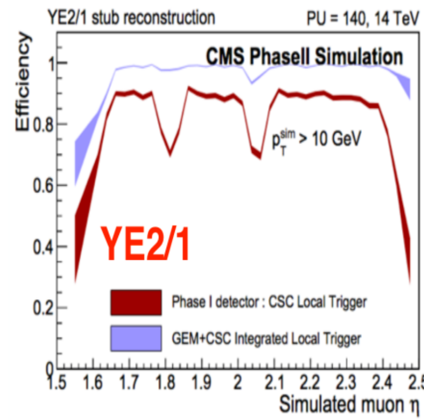
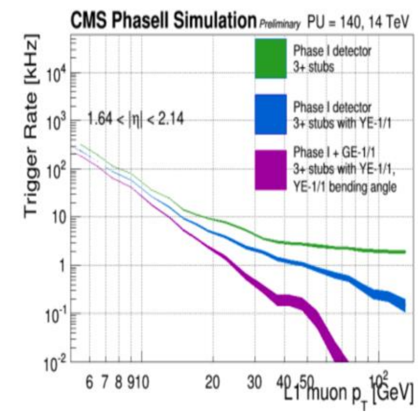
- * GEM4: Demonstrate that the combined trigger CSC-GEM trigger can be done (as for GE1/1-ME1/1). It seems that it is difficult to do in the same way as for GE1/1 since they sit in different disks. For the alternative of sending all the links to the trigger processors: work out the number and type of optical links, and make sure that Phase II trigger processors can handle all of the links. (Is it by then preferable for GE1/1 as well?)

- Answer GEM4:
- GEM information is already planned to be directed to the Track Finder in addition to the "integrated GEM-CSC path" that sends information as part of CSC trigger path. Once GE1/1 is installed, the trigger data will be routed to the muon endcap TF that has been commissioned in 2016 (it has been in the design in anticipation of GEM and/or RPCs). The reason for this path is not just to add a redundancy path just in case or because it is easy to do (which are both true), but for example it could be important for physics with multiple nearby muons, e.g. "lepton jets" types. CSC has a limitation that only 2 stubs can be sent per BX from a particular CSC chamber. In case of multiple muons, CSC chambers in different stations will send subsets of all stubs, which may or may not add up into muon candidates. For such signatures, GEM will be able to deliver all muon hits enabling L1 to recognize such multi-muon signatures and record such event. GE2/1 trigger data will be routed to muon TF as well.
- Regardless, maintainig the main "integrated trigger" option is much preferred because it allows recovery of CSC inefficiency, resolving ambiguities, correcting timing mismeasurements leading to incorrect BX assignment of either CSC or GEM information. We belive the integrated trigger can be implemented in the case of GE2/1-ME2/1 pairs, despite the fiber path lengths being higher in the case of GE2/1. What matters for trigger data alignment, is the difference of path lengths from ME2/1 to CSC peripheral crate (up to 10m) and from GE2/1 to the same peripheral crate (up to 46m). This leads to "extra latency" of 4.9 ns/m * (46m-10m) ~7 BXs. The effective latency is however reduced by 2 BX due to shorter lengths of optical fibers from ME2/1 peripheral crates to the TrackFinder crate compared to the longest length among all CSC stations. The effective extra latency is therefore 5 BXs =7 BXs - 2 BXs. One should next note that the OTMB algorithm latency (excludes any optical deserializations etc.) is 19 BXs and the algorithm includes GEM infromation at the last step in the algorithm, so it should not be a problem if GEM data arrives shifted relative to CSC data as it can be naturally accounted for in the firmware of the OTMB. Finally, one should remember that GE2/1 is designed for Phase-2, where the overall latency doubles (from 124 to 248 BXs. In addition, given this large increase and that muon L1 data needs to arrive with the arrival of L1 track trigger candidates, a request of a few BXs to be added to muon trigger step is not likely to cause a lot of controversy.

GE2/1 Motivation: Prompt Muon Trigger

- Better prompt muon triggering
  - Similar to GE1/1, GE2/1 improves local stub finding efficiency and measures muon direction
    - Near stations are critical for good momentum measurement
    - Increases parameter space for trigger optimization (direction based p_T + direction in station 1 + direction in station 2)
      - Better efficiency at a fixed trigger rate (work in progress)



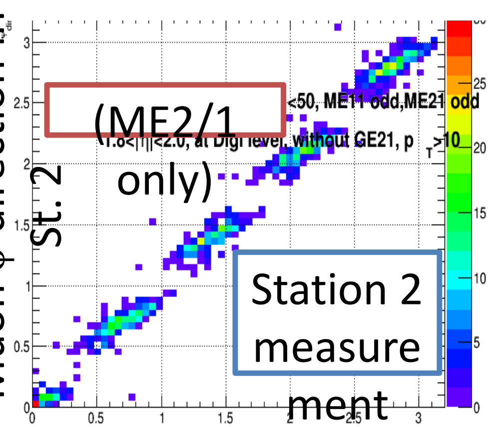


GE1/1 trigger rate improvement (right) both from better local efficiency (better resolution reduces mismeasurements) and direction measurement (reject soft mismeasured muons)

- GE2/1 serves as the only backup for direction measurement if ME1/1 performance reduces with aging
  - While ME2/1 is thicker than ME1/1, it's ability to measure directions in insufficient at this high eta (small bending)

Muon ϕ-direction in St. 2

(ME2/1 only)

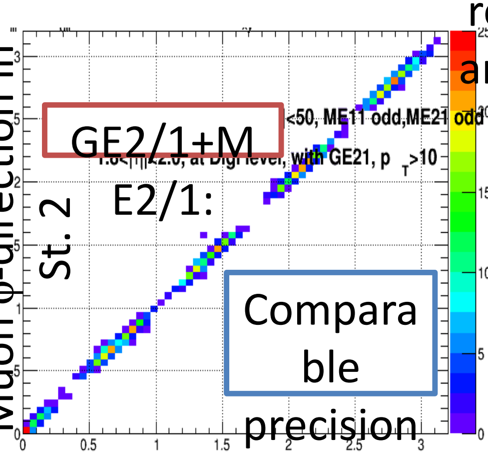


Station 2 measurement too crude

Muon ϕ-

Muon ϕ-direction in St. 2

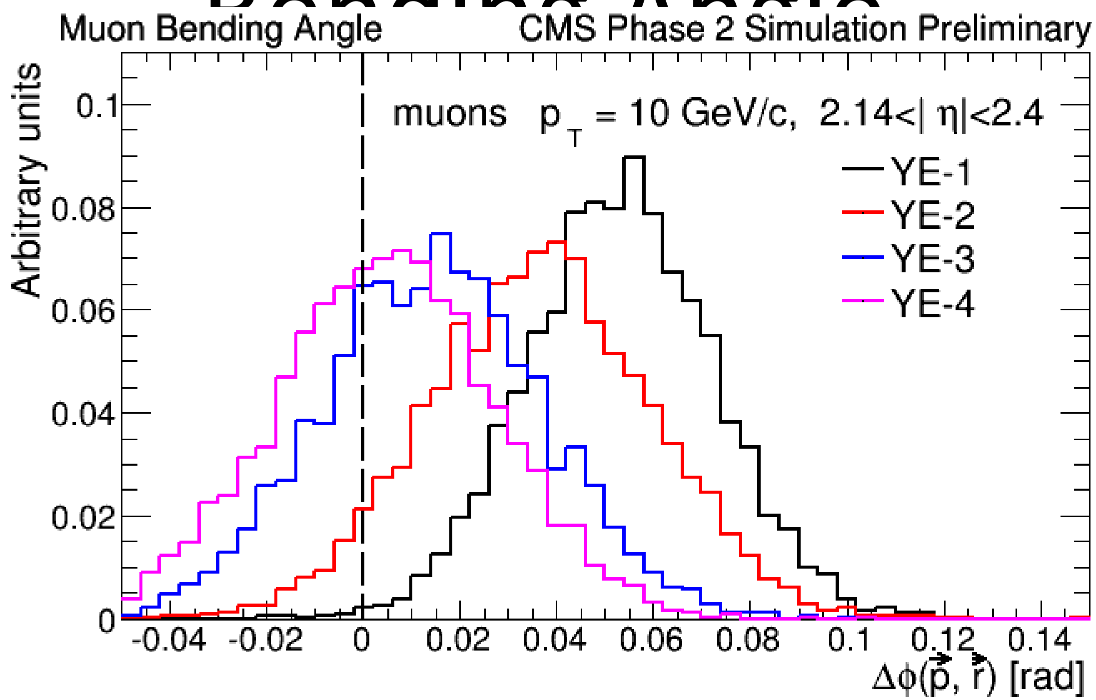
GE2/1+ME2/1:



Comparable precision (trigger level)

Muon ϕ-

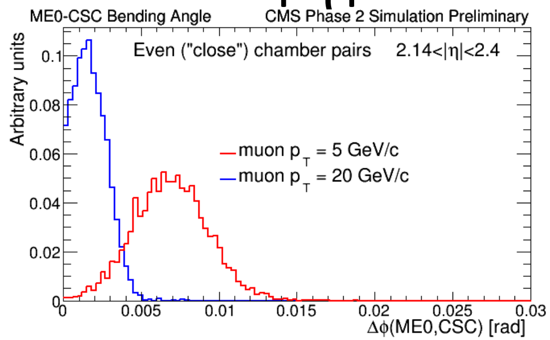
Bending Angle

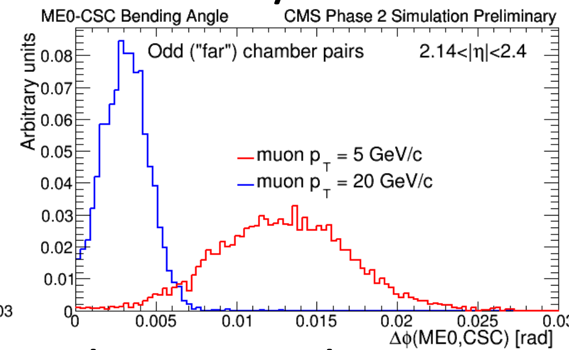


- The muon track bending angle distribution for measurements performed at the locations of the four CMS muon stations YE-1, 2, 3 and 4 using CMS detector simulation for muons with p_T=10 GeV CMS simulation. In this figure, bending angle is calculated assuming detectors with perfect spatial resolution and is determined by the magnetic field configuration and multiple scattering only. Lower momentum muons, which dominate the Level-1 trigger rate, can be identified by measuring the bending angle (high momentum tracks have zero bend). This figure shows that good discrimination of soft muons is achievable by measuring track bending angle in station YE-1. The effect is reduced but still provides an appreciable improvement in station YE-2. The radial component of the B-field reduces the track bend by the time the tracks arrives to stations YE-3 and YE-4 while multiple scattering broadens the distribution further reducing the separation of soft and hard muons.

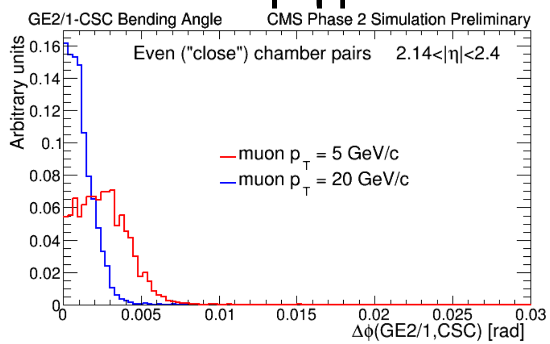
Bending Angle Performance

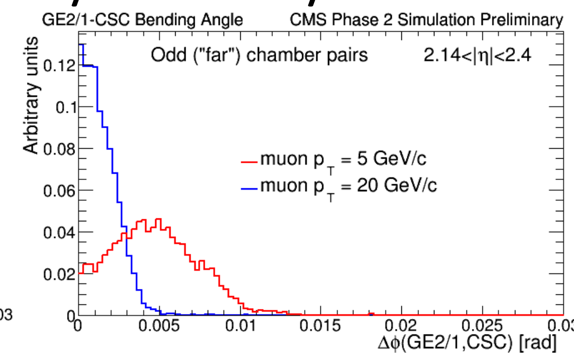
2.1<|η|<2.4: ME0 – ME1/1a





2.1<|η|<2.4: GE2/1 – ME2/1





Accurate measurement of the track bending angle using an large lever arm created between the pairs of the existing CSC chambers and the new high precision GEM chambers in the same station allows a strong improvement of muon momentum resolution in the Level-1 trigger. Bending angle $\Delta\phi$ is defined as the difference in global ϕ between the CSC Local Charged Track position at the CSC key layer and the position of the measured stub in the GEM chamber. The plot shows that the bending angle measurement can be utilized in the trigger to discriminate high momentum muons from low p_T muons, which dominate the muon trigger rate. A significant trigger rate reduction by a factor of x3-4 can be achieved if the new detectors are installed in the nearest to the interaction point locations (in front of ME1/1 and next to ME2/1). Measurement of the bending angle using high precision chambers installed in farther stations (YE-3 or YE-4) does not improve momentum resolution due to reduction of the bend by the radial component of the B-field and smearing due to multiple scattering.