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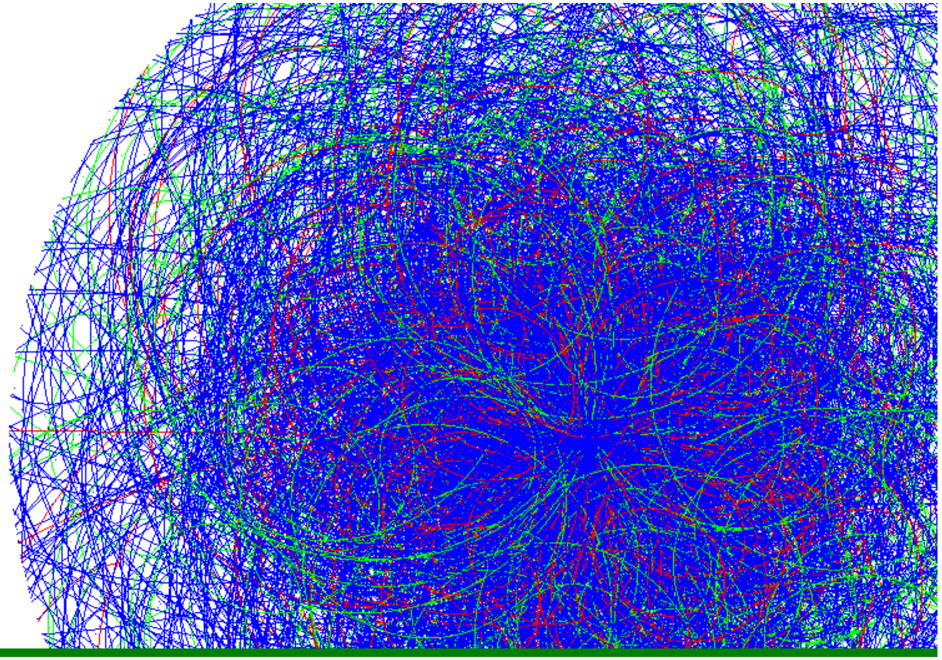

# CMS L1 Tracking Trigger Simulations

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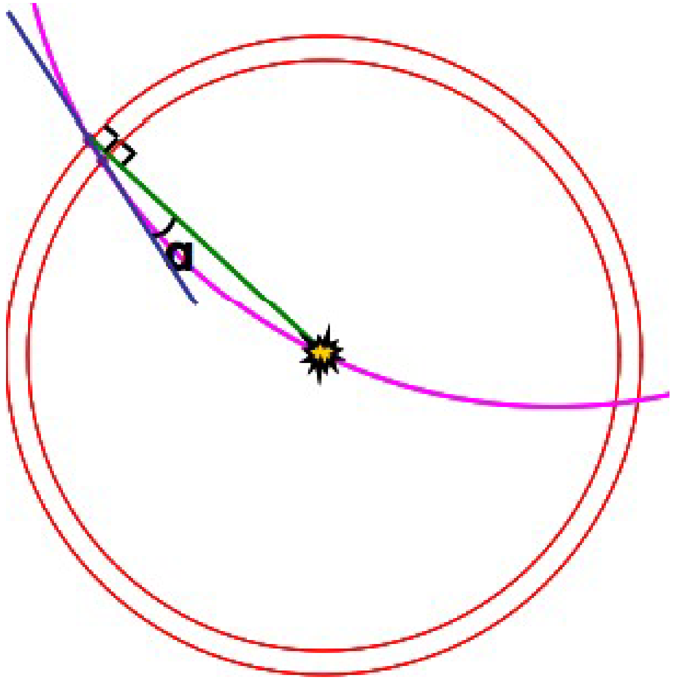
# Stacked Tracking Trigger

**Idea is to correlate hits between closely separated pixel sensors using a simple matching algorithm**

**Correlated hits can provide an effective geometrical cut on track transverse momentum and reduce the detector data rate**

**Implementing multiple stacks of pixels sensors, operating in the same fashion, allows for effective track reconstruction if their correlated hits can be combined**

**Alternative tracking trigger approach using cluster width discrimination and associative memories is not discussed here**




**Feasibility of the stacked tracking trigger requires realistic simulations of layers of stacked pixel sensors**

J. Jones, C. Foudas, A. Rose

- *A Study of a Tracking Trigger at First Level for CMS at SLHC*
- *Stacked Tracking for CMS at Super-LHC*

**A layer of stacked pixel sensors has been implemented within CMS simulation software**

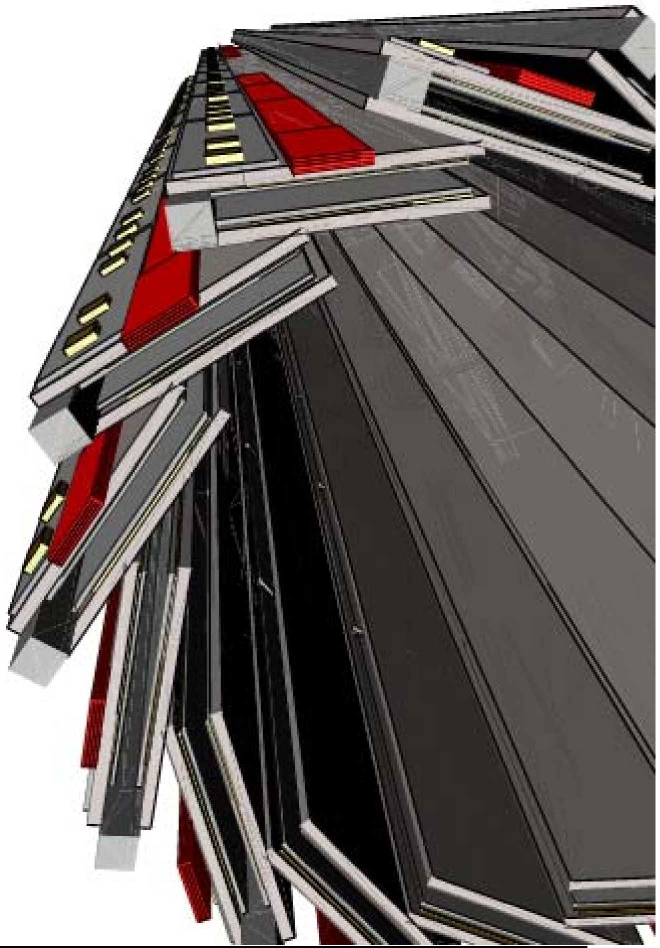
**The stacked layer is:**

- **configurable** – parameters such as layer radius, layer length, sensor separation, sensor thickness, sensor pitch etc can be modified easily to vary the performance of the trigger layer

- **realistic** – preliminary conceptual construction is realistic with regards to material added to the detector (extrapolated from current pixel system)

    - includes provisions for cabling, cooling and structural support

    - all material effects, interactions etc simulated fully using GEANT



# Constraints

**Huge parameter space to explore. What do we need from a tracking trigger built from stacked pixel layers?**

**Electron trigger – a hit validating a calorimeter projection**

- ideally close to the vertex - low brem probability
- an extra hit near the calorimeter could reduce fakes from pileup / identify photons

**Muon trigger – a hit in an ηϕ window which can be matched to a muon system object**

**Jet trigger – information/identification of jets (position, density of tracks)**

- requires triggering of tracks with $p_t > 2$ GeV at least for track isolation cuts

**Vertexing – identify primary vertex**

**Coverage – full coverage in η up to |η|<2.5**

# Constraints

**But we need to keep in mind:**

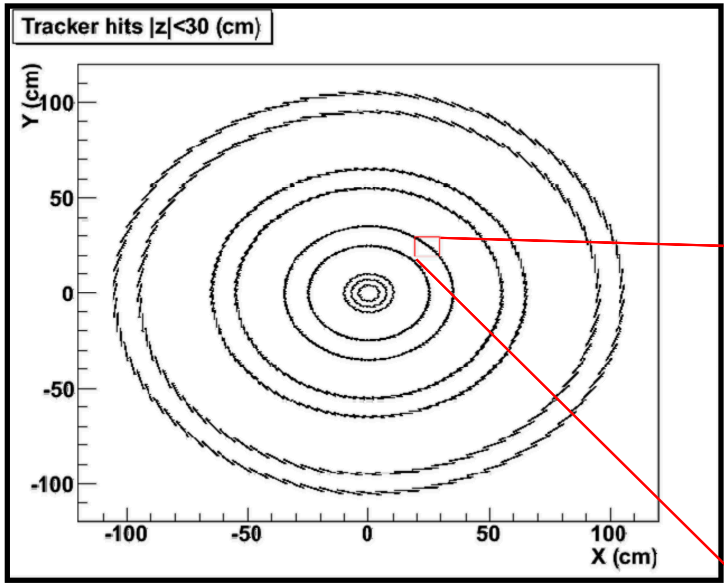
- **Power**
- **Material**
- **Effect on tracking performance**
- **Trigger readout rates**
- **Cost**
- **Simplicity**

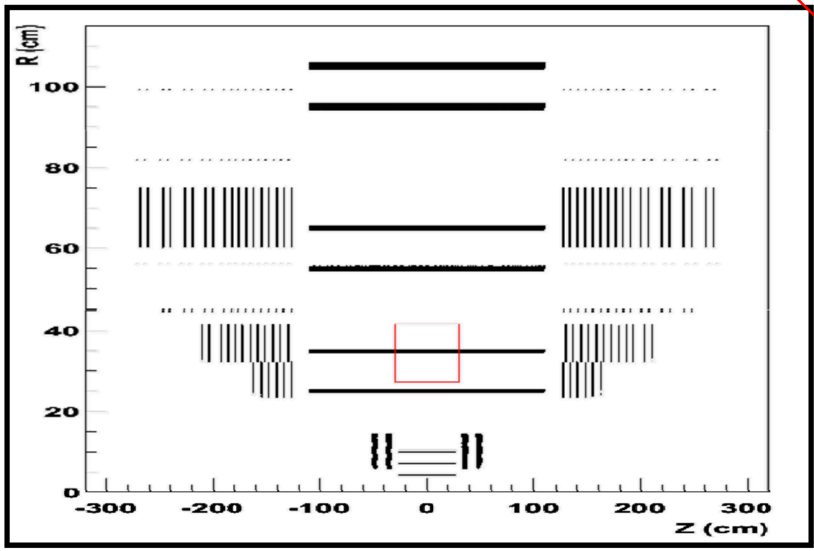
**e.g.**

**Can we afford (cost/power/simplicity) to have trigger layers in the outer tracker?**
**What about coverage at $|\eta|>0.9$?**

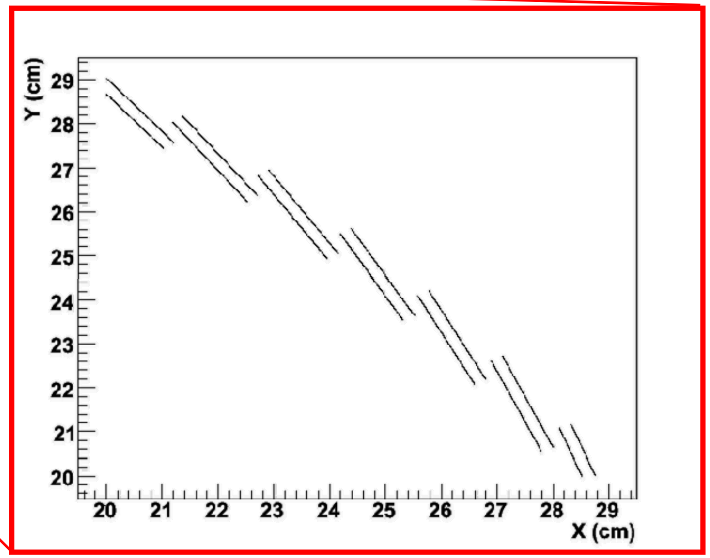
**What $p_t$ can we afford to cut at – dependent on data rates & power requirements of link choice, sensor readout and correlation/module architecture**

# Simulation Geometries




**Selection of concept geometries are being built, some using stacked pixel layers, and are being used in simulations**

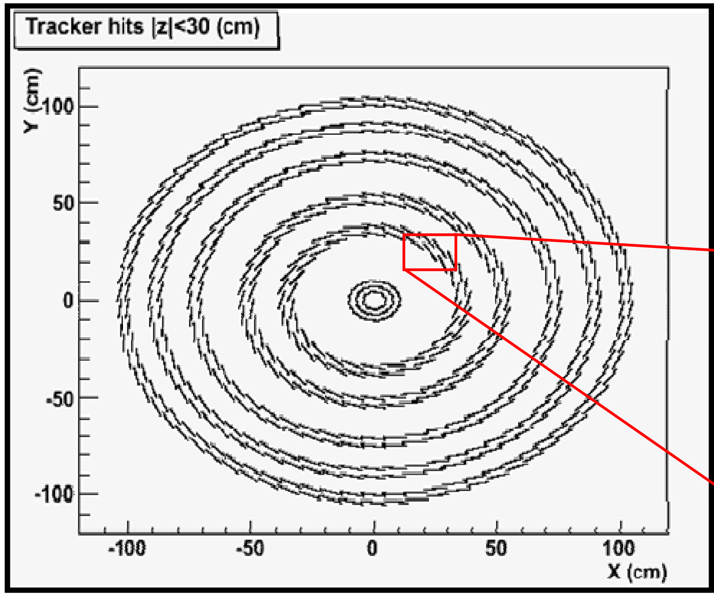



- 3 pixel barrel layers and 2 pixel disk endcaps (as in current pixel detector system)

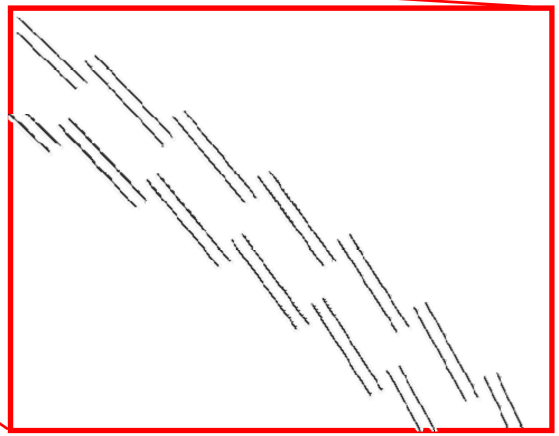
- 6 stacked pixel layers at varying radii (limited coverage for triggering)

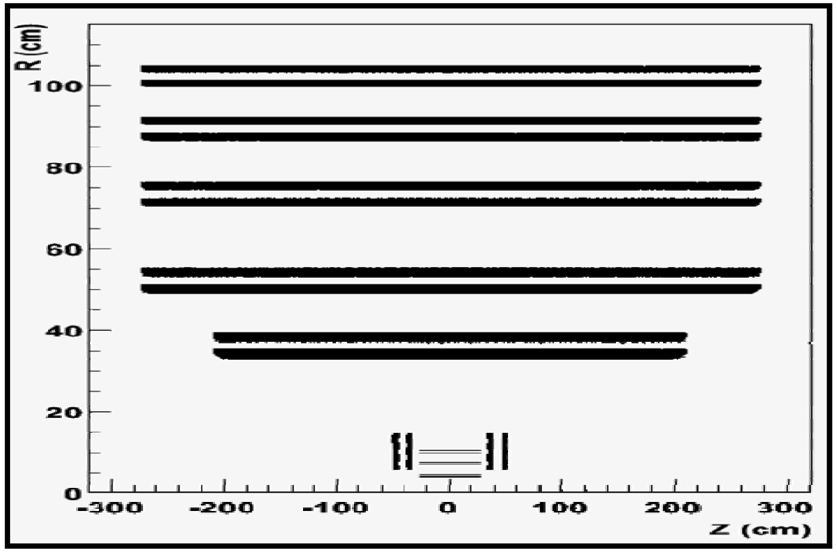
- Silicon strip endcaps providing full coverage for tracking

# Simulation Geometries



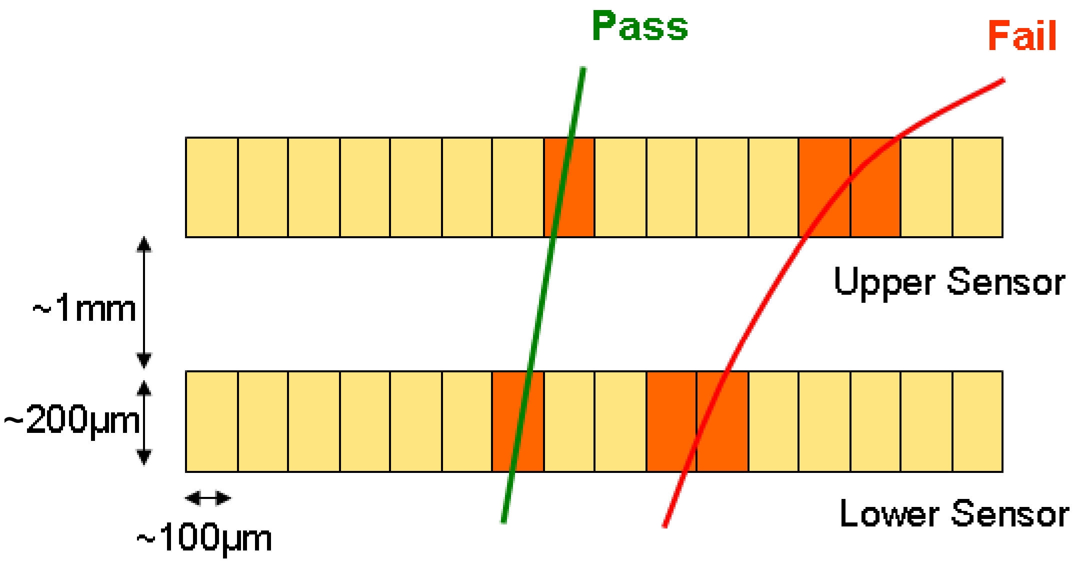

**Another example….**





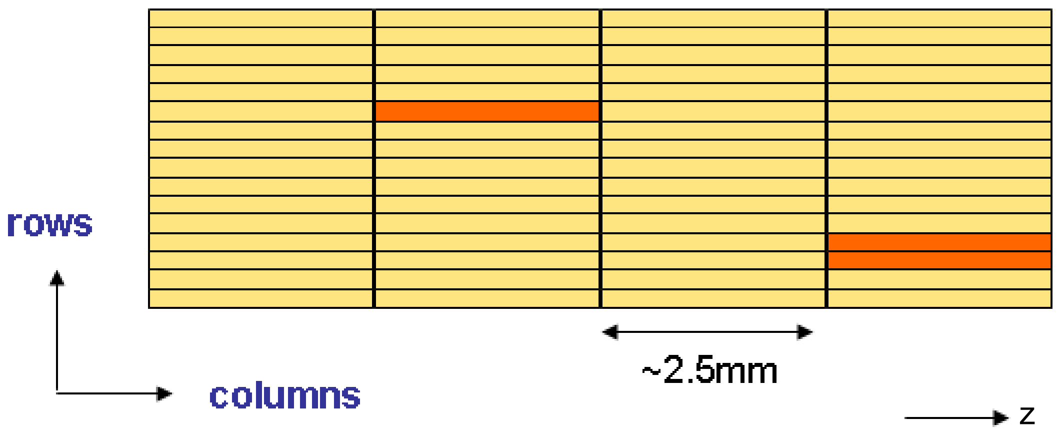

- 3 pixel barrel layers and 2 pixel disk endcaps (as in current pixel detector system)
- 10 stacked pixel layers, arranged in pairs, at varying radii (full coverage for tracking and triggering)

# Correlation Algorithm




**Comparison between hit pixels on upper and lower sensors**

- **Assume binary readout**
- **High $p_t$ tracks can be identified if hits lie within a search window in r-$\phi$ (rows)**

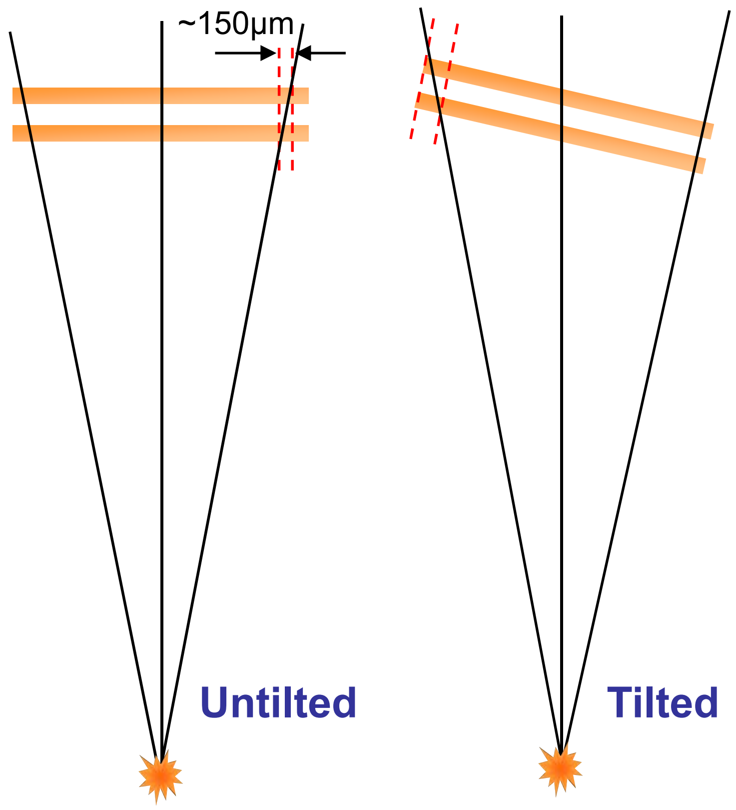



Sensor separation and search window determines $p_t$ cut

Row pitch affects $p_t$ resolution but is constrained by power/granularity and alignment issues

Column length is constrained by the size of the luminous region and search window in z

# Correlation Algorithm




**r-ϕ view**

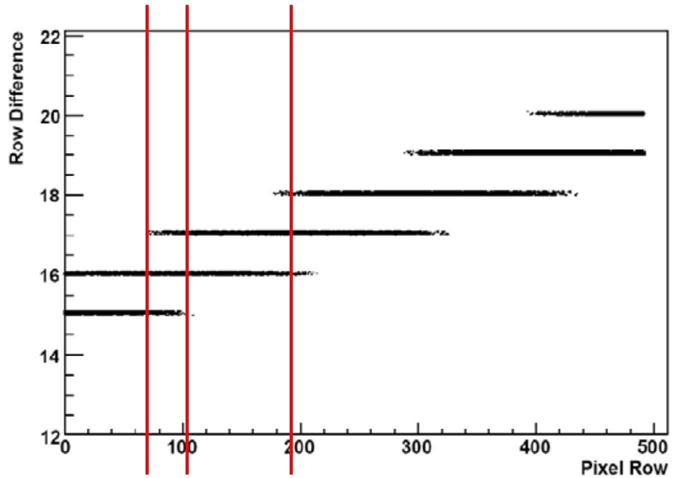
### Position dependent correlation logic beneficial

- Modules are flat – can gain efficiency
- Alignment issues can be solved on detector

**BUT**

### A requirement if sensors are tilted

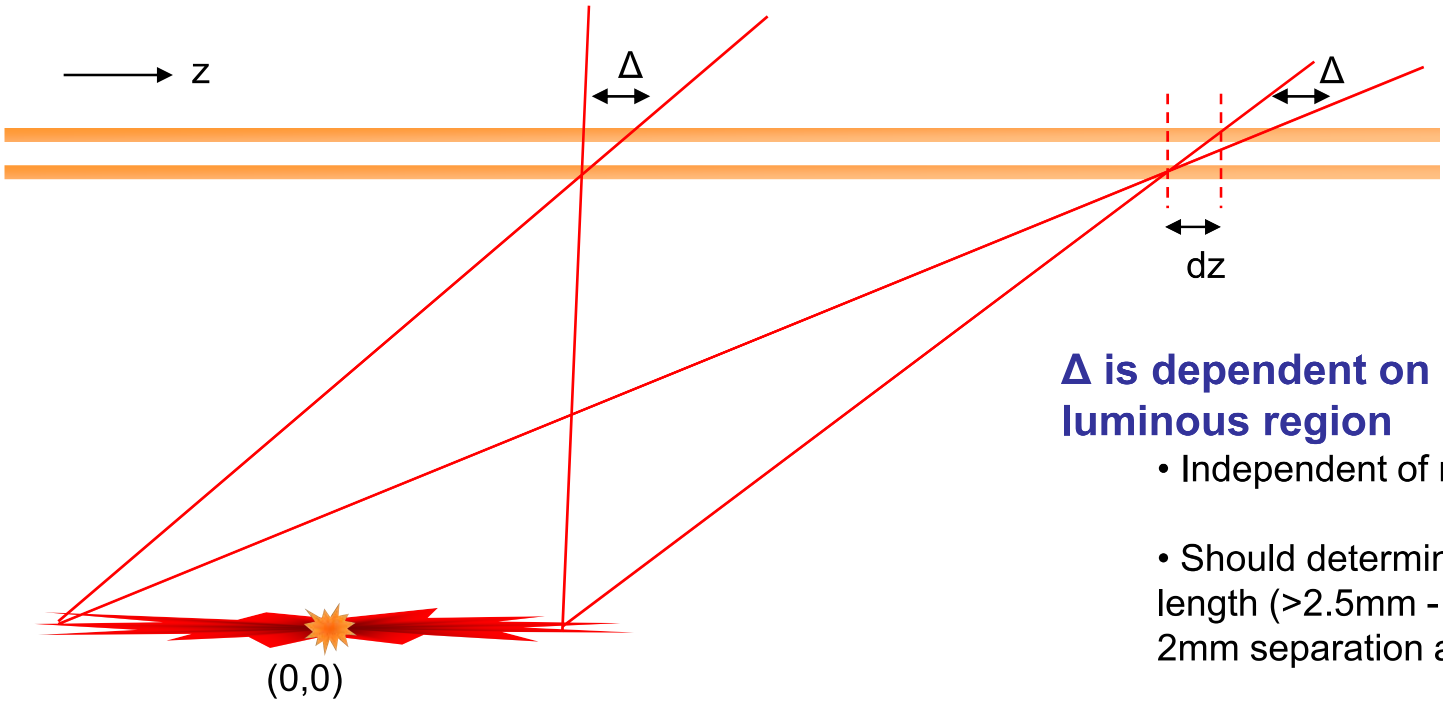
- Sensors are tilted to reduce the effect of Lorentz drift – smaller clusters

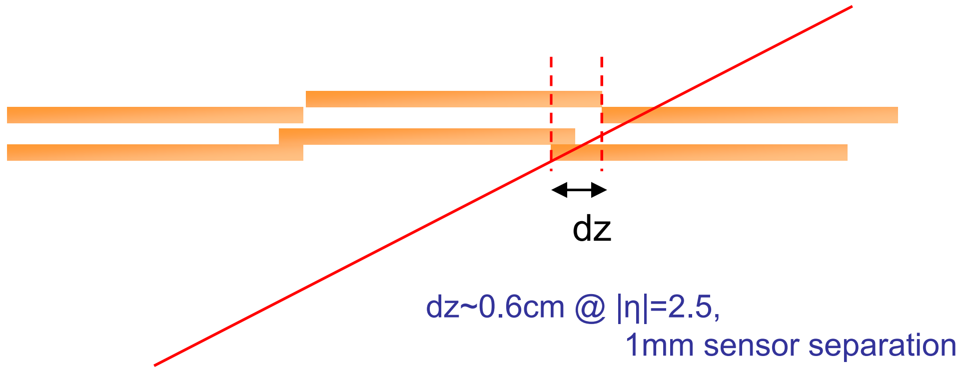



⇒ **Each pixel requires a correlation over 2-3 pixels and an offset over many pixels, dependent on position**

# Correlation Algorithm

**r-z view**




**Δ is dependent on the size of the luminous region**

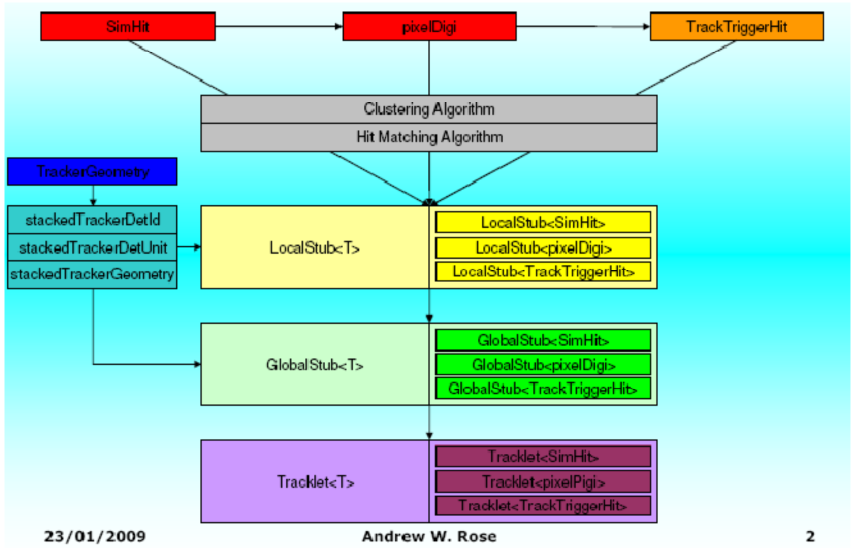
- Independent of η
- Should determine the pixel column length (>2.5mm - 25cm layer with 2mm separation and σ=5.3cm)

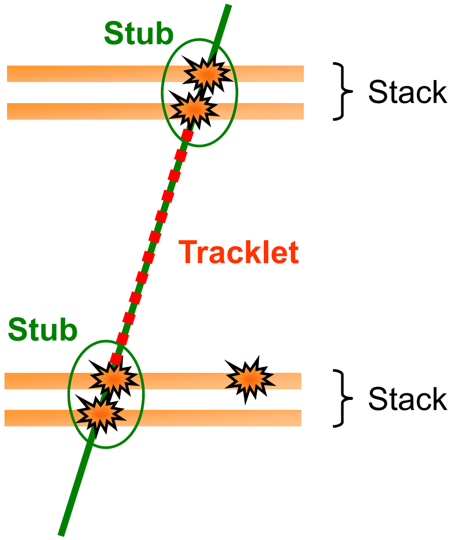
**dz increases with η**

- Geometry should implement a z offset between upper and lower sensors dependent on η
- This is so correlation is performed on a single module and over fewer columns/distance

Code to produce trigger primitives is ready

- Correlation algorithm identifies high $p_t$ tracks with a stub
- With two stacked layers, stubs can be combined to form tracklets




However, for every change in parameter -

Geometry must be checked
e.g. z offsets, sensor overlaps

Correlation cuts must be re-calculated
e.g. row offset and window vs. row number, column window

# Single Stack Performance

**Starting with a single trigger layer, simulations of triggering performance measured as a function of each of its parameters**

**25cm radius**
**2mm sensor separation**
**100µm x 2.37mm pixels**
**23° sensor tilt**
**coverage |η|<2.14**

## Correlation Window Cuts

**In order for a >95% trigger efficiency, correlation must be performed with both row and column windows of 2 or more**

- Larger row window required if sensor separation decreases and the same $p_t$ cut is needed
- Larger column window required if sensor separation increases
- Larger windows required when sensors are left untilted due to Lorentz drift effects

**Row comparison for this configuration requires matching of hits 5-10 pixels in distance (row offset)**

Stub efficiency [%] for high $p_t$ tracks when using a fixed window for the whole layer

| Column \ Row | 1 | 2 | 3 |
|---|---|---|---|
| 1 | 19.05 | 41.96 | 42.085 |
| 2 | 44.075 | **95.585** | **95.89** |
| 3 | 45.155 | **97.745** | **98.07** |

# Single Stack Performance

## Sensor Separation

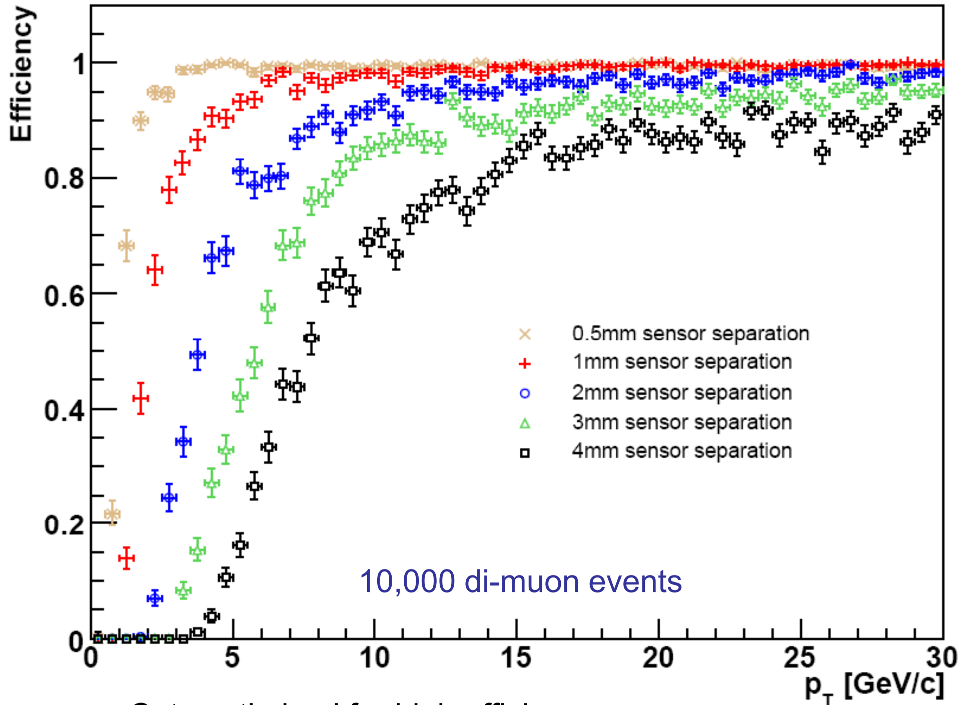
**Sensor separation provides an effective cut on $p_t$**

**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**

- tracks leave hits in different modules




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

**A small sensor separation (~1mm) is ideal as the transition region is reduced and windows are kept small – although data reduction is not as significant**

# Single Stack Performance

## Sensor Separation

**A 1mm separation at 25cm seems an ideal trade off**

- High efficiency
- Row/column window cuts < 3 (can be reduced)
- Alignment of sensors may be easier
- Data rate reduction factor ~20

| **Separation [mm]** | **Max Efficiency [%]** | **Fake [%]** (or average number/event) | **Reduction Factor** |
|---|---|---|---|
| 0.5 | 99.05 | 0.73 (12.22) | 8.04 |
| **1.0** | **99.35** | **4.14 (25.58)** | **22.26** |
| 2.0 | 97.745 | 17.83 (18.74) | 95.99 |
| 3.0 | 96.00 | 39.08 (23.76) | 210.28 |
| 4.0 | 92.95 | 47.27 (32.39) | 254.35 |

**Occupancy measured from simulations for this sensor configuration ~ (0.27±0.1)%**
**for 400 interactions/bx @ 20MHz**

A 1mm separation stacked layer reduces this to 0.02% in worst case => 1 stub / 5000 channels
16bits/stub[G.Hall] x 20MHz => 320 Mbps
Hence one 2.56Gbps link can read out (2.56Gbps / 320Mbps) x 5000 => 40,000 channels
Power / 2.56Gbps link = 2W, hence 2W / 40000 channels => **50μW/channel**

**Link power appears to dominate the power budget (150μW/channel per trigger layer) and scales with rate, hence a rate reduction factor of <10 may be unmanageable**

# Single Stack Performance

## Other Studies

Effect of layer radius on performance

Effect of sensor pitch on performance

Effect of sensor thickness on performance

Effect of sensor tilt on performance

Effect of sensor pitch on performance

Effect of pileup/occupancy on performance

Effect of local occupancy fluctuations on performance (jet events)

Effect of realistic readout schemes on performance

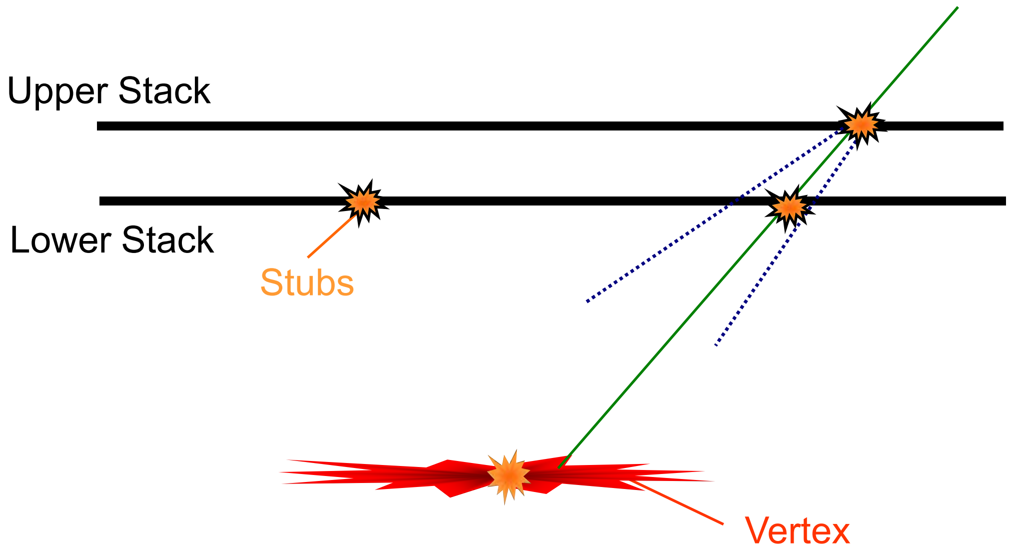
**Simulation effort is growing and effort to complete these studies is accelerating - software is stabilising**

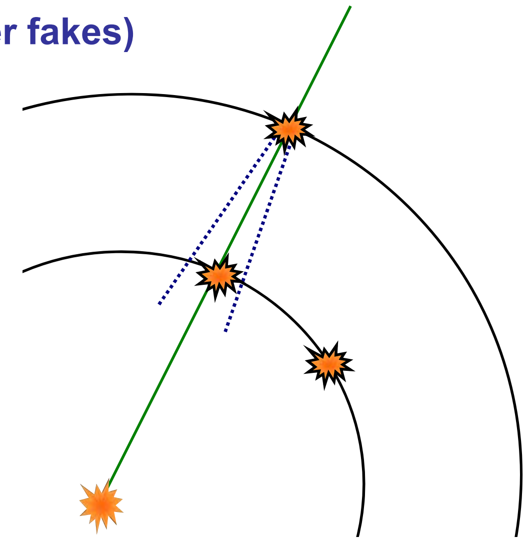
# Double Stack Correlation

**Is a single stacked layer sufficient for matching to other subdetector trigger primitives? Do two stacks provide a secondary data rate reduction and/or track information?**

**Correlate stubs in upper sensor with stubs in lower sensor to form tracklets using upper sensor as seed (fewer stubs, fewer fakes)**

- Most likely to be performed off detector



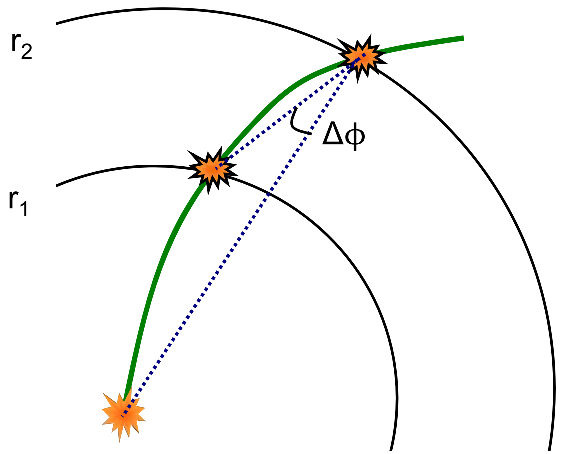



Window cut in $\phi$ applied – wide enough to allow for low $p_t$ tracks and scattering

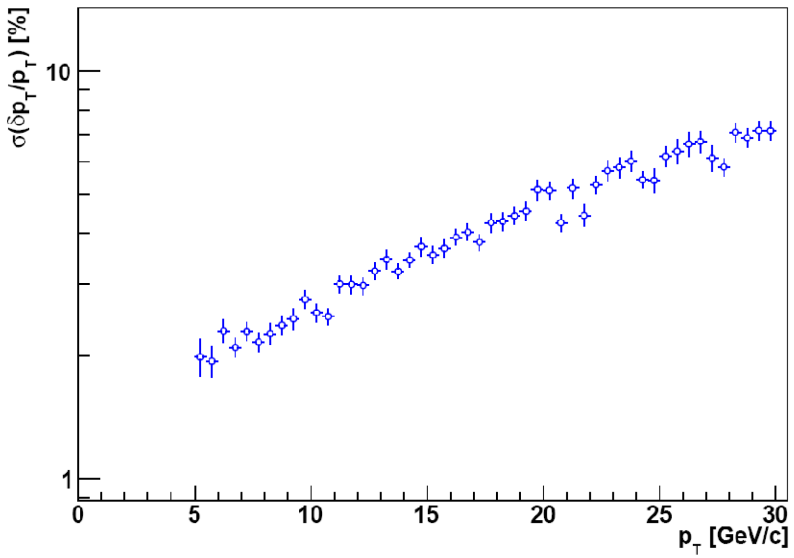
Window cut in $\eta$ applied – wide enough to allow for vertex smearing

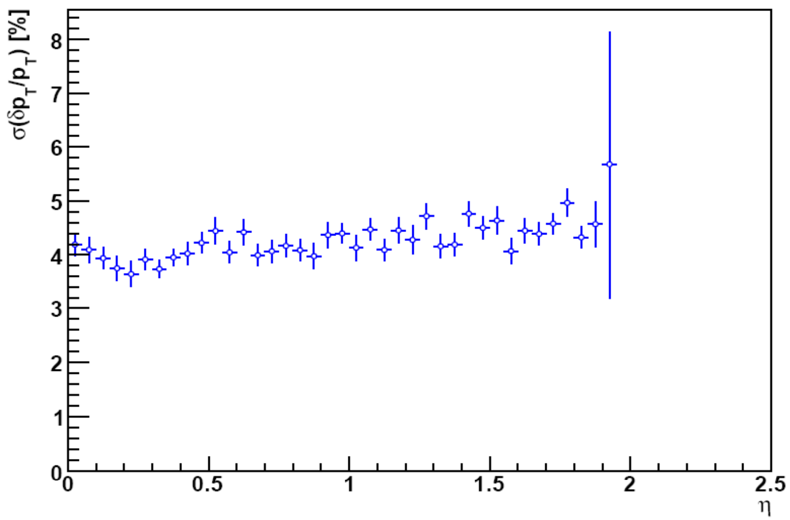
**If the stubs are correlated, we can use the two stubs plus the vertex as r,$\phi$ points for a 3-point track $p_t$ measurement**

– assumes track originates from (0,0)




$$p_T(\text{GeV/c}) = \frac{0.6\sqrt{r_1^2 + r_2^2 - 2r_1 r_2 \cos\Delta\phi}}{\sin\Delta\phi}$$

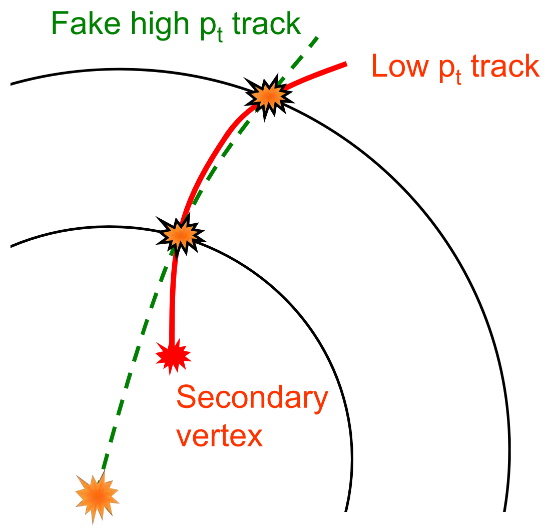



Tracklet $p_t$ resolution vs. track $p_t$ and η when using a 3-point $p_t$ reconstruction measurement for 10,000 0-30GeV di-muon events with smearing

# Double Stack Correlation

**Track $p_t$ reconstruction performance is good for single muon events, $\sigma(p_t)/p_t \sim 1\text{-}10\%$**




**Performance in maintained at $10^{35}$ $cm^{-2}s^{-1}$ pileup, but a significant fraction of background tracks are reconstructed with extremely high $p_t$**

- Combinatorial fakes are not the issue (<4%)
- Instead, tracks are interacting in the inner pixel layers and are passing both the single and double stack $p_t$ cuts due to their secondary vertex (~60%)

**This is not an easy effect to reduce unless an extra layer is implemented at larger radius**

**It is possible that this is not such a problem if the tracklets can be matched/rejected against other trigger objects e.g. muons**

- If the $p_t$ cut is raised, then there are only a few tracklets per event passed for matching
- Trigger studies combining tracking and other subdetector primitives are starting

# Summary

**A realistic trigger layer has been implemented within the CMS simulation software package. The layer is also configurable. It has demonstrated that**

> On detector hit correlation is a non trivial process. The readout scheme and algorithm must be able to perform comparisons over many pixels with different calibrations for each pixel while remaining low power and easy to implement electronically
>
> Effects such as Lorentz drift, multiple scattering etc. are important considerations when defining the layer, e.g. tilting the sensors to reduce clusters reduces the rate but increases the algorithm complexity

**Single layer performance is good and demonstrates the viability of the stacked tracking concept**

**Two layers provide a good estimate of the track $p_t$ but matching with other subdetector primitives for viable L1 triggers remains to be demonstrated**

**Simulations are beginning to guide geometry layouts – two baseline layouts are taking shape**