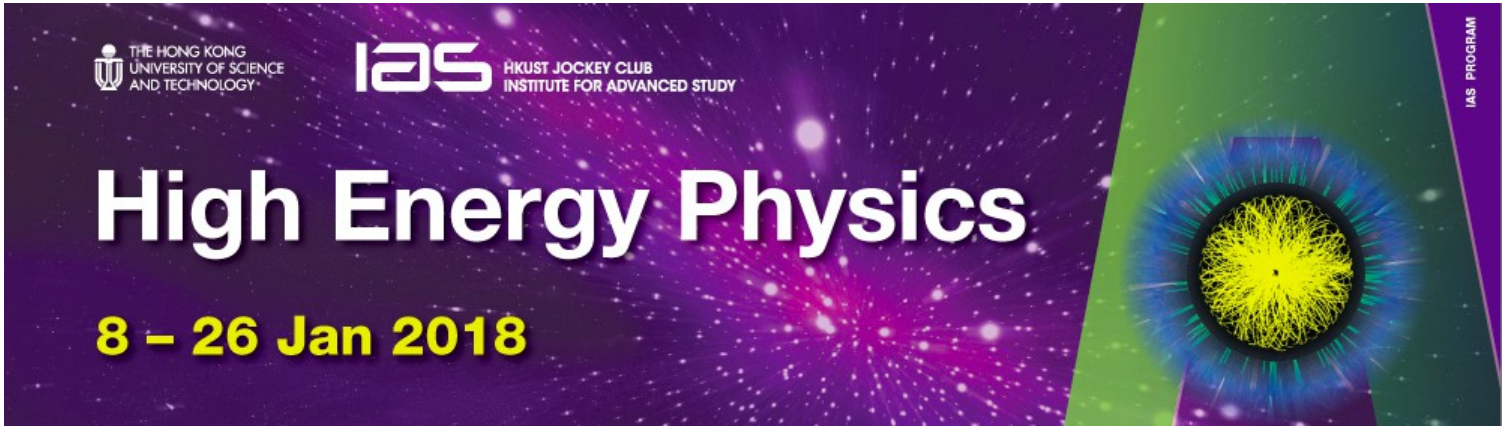


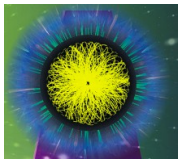
Central Calorimeters for high energy e+e- colliders

Introduction to detector workshop

Roman Pöschl

HKUST Jockey Club Hong Kong – January 2018

Prologue – Workshop charge and organisational matters



- Thank you very much for having agreed to contribute to this workshop

- Thanks to the organisers of the IAS Conference for giving us the opportunity to Hold this workshop in this beautiful and stimulating atmosphere

  Thanks in particular to Miss Prudence Wong for caring about the organisation

- Scientifically this workshop should review the status of granular calorimeters but should also pave the way forward

- The summary of the workshop will constitute the main part of my experimental on the last day of the IAS Conference

- During the workshop lunches will have to be self- organised
  Please consult the web pages of the IAS Conference for restaurants, coffee shops etc.

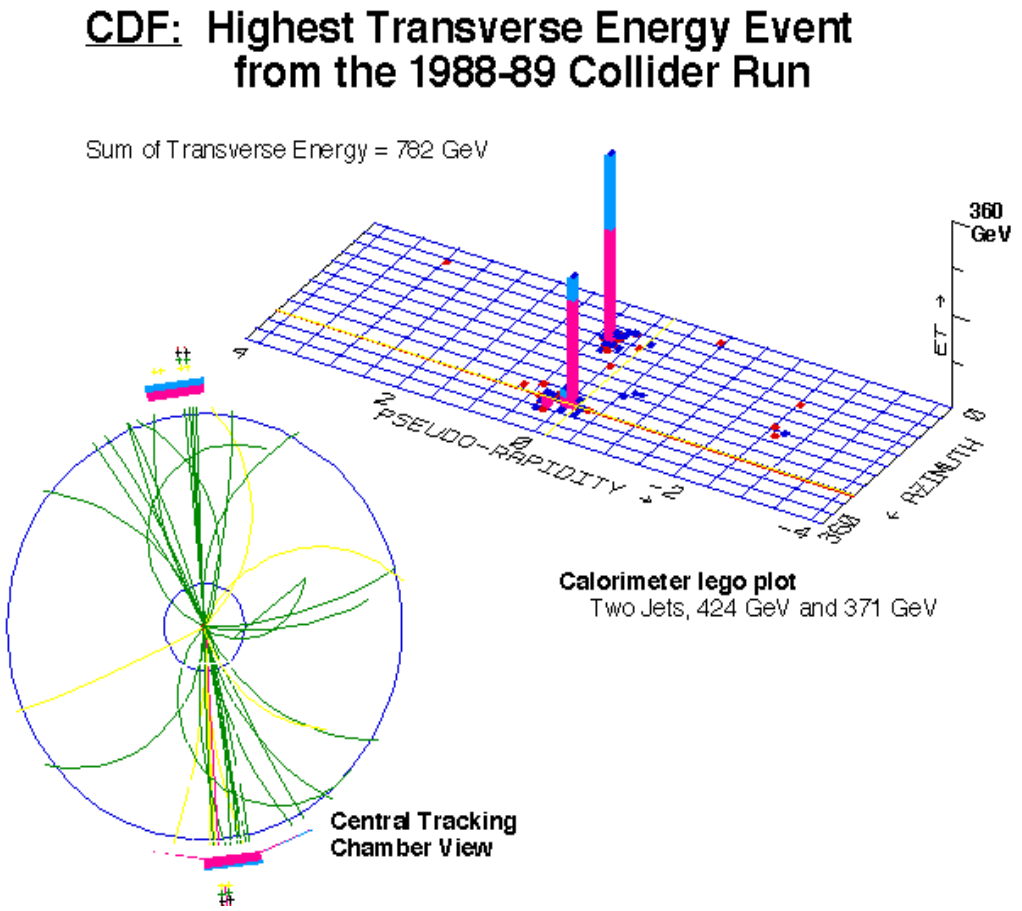
- Coffee breaks will be provided by the organisers

- For any question contact me and/or (preferred) the conference secretary Prudence Wong

Jet measurement – Classical approach

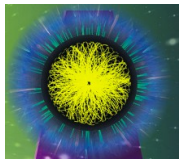
At collider experiments particles come typically in “jets”

- Jets are a collimated group of particles that result from the fragmentation of quarks and gluons
- They are measured as clusters in the calorimeter
- momentum of cluster is correlated to the momentum of the original quark



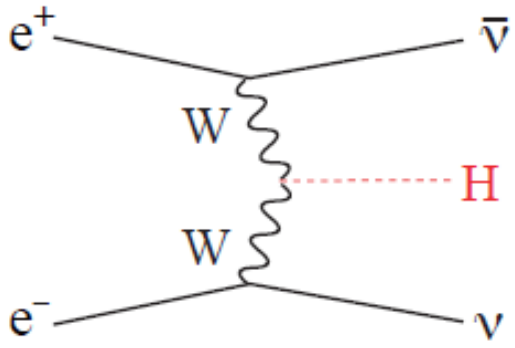
E. Garutti, IEEE2011, Calorimeter Lecture

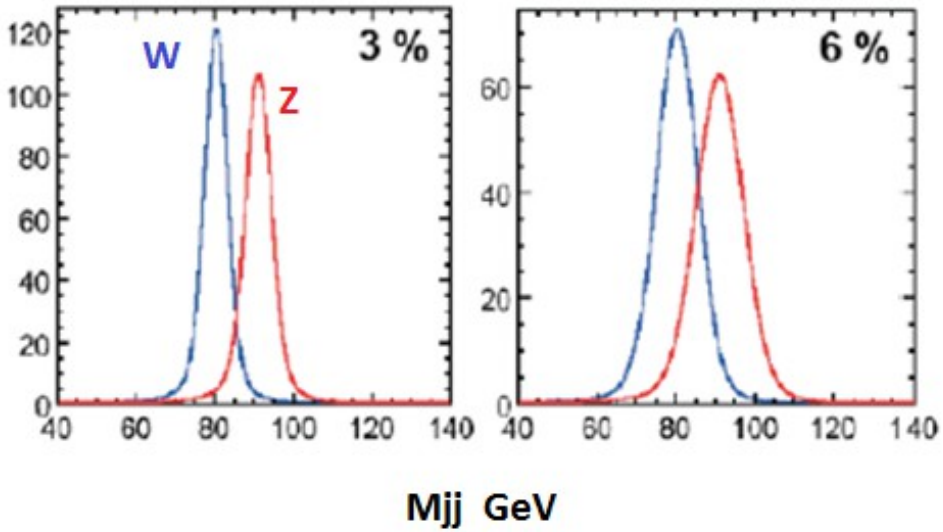
Detector requirements in high energy e+e- collisions

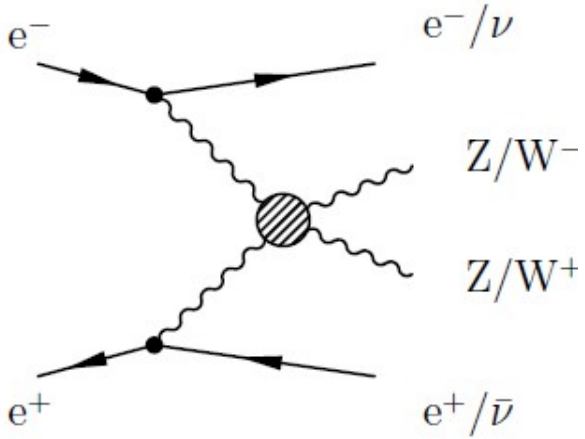


Examples:

- W Fusion with final state neutrinos requires reconstruction of H decays into jets
- Jet energy resolution of ~3% for a clean W/Z separation



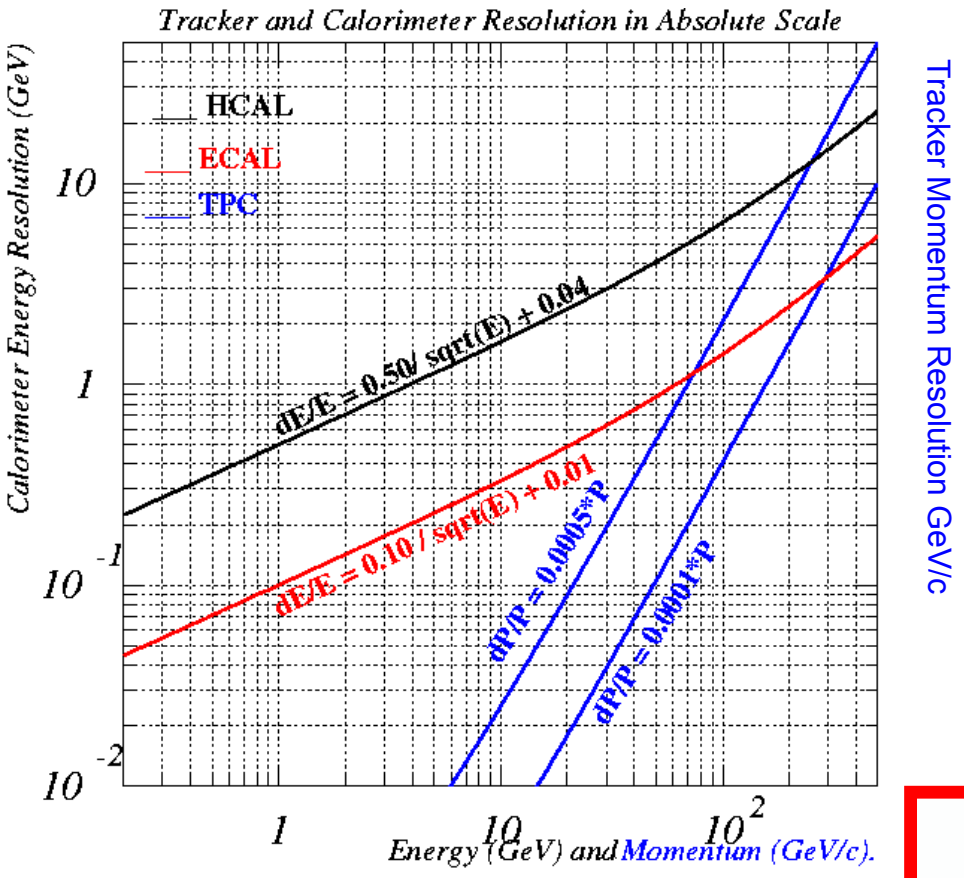




F. Richard at International Linear Collider – A worldwide event

Jet energy resolution

Final state contains high energetic jets from e.g. Z,W decays
Need to reconstruct the jet energy to the utmost precision !
Goal is around dEjet/E_{jet} - 3-4% (e.g. 2x better than ALEPH)



Jet energy carried by …

- Charged particles ($e^{\pm}$, $h^{\pm}$,$\mu^{\pm}$65% :((
  Most precise measurement by Tracker
  Up to 100 GeV

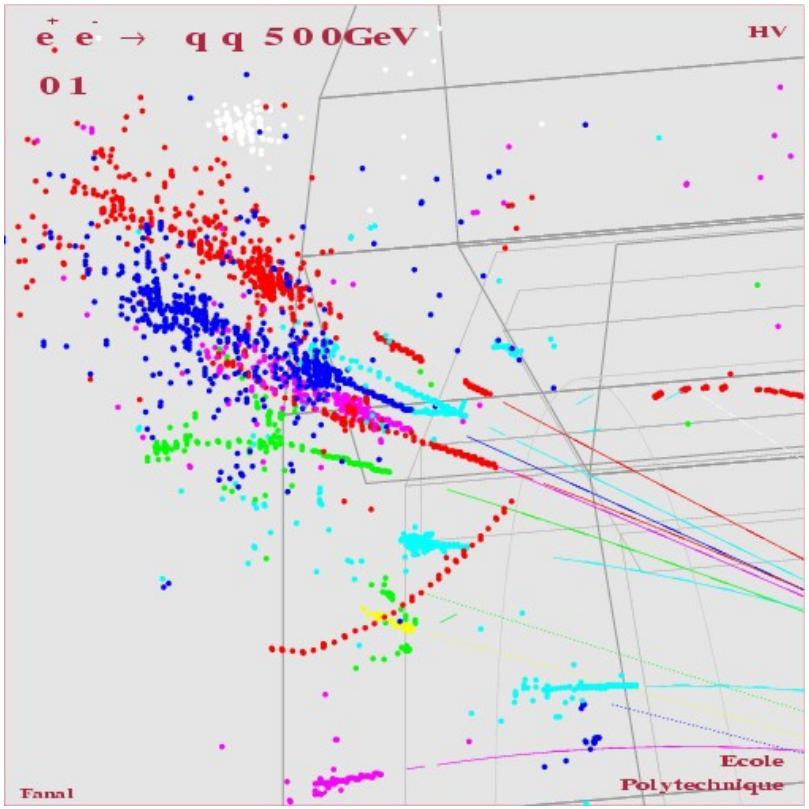
- Photons: 25%
  Measurement by Electromagnetic Calorimeter (ECAL)

- Neutral Hadrons: 10%
  Measurement by Hadronic Calorimeter (HCAL) and ECAL

$$\sigma_{Jet} = \sqrt{\sigma^2_{Track} + \sigma^2_{Had.} + \sigma^2_{elm.} + \sigma^2_{Confusion}}$$

Confusion term

- Base measurement as much as possible on measurement of charged particles in tracking devices
- Separate of signals by charged and neutral particles in calorimeter



- Complicated topology by (hadronic) showers

- Overlap between showers compromises correct assignment of calo hits

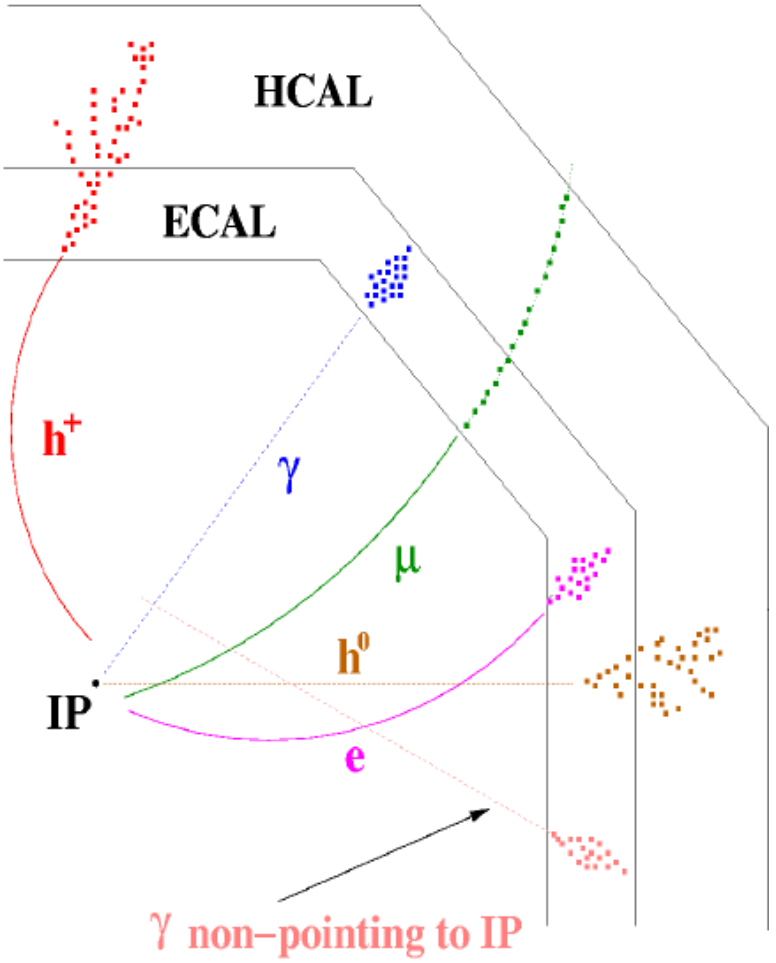
 Confusion Term

Need to minimize the confusion term as much as possible !!!

Partice Flow Detector

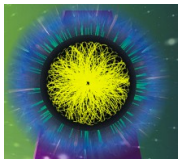
Jet energy measurement by measurement of **individual particles**
Maximal exploitation of precise tracking measurement

- large radius and length
  - → to separate the particles
- large magnetic field
  - → to sweep out charged tracks
- "no" material in front of calorimeters
  - → stay inside coil
- small Molière radius of calorimeters
  - → to minimize shower overlap
- **high granularity of calorimeters**
  - → to separate overlapping showers



Physics goals at the ILC demand the construction of highly granular calorimeters!!!
Emphasis on tracking capabilities of calorimeters

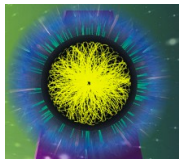
Assets of particle flow calorimeters



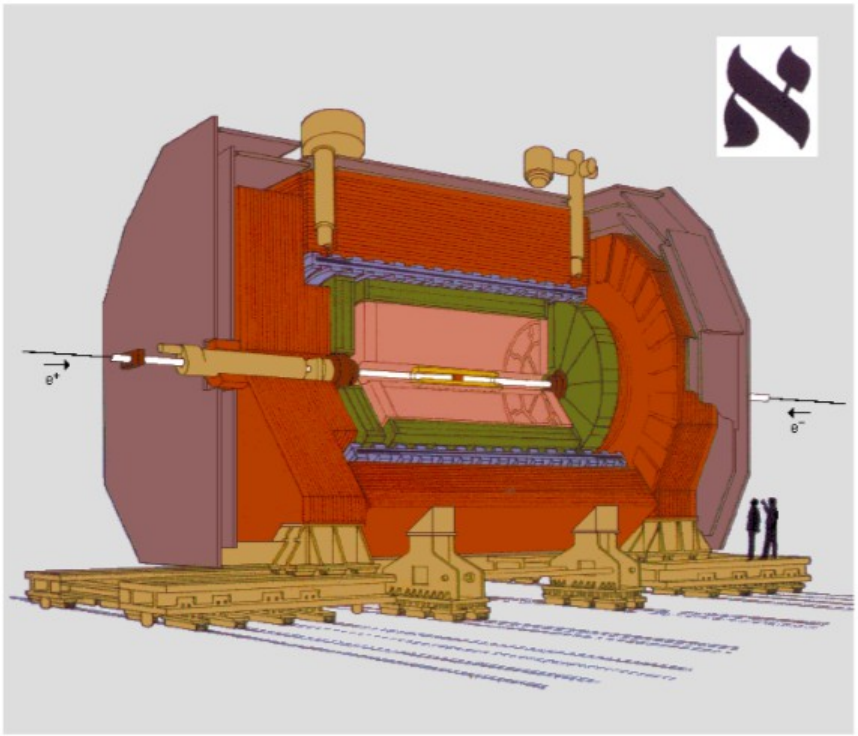
… from the calorimetric point of view

- Detailed view into hadronic showers
  - Lots of information to cope with shortcomings in energy resolution that may occur due to high sampling frequency
    => Opportunities for software compensation
  - Resolution of shower substructure allows for in-situ calibration of detectors with track segments
    => In situ calibration and no or few calibration runs needed during detector operation
- Leakage correction
- Particle ID

ALEPH – Pioneering Particle Flow Calorimetry



... well actually energy flow ....



The ALEPH Detector

- LEP Experiment
- Running 1989 - 2000

- First detector "designed" for PFA

- TPC

- Highly Granular Calorimeters
  e.g. Ecal
  3 Layers
  220000 Cells
  R&D since beginning of 80s

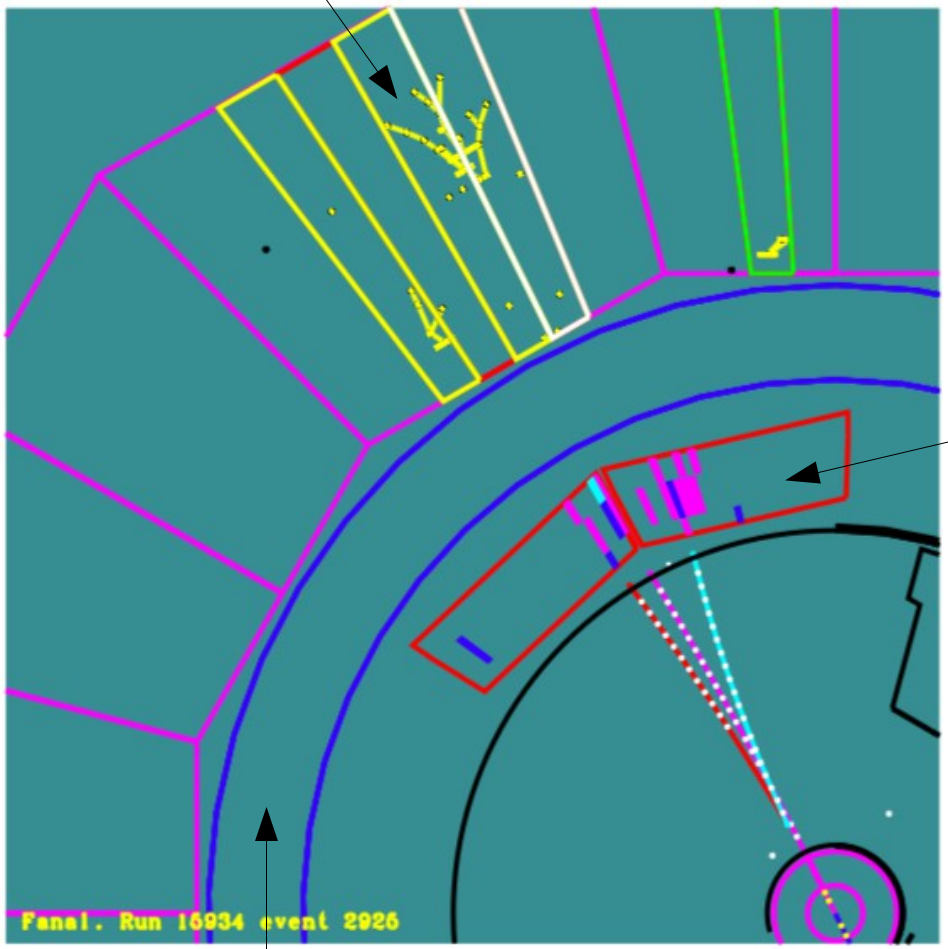
- ALEPH benefited from progress in electronic chip improvement (dixit J. LeFrancois)

References for the following
- J. Le Francois "Role of Pisa in ALEPH" talk
- H. Videau, hal-in2p3-00069714
- H. Videau, NIM 225 (1984) 481

ALEPH – Event display

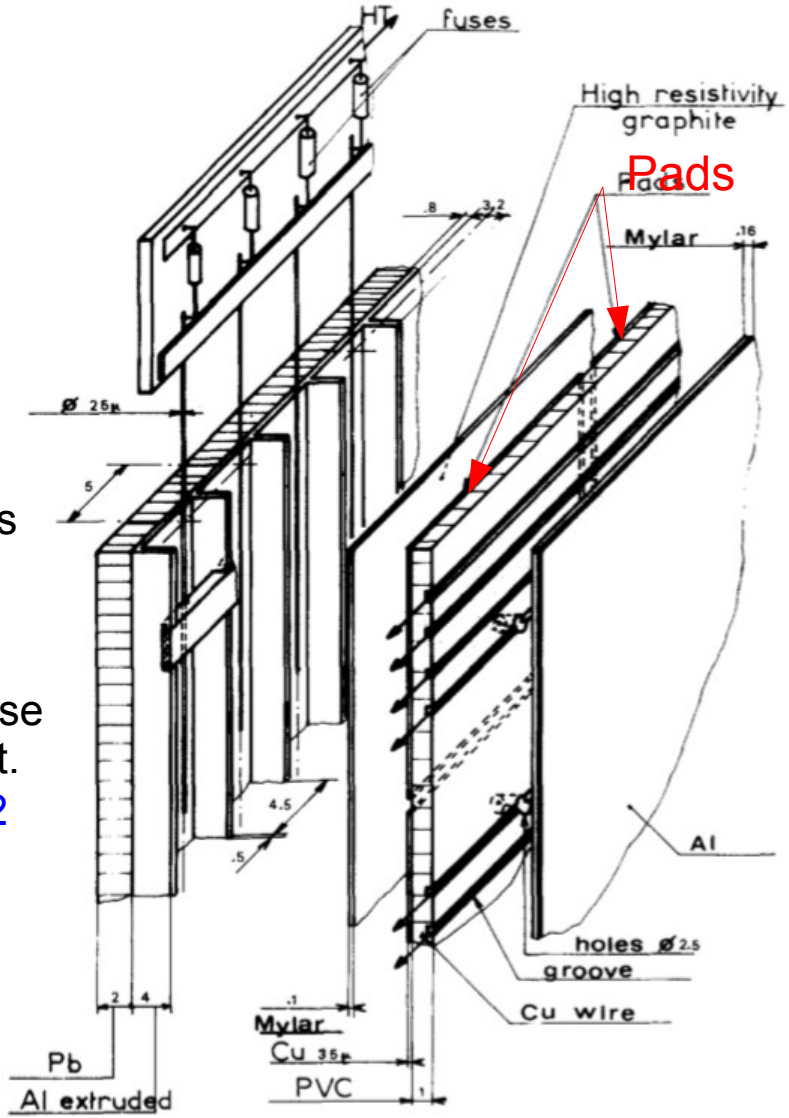
Hcal (Iron absorber, streamer tubes)

Energy by analogue sum of Towers
Shower pattern by digital r/o of pads



Ecal

- Gaseous detector
- 3 layers
- High transverse segment.
  3x3 cm2

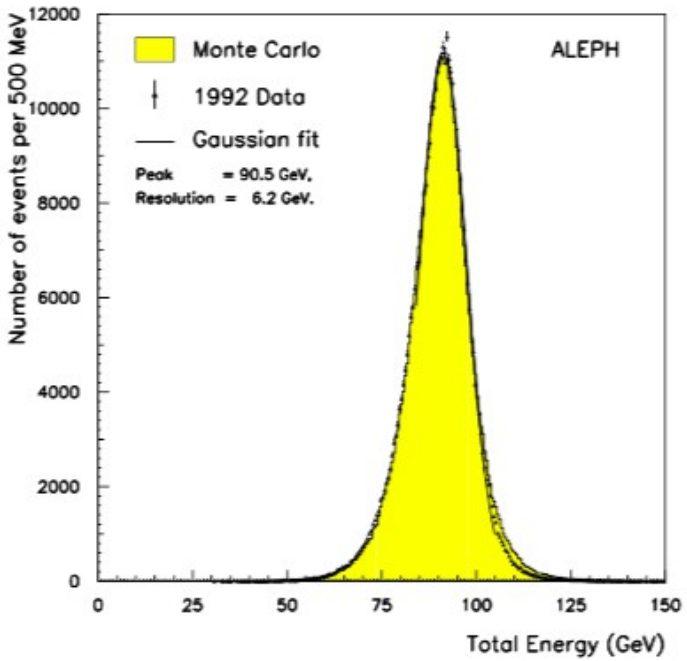


Magnetic Coil between calorimeters :-(

Jet energy resolution and diboson scattering

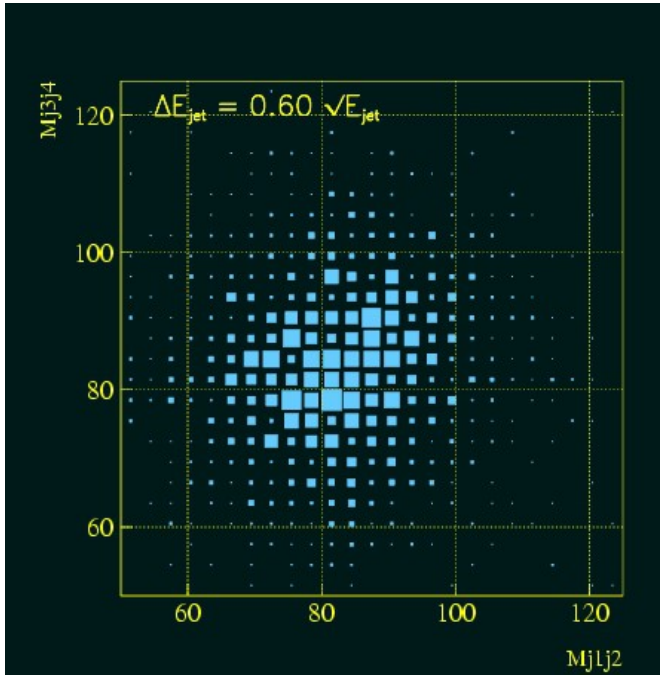
ALEPH: jet energy resolution based on pure calorimetric information 120%/√E

Z-> jets

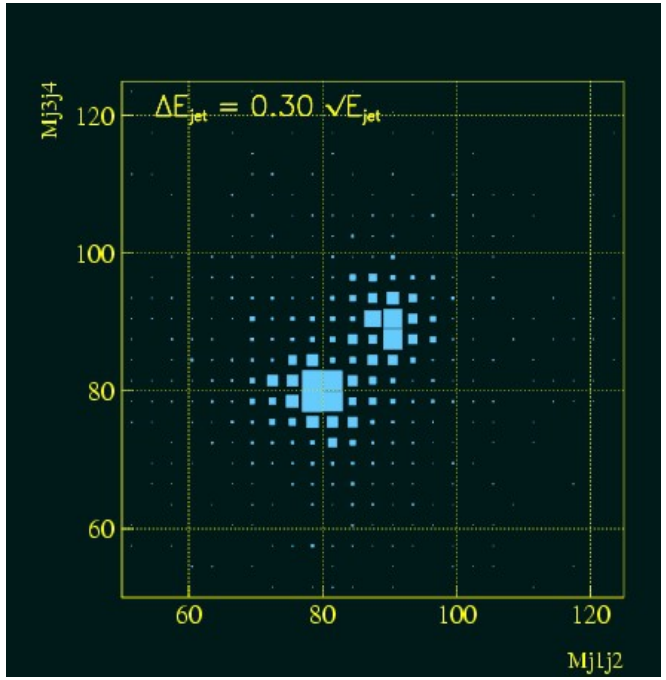


60%/√E

ee->WW, ZZ

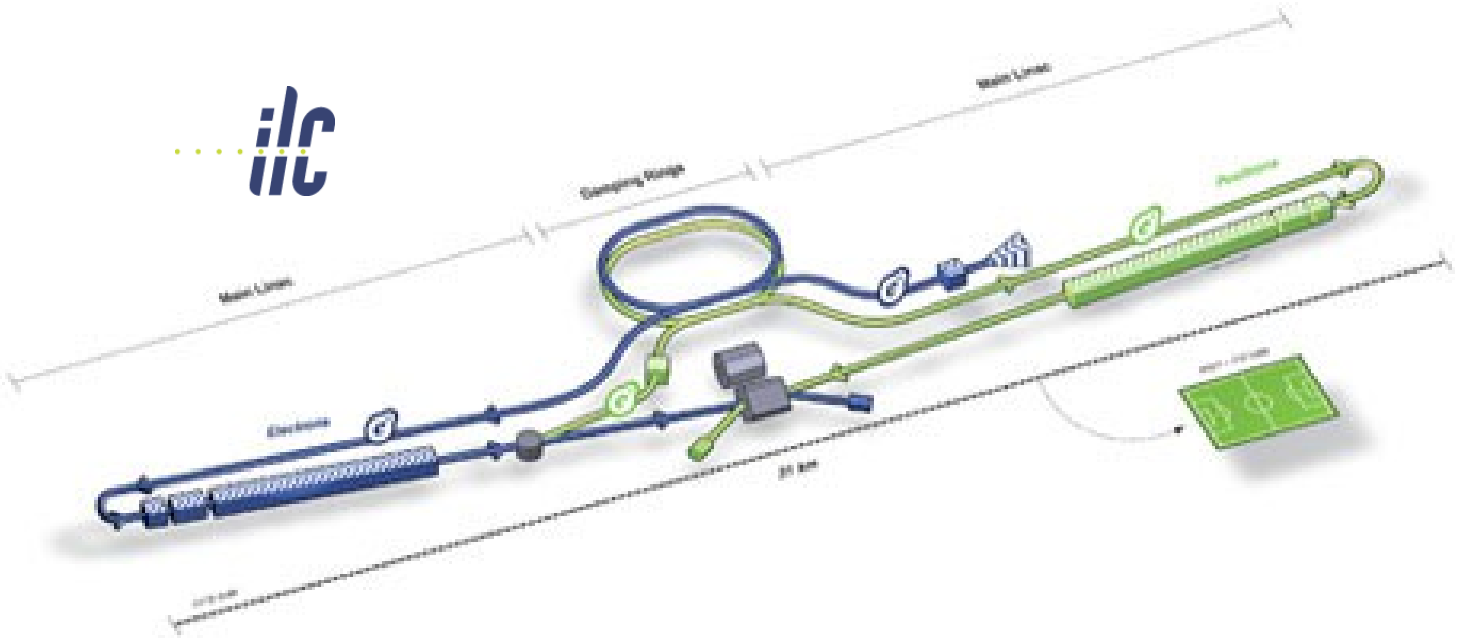


'ALEPH resolution"

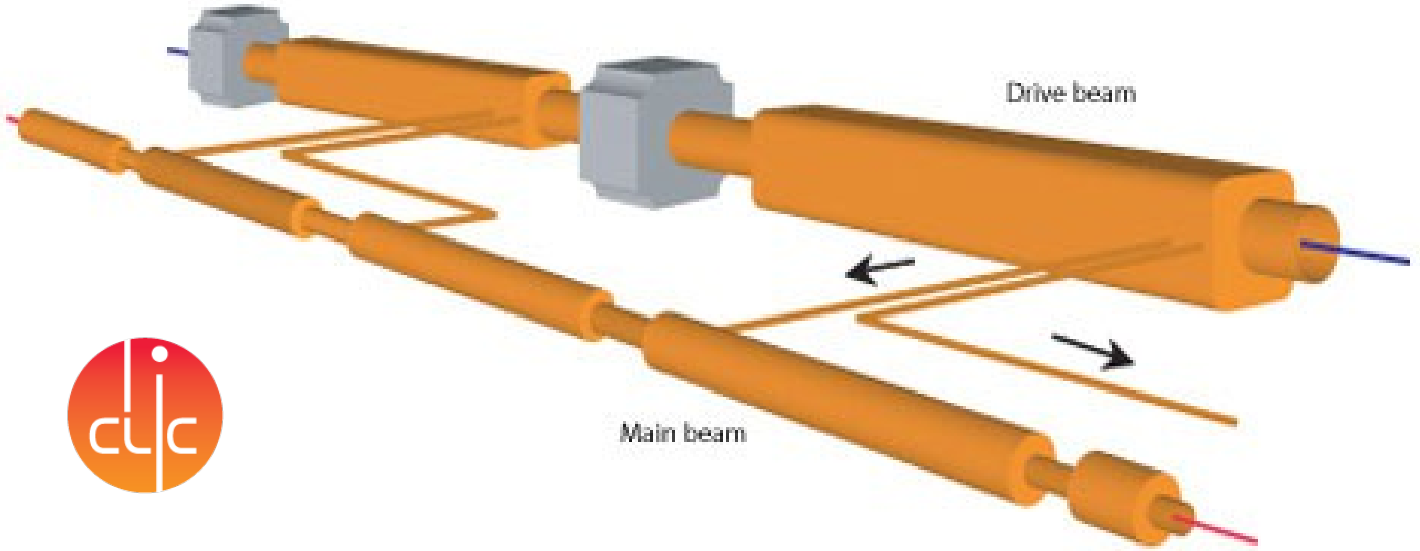


30%/√E

Linear Electron-Positron Colliders Projects



Energy: 0.1 - 1 TeV
Electron (and positron) polarisation
TDR in 2013
+ DBD for detectors
Footprint 31 km

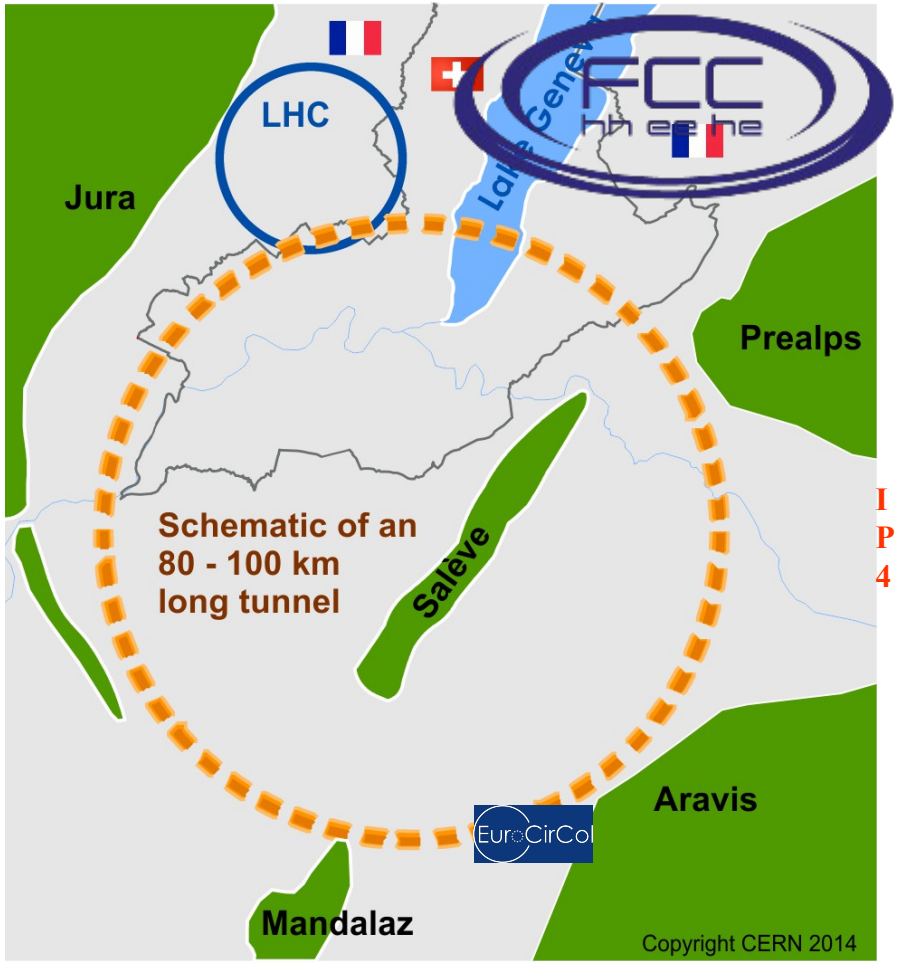


Energy: 0.5 - 3 TeV

CDR in 2012

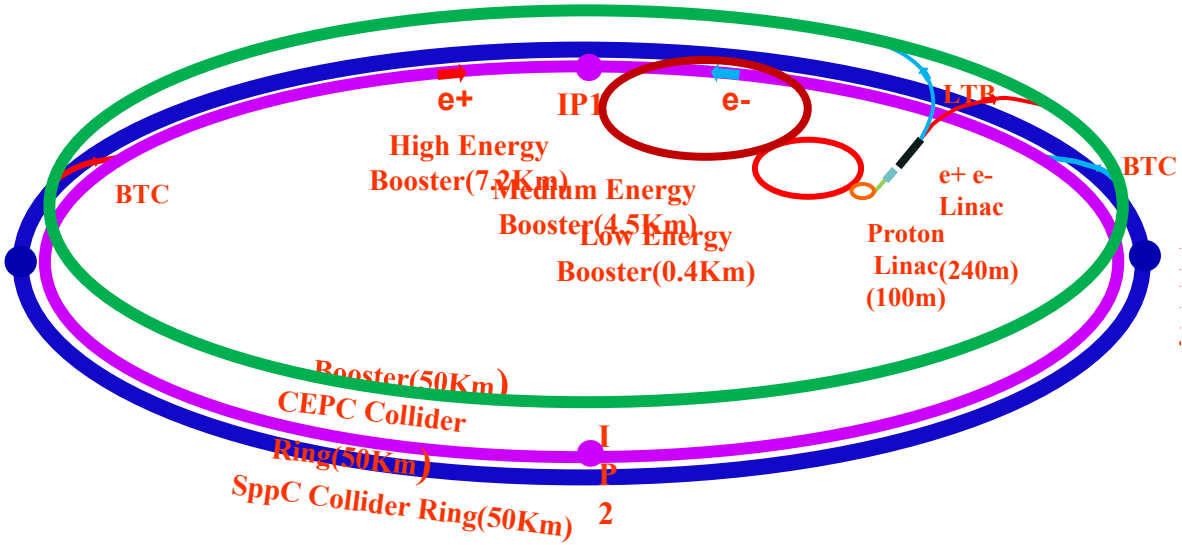
Footprint 48km

Circular Electron-Positron Colliders Proposals



- ~100 km storage rings
- Coupled to hadron collider proposal
- 90 – 350 GeV cms energy
- No long. beam polarisation
- CDR Phase

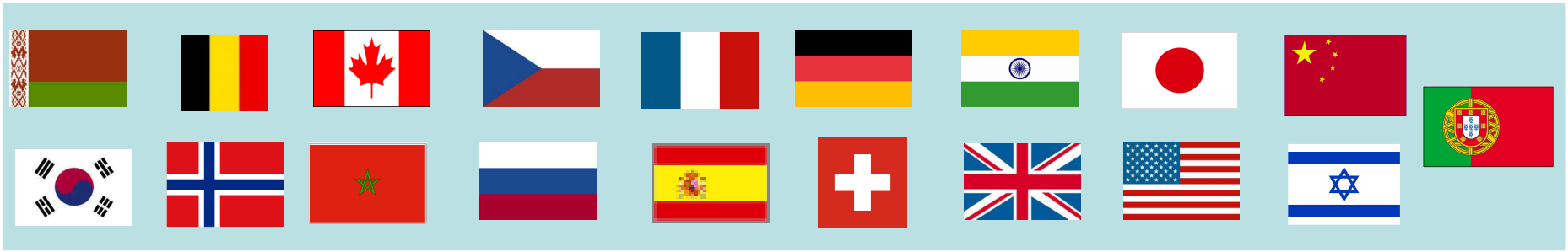
CEPC



- ~50 km storage rings
- Coupled to hadron collider proposal
- 90 – 240 GeV cms energy
- No long. beam polarisation
- (Pre-)CDR Phase

The CALICE Collaboration

Calorimeter R&D for the  … and beyond



~360 physicists/engineers from 60 institutes
and 19 countries from 4 continents

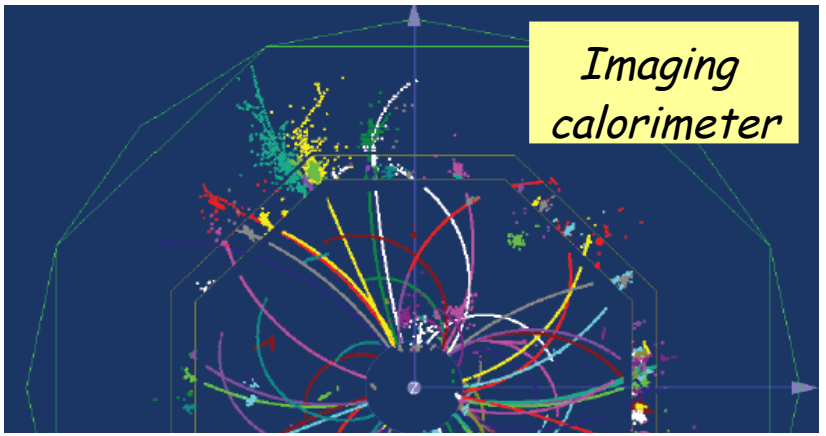
- Integrated R&D effort

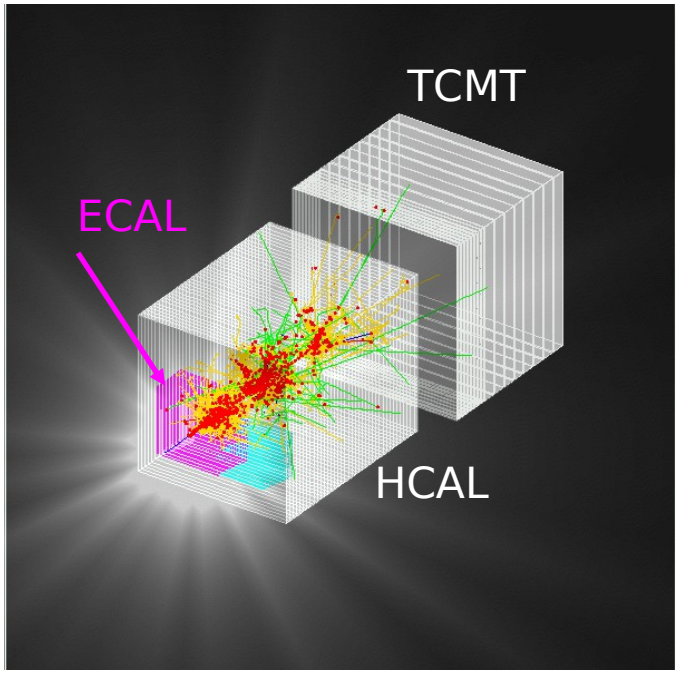
- Benefit/Accelerate detector development due to *common* approach

CALICE Mission

Final goal:

A highly granular calorimeter optimised for the Particle Flow measurement of multi-jets final state at the International Linear Collider



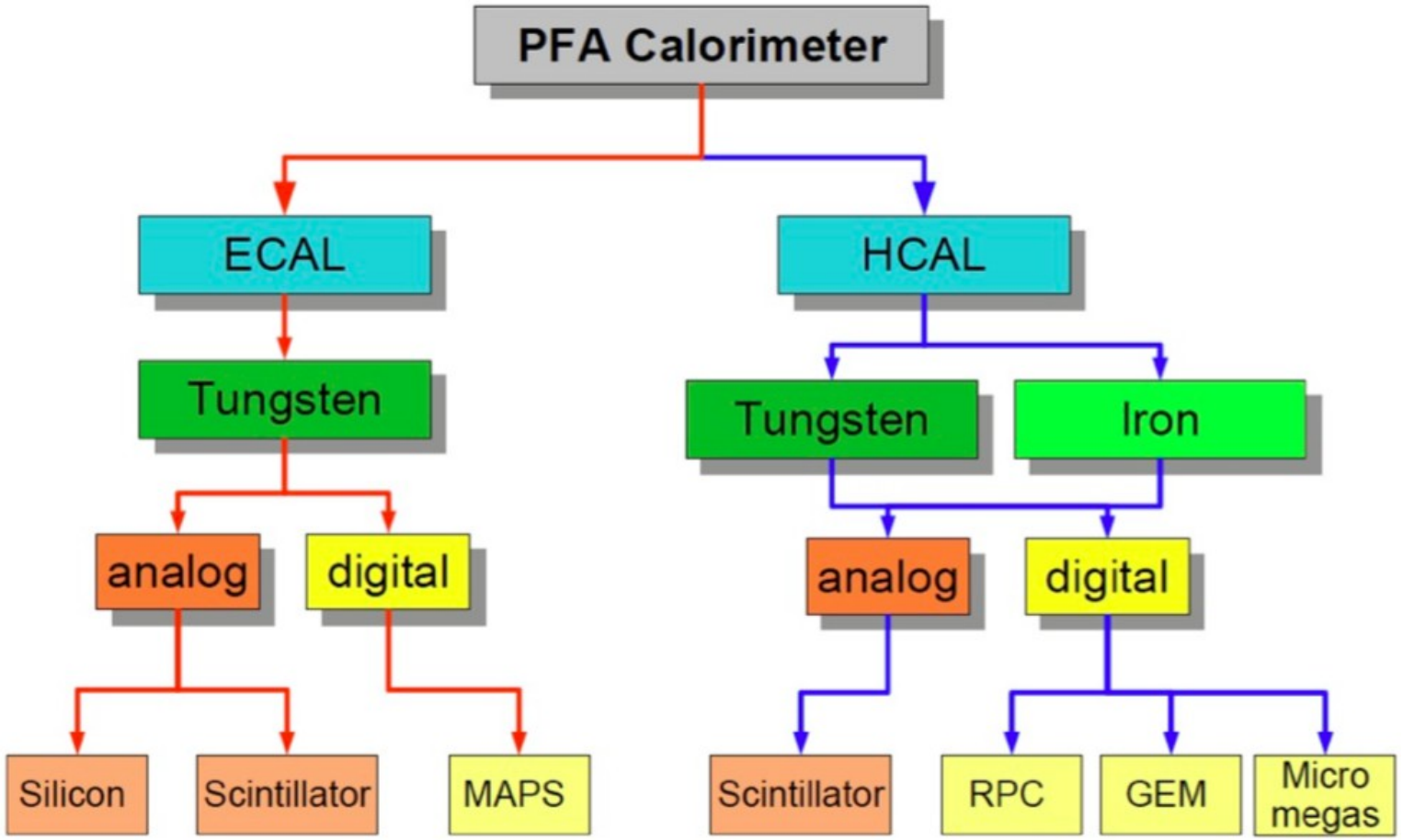


Intermediate task:

Build prototype calorimeters to
- Establish the technology
- Collect hadronic showers data with unprecedented granularity to

- tune clustering algorithms
- validate existing MC models

Calorimeter technologies for PFA Detectors

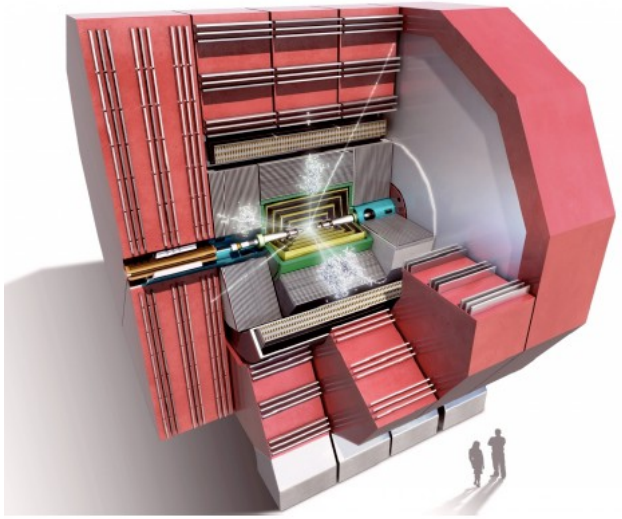


All aspects will be presented and discussed at this workshop

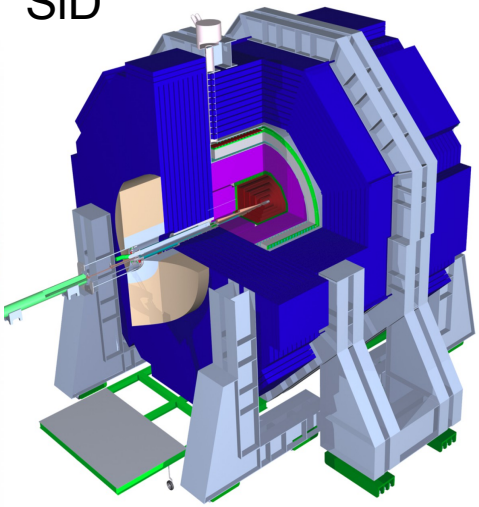
“Clients” for particle flow

e+e- detector concepts

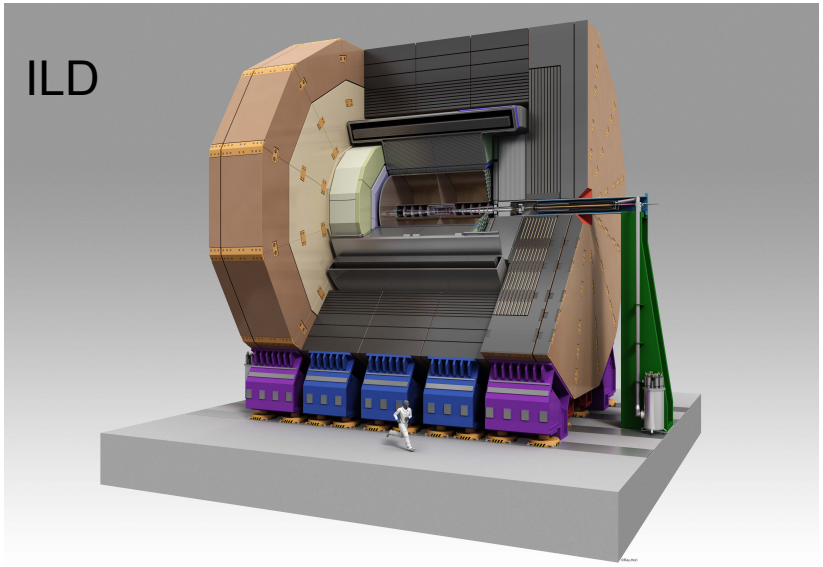
CLIC Detector



SiD



ILD



Highly granular calorimeters

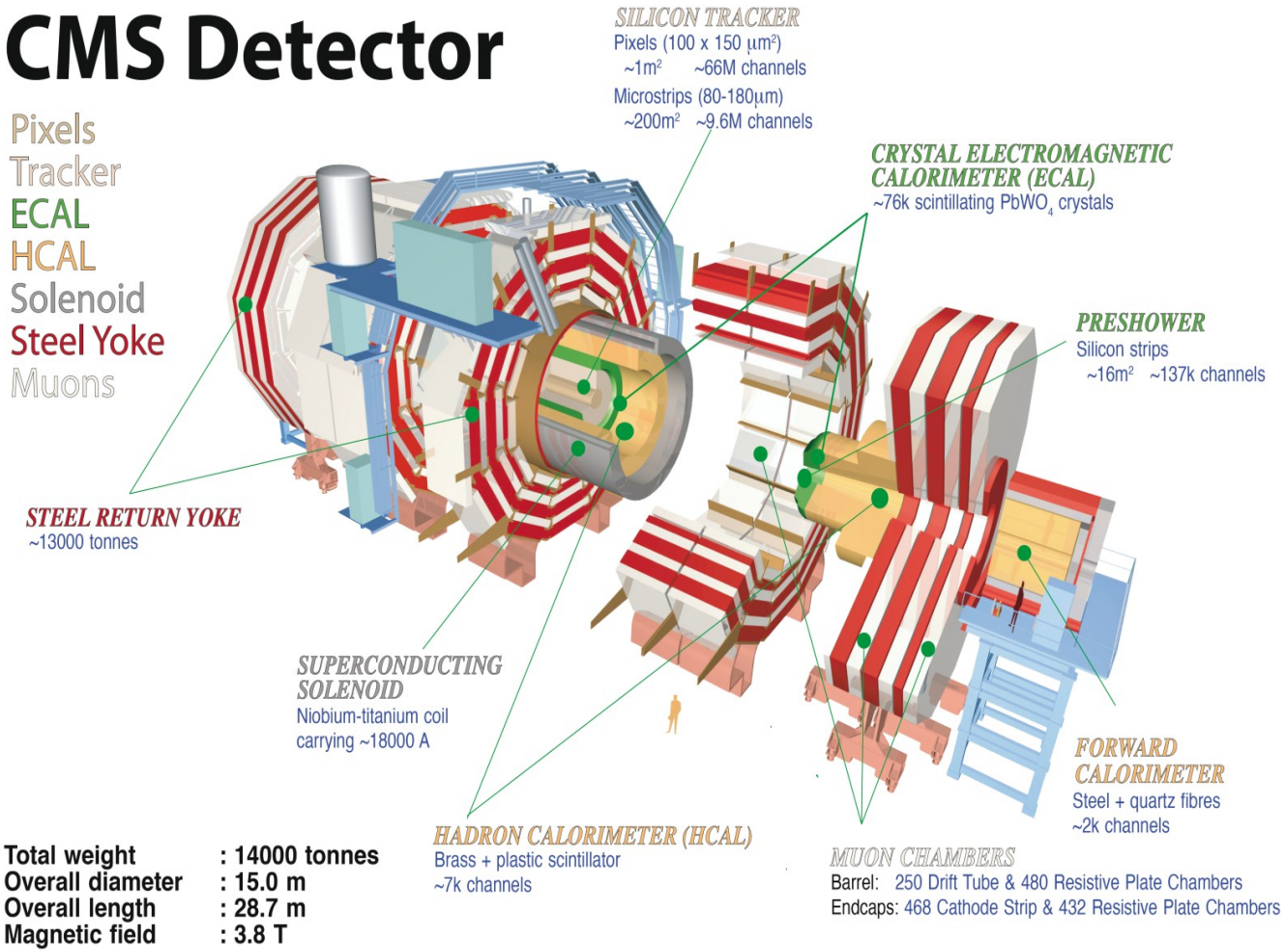
Central tracking with silicon

Central tracking with TPC

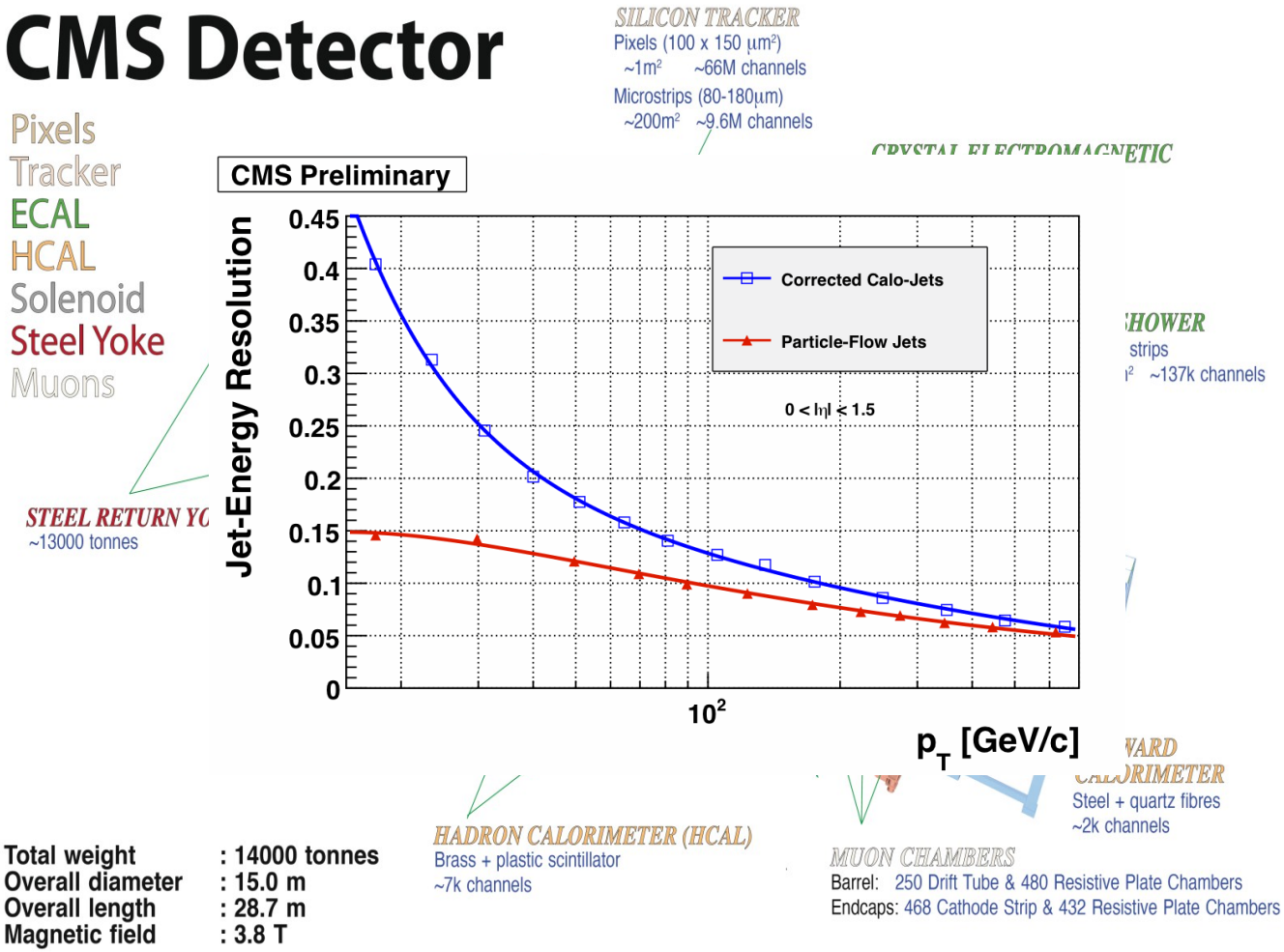
Inner tracking with silicon

Detailed discussion at this workshop

PFA in LHC Experiments - CMS



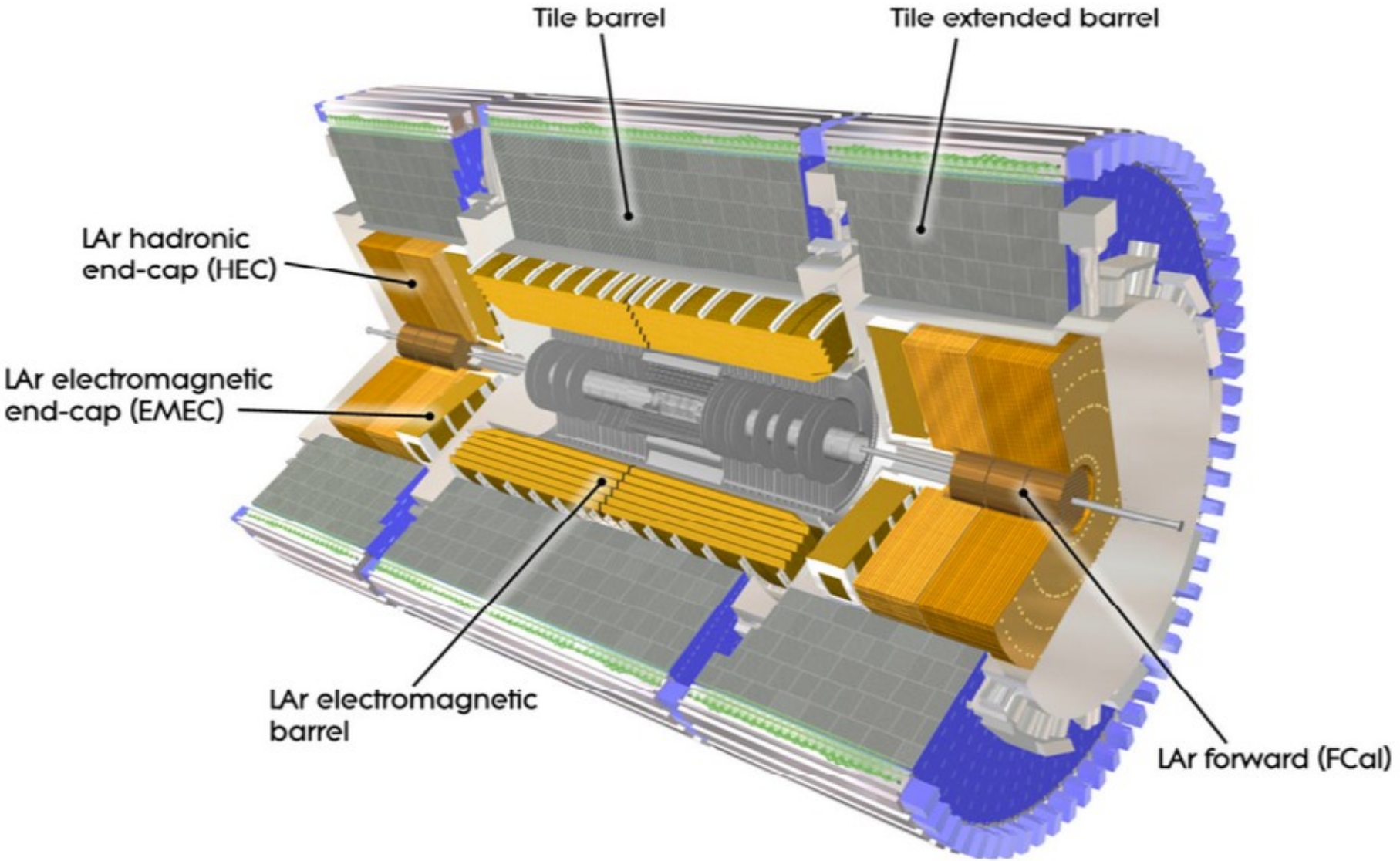
PFA in LHC Experiments - CMS



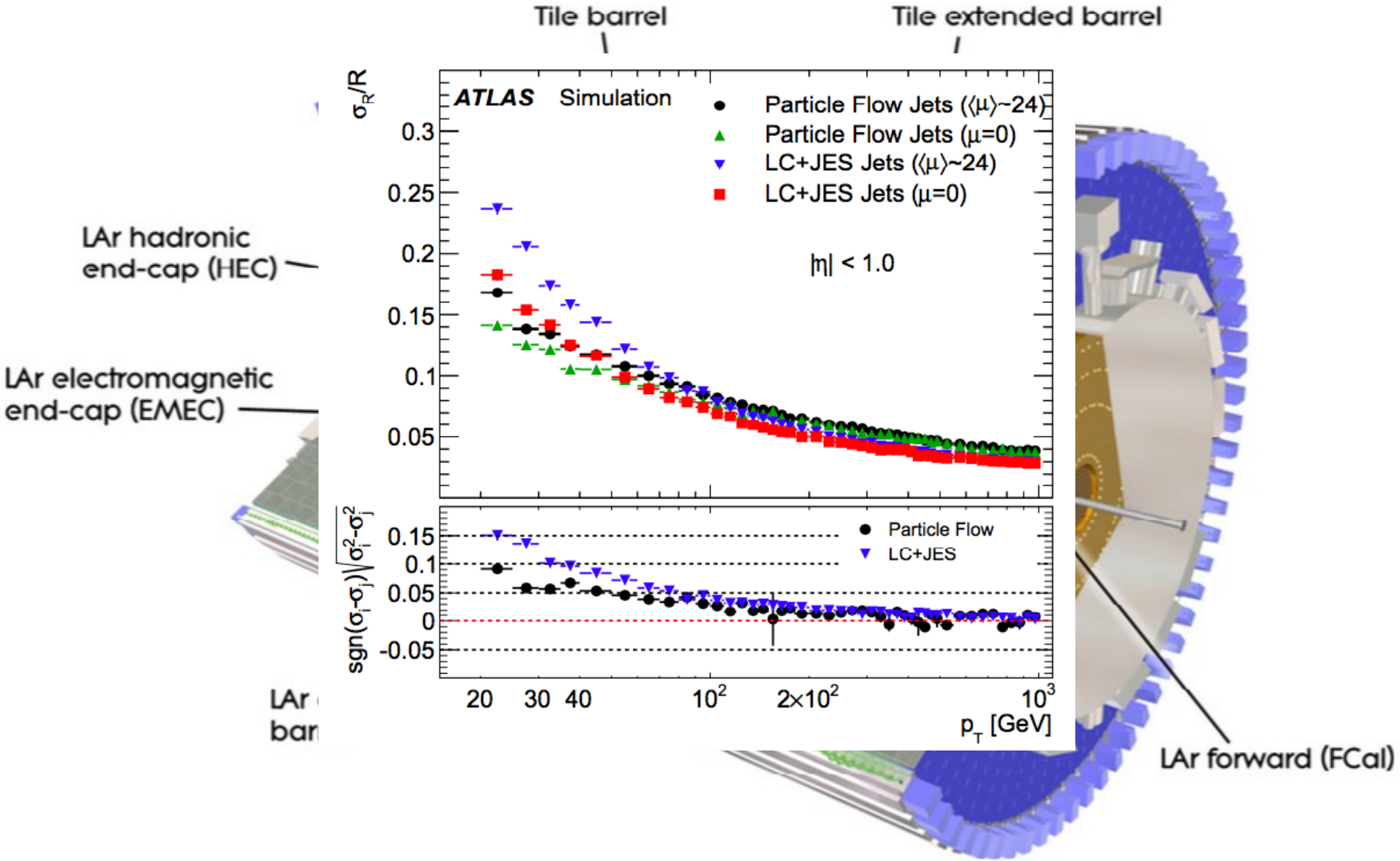
Particle flow works even in harsh hadron environment

More on PFA in CMS at this workshop

PFA in LHC Experiments - ATLAS



PFA in LHC Experiments - ATLAS

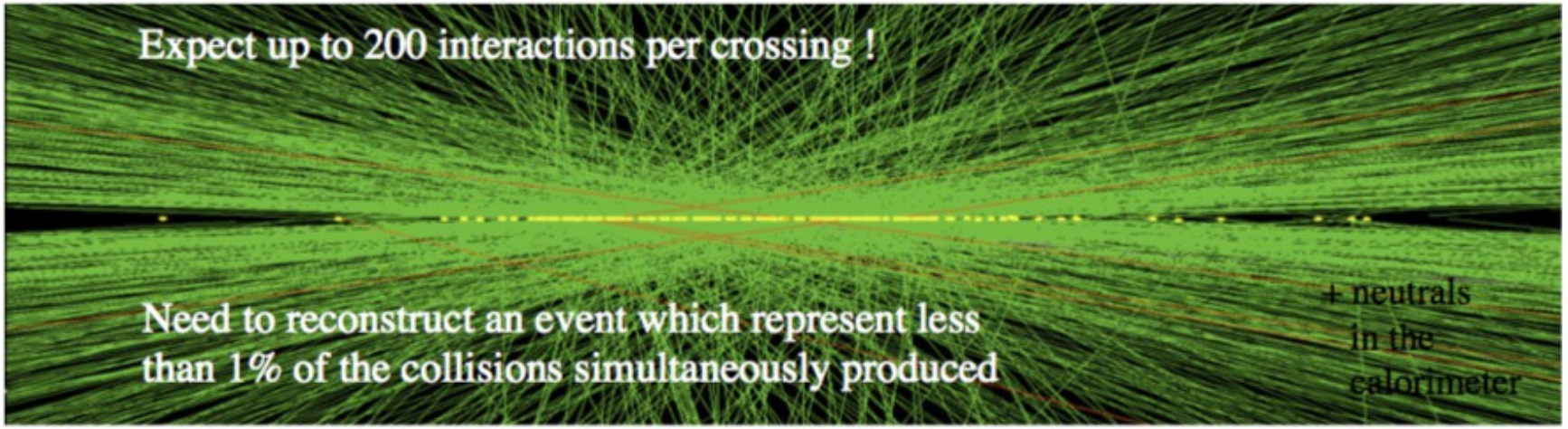


... even pile-up can be mitigated with PFA Approach

EPJC (2017) 77:466

New kid on the block - Timing

LHC Challenge



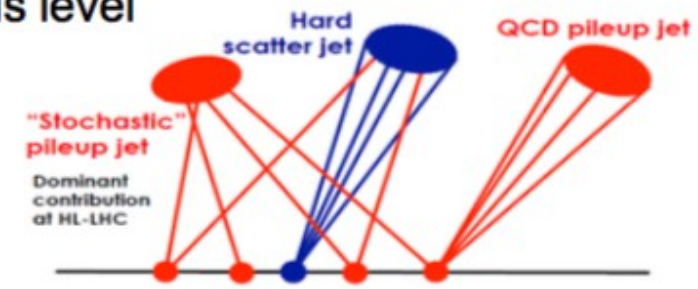
Spatial separation: Mean z-spacing of vertices down to ~ 500 µm

For a Poisson distributed probability per unit length for a beam interaction
- → spatial separation of two neighbouring vertices is exponentially falling
- → **significant overlap probability in vertex reconstruction**
- → PF algorithms start to fail in end cap region for <PU> ~200

Timing separation The RMS spread of vertices is ~ 150 ps

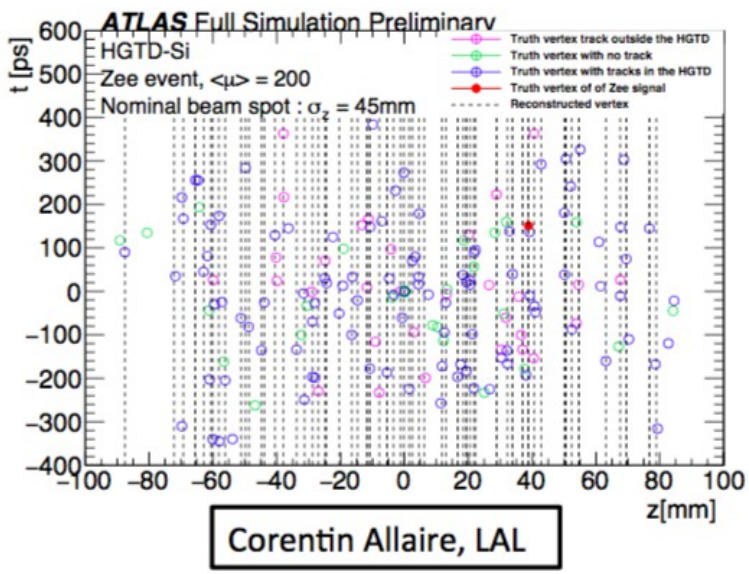
Goal: maintain or improve the performance of the forward detector at HL-LHC with <PU> ~ 200 at trigger or analysis level

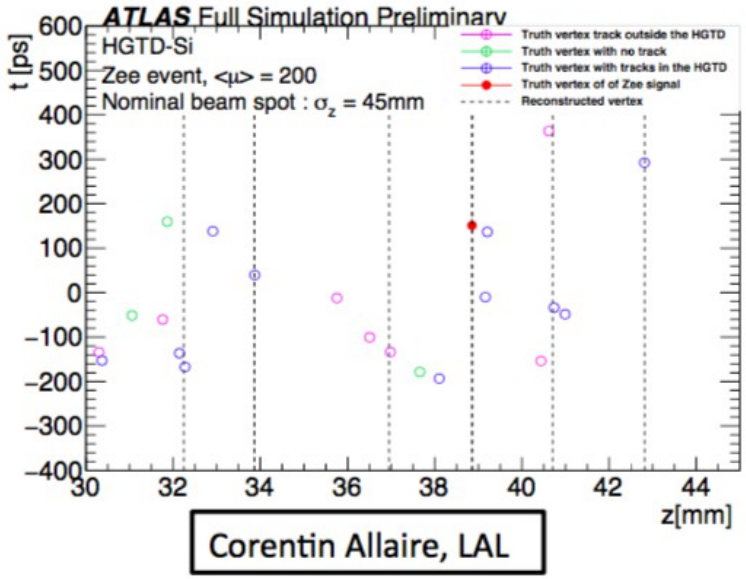
Benchmark processes:
- Primary vertex for H -> γγ
- VBF production with X 2> invis. against Z + jet & fake forward jets



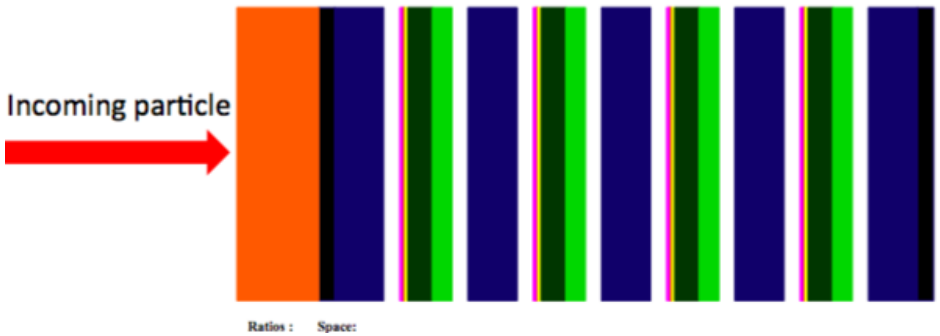
Cleaning up LHC Events

Z->ee: Timing allows for filtering the correct vertex

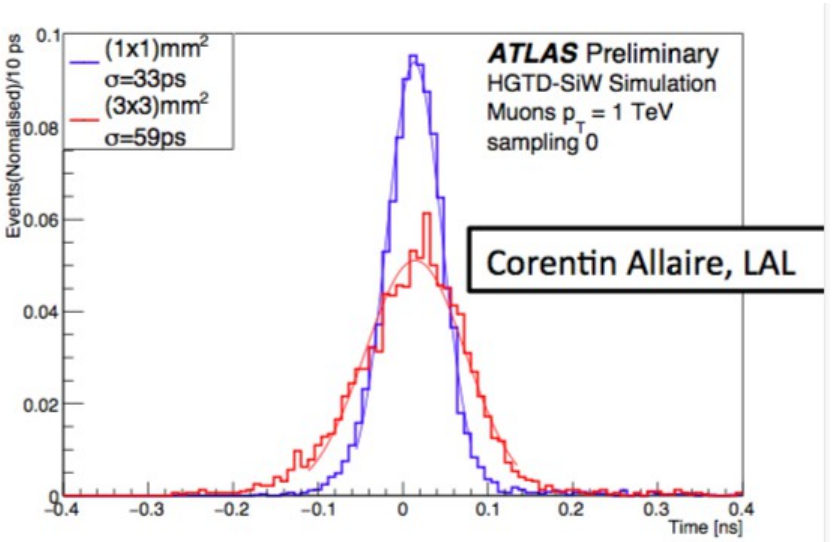




Optimal cell size?

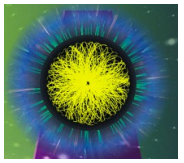


- HGTD Si: 43 mm, 4 Si sensors
- Timing simulation based on beam test results



More on timing at CMS in talk by Huaqiao

... and in e+e- detectors?

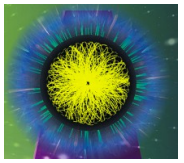


- Timing may be useful to clean up hadronic showers
  Identification of slow/fast component of hadron shower
  Time resolution needed O(1ns)

- Timing for Particle ID
  Use the calorimeter as “hodoscope” or by inferring timing
  Information from signal formation by large energy deposits
  Time resolution needed O(10 ps)

- (Major) hardware and software challenges ahead
  “Do we have time for timing?” (dixit Henri Videau)

Conclusions



- LAL team got reinforced by electronics engineers over summer and additional mechanics engineers
-

Backup