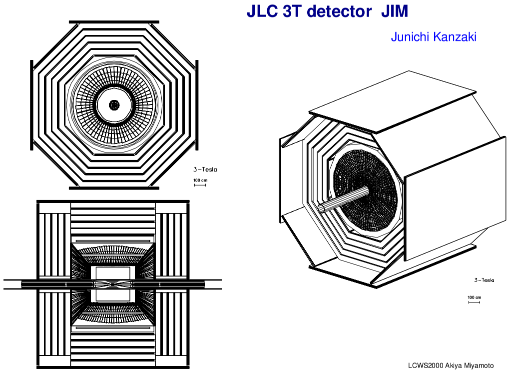
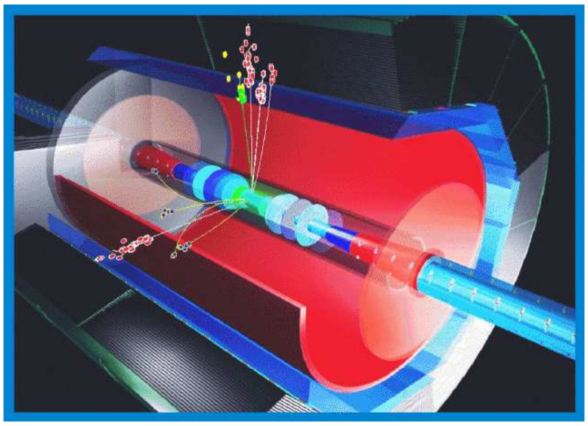
# Detectors for a Linear Collider



- **LC Physics: a short overview**
- **Machine conditions (TESLA)**
- **Detector Concepts**
- **Tracking**
- **Calorimeters**
- **Expected performance**

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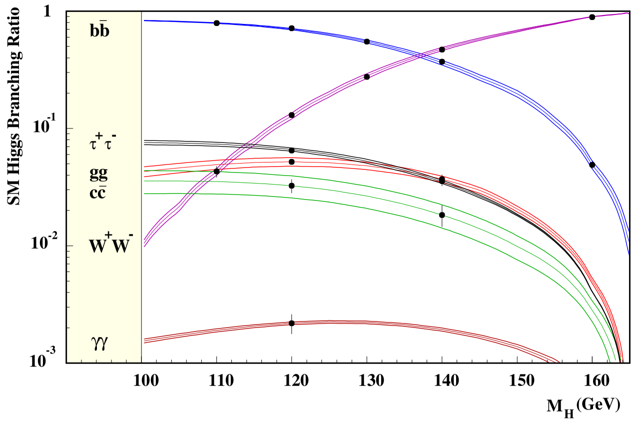
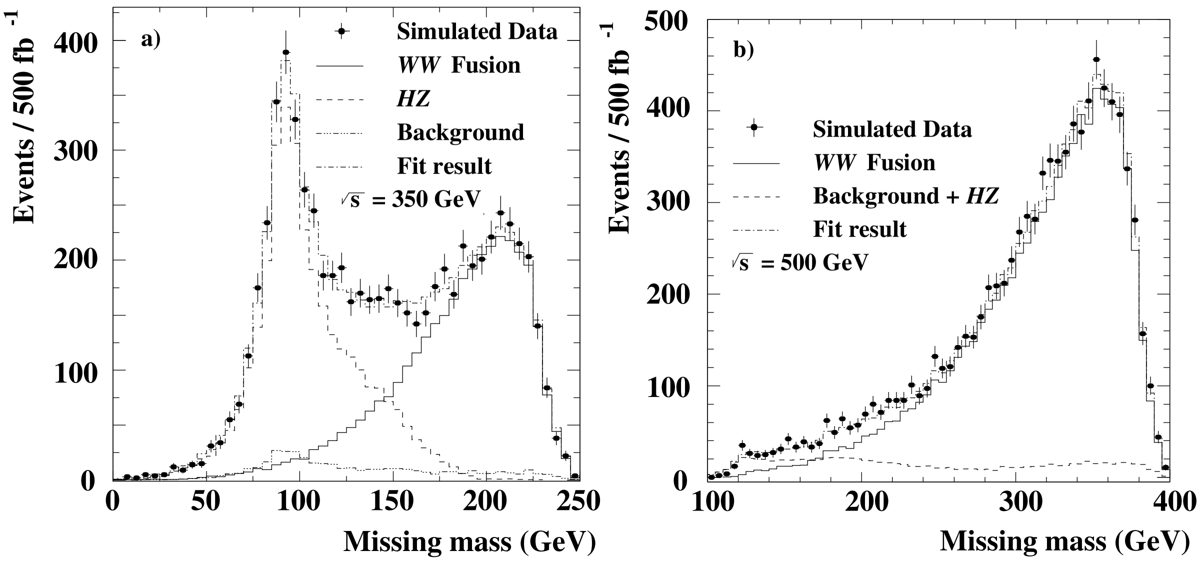
TESLA (Det. TDR): Authors from 52 Institutes
NLC (Snowmass 2001): Authors from 59 Institutes
JLC (http://www-jlc.kek.jp/): Authors from 23 Institutes

# LC Physics: a short overview

- **Higgs**profile
  - hadronic Higgs decays: $b\bar{b}$, $c\bar{c}$ ( $+\ gg$)
    jet flavour tagging $\Rightarrow$ excellent vertex detector




  - Fusion: $\sigma_{WWH}$ from $b\bar{b}\nu\bar{\nu}$ final state
    excellent $E_{jet}$ reconstruction

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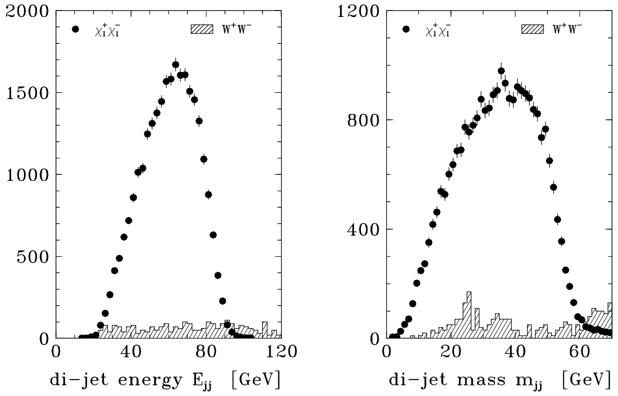
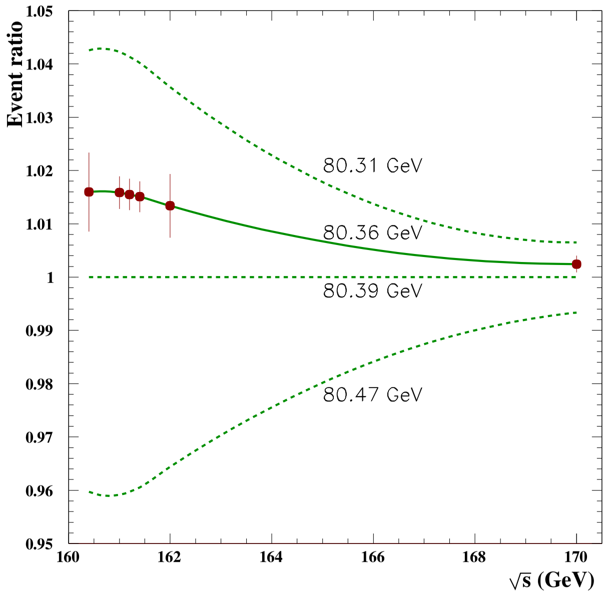
- Supersymmetry
  - several channels with $\not{E}$: hermeticity
  - $e^-_L e^+_R \to \tilde{\chi}^-_1 \tilde{\chi}^+_1 \to l^{\pm}\tilde{\chi}^0_1 q\bar{q}'\tilde{\chi}^0_1$: $E_{jet}$




- top physics
  - $t \to b + W$ 6 jets, high multeplicity: $\epsilon_{tk}$
- Low Energy: Z, $M_W$
  - $A_{LR} =$
$$\sqrt{\frac{(\sigma_{++}+\sigma_{-+}-\sigma_{+-}-\sigma_{--})(-\sigma_{++}+\sigma_{-+}-\sigma_{+-}+\sigma_{--})}{(\sigma_{++}+\sigma_{-+}+\sigma_{+-}+\sigma_{--})(-\sigma_{++}+\sigma_{-+}+\sigma_{+-}-\sigma_{--})}}$$
  - W threshold production: measure cross section

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# Machine conditions

## DAQ

- Long time between bunch trains: 199 ms
- Bunch separation in a train: 337 ns
- Train length: 950 $\mu$s (2820 BX)
- $L = 3.4 \cdot 10^{34}\text{cm}^{-2}\text{s}^{-1}$, $\sigma$, background
  $\Rightarrow$ 220 MBytes/train

$\Downarrow$

- Hardware trigger unnecessary
- Data in pipeline for 1 ms, no dead time
- 200 ms for pipeline ready
- Software event selection
- Moderate throughput w.r.t. LHC

## Beamstrhlung

- $\delta E \sim 3\%$

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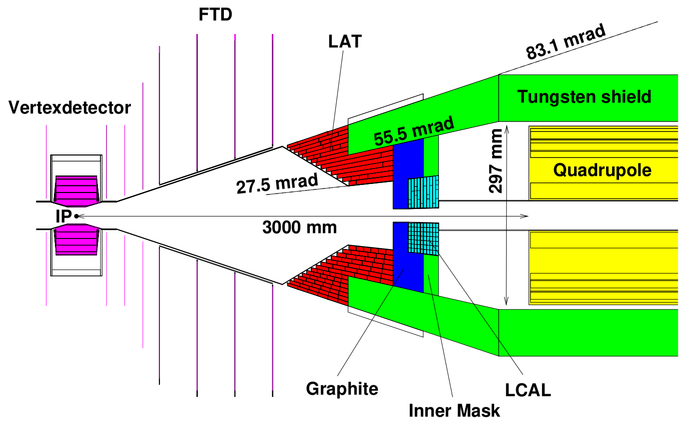
## Background

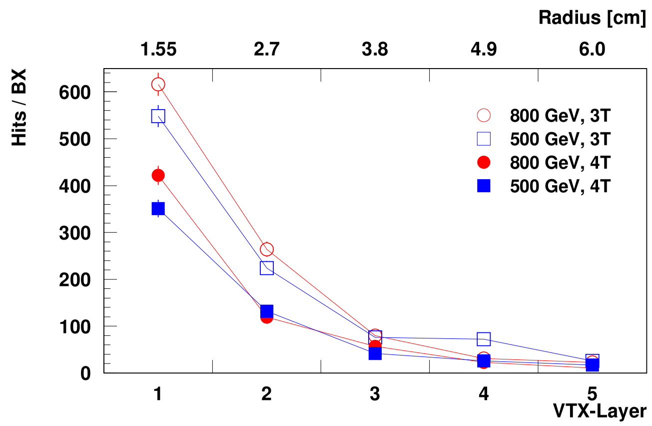
- Beamstrahlung photons $\Rightarrow$ secondary effects:
  $e^+e^-$ pairs (few GeV)
  hadronic interactions
- Radiative bhabhas
- Neutrons

The $e^+e^-$ pairs in **B** move towards the quadrupoles creating a large number of secondaries.

$\Downarrow$

- W mask system
- **B** field intensity
- Minimum radius for the vertex detector (VTX)



# Detector Concepts

- Excellent vertex resolution to identify heavy flavours (b,c,$\tau$) $\Leftarrow g_{Hff}$
- Tracking system with good $\delta p$
  and high efficiency for multi-jet events
  $\Leftarrow HZ \to Hl^+l^-$
- Good Energy flow
  $\Leftarrow W, Z \to q\bar{q}(\prime)$,SUSY
- Hermeticity and good forward E determination
  $\Leftarrow$ SUSY
- Luminosity spectrum (beamstrahlung)
  $\Leftarrow \sigma$ at threshold
- Excellent lepton identification

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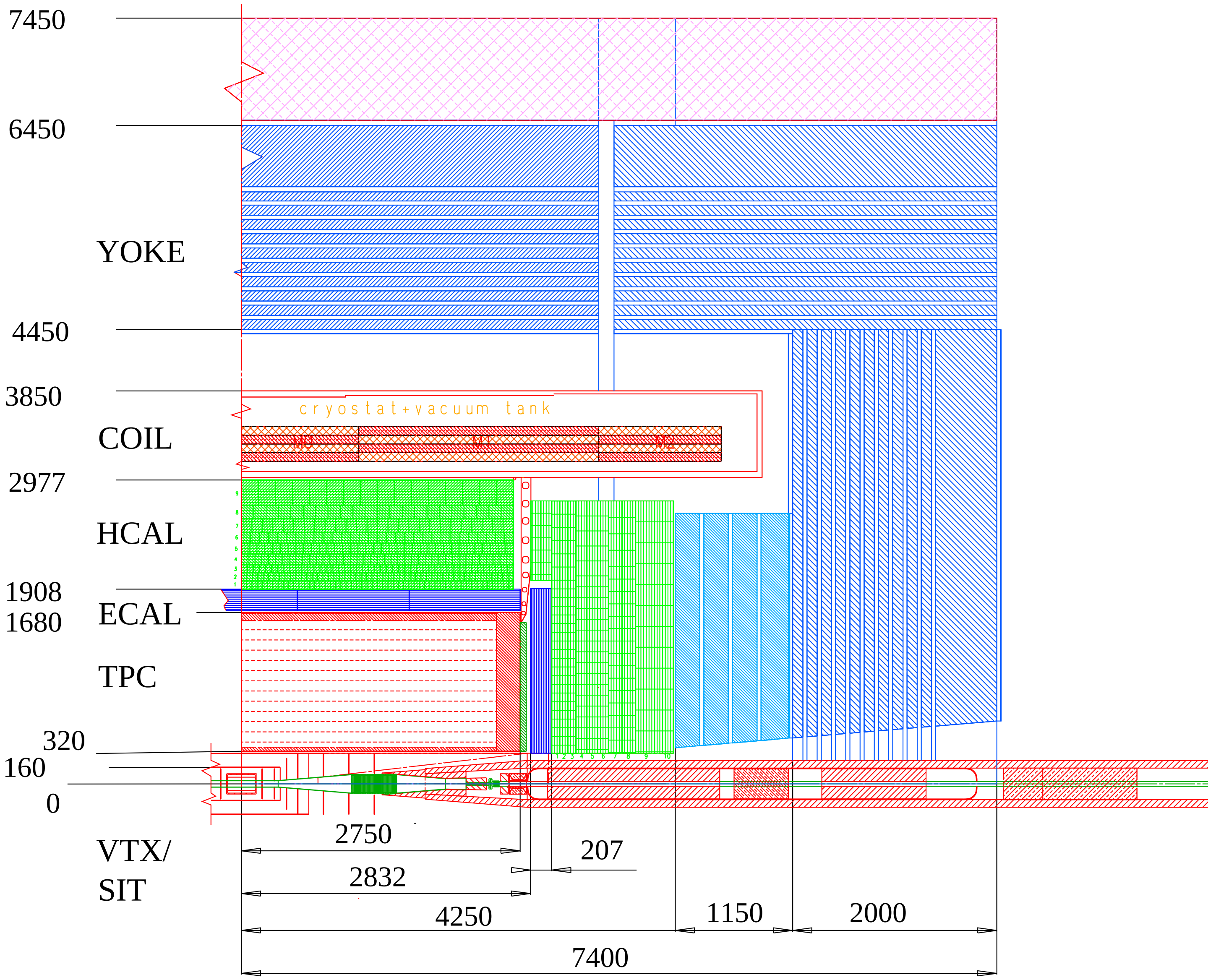
# Detector for TESLA




VTX $\Rightarrow \delta(I.P.) \leq 5\mu m \oplus \frac{10\mu m}{p sin^{3/2}\theta}$

TPC $\Rightarrow \delta\frac{1}{p_t} < 2\cdot 10^{-4}$, Tracking $\delta\frac{1}{p_t} \leq 5\cdot 10^{-5}\,\frac{GeV}{c}^{-1}$

ECAL $\Rightarrow \frac{\delta E}{E} \leq 0.10\frac{1}{\sqrt{E(GeV)}} \oplus 0.01$, granularity

HCAL $\Rightarrow \frac{\delta E}{E} \leq 0.50\frac{1}{\sqrt{E(GeV)}} \oplus 0.04$, granularity

COIL $\Rightarrow$ 4 T, uniformity$\leq 10^{-3}$

EFLOW$\Rightarrow \frac{\delta E}{E} \sim 0.3\frac{1}{\sqrt{E(GeV)}}$

Low Angle + Lumi CAL down to $\sim$ 5 mrad (veto)

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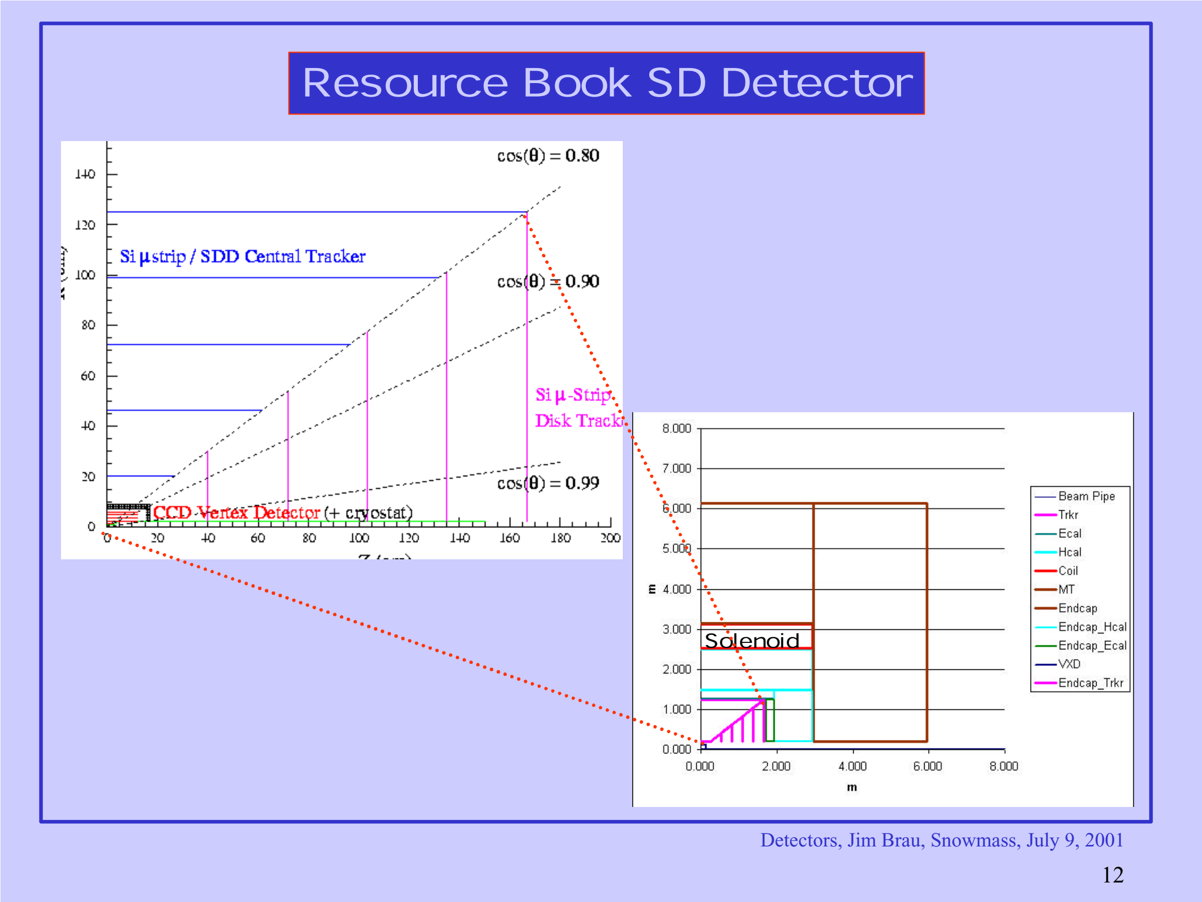
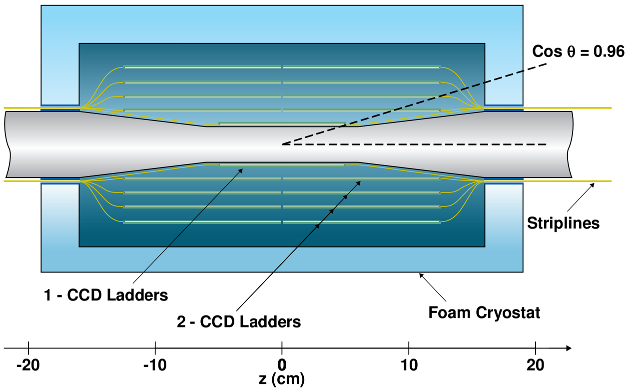
- NLC: L (large detector) similar, SD (silicon detector)




- JLC: drift chamber, 2 T or 3 T model

# Tracking system

## Vertex Detector




- Impact parameter optimization:
  minimize R $\Leftrightarrow$ machine background
  if B=4 T $R_1$=1.5 cm possible <0.1 hit/mm$^2$
  minimal multiple scattering $\Rightarrow$ thickness
- Maximal solid angle:
  forward region $|cos\theta|$
  geometry dipends on thickness (conical end-caps)
- Tecnologies:
  CCD
  CMOS
  Pixels

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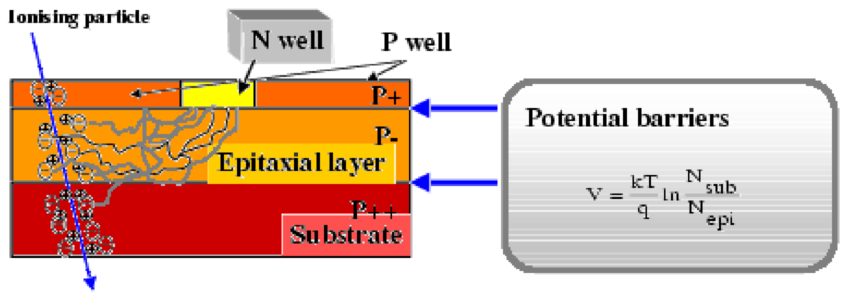
- CCD
  needs R&D:
  reduction of material with unsupported Silicon
  improving of the clocking rate
  improving the radiation hardness

| Layer | Radius | CCD L×W | CCD size | Ladders and CCDs/lddr | Row clock fcy & Readout time | Bgd occupancy | Integrated bgd |
|---|---|---|---|---|---|---|---|
| | mm | $mm^2$ | Mpix | | | Hits/$mm^2$ | KHits/Train |
| 1 | 15 | $100 \times 13$ | 3.3 | 8/1 | 50 MHz/50 $\mu s$ | 4.3 | 761 |
| 2 | 26 | $125 \times 22$ | 6.9 | 8/2 | 25 MHz/250 $\mu s$ | 2.4 | 367 |
| 3 | 37 | $125 \times 22$ | 6.9 | 12/2 | 25 MHz/250 $\mu s$ | 0.6 | 141 |
| 4 | 48 | $125 \times 22$ | 6.9 | 16/2 | 25 MHz/250 $\mu s$ | 0.1 | 28 |
| 5 | 60 | $125 \times 22$ | 6.9 | 20/2 | 25 MHz/250 $\mu s$ | 0.1 | 28 |

Key parameters of the CCD-based vertex detector design

- CMOS
  - Charge collection by diffusion in undepleted epitaxial layer
  - Fill factor 100%
  - Detector inseparable from RO electronics
  - Low cost
  - Test results: $\epsilon > 99\%$, $20\mu m$ pitch $\Rightarrow \sigma \sim 2\mu m$

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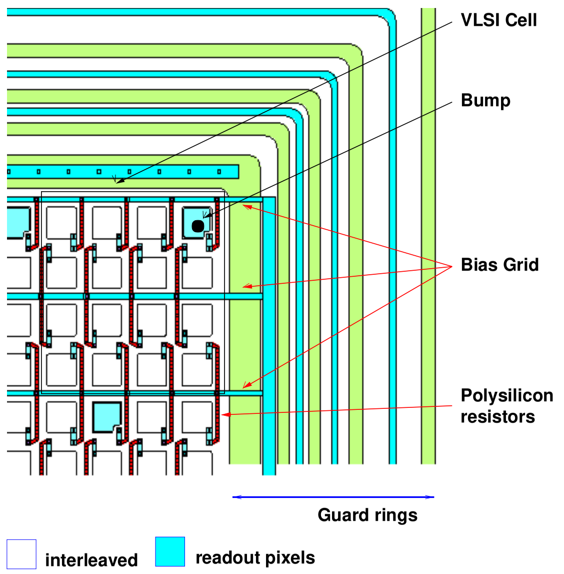
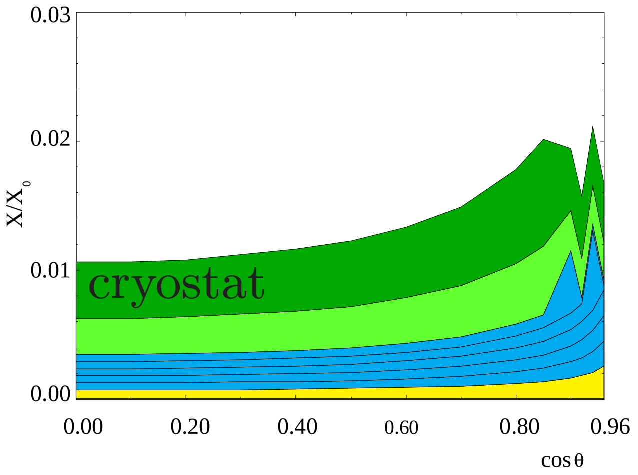
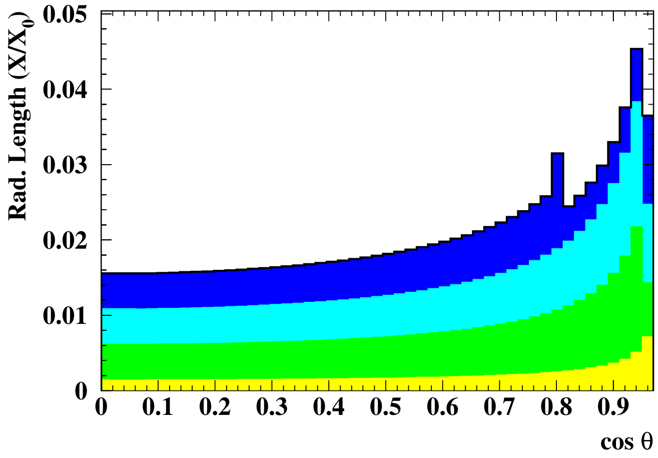
- Hybrid Pixels
  in use (DELPHI + LHC)
  capacitive coupling: goal $\sigma < 7\mu m$

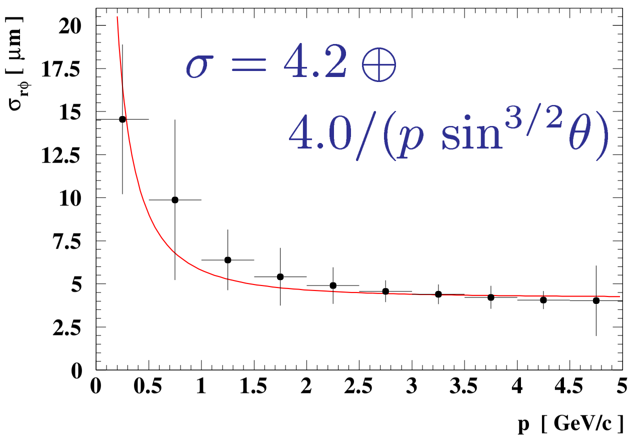



CCD




Pixels

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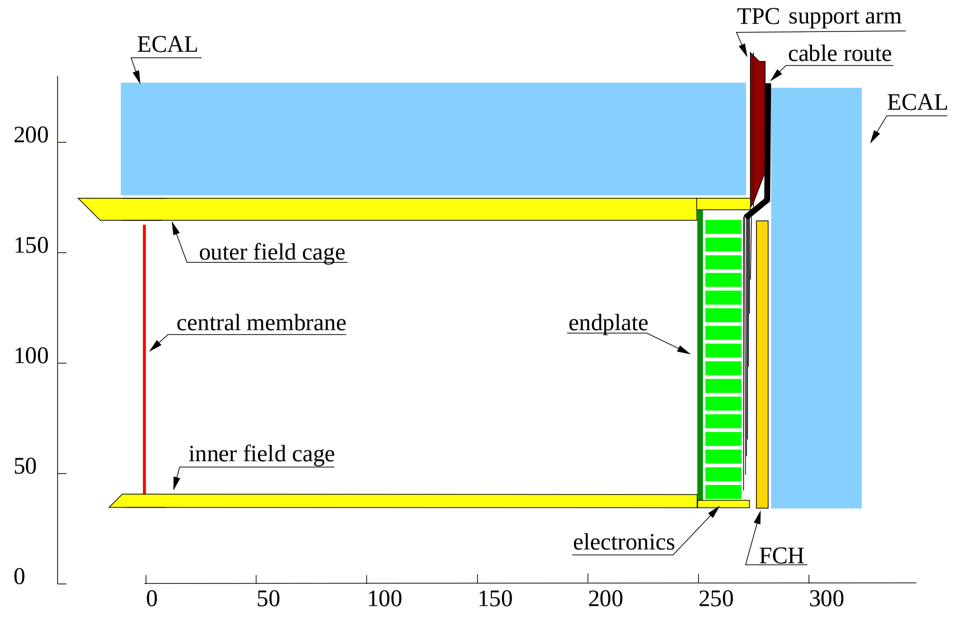
## Central Tracking: TPC (TESLA, L)




- In use (LEP + STAR , ALICE )
- much less tracks
- event pile-up from many BX
  $\Rightarrow$ good time information
- continuous operation during a train
  $\Rightarrow$ ReadOut system
  gating scheme
- minimize end-plate material
- Internal Radius $\Leftarrow$ mask system
- External Radius $\Leftarrow \delta \frac{1}{p_t} < 2 \cdot 10^{-4} (\mathrm{GeV/c})^{-1}$
- RO: GEM, Micromegas, w. ch.$\Leftarrow$ B=4 T

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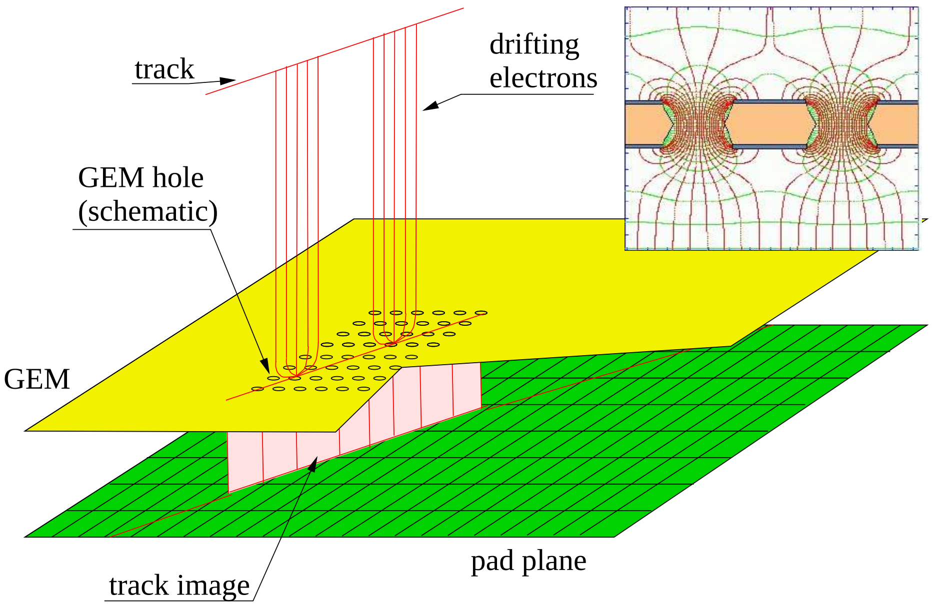
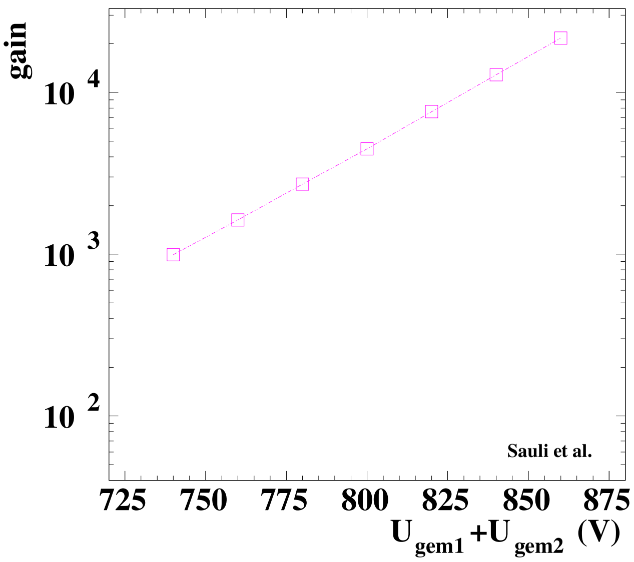
# GEM

Thin polymer foil with metal coating on both sides
holes $\sim 100\mu m$ apart,
$\Delta V \Rightarrow \mathbf{E}\sim 80\mathrm{kV/cm}$




- Gain $\mathcal{O}(10^3)$
- 2 GEM cascade




- ion density to an acceptable level

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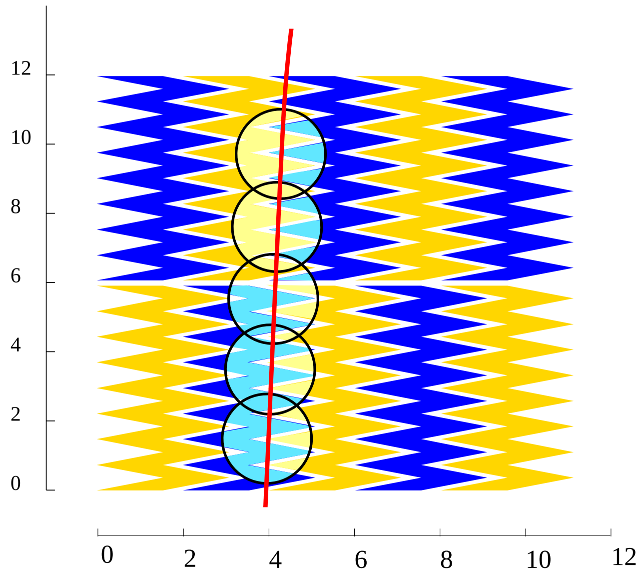
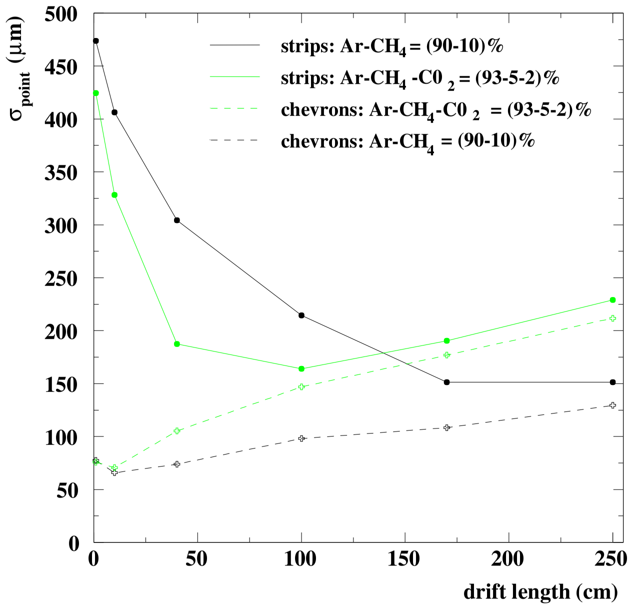
- Resolution optimization $\Rightarrow$ *Chevron* pad
  200 points/track




- $2 \times 6\ \mathrm{mm}^2 \Rightarrow 0.6$ M channel/side
  $\sigma_{\frac{dE}{dx}} = 4.3\%$ $\delta\frac{1}{p_t} \sim 1.5 \times 10^{-4}(\mathrm{GeV/c})^{-1}$




- Calibration: local distortions$\leq 10\mu m$

# Calorimeters

## General Overview

- From Physics:
complex hadronic final states (i.e. $t \to bW$)
missing energy (i.e. $\nu$, $\tilde{ini}$)

- hermeticity down to low angles
- lepton id
- angular resolution
- jet 4-vector reconstruction (partons)
  strategy: *energy flow* algorithms as
  $E = \Sigma_{ch} p^{tk} + \Sigma_{\gamma} E^{ecal} + \Sigma_{neut.} E^{hcal}$
  $\Downarrow$
  high granularity to disentangle contributions

  JLC: Hardware compensation
  calorimeters inside the coil

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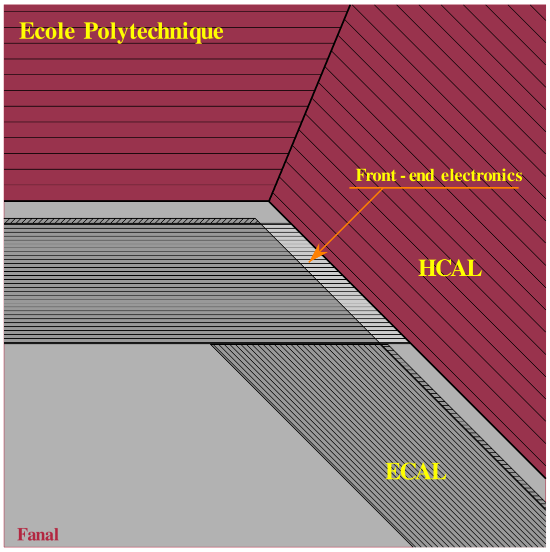
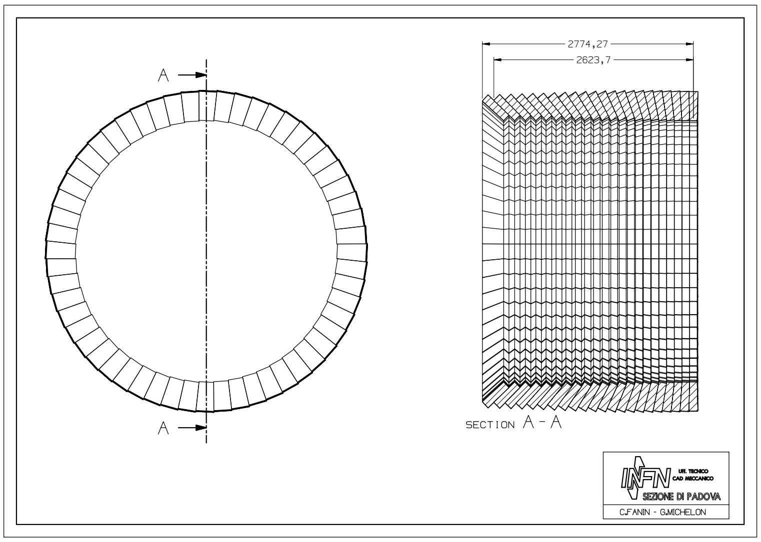
## Electromagnetic Calorimeter

- Where granularity has the largest importance

- TDR: 2 solutions

| | SiW | Shashlik |
|---|---|---|
| Absorber ($X_0$/layer) | W $0.4 \div 1.2$ | Pb 0.18 |
| Detector | Si 500$\mu$m | Scintillator 1 mm |
| # of layers | 30+10 | 140 |
| Transv. Dim. (cm$^2$) | $\sim 1 \times 1$ | $\sim 3 \times 3$ |
| Longit. Segm. | 40(20?) | 2÷3 |
| # of channels | $\sim$ 30(15) M | $\sim$ 58 k |
| Geometry | flat | pointing |
| Total thickness ($X_0$) | $\sim$ 24 | $\sim$ 25 |

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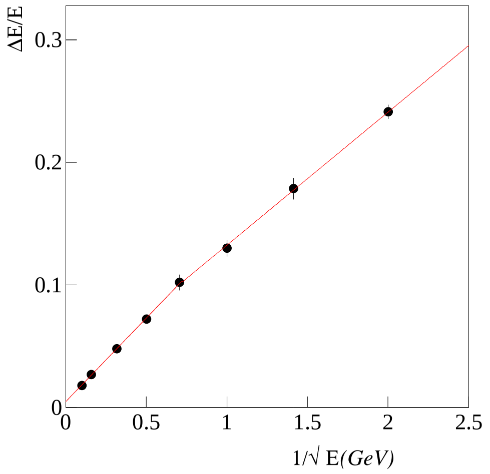
## SiW

- Problems with the project dimension

SiW MC

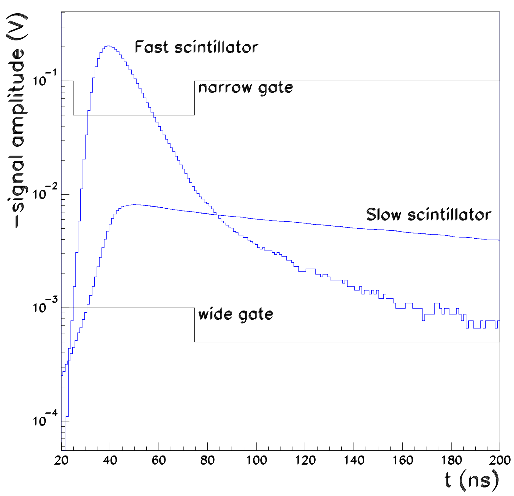
$$\frac{\Delta E}{E} \sim \frac{11 \div 14\%}{\sqrt{E}}$$

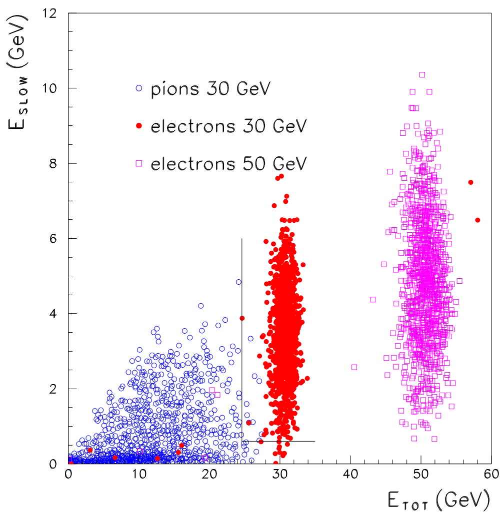



## Shashlik

- R&D for long. segm. done
  CALEIDO: thin vacuum photodiodes or

  Scintillators with different decay times




- $\Delta E/E \sim 10 \div 15\%/\sqrt{E} + 1\%$

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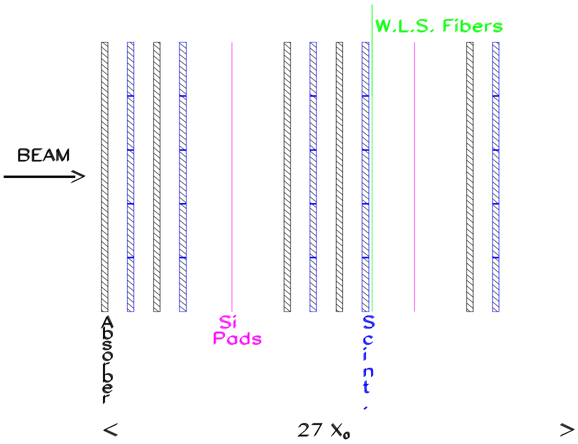
## JLC, NLC solutions

Pb/Sc + WLS $\sigma$ tail fibers

TESLA R&D:

Prototype Pb(W)/Sc + Si:

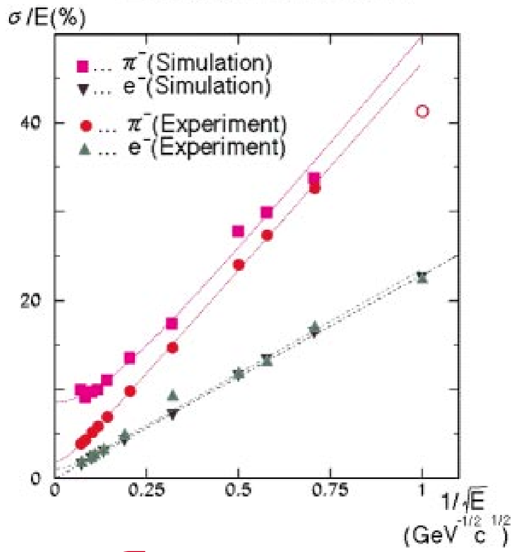



- 50 layers: $25 \times 25 \times 0.3(0.2)$ cm$^3$ Pb (W)
- $25 \times 25 \times 0.3$ cm$^3$ Scint.:
  25 Cells $5 \times 5$ cm$^2$, .....
- 3 planes:
- $1 \times 1$ cm$^2$ Si Pads
- at: 2, 6, 12 $X_0$

## Hadronic Calorimeter

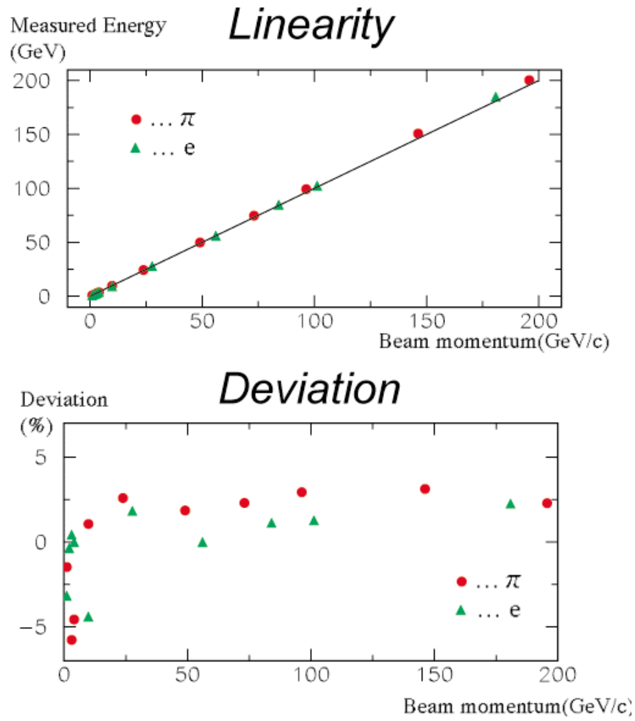
- $\sigma$ tail
  TESLA: 38 layers Fe/Sc/fibers (mm) 20/5/1.5
  Transv. Dim (cm$^2$) $5 \times 5 \div 25 \times 25$
  JLC: 130 layers Pb/Sc/fibers (mm) 8/2/0.8
  Transv. Dim (cm$^2$) $20 \times 20$

### Beam Test Results at KEK and FNAL




$\pi^-$ : $\frac{\sigma_E}{E}$ = 45.9% ± 1.5%

to be investigated toward the design value of 40%




Hardware compensation works.

- TESLA: digital (binary)
  38 layers Fe/RPC- limited Geiger w. ch.- w. ch.
  Dim. Transv. (cm$^2$) $1 \times 1$
  Long. Segm 38
  Saturation?

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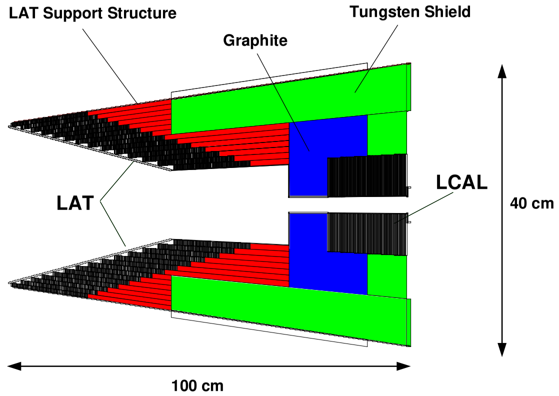
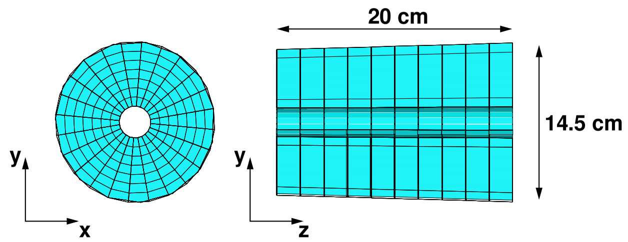
## Forward Region

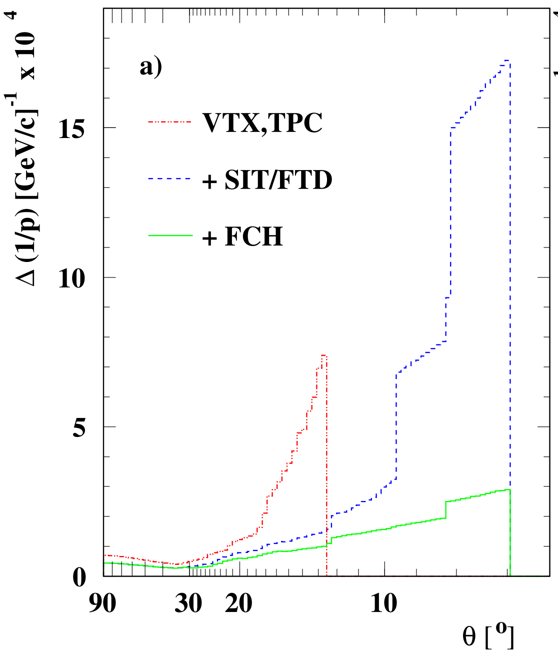


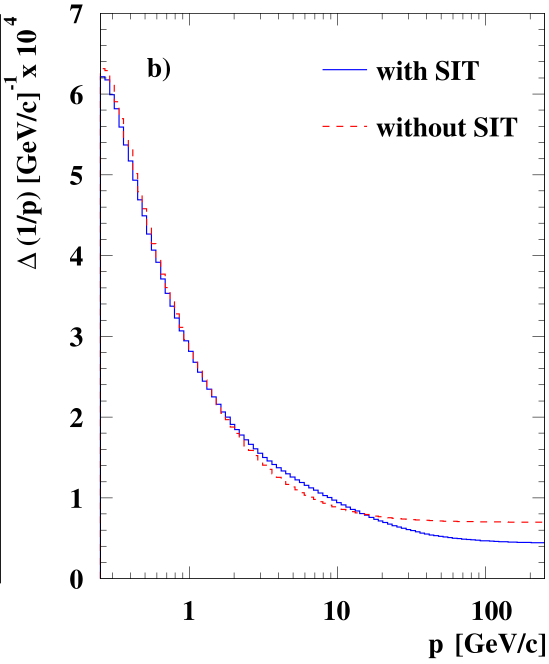

- Low Angle Tagger
  83.1 ÷ 27.5 mrad
  63 layers W/Si (mm) 2.6/0.5 $\Rightarrow \sim 47X_0$
  14 segments r, 24 $\phi$
  $\Delta E \sim 20 \div 25\% \times \sqrt{E}$
  up to E=E$_{beam}$
- Luminosity CALorimeter
  $\theta_{min} = 4.6$mrad
  63 layers W/Si(C) (mm) 2./0.5 $\Rightarrow \sim 36X_0$
  7 segments r, 24 $\phi$
  Integrate 20 TeV/BX
  background subtract. dominates resolution
  $e^{\pm}$ with E> 50 GeV from $\theta_{min} = 5$mrad

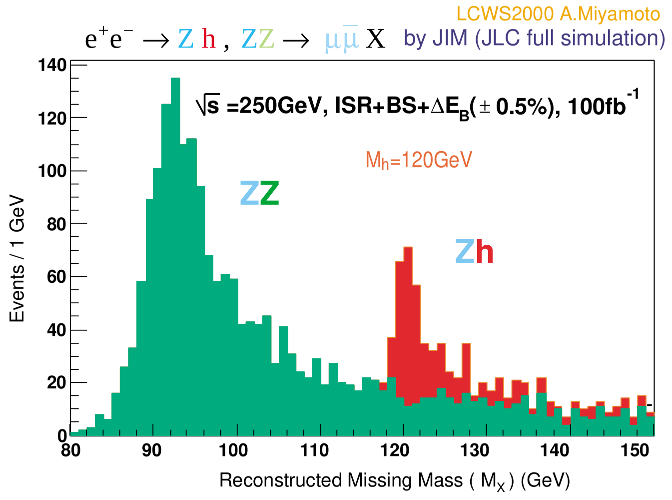


# Performance

- Momentum resolution

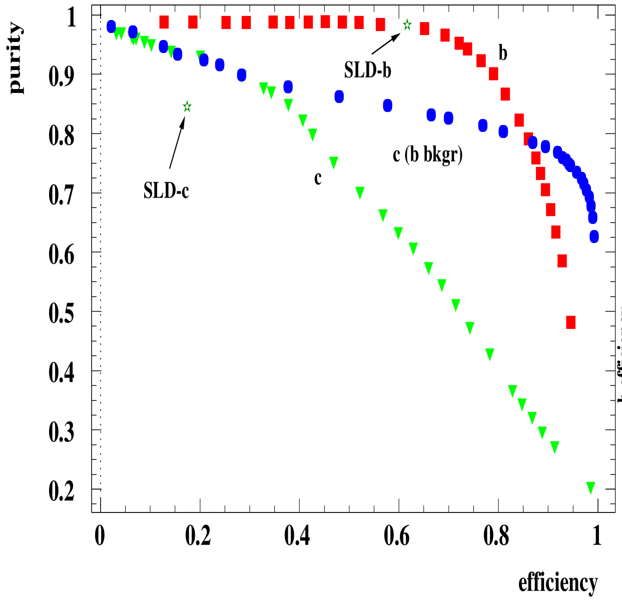


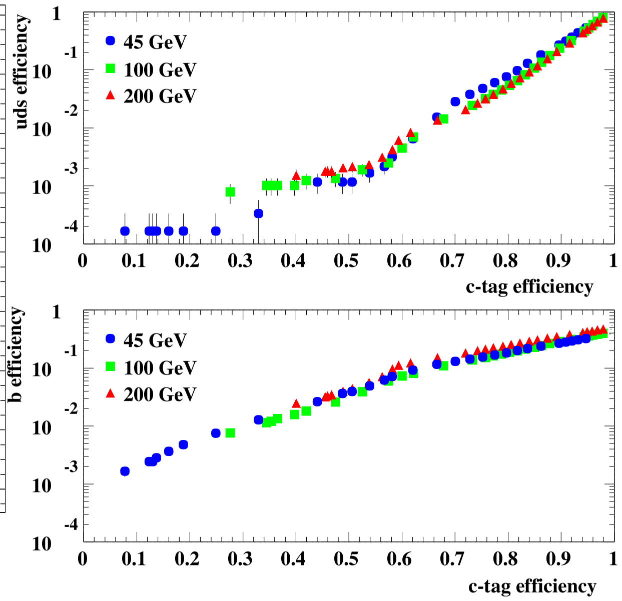



# Performance (TESLA)

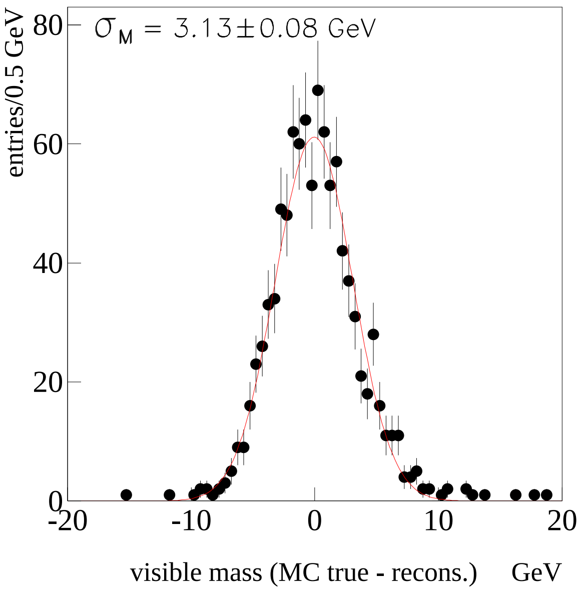
- Heavy flavour Id.




- Jet energy
  $\Delta E/E = 33\%/\sqrt{E}$

$Z^0 \to q\bar{q}$ at rest

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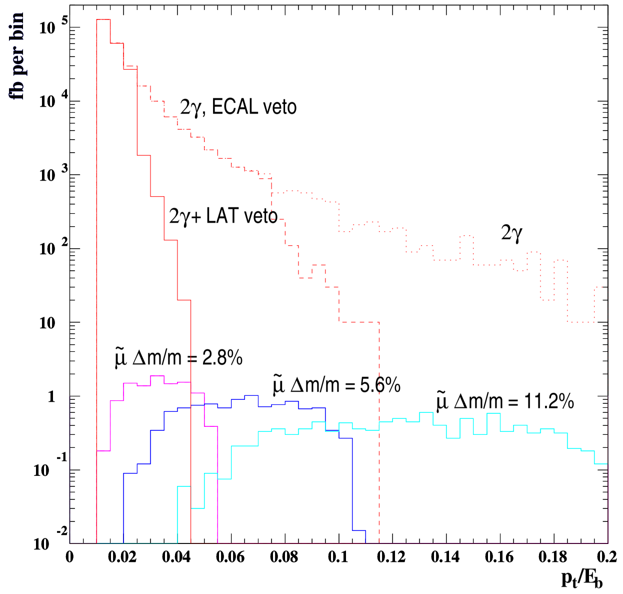
# Performance (TESLA)

- Hermeticity

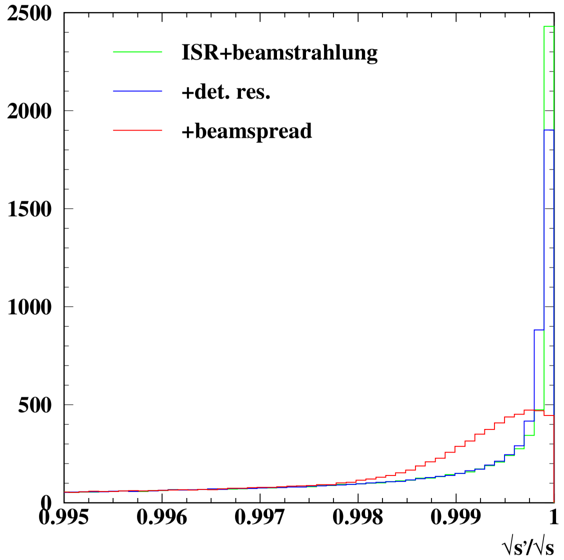
  $p_t$ with mask calorimeters

$$\tilde{\mu}\tilde{\mu} \rightarrow \mu^- \tilde{\chi}^0_1 \mu^+ \tilde{\chi}^0_1$$




- Luminosity spectrum

  Bhabha events in FTD



# Conclusions

- High precision Physics requires
- High precision Detector
- which may need R&D...
- ... but which could be builded tomorrow
- No big principle problems:
- excellent momentum resolution
- impact parameter precision
- and jet energy reconstruction
- No doubts on the Physics program:

**We simply need the Machine**

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