ILD silicon tracker elements

Marcel Vos – IFIC Valencia

thanks to the SiLC collaboration, especially Aurore Savoy Navarro, Valeri Saveliev and Alberto Ruiz

LDC/GLD convergence to ILD

LDCPrime					
Sub-Detector	Parameter	GLD	LDC	GLD'	LDC'
TPC	R_{inner} (m)	0.45	0.30	0.45	0.30
	R_{outer} (m)	2.00	1.58	1.80	1.80
	Z_{max} (m)*	2.50	2.16	2.35	2.35
Barrel ECAL	R_{inner} (m)**	2.10	1.60	1.85	1.82
	Material	Sci/W	Si/W	Sci/W	Sci/W
Barrel HCAL	Material	Sci/W	Sci/Fe	Sci/Fe	Sci/Fe
Endcap ECAL	Z_{min} (m)***	2.80	2.30	2.55	2.55
Solenoid	B-field	3.0	4.0	3.50	3.50
VTX	Inner Layer (mm)	20	16	18	18

From Frank Gaede, December 6th.

Convergence for detector parameters linked to B or R. TPC inner radius or innermost silicon unchanged in "Primed" layouts.

What do we want to learn???

Global layout:

TPC outer radius
magnetic field

} ILD wide

Tracker specific:

TPC inner radius
TPC endplate material
vertex detector layout

} Our neighbours

Silicon tracker specific:

number of layers in central inner tracker
resolution layout forward disks (short/long)
silicon tracking outside TPC

} **Silicon tracking community**

Differences: SIT vs BIT

REMEMBER:
Inner radius TPC enclosure: 30.05 (LDC') and 43 (GLD')
Inner active radius: 37.1 (LDC') and ? (GLD')

GLD: 4 BIT layers at radii 9-30 cm
LDC: 2 SIT layers at radii of 16-30 cm

BOTH suppose 0.5 % X_0/layer

Number of central inner tracker layers has an impact on:

- material budget
- momentum resolution
- pattern recognition (especially non-prompt tracks)

Differences: SIT vs BIT

REMEMBER:
Inner radius TPC enclosure [illegible]5 (LDC') and 43 (GLD')
Inner active radius: 37.[illegible]') and ? (GLD')

GLD: 4 BIT la[illegible]s at radii 9-30 cm
LDC: 2 SIT l[illegible]s at radii of 16-30 cm

BOTH s[illegible]ose 0.5 % X_0/layer

Preferred direction

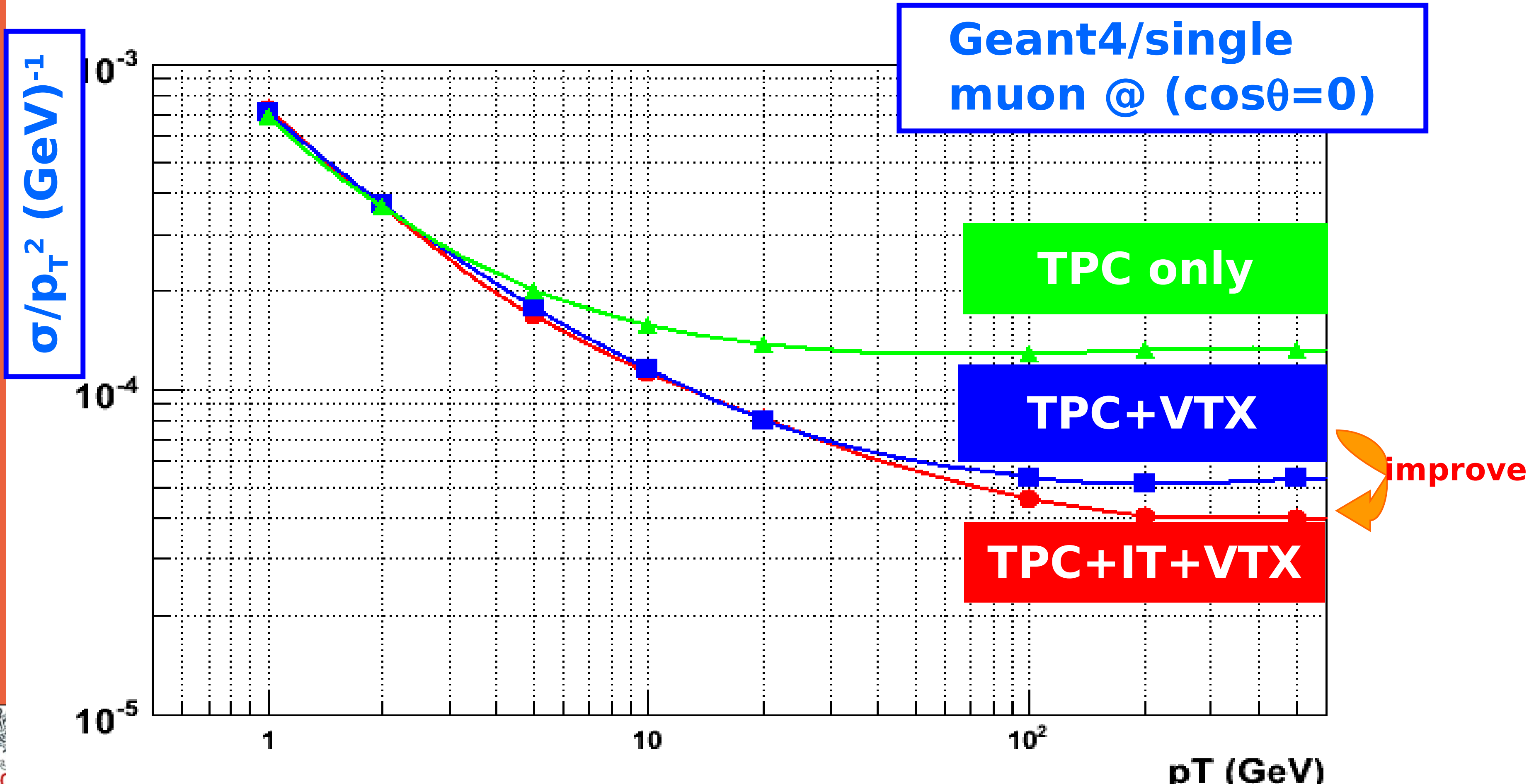
N[illegible]er of central inner tracker layers has an impact on:

↓ material budget

↑ momentum resolution
pattern recognition (especially non-prompt tracks)

Detector configuration of silicon inner tracker at GLD

Kim, Youngim, H.Park (Kyungpook National University) A. Miyamoto (KEK)



- **Without IT: 4.4 x 10^{-5} (GeV)$^{-1}$ (high momentum limit)**
- **With IT: 3.9 x 10^{-5} (GeV)$^{-1}$**

Detector configuration of silicon inner tracker at GLD

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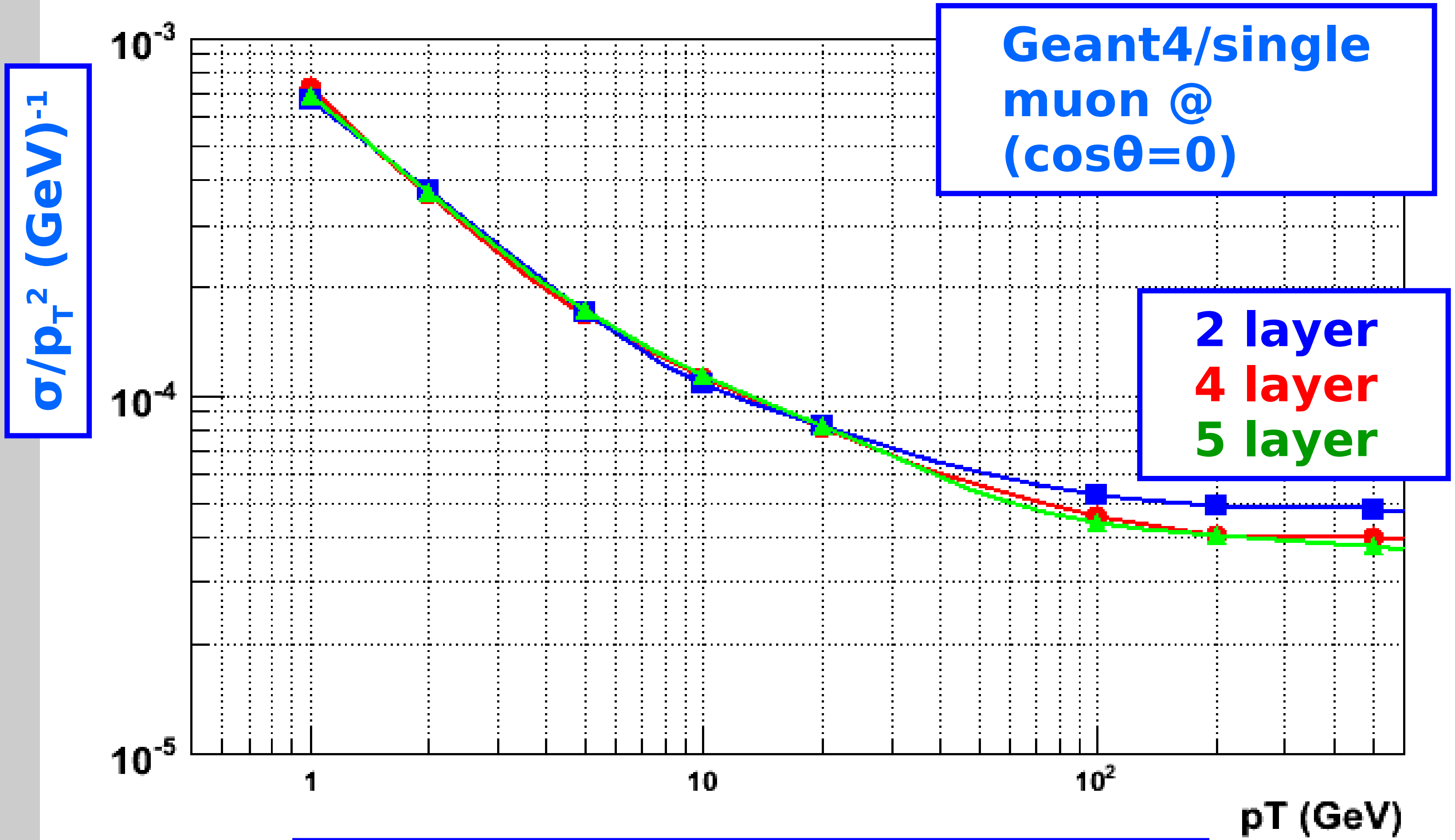

4 layer is probably enough

Detector configuration of silicon inner tracker at GLD

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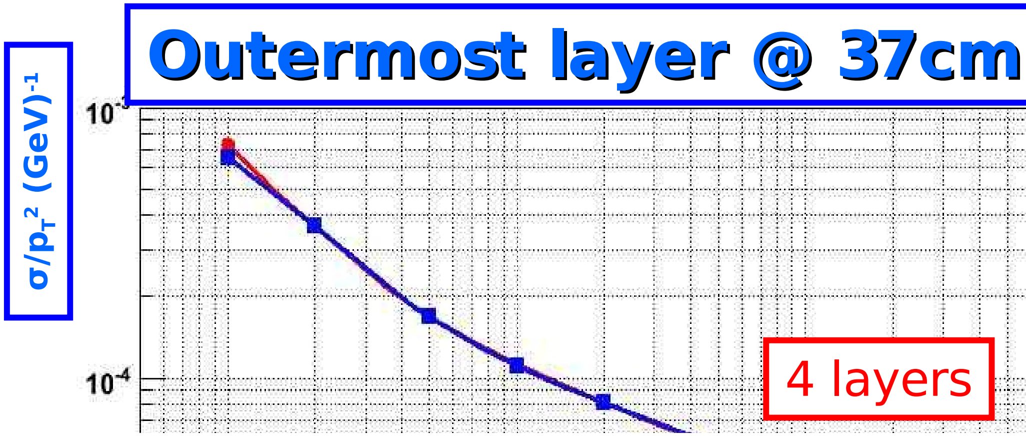
Also tried...

- **Varying**
  - -position resolution (10 μm to 20 μm)
  - -outermost layer @ 37 cm
  - -changing the thickness from 561 μm to 300 μm



Comparison with LDC studies (by Mikael Berggren, Santa Cruz, Vienna, Valencia and others) ongoing

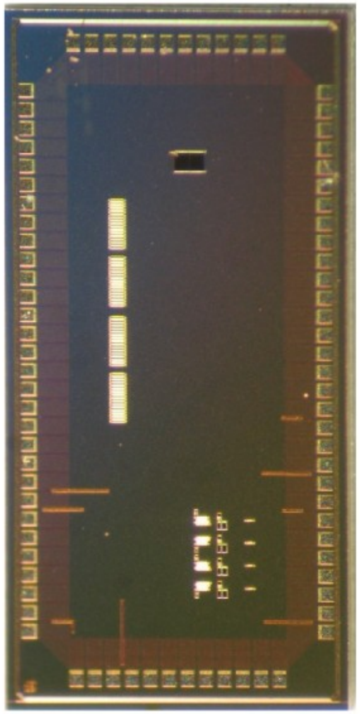
So far, the current configuration seems to be good (caution: at the level of the study with single muons)

The material

The main challenge is to build an excellent AND low-mass tracker; a large fraction of the SiLC effort is directed towards a reduction of the tracker material (see presentations in the VTX/TRK session)

Improving micro-strip detector technology

- ✔ SiTRA front-end chip has an instantaneous power consumption of 500 μW/channel (silicon area corresponding to each channel is 50 μm x 10-50 cm)
- ✔ Pulsed power will yield an duty cycle of 1 %
- ✔ Closer integration of sensors and front-end
- ✔ Sparsifying the data



SiTRA FE chip, J.F. Genat et al., LPHNE

Investigate other detector types

- ✔ In innermost tracker layers

The material

The material is estimated to be 0.5 % X_0 per layer (~half of it in the silicon, the other half in services/support)

This rough global estimate can be refined by defining penalty functions:

- ✔ for double-sided read-out; can we identify a vendor for true Double-Sided sensors?
- ✔ per Watt instantaneous power; measurements of power consumption per read-out channel exist, they need to be translated into kilograms of conductor; but, what about serial power distribution?
- ✔ per Watt average power (including the duty cycle): a step function when we cross the liquid cooling threshold; need estimate of threshold
- ✔ per byte of sparsified data; based on bandwidth and material of current opto-packages
- ✔ For mechanical support; size of the mechanical structure

The above is half of the story... the other half is the impact of the tracker material on the ILD physics potential

The risk

Optimizing the tracker layout for tracking performance with our favourite benchmark - the recoil mass reconstruction for Higgs-strahlung events where $Z \rightarrow \mu\mu$ – implies a risk:

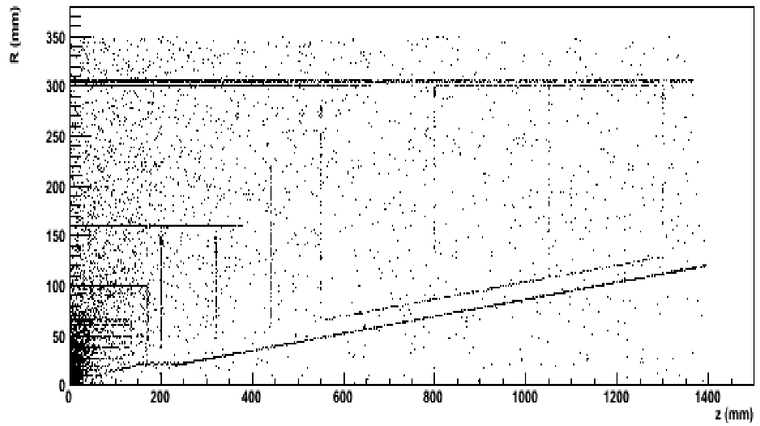
- ➔ 50 GeV muons are the only particles (apart from neutrinos) that get through 1 X_0 essentially unharmed.
- ➔ The best tracker for this channel (heavily instrumented, many layers) is not so great for someone else's favourite (e.g. the same analysis with electrons)

Balance of the benchmarks

The risk

- ✔ Need a measurement of the impact of the material budget from global performance:
  - ➔ electrons (several presentations this week)
  - ➔ photons
  - ➔ particle flow (surprisingly uniform performance in barrel/endcap?)

- ✔ Define a heavy counterpart to our current tracker layout (i.e. factor 2 in VXD, silicon tracker and TPC)



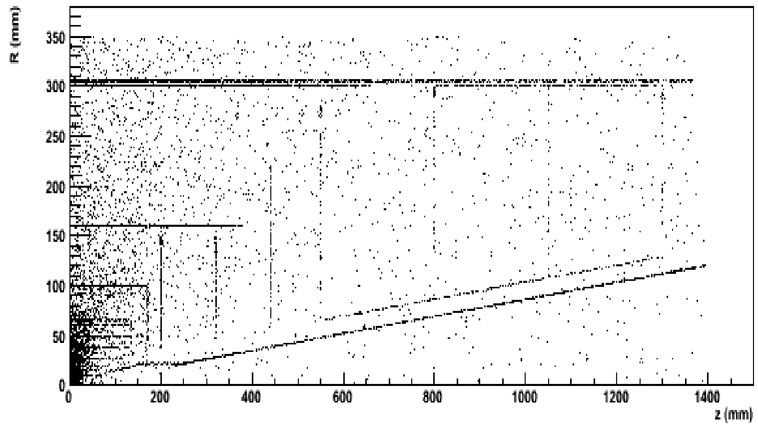
Tracker material map from nuclear interactions (MC truth) in 2000 MC events

The risk

- Need a measurement of the impact of the material budget from global performance:
  - ➔ electrons (several presentations this week)
  - ➔ photons
  - ➔ particle flow?

Establish:

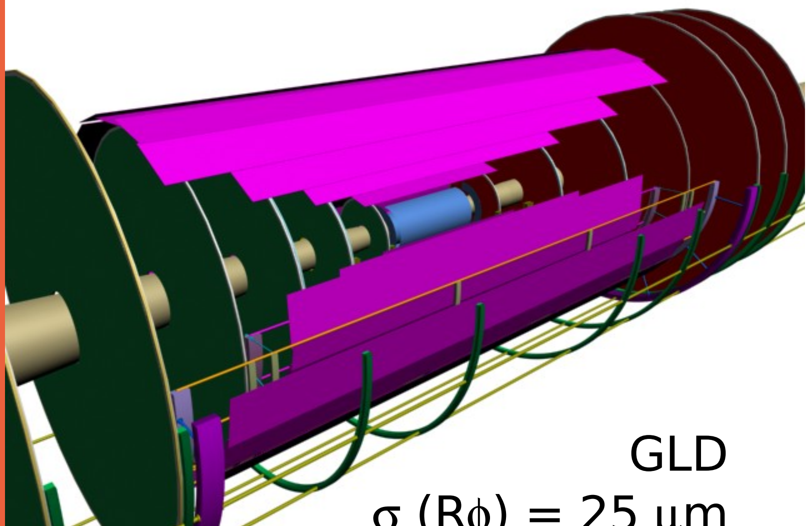
δ(physics) / δ(material)



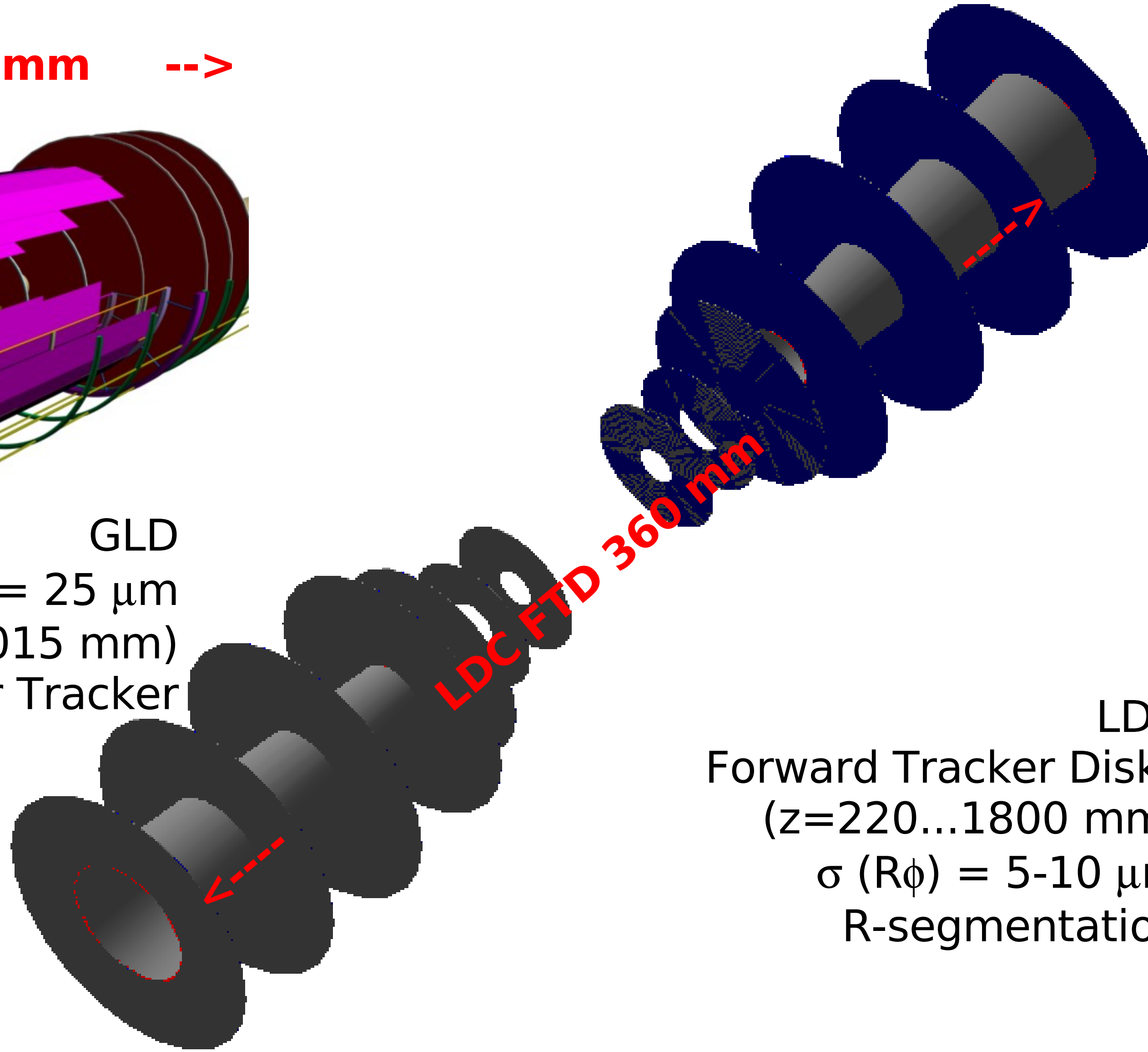
Tracker material map from nuclear interactions (MC truth) in 2000 MC events

Differences FIT/FTD

<-- GLD FIT 203 mm -->



GLD
$\sigma (R\phi) = 25\ \mu m$
(z=155...1015 mm)
Forward Inner Tracker



LDC
Forward Tracker Disks
(z=220...1800 mm)
$\sigma (R\phi) = 5\text{-}10\ \mu m$
R-segmentation

Differences FIT/FTD

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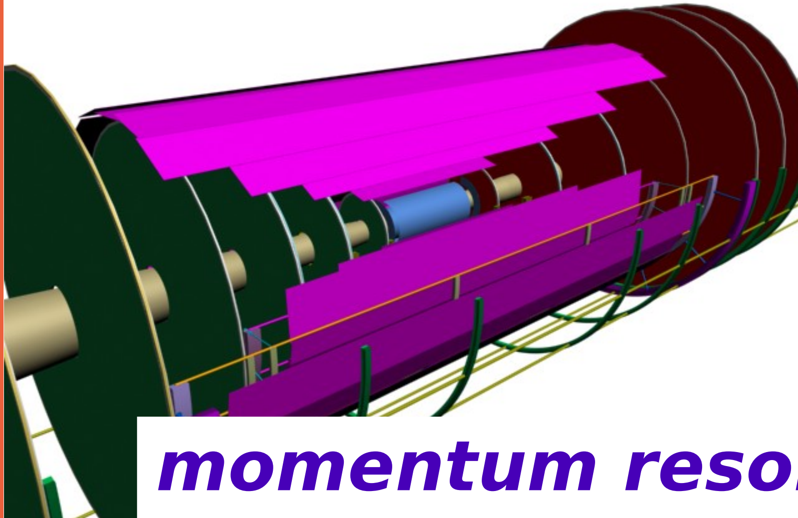
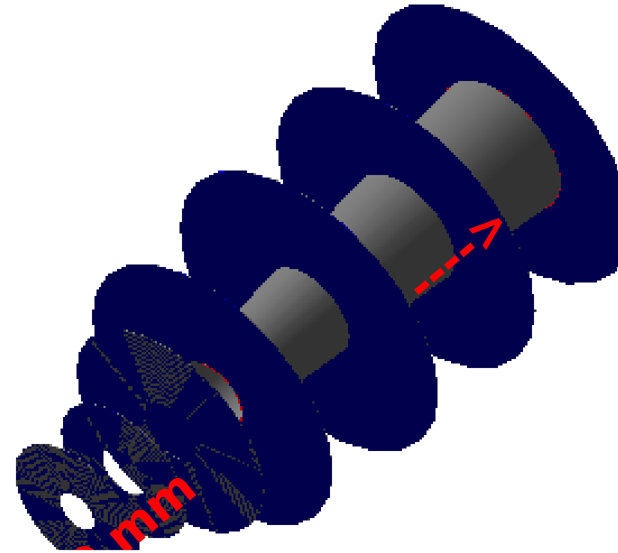
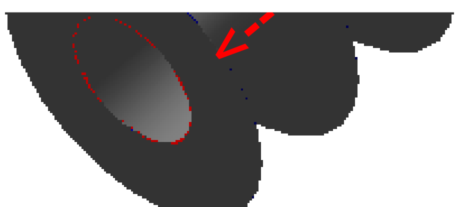




momentum resolution requires
full lever arm ***(see W. Mitaroff's talk at this week's VTX/TRK session)***

but pattern recognition, connection to the TPC, favours small inter-disk distance...



LDC
Tracker Disks
0...1800 mm)
σ (Rϕ) = 5-10 μm
R-segmentation

Differences FIT/FTD

GLD DOD proposes 25 μm R-ϕ resolution, quite imprecise compared to both the GLD central inner tracker BIT (10 μm) resolution and to the LDC view (< 10 μm)

This larger measurement propagates (proportionally) into the asymptotic momentum resolution (among other things)

FTD momentum resolution

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

Reference (TESLA) set-up

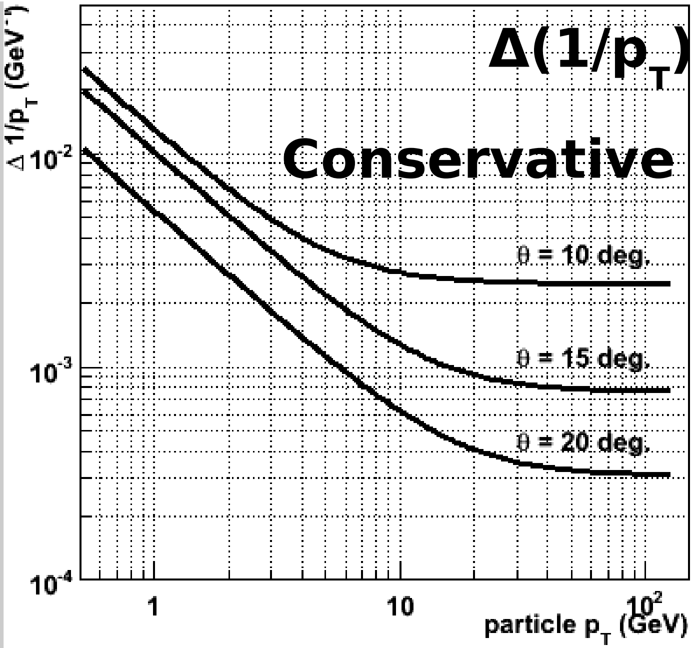
$1.8\times10^{-3}\oplus1.3\times10^{-2}/p_T$

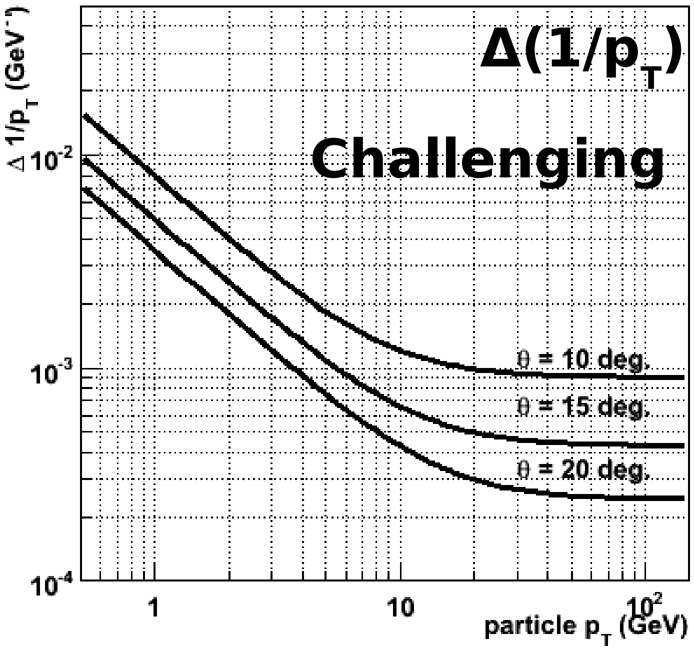
Challenging setup

(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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FTD momentum resolution

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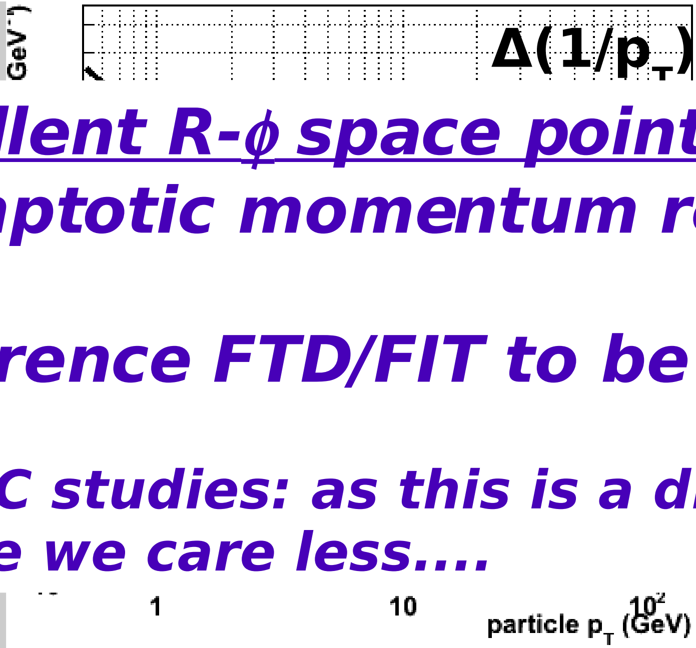

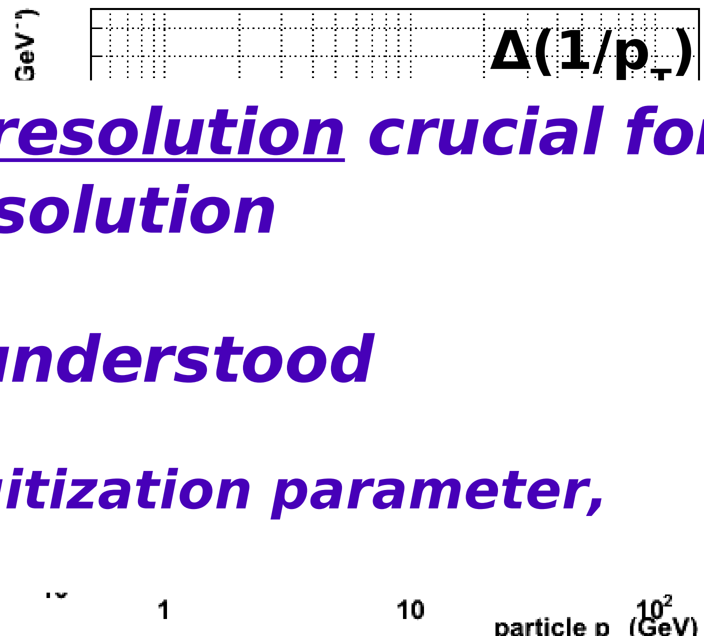

***Excellent R-ϕ space point resolution* crucial for asymptotic momentum resolution**

Difference FTD/FIT to be understood

For MC studies: as this is a digitization parameter, maybe we care less....

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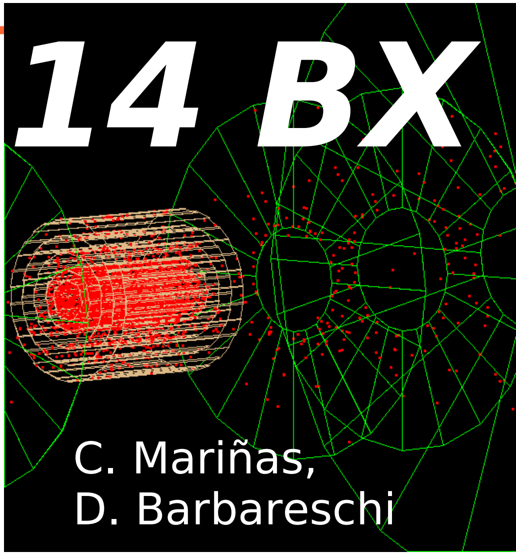
Pattern recognition in innermost detectors

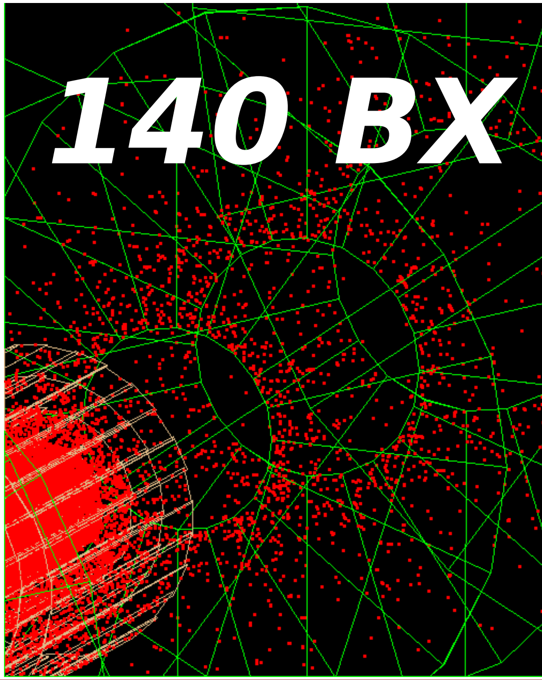


Cannot establish pattern recognition requirements of the innermost/forward layers without realistic backgrounds

The impact on the SIT and FTD design is non-negligible (see forward session)

Increased granularity, faster read-out

Increase the material and power



Pattern recognition in innermost detectors

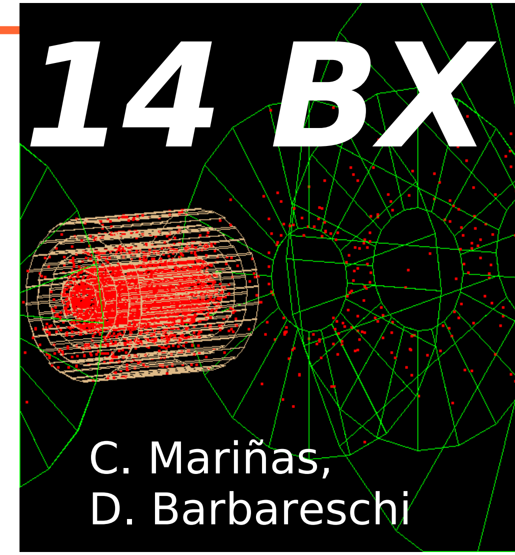
Cannot establish pattern recognition requirements of the innermost/forward layers without realistic backgrounds

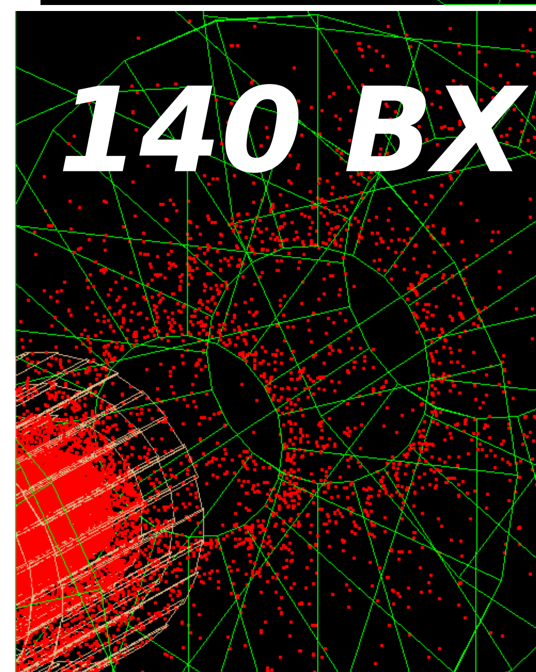
The impact on the SIT ar... design is non-neglig... session)

Increase... ...d-out

...e material and power

Can we avoid this loop by progress in technologies?

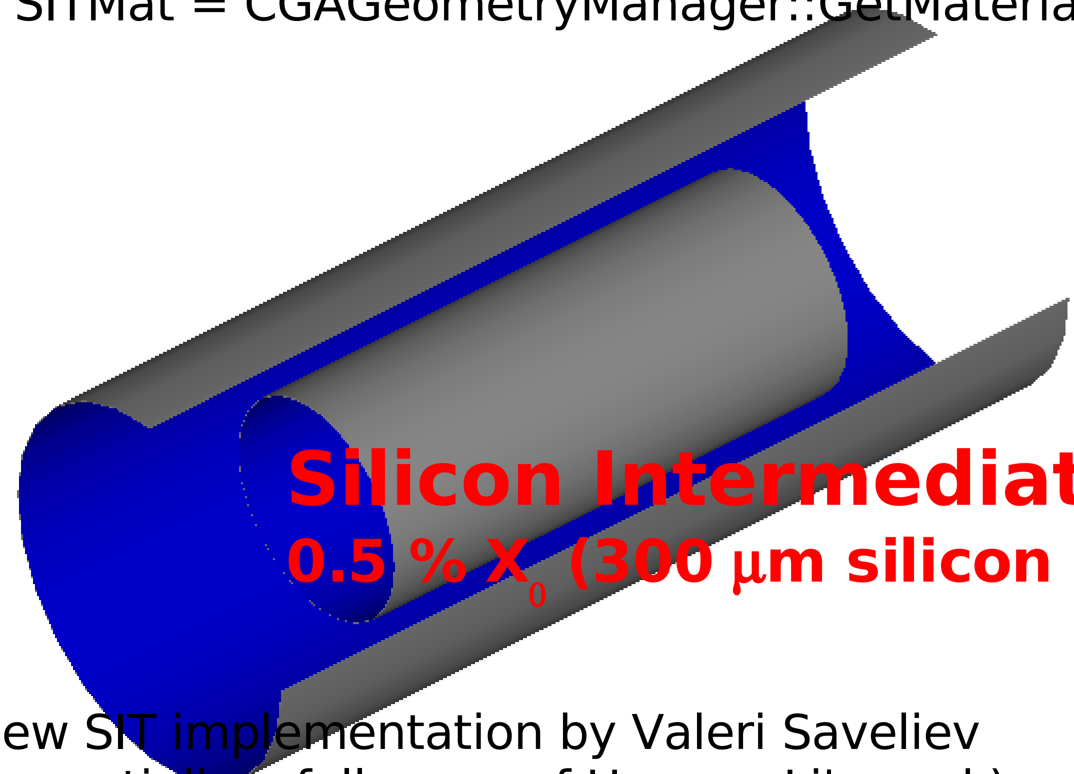




LDC inner silicon: Mokka implementation SIT

```
// sensitive silicon cylinders...
G4Tubs *SitSolid = new G4Tubs("Sit",
                inner_radious, inner_radious+sensitive_thickness,
                half_z, start_phi, stop_phi);

SITMat = CGAGeometryManager::GetMaterial("silicon_2.33gccm");
```



Silicon Intermediate Tracker (SIT)

0.5 % X_0 (300 μm silicon + C support)

New SIT implementation by Valeri Saveliev
(essentially a follow-up of Hengne Li's work)

super-drivers

Drivers for four silicon sub-detectors in LDC are available, including the Mokka database entries.

Valeri is working on super-drivers to make sure that different sub-detectors scale with relevant detector parameters:

FTD (TPC length)
ETD (TPC length, TPC inner, outer radius)
SIT (TPC inner radius)
SET (TPC outer radius, length)

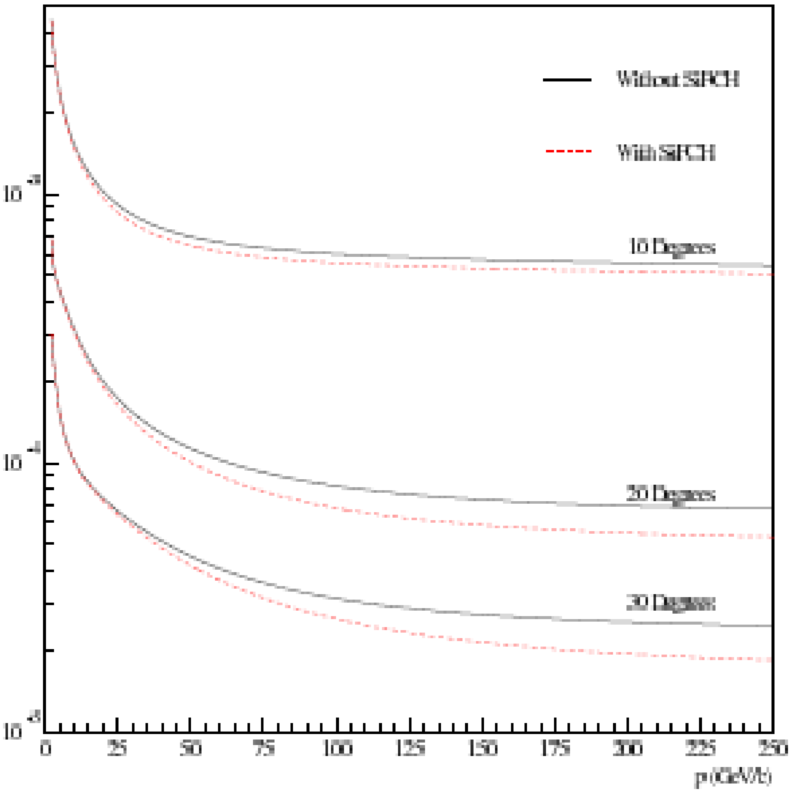
End-cap Tracker Disks, Silicon External Tracker

✔ **Impact on transverse momentum performance studied since long**

Mikael Berggren, LCWS04, compare forward chambers, either straw-tubes (TDR), or SET type long micro-strips, ie compare σ=100 μm to σ=25 μm. High p_T tracks

Complex interdependence with TPC resolution and end-plate material

Impact on particle flow?



Summary

Tracker optimization for momentum resolution studied since a long time in both concepts, either using fast simulation or full simulation of single muon events

Results on other aspects of tracker performance – particularly the pattern recognition performance – will be available at the time of the LOI

We're not alone. Establish impact of the tracker parameters on global performance and finally the optimum point for physics.

TPC inner radius (backup slide)

A crucial decision on the path to the LOI. Particularly important for the design of the inner silicon tracker (SIT/BIT) and (FTD/FIT)

The TPC geometries of GLDPrime and LDCPrime in the excel file sent by Jenny List last December:

inner radius; 39.5 cm (GLD') 30.05 cm (LDC')

inner radius sensitive volume; 43.0 cm (GLD') 37.1 cm (LDC')

Final TPC inner radius depends on a large number of issues:
Engineering constraints: Opening scenario foresees TPC to slide over Beam Delivery System. TPC Inner radius therefore limited by size of BDS.
Technology constraints: minimal TPC radius to cope with background and positive ion flux, minimal thickness (cm) of the TPC field cage?
Tracking performance: central detector global performance benefits from reduction in material associated with small TPC radius, forward track matching between FTD and TPC benefits from larger inner radius, two-track resolution in jets

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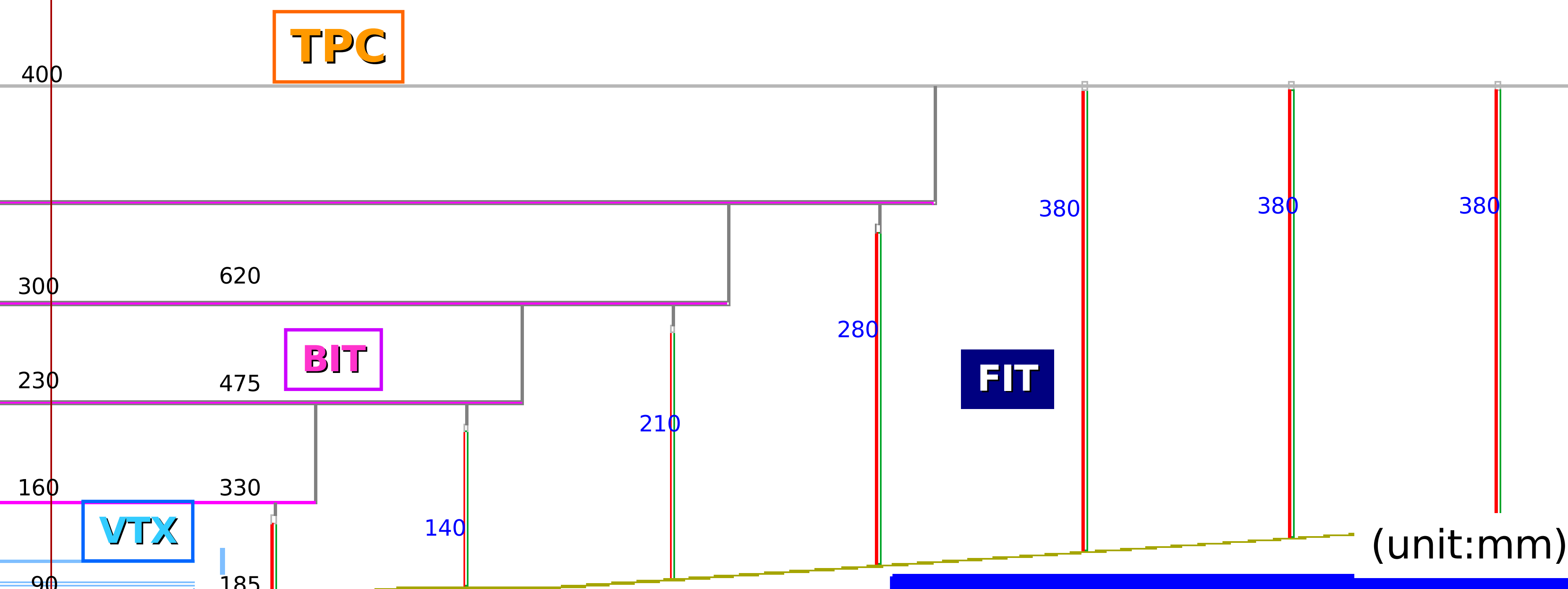
Barrel/Forward Inner Trackers

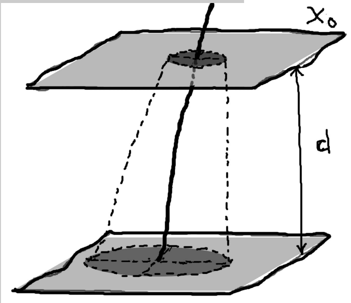


Forward IT

- spatial resolution 25 µm
- 7 layers (thickness 561 µm Silicon sensor)
- three inner planes : pixel-based sensors
- remaining four planes : silicon strip sensors

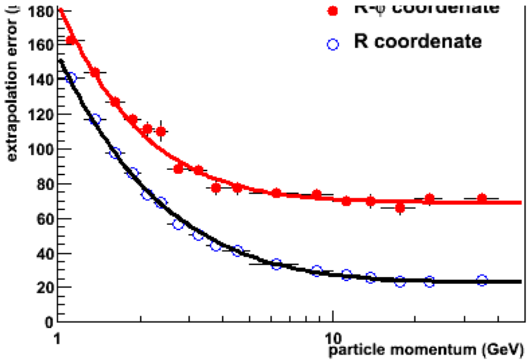
Module	Z	Rmin	Rmax
Layer1	155	24	76
Layer2	290	32	140
Layer3	435	37	210
Layer4	580	47	280
Layer5	725	57	380
Layer6	870	66	380
layer7	1015	76	380

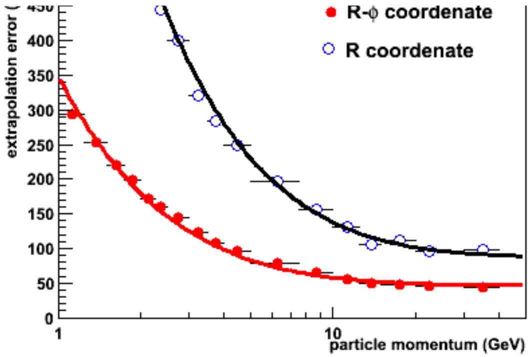
Pattern recognition: quality markers



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





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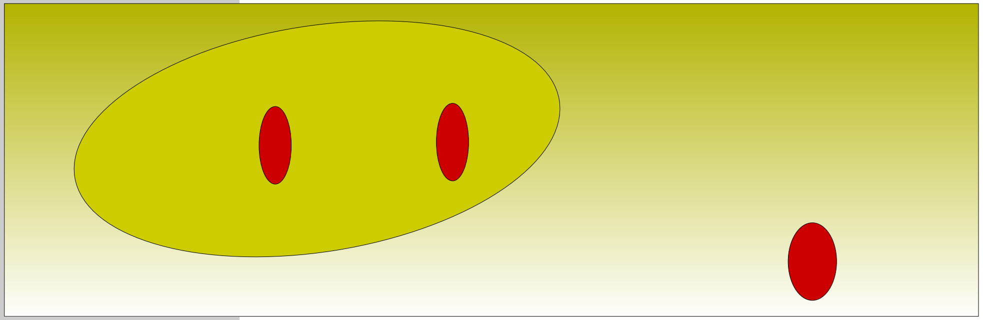
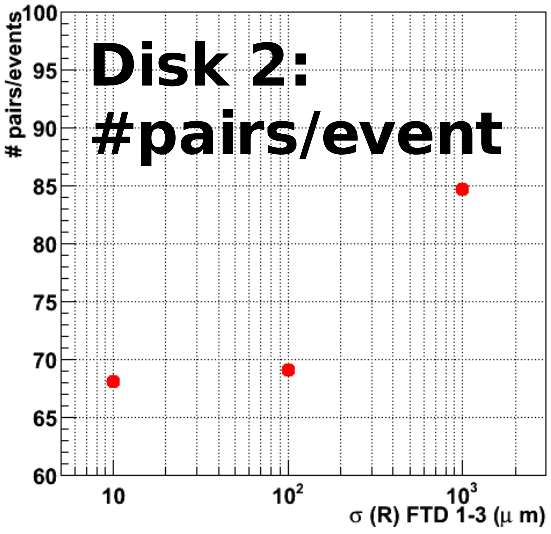
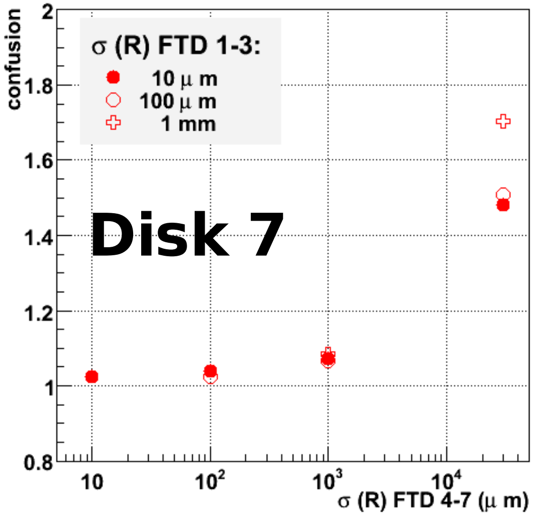


Confusion: the number of hits compatible with the extrapolated position

Confusion





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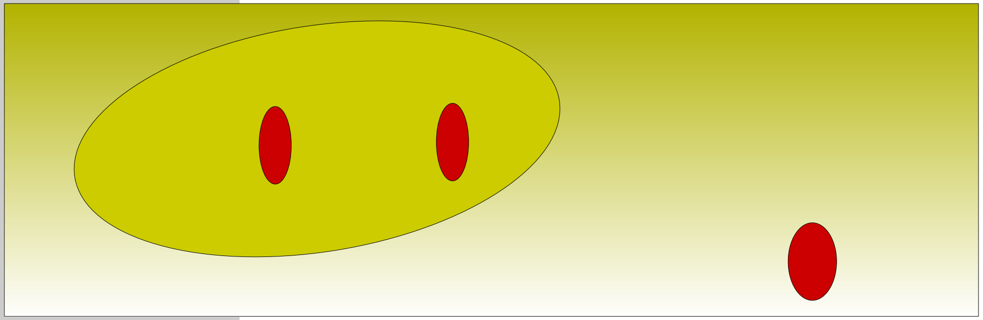
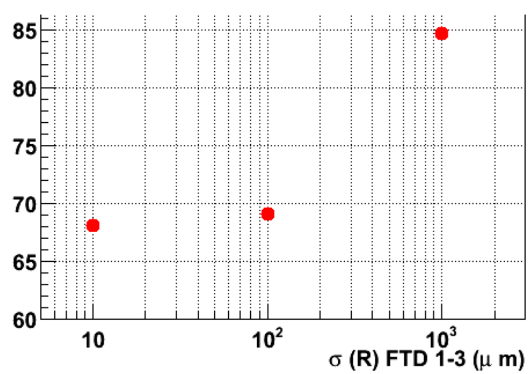
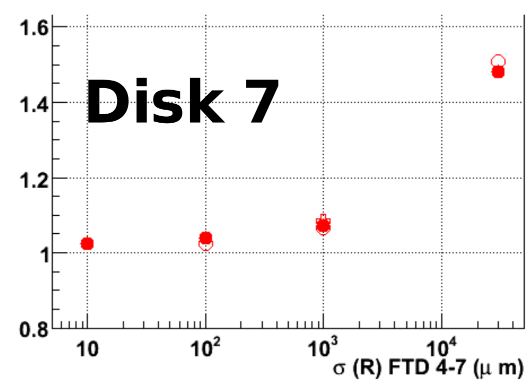


Confusion: the number of hits compatible with the extrapolated position

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





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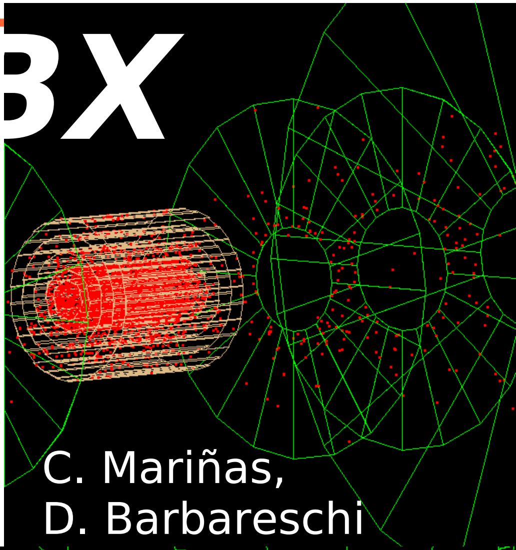
Pattern recognition: detector parameter scan

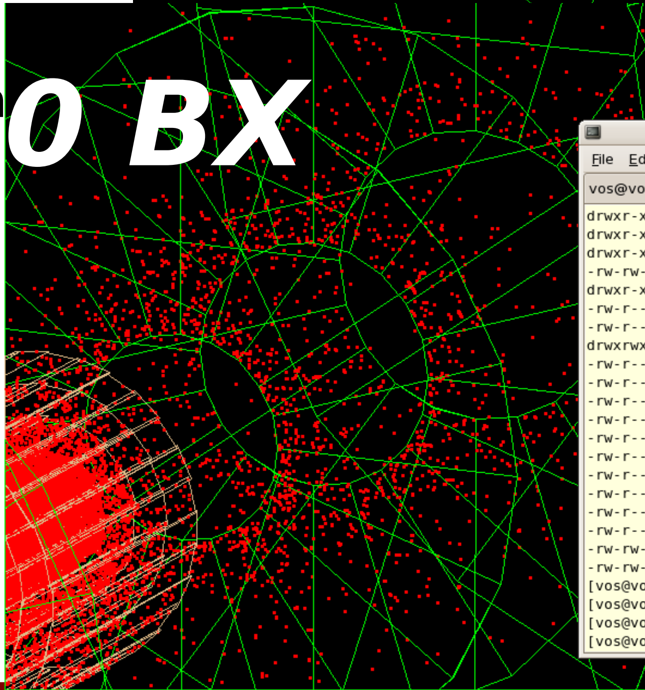
The stand-alone FTD is able to resolve patterns down to a p_T of 100 MeV, provided:

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





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