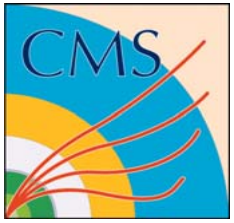

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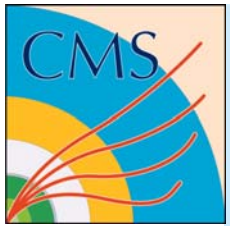
Cosmic Muon Reconstruction and Analysis

Chang Liu

Purdue University



Outline

- Motivation and Introduction
- Algorithm
  - Seeding
  - Navigation
  - Trajectory Building
  - Global Trajectory Building
- Performance
  - Barrel-endcap overlapping tracks from MTCC data
  - Traversing muons from cosmic MC data
- Conclusions

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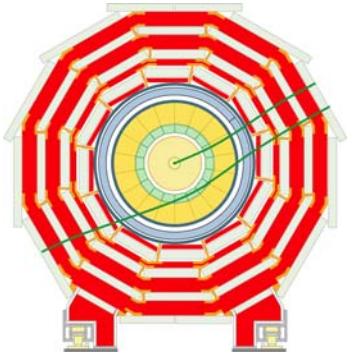
Motivation

- MTCC
  - Reconstruct muon trajectories using MTCC data
- Distinguish between muons from
  - collisions
  - cosmic rays
  - beam-halo
  - etc.
- Provide a tool to
  - debug software
  - align detector
  - understand trigger and reconstruction

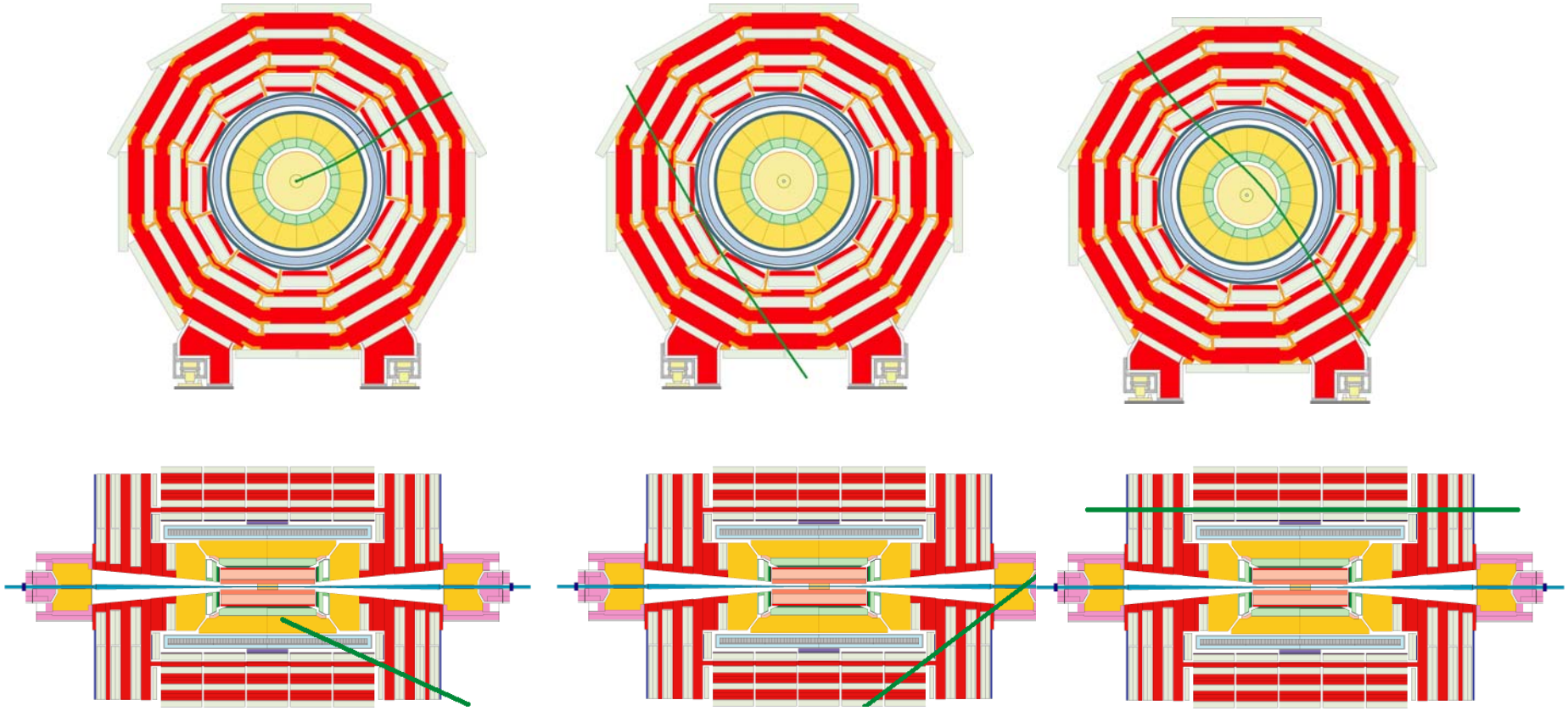
Introduction

- Not an alternative standalone/global reconstruction
  - The current implementation is optimized and efficient for muons from collisions
- Algorithm dedicated for the reconstruction of cosmic muons
  - Cosmic muons are different:
    - less constraint than muon tracks from collisions
    - Can have signals in 2 hemispheres
  - Try to use the same algorithm to reconstruct beam halo muons
- Main idea:
  - Focus on trajectories from outside



Use Cases

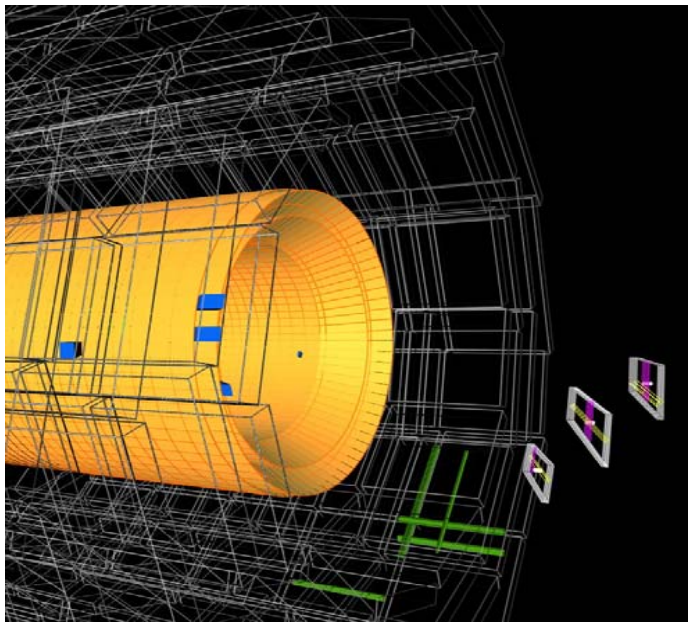
- Standard:
- Cosmic:

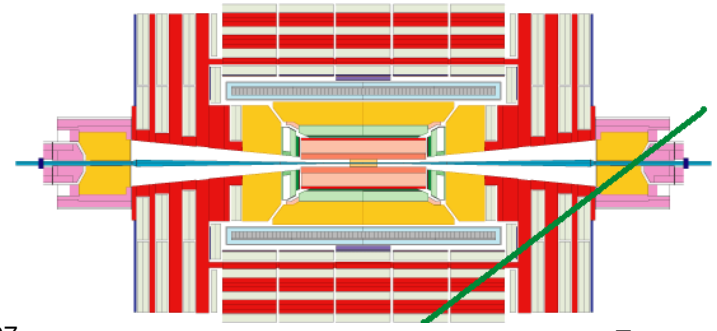


- Beam-halo

Algorithm

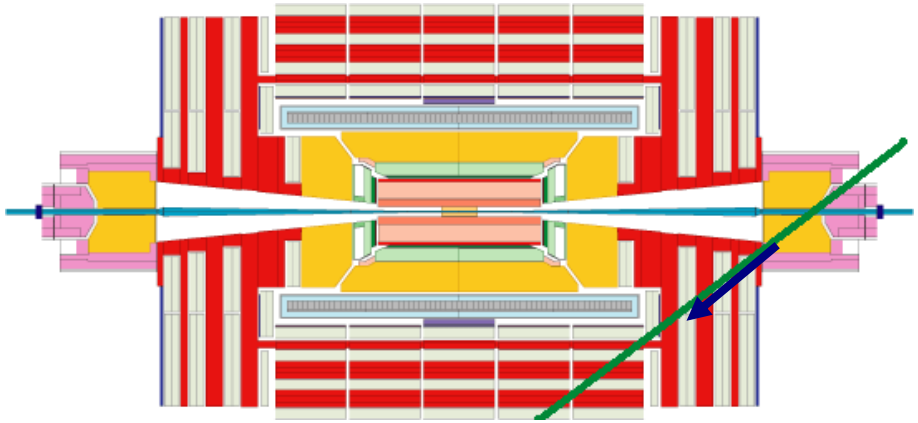
- Muon reconstruction:
  - Local reconstruction
    - DT need different tTrig Mode
      - wrong bunch crossing id
    - Not discussed here
      - For DT experts
  - Standalone reconstruction
    - Seeding (cosmic seed generator)
    - Navigation (direct muon navigation)
    - Trajectory Building (cosmic muon trajectory builder)
  - Global reconstruction
    - Matching with tk tracks
    - Combined fit
- Demonstrated with MTCC data





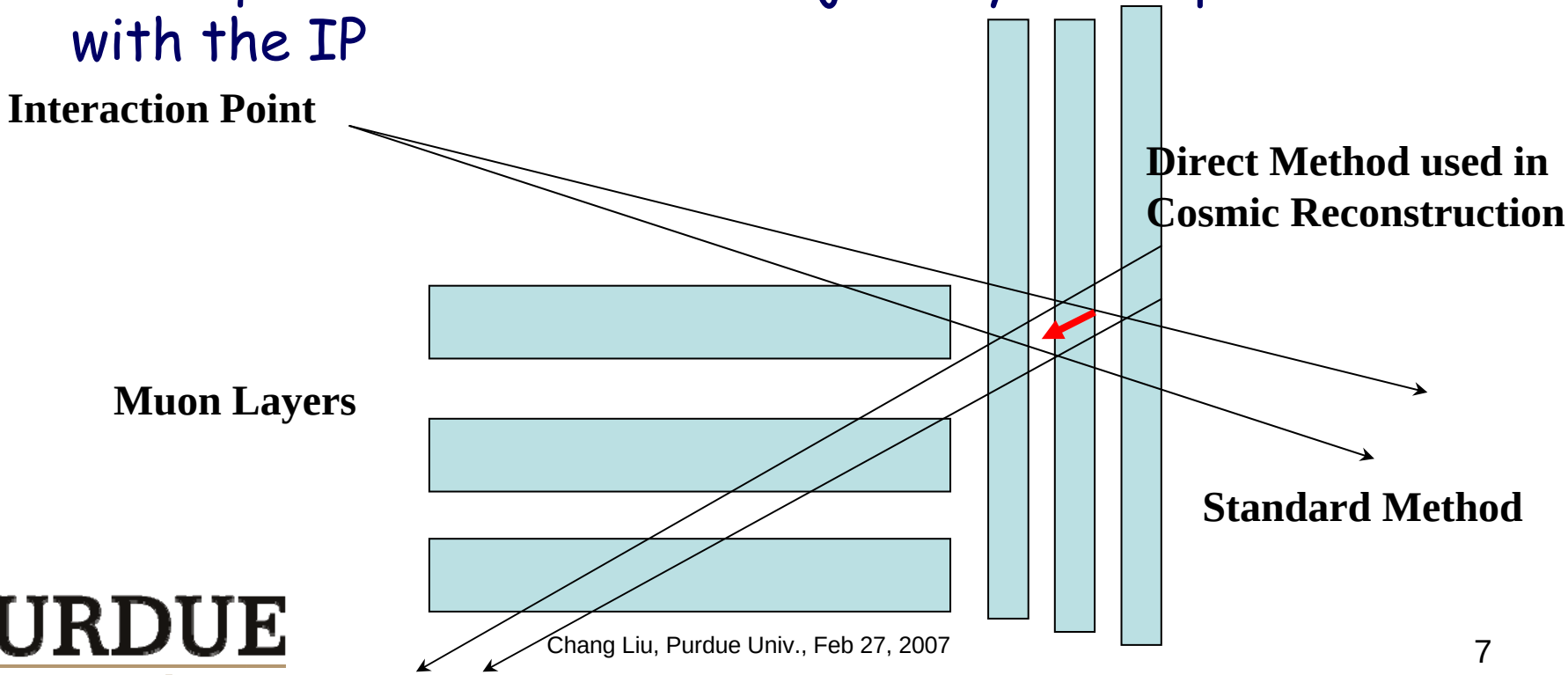
Seeding

- Trajectory Seed
  - Starting point of a trajectory
- Get 4D segments on top (global y) from DT and CSC
  - Direction of seed given by direction of segment
  - rescale momentum
  - Set direction downward



Navigation

- Navigation determines the relations among layers for a given trajectory state
- All layers that intersect the possible path of a trajectory are defined as compatible layers
- No requirement that the trajectory is compatible with the IP

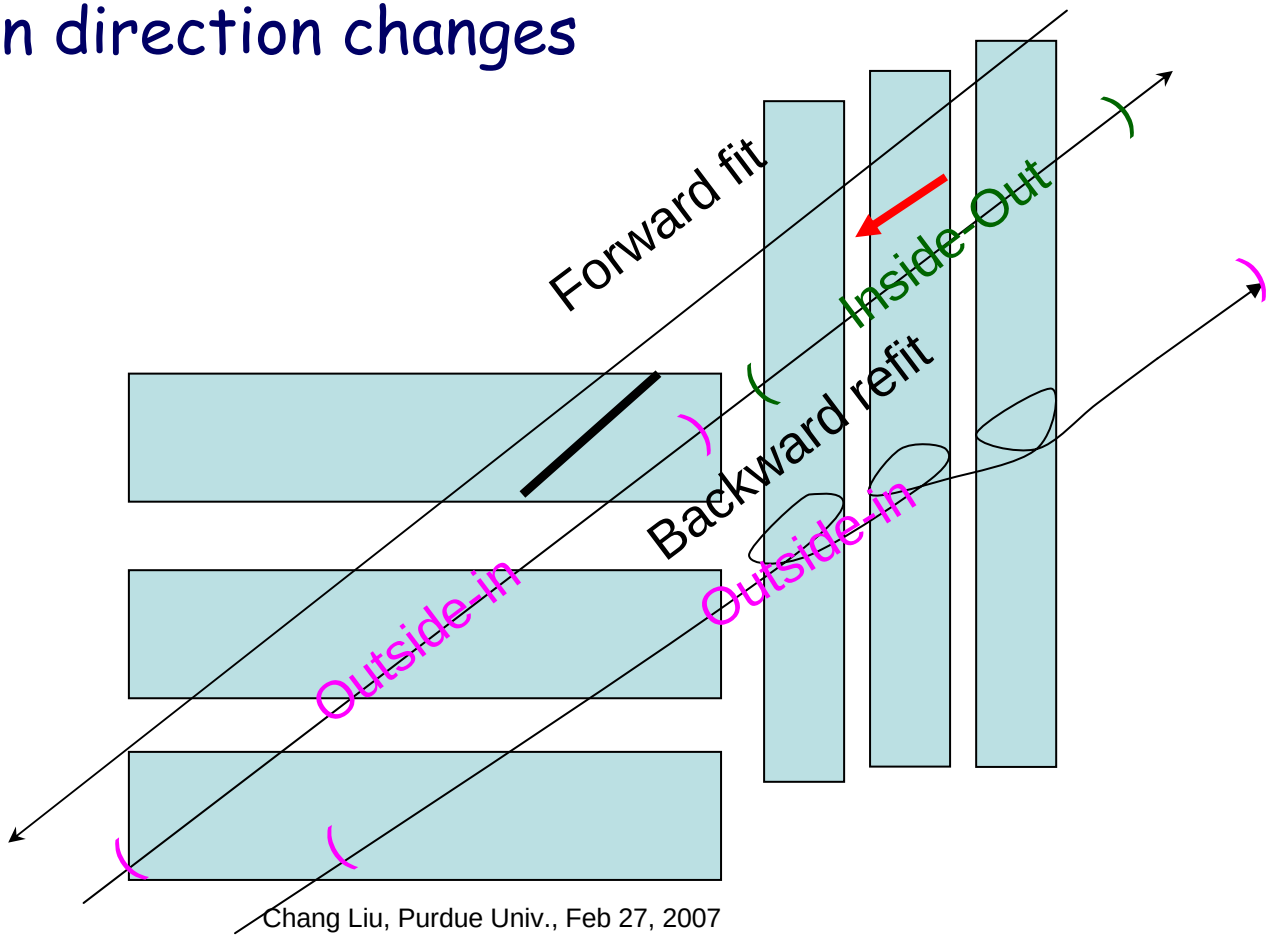


Trajectory Building

- Start from the Trajectory Seed, loop over compatible layers, grow trajectory by including measurements in detector
  - Using MuonBestMeasurementFinder
- Propagation Direction: (energy flow)
  - along momentum or opposite to momentum
- Navigation Direction: (put hits into trajectory)
  - outside-in or inside-out
    - By radii in barrel and |z| values in endcap
  - Constant for standard muons from collisions
    - along momentum ←→ inside-out
    - opposite to momentum ←→ outside-in
  - Not true for cosmic muons
    - need to check and may change (see next slide)

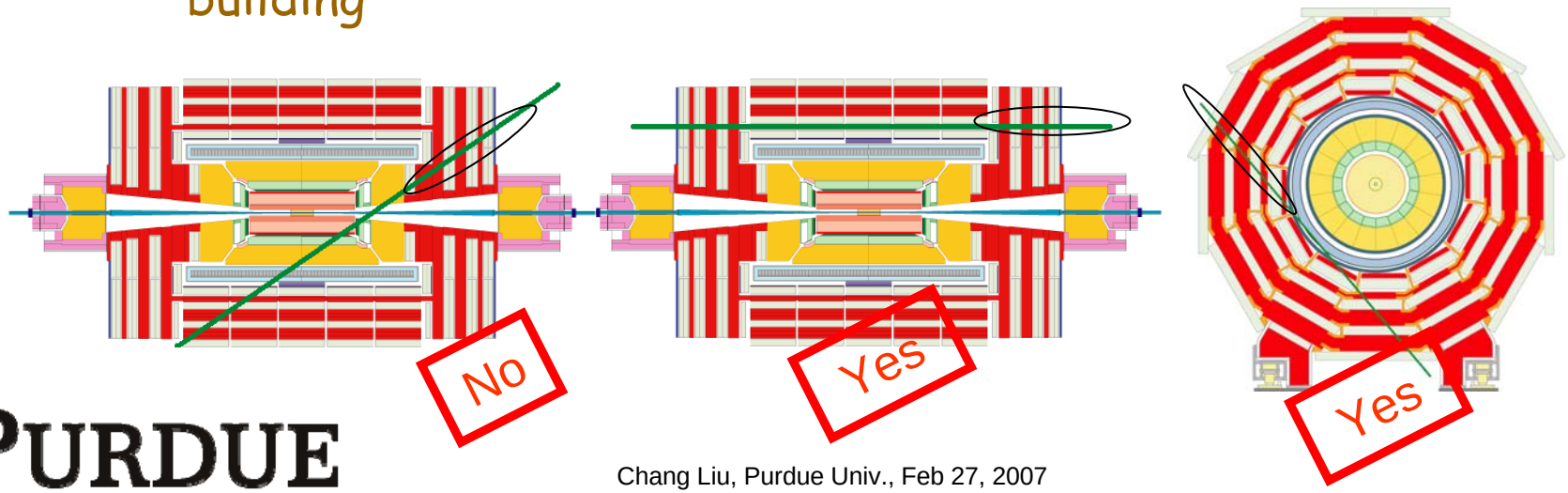
Trajectory Building

- Forward fit (along momentum)
- Backward fit (opposite to momentum)
- Navigation direction changes



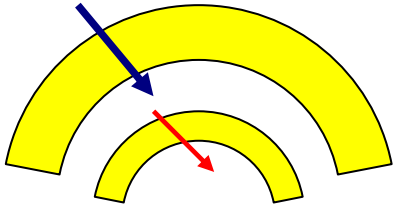
Traversing Muons

- Cosmic muons can traverse the whole detector and shows up as 2 pieces in 2 hemispheres
- Compatible layers provided by Navigation are not enough
- Activate "Traversing" mechanism if
  - One end of the trajectory is inside
  - There are enough hits not yet used during trajectory building

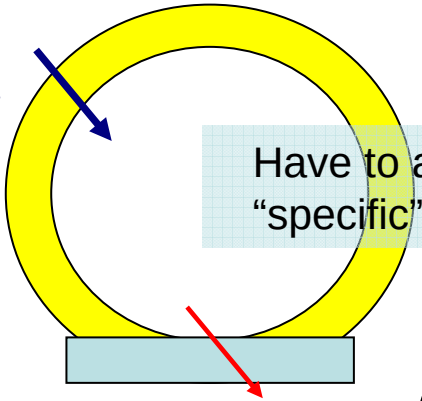


Traversing Muons in Barrel

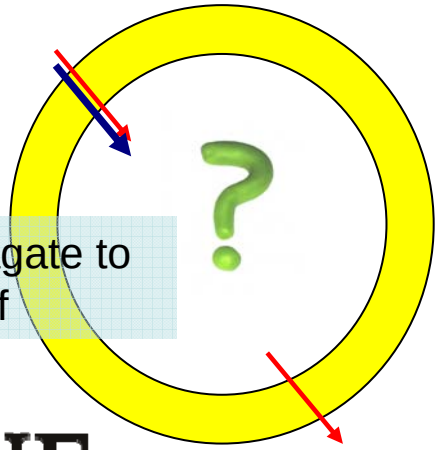
- Trajectory building layer by layer does NOT work
  - Layers are cylinders in barrel
- Propagate a trajectory state to a cylinder
  - 2 possible predicted states
  - Usually the one on the same side chosen
- Use Det Surface instead
- Propagate into "center" first



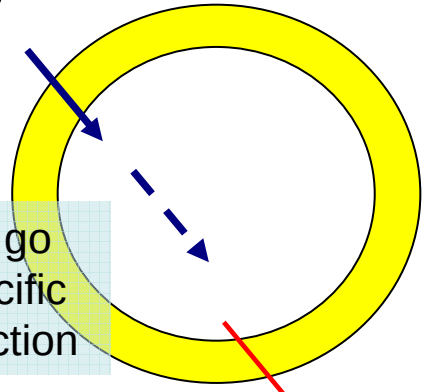
Well defined



Have to ask for a "specific" surface



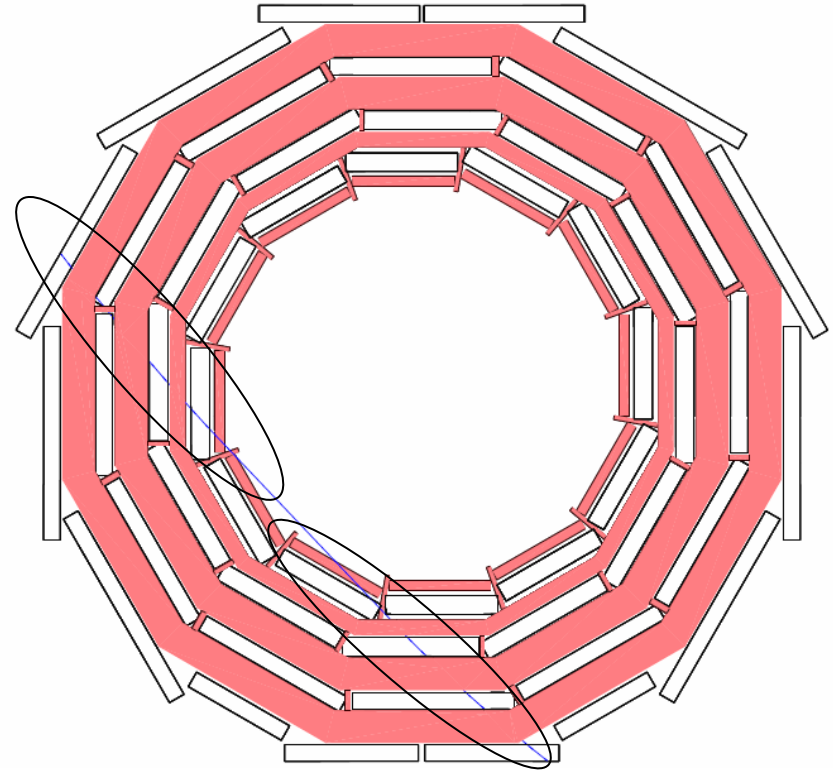
May propagate to itself



Force the state go inward, and specific propagation direction

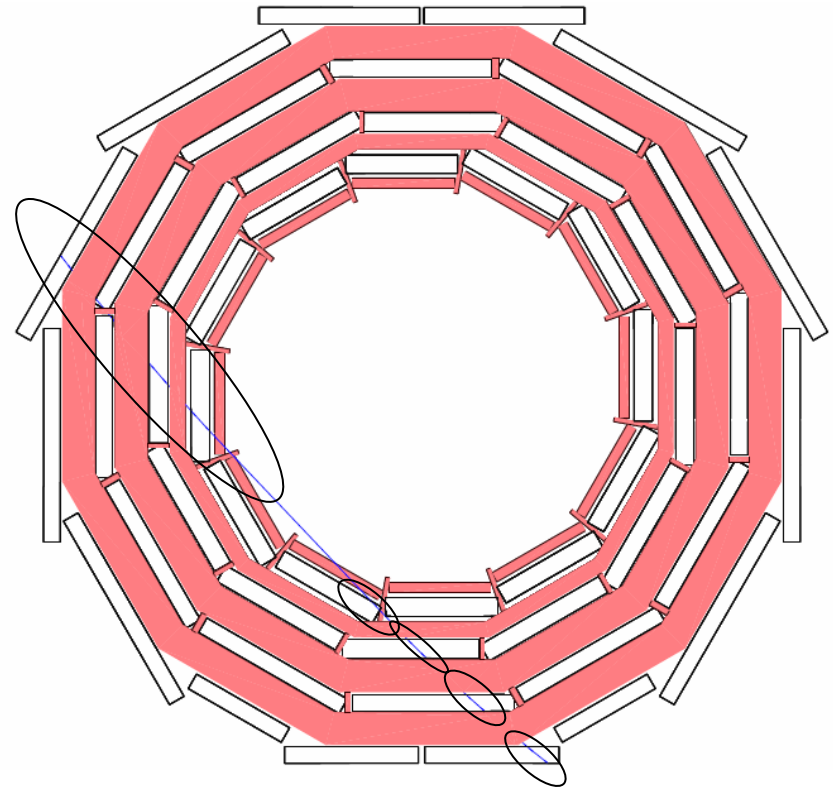
Building Strategy I

- Build two parts in opposite hemispheres first
- Collect all trajectories in the event
- Match them
- Refit
  - Navigation direction flips
- Pro
  - Fast and straight-forward
- Con
  - Need 2 trajectory cleaners
  - break current structure
- Studied but aborted



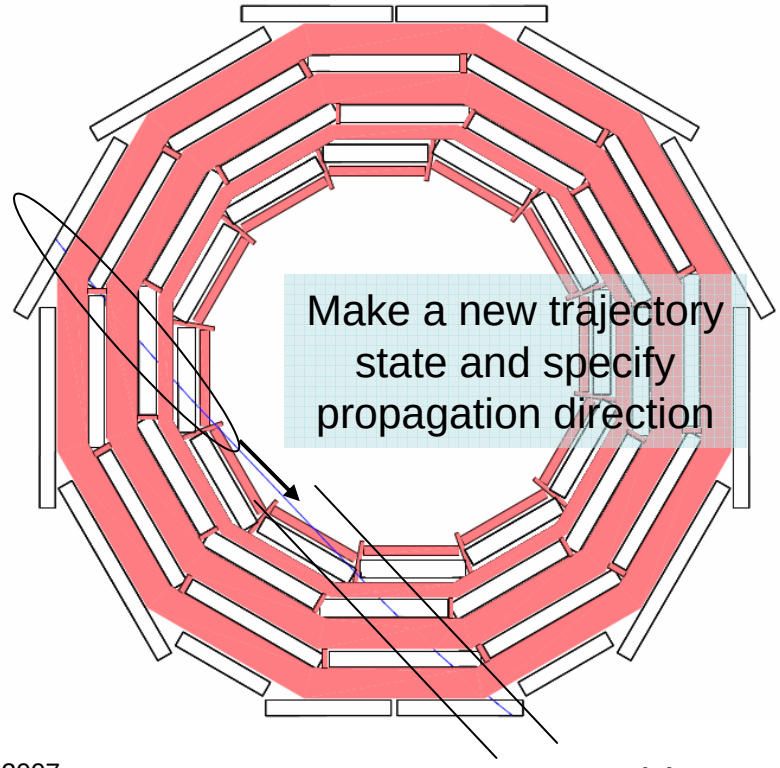
Building Strategy II

- Build a part in one hemisphere first
- Collect all hits from chambers not yet used
- Select and sort unused hits
- Update trajectory with hits
  - Navigation direction flips
- Pro
  - Fits with reco structure
- Con
  - Can not work with bkgd
- Committed in CMSSW
  - Not good enough
  - May improve selection step



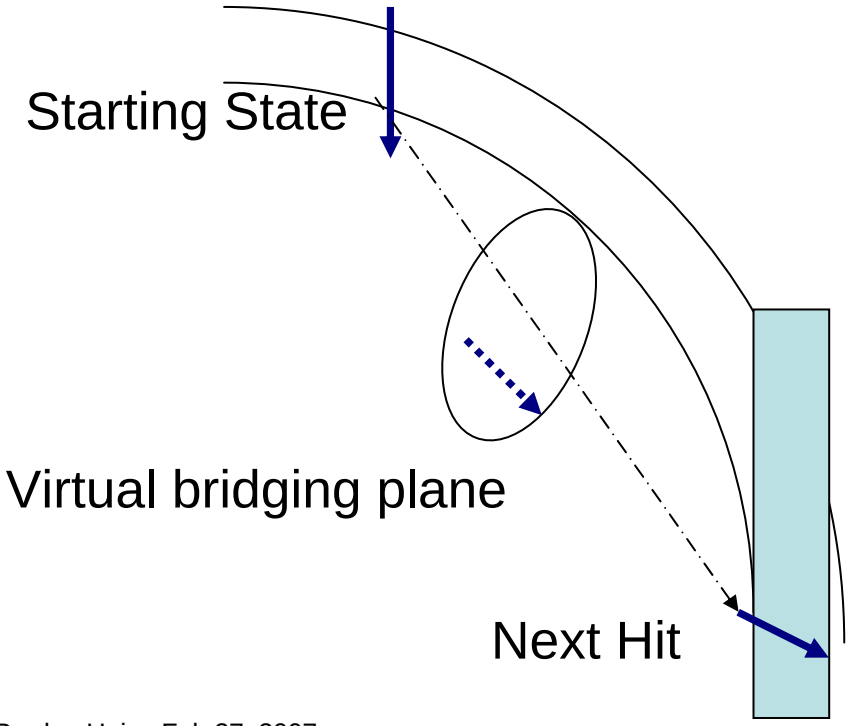
Building Strategy III

- Build a part in one hemisphere first
- Make it outside-in and propagate to inside
- Starting from the trajectory state inside
- Specify propagation direction
  - Avoid getting back
- Continue pattern recognition
  - Navigation direction flips
- Pro
  - Robust
  - Fits with current reco structure
- Con
  - Specify propagation direction
- Will be committed soon



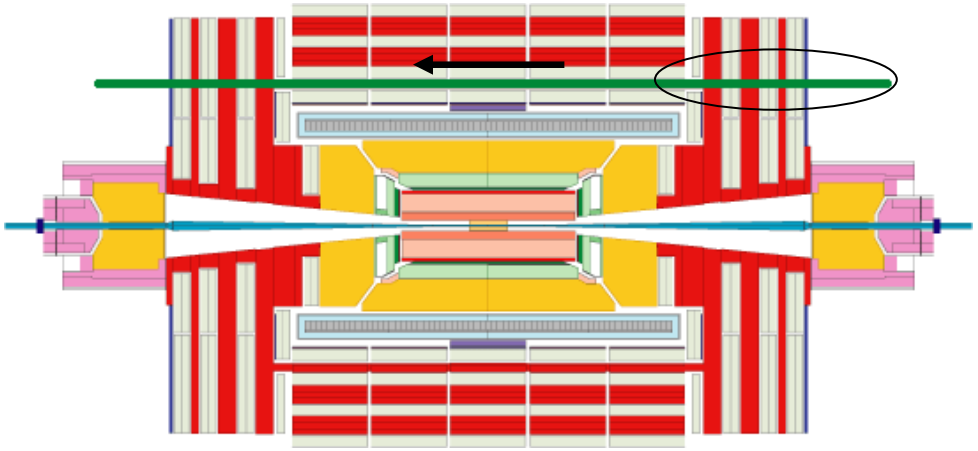
Propagation inside

- The propagation from a starting state to the next hit as indicated is done with virtual planes
  - they may be not necessary by improving implementation of propagator



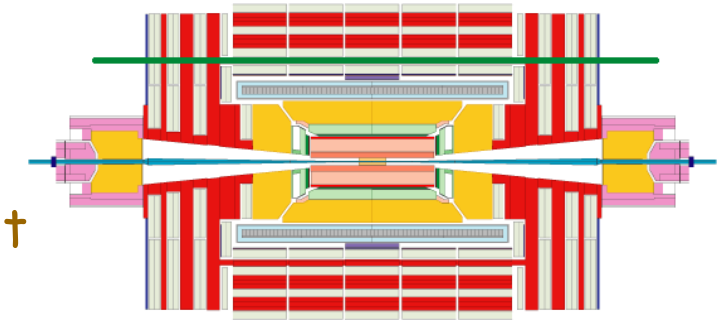
Traversing Muons in Endcap

- Trajectory Building layer by layer can work
  - If the trajectory is parallel to beam line, reconstruct it as Beam-halo muons
    - Collect all layers from opposite endcap
    - Skip all barrel layers



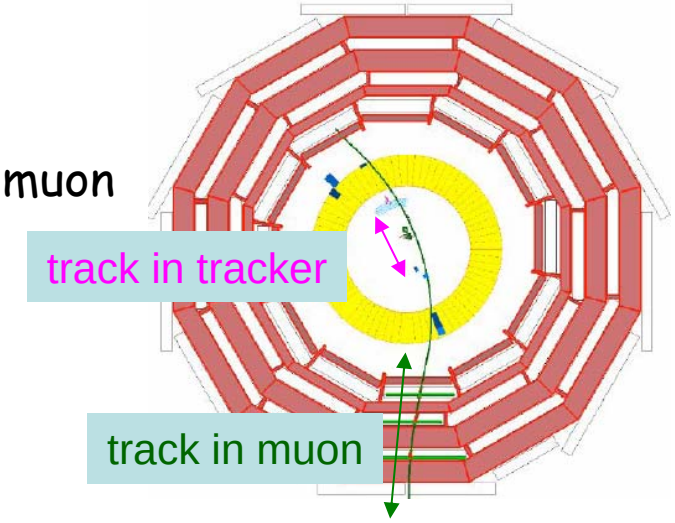
Direction Determination

- From left or right?
- **Time of flight**
  - Need time resolution <~ 10 ns
  - RPC can not be used for time-of-flight
- **Energy loss**
  - Track refit
    - Refit the track from left and right
    - The one with smaller chi2 is supposed to be correct
      - Works for most of muon tracks
      - But beam-halo may be different
- Under investigation



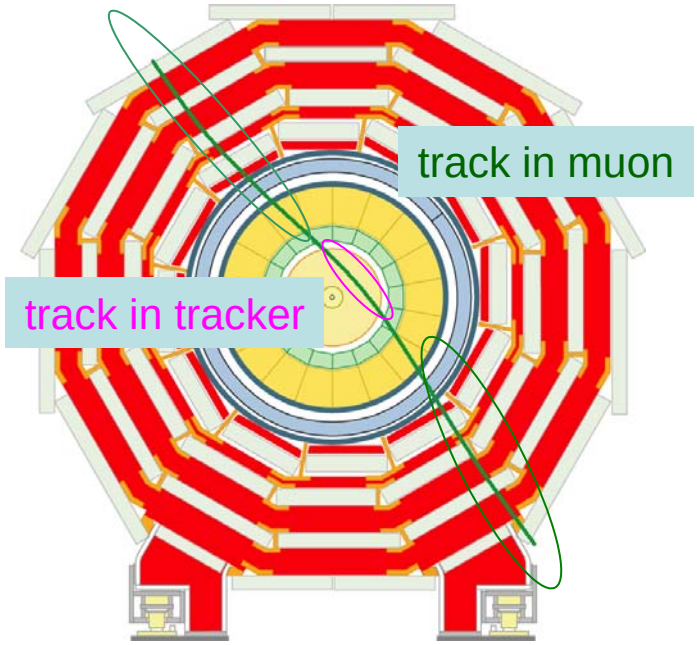
Global Cosmic Muons

- Match track in muon system with track in tracker
- Only studied for MTCC
  - Probably not needed after LHC start-up
    - Possibility for cosmic muons passing tk is too small
- Difference from standard global reco:
  - for muons from collisions
    - There are many tracker tracks
    - Need to find the matched one
  - for cosmic muons
    - Tk track may not come from the same muon
- Apply a looser cut
- Use standard combined fit



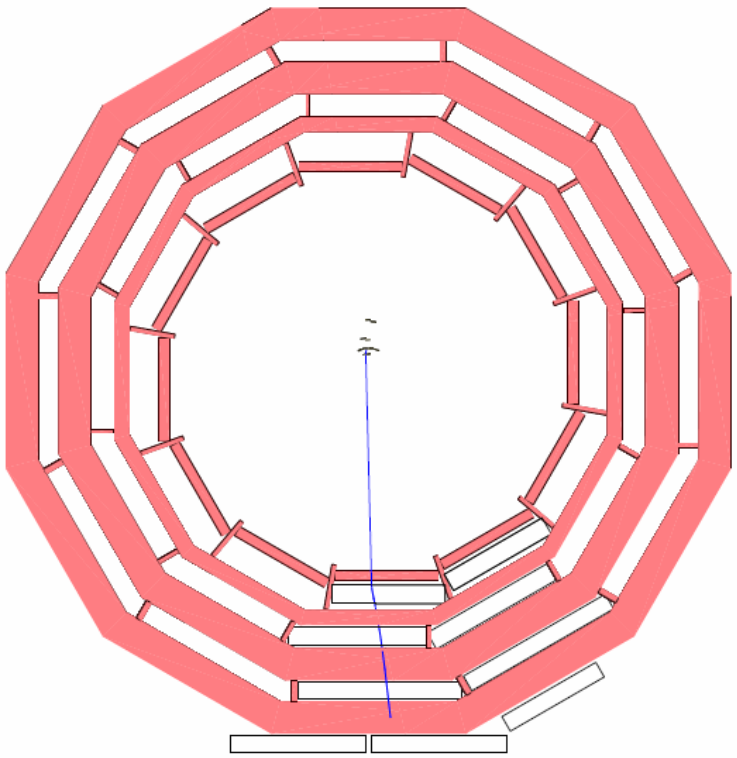
Global Cosmic Muons

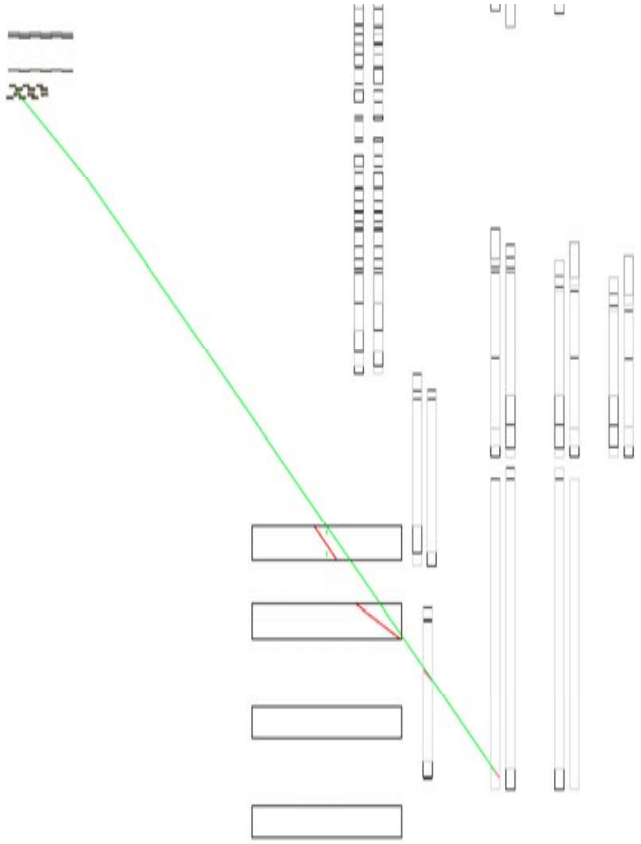
- Track in muon (2 pieces in opposite hemispheres)
- + Track in tracker
- Divide the muon track into 2 pieces according to the radii & φ values of hits
- Sandwich the tracker hits
- Standard combined fit



Global Cosmic Muon in MTCC

8 CSC 2D RecHits +
15 DT 1D RecHits +
6 Tracker 2D RecHits





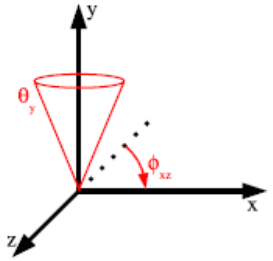
Run 2621 Evt 68563

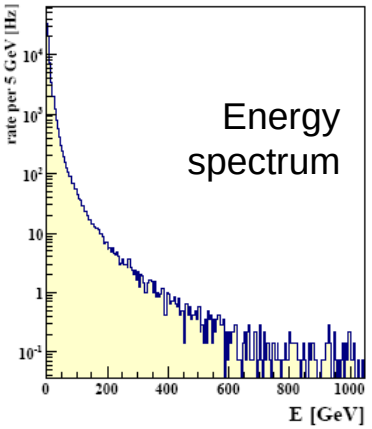
MTCC Data

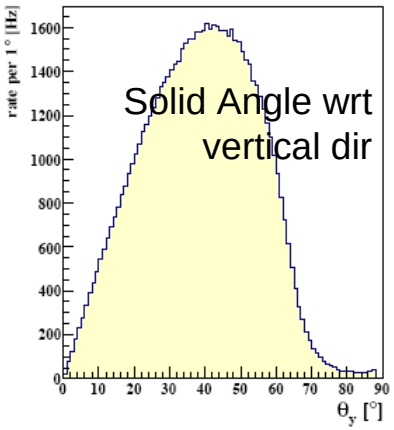
- Run 2621
  - Aug. 2006
  - Trigger:
    - DT(HW0) .or. CSC(HW1) .or. RBC1(HW2) .or. RBC2(HW3) .or. RPCTB(HW4)
  - Total number of events:
    - 868771
  - Magnetic Field:
    - 3.8T
- Run 4045
  - Oct. 2006
  - Trigger:
    - DT (B1, 2, 3, all sectors) CSC (ME 1, 2, 3 singles)
  - Total number of events:
    - 3.1 M
  - Magnetic Field
    - 3.8T

Cosmic MC Data

- Total number of events
  - 997500
- Muons generated from outside of detector
- Two sets
  - MTCC Geometry
    - Compare with real data
    - Pseudo-trigger filter applied
      - to mimic MTCC trigger
  - Full Geometry
    - More use cases than MTCC
      - Traversing muons







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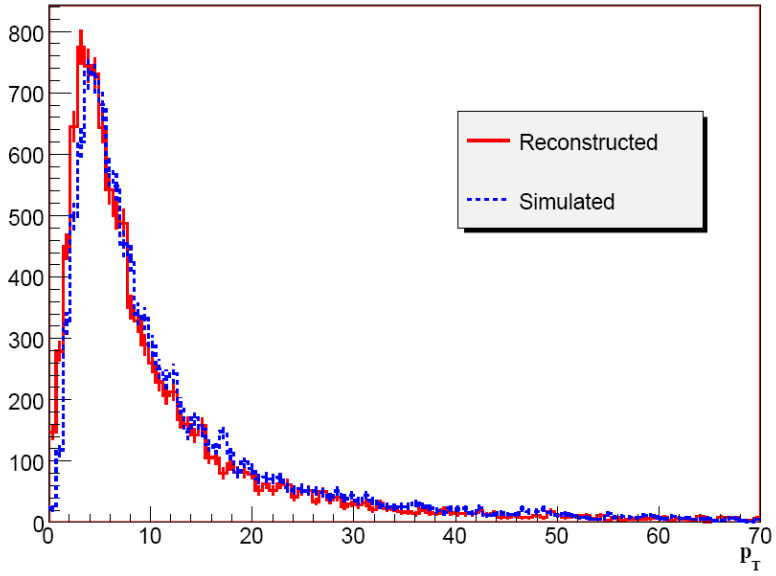
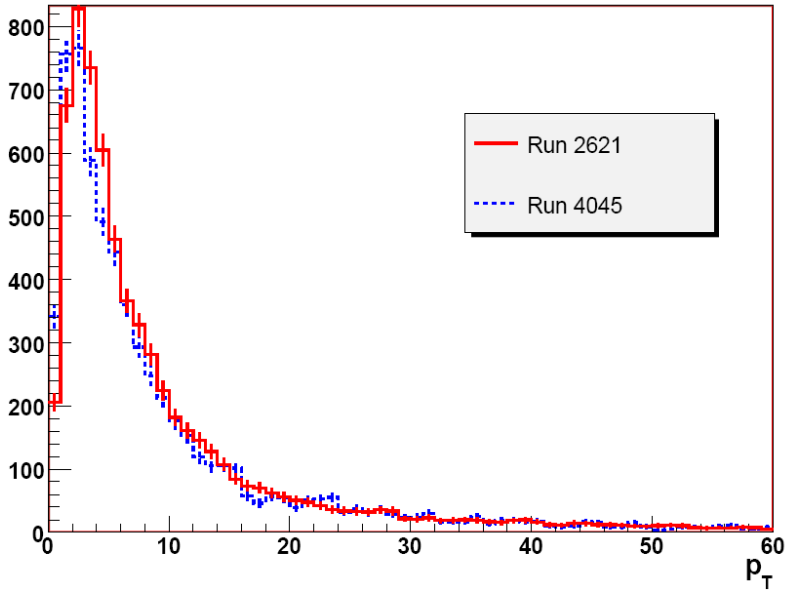
MTCC data

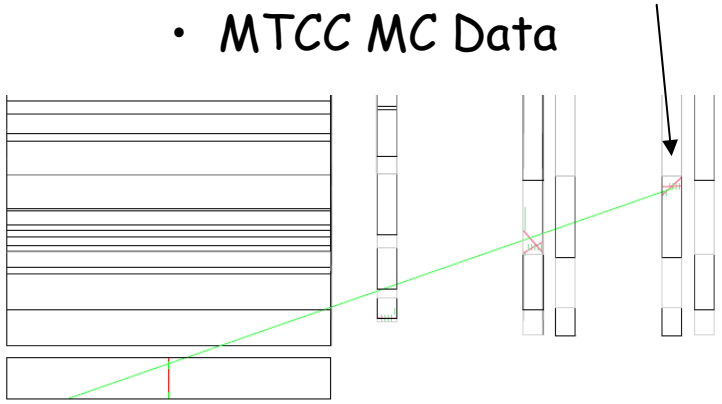
- Simulated and Real data are in agreement
- p_T spectrum at innermost state
  - Compare the first state with its closest SimHit



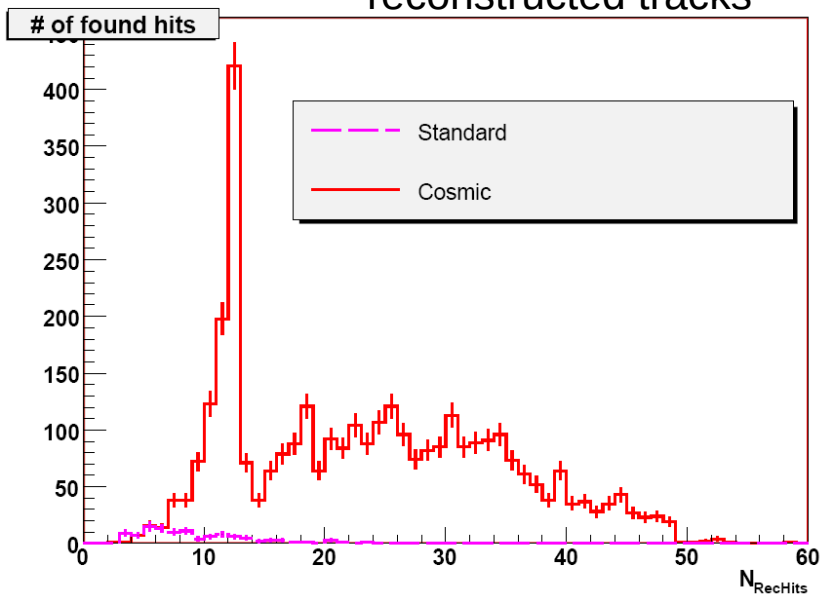


Performance on MTCC Data

- Selection: (>=1) DT segment + (>=1) CSC segment
- Reconstructing barrel-endcap overlaping tracks with:
  - Cosmic reco
  - Standard STA reco
- Largely improves efficiency!
- Overall p_T resolution
  - 26% at innermost state
    - MTCC MC Data

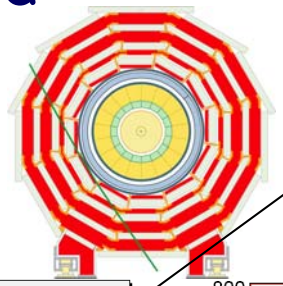


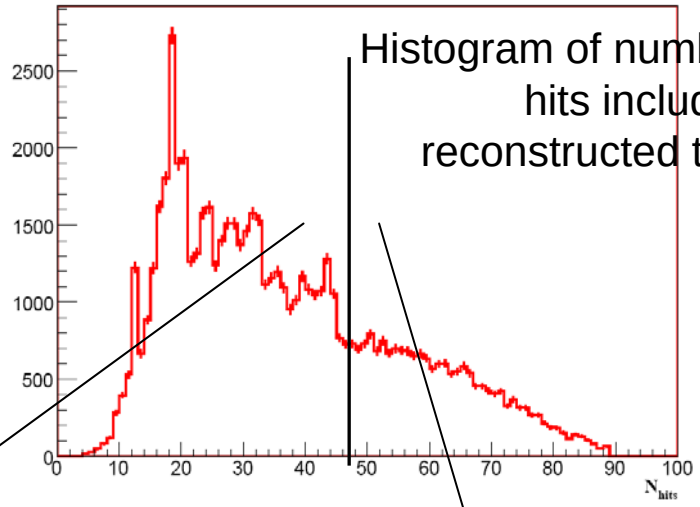
Histogram of number of hits included in reconstructed tracks

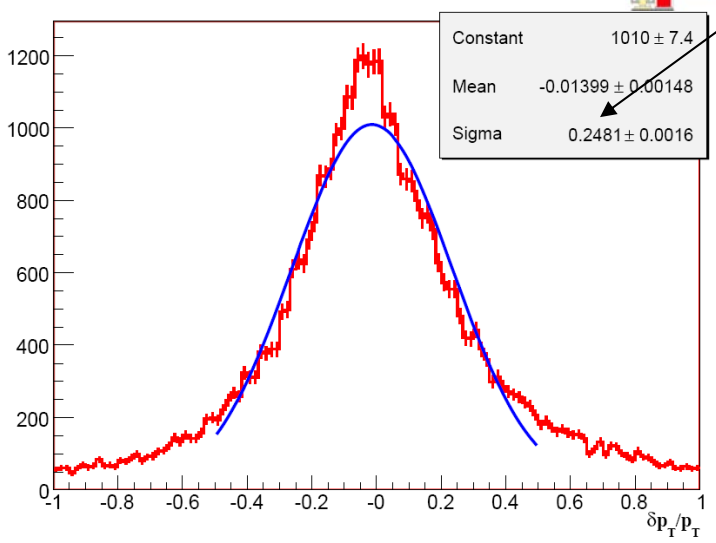


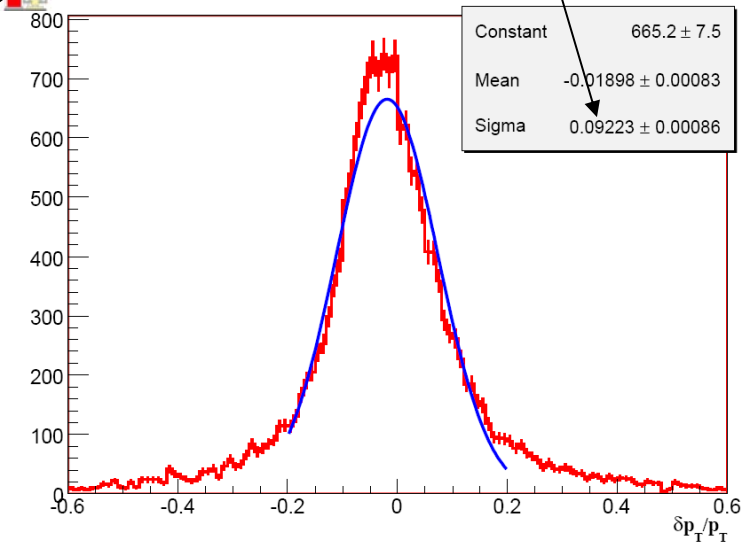
Performance on Traversing Muons

- Traversing muons
- More hits, better resolution
- p_T resolution improved
  - From 25% to 9%
    - cut at 46









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Efficiency

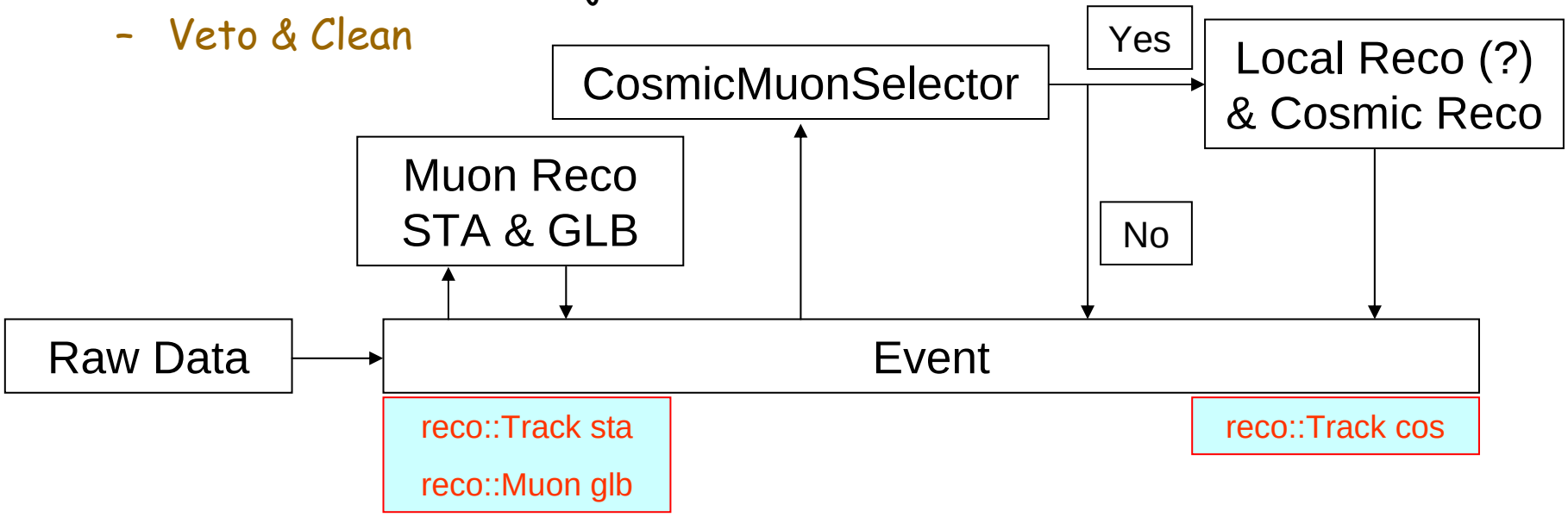
Event Description	Efficiency Definition	Efficiency (%)
MTCC	# evts w tracks/ # evts w 2 segments	93 (Data) 90 (MC)
MTCC barrel-endcap overlapping tracks	# evts w tracks/ # evts w 2 segments	90 (Data) 85 (MC)
MTCC global cosmic muon tracks	# evts w tracks/ # evts w m&t tracks	(> 50) (Data)
Traversing muons in full detector	# evts w tracks/ # evts w 2 subtracks	(>50) (MC) Difficult to estimate
Global cosmic muons in full detector	# evts w tracks/ # evts w m&t tracks	(> 50) (MC)

Preliminary
With experimental code

DT local reco with 106, rest reco with 110. Better results expected with later releases.

Proposal for Offline Processing

- Cosmic & Beam-Halo Trigger
- Collisions Trigger
  - Process with standard STA and GLB first
  - Select events that look like containing cosmic or beam-halo muons
    - Muon segments unused by STA
    - STA Trajectory not from IP
    - Correlated STA Trajectories
  - Veto & Clean



Conclusions

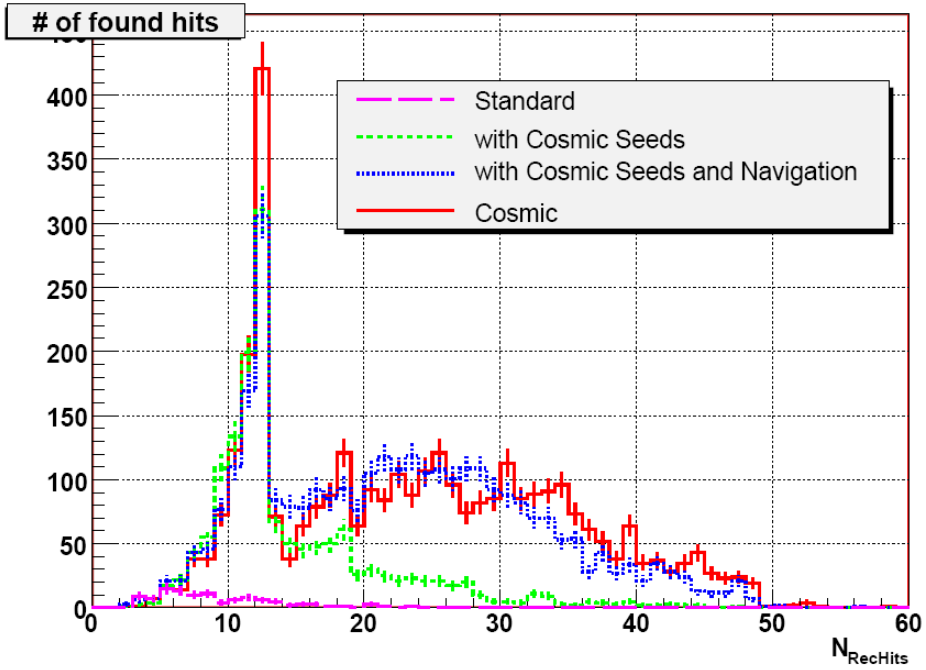
- Cosmic reconstruction works in different scenarios
  - Tested with MTCC & MC data
    - High efficiency
  - Good resolution with "double sides" of muon system
- Most of the code committed and released
- Under development
  - Need to optimize
    - Seed generator
    - Traversing tracks
- Need to test with beam-halo muons
  - First version of MC generator committed 3 weeks ago
  - Generating a big sample
- Ultimate goal
  - Have a well-tested cosmic reco with high performance ready for pilot run
- CMS note in preparation
  - First version expected in 2 weeks

Backup

- backup

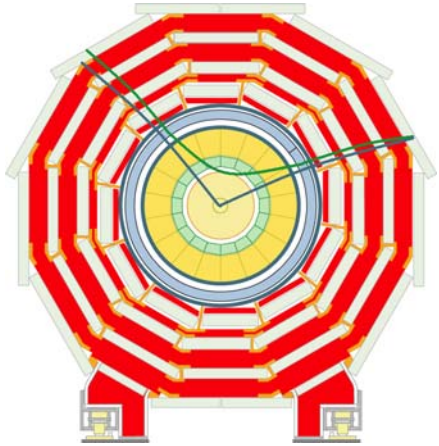
Barrel-endcap Overlap Tracks

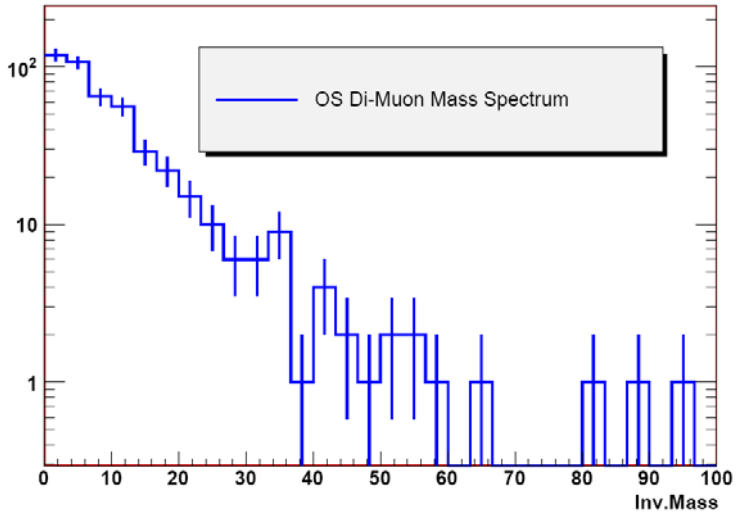
- Reconstruct MTCC barrel-endcap overlap tracks with 4 methods:
  - Standard reco (MuonSeed + STAMuon)
  - CosmicMuonSeed + STAMuon
  - CosmicMuonSeed + STA with NavigationType as "Direct"
  - Cosmic reco

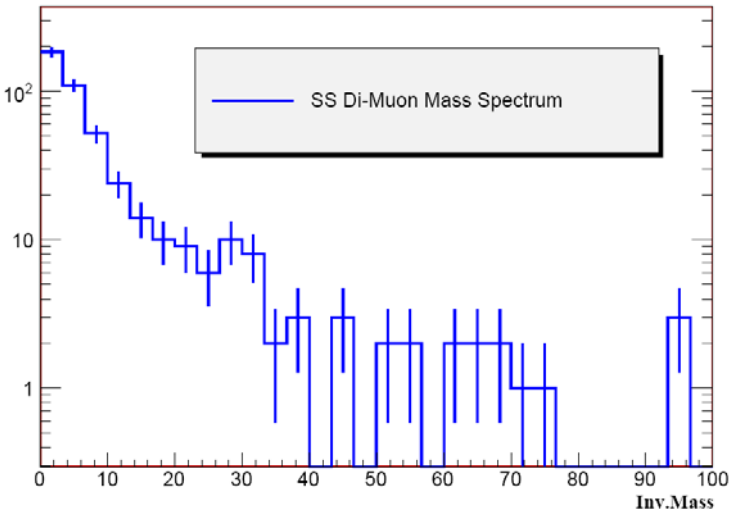


Fake Di-muon Events

- Possible for both Opposite Sign and Same Sign Di-Mu
- Dangerous bkgd







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