Large (Tesla) detector concepts

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Large (Tesla) detector concepts

Summary

Introduction

Tracking

Calorimetry

Magnet + μ detector

Expected performance

Conclusions

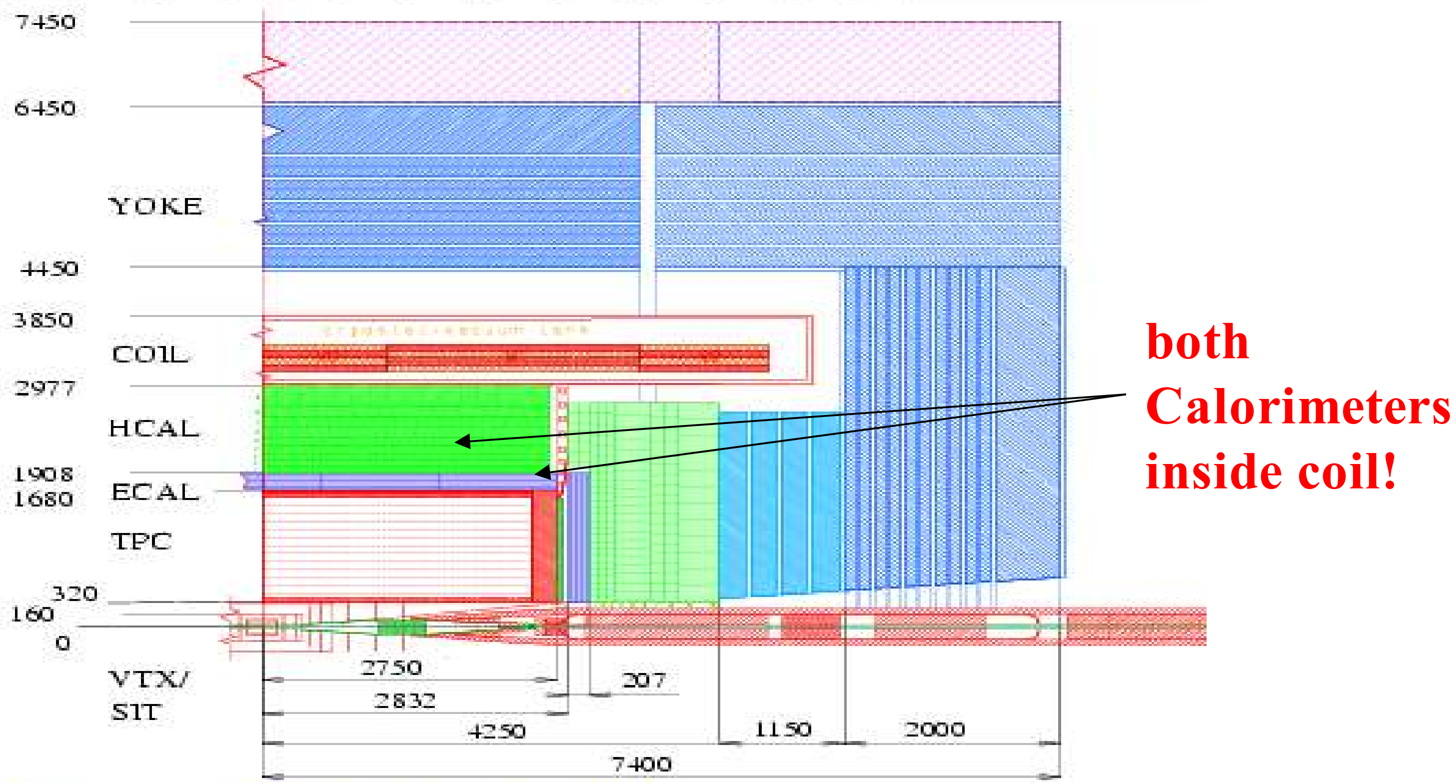
Introduction

Requirements-solutions

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

	TESLA	SD	LD	JLC
Tracker type	TPC	Silicon	TPC	Jet-cell drift
ECal				
$R_{\min}$ barrel (m)	1.68	1.27	2.00	1.60
Type	Si pad/W	Si pad/W	scint. tile/Pb	scint. tile/Pb
Sampling	$30 \times 0.4X_0$ $+10 \times 1.2X_0$	$30 \times 0.71X_0$	$40 \times 0.71X_0$	$38 \times 0.71X_0$
Gaps (active) (mm)	2.5 (0.5 Si)	2.5 (0.3 Si)	1 (scint.)	1 (scint.)
Long. readouts	40	30	10	3
Trans. seg. (cm)	≈ 1	0.5	5.2	4
Channels ($\times 10^3$)	32000	50000	135	5
$z_{\min}$ endcap (m)	2.8	1.7	3.0	1.9
HCal				
$R_{\min}$ (m) barrel	1.91	1.43	2.50	2.0
Type	T: scint. tile/S.Steel D: digital/S.Steel	digital	scint. tile/Pb	scint. tile/Pb
Sampling	$38 \times 0.12\lambda$ (B), $53 \times 0.12\lambda$ (EC)	$34 \times 0.12\lambda$	$120 \times 0.047\lambda$	$130 \times 0.047\lambda$
Gaps (active) (mm)	T: 6.5 (5 scint.) D: 6.5 (TBD)	1 (TBD)	2 (scint.)	2 (scint.)
Longitudinal readouts	T: 9(B), 12(EC) D: 38(B), 53(EC)	34	3	4
Transverse segmentation (cm)	T: 5–25 D: 1	1	19	14
$\theta_{\min}$ endcap	5°	2°	2°	8°
Coil				
$R_{\min}$ (m)	3.0	2.5	3.7	3.7
B (T)	4	5	3	3

TESLA TDR



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

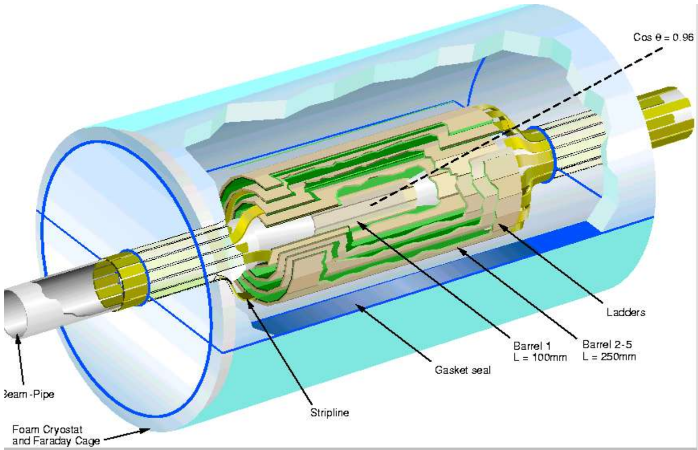
HCAL $\Rightarrow \frac{\delta E}{E} \leq 0.50\frac{1}{\sqrt{E(GeV)}} \oplus 0.04$, granularity

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)

Tracking: Vertex Detector



TESLA

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

layout for all technologies :

- **Pixels (3D)⇒ 1 Gpixel**
- **inner layer as closest as possible to I.P.**
- **5 layers for independent tracking**
- **layer thickness ~ 0.1 X_0**
- **Point precision < 5 μm/layer**
- **Good segnal/noise ratio**
- **Not extreme radiation resistence required**

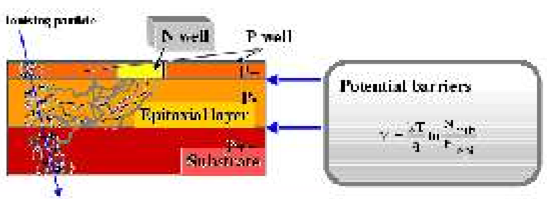
Tracking :V.D.

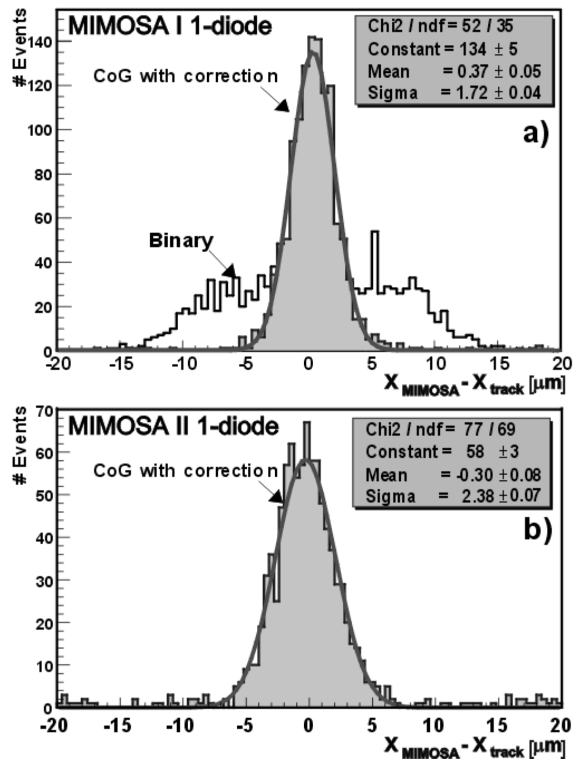
- CCD
  needs R&D:
  reduction of material with unsupported Silicon
  improving of the clocking rate
  improving the radiation hardness

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 × 13	3.3	8/1	50 MHz/50 μs	4.3	761
2	26	125 × 22	6.9	8/2	25 MHz/250 μs	2.4	367
3	37	125 × 22	6.9	12/2	25 MHz/250 μs	0.6	141
4	48	125 × 22	6.9	16/2	25 MHz/250 μs	0.1	28
5	60	125 × 22	6.9	20/2	25 MHz/250 μs	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: ϵ>99%, 20μm pitch $\Rightarrow \sigma \sim 2\mu m$



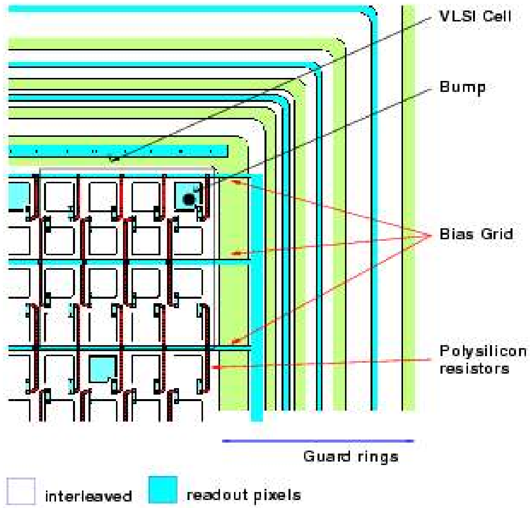


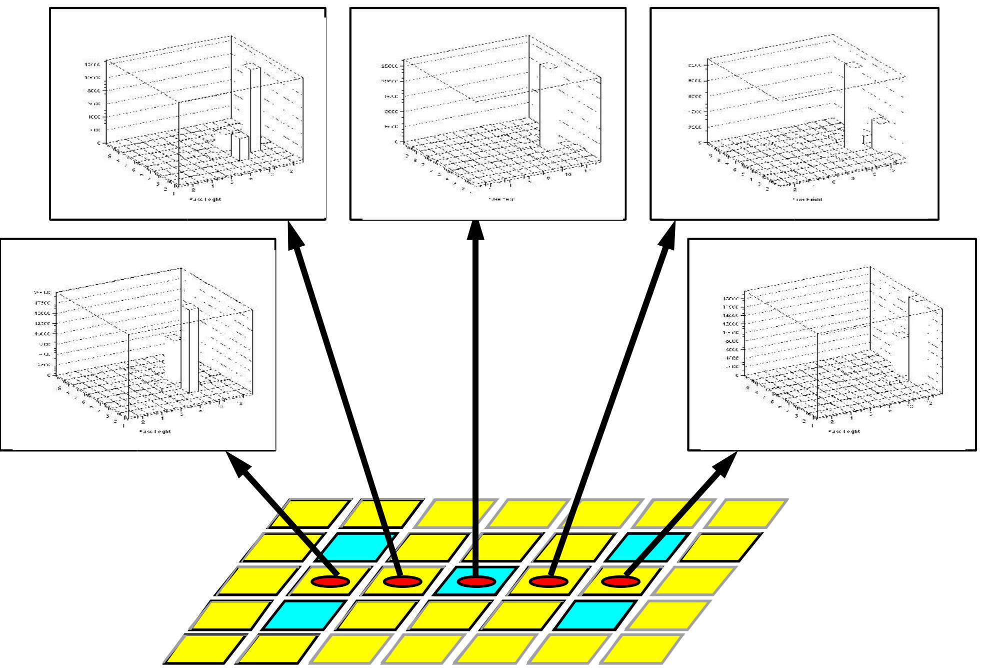
Tracking :V.D.

• **pixels**

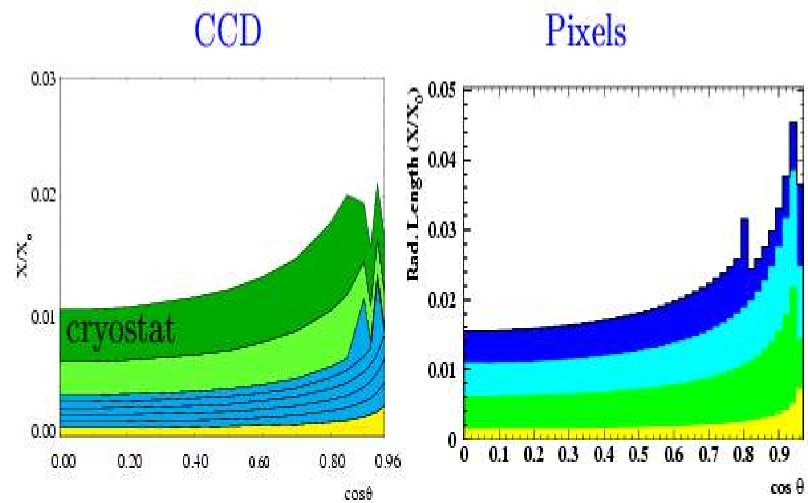
segnals with alternate read-out: capacitive charge division

goal: $\sigma < 7\ \mu m$



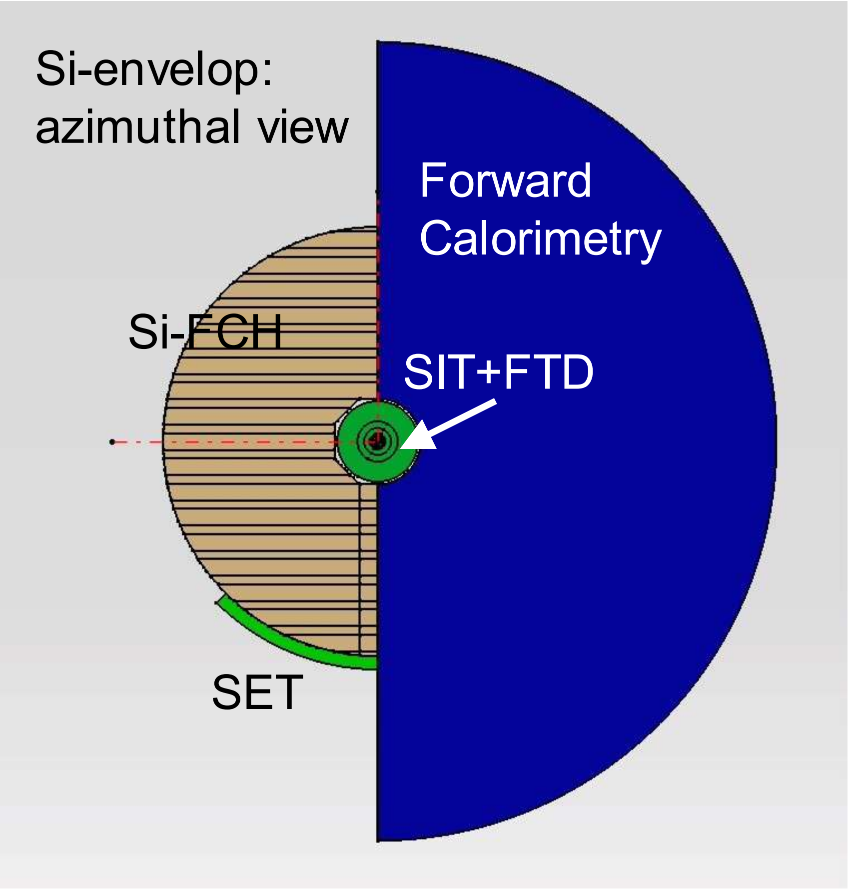


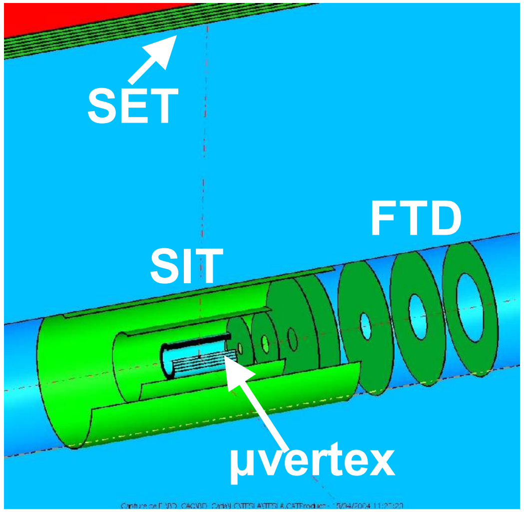
Matherial budget



The Si-Envelop and integration issues

(Intermediate tracking)+…





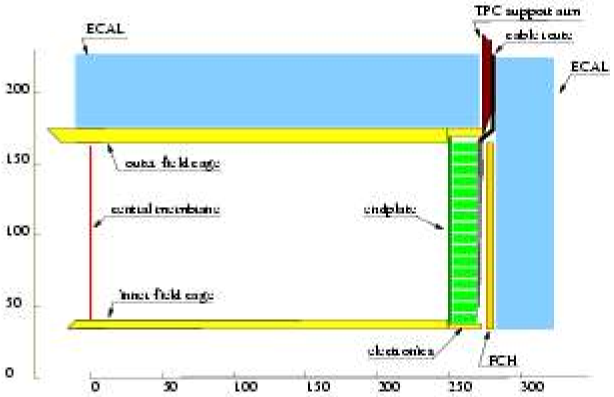
The Si-envelop is presently made of:
SIT (2 double-sided layers)
+ FTD (7 wheels, 3 pixels + 4 microstrips)
SET (3 layers: 2 single sided+1double-sided)
+Si-FCH (4 XUV planes)
The technology (all but FTD)=long μstrips

In the case of a large detector (i.e. with a TPC as central tracker), the components of the Si-Envelop are in strategic positions.

The integration issues are addressed both on the mechanical and simulation sides

*from A. Savoy-Navarro

TPC



- In use (LEP + STAR , ALICE)
- much less tracks

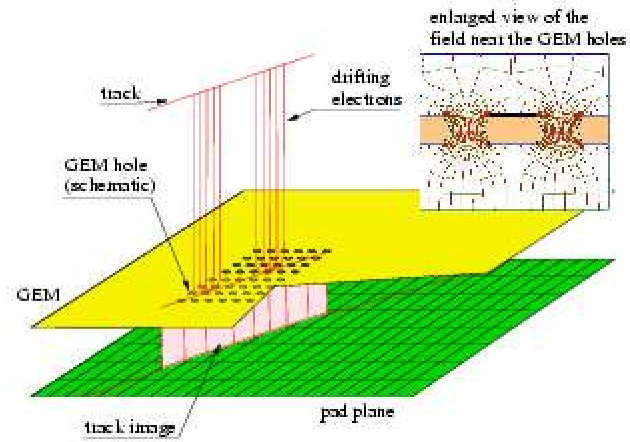
tracks 3 d,~ no P.R.

- 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

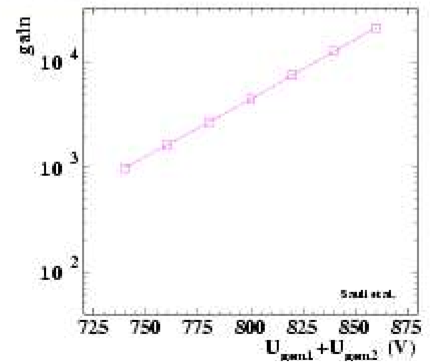
problems with MWC (ExB, ions, end plate thickness?) solutions: GEM, Micromegas

GEM

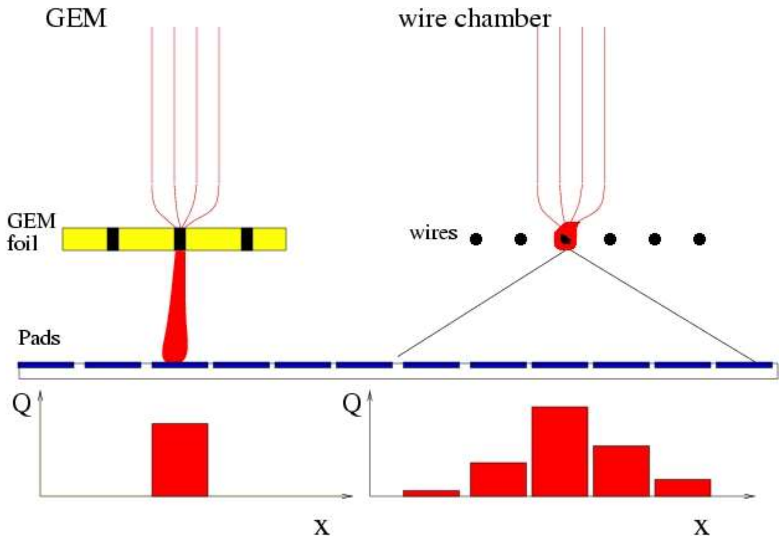
Thin polymer foil with metal coating on both si
holes $\sim 100\mu m$ apart,
$\Delta V \Rightarrow$ **E**$\sim$ 80kV/cm



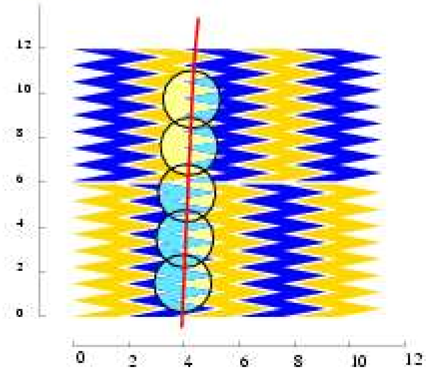
- Gain $\mathcal{O}(10^3)$
- 2 GEM cascade



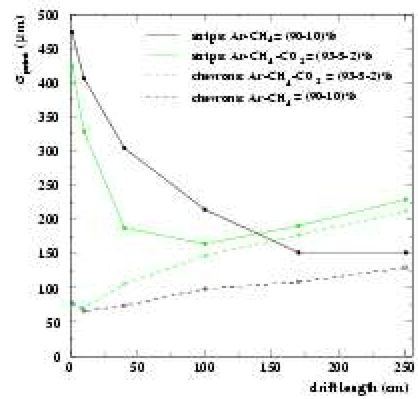
effect comparison



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



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



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

Calorimetry

General overview

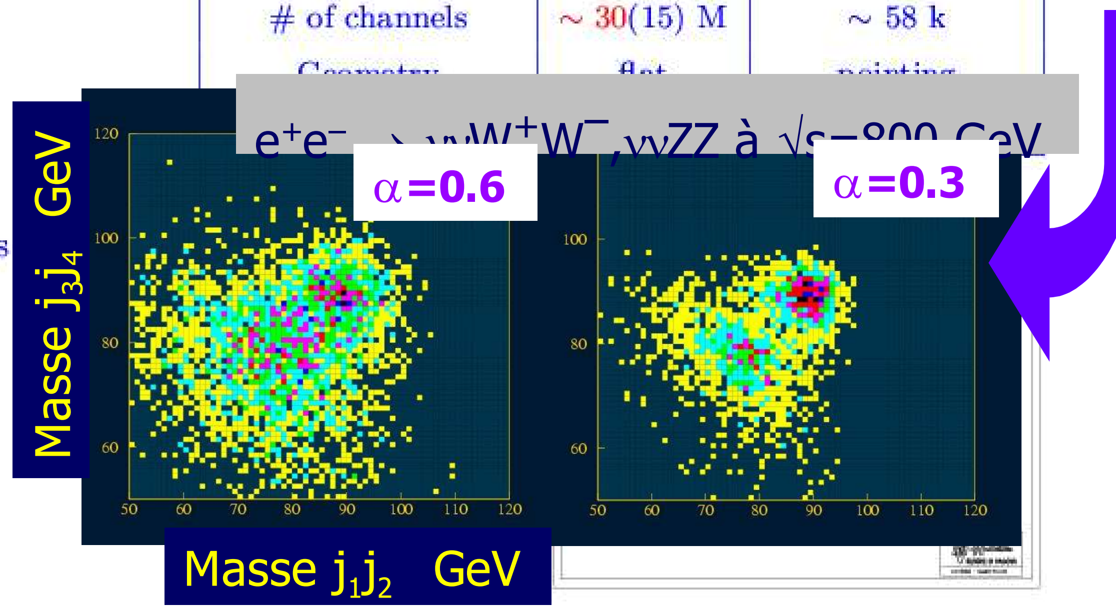
- From Physics:
complex hadronic final states (i.e. $t \to bW$)
missing energy (i.e. ν, $\tilde{\nu}$)

- 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
  calorimeters inside the coil

- Where granularity has the largest importance

- TDR: 2 solutions

	SiW	Shashlik
Absorber (X_0/layer)	W 0.4 ÷ 1.2	Pb 0.18
Detector	Si 500μm	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

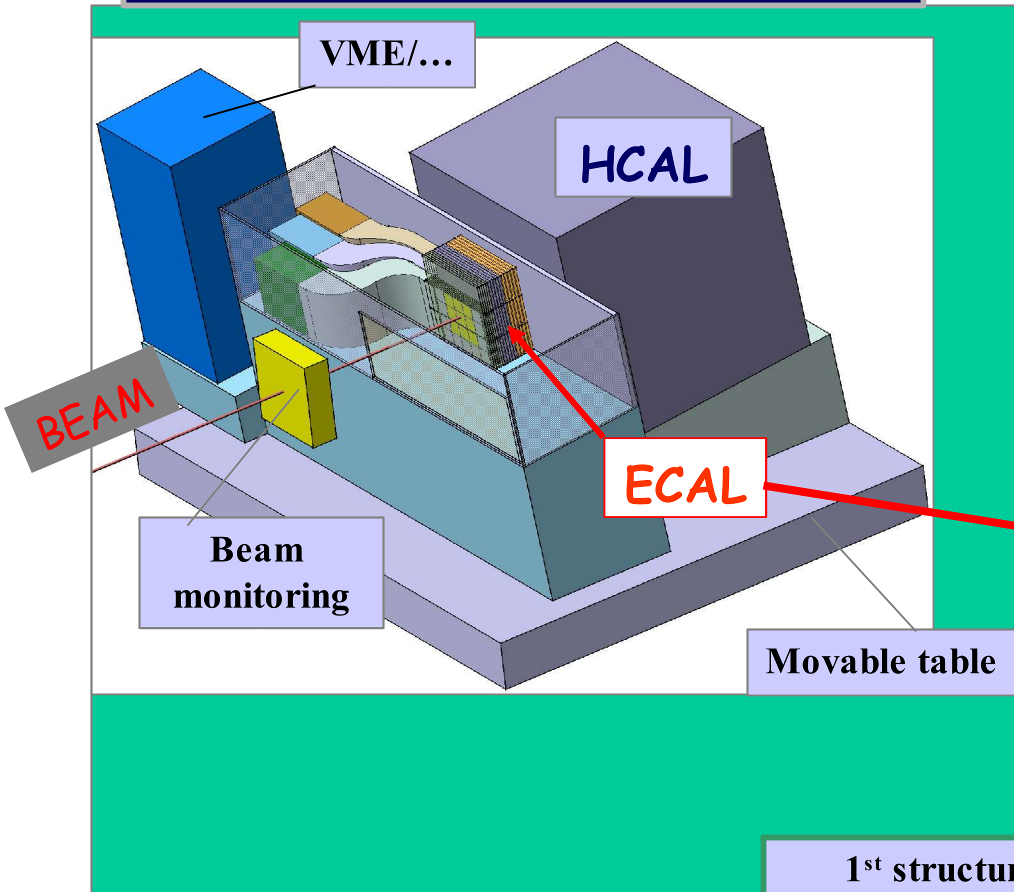


* $\delta E/E = \alpha/\sqrt{E} =$

60%x≈0 +25%x≈10%/√E +10%
x≈80%/√E + $\delta_{confusion}$

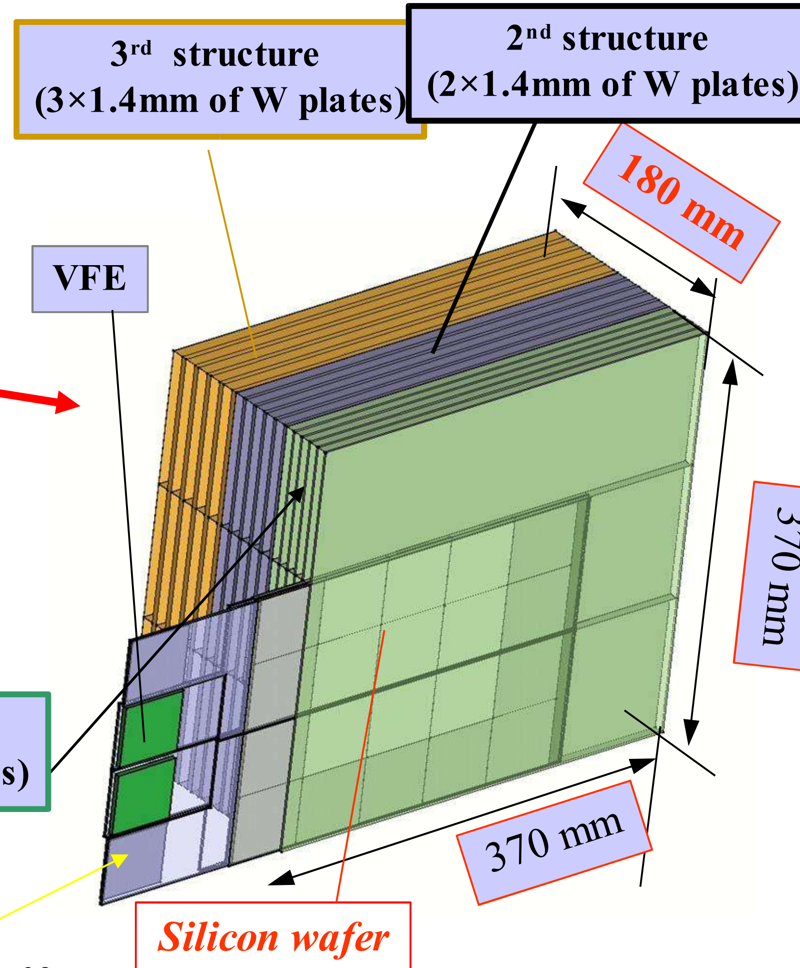
SiW

Global view of the test beam setup

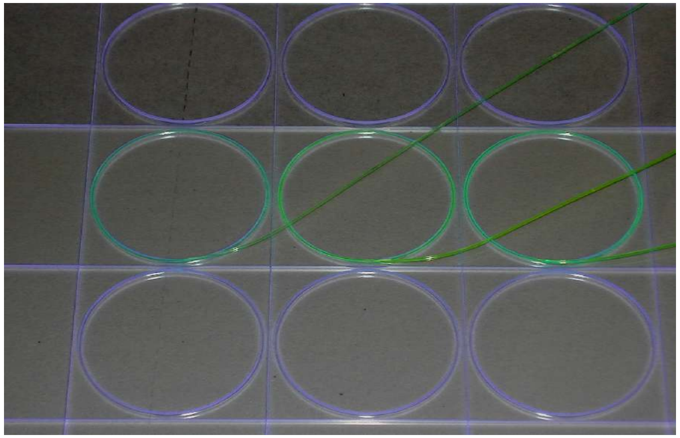


Prototype overview

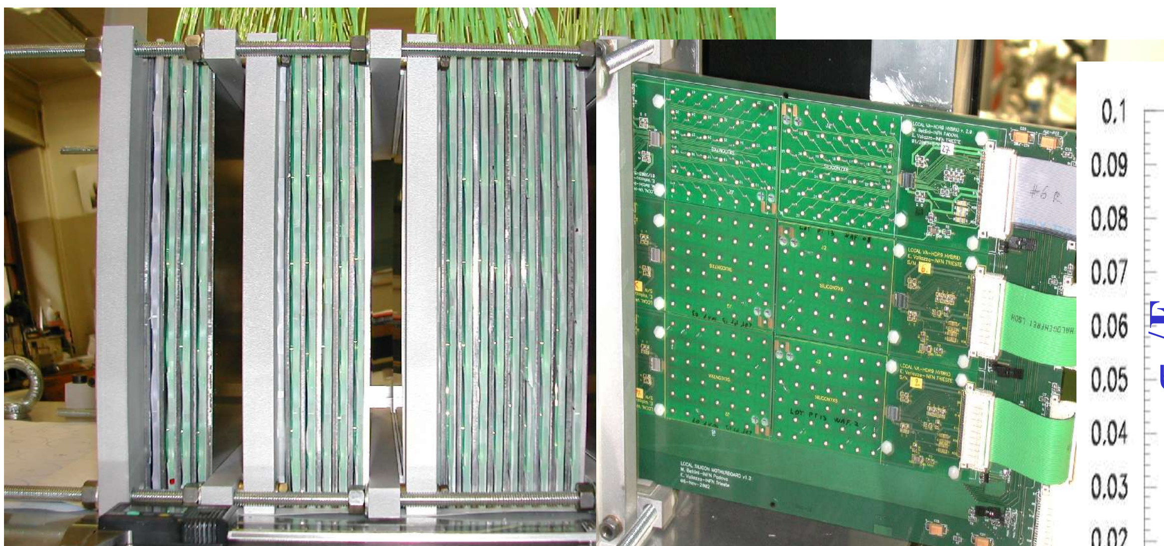
ECAL general view



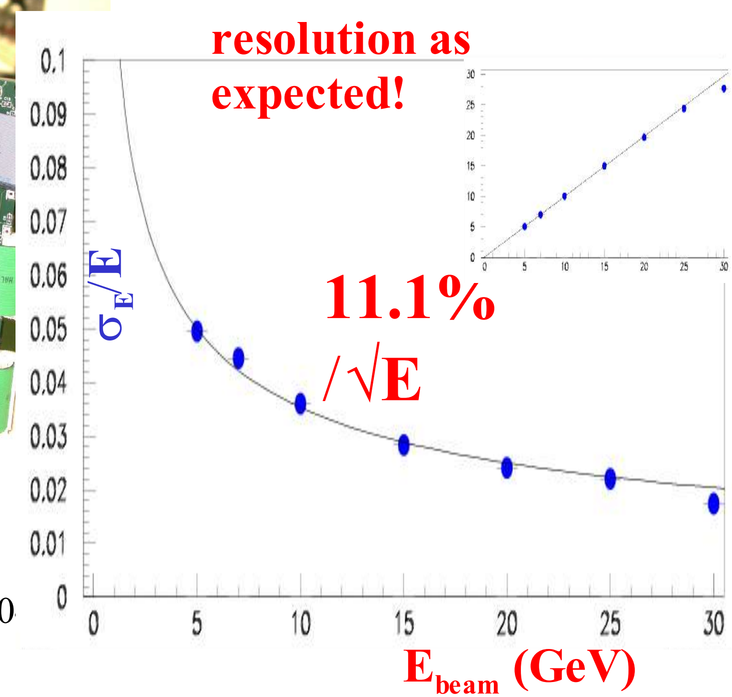
Alternative Hybrid Solution: LCCAL



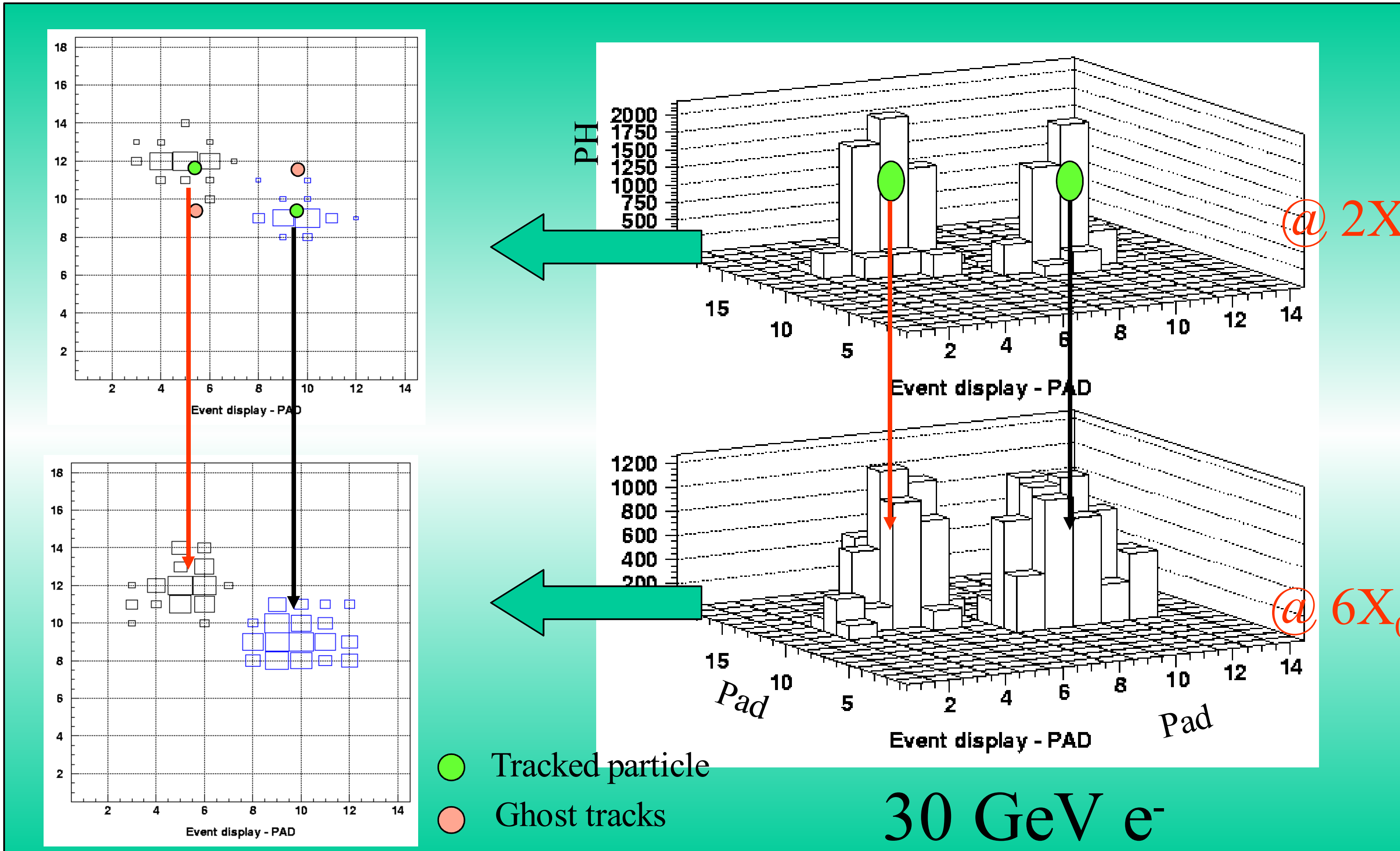
- 45 layers
- 25 × 25 × 0.3 cm³ Pb
- 25 × 25 × 0.3 cm³ Scint.: 25 cells 5 × 5 cm²
- 3 planes:
- 252 .9 × .9 cm² Si Pads
- at: 2, 6, 12 X_0



Test Beam: E resolution as expected!



Test beam results: Si Pad two particle separation

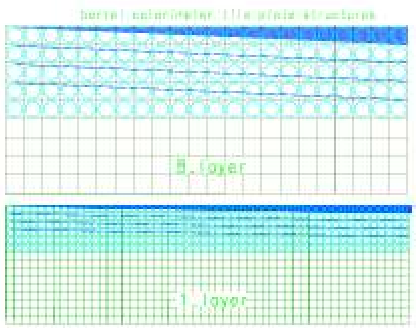


Hadronic Calorimeter

TESLA

- 2 solutions 4.5λ

- σ tail
  38 layers Fe/Sc/fibers (mm) 20/5/1.5
  Transv. Dim (cm^2) $5 \times 5 \div 25 \times 25$
  Long. Segm. 9
  Layers per segm. $3 \div 7$



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

- MiniCal prototype operational in e+ beam @ DESY
- 3 types of photo-detectors tested (PM, SiPM, APD) See i.e. E.Garutti this LCWS….

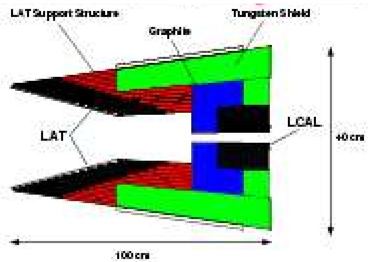
❖ Scin "pixels"/SS	Digital	9 cm^2 hexagonal tiles NIU
❖ RPC/SS	Digital	1 cm X 1 cm pads (many)
❖ GEM/SS	Digital	1 cm X 1 cm pads (UTA)
❖ Cerenkov compensated	Analog	

14-11-03, ECFA workshop G. Eigen, U Bergen/DESY 18

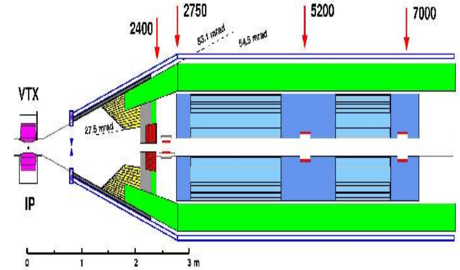
…+ all the excellent work shown in this LCWS

Calorimetry: Forward Region

TDR L*=3m



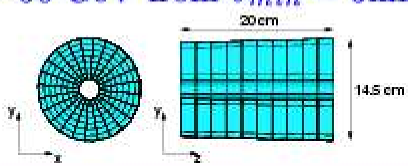
L*=5m



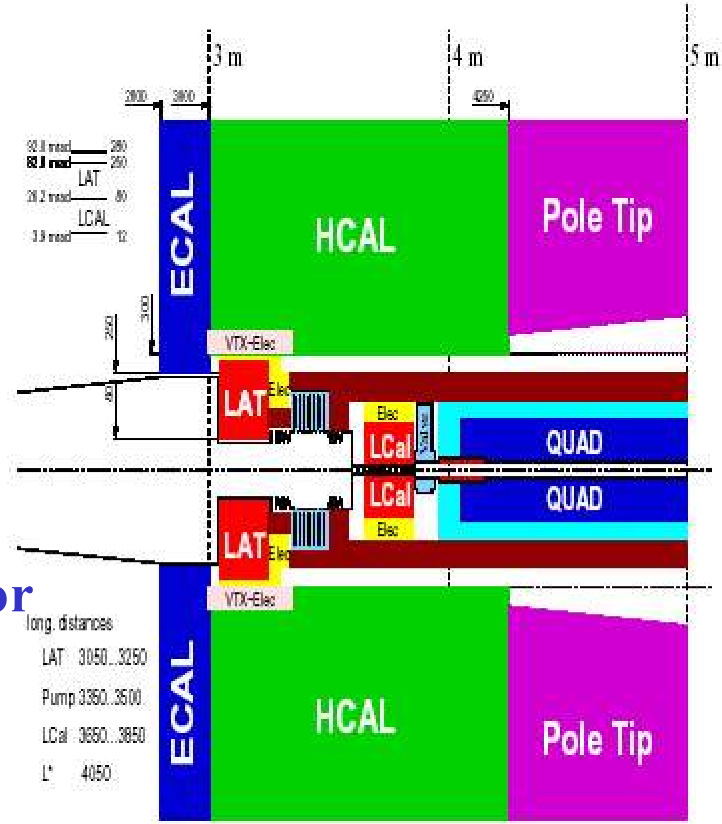
- Low Angle Tagger
  $83.1 \div 27.5$ mrad
  63 layers W/Si (mm) 2.6/0.5 $\Rightarrow \sim 47X_0$
  14 segments r, 24 ϕ
  $\Delta E \sim 20 \div 25\% \times \sqrt{E}$
  up to E=E_{beam}

SiW

- Luminosity CALorimeter
  $\theta_{min} = 4.6$mrad
  63 layers W/Si(C) (mm) 2./0.5 $\Rightarrow \sim 36X_0$
  7 segments r, 24 ϕ
  Integrate 20 TeV/BX
  background subtract. dominates resolution
  $e^{\pm}$ with E> 50 GeV from θ_{min} = 5mrad

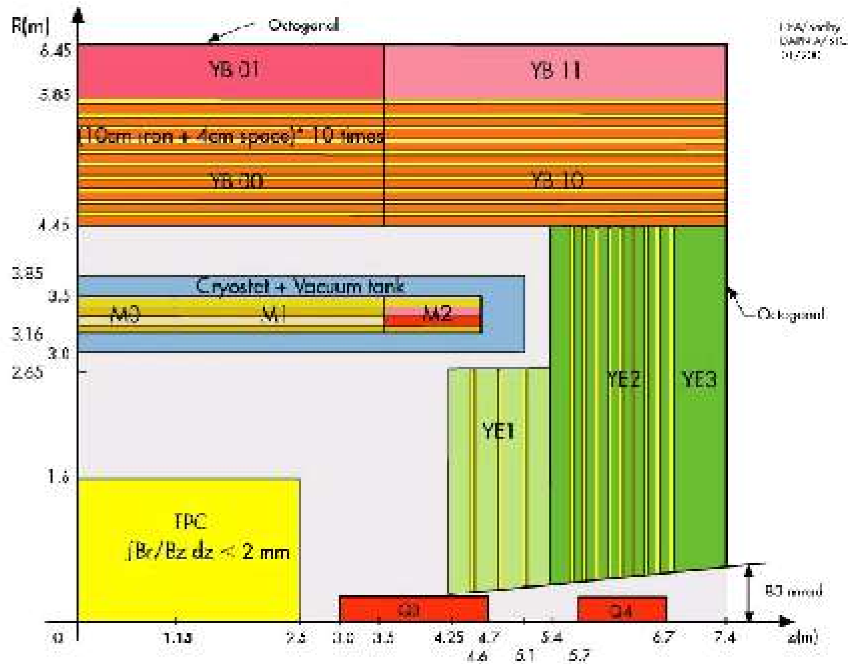


SiW or Diamonds/W or Cristals



goal: $\Delta L/L \sim 10^{-4}$

Magnet and muon detector

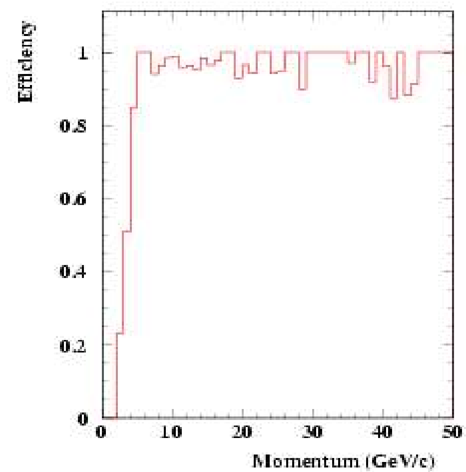


- Based on CMS design
- B=4 T in 6 m diameter di, 9.2 m length
- high omogeneity (TPC)
- Coil: 5 modules, 4 windings
- Correction in the external modules
- Yoke: 10 layers Fe/μch 10/4 cm

μ layout:

-12 (end-cap:11) RPC or streamer tube layers
- 3 parts/layer: 370,700,370 cm
- 6 modules (122 cm), 12 modules (115 cm)
- ~3 cm strips, 25x25 cm^2 pads
- ~5000 m^2 in total

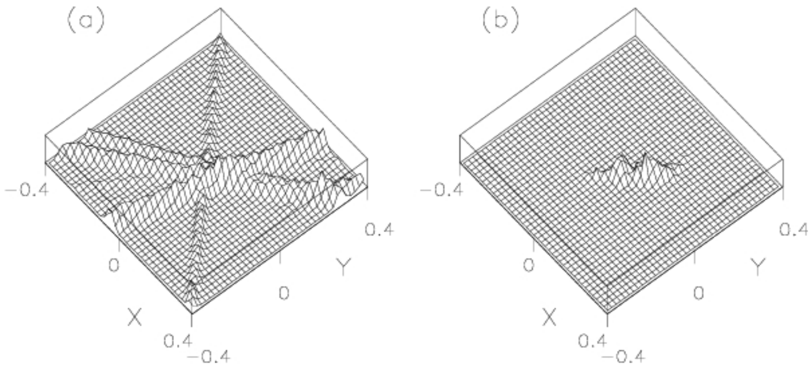
μ identification (to be ass. to the centr. detect.)

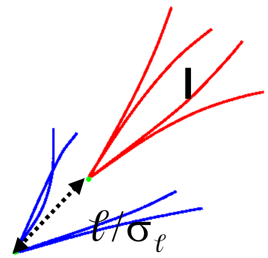


- measure hadronic shower tails
ΔE~150%$\sqrt{E}$ $\oplus$20%

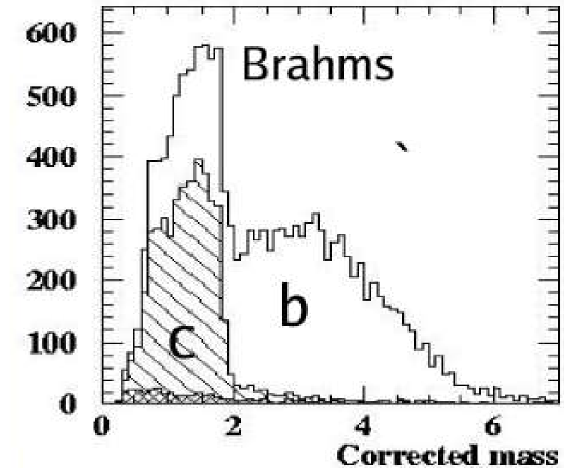
Expected Performance:Flavour Id.

topological vertex*



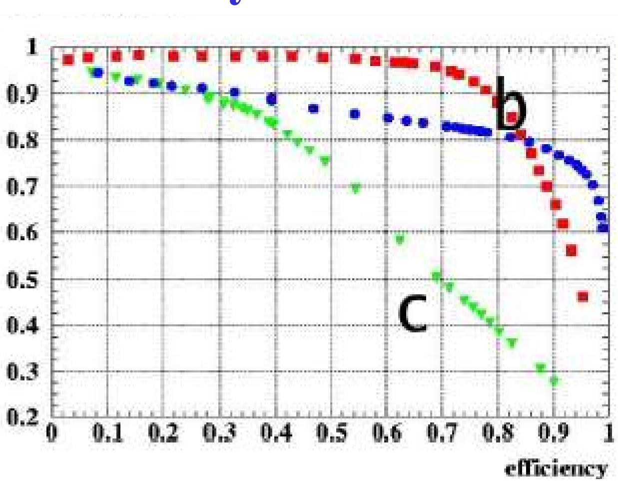


vertex mass

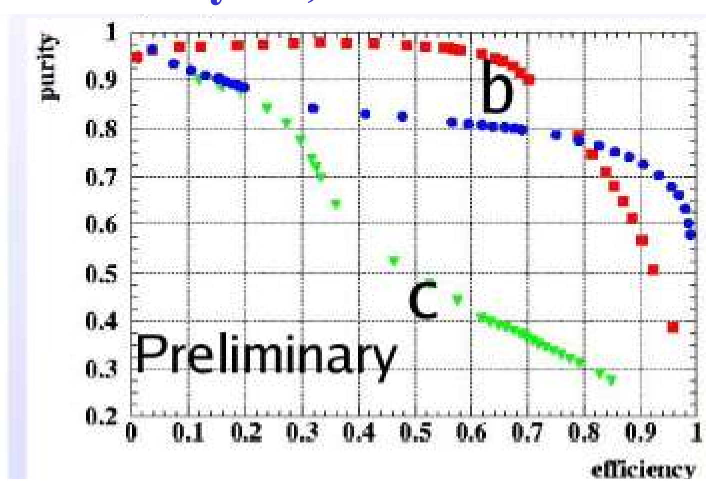


use Neural Network:

5 layers

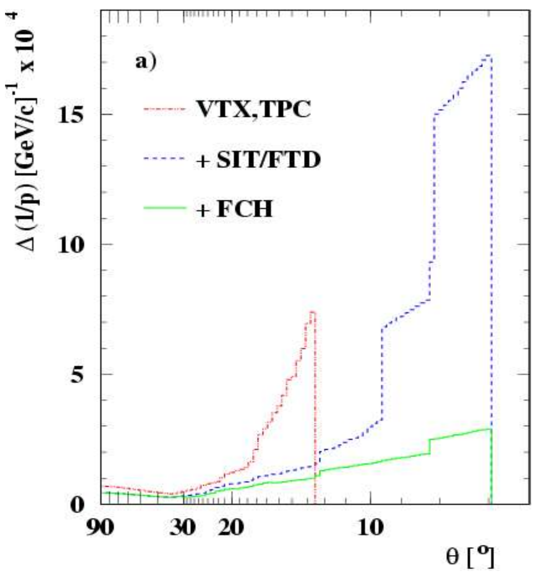


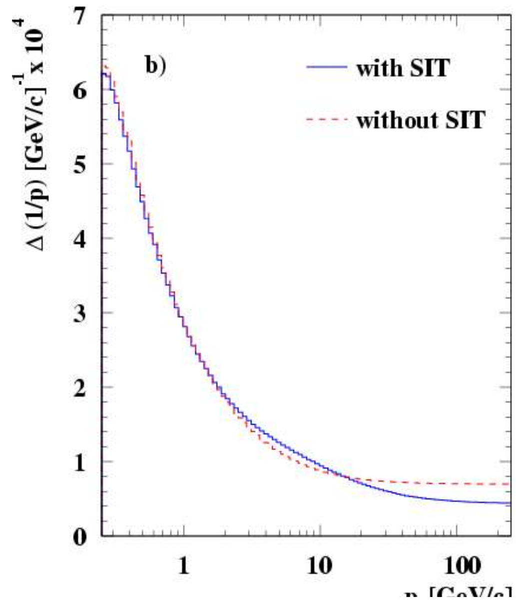
4 layers,double thickness



*T. Kuhl Amsterdam 2003

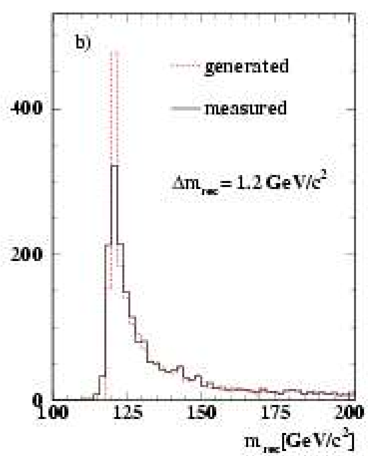
Expected Performance: momentum resolution

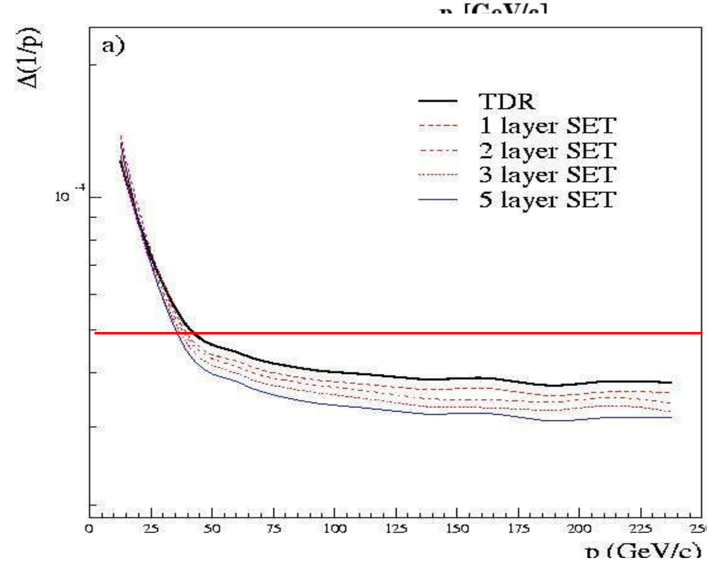




$e^+e^- \to ZH \to l^+l^- H$

BRAHMS + fit:
complete
simulation/recostr.



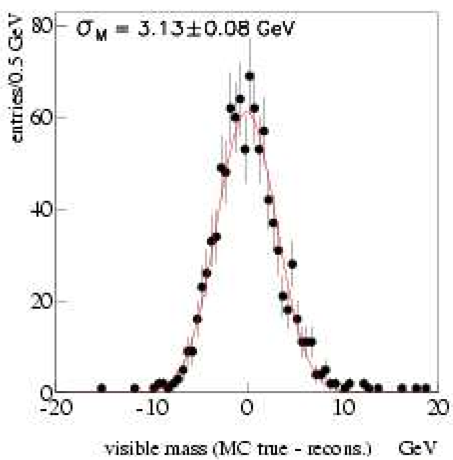


$5x10^{-5}$

Expected Performance:

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

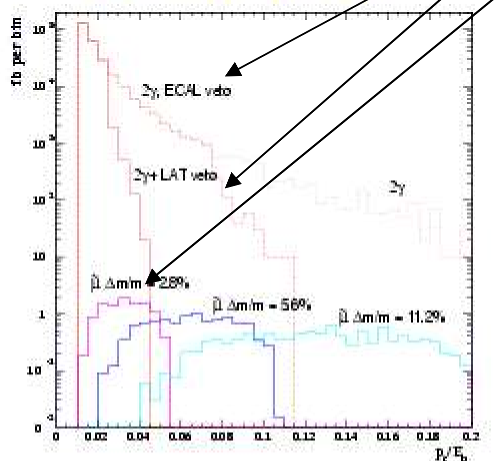
$Z^0 \to q\bar{q}$ at rest



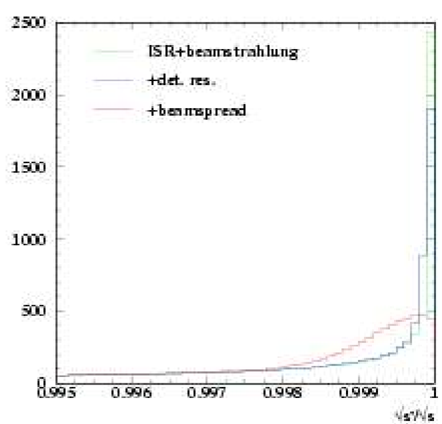
- Hermeticity
  p_t with mask calorimeters

veto on the outgoing electron

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



- Luminosity spectrum
  Bhabha events in FTD



Conclusions

A "Large" detector as the TESLA one is adequate for the Physics Program of a Linear Collider

- still R&D (done and) to be done but…
- No big principle problems

    excellent momentum resolution

    high precision in impact parameter (Flavour tagging)

    jet energy recostruction (with many solutions for calorimeter realization)

    hermeticity

Backup

machine conditions

DAQ

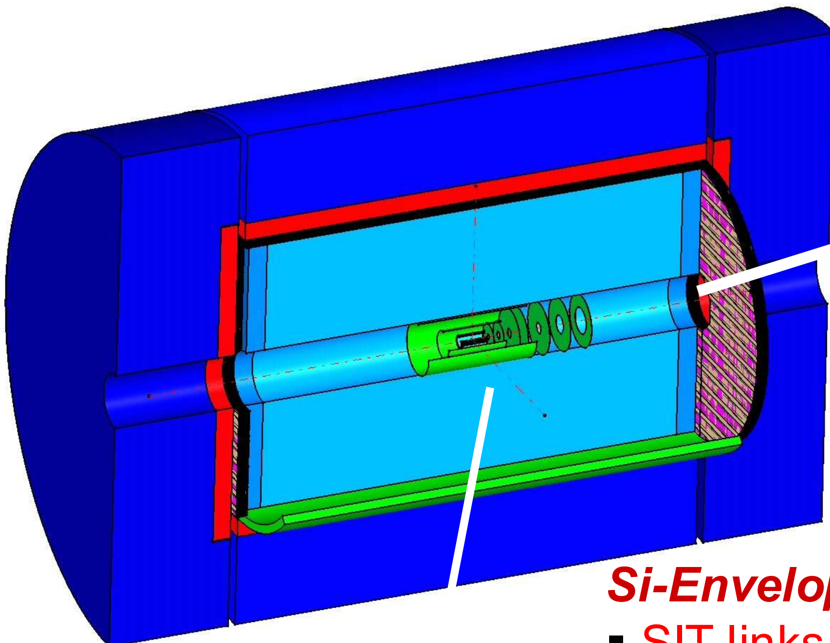
- Long time between bunch trains: 199 ms
- Bunch separation in a train: 337 ns
- Train length: 950 μs (2820 BX)
- $L = 3.4 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, σ, background
  $\Rightarrow$ 220 MBytes/train

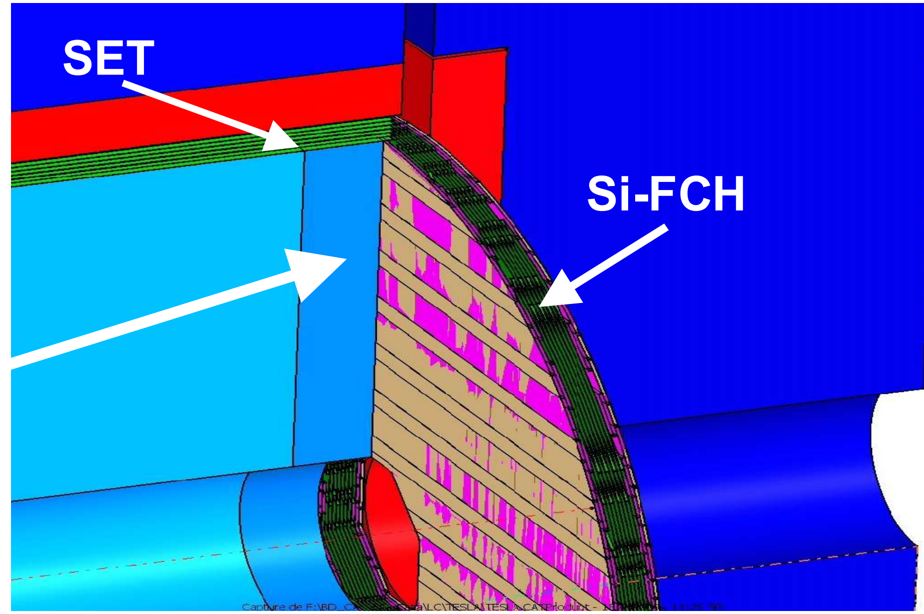
$\Downarrow$

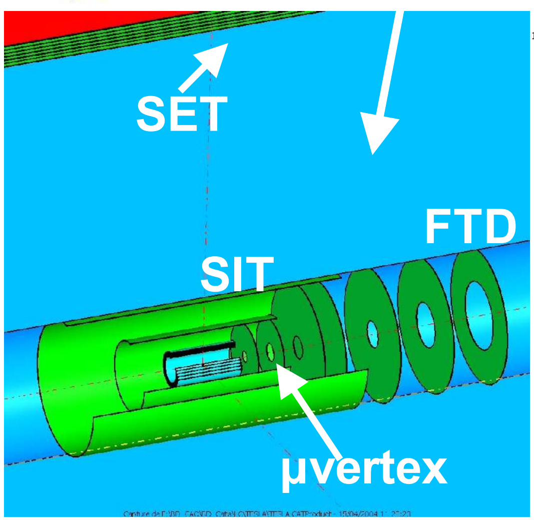
- Hardware trigger unnecessary
- Data in pipeline for 1 ms, no dead time
- 200 ms for pipeline ready
- Software event selection
- Moderate throughput w.r.t. LHC

Beamstrhlung

- $\delta E \sim 3\%$







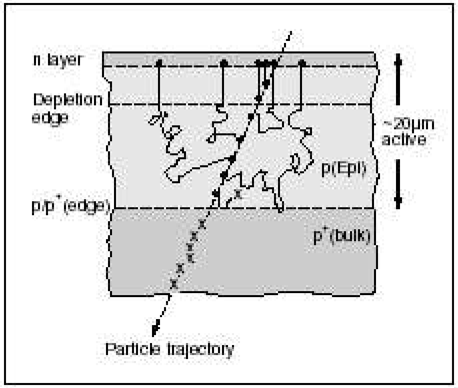
Si-Envelop components fulfill the following roles:

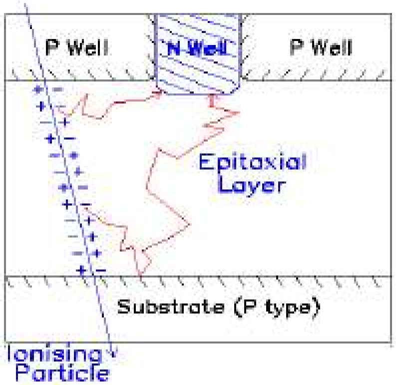
- SIT links μvertex (σ~2-3μm) with TPC (σ~100μm)
- SET links TPC with calorimetry
- Similarly in the FW region: FTD and Si-FCH.

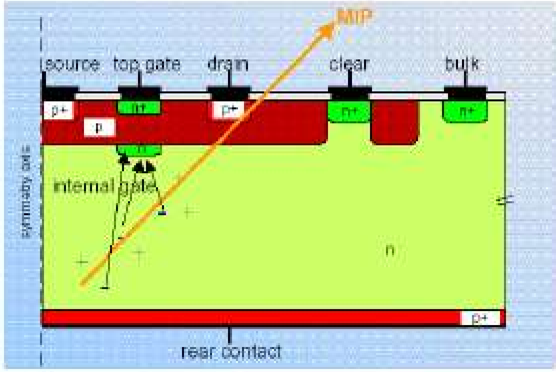
Questions to be answered:

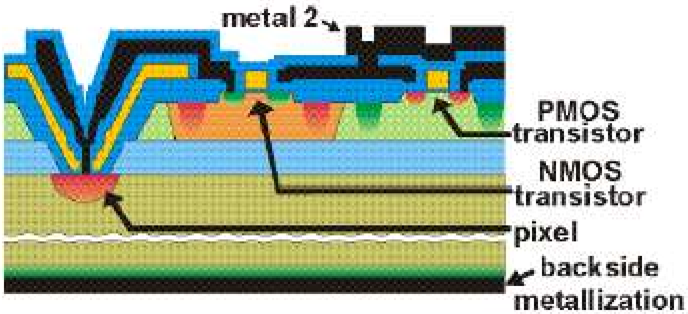
In the case of SET & Si-FCH especially:

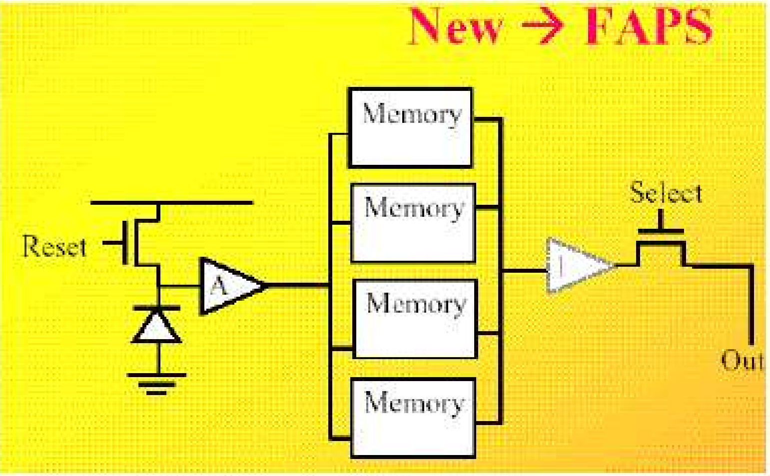
- ➢ One point? What precision?
- ➢ One segment?
- ➢ One track? (requested length of tracking level arm?)
- ➢ How this design compares with SD in central & FW?
- ➢ How they improve the overall detector performances?

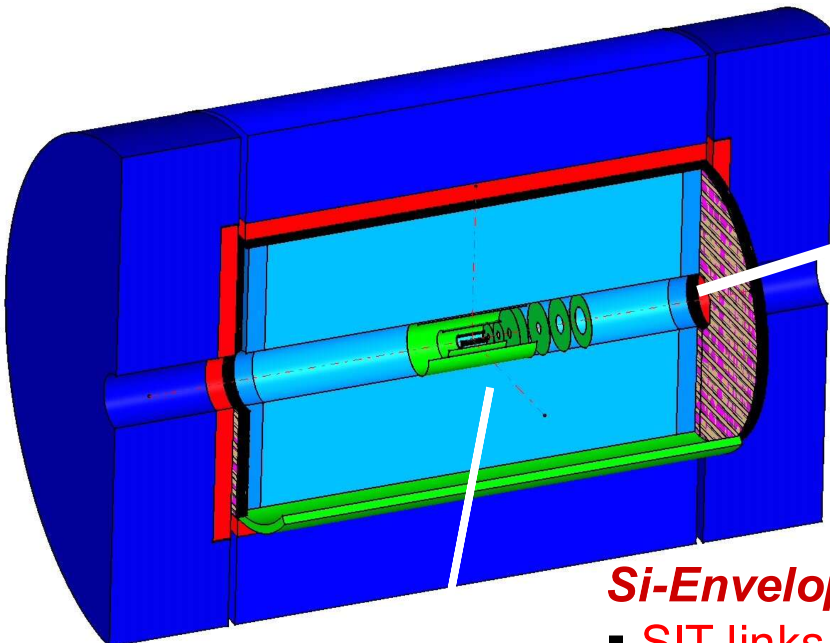

n layer
Depletion edge
~20µm active
p(Epi)
p/p+(edge)
p+(bulk)
Particle trajectory

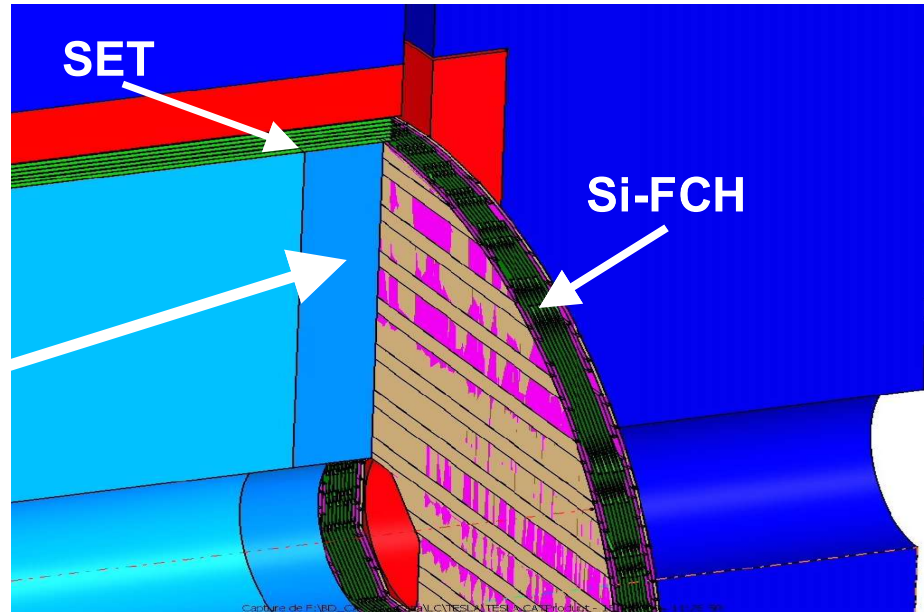

P Well
N Well
P Well
Epitaxial Layer
Substrate (P type)
Ionising Particle

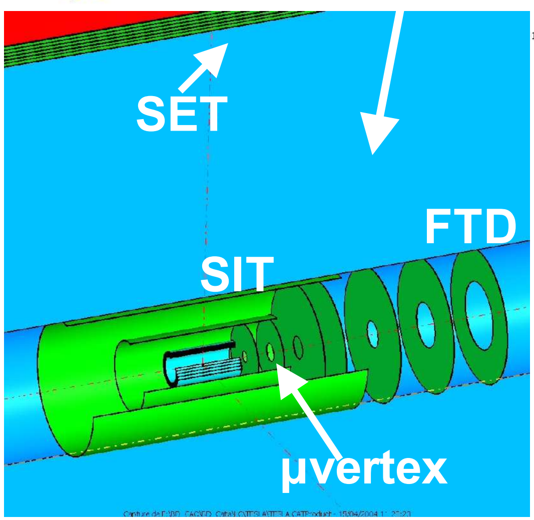

MIP
source
top gate
drain
clear
bulk
p+
n+
p
internal gate
symmetry axis
n
rear contact


metal 2
PMOS transistor
NMOS transistor
pixel
back side metallization


New → FAPS
Reset
A
Memory
Memory
Memory
Memory
Select
Out







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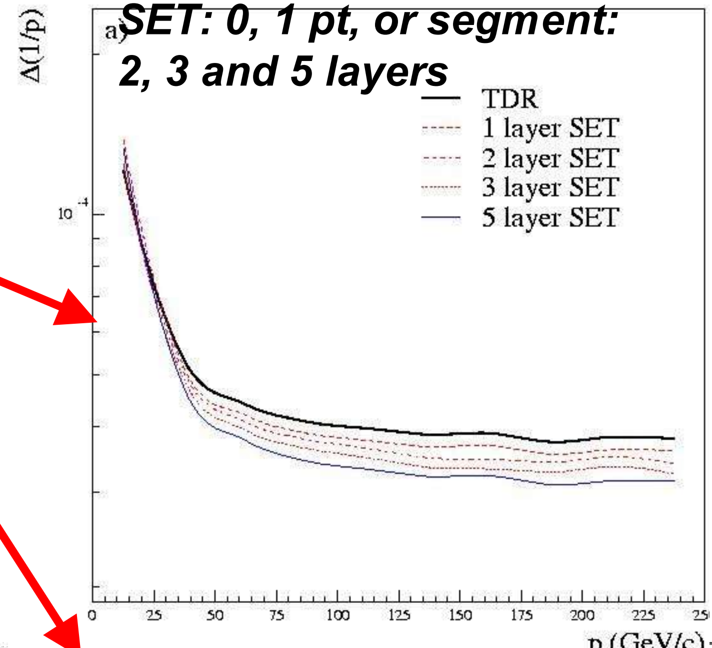
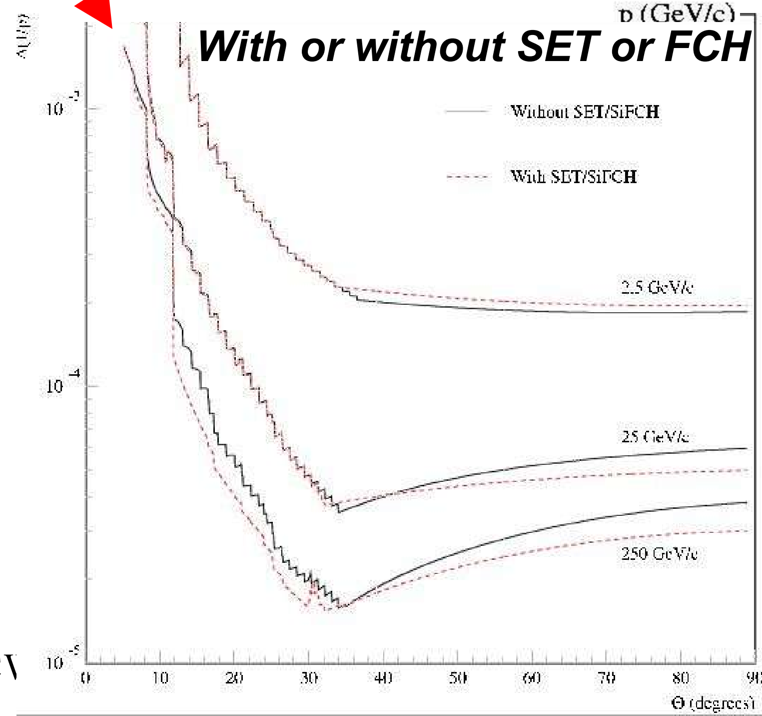
Simulation studies

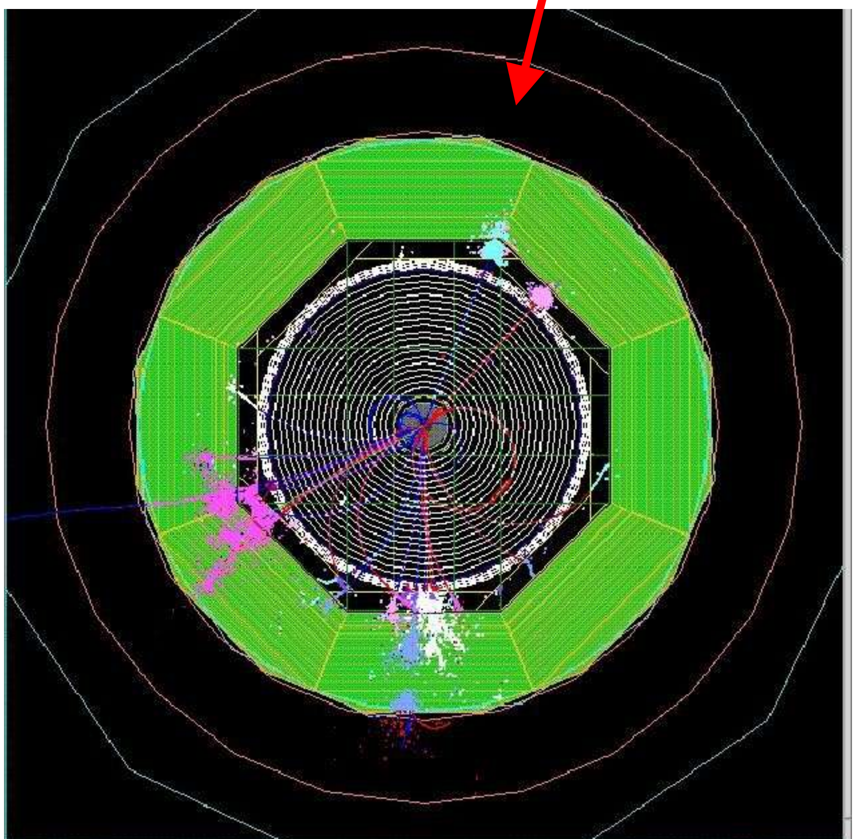
To answer previous questions and study detector performances use of SGV fast simu, with first answers.
And work in progress with full simu BRAHMS & MOKKA + G4

SET: 0, 1 pt, or segment: 2, 3 and 5 layers



With or without SET or FCH





Full G4 simulation of H→bb Z→e+e- including SET (white detector)