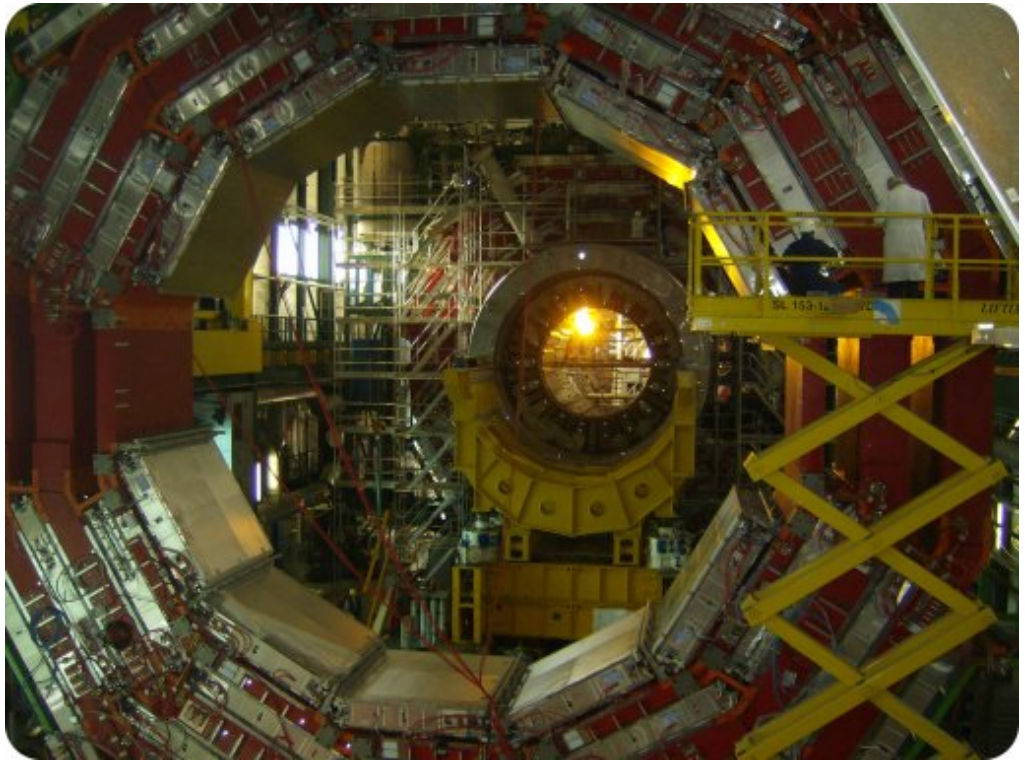
# Track-based alignment of the CMS muon detector



Jim Pivarski, Alexei Safonov
Texas A&M University

American Physical Society April Meeting
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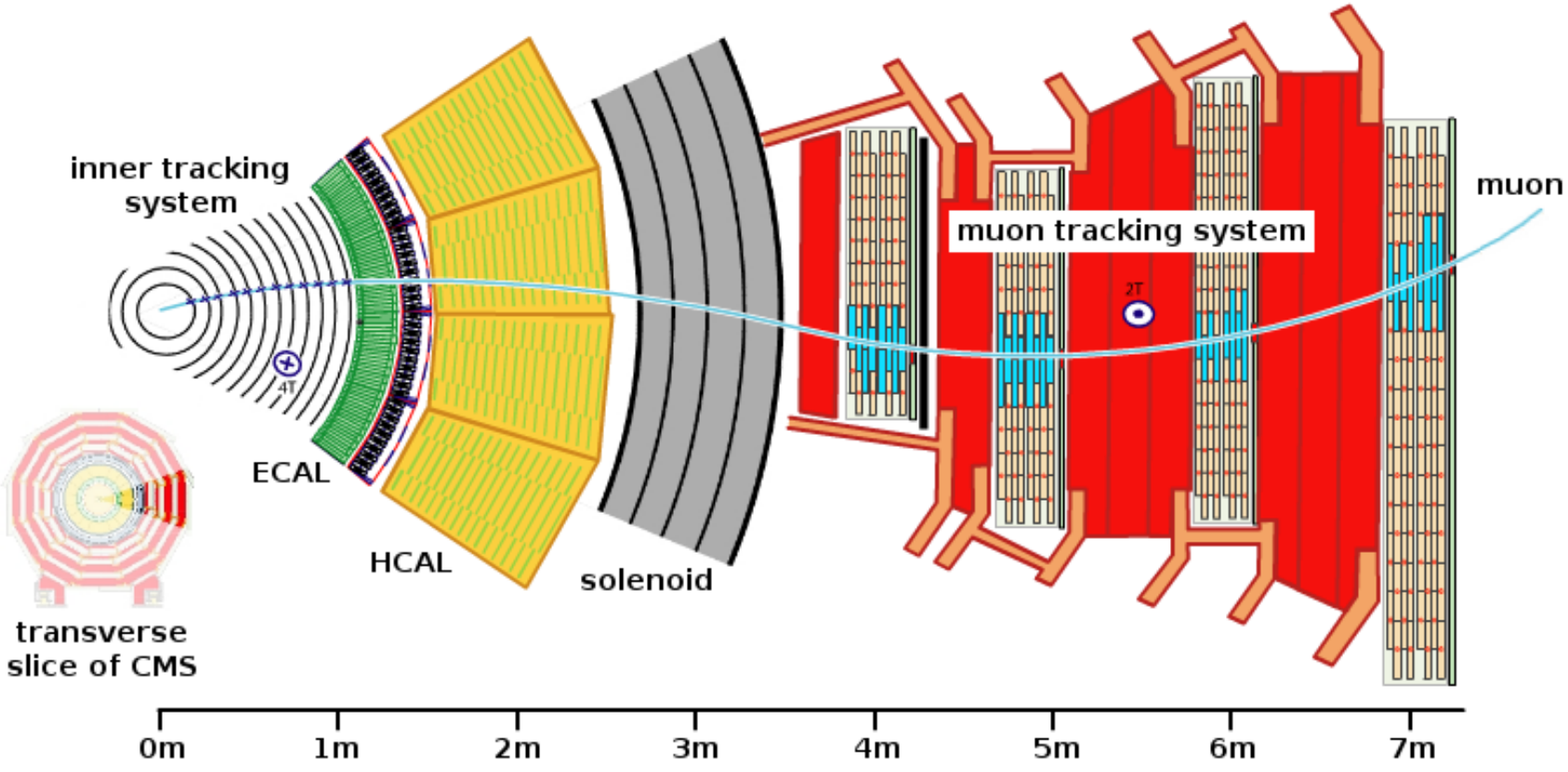
# CMS muon tracking system



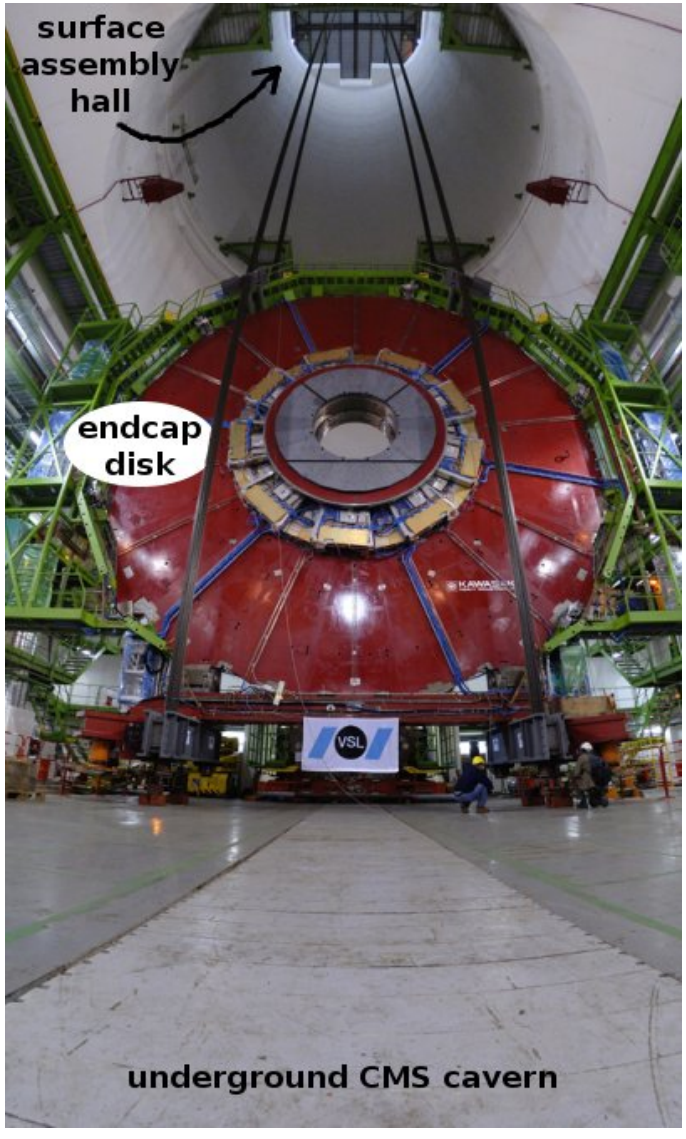
Outermost part of the Compact *Muon* Solenoid (CMS)

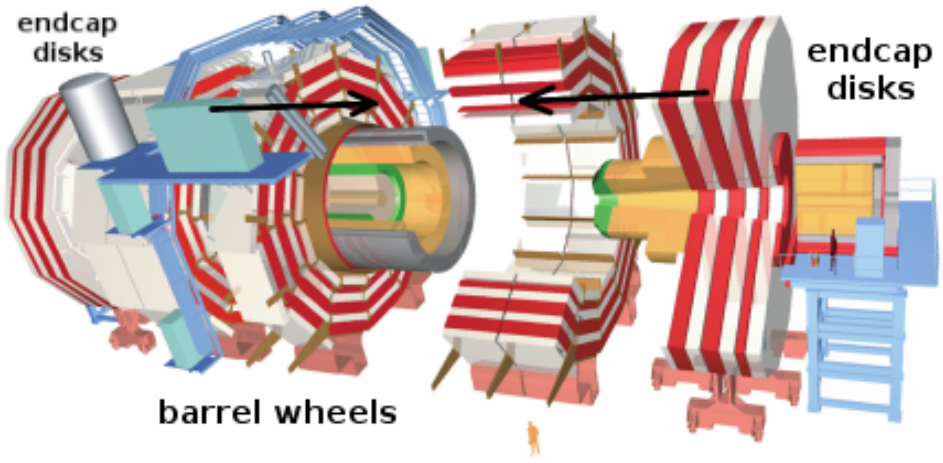



- Typical muon leaves a trail of 24–44 hits in muon system
- A complete tracking system in itself!
- Measure muon momentum by curvature of its 7-meter long track

# Independent components





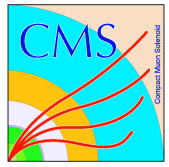




- Built in an assembly hall and lowered, piece by piece, to the interaction point
- Iron disks shift and bend centimeters in CMS's 4-Tesla magnetic field
- 790 chambers mounted on ball-joints to remain internally rigid

Hit resolution depends on precise knowledge of chambers' position and orientation in space

# Does muon alignment matter?







- Triggering and muon-id are insensitive to misalignment, by design
- Inner tracker dominates in $p_T$ resolution because hits are $\sim$10 times more precise
  - Inner tracker: 10–50 $\mu$m silicon strip measurements
  - Muon chamber: 200 $\mu$m drift tubes and cathode strips

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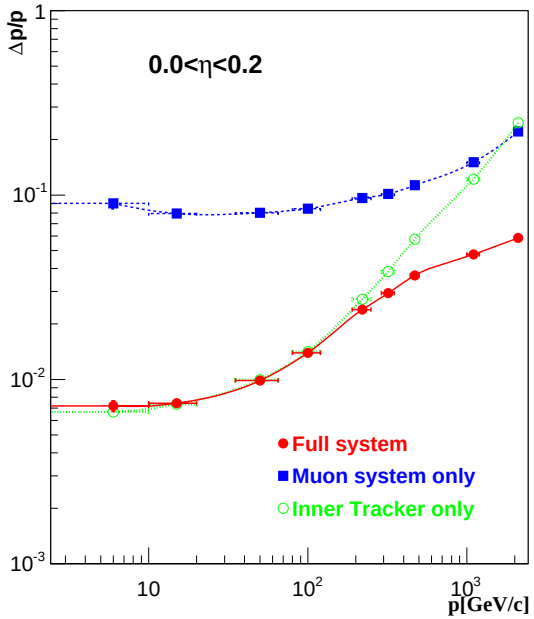
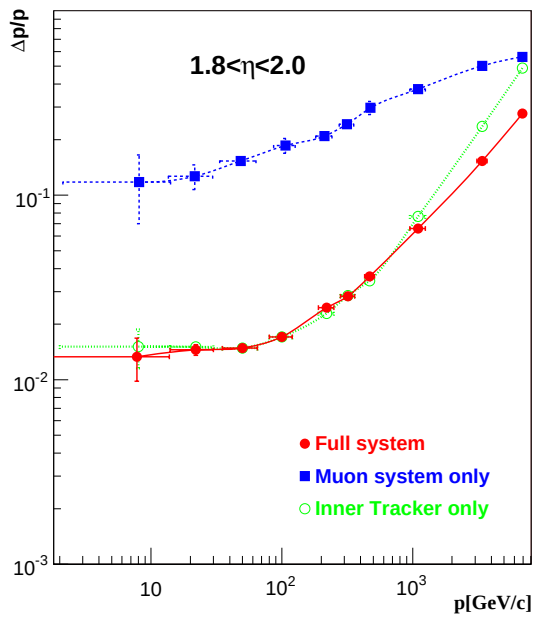
. . . but only below 1 TeV



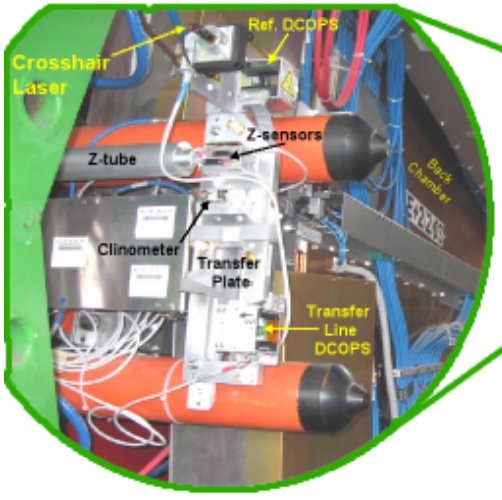

- TeV tracks are so straight that muon system's lever arm contributes significantly to momentum resolution: it matters!

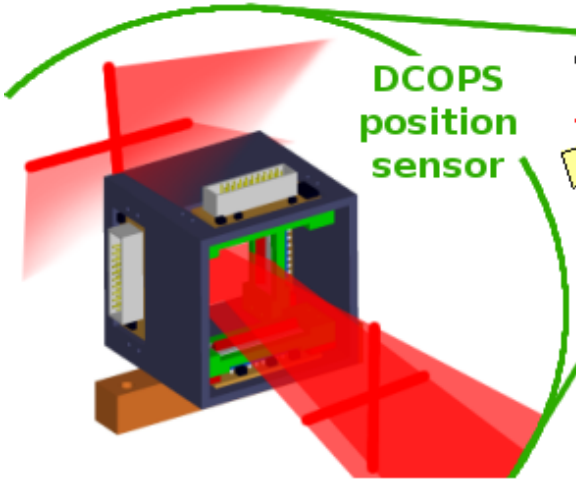
# Hardware alignment system

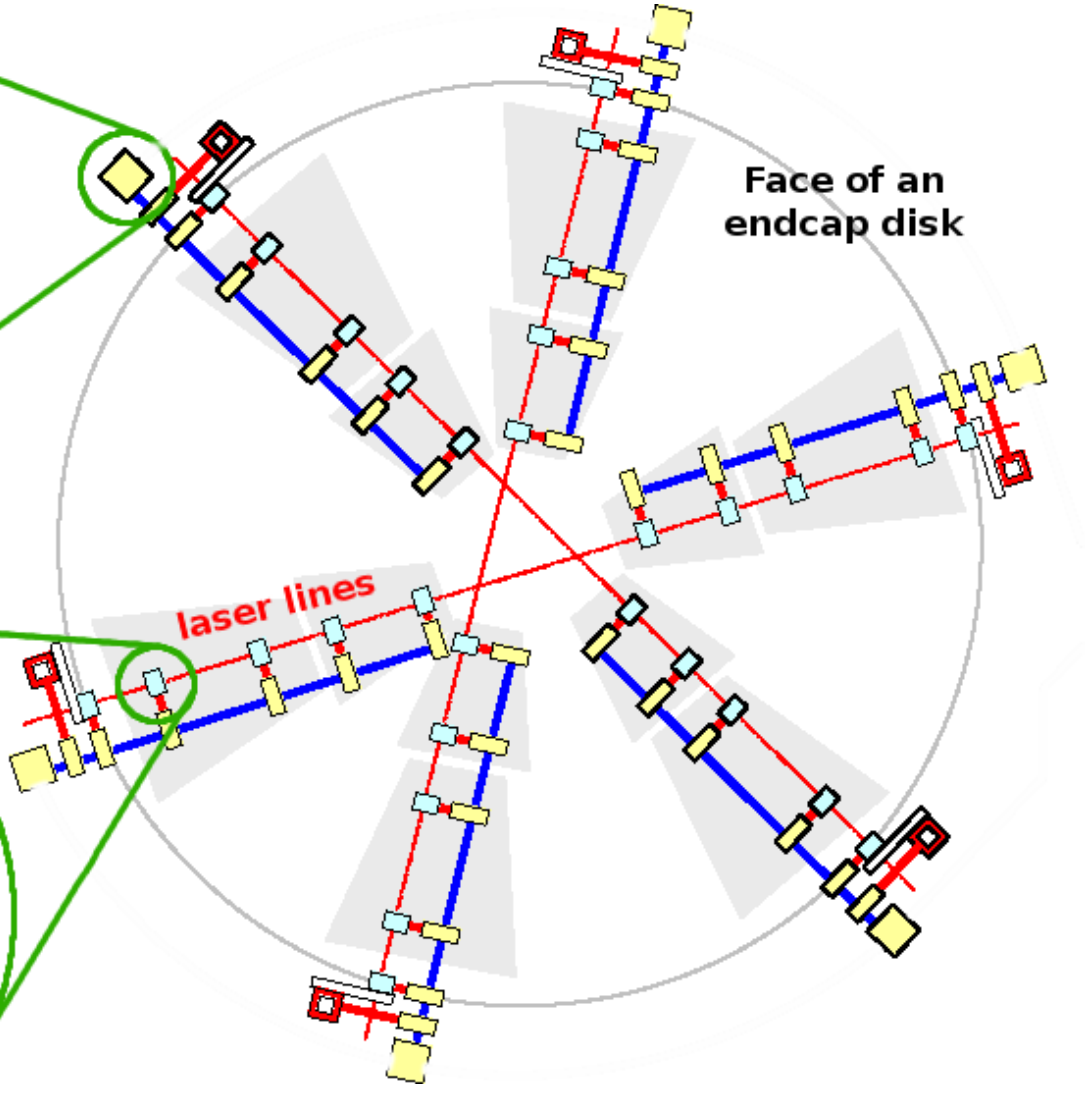


System of lasers and calipers mounted on chambers

Measure positions and monitor changes

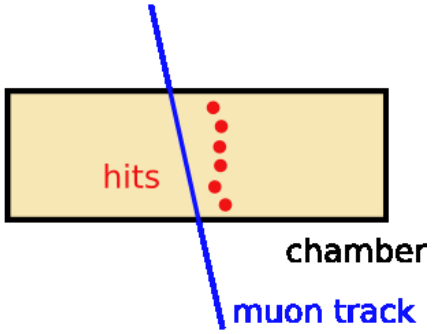


# Track-based alignment



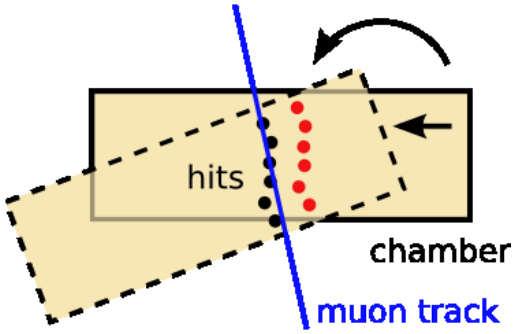



Find corrections to assumed chamber positions by minimizing track-minus-hit residuals

- Independent alternative to Muon Hardware Alignment System
- Aligns active sensors directly, rather than the boxes they live in
- Parameter resolution is proportional to sensitivity of track-fitting: best resolution on the parameters that matter most

# Track-based alignment



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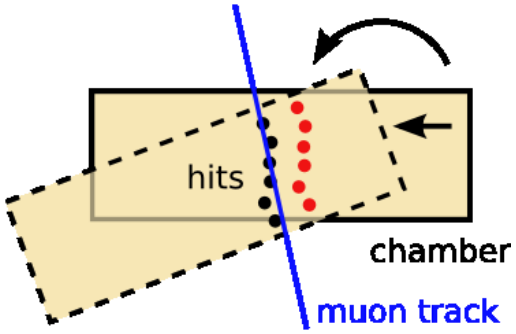


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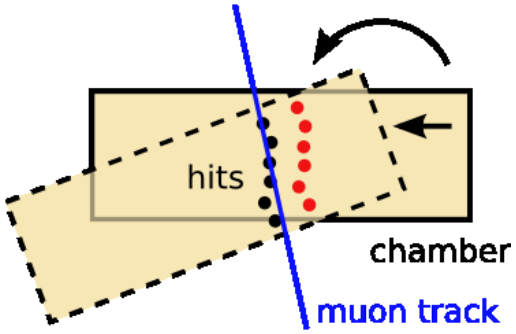
# Challenges and solutions

- Ordinarily, a chicken-and-egg problem: tracks are fit by minimizing residuals, too!
  - We can use the inner silicon tracker as a reference

# Track-based alignment



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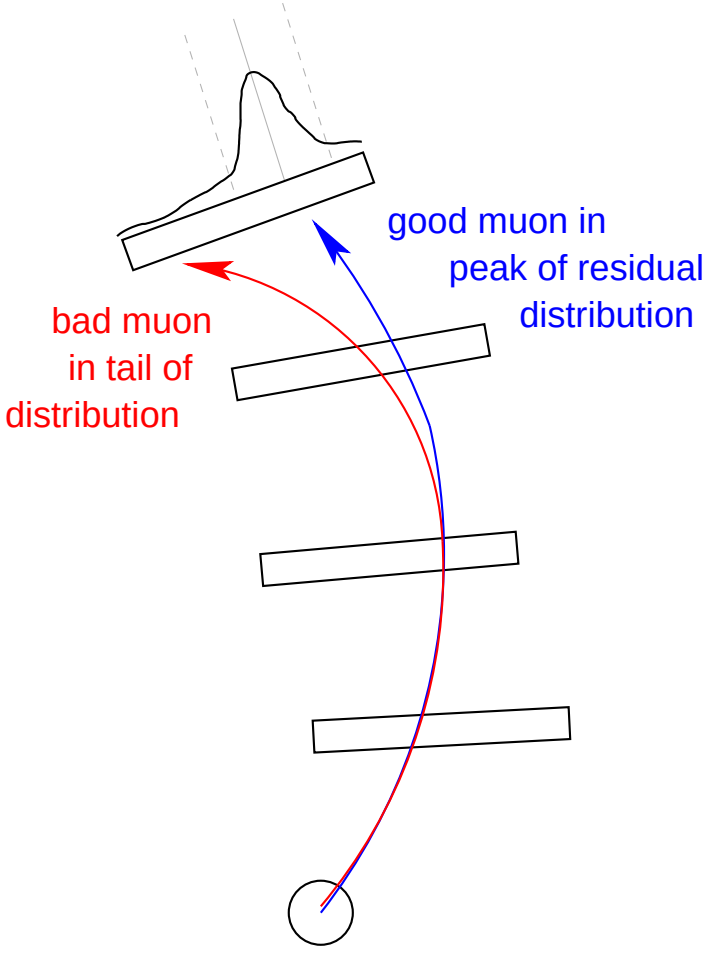
# Challenges and solutions

- Ordinarily, a chicken-and-egg problem: tracks are fit by minimizing residuals, too!
  - We can use the inner silicon tracker as a reference
- Muon system has a lot of iron: multiple-scattering distorts track
  1. Remove highly scattering tracks from sample
  2. Re-fit tracks using local information

# Muon Alignment Techniques






- Use redundancy of muon system to identify multiply-scattering tracks
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  - Dozens of residual distributions per track: one for each layer hit
- Scattering bias is antisymmetric with charge, only affects low momentum

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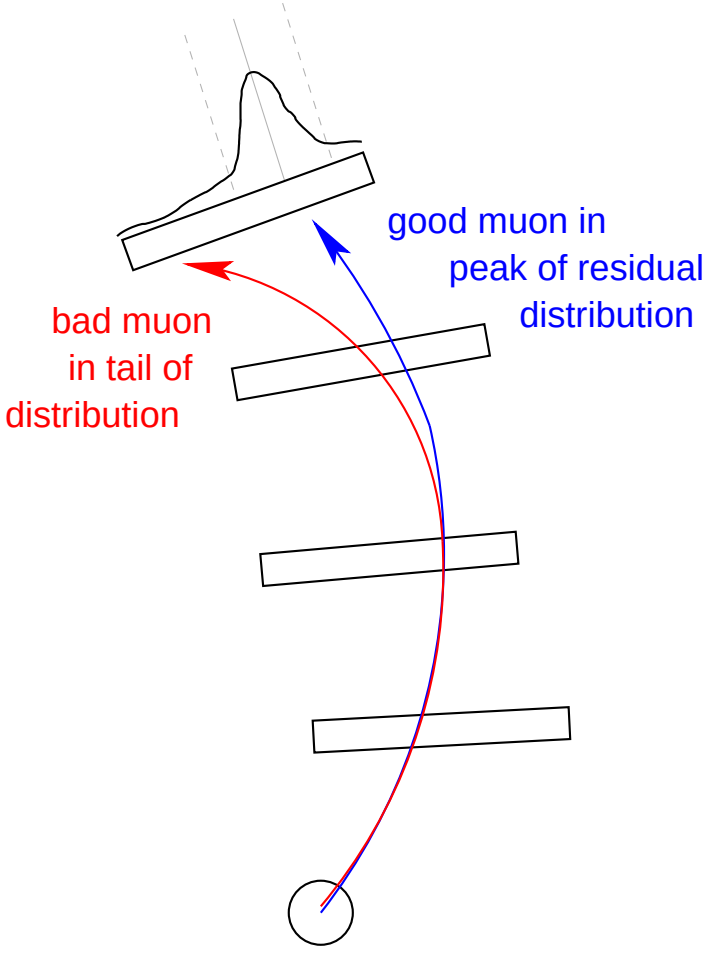


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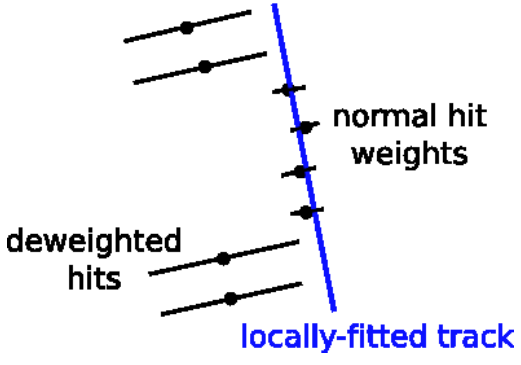

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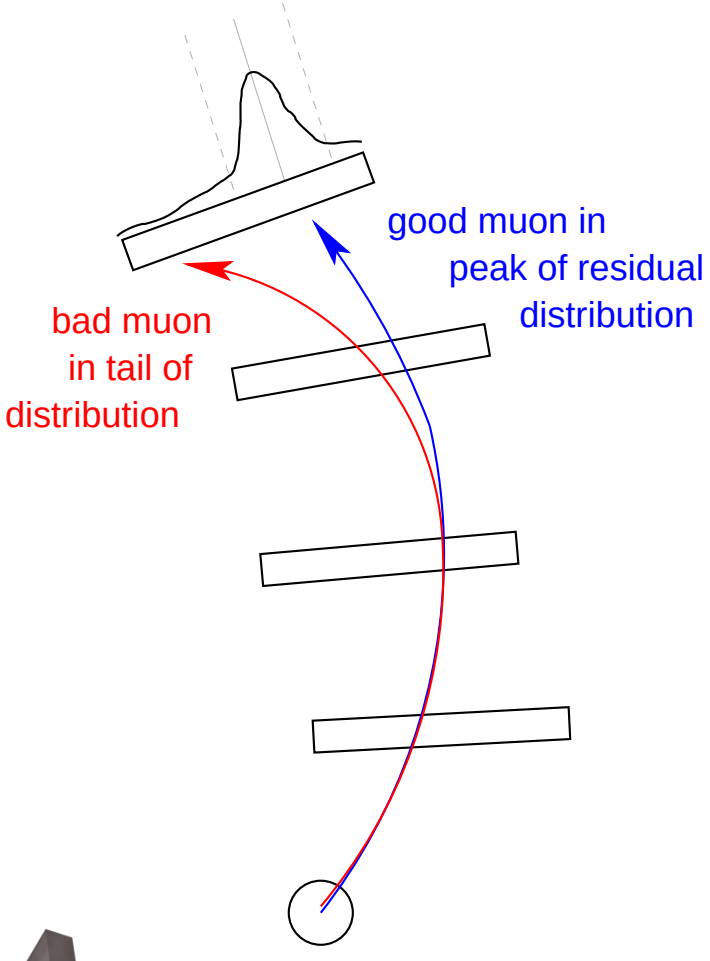


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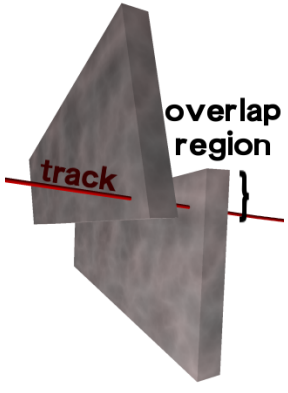
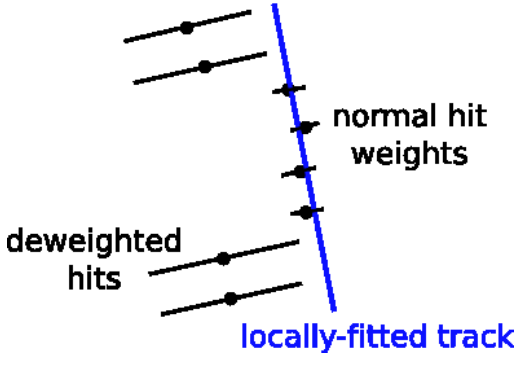
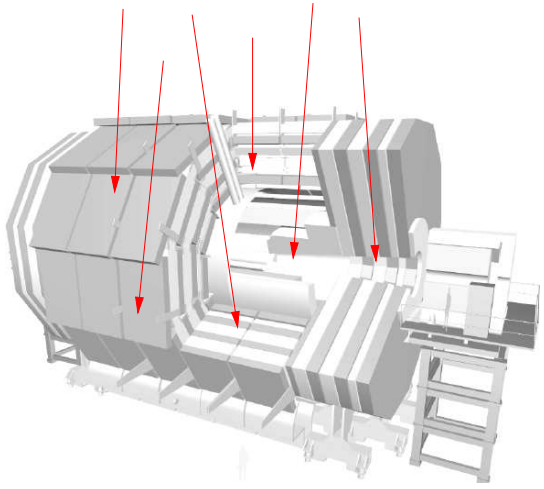



- Some chambers overlap without intervening iron layer
  - local-fit shared track segment
  - align chambers relative to one another

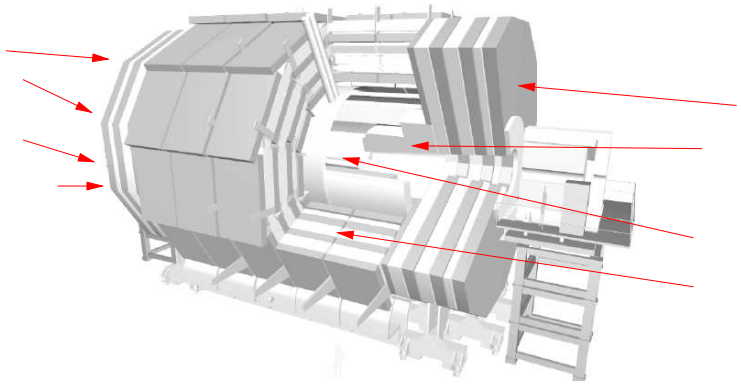


# Start-up alignment methods





Cosmic rays for barrel



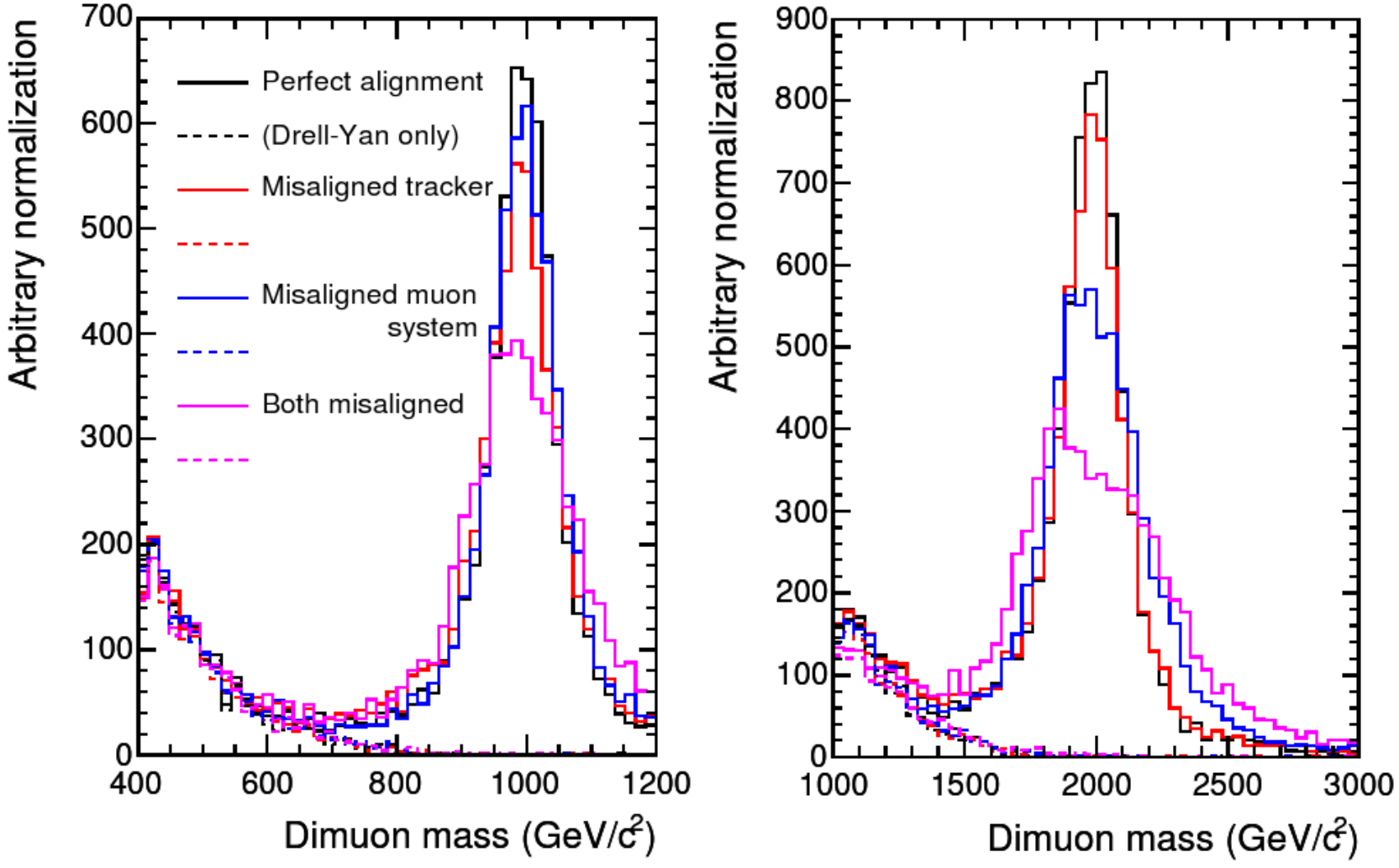
Beam-halo for endcaps

## Strategy:

1. Find relative chamber alignments within modular structures (barrel wheels and endcap disks) using cosmics, beam-halo
2. Align modular structures to inner tracker with first collisions
   - These structures cover large solid angles
   - Not many tracks are needed for a precise alignment

# TeV dimuons with misalignment

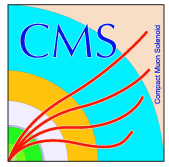
Simulated $Z'$ peak shape with residual misalignment




Misaligned muon system matters a lot more at 2 TeV, as expected

# Conclusions







- CMS muon detector is a many-layered tracking system
- Modular structure requires alignment
- Track-based alignment poses a unique set of challenges in this environment
- Significant impact on early physics: width of $Z'$ resonance