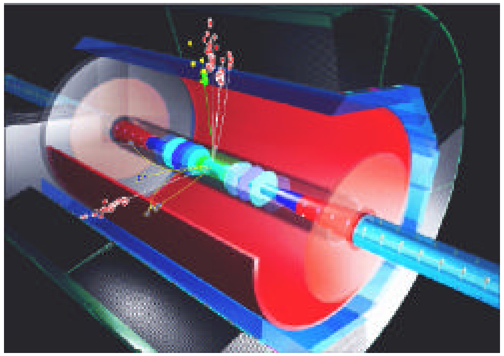
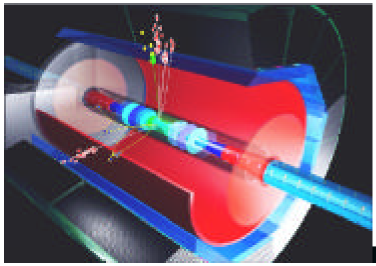


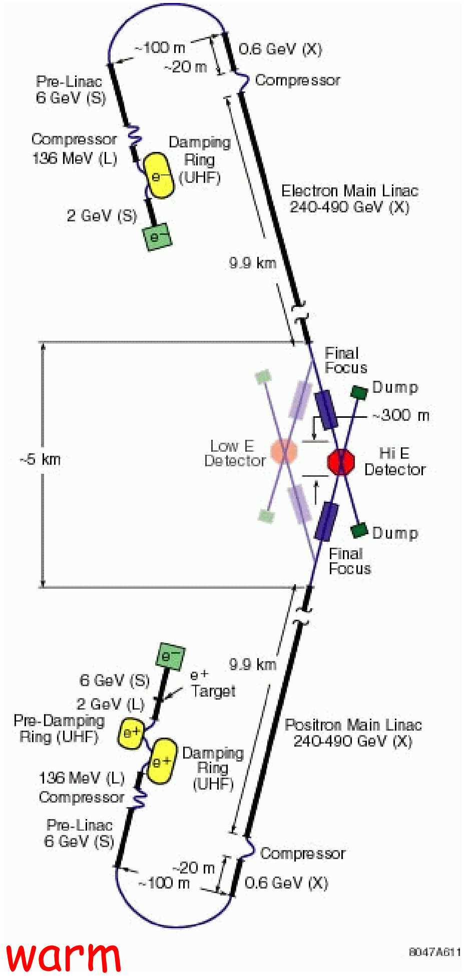
Performance Goals and Design Considerations for a LC Calorimeter

Felix Sefkow
DESY
CALICE Collaboration

CALOR 2004, Perugia
April 2, 2004



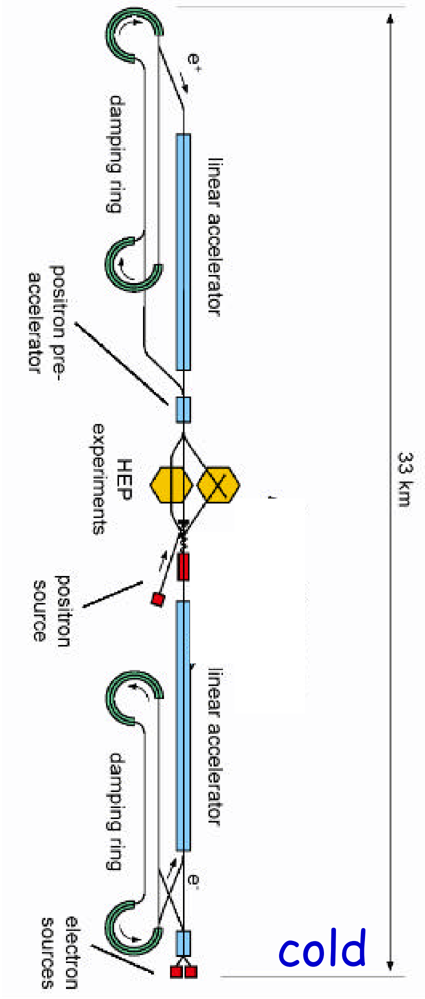
The Linear Collider consensus

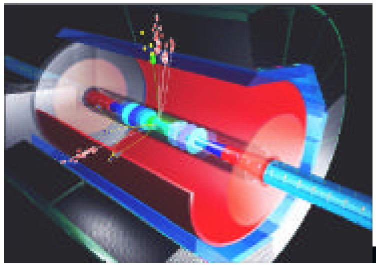


- 200 GeV < $\sqrt{s}$ < 500 GeV
- Integrated luminosity ~ 500 fb^{-1} in 4 years
- Upgrade to 1TeV

- Technology choice **2004**
- Concurrent running with the LHC:
  - ready for approval **2007**
  - start commissioning **2015**

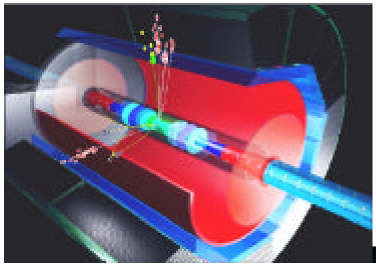
- Prepare basic detector design choices **now**





Outline

- Physics Performance Goals
- The Particle Flow Paradigm
- Design Considerations



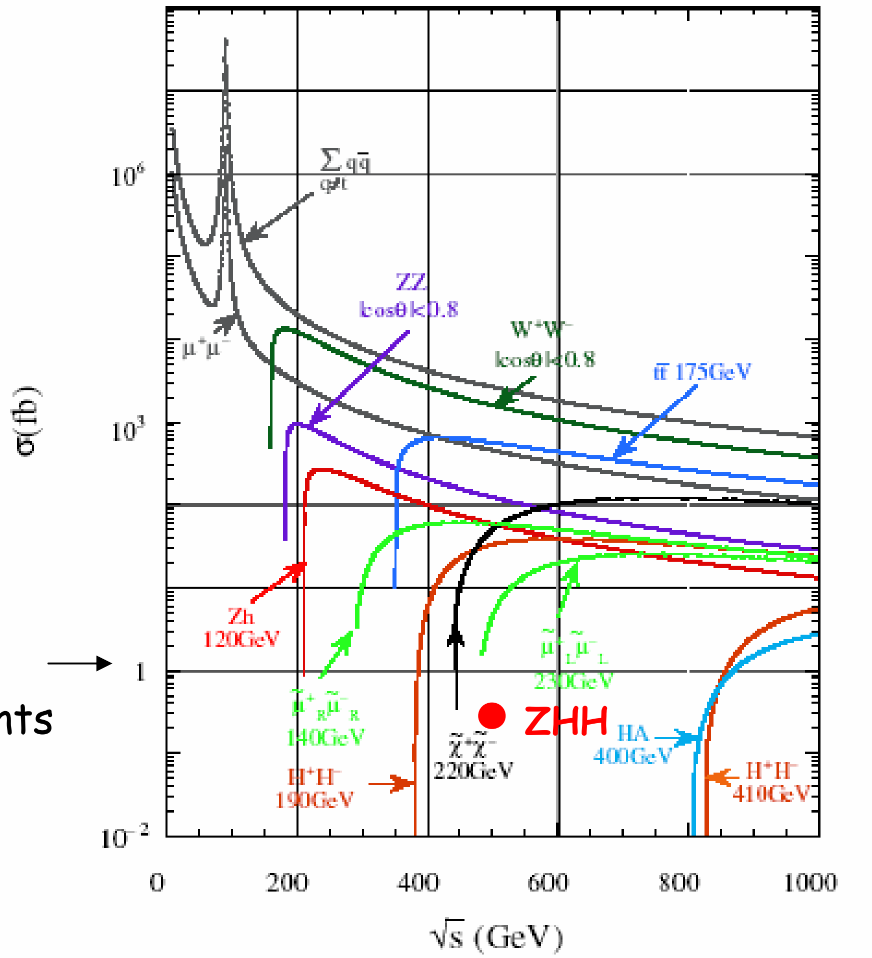
Precision physics

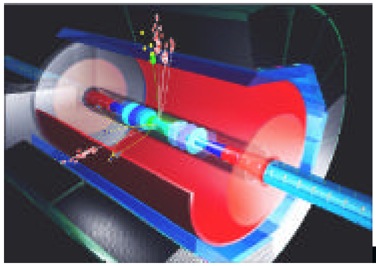
- Discoveries and precision measurements

- rare processes
- often statistics limited
- final states with heavy bosons **W, Z, H**
- need to reconstruct their hadronic decay modes, **multi-jet events**

- in general no kinematic fits

500 events →

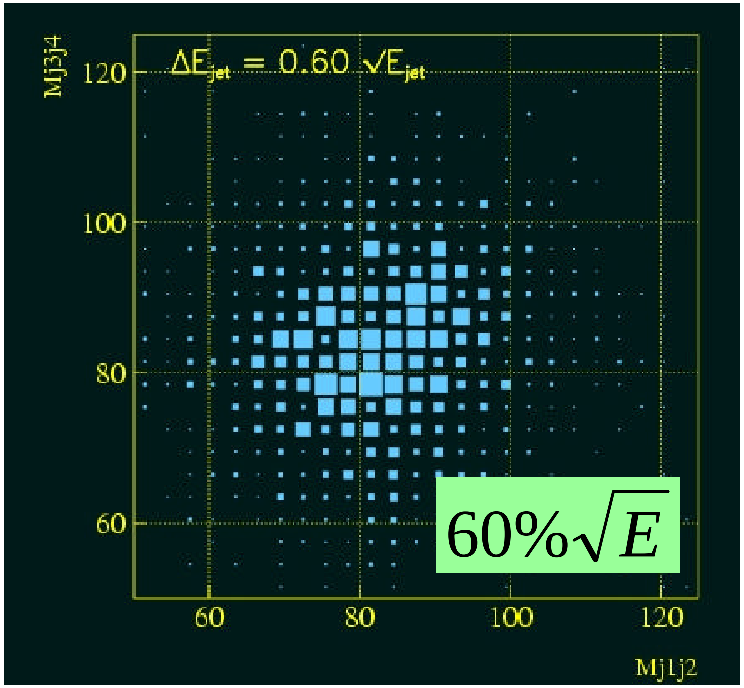




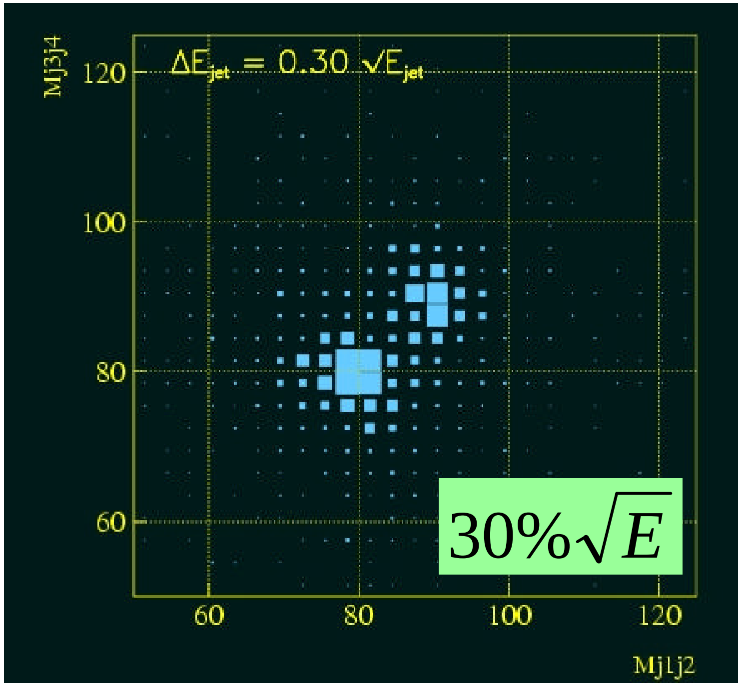
Jet energy resolution

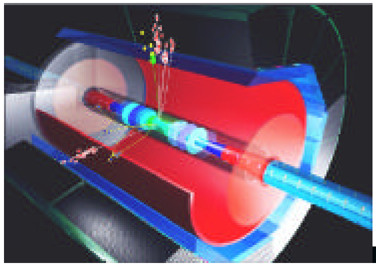
- Challenge: separate W and Z in their hadronic mode
- Dijet masses in WW, ZZ events:

LEP-like detector



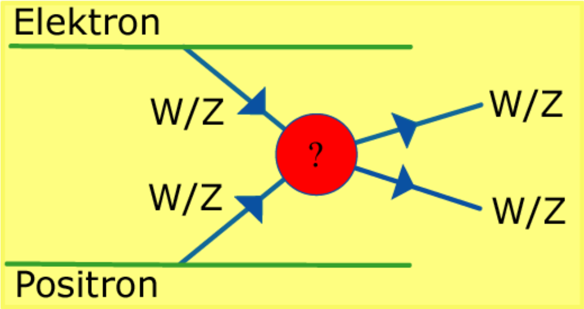
LC design goal





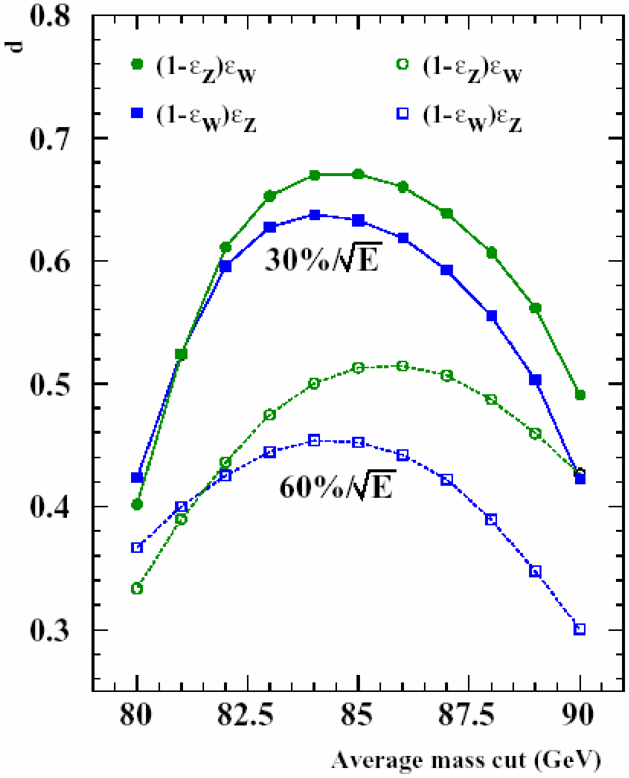
W, Z separation

- Imagine – there is no Higgs: WW scattering violates unitarity at ~ 1.2 TeV, or new forces show up

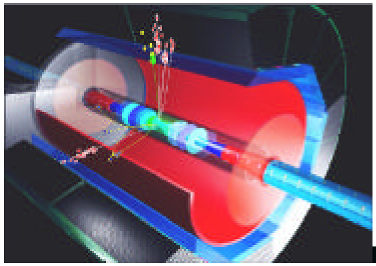


- irreducible background: ZZ

- probe quartic gauge couplings up to EWSB scale of ~3 TeV

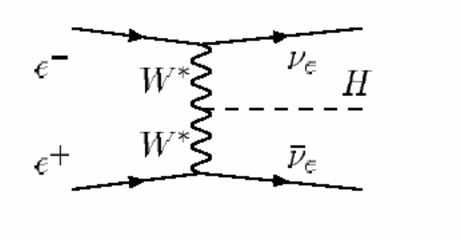


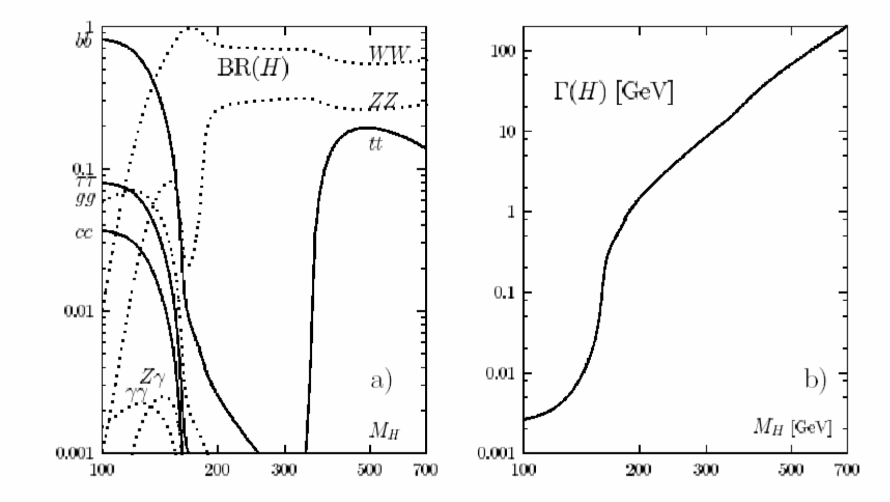
Dilution factor vs cut:
integrated luminosity equivalent



The Higgs boson total width

- gives access to all couplings
- for low M_H from s (WW fusion)



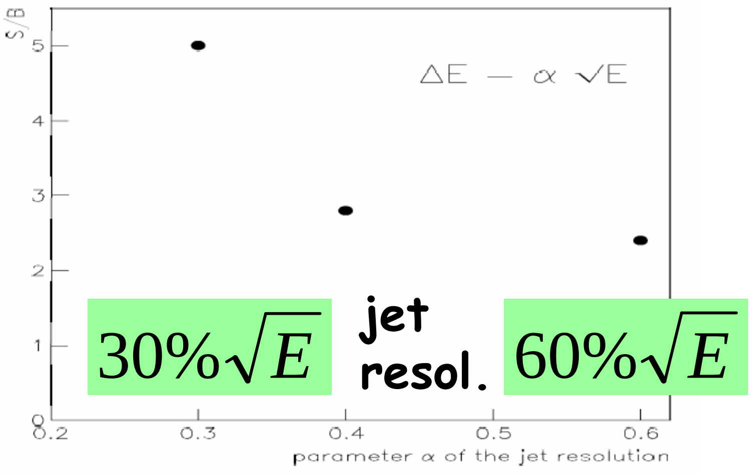


- and BR (H ? WW*)

s/B in
ZH ? ZWW
? 4jets l ?

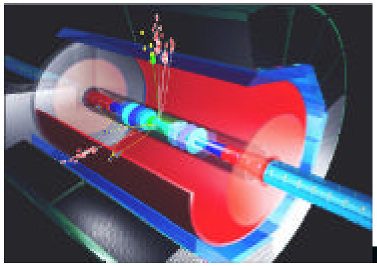
5

2



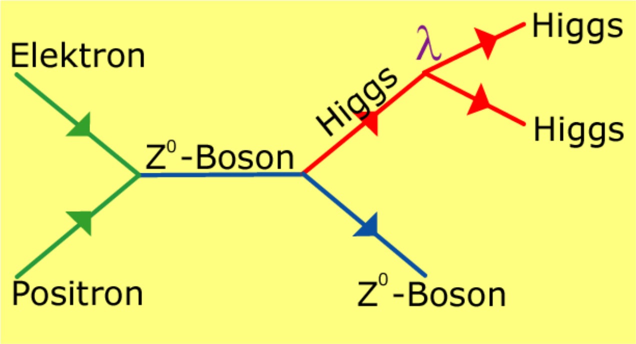
$30\%\sqrt{E}$ **jet resol.** $60\%\sqrt{E}$

- worth 20% precision, 40% lumi, again

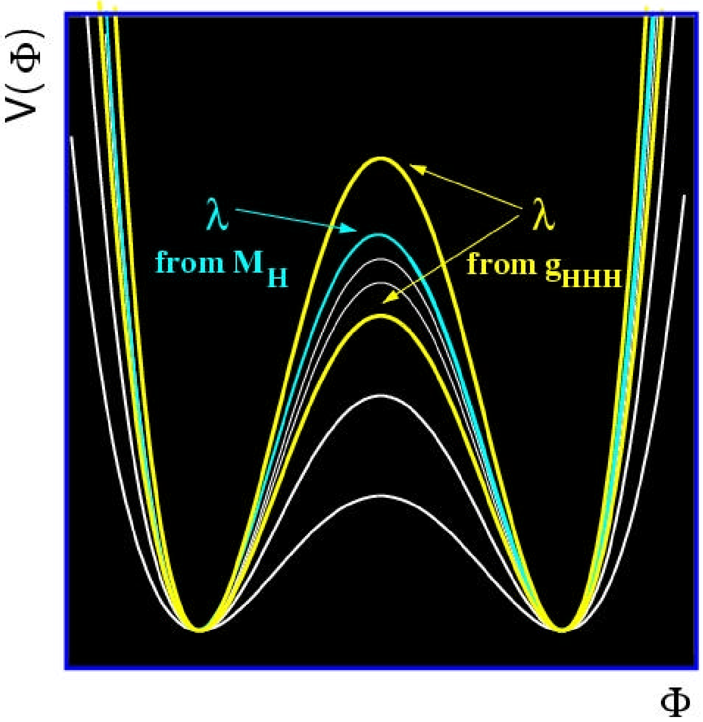


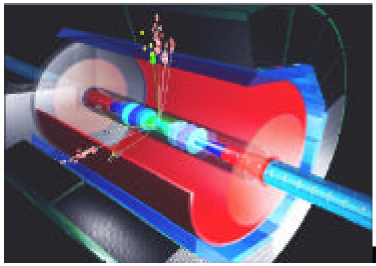
The Higgs potential

- **Is** the Higgs the Higgs?
- Check ? = $M^2_H/2v^2$



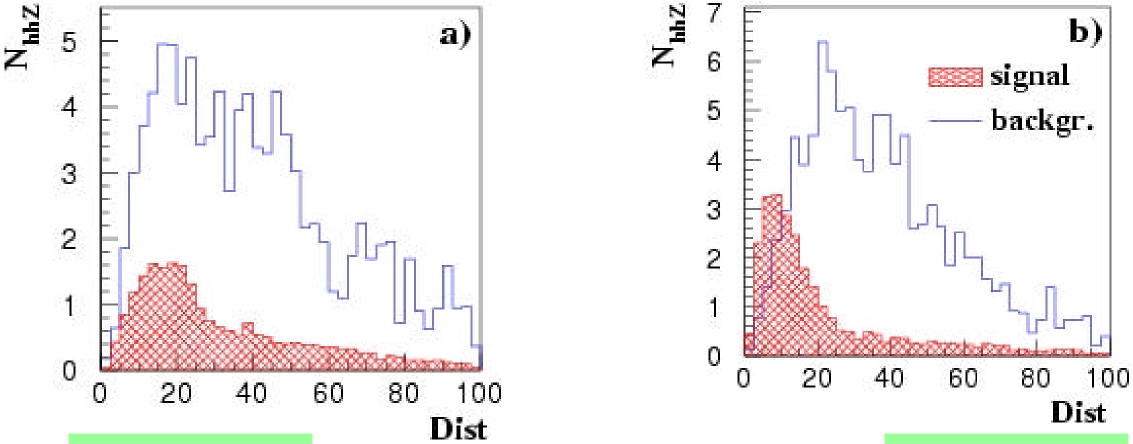
6 jets





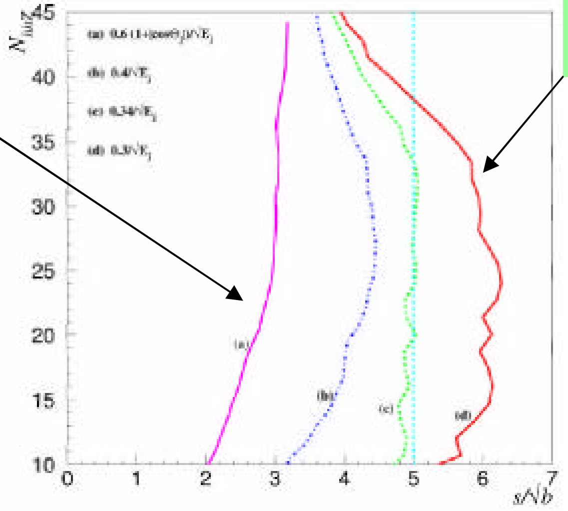
Triple Higgs signal

- few tens of events
- reconstruct observable from 3 dijet masses
- impossible with a LEP-like detector



$60\%\sqrt{E}$

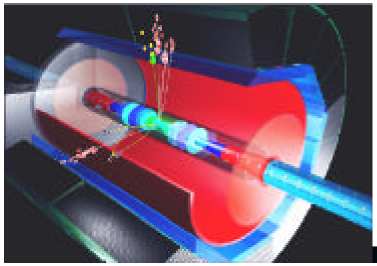
$30\%\sqrt{E}$



N_{ev}
($1ab^{-1}$)

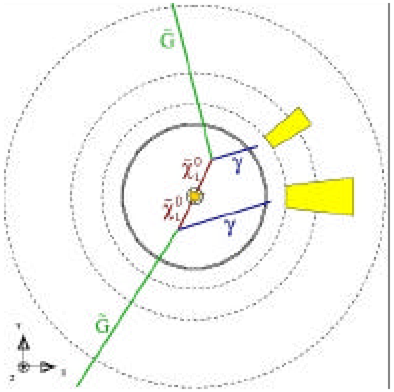
5 sigma

s/√B

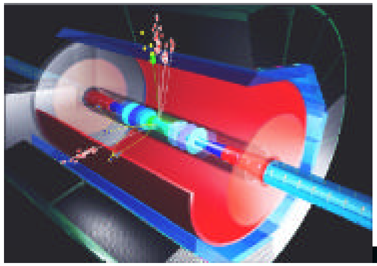


Other requirements

- directional resolution
  - photon impact parameter (need e.g. few cm @ 20 GeV)
- hermeticity
  - suppress two photon background to SUSY events
- lepton identification
- timing

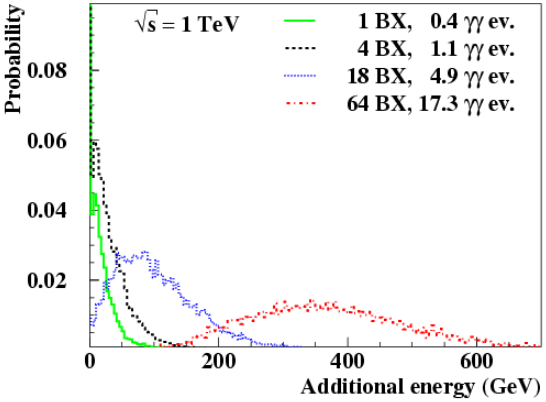


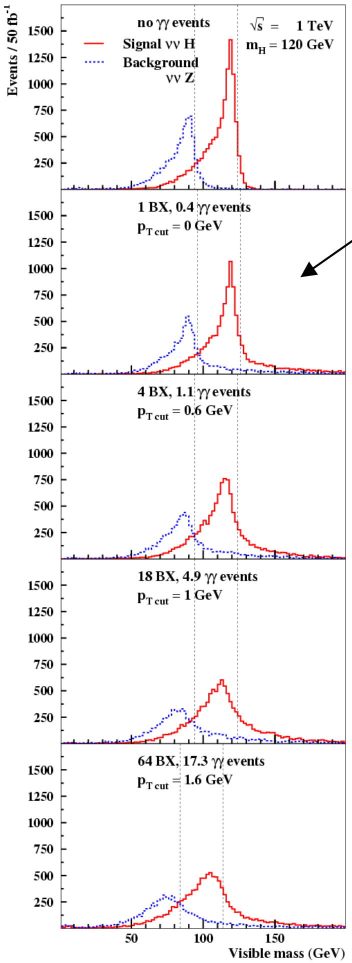
decay of a
longlived neutralino



Time resolution

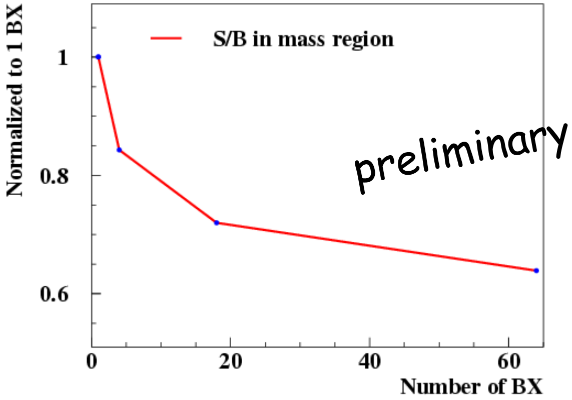
- background pile-up from ?? ? hadrons can be a problem at the LC
- ~ 1 event every 2 - 4 BX
- on average 6 GeV per event in main calorimeter:



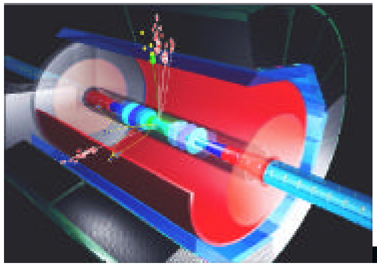


- example: Higgs mass signal in WW fusion

re-optimize cuts and window for each case

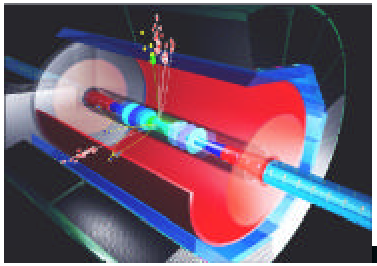


- capability to time-stamp detector signals does affect physics performance



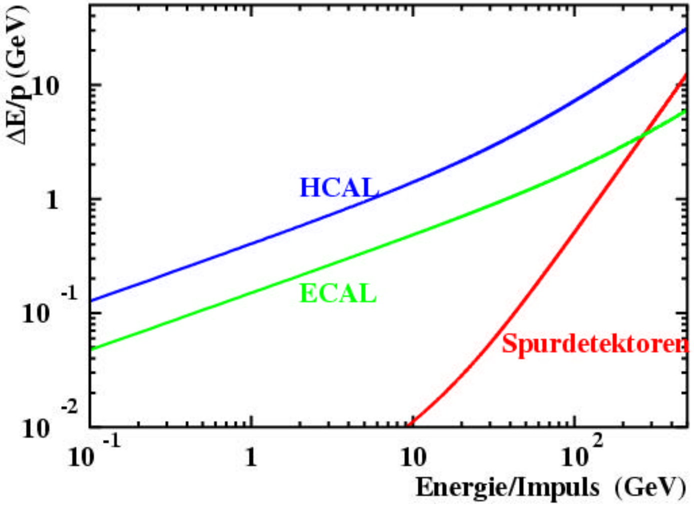
Physics performance goals

- The excellent precision physics potential of an electron positron linear collider has to be matched by an unprecedented detector performance
- The W vs. Z boson mass separation dictates a jet energy resolution of 30% / vE - twice as good as achieved in LEP detectors
- Some key physics topics are exclusively accessible with such an advanced detector



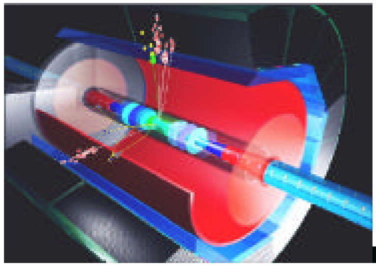
Particle Flow Algorithms

- Best jet energy resolution with minimum calorimetry
  - tracking detectors to measure energy of charged particles (**65%** of the typical jet energy)
  - EM calorimeter for photons (**25%**)
  - EM and HAD calorimeter for neutral hadrons (**10%**)



$$E_{\text{jet}} = E_{\text{charged}} + E_{\text{photons}} + E_{\text{neut. had.}}$$

$$\sigma^2_{E\text{jet}} = \sigma^2_{E\text{charged}} + \sigma^2_{E\text{photons}} + \sigma^2_{E\text{neut.had.}} + \sigma^2_{\text{confusion}}$$



Contributions to σ(Ejet)

$$s^{2}_{Ejet} = s^{2}_{Echarged} + s^{2}_{Ephotons} + s^{2}_{Eneut.had.} + s^{2}_{confusion}$$

- With anticipated resolutions:

$$s^{2}_{Echarged} \approx \left(5\times10^{-5}\right)^{2} \sum \frac{E^{4}_{charged}}{\mathrm{GeV}^{2}} \approx \left(0.02\,\mathrm{GeV}\right)^{2} \tfrac{1}{10} \sum \left(\frac{E_{charged}}{10\,\mathrm{GeV}}\right)^{4}$$

$$s^{2}_{Ephotons} \approx \left(0.11\right)^{2} \sum \left(E_{photon} \cdot \mathrm{GeV}\right) \approx \left(0.6\,\mathrm{GeV}\right)^{2} \frac{E_{jet}}{100\,\mathrm{GeV}}$$

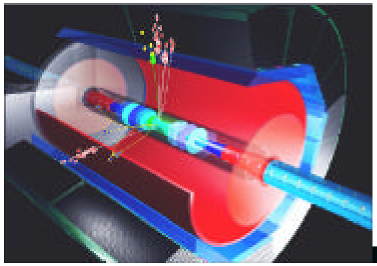
$$s^{2}_{Eneut.had.s} \approx \left(0.40\right)^{2} \sum \left(E_{neut.had.} \cdot \mathrm{GeV}\right) \approx \left(1.3\,\mathrm{GeV}\right)^{2} \frac{E_{jet}}{100\,\mathrm{GeV}}$$

Ideally

realistically

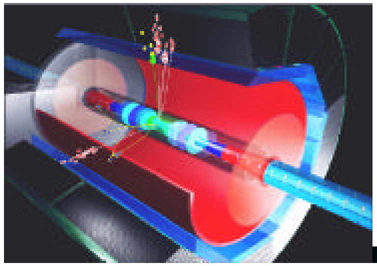
$$s^{2}_{Ejet} \approx \left(0.14\right)^{2} \left(E_{jet} \cdot \mathrm{GeV}\right) + s^{2}_{confusion} \approx \left(0.3\right)^{2} \left(E_{jet} \cdot \mathrm{GeV}\right)$$

(courtesy D.Karlen)

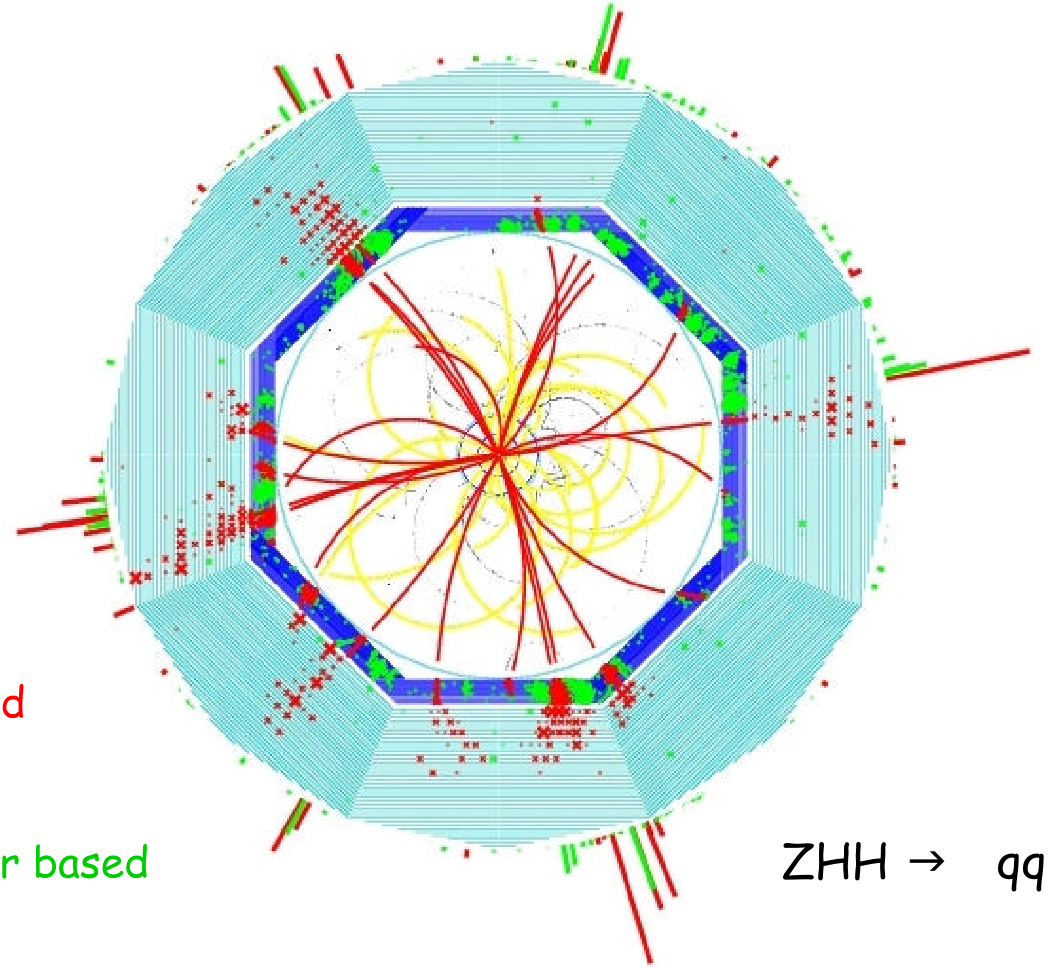


The PFLOW paradigm

- The confusion term dominates
- Each particle should be reconstructed and measured separately
- For the jet energy measurement spatial resolution / particle separation power is more important than energy resolution



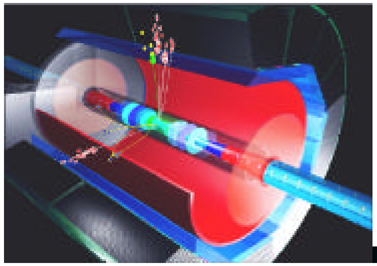
Imaging calorimetry



red:
track based

green:
calorimeter based

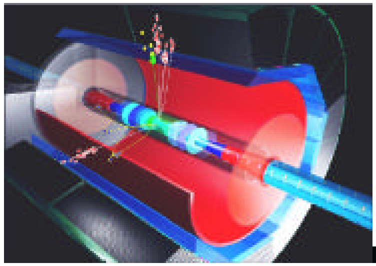
ZHH → qqbbbb



Calorimeter concept

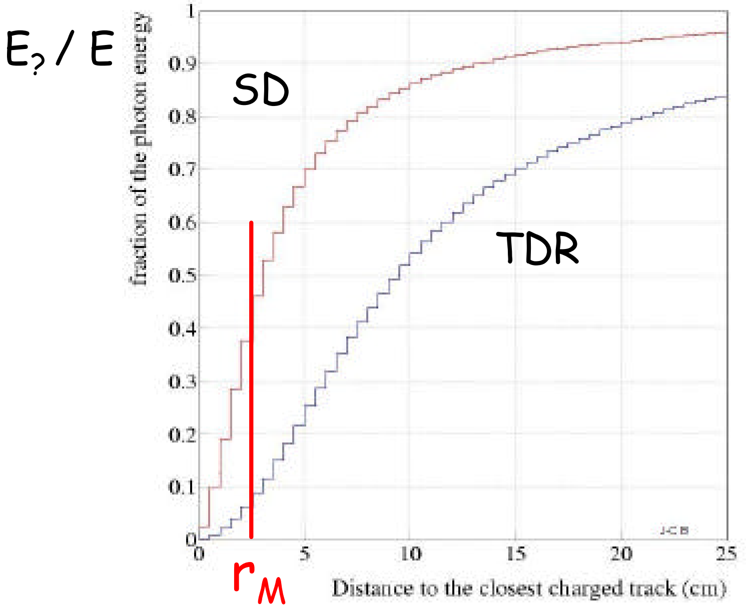
- large radius and length
  - to separate the particles
- large magnetic field
  - to sweep out charged tracks
- “no” material in front
  - stay inside coil
- small Moliere radius
  - to minimize shower overlap
- small granularity
  - to separate overlapping showers

- figure of merit: $B\,R^2_{calo} / (r^2_M + r^2_{cell})$



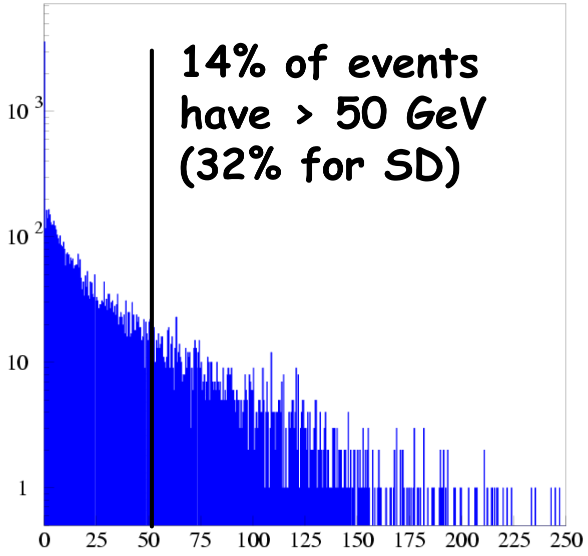
Photon hadron separation

- for smaller R_{calo} can “buy” separation power with B, but…
- magnetic field limited by mechanical stability : B^2R_{coil} < ~ 60 T^2m
- photons closer than r_M to ch. hadron are difficult to reconstruct



(SD: R=1.27 m, here with 6T,
TESLA TDR: R=1.68m, B=4T)

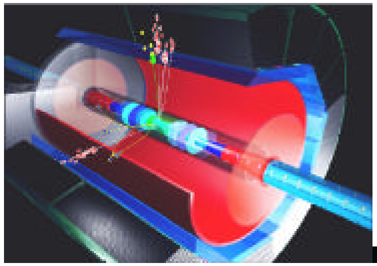
e^+e^- ? WW @ vs = 800 GeV



Energy sum of close photons
(GeV)

(JC Brient)

push r_M and
photon
reconstruction
to the limit

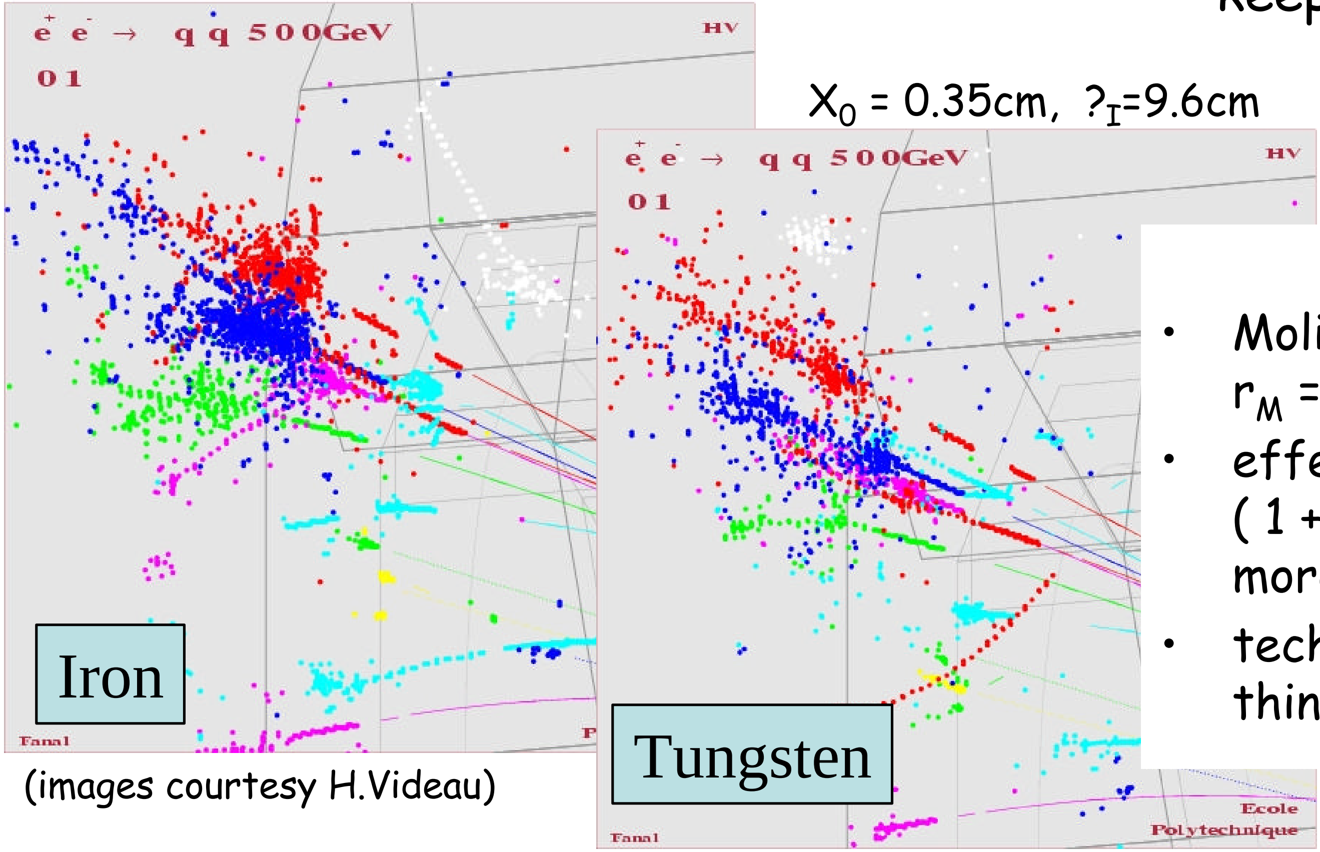


Tungsten vs. iron

- elm./had separation:
  keep X_0 / $?_I$ small

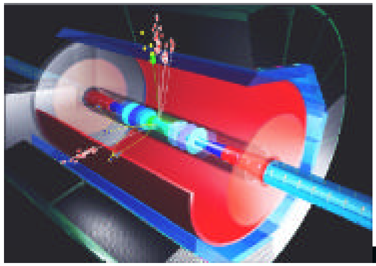
X_0 = 1.8cm, $?_I$=17cm

X_0 = 0.35cm, $?_I$=9.6cm

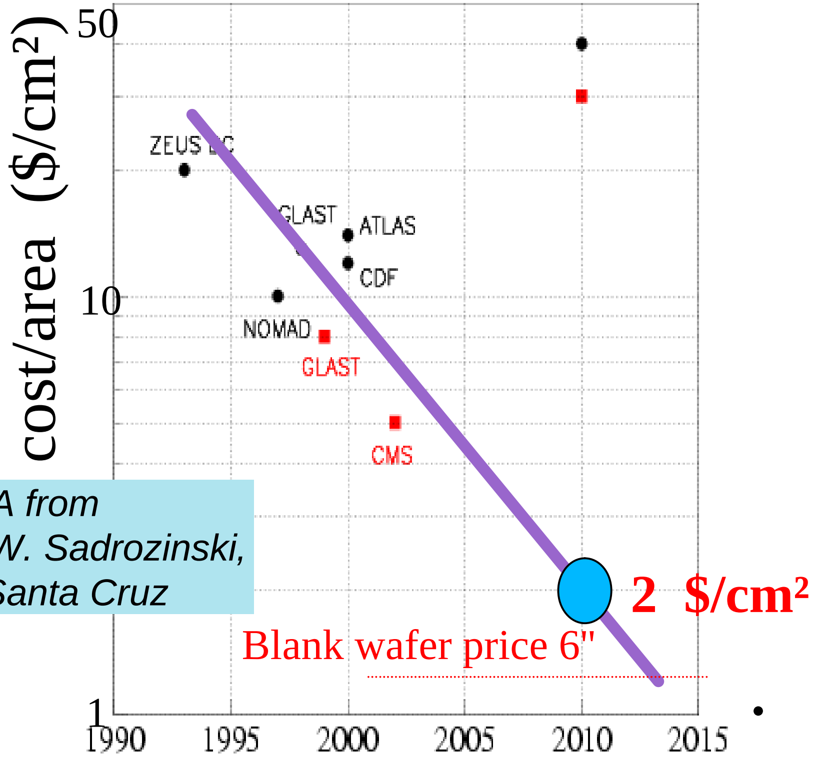


(images courtesy H.Videau)

- Moliere Radius for W: r_M = 0.9cm
- effectively a factor (1 + Gap / 2.5mm) more
- technology challenge: thin readout gap



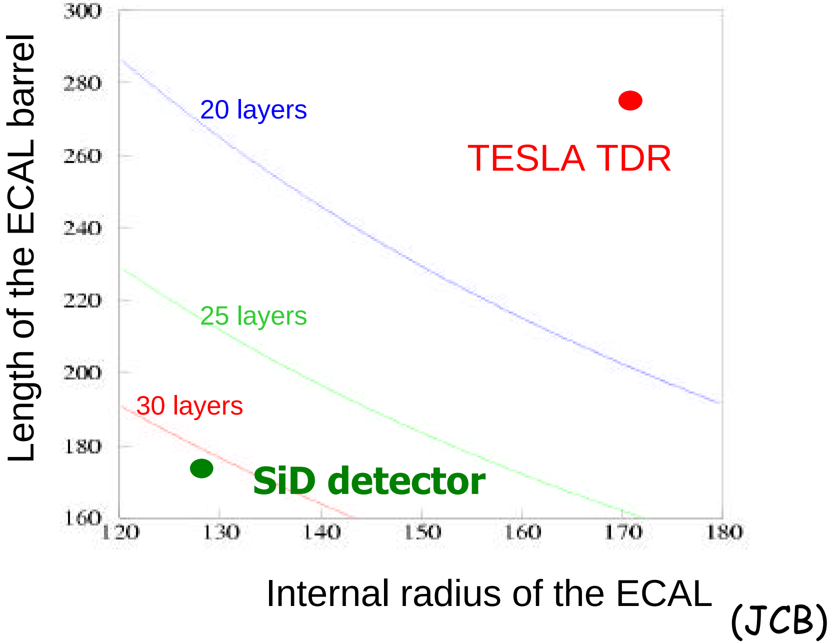
Silicon cost and area



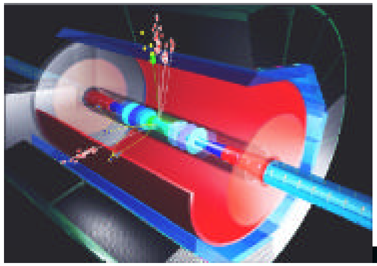
DATA from
H.F-W. Sadrozinski,
UC-Santa Cruz

~3000 m² needed

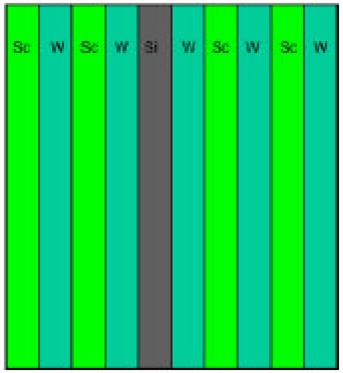
Curves of constant cost



- optimize together with tracking system:
  # layers, radius and length
- PFLOW emphasizes size over sampling



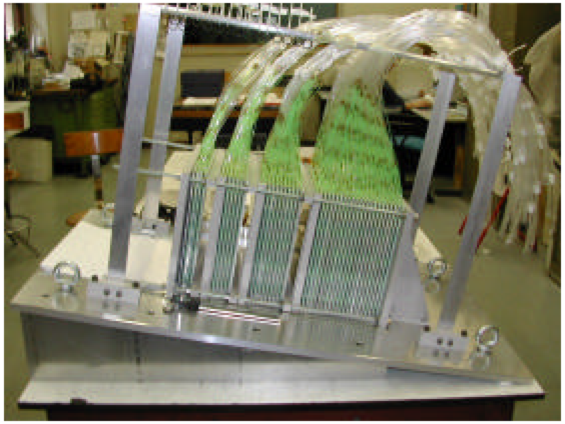
ECAL optimization



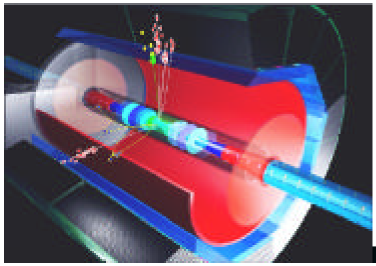
- overall detector geometry
- thin sampling layer technology
- photon reconstruction / separation

Follow also other lines of development:

- don't completely forget energy resolution!

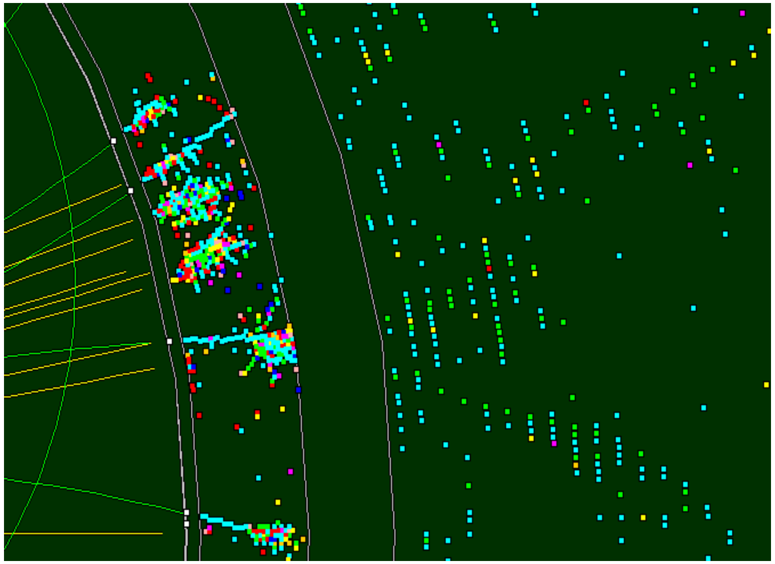


- lead or tungsten scintillator calorimeters (Asia, Colorado)
- hybrid silicon and scintillator sampling (Italy, Kansas)



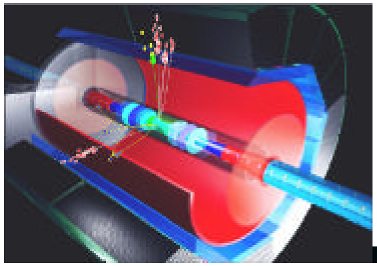
Hadron calorimeter concepts

- The HCAL should be imaging, too
- Tungsten would be best, but chose iron for cost reasons



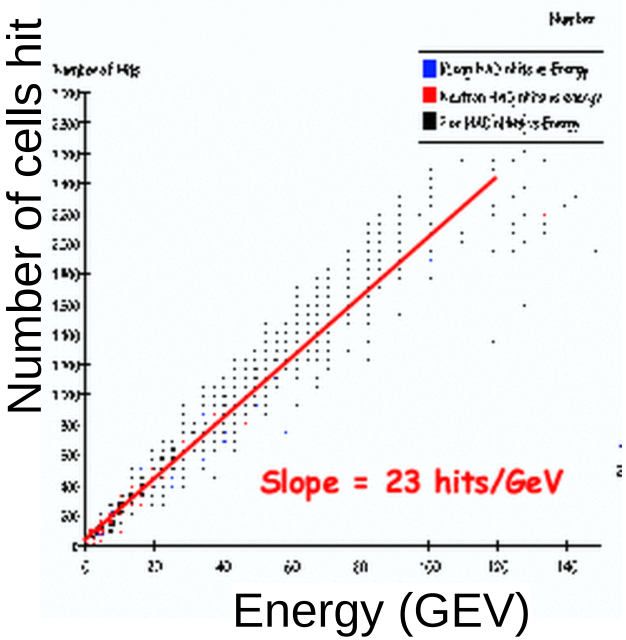
Readout options:

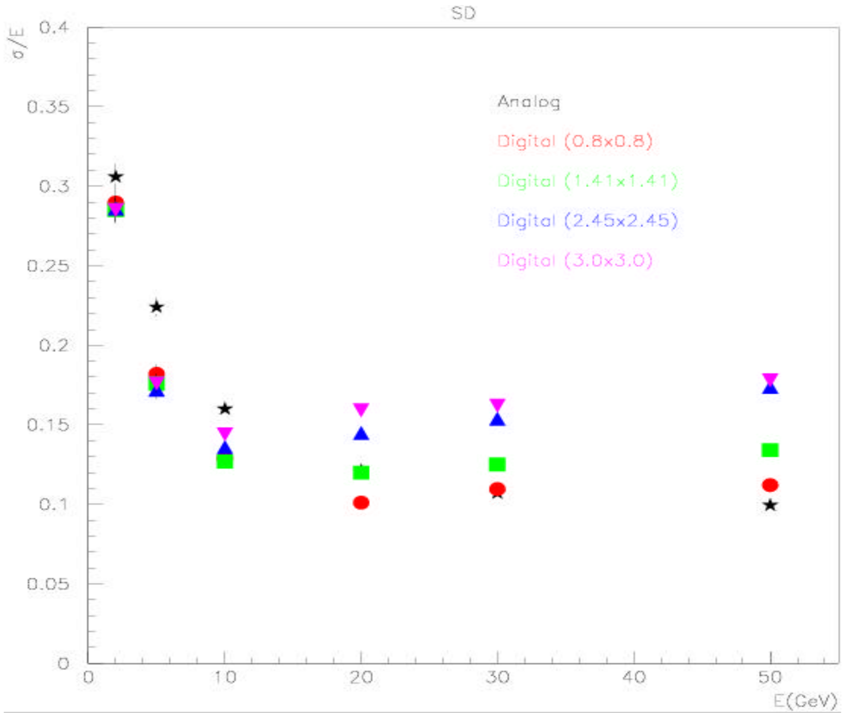
- Digital: radically imaging; counting hits with gas or scintillator
- Analogue: classical scintillator – but pushing the granularity
- semi-digital: scint. with small # of thresholds (2 bit ADC)



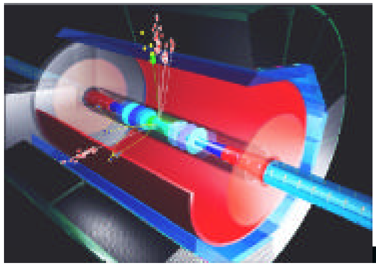
Analog vs. digital

- Digital: pad size 1cm asymptotic value
- suppress Landau fluctuations: at low E superior to analogue
- need ideas for high E, e.g. multiple thresholds (semi-digital)





(V.Zutshi)

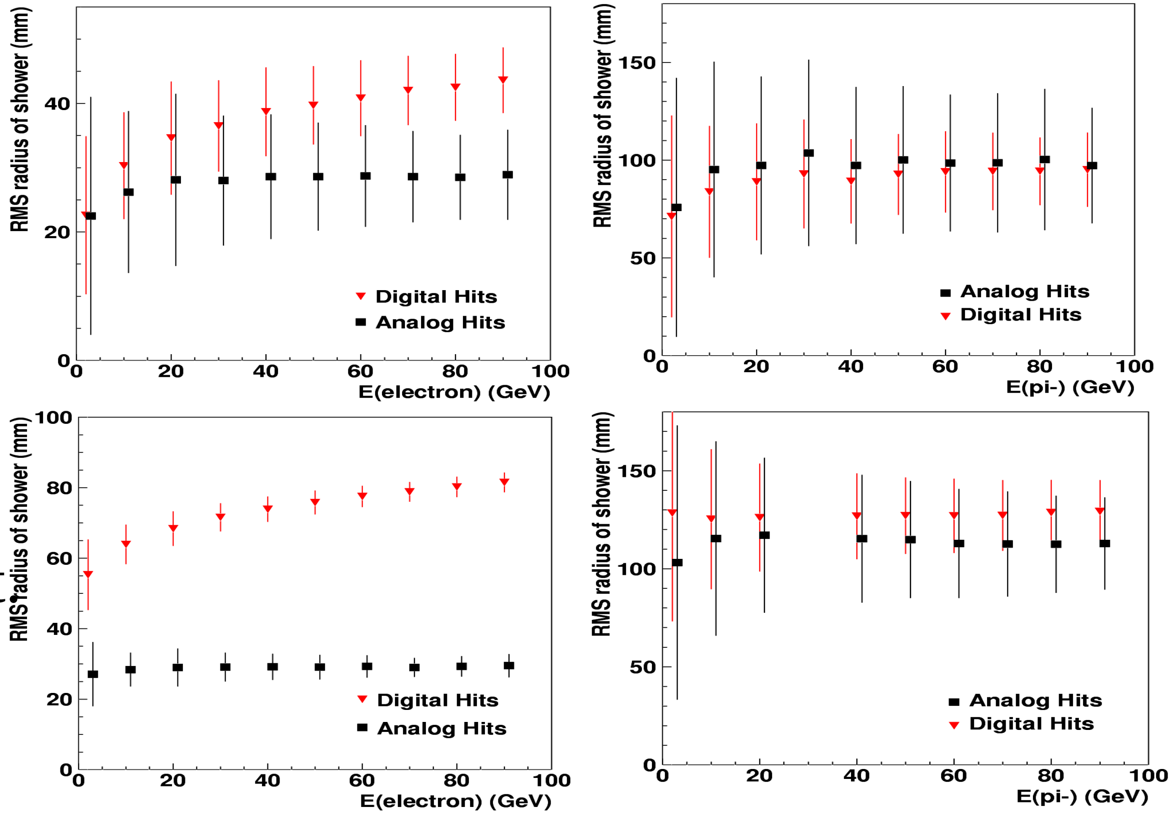


Gas vs. scintillator

- width of shower pattern appears larger in scintillator
- will be recovered using amplitude or density information

RPC

Scint



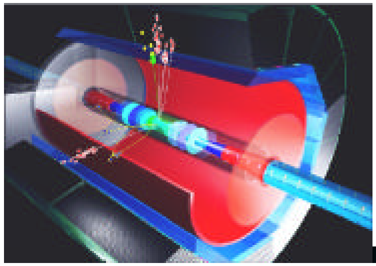
$$\sqrt{\frac{\sum E_i \Delta^2 r_i}{\sum E_i}}$$

analog

$$\sqrt{\frac{\sum \Delta^2 r_i}{N}}$$

digital

(L.Xia)

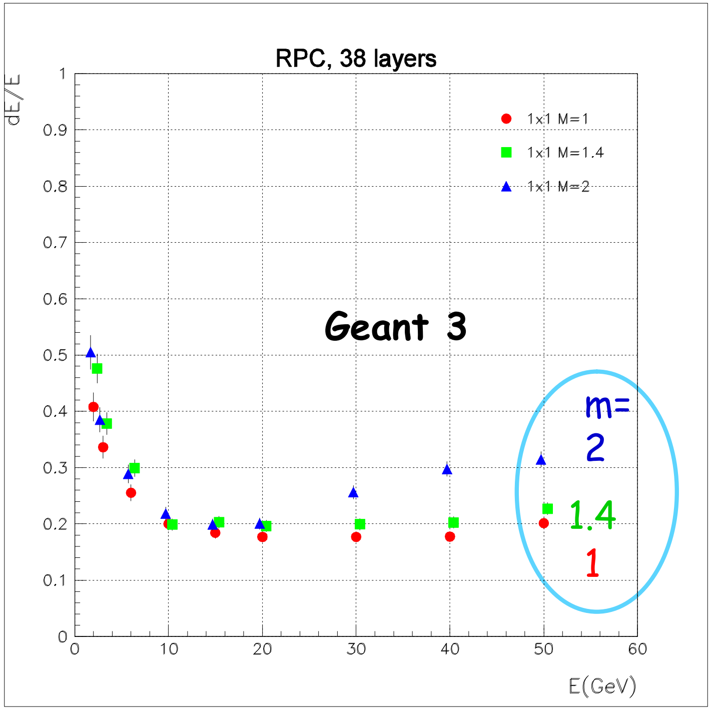


Gas HCAL optimization

- **RPC**: comparison avalanche vs. streamer mode

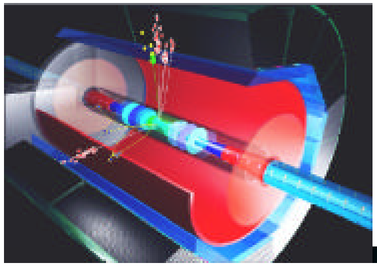
?	Item	avalanche	streamer
1	Working mixture	TFE/Iso/SF6=93/5/2	TFE/Iso/Ar=80/10/10
2	HV working point, kV	8.4	7.4
3	Induced charge, pC	3.4	200
4	Threshold on 50W, mV	1-2	300
5	Efficiency, %	>99	~95
6	s_Q / Q	~ 1	~ 0.6
7	Pad multiplicity	1.4-1.5	1.2 - 1.3
8	Noise, Hz/?m^2	~ 0.5	~ 0.1
9	Rate capability, Hz/?m^2	100	2 - 3
10	Ageing effects	no	observed

- pad multiplicity and energy resolution



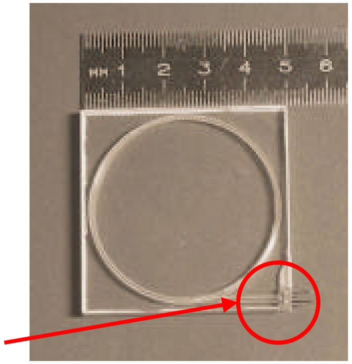
(V.Ammosov)

- Alternative: **GEM** foils
- R&D issues for **both**:
  - large area detectors, reliability
  - low cost electronics concept



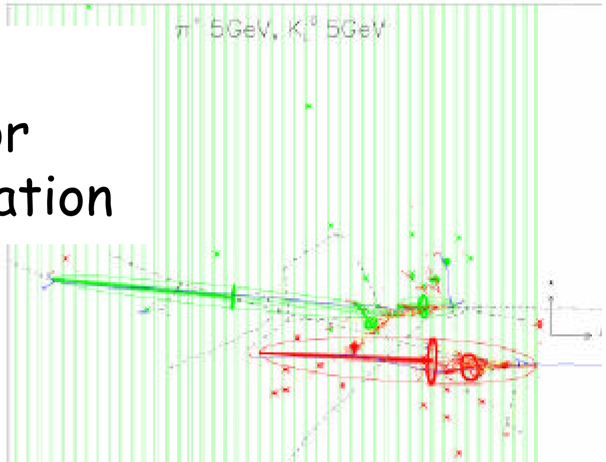
Scintillator granularity

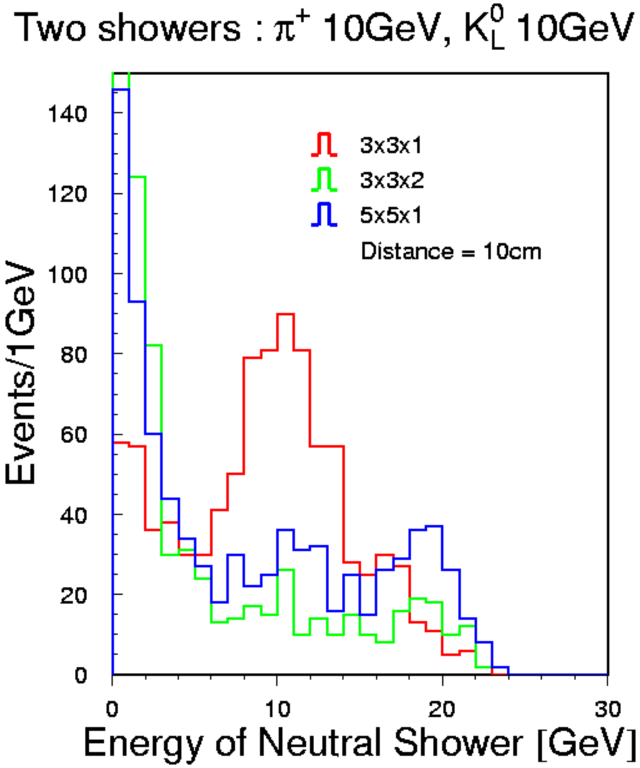
- new photodetectors allow individual readout of small tiles



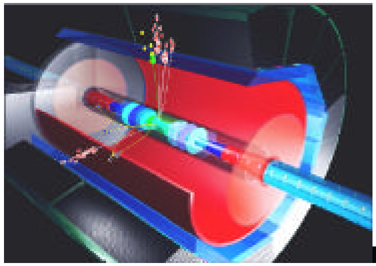
Si Photo-Multiplier

- optimize granularity for shower separation





(A.Raspareza)

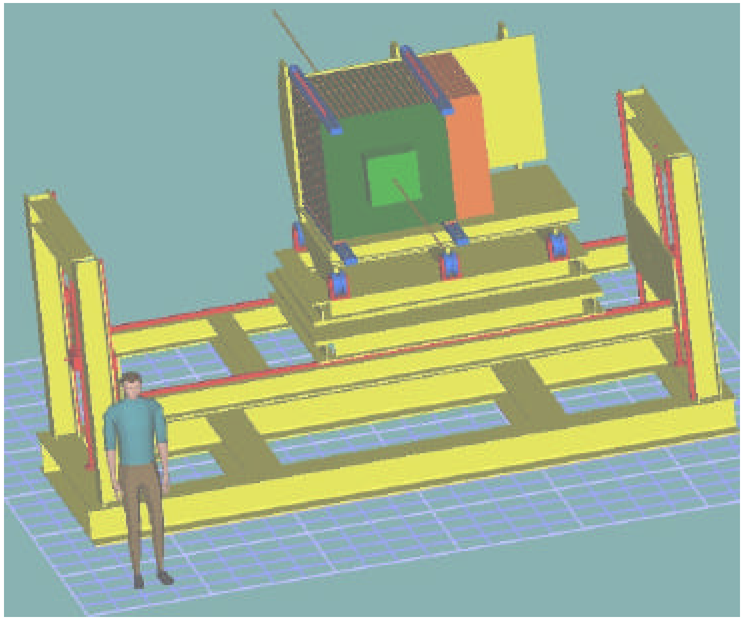


HCAL optimization

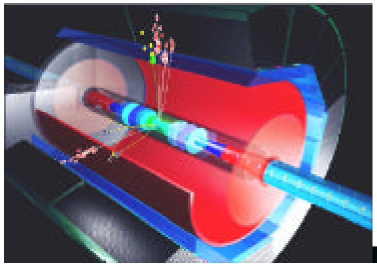
For the scintillator option

- granularity vs. amplitude for position and energy
- optimize the new photodetectors
  - and study alternatives (APD, …)
- calibration and monitoring
  - nonlinear systems

- pattern recognition software
- (De-) tails are important:
- confront high granularity HCALs with hadron beam



stack for different HCAL options

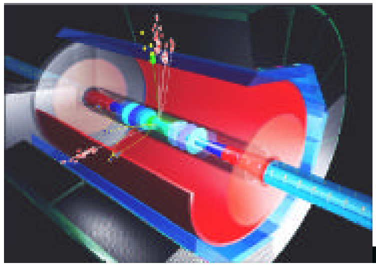


International effort

- Linear collider detector R&D is partially organized in (open) proto-collaborations, e.g. CALICE:

  164 Physicists, 28 Institutes, 9 Countries: 3 Regions

- CALICE prepares beam test series in 2005-06
- ECAL and HCAL together, different options
- electron and hadron beams, start end 2004 at DESY



Conclusion

- The linear collider physics represents a formidable challenge for calorimeters,
- met by a world-wide R&D effort, internationally coordinated
- An interesting test beam period is ahead of us, to sharpen our views on imaging calorimetry and particle flow algorithms,
- to further push for overall optimized detector concepts