LC Calorimetry: Overview

Ray Frey, U. of Oregon

Chicago LCW, Jan 7, 2002

- Present Ideas: the Energy Flow Concept
- How well can one do?
- Excellent Jet Reconstruction: Physics Case
- Current Calorimeter Concepts/Designs
- Work to be Done ...

Goal: See if we can build a detector which is much better than the present generation of outstanding e^+e^- detectors.

Energy Flow

1. Charged particles in jets more precisely measured in tracker
2. Typical multi-jet event comp:
   - 64% charged energy
   - 25% photons
   - 11% neutral hadrons

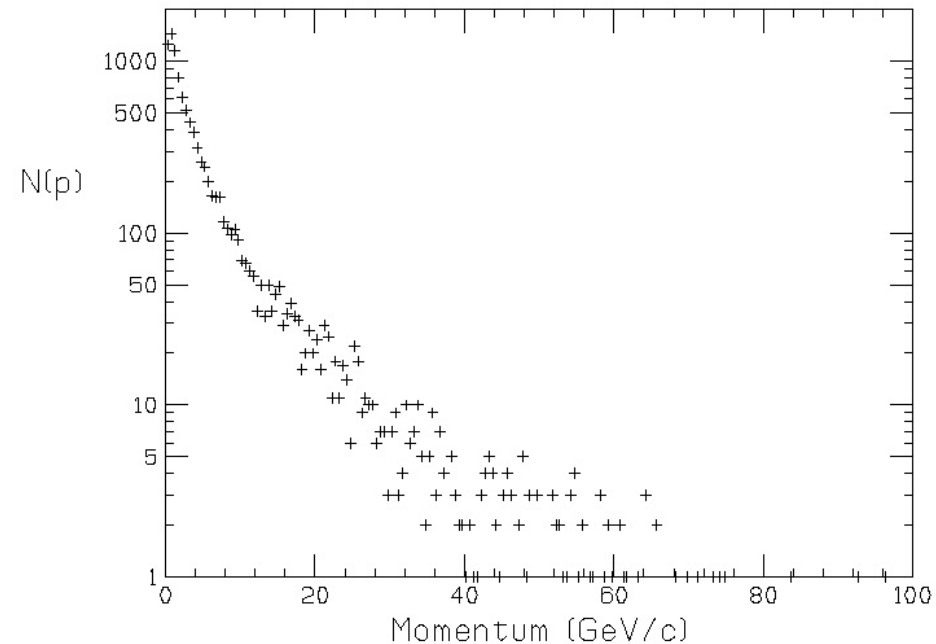
- Use tracker for charged
- Calorimeter for neutrals
- Requires dense, granular cal. to separate and id. each particle
  - FoM: BR^2/R_m (EM Cal.)

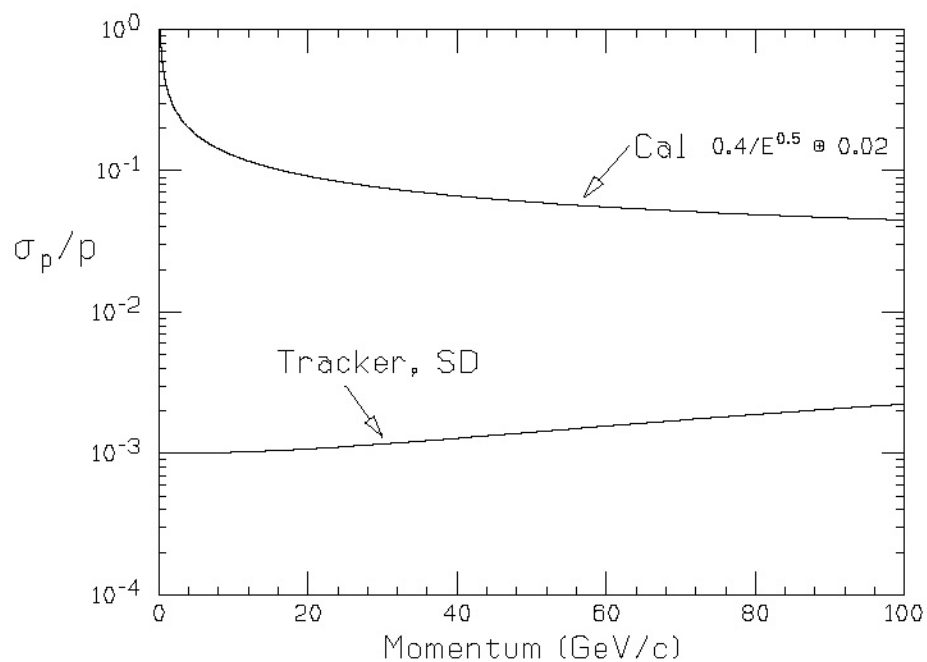
<u>Additional benefits</u> :

- Exc. electron, photon position
  → Non-pointing photons
- A muon tracker

<u>Question</u> :

How good (and costly) does it have to be?



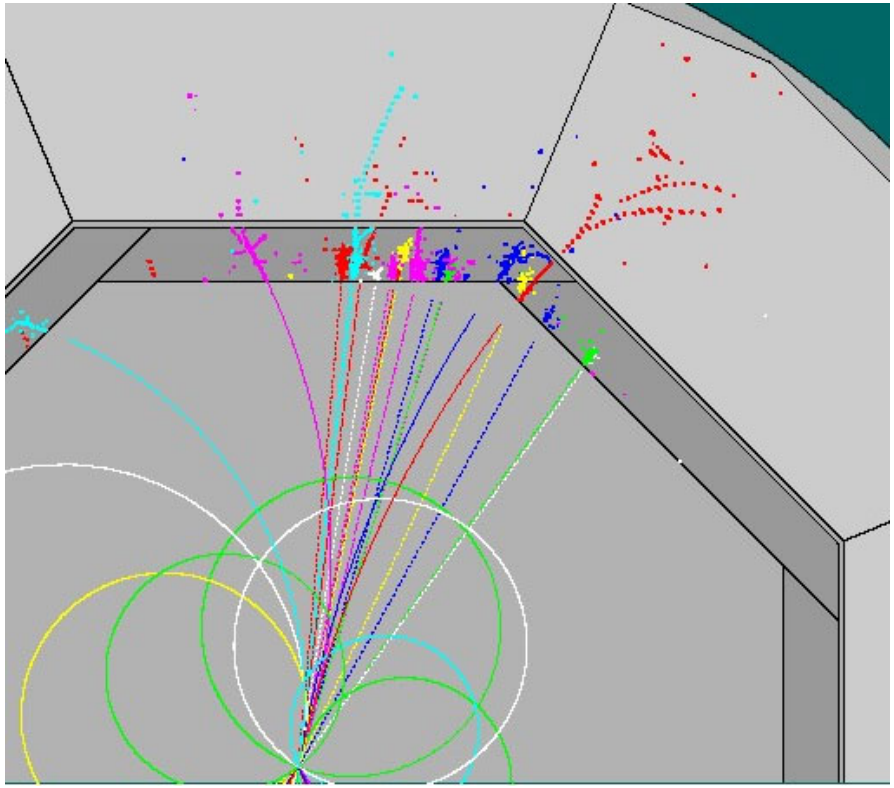


- Si/W Energy Flow det. proposed by "NLC Detector Group", Snowmass 96
- Much progress in Europe
- By '99, the standard TESLA config.
- New: "digital" Hadron Calorimetry

- One point of view:
  - LC detectors will require large solenoidal B fields to achieve excellent vertexing and tracking
  - In this case, jet recon. with comp. calorimetry is poor

➢ So EFlow will be necessary.

➢ And if done well, promises to provide excellent jet recon., better than standard techniques.



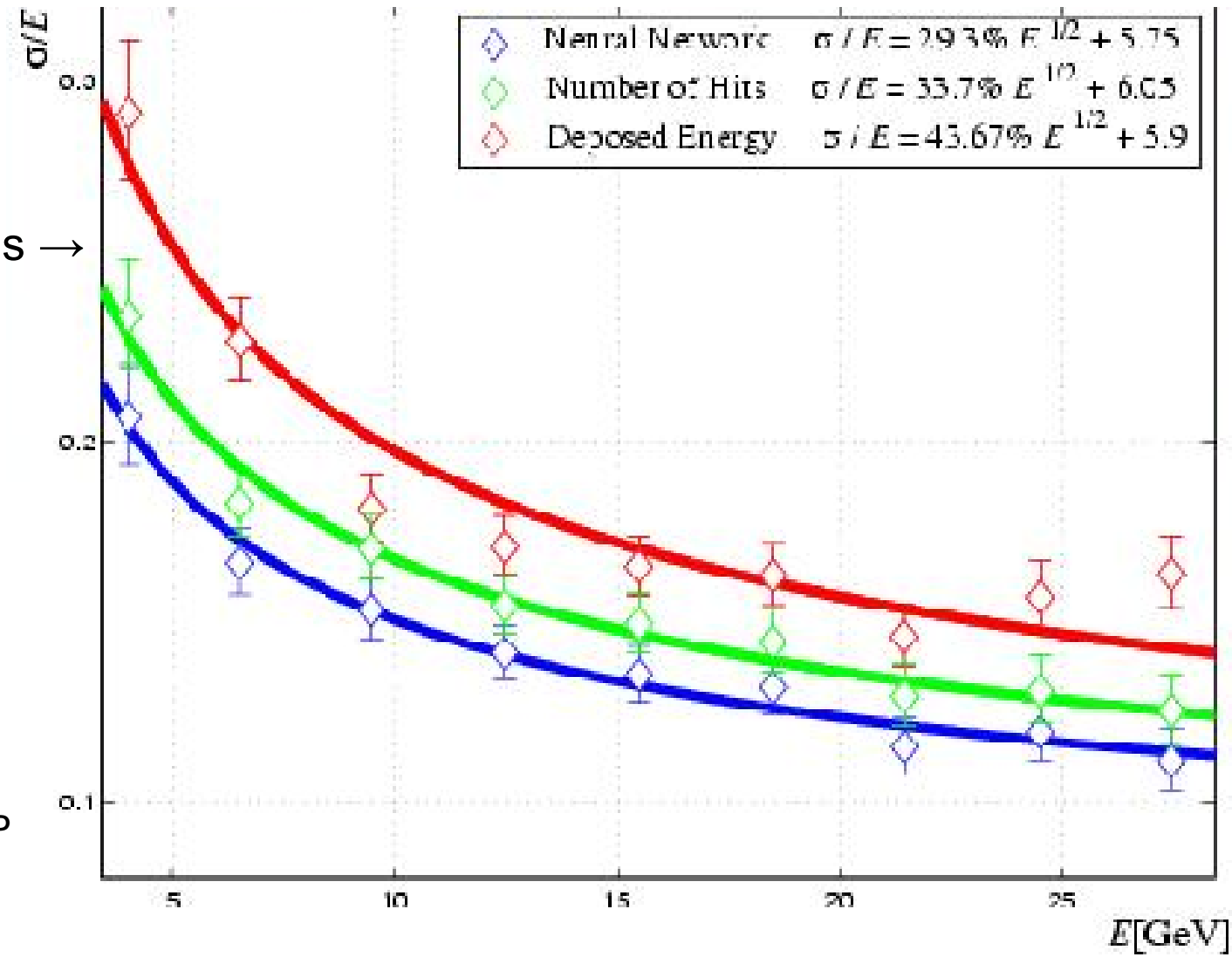
TESLA event

$\tau \rightarrow \rho\nu \rightarrow \pi^{+}\pi^{o}\nu$

Digital HCal

- Sufficiently small segmentation → 1 bit readout (2?)
- Use cheap, highly-segmented detectors

Single charged pions →



H. Videau, LPHNE-EP

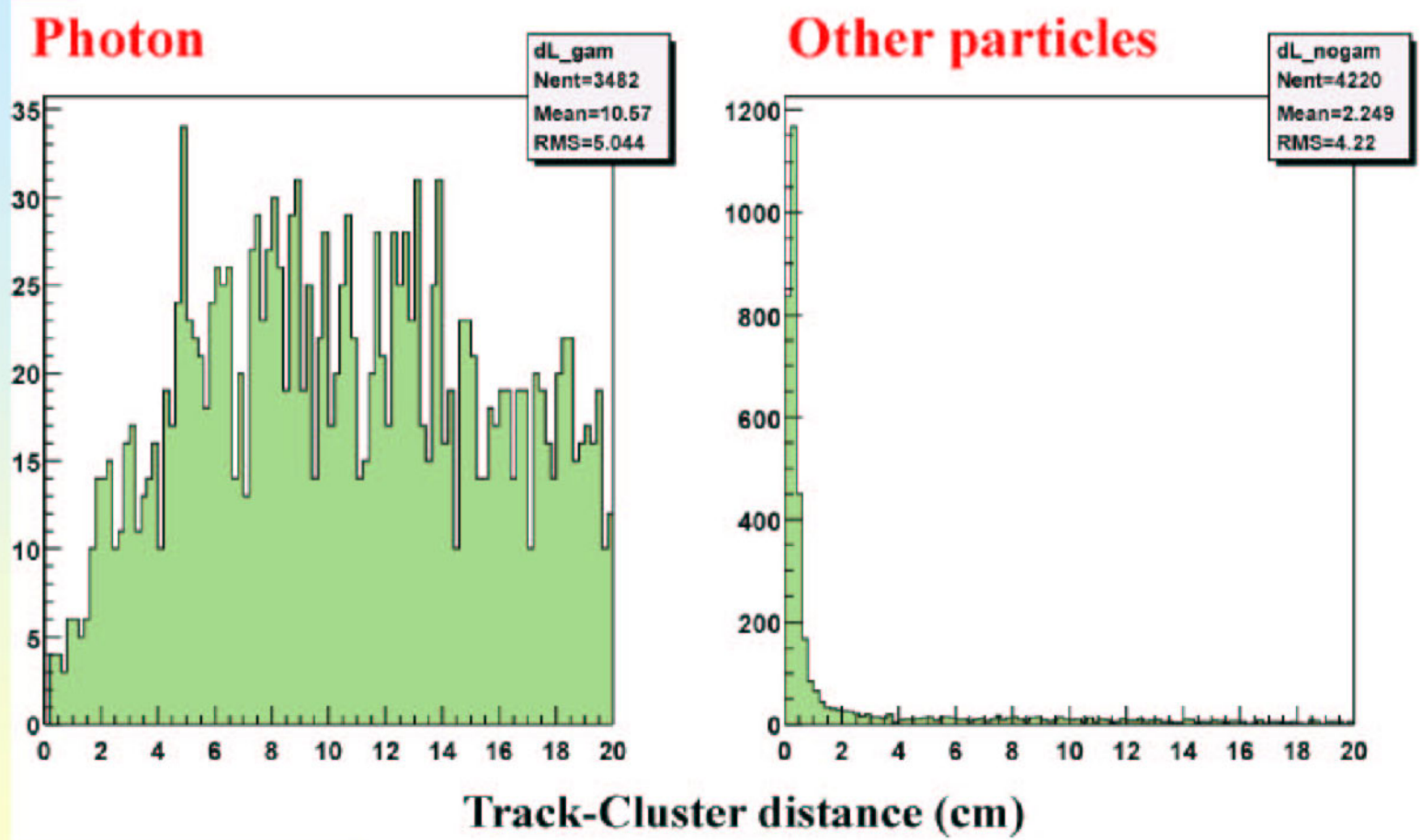
What determines the transverse segmentation?

- BR^2 and R_m
- And the physics:

M. Iwasaki

1) Extrapolate Charged tracks to the Cluster radius,
2) Associate the nearest track to the cluster

$e^+e^- \rightarrow t\,\bar{t}$

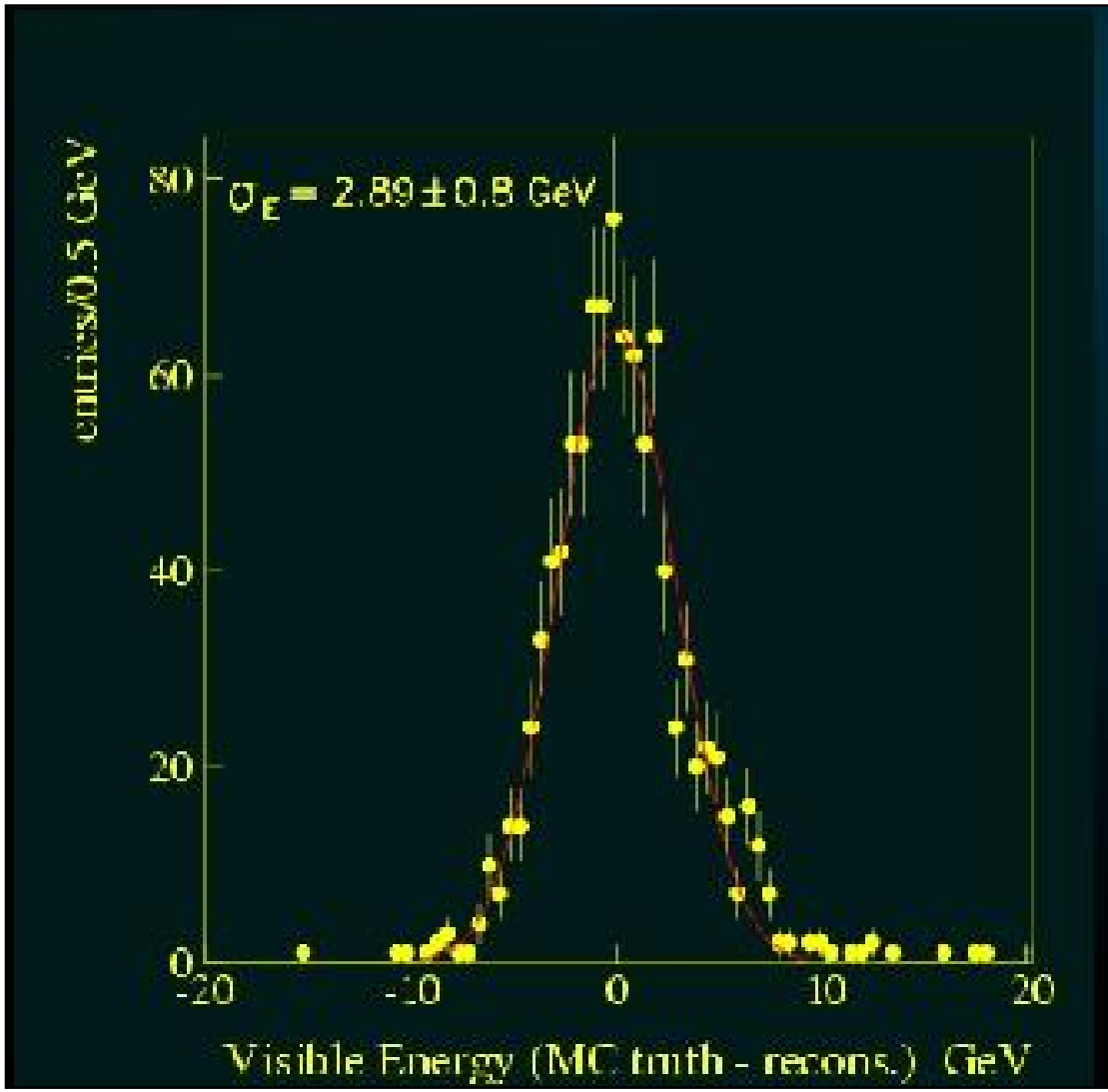


What jet resolution can be achieved ?

- TESLA studies are giving ≈30% / $\sqrt{\text{Ejet}}$ using current hybrid simulation and recon.
- ALEPH achieved ≈ 80%
- Complete recon. using fully simulated events requires a big investment in tool and algorithm building.
  - ECal and HCal clustering, tracking, and pattern recognition
  - hypothesis testing/fitting

- What is the best possible ?

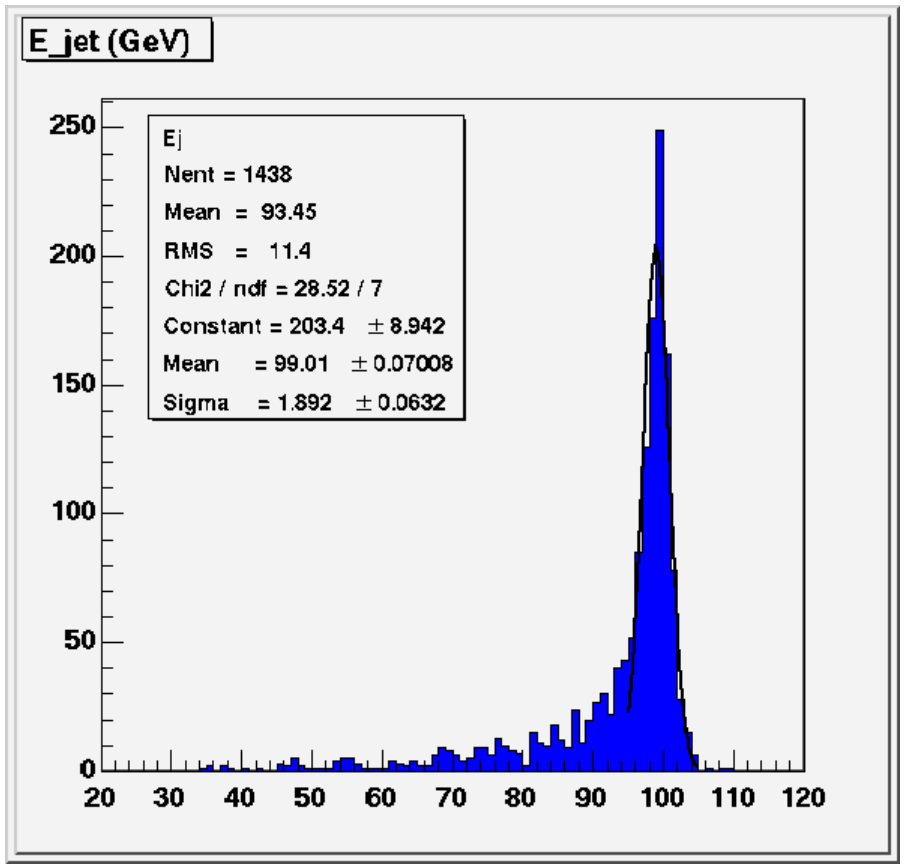
$e^+e^- \rightarrow q\,\bar{q}$

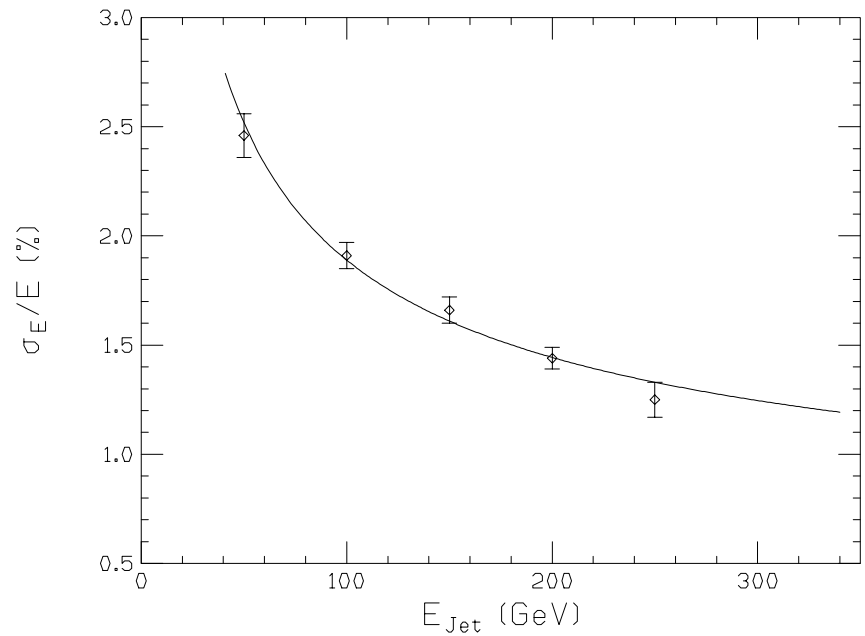


H. Videau

- Assume perfect charged/neutral separation
- Use single-particle cal. resolutions for neutrals (talk by Bower/Cassell)
- Use tracker for charged

SD detector $e^+e^- \rightarrow \bar{q}\, q$

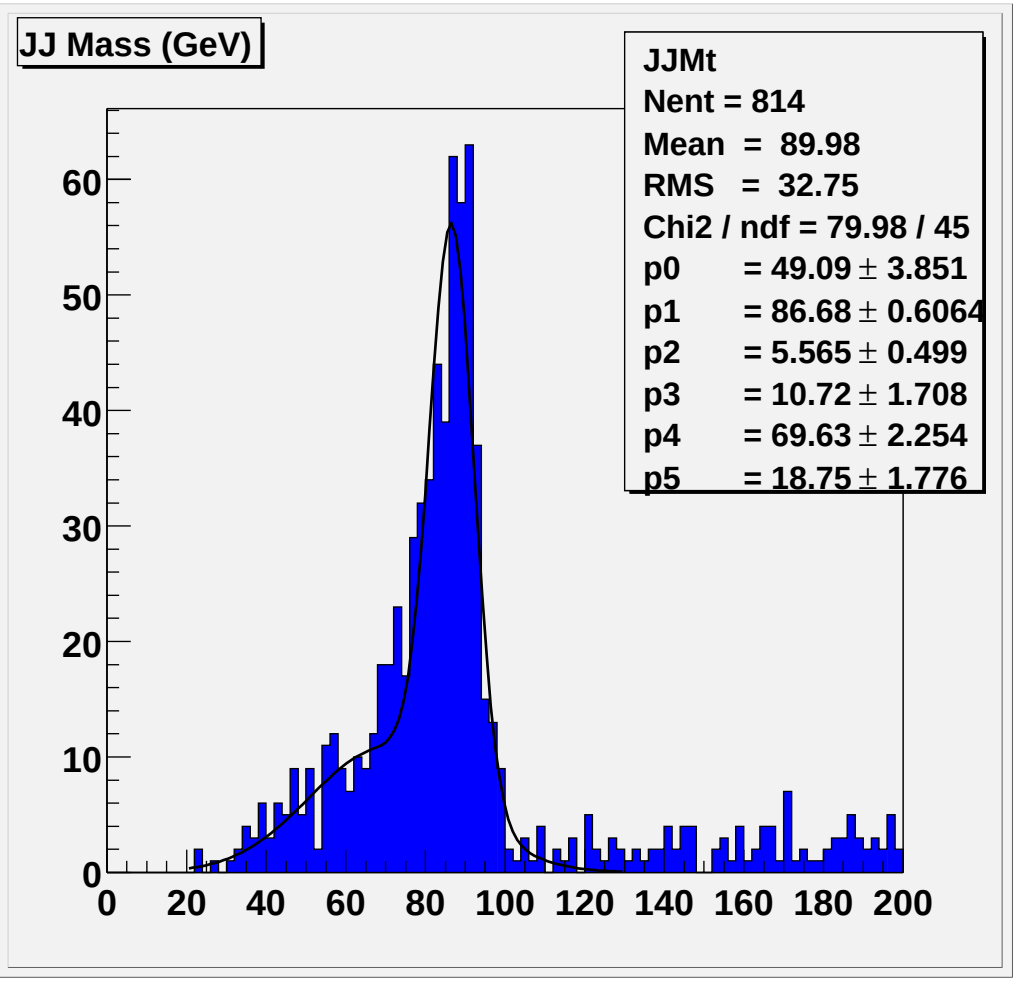


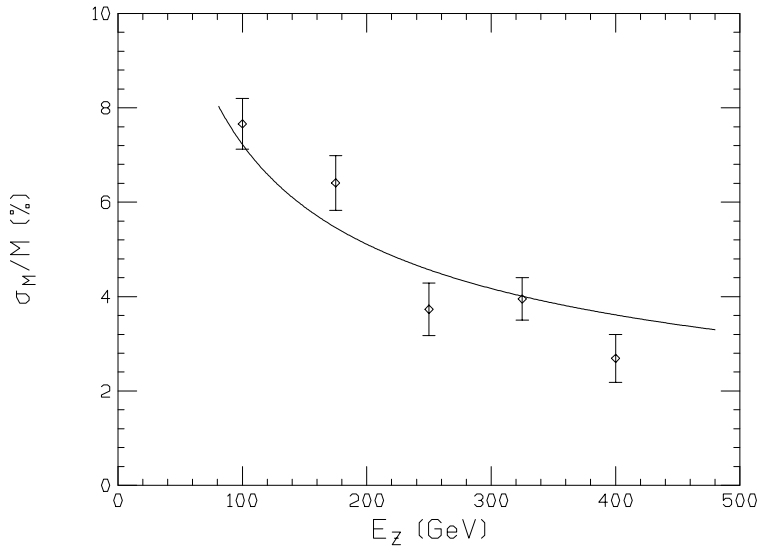


$$\sigma_{E_j}/E_j = 0.15/\sqrt{E_j}$$

Multi-jet mass for more complicated events

- e+e- → ZZ → 4q
- SD detector



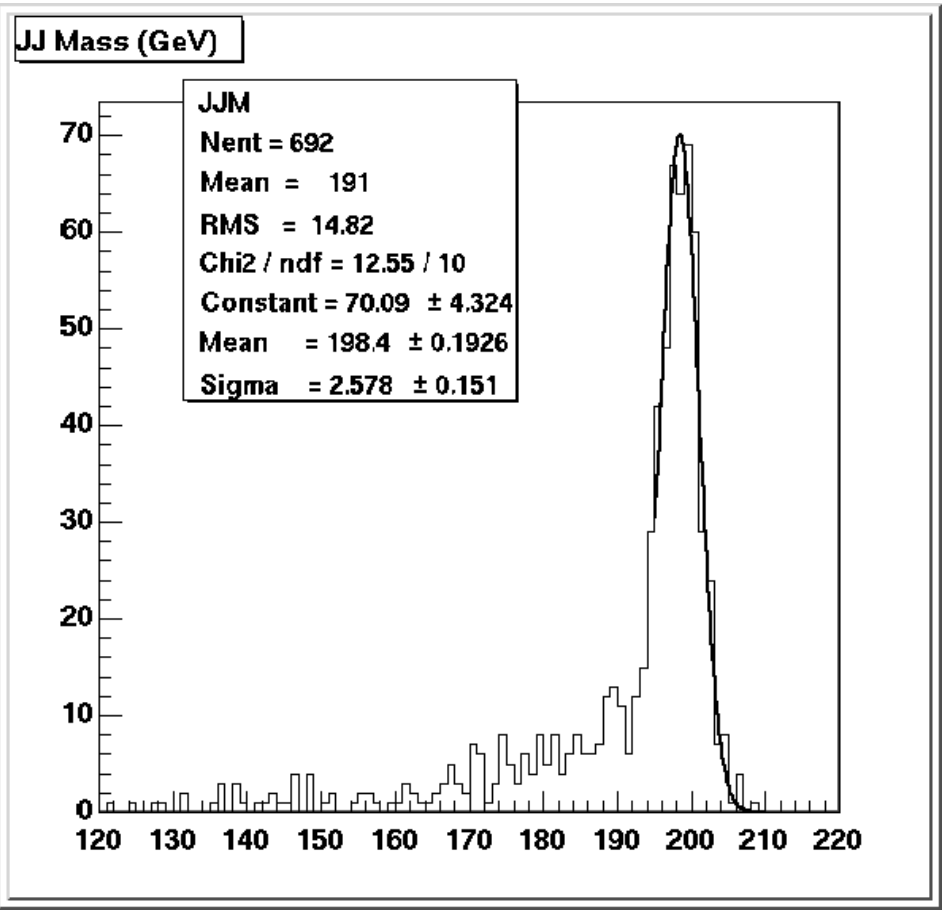


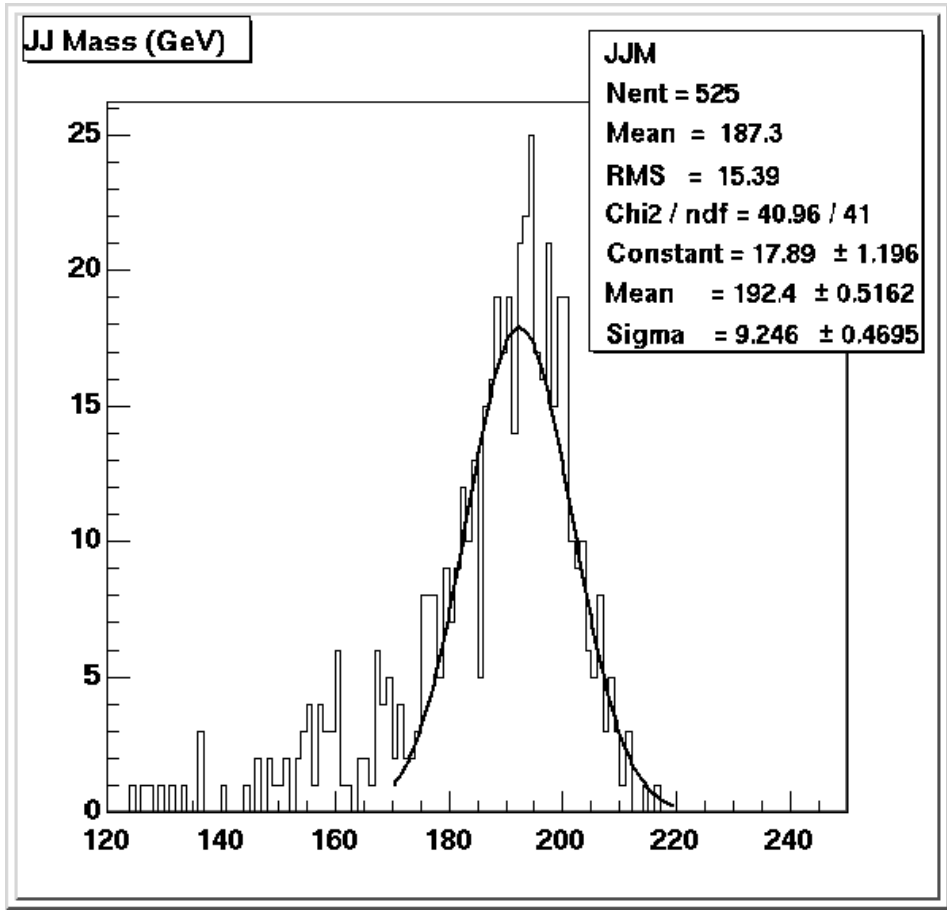
$$\sigma_{M_{jj}}/M_{jj} = 0.72/\sqrt{E_Z}$$

√ s = 350 GeV

Compare Ideal Energy Flow with Ideal Compensating Calorimeter

SD detector, $e^+e^- \to q\bar{q}$, $\sqrt{s} = 200$ GeV





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

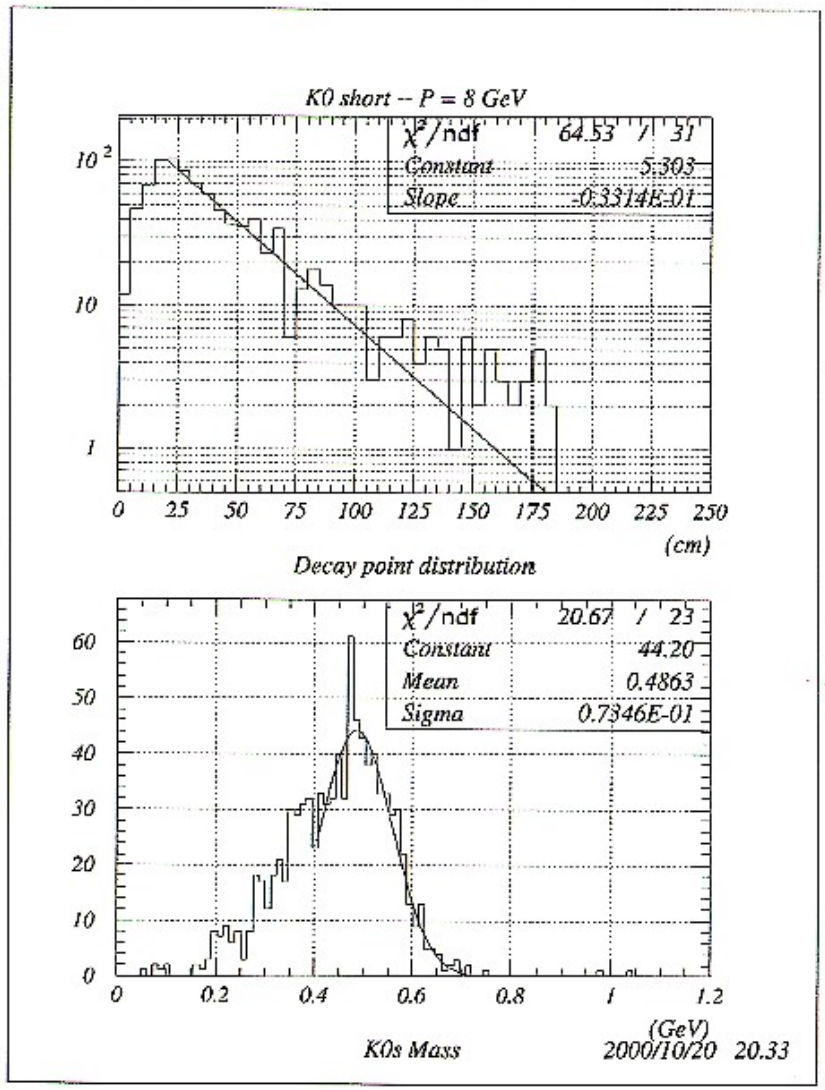
Comp Cal. $\sigma(Mjj) = 9.2$ GeV/c^2

Given energy-momentum constraints in e^+e^-, do we really need superb jet reconstruction and/or resolution?

<u>Physics List</u>
(to be expounded and expanded)

- ZH *vs* WW *vs* ZZ final states
- H→ZZ *vs* H→WW
- HHZ: Higgs self-coupling (Tesla)
- ttH (8 jets, 4 b-jets)
- t-chan WW *vs* ZZ (Tesla)
- Anomalous Couplings
  - top→3 jets
  - WW→jets
- SUSY
  - Decay chain recon.
  - Non-pointing photons ⟶

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



V. Morgunov

Impact of the jet resolution on the physics programme

Parametrising $\Delta E_{jet} = \alpha \sqrt{E_{jet}}$

$e^+ e^- \to Z H H$ 6 jets L=1 ab^{-1} $\alpha = 0.6 \Rightarrow 3\sigma$ $\alpha = 0.3 \Rightarrow 6\sigma$

$e^+ e^- \to t \bar{t} H$ work in progress

$e^+ e^- \to Z H$, $Z \to q \bar{q}$, $H \to W W^*$ α 0.3 $\Rightarrow$ 0.6 = loosing 45% of L

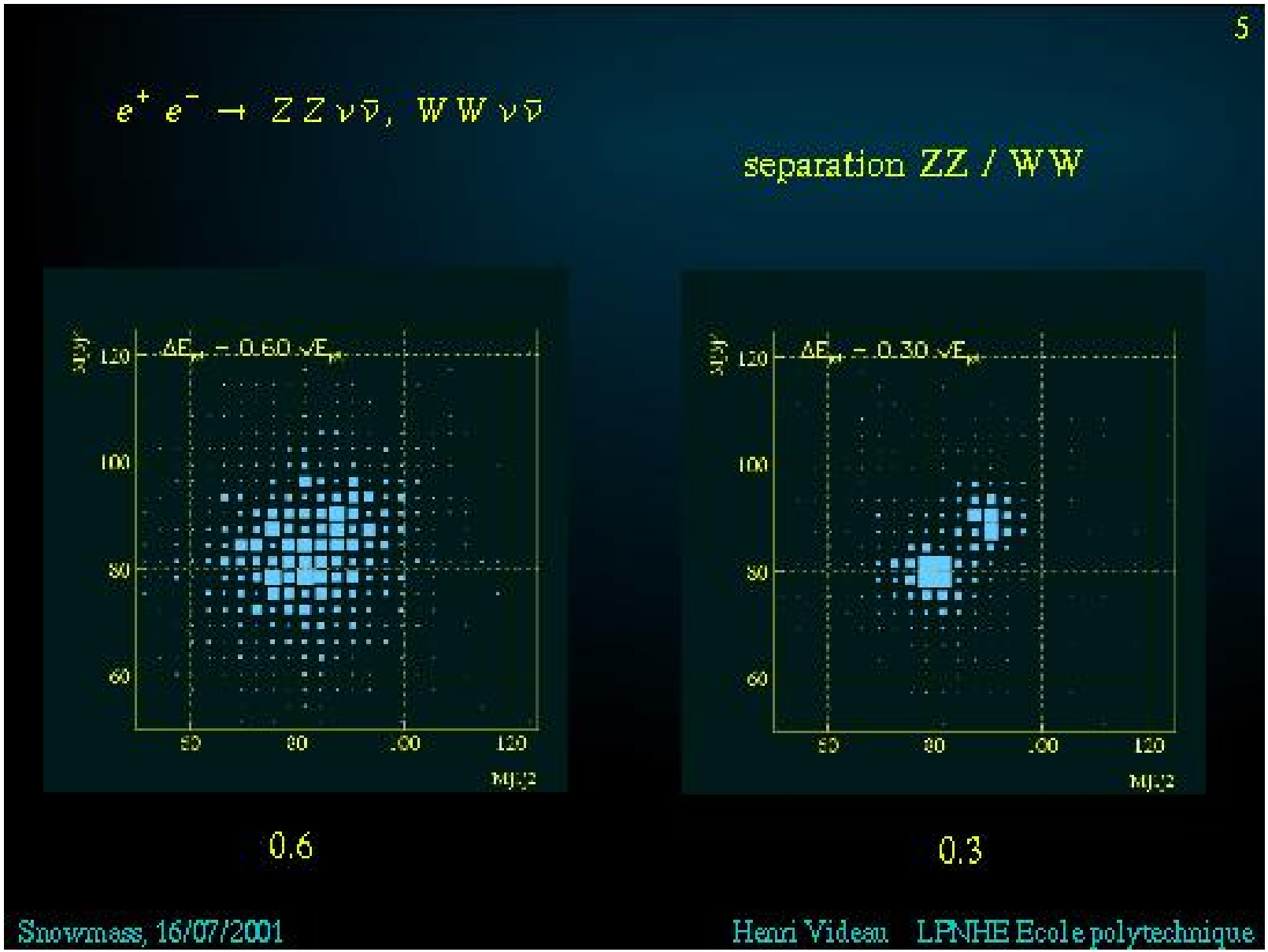
$e^+ e^- \to Z Z \nu \bar{\nu}$, $W W \nu \bar{\nu}$ in the separation ZZ / WW

α 0.3 $\Rightarrow$ 0.6 = loosing 40% of L

a lot more work to assess the effect on all the programme

$e^+e^- \rightarrow W\,W\,\nu\nu$, $ZZ\,\nu\nu$

H. Videau

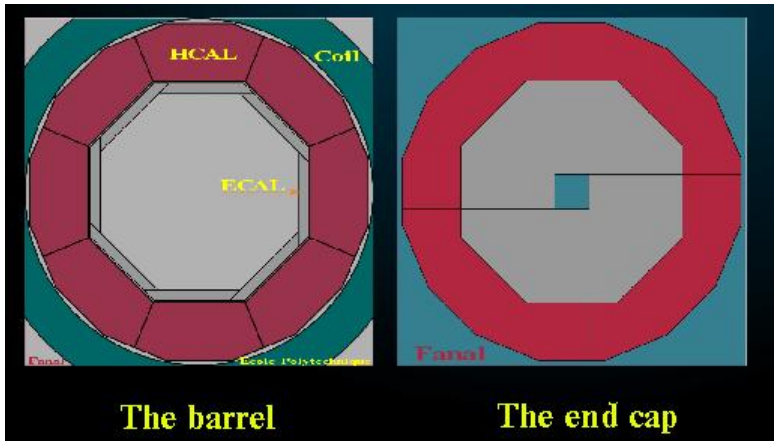


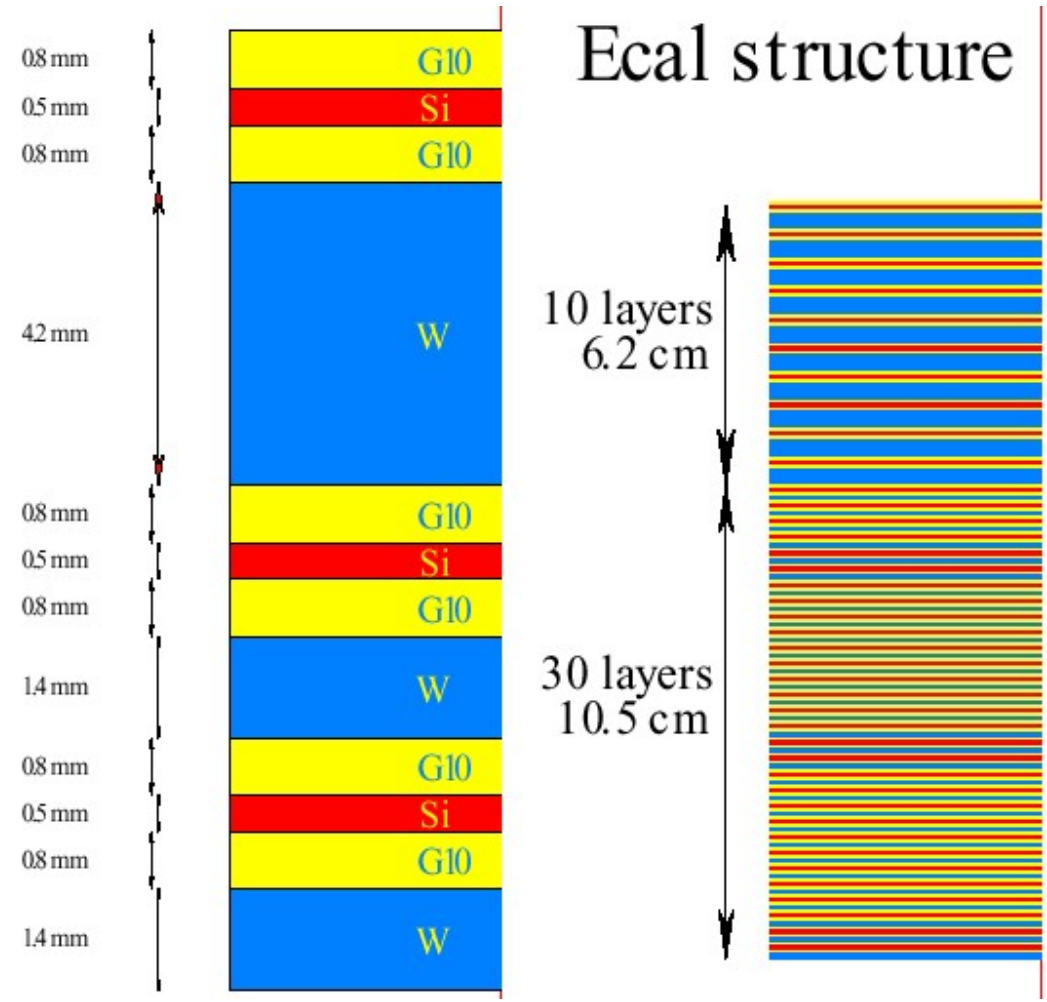
0.60/√Ejet

0.30/√Ejet

- Build these “known” case
- But also be ready for the unknown!
  - A major advantage of e^+e^- is access to *all* final states
  - Difficult to recon./separate hadronic final states at hadron colliders
  - Complementarity suggests we pursue this advantage. (And I believe we can, and we should.)

The TESLA Design





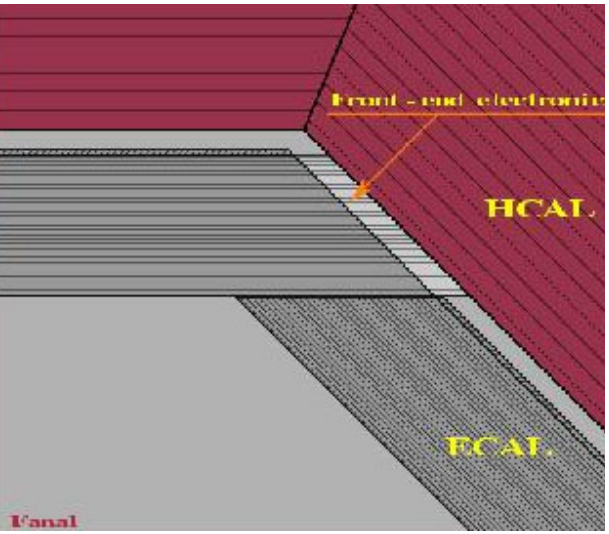
<u>W/Si EM Cal</u>.

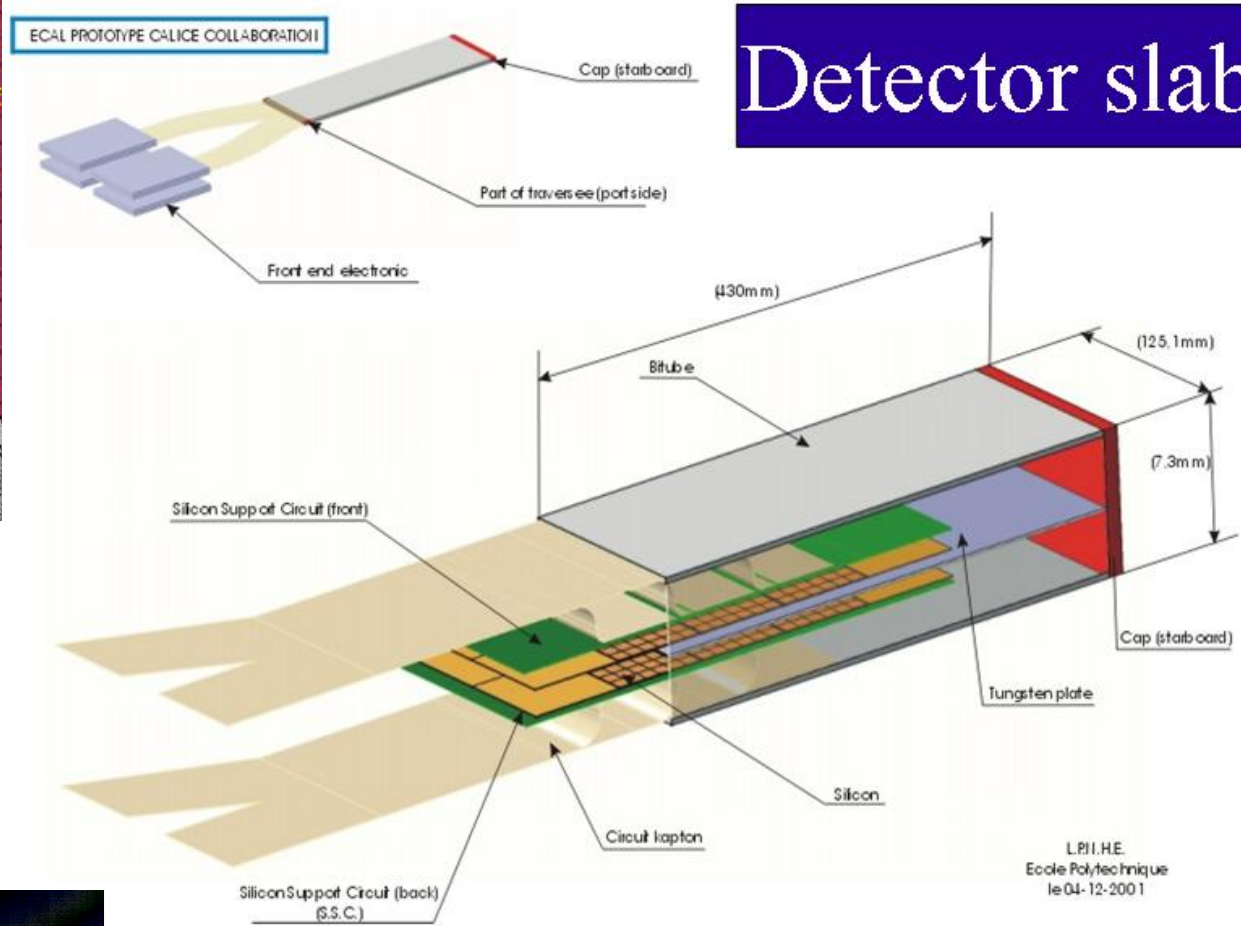
- 2 sampling sizes: 2.8,8.4 mm
- 20 layers; 1700 m^2 total
- 15x15 mm^2 segmentation
- 0.5 mm thick Si
- ≈16 channels per readout chip

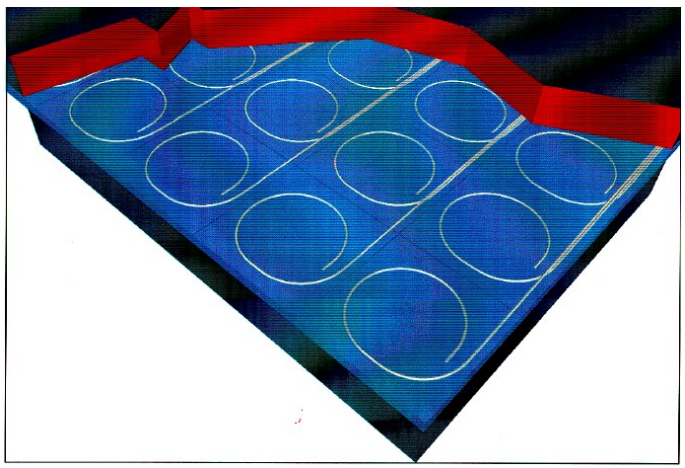
<u>HCal – 2 options</u>:

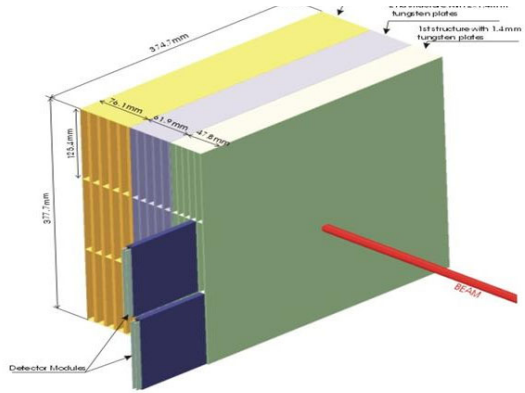
1. Digital
   - 1x1 cm^2 seg.
   - RPCs a possible detector
2. Scint. Tiles
   - 5x5 cm^2 seg.

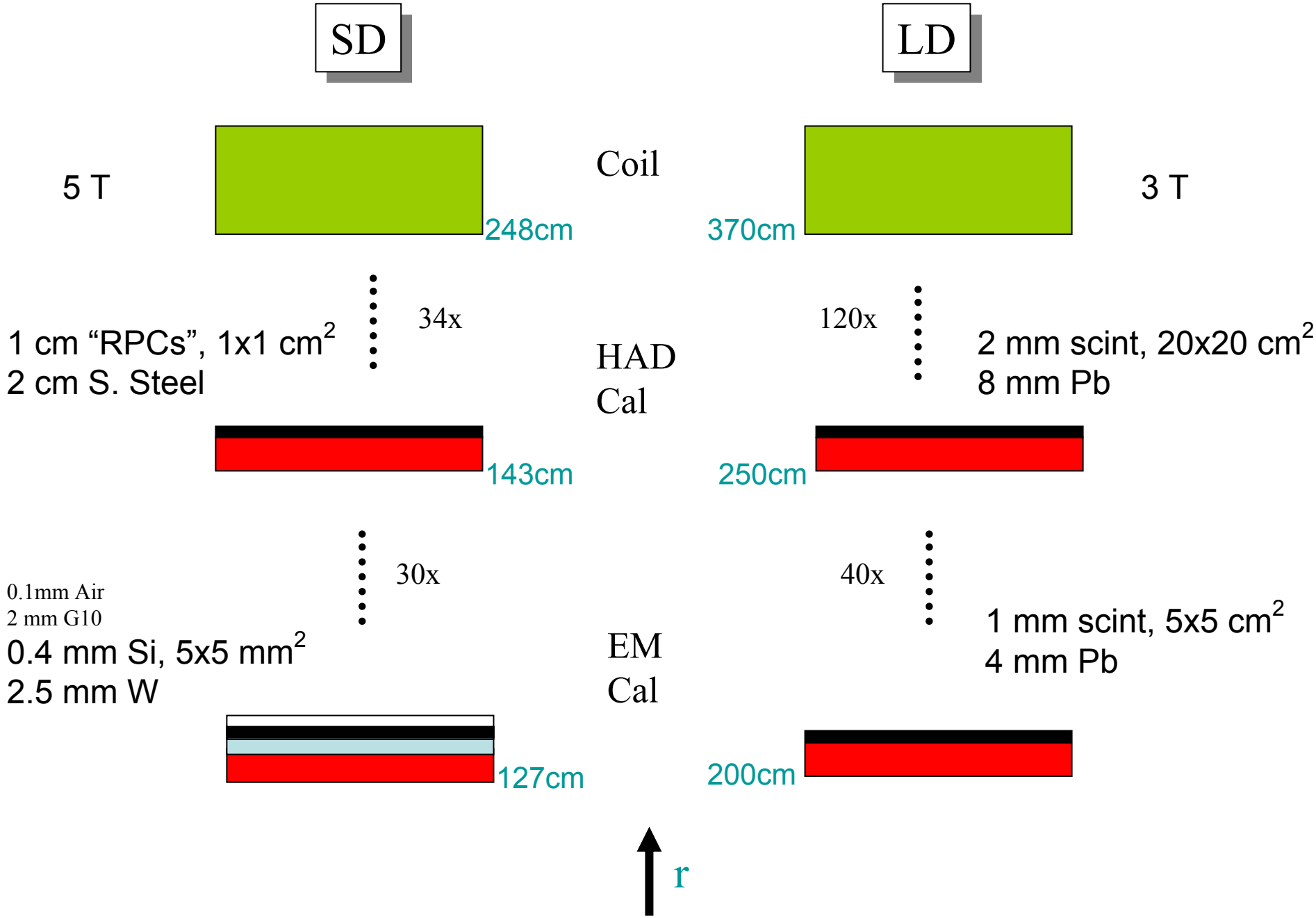
Detector slab










SD
LD
Coil
5 T
248cm
370cm
3 T
34x
120x
1 cm "RPCs", 1x1 cm2
2 cm S. Steel
HAD
Cal
2 mm scint, 20x20 cm2
8 mm Pb
143cm
250cm
30x
40x
0.1mm Air
2 mm G10
0.4 mm Si, 5x5 mm2
2.5 mm W
EM
Cal
1 mm scint, 5x5 cm2
4 mm Pb
127cm
200cm
r

SD

- High Quality Energy Flow (~TESLA)
- $BR^2/R_m \approx 5$ (≈TESLA?)

Si/W EM:

- $R_m \approx 9mm(1+ gap(Si)/2.5mm)$
- 5x5 mm^2 segmentation
- 2.5mm (0.71 X_o) sampling
- ~10^3 m^2 Si
  - → Avoid N_{chan} scaling
  - → Cost per cm^2 of Si

Granular HAD:

- "Digital" ?
- 1x1 cm^2 segmentation
  - → RPCs? Scint? aSi?
- 5 λ total depth

LD

Philosophy unclear:

- $BR^2/R_m \approx 6$
- segmentation too coarse for EF?
- Pb/scint = 4/1 (compensation?)

Pb/Scint EM:

- Long: 4mm Pb/1mm scint
- Tran: 50x50 mm^2 scint tiles
- R_m = 20 mm
- Possibly add Sh. Max Si Layer?

Pb/Scint HAD:

- 8mm Pb/2mm scint
- 20x20 cm^2 tiles
- 7 λ total depth

What is best alternative to Si/W

- for large R calorimeter ?
- for less costly calorimeter ?

Event display

t-tbar event, 500 GeV

SD detector

GISMO simulation

LCD Root analysis framework

Work to be Done: Critical R&D

- Physics Simulations
  - ≫ Continue to build (or not) case for jet physics
  - ≫ Other: Leptons, isolated photons, ...

- General Concepts (Assuming EFlow)
  - ≫ Alternative to Si/W ECal ?
  - ≫ HCal
    - ◦ Digital or not ?
    - ◦ HCal/Coil position
    - ◦ Standalone muon id ?
  - ≫ Framework for cost/performance optimizations
  - ≫ For a low-E IR at Z-pole, forget all of this

- <u>Software:</u> Develop reconstruction tools
  - ≫ Basic pattern recog.: Clustering, cal. tracking, merging, etc.
  - ≫ Combined ECal and HCal
  - ≫ Coordinate areas of emphasis with international partners

- <u>Hardware I:</u> Si detectors and readout
  - ≫ Integration of detectors/readout
  - ≫ Reduction of electronics channels
  - ≫ Cost of detectors (Tesla: 3 Euros/cm^2)
  - ≫ Si gap size
  - ≫ Transverse segmentation
  - ≫ Dynamic range

- <u>Hardware II:</u> Digital HCal

  $\gg$ What segmentaion is required ?

  $\gg$ What detector type ?

  $\gg$ An inexpensive readout

- Coordinate our efforts internationally

Calorimetry Parallel Session, Tues 2:00 – 3:45

R. Frey, Oregon	Overview and Issues	5 min
Renyuan Zhu, Caltech	Crystal Calorimeters at LC	20
Masako Iwasaki, Oregon	Full Sim. EFlow Jet Recon. Criteria	20
M. Breidenbach, SLAC	How to Beat N-Scaling in Si/W	15
R. Frey, Oregon	Si/W Design Study	5
Dhiman Chakraborty, NIU	The NIU/NICADD/UTA DHCal Proposal	10
Vishnu Zutshi, NIU	First Digital HCal Simulation Results	10
Steve Magill, ANL	Status of ANL HCal Optimization Studies	10
Jose Repond, ANL	HCal with Resistive Plate Chambers	10
G Bower & R Cassell,SLAC	LCD Cal. Simulation Results Potpourri	20

Simulations/Calorimetry/Vertexing Joint Parallel Session, Tues 4:15 – 6:00

Norman Graf, SLAC	Moving Forward	10
Rob Macintosh, NIU	Getting Started with Simulations	10
M Iwasaki / T Abe, Or/SLAC	First LCD GEANT4 Results	15
Aaron Chou, SLAC	Optimizing the Vertex Det. for Physics	15
Haijun Yang, Michigan	A First Look at Track Recon with High Machine Backgrounds	15
Ties Behnke, DESY	European Sim. Group Status/Plans	15