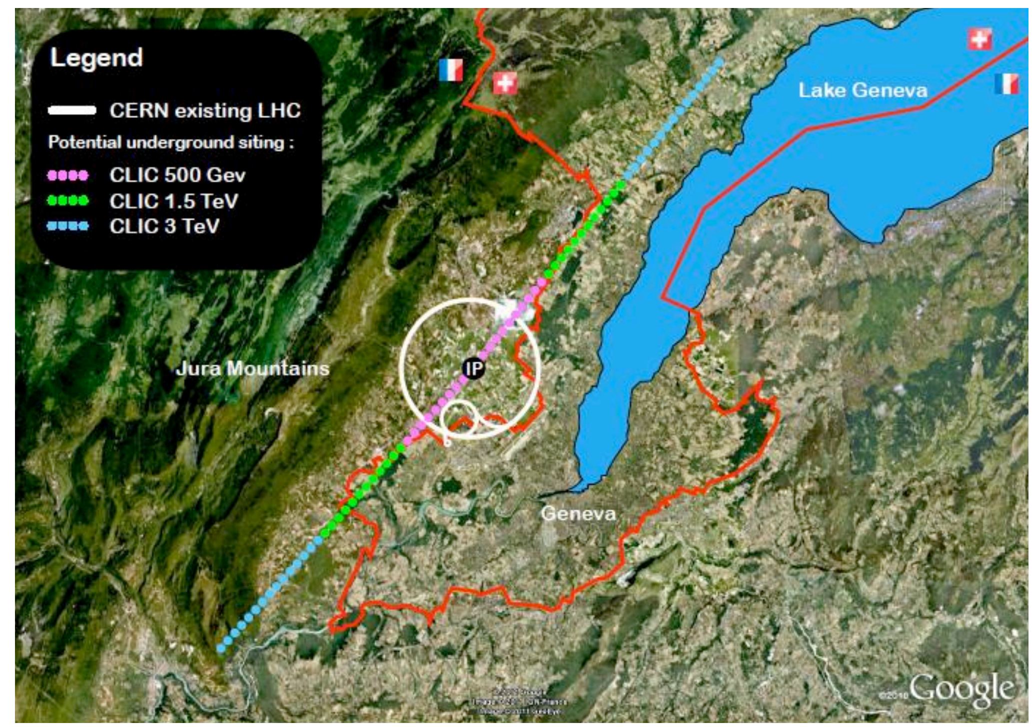
R&D for the vertexing at CLIC

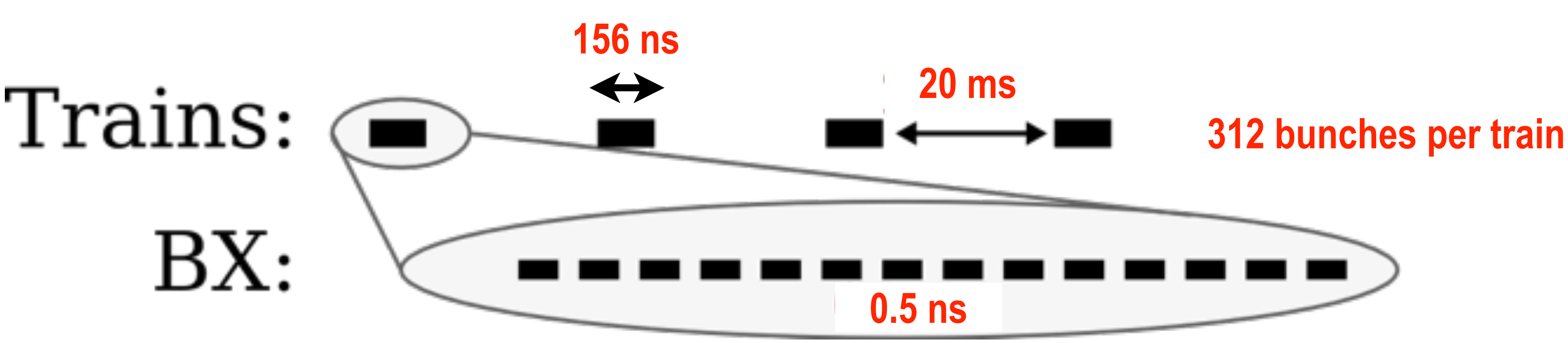
Sophie Redford (CERN) on behalf of the CLICdp collaboration

VERTEX 2014 - Mácha Lake - 16th September 2014

CLIC - a collider for the future

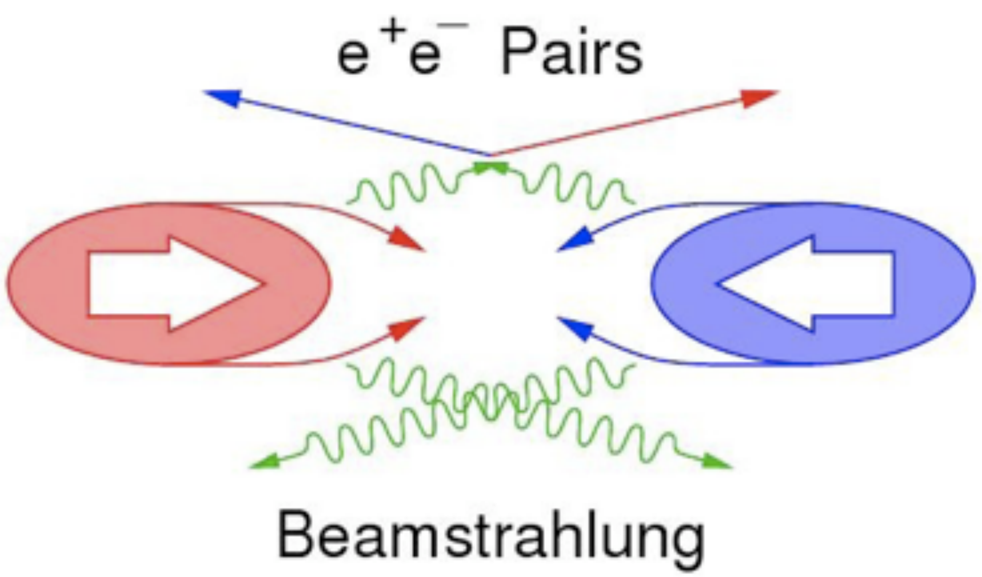
- Linear electron-positron collider
- $\sqrt{s}$ = 3 TeV (staged construction)
- High luminosity: few x 10^{34} $cm^{-2}s^{-1}$
- Small bunch size: σ_{xyz}(40 nm, 1 nm, 44 μm)
- Beam structure:

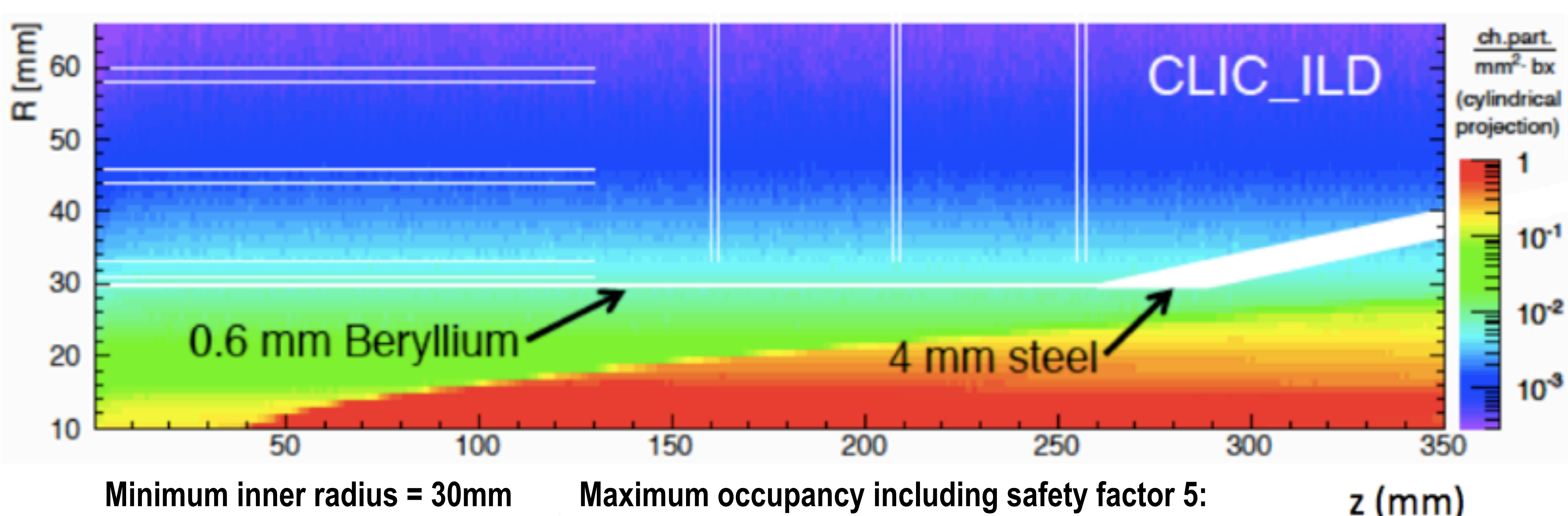




Detector environment

- 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

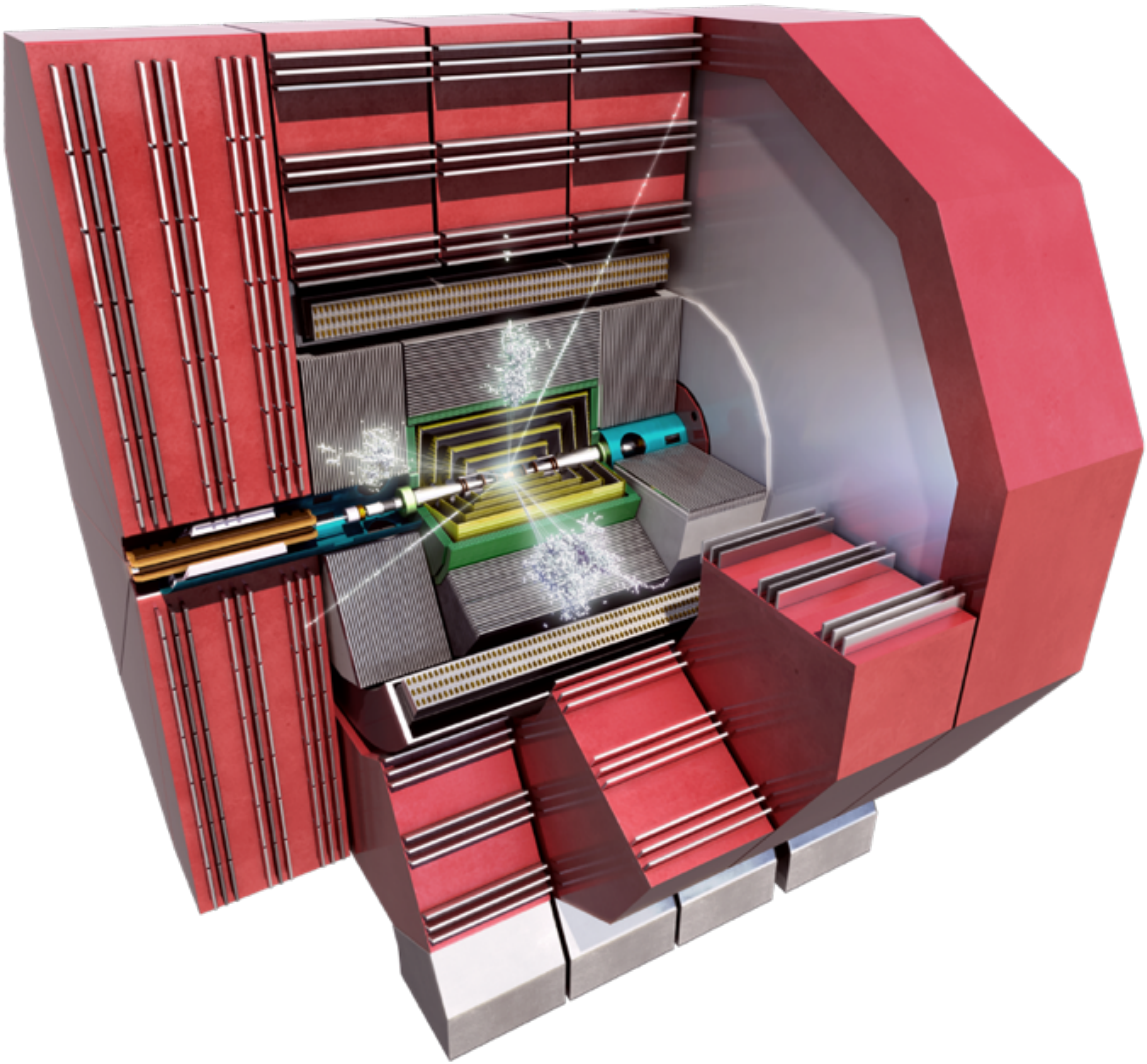




Minimum inner radius = 30mm

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

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

All silicon tracker

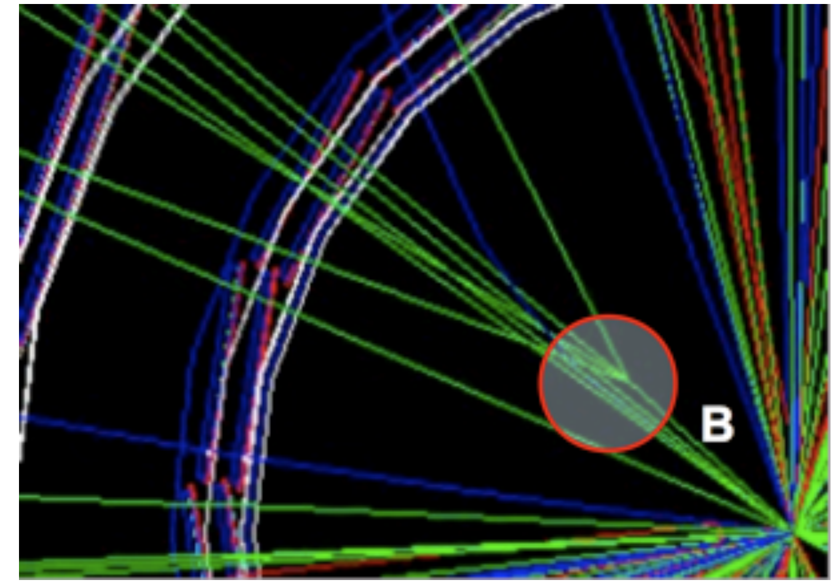
Instrumented steel return yoke

Complex forward region

Vertex detector requirements

Goal

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



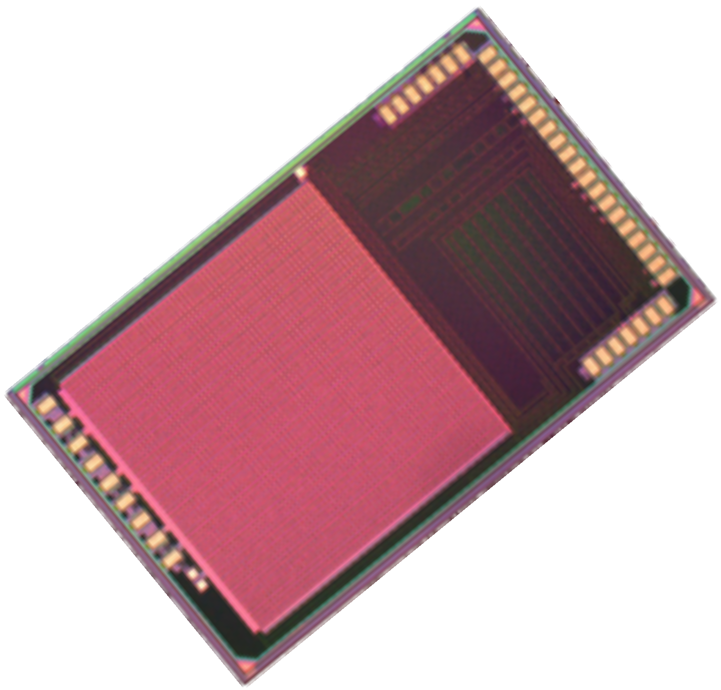
Multi-layer barrel and endcap pixel detectors

- 560 mm in length
- Barrel radius from 30 mm to ~70 mm

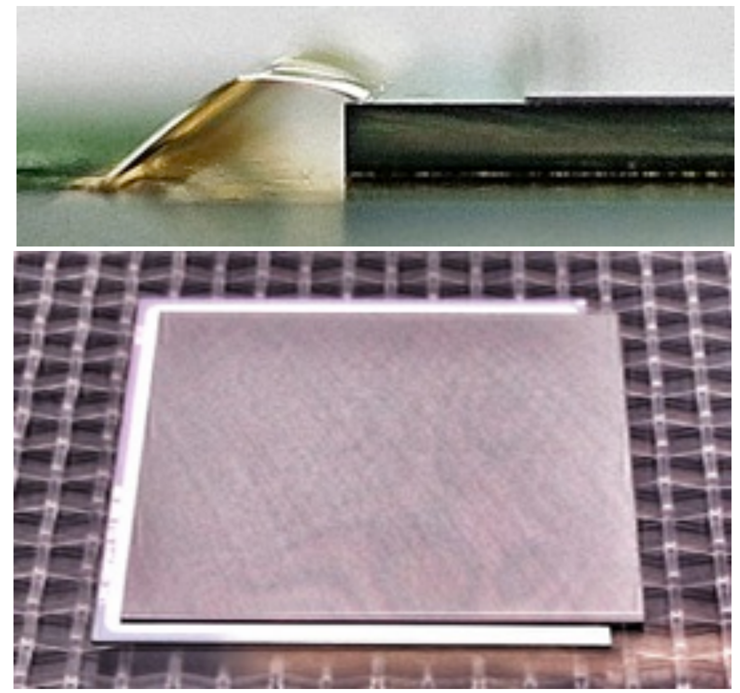
- Single point resolution of 3 μm
- Material budget of < 0.2% of a radiation length per layer
- No active cooling elements - use forced air flow cooling
- Limit the power dissipation to 50 mW/cm^2 in sensor area
- Hit time slicing of 10 ns

R&D programme

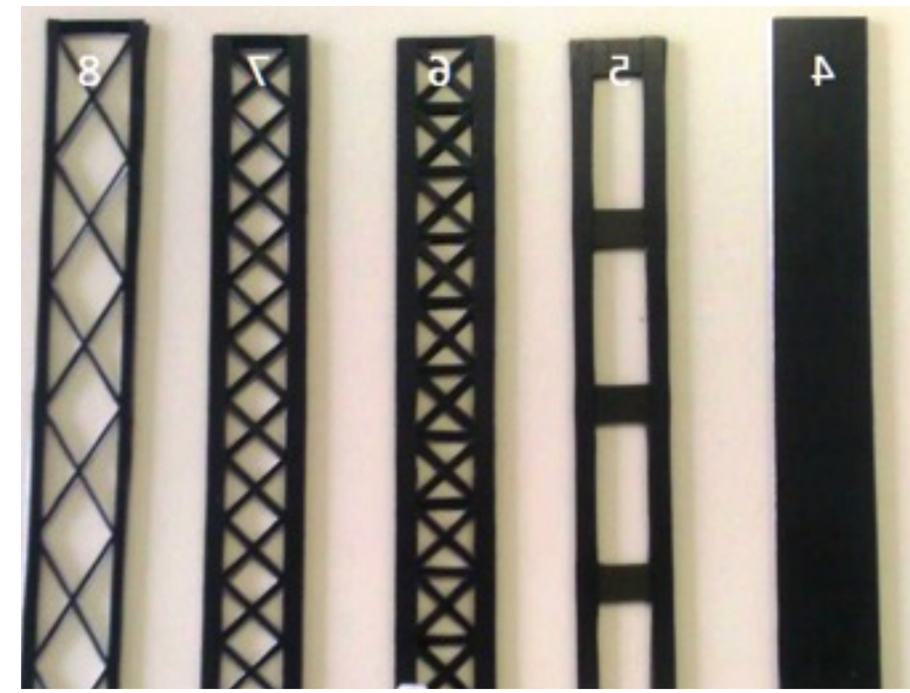
Readout

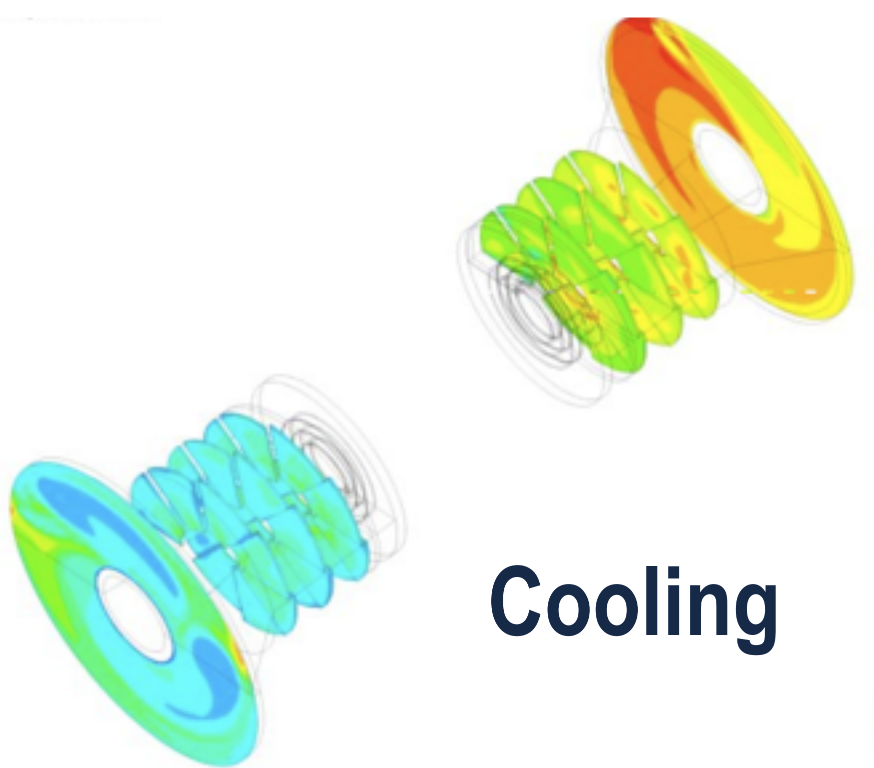


Thin assemblies

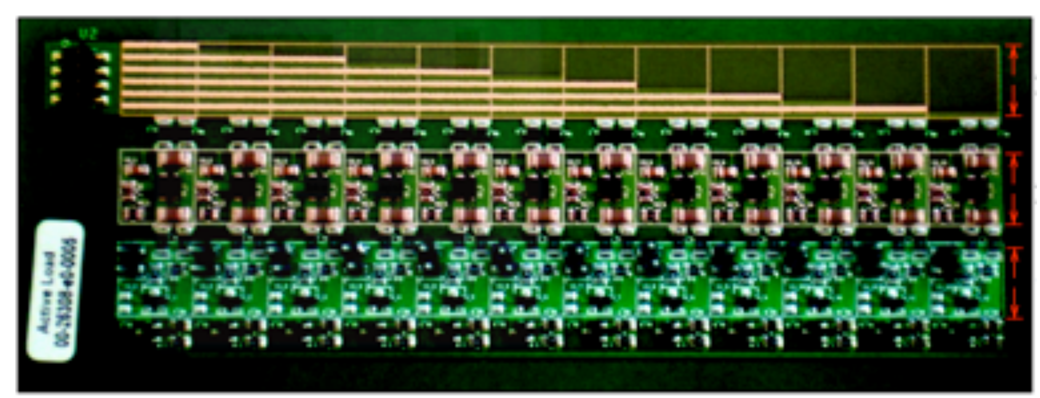


Supports



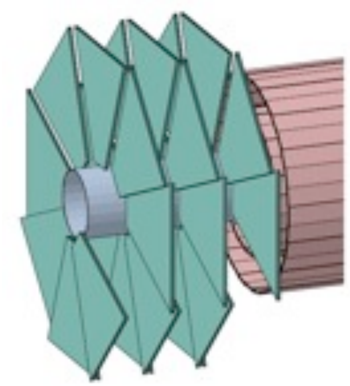


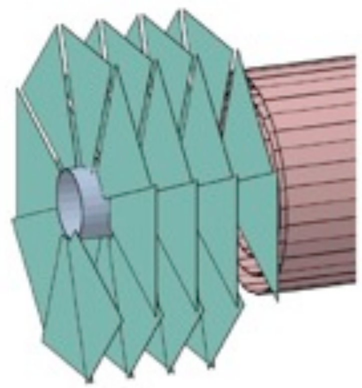
Cooling



Powering

Geometry optimisation studies



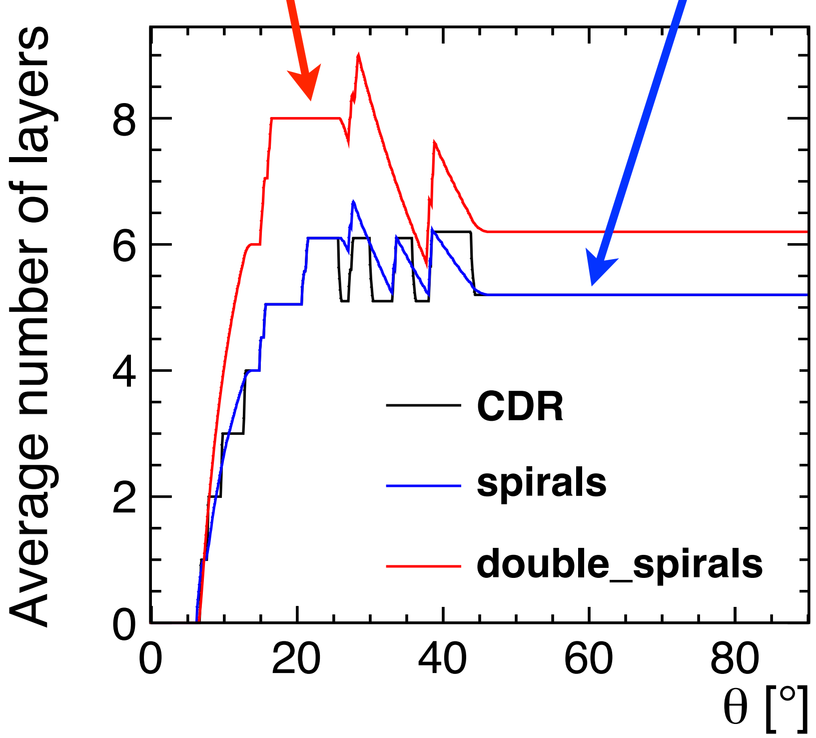


3 double-sided barrel layers

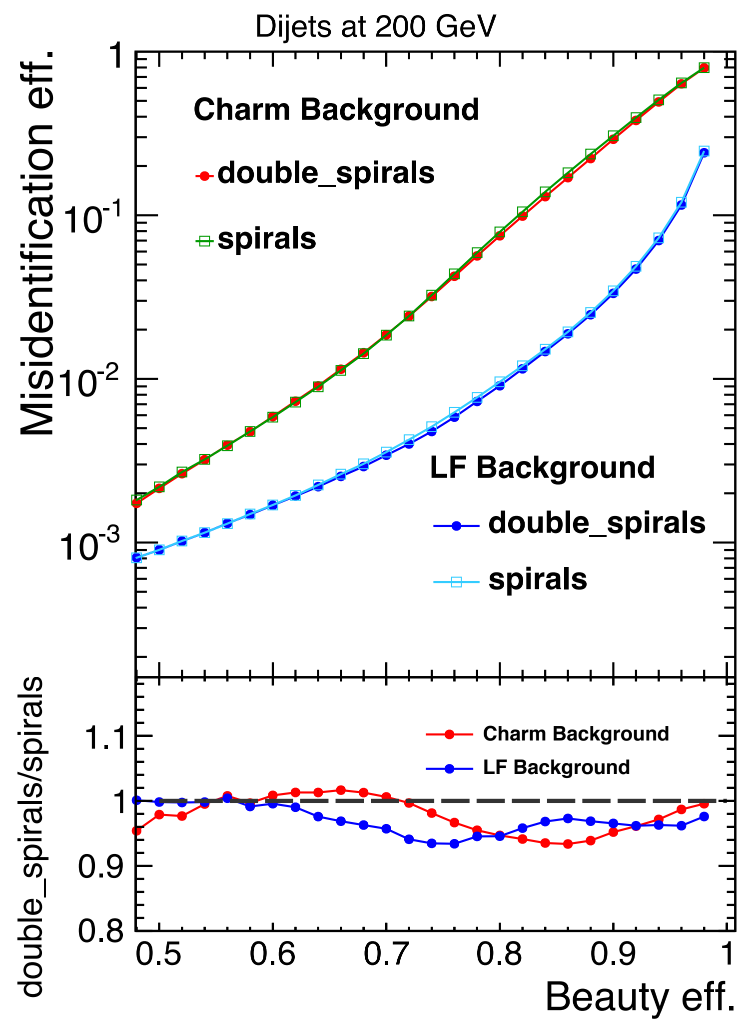
3 double-sided endcap layers

5 single-sided barrel layers

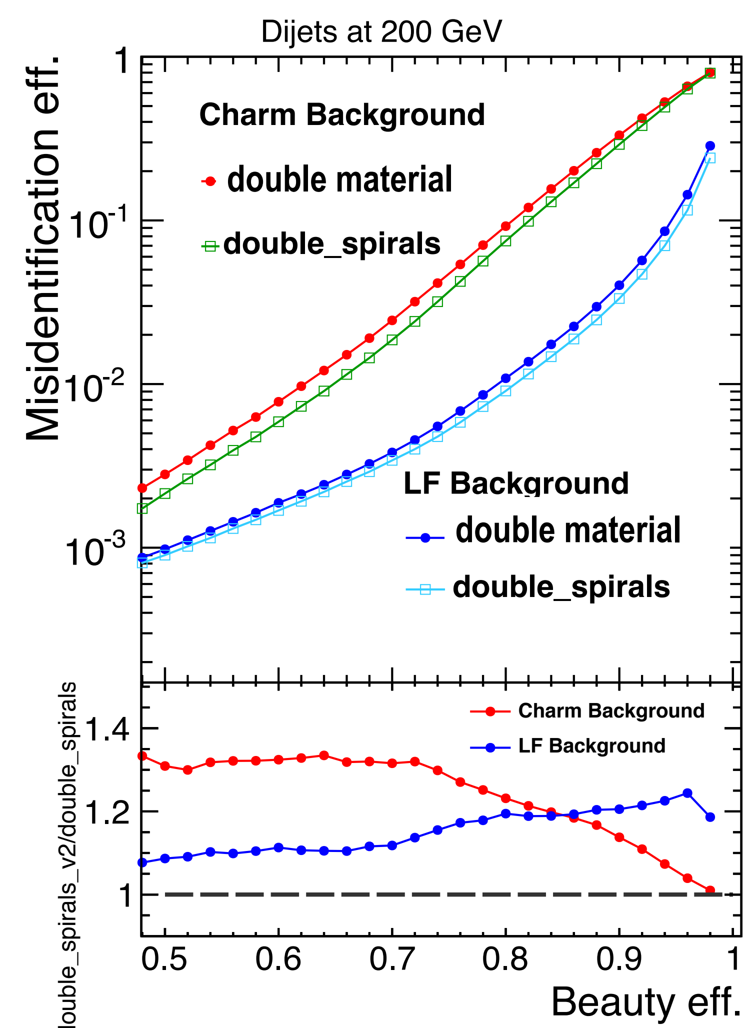
4 single-sided endcap layers



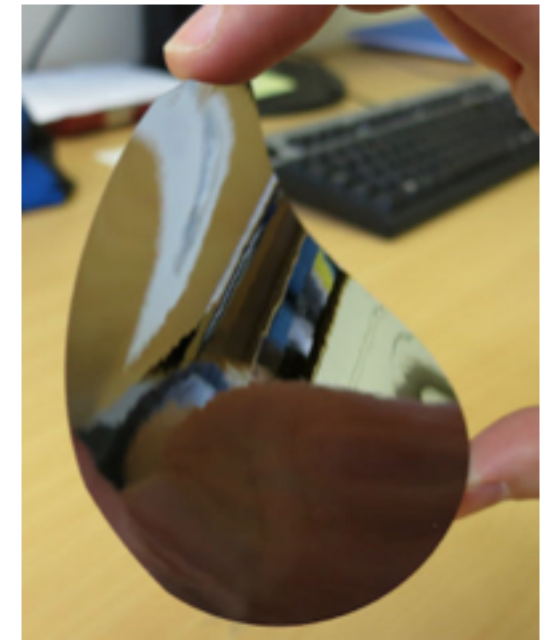
Similar flavour tag performance for two considered layouts



Increasing the material has a larger impact than the layout

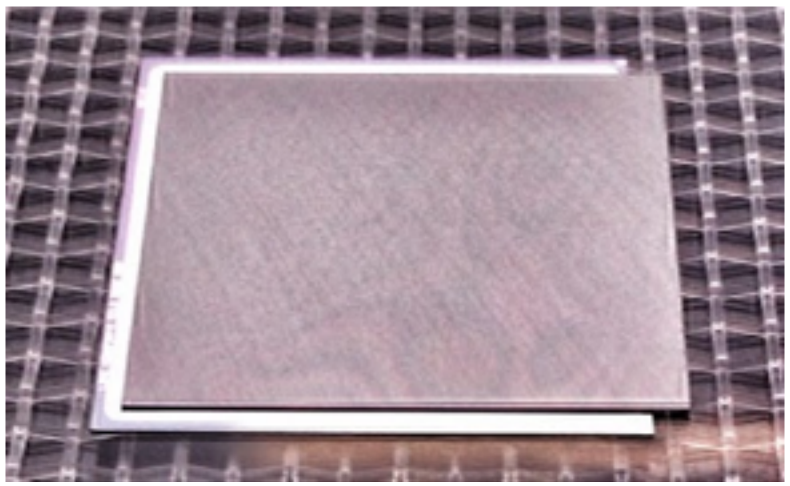


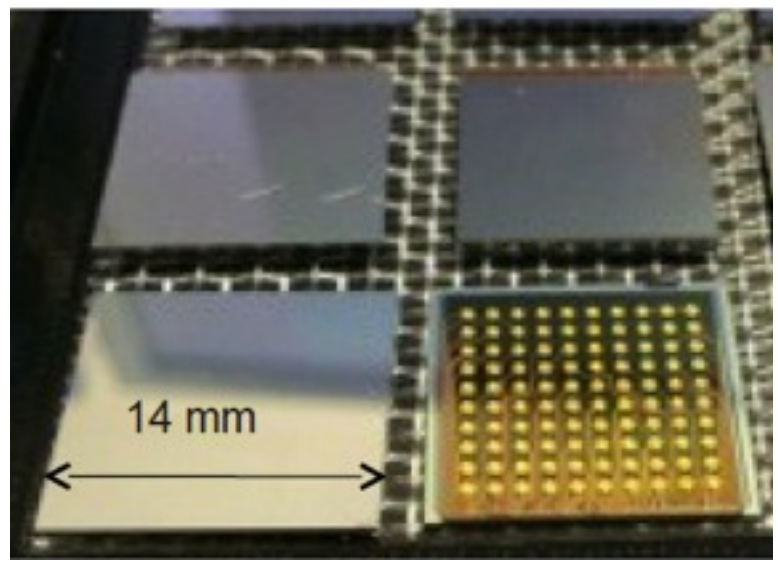
Thin sensor assemblies



50 µm thick silicon wafer

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





TSVs:

- Vertical electrical connection - no wire bonds
- Sensors buttable on all sides - better tiling
- 60 µm hole diameter
- Wafer thinned to 120 µm
- 5 µm copper layer for TSV

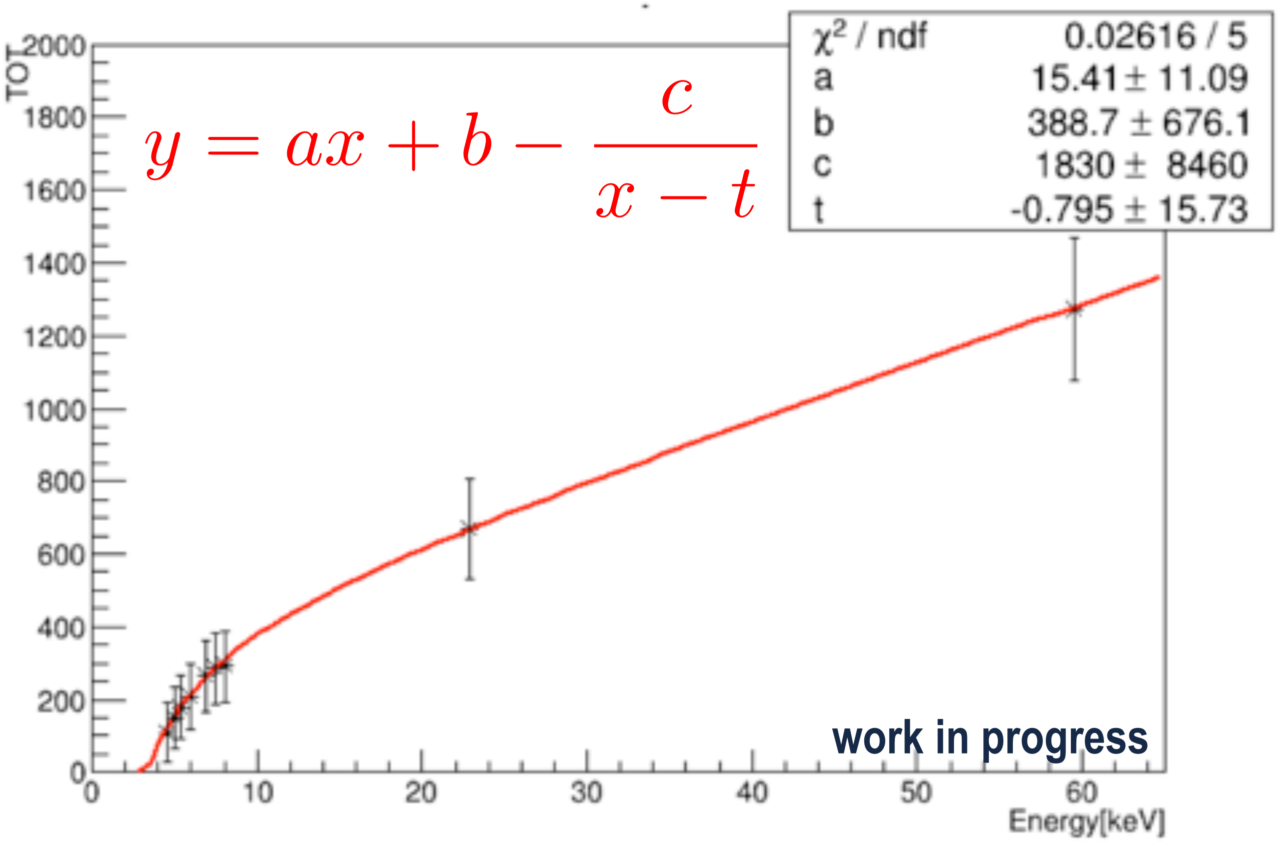
Using the Medipix/Timepix family of readout chips:

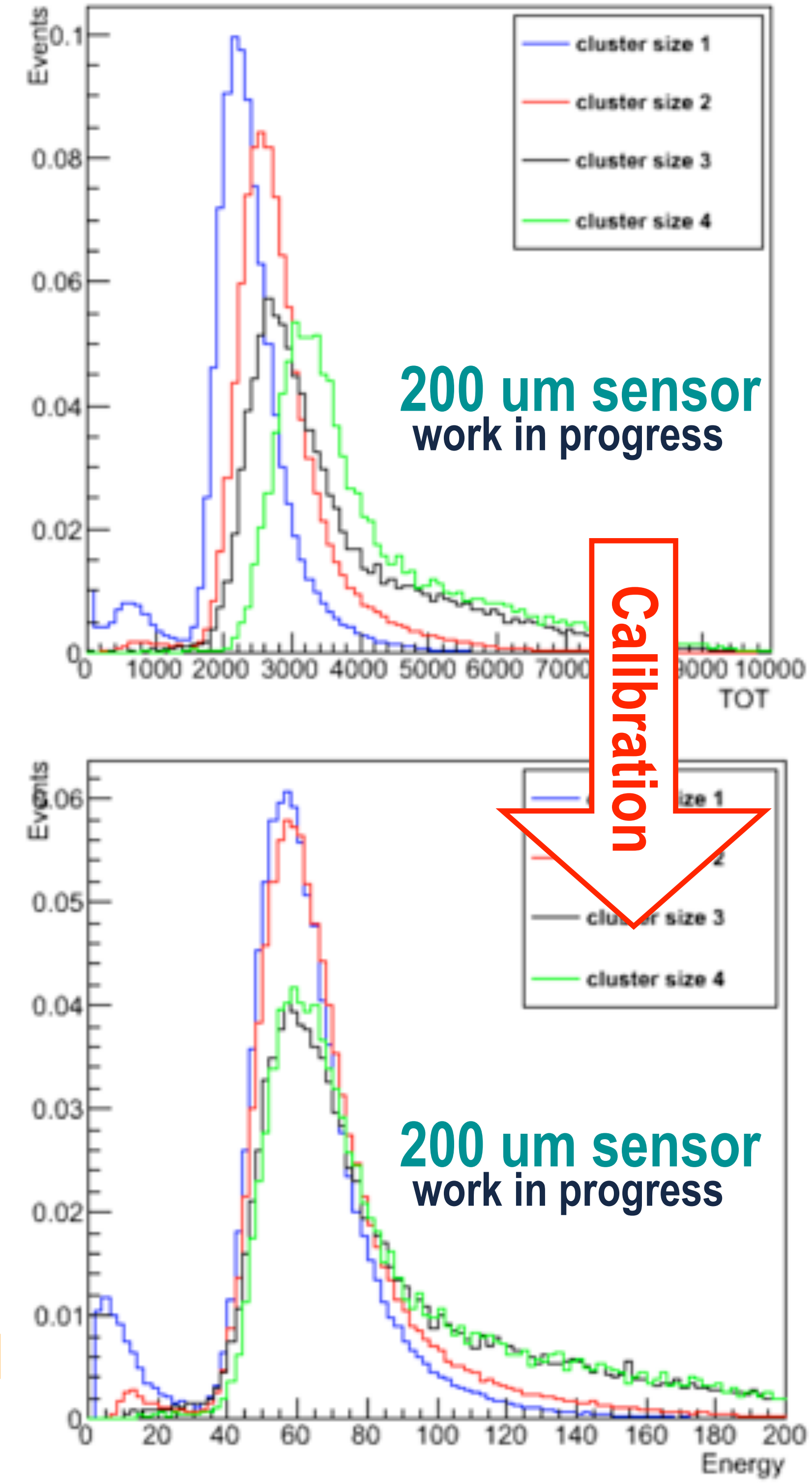
- Timepix: DESY test beam 2013, lab tests CERN, LNLS
- Timepix3: CERN PS test beam 2014
- CLICpix: CCPDv3 (capacitive coupling) in CERN PS test beam 2014, future bump-bonding trials at SLAC

First Medipix3 image using TSV

Sensor calibration

- Calibrate TOT values by measuring response to photons of known energy
- Fit accounts for non-linearities in response
- Calibration aligns Landau's





Target/Source	^{55}Fe	Brass	^{09}Cd	Indium	^{241}Am	^{241}Am
E (kα) in keV	5.8	8.1	22.9	24	26.2	60

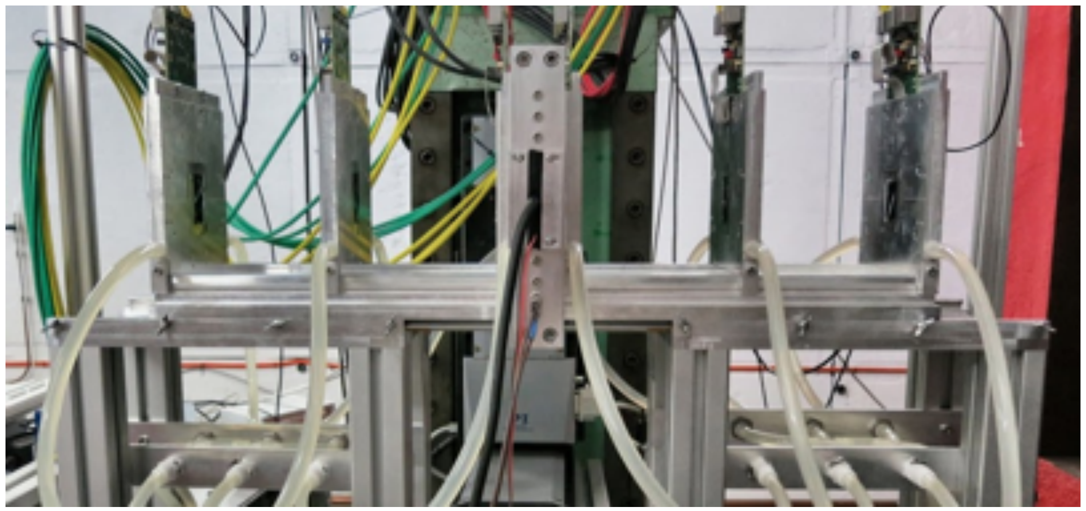
CERN

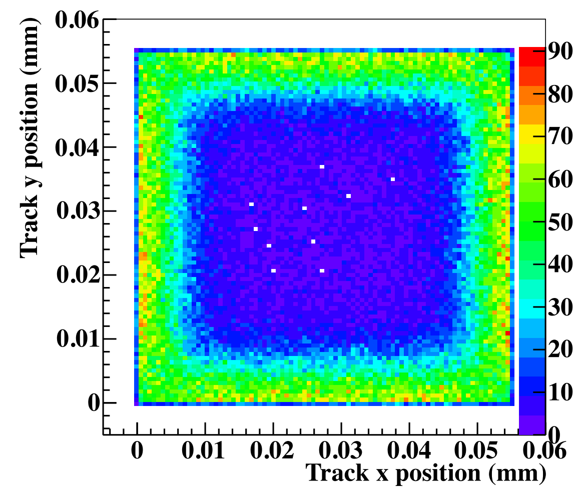
Target	Co	Cr	Cu	Fe	Mn	Ni	Ti	V	Zn
E (kα) in keV	4.51	4.95	5.414	5.89	6.4	6.93	7.47	8.04	8.63

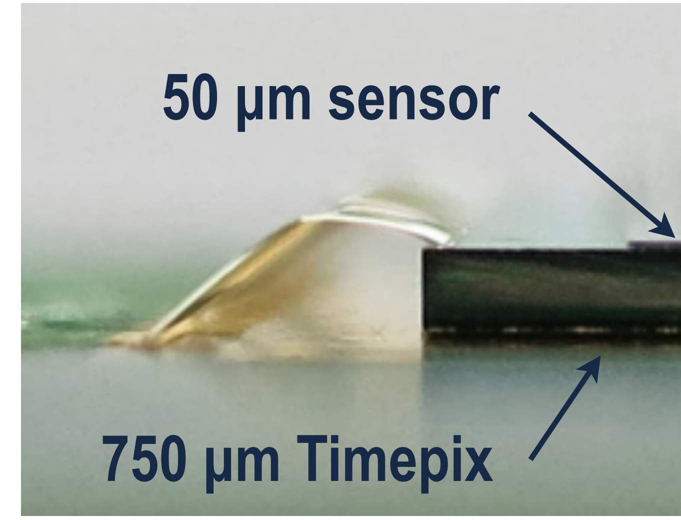
LNLS

Timepix test beam

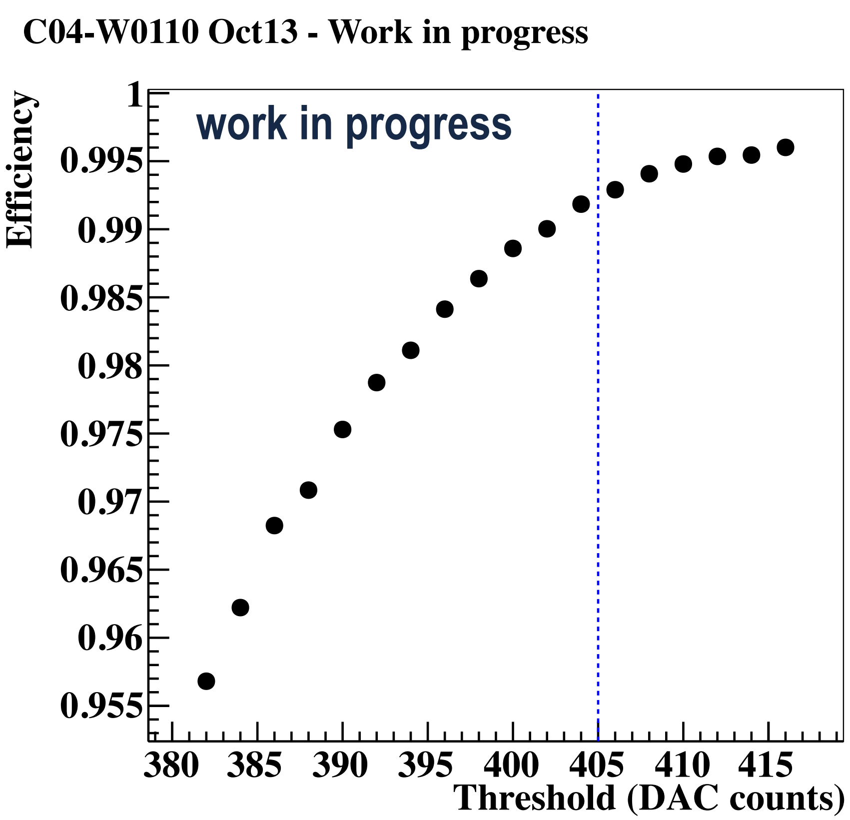
- Thin sensors (50 - 300 µm) bump-bonded to Timepix chips
- Data recorded at DESY: 5.6 GeV electron beam, EUDET telescope



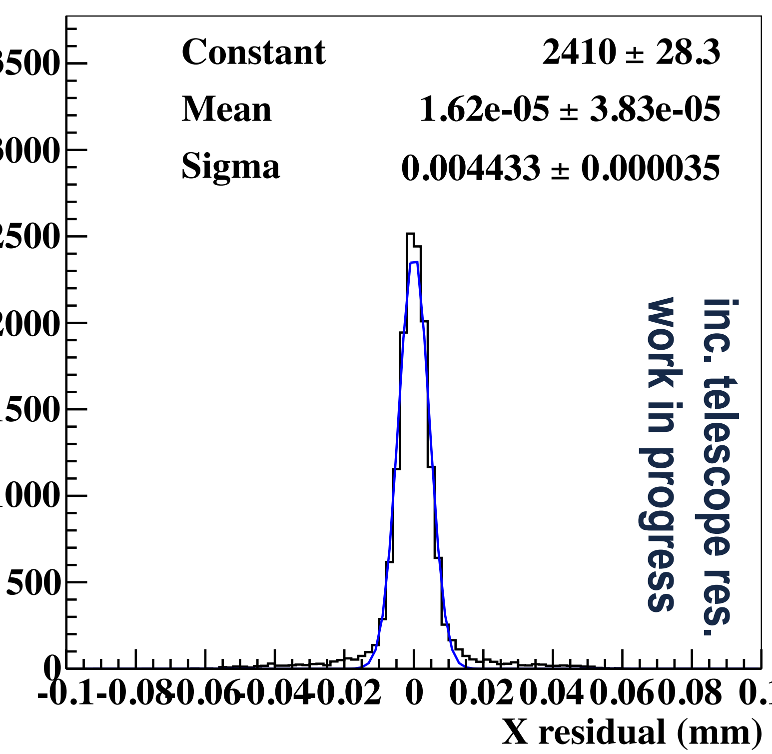




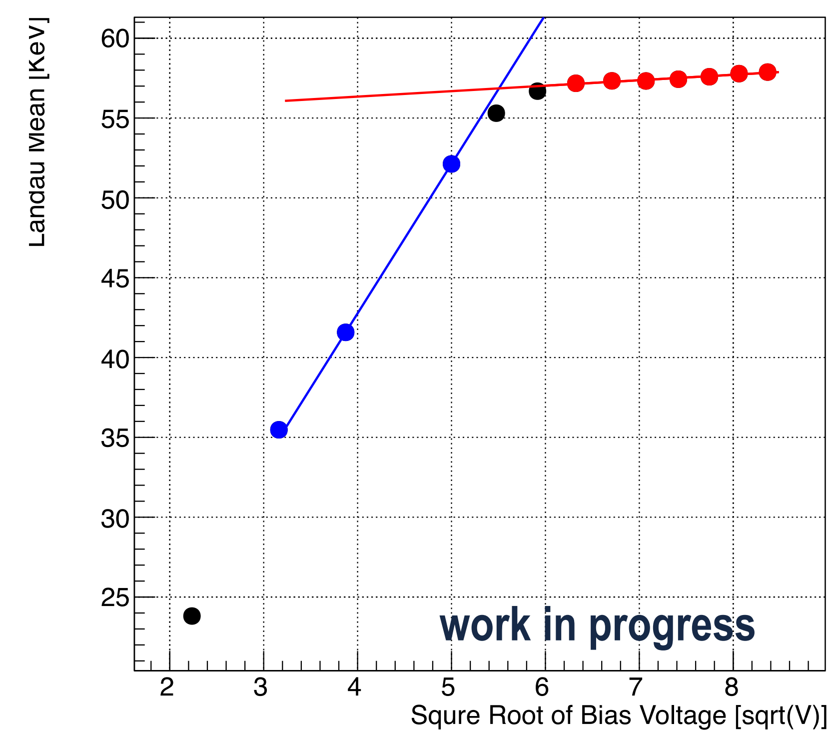
Track position: cluster size 2
low charge sharing



50 µm thick sensor efficiency
99.2% at operating threshold



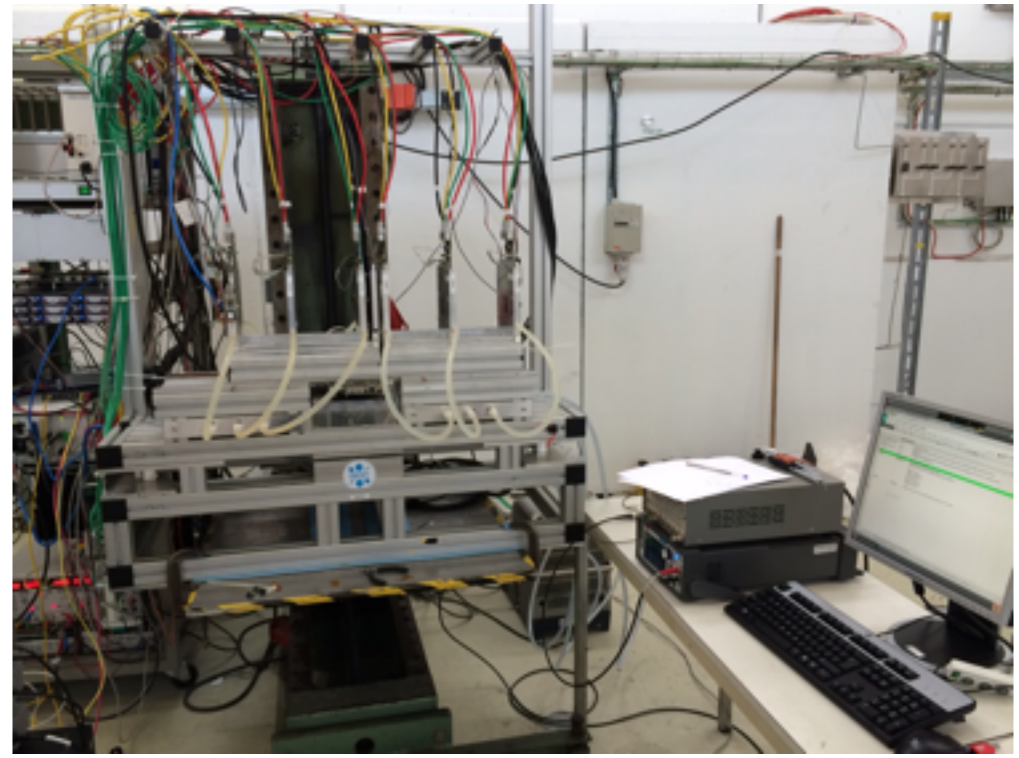
100 µm thick sensor two-hit cluster resolution ~4.5 um



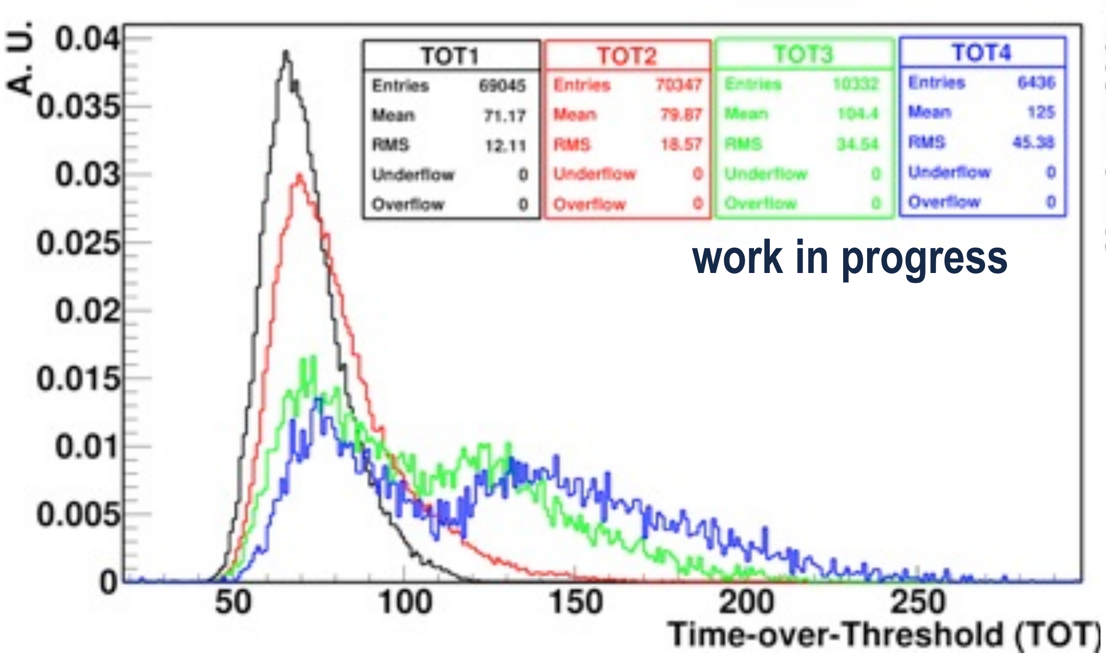
200 µm thick sensor
depletion voltage ~30 V

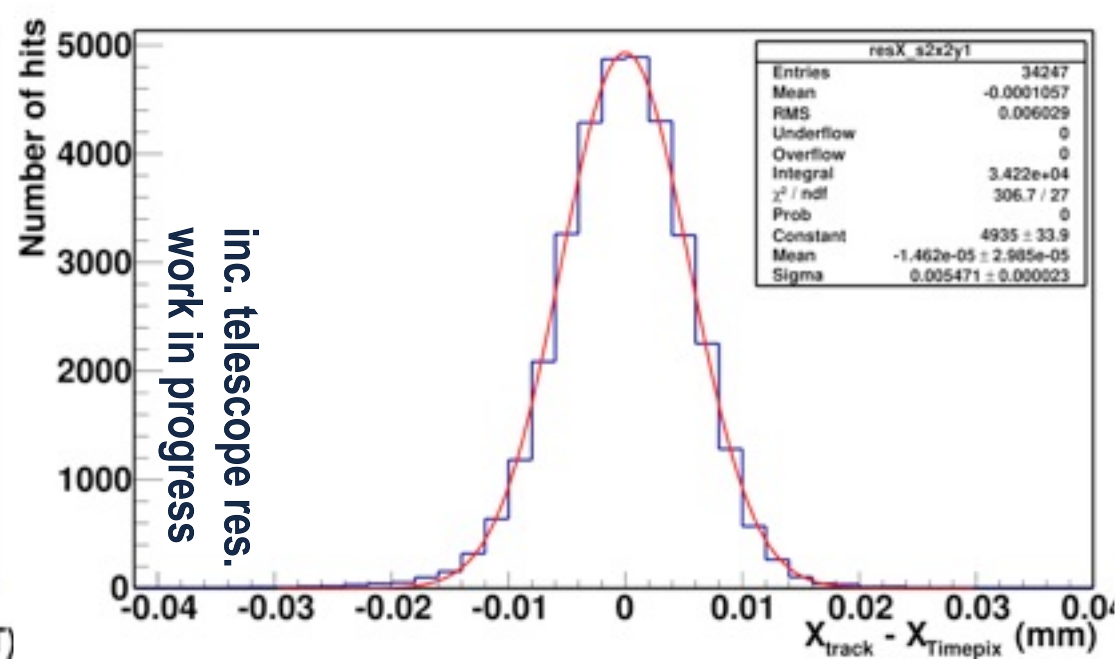
Hot off the press!

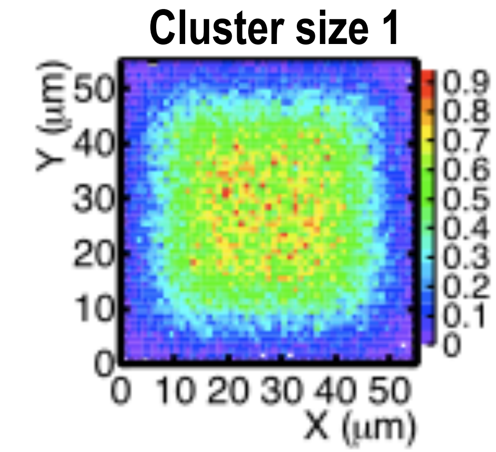
Timepix3 test beam

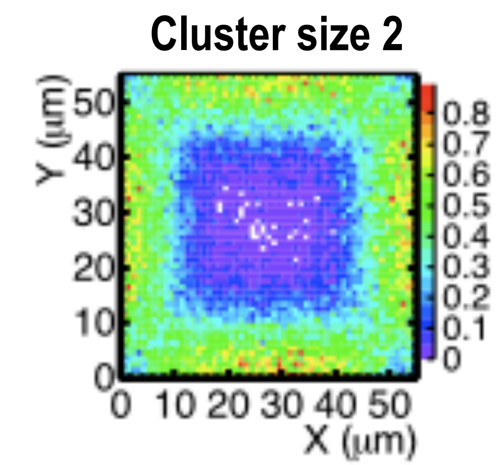


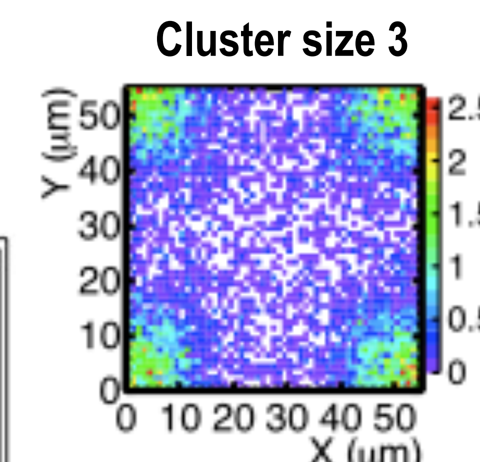
- Thin sensors (300 μm) bump-bonded to Timepix3 chips
- Data recorded at CERN PS, using EUDET telescope
- Testing telescope integration and DAQ workflow
- Good efficiency
- Up to 10k tracks / 400ms recorded

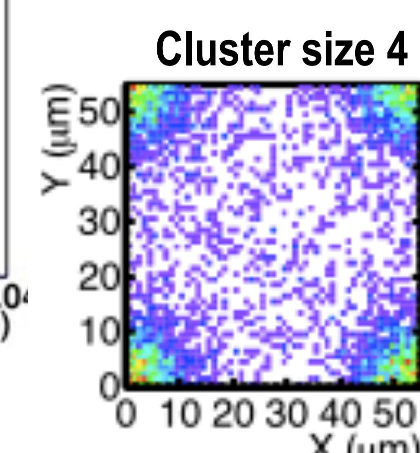












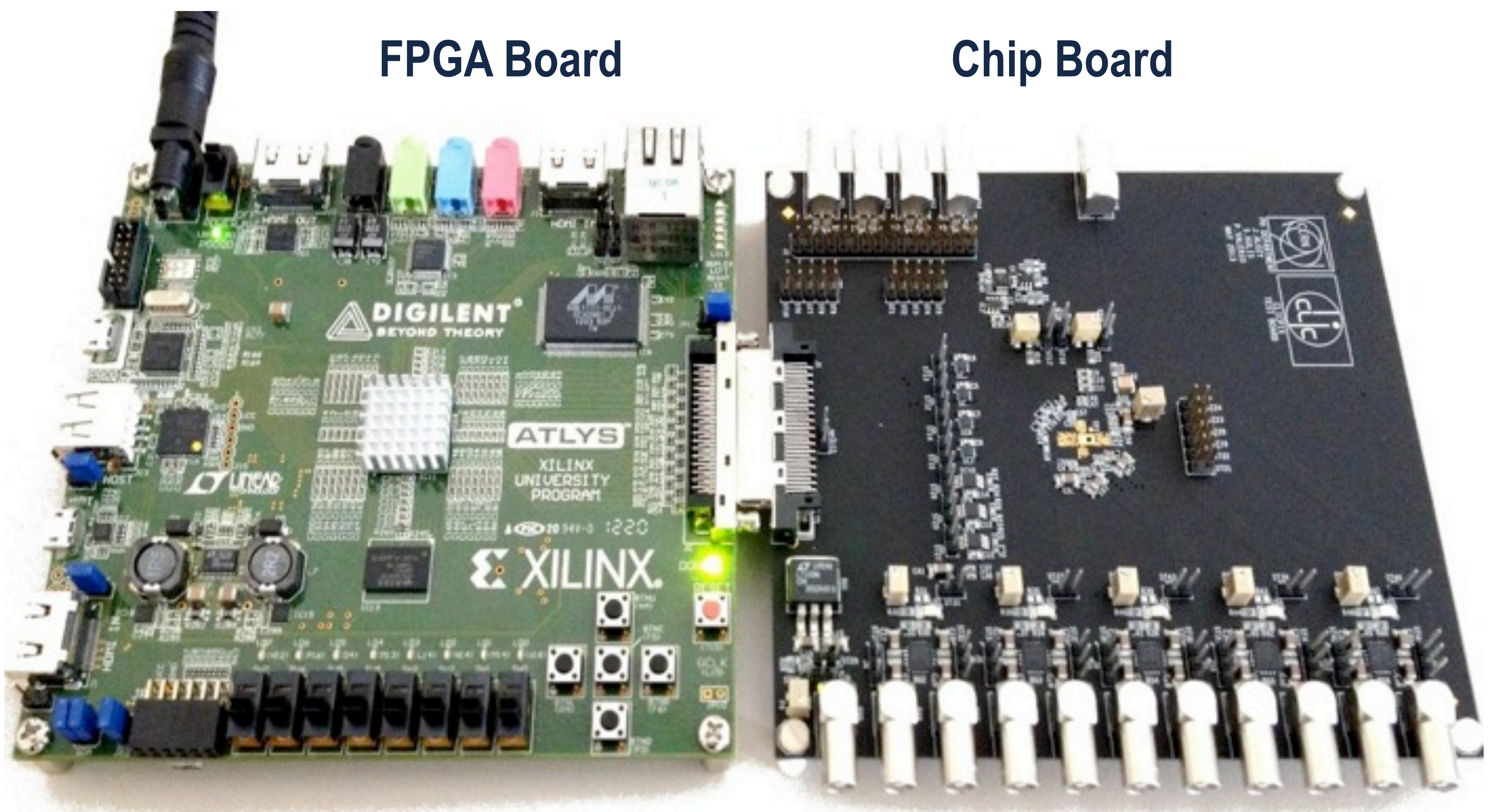
Readout ASIC: CLICpix

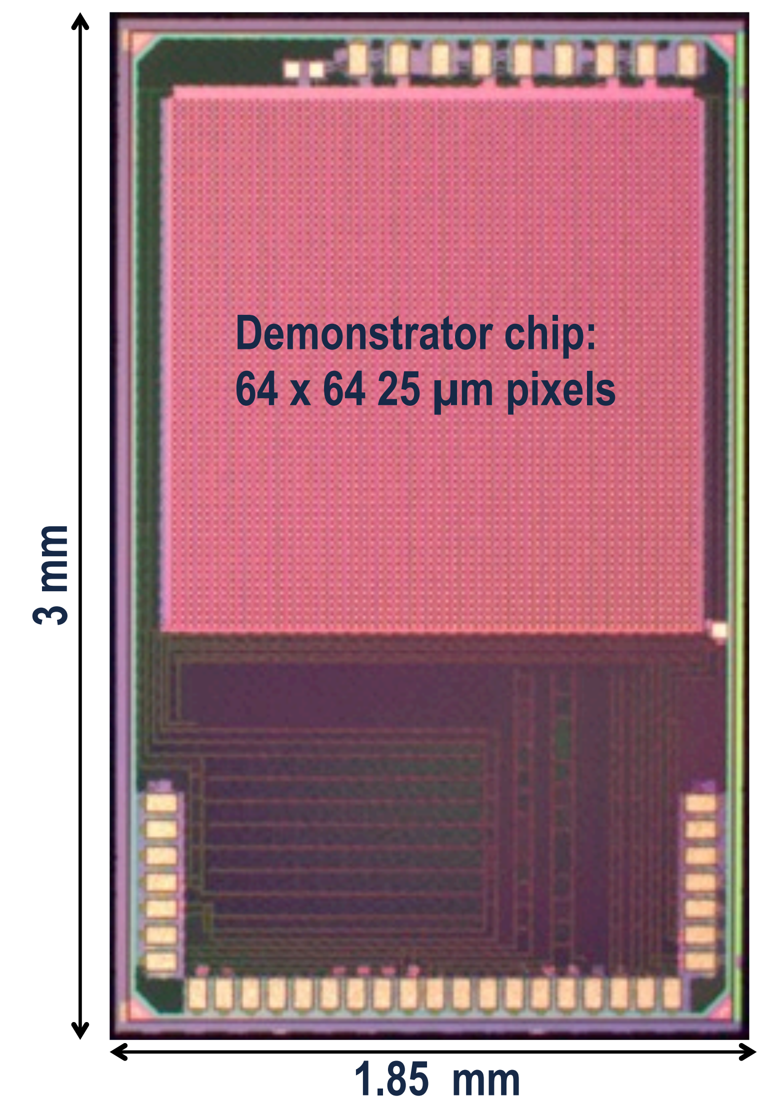
- The CLICpix ASIC: a fast, low power readout chip with 25 μm pitch
- 4-bit TOA and TOT measurements for each pixel
- Supports power-pulsing and data compression
- Implemented in 65 nm CMOS technology

For more details see talk by P. Valerio, Friday 10 am

FPGA Board

Chip Board

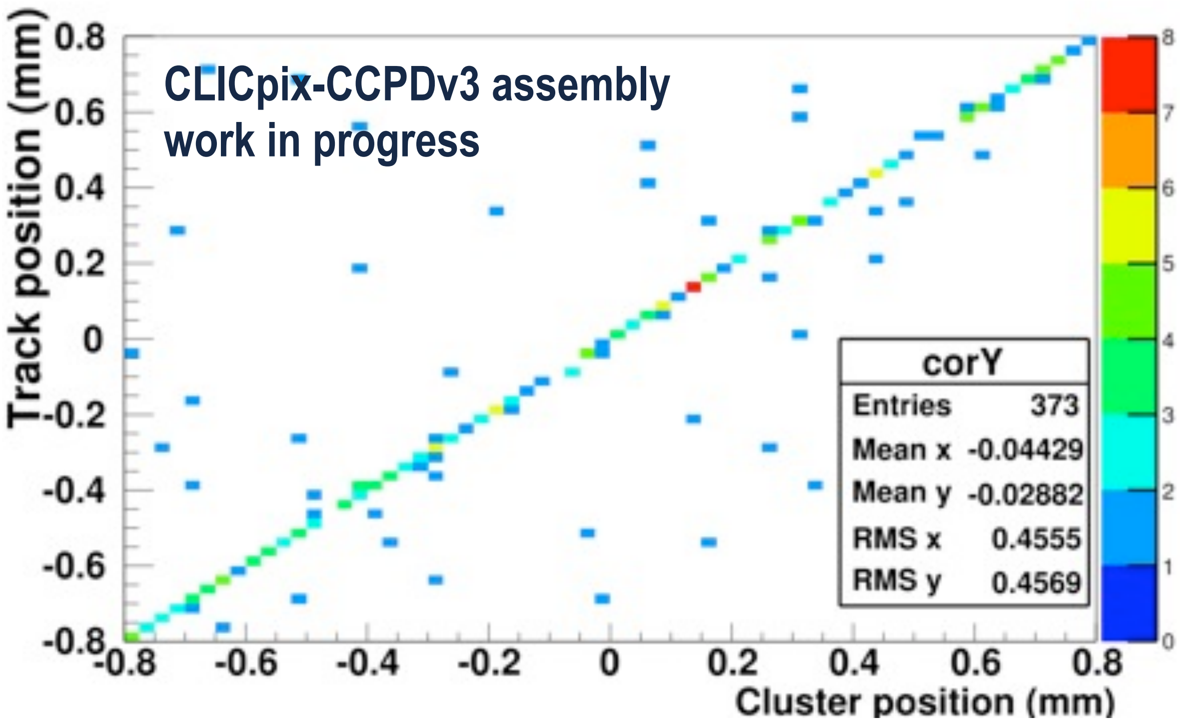


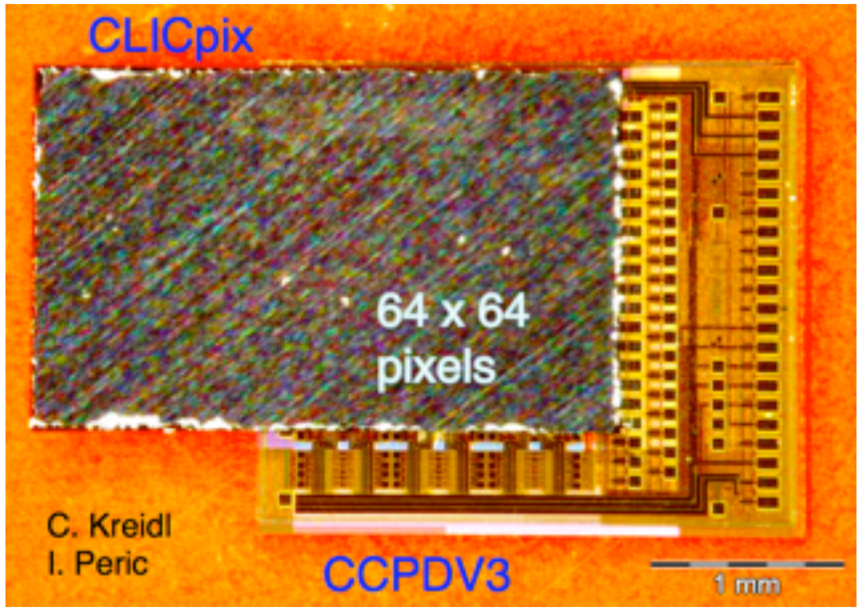


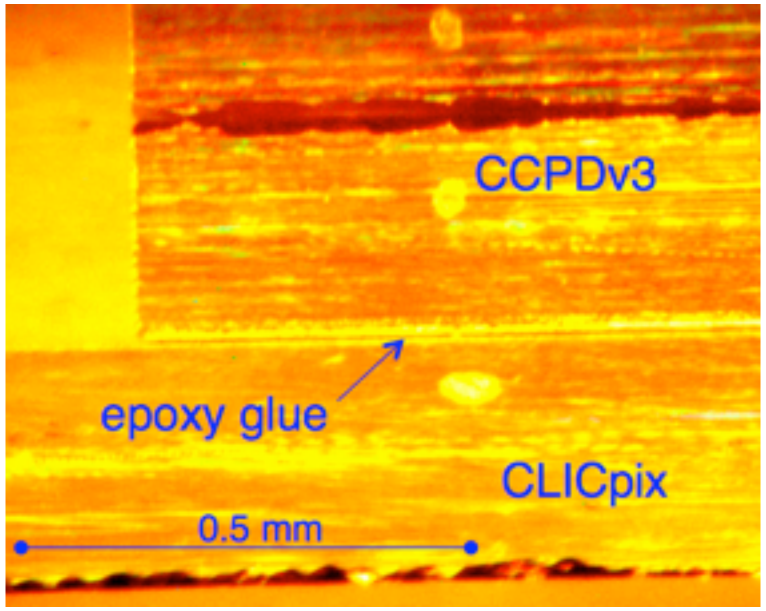
CLICpix test beam

Capacitive coupled pixel detector (CCPDv3):

- Active sensor with two-stage amplifier in each pixel
- Implemented in AMS H18 180 nm HV-CMOS process
- Capacitive coupling to CLICpix bond pads through layer of glue
- Test beam integration successful, results to come





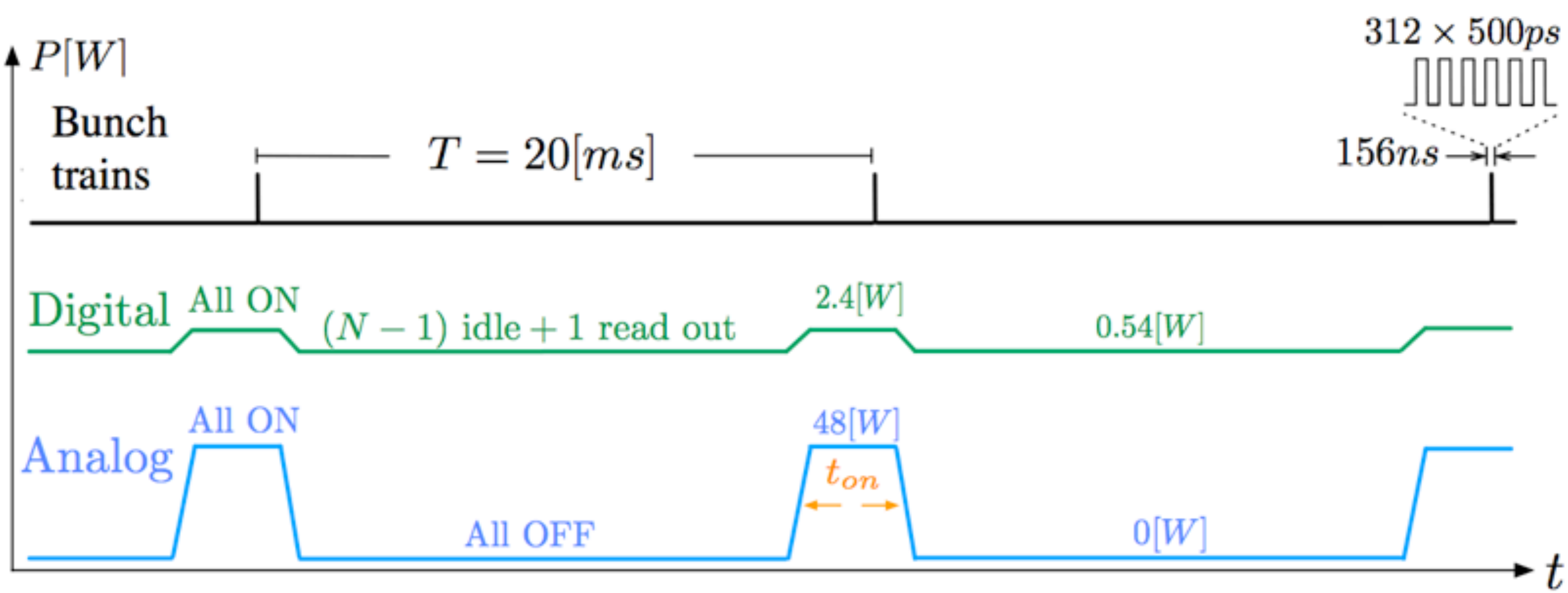


Next:

- First trials of bump-bonding to CLICpix to take place at SLAC (awaiting sensor delivery)

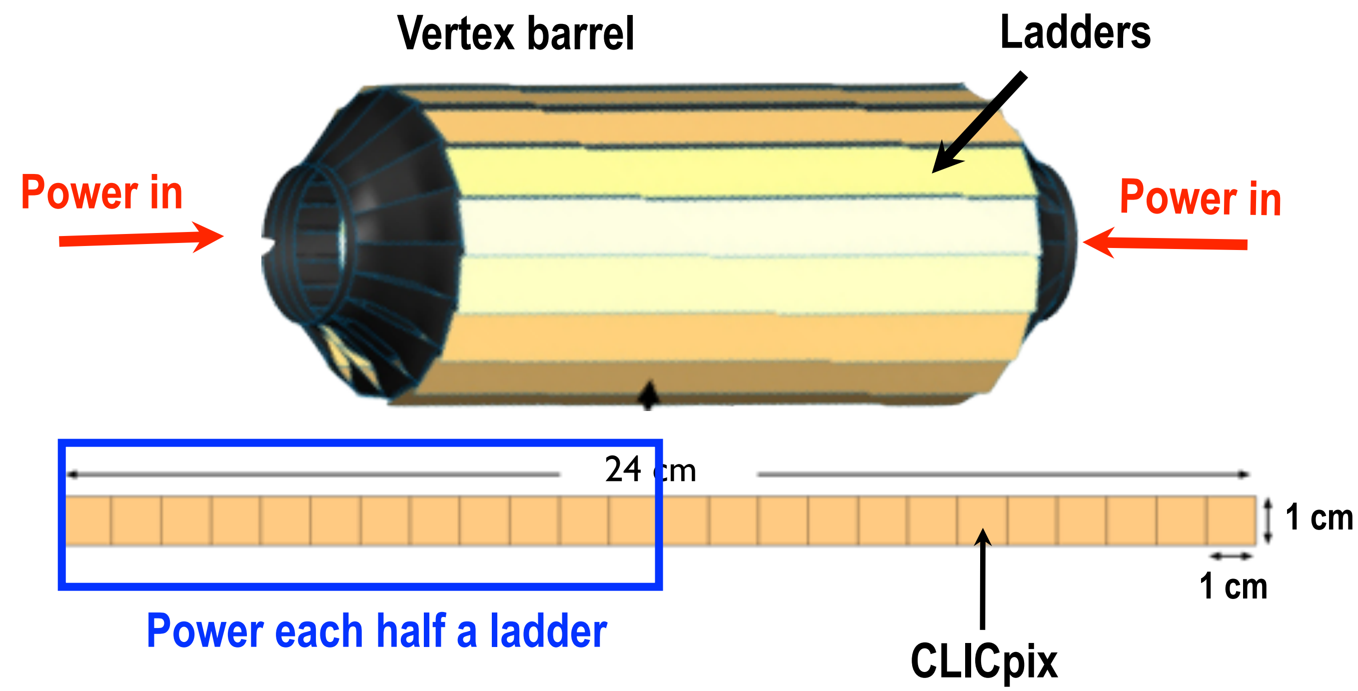
Power-pulsing strategy

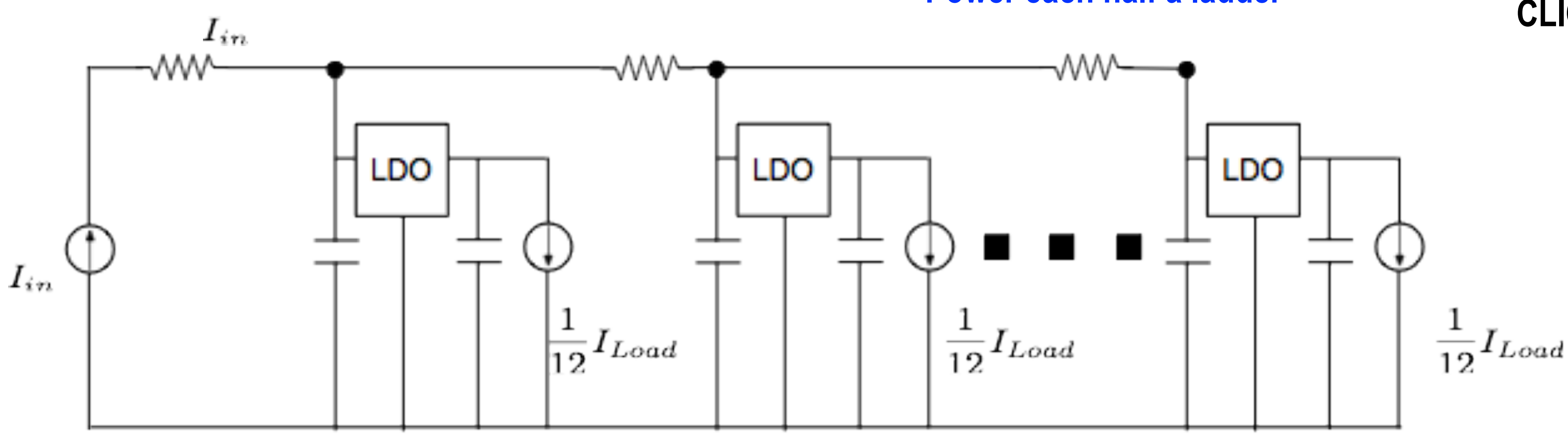
- Power pulse CLICpix ASIC to achieve dissipation <50 mW/cm^2 in the sensor area
- Analog electronics can be turned off: 2 W/cm^2 → 2 mW/cm^2
- Digital electronics in idle except during readout: 100 mW/cm^2 → 13 mW/cm^2



Power delivery

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

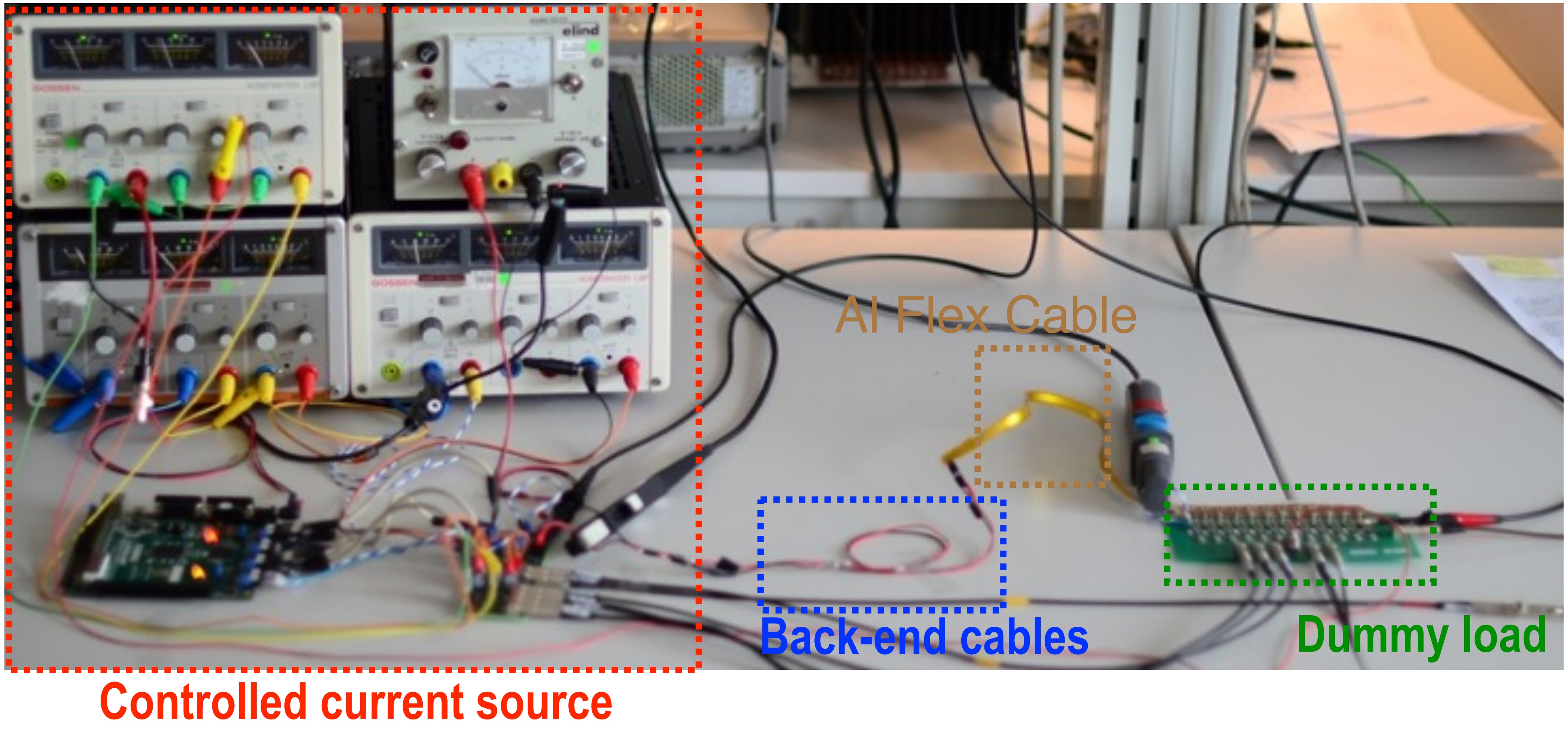




Material budget:

- Aluminium flex cables and silicon capacitors reduce material
- Powering currently adds 0.1% X_0 per layer.
- Projected: < 0.05% X_0 (improved storage capacitor power density, thinner conductors)

Power-pulsing lab tests



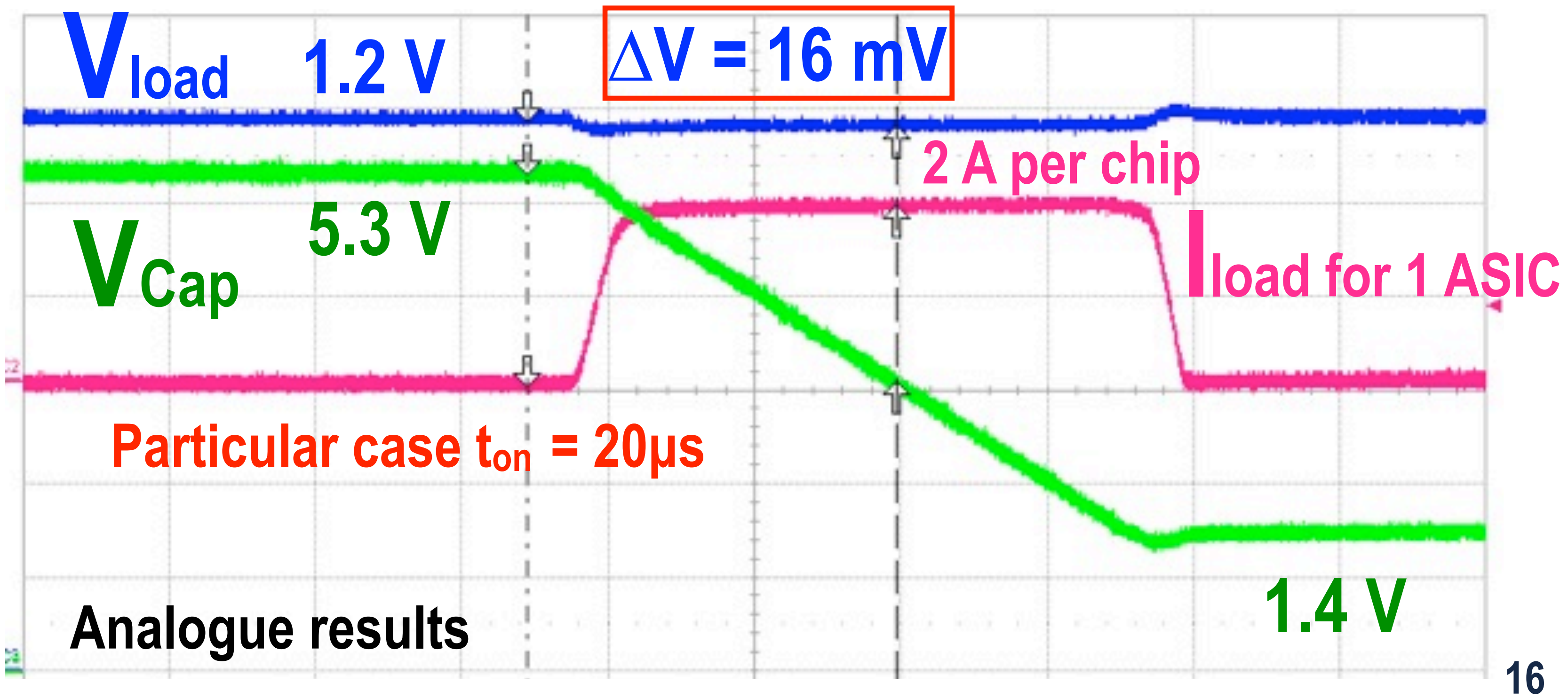
Analogue:

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

Digital:

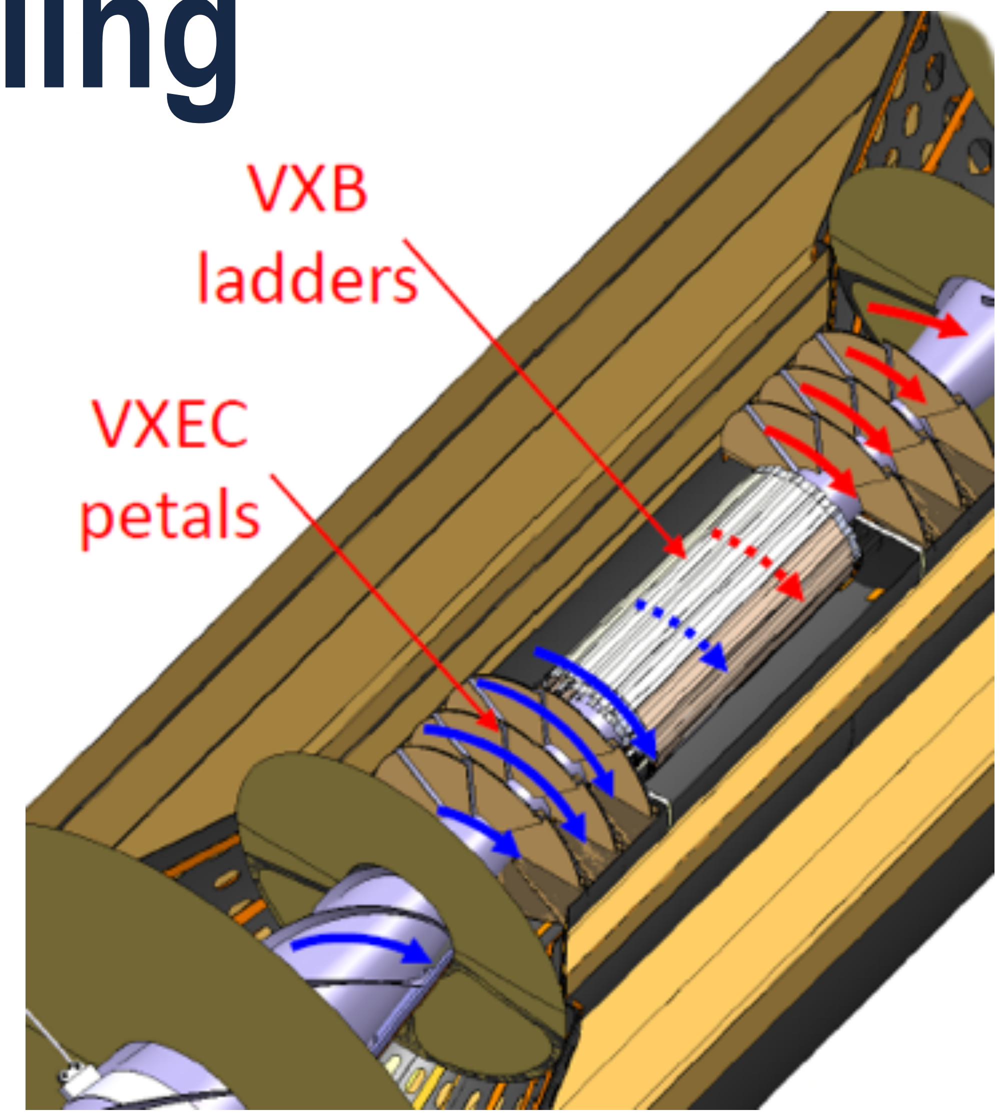
- Measured average power dissipation < 35 mW/cm^2

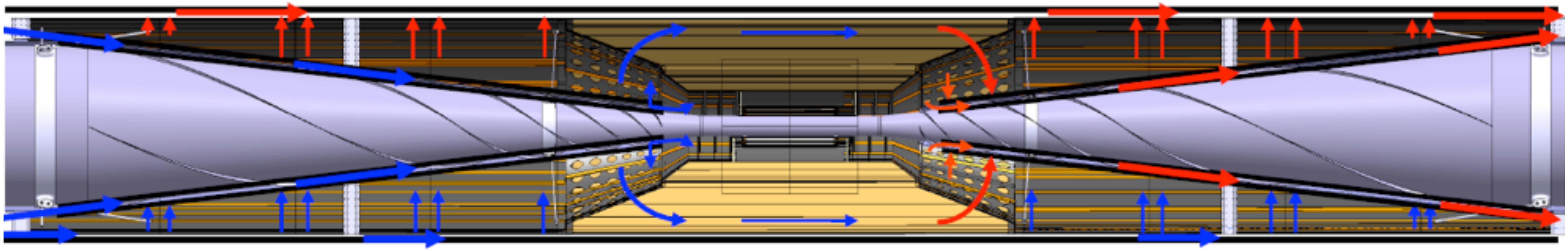
Total dissipation: < 50 mW/cm^2



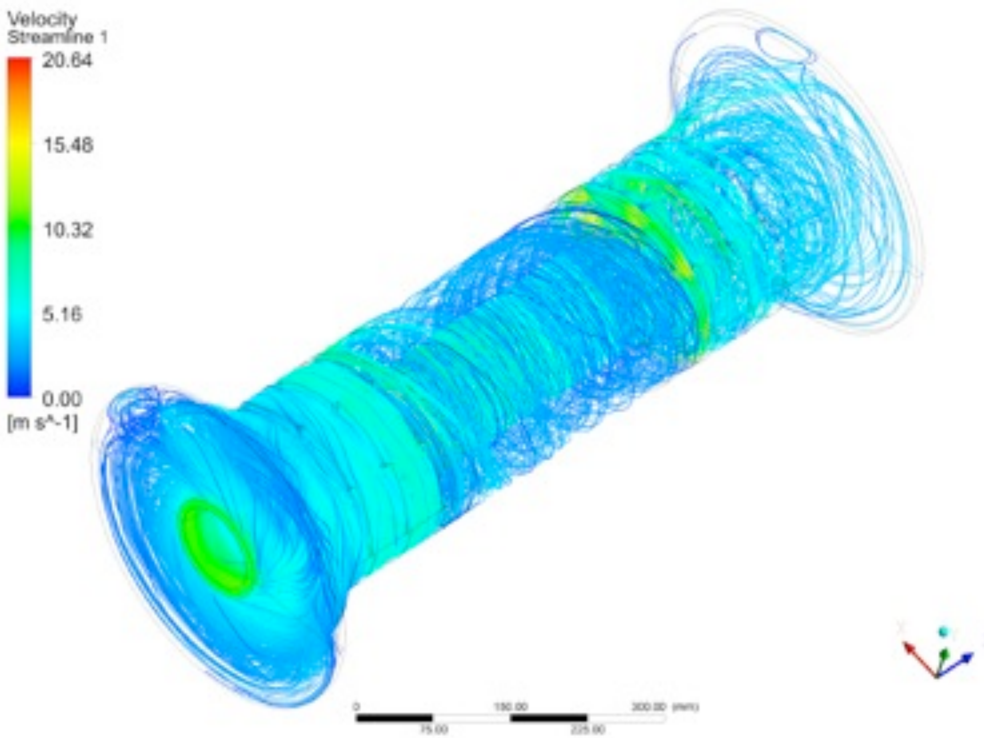
Air-flow cooling

- 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



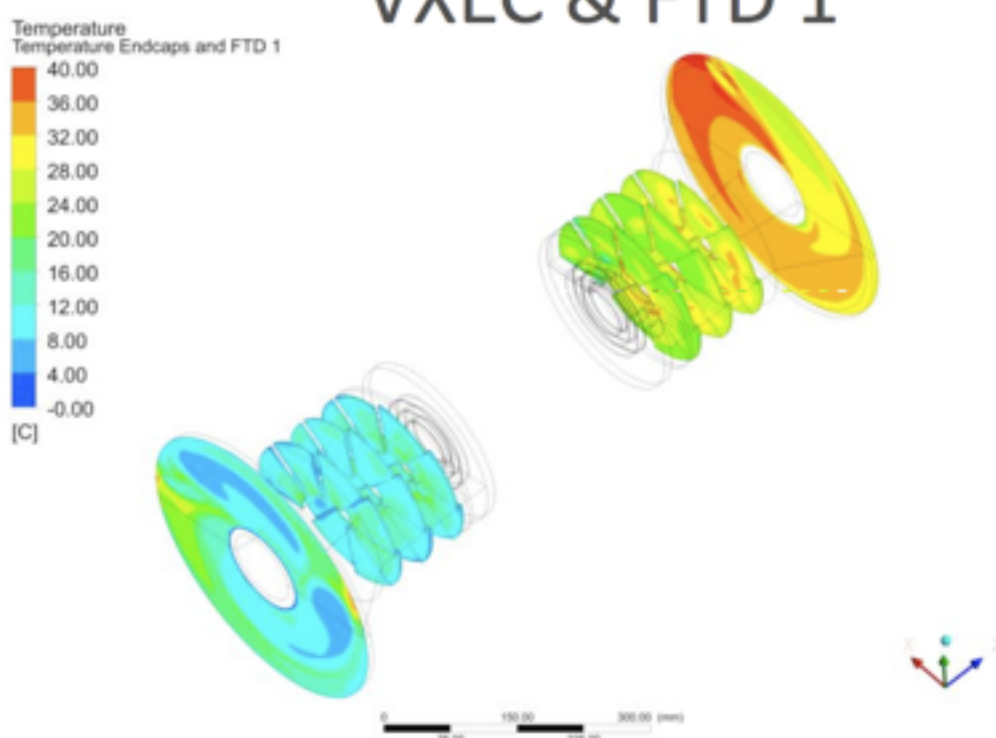


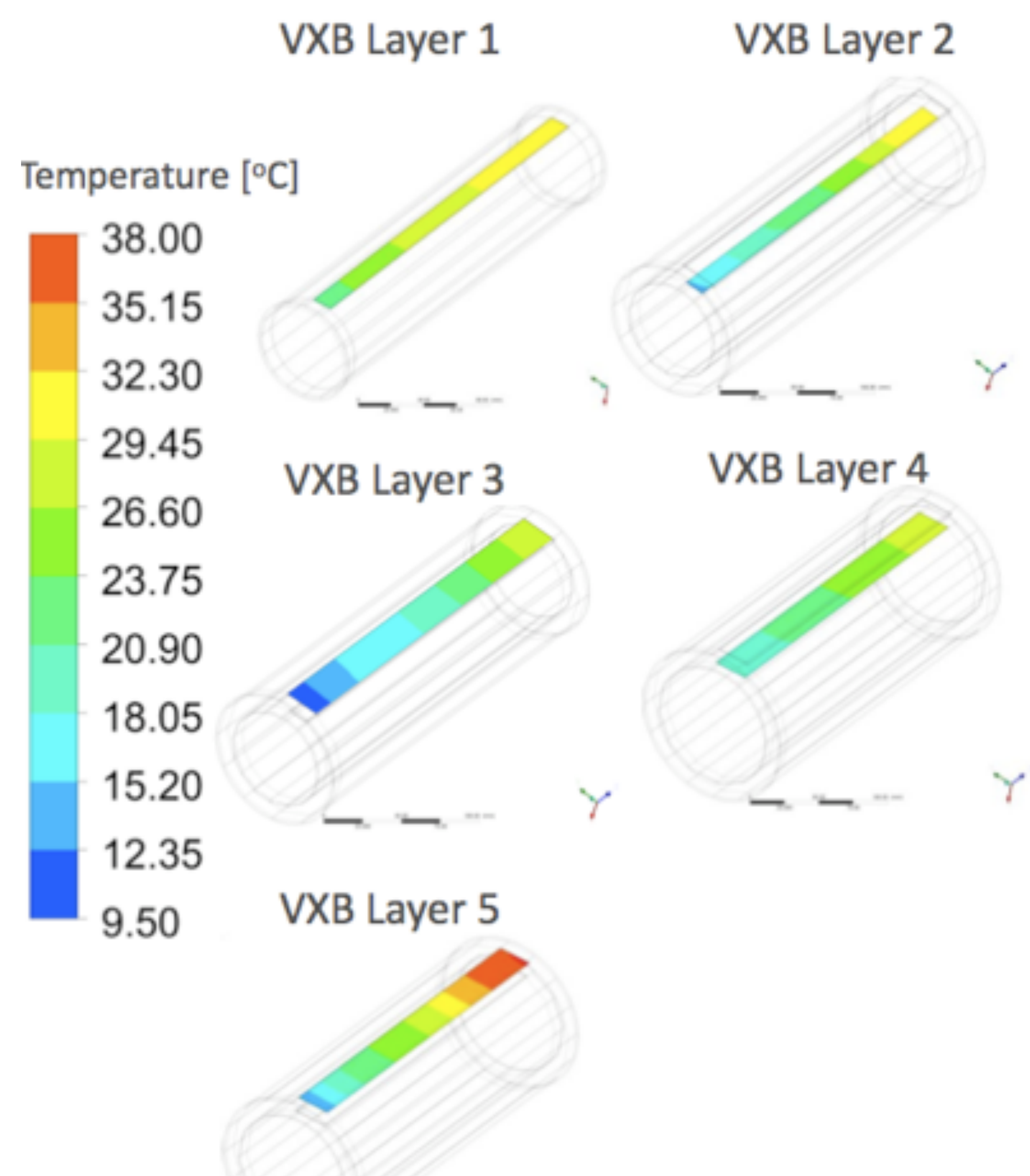
Air-flow simulations



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

VXEC & FTD 1*

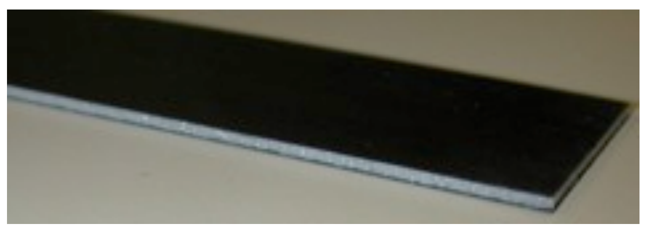




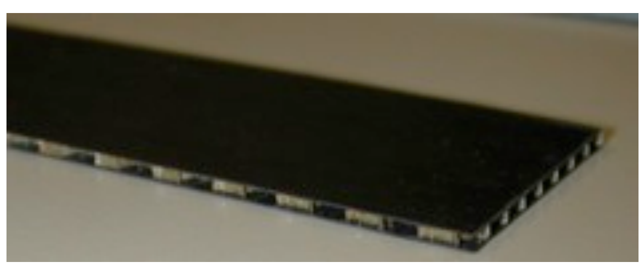
Mechanical support structures

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

Full sandwich stave

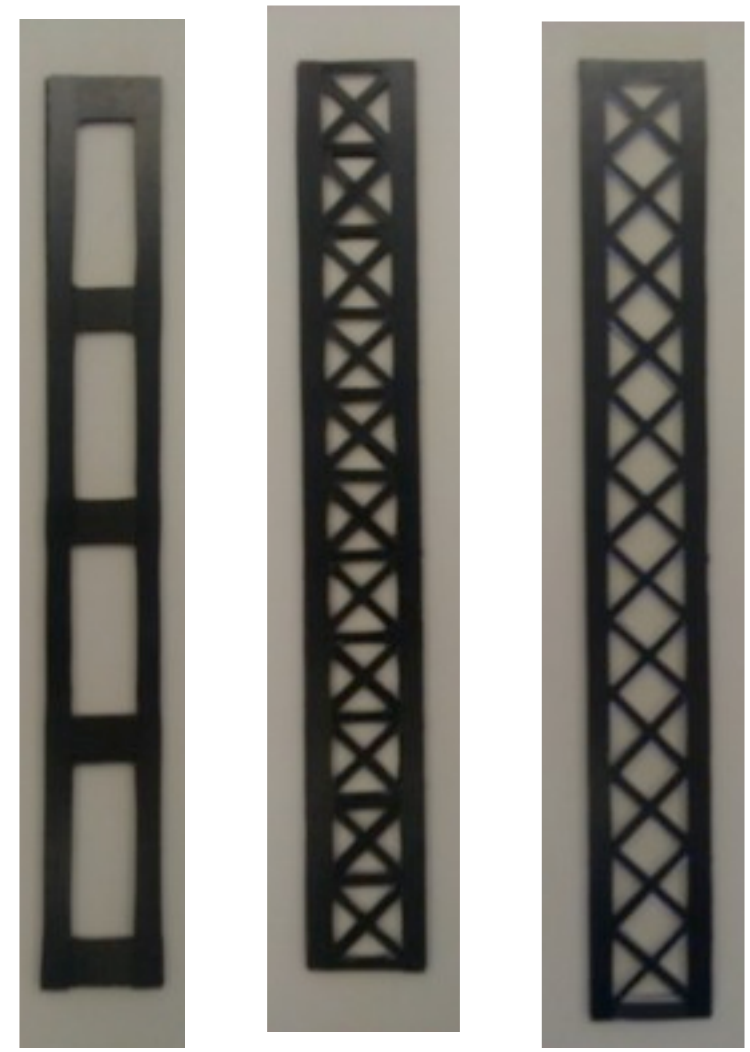


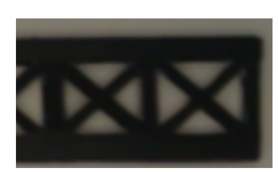
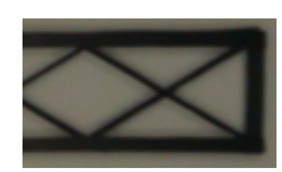
Rohacell core (PMMA)



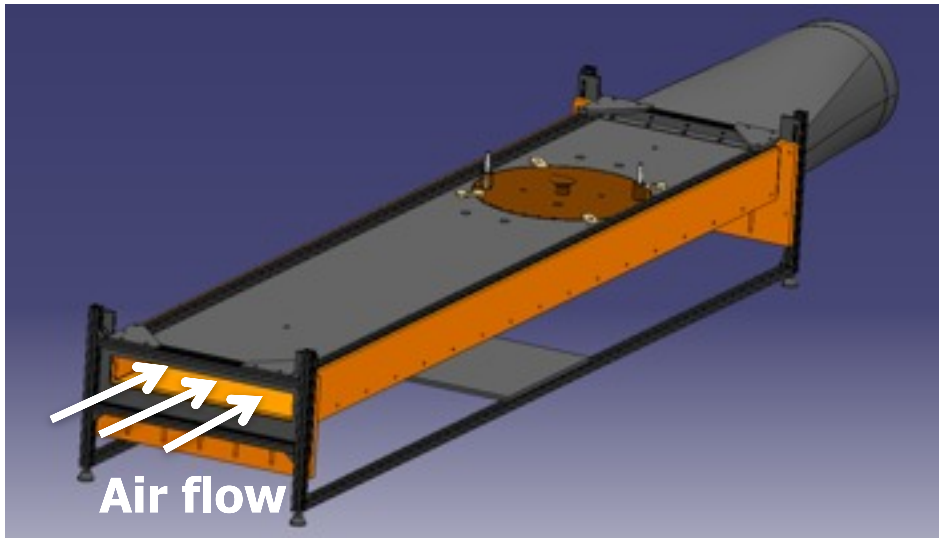
Honeycomb core
(Nomex and Carbone)

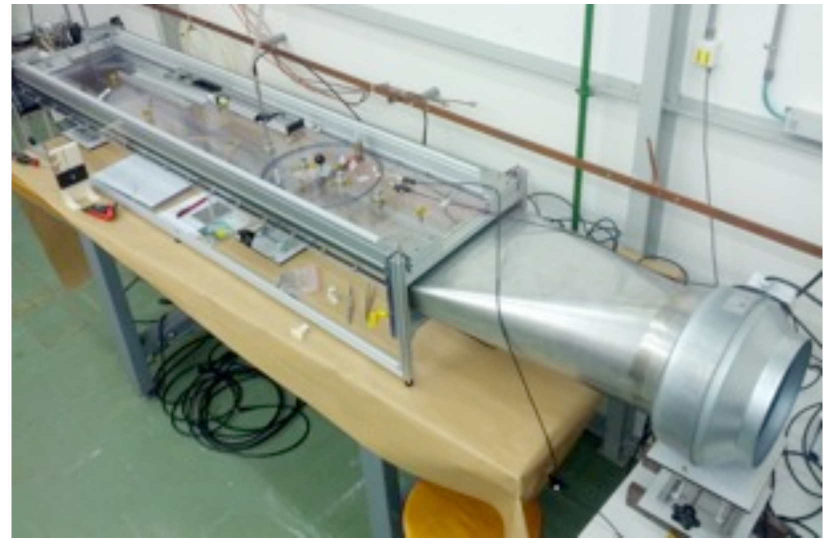
Cross braced staves

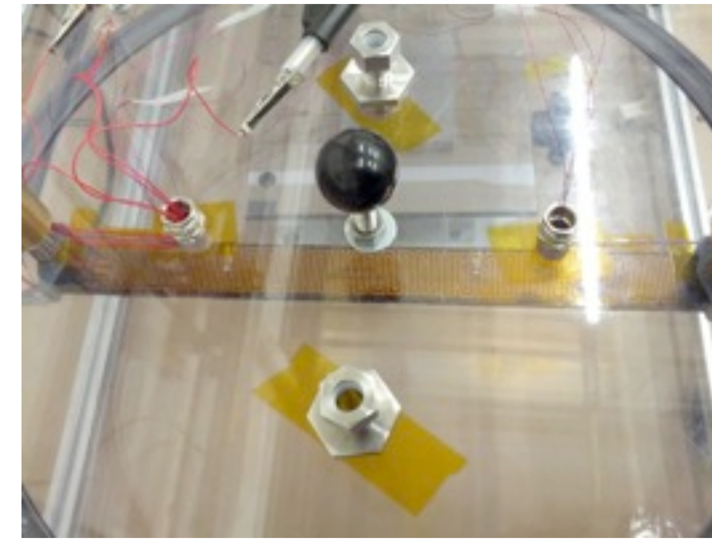


					
Mass	3.74 g	3.45 g	3.08 g	2.74 g	1.76 g
X/X_0	0.121%	0.112%	0.118%	0.068%	0.051%

Thermo-mechanical test bench

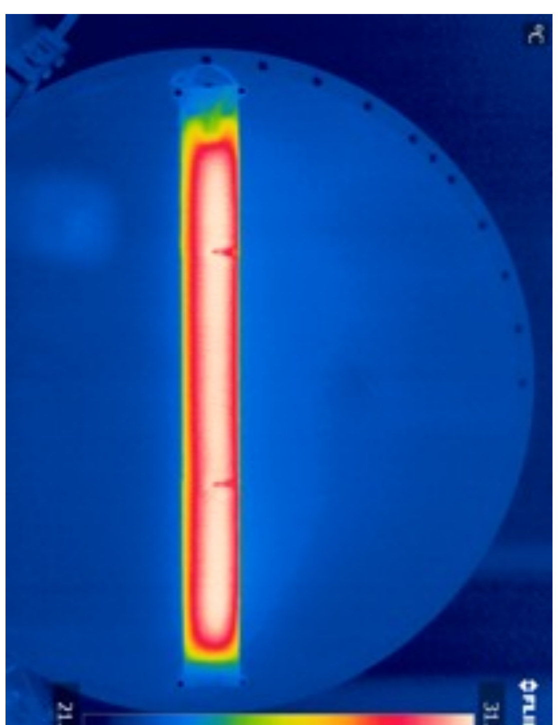




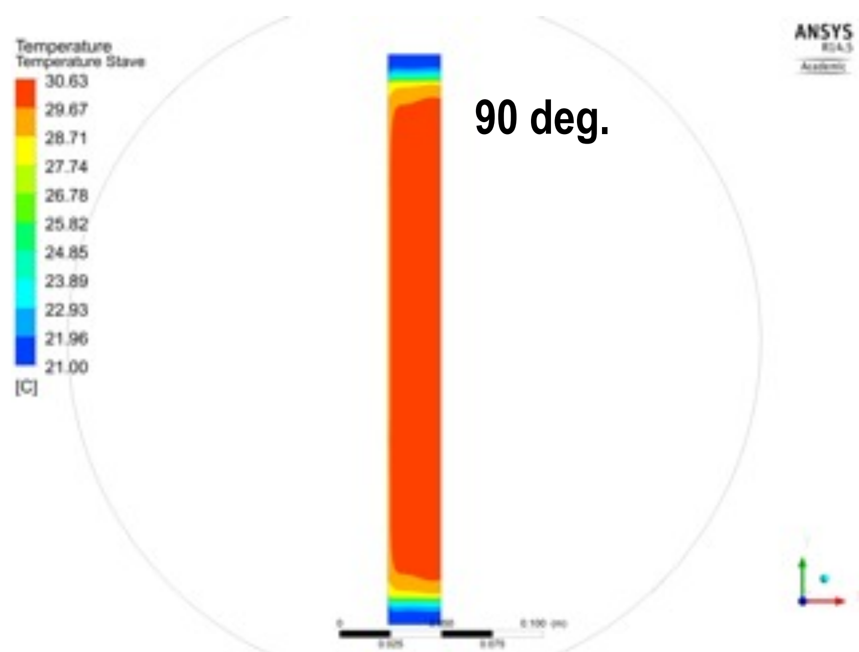


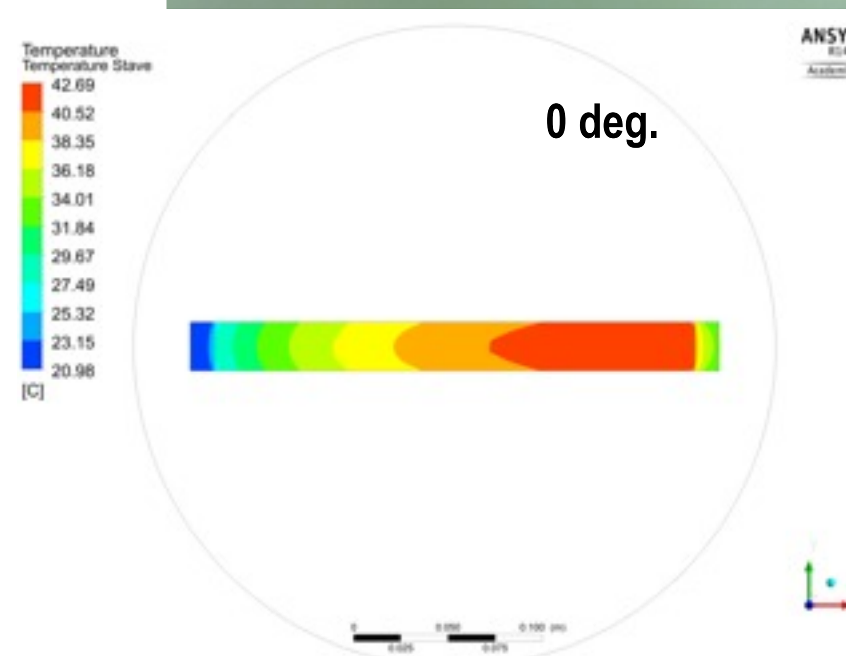
- Measure wind speeds, stave temperatures, stave vibrations
- Allows validation of simulations

Thermal camera



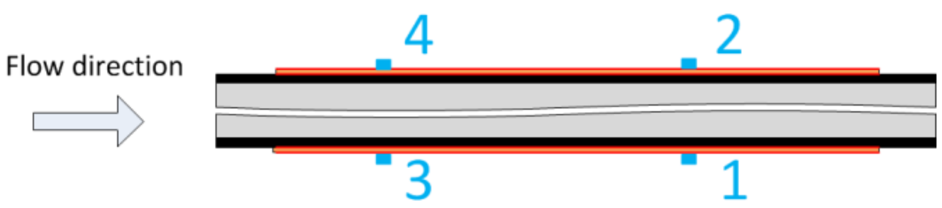
Simulation

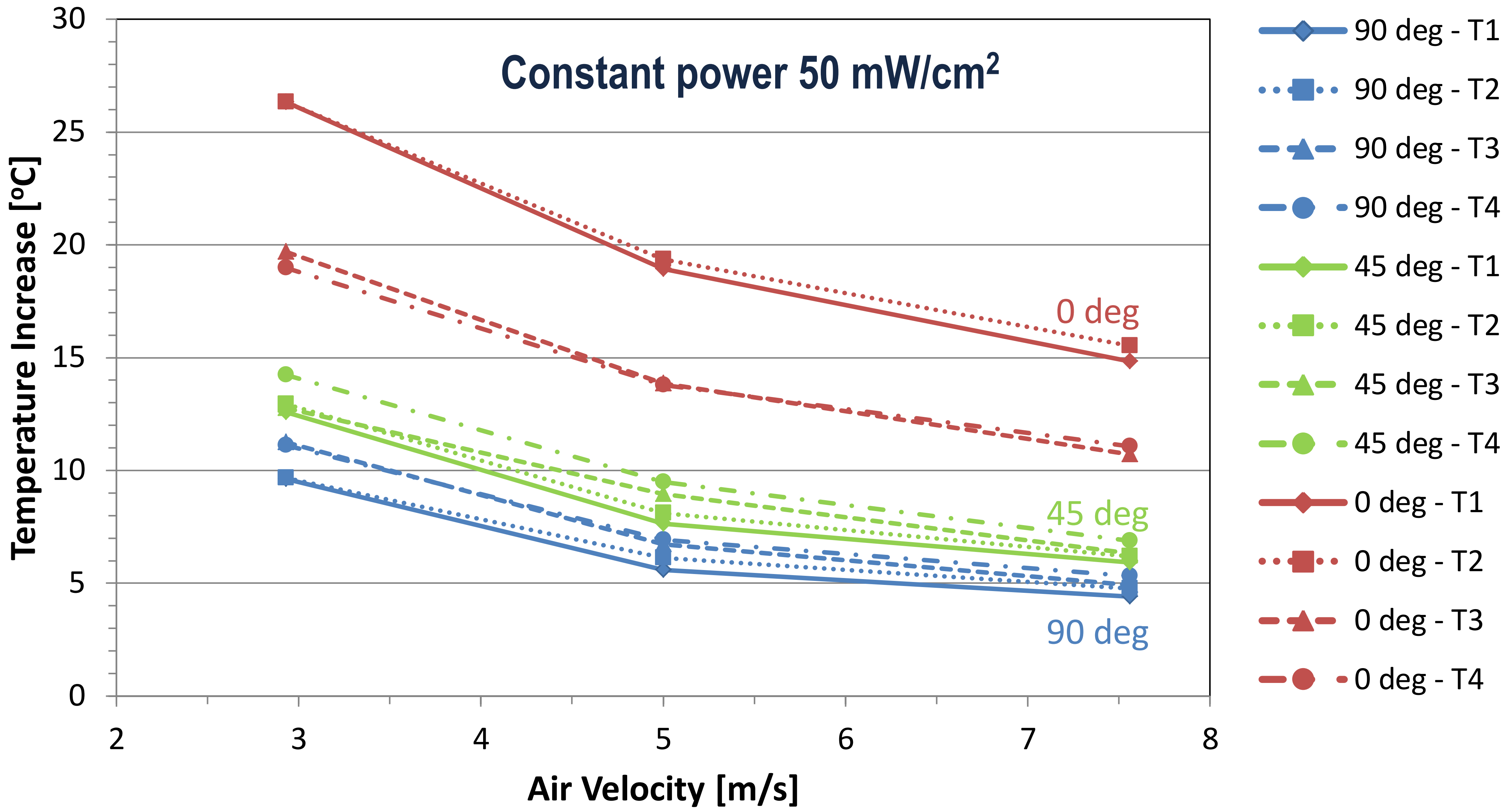




Test bench results - temperature

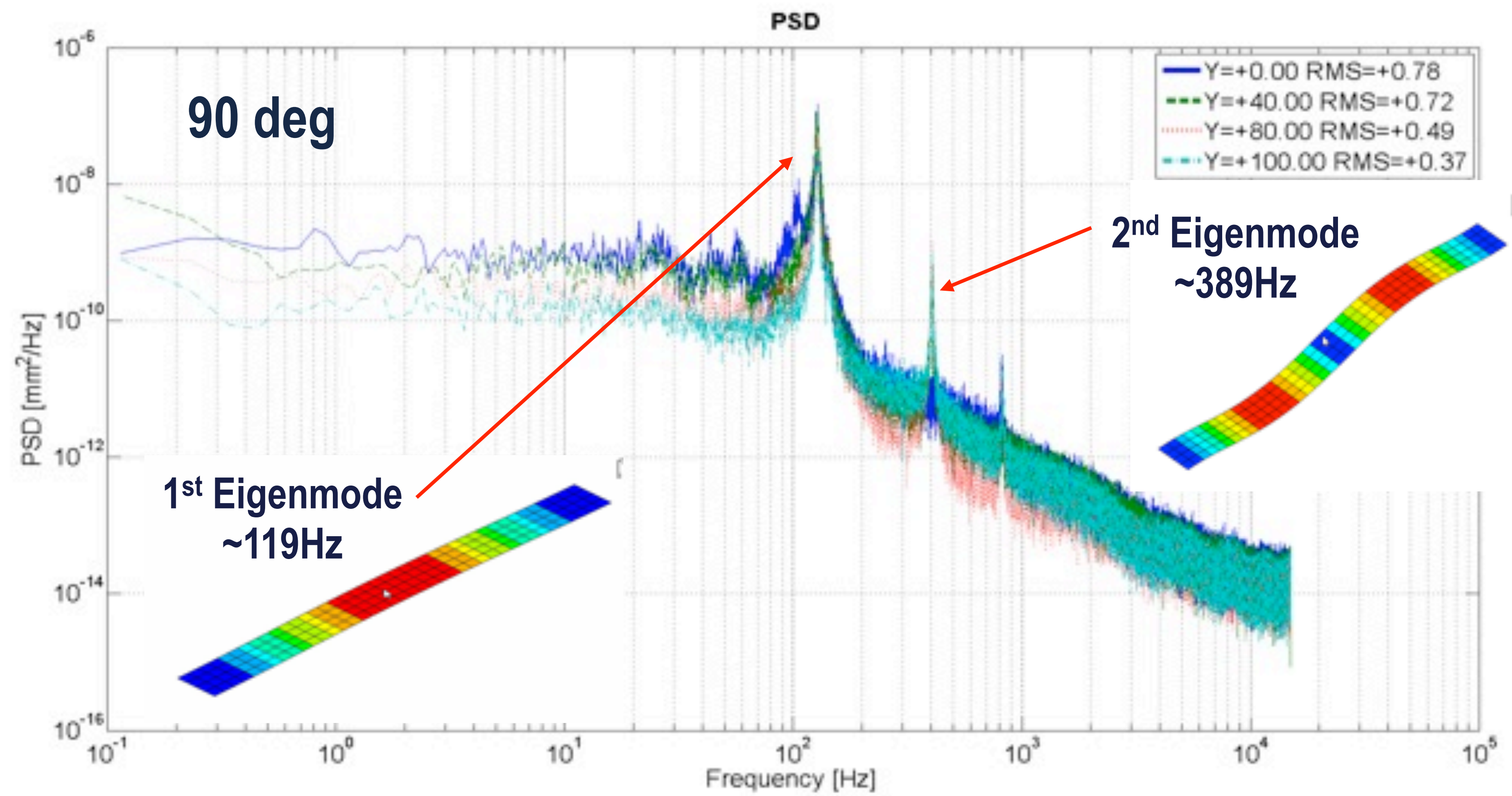
- Temperatures decrease asymptotically for increased air flow
- Perpendicular flow gives lowest and most homogeneous temperature
- Difference between 90° and 45° is small



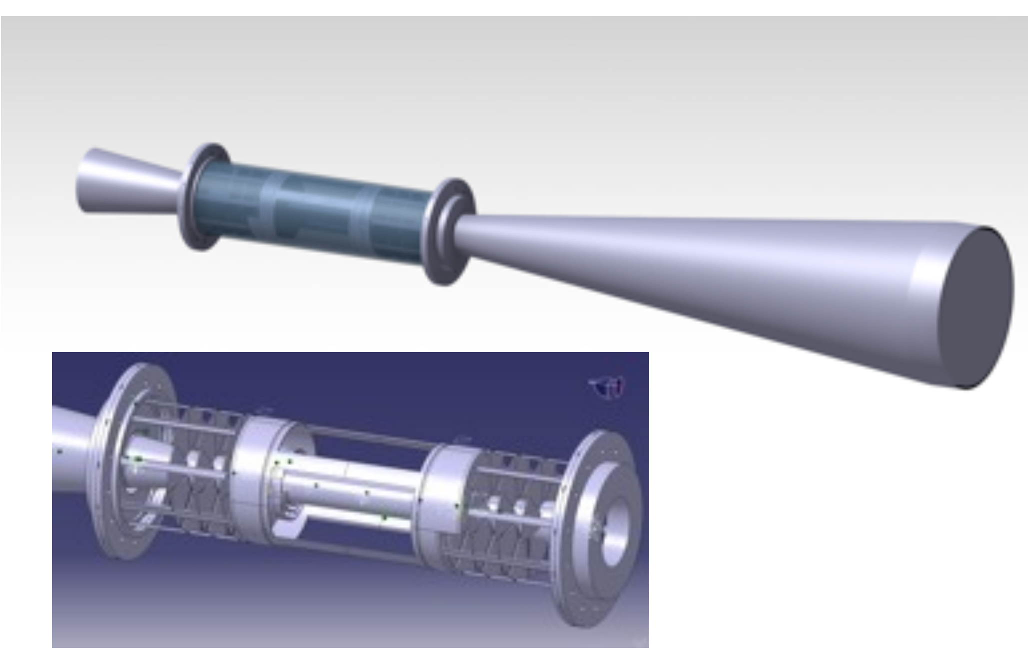


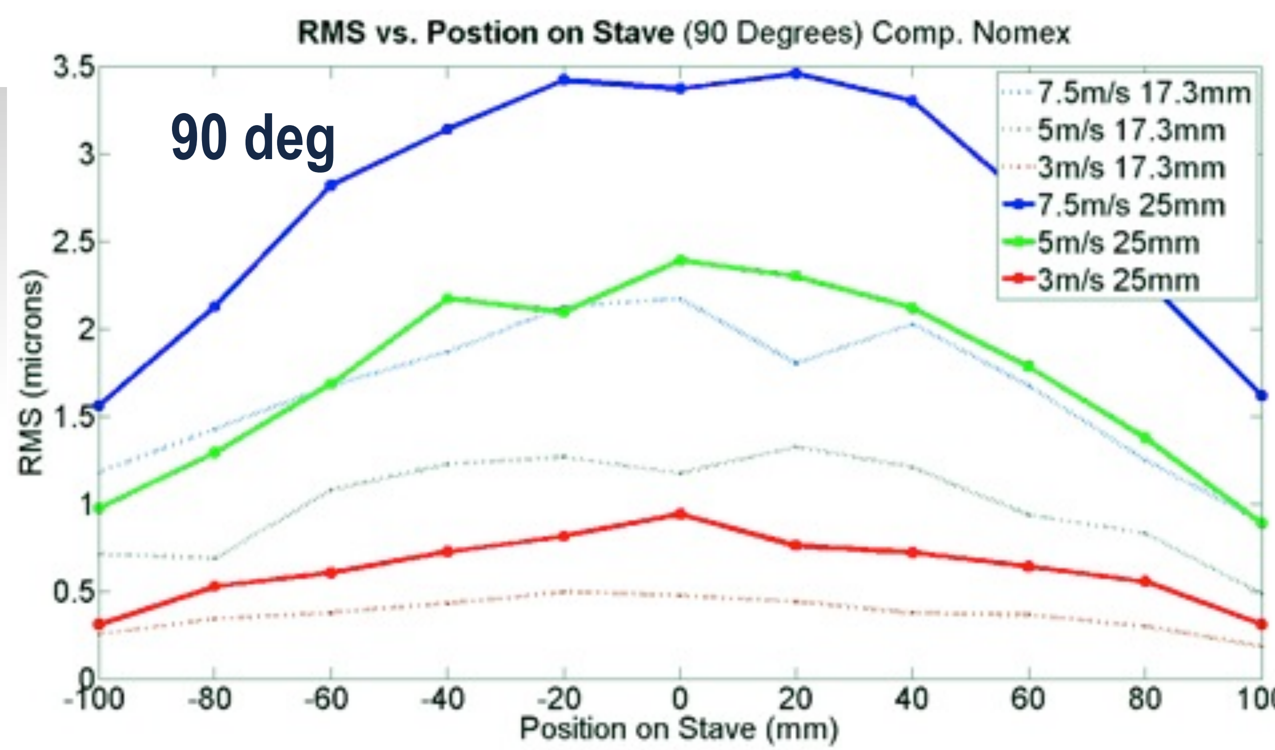
Test bench results - vibration

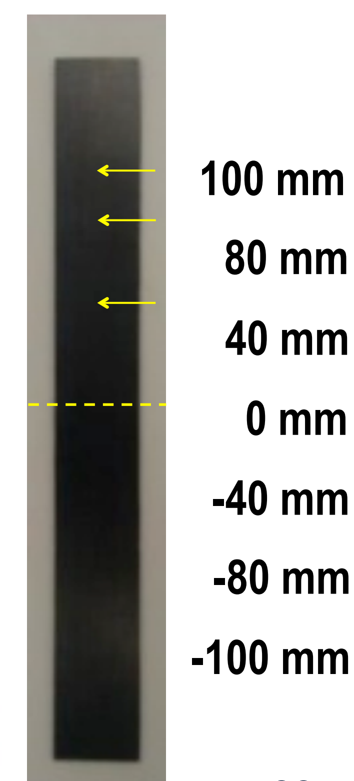
- Vibrations measured along stave with varying wind speeds and channel heights
- Identify eigenmodes of stave and their frequencies
- Maximum displacement (in z) of stave ~ 3um. Reduces with incident wind angle.



Next: 3D printed scale model!



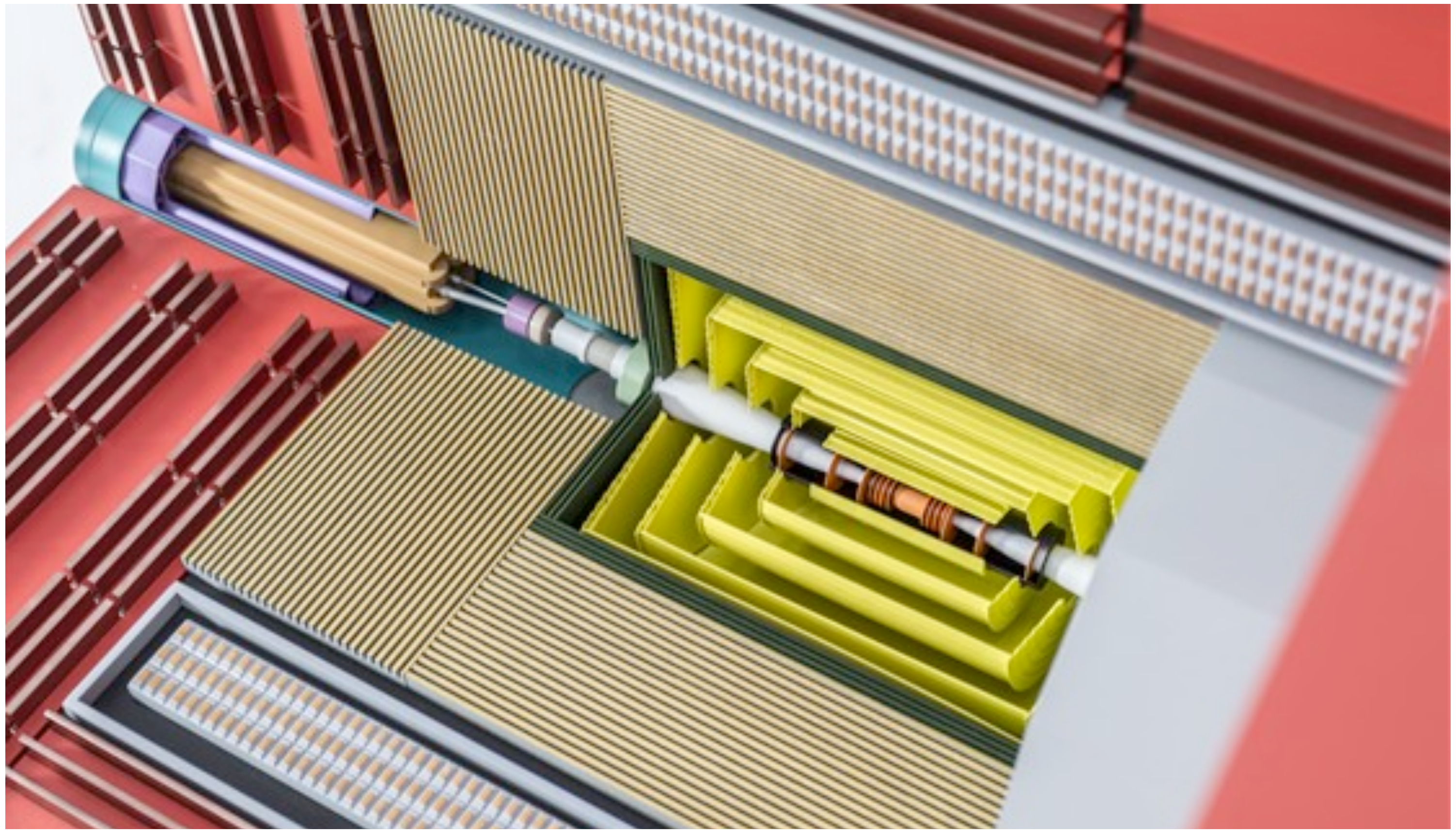




Summary

- CLIC machine and physics requirements place challenging demands on the vertex detector
- Progress made in many areas
- R&D performed 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!