Calorimeter Status and Possible Next Steps

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I. Where we are (I think)

- Overall Picture
- updates from Snowmass

II. What R&D is needed (I believe)

- Simulations and physics
- Software
- Hardware

III. Towards a plan of future action (I hope)

Who is going to do this in the US ?

Current Scene

- EFlow represents a paradigm shift of sorts

- No existing templates

- Intrinsically complex
  $\Rightarrow$ Speedy evaluation not easy

- On the other hand:

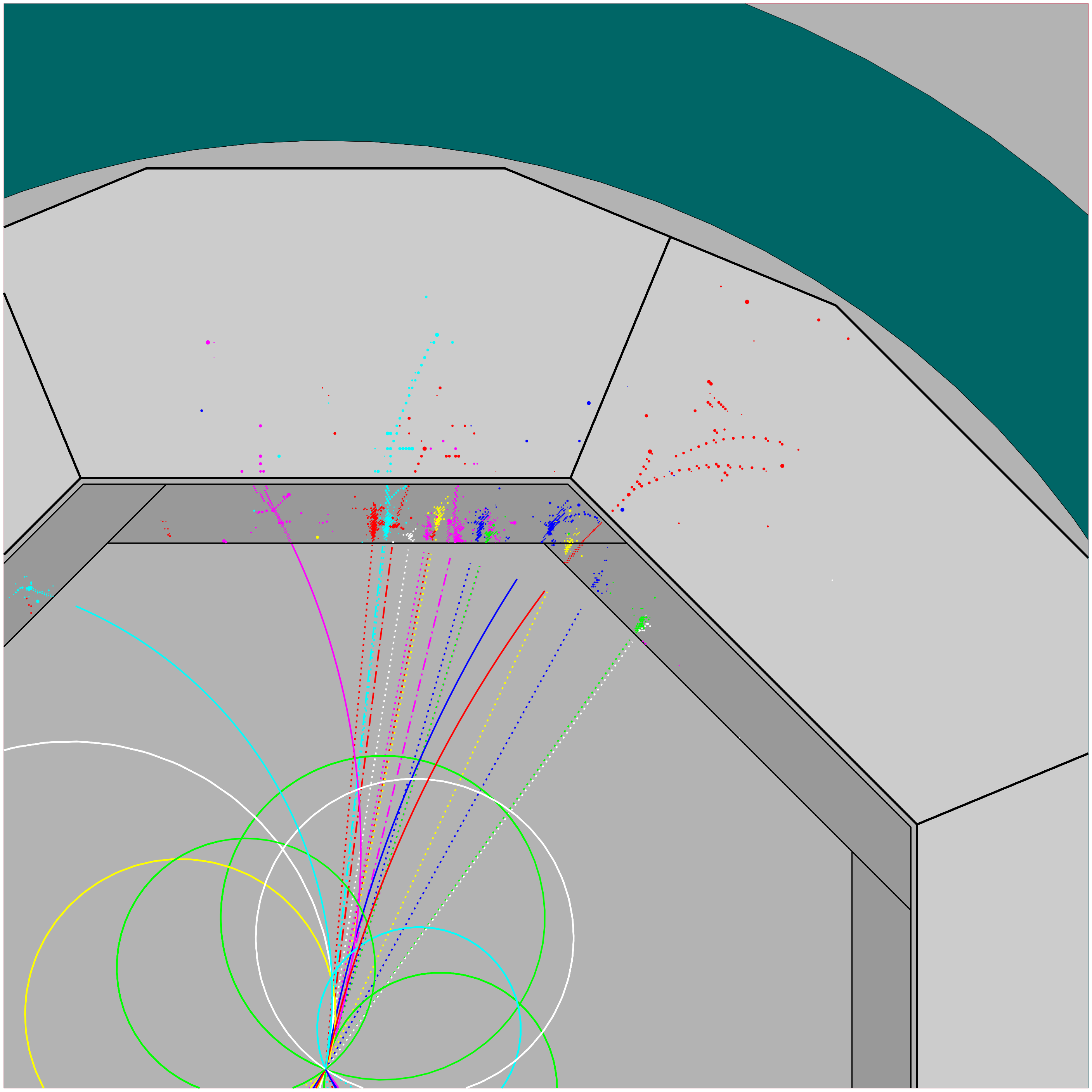
  * Potentially quite powerful

  * Interesting and fun!

- Proposed by NLC group, Snowmass 96

- Pushed hard by TESLA

- Requires dense, highly segmented ECal and highly segmented HCal



Zoom on the transverse view of the detector

Visualization performed w/ `FANAL` package developed by H.Videau

(contd)

- Primary EFlow asset: Jet Reconstruction and Resolution

- What comes along for free:
  * Excellent Lepton id. (HCal is also muon tracker)
  * Isolated and non-pointing photons/neutrals

- Typical single-particle resolutions:
  * $e^{\pm}$, γ : (10 to 20%)/$\sqrt{E}$
  * h^0 : (40 to 50%)/$\sqrt{E}$
  * $h^{\pm}$: tracker

- Jet resolution: (20 to 30%)/$\sqrt{E_J}$
  (using $e^+e^- \to q\bar{q}$)

Alternative pov: Vertexing requires large B, for which traditional calorimetry doesn't work well. So we might as well make the best of it!

" τ tagging is difficult "
" $\varepsilon_\tau \sim 0.5$ "

" τ polarisation for tan β "
" in $\tilde{\tau}$ decay "

300 GeV $\tau \rightarrow \nu_\tau \rho$

$\rho \rightarrow \pi^{\pm} \pi^{0}$

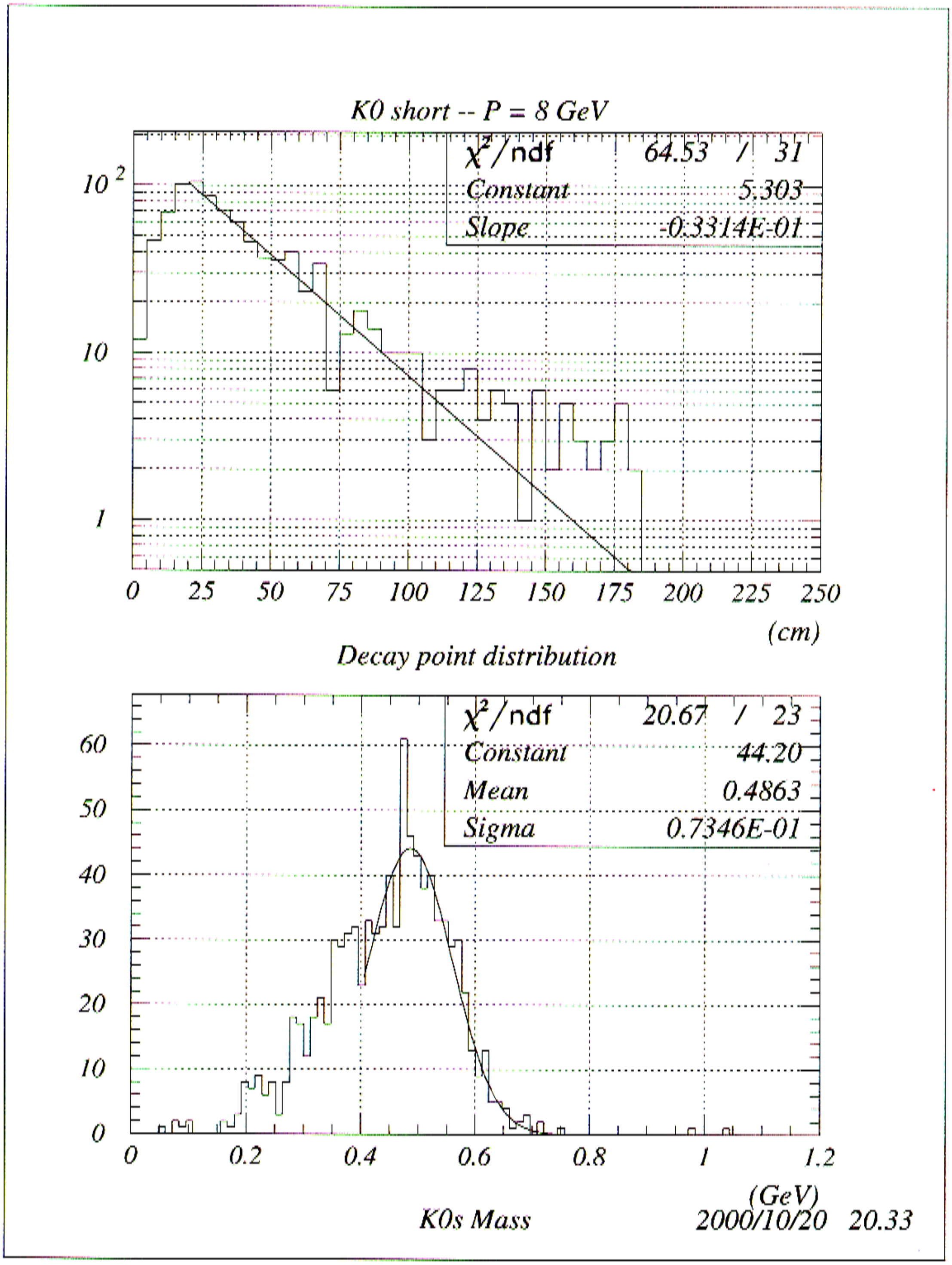
TESLA

A high granularity ECAL and HCAL

Cell size 1x1x0.5 cm^3

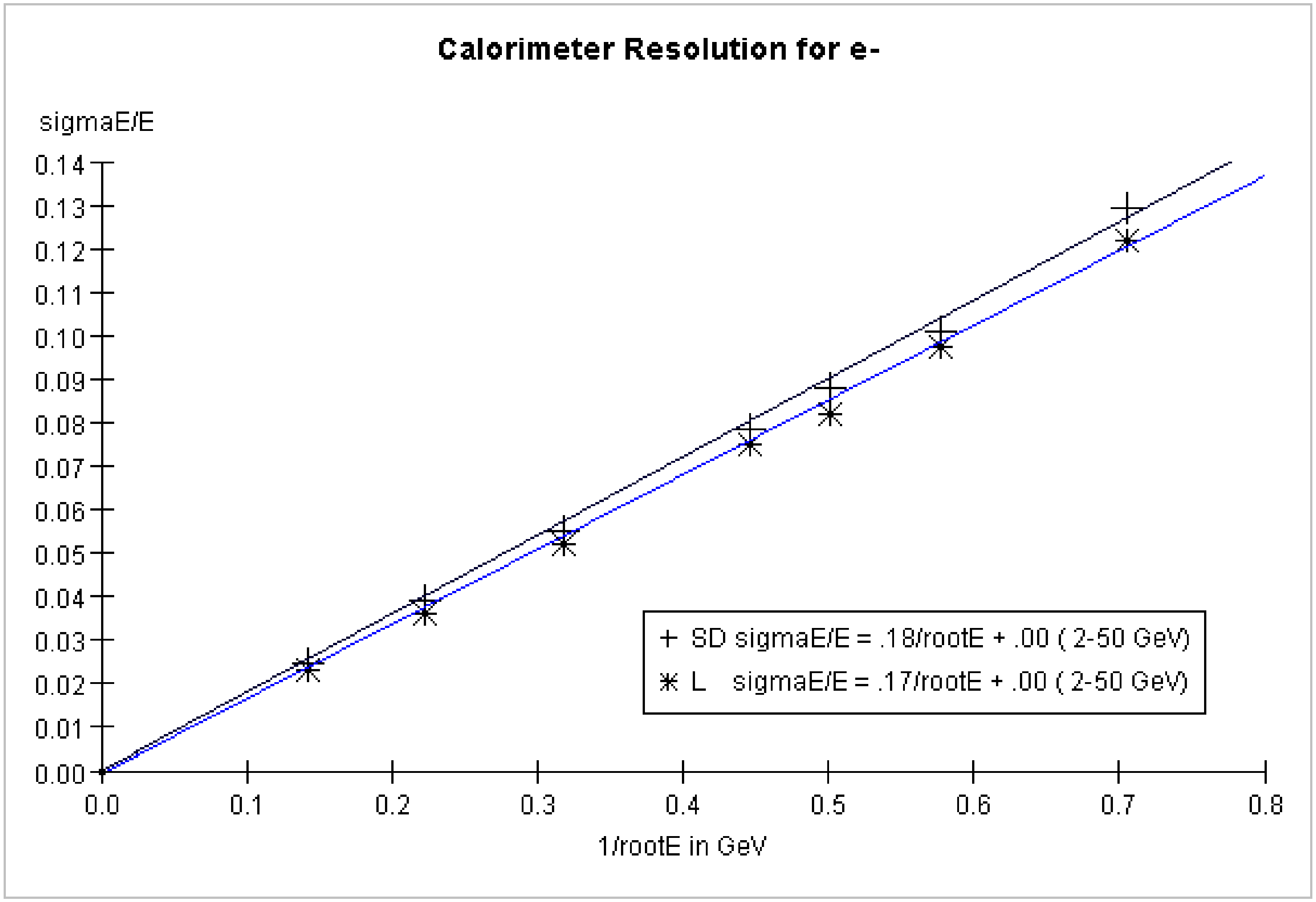
Back to bubble chambers?

$K_s^0 \rightarrow \pi^0\pi^0 \rightarrow \gamma\gamma\gamma\gamma$

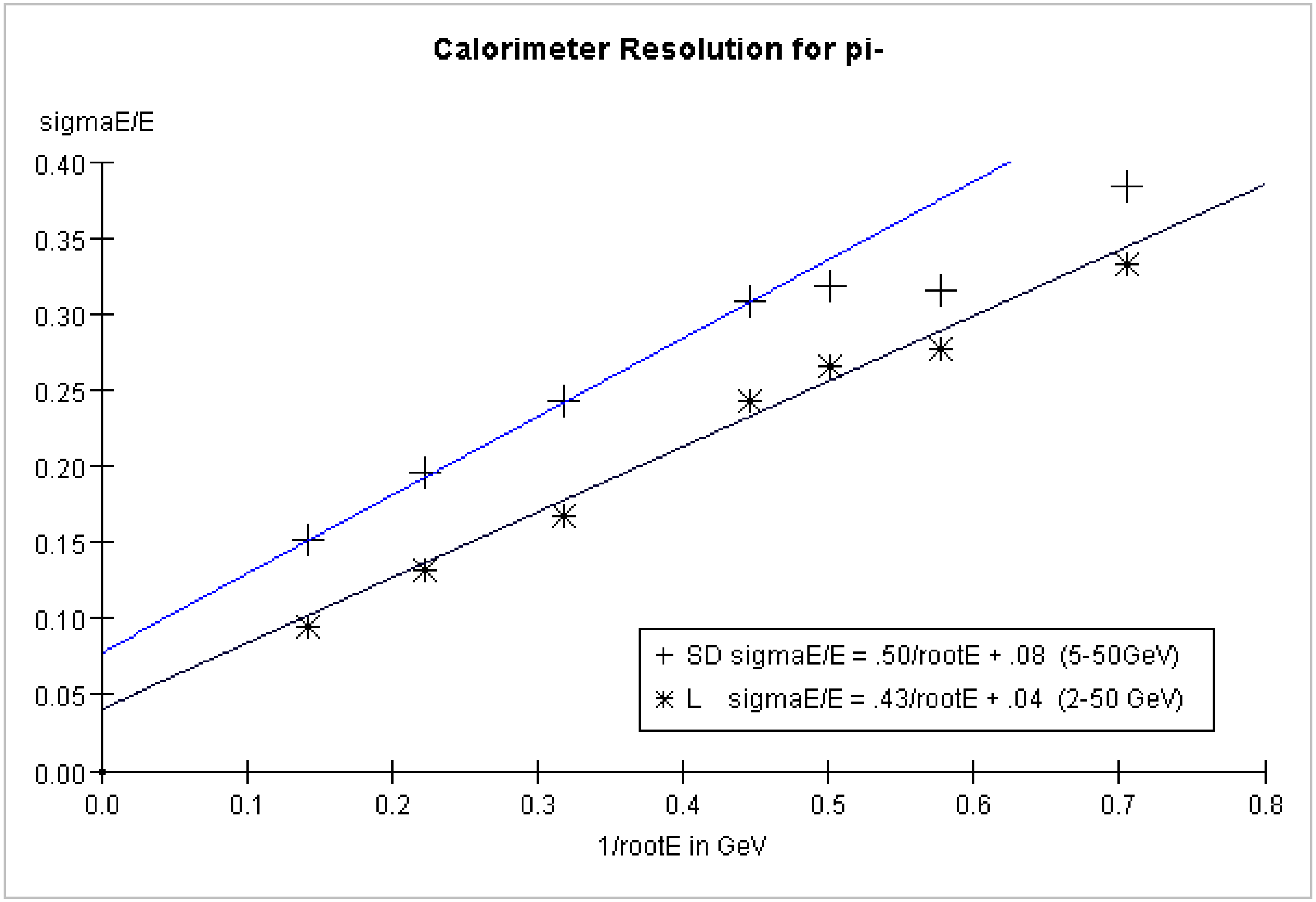


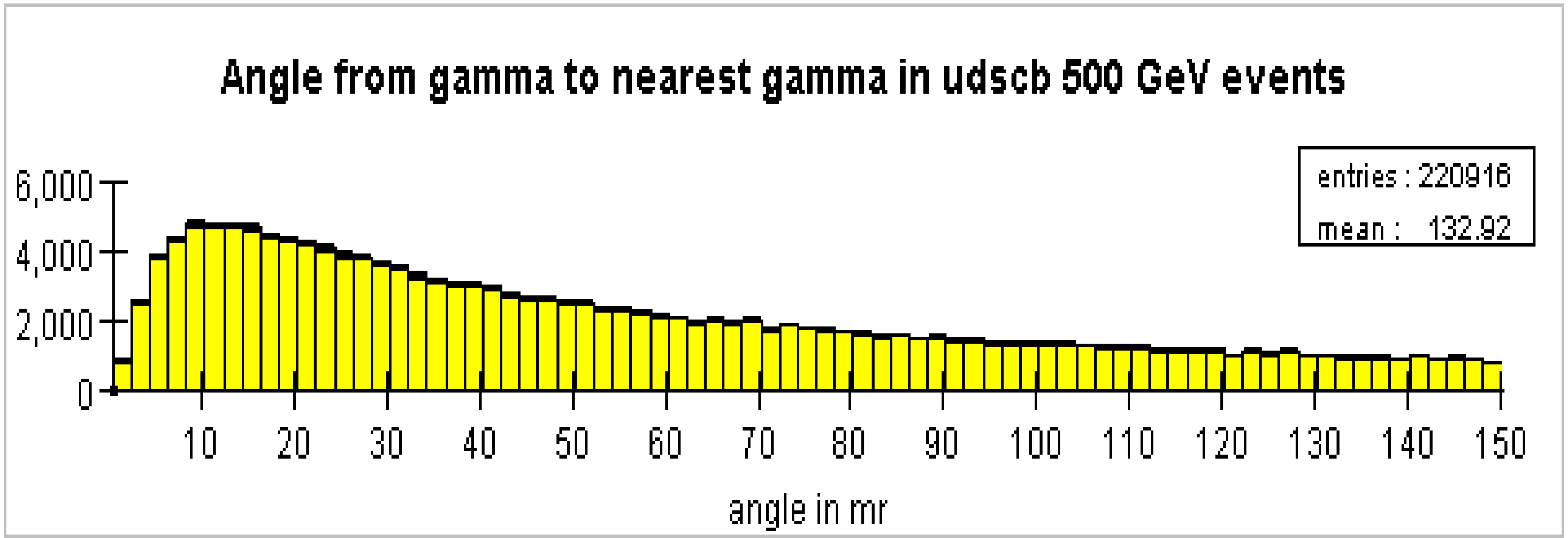
– no kinematic constraint was used at this stage

Resolution, e-

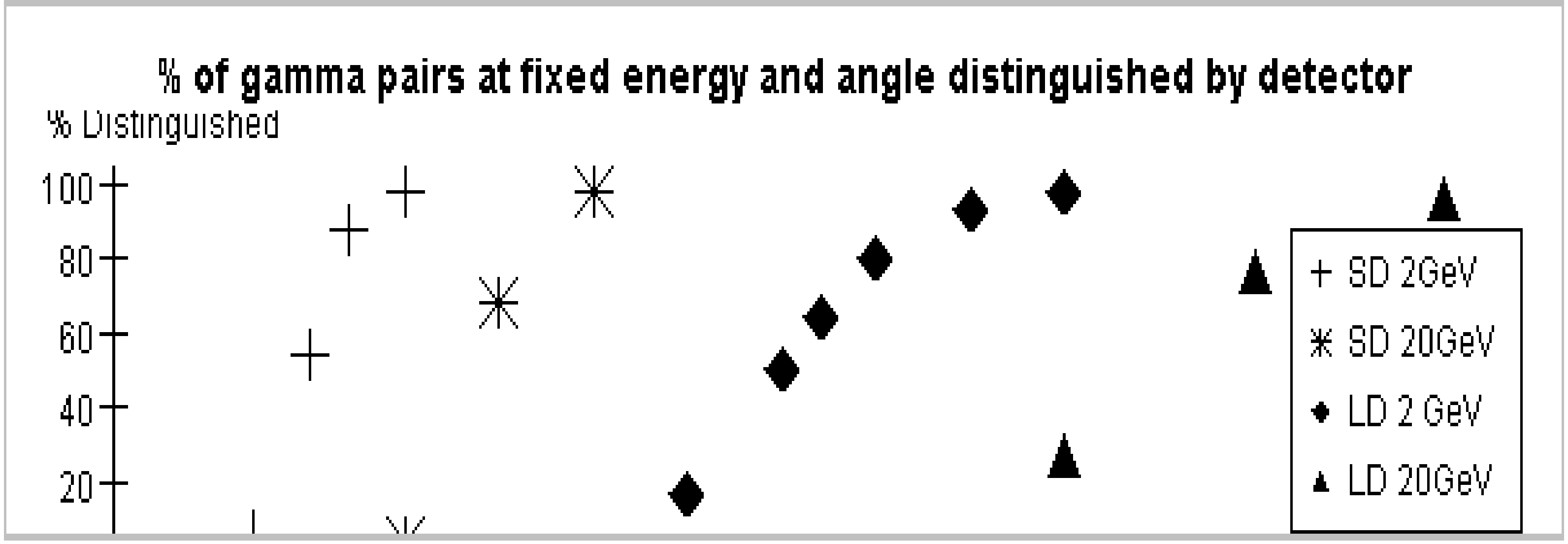


Resolution, pi-



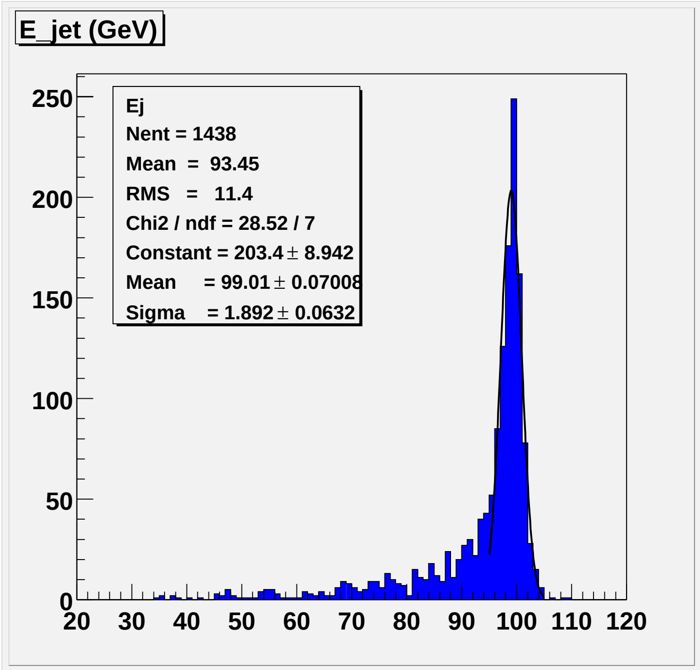


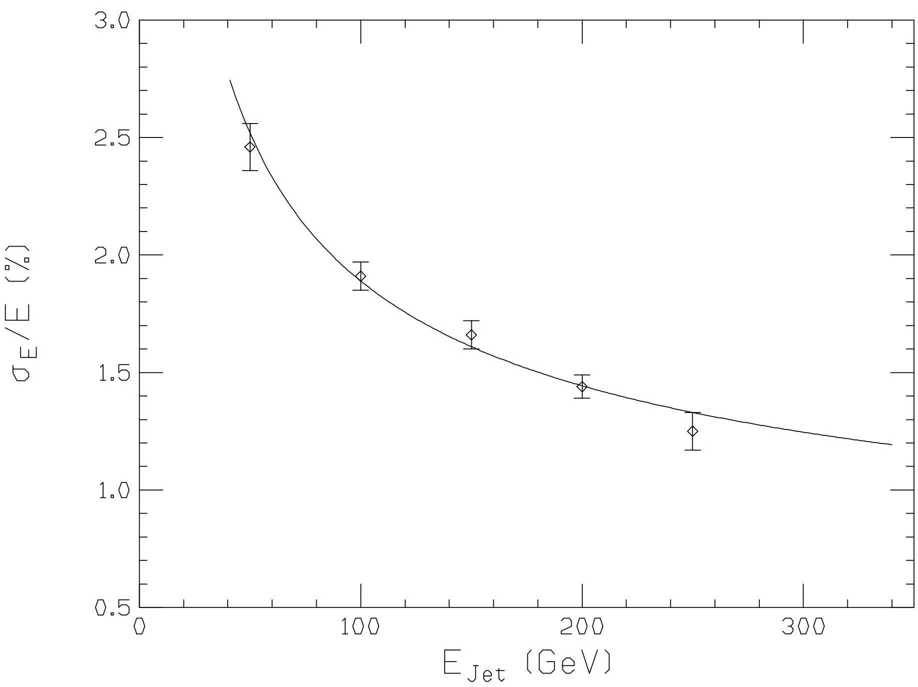
Angle from gamma to nearest gamma in udscb 500 GeV events
entries : 220916
mean : 132.92
6,000
4,000
2,000
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
angle in mr



% of gamma pairs at fixed energy and angle distinguished by detector
% Distinguished
100
80
60
40
20
SD 2GeV
SD 20GeV
LD 2 GeV
LD 20GeV

LCD SD Detector
"Ultimate" Jet Energy Resolution, $e^+e^- \rightarrow q\bar{q}$

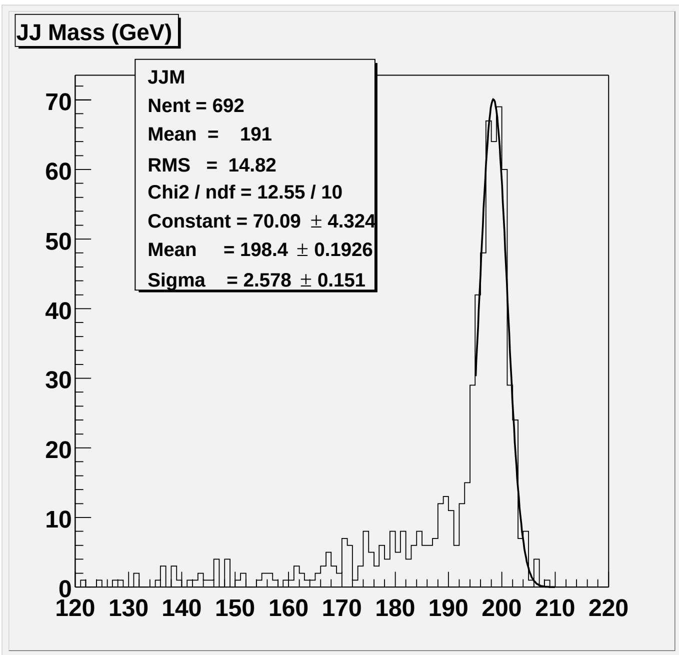




$$\sigma_{E_j}/E_j = 0.15/\sqrt{E_j}$$

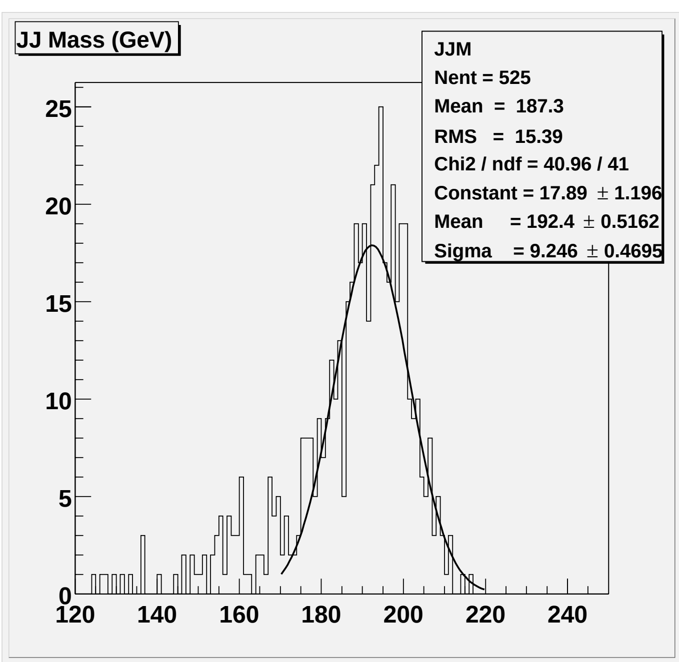
Compare (perfect) EFlow with (perfect) calorimeter-only jet reconstruction (”by hand” compensation), (SD detector, $e^+e^- \to q\bar{q}$, $\sqrt{s} = 200$ GeV)

- EFlow:



$\sigma(Mjj) = 2.6$ GeV/c^2

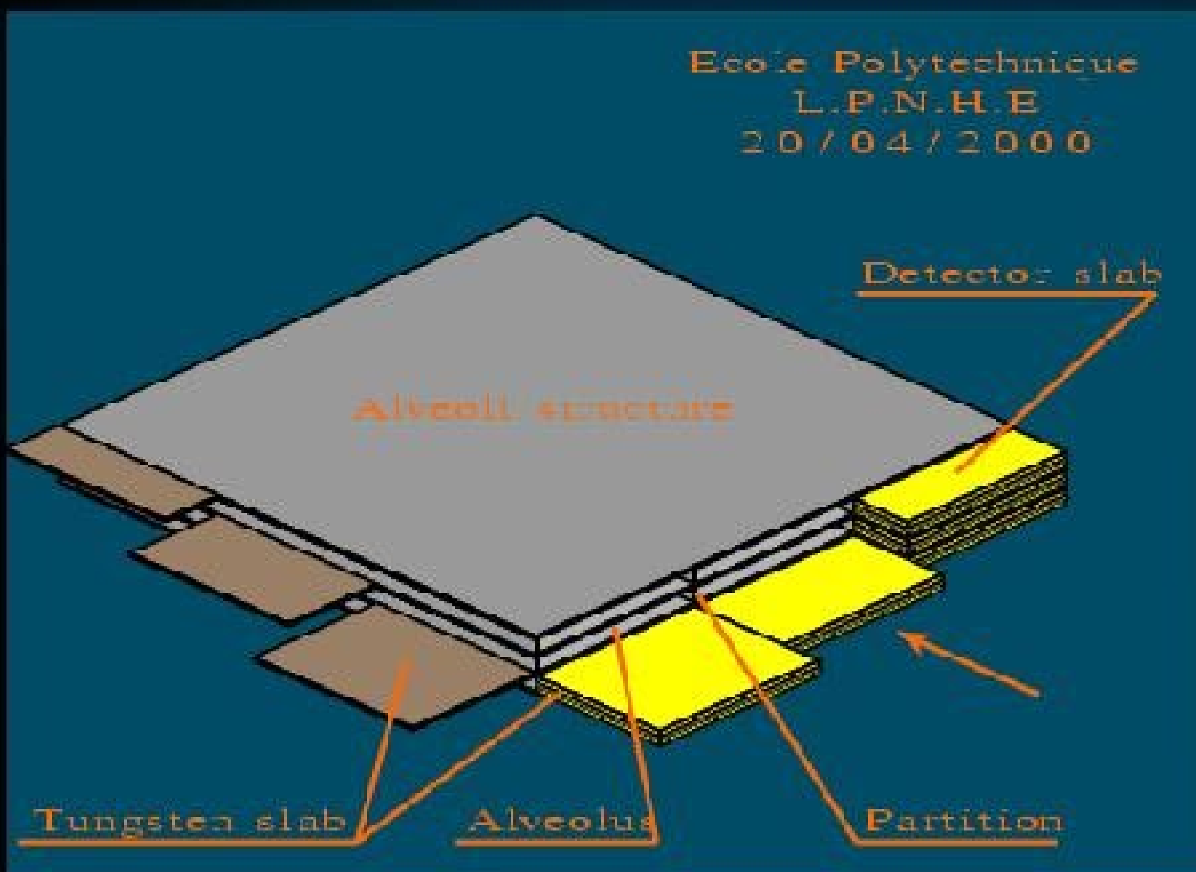
- Calorimeter Only:

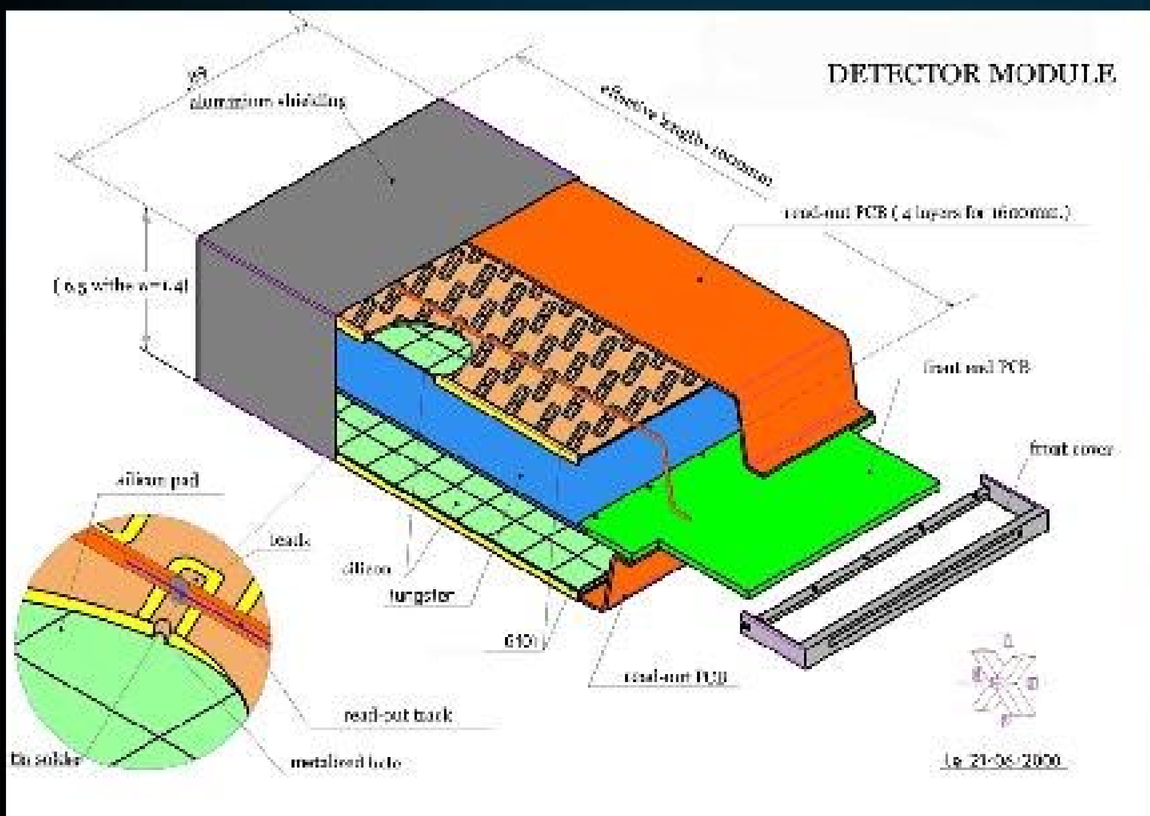


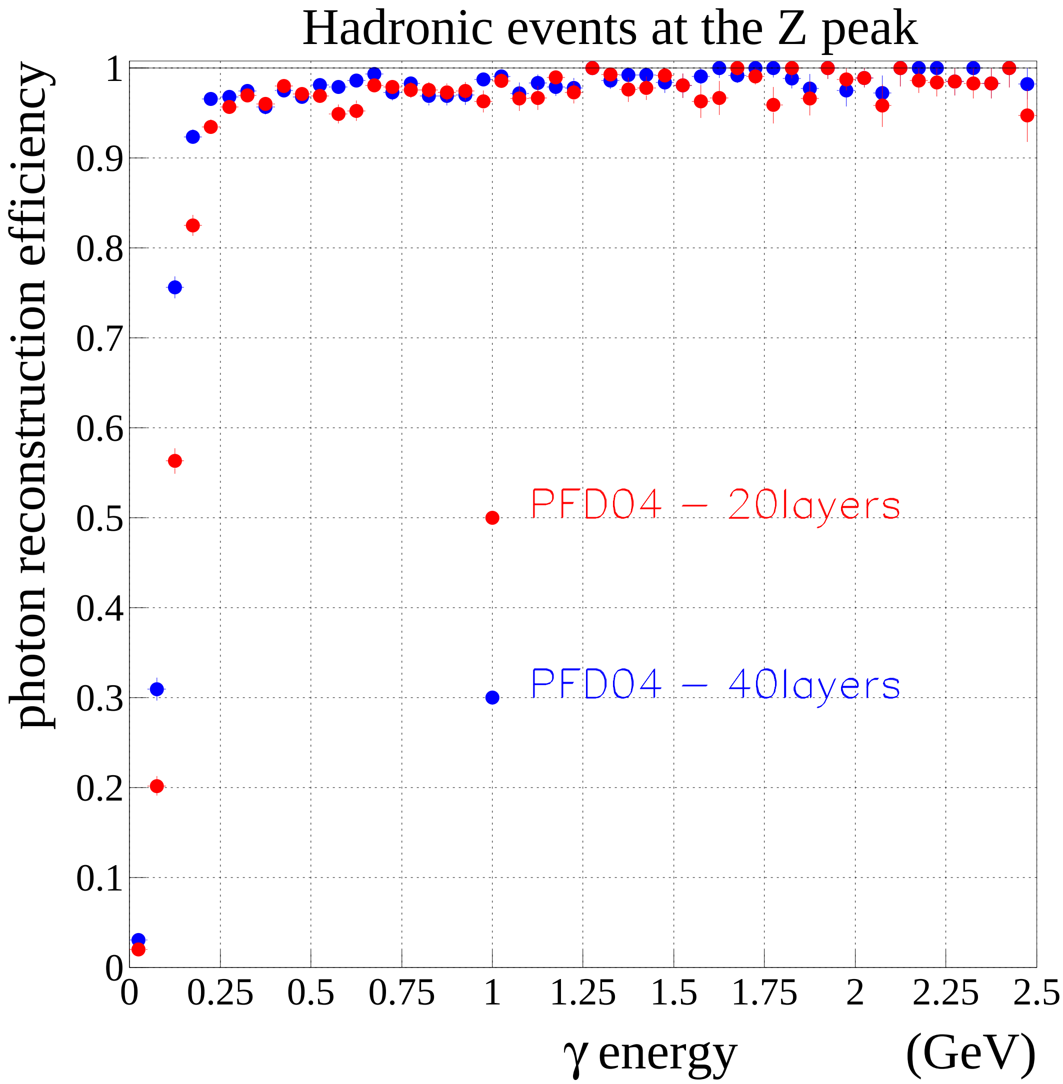
$\sigma(Mjj) = 9.2$ GeV/c^2

Current Approaches

- Europe
  - * ECal: Si/W
    - ◦ layers: 40 → 20 ($15 \times 0.8X_0 + 5 \times 3.2X_0$)
      3500 m^2 Si → 1700 m^2
    - ◦ segmentation: 1 cm^2 → 1.5 cm^2
  - * ECal alternative: Shaslik
  - * HCal: “digital” *vs* scint. tile
    - ◦ digital: 1 cm^2 seg. (RPCs? fibers?)
    - ◦ tiles: > 25 cm^2
  - * Making good progress with software dev.
- Asia
  - * Pb/scint. tile ECal and HCal with presampler
  - * going route of “traditional” compensating cal.

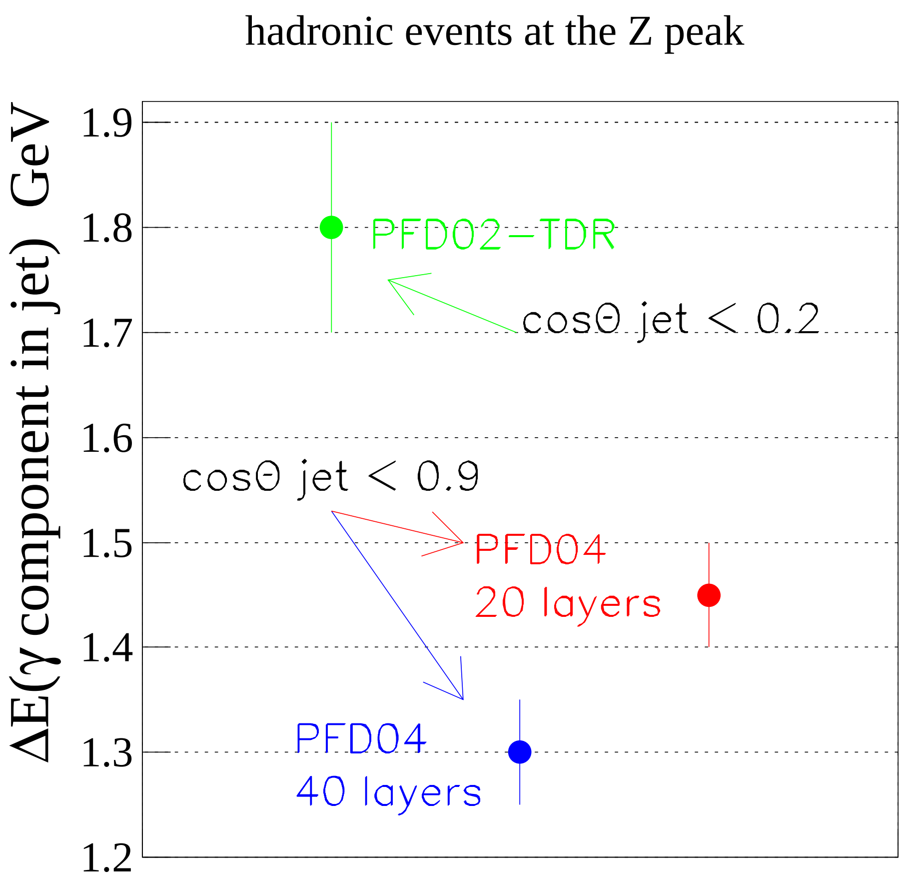

Ecole Polytechnique
L.P.N.H.E
20/04/2000
Detector slab
Tungsten slab
Alveolus
Partition


DETECTOR MODULE
aluminium shielding
front end PCB
front cover
silicon pad
leads
silicon
tungsten
read-out PCB
read-out track
metalised hole
tin solder



The fake rate is about 1.6(1.7) fake photon/event with a mean energy of 0.4(0.4)GeV for the 40(20) layers

The jet energy resolution

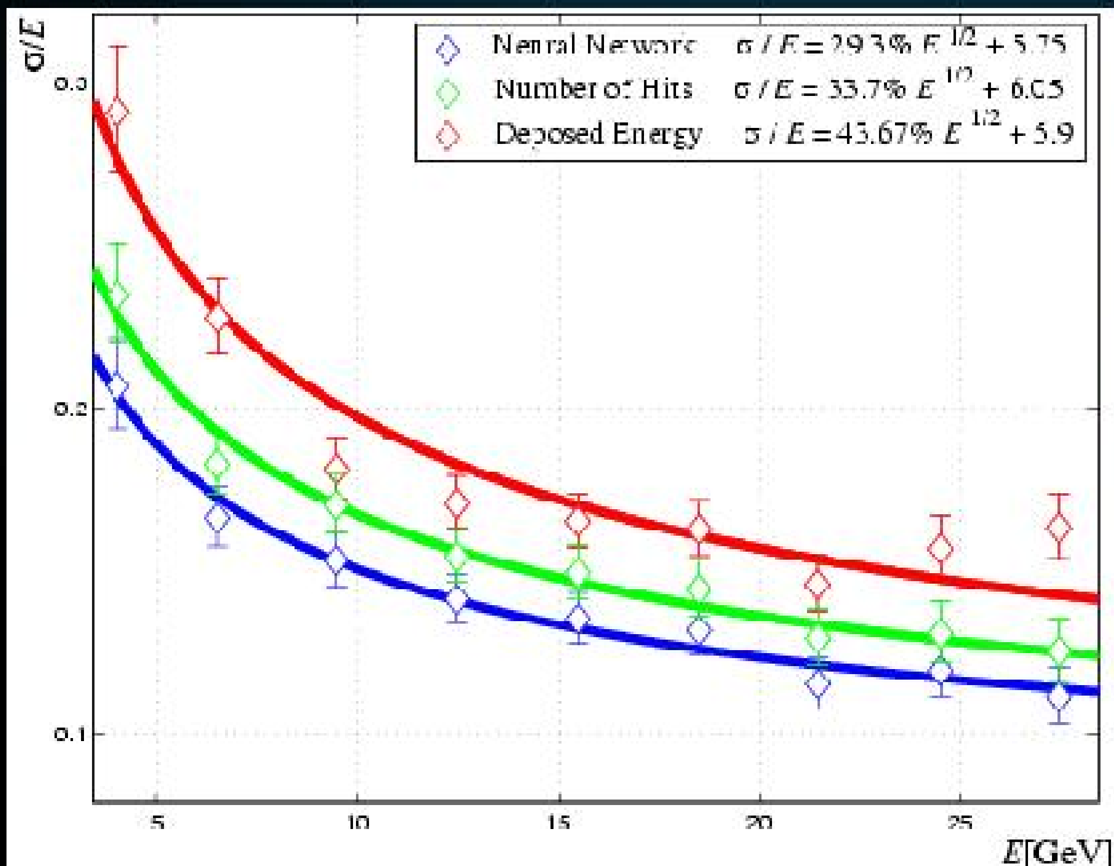


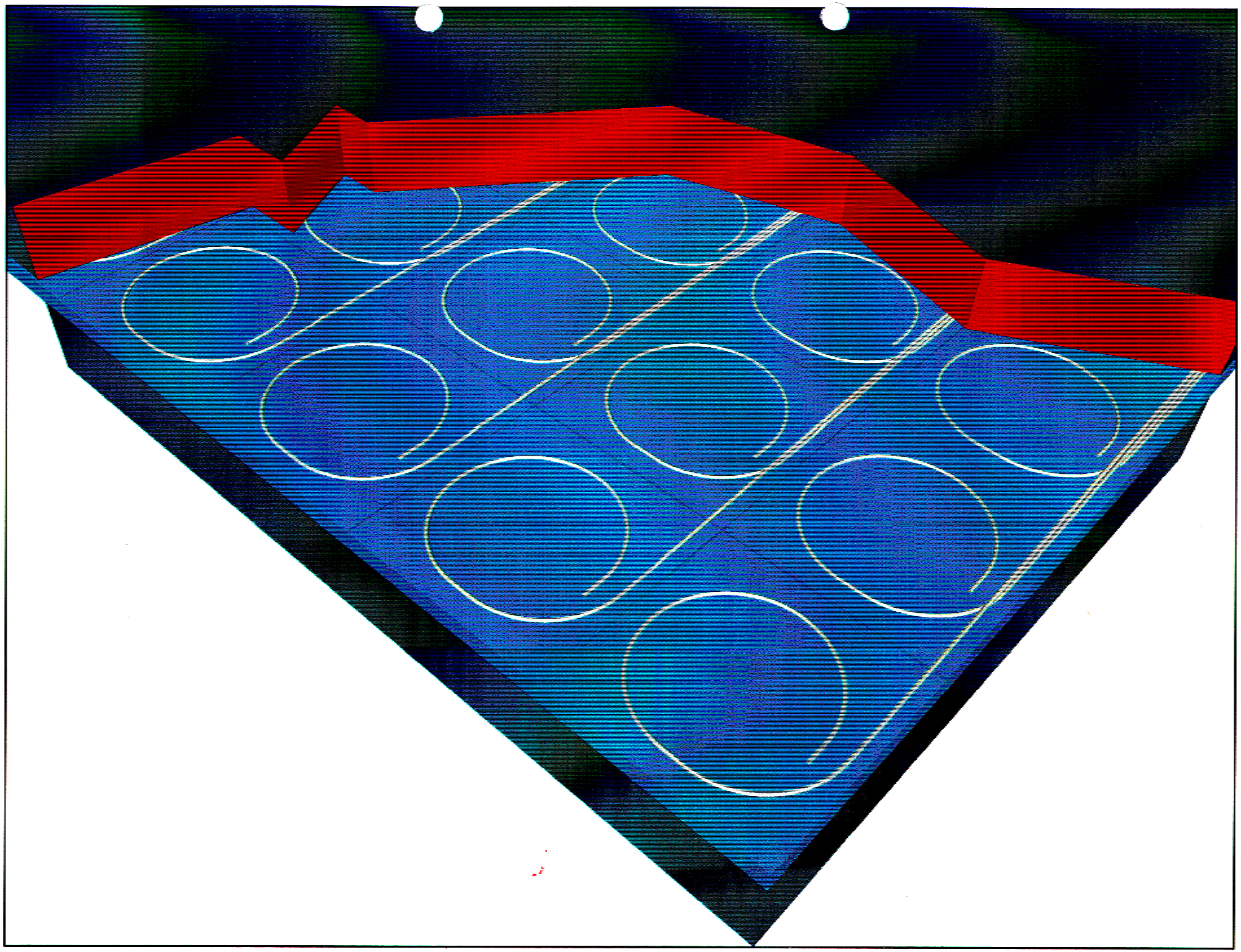
The jet resolution at Z peak **if neutral hadron reconstruction doesn't depend on W-Si number of layers**

W-Si type	ΔEvis GeV
40 layers - PFD04	2.9 GeV
20 layers - PFD04	3.0 GeV

The resolution is dominated by the neutral hadron reconstruction, therefore

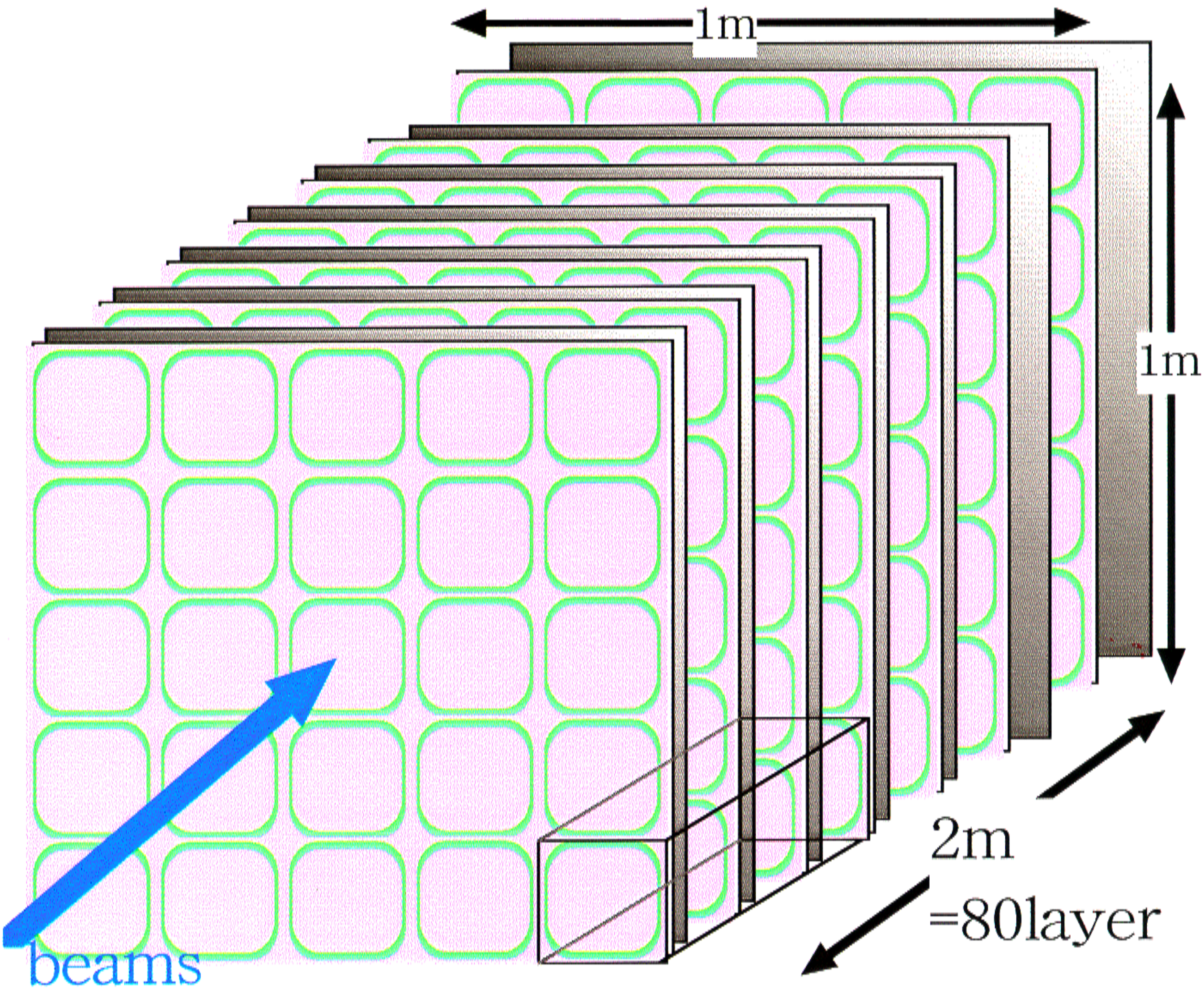
HCAL granularity is of major importance


σ/E
Neural Network σ / E = 29.3% E 1/2 + 5.75
Number of Hits σ / E = 33.7% E 1/2 + 6.05
Deposed Energy σ / E = 43.67% E 1/2 + 5.9
0.3
0.2
0.1
5
10
15
20
25
E[GeV]



JLC-HCAL test module

tile/fiber



tower=20layers

5x5 towers X 4sectios

scinti.2mm+Pb8mm

$127X_0, 4.2\lambda_I$,9t

$+1.7\lambda_I$

+Straight groove CAL

US Scene

- SD: $\approx$ TESLA superficially
  - ∗ Many major design elements still under review (should remain that way for awhile!)
    - ◦ ECal seg and layering (0.25 cm^2, $30 \times 0.7 X_0$)
    - ◦ gap thickness (0.25 cm/ly)
    - ◦ HCal absorber, seg., and active elements
- LD: What is it?
  - ∗ Large $BR^2 \Rightarrow$ EFlow ?
    - ◦ But marginal transverse seg with scint tile/Pb
    - ◦ 4.2 cm $\times$ 4.2 cm is spec.... Is this realistic?
  - ∗ 4:1 ratio Pb:scint $\Rightarrow$ compensating ?
    - ◦ 1 mm scint layers: insufficient light $\Rightarrow$ gang?
  - ∗ What do we want for LD ? Start over ?
- Ignore PD for now

Some Open Questions/Issues for LCD Calorimetry
Feb 2001

- Develop means for evaluating energy flow performance
  - Full simulations
  - parameterizations of full sim.
  - clustering techniques
  - charged pion rejection
  - neutral hadron rejection
- Figures of merit
  - Jet-jet Mass
  - Mjj vs cost
  - Missing energy
  - Lepton id.
  - non-pointing track/shower recon.
- Particularly relevant physics processes
  - HZ vs WW vs ZZ
  - HHH coupling (see talk by P. Gay at LCWS2000)
  - WW -> jets full recon from sqrt(s)=180 to 1500 GeV
  - top full recon.
  - non-pointing photons
  - SUSY: selectron t-channel?
  - Others?
- How to compare various detector designs
  - Do Fast Sim. comparisons have any meaning?
  - Are single-particle resolutions meaningful?
  - How to evaluate full sim without good reconstruction?
  - What do we do, short of exhaustive full sim. and recons studies?
- Track finding in the EM Cal.
- Luminosity spectrum
  - role of endcap
  - What spatial resolution is required?
  - What is role of small-angle cal., if any, for this
- Other issues related to EFlow designs:
  - optimization of EM layer config. for cost & performance
  - Silicon gap reduction and mechanical design
- Alternatives to Si/W for EM Cal EFlow
  - Is the L EM scintillator design feasible?
  - What about a hybrid scint/Si design?
  - Inserting Silicon layers in a LAr or scint design
- Hadron calorimeter
  - Inside or outside the coil: Figures of merit
  - Absorber
  - digital detectors?
  - integrated muon id.
- Timing
  - Do we need to resolve bunches?
  - What does the physics require?

- What the technologies could deliver
- Forward Tagger
  - 2-photon vs SUSY: what are the requirements?
  - What would this look like?
  - Does it fit the interaction region design?
- electron/photon energy resolution
  - Is very good resolution required for any physics?
  - Optimization of silicon thickness
- Readout Issues
  - Required dynamic range in EM cal
  - How to implement: overlapped ADCs? How much overlap?
  - How to get light out of small scint. tiles
- Getting beyond sky hooks and non-supporting structures
  - module designs
  - integrating readout
  - heat loads?
  - endcaps and long barrels
- Cost of silicon
  - What should we expect?
  - Can electronics be integrated with the detectors?
- Other component costing issues
  - HPDs
  - absorbers
- Uniform costing criteria for L,SD, and P
- What EM energy resolution is required at v. high energy (ie what constat term) ?
- Parameterization of performance for non-full simulations
  - E res
  - shower position res
  - How to parameterize EFlow performance?

Updated March 2001
Ray Frey

R&D Items (EFlow-related)

A. Physics and (fast) simulations

1. Further develop case for *excellent* EFlow cal. (or not)
   - General argument of complementarity and hadronic final states
   - Specific processes:
     - Higgs self coupling (Gay)
     - WW/ZZ at high energy (Videau)
     - Recon of top and W for anom. couplings ? (Masako)
     - Many others to be explored: SUSY decays; Br(H), $M_H > 160$, ...
2. Integration of EFlow with flavor tagging
3. Parameterizations of EFlow performance for fast sim. (e.g. γ and K_L^0 effic as fn of separation)
4. What is required for forward tagger?

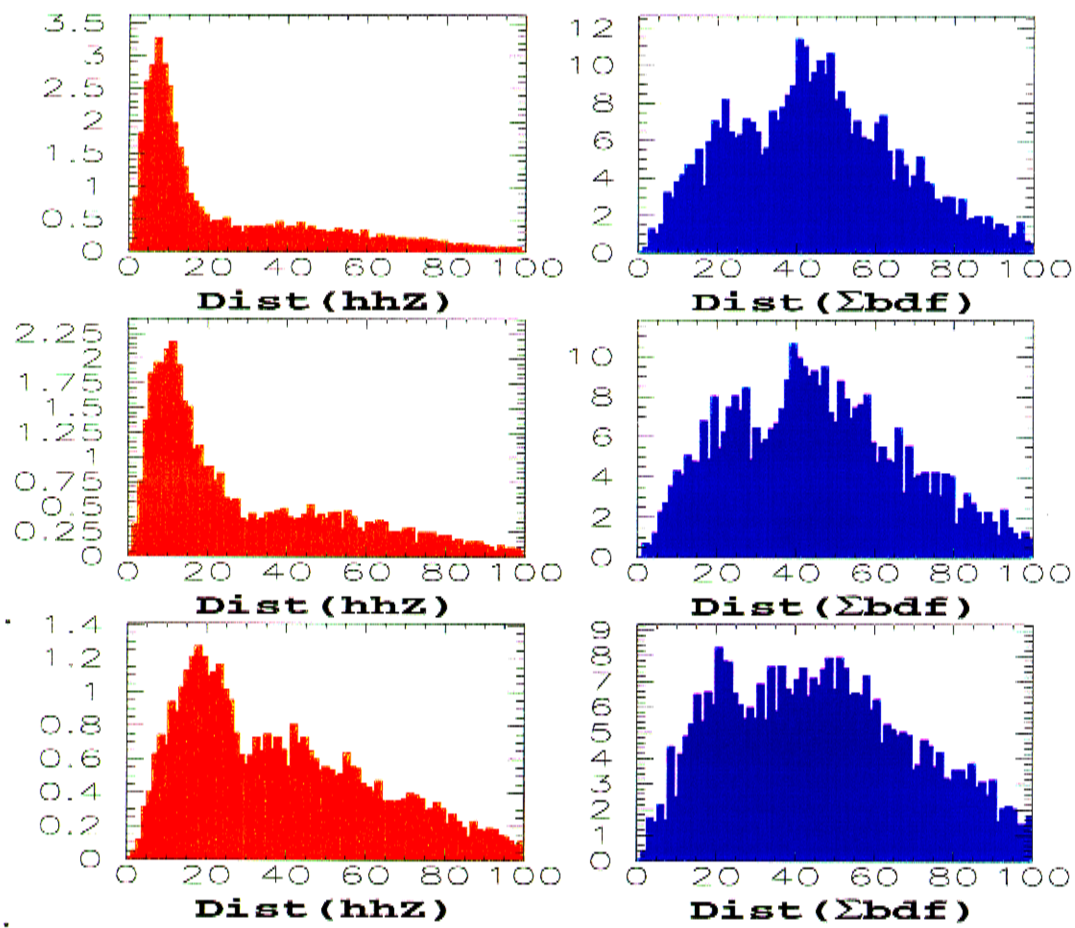
Summary of the Eflow studies

▷ Impact on Physics

P.Gay uses the measurement of the Higgs self-coupling to study the impact of the jets resolution.

Running from 60% to 30% for the jet energy resolution

- the background changes by a factor 6
- the precision on the cross section hhZ, by a factor 1.6



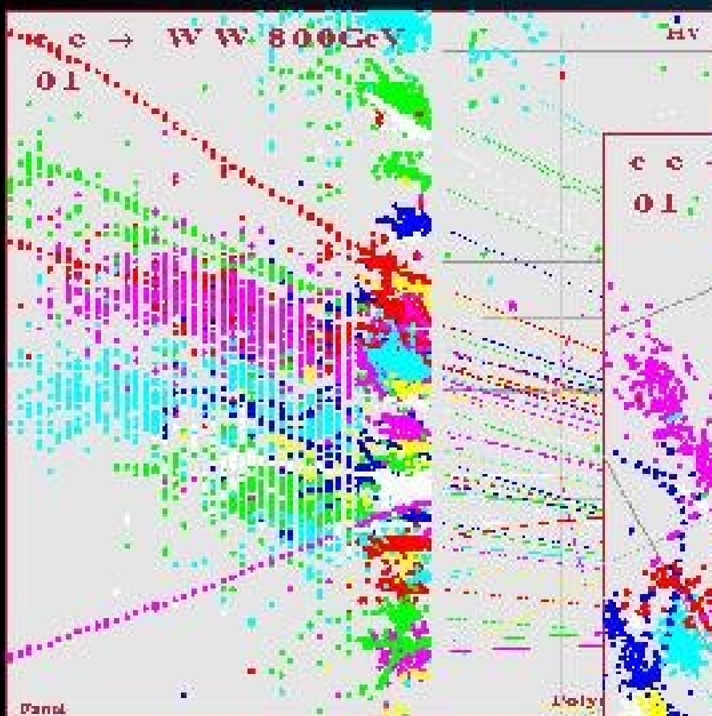
$30\%\ \sqrt{E}$

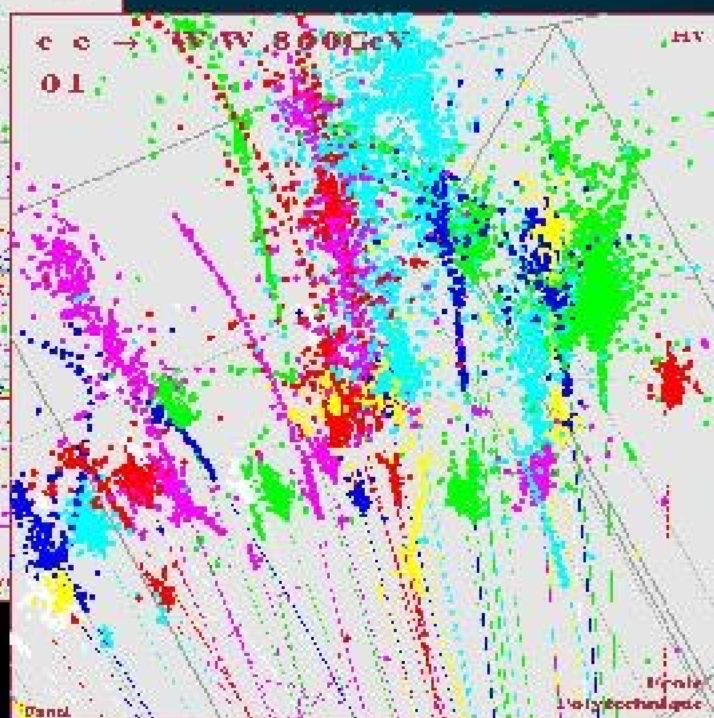
$40\%\ \sqrt{E}$

$60\%\ \sqrt{E}$

At least $40\%\ \sqrt{E}$ for jets energy resolution seems to be mandatory for this measurement

Two orthogonal views



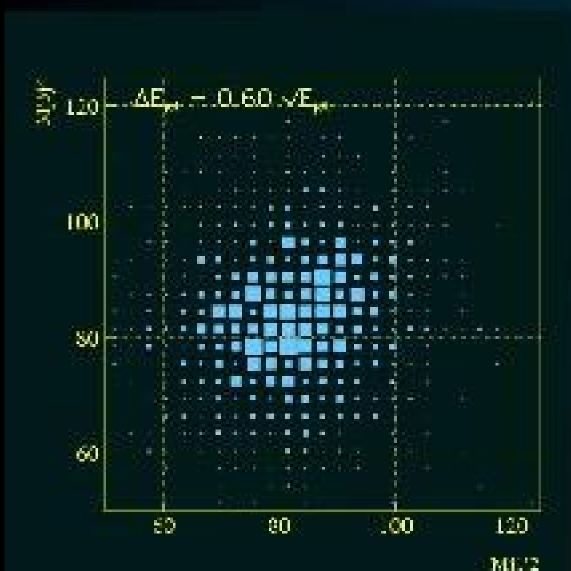


of a W hitting an end cap

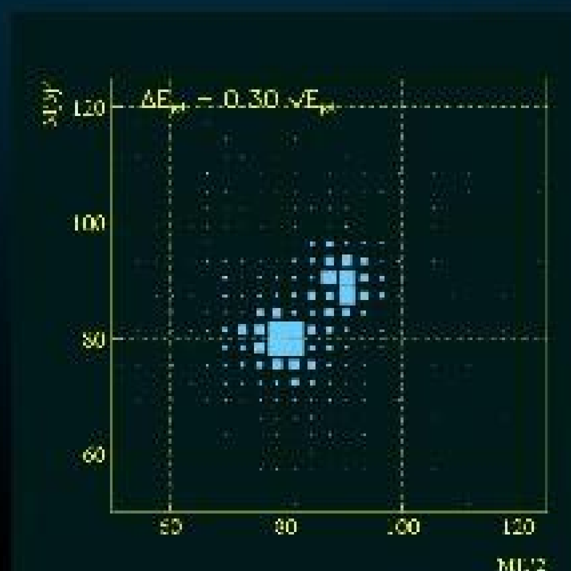
in the digital version

$e^+ e^- \to ZZ\nu\bar{\nu},\ WW\nu\bar{\nu}$

separation ZZ / WW

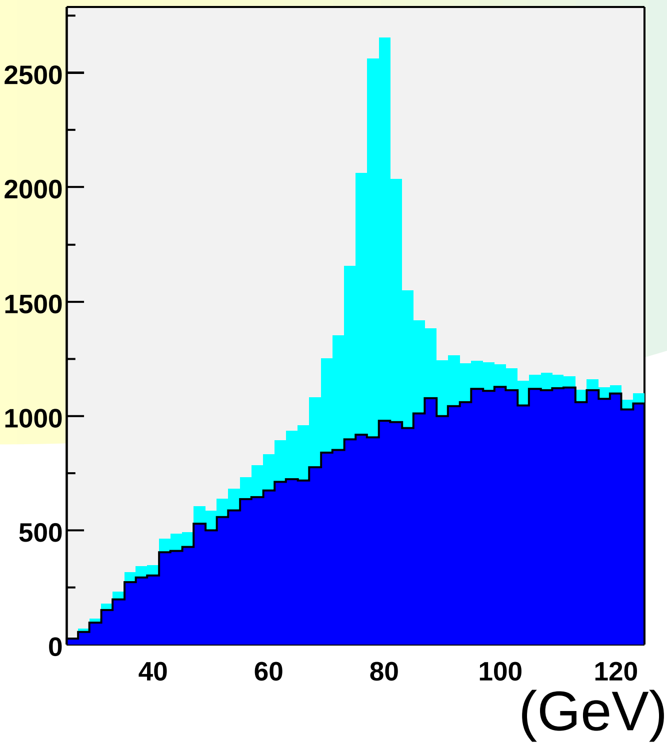


0.6

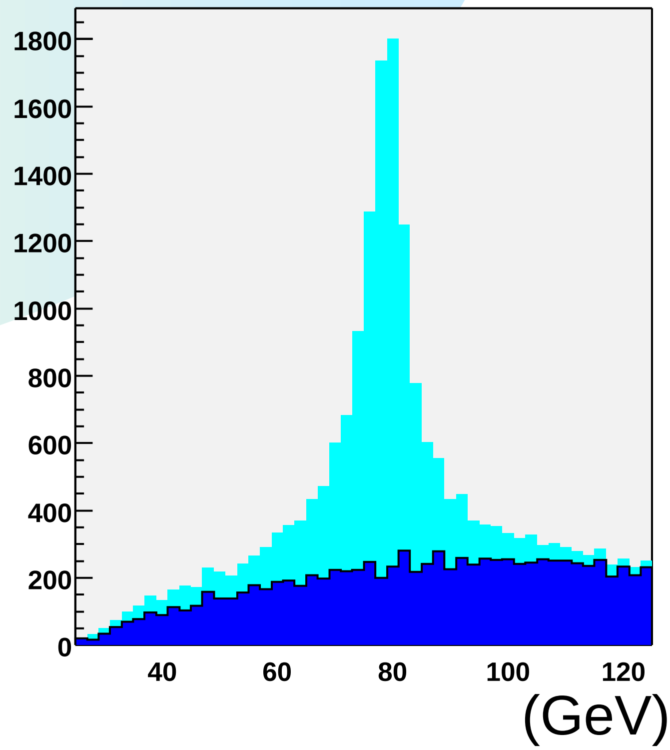


0.3

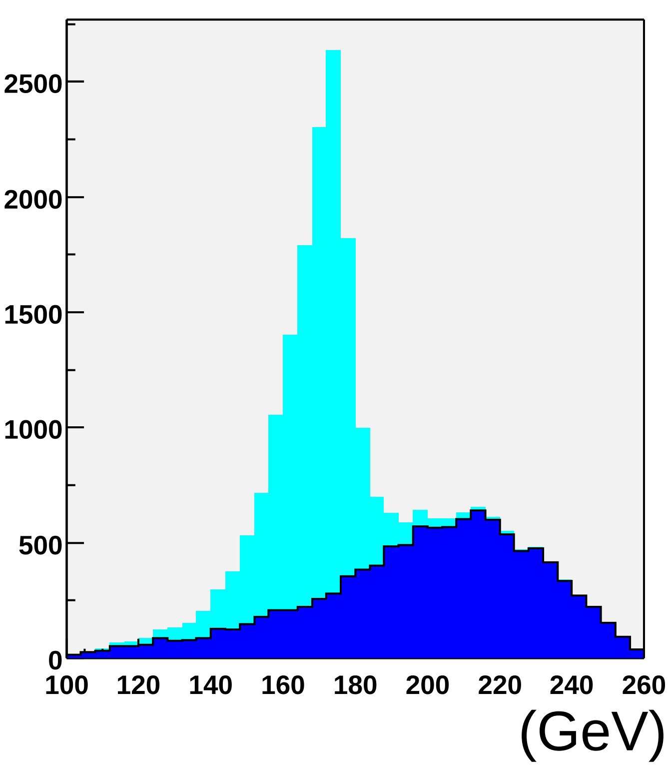
Reconstructed W with 2 jets



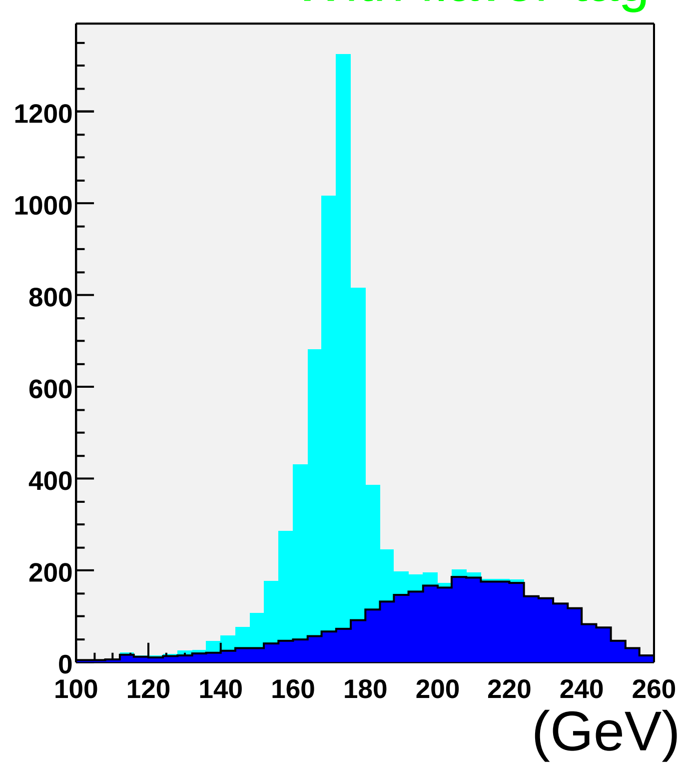
With flavor-tag



Reconstructed top with 3 jets



With flavor-tag



B. Software development

1. Clustering

    * recognition of EM vs HAD showers vs MIPs

    * optimization for position

    * optimization for energy

    * optimization for angle (extrap. to IP)

2. Tracking in cal.

    * merge tracks with showers ($h^{\pm}$ id)

    * muons

    * integrated tracker/cal tracking

3. Digital Cal.: Pattern recog. and resolution

4. Geant4 (e.g. doesn't require towers)

5. Detector parameter tradeoffs (R, seg, layering, coil in/out, etc.)

6. Extract parametrizations for fast sim.

C1. Hardware (Si/W)

1. Integration of electronics with Si detectors

   ∗ beating straight channel counts (Marty)

2. Si detector cost reduction

   ∗ apparently not dominated by cost of Si wafers

3. Gap reduction (R_m reduction)

4. Mechanical/assembly issues

5. $B = 5$ T ?

C2. Hardware (HCal)

− digital design technology choice –
low cost and ≈1 cm transverse seg

C3. Hardware (non-Si ECal)

- Scint. tile

  1. Is $\lesssim 2$ cm seg possible?
     light yield? fiber coupling? gap thickness?
     response uniformity?

  2. Readout (HPD/APD ?)

  3. Is it really cheaper than Si ?

- Other technologies?

What Next?

- Extreme EFlow is something which requires a thorough understanding – we're not close

- US manpower effort presently below threshold

- Need several people working consistently and talking to each other
  (i.e. similar to TESLA recon/sim efforts)

- We should start doing some hardware R&D in parallel with sw/sim

- TESLA group strength is presently in EFlow recon development

- Everything ≈wide open for new people

- I'd like to see a framework for cooperative international R&D be developed ASAP (Krakow?)
  (as simple as a list to start with)