Generic Detector Developments for future facilities

Ties Behnke, DESY

Content

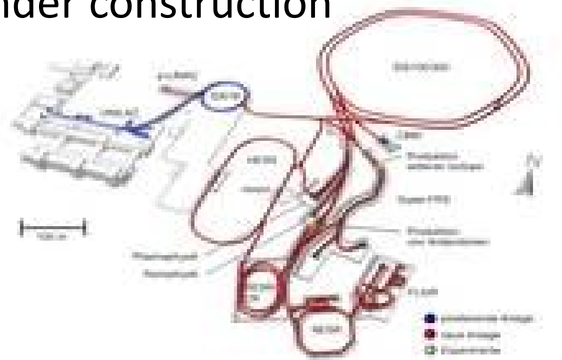
- General trends
- Position sensitive detectors
- Energy Measurements
- Data Transfer
- Summary/ Conclusion

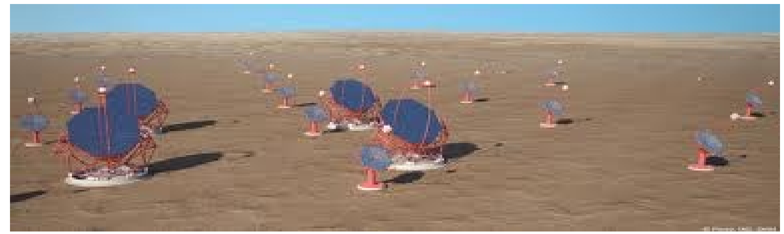
Not discussed here:

- “approved” upgrades of LHC experiment and other experiments
- Probably many other exciting developments

Future Facilities

FAIR: Facility for Antiprotons and Ions Research, under construction

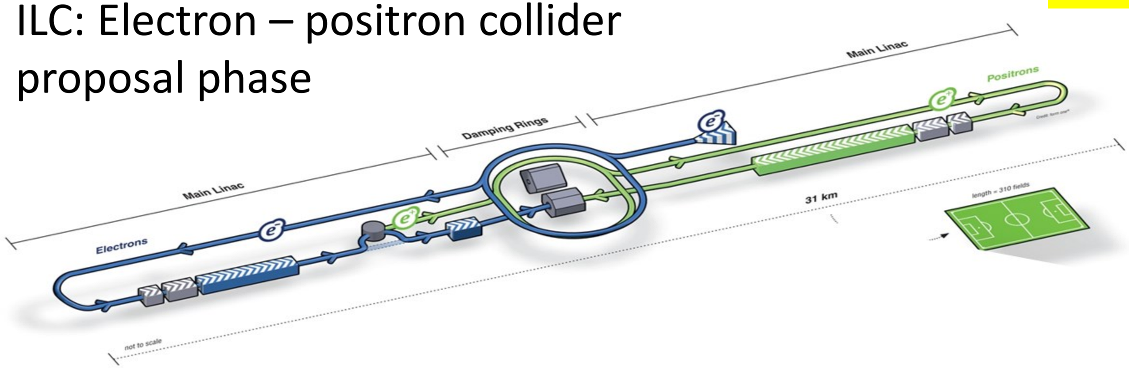




CTA: Cerenkov Telescope Array

Precision physics, rare processes high data rates

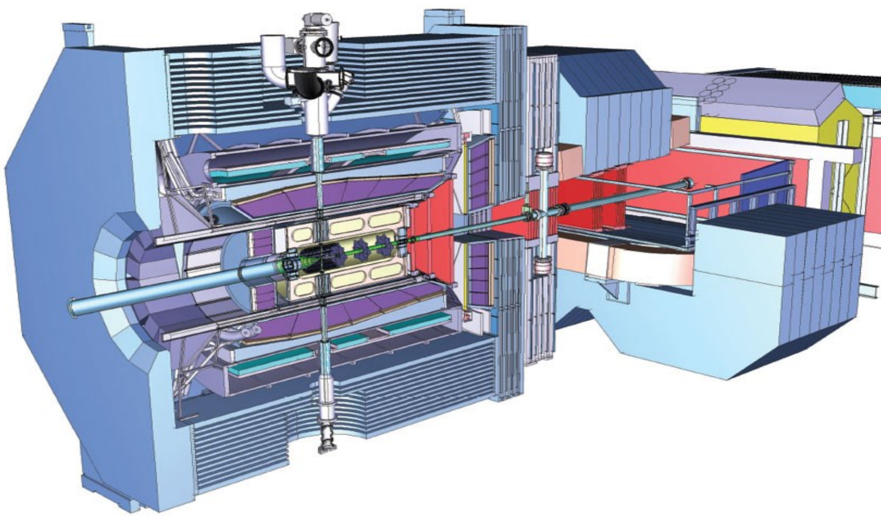
ILC: Electron – positron collider proposal phase

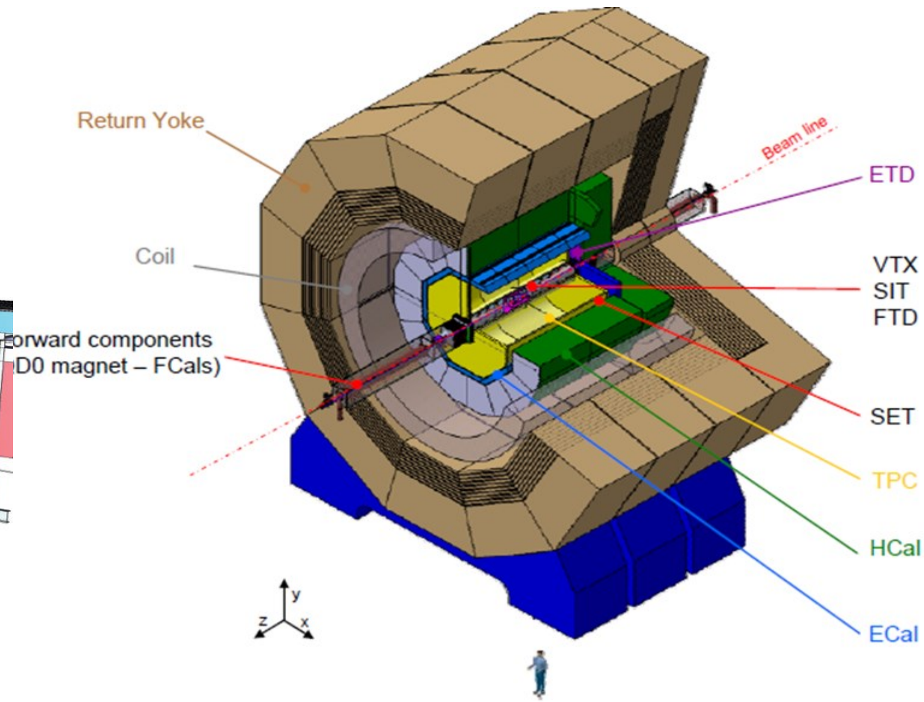


Future Experiments

ILD at the ILC

PANDA at FAIR



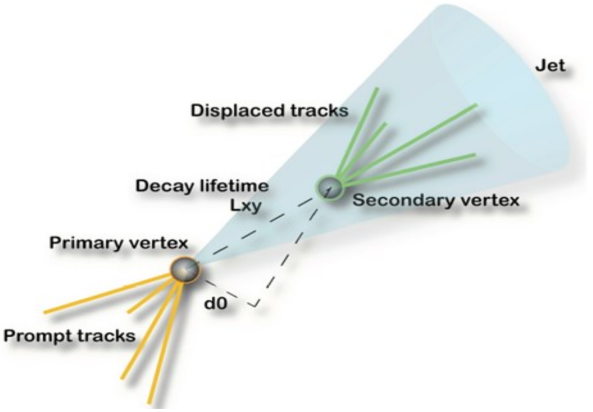


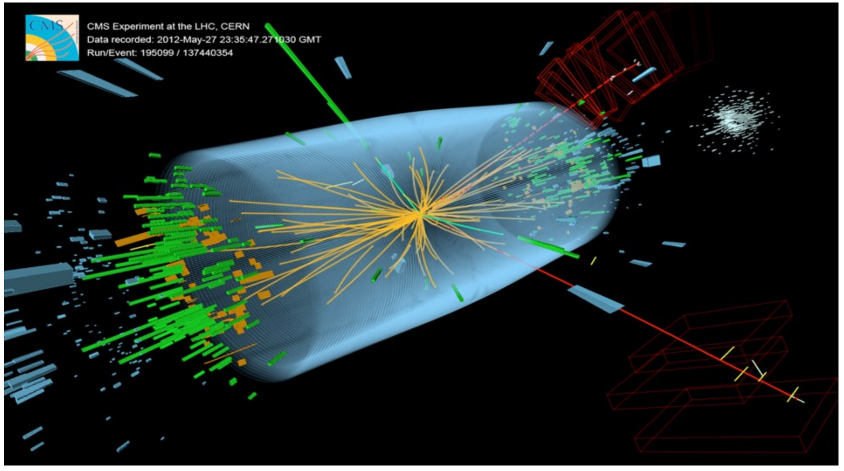
Plus many other experiments small and large

Precision

Precision for individual parameters

example: pixel detectors with very small pixels





Precision for the overall event reconstruction

Complex detectors, feature extraction, topological detail

The Challenges

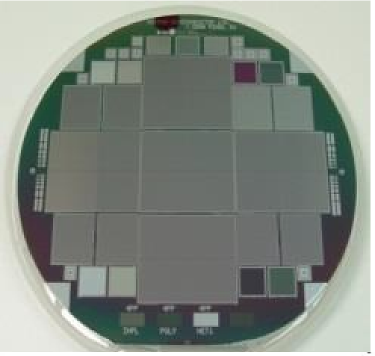
Precision (resolution)

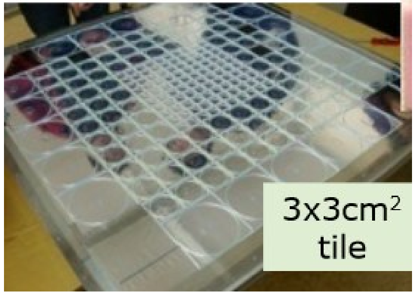
Granularity

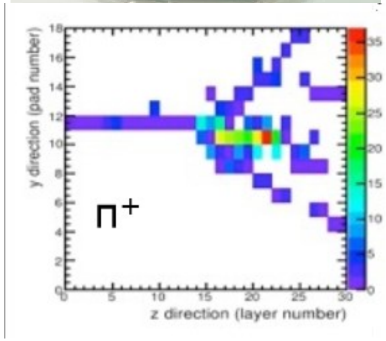
Power consumption

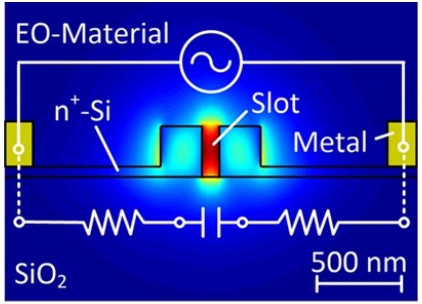
Readout Speed

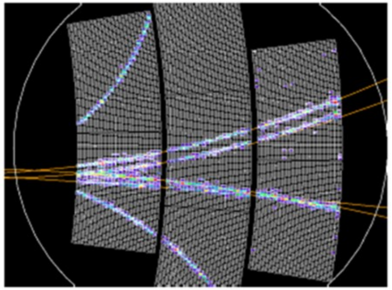
Material budget







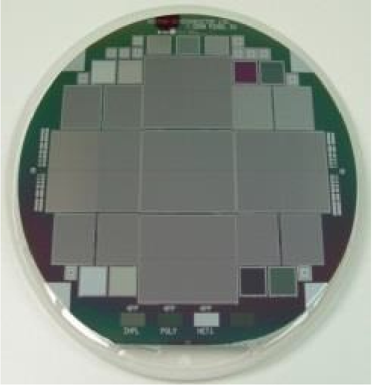




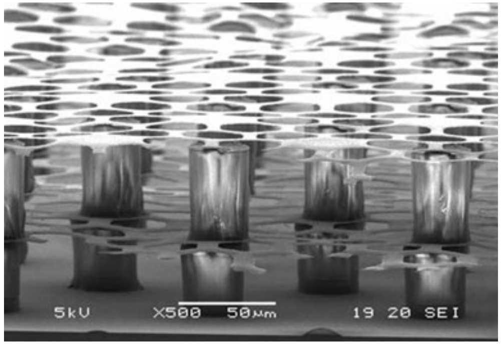
Position Sensitive Detectors

Semi-conductor detectors

- Pixel technologies
- Alternative materials



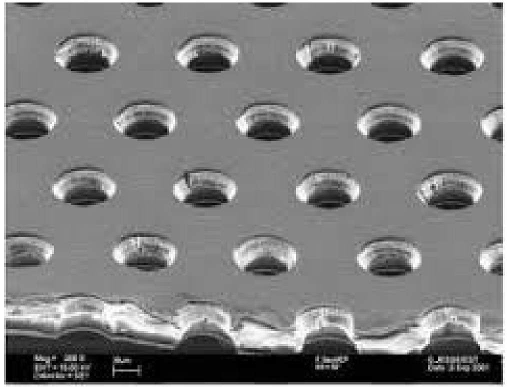
Gaseous goes silicon
- Pixel TPC



Power and heat management
Material management

Gaseous detectors

- Resolution
- Robustness
- Large area

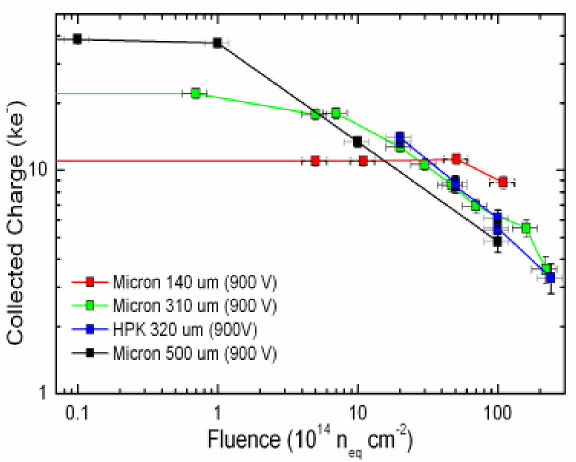


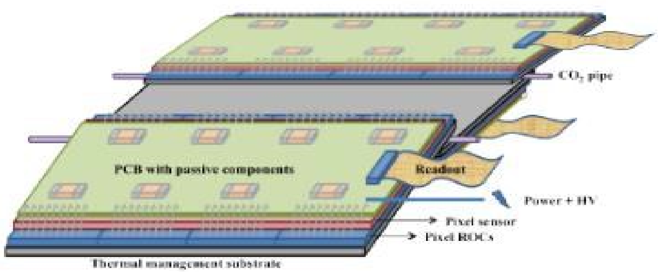
SEMICONDUCTOR DETECTORS

Pixel Detectors

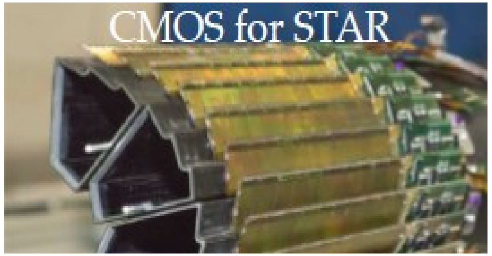
… everyone wants pixels everywhere ..

LHC: radiation hardness is key parameter

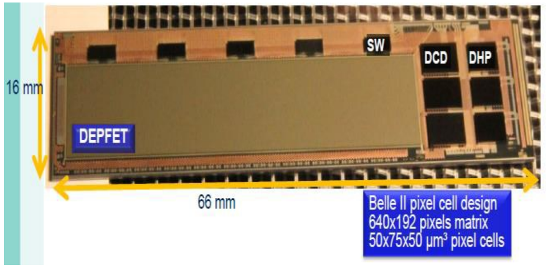




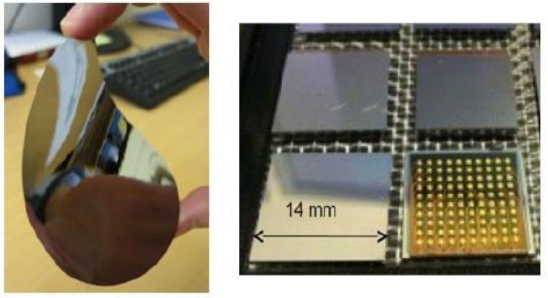
Non LHC applications
Lepton Collider



Different technologies
CMOS
DEPFET
FPCCD
3D
Chronopixel
SoI
HV-CMOS hybrid



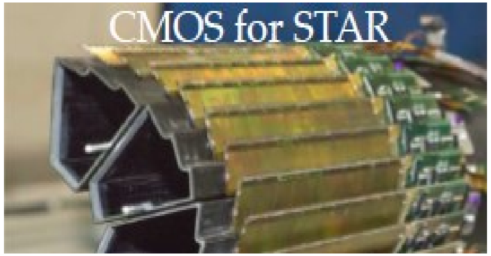
Trends:
- Small pixels
- Low mass
- Local intelligence

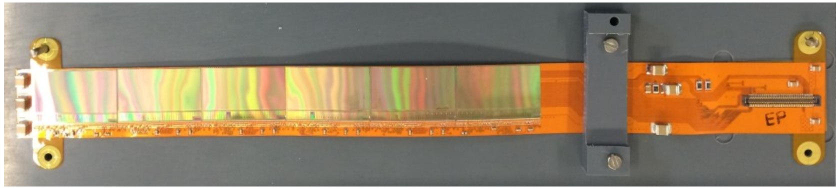


Pixel Detectors

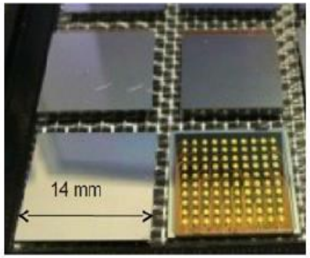
Challenges:

Resolution: **<5µm** single point,
Material: goal **<0.15%** radiation length/ layer
Readout speed (in particular CLIC)





Plume ladder prototype: achieved 0.2%

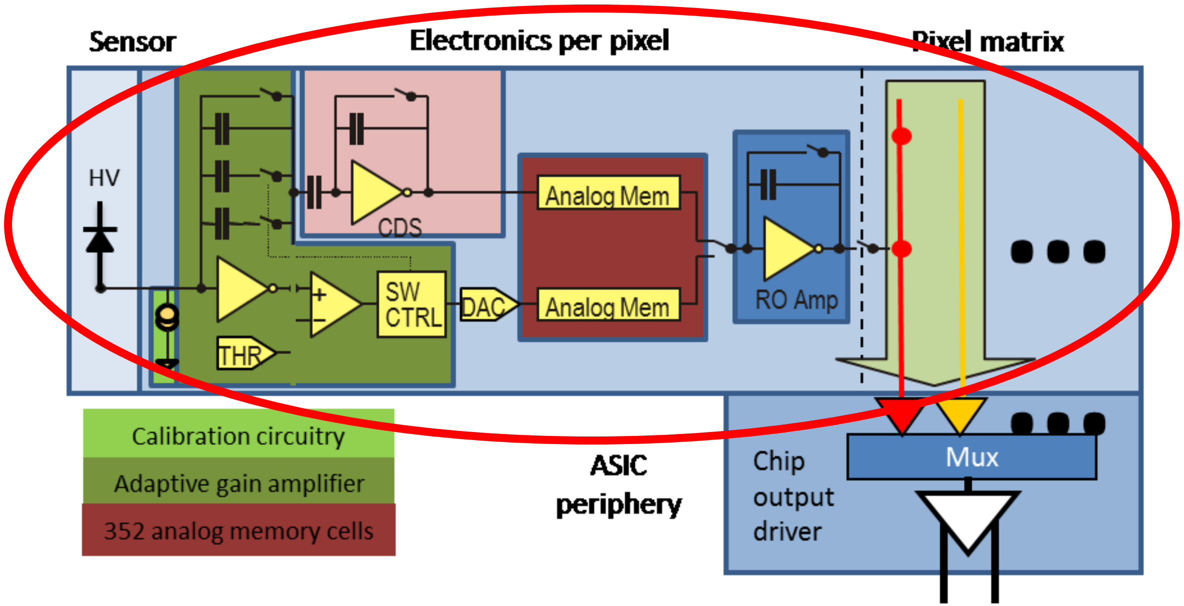


LHC upgrade: 0.3%/ layer

Pixel Technologies

Profit from the fast progress in Silicon technology:

- Higher integration
- More local intelligence possible



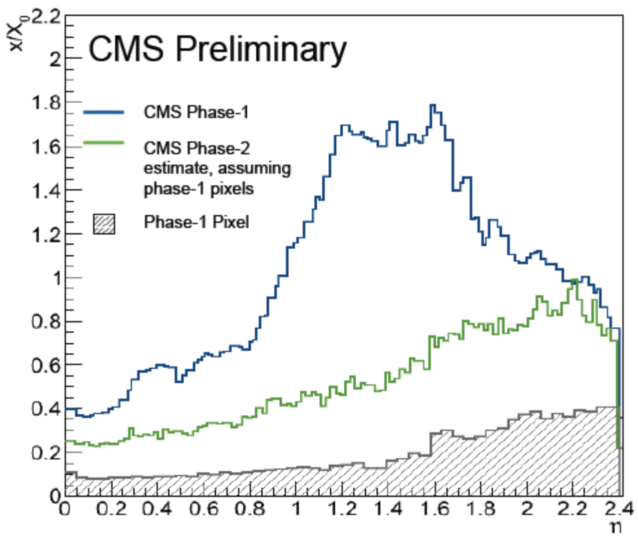
Per pixel:

- Sensing
- Storage (multiple hits)
- Hit-pre-processing

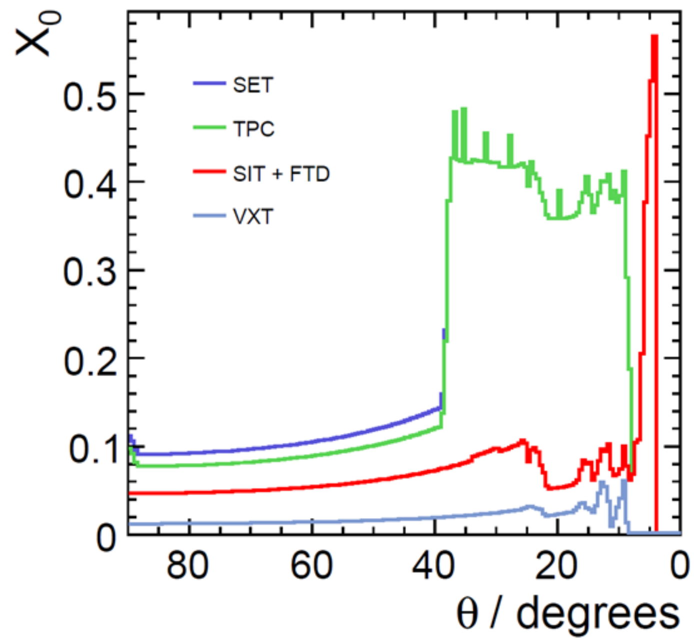
Can be important for "fast" readout, e.g. at ILC or CLIC

The Material Challenge

CMS tracker upgrade scenario:
reduce by factor 2



ILD estimate



The Material Challenge

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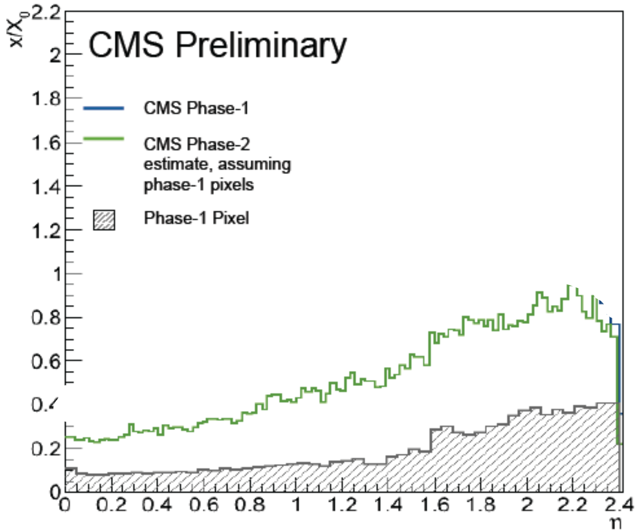
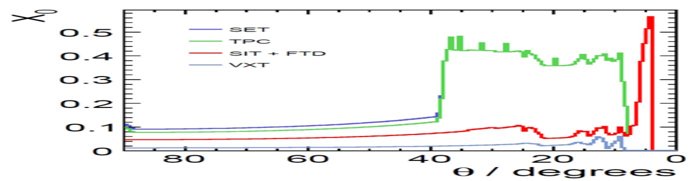


ILD estimate

Same scale as CMS plot:

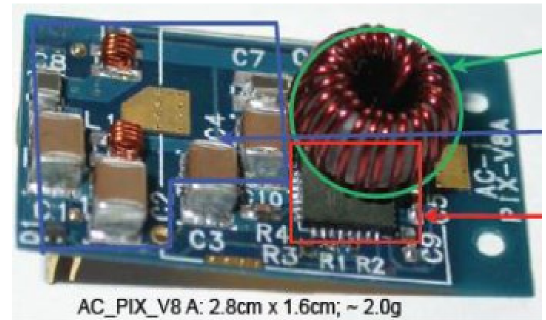


R&D done within LC and LHC communities has paved the way towards significantly thinner detectors.

But be aware of services…

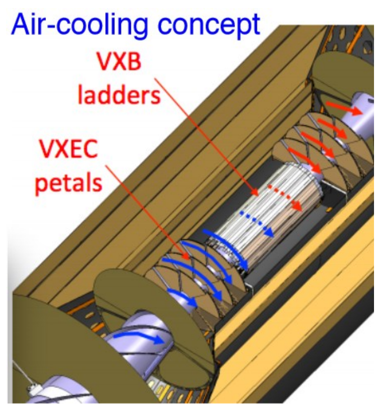
Power Management

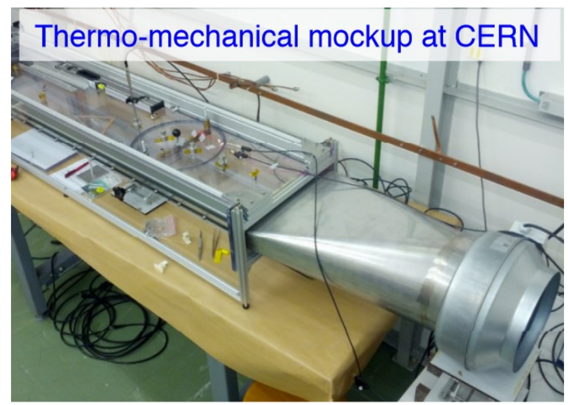
Powering:
- Services are major part of material budget
- Advanced powering schemes can help:
  - DC-DC
  - Power capacitors…



Air cooling concept studies

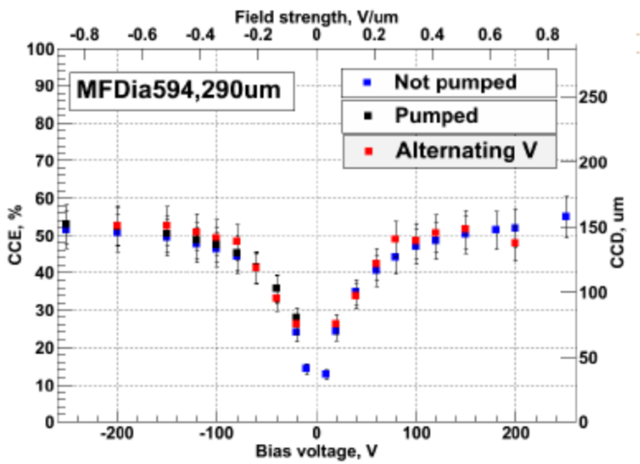
- Low mass
- Sufficient for ILC/ CLIC conditions?



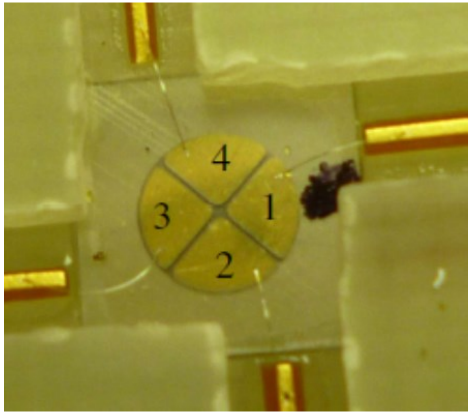


Novel Sensor Types

Diamond: fast, radiation hard



Sensor: 4.9x4.9 mm^2, 290 μm thick



Availability of large detector-grade material still a problem

- CVD diamond
- Monocrystalline
- New technology: grow on Iridium

- Niche applications (beam monitoring, see CMS, FLASH)
- Small signals
- Still rather expensive

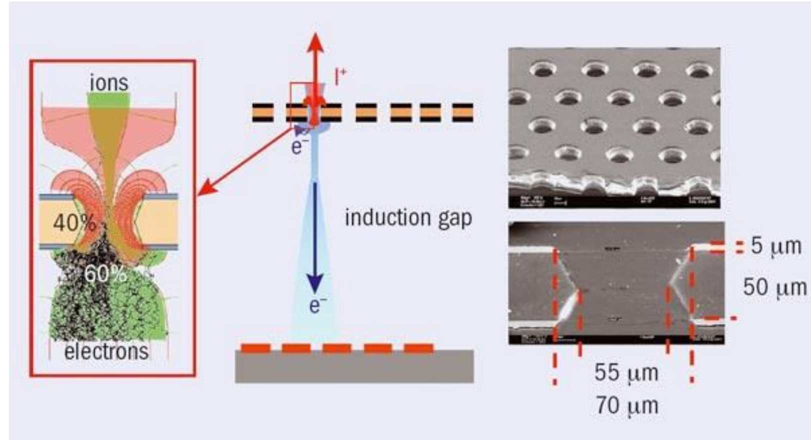
Other options: Sapphire, GaAs (non-HEP,NP, ..)

GASEOUS DETECTORS

Gaseous Detectors

Gaseous detectors:

- Granularity
- Robustness
- Relative low cost for large volumes



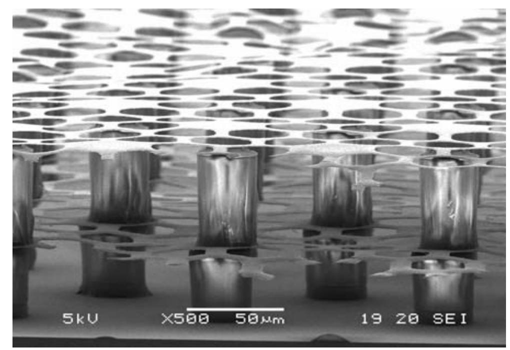
Applications in

- Tracking detectors
- Calorimetric detectors
- Muon systems
- Other experiments

Focus of new developments:
Gas amplification systems based on
Micro pattern gas detectors

Integration of
gas amplification
into Silicon technology:

INGRID and friends



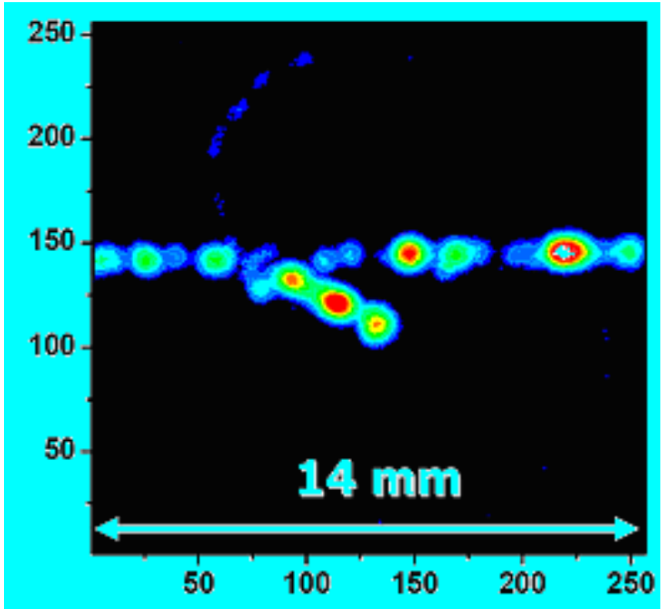
Gaseous Detectors

Time projection chambers

- ALICE
- PANDA
- ILC (?)
- Rare events searches
- …

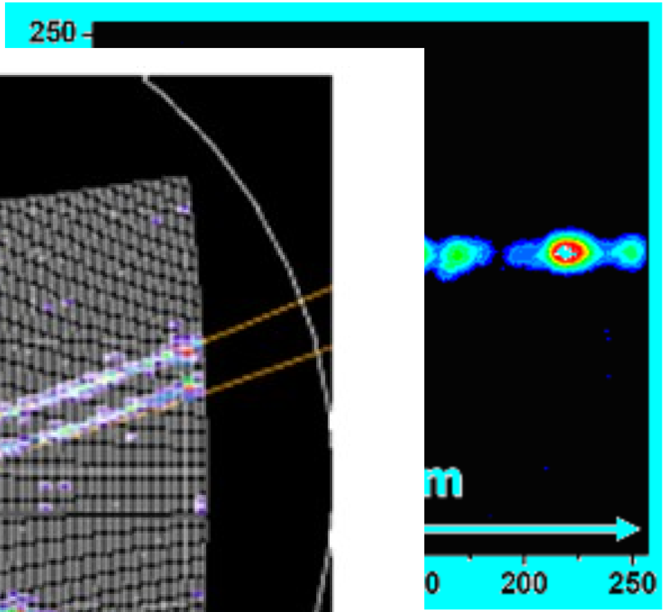
Established technology, broadly used

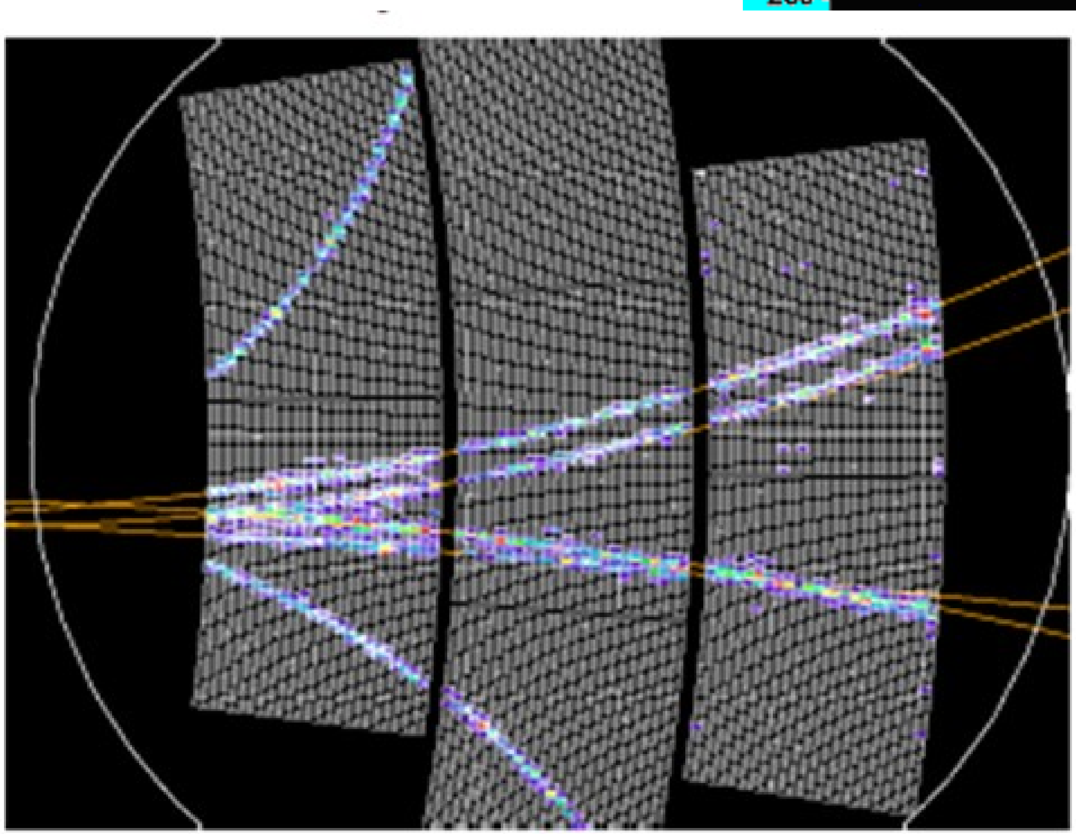
- Move to highly pixelated readout structures
- Merge the advantages of Si technology with gaseous technology



Picture of track in a TPC recorded with a TPC quipped with pixel readout (50 um pixel). Structure of ionization becomes visible.

Gaseous Detectors





Time projection cl

- ALICE
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- …

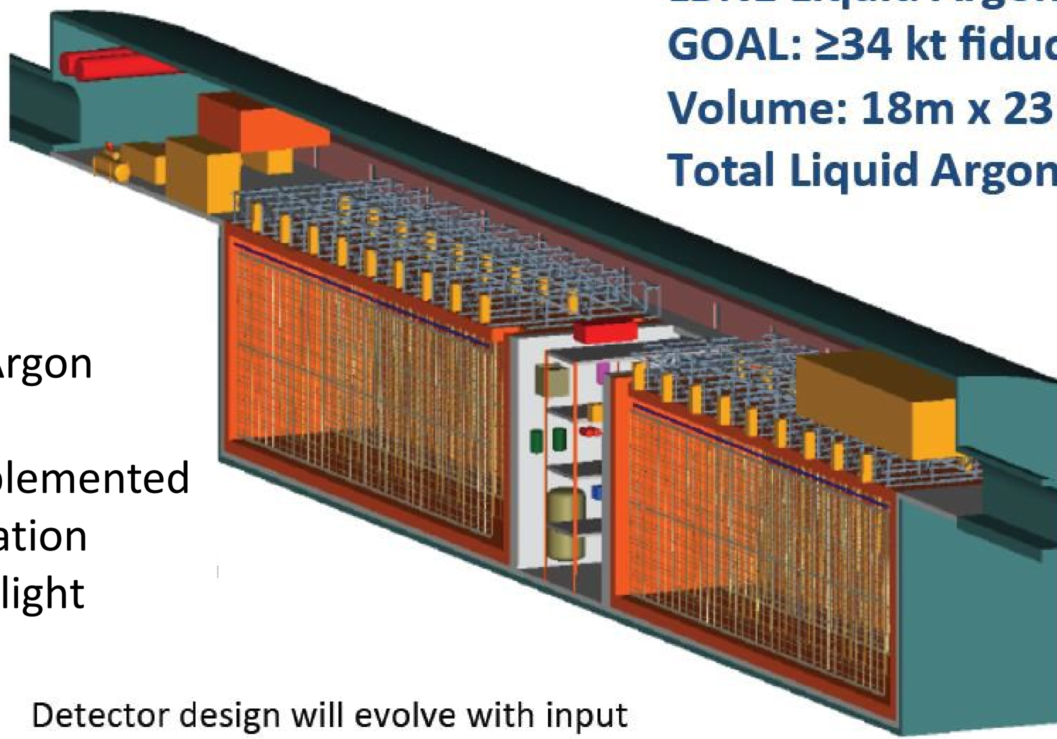
Established techn

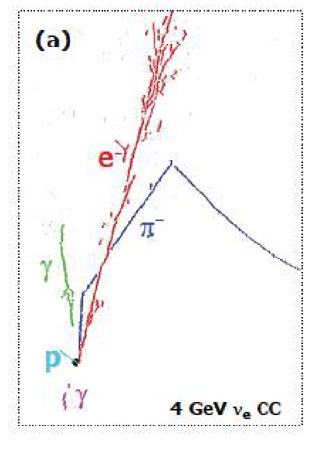
- Move to highly
- Merge the adv
  gaseous techn

TPC recorded
with
pixel).
on becomes
visible.

TPC in Neutrino Physics

LBNE Liquid Argon TPC
GOAL: ≥34 kt fiducial mass
Volume: 18m x 23m x 51m x 2
Total Liquid Argon Mass:~50 kton



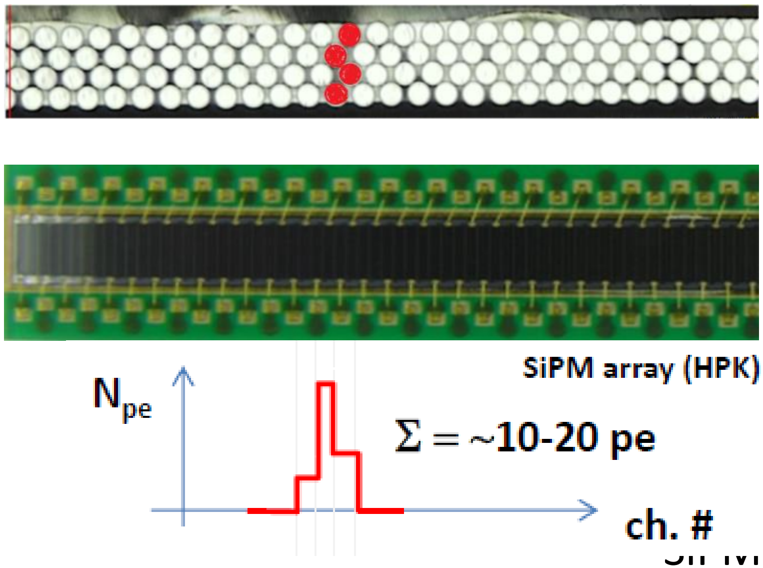


TPC based on liquid Argon

TPC information supplemented by fast timing information from LAr scintillation light recorded with SiPM

Detector design will evolve with input from new partners and R&D program

Scintillating Fibre Tracker R&D



SiPM make small and dense fibre tracker feasible:

LHCb: 3 stations, stereo angle, 250um fibres 2.5m long

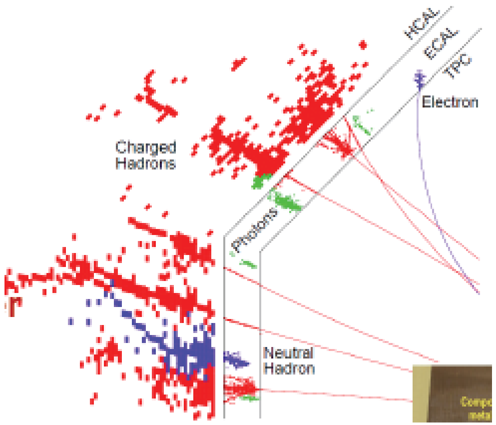
Attractive alternative for “intermediate” resolution and planar geometries.

Availability of integrated and miniaturised readout systems opens new possibilities.

CALORIMETRY

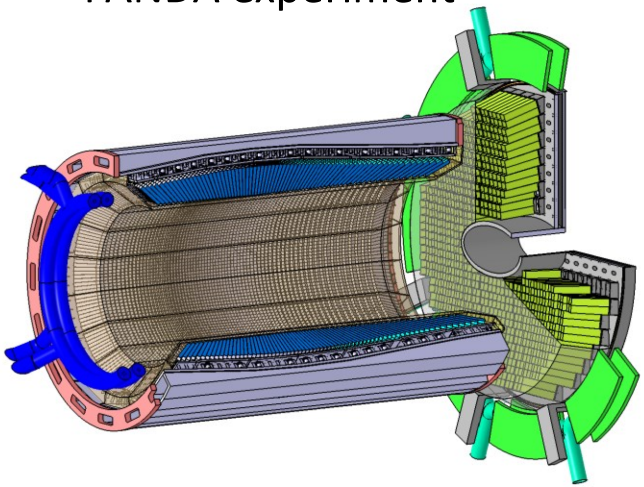
Calorimetry

Calorimetric detectors:
core part of modern detectors

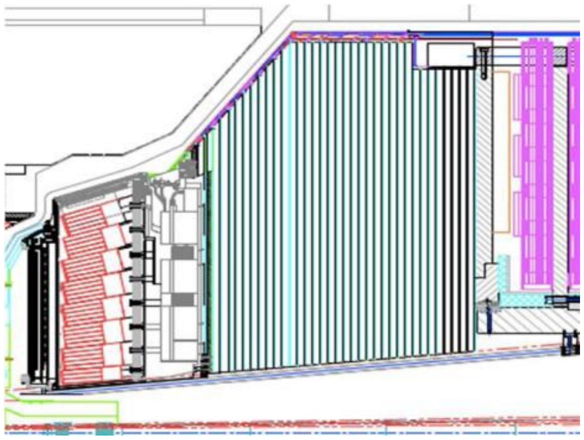


Exp.	Year	channels
TASSO	1975	12k
ALEPH	1989	72k
D0	1995	120k
ATLAS	2008	175k
ILD	2020	100000k

Full absorption: Crystall
PANDA experiment



Sampling calorimeter
CMS HCAL



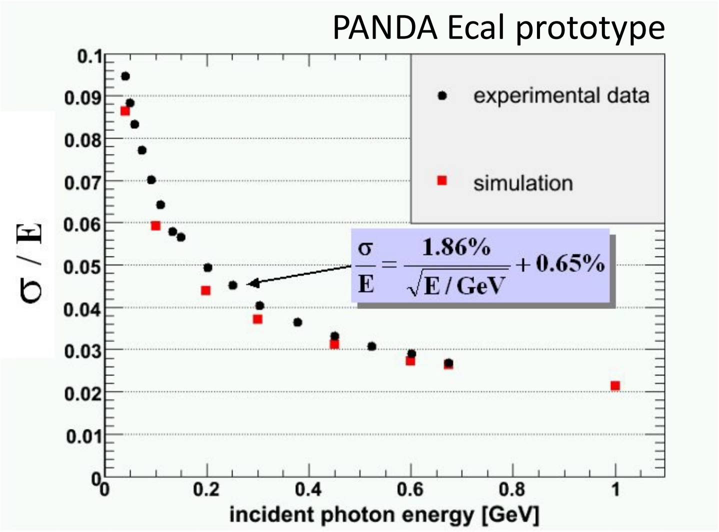
- Shower physics
- Reconstruction
- Resolution

Calorimeter Technologies

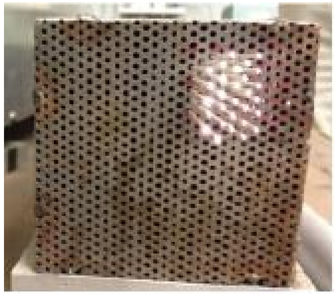
Crystal technology

Examples: CMS, PANDA

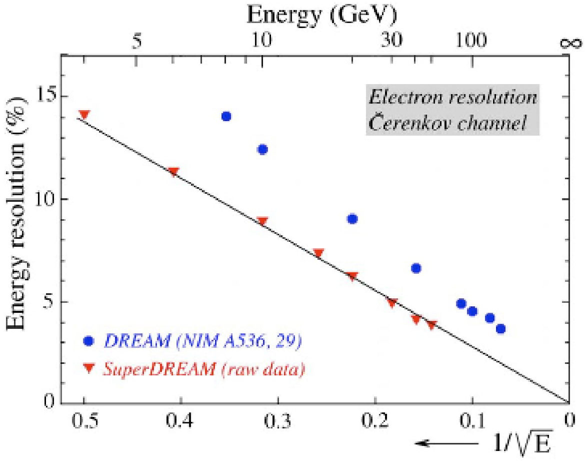
PbW crystals, dense, small
Excellent energy resolution
Limited segmentation



Dual readout technology



DREAM:
Combine scintillation with Cerenkov for improved energy reconstruction

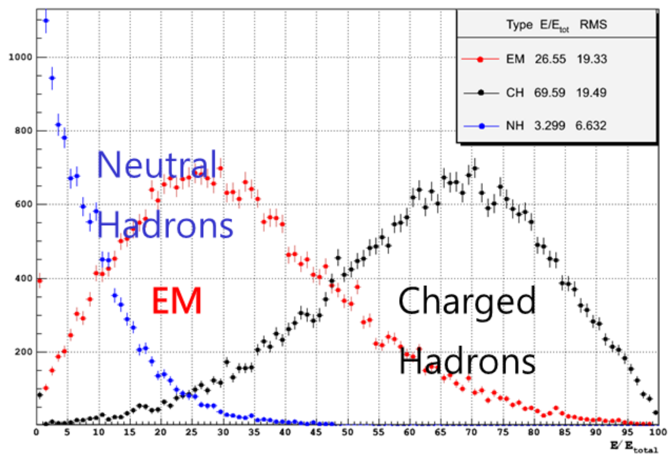


Wigmanns, Calor 2012

Particle Flow

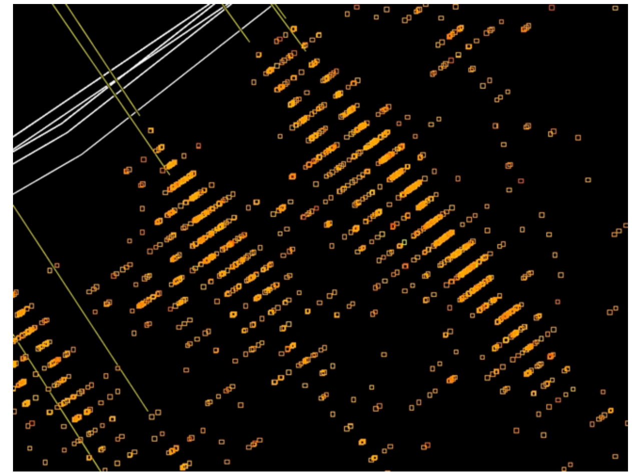
Particle flow:

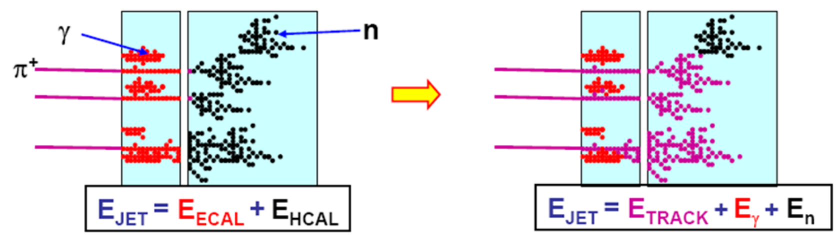
A concept to reconstruct complex events (hadronic final states)
Relies on tracking and calorimetry



Particle Flow (PFA) is a way to handle fluctuations

Simulated shower in a highly granular calorimeter



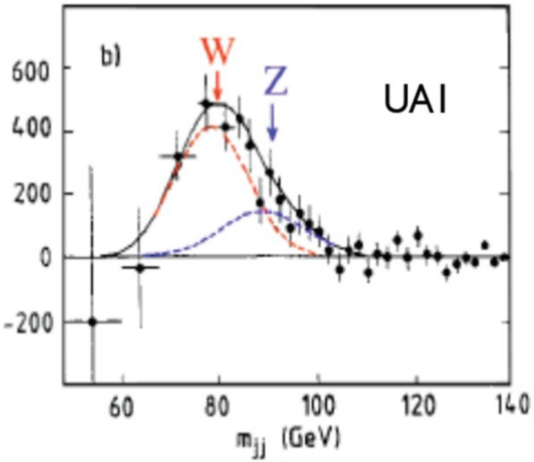


Granularity is stressed more than intrinsic energy resolution

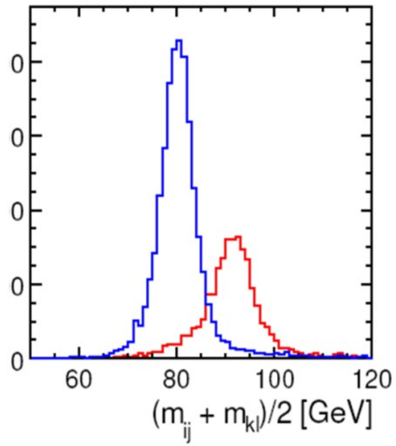
Particle Flow

Complex final states (e.g. W/ Z)

Traditional approach



Particle Flow approach

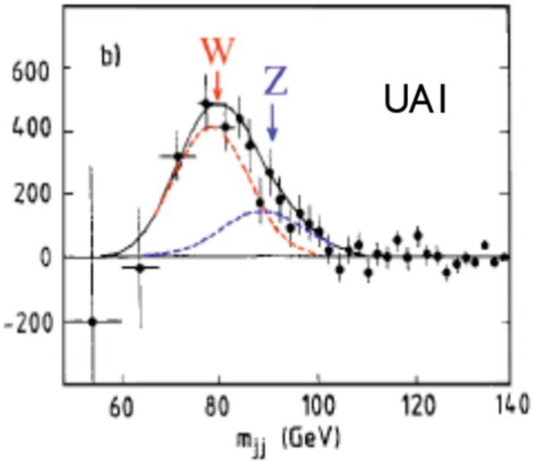


Jet-jet mass resolution

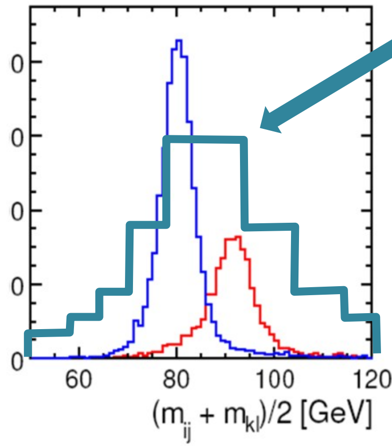
Particle Flow

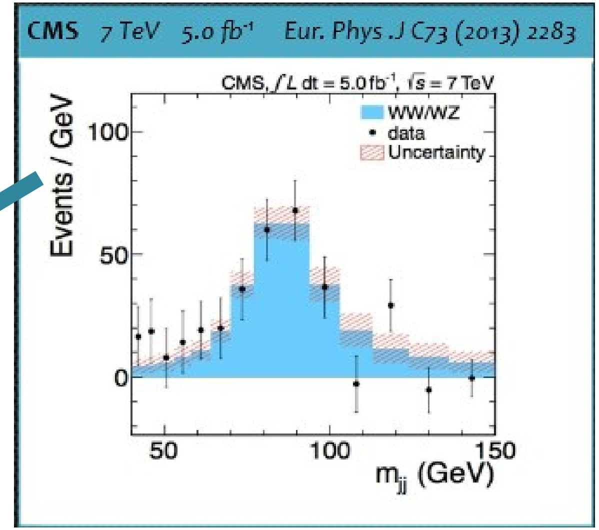
Complex final states (e.g. W/ Z)

Traditional approach



Particle Flow approach





Jet-jet mass resolution

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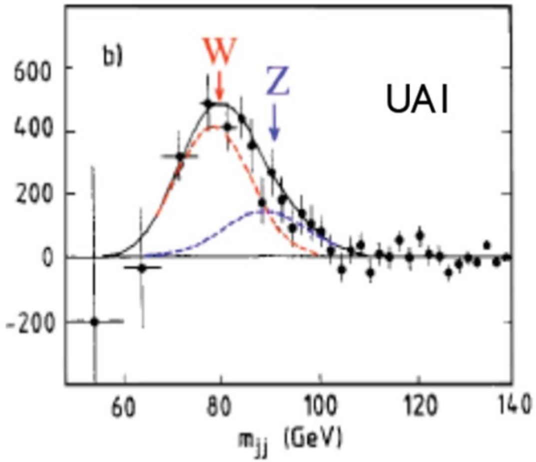
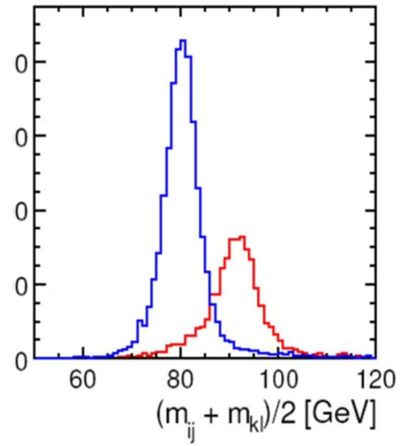


Particle Flow approach



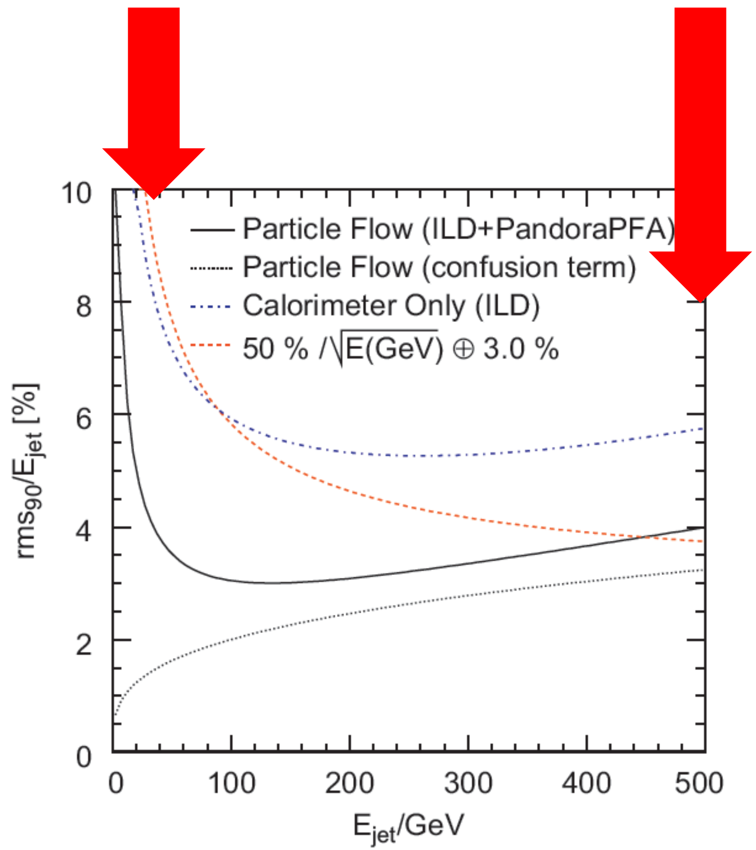
Jet-jet mass resolution

Particle flow is better than pure calorimetry

At high energies the advantage is less.

Energy resolution

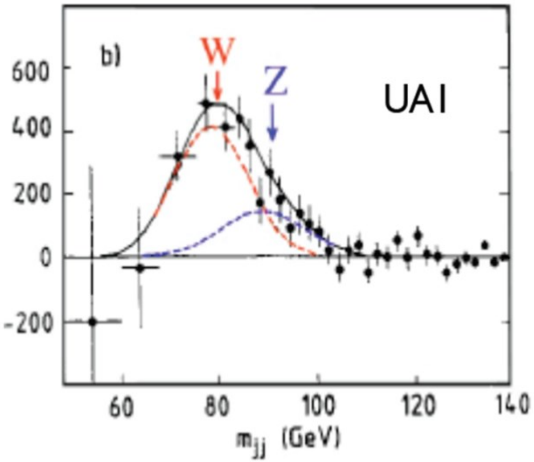
Confusion



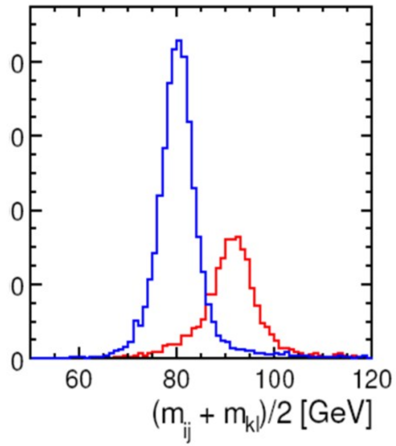
Particle Flow

Complex final states (e.g. W/ Z)

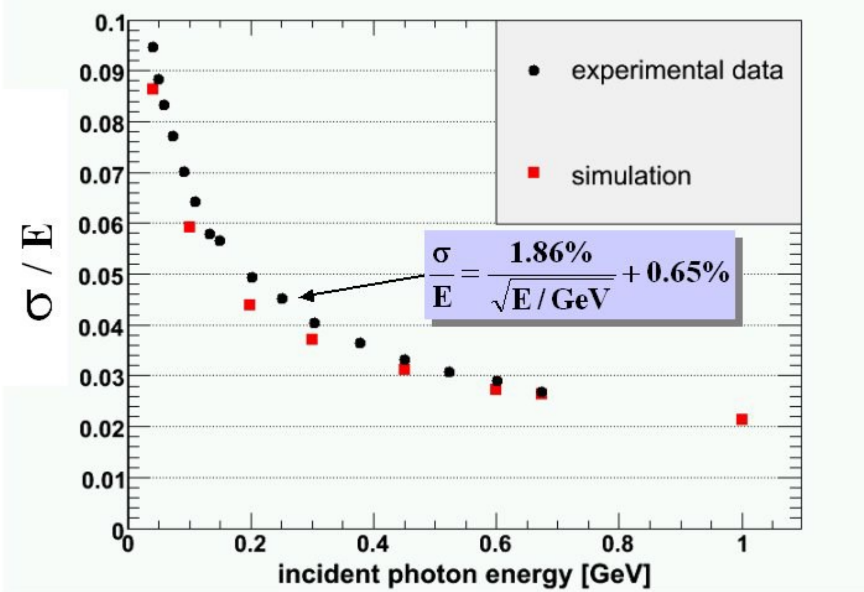
Traditional approach



Particle Flow approach



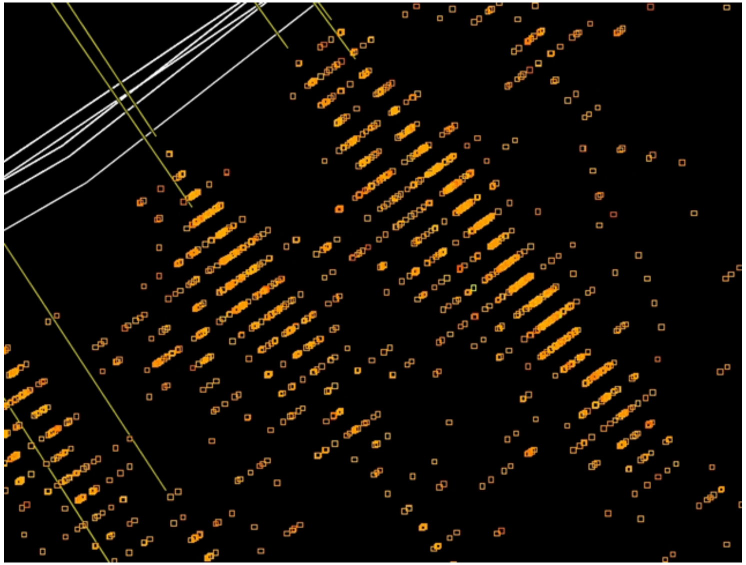
PANDA ECAL: Lead Tungstate crystals



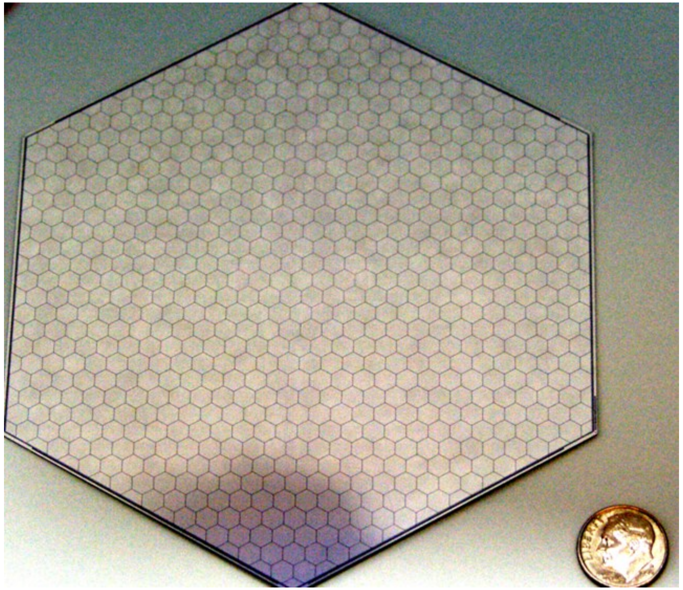
Physics with exclusive final states
(e.g., PANDA with multiple photons in FS)
Focus on photon resolution rather than topological reconstruction

Sampling Calorimeters

Segmentation

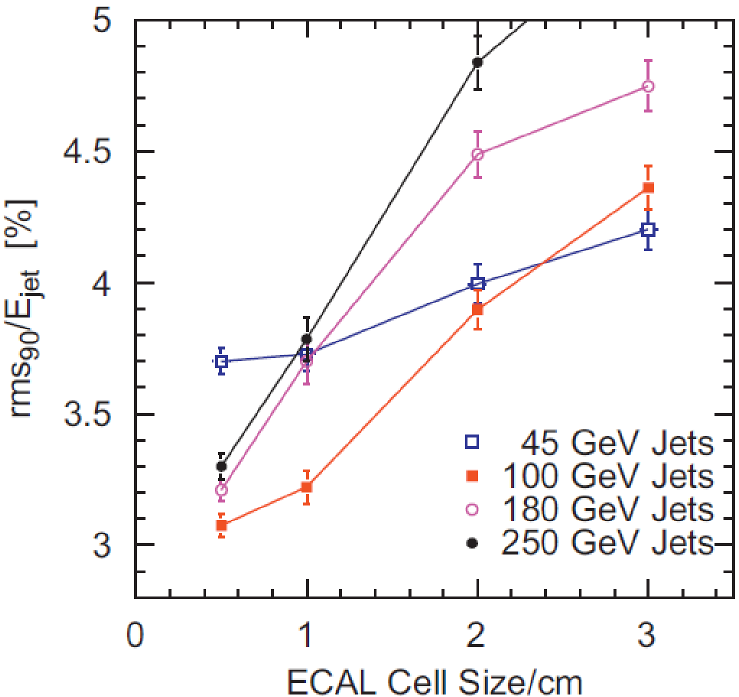


Particle flow = granularity
Optimize relative to particle flow performance



Proposal for a Si-ECAL
(Breitenbach/ Strom/ Frey)

Sampling Calorimeters



Cell sizes typically 5x5 mm^2

Integration of readout into the sensitive plane to save space and cabling

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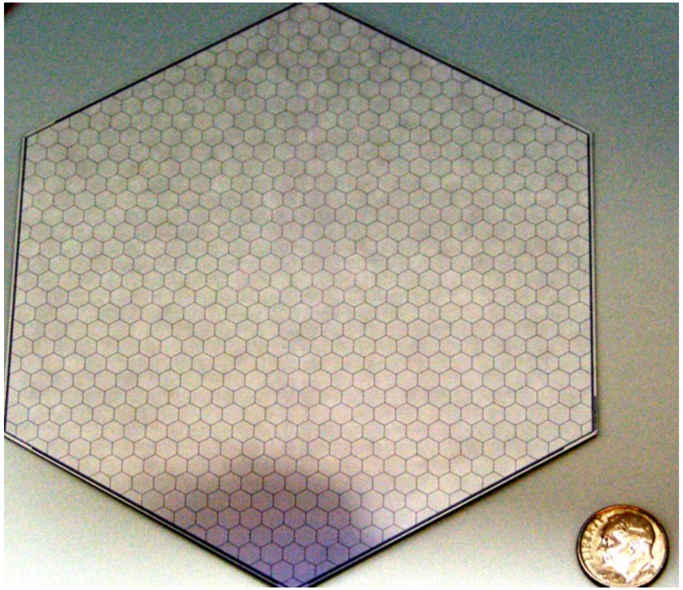

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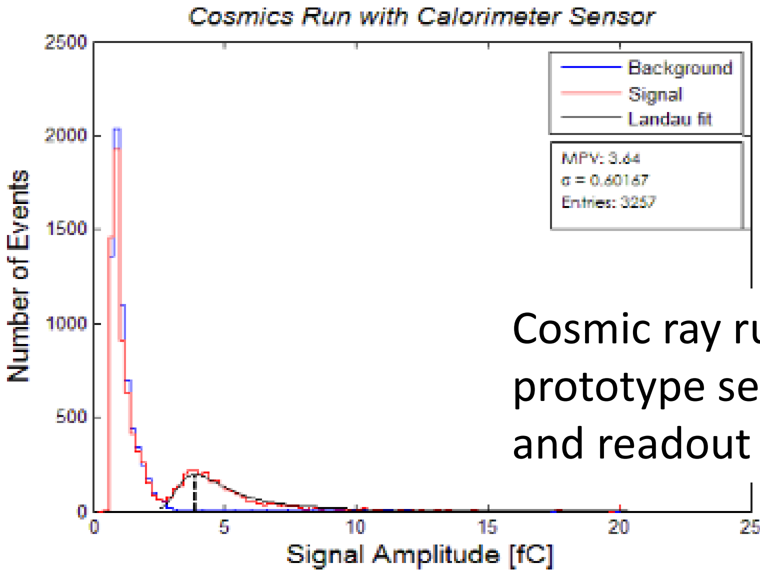
Sampling Calorimeters: Silicon



Cosmic ray run of prototype sensor and readout

Cell sizes typically 5x5 mm^2

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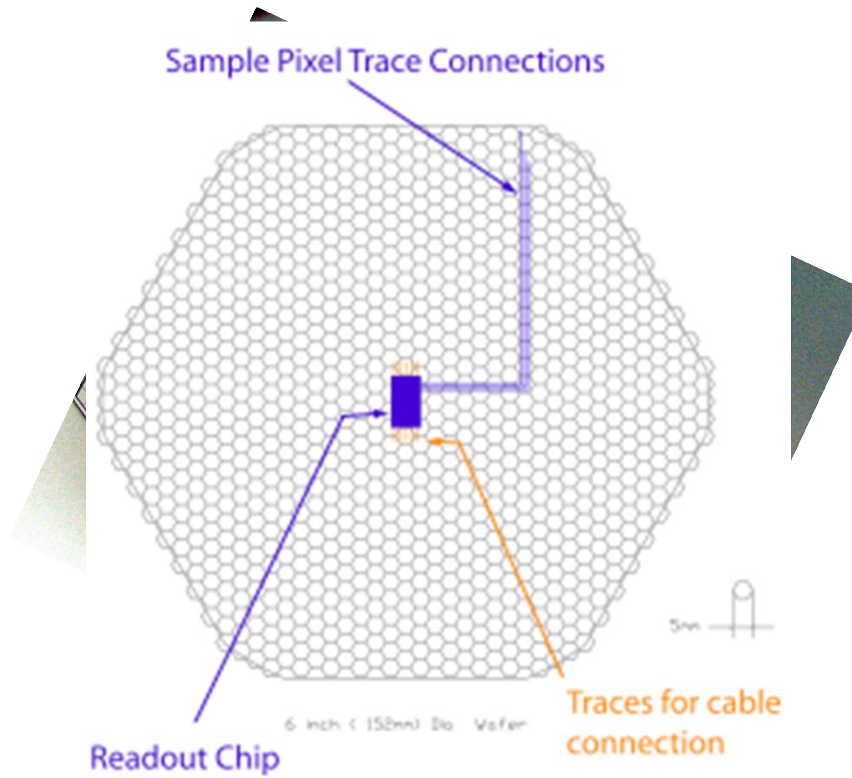
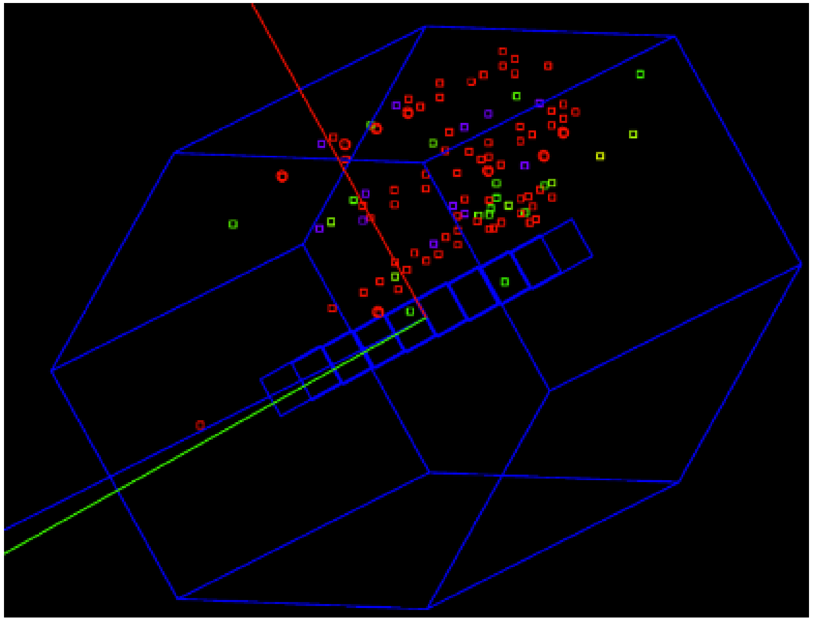


Similar proposal made in Europe by Brient/ Videau etal. (CALICE)

Sampling Calorimeters: Silicon

Test beam results from SLAC



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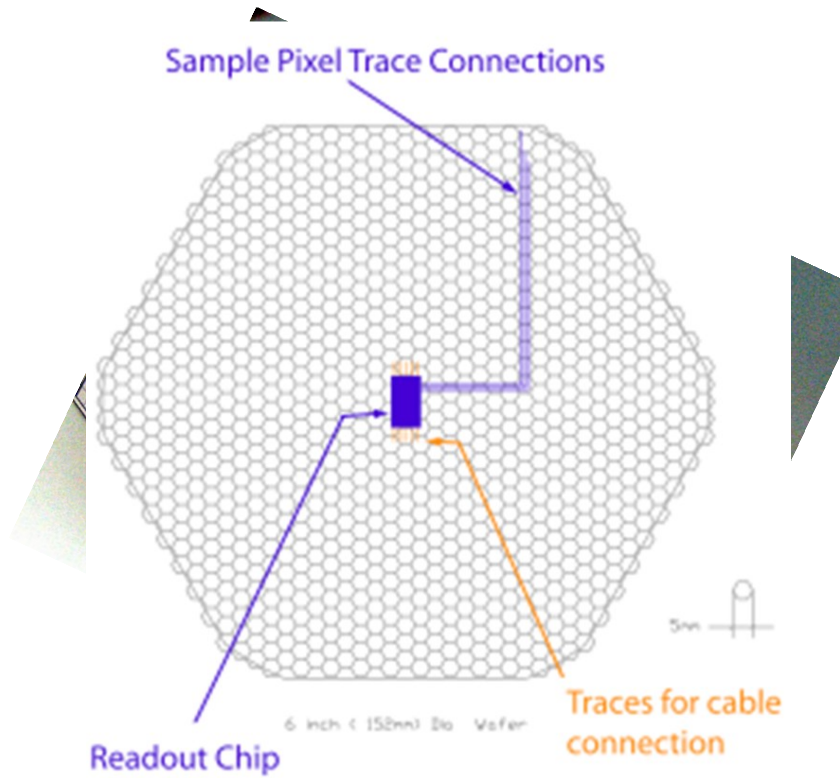
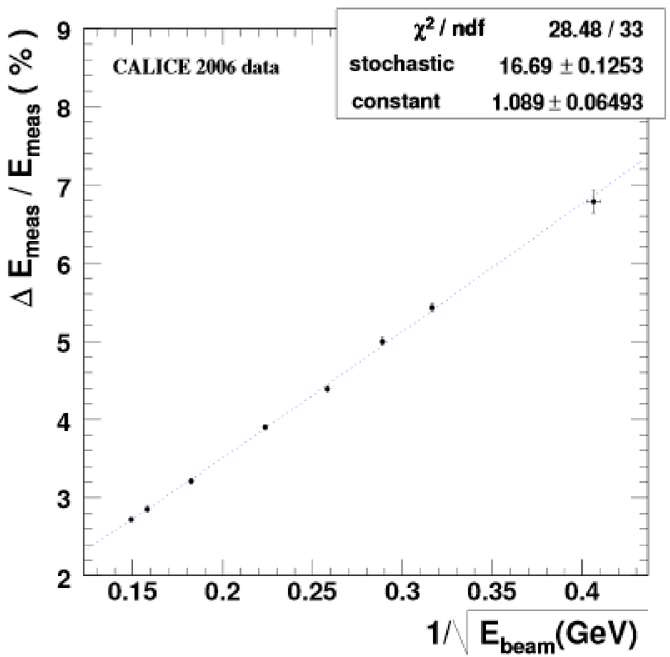


Similar proposal made in Europe by Brient/ Videau etal. (CALICE)

Silicon based Calorimetry

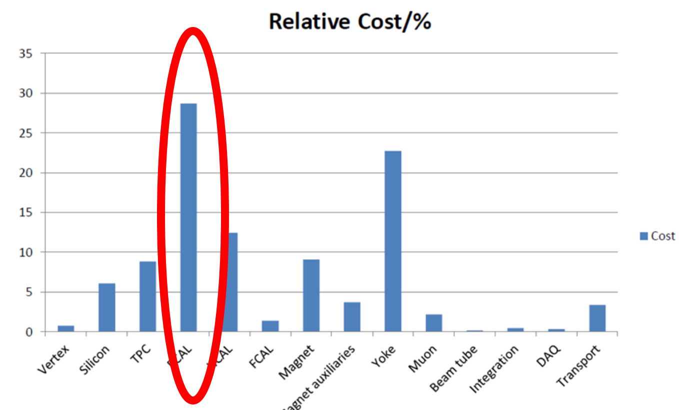
- Sampling calorimeters with silicon based sensitive planes are an attractive option.
- Large progress over the last years in hardware and in understanding
- CALICE: convincing test beam results to demonstrate the feasibility



Relative energy resolution of CALICE SI-ECAL

- Challenge:
  - Integration
  - Costs!

Example: ILD detector at the proposed ILC ECAL 100Mio channels



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Example: ILD detector at the proposed ILC
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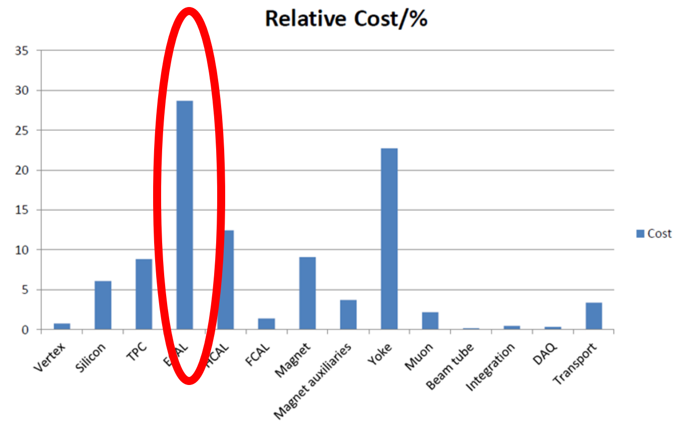
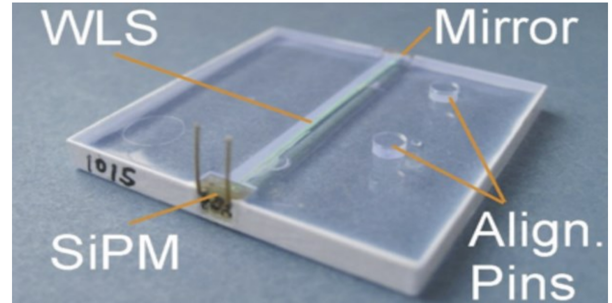
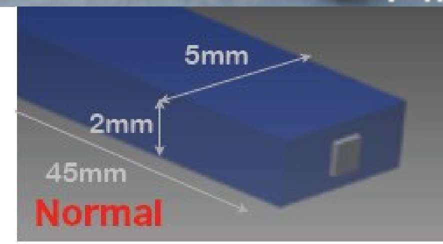
Key technological challenge:
- Handle the integration aspects
- Develop fully integrated designs
- Handle the power issues
- costs

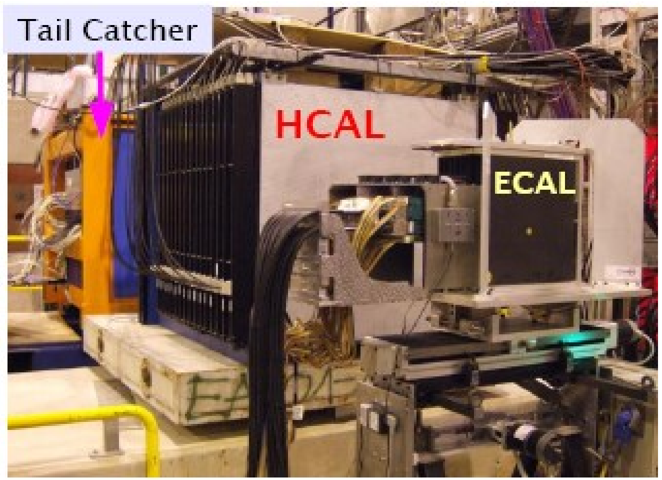


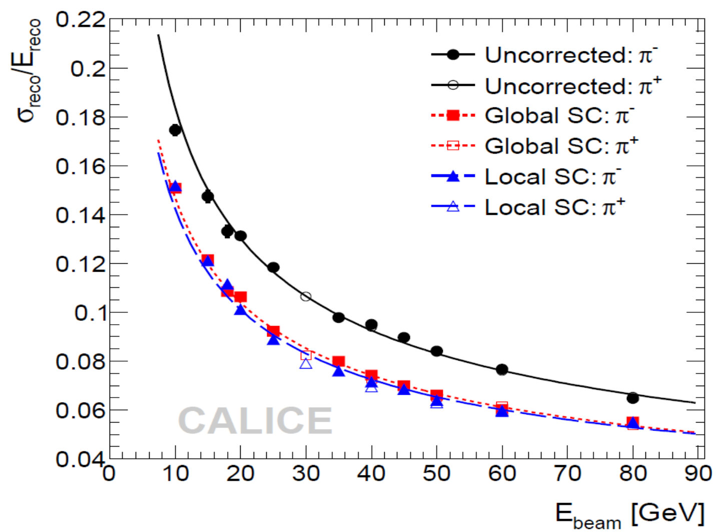
Scintillator Based Calorimeter





- Availablity of SiPM allows highly granular scintillator based designs
- HCAL: $3x3cm^2$ segmentation of 3mm thick scintillator read out by SiPM through wavelength shifting fiber (Elimination of WLS under study)
- Software compensation (e/p ~1.2) technique was show to work well through beam tests: $58\%/E^{1/2}$ → $45\%/E^{1/2}$





Scintillator Based Calorimeter

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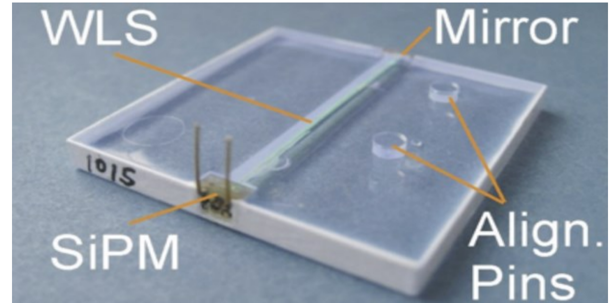
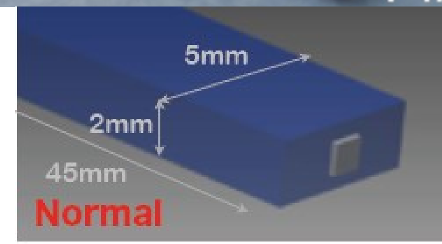
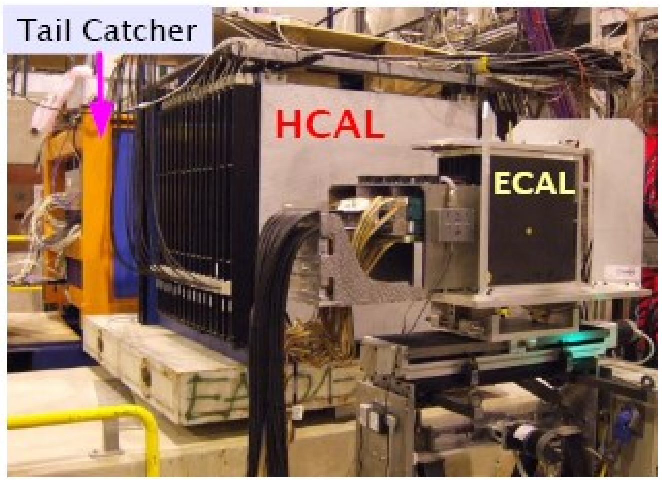
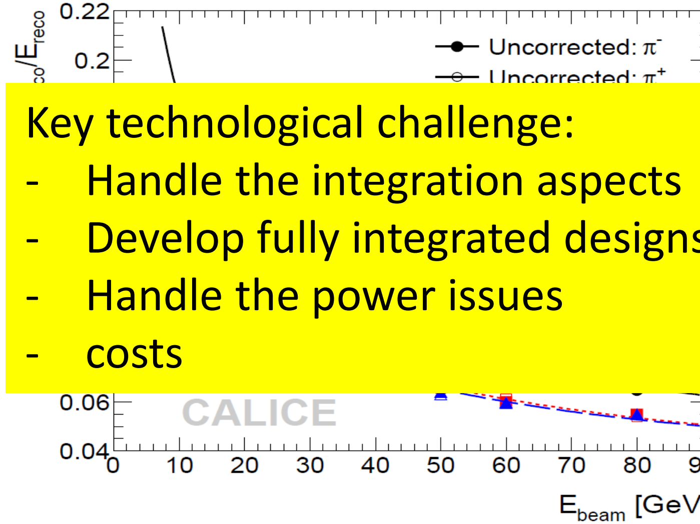
- Software compensation (e/p ~1.2) technique was show to work well through beam tests: $58\%/E^{1/2}$ → $45\%/E^{1/2}$
- Test beam results are also used for evaluation of GEANT4 physics list









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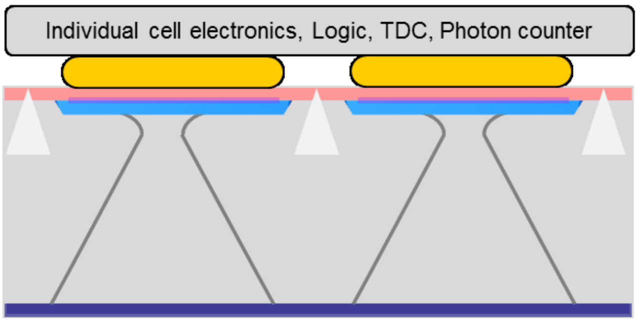
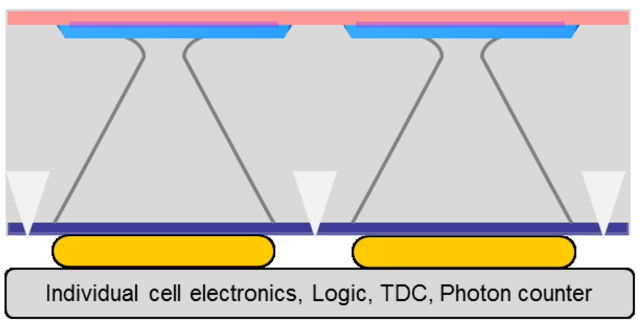
SiPM Developments

Ultra fast particle tracker - ***High energy physics application***



Ultra fast single photon sensitive imager – ***Photon science***



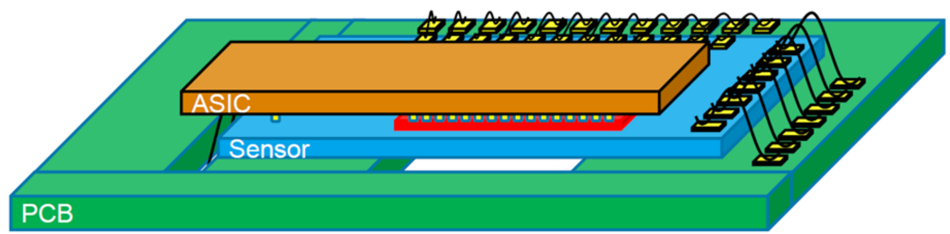
Silicon based photo detectors:

- Allow granular scintillator based detectors
- Applications in many other areas

Commercially available

New development: digital SiPM

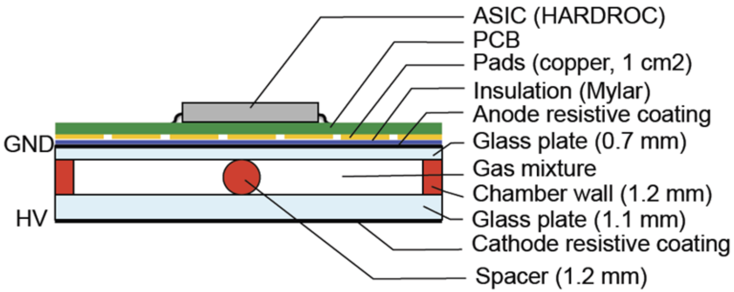
- Readout every pixel
- Broad applications



Digital Calorimetry

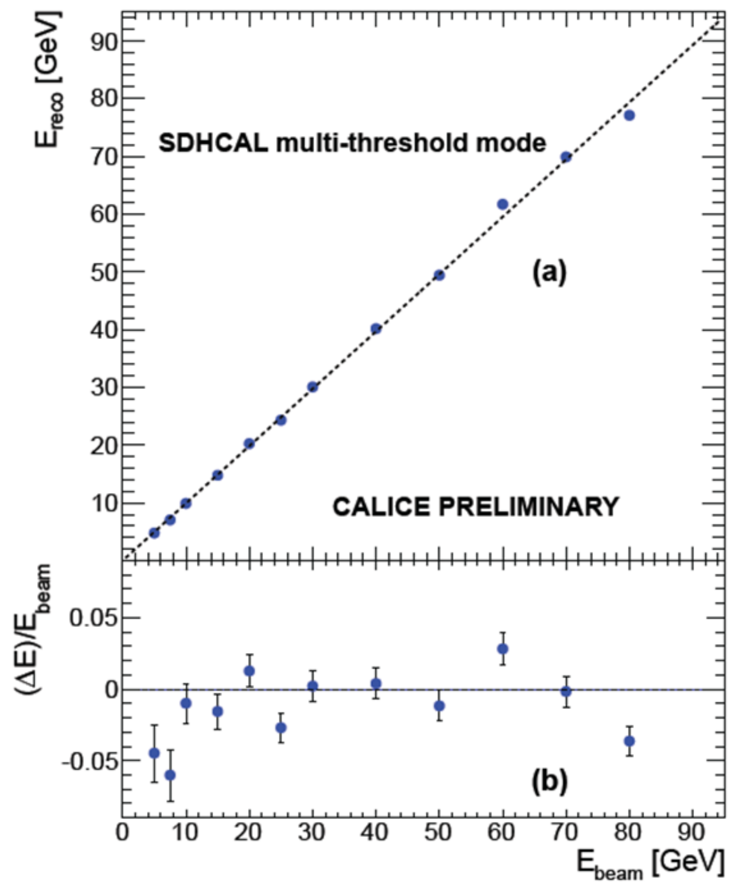
Digital calorimetry:

- Measure the energy of a particle through the number of cells hit
- Was tried already in the 80's (unsuccessfully), has seen a renaissance lately due to the availability of very granular systems.



Active medium: gas RPC's

Test beam results from a large prototype detector



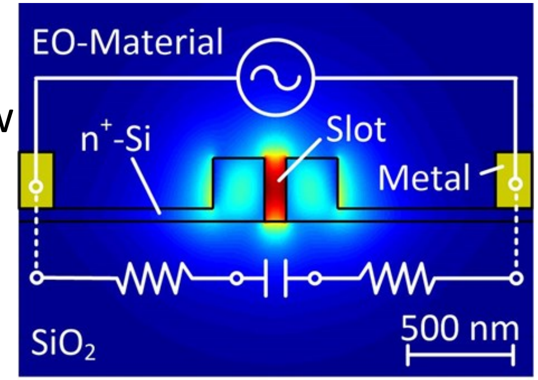
Data Transfer

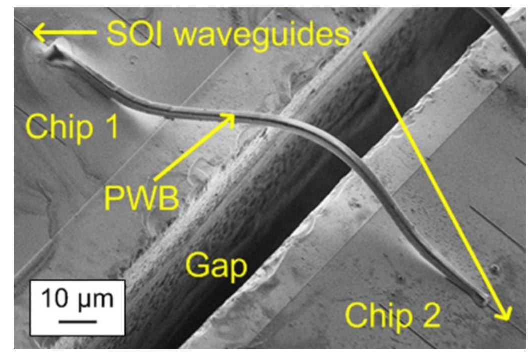
Modern detectors

- Highly granular systems: many channels
- Untriggered systems (PANDA, ILC): large continuous data flow

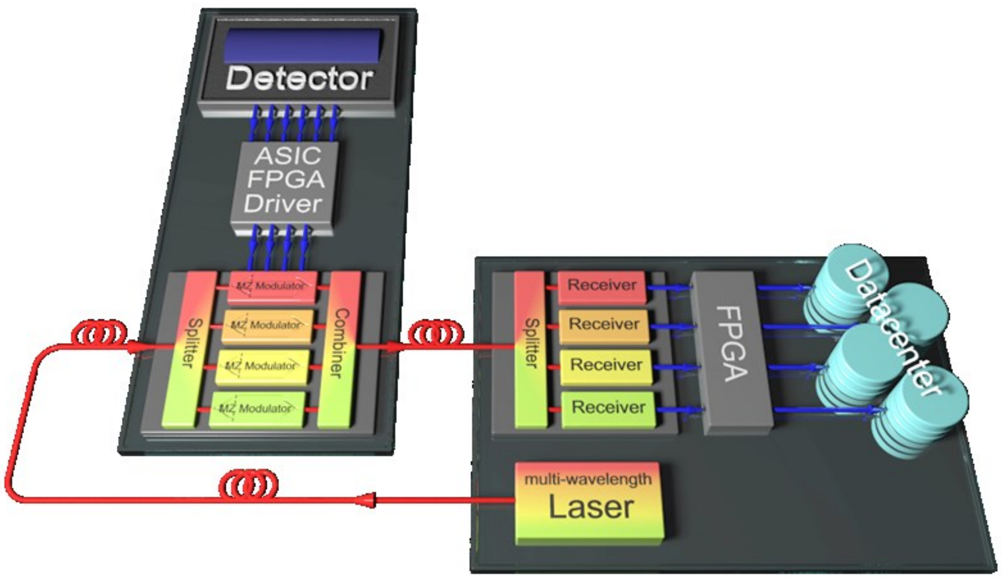
3/s

Optical transmission on a chip: waveguides





Photonic wire bond.



Integrate optical communication on the chips

Comments (instead of Conclusions)

Detector development is a very active field

I could only cover a few selected examples, and do not claim to be even close to complete. In particular I did not do justice to the field of neutrino physics/ astroparticle physics: apologies

Detector R&D is essential for our field

Comments (instead of Conclusions)

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Detector R&D is essential for our field

Detector R&D is driven by the scientific needs of our fields: close integration into the science community is essential,
but cooperation with neighbouring fields is equally important and very useful

Support for detector R&D is often difficult to get, in particular for far-future ideas.

We need to improve the attractiveness of the field to young researchers and make this a viable option for their career.