ECFA Study

Physics and Detectors for a Linear Collider

DEVIL'S ADVOCATE

Merriam-Webster DICTIONARY

Function: *noun*

Etymology: translation of New Latin *advocatus diaboli*

Date: 1760

1 : a Roman Catholic official whose duty is to examine critically the evidence on which a demand for beatification or canonization rests

(who is to be canonized ?

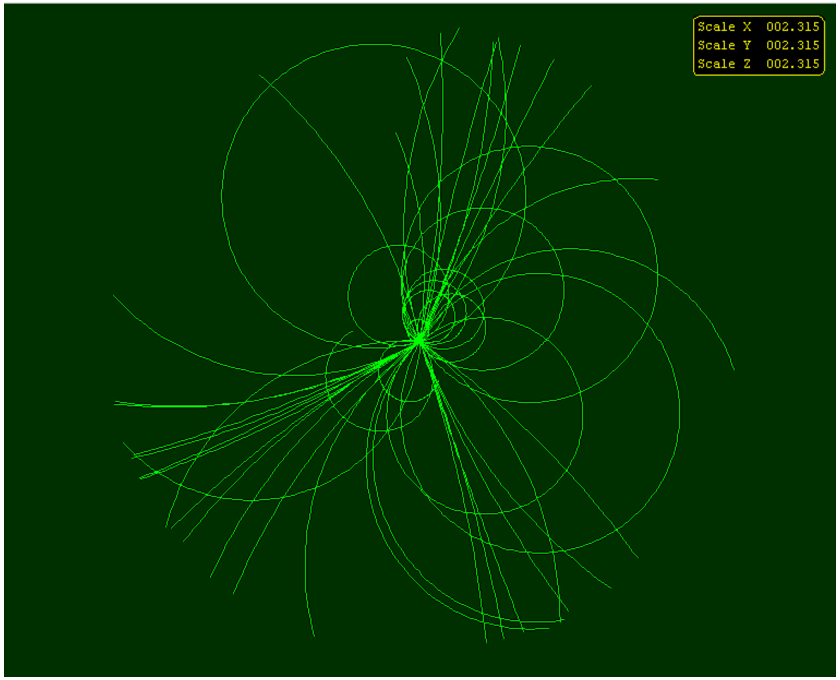
and who is the devil ??)

2 : a person who champions the less

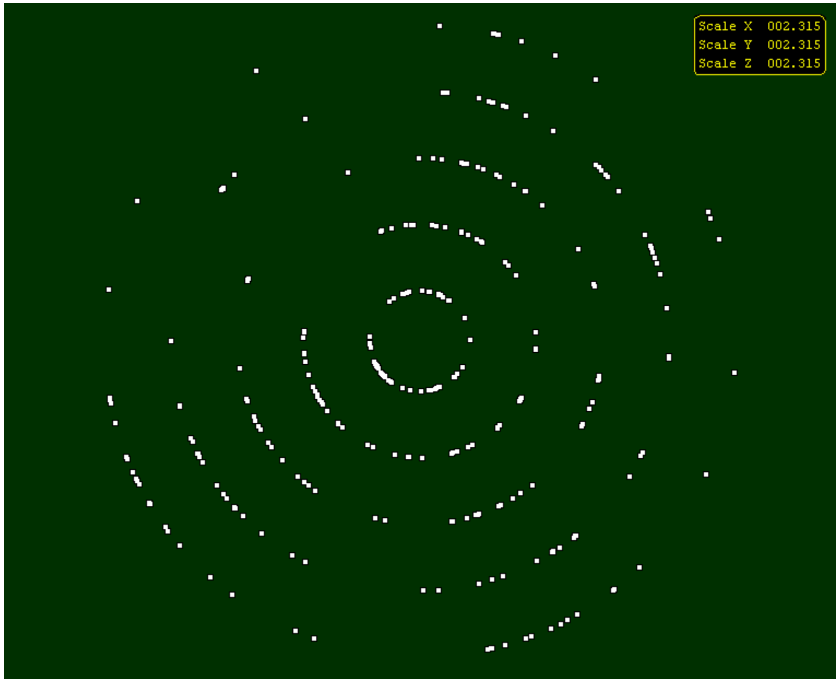
Gaseous or Silicon Central Tracking Detector?

Rolf Heuer, TPC meeting, LBL October 2003

gaseous



silicon



End of the argument ! …?

-not advocating an alternative design

-but a critical look at design criteria,

and whenever useful compare TDR with the all silicium proposal, in order to

-get the best possible performance

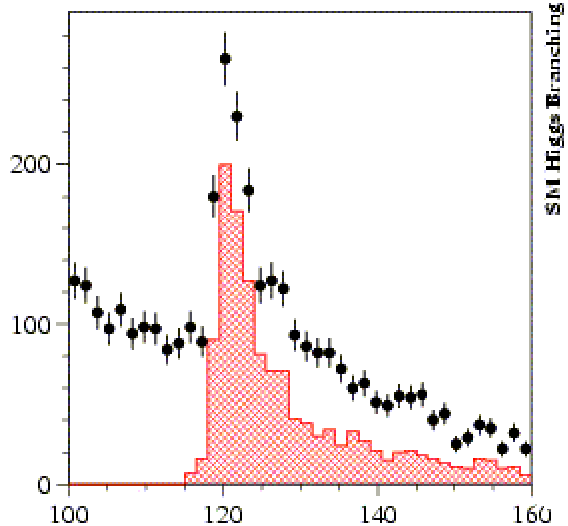
-and (second priority) weigh the impact on costs.

These studies were made years ago by the hard work of the then ECFA-DESY working groups so I do not plan to re-discover the wheel, but

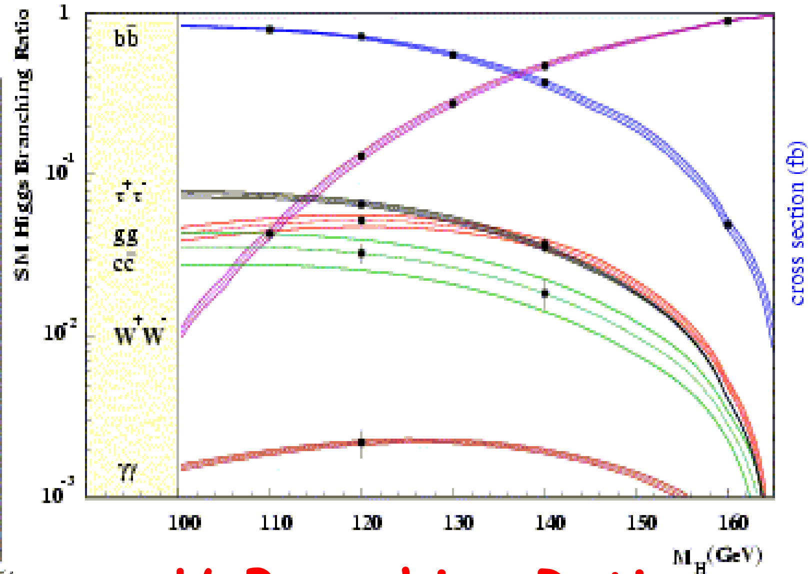
likely useful to re-do this regularly, in view of technical and scientific progress, until the real detector is built!

This presentation was prepared with Jan Timmermans and Mark Thomson ... but anything wrong is my

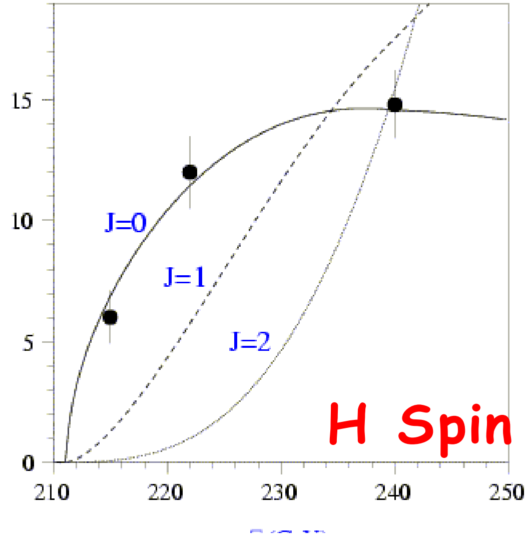
Physics



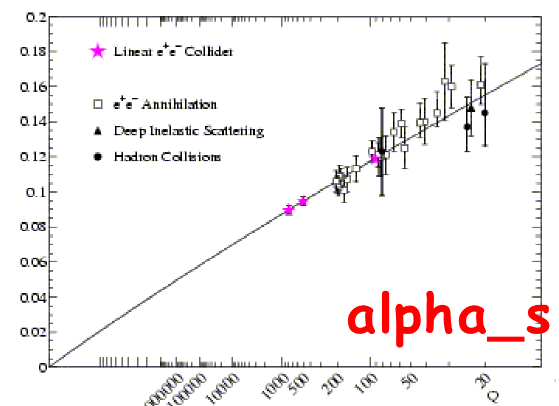
Inclusive Higgs:
Z Recoil mass



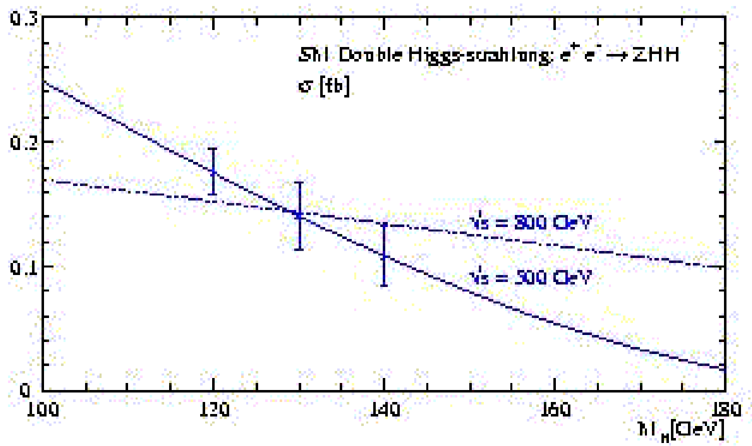
H Branching Ratios



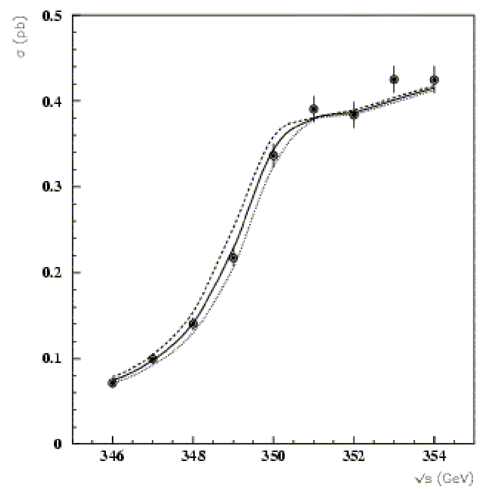
H Spin



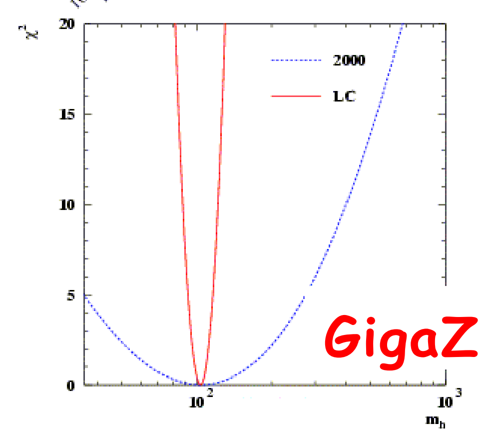
alpha_s



ZHH



Top quark mass



GigaZ

... and much much more

Main Colliders Parameters

	TESLA		NLC/JLX(X)		CLIC
c.m energy **GeV**	500	800	500	1000	3000
RF frequency **GHz**	1.3		11.4		30
Luminosity $10^{34}/cm^2/s$	3.4	5.8	2.5		8
nb bunches/pulse	2820	4886	192		154
N± /bunch (10^{10})	2	4	0.75		0.4
Bunch separation **ns**	337	176	1.4		0.67
Repetition rate **Hz**	5	4	150	100	100
σ_y at Xing point **nm**	5	2.8	3	2.1	0.7
$\Delta E/E$ beamstrahlung	3.2%	4.3%	4.6%	7.5%	21.1%
Accel. Gradient **MV/m**	23.4	35	65/50*		172/150*
Total AC power **MW**	140	200	243	292	410
Site length **km**	33		32		33.2

* loaded

LC Detector Requirements

TDR

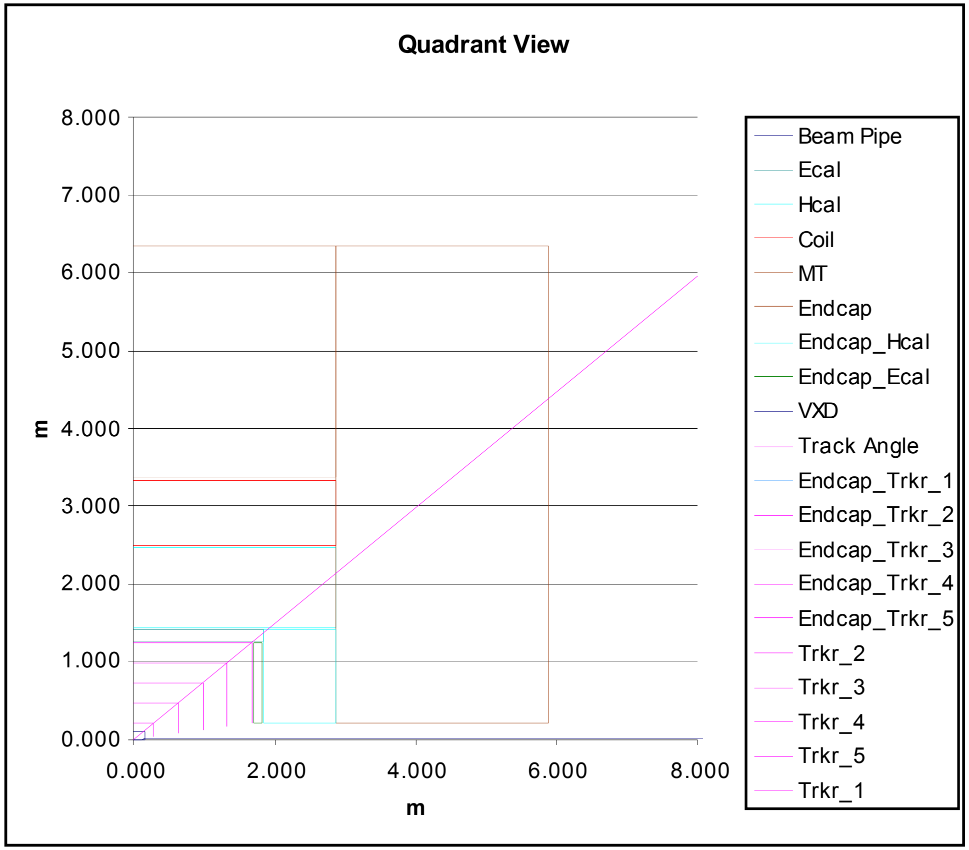
- a) Two-jet mass resolution comparable to the natural widths of W and Z for an unambiguous identification of the final states. — E-flow
- b) Excellent flavor-tagging efficiency and purity (for both b- and c-quarks, and hopefully also for s-quarks). — vertexing
- c) Momentum resolution capable of reconstructing the recoil-mass to di-muons in Higgs-strahlung with resolution better than beam-energy spread . — id.
- d) Hermeticity (both crack-less and coverage to very forward angles) to precisely determine the missing momentum. — id.
- e) Timing resolution capable of separating bunch-crossings to suppress overlapping of events . — new

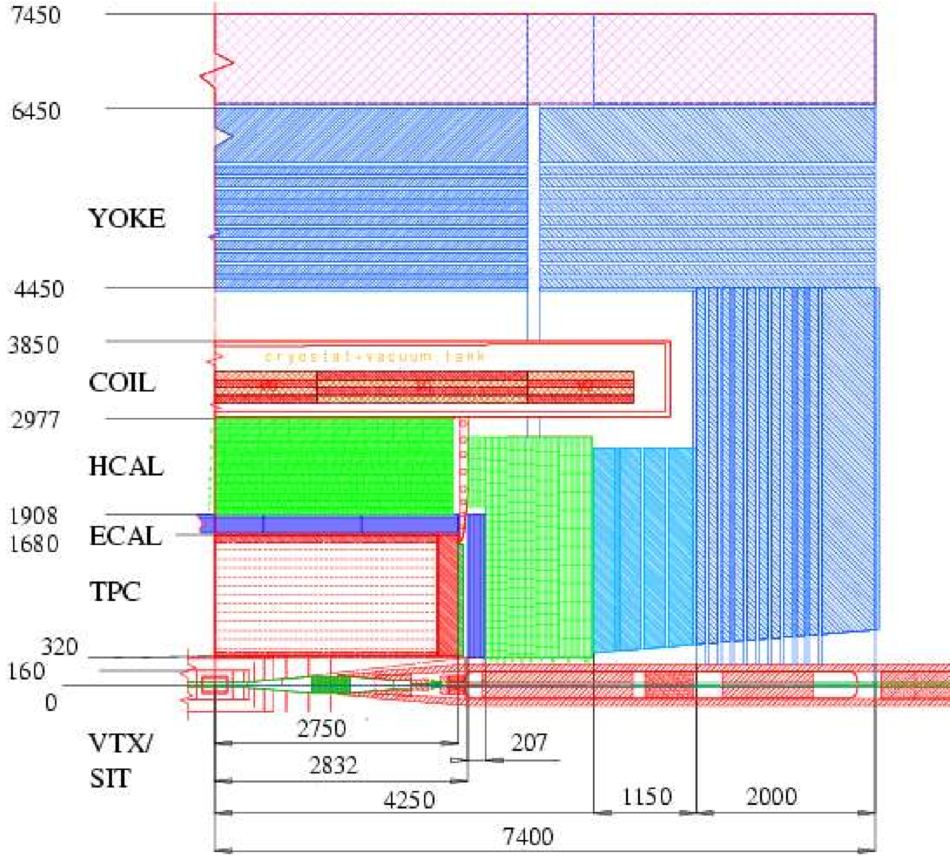
M.Breidenbach, Cornell 2003

TESLA Detector basic performance & parameter goals

Subdetector	Goal	Technologies
Vertex Detector (VTX)	$\delta(IP_{r\phi,z}) \leq 5\,\mu\text{m} \oplus \frac{10\,\mu\text{m GeV}/c}{p\sin^{3/2}\theta}$	CCD, CMOS, APS
Forward Tracker (FTD)	$\frac{\delta p}{p} < 20\,\%$, $\delta_\theta < 50\,\mu\text{rad}$ for p=10-400 GeV/c down to $\theta \sim 100\,\text{mrad}$	Si-pixel/strip discs
Central Tracker (TPC)	$\delta(1/p_t)_{\text{TPC}} < 2\cdot10^{-4}(\text{GeV}/c)^{-1}$ $\sigma(dE/dx) \leq 5\%$	GEM, Micromegas or wire readout
Intermediate Tracker (SIT)	$\sigma_{point} = 10\,\mu\text{m}$ improves $\delta(1/p_t)$ by 30%	Si strips
Forward Chamber(FCH)	$\sigma_{point} = 100\,\mu\text{m}$	Straw tubes
Electromag. Calo. (ECAL)	$\frac{\delta E}{E} \leq 0.10\frac{1}{\sqrt{E(\text{GeV})}} \oplus 0.01$ fine granularity in 3D	Si/W, Shashlik
Hadron Calo. (HCAL)	$\frac{\delta E}{E} \leq 0.50\frac{1}{\sqrt{E(\text{GeV})}} \oplus 0.04$ fine granularity in 3D	Tiles, Digital
COIL	4 T, uniformity $\leq 10^{-3}$	NbTi technology
Fe Yoke (MUON)	Tail catcher and high efficiency muon tracker	Resistive plate chambers
Low Angle Tagger (LAT)	83.1–27.5 mrad calorimetric coverage	Si/W
Luminosity Calo. (LCAL)	Fast lumi feedback, veto at 4.6–27.5 mrad	Si/W, diamond/W
Tracking Overall	$\delta(\frac{1}{p_t}) \leq 5\cdot10^{-5}(\text{GeV}/c)^{-1}$ systematics $\leq 10\,\mu\text{m}$	
Energy Flow	$\frac{\delta E}{E} \simeq 0.3\frac{1}{\sqrt{E(\text{GeV})}}$	

Si Det vs. TESLA TDR





Main differences

	SiD	TDR
Ecal radius	1.3m	1.7m
Tracker	all Si	TPC
Magn. Field	5T	4T
Solenoid length	3m	5m
radius	3m	3.4m
tan θ_{corner}	.75	.61

Consensus

Vertex detector best possible

Si-W ECAL ...but Scintillator+Lead (+Si) still a contender

HCAL inside coil, digital most likely.

Muon Det, Forward Det. outside this

(very) Preliminary Estimated costs

	SiD(M$)		TDR(M€)	
VTX	6		3	
Int. Tracker			5	
Central tracker	18		22	
SiW ECAL	93	32% } 48%	133	48%
Electronics	48	16%		
HCAL+Muons	21		26	
Magnet	90	31%	65	23%
Other	19		26	
TOTAL	295 (245+ labor)		280	
	MB 2/6/01		TDR 03/01	

Magnetic Field discussion

A. is **BR^2** really the figure of merit for the Ecal ?

B. if **B** determines the minimum radius of the VTX det, would higher **B** allow smaller VTX radius and enhance flavour tagging?

C. is **B** limited by field uniformity requiremts of TPC? … + length of coil, iron pole tip What is the maximum useful (affordable) field? Effect on HADCAL.

D. but **BR^2** is the figure of merit

A)Radius of Si-W EMCal

M.Breidenbach:

- **Figure of merit something like BR^2/σ,**

  where $\sigma = r_{pixel} \oplus r_{Moliere}$
- **Maintain the great Moliere radius of tungsten (9 mm) by minimizing the gaps between ~2.5 mm tungsten plates.**

  dilution is

  $(1+R_{gap}/R_w)$
- What is EMCal optimum radius?
  E-flow degradation between 1.7m and 1.3m?
- best σ identical, then **BR^2** from 11 to 8 Txm^2
- If 11 mandatory, then need ~7 Teslas !

Remember…

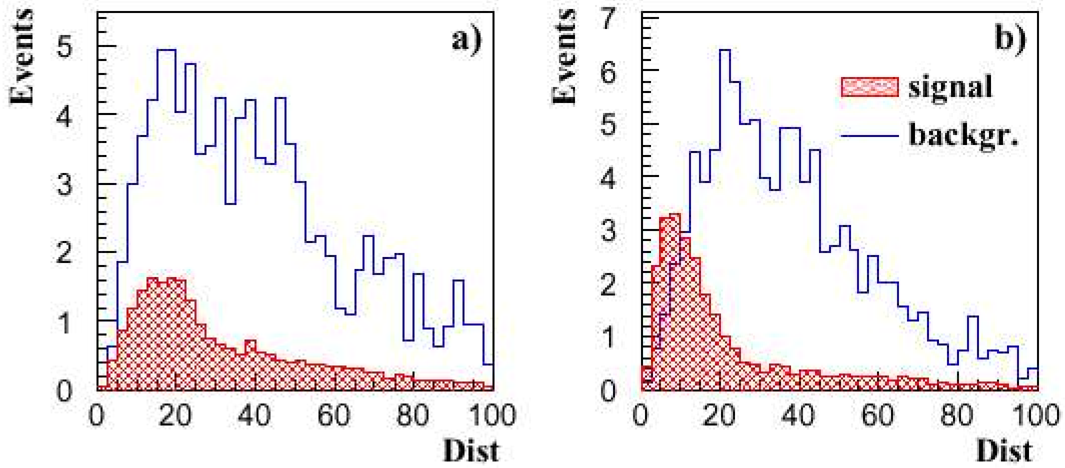


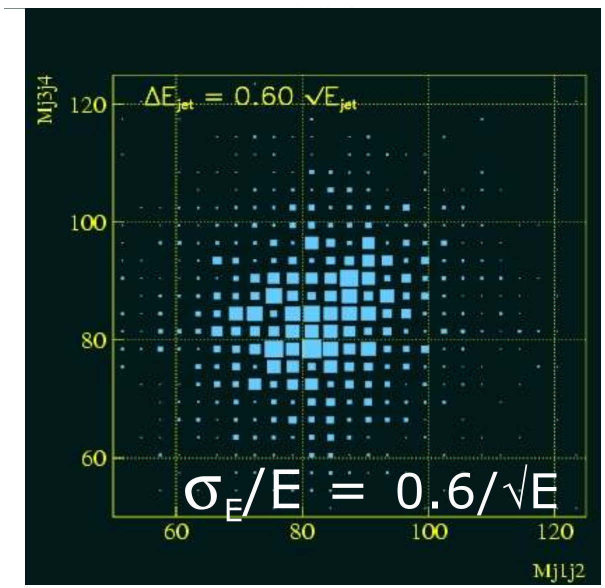
Figure 9.4.2: *Distance variable for signal and background assuming a): $\Delta E/E = 60\%(1+|\cos\theta_{\rm jet}|)/\sqrt{E}$ or b): $\Delta E/E = 30\%/\sqrt{E}$. For details see text.*

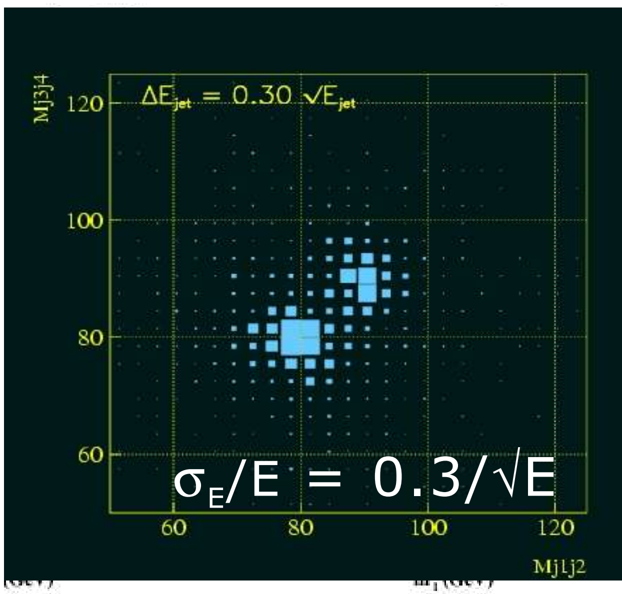
Physics Motivation I: Higgs Self-Coupling with no beam constraint

ZHH events

S.Kuhlmann, Prag 2002

Physics Motivation II: Electroweak symmetry breaking without an elementary Higgs (also no beam constraint)





$\nu\nu$WW events

Mark Thomson, Amsterdam 2002

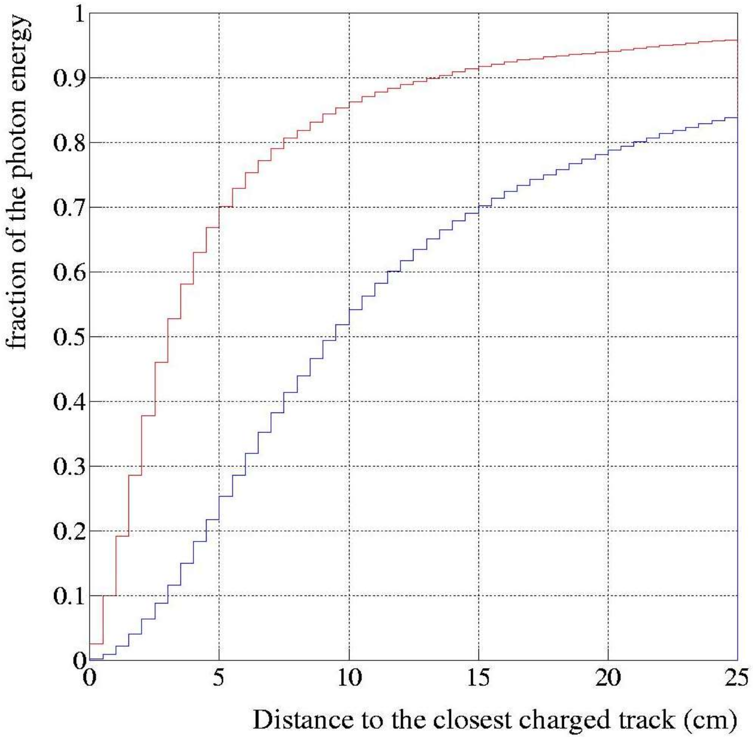
Small versus Large

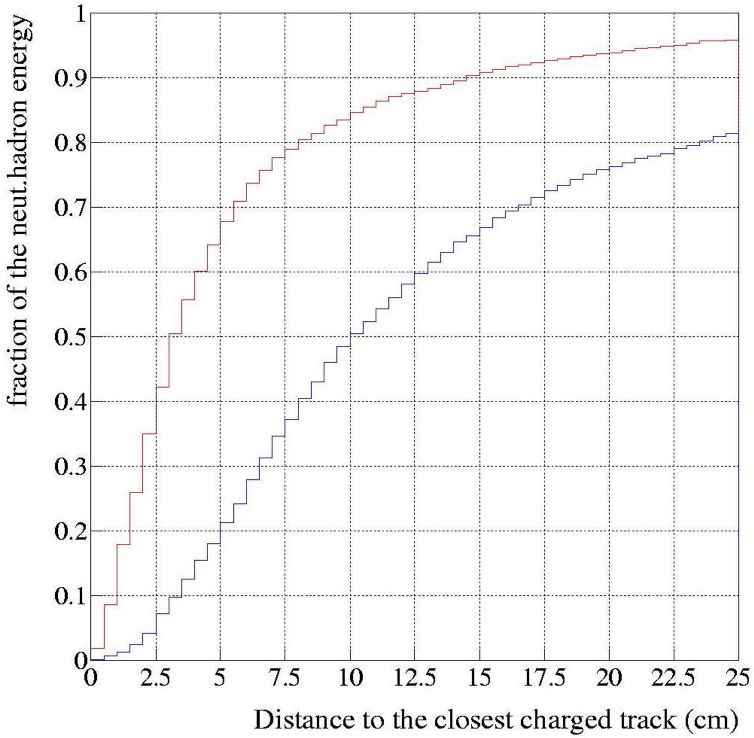
$e^+e^- \rightarrow Z\ h(140)$ at $\sqrt{s} = 500$ GeV

EM CAL

5cmx5cm pads…

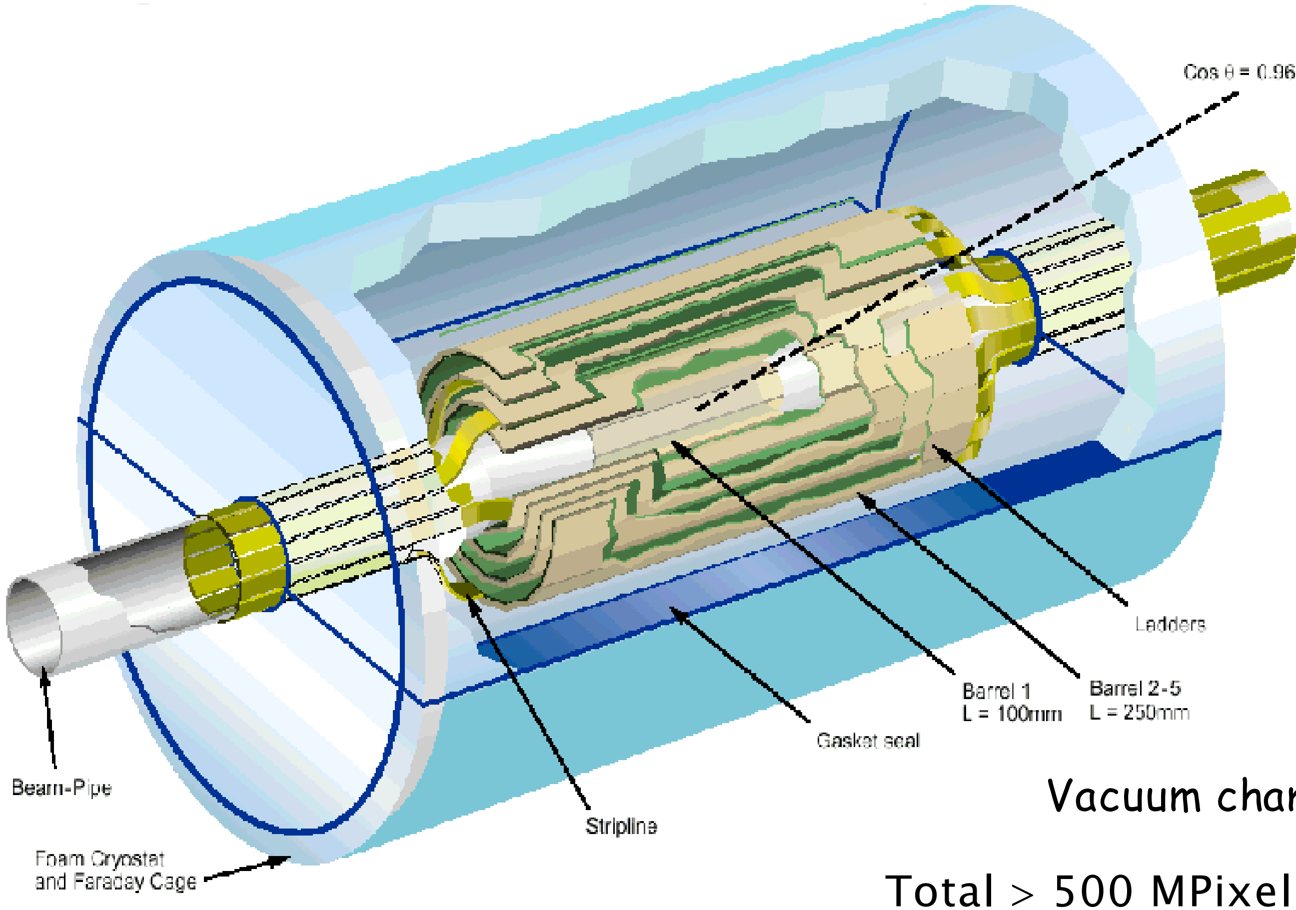
with $Z \rightarrow \nu\bar{\nu}$ and h in 2 jets(b,c...)





Detector models	photon dist<5 cm	photon dist<10 cm		neutral hadron dist<5 cm	neutral hadron dist<10 cm
Large	**11%**	30%		**10%**	28%
Small	**47%**	67%		**41%**	63%

B)Vertexdetector



<u>Options:</u>
CCD
MAPS
HAPS
DEPFET

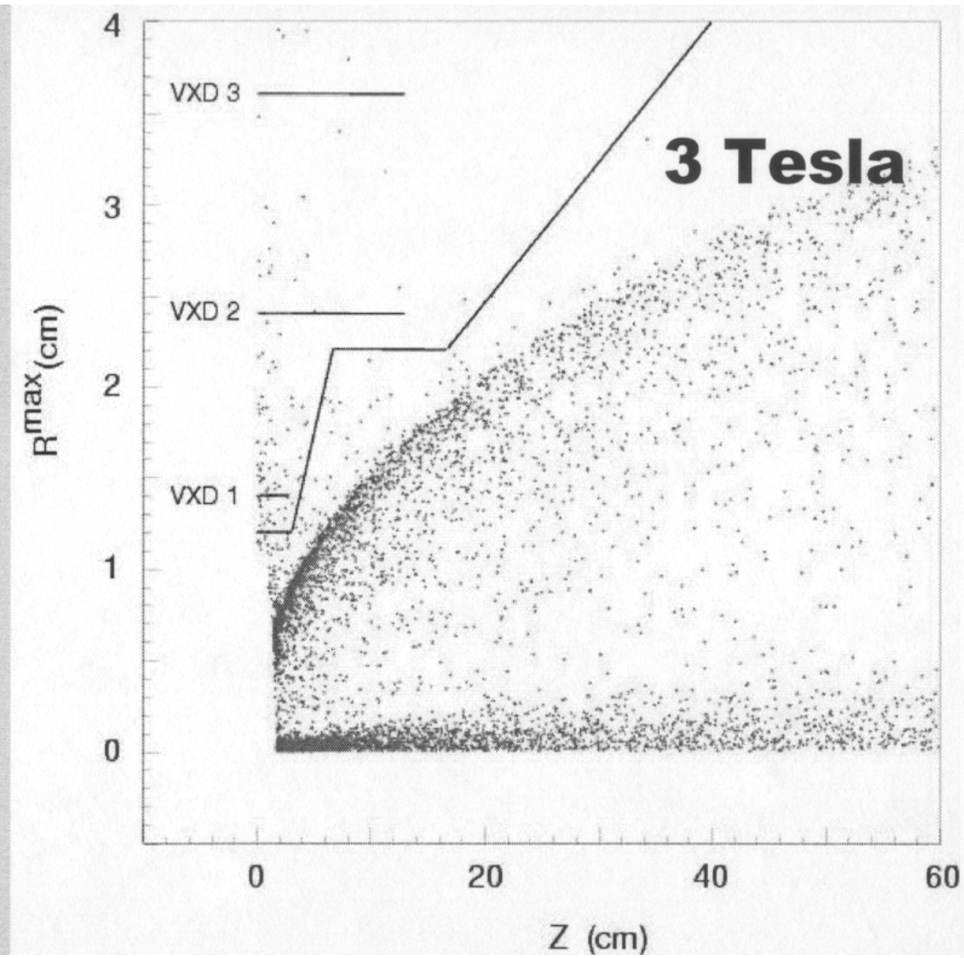
Vacuum chamber radius 14 mm

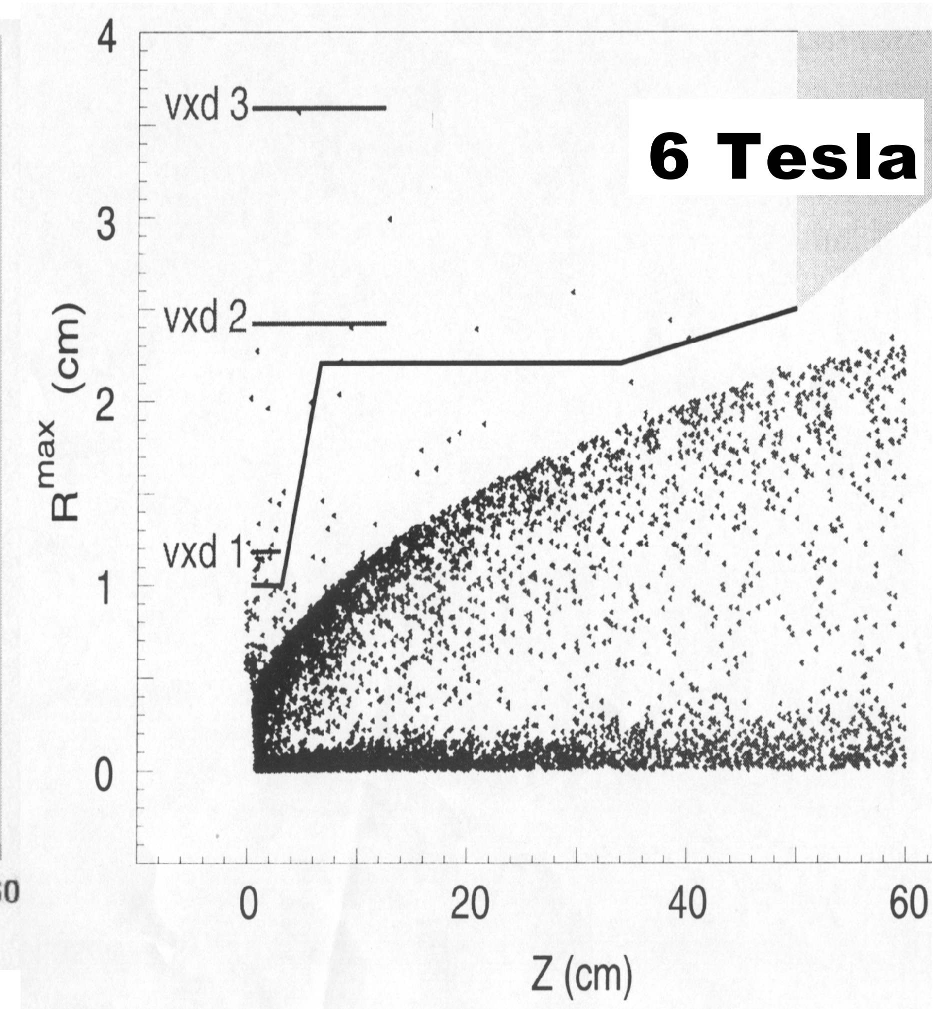
Total > 500 MPixel (with 25x25 µm pixels)
(read out in 40 µs)

$$\delta(IP) \leq 5\mu m \oplus (10\ \mu m / p \sin^{3/2}\theta)$$

M. Schumacher, Prag 02

Pairs in 3T and 6Tmagnetic field



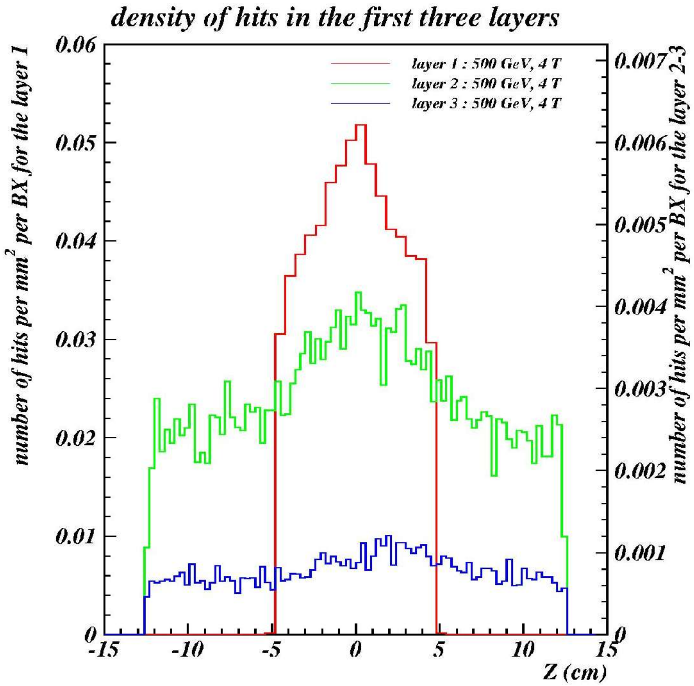


Cf. Markiewicz,Maruyama,Sitges,9

Density of parasitic hits

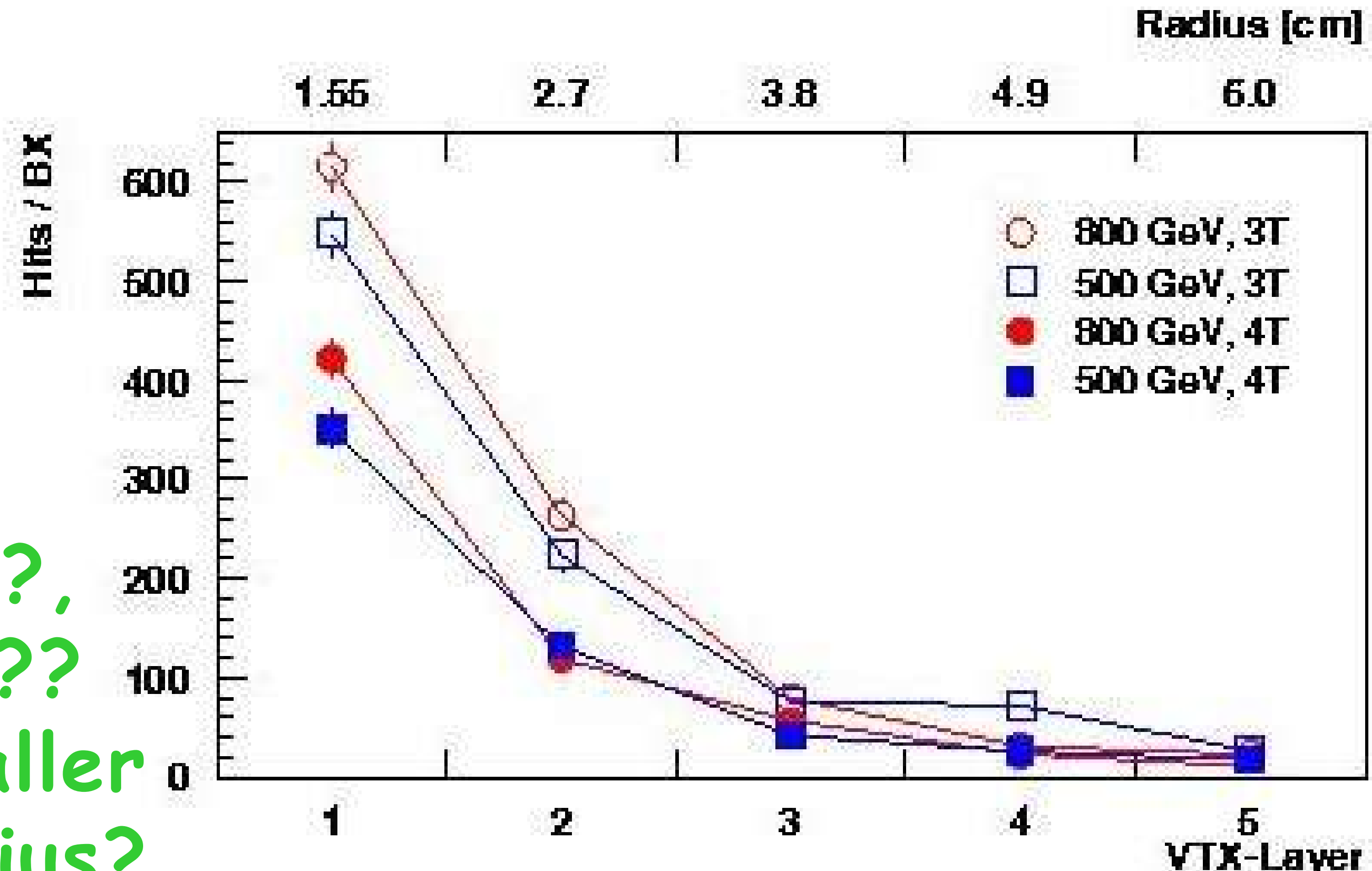
e+e- pairs at 4 teslas

- Mean density on layer #1
  - 0.04 hits/mm²/BX ($\sqrt{s}$ = 500 GeV, B =4 T)
    - ~ same value in TDR (1 BX only)
- Distribution along the beam direction
  - not really a flat distribution
    - variation of ±20 % around the mean value



M.Winter, Prag 2002

Hits from pairs



5T?, 6T?? Smaller Radius?

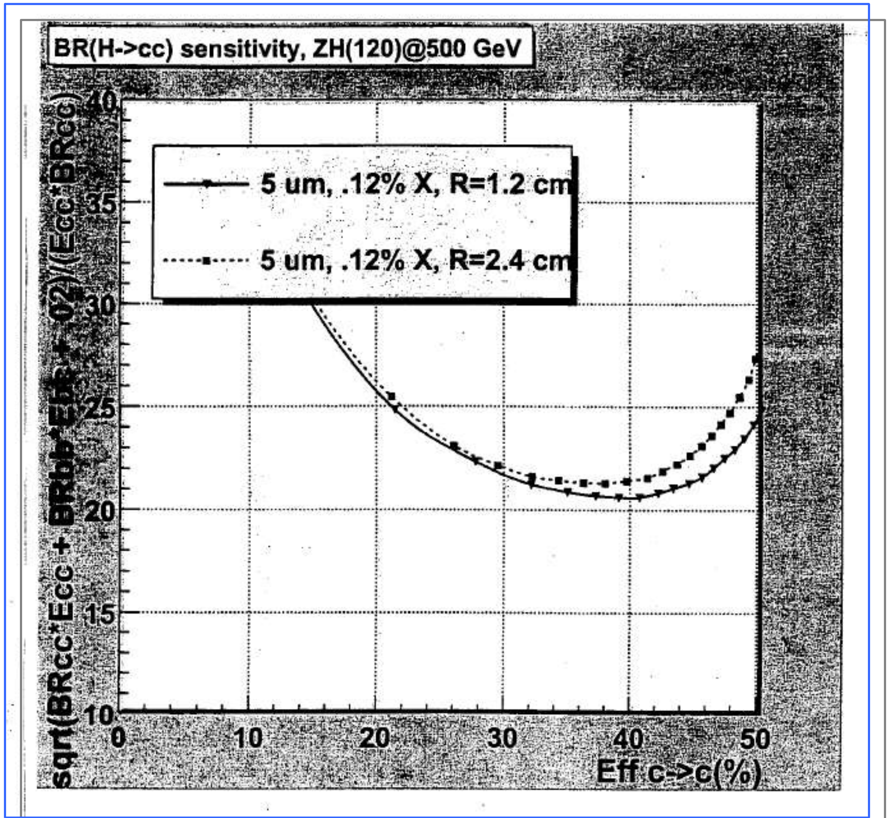
C.Hensel, LC-DET-2000-001

?

Vertex radius discussion*

J. Jaros
4/4/03

LC Beam Pipe Radius and Vertexing



From studies by Aaron Chou

V. Conclusions

A. I know of no study that demonstrates that either an extremely small beam pipe radius or an extremely thin vertex detector is needed to do justice to LC physics.

B. The studies cited above show very minor performance improvements when the beam pipe radius is reduced from 2 cm to 1 cm, as expected from the qualitative observations above. Radius of 1.5 to 2.5 cm is OK to my thinking.
]

C. Motherhood: Smaller radius is better, for vertexing resolution. We may learn new vertexing tricks that exploit very high resolution in the future, or see that particular analyses can really benefit from very high resolution.

So, beam pipe radius should be minimized, but subject to constraints imposed by operational stability of the machine, luminosity considerations, and background considerations.

Agreed that VX radius is, in certain extents, a free parameter that accelerator physicists can optimize

*) This discussion took place in a context of 500GeV CM. The low energy requirements need to be discussed again

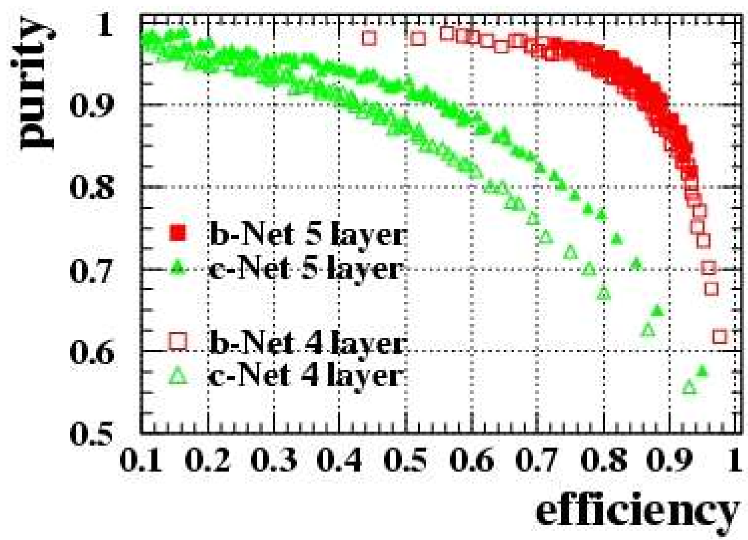
From A.Seryi, 07/14/03,

Flavour Tagging : Recent Studies

- ★ Inner layer at **1.5cm** is very important, e.g. $e^+e^- \to Z^* \to ZH$

  $ZH \to llbb$, $ZH \to llcc$, $ZH \to llgg$

If inner layer is removed (event-wise) charm tagging degraded by 10%



Thorsten Kuhl

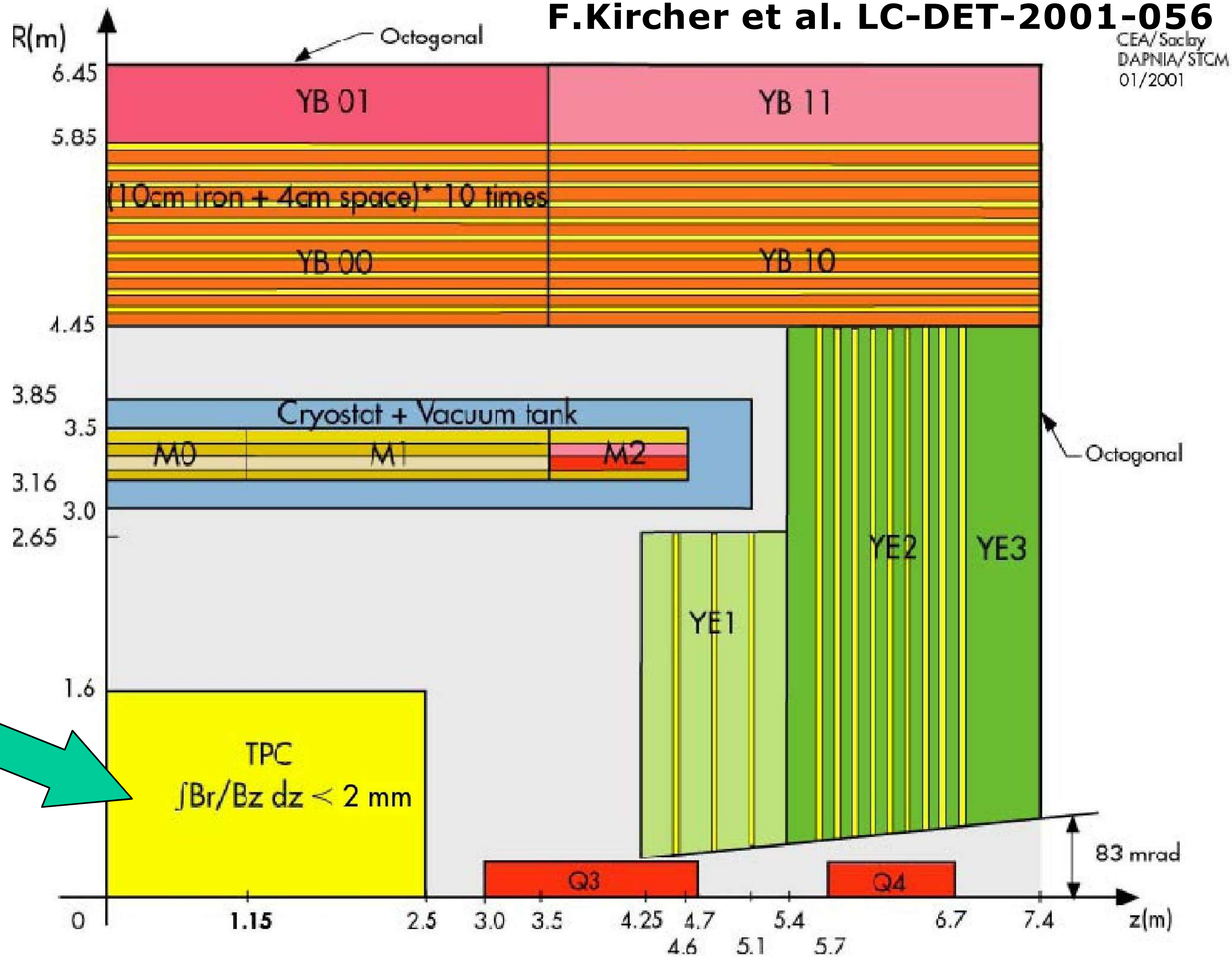
Future Optimization

- ★ Optimize for physics performance:
  - charm tag
  - vertex charge
  - charge dipole
  - conversion ID
- ★ Minimize inner radius
- ★ Minimize material

Mark Thomson, Amsterdam 2002

C)TESLA TDR magnet

F.Kircher et al. LC-DET-2001-056



Field uniformity

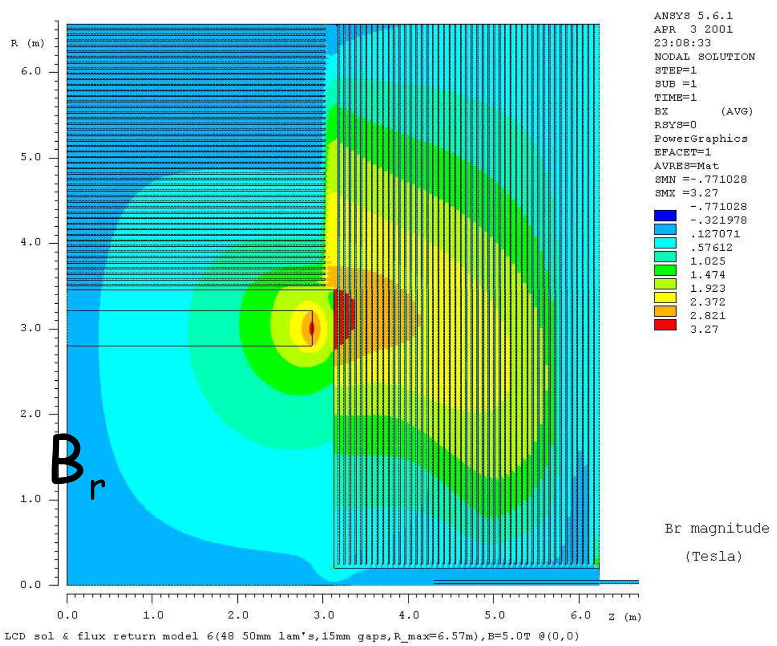
Negative ion TPC?

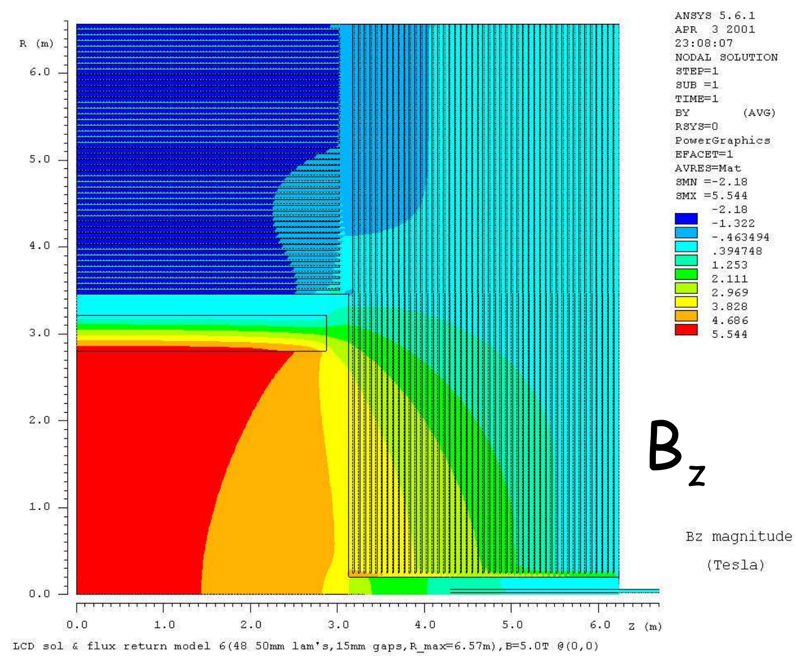
TPC length

Coil and Iron

- Solenoid field is 5T – 3 times the field from detector coils that have been used in the detectors. - CMS will be 4T.
- Coil concept based on CMS 4T design.
- Stored energy about 1.5 GJ (for Tracker Cone design, R_Trkr=1.25m, $\cos\theta_{barrel}$=0.8).

(TESLA is about 2.4 GJ) [Aleph is largest existing coil at 130





M.Breidenbach, Cornell03

Magnetic Field Limitations

F.Kircher: not cost… but

mechanical stability of coil

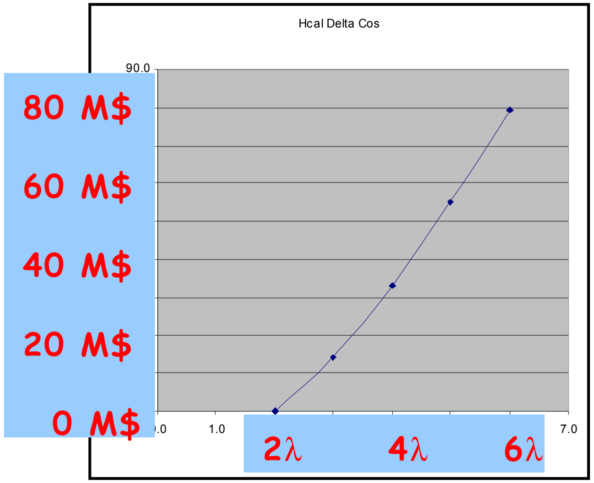
$\Rightarrow$ **B^2R_{coil} < ~60 T^2m.** **(Erice, Sept.2003)**

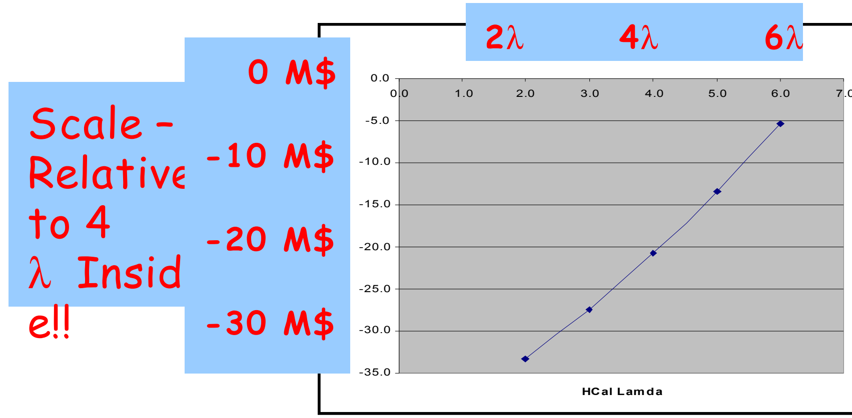
TDR 4^2x3.4=55 …could reach 4.5T?

SiD 5^2x3=75 …oops!

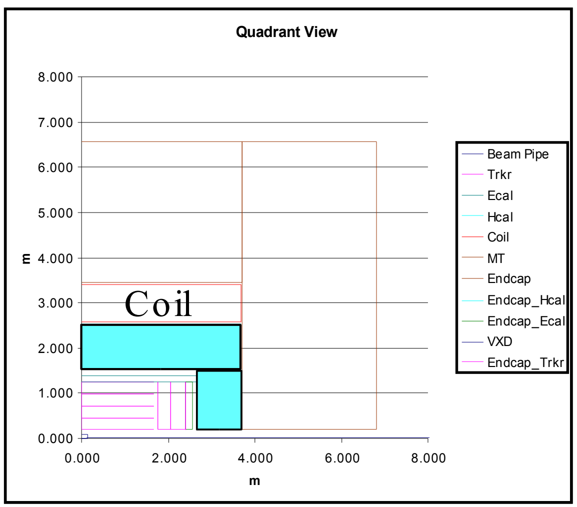
HCal Location Comparison

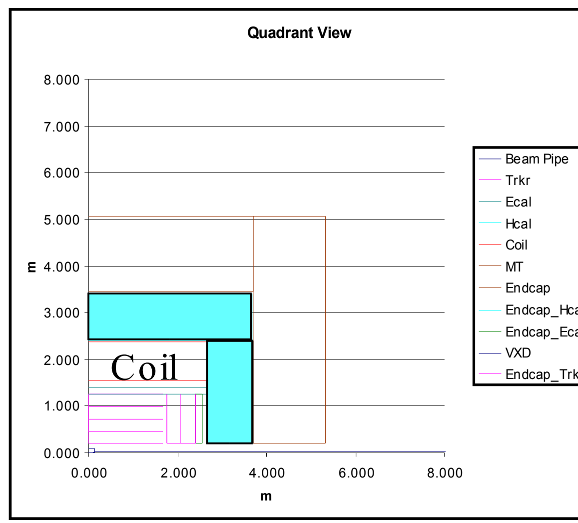
M.Breidenbach, Cornell03





Hcal inside coil

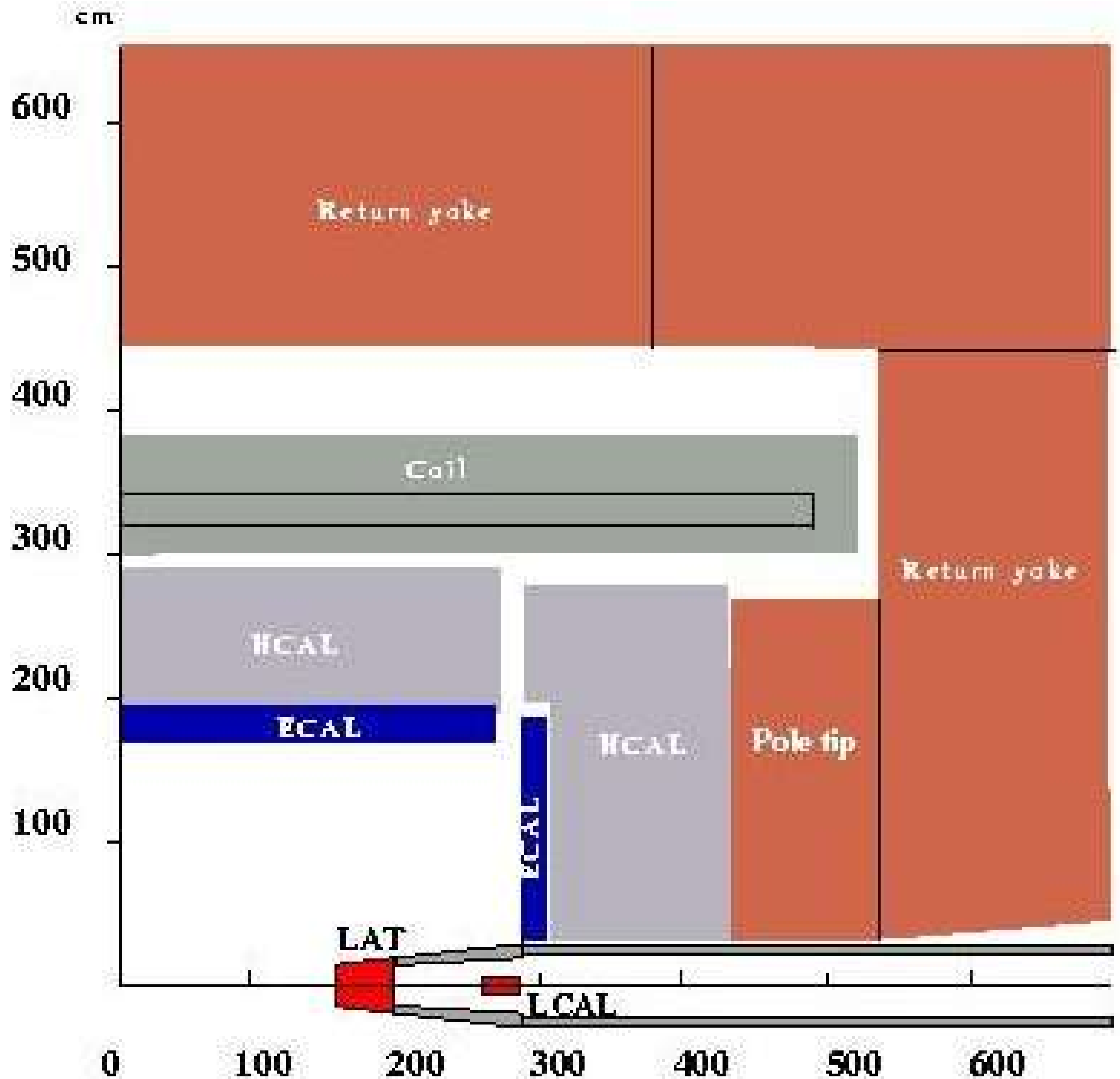




HCAL outside coil

B^2R_{coil} 75 T^2m 50 T^2m

TESLA TDR Calorimeters



D)Tracking discussion

SD issues:

<u>Track finding</u> in VTX (+Si), lack of redundancy
decays in flight?

Thickness, upstream of barrel ECAL

No relativistic dE/dx

TPC issues:

Systematics, calibration & alignment

z resolution, **effect on inclusive Higgs**

End plate thickness

uniformity of magnetic and electric fields

Common issues

Overall Hermeticity

Cooling of electronics

Bunch tagging

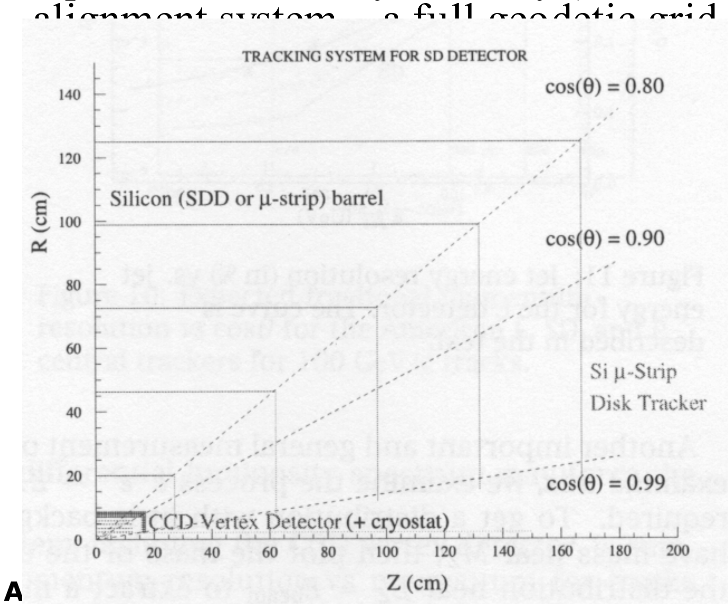
Silicon Tracker

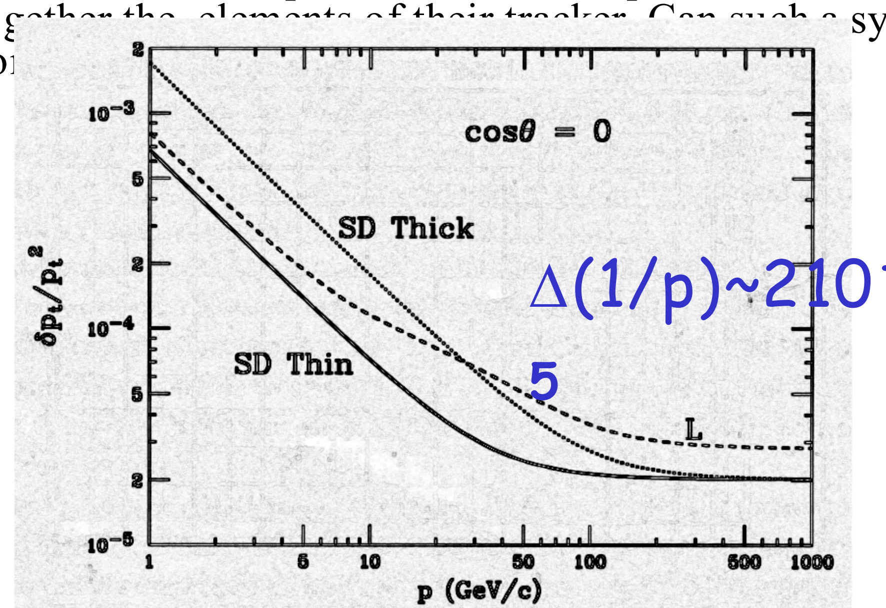
M.Breidenbach, Cornell03

- SLC/SLD Prejudice: Silicon is robust against machine mishaps; wires & gas are not.
- Silicon should be relatively easy to commission – no td relations, easily modeled Lorentz angle, etc.
- SD as a *system* **should have superb track finding**.
  - 5 layers of higly pixellated CCD's
  - 5 layers of Si strips, outer layer measures 2 coordinates
  - EMCal provides extra tracking for Vee finding - ~1mm resolution!
- Mechanical:

-Low mass C-Fiber support structure. Goal is support for a 10 cm x 4 m ladder of ~125 grams!

-Chirped Interferometry Geodesy (Oxford System) Atlas has developed a beautiful chirped interferometric alignment system – a full geodetic grid tieing together the elements of their tracker. Can such a system ... precisio...





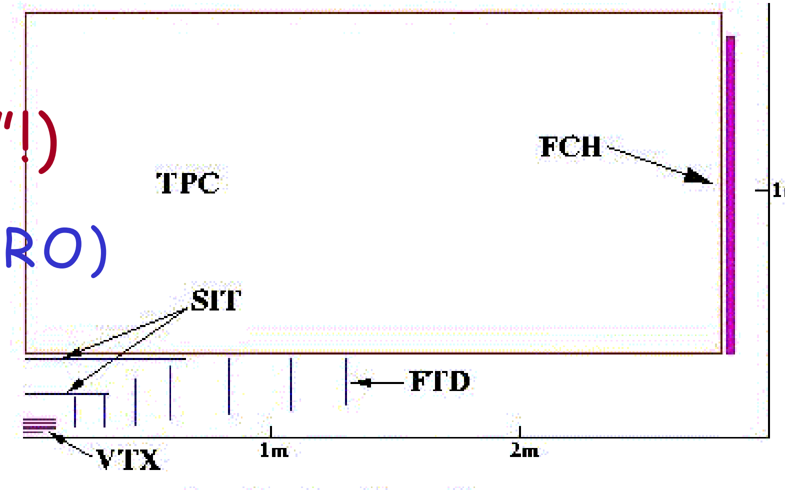
TDR Track detector

TPC: $dE/dx \approx 4.5\%$ (**NOT** "for free"!)

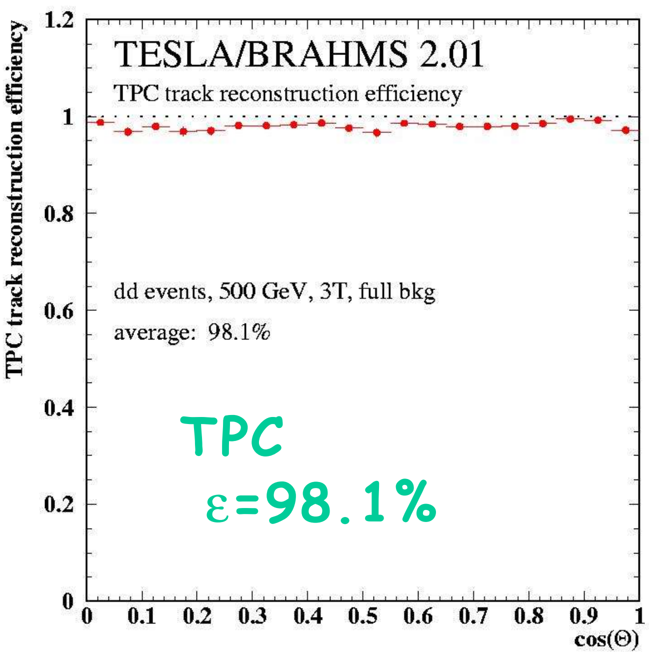
$\Delta(1/p) \leq 2 10^{-4}$ (GEM, Micromegas RO)

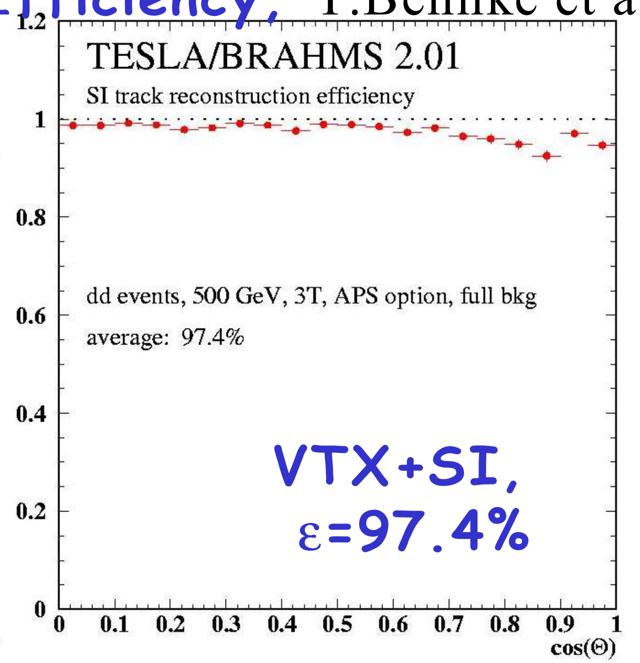
Overall Tracker

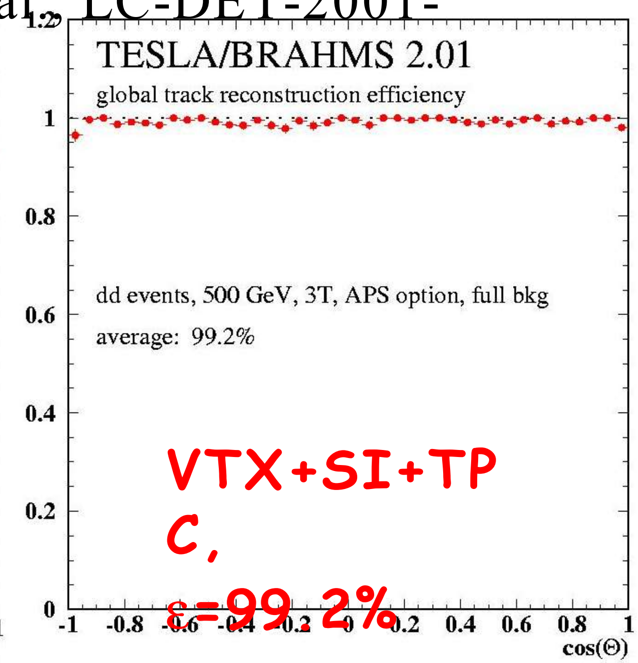
$\Delta(1/p) = 5 10^{-5}$



Track Reconstruction Efficiency, T.Behnke et al. LC-DET-2001-

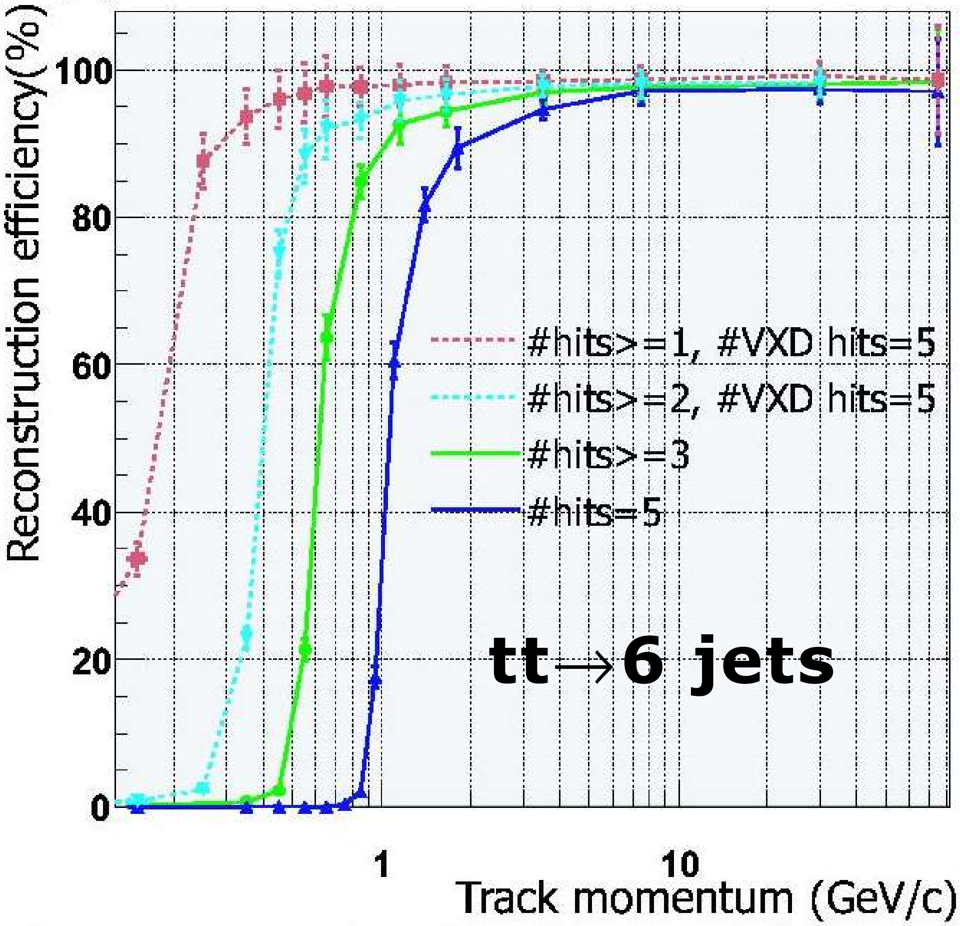


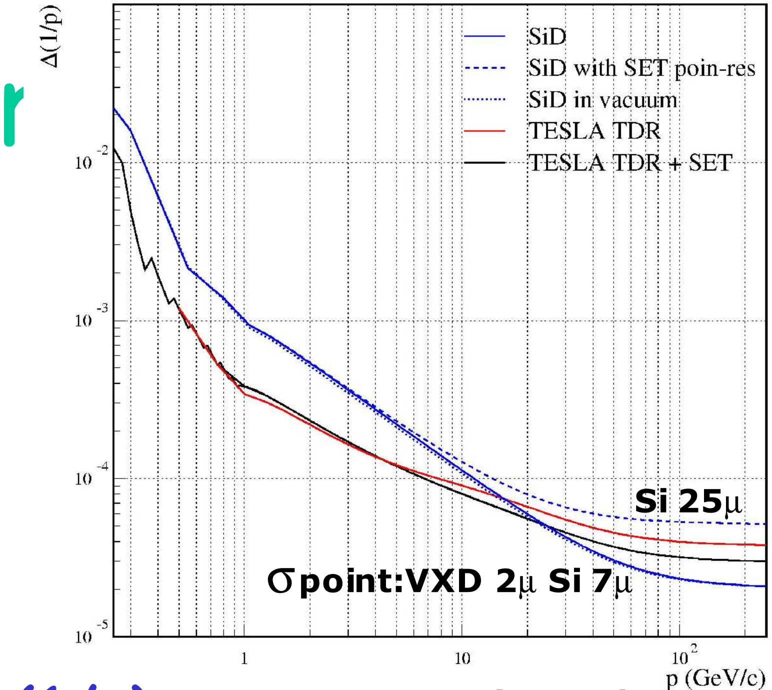




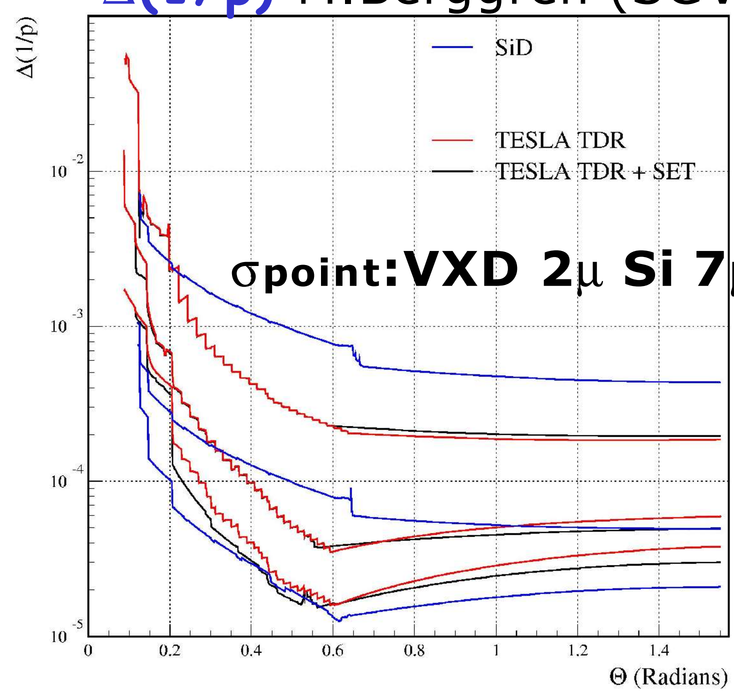
SiD Track detector

Track Reconstruction Efficiency, M Iwasaki, hep-ex/0303017





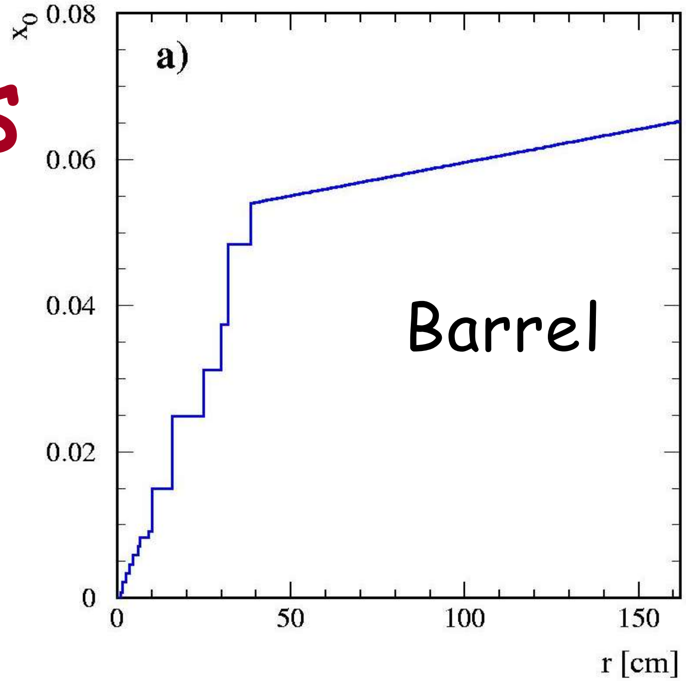
Δ(1/p) M.Berggren (SGV)

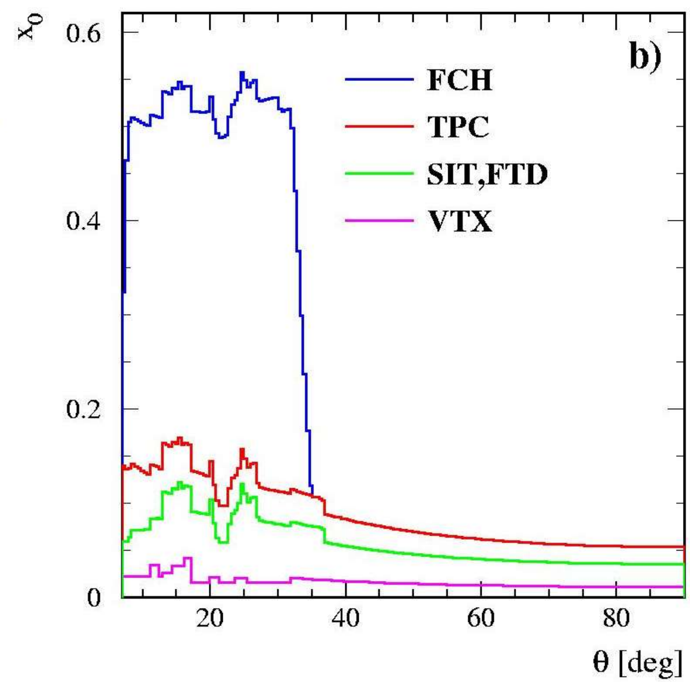


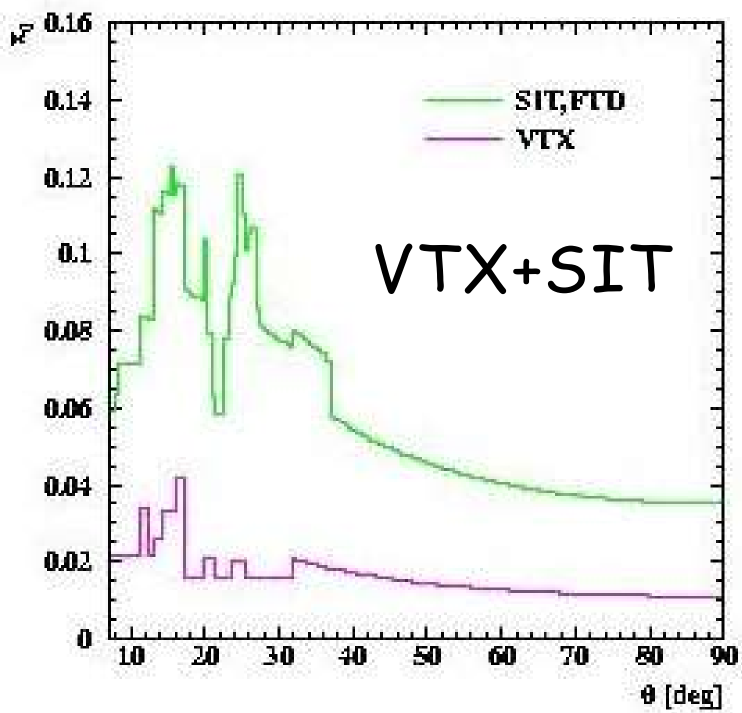
2.5 GeV/c
25
250

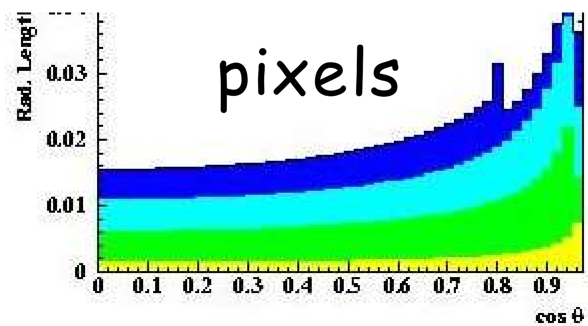
Includes 2000 γ-background hits/Xing

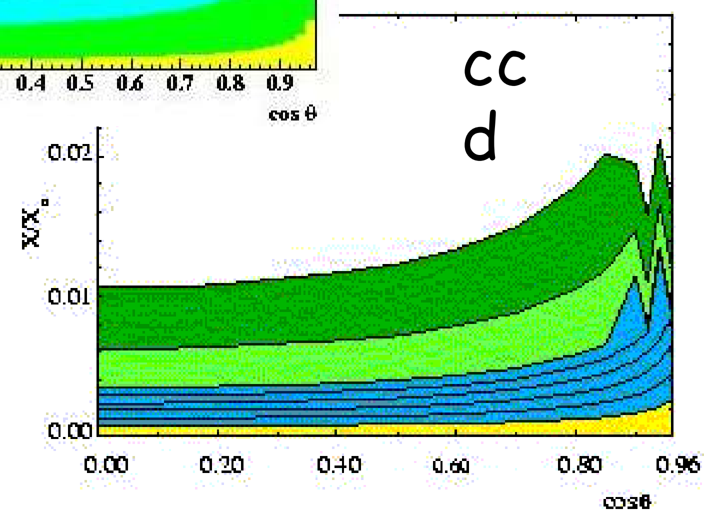
TDR Thickness











Thickness before Barrel ECAL(% X_0)

	SiD	TDR
Vac.Ch&VTX	1.1	1.1
SIT	-	2.4
TPC/Si	2.5 to 7.5*	3.5
	3.6 to 8.6	6.5
SET	-	1 to 3

* 5x0.5% or 5x1.5%

Note 1: CMS ~ 3%X_0 per layer; 270μ Si= 0.3%X_0

Note 2: 1/sinθ from 1 to 1.66(SiD) or to 1.92 (TDR)

Note 3: TPC endplate+FCH: 35%X_0 for cosθ>0.85

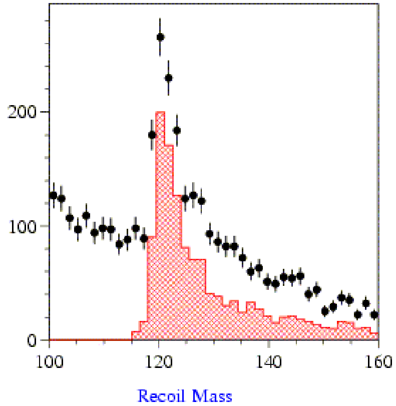
TPC systematics calibration & alignment

to be controlled in r-phi to < 10 microns… (~150/√200)
in z to < 50 microns… (~700/√200)

a) Mechanical stability vs. thickness

gas pressure following the atmosphere

mechanical effect of magnet



s

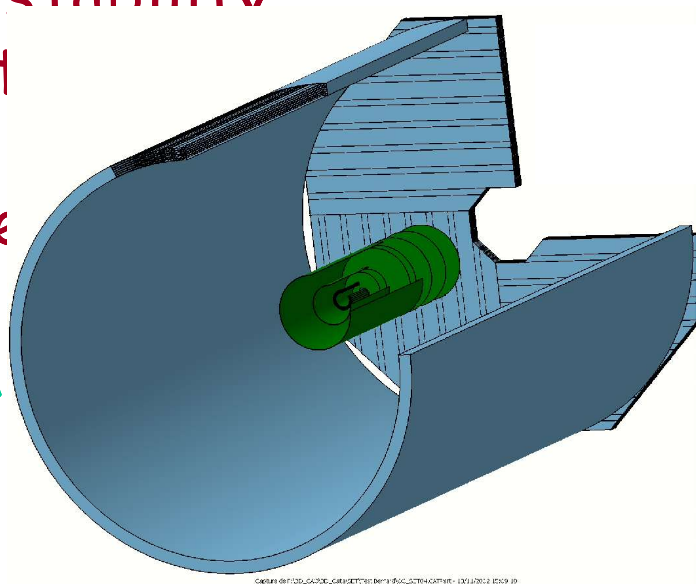
cy needs vdrift at 2 10^{-5} level

E field: source stability

temperat… …or

pressur…

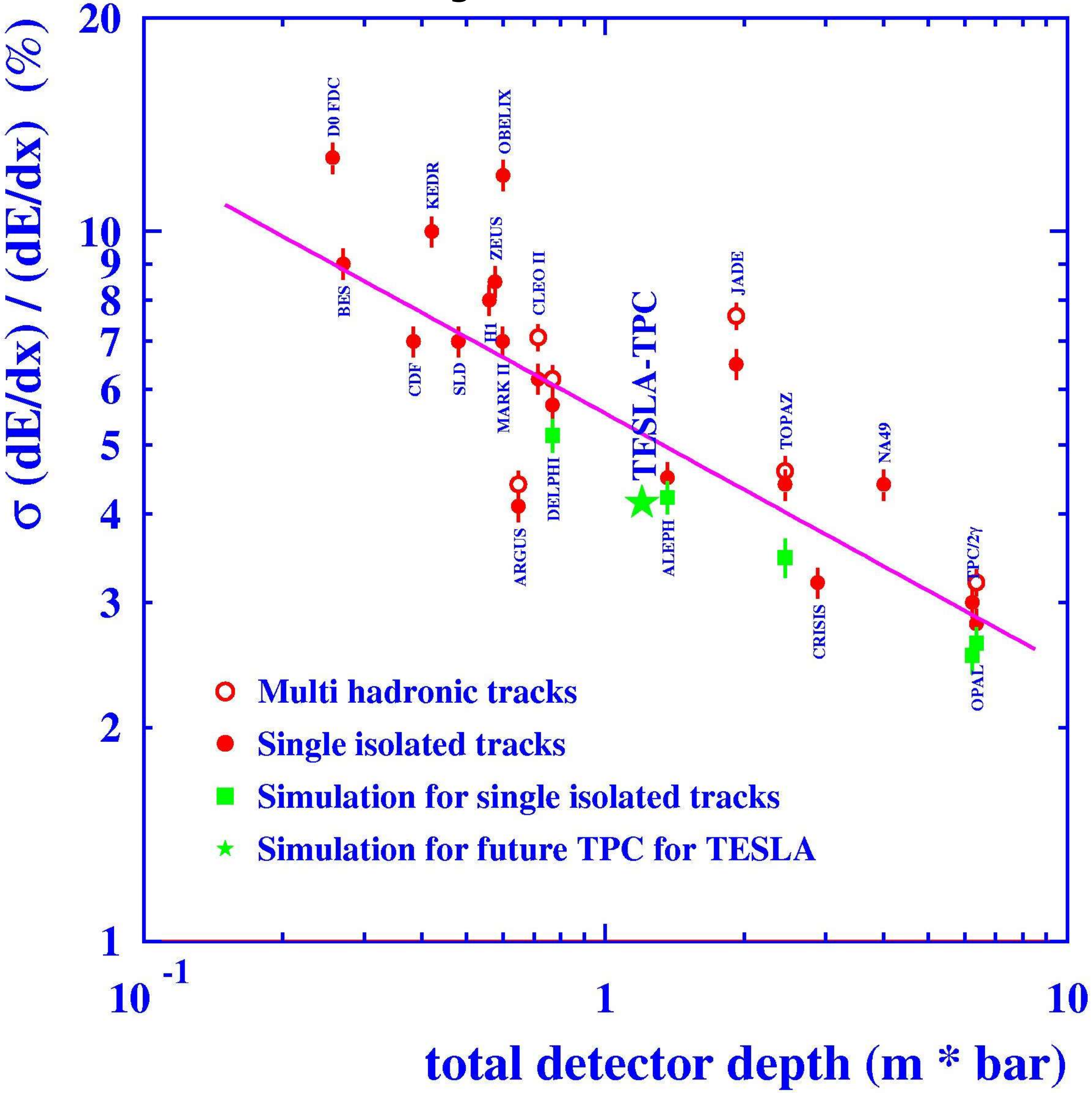
volume

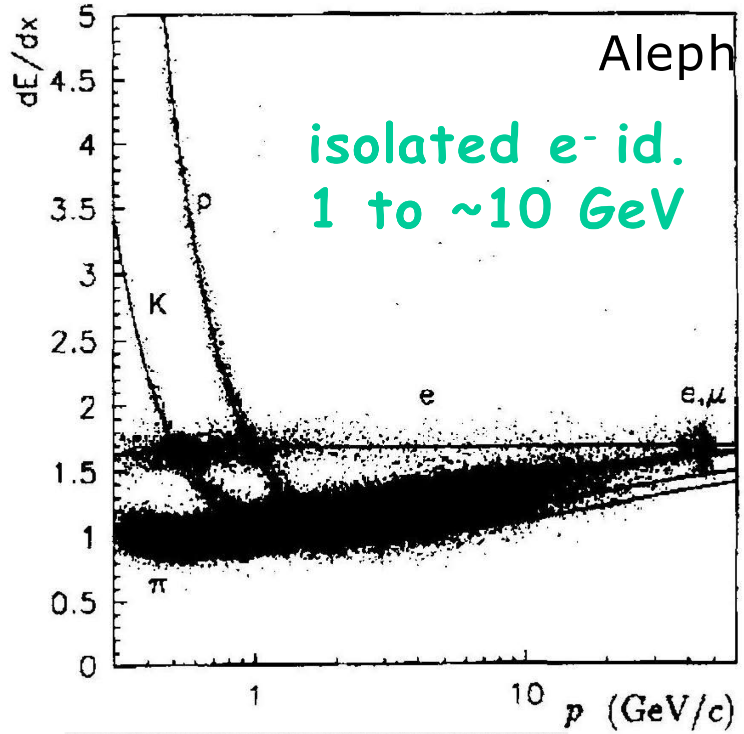


z accuracy importa…
for missing mass
resolution

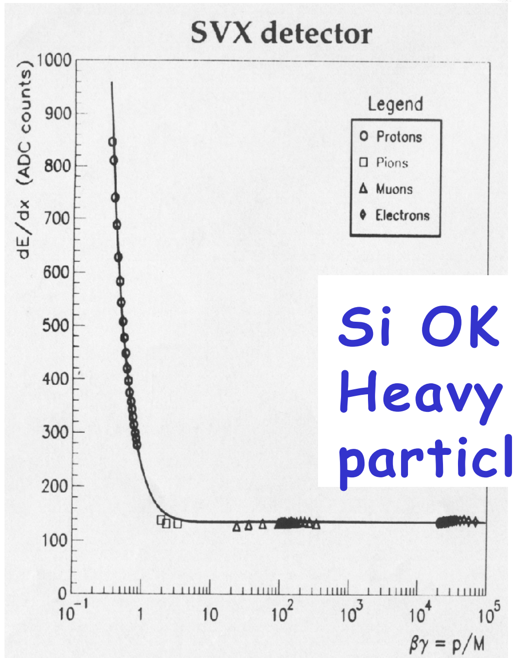
dE/dx TPC

Magali Gruwé LC-DET-2001-043





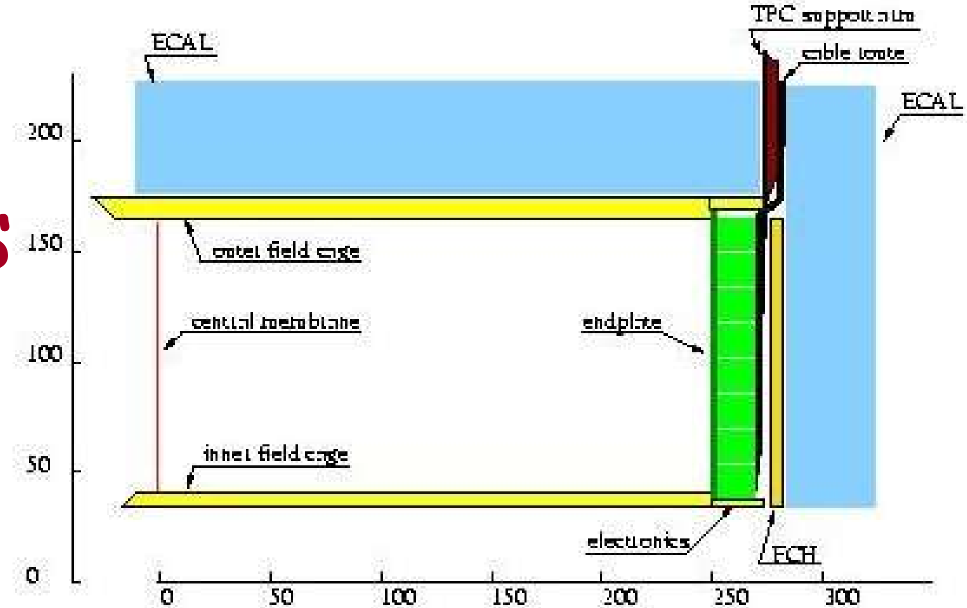
isolated e⁻ id.
1 to ~10 GeV



Si OK for
Heavy stable
particles id.

Hermeticity

End plate thickness
pulsed electronics
cooling & all that



-only power cables in and optical fibers out,

no water, no copper pai

~0.6 million channels/side

Alice TPC; **42mW/channel, ~1/3 FE, 1/3 pipeline, 1/3 ZS & Opt**

Cooling costs about 10-30%X_0/(KW/m2) **(?)**

⇒Pulsed electronics mandatory

can pulse to zero power with rising time of 100μs (R&D UCSC)

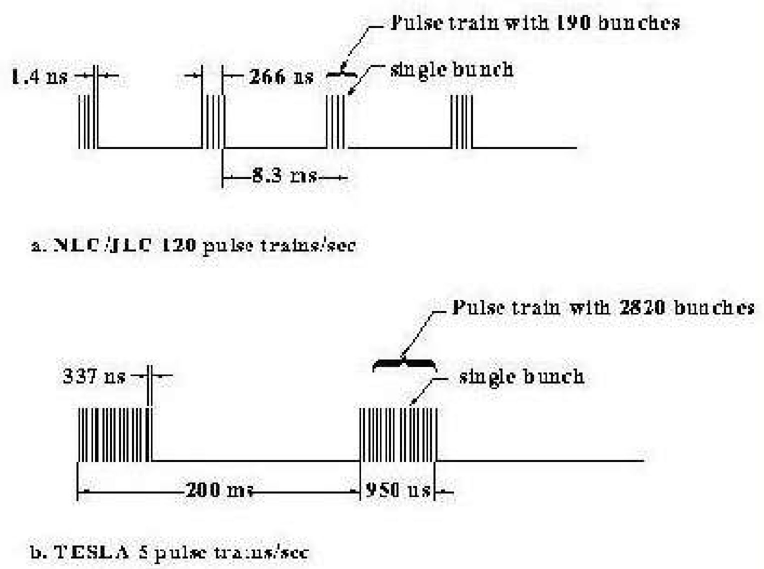
or quiescent at 5% power rising in 200 ns (commercial specs)

⇒Power/10 at least, could it be /100

Bunch Tagging

NLC/JLC-X 1.4 ns

TESLA 337 ns to 176 ns



main point: underlying γ-γ event rate (?)

Gas Tracker (JetCh, TPC) accuracy 2ns

see K. Fujii, LBL-TPC 2003

Si better or worse?

Topology rejection LC-PHSM-2000-052 Battaglia&Schulte

Rates Table

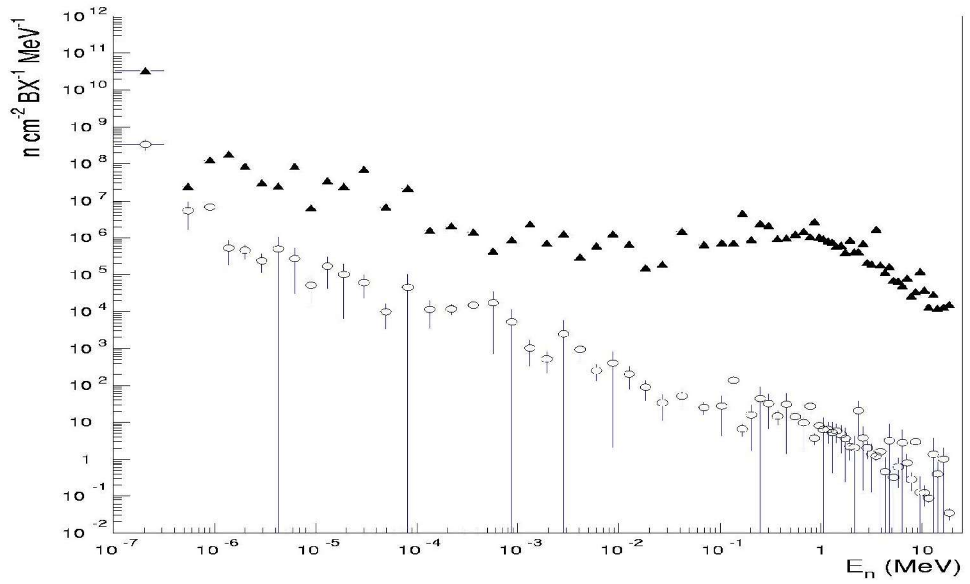
Centre of mass energy		TESLA Parameters 0.5 TeV	0.8 TeV
Beam properties			
$\mathcal{L}$	$[10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	3.4	5.8
Trains/s		5	4
Bunches/train		2820	4886
Interbunch spacing	[ns]	337	176
Bunch sizes			
σ_x/σ_y	[nm]	553/5	391/2.8
σ_z	[mm]	0.3	0.3
Backgrounds			
$\gamma\gamma$ ev./BX ($p_T^{min} = 2.2\,\mathrm{GeV/c}$)		.02	0.1
Physics events			
Bhabha ($\theta > 20$ mrad)	$[s^{-1}]$	350	240
W^+W^-	$[h^{-1}]$	930	810
$q\bar{q}$	$[h^{-1}]$	330	210
$t\bar{t}$	$[h^{-1}]$	70	54
$\nu\nu H_{SM}$ ($M_{H_{SM}} = 120$ GeV/c^2)	$[h^{-1}]$	10	35
ZH_{SM} ($M_{H_{SM}} = 120$ GeV/c^2)	$[h^{-1}]$	7	4

Neutron Background

✦ Neutrons produced in giant dipole resonance excitation, pseudo-deuteron mechanism and photo-pion reaction by spent beams, beamstrahlung (300 kW/BX), pair (260 GeV/BX) and radiative Bhabha (2100 GeV/BX) fluxes;

✦ Main source of neutrons reaching the TPC volume is pair dump and the estimated flux is $\simeq 15000\ n\ \mathrm{BX}^{-1}$ for TESLA at 500 GeV.

ENERGY SPECTRUM FROM FLUKA SIMULATION



from M.Battaglia

Neutron background does not seem to be consistently

Conclusion

The Detector Performance Group
work
is important!

(very personal) Conclusion

A) Need a full sim comparison of E-Flow for various ECAL parameters: radius, pad size, etc…
B) Can one have HCAL outside the coil? Can one reduce HCAL Thickness?
C) Reconstruction of K^0, Λ and late decays seems possible in SiD. Is this true?
D) Need of K^0, Λ and hadron id. on E-Flow ? Effect of tracking inefficiencies on E-flow?
E) Hermeticity requires pulsed electronics!
F) BACKGROUNDS to be evaluated & introduced in all studies
G) How important is bunch tagging in NLC case?

…..

The Small SiD is less studied than TDR

SiD is (still) a viable