Endcap Muon (CSC) Trigger Phase I and II Upgrade Plans and Status

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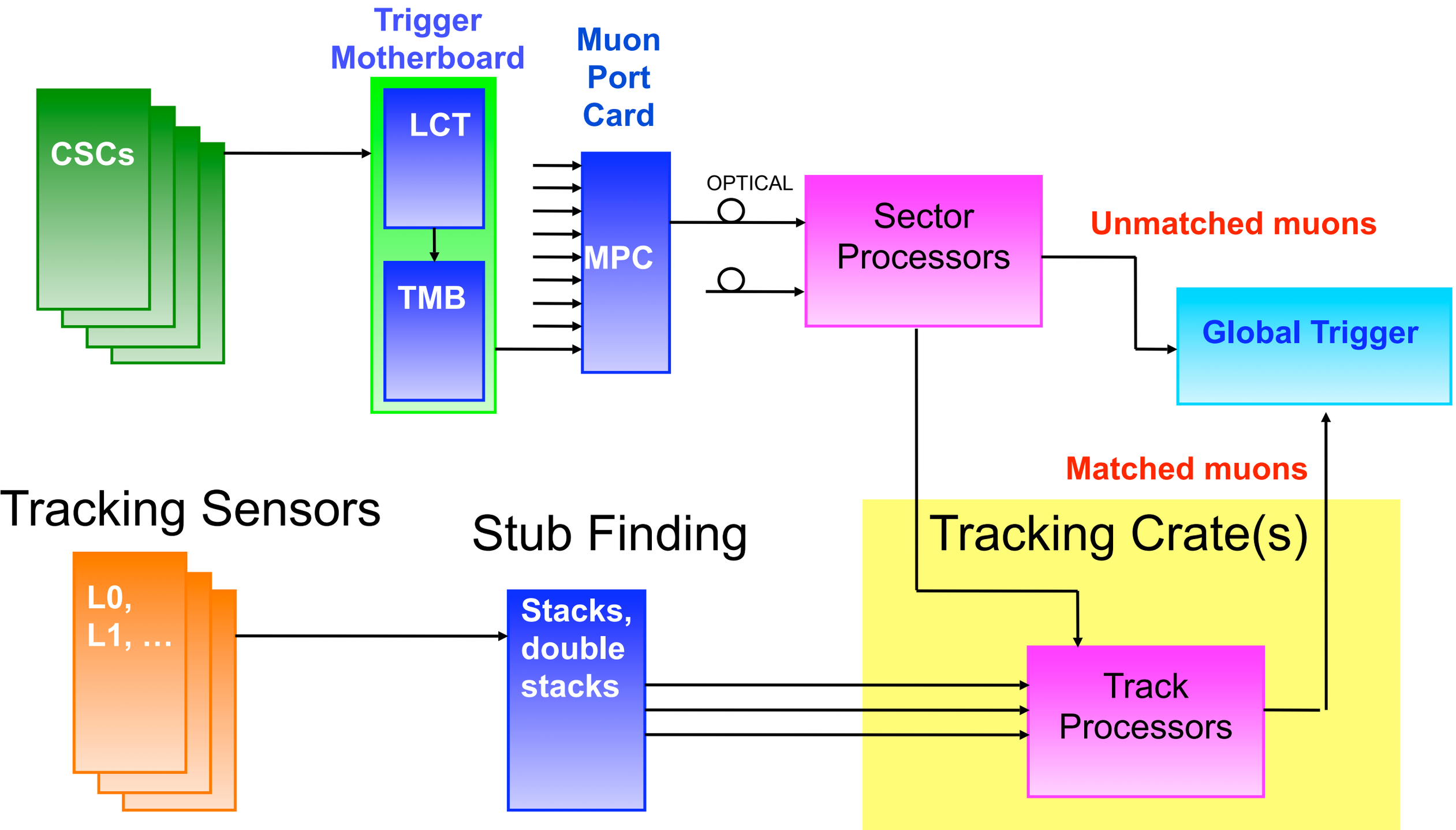
on behalf of the CSC Detector and Trigger communities

Overview

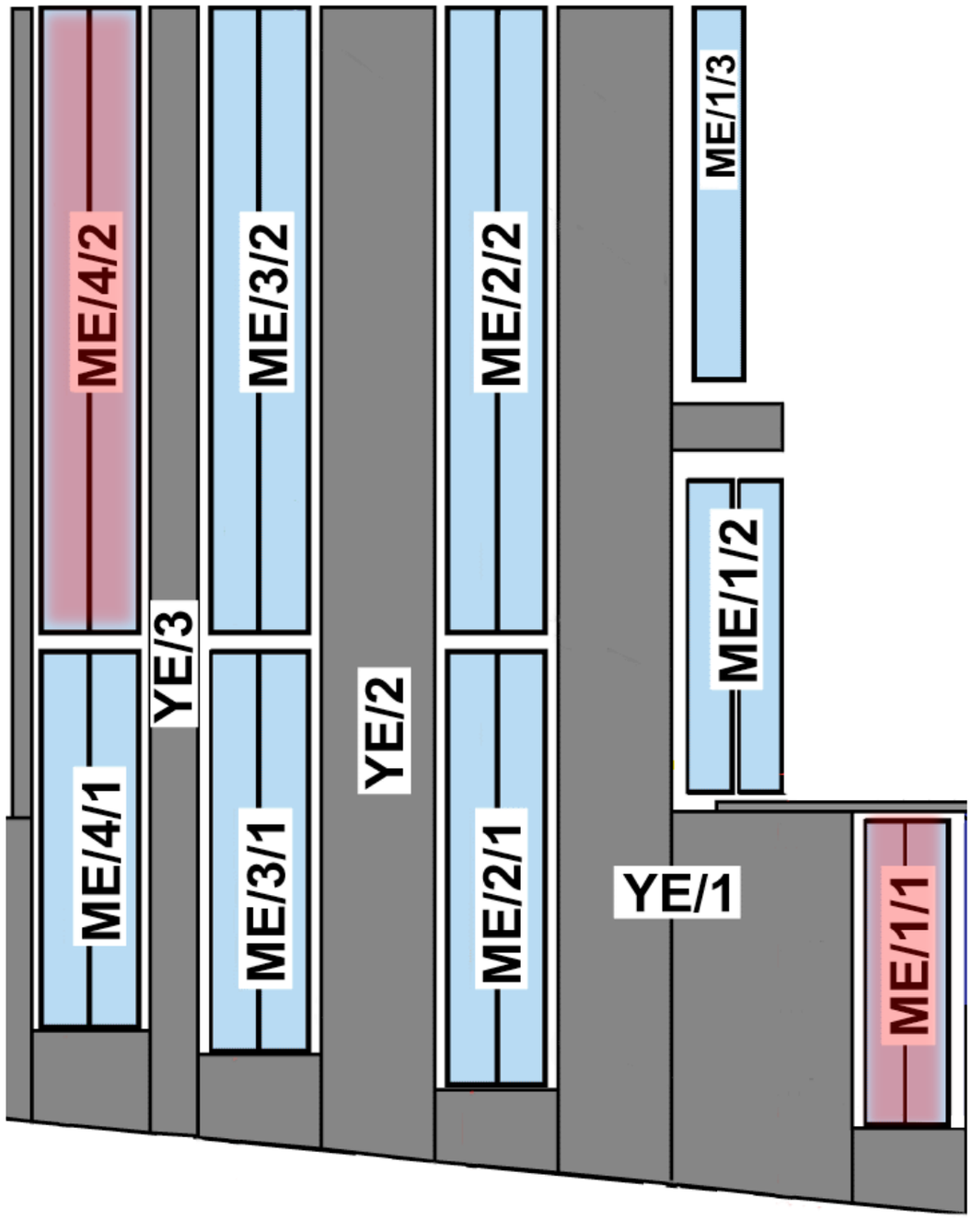
- CSC - “low” occupancy in LHC running
- utilized in design of trigger, DAQ data flow
- SLHC challenge: handle internal rates, control trigger?
- Phase I:
  - Detector upstream: trig primitive quality good enough, focus is on handling increased rate
  - Track Finder: handle increased rate + improve CSC standalone momentum resolution
- Phase II:
  - Detector upstream: relax upper limits on number of trigger primitives (another internal rate increase)
  - Track Finder: combine CSC and tracker information for ultimate momentum resolution

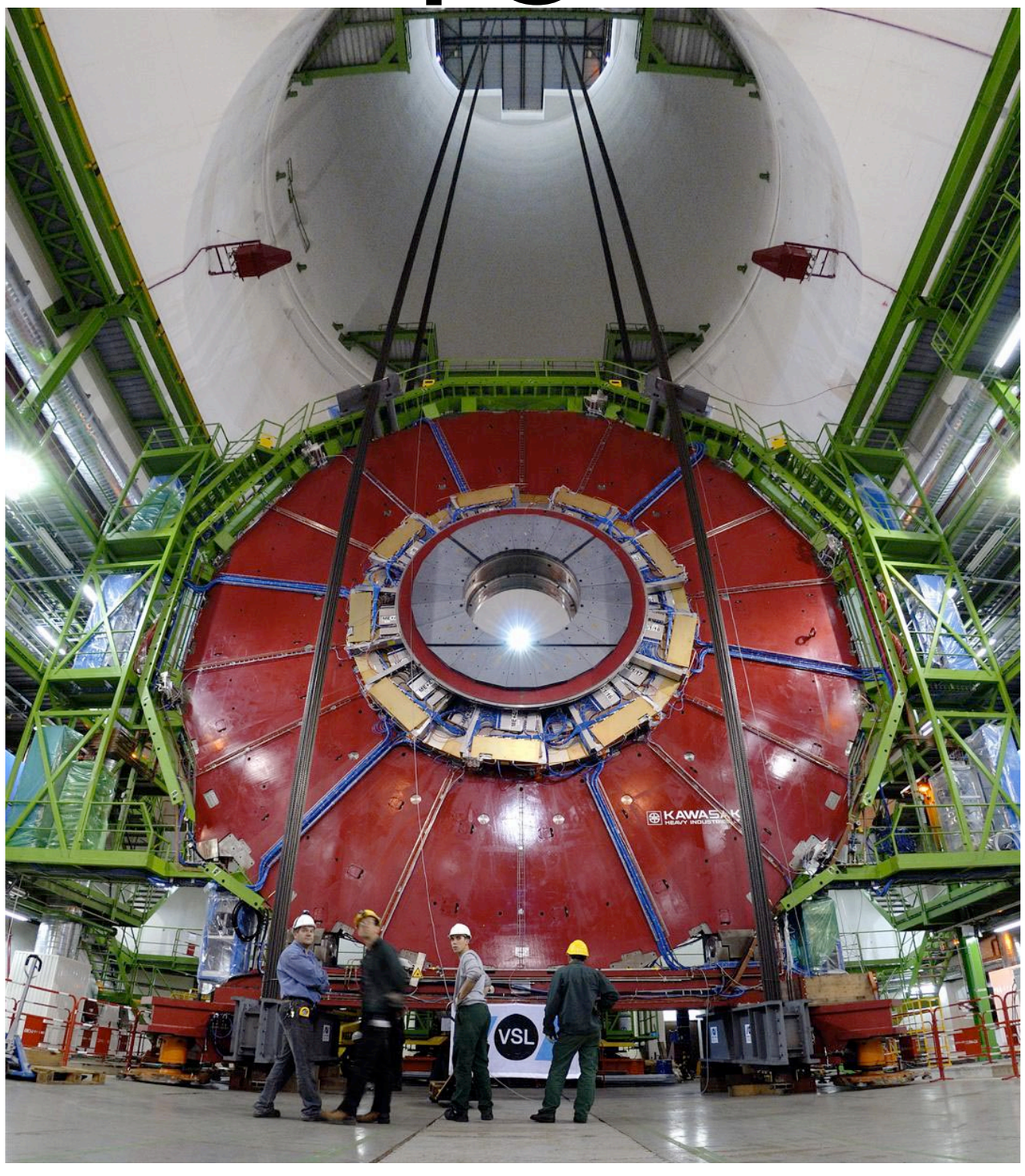
Dataflow Architecture Sketch

Chambers Peripheral Crates CSC Track-Finder Crate



ME4/2 and ME1/1 upgrades



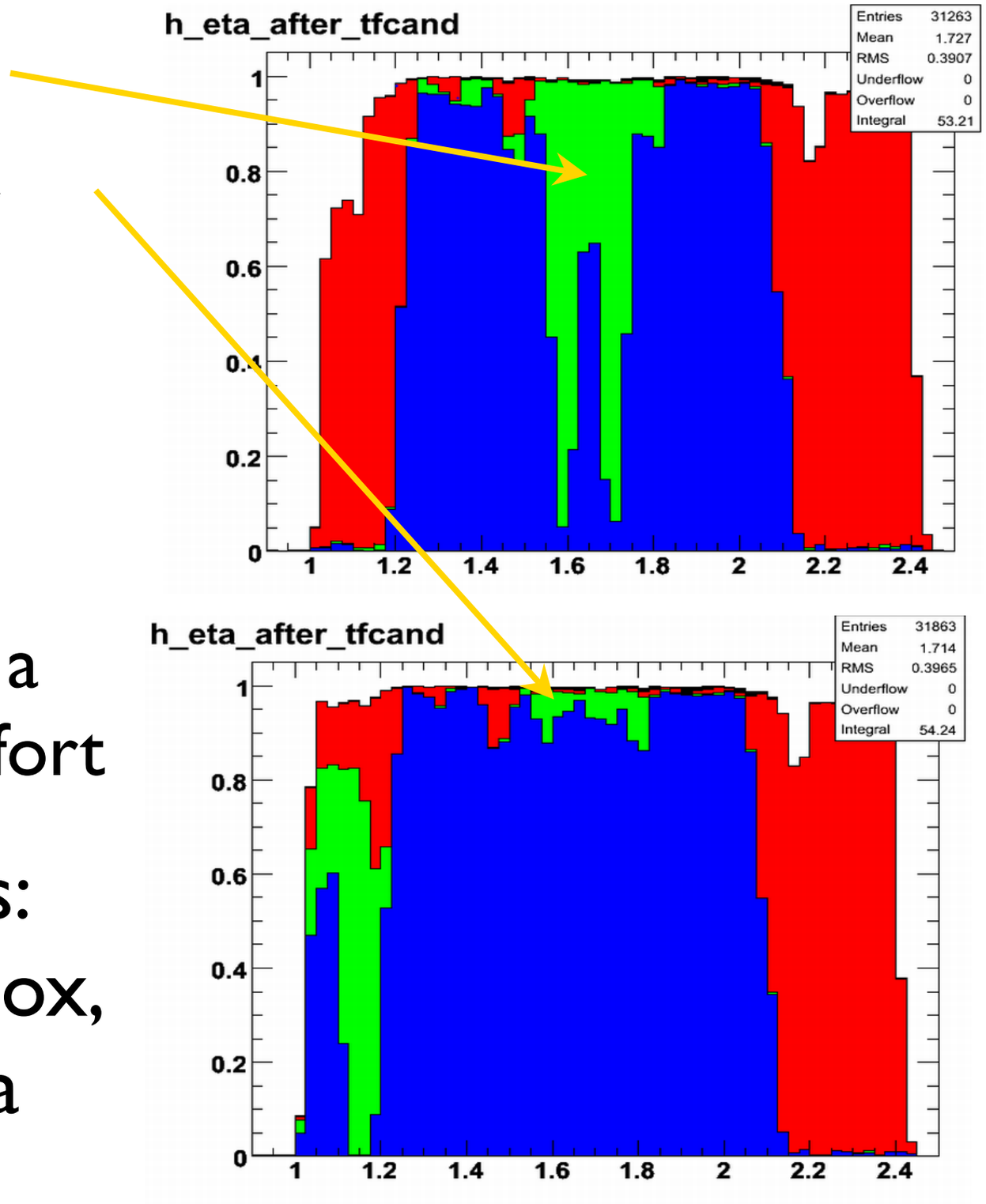


“Empty” YE3 disk ready for ME4/2

Simulation result (May '09)

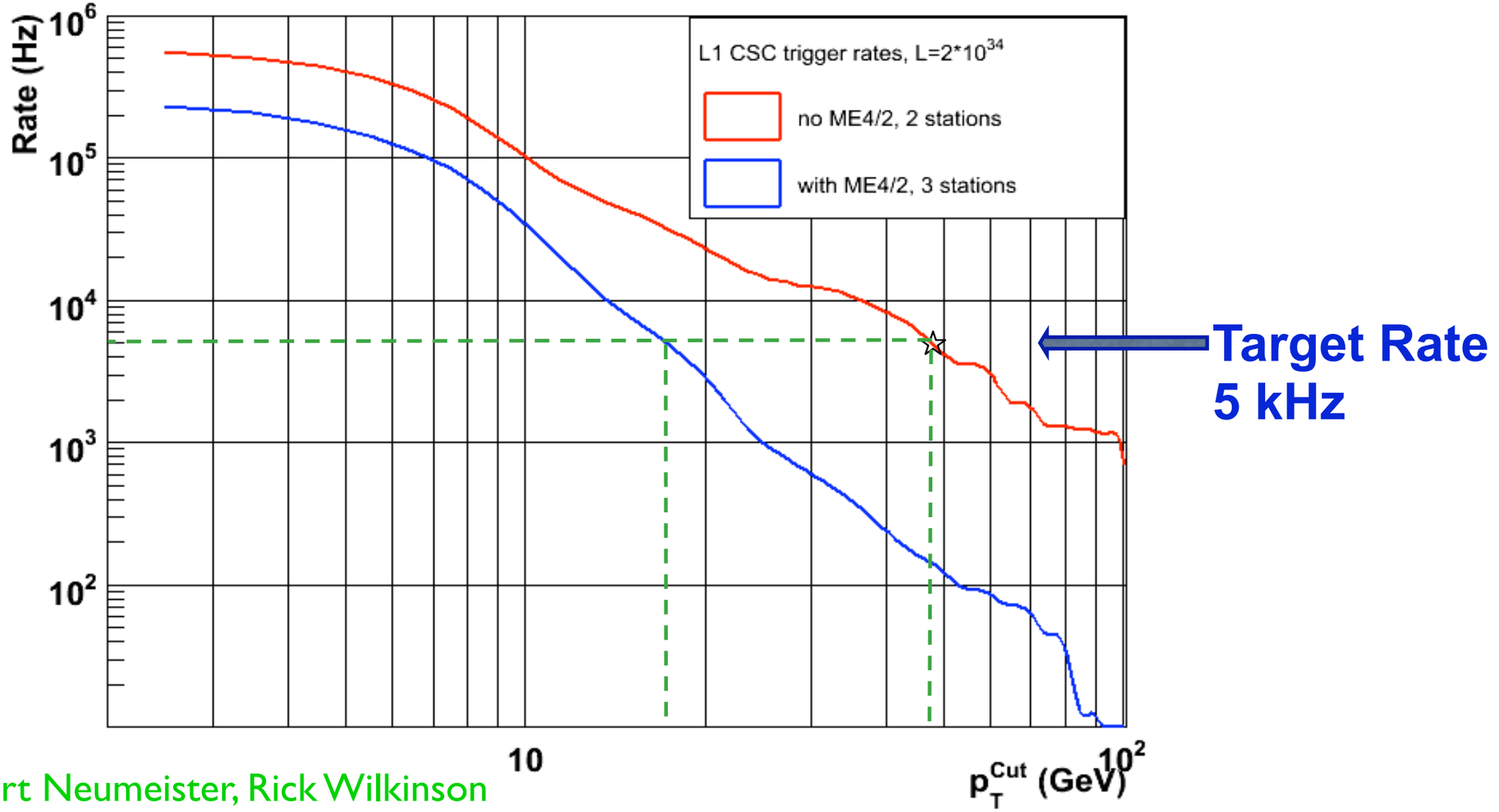
(Vadim Khotilovich, Alexei Safonov)

- Efficiency gaps for good quality TF tracks disappear with addition of ME4/2
- ME4/2 will be included by default in 31X
- Back-porting to 22X took a considerable amount of effort
  - Thanks to the experts: Rick Wilkinson, Tim Cox, Oana Boeriu and Slava Valuev!



ME4/2 upgrade motivation

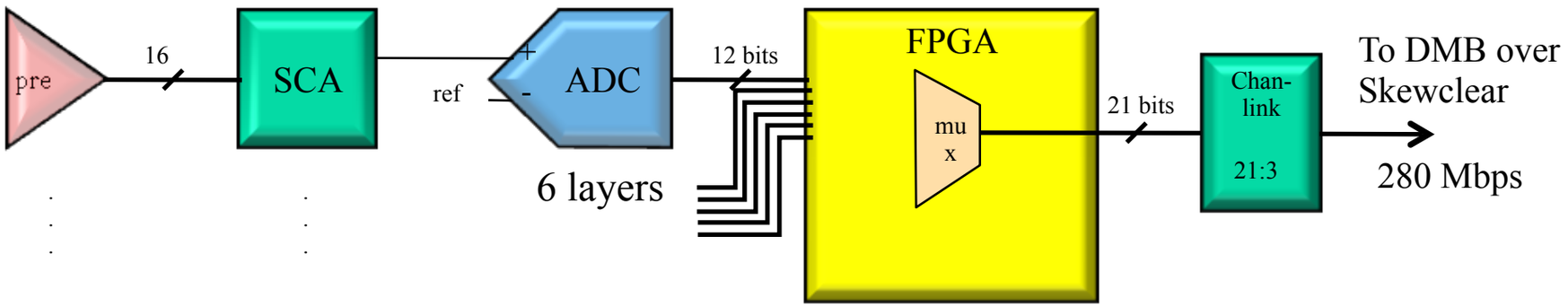
- Triggering with & without the ME4/2 upgrade:
  - The high-luminosity Level 1 trigger threshold is reduced from 48 → 18 GeV/c



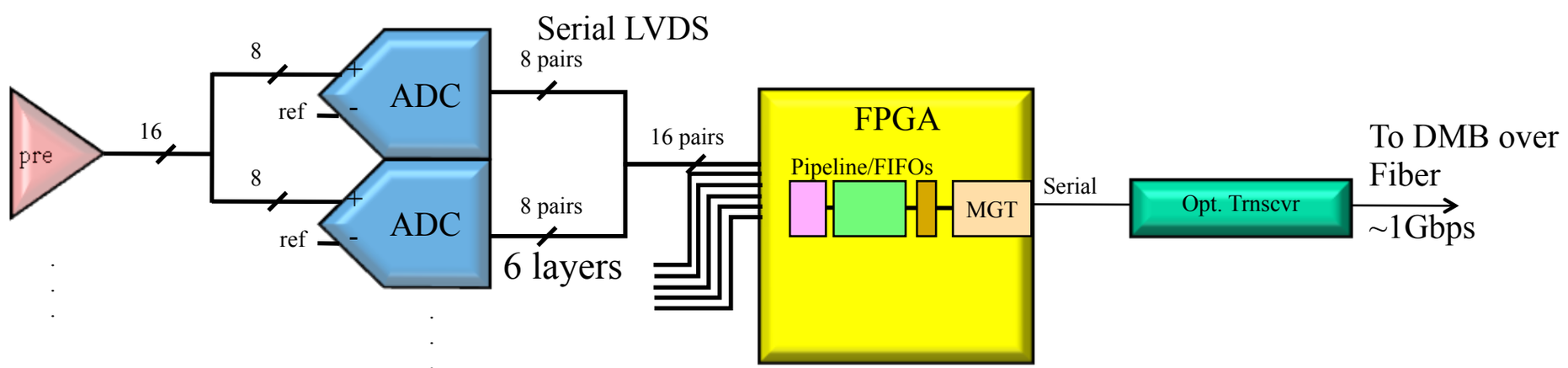
Ingo Bloch, Norbert Neumeister, Rick Wilkinson

“Digital CFEB” cathode board

- **CSC principle: digitize cathode charges to ~1%, interpolate for fine position**
- **Current CFEB: the ADC is multiplexed 16:1**
  - **Requires analog charge storage ASIC (SCA)**
  - **Serial digitization after L1A**

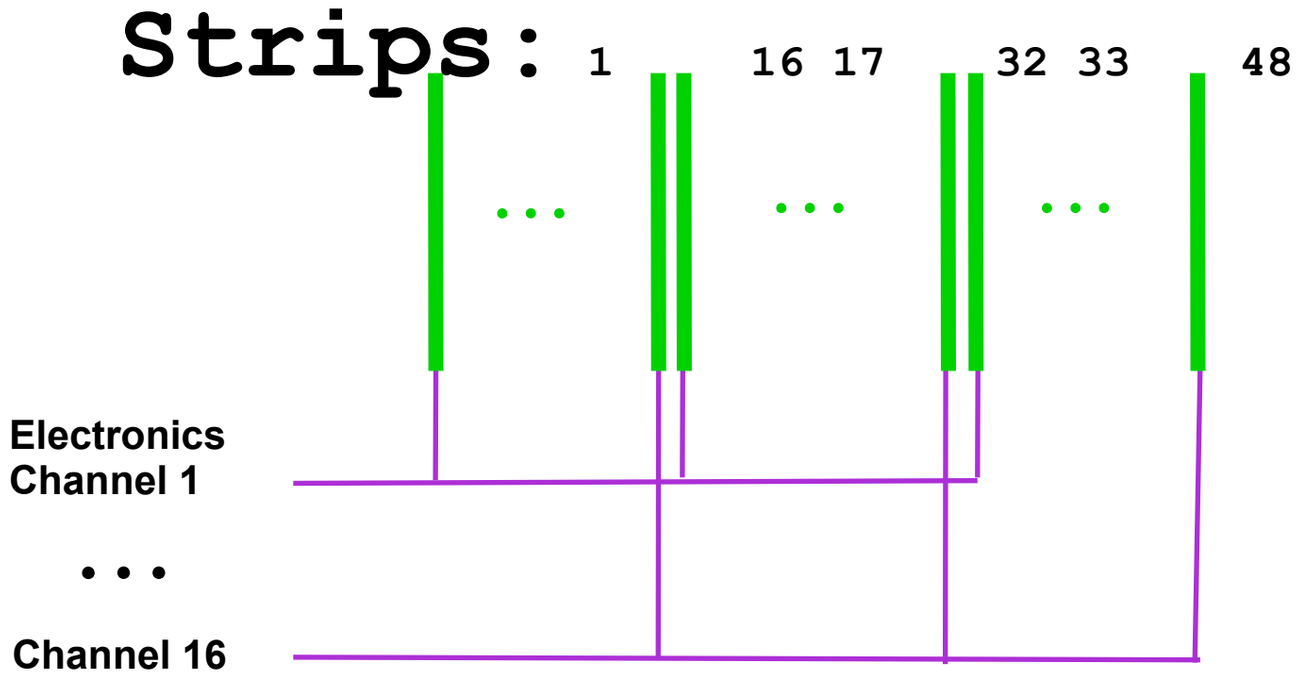


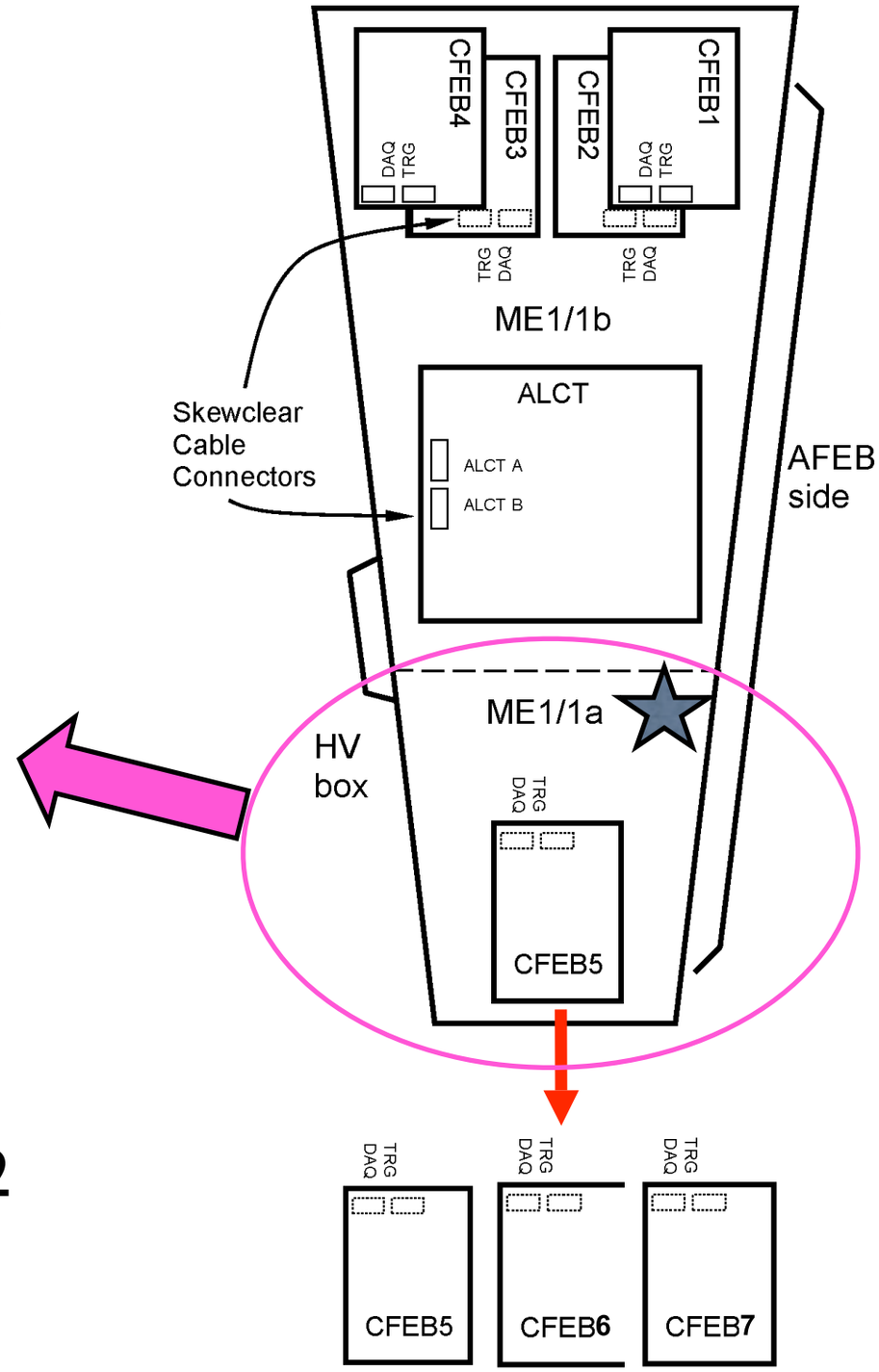
- **Digital CFEB uses Flash ADCs:**
  - **Continuous and deadtimeless digitization**



ME1/1 Restoring η 2.1-2.4

- High-η section of ME1/1
  - Cathode strips are currently ganged 3:1

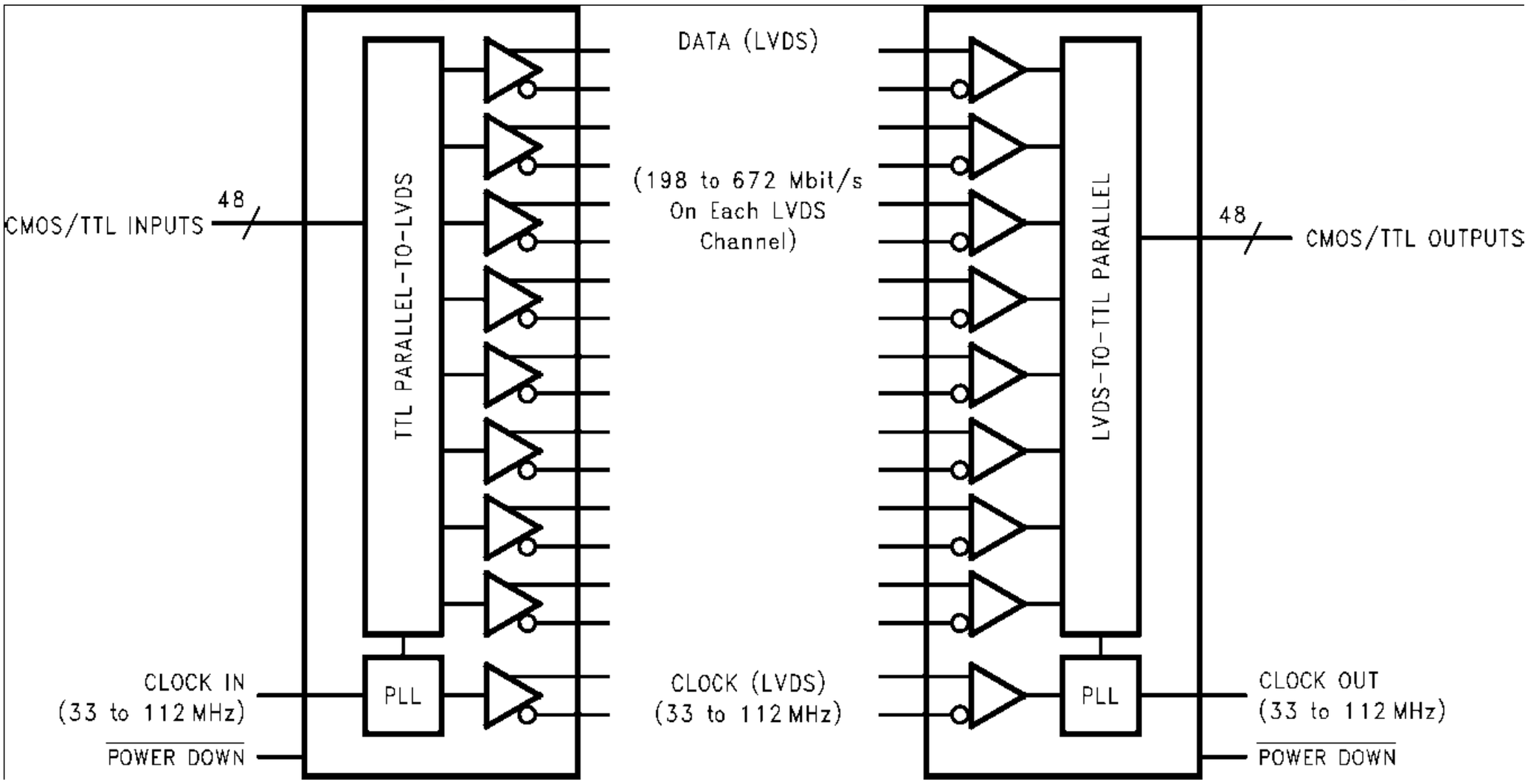




- Plan:
  - Install DCFEB boards on ME1/1
  - Move existing CFEBs from ME1/1 to ME4/2
  - Takes ~2.5 months per endcap

- 72 new TMB and DMB boards needed to accommodate additional inputs, optolinks

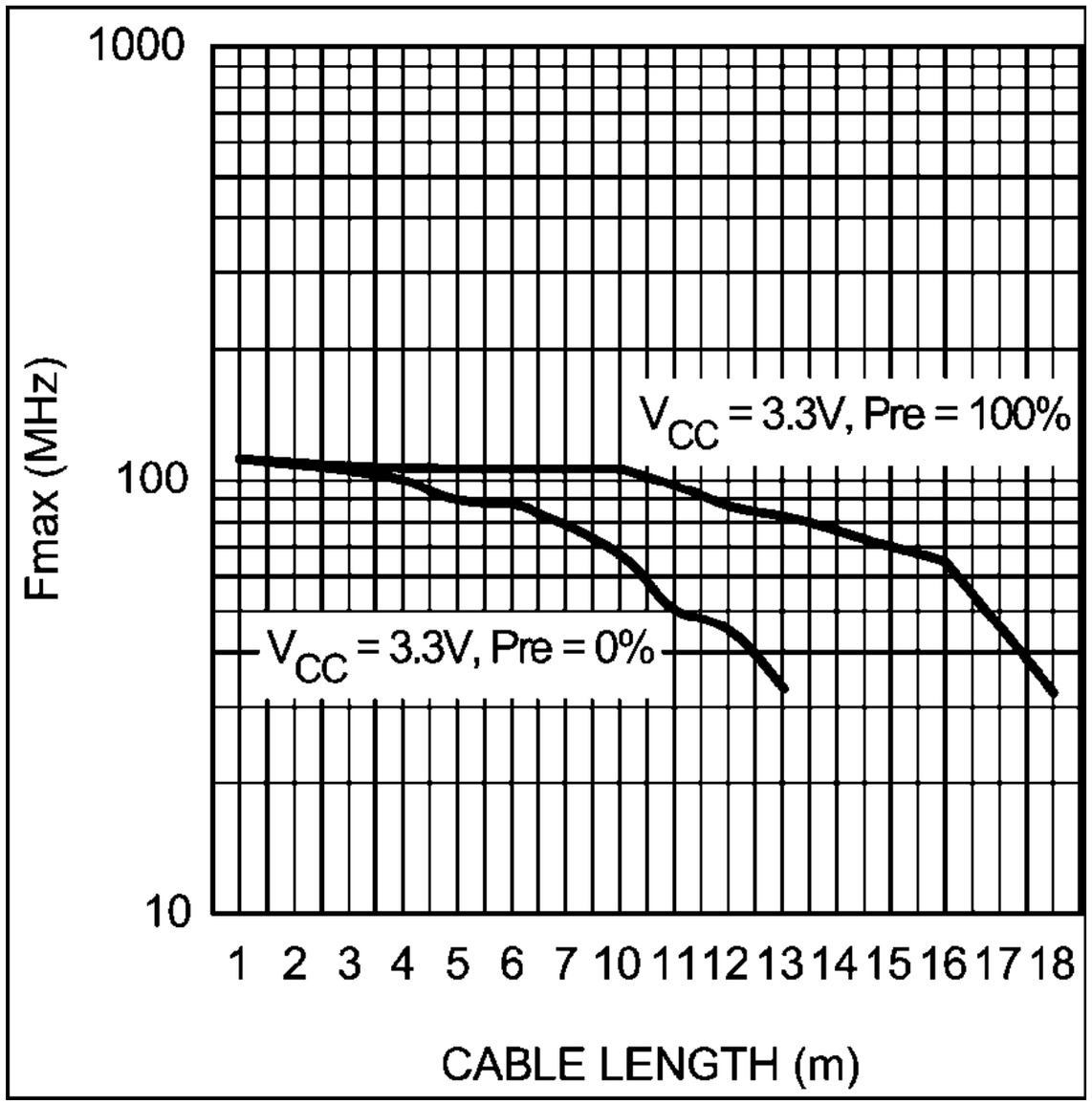
Comparator dCFEB-to-TMB option



- Channel Link: DS90CR483/484A
- 48-8 bit Ser/Deser, requires 19 conductors per CFEB
  - Use 20th conductor as "cable detect" to control Power-Down
- Has options for pre-emphasis and DC balancing
  - Provides for reliable operation, even on our longest cables

- Adds ~3 BX to the trigger latency (~same as Fiber options)

Channel Link Performance Spec



- Performance exceeds our needs: 14 m cable @40 MHz

- Use the same 50-pin SkewClear, 5 cables to TMB!
  - Each cable can carry one OR two CFEB's comparator bits
    - Two-CFEB case gets appropriate fan-out at ME1/1 Patch Panel

TMB-to-MPC

For ME1/1 the rates are very high…

- How to send 4 LCTs per BX to MPC?
  - Efficiency will suffer if we don't do this
- Review Virtex-5 capabilities: SelectIO
  - Up to 800 Mb/sec on single ended lines
  - Up to 1250 Mb/sec on differential lines

Using current backplane resources, what can we do?

- Consider differential signals at 320 Mb/sec, FPGA-to-FPGA:
  - Must go from one mezzanine connection to the other…

    …through two backplane connectors!
  - This will double the bandwidth, allows 4 LCTs per BX
    - Requires much "proof-of-concept" testing
    - Is it reliable? Should we abandon the mezzanine?
  - Signal distance is only ~0.5 m: Can it work?

Port Cards

- Current design is adequate for LHC luminosity
  - 2 LCTs (di-muon signal) + 1 (background) = 3 LCTs per Port Card per BX
- With luminosity upgrade, we expect ~7 LCTs per Port Card per BX.
  - Preliminary simulated data, no measurements so far
  - Reality could be **worse**
  - Port Card becomes a **bottleneck**
  - Solution:
    - Keep 2 Trigger Primitives per chamber
    - Bring all LCTs to SP (18 per Port Card per BX), no filtering
      - May keep the filtering option in Port Cards, in case it's needed
- Port Cards have to be redesigned and replaced system-wide
  - Faster data links evaluated.

Trig. Primitives → Coordinates

- Presently, conversion is done using large LUTs
  - 4MB per primitive
- For upgrade:
  - Using large LUTs impossible: too much memory
  - Make conversion inside FPGA
    - Combine LUTs and logic to reduce memory size
- Use θ instead of η
  - Using θ allows for uniform angular extrapolation windows, no need to adjust them depending on θ

Track reconstruction logic: Expanding Current design

Module	% in current design	increase factor	% upgraded
Multiple Bunch Crossing Analysis (BXA)	8%	36	282%
Extrapolation units (EU)	23%	11	262%
Track assembly (TAU)	1%	4.5	4%
Track parameters assignment (PAU)	13%	4.5	57%
Sorting, ghost cancellation (FSU)	51%	20	1012%
Output Multiplexor (MUX)	2%	4.5	9%
BX adjustment to 2nd trig. primitive (BXCORR)	2%	1	2%
Total	100%		1628%

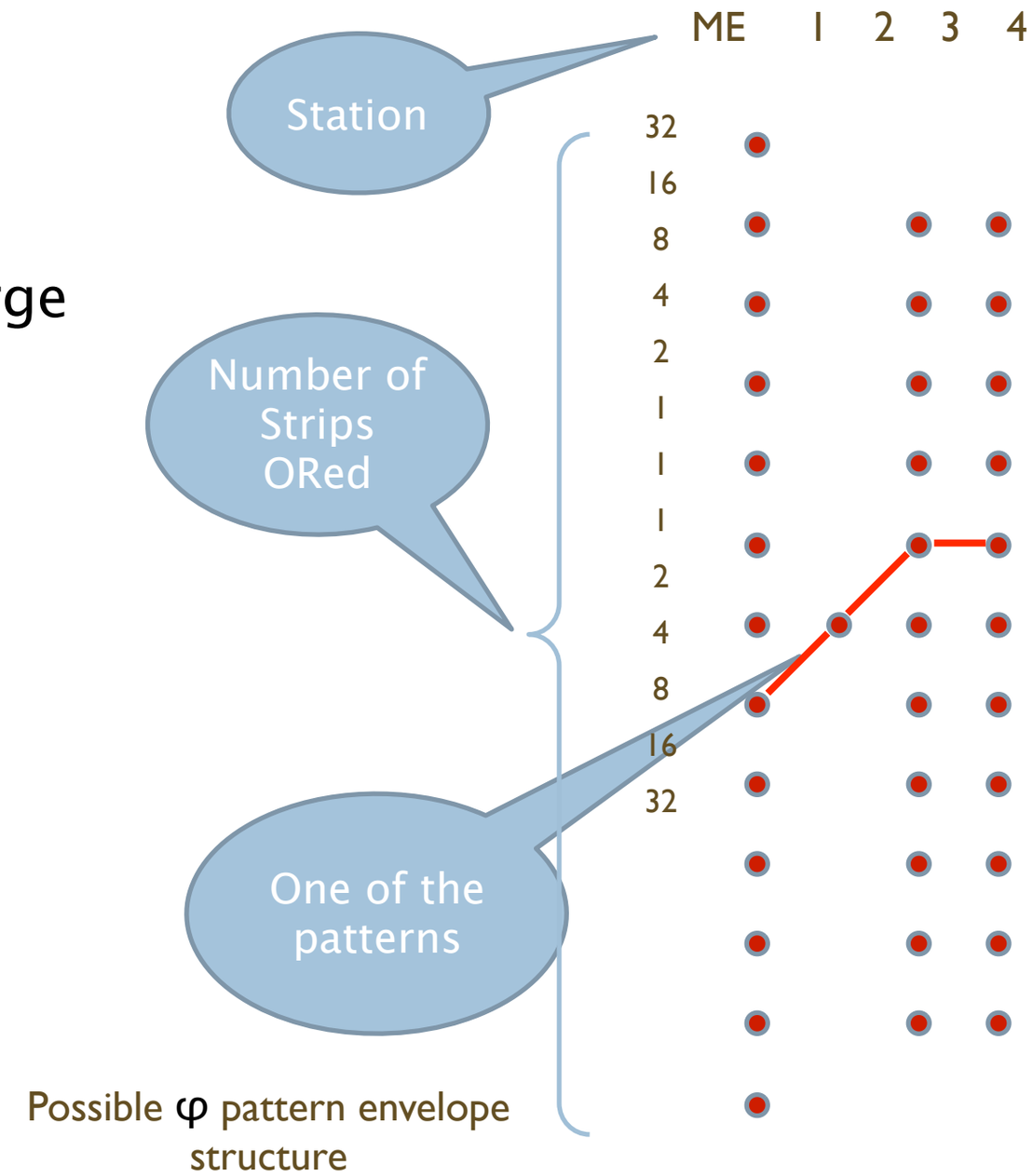
Total upgraded design size relative to current: about 16 x bigger

Main contributors: FSU, BXA, EU

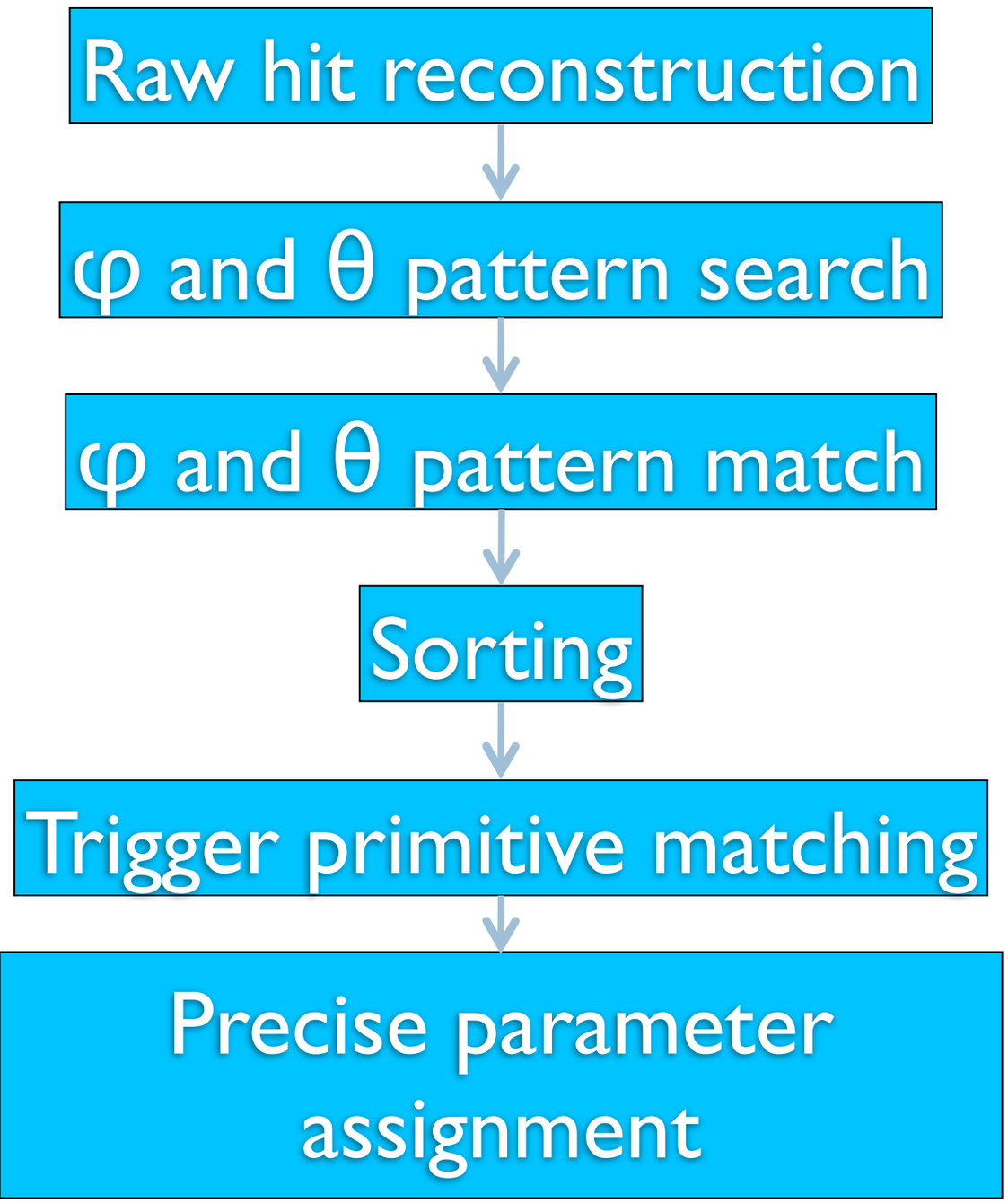
That's too big, may not find suitable FPGA for reasonable cost.

Pattern-based TF

- Investigating another approach:
  - Pattern-based detection
  - Separately in φ and θ
  - Once the patterns are detected, merge them into complete 3-D tracks
- Benefits:
  - Logic size reduction
  - Certain processing steps become “natural”, logic for them is greatly simplified or removed
    - Multiple Bunch Crossing Analysis
    - Ghost Cancellation
    - Automatic track timing on 2nd trig. primitive

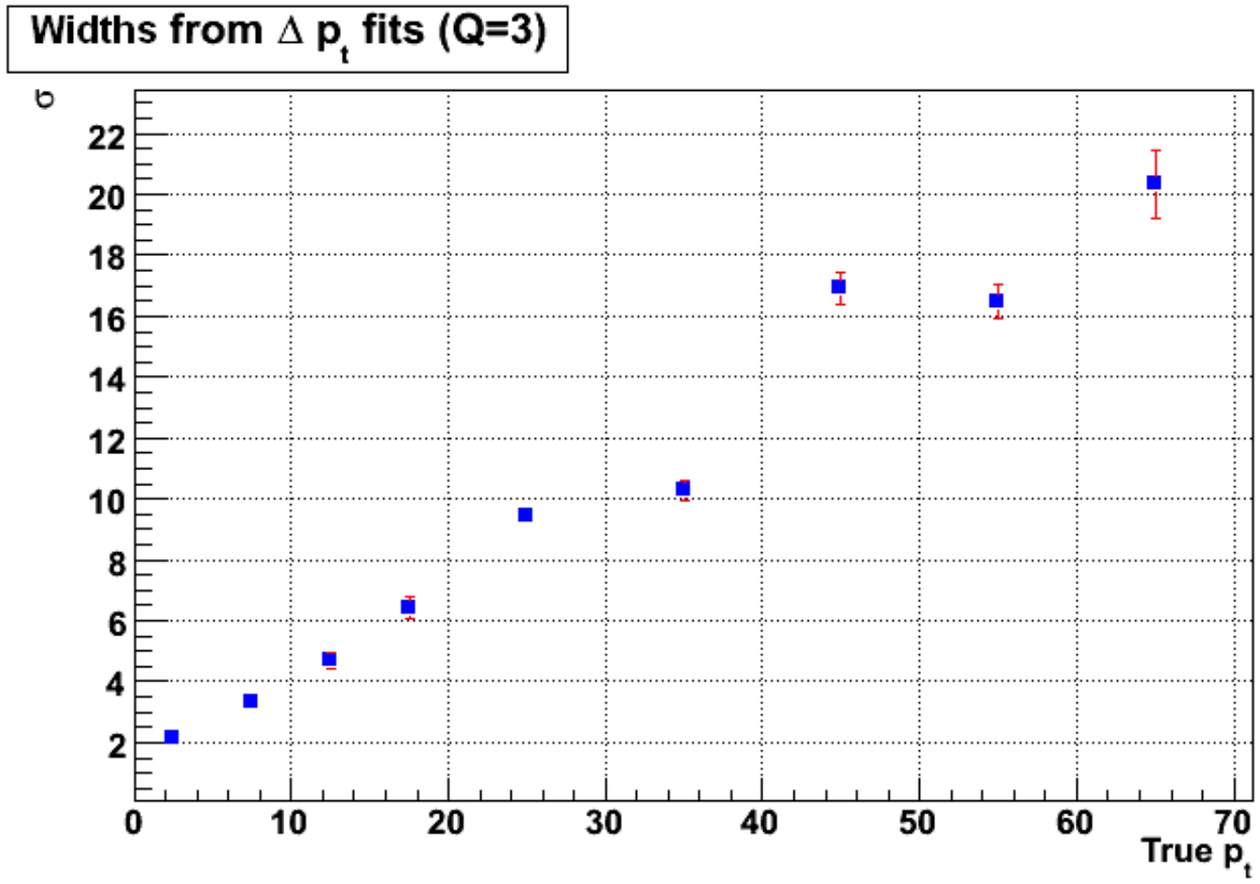


Pattern-based finding



- Similar to pattern search logic in front-end boards (ALCT)
- Sector is split to 5 φ zones and 6 θ zones defined by chamber coverage
- Patterns detected independently in each zone
- Best φ and θ patterns matched together to make 12 track candidates
- Best three are selected by sorting logic
- Corresponding trig. primitives found, precise parameters assigned.

CSC TF Resolutions



- p_T resolution of TF: current LUT's - 40%
- better LUT's developed, not deployed yet - 30% [E. Berry (Princeton), A. Kropivnitskaya (UF)]
- design predictions - 20-30% below 30 GeV/c

Further Improvements

- There is unused information in the TF fit:
  - phi information is truncated in fit
  - ignore track direction in chambers
  - ignore staggering in Z of chambers
  - eta information truncated to 4 bits in fit
  - segment quality ignored
- room for further improvement of CSC standalone track finding
- follow up with simulation work to estimate impact

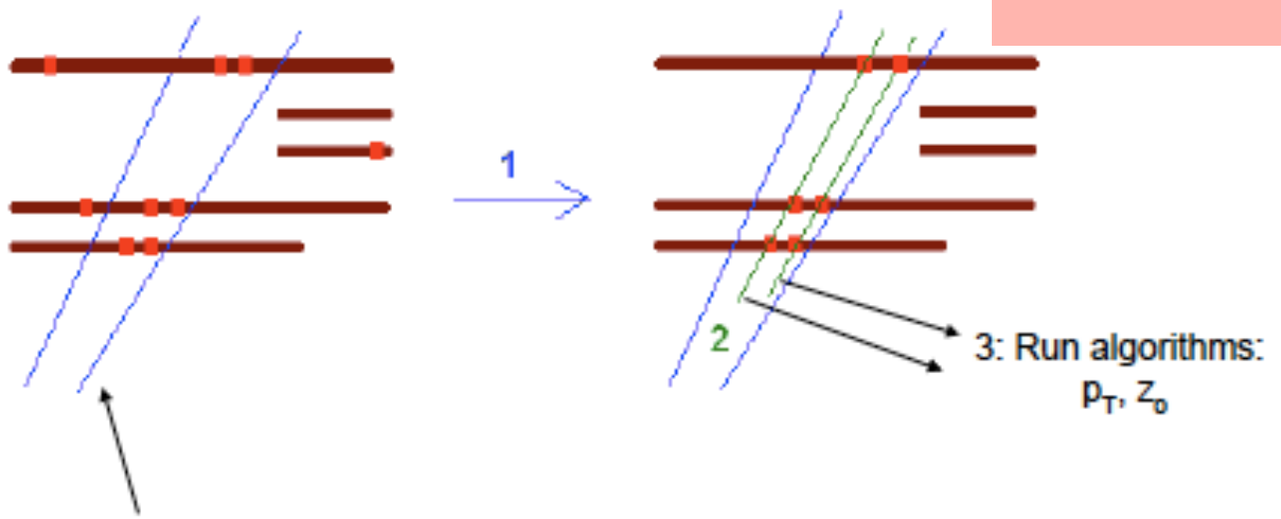
Phase I Summary:

- Detector electronics upgrades deal with increased internal rates and occupancy
- ME 4/2 increases high quality track coverage
- Track Finder expects significant I/O and processing challenge due to increased occupancy
- investigating pattern based approach as solution
- TF fit can incorporate more information to improve momentum resolution measurement
- follow up with simulations to evaluate impact
- Phase II studies found resolution important for track seeding window width, efficiency
- upgrade needs to incorporate both increased volume and better resolution - next major push

Phase II: CSC + Tracker Trigger

More details: talk by B. Scurlock, Muon Phase II session

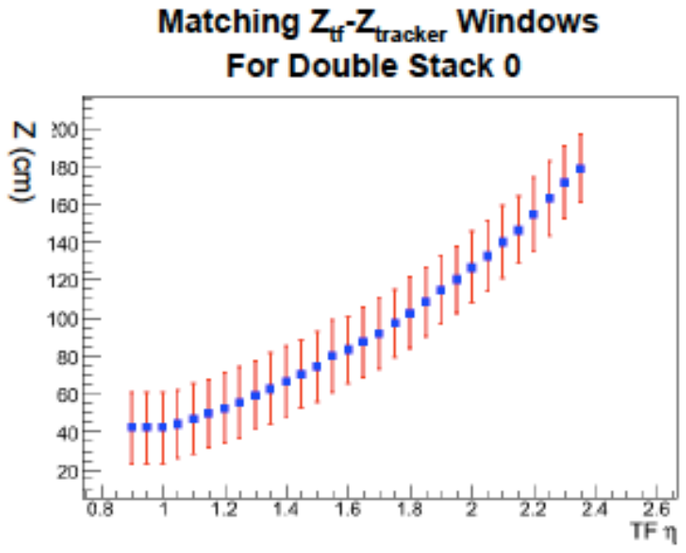
Illustration



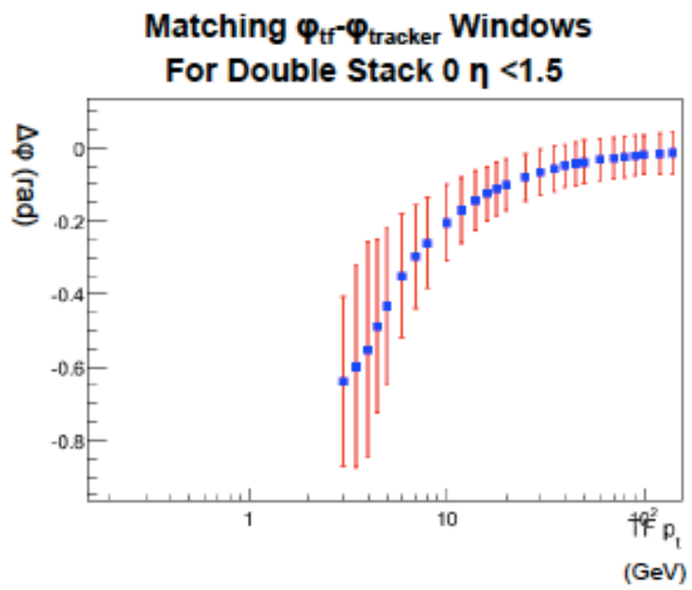
- Step 1: Use matching windows to cut stubs based on Trackfinder$_{z,\varphi}$ -Tracker$_{z,\varphi}$
- Step 2: Only keep stubs that are correlated in $\Delta\varphi$ & $\Delta\cot\theta$ (ie $\varphi_{dstack2}-\varphi_{dstack0}$)
- Step 3: Apply r–z algorithm → cot(θ) & z_o and r–φ algorithm → p_T

CSC+Trigger Matching Windows

Examples of **For Double Stack 0 :**



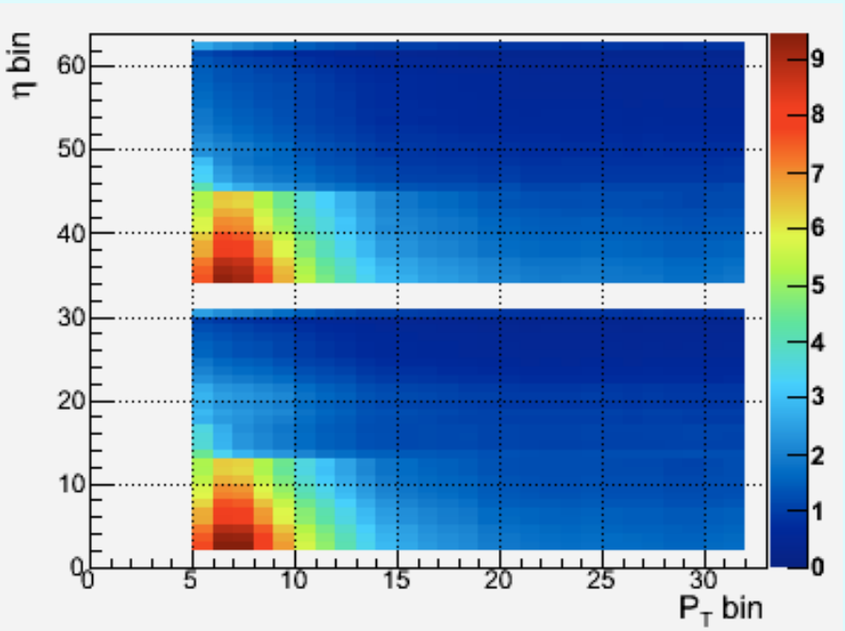
Widths ~ 6 cm



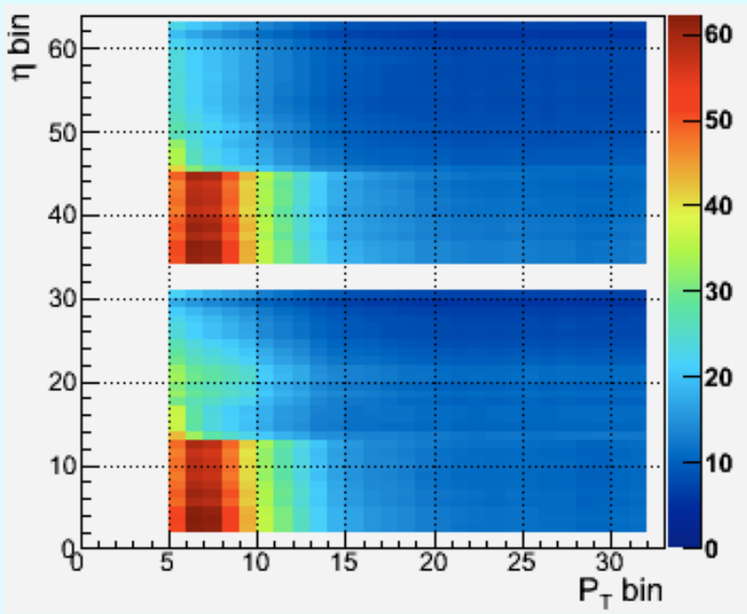
Widths =O(~0.1) - O(~0.01) rad
η dependence low p_T due to inhom. B-field
Can be tightened if necessary6

Matching windows are defined for all possible CSCTF-P_T (5 bits) and CSCTF-η (5 bits per endcap) values. Average match-window-occupancy plots shown below are a function of these CSCTF bins and were made with min bias events (200 PU).

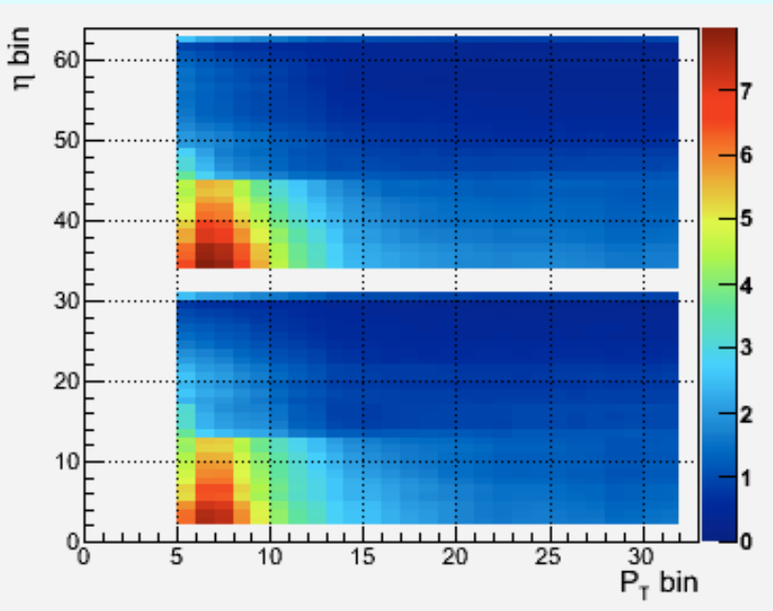
Stubs from simHits



Stubs from unclustered PixelDigis



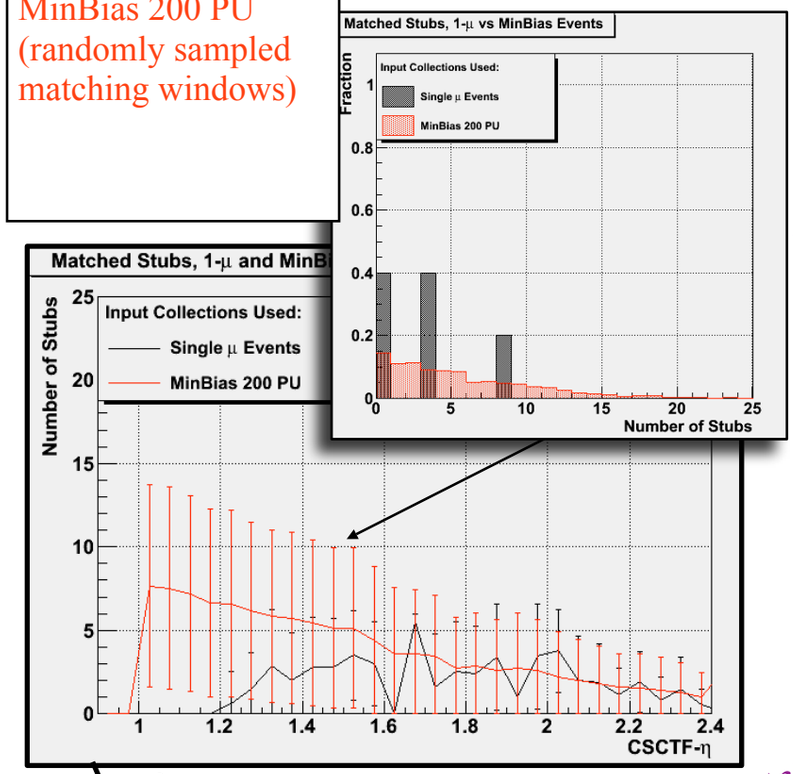
Stubs from clustered PixelDigis

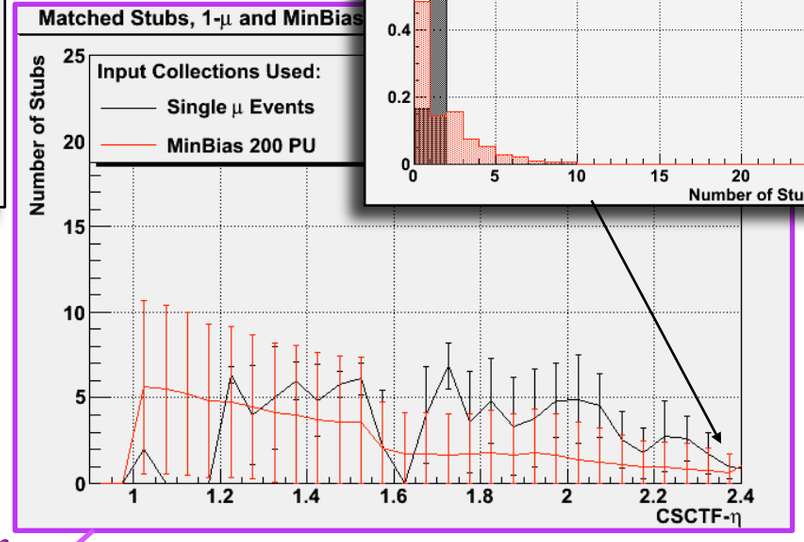


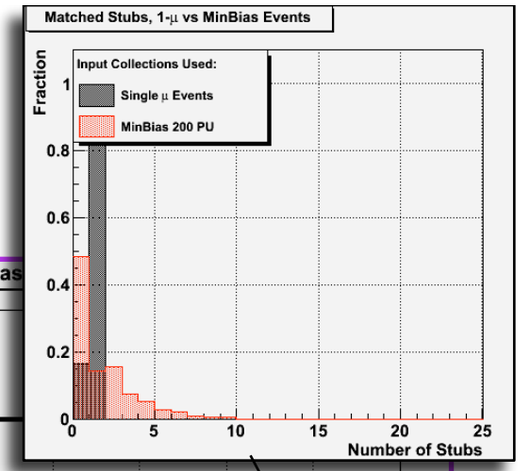
Matching Windows: Signal versus Background

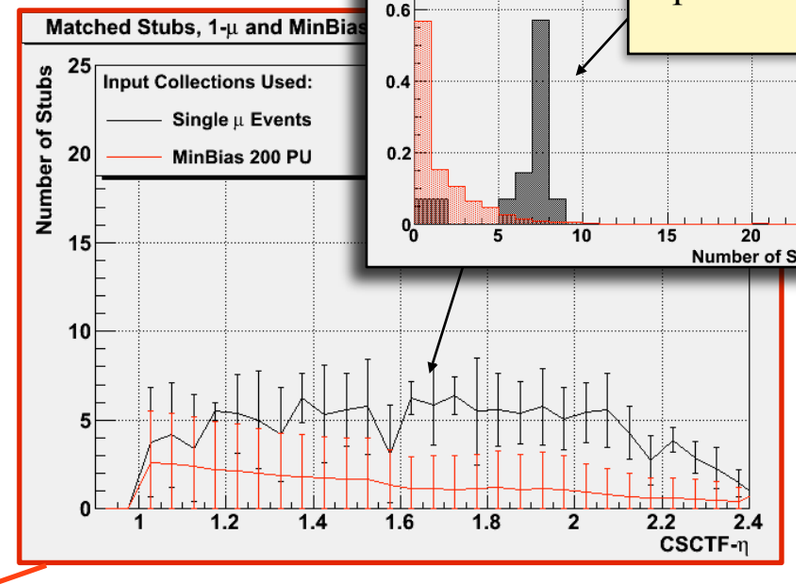
Single muon events

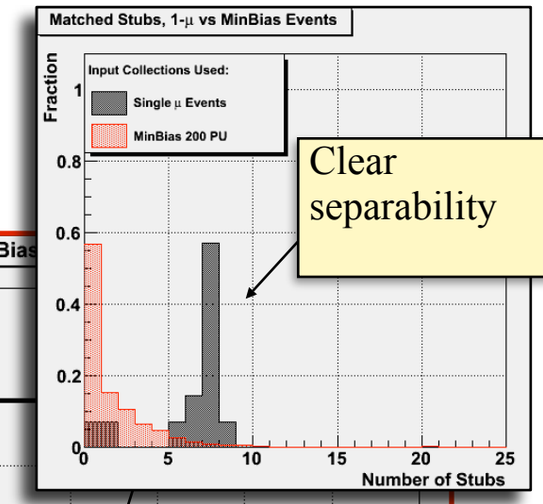
MinBias 200 PU (randomly sampled matching windows)









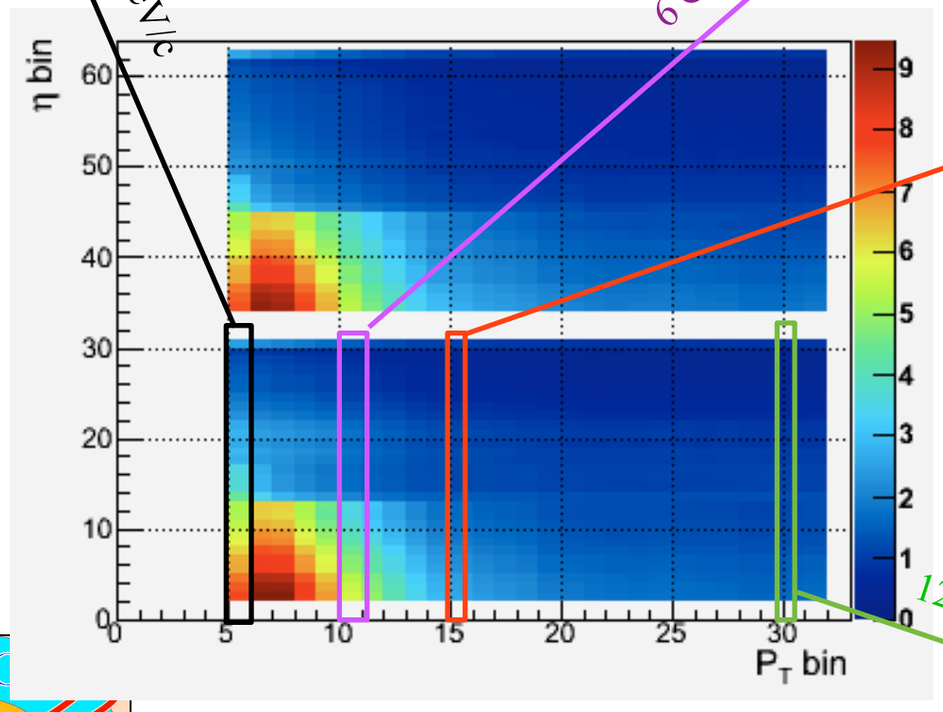


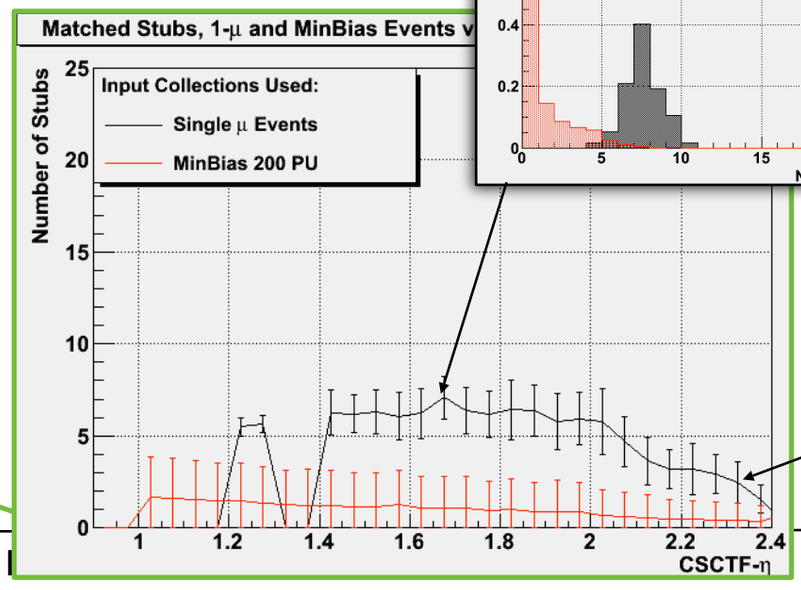
3 GeV/c

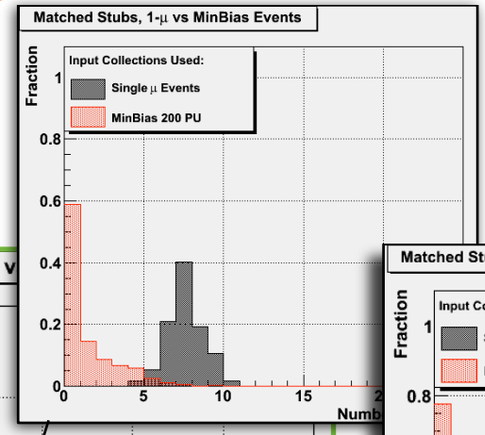
6 GeV/c

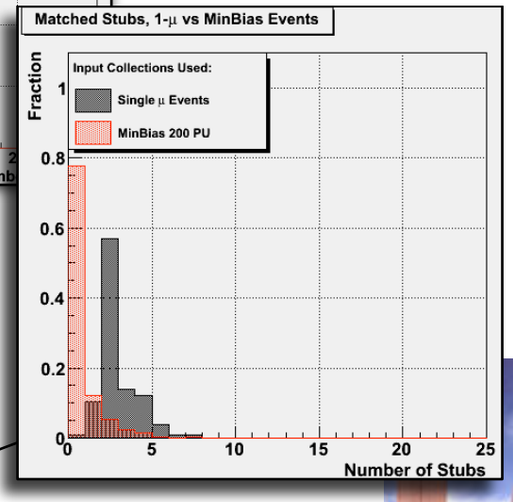
14 GeV/c

120 GeV/c

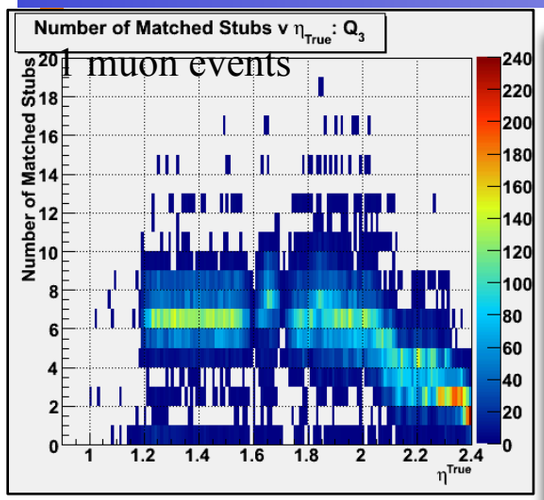




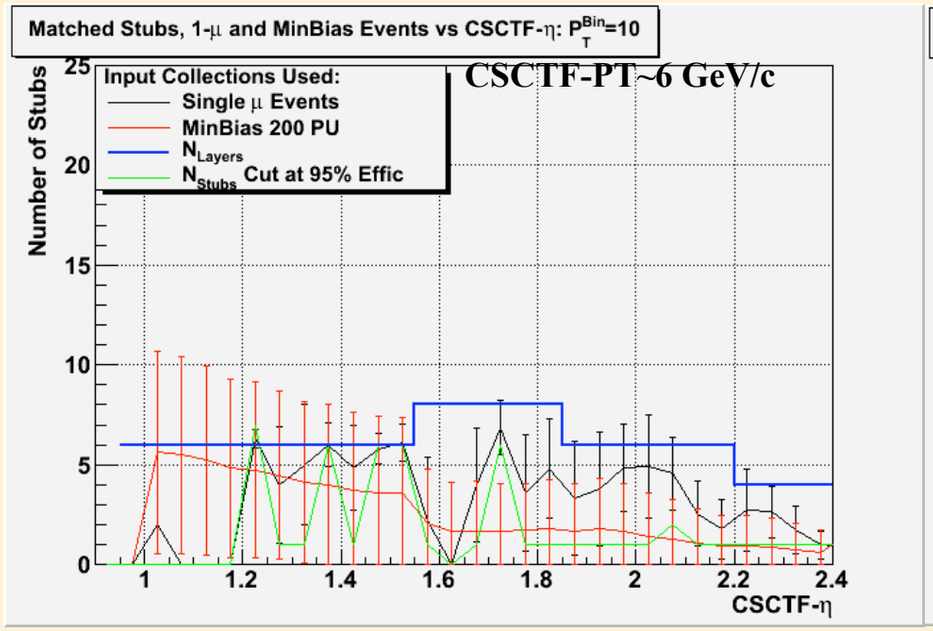


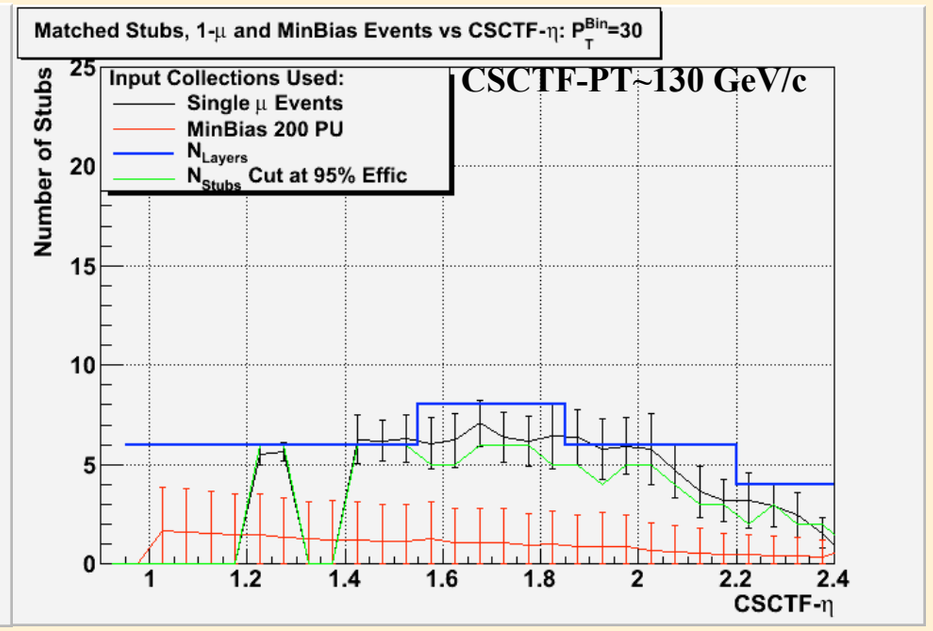


Matching Windows: Separating Signal from Background



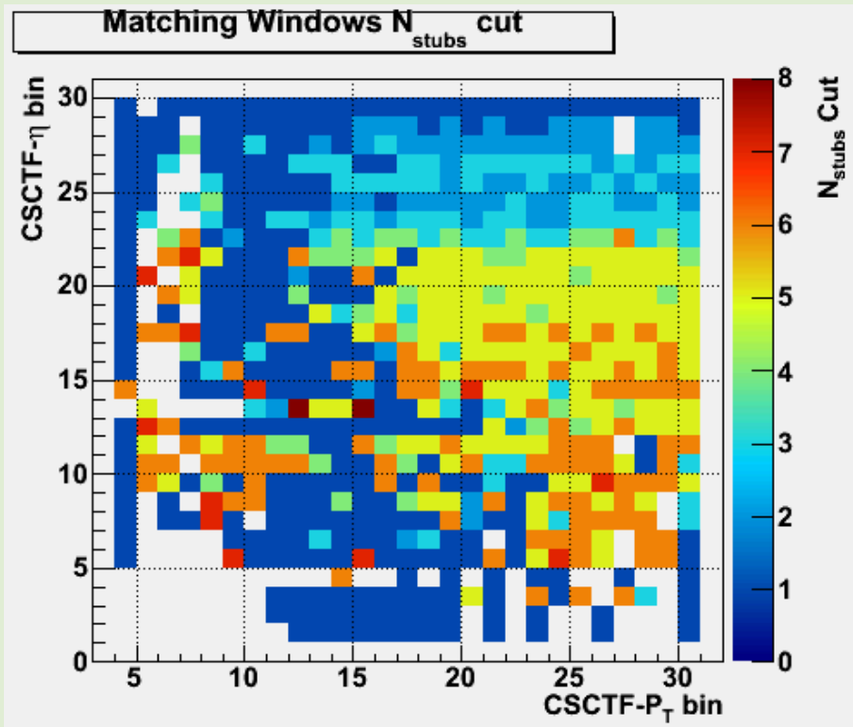
Signal and Background vs CSCTF-η

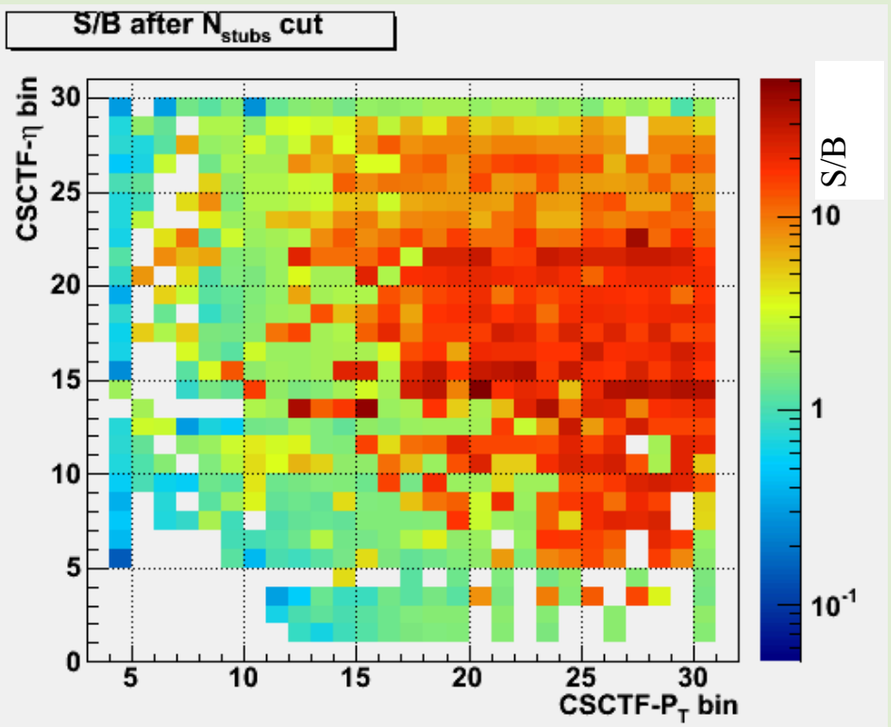




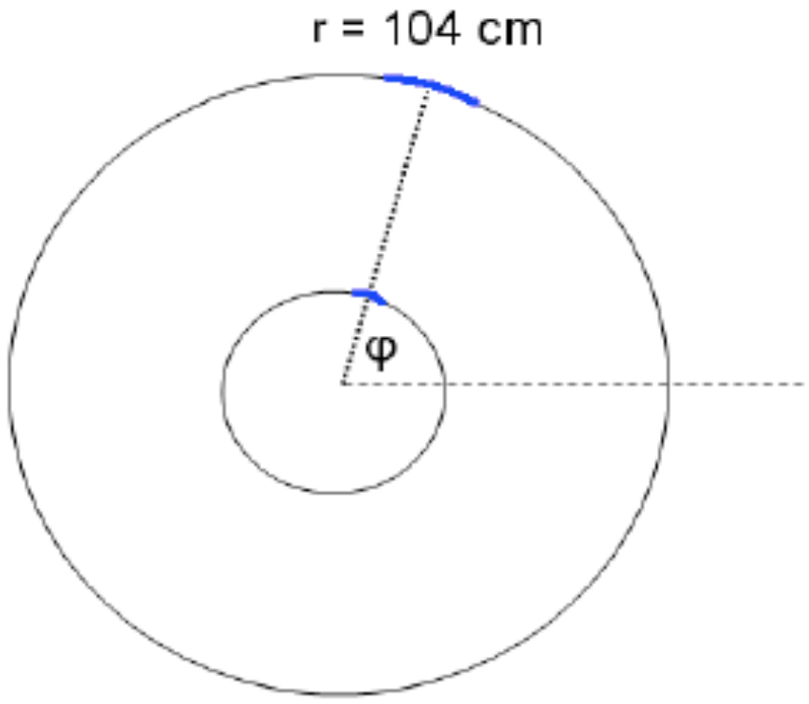
Once matching windows are re-tuned, expect that counting can provide a powerful handle for rate reduction from noise and CSCTF mis-measurement.

Example exercise: tune matching window bin-by-bin N_{stubs} threshold to accept 95% of signal stubs. Cuts and S/B versus bin seen on right ➙





P_T Estimate 1: Using Δφ



Circle Fit Approximation:

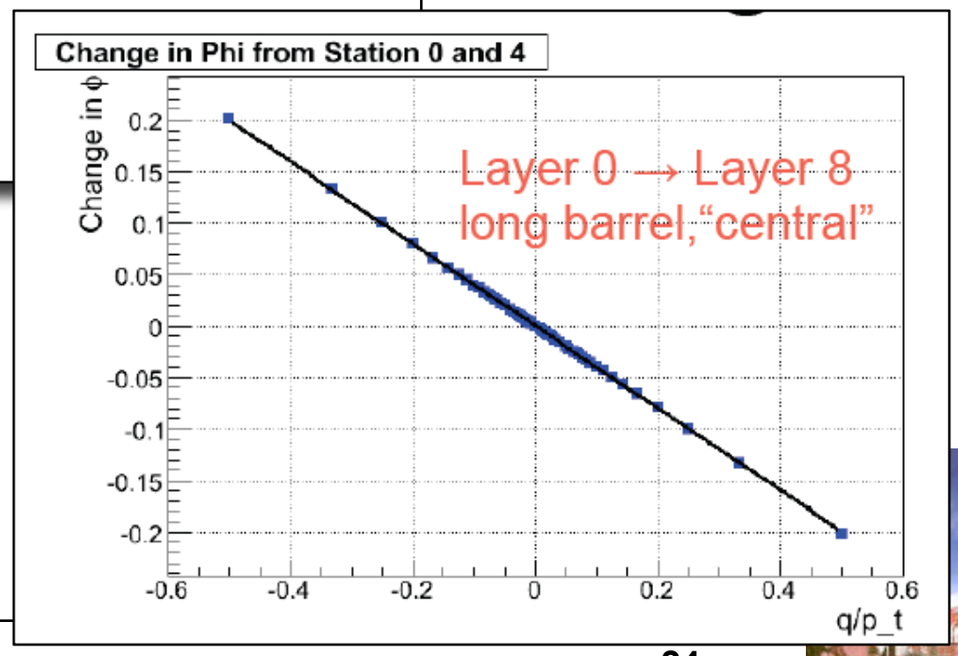
$\phi = \phi_0 + \arcsin(\zeta R / p_T)$

linear approximation:

$\Delta\phi \sim 1/p_T$

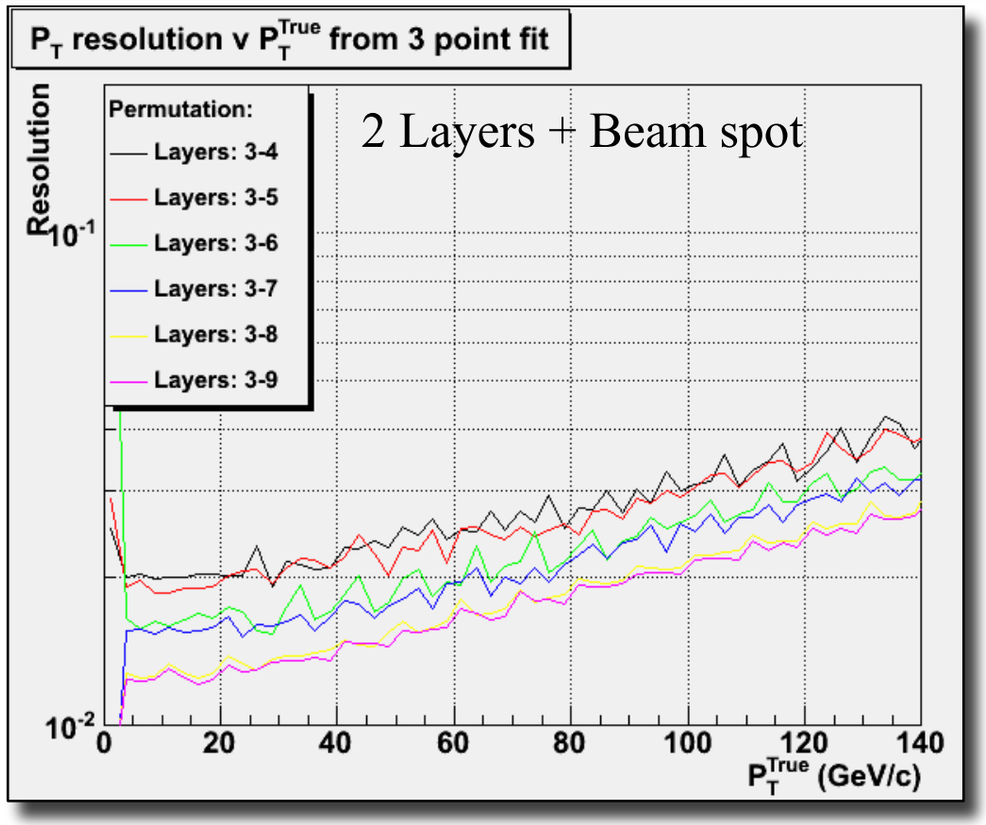
$\Delta\phi \sim \Delta R$

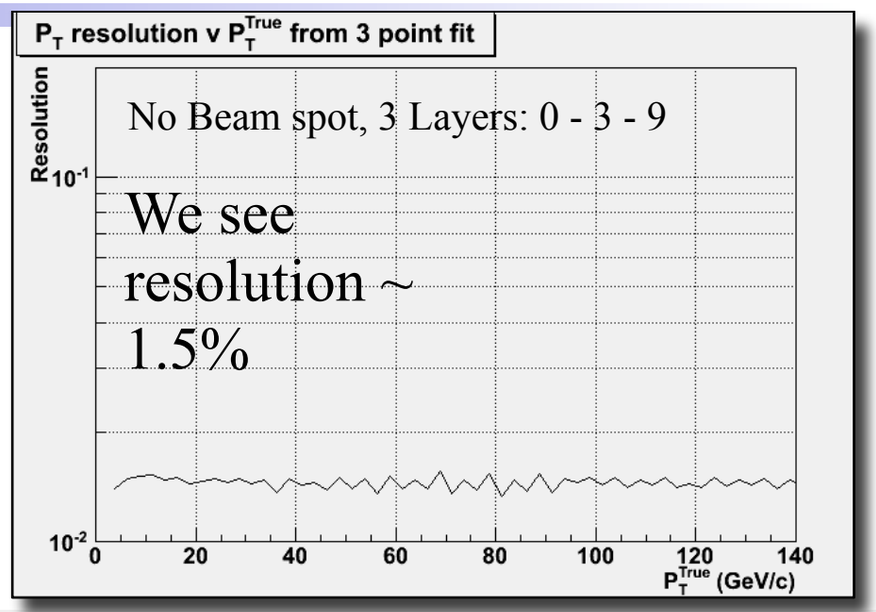
- sensors report local coordinate → global ϕ
- measure ϕ in 100 μm units of arc length at 104 cm
- $\Delta\phi_{09} = \Delta\phi_{ij} \cdot \Delta R_{09} / \Delta R_{ij}$
- $\Delta\varphi_{09} \rightarrow 1/p_T \rightarrow p_T$



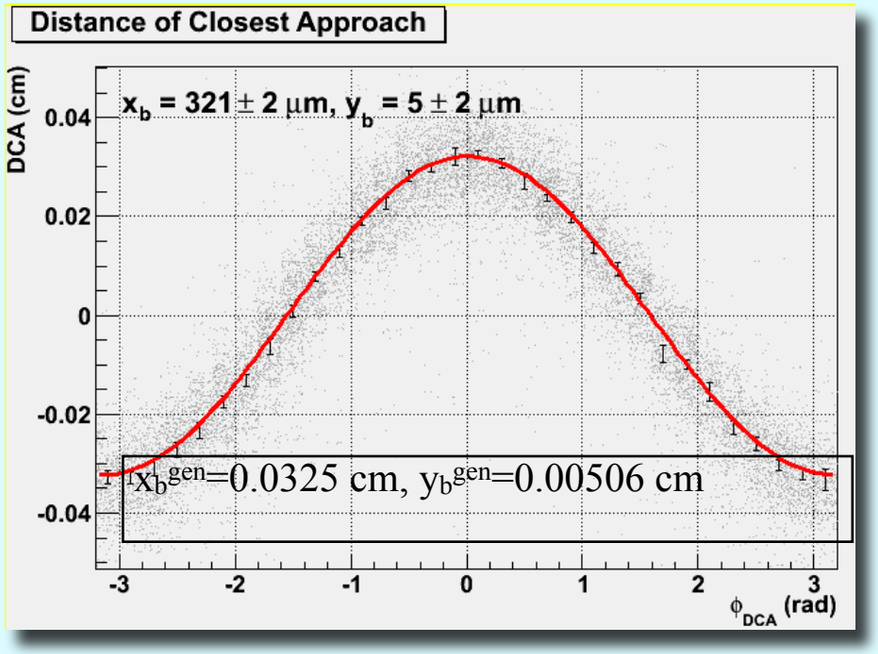
Approach demonstrated to achieve 2% P_T resolution

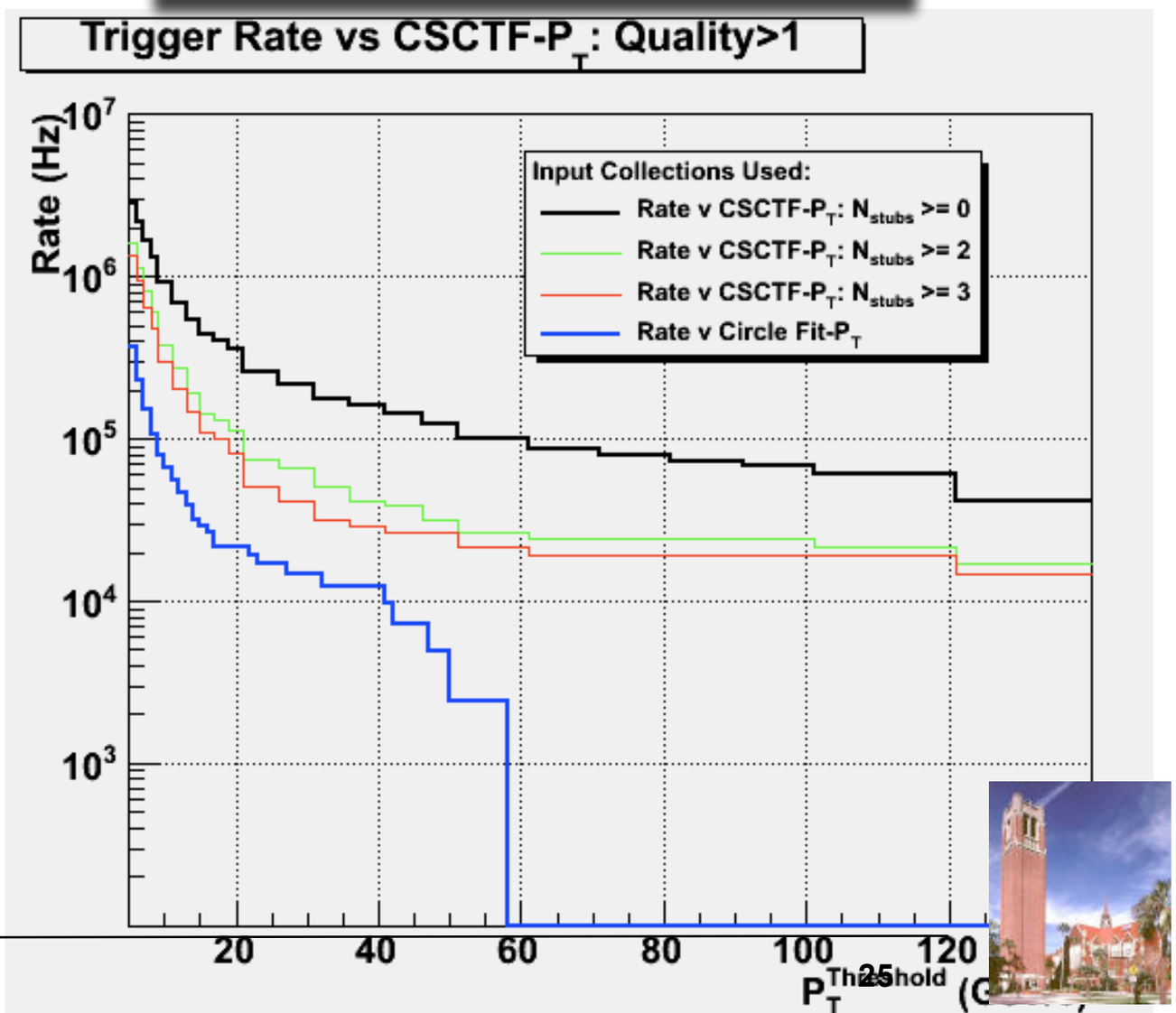
P_T Estimate 2: Circle-Fit Resolutions



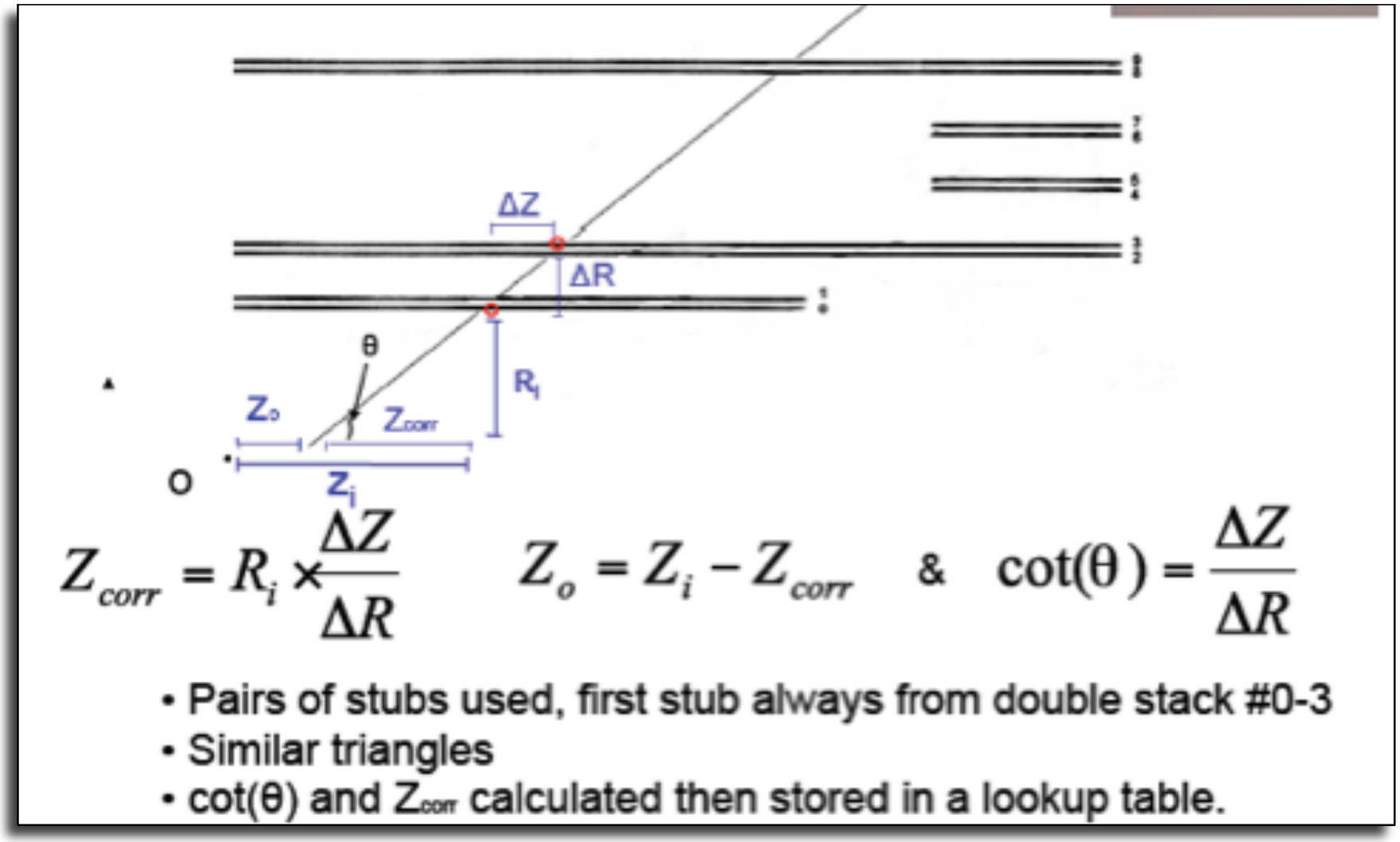


Use DCA to find beam spot





cot(θ) & Z_0



$$Z_{corr} = R_i \times \frac{\Delta Z}{\Delta R} \qquad Z_o = Z_i - Z_{corr} \quad \& \quad \cot(\theta) = \frac{\Delta Z}{\Delta R}$$

- Pairs of stubs used, first stub always from double stack #0-3
- Similar triangles
- cot(θ) and Z_{corr} calculated then stored in a lookup table.

CSTT model has been demonstrated to achieve z_0 resolution 640 μm and cot(θ) resolution 0.002

Phase II Status:

- New manpower: B. Scurlock (UF)
- reviewed and integrated code used in summer studies, validated internal consistency
- results reported in July still stand, further developed
- new studies:
  - counting tracker stubs in matching window rejects background. More tracker layers in trigger lead to more reliable trigger output
  - 3 layers of tracker in trigger allow for beam spot independent pt measurement and beam spot estimation on line (track beam position in real time)

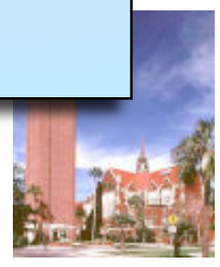
Conclusions:

- CSC electronics upgrades will increase internal data throughput for high luminosity running
- CSC TF Phase II studies with LB geometry converged.
- Recently full CVS permissions, committing code in the upcoming few days
- CSC TF Phase I challenge: increased multiplicity + better resolution, both at the same time

Supporting Material

Phase II: CSCTT Algorithm

- Define regions of interest to help pre-sparsify tracker readout
- Assume stub information is read out from tracker
- Define narrow roads in ϕ, z to further filter tracker readout
- Tracker stubs have excellent positional resolution – utilize internal correlations
- Attempt fit using tracker-only information (best measurement at low momenta
- **Current CSCTT model developed in context of the Long barrel geometry**
- **CSCTT code is now in CVS**



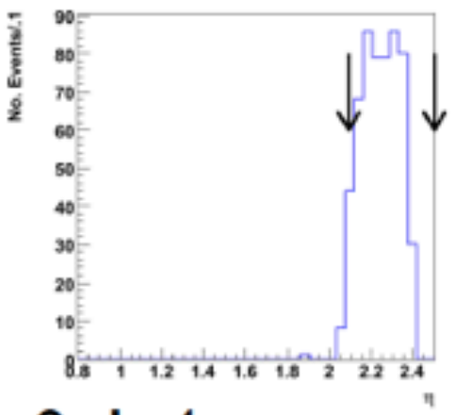
Expected Eta Coverage (Longbarrel)

Geometry Validation: Eta Coverage

Arrows show range of η covered by tracker stations

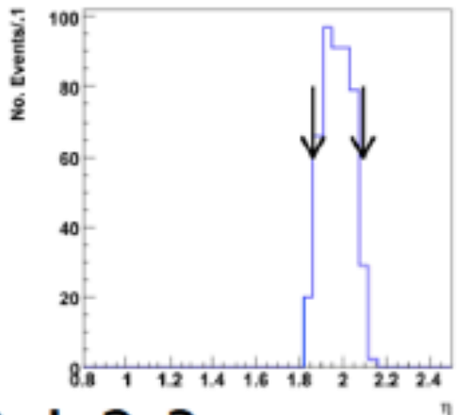
0-1

Expect: <Nstubs>~4



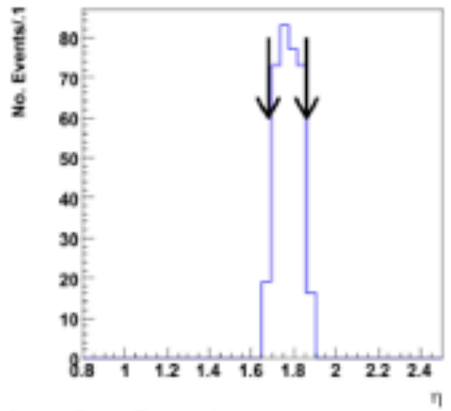
0-1-2

Expect:<Nstubs>~6

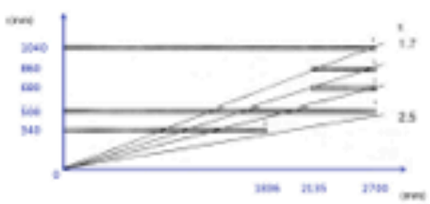


0-1-3

Expect: <Nstubs>~6

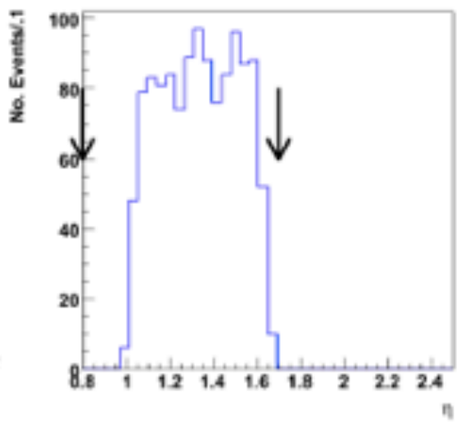


*These Combinations of hits are very rare



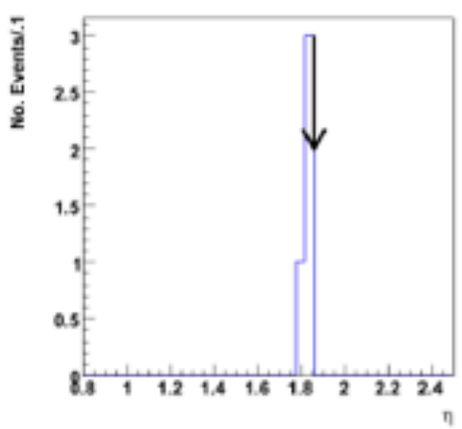
0-1-4

Expect: <Nstubs>~6



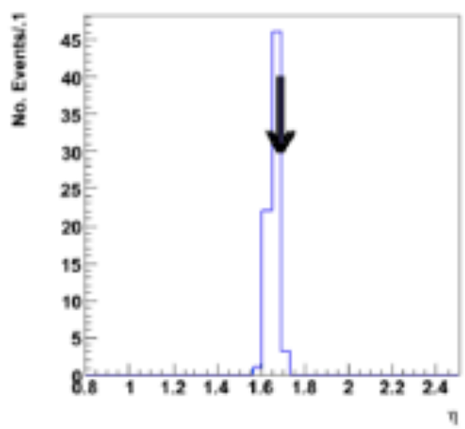
***0-1-2-3**

Expect: <Nstubs>~8



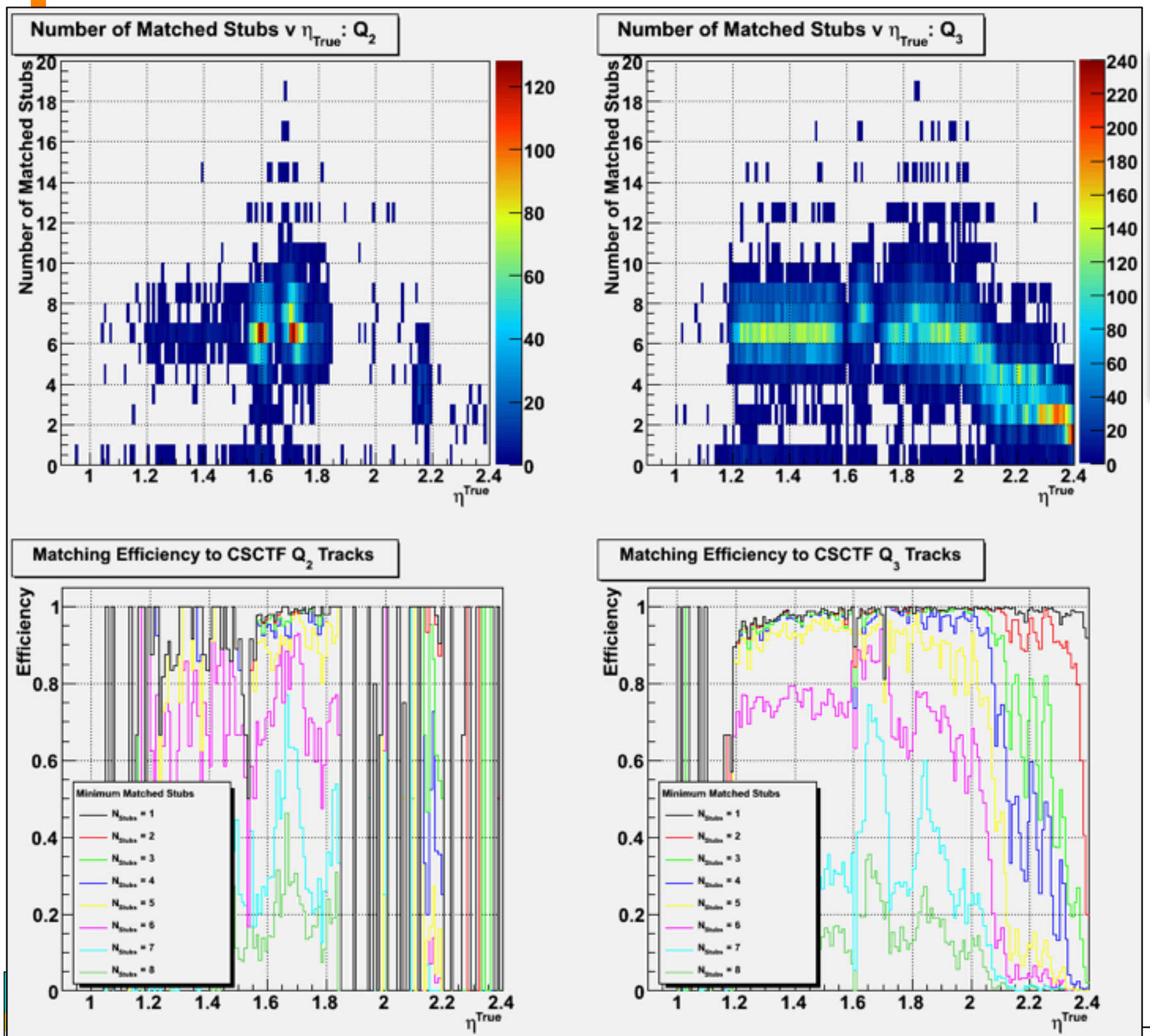
***0-1-3-4**

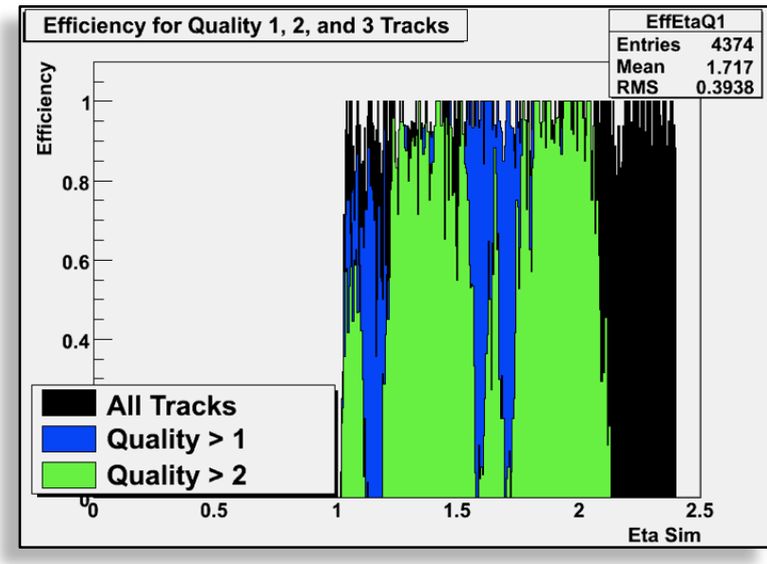
Expect: <Nstubs>~8



5

Matching Windows Efficiency (room for fine-tuning)



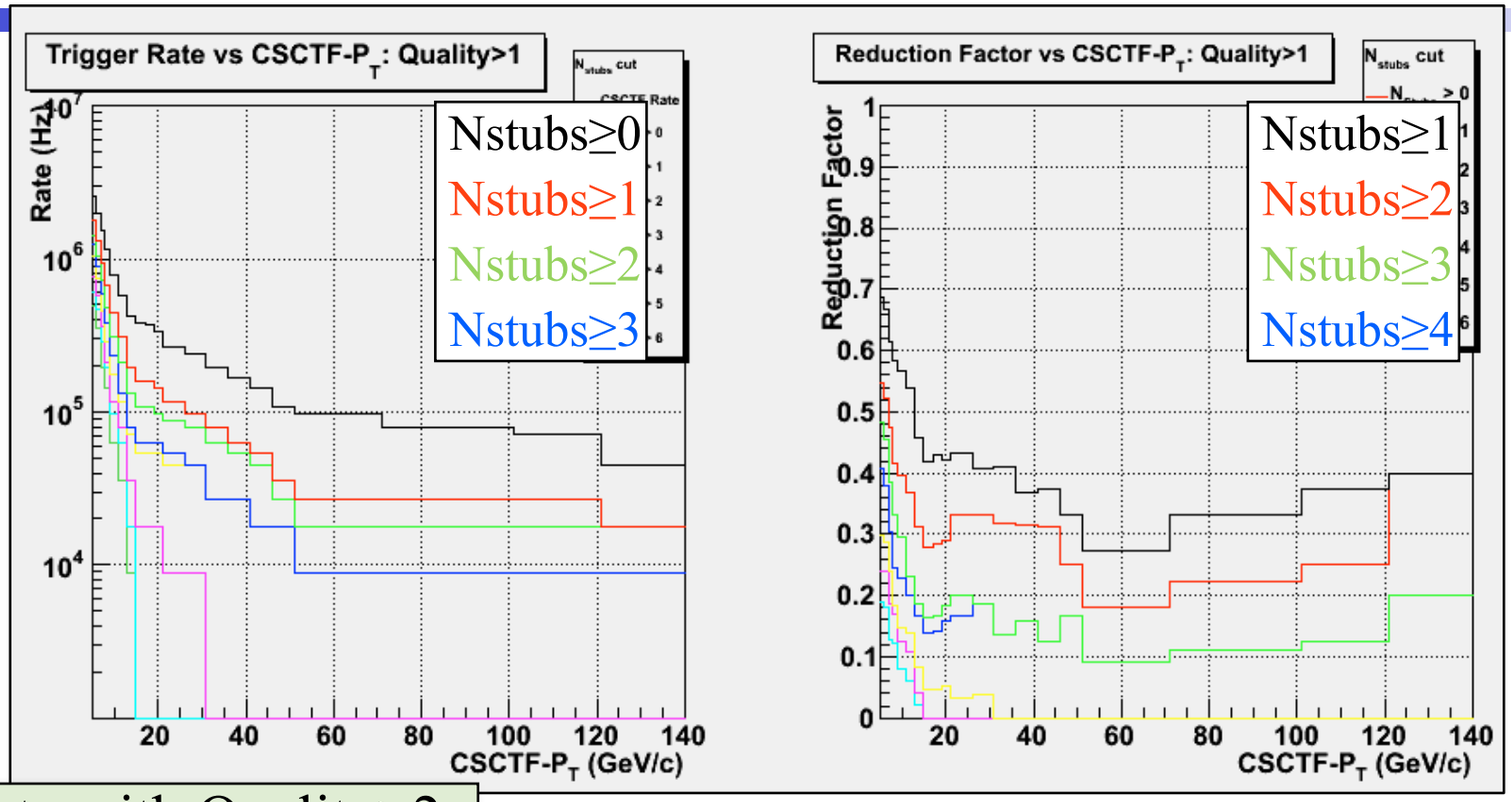


Here we see origin of inefficiency caused by Nstubs cut.

(1) |Eta|>2.1 Nstubs is seen to drop to ~2 (expect 4)

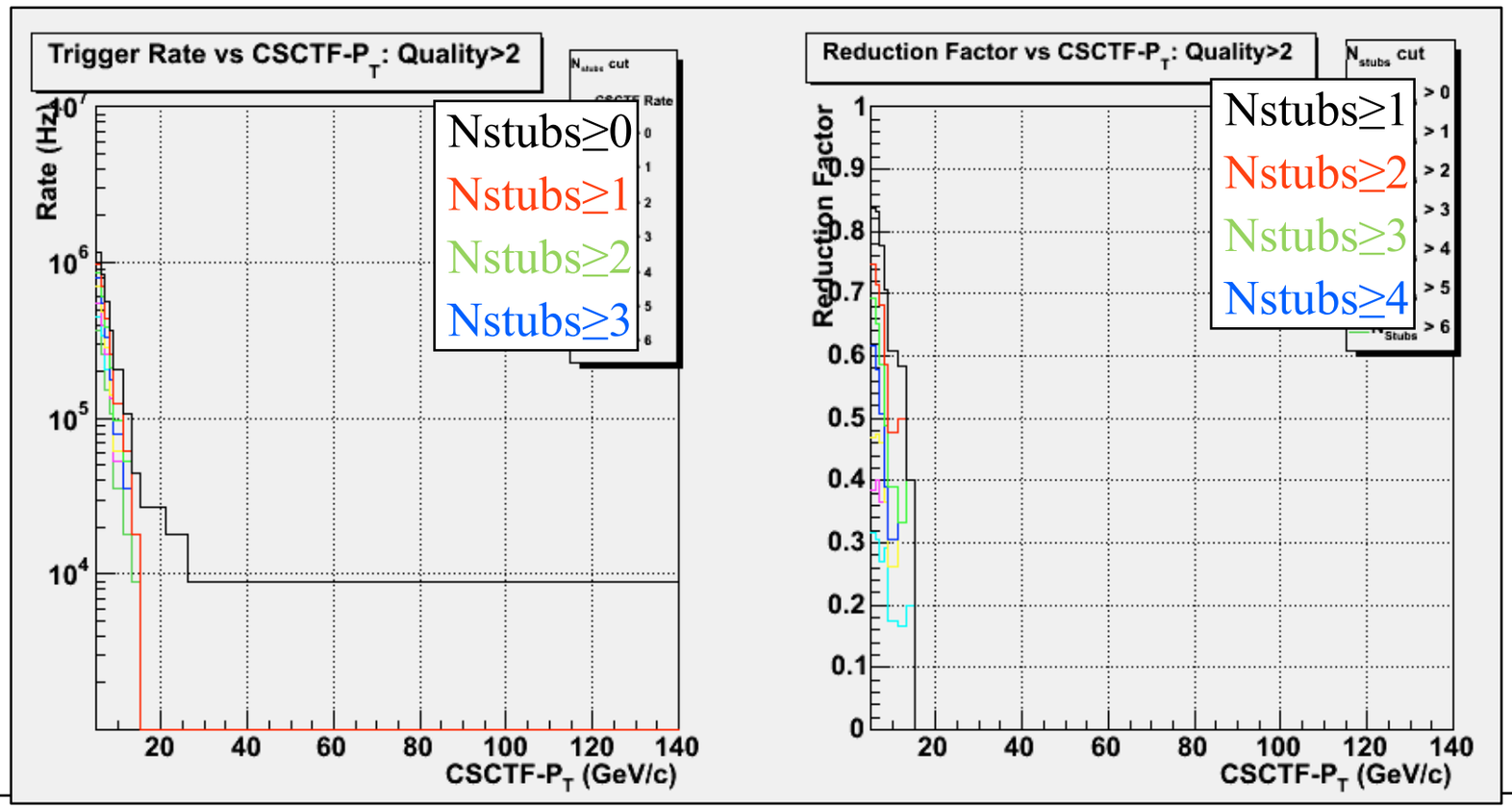
(2) Eta dependent switch in CSCTF-track quality assignment due to gap between inner and outer rings of ME2 and ME3 (matching windows are tuned for Q3 tracks). Q3:Q2 ~ 8:1 for 1 mu events (cf Q3:Q2 ~ 2:1 for MinBias)

Rate Reduction from stubs



Rate and relative reduction contours with Quality>1 CSCTF Tracks (versus Nstubs matching window cuts)

Rate with Quality>2 CSCTF Tracks



Rate reduction power is mostly related to CSCTF Quality. Improperly seeded windows miss underlying stubs. This can be a powerful weapon against CSCTF mis-measurement!

P_T with Beam spot drift

- Current algorithm takes filtered stub candidates and assigns P_T by finding effective $\Delta\varphi_{09}$ between tracker Layers
  - Uses linear fit between $1/P_T$ and $\Delta\varphi_{09}$, with (0,0,0) beamspot
  - This algorithm can be re-tuned to accommodate off-center (not investigated yet)
- Can we use the CSCTT model framework to accommodate beam spot drift?
  - Take filtered stub candidates and use a 3-point circle fit to find P_T
    - Algorithm 1: Assume a known beam spot and use stubs available from two tracker Layers
    - Algorithm 2: Assume unknown beam spot and use stubs available from three tracker Layers
      - Can then use DCA to provide beam spot location
    - Both algorithms fit two lines: L1 = Point_i to Point_{i+1} and L2 = Point_{i+1} to Point_{i+2} (points increasing in radius). Solve for the intersection of the two orthogonal lines which bisect L1 and L2
    - Working with engineer to understand how we can implement algorithm in HW