Simulation Tools and Studies for CMS Tracker Upgrades at SLHC

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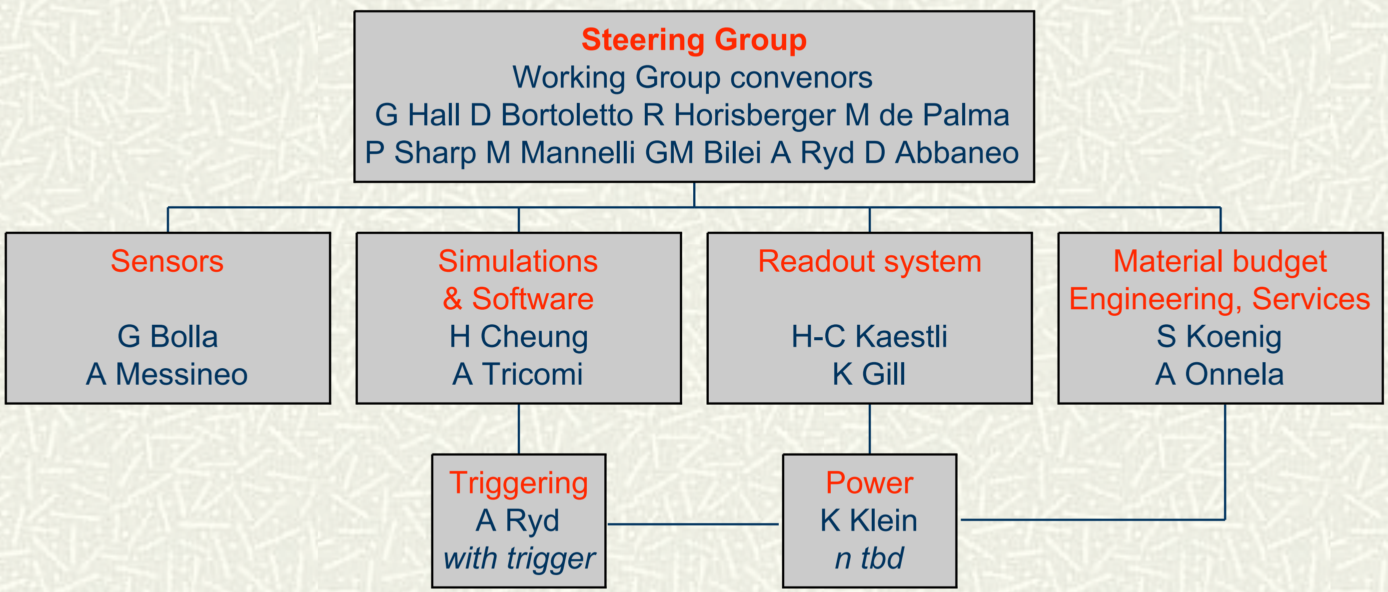
Outline

- Simulation group priorities
- Trigger Layer
- Strawmen A & B, and Long Barrel
- Software Tools in Development
- Conclusions

SLHC Simulations Task

- https://twiki.cern.ch/twiki/bin/view/CMS/SLHCTrackerSimuSoftTools
- Group's Mission is to do the simulations studies to help design a new tracking system
- Coordinators
  - Harry Cheung (FNAL) and Alessia Tricomi (Catania)
- Technical meeting every Monday at 10am [Fermi]
- General meeting every 1-2 months at CERN
- Priorities
  - Perform studies and to provide input to other WG



Current Group Priorities

Simulation Studies

- Studies to see whether a (buildable) trigger doublet would work, how many do we need, where it (they) would go in radius, and what should the pixel doublet parameters be (granularity and separation)? Does the doublet idea work for the forward region?
- Studies for an extra 4th barrel pixel layer (and 3rd pixel disk) for both Phase 1 and 2
- Study if a realistic strawman A has as good tracking performance at high pileup (10^{35}) as the standard CMS geometry at design pileup (10^{34}). Included should be studies of the forward region
- Studies to see if a realistic strawman B has superior features to strawman A at high pileup, and to merge these into a common baseline strawman geometry. Included should be studies of the forward region
- Studies of very long barrel mini-strip or strixel layers
- Studies of Roland's option 1 to 4 for Phase 1.
- Studies to show the tracking performance for the standard CMS geometry at Phase 1 luminosities (2x1034)
- Investigate the effect of other L1 tracking trigger ideas on the tracking system geometry.

Table of Simulation Tasks

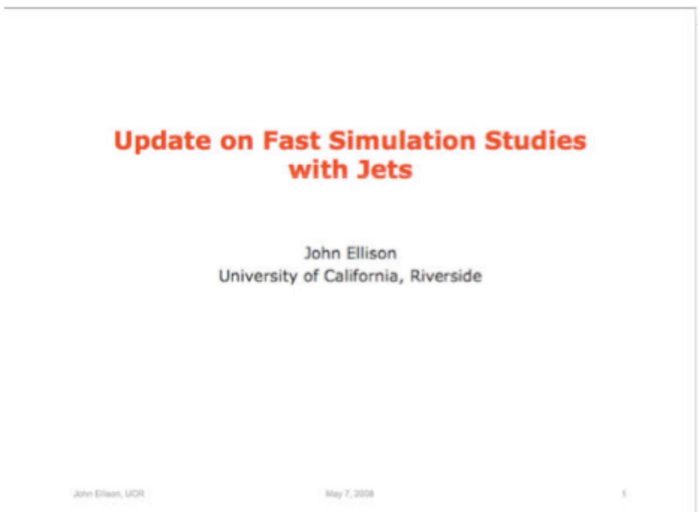
Task	People working on it	Document link
Performance of 1-2 pixel doublet(s) for L1 Muon Trigger	Eric Brownson, Harry Cheung, Mike Weinberger	L1 Muon Track Trigger Studies ?
Performance for an extra 4th inner barrel pixel layer	Carlo Civinini, Kevin Givens, Xingtao Huang, Alessia Tricomi	4th Pixel Layer Studies ?
Tracking performance of strawman A	Carlo Civinini, Alessia Tricomi	Strawman A Studies ?
Tracking performance of strawman B	Mark Pesaresi	Strawman B Studies ?
Tracking performance of long barrel strawman	Mike Weinberger	Long Barrel Studies ?
Study Roland's option 1 to 4 for Phase 1 pixel upgrade	Carlo Civinini, Alessia Tricomi	
Study performance of CMS for Phase 1 luminosity	Carlo Civinini, Mario Galanti, Alessia Tricomi	
Performance of cluster size based L1 tracking trigger	Fabrizio Palla	

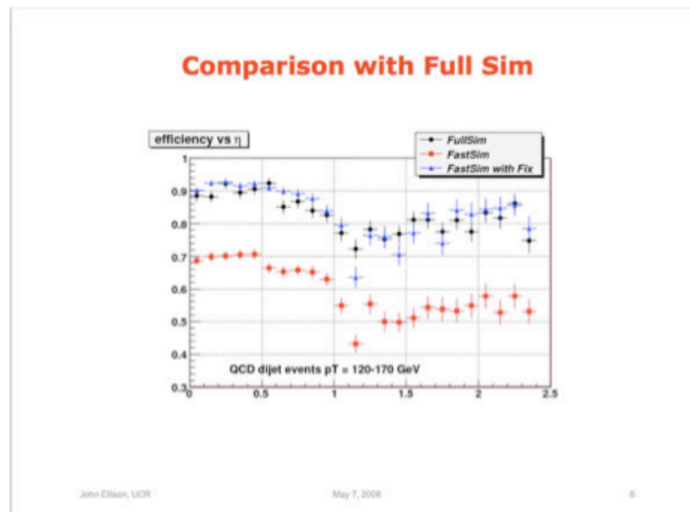
Group Priorities Continued

- Simulation Software and Performance Benchmark Tools
  - Create a set of performance benchmarks or plots for comparisons of tracking and trigger performance for studies of different tracking system geometries
  - Continue to develop code for the two strawman geometries and for the baseline tracking geometry
  - Create interface code for use by the trigger group to create L1 track trigger primitives.
  - Work on making the pileup simulation for the FastSimulation more realistic (e.g. include out-of-time pileup as needed) to address the differences between the FastSimulation and the Geant simulation, e.g. occupancies, fakes rates
  - Work on remaining parts that are needed to simulate in the FastSimulation all the L1 objects that are needed for studies, e.g. ECAL objects

Bug Caught in FastSim

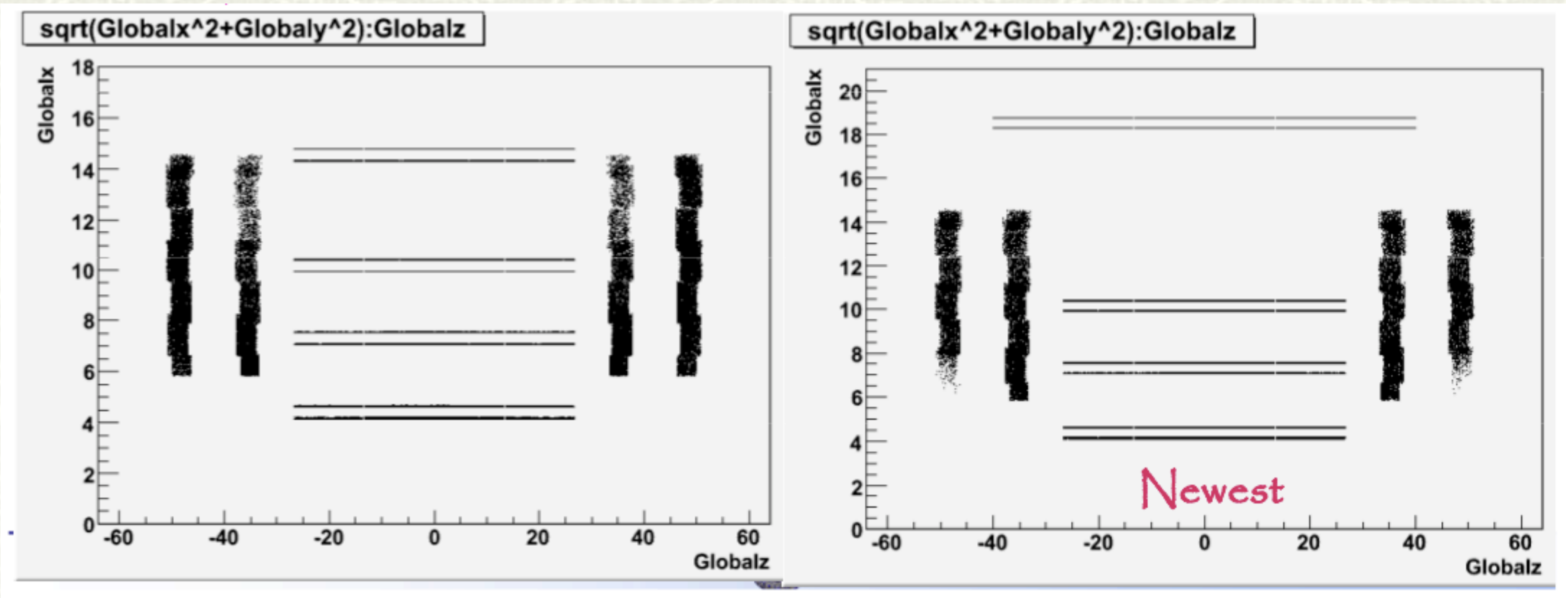
- **Uncovered bug in TrackingParticle collection in FastSim**
  - John Ellison and Avdhesh Chandra interested in tracking efficiency in jets for upgrade, looked at FastSimulation and found a difference compared to Full simulation, presented to a FastSimulation meeting in Mar. 2008 http://indico.cern.ch/conferenceDisplay.py?confId=28534
  - Problem turned out to unstable particles (e.g. Δ^-, $K^*(892)^+$, $\rho(770)^+$, Δ^{++}, Σ^-) were included in the TrackingParticle collection for FastSim affecting the MultiTrackValidator for FastSim. Update presented by John at the May 7th tracker upgrade simulation meeting http://indico.cern.ch/conferenceDisplay.py?confId=33117





Strawman0 for Phase 1

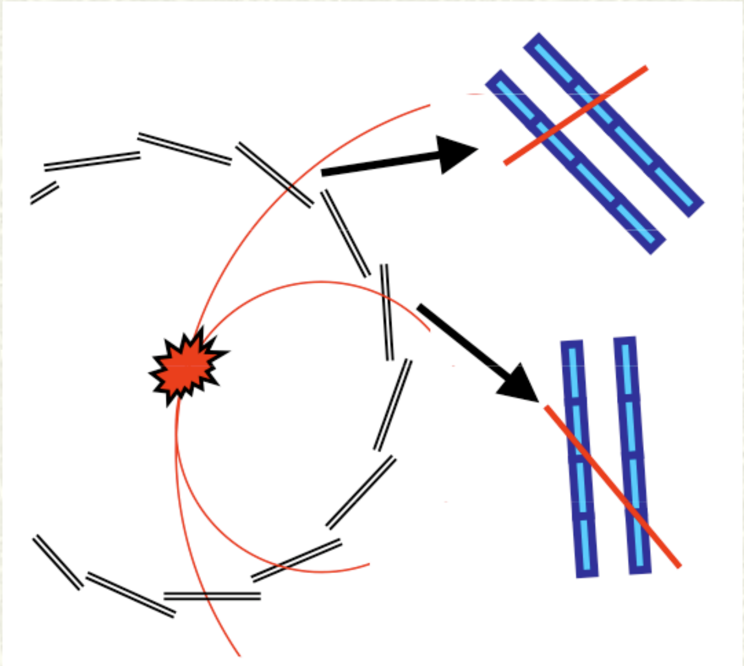
- Carlo Civinini (Firenze), Alessia Tricomi (Catania) Only change is to have 4 inner pixel layers
- No change in the forward pixel disks for the moment
- Original Layer 4 placed at R = 14.5, now moved to 18.5
- Currently being ported to 2_1_X which has the correct materials



Pt Layer for Triggering

- Proposal to allow trigger from Tracker
  - Currently studying for realistic simulations and detectors
- Use geometry of doublet layer hits to cut out low Pt tracks

•Current Strawmen use layer separation of 5mm
•Matching code needs to correct for position of the track in the sensor and tilt of sensor to get matching correct

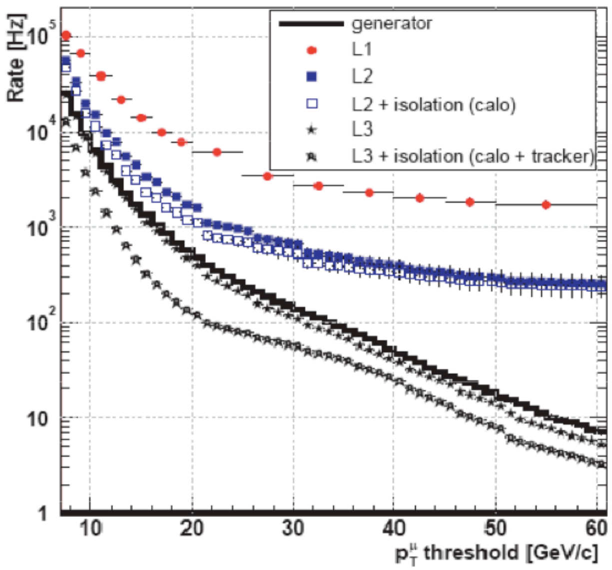


Interface to Trigger

- Working with trigger upgrade group
- Will provide the tracker TPGs to allow testing of SLHC trigger in simulation
- New data formats are in place, code to fill them is currently being written
  - Trigger hit similar to digi
    - Created separately to allow for changes in algorithm
  - Trigger stub
    - Vector of hits in doublet

Muon Trigger Rate

- Using the doublet trigger info to do studies of moun trigger rate
- Currently able to reproduce LHC plot, next step to add in trigger doublet to look at rate reduction



Single-muon trigger rates

Shown for 10^{34} $cm^{-2}s^{-1}$

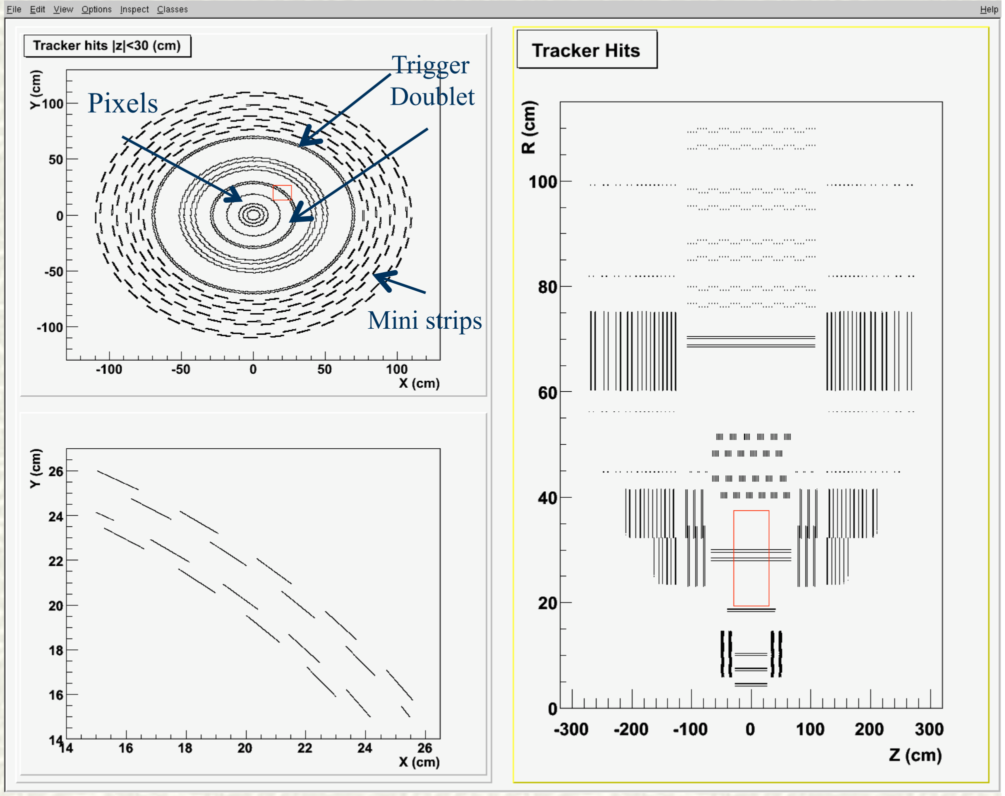
- SLHC → Higher rates
  - Raise P_T^μ threshold → physics loss
  - Add tracking to L1
    - Large rate decrease at L3 with tracking information
    - High-P_T tracks → tracking doublets

Strawman Proposals

- Set up Strawman Geometry as starting point for studies
- Not supposed to be a final proposal, but a framework to allow modifications
- Are ready to be used in Full or Fast Simulation
- Very configurable
  - Size of pixels and strixels
  - Position and number of layers
  - Ladder length, pitch, …
- Instructions on Webpage on how to
  - remove layers
  - add layers
  - add long layers
  - add strip layers with short strip length
- We are encouraging people to use the strawman geometries already set up and the configurability to setup what they want

Strawman A

- Modification of standard geometry
  - 4 inner pixels
  - 2 TIB strixels
  - 2 TIB short strips
  - 2 TOB strixels
  - 4 TOB short strips
- Very configurable
  - Currently being modified to allow for a more reasonable number of channels
- Instructions for CMSSW_1_8_4:
  - https://twiki.cern.ch/twiki/bin/view/CMS/ExampleStrawmanA
- Not realistic due to number of channels
  - Modifications are coming



Use strixels at trigger layer

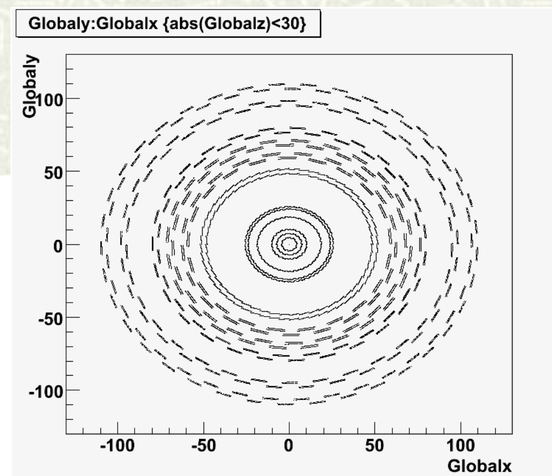
Channels for Strawman A

- Need to reduce number of channels to more realistic amount
  - Reduce trigger doublets radii
  - Reduce mini-strip layers
  - Remove outer trigger doublet
  - Add in standard TOB Stereo layers
  - Third forward disk added
  - Stereo ministrips in TOB 1 & 2

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

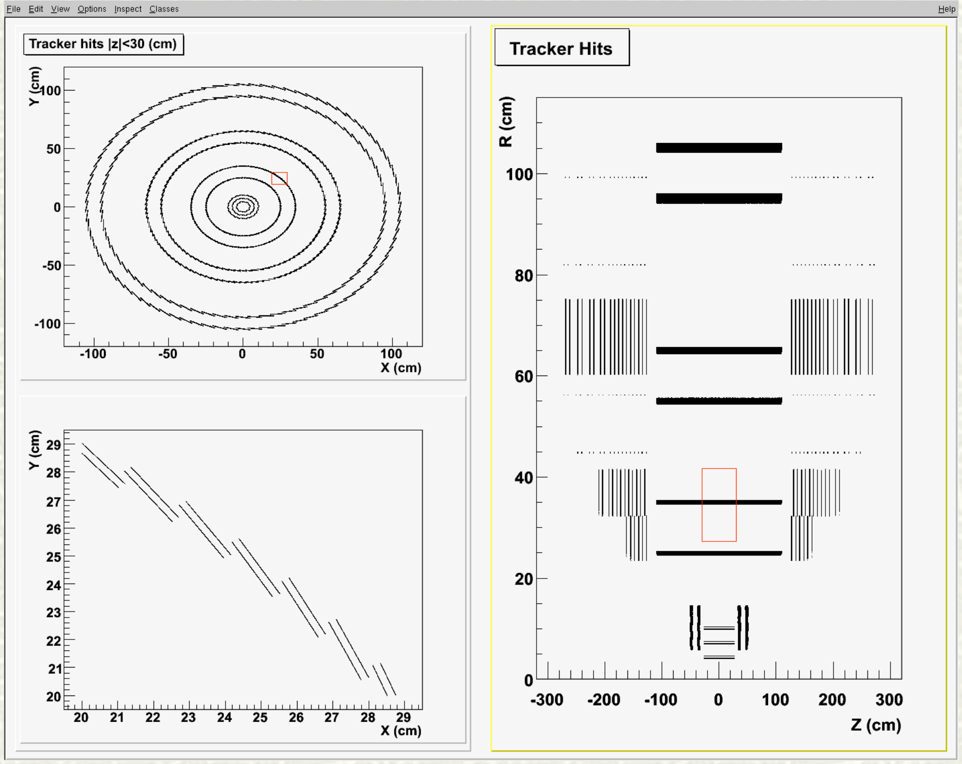
Strawman A	Active Surface [cm2]	ROCs	# channels	modules
Barrel - Pixels (PXB)	251522.3	79552	330936320	24240
Endcap - Pixels (PXF)	2834.4	4320	17971200	672
Barrel - Strips (TIB + TOB)	616886.2	85968	11003904	18132
Endcap - Strips (TID + TEC)	902046.7	34624	4431872	7216

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



StrawmanB

- TIB and TOB replaced with 3 doublet superlayers
- Each superlayer consists of two doublet layers
- Can use correlations within superlayer to make further trigger selections
- https://twiki.cern.ch/twiki/bin/view/CMS/ExampleStrawmanB



Number of StrawB Channels

Layer name	Mean Radius (barrel) [cm] Min. Radius (endcap) [cm]	Max Radius (endcap) [cm]	Layer half-length (barrel) [cm] Mean z position (endcap) [cm]	Sensitive surface [cm2]	# ROCs	# channels
PXB1	4	0	27	1,512	2,304	9,584,640
PXB2	7	0	27	2,519	3,840	15,974,400
PXB3	10	0	110	75,227	81,920	26,214,400
PXB5	35	0	110	105,318	114,688	36,700,160
PXB6	55	0	110	174,288	90,112	28,835,840
PXB7	65	0	110	205,976	106,496	34,078,720
PXB8	95	0	110	308,632	77,824	24,903,680
PXB9	105	0	110	448,457	86,016	27,525,120
	Tot Layer 1-9			1,321,929	563,200	203,816,960
	Tot Layer 4-9			1,317,898	557,056	178,257,920

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
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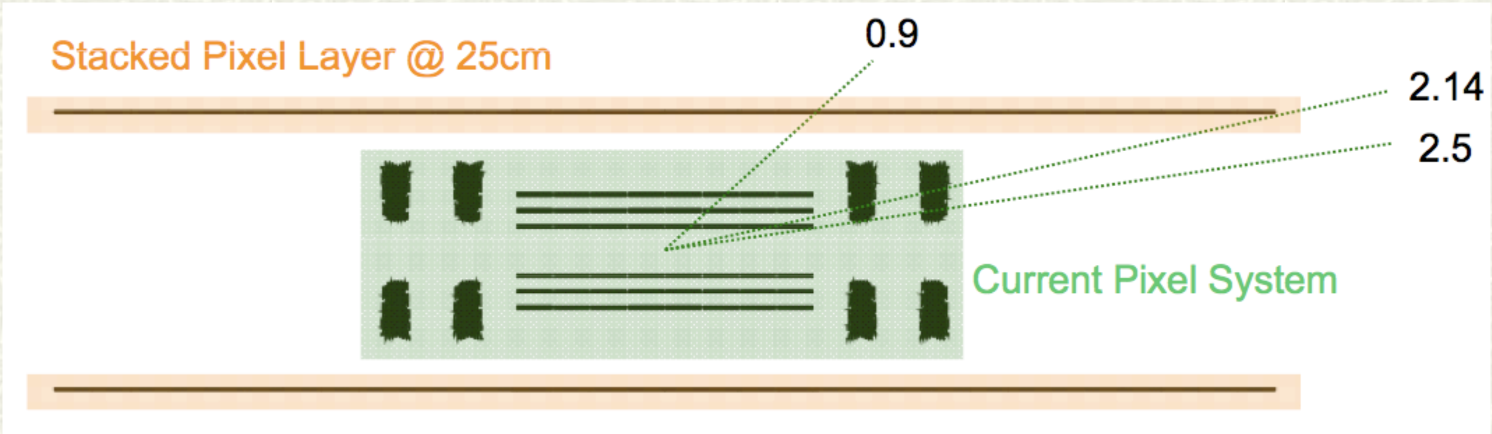
StrawB in single doublet studies

Mark Pesaresi, Imperial College

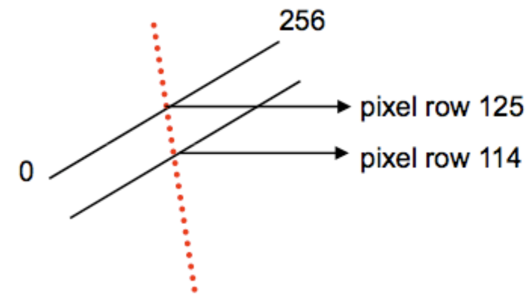
- Use StrawB geomtery as a starting point to study single doublet layer for trigger
- Single layer at r=25cm, length=221cm
- Ignore outer geometry for now



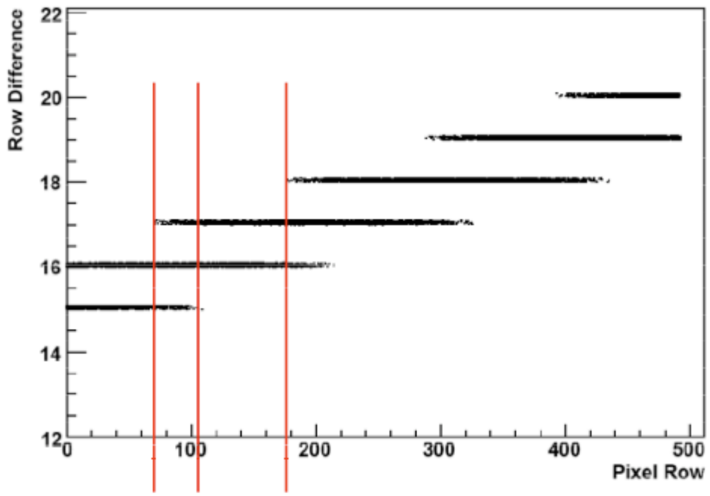
Correlation Calculation

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

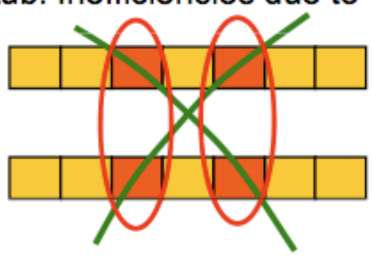
Column difference is not symmetrical – dependence on whether hit is in detector +/-z. Can be exploited to maximise rate reduction.

Algo Performance

Separation [mm]	Max Efficiency [%]	Fake [%]	Reduction Factor
1.0	99.35	4.14	22.26
2.0	97.745	17.83	95.99
3.0	96.00	39.08	210.28
4.0	92.95	47.27	254.35

Performance of a detector stack at r=25cm for sensors with pitch 100µmx2.37mm.
Correlation cuts optimised for high efficiency

Max Efficiency: Average maximum efficiency for a high p_t track to form a stub. Inefficiencies due to sensor doublet acceptances and algorithmic efficiency (window cuts)



Fake: Average fraction of stubs per event generated by correlating hits from different tracks

Reduction Factor: Average data rate reduction factor per event (N_{Stubs} / N_{Digis}) where N_{Digis} is number of hits with charge $>adc_{digi}$ for the whole stacked layer

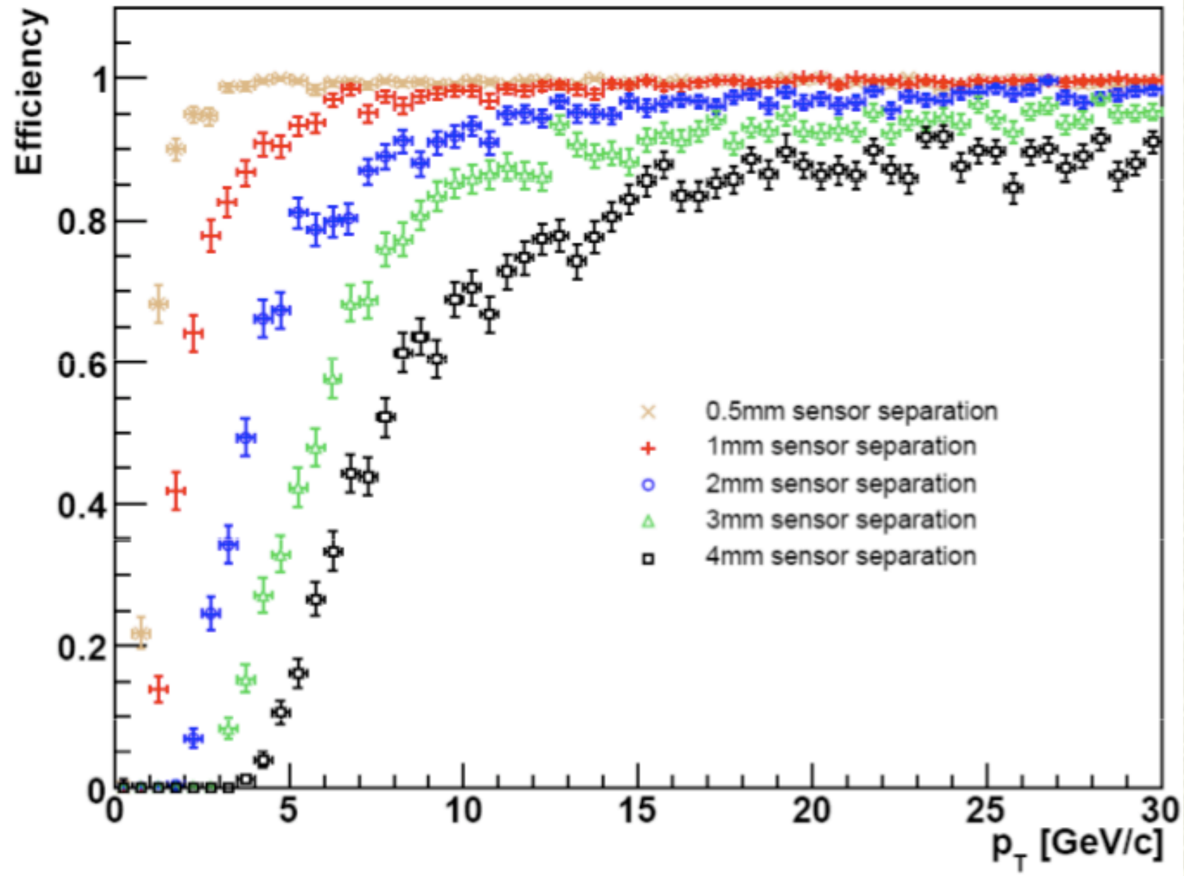
Separation Efficiency

Sensor separation is again an effective cut on p_t – as with the stacked strips

Again, the width of the transition region increases with separation. Due to:

- pixel pitch
- sensor thickness
- charge sharing
- track impact point

Efficiencies decrease with sensor separation due to the larger column window cuts – sensor acceptances and fake containment are issues



p_T discriminating performance of a stacked layer at r=25cm for various sensor separations using 10,000 di-muon events with smearing

Cuts optimised for high efficiency:

Row window = 2 pixels

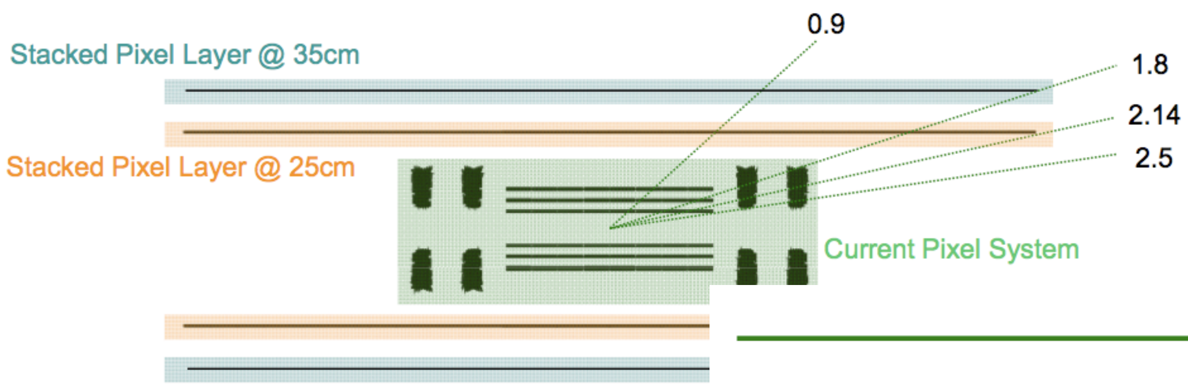
Column window = 2 pixels @ 0.5mm; 3 pixels @ 1mm, 2mm; 4 pixels @ 3mm; 6 pixels @ 4mm

Considering now two stacked pixel layers at: r=25cm, length=221cm
r=35cm, length=221cm

Current pixel system included in geometry

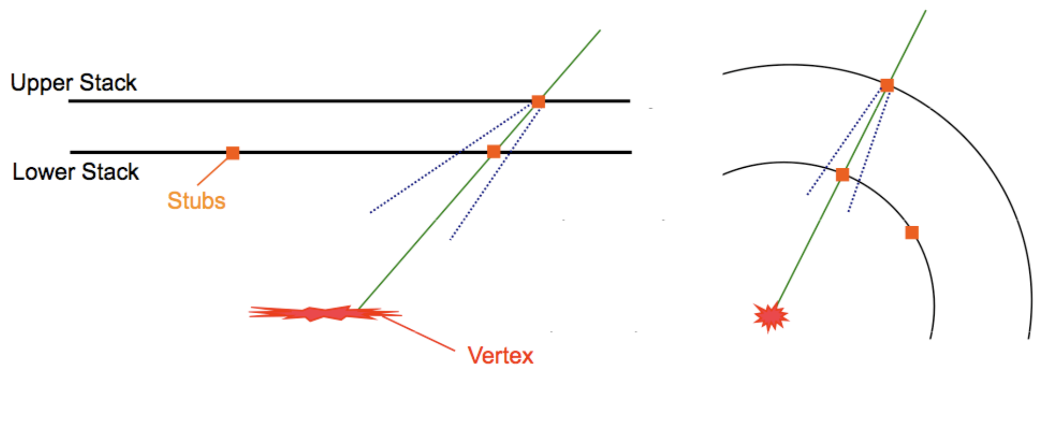
Outer geometry unnecessary at this point

Using same sensor geometry for each layer



Double Stack Correlation Algorithm

Correlate stubs in upper sensor with stubs in lower sensor – use upper sensor as seed (fewer stubs, fewer fakes)



Window cut in η applied – wide enough to allow for vertex smearing

Window cut in ϕ applied – wide enough to allow for low p_t tracks and scattering

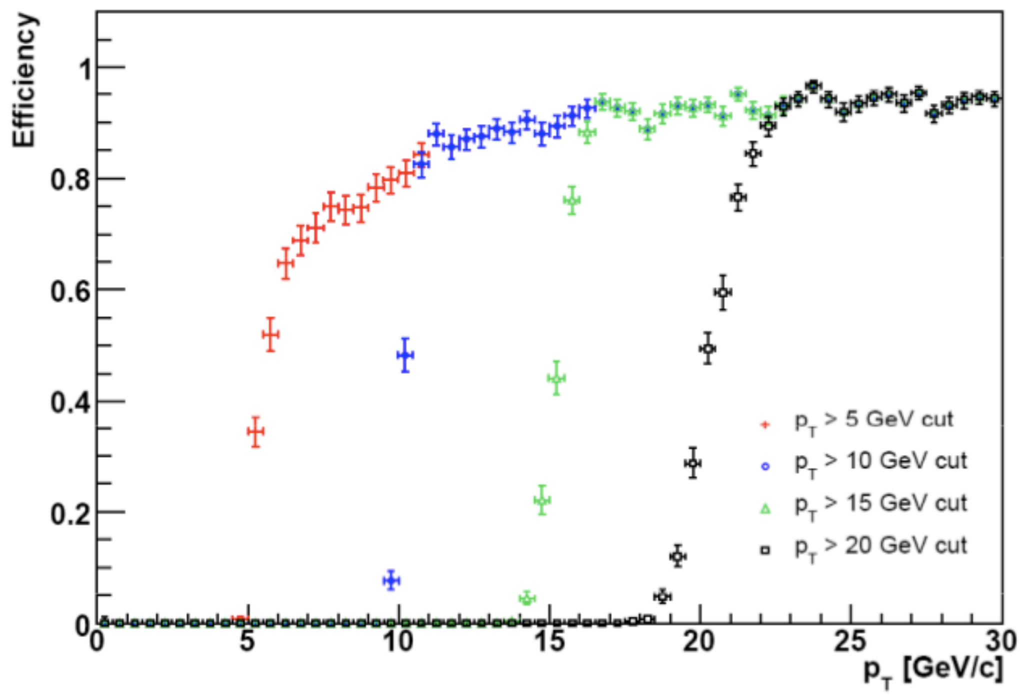
Double Stack Algorithm Performance

With a momentum measurement using two stacks, an effective cut on track p_t can be placed

Maximum efficiency is still determined by that of the single stack

A better track pt resolution using the double stack means that the transition region can be reduced

We would like to have better efficiencies at low p_t – this would require stacks with smaller sensor separations (or larger windows) increasing the number of stubs per layer and the number of combinatorics for the double stack algorithm

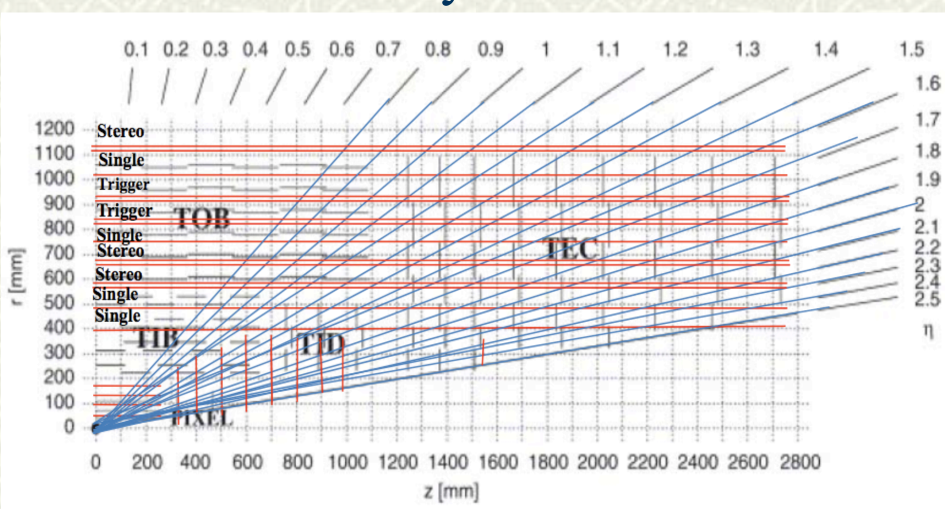


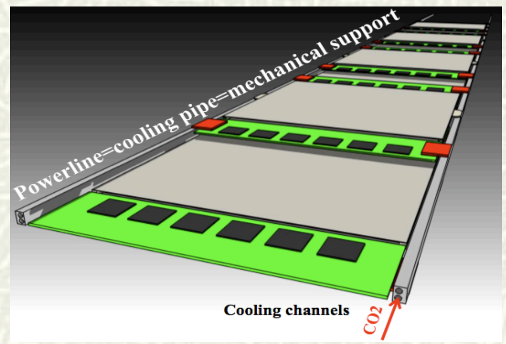
p_T discriminating performance using double stacks for 10,000 0-30GeV di-muon events with smearing

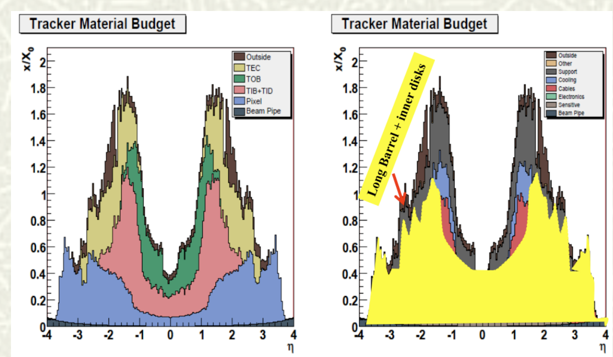
Using double stack correlation window cuts
$|\Delta\eta| < 0.2$, $|\Delta\phi| < 0.015$

Long Barrel Strawman

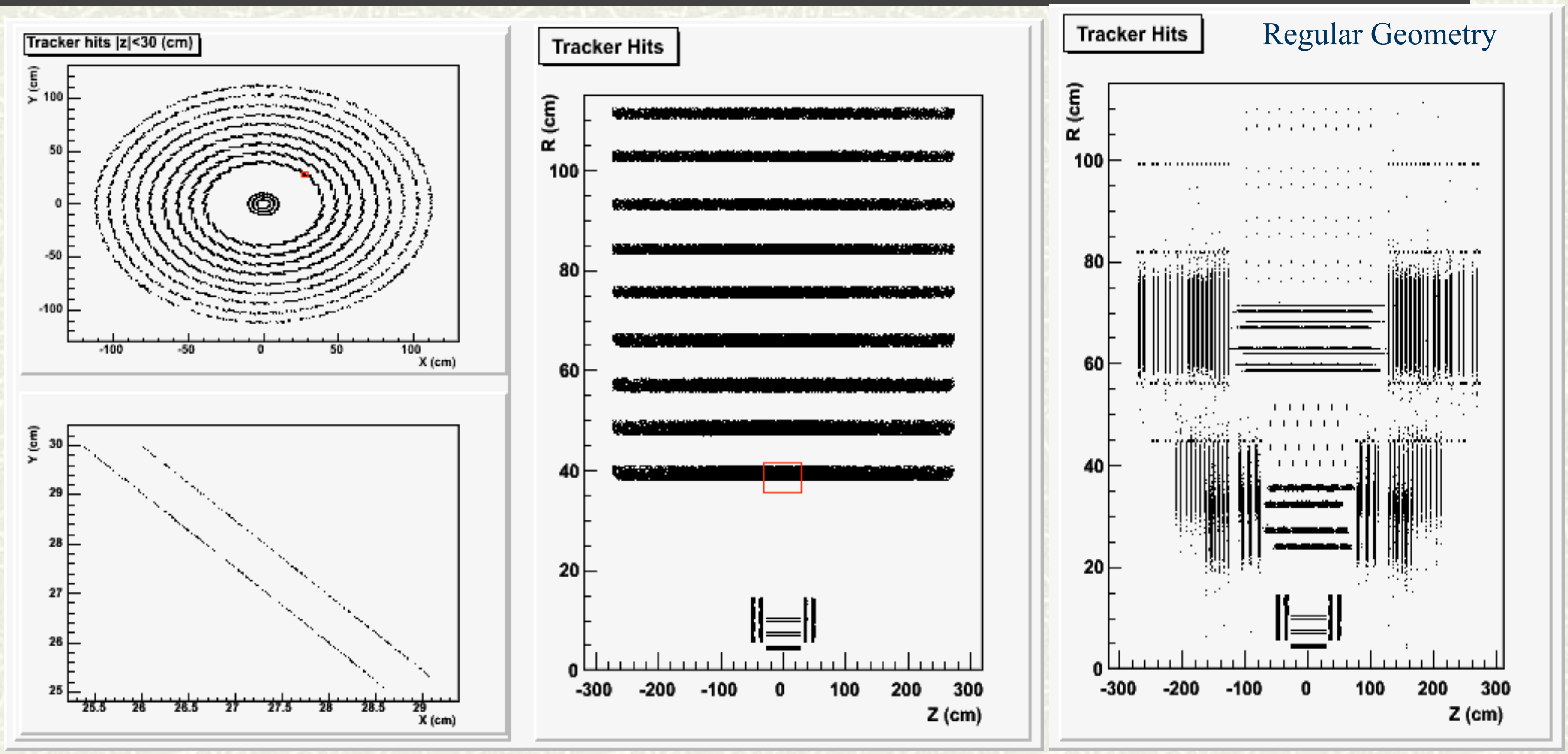
- Another possibility is a long barrel proposal from Karlsruhe
- Use CO_2 cooling, allowing for replacement of TEC with barrel
  - Physical long ladder already built and functioning
- Eliminates material as no longer have endcap support
- Only recently started setting up simulation, so not publicly available yet







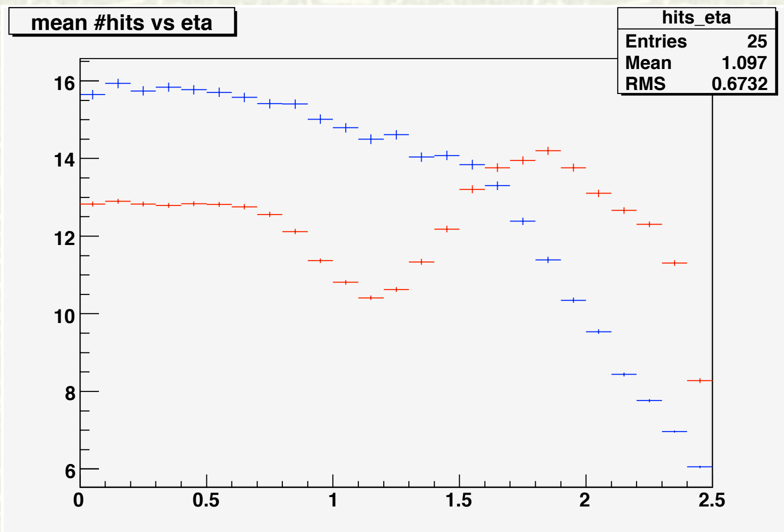
Layout vs Regular Geometry

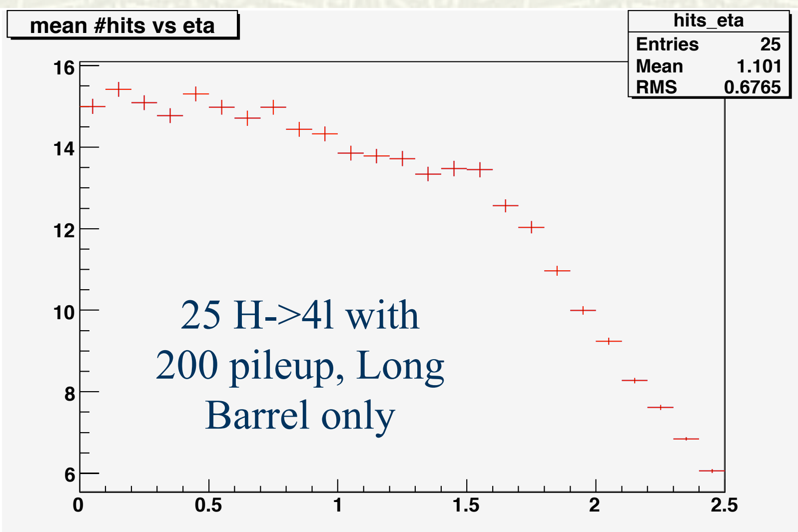


- Still need to add single layers, and stereo
- also extra TID disks

Number of Hits vs. Eta

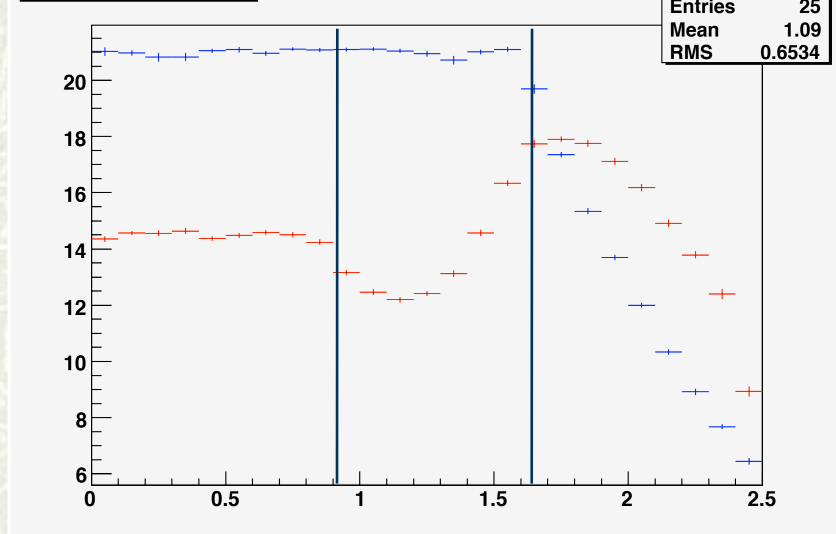
1k H->4l with 5 pileup





End of reg barrel

End of Long barrel



5k single muon 0-100 GeV

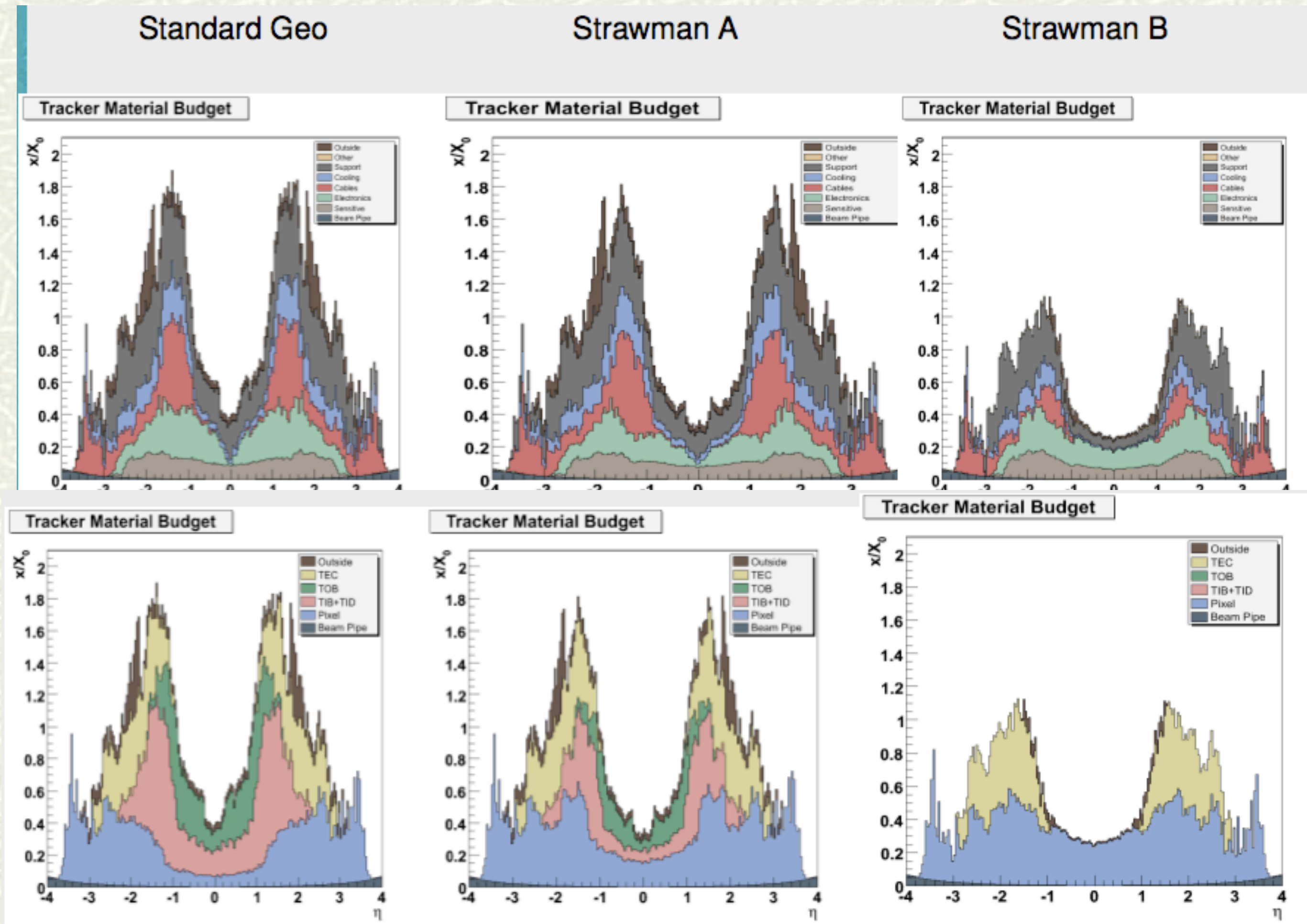
Red = stdGeom
Blue = LongBarrel

Software Tools

- In addition to the strawman simulations, the group is also creating software tools to allow testing and comparison of different geometries
- Most are in development stages, but will be released soon
- Keep checking the Twiki page for more progress

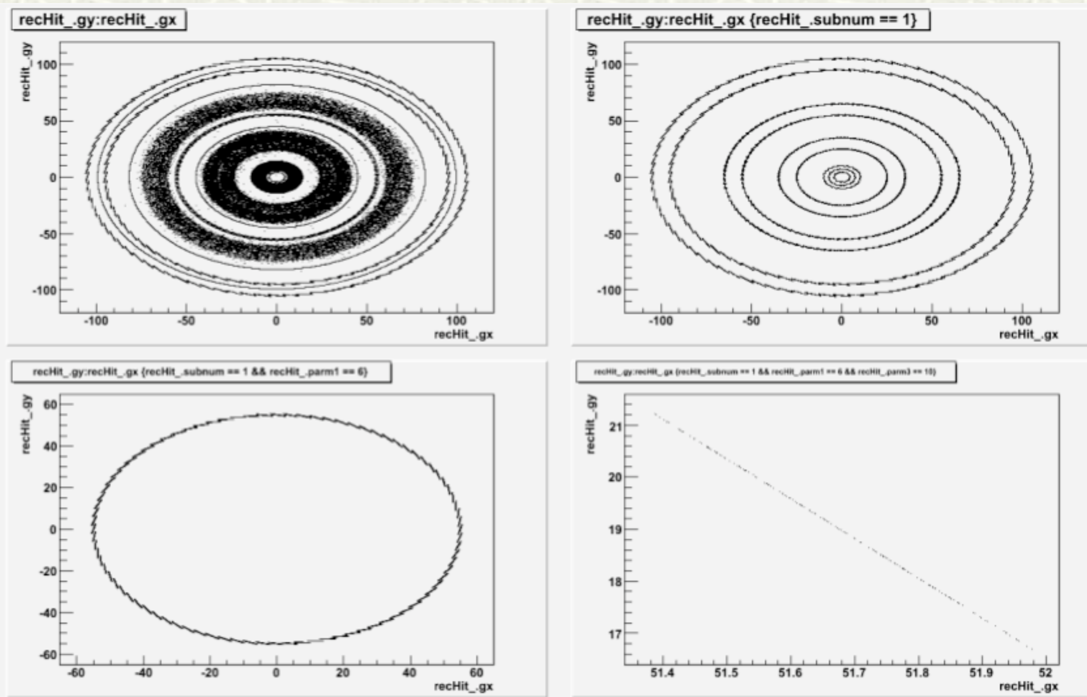
Material Budget [Kevin Givens]

- Comparisons of regular, StrawA and StrawB geometries



Geometry Validator

- Allow for ease of validation with low level quantities
  - Hits, Tracks, MCTruth
- Looks at Rechits organized into subdetector, layers, position
- Use root macros to explore the geometry



Using Jets for Validation

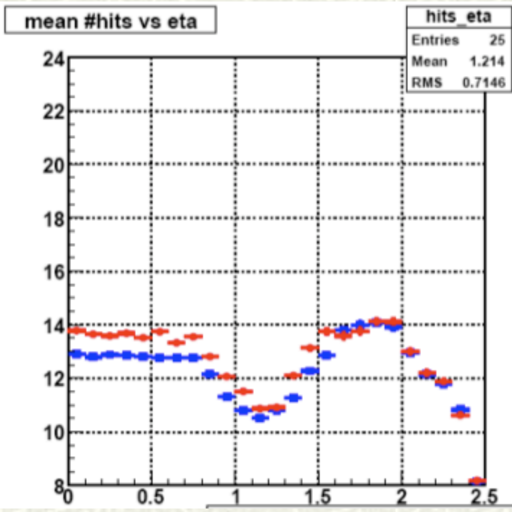
- Avdhesh Chandra and John Ellison
- Using the TrackValHistPublisher.C, which gets the plots from the MultiTrackValidator to make sets of plots, and compares two runs [or two geometries]
- Currently using Full sim and no pileup
- Looks at:
  - Efficiency and fake rates
  - Number of hits and tracks
  - Number of reco, sim and associated tracks
  - Track parameter resolutions
  - Track parameter pulls
  - Track chi-squared
- Working on adding in StrawB to studies
  - Seeing comparable results as from StrawA

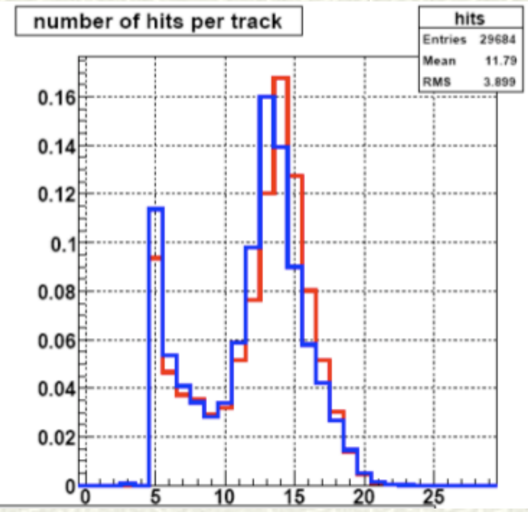
Jet Tracking Plots

- QCD dijet events
  - p_T = 120 – 170 GeV
  - $|\eta| < 2.5$

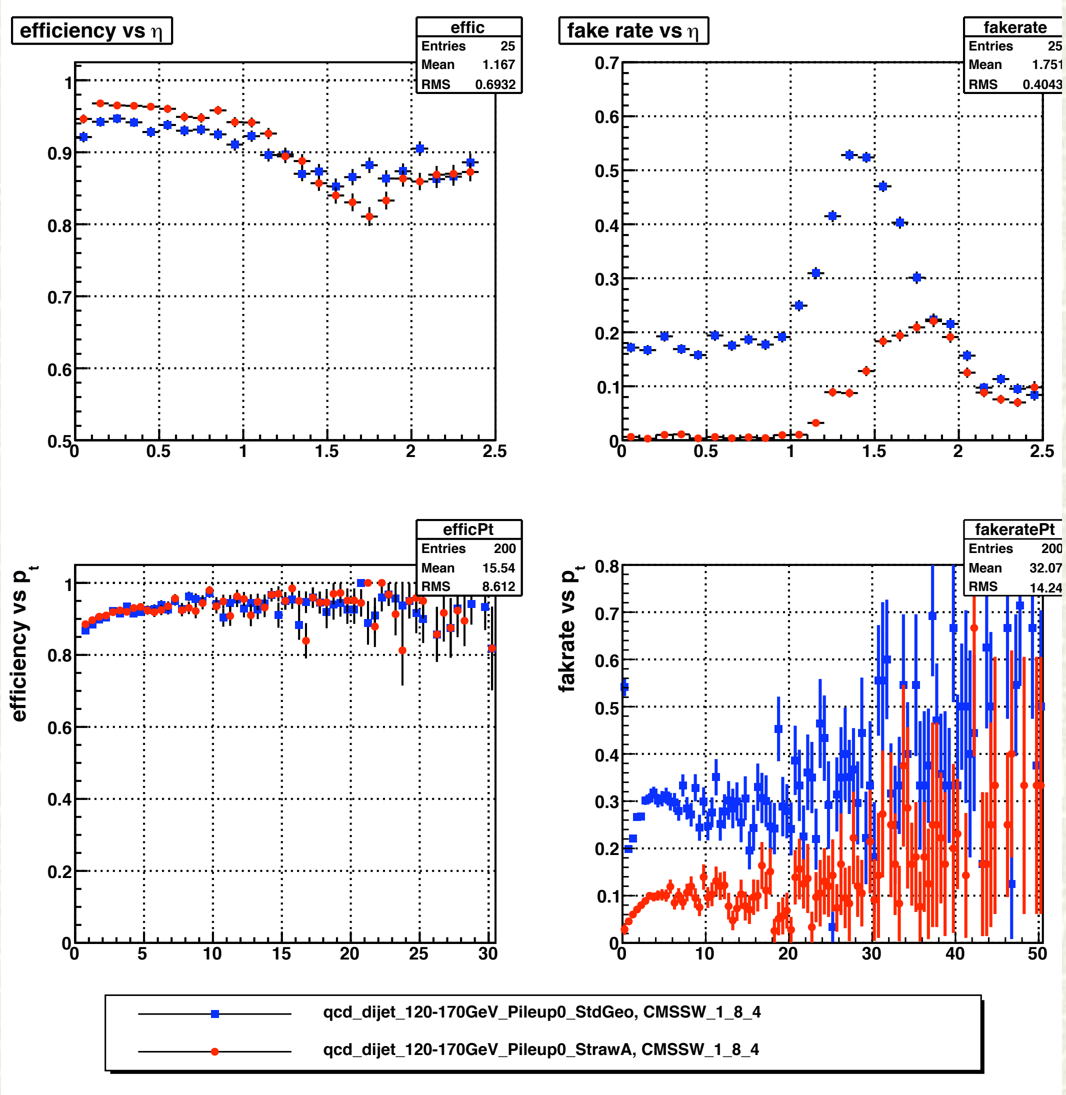
Blue = Std Geo

Red = Strawman A





Efficiencies and Fake Rates

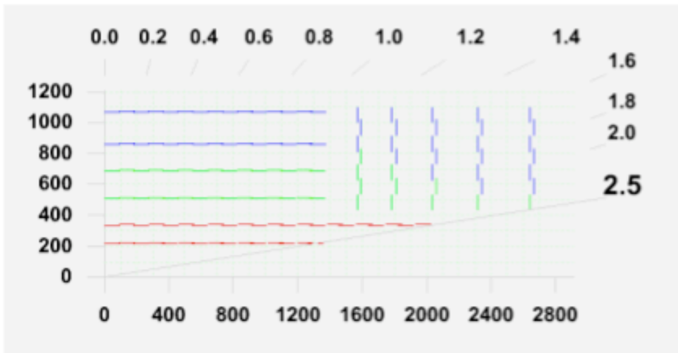


Blue = Standard

Red = StrawA

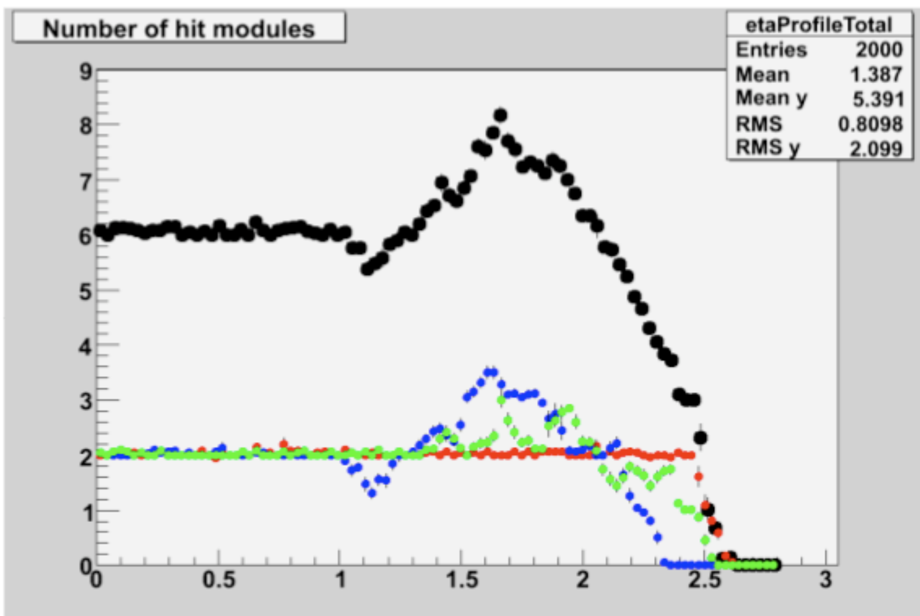
- Reason for lower fake rates is still being explored
- Due to less reco tracks in event
- Also seen in preliminary StrawB studies

Standalone Geometry Tool



Example of layout - Features:

+ Keep EC "above" barrel (with some clearance)
- Non optimal coverage close to η = 2.5
+ Possibly an option to route service of the Pt layers out of the η acceptance
+ One type of Pt module only
- Inefficient use of Pt modules (→more channels, power, money…)
- Likely one structural cylinder between Pt and strips



Instructions

Further developments

Completed:

• Graphical User Interface to select detector types on a given geometry (N. De Maio). Instructions for installation and use at
http://code.google.com/p/tkgeometry/wiki/GUIQuickStart

Ongoing:

• Generate a (small) set of inactive volumes matching any of the geometries studied
Through configurable functions, attribute to active and inactive volumes a mass that accounts for electronics, cooling, mechanics etc... starting from the present Tracker to derive appropriate parameterizations.

To start asap:

• Translate the generated geometries (active and inactive volumes) in a format that can be used (easily, or even automatically?) as input for the detector simulation

More infos and details about the material presented at
http://abbaneo.web.cern.ch/abbaneo/tkgeometry/summaries/

Summary

- A extensive effort by a relatively small number of people over the last year has allowed rapid progress to be made
- More people have joined the group, but most are part time. Always need more people to help out
- Two strawmen are ready for testing [with long barrel ~1 month]
  - Also studies of Phase 1 studies with Strawman0 are being performed
- Stand alone testing suites for geometry and tracking are being worked on and will be ready soon