Forward Tracking;
physics case, challenges and design

The 3rd ILD Workshop

February 16 - 18, 2009

Ewha Womans University, Seoul, Korea

Marcel Vos (IFIC – U. Valencia/CSIC)

on behalf of ILC-Spain

Coordinated ILC effort in Spain

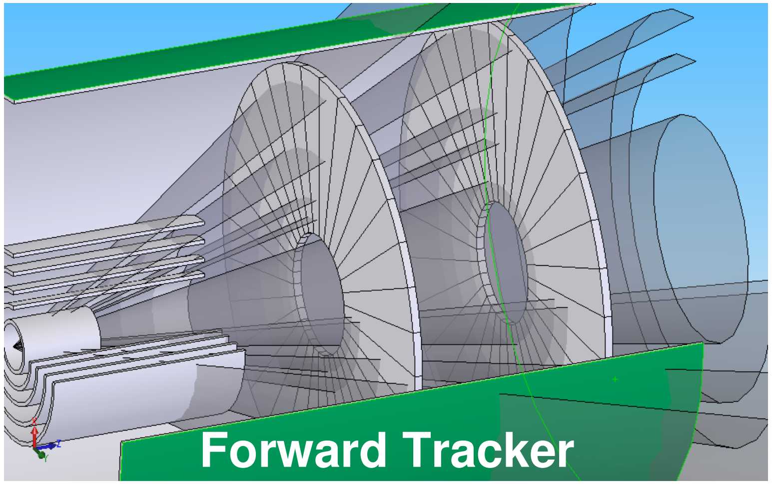
Strong Spanish participation in DEPFET
IFIC (since 2005)
USC, UB, URL, CNM (since 2008)

Silicon for Large Colliders

IFIC, IFCA, UB, CNM, USC
one EUDET member, several associates

CALICE

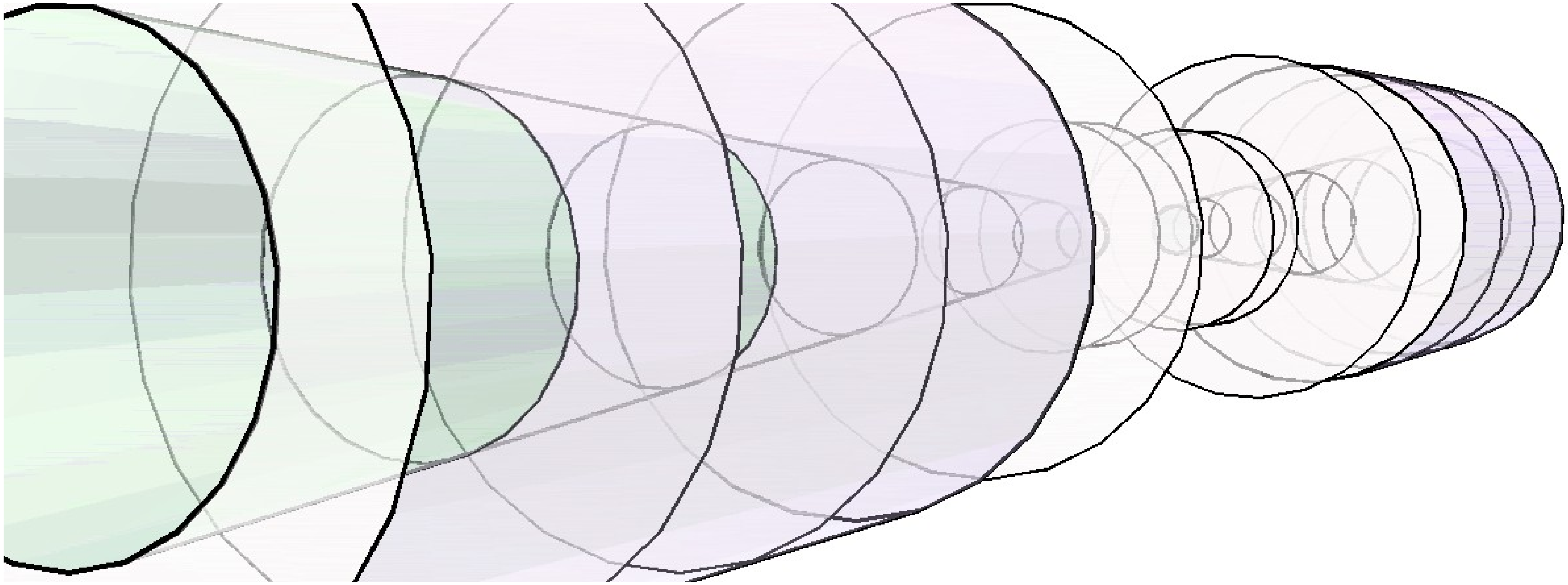
CIEMAT Madrid



Coordinated effort (led by A. Ruiz):

- **regular meetings**
- **funding/projects**
- **R&D interests**
- **the forward tracker**

The scope of this talk



ILD's Forward Tracking Disks

The forward region = $6^o < \theta < 25^o$

(0.1 rad < θ < 0.45 rad, 0.9 < cos θ < 0.995, 1.5 < | η | < 3)

in future e^+e^- colliders in 0.5-1 TeV range

Why is forward tracking performance important?

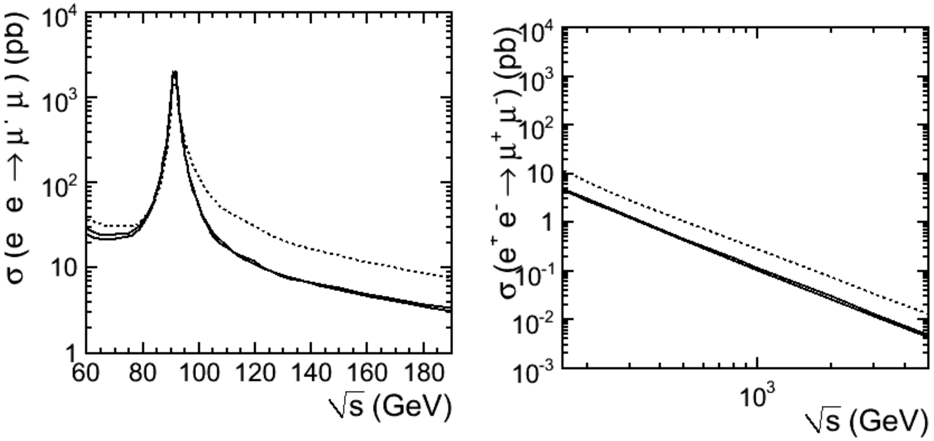
There is a series of very relevant physics processes where final state particles are predominantly emitted at small polar angle

Mostly electrons, but also muons, t, b- and c-jets

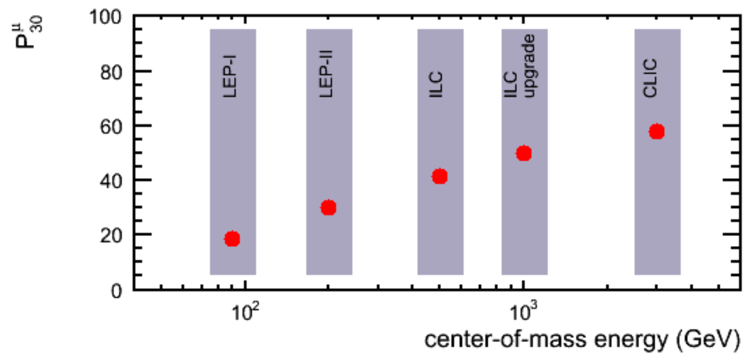
From LEP-I to the ILC (to CLIC)

$e^+e^- \rightarrow Z/\gamma* \rightarrow \mu^+\mu^-$

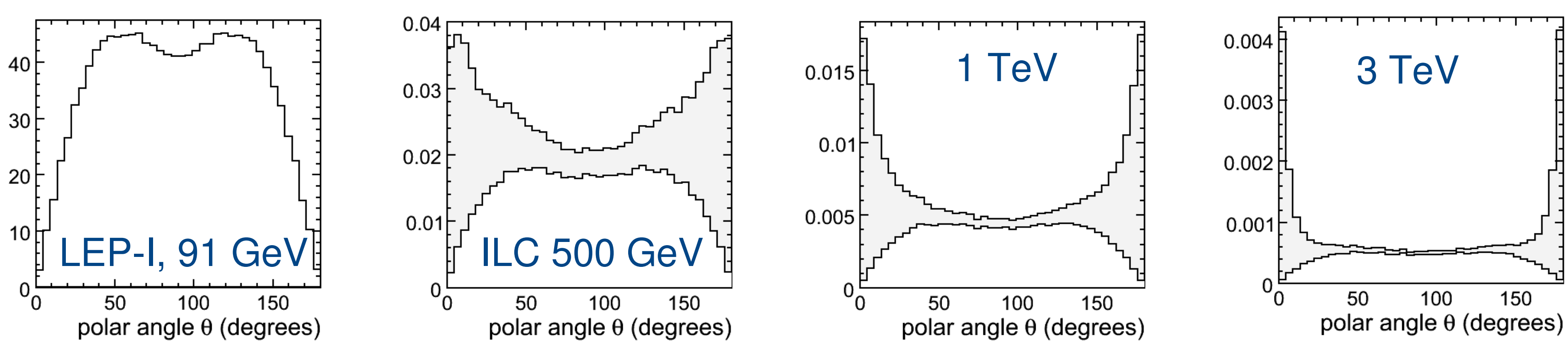
with(----)/without(- - -) ISR



P^X_{30}: Probability that final state product X is emitted at a polar angle of < 30°



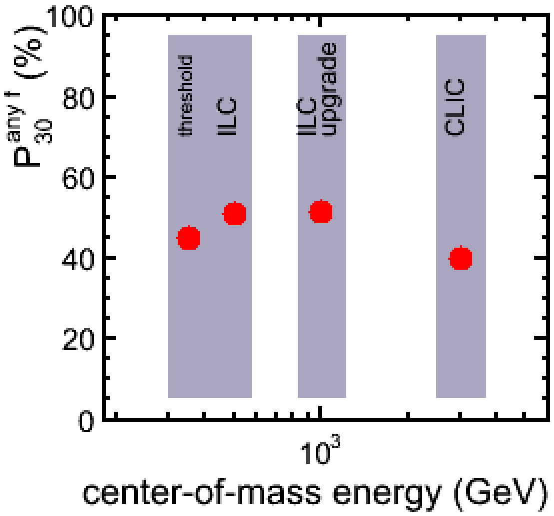
Determine the relevance of the forward region in several key processes for a number of scenarios increasing center-of-mass energy



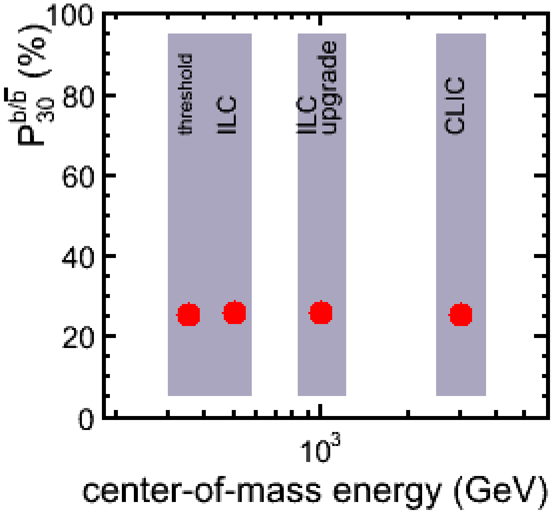
Multi-fermion final states

$e^+e^- \rightarrow Z \rightarrow tt$, no ISR

At least 1 (of 6) fermions



At least 1 (of 6) b-quarks



Final states with many fermionsb(like ordinary SM tt-events) are hardly ever fully contained in the central detector

P (θ < 30)	√s = 500 GeV	√s = 1 TeV	√s = 3 TeV
at least one top	0.15	0.17	0.22
at least one b	0.22	0.25	0.25
any fermion	0.59	0.51	0.4

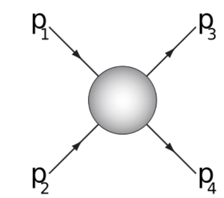
Tag a forward b-jet in 1 out of 4 events: requires vertexing

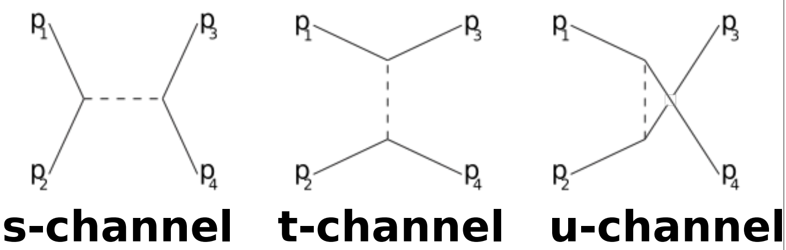
The importance of the t-channel

With increasing center-of-mass energy
(from LEP-I to to LEP-II to ILC to CLIC)
the importance of the t-channel increases

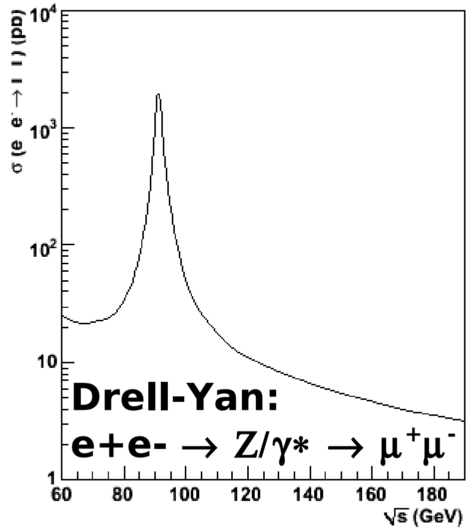
Example: scalar lepton production in SUSY (SPS benchmark point 1a)

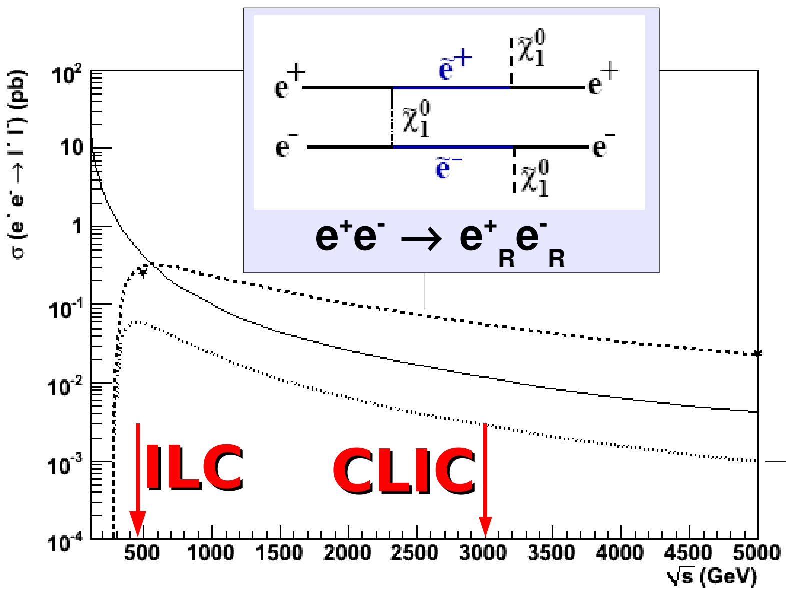
$$s = (p_1 + p_2)^2 = (p_3 + p_4)^2$$
$$t = (p_1 - p_3)^2 = (p_2 - p_4)^2$$
$$u = (p_1 - p_4)^2 = (p_2 - p_3)^2$$

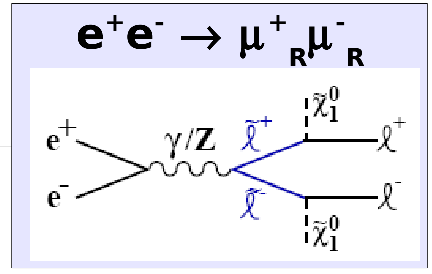




MadGraph/MadEvent (hep-ph/0208156)

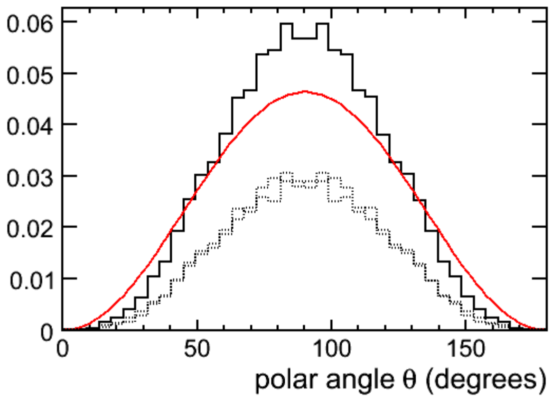


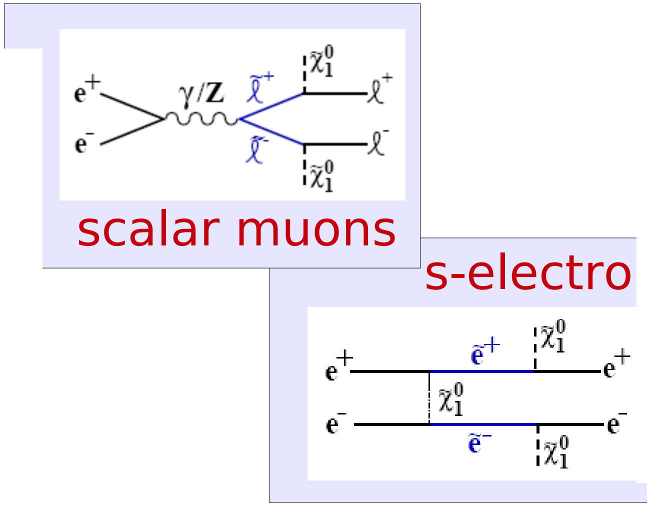


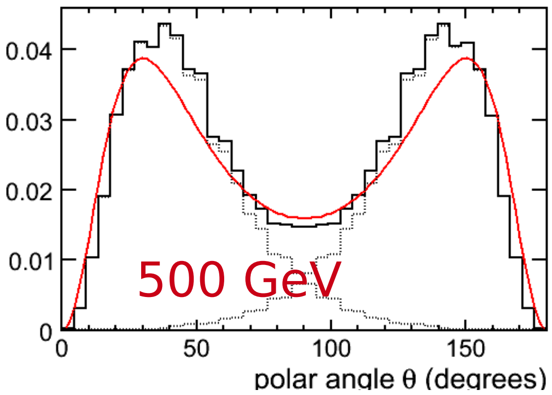


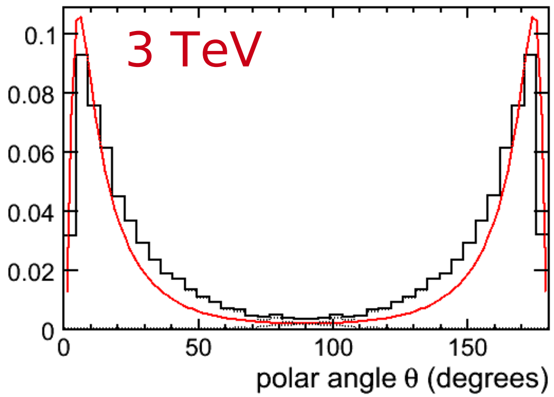
The importance of the t-channel

polar angle distribution for s-lepton production









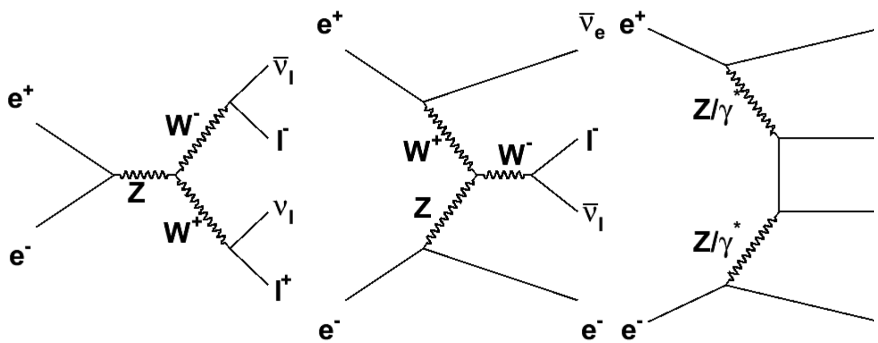
Products from t-channel prefer the forward region (and increasingly so with higher center-of-mass energy)

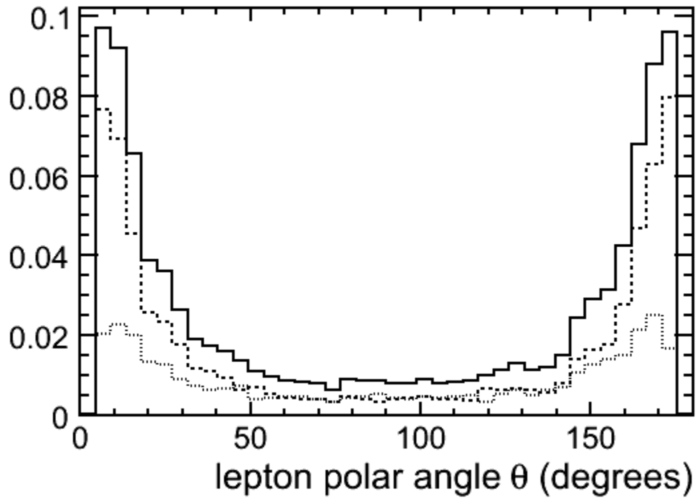
Fraction of forward s-electrons ($\theta < 30^o$) for s-electron pair production in SPS1a

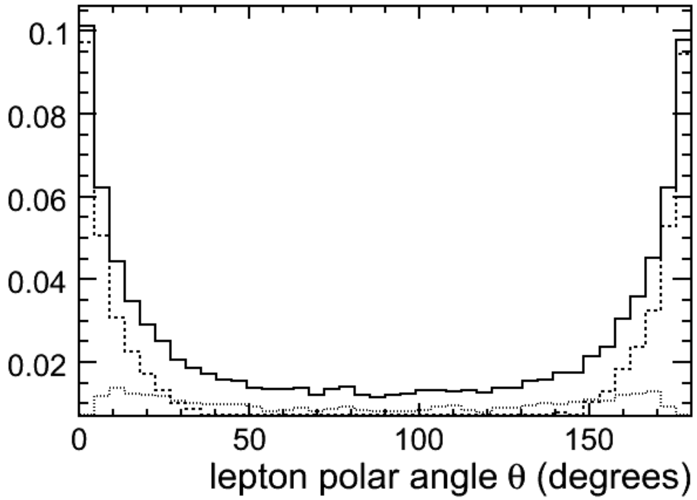
@ 500 GeV **24 %** **@ 1 TeV** **50 %**

Scan SUSY space (analytical expression for polar angle distribution)

The challenge







The last example: di-boson production
Polar angle distribution of electrons extre
peaked in forward direction

Next: Study a representative list of be
channels in a quantitative way
(to be published soon)

Forward tracking physics case

Forward tracking requirements at the next e^+e^- collider
part I: the physics case for forward tracking

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[v] IFIC Valencia

February 12, 2009

Abstract

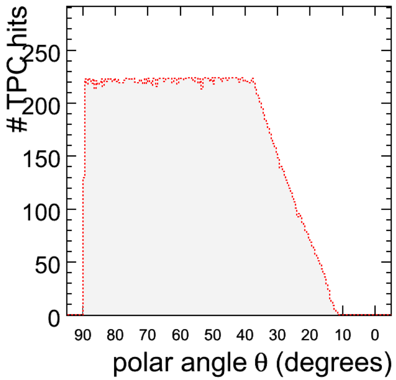
In this note we explore the detector requirements of the forward tracking region for a future e^+e^- collider with a center-of-mass energy in the range from 500 GeV to 3 TeV. The relevance of the forward region is explored for a wide range of physics processes.

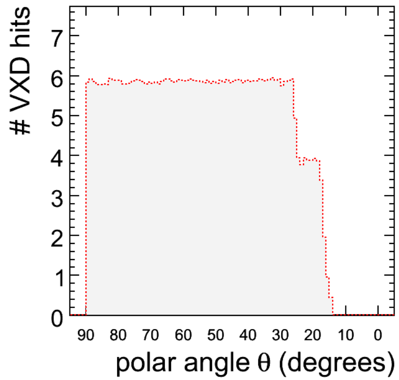
Forward tracking physics case:
Little guidance from standard benchmark reactions (cos θ < 0.95)
In this document some physics cases are explored that are particularly relevant for this detector region.

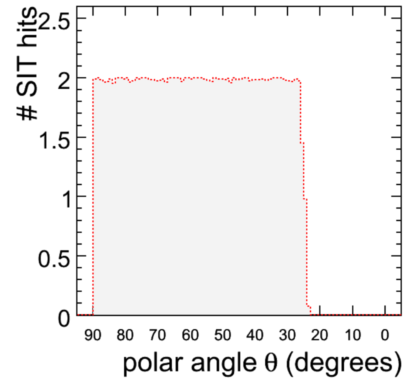
Why is forward tracking challenging?

The material!
Hermetic coverage
Significant background at smallest radii
The unfavorable orientation of the magnetic field
Abundant low momentum tracks – pattern recognition

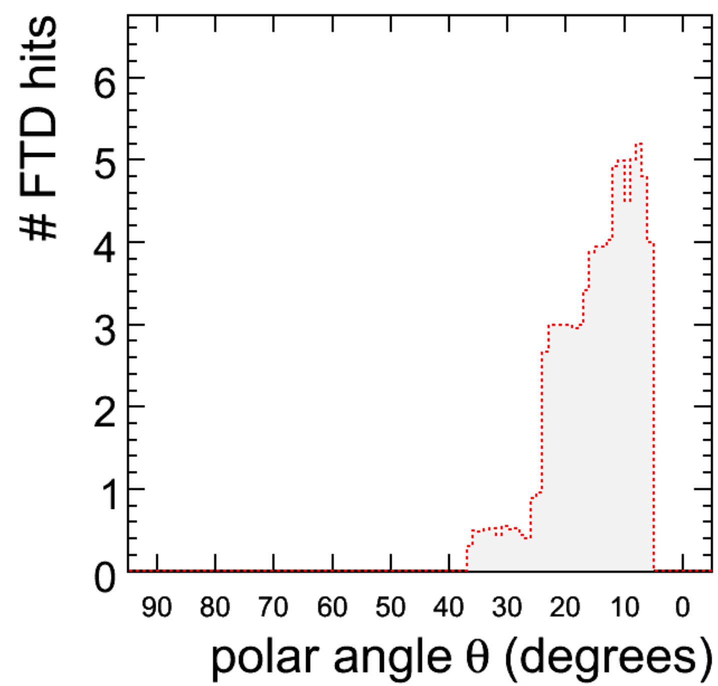
Coverage



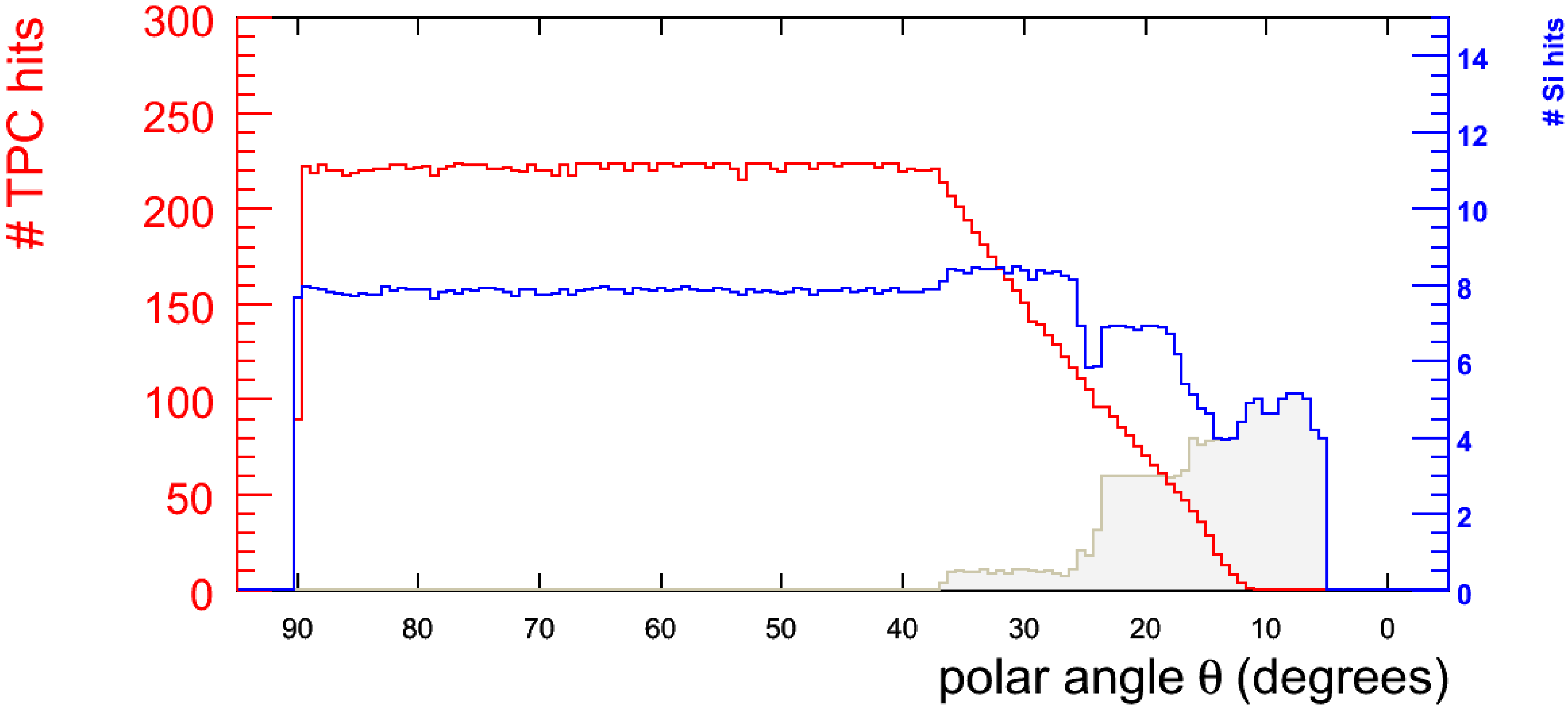




Concept	Magnetic Field	Angular 5-point	Coverage 3-point
SiD	5 T	12.5 (43 barrel)	9
LDC	4 T	26	19
GLD	3T	26 (6 points)	18 (4 barrel + 2 disk)
ILD	3.5 T	26 (6 points)	17

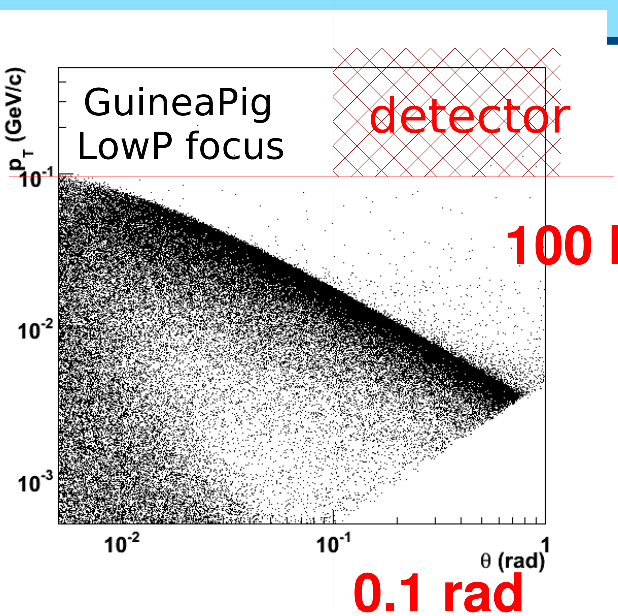


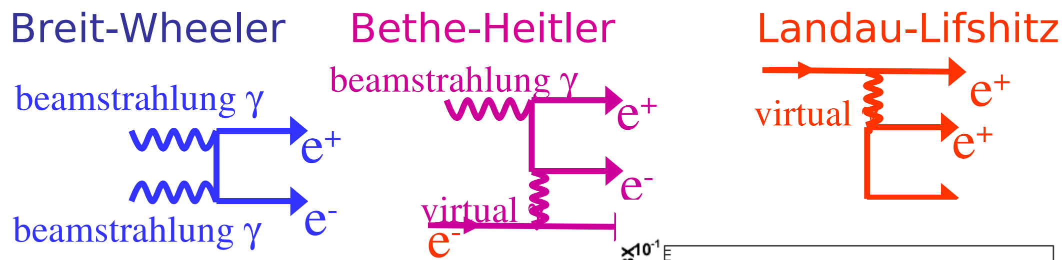
Coverage

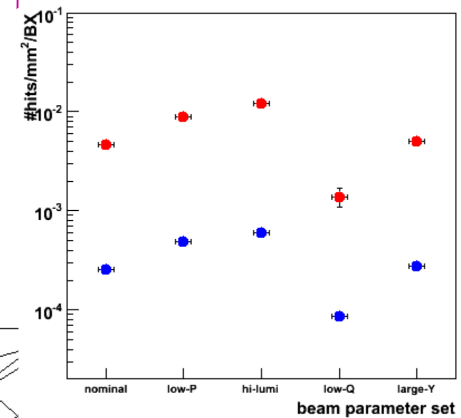


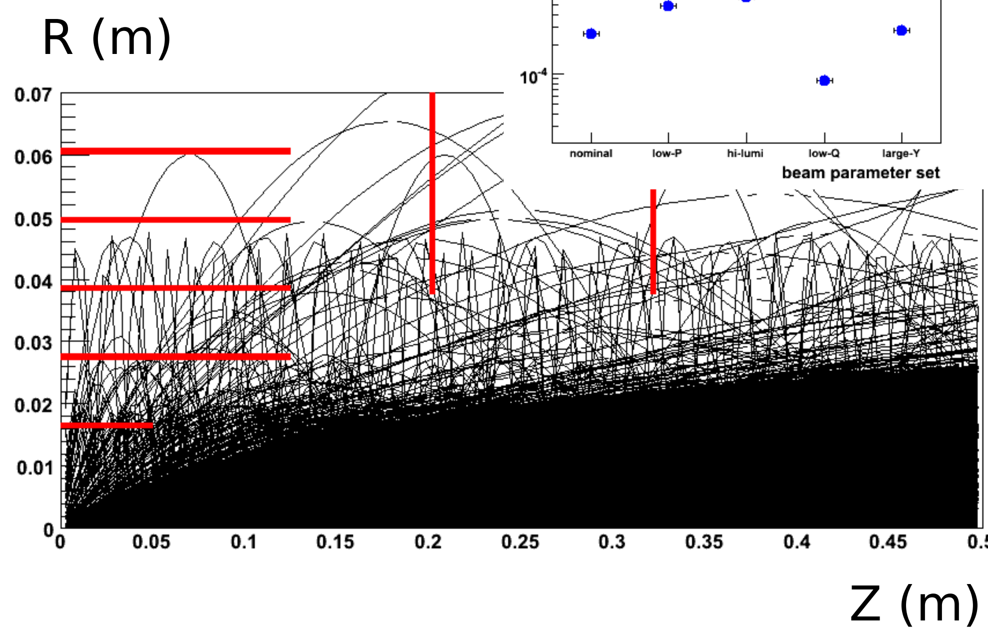
TPC hits
300
250
200
150
100
50
0
Si hits
14
12
10
8
6
4
2
0
90
80
70
60
50
40
30
20
10
0
polar angle θ (degrees)

Environment: background level



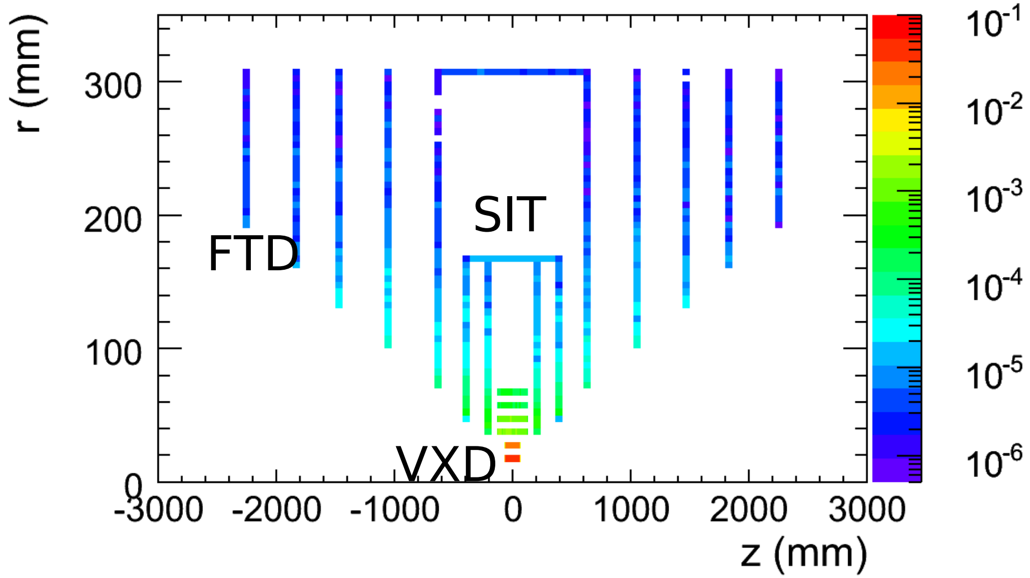






Incoherent e^+e^- pair production off beamstrahlung photons produces a very large number of electrons and positrons each BX. The large majority is soft and/or emitted at low angle and are trapped in the "accumulation zone"

Pair background



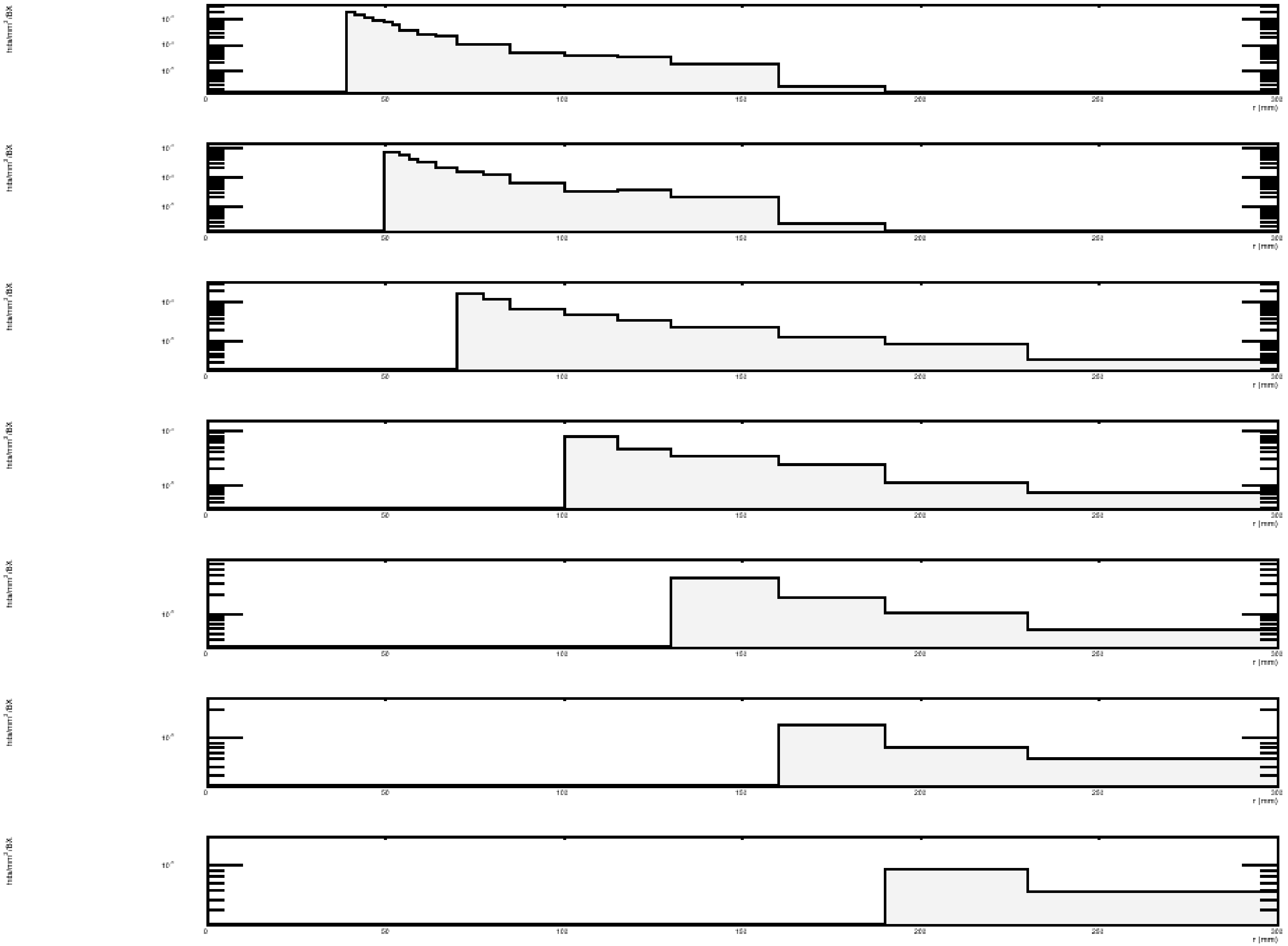
GEANT4 simulation of GUINEA-PIG events by Toni Harlin
(thanks also to A. Vogel and Katarzyna Wichman)

Hit density
(#/mm^2/BX)

detector	min	typical	max
VXD 1		4×10^{-2}	
VXD 6		3×10^{-4}	
FTD1	$<10^{-5}$	1×10^{-4}	2×10^{-3}
FTD7	5×10^{-6}	7×10^{-6}	9×10^{-6}
SIT 1		3×10^{-5}	
SIT 2		3×10^{-6}	

Hit density = number of GEANT4 energy deposits per unit area per ILC bunch crossing
Does not take into account the number of channels fired by a single hit

	Typical area sensitive elements	time resolution:
pixel:	25 x 25 μm^2 = 6.25 x 10^{-4} mm^2	100 BX
strips:	50 μm x 10 cm = 0.5 mm^2	1 BX



	direct hits (%)
VTX 0	84
FTD 1	81
FTD 2	79
FTD 3	60
FTD 4	38
FTD 5	36
FTD 6	48
FTD 7	46
FTD	63
SIT 1	31
SIT 2	25
SIT	28

Detector specifications

ILC detectors: intentions

VXD: impact parameter resolution 5 – 10 μm.

This precision is required to achieve excellent heavy flavour tagging, particularly for couplings of the Higgs boson to charm ($c\tau$ ~150 μm) and bottom ($c\tau$ ~ 450 μm)
Resolution in central region well understood. Forward region more complex...

TRK: momentum resolution $\Delta(1/p_T) < 5 \times 10^{-5}$ (GeV^{-1})

Precision required to reconstruct the Higgs boson using the recoil method, and to reconstruct SUSY end-points long-standing fast simulation results in central and forward region confronted to ILD_00 full simulation (single muon samples) and FullLDCTracking

CALO: energy resolution $\Delta E/E < 30\%/\sqrt{E}$

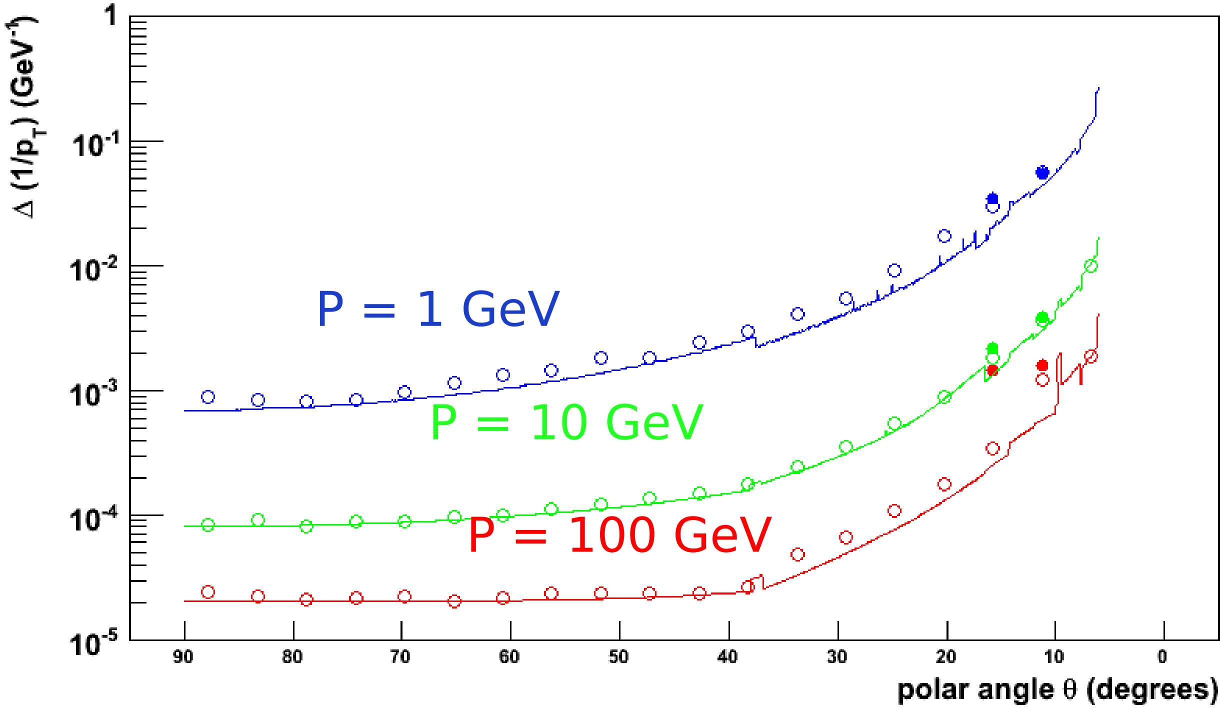
Precision required to distinguish hadronic decays of W and Z
Impact of tracker in central region well understood. Contribution to forward region expected.

Transverse momentum resolution versus polar angle
Measured on three single-muon samples with fixed |p|

LiCToy on ILD00 (full KF fit), *M. Valentan, HEPHY Vienna*

FullLDCTracking on ILD00 (Mokka/MarlinReco) *Vos/Duarte/Iglesias*

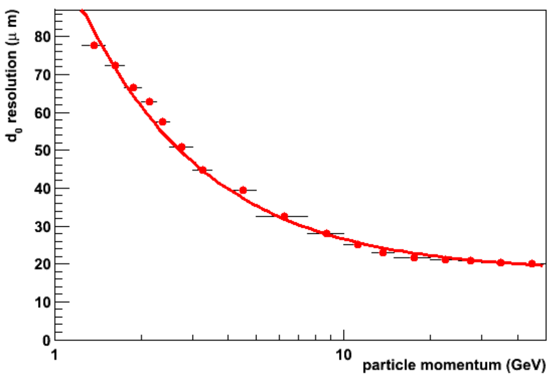
CMS KF Track Fit on standalone FTD *Vos/Duarte/Iglesias*



Impact parameter

$$\sigma_{IP} = a \oplus \frac{b}{p \sin^{3/2}\theta}$$

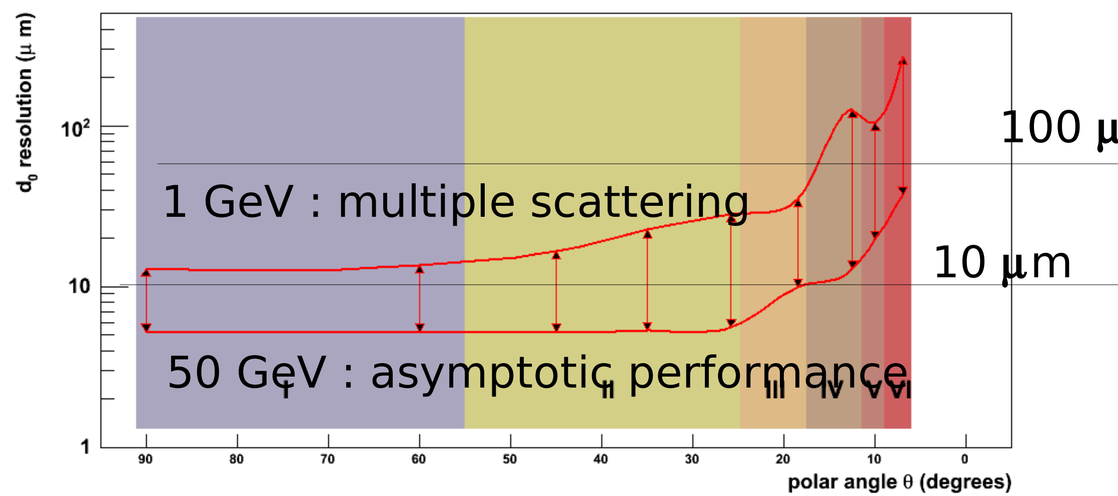
	a (µm)	b (µm GeV)
LEP	25	70
SLD	8	33
LHC	12	70
ILC	5	10



Unprecedented precision
(small pixels, 20x20 µm^2)

Strongly reduce the multiple Coulomb scattering term
(material: 0.1 % X_0 / layer
~ 100 µm Si)

- * I 35 < θ < 90 5 VXD + SIT
- * II 25.8 < θ < 35 5 VXD + FTD1
- * III 18.5 < θ < 25.8 3 VXD + FTD1+2
- * V 10 < θ < 12.5 FTD1,...
- * IV 12.5 < θ < 18.5 VXD2 + FTD
- * VI 6.5 < θ < 10.0 FTD2,...



Transverse impact parameter resolution versus polar angle
Measured on three single-muon samples with fixed |p|

LiCToy on ILD00 (full KF fit), *M. Valentan, HEPHY Vienna*

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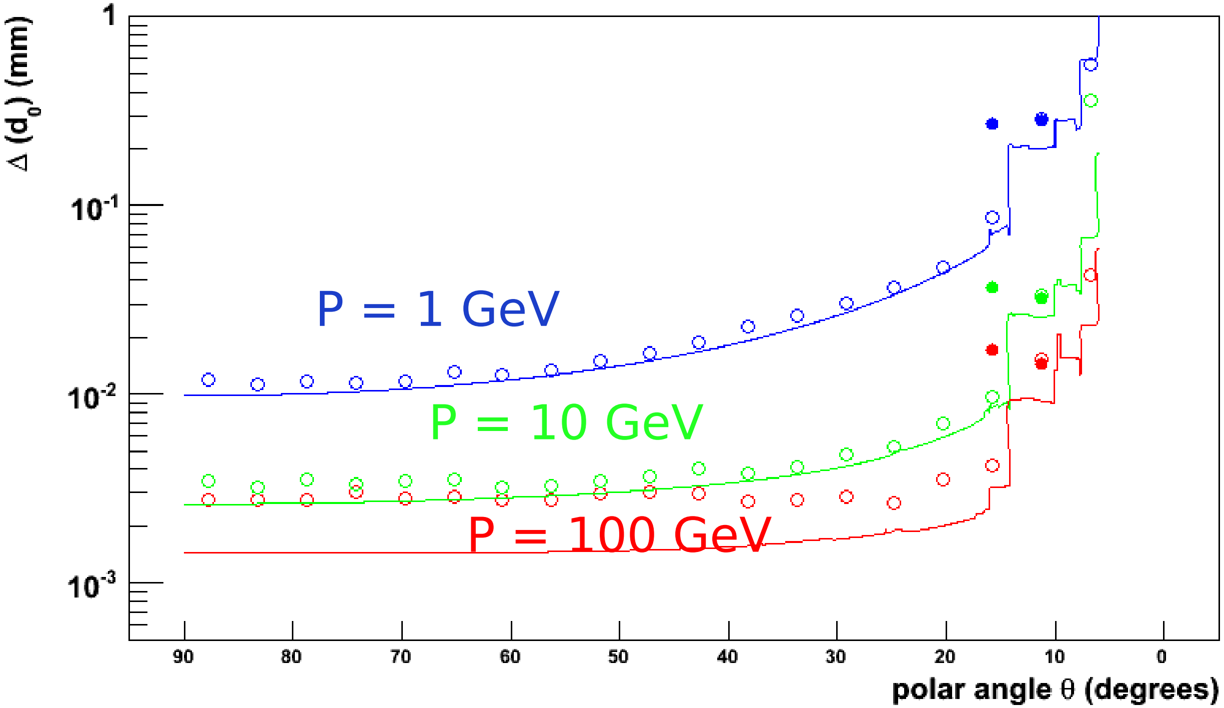
CMS KF Track Fit on standalone FTD *Vos/Duarte/Iglesias*



Towards an engineered design

Calibration/alignment
Mechanical support
Services

Laser alignment system

Marcos Fernandez, IFCA

- Laser alignment system (AMS/CMS)
  - Near IR laser beam provides pseudo-track
  - No mechanical transfer between aligned object (i.e. jewel) and sensor
  - Minimal distortion of system (laser brought into the detector along a fiber)
- Develop IR transparent μ-strip detector:
  - Identify a *minimum* set modifications in detector structure to increase its optical transmittance in NIR spectrum up to 70-80 %
  - design and produce IR-transparent Silicon microstrip detectors **IFCA (Santander)/IMB-CNM (Barcelona)**
  - Consider option of aluminum electrodes or transparent electrodes

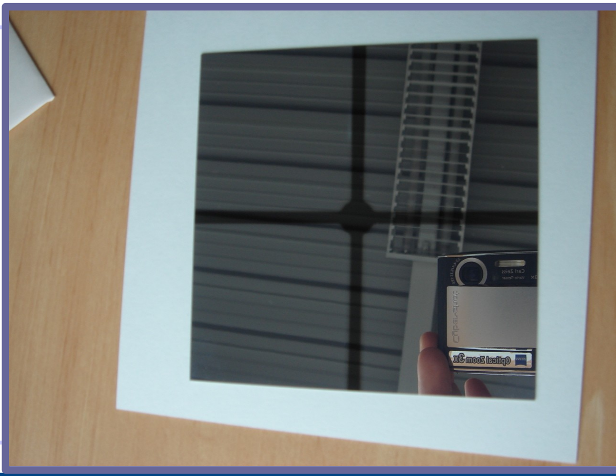
EUDET prototype AMS-like

Implemented:

- ∅~10 mm window where Al back-metalization has bee

Suggested (not cost effective for small batches):

- Strip width reduction (in alignment window)
- Alternate strip removal (in alignment window)



Laser alignment system

• **IMB-CNM** Barcelona provides **samples** of each of the materials. Manufacturing and processing granted by Spanish Program to Access Large Research Facilities (ICTS).

Shown to the right wafers from **TOPSIL**, (high resistivity, double polished,300± 20 µm thick).

— Different wafers have different doping levels
— Wafers divided into quadrants.
— In each quadrant only one new material has been deposited.
— We also have one wafer with pad sensors and no backmetal to study the effect of diffraction at strips
— Also available a raw wafer (unprocessed)

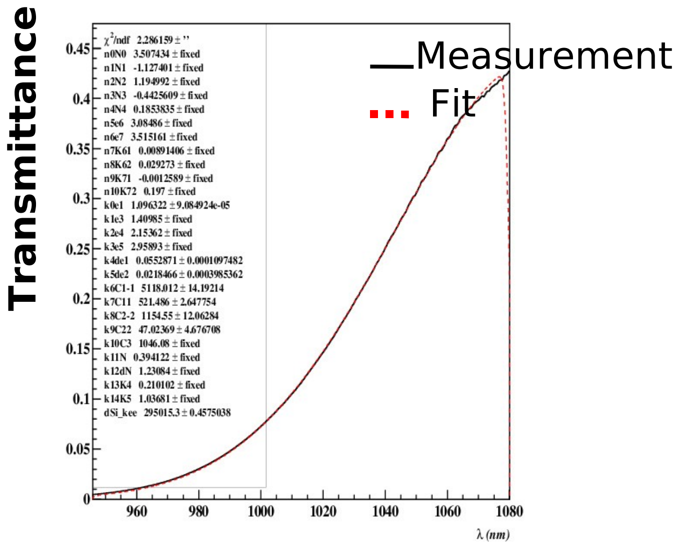
• The **goals** of these **measurements** are:

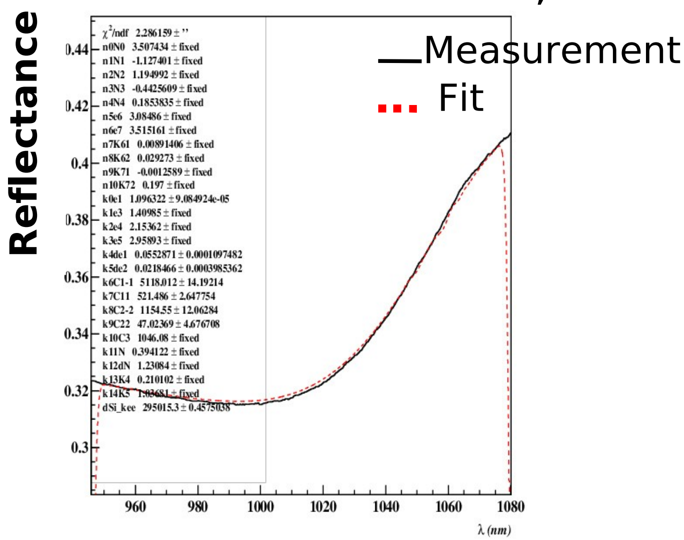
— **Characterize** each material as produced by the manufacturer
— Study **thickness tolerances** of the materials and, if needed, establish upper limits
— Study of transparent electrodes as a solution for the strips of the sensor

Marcos Fernandez, IFCA

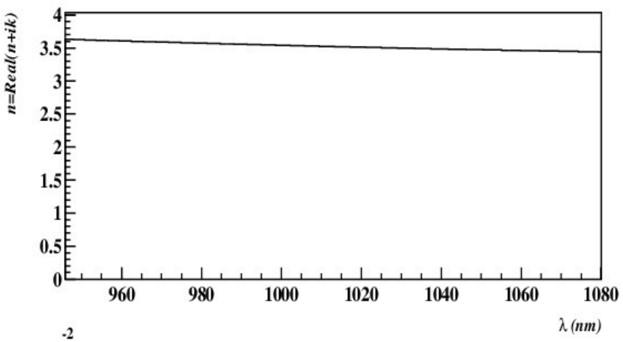
Simulation

Marcos Fernandez, IFCA

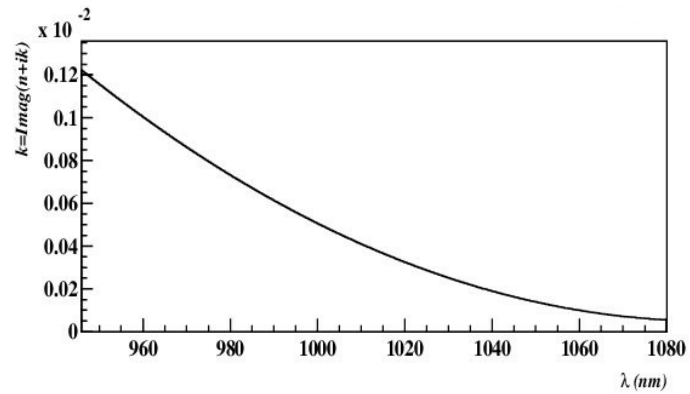




λ (nm)



λ (nm)

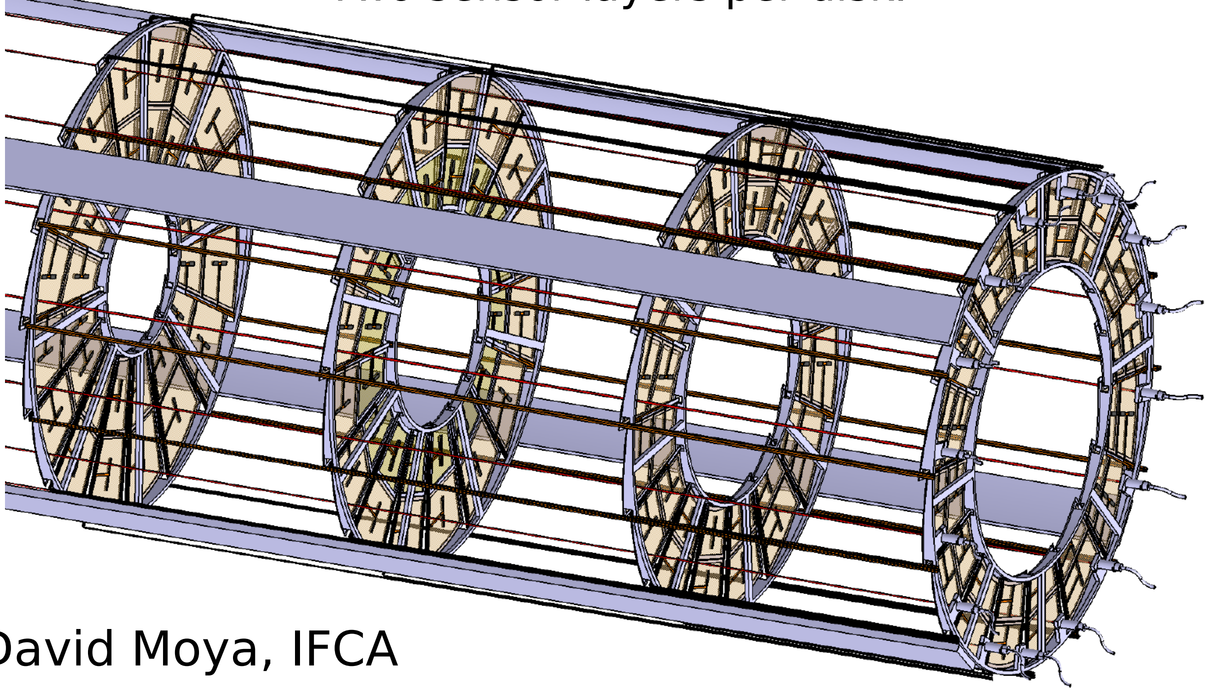


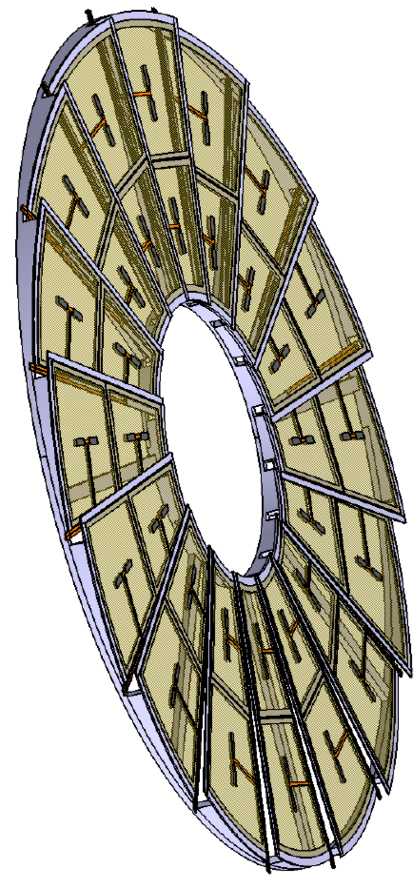
Simulation of IR properties of silicon sensors now sufficiently mature to design and manufacture prototype sensors

— If needed, technology transfer to larger manufacturer

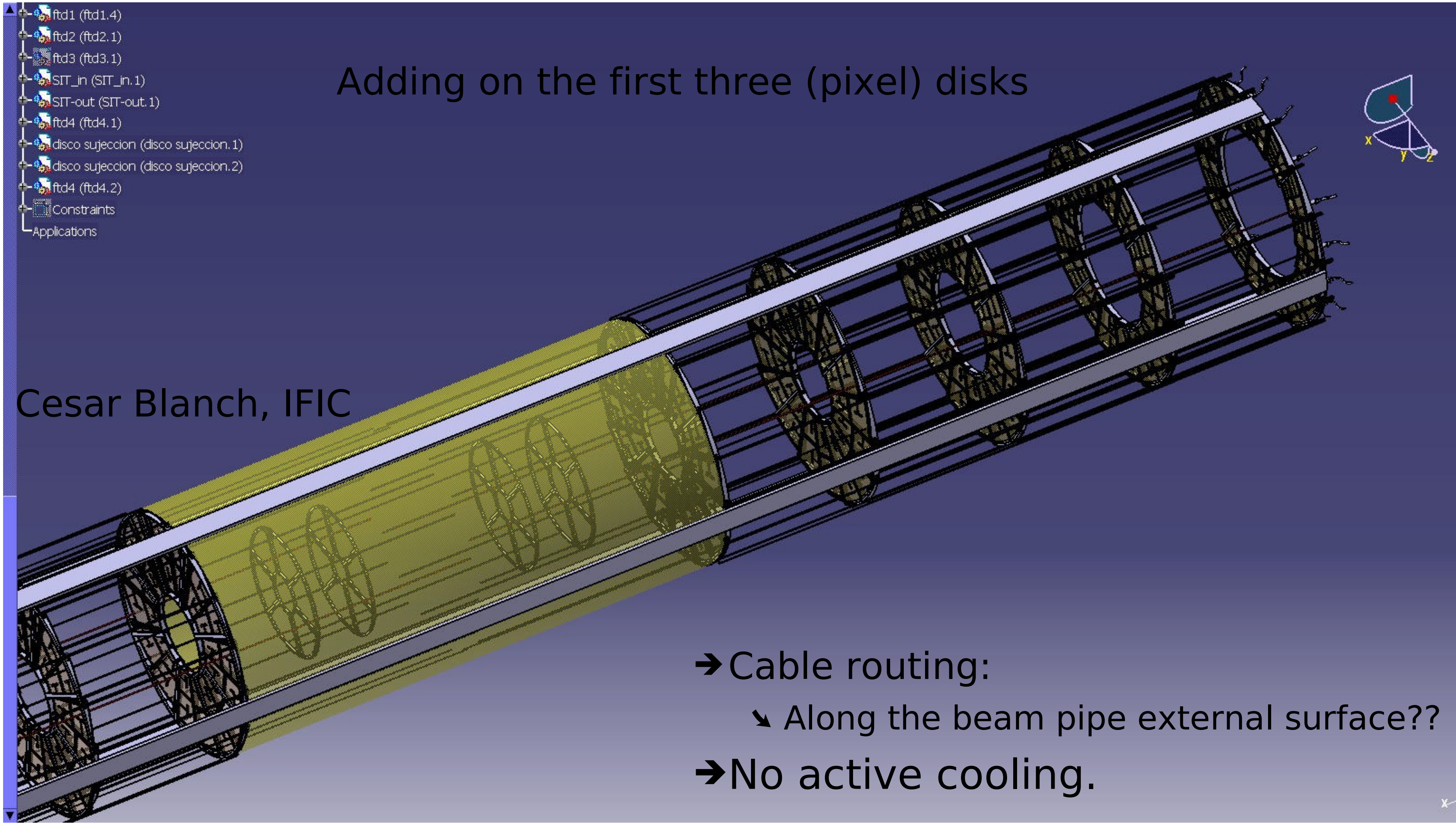
Towards an FTD design

- ➔ Micro-strip module guidelines:
  - ➘ ROC on sensor
  - ➘ ROC thinned to 50-100 um
  - ➘ 6” wafers (approx 10 cm x 10 cm sensors)
  - ➘ 150 μ m thickness
    - ➘ Two sensor layers per disk.





David Moya, IFCA



Adding on the first three (pixel) disks

Cesar Blanch, IFIC

➔ Cable routing:
  - ➘ Along the beam pipe external surface??

➔ No active cooling.

Conclusions

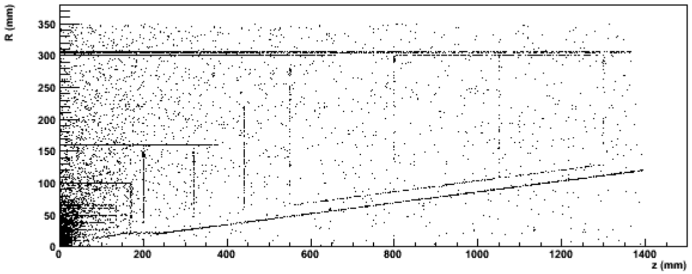
Interest of the forward region:
in several interesting physics cases the final state products have a strong preference for the forward region

Specific challenges:
momentum resolution under unfavorable field orientation
impact parameter measurement for very forward tracks
non-negligible background level (read-out speed)
standalone pattern recognition (background, low p tracks)
minimal distortion of particles/global performance

Requirements:
granularity @ reasonable speed staying within the power budget

Laser alignment:
the only “many-layer” silicon system in ILD

Towards a design:
engineering studies of FTD



More information on
http://ific.uv.es/~vos/ilc

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