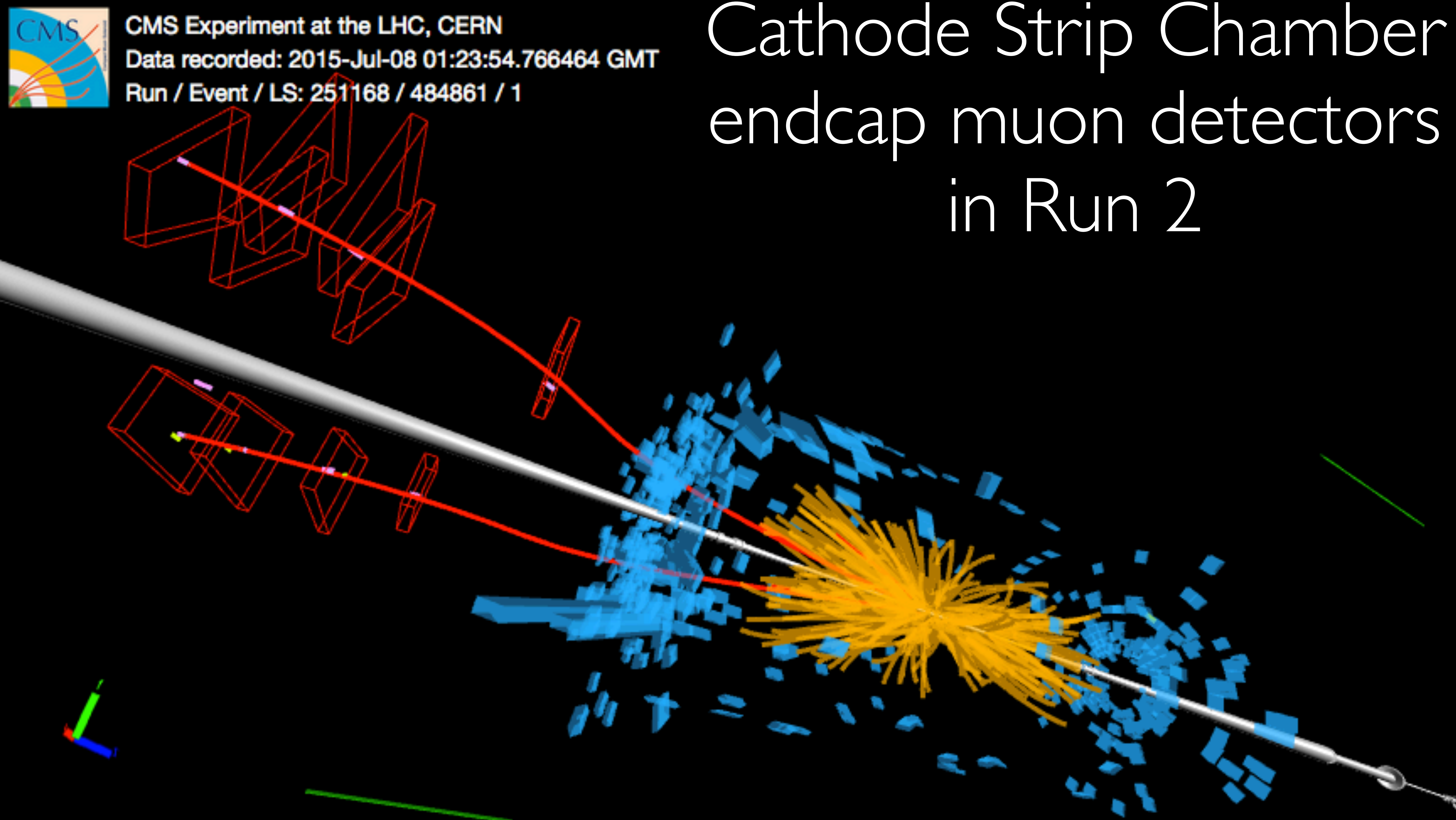
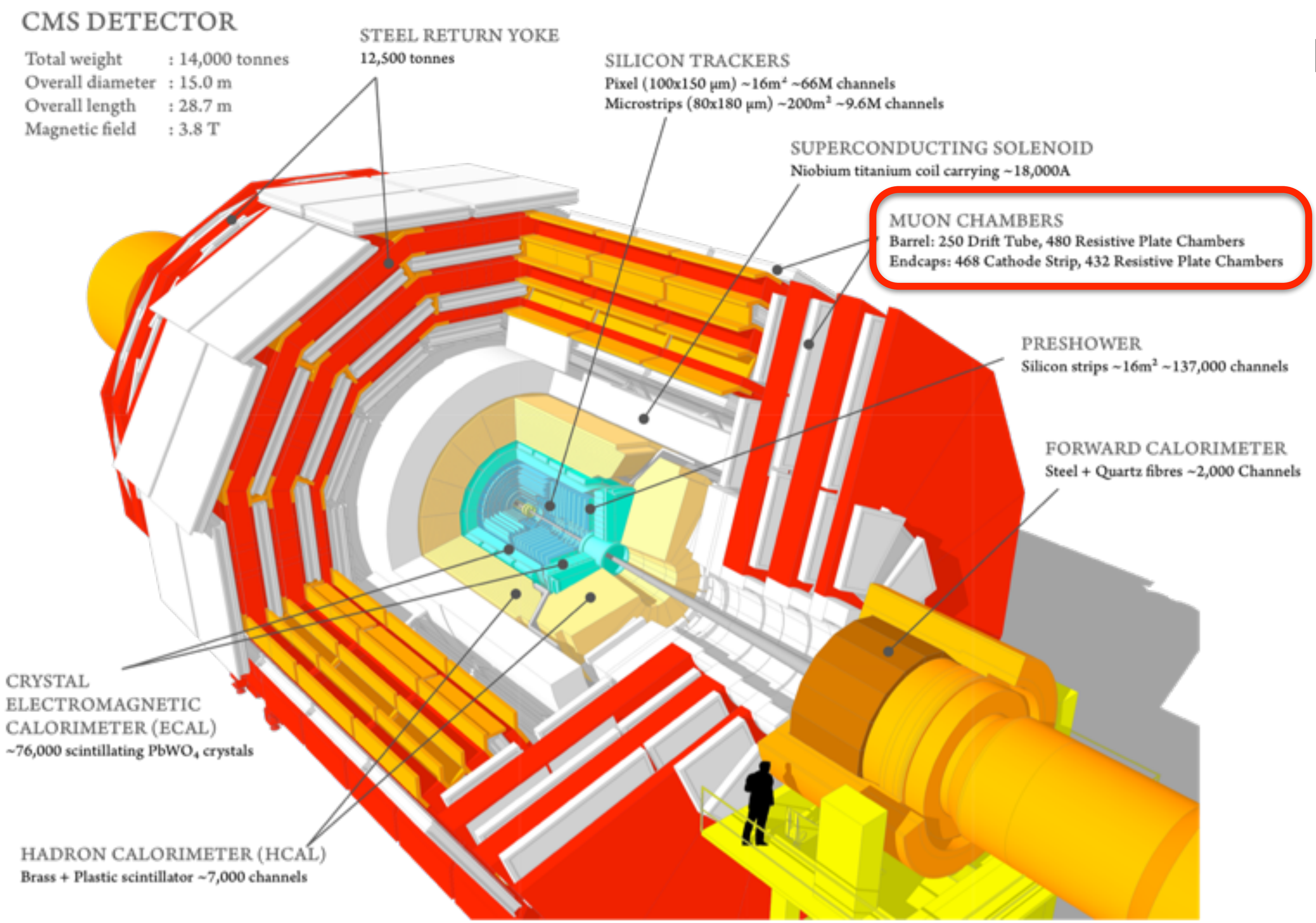
Performance of the CMS Cathode Strip Chamber endcap muon detectors in Run 2



Wells Wulsin, on behalf of the CMS Collaboration

5 Aug 2015
APS Division of Particles and Fields
Ann Arbor

CMS:
Muon is our middle name

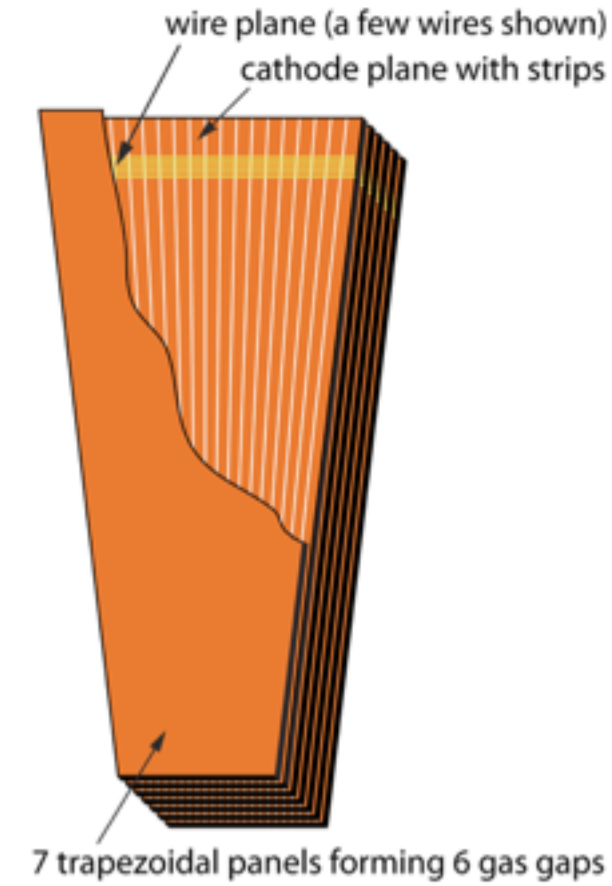


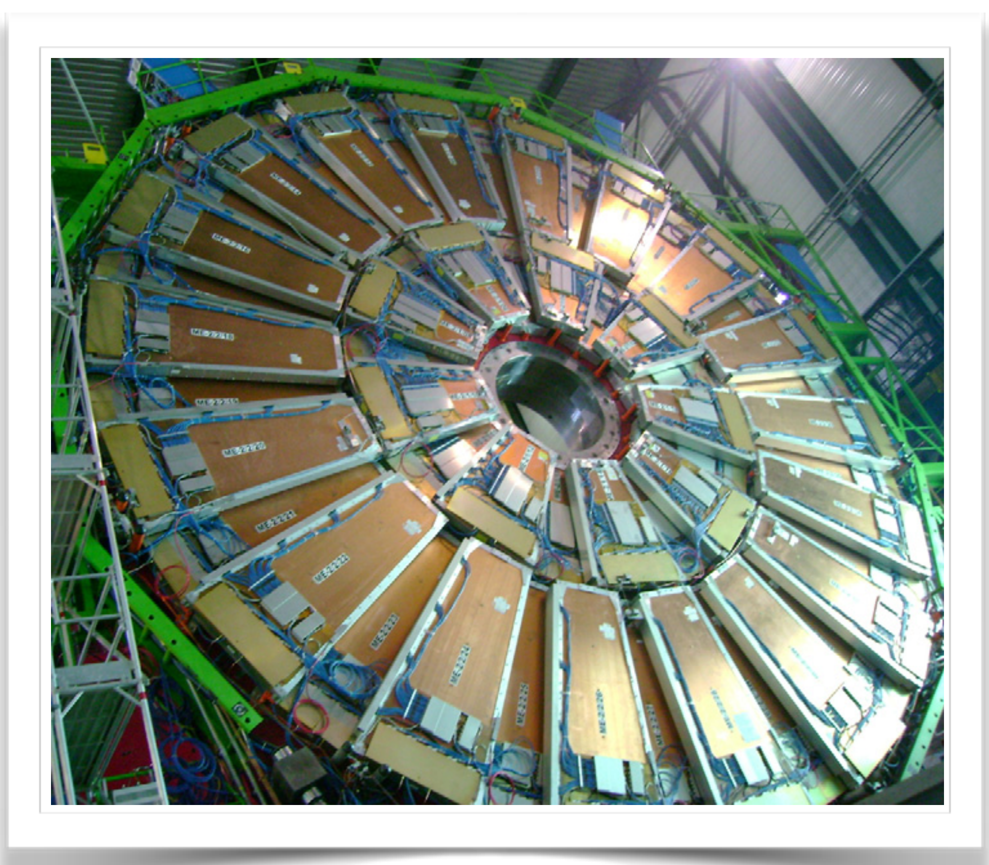
Muon subdetectors employ 3 technologies

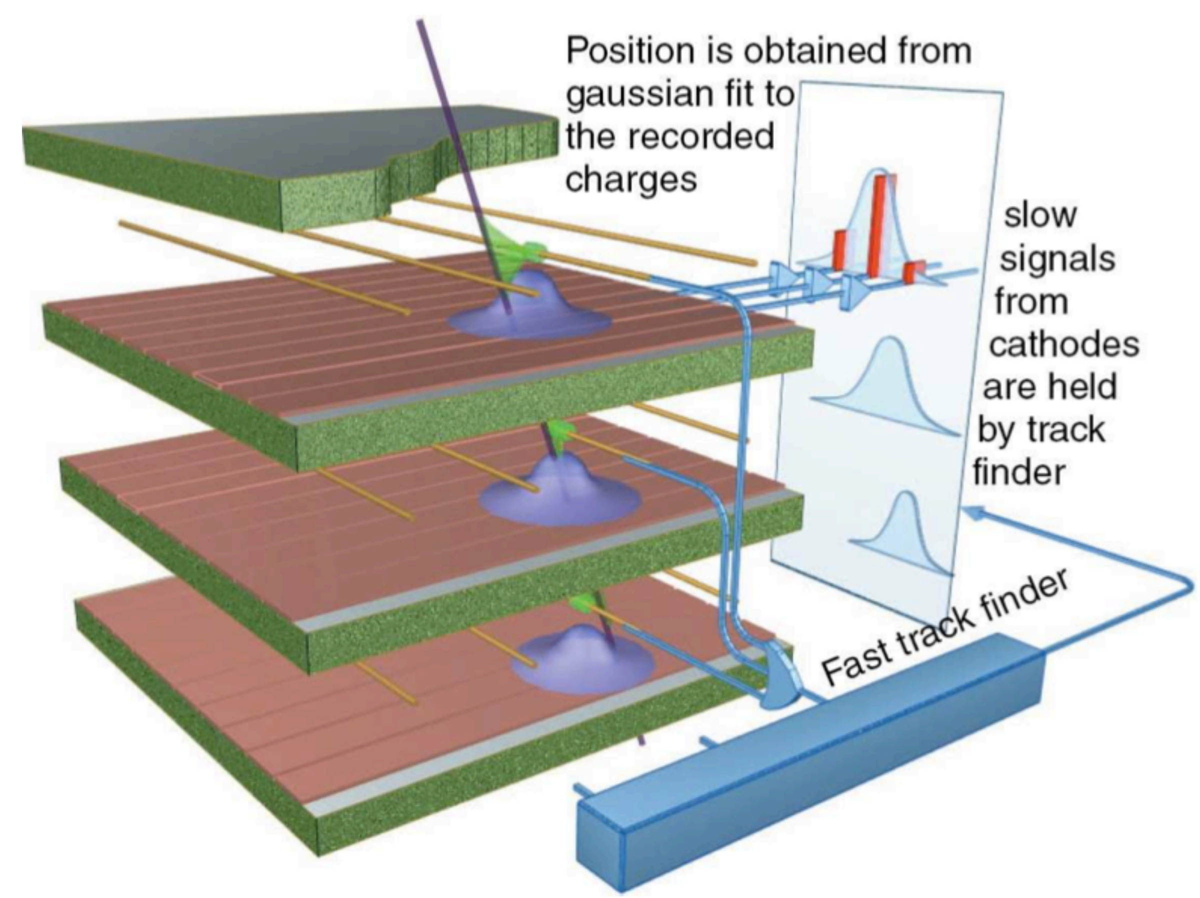
- Drift Tubes (barrel)
- Resistive Plate Chambers (barrel & endcap)
- **Cathode Strip Chambers (endcap)** - the focus of this talk

Cathode Strip Chambers record muons in $0.9 < |\eta| < 2.4$

- cope with non-uniform magnetic field, high radiation rate
- 468 multiwire proportional chambers (in Run 1)
- Each chamber is constructed from 7 copperclad trapezoidal panels forming **6 gas-gap layers**
- **anode wires** (at 2.9 - 3.6 kV) measure the R coordinate and timing
- **cathode strips** (3-16 mm wide) are etched onto panels; measure Φ coordinate → critical for p_T measurement
- 3D segment obtained by fitting 2D points; local charged tracks are trigger primitives

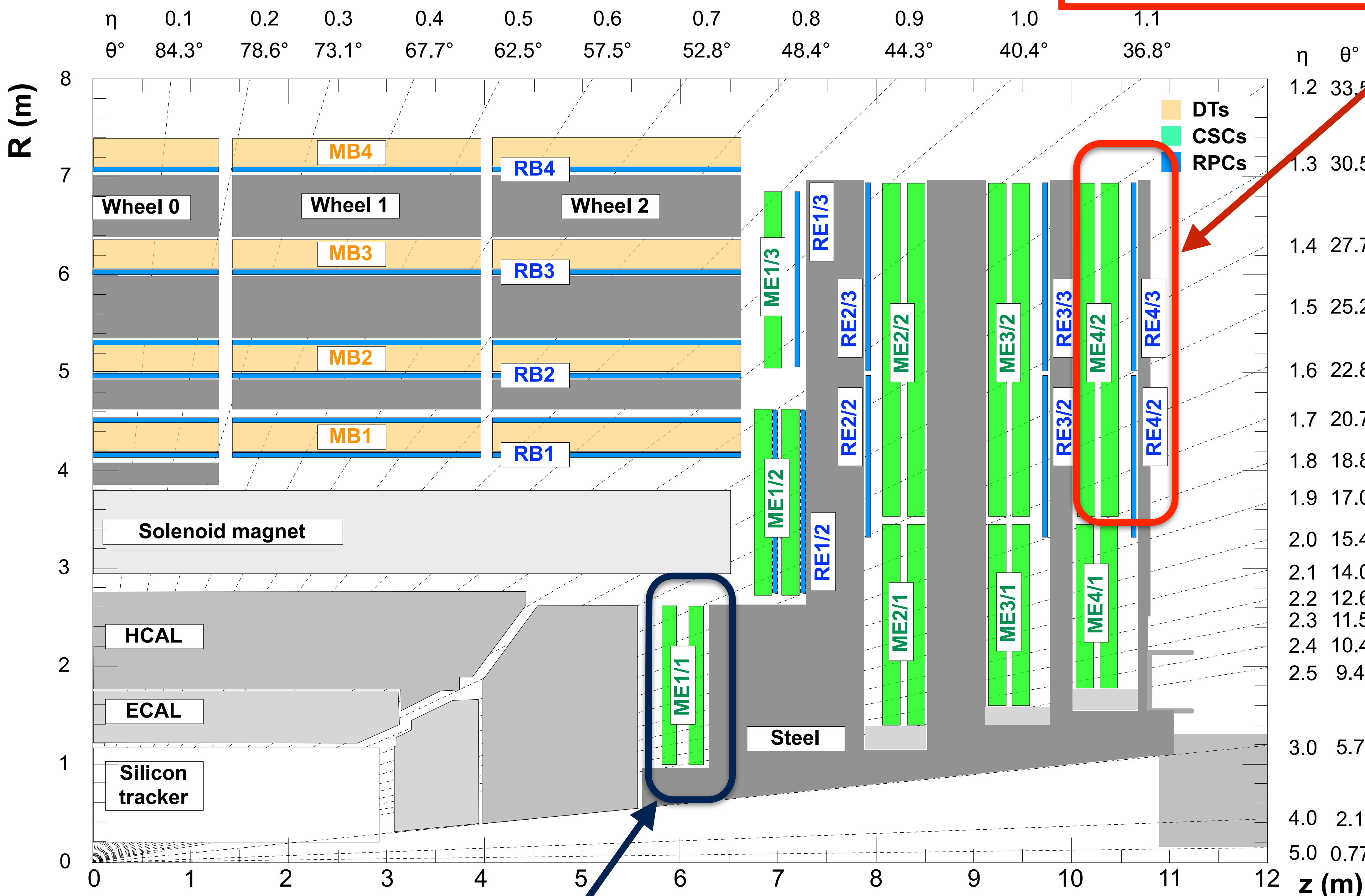






Two CSC upgrade efforts in first LHC Long Shutdown

Installation of 72 new **M**uon**E**ndcap4/2 chambers (missing in Run 1)

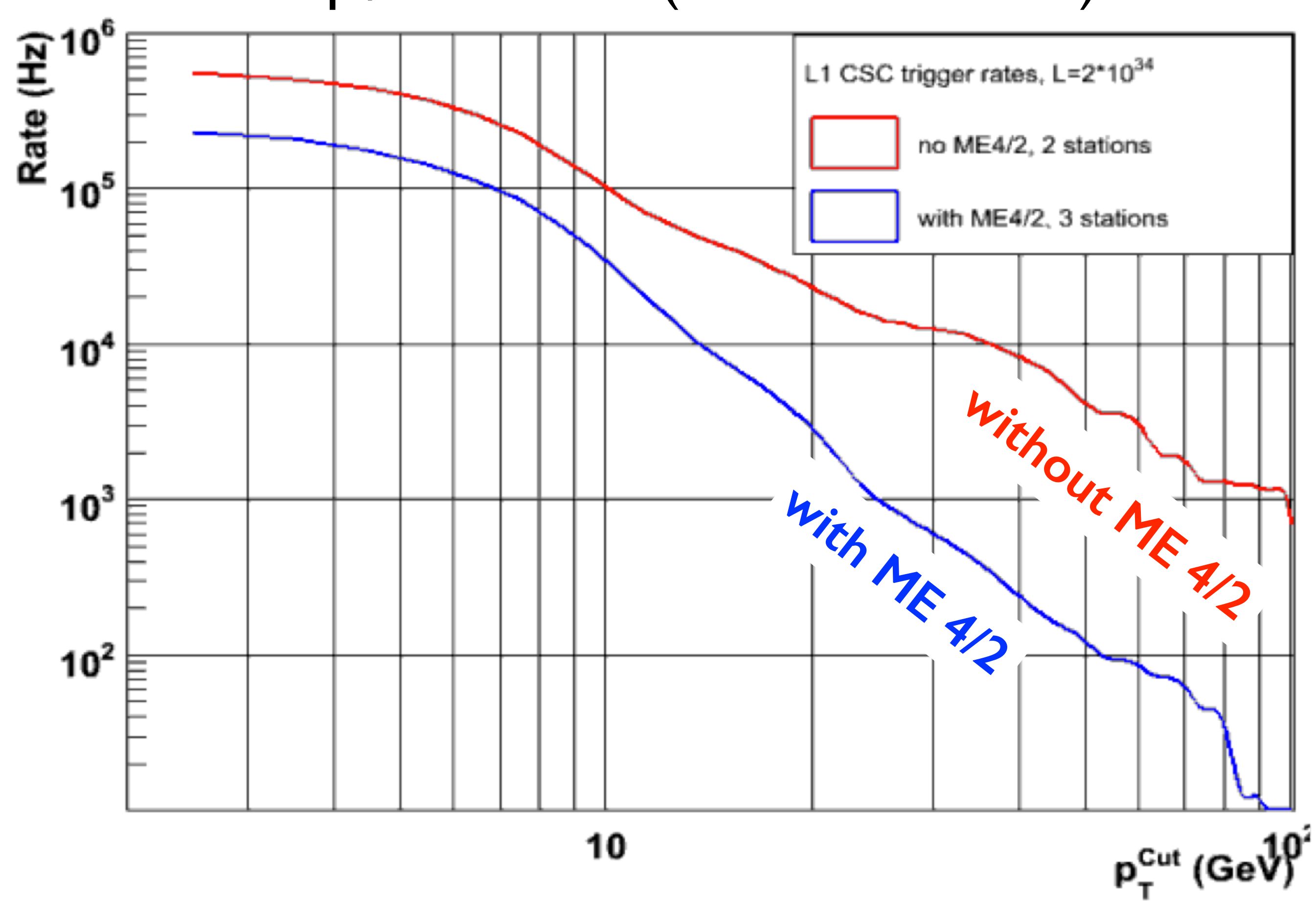


Upgraded electronics for 72 ME1/1 chambers to cope with larger rates

72 new ME4/2 chambers have been installed and commissioned

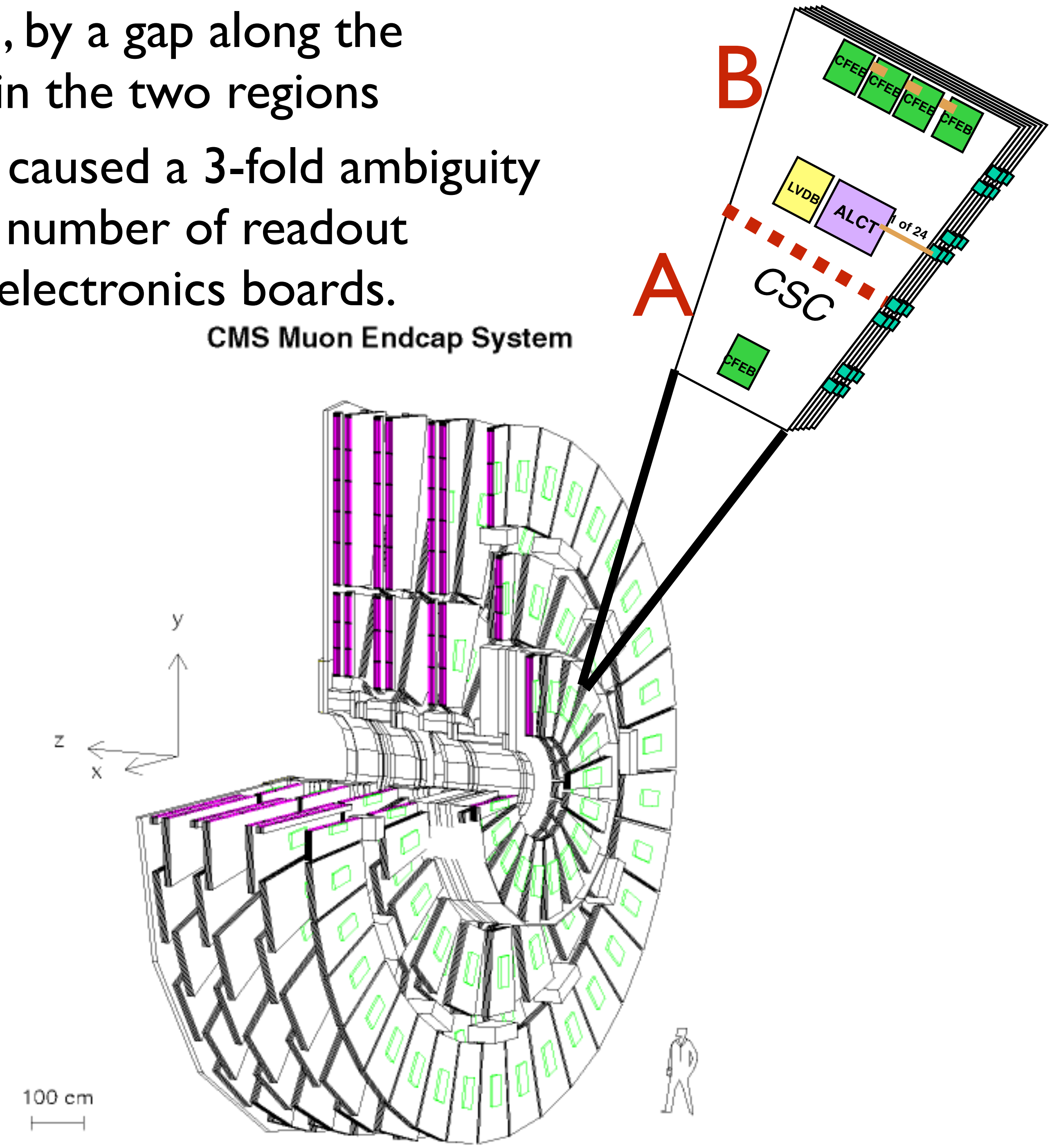
- provides four-station redundancy over full $0.9 < |\eta| < 2.4$ range
- improved efficiency in region $1.2 < |\eta| < 1.8$
- reduction in muon fake rate for trigger and offline reconstruction
- chamber panels cut, milled, cleaned, polished at Fermilab
- chambers constructed (wire winding, assembly, instrumentation) at CERN
- tested on surface before installation, then tested in situ

hardware (Level 1) trigger rate vs. muon p_T threshold (2010 simulation)

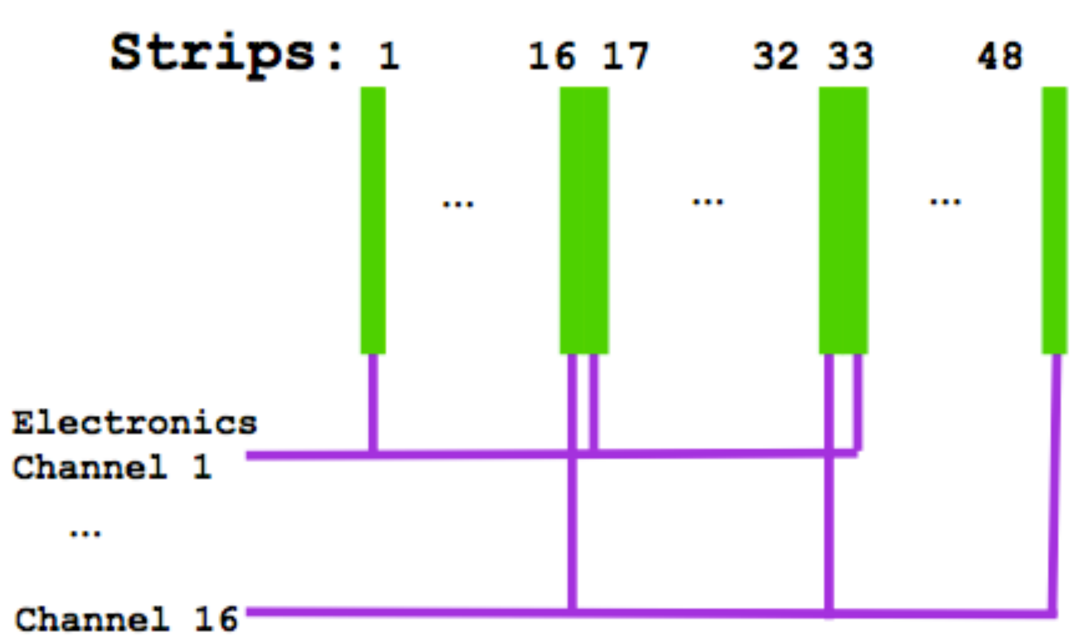


ME1/1 electronics upgrade motivation

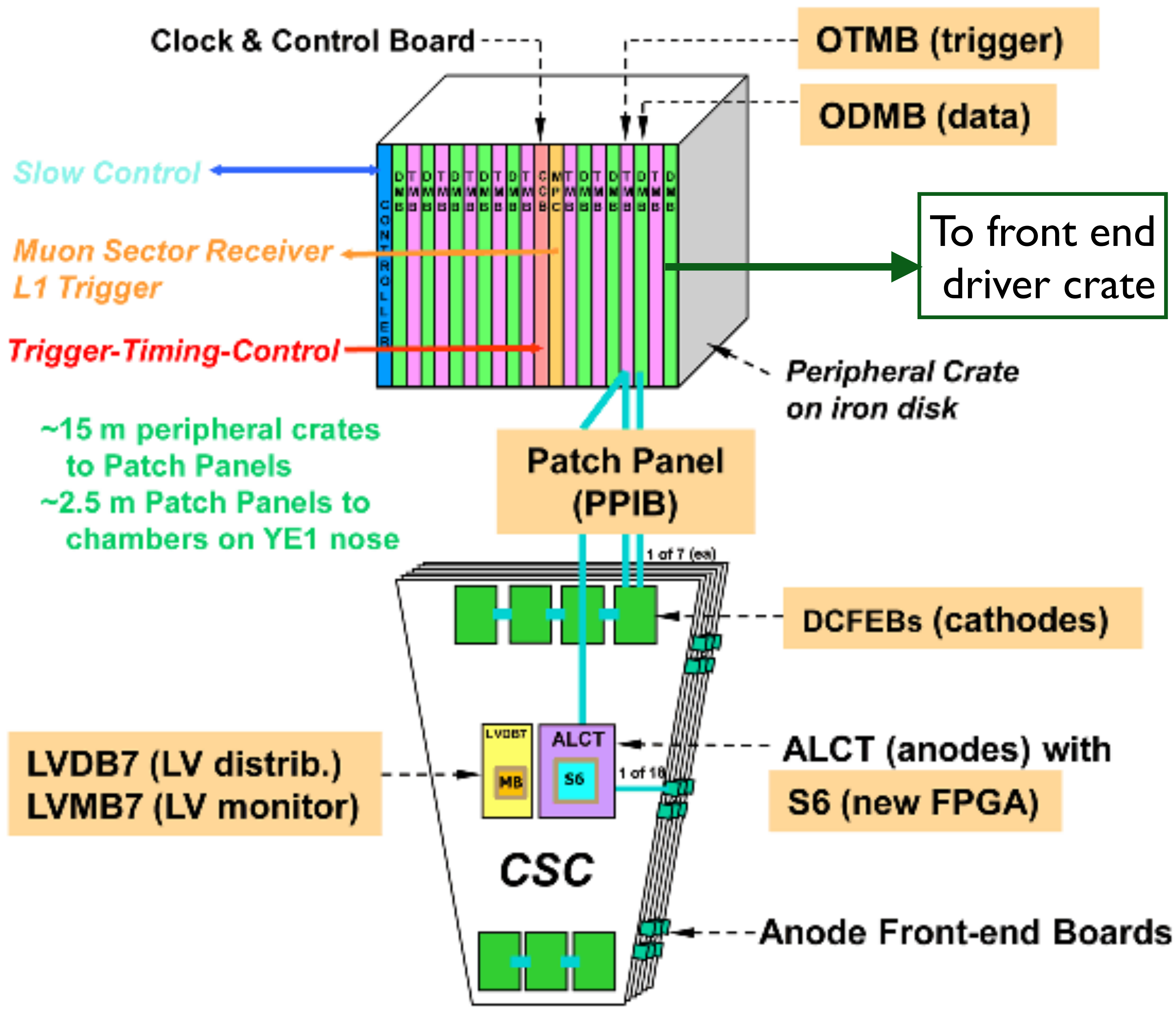
- ME1/1 chambers are closest CSC's to the interaction point ($1.6 < |\eta| < 2.4$): face the largest muon flux
- segmented into 2 sub-chambers (ME1/1a & ME1/1b), by a gap along the cathode strips - different wire spacing / orientation in the two regions
- ME1/1a strips were triple-ganged every 16 strips → caused a 3-fold ambiguity in triggering and reconstruction. Chosen to reduce number of readout channels; since Run 1 added 2 on-chamber readout electronics boards.



pre-Upgrade ME1/1 a strip "ganging"



Readout ME1/1 electronics upgraded **on chambers**, in **peripheral crates**, and in **front end crates**



New board acronyms:

- OTMB Optical Trigger MotherBoard
- ODMB Optical Data MotherBoard
- PPIB Patch Panel Interface Board
- DCFEB Digital Cathode Front-End Board
- LVDB7 Low Voltage Distribution Board (7 DCFEB version)
- LVMB7 Low Voltage Monitor Board (7 DCFEB version)
- S6 Spartan-6 mezzanine board

72 chambers were extracted, re-instrumented, tested, & reinstalled

Upgrade of on-chamber ME1/1 electronics

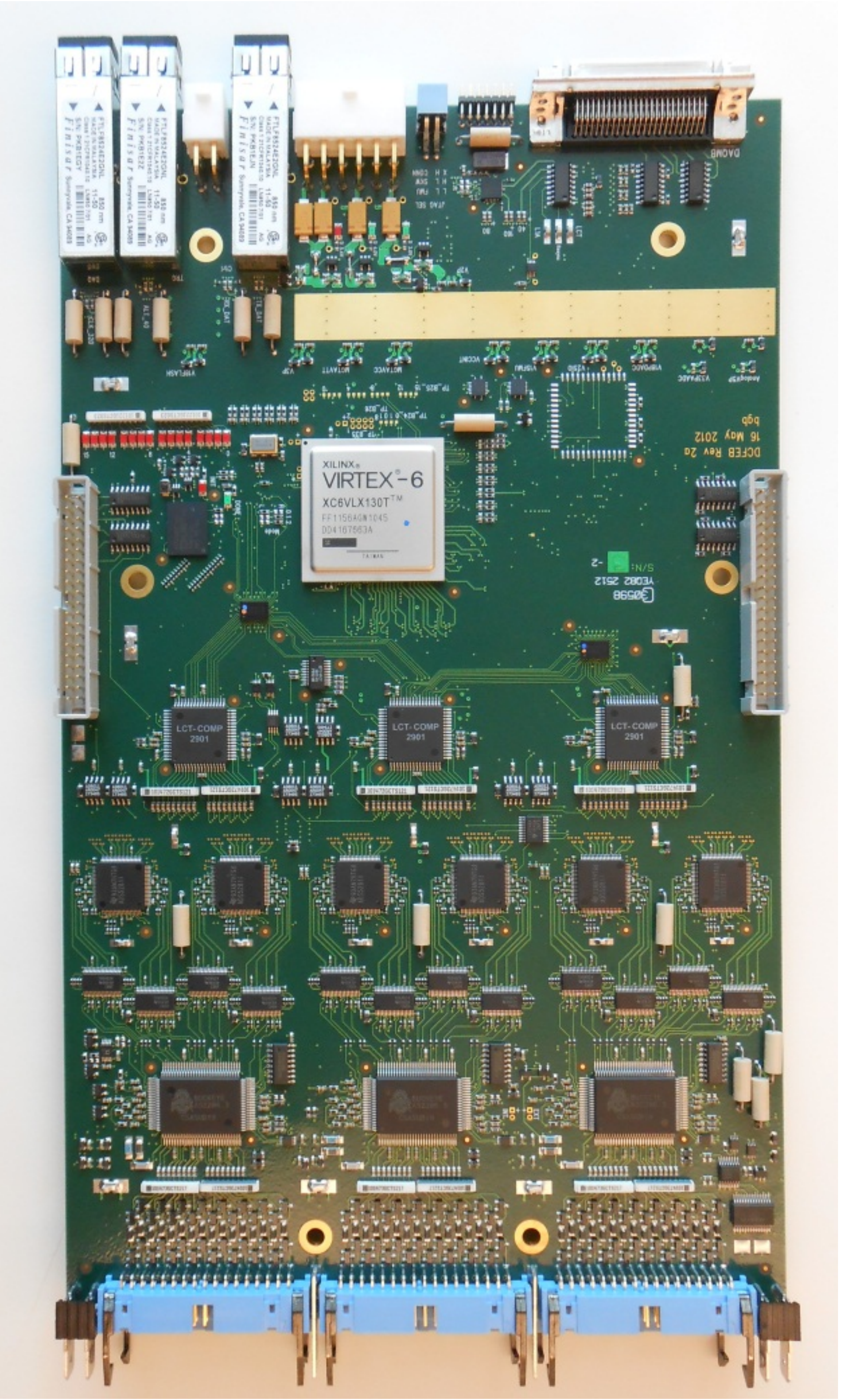
CFEB → DCFEB

(Digital Cathode Front End Board)

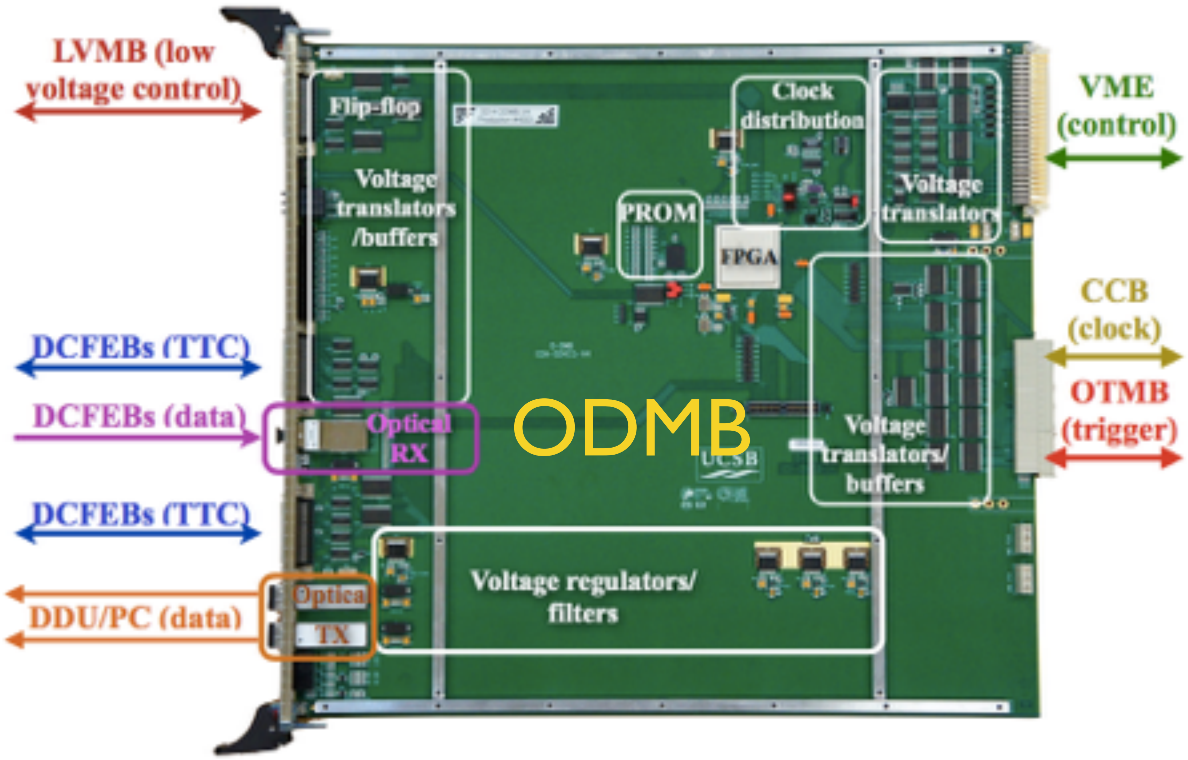
- Replace old (analog) CFEBs, which were transferred to new **ME4/2 chambers**
- Over 2400 individual electronics components
- **flash ADCs** replace switch capacitor array
- **fully digital pipeline**: effectively no deadtime, better able to handle pile-up
- improved **FPGA** (Virtex 6)
- **optical** data read out
- 5 CFEBs → 7 DCFEBs (no triple-ganging in ME1/1a)
- 554 boards (incl. spares) produced & tested
- extensive radiation testing

Other new electronics

- new **low voltage** distribution and monitoring boards to handle increased consumption / channels from 7 DCFEBs
- **Anode local charge track** board equipped with Spartan 6 FPGA to handle larger rates.



Upgrade of peripheral crate ME1/1 electronics

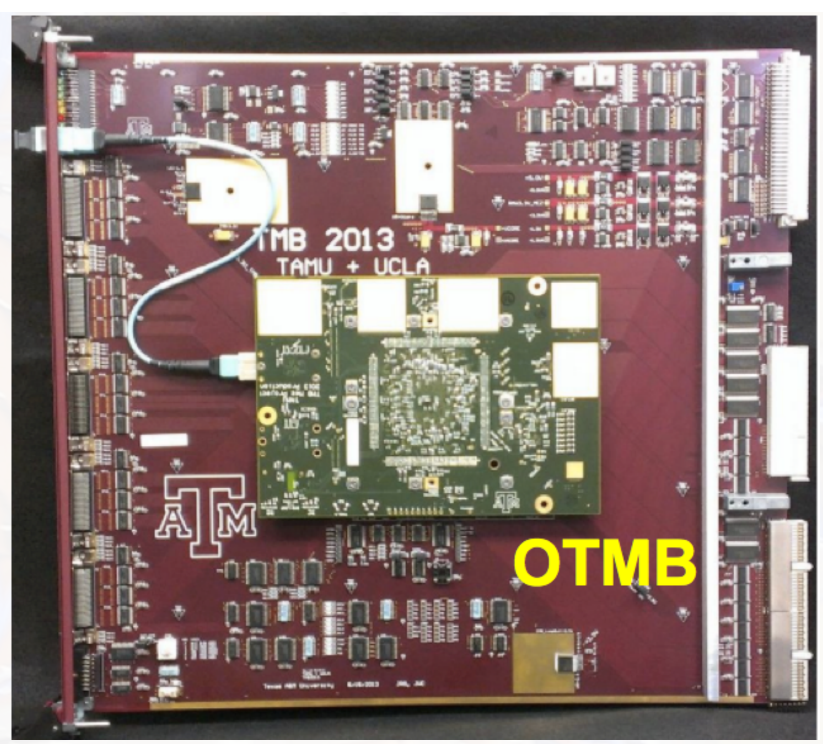


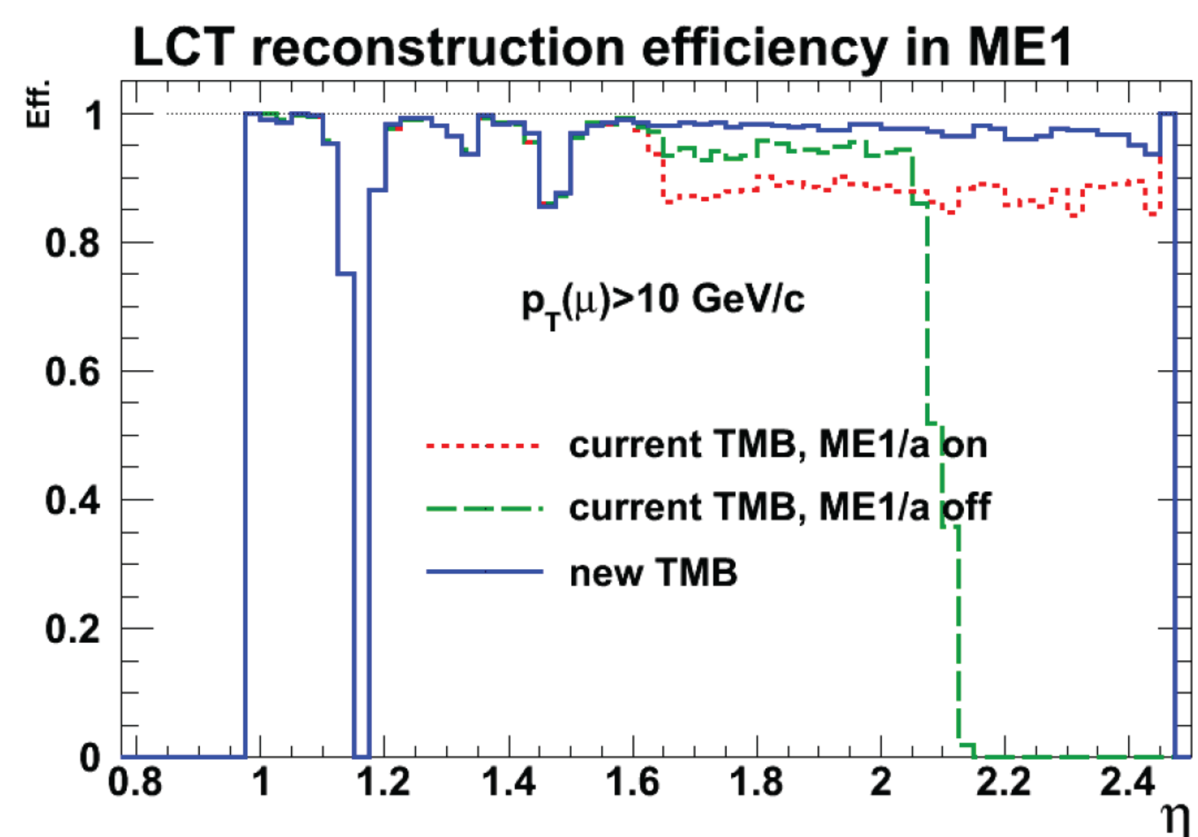
DMB → ODMB (Optical DAQ Mother Board)

- Two main tasks, both related to DCFEBs:
    - Trigger, timing and control distribution.
    - Data acquisition.
- Upgrade: Improved FPGA (Virtex 6) to handle 7 DCFEBs & optical readout.

TMB → OTMB (Optical Trigger Mother Board)

- Constructs cathode track segments and performs matching to anode tracks for triggering.
- New mezzanine board with upgraded FPGA → improved trigger logic.
- Receives data optically.

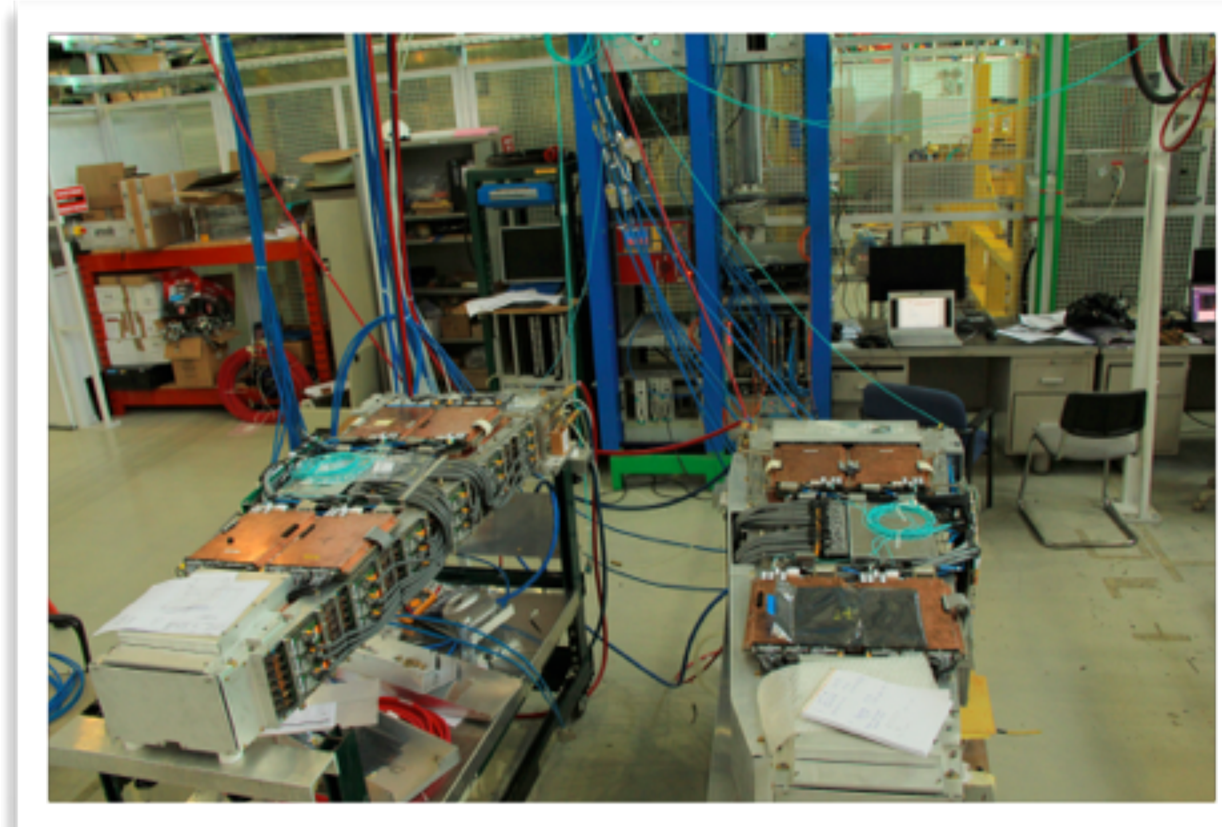


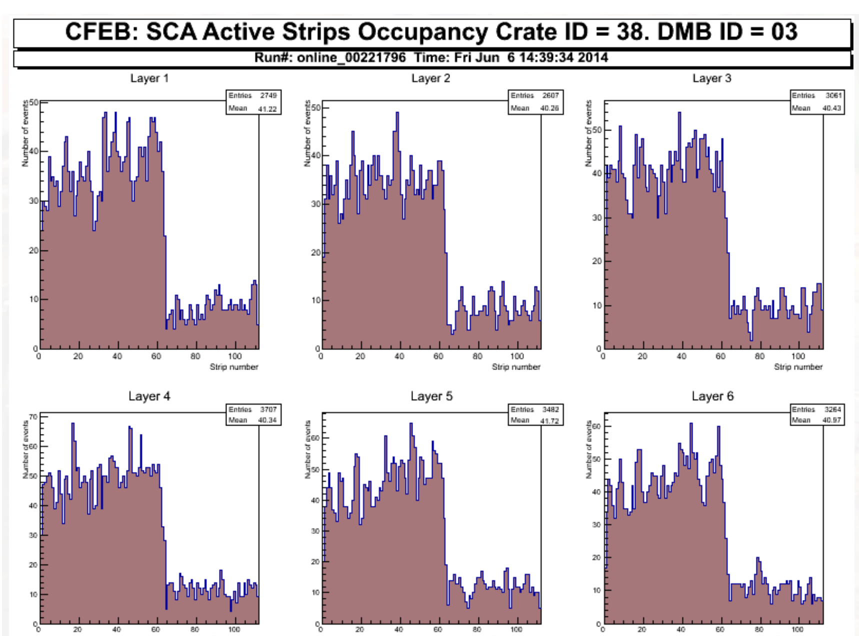


Simulation with pileup=100

ME1/1 and ME4/2 chambers were tested thoroughly before (re)installation

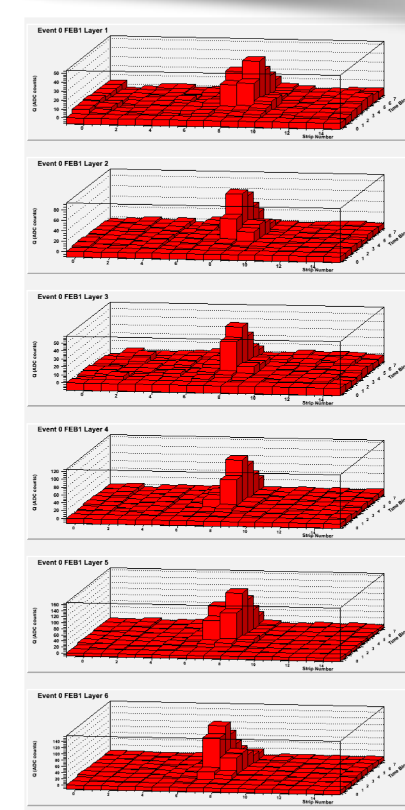
- comprehensive suite of tests: basic functionality, connectivity, trigger logic, data quality & noise levels
- use generated pulses and cosmic rays
- 4-weeks of high voltage monitoring & gas leak tests
- all connectivity and data quality tests repeated in situ
- included in global CMS cosmic ray data taking
- a few problems identified and repaired: bad boards, loose connections, etc.





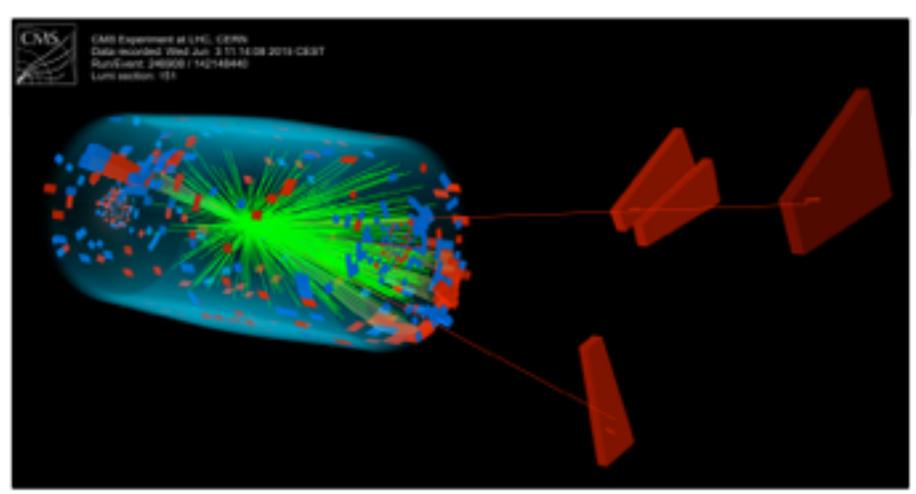
Sample data quality plot: strips occupancy.

Event display of a triggered cosmic ray muon detected in 6 layers of strips.



Run 2 CSC performance

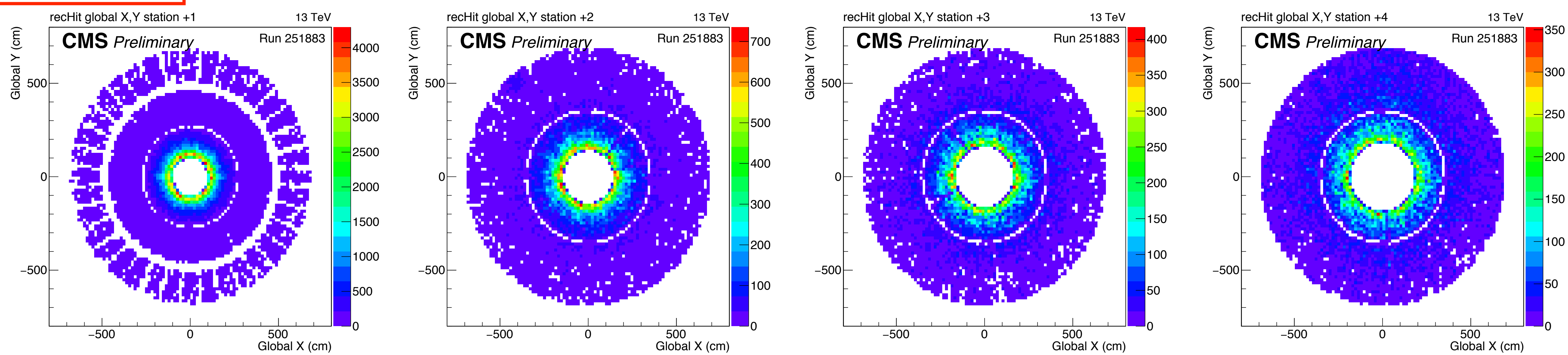
First stable
13 TeV collisions
June 3, 2015



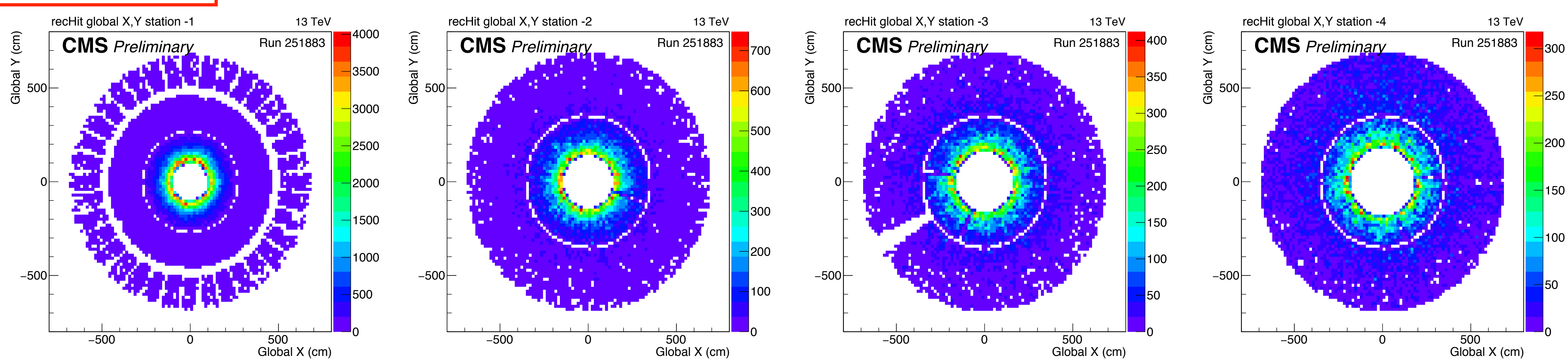
The reconstructed hit occupancy is uniform across all stations

- Problematic chambers typically produce low or high occupancy.
- One chamber (ME-3/2/22) had been disabled because of a faulty board, since replaced.
- Otherwise occupancy is good in all chambers.

Plus endcap:

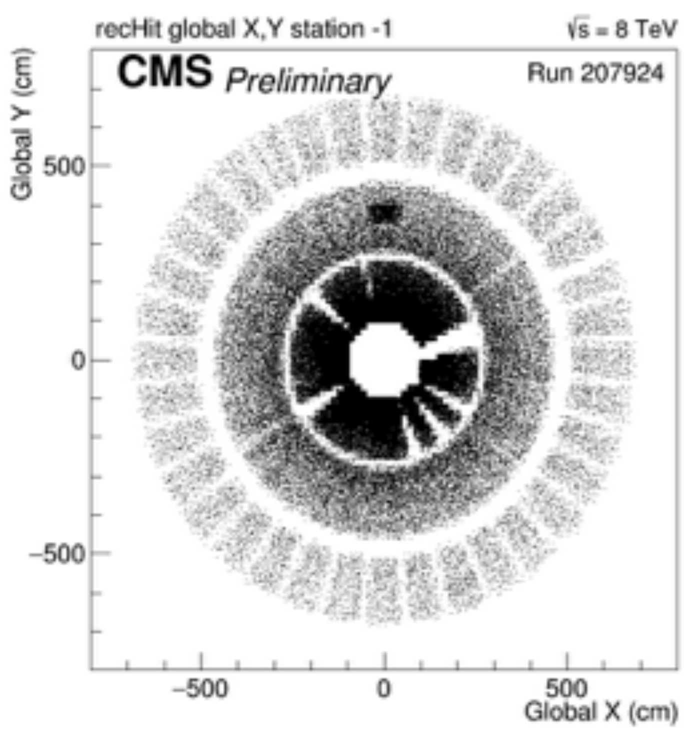


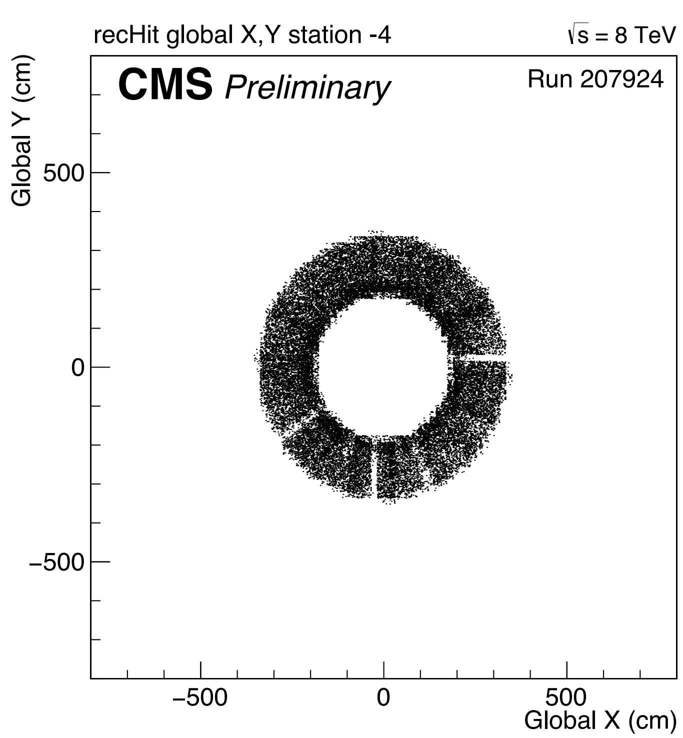
Minus endcap:



The hit efficiency has improved since Run 1

Run 1

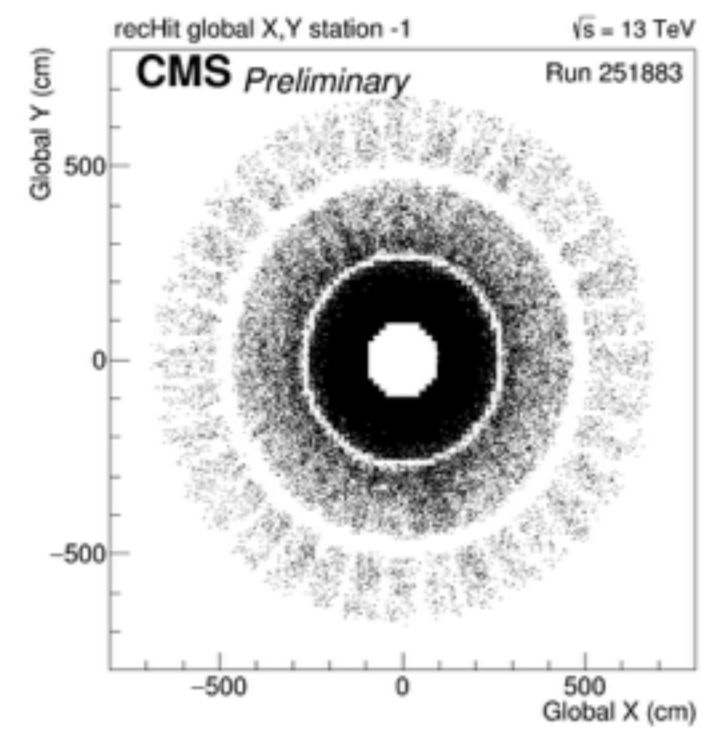


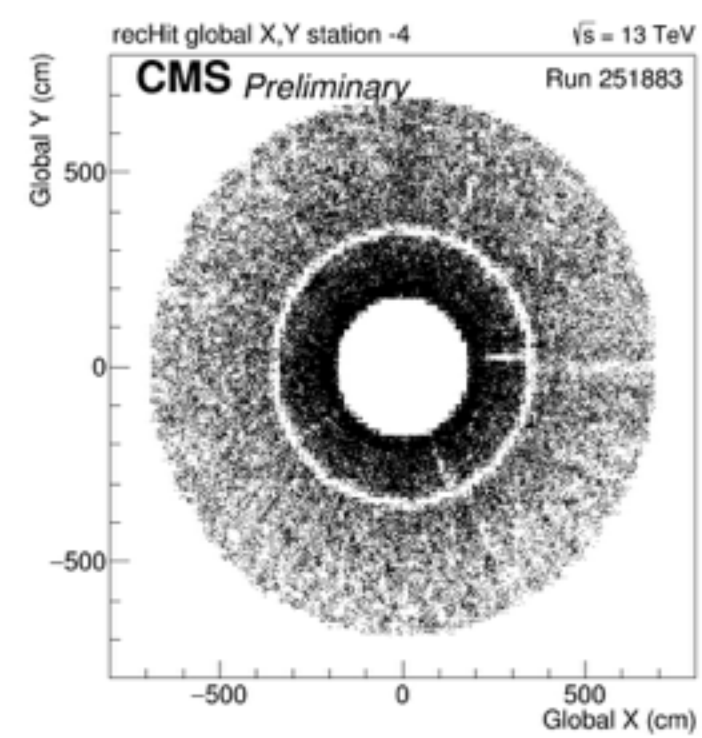


Problematic chambers in ME1/1 repaired

ME4/2 chambers installed

Run 2

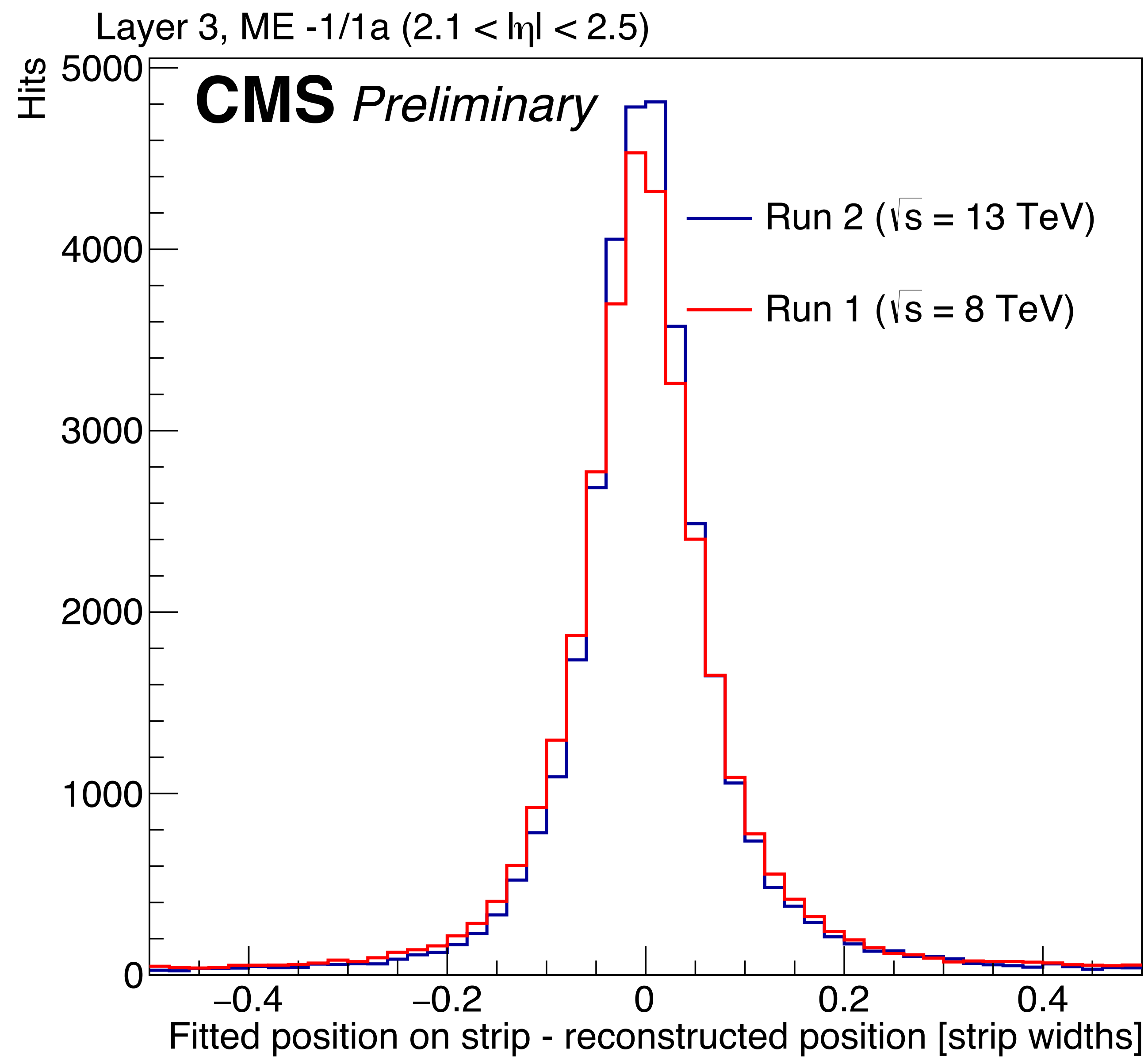




The hit position resolution has improved in ME1/1a ($2.1<|\eta|<2.5$)

The difference between the position of a reconstructed hit in layer 3 and the position obtained by fitting a segment with hits from the other 5 layers.

- The improvement in resolution in ME1/1a is primarily from the removal of triple-ganging the strips. This reduces the capacitance, which in turn decreases the front-end noise.
- Resolution in all CSC stations varies from 50 - 140 μm, depending on the station. Corresponds to resolution in Φ of ~0.1 mrad.

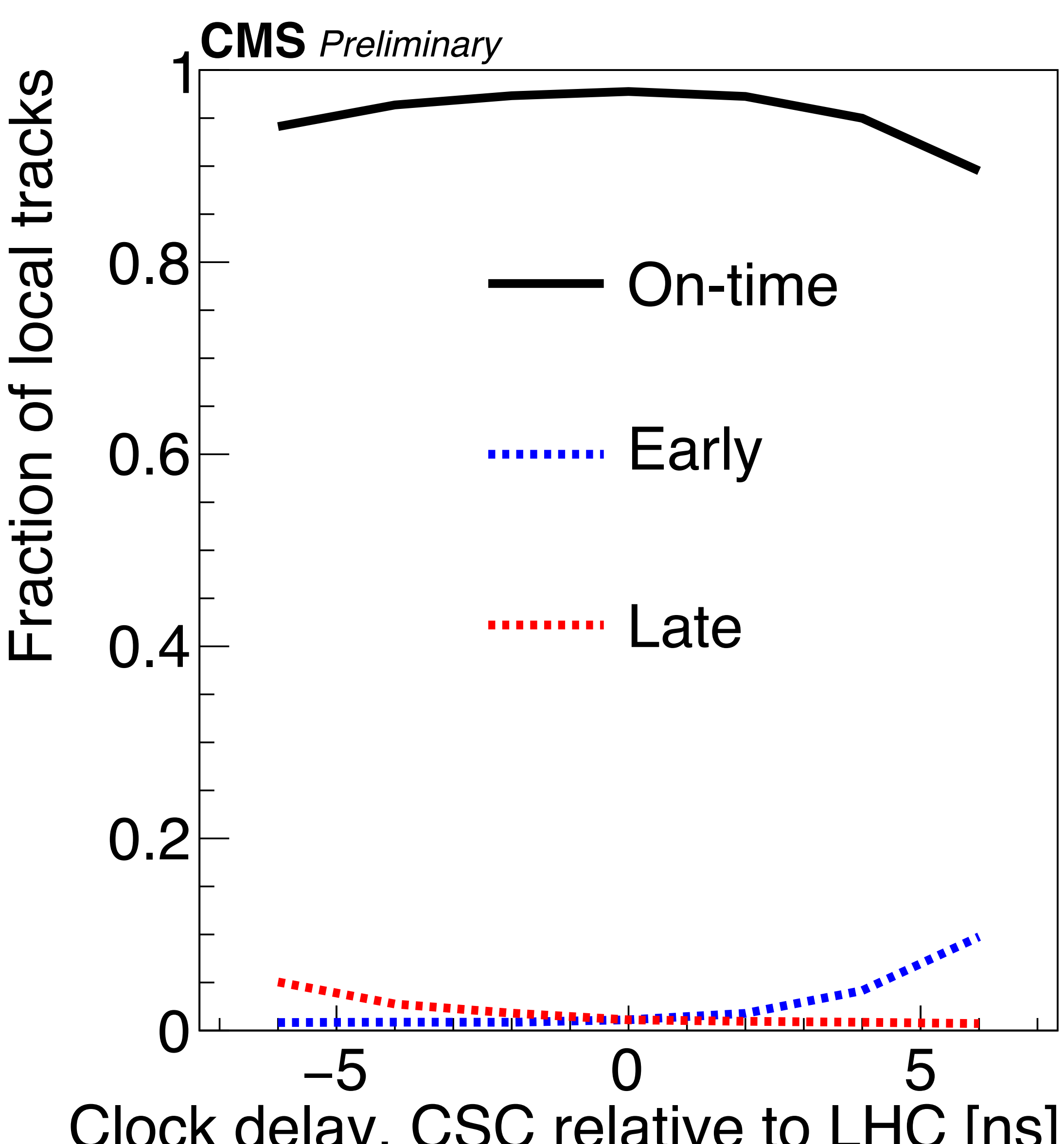


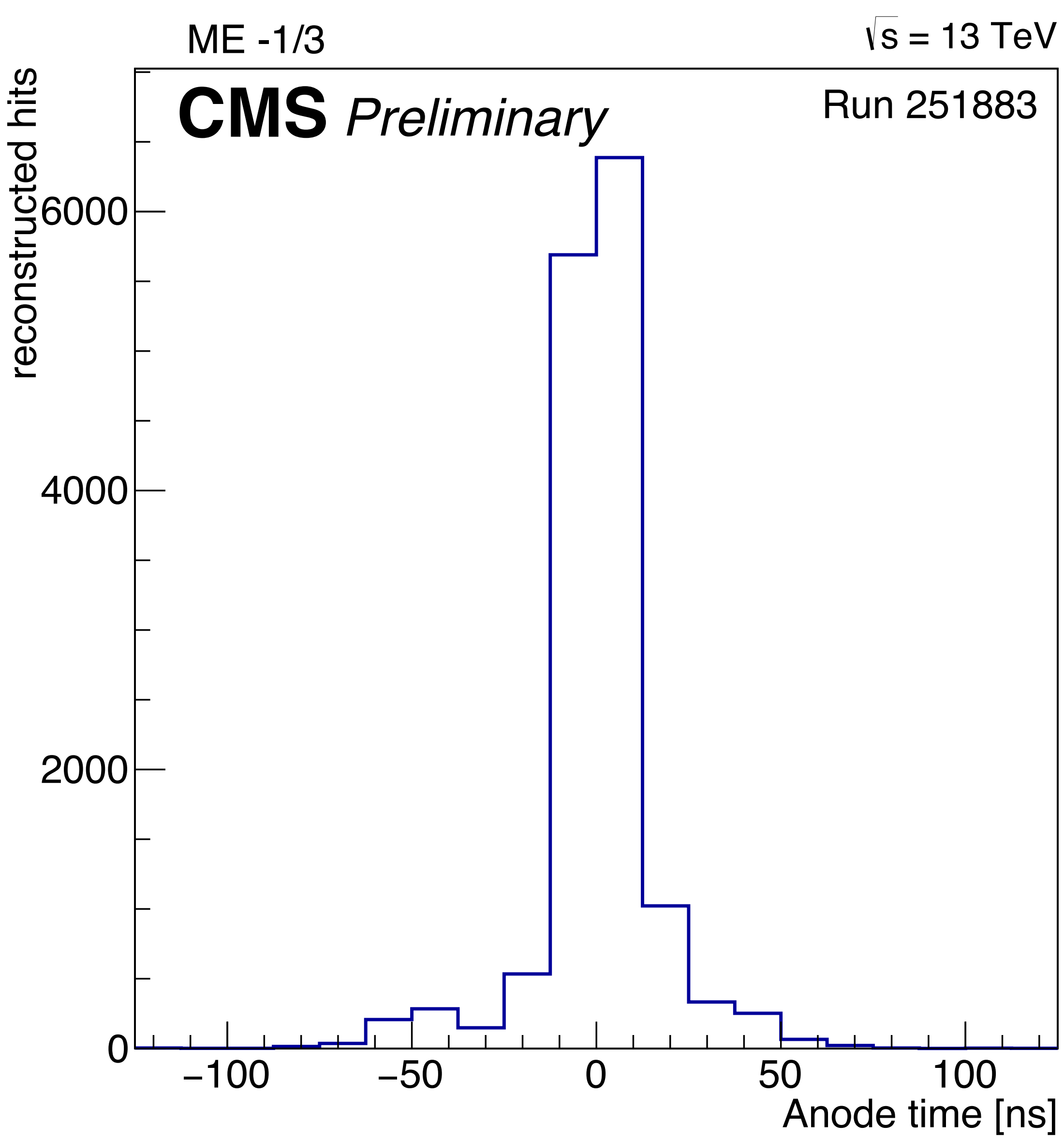
ME1/1a resolution improved by 20%
Run 2: σ = 51 μm
Run 1: σ = 64 μm

The chambers are timed-in

Timing study
For each station, find the clock delay that maximizes # local tracks in correct time window.

The interaction point time of reconstructed hits is centered at 0, as expected for timed-in chambers. The timing and synchronization accuracy is at the level of Run 1.

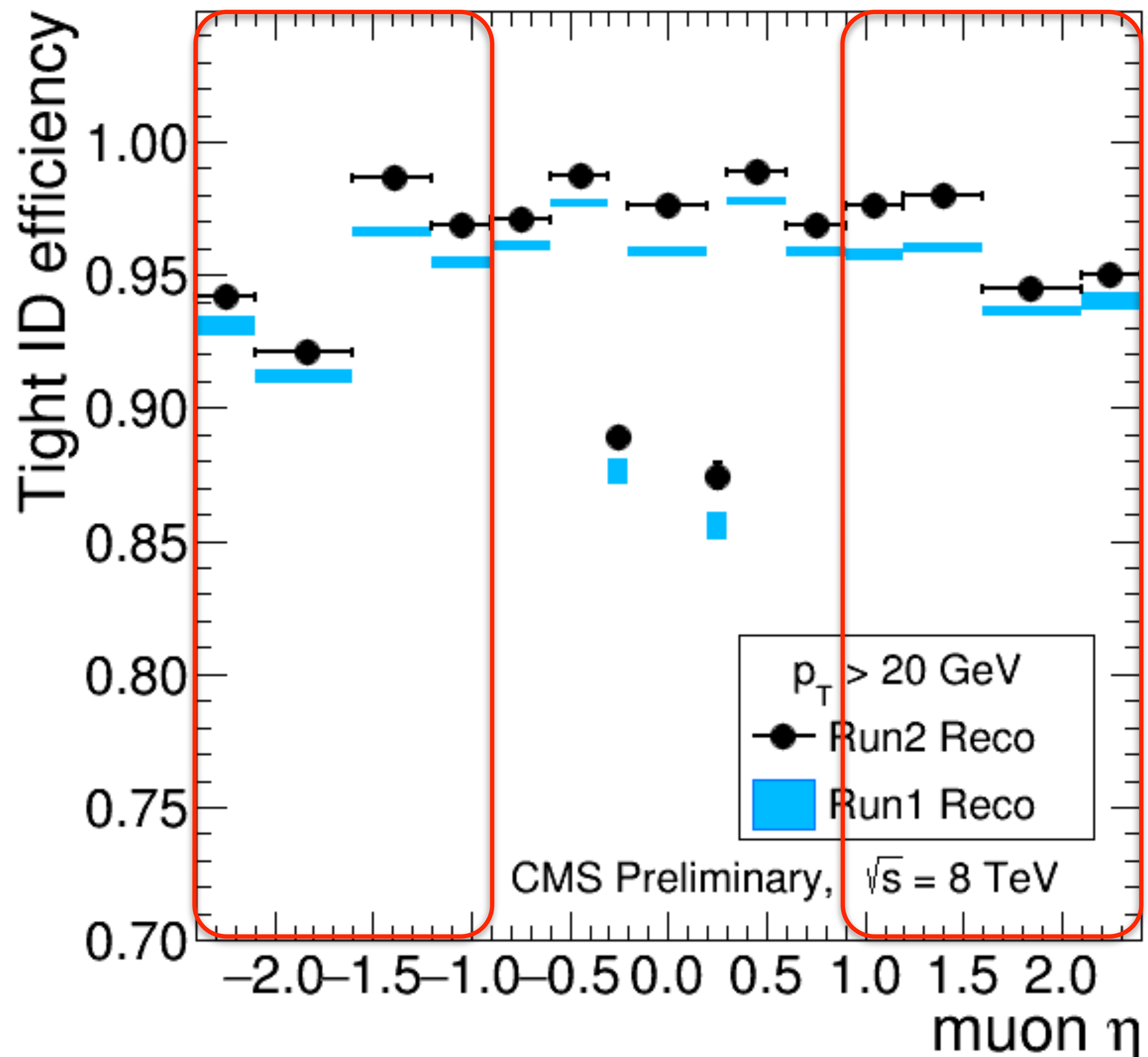




Readiness of entire muon system in Run 2

The muon reconstruction efficiency has improved by 1-2%

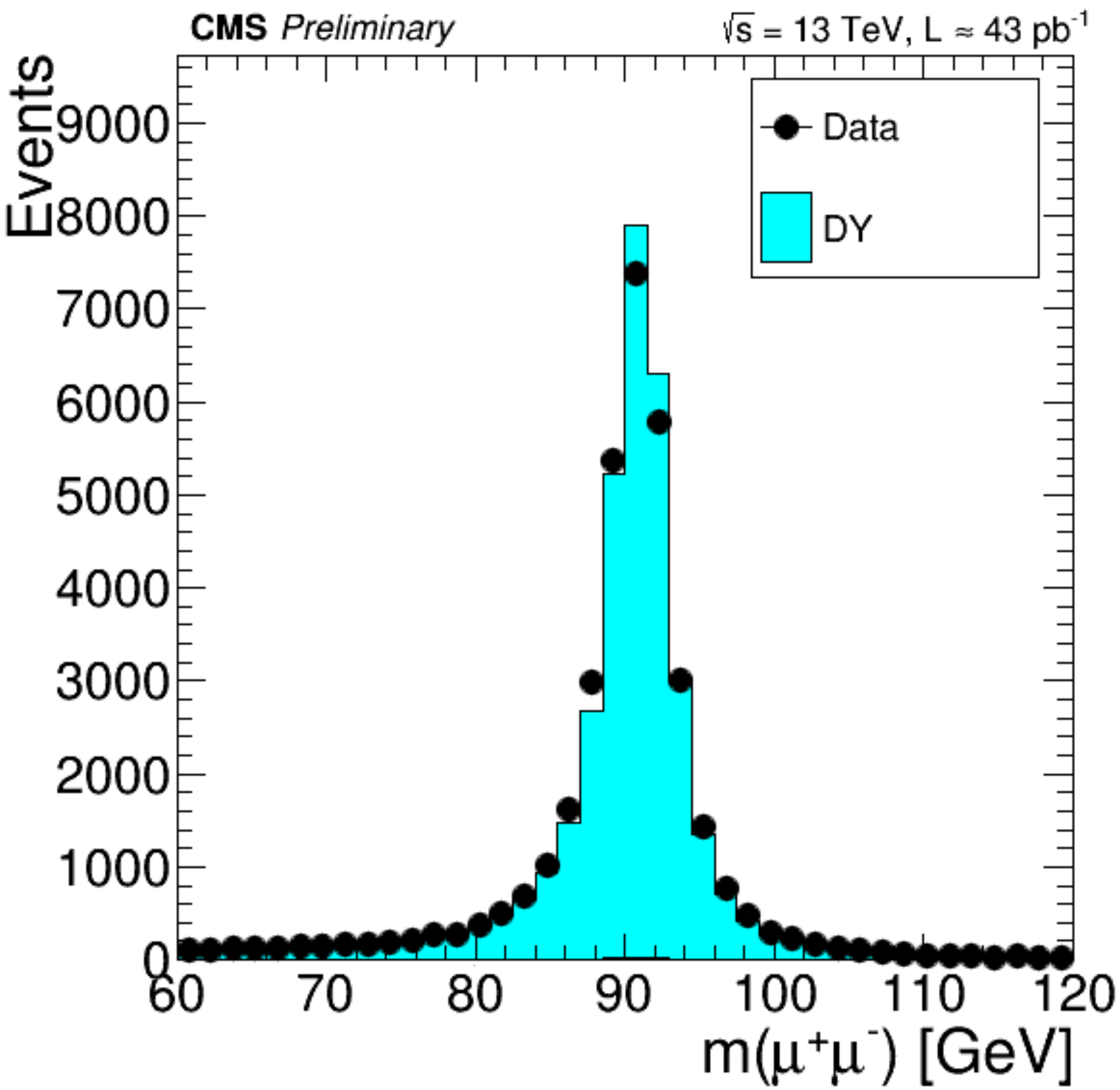
- Efficiency to pass tight muon ID is measured with $Z \rightarrow \mu\mu$ **tag and probe** study.
- The Run 1 and Run 2 muon **reconstruction algorithms** are applied to the same set of Run 1 data.
- Improved performance is mainly due to new **muon-specific tracking iterations**.
- Improvement is independent of pseudorapidity (shown here) and number of vertices (not shown).

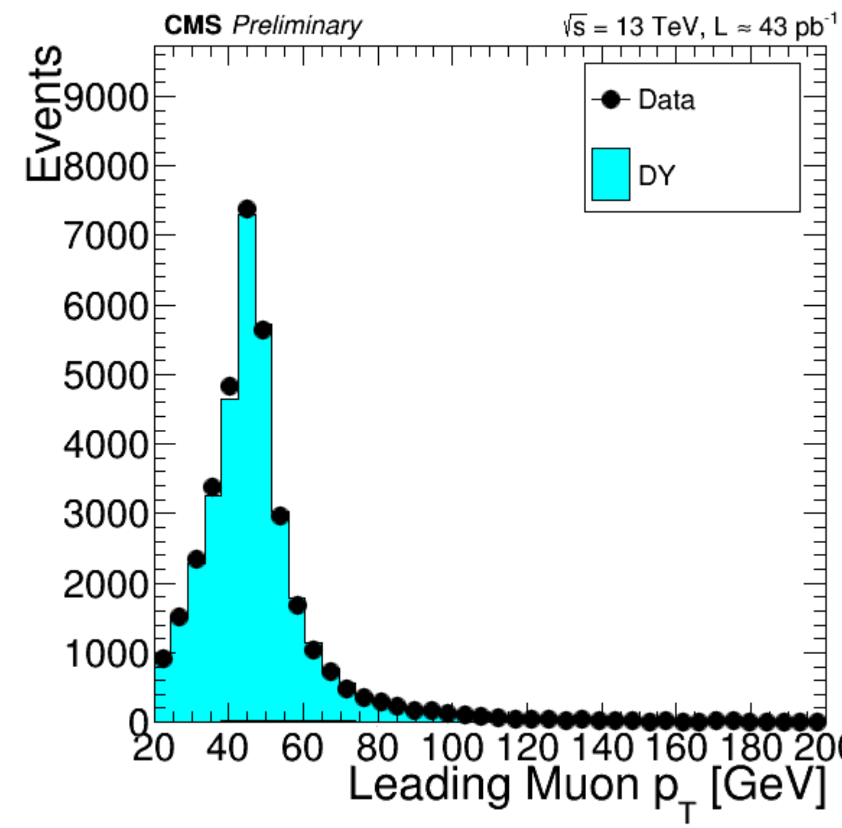


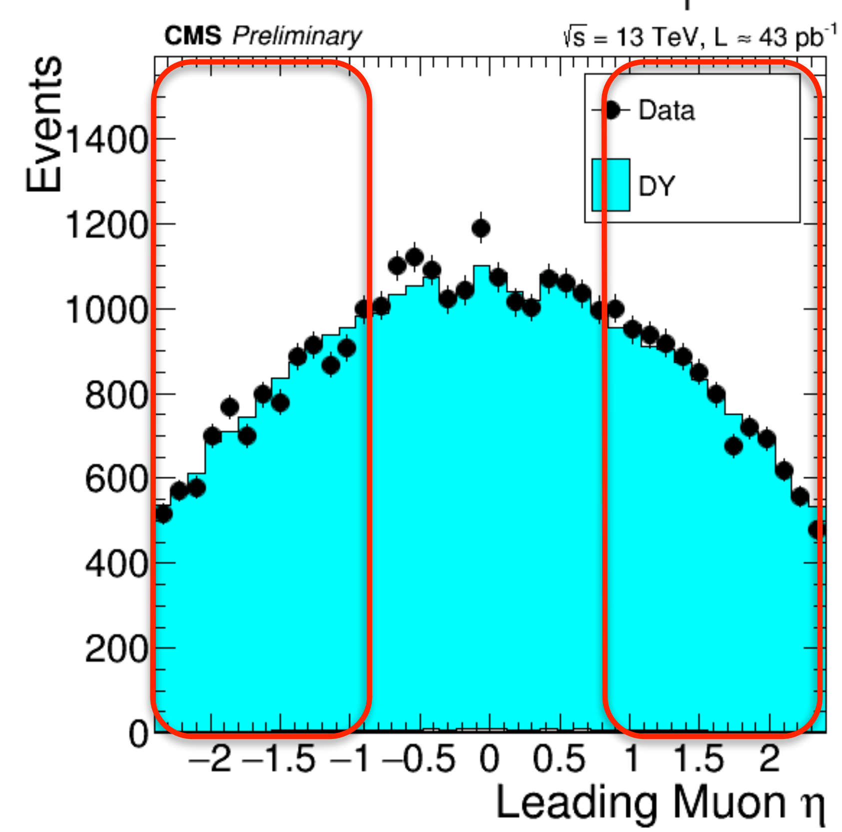
region of CSC coverage

First look at 13 TeV data: Z→μμ events

- $p_T > 20$ & 10 GeV, $|\eta| < 2.4$, loose isolation requirement
- MC:
  - alignment & calibration conditions as expected after 1 fb^{-1}
  - no pile-up reweighting
- **Simulation agrees with data**



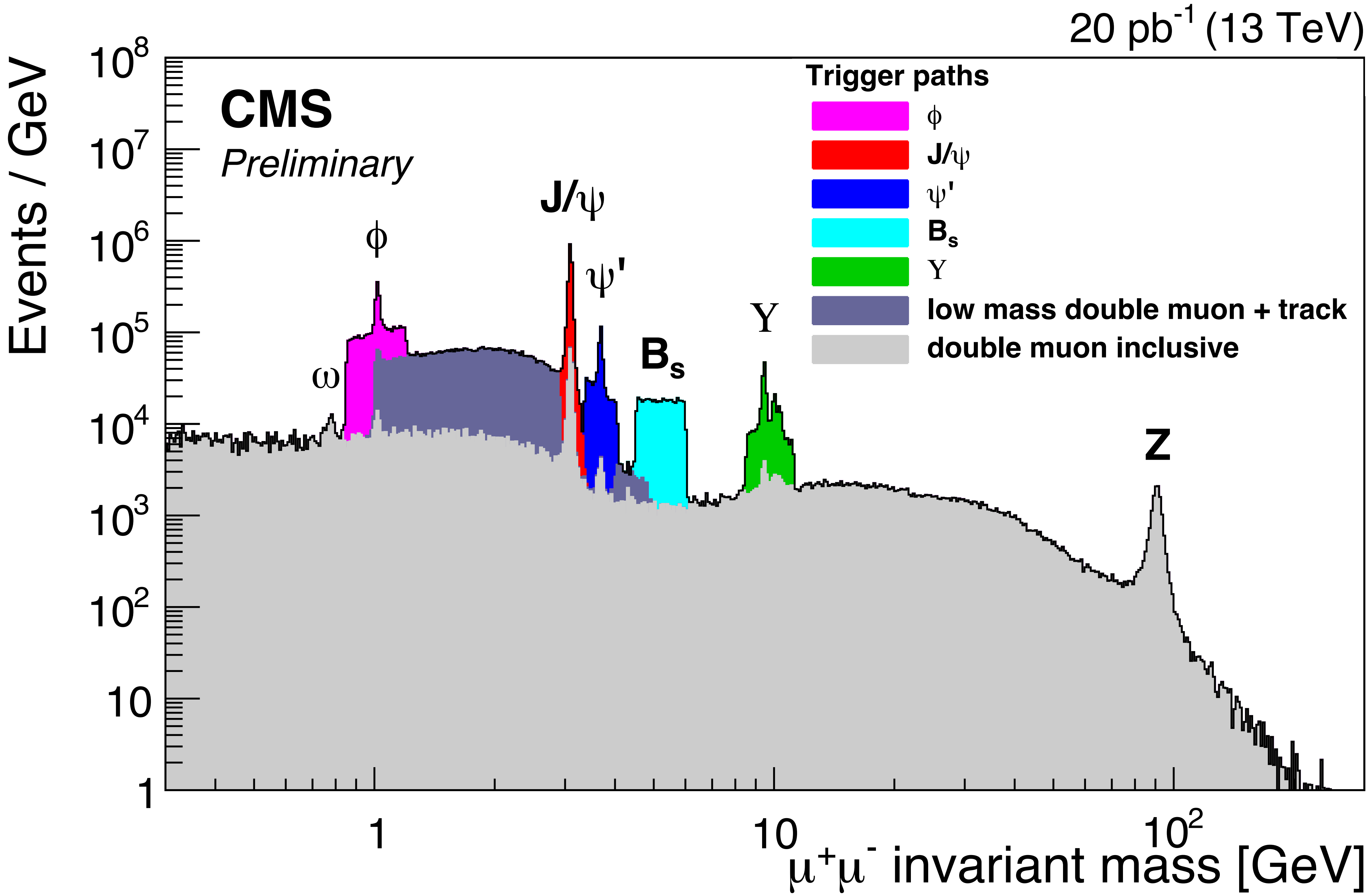




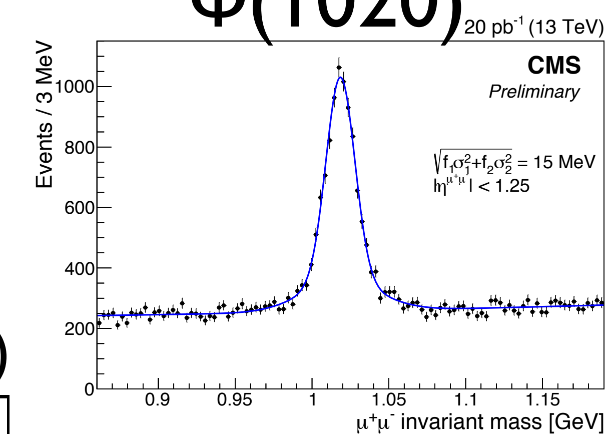
region of CSC coverage

The history of particle physics for the first time at $\sqrt{s}$=13 TeV

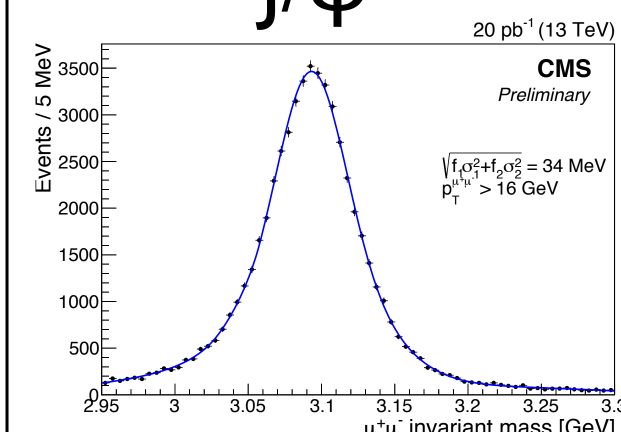
- Dedicated triggers target various resonances.
- Data around resonance peaks well-described by fits.



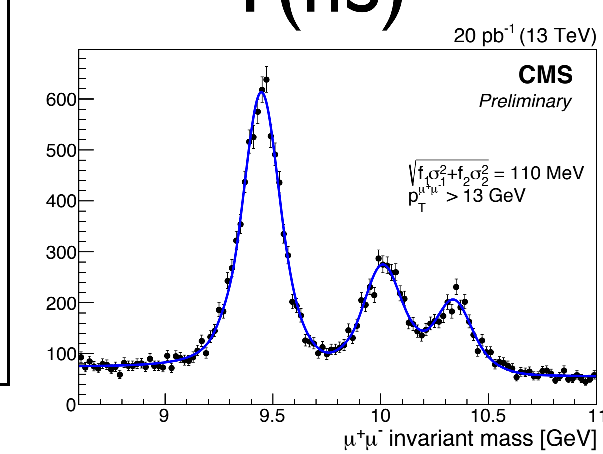
Φ(1020)



J/ψ



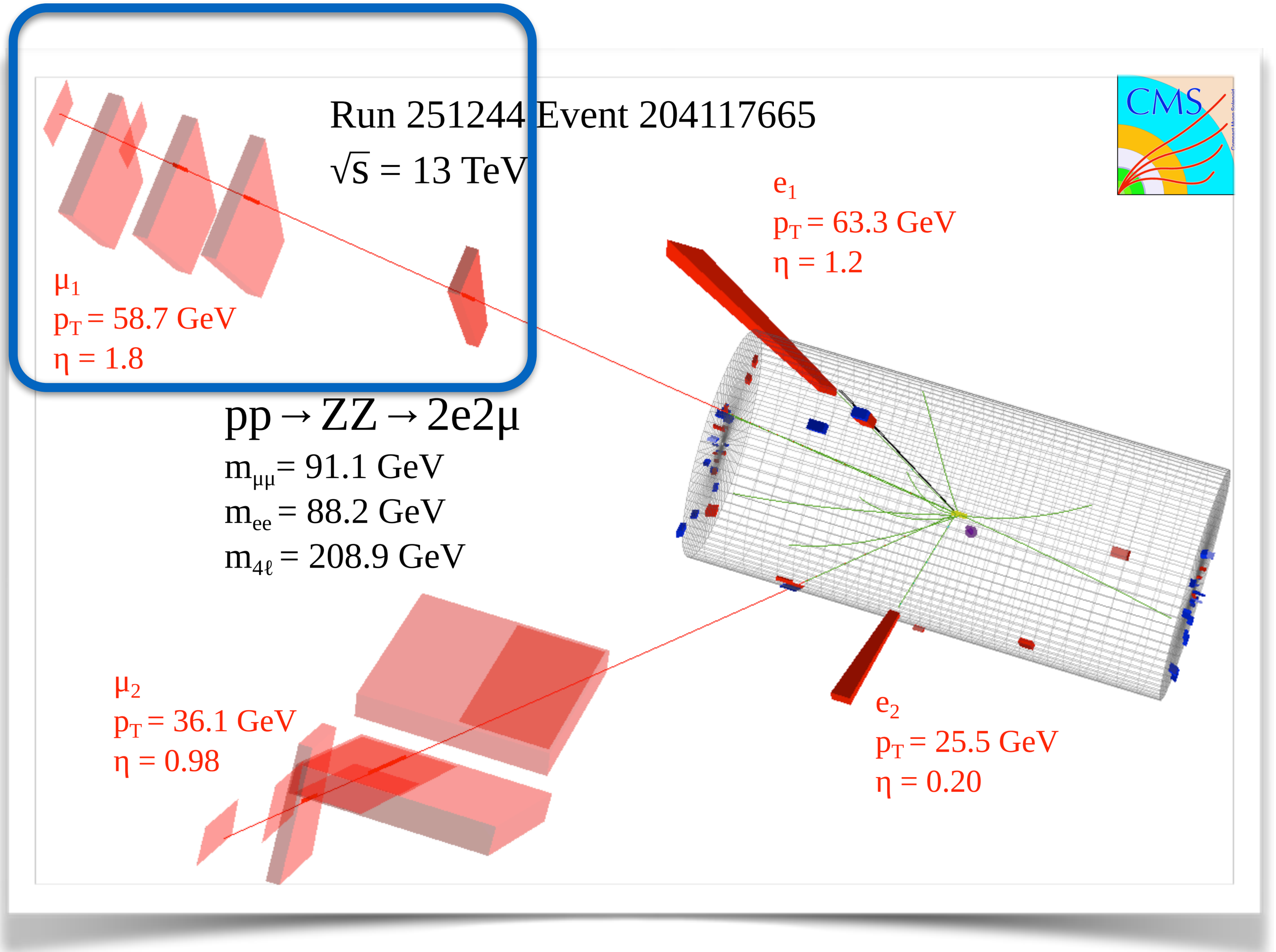
Υ(nS)



The CMS Cathode Strip Chambers are ready for Run 2

- A **great effort** of **many people** over the past **2+ years** has gone into preparing the CSC's for Run 2.
- **Improved ME1/1 electronics** remove ambiguity from triple-ganging of strips in ME1/1a, reduce deadtime by storing data in digital pipeline.
- **New ME4/2 chambers** provide 4-station redundancy → reduce fake rates and improve efficiency.
- The CSC's have been timed in and are taking data with **high efficiency**.
- Performance of CSC's in early stages of Run 2 is **improved** from Run 1.

muon detected by CSC's



We expect many interesting events like this one in the months/years ahead!