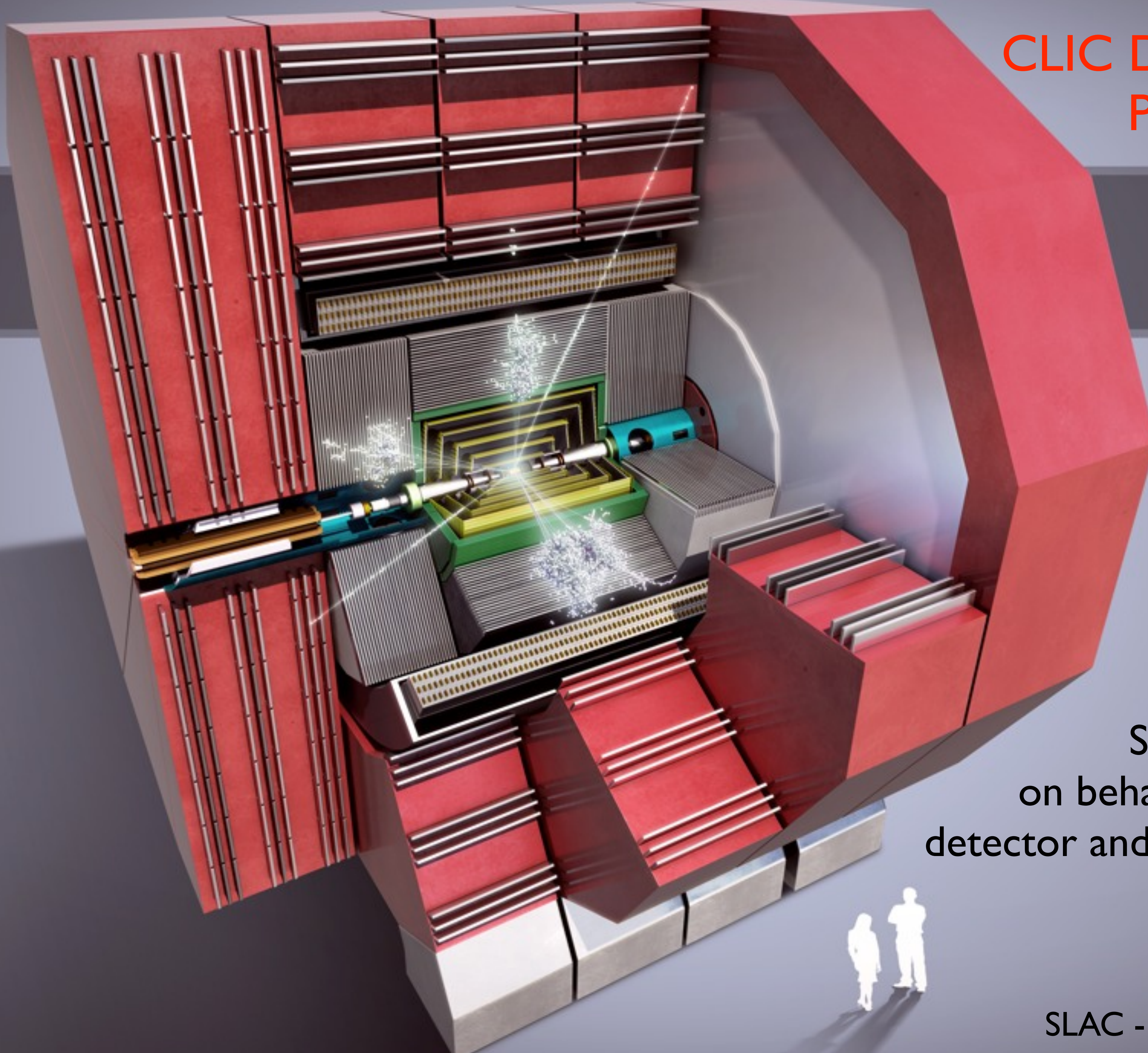
CLIC Detector and Physics News



Sophie Redford
on behalf of the CLIC
detector and physics group

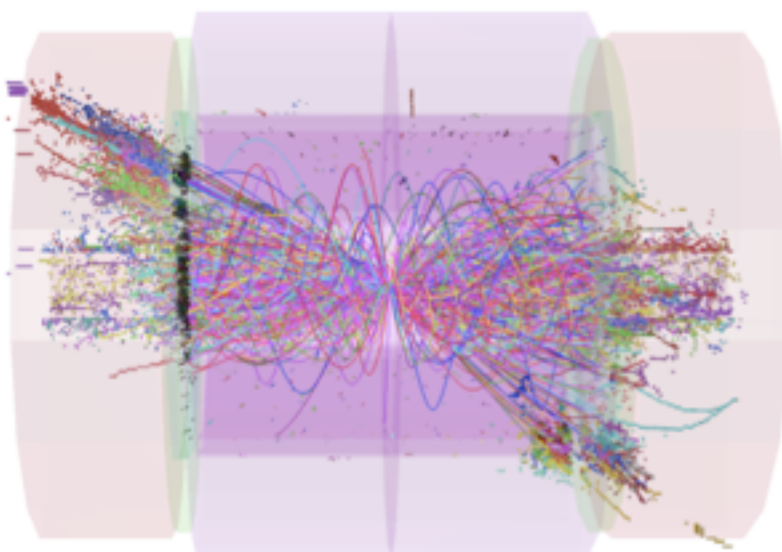
SiD workshop
SLAC - 14 October 2013

Outline

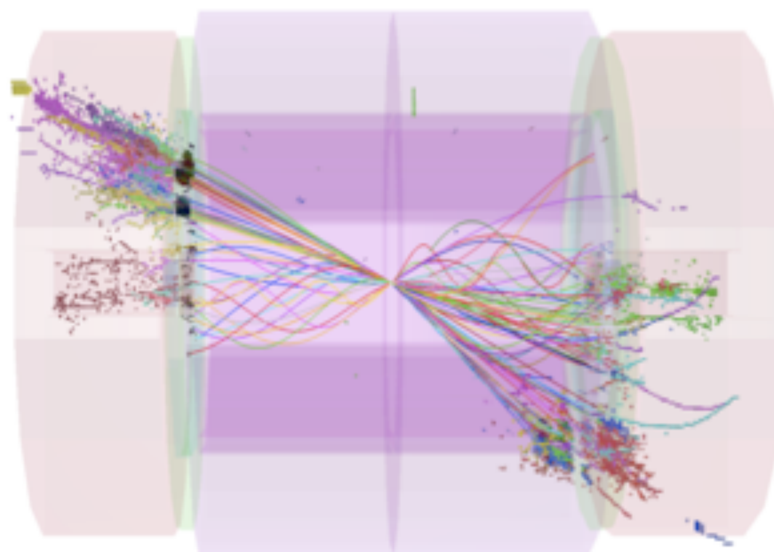
1) Experimental conditions and detector requirements
2) Vertex detector: Thin sensor assemblies; Readout chip: CLICpix; Power-pulsing; Cooling; Geometry
3) ECAL: Cost effectiveness study; Scintillator tile lab tests; Scintillator saturation
4) HCAL: DHCAL testbeam analysis
5) ILCDIRAC
6) Physics benchmarking analyses
7) CLICdp collaboration news

Impact of background on detector design

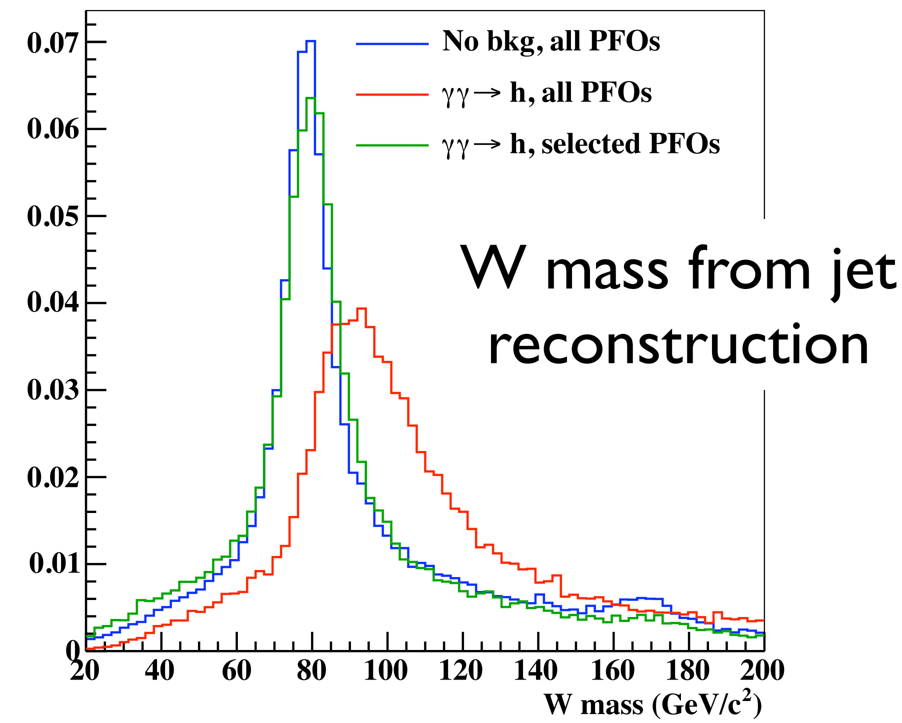
- Time stamping hits and imposing time and momentum cuts reduces $\gamma\gamma \rightarrow$ had backgrounds.
  Timing precision requirement



Before time and momentum cuts



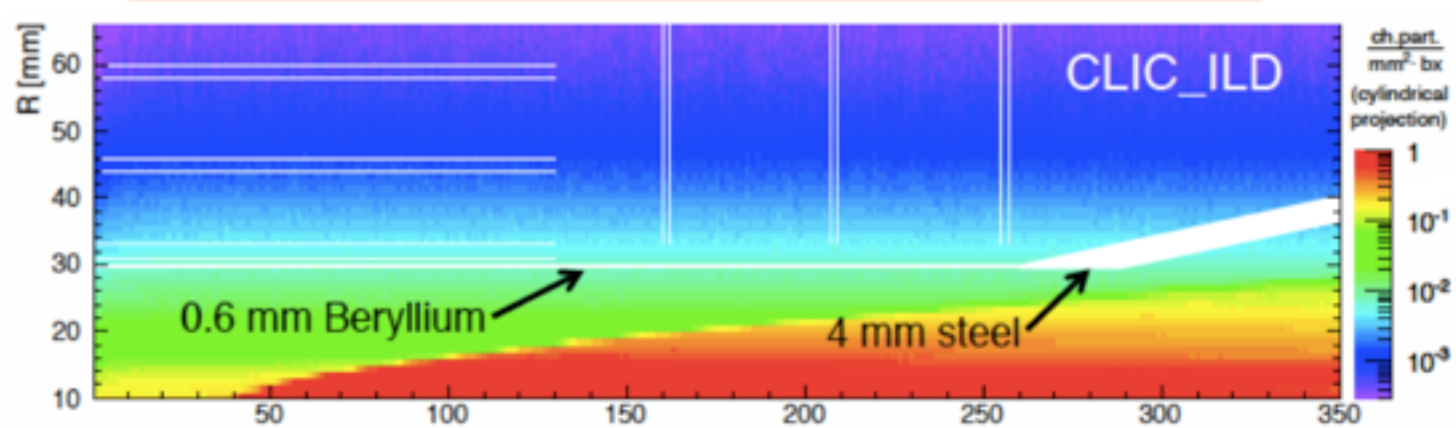
After time and momentum cuts



W mass from jet reconstruction

- Inner radius of vertex barrel and disc positions determined by incoherent pair background.
  Geometric requirement

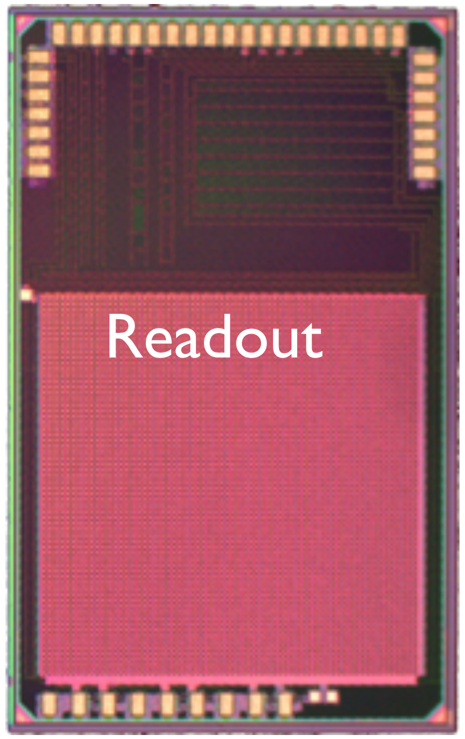
Background considerations influence layout choices of vertex detector

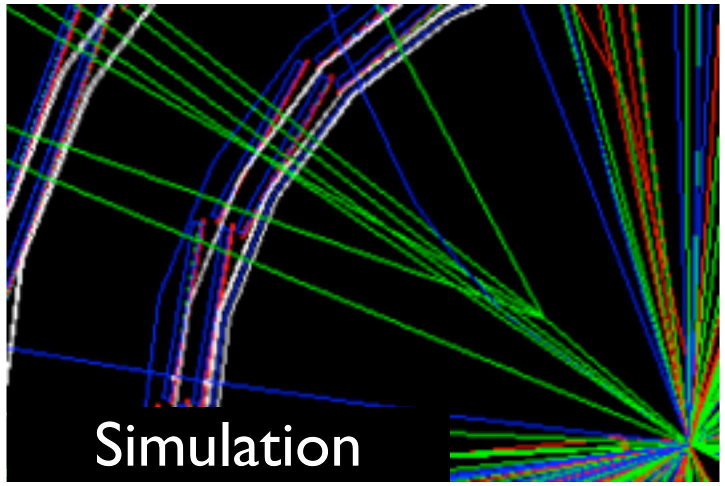


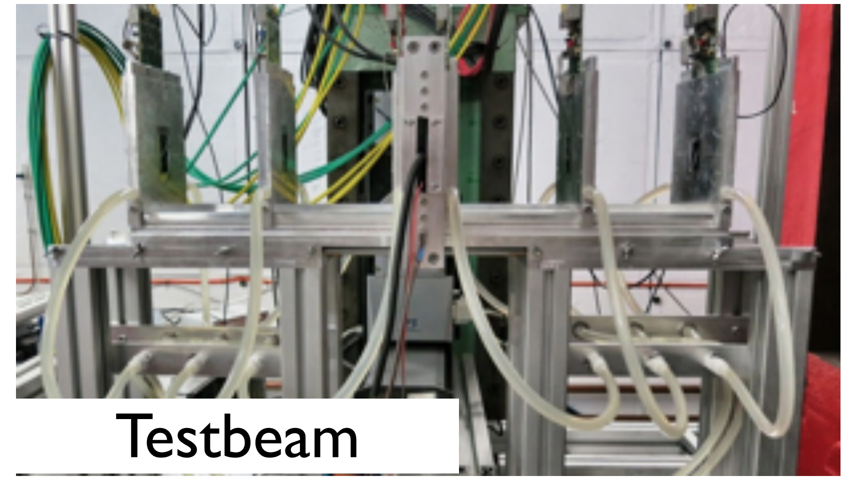
R_{min} = 27 mm CLIC_SiD
R_{min} = 31 mm CLIC_ILD
} Maximum occupancy 1.9% per pixel (including safety factor of 5)

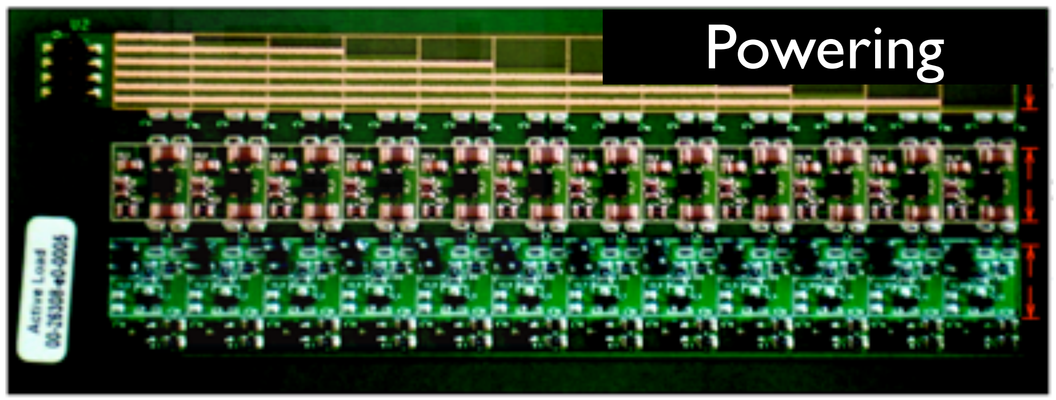
z (mm)

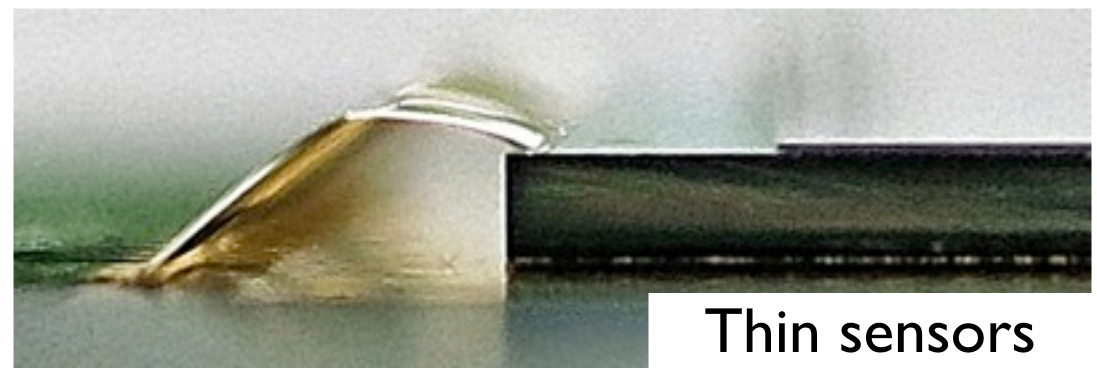
Vertex detector

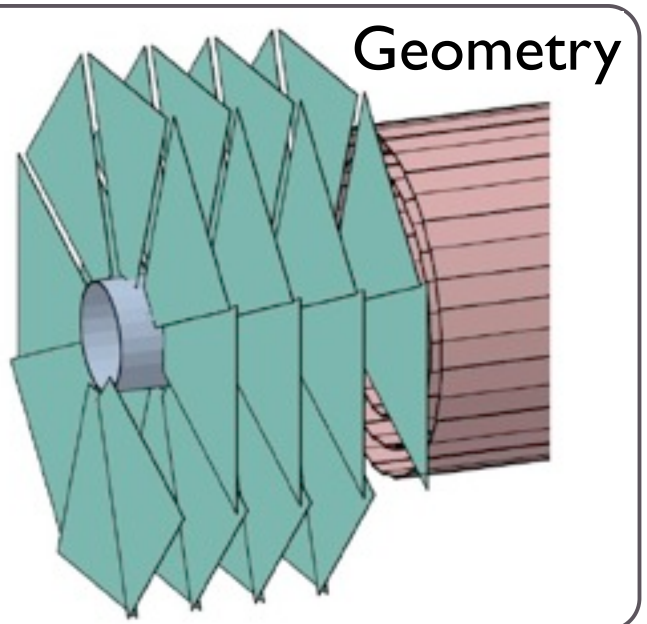


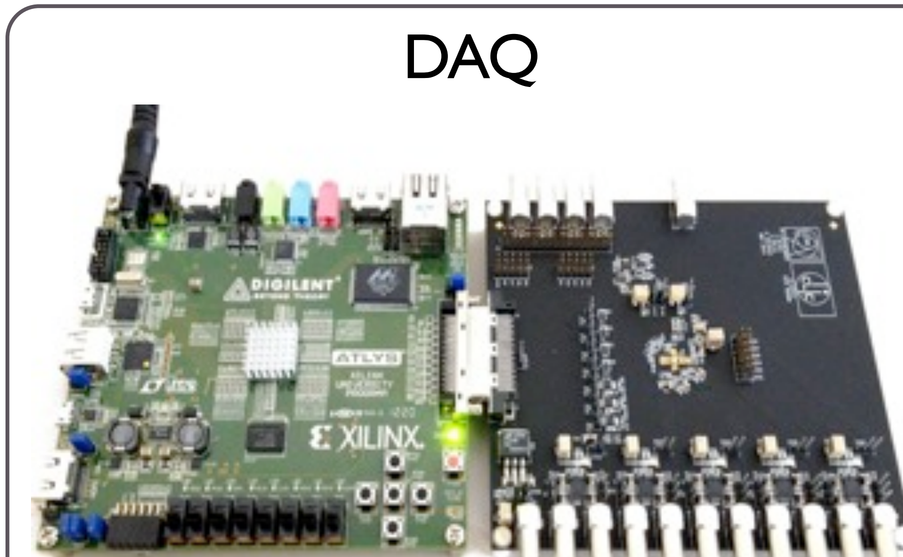


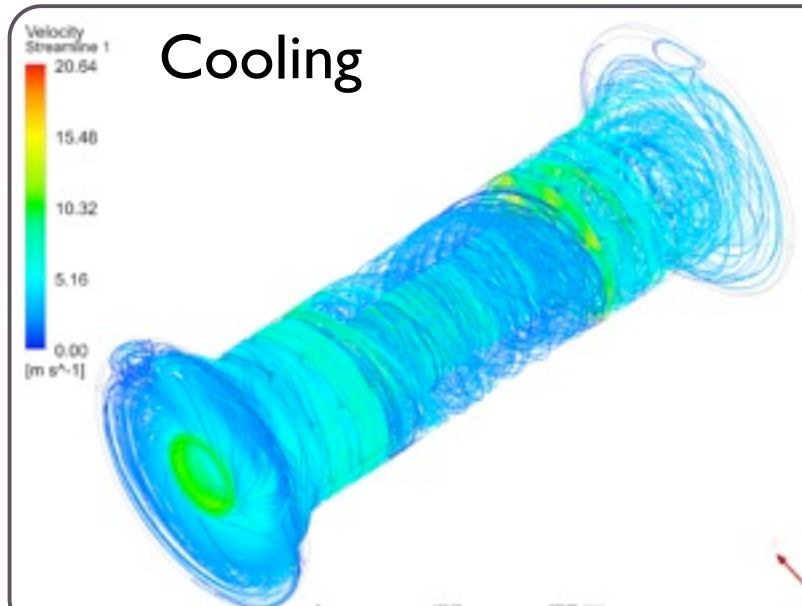








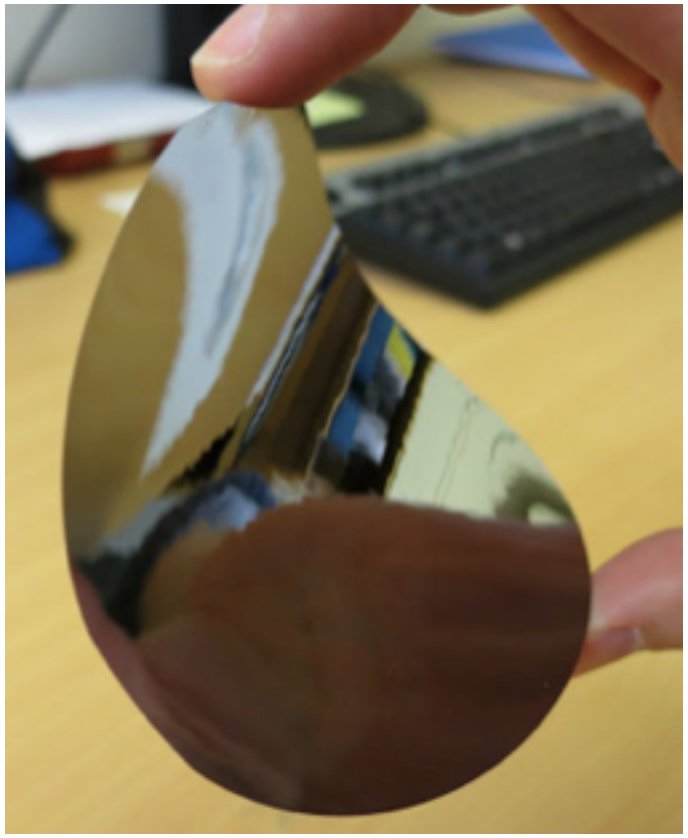




Thin sensor assemblies

- Ultimate goal: 50 µm thick sensors + 50 µm thick ASICs, 25 µm pixel pitch

- Thin sensor + "normal" Timepix assemblies
  - Feasibility tests of ultra-thin sensors
  - Assemblies with 50, 100, 200 µm sensor

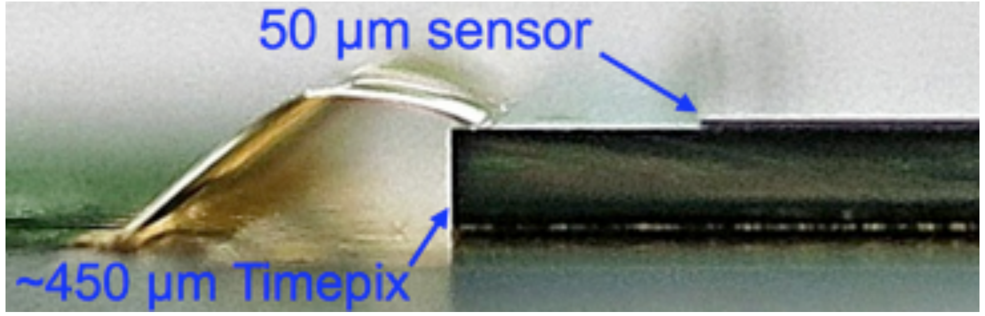


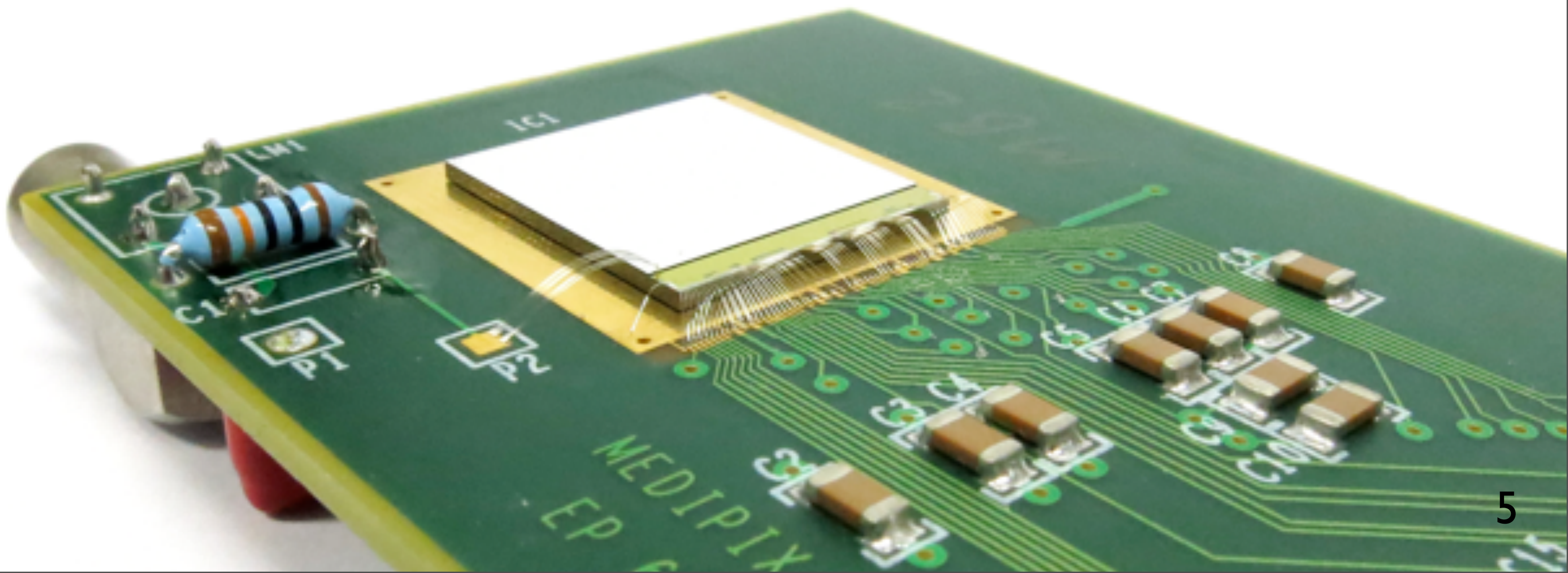
Advacam

- 50 µm thin with 20 µm and 50 µm active-edge assemblies on standard thickness Timepix ASIC (delivered July 2013)
- 5 x assemblies tested at DESY

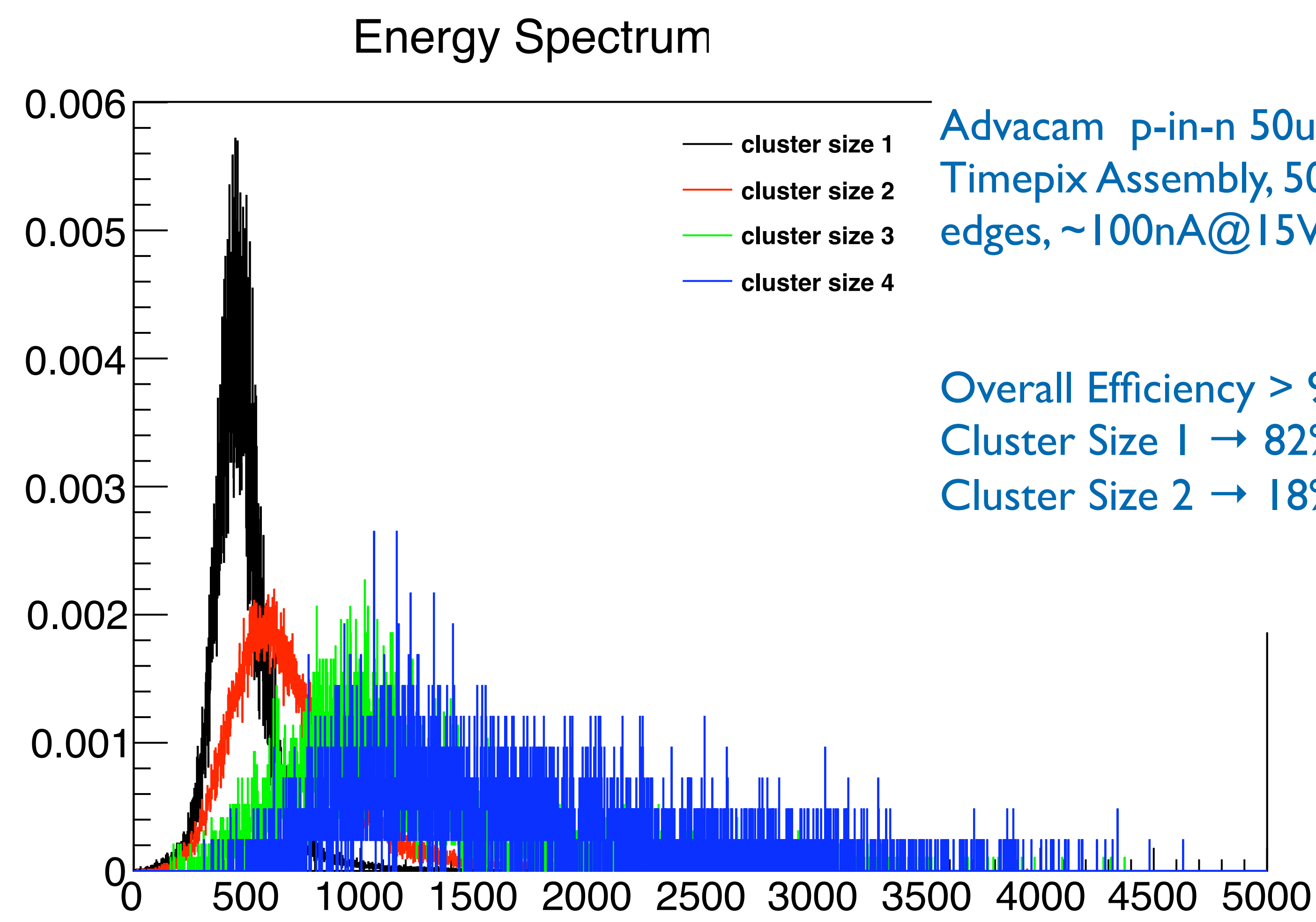
Micron Semiconductor + IZM

- 100, 150, 200 µm pixel sensor (Timepix compatible)
- 3 x 100 µm assemblies tested at DESY



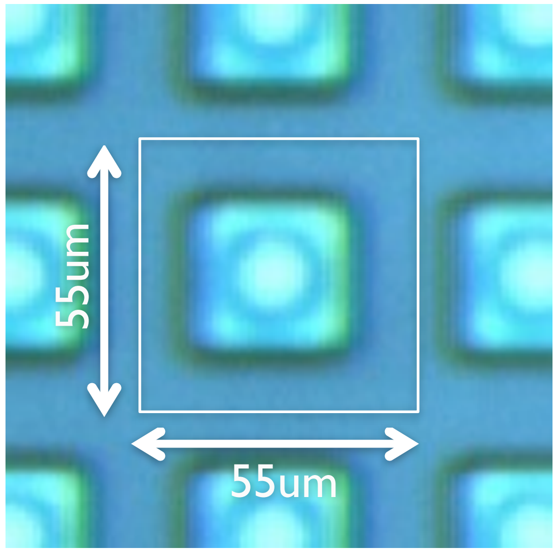


DESY testbeam results

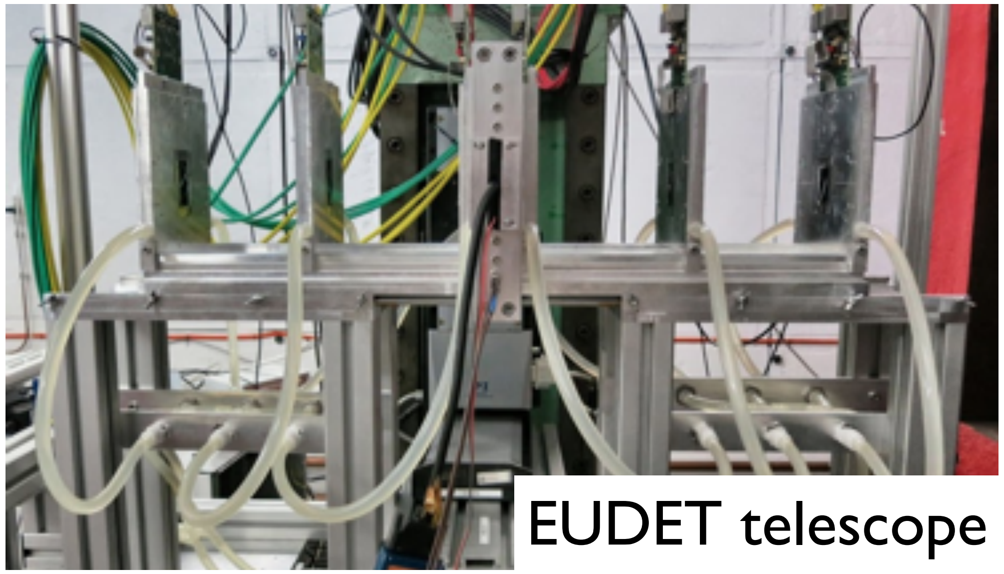


Advacam p-in-n 50um thin Timepix Assembly, 50um edges, ~100nA@15V

Overall Efficiency > 98.4%
Cluster Size 1 → 82%
Cluster Size 2 → 18%

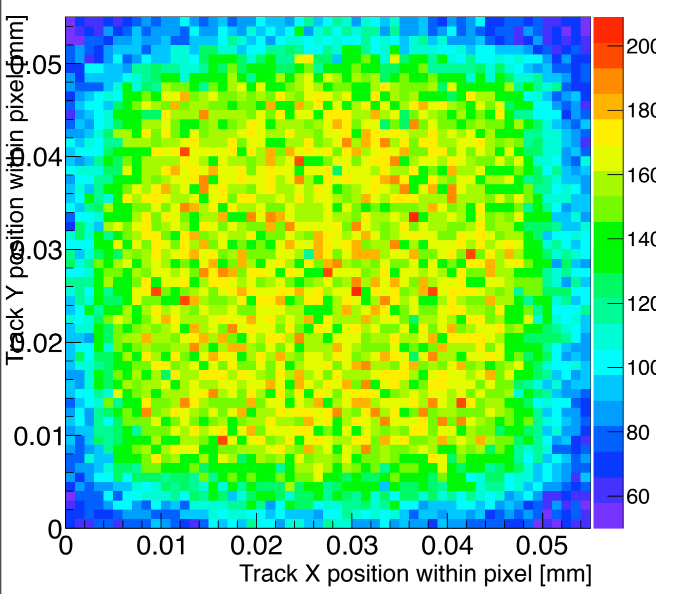


Sensor pixel

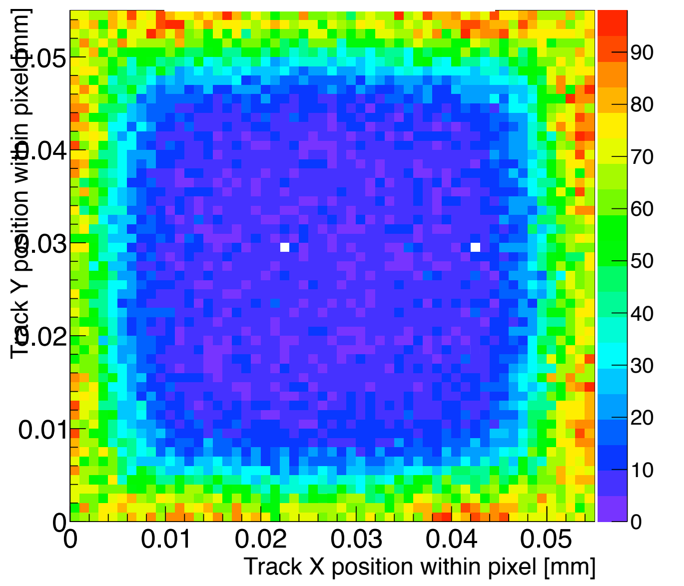


EUDET telescope

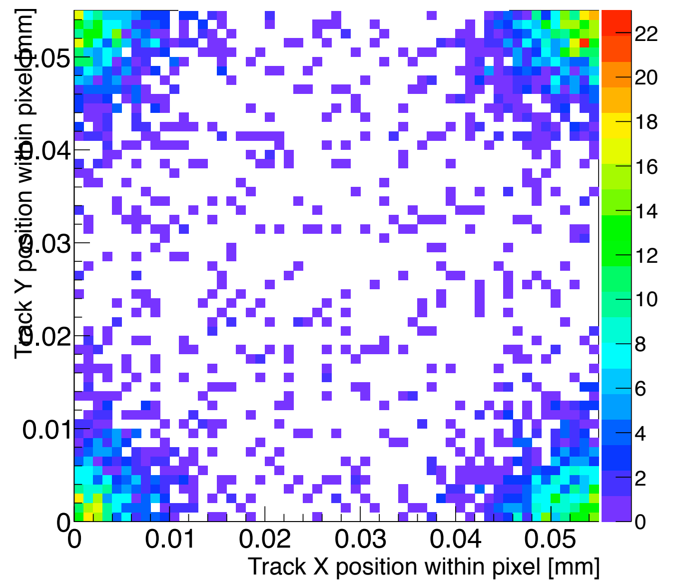
Cluster Size 1

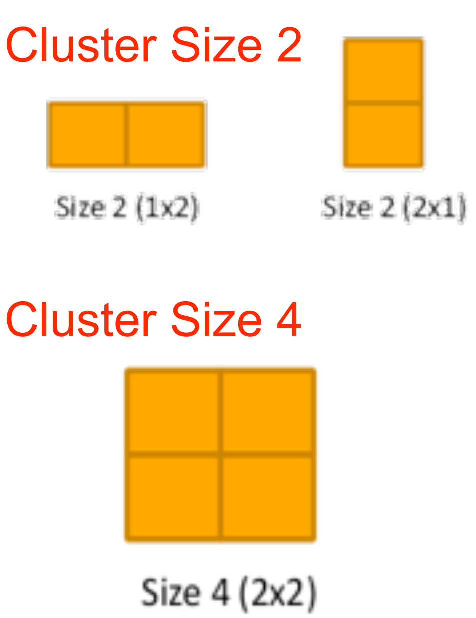


Cluster Size 2



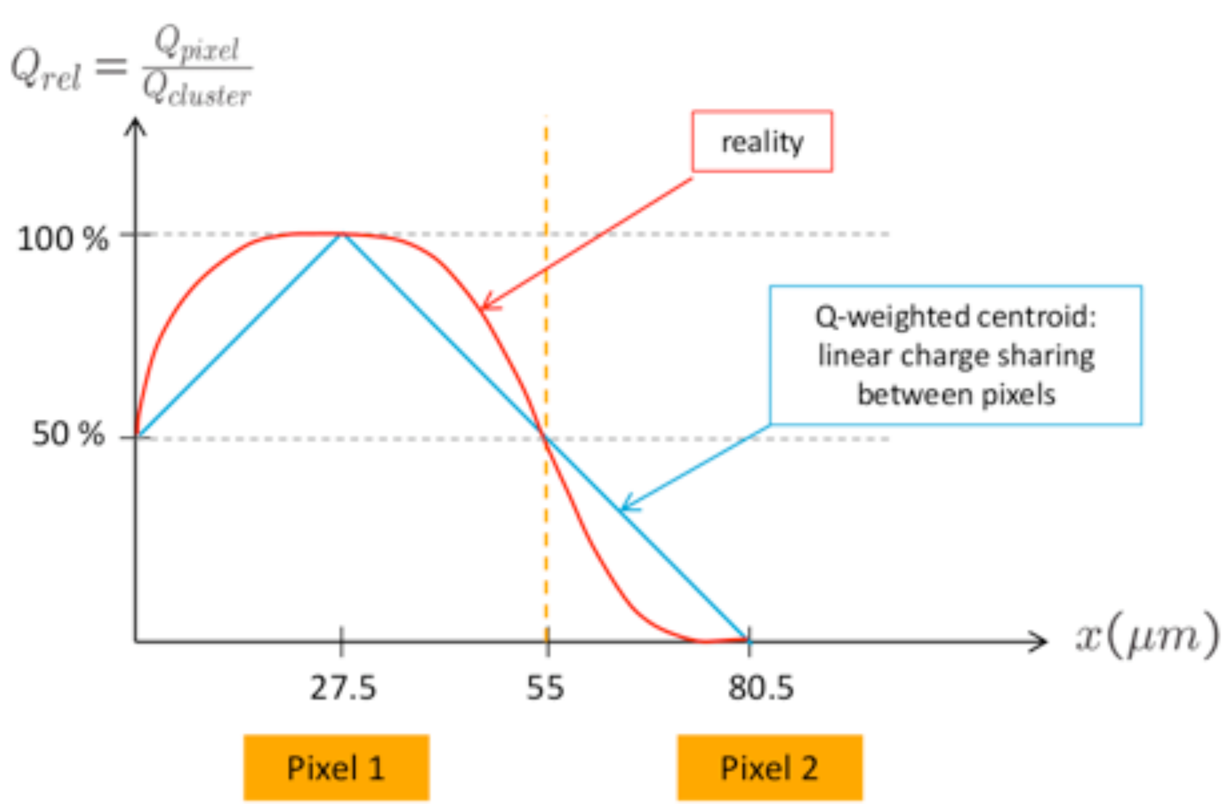
Cluster Size 4



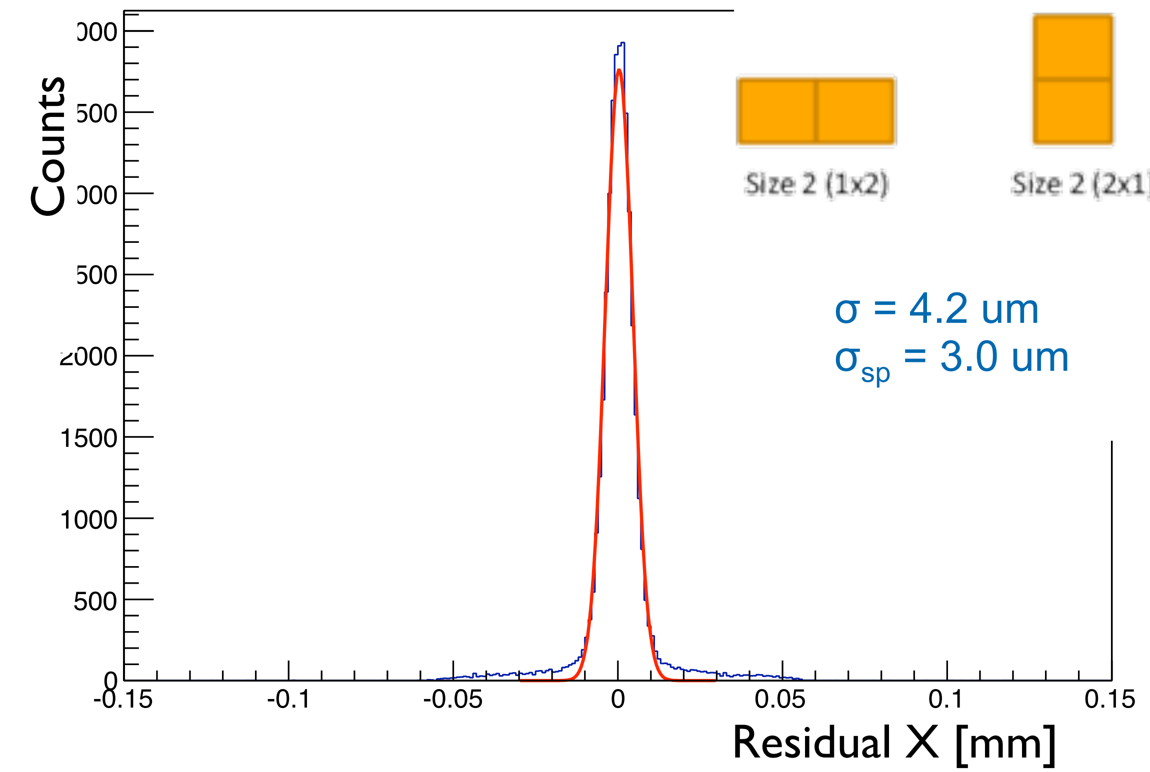


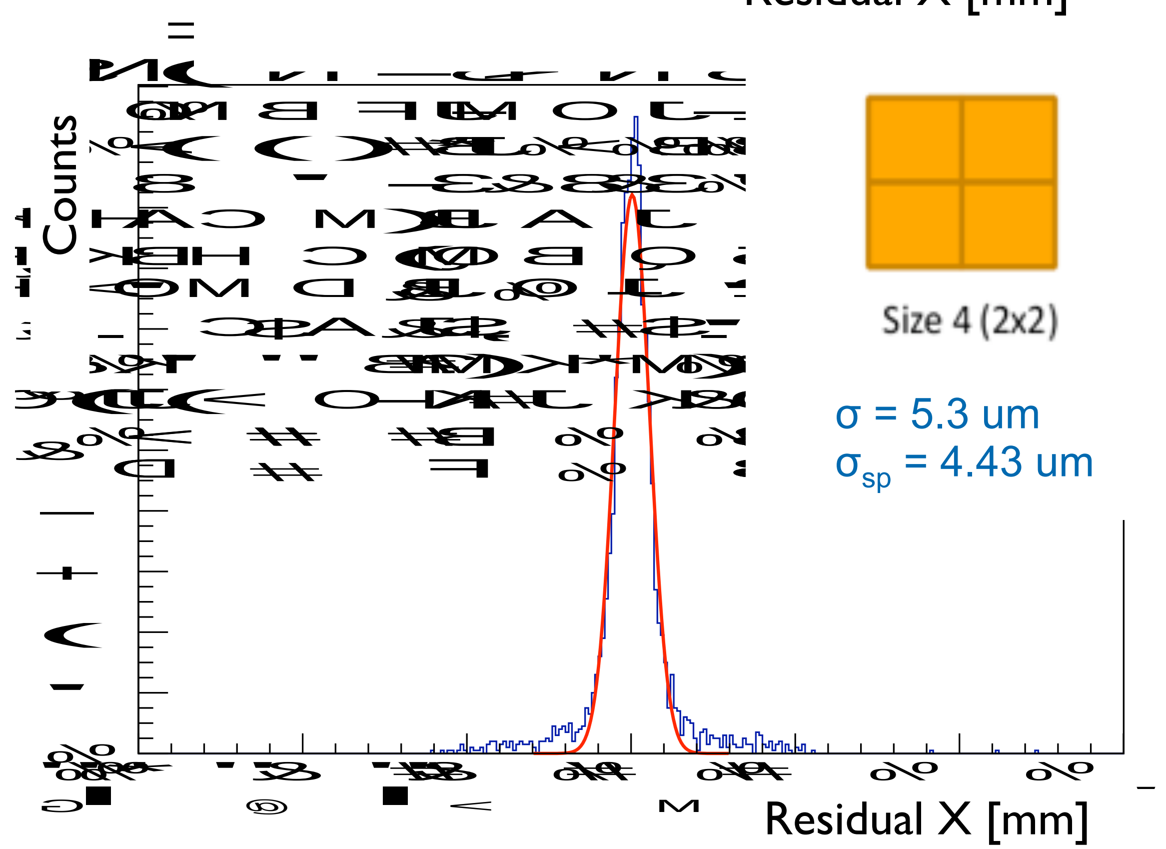
DESY testbeam results

- Minimisation of tracking resolution by proper arrangement of telescope
- Charge weighting: common to improve resolution to sub pixel size
- Eta correction: using TOT information to correct for non-linearities in charge sharing
- Our 50 µm sensors only charge share 20% of the time. Need smaller pixel size to benefit more



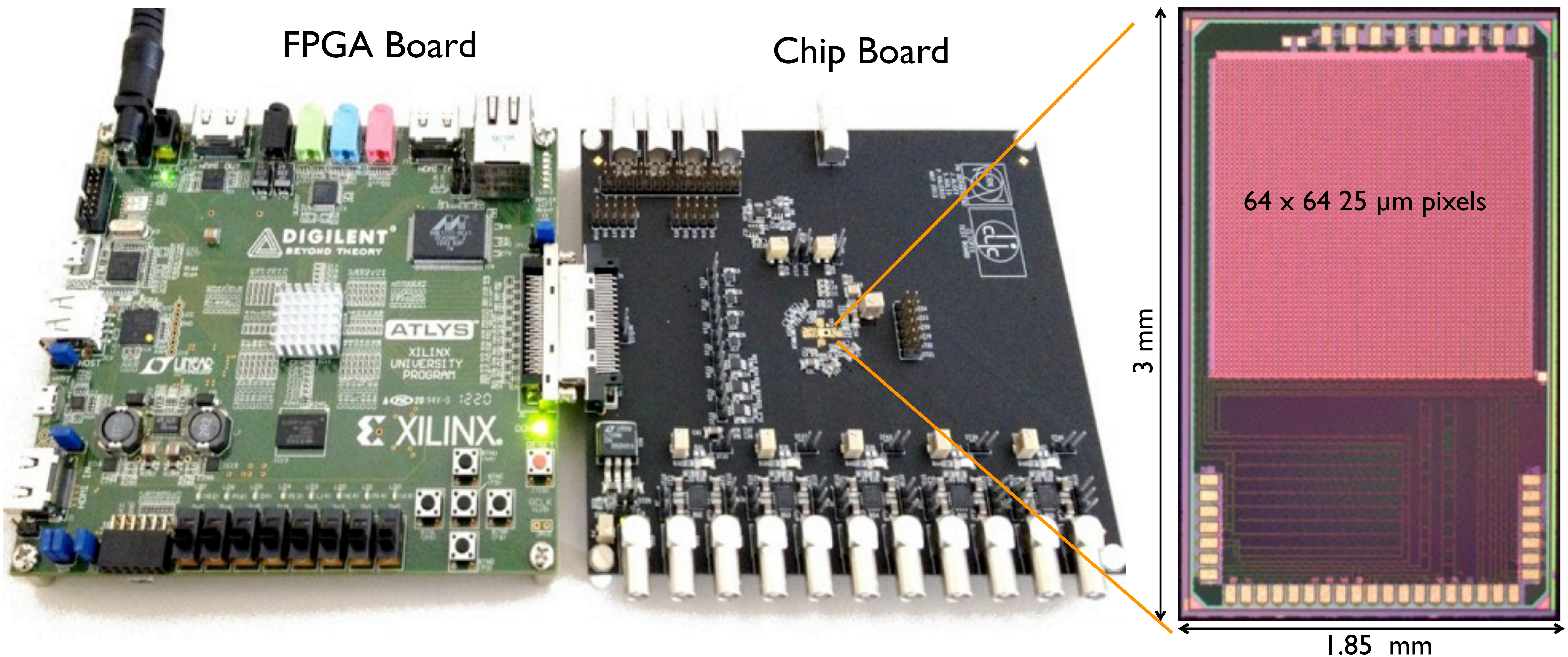
Charge weighted and eta corrected



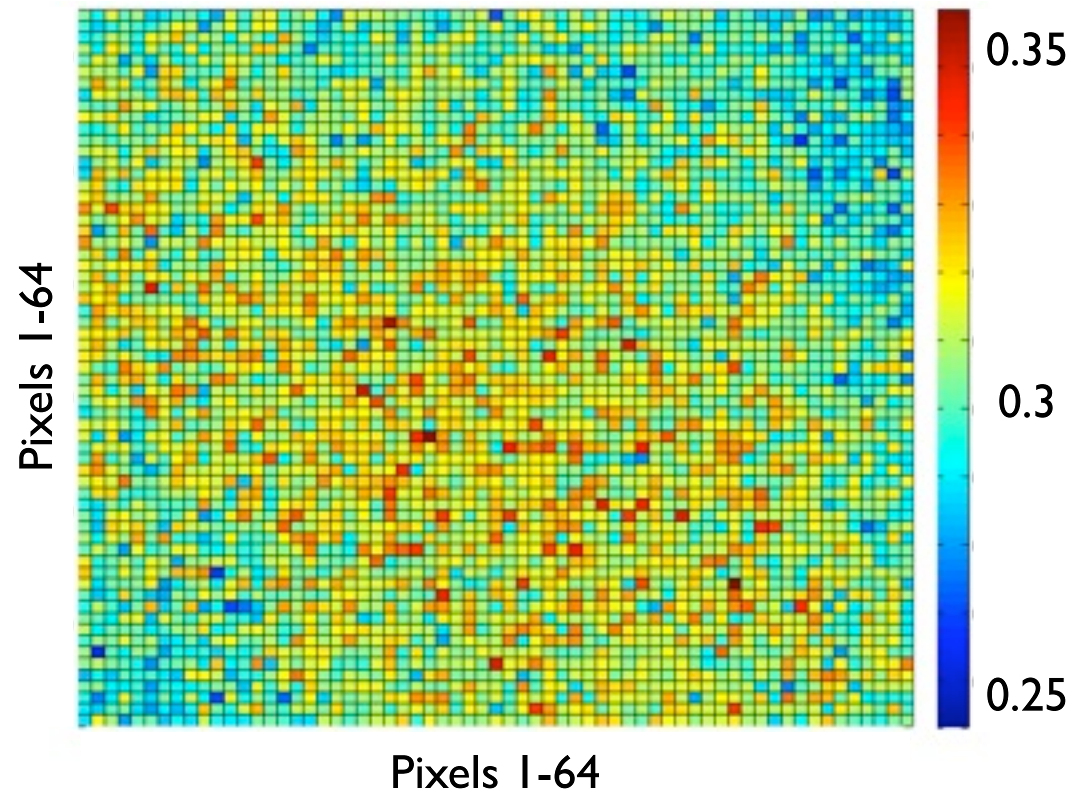


Readout chip: CLICpix

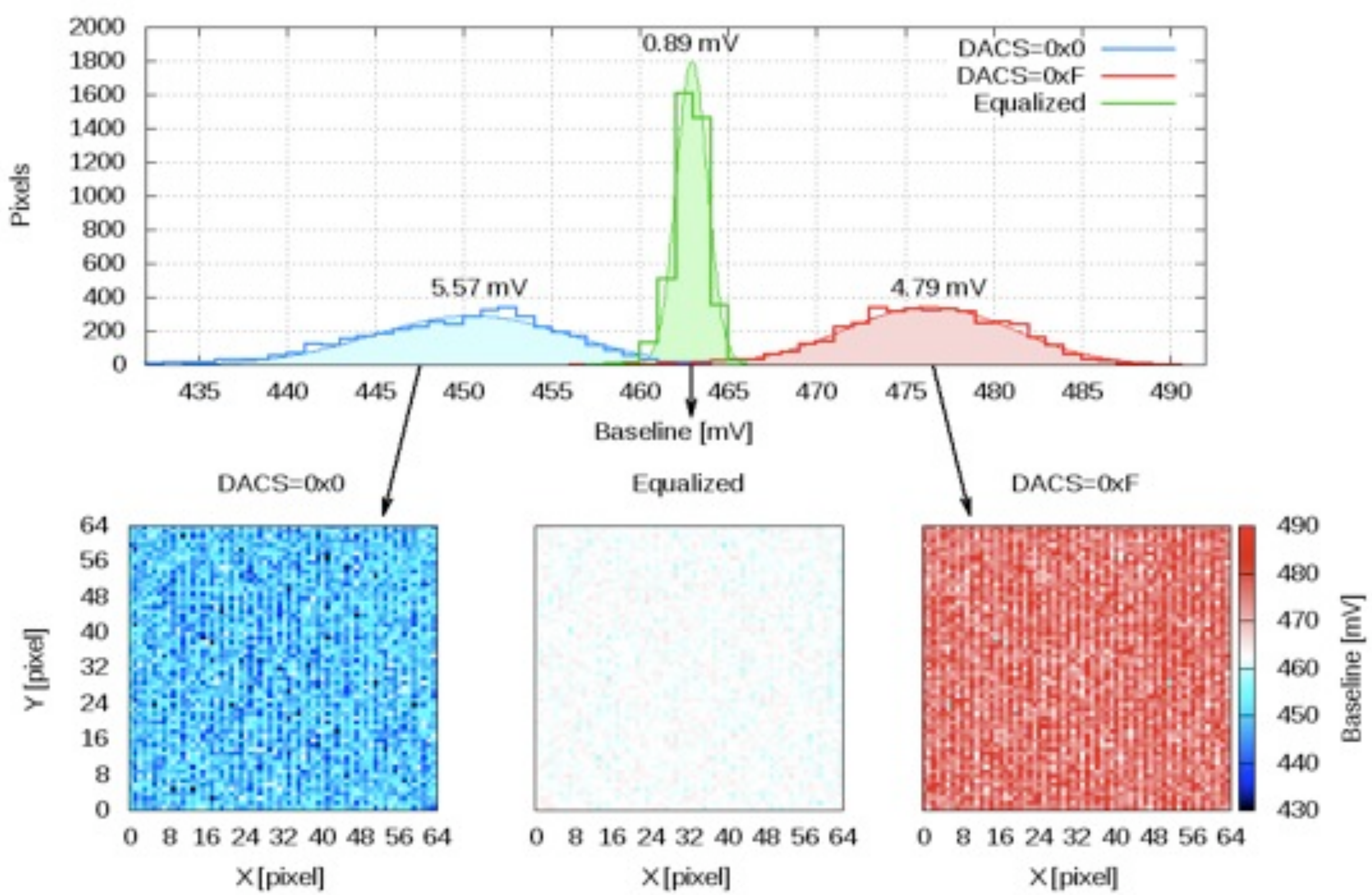
- CLICpix is a hybrid pixel detector to be used as the CLIC vertex detector
- A demonstrator of the CLICpix architecture with an array of 64 x 64 pixels has been produced using 65 nm technology and tested
- Main features: 25 μm pixel pitch, simultaneous TOA and TOT measurements, power pulsing, data compression



CLICpix prototype characterisation



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

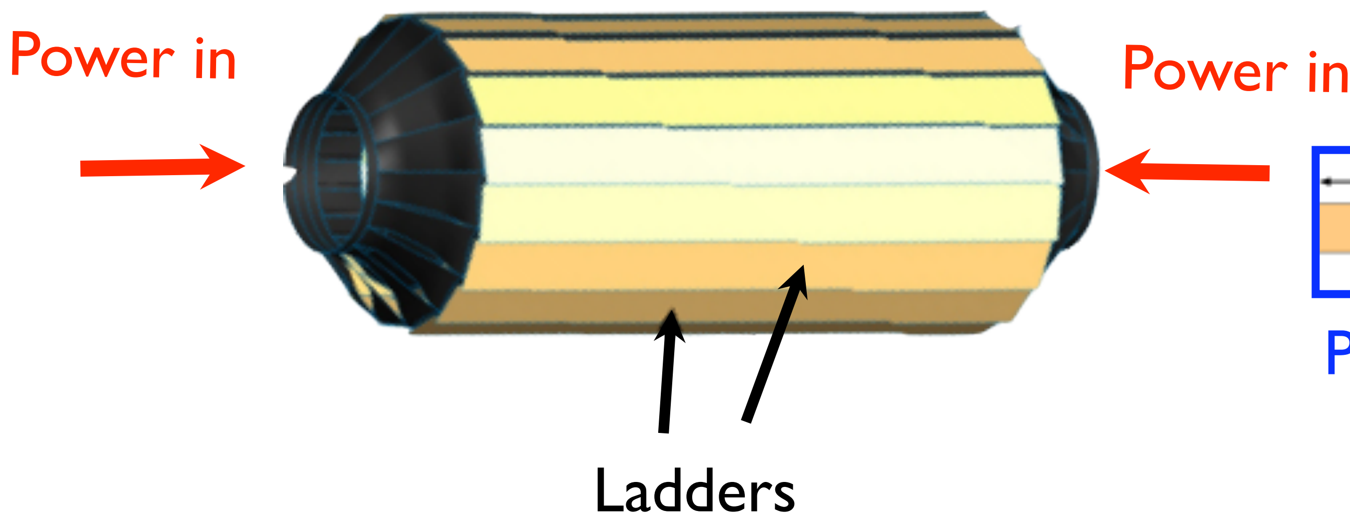


- Matrix equilisation
- Calibrated spread is 0.89 mV (about 22 e$^-$) across the whole matrix
- (Expect a signal of ~thousands of electrons in 50 µm sensor)

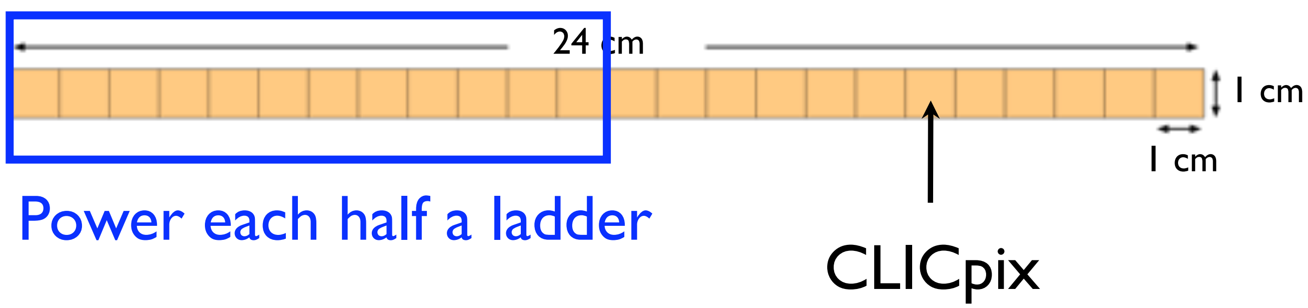
Power pulsing

- Goal: to power pulse the CLICpix ASIC (analogue and digital electronics)
- Total power dissipation required to be <50 mW/cm^2 in the sensor area

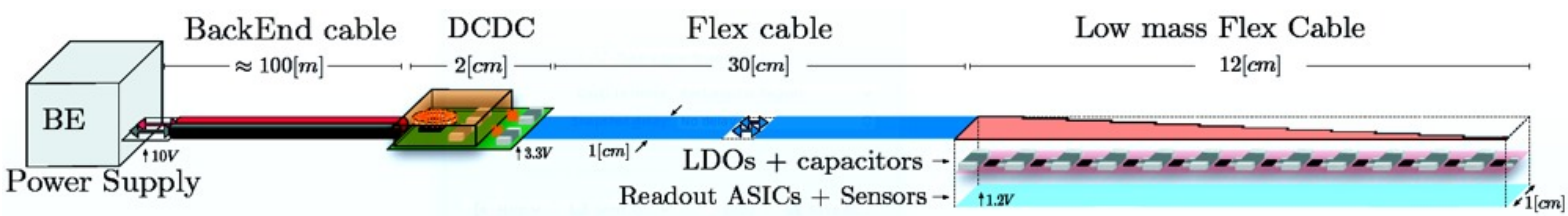
Vertex barrel



The ladder is formed by 24 readout ASICs (CLICpix)

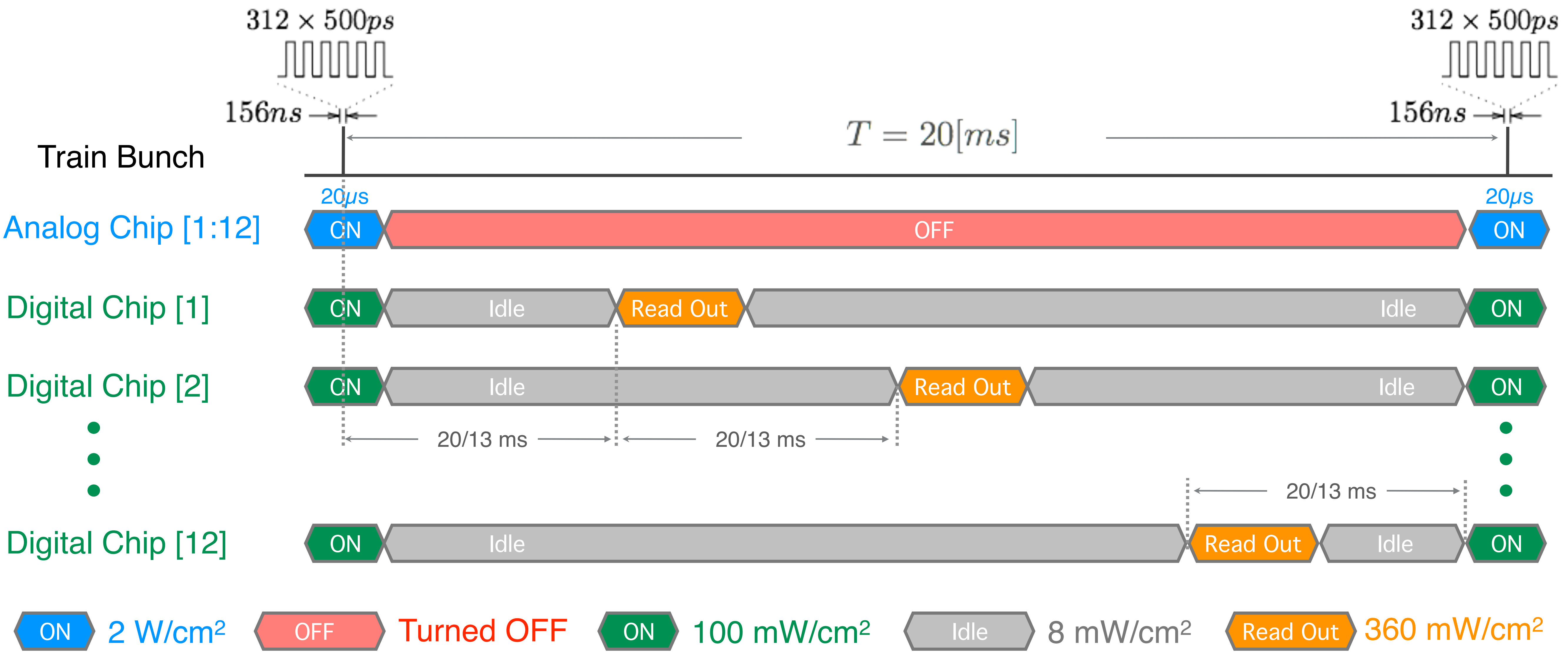


- Aluminium flex cables and silicon capacitors reduce material budget
- Current material budget 0.1% X_0 per layer. Projected budget: < 0.05% X_0

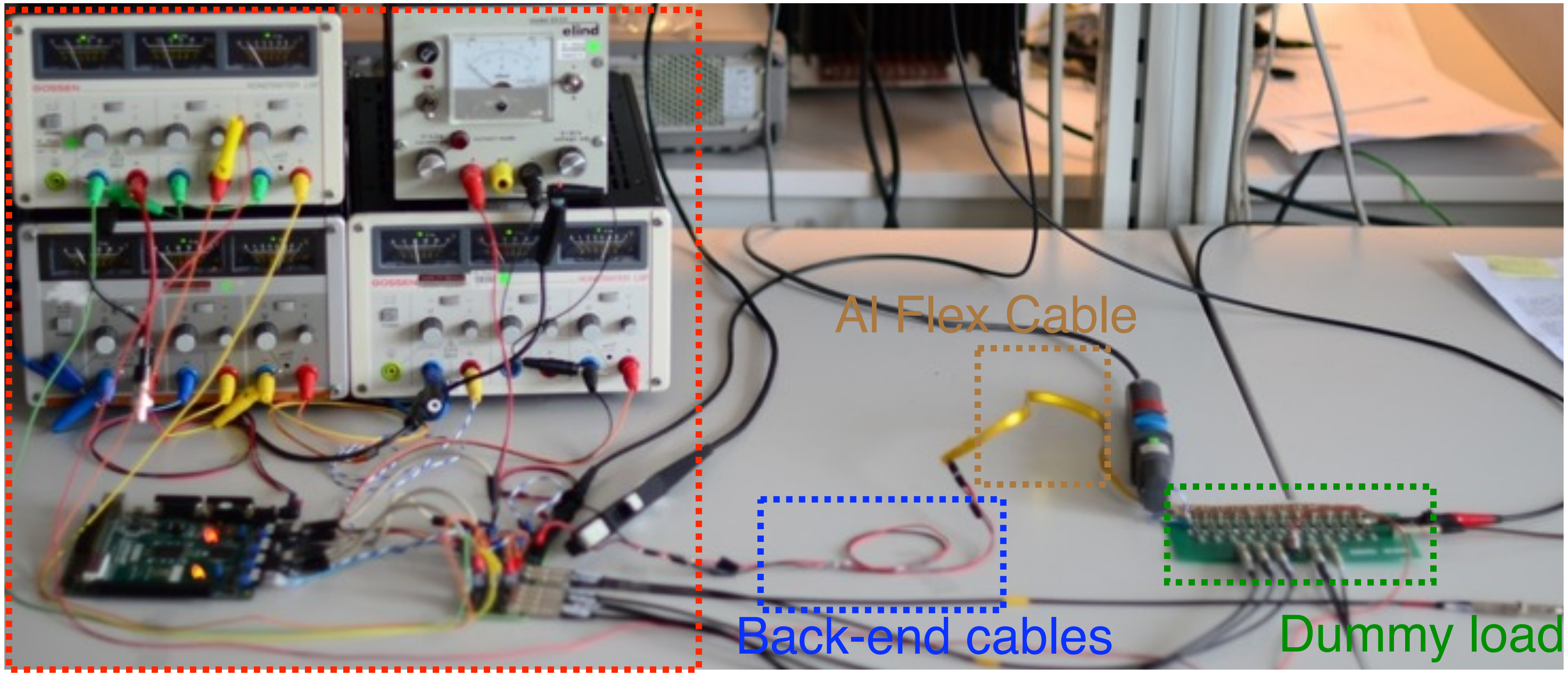


Power pulsing

- Analog electronics can be turned OFF (power pulsing) to reduce the average power consumption (2 mW/cm^2 instead of 2 W/cm^2 if it was ON all the time)
- One digital chip is readout every 20/12 ms. The time the chip needs to be read out depends on the occupancy, which maximum is 3% (300 μs). Avg power consumption = 13 mW/cm^2



Power pulsing - lab tests

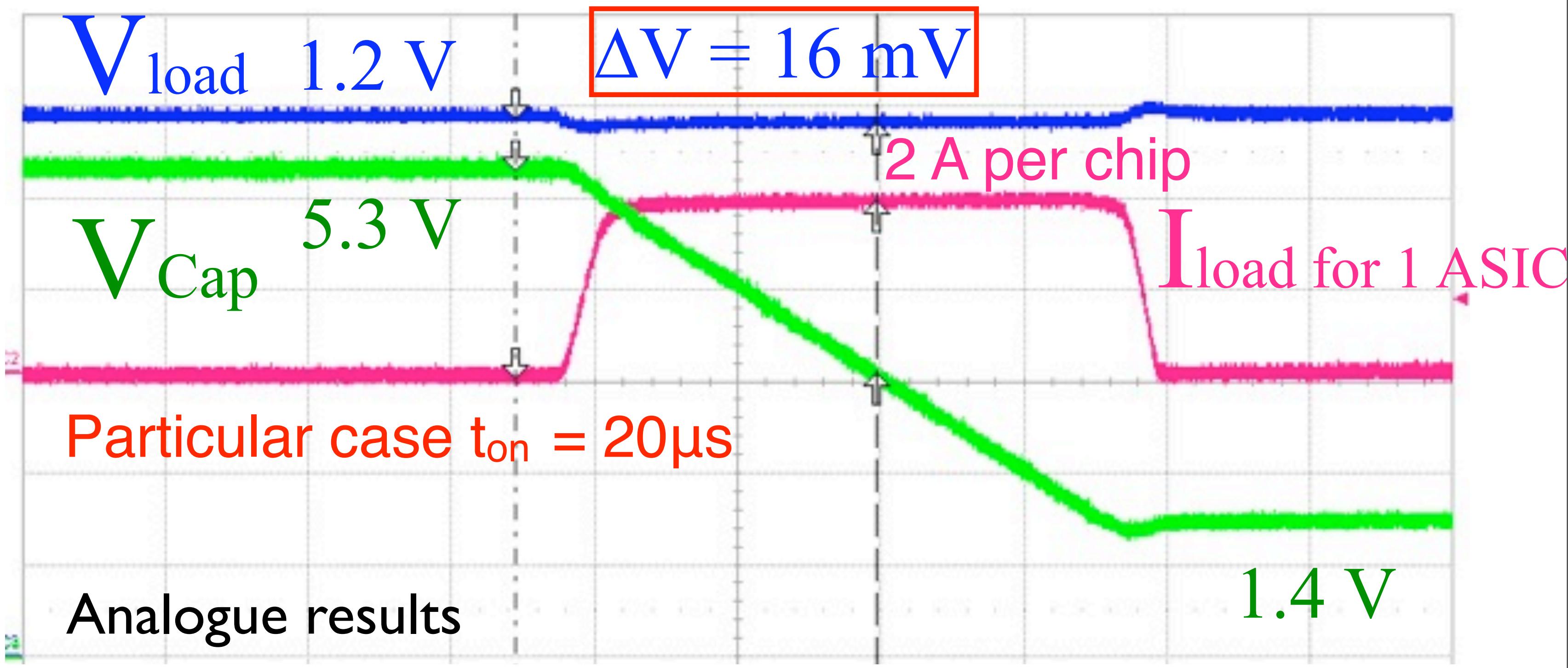


Analogue

- Voltage drop < 20 mV
- Measured average power consumption < 10 mW/cm²

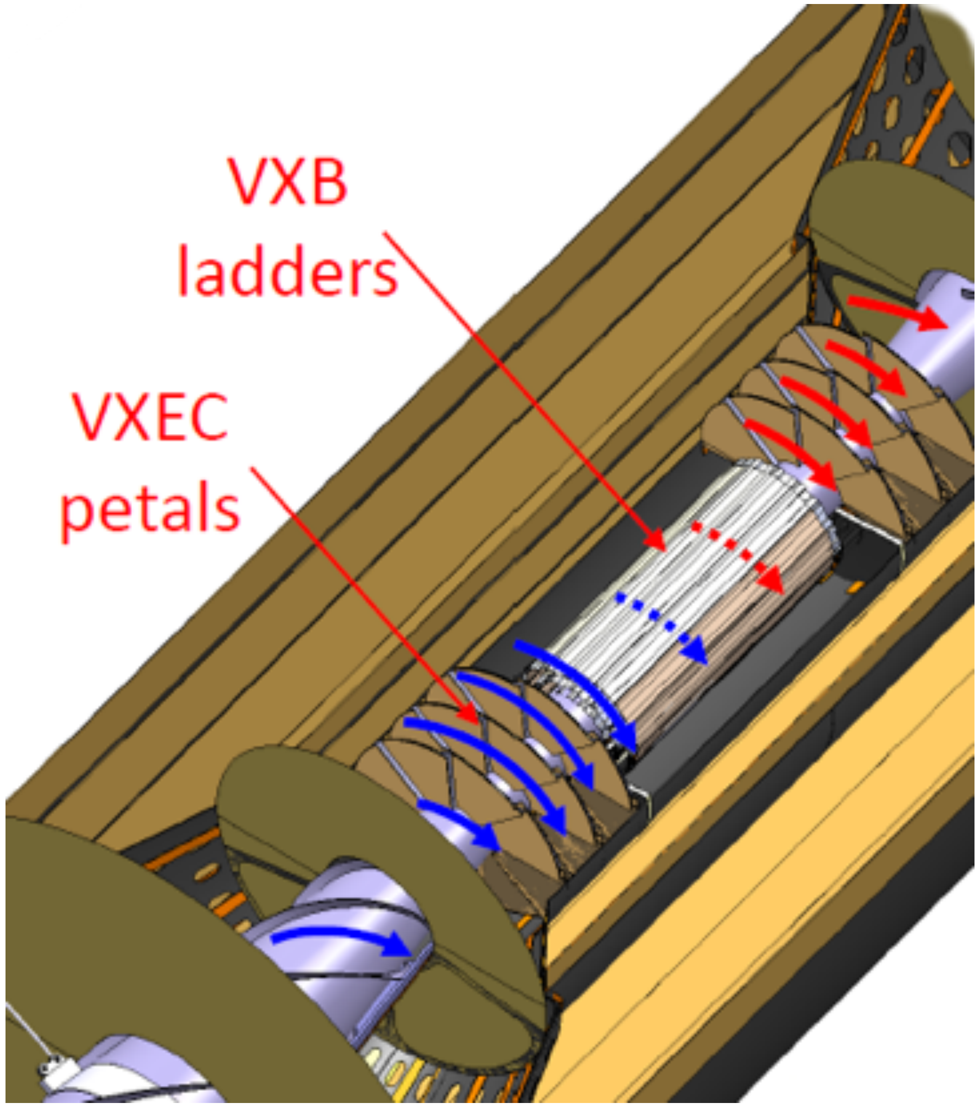
Digital

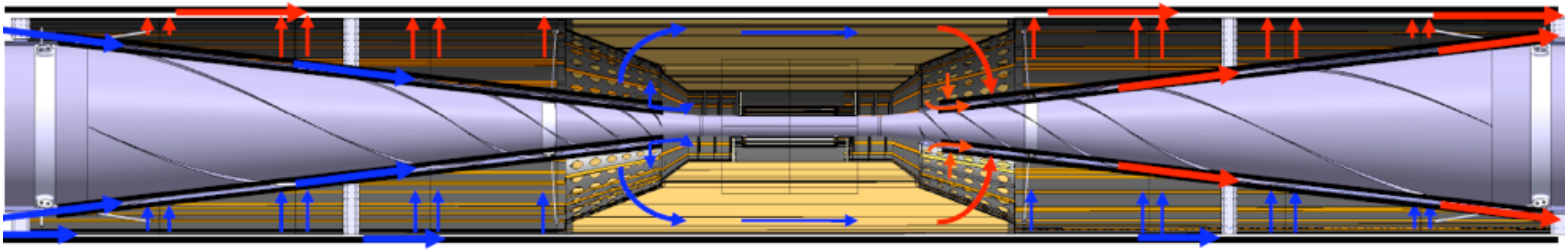
- Voltage drop < 70 mV
- Measured average power consumption < 35 mW/cm²



Cooling

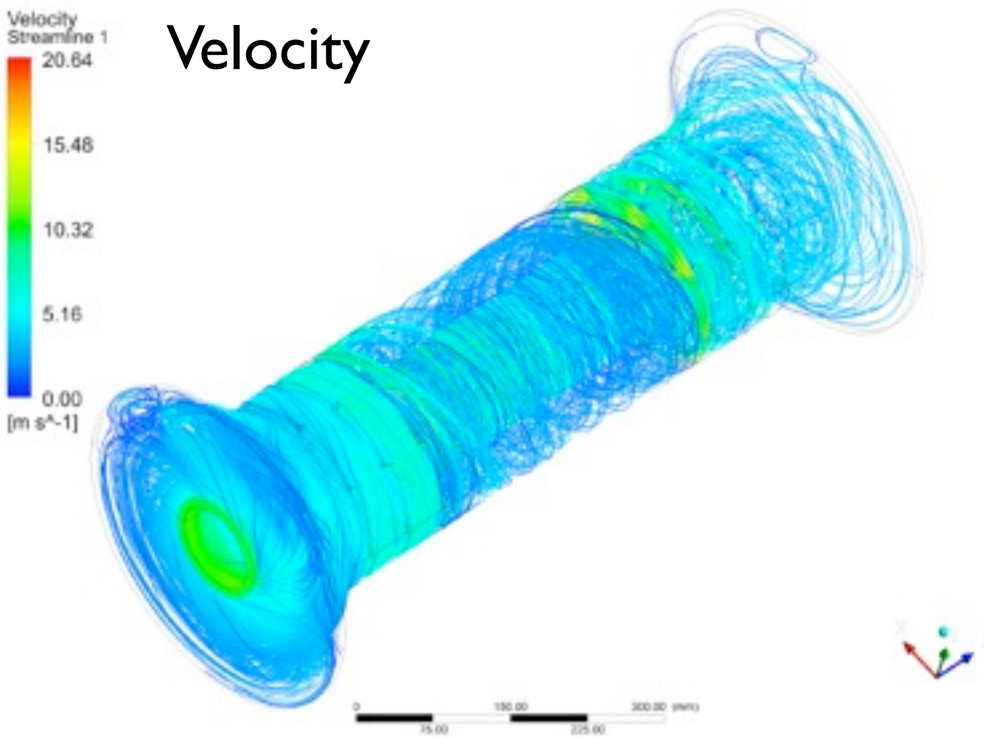
- Total heat load after power pulsing ~470 W
- Want room temperature operation and low material budget
- Dry gas cooling (Nitrogen)



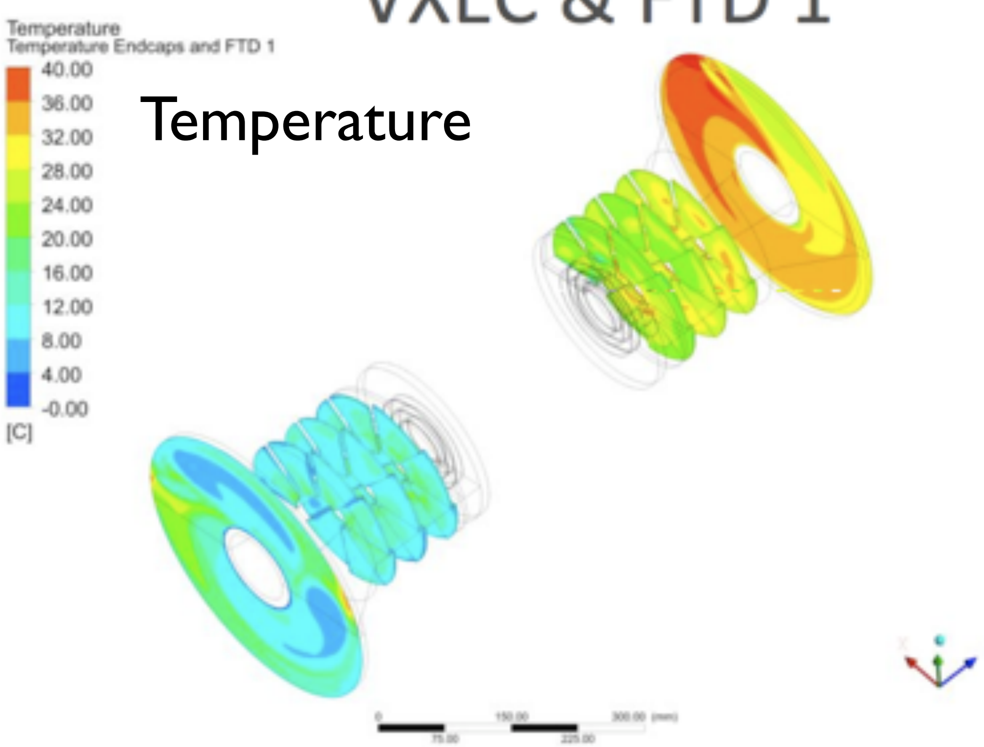


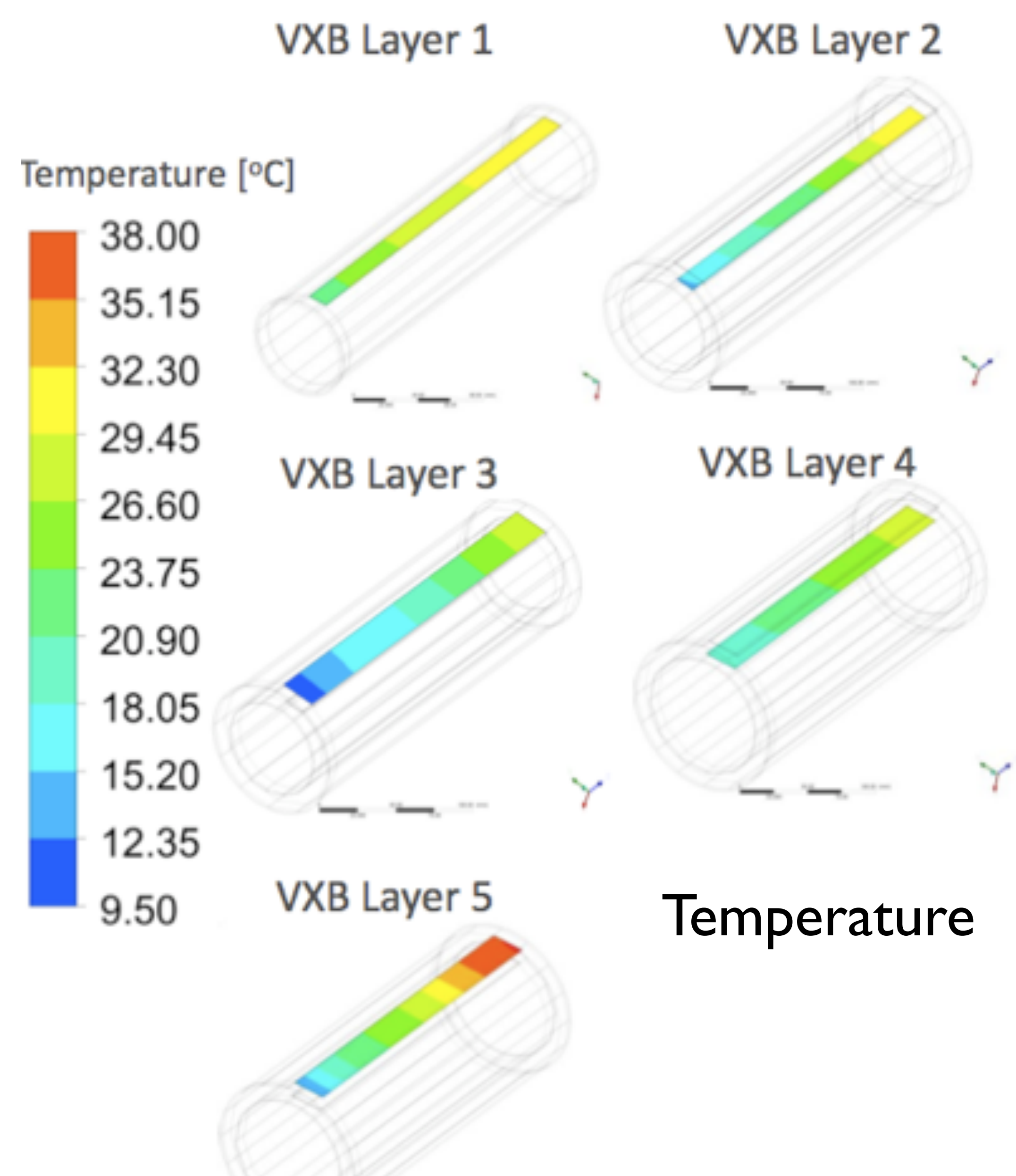
Cooling simulations

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



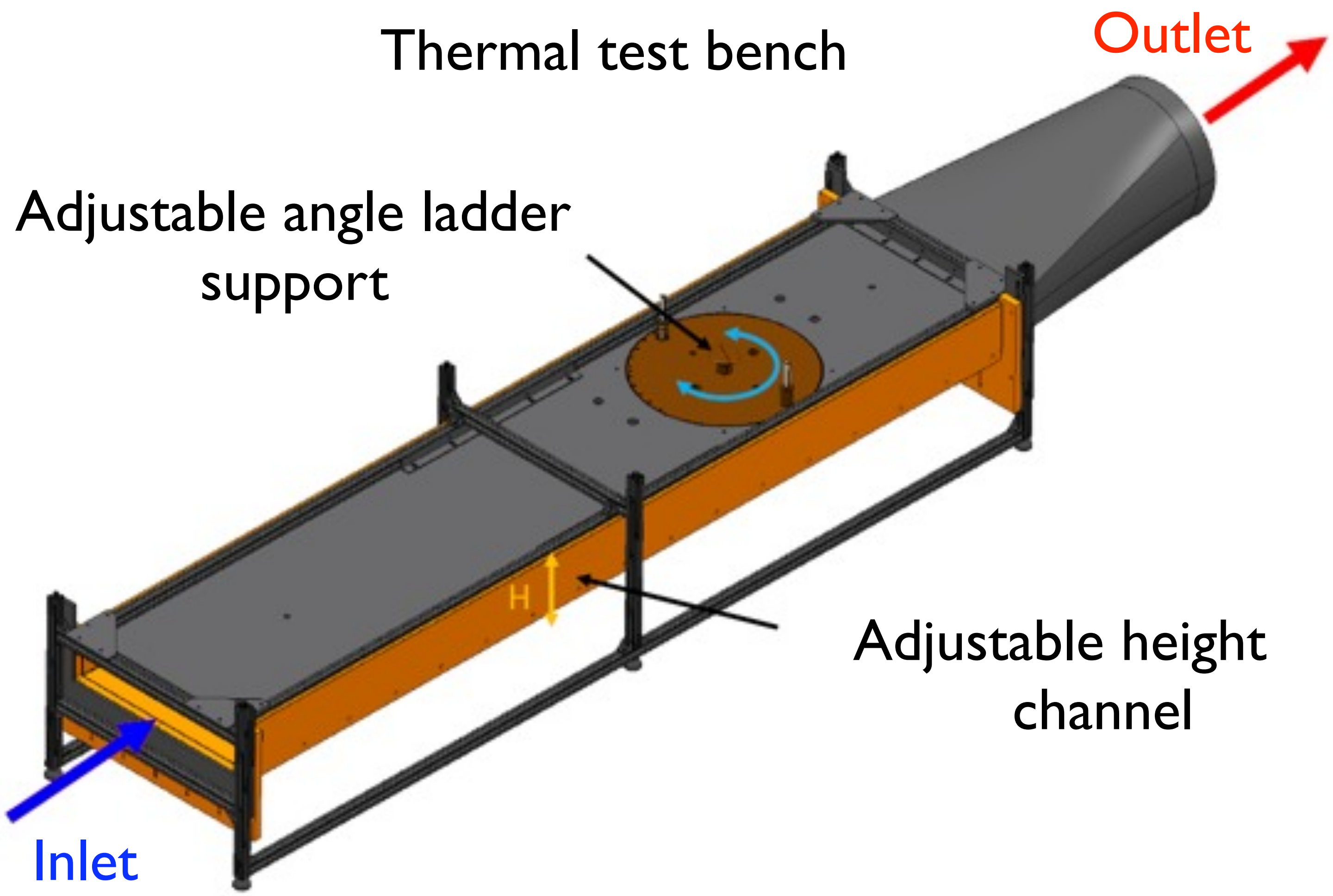
VXEC & FTD 1*

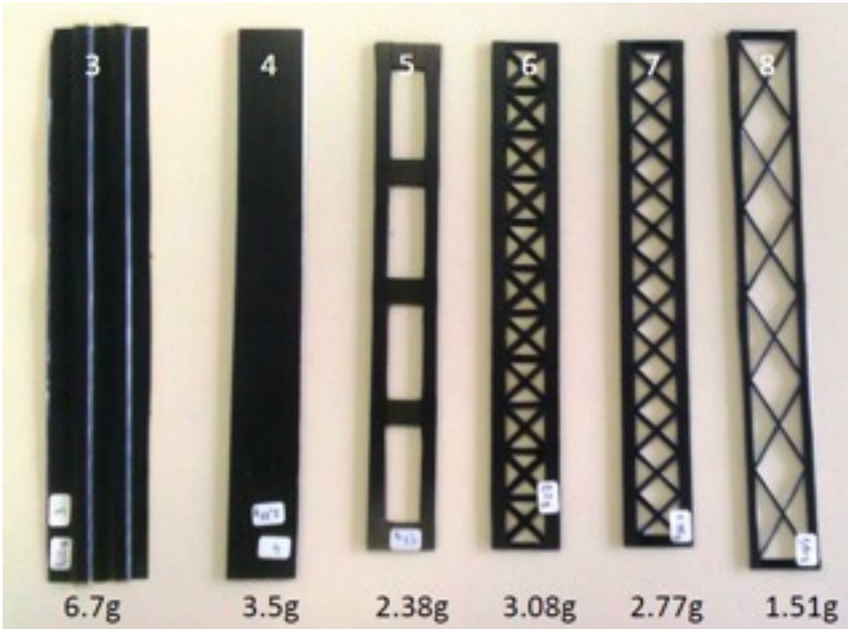




Cooling test bench

- Evaluate forced convection air cooling
  - Validate the dedicated finite element simulations
- Measure & characterise air-flow induced vibrations
  - Develop and characterise low-mass ladder support (~0.05% X_0)



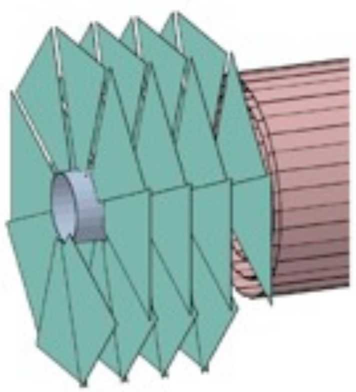


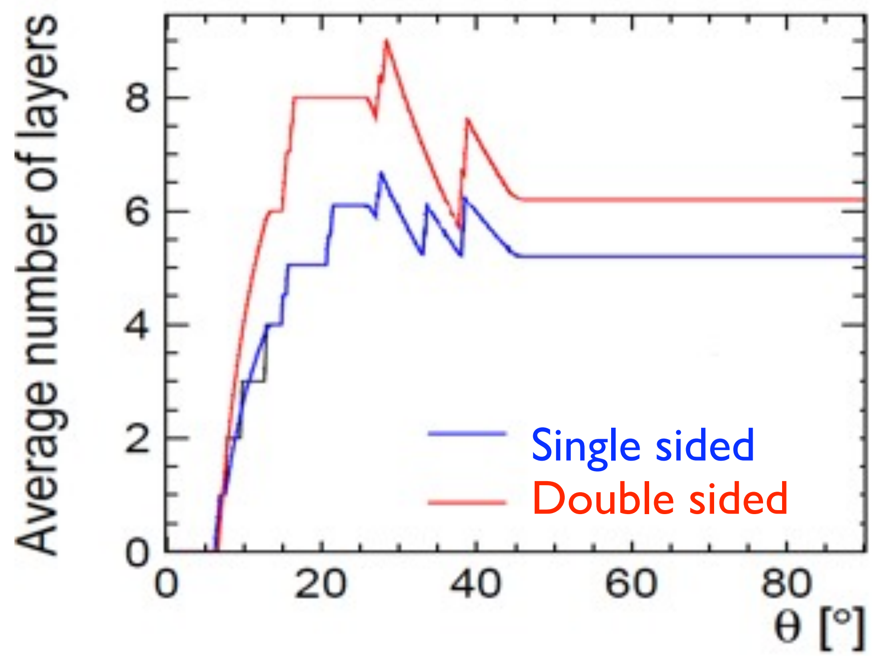
Ladder support structure prototypes

Geometry and physics impact

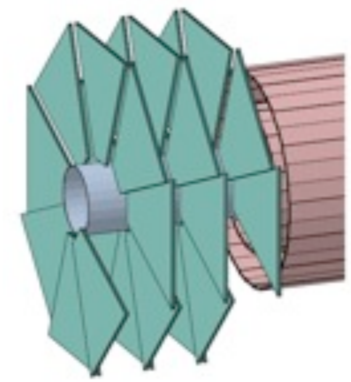
Use flavour-tagging performance as benchmark for detector layout optimisation

Single sided spiral
(5 barrel + 4 endcap)

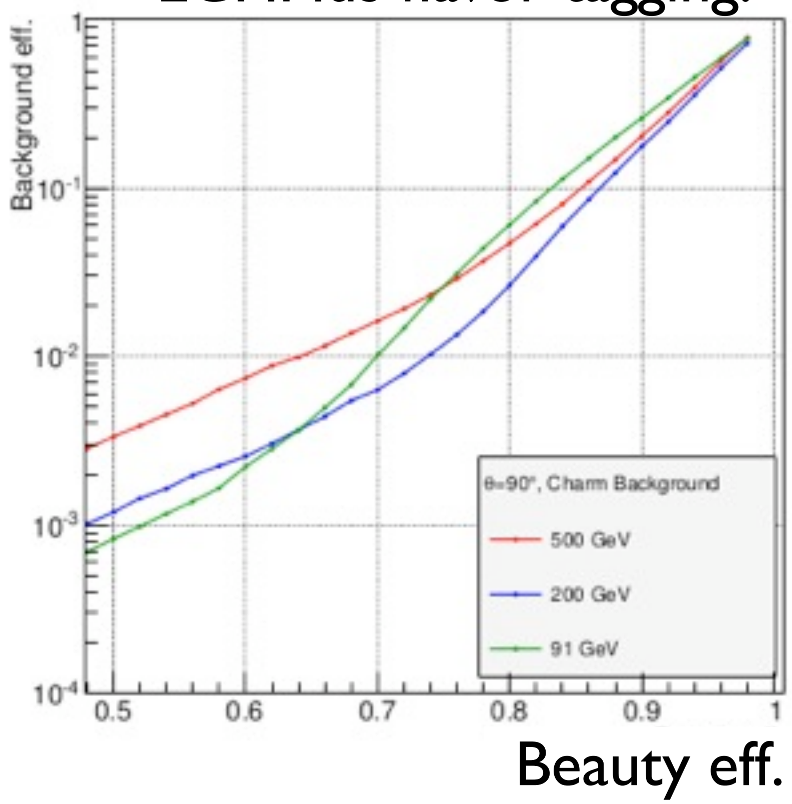


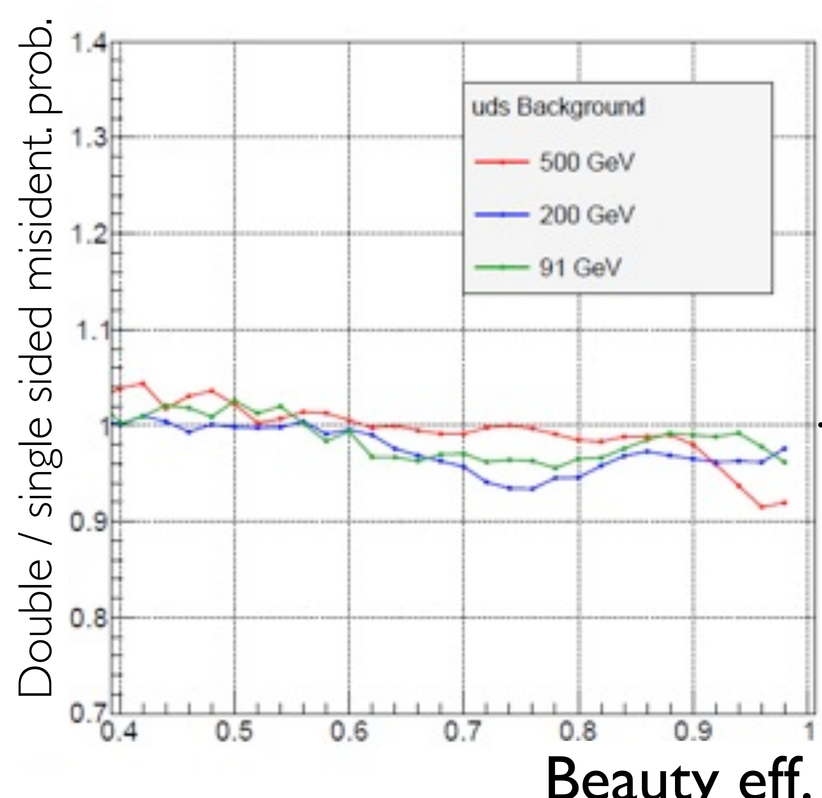


Double sided spiral
(3x2 barrel + 3x2 endcap)



Full GEANT4 detector simulation,
LCFIPlus flavor tagging:



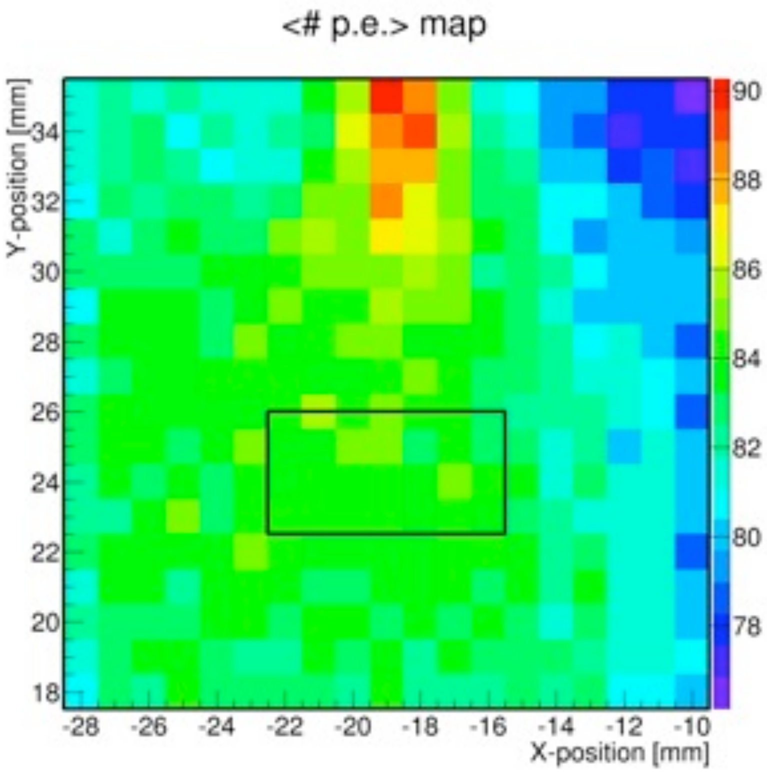


Double sided better than Single sided

Single sided better than Double sided

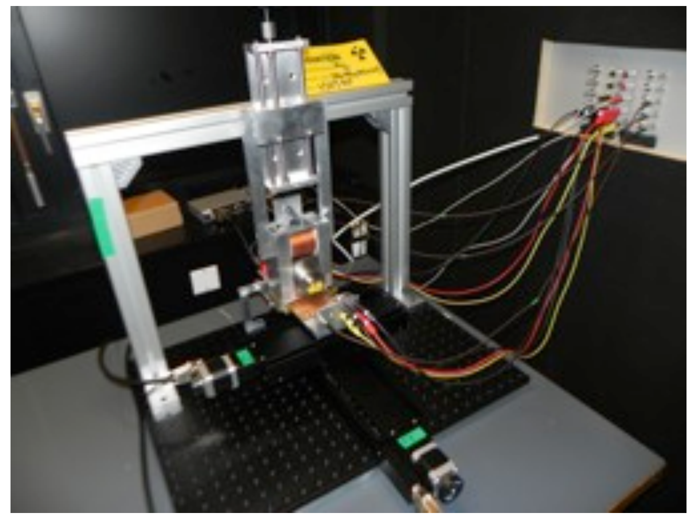
Very similar performance for both geometries

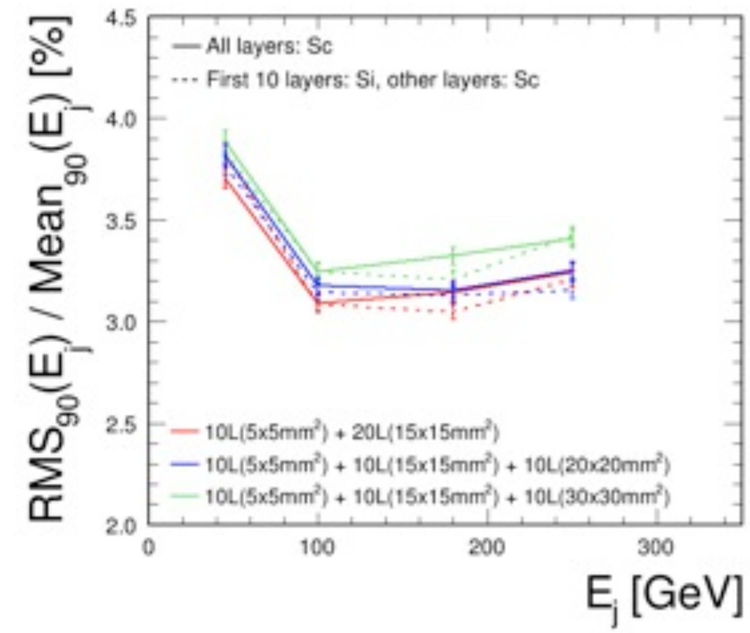
ECAL

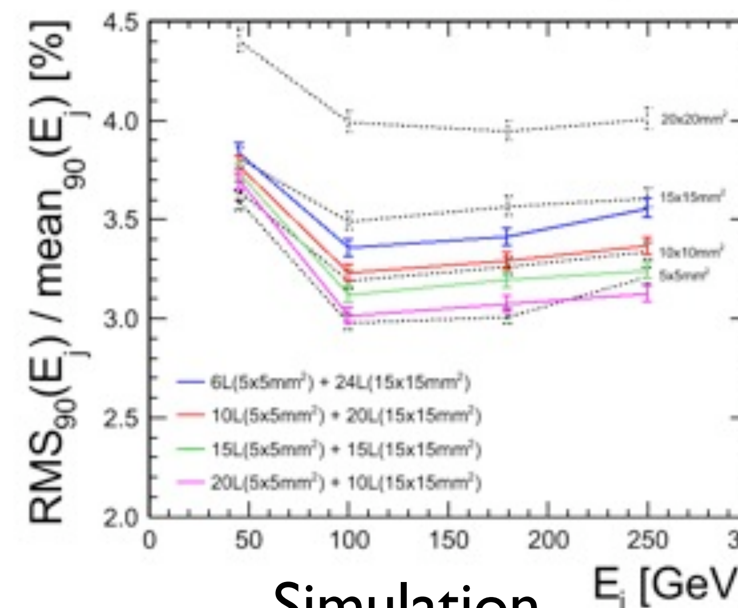


Tile scans

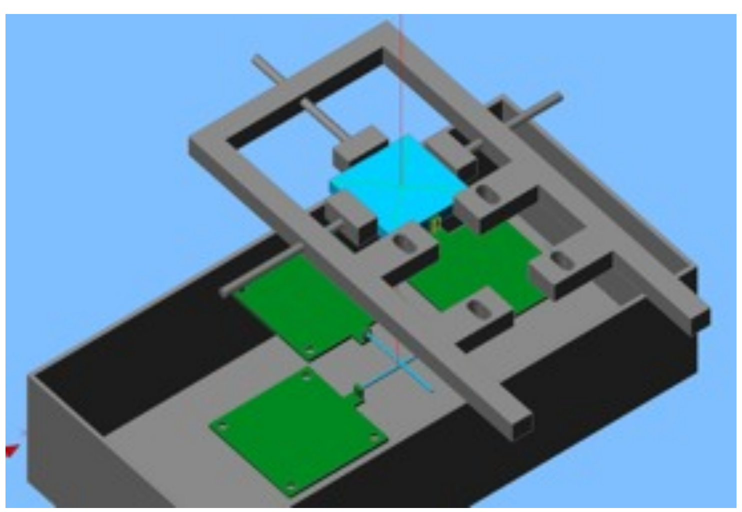
Lab tests





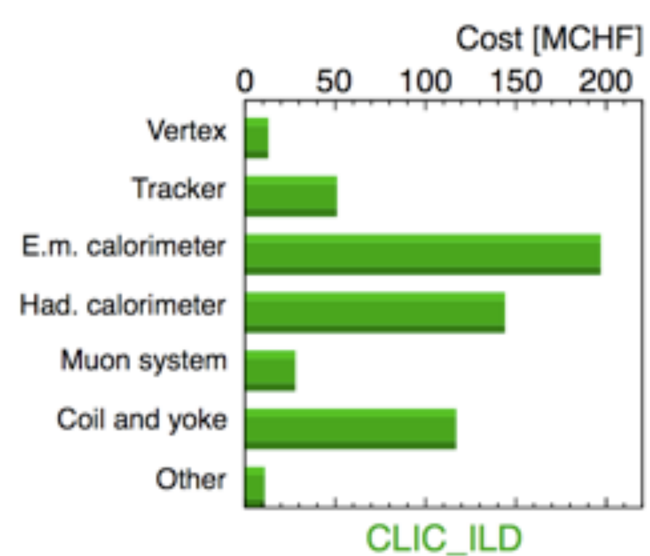


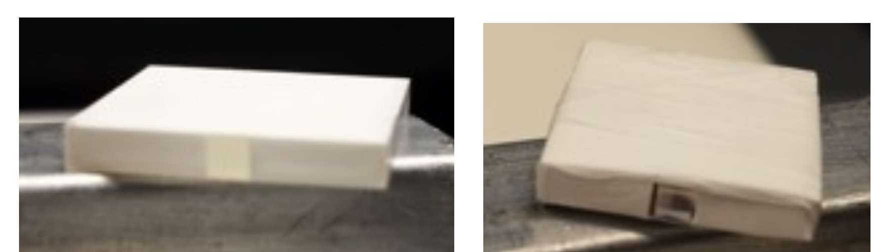
Simulation



Lab development

Cost effectiveness

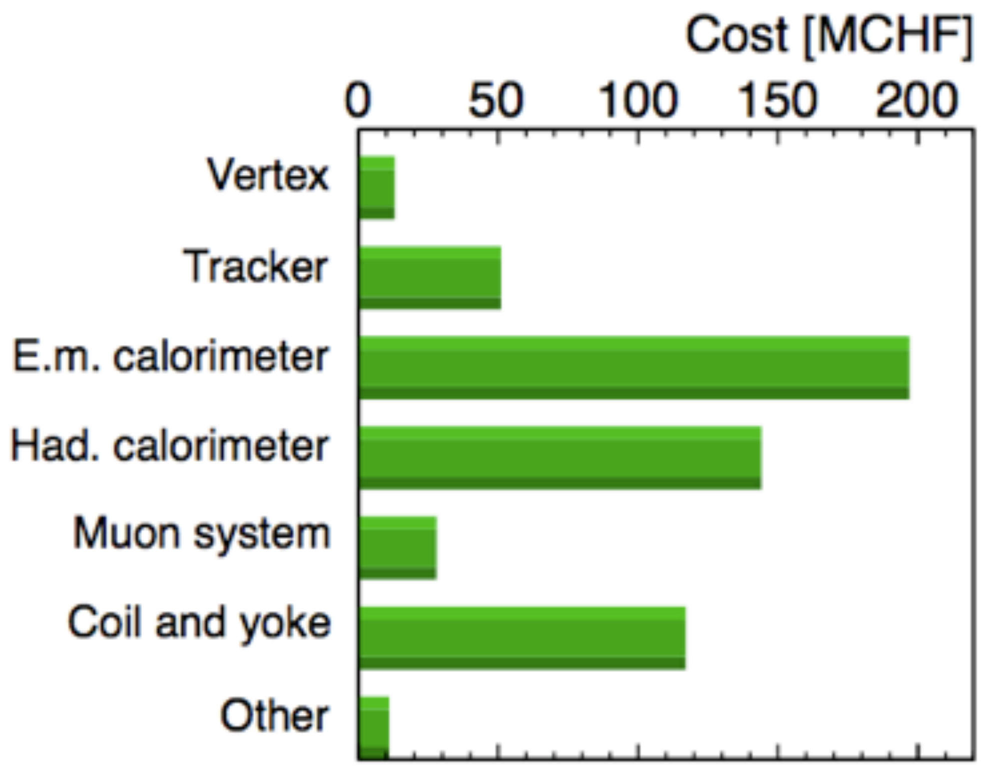




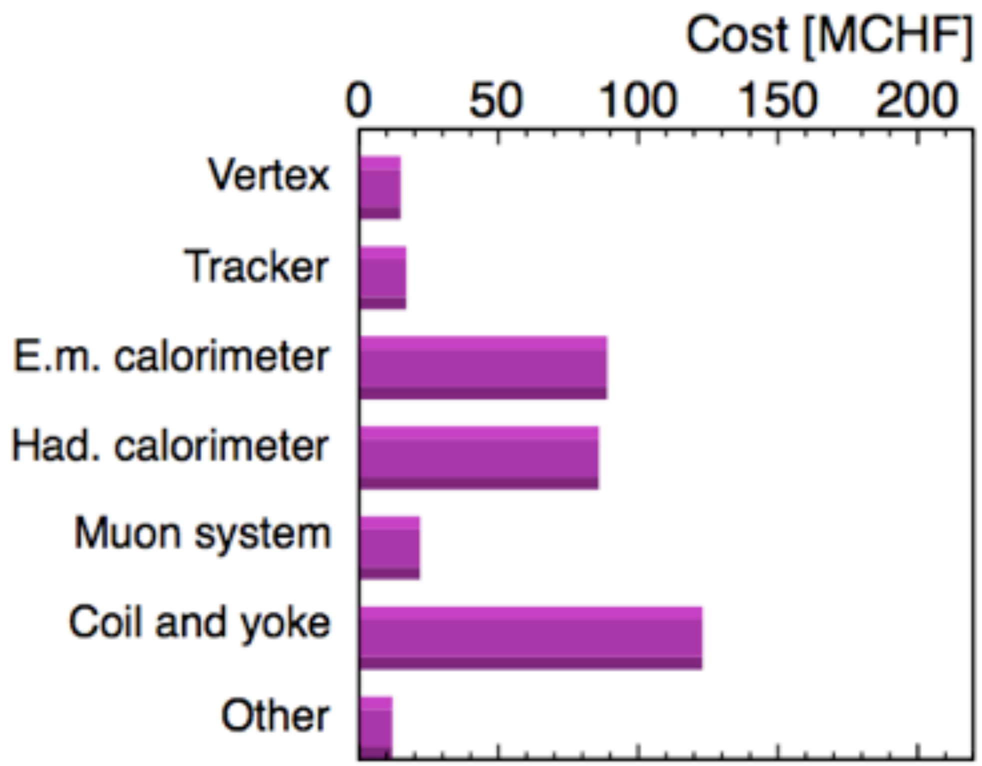
Tile packaging

ECAL cost-effectiveness study

- The ECAL is one of the most costly sub-detectors in both detector concepts
  - 35% of the total in CLIC_ILD
  - 25% of the total in CLIC_SiD
- To better understand the requirements of the ECAL, many models and parameters are under investigation in simulation studies, for example:
  - Transverse granularity
  - Regions of different transverse granularity
  - Si/Sc hybrid models
  - Number of ECAL layers



CLIC_ILD

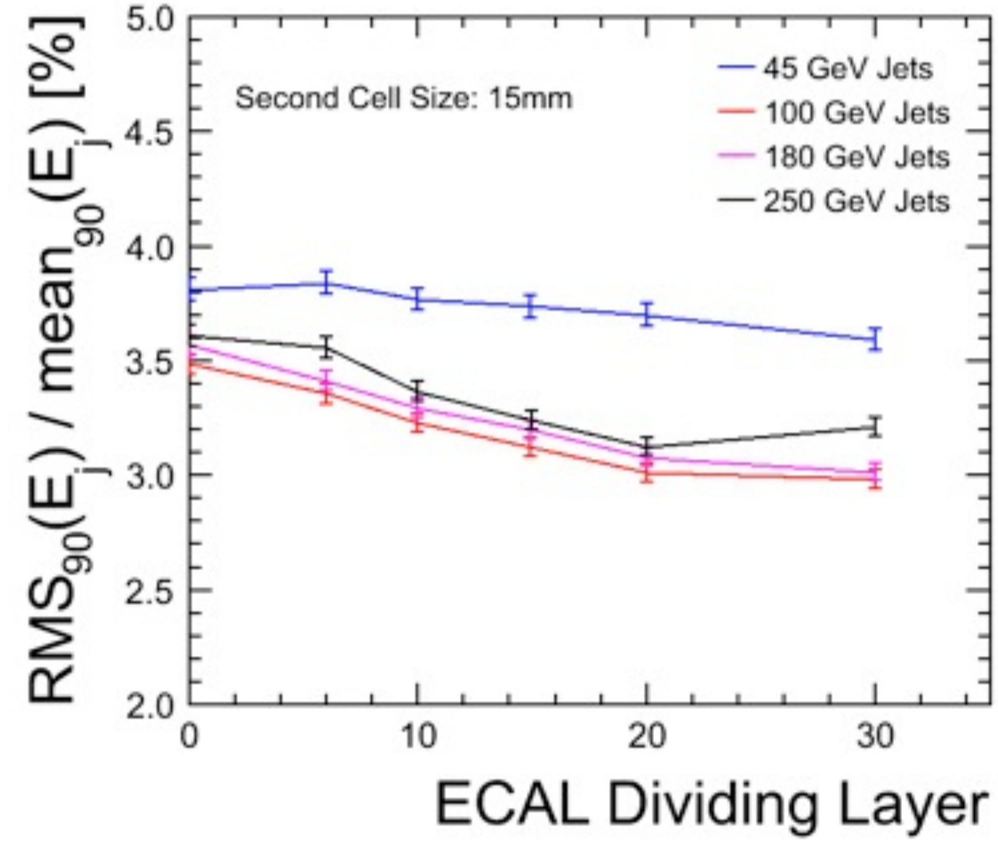


CLIC_SiD

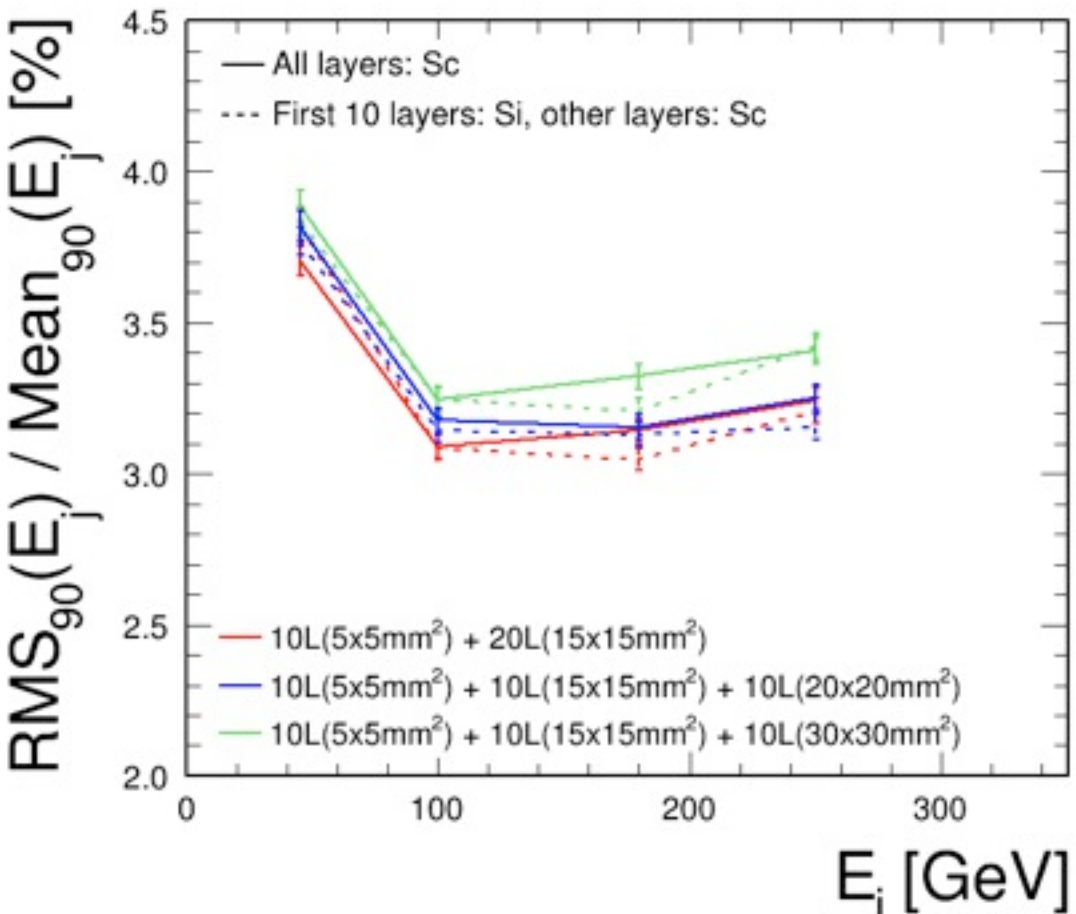
ECAL simulation study

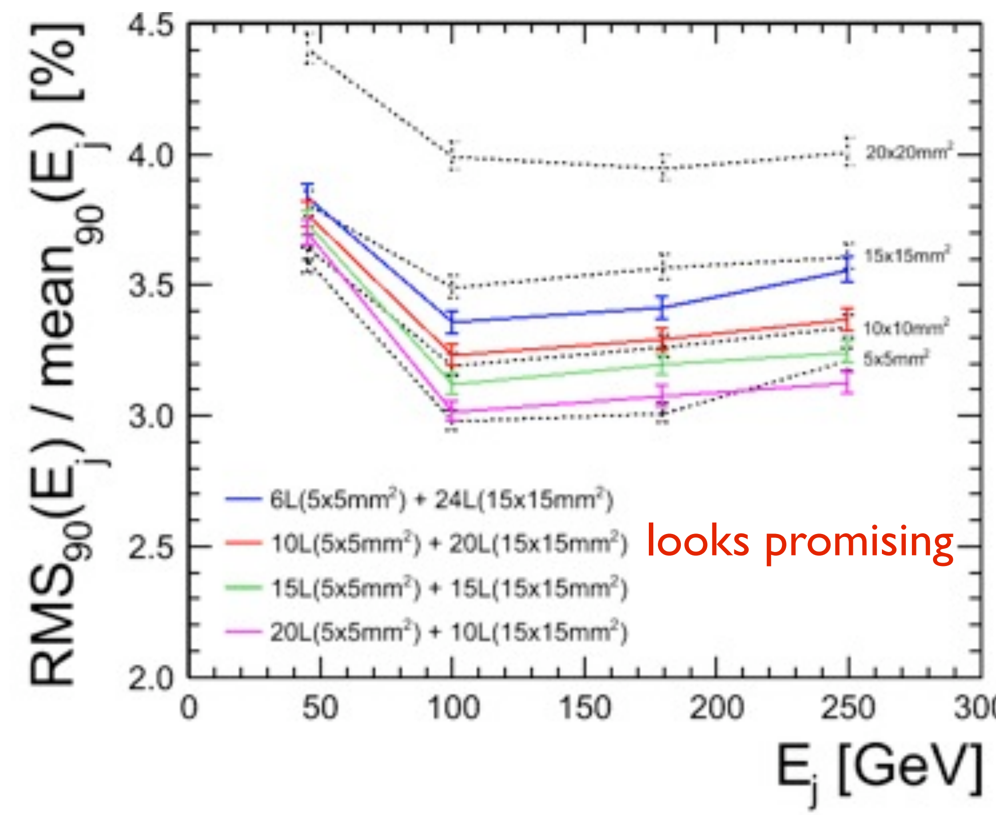
ScW ECAL models with two transverse segmentations.

- First region comprises 5x5 mm^2 cells. Study:
  - The size of square Sc cells used in second region
  - The layer at which the Sc cell size changes
- Sc thickness is 2.0 mm, W absorber thickness is 4.2 mm



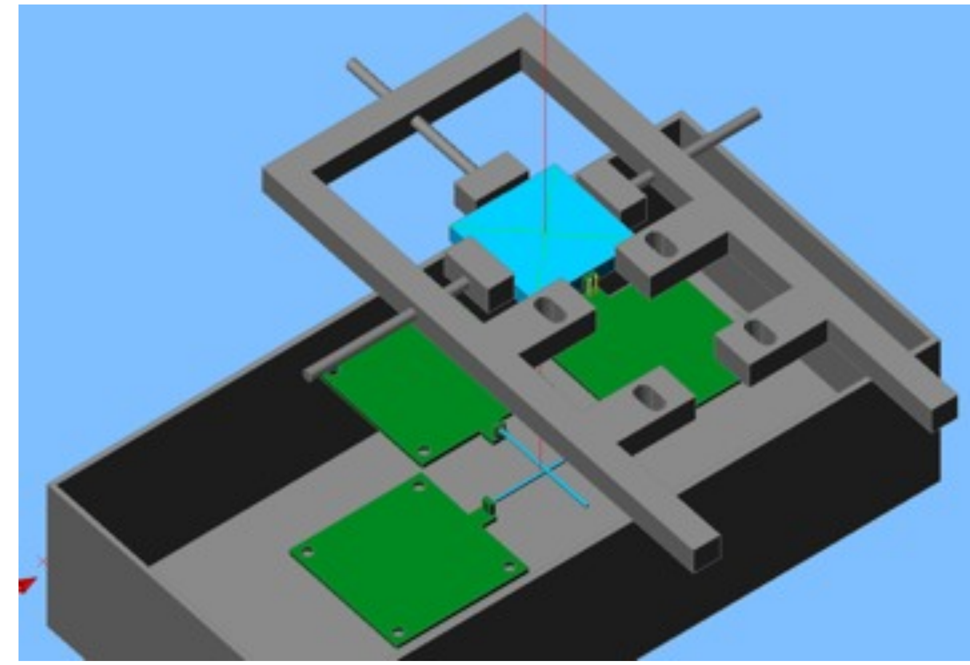
Benefit of using Si (0.5 mm thick) in the first 10 layers:



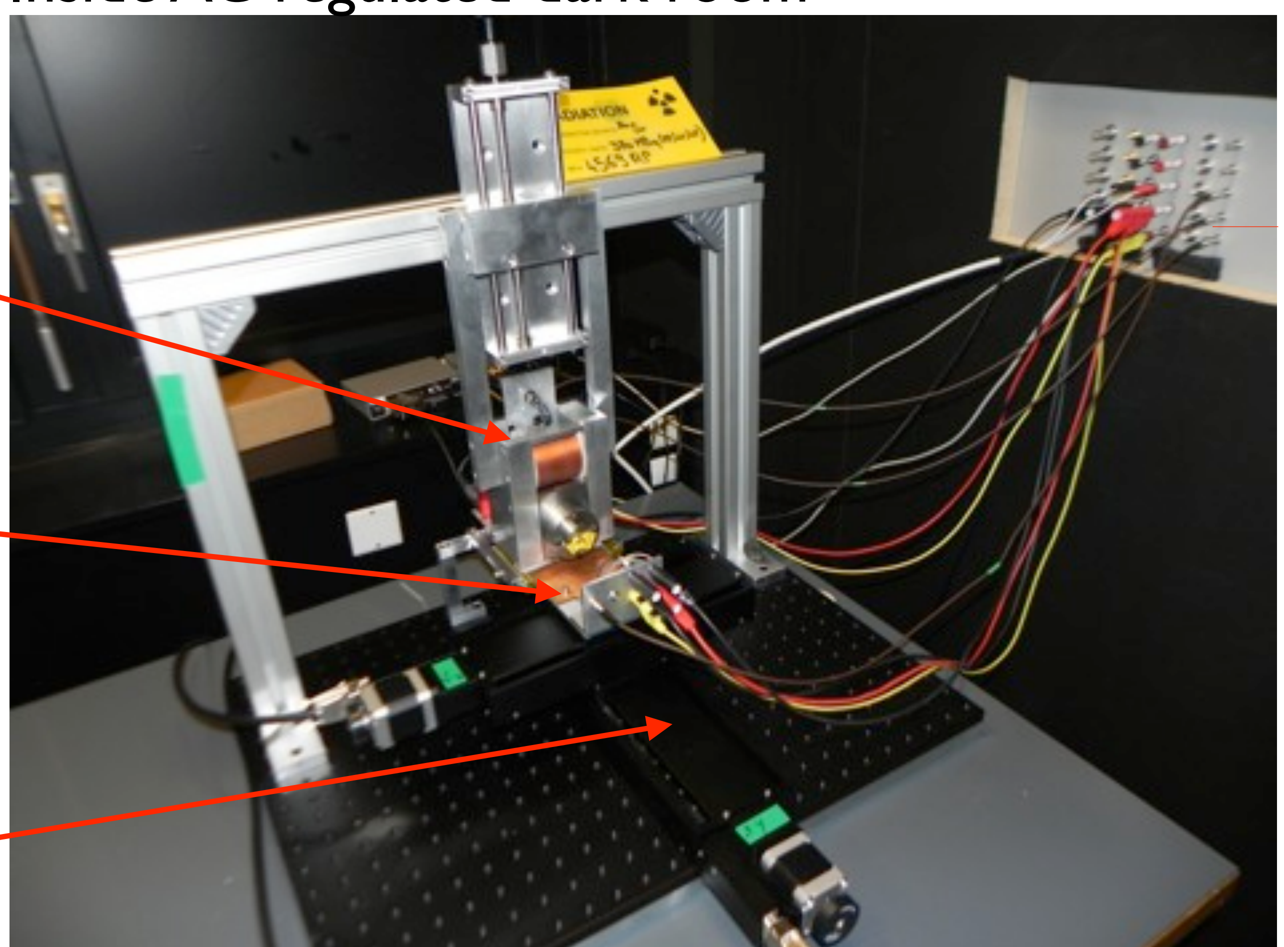


Scintillating tile lab at CERN

- New scintillator lab to build expertise
- Preliminary setup for tile scans to study geometry, packaging SiPM coupling
- Electron gun with ~350 MBq Sr90 source



Inside AC regulated dark room



Tile packaging

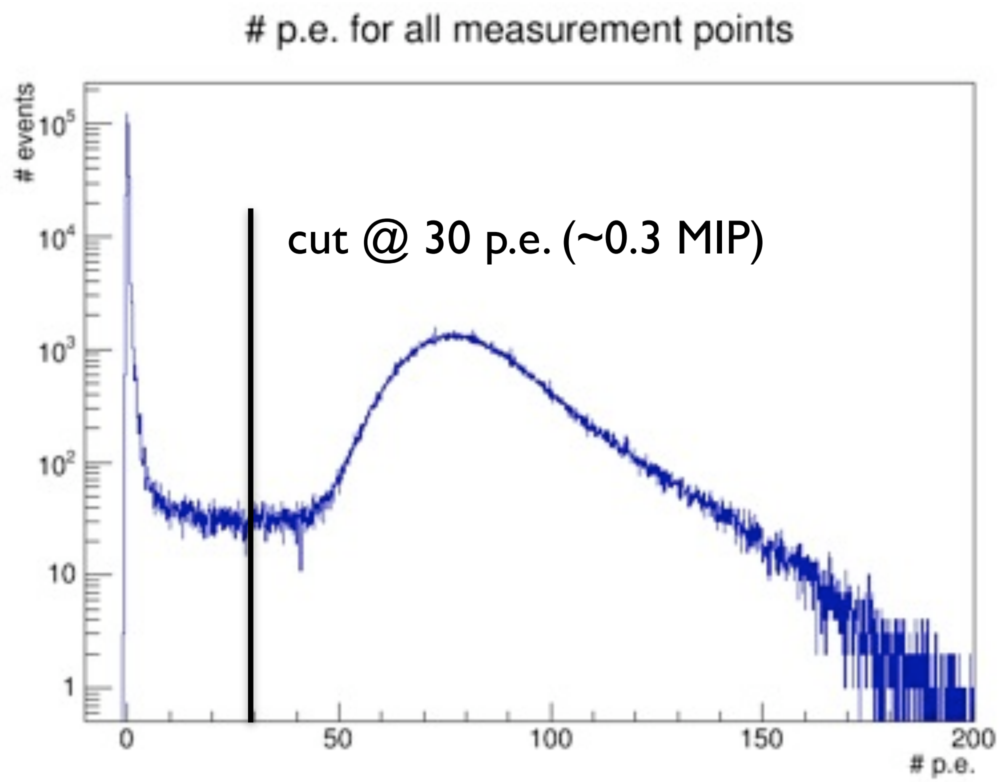
3M reflective foil, 70 µm thick

White reflective paint, 2 coats

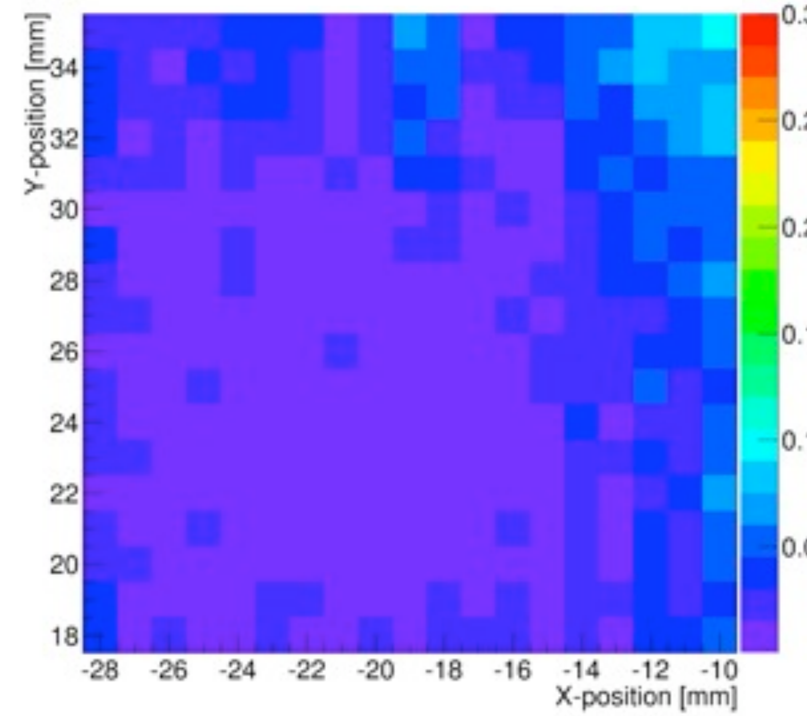
Scintillating tile lab results

- First tests study light yield of MIPs as a function of position and packaging in 20x20x2 mm tiles
- Foil packaging gives higher light yield, and better uniformity

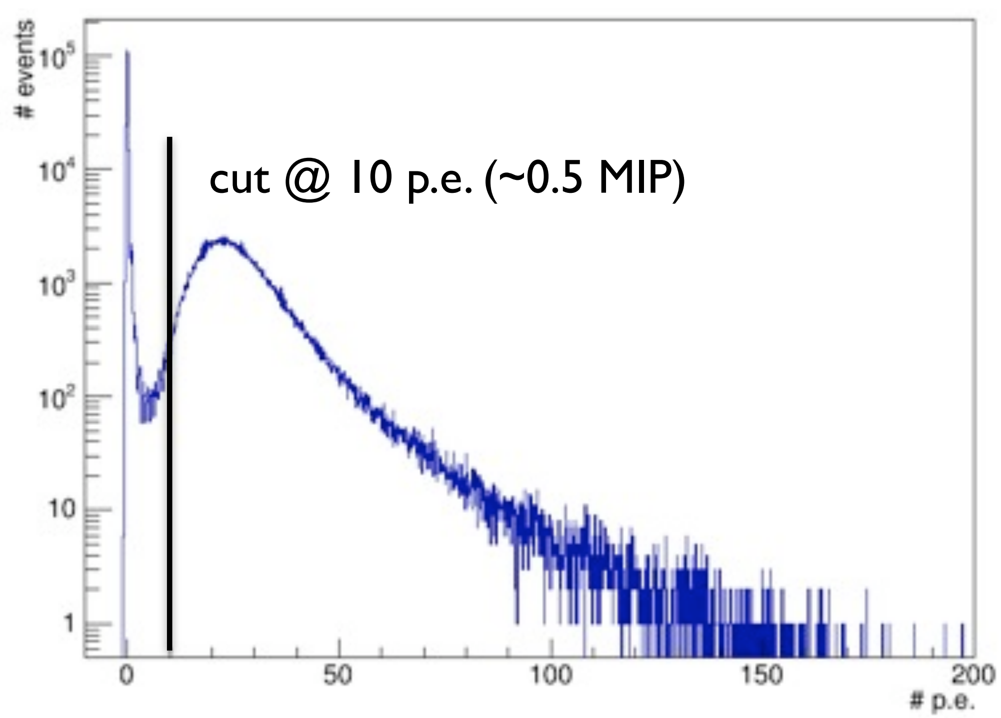
Wrapped in 3M reflective foil 70 µm thick

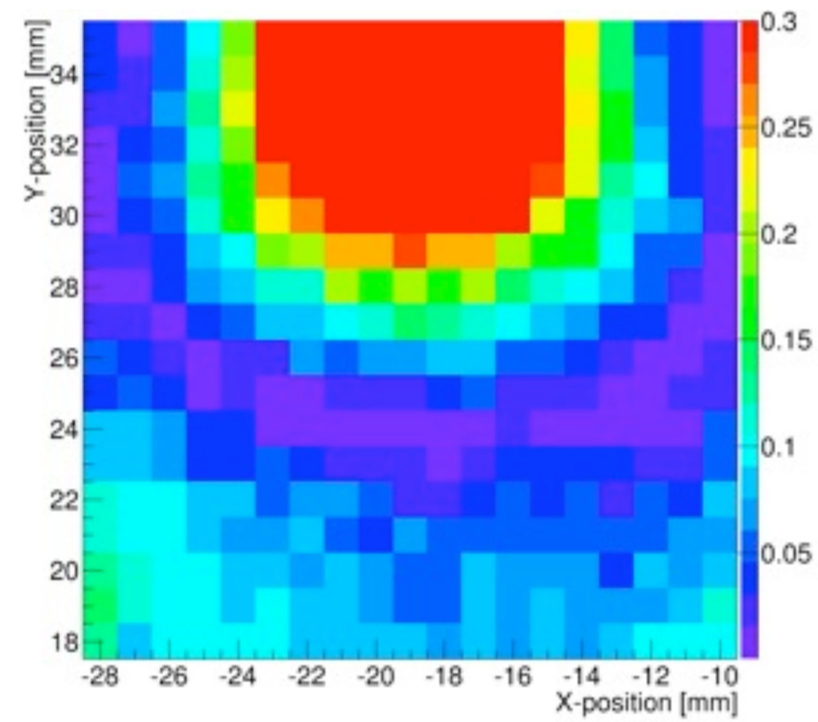


Uniformity of light yield



Painted in white reflective paint



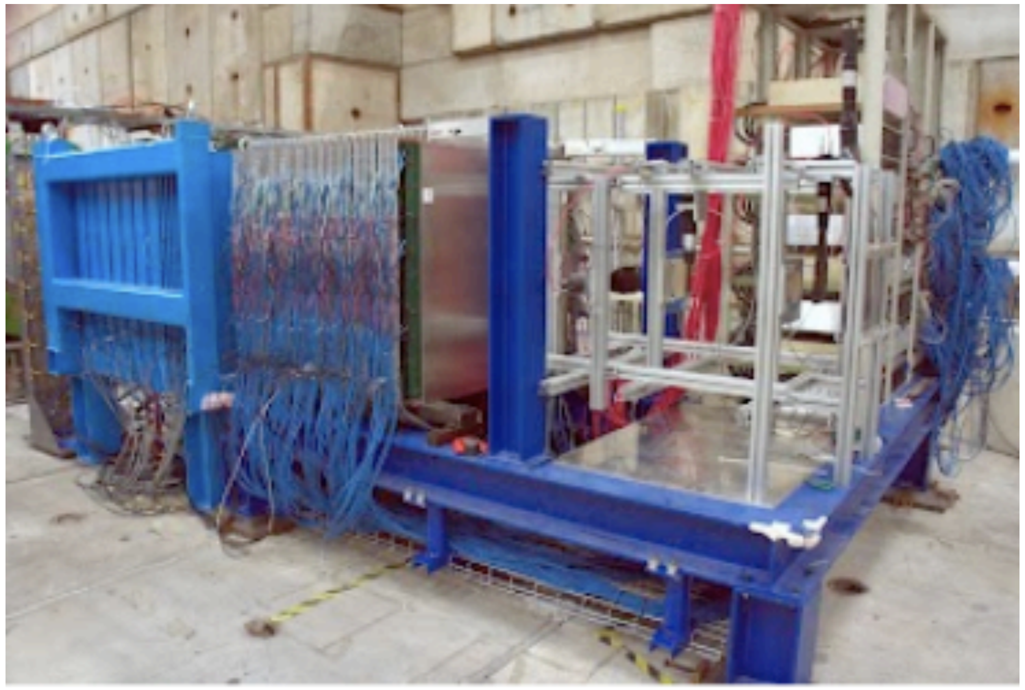


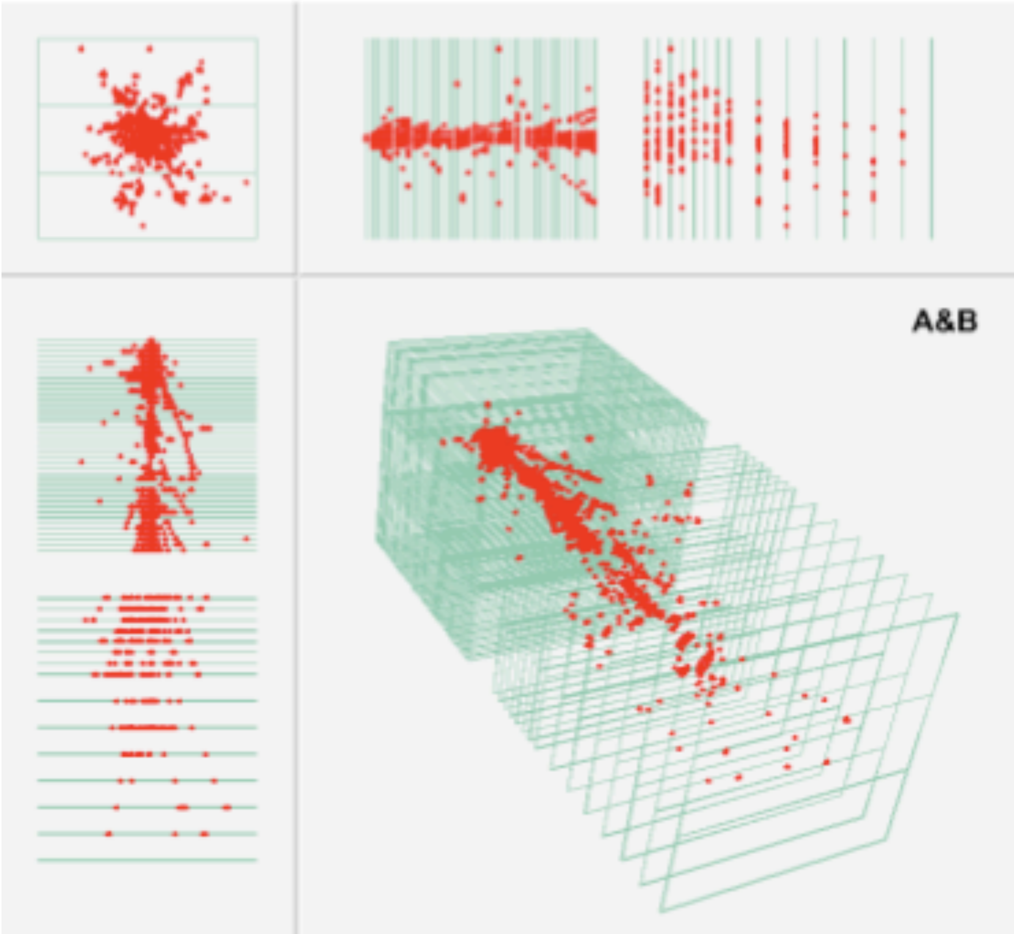
HCAL

- CLIC HCAL will use tungsten as absorber

Material	X_0 [cm]	λ_I [cm]
Steel	1.73	16.9
Tungsten	0.37	10.2

- Long term testbeam campaign to better understand the requirements of the HCAL and to validate GEANT4 simulation
  - AHCAL 2010-2011
  - DHCAL 2012
- CERN PS and SPS testbeam:
  - 1-10 GeV and 10-300 GeV beams
  - 30 million events recorded in 2012

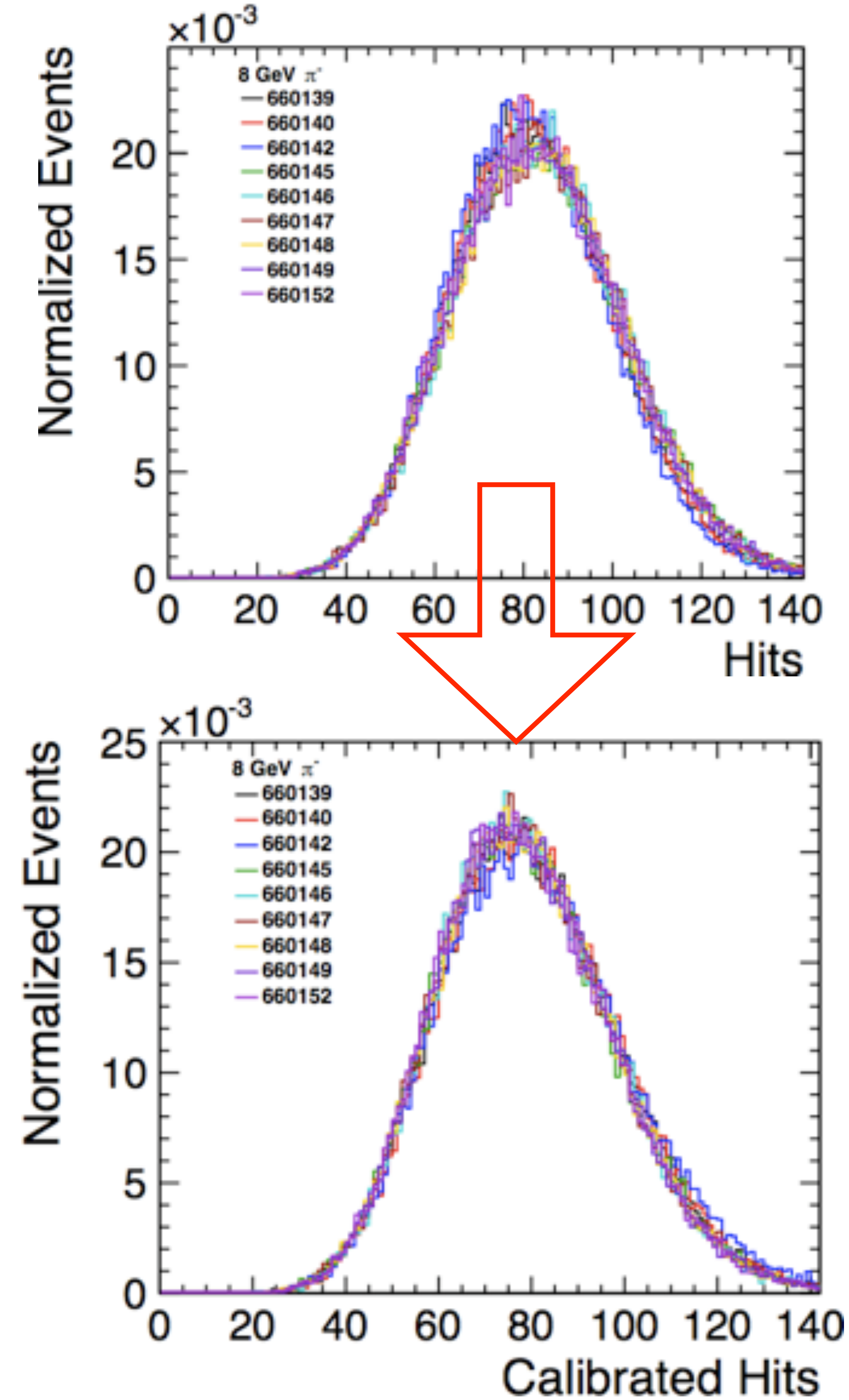


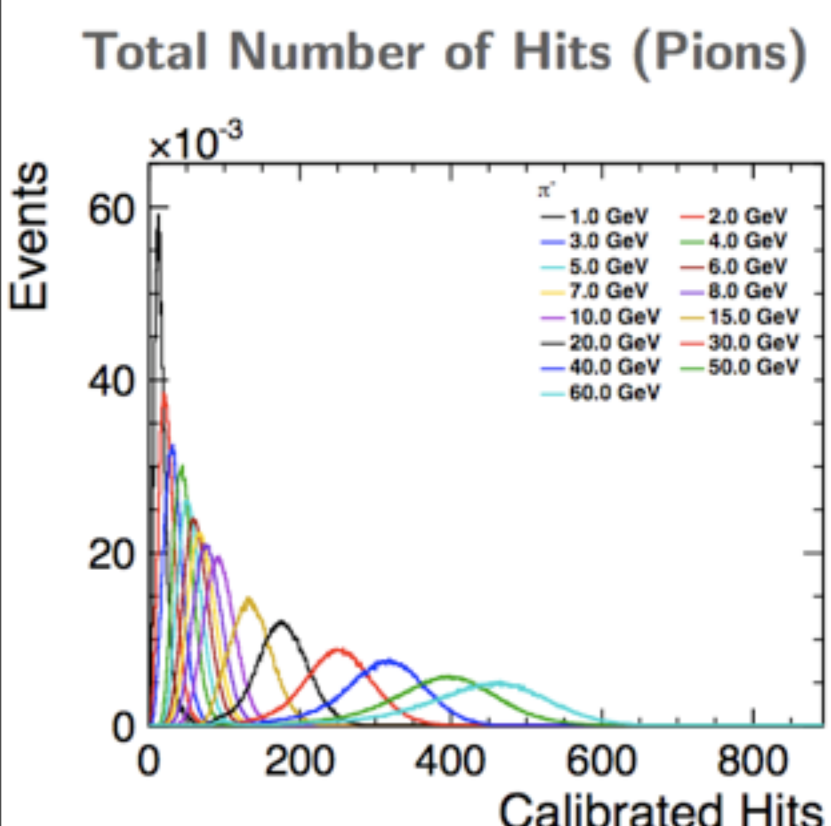


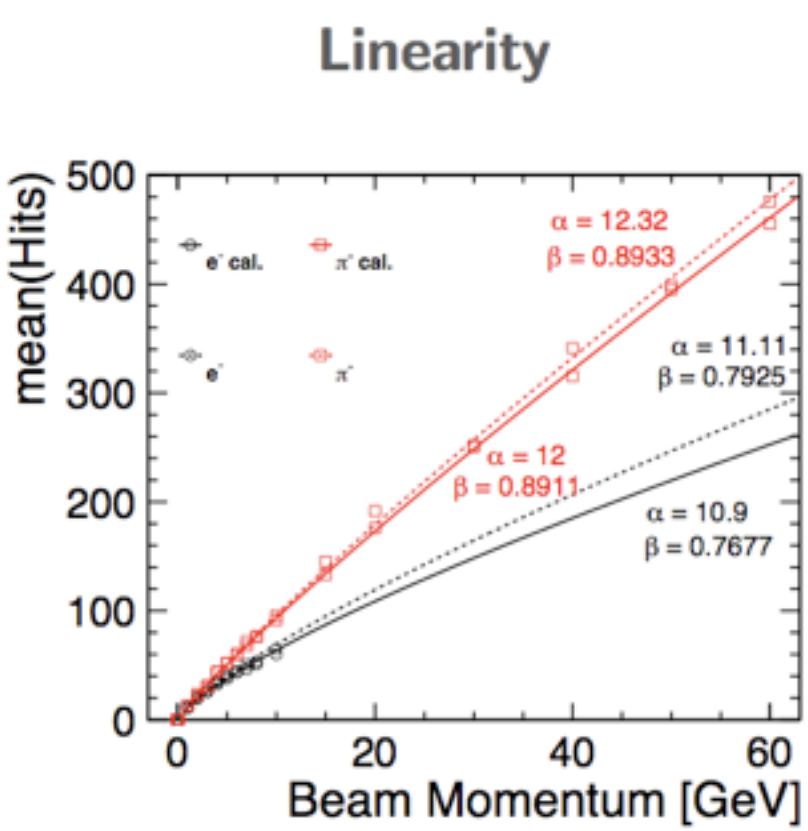
DHCAL testbeam at CERN

DHCAL testbeam analysis

- Data recorded at CERN in 2012 now being analysed
  - Cleaned (1/1000 cells removed)
  - Layer to layer calibration done with muons
- Now tuning simulation and digitisation model to match muon and electron data
- Lead to predictions for pions e.g. longitudinal shower

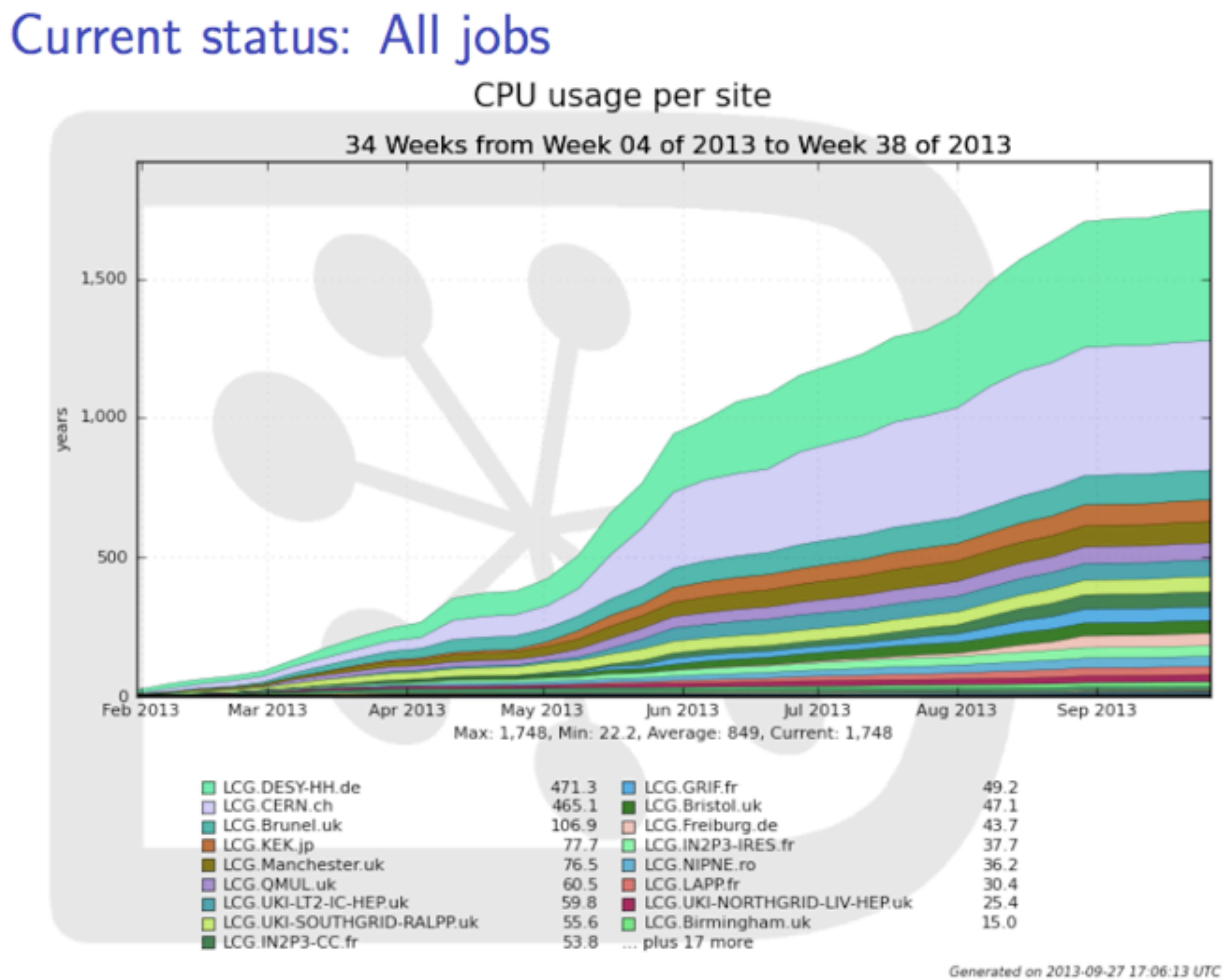






ILCDIRAC

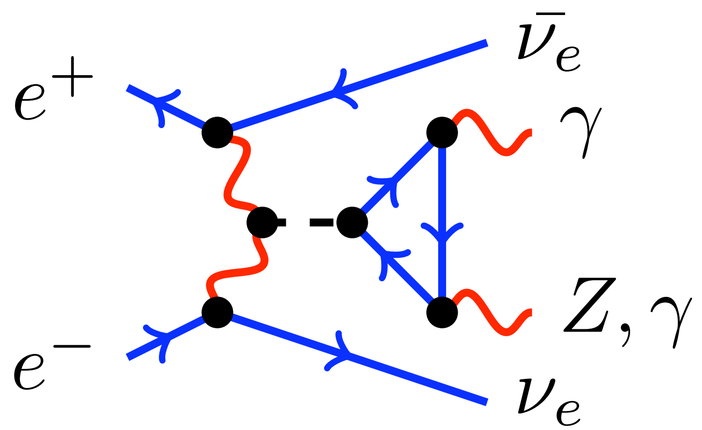
- Stable release
- Over 100 users
- Production and user jobs
- File catalogue knows all files used for SiD DBD
- See talk by Christian Grefe, Tuesday 14h00

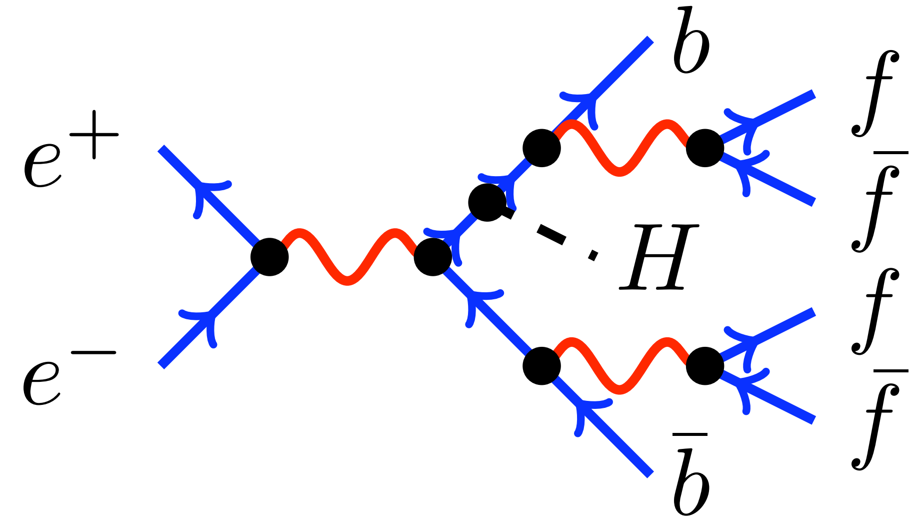


Physics benchmark studies

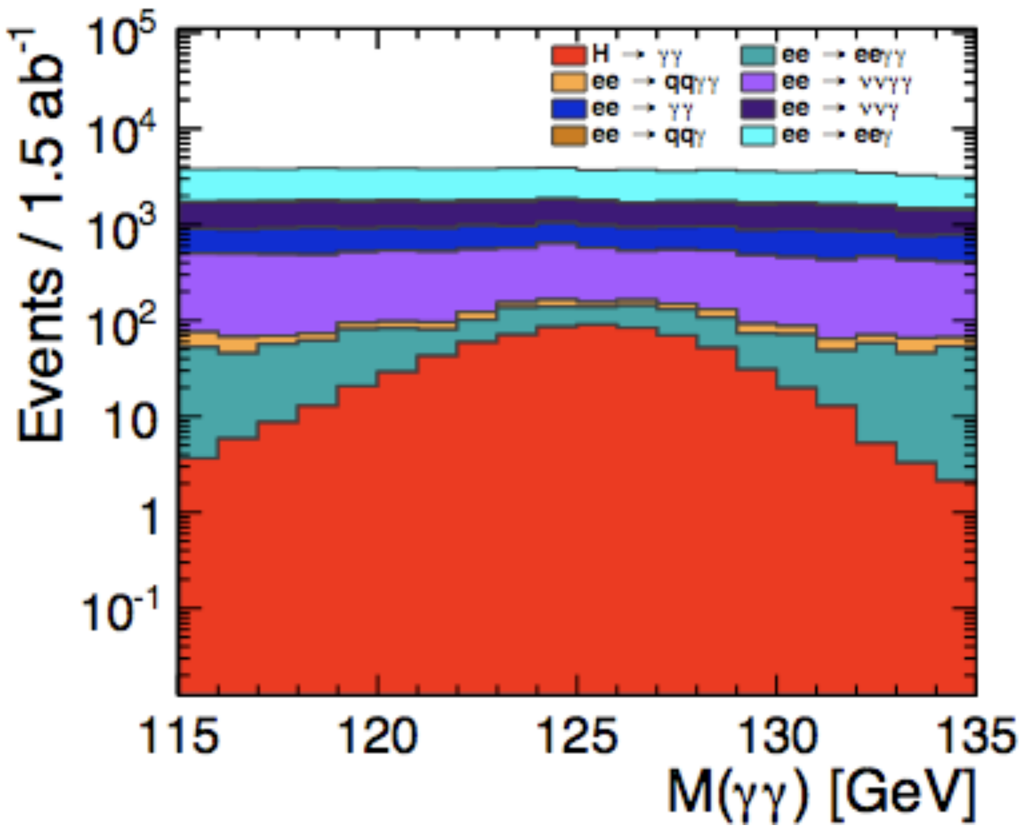
- Recent studies focused on Higgs analyses
  See talk by Sophie Redford, Monday 14h00

Nobel Prize in Physics
for the Higgs mechanism
8.10.13

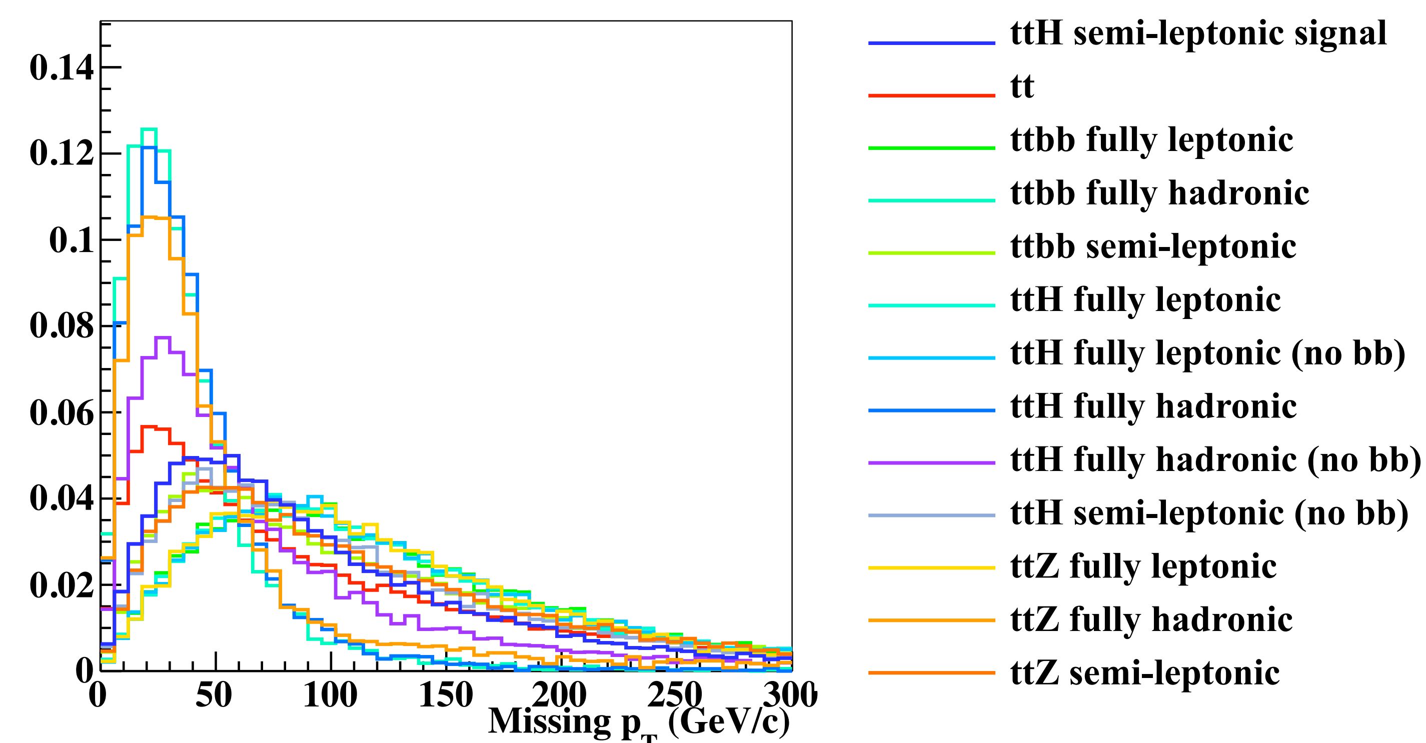




H→γγ signal in 1.5 ab^{-1} at 1.4 TeV
BDT selection gives result σ = 6.8



Missing pT in ttH semi-leptonic channel
Combined analysis: δg_{ttH} = 4.3%



CLICdp collaboration

19 institutes have signed the Memorandum on Cooperation (MoC):

Australia: ACAS; Belarus: NC PHEP Minsk; Chile: The Pontificia Universidad Católica de Chile, Santiago; Czech Republic: Academy of Sciences Prague; Denmark: Aarhus Univ.; France: LAPP Annecy; Germany: MPI Munich; Israel: Tel Aviv Univ.; Norway: Bergen Univ.; Poland: Cracow AGH + Cracow Niewodniczanski Inst. ; Romania: Inst. of Space Science; Serbia: Vinca Inst. Belgrade; Spain: Spanish LC network; UK: Cambridge Univ. + Oxford Univ. + Birmingham Univ.; USA: Argonne lab; CERN

CLICdp structure

- Institute board: formed by the 19 member institutes
- Frank Simon: elected as chairperson of CLICdp Institute Board

- Executive team:
- Lucie Linssen: elected as spokesperson for CLICdp
- Mark Thomson: elected as member of the executive team

- Publication and Speakers committee:
- Aharon Levy: elected as chairperson of the Publication Committee
- Erik van der Kraaij: elected as chairperson of the Speakers Committee

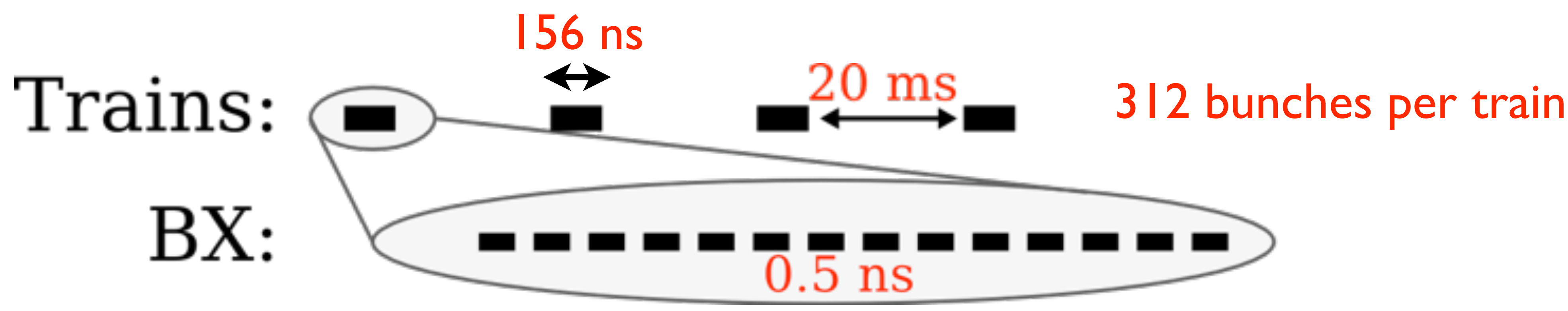
Summary

CLIC_SiD detector mock up as seen
on the CERN Open Days

- ☑ Research progressing on many fronts
- ☑ Vertex detector: integrated approach
  - Thin sensors
  - CLICpix
  - Power pulsing
  - Cooling
- ☑ ECAL: simulation and lab tests
  - Cost-effective layer strategy
  - Scintillator tile lab tests
- ☑ HCAL: testbeam analysis
- ☑ CLICdp collaboration growing

Backup slides

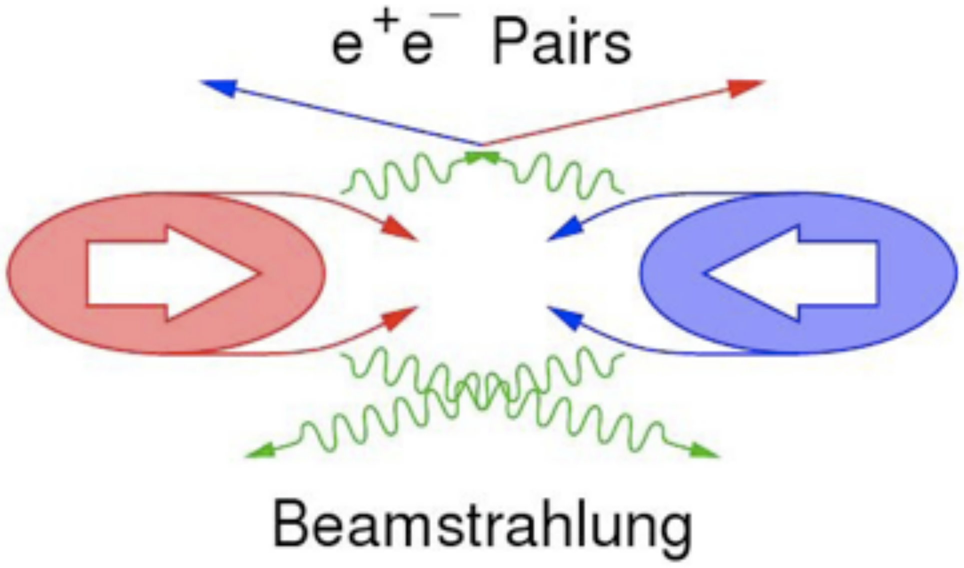
Experimental conditions - beam structure

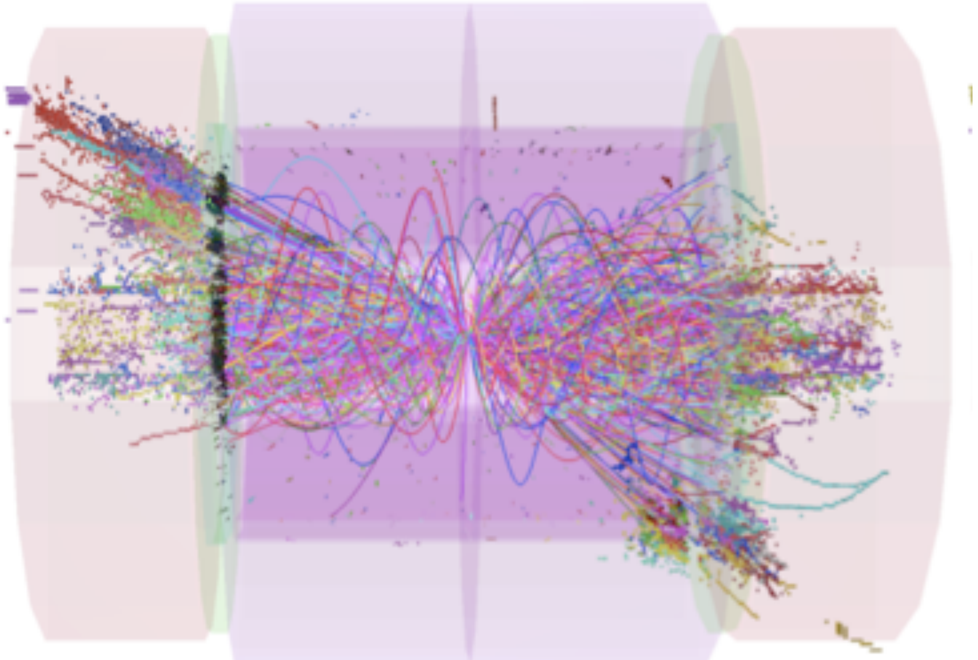


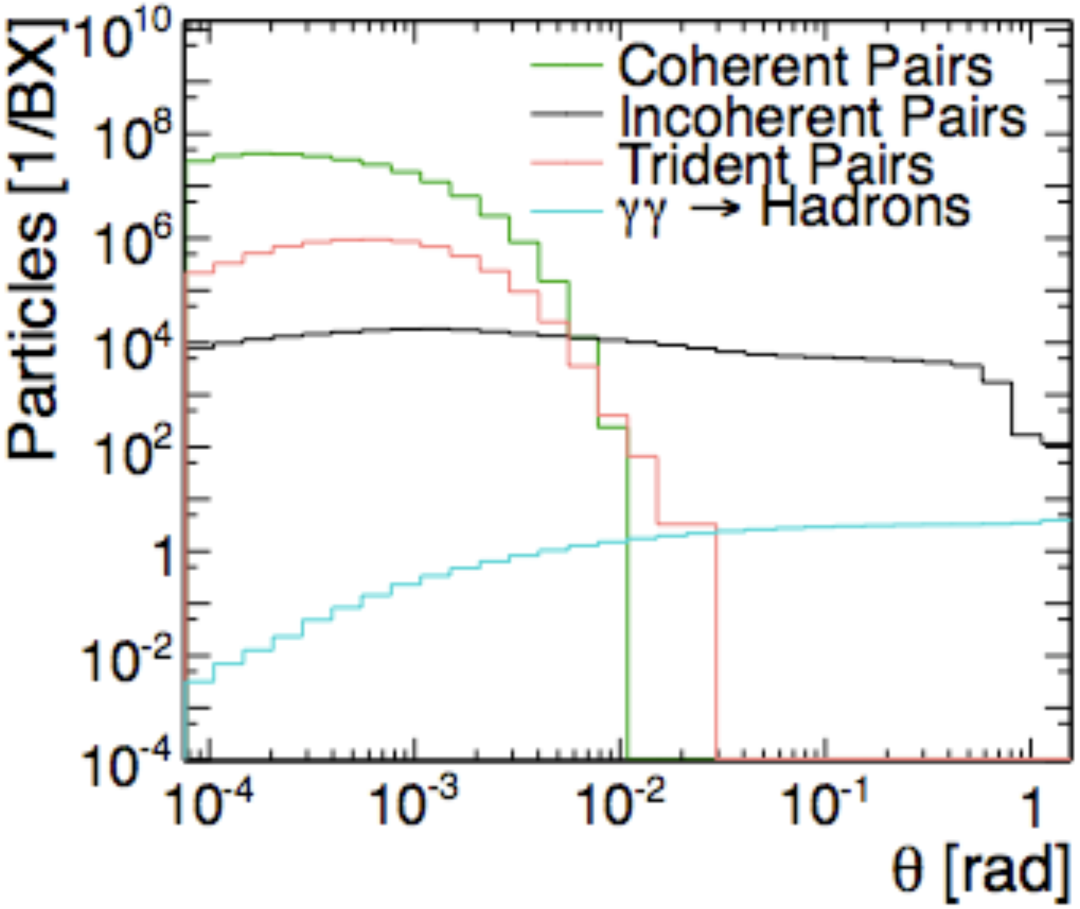
- Bunch train every 20 ms (50 Hz)
- Train of 312 bunches (156 ns)
  - Small duty cycle
  - Possibility of power pulsing
- Within a train, bunch crossing every 0.5 ns
  - Detector integrates over several crossings
  - Background rejection requires precise (10 ns) time stamping of hits

Experimental conditions - beam collisions

- High bunch charge density means that electrons and positrons radiate strongly in the em field of the other beam.
- Beamstrahlung photons convert through various processes to e+e- pairs
  - Most at small angle
- Two photon interactions γγ→ had
- Expect 3.2 events per BX:







Detector requirements for physics

- Track momentum resolution
- ▸ Material budget requirement

$$\sigma_{p_T}/p_T^2 \lesssim 2 \cdot 10^{-5}\ \text{GeV}^{-1}$$

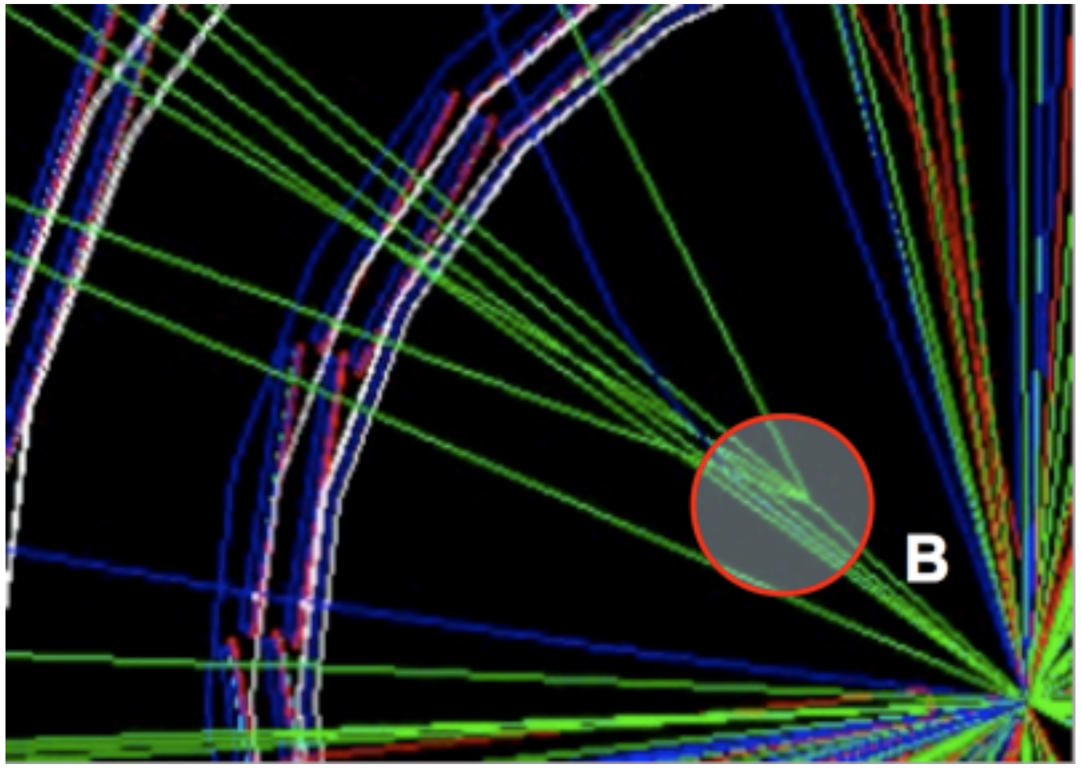
- Impact parameter resolution
- ▸ Single point resolution requirement

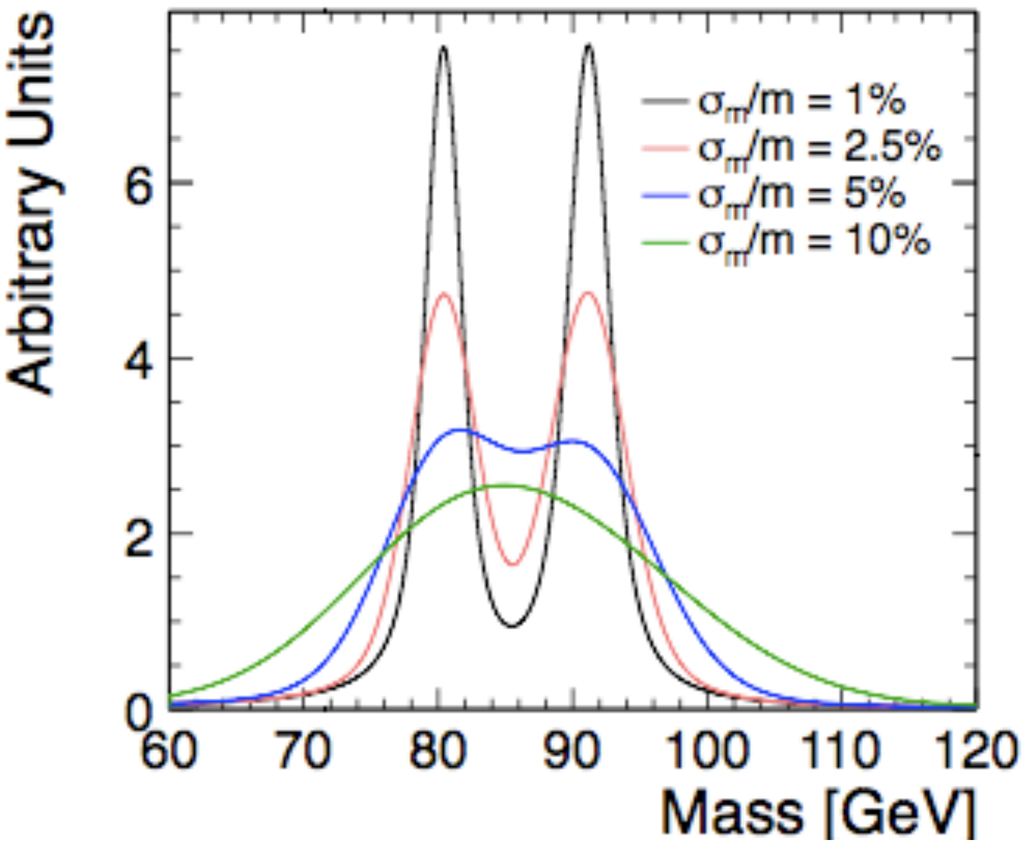
$$\sigma_{d_0}^2 = a^2 + \frac{b^2}{p^2 \sin^3\theta}$$

$$a \lesssim 5\ \mu\text{m and } b \lesssim 15\ \mu\text{m GeV}$$

- Jet energy resolution
- ▸ Granularity requirement

$$\sigma_E/E \lesssim 5 - 3.5\%$$





ECAL scintillator saturation?

- Literary review of Dose Rate Saturation. Study of different scintillators and their response to different electron doses:

Stevens and Knowlen: Transient Nonlinear Response of Plastic Scintillators (IEEE Transactions on Nuclear Science (Volume:15, Issue: 3))

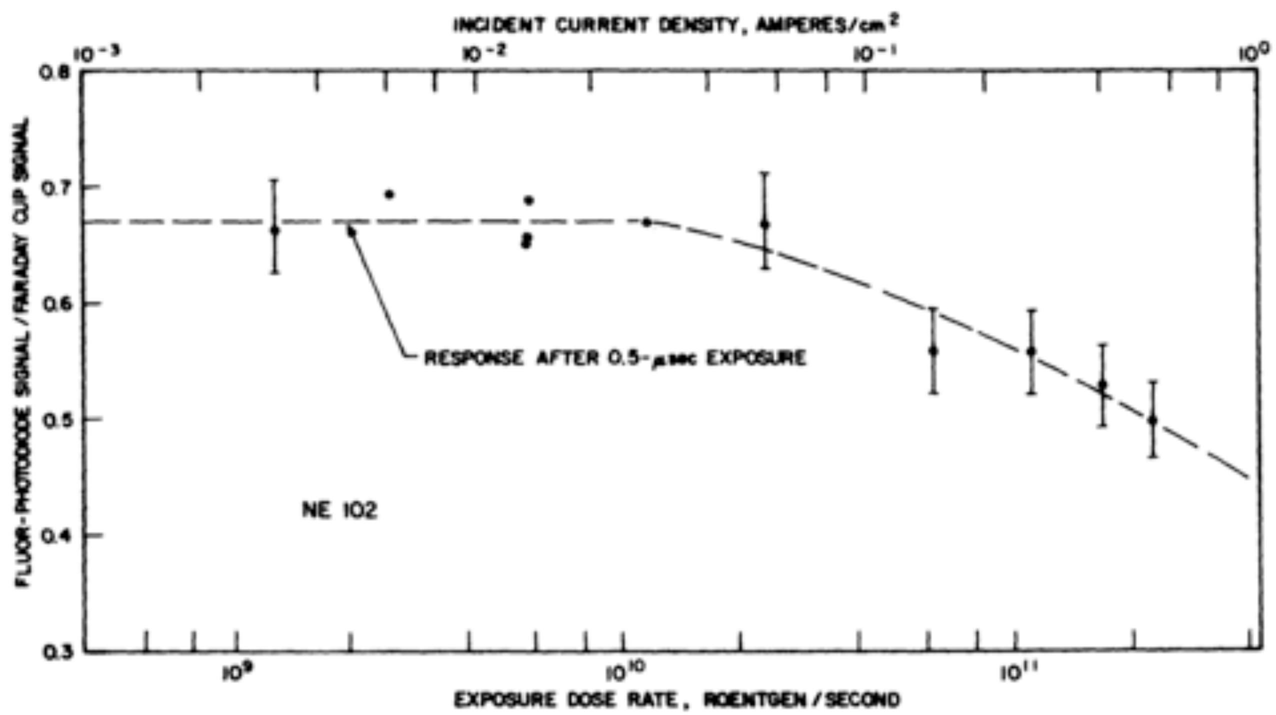


Fig. 8. Fluor light output per incident dose rate versus incident dose rate (after 0.5-microsecond exposure).

- Findings: Non-linear response starts at 10^{10} Roentgen per second, or 3×10^{-2} Ampere/cm^2
- Unit conversions: Ampere is Coulomb per second, so this is 1.8×10^8 particles per (cm^2 ns)
- Or, taking the area/mass of the sample, and 0.01 Gray per Roentgen, estimated dose at which saturation starts to be 2.5×10^5 GeV/(cm^2 ns)
- Saturation starts about 4 orders of magnitude above the expected energy deposits at CLIC