L3 Muon Reconstruction in CMS: a Status Report

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Outline

• Overview of the muon HLT: focusing on L3 muon reconstruction
  ➔ Regional seeding in the tracker
  ➔ Pattern recognition in the tracker
  ➔ Global matching and global refit

• Lots of improvement in the recent months
  ➔ Overview and prospective

• Global matching issue in tau→3μ
  ➔ Will talk about that
Code Architecture

A snapshot of the “past”

• Code as it is, up until 180 (included)

“L3 Muon” is just one module that does it all
  → Seeding in the tracker
  → Pattern recognition in the tracker
  → Arbitration of trajectories
  → Global refitting

Issues
• No intermediate products
• Maintenance is not easy
• Does not automatically inherit from improvement in the tracker code
• One set of tracks: hltL3Muons
  no by products without arbitration/global refit

Not talking about muon HLT isolation in this presentation
Code Architecture

A snapshot of the present

- Code as it is, in 200

http://indico.cern.ch/conferenceDisplay.py?confId=29596 (A. Everett)

Issues solved
- No intermediate products: solved
  - TrajectorySeed
  - TrackCandidate (tracker only, no arbitration)
- Maintenance is not easy: solved
  - Simple module for each step
- Does not automatically inherit from improvement in the tracker code: solved
  - Use plain RecoTracker modules
- One set of tracks: hltL3Muons
  no by products without arbitration/global refit: solved
  - see above

Same functionalities, but in simple separate modules.
Next slides: describe functionalities
L1 Muon

L2 Muon Seed

L2 Muon

L3 Muon Seed

Tracker Pattern Recognition

Tracker only refit

L3 Muon

Next slides:
Seeding in the tracker
Tracker Trajectory Seeding

Description valid for all versions of CMSSW

- Two major **type** of seeds
  - **Hit-based:**
    - Pair/triplet of rechits in a region of the tracker
  - **State-based:**
    - In L3 reconstruction, there is already a good estimate of the track state: the L2Muon track
    - Use this state, propagated to a tracker layer as a seed

- Two major **method** of seeding/pattern recognition
  - **Inside-out:**
    - Uses inner layers of SiPixels or SiStrip
  - **Outside-in:**
    - Uses outer layers of SiStrip tracker

OUTSIDE-IN seed (state-based, offset because of the L2 reconstruction in this particular case)

INSIDE-OUT seed (from pixel pair, 3 seeds overlaid because of seeding redundancy)
Tracker Trajectory Hit-based Seeding

Description valid for all versions of CMSSW

Inside-out

• Define a region around L2 track
  ➢ Definition has improved

• Combinatorial pair/triplet seed generator
  ➢ Commonly used in CMSSW

➢ Requires seeding cleaning
  ➢ Used to give too many seeds
  ➢ Tracker seed cleaning inherited with modularization
  ➢ Recent improvements to be validated

Outside-in

• Propagate the L2 track to outer surface
  ➢ Significantly rescale the error matrix

• Look for compatible hits
  ➢ Equivalent to the first step of pattern recognition

• Update state with found hits
  ➢ Recent improvements to be validated
Tracker Trajectory State-based Seeding

Description valid for all versions of CMSSW

http://indico.cern.ch/conferenceDisplay.py?confId=17939 (J-R Vlimant)

Inside-out

- Propagate the state to the first layer/disk of pixel it can find
- Go to forward SiStrip disk if no state is found

Outside-in

- Propagate the L2 to the tracker envelop
  - $r=1.15$ m or $|z|=2.8$ m

- State on the outer barrel or forward disk depending on state location
  - Specific case for the $\eta\approx1$ “gap”: state on barrel layer 5,4,3,...
Tracker Trajectory Seeding

- All four seeding methods are available from 16X-on
  → Show different behaviors, see later on.
- Pixel pair/triplet finding uses the *BeamSpot* from the *Event*

- Further developments in the pipeline
  → Seeding cleaning by L2 direction: **implemented**
    reject pixel pair/triplet according to L2 direction
  → Redundant seeding:
    Combine two seeding methods
  → Conditional seeding:
    Use different methods in separate seeding phase space
  → Cascade seeding:
    If one seeder fails for a L2, use another one

→ Seeding from L1: **implemented**, need some adjustments
  [http://indico.cern.ch/conferenceDisplay.py?confId=23152](http://indico.cern.ch/conferenceDisplay.py?confId=23152) (M.Konecki)
Previous slides: seeding functionality

Next slides: pattern recognition
L2 Muon Error Rescaling

Description valid for all versions of CMSSW

• Reported errors on L2 Muon tracks are under-estimated
  → let's say it's “alright”, we don't use them directly

• Reported errors on L2 Muon tracks after update to beam spot are completely biased because of constraint fit
  → Need to adjust these errors if one want to use them
    → Crucial for state-based seeding
      http://indico.cern.ch/conferenceDisplay.py?confId=7692 (J-R Vlimant)

• Rescaling actually done at state-base seeding time.
  → Rescale factors based on muon gun MC
    http://indico.cern.ch/conferenceDisplay.py?confId=20377 (F.Rebassoo)
  → 1.0 to ~4, eta and pT dependent
Limited Number of Tracker Hits

Description valid for all versions of CMSSW

• Regular Ckf pattern recognition

• HLT exercise (13X cycle)
  ➔ Number of hits limited to 7 (>5) for timing purpose
    ✗ Has been shown to degrade pT resolution from 2% to 6%
    http://indico.cern.ch/conferenceDisplay.py?confId=19406 (J-R. Vlimant)

• 16X-on
  ➔ No limitation on number of hits
    ✔ Optiminal pT resolution from tracker
    ✗ Timing increases
    http://indico.cern.ch/conferenceDisplay.py?confId=27058 (M. Pierini)
    ✔ Other timing improvements buy us the extra timing
Tracker Pattern Recognition Module

Comments only valid for 200

- Use CkfTrajectoryMaker module
  - Siamese to the well known CkfTrackCandidateMaker
    - Benefit from well supported tracker code
    - Trajectory is a transient version of TrackCandidate

  - Trajectory is the input to the next module (L3 Muon)

  - Optional TrackCandidate collection can be put in the EventContent
    - If OK with memory footprint: seems to be the case
    - If OK with event size: seems to be the case

  - TrackCandidate are important for
    - Refitting tracker track without arbitration (c.f. $\mu\mu$ filter, see later on)
    - Diagnostics of muon HLT (DQM, off-line analysis)
Performance: Timing

\[ pp \rightarrow \mu + X \]

- State-based seeding/pattern recognition is faster (1.6.5 see above) indication that difference has been reduced with recent developments
- On-demand unpacking brings significant timing improvement (shared with other trigger path)

http://indico.cern.ch/conferenceDisplay.py?confId=23151 (J. Richman)

http://indico.cern.ch/conferenceDisplay.py?confId=25552 (J-R Vlimant)
Performance: efficiency

Performance in 180_p6
- Single muon and ttbar
- Inside-Out and Outside-In give similar performance

http://indico.cern.ch/conferenceDisplay.py?confId=25446 (A. Everett)
Previous slides:
- pattern recognition

Next slides: L3 muon
- Matching
- Global fit
Global Track Matching “Old”

- For **one** L2, we get **N** tracker trajectories
  - Goal is to select **one** out of **N**
  - Match trajectories to L2 tracks

- “**OLD**” method: Matching at tracker outer surface
  - Propagate L2 and trajectory states to
  - Estimate parameter chi2, position ΔR, momentum ΔR

  - Reported to get confused in dense environment
    [Link](http://indico.cern.ch/conferenceDisplay.py?confId=23151) (J. Richman)

  - Cause for low pT inefficiency in tau->3muon
    [Link](http://indico.cern.ch/conferenceDisplay.py?confId=28907) (M. Giffels)

  - **Recent fix** back-ported in 16X (will be in 16.11)
Global Track Matching “New”

• “NEW” method: Matching at first L2 muon hit surface (muon system surface)
  ➔ Utilizes the fine pointing resolution from the tracker
  ➔ Propagate trajectory states to surface of the innermost hit of L2 muon
    • Estimate parameter chi2, position distance, position $\Delta R$, momentum $\Delta R$

  ✔ This is the fix back ported in 16X (will be in 16.11) and present in 18X and 20X.

new method

Efficiency improvement for muon in ttbar.
Using a similar fix to the official fix

![Efficiency Improvement Graph]
• Generated muons are really close together
Tau→3μ Issue “Solved”

OLD track matcher

- 25% more tracks
- Mostly muon track from tau decay

“NEW” track matcher

No L2/L3 filtering in these plots
Next slides: tracker only tracks
Tracker L3 Tracks

Feature only available for 200

- Tracker TrackCandidate before arbitration are available
- Natural input to the well known ctfWithMaterialTracks
- Natural input to displaced muon filters
- Potential significant timing improvement for displaced muon trigger
Muon Related Trigger Path

- The ones using \textit{l3muonreco} sequence
  - HLT1MuonIso
  - HLT1MuonNoIso
  - CandHLT1MuonPrescaleVtx2cm
  - ...

- The ones redoing l3 muon reconstruction
  - HLTBJPsiMuMu
  - $\mu\mu$k proposal
    
    \url{http://indico.cern.ch/conferenceDisplay.py?confId=28907} (M. Giffels)

- Actual seeding and pattern recognition are not that different
- Wasting precious time in duplicating pattern recognition
- Should work toward merging HLT paths: use only “one” l3 muon reco
  - to clearly identify the issue of muon HLT, when there is one
μμķ Proposal: Revised

Algorithm:

L1 Muon → L2 Muon → L3 Muon Seed → Tracker Pattern Recognition → Tracker only refit → L3 Muon

Use tracker tracks before arbitration

- L2.5 Mu Tracks
  - At least 2 muons above certain p_t and within eta region

True:
- Lxy significance
- Chi^2 VtxFit
- Pointing Angle

False:
- Kalman Vertex Fit
- Invariant mass around tau mass

Combined 3 Track Candidates
Conclusions

• tau→3μ
  → identified source of inefficiency (there might be others)

• A lot of improvement in the past year for L3 Muon reconstruction
  → Different seeding methods and much more for a robust muon HLT
  → Timing improvement for a faster muon HLT
  → Thorough investigation in specific physics samples lead to improvements
  → Modularization for a more robust and flexible muon HLT

• Realistic possibility of merging displaced μμ trigger
  → Centrally monitored and maintained l3 muon reconstruction

• Did not talk about filtering or isolation
  → Needs a dedicated presentation on filtering
  → Room for improvement in isolation: please volunteer

The muon HLT is in great shape! Thanks to the constant effort of the whole μHLT team