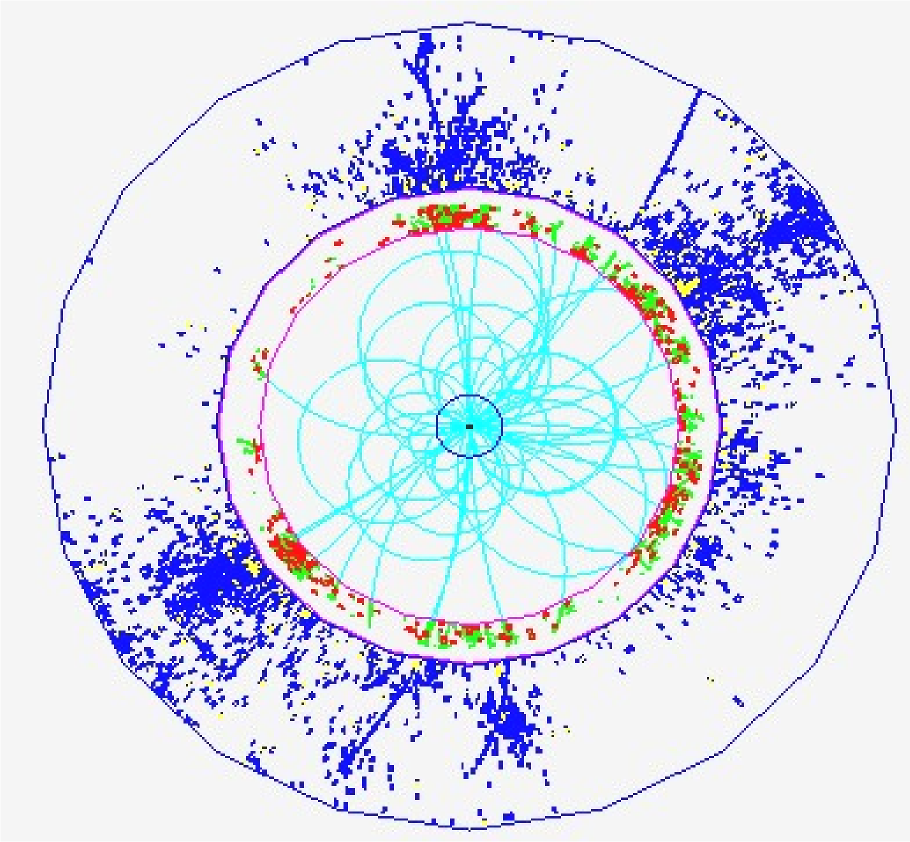
LC Calorimeter Ideas and R&D Opportunities

Ray Frey, U. Oregon
Cornell, Apr 19, 2002

- Physics implications
- The environment
- The “energy flow” concept
- Current ideas and plans
  - Europe
  - Asia
  - N. America
- Critical R&D (my view)



e+e- → tt → 4 jets

500 GeV, SD detector

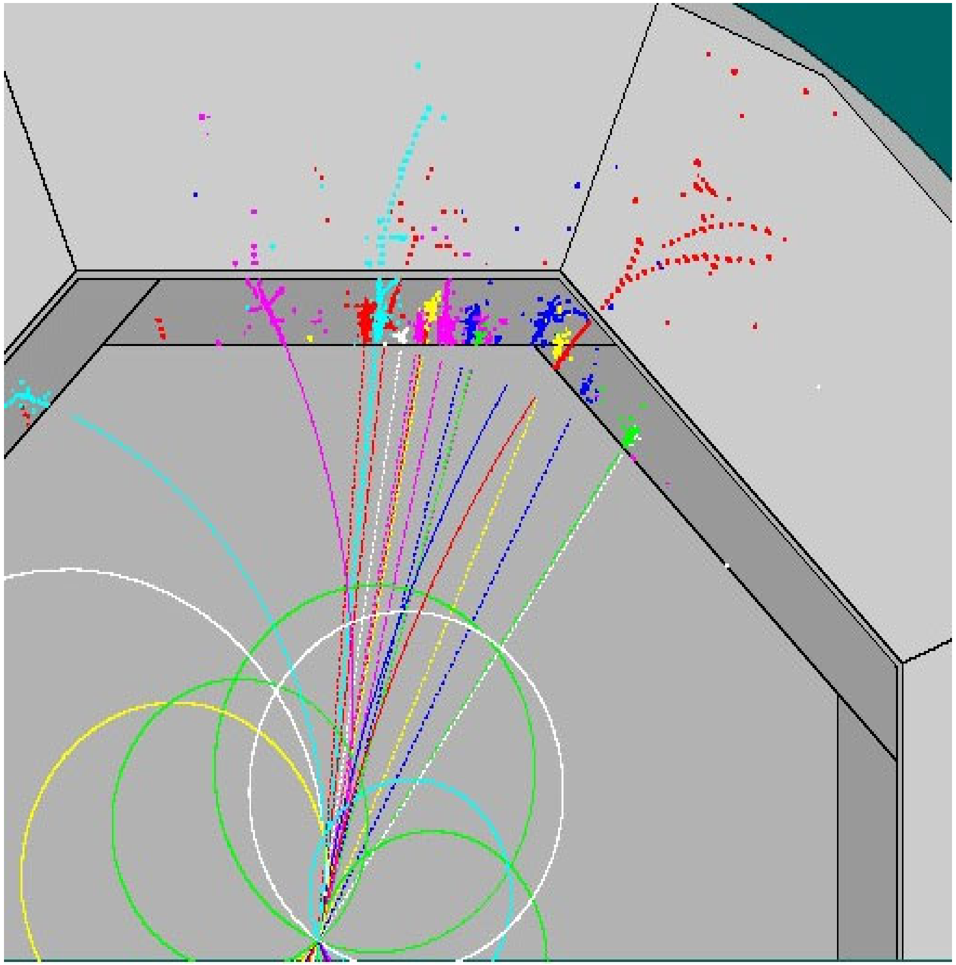
Physics: Jets!

- Complementarity with LHC :

  LC should strive to do well what
  LHC finds problematic

- Primary goal: Uncover the nature of electroweak symmetry breaking (Higgs, supersymmetry, extra dimensions, or “something else”)
- *e.g*. Higgs decays to quarks important to measure well
- May not always be possible to rely on e+e- beam constraints
  - e+e- → WW/ZZ → 4 jets

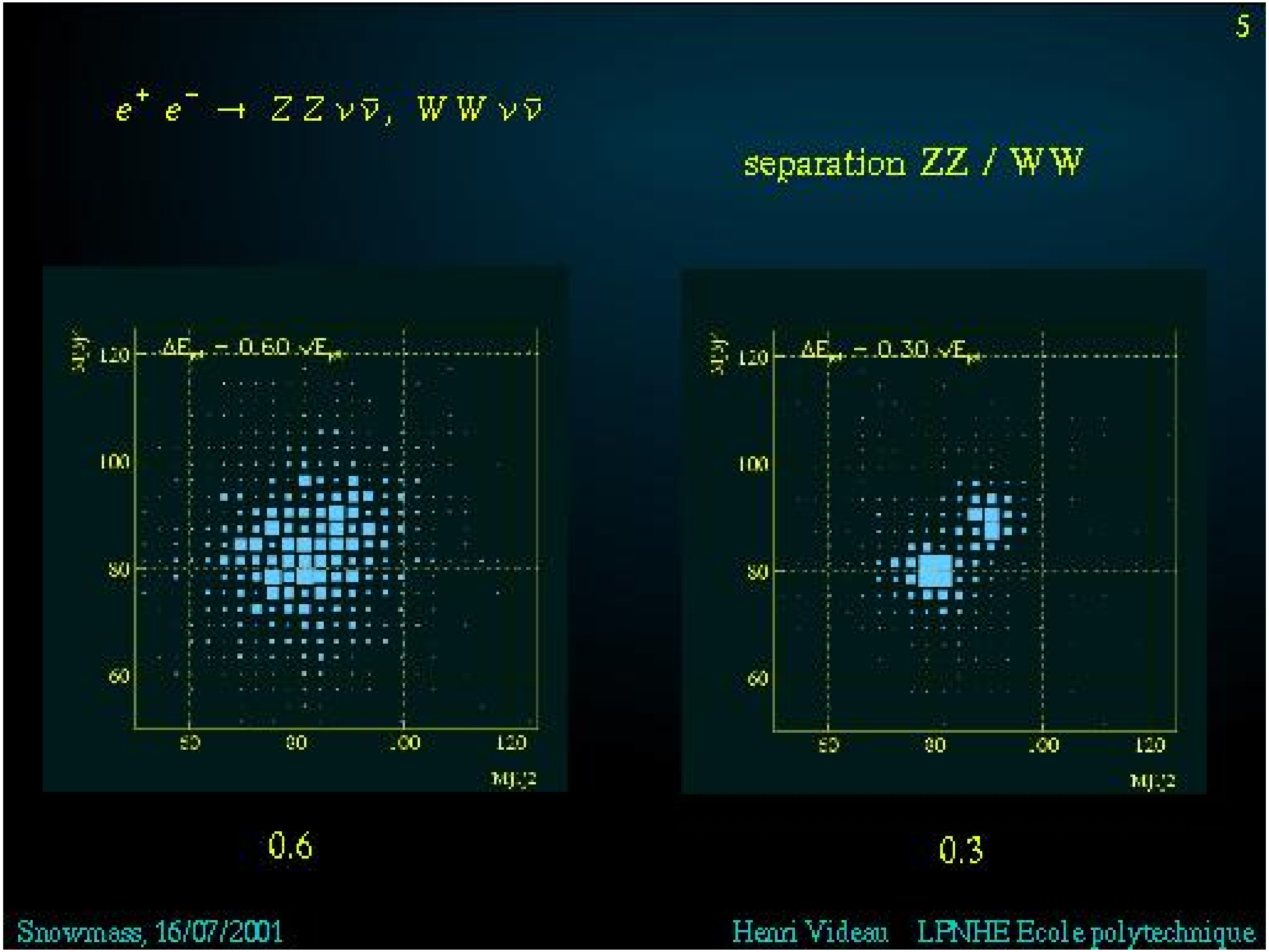
- Will get excellent results for leptons, photons, missing energy “for free”



TESLA event sim.

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

H. Videau



5

$e^+ e^- \to Z Z \nu\bar{\nu}$, $W W \nu\bar{\nu}$

separation ZZ / WW

0.6

0.3

Snowmass, 16/07/2001

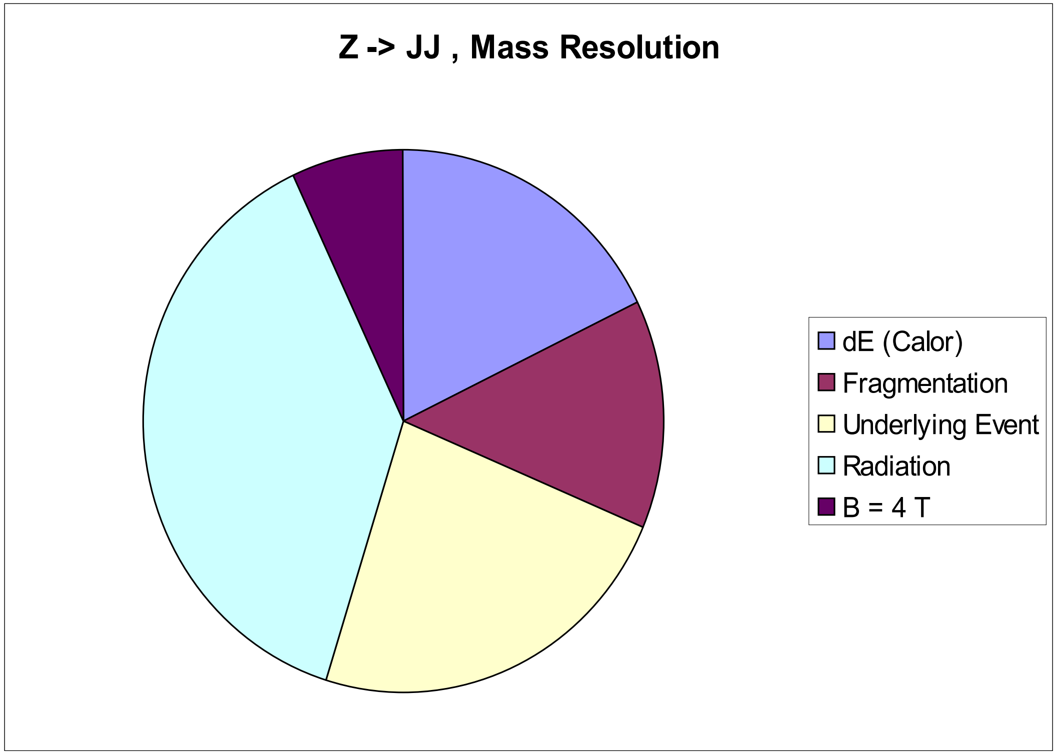
Henri Videau LPNHE Ecole polytechnique

0.60/√Ejet

0.30/√Ejet

Dan Green, Calor2002

- **LHC Study: Contributions to dijet mass resolution**
- **Z -> JJ. dM/M ~ 13% without FSR.**

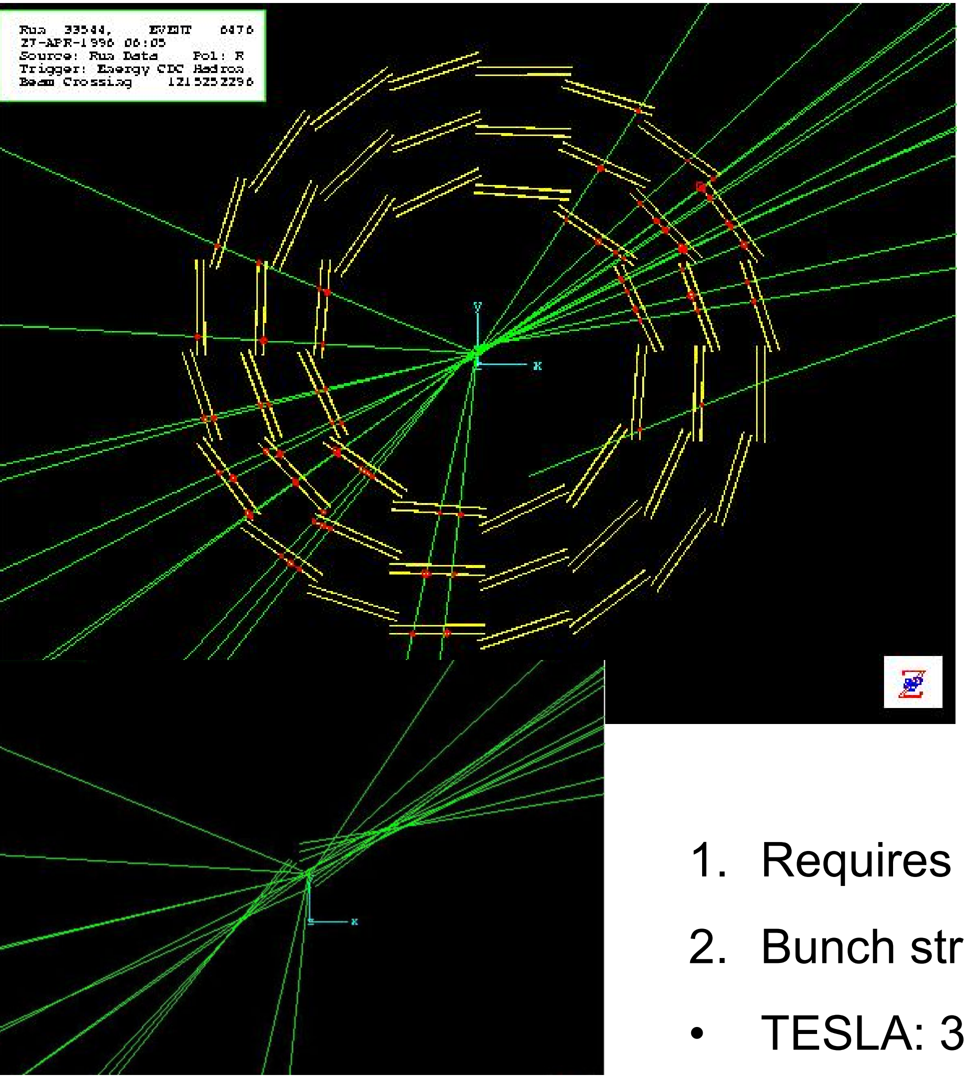


FSR is the biggest effect. The underlying event is the second largest error (if cone R ~ 0.7). Calorimeter resolution is a minor effect.

⇒ At the LC, detector resolution can have a bigger impact on jet physics

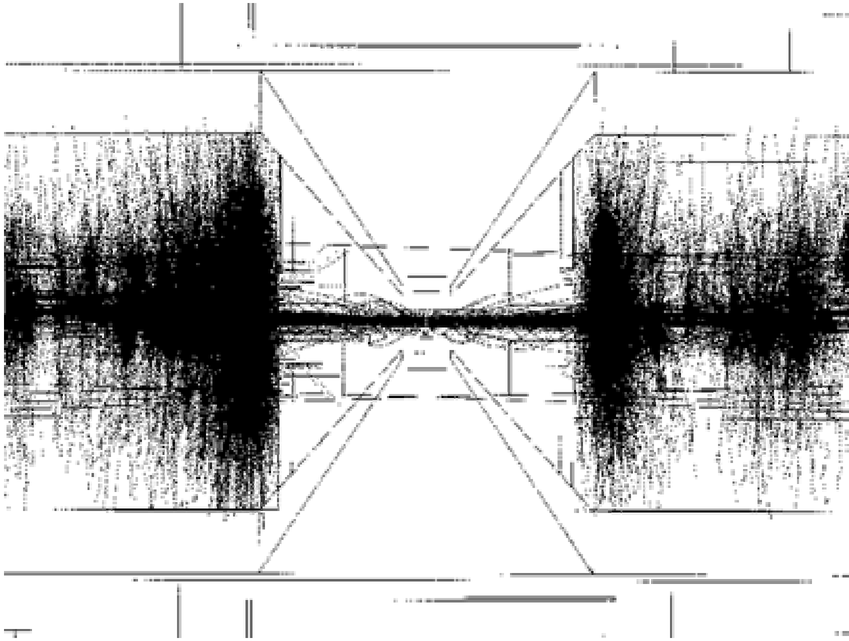
The Environment

“clean!”



but…

Low-p_t pairs

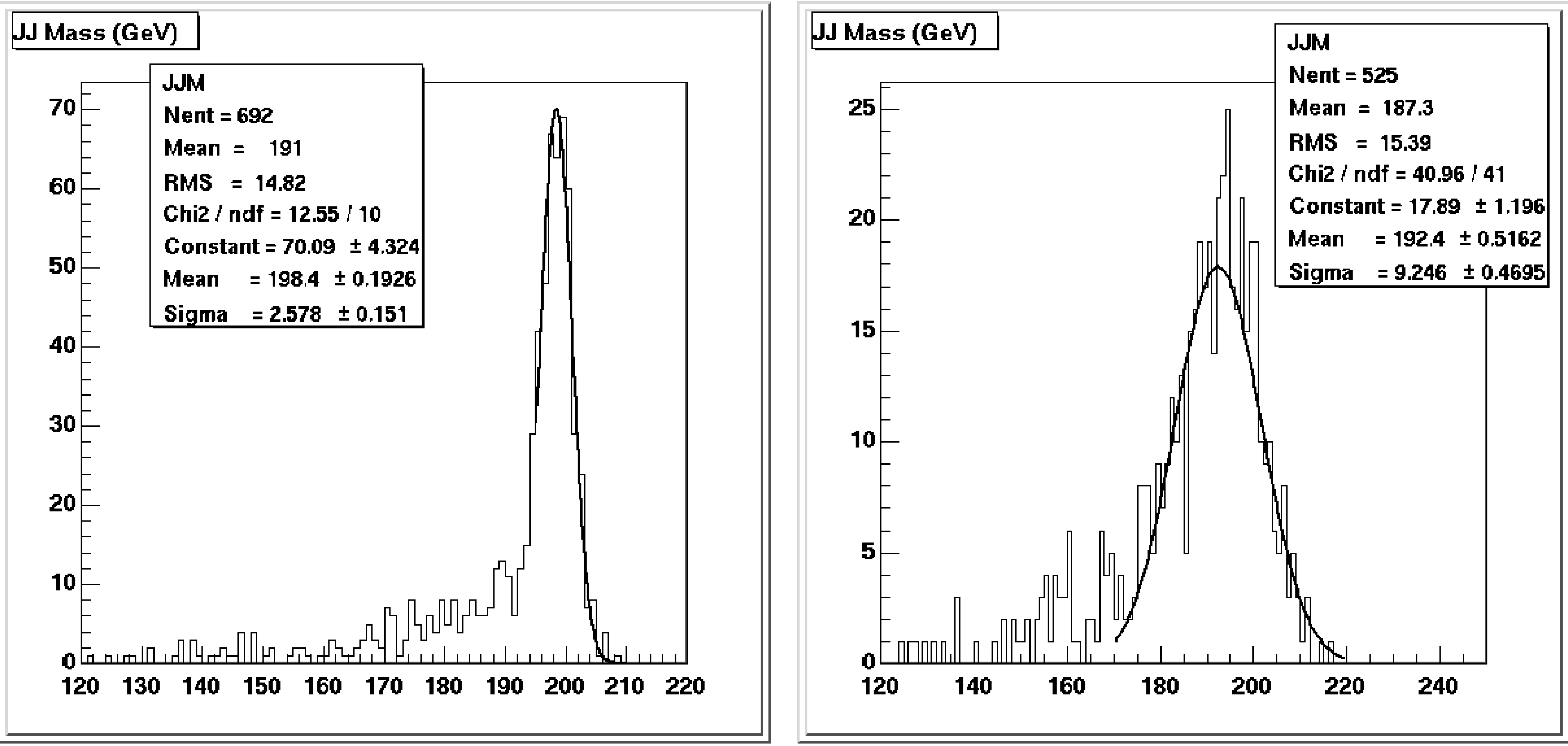


1. Requires large (solenoidal) B field: 3-5 T
2. Bunch structure: bunches in trains

- TESLA: 300 ns Xs in 1ms trains at 5 Hz
- NLC/JLC: 2ns Xs in 300 ns trains at 180 Hz

In e+e-, jet reconstruction done with tracker aided by calorimeter
(compared with calorimeter-only jet reconstruction)
And for large B, calor.-only becomes worse

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



Ideal calor.
+ tracking

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

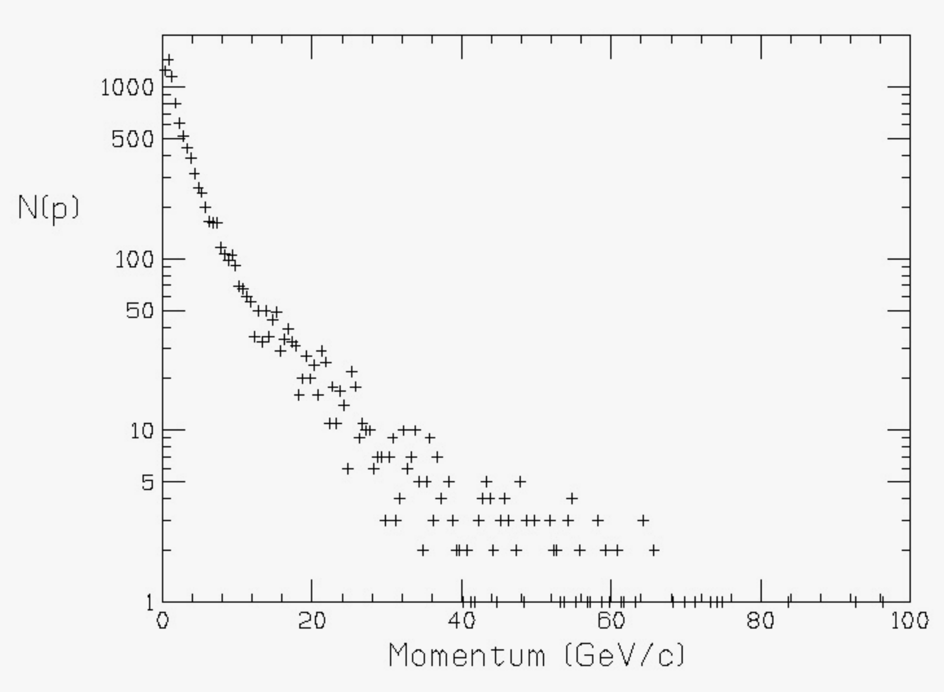
Ideal calor.
only

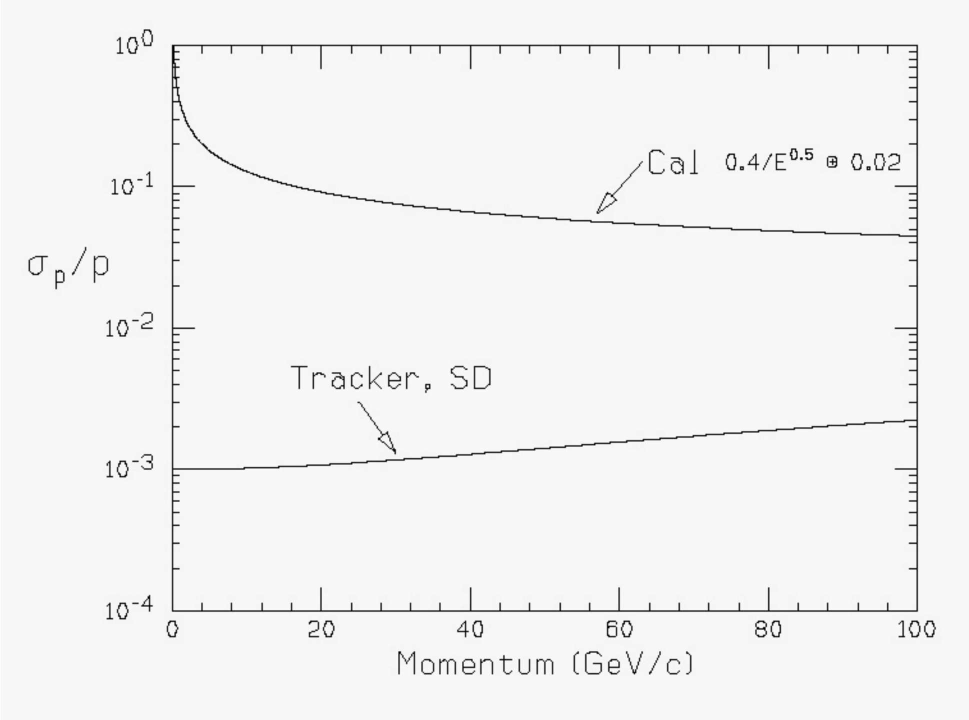
$\sigma(Mjj) = 9.2 \text{ GeV/c}^2$

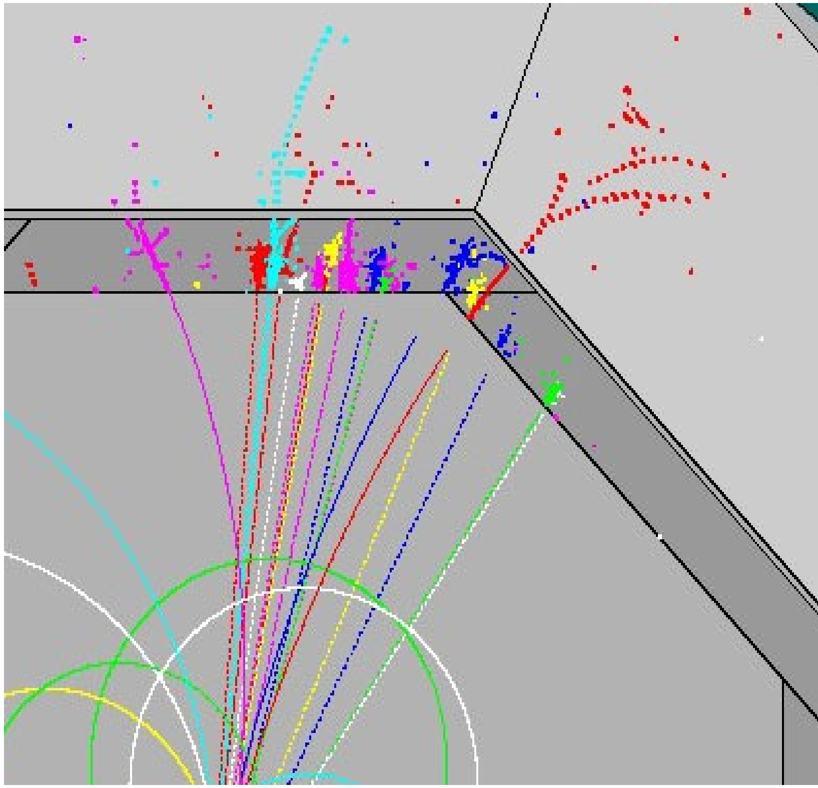
Energy Flow

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

- Use tracker for charged
- Calorimeter for neutrals
- Must locate and remove charged calor. energy







- Ignoring neutral hadrons, ideal calor.:

  h/e → 0

- Reality: separate charged/neutral with **dense, highly-granular** EM and HAD

  ⇒ An "Imaging Calorimeter"

- Figures of merit:
  - EM: BR^2 / R_m large
  - Transverse seg.~ R_m
  - X_0 / λ_I small

- Alternative viewpoint (JLC): use compensating calor. (neu. hadrons)

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

Current Paradigms in Broadbrush

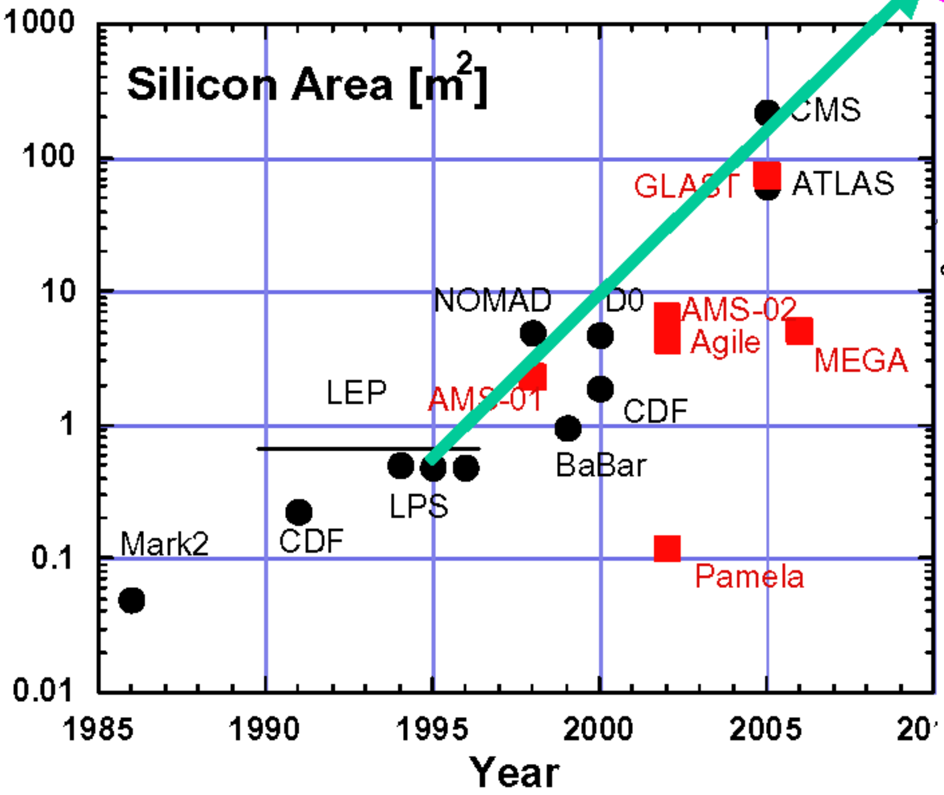
- ECal: Si/W a natural possibility
  - R_m= 9 mm
  - Easily segmented
- Used successfully in Lum. monitors at SLC and LEP
- Si/W Energy Flow detector by “NLC Detector Group”, Snowmass 96
- ~20 long. layers; ~1000 m^2 of Si
- Much progress in Europe -- by ‘99, the TESLA standard
- Main issue: Si cost (~70% of ECal total)

- HCal: Several possibilities being considered
  - Scint. Tiles
  - “digital” Hadron Calor.
  - with RPCs?

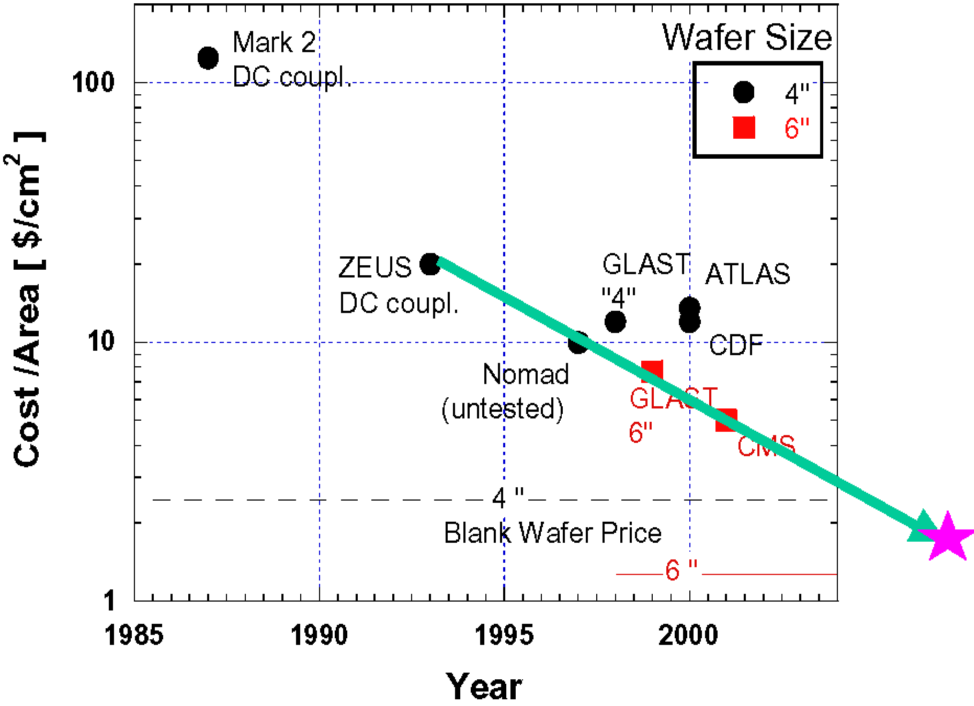
- Alternative (JLC): 4:1 Pb/scint-tile sandwich
  - Sufficient segmentation?

Moore's Law for Silicon Detectors

Year	2005	2010
Si Area [m²]	230 (CMS)	2,000
# of Channels	10M (CMS)	100M
Cost [$/cm²]	5 (CMS)	< 2



Cost /Area of Single-sided Silicon Strip Detectors (double-sided factor 2.5 higher)

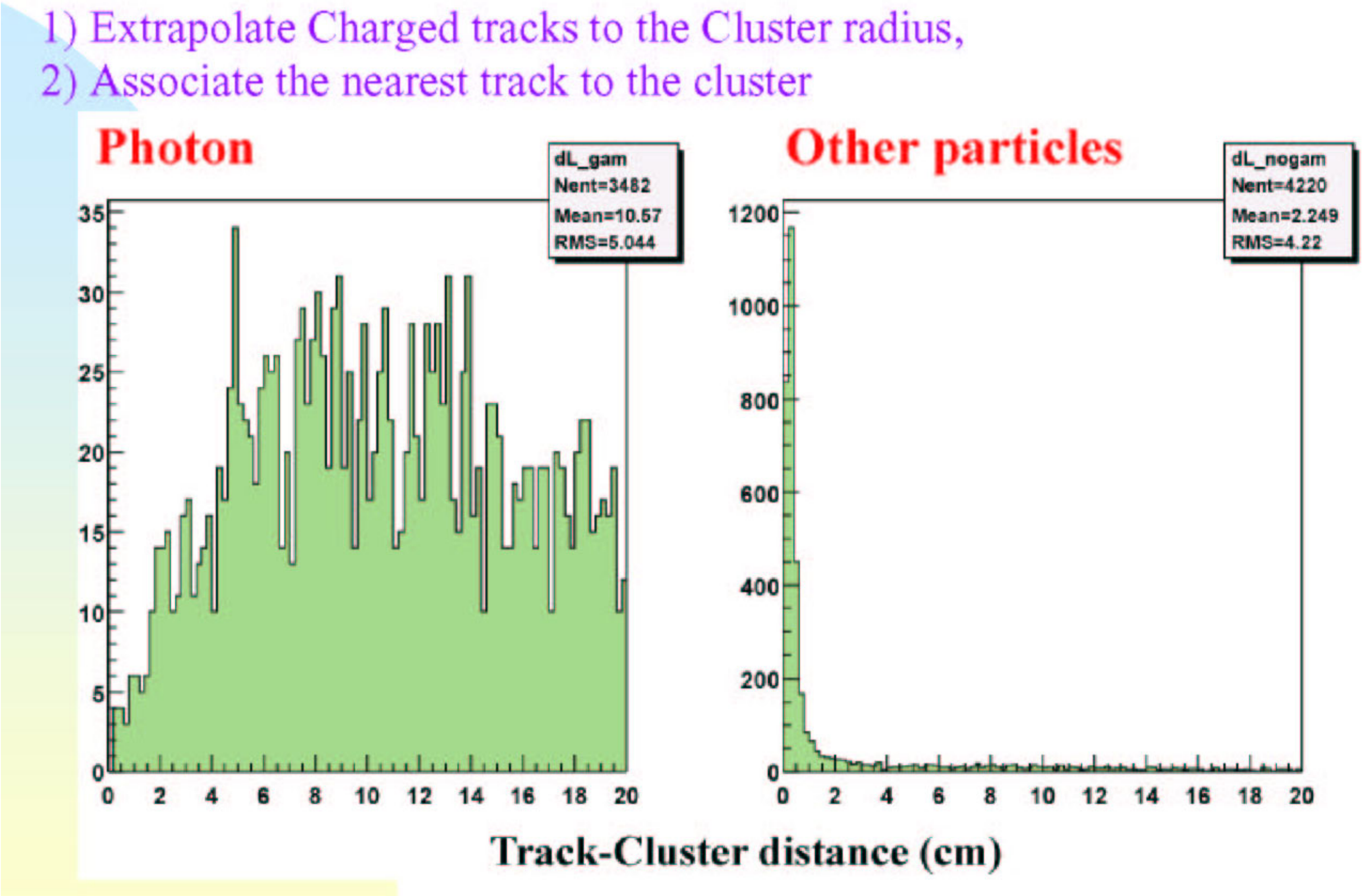


What determines the transverse segmentation?

- BR^2 and R_m
- And the physics:

M. Iwasaki

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

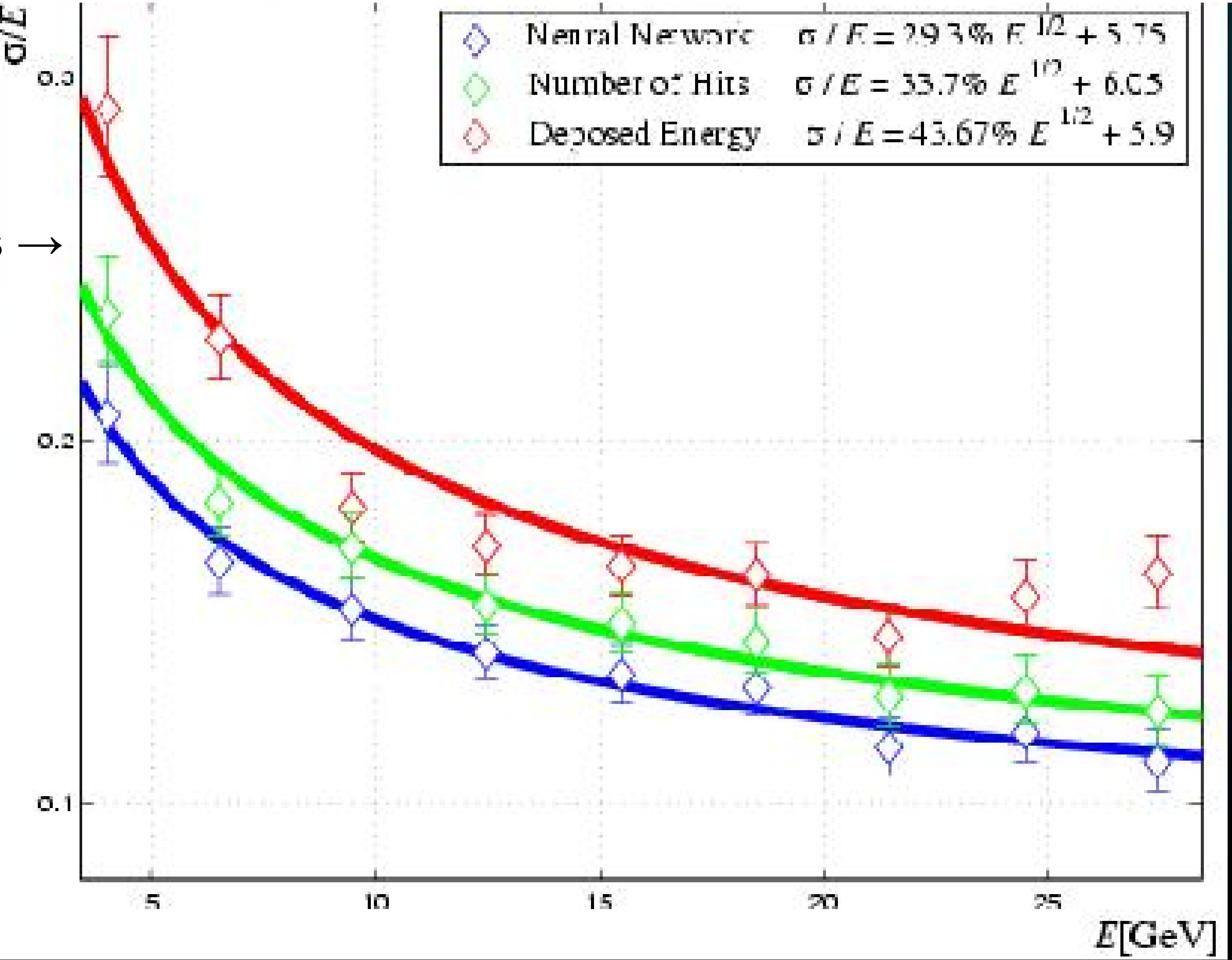


1) Extrapolate Charged tracks to the Cluster radius,
2) Associate the nearest track to the cluster

Digital HCal

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

Single charged pions →



H. Videau, LPHNE-EP

What jet resolution can be achieved ?

- TESLA studies: ≈ 30% / √ Ejet

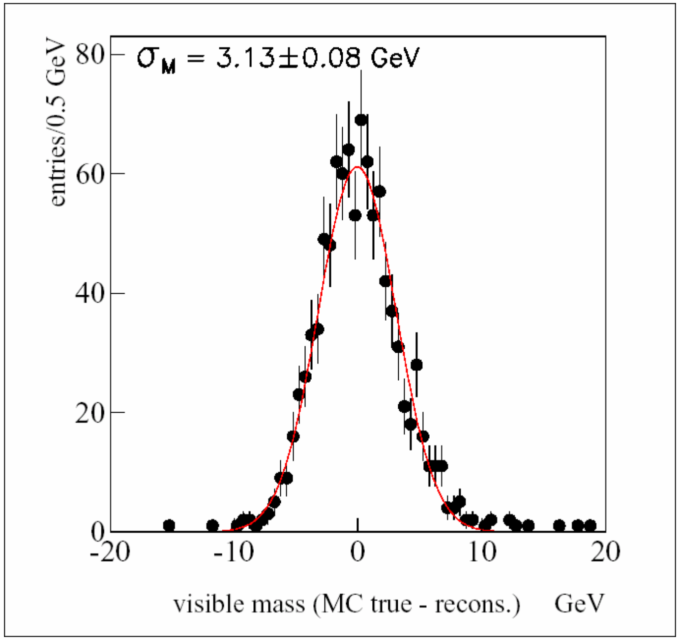
  using current hybrid full simulation and reconstruction

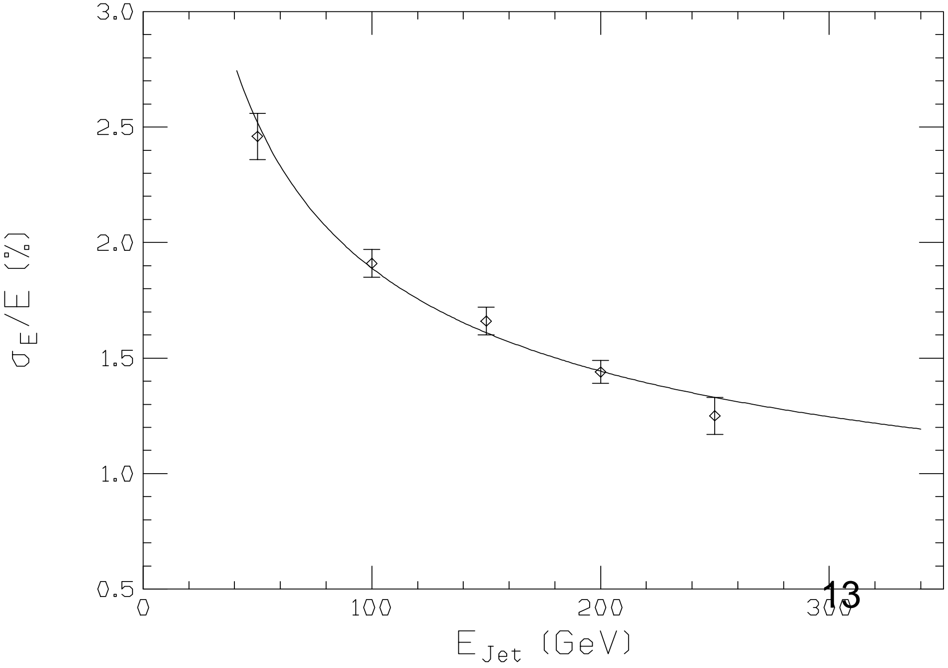
- What is the best possible ?

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

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

H. Videau





EFlow also useful at had. colliders (<VLHC) with sufficient segmentation:

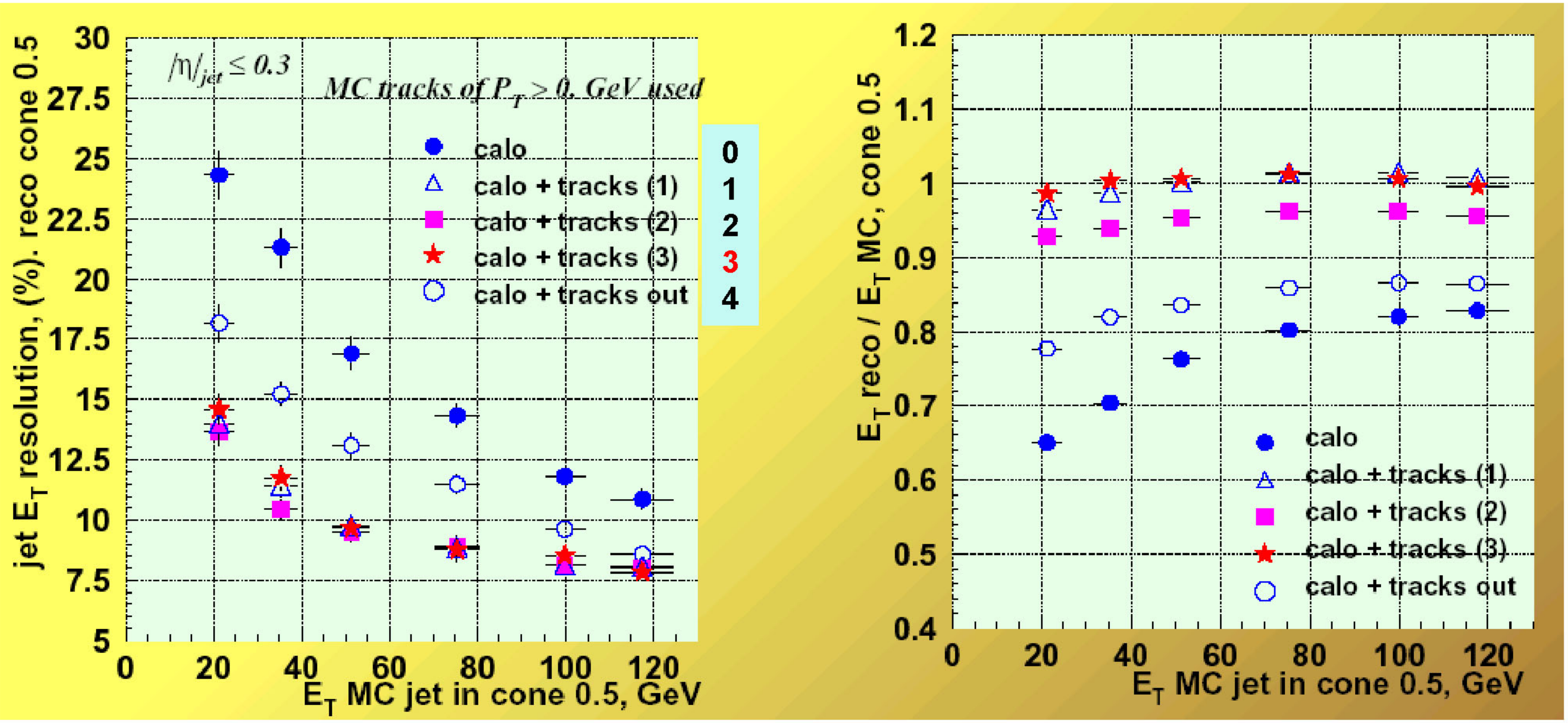
Using Tracks (#5)
Resolution & E_T Scale

Resolution

20GeV 24% → 14%
100GeV 12% → 8%

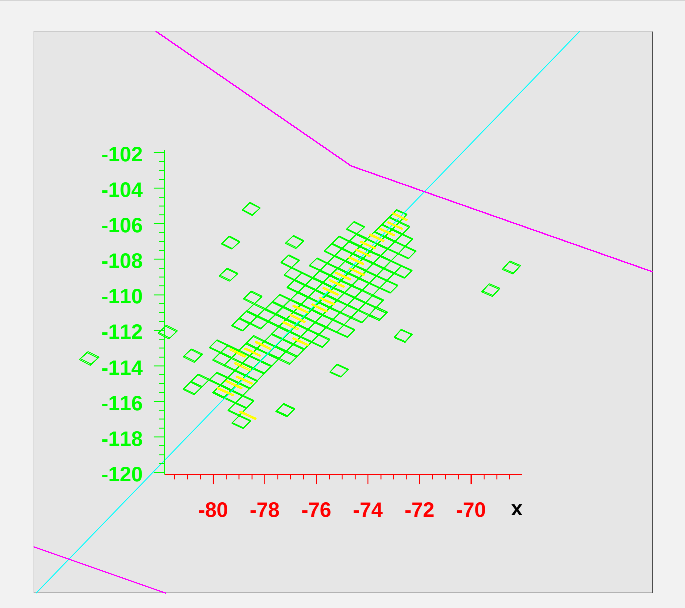
E_T Scale

< 2% in 20-20GeV



0: no correction (calorimeter only) 1: calo response - simple average 2: calo response – library
3: full correction (library of response, track-cluster match, out-of-cone tracks)
4 out-of-cone tracks correction only

Highly-segmented EM Cal as a Tracking Detector

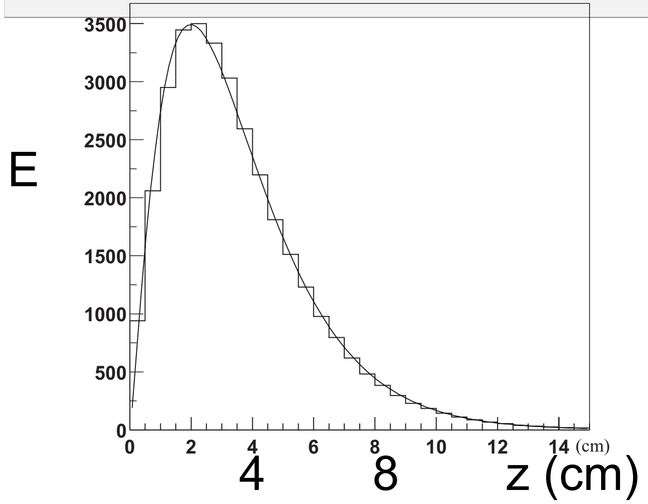


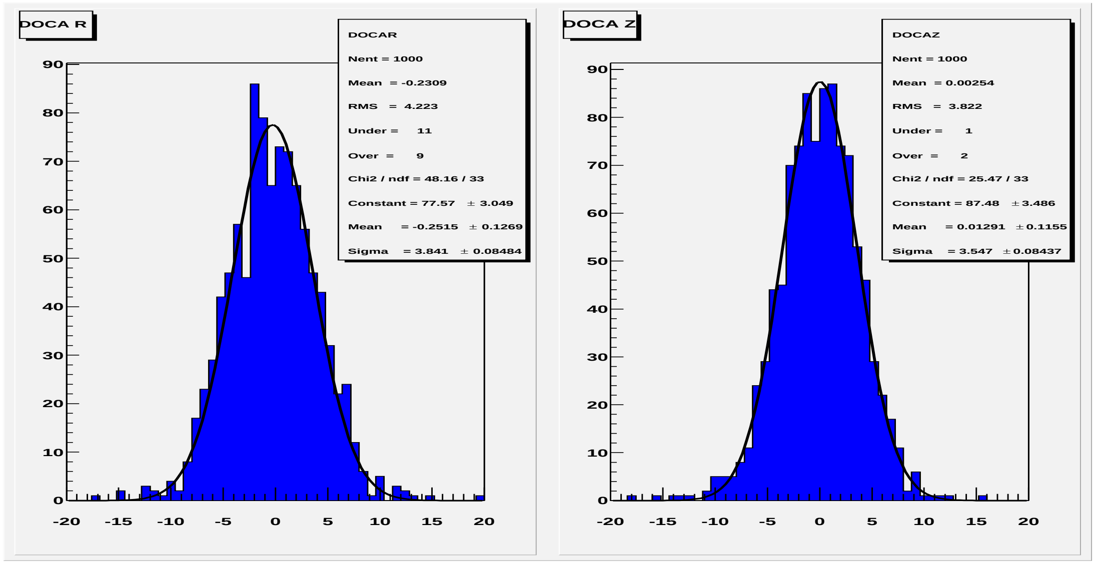
<u>Photon tracking</u>

- Isolated photons, displaced from IP
  - *e.g.* some SUSY models
- 10 GeV photons, Geant4, SD detector
- Fit shower (1mm reso.)
- Extrapolate back to IP

T. Abe

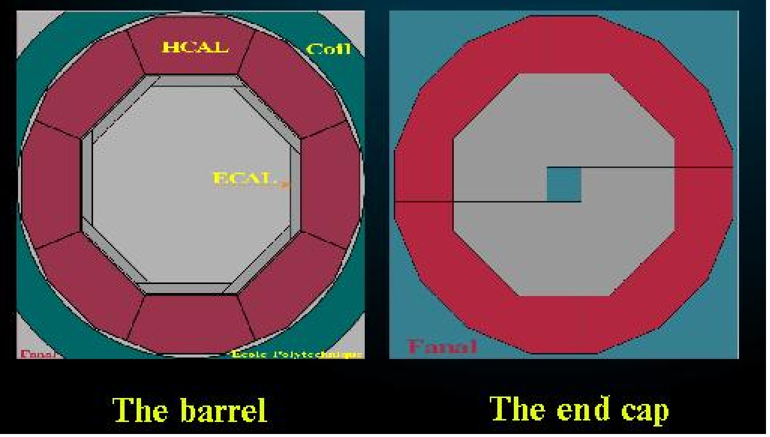
σ_R, $\sigma_z \approx 3.5$ cm





(1 cm for charged tracks!)

The TESLA Design



The barrel

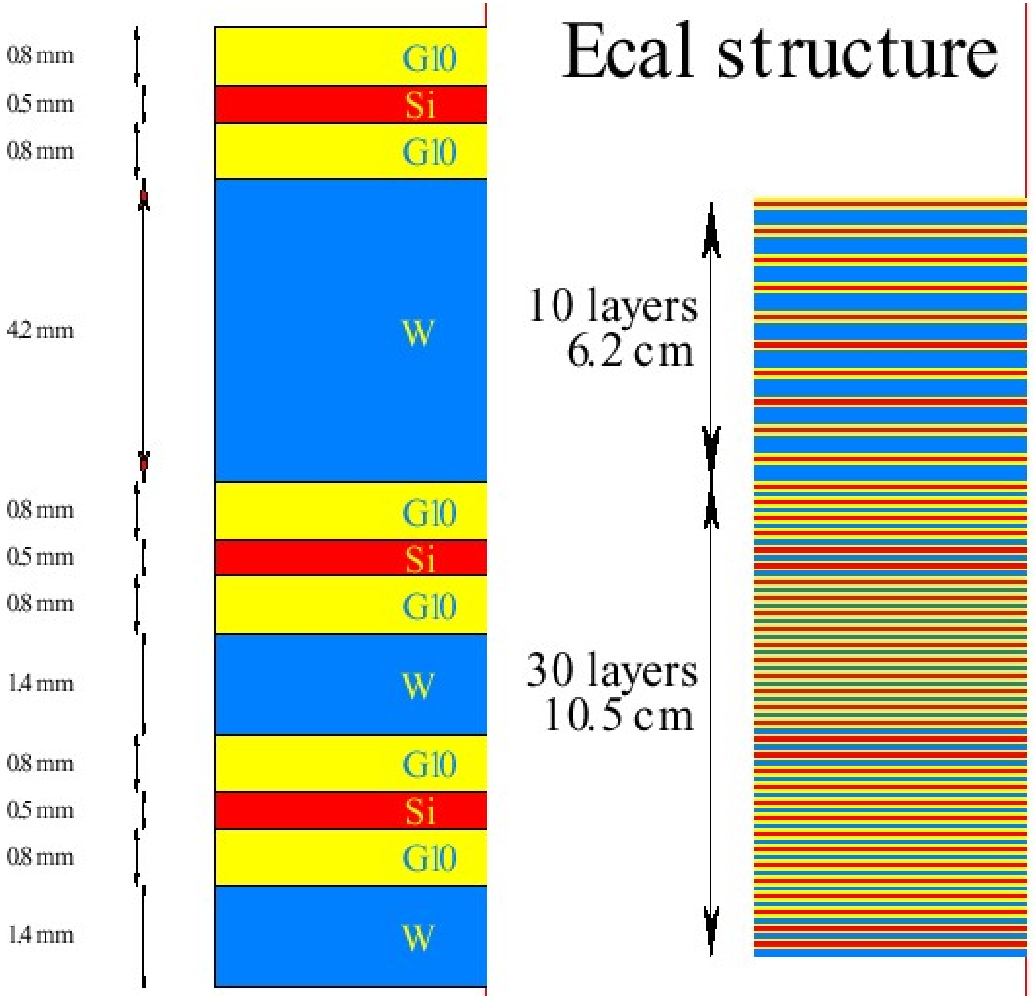
The end cap

ECal:

1. Si/W
    - 2 W thick: 2.8,8.4 mm
    - 20 layers; 1700 m^2 total
    - 15x15 mm^2 segmentation
    - 0.5 mm thick Si
    - ≈16 (128) chan per readout chip
2. Shashlik

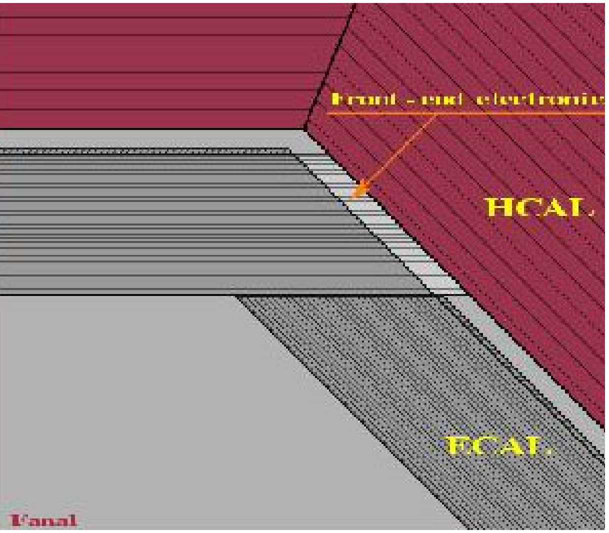
HCal – 2 options:

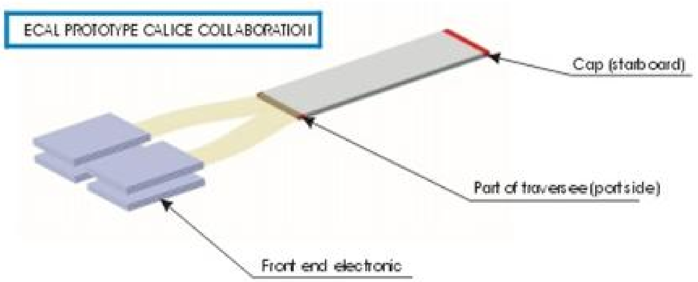
1. Scint. Tiles
    - 5x5 – 25x25 cm^2 seg
2. Digital
    - 1x1 cm^2 seg.
    - RPCs a possible detector

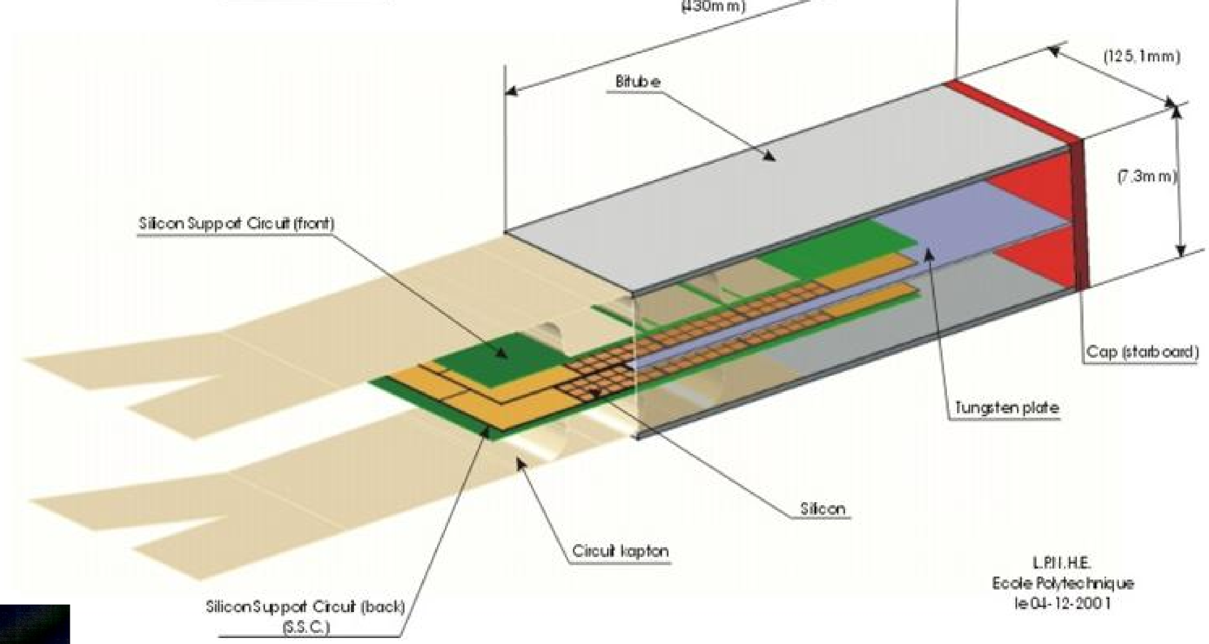


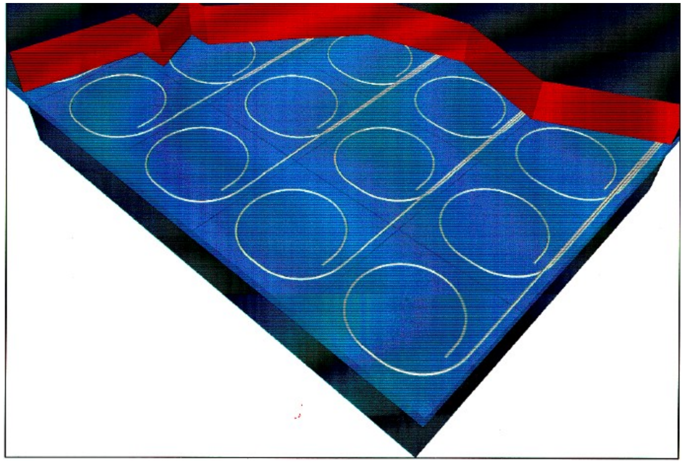
Ecal structure

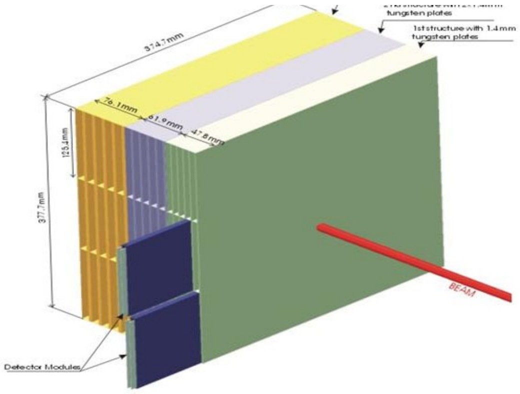
Detector slab

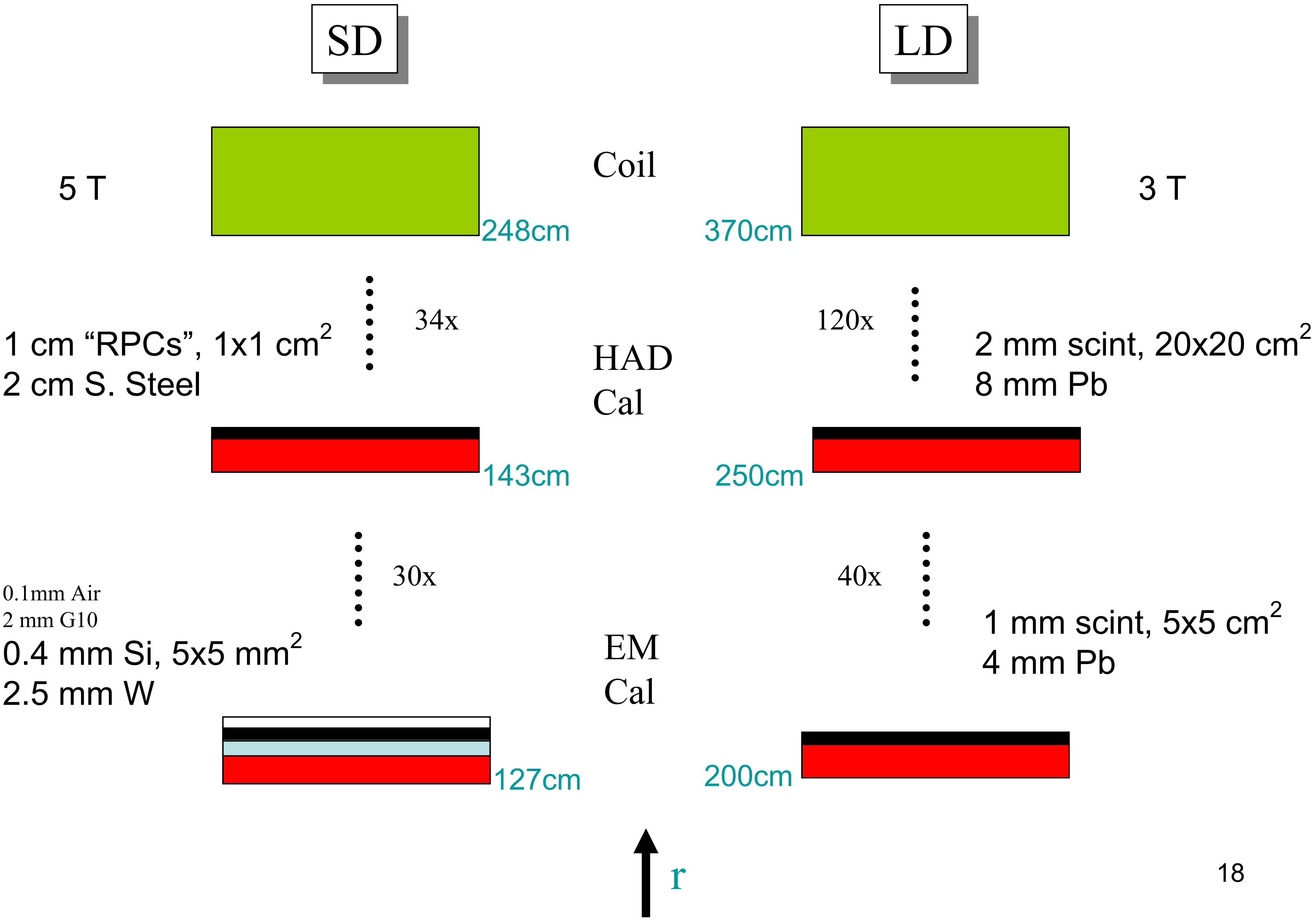












SD

5 T

248cm

34x

1 cm “RPCs”, 1x1 cm^2
2 cm S. Steel

143cm

30x

0.1mm Air
2 mm G10
0.4 mm Si, 5x5 mm^2
2.5 mm W

127cm

Coil

HAD
Cal

EM
Cal

r

LD

3 T

370cm

120x

2 mm scint, 20x20 cm^2
8 mm Pb

250cm

40x

1 mm scint, 5x5 cm^2
4 mm Pb

200cm

SD

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

Si/W EM:

- $R_m \approx 9$mm(1+ gap(Si)/gap(W))
- 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 (can increase)

LD

- $BR^2/R_m \approx 6$
- 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:

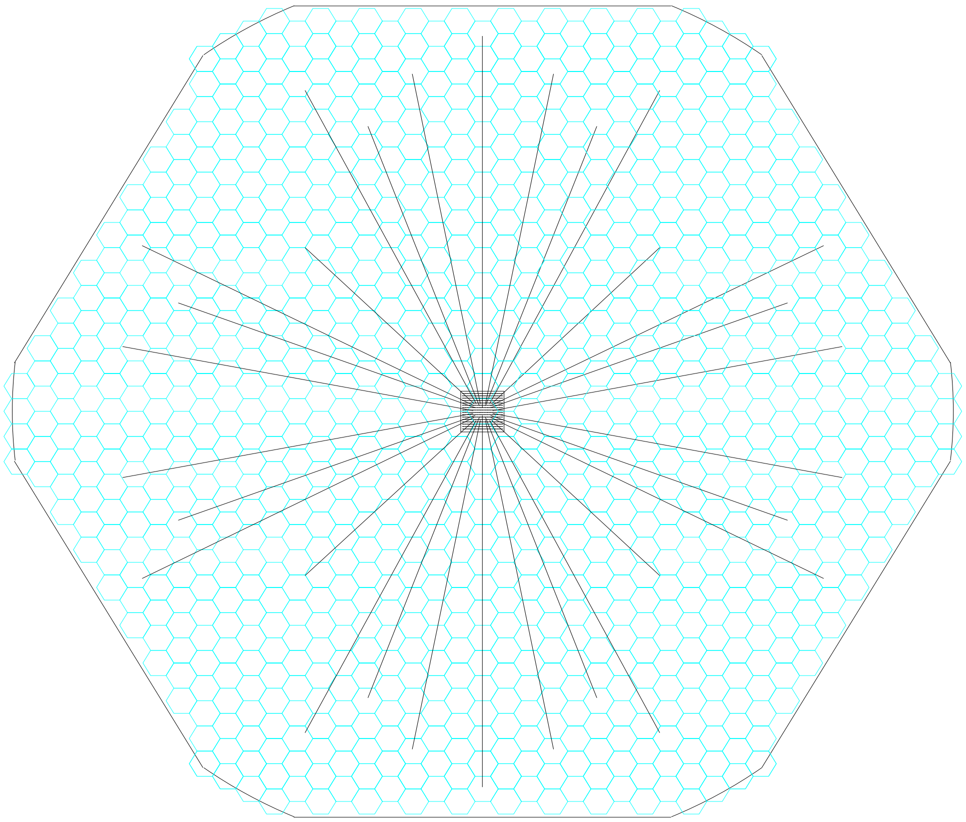
- 8mm Pb/2mm scint
- 20x20 cm^2 tiles
- 7 λ total depth

What is best alternative to Si/W

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

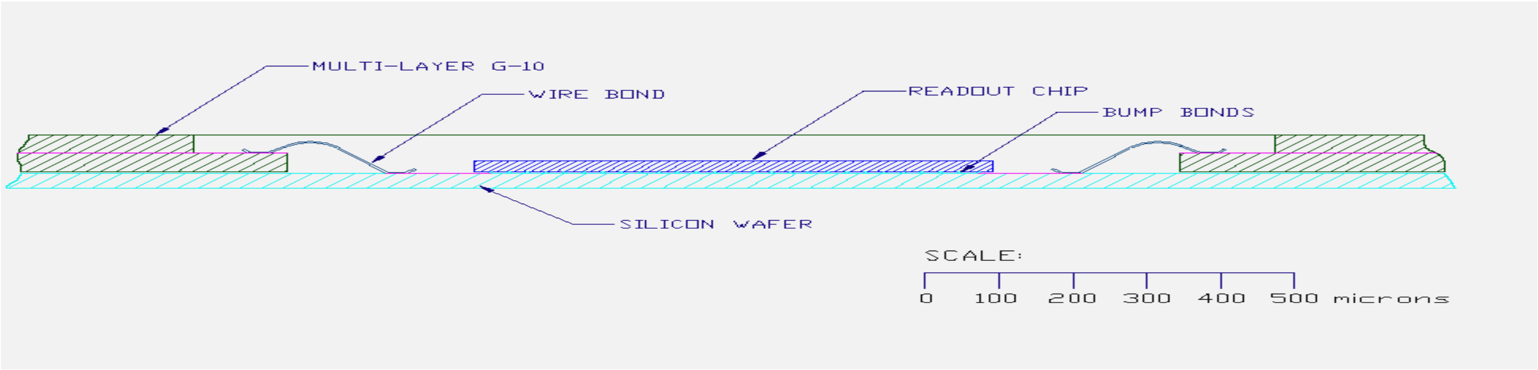
Si/W Readout-SD

- ~50 M pixels, 5x5 mm^2
- Do NOT scale electronics by this number
- 1 chip per wafer (6” or larger)
- 1 chip per ~1 m^2 of wafers
- Large dynamic range
- Cooling: 10^{-3} duty cycle (NLC)
  → power cycling; minimal

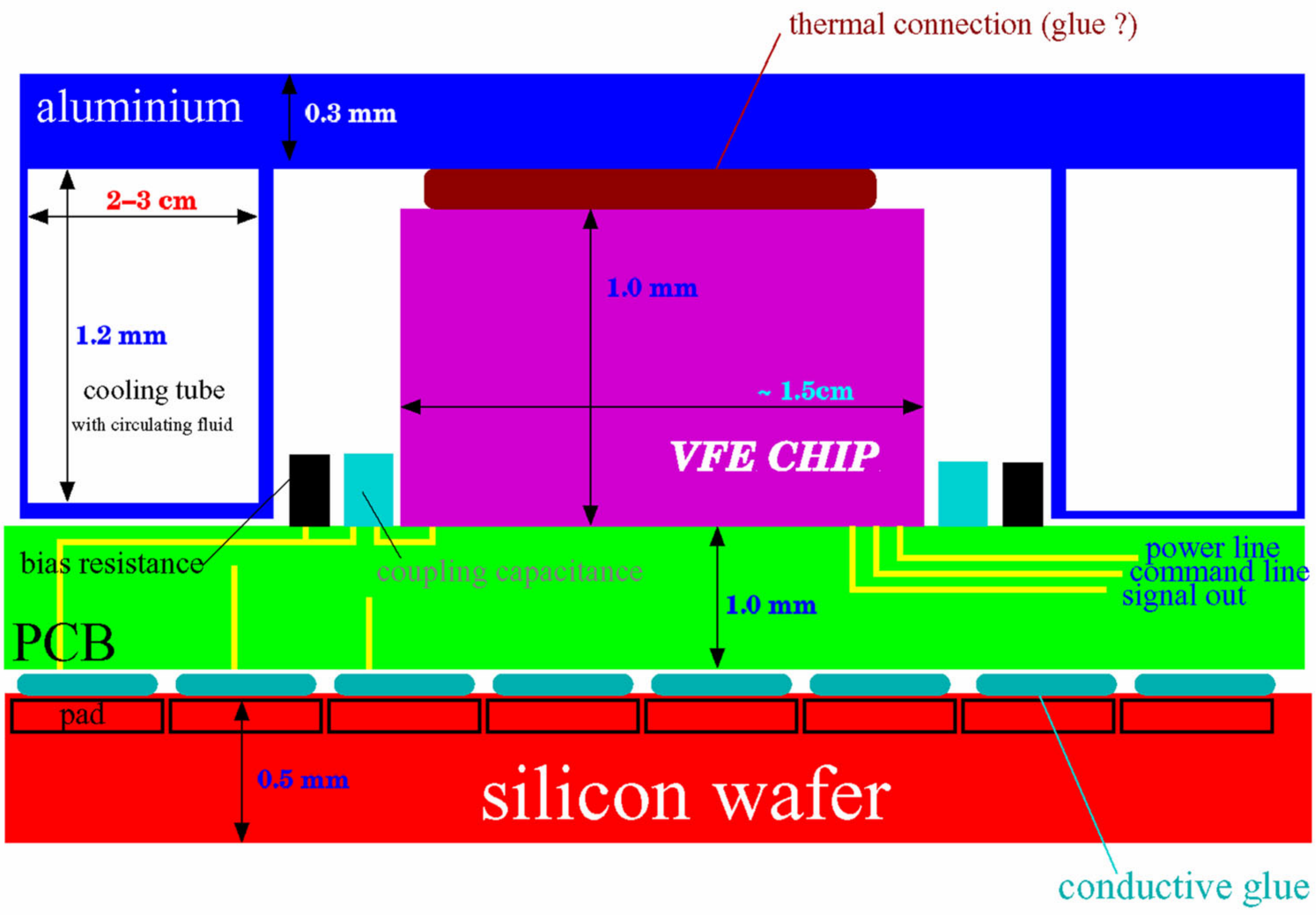


6 inch (152mm) WAFER

1,027 (5mm) CELLS

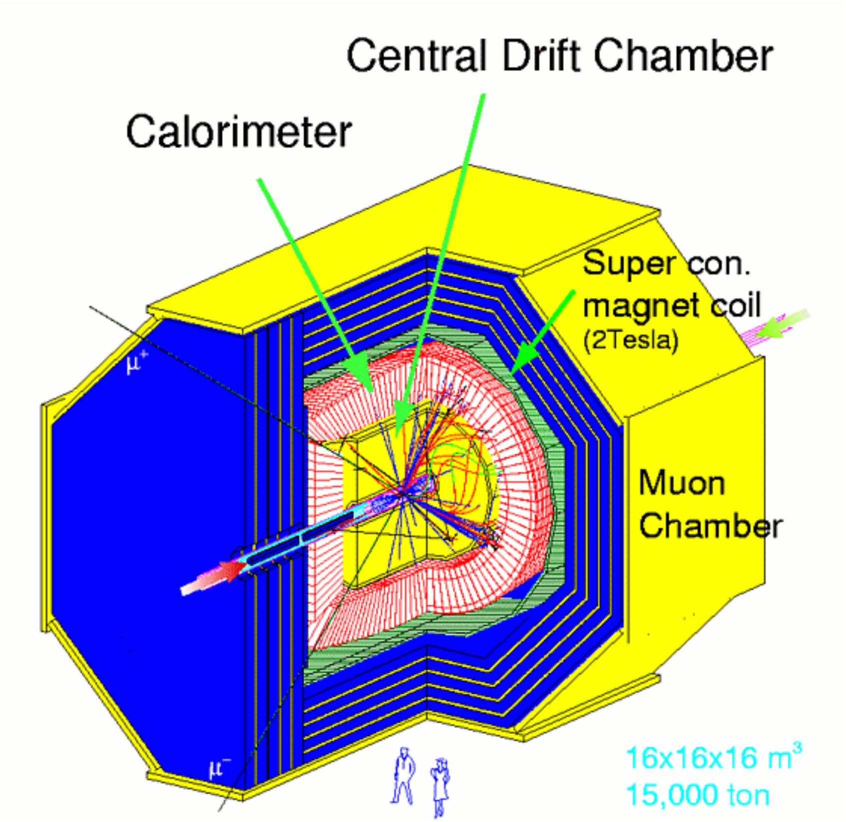


TESLA- Possible new Si/W config.



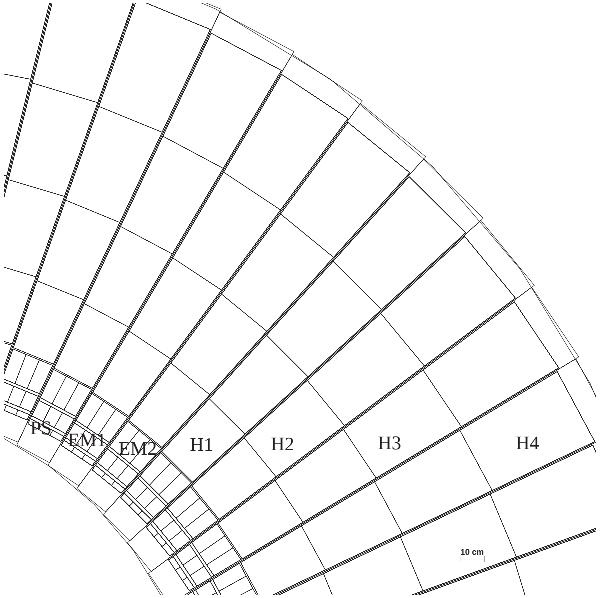
ECAL – detector slab – active layer
transverse view

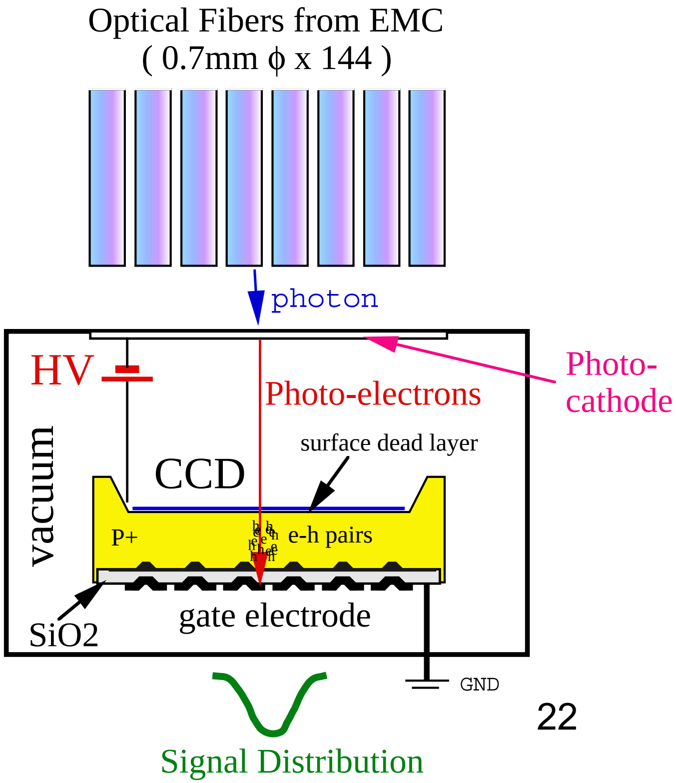
JLC Detector



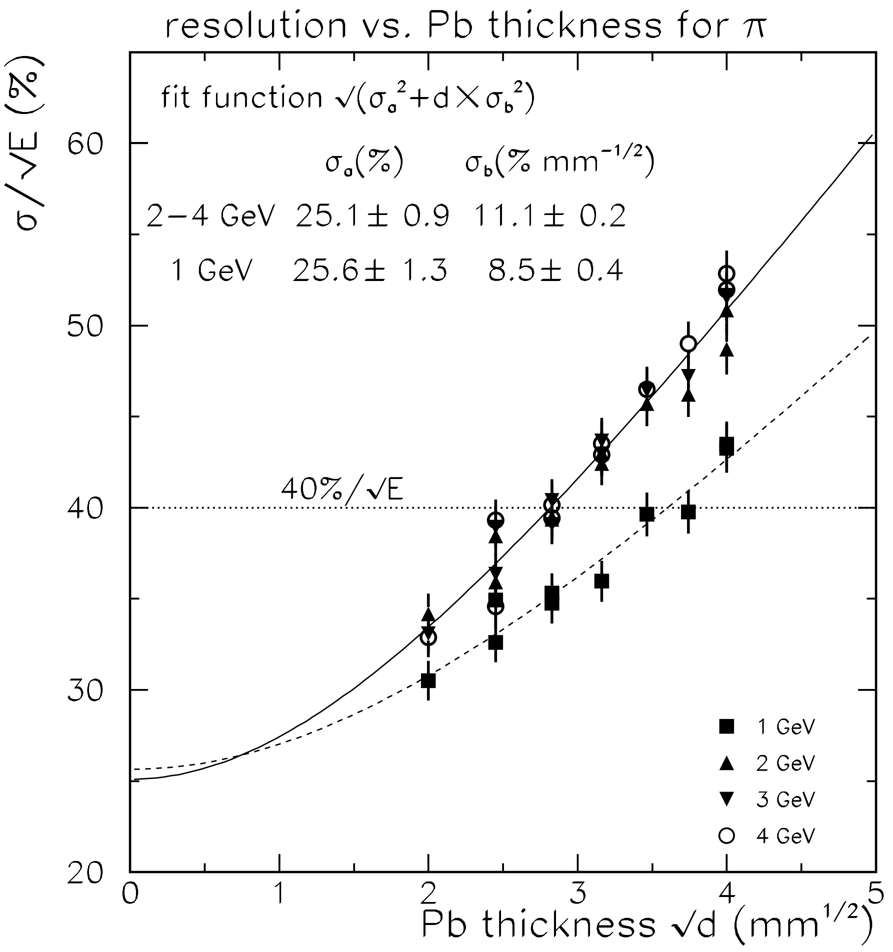
- 4mm:1mm Pb/scint-tile sandwich
- ECal: 4cm x 4cm x 3

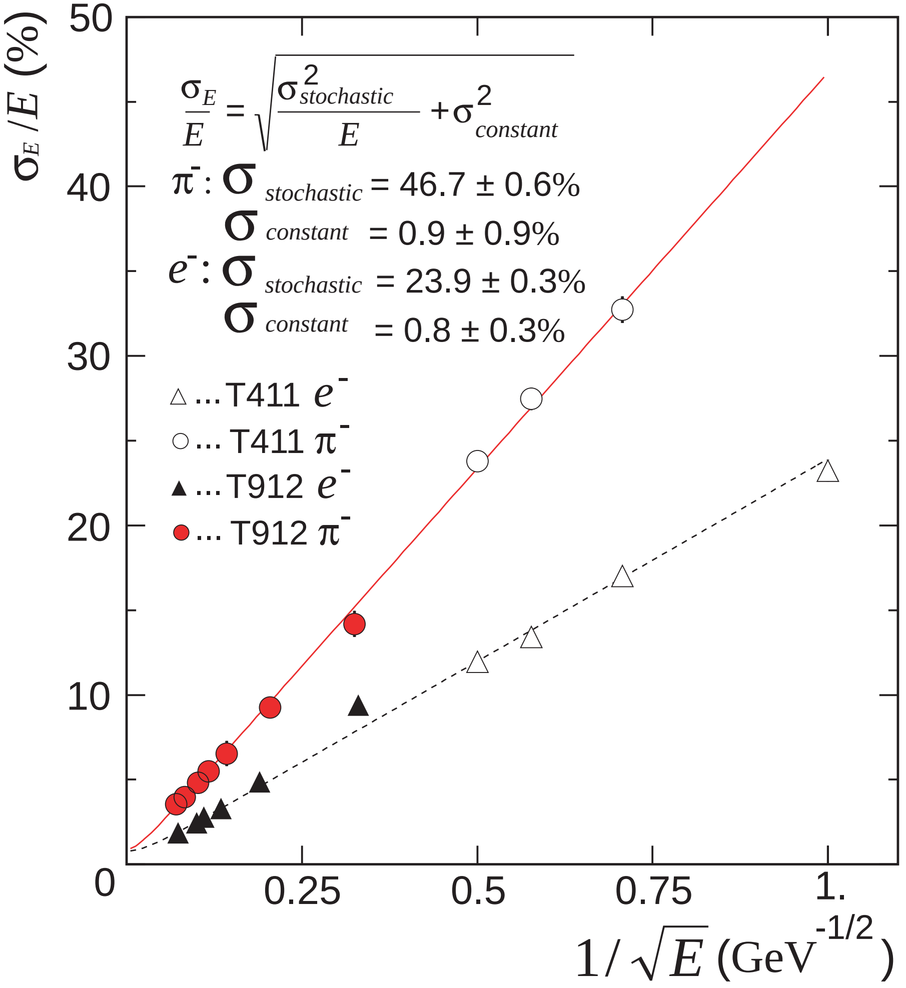
  (option: embedded Si strip layers)
- HCal: 14cm x 14 cm x 4





JLC Beam Test Results





igure 5.22: Energy resolution vs. Pb thickness for π's Solid and dashed curves shown n the figure are fitting results to Eq. (5.2) except for 1 GeV and 1 GeV. Dotted line in the figure is the requirement of the energy resolution for the JLC hadron calorimeter.

Some R&D Issues

Simulations

- ➢ Evaluate EFlow
  1. Full simulation [Gismo→Geant4]
  2. Pattern recognition algorithms [emerging…] , merge with tracks, etc → Full reconstruction [JAS, Root]
  3. Optimize detector configuration

SLAC

NIU-NICCAD

Argonne

Oregon

Opportunities: algorithm development, validity of Geant4, parameterizations, detector ideas

- ➢ Case for jet physics
  - Low-rate processes (*eg* Zhh, tth)
  - Beam constraints *vs* not
    - t-channel
    - reduce combinations for mult-jet recon. (eg tt→6 jets)
  - How to combine with other info. (*eg* flavors from vxd)

All !

- ➢ e, photon id; muon id; forward (2-photon), missing E

R&D (2)

ECAL

- Si/W
  - Cost, readout config., packaging, cooling
  - Mechanical structure
  - Optimize sampling vs Si area

SLAC & Oregon

Kansas St

Opportunities: generic detector development;
detector and electronics prototyping;
comparative and detailed simulations

- Alternatives! [issues]
  - Scint. tiles [segmentation, light output, readout]
    - With Si layer(s) ?
  - Shashlik [segmentation]
  - Crystals [segmentation, physics case for reso.?]
  - LAr

Colorado

Caltech

R&D (3)

HCAL

- Required segmentation for EFlow?
- “Digital’’ detector [issues]
  - RPCs [reliability, glass?, streamer/avalanche]
  - Scint. [segmentation, light, readout]
  - GEMs [reliability]
  - Other?
- Other options
  - Scint. tiles, ….?
- Generic Issues:
  - In/out –side coil
  - Compensation (partial?)
  - Absorber material and depth
  - Integrate muon id with dedicated muon det.

Argonne
NIU-NICCAD
UT Arlington

Opportunities: Wide open: detailed simulations in conjunction with various detector options; detector prototyping

Summary

- Optimize calorimeters for tracker-cal. jet reconstruction
  - Energy flow with highly segmented calorimetry (Si/W ? Digital?)
  - Compensating calor. (JLC)
- Still in early stages of development
- Designs fluid, but prototyping has begun
- Simulations progressing: Require full simulations and realistic reconstruction algorithms to evaluate
  - → A large, systematic effort required

- Attempt to push overall detector performance to new level – try to explore limits before forced to retreat ($)