MUON SORTER STATUS AND PLANS

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CMS Forward Muon Trigger & DAQ Workshop

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OVERVIEW

- Isolation Studies Update
- Muon Sorter Hardware

MUON ISOLATION METHOD

- Muon isolation to remove low p_t muons generated in jets
- Isolation joined with a p_t trigger threshold may reduce rate
- Two methods of isolation:

$$\text{Absolute Isolation} = \sum_R E_t$$

$$\text{Relative Isolation} = \frac{\sum_R E_t}{p_{t,\mu}}$$

$$R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

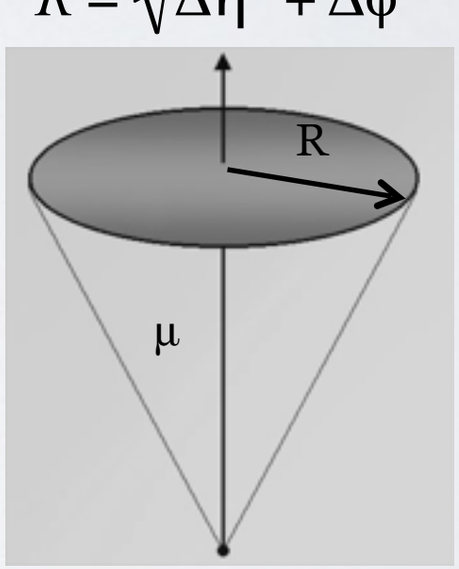
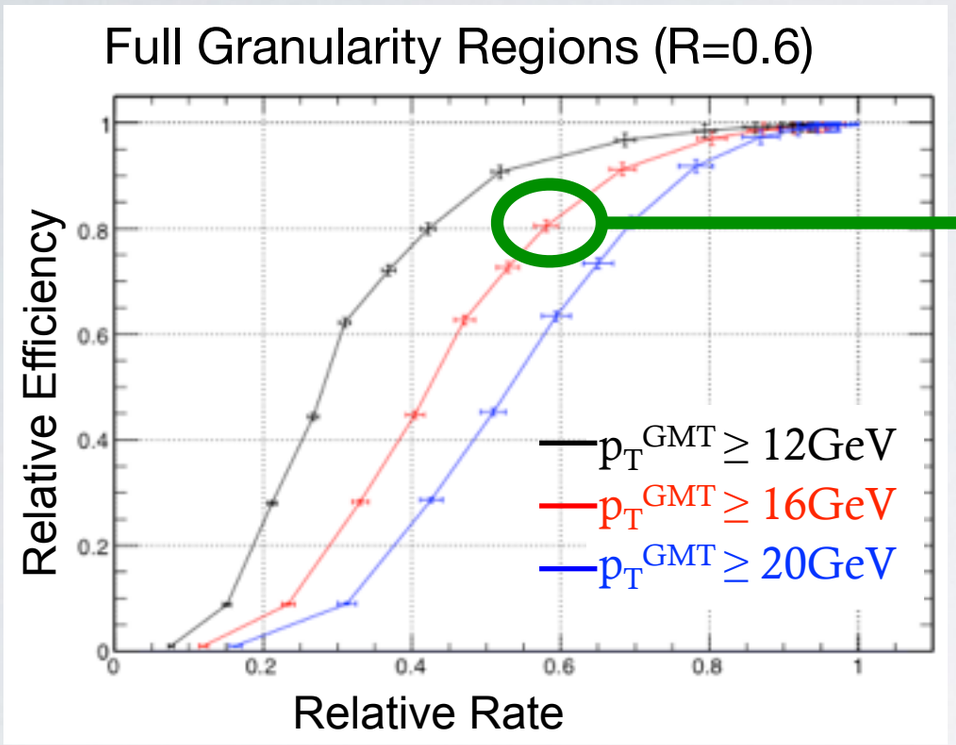
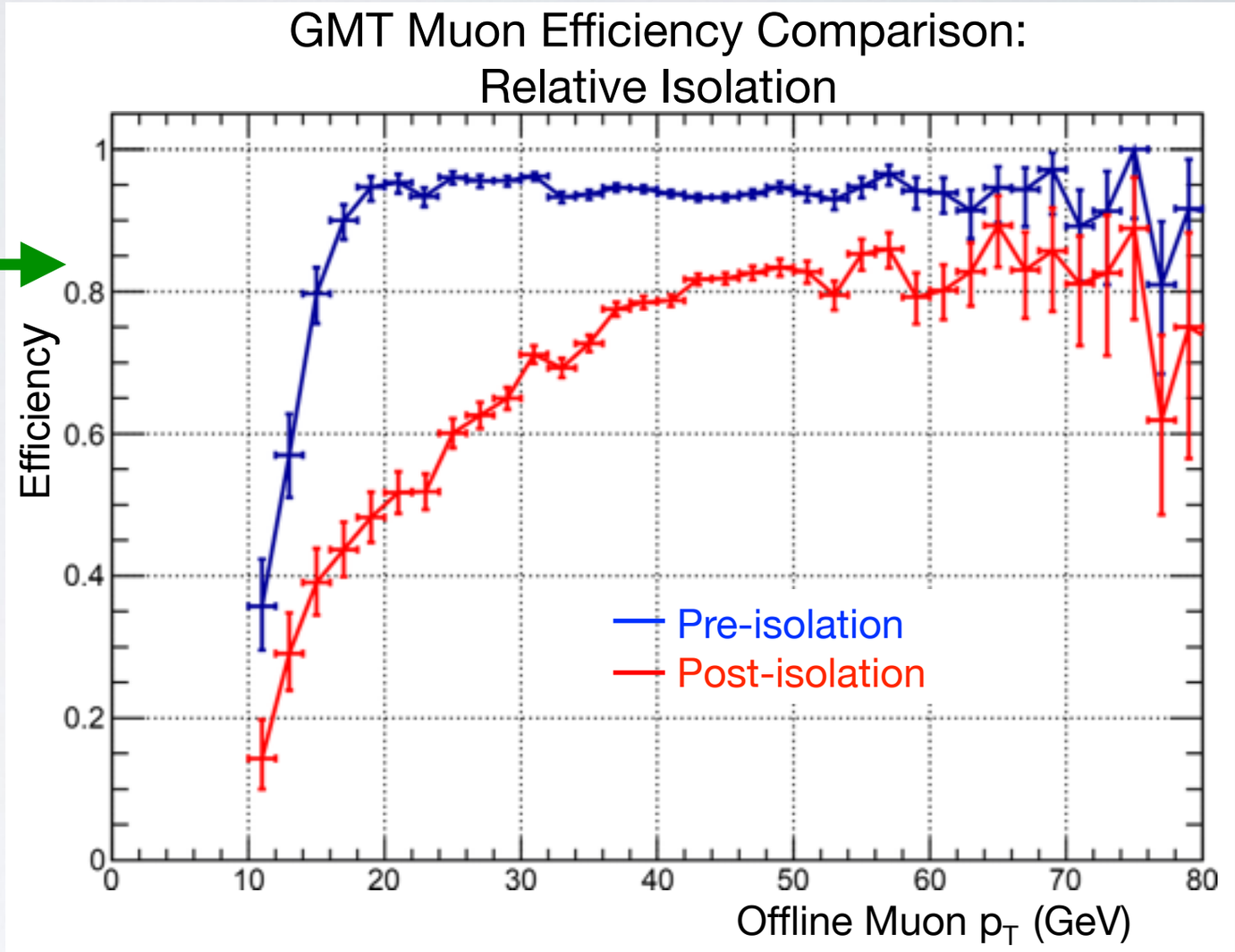


Illustration of isolation region with area characterized by radius R

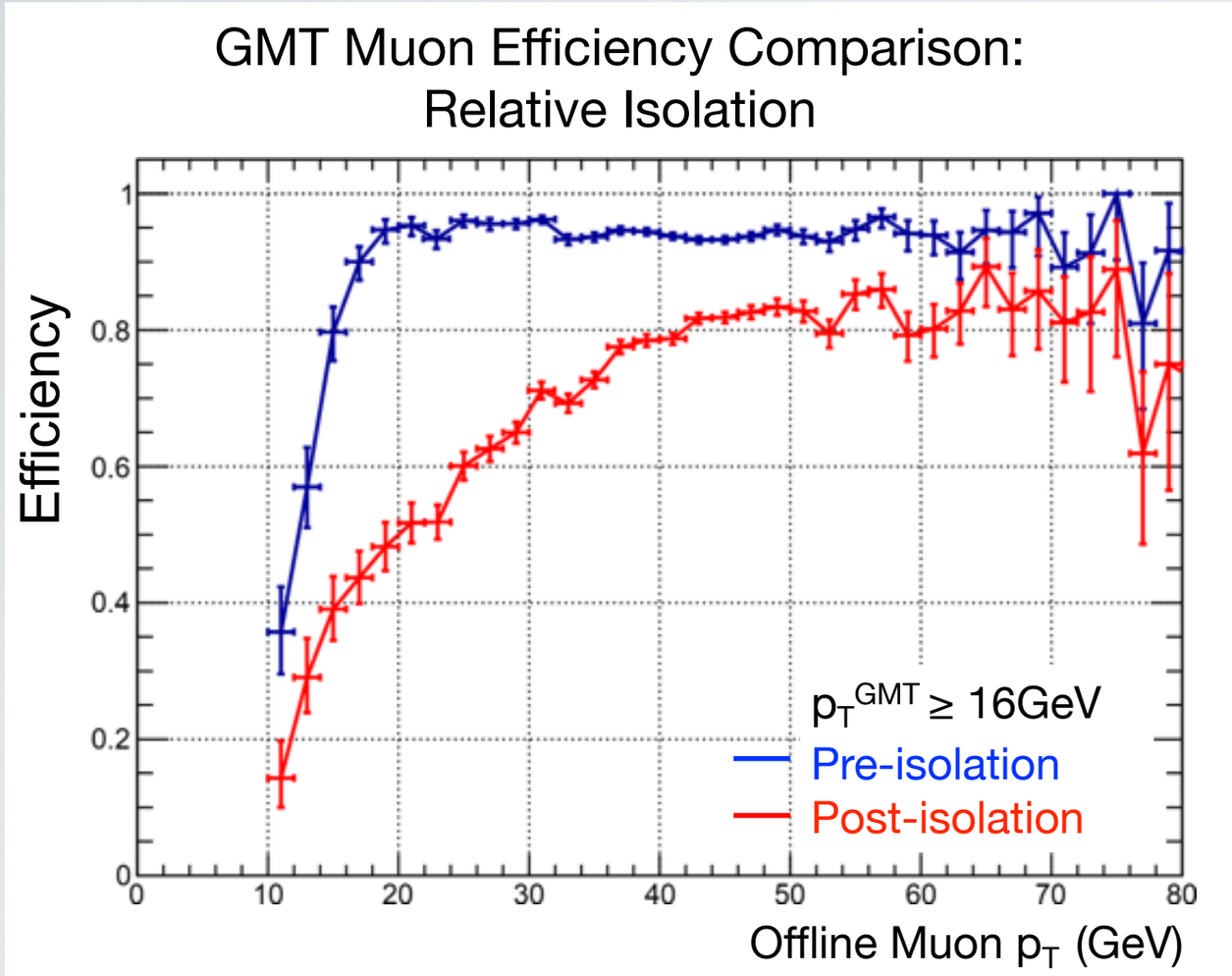
GMT RATE OF CHANGE PLOT

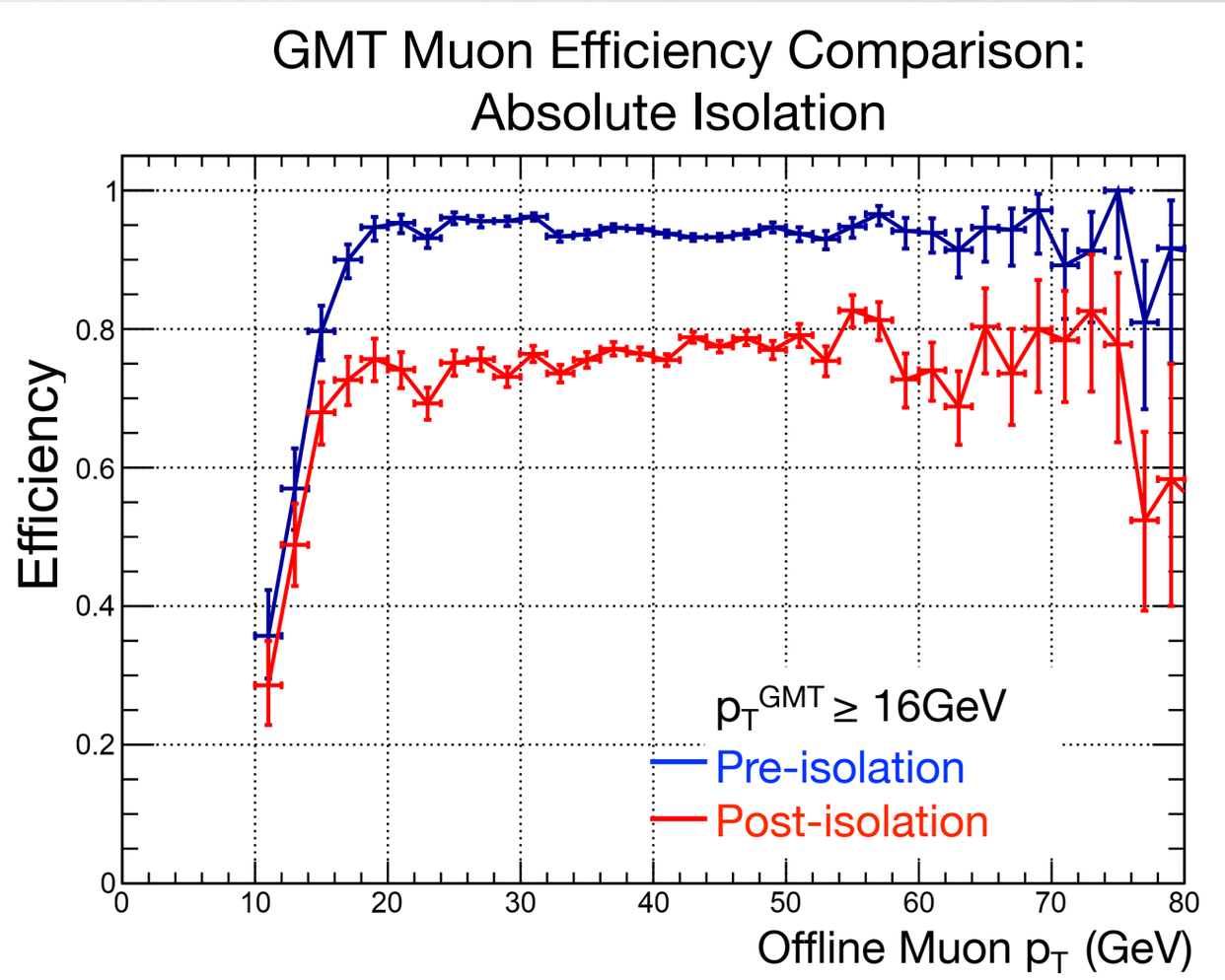




- Each point corresponds to a set of isolation cuts
  - Each point has an associated efficiency curve
  - Said curve will indicate which muons are eliminated

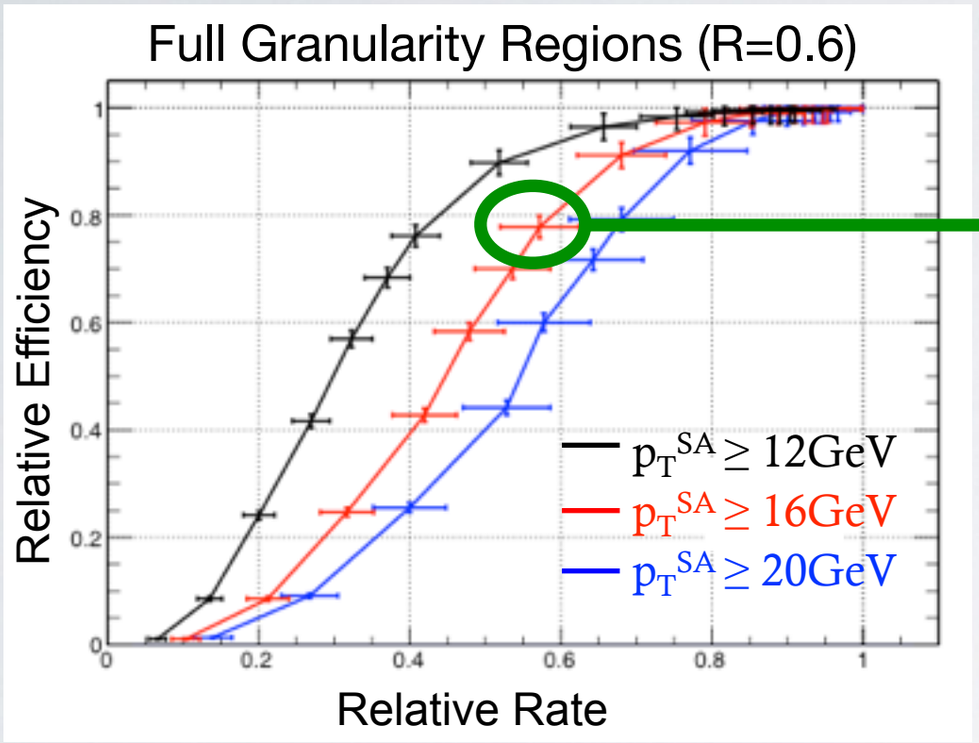
GMT MUON ISOLATION PERFORMANCE

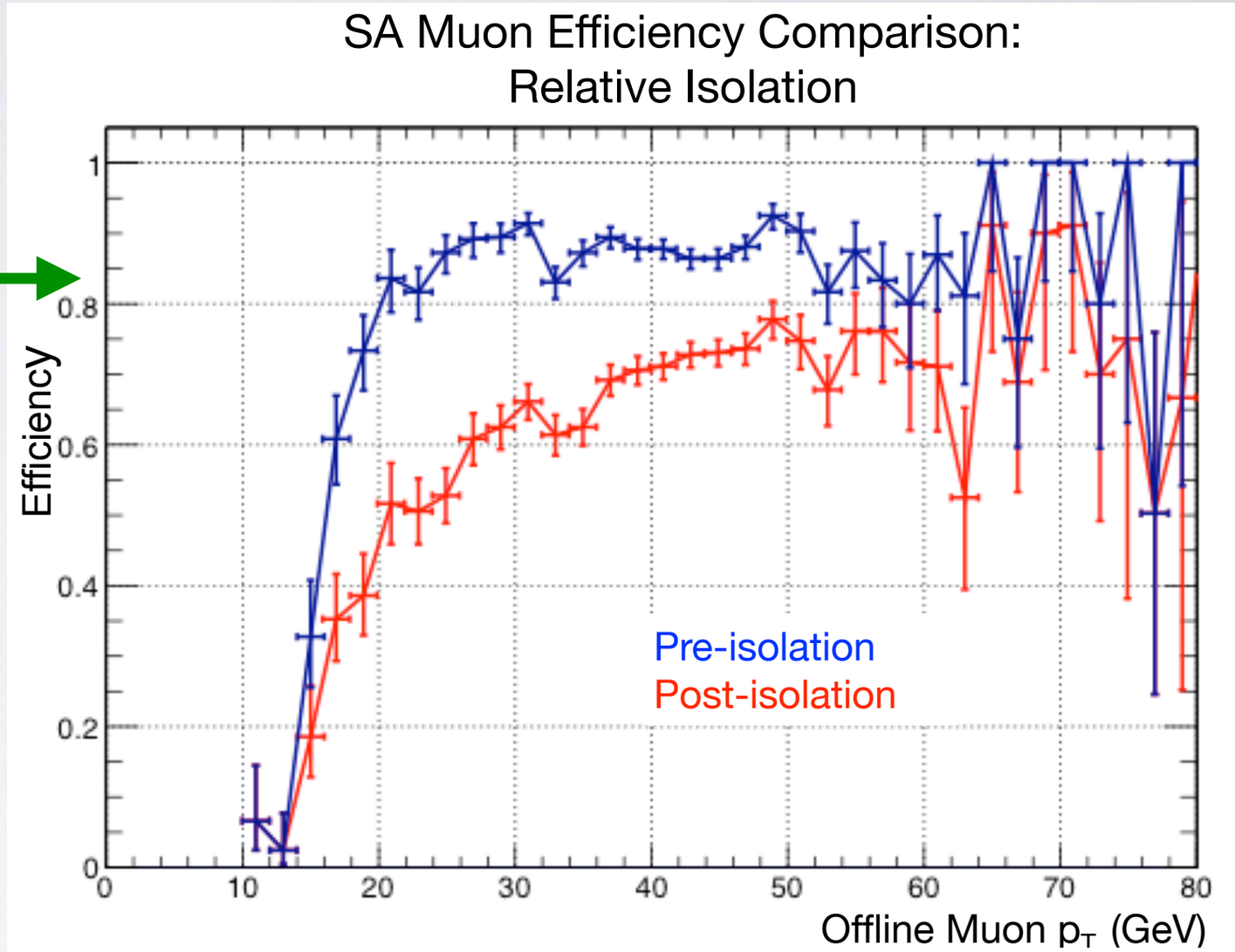




- Previous examination revealed GMT muon efficiency was reduced by isolation criteria
- Studied Stand Alone muons; they are the “best case” for what can be done online

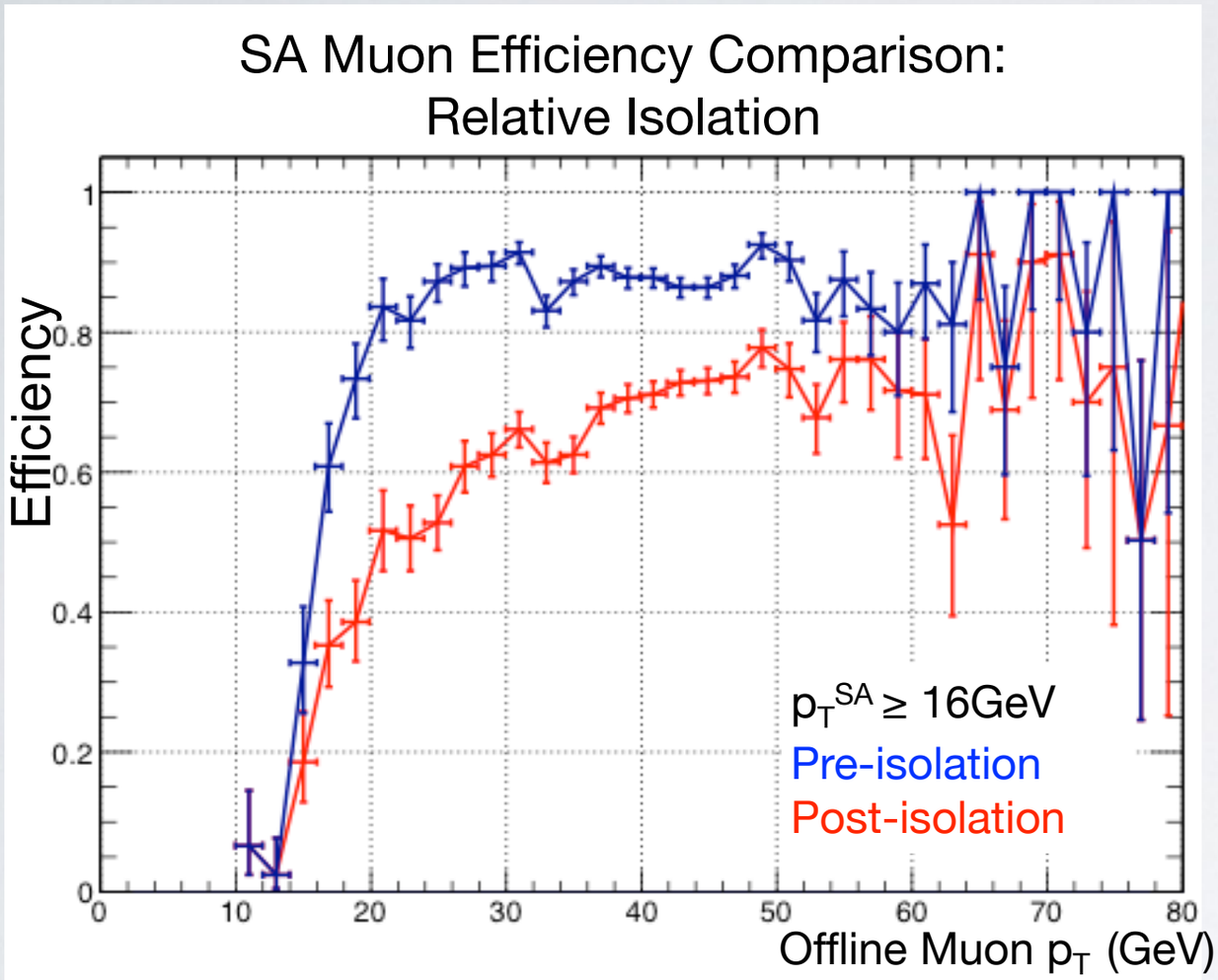
STAND ALONE RATE OF CHANGE PLOT

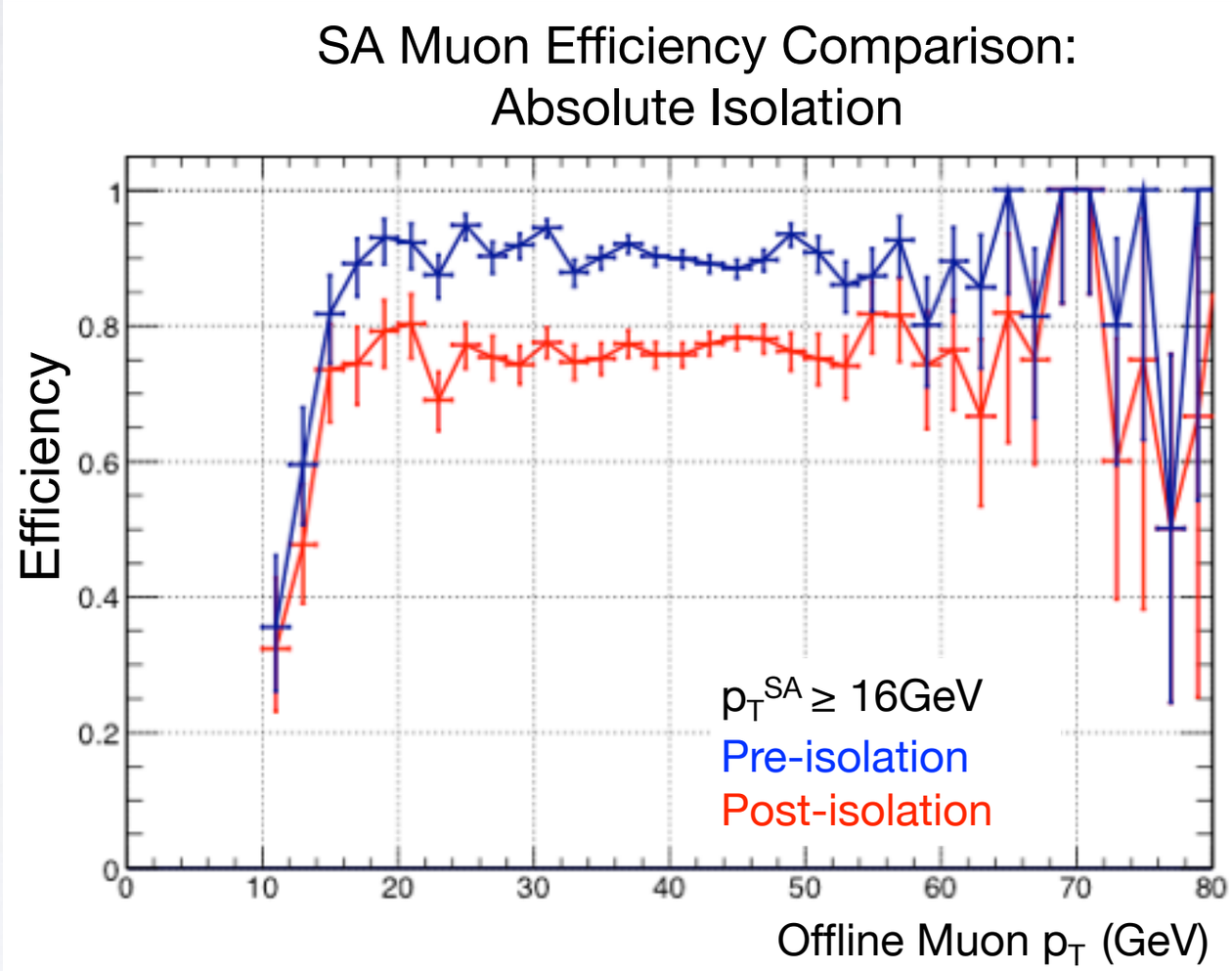




- Similar behavior was observed on the Stand Alone (SA) muon rate of change plots

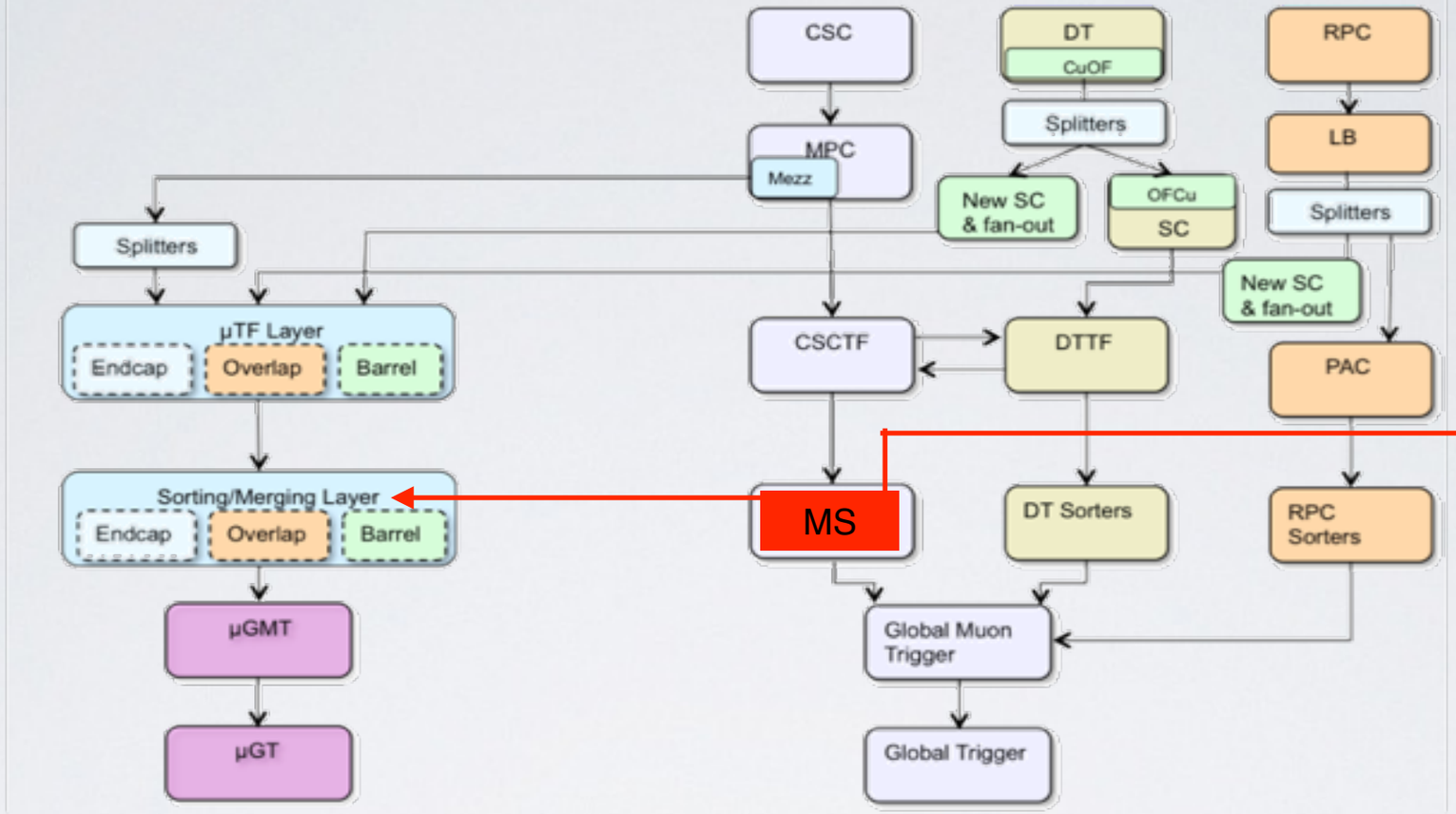
STAND ALONE MUON ISOLATION PERFORMANCE





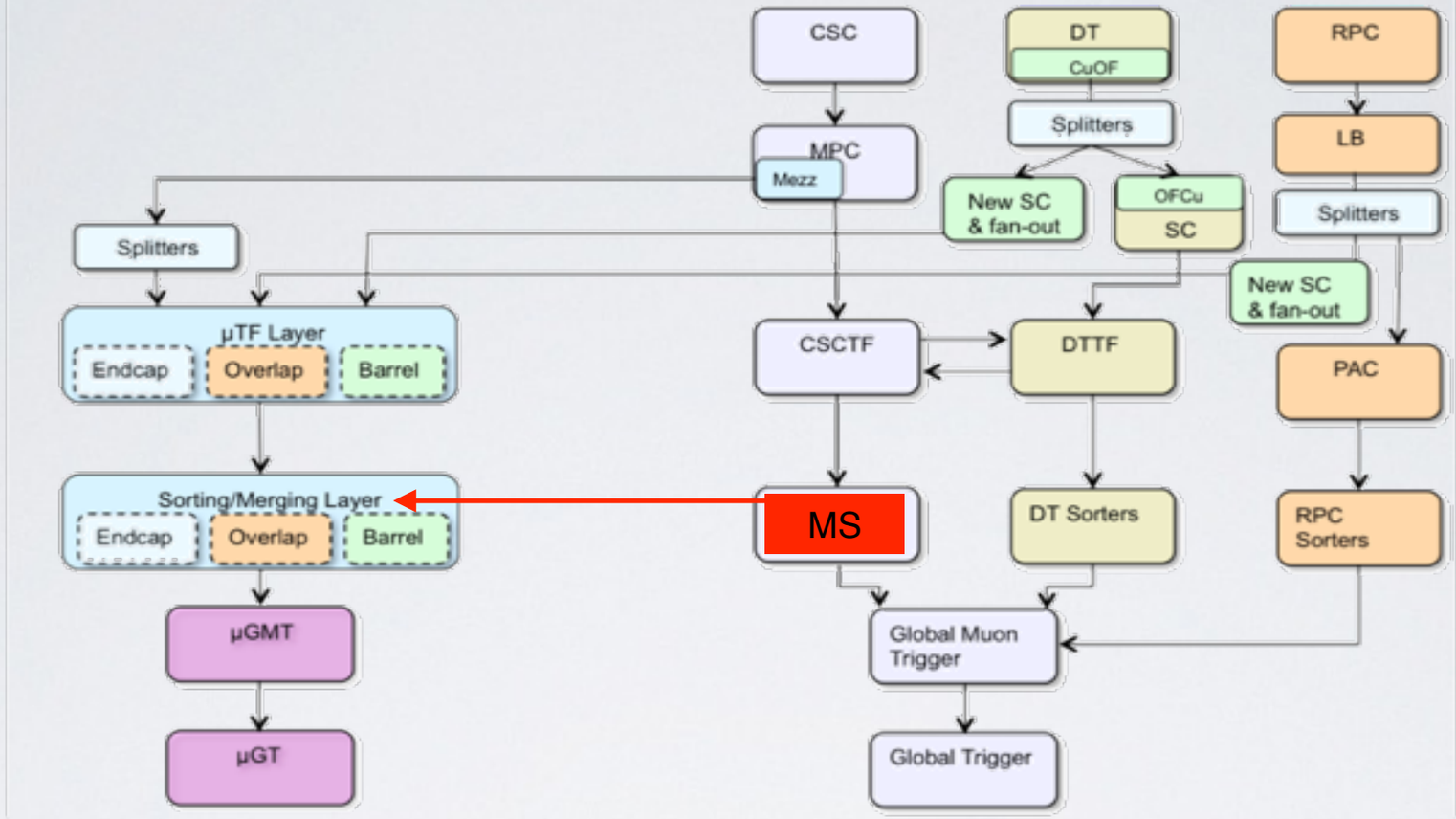
- In both relative and absolute isolation, the isolation cuts adversely affect the efficiencies
  - Relative: biased against low p_t muons, effectively raising the trigger threshold
  - Absolute: uniform rejection distribution in p_t, effectively acting as a prescale
- **Neither isolation technique is suitable for rate reduction**

MEZZANINE MUON SORTER UPGRADE



- Current Muon Sorter Improvements
  - Communicate with calorimeter trigger
  - Optical readout to uTCA electronics in parallel with copper readouts
- Later Muon Sorter improvements
  - 8 tracks sent to GMT (currently 4)
  - increase momentum resolution
  - sensitivity to muon jet signatures
  - completing the ϕ coverage of the track finding system

MEZZANINE MUON SORTER UPGRADE



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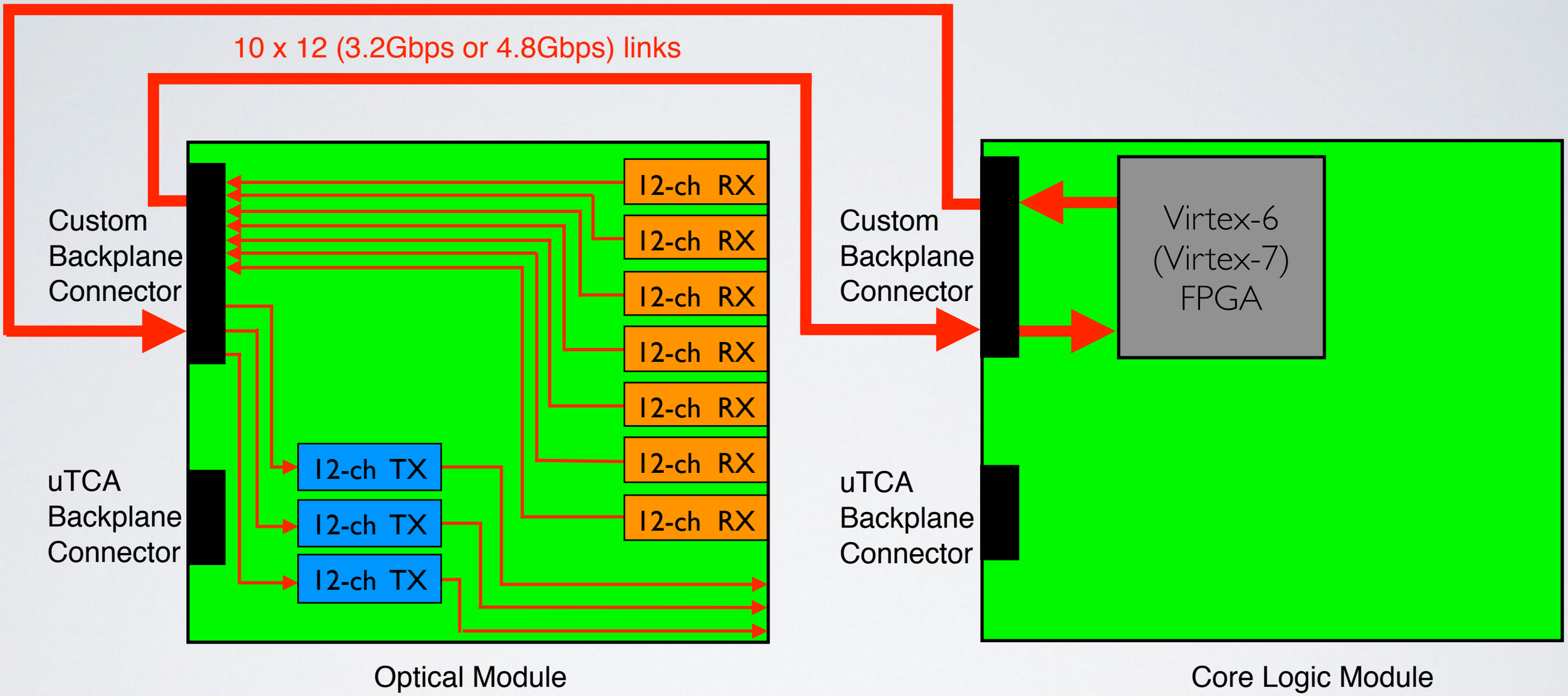
UPGRADED MUON SORTER I/O

Name	Description	Bit cout, existing MS	Bit count, future MS
Eta	Pseudorapidity of the muon	6	9
Phi_outer	Outer Φ of the muon	8	10
Phi_inner	Inner Φ of the muon		10
Pt	transverse momentum of the muon	5	9
Quality	Muon quality	3	4
VC	Valid charge flag	1	1
C	Charge (1=negative)	1	1
Halo	Halo muon flag	1	1
SE	Syncronization error	1	1
BC0	Bunch crossing zero flag	1	1
BX[2:0]	Lower three bunch crossing bits	3	3
Reserved	Parity and reserved bits	1	10
	Total bits per muon	31	60

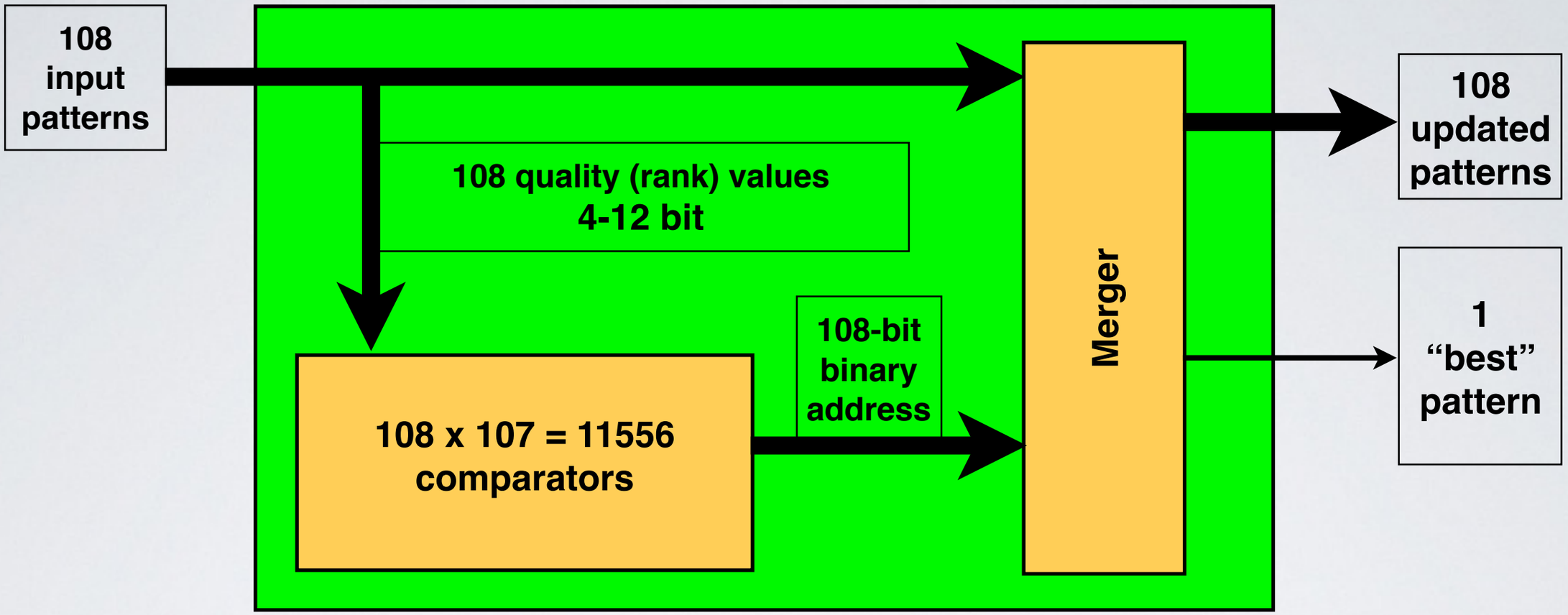
- 60 bits represent one “upgraded” muon from the Sector Processors (SP)
- Each SP provides 3 muons to the Muon Sorter, or 180 bits
- At 3.2Gbps, every muon can be squeezed into one link (4 frames with 8B/10B encoding)
- Only 36 optical links (out of 84 available on MTF6) would be needed to implement the MS inputs
- 4-8 output optical links (out of 36 available on MTF6) at 3.2Gbps rate would provide outputs to the Global Muon Trigger

DIAGRAM OF UPGRADED MUON SORTER



- Similar to uTCA Sector Processor
- 2 Slots in uTCA crate

MUON SORTER RESOURCES



- Target device is Xilinx Virtex-7 XC7VX690T
  - Common to UF MTF7 and Imperial MP7 boards
  - For 4-bit input patterns the resource usage of slice LUTs was 7%
  - For 8-bit input patterns the resource usage of slice LUTs was 15%
  - For 12-bit (13-bit) patterns the usage would be at least 22% (estimate)
- To select “8 best out of 108” it would take 8 such blocks; this is well above the chip limits for input patterns of 8 bits or higher!

SUMMARY / CONCLUSIONS

- Isolation Study
  - Relative isolation *appears* to perform better than absolute isolation
  - Further scrutiny shows neither isolation method is effective
- Muon Sorter Upgrade
  - Isolation does not support communication with calorimeter
    - No longer propose link to calorimetry system
  - Upgrade of current Muon Sorter to uTCA version

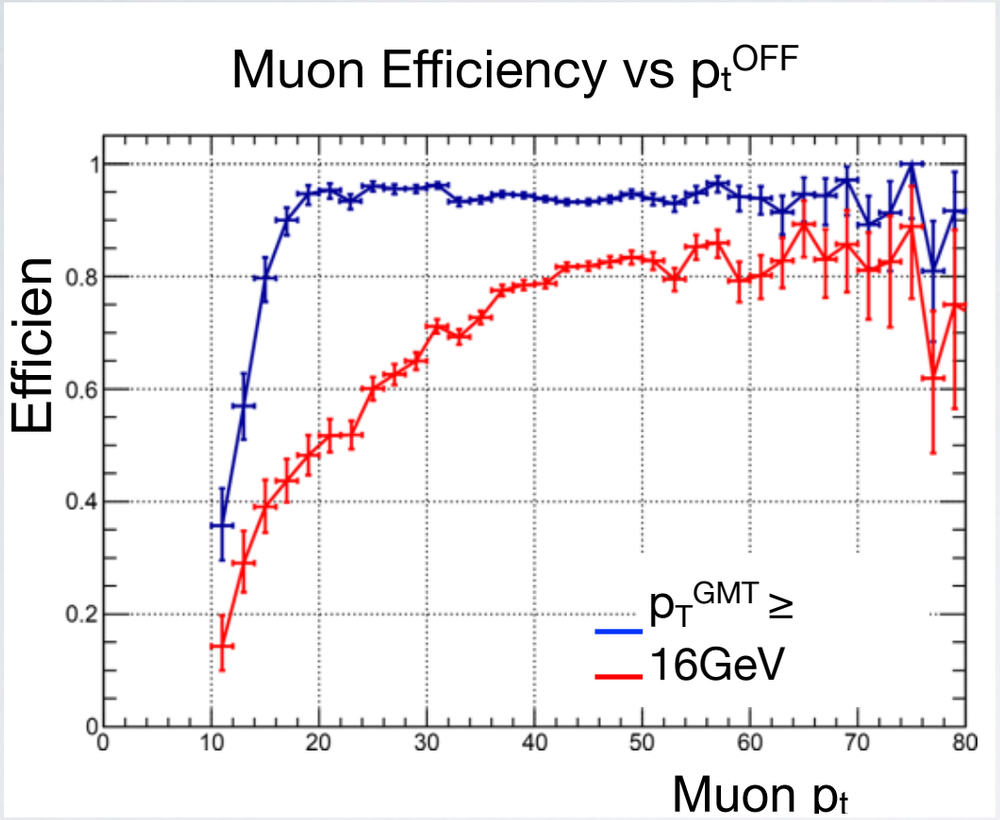
ACKNOWLEDGEMENTS

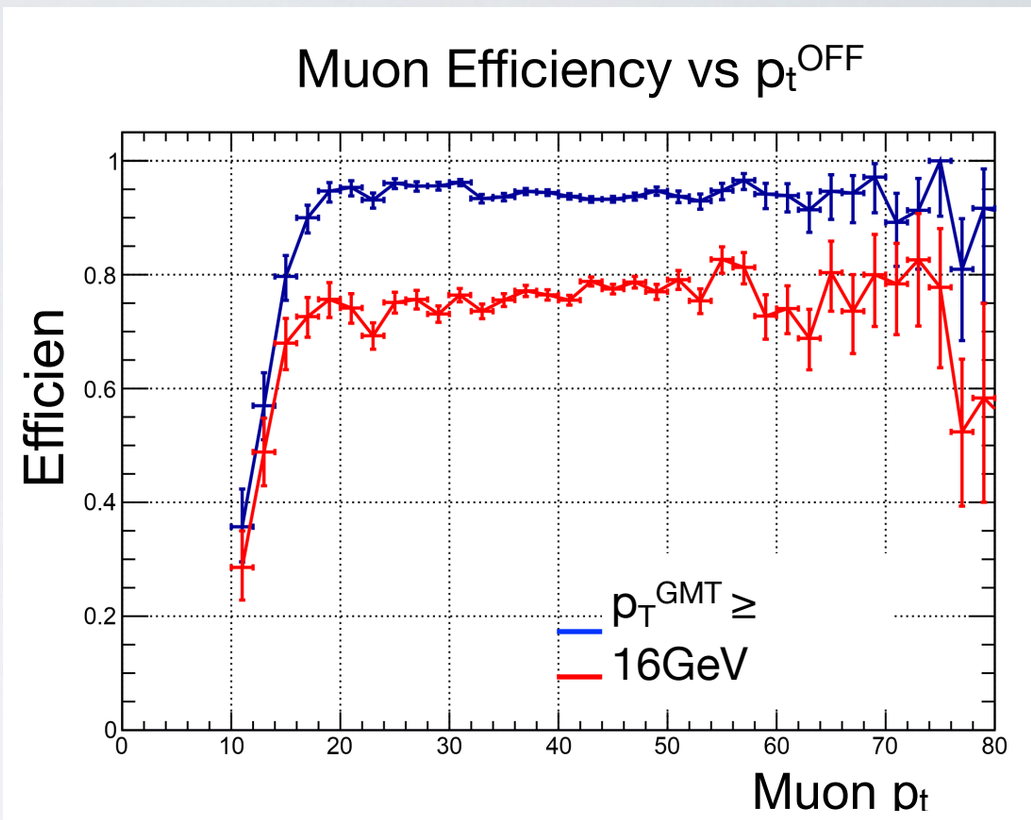
- Isolation Study
  - Ben Michlin, Rice University
  - Joschka Lingemann, Rheinisch-Westfaelische Tech. Hoch.
  - Hannes Sakulin, CERN
- Muon Sorter
  - Mike Matveev, Rice University
  - Paul Padley, Rice University

Thank You

BACKUP SLIDES

COMPARISON


Muon Efficiency vs p_t^{OFF}
Efficien
Muon p_t
$p_T^{GMT} \geq$
16GeV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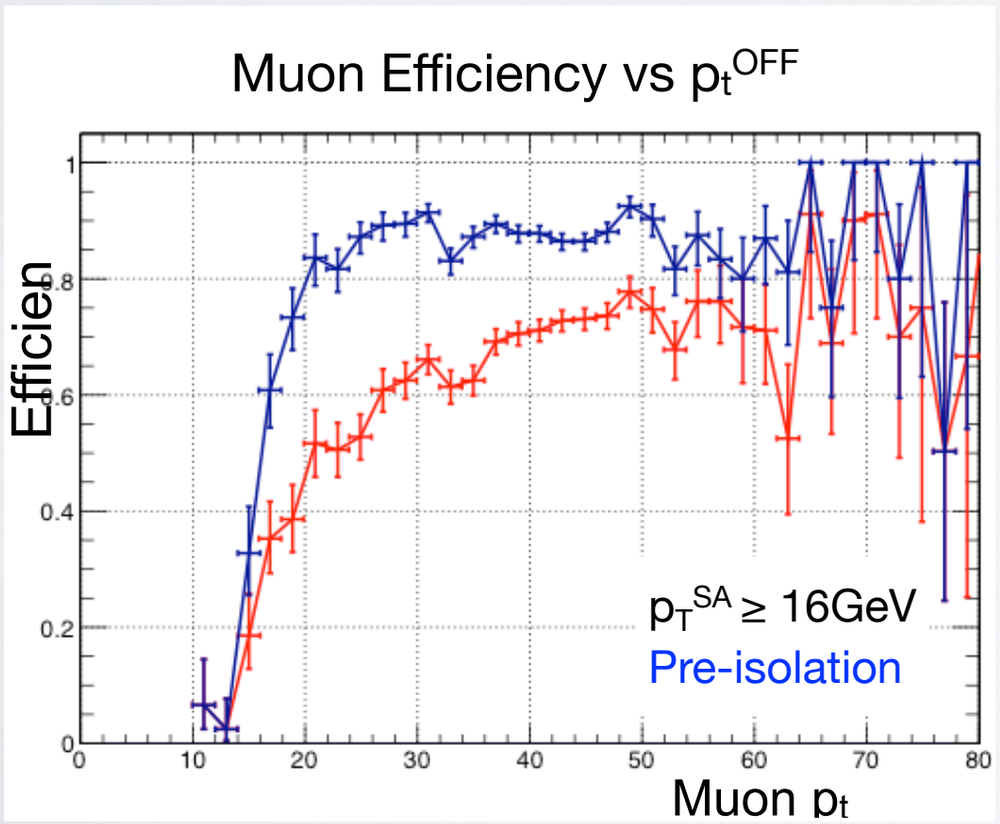
Muon Efficiency vs p_t^{OFF}
Efficien
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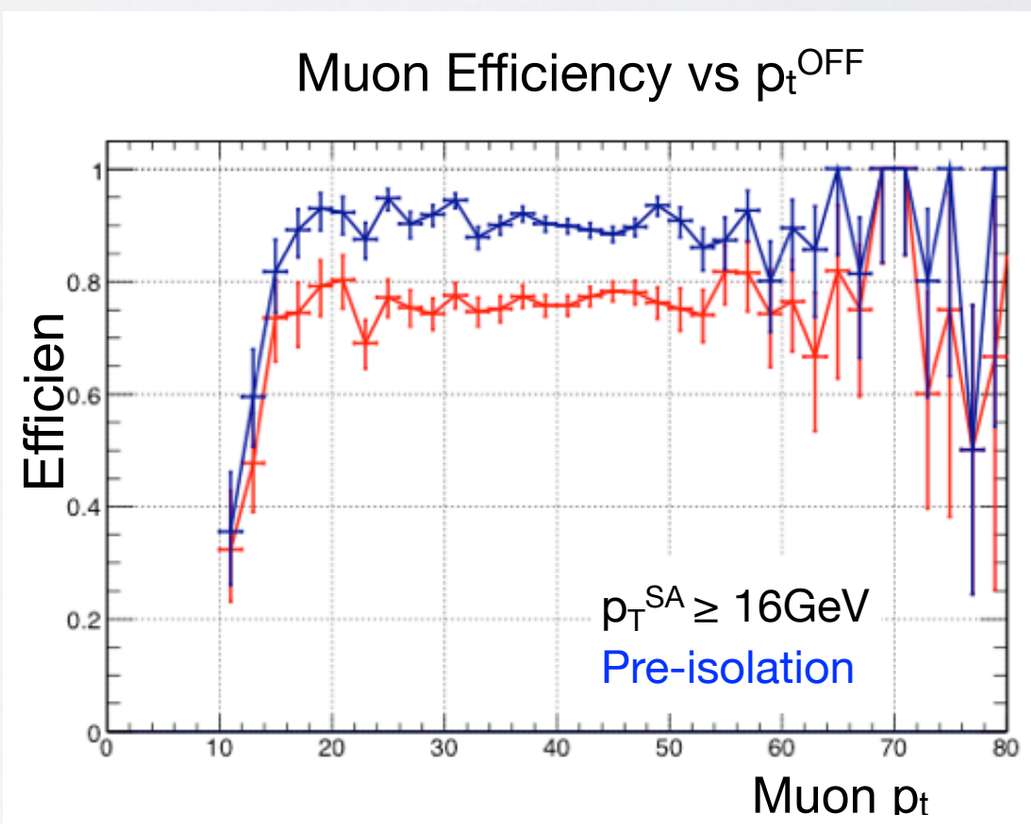
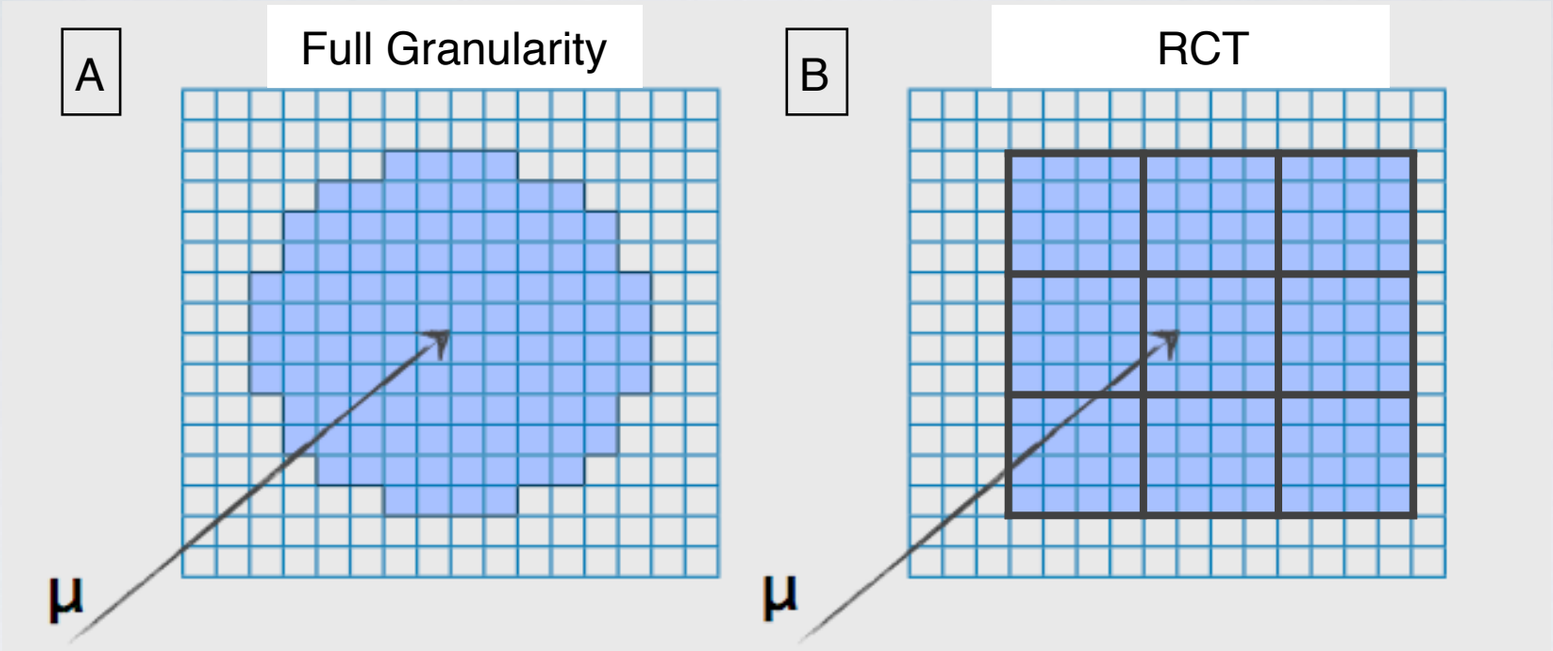
$p_T^{SA} \geq$ 16GeV
Pre-isolation


Muon Efficiency vs p_t^{OFF}
Efficien
Muon p_t
$p_T^{SA} \geq$ 16GeV
Pre-isolation

TRIGGER THRESHOLDS

- p_t^{GMT}: Global Muon Trigger (GMT) p_t
  - Used to show current capabilities.
  - Online muon $p_t \geq$ Trigger Threshold
- p_t^{SA}: Standalone (SA) p_t
  - Used to simulate best possible scenario with increased p_t resolution after upgrade.
  - Implies an offline match to online muon with $p_t^{GMT} \geq$ Trigger Threshold.
  - Standalone muon $p_t \geq$ Trigger Threshold
- p_t^{OFF}: Offline (OFF) p_t
  - Used to show absolute best possible performance of isolation.
  - Helpful in determining how p_t resolution affects isolation.
  - Offline muon $p_t \geq$ Trigger Threshold

TYPES OF ISOLATION REGIONS



Muon in the calorimeter as seen with A) Full granularity and B) RCT Regions.

- Full Granularity
  - Individual calorimeter towers used to define shower
  - Constant size in η-ϕ space
  - Size in physical space decreases as η increases
- Regional Calorimeter Trigger (RCT)
  - Each RCT region is constant size in the lab frame as are jets
  - Online(L1) - Offline p_t comparison not as good as full granularity

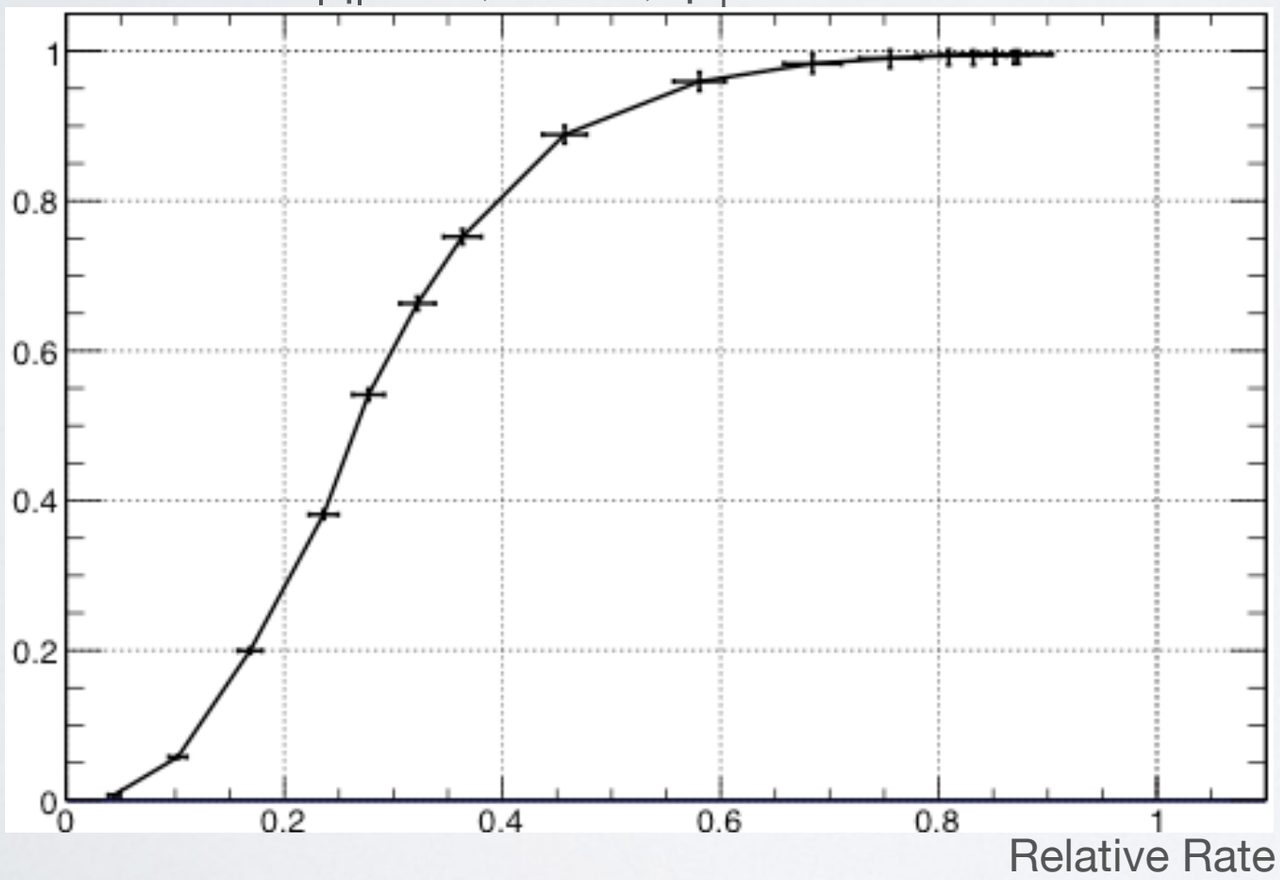
RATE OF CHANGE PLOTS

$$\text{Relative Rate} = \frac{\#\text{ events with } \mu \text{ that pass selection \& isolation}}{\#\text{ events with } \mu \text{ that pass selection}} \quad \text{(MinBias sample)}$$

$$\text{Relative Efficiency} = \frac{\text{Efficiency with isolation}}{\text{Efficiency without isolation}} \quad \text{(Z}\rightarrow\mu\mu\text{ sample)}$$

Full Granularity Regions, Relative Isolation

$|\eta| < 2.1$, R=0.6, $p_T^{SA} \geq 12$ GeV

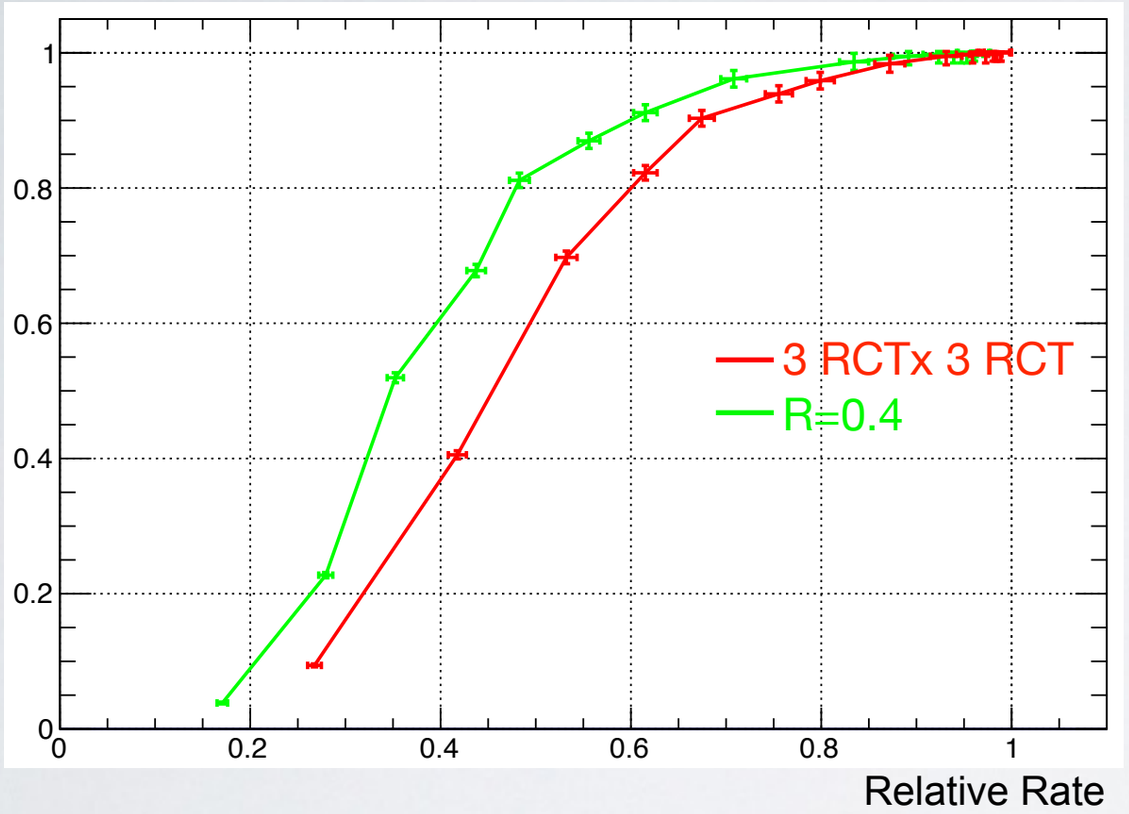


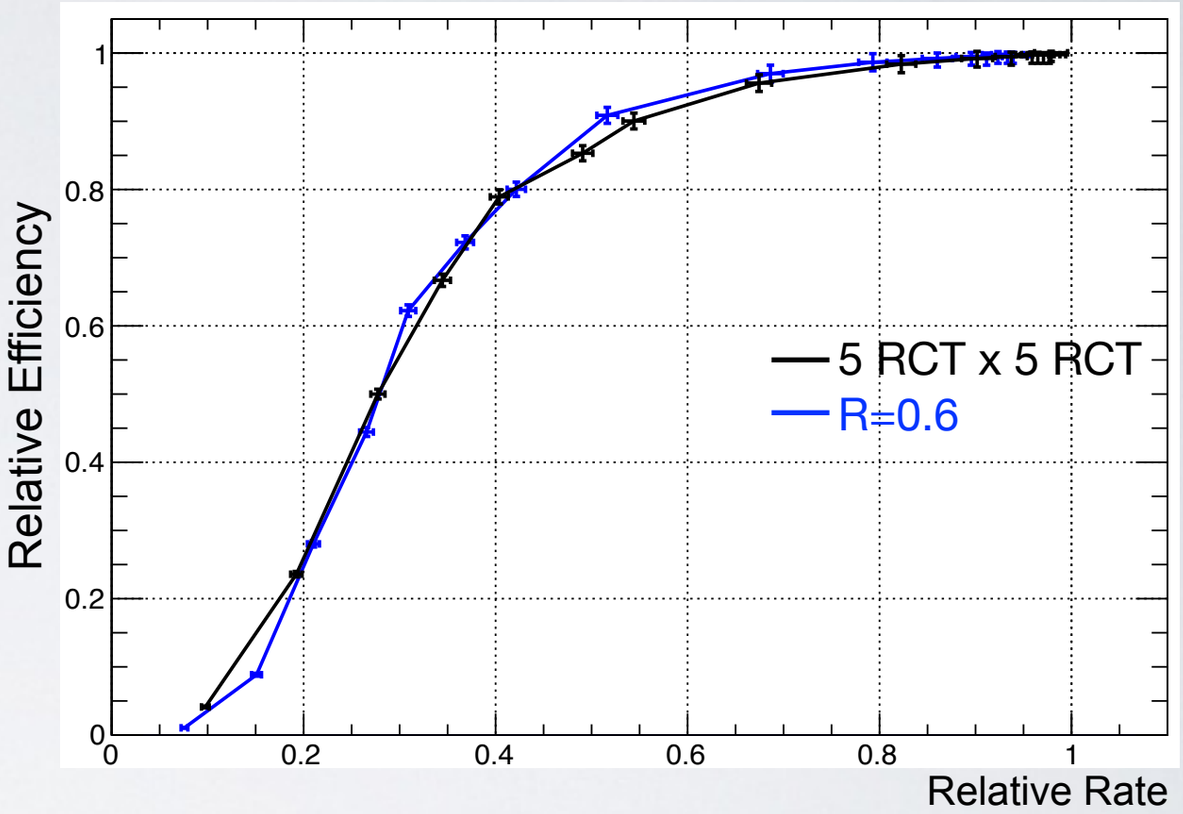
- Each point is a specific isolation cut.
- Region is specified for each plot ($|\eta| < 2.1$).
- The specified p_T^{SA} is the L1 trigger threshold used.
- E_T is used for relative rate calculation for Full Granularity regions.
- E is used for RCT regions.

The i^{th} point along the curve has the same isolation cuts in all Rate of Change (RoC) plots.

RATE OF CHANGE PLOTS

$|\eta| < 2.1$, $p_T^{GMT} \geq 12GeV$, Relative Isolation



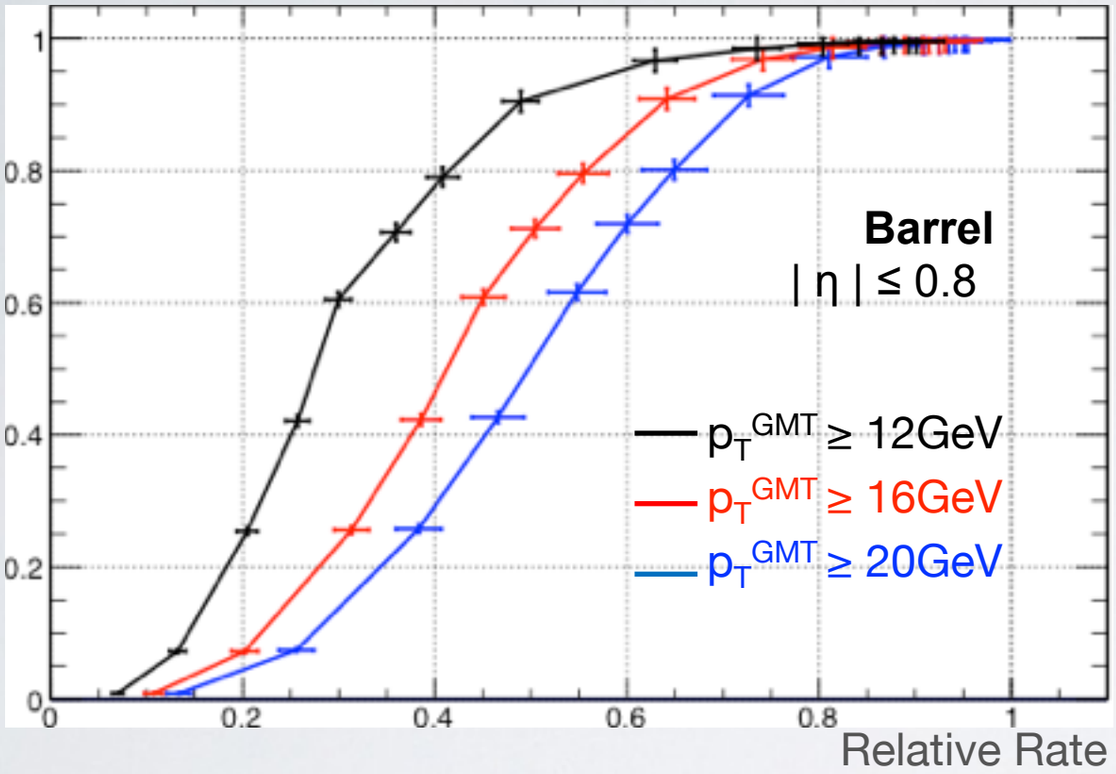


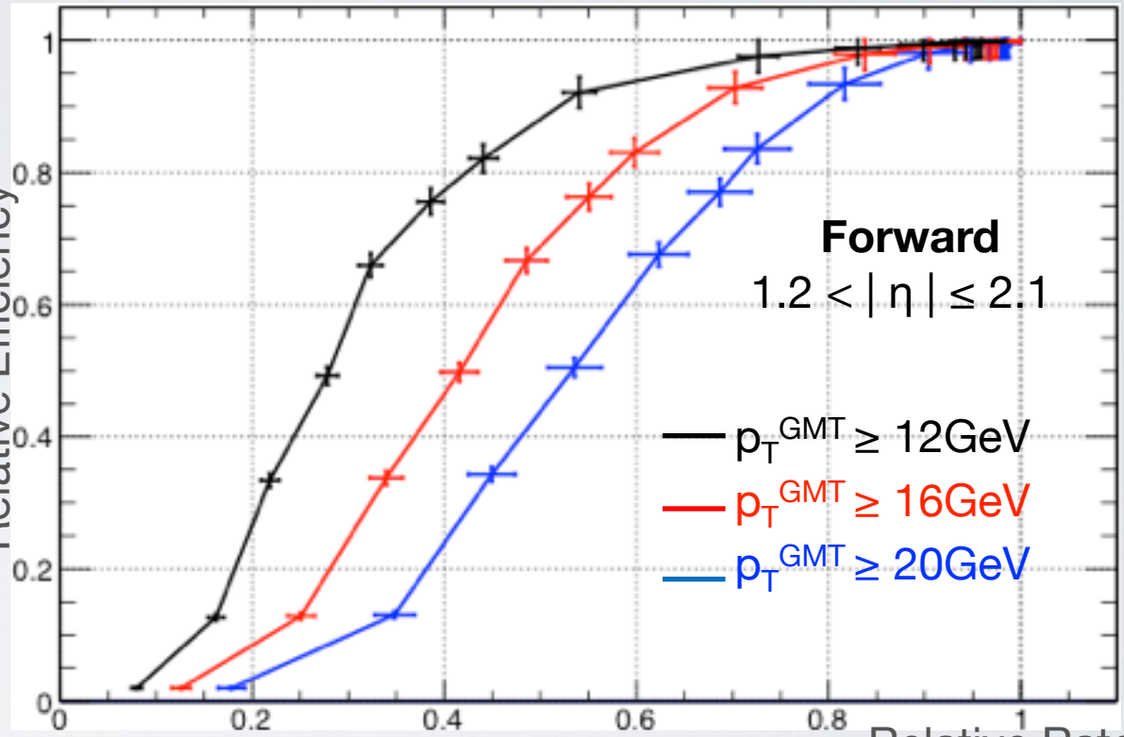
A 3 RCTx 3 RCT area in the barrel is comparable to a full granularity region with R = 0.4

- Comparing RCT and full granularity
  - A 3 RCT x 3 RCT region consistently yields poorer efficiency for a given relative rate than a comparable area with full granularity
  - For isolation areas above 5 RCT x 5 RCT, the RCT and full granularity RoC curves converge.

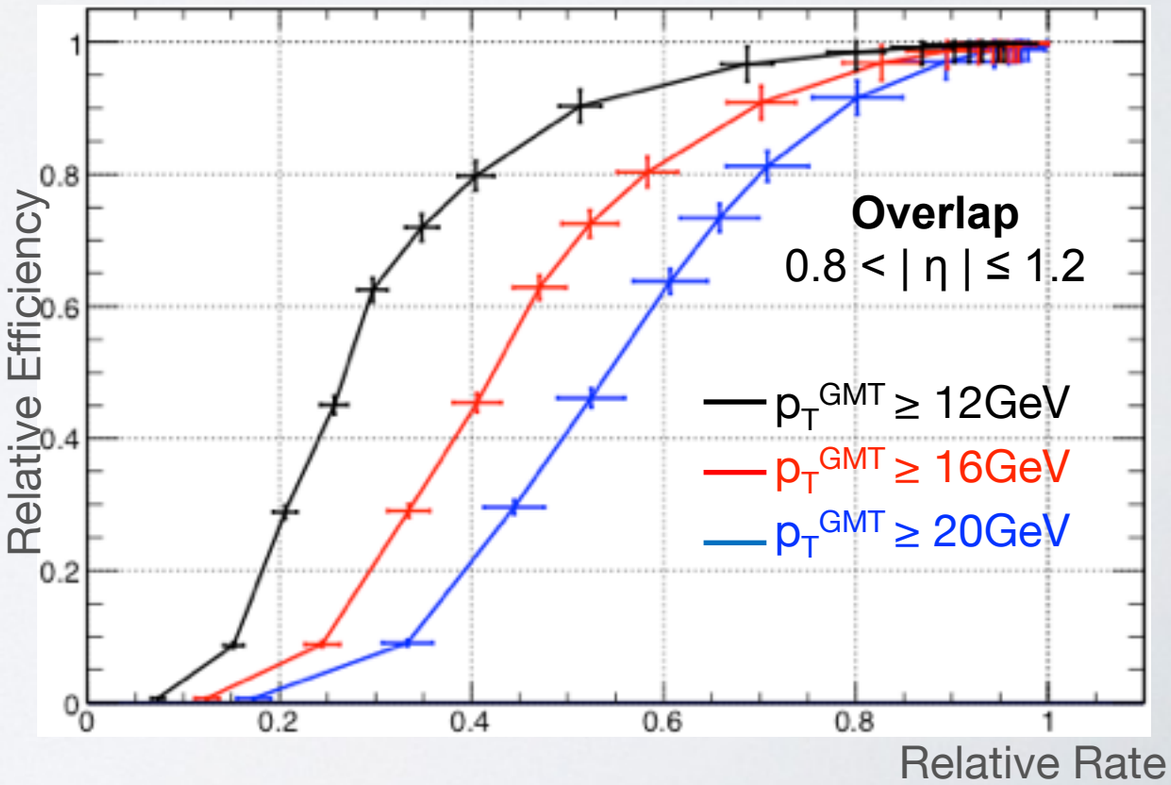
RATE OF CHANGE PLOTS

Full Granularity Regions (R=0.6), $p_T^{GMT} \geq$ Trigger Threshold

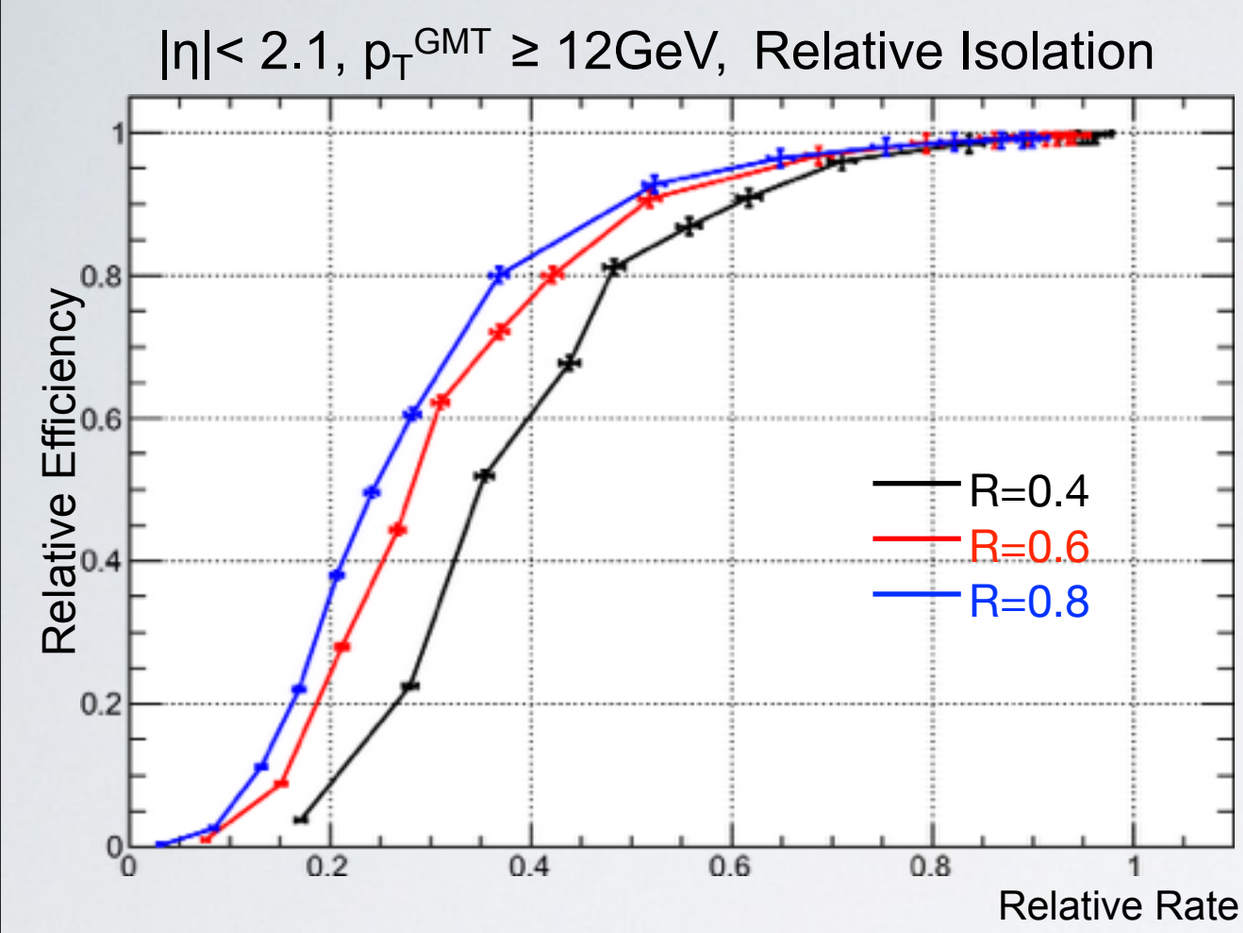


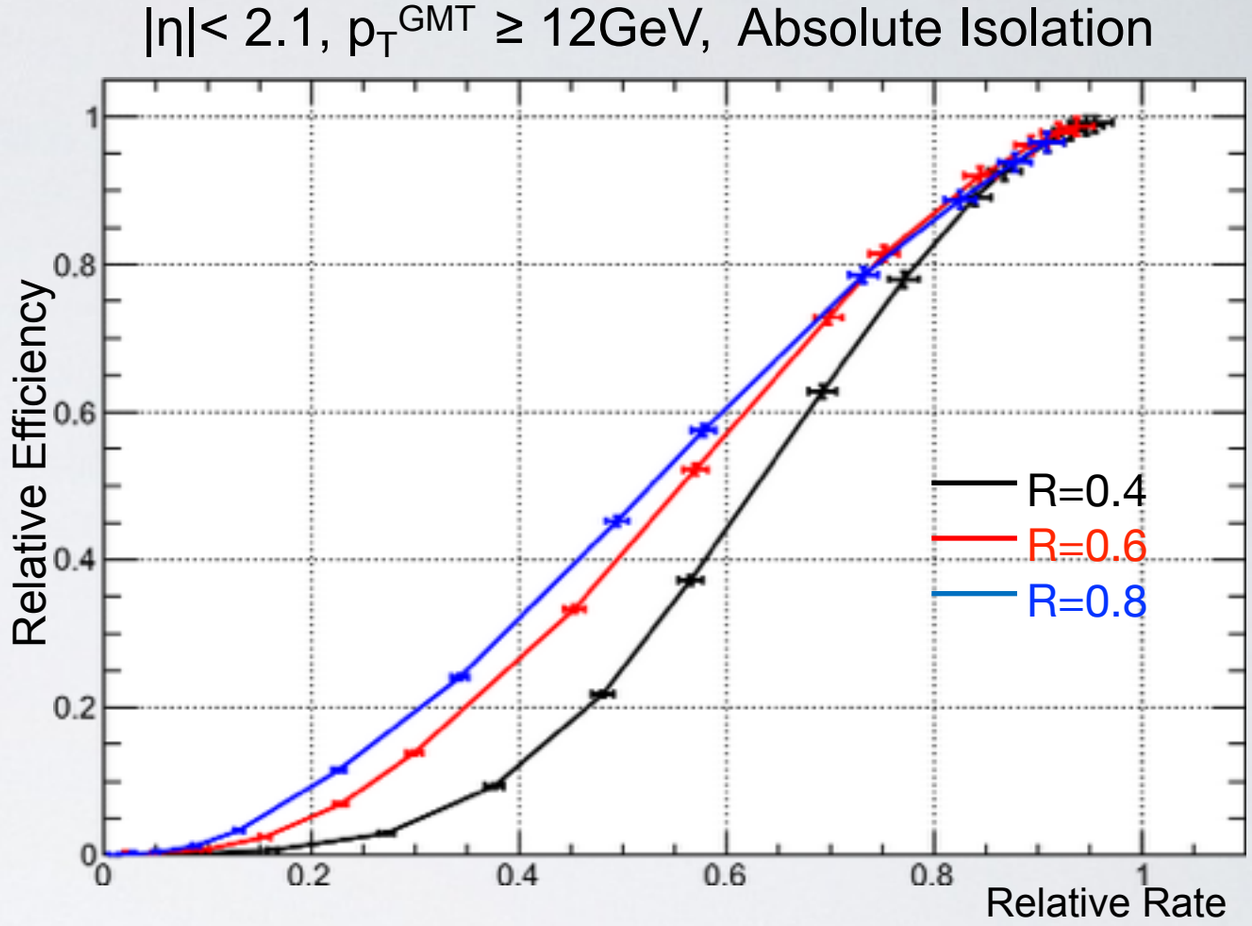


- RoC plots studied in different detector regions
- Confirmed similar performance in different detector regions



RATE OF CHANGE PLOTS





- Increasing the isolation area yields higher relative efficiency for a given relative rate
- Relative isolation appears to return higher efficiencies than absolute isolation for a given rate
- What causes this better performance?

PROPOSED IMPLEMENTATION

Upgraded Muon system allows for two isolation region possibilities in the L1 system:

- Calorimeter data sent to Global Muon Trigger (GMT)
- Isolation calculated at GMT
- RCT (4x4 calorimeter tower) isolation regions

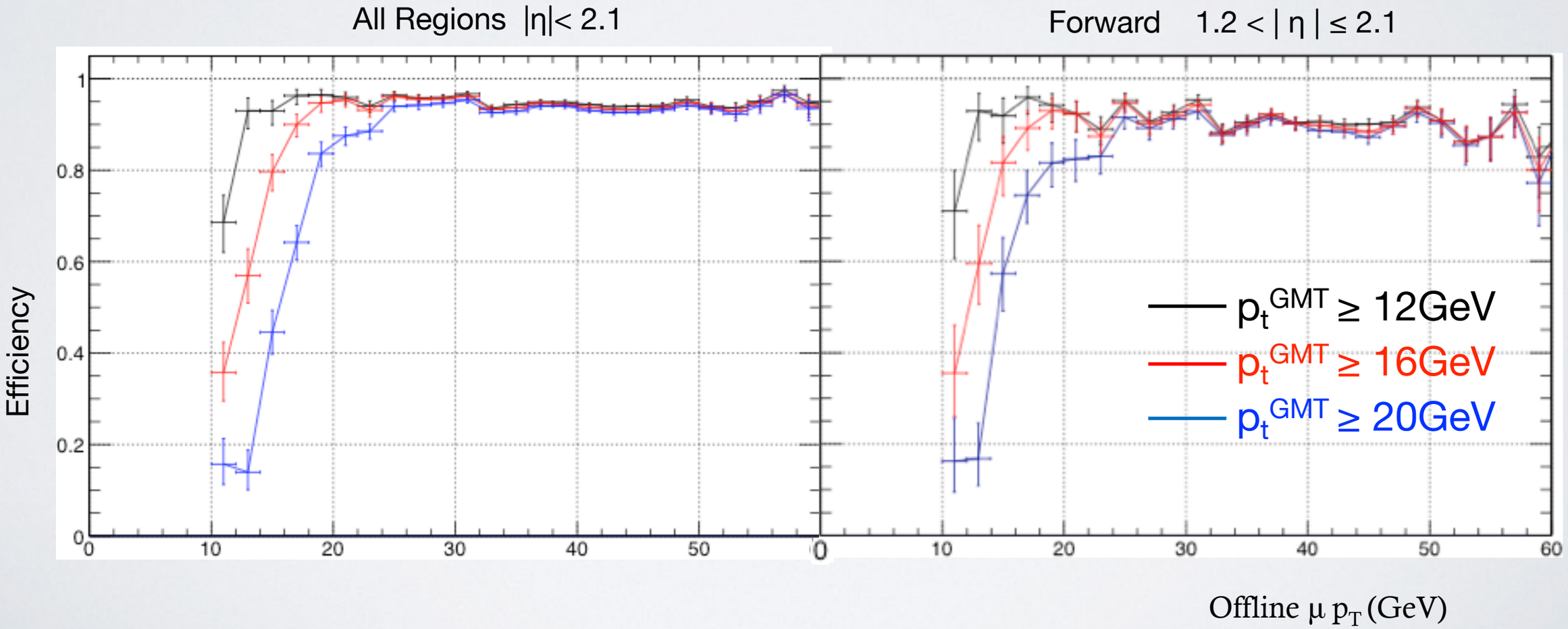
- Muon Sorter (MS) data sent to the calorimeter trigger from muon endcap ($|\eta|>1.2$)
- Isolation calculated at calorimeter trigger
- Allows for full granularity (1x1) isolation regions.

DATA AND EMULATION

- All data comes from **2012C**.
- Efficiency sample using counting Tag & Probe: **Z(μμ) Skim**
  - /SingleMu/Run2012C-Zmu-PromptSkim-v3/RAW-RECO
  - L1Trigger_Run2012C_JSON_202500-204000_v1.json
  - “HLT_IsoMu24” with “|eta| 2.1"
  - pT> 10 GeV for 2nd muon
- Rate Sample using single muons: **MinBias**
  - /Commissioning/Run2012C-PromptReco-v2/RECO
  - L1Trigger_Run2012C_JSON_202500-204000_v1.json
  - HLT_L1SingleMuOpen pass through
- Upgraded L1 calorimeter towers emulated with **SLHCUpgradeSimulations** package

PRE-ISOLATION EFFICIENCIES

- Establish baseline
- Using counting Tag & Probe method



Efficiency (Tag & Probe) and Rate Selections

- Event Selection
  - Exactly 2 muons
  - Same vertex
  - Opposite charge
  - Invariant mass 91 ± 15 GeV
- Matching
  - $\Delta R(\text{Offline, L1}) < 0.5$
  - Online $p_T \geq$ Trigger Threshold
- Rate Selection
  - $|\eta| < 2.1$
  - Quality > 5 || Quality = 5 && BX = 0
  - Online $p_T \geq$ Trigger Threshold
- Tag Selection
  - Fired HLT (Has L1 Candidate)
  - $P_T > 32$ GeV
  - $|\eta| < 2.1$
  - Tight Muon Selection
  - Relative Particle Flow Isolation < 0.1
- Probe Selection
  - $P_T > 10$ GeV
  - $|\eta| < 2.1$
  - Quality > 5 || Quality = 5 && BX = 0

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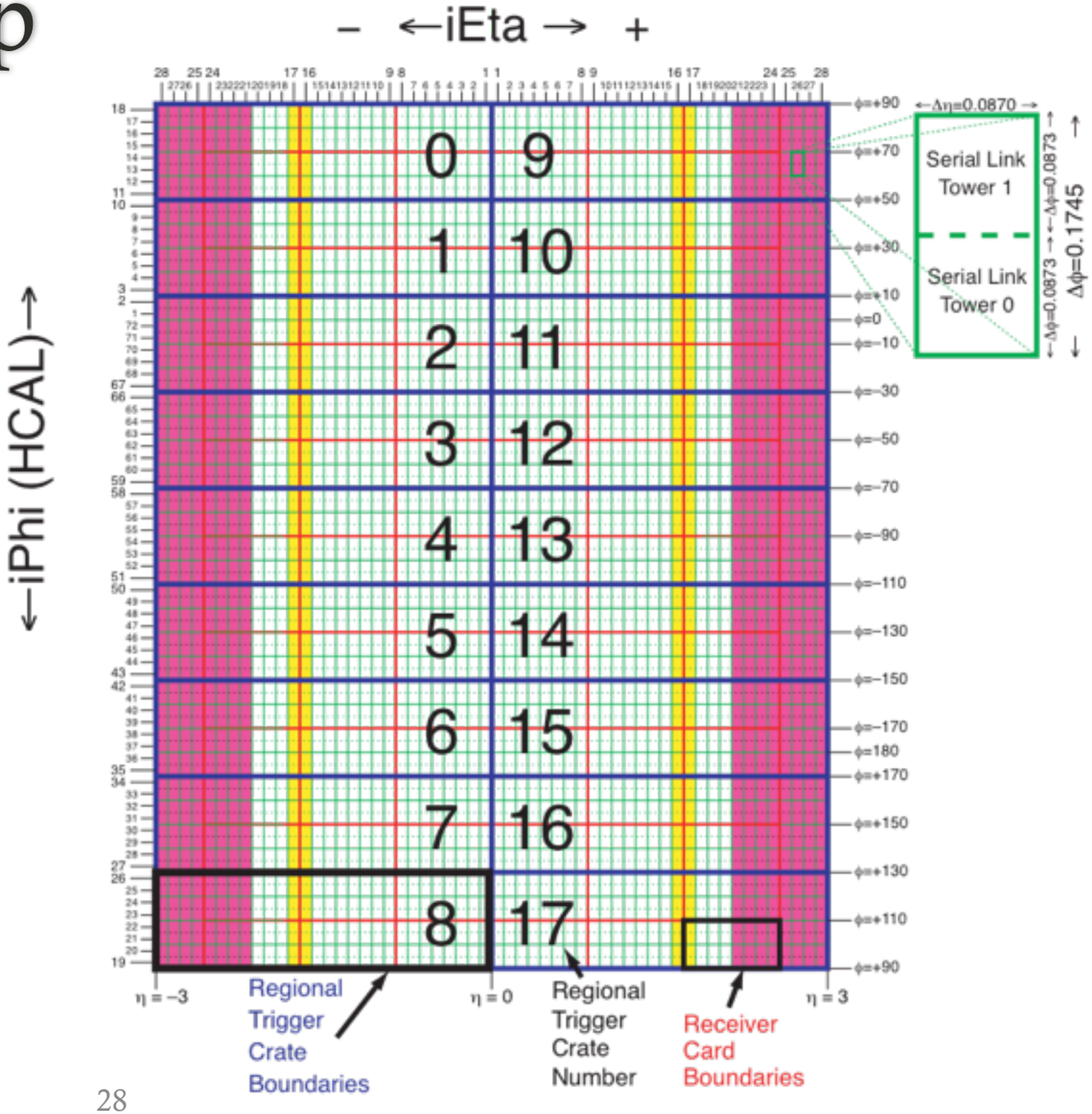
RCT Region Map

- Each RCT region covers ~5.0 x 0.7 (in η-ϕ space)
- Not all regions are actually 4x4 calorimeter tower regions to maintain a constant physical area.



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ϕ-Extrapolation for Efficiency

- Online (GMT) ϕ is calculated at the calorimeter
- Offline (RECO) ϕ is calculated at the origin
  - Offline ϕ is extrapolated to the muon system for GMT-RECO matching
    - This calculation is performed in the algorithm
    - The offline ϕ is altered (rather than the online value) to preserve the integrity of the online information

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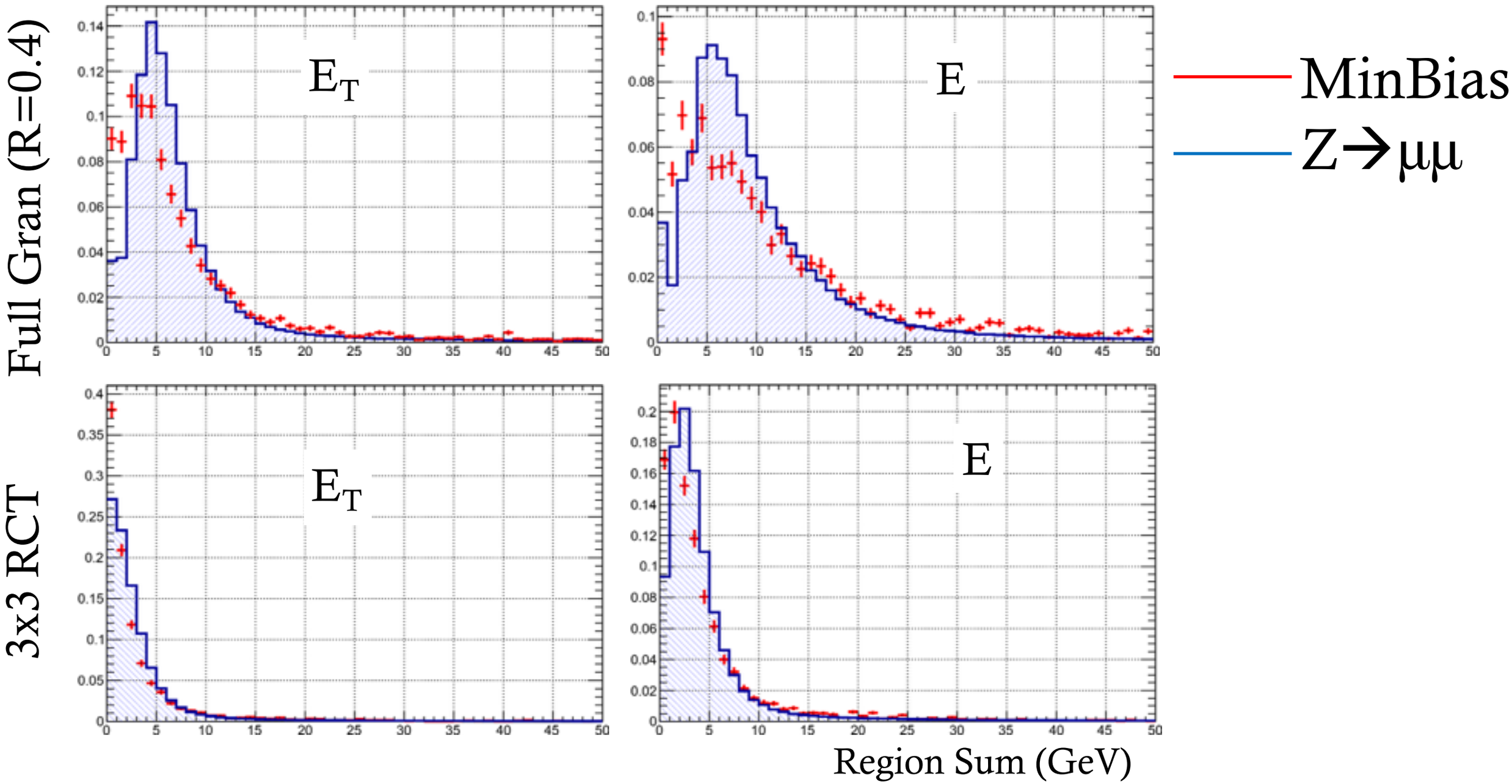
Absolute Isolation Variable



Full Granularity:

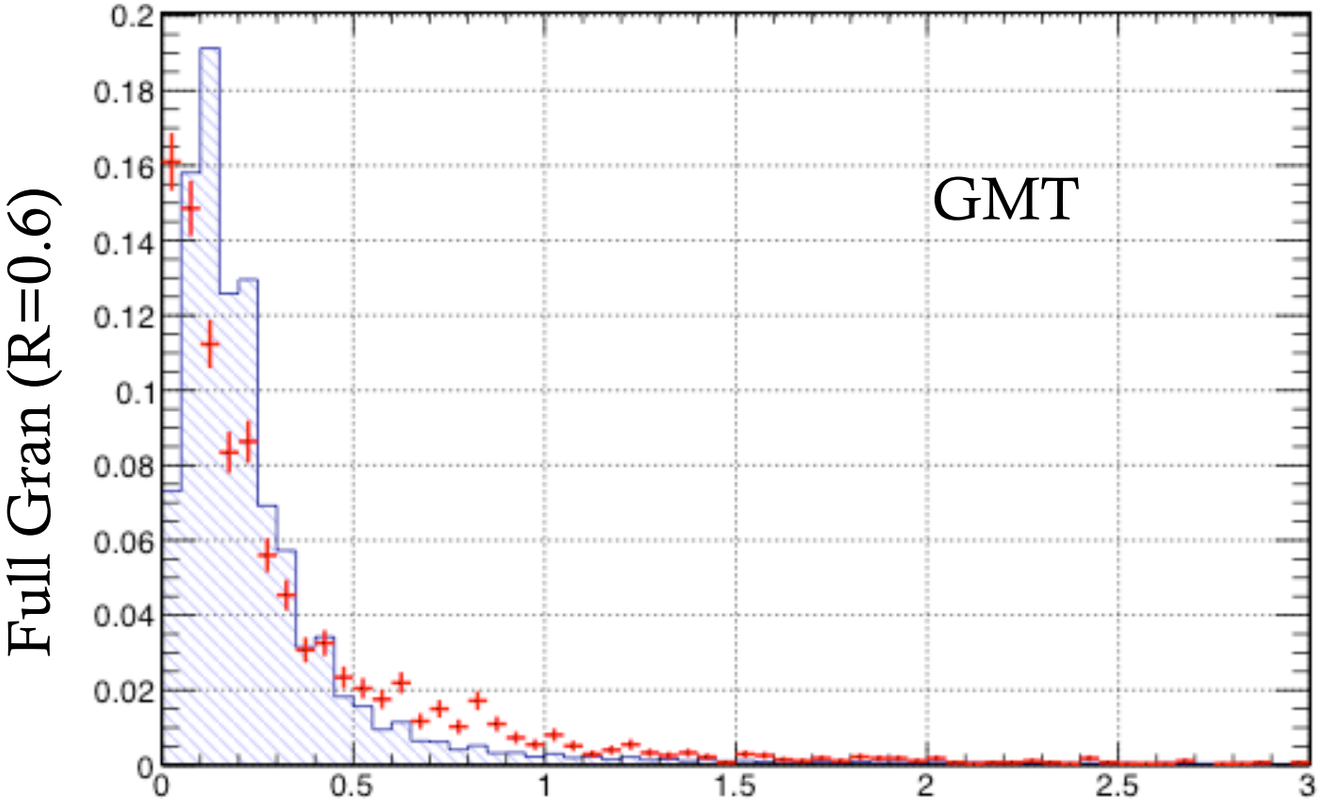
- ✓ E_T provides better discrimination between Z→μμ & MinBias

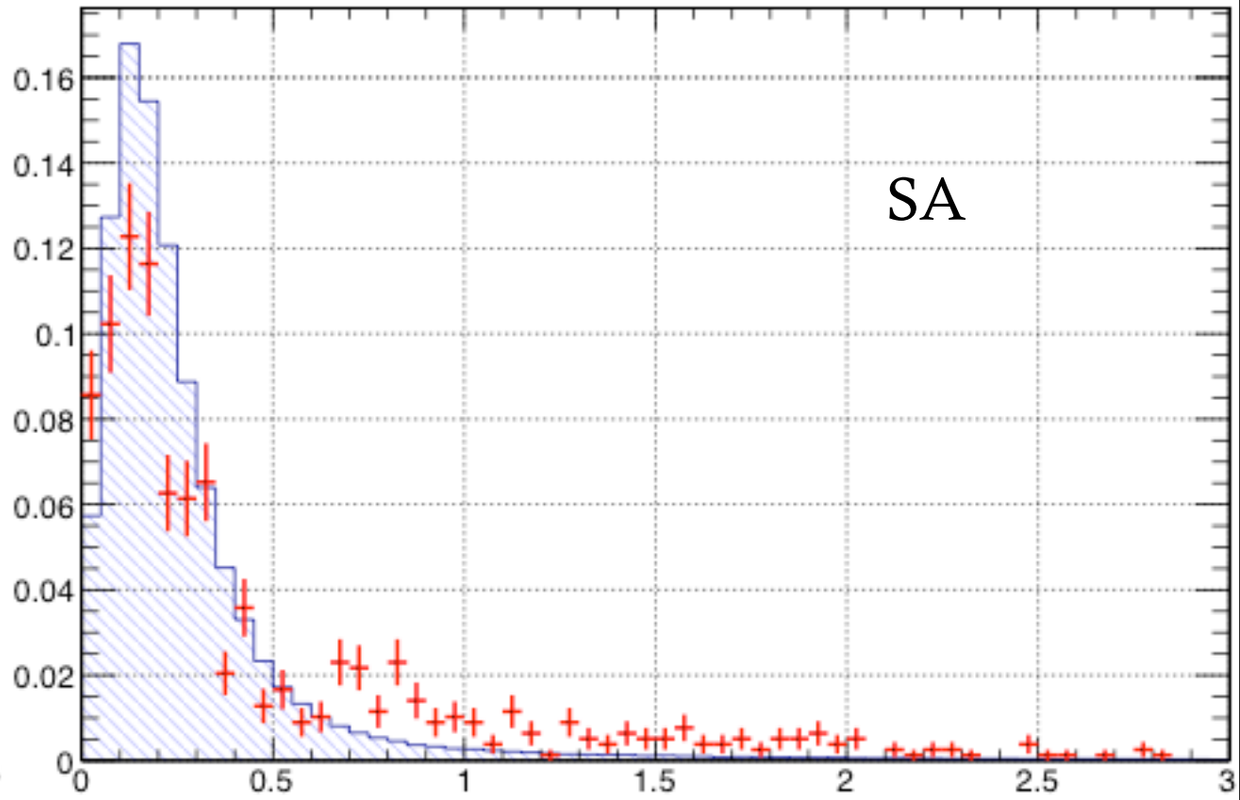
RCT Region:

- ✓ E provides better discrimination between Z→μμ & MinBias

*Discrimination determined by-eye

Relative Isolation Variable by p_T Resolution

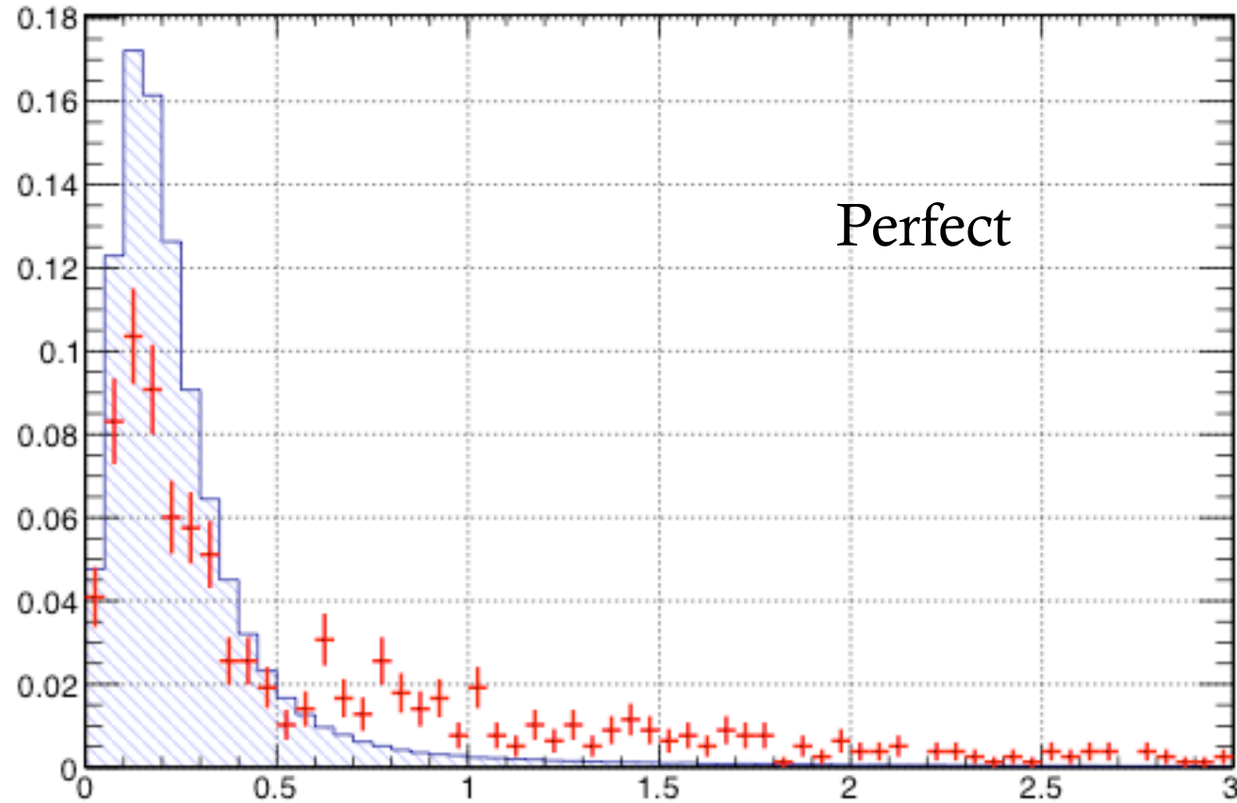




MinBias

$Z \rightarrow \mu\mu$

- Expect increasing discrimination with increasing p_T resolution.



Acknowledgements

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- Dr. Ivan Furic, University of Florida