Calorimeter R&D update

LCWS 2018 @ UTA

Daniel Jeans, IPNS / KEK

Material from many colleagues
Impossible to cover everything:
many more details in Calo/Muon sessions

Calorimeters at LC

destructively measure
particles' energy and direction

For typical energies of particles produced at LC
[tracker + B-field] provides significantly better
precision than calorimetry for charged particles
less so in the very forward region

Calorimeters needed when tracking not applicable,
particularly to measure electrically neutral particles

Also provide essential particle type identification:
→ distinguish hadrons, electrons, muons
over a wide range of energies

Majority of events produced at lepton colliders
contain some hadronic jets [dominant decays of Z, W, H, γ^*]
→ essential to measure as precisely as possible

Calorimeters for CLIC/ILC detector concepts are
designed for optimal reconstruction of hadronic jets by **Particle Flow**

Tracker measurements used to very precisely estimate
charged particles' energies [~65% of jet energy on average]

Calorimeters used to estimate momentum of
neutral particles: photons [~25%] and neutral hadrons [~10%]

Can achieve 3~4% jet energy resolution over wide jet energy range
→ significant improvement with respect to other detector systems

Challenge:

design calorimeter system which
allows us to make as little use as possible of
calorimeter measurements, in favor of tracker measurements

not a trivial task!

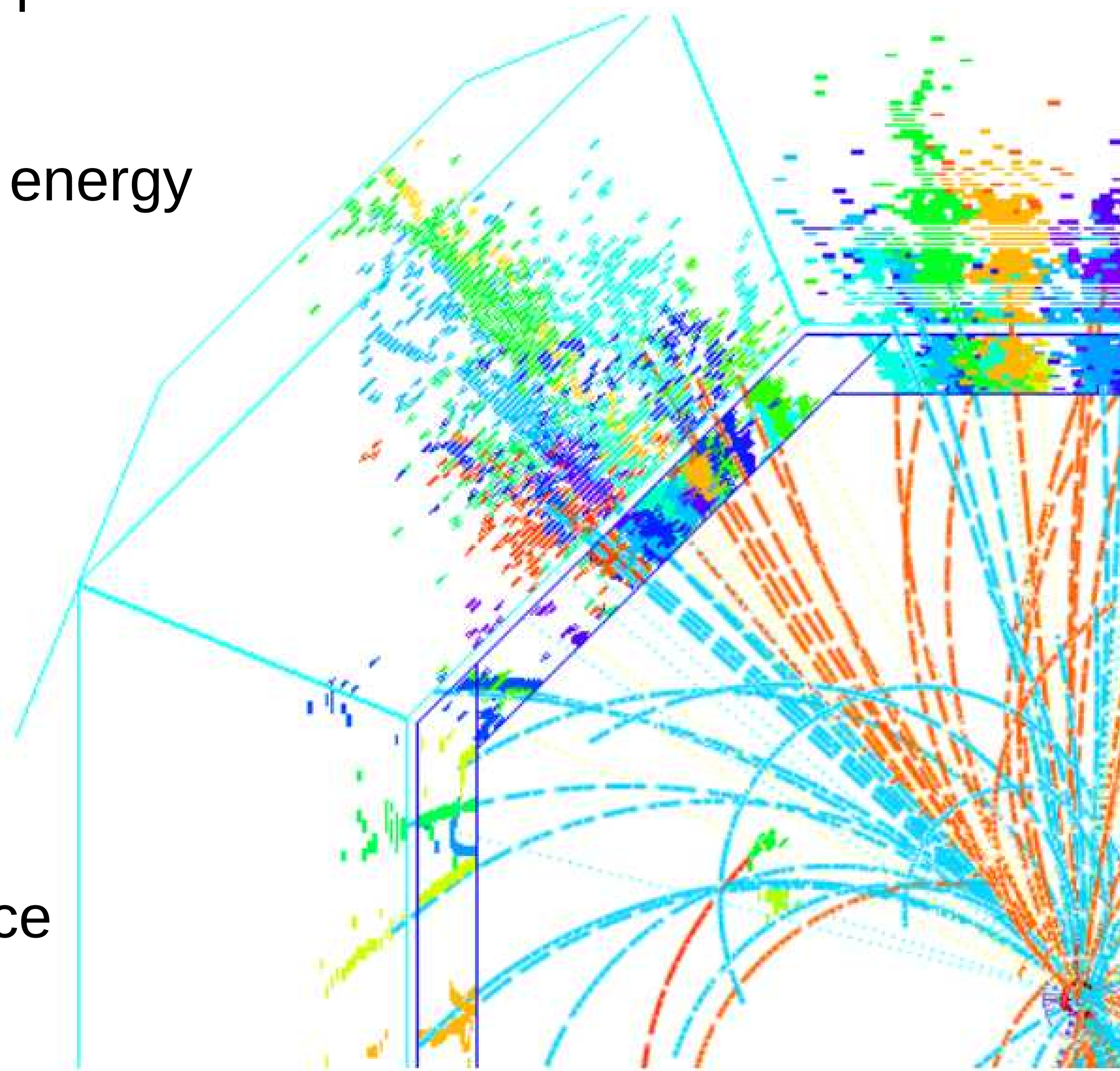
Key to successful PFA:

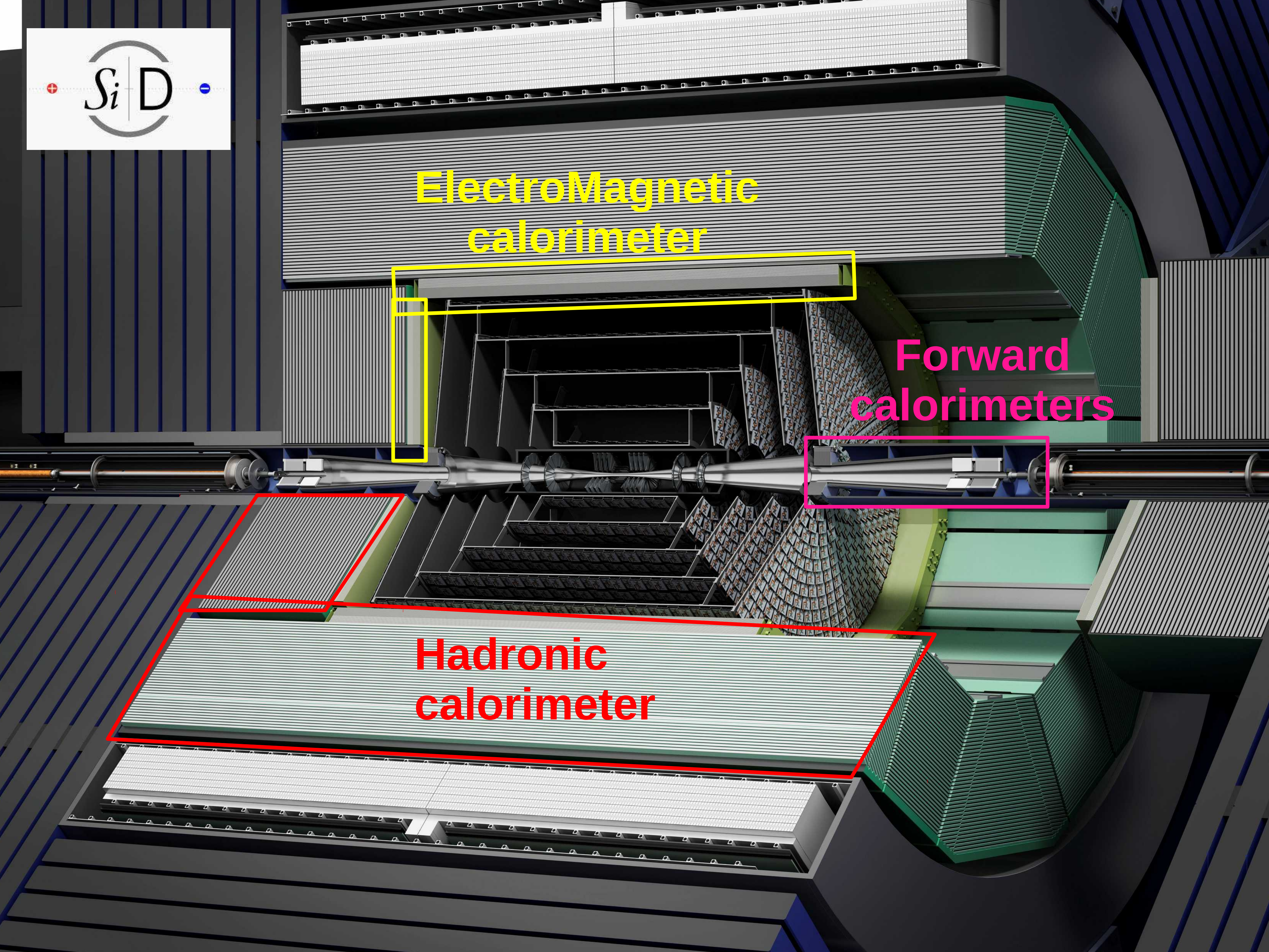
distinguish calorimeter signals induced by neutral and charged particles

→ avoid double - or under - counting of energy when estimating energy of an ensemble of particles using combination of tracker and calorimeter

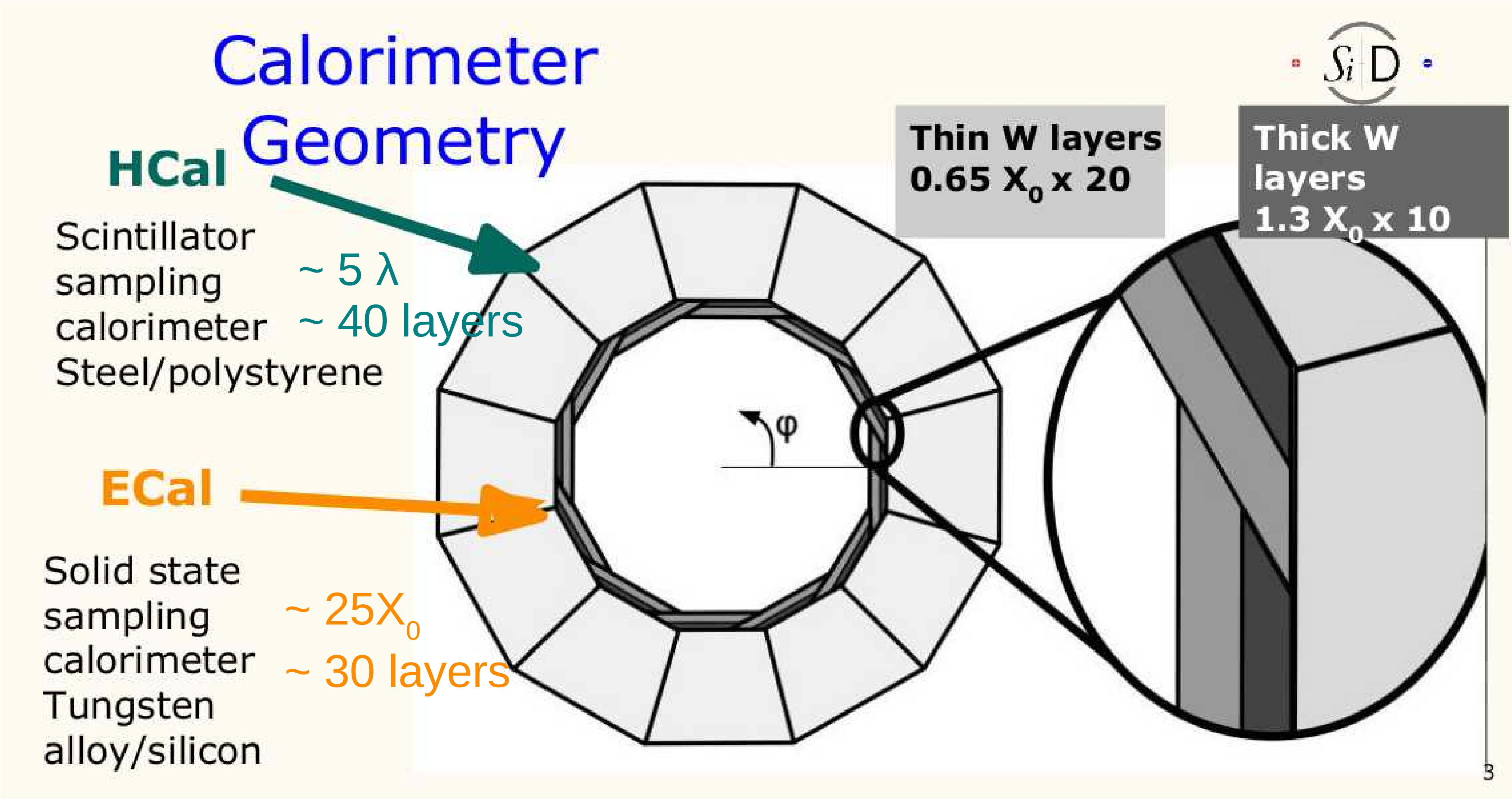
→ calorimeter with highly segmented readout

Segmentation should be
→ significantly smaller than typical inter-particle distance
→ significantly smaller than typical shower size





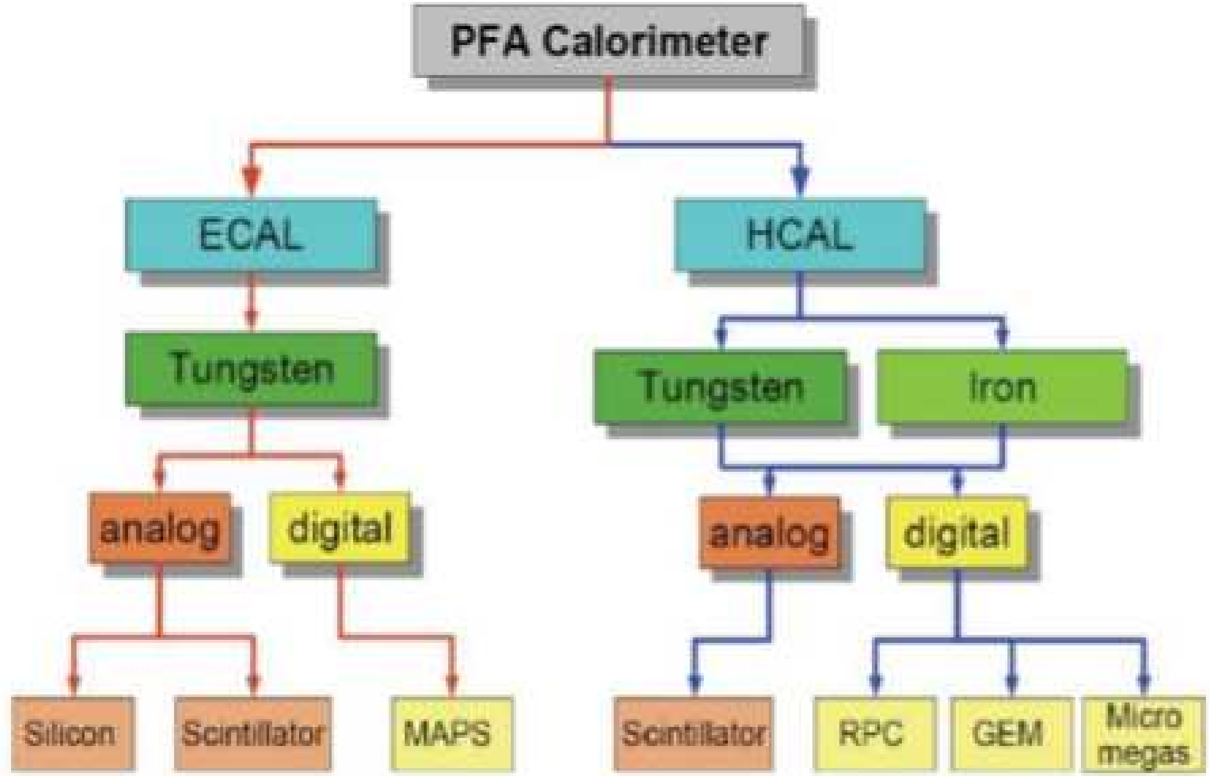
SiD
ElectroMagnetic calorimeter
Forward calorimeters
Hadronic calorimeter



Several 1000m^2 of detection layers

Many 10s of millions of individual readout channels
→ these calorimeters requires highly integrated readout systems

Several readout technologies being investigated for LC calorimeters



“horizontal” collaborations

LC detector concept groups

And closely related work for upgrades of LHC detectors, detectors at other future facilities

LC calorimeters are large, highly complex detectors

→ long construction time
→ industrialised production
→ industry-like quality control

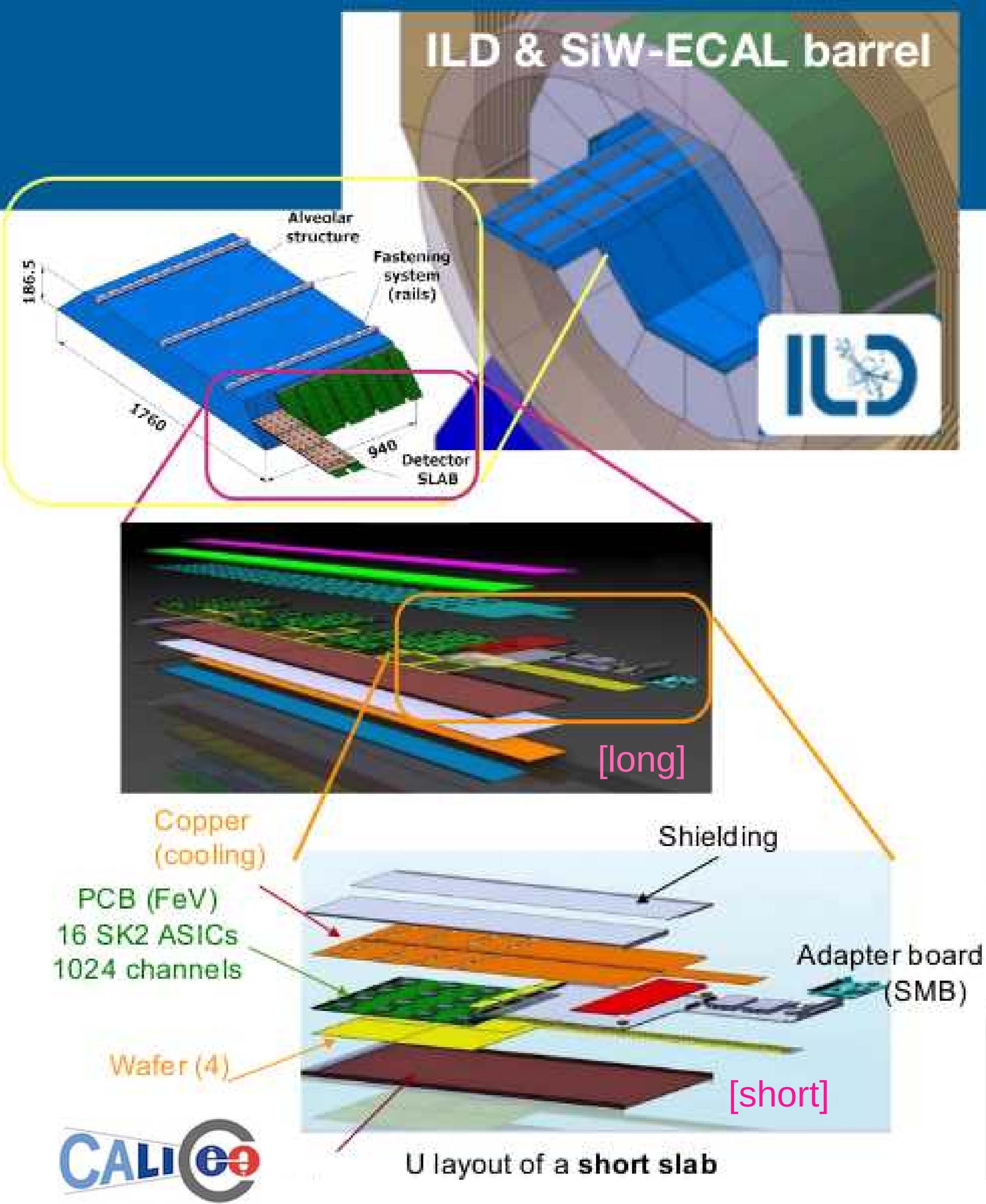
In recent years a lot of focus has been on developing

- large-scale prototypes of various critical parts,
- construction & quality assurance techniques required to realise them
- how to integrate within detector

Also work on newer ideas with potential to bring additional benefits

- precise timing information
  → Time Of Flight, PFA reconstruction
- integrated sensor/readout systems

CALICE / ILD SiW ECAL



Recent beam tests of "short slabs"

running rather stably

Additional semi-automatic production line in Japan

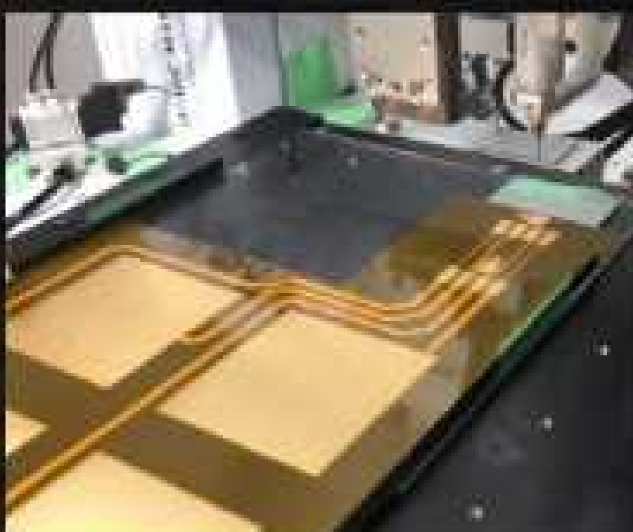
Significant progress on "long slab" with dimensions similar to those of final detector elements

Assembly procedure

[new setup in Japan]

Dispense conductive glue

Place sensors → 1 day cure



Dispense glue to flex

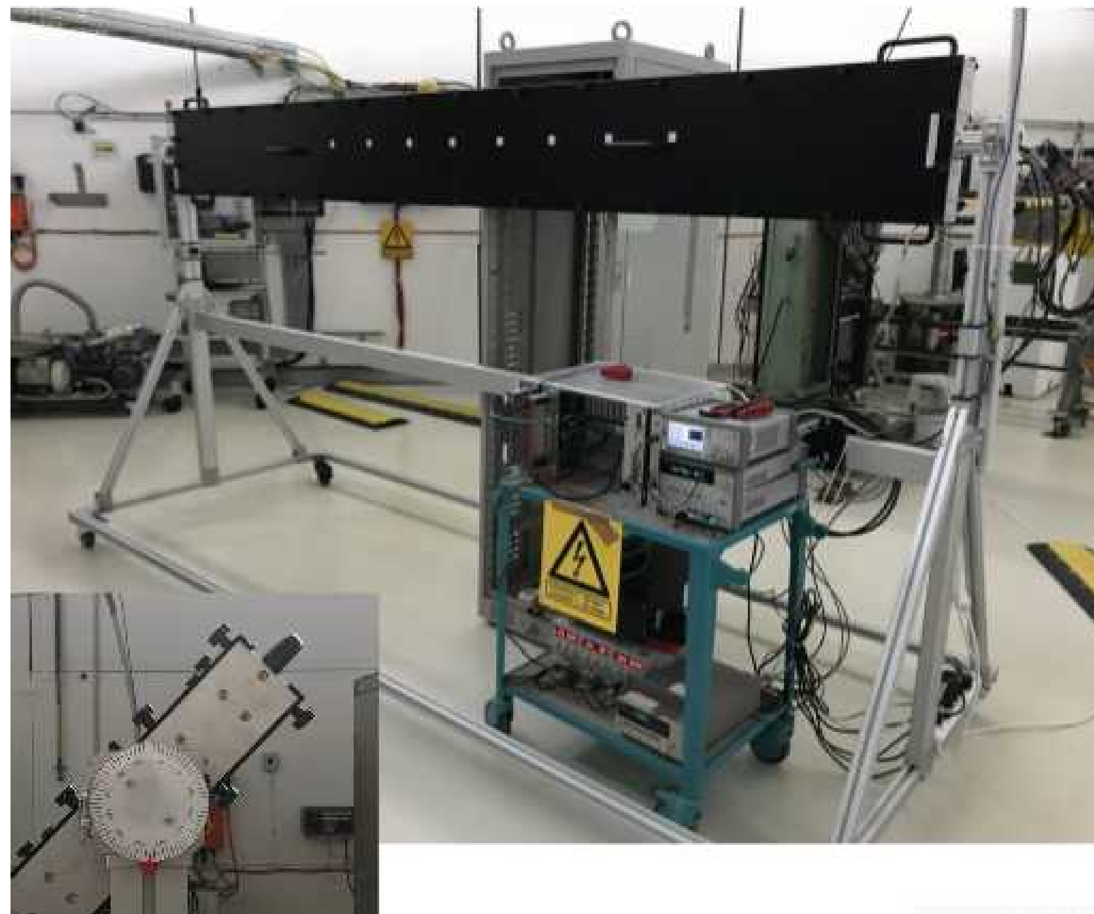
Mount sensor+PCB → 1 day cure

“long slab”

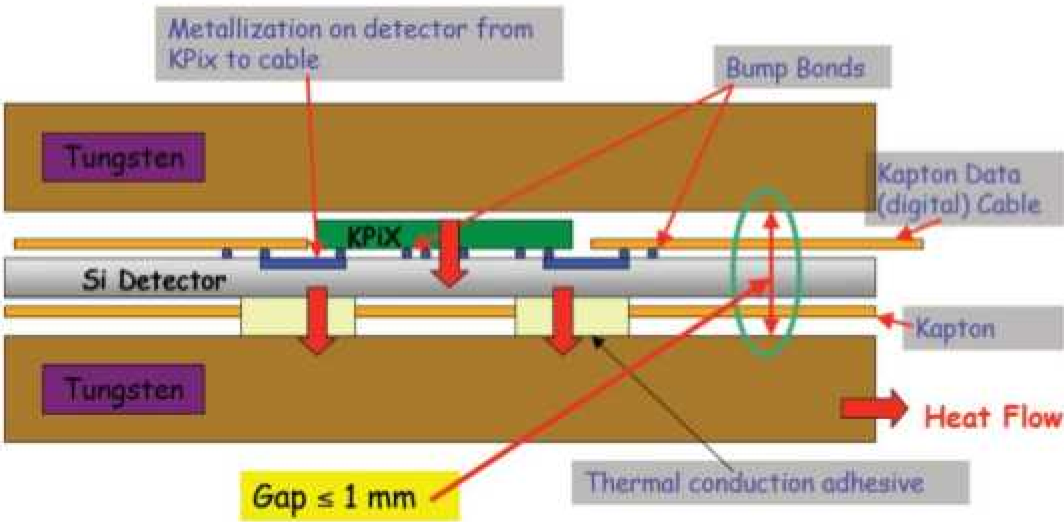
Chain of 8 individual elements (“ASUs”)

Interconnections, signal&power propagation

Tests in lab and particle beams



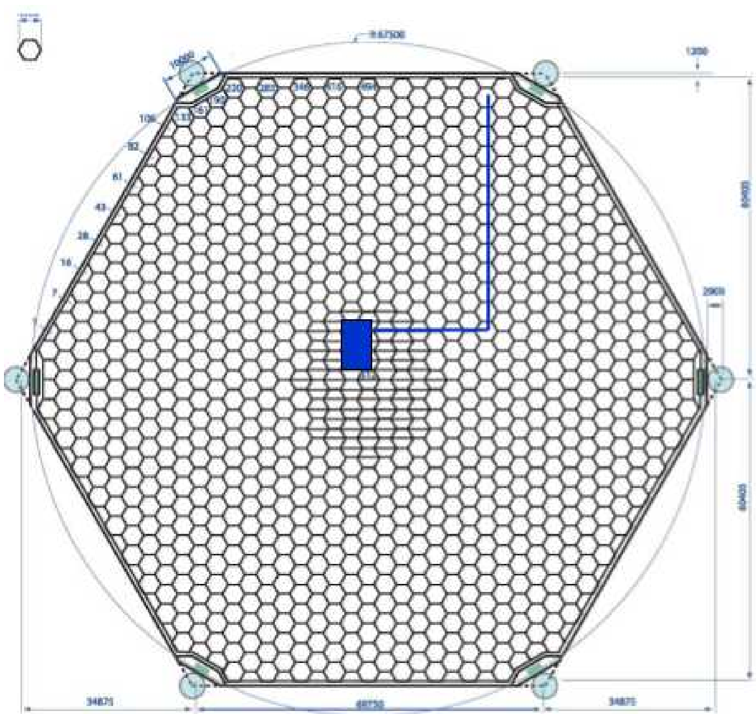
SiD Si-W ECAL

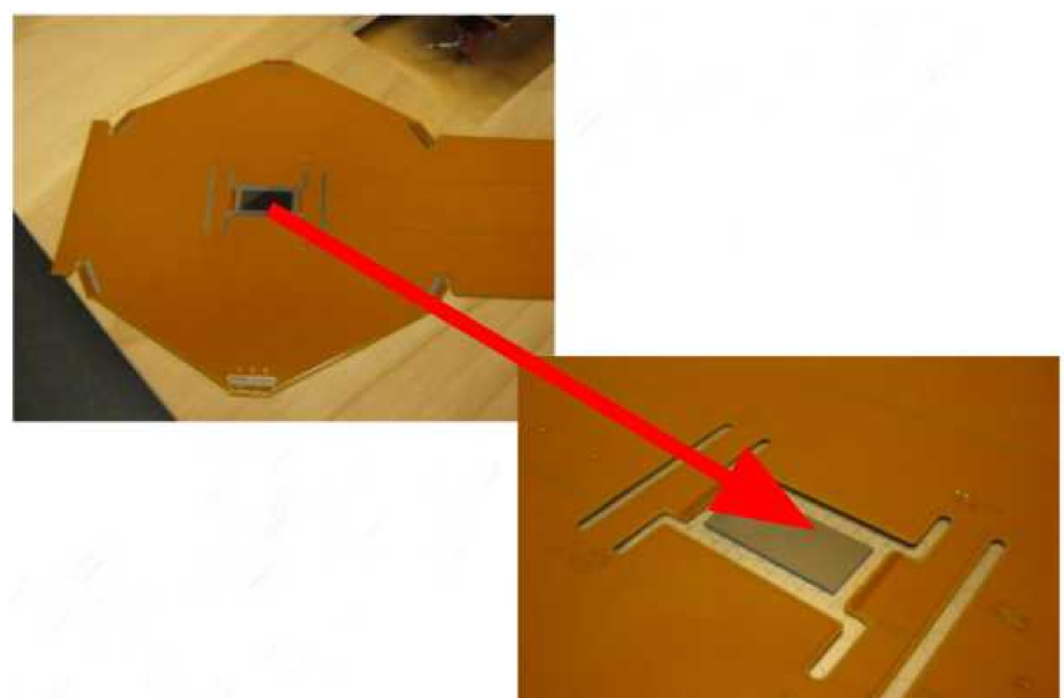


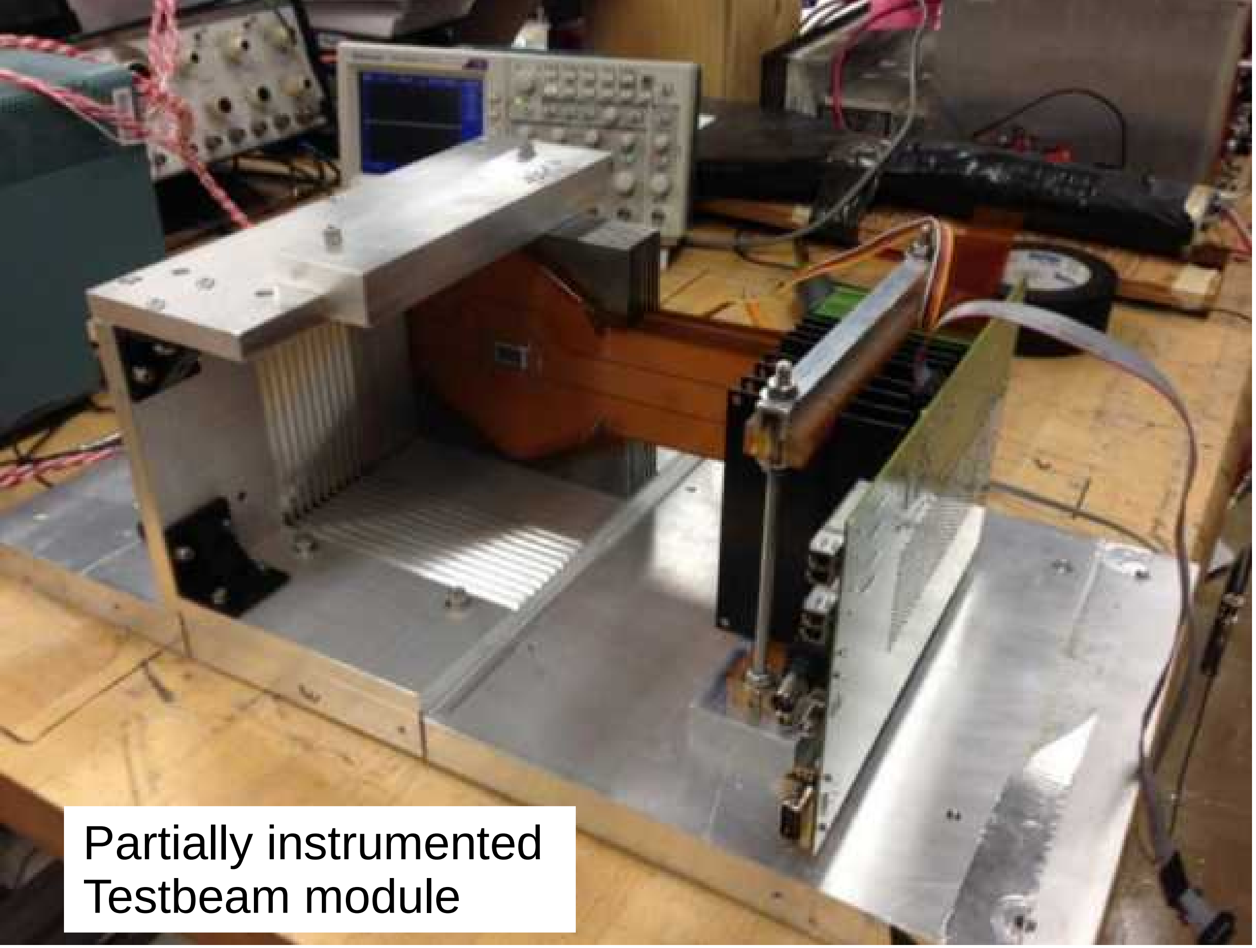
Very compact layer structure,
kPix bump-bonded to sensor

Analyses of first prototype

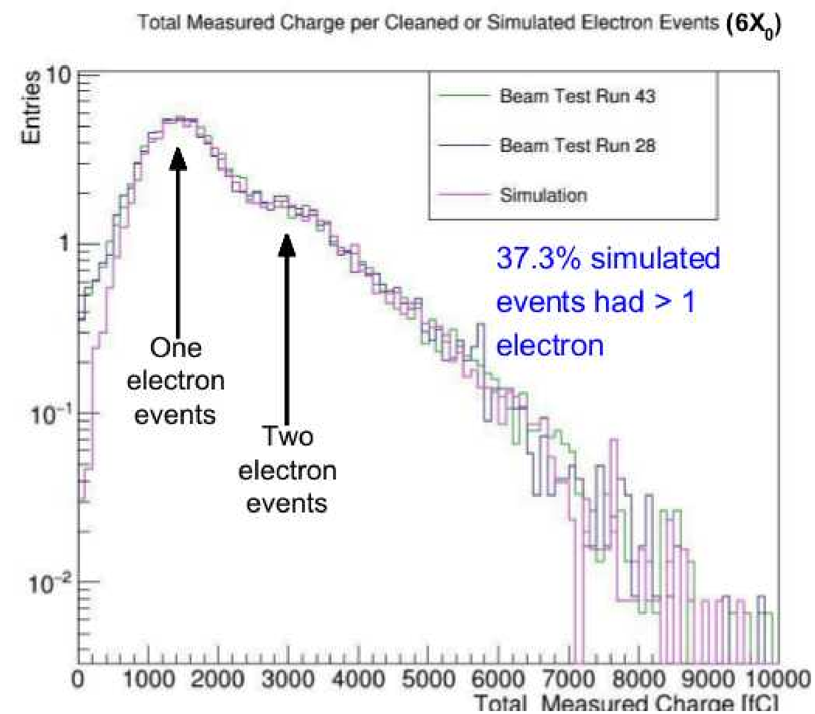
Recent improvements to sensor design should mitigate cross-talk
→ sensors being tested



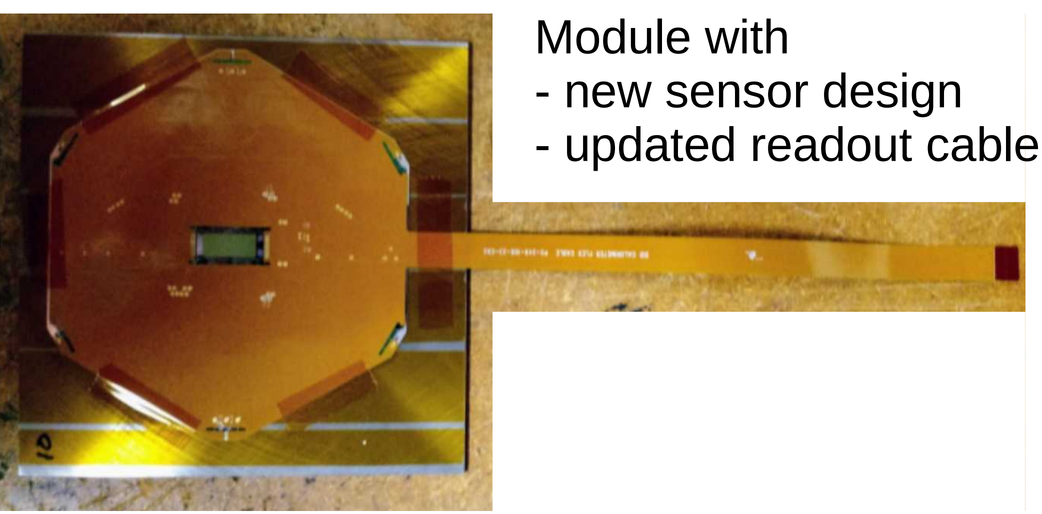




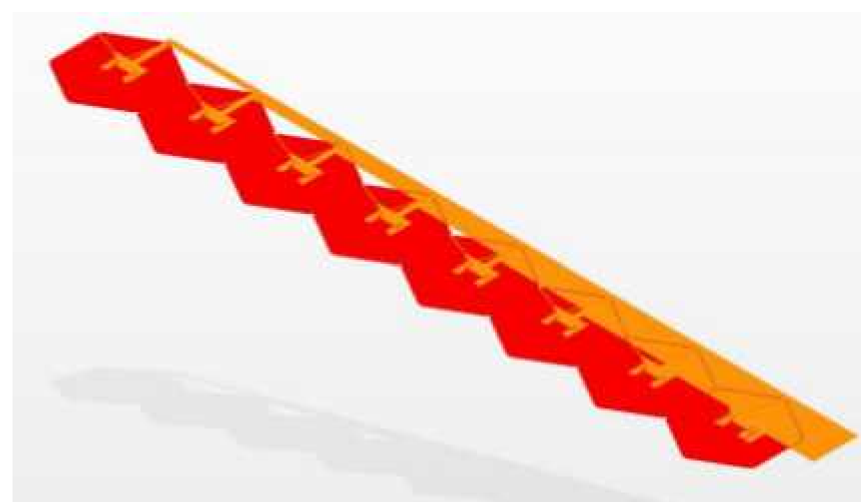
Partially instrumented
Testbeam module



Testbeam data well
described in simulation



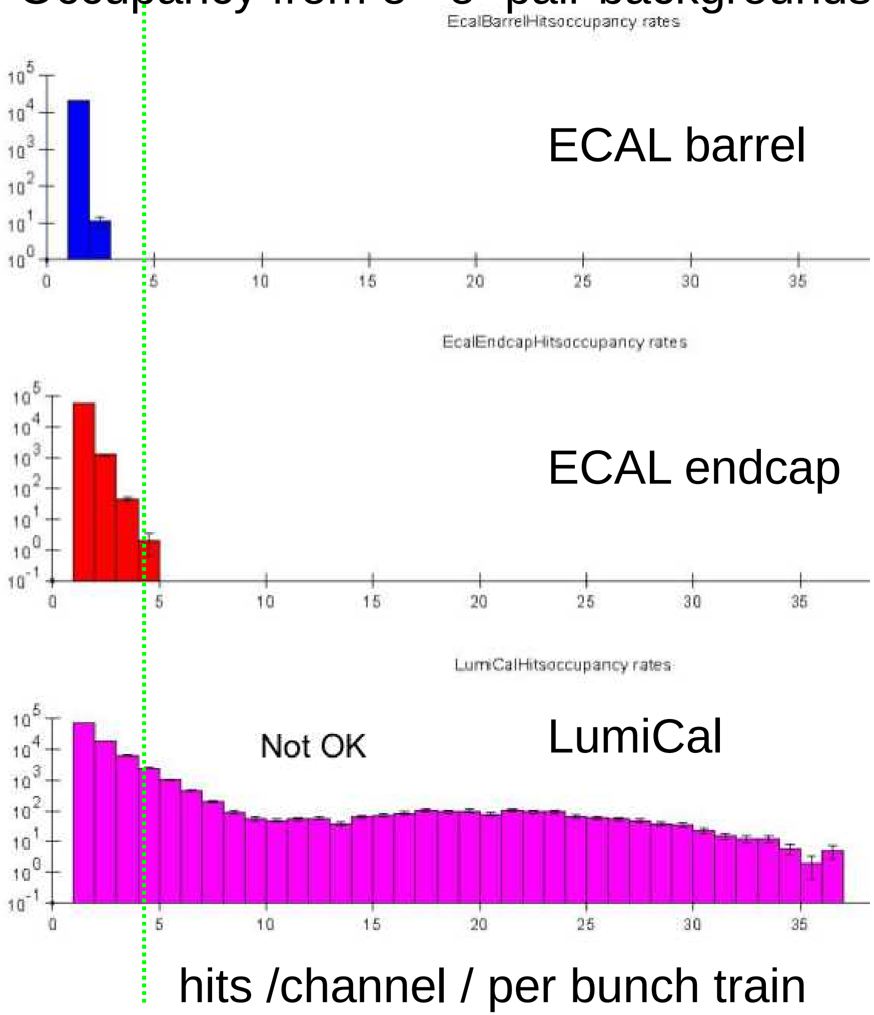
Module with
- new sensor design
- updated readout cable design



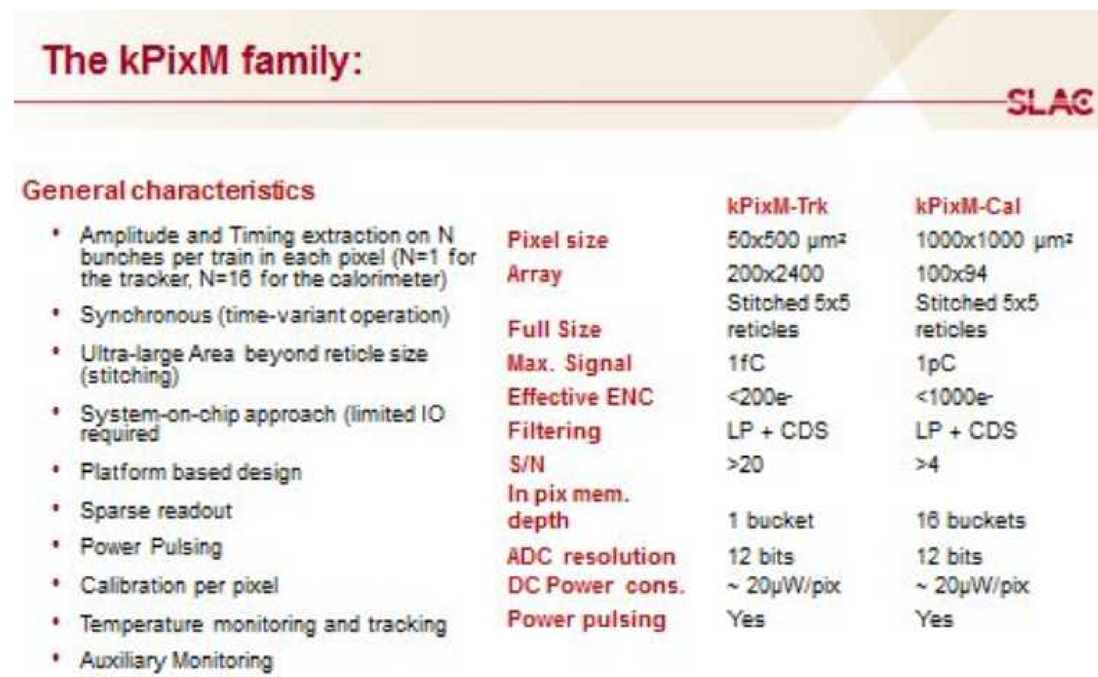
Ideas for future developments

Extend kPIX buffer depth in forward region?

Occupancy from e+ e- pair backgrounds:



kPixM - new design based on monolithic pixel architecture, specific designs for ECAL and Tracker



The kPixM family:

SLAC

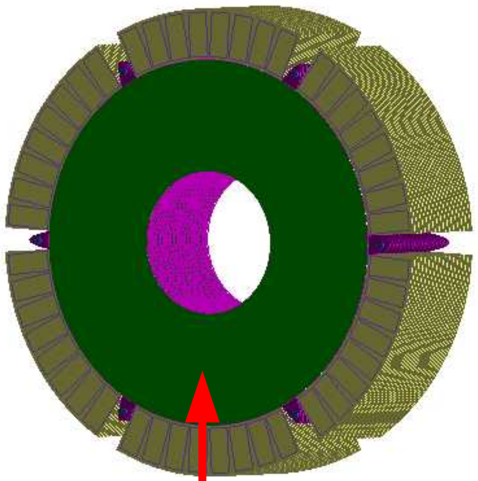
General characteristics

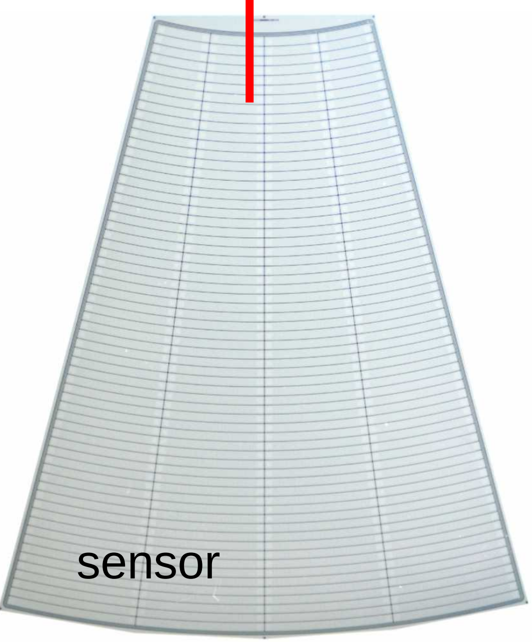
- Amplitude and Timing extraction on N bunches per train in each pixel (N=1 for the tracker, N=16 for the calorimeter)
- Synchronous (time-variant operation)
- Ultra-large Area beyond reticle size (stitching)
- System-on-chip approach (limited IO required)
- Platform based design
- Sparse readout
- Power Pulsing
- Calibration per pixel
- Temperature monitoring and tracking
- Auxiliary Monitoring

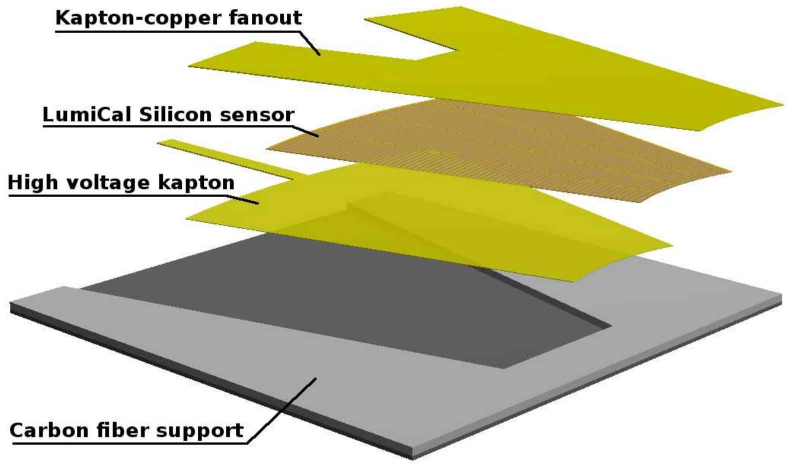
	kPixM-Trk	kPixM-Cal
Pixel size	50x500 μm²	1000x1000 μm²
Array	200x2400	100x94
Full Size	Stitched 5x5 reticles	Stitched 5x5 reticles
Max. Signal	1fC	1pC
Effective ENC	<200e-	<1000e-
Filtering	LP + CDS	LP + CDS
S/N	>20	>4
In pix mem. depth	1 bucket	16 buckets
ADC resolution	12 bits	12 bits
DC Power cons.	~ 20μW/pix	~ 20μW/pix
Power pulsing	Yes	Yes

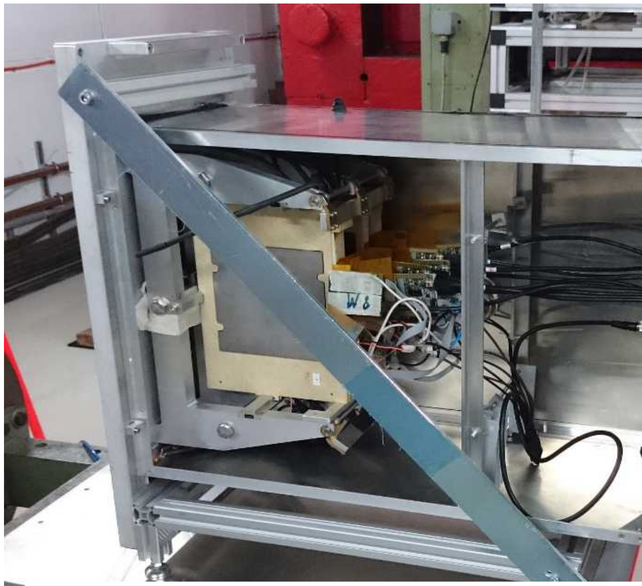
LumiCal – EM calorimeter in forward region
measure ILC luminosity via Bhabha scattering

Compact design to minimise Moliere radius

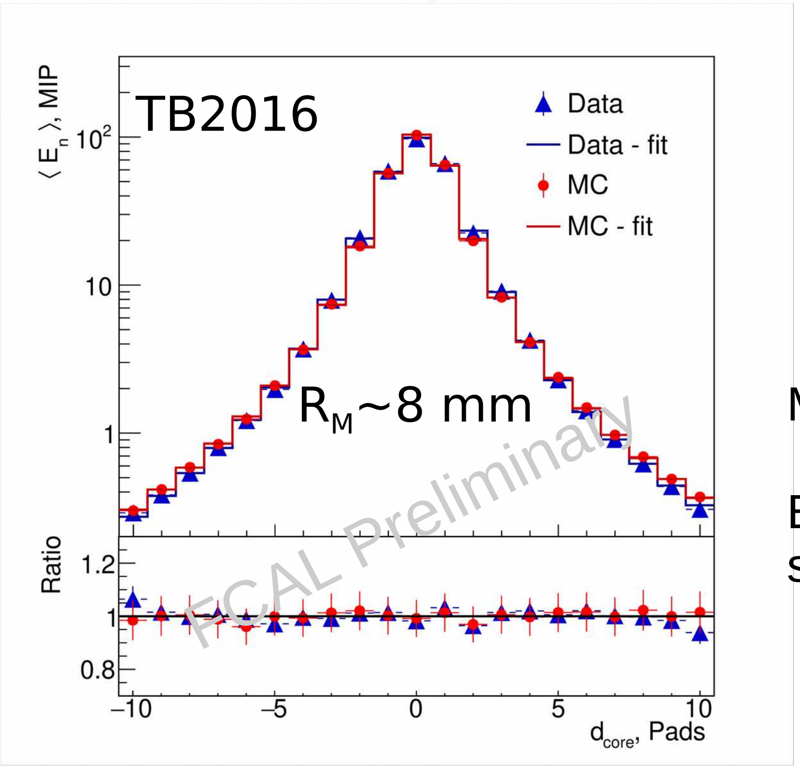








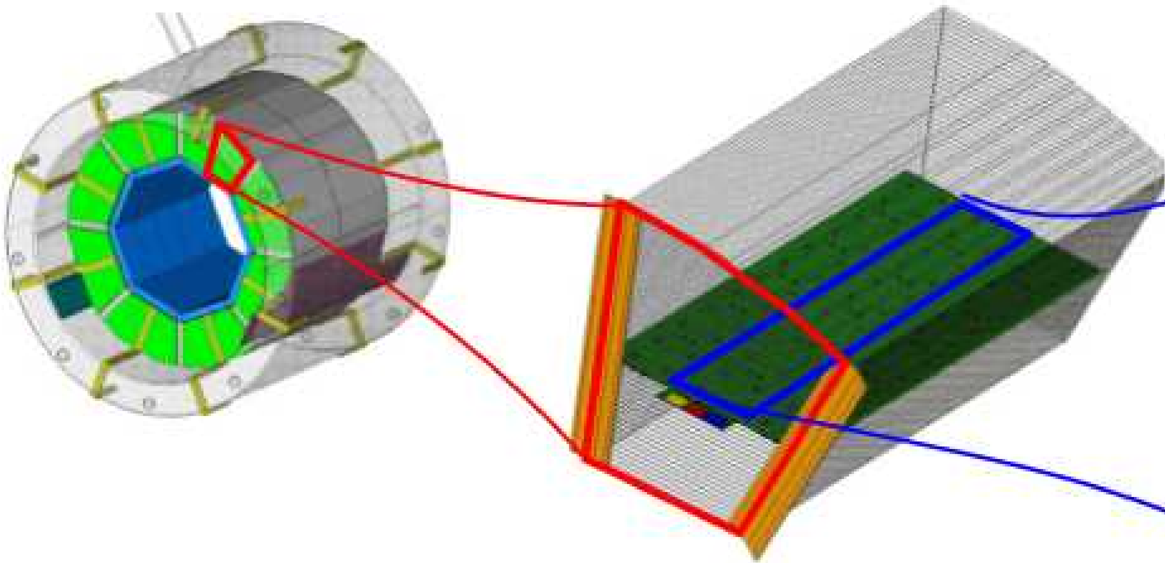
Prototype detector elements tested in beams

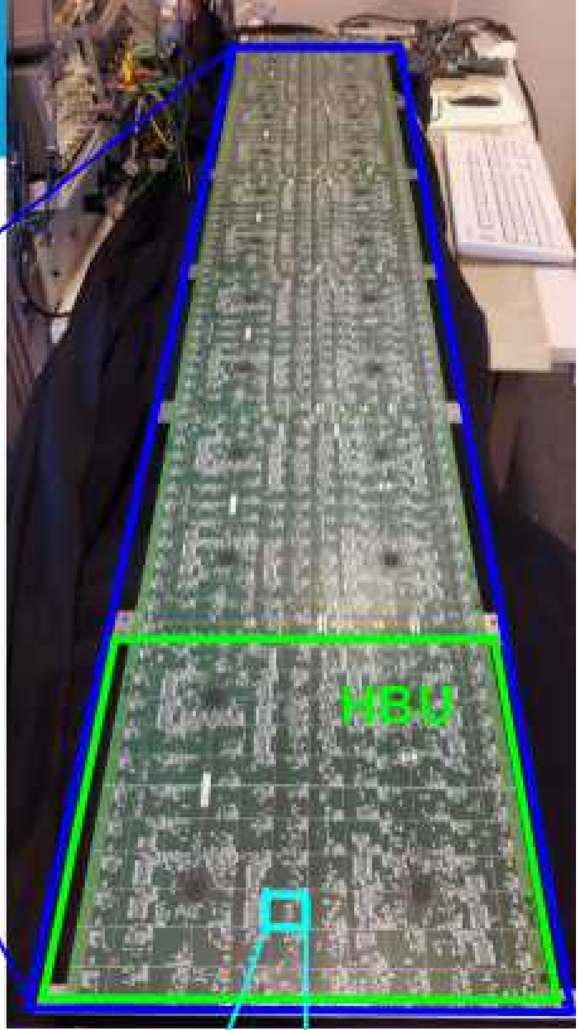


Moliere radius of 8mm

Excellent agreement with simulations

AHCAL technological prototype



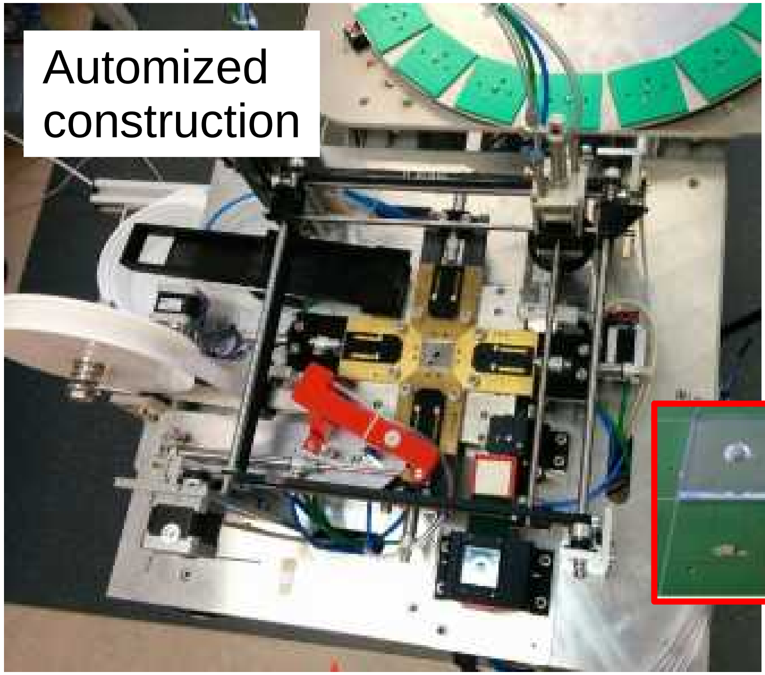


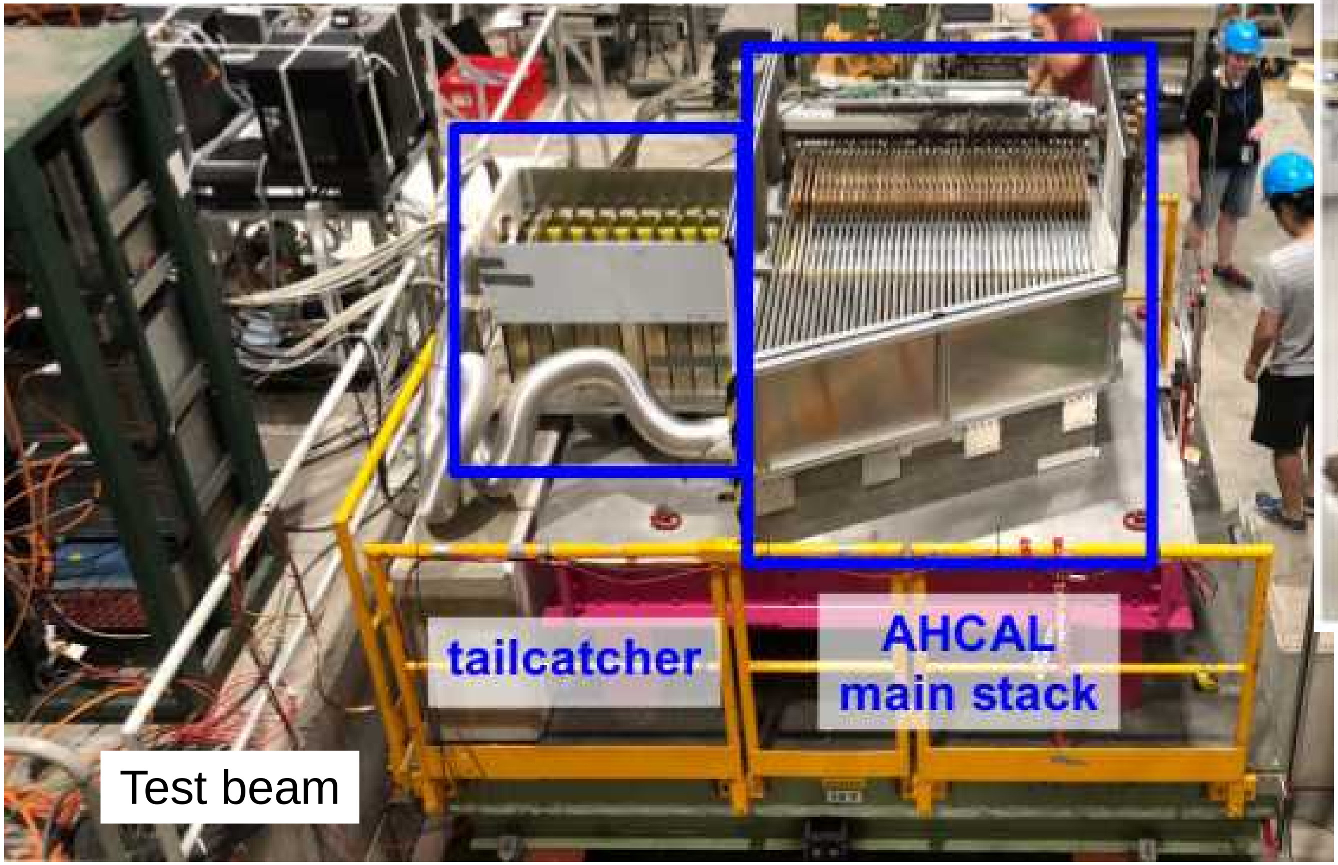
- highly granular scintillator SiPM-on-tile hadron calorimeter, 3*3 cm² scintillator tiles
- fully integrated design
  - front-end electronics, readout
  - voltage supply, LED system for calibration
  - no cooling within active layers
- scalable to full detector (~8 million channels)
- **H**CAL **B**ase **U**nit: 36*36 cm^2, 144 tiles, 4 ASICs
  - slabs of 6 HBUs
  - up to 3 slabs per layer

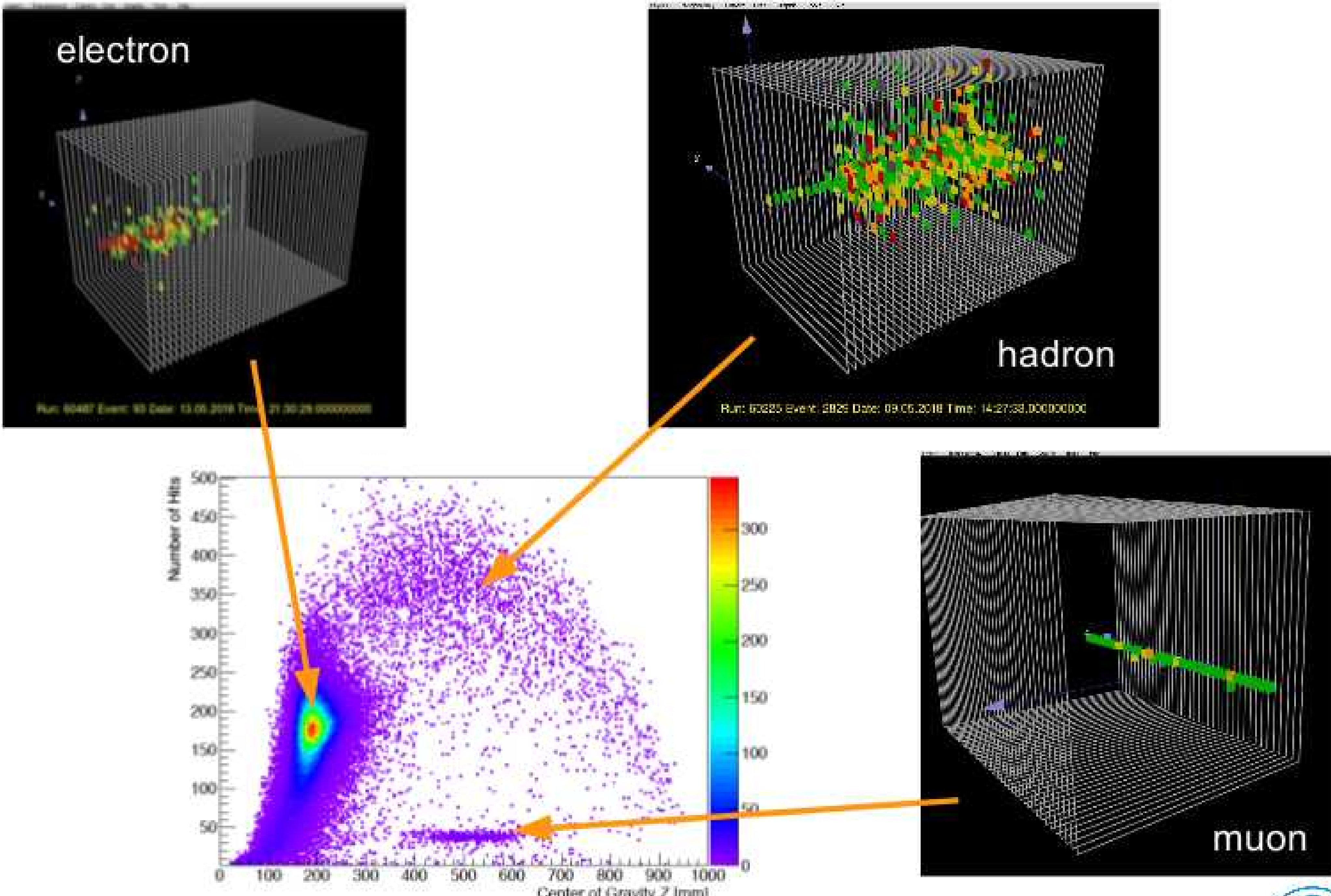
AHCAL “technological” prototype completed

Highly automated construction

Successful testbeams during 2018






electron
hadron
muon
Number of Hits
Center of Gravity Z [mm]
0 100 200 300 400 500 600 700 800 900 1000
50 100 150 200 250 300 350 400 450 500
0 50 100 150 200 250 300

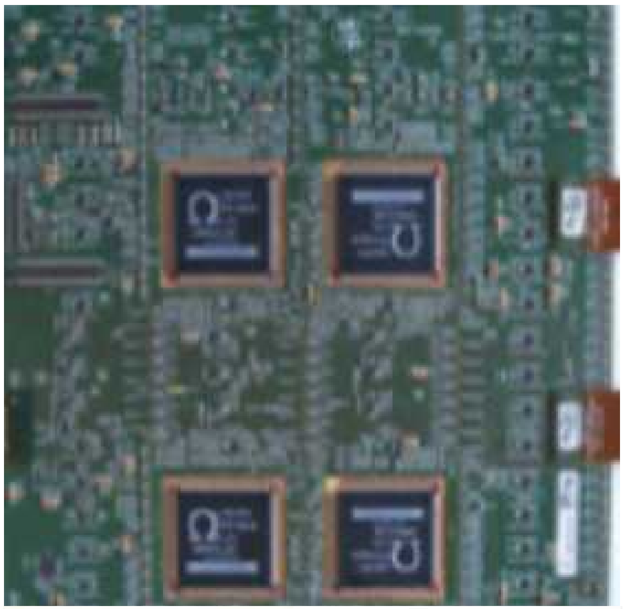
CALICE Sc-ECAL

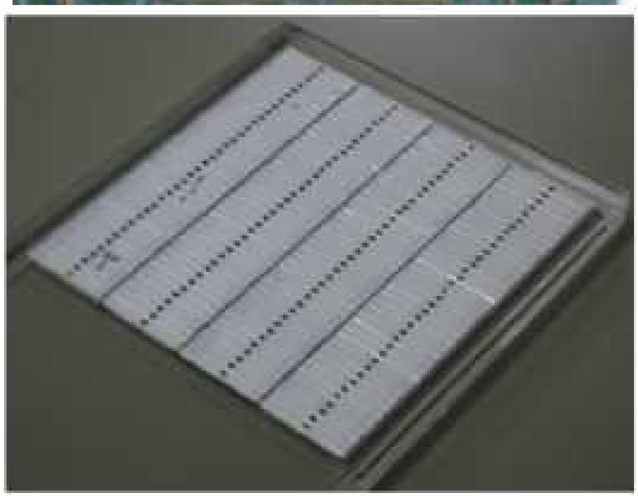
Similar technology to A-HCAL
→ strong synergies

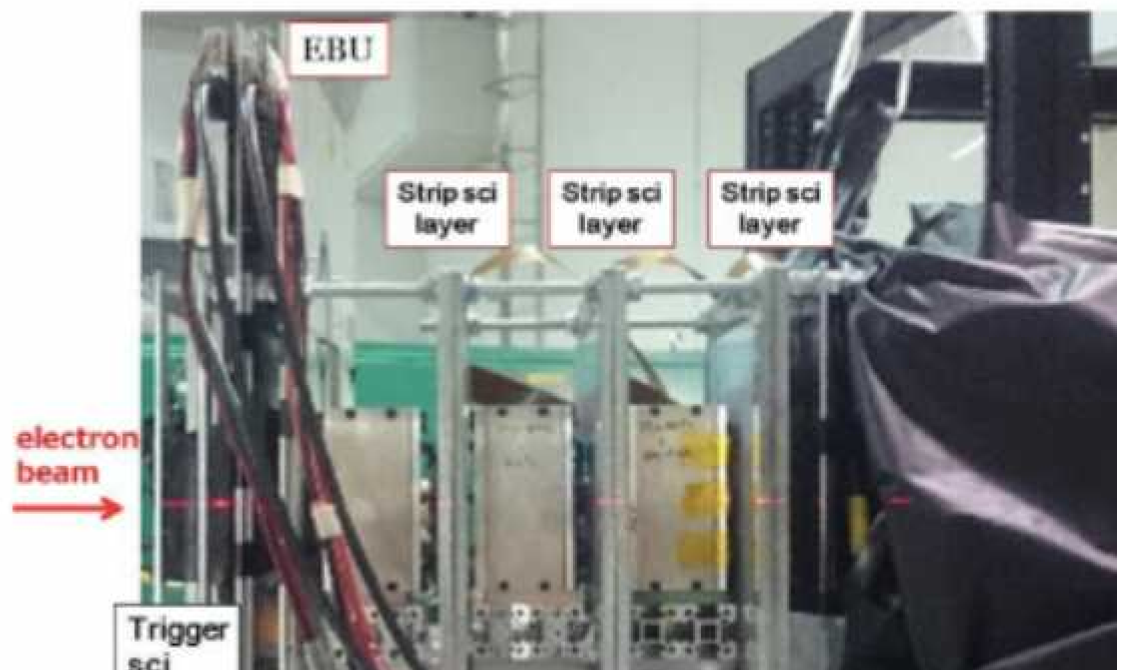
45x5 mm^2 scintillator strips to provide effective 5x5 mm^2 granularity

Additional challenge:
wide dynamic range for EM showers
→ SiPM/MPPC with high pixel count

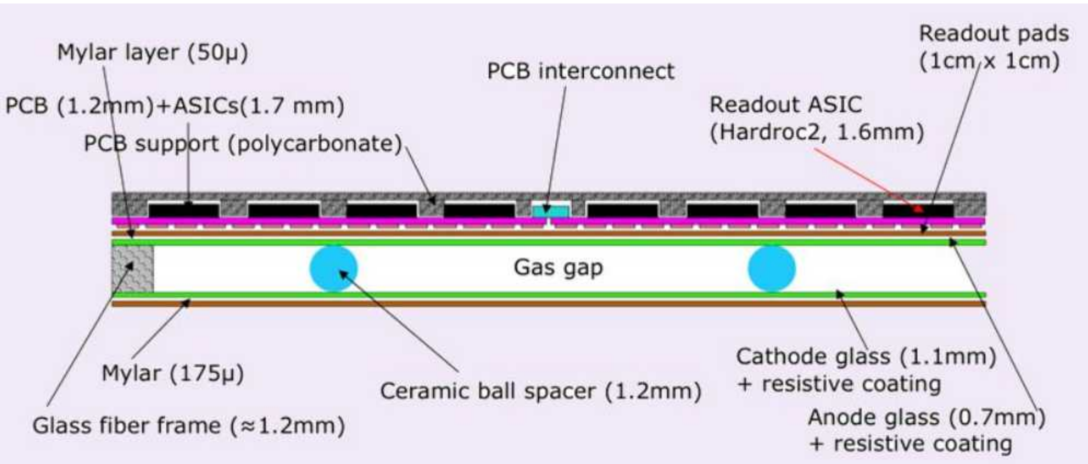
10x10 μm^2 and 15x15 μm^2 pixels sizes being studied

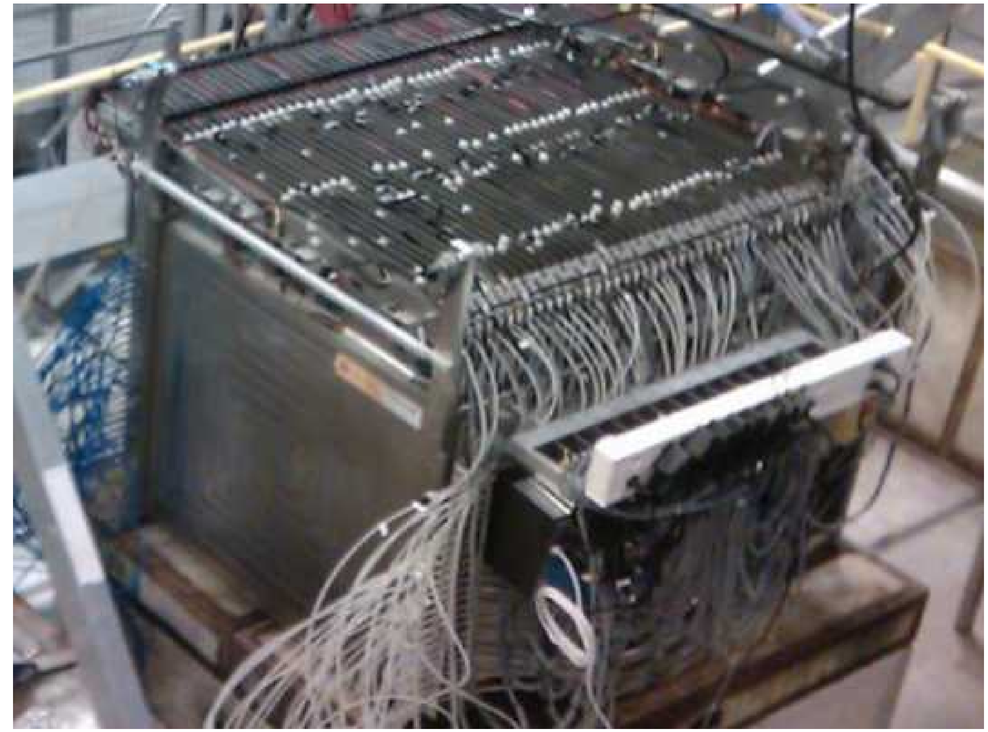




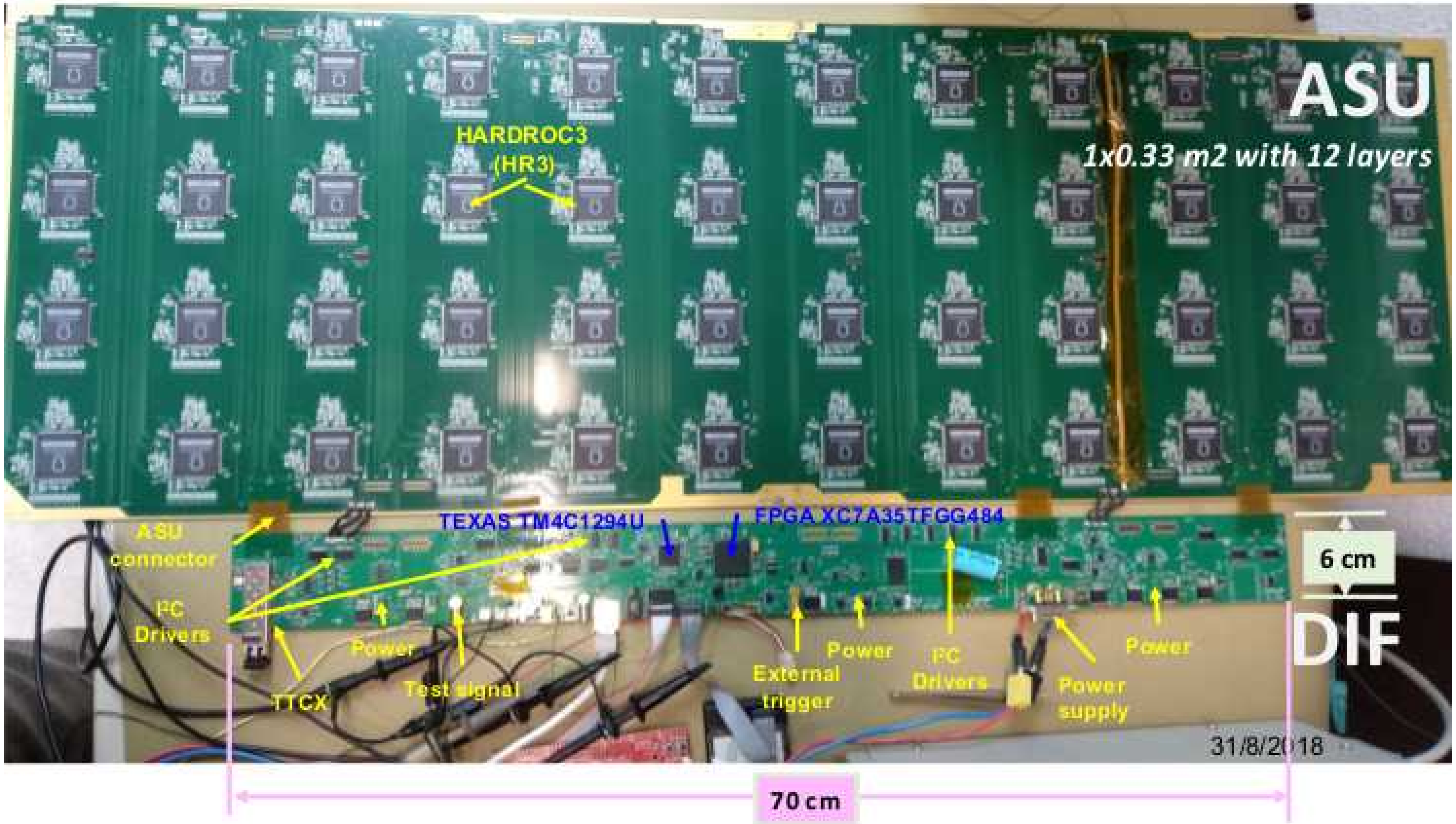


Semi-Digital Hadronic Calorimeter (SDHCAL)
based on glass resistive plate chambers





1 m^3 technical prototype running smoothly for several years



Currently preparing larger 2m-long RPC chambers,
as will be needed for LC detectors

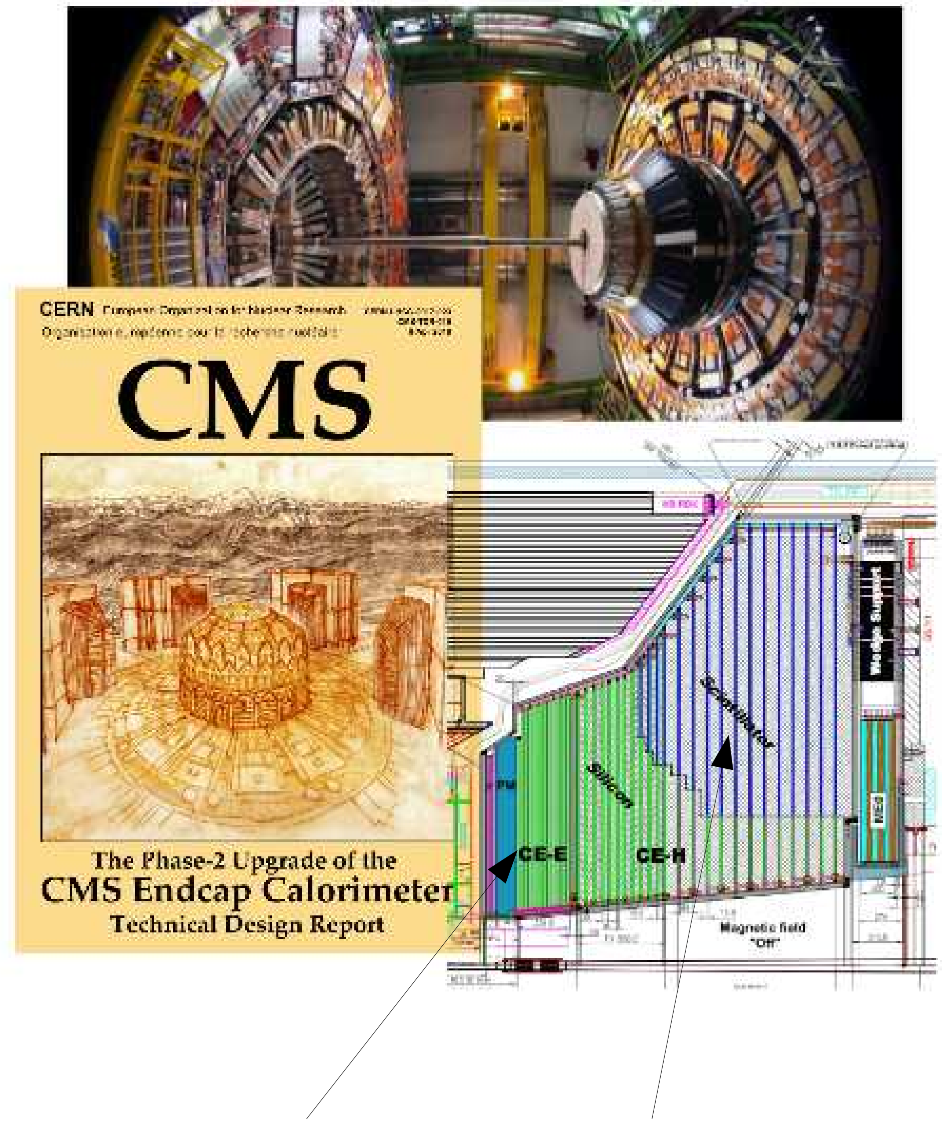
New generation readout electronics
→ updated DAQ systems

HCAL: large-scale mechanical structures using electron-welding construction

RPC gas recycling system

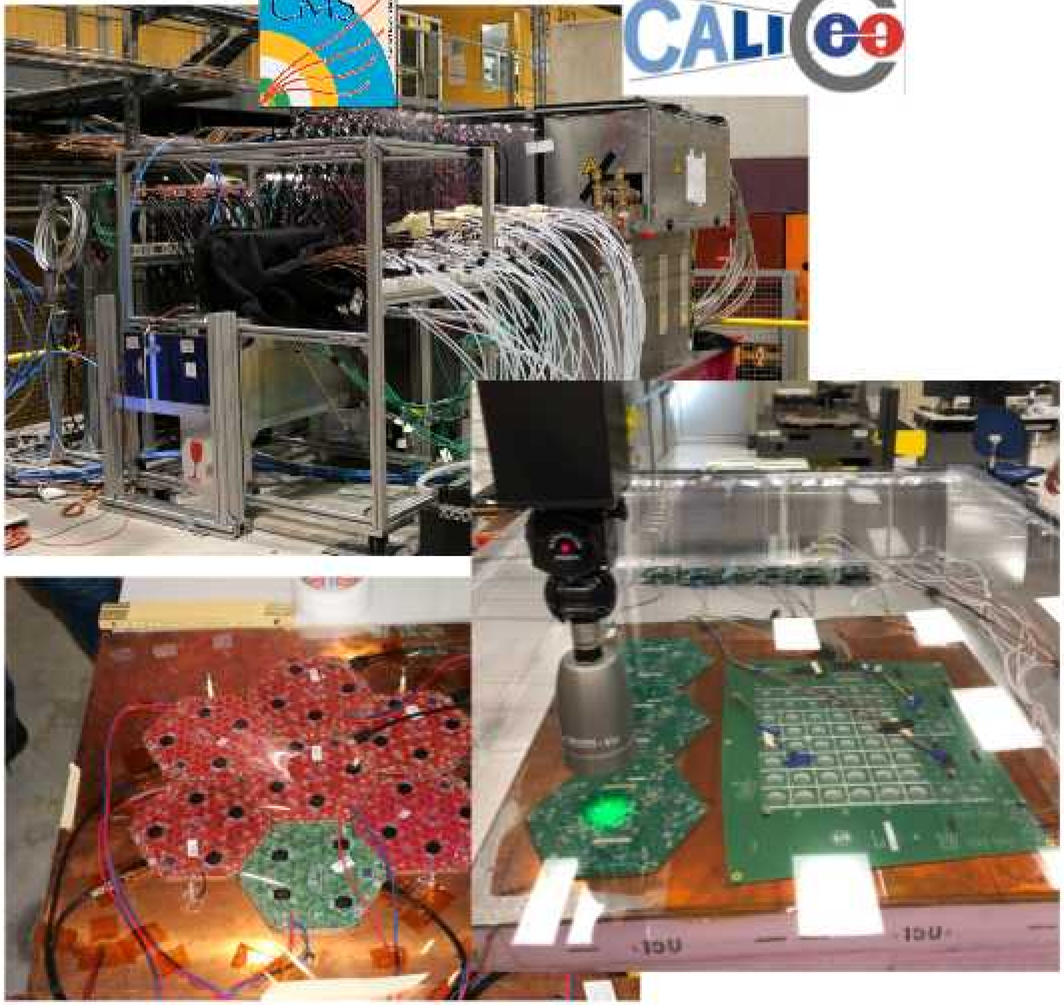
HGCAL: CMS Endcap Calorimeter Upgrade

- Highly granular calorimeters for high-luminosity LHC phase II upgrade
  - 600 m2 silicon
  - 500 m2 scintillator (400k SiPMs) where radiation levels permit (fluence < 5e13 n/cm^2)
- Inspired by linear collider developments – but many new challenges
  - radiation tolerance, rates, cooling, geometry
- TDR approved in April, EDR end 2020
- Several CALICE groups involved in silicon and scintillator parts
  - CERN-LCD, DESY, LLR, OMEGA, NIU, Russian groups,…



CMS HGCAL: Some Recent Highlights

- Common beam test CALICE-CMS (on-going as we speak)
  - Silicon electromagnetic and front hadronic section: 90 modules with 6” wafers
  - SiPM-on-Tile backing section = CALICE AHCAL prototype
  - Common DAQ: EUDAQ2 AIDA2020
- CO2 cooling of SiPMs through PCB
  - Cassette thermal mock-up at Fermilab



Summary

Calorimeter design for Particle Flow reconstruction
    is now well understood

Several different technologies being studied
    silicon, scintillator, gas-based detectors

Basic performance well understood,
    emphasis now on large-scale prototypes,
    with fully integrated services,
    suitable for installation into LC detectors

PFA calorimeter ideas have spread beyond the LC world
    CMS endcap calorimeter upgrade is a particularly
        relevant case
    → real large-scale devices using LC-like technology
    → significantly enlarge community of experts in
        these calorimeter techniques