# The TESLA TDR Detector

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- Introduction
- Detector requirements from physics and machine
- Tracking system
- Calorimetry
- Detector performance
- Conclusions

# Introduction

- The TESLA TDR has been submitted in March and is currently reviewed by the German science council

- The TDR contains a costed detector design which is presented in this talk

- This design is meant as a proof that we can do the physics we we want to do with TESLA

- For simplicity and to bundle forces we agreed to work within one conceptual design and to allow alternatives only for exchangeable modules

- By no means we want to prevent people from thinking further in all possible directions

# Requirements from physics

- momentum resolution:
  - benchmark process: $e^+e^- \to HZ,\ Z \to \mu^+\mu^-$
  - need $\Delta m(\mu\mu) < \Gamma_Z$ and $\Delta m_{rec} \approx$ limit from beam energy spread

  ➠ $\Delta 1/p \approx 5 \cdot 10^{-5}/\mathrm{GeV}$
- b-tagging:
  - need very high b-tag efficiency and purity to separate multi-b processes like $e^+e^- \to ZHH$ or $e^+e^- \to t\bar{t}H$ from huge background
  - need good b/c separation to measure $BR(H \to c\bar{c})$ $(BR(H \to c\bar{c})/BR(H \to b\bar{b}) \sim 0.03)$
- energy flow in jets
  - benchmark reactions: $e^+e^- \to ZHH$, $e^+e^- \to \nu\nu WW, \nu\nu ZZ$

  ➠ $\Delta E/E \approx 30\%/\sqrt{E}$
- hermeticity
  - many processes like $e^+e^- \to WW$ peak in the forward region

  ➠ need hadronic energy and tracking down to lowest possible angle

– some processes like $e^+e^- \rightarrow \nu\nu WW$ or $e^+e^- \rightarrow \tilde{\mu}^+\tilde{\mu}^-$ with $m_{\tilde{\mu}} - m_{\chi^0_1}$ small have large two-photon background

➡ need electron veto even lower

## Machine constraints from TESLA

### Energy and Luminosity:

- Energy range: 90 – 800 GeV
- Luminosity:

$$\begin{aligned}\mathcal{L} = \; & 0.5 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}(91\,\mathrm{GeV}), \\ & 3.4 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}(500\,\mathrm{GeV}), \\ & 5.8 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}(800\,\mathrm{GeV})\end{aligned}$$

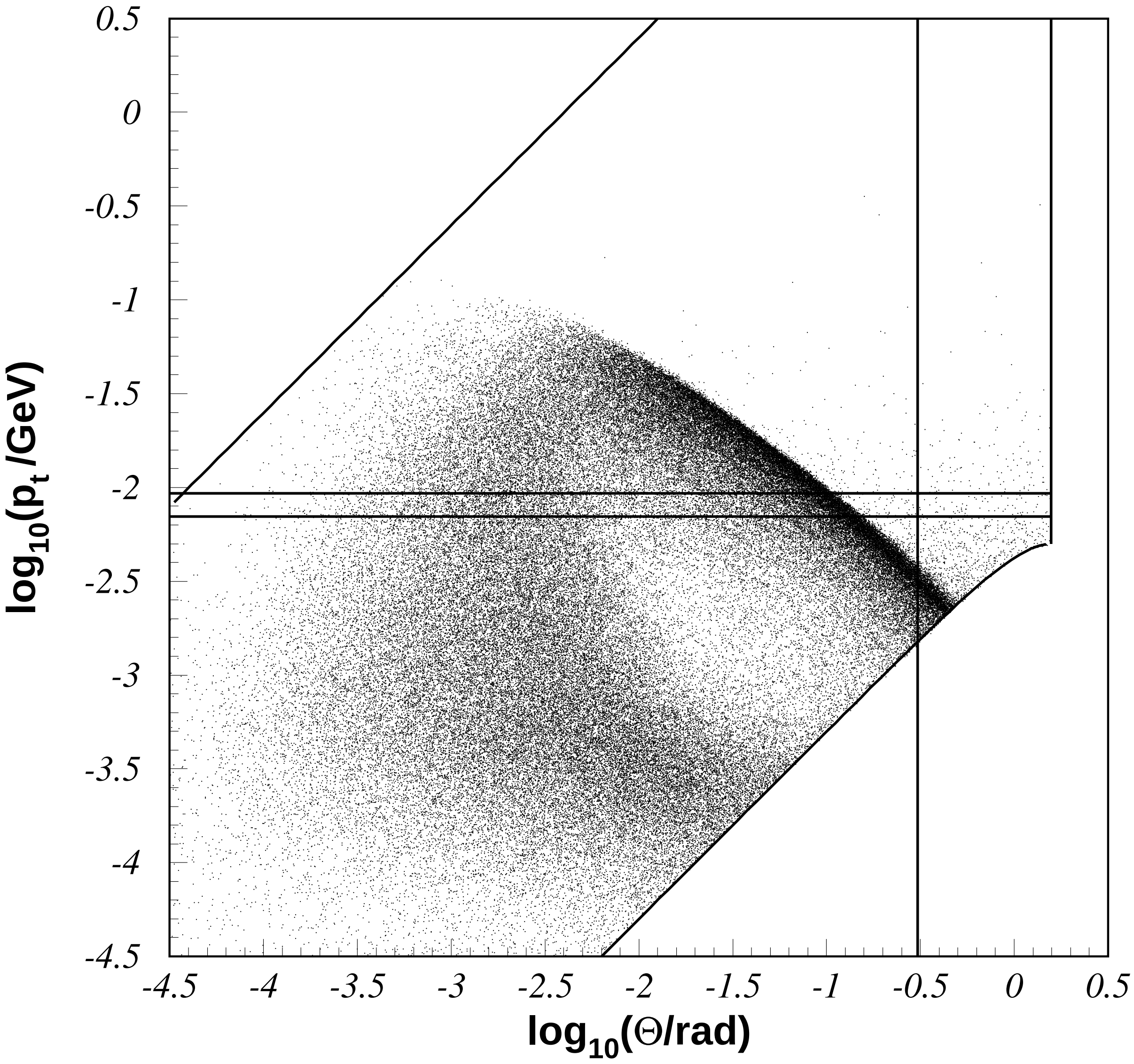
### Time structure (500 GeV)

- 5 trains/s
- 2800 bunches/train
- bunch spacing: 340 ns

➡ should impose no problem on detector (apart from microvertex readout)

➡ long bunch spacing allows head-on collisions

## Main issue: $e^+e^-$ pairs from beamstrahlung




- need high B-field to keep electrons at small radius
- minimal beampipe radius 1.4 cm
- background in innermost layer: 0.04 hits/mm$^2$/bunch crossing
- need mask below $\theta < 5^\circ$

## Other backgrounds almost negligible

# The energy flow concept

## Typical hadronic jet:

- 70% hadronic energy
- 30% electromagnetic energy

➨ need $\Delta E/\sqrt{E} \sim 35\%$ for hadron calorimeter to reach $\Delta E/\sqrt{E} = 30\%$ for jets with calorimetry
➽ very hard

## on the other hand: typical jet:

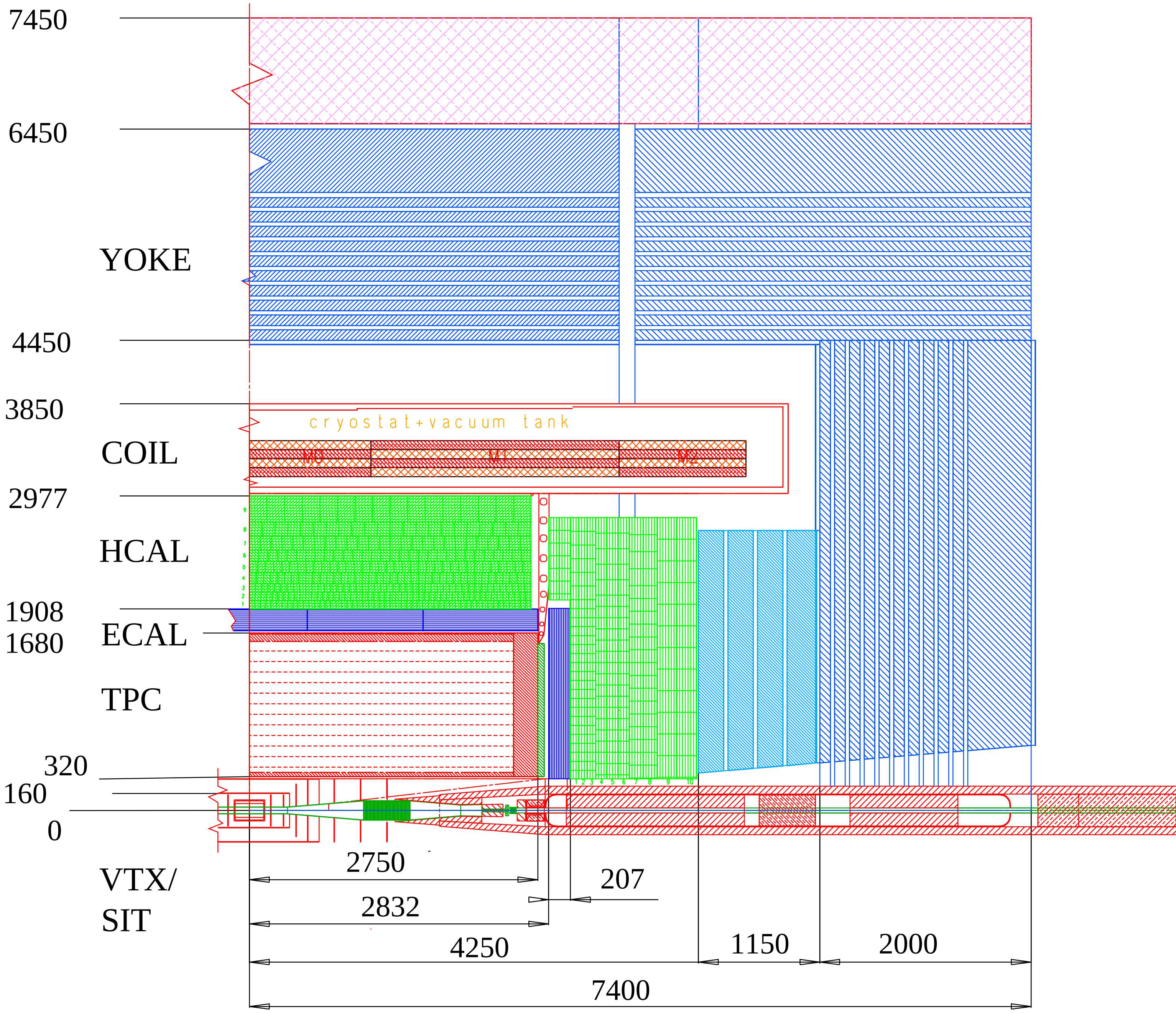
- 60% charged energy
- 30% neutral electromagnetic energy
- 10% neutral hadronic energy

So sum up

$$\Sigma p_{\text{charged}} + E_{\text{neut,ECAL}} + E_{\text{neut,HCAL}}$$

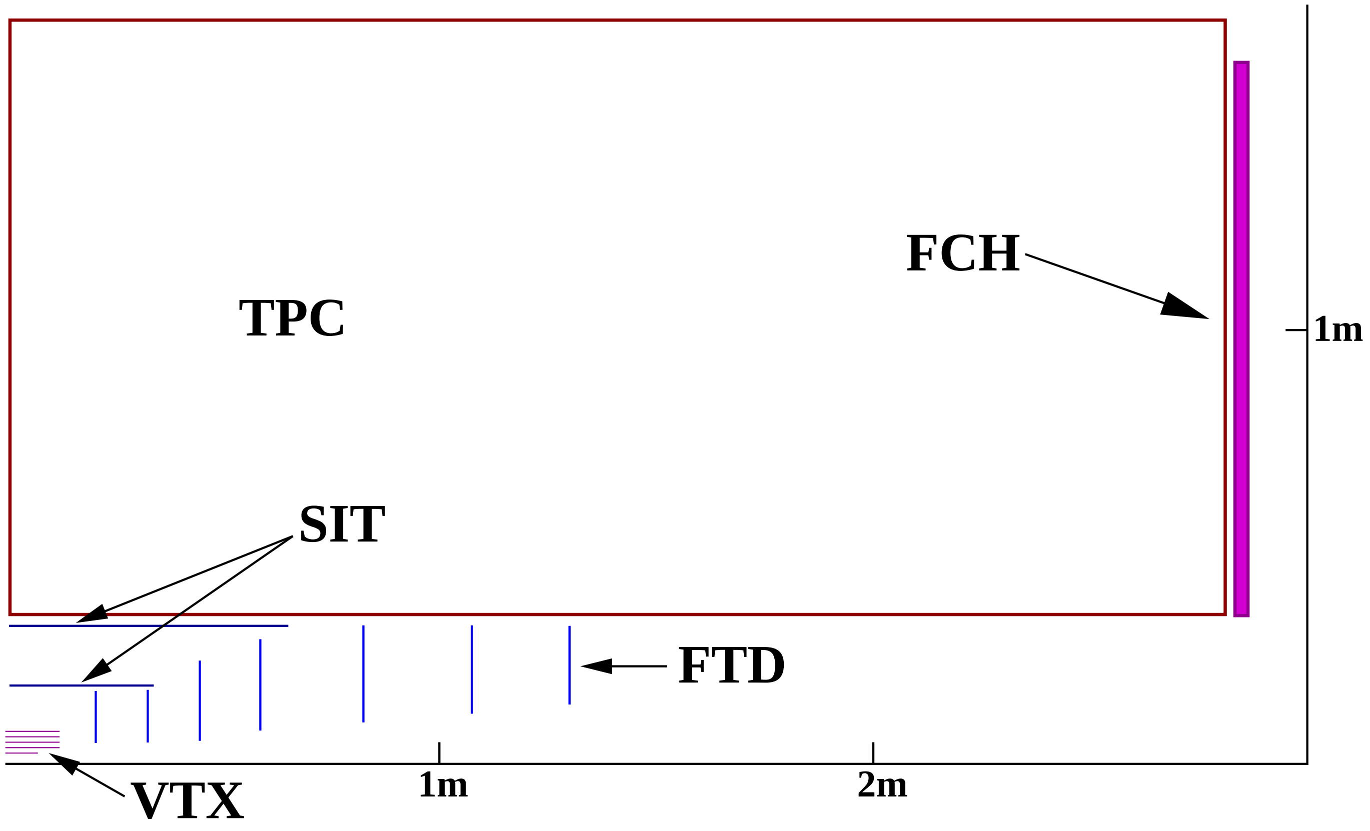
- resolution from charged tracking almost negligible
- moderate resolution for ECAL ($\sim 20\%/\sqrt{E}$)
- $100\%/\sqrt{E}$ for HCAL more than sufficient
- need however excellent granularity to separate showers from charged and neutral particles

# Detector layout



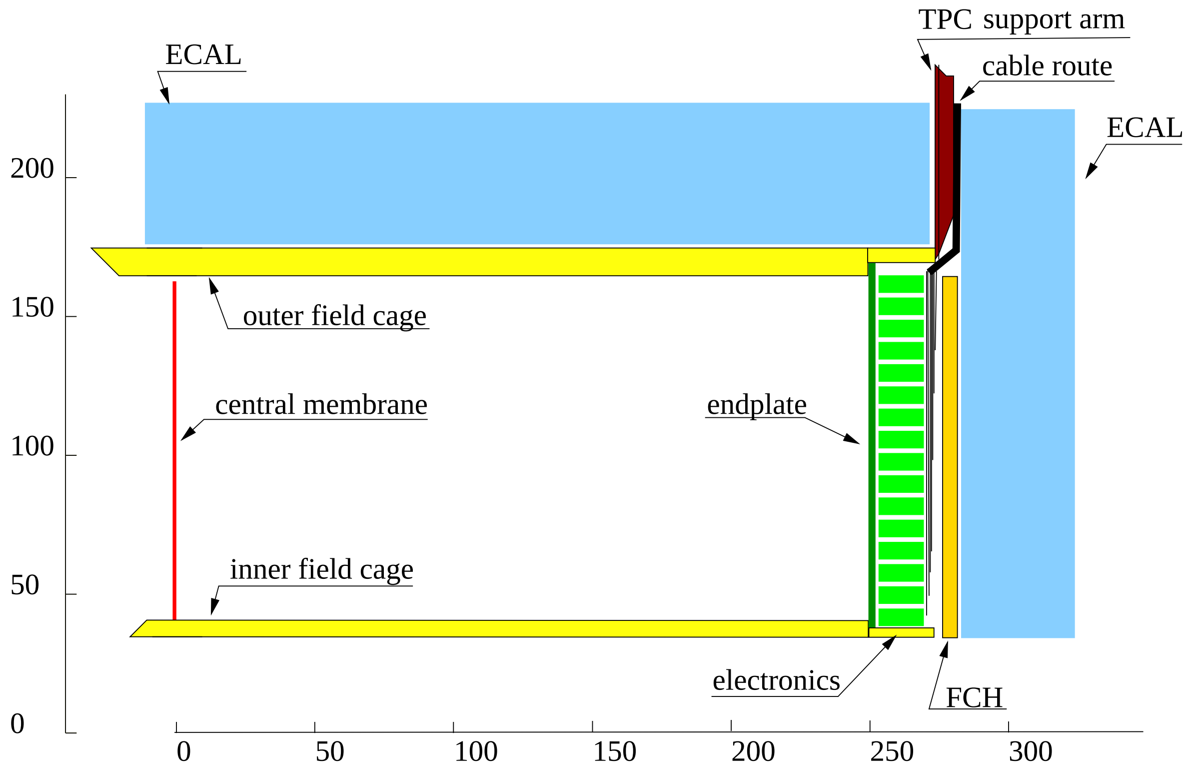

- Superconducting solenoid with $B = 3 - 4T$
- charged tracking with precise vertex detector
- Electromagnetic and hadronic calorimeter
- Instrumented mask in the forward region

# The tracking system




- Large TPC
- Vertex Detector
- Intermediate silicon tracking
- Forward chamber behind the TPC endplate

# The TPC




- In principle like existing TPCs (ALEPH, DELPHI)
- Because of photon background many more pad rows are needed (100–200)
- Studies of alternative readout schemes are ongoing (GEM, Micromegas)
  - New technology
  - Potential for better resolution ($\sim 50\mu$m)
  - GEMs should reduce ion return
  - large R&D program

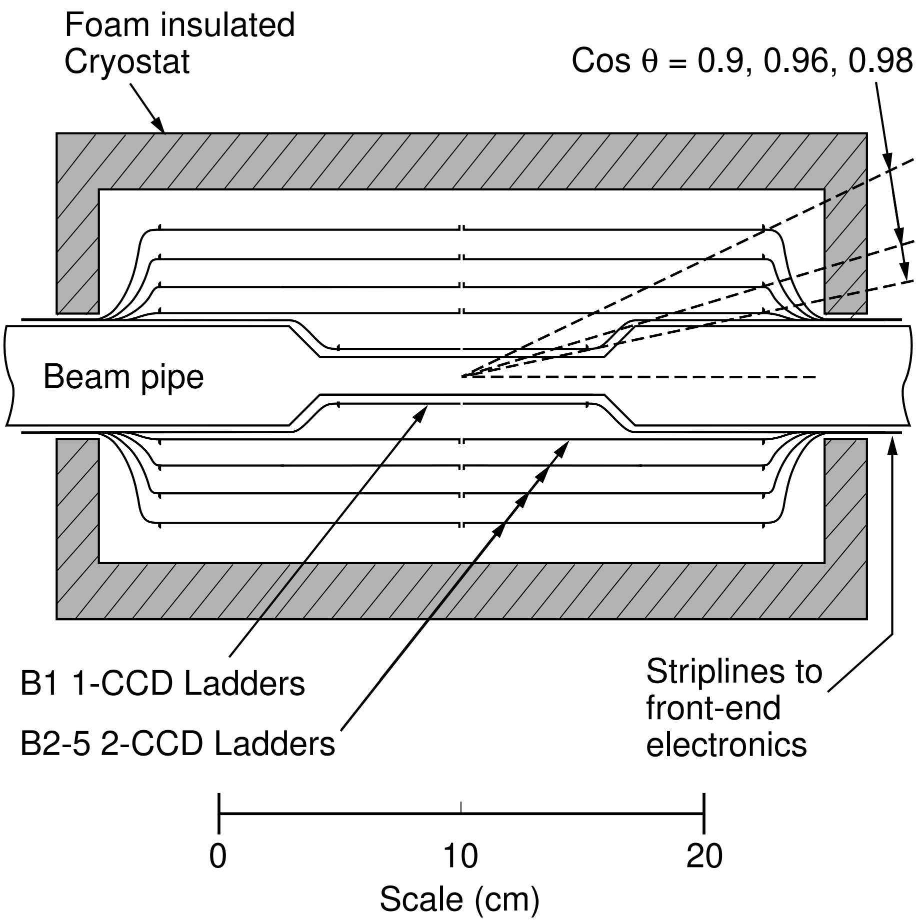
# The Vertex Detector

## Design Criteria:

- good point resolution
- small radius to keep the extrapolation error small
  however 0.04 hits/mm$^2$/BX at $B = 4T$, $r = 1.5$cm
- as little material as possible to keep multiple scattering small

## Technologies:

### CCDs



- point resolution: $\sigma_p \approx 3.5\mu\mathrm{m}$
- layer thickness: $\sim 0.12\% X_0$

$\Rightarrow$ IP resolution: $\sigma_{IP} \sim 4.2\mu\mathrm{m} \oplus \frac{4.0\mu\mathrm{m}}{p \sin^{3/2}\theta}$

## Typical CCD problem: large readout time

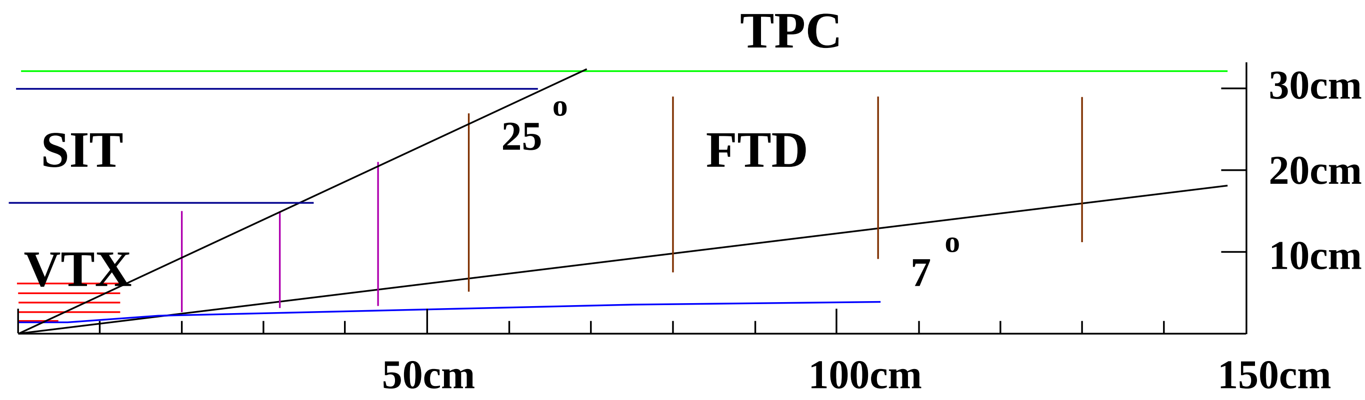
- column parallel readout
- readout frequency: 50 MHz
- continuous readout

$\Rightarrow$ one complete readout over $\sim$ 100 bunch crossings

## Alternative Technologies

- APS
  - Technology similar to ATLAS
  - development towards thinner detectors
  - test of non read out "intermediate Pixels" to improve resolution by charge division
    $\rightarrow$ 10$\mu$m already reached
- CMOS
  - monolithic CMOS pixel of $20 \times 20\mu\mathrm{m}^2$
  - Large potential (fast, precise, cheap)
  - however in very early stage

## Intermediate tracker

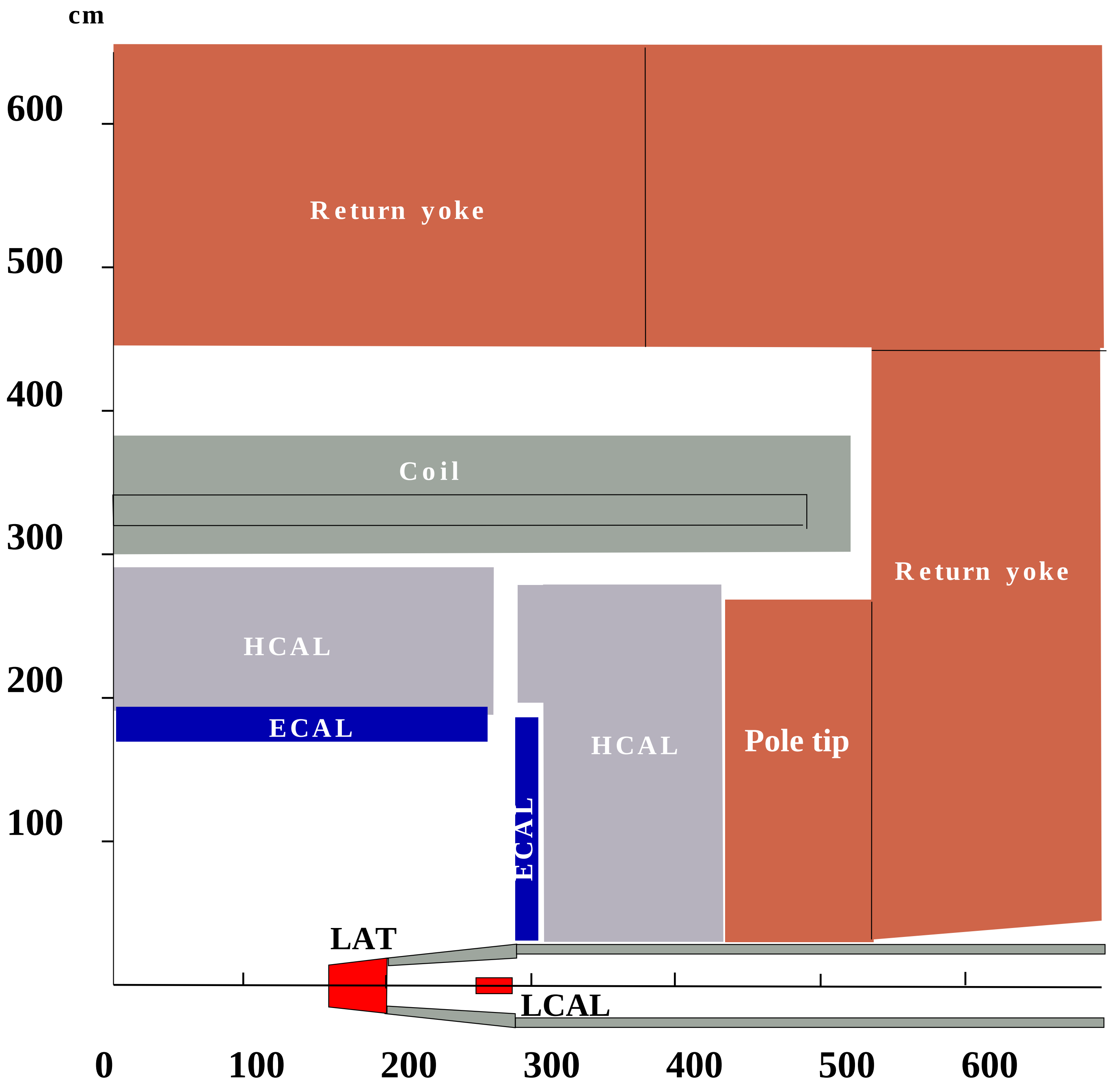



- Silicon strips and pixel with intermediate resolution
- improve significantly momentum and angular resolution
- no special R&D needed

## The forward chambers

- Need space point with $\sim 50\mu$m accuracy at small angles to improve momentum resolution
- possible technology: 12 planes straw-tubes with $100\mu$m resolution in three orientations
- should be no big problem, too

# Calorimetry




- Electromagnetic calorimeter (ECAL)
- Hadron calorimeter (HCAL)
- instrumented yoke as tailcatcher and muon id
- instrumented mask (LCAL+LAT)

# Electromagnetic calorimeter

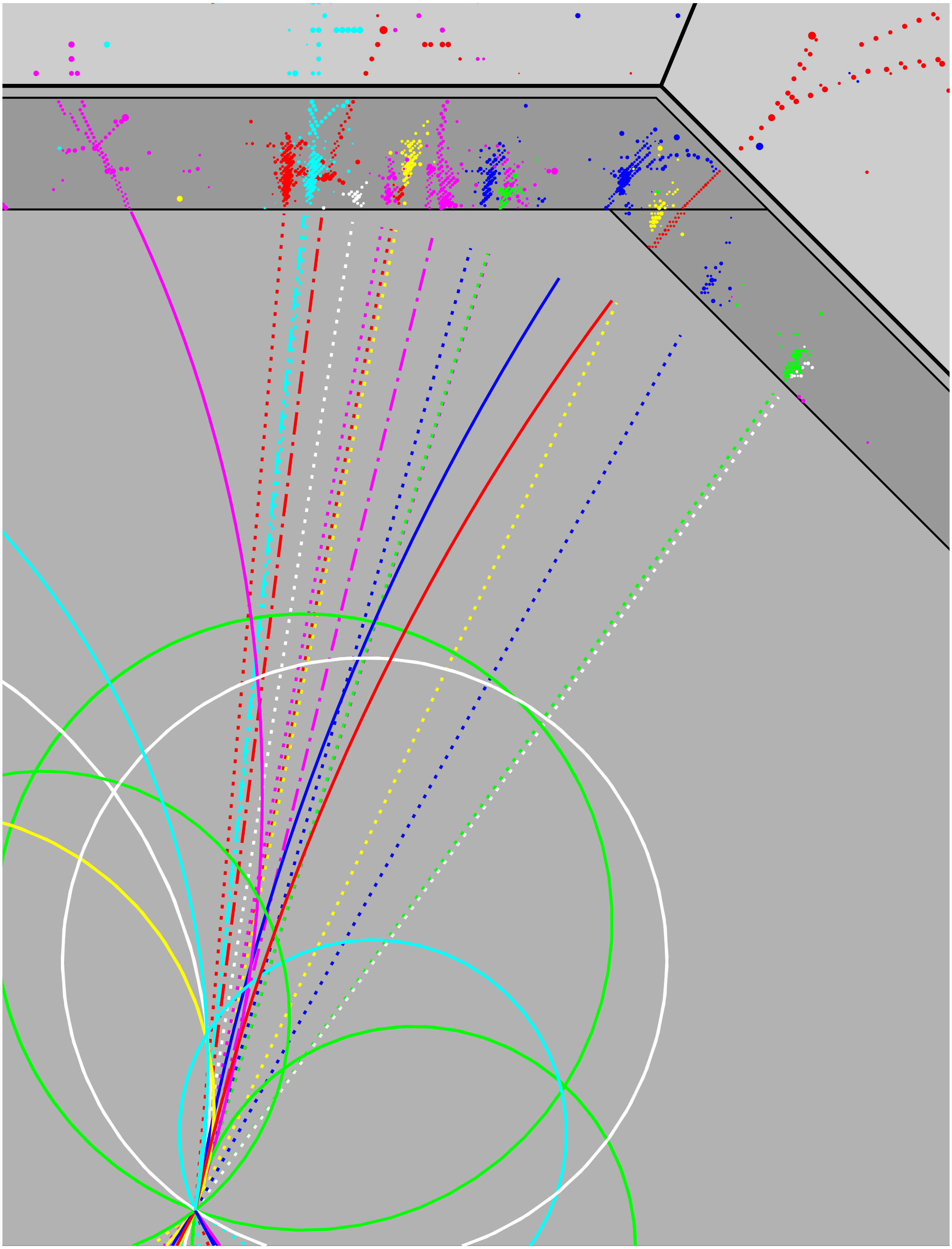
## Two options

- SiW
- shashlik

## SiW

- SiW calorimeters are very compact, $25x_0$ in 20cm are possible
- the Molière-radius of tungsten 1cm
  $\Rightarrow$ high granularity is possible
- planned calorimeter: 40 layers of 1cm$^2$ silicon pads
- energy resolution $\Delta E/E = 10 - 15\%/\sqrt{E}$
- problem: price about 130MEuro
- intensive R&D going on

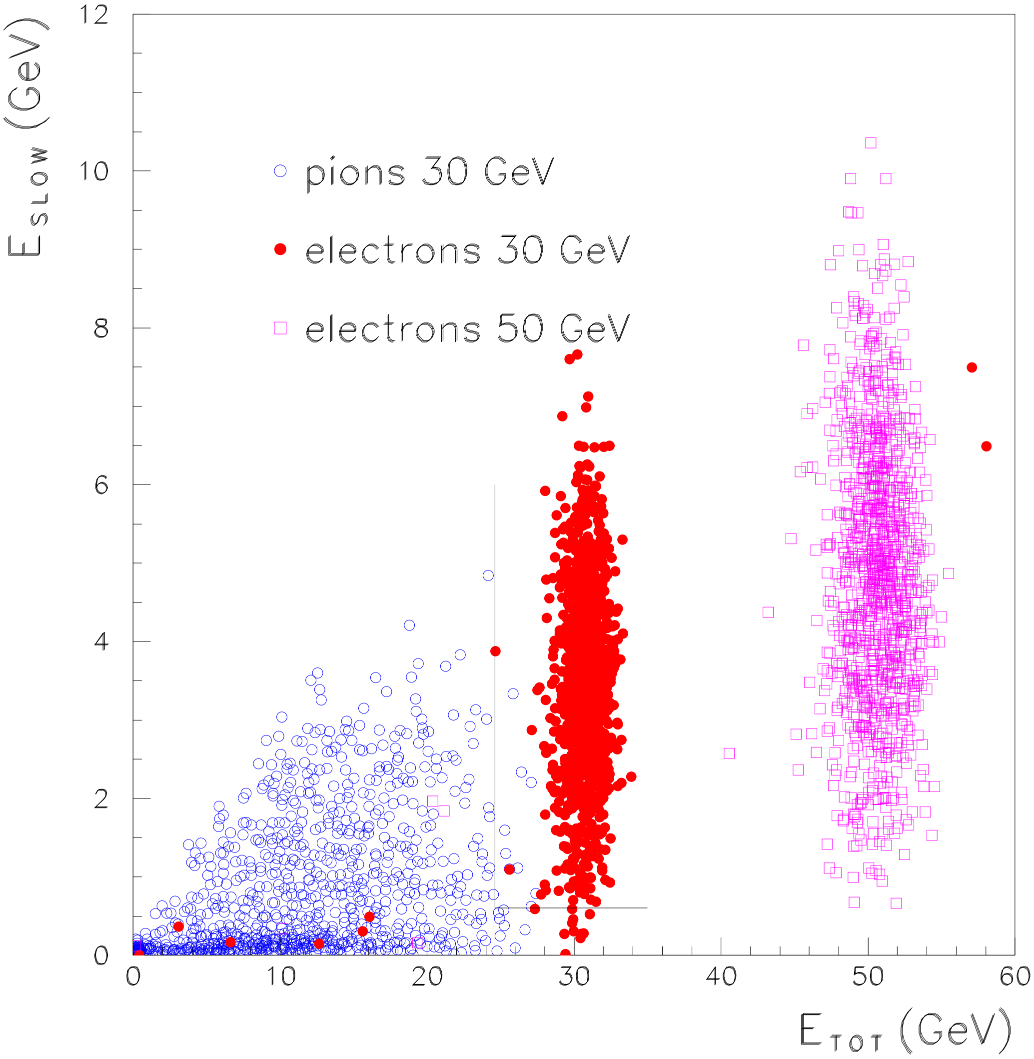
# Part of a q$\bar{q}$-event at $\sqrt{s} = 91\,\mathrm{GeV}$



# Shashlik

- established technology
- planned: lead-scintillator sandwich with $3 \times 3\text{cm}^2$ readout granularity
- possible longitudinal granularity with two scintillators with different decay time
- gains about factor two in pion mis-id
- much cheaper ($\approx$ 20MEuro)

Separation of electrons and pions



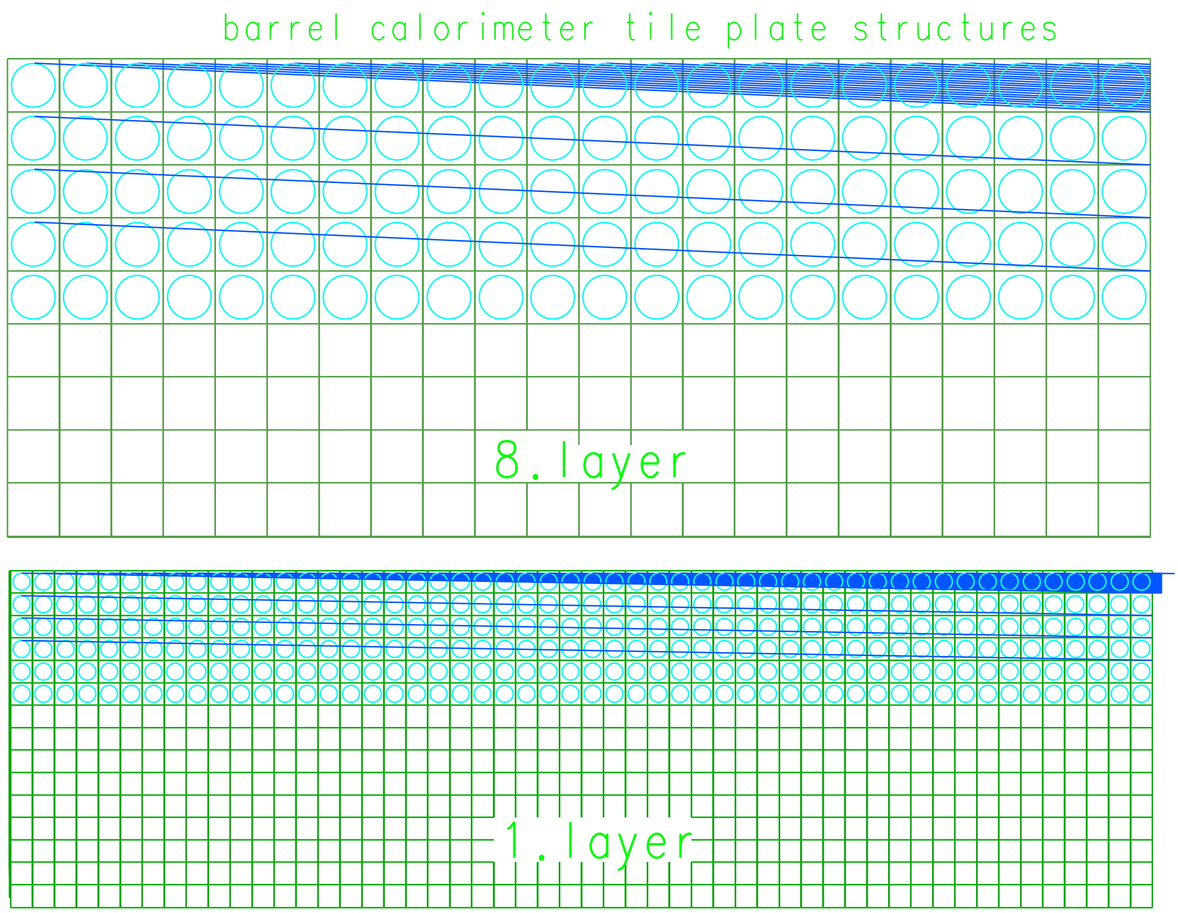
# Hadron calorimeter

## Again two options

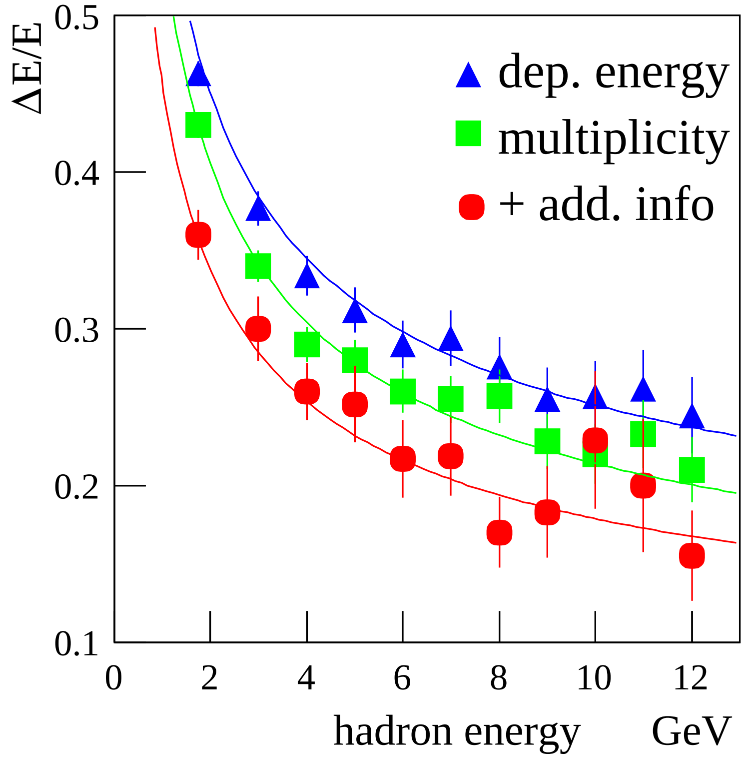
- Scintillating tiles
- digital calorimeter

## Scintillating tiles

- thickness $> 4.5\lambda$ in barrel, $> 6.2\lambda$ in endcap
- $\geq 38$ layers with longitudinal segmentation $\geq 12$
- tile size $5 \times 5\mathrm{cm}^2$ in front part and $25 \times 25\mathrm{cm}^2$ in back part

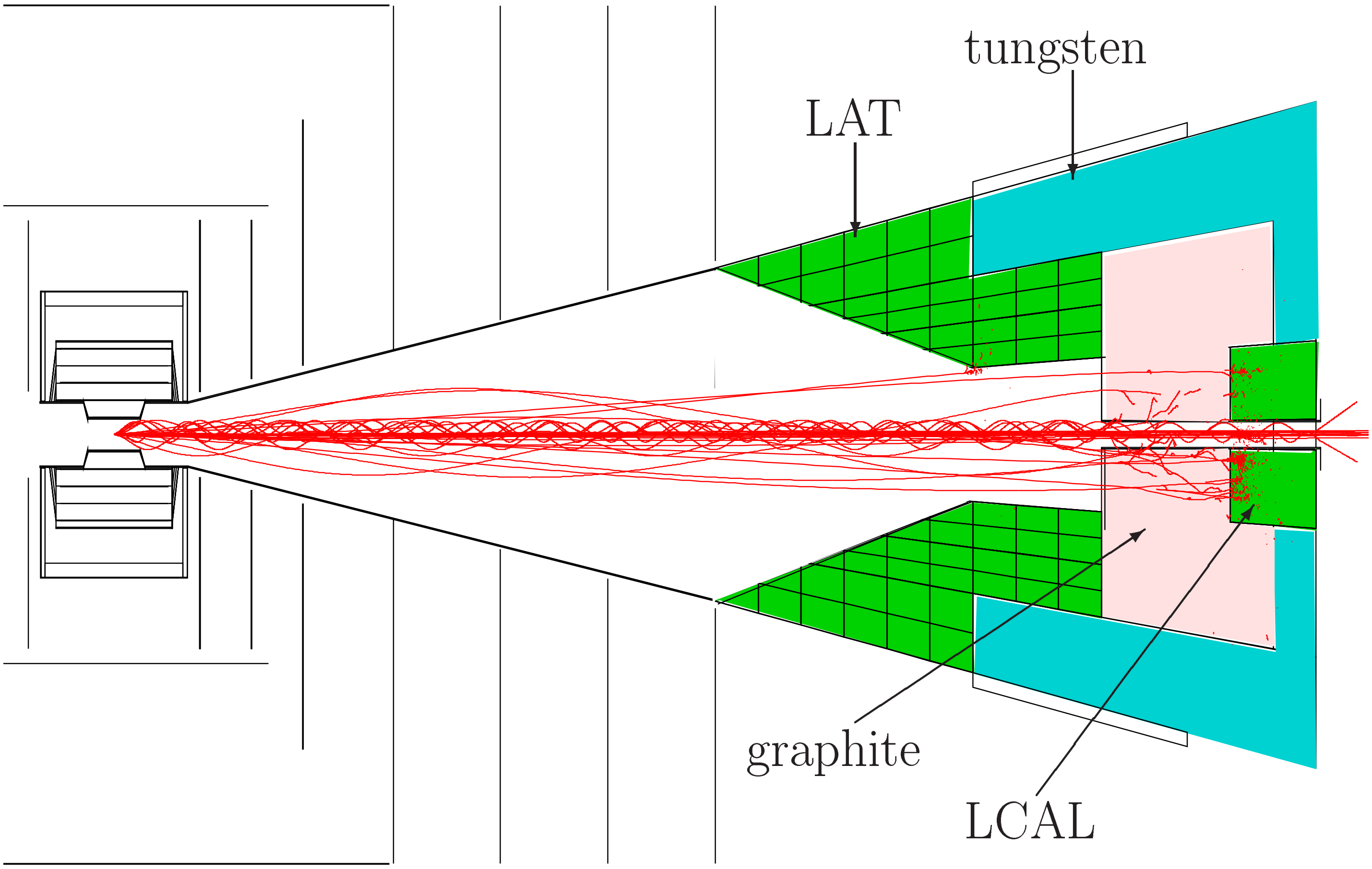


# Digital HCAL




- Hadron-calorimeter with very high granularity well matched to SiW ECAL
- "digital" (=binary) readout in this case even better than analogue
- can be realised e.g. with $1 \times 1\mathrm{cm}^2$ Geiger-counters
- needs very sophisticated software for optimal reconstruction

# The mask




- LAT ($\theta > 1.5°$)
  - can be used as hermeticity calorimeter and for precise luminosity measurement
  - envisaged technology: SiW
- LCAL
  - mainly used as luminometer for machine tuning
  - some use for hermeticity may possible in the outer part
  - huge radiation, maybe W-diamond

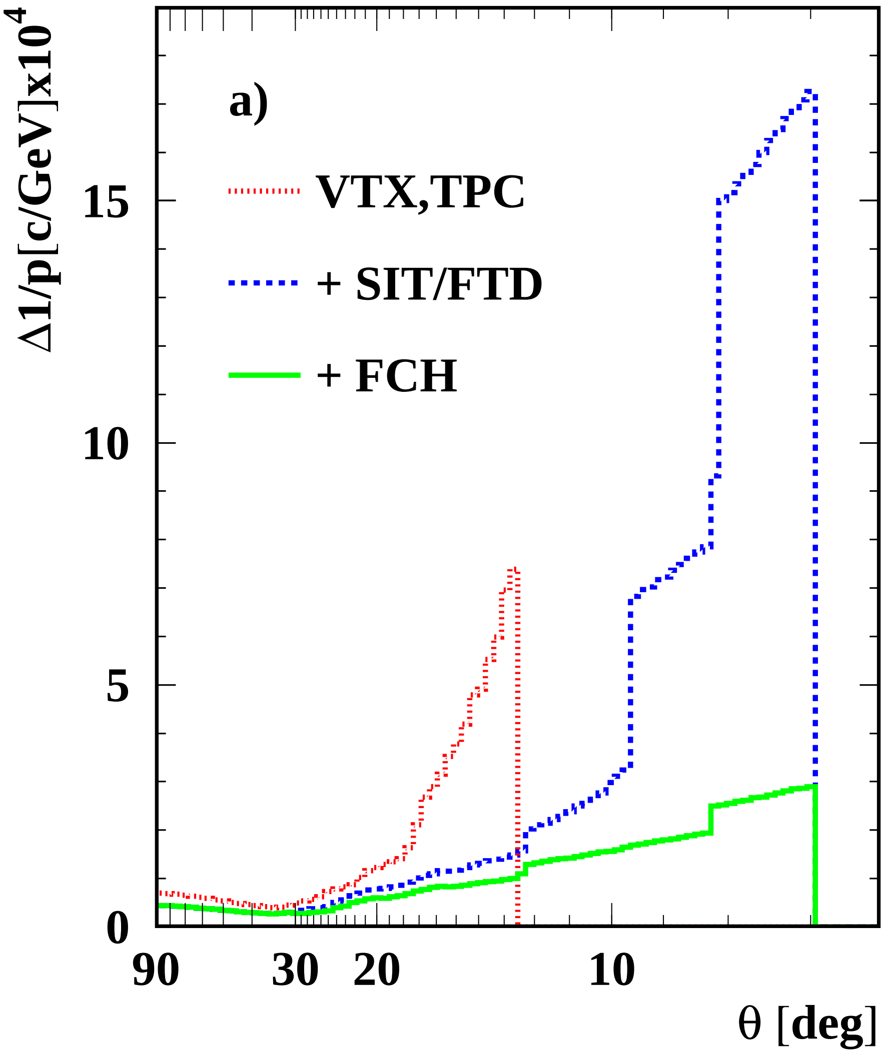
# Trigger

- Detector is designed without hardware trigger
- the full train is read out and sent to a PC farm
- bandwidth not larger than level 2 at LHC
- the system is completely deadtime free
- the complete detector information is available for event selection
- no need for fast detectors for triggering

# Detector performance

## Momentum resolution

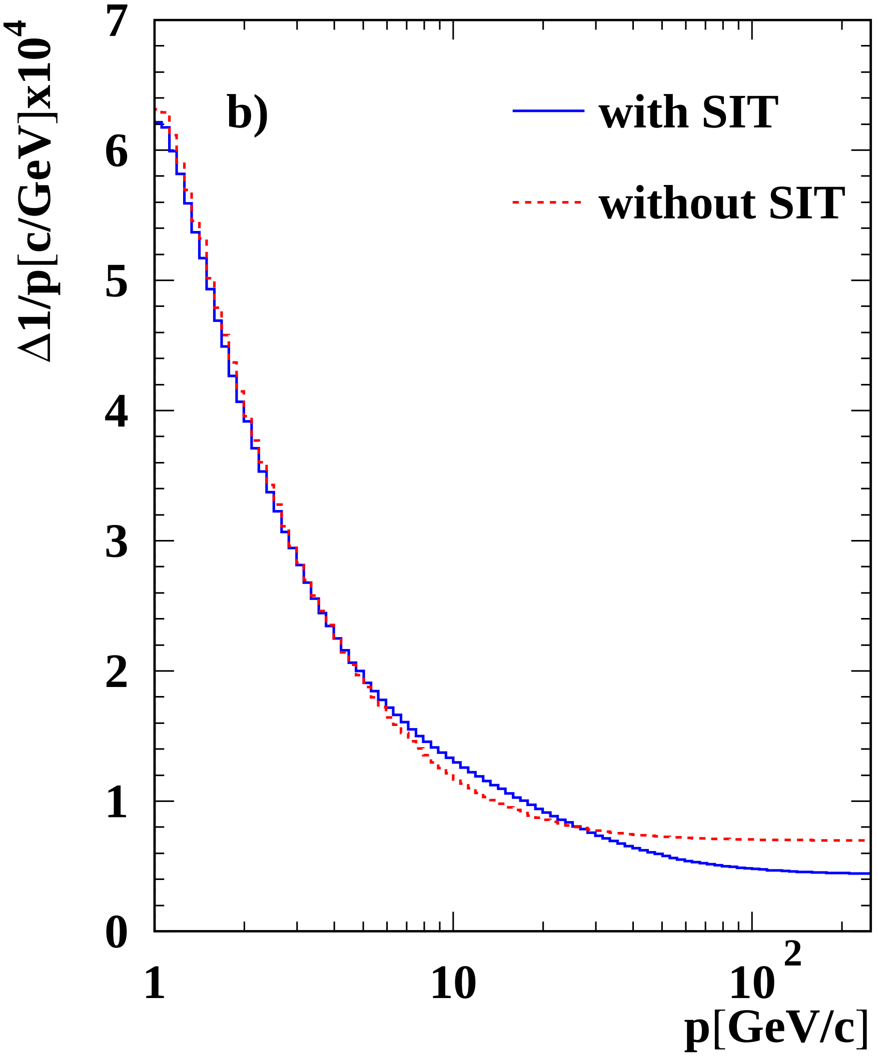
Resolution for 250 GeV muons:




Unique charge identification up to the maximal energy outside the mask

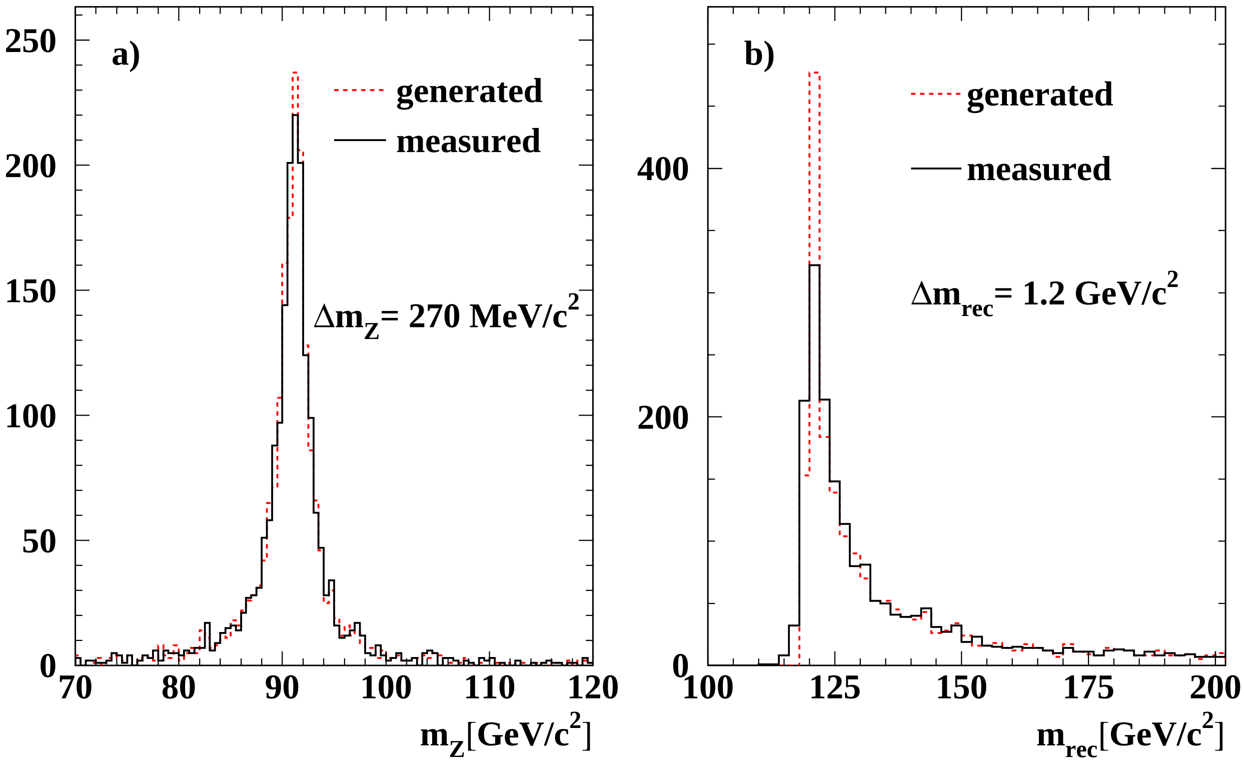
(e.g. 7% momentum error for 250 GeV muons at 7°)

## Resolution as a function of the momentum:



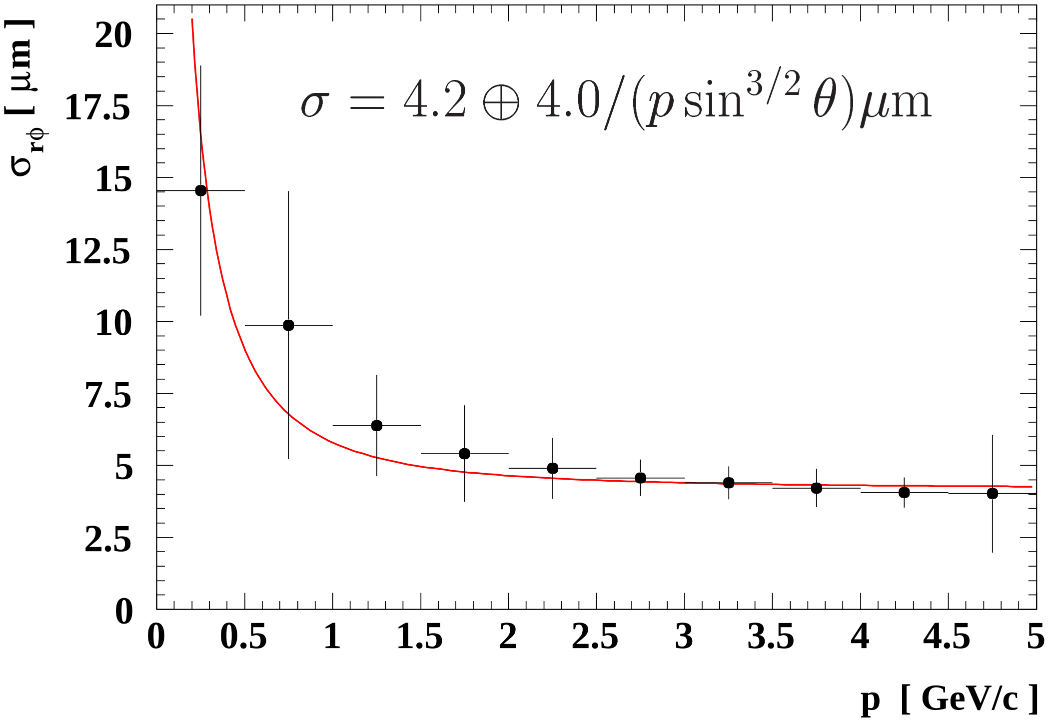

$\Delta\frac{1}{p} \approx 4 \cdot 10^{-5} / \,\mathrm{GeV}$ for large momenta

- Z-mass resolution in $e^+e^- \to ZH \to \mu^+\mu^-$ totally dominated by Z-width
- Recoil mass resolution slightly worse than width from beam energy spread

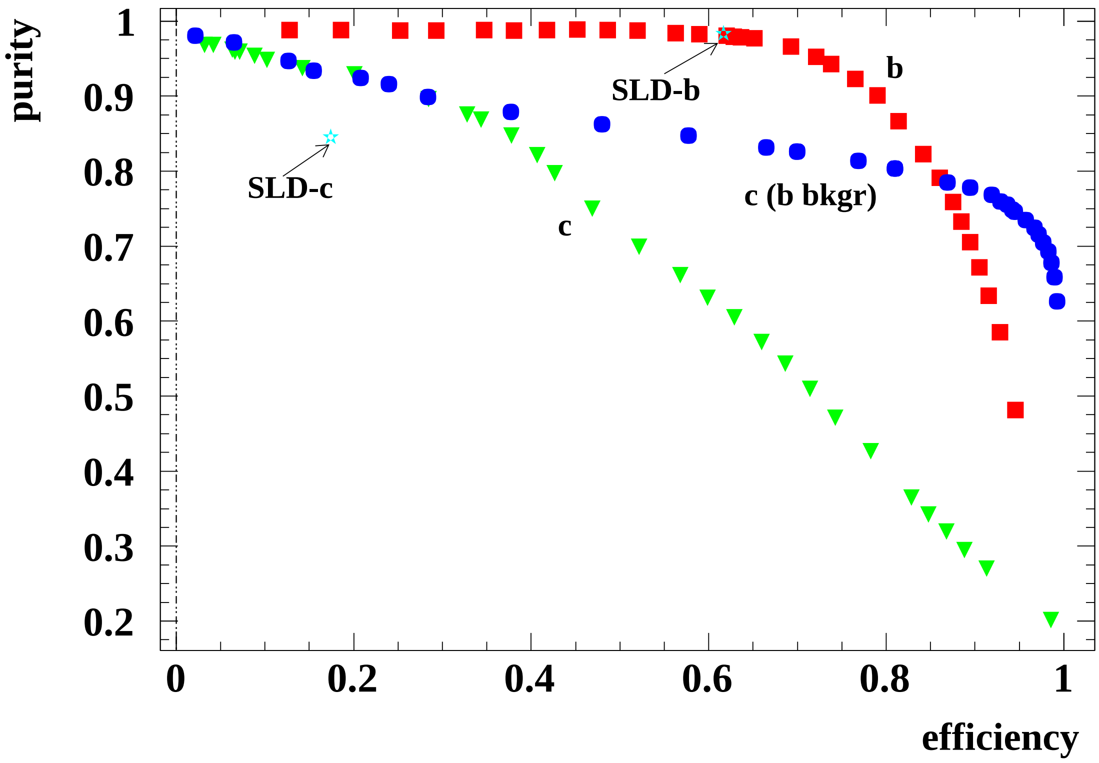


# b-tagging

## CCD impact parameter resolution:



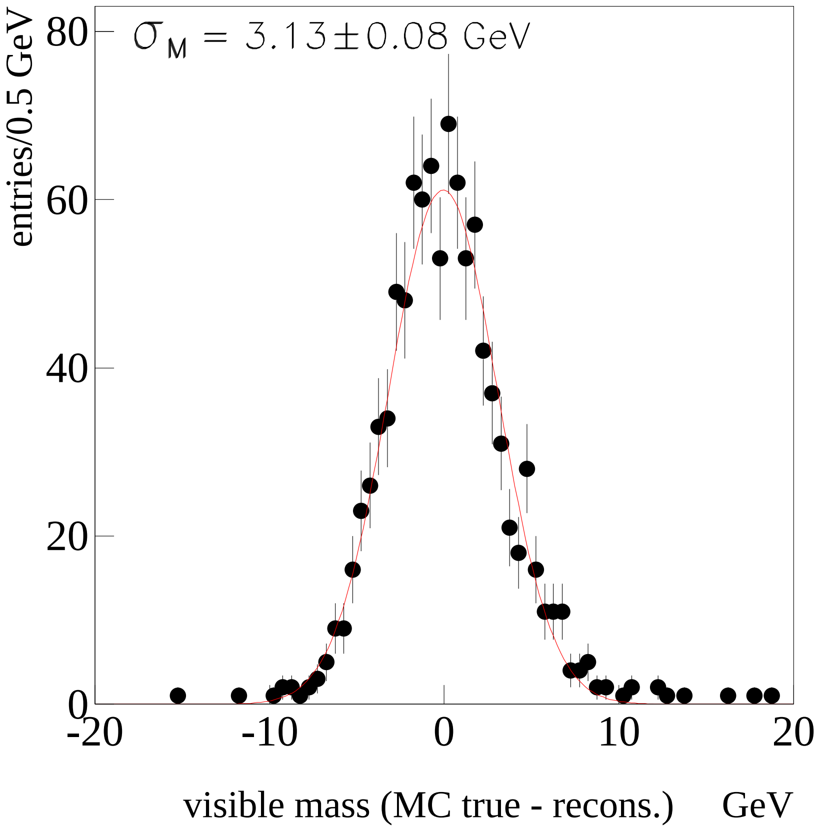

## b-tagging performance on Z-events with ZVTOP package (SLD) optimised for TESLA



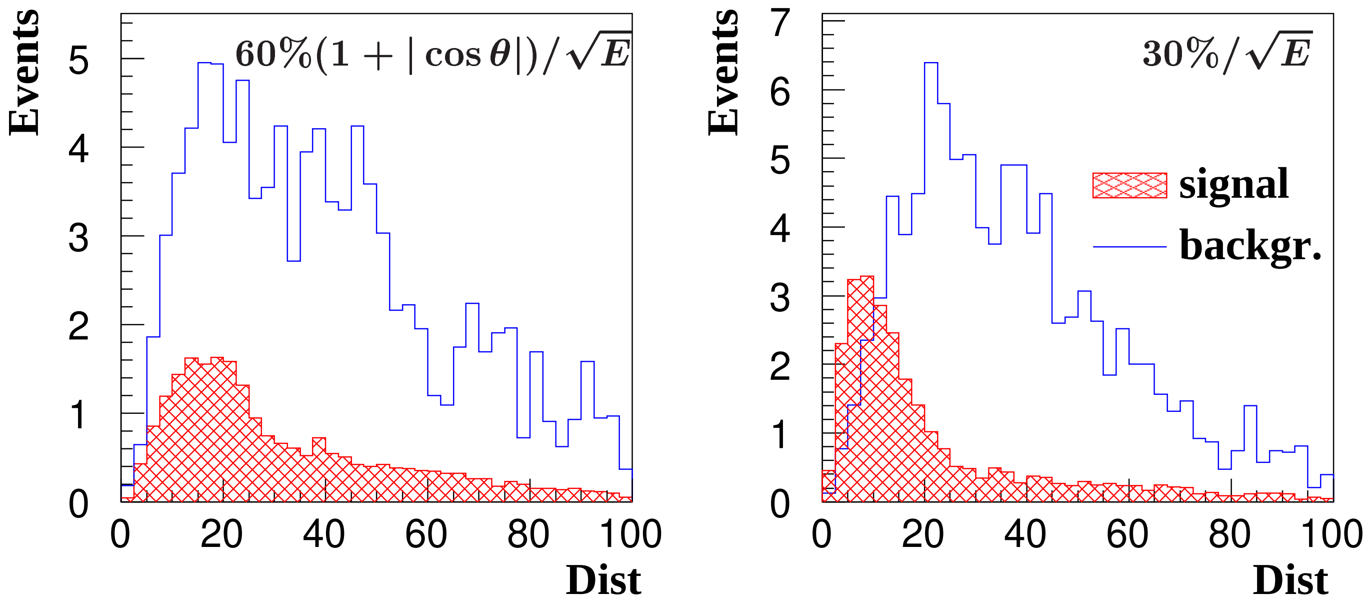
# Energy flow

$\Delta E/\sqrt{E} = 30\%$ reached with SiW+digital HCAL

$Z \to \mathrm{q}\bar{\mathrm{q}}$

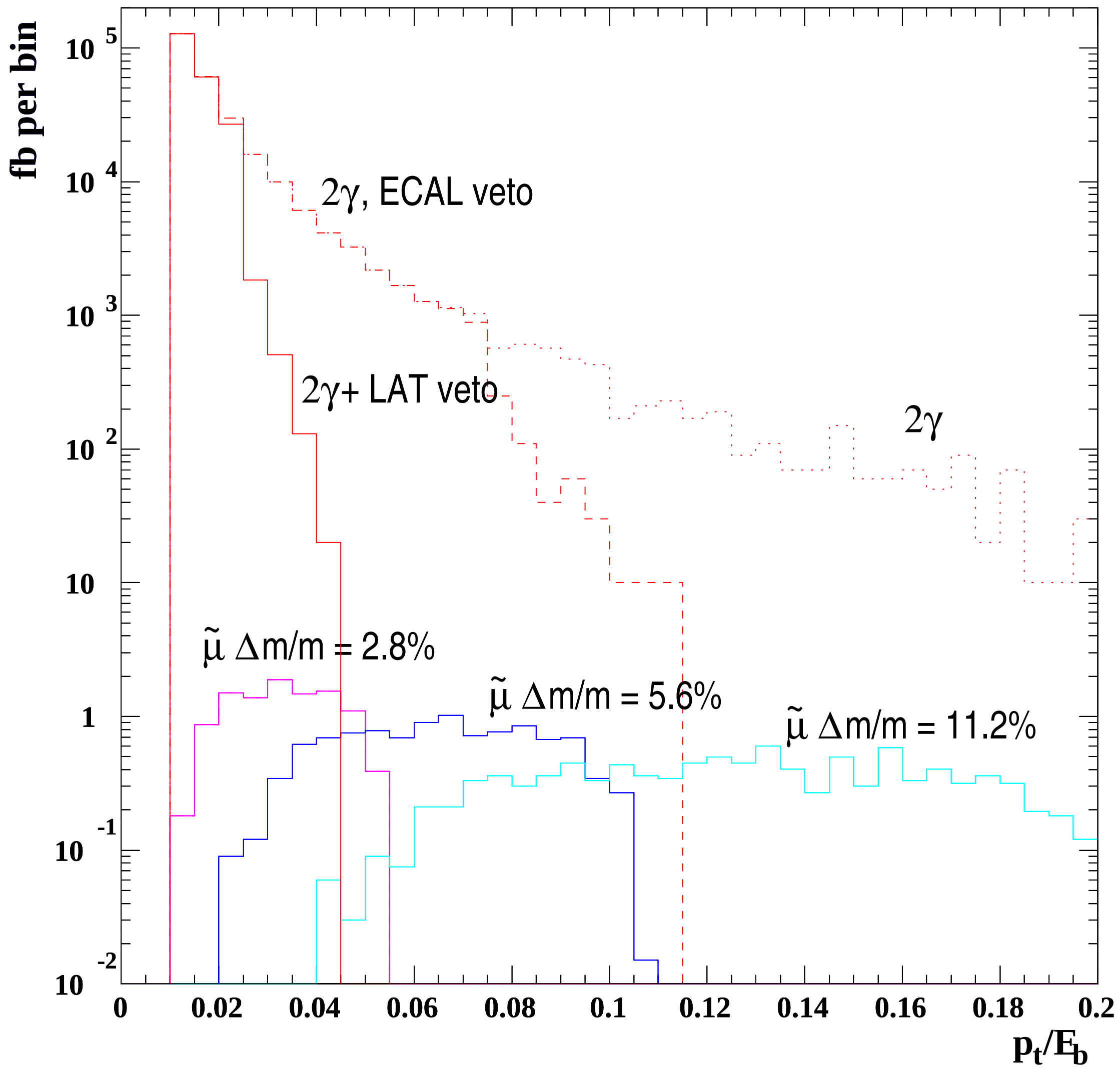



enables measurement of $\mathrm{e}^+\mathrm{e}^- \to ZHH$



# Hermeticity

## e.g. $\Delta m$ reach in $e^+e^- \to \tilde{\mu}^+\tilde{\mu}^-$



# Cost estimate

| | |
|---|---|
| Total cost of the detector | 160 – 280 MEURO |

Most expensive items:

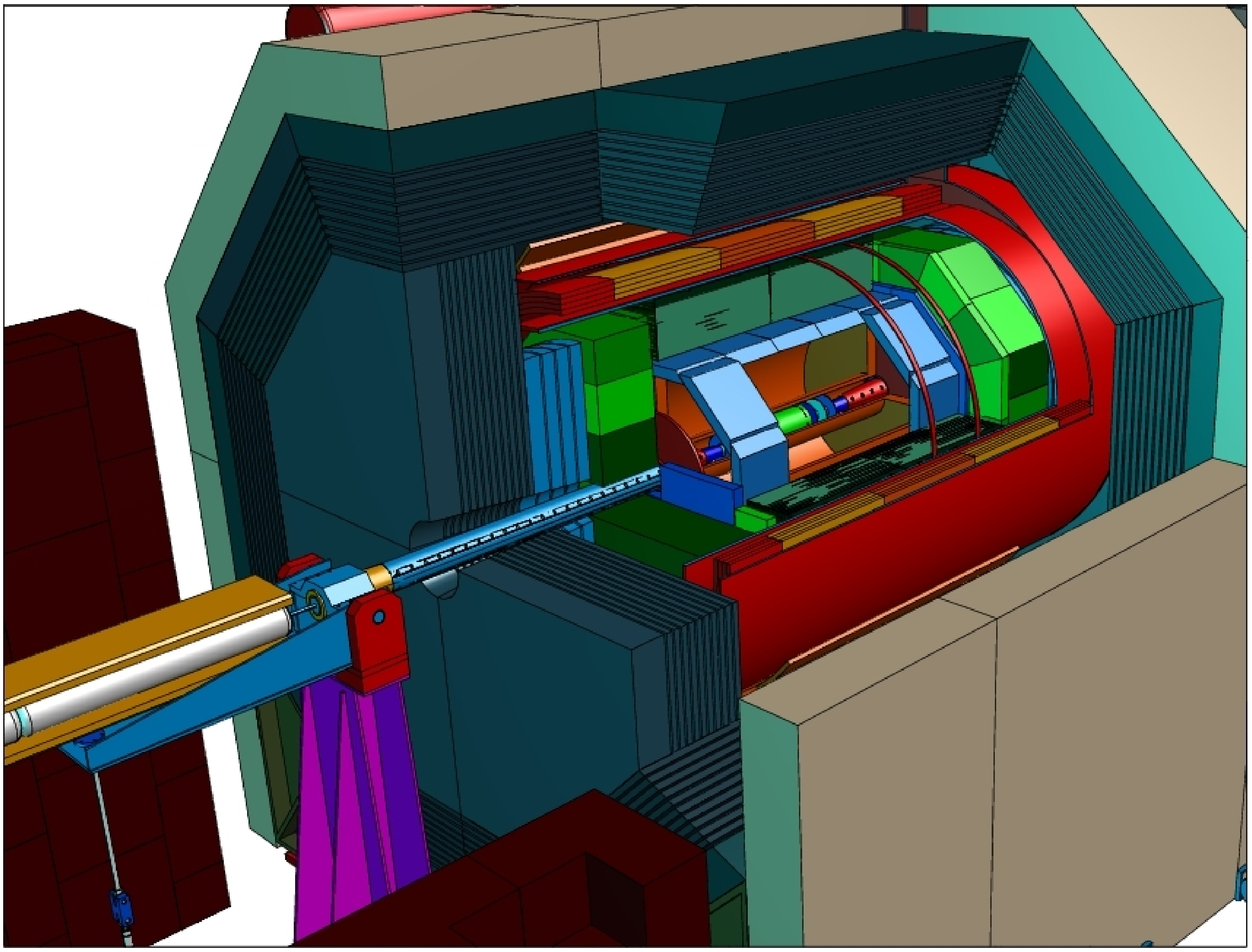
- ECAL:
  - SiW: 130 MEURO
  - shashlik: 20 MEURO
- HCAL: 20 MEURO
- coil: 65 MEURO
- TPC: 20 MEURO
- DAQ: 20 MEURO

Some remarks:

- we have shown, that we reach the Eflow goal with the SiW, but we don't know (yet) if we reach it with the shashlik
- the running cost of TESLA is about 120 MEURO/year

➠ already gaining 10% of the error in a 5 year program would be worth the additional investment for the SiW

## Conclusions



- A detector has been designed that can do the physics we want to do at TESLA.
- With this detector we can do the physics we want to do from $\sqrt{s} = 91\,\mathrm{GeV}$ to $\sqrt{s} = 800\,\mathrm{GeV}$.
- The degradation of the physics signals due to the detector is generally small.
- The status of and the need for R&D for this detector will be covered in the next talks.