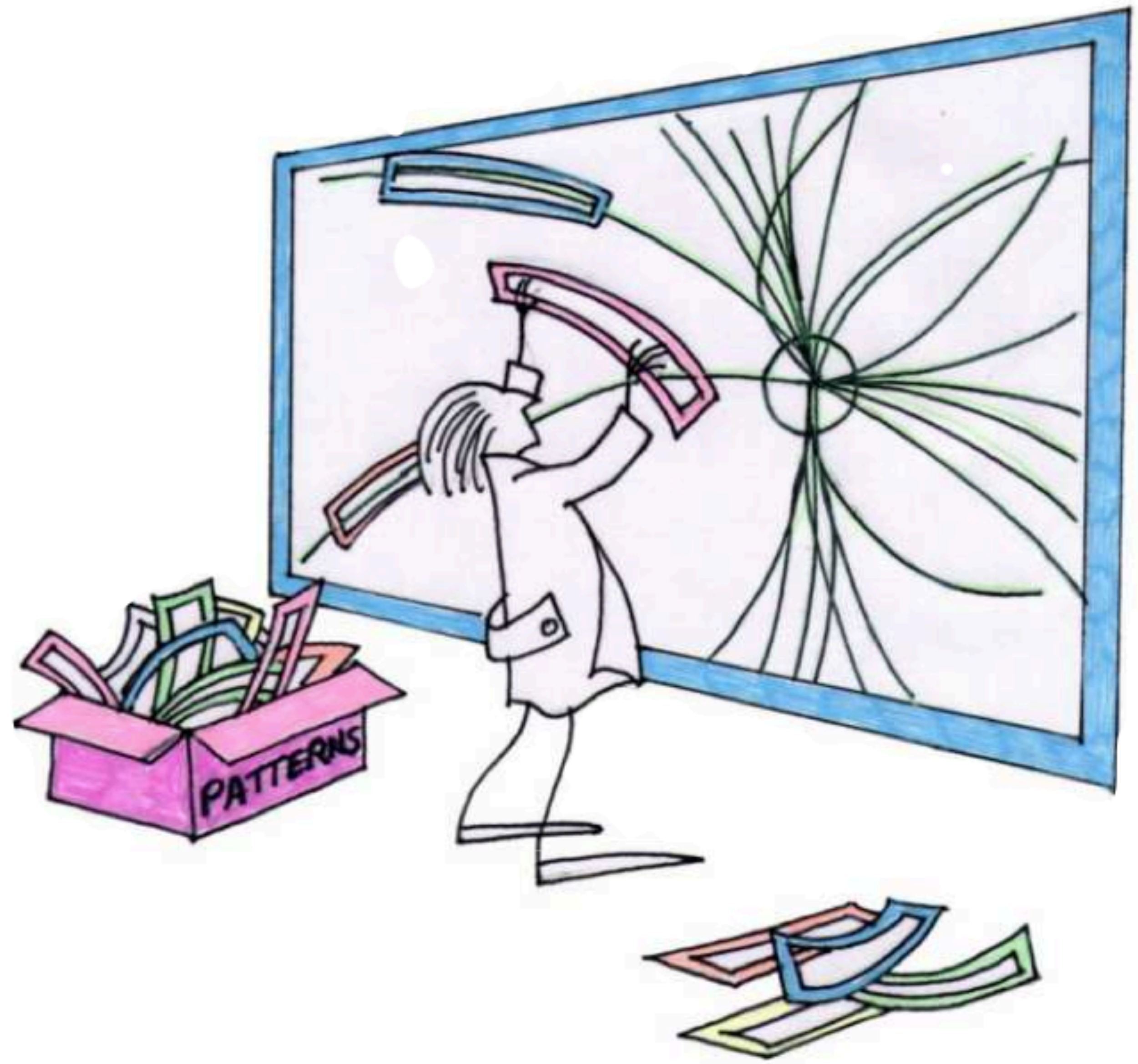
The CMS L1 Track Trigger at the HL-LHC



Marco Trovato - Northwestern University
(on behalf of the CMS collaboration)

Why add a track-trigger @ L1?

Expected improvements

- charged lepton ID/PT resolution
- isolation of e/γ

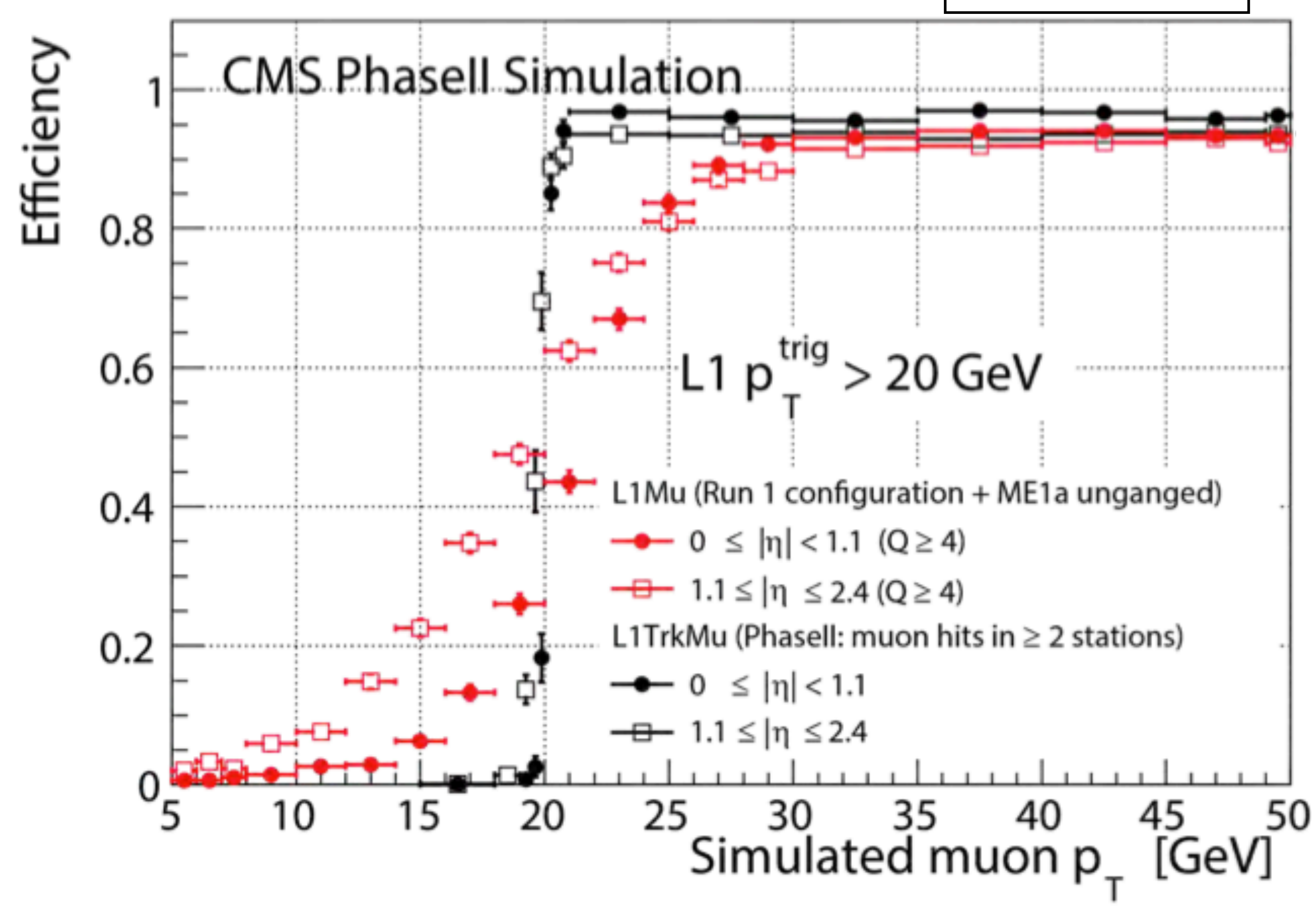
Novelties

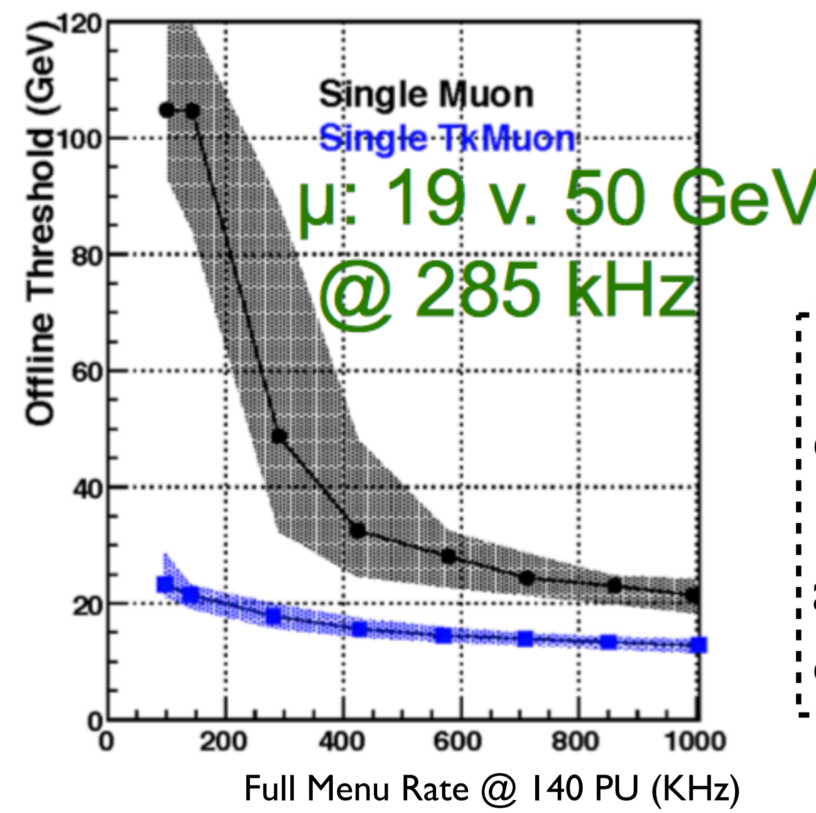
- vertex reconstruction from L1 tracks
  - reject PU jets
  - improve MET performances
  - ...

Great complements to current triggers

W. Smith - Tracking Trigger Workshop @FNAL

PU 140, 14 TeV

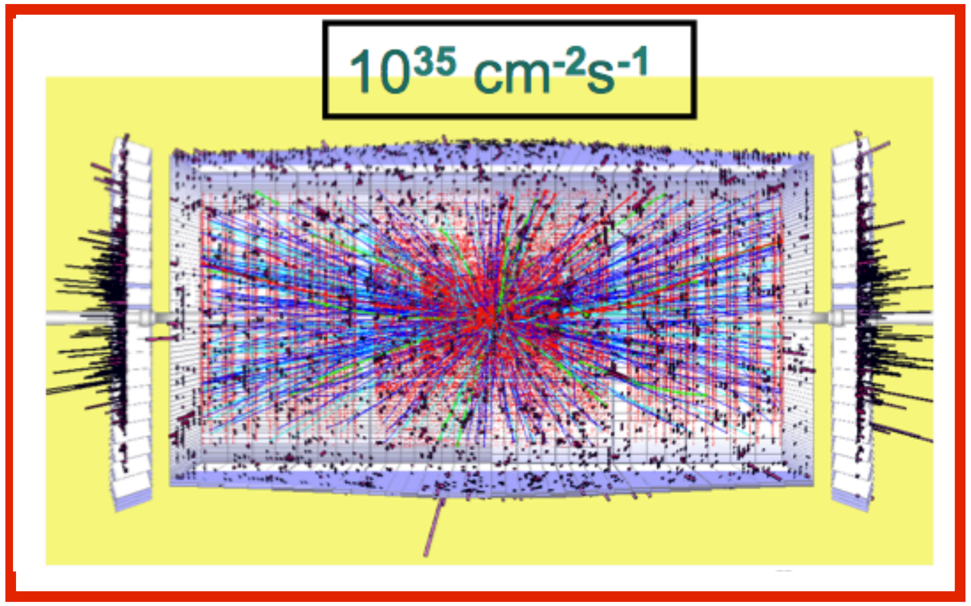




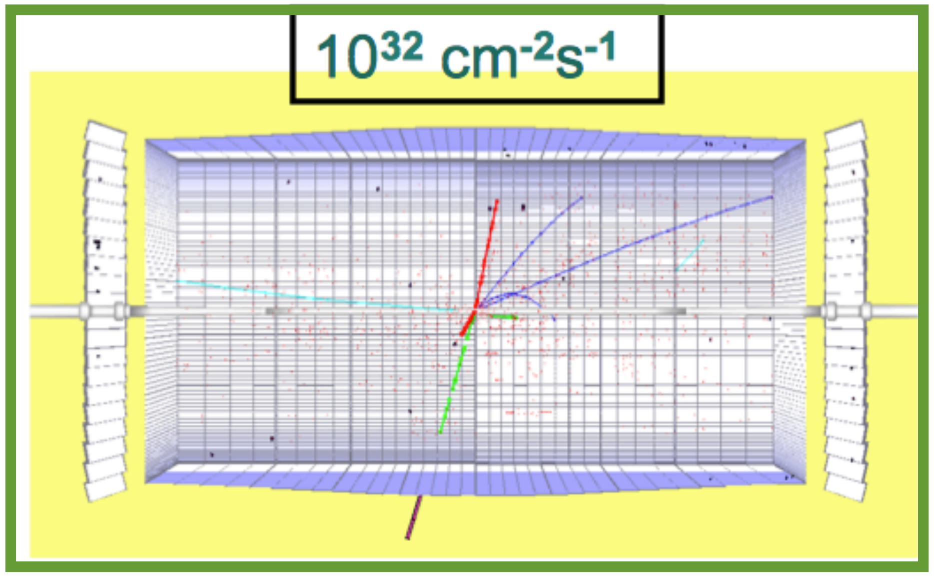
✓ Sharp turn-on efficiency curve
✓ Rate reduction allows for low object thresholds

Track-trigger for HL-LHC: the challenge

- Want to reconstruct the trajectory of charged particles
  - in an extremely dense environment (<PU> ~ 140)
    [<PU> ~ 30 at highest instaneous luminosities in LHC Run-1]
  - at an input rate of 40 MHz
  - with few μs of latency
    [total allowed latency for L1 trigger ~ 12.5 μs]



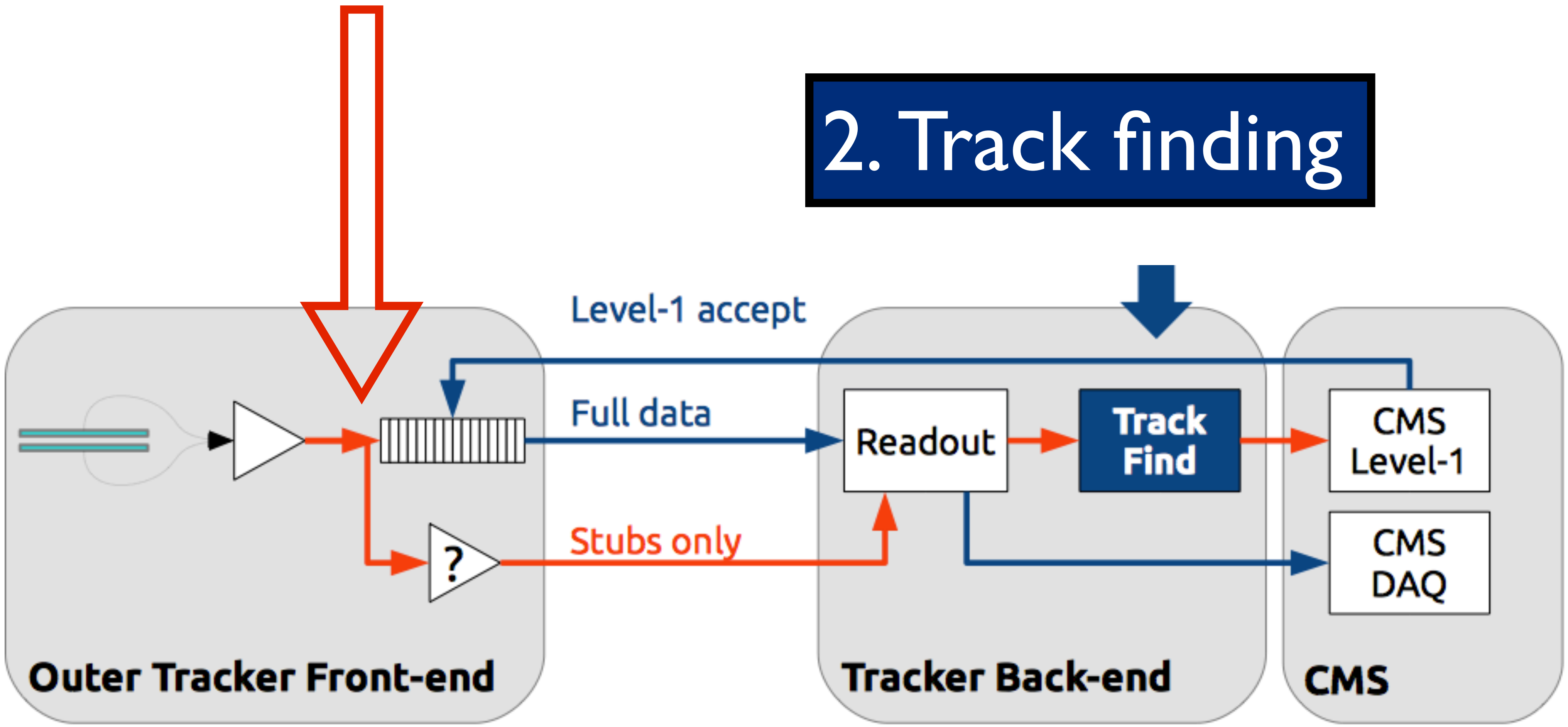
- Never done before with such conditions
  - ✓ a track-trigger was implemented at CDF (Tevatron)
    - tracks were reconstructed at L2
      [input ~ 30 KHz, latency 20 μs]
    - in a less dense environment
  - ✓ a track-trigger will be part of the ATLAS Phase-I upgrade
    - will operate at lower input rates
      [after L1 (~ 1 KHz ouput rate)]



A track-trigger in two steps

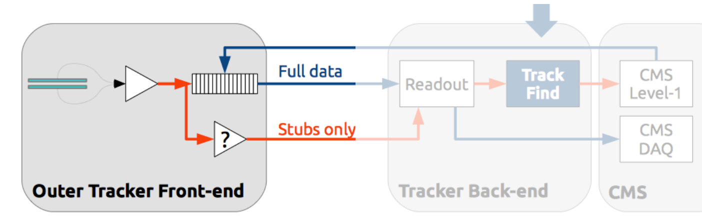
1. Selection of high P_T stubs

2. Track finding



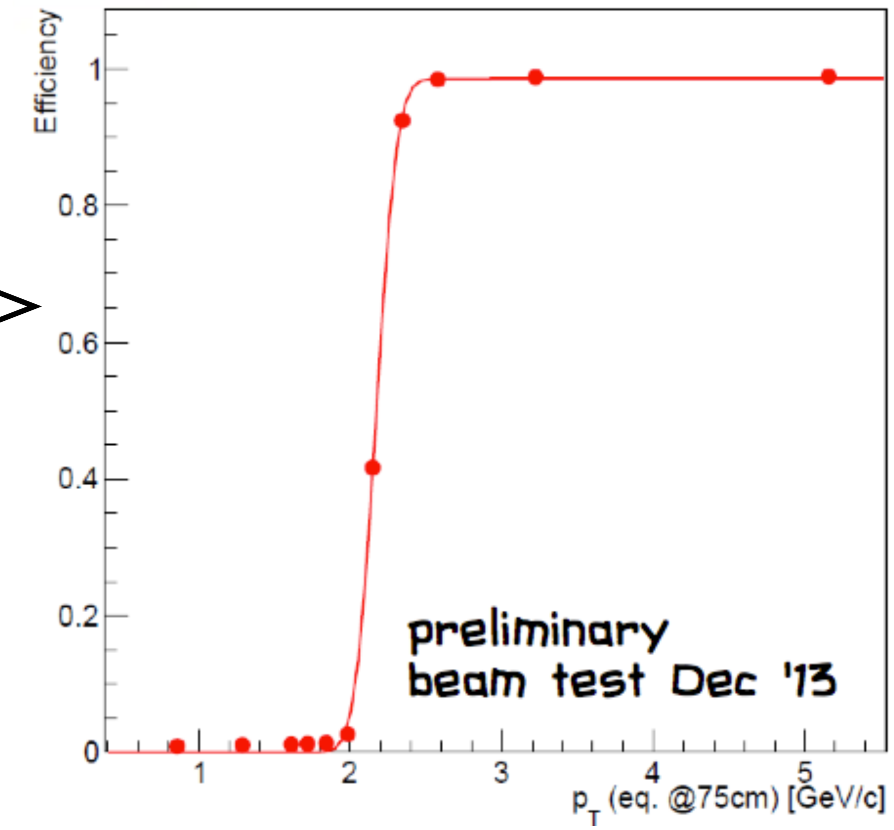
@ 40 MHz – Bunch crossing
@ ~ 500 kHz – CMS Level-1 trigger

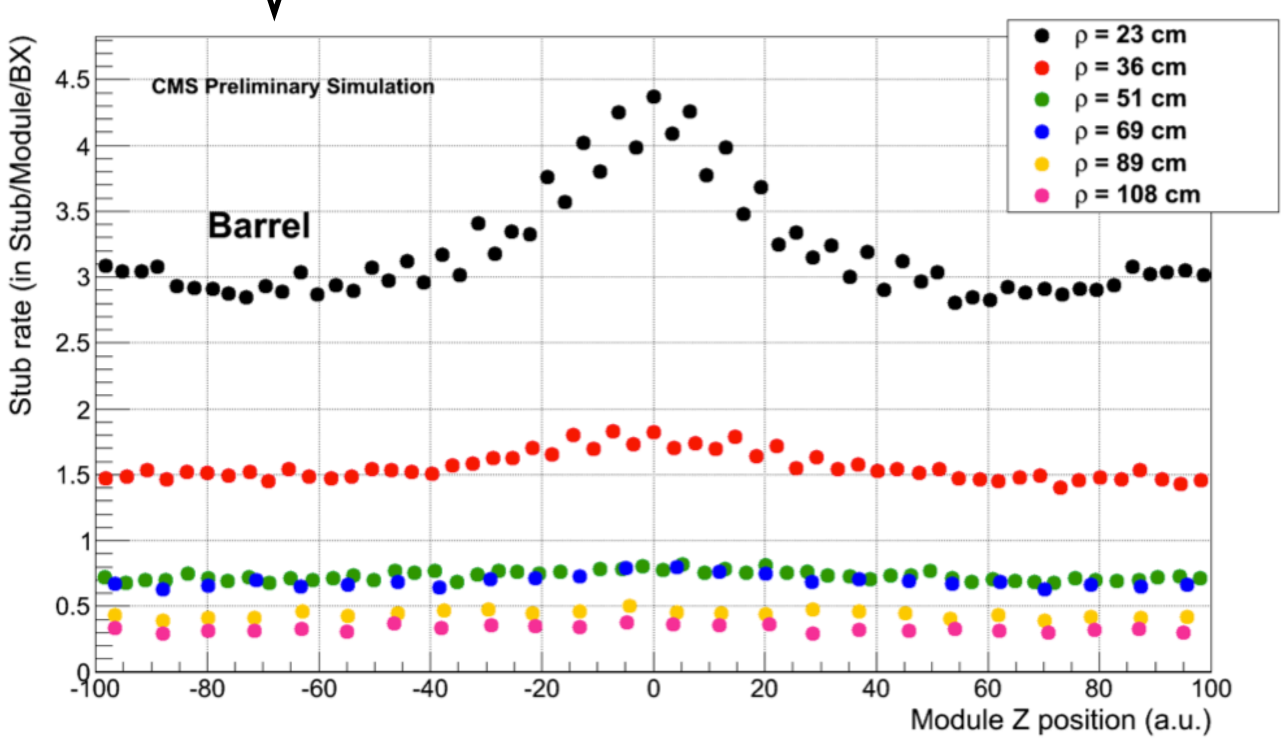
First step



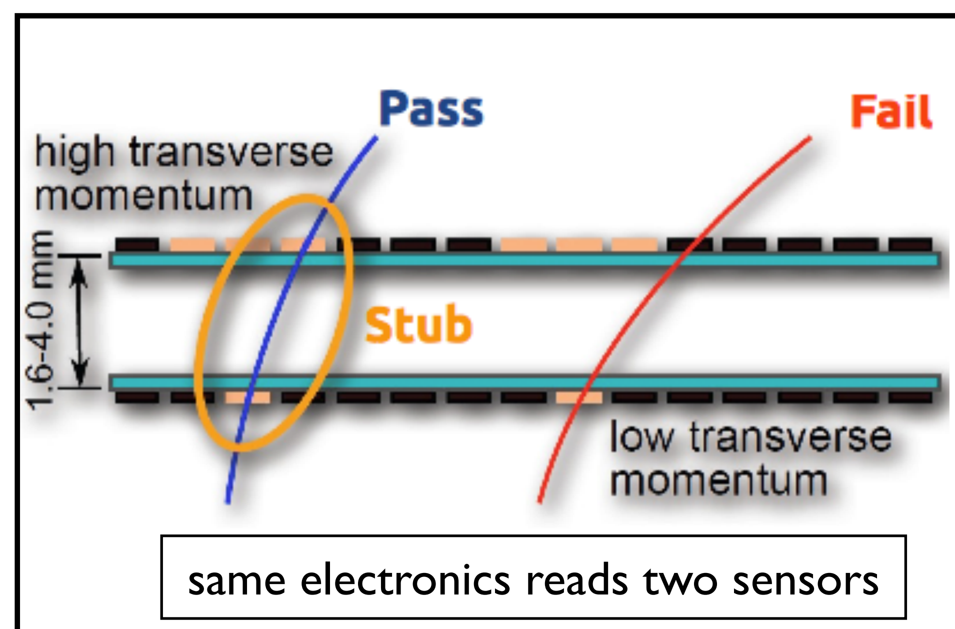
- Goal: reduce the input rate to something bearable
- Solution: select only high-P_T stubs
  - chosen (preliminary) threshold: 2 GeV/c

  [getting close to the limit of the available bandwith in the first layer]
  - Data reduction of one order of magnitude
    - Full efficiency at ~2.2 GeV/c





- Implementation: "P_T modules" (see next slides)



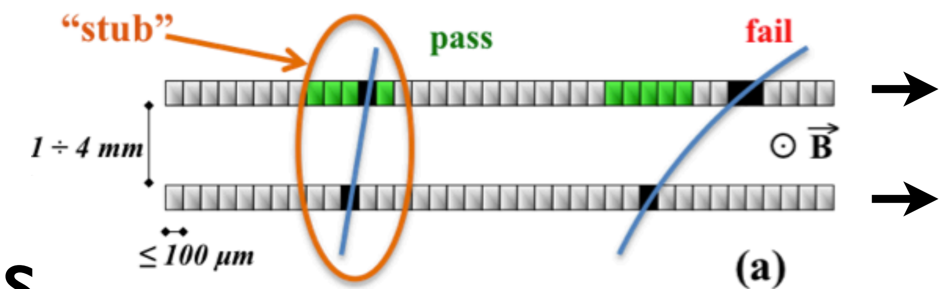
more details in Jeremiah Mans' talk

P_T modules

Characteristics

- two closely-spaced silicon sensors
- read out by common front-end ASICs

[different sensor spacing over the tracking volume (e.g: large spacing at large radii)



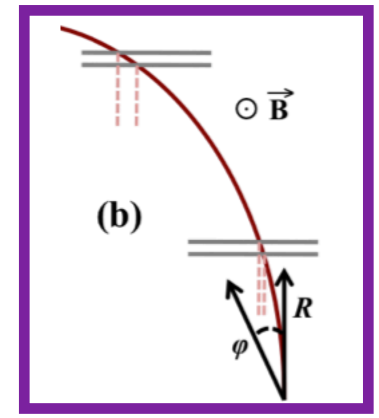
same read out

- radiation hard

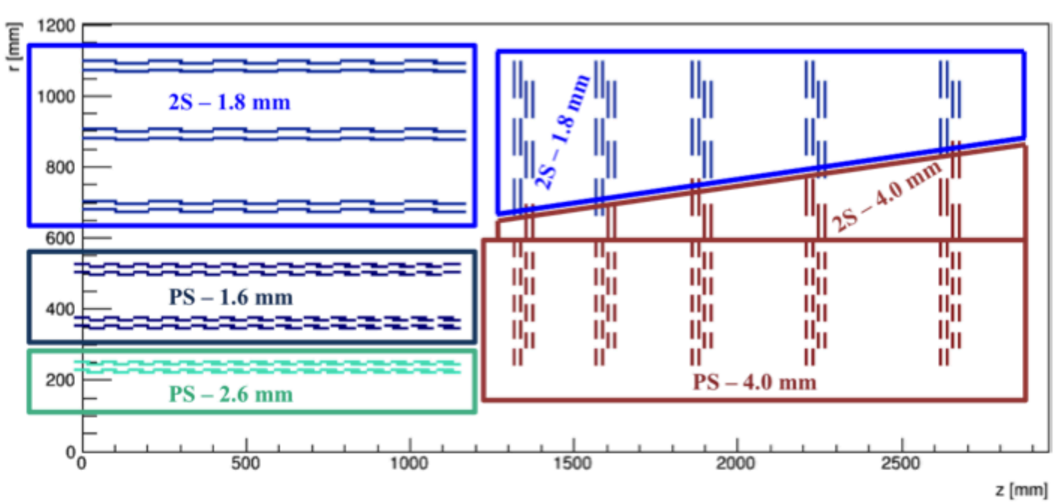
[need to survive 3000/fb]

- less material

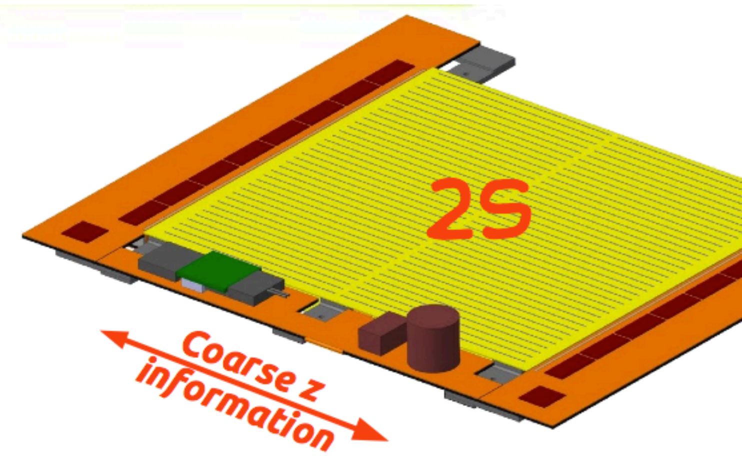
[~no electrical connectivity in the tracking volume]



▸2 Types under development:



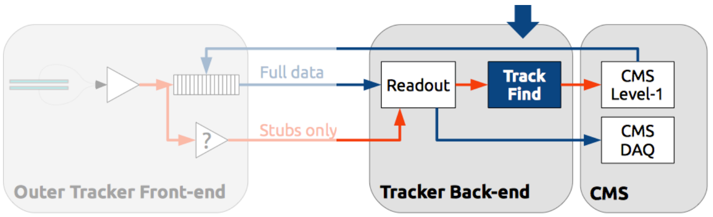
2 Strip sensors
Strips: 5 cm × 90 µm
Strips: 5 cm × 90 µm
P = 2.7 W
~ 92 cm² active area
For r > 40 cm

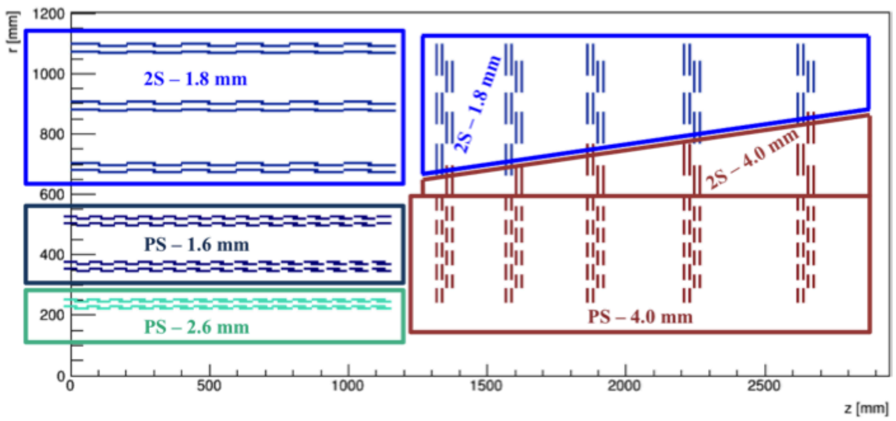


Pixel + Strip sensors
Strips: 2.5 cm × 100 µm
Pixels: 1.5 mm × 100 µm
P = 5.0 W
~ 44 cm² active area
For r > 20 cm

S. Mersi-
Tracking Trigger Workshop @FNAL

Second step: track finding





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Time/Regional Data Multiplexing

*

Pattern Recognition

*

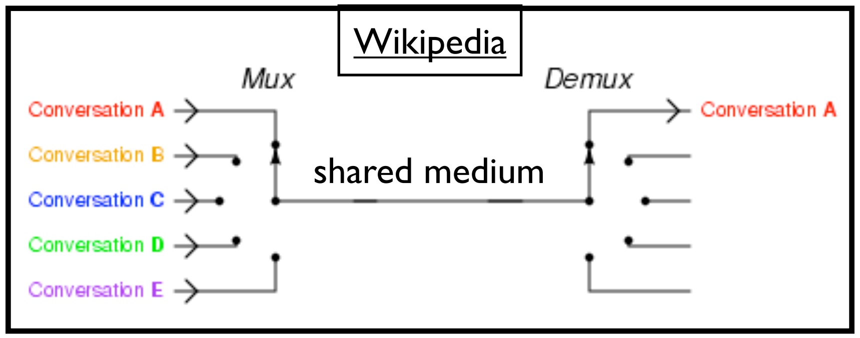
Track Fitting

Track reconstruction

*: data transfer not in this talk

Time/Regional Multiplexing (MUX)

- *MUX is a general approach used in telecommunications*
  - ◉ aims: share expensive resources, **parallelize processes**
  - ✓ already proposed for the Phase-1 upgrade of the calorimeter trigger



- *Two MUX proposed:*
  1. Regional multiplexing: Partition detector in different trigger towers/sectors
  2. Time multiplexing: multiple process engines are assigned to the same tower

- *Requirements:*
  - high bandwidth/low latency
  - flexible time communication

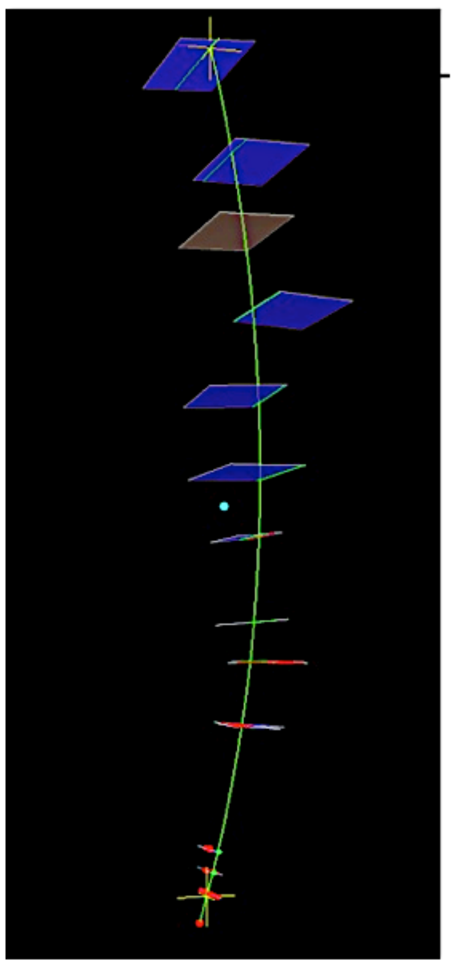
[should not be a problem given the rapid technological progress expected in the coming years]

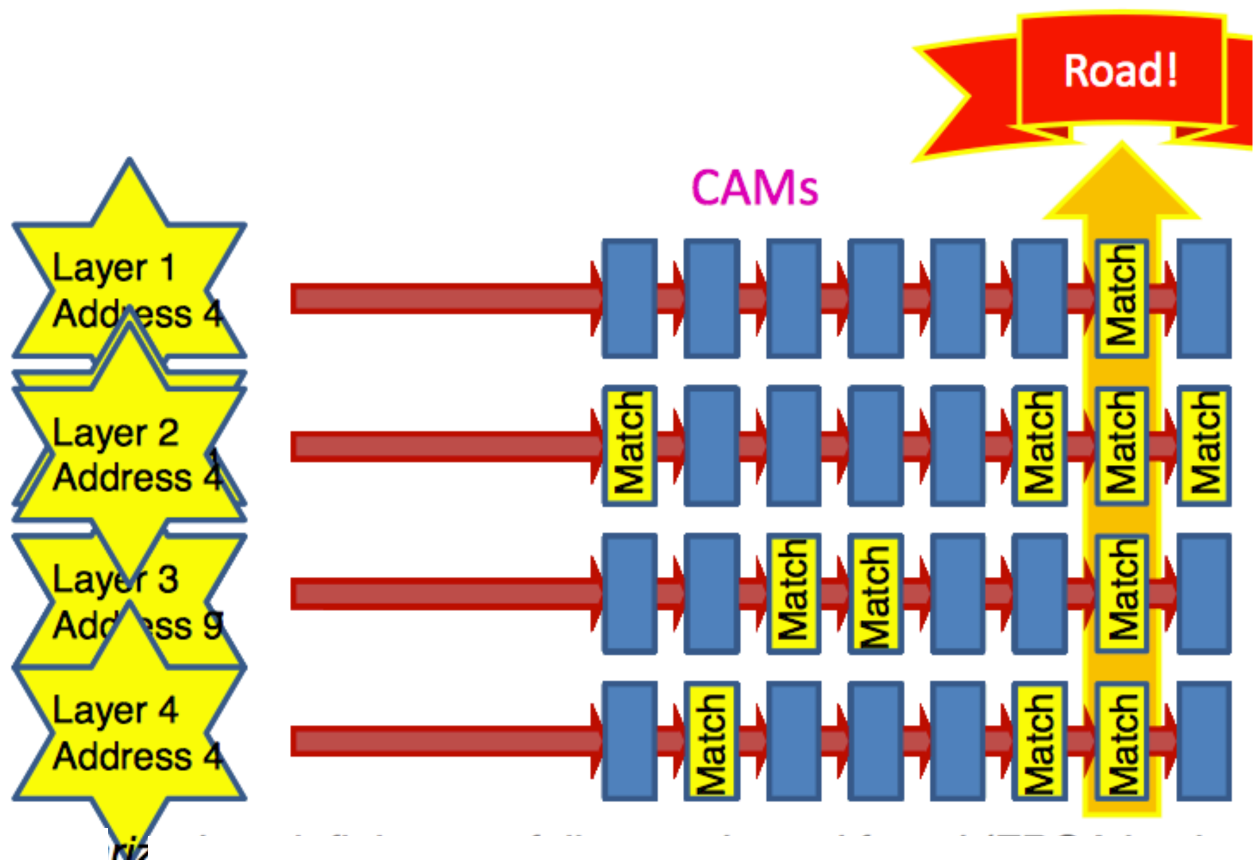
Pattern Recognition (PR) and Track Fitting

Two approaches being explored at CMS

1. **A**ssociative **M**emory Approach:

- <u>PR performed before track fitting to speed up the fitting stage</u>
  - many coarse patterns (“roads”) pre-emptively stored in the AM chip
  - when a road has stubs in all (or all but one) detecting layers a track candidate is found





<u>similar to ATLAS FTK</u>
<u>(see Anadi Canepa's talk)</u>

- Track fitting performed in the FPGA
  - possible track fitting algorithms: Principal Component analysis, Hough transform, and Retina

Pattern Recognition (PR) and Track Fitting

2/2

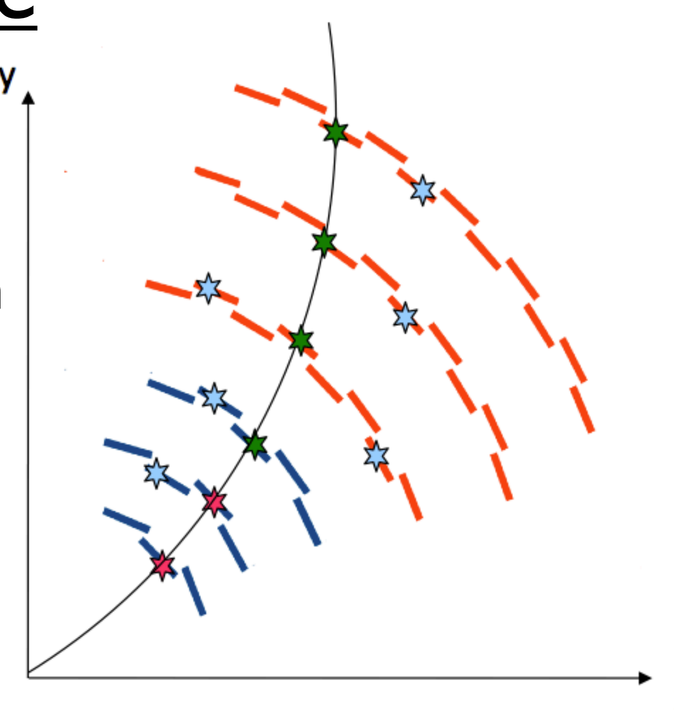
2. Fully FPGA Approach ("tracklet" approach as example):

- <u>PR and track fitting performed at the same time</u>

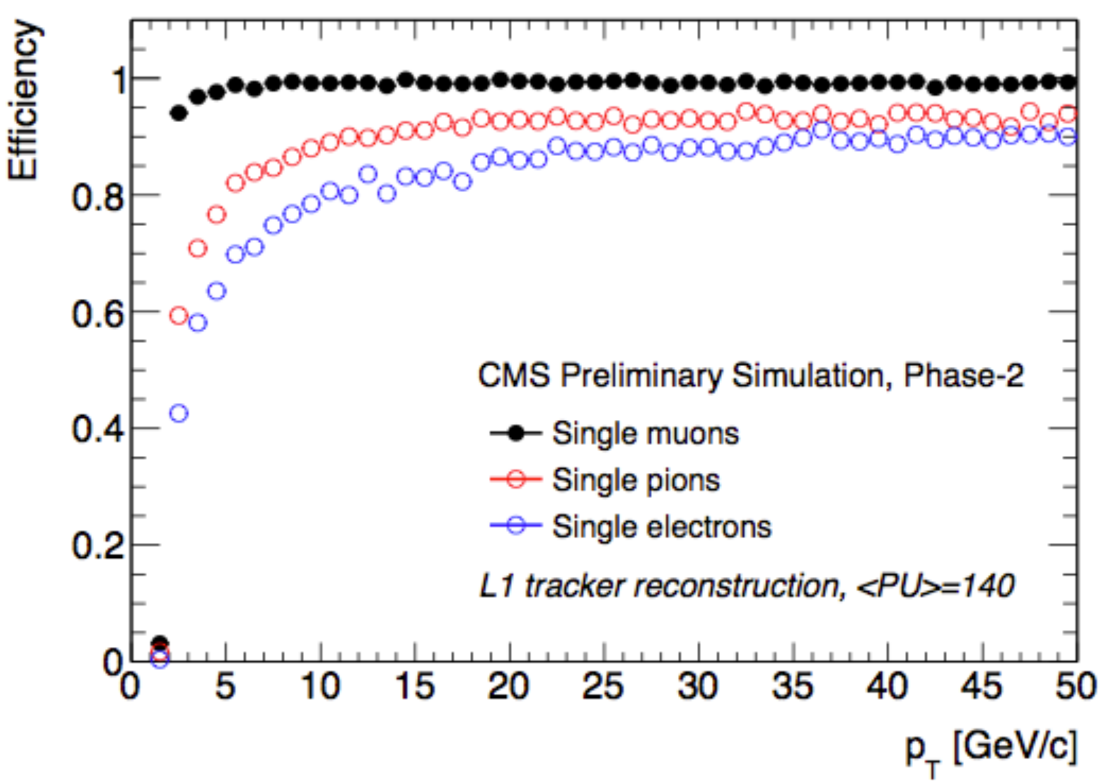
[similar to the traditional offline search]

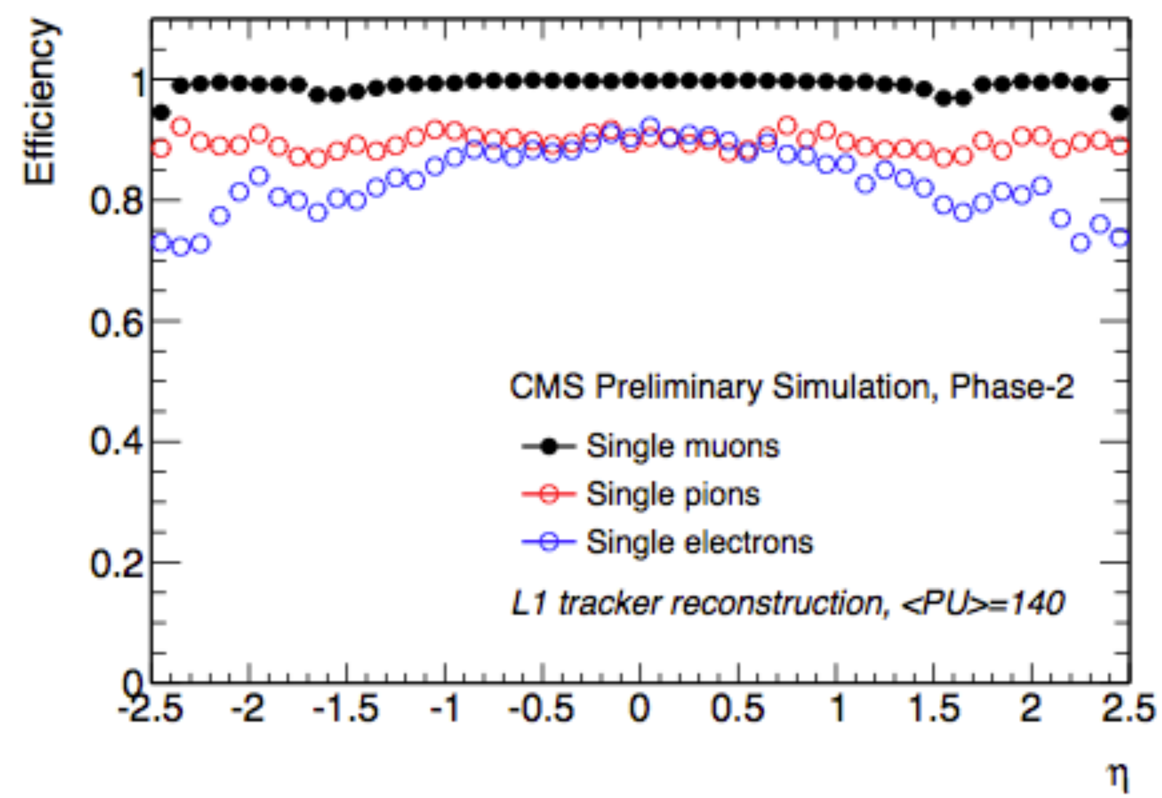
  - form track seeds ("tracklets") by compatible pairs of stubs

    [*all tracklets assumed to have the same origin*]
  - tracklets are projected to other layer searching for matching stubs in neghboring layers
  - track parameters are extracted using a linearized χ2 fit over the hits matched to the tracklets



Expected performances of the tracklet approach



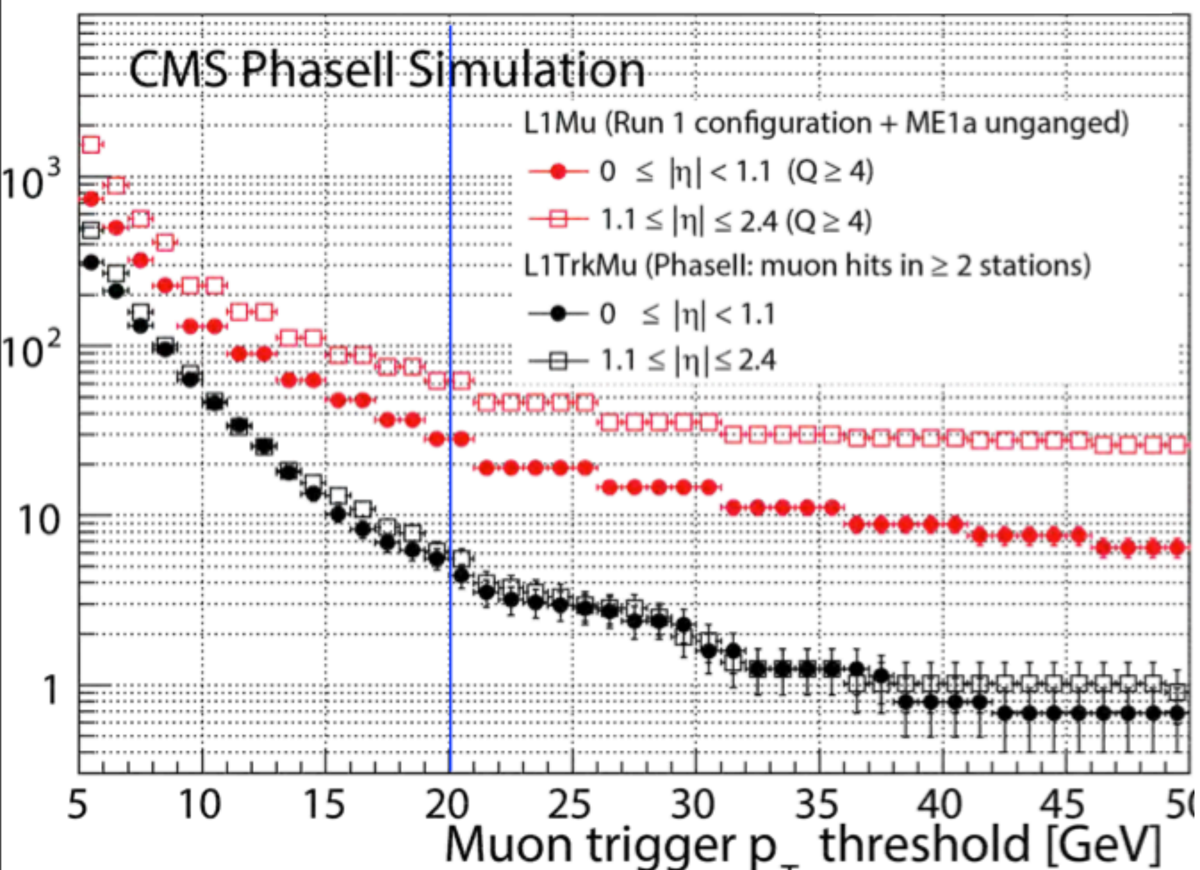


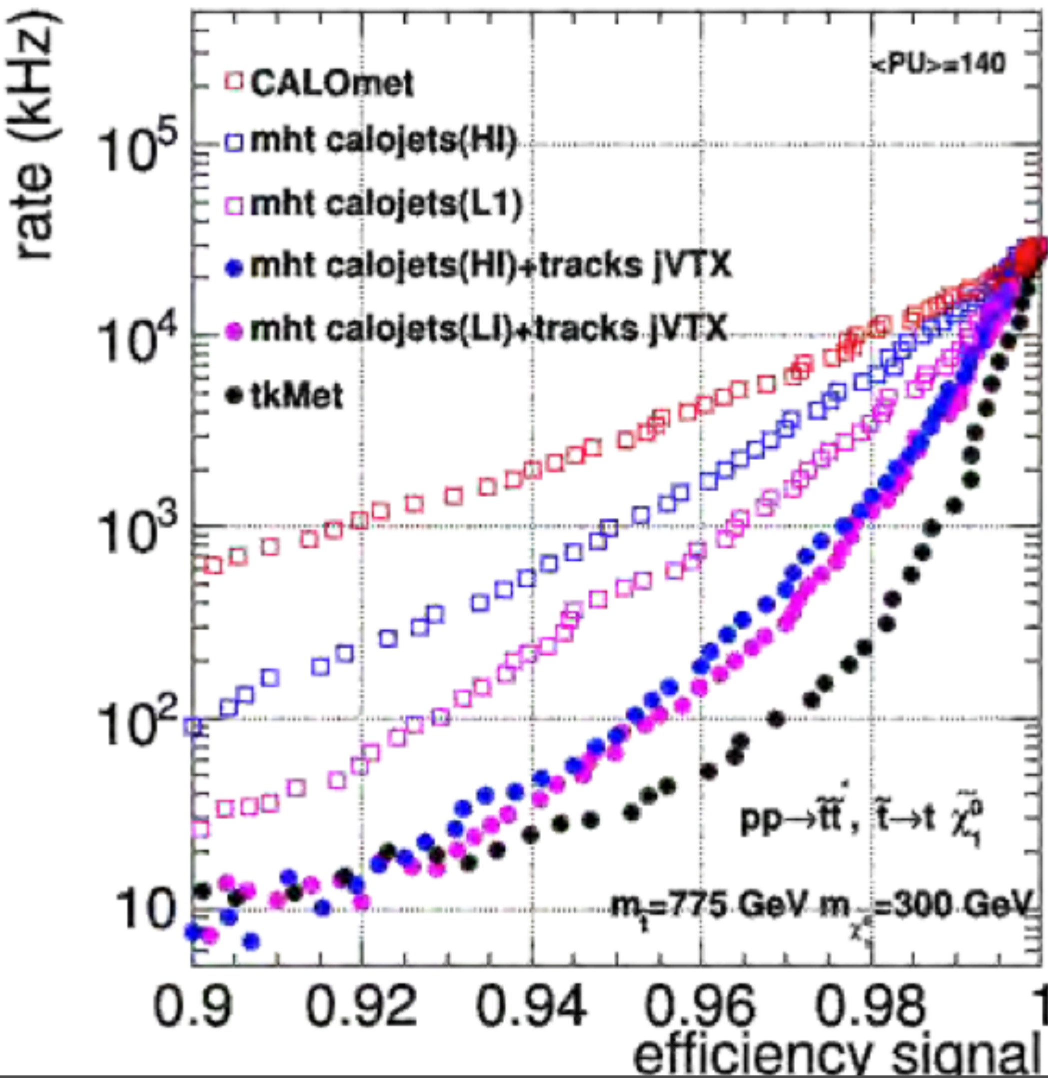
Conclusions

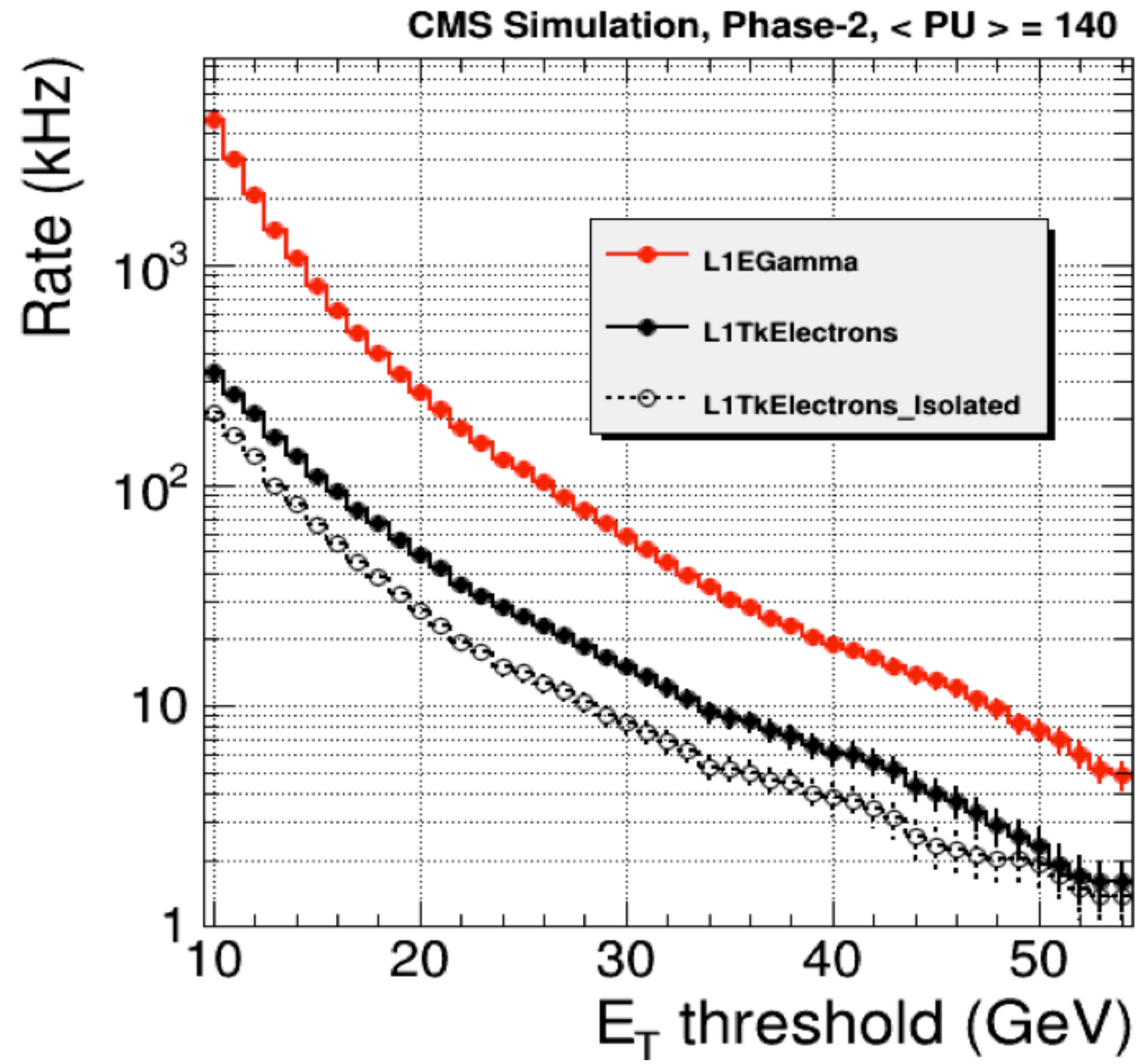
- Physics case established: a track-trigger for HL-LHC is something we "must have" for an optimal physics reach [PU mitigation, improved lepton ID for lower thresholds, etc...]
- CMS tracking trigger R&D project is a pioneering effort which will pave the way for future hadron colliders
- Exploring two approaches in CMS, system demonstrations planned for 2016

backup

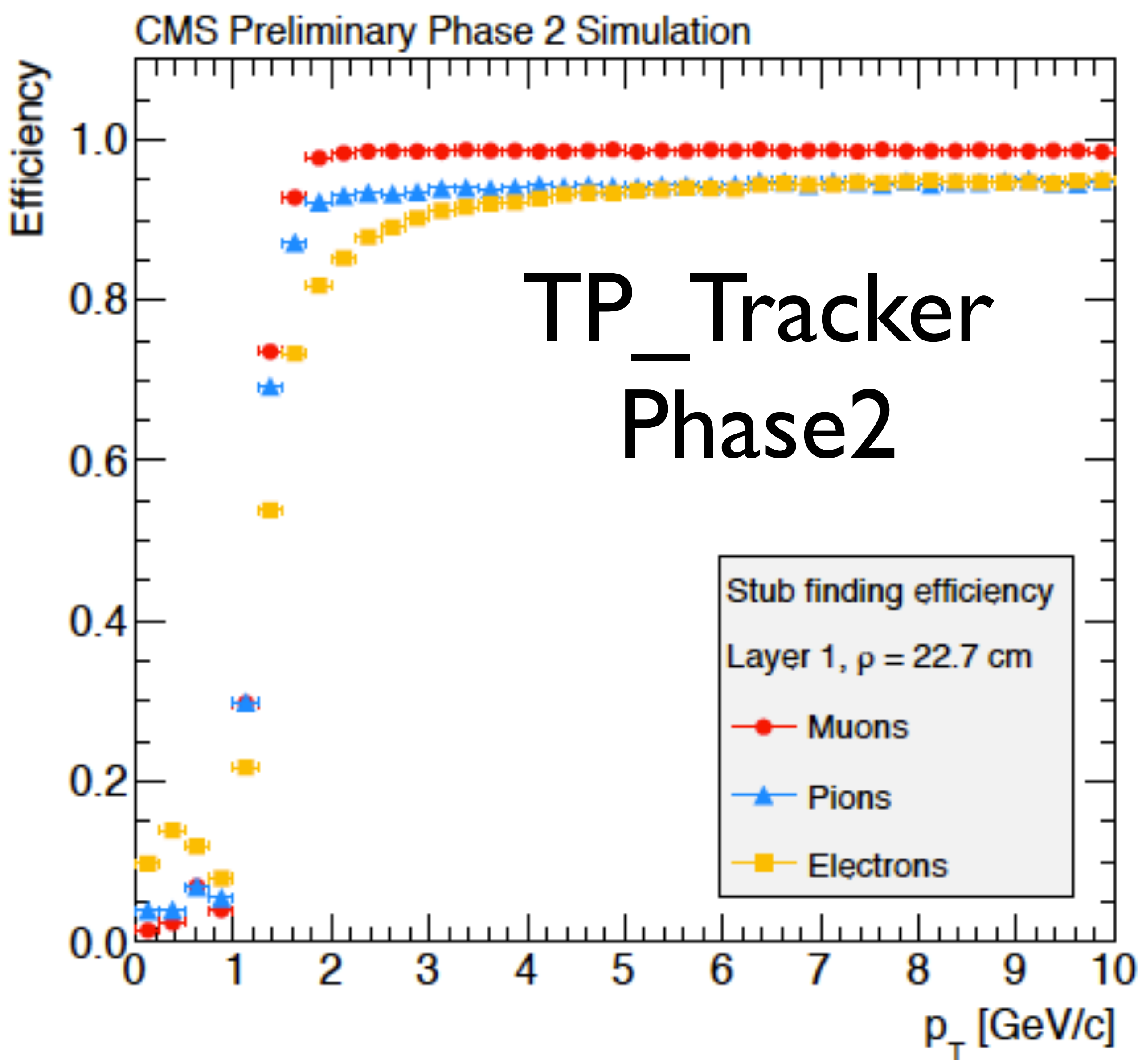
PU = 140, 14 TeV







More details in W. Smith's talk



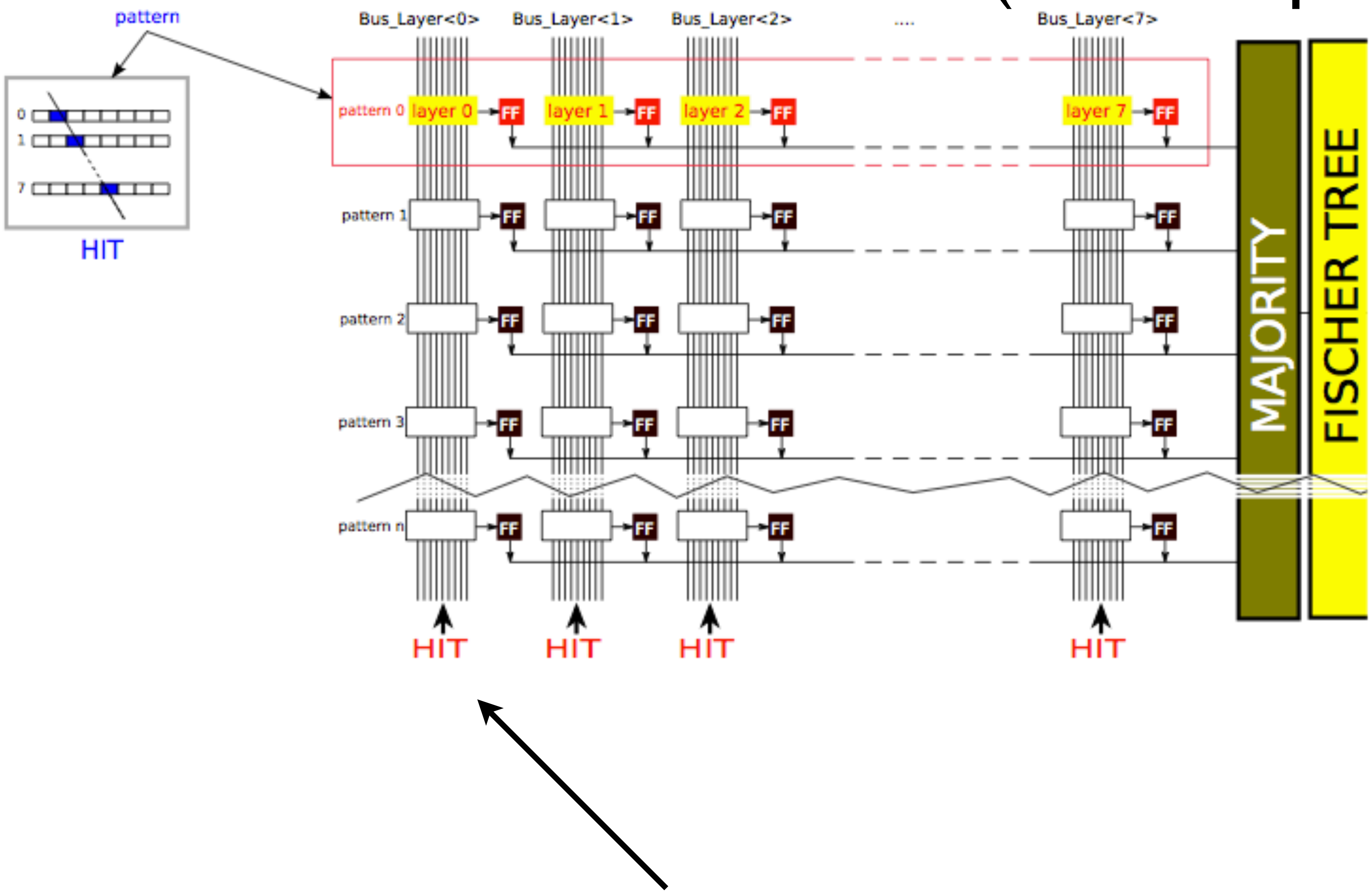
CMS Preliminary Phase 2 Simulation
Efficiency
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
p_T [GeV/c]
TP_Tracker
Phase2
Stub finding efficiency
Layer 1, ρ = 22.7 cm
Muons
Pions
Electrons

link

As previously said, the transmission of the trigger information by the CIC is fully synchronous. Therefore, the amount of information which could be transmitted is strictly limited by the size of the trigger block in the CIC word. In our case, this size is 256 bits for eight bunch crossings, and eight CBC/MPA chips.

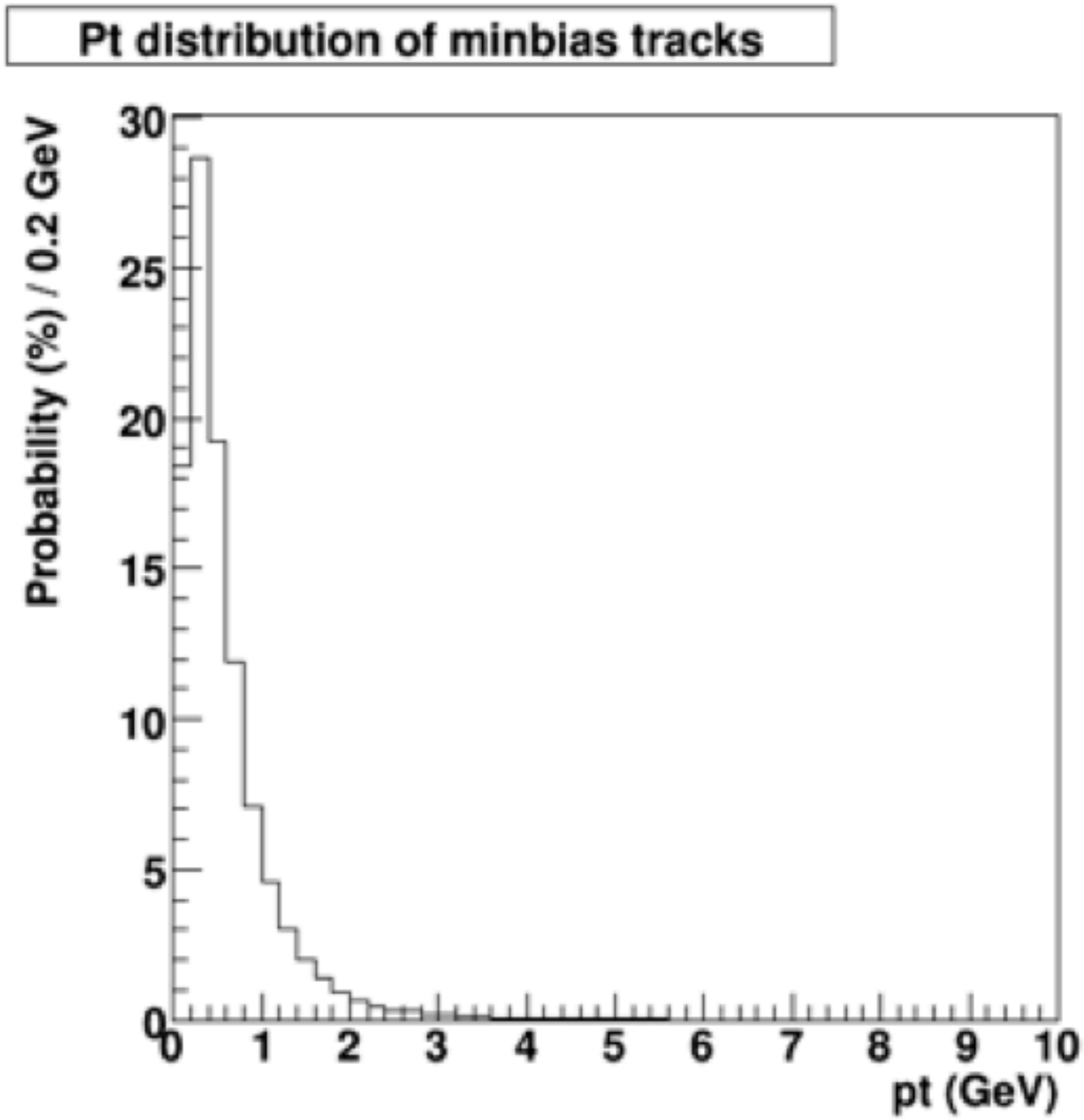
The format of the CIC trigger block has been described in details in [2]. In the baseline scenario, coding a stub from the MPA/CBC in the CIC block requires 23/19 bits respectively. Using this encoding, we show in [2] that the CIC can transmit up to 10/12 MPA/CBC stubs per block. This corresponds to a maximum rate of 2.5/3 stubs/module/event in the PS/2S modules respectively. If we consider a safety factor of 2, the maximum acceptable average rate in the PS/2S, for the baseline configuration, is therefore 1.25/1.5 stubs/module/event.

match finding through “rows” (1 row 1 pattern)

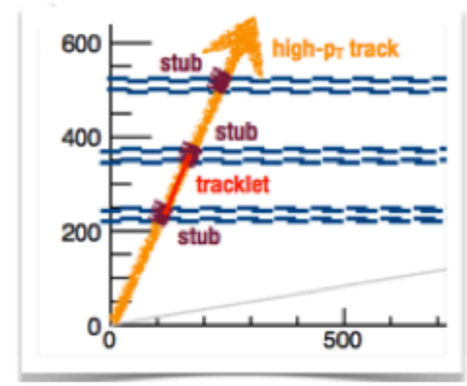


hits distribution through “columns”

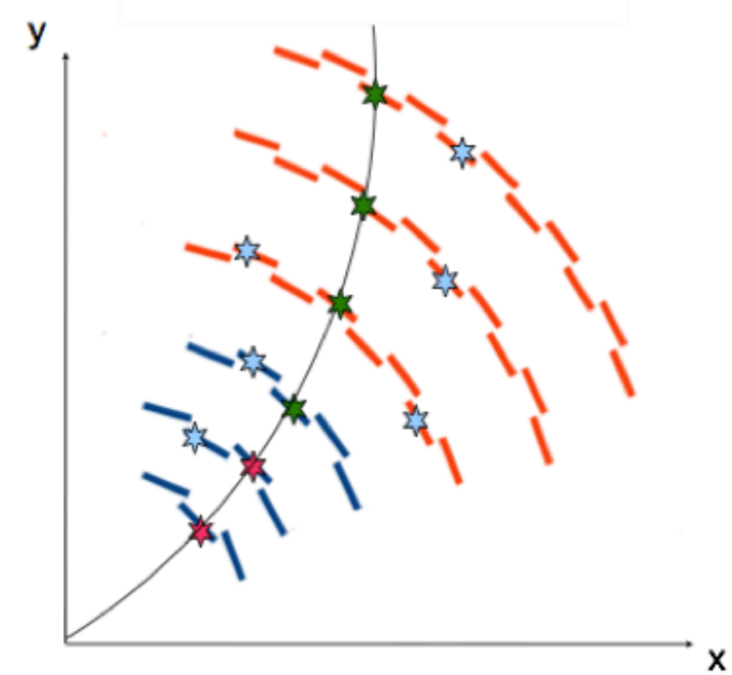
link


Pt distribution of minbias tracks
Probability (%) / 0.2 GeV
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
pt (GeV)

Tracklet Algorithm

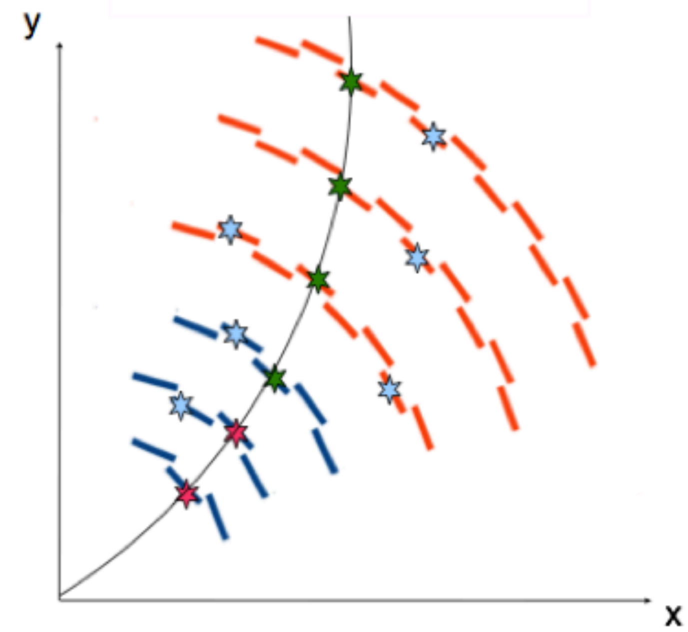


- Two stubs form seeds (tracklets)
- Seeding in neighboring layers
- Project the tracklets to the other layers using the IP as a constraint
- Look for stubs in a window around the extrapolated track position
- Refit for final track parameters using all the stubs
- The algorithm is similar to ones used for offline tracking



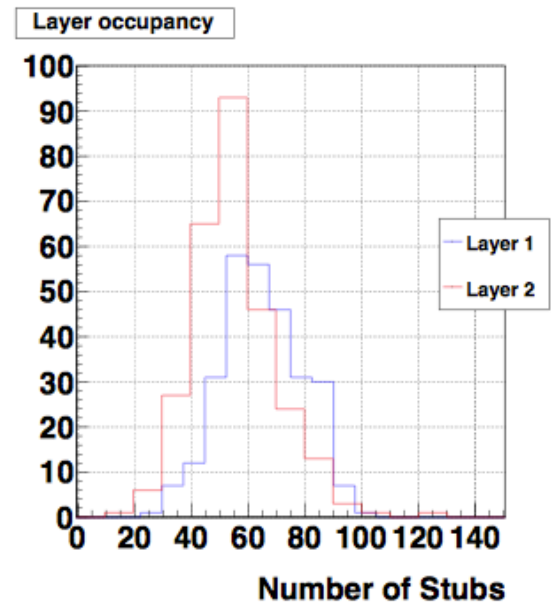
Match Stubs

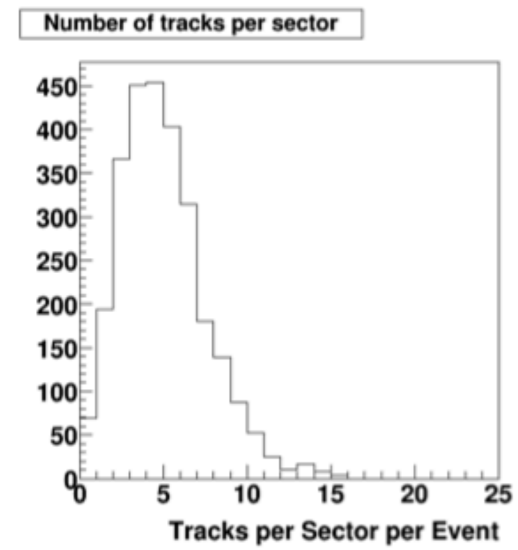
- Divide the detector in 28 ϕ sectors
  - Largest number of sectors to only have nearest neighbor communication
- The projected position of the tracklets is sent to the modules where stubs are expected
- A 2GeV p_T track can bend considerably and be projected to a layer in a different ϕ sector
  - This data transfer is yet to be implemented
- If a stub is found within a certain distance in ϕ and z of the projected tracklet, the stub is part of the track
  - Here we need to take in only selected tracklets since we have to loop over all the stubs in the module
- These distances (residuals) are stored since they will be used in the final track fit



Data Input

- At an average pileup of 140, in each of the 28 ϕ sectors there are on average 65 stubs on the inner most layer and 55 on the second layer.
- This leads to an average of 3600 possible stubs combinations to form a tracklet
- The tails of these distributions are the biggest concern, but we have a way to deal with them
- The number of real tracks is much lower, with a mean of 4.5





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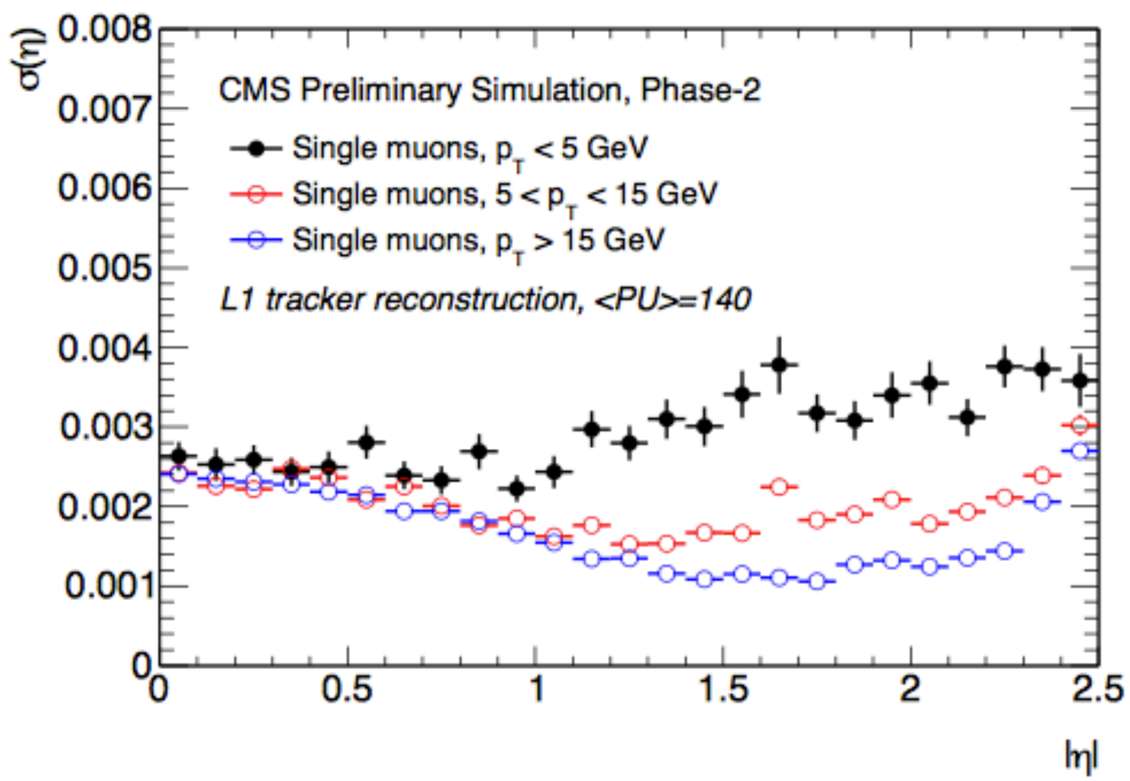
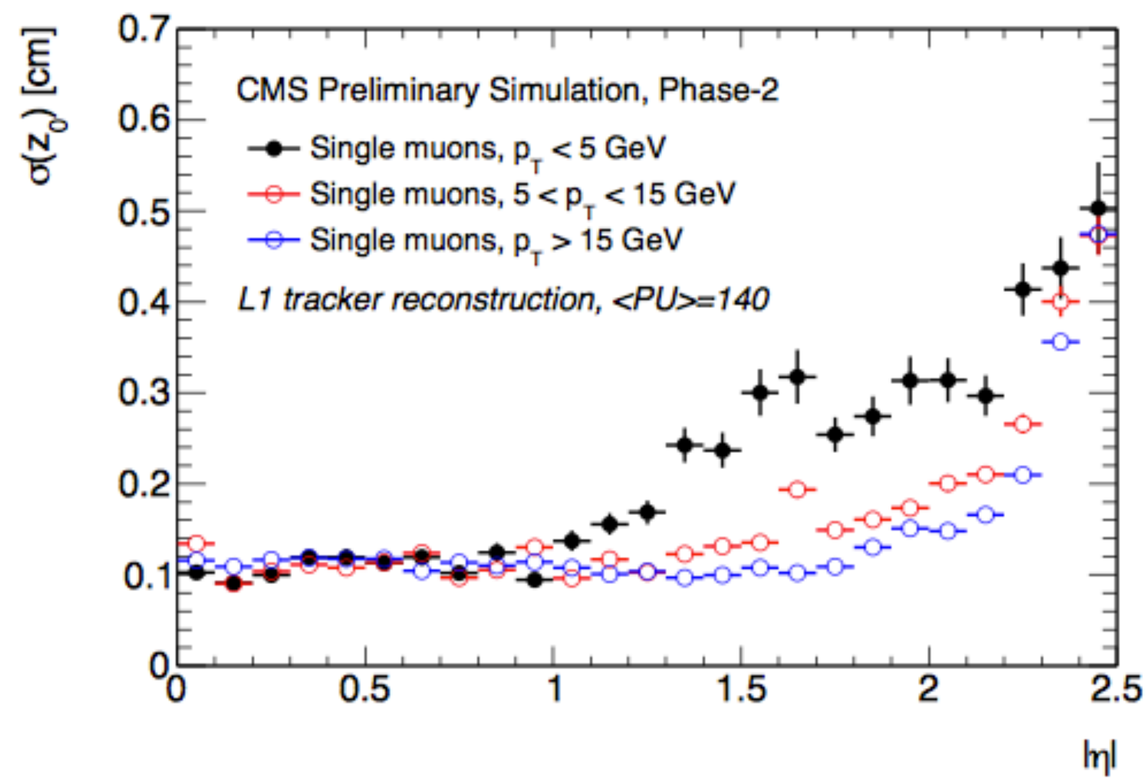
Track Resolutions

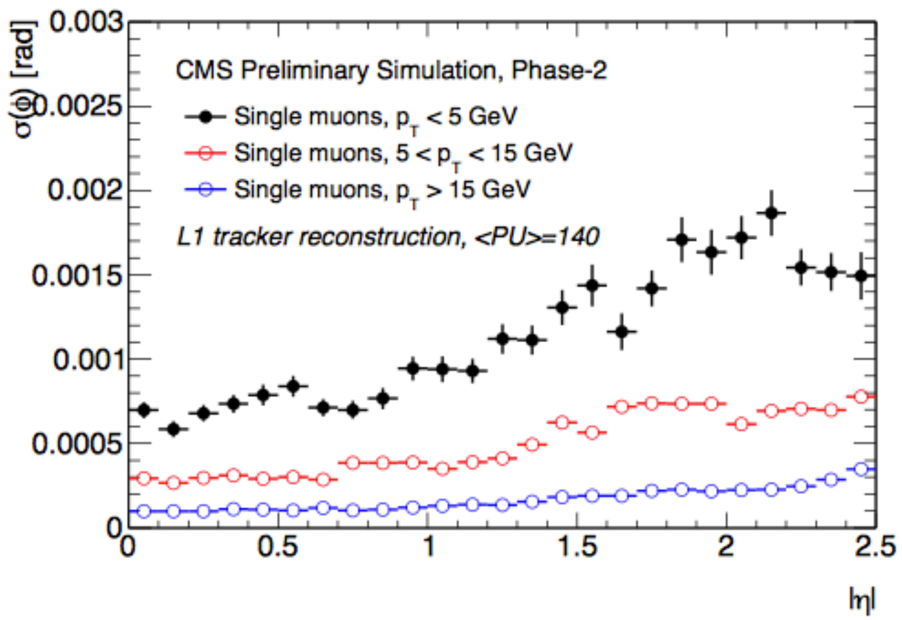
- L1 track parameter resolutions for single muons in events with <PU>=140
- Here, η & z_0 resolution vs |η| for three ranges of p_T
  - **σ(η)** ~0.002 for high p_T tracks
  - **σ(z_0)** ~1mm for a wide range of η despite large extrapolation distances thanks to PS modules

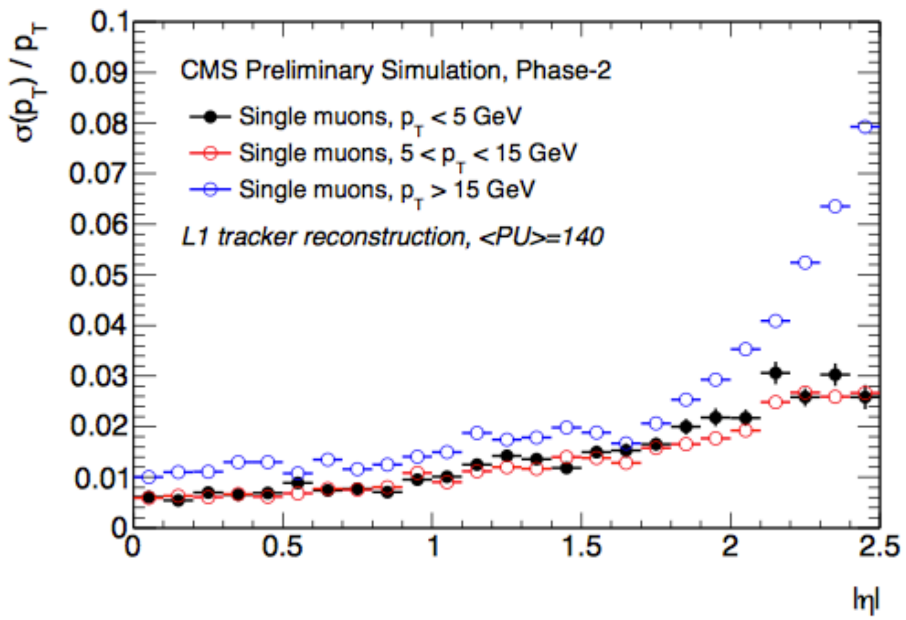




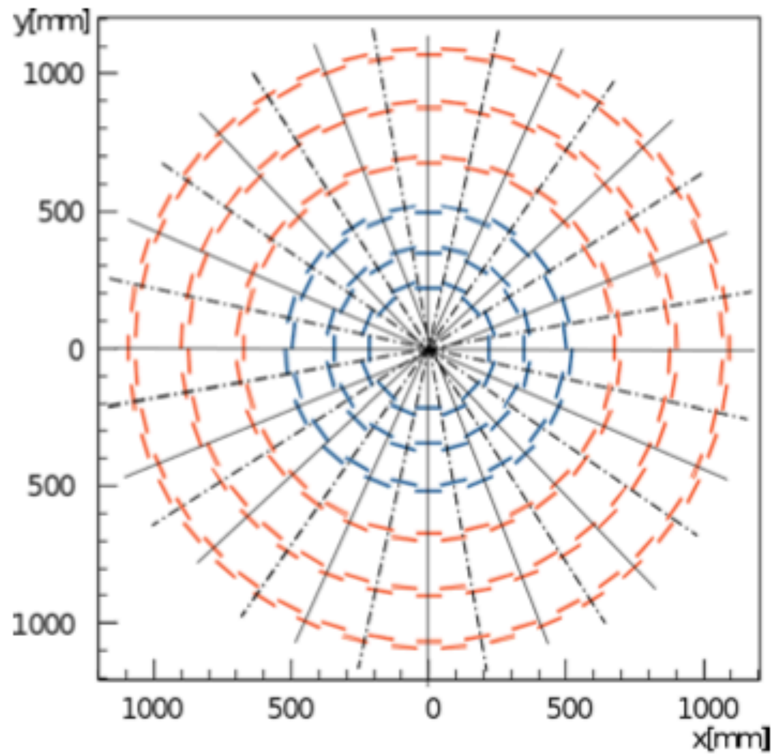
Track Resolutions

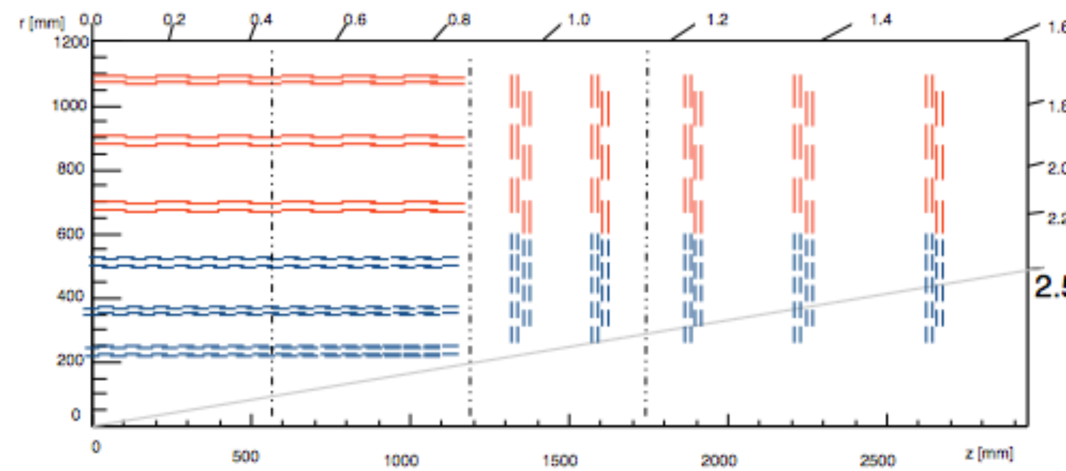
- L1 track parameter resolutions for single muons in events with <PU>=140
- Here, ϕ & p_T resolution vs $|\eta|$ for three ranges of p_T
  - **$\sigma(\phi)$** ~0.0003 for 10 GeV track at central η
  - **$\sigma(p_T)/p_T$** ~1% at central η for high-p_T track





Data Organization





- Divide the detector into smaller pieces in order to manage the amount of incoming data
  - Divide detector in 28 ϕ sectors and 4 z regions
  - On odd layers, subdivide each ϕ sector into 3 virtual modules
  - On even layers, subdivide each ϕ sector into 4 virtual modules
    - Tracklets are contained in one sector
  - Subdivide each z region in the barrel into 2