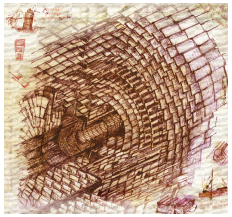
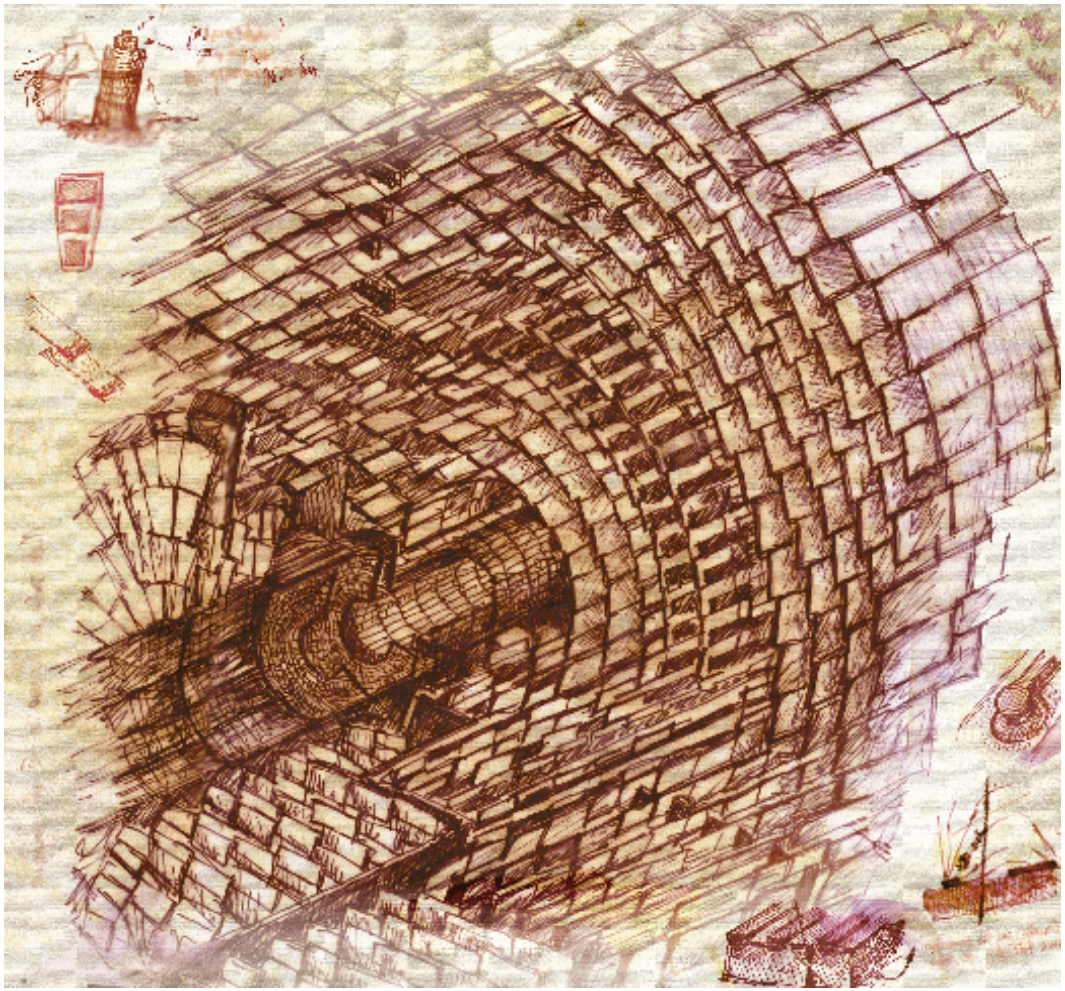
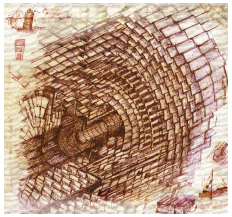


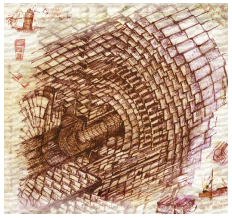
Intelligent Trackers as L1 Trigger Providers for the SLHC





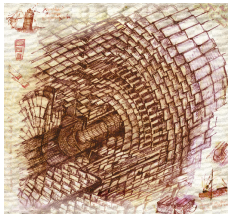
Outline

- **Motivation for an L1 Tracking Trigger, and reminder of Requirements**
- **Local Data Reduction**
  - **Using Track Vectors, or Stubs**
  - **Derived from "Stacked Modules"**
- **A Hierarchical Scheme with Double Stack Layers**
  - **Provides L1 Tracklets, in addition to Stubs, in a "local" and computationally efficient way, which provide good High Pt discrimination and which can be combined across layers**
- **A Long Barrel Straw Man Layout**
  - **Which uses Double Stack Layers for both L1 Tracking Trigger and Full Track Reconstruction**
- **Summary and Conclusions**

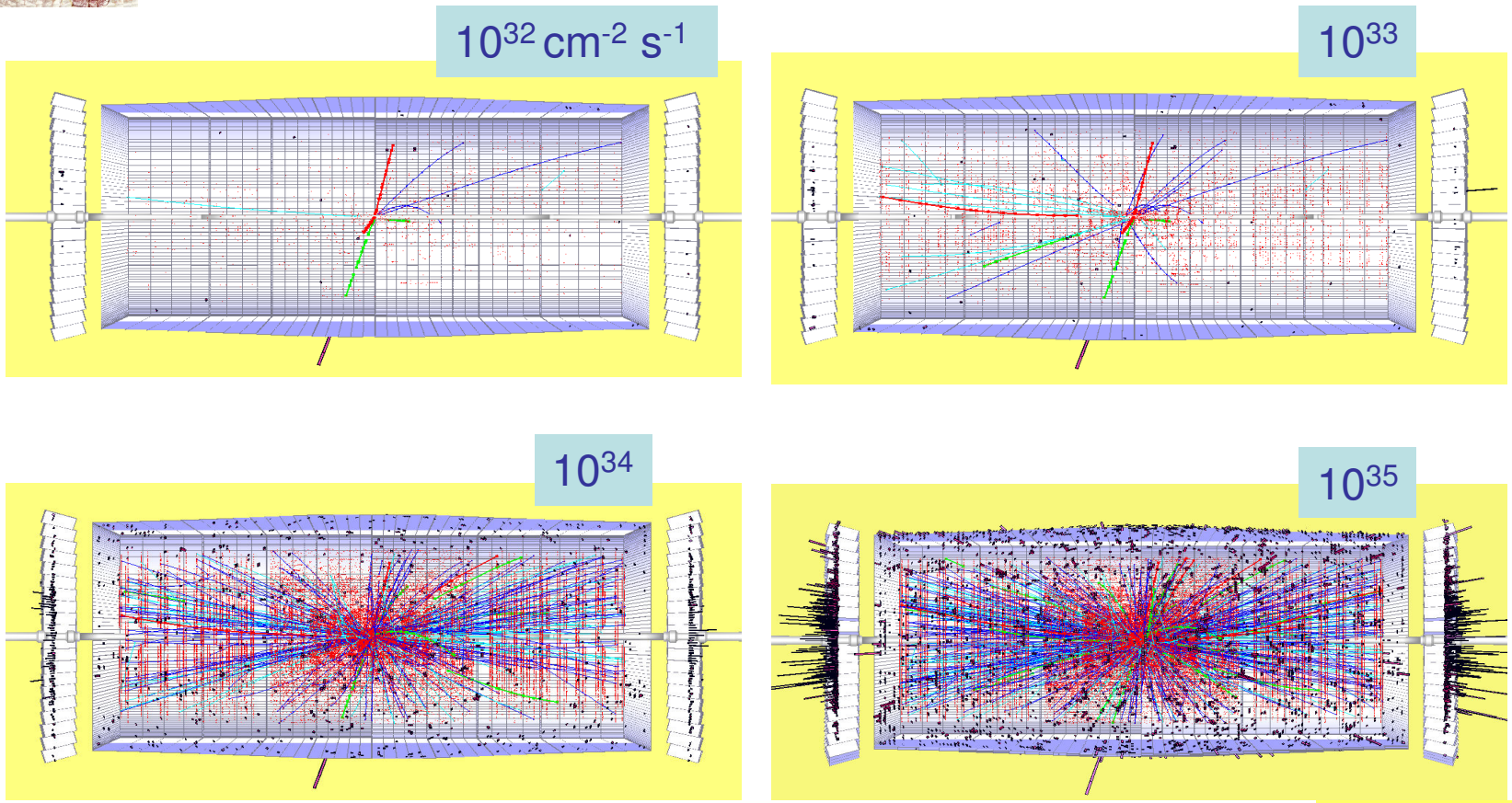


Scope of this Discussion: Outer Tracker

- **The region of the inner-most Pixel Layers is fundamentally challenging at the SLHC, especially for the Sensor Technology**
  - One may speculate as to the most promising way forward
  - B-tagging, e/γ discrimination remain Very Important
- **Assume 4 or 5 Layers of Fine-Pitch Pixels**
  - To be better defined
  - Possible L1 Trigger primitives formation under study, but no viable schemes identified yet
- **Here focus on Outer Tracker as providing also L1 Trigger Primitives**
  - Assume boundary between inner-most Pixel Layers and Outer Tracker is somewhere between 20 ~ 40cm
  - In any future baseline layout, Outer Tracker and inner-most Pixel Layers will have to make a coherent Tracking System

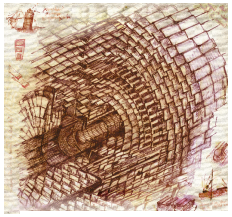


CMS from LHC to SLHC
Motivation for L1 Tracking Trigger



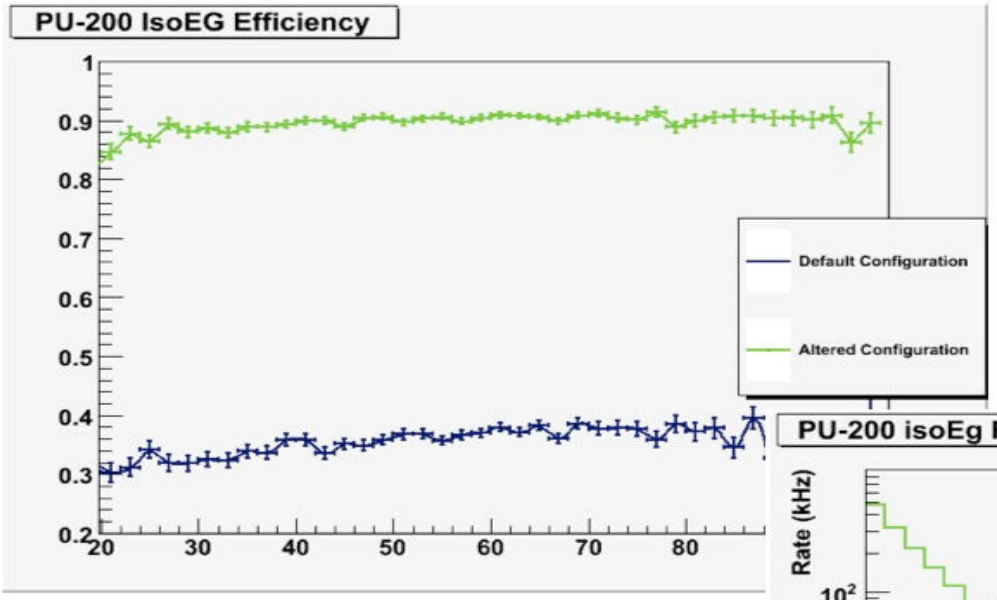
I. Osborne

At SLHC CMS faces new challenges, in particular for both Tracking and Triggering



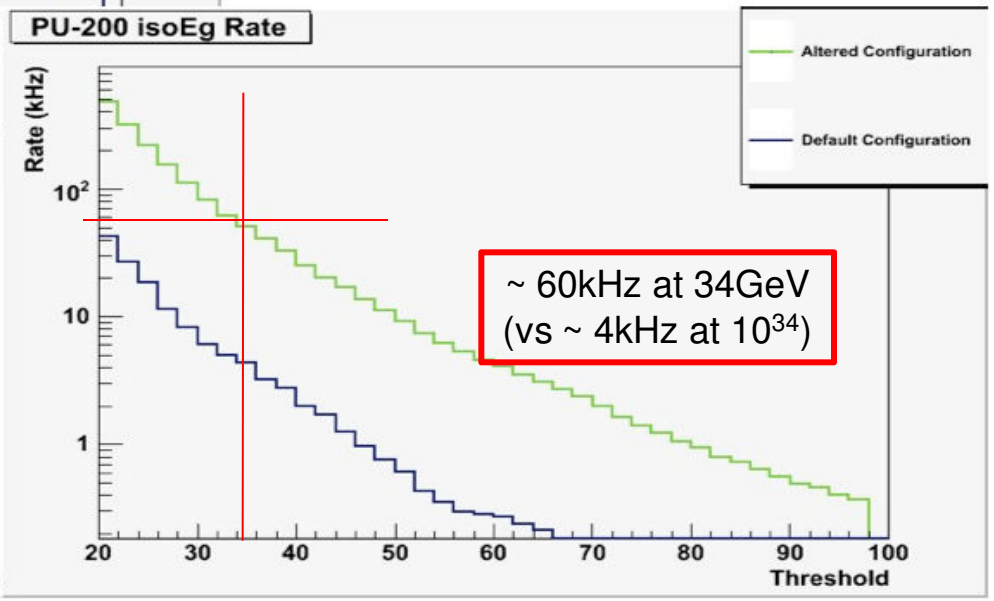
CMS from LHC to SLHC
Motivation for L1 Tracking Trigger

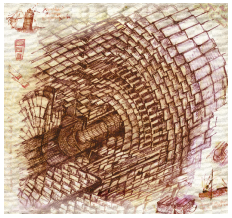
Isolated Electron-Photon L1 Trigger with 200 event Pile Up



Optimized for 10^{34}

Retuned for ~ 90% Efficiency at 10^{35}





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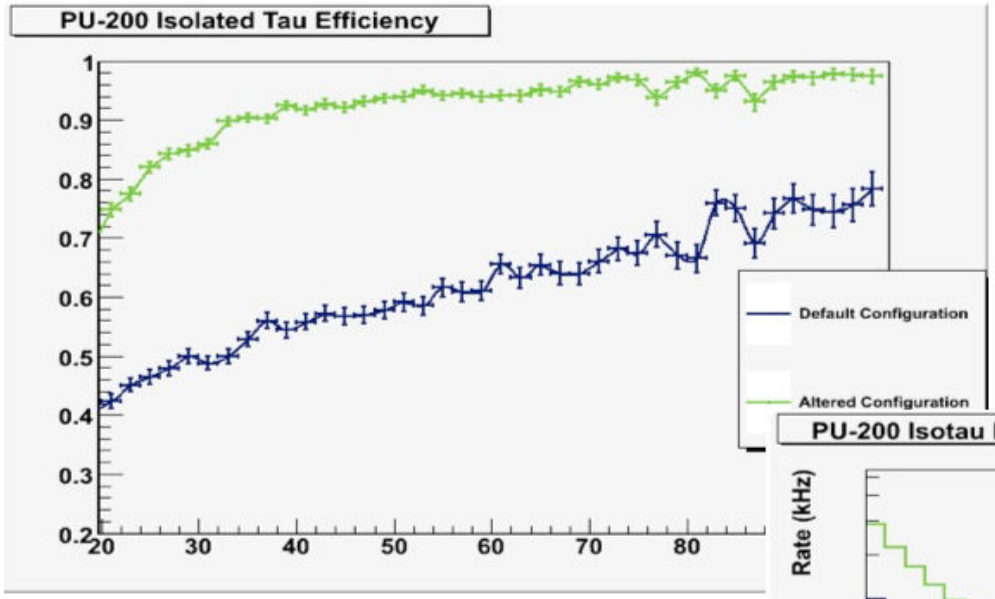

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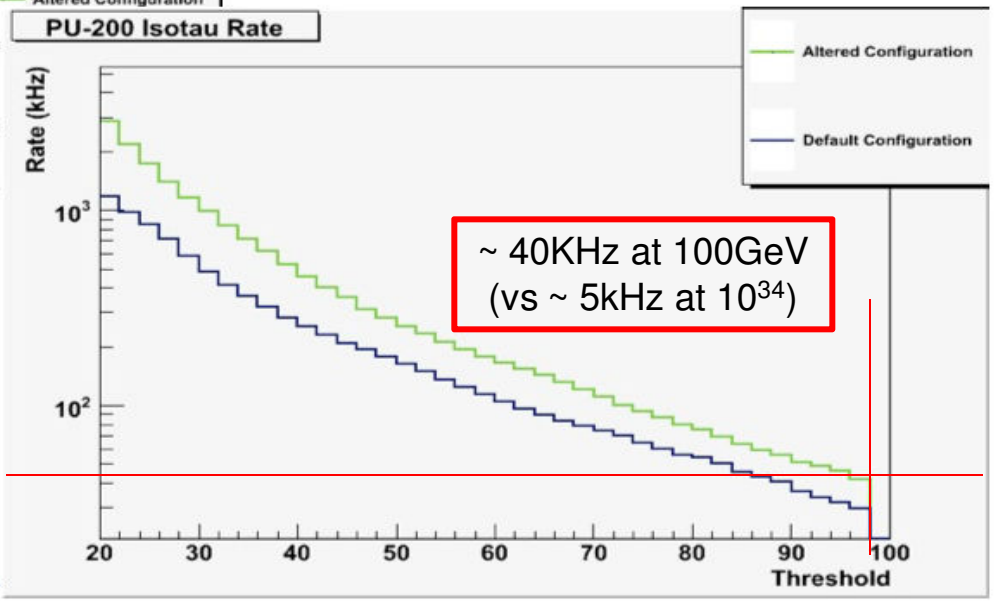
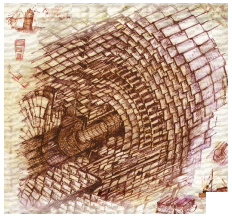




CMS from LHC to SLHC
Motivation for L1 Tracking Trigger

CMS SLHC Tracking Trigger

L1 Trigger without tracking

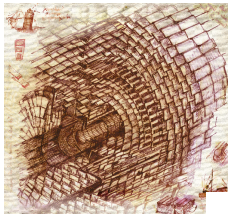
- Possible to improve to ultimate performance stand-alone to cope higher than 10^{34} but not out to 10^{35}.
- These improvements involve patterns and granularity more fine than in the present trigger
- These are required in any case for use with a L1 tracking trigger.

L1 trigger with tracking

- Prospects to cope up to 10^{35} look reasonable
- Based on what we know from HLT simulation results
- Moreover, tracking provides a "game-changing" opportunity to keep or reduce the 10^{34} physics thresholds at 10^{35}.

All of this needs validation with simulation

Wesley Smith, U. Wisconsin, November 20, 2008 — CMS Upgrade Workshop – Tracking Triggers 22



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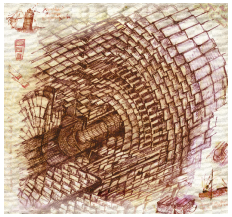
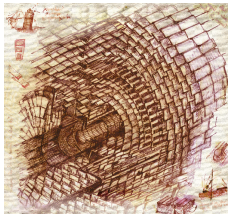
"An L1 Track Trigger for SLHC is not an Elective Project"

Wesley Smith, U. Wisconsin, November 20, 2008 — CMS Upgrade Workshop – Tracking Triggers 22



SLHC L1 Tracking Trigger: Reminder of Required Functionality

- **Electrons/Photons**
  - Rate dominated by high Pt π^0 from jets
  - Is there a high Pt charged track consistent with L1 ECAL Cluster?
    - Is it Isolated?
- **Muons**
  - Rate dominated by miss measured muons from jets, below the Pt threshold
  - Is there a matching high Pt charged track above the Pt threshold?
    - Is it Isolated?
- **Taus**
  - Rate dominated by ~ narrow high Pt jets
  - Is there a narow low multiplicity jet associated to the L1 Calo Cluster?
  - Is it Isolated?

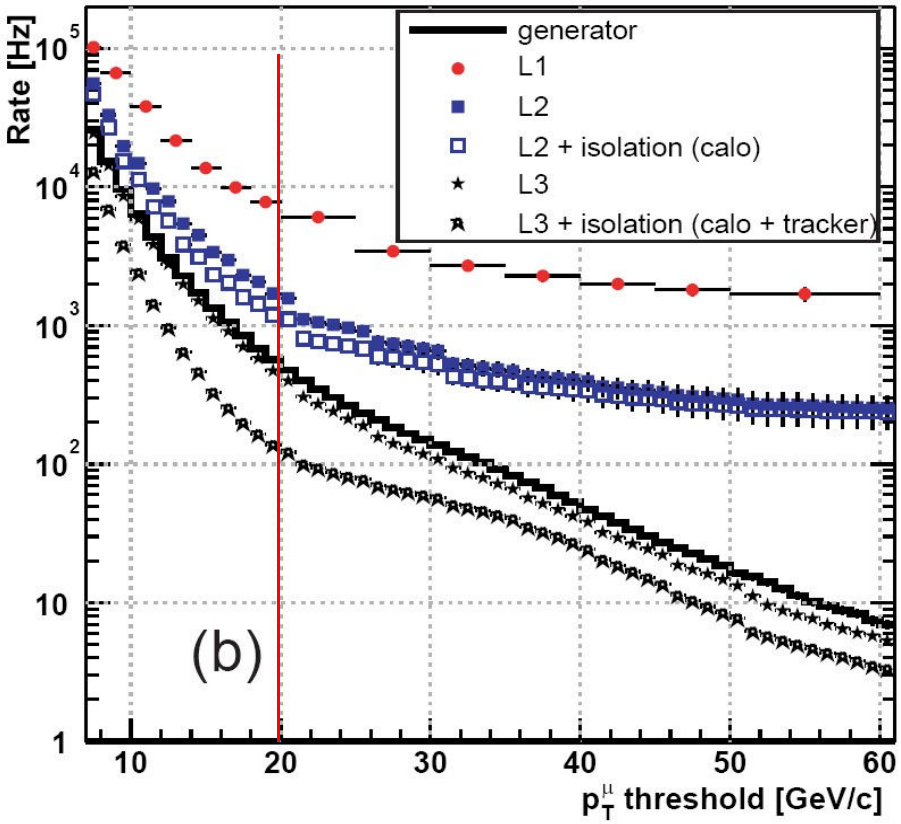


Required Functionality
L1 Trigger: Muons

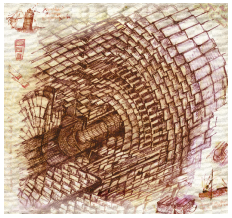
- **Confirmation of High Pt Muon Candidates: now done in HLT**

- **Accurate measurement of Tracks with Pt > 15 ~ 20 GeV**
  - **Reduce L1 rate by ~ 1/10**
  - **Fast, Efficient high Pt Tracking**
  - **1 ~ 2% Pt resolution for $\eta < 2$**

- **Isolation ?**
  - **Further reduce rate by ~ 1/10**
  - **…**

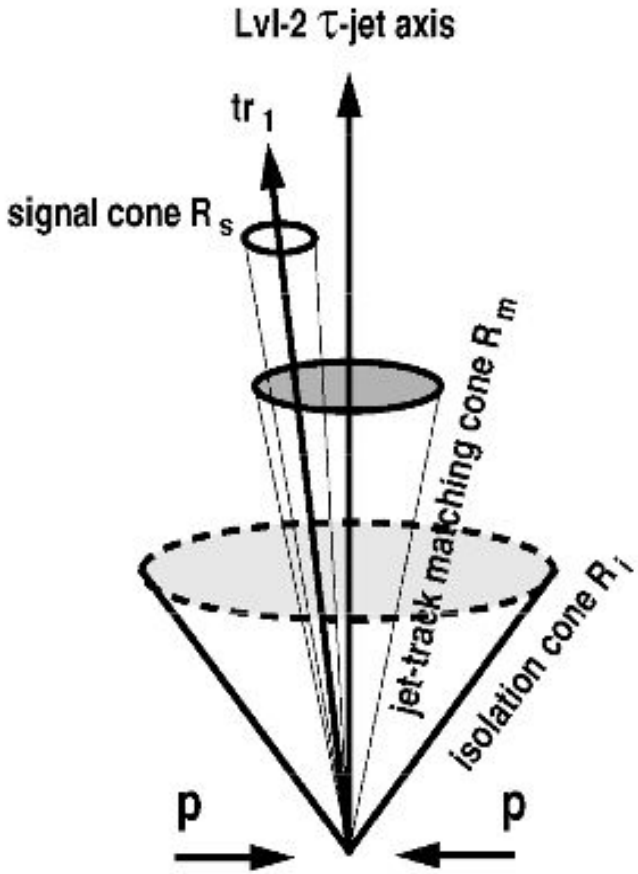


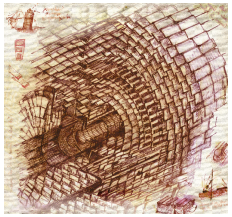
Factor ~ 100 rate reduction for same Pt threshold



Required Functionality
L1 Trigger: Taus

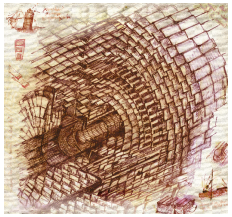
- **Confirmation of High Pt Narrow Jet Candidates**
  - Tracks with Pt above ~ 10 GeV
  - Fast, Efficient high Pt Tracking
  - Good Pt resolution
- **Isolation**
  - Tracks with Pt above ~ 2 GeV
  - Fast, Efficient and Clean Tracking down to Pt ~ 2GeV
- **Longitudinal Primary Vertex association**
  - Required to maintain efficiency at 10^{35}
  - Tracks with Pt above ~ 2 GeV
  - Good Z Vertex resolution





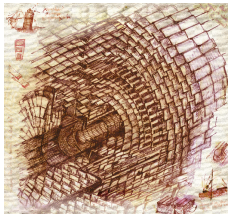
An additional Desirable Feature: rejection of Uncorrelated Combinations

- **Rejection of Uncorrelated Combinations, from different primary vertices?**
  - **At 10^{35} expect ~ 200 pile-up interactions for each 25ns bunch crossing**
  - **Uncorrelated Trigger Primitives from different primary vertices may force higher thresholds Combined Triggers**
  - **Longitudinal of Trigger Primitives with Tracks at Vertex would avoid this**
  - **May be possible if track Longitudinal Vertex Association, required for Isolation cuts, is available**



Local Occupancy Reduction

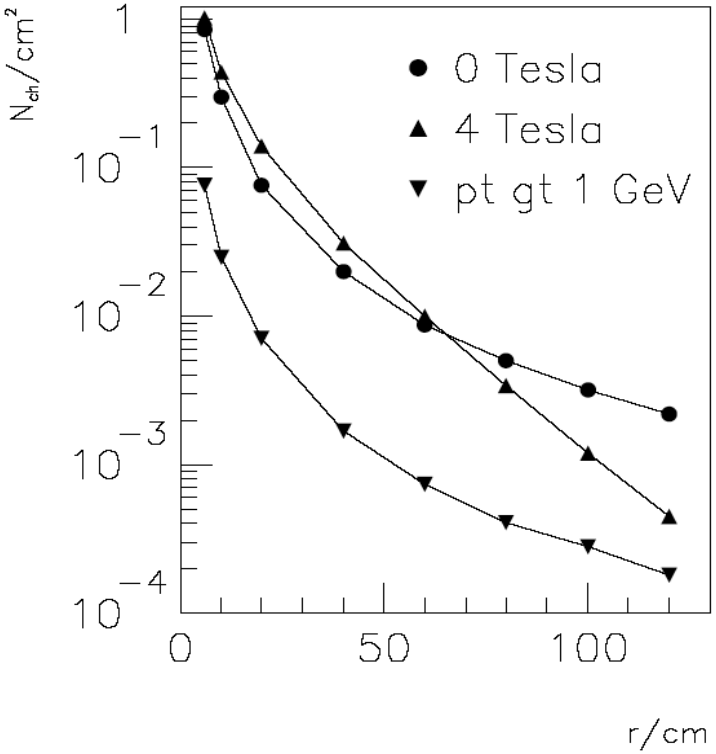
- **Cannot possibly transfer all Tracker data at 40MHz !**
- **Crossing Frequency / Event Read-Out ~ 40MHz / 100kHz ~ 1 / 400**
  - **L1 Data reduction by a factor of 10 ~ 100 is required**
- **For L1 Trigger propose to transfer only hits from tracks with Pt > ~ 2 GeV**
  - **The aim is to provide useful Isolation information**
  - **Tracks with Pt > ~ 2 Gev are less than 1% of the Tracks inside acceptance**
  - **This corresponds to the maximum plausibly manageable L1 data rate**
- **In addition, must provide means of rapidly & reliably identifying high Pt (isolated) tracks (Pt > 10 ~ 25 GeV)**

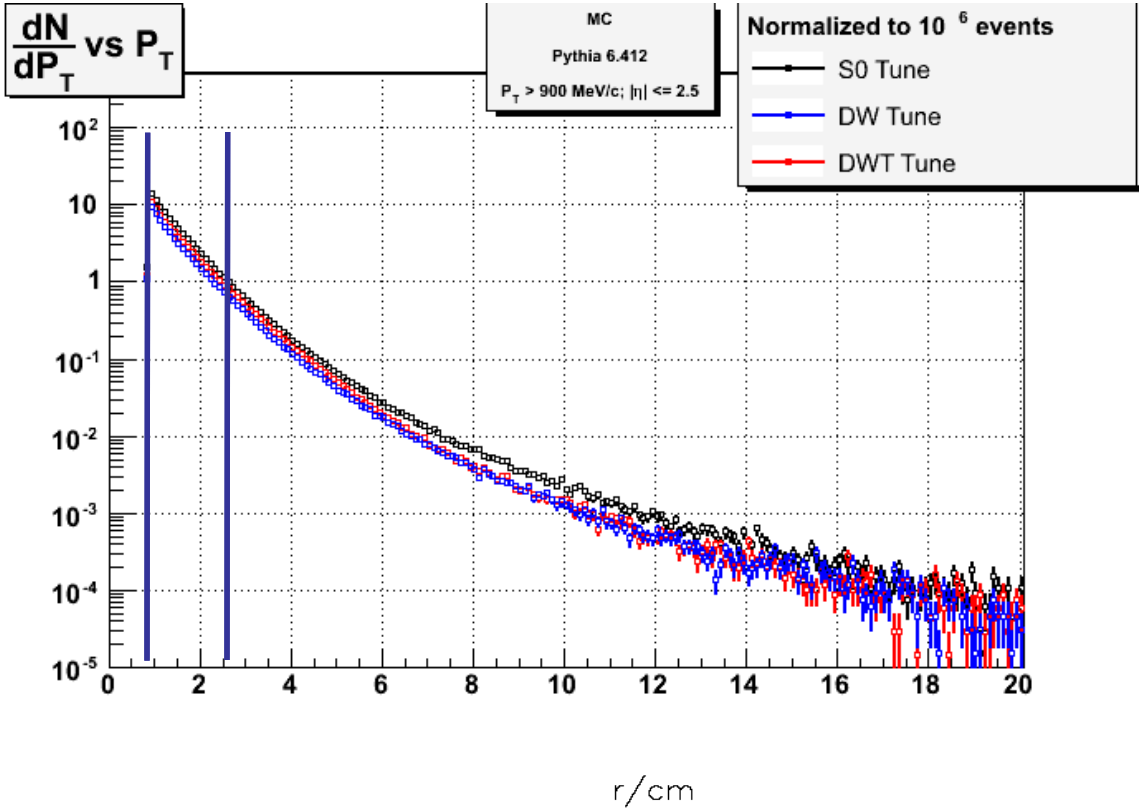


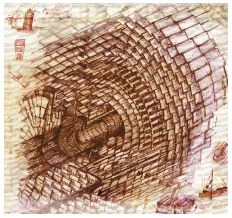
Local Occupancy Reduction

Tracks with Pt > 1 GeV
< 10% of Tracks in acceptance

Tracks with Pt > 2.5 GeV
< 10% of the remaining Tracks



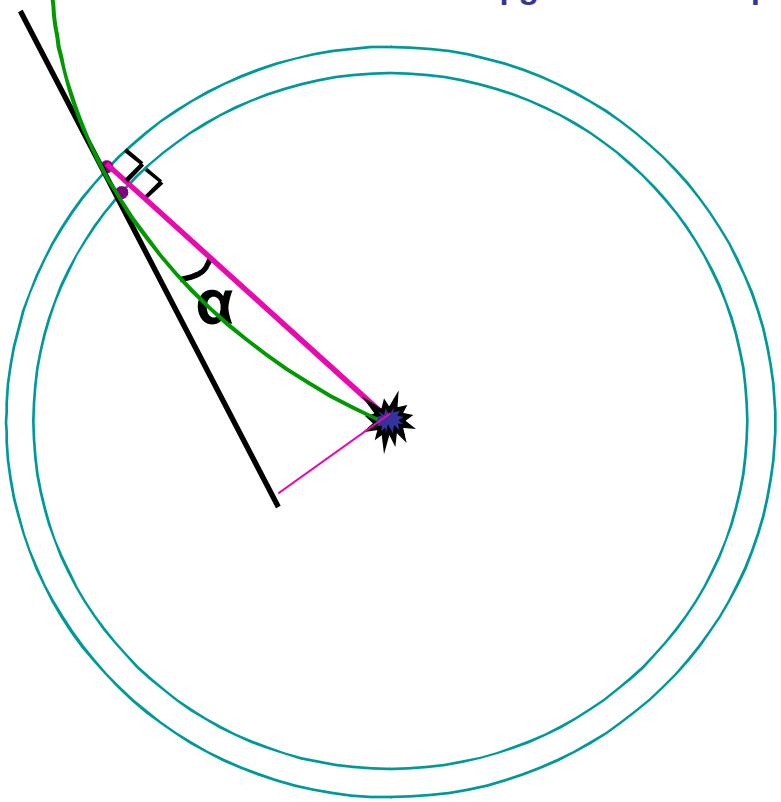


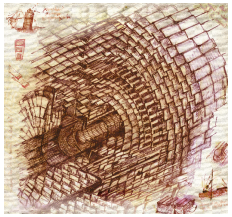


Local Occupancy Reduction with Local Track Vectors

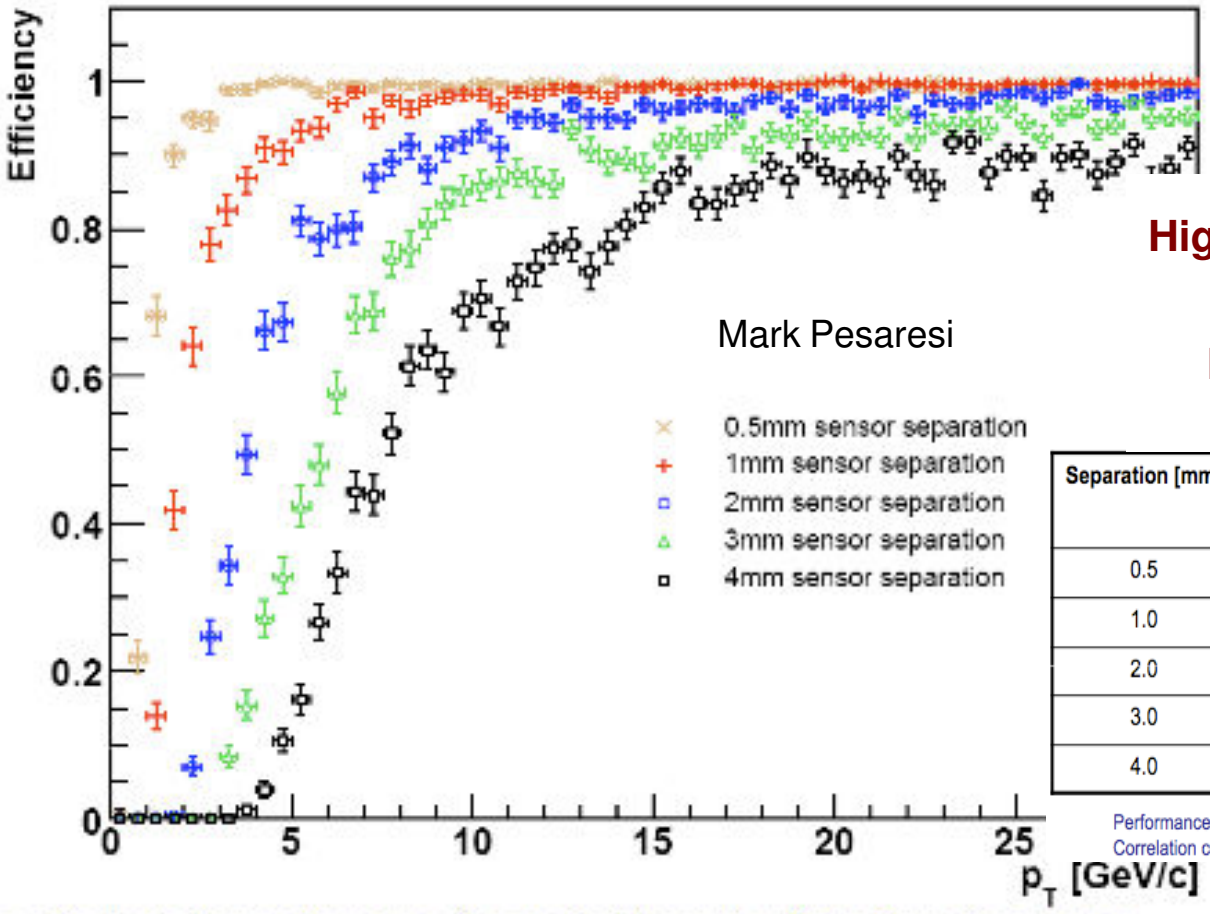
- Pairs of Sensor Planes, for local Pt measurement
- High Pt tracks point towards the origin, low Pt tracks point away from the origin
- Use a Pair of Sensor Planes, at ~ mm distance
  - Pairs of Hits provide Vector, that measure angle of track with respect to the origin
  - Note: angle proportional to hit pair radius
- Keep only Vectors corresponding to high Pt Tracks

J. Jones (~2005)
CMS Tracker SLHC Upgrade Workshops





Early results for a Stack of closely spaced sensors: pitch ~ 100um*2.4mm (M. Pesaresi)



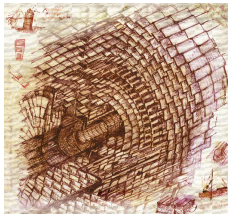
p_T discriminating performance of a stacked layer at r=25cm for various sensor separations using 10,000 di-muon events with smearing

High rejection factors possible

Much Sharper Threshold For Low Threshold Value

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

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



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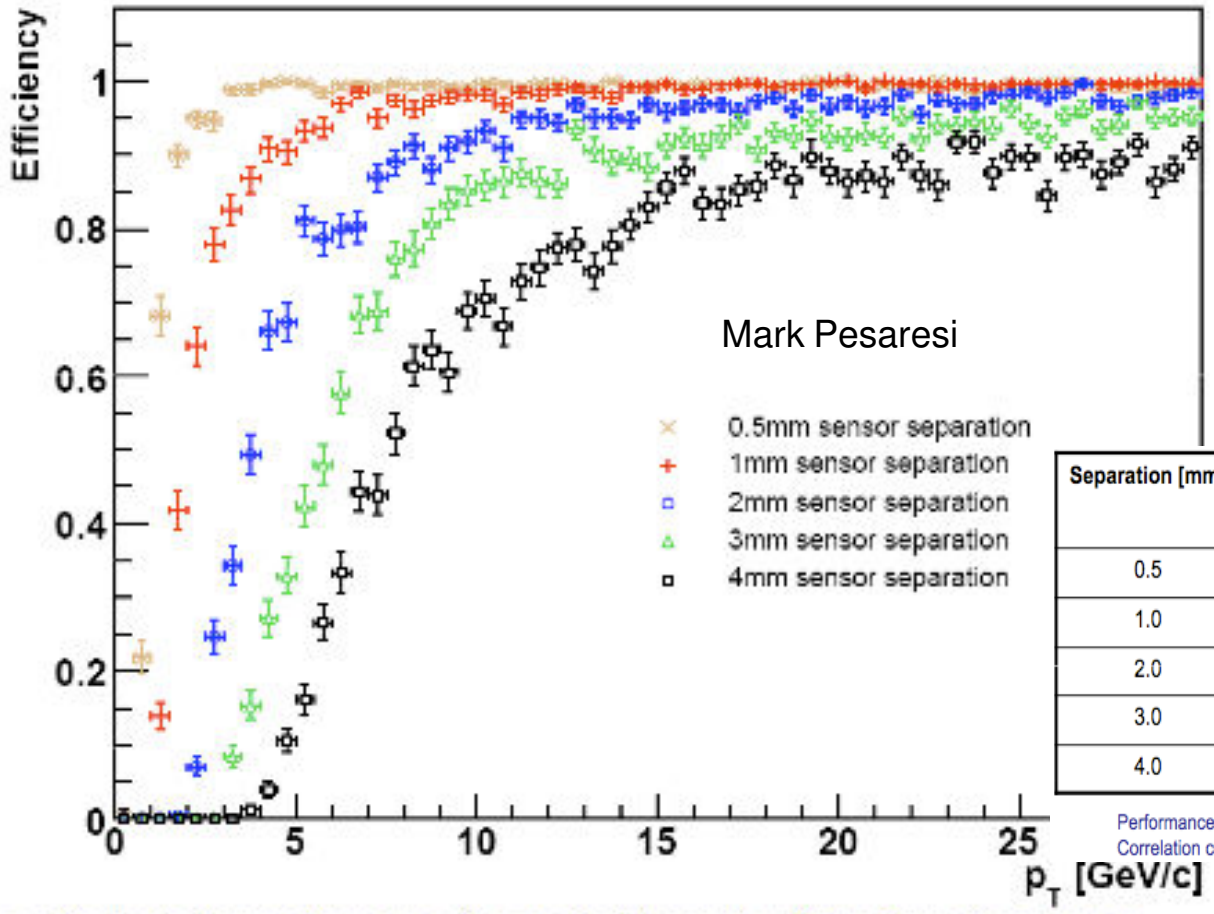

p_T discriminating performance of a stacked layer at r=25cm for various sensor separations using 10,000 di-muon events with smearing

No useful discrimination at Pt ~ 20 GeV

Separation [mm]	Max Efficiency [%]	Fake [%] (or average number/event)	Reduction Factor
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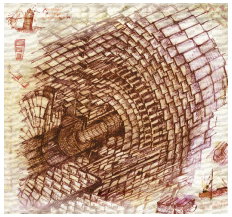
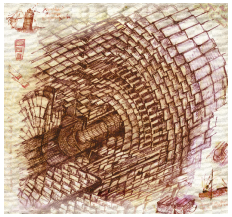


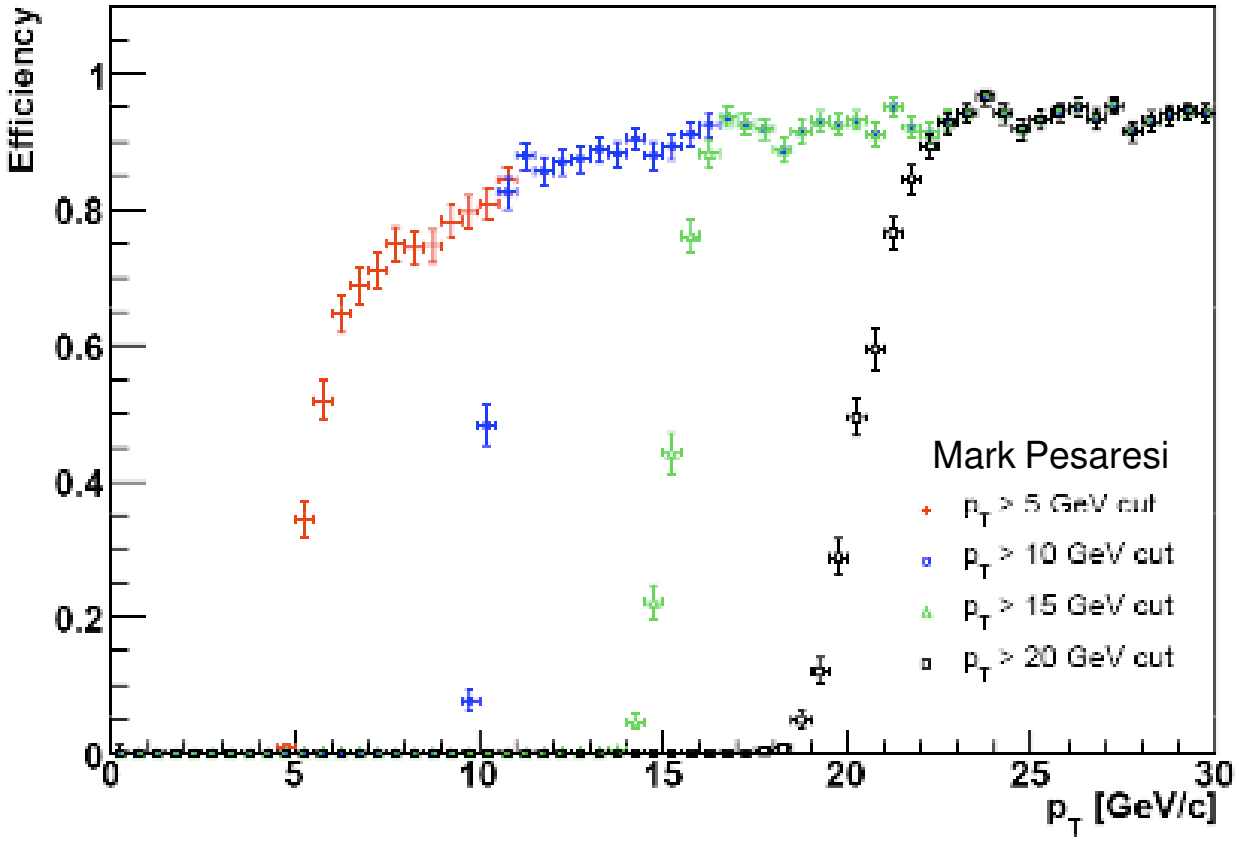
Local Occupancy Reduction
a Hierarchical scheme with Double Stacks

Local Information Gathering, and Processing Hierarchy

- **Within a Stacked-Sensor Module**
  - Collect Hits from each Sensor
  - Match into Stubs& Reject Stubsfrom Very low Pt Tracks: Pt < ~ 2GeV
  - Nb one datum / Hit Pair
- **Within a Double Stack**
  - Collect Stubsfrom each Sensor Doublet Module
  - Match into Tracklets
- **Combine with other layers, and use to provide High Pt & Isolation L1 Track Trigger Primitives**

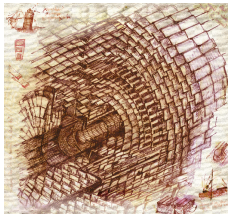


Early results for a pair of Double Stacks spaced ~ 10cm apart (M. Pesaresi)



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

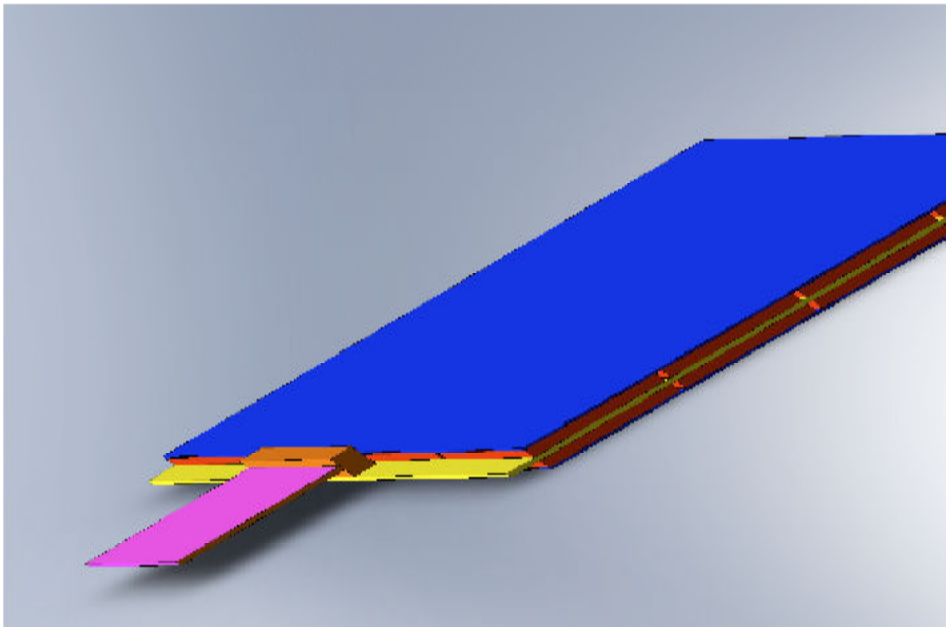
Good discrimination up to Pt ~ 20 GeV

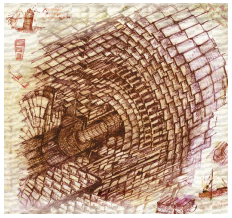


Straw Man Sensor Stacked Module: Vertically Integrated Hybrid Module

- **Example of Vertically Integrated Hybrid Module:**
  - **Chips are bonded to sensors (Pixels ~100um pitch * 1.25 ~ 2.5mm length)**
  - **And connected to central (Si) pcb through vias to back-side of Chip**
  - **Direct Vertical Chip-to-Chip transmission: minimizes Power**
    - **Analogue connection of top sensor to bottom chips also under study**
  - **A Challenge for Interconnect, Bonding and Assembly technologies**

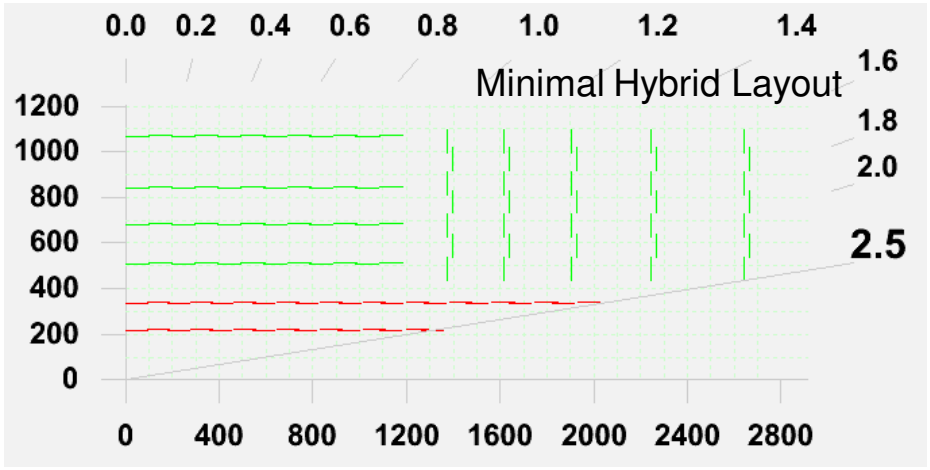
See presentations by G.Hall, A.Marchioro, R. Lipton, B.M. Tripathi, J. Alexander…

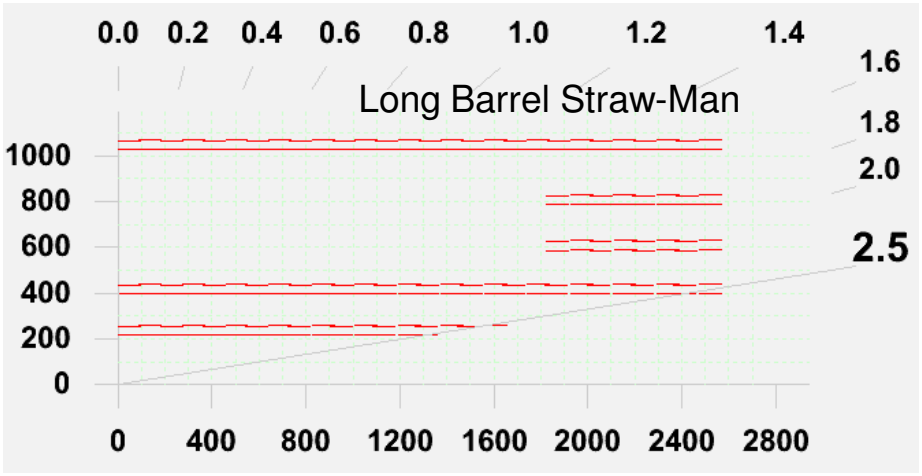


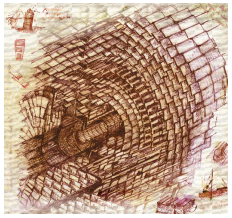


Possible Tracker Layouts Incorporating Stacked Module Layers

- **Several potential layouts for an SLHC Outer Tracker are under study**
  - **Want to increase granularity as well as minimize material in future tracker**
  - **Need to understand how many triggering layers (in red), and where they need to be located in order to provide adequate triggering capability**
- **No final decision on layout of tracker until final requirements determined**







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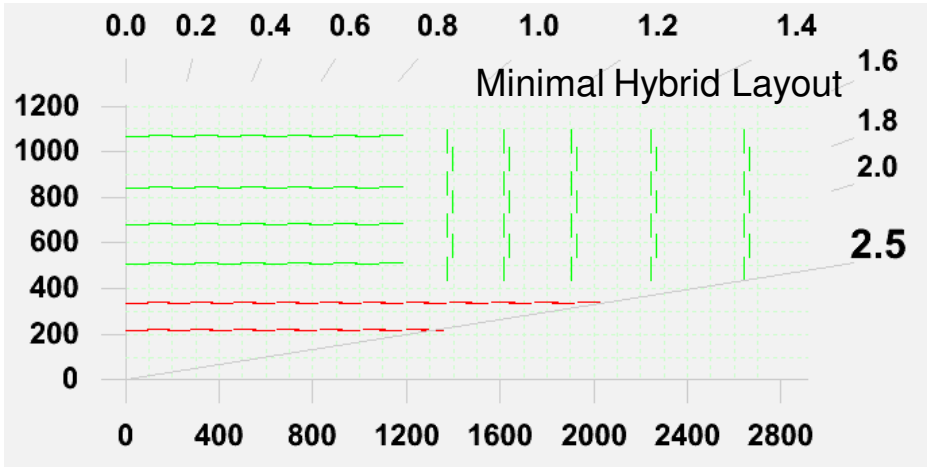
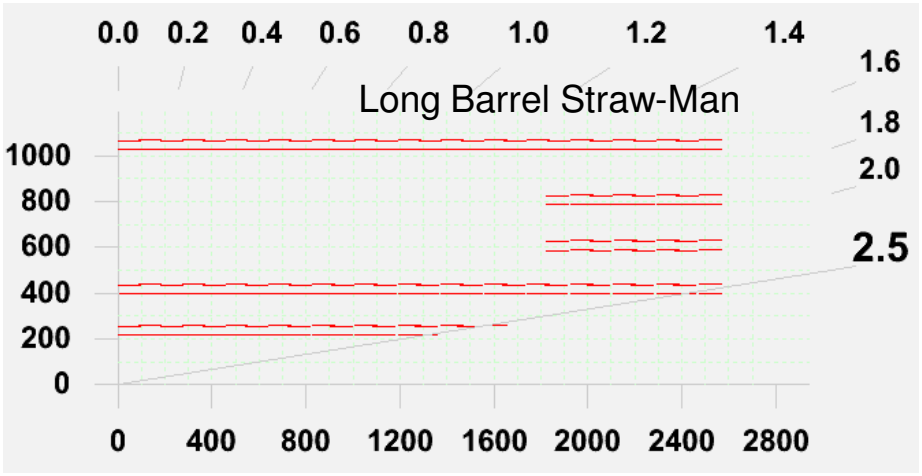
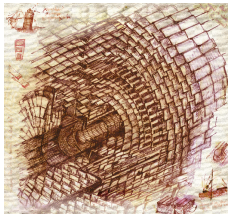
- **Here focus on the Long Barrel Straw Man as it is the most thought provoking**

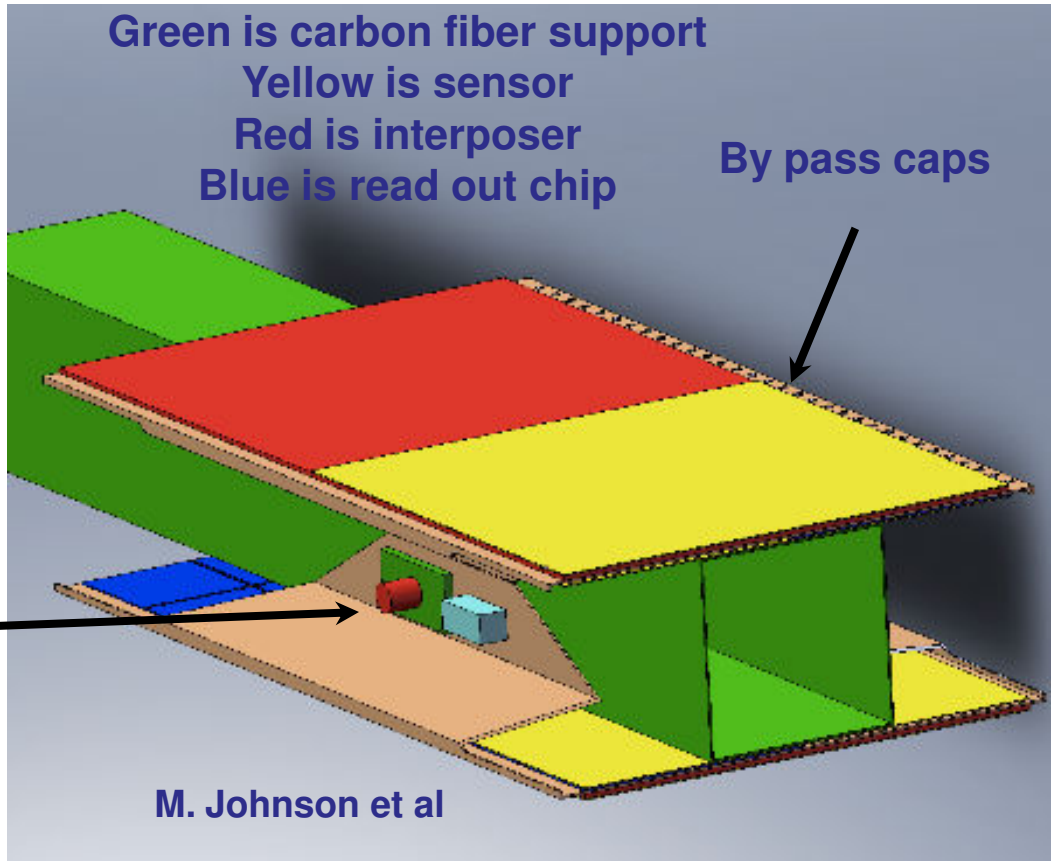


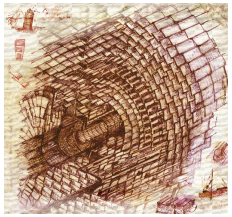




CMS SLHC Tracker
Long Barrel Straw Man Double-Stack Layer

- **Modules are arranged on long ROD's or BEAMS, to form log barrells of Double-Stack Layers**





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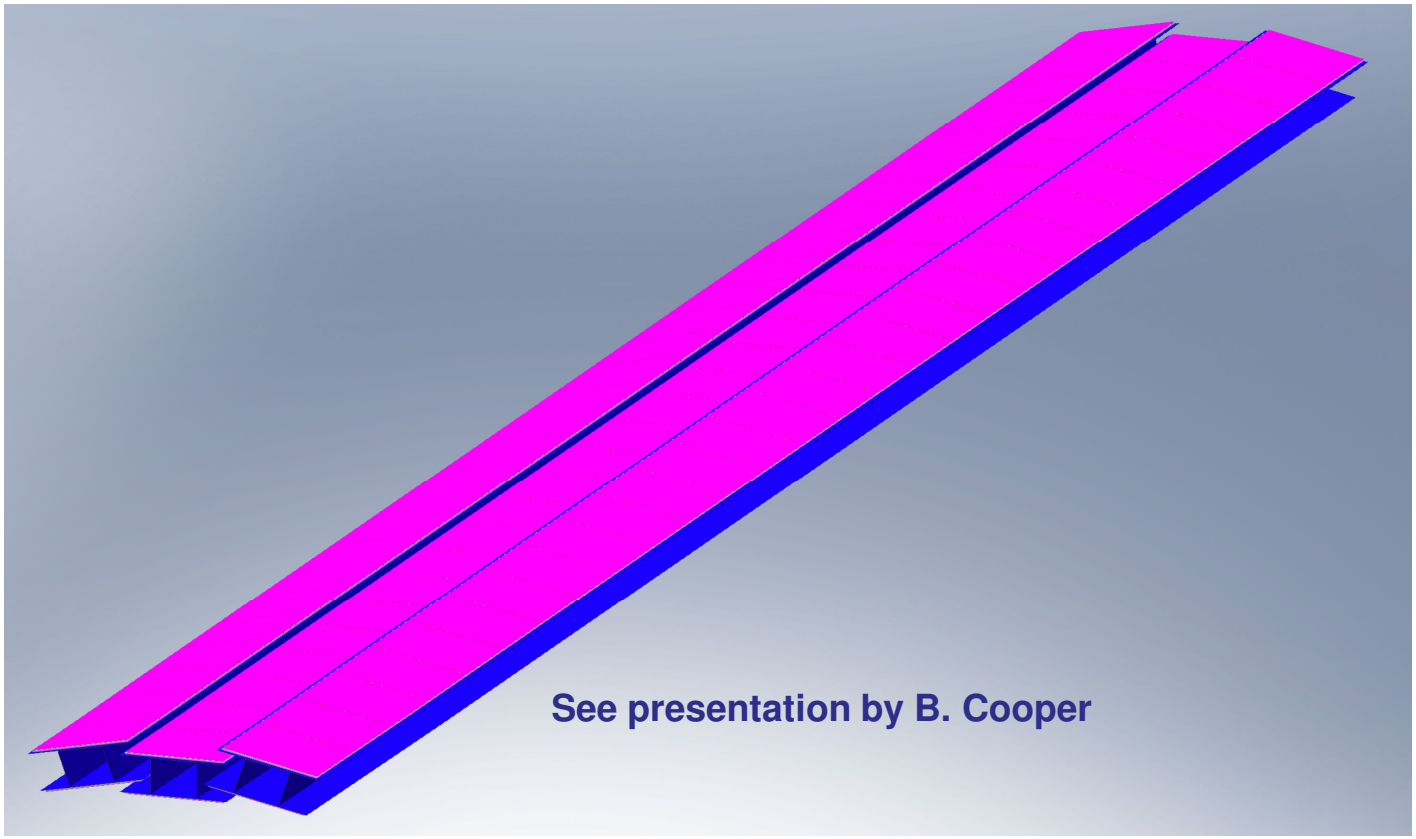
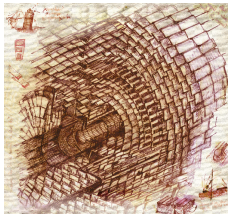
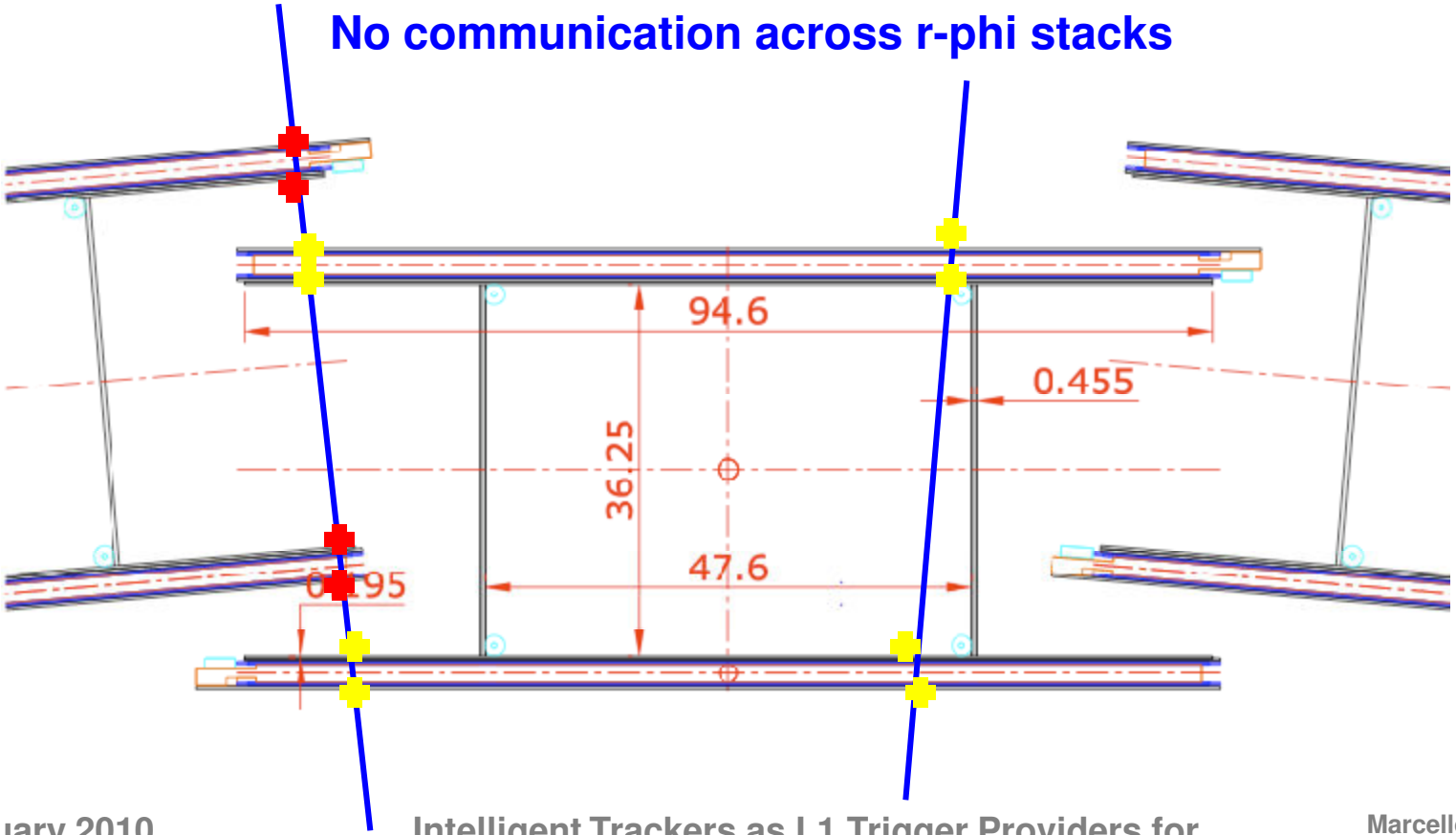


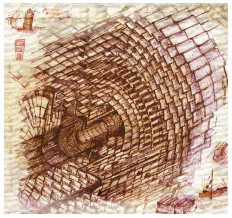


CMS SLHC Tracker
Long Barrel Straw Man Double-Stack Layer

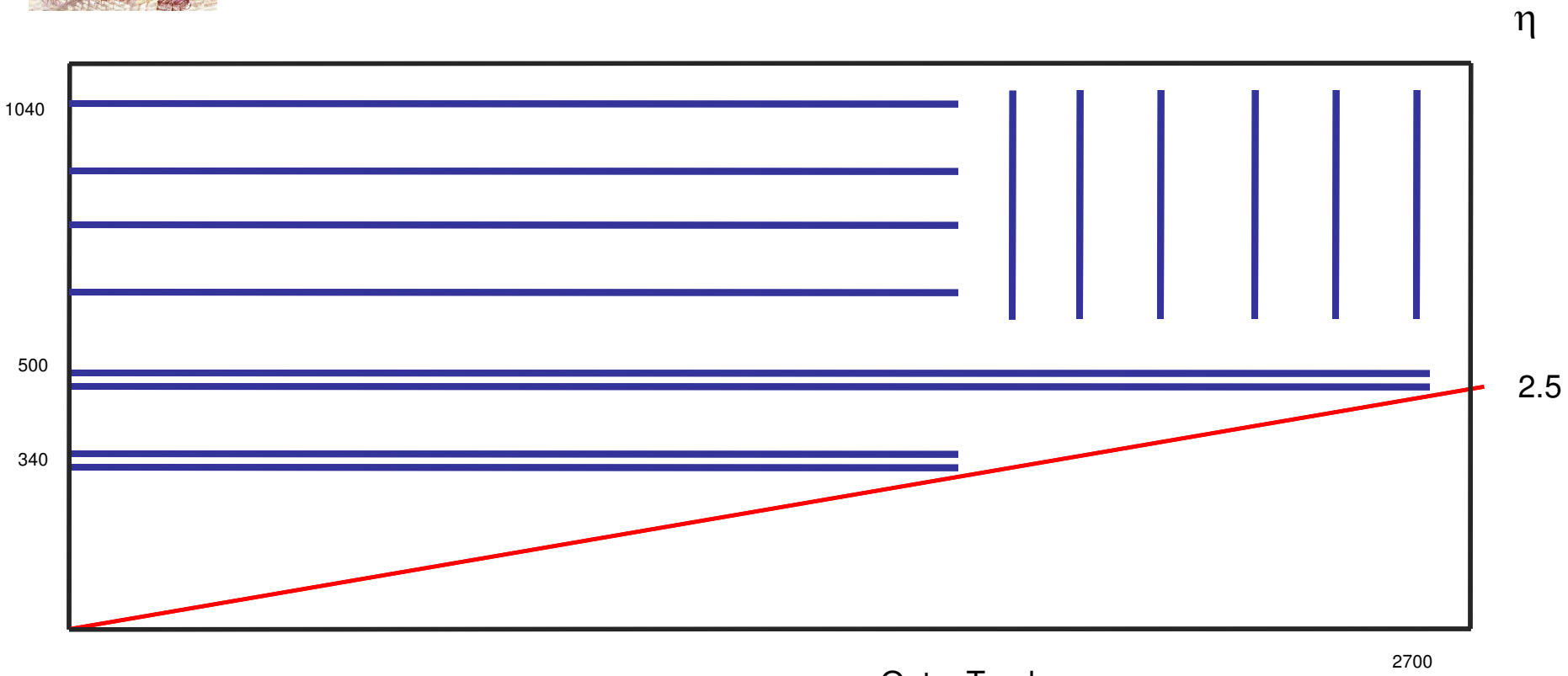
R-Phi Hermitic Double Stacks:
Get all 4 hits from a track in one ROD or in the neighbor

No communication across r-phi stacks



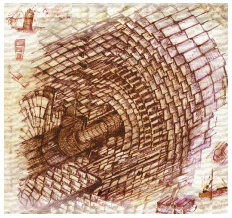


Example of Hybrid Straw Man Layout: 2 Double Stack Layers + Outer Tracker

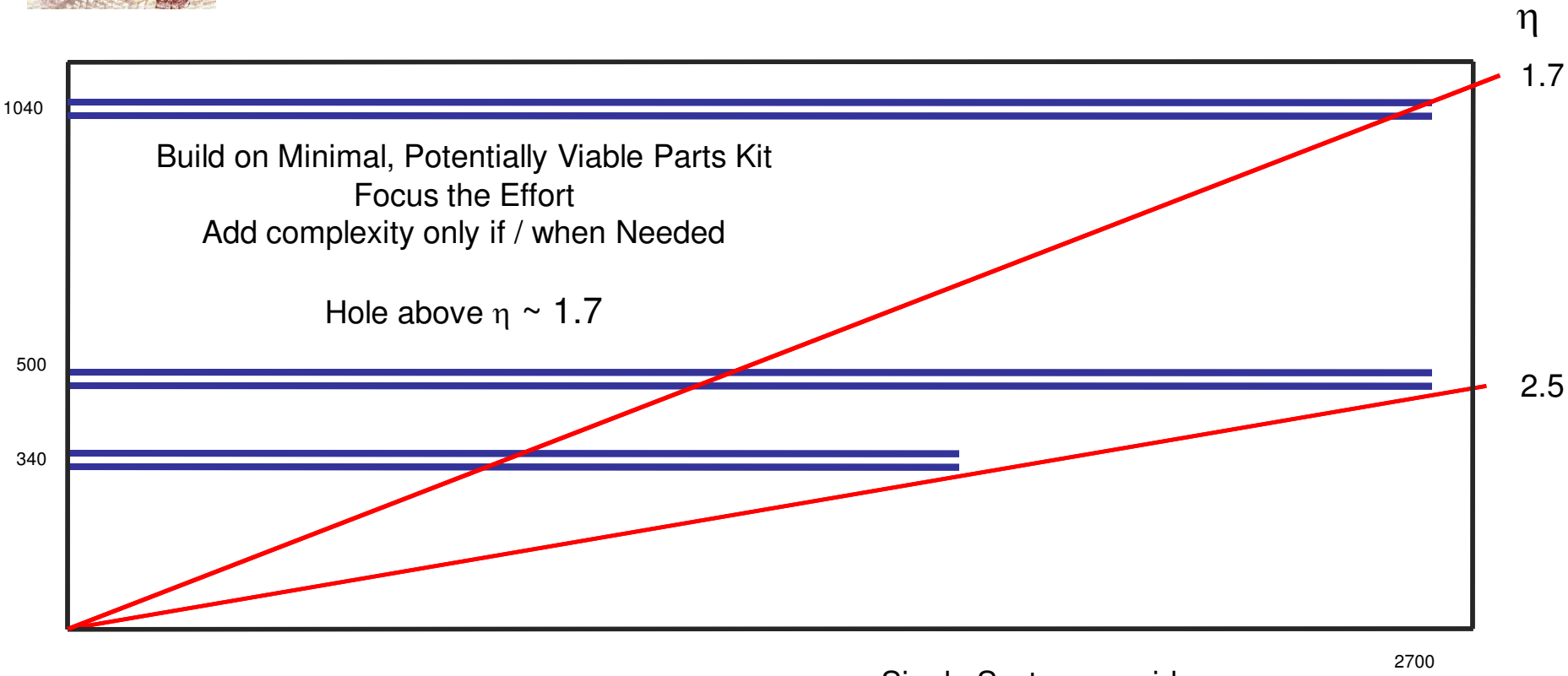


2 Double Stack L1 & Tracking Layers,
with full acceptance up to η ~ 2.5:
Each Layer provides 2 * 2 = 4 hits
2 Layers = 8 hits

Outer Tracker:
Optimized for Tracking
No L1 functionality
Introduces 3'rd System, in two "flavors"

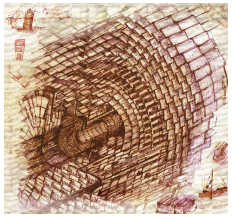


Long Barrel Straw Man Layout: 3 Double Stack Layers

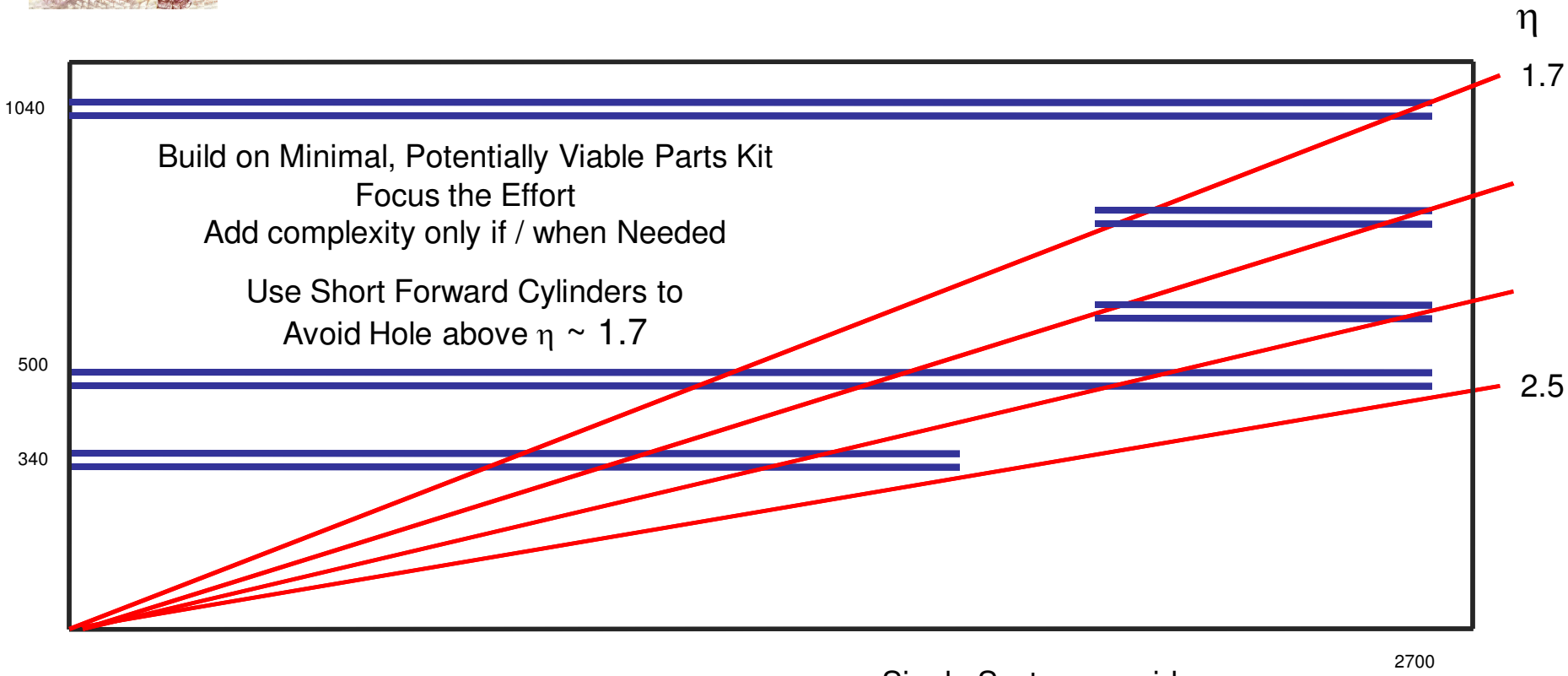


3 Double Stack L1 & Tracking Layers,
with full acceptance up to η ~ 1.7:
Each Layer provides 2 * 2 = 4 hits
3 Layers = 12 hits

Single System provides
Full L1 & Tracking functionality

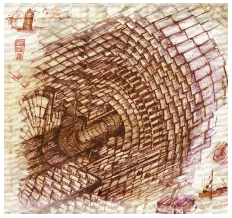


Long Barrel Straw Man Layout: 3 Double Stack Layers + 2 Short Fwd Barrels

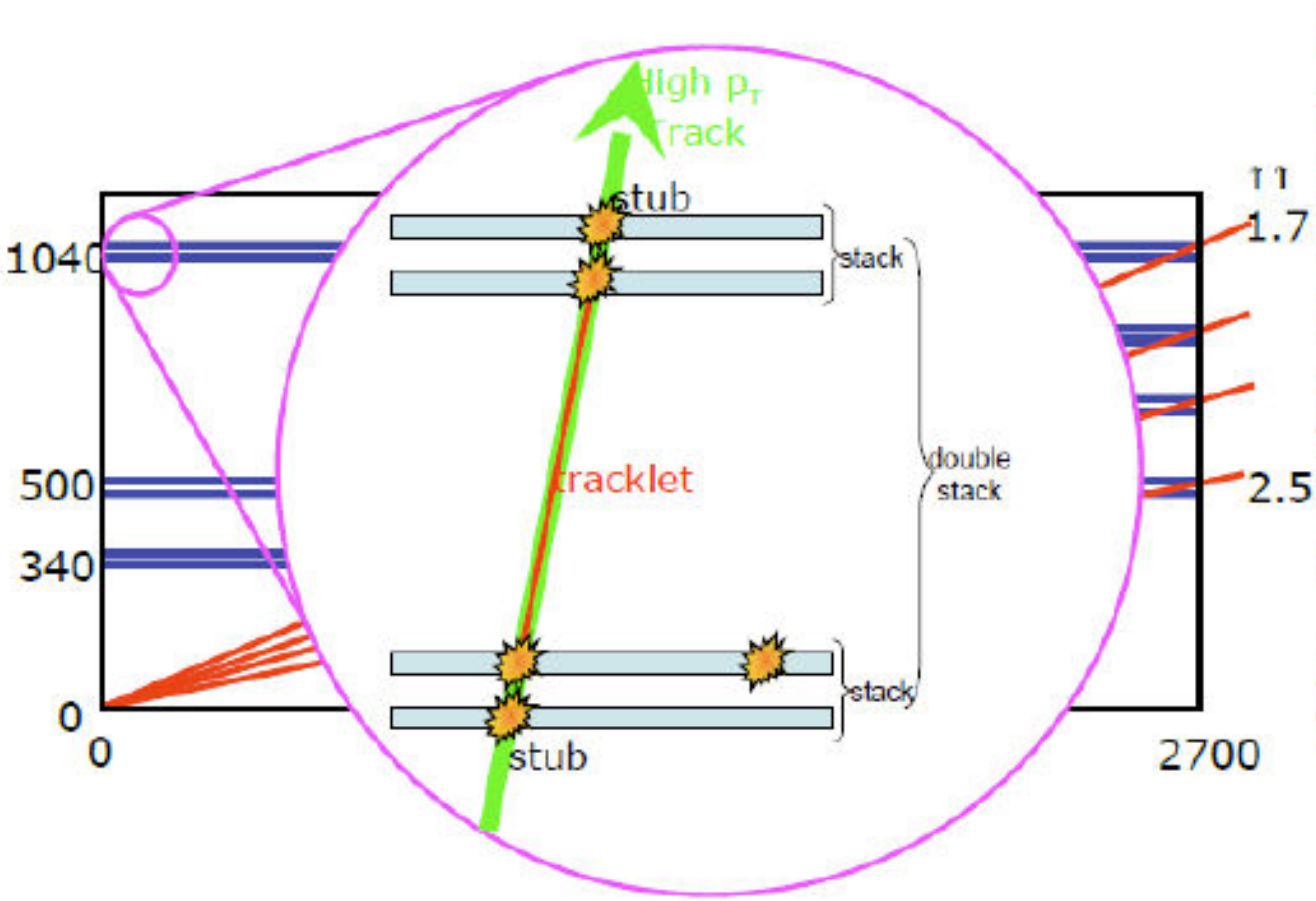


3 Double Stack L1 & Tracking Layers,
with full acceptance up to η ~ 2.1:
Each Layer provides 2 * 2 = 4 hits
3 Layers = 12 hits

Single System provides
Full L1 & Tracking functionality
Short FWD Cylinders close acceptance
Total Silicon Surface ~ 375m^2
Present Tracker ~ 210m^2



Long Barrel Straw Man Layout: 3 Double Stack Layers + 2 Short Fwd Barrels



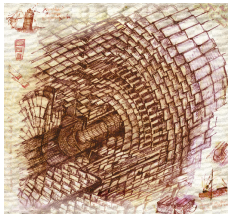
Stack: pair of closely spaced sensors (~1mm)

Stub: correlated pair of hits in stub

Double stack: Two stacks separated by few cm.

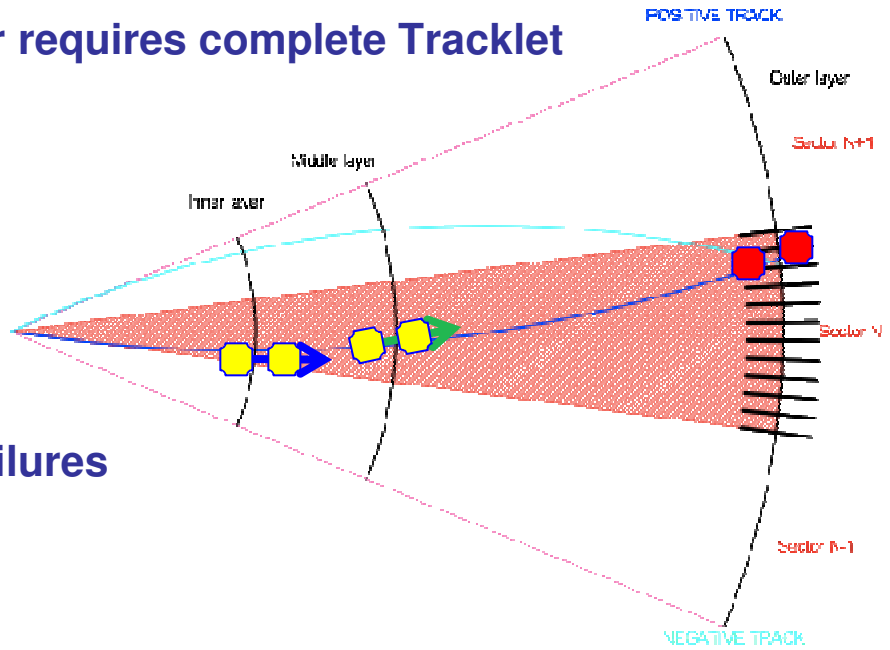
Tracklet A matched pair of stubs.

A layer is one stack in this talk.



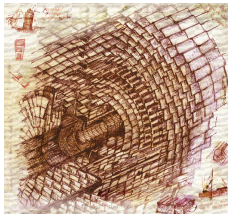
Use Tracklets from a Double Stack Layer to project onto other layers & find matching Stubs and/or Tracklets

- **For example, project Tracklets from inner 2 layers to outer layer segment (independently)**
  - **Projection from an Inner Layer requires complete Tracklet**
    - 2/2 Stubs, 4/4 Clusters
  - **Outer layer uses stubs**
  - **Reduces effect of hardware failures**



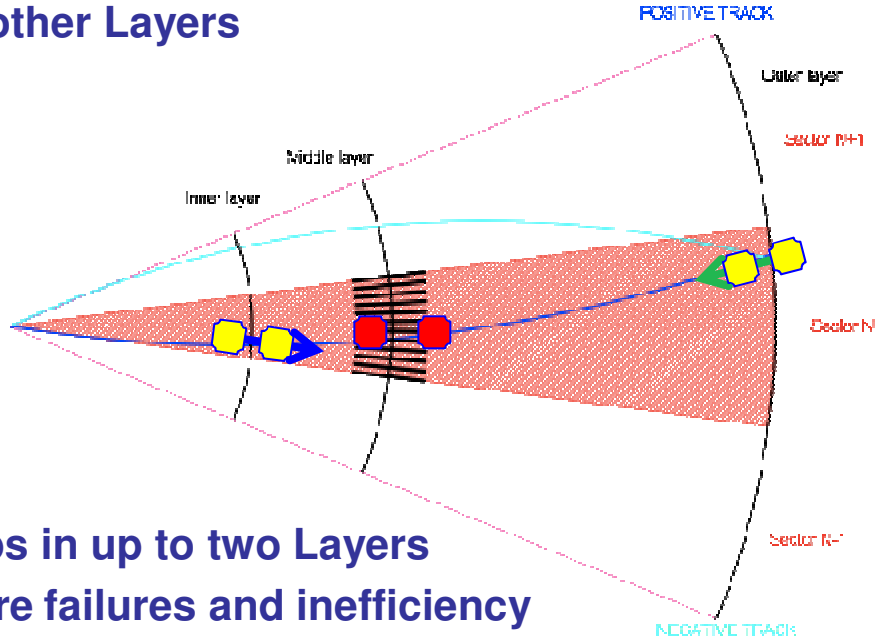
- **Segments must overlap due to imprecise projection**

M. Johnson, U. Heintz et al
See presentation by U. Heintz



Use Tracklets from a Double Stack Layer to project onto other layers & find matching Stubs and/or Tracklets

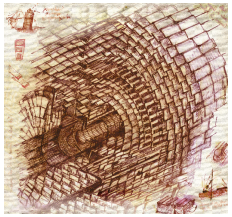
- **Repeat for the other Layers (independently)**
  - With this scheme Tracklets in a given layer can be put into coincidence with Tracklets or Stubs in the other Layers



  - Recover possible missing stubs in up to two Layers
  - Minimize sensitivity to hardware failures and inefficiency

- **Must remove duplicates**

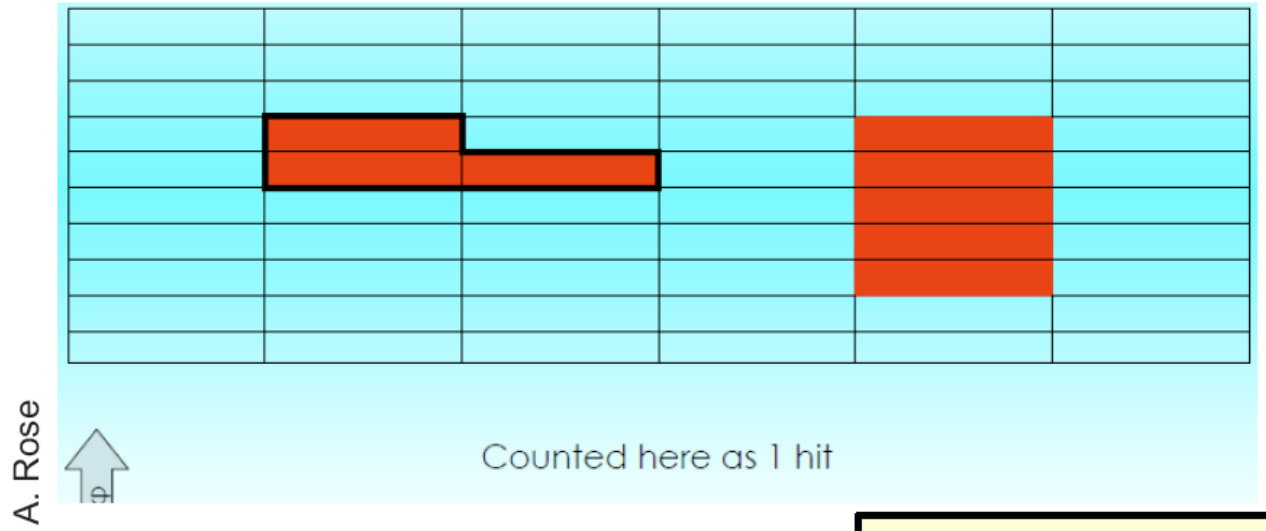
M. Johnson, U. Heintz et al
See presentation by U. Heintz



Track Trigger Primitive Simulations

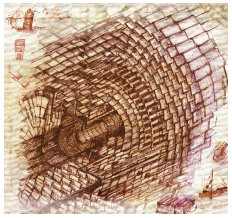
Available Clustering Algorithms:

- **2D clustering algorithm with width cut:**



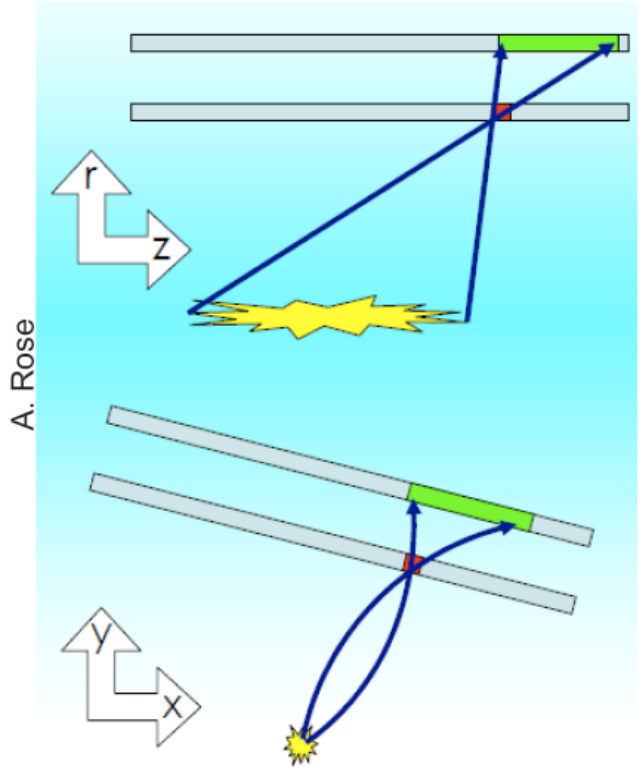
Further clustering algorithm work is ongoing

Good clustering performance, but clusters with width>2 are supressed, causing inefficiencies



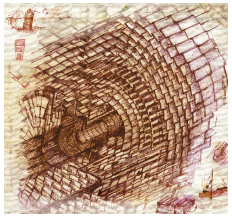
Track Trigger Primitive Simulations

Construction of Track Trigger Primitives:



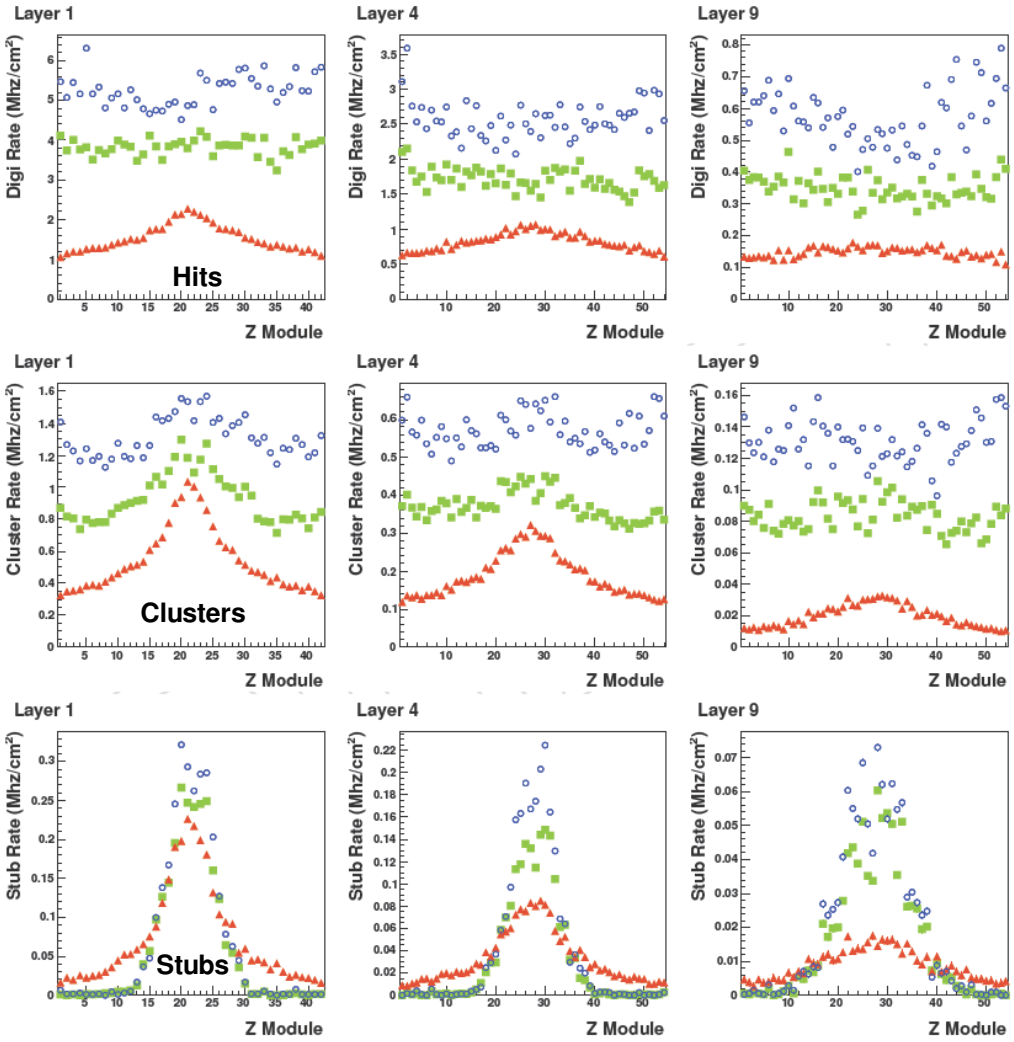
- CMSSW packages exist to create Track Trigger Primitives:
- Stubs and are formed from pairs of hits (SimHits or PixelDigis) on neighboring sensors based on matching windows in r-phi and r-z
- Tracklets are formed from pairs of stubs on neighboring stacks, also using matching windows in r-phi and r-z

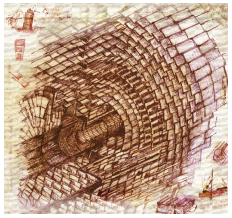
https://twiki.cern.ch/twiki/bin/view/CMS/TrackTriggerHitsAndStubs



Track Trigger Primitive Simulations

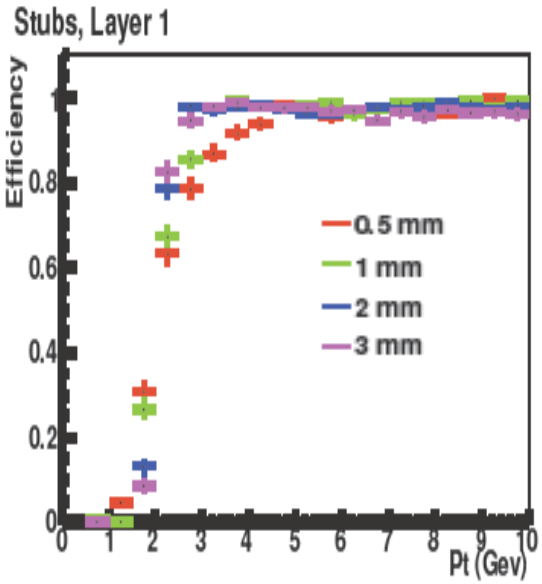
- **Comparison of**
  - Full Simulation
  - Full Sim no ou-of-time PU
  - Fast Simulation
- **Detailed Simulations in place**
- **There still remain**
  - Substantial Discrepancies
  - Peculiar Features
- **=> Uncertainties in Rates…**
  - Work with Fast Simulation
  - Present thinking based on conservative assumptions

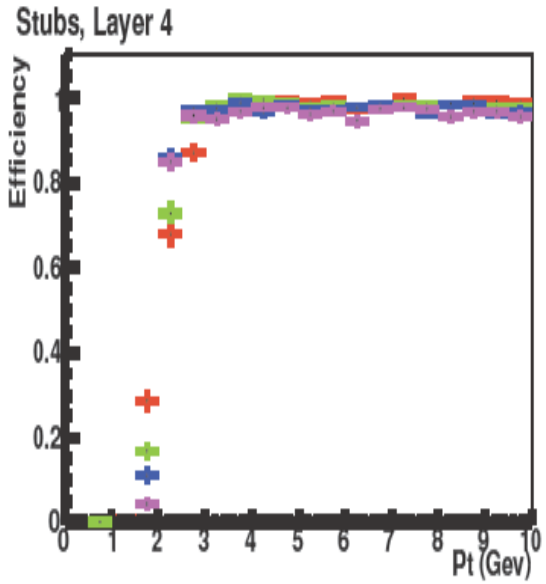


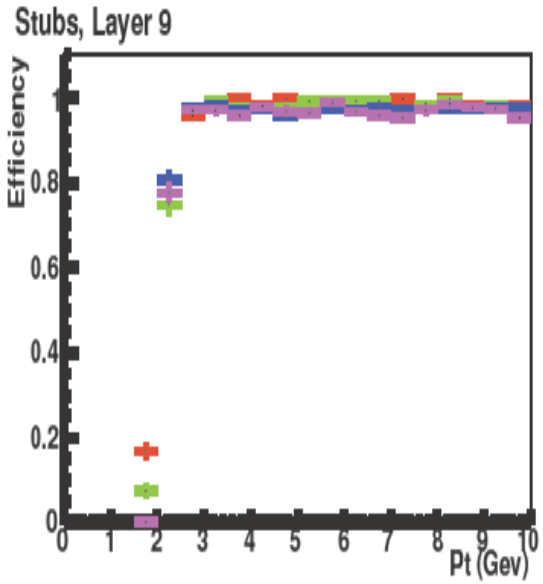


Track Trigger Primitive Simulations

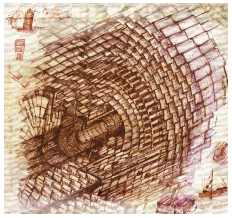
- **Simulated threshold curves for Stubs and Tracklets, with 2GeV pt acceptance cut, for various sensor separations within a Stack, in different Barrel Layers**





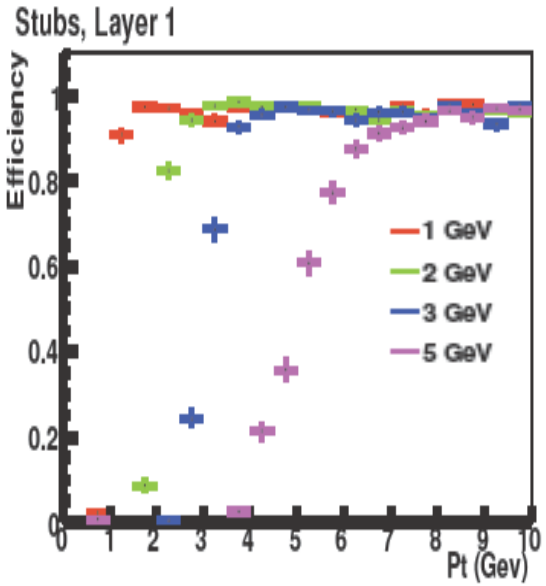


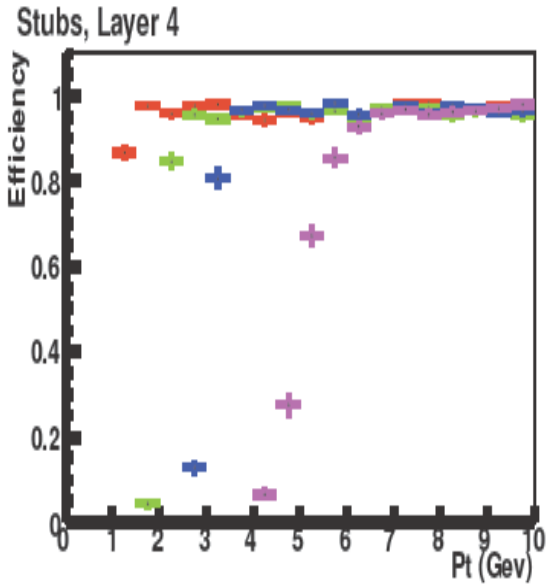
  - **The Pt thresholds are sharper at larger radii, as expected**

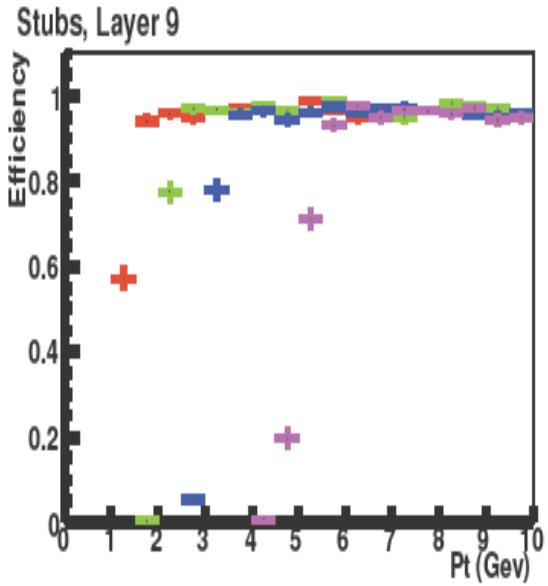


Track Trigger Primitive Simulations

- **Simulated threshold curves for Stubs and Tracklets, with a 1mm Sensor separation within a Stack, for various Pt acceptance cuts, in different Barrel Layers**







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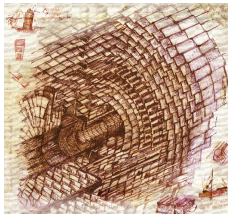
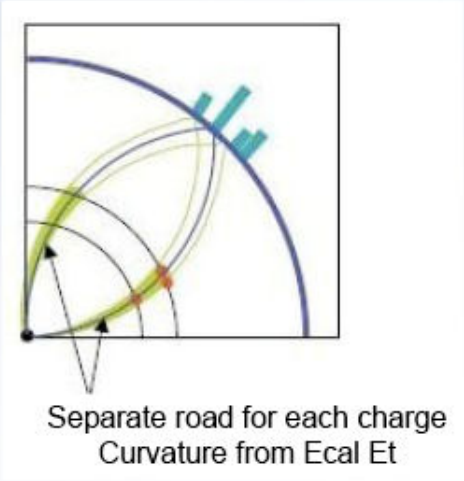


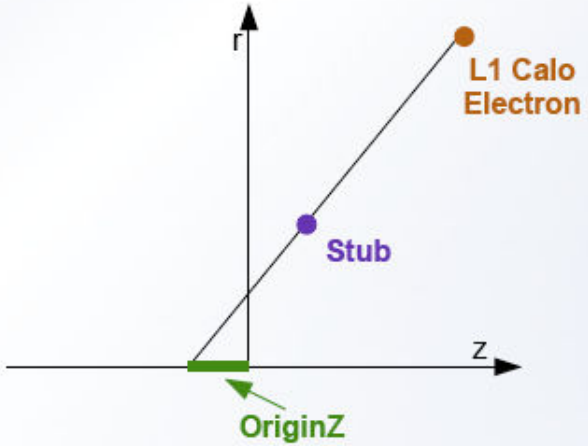
Illustrative Performance Studies: Single Electrons

Electron Algorithm

L. Fields

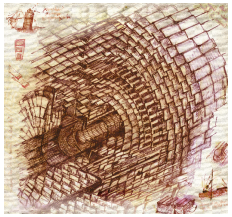
First Step: identify all stubs in two broad "roads" using ecal position and Et:





Hit are identified through two variables:

- Δφ: width of roads in r-φ
- originZ: z intercept of line connecting cluster and hit in r-z

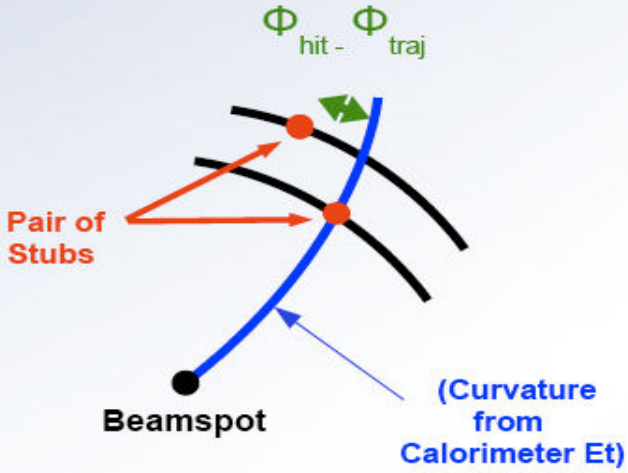


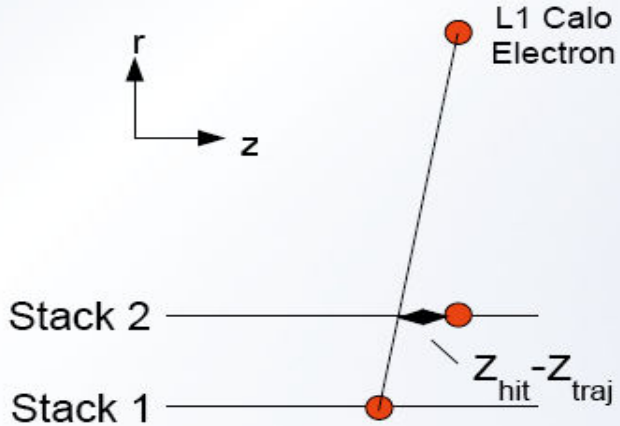
Illustrative Performance Studies: Single Electrons

Electron Algorithm

L. Fields

Second Step: identify **pairs** of hits consistent with cluster

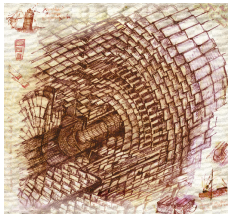




Hit pairs ("seeds") are identified through two variables

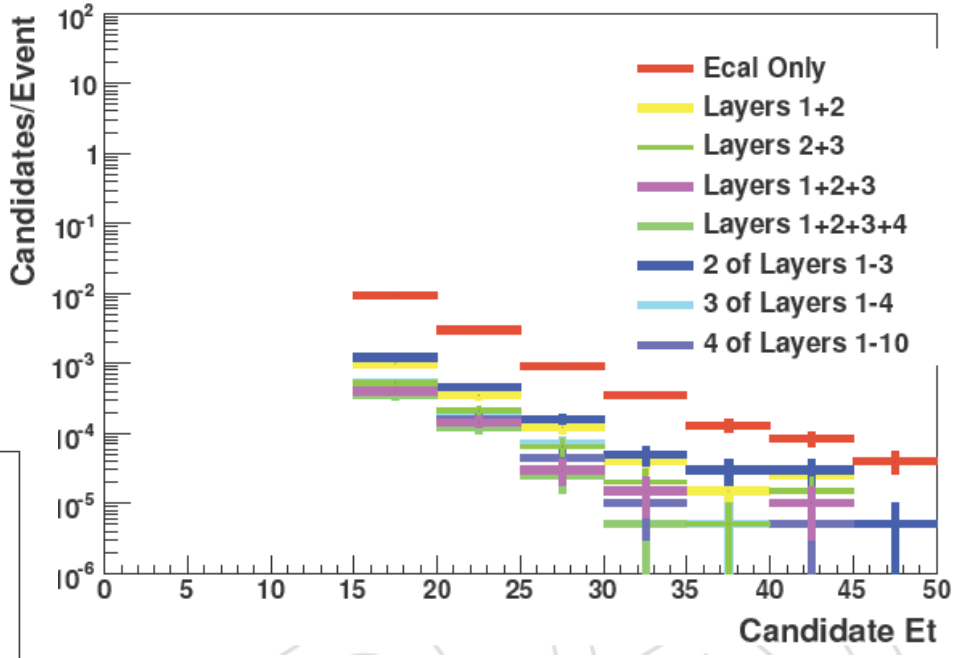
$$\Phi_{miss} = |\varphi_{hit} - \varphi_{traj}|$$

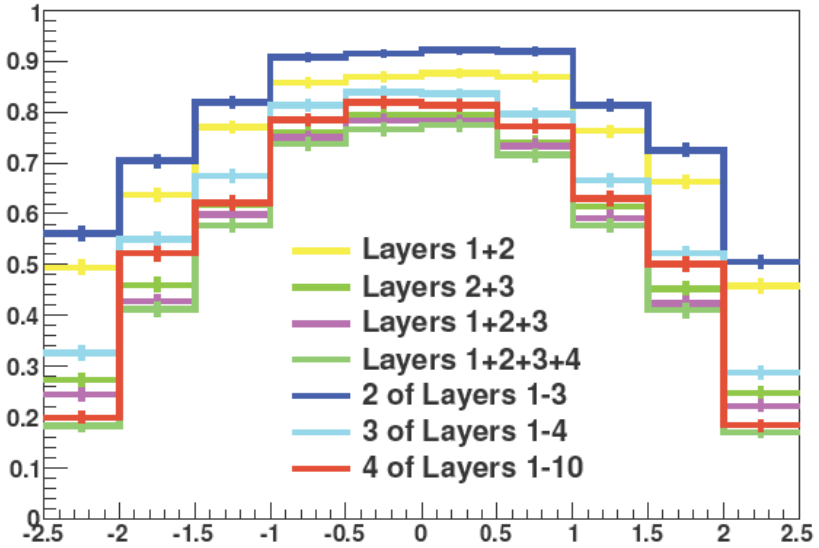
$$z_{miss} = |z_{hit} - z_{traj}|$$



Illustrative Performance Studies: Single Electrons

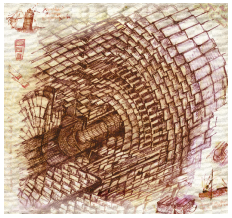
- Can obtain rate reductions by factor of 10 ~ 20 Using a variety of layer combinations





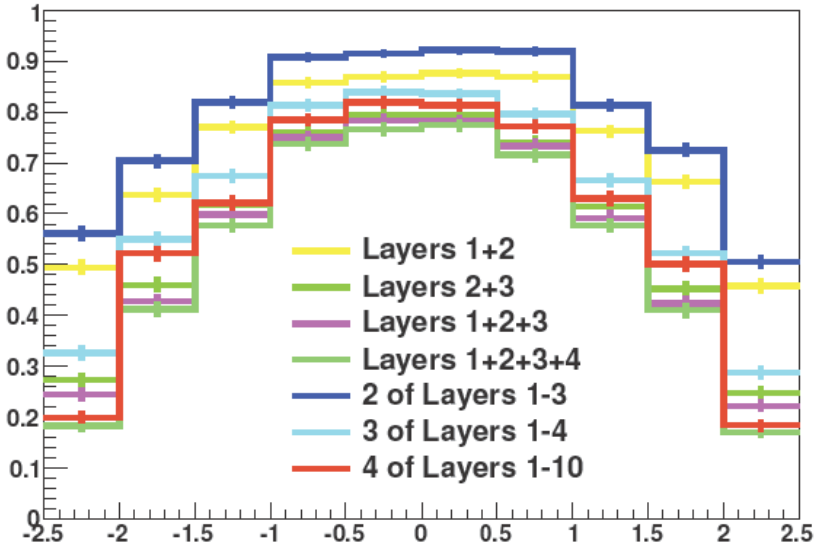
- There is substantial inefficiency in particular a higher η

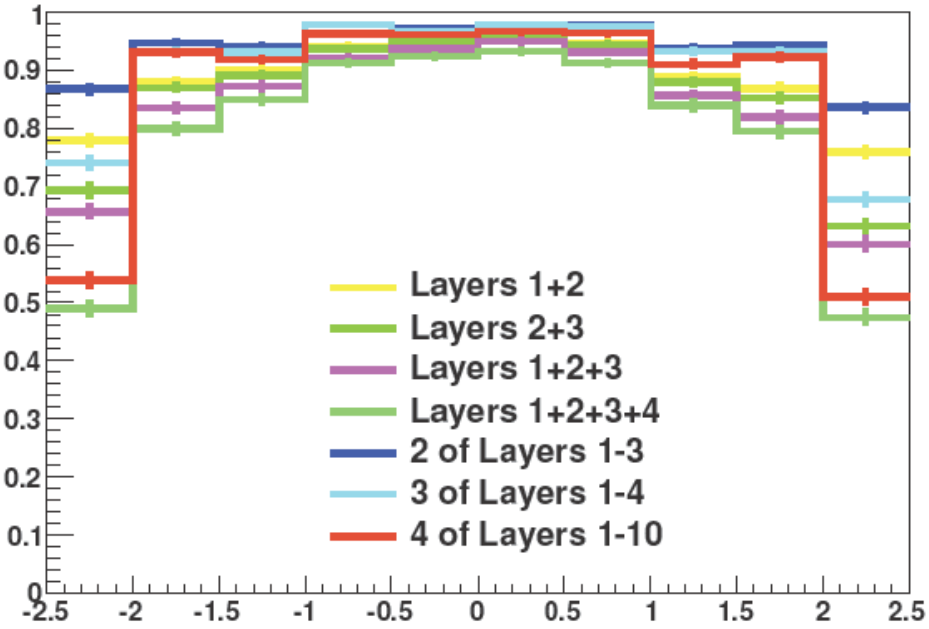
L. Fields et al



Illustrative Performance Studies: Single Electrons

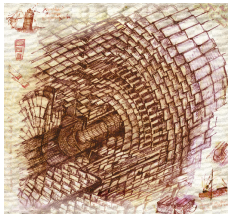
- The efficiency is ~ 95% if Tracker Material removed…
- Material budget is crucial for Electron-Photon Triggers



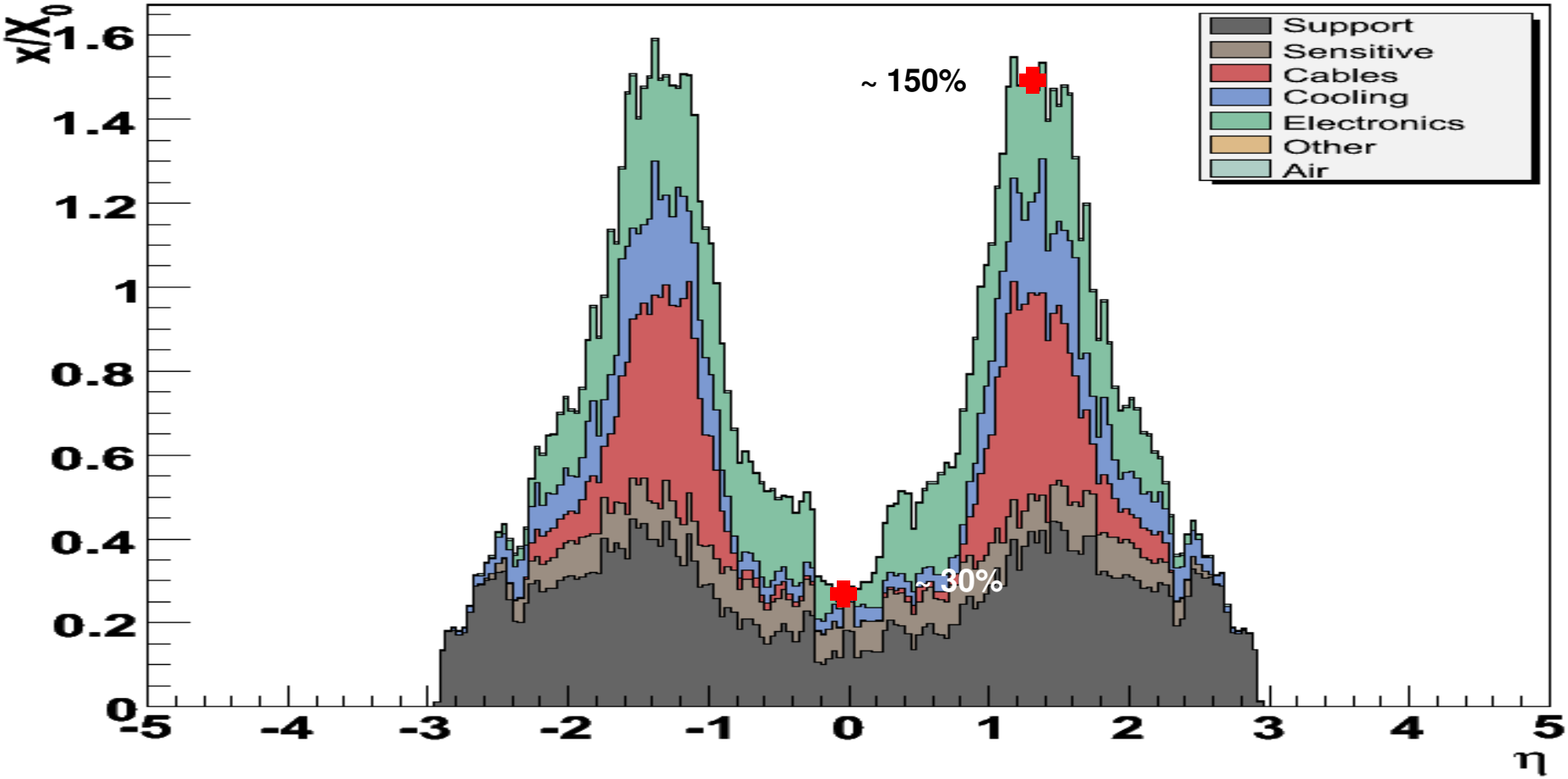


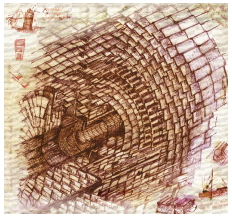
- There is substantial inefficiency in particular a higher η

L. Fields et al



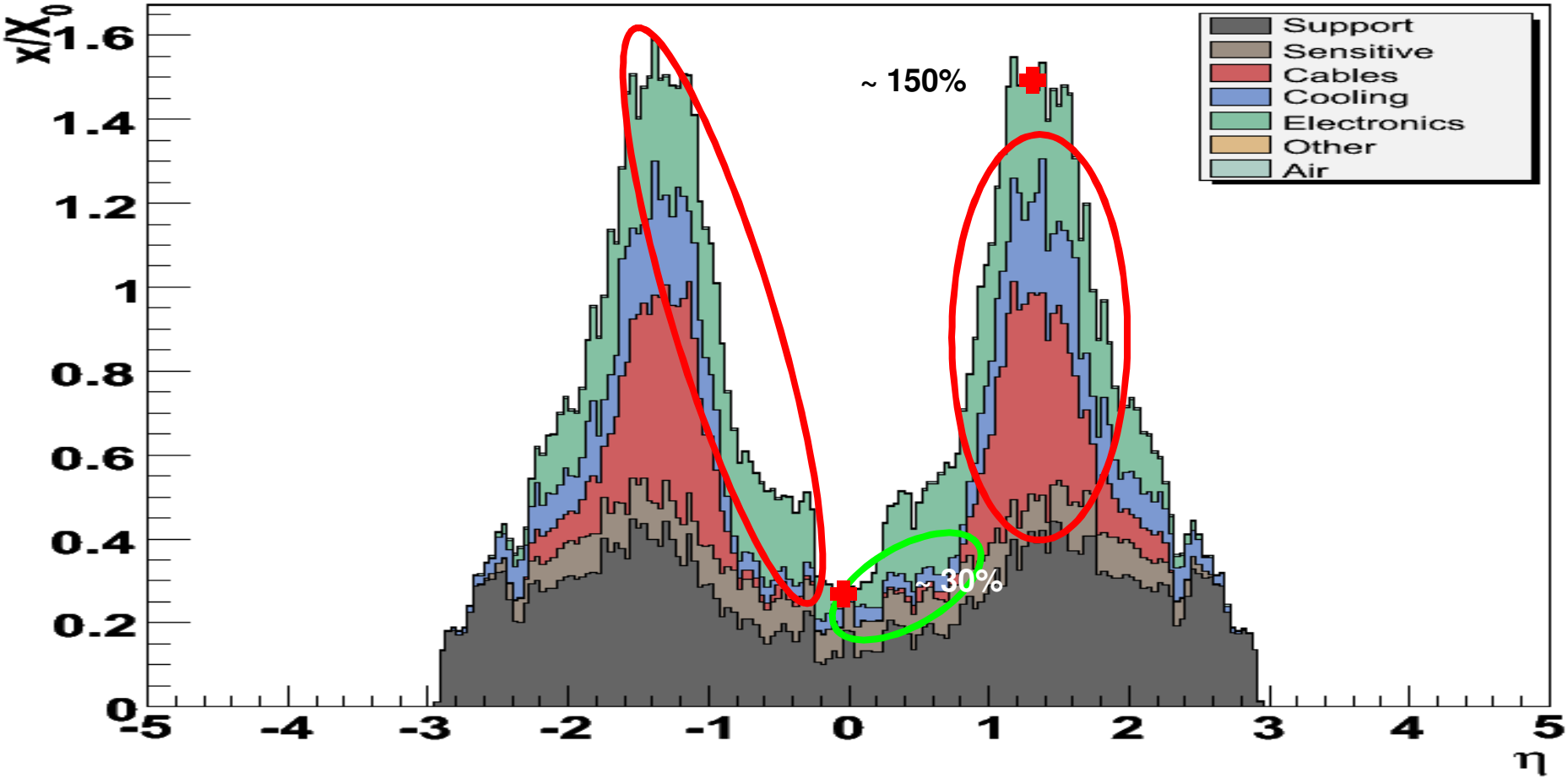
Material Budget
The CMS All Silicon Strip Tracker

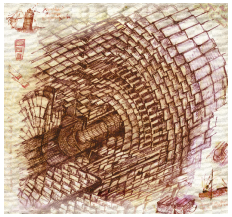




Material Budget
The CMS All Silicon Strip Tracker

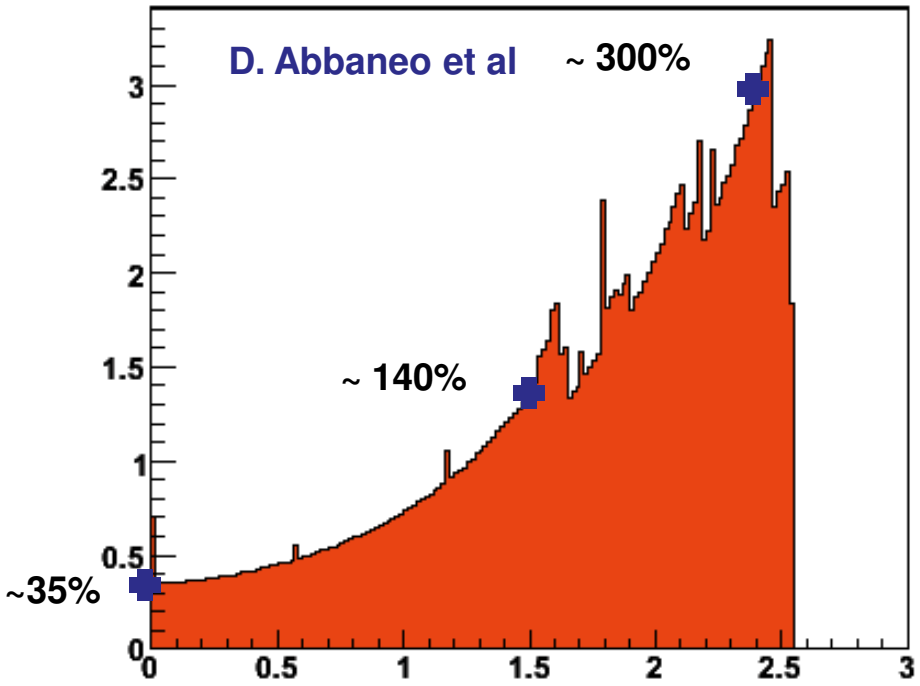
In the present Tracker, pipes & cable are relatively light within Barrels
They blow up when exit barrels: connectors, manifolds, routing
There is a lot of "Electronics": Inter-Connect Boards, Opto-hybrids, CCU etc

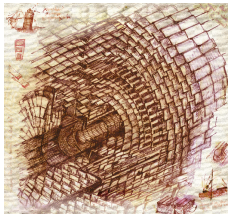




Material Budget
Long Barrel Straw Man, First Estimate

- **Estimate based on present developments + existing objects**
  - **Deliberately "not excessively optimistic" assumptions**
  - **Excessively heavy, especially for $\eta > 1.6$**
    - **Power & Cooling dominate: ~80kW FE chips + ~ 70kW Data links = 150kW Total**





Material Budget
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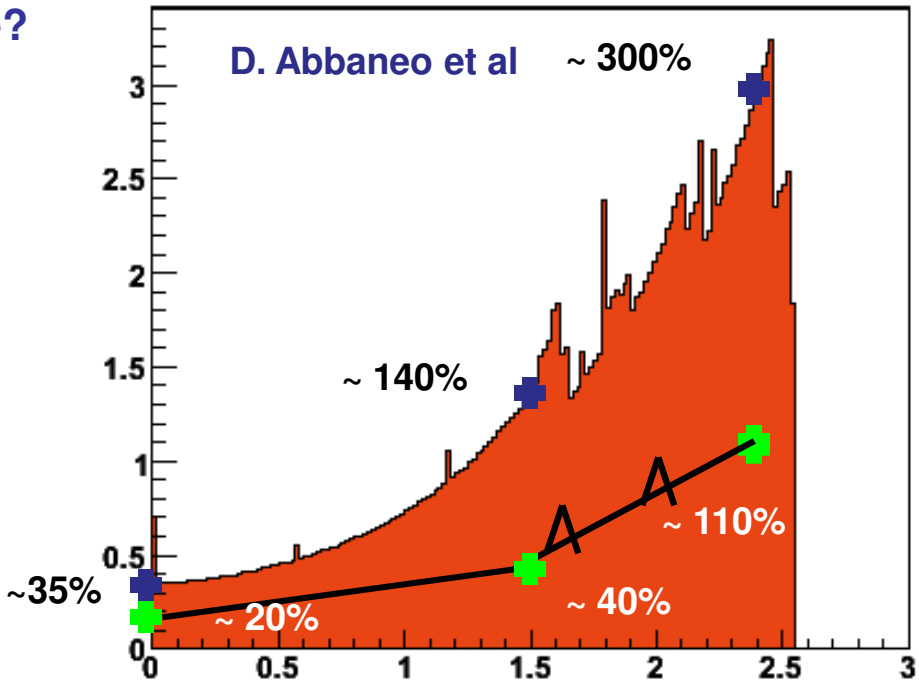
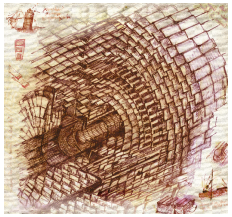
  - **Attractive, if achievable**





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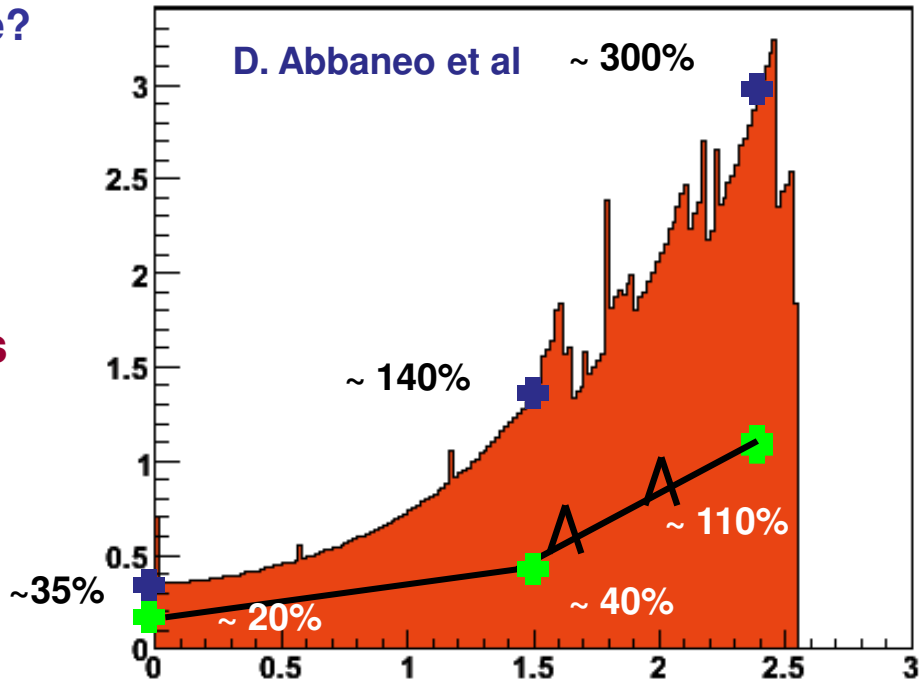
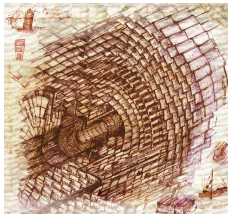
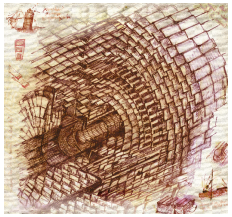
- **Need Low Power High Band Width**
  - FE chips, Data Links
- **DC-DC and Low Mass Power Cables**
- **Efficient Low Mass Cooling (CO_2)**
- **Rigid Low Mass Mechanics**





Summary and Conclusions

- **Several potential layouts for an SLHC Outer Tracker are under study, incorporating Stacked Module Layers to provide an effective L1 Tracking Trigger capability for CMS**
  - **These range from Hybrid layouts with a minimal deployment of Stacked Module Layers, complemented by ~ conventional (but improved, lighter) Tracking Layers**
  - **To a Long Barrel layout, entirely based on Stacked Module Layers**
- **In the Long Barrel design, 3 Double Stack Layers are used to provide both L1 Tracking Trigger AND full Track Reconstruction**
  - **This layout provides L1 Tracklets, in addition to Stubs, in a "local" and computationally efficient way, which provide good High Pt discrimination and which can be combined across layers**
  - **Detailed simulation studies are ongoing. So far, the basic assumptions on which this layout is based appear to be validated**
  - **This layout appears to have the potential to provide the required L1 Trigger performance, as well as the required Tracking performance**



Summary and Conclusions

- **These stacked layer designs are Technologically Challenging, and have motivated a number of R&D initiatives, aimed at meeting these challenges**
  - **Module Architecture and Packaging**
  - **Low Power Front End read-out electronics, with high bandwidth digital processing**
  - **Low Power, high bandwidth data links for local (electrical) and long-distance (optical) data transfer**
  - **DC-DC power distribution, with low mass cables etc.**
  - **Low mass evaporative CO_2 Cooling**
  - **Low mass mechanical supports and integration of Modules and Services**
  - **Etc.**
- **If Successful, could lead to a Next Generation of Tracker for CMS with Innovative Performance**