CMS Tracker Upgrade Simulations

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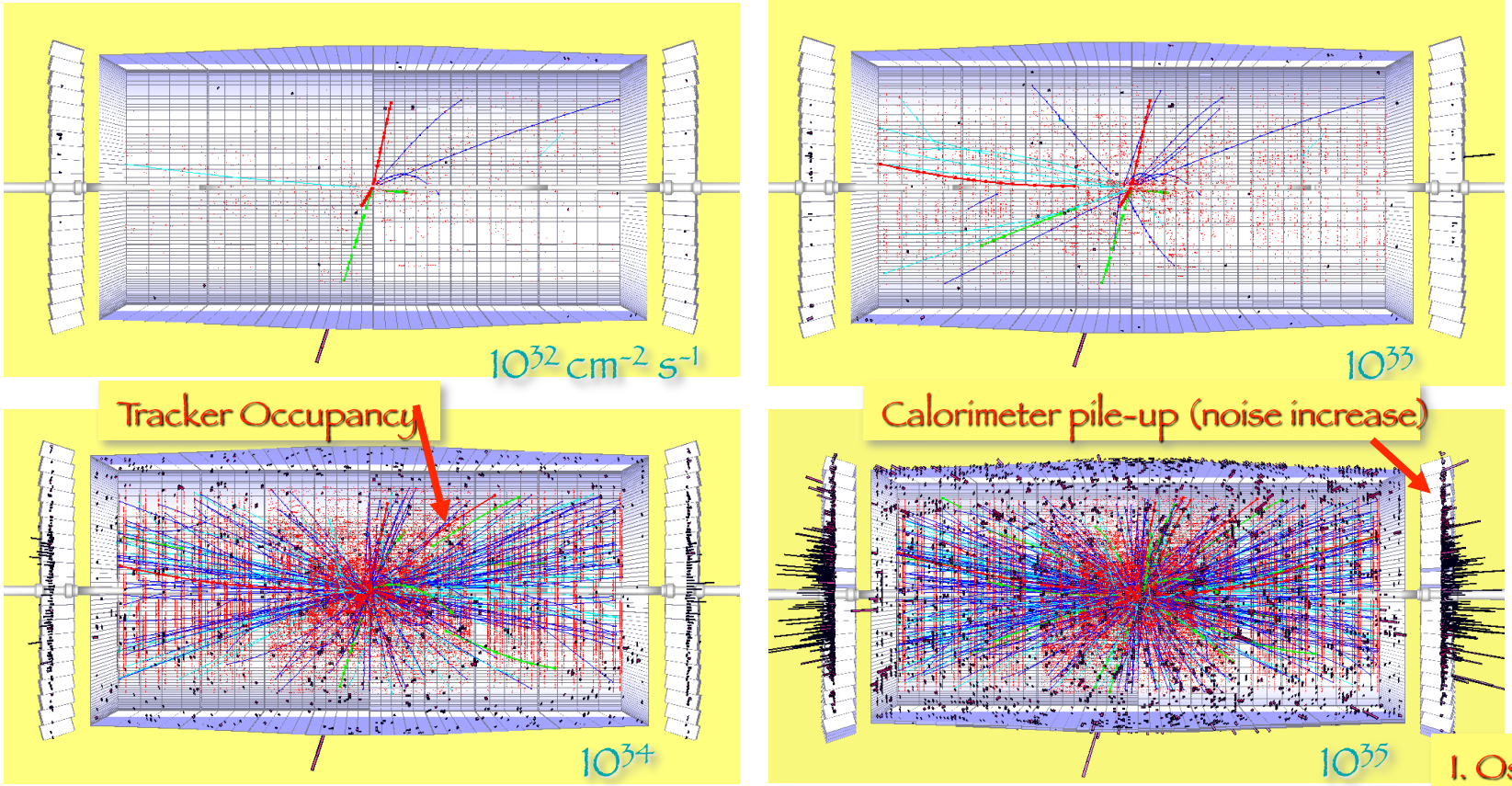
https://twiki.cern.ch/twiki/bin/view/CMS/SLHCTrackerSimuSoftTools

HyperNews: hn-cms-slhc-trackersim@cern.ch

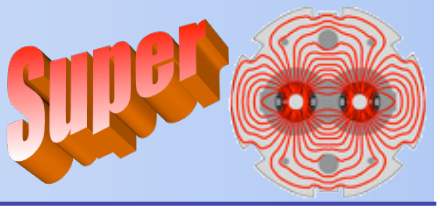
Considerations for Trackers at $10^{35}cm^{-2}s^{-1}$



The tracker is the key detector which will require upgrading for SLHC

If same granularity and integration time as now: tracker occupancy and radiation dose in central detectors increases by factor ~10, pile-up noise in calorimeters by ~ 3 relative to 10^{34}

Performance and Layout WG



- The Performance&Layout Working Group was born in March 2007
- Aims: the Performace&Layout group is intended to be the forum in which software and hardware experts will contribute to develop the design of a new layout for the Tracker upgrade @ SLHC
  - Perform simulations & performance studies
  - Develop a common set of software tools to assist these studies
  - Develop set of common benchmarks for comparisons
  - Maximize the overlap of these common software tools with those in use for CMS@LHC (assist current efforts where possible)
  - Get good integration between Tracker and (Tracking) Trigger design
- The group should provide the relevant software tools to properly simulate different layouts and study the SLHC-Tracker performances
- Web Page: https://twiki.cern.ch/twiki/bin/view/CMS/SLHCTrackerSimuSoftTools
- Hypernews forum: hn-cms-slhc-trackersim@cern.ch

Task List

- A first task list (March 2007-September 2008) was defined with main focus on new geometry development and relevant software tools production/optimization (we contributed also in the "standard CMS" code)
  - Strawman approach
    - Not baseline tracking systems, just 2 example layouts as the starting points for simulation studies
  - Fast/full simulation development for Tracker @SLHC
- Initial task list mainly focussed on Phase II
  - Phase I concept came later
- The existing task list was dynamically updated and a large amount of time/work was dedicated also to the full simulation

The starting point

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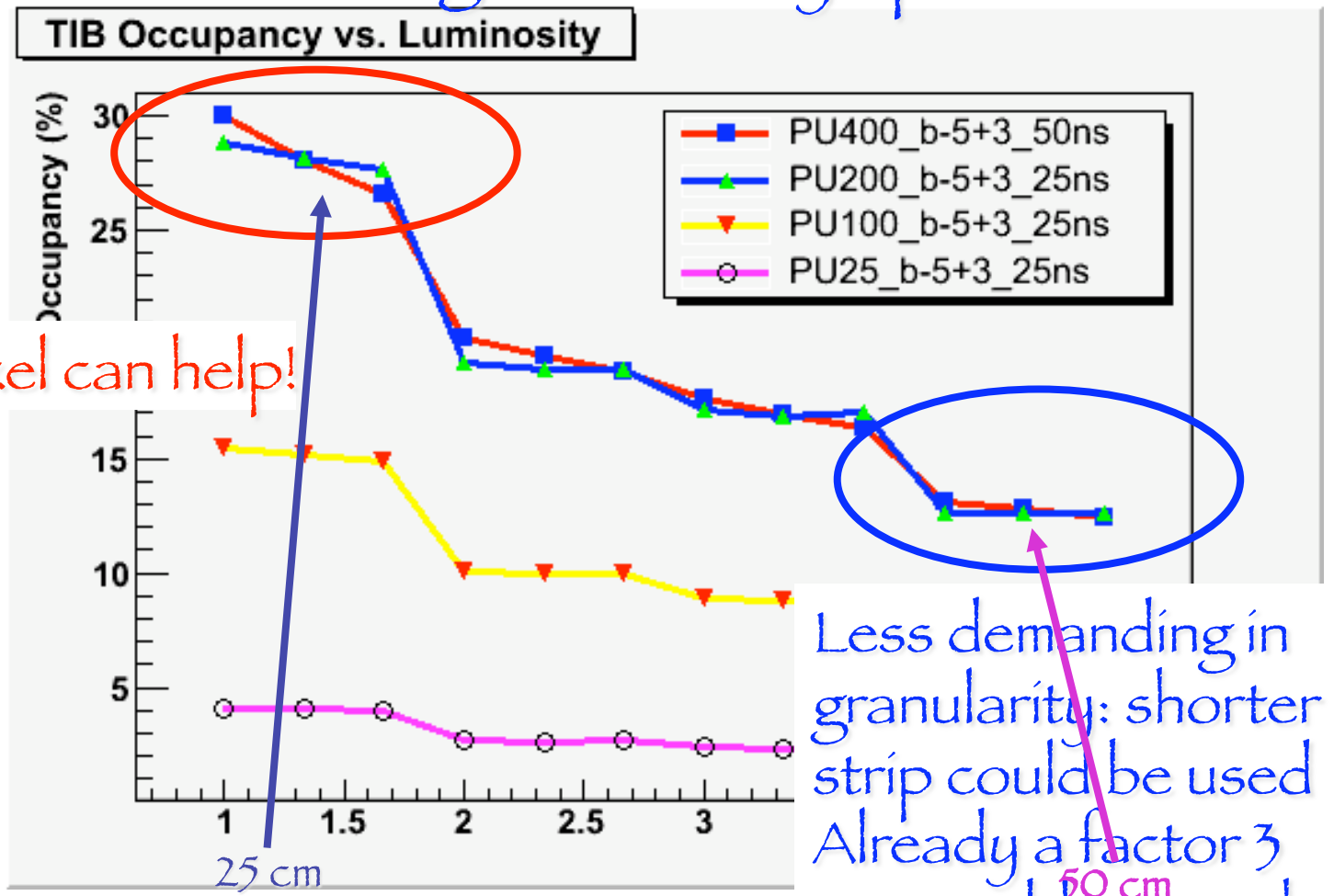
nesses in the
for future

LHC Tracker @ SLHC
Occupancy vs Luminosity

From LHC design luminosity up to SLHC



Only pixel can help!

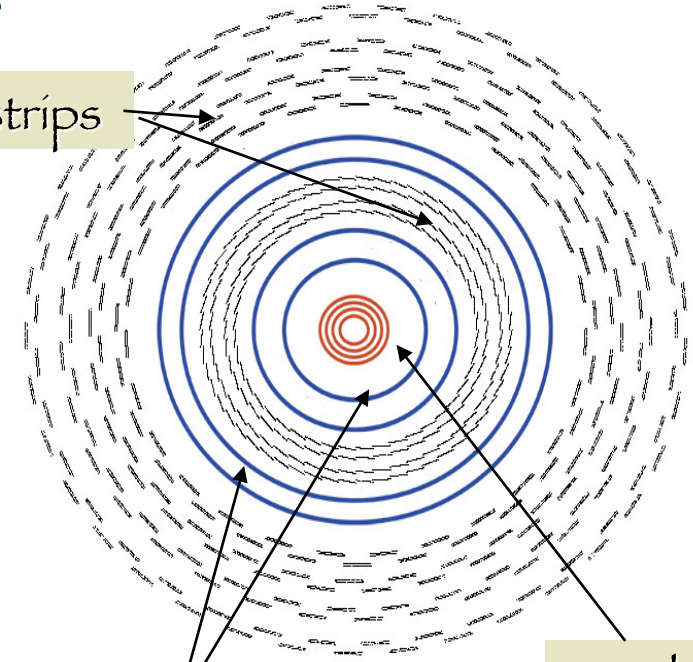
Less demanding in granularity: shorter mini-strip could be used
Already a factor 3 reasonable enough

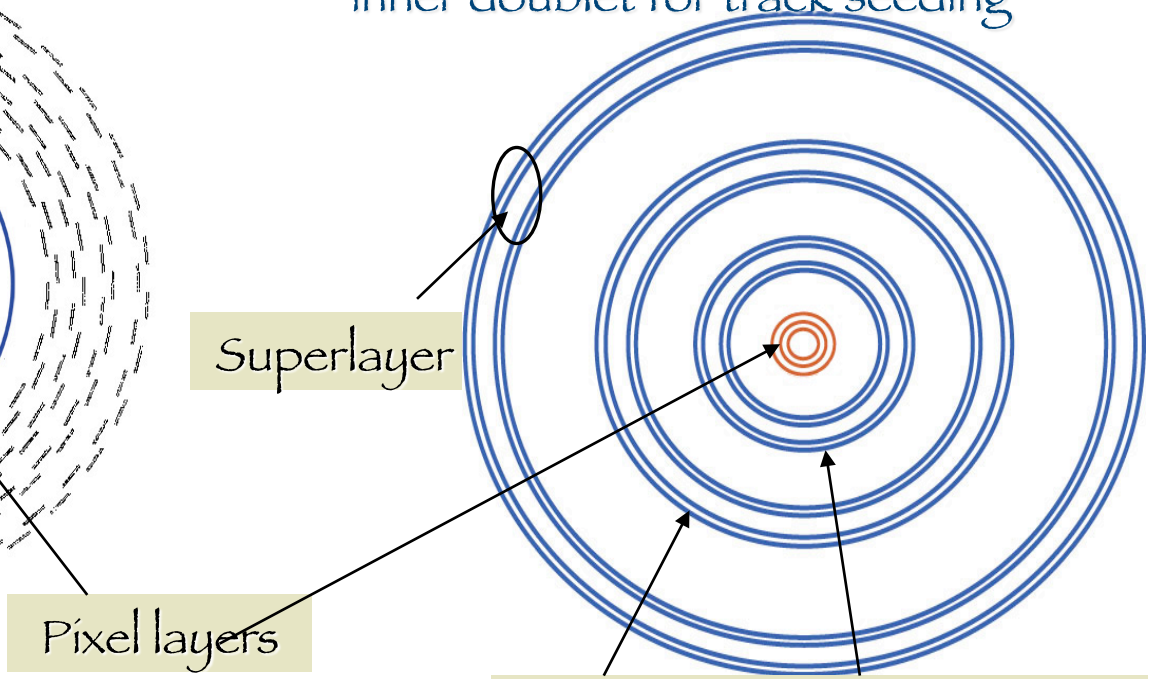
Phase II: Strawman A &B

Barrel Strawman A and B

Strawman A Geometry:
Perturbation of current tracking system
4 Inner pixel layers, 2 strixel + 2 short strip layers (TIB), 2-strixel + 4 short strip layers (TOB); strixel layers can be doubl

Strawman B Geometry:
Design more radically different from current tracking system
Super-layers, each with two doublet layers (integrated tracking/ triggering layers); 3 inner Pixel layers; can use inner doublet for track seeding

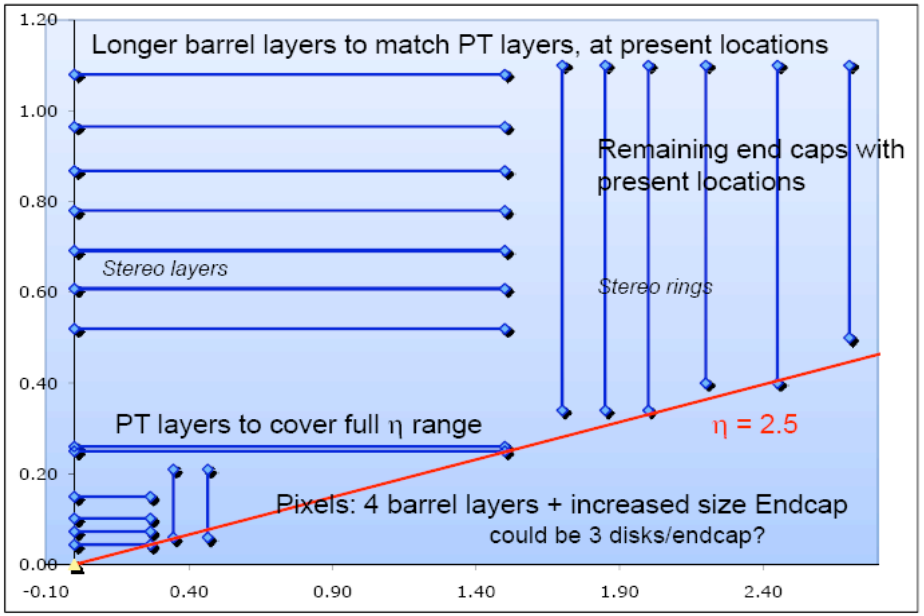




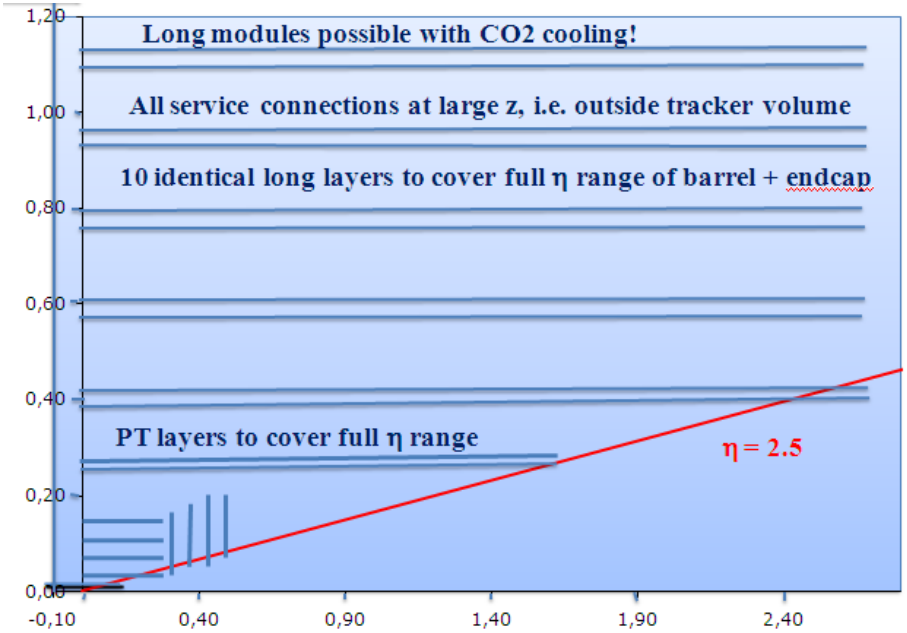
(Layers simplified as rings for illustration!)

From July plenary meeting…

- Wide discussion about a single realistic straw man but still not a unique solution



G. Hall

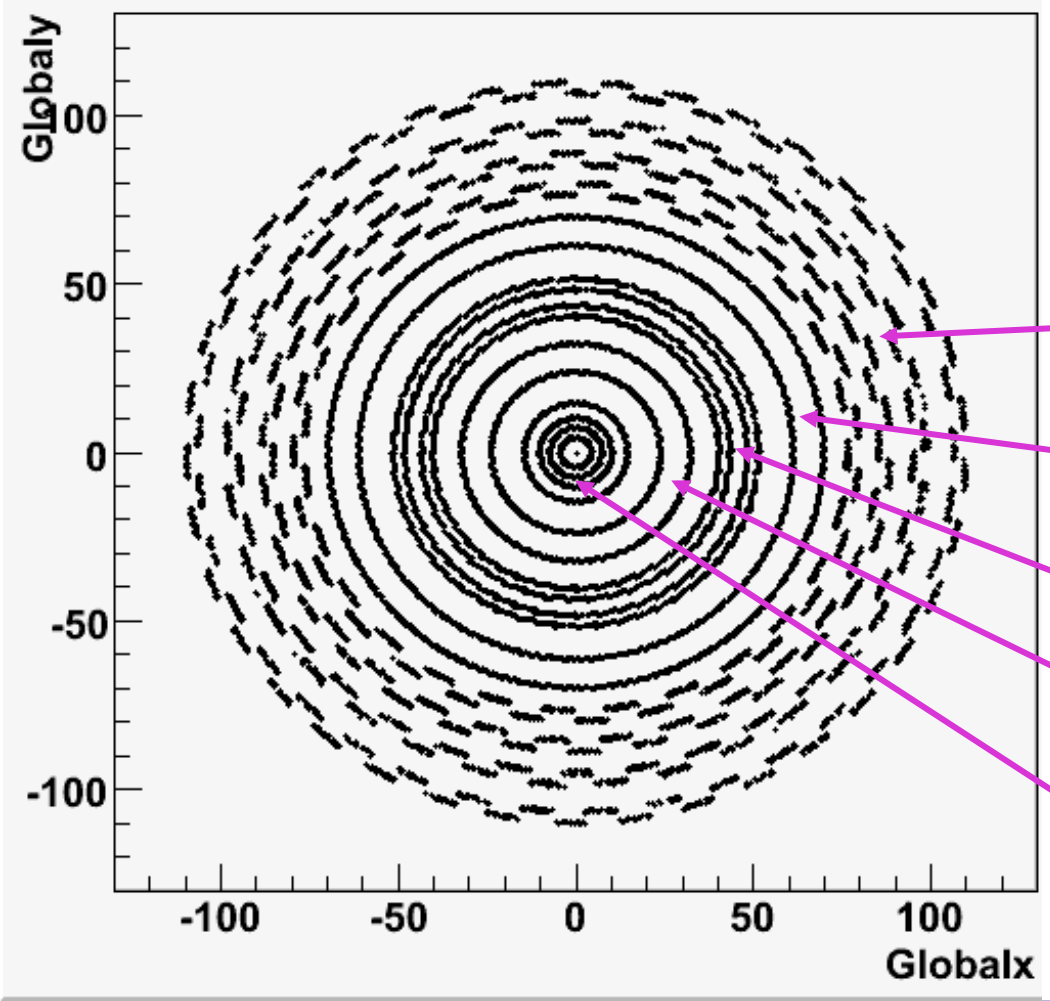


W. De Boer

Main conclusion: move initial straw man A & B to a more realistic solution

Towards a more realistic Straw man A

- Straw man A was intended as a "family of possible straw man"
- A working idea (Carlo and Alessia): Remove 1 "TIB" and 1-2 "TOB" layers



Strawman A r-phi view (RecHit 'radiography')

4 TOB short strips
Remove 2

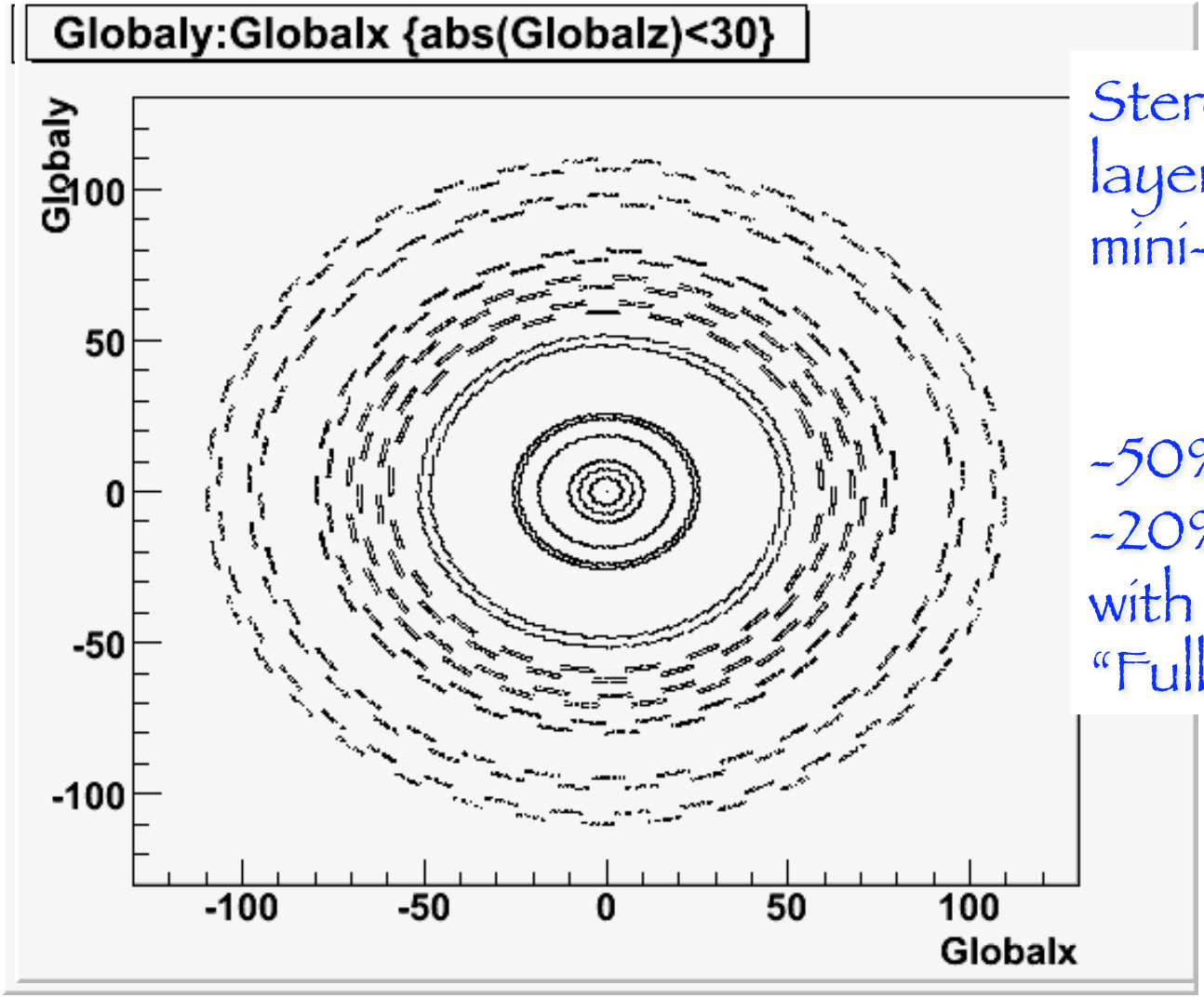
2 TOB strixels
Adjust chn count

2 TIB short strips
Remove 1

2 TIB strixels
Adjust chn count

4 inner pixels

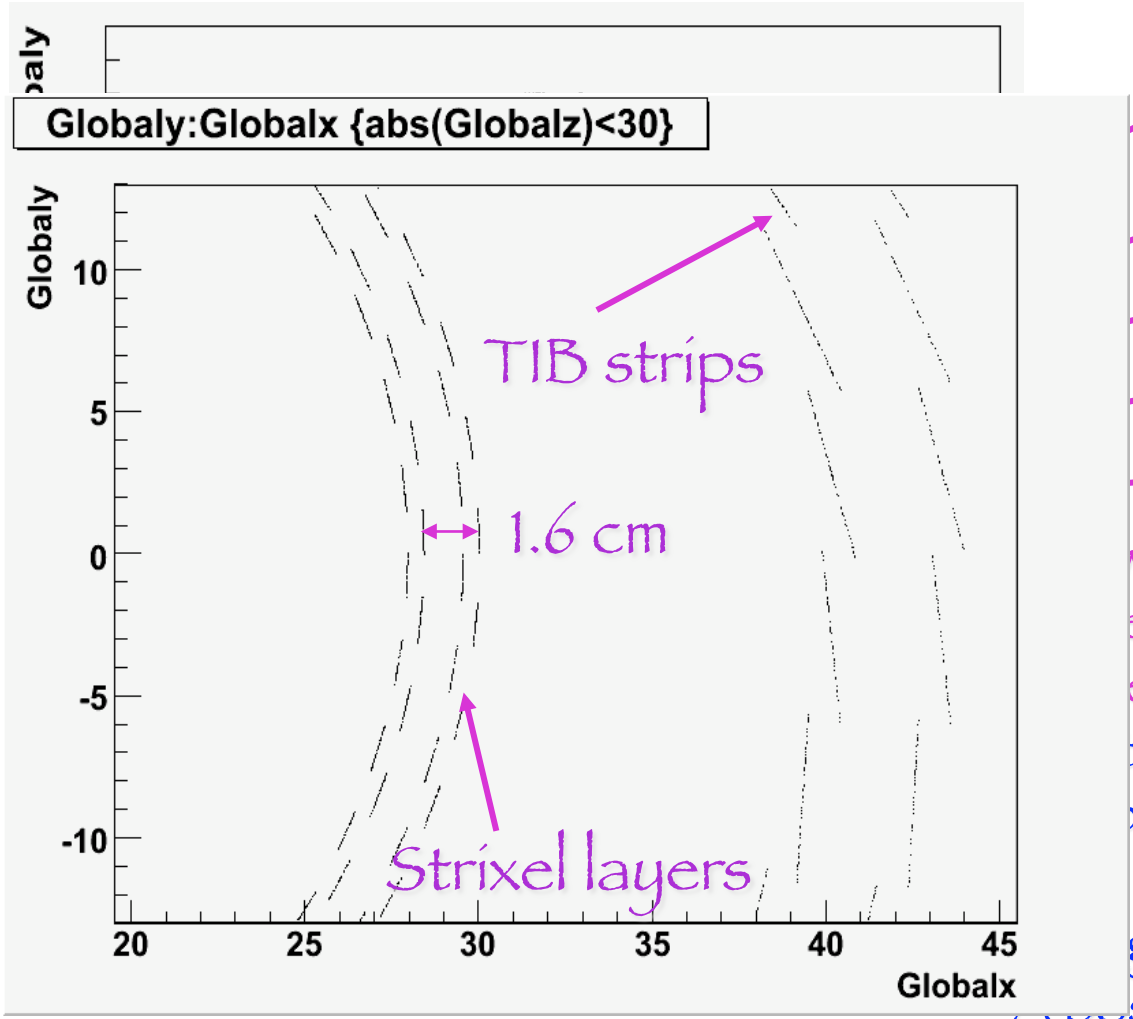
New Strawman A



Stereo TOB layers build with mini-strips

-50% pixel ch.
-20% strip ch.
with respect to "Full" Strawman A

Strawman A status: trigger



Trigger version: collapsed strixel layers

4 inner pixels

2 TIB strixels

2 TIB short strips

2 TOB strixels

4 TOB short strips

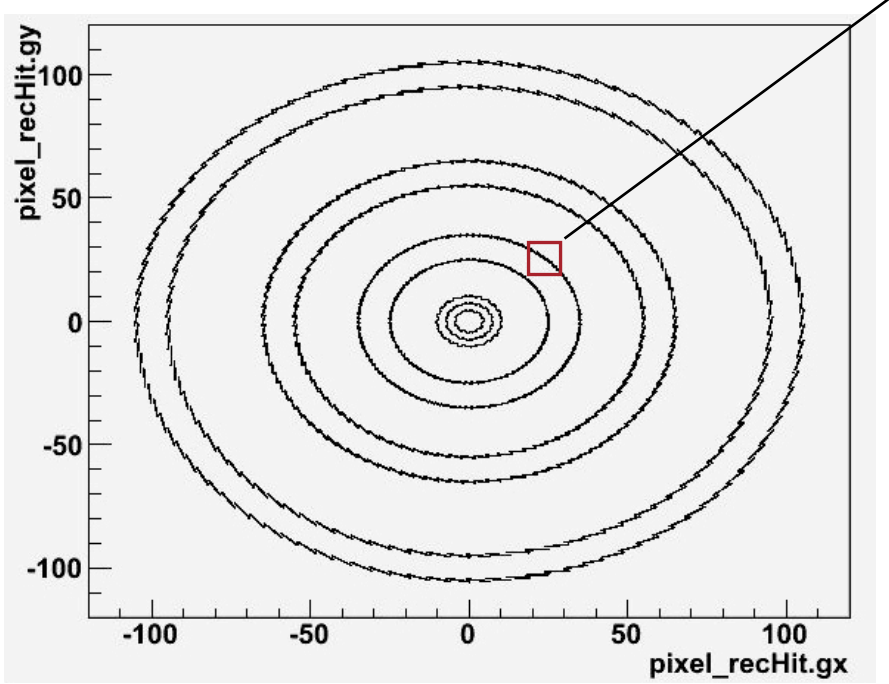
v man A can be used to test
er algorithms: well suited both for
er width and stacked stub method
wo strixel doublets or any
ination strixel-ministrip can be
to simulate a possible trigger
guration

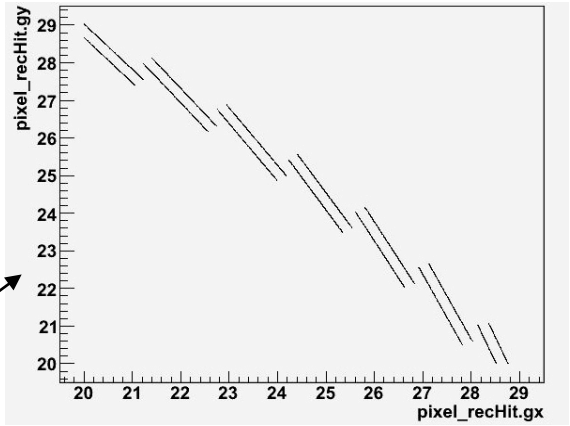
ossible layout (with <Δr> = 1.6cm):
R1 = 28.20cm R2 = 29.80cm
R3 = 68.70cm R4 = 70.30cm

More realistic Straw man B

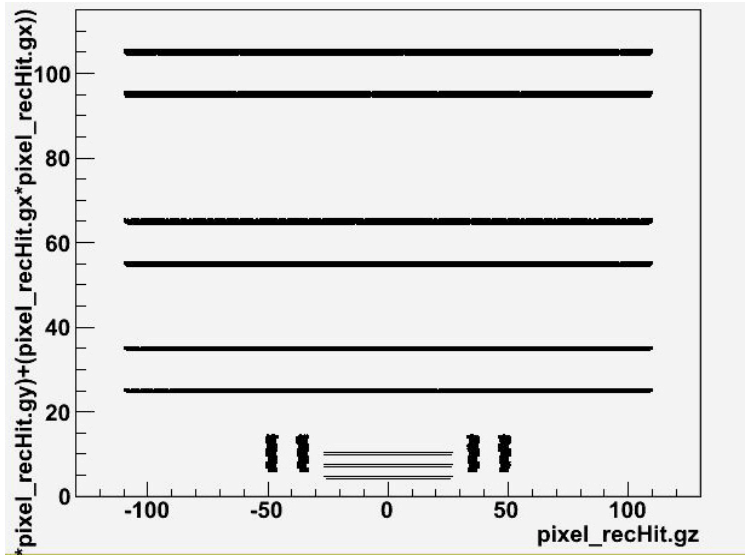
- Adjust granularity (channel count) of Strawman B layers
  - Keep the TEC for now until someone can work on the endcaps

Strawman B r-phi view
(RecHit 'radiography')





r-z view



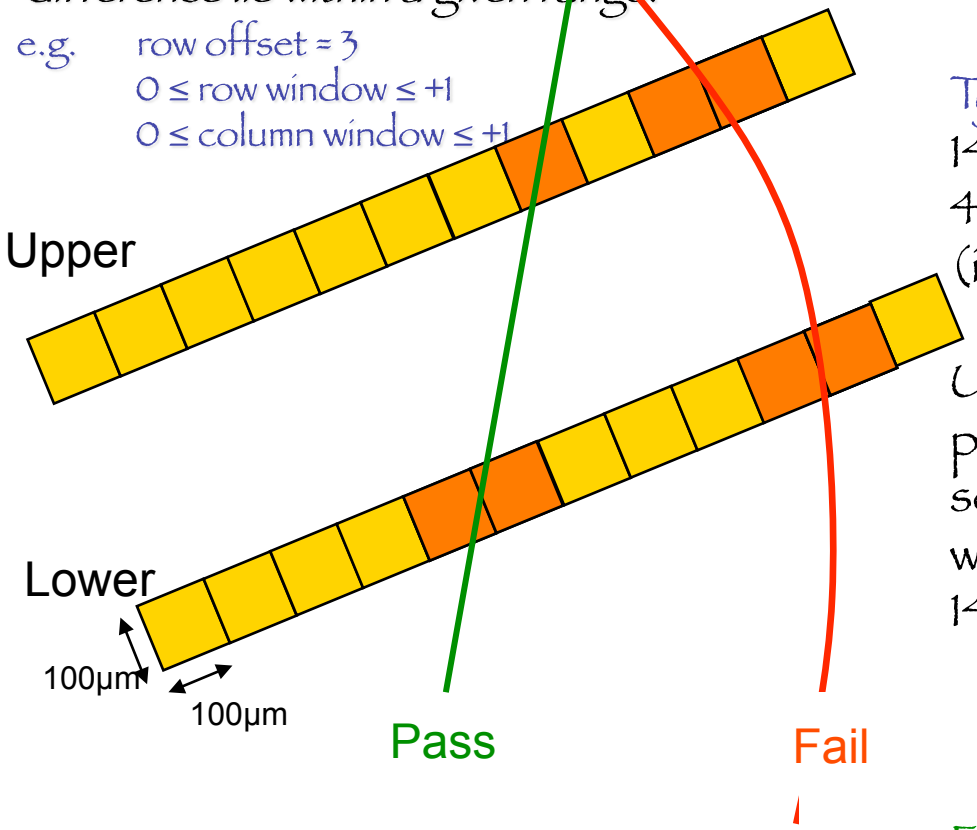
Strawman B: Trigger studies

Correlation Algorithm

Stub generation

A stub is created when both the row and column difference lie within a given range.

e.g. row offset = 3
0 ≤ row window ≤ +1
0 ≤ column window ≤ +1



M. Pesaresi, Oct. 7th

Performance of algorithm in ideal conditions measured ~95% maximum efficiency of detecting high pt tracks, ~ x100 reduction in data rate

Typical MinBias event at SLHC:
1455 tracks > 2 GeV
4 tracks > 8 GeV
(in region |eta| < 2.14)

Using a stacked pixel layer at 25cm with pixel pitch 100 μ mx2.37mm and 2mm sensor separation [row window=2, column window=3]
140 stubs
includes 25 fake stubs
includes 20 duplicate stubs

Every event is triggered
A second stacked layer would reduce the number of fakes

Phase I: Strawman 0

Pixel Upgrade Options 1-5

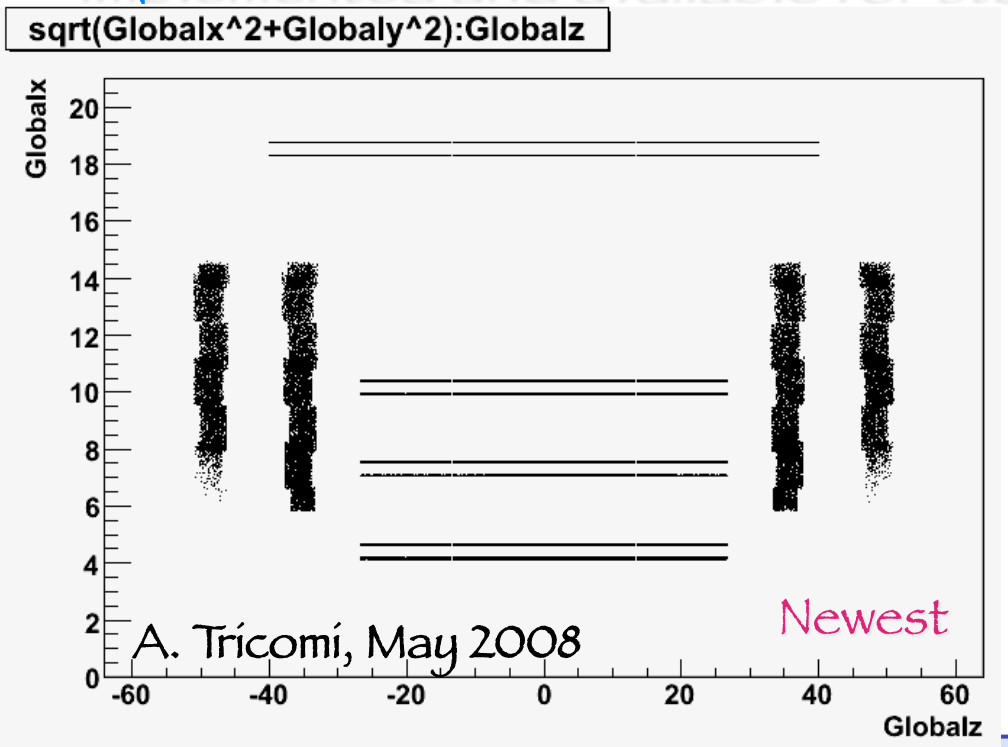
	Option	Layer/Radii	Modules	Cooling	Pixel ROC	Readout	Power
as 2008	0	4, 7, 11cm	768	C_6F_{14}	PS46 as now	analog 40MHz	as now
	1	4, 7, 11cm	768	C_6F_{14}	2x buffers	analog 40MHz	as now
	2	4, 7, 11cm	768	CO_2	2x buffers	analog 40MHz	as now
	3	4, 7, 11cm	768	CO_2	2x buffers	analog 40MHz μ-tw-pairs	as now
	4	4, 7, 11cm	768	CO_2	2xbuffer, ADC 160MHz serial	digital 320MHz μ-tw-pairs	as now
	5	4, 7, 11, 16cm	1428	CO_2	2xbuffer, ADC 160MHz serial	digital 640 MHz μ-tw-pairs	DC-DC new PS

Roland Horisberger

Baseline for Phase I studies

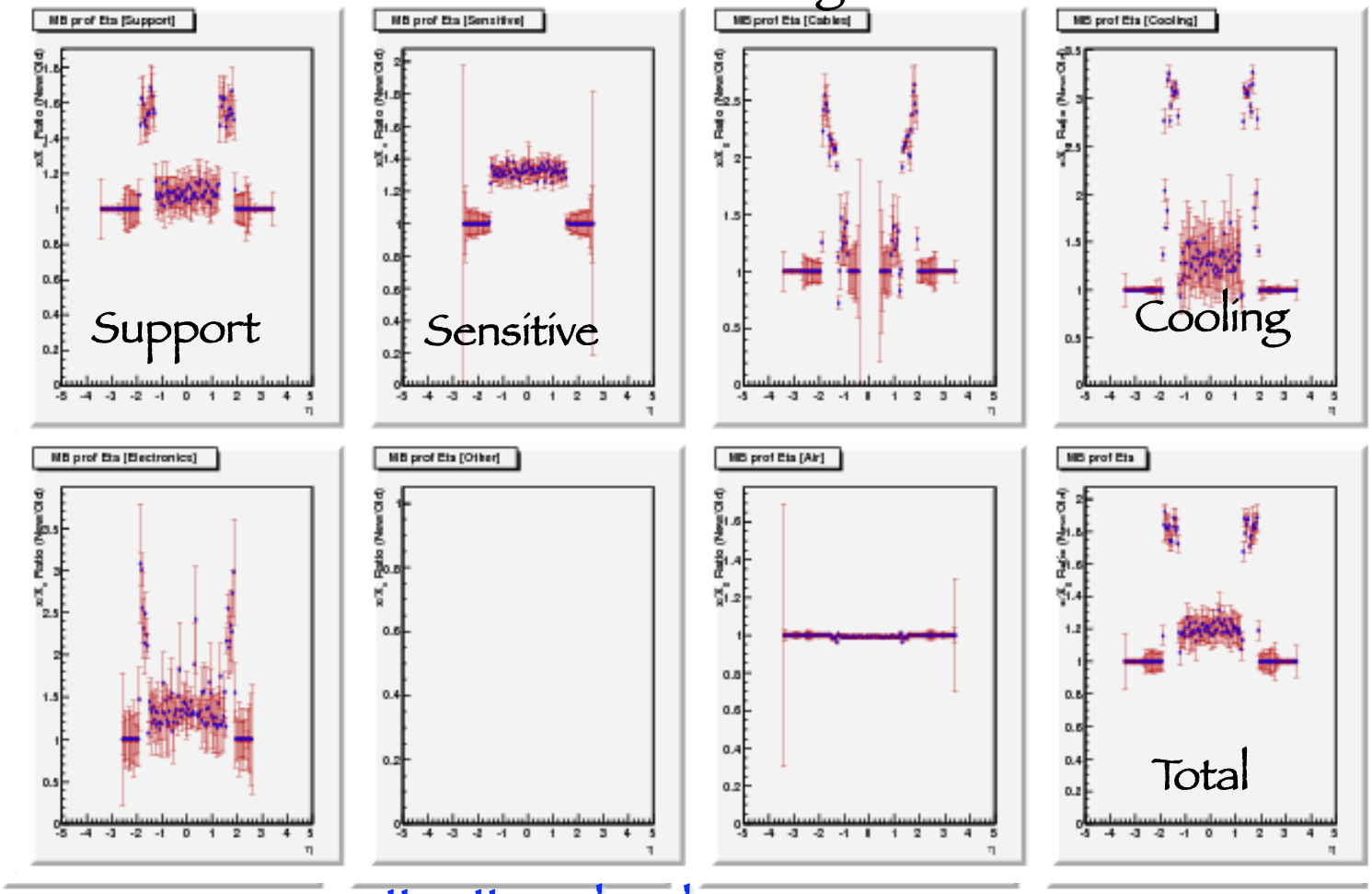
Strawman 0

- 4 inner pixel layers
- Pixel material rescaled according to Horisberger's estimate
  - Cooling Fluid: C_6F_{14} replace by CO2
  - Cooling Tube: Aluminium replaced by Steel but Mass reduced by ~ a factor 10
- No change in the forward pixel disks but a third disk already implemented and available for studies



Material budget comparison (Project 3-5)

Ratio of Material Budget vs eta



Standard Geometry vs Straw man 0

Standard Material vs New Material

Strawman 0: some examples

First performance studies done with old CMSSW version (1_8_4), however pixel material in 1_8_4 not realistic

Need to move to 2_1_10 (done since few days)

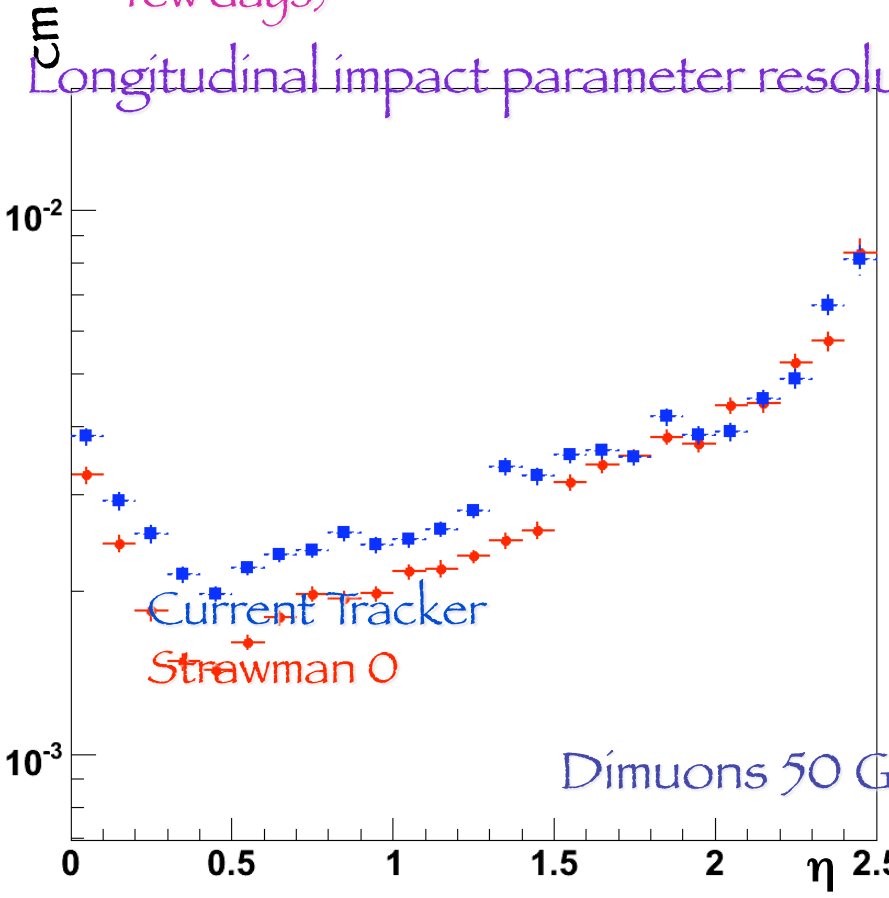
Estimate performances for

Standard Geometry (3 pixel-new material)

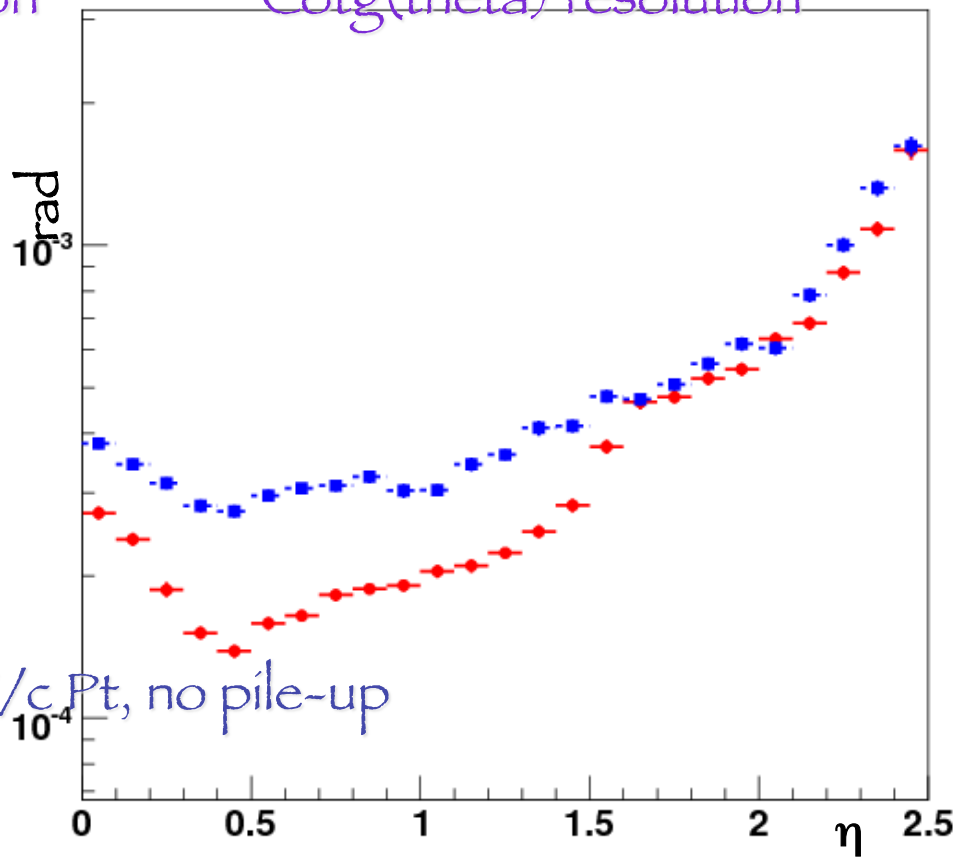
4 Pixel Barrel Layer new material

3 End cap disks new material

Longitudinal impact parameter resolution

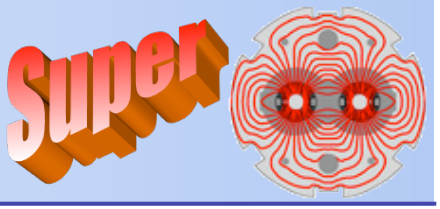


Cotg(theta) resolution



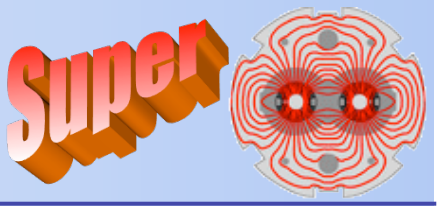
Dimuons 50 GeV/c Pt, no pile-up

What we have now



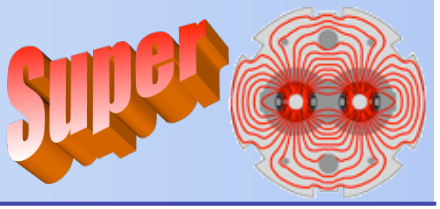
- Straw man A & B can be configured to study various geometry parameters
  - Numbers and location in radius of layers
  - Addition of strixels, mini-strips, and doublet layers
  - Configurable pixel and strixel granularity in XML files
  - Input/feedback from other WG to reach more realistic geometries
- Straw man 0 for Phase1
- A modified version of the FastSimulation that can properly account for the tracking system granularity
- A set of tools to validate the standard tracking performance
  - Work to do in simplifying the performance packages for our studies
  - Work to do in enabling fast highest pileup running, and more realistic pileup for the FastSimulation

Simulation WG new Task List



- Now that the basic straw man geometries and sw tools are available a new Task list has been identified with emphasis on tracking/trigger performance at high luminosity and on Phase I studies
  - Feasibility and performance of trigger doublet layers
  - Performance studies with an extra 4th barrel pixel layer and extra forward disk
  - Study tracking and trigger performance of straw man A & B at $10^{35} cm^{-2} s^{-1}$
  - Studies of Horisberger's option 1 to 4 for Phase I LHC upgrade
  - Studies of the tracking performance of the standard CMS detector at Phase I luminosities

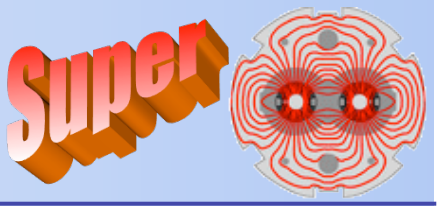
Summary



- We made good progress on the most important items on our WG initial task list, and it is time to consolidate and focus on simulation studies, including studies needed for Phase 1
- We have a new prioritized task list with a set of simulation studies that we need to do to give input to the other tracking upgrade working groups
- The software tools are ready to enable people to start the simulation studies; and some studies have started (mainly for Phase 2)
  - The two straw men are ready to use
    - Easy access from CVS
    - People already started to test them and to produce first results
    - Everybody interested is encouraged to try to use
- We need more work on the simulation studies, in particular for Phase 1
- Italian contribution quite sizeable in term of work but not in FTE (!) for geometry and performance studies

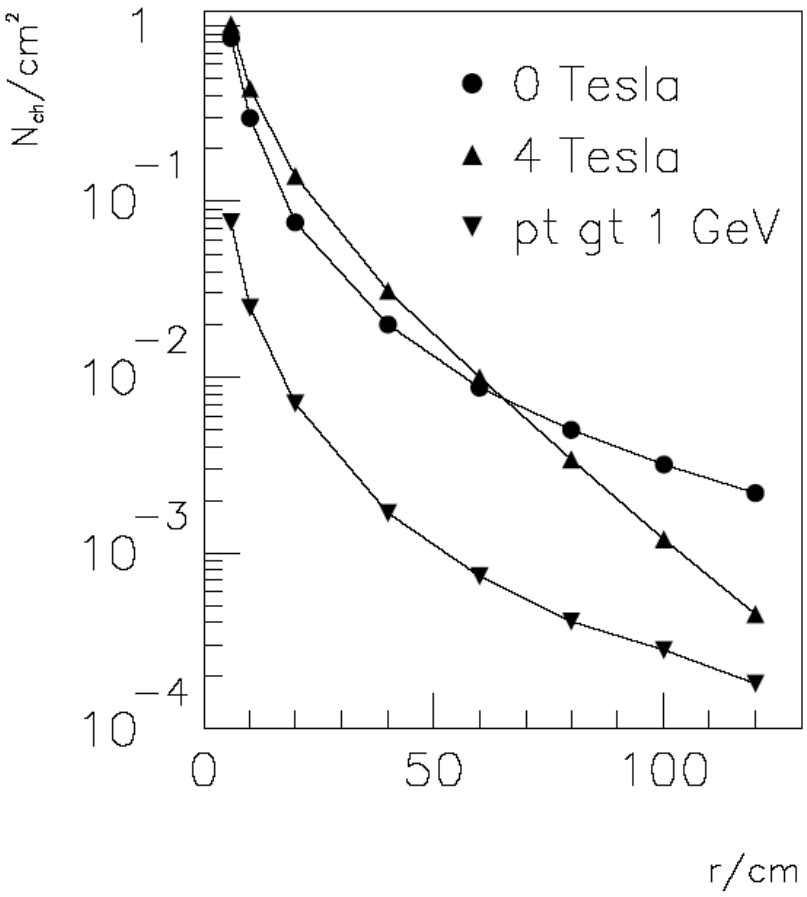
Back up

Purpose of simulation studies



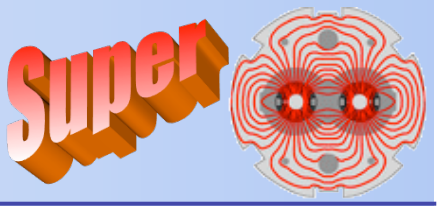
- Investigate "big picture" geometry strategies
  - Number and type of tracking layers, granularity, choices of technology or materials, readout choice, location of active and passive components and integration with rest of CMS
- Study various tracking/trigger algorithms
  - Study performances of existing tracking algorithms in SLHC environment, reconstruction efficiencies, fake rates,…
  - Compare different tracking algorithms
  - Look at timing, trigger efficiencies, reconstruction efficiencies for benchmark physics signals, fake rates,…
  - Compare different trigger algorithms
- Study effect of realistic hardware design choices
  - Compare different geometries, impact of overlaps, noise, details of the readout and resets and information being readout
- Study details of realistic conditions
  - Beam conditions, beam related backgrounds, pileup, noise, non-Gaussian tails in distributions, machine components near IP, overlap regions, inefficiencies

LHC-Tracker: occupancy



Layer #	Avg. radius	Modules in phi	Pitch phi	Pitch stereo
Pix1	4.44			
Pix2	7.33			
Pix3	10.19			
TIB1	25.5	26-30	80	80
TIB2	34.0	34-38	80	80
TIB3	43.0	44-46	120	-
TIB4	52.0	52-56	120	-

Towards a realistic 'strawman A'



- Strawman A has a number of channels (mainly pixels from trigger layers) which is too high to be considered affordable

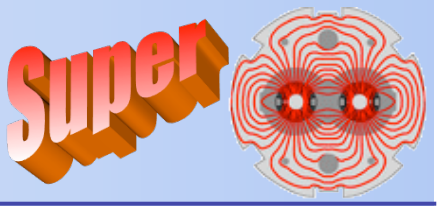
Tables from SLHCUpgradeSimulations/Geometry/test/trackerModuleInfo_StrawmanA.cfg

Strawman A	Active Surface [cm2]	# ROCs	# channels	# modules
Barrel - Pixels (PXB)	251522.3	79552	x 7	24240
Endcap - Pixels (PXF)	2834.4	4320	17971200	672
Barrel - Strips (TIB + TOB)	616886.2	85968	x 2.2	18132
Endcap - Strips (TID + TEC)	902046.7	34624	4431872	7216

Original Geometry	Active Surface [cm2]	# ROCs	# channels	# modules
Barrel - Pixels (PXB)	7558.26	11520	47923200	768
Endcap - Pixels (PXF)	2834.36	4320	17971200	672
Barrel - Strips (TIB + TOB)	1103896.7	38160	4884480	7932
Endcap - Strips (TID + TEC)	902046.7	34624	4431872	7216

Carlo Civinini, 7 Oct 2008

Old Vs New StrawmanA



Full geometry table in:
http://hep.fi.infn.it/CIVININI/slhc/GeometryTable.xls

Strawman A	Active Surface [cm2]	# ROCs	# channels	# modules
Barrel - Pixels (PXB)	251522.3	79552	330936320	24240
Endcap - Pixels (PXF)	2834.4	4320	17971200	672
Barrel - Strips (TIB + TOB)	616886.2	85968	11003904	18132
Endcap - Strips (TID + TEC)	902046.7	34624	4431872	7216

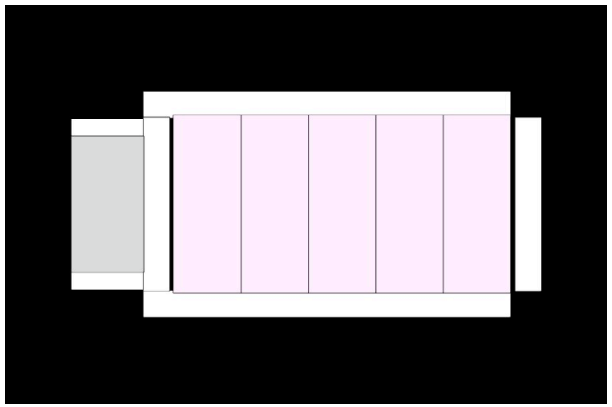
Realistic Strawman A	Active Surface [cm2]	# ROCs	# channels	# modules
Barrel - Pixels (PXB)	58030.73	41408	172257280	5680
Endcap - Pixels (PXF)	2834.36	4320	17971200	672
Barrel - Strips (TIB + TOB)	829242.6	72288	9252864	14712
Endcap - Strips (TID + TEC)	902046.7	34624	4431872	7216

Strawman A Status

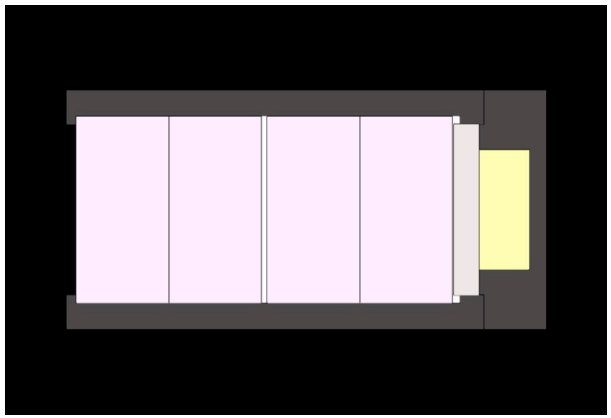
- Barrel Strawman A Components
  - Short strips for outer TIB and TOB layers

Material/Images from Carlo Civinini

New TIB modules: 1/5 length
(Iguana view)



New TOB modules: 1/4 length
(Iguana view)

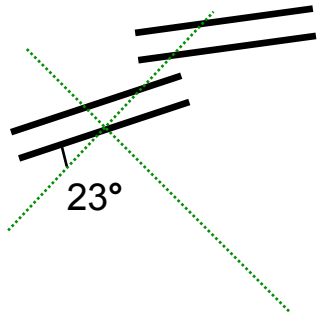


  - Strixels for inner TIB and TOB layers
    - Strixel 1 and 2 (ex-TIB) with 100μm x 600μm strixel size
    - Strixel 3 and 4 (ex-TOB) with 100μm x 1200μm strixel size
  - Short strips and Strixels differ in that Strixels are implemented as "pixel layers", and the track reco packages treat "pixel" and "strips" differently.
- For More information see Carlo's talk at March 13th meeting and our geometry twiki pages (see twiki link on the first slide of this talk)
  - http://indico.cern.ch/conferenceDisplay.py?confId=29558

Strawman B: sensor geometry

Strawman B parameters modified in pixbar.xml and trackerStructureTopology.xml

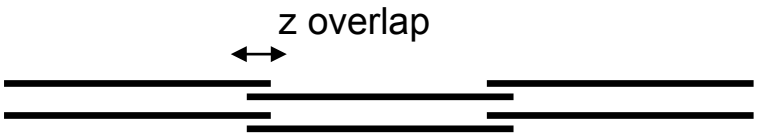
Sensor choice: **tilted at 23°** – to reduce cluster width by minimizing Lorentz drift



100µm thickness

28mm x 72.8cm sensor dimensions

z overlap – to fill gaps in z



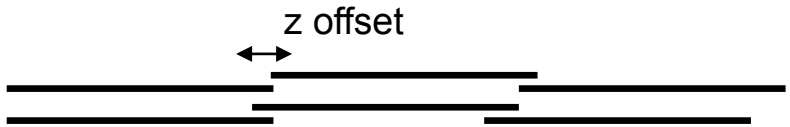
100 µm x 2.37mm pixel pitch

256 x 30 pixels per module

Sensor separation varied between 1-4mm

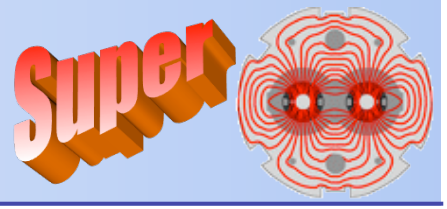
Modification made to geometry to aid trigger studies – not yet part of StrawmanB

z offset – to match columns in top and bottom sensors with increasing eta



M. Pesaresi, Oct. 7th

Strawman B: Trigger Studies



Stacked Layer Digis
[detId, row, column, adc]

adc cut & sorting

$adc_{digi} > 30$

sorted by detId into modules with upper and lower sensors

Sorted Digis
[detId, row, column, adc]

correlation algorithm

hits between upper and lower sensors are correlated to check for high p_t tracks

modifiable search window cuts can be applied

Stubs
[$detId_{high}$, row_{high}, $column_{high}$, adc_{tot}, row difference, column difference, $simTrackId_{high}$, $simTrackId_{low}$]

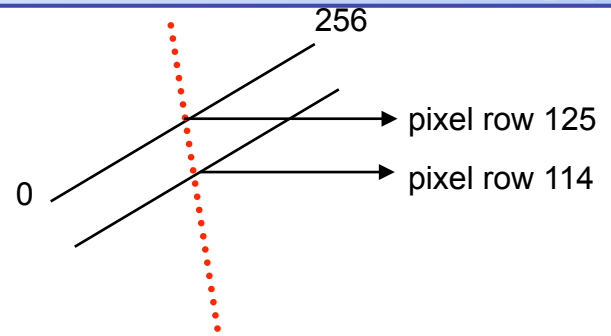
M. Pesaresi, Oct. 7th

Strawman B: Trigger studies

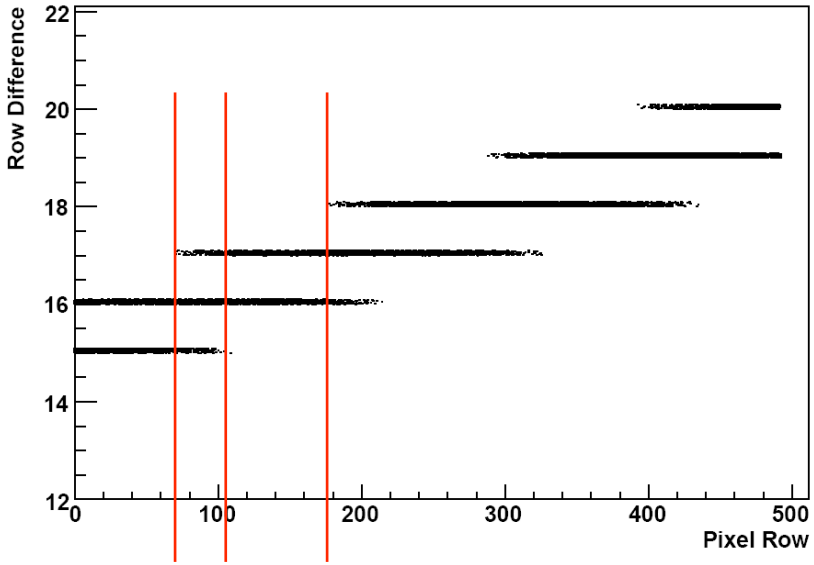
Correlation Algorithm

Row difference calculation

Since the sensors are tilted, there is a difference between the position of the higher and lower sensor hits for a high p_t track which is also dependent on the position of the incident track on the sensor



The fixed offset as a function of the row number can be applied to calculate the true row difference



Equivalent to an on detector map between the hit position on the higher sensor to a set of positions on the lower sensor

Column difference calculation

Column difference is not symmetrical – dependence on whether hit is in detector +/-z. Can be exploited to maximise rate reduction.

M. Pesaresi, Oct. 7th

Trigger studies with Strawman B

Strawman B has been used as the basis to commence trigger studies using a stacked pixel layer at 25cm

- Algorithm to correlate digi hits from high p_t tracks has been written
- Performance of algorithm in ideal conditions measured - ~95% maximum efficiency of detecting high p_t tracks, ~ x100 reduction in data rate

Next step will be to correlate stubs from this layer to those from a layer further out – such as a stacked strip layer at large radius or a stacked pixel layer at mid radius

- Will be possible to then estimate pt resolutions, trigger rates etc

Possible methods of reading out sensor data have been looked at

- Block correlation is successful but needs some refining
- Other methods still need analysing

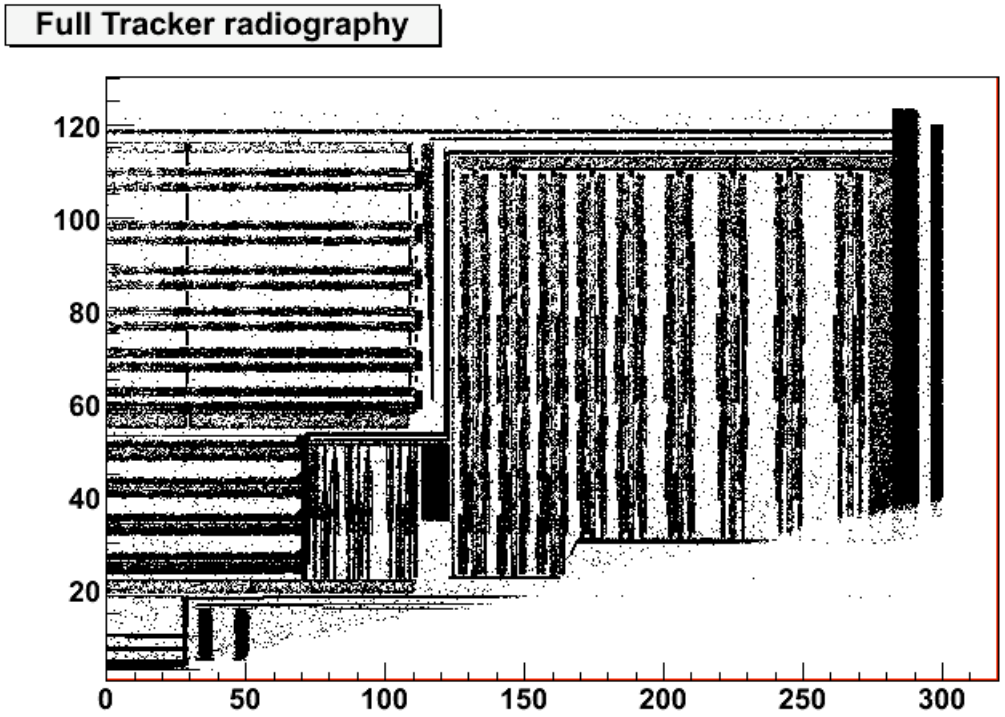
Still plenty to investigate…

- Effect of occupancy on performance
- Effect of changing layer radii
- Effect of changing pixel pitch, short/long pixel strips
- Possibility to extend layers to high eta
- …

M. Pesaresi, Oct. 7th

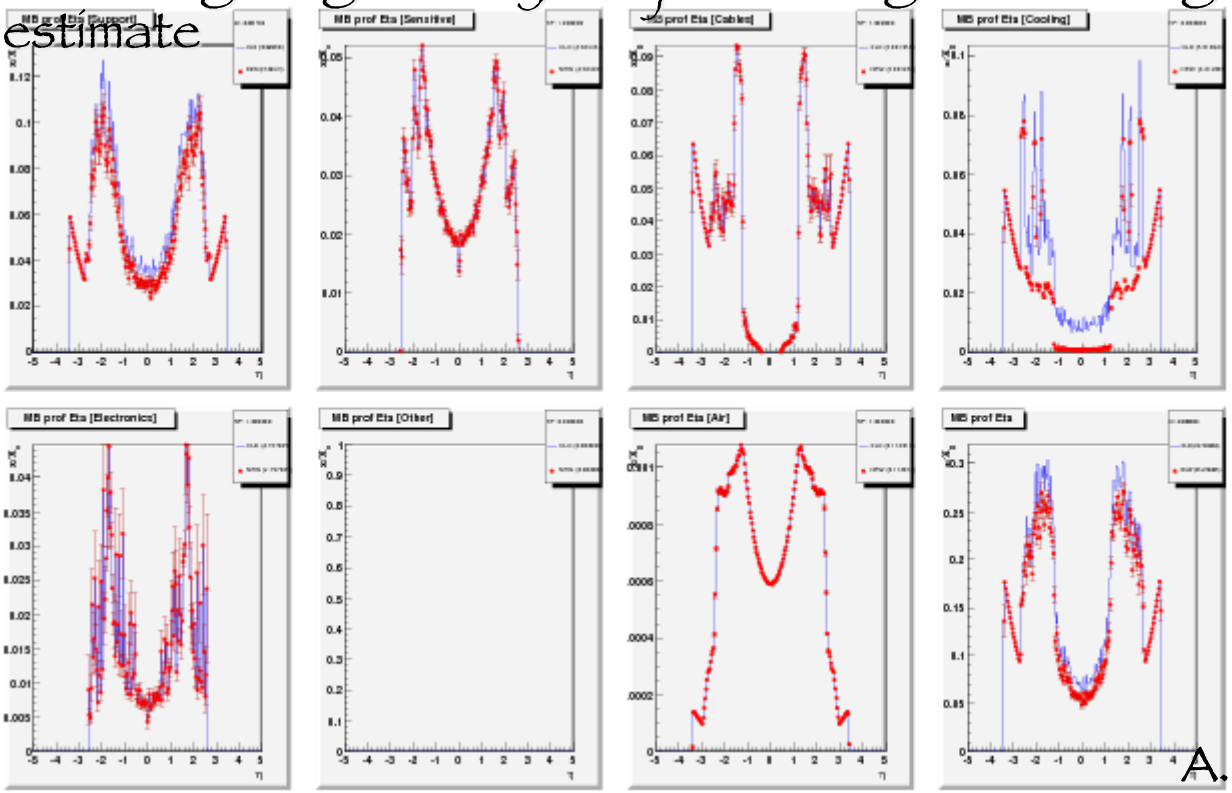
What about endcaps?

- Endcaps need work (no one is addressing them for the time being)
  - Strawman A - several options: add 3rd pixel disks, stay with TID and TEC or replace TID and/or TEC with longer barrel, etc.
  - Strawman B - Longer barrel replaces TID, keep TEC with barrel same length as the TOB



Material Budget

- Project 3-5:
  - Cooling Fluid: C_6F_{14} replace by CO2
  - Cooling Tube: Aluminium replaced by Steel but Mass reduced by ~ a factor 10
    - no change in geometry but just re weight according to Roland's estimate



A. Tricomi, May 2008