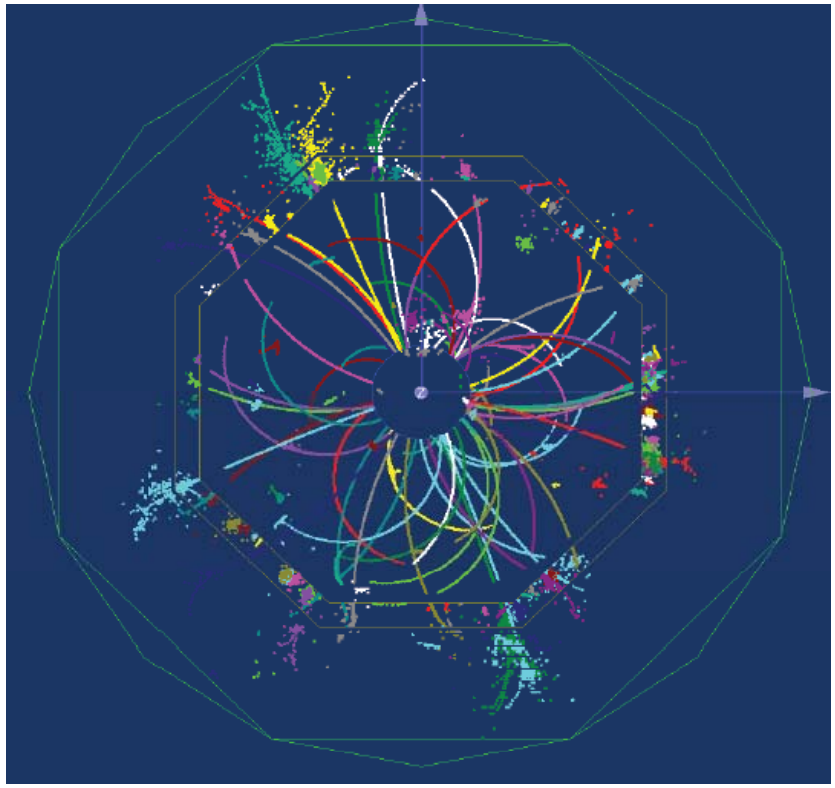
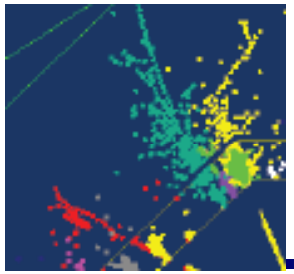


Calorimetry and Muon Overview

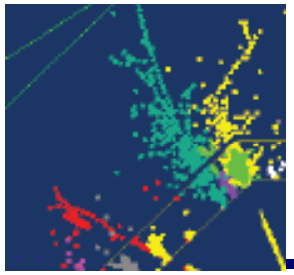
Felix Sefkow

LCWS08
Chicago, November 15-20, 2008



Not a summary

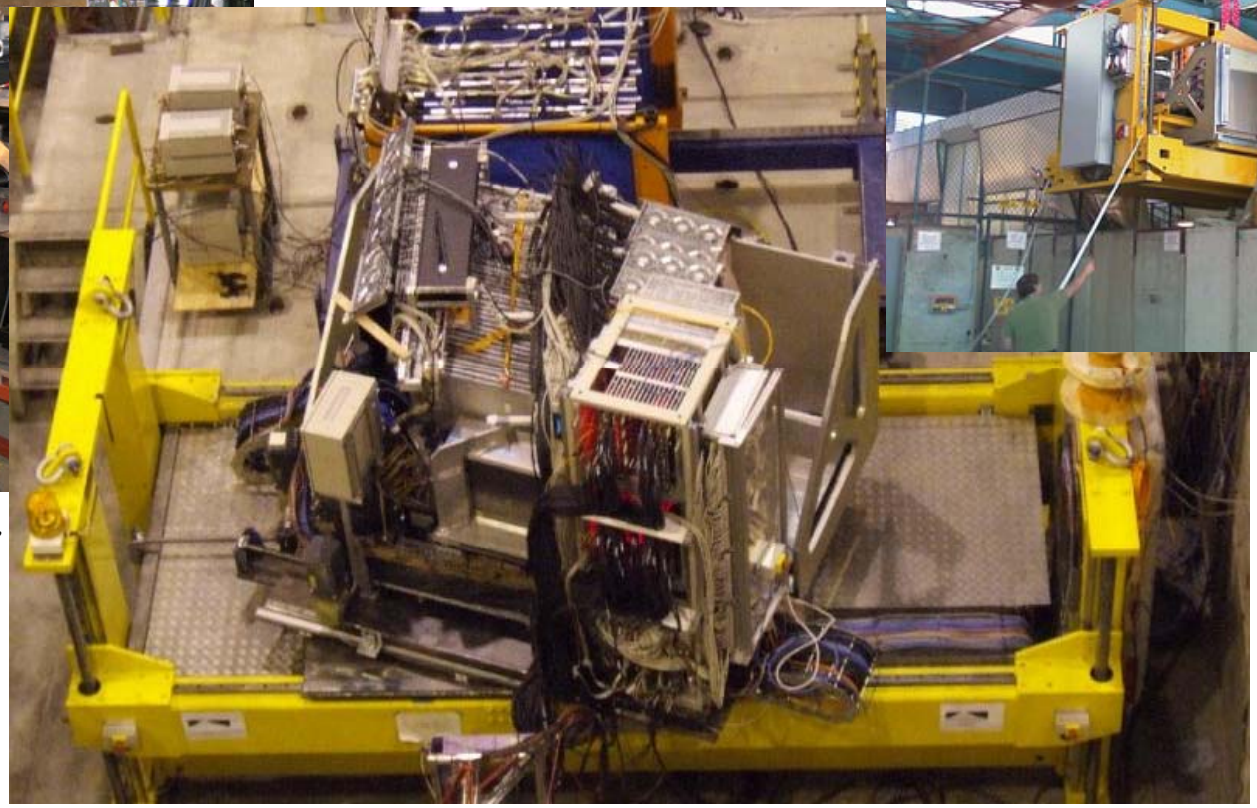
- 6 parallel sessions with 27 talks
- Thanks to all speakers for excellent and inspiring presentations
- And apologies for not even attempting to give balanced summary here
- The CALICE results and programme comprehensively presented by Jean-Claude Brient in Monday's plenary
  - Goal: ready for proposing a realistic detector with engineer-backed price tag by 2012 and start pre-production prototypes



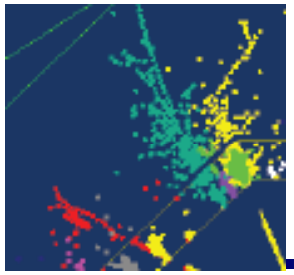
Test beam experiments

DESY 2005

CERN 2006-2007

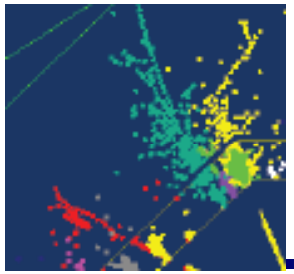


FNAL 2008



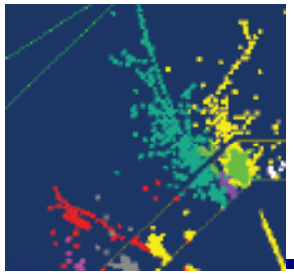
CALICE summary

- First round of test beam experiments completed
- Si W ECAL and Scintillator/SiPM Fe HCAL perform according to expectations - as implemented in particle flow simulations
- Experimental proof of principle for a PFLOW detector delivered
- Scintillator ECAL test beam ongoing
- Tests with gaseous (semi-) digital large prototypes upcoming
- Scalable realistic technology prototypes addressing the challenging integration issues of a compact detector underway



Outline

- The conceptual frontier
  - A personal view
- The technology frontier
- The engineering frontier

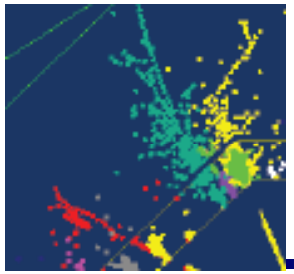


Problem of hadron / jet calorimetry

- Large variety of physics processes and smaller number of interactions
- Large fluctuations in shower development and detector response
  - Around 40% electromagnetic energy fraction, fluctuating and rising with energy
  - The rest contains about 20% of invisible energy (and 5% neuron E)
- Non-linearity and insufficient resolution

- Classical jet measurement yields single hadron response also for well measured tracks and photons – or worse (LHC: 100%/√E)

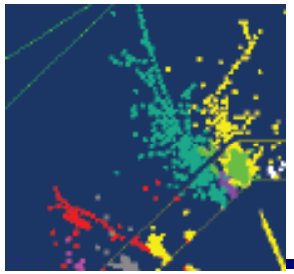
- Strategies in the past: compensation
  - Hardaere: suppress em, enhance had (neutron) response
  - Software: re-weight according to density (segmentation)



New concepts

- Hardware (and software): ultimate compensation by directly measuring the electromagnetic component in each event, in addition to the total energy, and correcting for it
- ➔ dual readout calorimeters

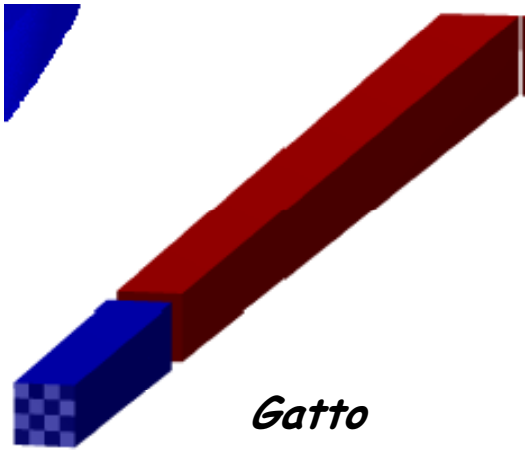
- Software (and hardware): measure each particle in a jet individually and limit the problems of hadron calorimetry to the 10% or so of K_L and n in the jet; needs imaging granularity
- ➔ particle flow approach



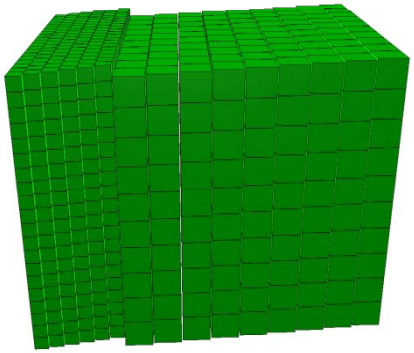
Dual readout

- Cerenkov light emitted from relativistic particles in the shower only – thus essentially measures the e.m fraction

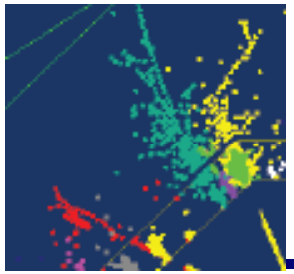
- Detector options
  - DREAM: scintillation and Cernekov fibre matrix
  - Possibly complemented by crystal em section
    - Separate light using directionality, colour or pulse timing
  - Total absorption (all-crystal) em+had calorimeter



Gatto

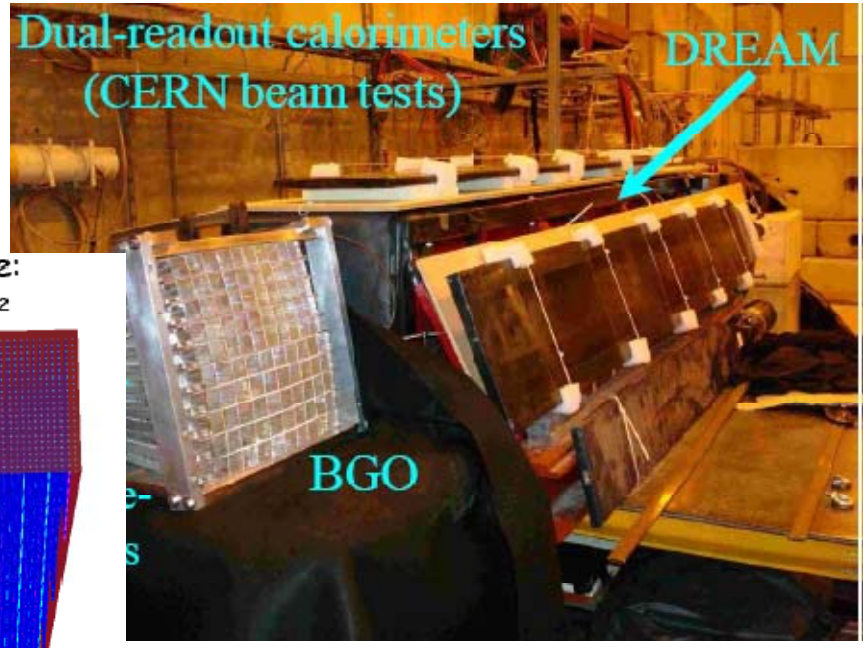


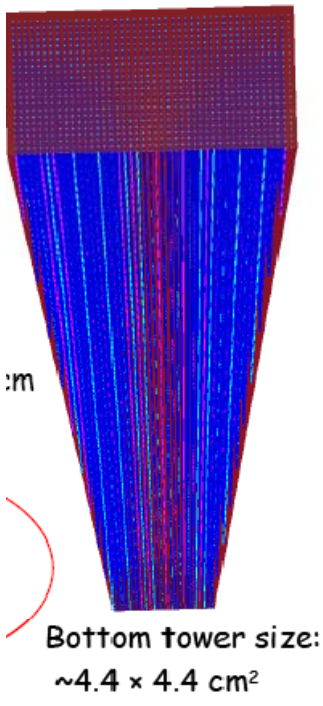
Para



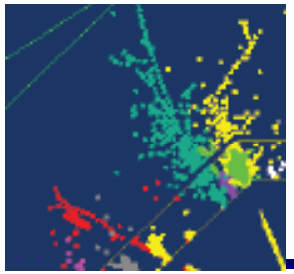
DREAM

- Beam test results with DREAM fibre matrix and BGO, so far separately only
- Interpretation hampered by limited size of detector and significant leakage
- Light yield basis of 4th concept simulations





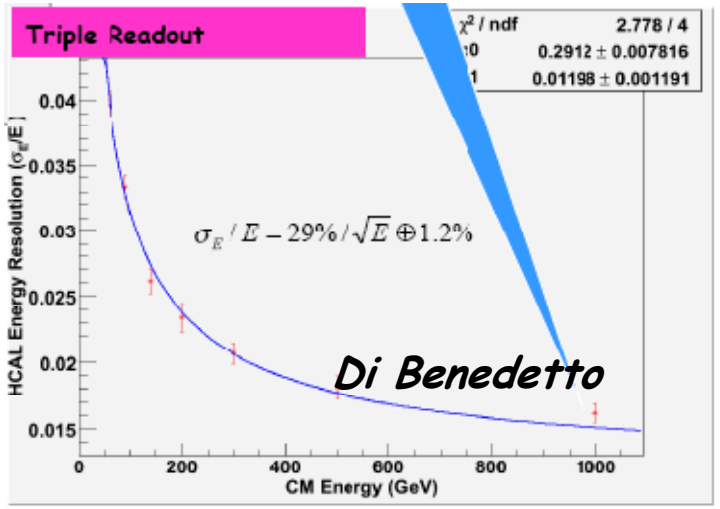
Hauptmann

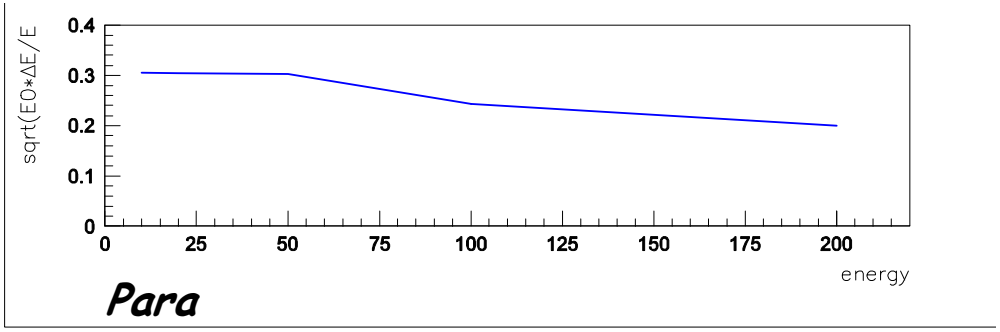


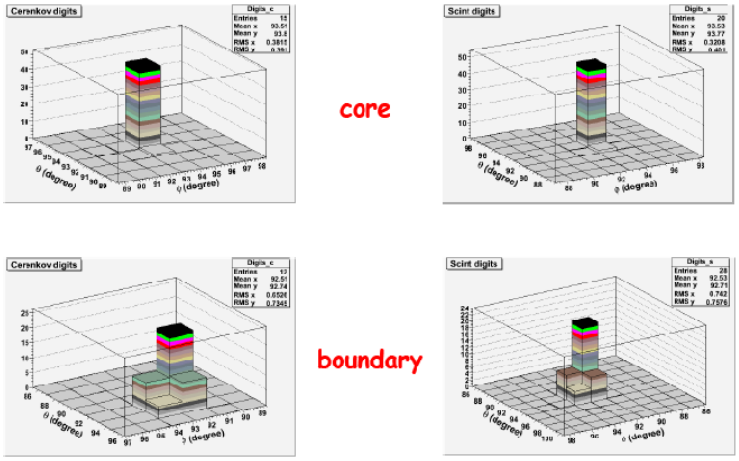
Dual readout simulations

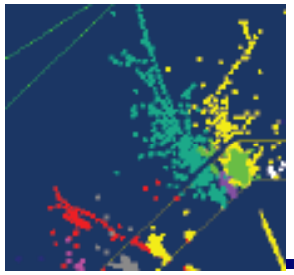
- 4th concept: very good stochastic term, constant term to be understood
- And eliminated - if possible

- Total absorption: very promising
- But: crude simulation s far







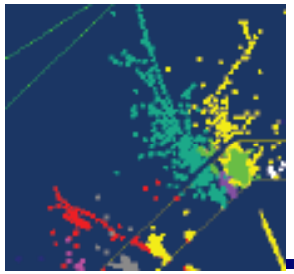


Dual readout

- Attractive ideas – yet many open questions
- Concepts need to be married with technologies
- Interplay crystals and fibres to be understood

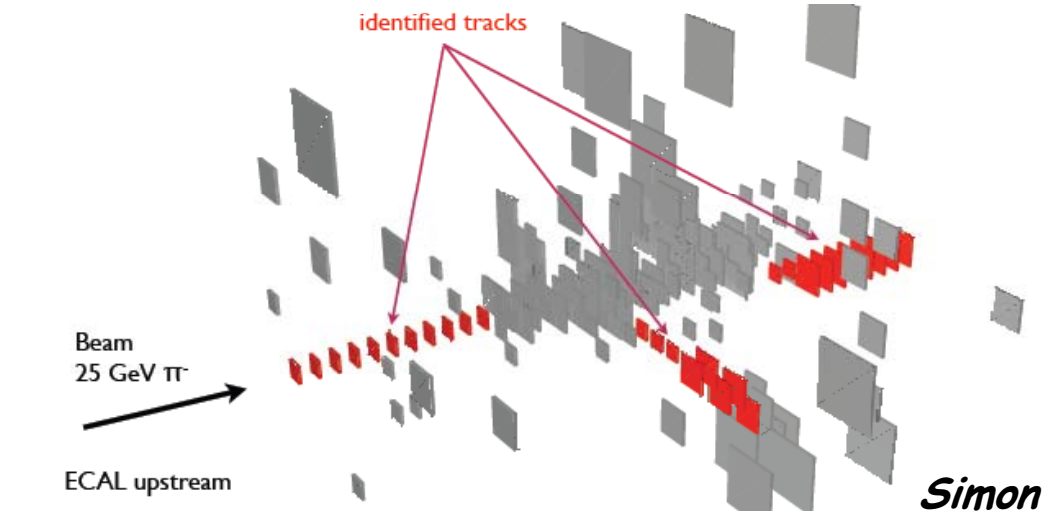
- Light yield, photo-sensors, electronics, calibration system
- p.e. statistics, noise, stability
- integration, dead material, cost
- Operational experience, in-situ calibration strategies

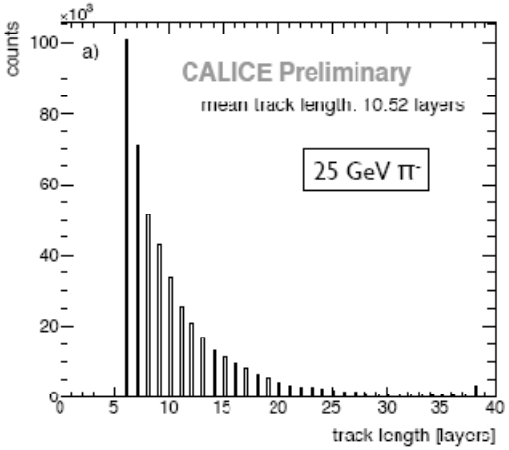
- Beam tests – more realistic, or first at all, to be conceived

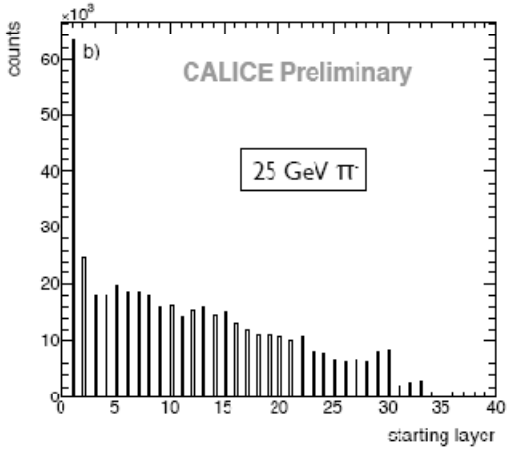


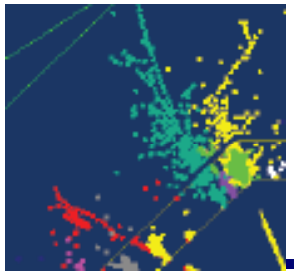
Imaging calorimetry

- Separate particles
- Resolve substructure in the shower
- New possibility for calibration on MIP scale using track segments in the cascade
- 1.7 tracks / hadron on average



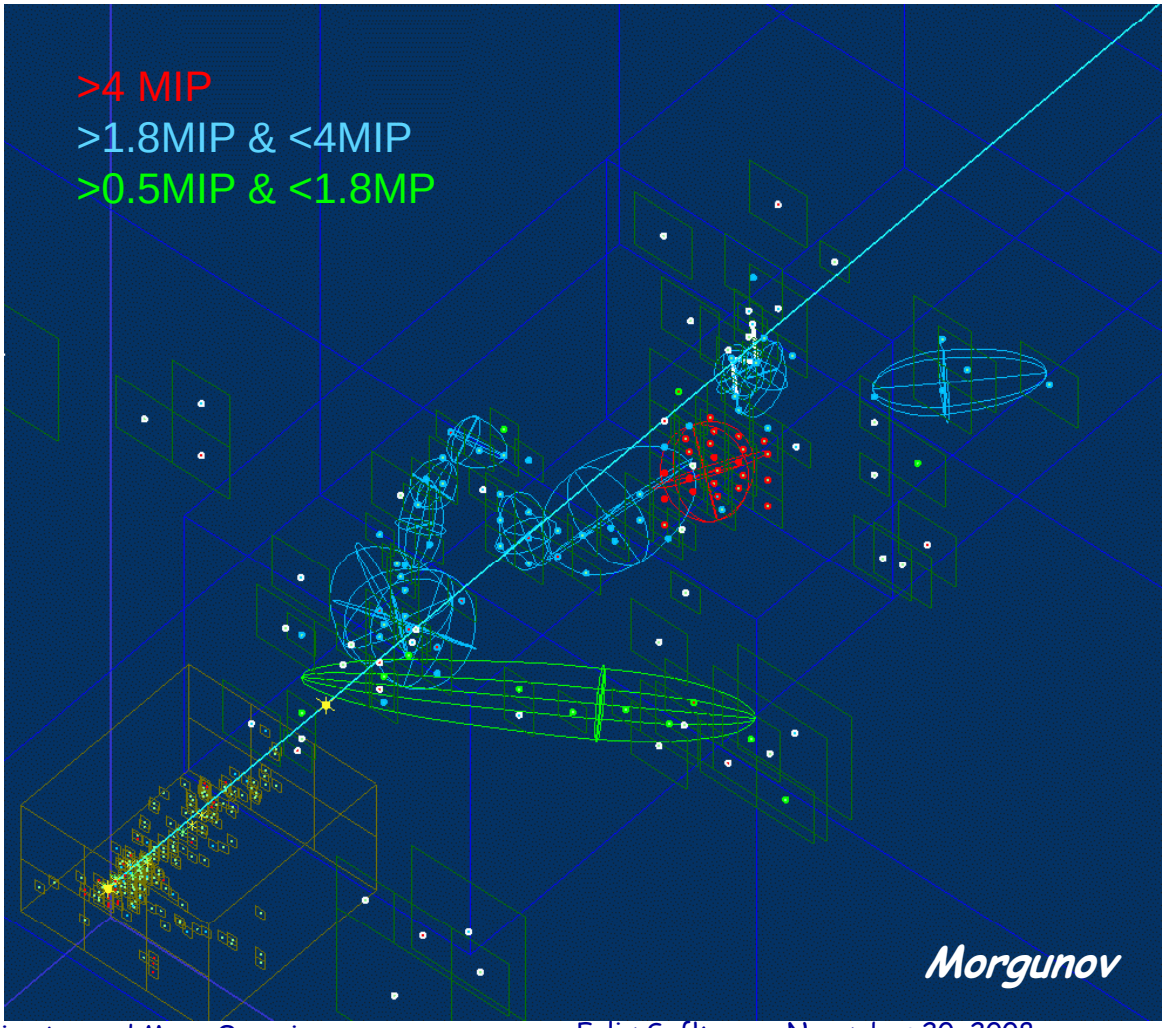


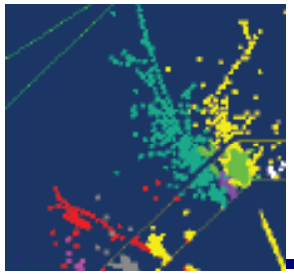




Shower decomposition

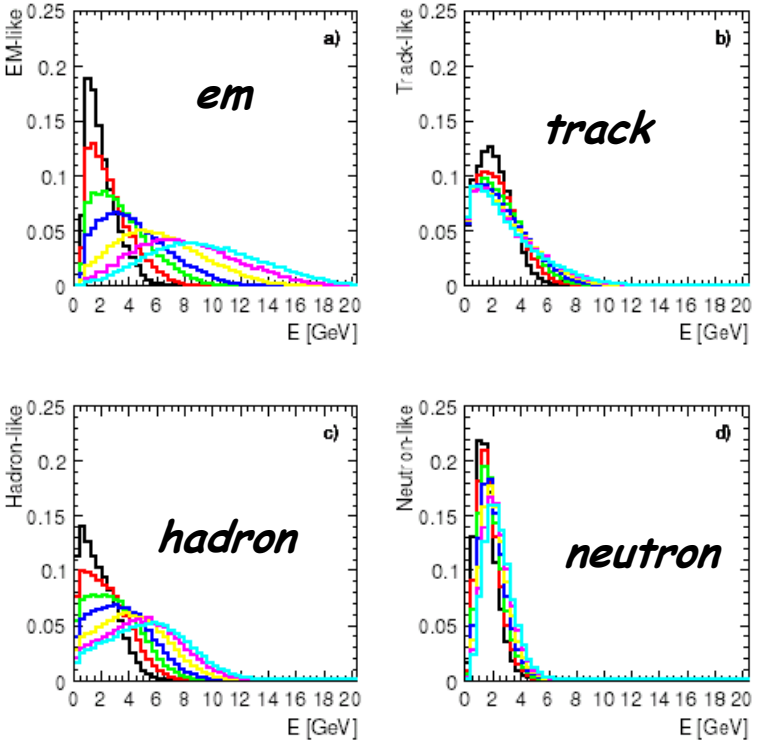
- Substructure visible
- Classification according to amplidude and topology
  - EM like
  - MIP like
  - Hadron like
  - Neutron like
- Starting point for weighting procedures

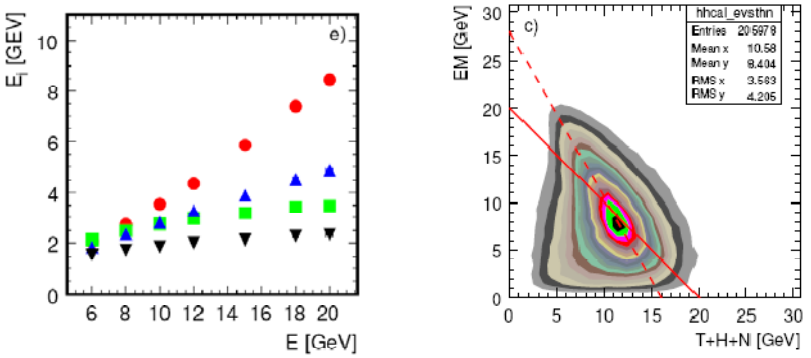




"Deep analysis"

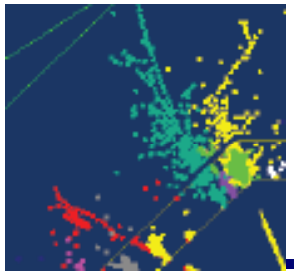
- Ideas V.Morgunov, first steps M. Groll (PhD thesis)
- Shower decomposition, using energy and topology





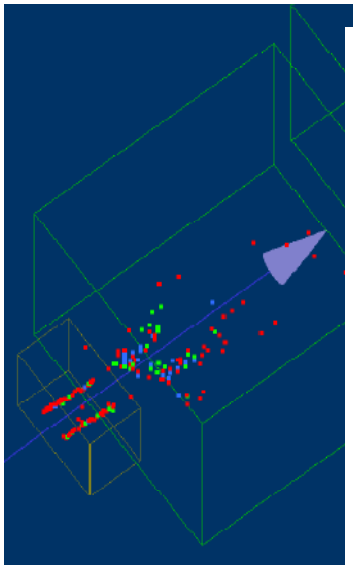
Energy dependence, correlation

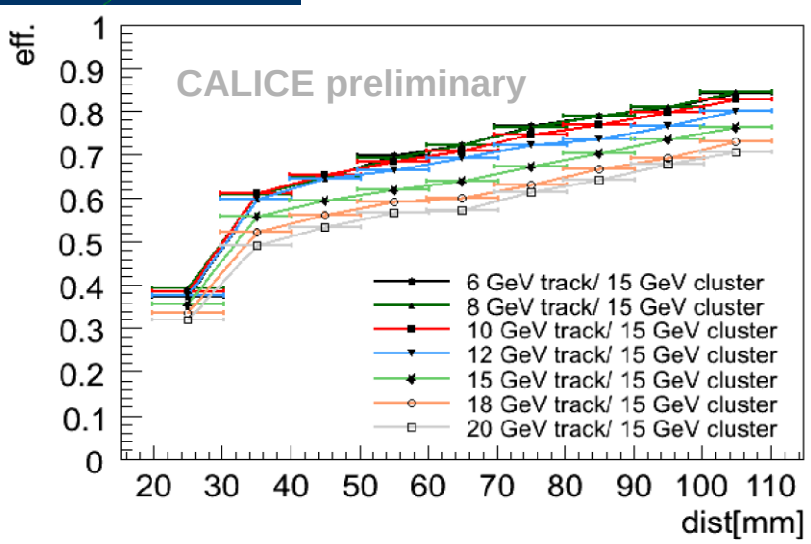
Ultimate challenge:
Compensation with quadruple readout
Can add neutron timing

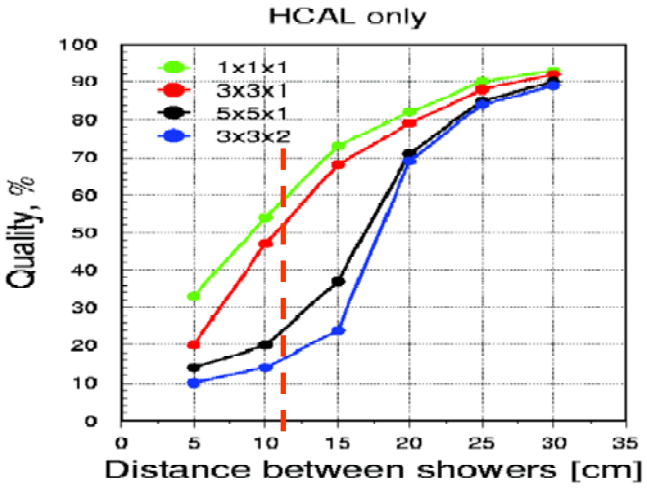


Validate PFLOW performance

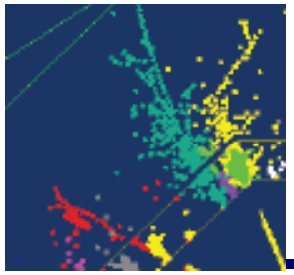
- Test beam 'jets' would require magnet and tracker (future)
- Jet energy resolution depends on hadronic energy resolution and confusion
- High granularity, low occupancy: use event overlay techniques
- Two particle separation in test beam data and Monte Carlo:







A. Raspereza



PFLOW at CLIC? Yes!

★ Traditional calorimetry $\sigma_E/E \approx 60\%/\sqrt{E/\mathrm{GeV}}$

★ Does not degrade significantly with energy (but leakage will be important at CLIC)

★ Particle flow gives much better performance at "low" energies
- very promising for ILC

What about at CLiC ?

★ PFA perf. degrades with energy

★ For 500 GeV jets, current alg. and ILD concept:

$\sigma_E/E \approx 85\%/\sqrt{E/\mathrm{GeV}}$

★ Crank up field, HCAL depth…

$\sigma_E/E \approx 65\%/\sqrt{E/\mathrm{GeV}}$

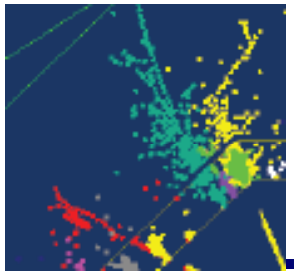
★ Algorithm not tuned for very high energy jets, so can probably do significantly better

rms90 — PandoraPFA v03-β

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	23.8 %	3.5 %
100 GeV	29.1 %	2.9 %
180 GeV	37.7 %	2.8 %
250 GeV	45.6 %	2.9 %
500 GeV	84.1 %	3.7 %
500 GeV	64.3 %	3.0 %

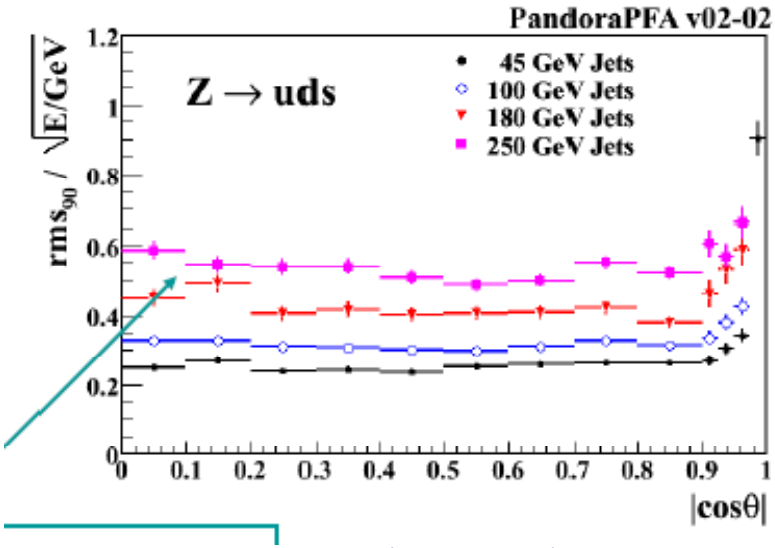
63 layer HCAL (8 λ_I)
B = 5.0 Tesla

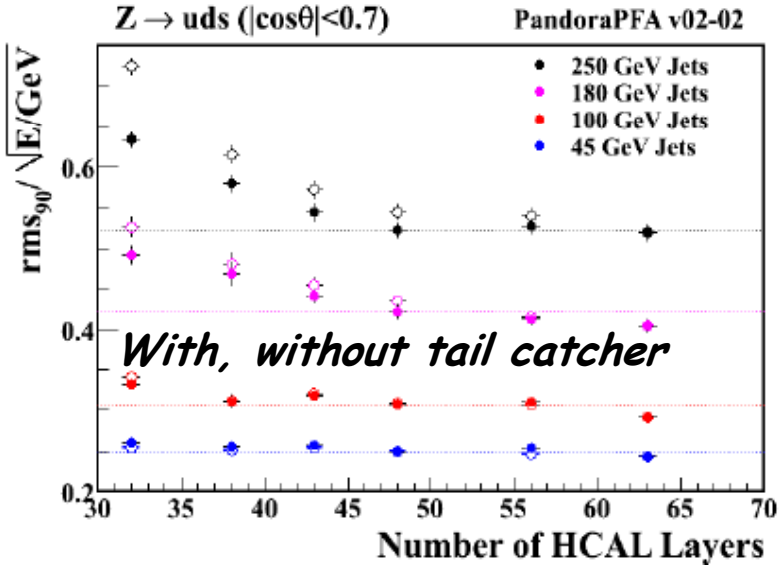
Conclude: for 500 GeV jets, PFA reconstruction not ruled out

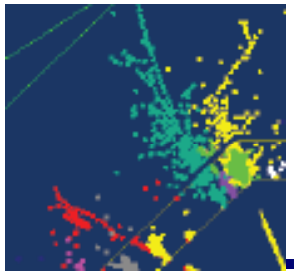


At high energy

- Algorithms need a clever transition to "classical" jet measurement
- HCAL and jet performance limited by constant term:
  - Calibration and monitoring
  - uniformity
  - Compactness and dead material
  - And leakage!





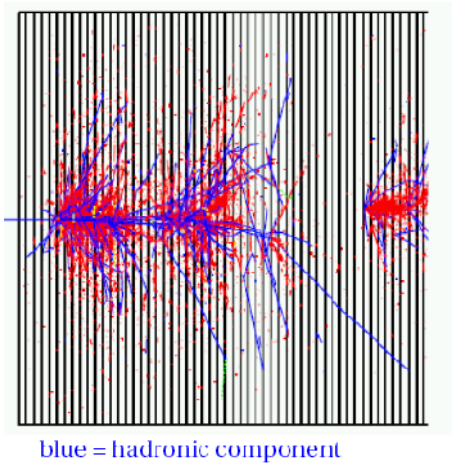


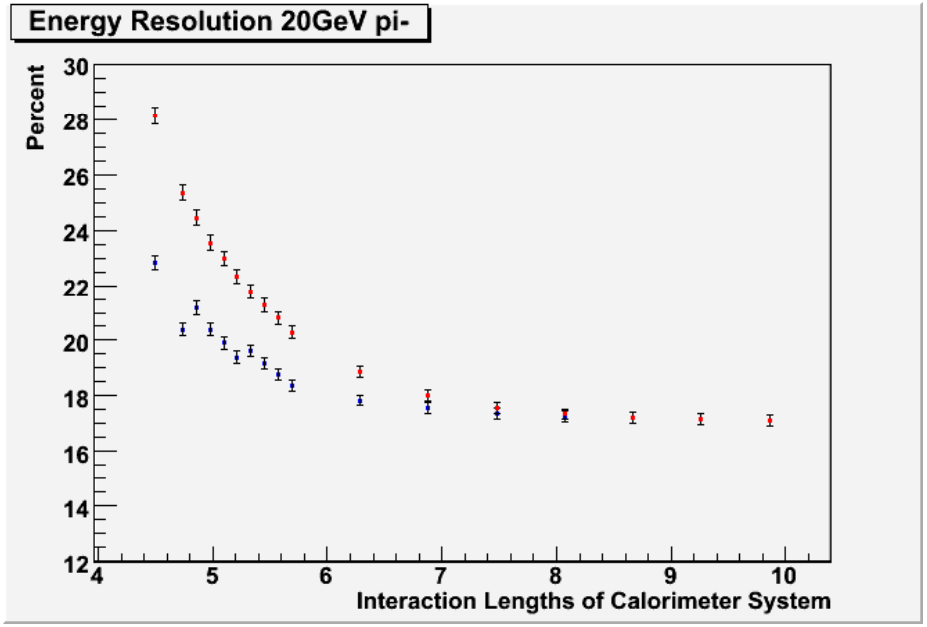
Tail catcher impact

- Tail catcher improves energy resolution even after of 2λ coil
- Can be studies with CALICE data

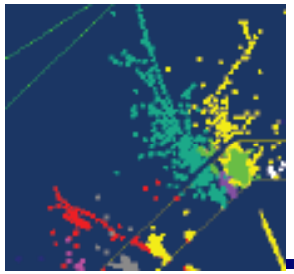
TC optimization!!

- Million $ question: what can topological analysis do?

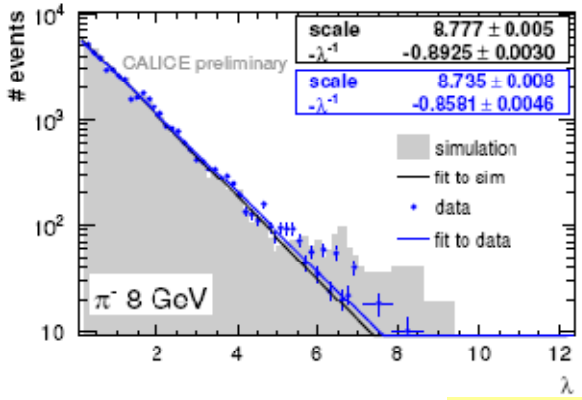




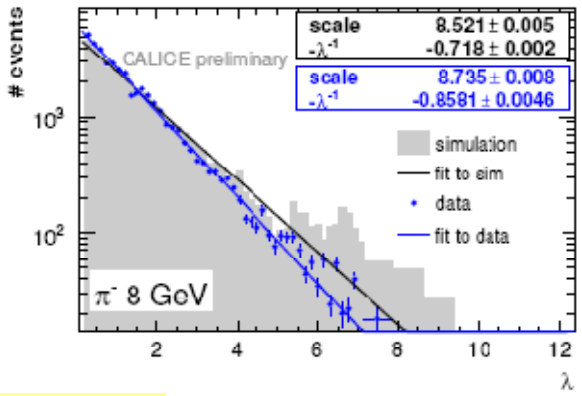
RED: ECAL + HCAL + n TCMT Layers
BLUE: ECAL + HCAL + n TCMT Layers + 1.5 λ coil + remaining layers of TCMT



HCAL shower leakage study



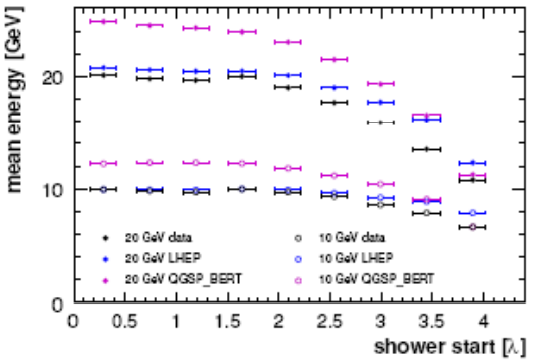
(a) LHEP



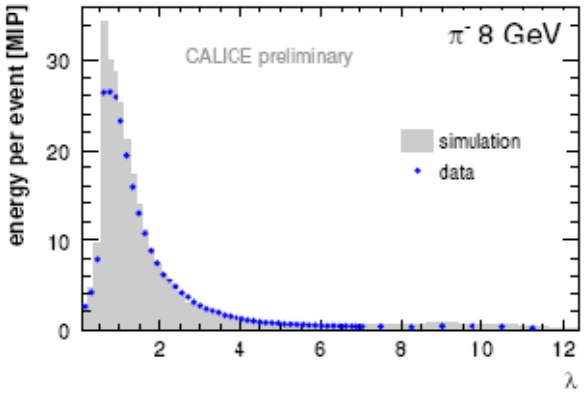
(b) QGSP_BERT

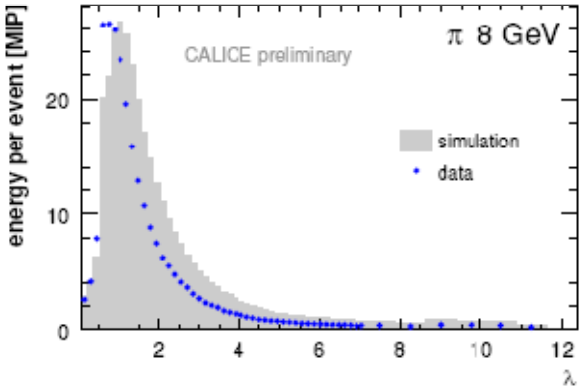
Identify shower starting point

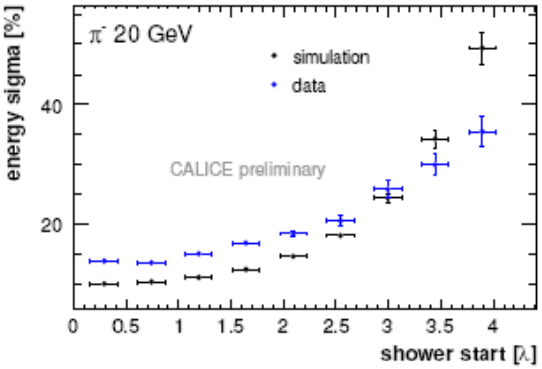
Energy vs. starting point



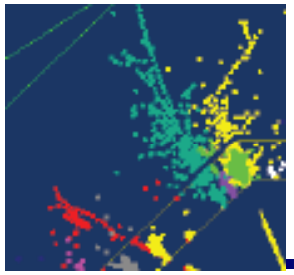
Resolution vs. starting point





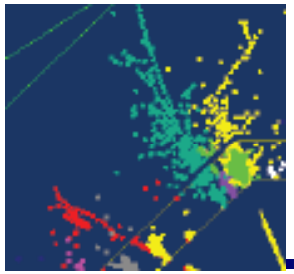


Shower profile w.r.t. starting point



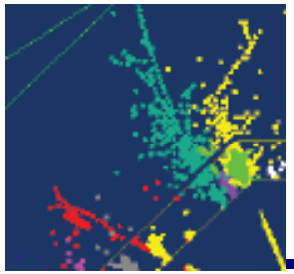
Conceptual frontier

- Particle flow and dual read-out: not a question of energy range
- Both are continuations of the "compensating calorimetry" idieas
- Both suffer from leakage at high energy (if inside coil)
- Different time horizon of development



Technology frontier

- No time to cover, but still mention:
  - Crystals: candidates for total absorption HCAL
  - Interconnection technologies for ultra-compact ECAL
  - Improvements in SiPM properties
  - scintillator uniformity, direct coupling schemes
  - Application of SiPMs for muos strip detector
  - SiPM test facilities and characterization results
  - RPC and micromegas properties, integration with EUDET electronics and KPiX chips
  - FCAL electronics prototypes for extreme demands

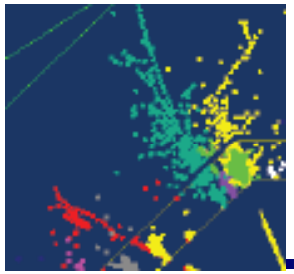


Engineering frontier

- Compactnessis the issue
- Again refer to Jean-Claude's talk

- Micro-electronics is the key: Gunter Eckerlin's talk

- And integration, interplay of different detectors
  - Integrated beam test facility for vertex, tracking and calorimeters has been proposed



Conclusion

- Calorimetry and muon community is progressing on all frontiers
- Exciting developments: concepts, technologies, integration
- Varioius opportunities to match LC time scales as they arise