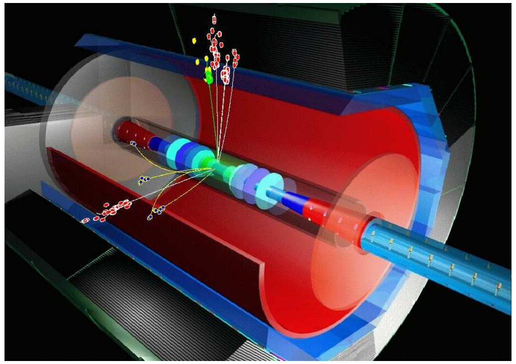
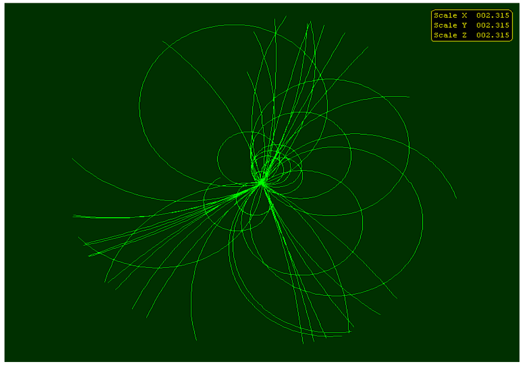
# The ‘Large’ Detector Concept for the ILC

Klaus Desch
University of Freiburg






Karlsruhe
5th RTN workshop - The 3rd generation as a probe for new physics
23/02/05

**Physics first!**

Physics case worked out in much detail over the past decade and well documented (TESLA TDR, Snowmass report, ACFA study etc.)

Whatever LHC will find, ILC will have a lot to say!

‘What’ depends on LHC findings:

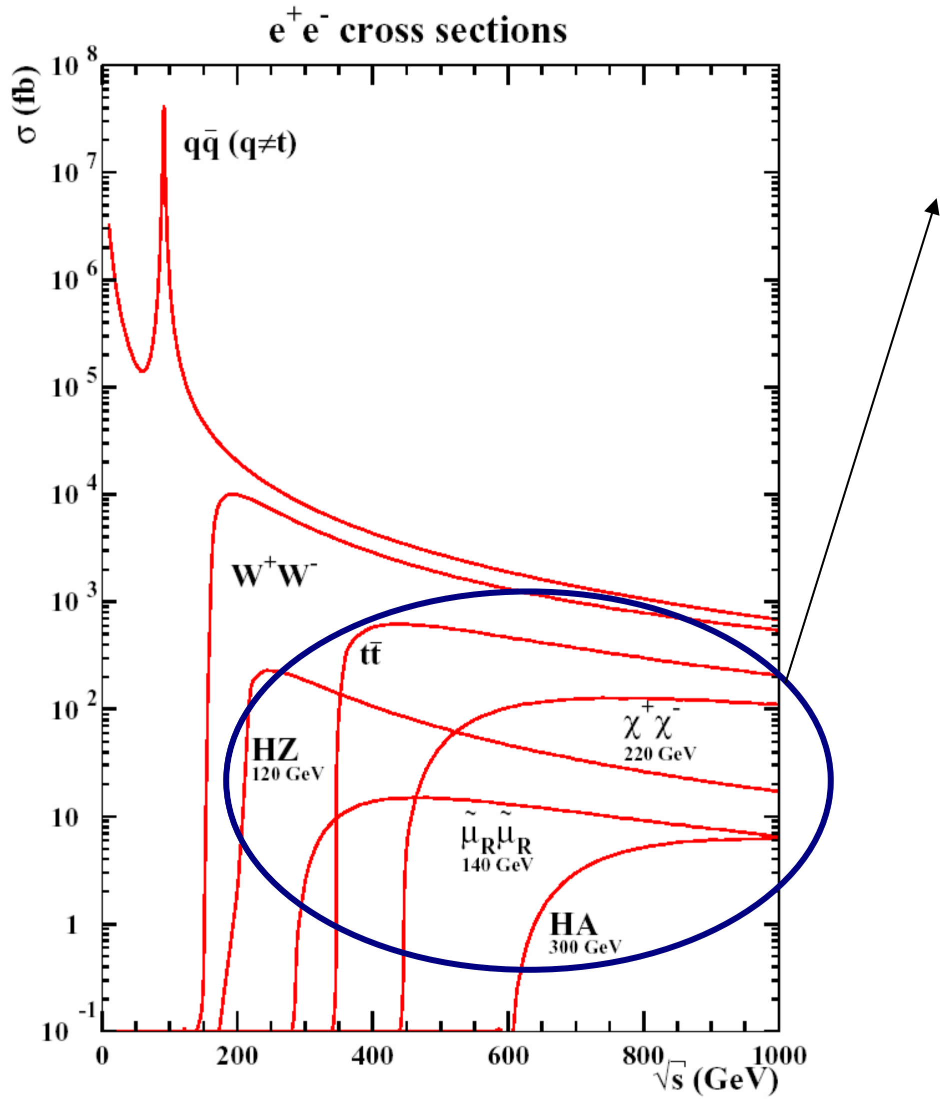
1. If there is a ‘light’ Higgs (consistent with prec.EW)
   ⇨ verify the Higgs mechanism is at work in all elements

2. If there is a ‘heavy’ Higgs (inconsistent with prec.EW)
   ⇨ verify the Higgs mechanism is at work in all elements
   ⇨ find out why prec. EW data are inconsistent

3. 1./2. + new states (SUSY, XD, little H, Z’, …)
   ⇨ precise spectroscopy of the new states

4. No Higgs, no new states (inconsistent with prec.EW)
   ⇨ find out why prec. EW data are inconsistent
   ⇨ look for threshold effects of strong EWSB

## Detector considerations




Interesting new processes often only smaller by 0-2 orders of magnitude

But 1/s suppression calls for very high luminosity (1000-10000 x LEP!)

Physics backgrounds are not driving the detector design

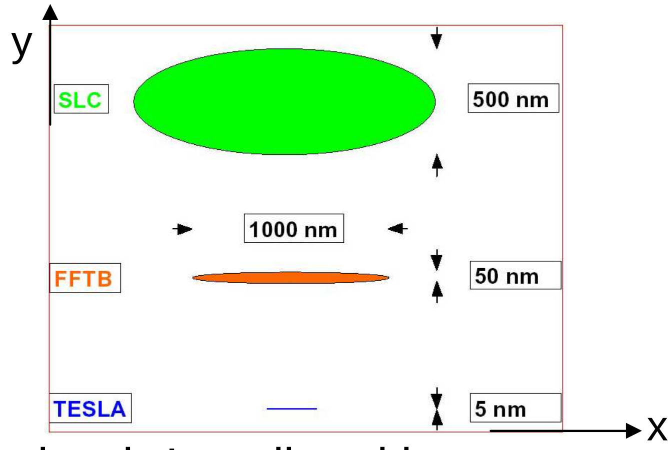
Small exception:
two-photon processes require good forward coverage

Typical event rates in a 500 $fb^{-1}$ sample

| event type | o(# events) | √s (GeV) |
|---|---|---|
| HZ ($m_h$=120 GeV) | $10^5$ | 300 |
| tt | 3.5 $10^5$ | 350 |
| $W^+W^-$ | $10^6$ | 500 |
| Z | $10^9$ | 91 |
| $\tilde{\mu}\tilde{\mu}$ (m=140 GeV) | $10^4$ | 400 |
| $\chi^+\chi^-$ (m=220 GeV) | 5 $10^4$ | 600 |
| ttH ($m_h$=120 GeV) | $10^3$ | 800 |
| HHZ ($m_h$=120 GeV) | $10^2$ | 500 |

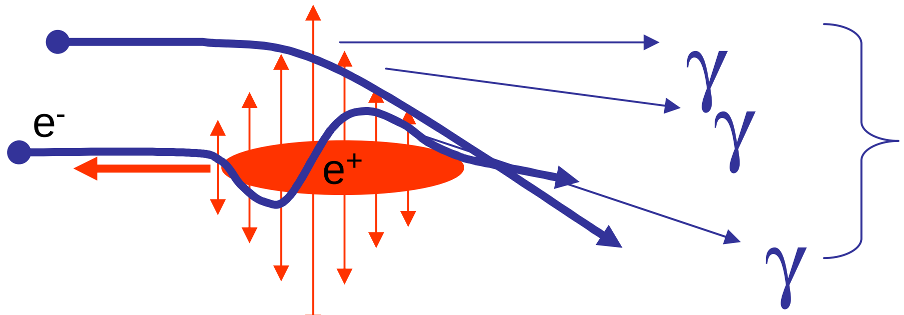
Many processes with o(%) or better statistical precision
Match this precision with a high-resolution detector
Need to measure complex leptonic + hadronic final states

## 1. Introduction | Detector considerations: Backgrounds




This is not LEP (nor SLC)!

- Beamstrahlung
- Bunch Crossing Rate




hard γ's radiated by intense electric field = Beamstrahlung

RMS Energy Loss:

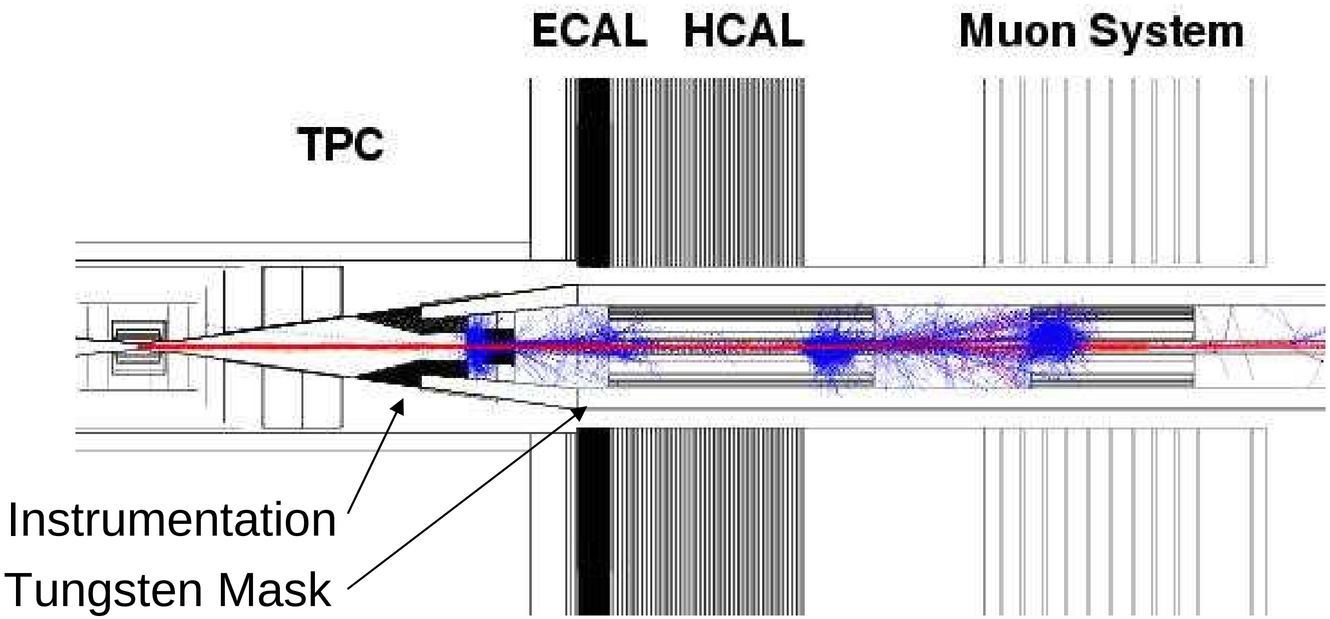
$$\delta_{BS} = \frac{\Delta E}{E} \propto \frac{E_{cm}}{\sigma_z}\left(\frac{N}{\sigma_x^* + \sigma_y^*}\right)^2$$

Minimize while keeping $\sigma_x^*\sigma_y^*$ (luminosity!) constant by chosing flat beams ( $\sigma_x^* \gg \sigma_y^*$ )

Beamstrahlung creates:

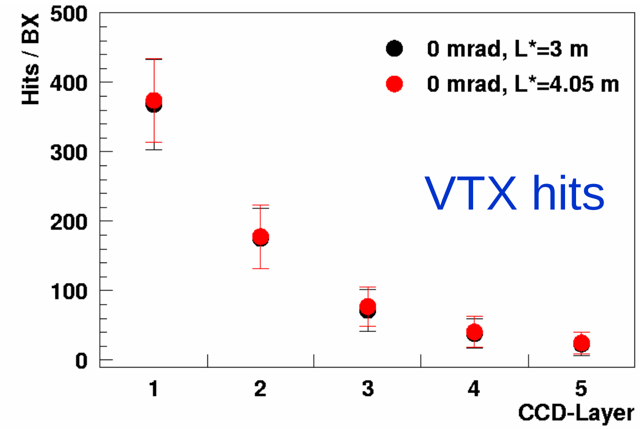
$6 \times 10^{10}$ photons/BX (1.3-1.5 photon/electron)
140000 $e^+e^-$ pairs
secondary particles from $\gamma\gamma \rightarrow$ hadrons

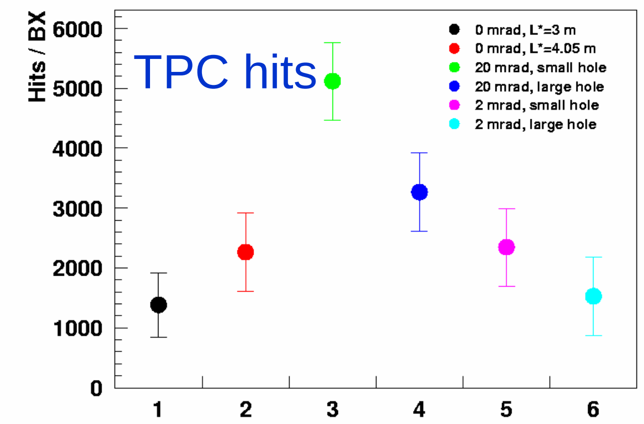
Photons and most of pairs vanish in beampipe (high B-field!) but need to shield detector from backscattered secondaries!



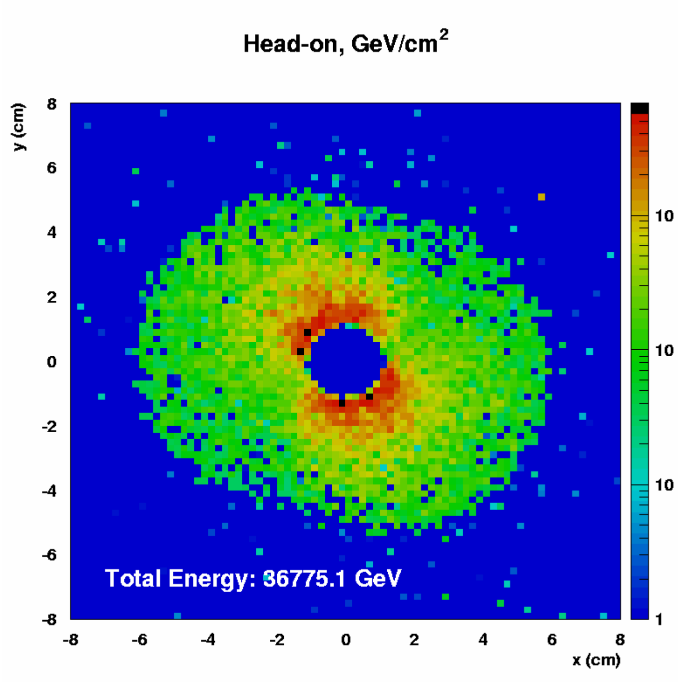
Backgrounds in detector are moderate

Radiation hardness an issue only for very forward calorimeters



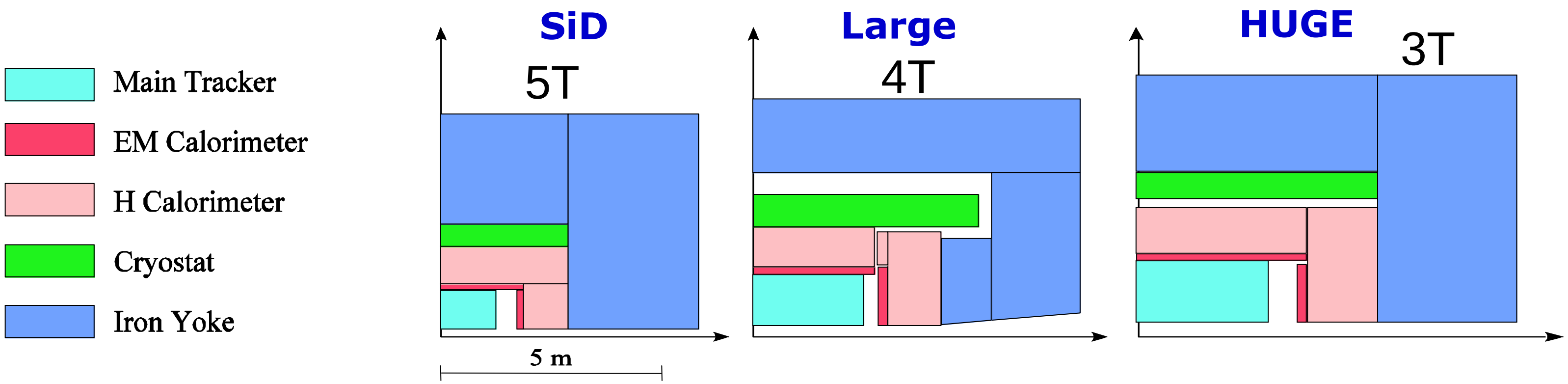




Energy around beampipe:




K.Büßer

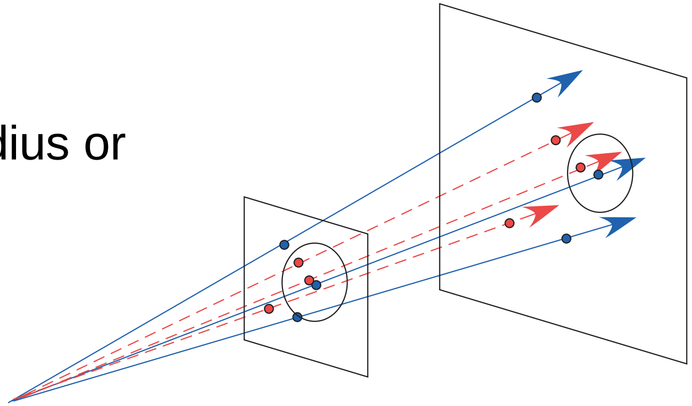
2-3 global concepts are emerging




Main design issues
- Si or gaseous tracking ?
- Si/W ECAL (1x1cm) at small-medium radius or
  coarser Sc/W ECAL at larger radius ?

Particle separation at Calorimeter surface:

$B \times L^2 / R_{Moliere}$

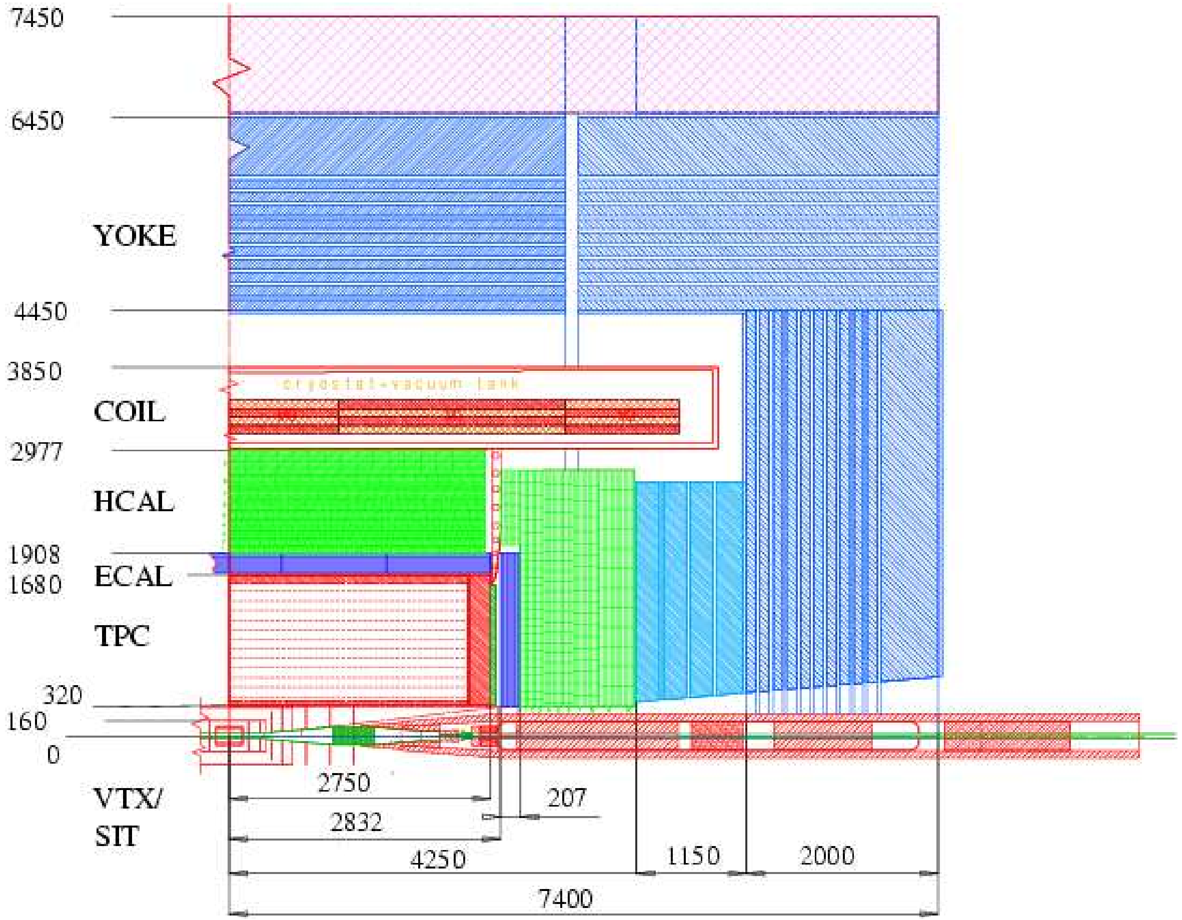


Those are open concepts not collaborations!
Many sub-detector R&D items in common

| 2. 'Large Detector' | Paradigms |
|---|---|

1. Precision Vertexing
2. (Mainly) Gaseous Tracker (TPC)
3. Particle Flow

e.g. TESLA concept



## 2. 'Large Detector' | Requirements

Momentum: $\sigma_{1/p} < 7\text{x}10^{-5}/\text{GeV}$ (1/10 x LEP)

(e.g. Z mass reconstruction from charged leptons)

Impact parameter: $\sigma_{d0} < 5\mu m \oplus 5\mu m/p(\text{GeV})$ (1/3 x SLD)

(c/b-tagging for Higgs, tau-tagging)

Jet energy : $dE/E = 0.3/E(\text{GeV})$ (1/2 x LEP)

(e.g. W/Z invariant mass reconstruction from jets)

Hermetic down to : $\theta = 5$ mrad

(for missing energy signatures e.g. SUSY, two-photon BG)

Sufficient timing resolution to separate events from different bunch-crossings

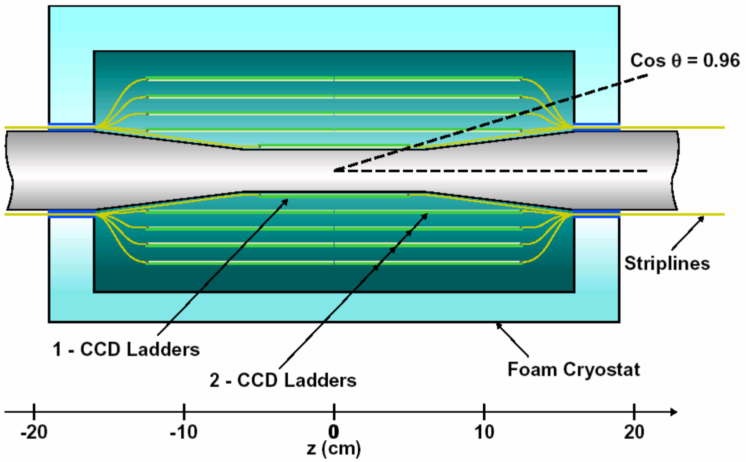
High jet multiplicities (6+ jets): high granularity, robust pattern recognition, good double-track resolution

The "LARGE DETECTOR" concept is a possible design which meets these goals. Is it optimal ? Is it cost effective ?

High resolution pixel detector, 5 layers, innermost layer at r=1.2cm

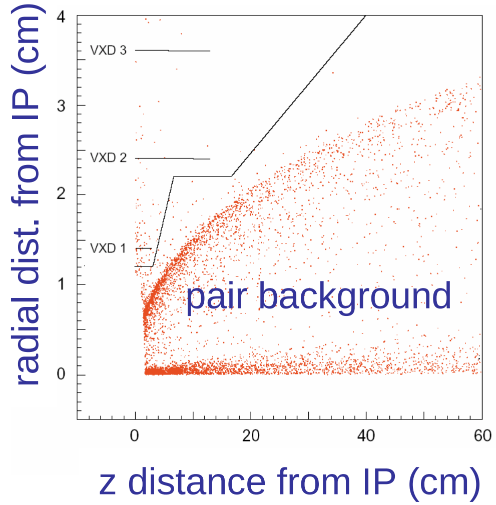
Driving physics:

- Flavour tag (b/c) for Higgs BR's
- $\tau$ lifetime tag
- improve momentum resolution+ pattern recognition for main tracker




R&D ongoing in various directions:

- CCDs
- CMOS pixels
- DEPFET
- SoI Pixels

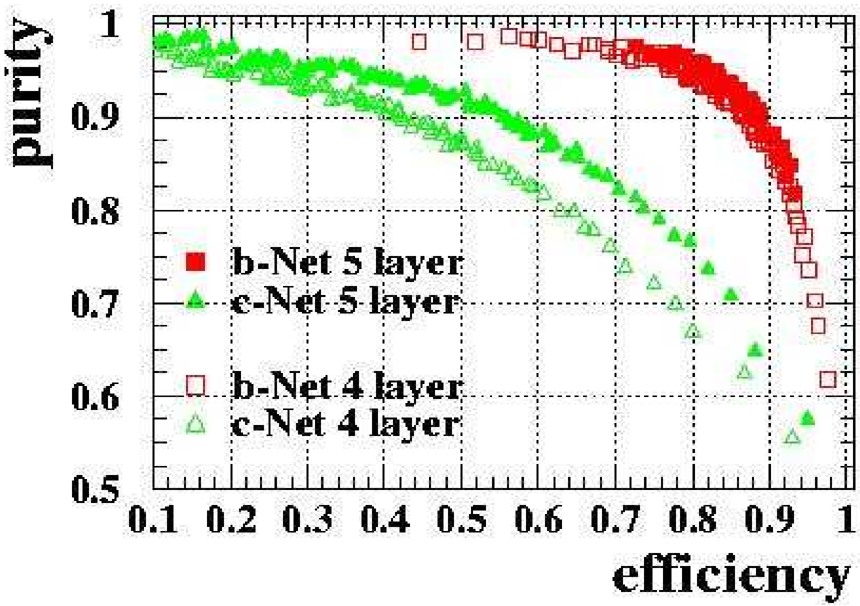



Critical issues:

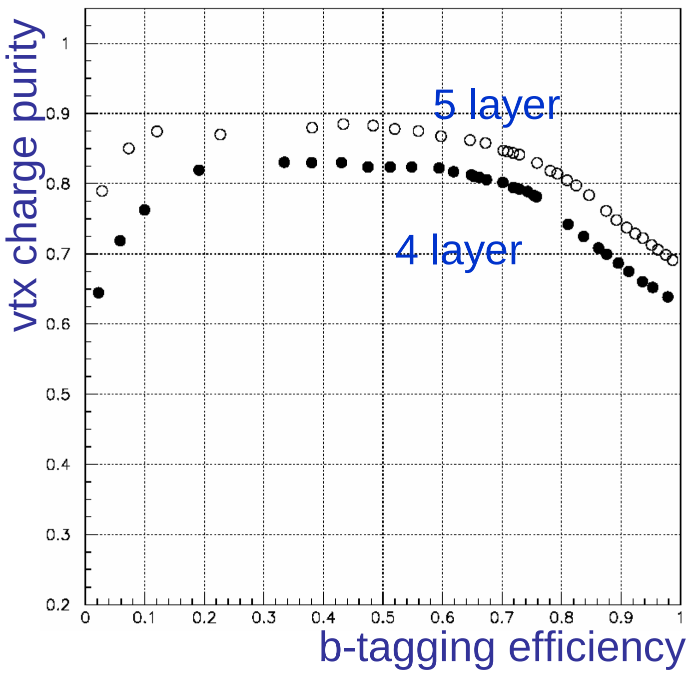
- fast (column parallel) readout
- beamstrahlung pairs (high B-Field (4T) helps)
- ultra-thin detectors (0.1%$X_0$/layer)
- power consumption/cooling (material)

## Performance:

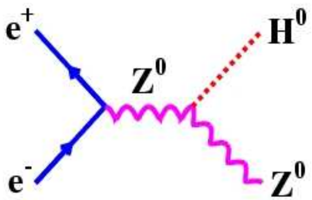
b/c jets from Z decays:




vertex charge reconstruction



# 3. Components | Main tracker




Gaseous tracker (TPC)
Driving physics:

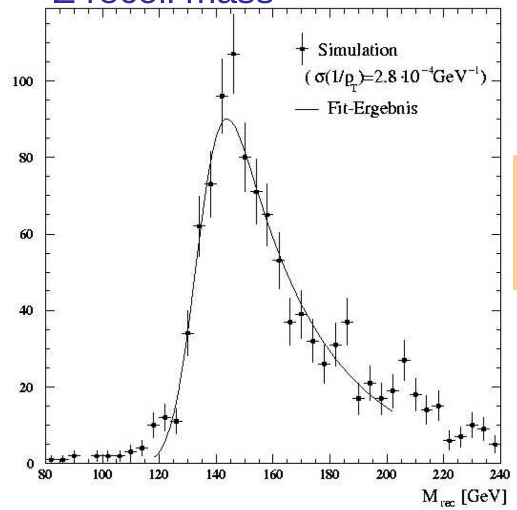
1. Excellent momentum resolution, e.g. for $Z \rightarrow \mu\mu$ (Higgs recoil mass)

momentum resolution:
$\Delta(1/p) = 7 \times 10^{-5}$/GeV (1/10xLEP)

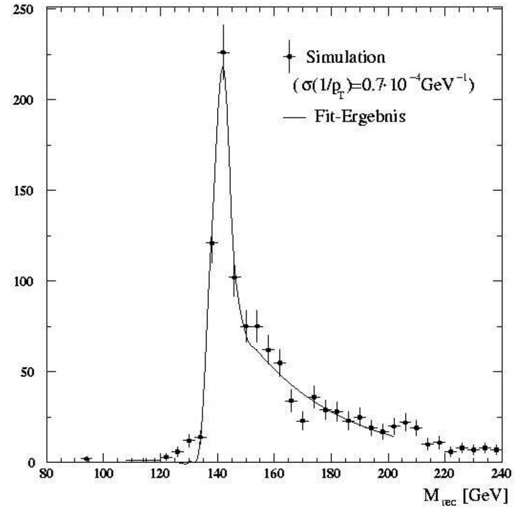
⇨ $\Delta M(\mu\mu) < 0.1\ \Gamma_Z$
⇨ $\Delta M_H$ dominated by beamstrahlung

2. Robust and efficient charged track reconstruction for particle-flow jet reconstruction

Z recoil mass




a la LEP

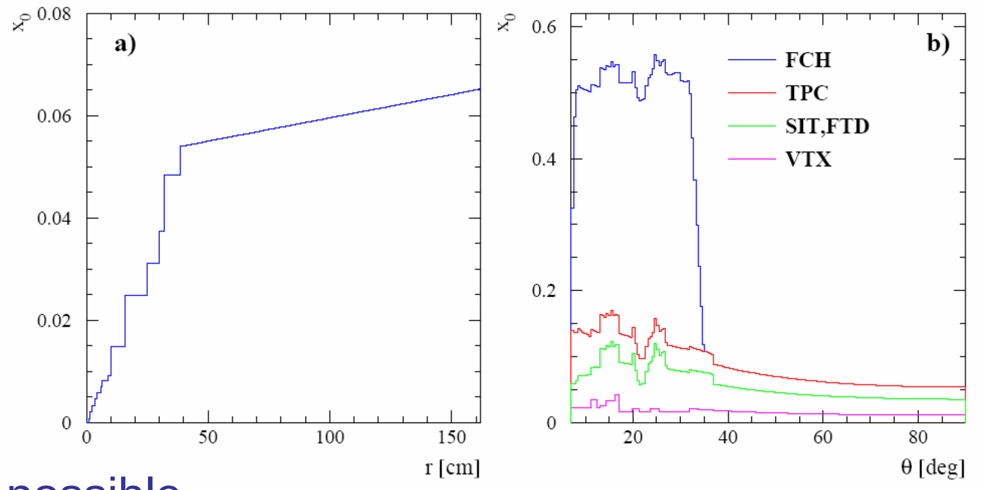



a la ILC

# 3. Components | Why a TPC?

Advantages of a TPC:

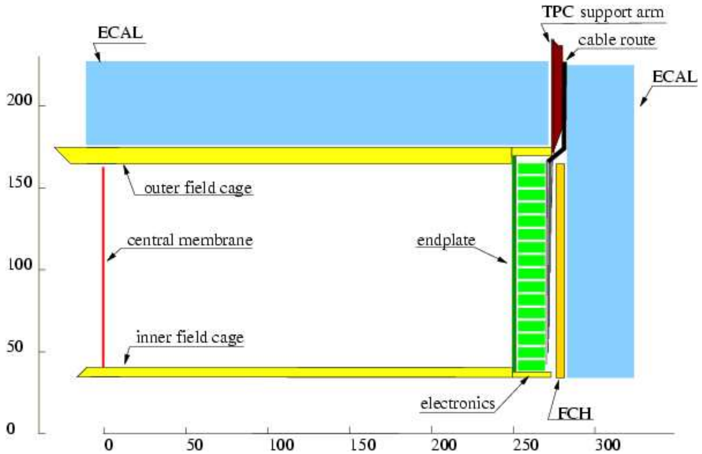
- Large number of 3D space points
  - good pattern recognition in dense track environment
- Good double-track resolution
- Minimal material
  - small multiple scattering
  - small impact on ECAL
  - small conversion rate




- dE/dx for particle identification possible
- Identification of non-pointing tracks
  - helps for particle flow reconstruction of $V^0$
  - signals for new physics, e.g. GMSB SUSY

World-wide R&D effort on TPC

| 3. Components | TPC |
| --- | --- |




Readout on 2x200 rings of pads

Pad size 2x6mm

Hit resolution: σ < 140 mm

even better? (Si-pixel readout of TPC)
- smaller R/lower B-field ?
- dE/dx by cluster counting ?

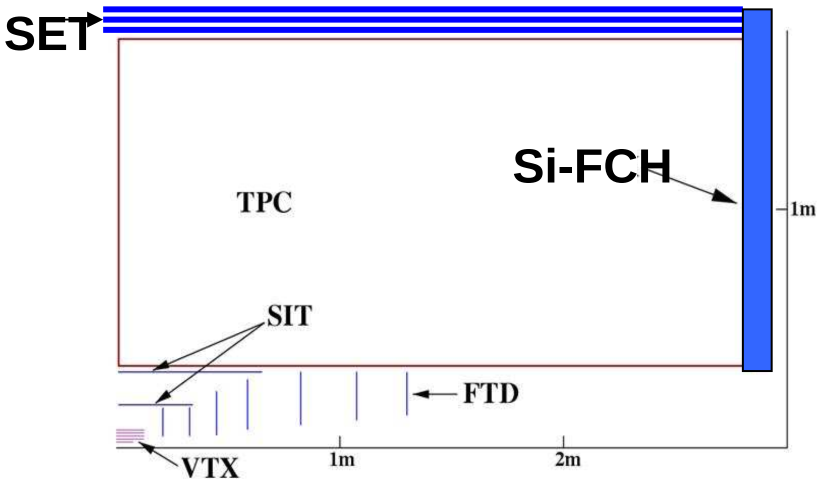
Drift velocity ~5cm $\mu s^{-1}$ (for $ArC0_2$-$CH_4$ (93-2-5)% )
Total Drift time ~ 50μs → integrate over 160 BX

Background o($10^5$) hits in TPC
~$10^9$ 3D readout voxels (1.2 MPads+20MHz sampling)
0.1% occupancy
No problem for pattern recognition/track reconstruction even when taking into account background !
- verified with full simulation!

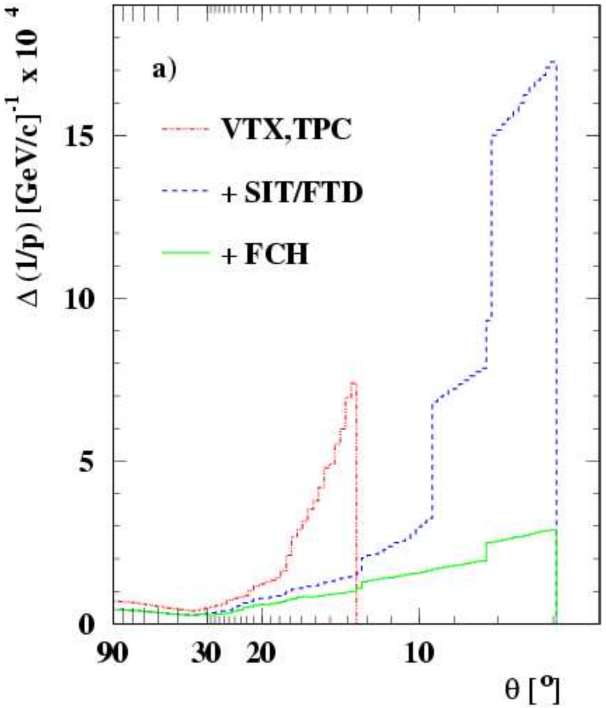
## Additional Silicon Tracking

The complete tracking system:

- VTX to do precise vertexing
- TPC to do precise pattern recognition
- FTD (forward SI) for full coverage to small angles
- SIT to join the two
- possibly external precise detectors (SET, FCH) to help extrapolate




TPC : $\sigma(1/p) = 2.0 \times 10^{-4}$ GeV$^{-1}$
+VTX: $\sigma(1/p) = 0.7 \times 10^{-4}$ GeV$^{-1}$
+SIT : $\sigma(1/p) = 0.5 \times 10^{-4}$ GeV$^{-1}$



## Particle Flow

Ideally would like to treat quarks as any fermion ⇨ optimize jet energy res.

Method: particle flow paradigm

= most exclusive reconstruction of charged and neutral particles in a jet

⇨ Use tracking detectors to measure energy of charged particles (65% of the typical jet energy)

⇨ EM calorimeter for photons (25%)

⇨ EM and Hadron calorimeter for neutral hadrons (10%)

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

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

$$\sigma^2_{\text{Ejet}} \approx (0.14)^2 \left(\text{E}_{\text{jet}} \cdot \text{GeV}\right) + \sigma^2_{\text{confusion}} \overset{!}{\approx} (0.3)^2 \left(\text{E}_{\text{jet}} \cdot \text{GeV}\right)$$

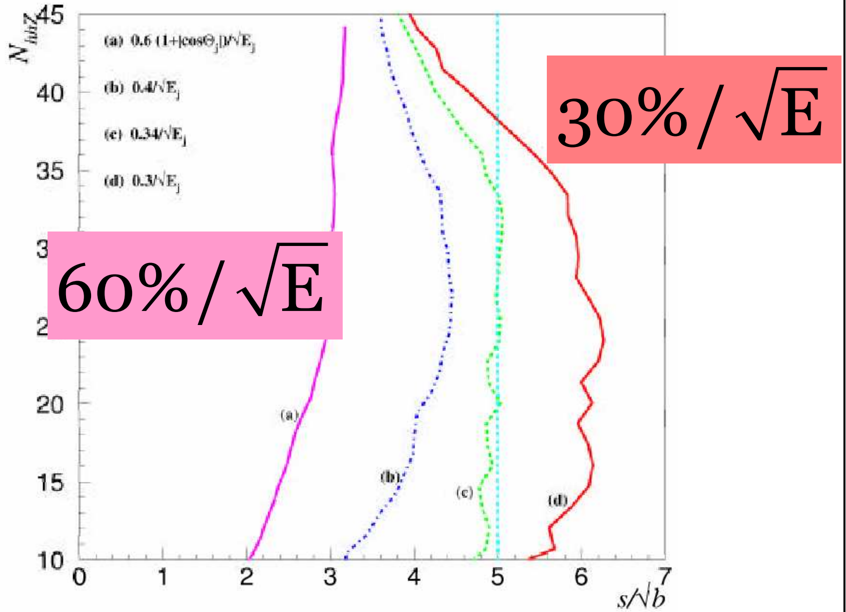
$\sigma^2_{\text{confusion}}$ is the largest contribution!

| 3. Components | Particle Flow |
|---|---|

To reduce confusion in the calorimeters:

- Have large B field and large calorimeter inner radius
  - to separate the particles
- Use materials with small Moliere radius
  - to reduce shower overlap
- Finely segment calorimeters (in 3D)
  - to allow separation of neighbouring showers
- Place calorimeters inside coil, no cracks
- Develop smart algorithms

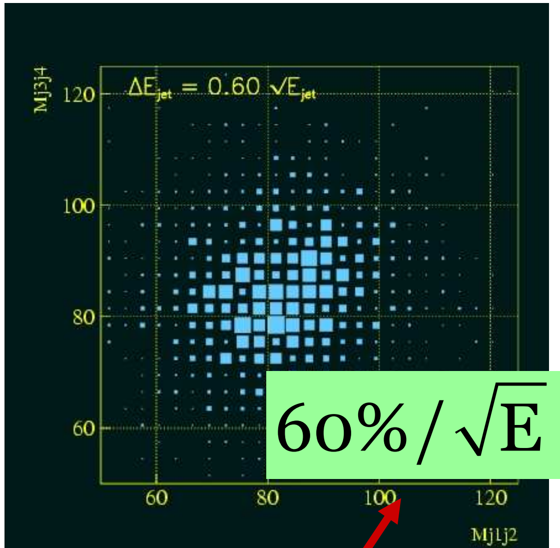
Significance of HHZ signal for $500 fb^{-1}$ :

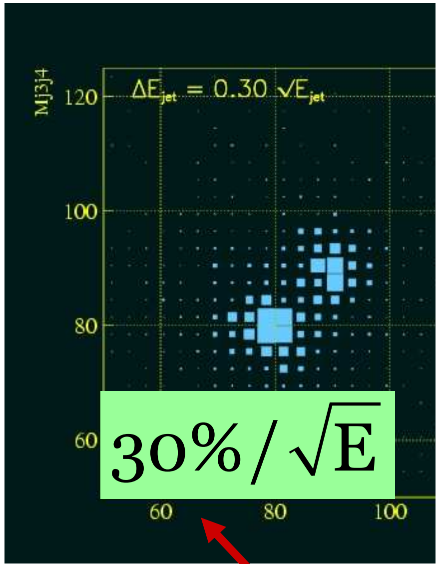


## Di-jet mass resolution

distinguish W and Z in their hadronic decay modes:

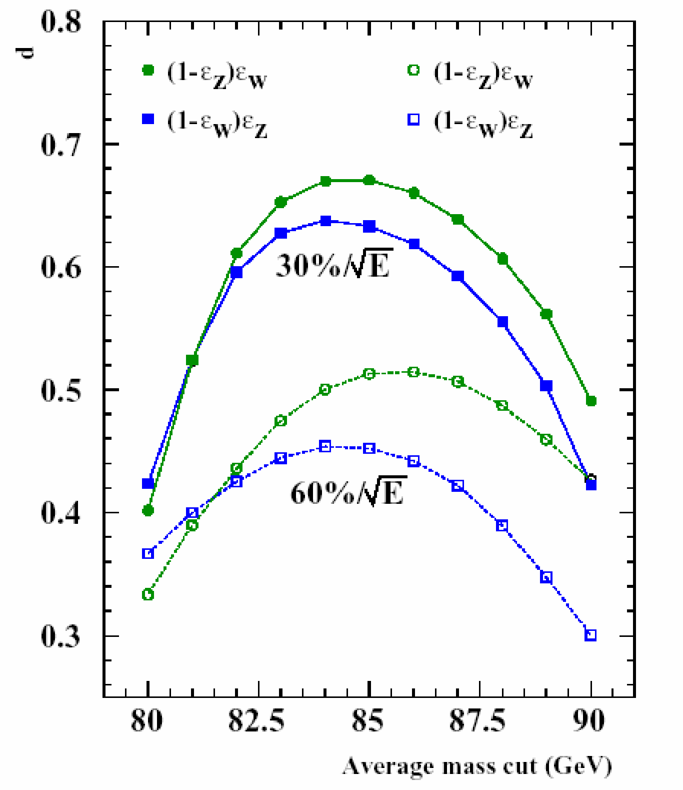
$$e^+e^- \rightarrow WW\,\nu\bar{\nu} \quad , \quad e^+e^- \rightarrow ZZ\,\nu\bar{\nu}$$




LEP-like resolution

LC goal




Dilution factor vs cut:
integrated luminosity equivalent

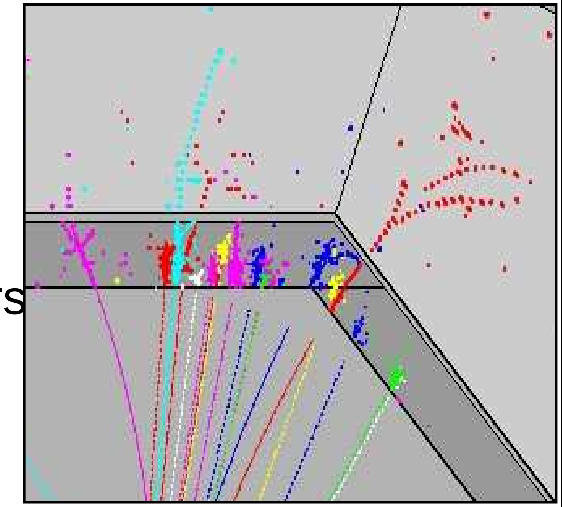
## 3. Components | Calorimeter

- Excellent energy resolution for jets – i.e. high granularity
- Good energy/angular resolution for photons
- Hermeticity
- Reconstruction of non-pointing photons

Particle flow drives calorimeter design:

Separation of energy deposits from individual particles

- small $X_0$ and $R_{Moliere}$ : compact showers
- high lateral granularity : O($R_{Moliere}$)



Discrimination between EM and hadronic showers

- small $X_0/\lambda_{had}$
- longitudanal segmentation

Containment of EM showers in ECAL

SiW sampling calorimeter is a natural (if costly) choice

successfully used in ALEPH/OPAL luminosity detectors

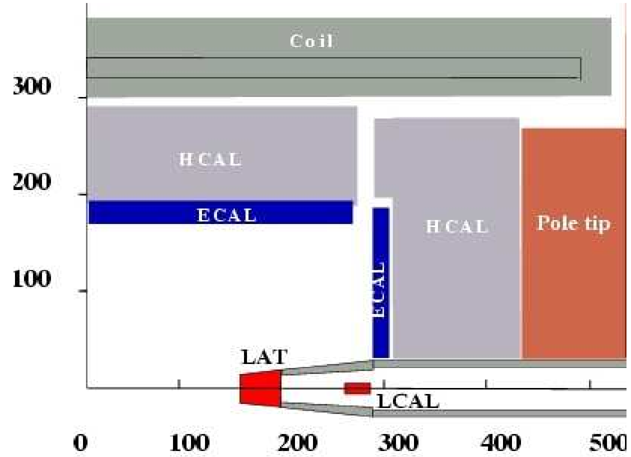
Tungsten is great ! $X_0 / \lambda_{had}$ = 1/25, $R_{Moliere}$ ~ 9mm

EM showers are short and narrow/Had showers long

ECAL and HCAL inside coil

SiW ECAL can meet design requirements

BUT it is far from cheap
are there alternatives?




TESLA TDR ECAL

- Lateral segmentation: $1cm^2$ matched to $R_{Moliere}$
- Longitudinal segmentation: 40 layers ($24\,X_0$, $0.9\lambda_{had}$)
- Achieves Good Energy Resolution:

$$\sigma_E/E = 0.11/\sqrt{E(GeV)} \oplus 0.01$$

$R_{Moliere}$ ~ 9mm for solid tungsten
- gaps between layers increase effective $R_{Moliere}$
- an engineering/electronics issue

- $R_{Moliere}$ is only relevant scale once shower has developed
  - in first few radiation lengths higher/much higher lateral segmentation should help
- + Many optimisation issues !

## Highly Segmented – for Particle Flow

- Longitudinal: ~10 samples
- ~5 $\lambda_{had}$ (limited by cost - coil radius)
- Would like fine (1 $cm^2$ ?) lateral segmentation (how fine ?)
- For 5000 $m^2$ of 1 $cm^2$ HCAL = $5x10^7$ channels – cost !

Two(+) Options:

Tile HCAL (Analogue readout)

Steel/Scintillator sandwich

Lower lateral segmentation

5x5 $cm^2$ (motivated by cost)

Digital HCAL

High lateral segmentation

1x1 $cm^2$

digital readout (granularity)

RPCs, wire chambers, GEM`s

Active R&D ongoing!
goal $m^3$ prototype
in test beam

# Summary

- "Large Detector" concept seems to match the requirement for an ILC detector

- TESLA + US-LD concept as a basis

- Focus on highest precision, robust tracking with low material budget, particle flow concept

- Design is not optimized yet – need to study alternatives for all subdetectors with full simulation

- Many R&D items for subdetectors are in common for LD and SiD no need to 'join a club' now and forever

- Worldwide Subdetector R&D groups are open and welcome your ideas + help!

special thanks to Ties Behnke + Mark Thompson!