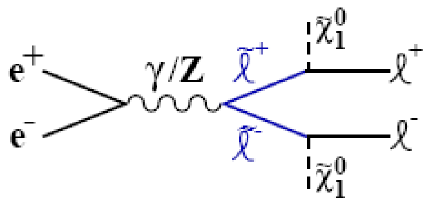
Forward Tracking Performance

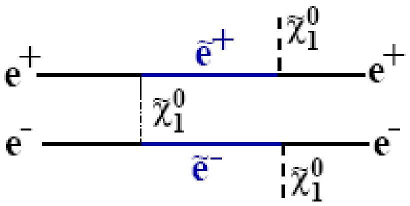
Carlos Mariñas, Marcel Vos – IFIC Valencia

IFIC

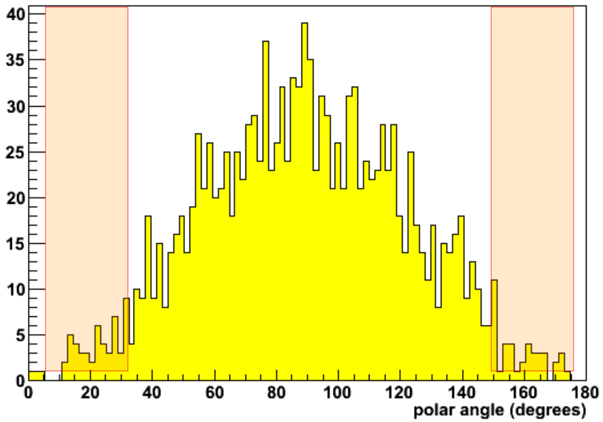
Forward physics

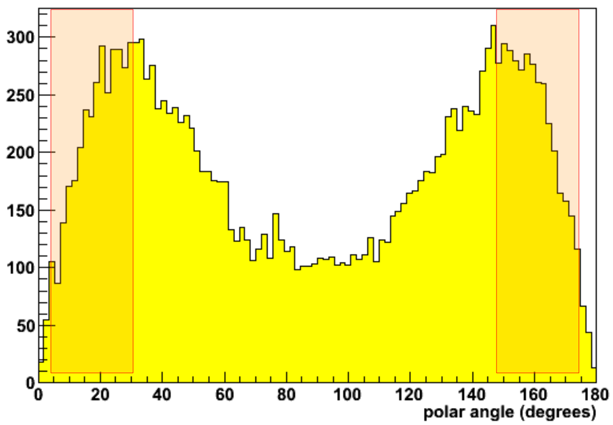


smuon and stau
s-channel
production



selectron:
t-channel



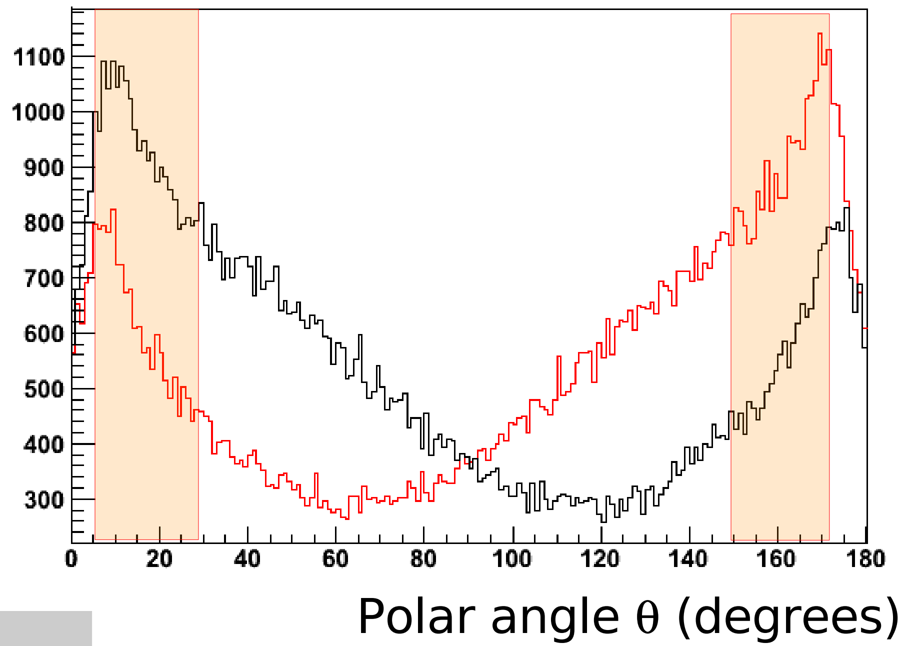


Very forward physics: selectron end-point reconstruction

see S. Gerbode et al., Snowmass 2005, H. Martyn, hep-ph/0408226, T. Barklow,

Polar angle distribution: For SPS1a t-channel selectron pair production @ 500 GeV (1 TeV), 24 % (50 %) of selectrons has $\theta < 30^o$

Very forward physics



Standard Model charm quark and anti-quark production vs polar angle.

200.000 events.

* A_{FB} in the cc system

see M. Battaglia, ILD meeting, Zeuthen.

* **Sensitive probe of forward vertexing performance**

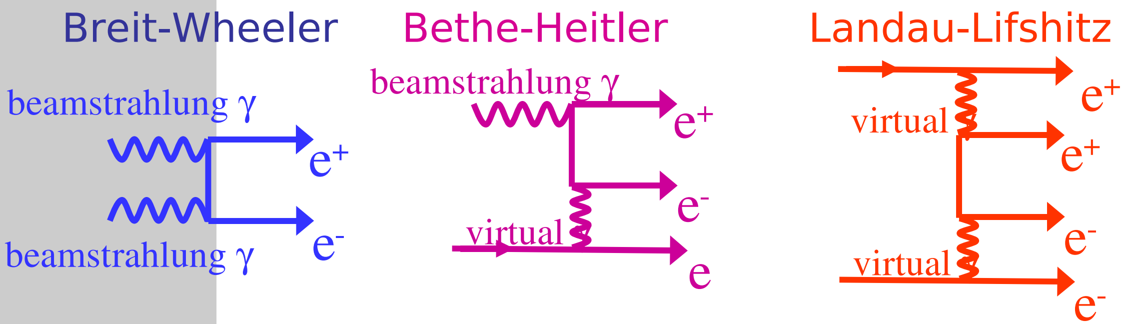
* **Polar angle distribution:** most of the statistics is in the forward tracker (the sensitivity to new physics is not necessarily in this region, though)

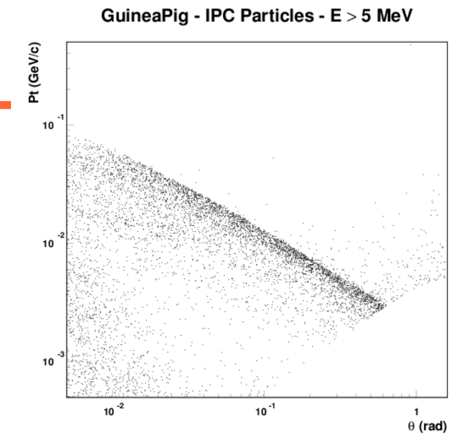
Boundaries

In this talk we will explore forward tracking, touching on several boundaries of the detector design:

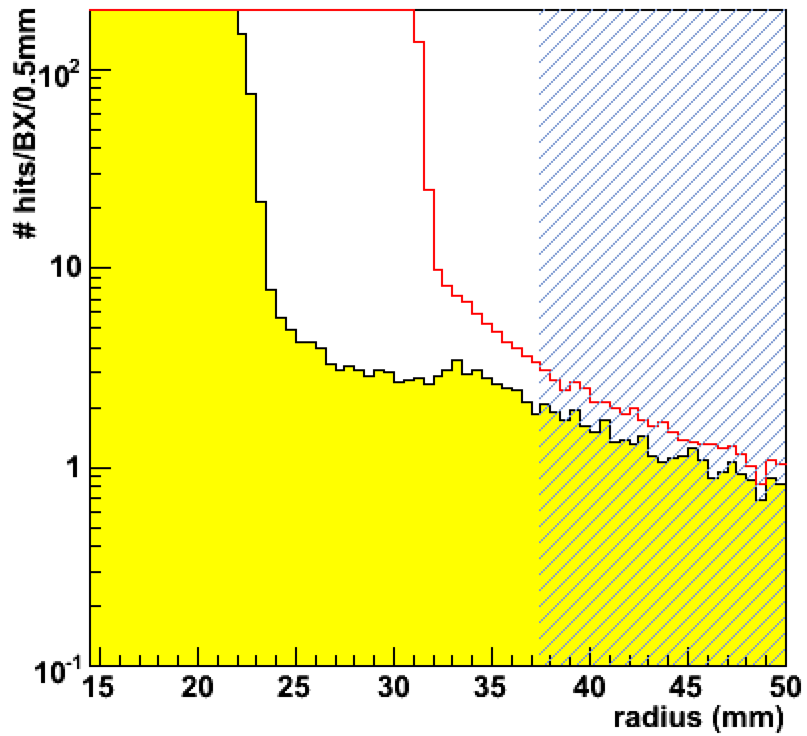
- the very forward region (i.e. the edge of the detector acceptance)
- the shady region where vertexing becomes tracking (in long barrel layout)
- the only tracker region with significant beam-background (relevant for read-out scheme)

Beam-induced background





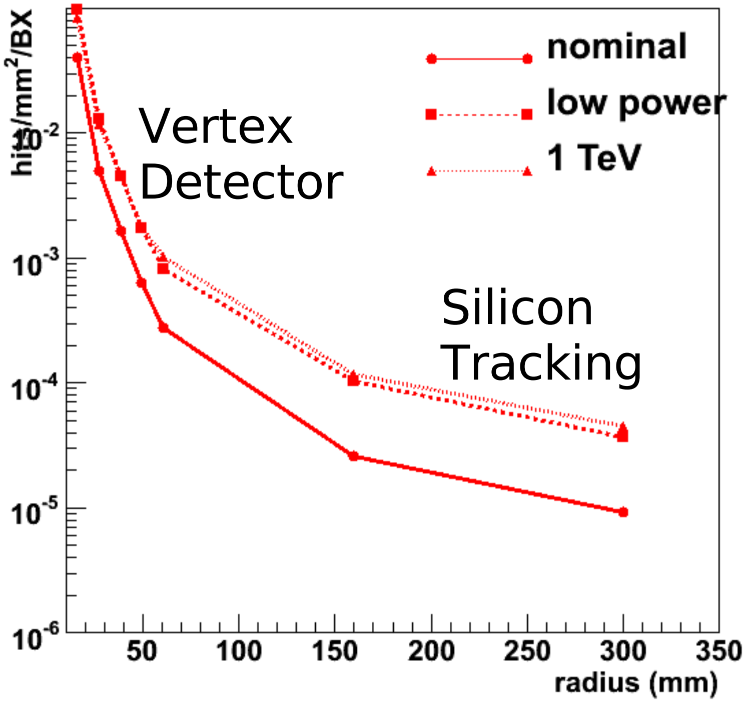
Incoherent pair production off beamstrahlung photons yields very signficant hit densities in innermost tracker elements:



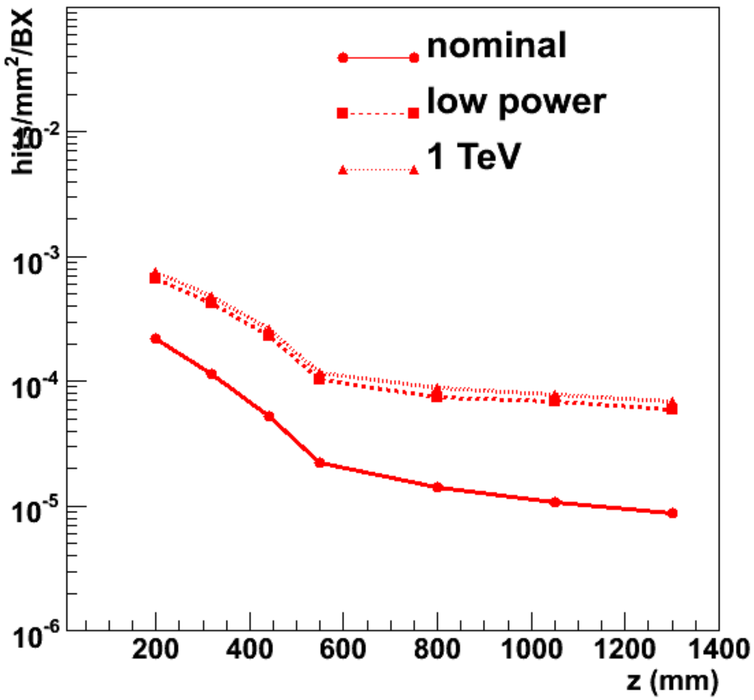
Hit density vs radius in LDC FTD 2.
Direct hits only.
Nominal (yellow) and high-lumi (open red)

Beam-induced background with radius

LDC central tracker:



LDC forward tracker:



Contrary to the outer regions of the central tracker (large R) the beam background does not vanish for very forward tracker (large z)

0.4 hits/mm^2/BX in innermost VXD layer (R = 1.6 mm)

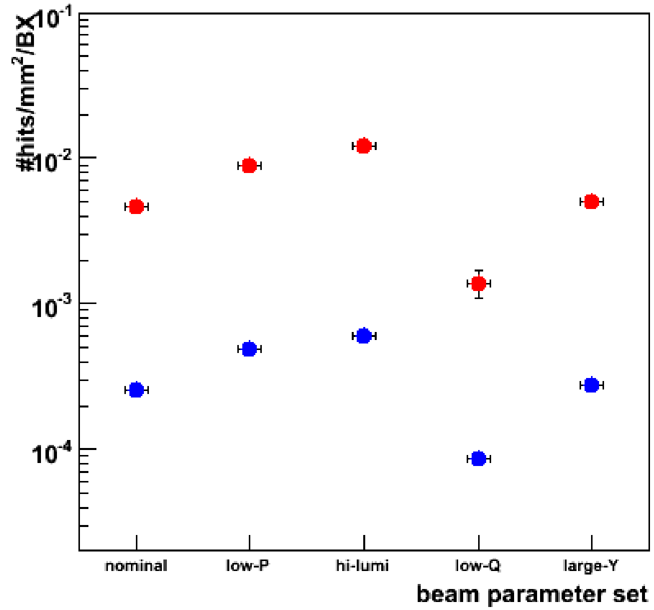
1-2 x 10^{-4} hits/mm^2/BX in first Forward Tracking Disks

Environment – machine bkg.

Incoherent pair production off beamstrahlung photons yields very signficant hit densities in forward tracker:

1-2 x 10^{-4} hits/mm^2/BX

in nominal conditions in the first three disks
- a large fraction (40-45%) of hits is indirect.
- Occupancy in inner ring of the disks is factor 5 larger than disk average.
- strong dependence on machine parameters (factor 2), and ILC energy (factor 2)
- distance to accumulation zone minimal for disk 2
- magnetic field yields factor ~2 / 0.5 Tesla



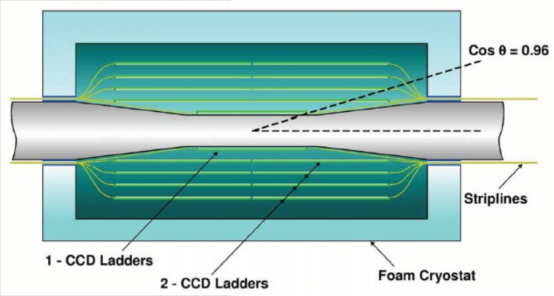
Hit density in LDC FTD 2 for different FF parameter sets.

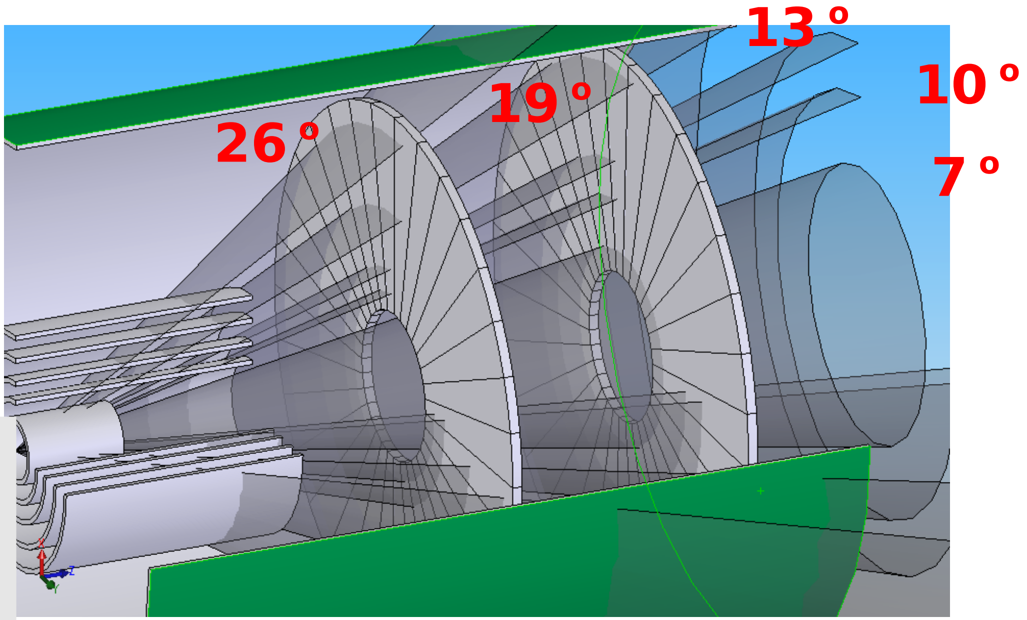
Forward Tracking: interplay with VXD

Concept	Magnetic Field	Angular Coverage 5-point	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)

Long barrel layout (LDC, GLD) has limited coverage for angular region from 7° to 25°

(Very) forward tracking with a "Long barrel" vertex detector



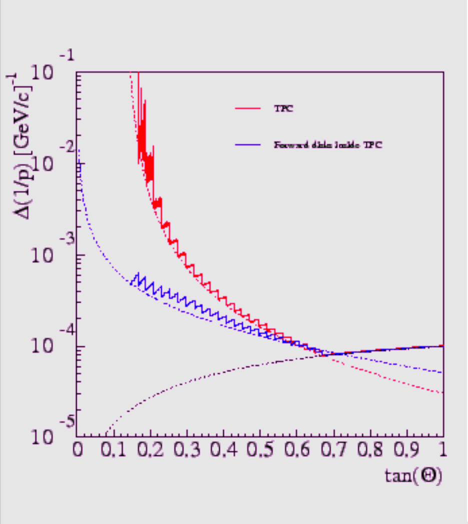


LDC inner tracker layout:
VXD (cylinders)
SIT (green)
FTD disk 1 and 2

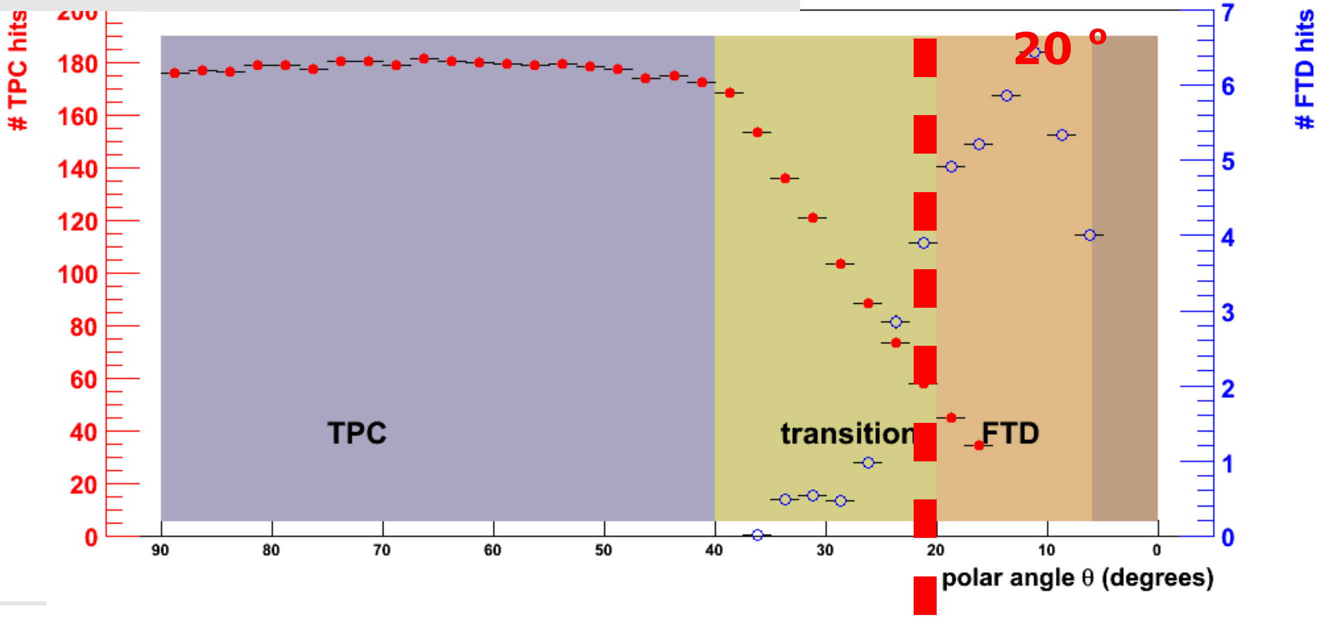
Forward tracking: interplay with central tracker

(Very) forward tracker in a gaseous + silicon tracker concept is "all-silicon"

For track polar angles below 40º reduced TPC coverage
Below ~ 30º FTD starts to contribute
Below ~ 20º FTD dominates the measurements



TPC/FTD hits vs. polar angle Large Detector Concept (Tesla layout of FTD)



Tools – track fitting

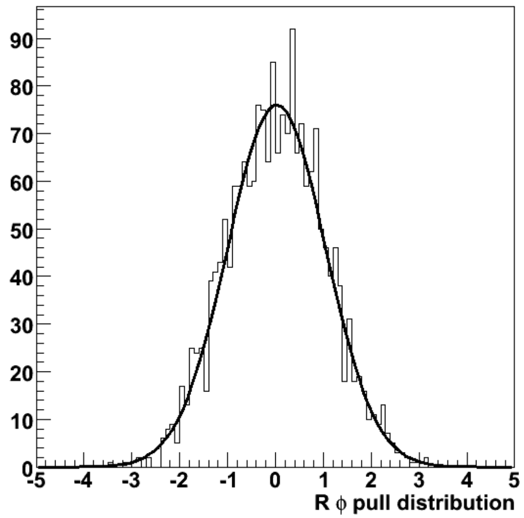
CMS Kalman filter tool-kit.

The result of years of work by a lot of people. Validated in large-scale MC productions.

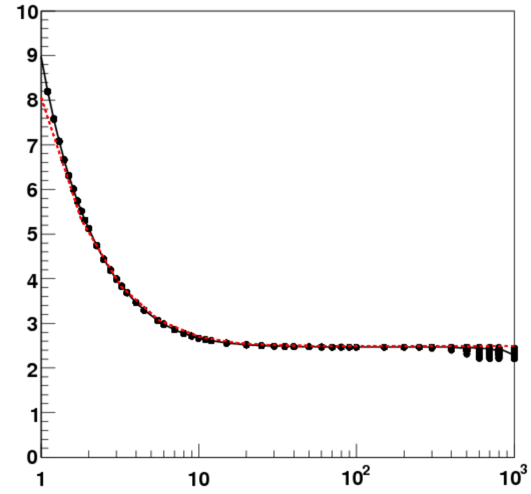
Extracted all relevant code in a series of libraries with limited external dependencies (CLHEP, ROOT).

Interfaced to toy geometries in standalone programme. Tested results for internal consistency and against existing fast-simulation packages.

Interfaced to MarlinReco (GEAR geometry, LCIO hits)



pull distribution R ϕ coordenate at last measurement plane



LCDTRK vs. KF: Transverse impact parameter resolution vs p_T

Momentum resolution II

$\Delta(1/p_T)$ @ 10 degrees :

Reference (TESLA) set-up

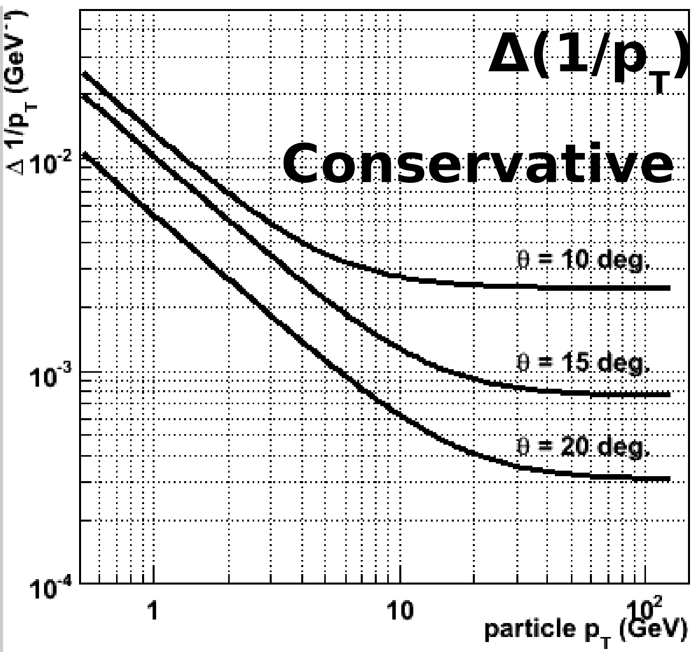
$1.8\times10^{-3}\oplus1.3\times10^{-2}/p_T$

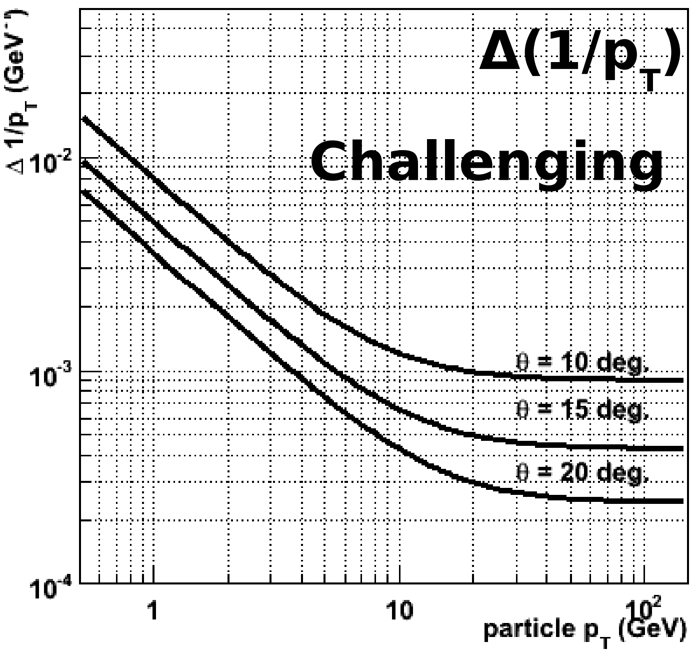
Challenging setup

(5 μ m Rφ resolution, 1.2 ‰ X0/disk for FTD1-3, 4 ‰ X0/disk for FTD4-7)

$\Delta(1/p_T)=0.9\times10^{-3}\oplus0.8\times10^{-2}/p_T$

Detector	*R ϕ (μm)*	*z/R (μm)*	*Material (% X_0)*
VXD	*5*	*5*	*0.12/layer*
FTD1-3	*10*	*50*	*1.2/layer*
FTD4-7	*10*	*1000*	*0.8/layer*
TPC	*120*	*300*	*1 (field cage)*





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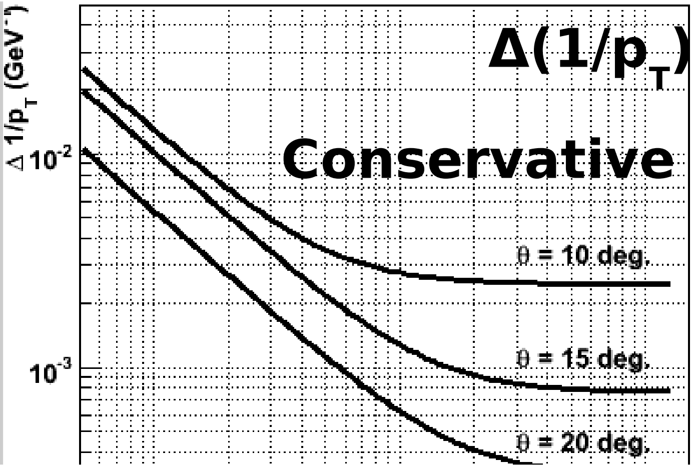
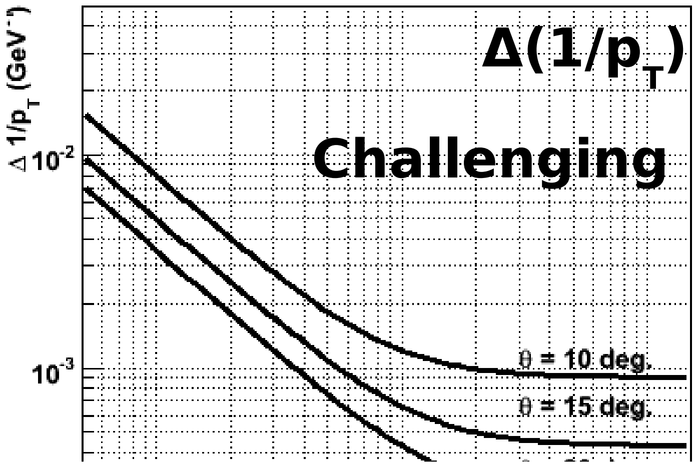
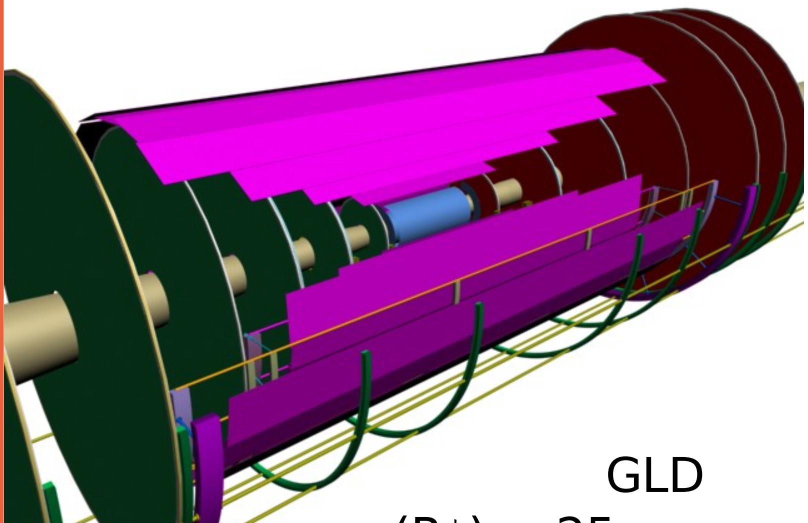




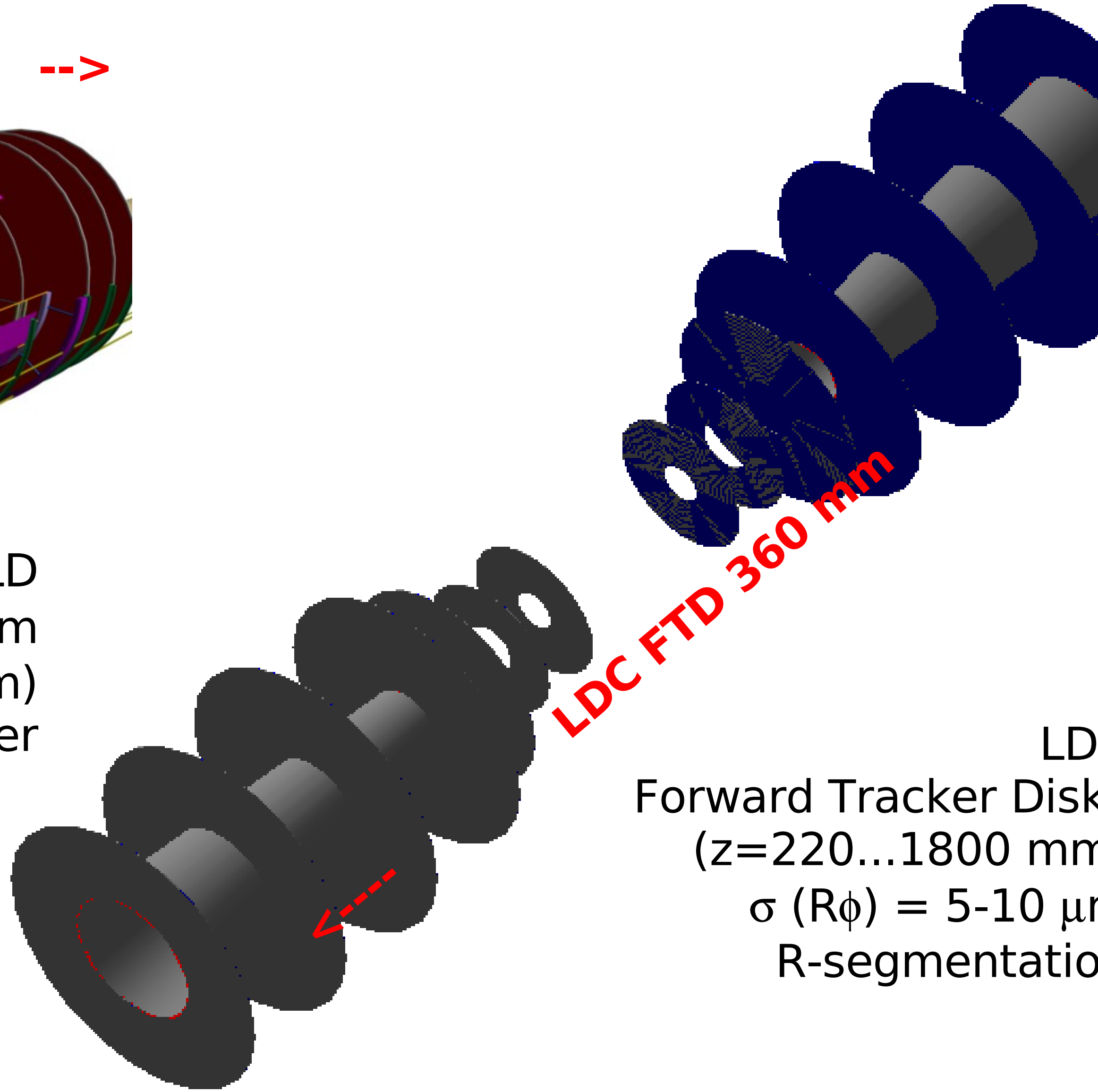
<u>Excellent R-φ space point resolution</u> crucial for asymptotic momentum resolution

Momentum resolution III

<-- GLD FIT 203 mm -->



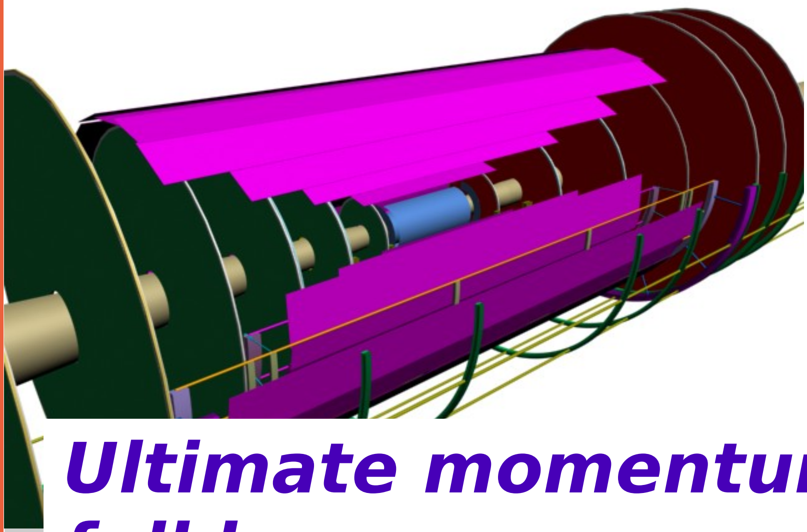
GLD
σ (Rϕ) = 25 μm
(z=155...1015 mm)
Forward Inner Tracker

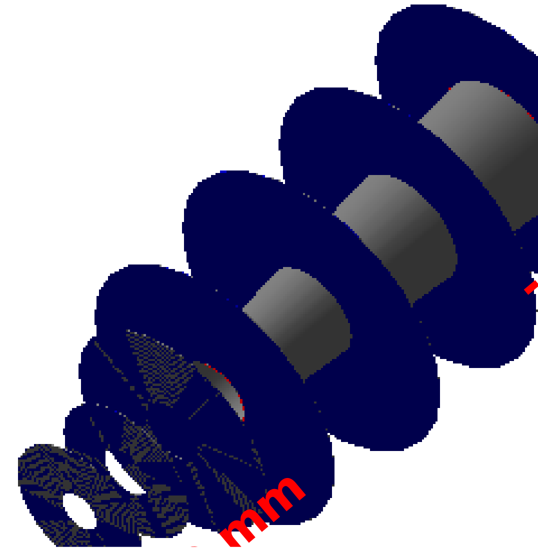


LDC
Forward Tracker Disks
(z=220...1800 mm
σ (Rϕ) = 5-10 μm
R-segmentation

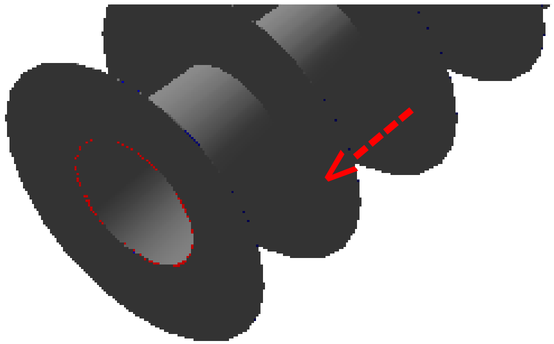
Momentum resolution III

<--   GLD FIT 203 mm   -->





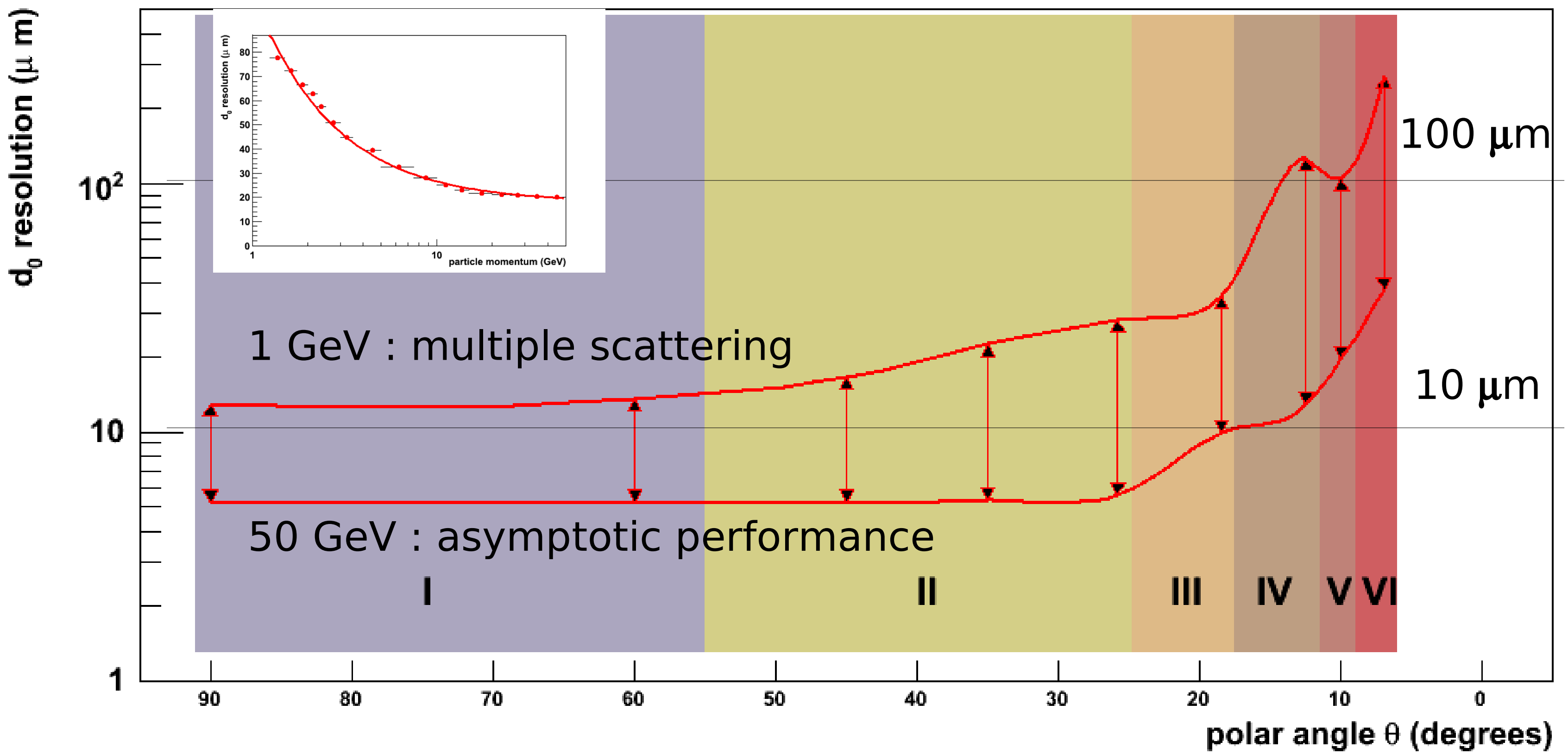
Ultimate momentum resolution requires ***<u>full lever arm</u>***, but pattern recognition favours small inter-disk distance... discussion within silicon tracker community



_DC
Forward Tracker Disks
(z=220...1800 mm
σ (Rϕ) = 5-10 μm
R-segmentation

Vertexing with forward tracks

* 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		
* IV	12.5	< θ <	18.5	VXD2 + FTD		
* V	10	< θ <	12.5	FTD1,...		
* VI	6.5	< θ <	10.0	FTD2,...		

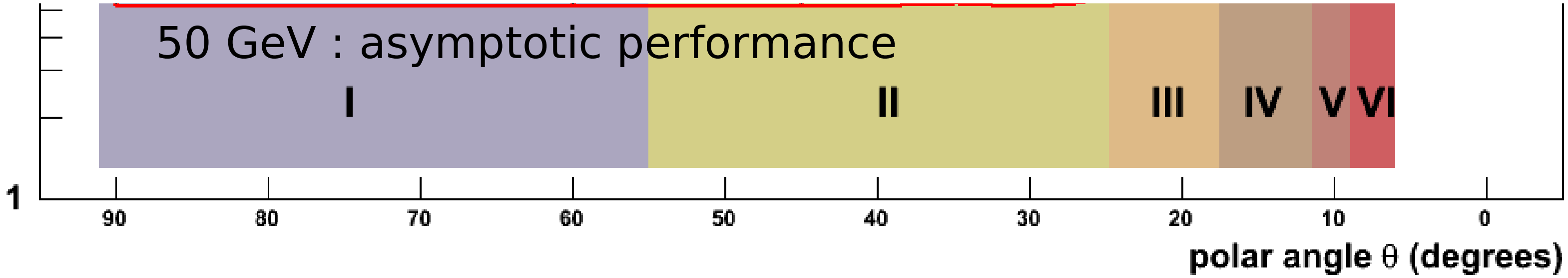


Vertexing with forward tracks

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

d_0 resolution well below the $c\tau$ of B-hadrons possible in a "long barrel" VXD layout, provided:

- *very little material in/before first tracking disk,*
- *excellent R ϕ resolution,*
- *smallest possible z-distance first disk.*

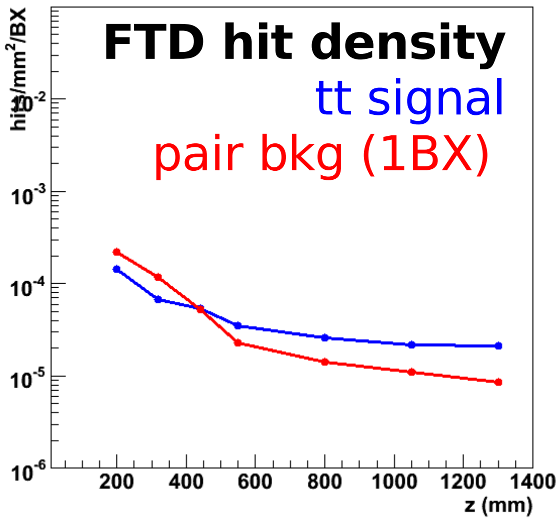


Pattern recognition

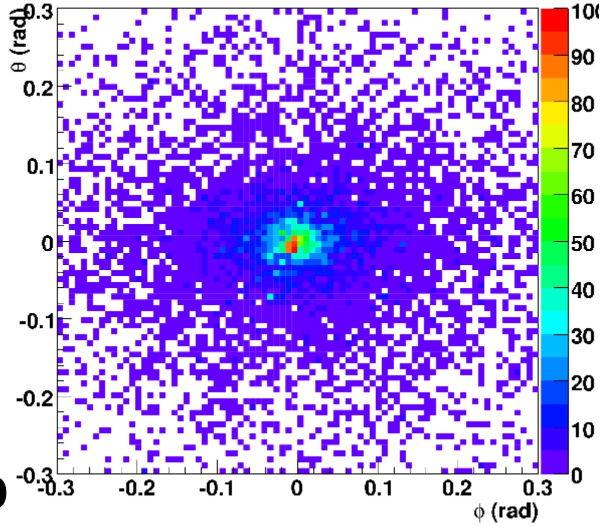
For very forward tracks (θ < 20°) FTD has to be capable of stand- alone pattern recognition with 7 space points over nearly 2 m, compared to:

central track in LDC: 5-6 VXD + 2-4 SIT + O(200) TPC

forward region in SiD: 4 VXD + 5 μ-strips.

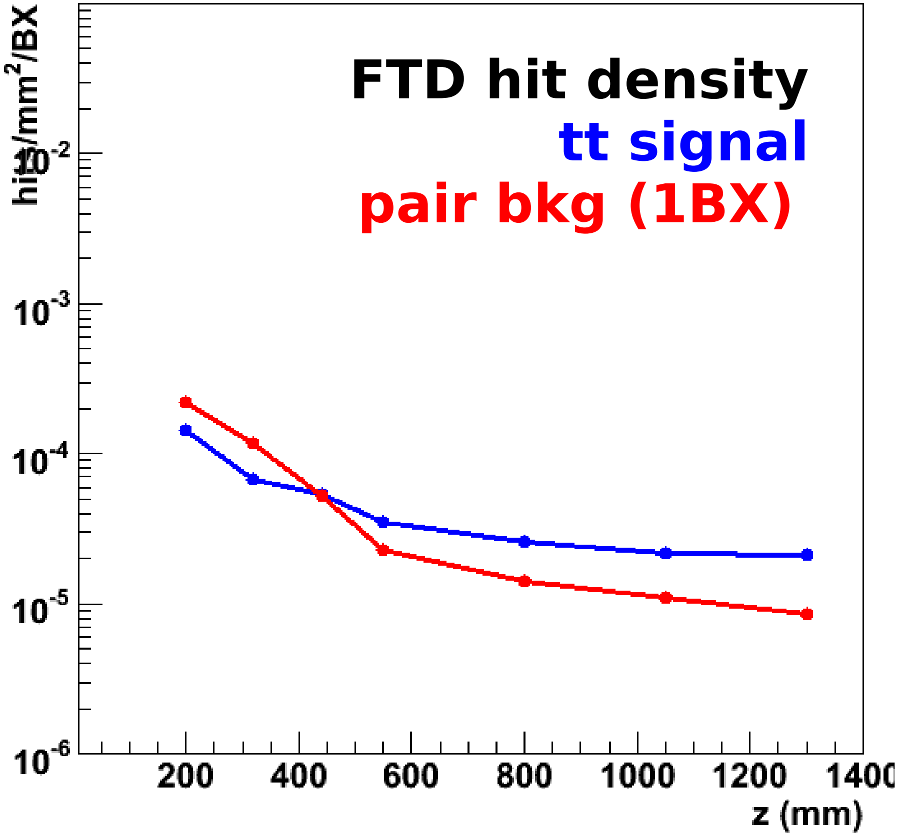


Moderate average occupancy, but... peak density much larger:
Signal (jets):.......... ....factor 100
Bkg (inner ring):...... ....factor 5



Pattern recognition

For very forward tracks (θ < 20°) **FTD has to be capable of stand- alone pattern recognition** **with 7 space points over nearly 2 m, compared to:**



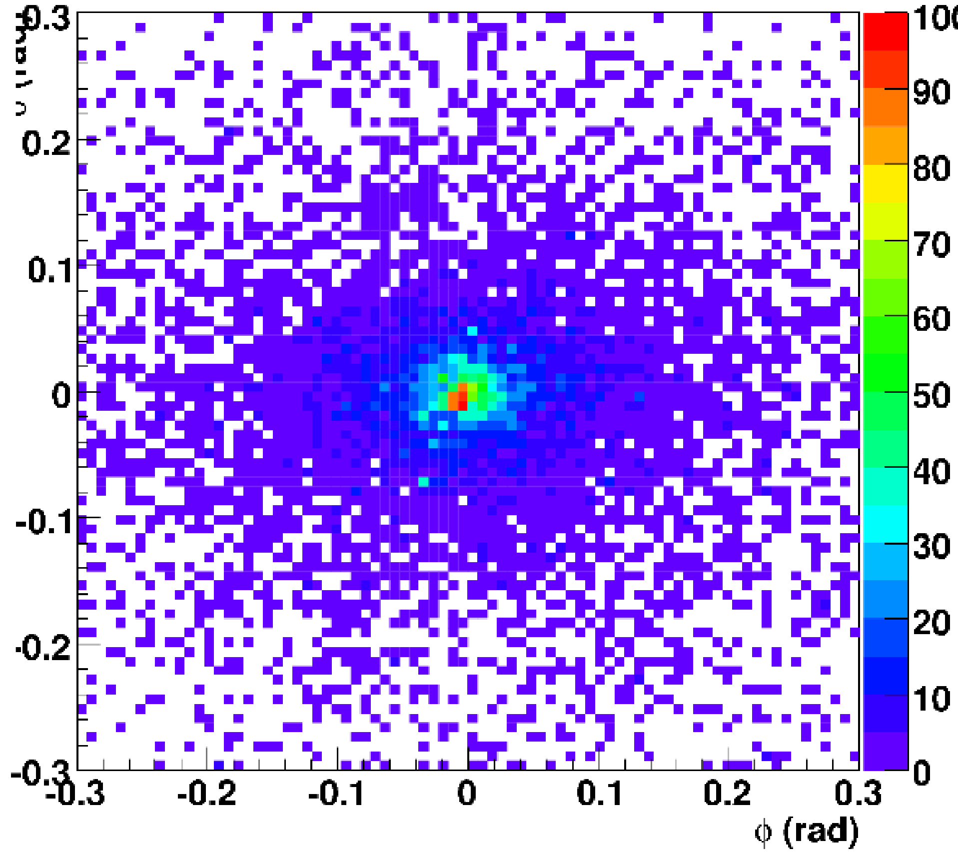
Significant background: hit density due to a single BX comparable to that of a tt-event

Pattern recognition

For very forward tracks (θ < 20°) FTD has to be capable of stand- alone pattern recognition with 7 space points over nearly 2 m, compared to:

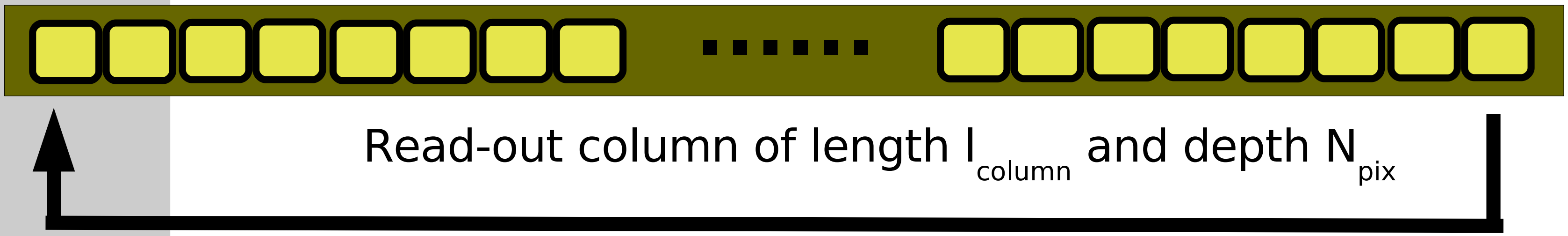
Moderate average occupancy, but... peak density much larger:

Signal (jets):.......... x 100
Bkg (inner ring):.... x 5



Read-out time

Integrating/Time slicing detector: Rolling Shutter read-out



For pixel size (along the column direction) d and a read-out time per pixel t_{pix} the integration time to read a complete frame is given by:

$$\mathbf{t_{frame} = t_{pix} \times N = t_{pix} \times l_{column} / d}$$

The pixel detector uncertainty principle:

$\boldsymbol{\delta x\ \delta t \sim C}$**,** for given power consumption

Hybrid pixel detectors are fast, but power-hungry/large pixels

See “all-pixel tracking”, Konstantin Stefanov, Chris Damerell in several ILC meetings

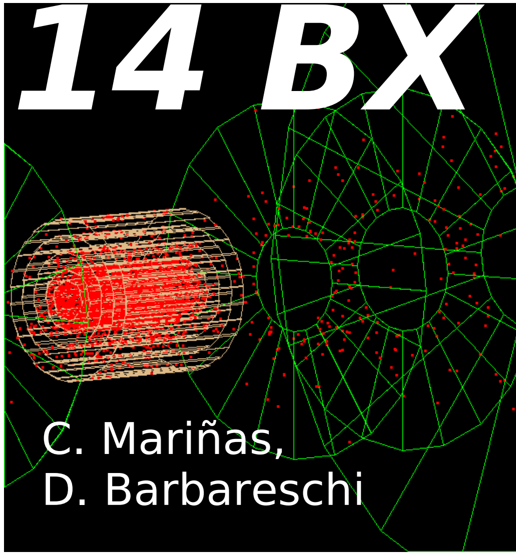
Pattern recognition : connect the dots

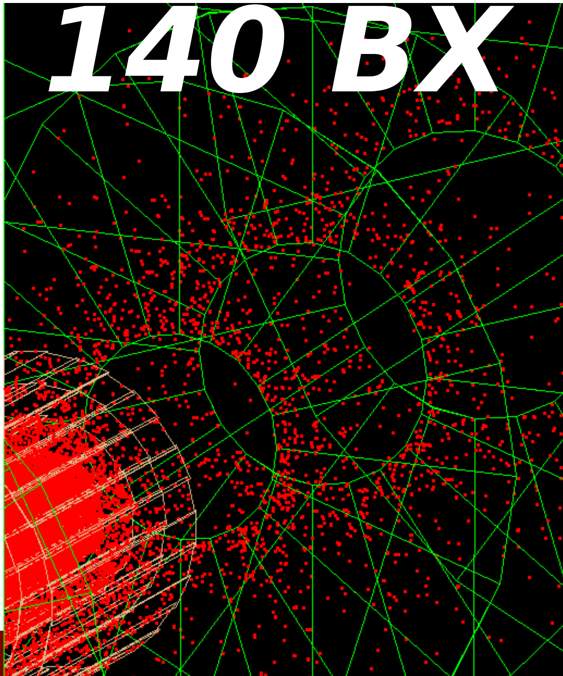
Under variations of the pixel size

(with fixed column length and pixel read-out time):

- the (dominant) background occupancy is constant

- the number of hits (per area) $\propto t_{frame}$, i.e. 1/d





Technology	Cell area (μm x μm)	Integration time	Peak occupancy
VXD	25 x 25	50 μs	$6 \times 10^{-6} + 1 \times 10^{-6}$/BX
Hybrid pixel	50 x 500	300 ns	$2 \times 10^{-4} + 4 \times 10^{-5}$/BX
μ–strip	50×10^{5}	300 ns	5 % + 1 %/BX

Typical occupancies on first FTD disks (signal + bkg/BX)

Pattern recognition: full simulation/reconstrucion

Combinatorial algorithm based on KF kit

The baseline algorithm of the ATLAS (arXiv:0707:3071)
and CMS (NIM A 559 143) experiments

Standalone FTD reconstruction implemented in MarlinReco processor

Run on tt events with superposed pair background.

Reference FTD (TESLA layout)

10 μm R-ϕ resolution

1.2 % X_0/disk (1-3) and 0.8 % X_0/disk (4-7).

Several scenarios for R-resolution, from pixel to single-sided strip.

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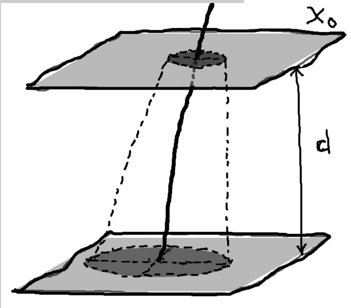
Pattern recognition: quality markers



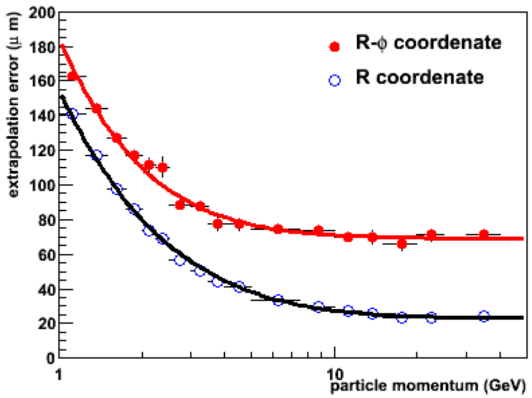
Compatibility of track stub and hit. Extrapolated window is a function of track parameter errors, material (multiple Coulomb scattering) and distance between disks.

Extrapolation precision

Innermost disks

R very precise (pixel detectors)

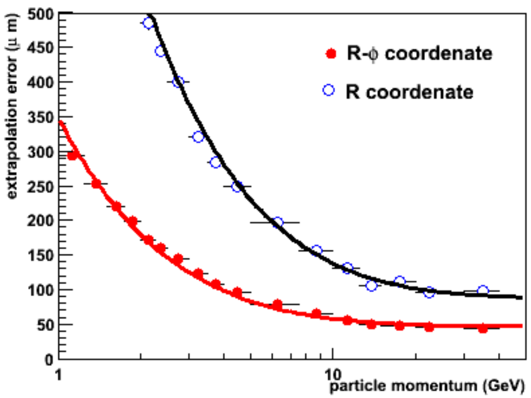
R ϕ -> weakly constrained p_T



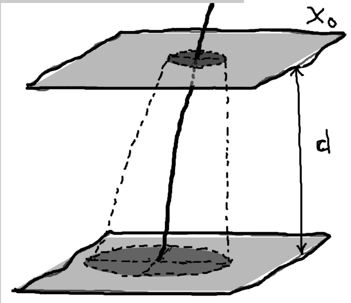
Outermost disks

R degraded (single sided strips)

R ϕ -> OK

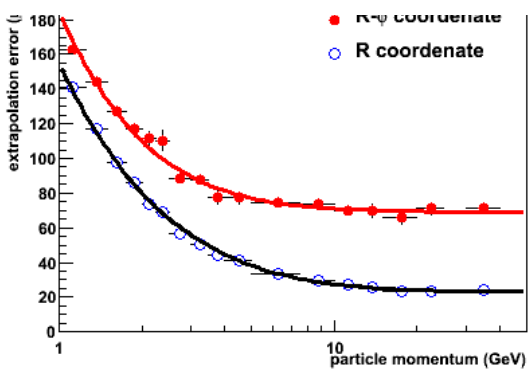


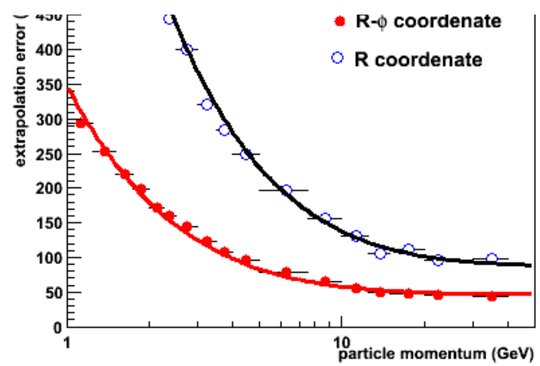
Pattern recognition: quality markers



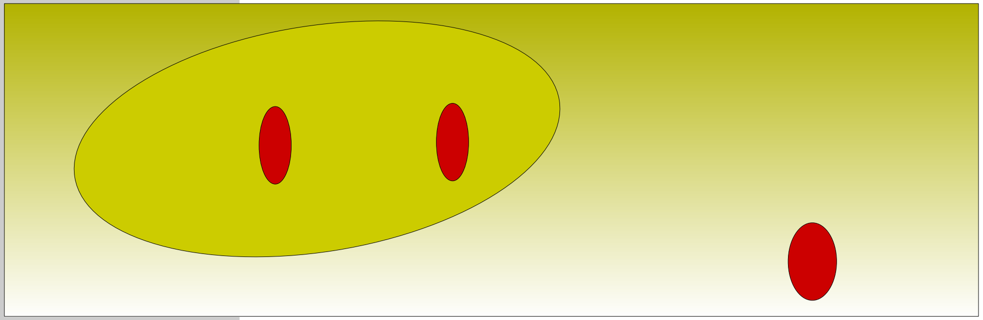
Compatibility of track stub and hit. Extrapolated window is a function of track parameter errors, material (multiple Coulomb scattering) and distance between disks.

Large distance (10-30 cm) between Forward Tracking Disks, in combination with abundant low momentum tracks (loopers), lead to large extrapolation errors



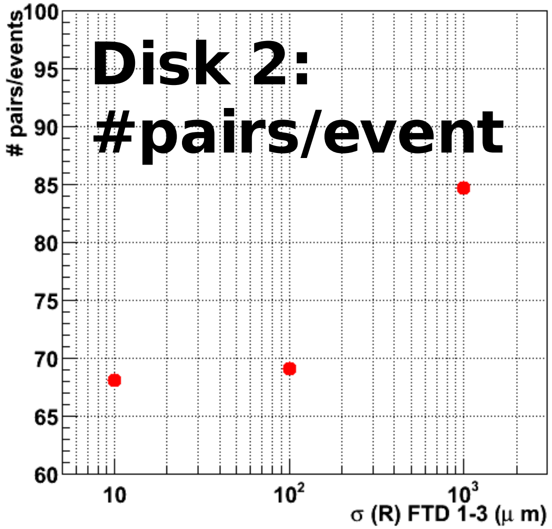


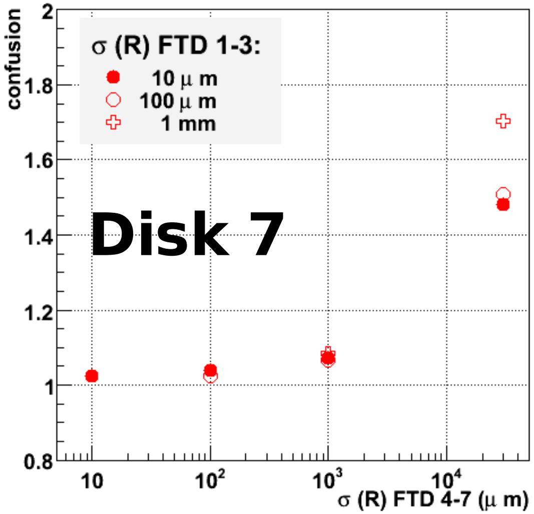
Pattern recognition: quality markers



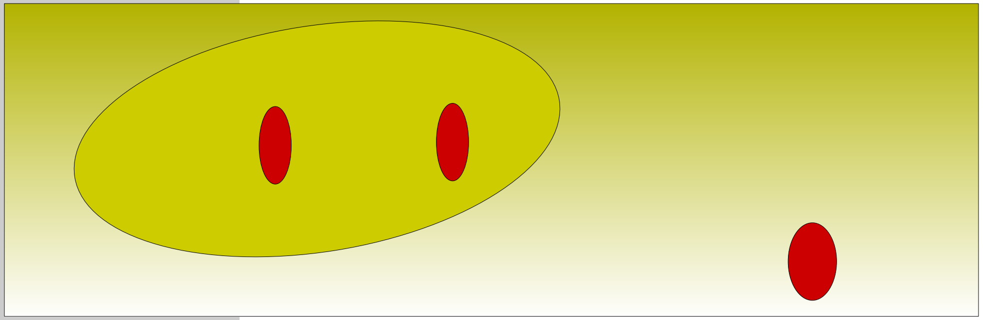
Confusion: the number of hits compatible with the extrapolated position

Confusion



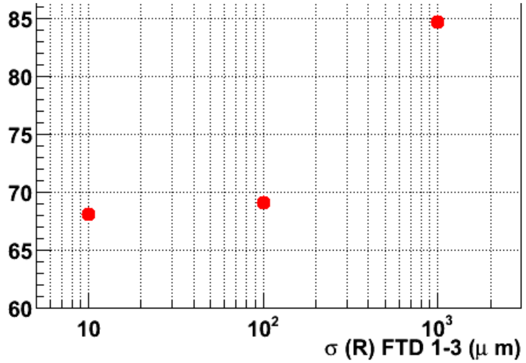


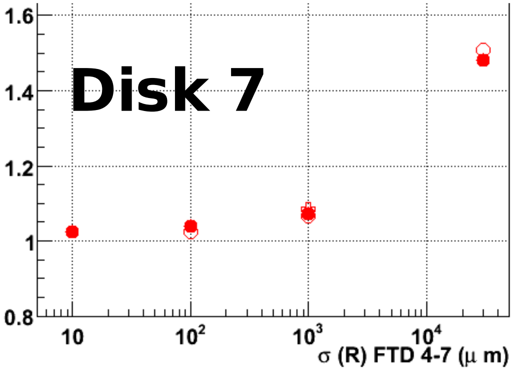
Pattern recognition: quality markers



Confusion: the number of hits compatible with the extrapolated position

Reduce frequent ambiguities in innermost tracking disks by fine segmentation
Moderate (stereo-measurement) segmentation sufficient in outermost disks





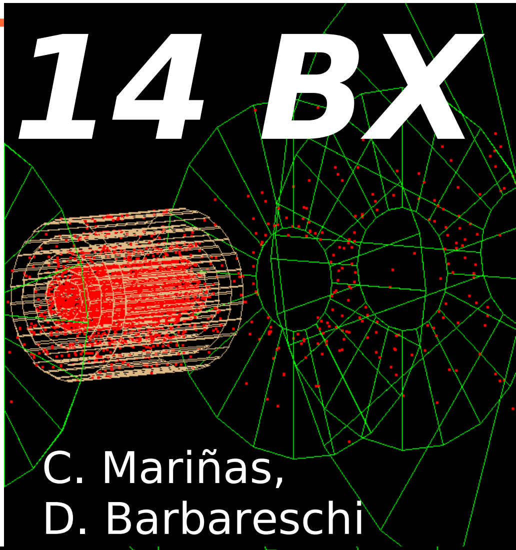
Pattern recognition: detector parameter scan

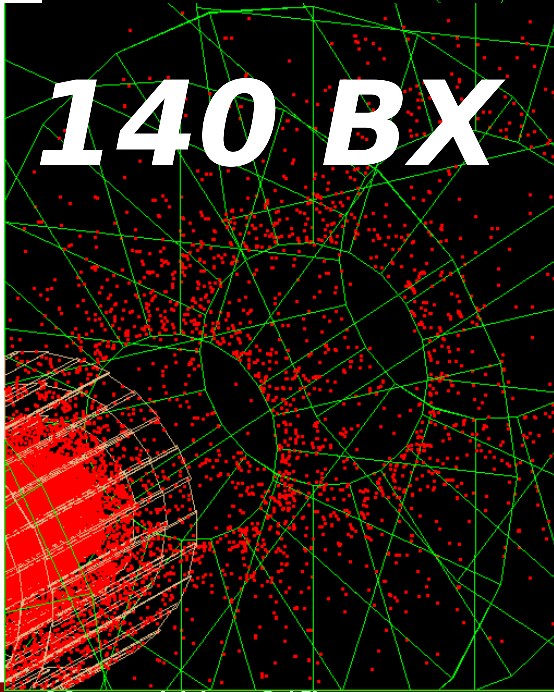
The stand-alone FTD is able to resolve patterns down to a p_T of 100 MeV, provided:

R-segmentation: in innermost disks < 500 μm,
in outermost disks O(1cm)

Read-out speed: beyond O(10) bunch crossings the density of low momentum tracks prevents algorithm convergence

Material: an increase of the material beyond 1%/disk has dramatic consequences on pattern recognition





Time-stamp

Phyiscs requirement: all tracks should be time-stamped.

Therefore, stand-alone FTD should be able to provide a robust and redundant time-stamp.

Innermost disks: tracks are matched to a corner of the TPC. This combination yields a very precise time-stamp.

Outermost disks: FTD time-stamp requires single BX-readout.

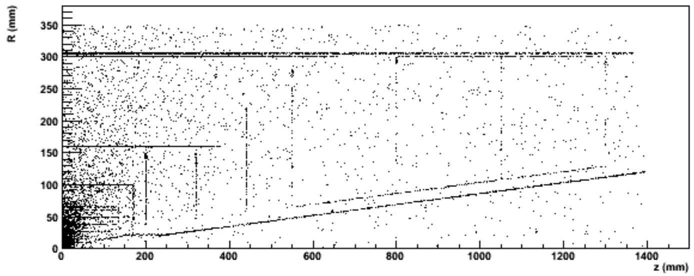
Forward tracking: challenges

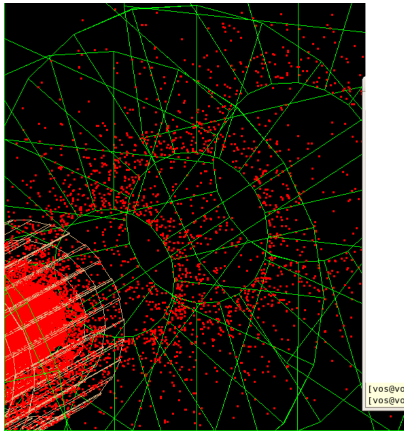
momentum resolution with unfavourable field orientation
lever arm, R-f resolution

impact parameter measurement for very forward tracks
material and resolution disk0 + VXD services

standalone pattern recognition in presence of background and low momentum tracks
R-segmentation, material, read-out speed

minimal distortion of particles/global performance
material





Forward tracking requirements

Challenges of ILC very Forward Tracker are being studied in detail . Write-up of results in progress
(see simulation session and http://ific.uv.es/~vos/ilc/ilcFastForward)

The very forward region has a specific set of environmental constraints and requirements:

- tight control of material budget $\rightarrow$ 0.2-0.5 % X0
- best achievable R ϕ resolution $\rightarrow$ 5 μm
- moderate segmentation in R $\rightarrow$ 500 μm – 1 cm
- moderate background level $\rightarrow$ 1-2 x 10^{-4} hits/mm^2/BX
- fast read-out $\rightarrow$ < 10 BX

FTD 1-3: investigating VXD technologies (hybrid pixels as back-up solution)
FTD 4-7: double sided micro-strips

Coordinated ILC effort in Spain

Coordinated ILC effort in Spain

Several of these groups have expressed an interest in finding solutions for very forward tracking…

Very forward tracking: the forgotten problem?

A few extracts from the tracking review document (Beijing, February 2007)

[...] it will be vital that the tracking system should for the first time perform as well in this [the forward] region as in the central region
executive summary, page 2

It is clear that excellent tracking performance in the forward region is obligatory
introduction, page 5

There is considerable uncertainty regarding the degradation in physics potential resulting from a given material budget, and this is a particularly serious issue in the forward region, where there tends to be an accumulation of material
introduction, page 5

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Momentum resolution

Physics requirement: in the literature one finds: down to

$$\Delta (1/p_T) = 10^{-5}\ \mathrm{GeV}^{-1}$$

the Higgs mass resolution in the recoil analysis is dominated by the tracker resolution.

Caveat I: Higgs-strahlung yields very central distribution

Caveat II: $\Delta (1/p_T)$ is only constant if multiple scattering can be ignored.

But: for Higgs-strahlung at $\sqrt{s}$ = 250 GeV and very forward muons – $\theta < 20$ degrees- the average p_T is reduced to a mere 13 GeV/c.

Caveat III: the very forward region – due to the less favourable orientation of the magnetic field – performs worse than the central tracker, even if it is equally well instrumented.

Must consider other benchmarks: sleptons, luminosity from $e^+e^- \rightarrow \mu^+\mu^-$

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