



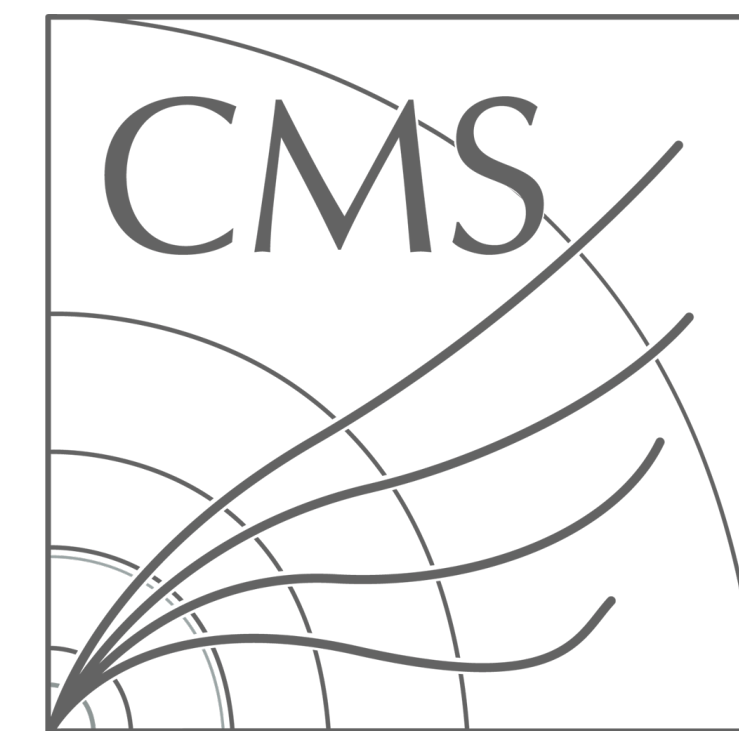
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Muon performance with CMS detector in Run2 of LHC

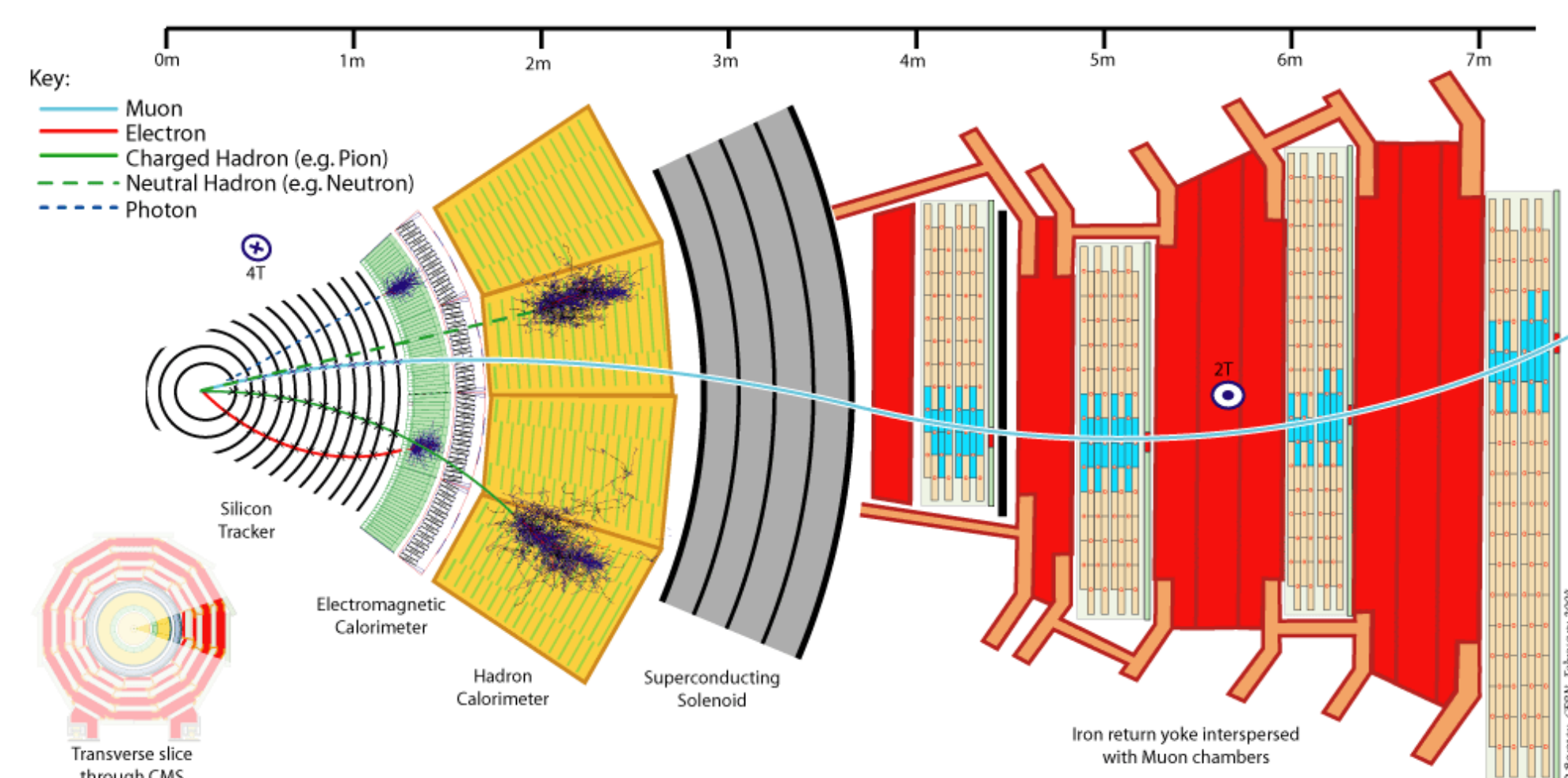
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EPS-HEP2019: European Physical Society Conference on High Energy Physics, 10-17 July 2019, Ghent (Belgium)



Offline muon reconstruction and identification with CMS:



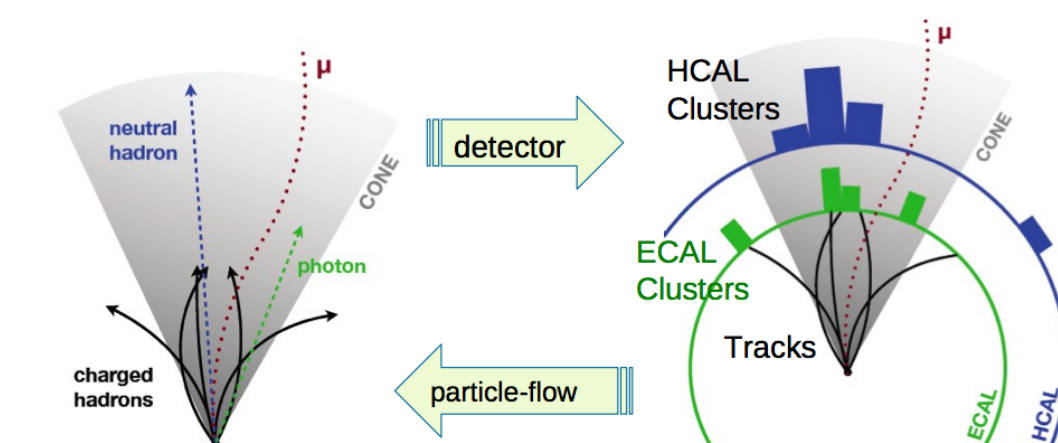
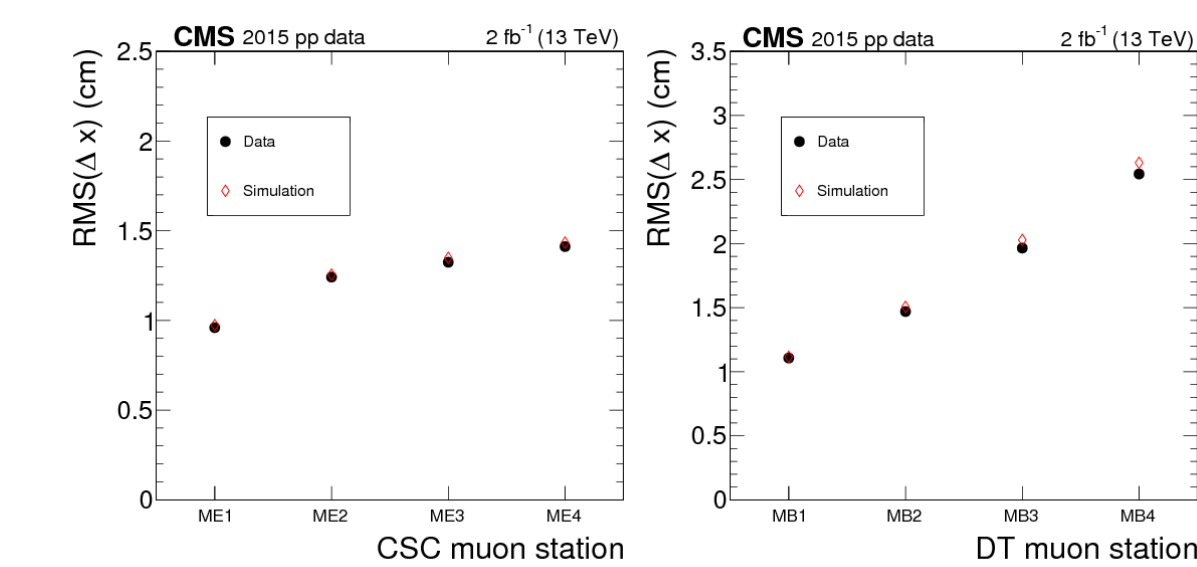
Muon reconstruction overview [1]:

- ▶ **local muon reconstruction**: segments from DT/CSC chambers, hit clusters for RPC
- ▶ **standalone muon tracks**: built in the muon system out of segments/clusters
- ▶ **tracker tracks**: built out of inner tracker hits
- ▶ **global muons**: combine standalone tracks with tracker tracks (refit performed)
- ▶ **tracker muons**: propagate tracker-tracks to muon system, match with segments

Reconstructed muons are **fed into the CMS particle flow** (PF) [2].

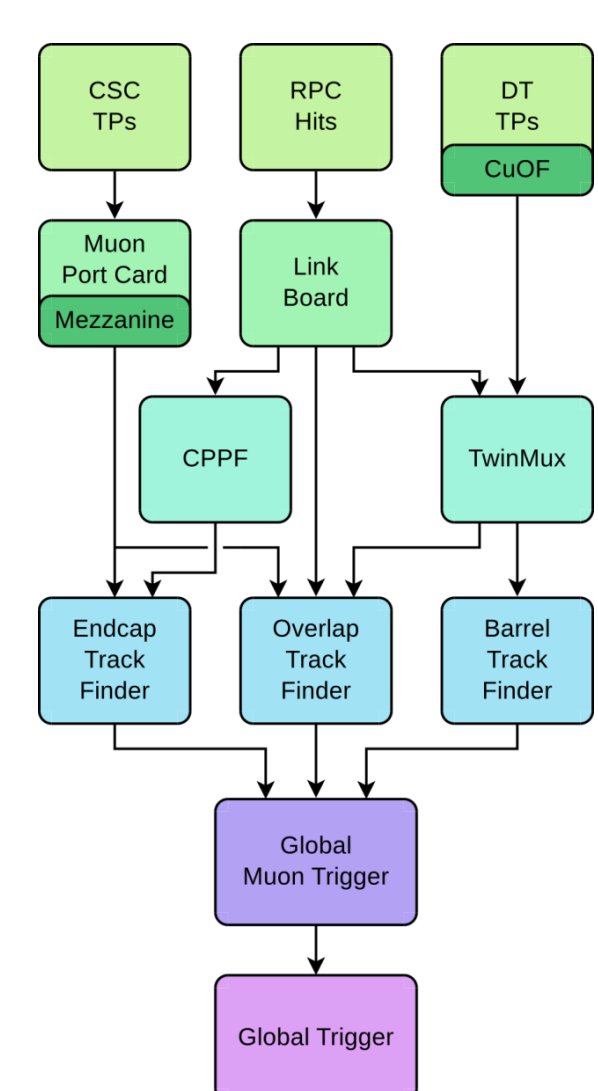
Identification and **isolation variables** also computed

- ▶ used to define selection criteria applied at analysis level

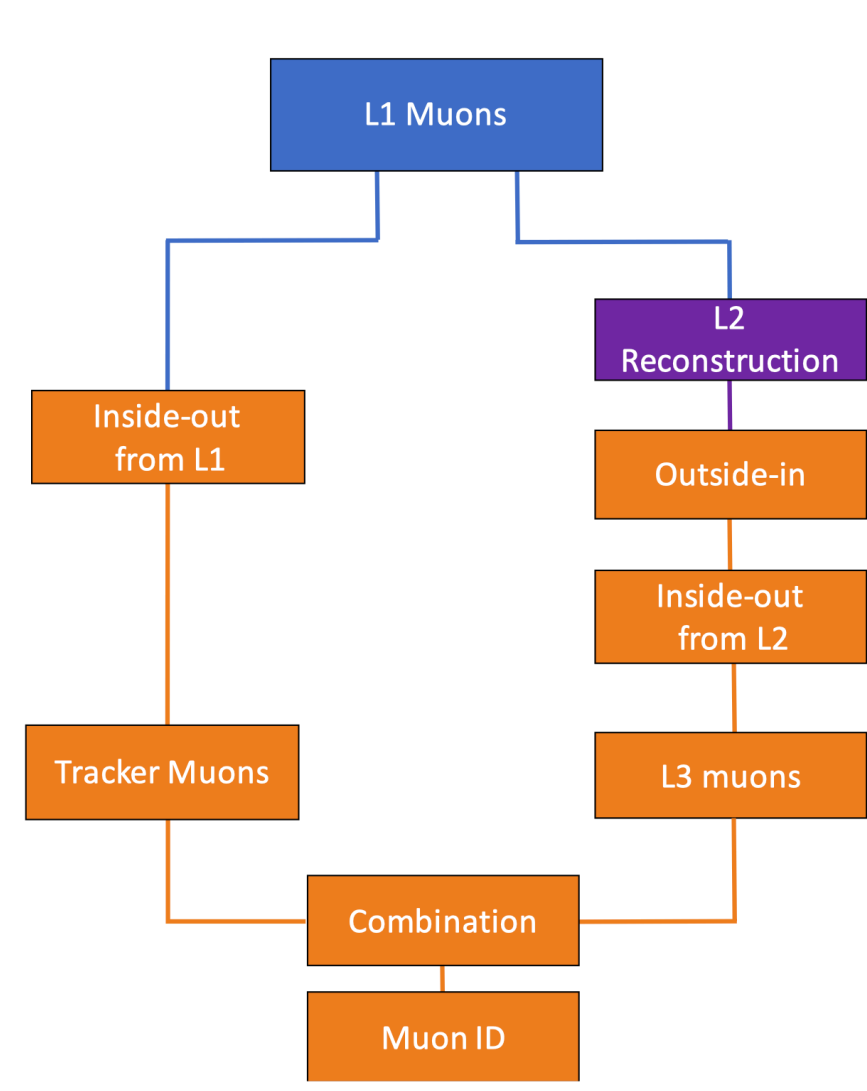


Muons in the CMS trigger:

L1T muon:



Muon HLT:



CMS trigger staged in 2 levels:

- ▶ **L1 trigger (L1T)**:
 - ▶ dedicated hardware
 - ▶ coarse data from muon system/calorimeters
 - ▶ rate: from 40MHz to < 100 kHz
- ▶ **High-Level Trigger (HLT)**:
 - ▶ software based
 - ▶ uses full detector information/granularity
 - ▶ rate: down to ~ 1 kHz

L1T and HLT significantly evolved along Run2, present description refers to 2018 “general purpose” triggers.

L1T muon:

- ▶ **trigger segments** (TP) built within **CSC/DT, hit clustering** performed for **RPC**
- ▶ TPs/clusters get combined at chamber level (e.g. in TwinMux) or within Track Finders
- ▶ **three Track Finders** (TF) **build tracks** in different $|\eta|$ regions, **estimate candidate p_T**
- ▶ information from different TFs combined by **Global Muon Trigger**

Muon HLT:

- ▶ starts using **L1T muon candidates as seeds**
- ▶ **local and standalone** muon reconstructions (L2) **similar to offline** counterpart
- ▶ runs **dedicated inner tracker reconstruction**
- ▶ produces **both tracker and global** (L3) **muon tracks**
- ▶ for certain triggers, **computes detector-based isolation**

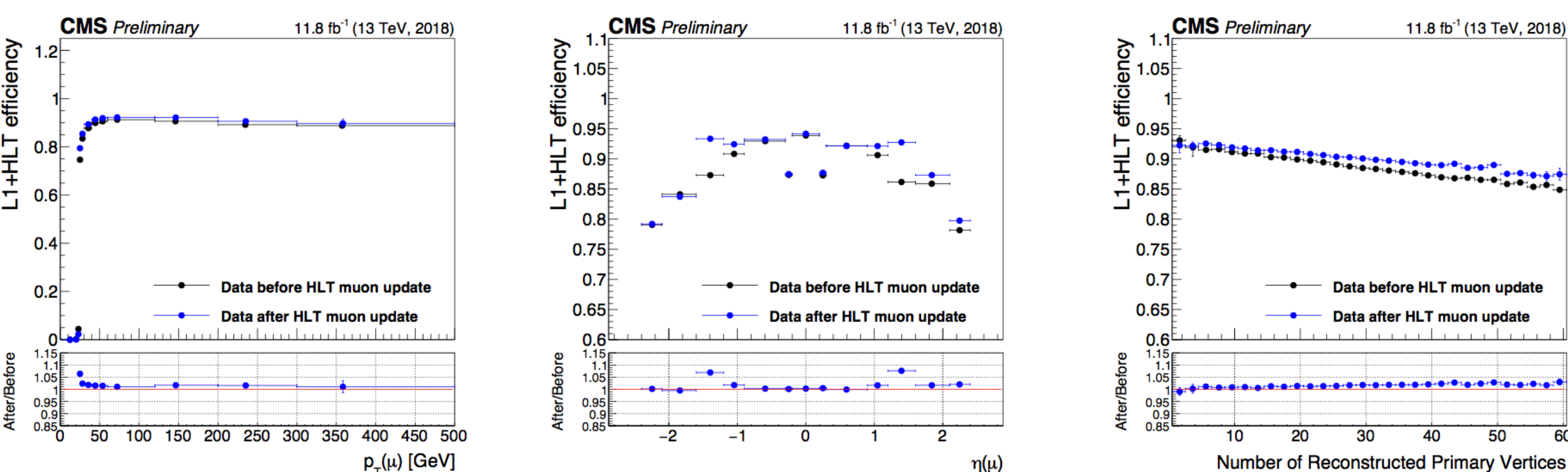
Muon trigger performance:

General purpose muon triggers used in 2018 (and rates @ $2 \cdot 10^{34} \text{ cm}^{-1}\text{s}^{-1}$):

- ▶ single isolated muon trigger: $p_T > 24 \text{ GeV}$ (~250 Hz)
- ▶ single non isolated muon trigger: $p_T > 50 \text{ GeV}$ (~49 Hz)
- ▶ double (isolated) muon trigger: $p_T > 17/8 \text{ GeV}$ (~30 Hz)

Single isolated muon trigger efficiency computed using a **Tag-and-Probe** method exploiting events with dimuons from Z decays collected by a single muon trigger [3]:

- ▶ overall plateau efficiency ~90% (L1T efficiency: ~94%)
- ▶ η dependence mostly driven by L1T
- ▶ mild pile-up dependence (mostly driven by isolation)

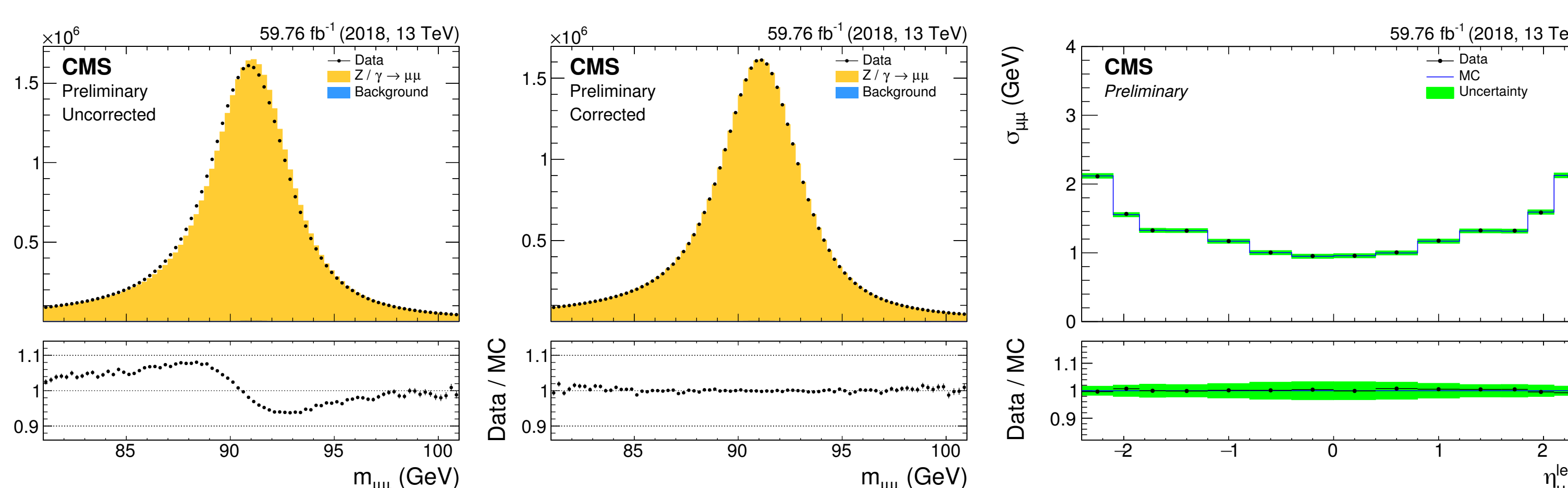


Scale and resolution:

Accurate **calibration of muon scale and resolution**, valid up to a p_T of ~ 200 GeV computed using dimuons from J/ψ and Z decays.

Use $\langle 1/p_T \rangle$ of muons from Z and peak of invariant mass distributions around resonances (J/ψ and Z) to derive **additive** (tracker misalignment) and **multiplicative** (energy-loss / B field modelling) **corrections to the muon curvature**, computed in bins of muon charge, η and ϕ .

The **resolution dependence** over η and p_T is **parametrised** and **smearing factors are computed** out of the width of invariant mass distributions. They are **applied in simulation to match the data**.



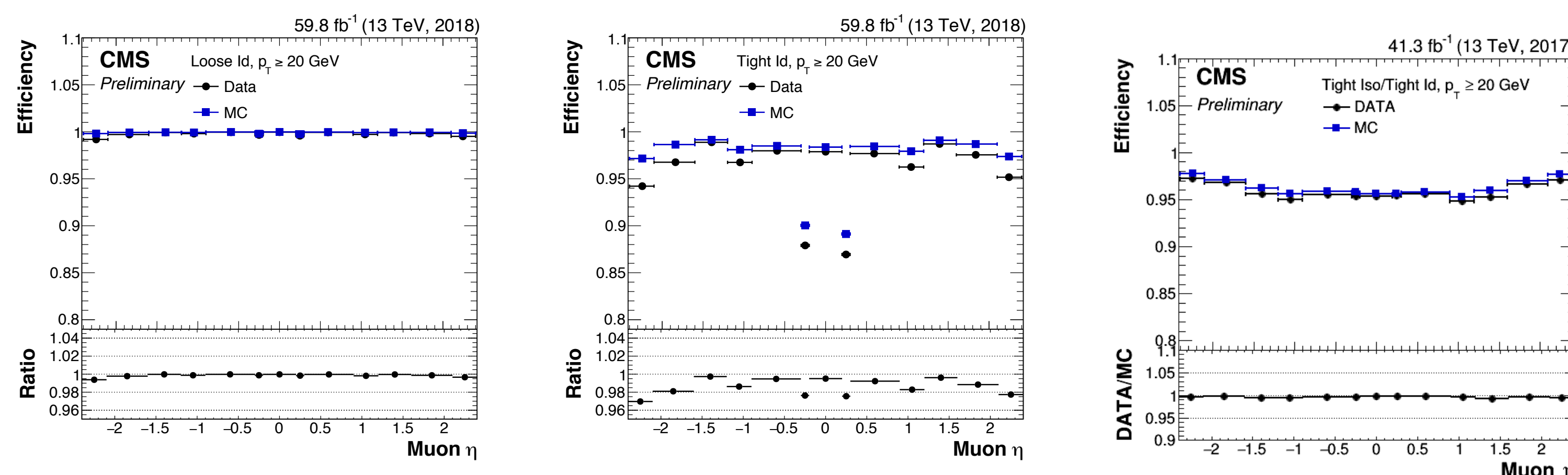
References:

[1] Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at $\sqrt{s} = 13 \text{ TeV}$, JINST 13 (2018) P06015.

[2] Particle-flow reconstruction and global event description with the CMS detector, JINST 12 (2017) P10003.

[3] Muon HLT Performance with 2018 Data, CMS DP-2018/034. [4] <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsMUO>

Offline identification and isolation:



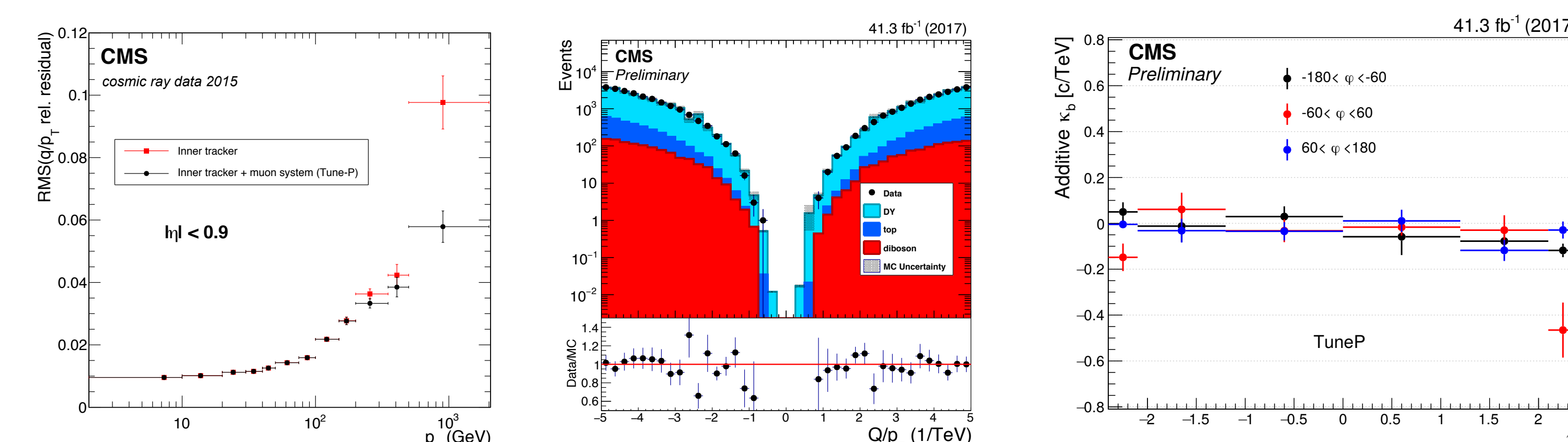
Efficiency of muon identification (ID) and isolation criteria measured with a **Tag-and-Probe method** [4] using events with dimuons from J/ψ or Z decays collected with triggers requiring the presence of, at least, a single muon.

Same method used in data and Monte Carlo (e.g. exploit simulated DY events). **Scale factors** are computed and **used as corrections in analyses**.

Summary of ID and isolation efficiency performance:

- ▶ efficiency to reconstruct and identify loose (PF) muons is ~100%
- ▶ tight ID criteria: ~97% efficient in data, with a scale factor ~ 98%
- ▶ tight PF isolation criteria: ~96% efficient, simulation models well the data

High-energy muons:



For muons of few hundreds GeV **combining information** from **inner tracker** and **muon system** significantly **improves the p_T measurement**. A set of combined fits is run in reconstruction and the “best” fit is selected by algorithms comparing all of them.

The **q/p_T resolution at high momentum** is **measured using cosmic muons** traversing CMS from top to bottom close to the beam line. The relative q/p_T difference is measured comparing the p_T of the muon legs reconstructed in the top and bottom halves of CMS.

Biases in the **momentum scale at high p_T** are measured **comparing the distributions of the muon curvature**, for opposite-sign dimuons, **in data and simulation**. Artificial curvature biases are added, in steps, to simulation and a χ^2 is computed to compare results for each “bias step” with data. The curvature bias in data is the one minimising such χ^2 .

