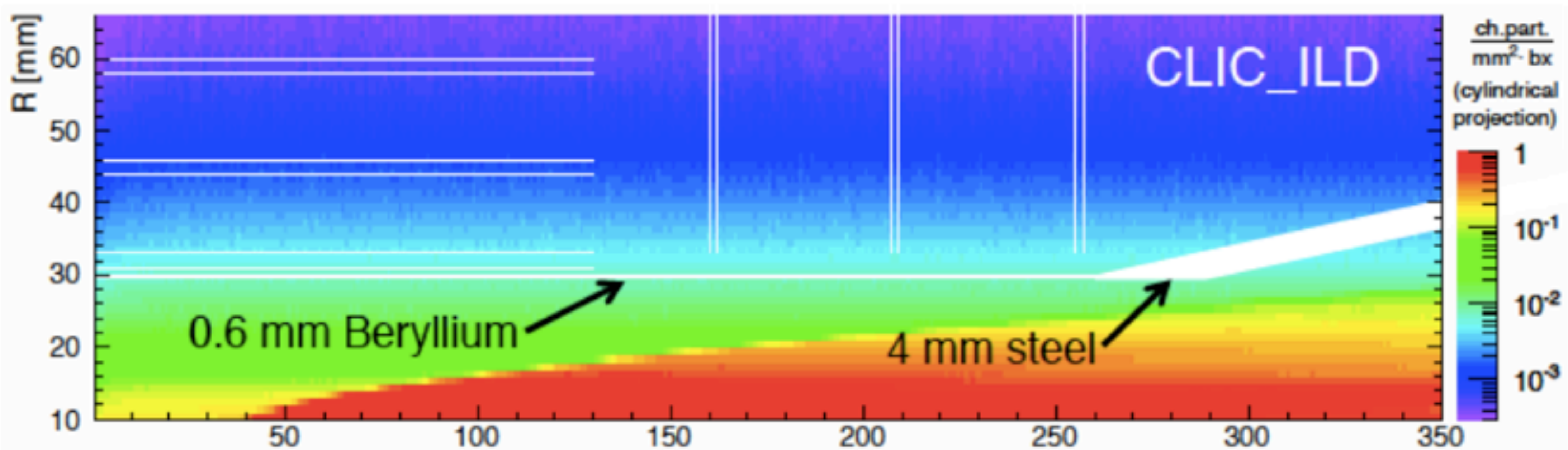


312 bunches per train

Detector environment

- Beamstrahlung creates high particle rate 'beam induced backgrounds'
  - most at low angle, low p_T, constrained by B field
- Inner radius of vertex detector restricted by particle density



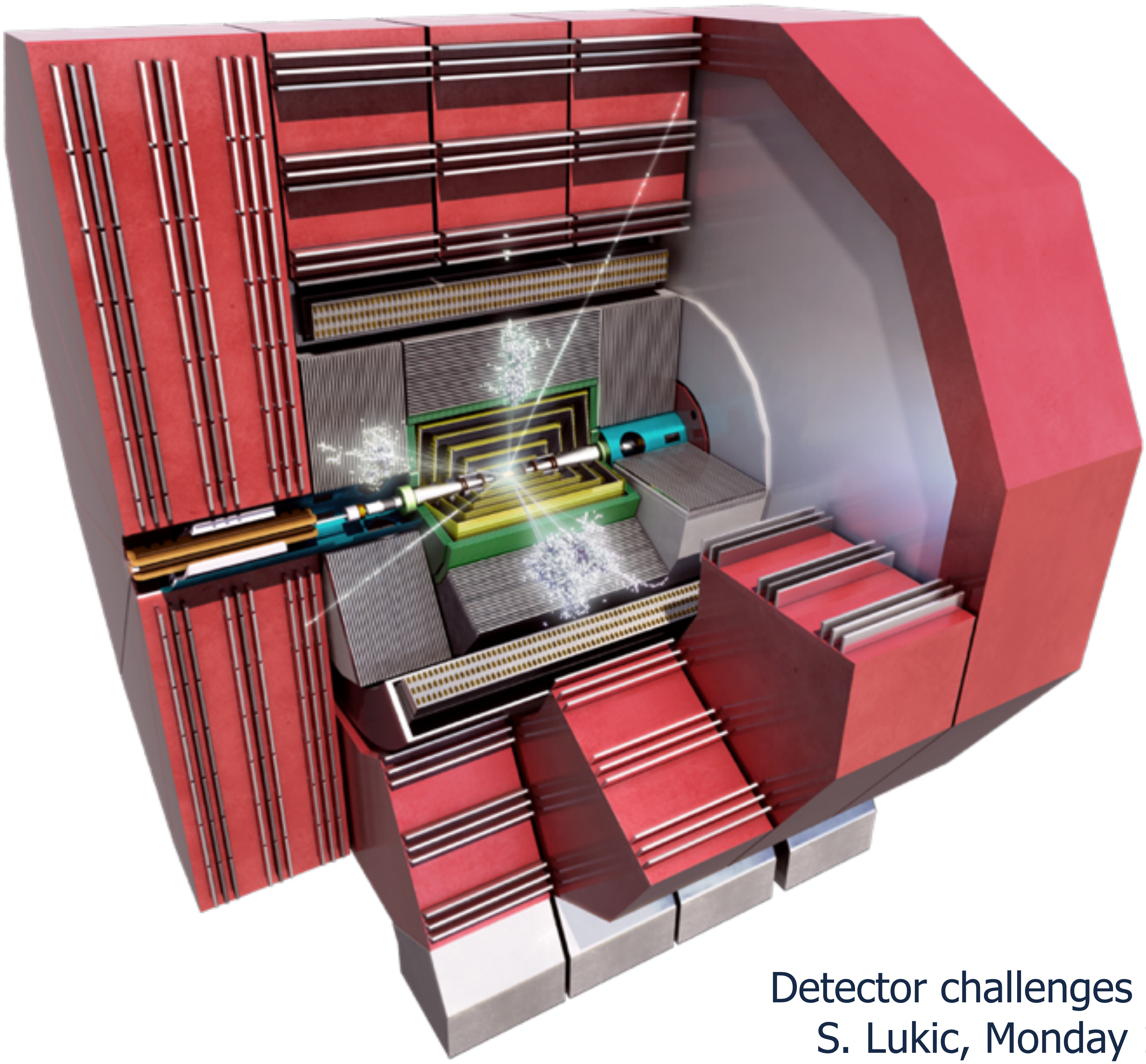


R_{min} = 27 mm CLIC_SiD
R_{min} = 31 mm CLIC_ILD

Maximum occupancy including safety factor 5:
1.9% per pixel in the barrel layers
2.9% per pixel in the forward layers

z (mm)

The CLIC detector



Precision physics in a challenging environment: broad programme of R&D

Highly granular particle flow calorimetry, using tungsten absorber

5.5 m diameter cryostat for superconducting solenoid, B field 4-5 T

Instrumented steel return yoke

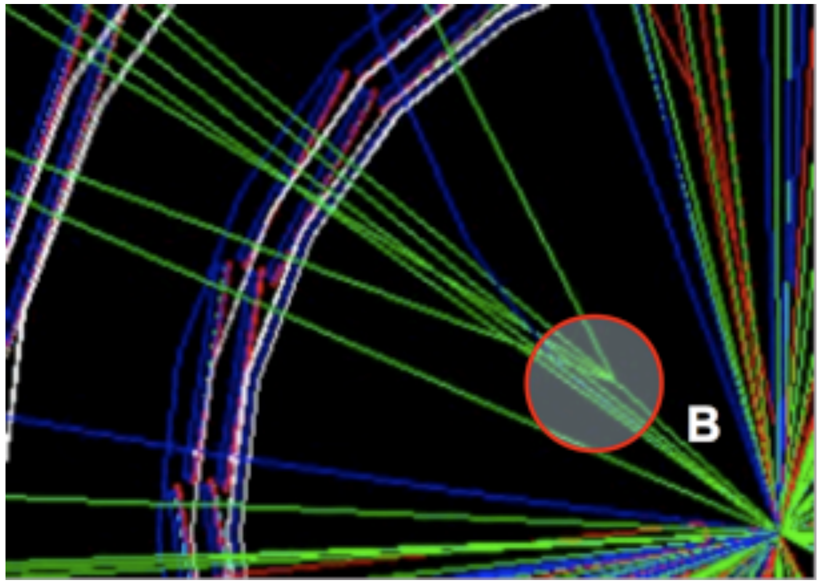
Complex forward region

Detector challenges at CLIC,
S. Lukic, Monday 17:00

Vertex detector requirements

Goal

Efficient tagging of heavy quarks through a precise determination of displaced vertices

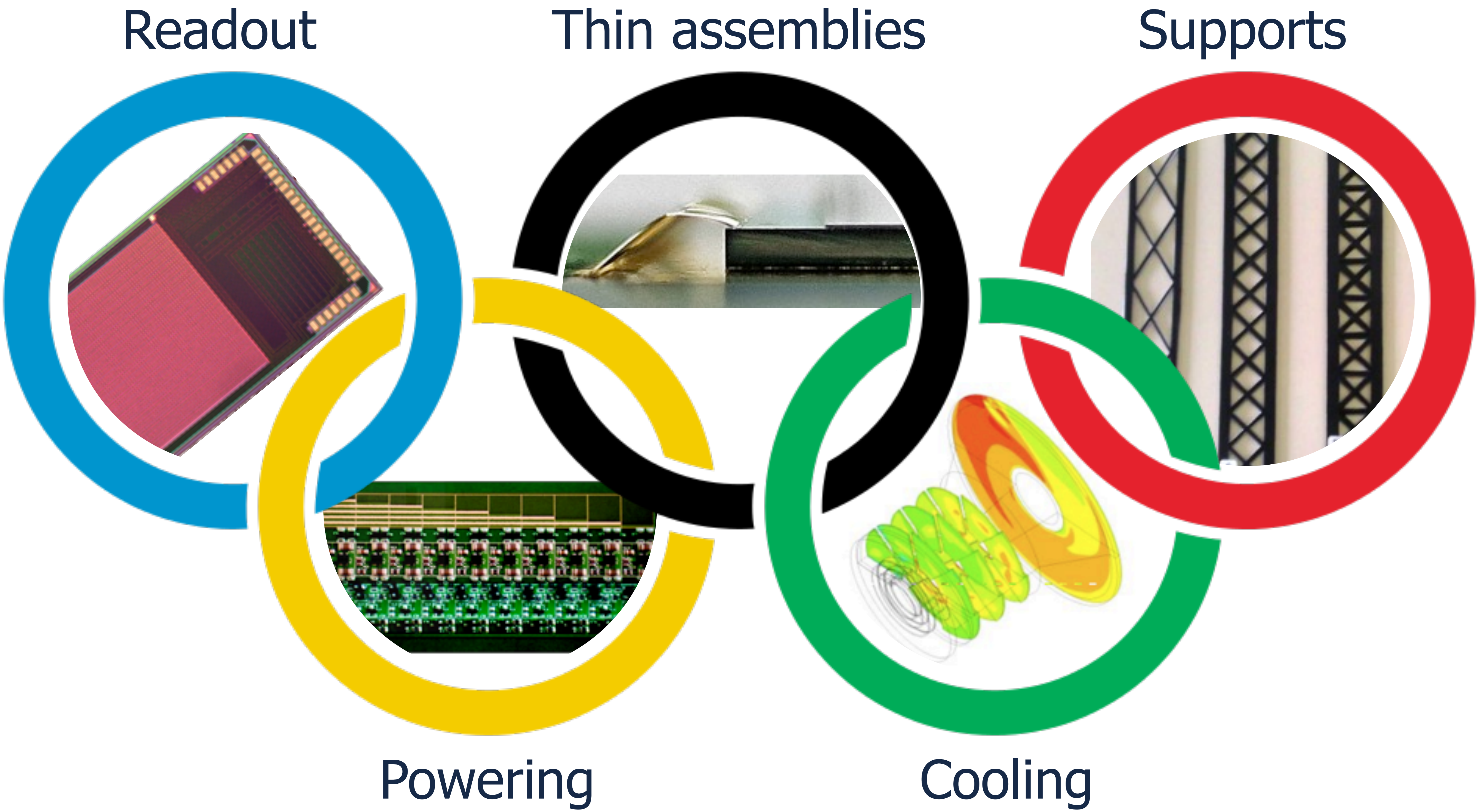


Multi-layer barrel and endcap pixel detectors

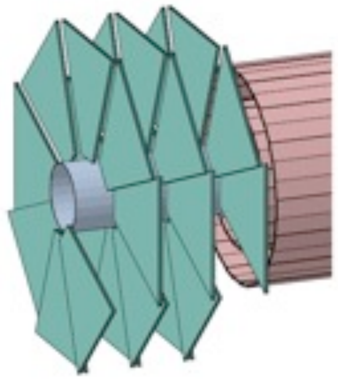
- 560 mm in length
- Barrel radius from 30 mm to 60 mm

- Single point resolution of 3 µm
- Material budget of < 0.2% of a radiation length per layer
- No active cooling elements - use forced air flow cooling
- Limit the power dissipation to 50 mW/cm^2 in sensor area
- Hit time slicing of 10 ns

Olympic programme of R&D

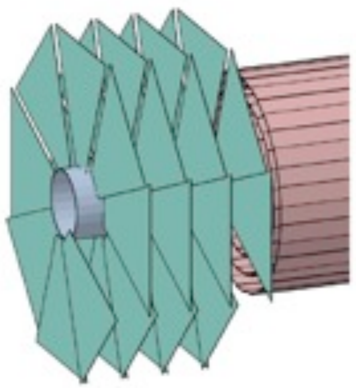


Geometry optimisation studies



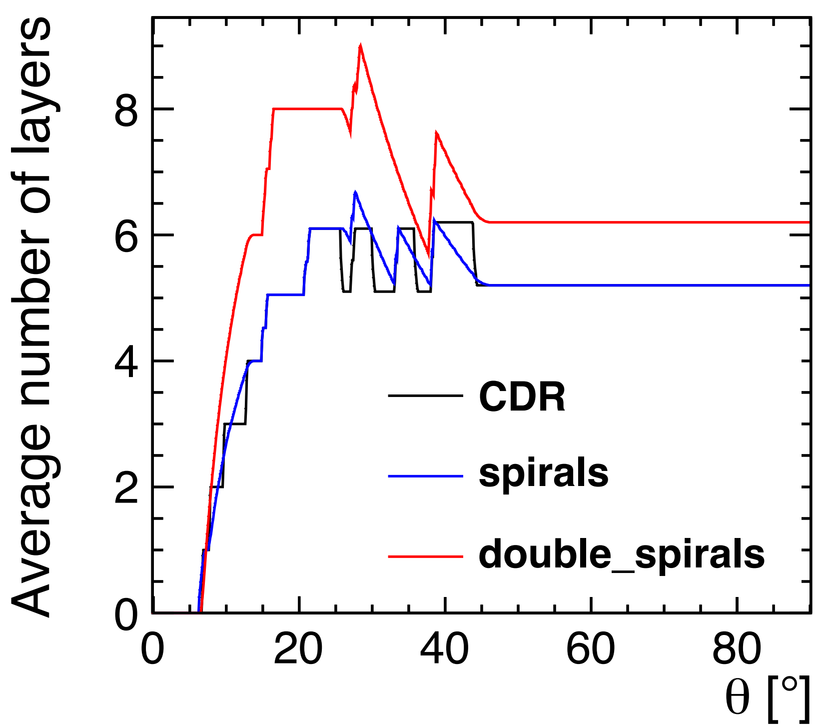
Double-sided layers

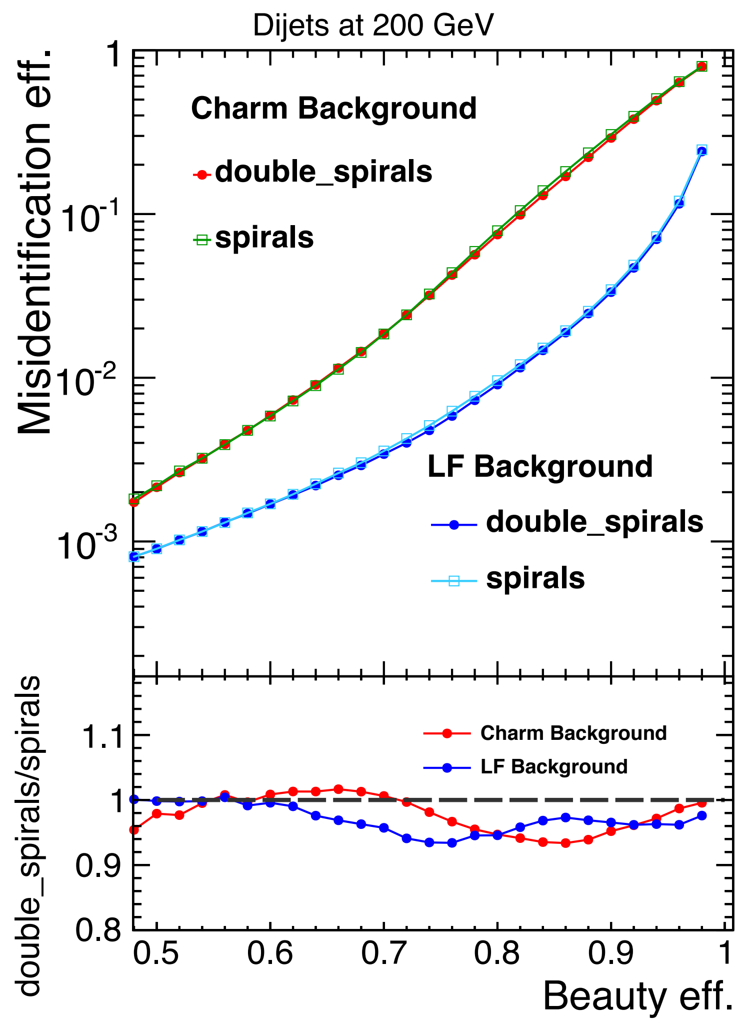
Comparison of 5 single-sided layers and 3 double-sided layers

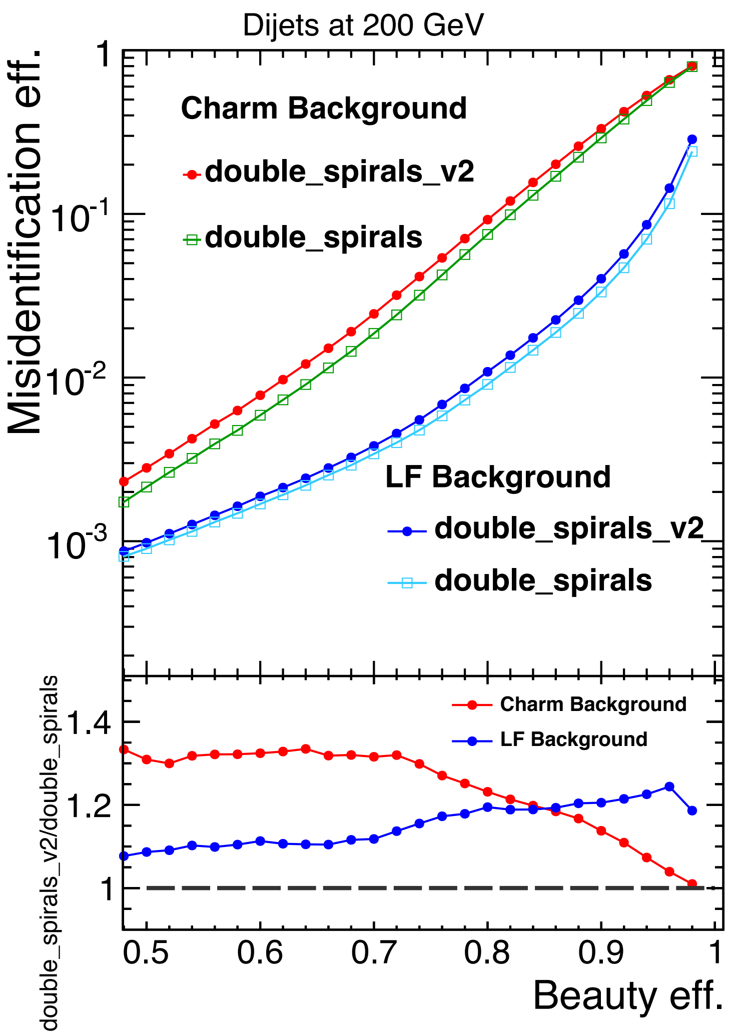


Single-sided layers

- Similar flavour tag performance for two considered layouts
- Increasing the material has a larger impact than the layout

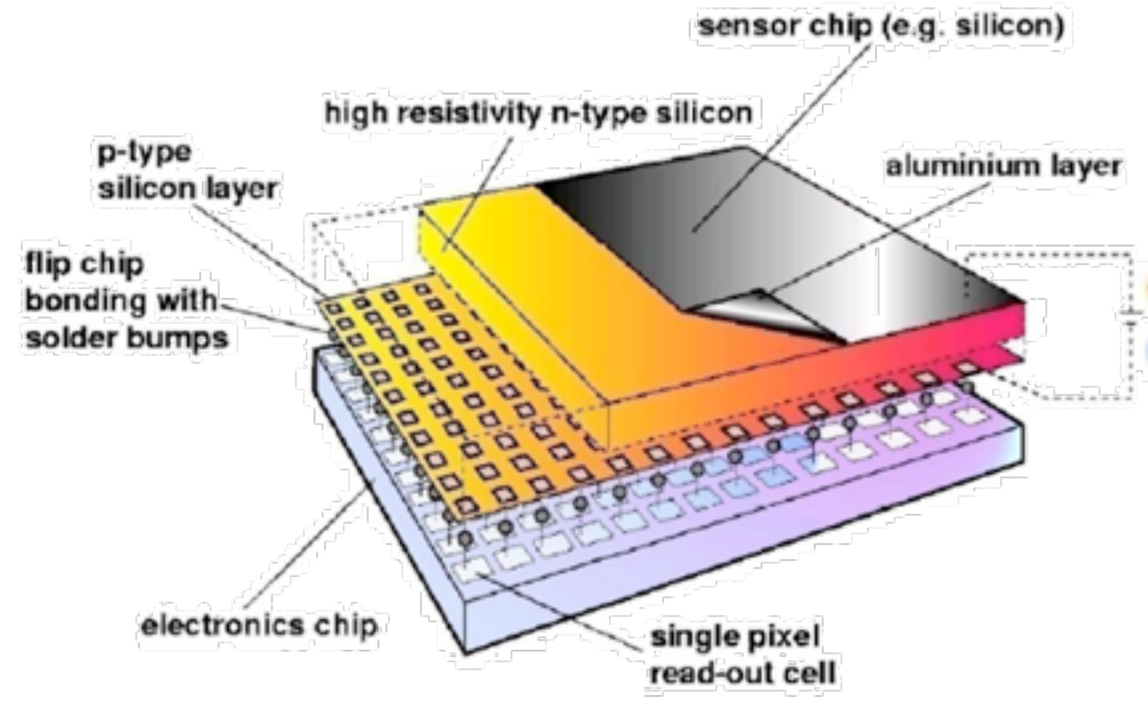


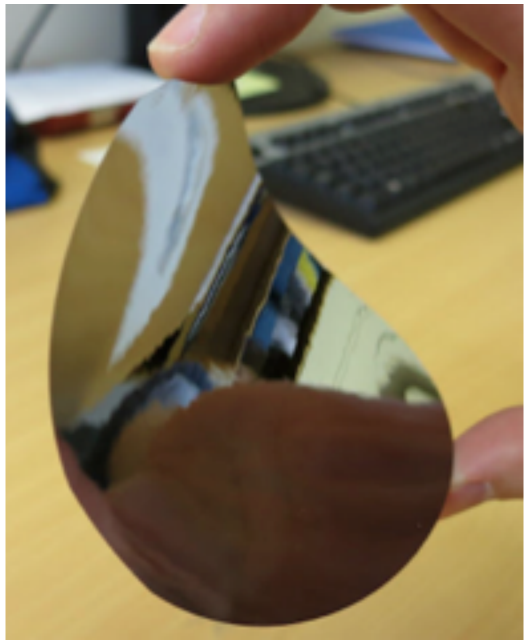




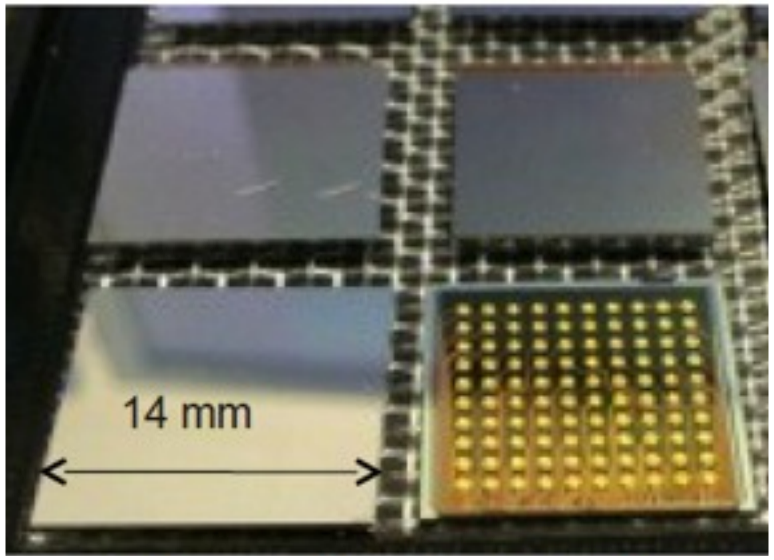
Thin sensor assemblies

- Hybrid planar pixel technology
- Ultimate goal: 50 µm sensor on 50 µm ASIC
- 25 µm pitch
- Thin edge sensors using Through-Silicon-Vias





50 µm thick silicon wafer



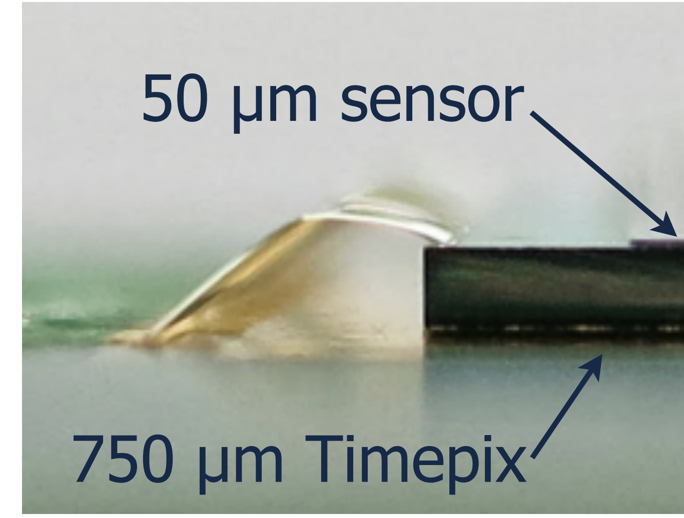
- 60 µm hole diameter
- Wafer thinned to 120 µm
- 5 µm copper layer for TSV

TSVs:

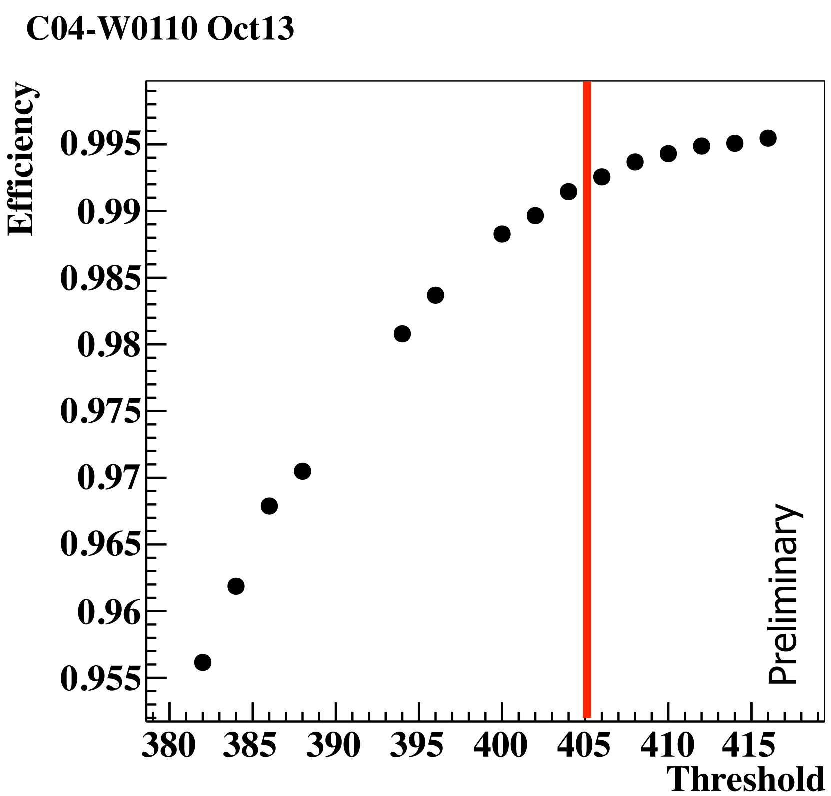
- Vertical electrical connection - no wire bonds
- Sensors buttable on all sides - better tiling

First Medipix3 Image using TSV

Testbeam analysis

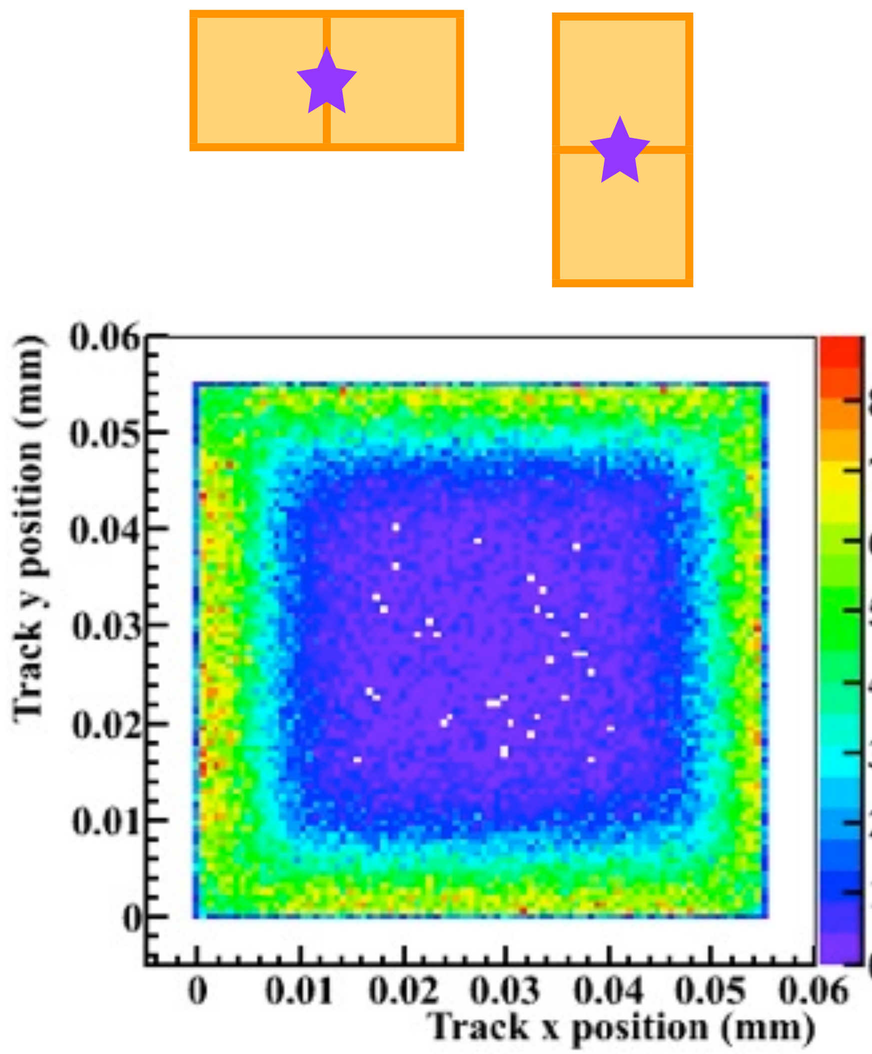


- Thin sensors (50 - 300 μm) bonded to normal Timepix chips
- One 100-on-100 μm assembly
- Data recorded at DESY: 5.6 GeV electron beam

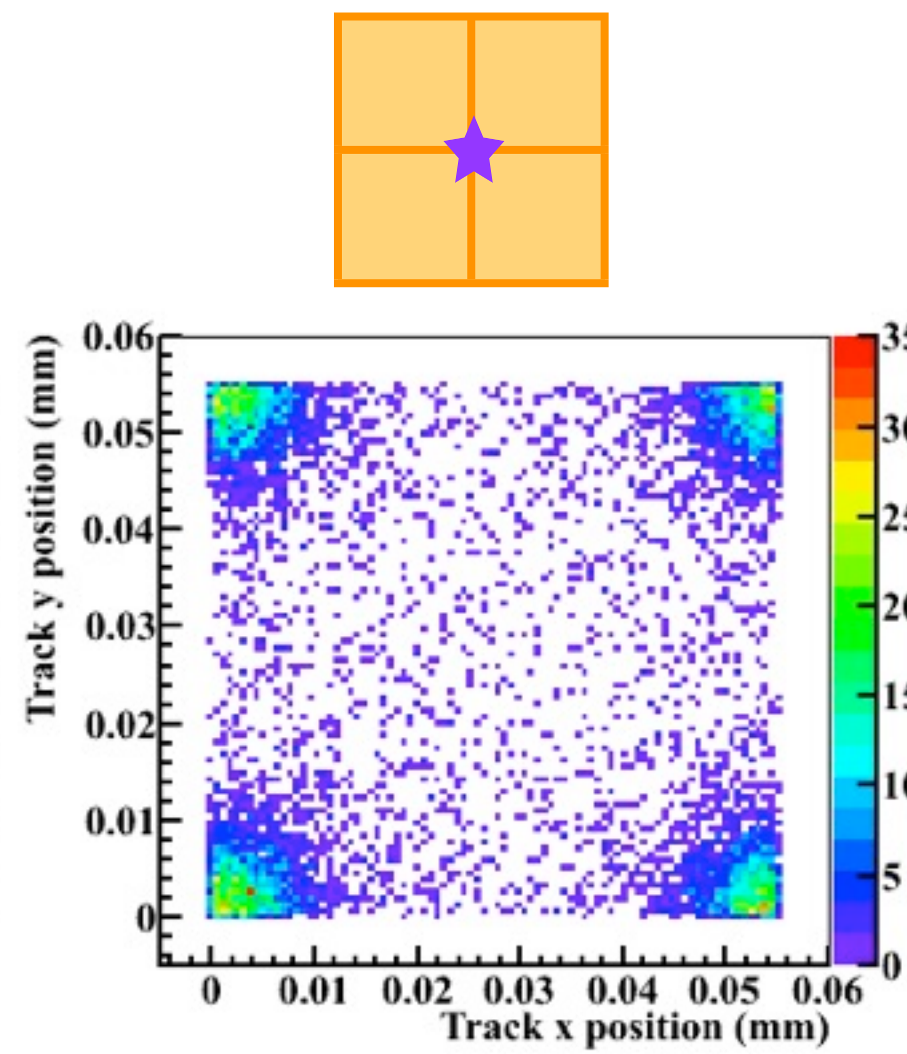


50 μm thick sensor
Efficiency 99.2% at
operating threshold

Track position: cluster size 2



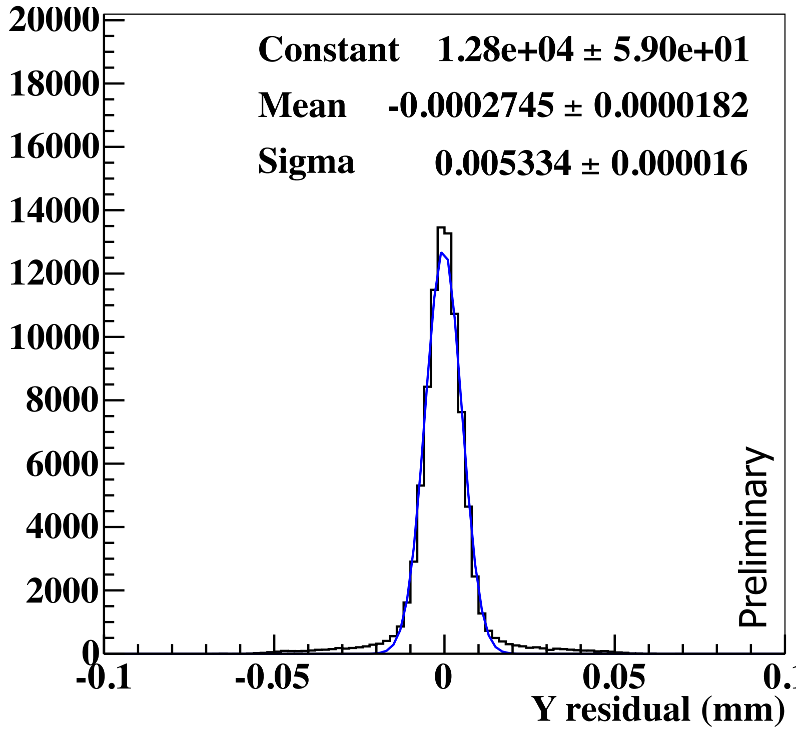
Track position: cluster size 4



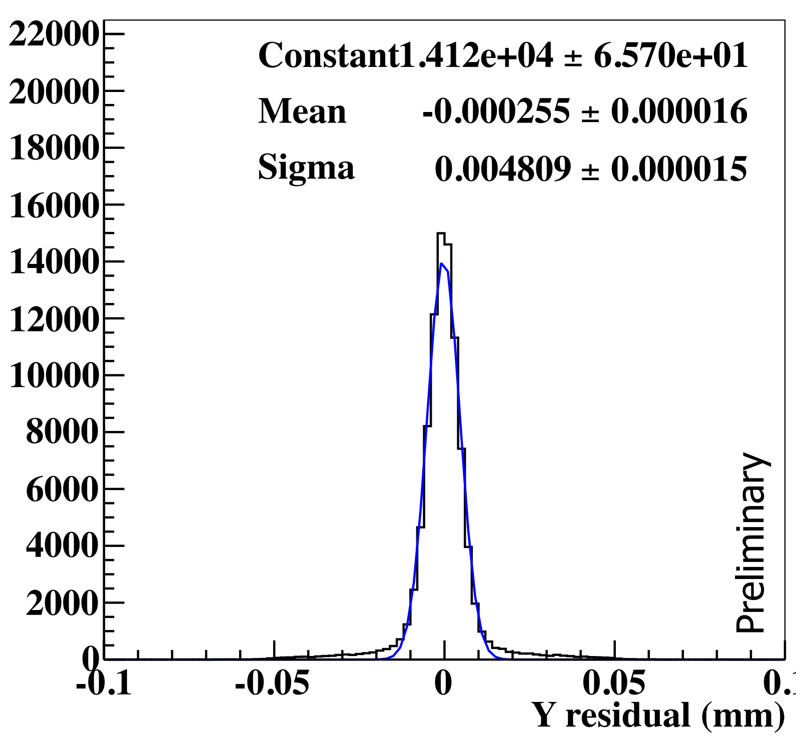
100 μm thick sensor - low charge sharing

Two-hit cluster resolutions

Digital centroid

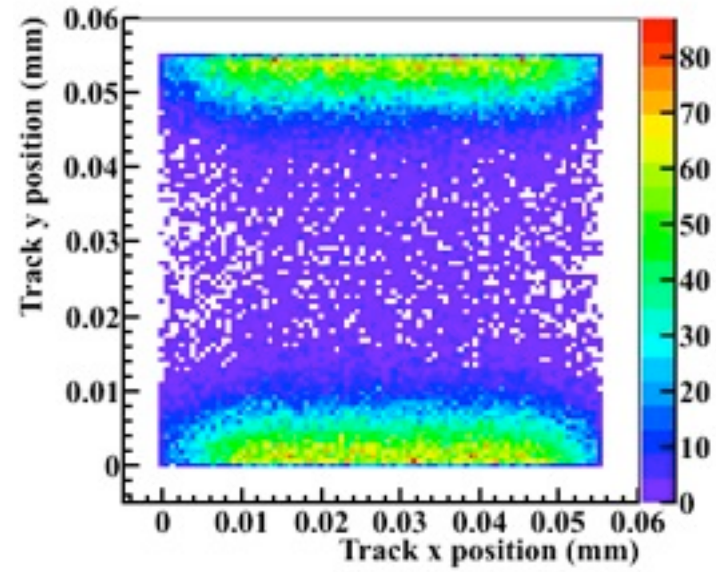


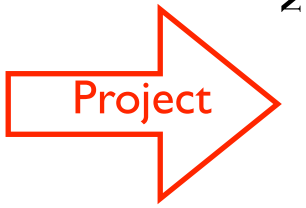
Charge weighting (eta corr.)

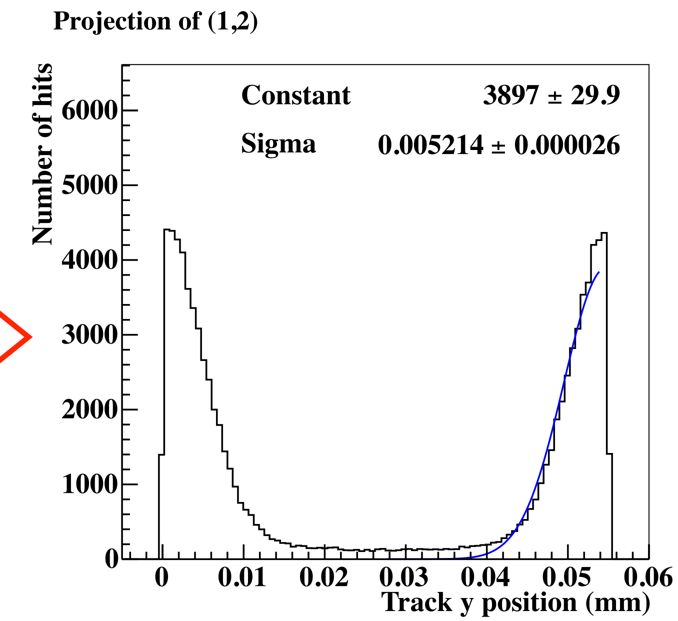


Resolutions include tracking resolution

- Tracking resolution of telescope ~3.5 µm
- Digital centroid method effective due to low charge sharing





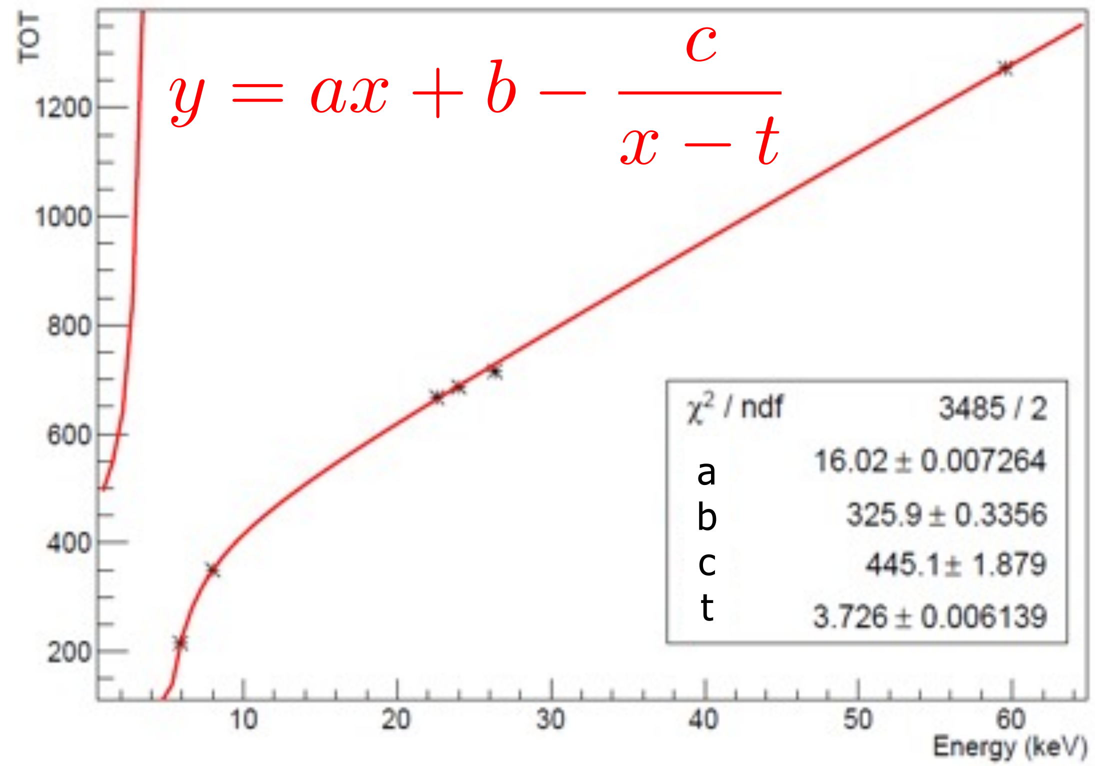


- Eta correction method of charge weighting best resolution: take into account non-linearities in charge sharing
- Unfolding the tracking resolution gives a single point hit resolution of 3.3 µm for 2 hit clusters

100 µm thick sensor

Sensor calibration

- Calibrate TOT values by measuring response to photons of known energy
- Accounts for non-linearities
- Calibration aligns Landau's and improves the resolution: 4.8 μm → 4.7 μm



^{241}Am 60 keV

^{241}Am 26.2 keV

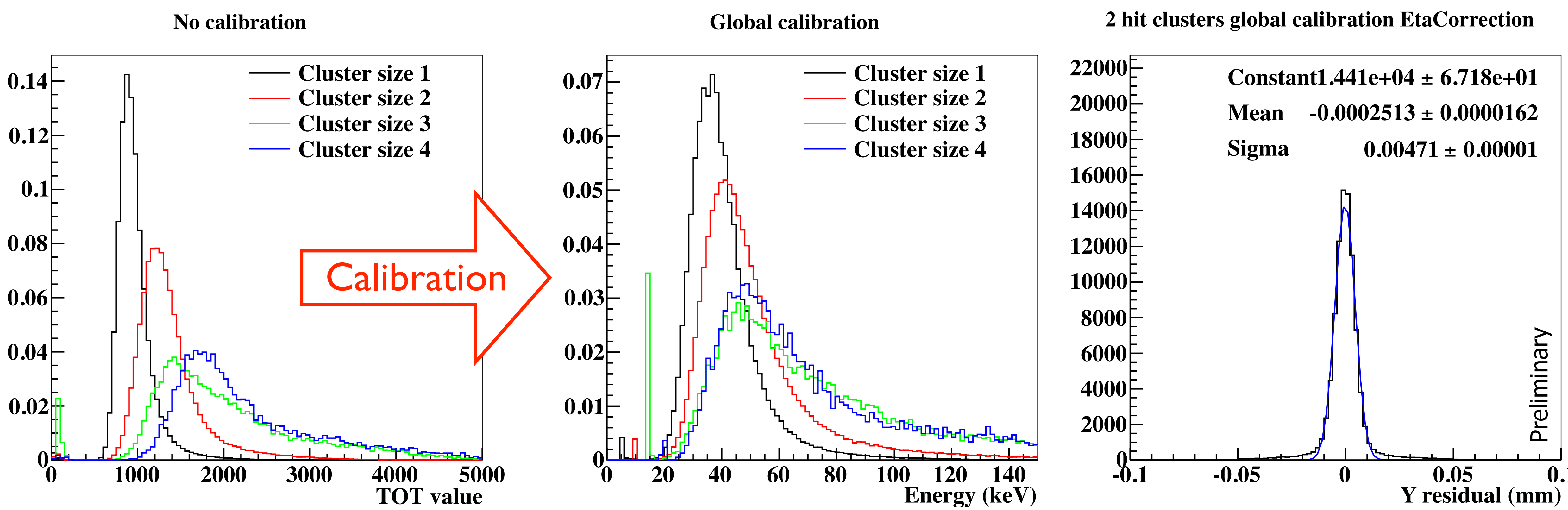
Indium 24 keV

^{09}Cd: 22.9 keV

Brass 8.1 keV

^{55}Fe: 5.8 keV

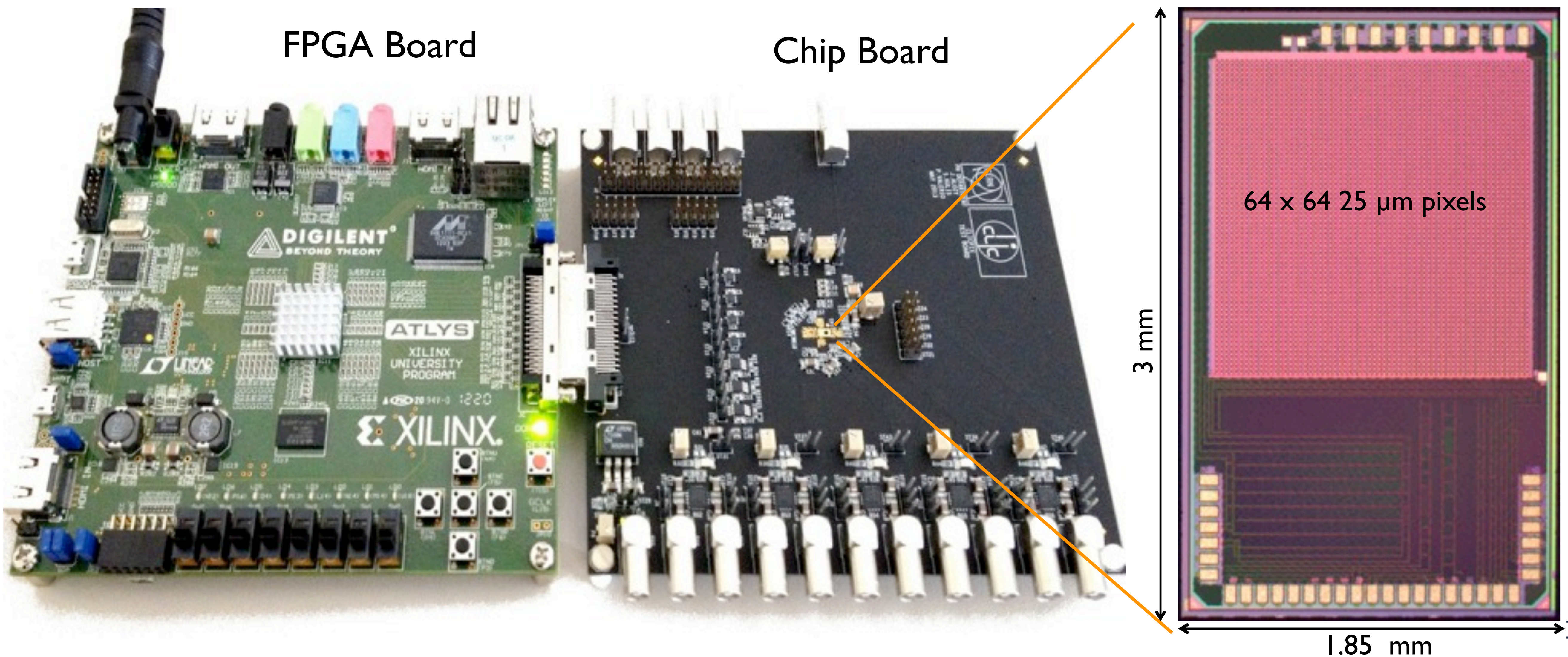
Sources and X-ray fluorescence



Resolutions include tracking resolution

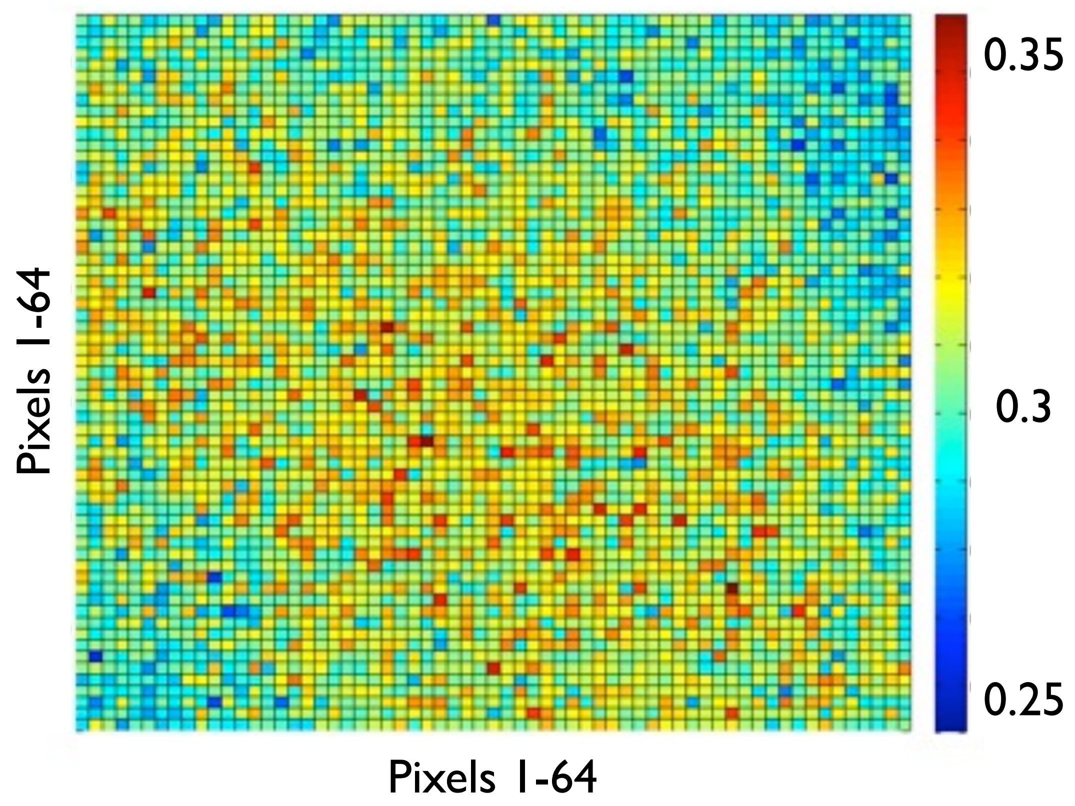
Readout ASIC: CLICpix

- The CLICpix ASIC: a fast, low power readout chip with 25 μm pitch
- Implemented in 65 nm CMOS technology
- 4-bit time and energy measurements for each pixel
- Supports power-pulsing and data compression

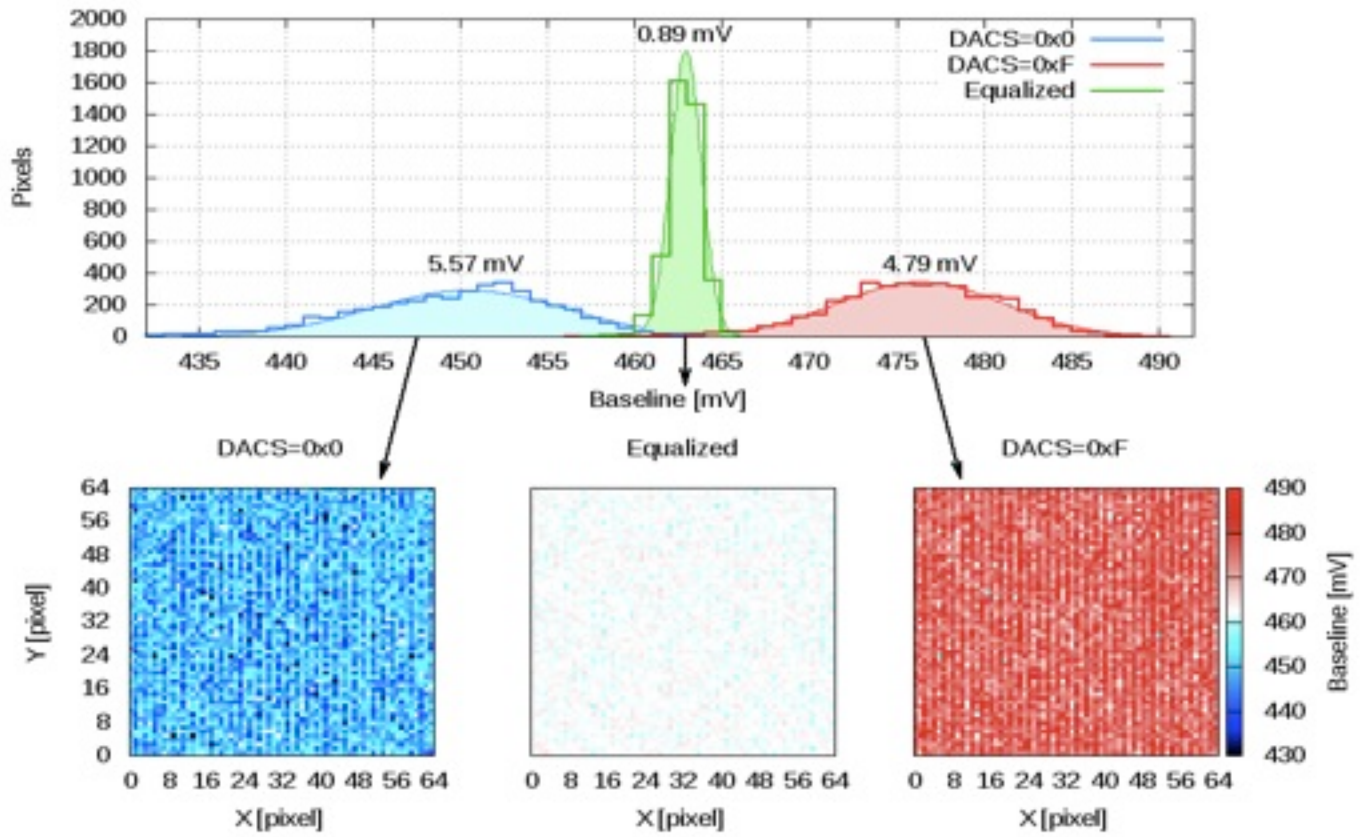


CLICpix characterisation

TOT gain distribution



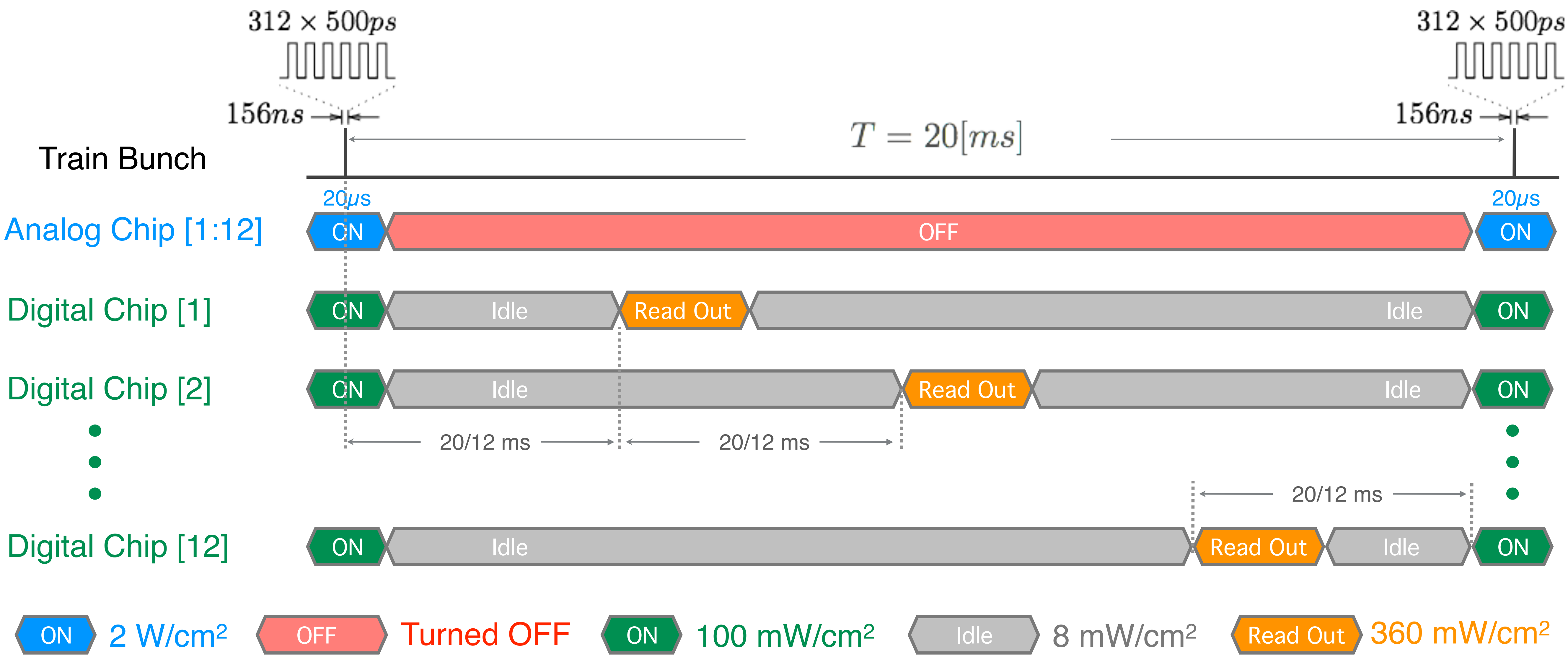
- Time Over Threshold gain distribution
- Uniform gain across the whole matrix
- Gain variation is 4.2% r.m.s. (for nominal feedback current)



- Matrix equilisation
- Calibrated spread is 0.89 mV (about 22 e^-) across the whole matrix
- (Expect a signal of ~thousands of electrons in 50 µm sensor)

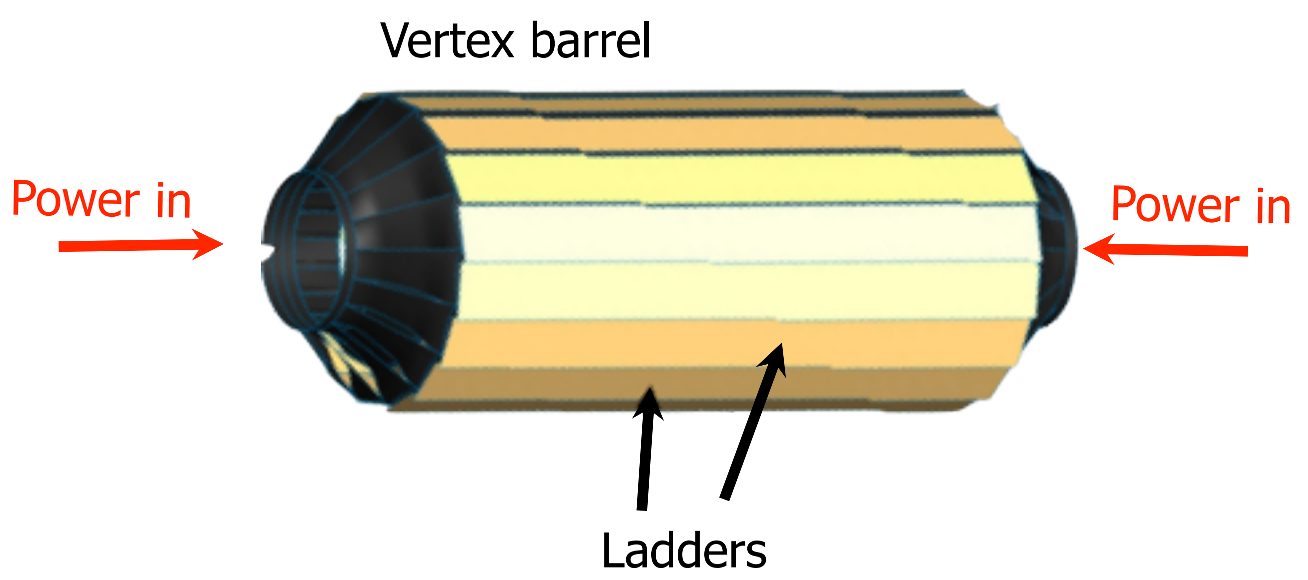
Power-pulsing strategy

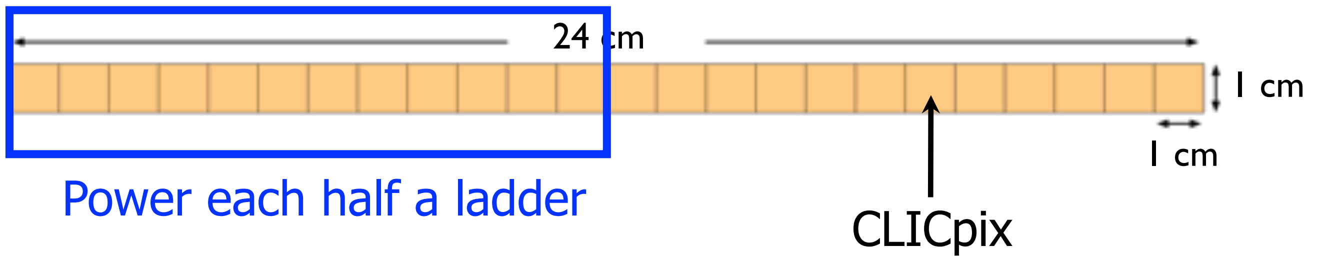
- Power pulse CLICpix ASIC to achieve dissipation <50 mW/cm^2 in the sensor area
- Analog electronics can be turned off: 2 W/cm^2 → 2 mW/cm^2
- Digital electronics in idle except during readout: 100 mW/cm^2 → 13 mW/cm^2

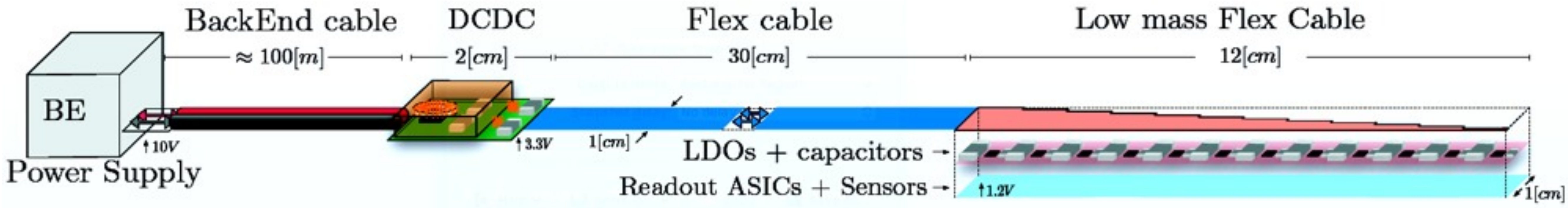


Power delivery

- Power ladders from each end of the barrel:
  - constant current sources, low dropout regulators, silicon capacitors



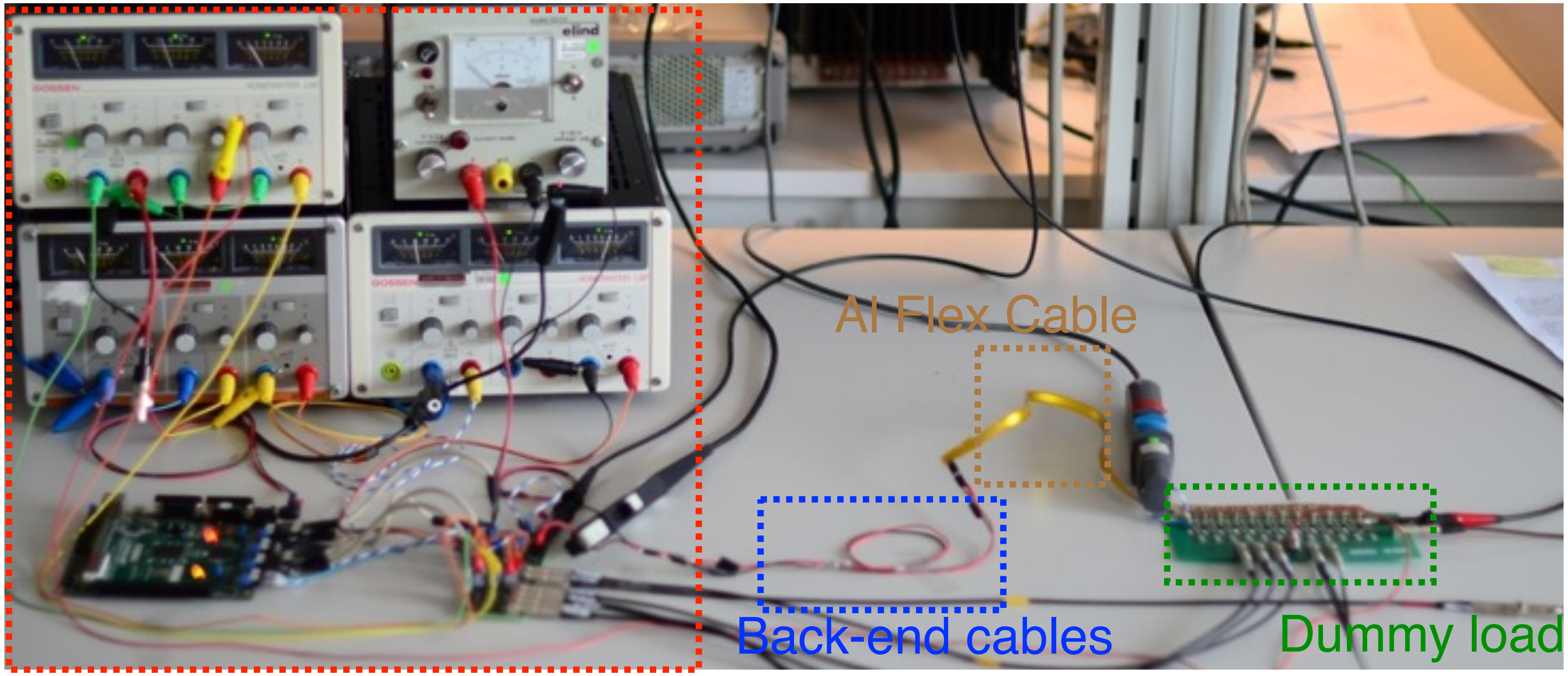




Material budget:

- Aluminium flex cables and silicon capacitors reduce material
- Powering adds 0.1% X_0 per layer. Projected: < 0.05% X_0

Power-pulsing lab tests



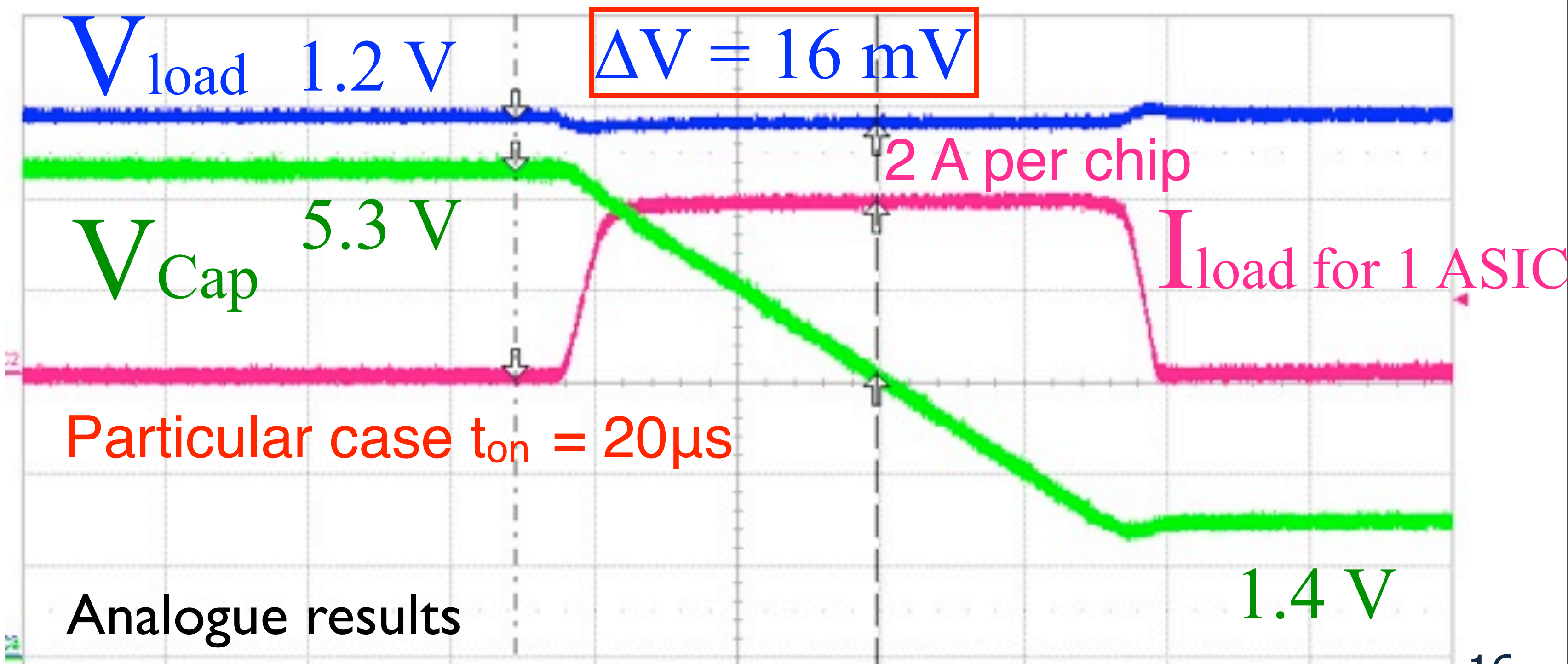
Analogue:

- Voltage drop < 20 mV
- Measured average power dissipation < 10 mW/cm^2

Digital:

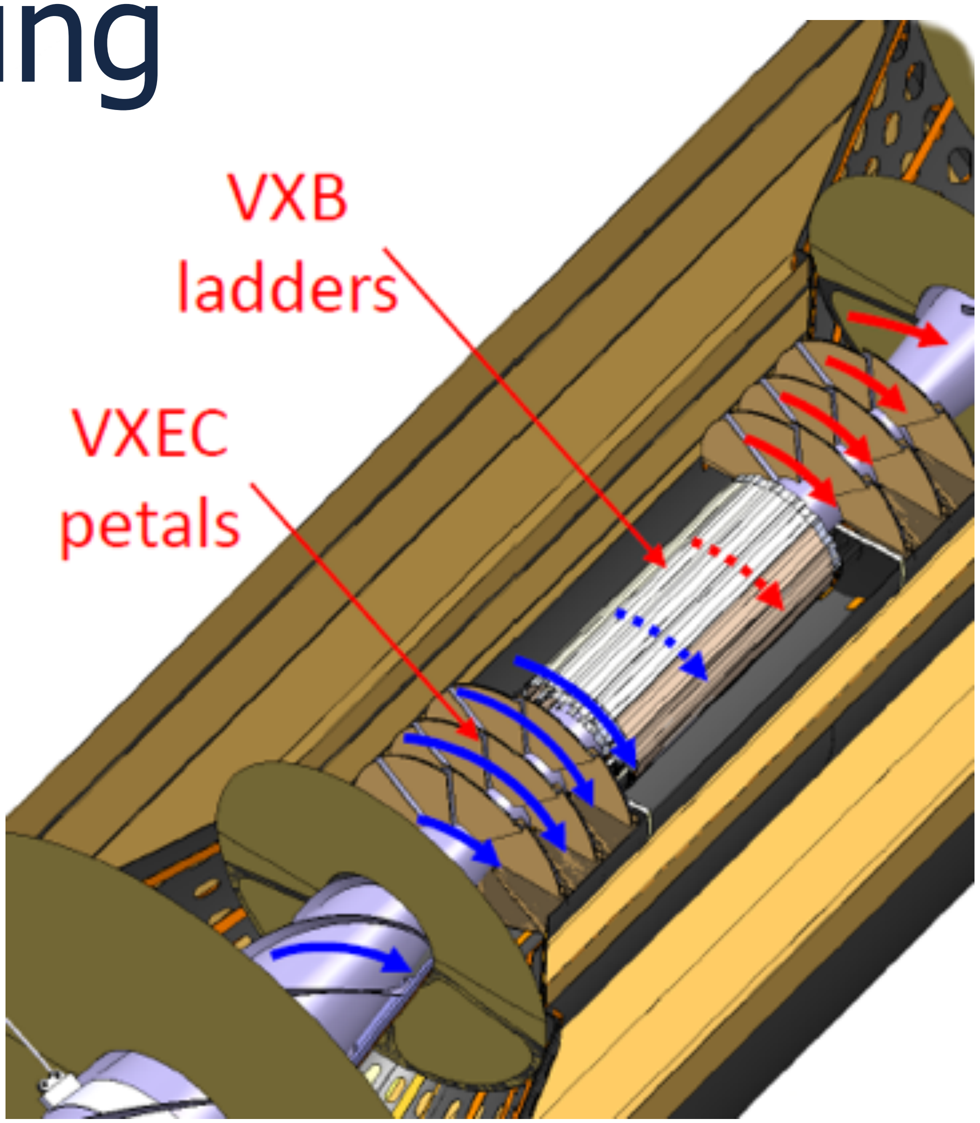
- Measured average power dissipation < 35 mW/cm^2

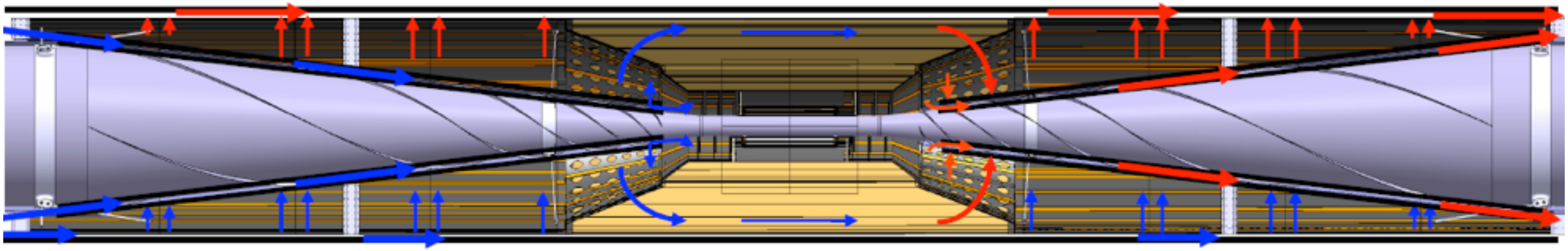
Total dissipation: < 50 mW/cm^2



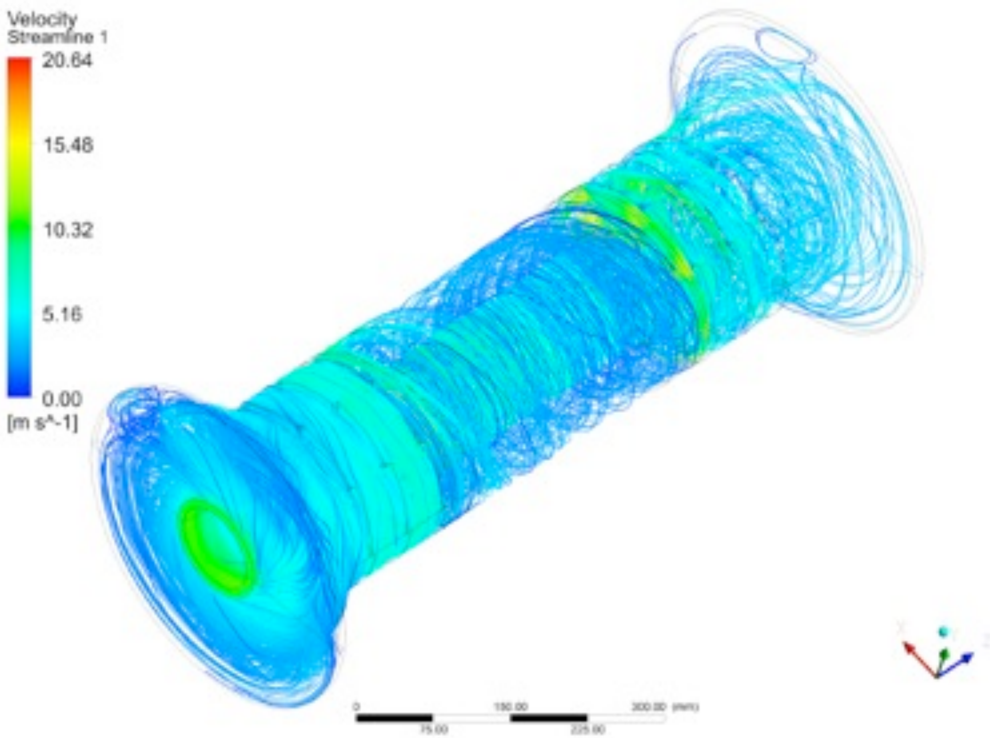
Air-flow cooling

- Total heat load after power-pulsing ~470 W
- Cooling provided by forced air-flow:
  - Dry air cooling at 0°C
  - Low material: radiation length of air ~310m

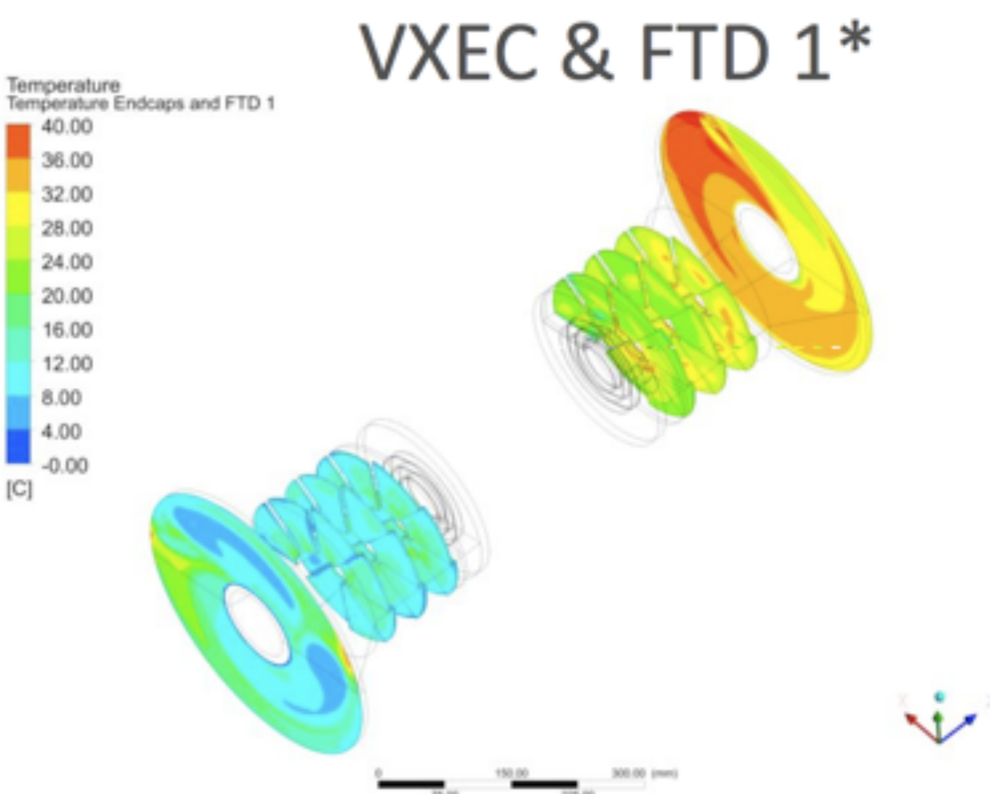


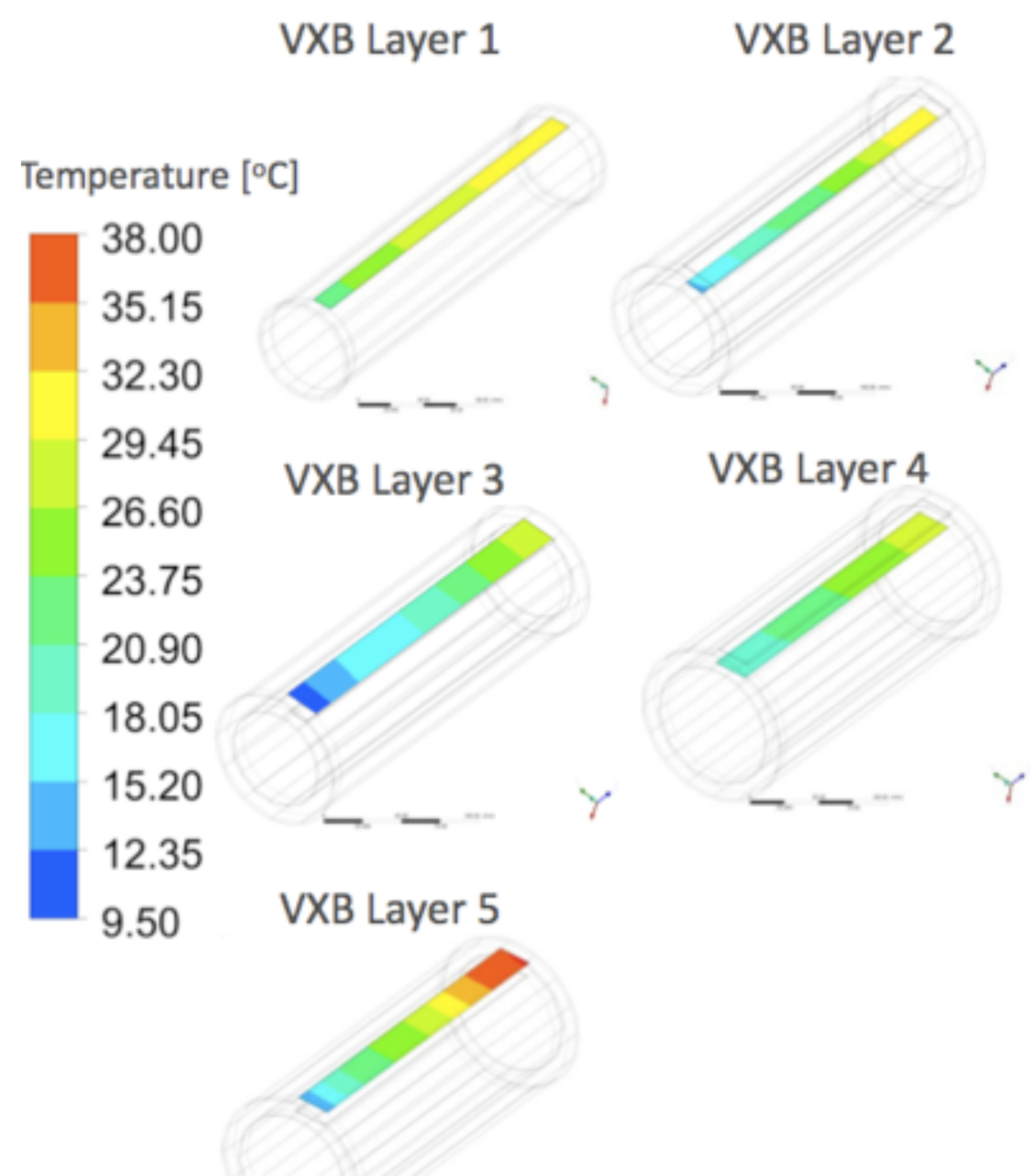


Air-flow simulations



- Mass flow: 19.9 g/s
- Avg. velocity in barrel: 6.3 m/s
- Silicon temperature below 40°C
- Conduction not taken into account



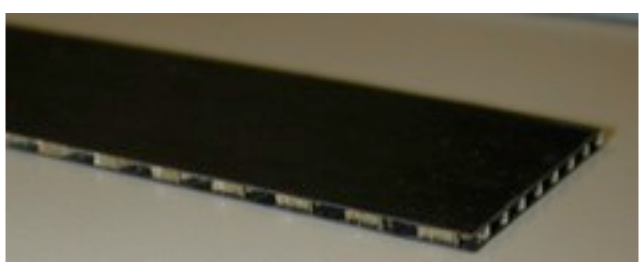


Mechanical support structures

- Develop and characterise low-mass carbon-fibre structures
- Stave dimension 1.8 mm*26 mm*280 mm
- Goal material per layer: 0.05% X_0

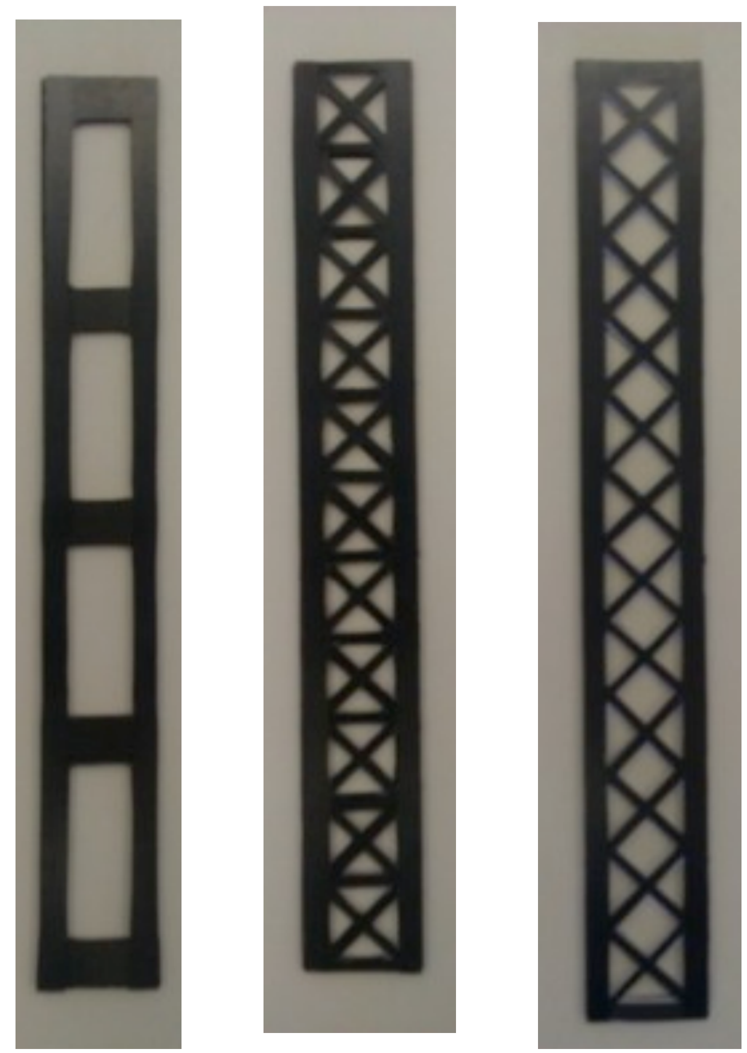
Full sandwich stave

Rohacell core (PMMA)

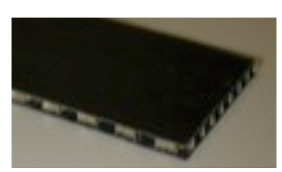
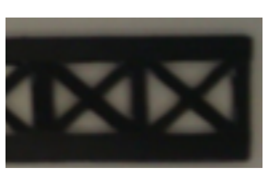


Honeycomb core
(Nomex and Carbone)

Cross braced staves

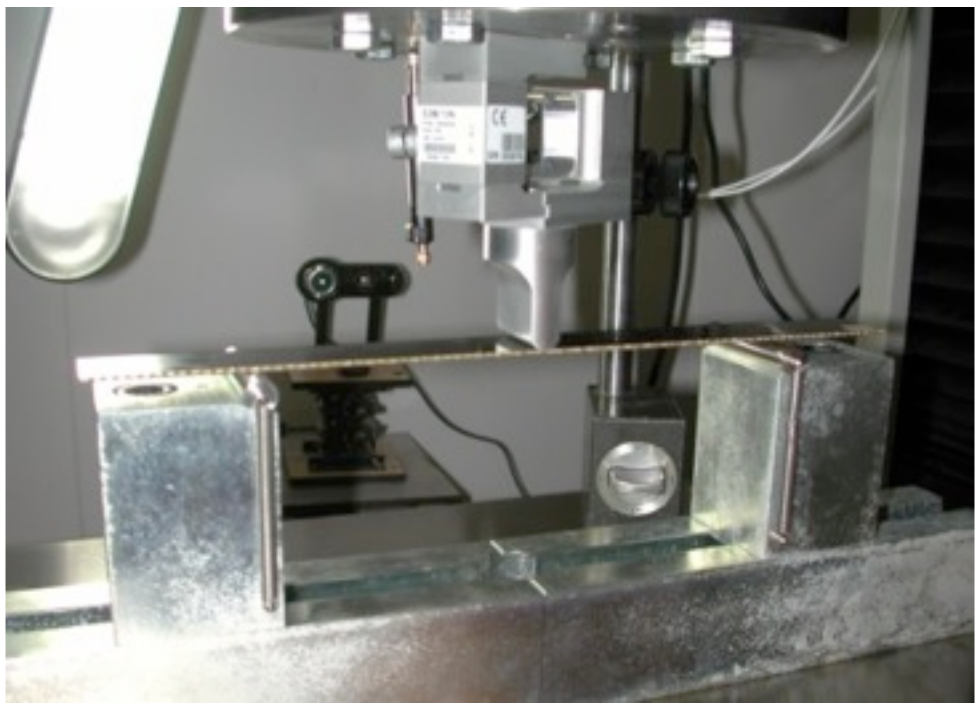


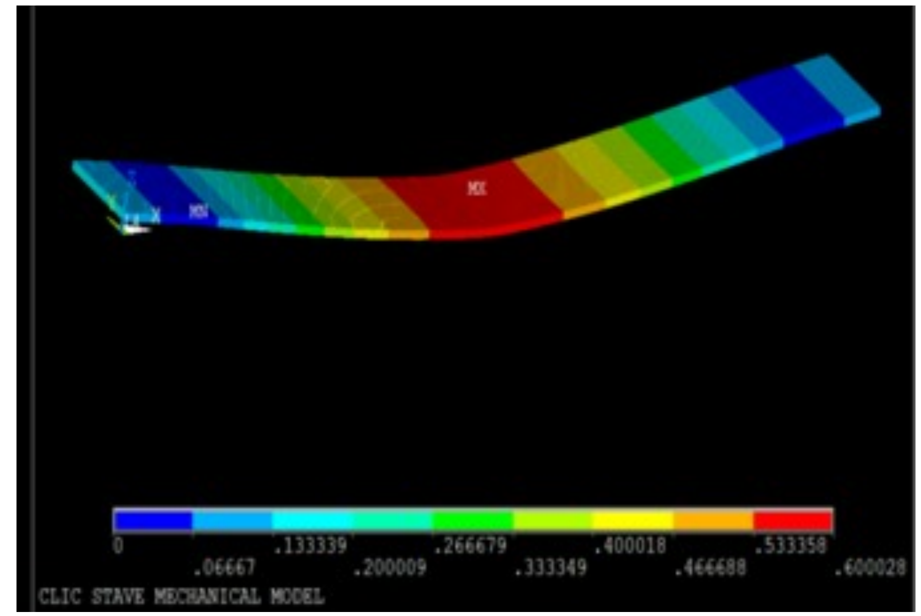
Skin stave

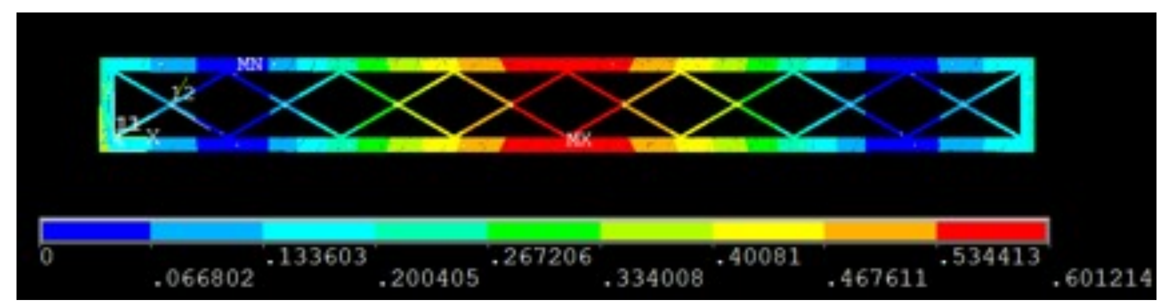
					
Mass	3.74 g	3.45 g	3.08 g	2.74 g	1.76 g
X/X_0	0.121%	0.112%	0.118%	0.068%	0.051%

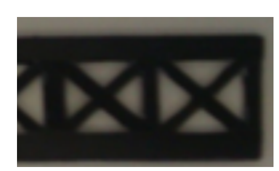
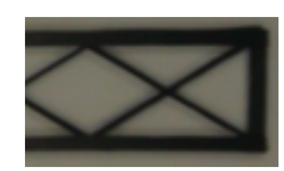
Stave mechanical characterisation

- Measure the flexural stiffness (resistance to bending) of the staves over span of 180 mm



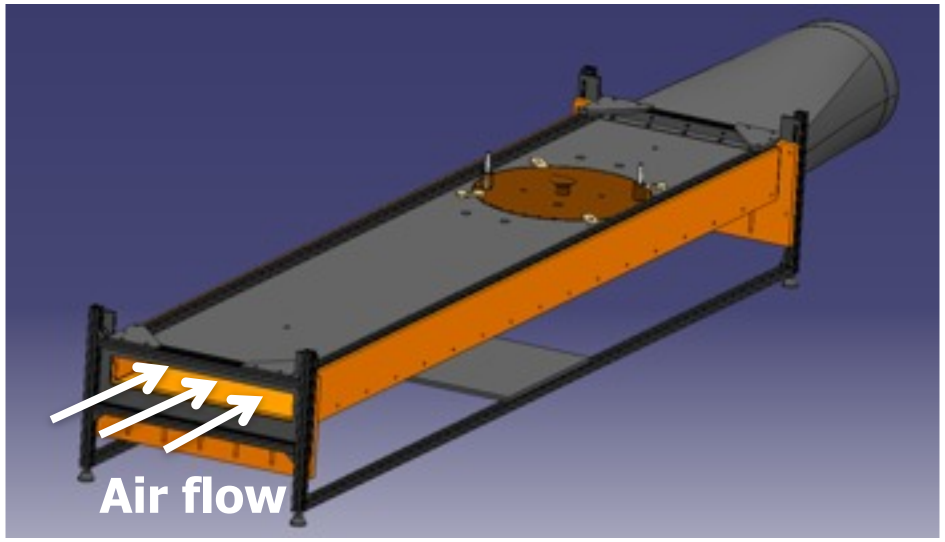


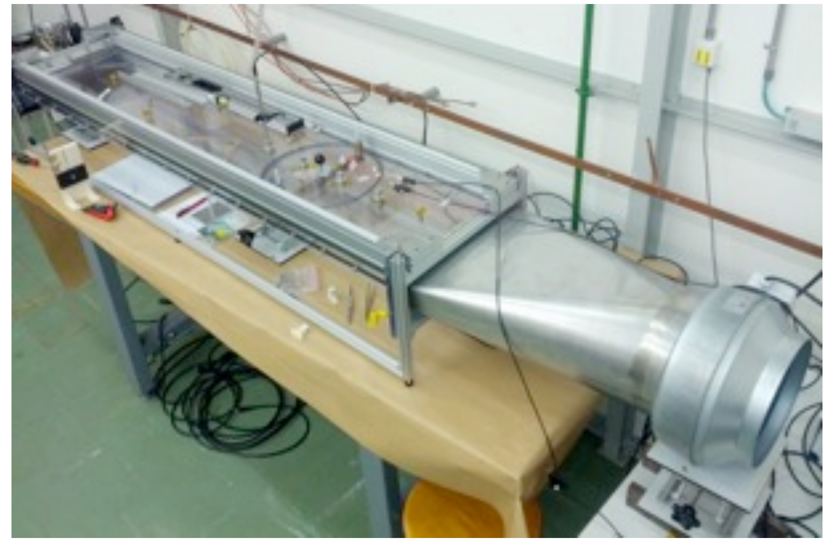


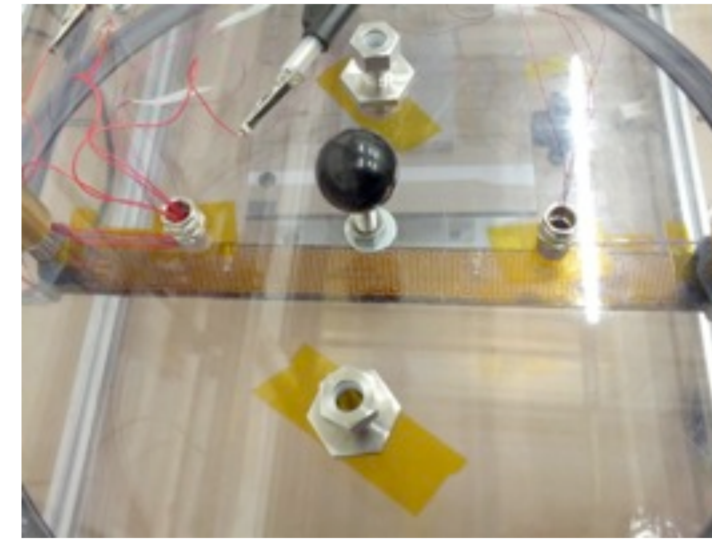
					
Measurements	6.95 N/mm	2.24 N/mm	3.3 N/mm	2.96 N/mm	2.23 N/mm
Simulations	6.95 N/mm	2.35 N/mm	-	-	2.30 N/mm

Next: measure the amplitude of stave vibration in air flow

Thermo-mechanical test bench

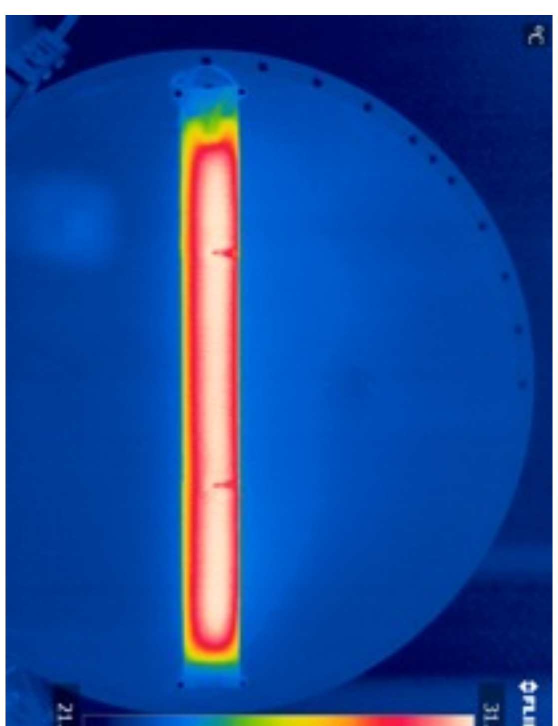




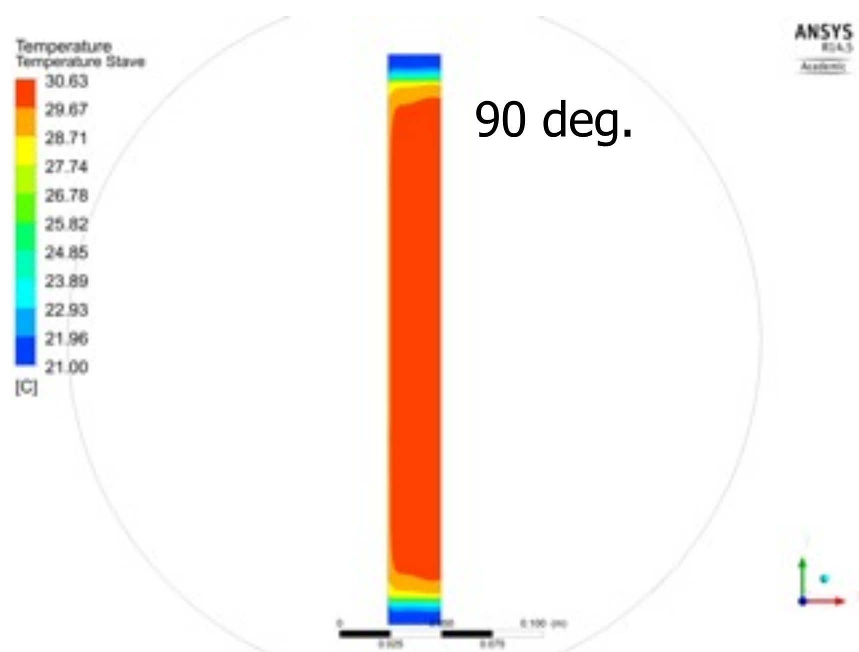


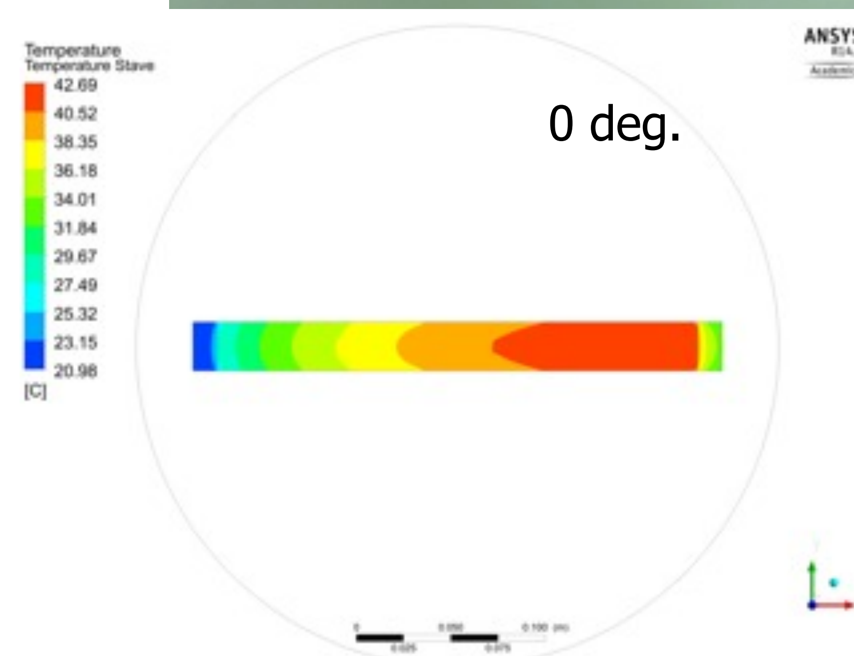
- Measure wind speeds, stave temperatures, stave vibrations
- Allows validation of simulations

Thermal camera

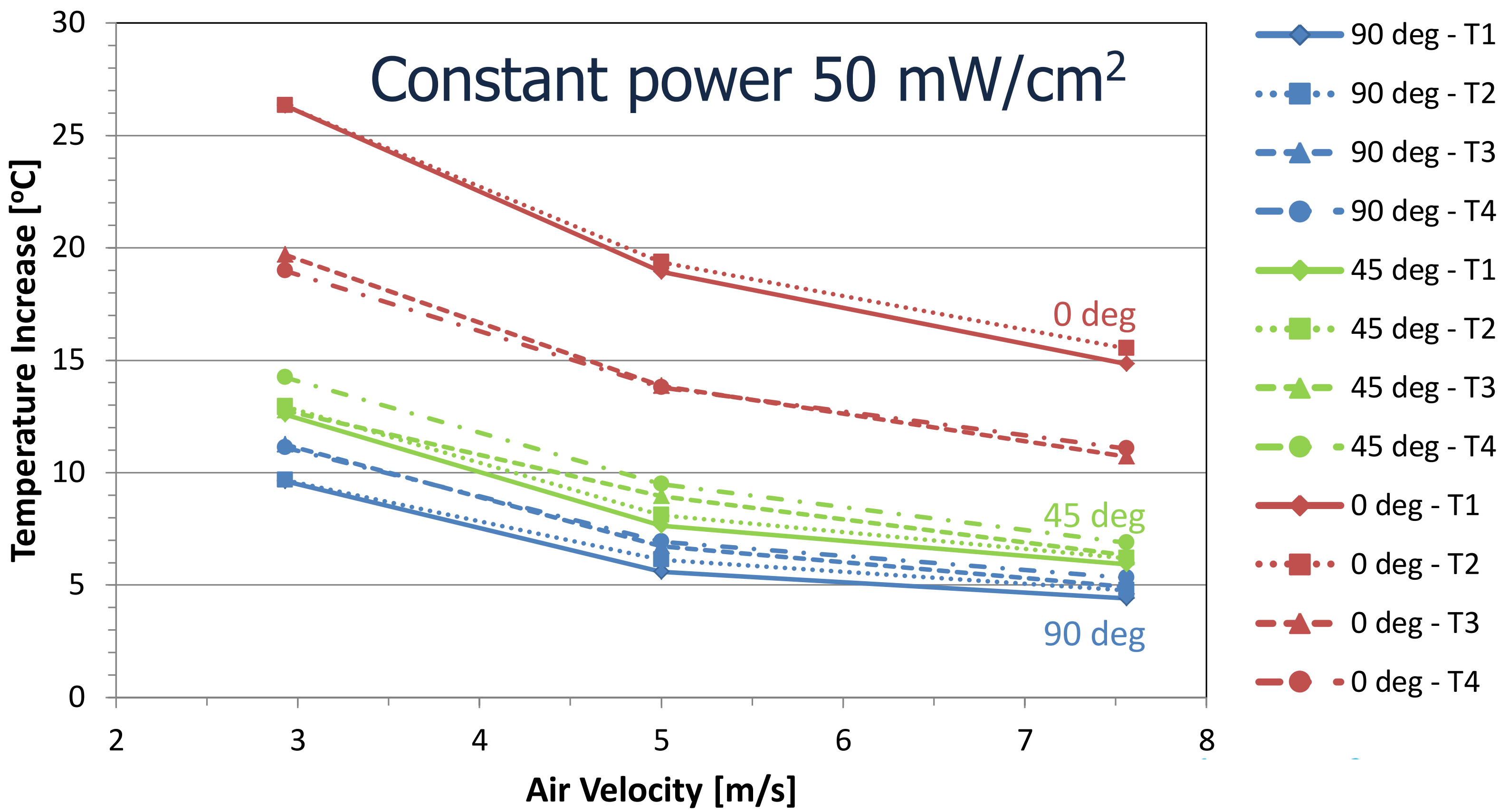


Simulation



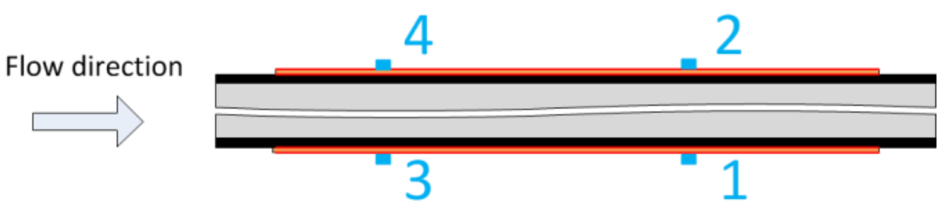


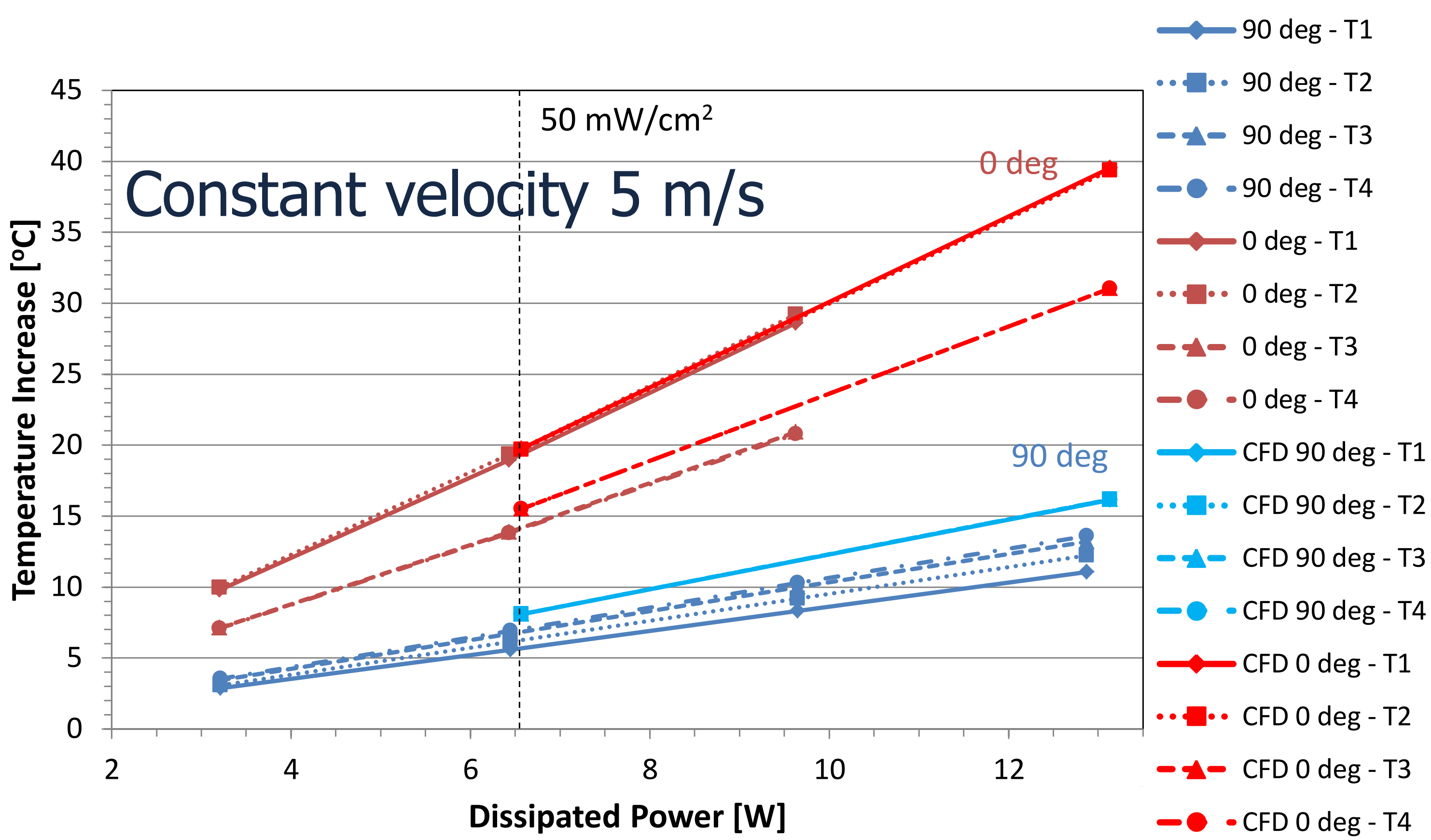
Test bench results



- Temperatures decrease asymptotically for increased air flow
- Perpendicular flow gives lowest and most homogeneous temperature
- Difference between 90° and 45° is small

- Simulation in good agreement with measurements

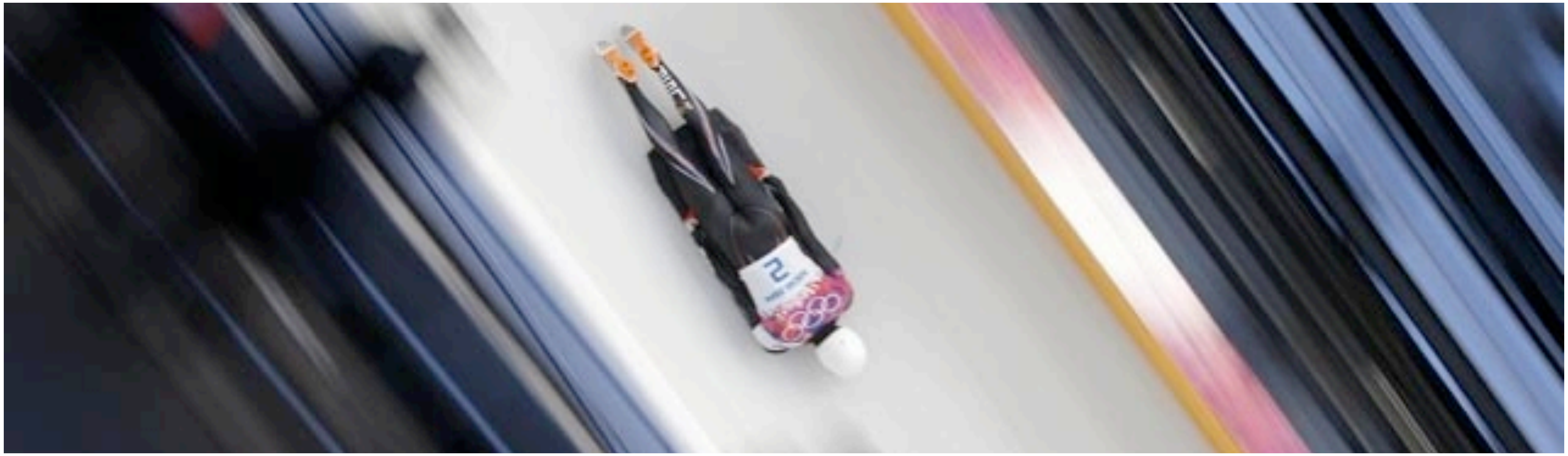




Summary

- CLIC machine and physics requirements place challenging demands on the vertex detector
- Initial layouts are being refined
- Active R&D into thin sensor assemblies and readout chips
- Powering, cooling and mechanical supports under design and test

The CLIC vertex detector: precision at high energy



Thanks for your attention!