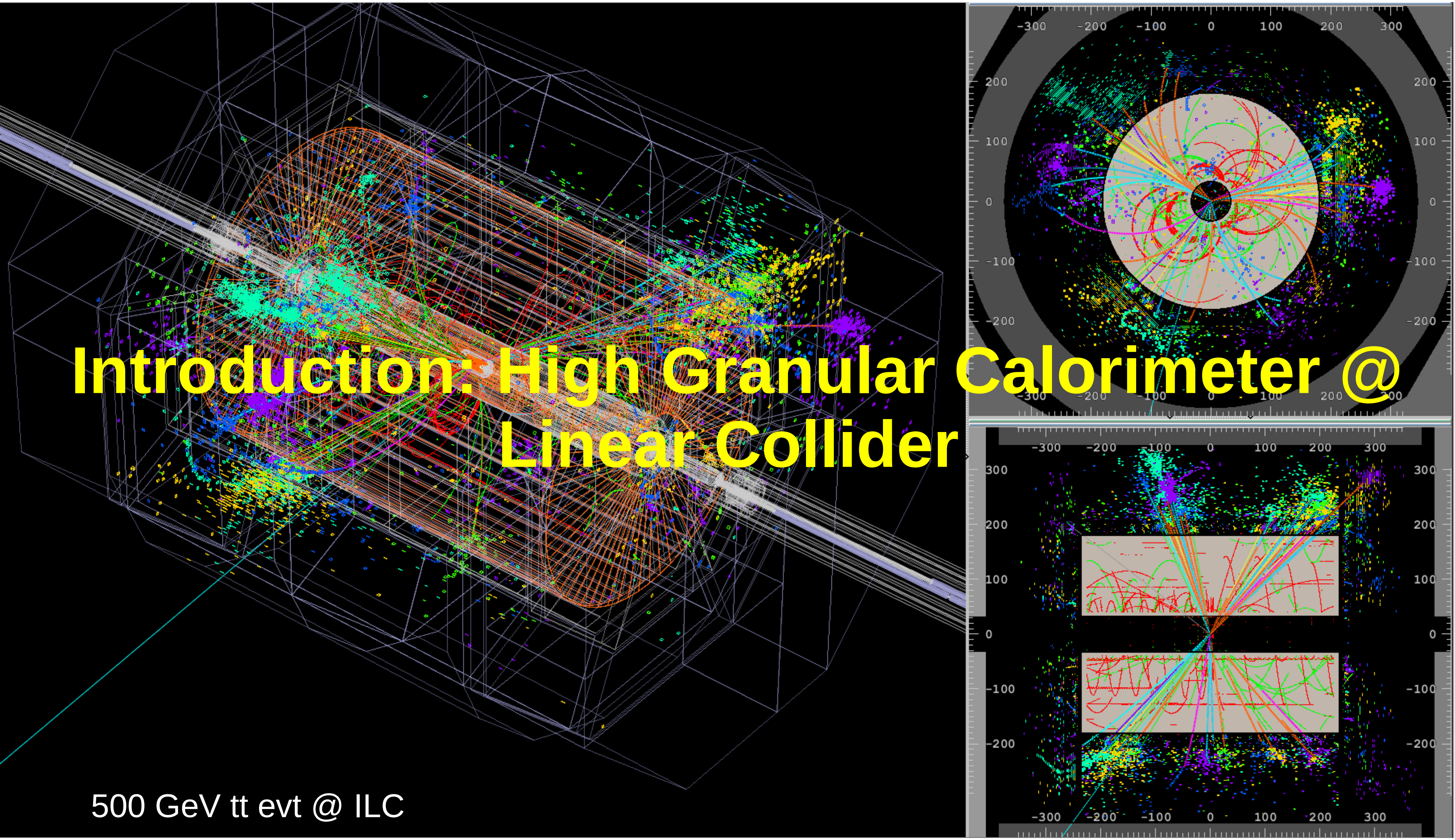
Fractal dimension analysis in a highly granular calorimeter

Manqi RUAN

Laboratoire Leprince-Ringuet (LLR)
Ecole polytechnique
91128, Palaiseau

Introduction: High Granular Calorimeter @ Linear Collider

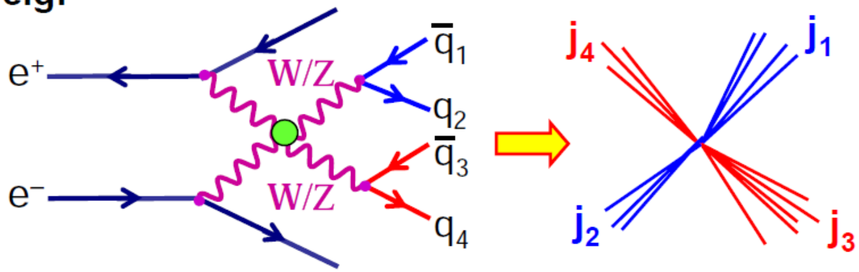


500 GeV tt evt @ ILC

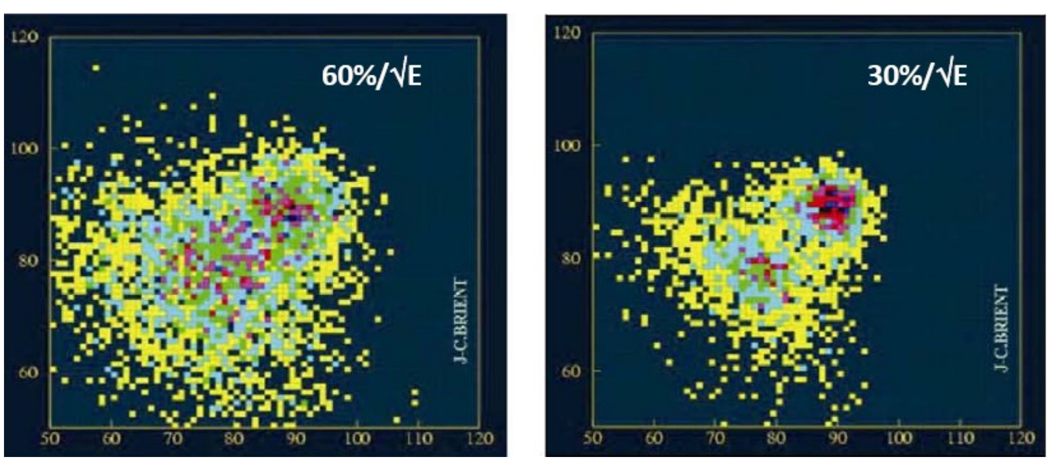
LC: Jet resolution & PFA

Multi bosons	Multifermions + Boson(s)
ZH	e^+e^- H , e+e− Z
WW	νν H , νν Z
ZZ	ttH
ZHH	e ν W
ZZZ	νν WW, νν ZZ
ZWW	ttbar

e.g.



Di-jet mass for WWνν & ZZνν @ 500GeV



Particle Flow Algorithm (PFA)

Measure jet particles separately in different sub detector!

$$E_{jet} = E_{charged\ tracks} + E_{\gamma} + E_{h^0}$$

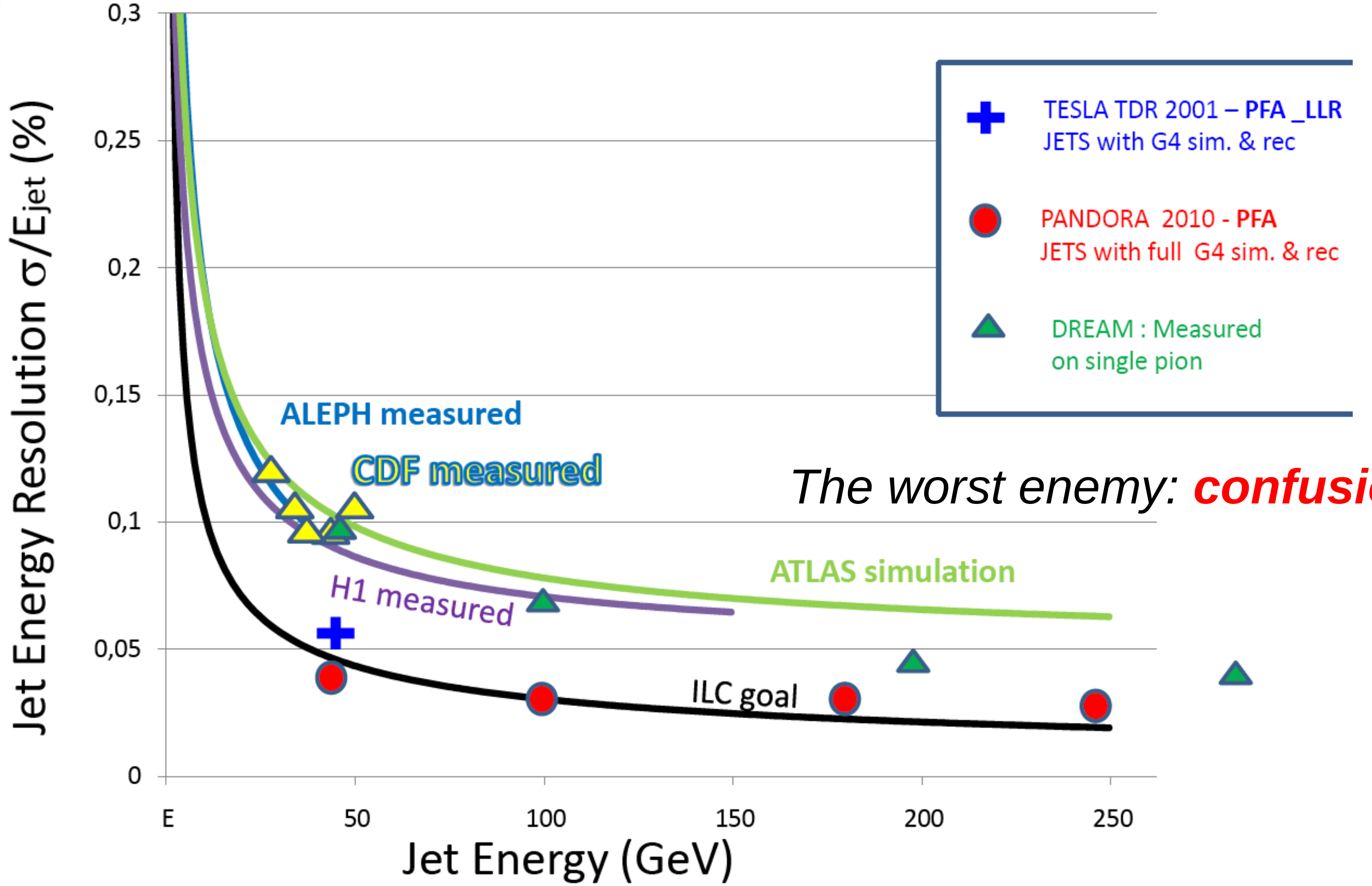
fraction: 65% (charged tracks), 26% (γ), 9% (h^0)

Charged Particle – Tracker:
$\Delta p/p^2$ ~ 2E-5 (1/GeV)
Photon – ECAL:
ΔE/sqrt(E) ~ 15%
Neutron Hadron – HCAL:
ΔE/sqrt(E) ~ 50%

If 100% separated:

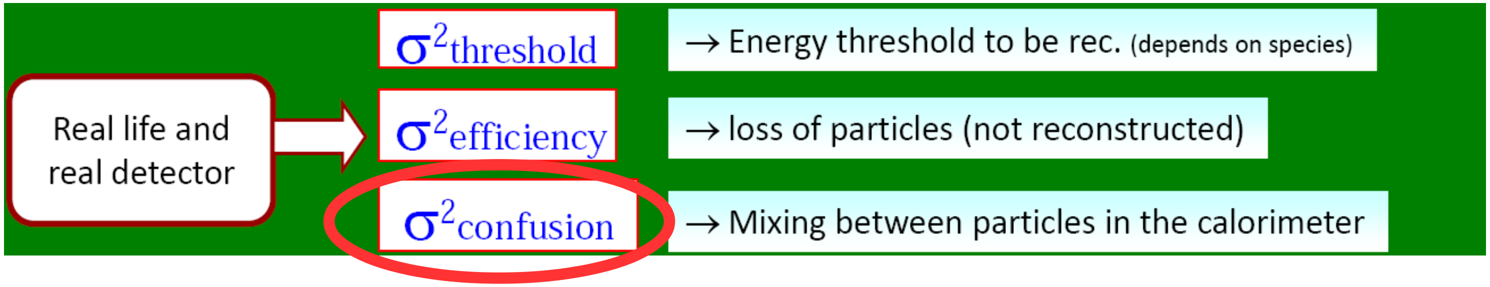
$\sigma^2_{jet} = \sigma^2_{ch.} + \sigma^2_{\gamma} + \sigma^2_{h^0}$ gives about $(0.14)^2 E_{jet}$

Jet energy resolution

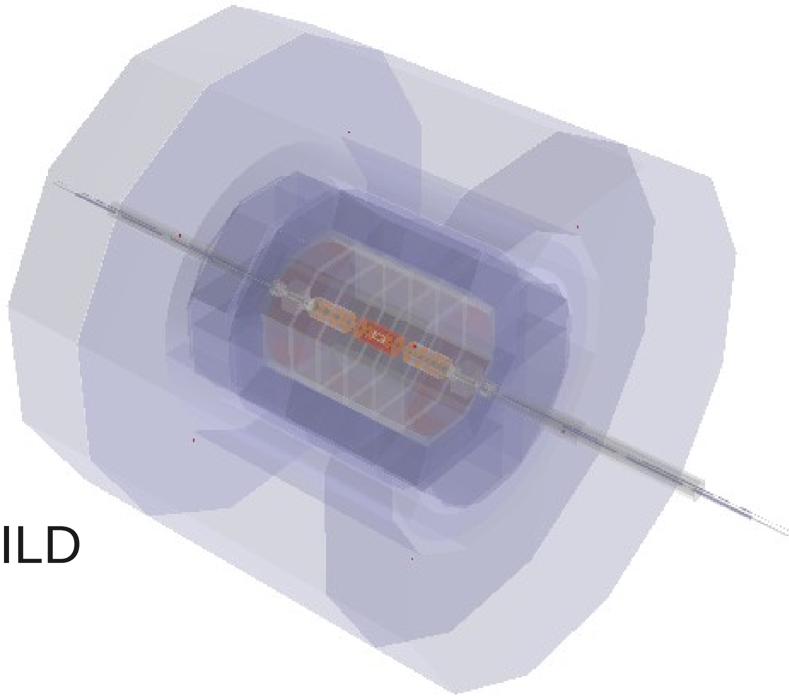


J-C. Brient - IWLC 2010

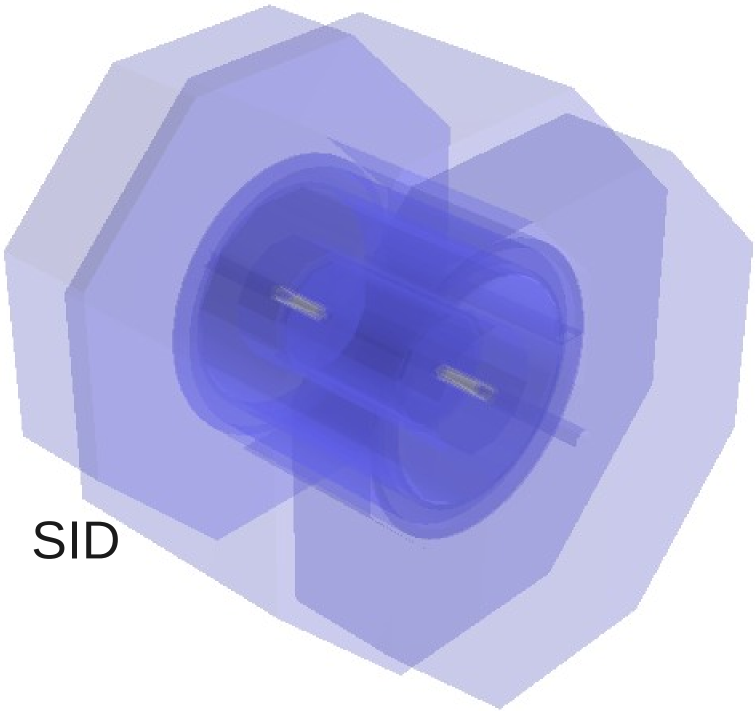
The worst enemy: ***confusion***



PFA Oriented LC detectors



ILD

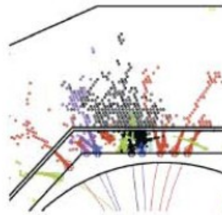


SID

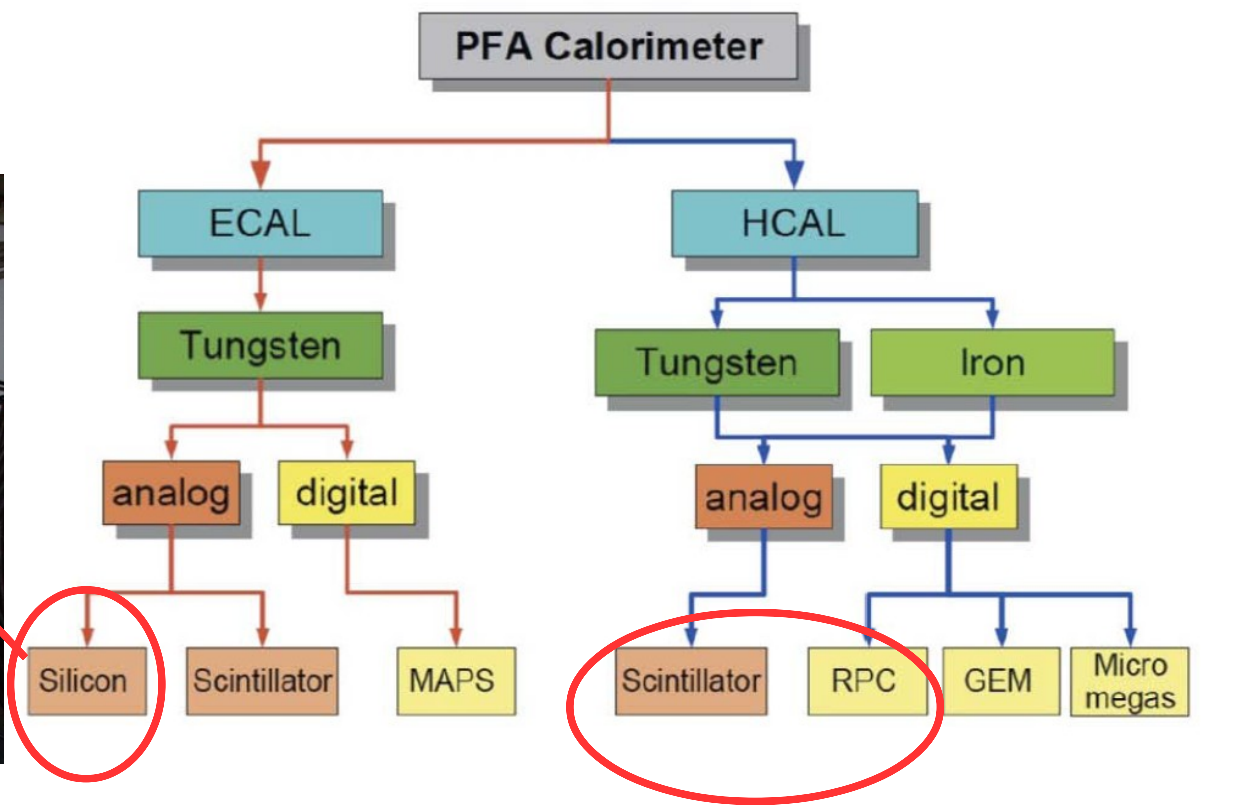
- PFA: less confusion ~ good separation ~ high granularity
  Granularity > Energy Resolution for the Calorimetry...
- PFA Oriented detector: > 100M electronic channels
  - ILD (European + Asia, International Large Detector): TPC (+ Silicon inner detectors) tracking with B = 3.5T
  - SiD (US, Silicon Detector): Silicon tracking with B = 4T

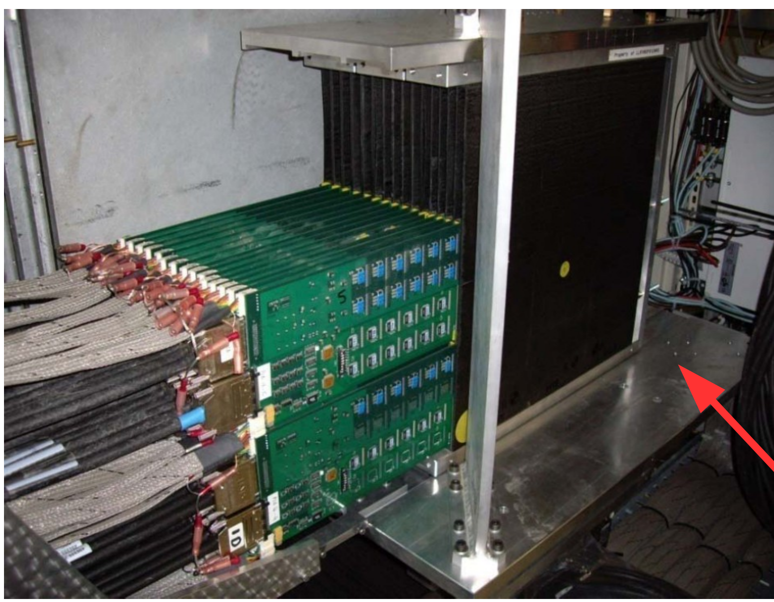
High granularity Calorimetry

eg: ECAL Prototype, 10k channels in a cube of 18 cm side ~ 1/8 of CMS ECAL



Technology tree



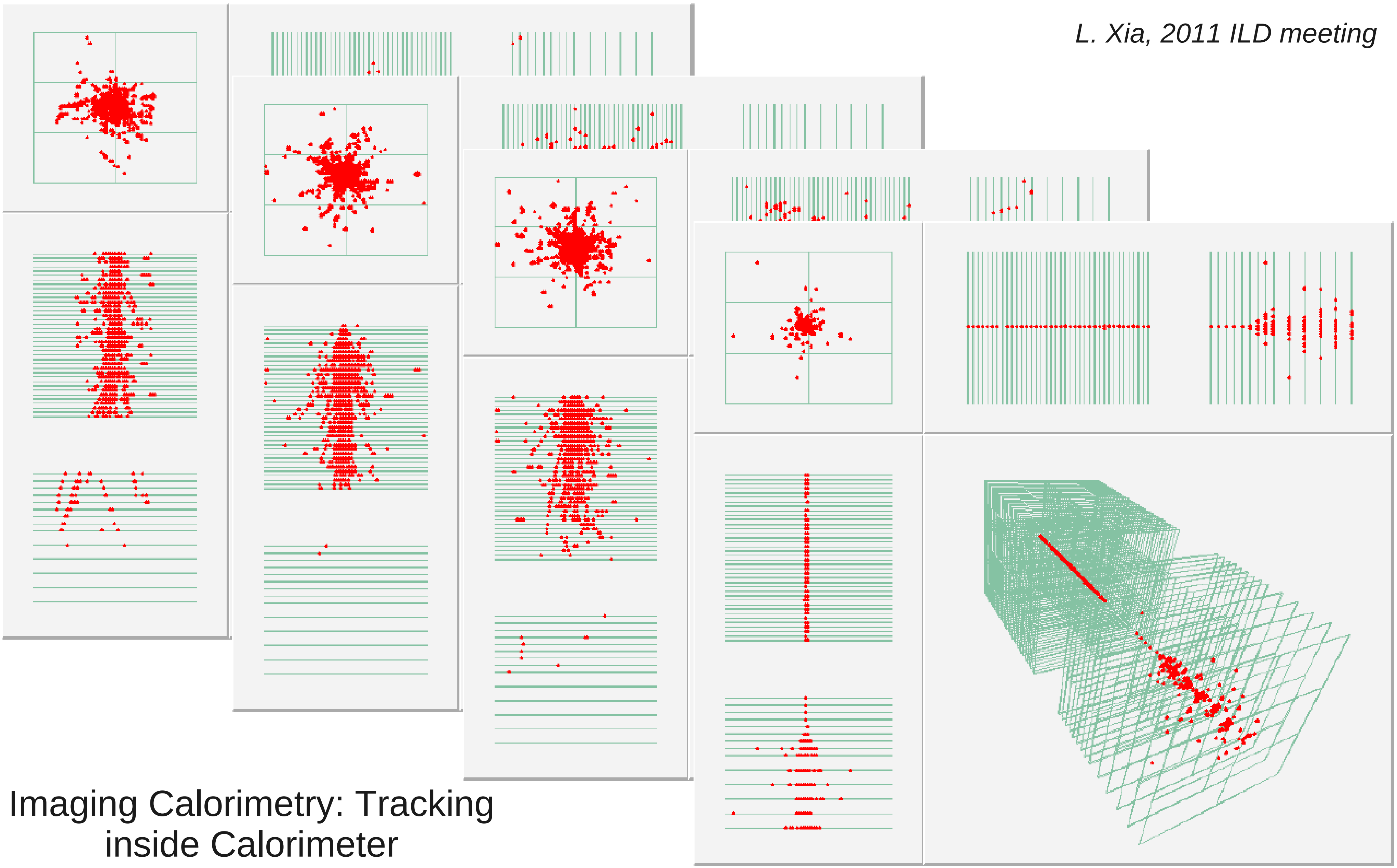


Scintillator AHCAL with 3 * 3 cm cell @ DESY

2 GRPC Digital HCAL with 1 * 1 cm cell: SDHCAL @ IPNL et al DHCAL @ Argonne

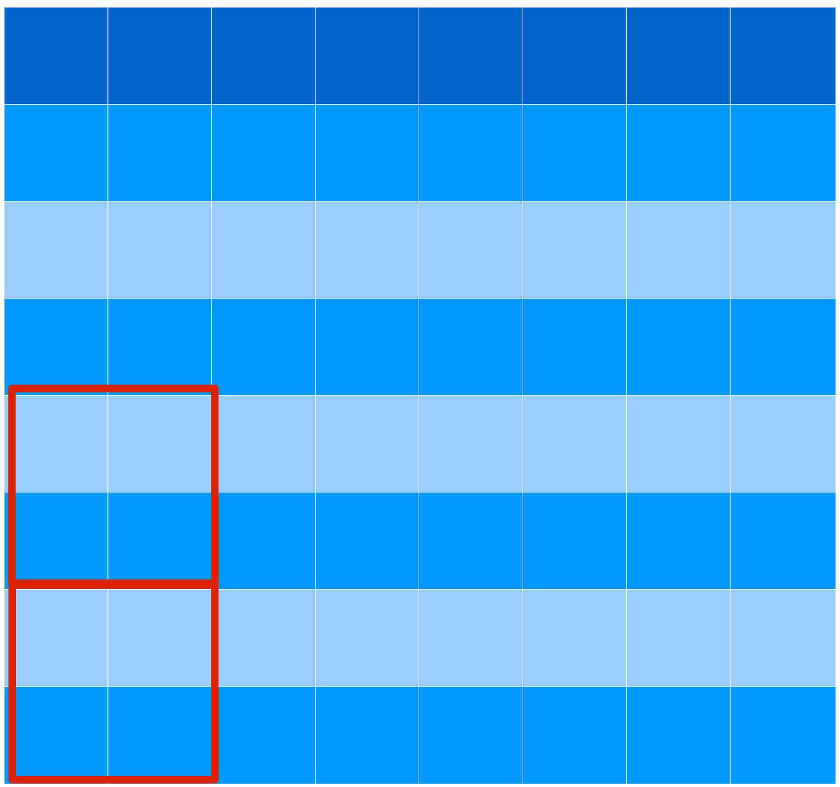
DHCAL test beam: 120 GeV pion shower

L. Xia, 2011 ILD meeting



Imaging Calorimetry: Tracking inside Calorimeter

Shower particle: to interact or not



shower ~ self similar *(Mandelbrot Set)*

Measure shower Fractal Dimension (FD) at high granularity calorimeter

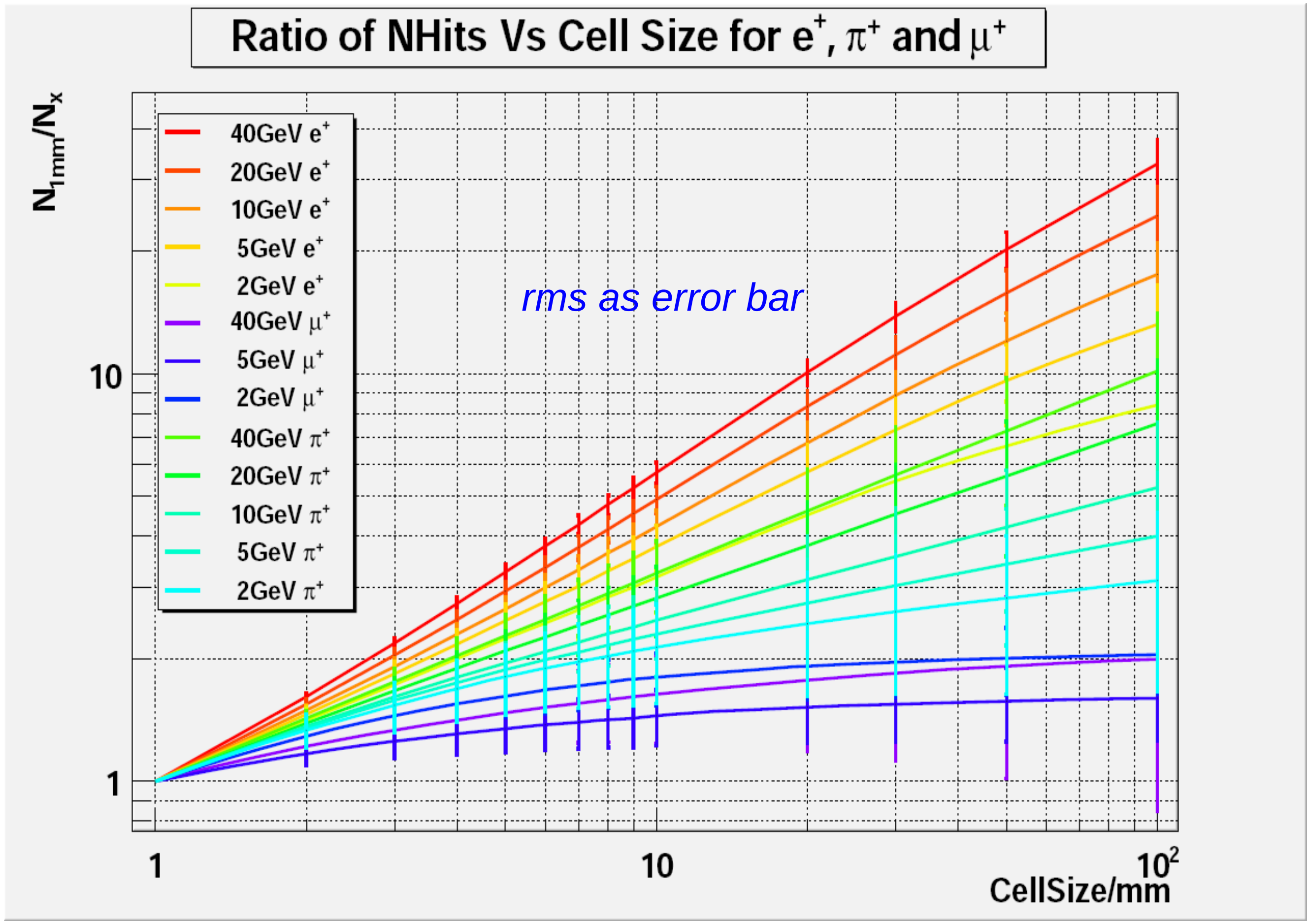
- Varying scale by grouping neighbouring cells
- Count Number of hits at different scale
  (define $RN_x = N_{1mm}/N_{xmm}$ *)*

Shower: Self Similar

- Characteristic constant depend on energy/PID:

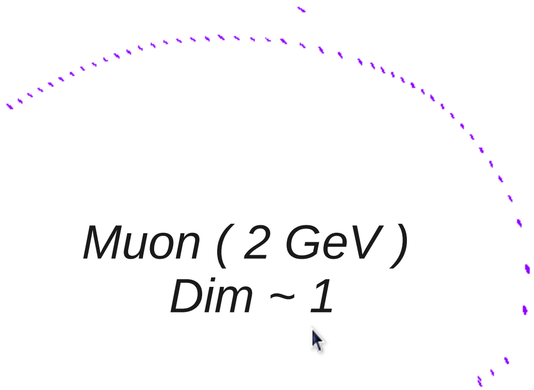
FD = 1 + < lnRNa/ln(a) >

  - Global parameter based on local density
  - *Cell Sizes: 2 – 10, 20, 30, 50, 60, 90, 120, 150mm.*
  - *Samples: Particles shot directly to GRPC DHCAL with only B Field*



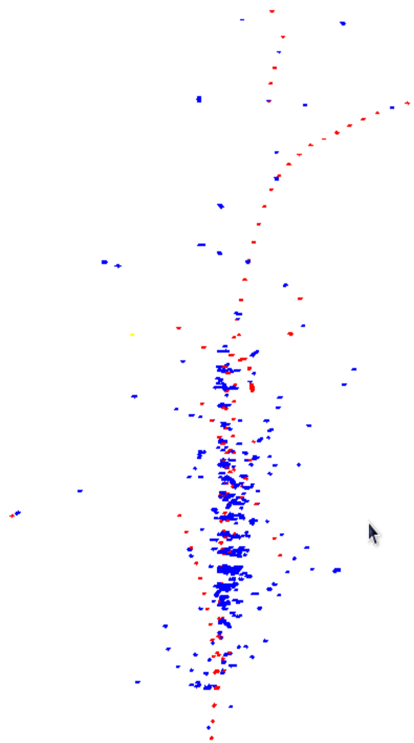
- Be observed within
  - Low scale: minimal interaction energy & sensor layer thickness (1.2mm)
  - High scale: fully containment ~ 1 hits per layer

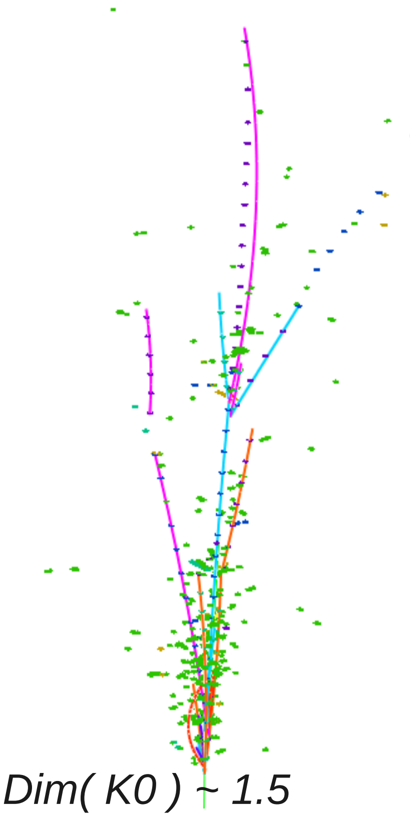
Fractals in Nature



Muon (2 GeV)
Dim ~ 1

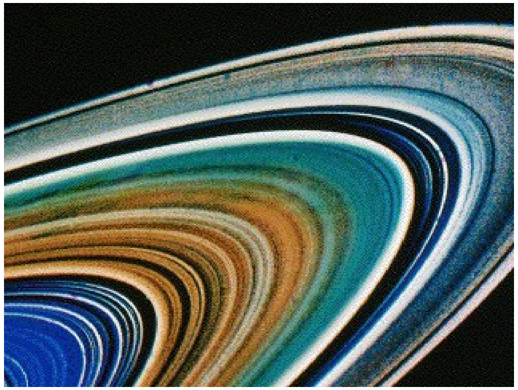
Straight line:
Dim = 1

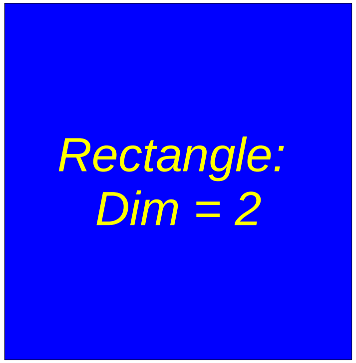




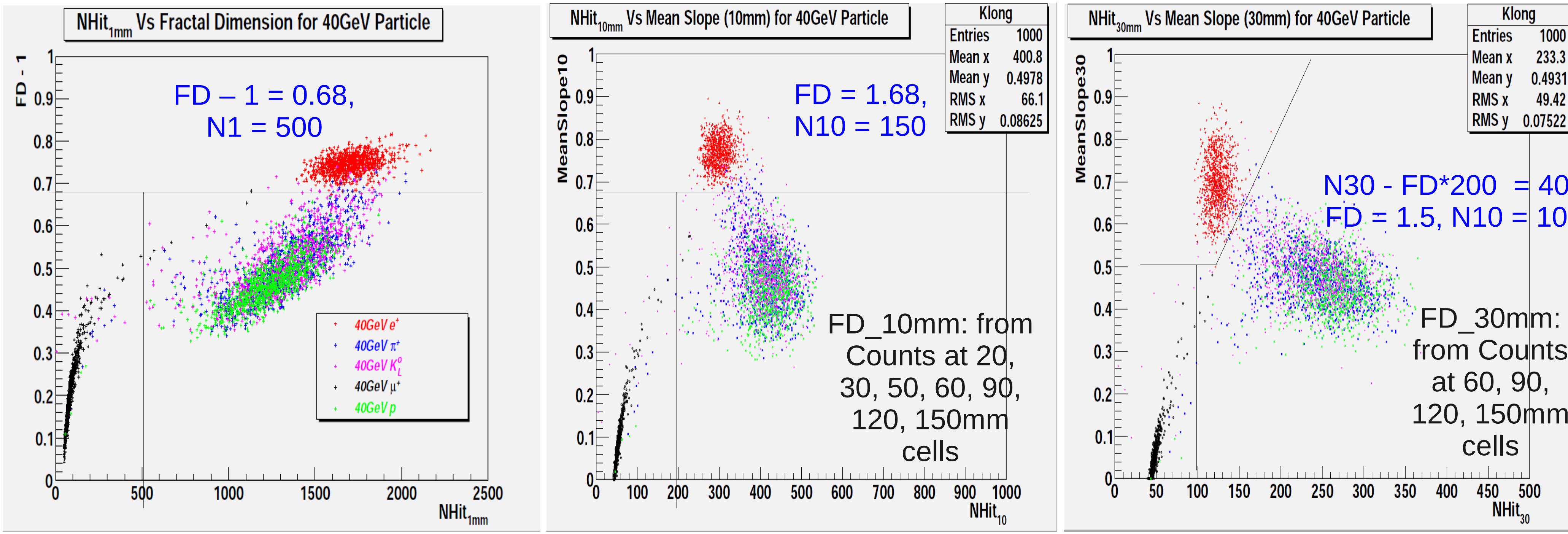
Hadrons: Dim(pi) < Dim(K0) ~ 1.5

Positron (40GeV)
Dim ~ 1.75





Potential tool for PID



FD together with other info (Nhits): Clear separation at different scales

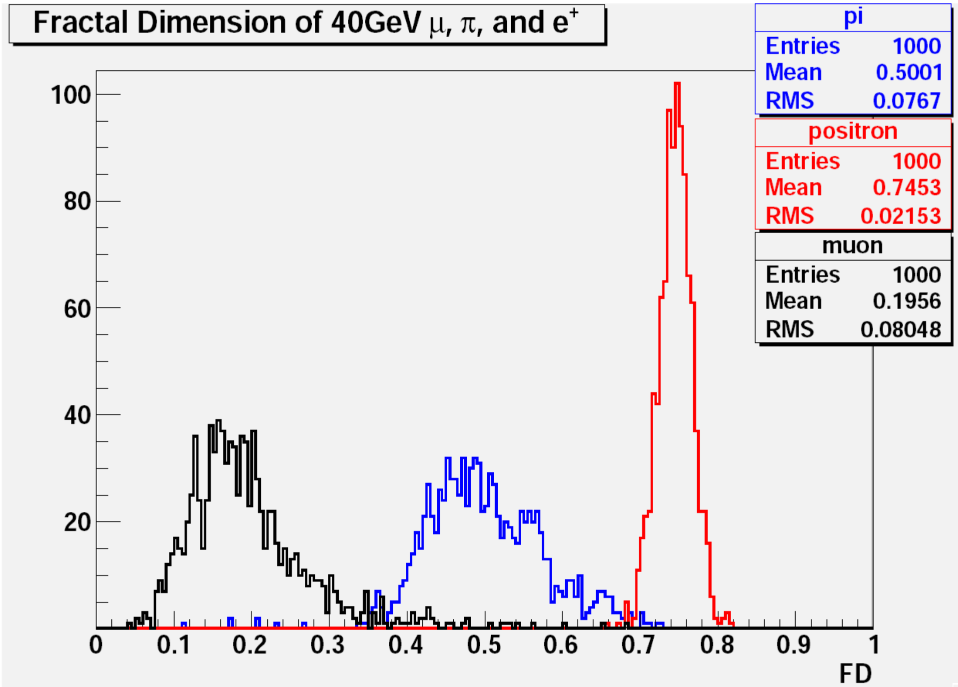
Remark: Energy dependent Cuts, easier for charged particles

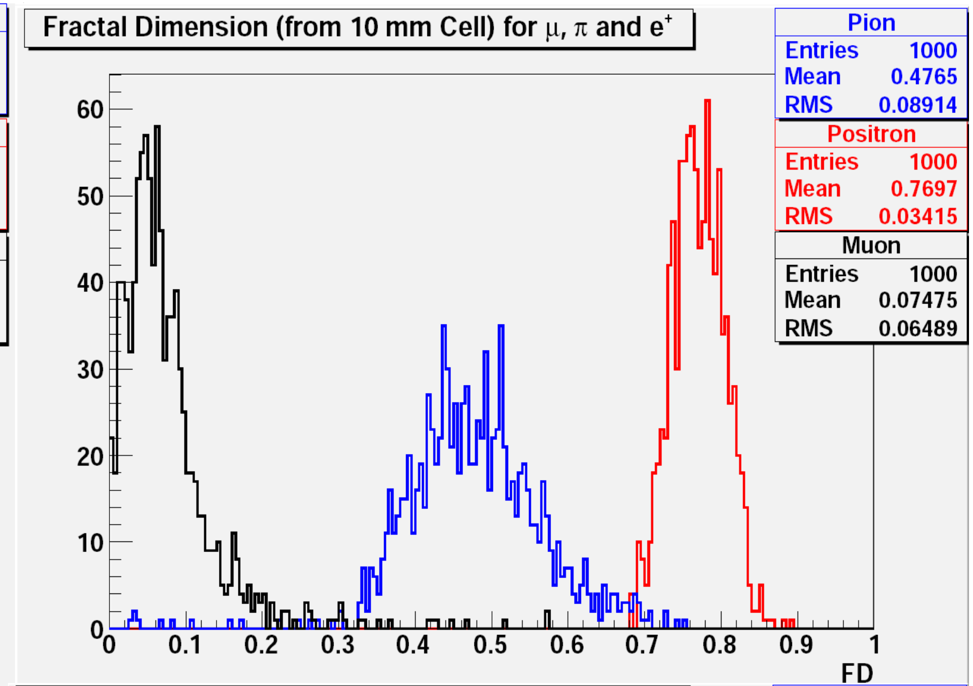
1mm	e+	u	h
e+	998	0	2
u	1	994	5
h	15	14	971

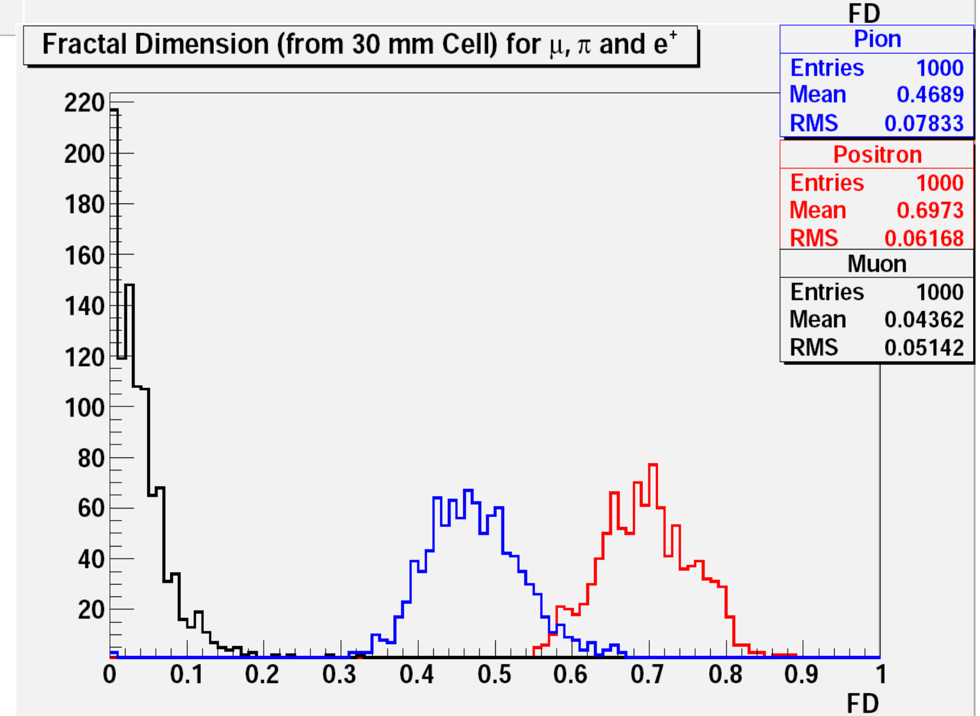
10mm	e+	u	h
e+	1000	0	0
u	0	995	5
h	17	14	969

30mm	e+	u	h
e+	1000	0	0
u	0	996	4
h	18	11	971

FD @ different size







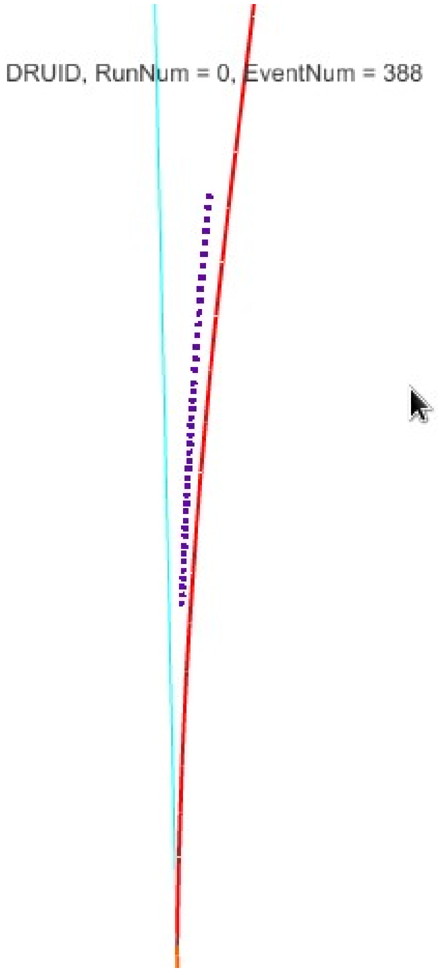
From FD(1mm) to FD(10/30mm):

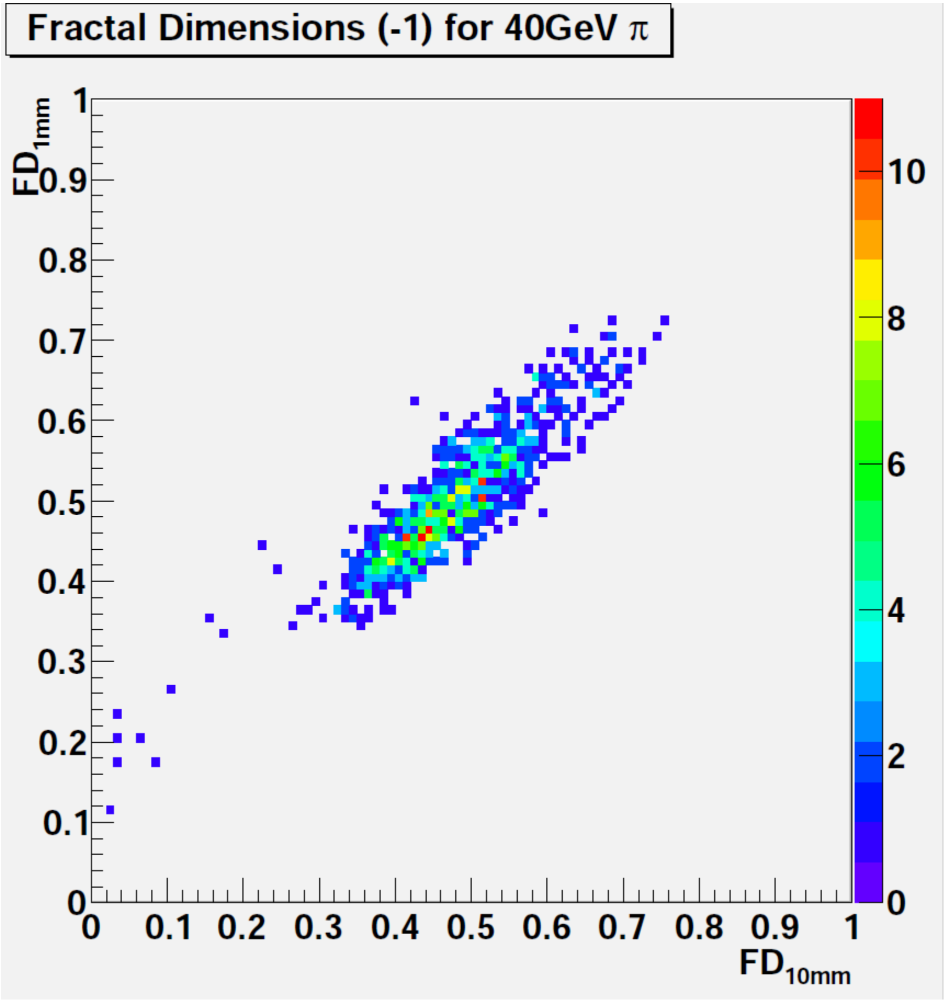
Positron Peak Smeared

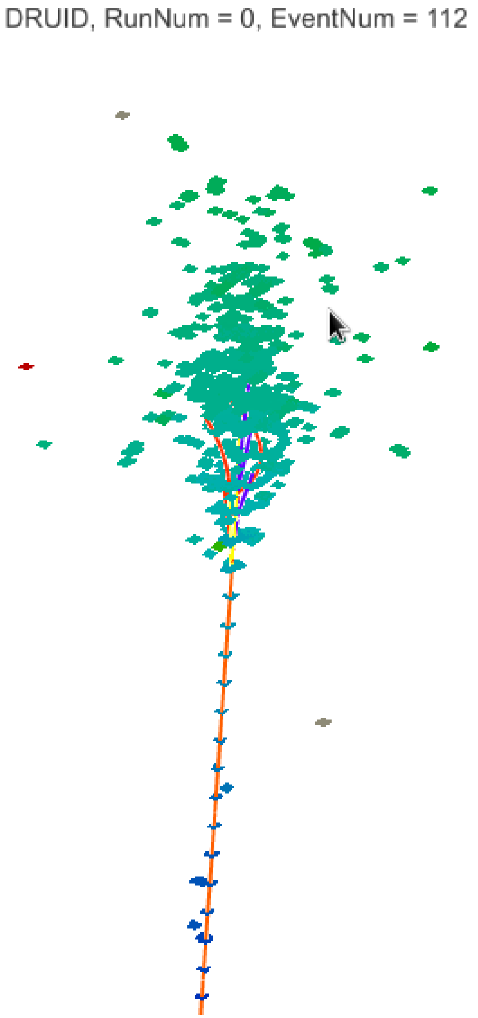
Better μ – h separation: μ acts more like a line (FD = 1); (Anyhow *we can create large cells from small ones...*)

π: continuous distribution from MIP to EM

Extreme Cases: Pion

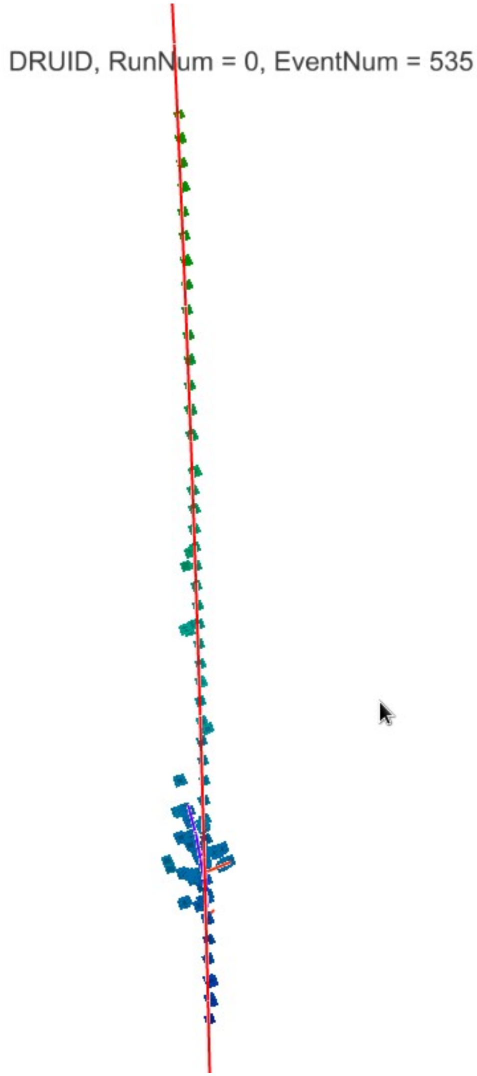


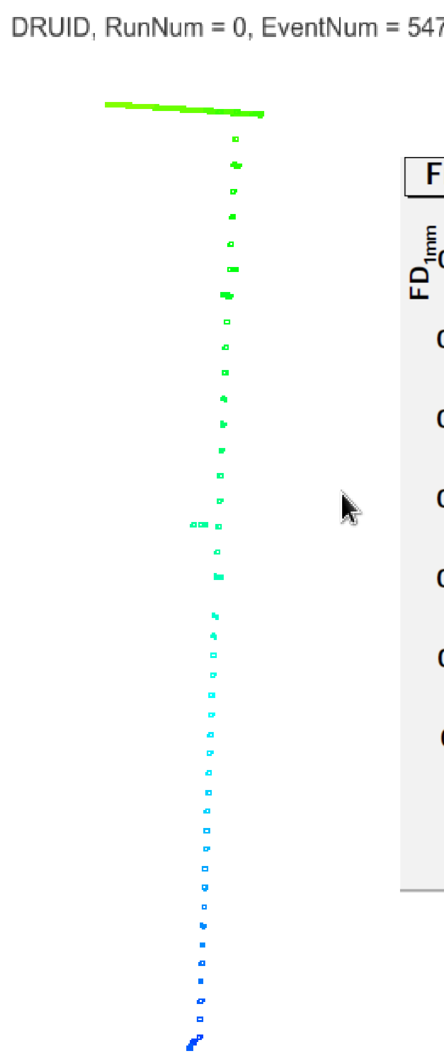


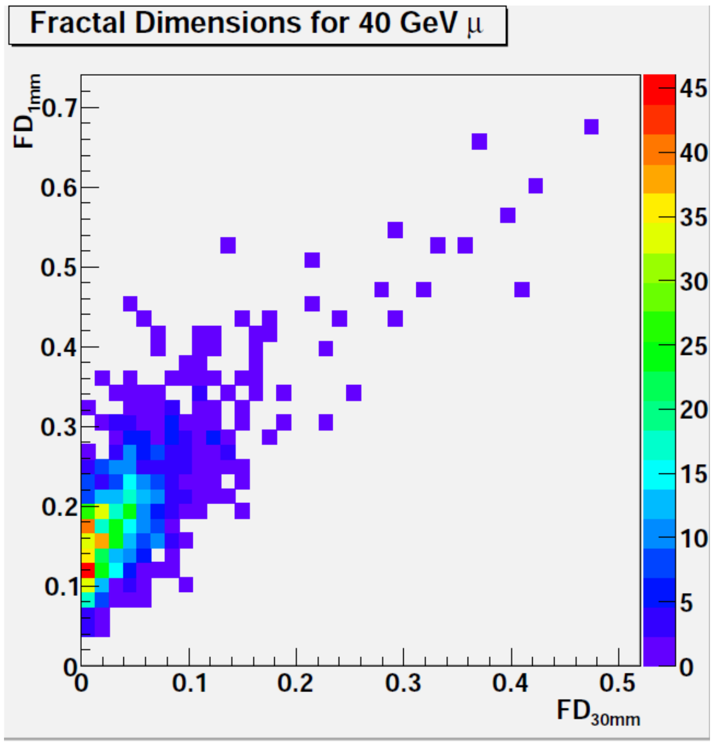


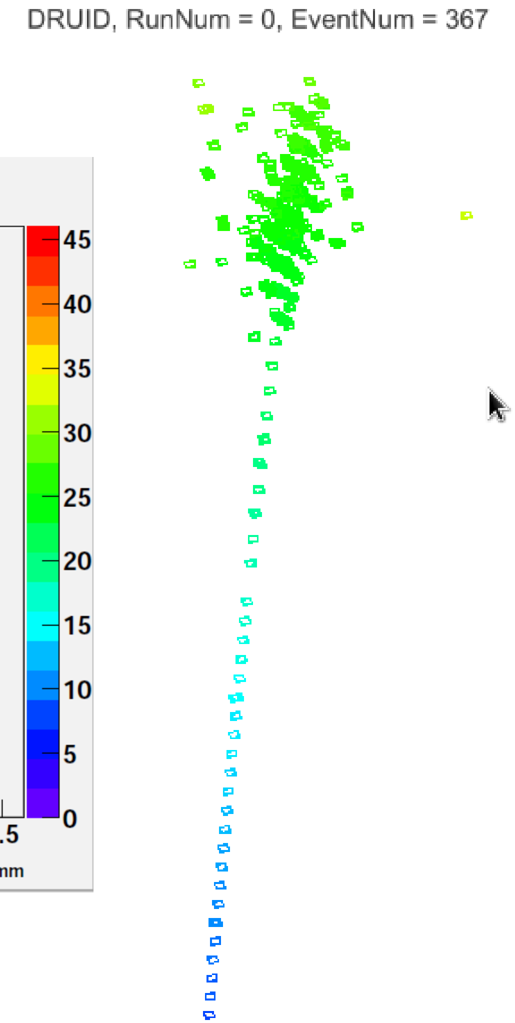
- Pion: MIP, Pion decay;
- EM interaction (pi + N = P + pi0); partially identified by interaction point tagging

Extreme Cases: Muon



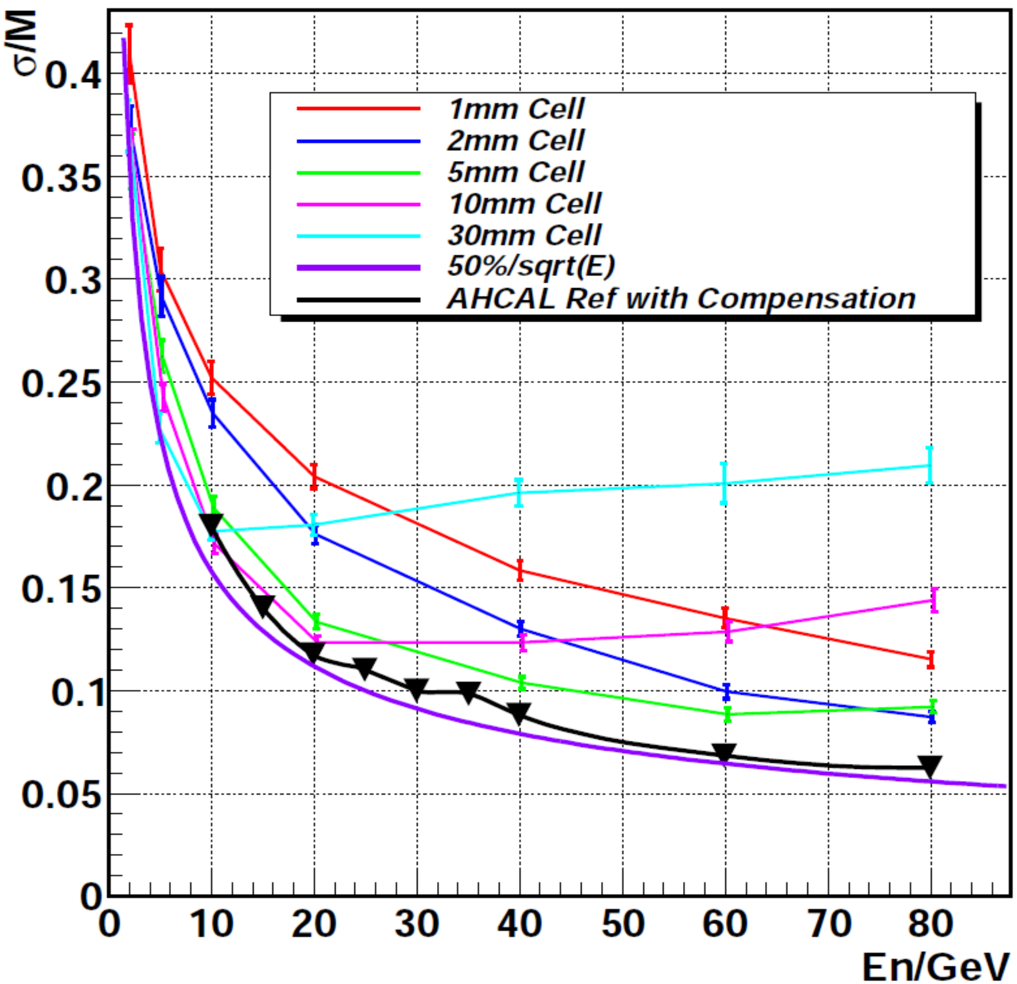


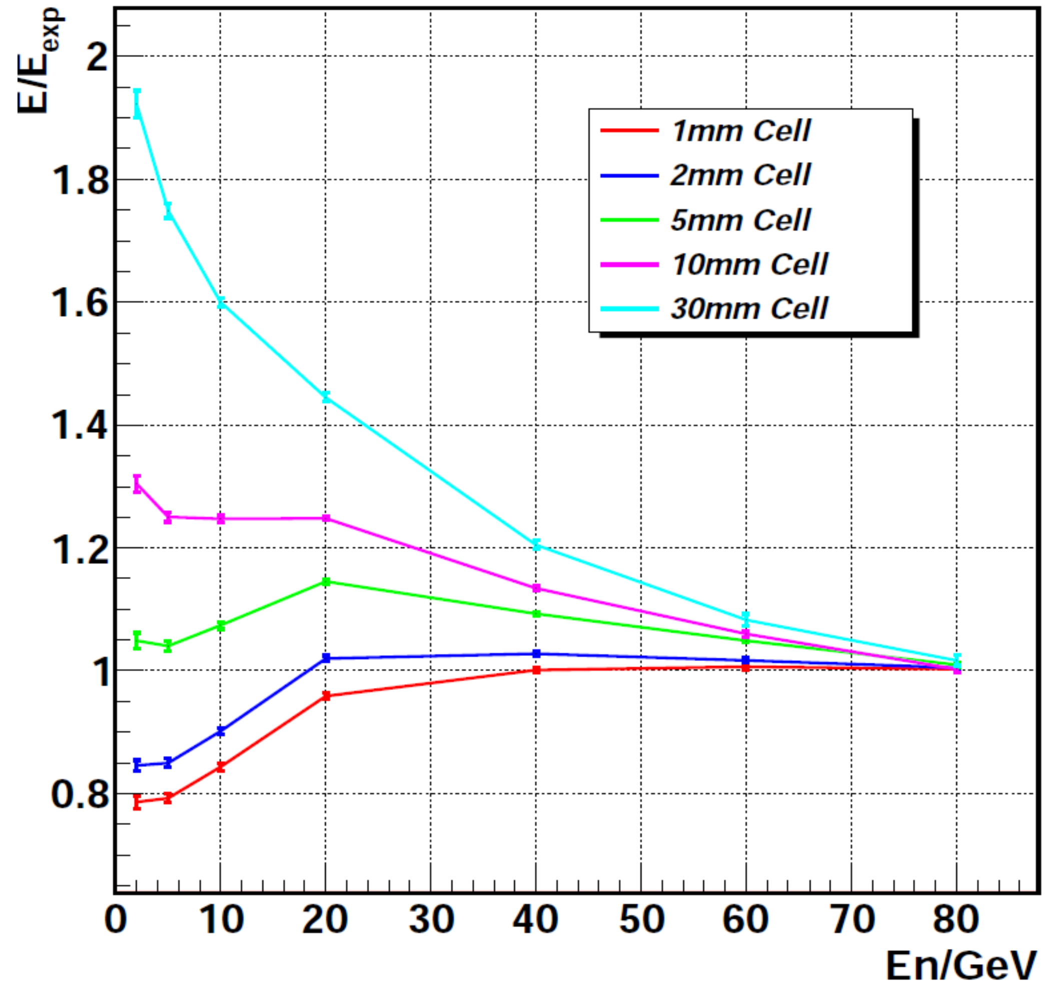




Together with Nhit information: to identify Muon radiation & String noise...

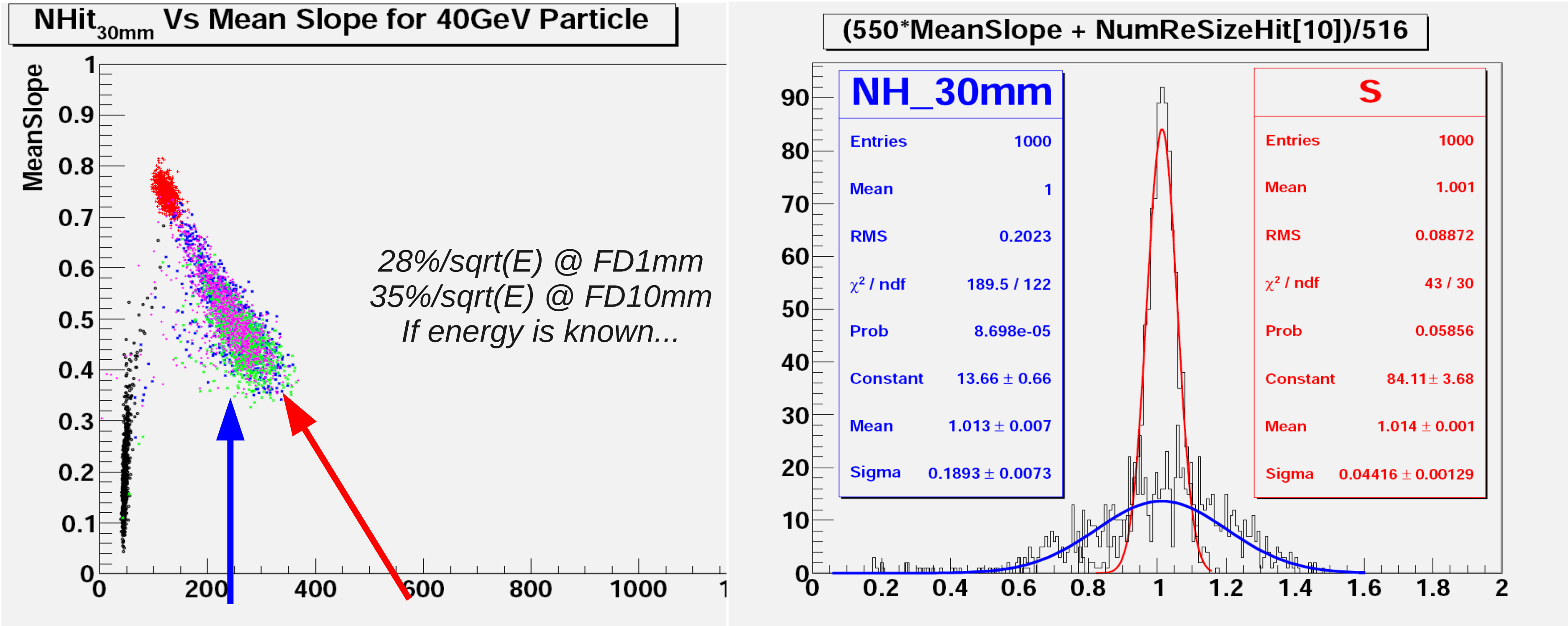
Energy Estimation: with Naive Counting





σ/M: Large cell better at low energy & Smaller cell at high energy.
Linearity: Better at 2 – 5 mm cell, strong saturation effects at larger cell...
Naively: 5mm seems a nice choice...

FD for Energy Estimation



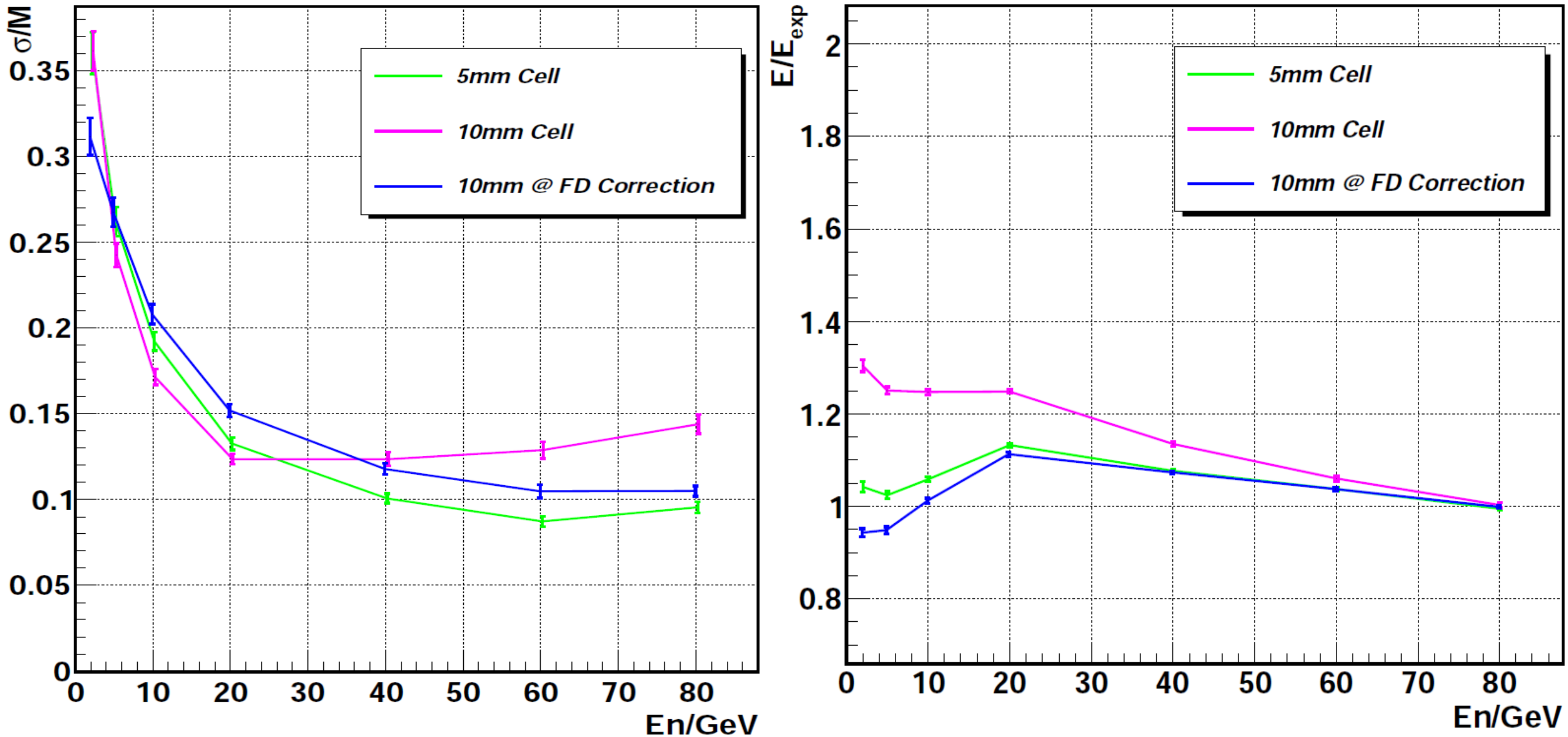
- For example: Compensation based on the correlation of NH_30mm & FD1mm:

  E = a * NH_30 + b * FD ~ 30%/sqrt(E)! But...

- Correlation coefficient depending on Energy: b ~ 0.0266*E. To measure cluster energy of charged particle (with track info): check matching

- A set of energy independent (LO) estimator: E = a' * NH_x/(1 – FD*b')

Energy Estimation with FD Correction

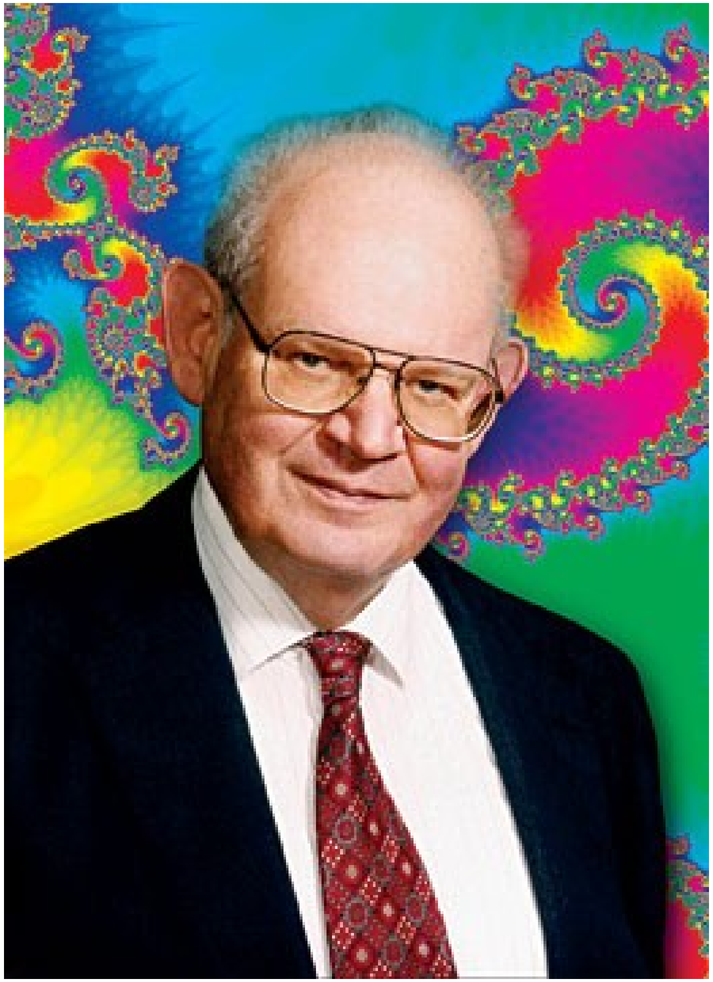


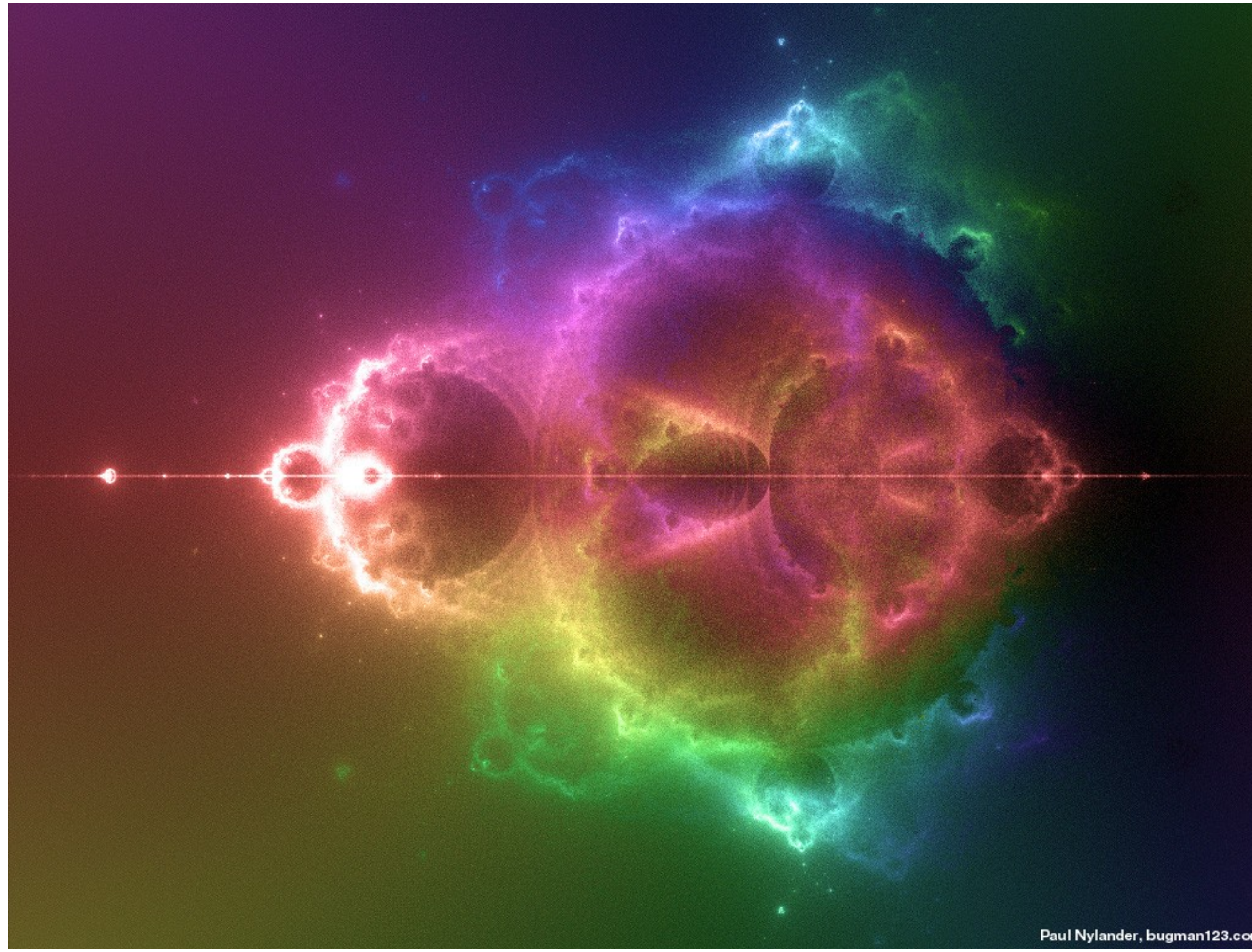
Hand put Energy Estimator with FD: NH10/(1-0.65*FD10)
Energy resolution improved at high energy: ~ saturation effect correction
Linearity improved: closed to 5mm Cell

Summary

- Calorimeter with extremely high granularity that can separate different showers is essential for the particle flow algorithm, which ensures good jet energy resolution at Linear Collider detector.

- Huge potential for reconstruction algorithm at high granularity
  - Tracking inside calorimeter...
  - Shower Fractal Dimensional analysis
    - Promising tools for PID
    - Better cluster – track linking for Particle Flow Algorithm
    - Correction for shower energy measurement
    - Not fully investigated yet...
  - Your dreamed but never realised algorithms

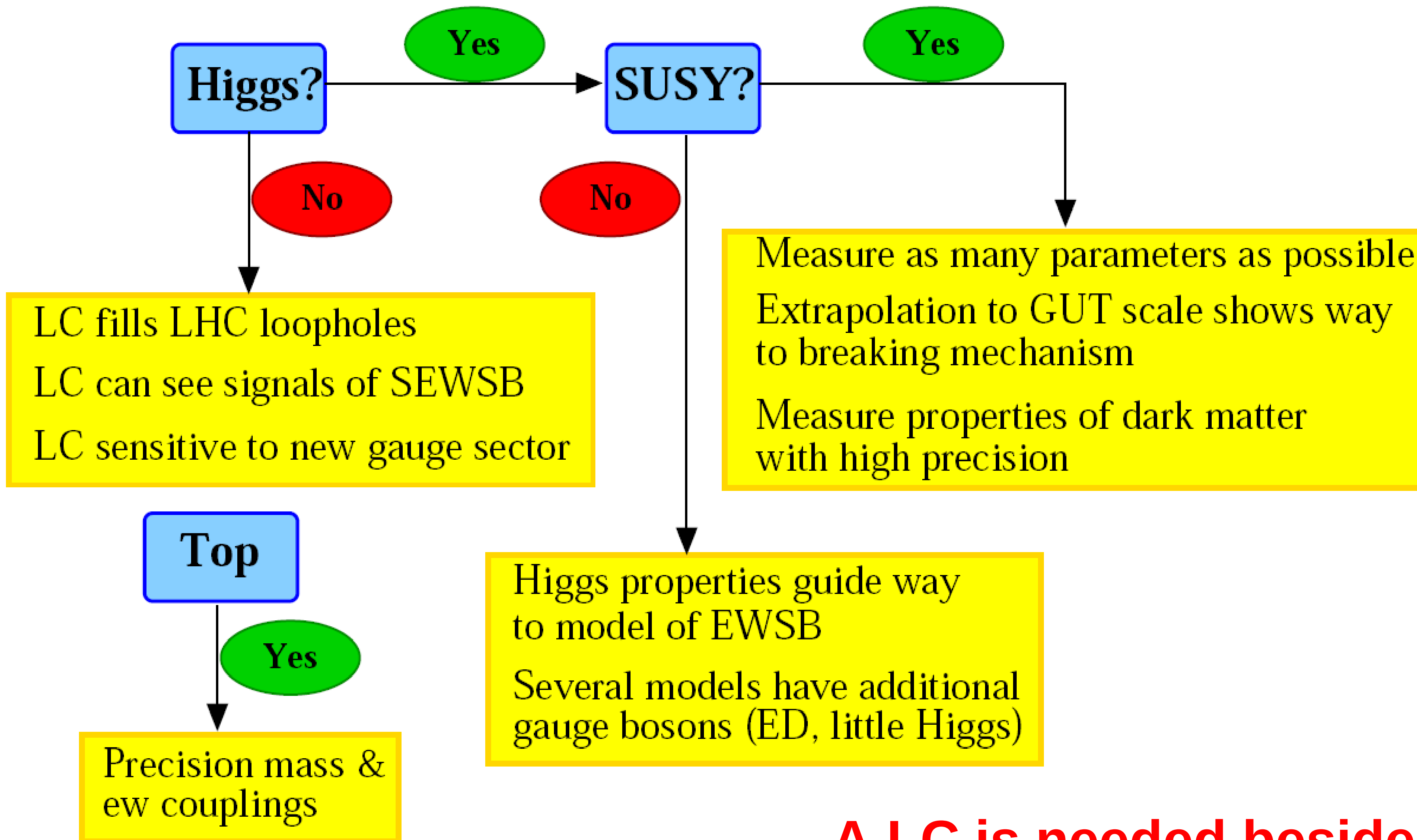




Special Thanks to ...

Spare slides

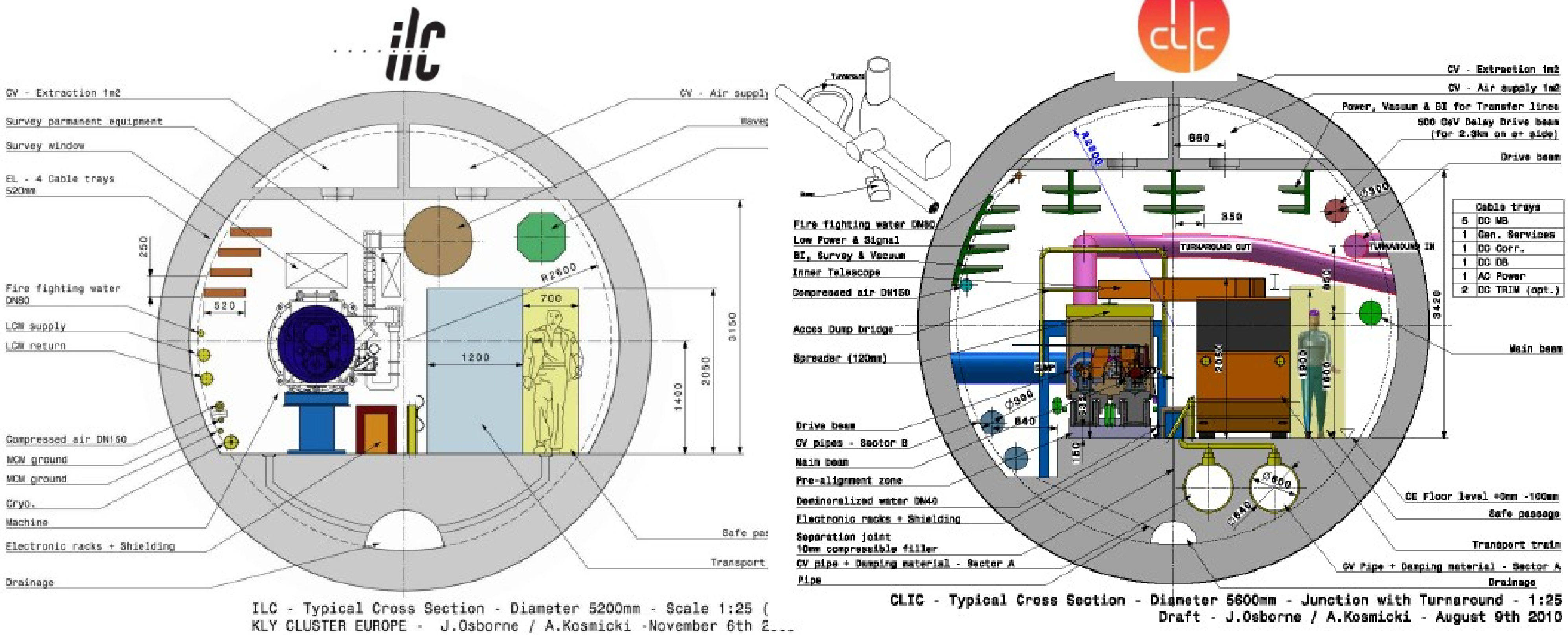
Physics @ LC



Klaus Moenig: Physics potential of LC

A LC is needed besides the LHC in any case

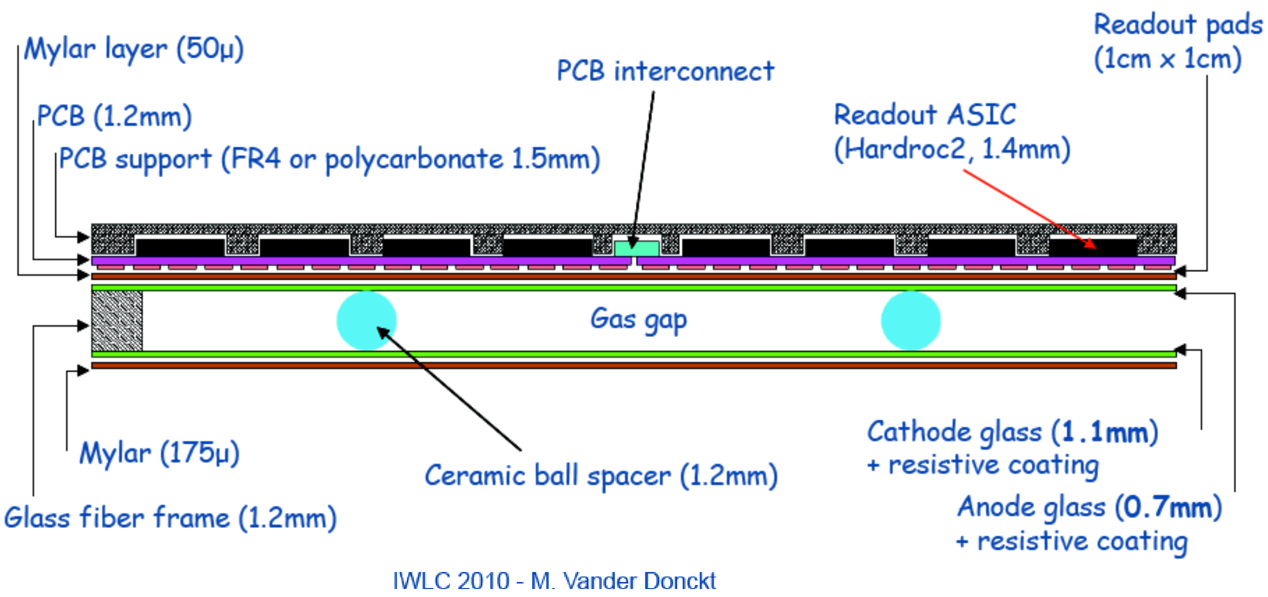
Candidate Linear Collider



- CLIC: Compact Linear Collier, center-of-mass energy: 0.5 - 5 TeV. Warm technology (Room temperature & high gradient (~ 100MV/m), small bunch spacing).
- ILC: International Linear Collider, center-of-mass energy: 0.5 – 1.0 TeV. Cold technology (2K & low gradient (~ 31.5 MV/m), large bunch spacing)
- CLIC & ILC: very different accelerators with similar detector.

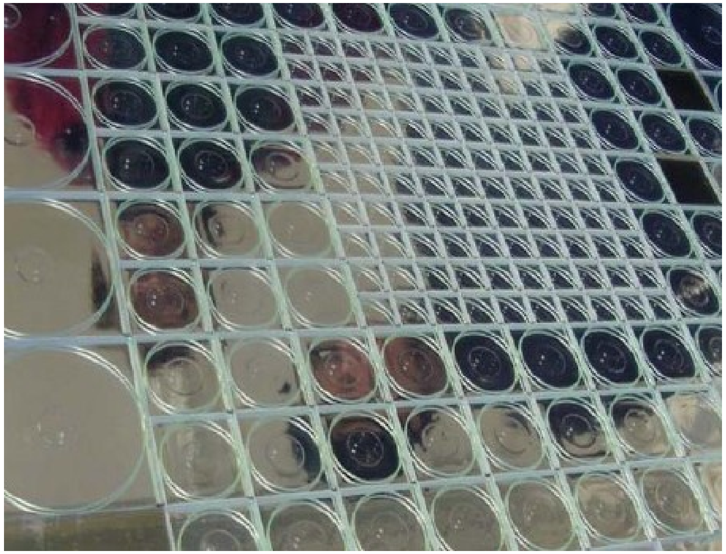
Gas Vs Scintillator

Gas: High granularity (1*1 cm) @ low cost



To compare:

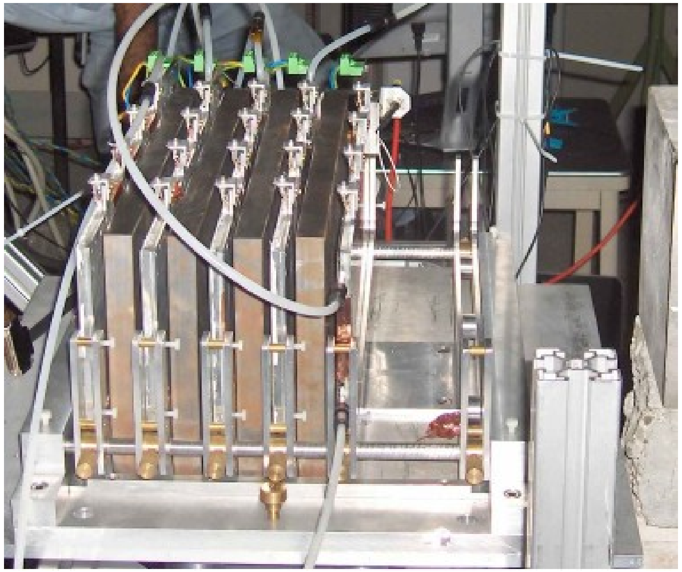
Sensor layer in Scintillator AHCAL. Cell size: 3*3 cm, 6*6 cm & 12 * 12 cm

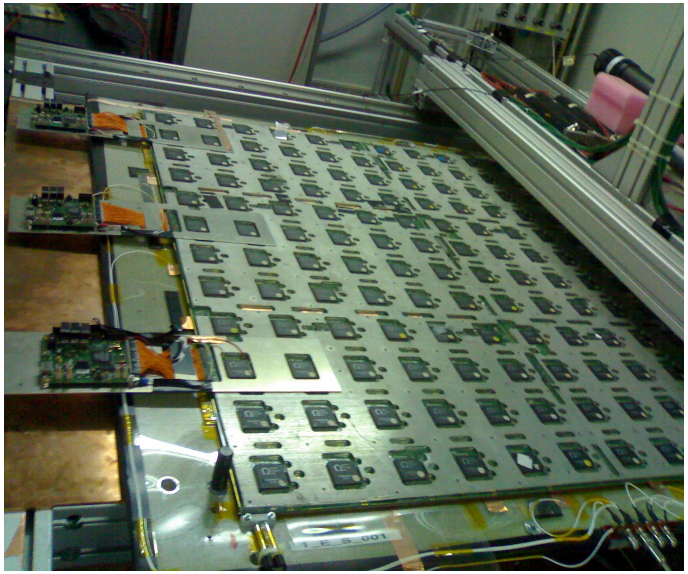


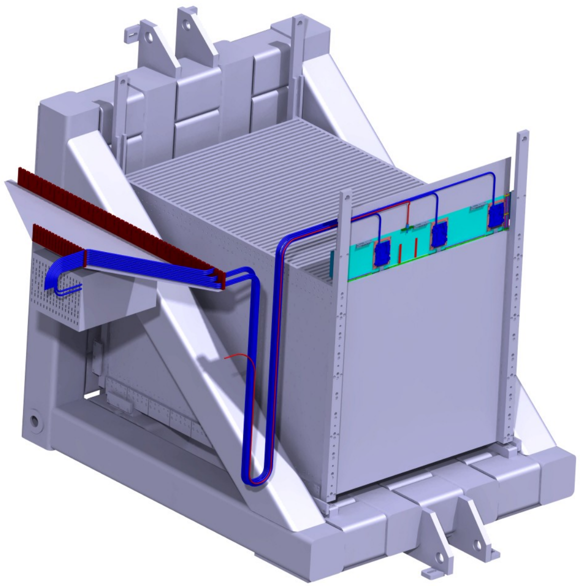
- Gaseous detector:
  - RPC: High efficiency, homogeneous, low cost, robust...
  - Huge fluctuation on induced charge: digital or Semi-digital (channel coded on 2 bits) readout...
  - Free of direct neutron hits

GRPC SDHCAL

- Prototypes & test beam
  - Toward the proof of principle for Detector Baseline Design (DBD, end of 2012)
  - Mini DHCAL, m² → m³ ANR DHCAL with various new technologies
  - Performance study @ test beam & cosmic ray: homogeneity, efficiency, multiplicity, stability, noise rate, induce charge spectrum...







1k channels → **10k** channels → **400k** channels!