Global displaced muon (HLT) reconstruction for Run 3

2022/05/25

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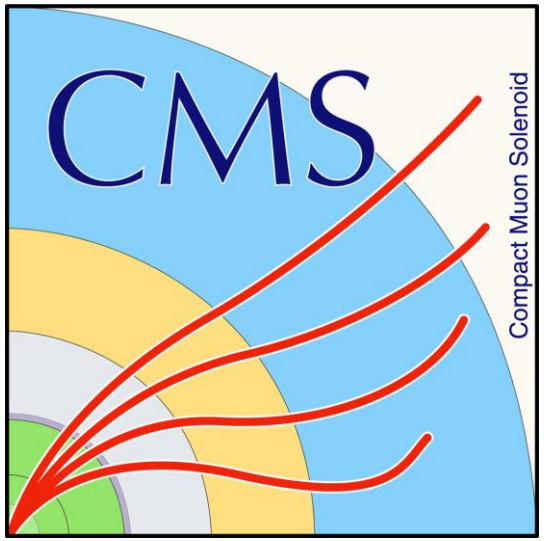
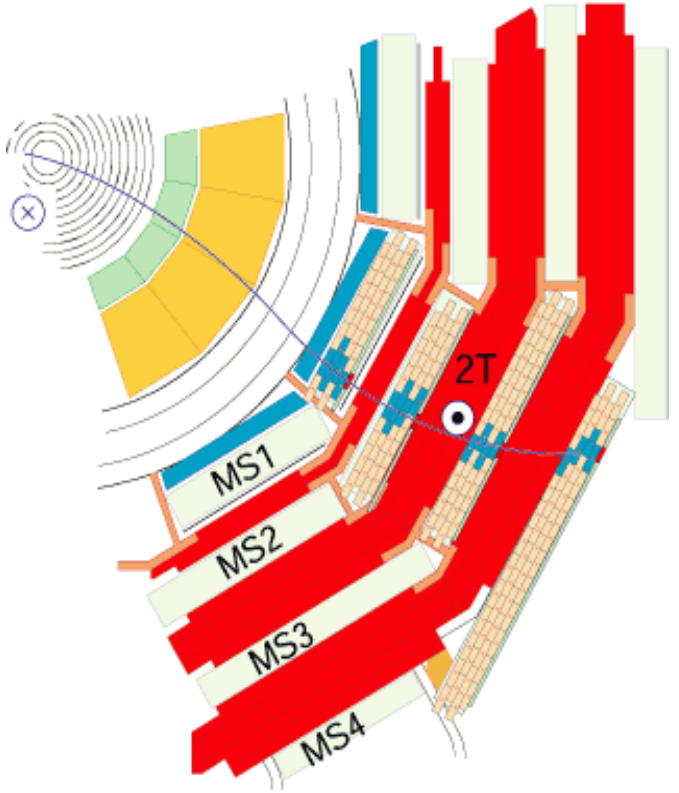


Overview

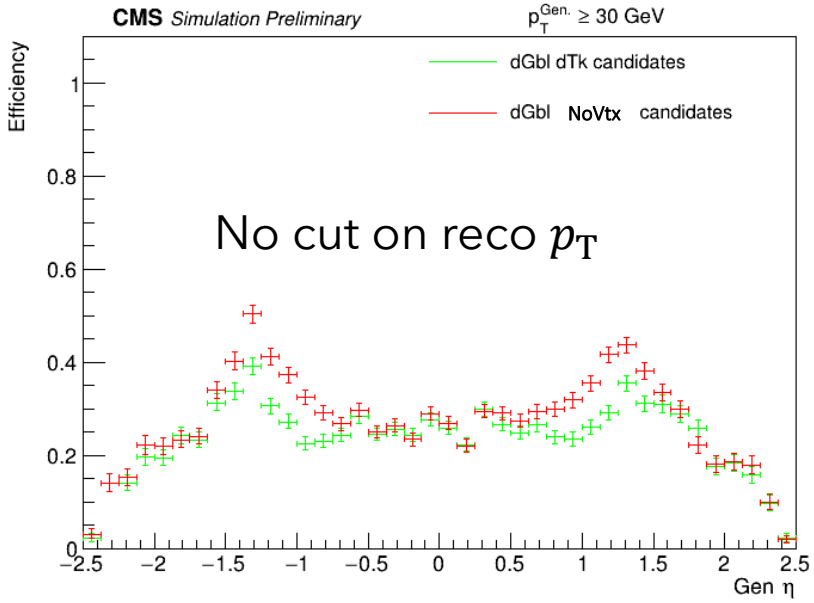
- **Contents:**
  - Introduction.
  - Problems found in the TSGForOIFromL2 module.
  - Updates on displaced global reconstruction for HLT.
  - Comparison with the existing reconstruction iterL3 (scouting path) and cascade reconstruction.
- **Previous presentation:** https://indico.cern.ch/event/1154993/#38-update-on-displaced-global
- **Objective:**
  - Provide a global displaced muon reconstruction similar to that used in offline reconstruction to replace the (existing) cascade and the **standard iterative reconstruction**.
- **Challenge:**
  - Get the best of both worlds and improve it.

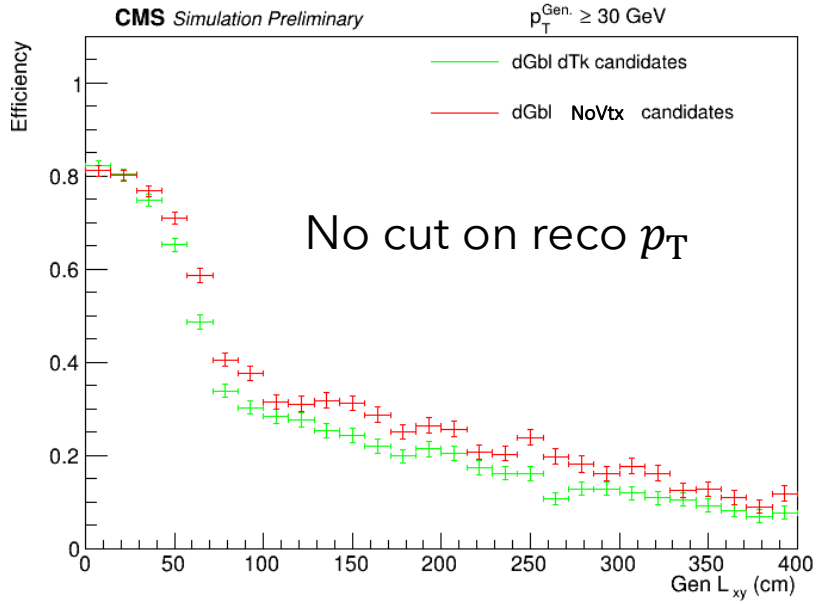


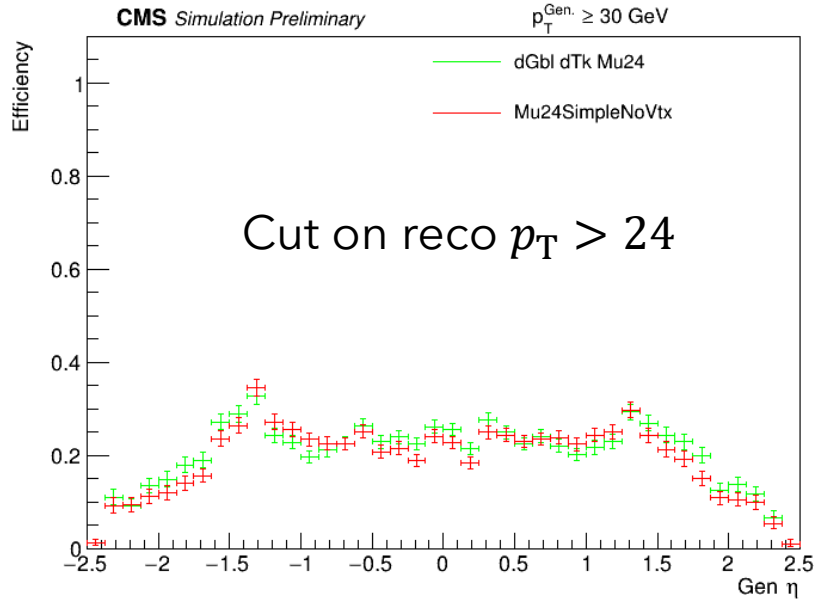
Problems found in the module TSGForOIFromL2

H to LL 1500 mm

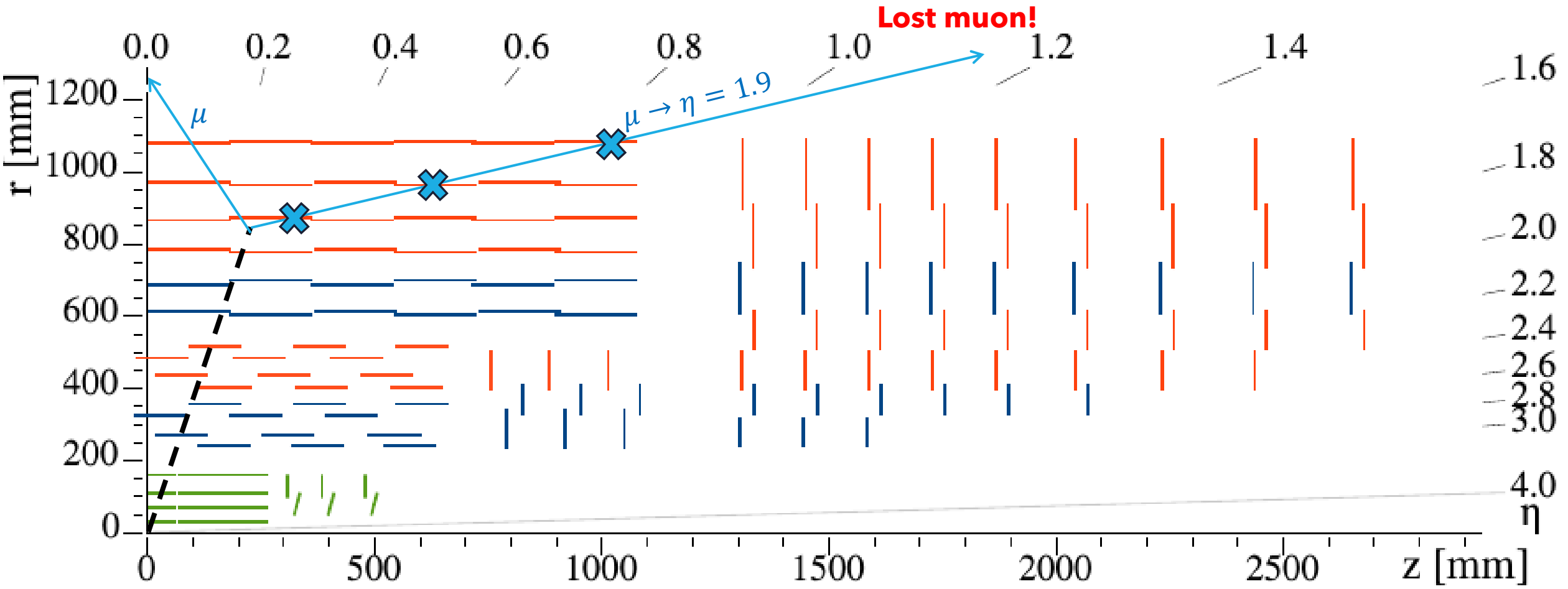
- We had two paths:
  - Single muon: $p_T > 24$ GeV with more eff than cascade
  - Double muon: $p_T > 10$ GeV with less efficiency than cascade.
- We lose efficiency for low p_T muons with medium displacement and in the overlap region $|\eta| \in [0.8,1.5]$.
- The seeding module has different seeding for TEC and TOB based on the L2 η.
- This may originate a loss of efficiency for displaced muons with an η that doesn't match its region.







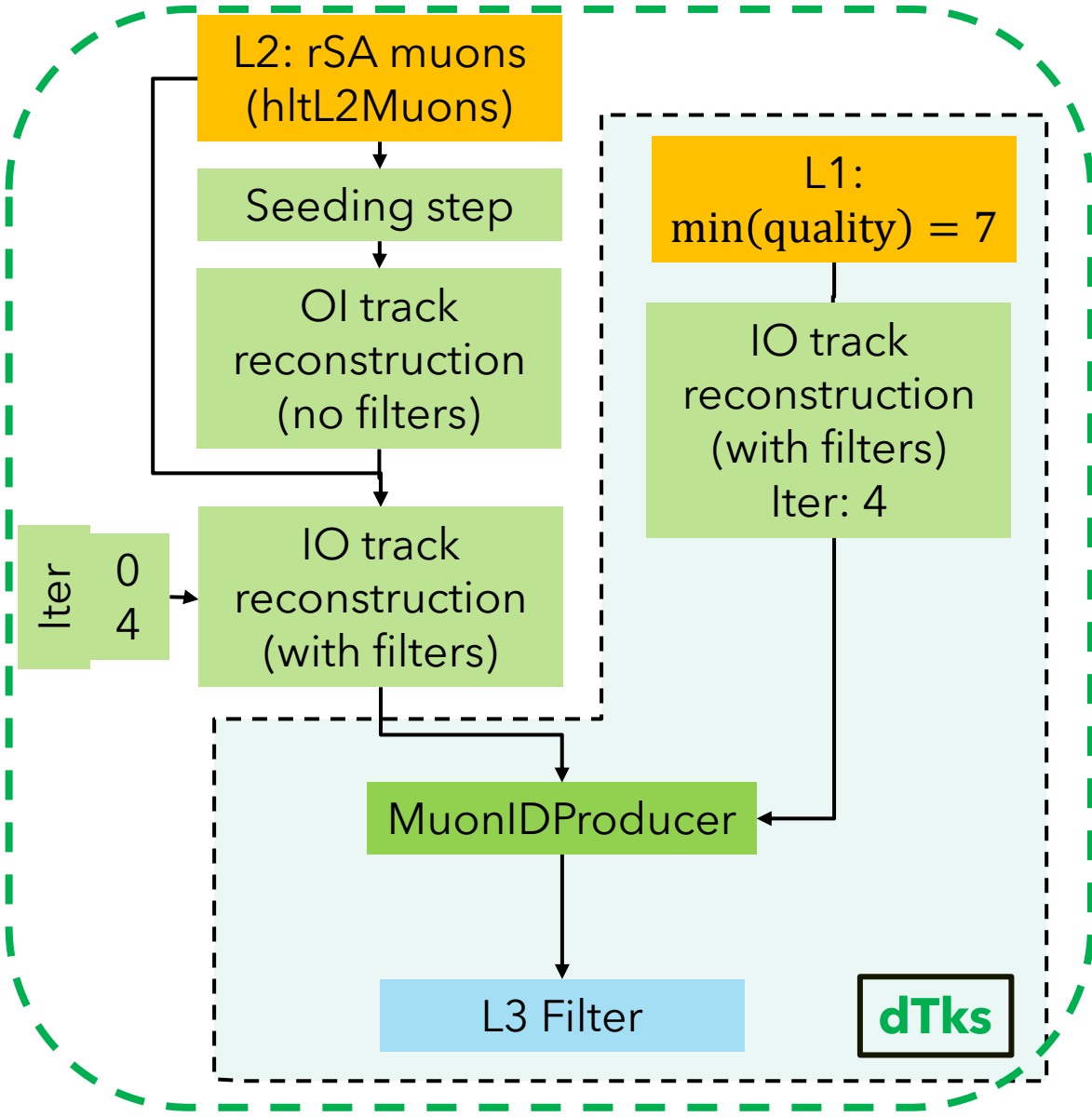
Why muons were lost with the previous logic



Displaced global reconstruction at HLT

We have built two single muon paths for displaced global muons:

- **HLT_L3Mu10SimpleNoVtx_Displaced_Run3_Iter3_v2**
  - It uses the reconstruction sequence HLTL3muonrecoSequenceNoVtx used in the scouting path DST_Run3_PFScoutingPixelTracking_v16 for Run 3.
  - For OI, seeds are produced with TSGForOIFromL2 module, this is not optimal for displaced muons.
  - The IO iteration is performed from L2 and L1 muons using pixel seeds (iter0).
  - Finally all the tracks are feeded into the MuonIdProducer.
- **HLT_Mu10GlbTkDisplaced_v1 (our proposal)**
  - For OI, seeds are produced using TSGForOIFromL2 module but with a modification to improve the seeding for displaced muons*.
  - The IO iteration is performed using pixel and strip seeds in the inner tracker (iter0 + iter4). The iter4 is also performed using L1 muons.
  - Finally al tracks are feeded into the MuonIdProducer.

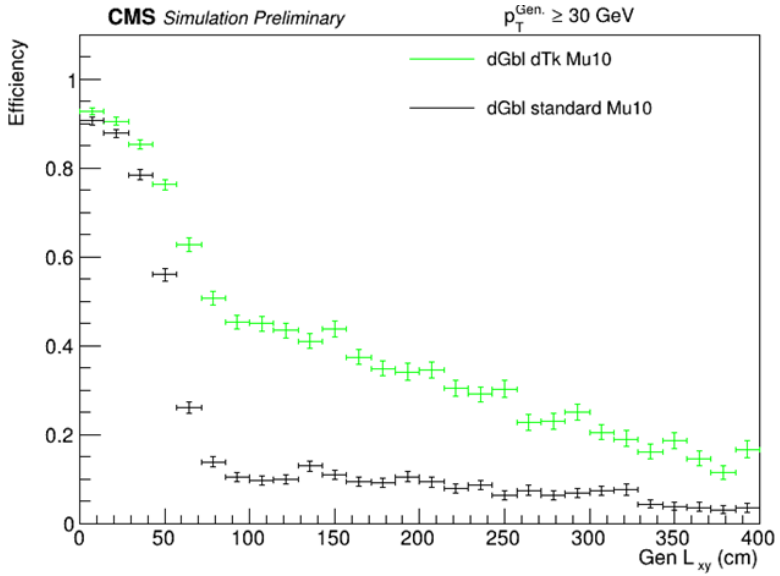


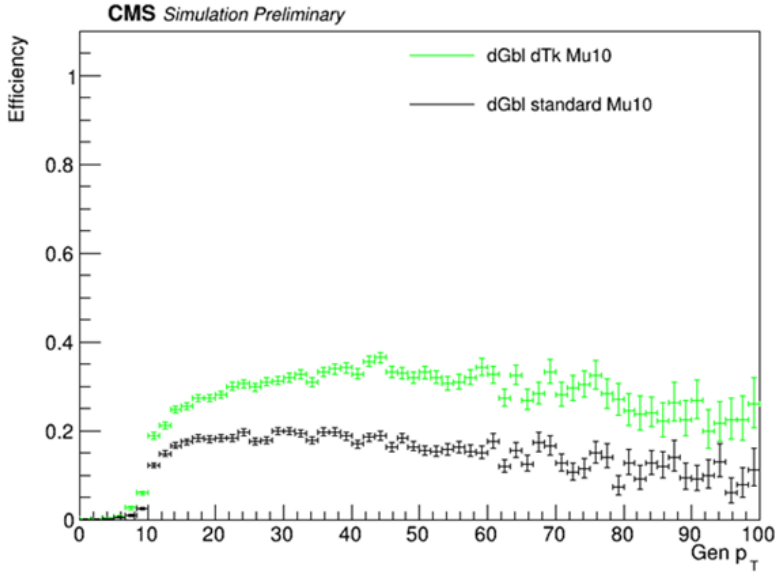
* This PR.

dGbl+dTk reconstruction

- Here we compare the efficiency of the **standard reconstruction** (used in scouting) and our proposal dGbl+dTks.
- Very good improvement in efficiency.
- Various reasons for this improvement:
  - Optimised OI seeding for displaced muons (this presentation).
  - Final estimate of the muon momentum based on the global track (if present) instead of only using the tracker track. More about this can be found in this PR: link.
  - Added the dTks (iter4) in the sequence.
  - Removed track filters for the OI sequence.

$$\varepsilon = \frac{\#\ \text{Reconstructed muons matched to gen muons}(\Delta R < 0.2)}{\#\ \text{gen muons}}$$





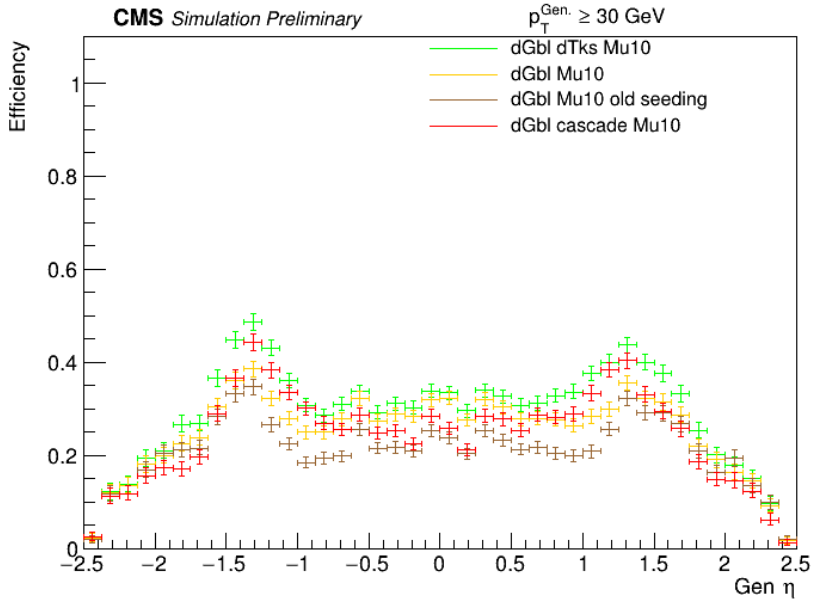
Results: efficiency and rate

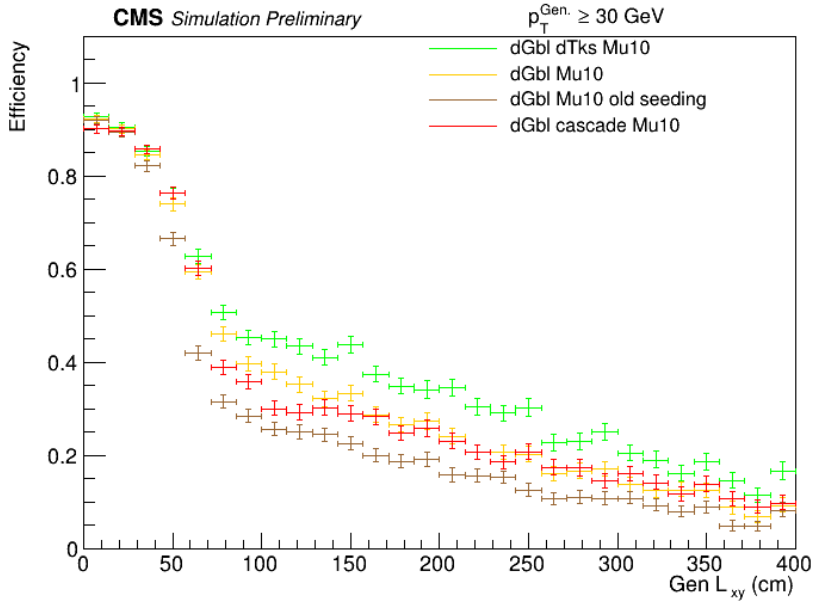
H to LL 1500 mm

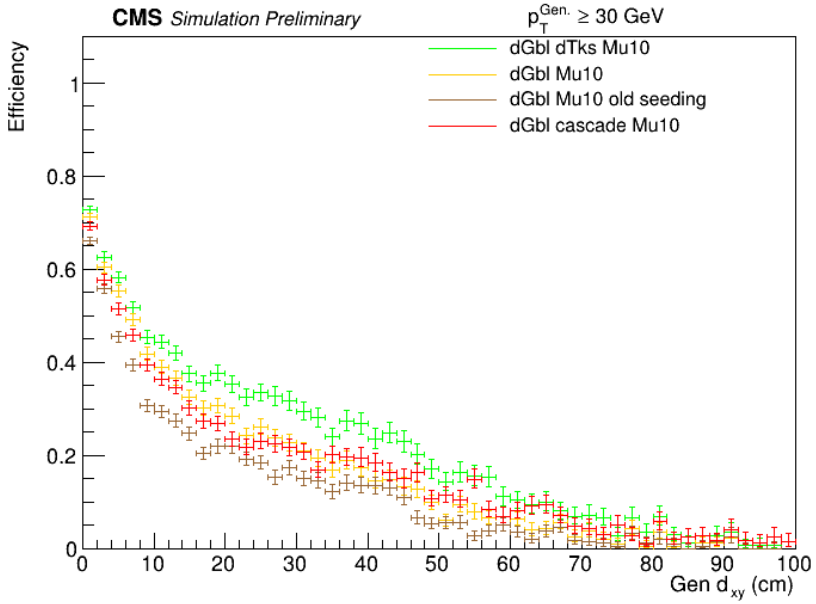
- We compare here the efficiency of four paths:
  - dGbl + dTks: with the improved OI seeding (our proposal).
  - dGbl with the improved OI seeding.
  - dGbl with the old OI seeding.
  - dGbl cascade reconstruction.

↕ Just to compare the global muons of our path with the cascade global muons

- The new OI seeding can bring the efficiency close to cascade and even improve it with the dTks.







Backup

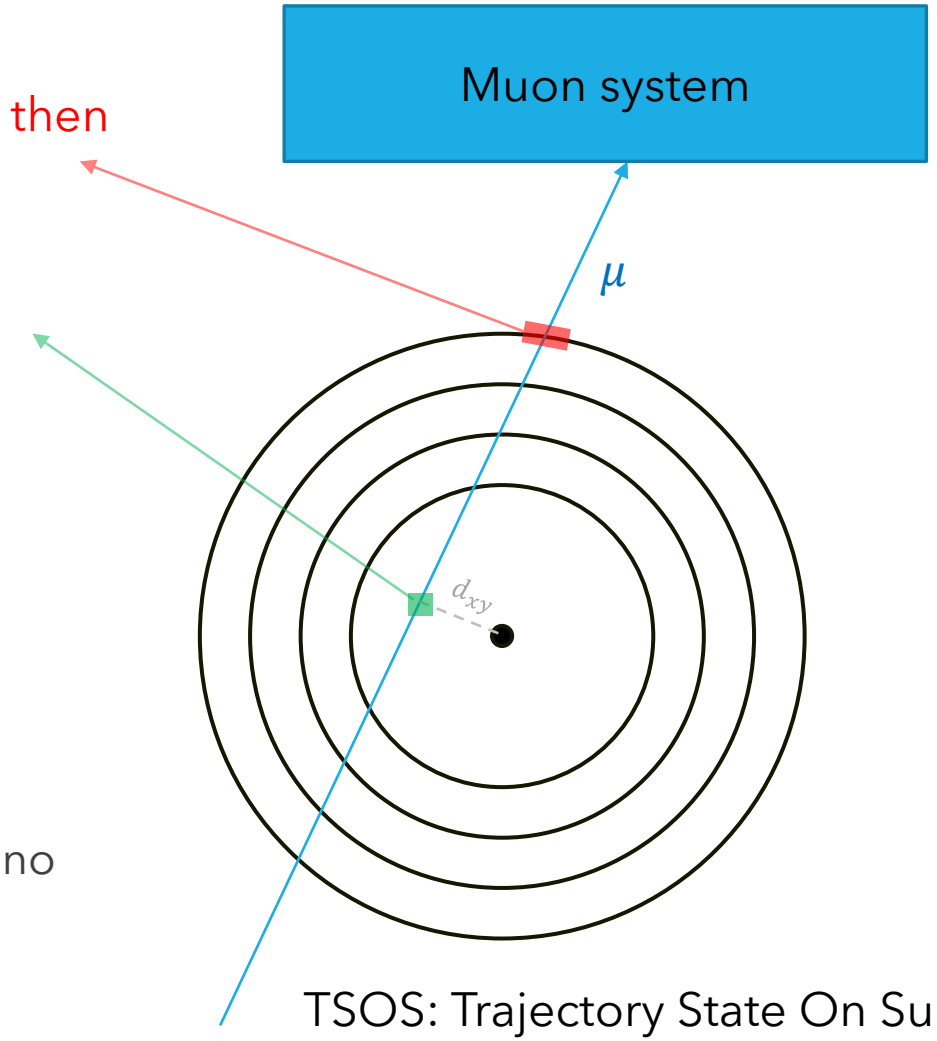
Logic of the module

TSOS at outer tracker boundary:

- First the muon is propagated to the muon stations and then backwards to the outer tracker.

TSOS at PCA:

- The muon is propagated to the PCA to the beamspot.



TSOS: Trajectory State On Surface

- Seeds are built using the first 6 layers (TOB) in barrel and 9 wheels (TEC) in the endcap.
- Pixel Layers are not used in building seeds.
- Two types of seeds: **hitbased** seeds and **hitless** seeds.
- If $\eta > 1.8$ no seeds in the barrel are produced and if $\eta < 0.7$ no seeds in the endcap are produced (problem for displaced).

Results: efficiency and rate

- We compare here the efficiency of one of the paths included in the V3 of the menu using cascade or the dGbl+dTks reconstruction.

Trigger path	Total rate / pure rate (Hz)	Eff - HtoLL 900 mm (%)	Eff - HtoLL 1500 mm (%)
HLT_DoubleL3Mu16_10NoVtx_DxyMin0p01cm_v1 (cascade reco)	16.7 / xx	19.4	19.9
HLT_DoubleL3dTkMu16_10NoVtx_DxyMin0p01cm_v1 (dGbl+dTks)	12.6 / 0	19.1	18.6
HLT_DoubleL3dTkMu16_9NoVtx_DxyMin0p01cm_v1 (dGbl+dTks)	17.1 / 4.48	19.6	19.4

- Rates are computed following the recommendations from the TSG group: twiki. Using the skimmed data in list_cff1.
- We achieve a reduction in rate, for the same thresholds, of 4.1 Hz. Also the pure rate is 0 Hz for the dGbl+dTks (same events are triggered by both paths).
- But also a reduction in efficiency of ~1%.
- Some efficiency can be recovered lowering the thresholds.

Timing for proposed reconstruction

- Timing is measured following the recommendations from the TSG: twiki.

Trigger path	Total timing (ms)	Pure timing (ms)
HLT_L3Mu10SimpleNoVtx_Displaced_Run3_Iter3_v2 (scouting)	10.99	5.28
HLT_Mu10GlbTkDisplaced_v1 (dGbl+dTks)	17.0	11.01
HLT_L3Mu10SimpleNoVtx_Displaced_Run3_v2 (cascade reco)	10.57	5.29

- If we sum all the specific modules of the cascade and scouting paths we get a pure timing of: 10.57 ms.
- Our path adds 0.5 ms of extra timing.
- If the dGbl+dTks reconstruction substitutes the other two reconstructions it is not a big change.

Results: efficiency and rate

- Comparison of the doubleMuL2 path with veto of prompt muons.

Trigger path	Total rate / pure rate (Hz)	Eff - HtoLL 900 mm (%)	Eff - HtoLL 1500 mm (%)
HLT_DoubleL2Mu10NoVtx_2Cha_VetoL3Mu0DxyMax1cm_v1 (standard reco)	5.7 / xx	33.3	
HLT_DoubleL2Mu10NoVtx_2Cha_VetoL3Mu0DxyMax1cmdTks_v1 (dGbl+dTks)	5.3 / 2.44	32.2	