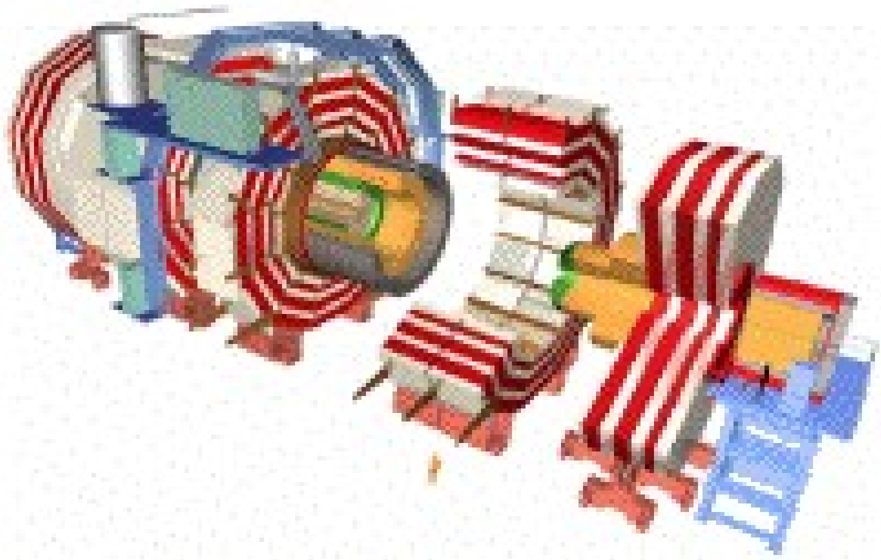
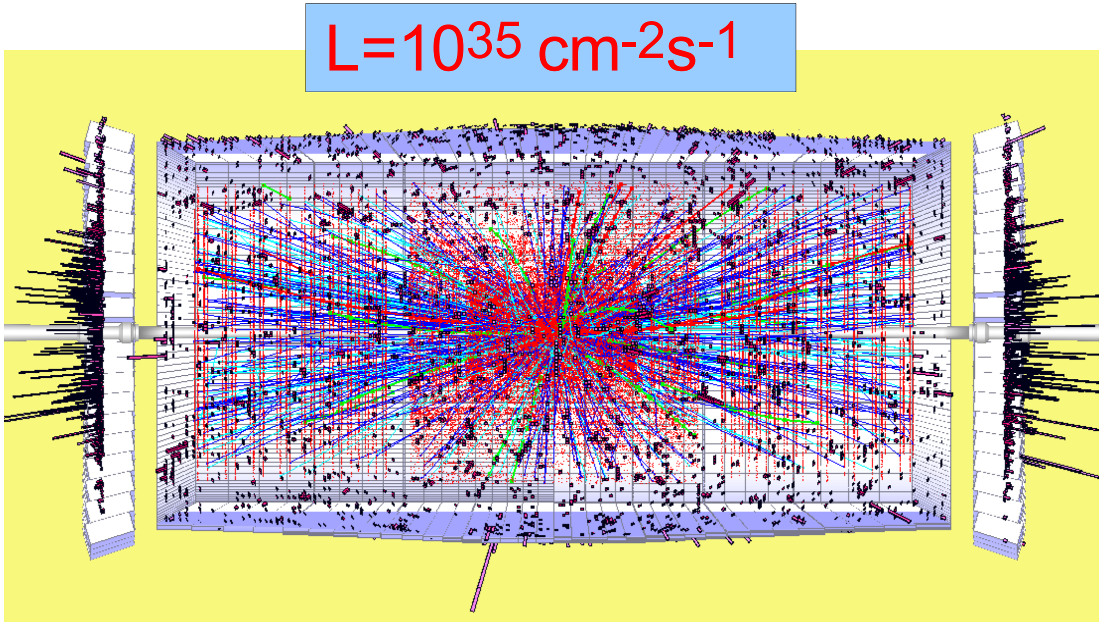
CMS L1 Track Trigger for SLHC



Anders Ryd
for the
CMS Track Trigger Task Force

Vertex 2009
Sept. 13-18, 2009



$L=10^{35}\ cm^{-2}s^{-1}$

Outline:

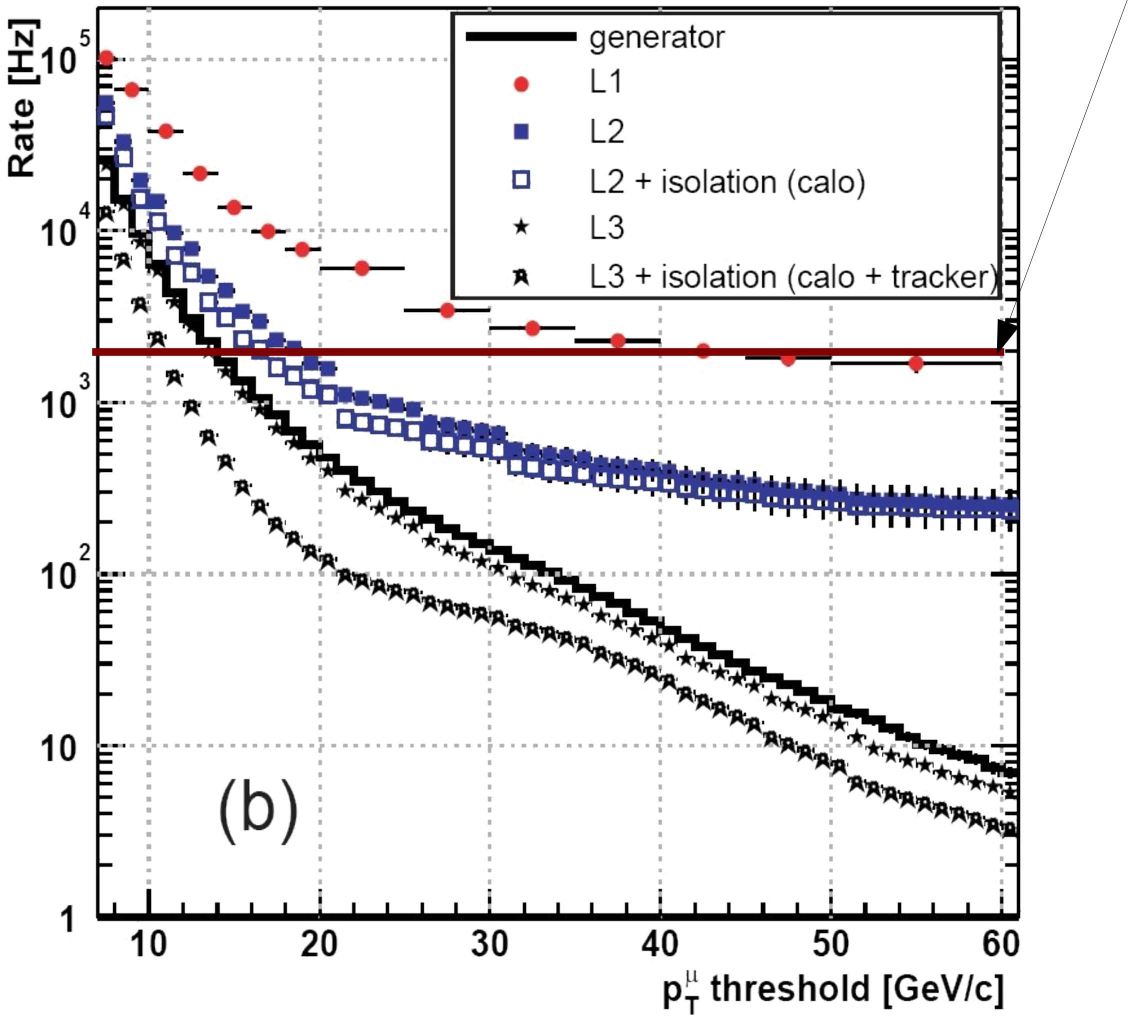
- SLHC trigger challenge
- Tracking triggers
- Track trigger modules
- Simulation studies

CMS Trigger and DAQ

- The current CMS trigger consists of two levels:
  - The L1 hardware trigger reduces the rate from 40 MHz to 100 kHz.
  - The HLT (High Level Trigger) reduces the rate from 100 kHz to a few hundred Hz which are logged.
  - The L1 latency is currently 3.2 μs, this would be upgraded to 6.4 μs.
- Currently tracking information is only available in the HLT.
- The basic idea is to try to implement in L1 some of the algorithms that are currently run in the HLT.
- Keeping the L1 rate below 100 kHz.
  - As examples I will consider the single electron and muon triggers.

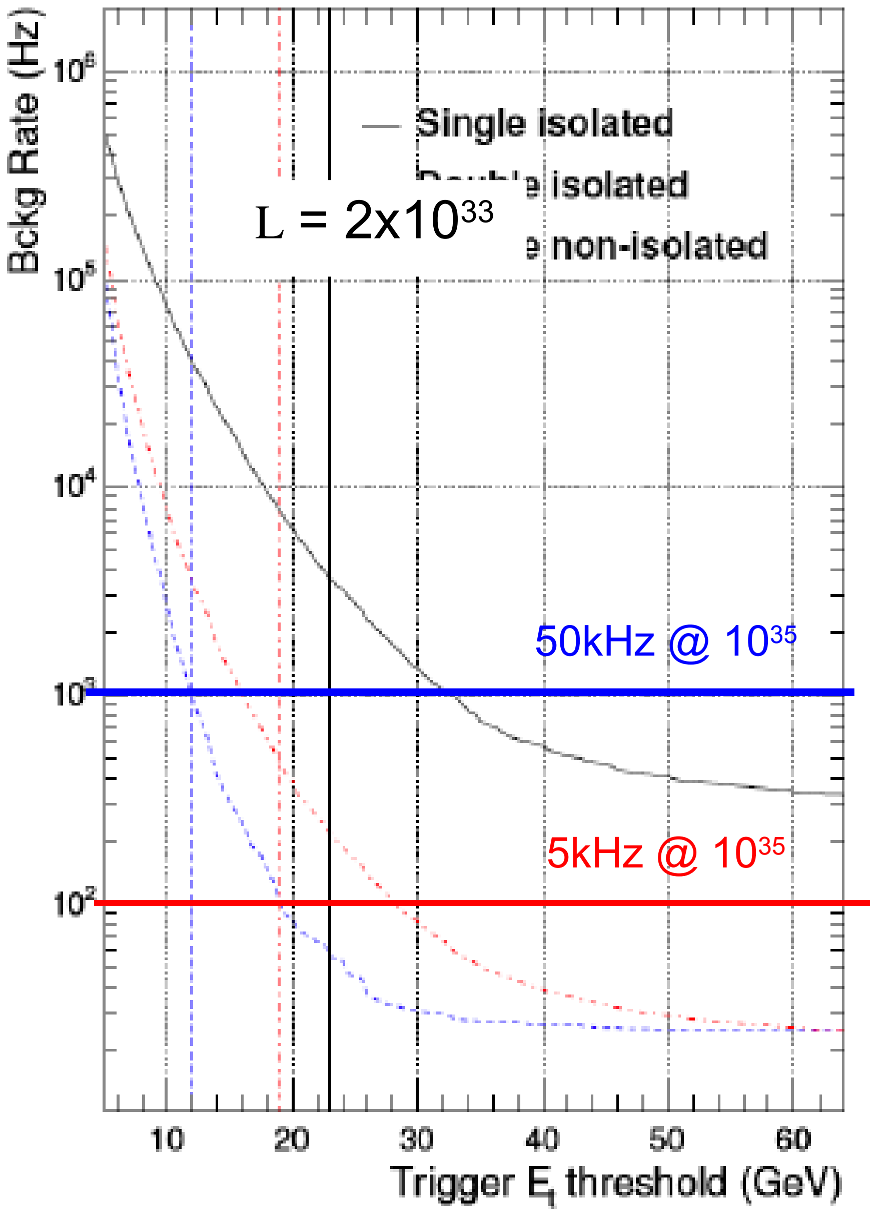
SLHC Muon Trigger Challenges

Muon rates at $L=10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$



- At $L=10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ we have a trigger rate of >20 kHz for muons.
  - The L1 rate is almost flat with p_T threshold
  - This is due to a poor momentum measurement in the L1 muon system
- Having tracking information available in L1 would allow a more precise momentum determination and L1 rate reduction.

SLHC Electron Trigger Challenges



- At $L=10^{35}$ cm^{-2}s^{-1} with a 30 GeV threshold we have a rate of over 50 kHz.
  - High rate of fake electrons from jets (π^0's)
  - We want to validate the electron candidates by looking for a matching track in the tracking detector.
- Currently done in the HLT, but we want to implement this in L1.

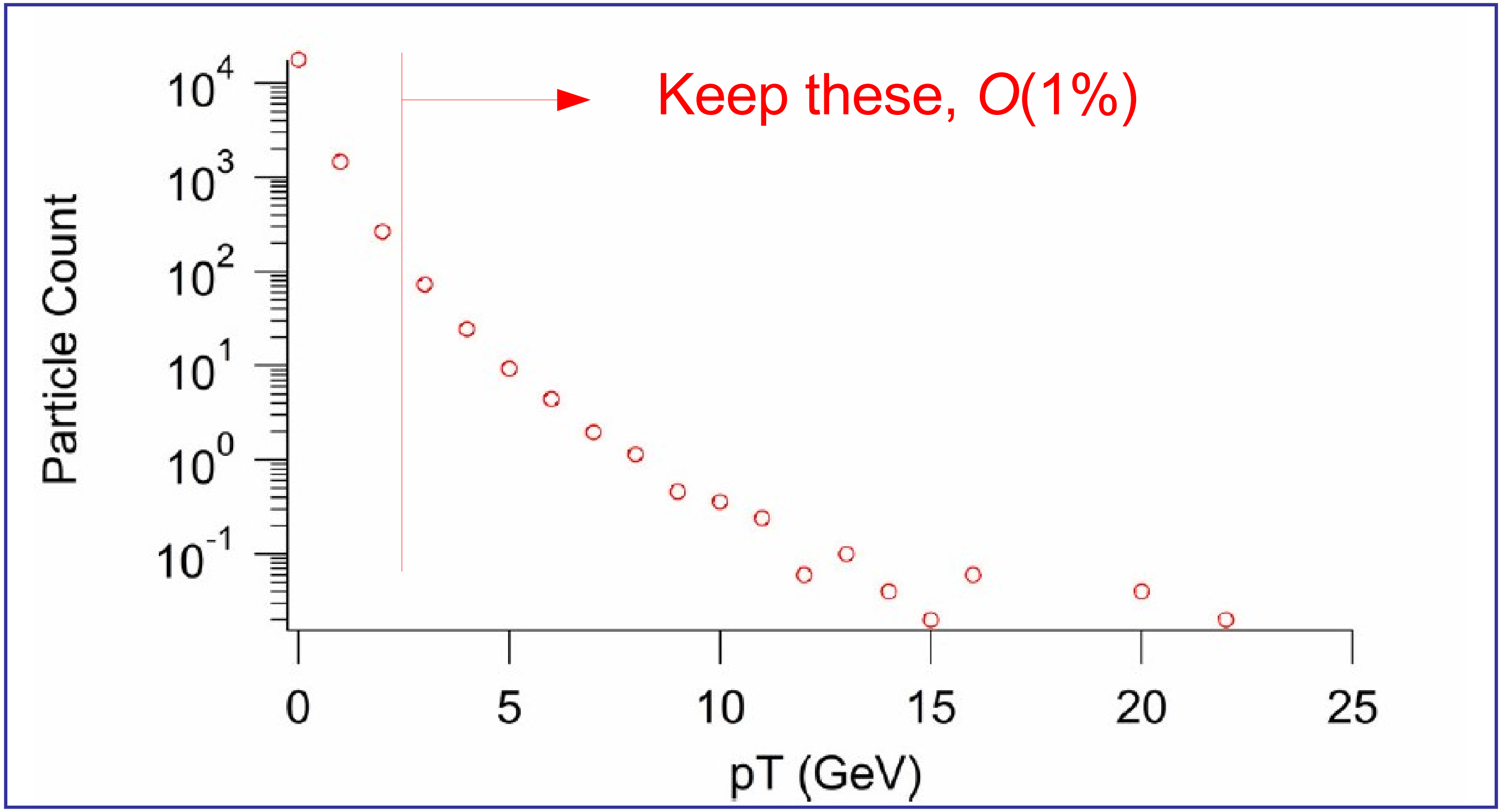
Track Trigger Goals

- From the examples discussed the track trigger has to provide hit information that can be matched to L1 electron and muons.
- In addition to this we would also like:
  - z-vertex determination to separate objects from different pp-interactions.
  - Ability to do track based isolation, *e.g.* for tau identification.
    - Need tracks down to ~2 GeV

- Can not compromise the tracking performance 'too much'.
  - I.e. we have to keep the material to a minimum.

Providing Tracking Data to L1

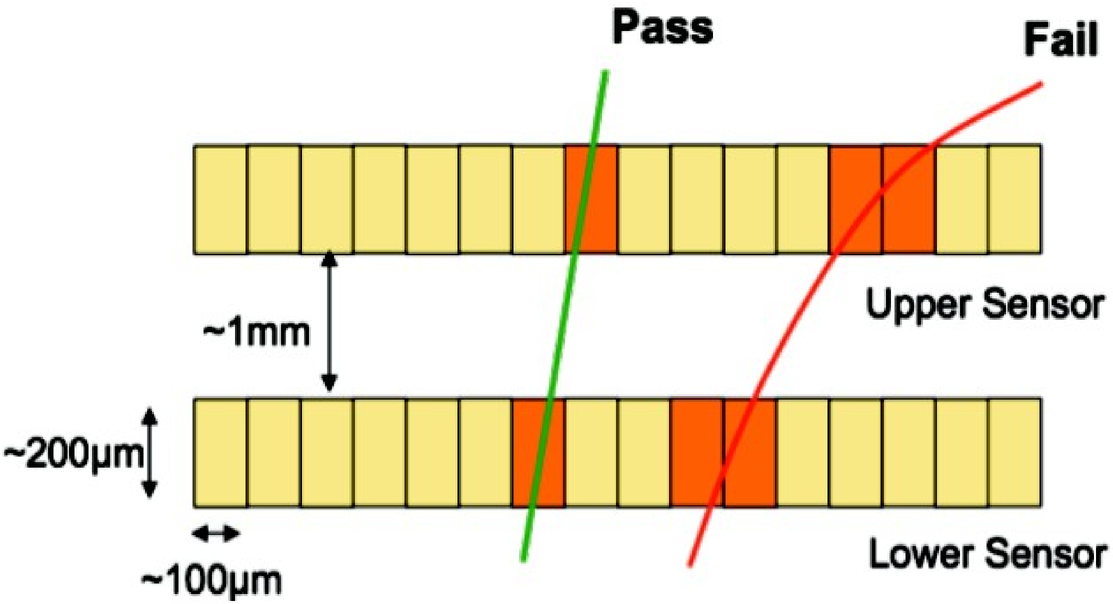
- The full data rate from the tracker can not be read out on every 40 MHz crossing
- Most hits are from relatively soft tracks. Rejecting hits from tracks with p_T below 1-5 GeV can reduce the data volume by a factor of 10 to 100.

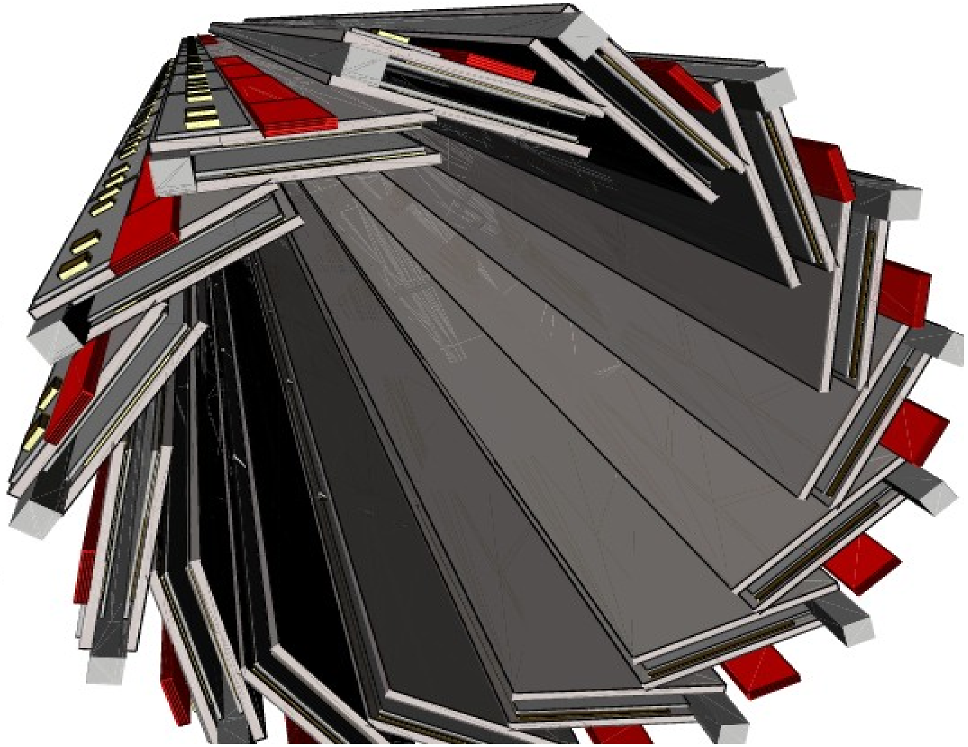


p_T Discrimination with Stacked Modules

- Use the 4 T magnetic field in CMS
- Low momentum particles bend in the magnetic field
- Require correlation in nearby layers – consistent with stiff track

J. Jones et al, 2005





Simulation Studies

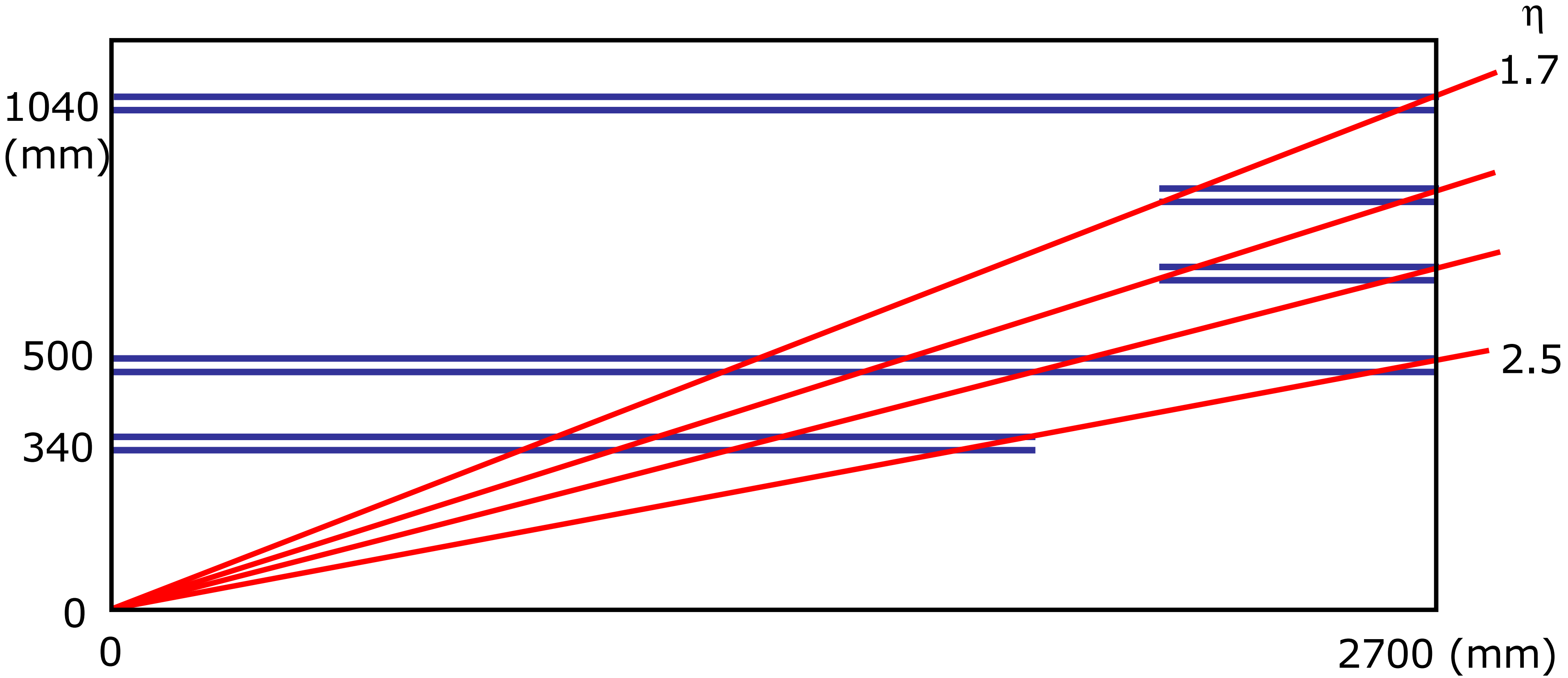
- To evaluate the performance of stacked modules a program to simulate the performance of the stacked modules has been started.
- Large parameter space:
  - Number of stacks and radii
  - Stack separation
  - Pixel pitch

- These studies are 'work in progress', I'll just show some examples of what we are doing for the electron triggers.

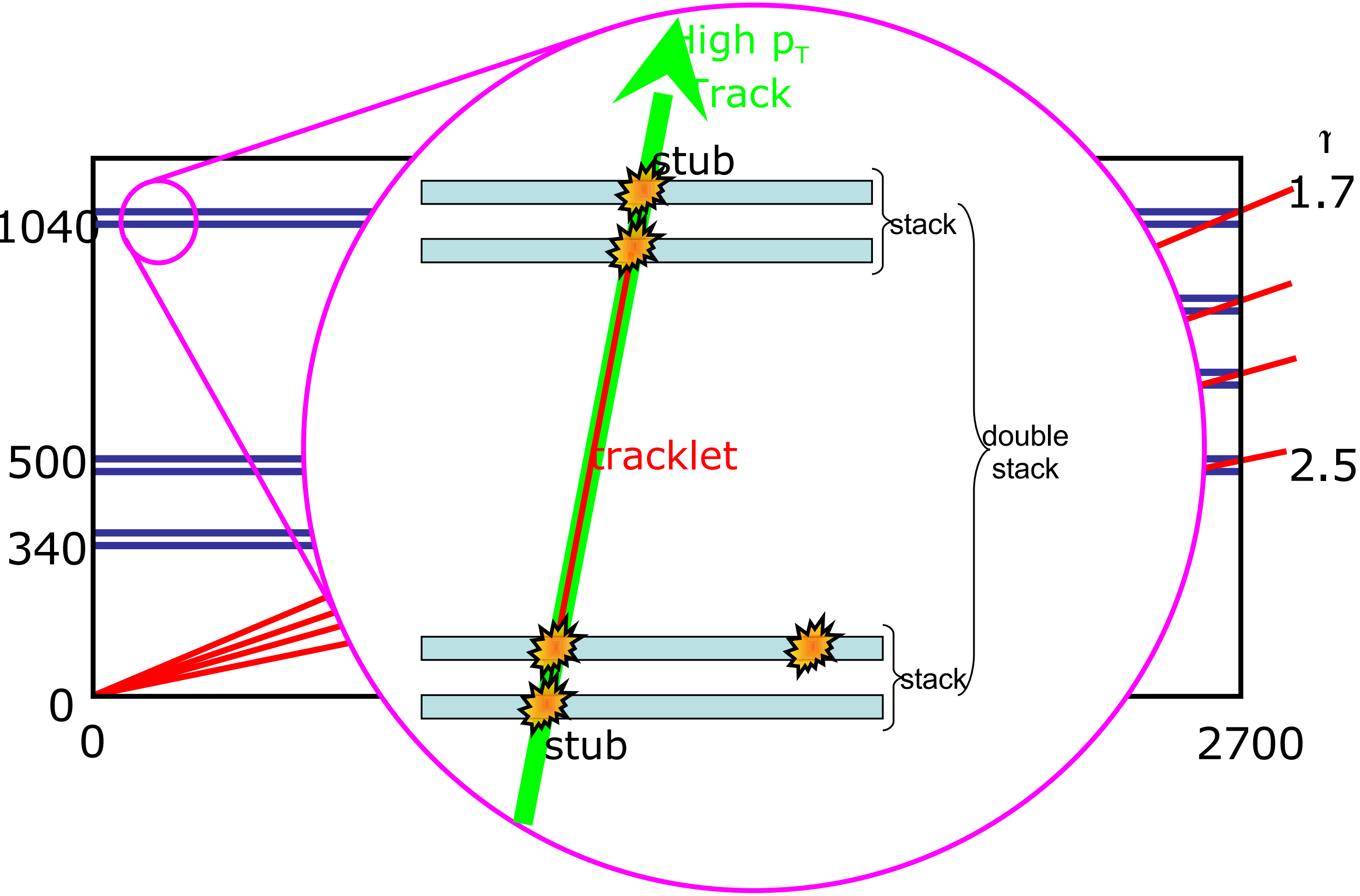
- Challenge with simulation of 200 to 400 PU. Currently using fast simulation.

'Long Barrel' Strawman

- Provides 'maximal' trigger information. All layers in tracker provide track trigger primitives.
  - 10 layers of stacks
  - organized as 5 double stacks with 4 cm separation



Nomenclature



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

Stub: correlated pair of hits in stack

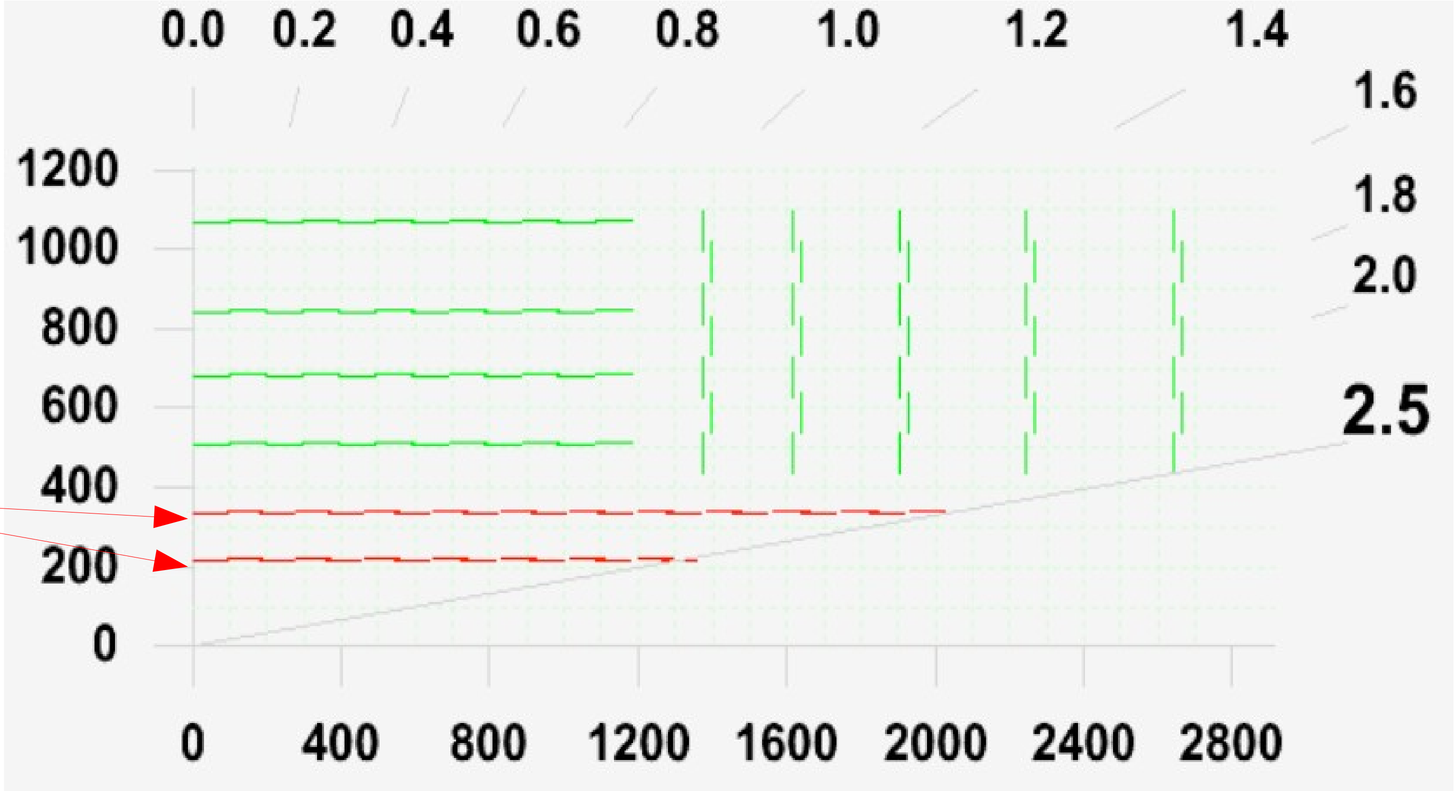
Double stack: Two stacks separated by few cm. Also referred to as a beam.

Tracklet A matched pair of stubs.

A layer is one stack in this talk.

“Hybrid” Strawman

- Minimal design; 2 stacked layers.
- Traditional tracker outside with barrel and endcaps.

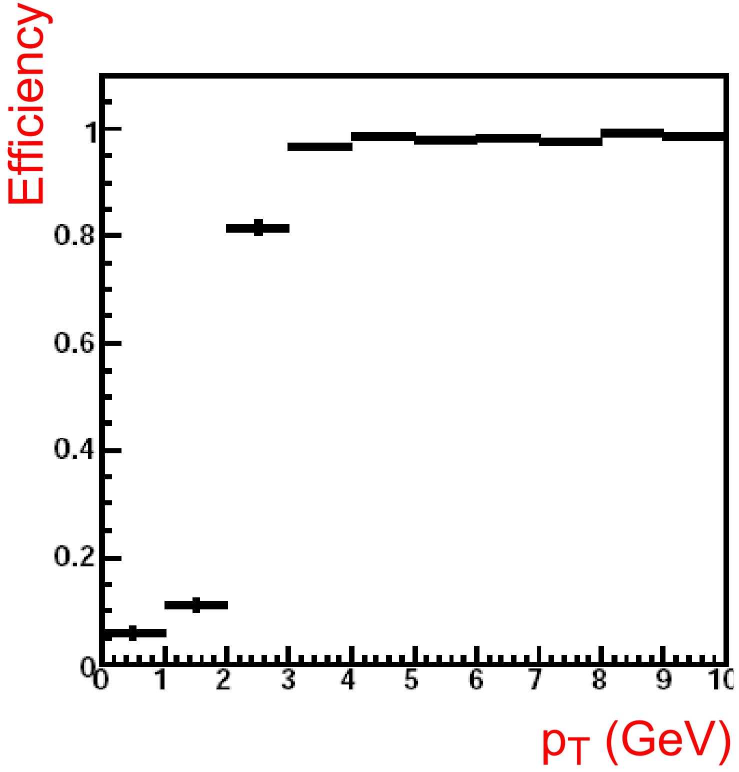


Trigger Primitive layers

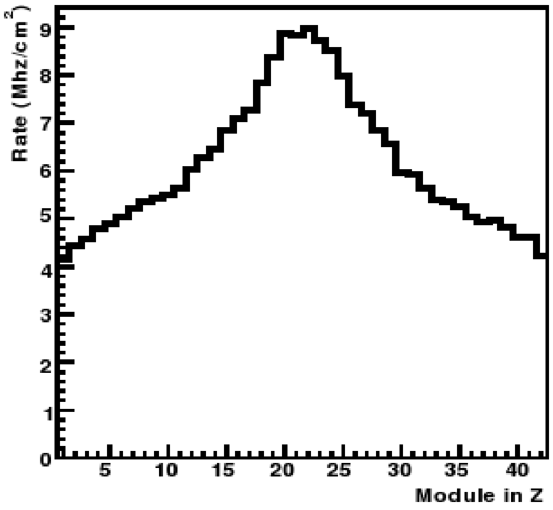
Track Trigger Simulations

- CMS are studying these layouts to understand the performance

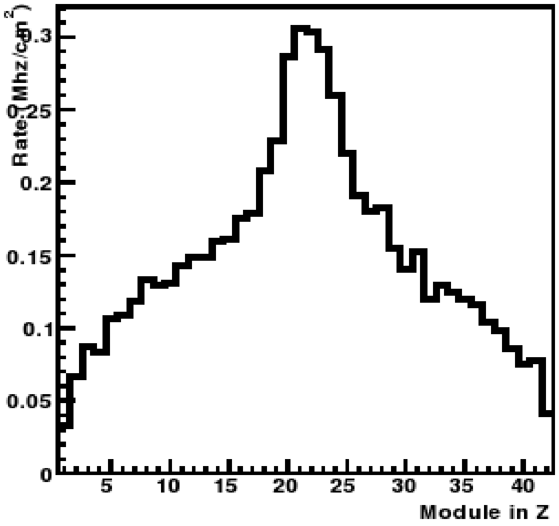
Stub finding efficiency as function of p_T. At r=35 cm for 1 mm stack separation.



Hit rate at r=35 cm



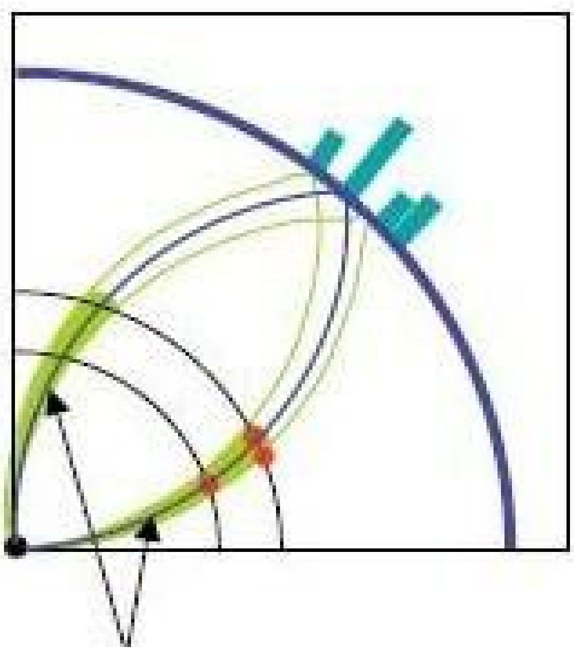
Stub rate at r=35 cm



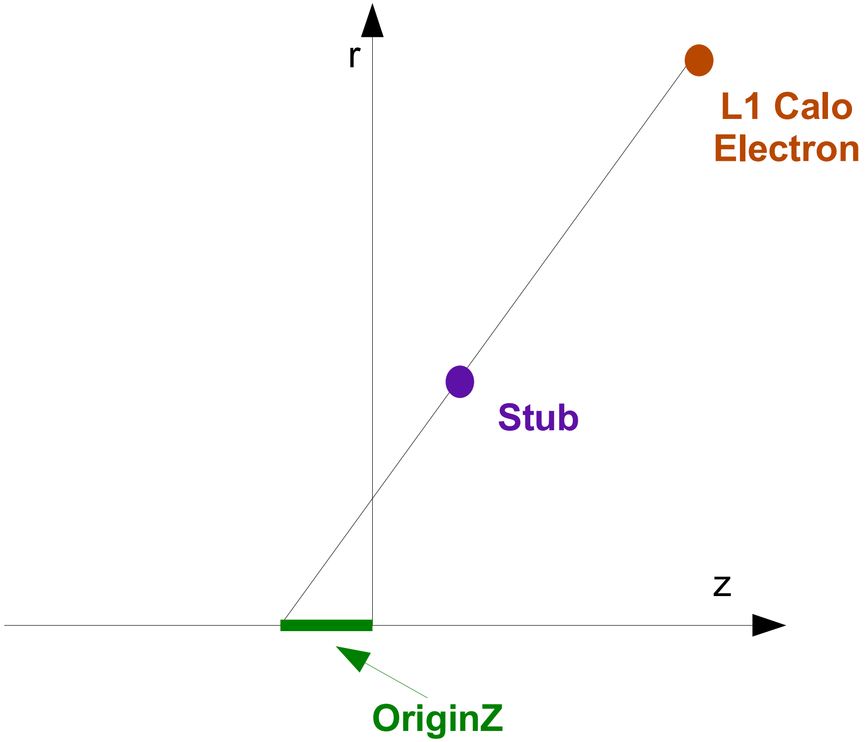
- Hit rate in 200 PU events.
- Using CMS fast sim. Does not include out of time PU.
  - Hit rate low by factor of ~2-3.
- Stub rate lower by a factor of 30

Electron Algorithm

First Step: Identify all stubs in two broad “roads” using L1 electron position and E_t:



Separate road for each charge
Curvature from L1 Et



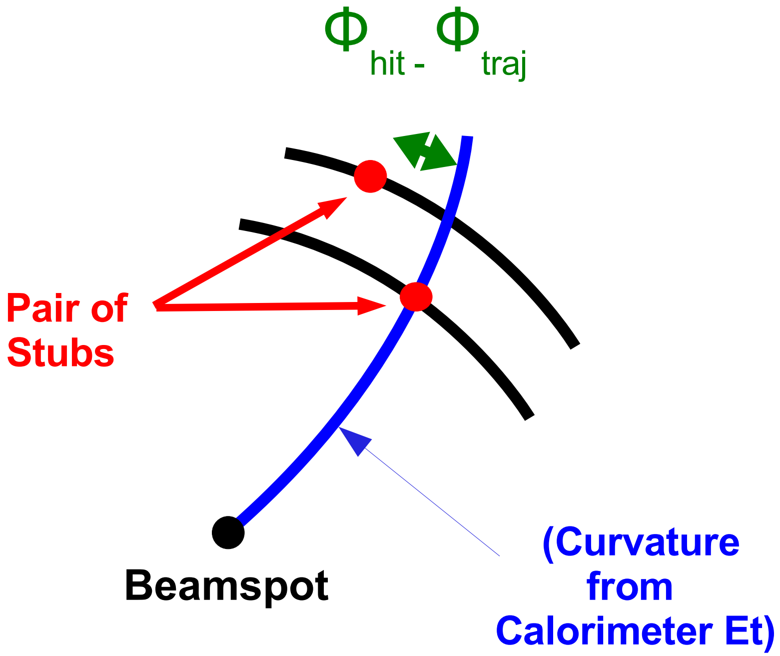
Hits are identified through two variables:

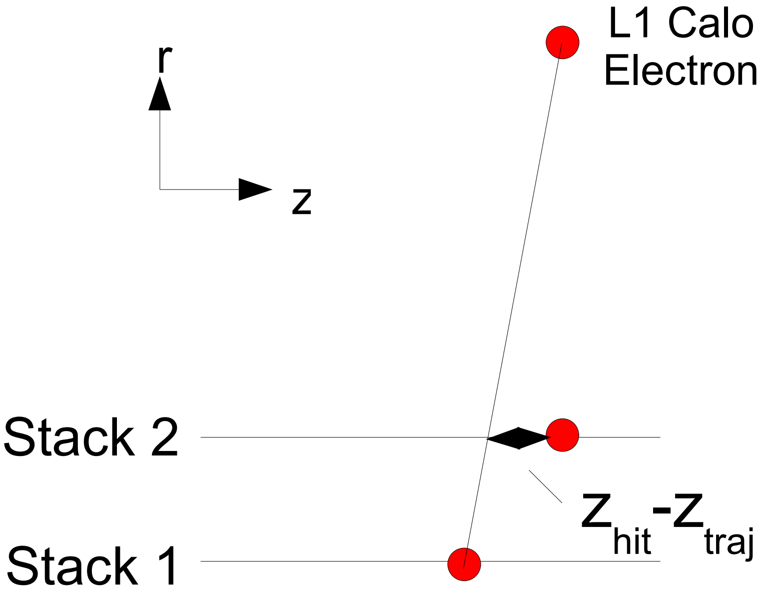
Δφ: width of roads in r-φ

originZ: z intercept of line connecting cluster and hit in r-z

Electron Algorithm

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



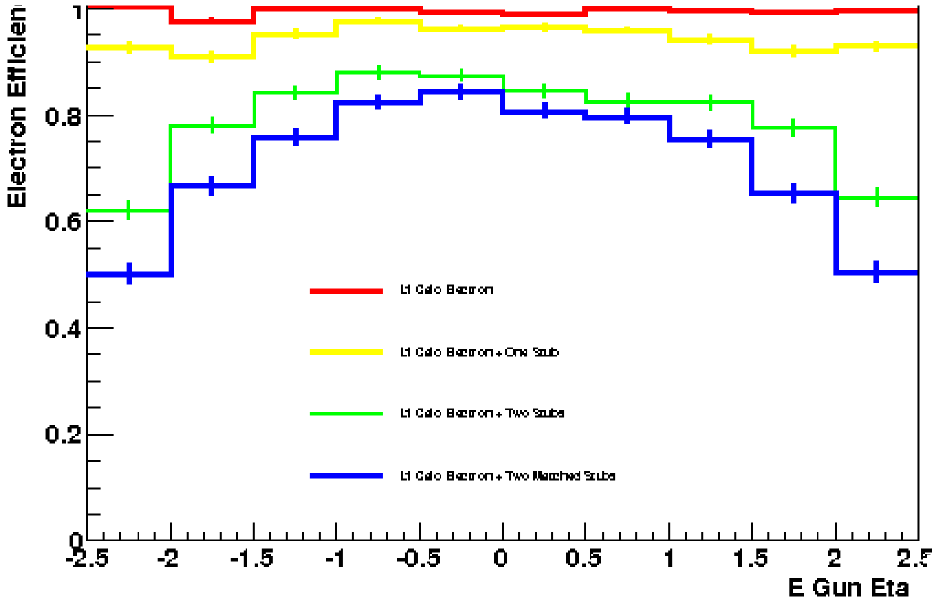


Hit pairs (“seeds”) are identified through two variables

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

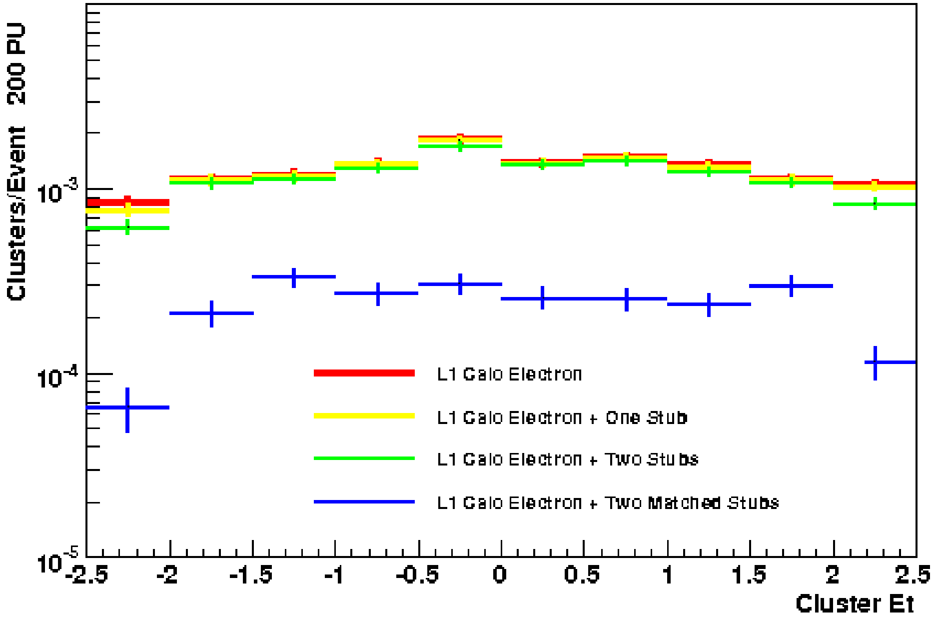
$$z_{miss} = |z_{hit}-z_{traj}|$$

Electron Trigger Performance



- Efficiency is about 80% in the central region.
- Efficiency falls in forward region due to material

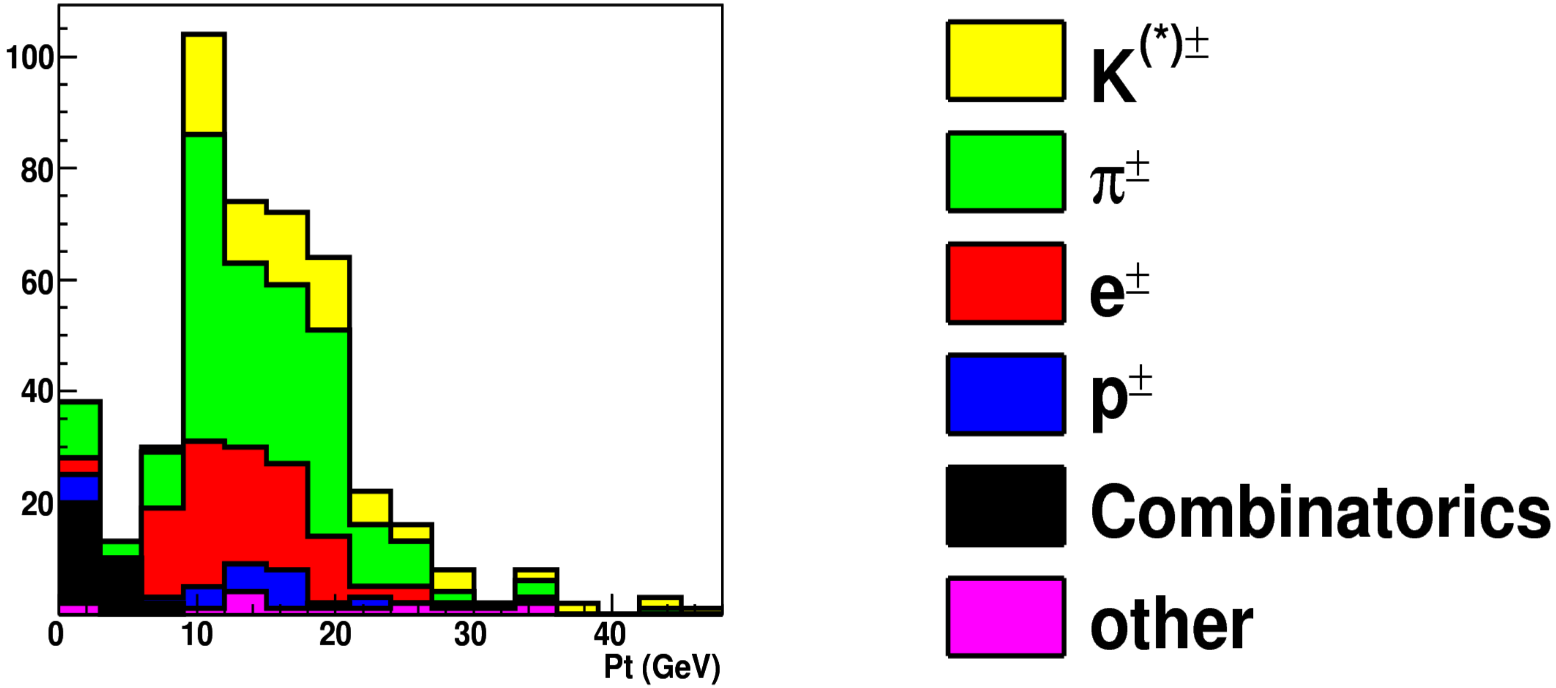
- Rejection factor with 200 PU is about 6.
- Fakes are largely real tracks in jets.
- Better calorimeter positions would improve performance



We are considering other combinations such as 2/3 or ¾ layers

Electron Backgrounds

- With stacks separated by 4 cm most tracklets are from real tracks.
  - Increasing the stack separation provides a more precise p_T estimate, but increases combinatorics.
- Limited by L1 calorimeter trigger resolution $\eta \times \phi$ of 0.044×0.044



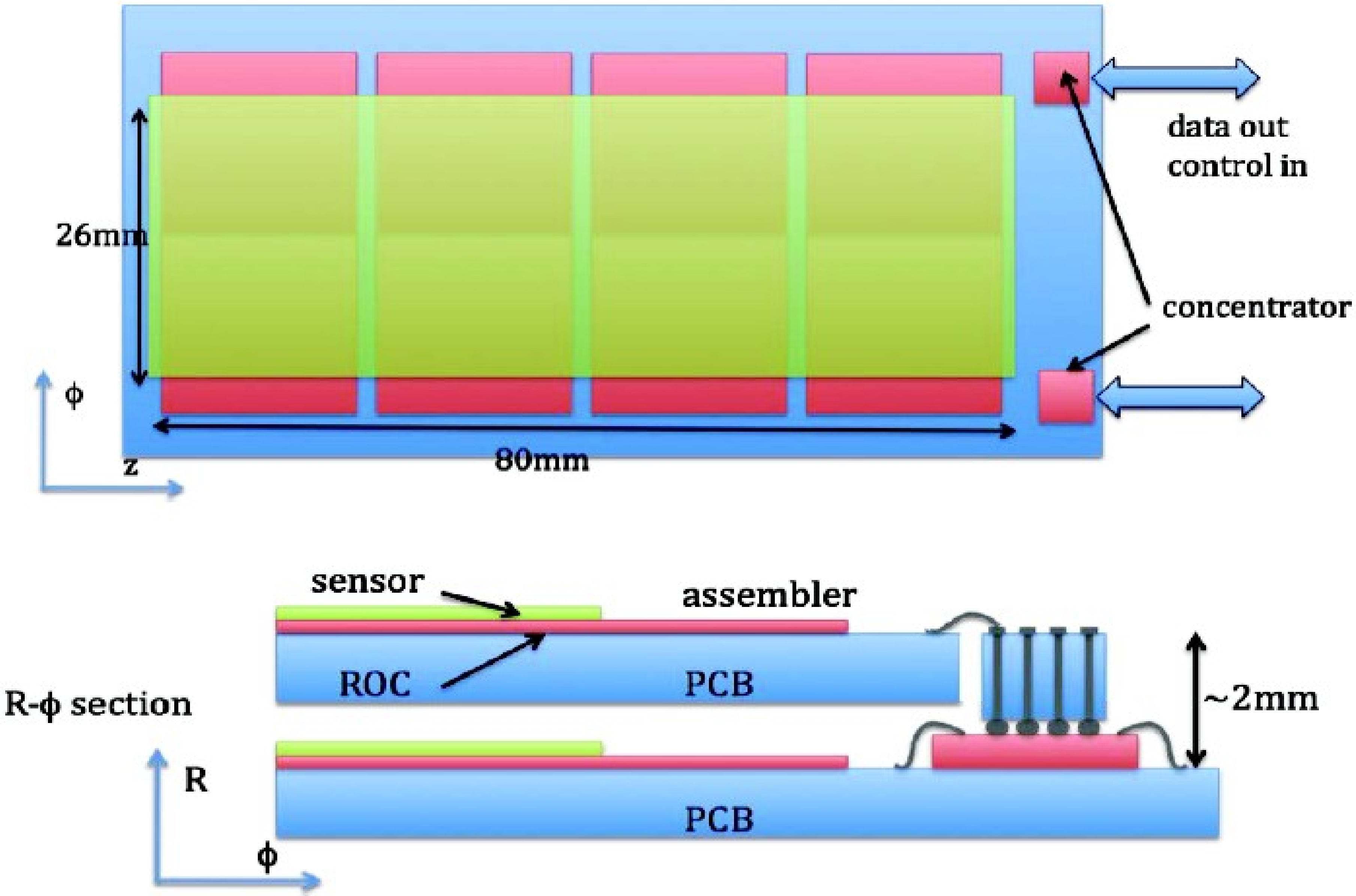
Summary of Triggers Simulations

- Have a simulation framework to simulate detectors for upgrades.
- Can generate stubs based on simple p_T match
- Studying algorithms for matching stubs to L1 electrons
  - Mostly finding real tracks within jets.
- Similar studies are underway also for muons and taus
  - We are also starting to look at the tracker isolation capabilities of these detectors.

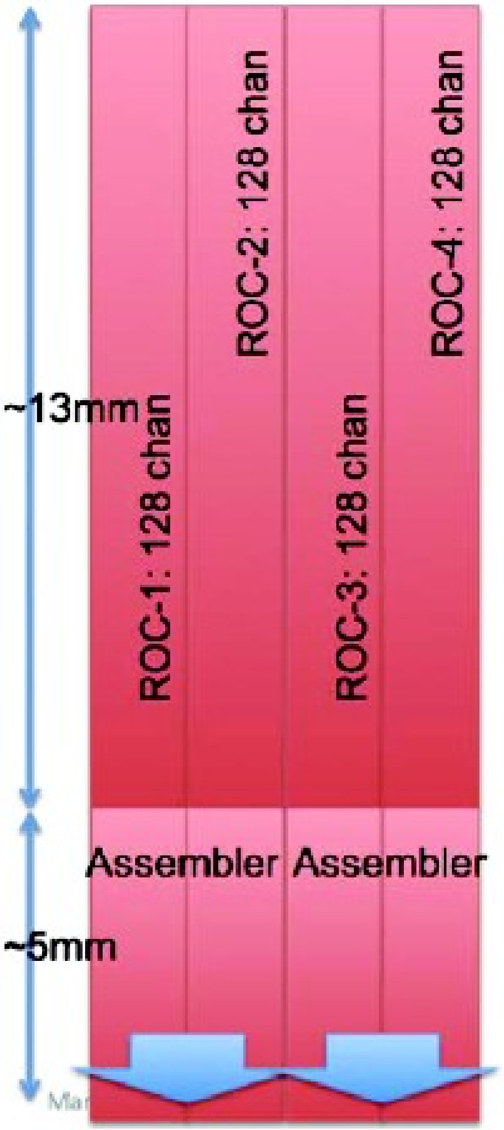
Trigger Module Concepts

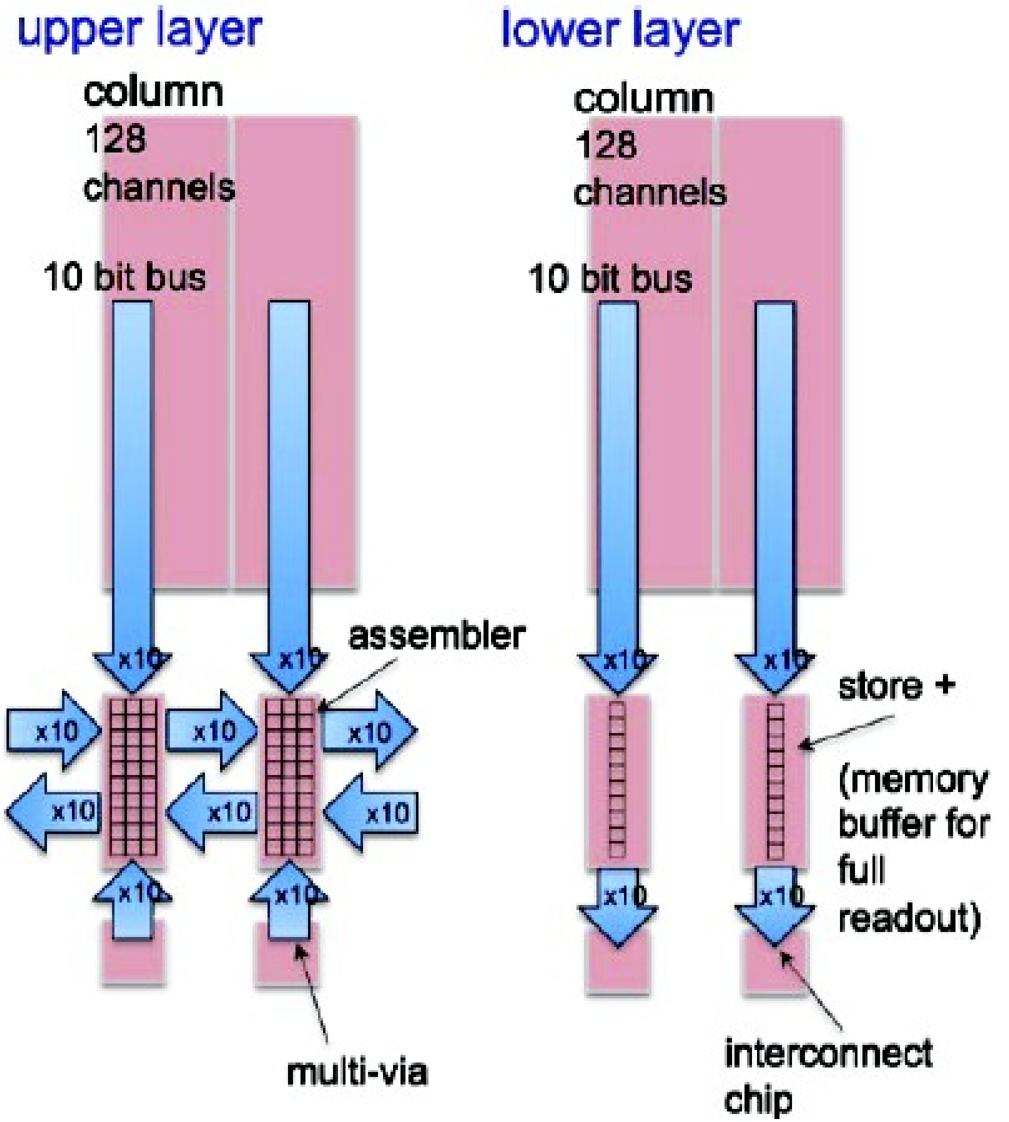
- CMS has started R&D projects to investigate how to build the modules required to provide the track trigger primitives (stubs).
- There are three main efforts:
  - pT-module – Uses largely existing technology to realize these modules. Emphasis put on demonstrating the functionality of these modules in test beams.
  - Vertically integrated modules – More basic R&D required to demonstrate 3D integration to realize these modules. If successful it would provide a very powerful technology.
  - Cluster width approach – Uses the cluster width to reject the soft tracks in a single sensor. Hard to use at inner radii and needs to be complemented by alternative technologies to cover the full eta range.
- These ideas will be briefly discussed on the next few slides.

'pT Module'


data out
control in
26mm
concentrator
φ
z
80mm
sensor
assembler
ROC
PCB
R-φ section
~2mm
R
PCB
φ

Correlation Logic - Ideas





Frontend Power Estimates

	P [µW] /pixel	**Functions**
Front end	25	amplifier, discriminator local logic, cf ATLAS 130nm
Control, PLL	10	1 PLL/ROC @ 5mW, x 2
Digital logic	8	comparison logic and transfer to edge: 1mW/column
Data transfer	2.5	few cm across module
Data transfer	10	transmission to remote GBT: 80mW/module @
Concentrator	5	buffer to and from GBT: 2 ASICs @ 20mW
Full readout	20	following L1 trigger, extrapolate from CMS pixel
Sub-total	~80	
Total with DC-DC	**~106µW**	75% efficiency for DC-DC conversion

Data Links and Total Power

For stacked layer (doublet)	
Pixel size	100µm x 2.5mm
ROC	8 x 128 channels
<Power>/pixel	175µW (250µW)
$\|\eta_{MAX}\|$	2.5
Bandwidth efficiency	100% (50%)

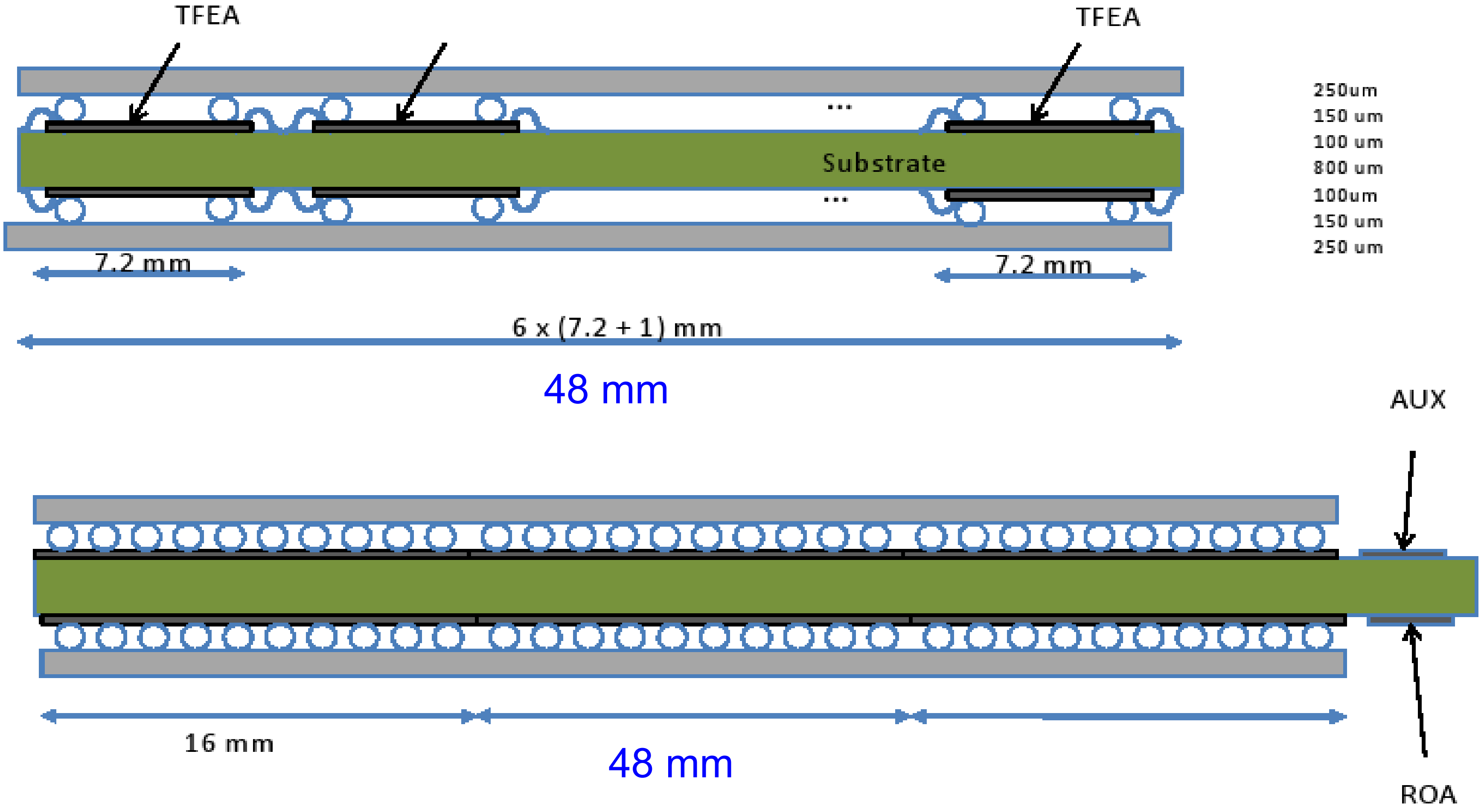
R [cm]	**L [m]**	**A [m²]**	**N_{face}**	**N_{chan}**	**N_{ROC}**	**N_{module}**	**N_{links}**	**P [kw]**
25	3.0	9.6	64	38.5M	38k	4700	1440 (2880)	6.7 (9.6)
35	4.2	18.7	88	75M	73k	9200	2810 (5610)	13.1 (18.7)

Numbers in red assumes a 50% link bandwidth utilization.

Alternative Layout

Option 2

Sensor separation ~1.3÷1.5 mm

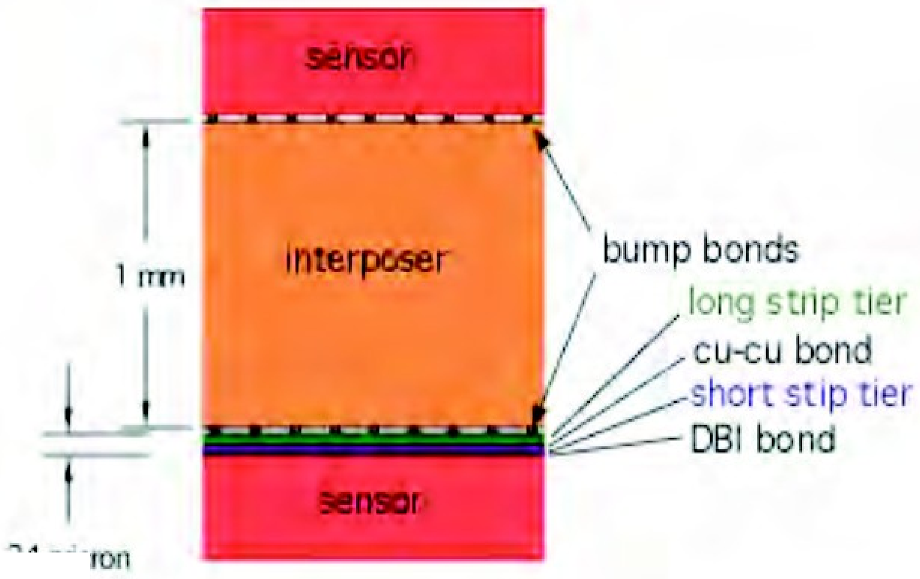


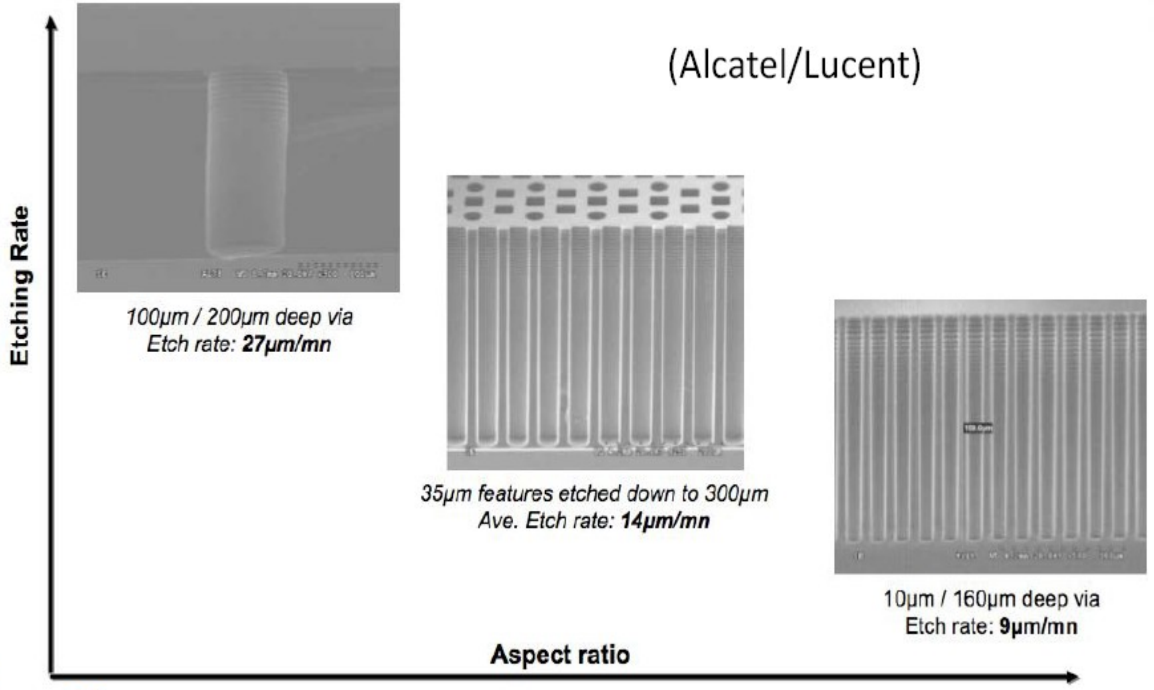
Module size = [6 * 8] x [3 * 16] mm

Encouraging feedback from packaging firms for this option

Vertically Integrated Modules

- Bring signals from one sensor to the other via an 'interposer'
- One readout chip for the two sensors. Through going vias on the readout chip.
  - FNAL is working with Tezzaron for TSVs and Ziptronix for direct oxide bonding technology.

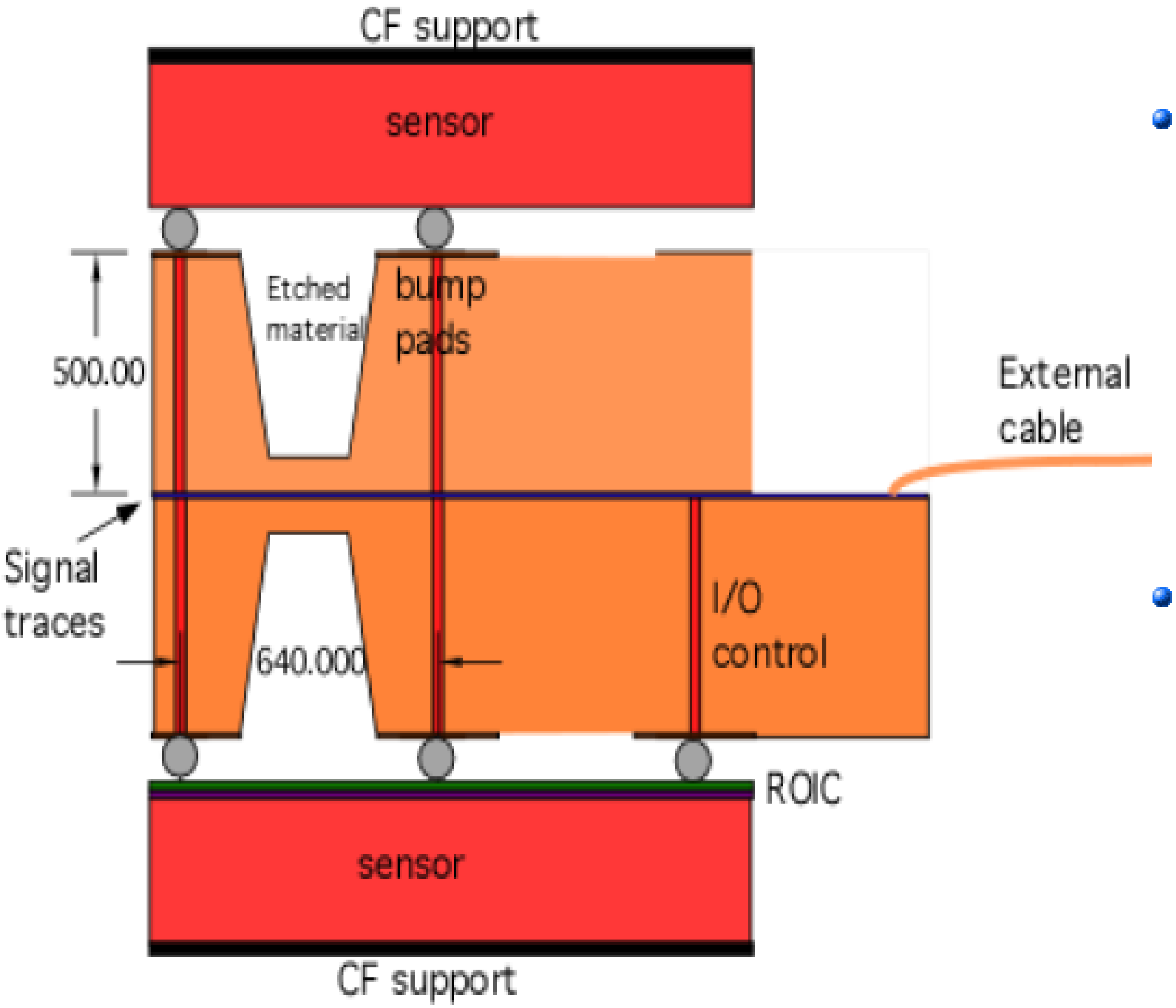




(Alcatel/Lucent)

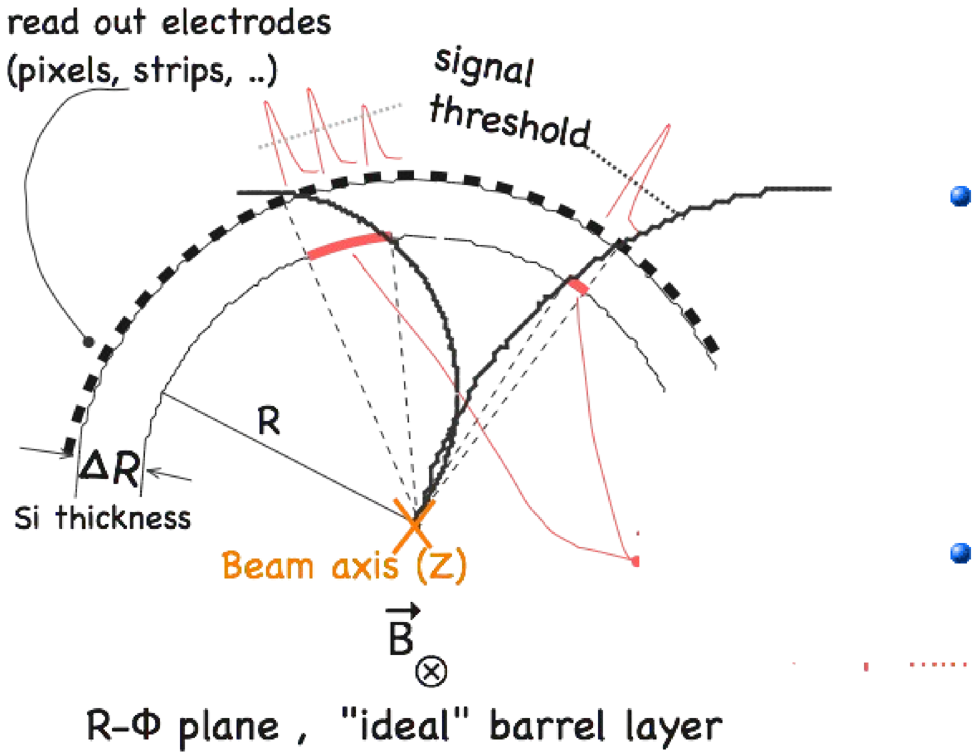
- A prototype is being assembled using the VICTR (Vertically Integrated CMS TRigger) chip.
- Currently prototyping interposers in Si.
  - The interposer is one of the critical components in this design.

'Ideal' Vertical Integrated Module



- Two layer interposer:
  - The interposer brings signals from top sensor to the lower sensor.
  - Power, clock, and other signals are distributed through the interposer.
- Most power dissipated in lower in lower layer.

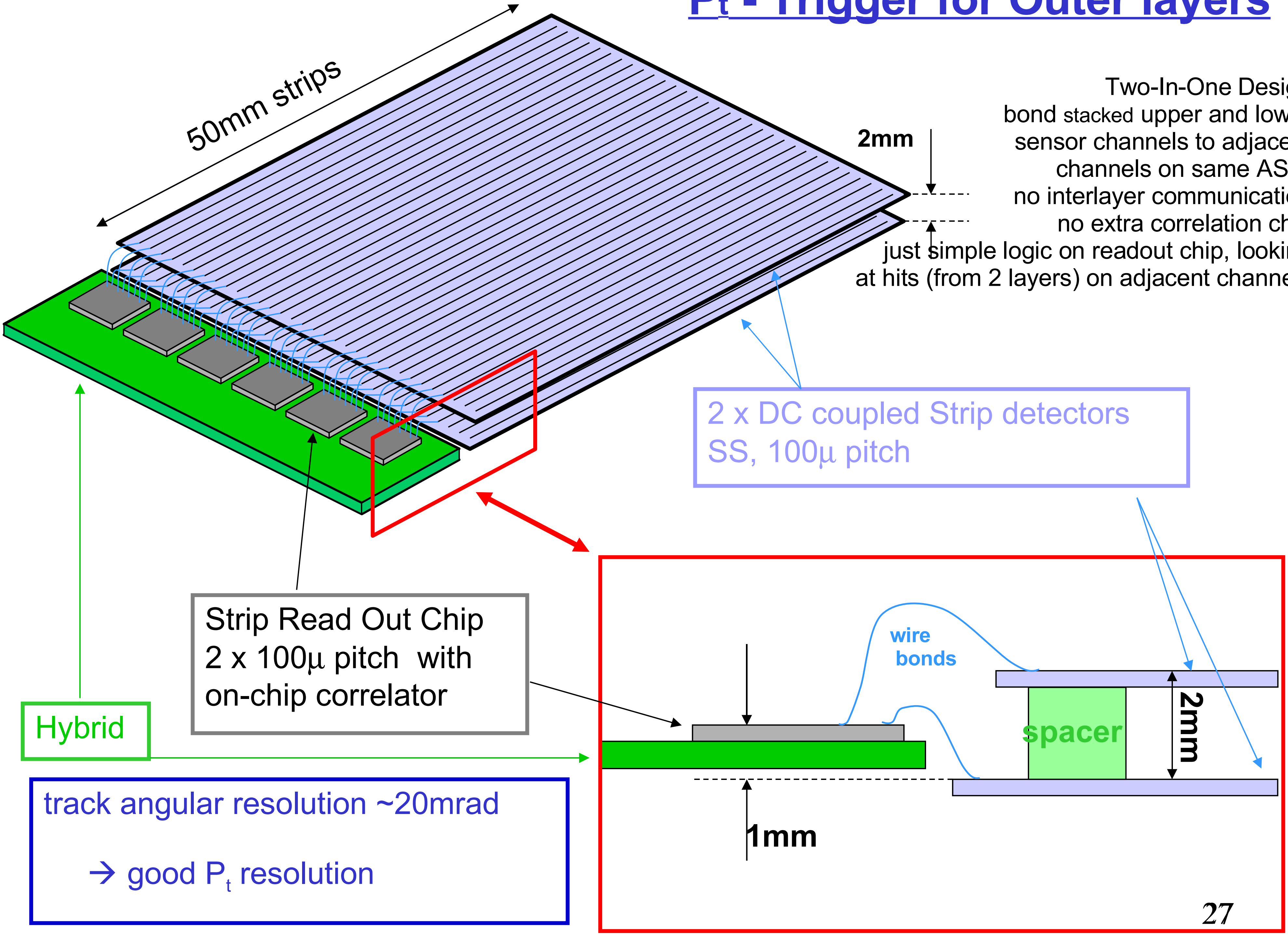
Cluster Width Discrimination



- Keep clusters with ≤2 hits.
  - Above 50 cm, using 50um pitch, about 5% of the total particles leave clusters with ≤2 hits.
- Associative memory to reconstruct tracks.

- Works best for larger radii (>0.5 m)
- Hard to cover the full eta range.
- Provides no useful z-information.

P_t - Trigger for Outer layers



Two-In-One Design
bond stacked upper and lower
sensor channels to adjacent
channels on same ASIC
no interlayer communication
no extra correlation chip
just simple logic on readout chip, looking
at hits (from 2 layers) on adjacent channels

2 x DC coupled Strip detectors
SS, 100μ pitch

Strip Read Out Chip
2 x 100μ pitch with
on-chip correlator

Hybrid

track angular resolution ~20mrad

→ good P_t resolution

* *http://indico.cern.ch/getFile.py/access?contribId=3&sessionId=0&resId=0&materialId=0&confId=36580*

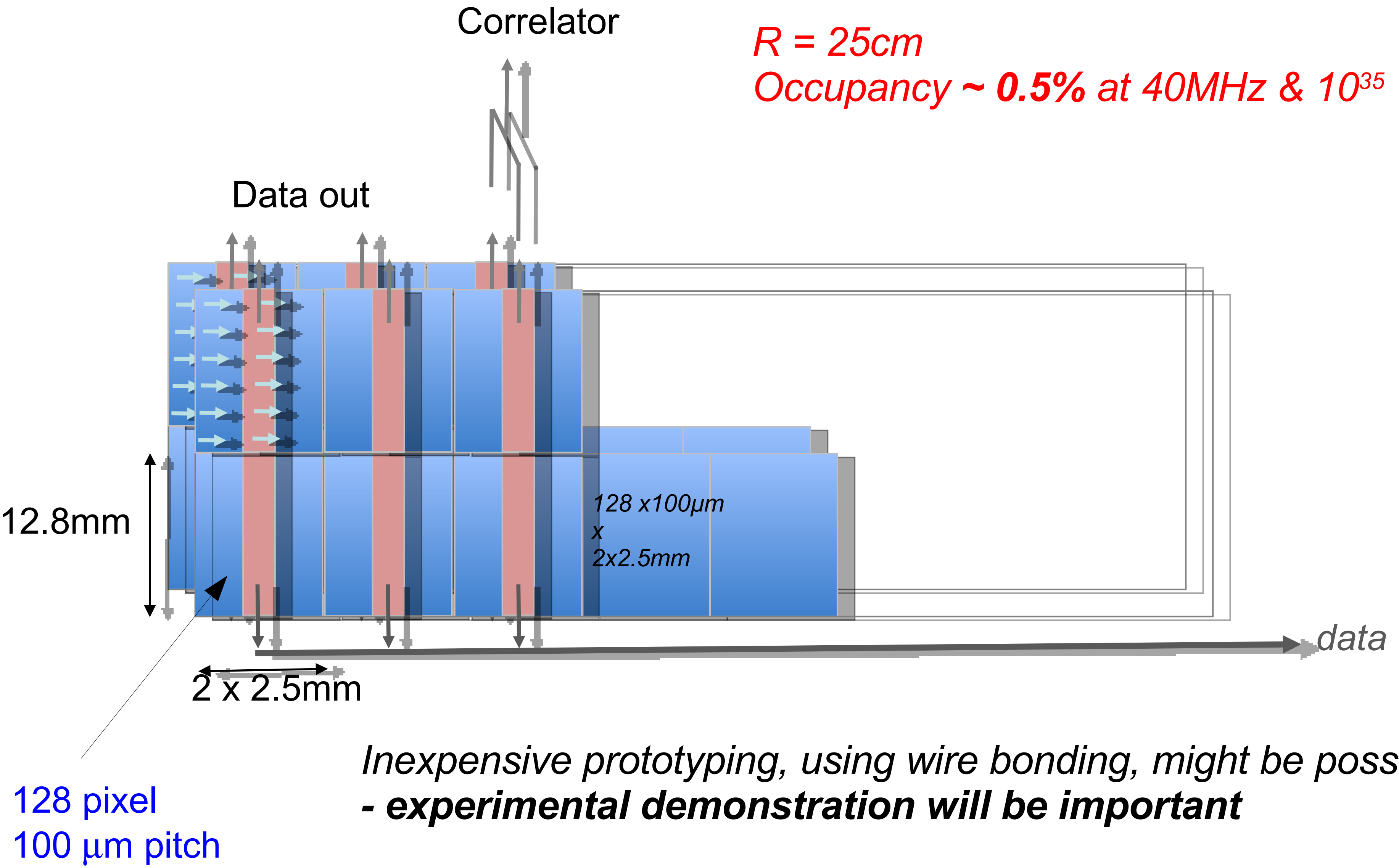
Summary

- CMS is considering track trigger capabilities in the L1 trigger as one of the main priorities for the phase 2 upgrade.
- To reduce the data volume hits are selected based on p_T.
- Simulation studies are underway to understand the performance.
  - Crucial to understand how these modules perform.
- R&D has started on the development of modules capable of providing the trigger primitives:
  - pT modules using, largely, existing technology
  - Vertically integrated modules using 3D integration
  - Cluster width approach
- These R&D activities has recently started
  - No results yet – we are just getting started.

Backup Slides

'pT' Module

R = 25cm
*Occupancy ~ **0.5%** at 40MHz & 10^{35}*



Correlator

Data out

12.8mm

128 x100µm
x
2x2.5mm

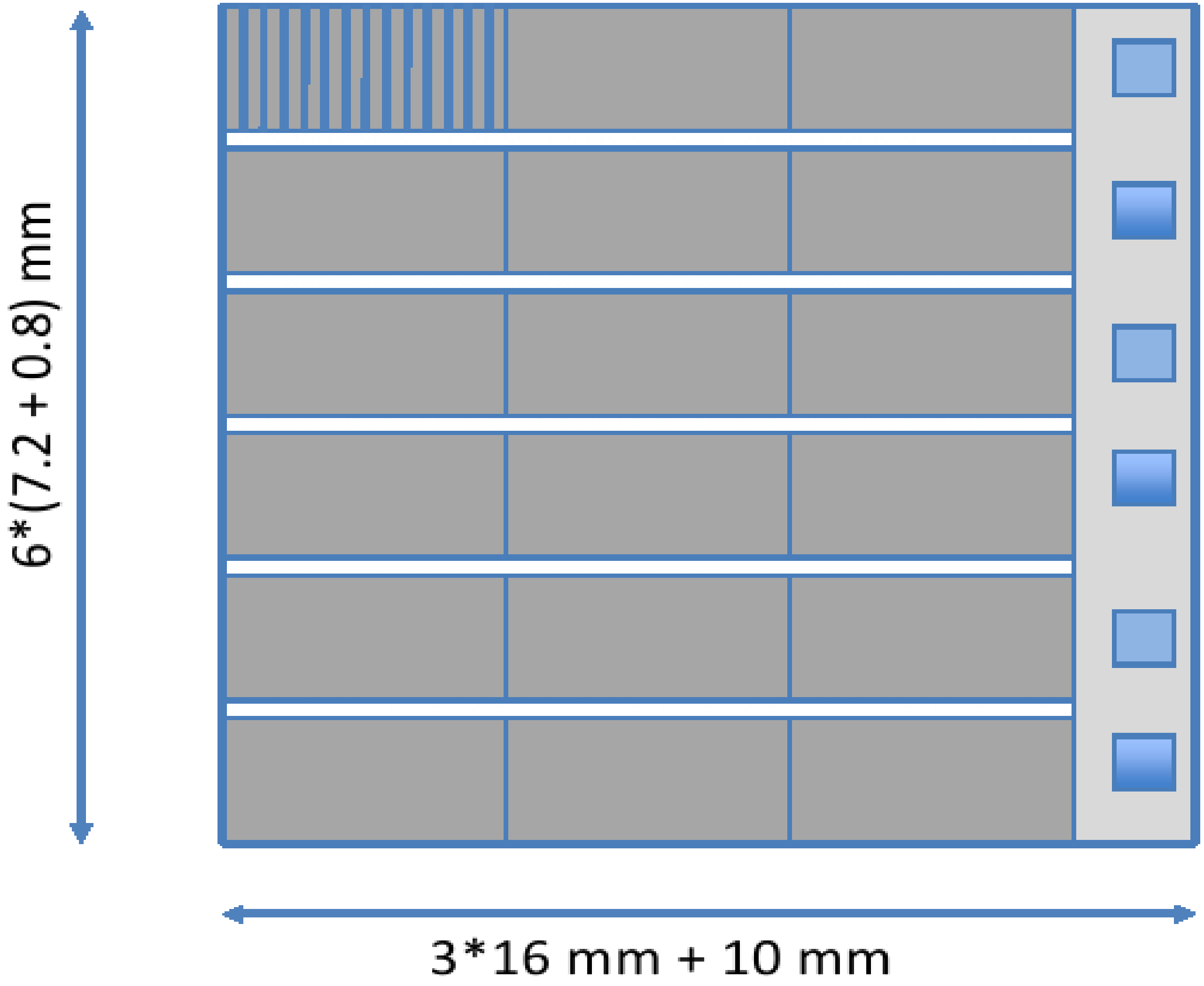
data

2 x 2.5mm

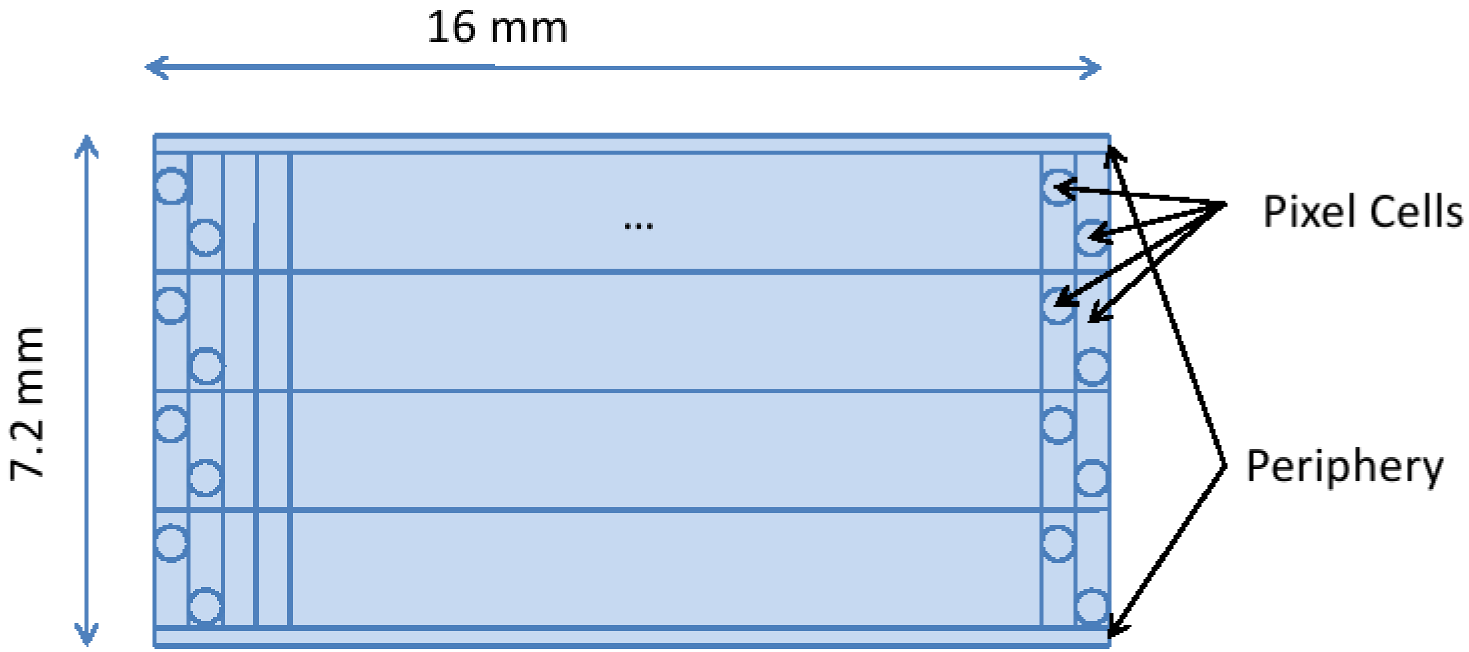
128 pixel
100 µm pitch

Inexpensive prototyping, using wire bonding, might be possible
- experimental demonstration will be important

Module Layout (6 by 3 ROCs)



ROC



ASIC size:
7.2 x 16 mm2
Strip size: ~ 100 um x 2000 um
Channel size: 100um x 1750um
channels: 160 x 4 = 640 channels
Total BW required for trigger: 25.6 Gbit

640*0.5/100 = ~ 3 hits /BX
10 * 3 / 25 = 1.2 bits / ns

~ 8 links @ 160 Mbits / sec

P ~ 1.3 mW = 2 μW / channel
OK even when adding a generous safety factor on top…

Abstract

For luminosities at the LHC from a few×10^{34} to 10^{35} $cm^{-2}s^{-1}$there are several issues that needs to be addressed with the CMS detector. Amongst these are 1) the current tracker has to be replaced as it can not cope with the occupancies and will have to be more radiation hard in order to survive in the harsh radiation environment and 2) the current trigger will not be efficient for the physics goals while keeping the rate below 100 kHz, which is the DAQ limit. To address both of these points CMS is considering adding trigger capabilities to the tracker. This talk will discuss some ideas that are being pursued. The basic idea is to use p_T discrimination to reduce the data rate that is required to be read out from the tracking detector in order to provide track trigger primitives.