CALICE Calorimetry Detectors for Particle Physics

CAP Congress in Fredericton

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François Corriveau

McGill University

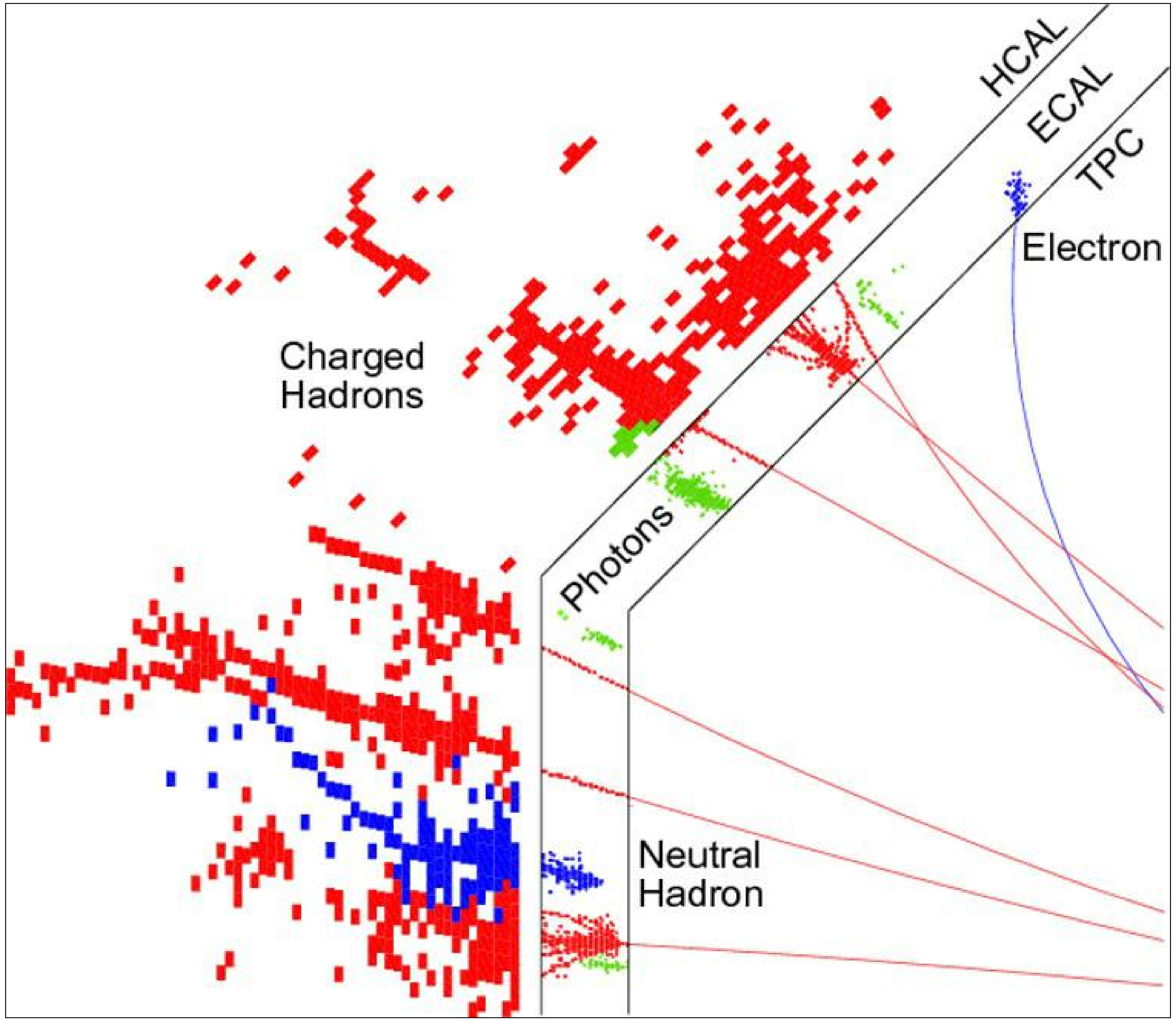
Calorimetry in Particle Physics

Modern detectors (obviously) need to get the best possible information from each physical event:

- good energy and position resolutions,
- particle identification,
- with large acceptance
- and high efficiency.

High energy physics has also to deal with "jets" of particles from hadronizing quarks and gluons, hence the concepts of:

- particle flow and
- high granularity



Particle Flow (PF) - Principle

1) Identify and follow each particle in the detector
2) Optimize the event reconstruction for energy/momentum/position/(time)
3) Use the best available information for each particle, such as:

- tracker information for charged particles (~60% of jet)
- electromagnetic calorimeter for photons (~29% of jet)
- hadronic calorimeter for neutral hadrons (~10% of jet)
- .. and their inter-correlations

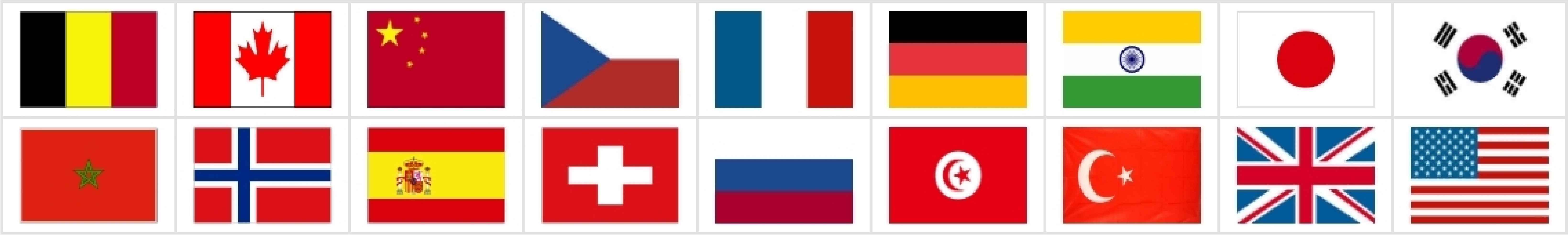
PF applications are especially well suited for e^+e^+ collider low background environment (such as the ILC).

Design **PFAs** = PF algorithms

This then requires from the detectors:

- accurate tracking with high efficiency
- minimum dead material in front of calorimeters (from trackers and supports)
- maximum hermiticity in containing particles (apart from neutrinos)
- **high granularity** calorimetry (for particle separation)

The CALICE Collaboration



A group of:

~350 physicists/
engineers
60 institutes
18 countries

The largest groups: France, Germany and Japan

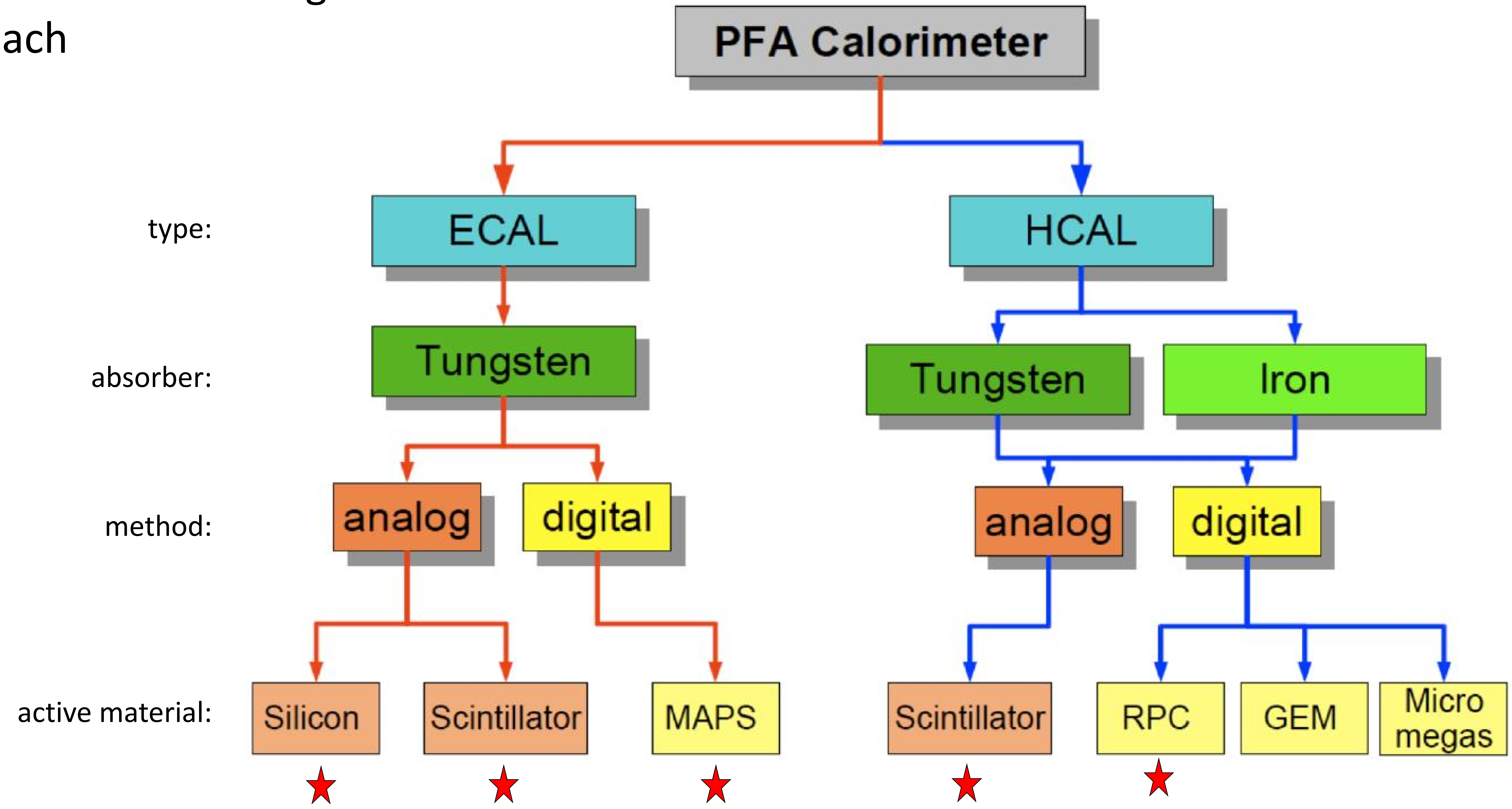
Canada: research supported by one of the few NSERC Individual Subatomic Physics Discovery Grants

McGill University: myself as PI with, over the years,
6 MSc students and
17 undergraduate students

Technologies

CALICE calorimeters are high granularity devices built along the PF approach

now also with dual readout calorimetry



CALICE in Canada

First, do not confuse CALICE, the name of the collaboration, with "calice" (pronounced "câlisse!"), one of the favorite French-Canadian swear words…

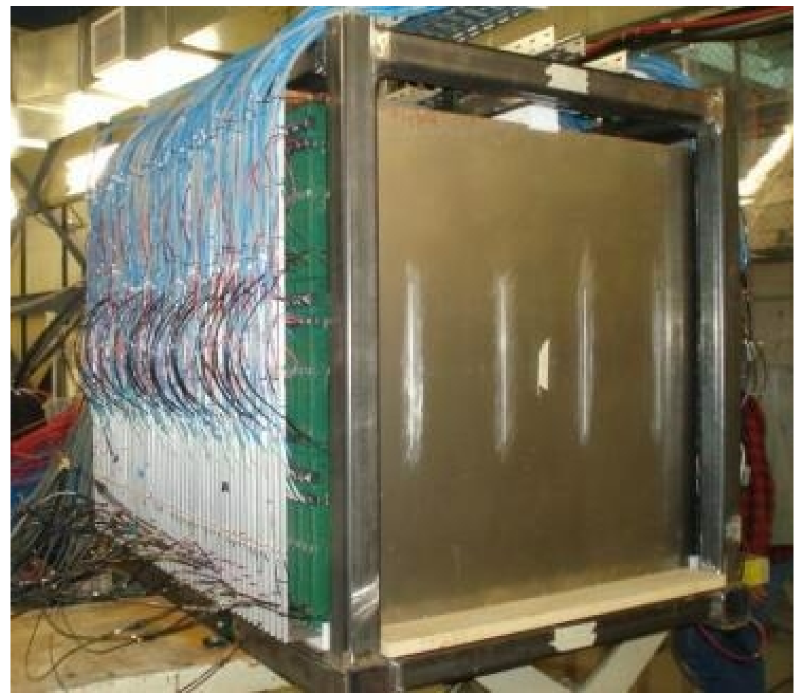
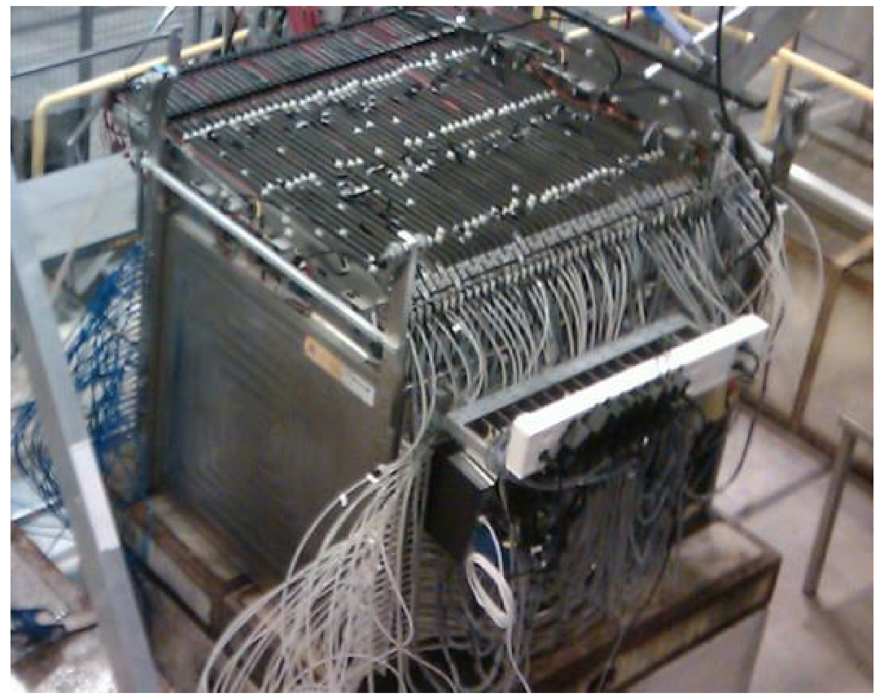
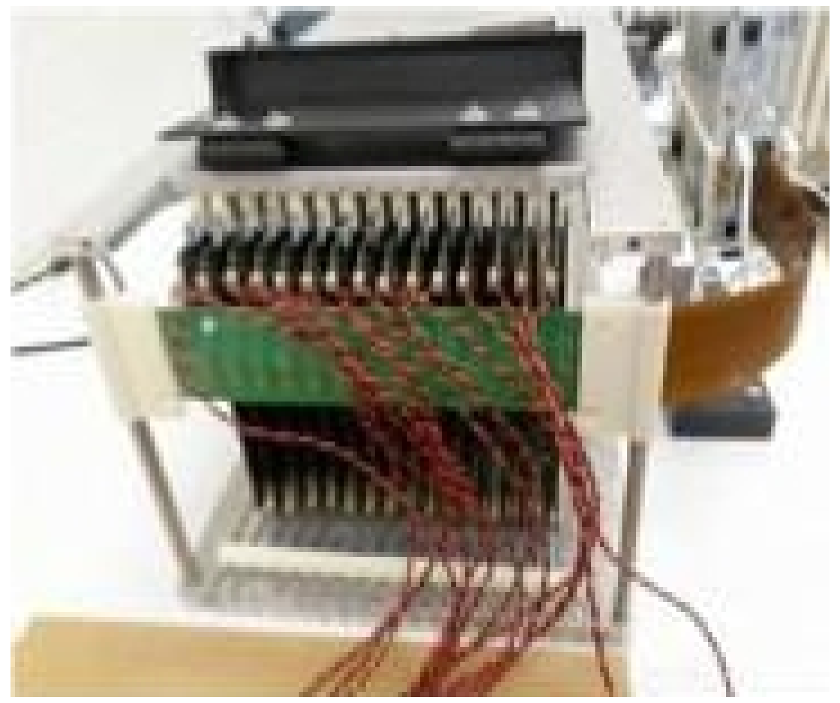
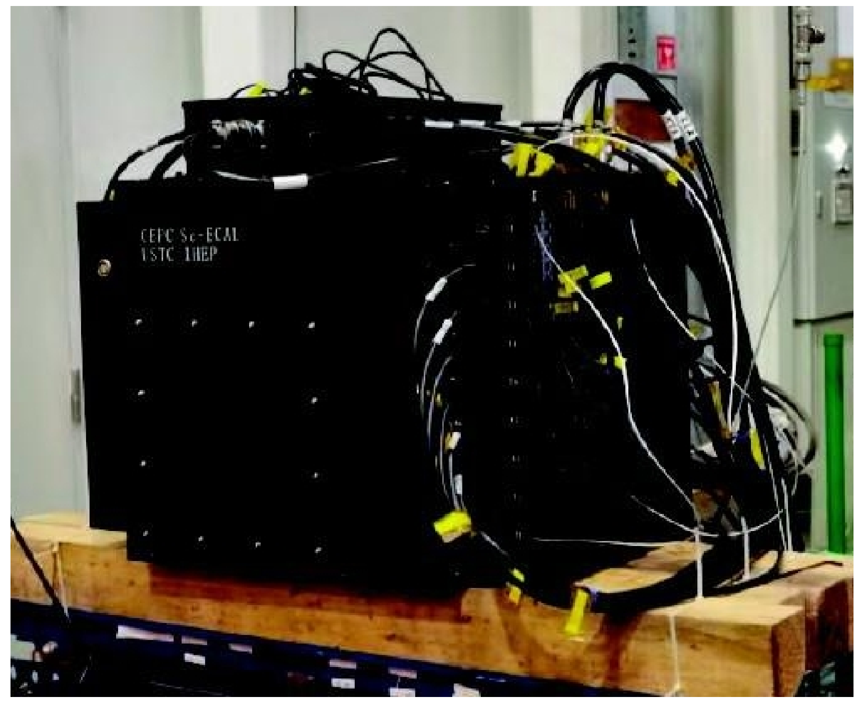
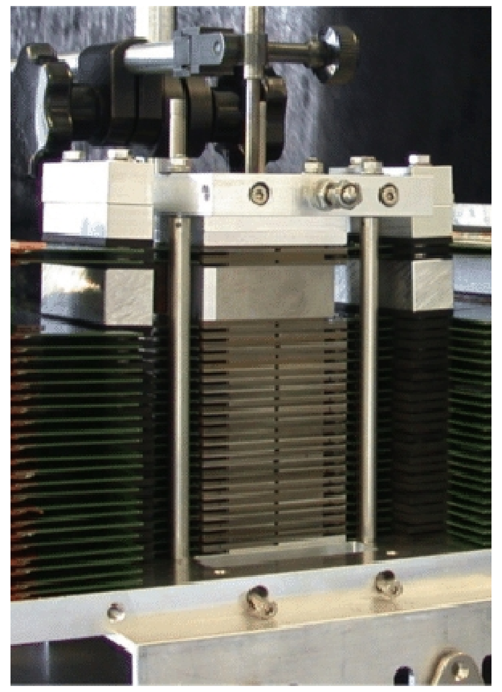
McGill joined CALICE in 2006, with first funding in 2010.

Two collaboration meetings were organized at McGill: May 2006 and March 2020.

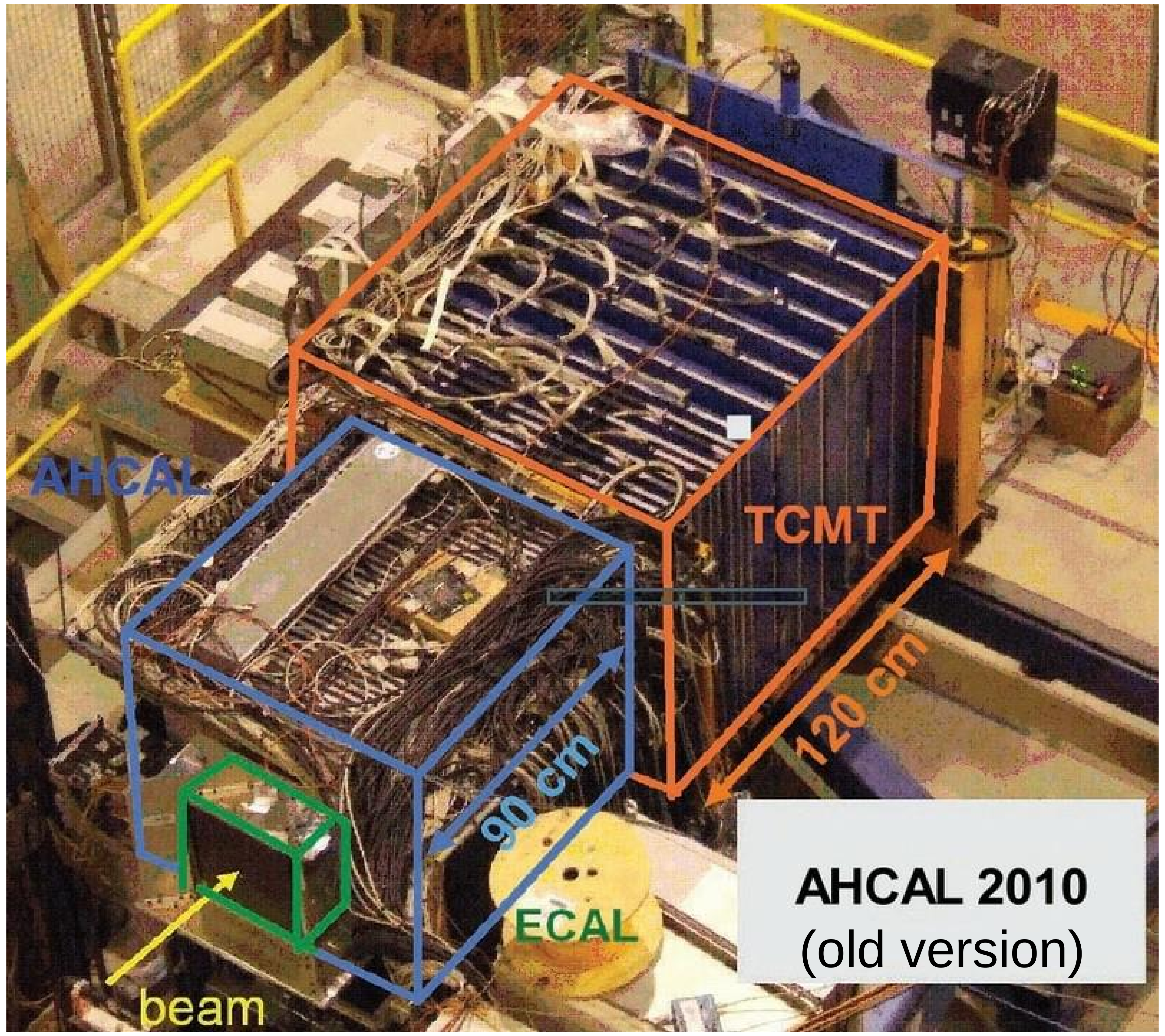
Because of the limited size of the collaboration, of the prototype groups and the constant exchanges between them, CALICE research is very well suited for **HQP** (highly qualified personnel): >20 students at McGill, with e.g. two of them in person at Argonne for the DHCAL construction, data taking and analysis.

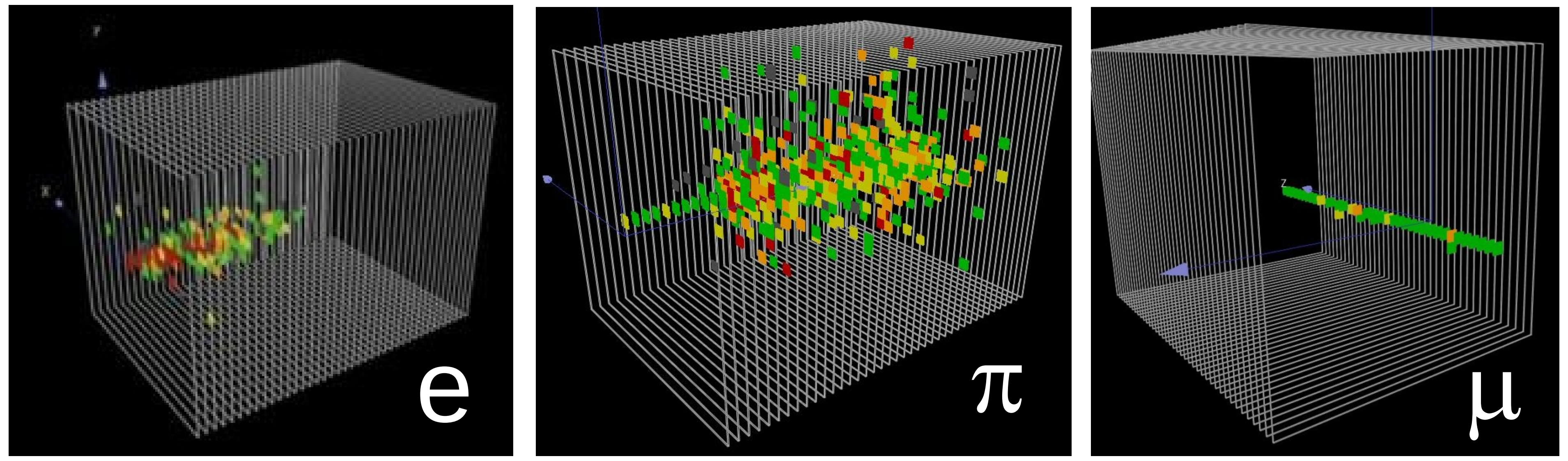
Roles in CALICE: CA representative, Speakers' Chair, Management Team *(4 years)*

Some of the Prototypes

AHCAL	DHCAL	SDHCAL	Si-W ECAL	Scint-W ECAL	FoCAL
					
3x3 cm^2	1x1 cm^2	1x1 cm^2	0.5x0.5 cm^2	0.5x4.5 cm^2	0.003x0.003 cm^2
38 layers	54 layers	48 layers	30 layers	30 layers	24 layers
Scint.+ SiPM	(G)RPC	GRPC	Si	Scint.+ SiPM	MIMOSA (CMOS sensors)
Fe	Fe/W	Fe	W	W	W

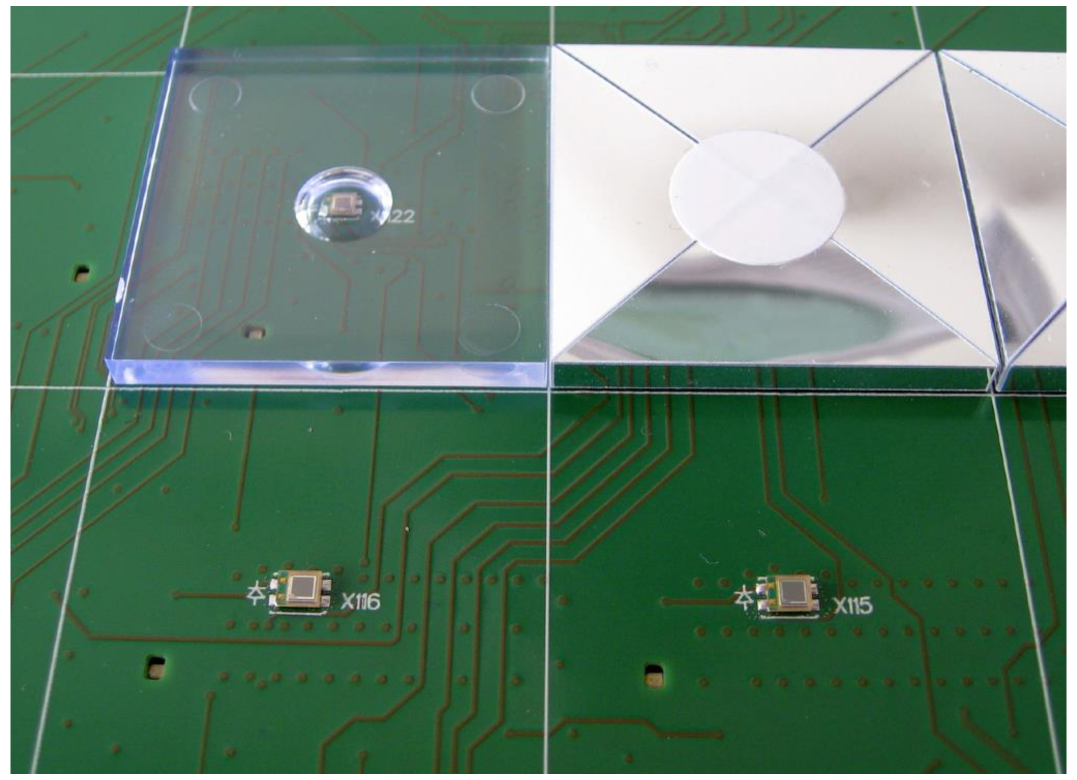
AHCAL





The Analog Hadronic Calorimeter is the most advanced of the prototypes.

38 layers of 3x3 cm^2 scintillator tiles, each read by a SiPM.



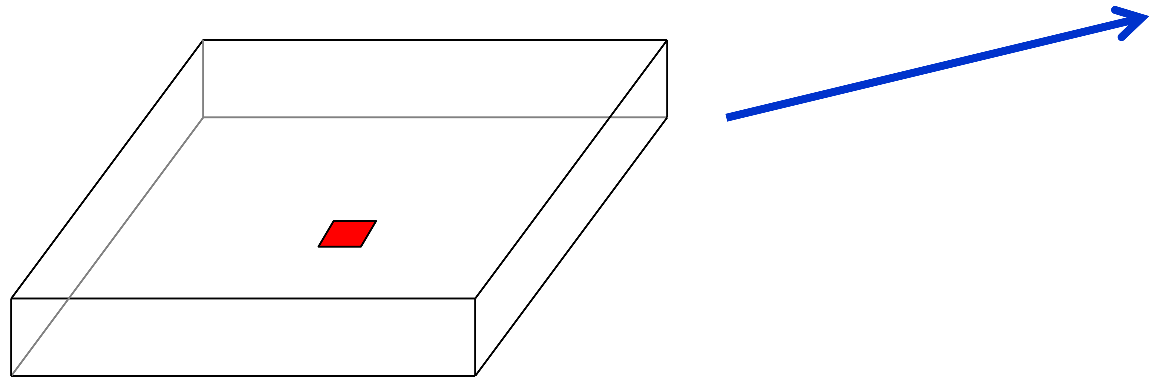
R&D on "megatiles" to ease manufacturing and assembly, with low (<3%) crosstalk.

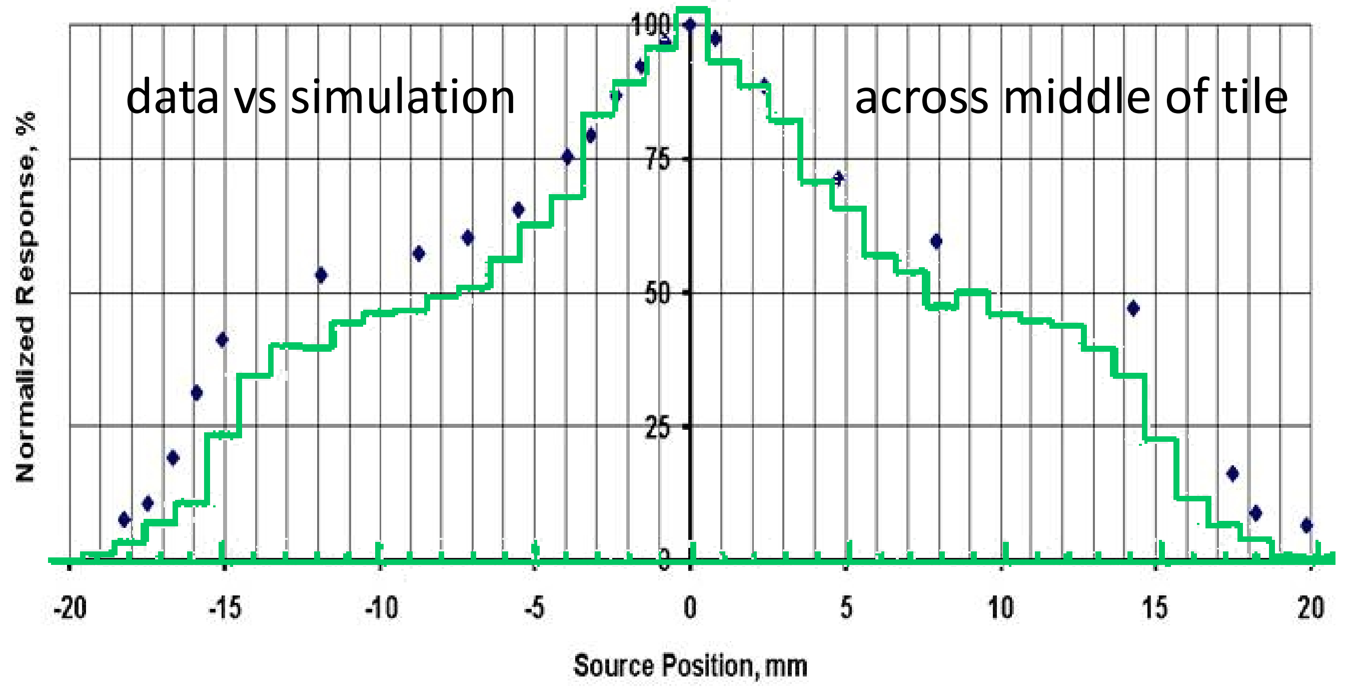
22,000 channels, 99.9% of them working.

Led to the development of generations of ASICs. The SPIROC2e now provides a hit time signal for each cell with *~0.8 ns* resolution.

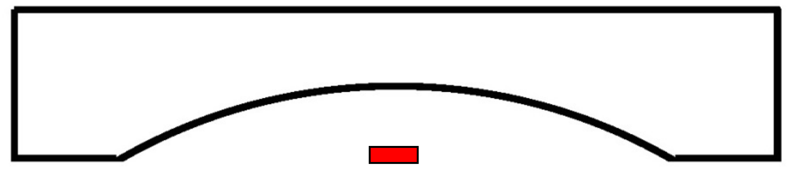
AHCAL at McGill – Selected Topics

1) Simulation of light collection in tile: where to place the SiPM on the tile? corner, side, bottom,..?





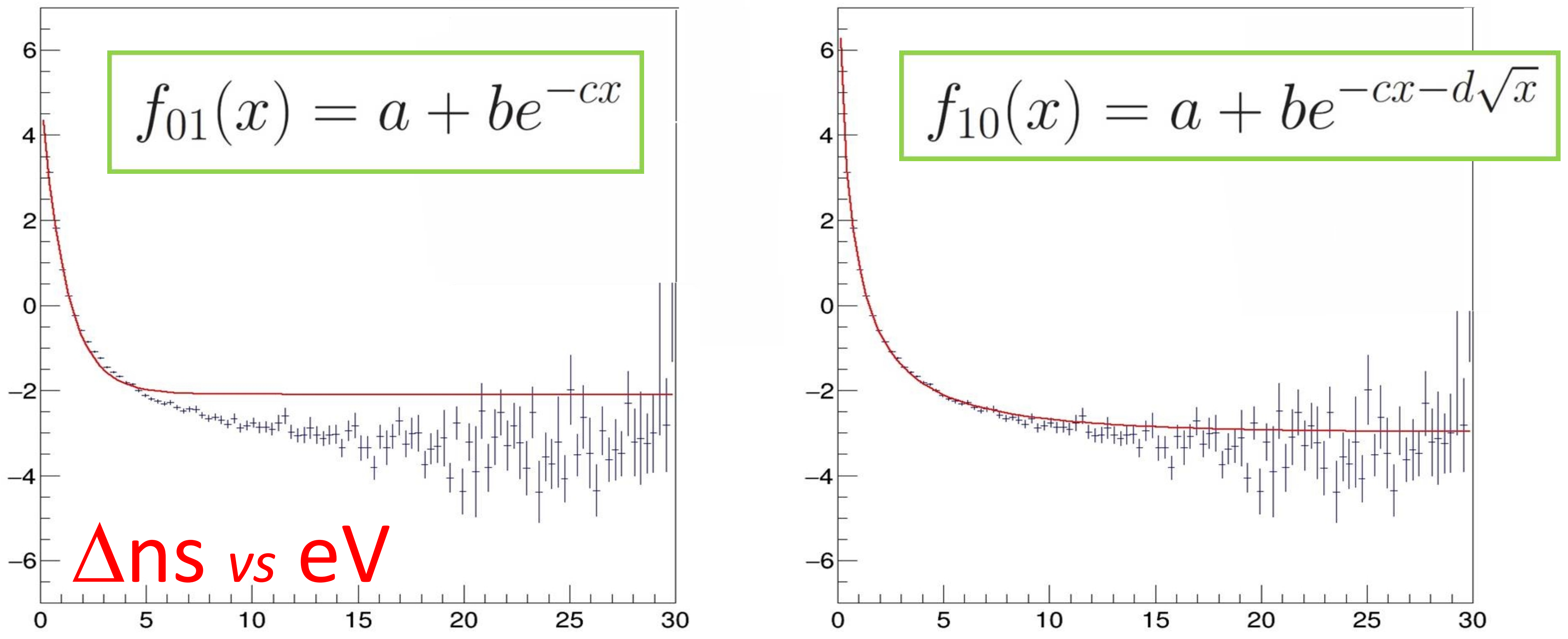
Final choice (2008):



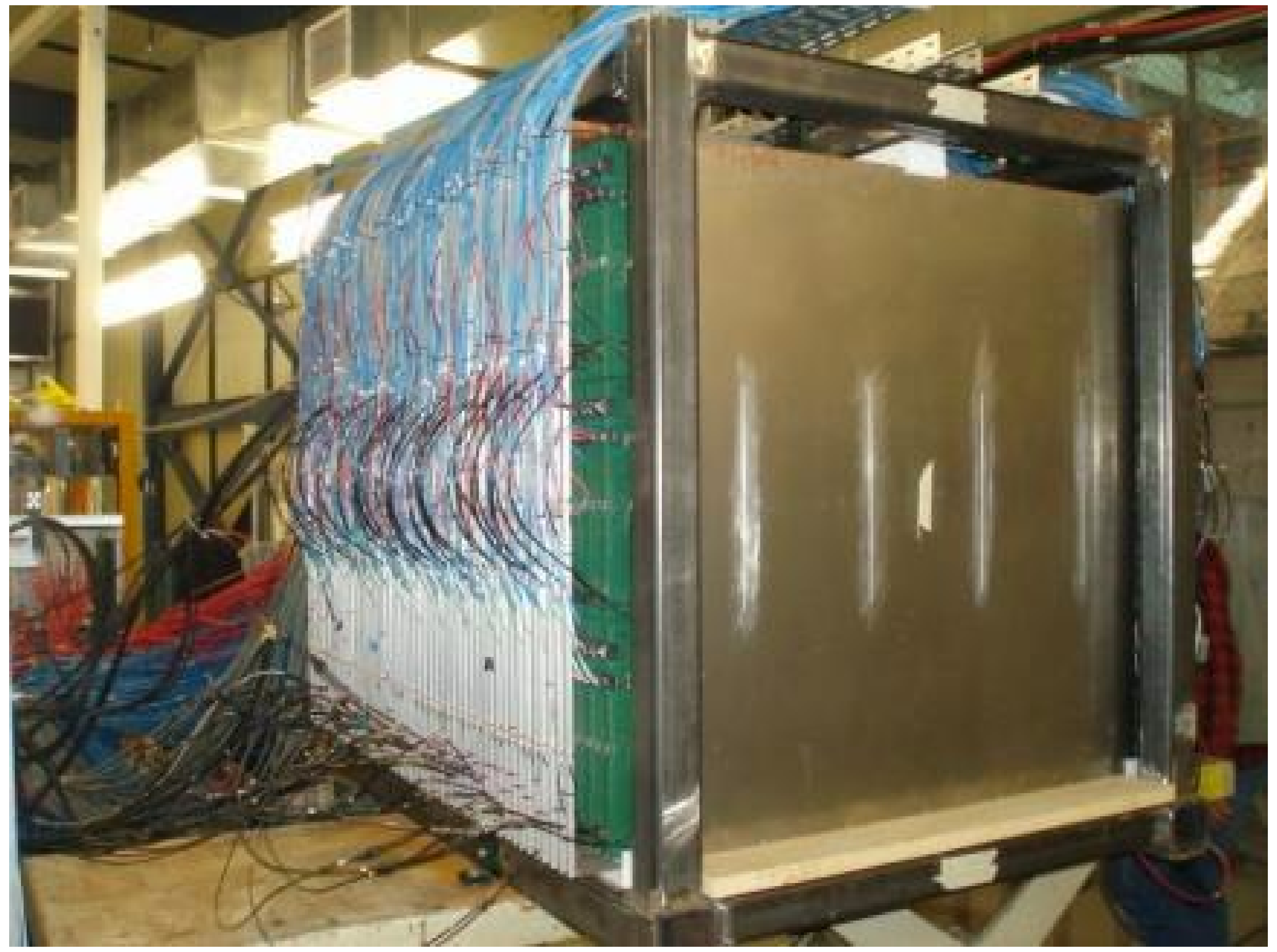
Spherical cutout to provide the best response uniformity

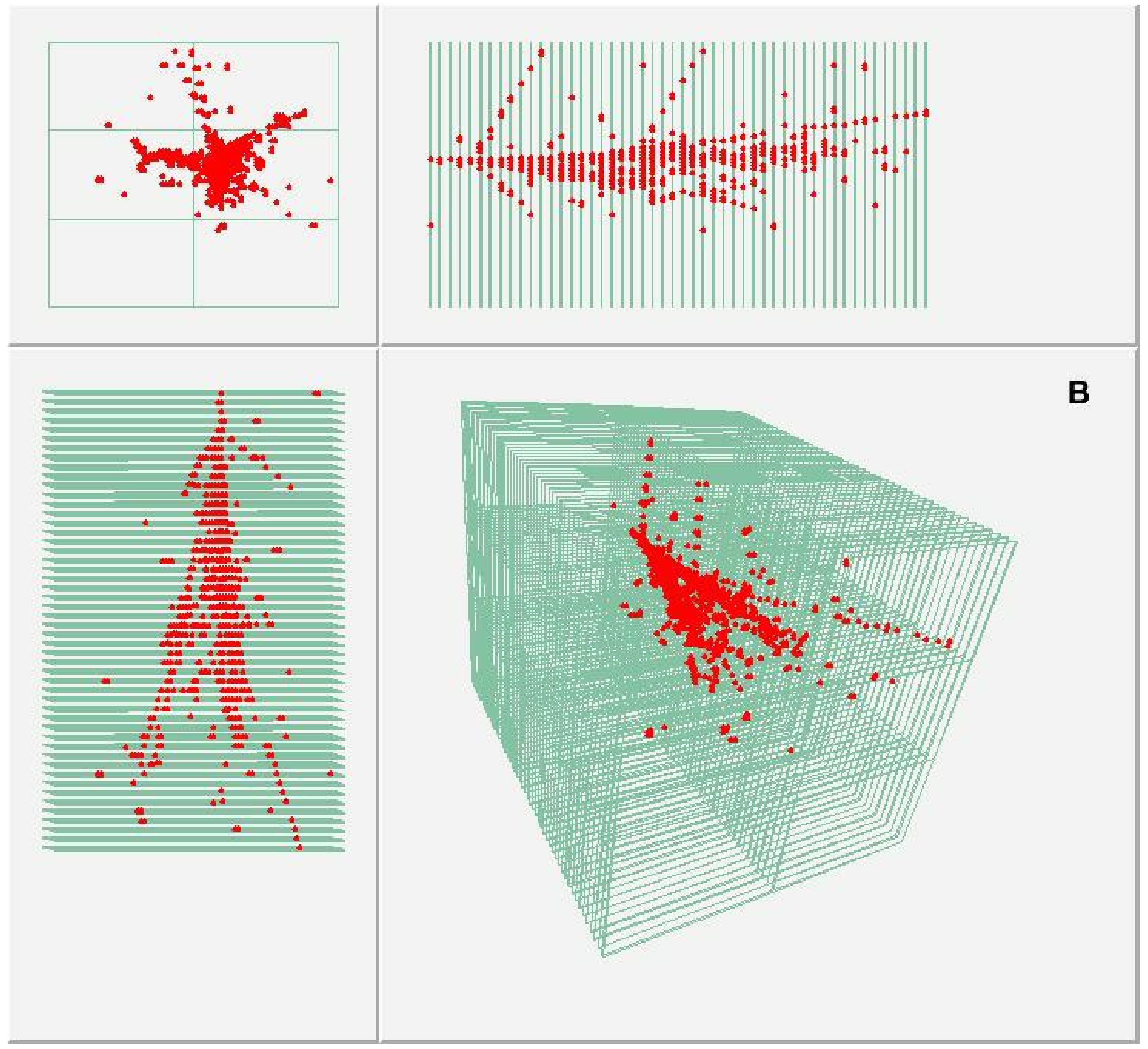
2) Time walk correction: the AHCAL provides hit time information for each cell, but the signal depends on the energy of the hit and needs correction.

Significant improvements in time resolution for all types of particles



DHCAL





The Digital Hadronic Calorimeter has a 1-bit readout per cell, i.e. does not measure energies but counts the numbers of cells hit. Threshold at ~½ MIP. Excellent E-resolutions.

Advantages:

- Huge number of 1x1 cm^2 cells (500,000/m^3)
- .. hence essentially a tracker
- Robust and cheap RPC active medium
- Imbedded frontend electronics
- Very fast read-out

Drawbacks:

- Saturation/non-linearity effects for high track density
- Limited to low background/rate environments *(e.g. ILC)*

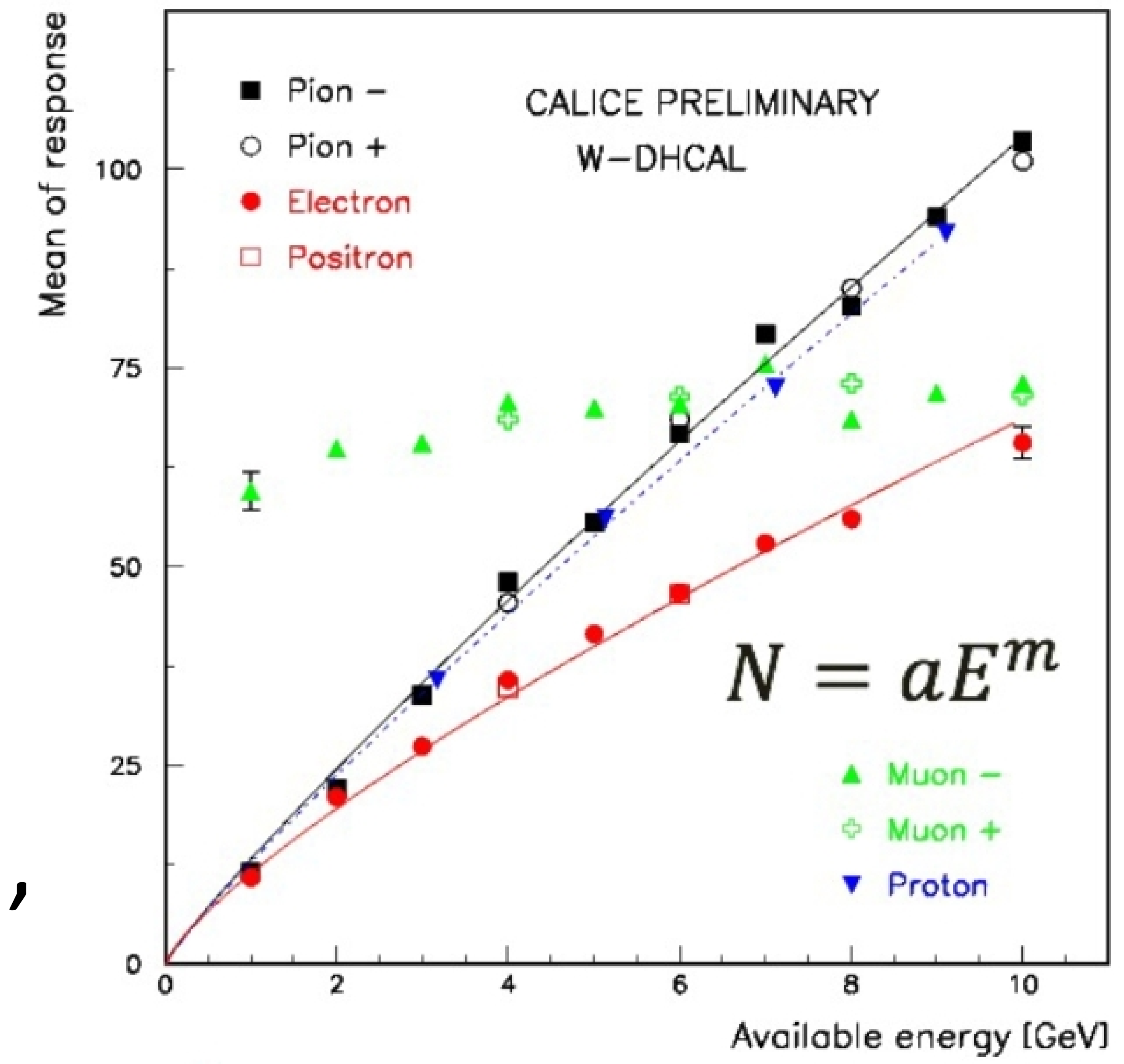
DHCAL at McGill – Selected Topics

1) Construction of DHCAL: McGill was instrumental in designing the spray booth to put uniform resistive paint over the glass planes of the resistive plate chambers (RPC). And subsequently help build, assemble, wire and beam test the detector at Fermilab and at the CERN PS/SPS.

2) Performance analysis: linearity and energy resolution, e.g. with the W-DHCAL at the CERN PS.

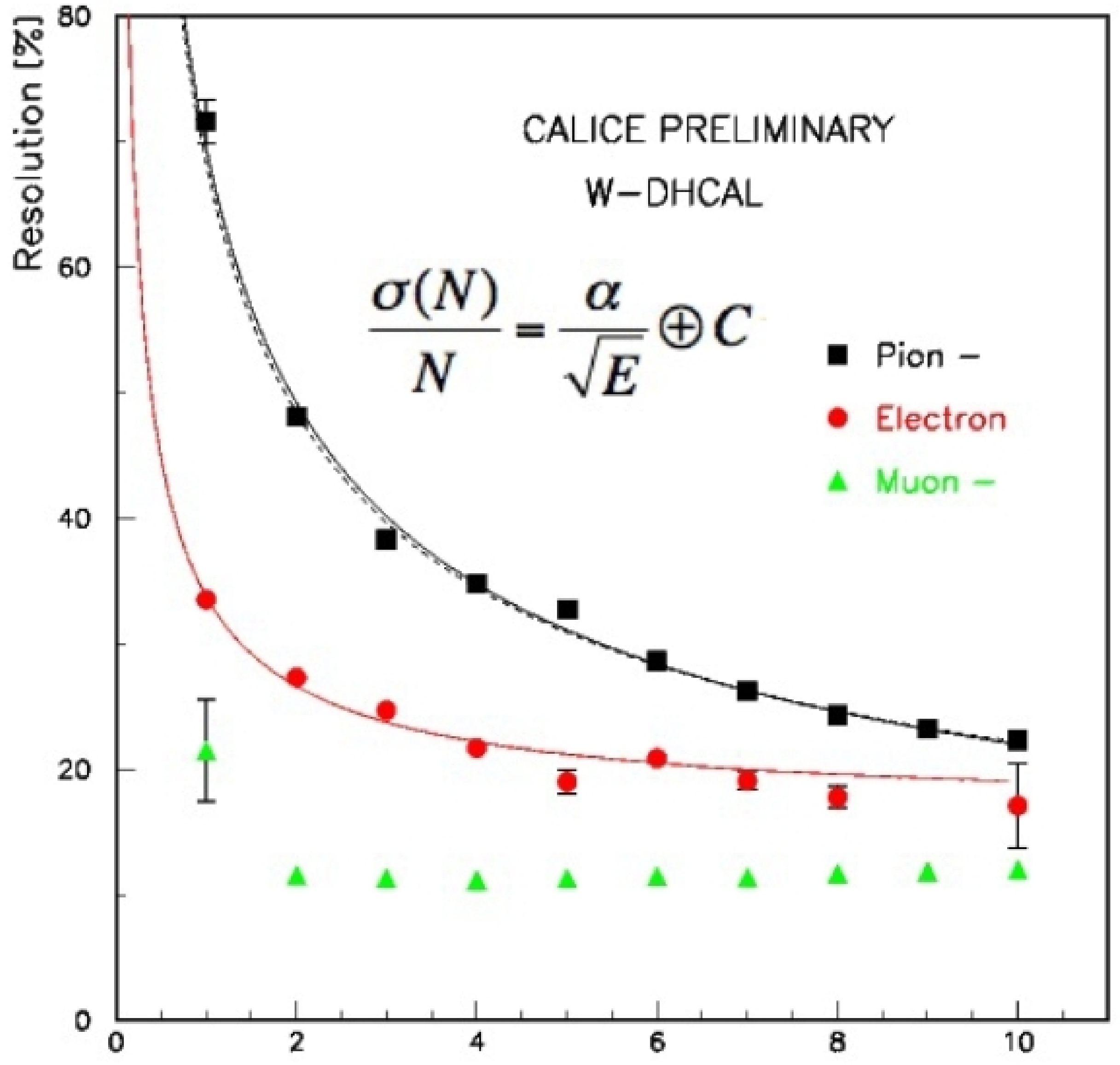
Saturation effects as expected, largely recoverable using hit densities algorithms.

Linearity



m = 0.90 (hadrons)
m = 0.78 (electrons)

Resolution



Particle	α	c
Pions	(68.0±0.4)%	(5.4±0.7)%
Electrons	(29.4±0.3)%	(16.6±0.3)%

DHCAL at McGill – Selected Topics

3) Minimum DHCAL: in this configuration, no absorber plate was put into the detector, thus letting low energy showers fill the whole detector and deliver unprecedented details of their structure $\rightarrow$ of special interest for the GEANT4 Collaboration!

With positrons: B.Freund *et al.* JINST 11 (2016) P05008
With pions: the work is currently being completed at McGill, with Beykent University.

4) *In situ* calibration: the fine granularity of DHCAL allows the observation of numerous shower MIP-tracks in the detector. These track segments can be used to calibrate the data anytime with itself and/or to monitor the stability of the calibration at ~%-level. *(This work was also performed at McGill with the AHCAL data, with very similar results)*

5) Alignment ECAL-DHCAL: data taken with both detectors proved that muon alignment could be done at 0.1 mm / 0.02° precisions. The DHCAL hadronic energy resolution was also effectively improved by 25% due to the presence of ECAL in front.

The CMS HGCAL - Forward Calorimeter

CALICE meets CMS

Common beam tests since 2017

- Common beam tests benefit from common approach within CALICE

The CMS High Granularity Calorimeter is being designed, tested and constructed for the High Luminosity LHC.

- Based on CALICE work
- Full PF doncept
- High 3D segmentation
- Silicon technology
- High precision timing *(<<ns)* for particle ID and pileup rejection.

The Future of CALICE

CALICE was originally planned for calorimetry at the International Linear Collider (ILC).
It has evolved into a generic calorimetry effort.

ECFA (European Community for Future Accelerators) is developing a global detector R&D roadmap for the post-LHC era.

A DRD (Detector Research and Development) Collaboration is envisioned for calorimetry.

CALICE should transition into this new entity, the DRD 6 Task Force and help shape it.

International collaboration (USA, Canada, ..) will be sought out.

Conclusion and Outlook

CALICE has made its international imprint in calorimetry for particle physics and is designing novel detectors.

Canada/McGill has made modest but steady and valuable contributions to the CALICE efforts.

Calorimetry R&D landscape is being globally re-shaped.
It is a good time to join and contribute !

Extras

Abstract

The international CALICE collaboration is dedicated to detector R&D in calorimetry for new experiments. All project concepts now use high granularity to maximally profit from Particle Flow Algorithms and thus improve jet energy resolution, device versatility and response performance. A review of innovative analog or digital detector types, using technologies such as silicon, scintillators or resistive plate chambers, will be presented, as well as results from recent work realized in Canada.

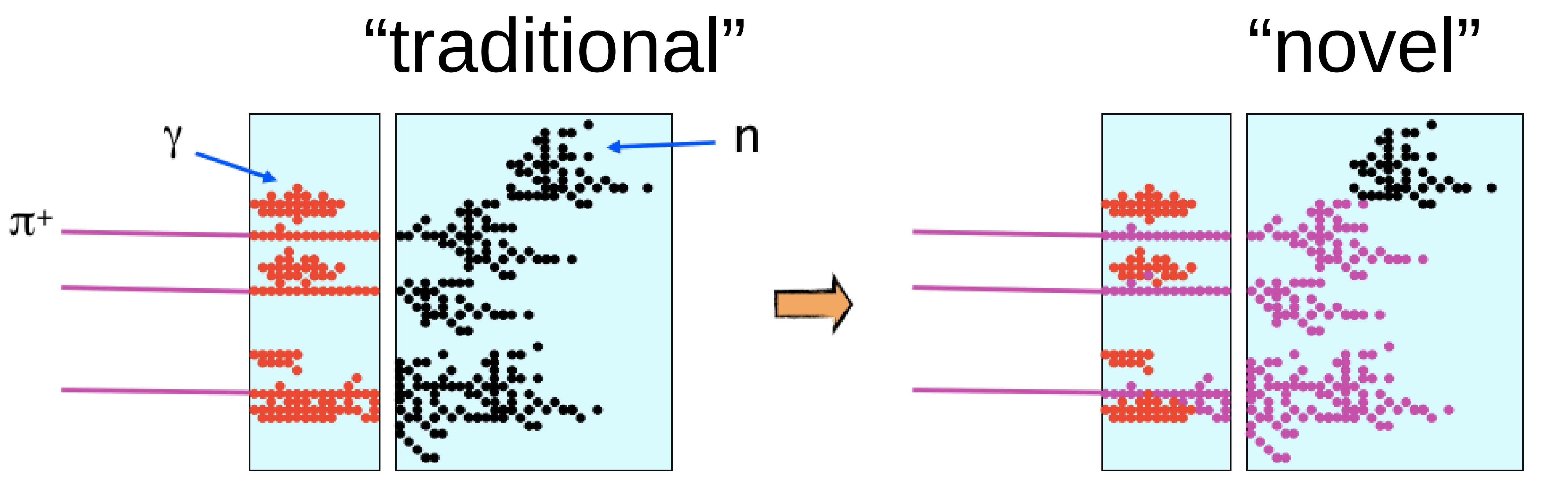
Pandora PFA

(also Arbor PFA, April, Garlic, ..)

M. Thomson, J.B. Marshall
Cambridge LC Group

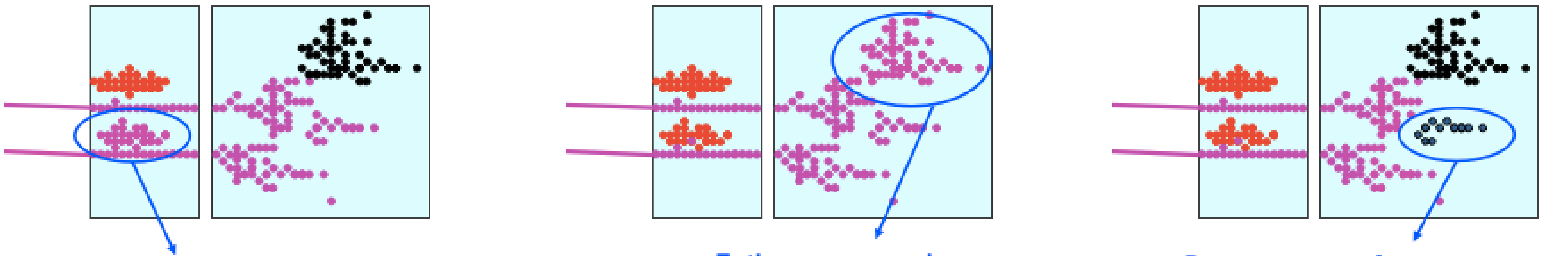
A PFA is a set of algorithms for pattern recognition and particle reconstruction.

arXiv:1308.4537



$E_{JET} = E_{ECAL} + E_{HCAL}$ $E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$

However, there might be *confusion* in particle reconstruction, such as:



Failure to resolve photons

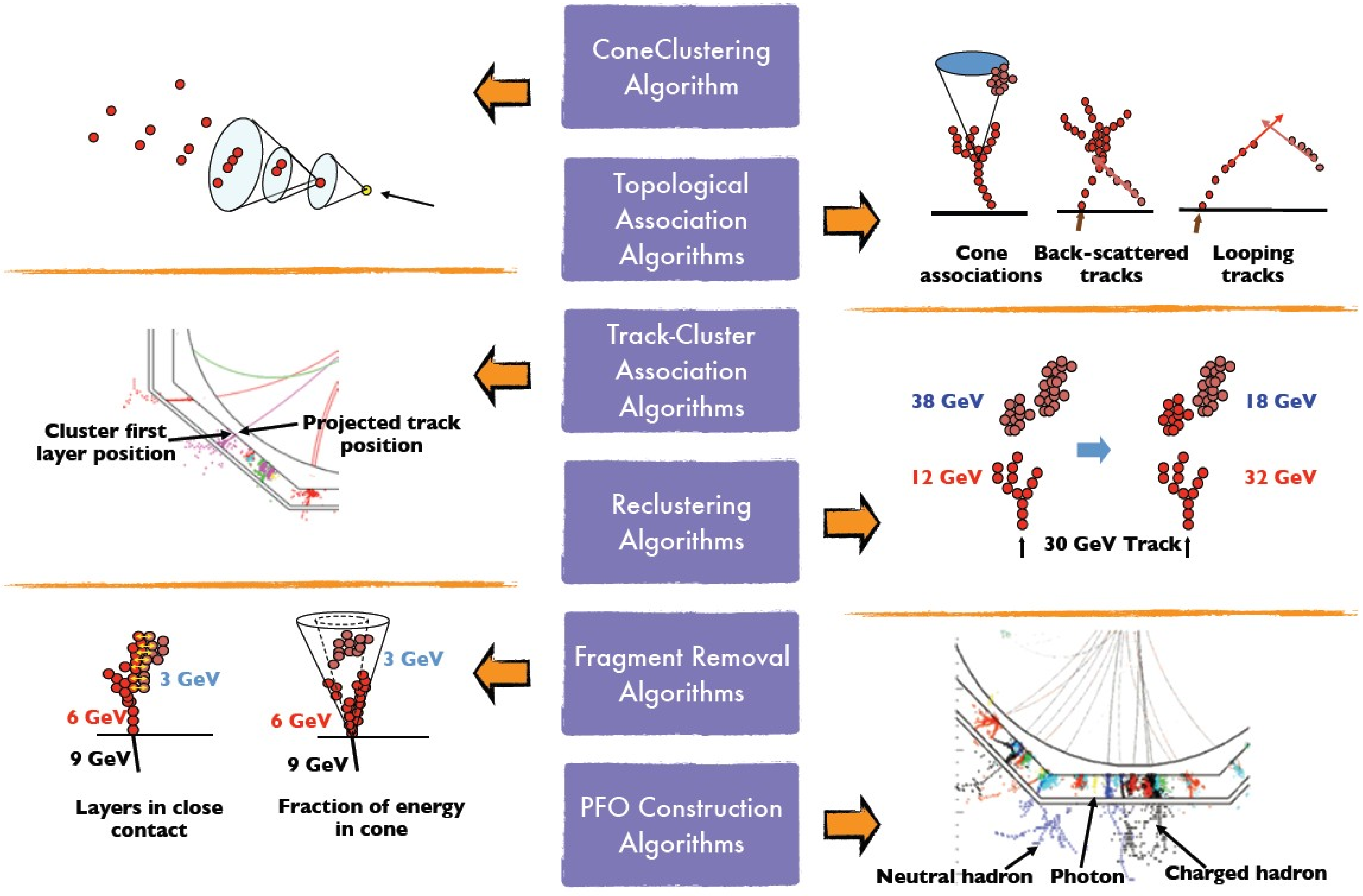
Failure to resolve neutral hadrons

Reconstruct fragments as separate neutral hadrons

Hence constraints on both calorimeters and software.

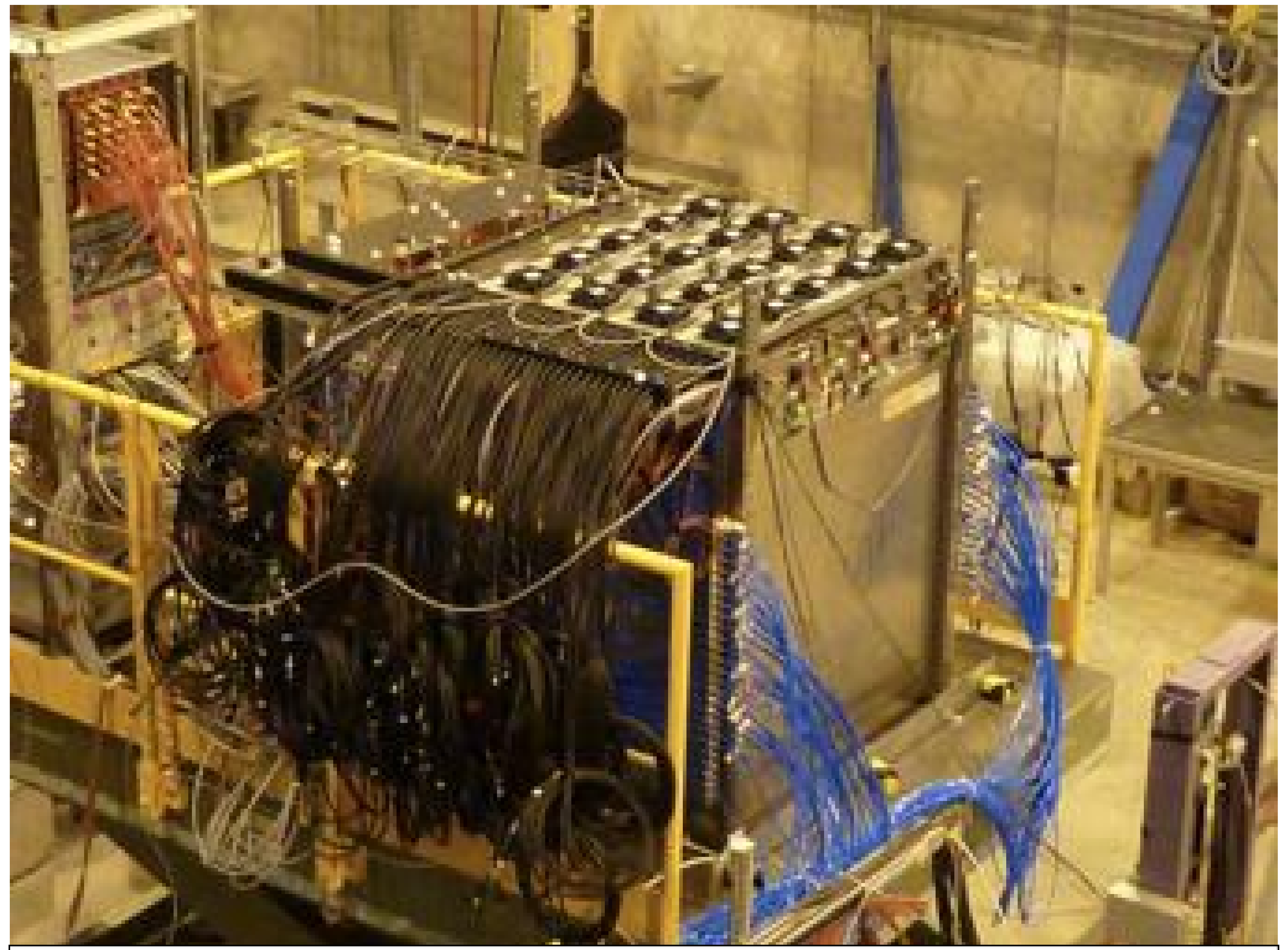
Pandora PFA - Approach

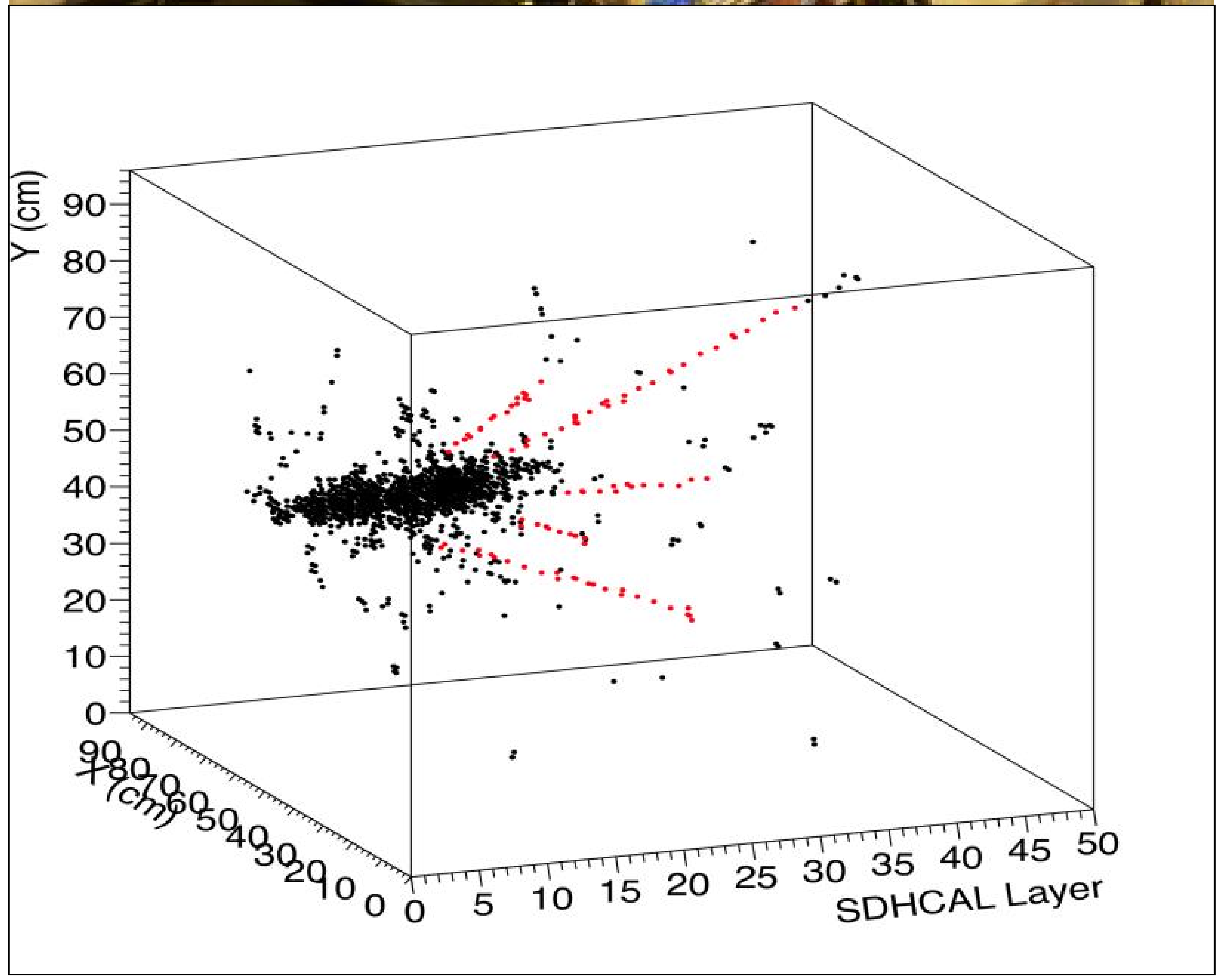
“Implement a large number of ‘decoupled’ pattern-recognition algorithms, each of which looks to reconstruct specific particle topologies, whilst carefully avoiding causing confusion”



working outwards
↓
topological merging
↓
tracker-calorimeter
↓
improve match
↓
neutral vs charged
↓
particle flow objects
↓
particle identification

SDHCAL





The Semi-Digital Hadronic Calorimeter has a 2-bit readout, with the thresholds set for response optimization and reduction of saturation / non-linearity effects.

The SDHCAL is currently being made to provide hit time signals.

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