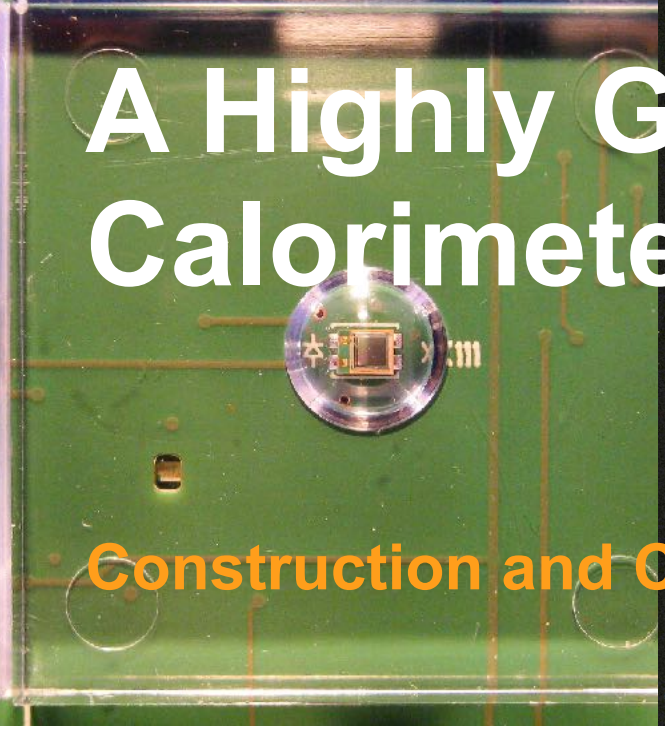
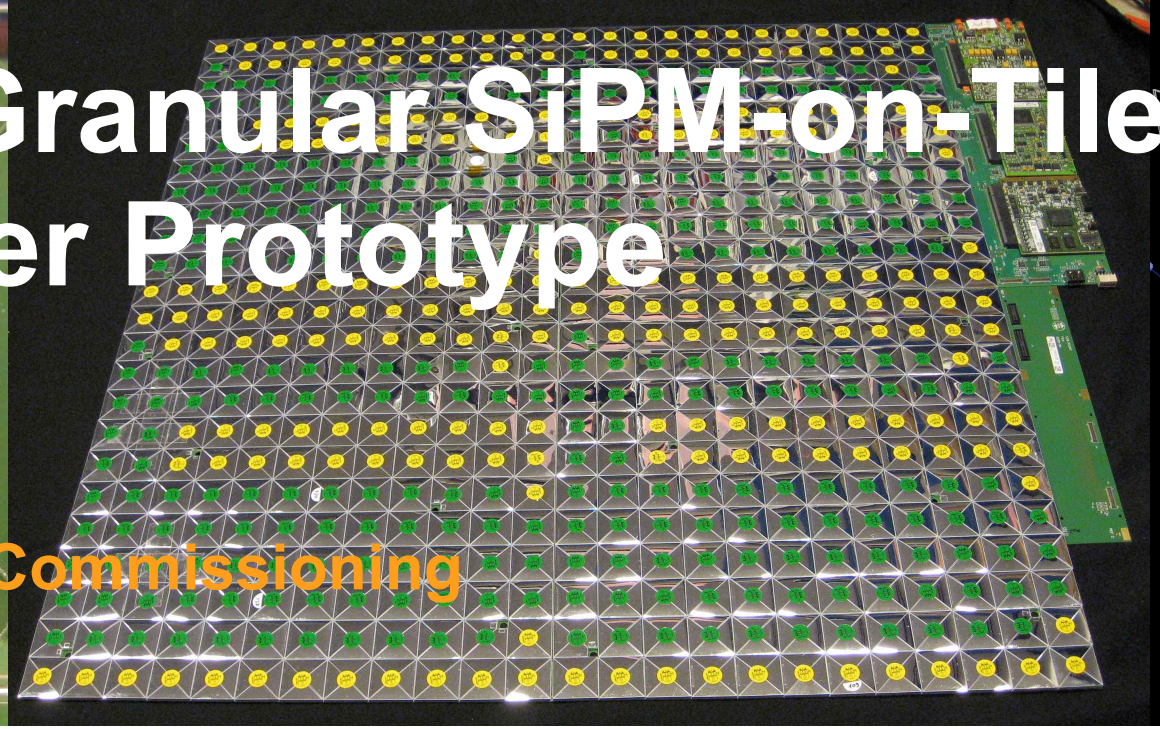
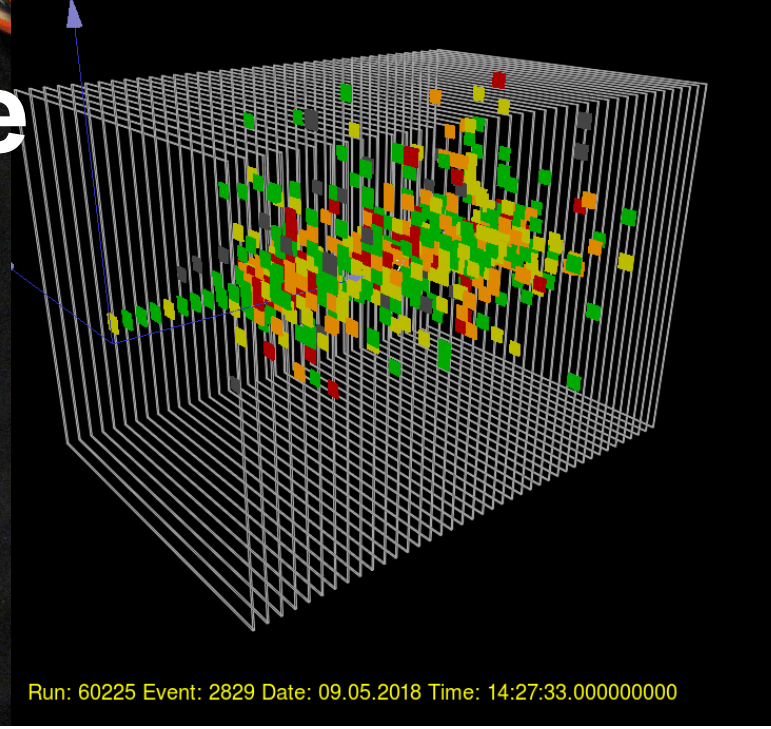






A Highly Granular SiPM-on-Tile Calorimeter Prototype

Construction and Commissioning

CALOR 2018

Eugene, OR, May 22, 2018

Felix Sefkow - On Behalf of the CALICE Collaboration
DESY

Outline

This Talk.

Design overview

- particle-flow driven

Construction and Quality Assurance

- automation and scalability

Commissioning and first experience

- DESY and CERN test beams (as we speak)

Design Principles

Particle Flow Paradigm

Tackle the jet energy challenge.

In e+e- physics every event counts - exclusive reconstruction possible

- Heavy objects - multi-jet final states

W / Z mass splitting dictates required jet energy resolution of 3-4%

- Cannot be archived with classical calorimeters (e.g. ZEUS: 6%)

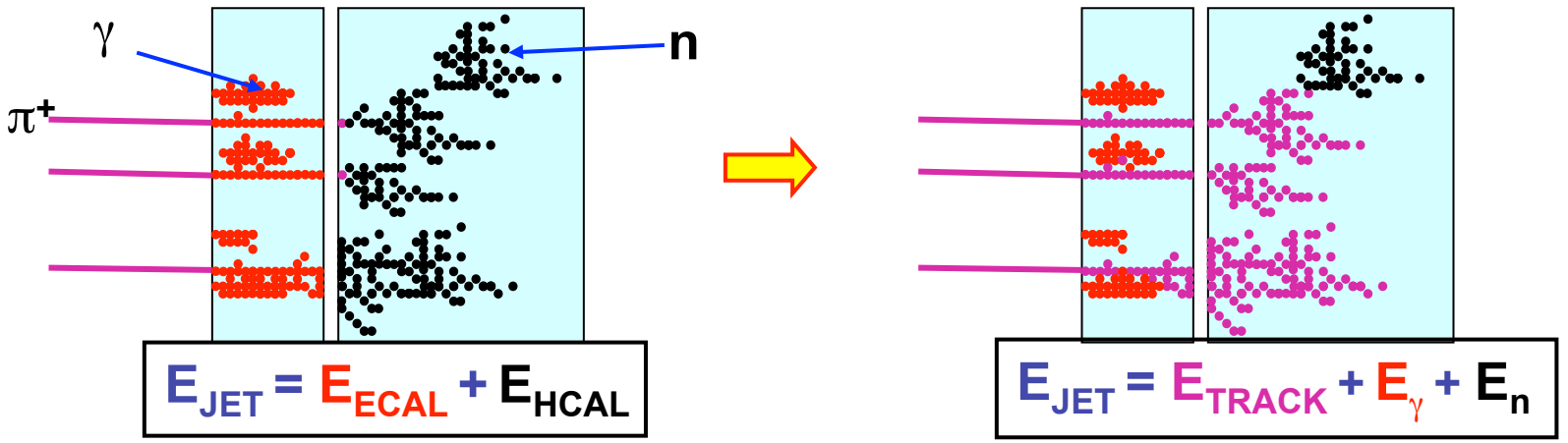
Reconstruct each particle individually and use optimal detector

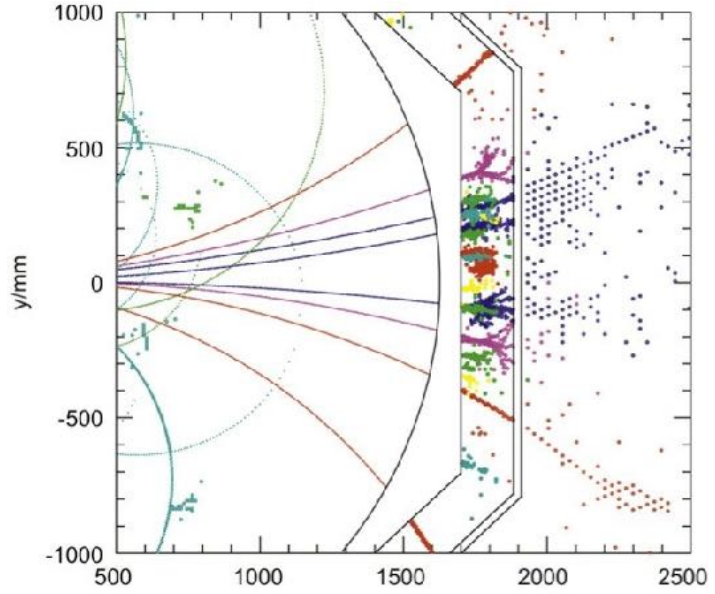
- 60% charged, 20% photons, 10% neutral hadrons

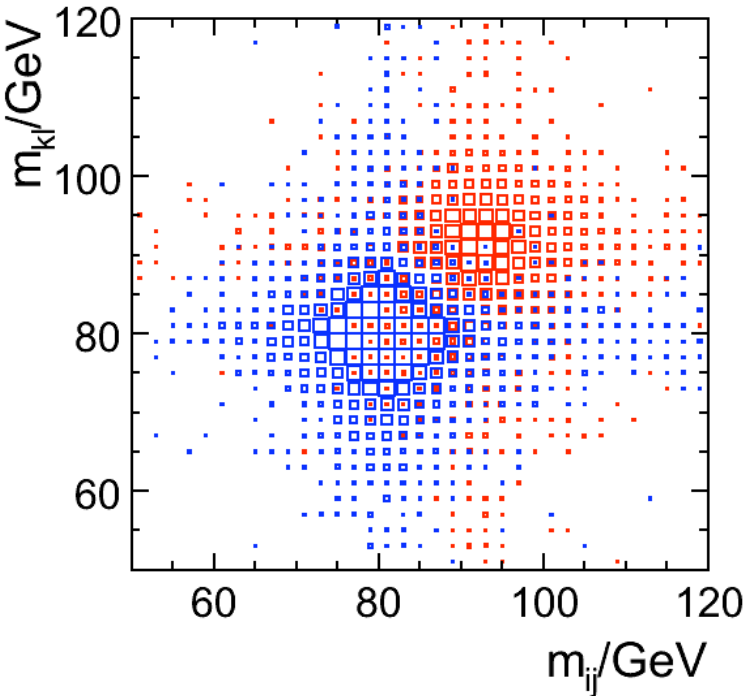
Requires fine 3D segmentation of and sophisticated software

- ECAL few 10 mm², HCAL 1-10 cm² - millions of channels

Today all linear collider detector concepts follow particle flow concept

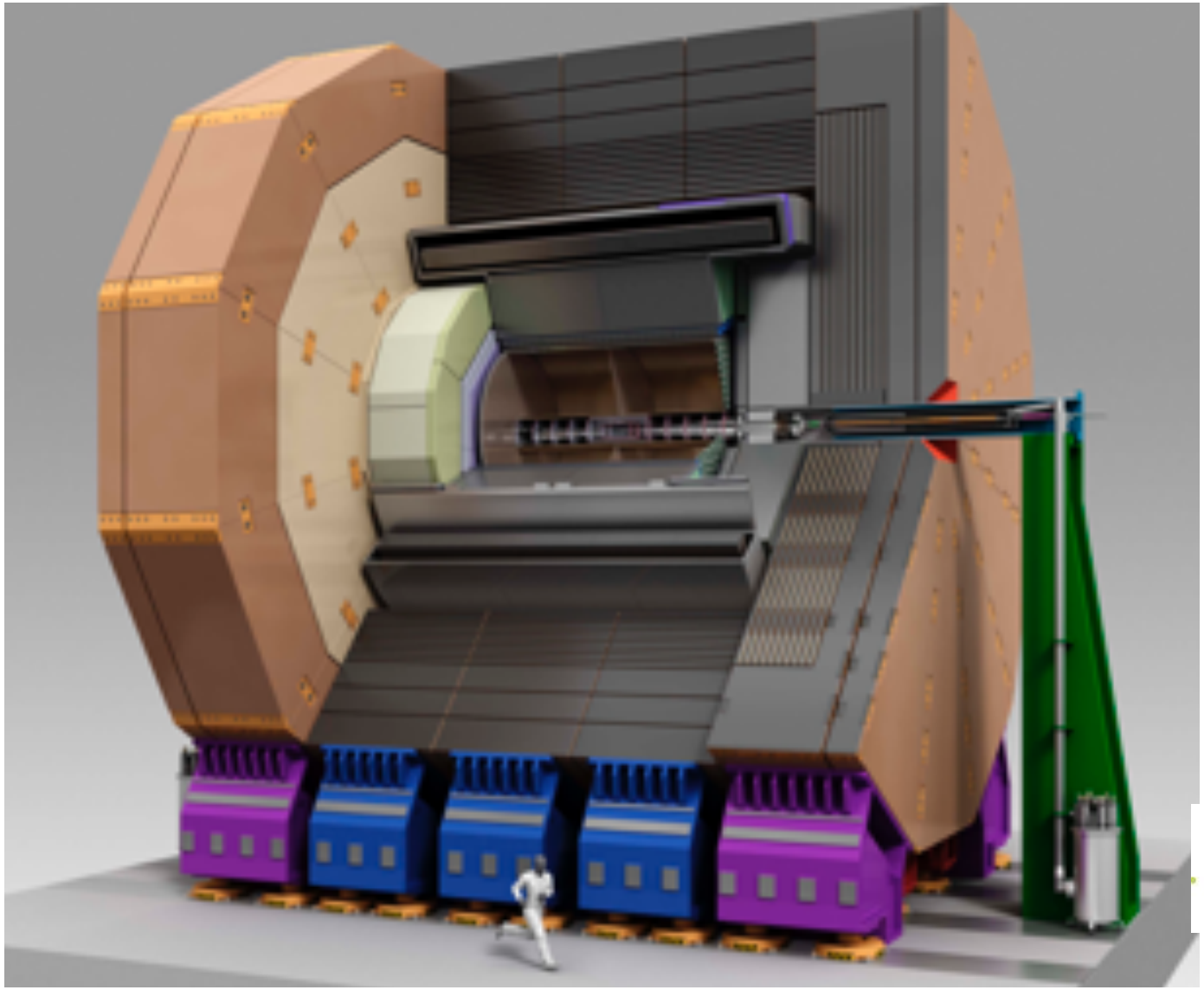


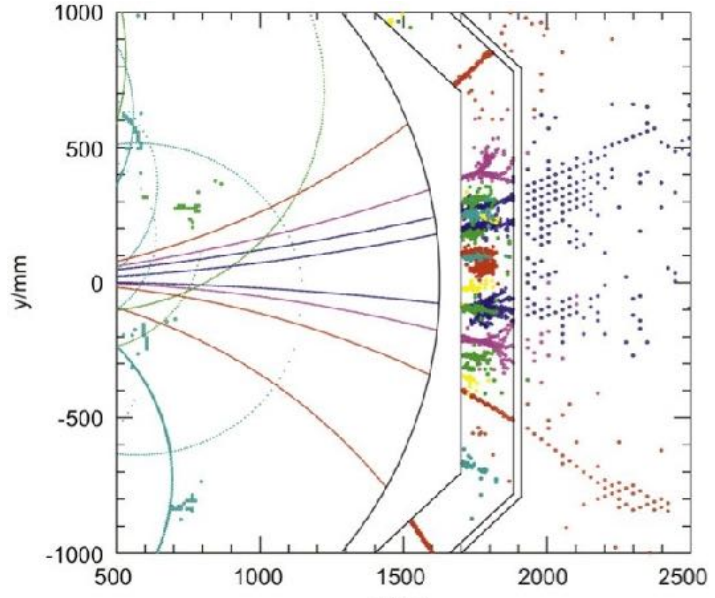


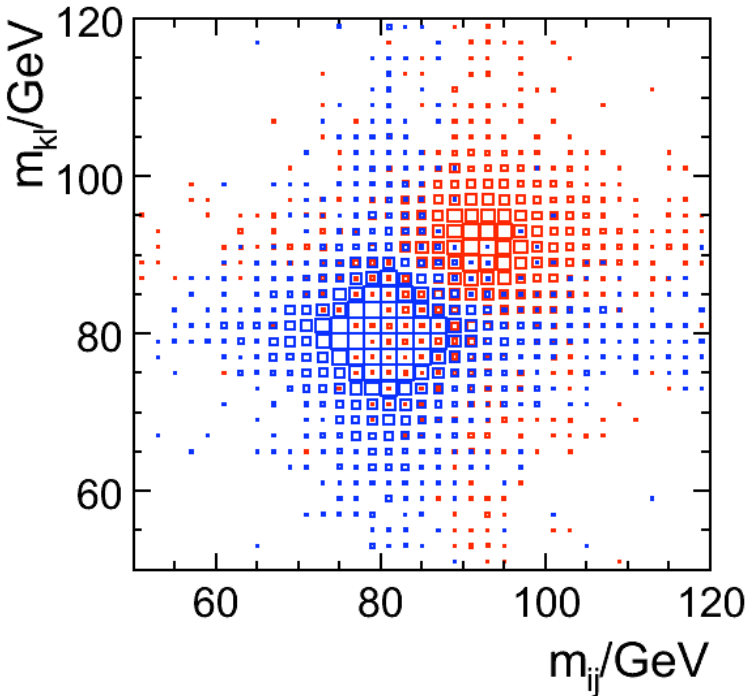


Particle Flow Paradigm

Tackle the jet energy challenge.







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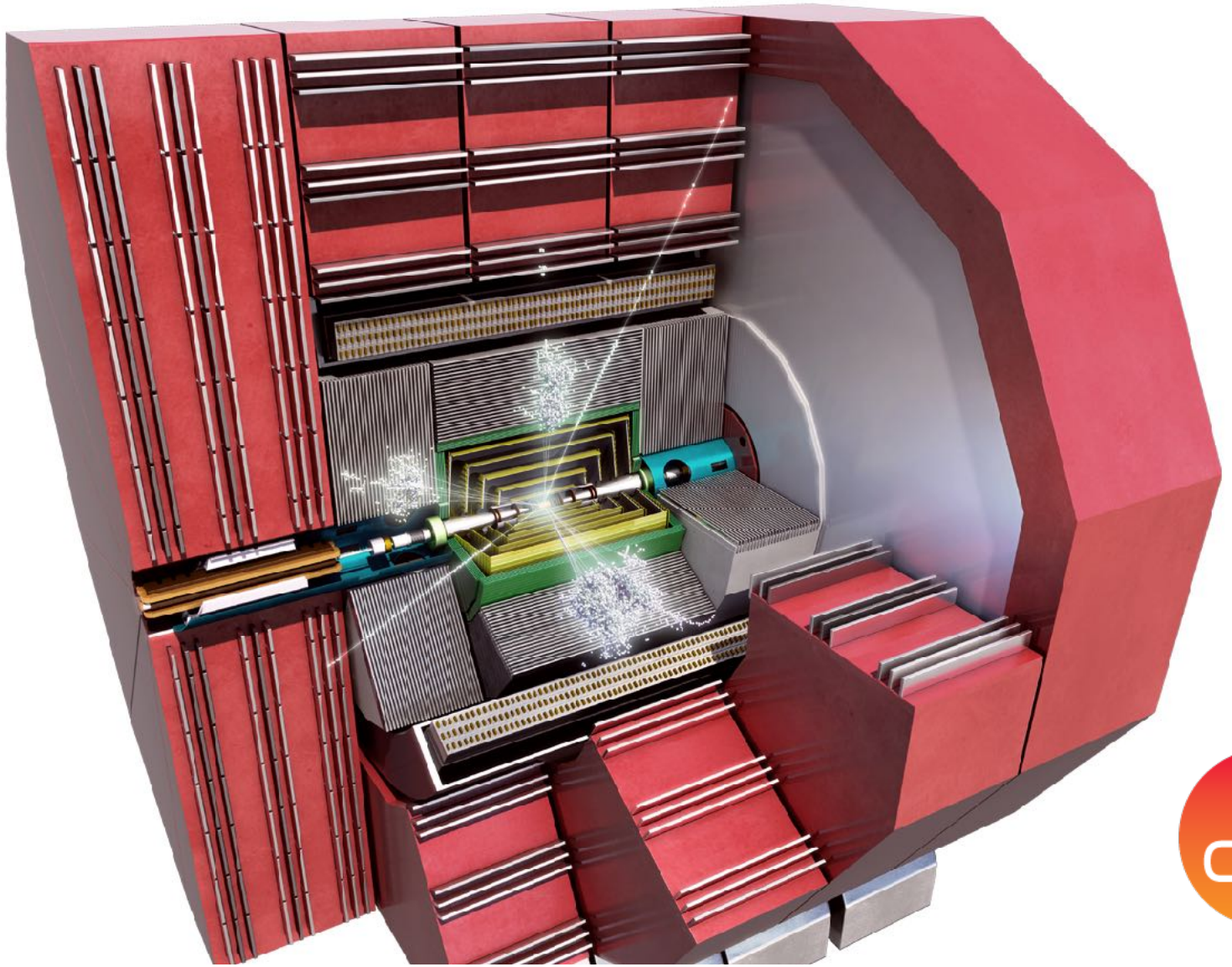
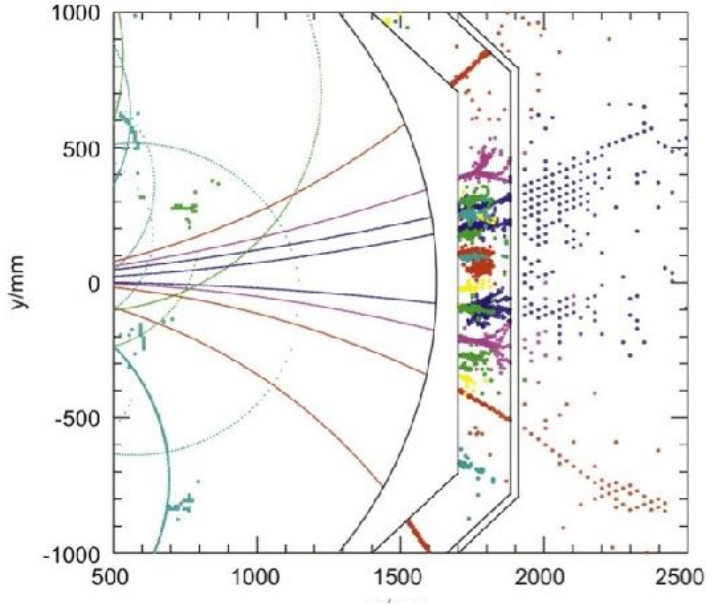
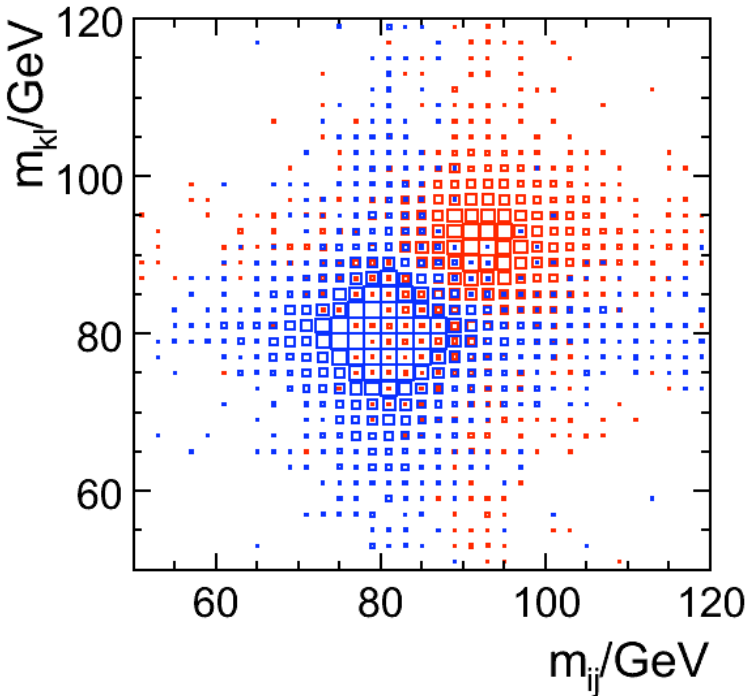






Technologies for Highly Granular Calorimeters

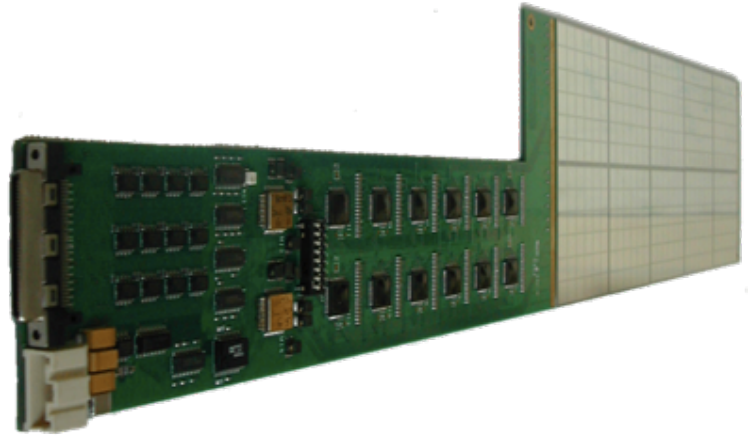
Because we can.

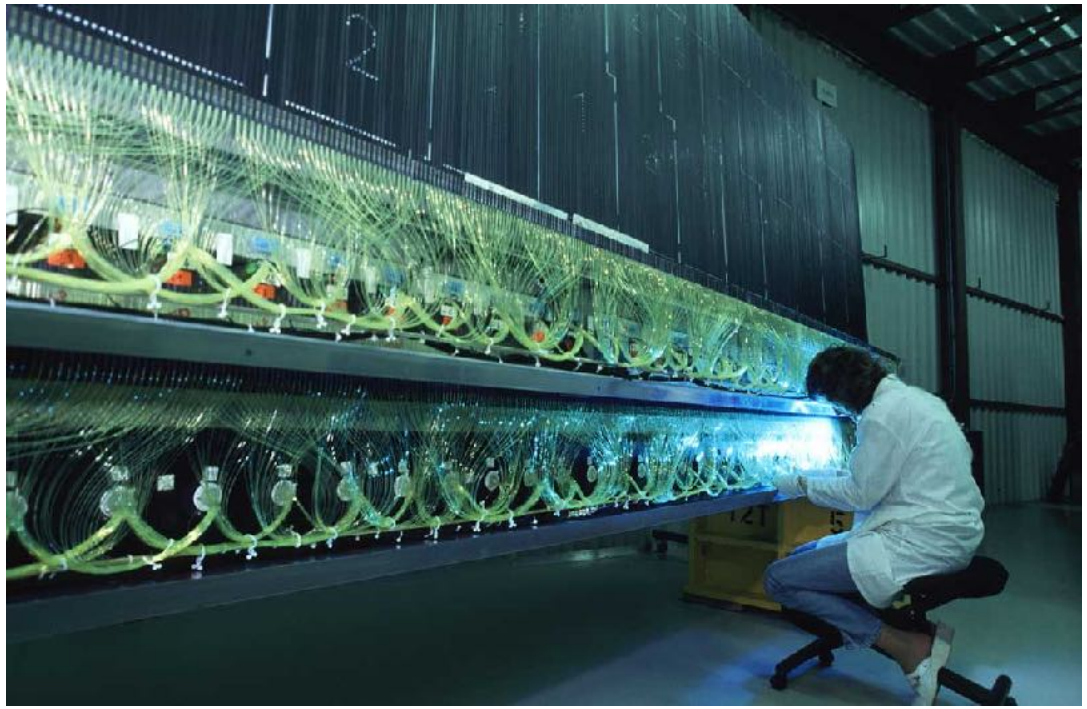
Large area silicon arrays

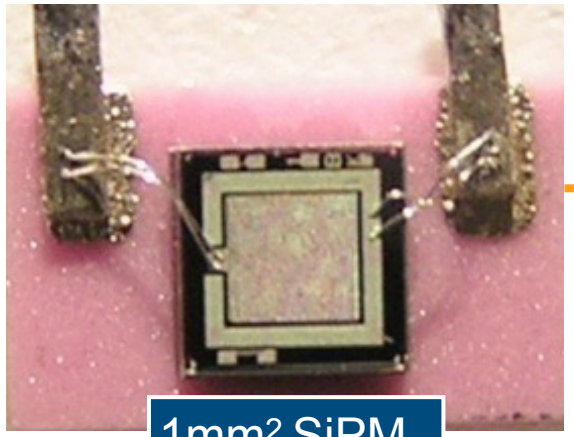
- silicon calorimetry grows out of the domain of small plug devices

New segmented gas amplification structures (RPC, GEM, µMs)

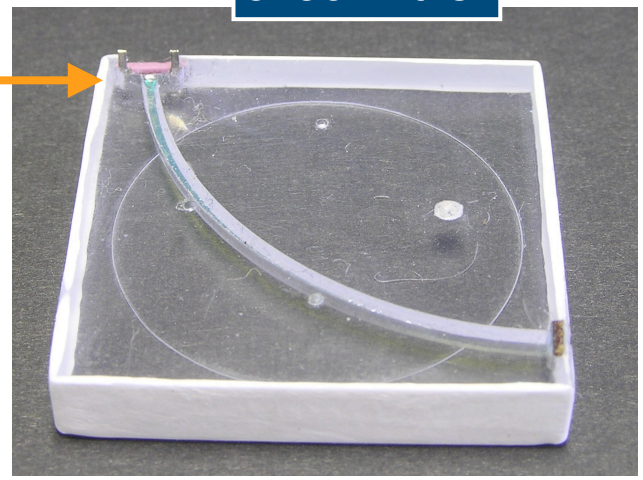
Silicon photomultipliers on scintillator tiles or strips







1mm² SiPM



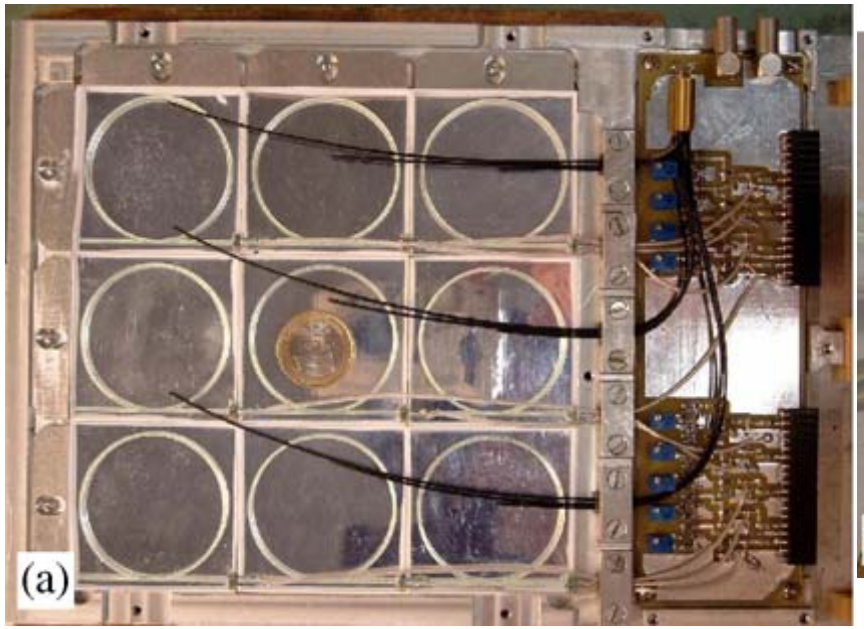
3x3cm² tile

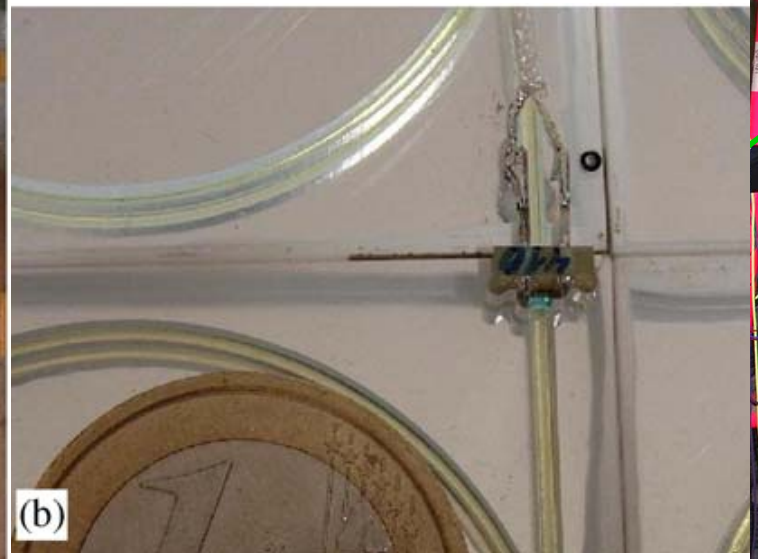
2004

small, B-insensitive, cheap, robust

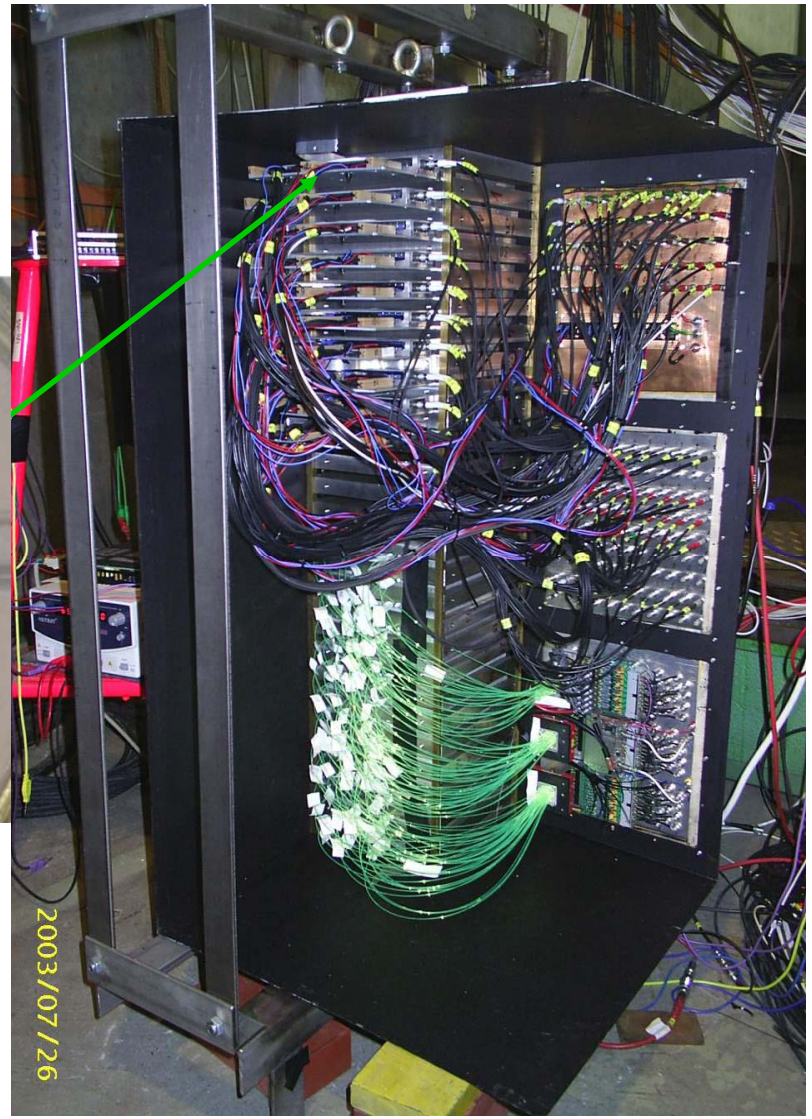
SiPM-on-Tile Evolution

A long way





2003: MiniCal



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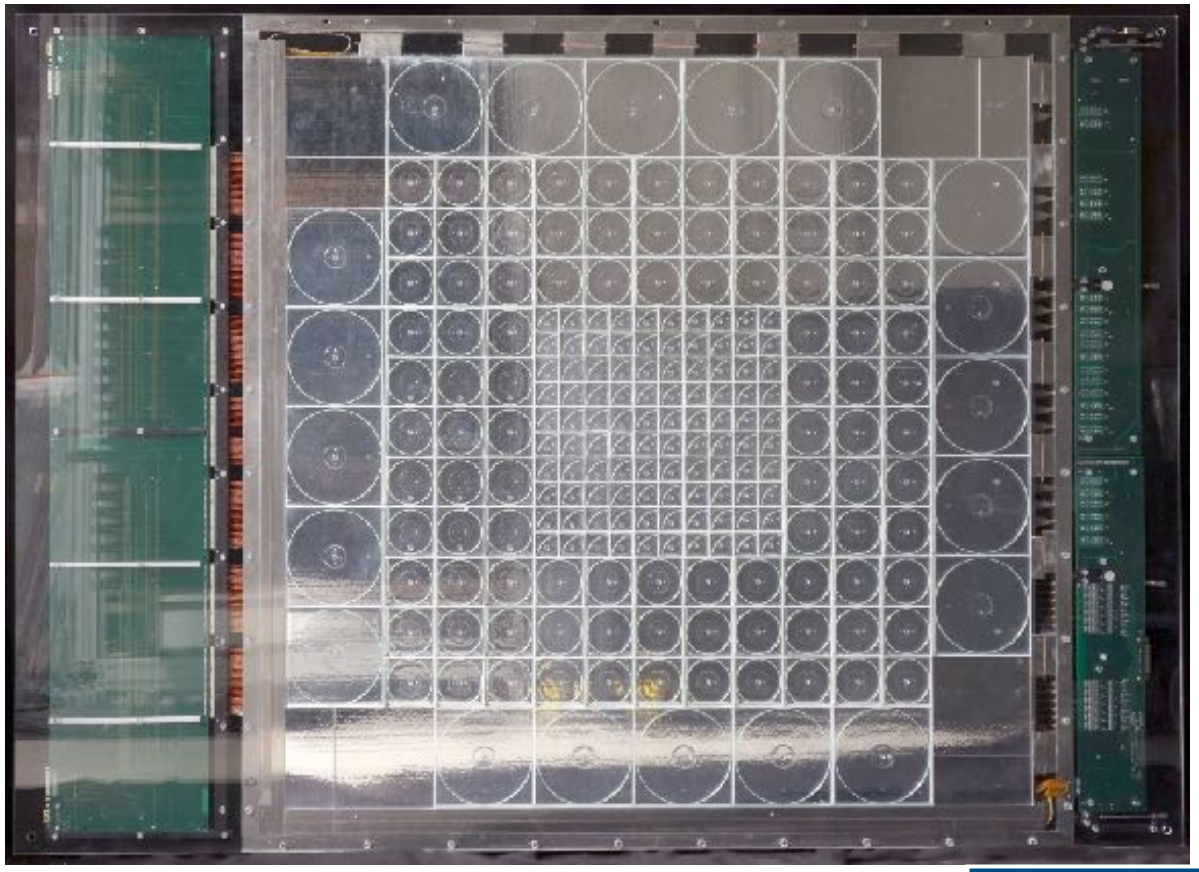
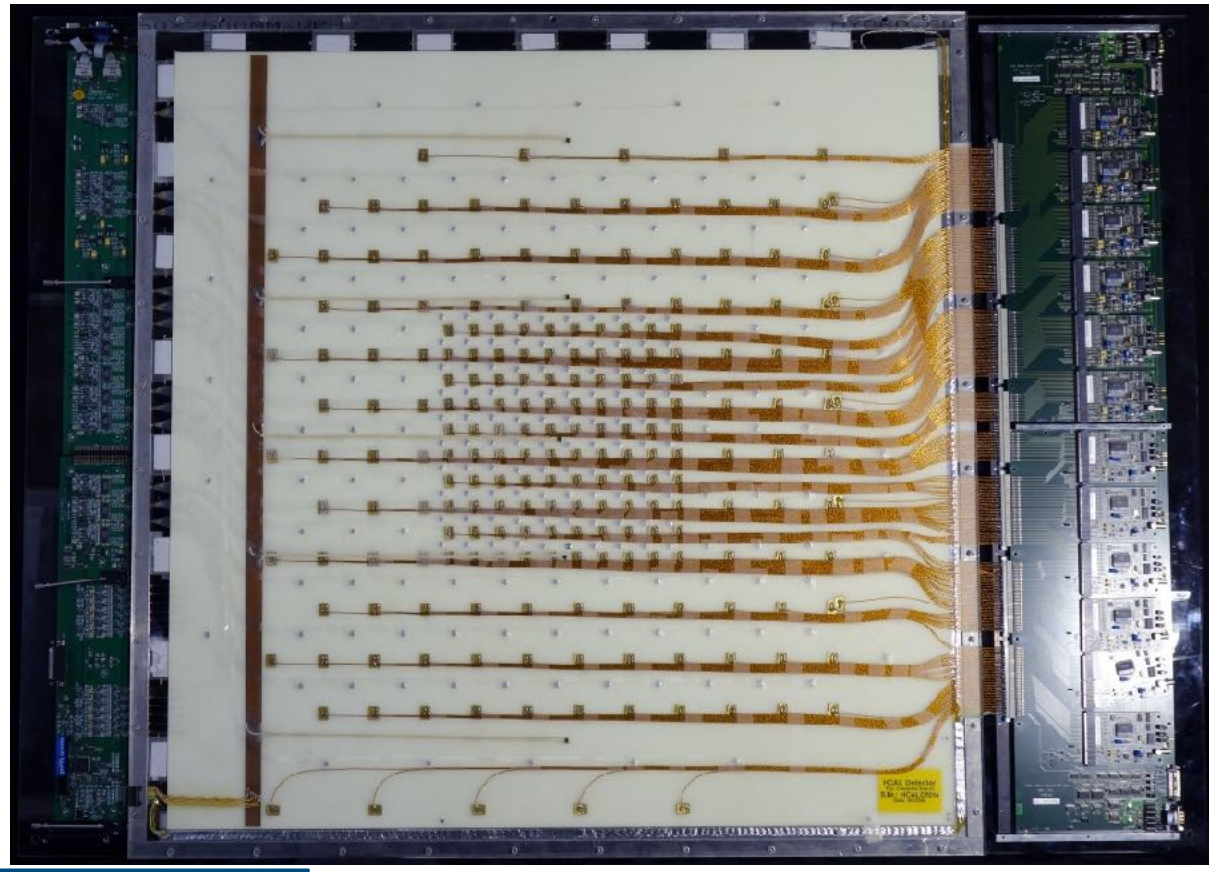
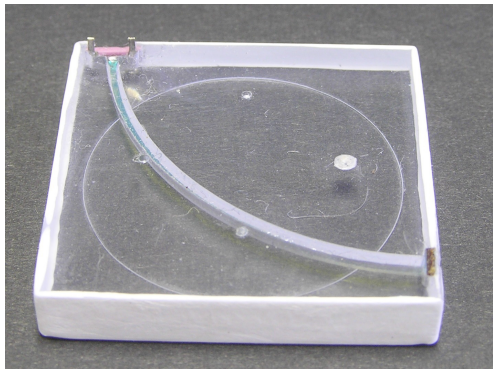


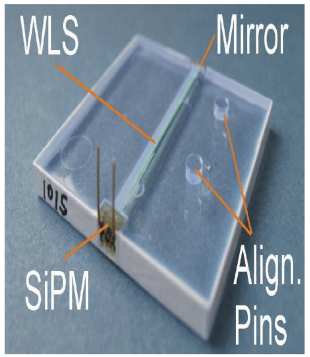


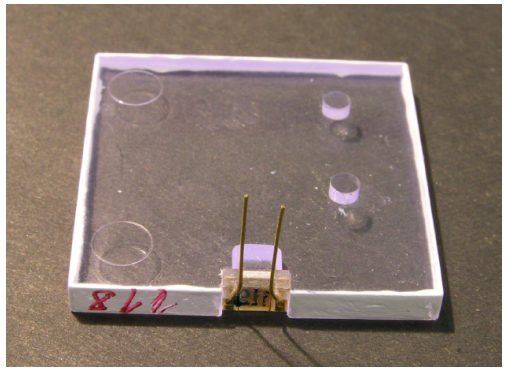
2006: Physics Prototype

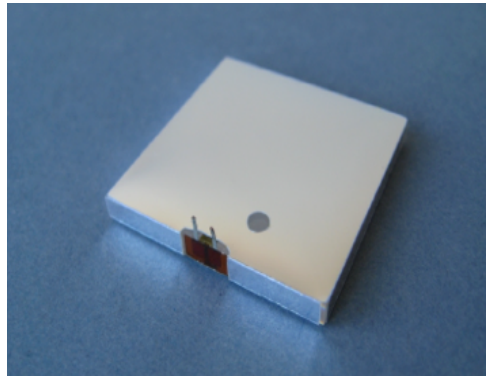
SiPM-on-Tile Evolution

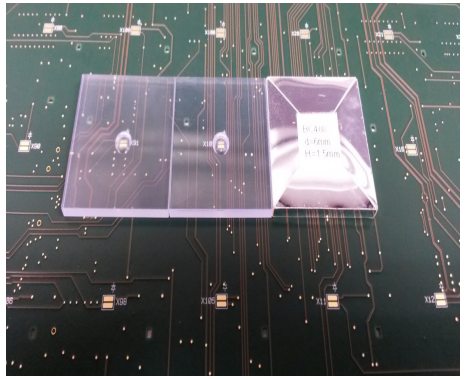
A long way





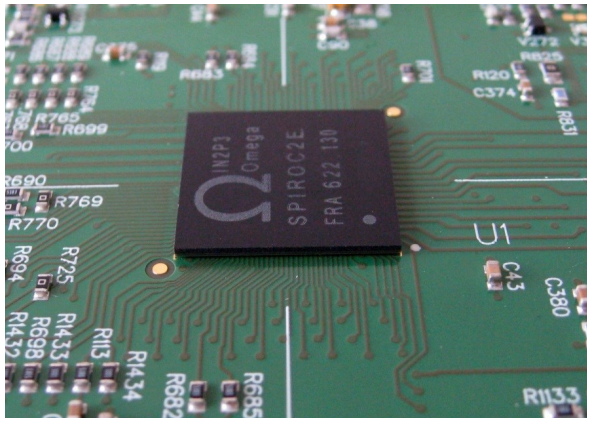


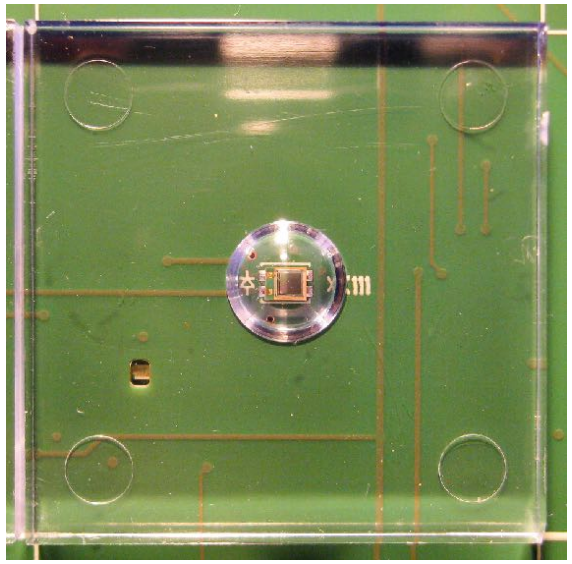


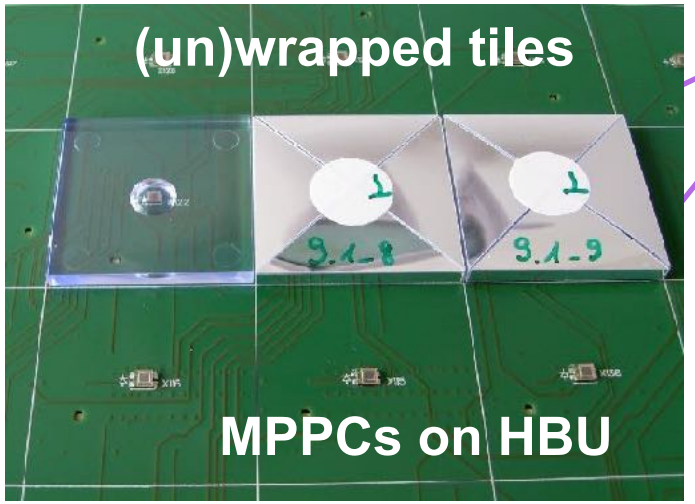


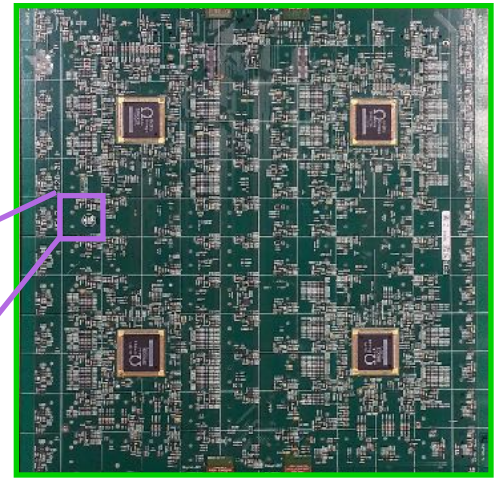
The Next Step: Scalability

Technological prototypes.

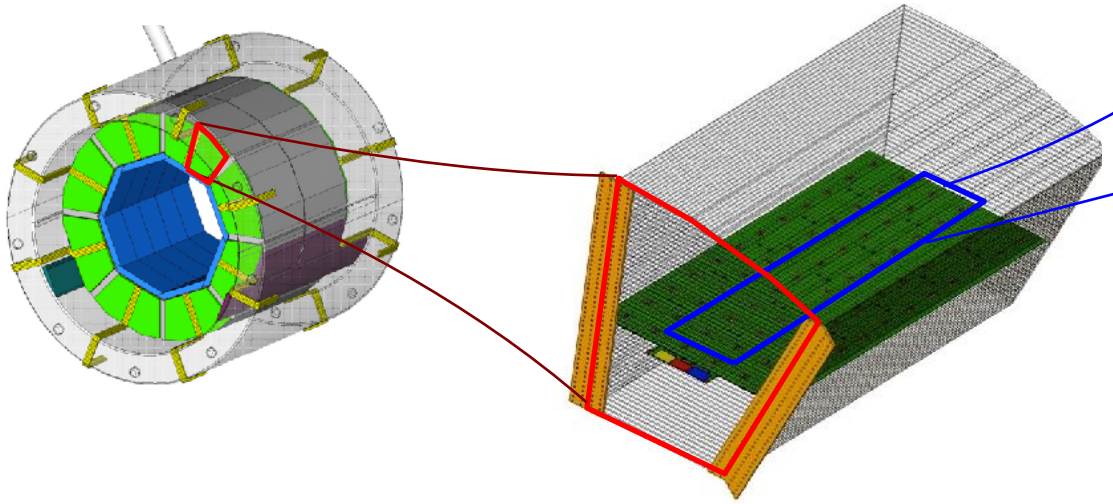


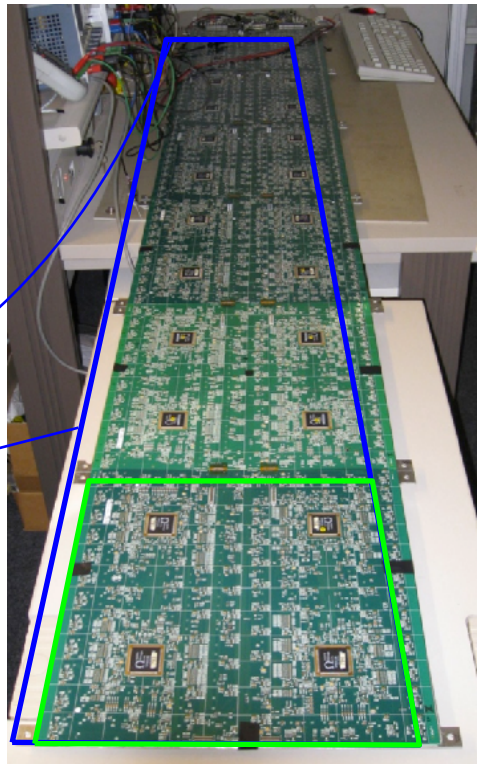






- 1000's of channels per m^2
- 1000's of m^2
- must embed electronics and go digital as early as possible; power pulsing
- Integrate SiPMs in read-out board, too

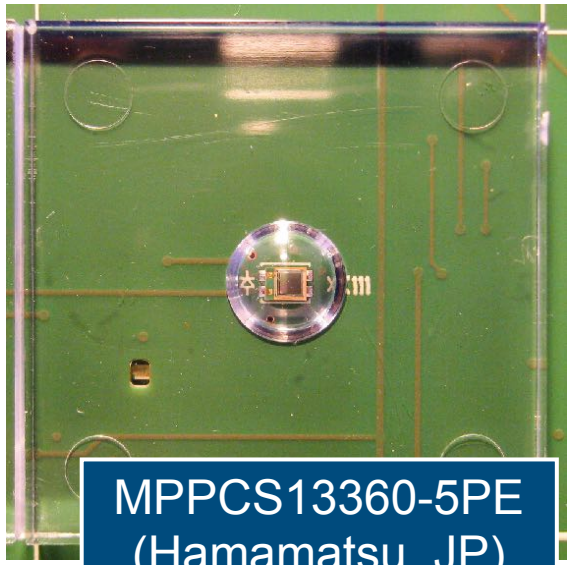




The Next Step: Scalability

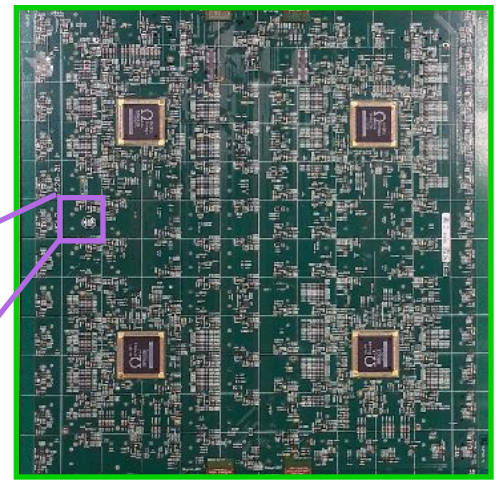
Technological prototypes.

SPIROC2E
(OMEGA, F)



MPPCS13360-5PE
(Hamamatsu, JP)

polystyrene tiles
(Uniplast, RU)
with ESR film



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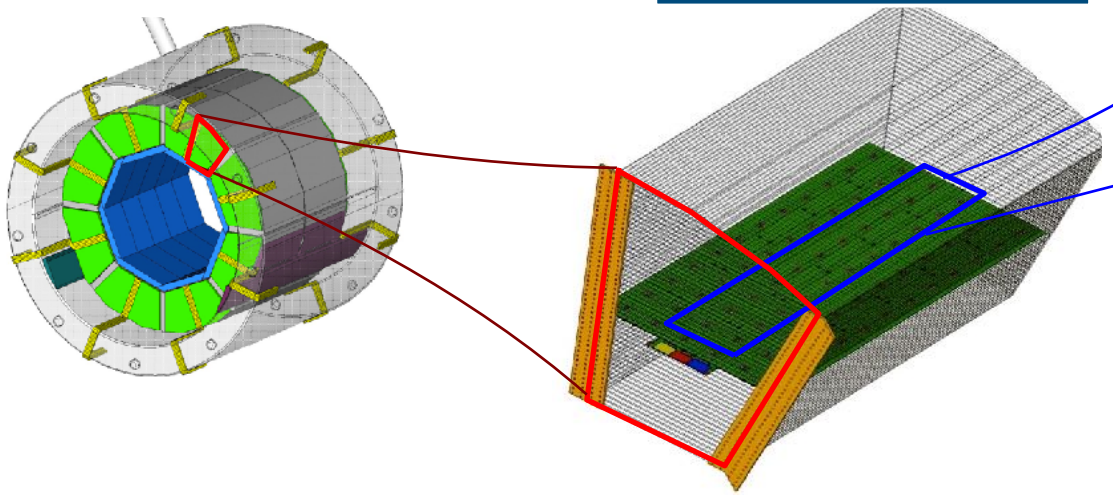
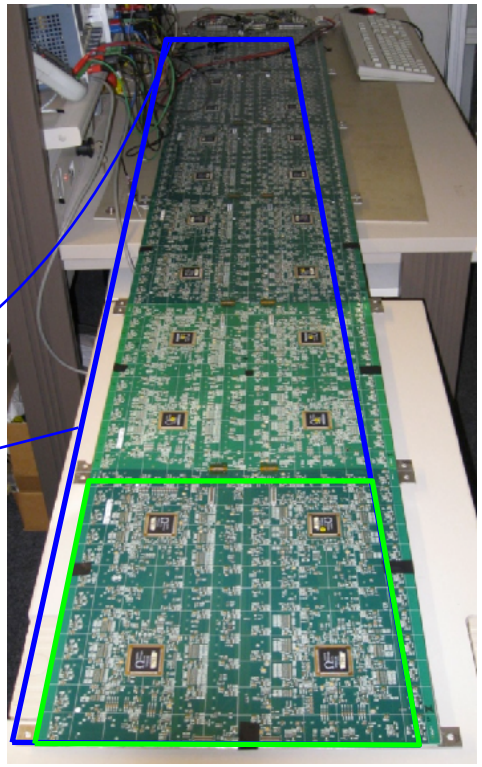




Goals of a New Prototype

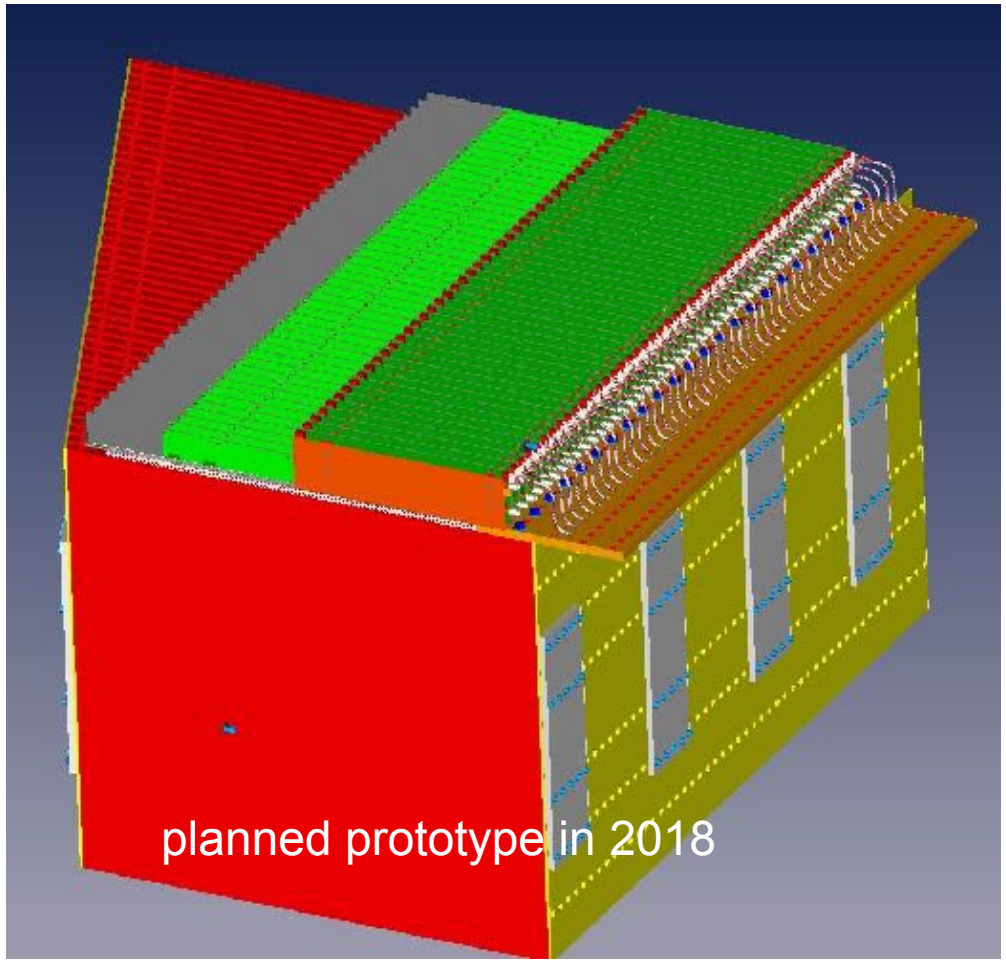
LC and beyond

Technology:

- establish the scalability of SiPM technology
- high granularity at the scale of a collider detector
- validate the automated construction and QA procedures
- establish operation with
  - active temperature compensation
  - on-detector zero-suppression
  - power pulsing
- re-establish calorimeter performance

Physics:

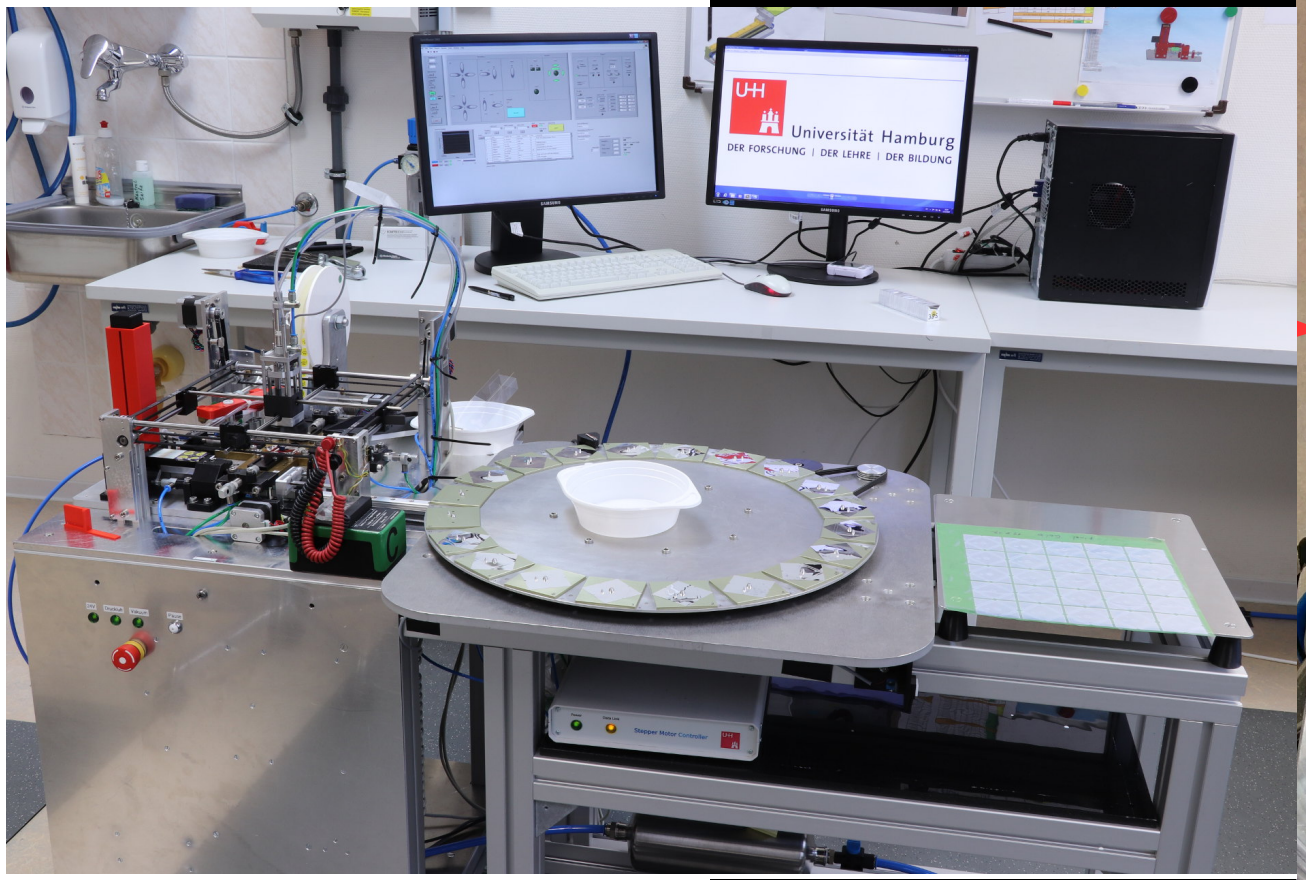
- study shower evolution in 5 dimensions
  - add timing capabilities (ns level) to electronics
- validate Geant4 in time domain
- study use of timing for particle flow
- use different absorber materials (Fe and W)

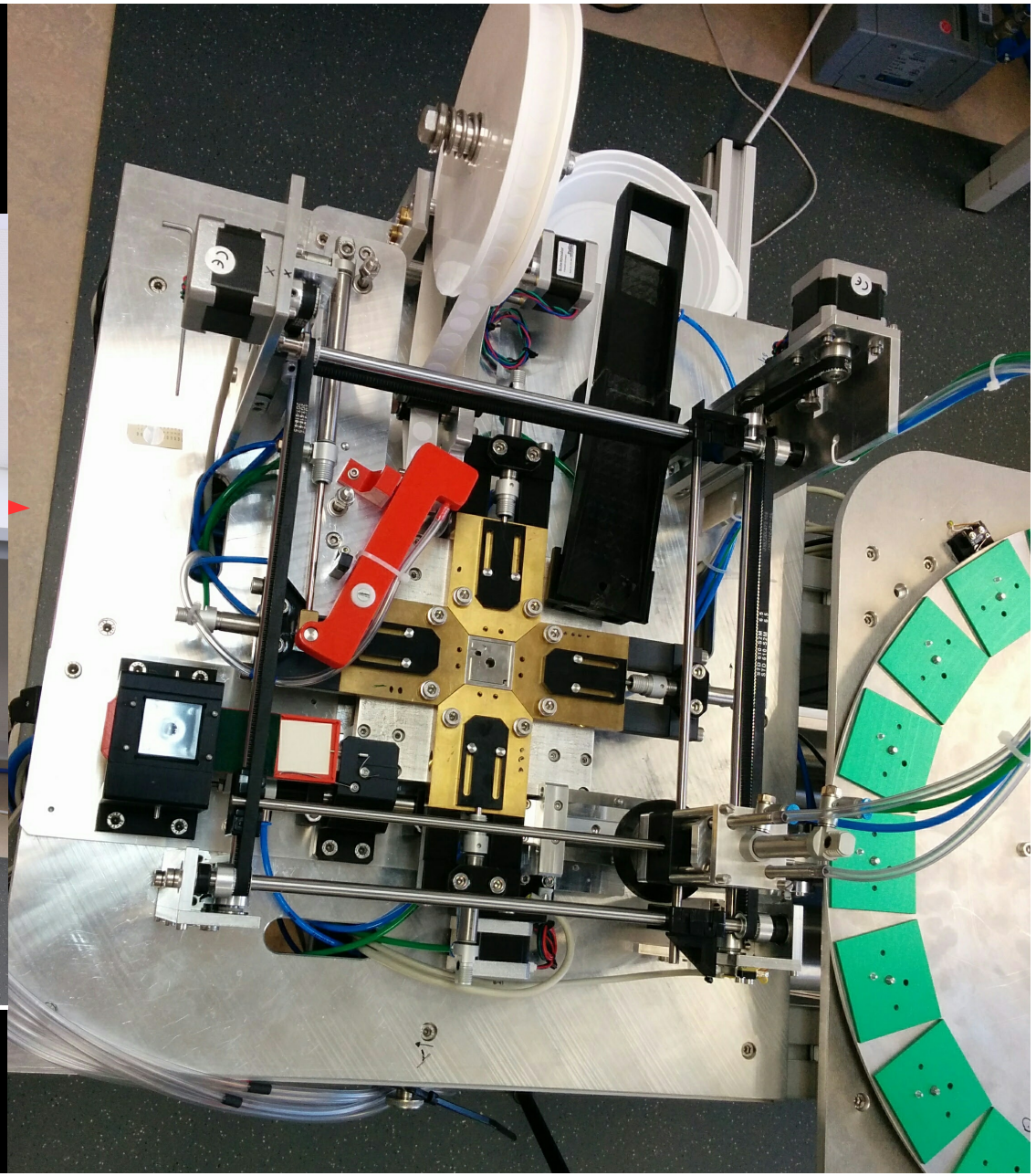


Construction and Quality Assurance

Tile Wrapping

Custom-made machine





- University of Hamburg

start in October

Tile Wrapping

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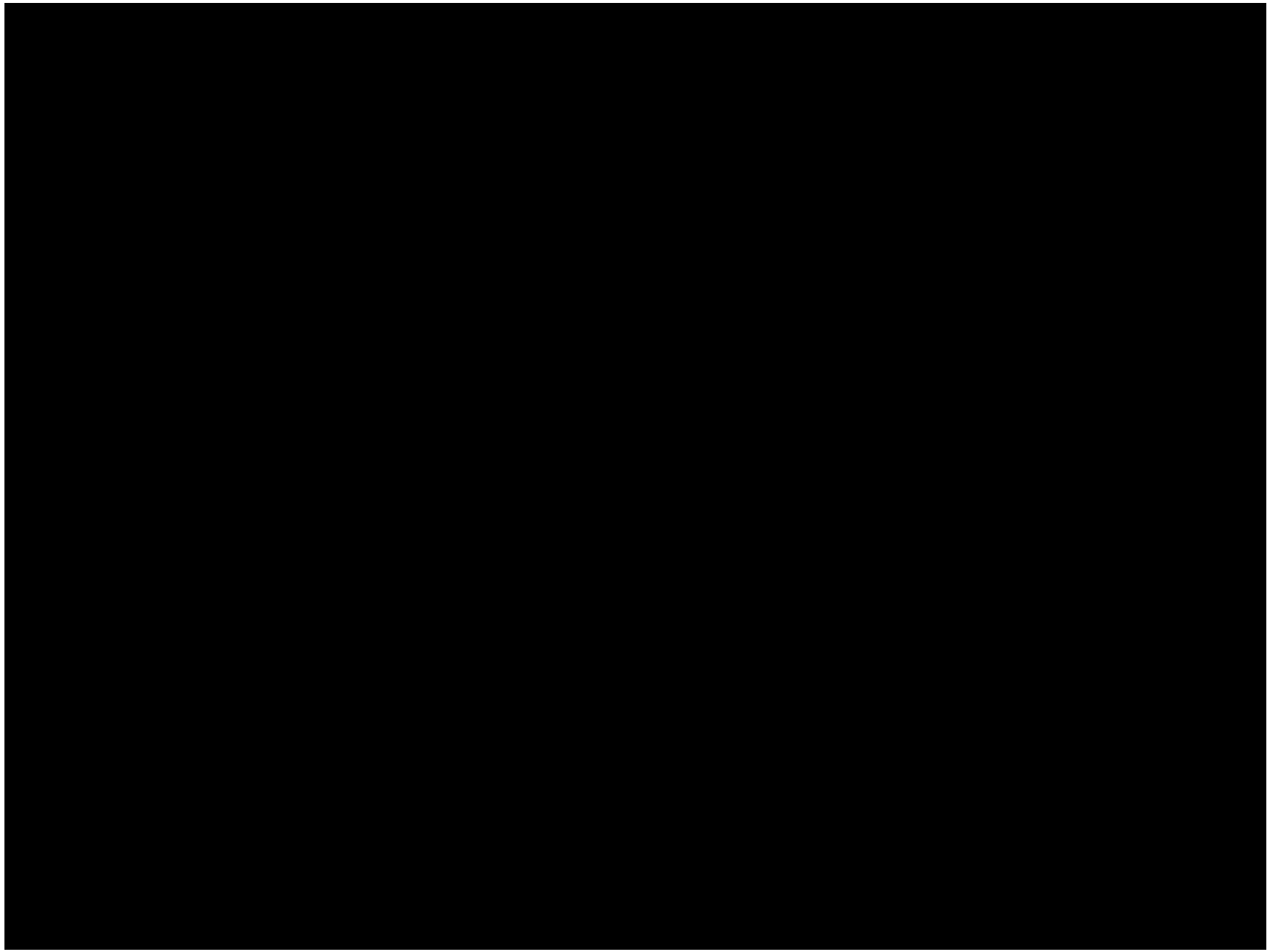

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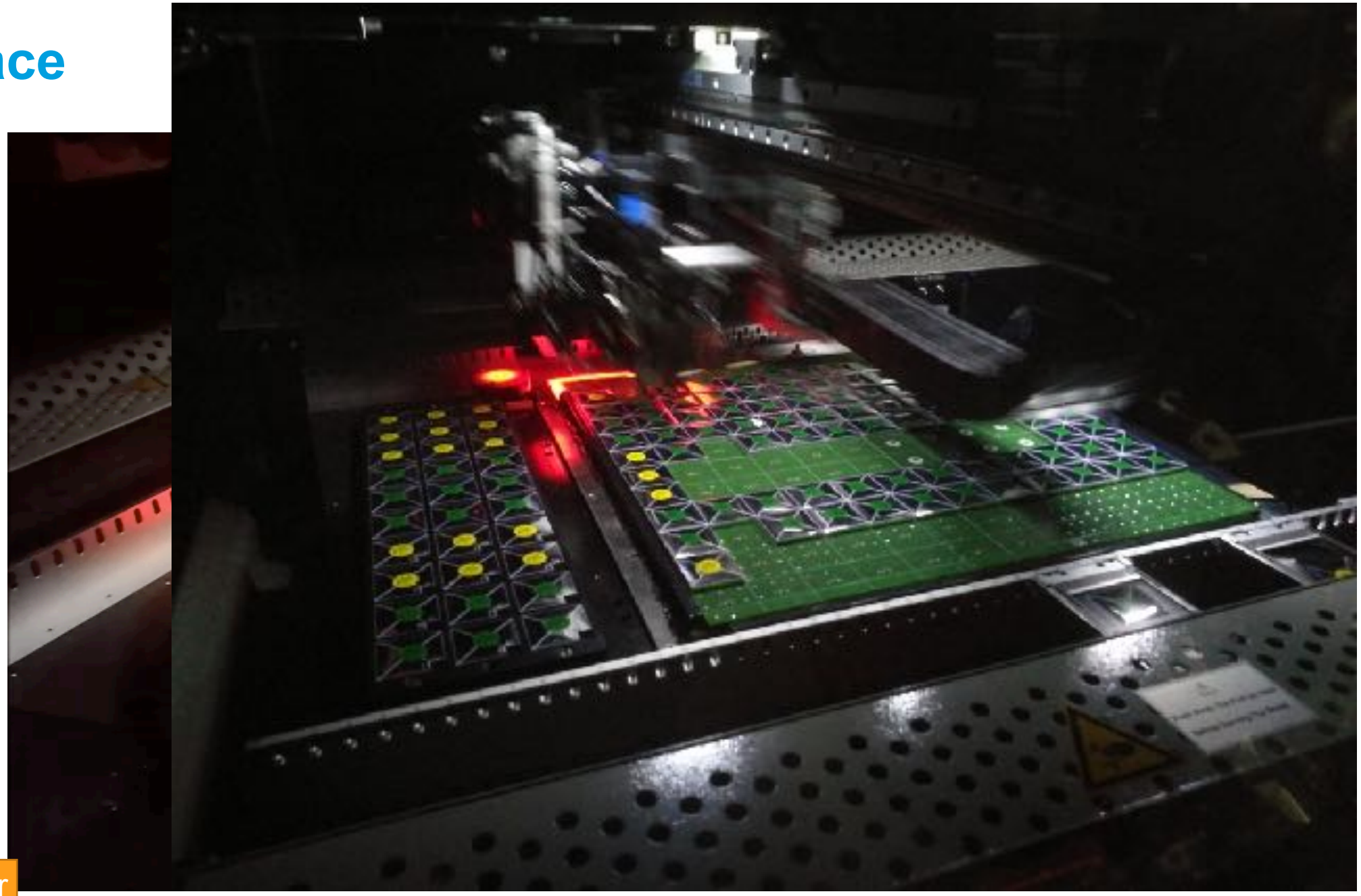
Pick & Place

Standard Machine



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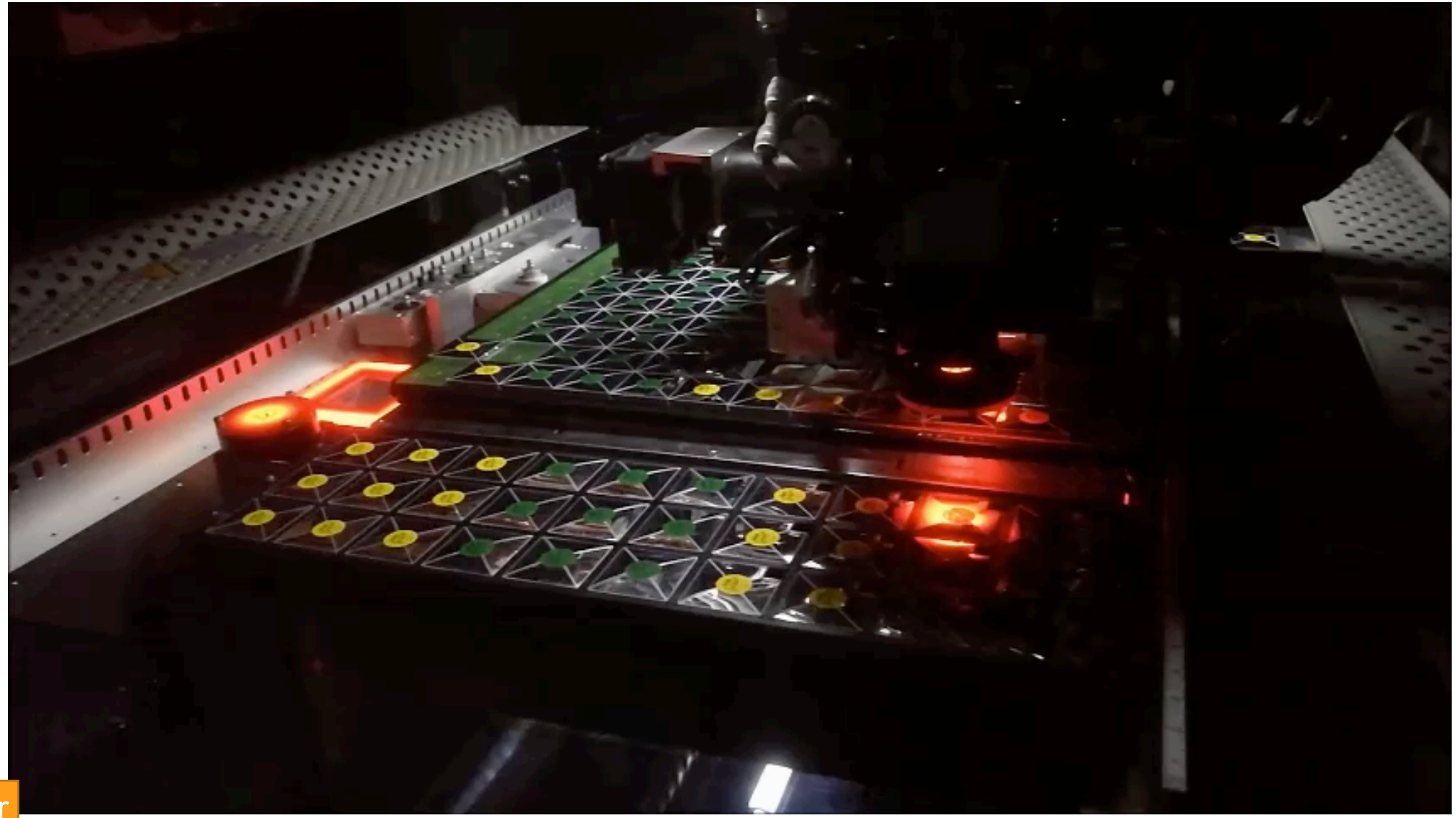
start in November

Pick & Place

Standard Machine



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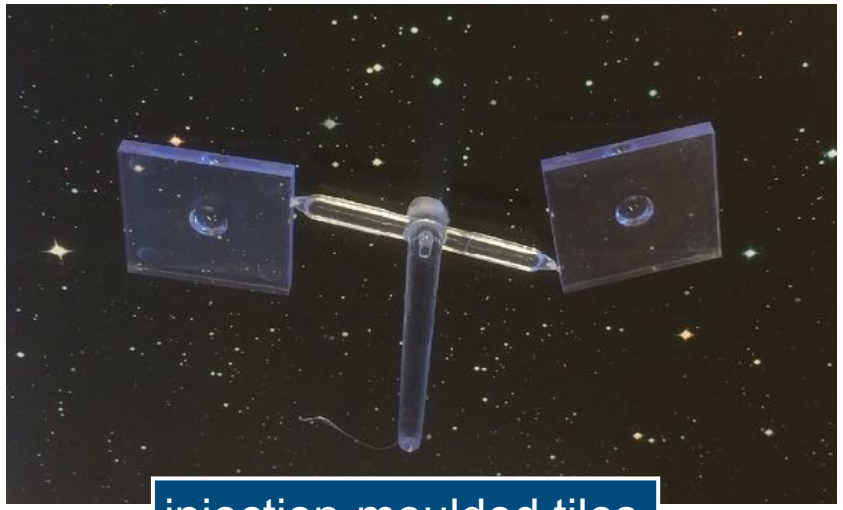
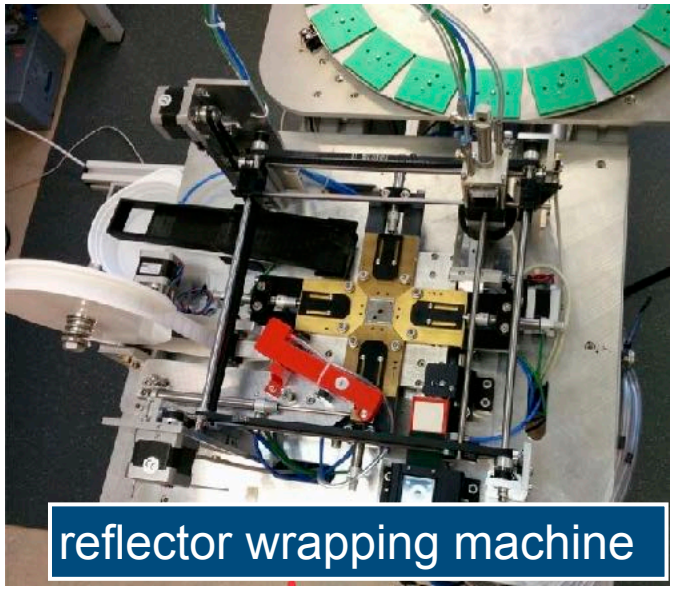
start in November

Automated Production and Quality Assurance

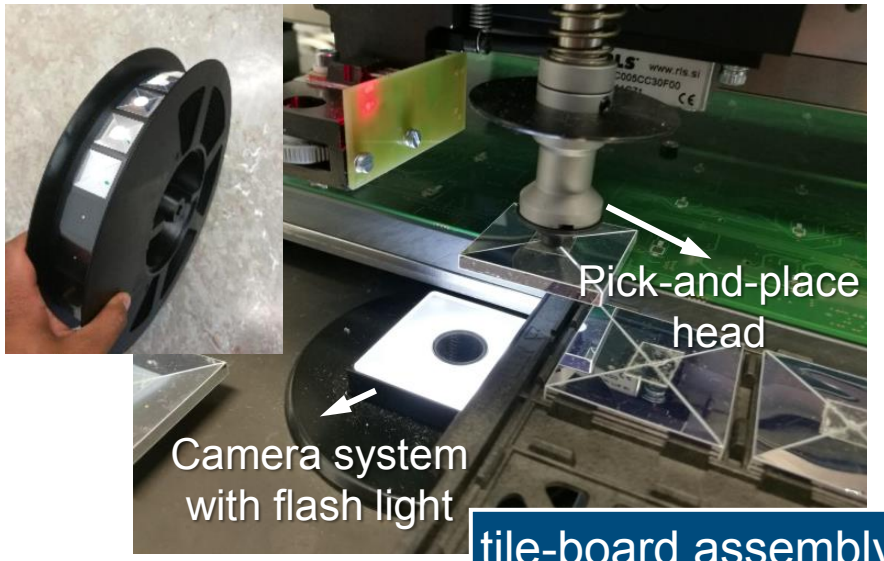
Establishing the concept.



injection-moulded tiles



reflector wrapping machine

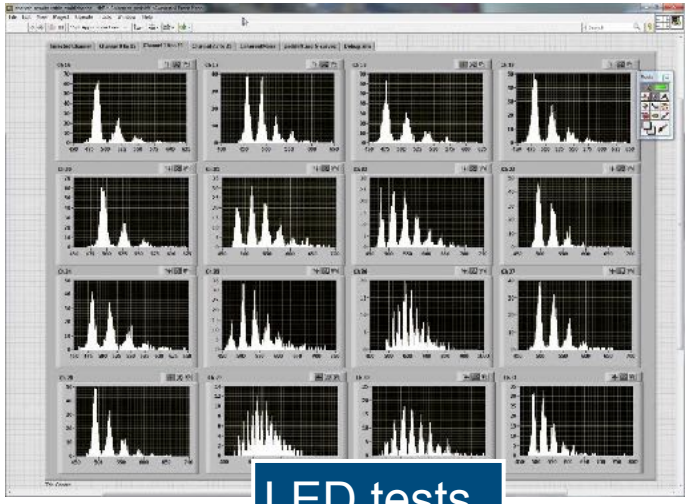


tile-board assembly

In addition test infrastructures:

- Multi-channel SiPM tests
- Automated ASIC tests
- PCB tests using LEDs
- Coscmic tests after tile assembly

read-out boards



LED tests

AIDA2020

Quality Assurance

at Each Step

Tiles:

- spot checked for mechanical tolerances
- some deviations affected automatic wrapping

SiPMs:

- spot checked for break-down voltage gain, noise, cross-talk
- all samples passed, excellent uniformity

ASICs:

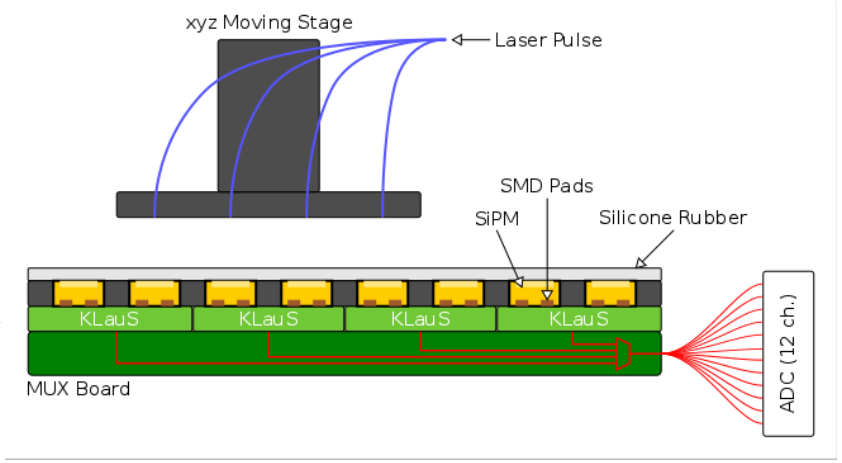
- semi-automated tests on dedicated board, yield ~ 80-90%

HBUs (bare):

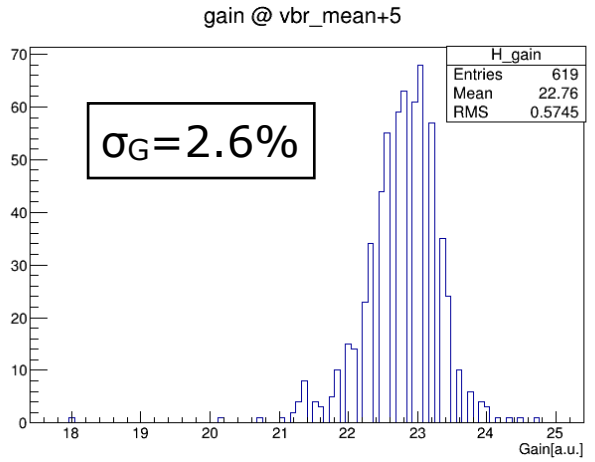
- tested with integrated LED system before mounting tiles (see previous page)
- 158 out of 160 boards OK

HBUs with tiles:

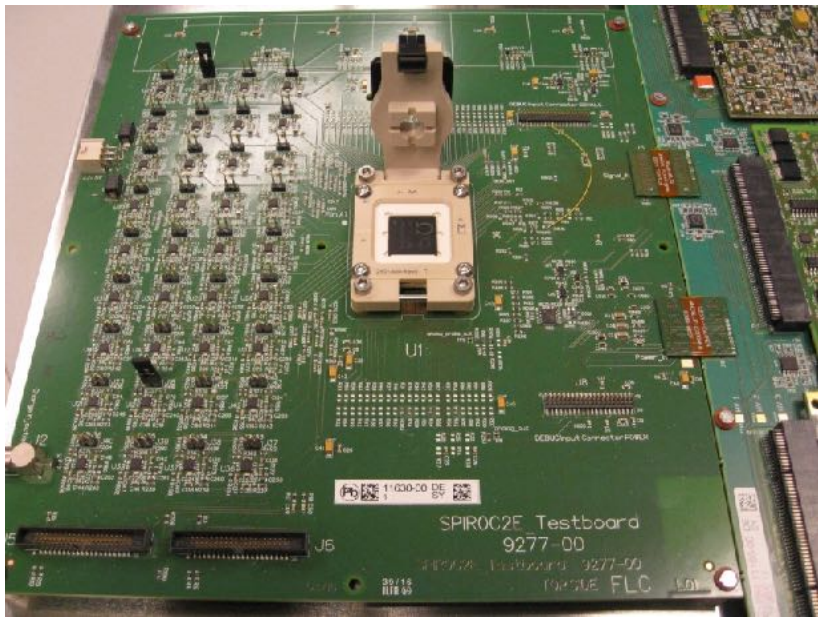
- Cosmics tests
- Most boards: very good light yield uniformity

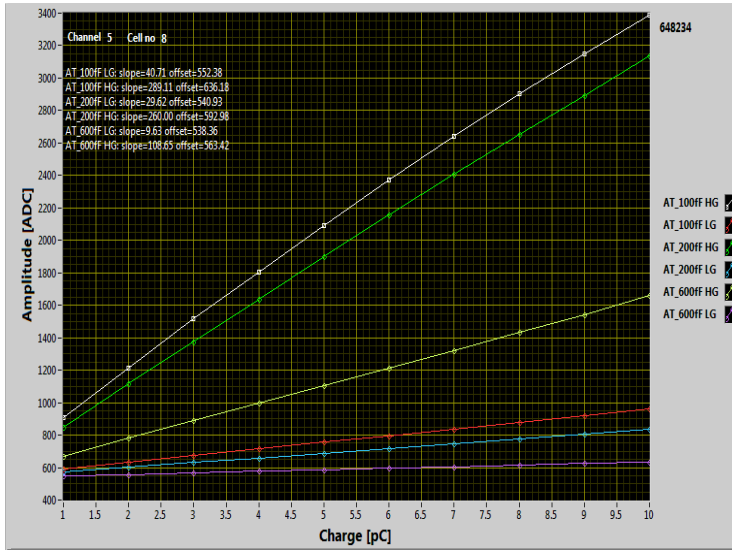


SMD SiPM schematic view



U Heidelberg





U Wuppertal

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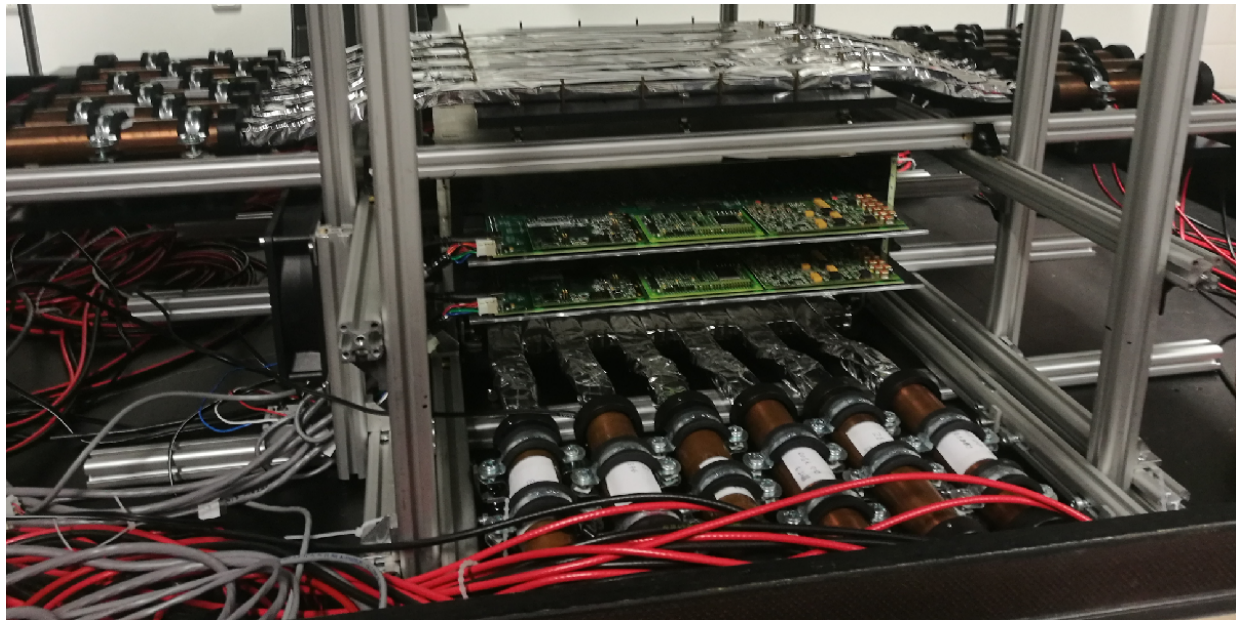

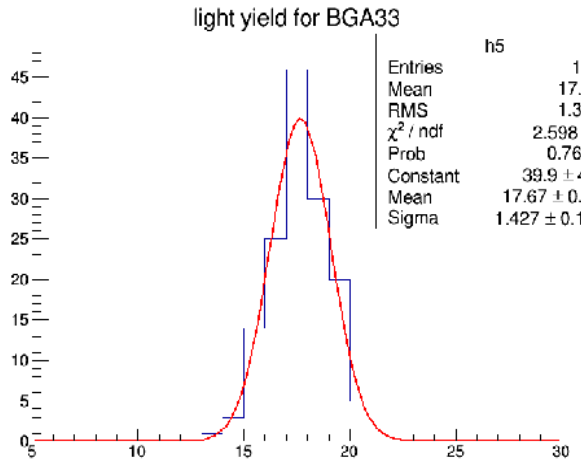

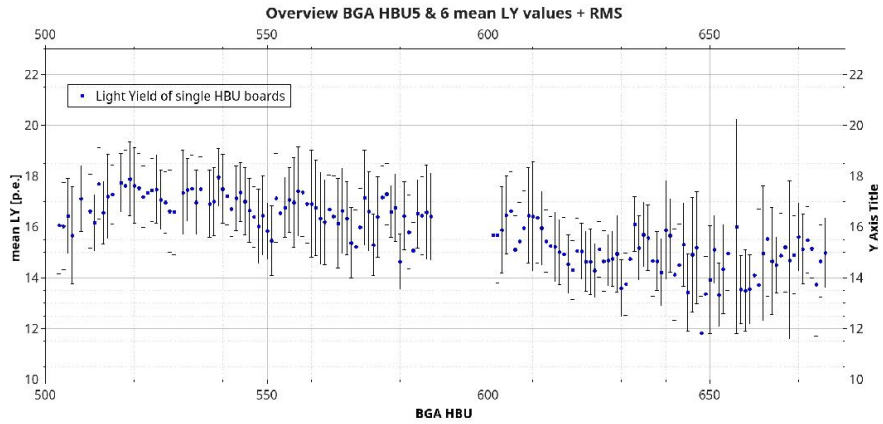

U Mainz

Active Layers: Cosmics and Beam

Cosmics and Beam Tests

Layer integration:

- one set of interface modules serves up to 18 HBUs
  - DIF: DAQ interface, data concentration,
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Commissioning with cosmic muons:

- strip hodoscope for central area
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Commissioning with DESY electron test beam:

- 5 layers at a time in “air stack"
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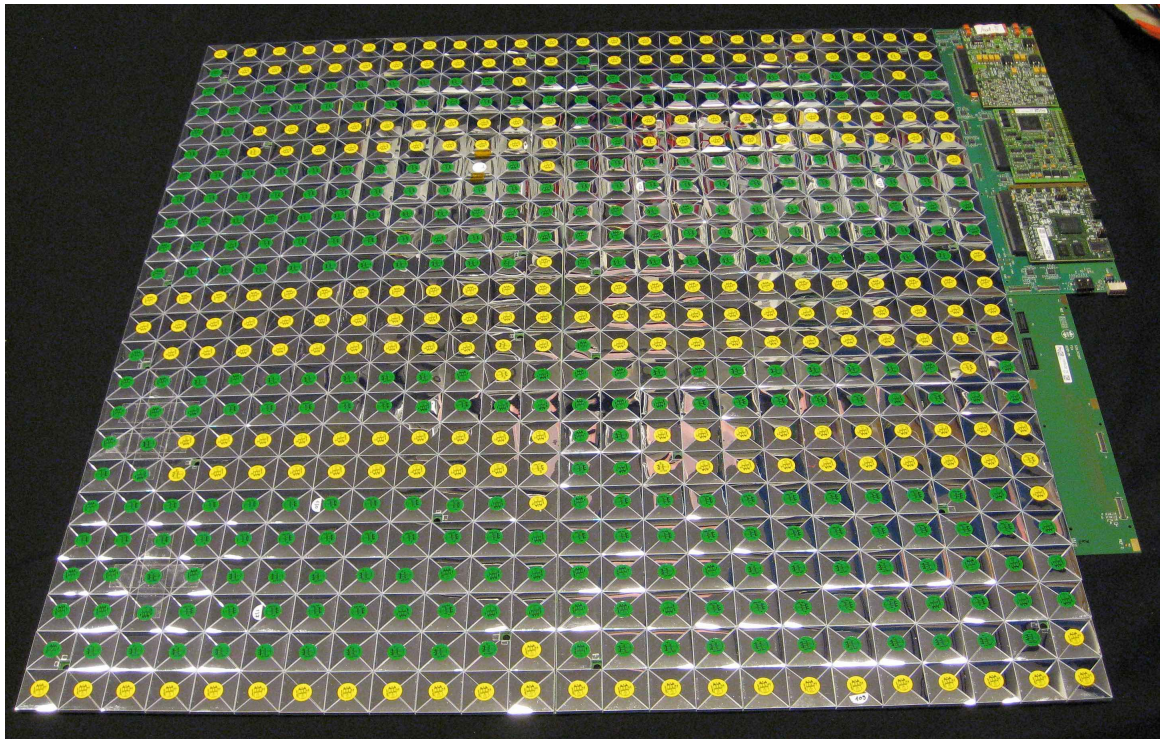
  - active temperature compensation ensures portability

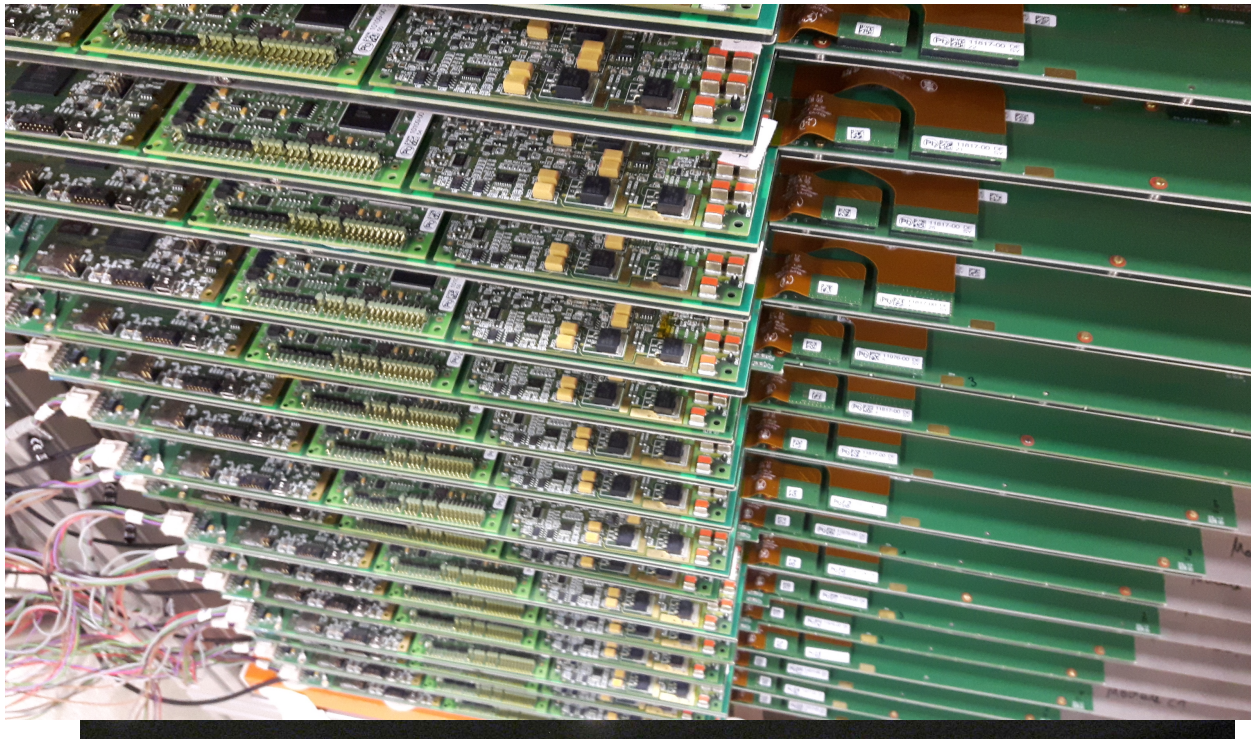
8 dead channels out of 21’888 total



January - March

Active Layers: Cosmics and Beam

Cosmics and Beam Tests



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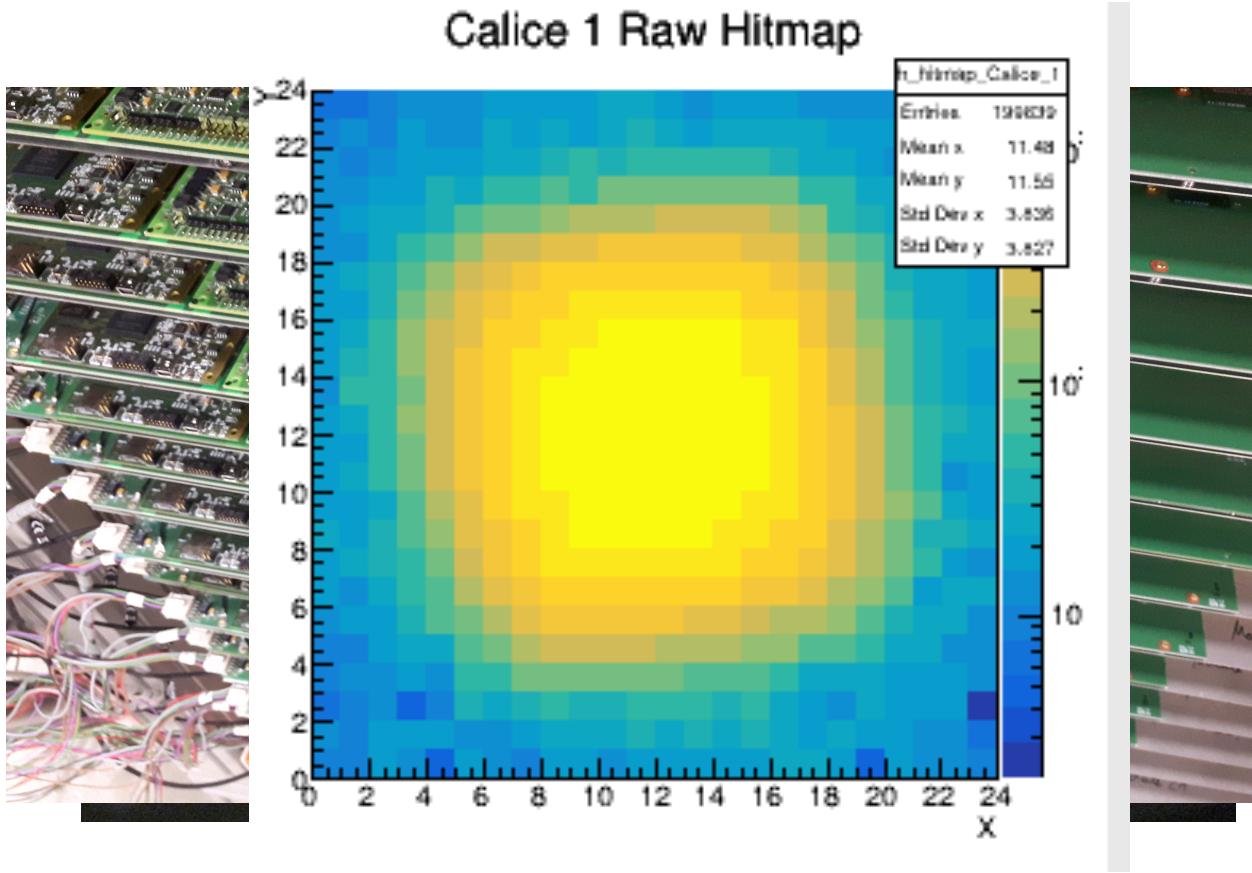

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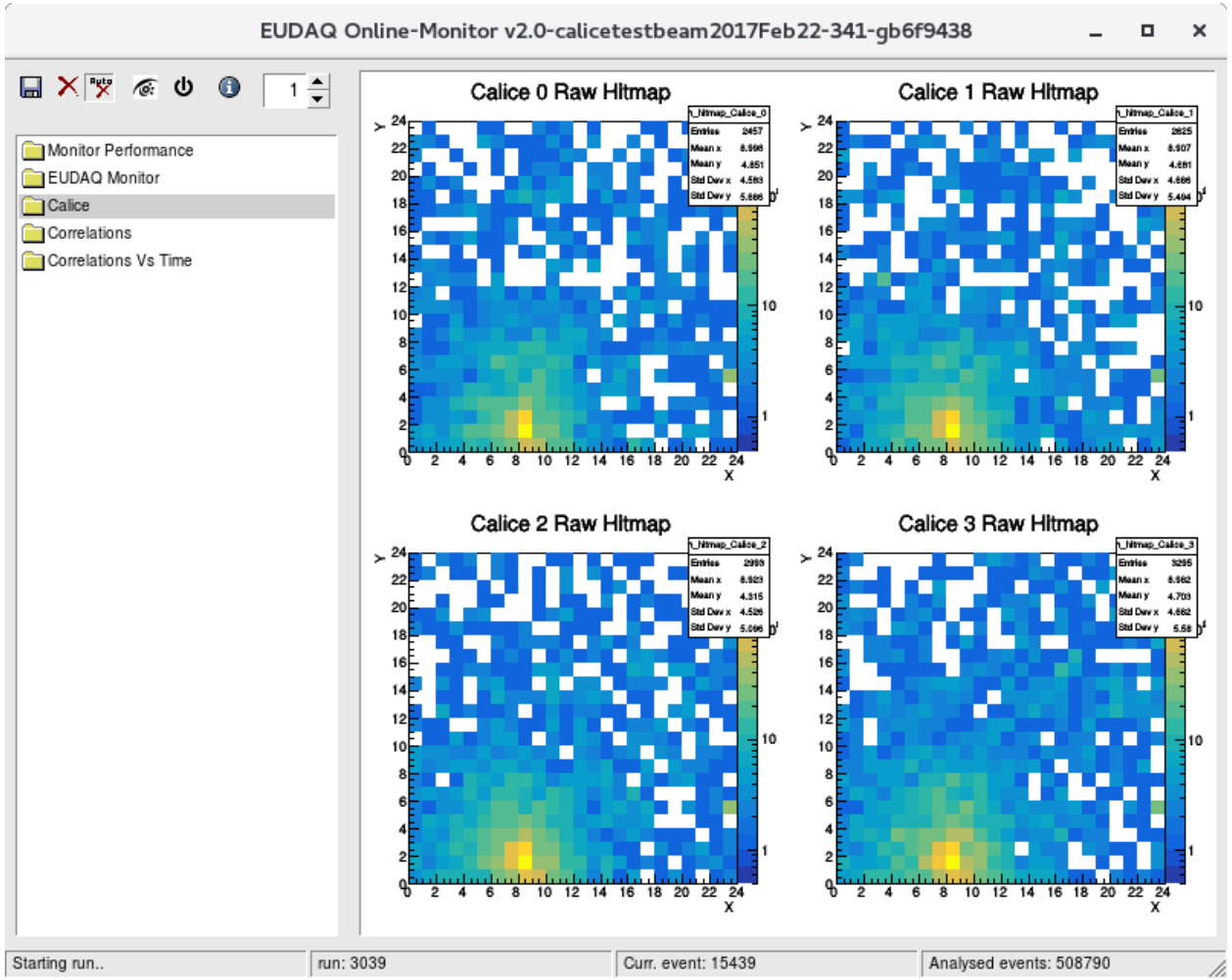

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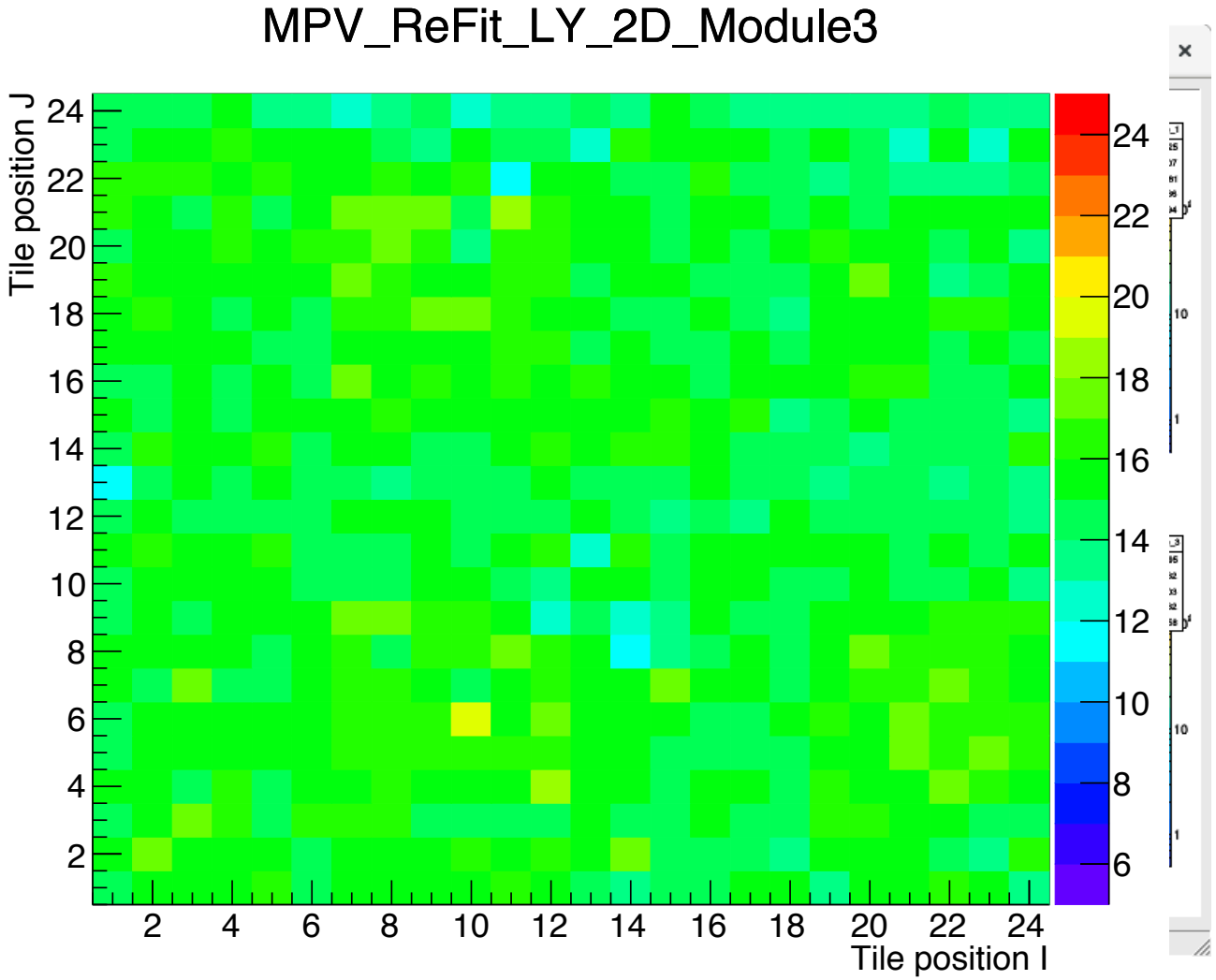

MIP MPV from DESY electrons

Stack integration

and Cosmic Test

Stack services dimensioned for full collider detector module

- Data concentration
  - output via single ethernet line
- Power distribution
  - 3 voltages per layer
- Cooling
  - pipe cross-sections suitable for “leak-less” operation

Commissioning with cosmics

- benefit from self-triggering capabilities
- test the full software chain

April

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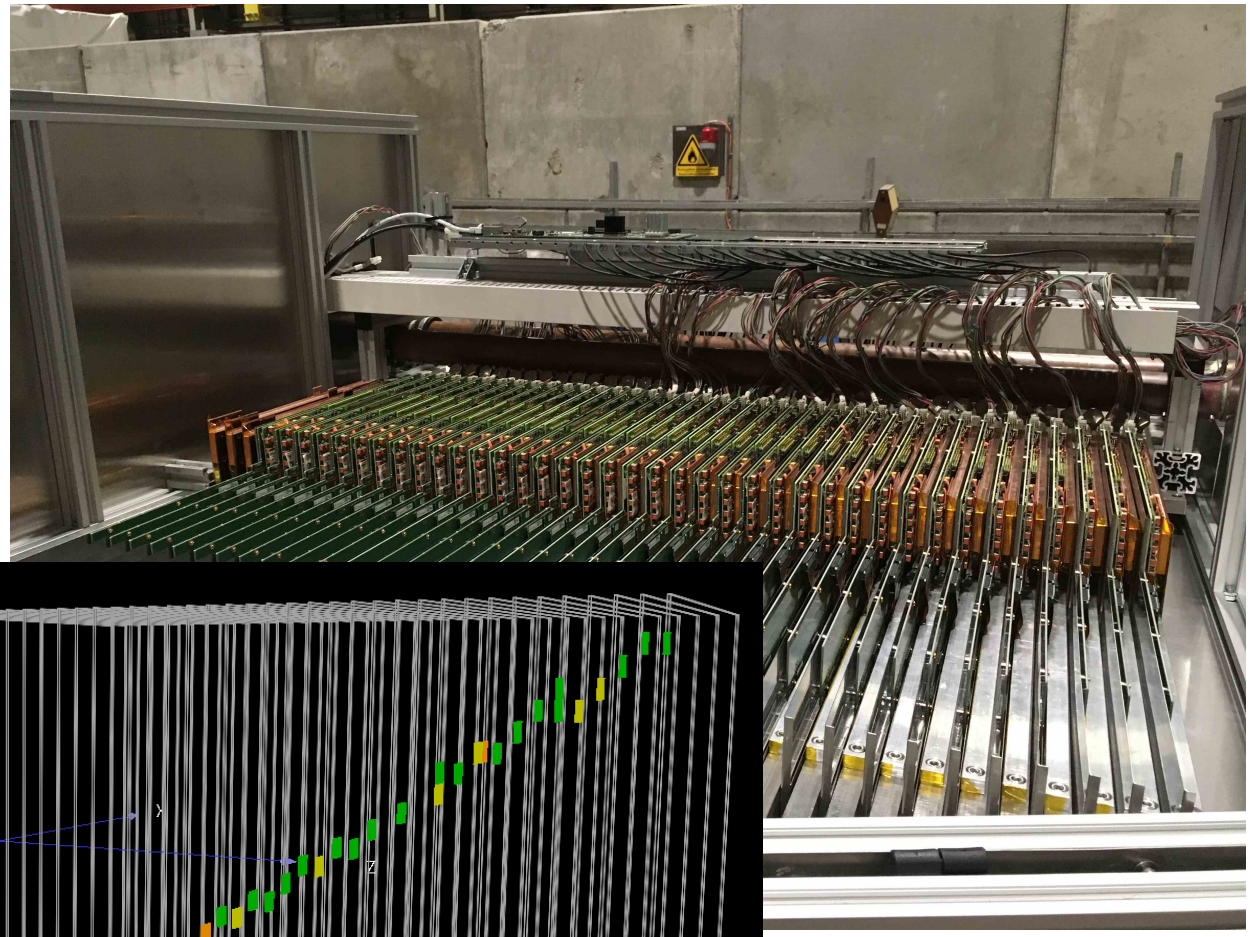

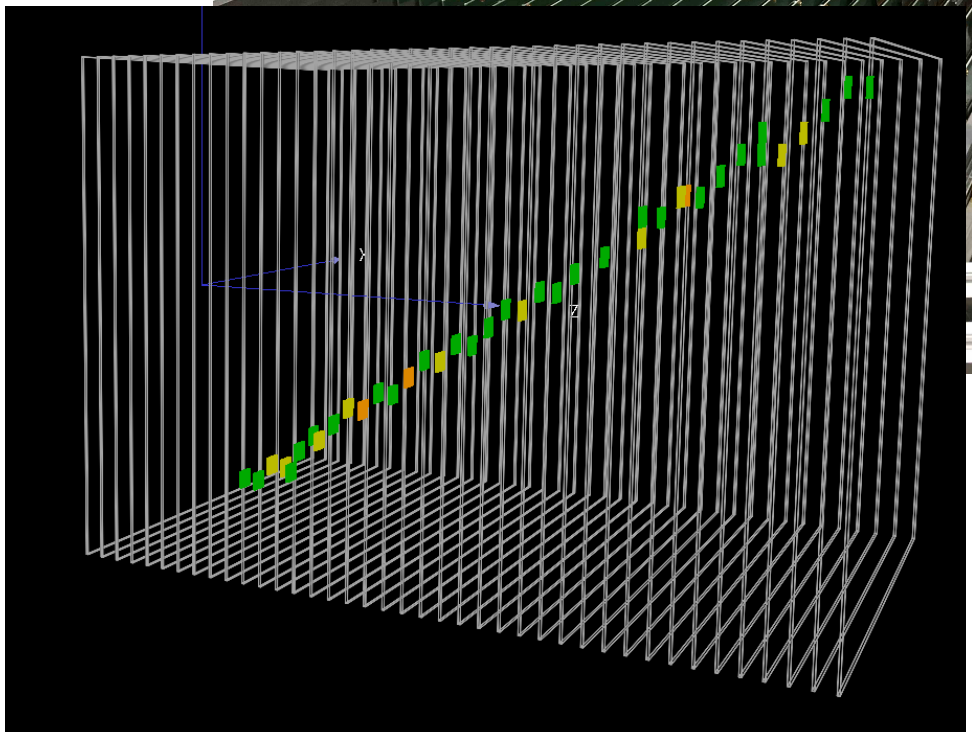

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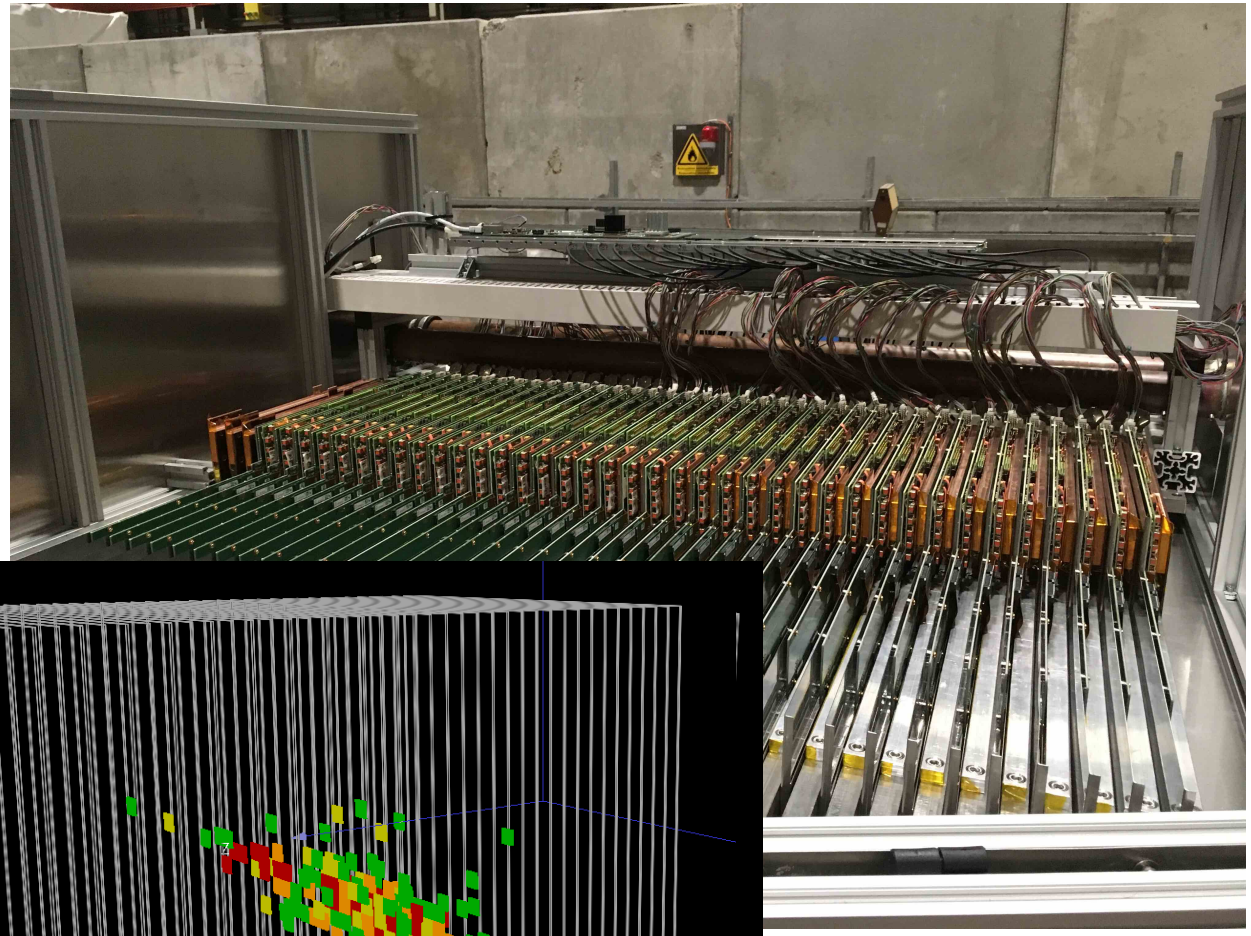

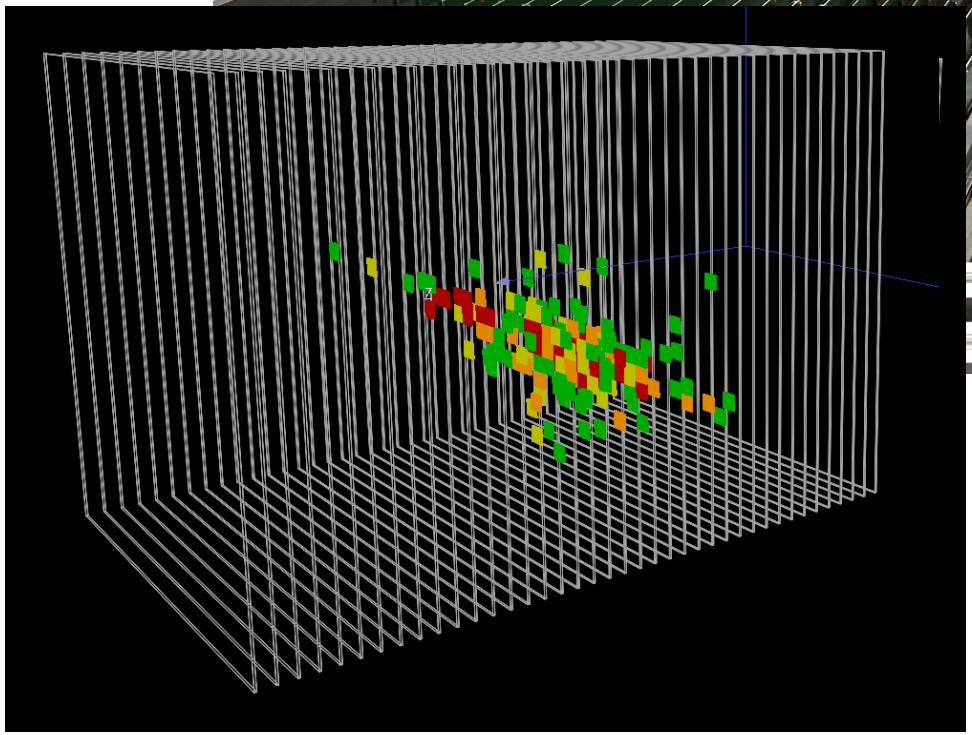

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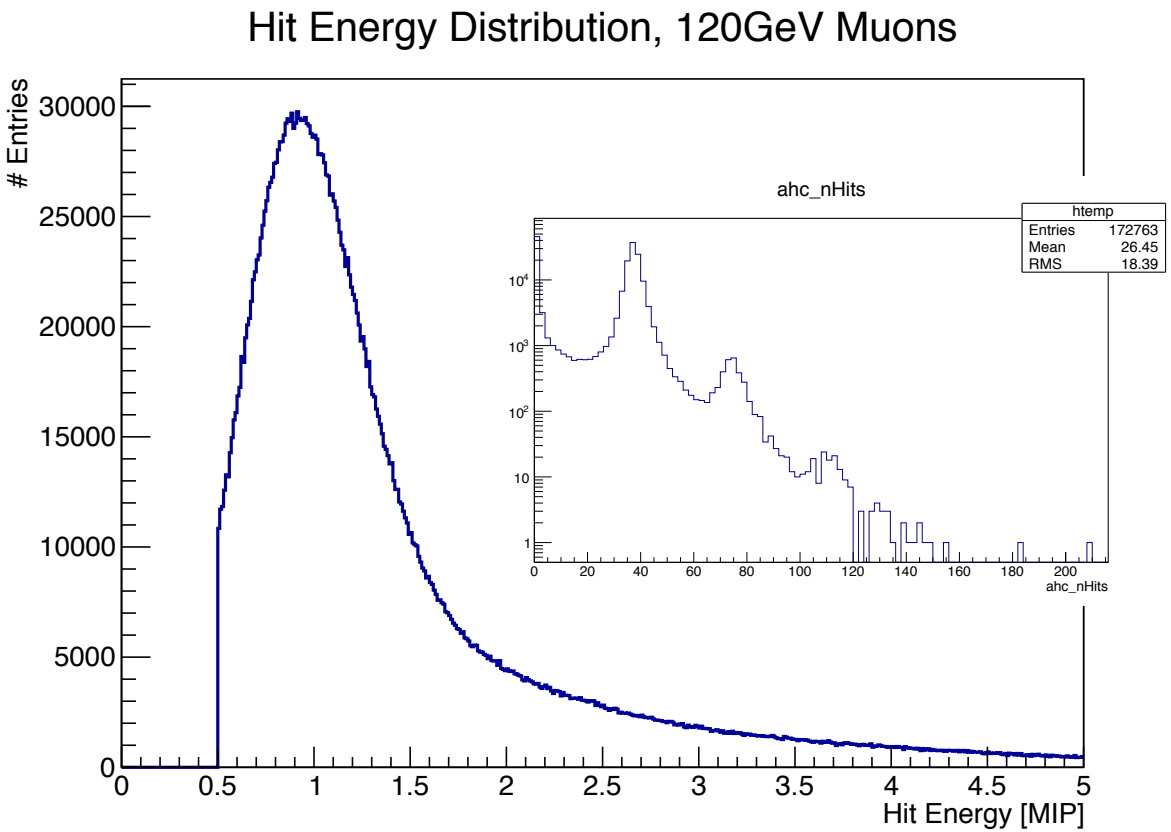
First impressions from Test Beam

May

Muon Calibration

at CERN SPS

- in principle only a cross-check
- full scan high statistics takes 24 h
  - sufficient for memory-cell dependent corrections



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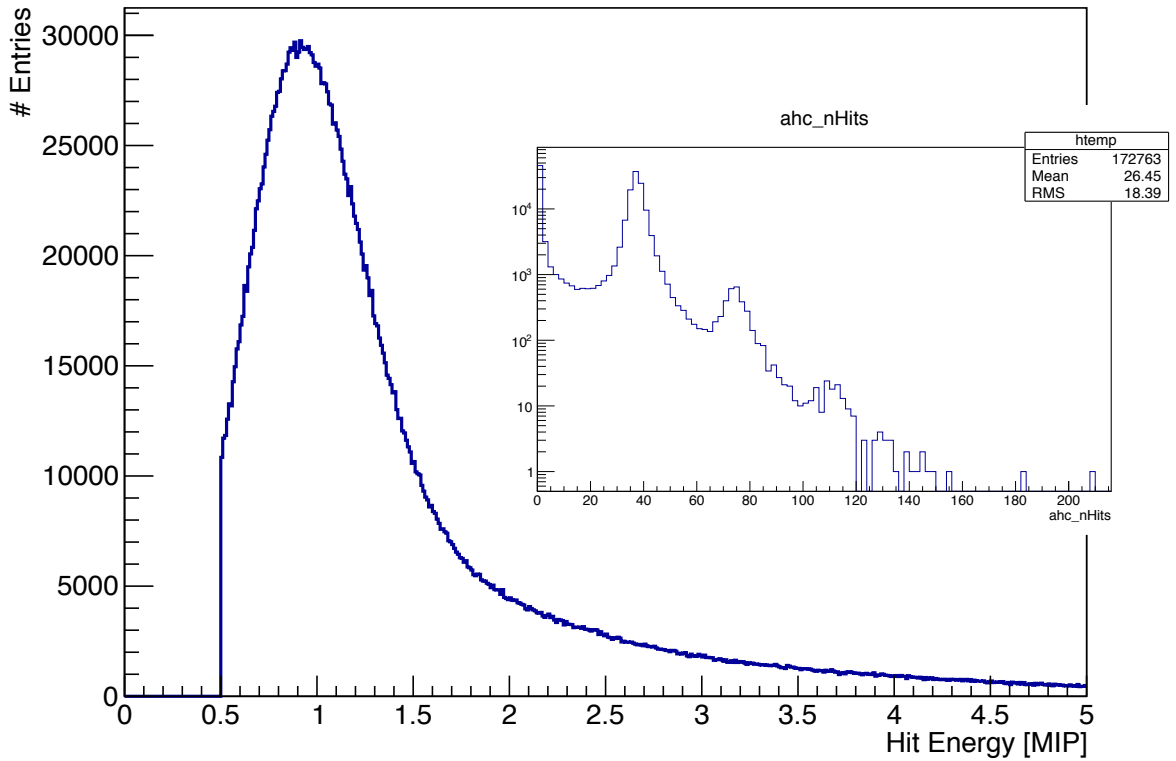
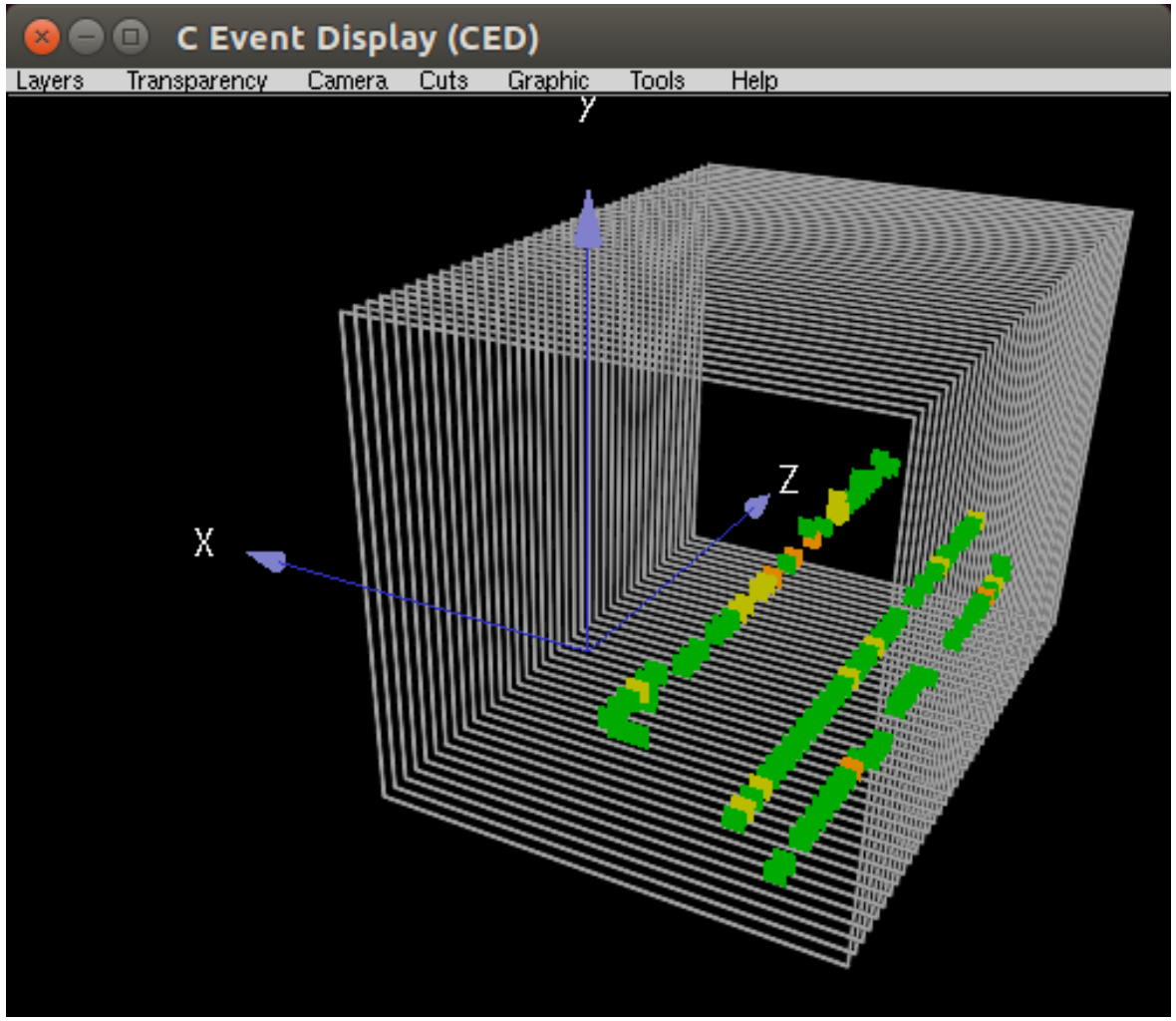
Hit Energy Distribution, 120GeV Muons





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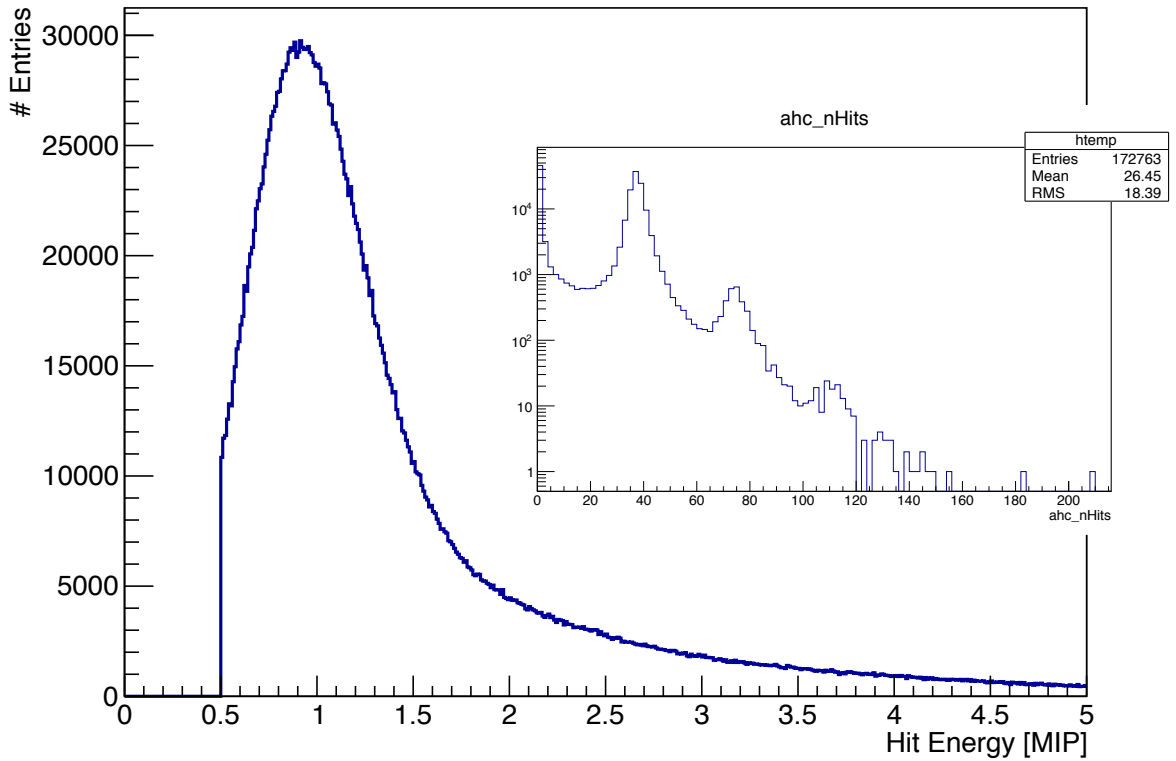
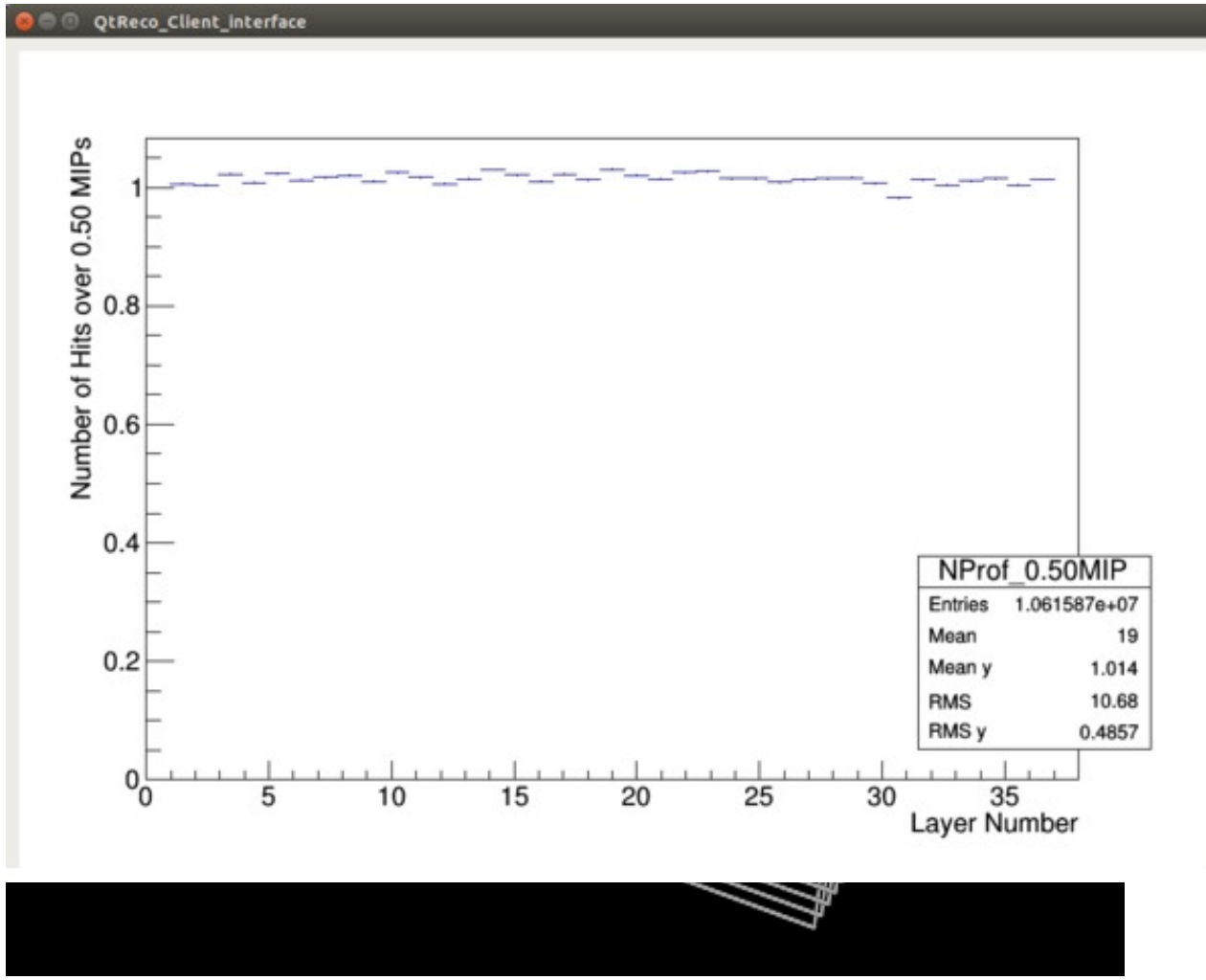
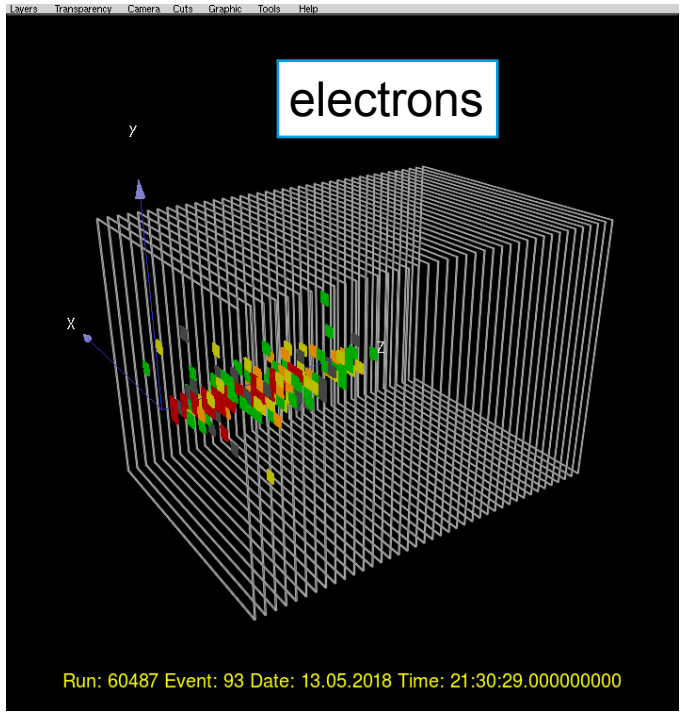


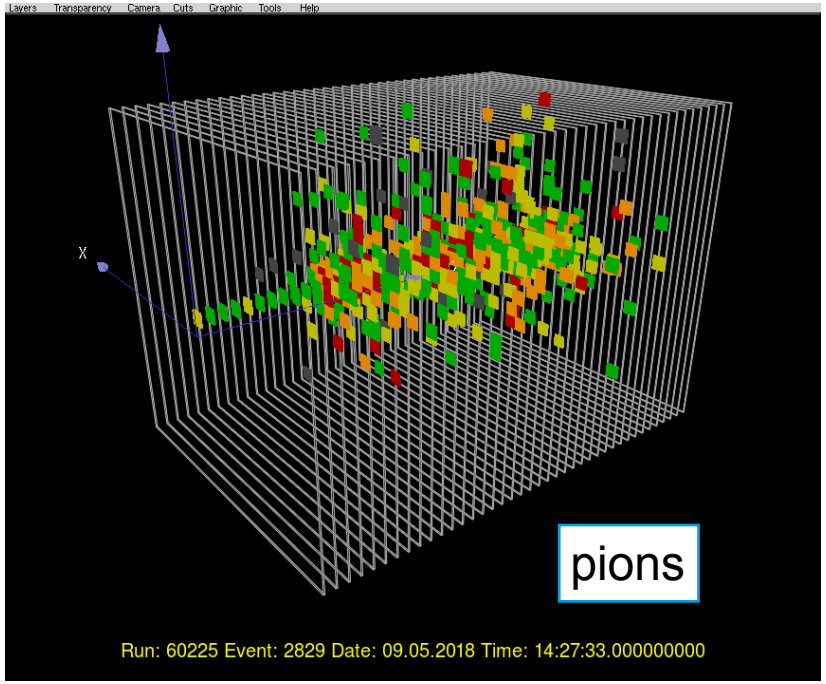


Electrons and Hadrons

Mixed Beams

- Electron data 10 - 100 GeV
- Hadron data 10 - 160 GeV





Today

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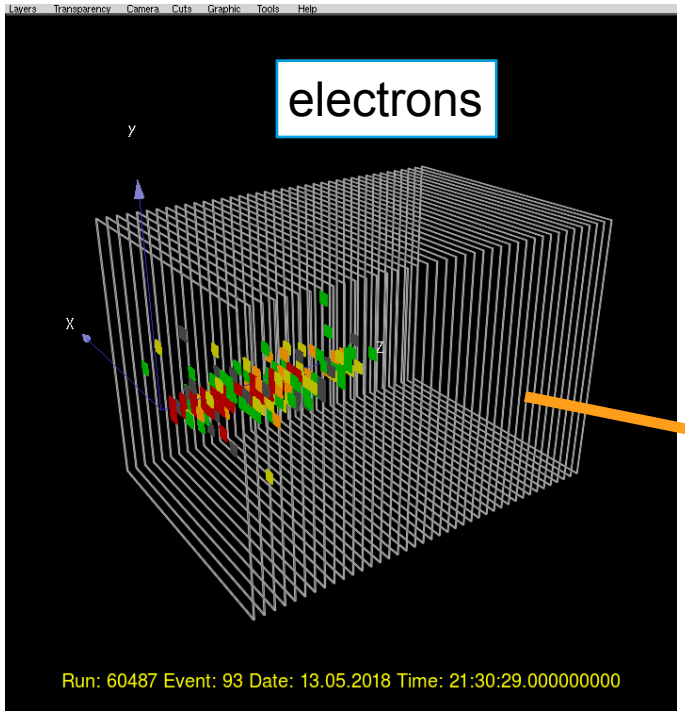

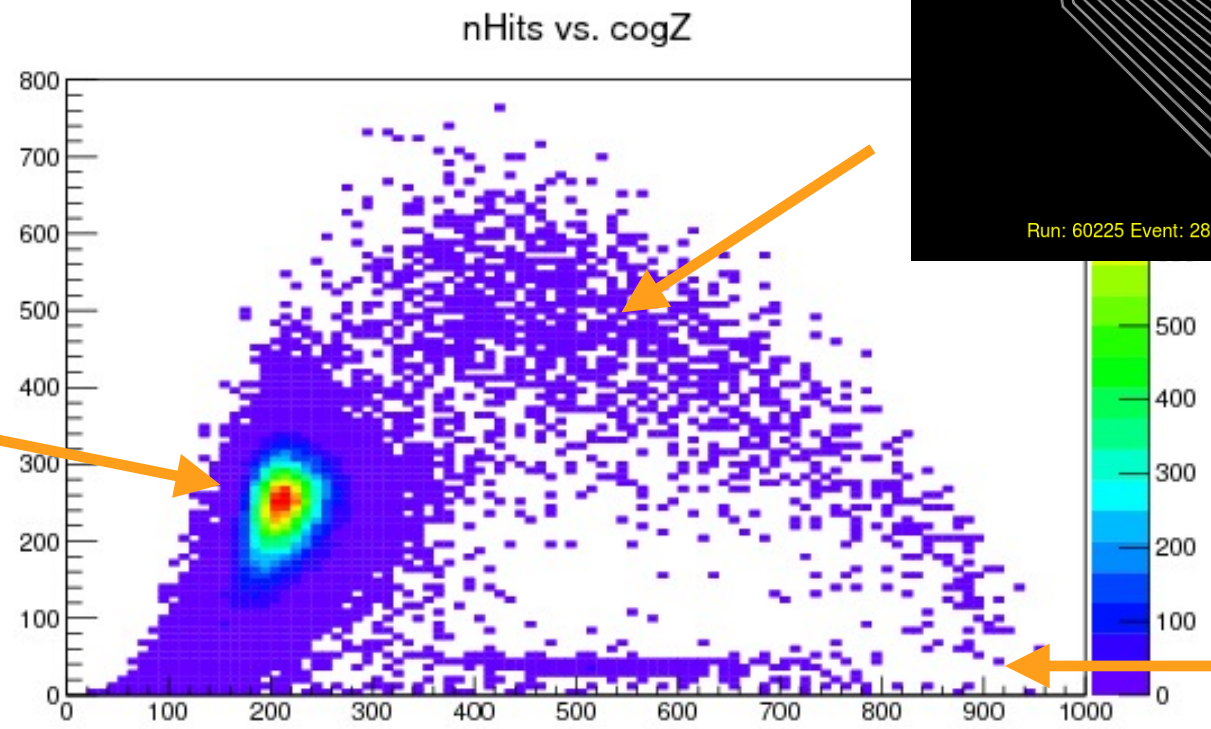

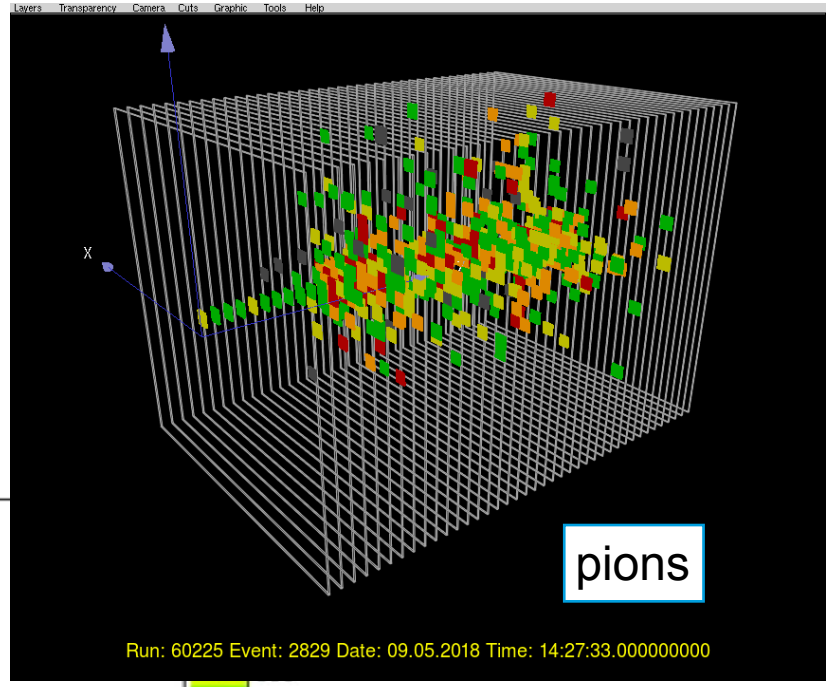

muons

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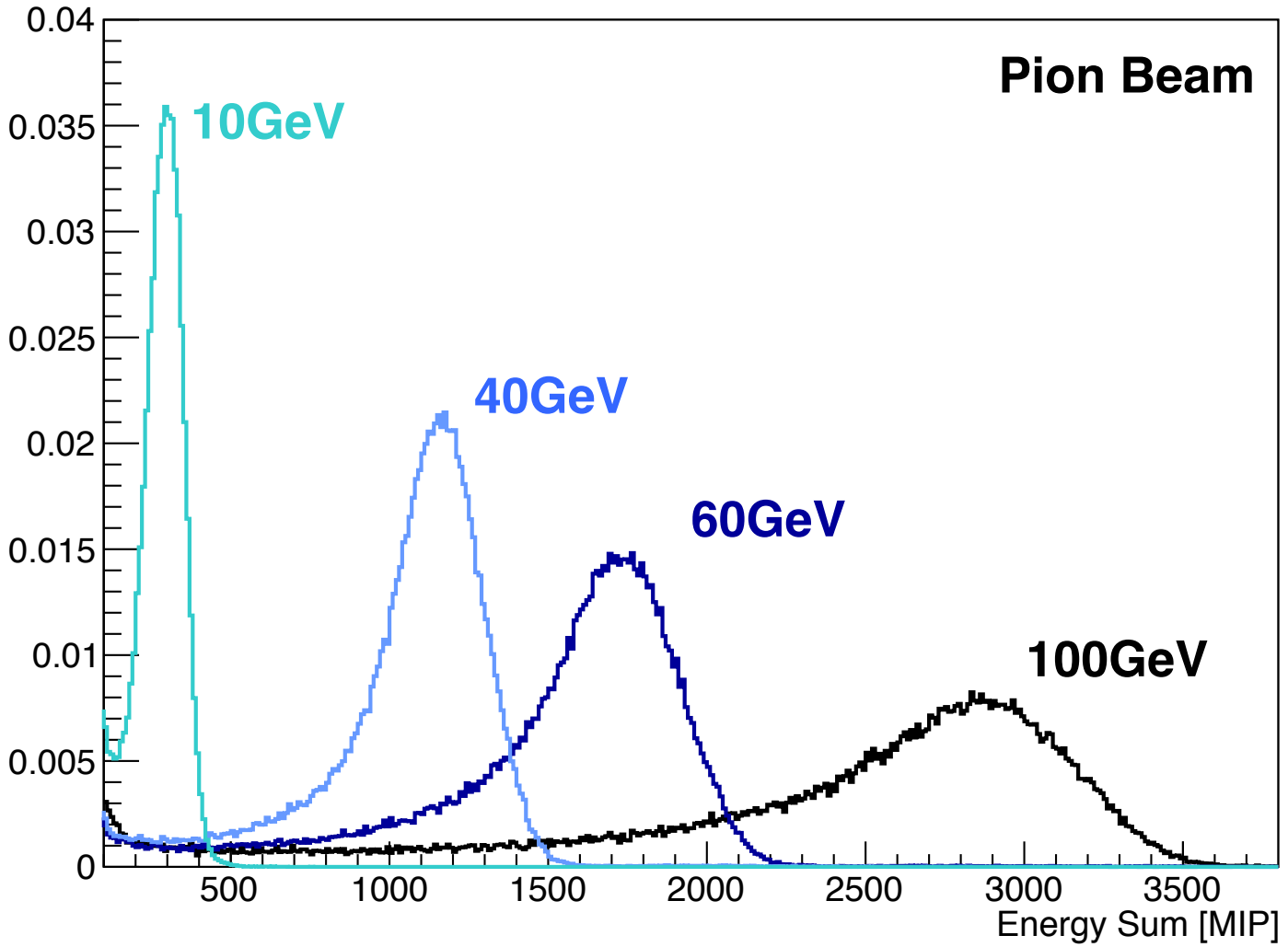

Today

Conclusions

and Outlook

CALICE SiPM-on-tile HCAL prototype with 22’000 channels built and successfully commissioned

Design and procedures for construction and QA are scalable to a full collider detector

Beam test at CERN SPS is on-going, more in June

- include layer with large (6x6cm^2) tiles

Combined test with CMS High Granularity silicon prototype this fall

- representing SiPM-on-Tile section of endcap hadron calorimeter

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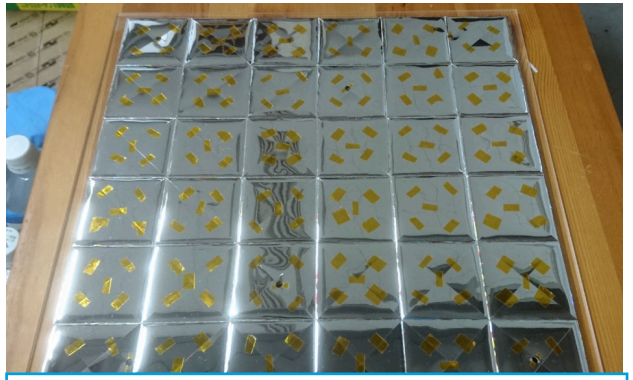
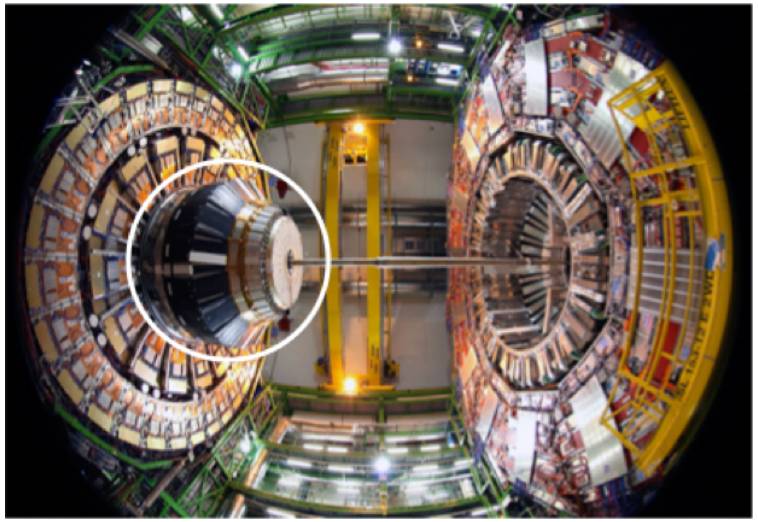


HBU with 6x6cm^2 tiles, U Tokyo



Back-up

Detector Requirements for LC and LHC

Accelerator environment.

Compared to LHC, LC radiation tolerance and bandwidth requirements are benign

Precision requirements are more demanding for LC:

- 2x for jet energies, 10x for track momenta, 5-10x for material budgets, 2x for strip and pixel dimensions

At LC, bunch train structure allows power cycled operation (~1%)

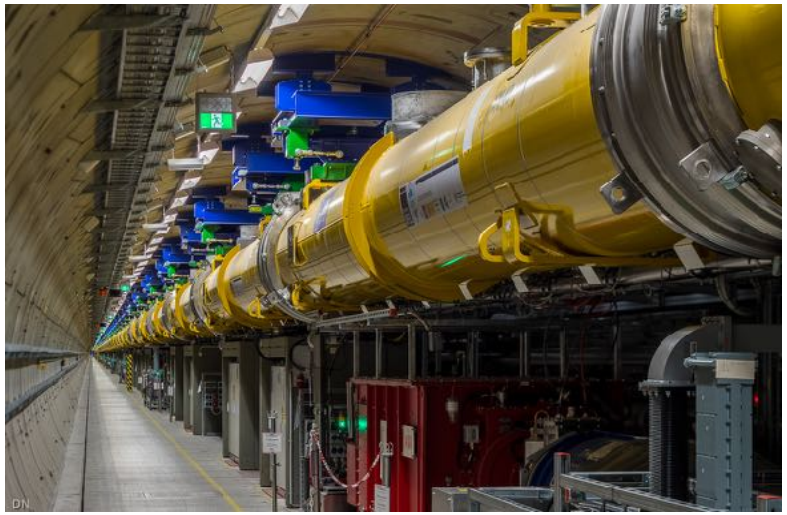
- simplifies powering and cooling: thinner trackers, denser calorimeters

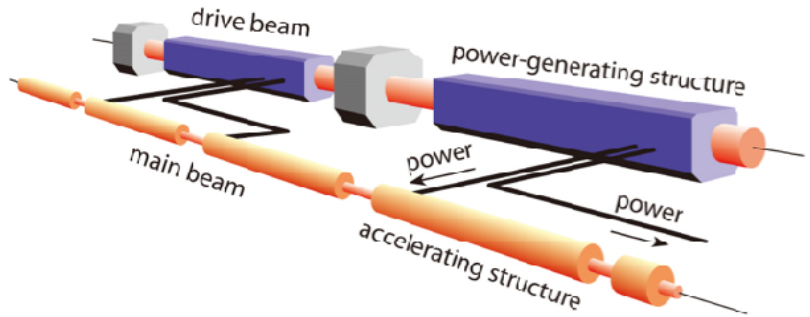
Backgrounds from beamstrahlung and hadronic 2-photon interactions

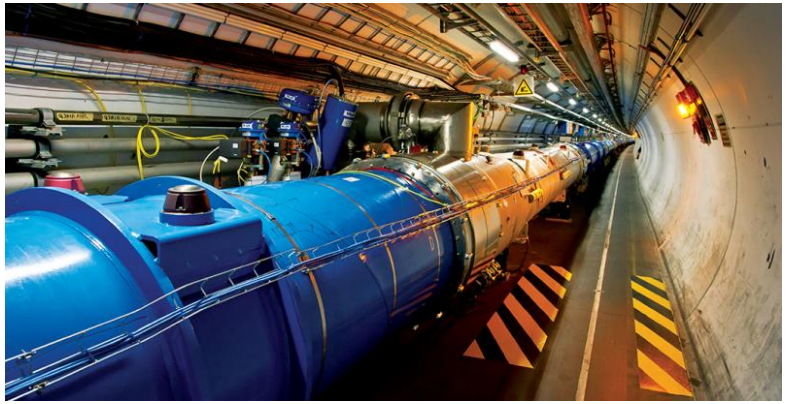
- more relevant for CLIC, higher E and smaller beam spot ($5x1nm^2$)
- somewhat higher emphasis on fine granularity and precise timing

Shifted focus and unwanted long time span led to development of new detector concepts up to TDR readiness level

- Imaging calorimeters
- Other examples: MAPS / ALICE ITS, ….







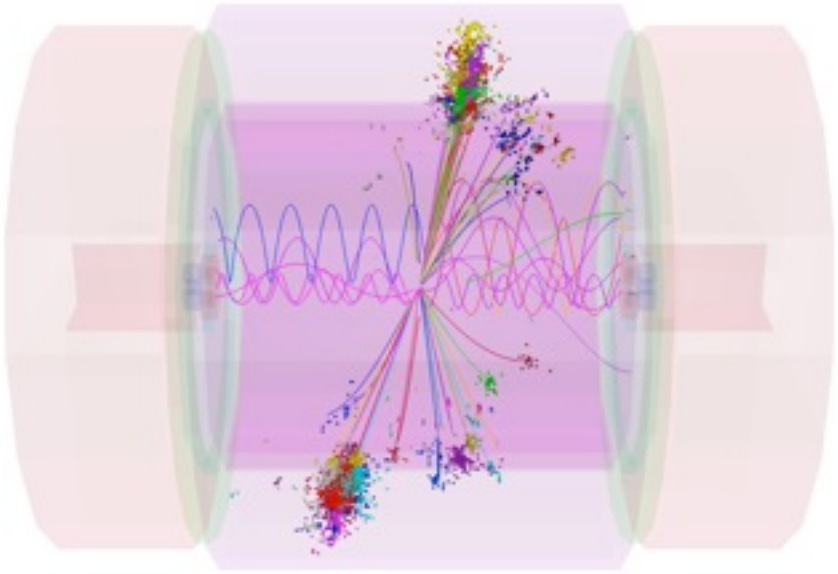
High Granularity and Pile-up

Particle flow with harsher backgrounds.

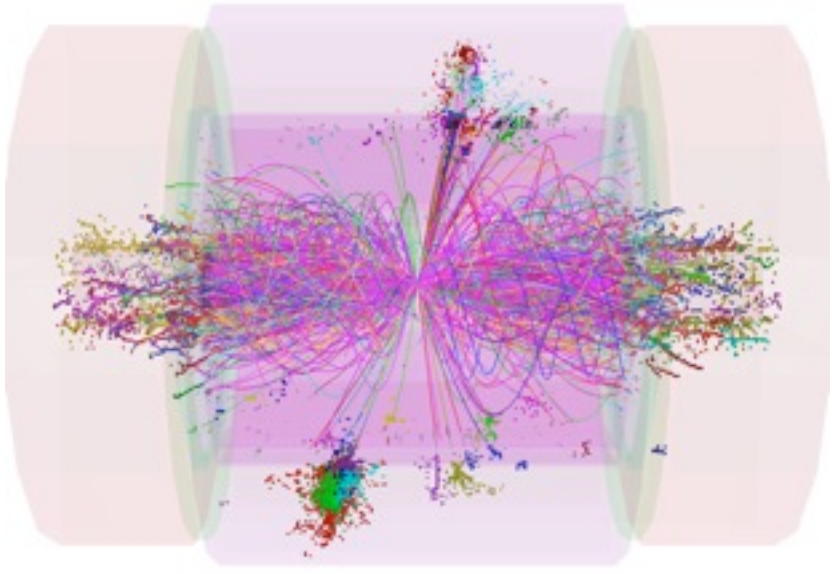
Studied intensively for CLIC: backgrounds from γγ → hadrons and short BX 0.5 ns

- Overlay γγ events from 60 BX, take sub-detector specific integration times, multi-hit capability and time-stamping accuracy into account
- Apply combination of topological, pt and timing cuts on cluster level (sub-ns accuracy)

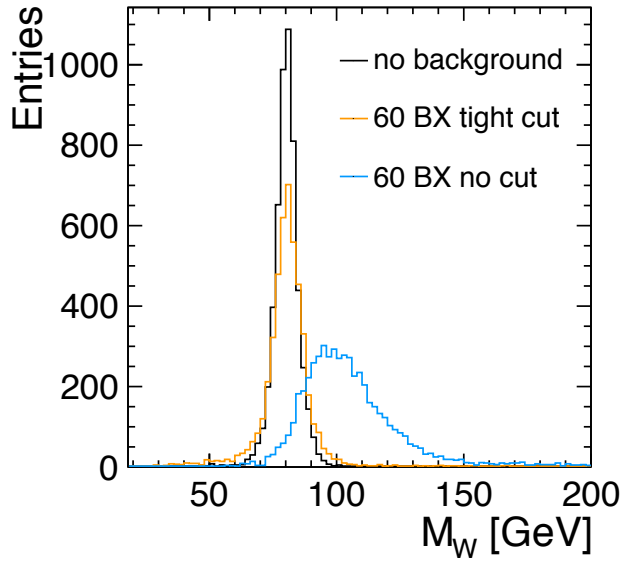
High granularity essential for pile-up rejection capabilities



Z @ 1 TeV



+ 1.4 TeV BG (reconstructed particles)



E_W = 500 GeV

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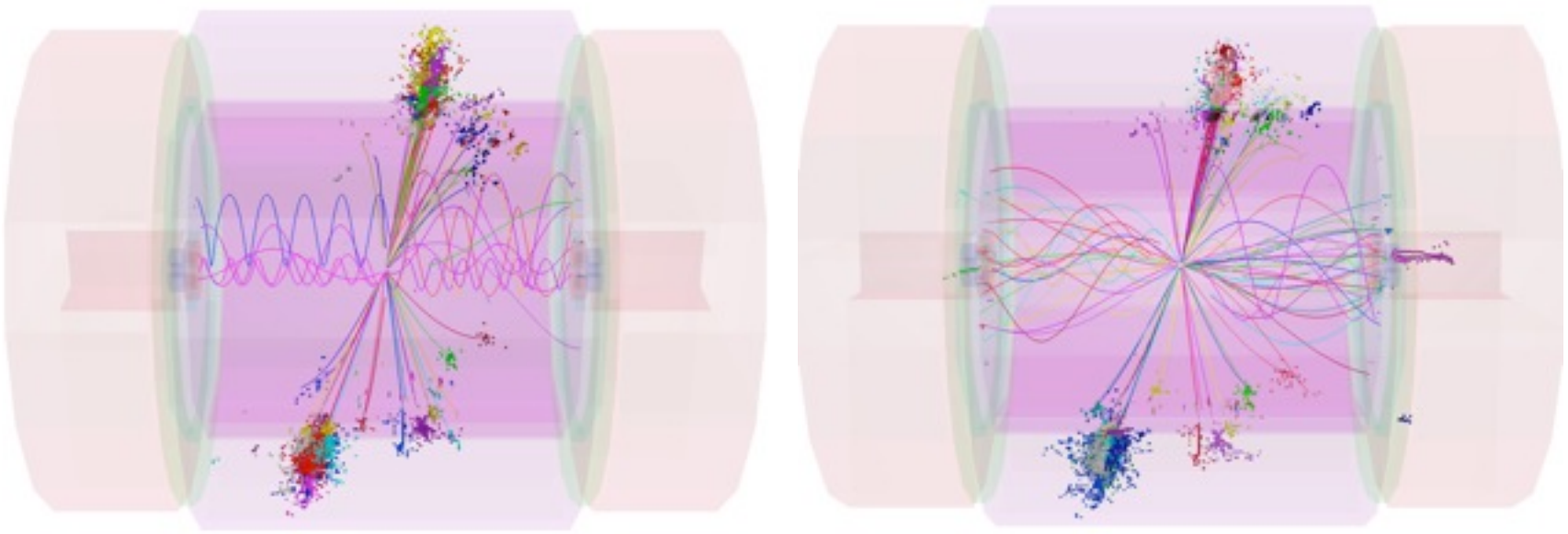

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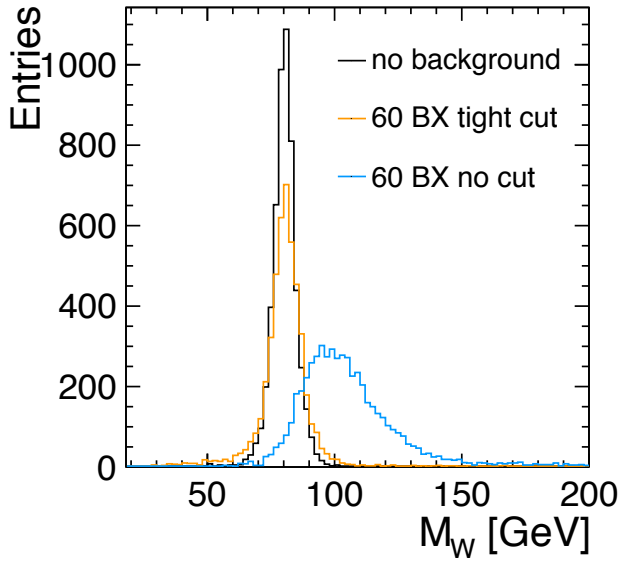

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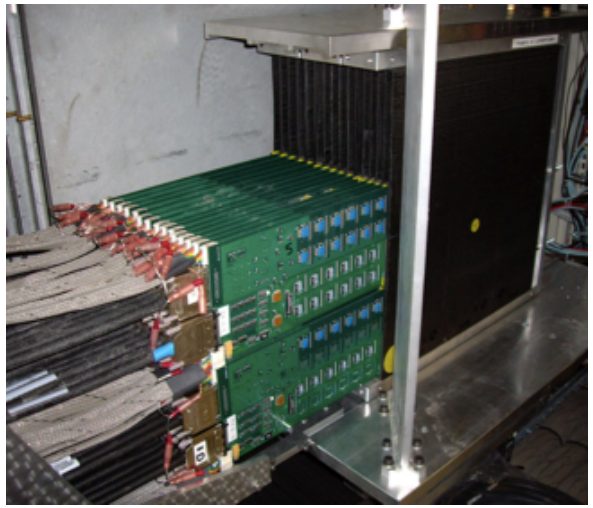
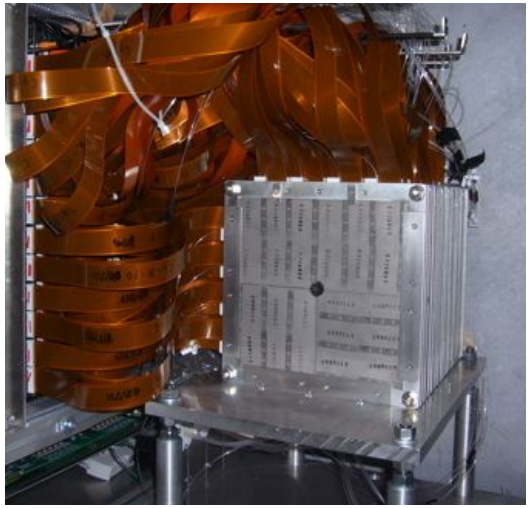
CALICE Test Beam Experiments

Large prototypes, complex systems.

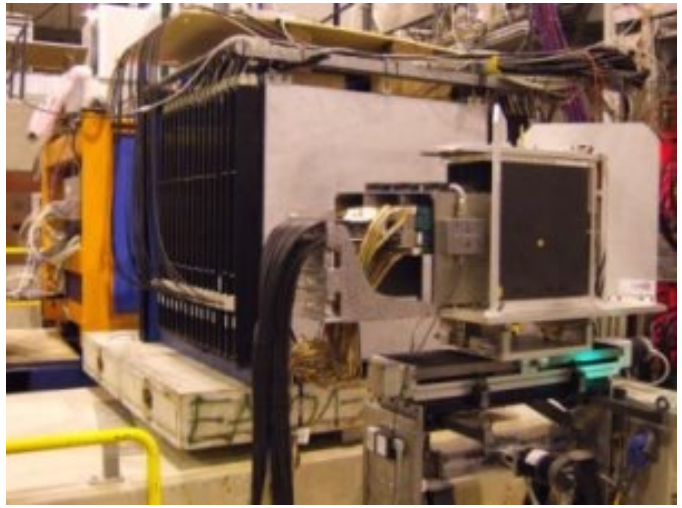
SiW ECAL



ScintW ECAL

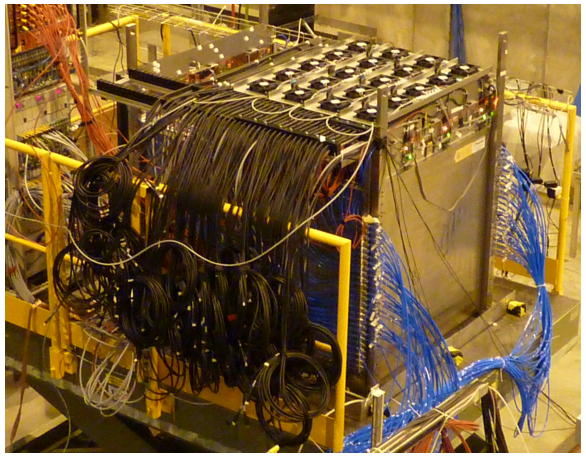


Scint AHCAL, Fe & W



RPC DHCAL, Fe & W

RPC SDHCAL, Fe



plus tests with small numbers of layers:

- ECAL, AHCAL with integrated electronics

- Micromegas and GEMs

CALICE Test Beam Experiments

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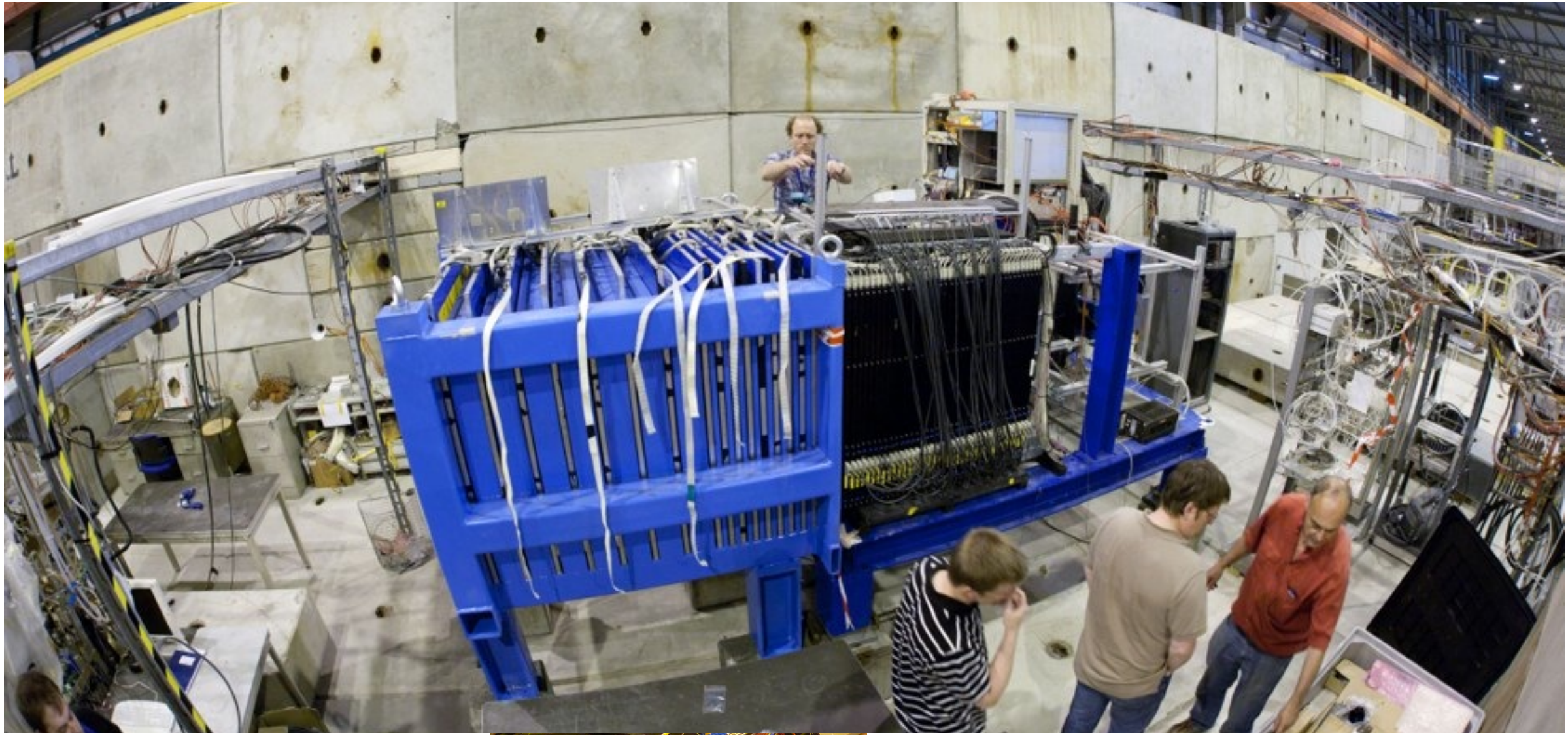
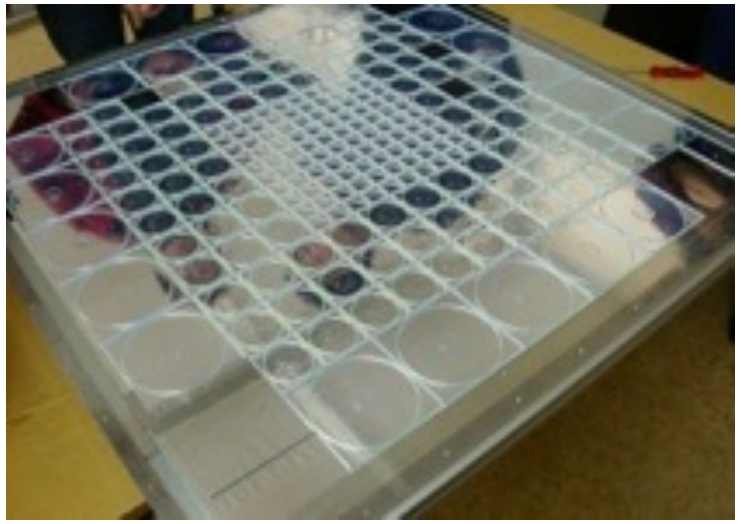
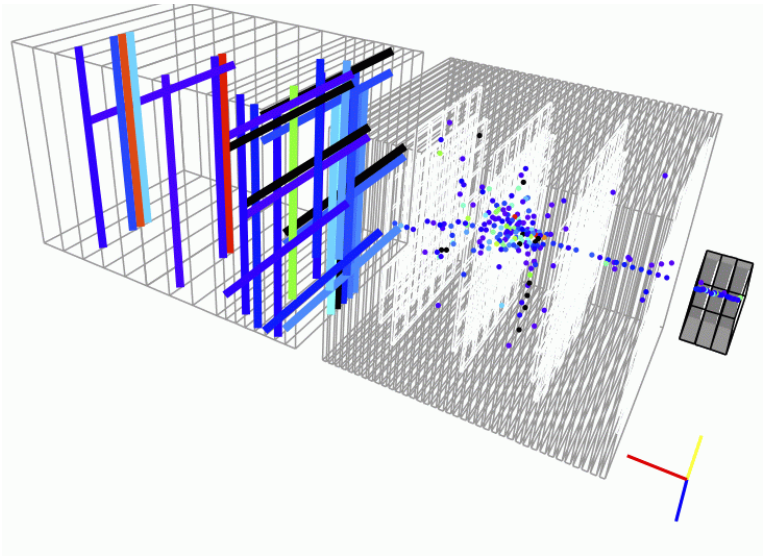
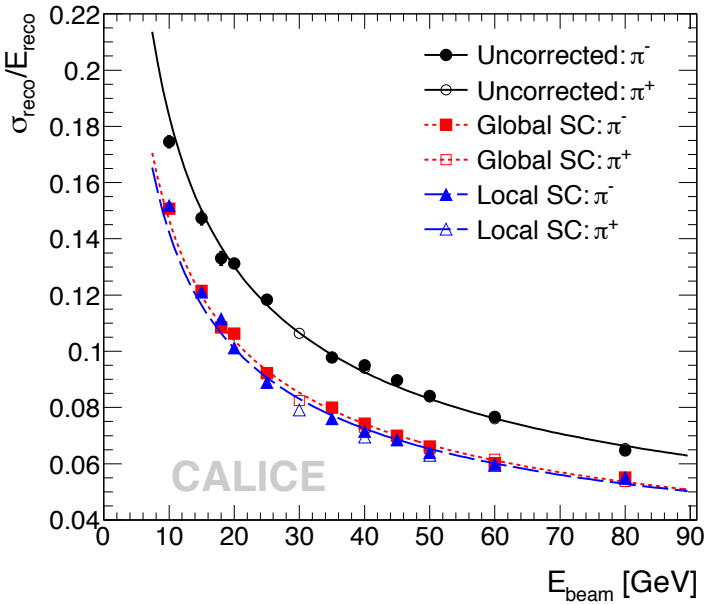


Proof-of-Principle

Validation of performances, simulations and algorithms.







- 38 layers, 7608 channels - first large-scale application of SiPMs
  - 6 years of data taking at DESY, CERN, Fermilab
- 12 journal papers (from SiPM-on-tile phototype alone)
  - resolution for electrons and hadrons, shower shapes and shower separation, different particle types and absorber materials,…
- All CALICE results
  - https://twiki.cern.ch/twiki/bin/view/CALICE/CalicePapers

$\sigma/E = 45.1\%/\sqrt{E} \oplus 1.7\% \oplus 0.18/E$

software compensation
now implemented in Particle Flow

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