measurement of the cosmic muon charge asymmetry

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for the CMS Collaboration

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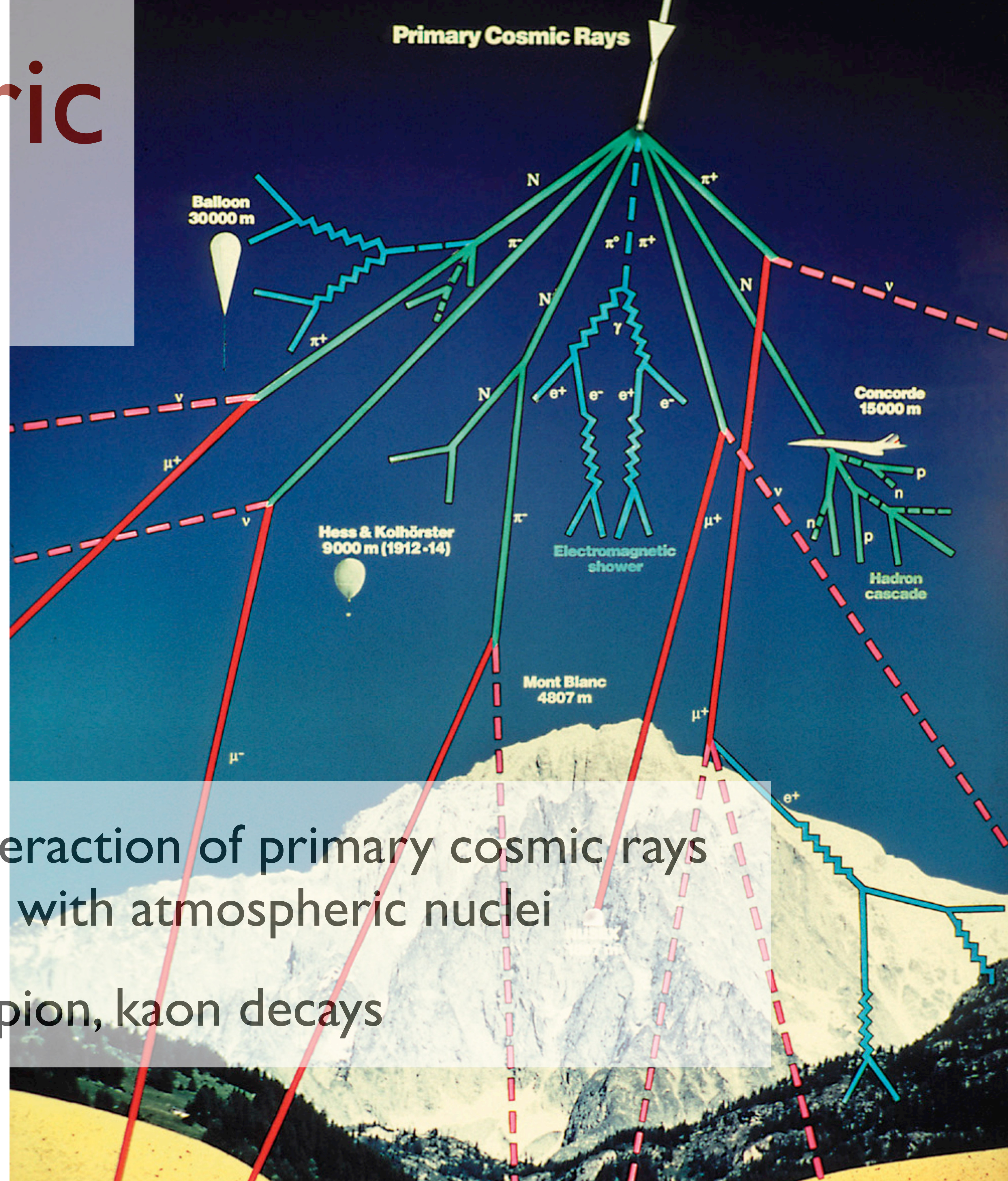
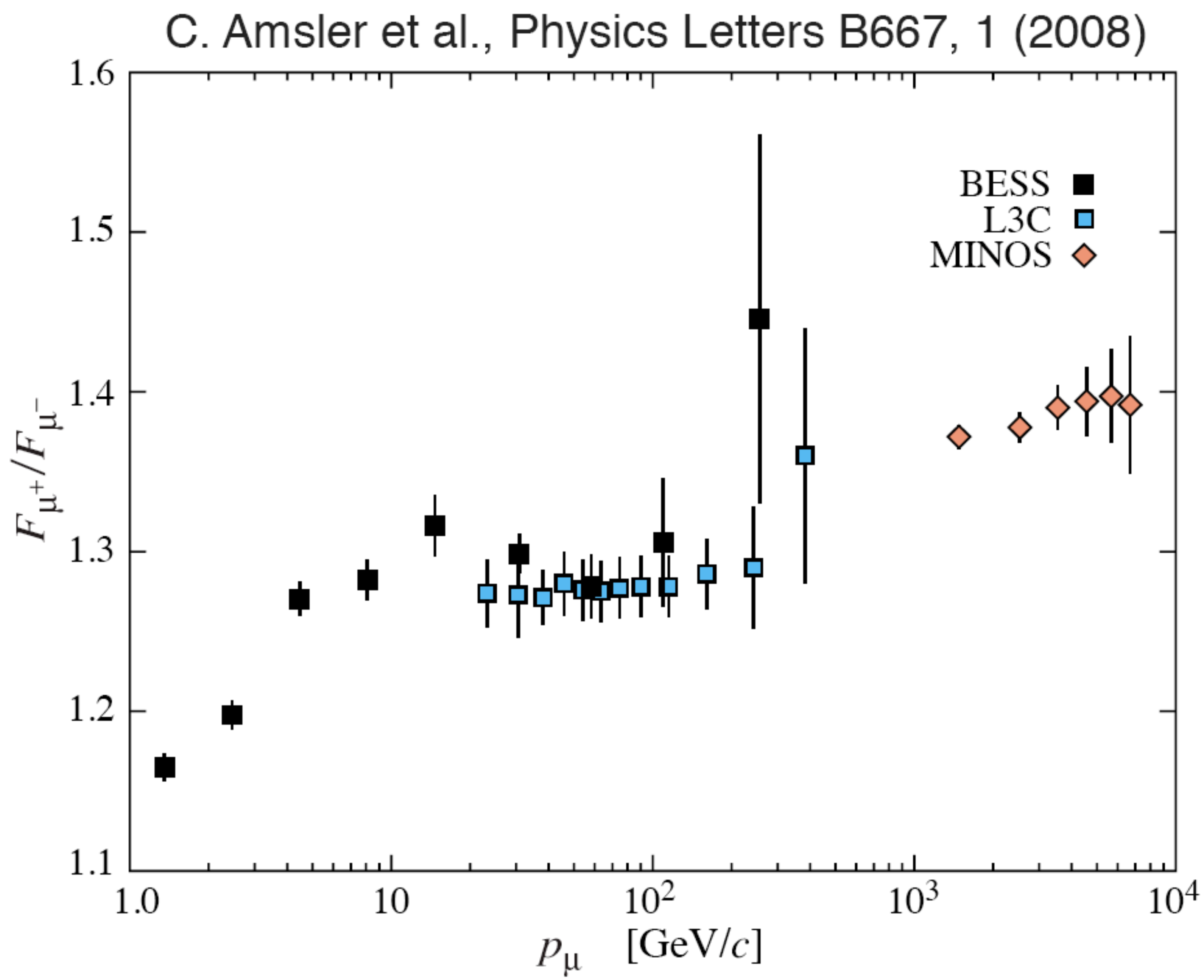
atmospheric muons



- produced in the interaction of primary cosmic rays (protons, neutrons) with atmospheric nuclei
- muons come from pion, kaon decays

- the muon charge asymmetry reflects π^+/K^+ excess over π^-/K^-

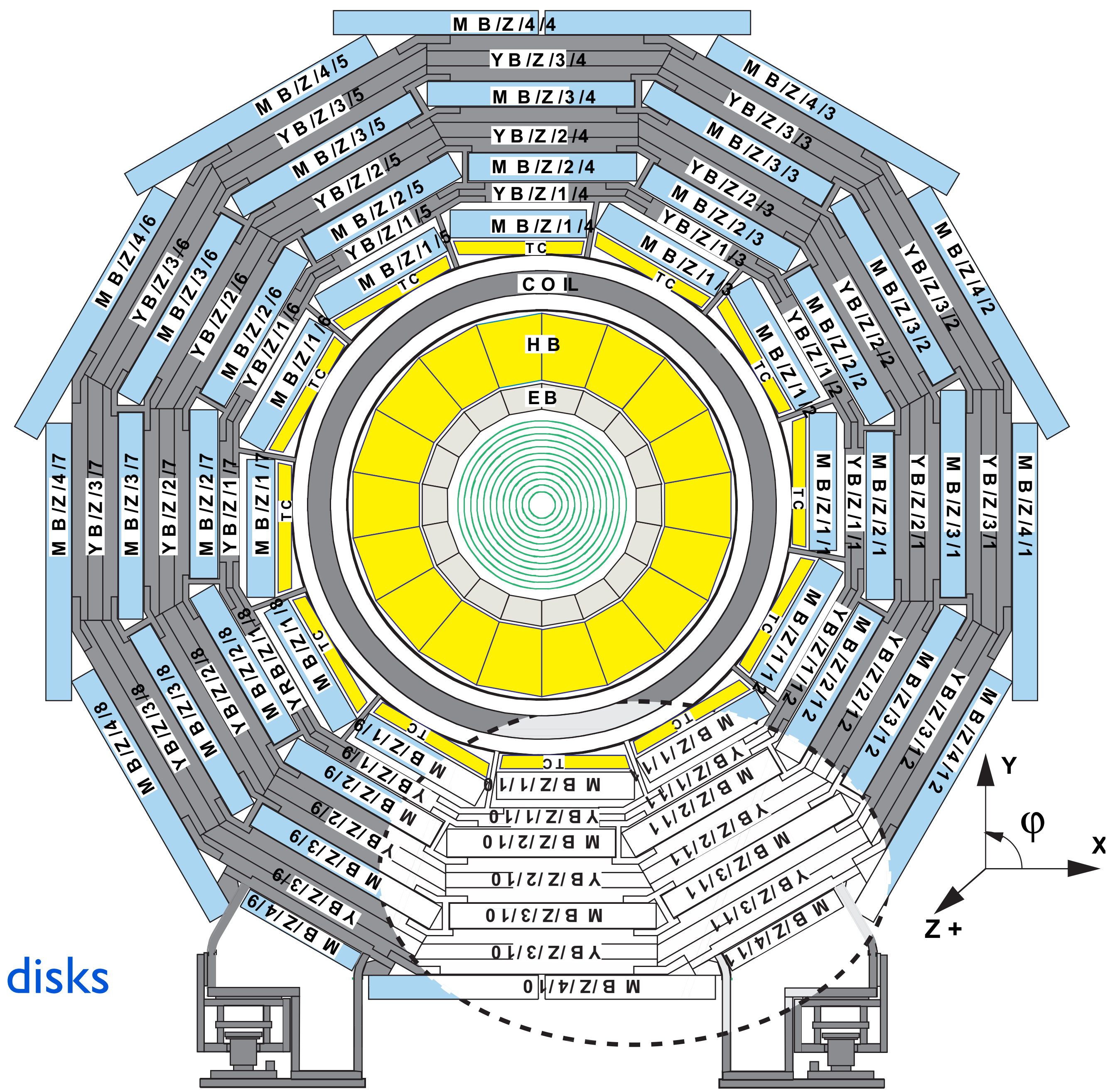


- our goal is measuring the cosmic muon charge ratio ***R(p)***
  - $R \equiv F_{\mu+} / F_{\mu-}$
  - ***p*** is the momentum at Earth's surface
  - no measurement from previous experiments between *400* and *1000 GeV*

MTCC *Magnet Test and Cosmic Challenge*

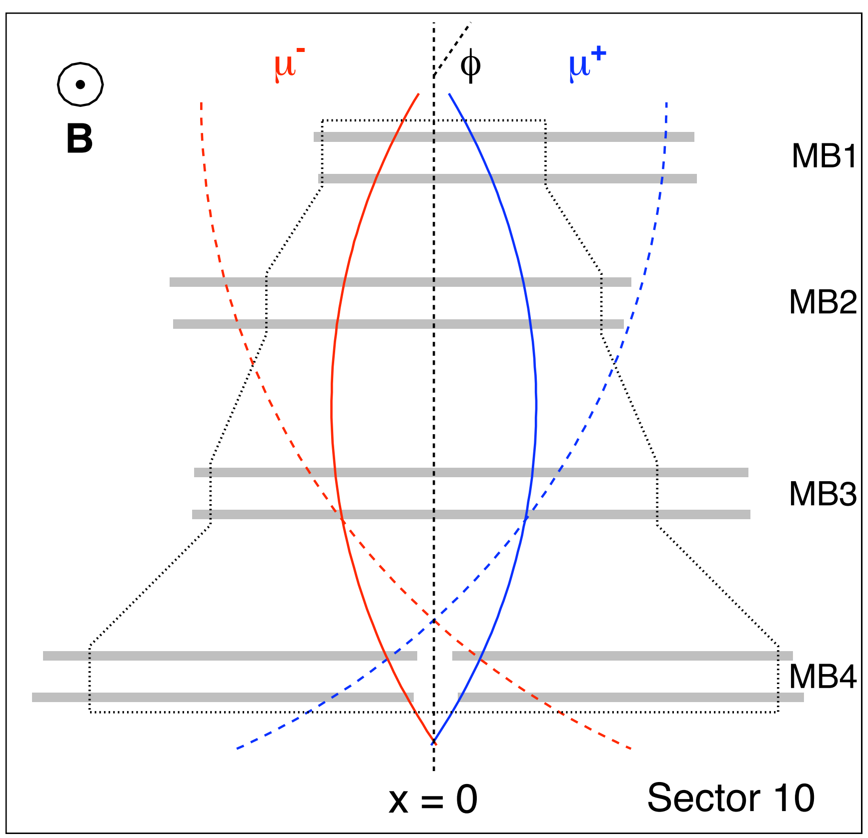
- 2006
  - CMS closed for the first time
  - still at Earth's surface
  - high μ rate
  - *4 T* magnetic field
- read-out
  - 60° slice of CMS ➠ sectors 10 and 11
  - 2 out of 5 wheels and adjacent end-cap disks

    see back up slides

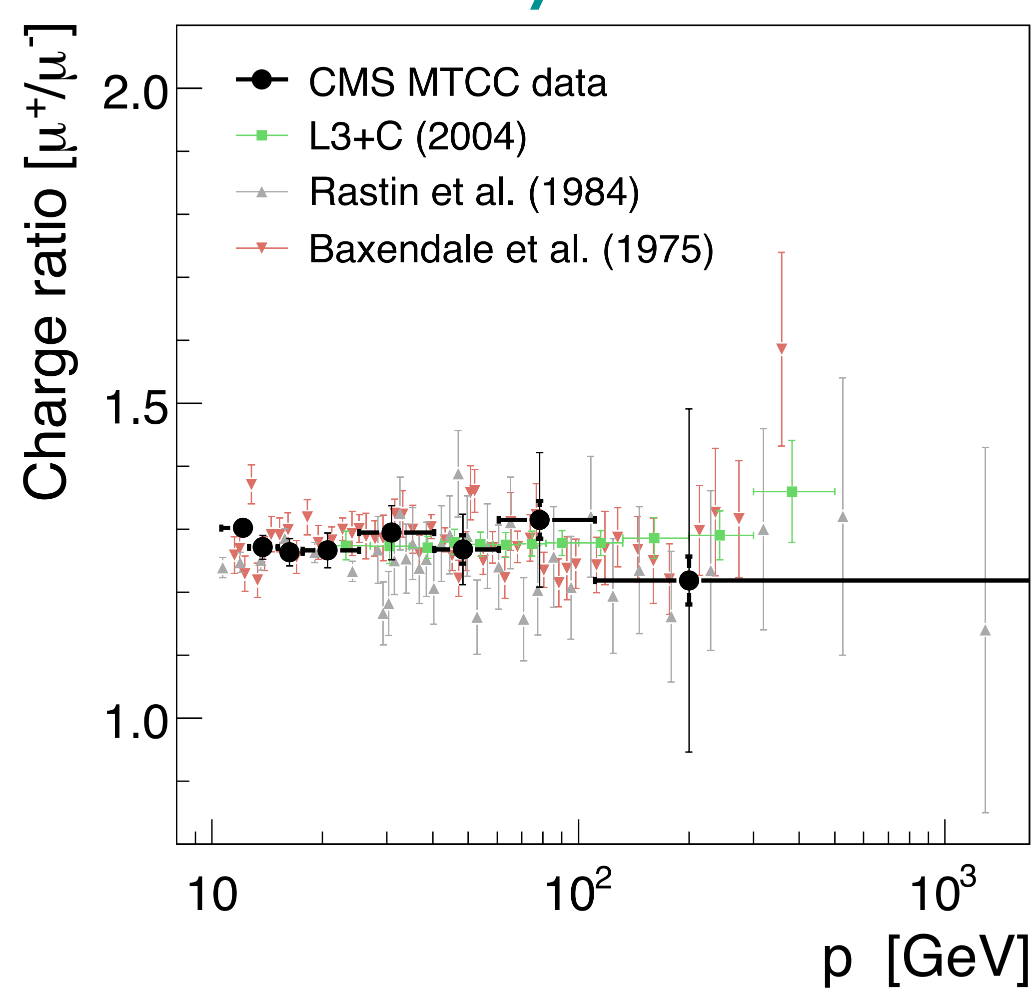


Barrel wheels YB+2 (S10, S11) and YB+1 (S10)

- detector geometry asymmetric for μ^+ and μ^-
  - left-right symmetry enforced ➠ no MC efficiency correction needed
- 337115 events after selection
- CMS result compares to other experiments
- large systematic uncertainty at high *pt*



first CMS Physics measurement



CRAFT *Cosmic Run At Four Tesla*

- getting ready for collisions
    - already in the cavern (*100 m* underground)
    - read-out fully operational

- CRAFT 08
    - 24/7 data-taking period for detector commissioning
    - from October 17 to November 11, 2008
    - *3.8 T* magnetic field
    - 376 million cosmic muon events collected
      see back up slides
    - we use this data to perform a physics measurement

challenge

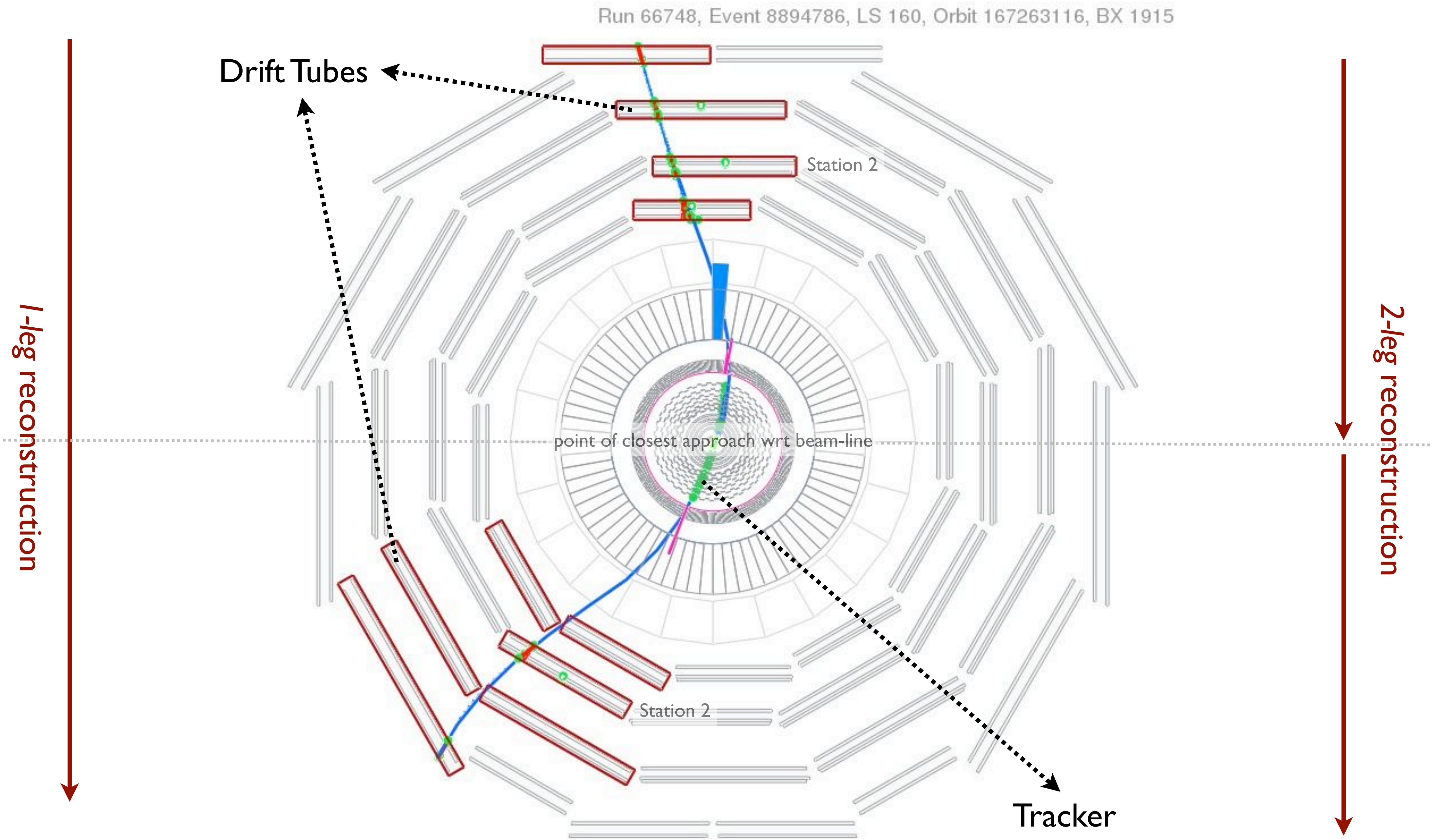
- CMS is not designed as a cosmic ray detector
  - beneath *100 m* of concrete / molasse
  - the amount of material over CMS changes across the detector cross section
  - trigger and read-out timing have been designed for particles from the beam spot
  - magnetic field makes μ^+ and μ^- traverse different trajectories
  - the tracker system is a small target for cosmic rays

- different from LHC conditions
  - muon reconstruction software
  - trigger and read-out timing

key ingredients

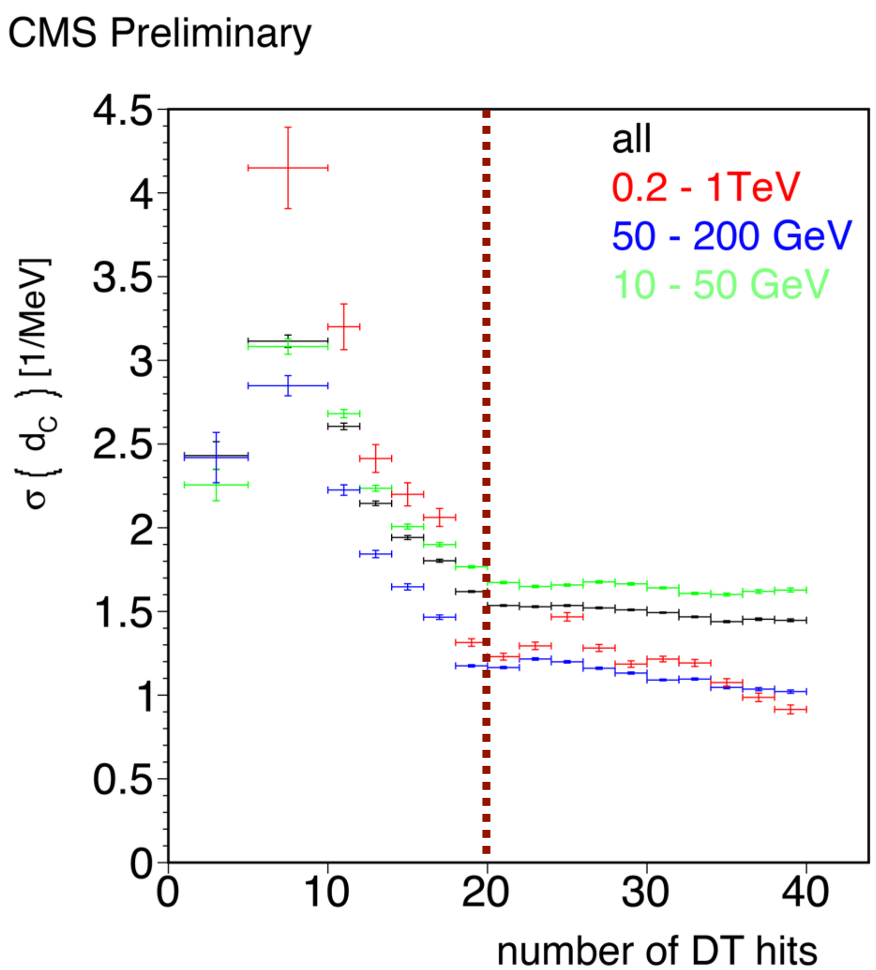
- select cosmic muons
  - understand trigger / reconstruction efficiency
- try not to introduce any bias
  - need to perform an unbiased muon selection
- need to understand detector effects
  - accurate MC needed
- data-driven methods
  - extract curvature resolution
  - study systematics

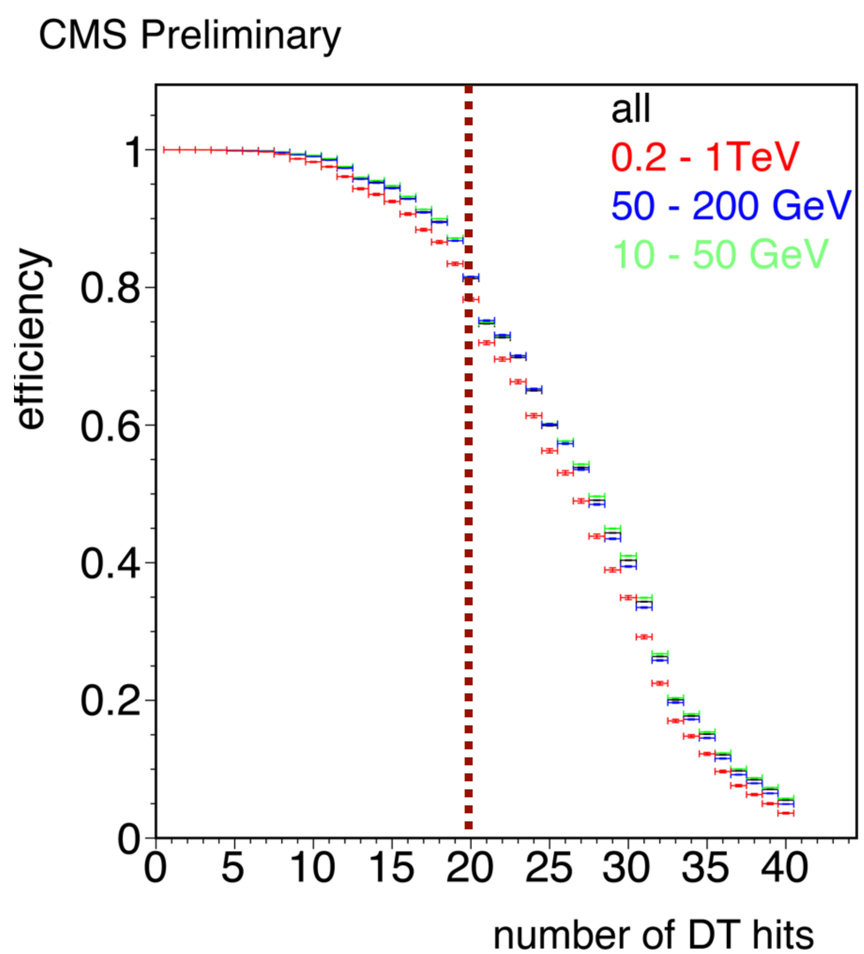
analysis components

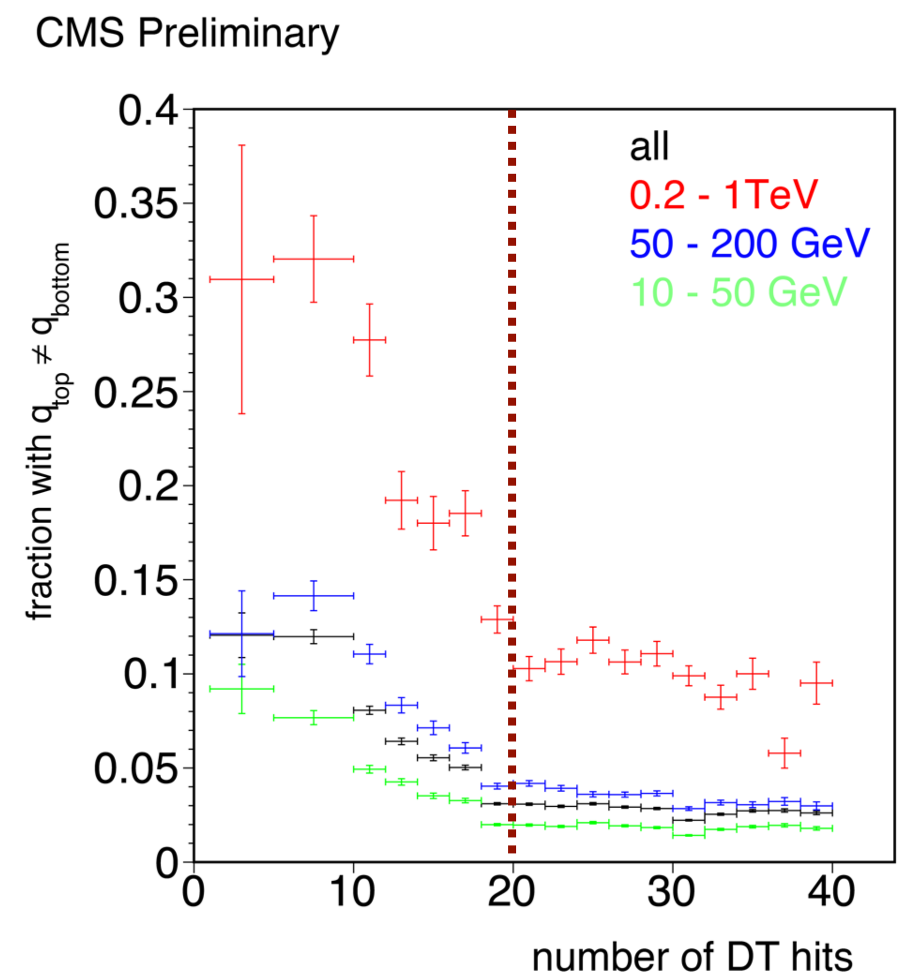


unbiased selection

- look for variables that don't bias the curvature distribution
- choose the cut value based on stability, staying efficient



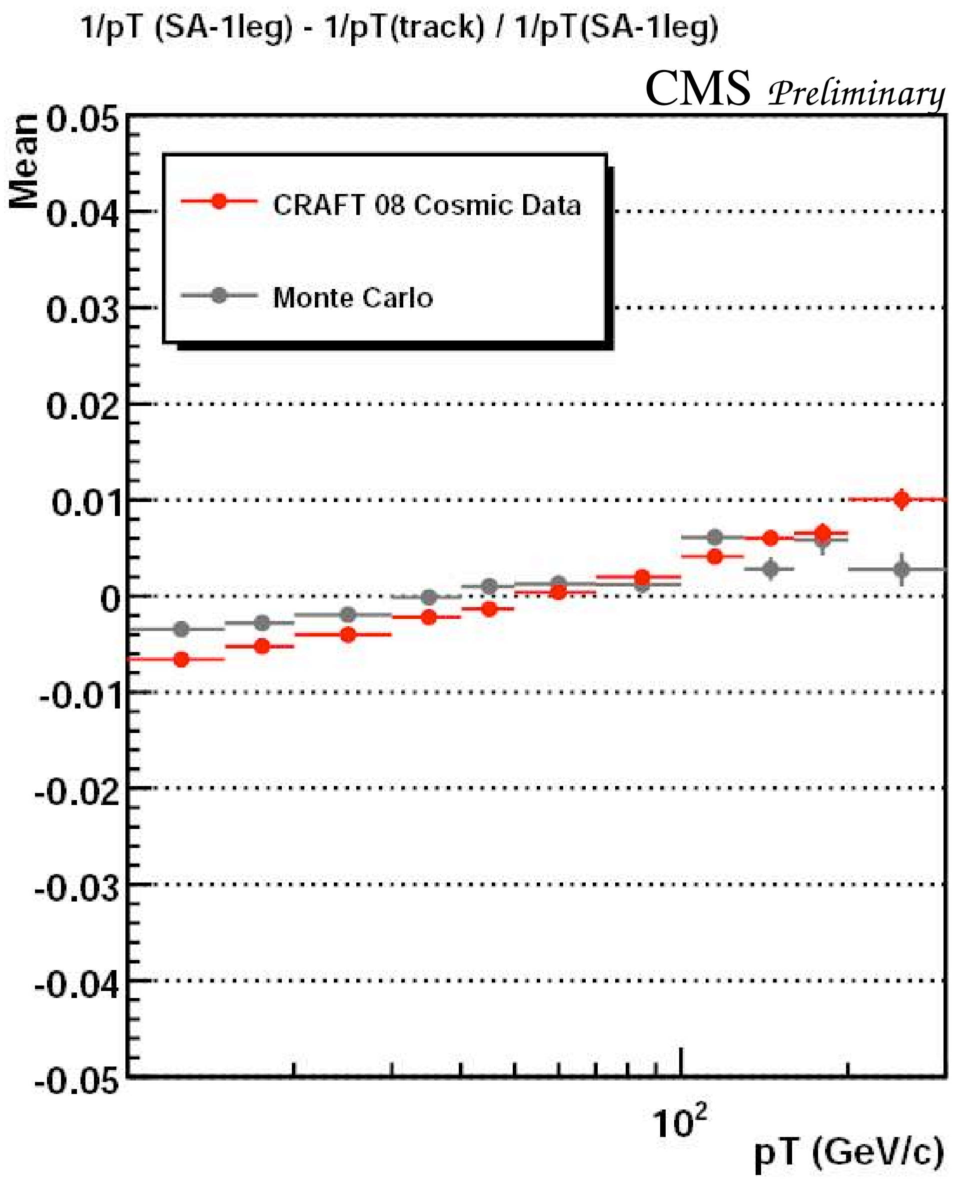


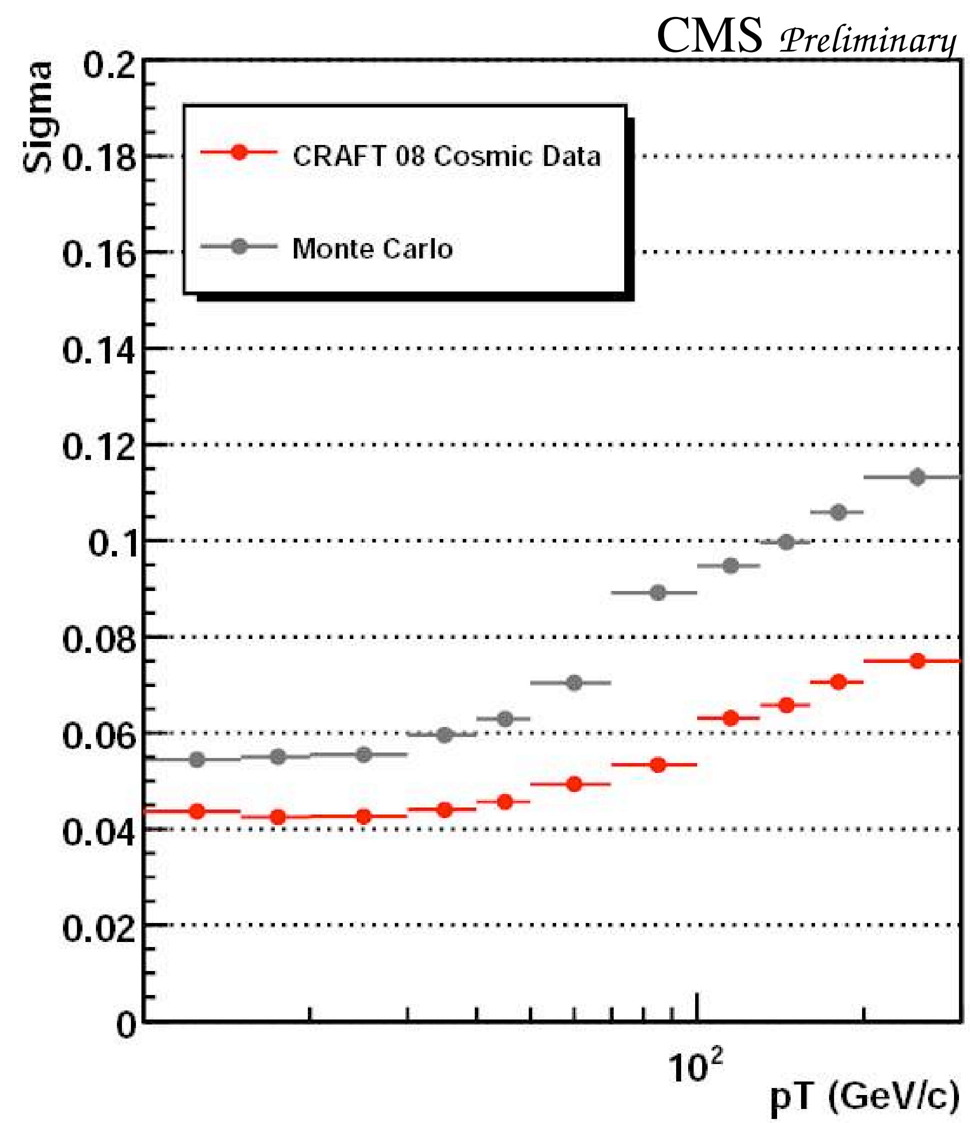


1-leg analysis

- based on the **muon Drift Tubes** information
- a cosmic muon is reconstructed as a single muon object
  - different from LHC reconstruction ➠ split it in two muon legs
  - a single muon has longer lever arm
- higher statistics compared to tracker analysis
  - DT volume >> tracker volume
- good resolution at high *pt* thanks to long lever arm

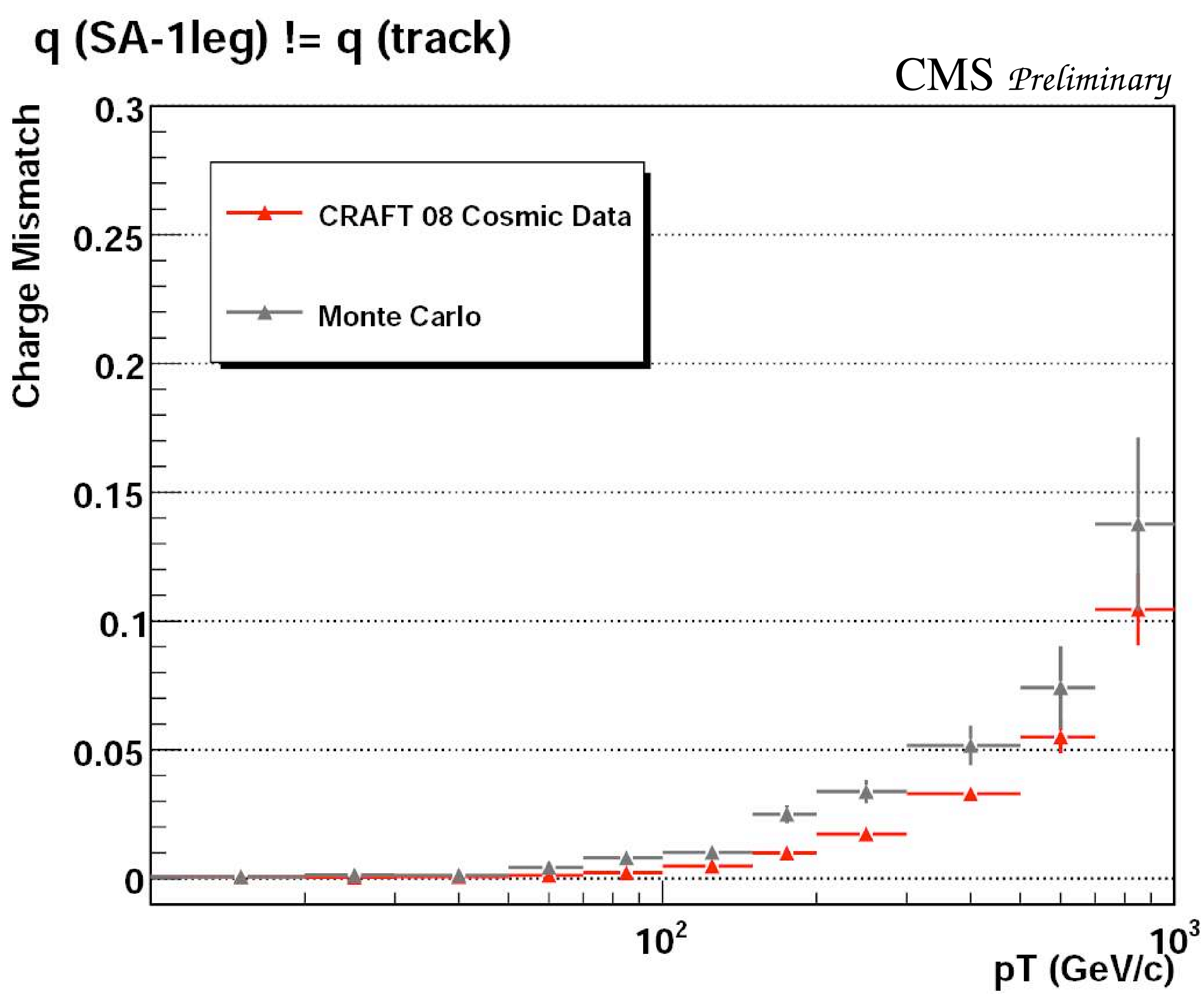
1-leg resolution





- compare DT *pt* with that from the tracker
  - (DT − tracker) scale within 1% for data and Monte Carlo
  - better resolution in data

1-leg charge study

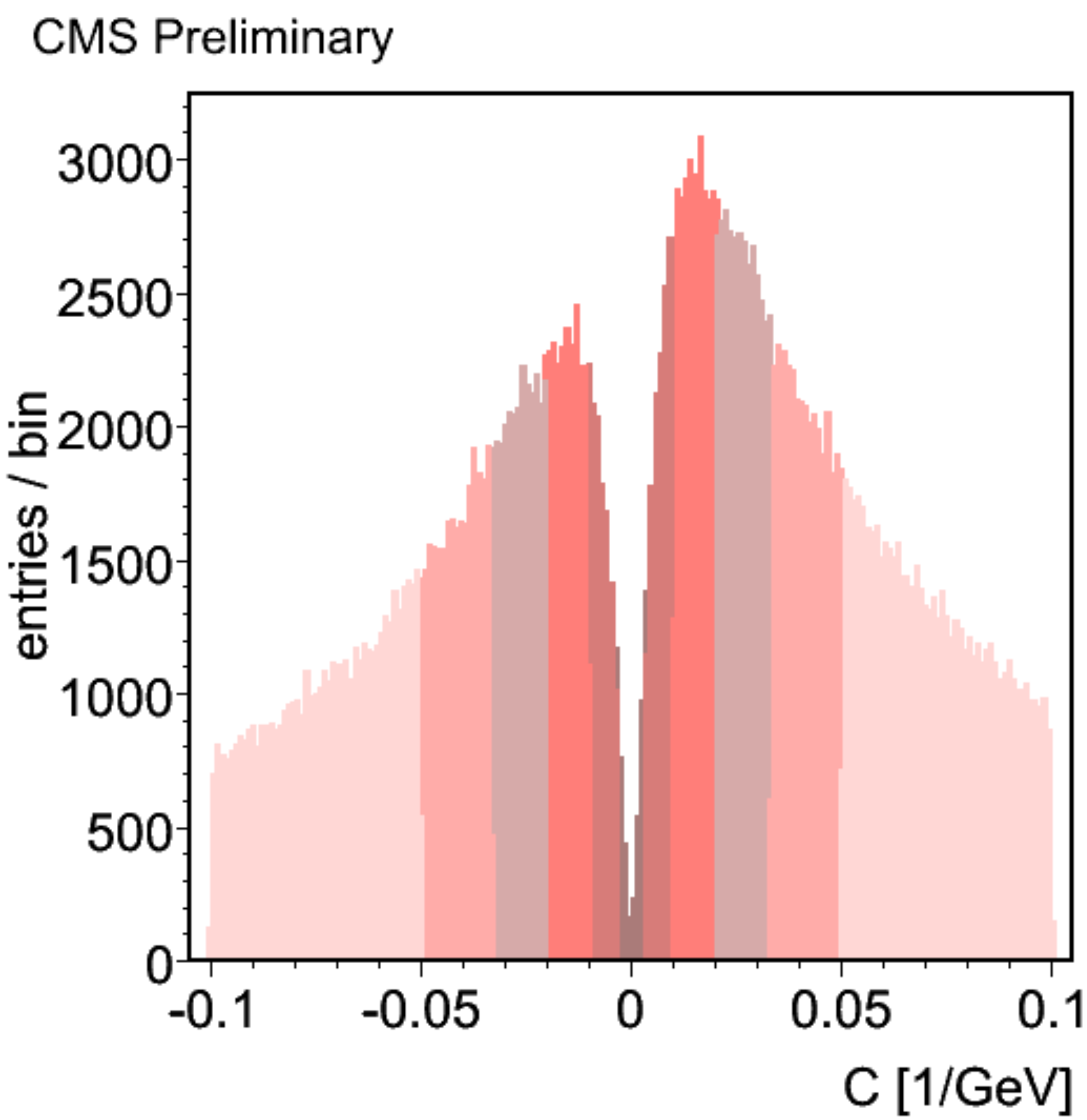


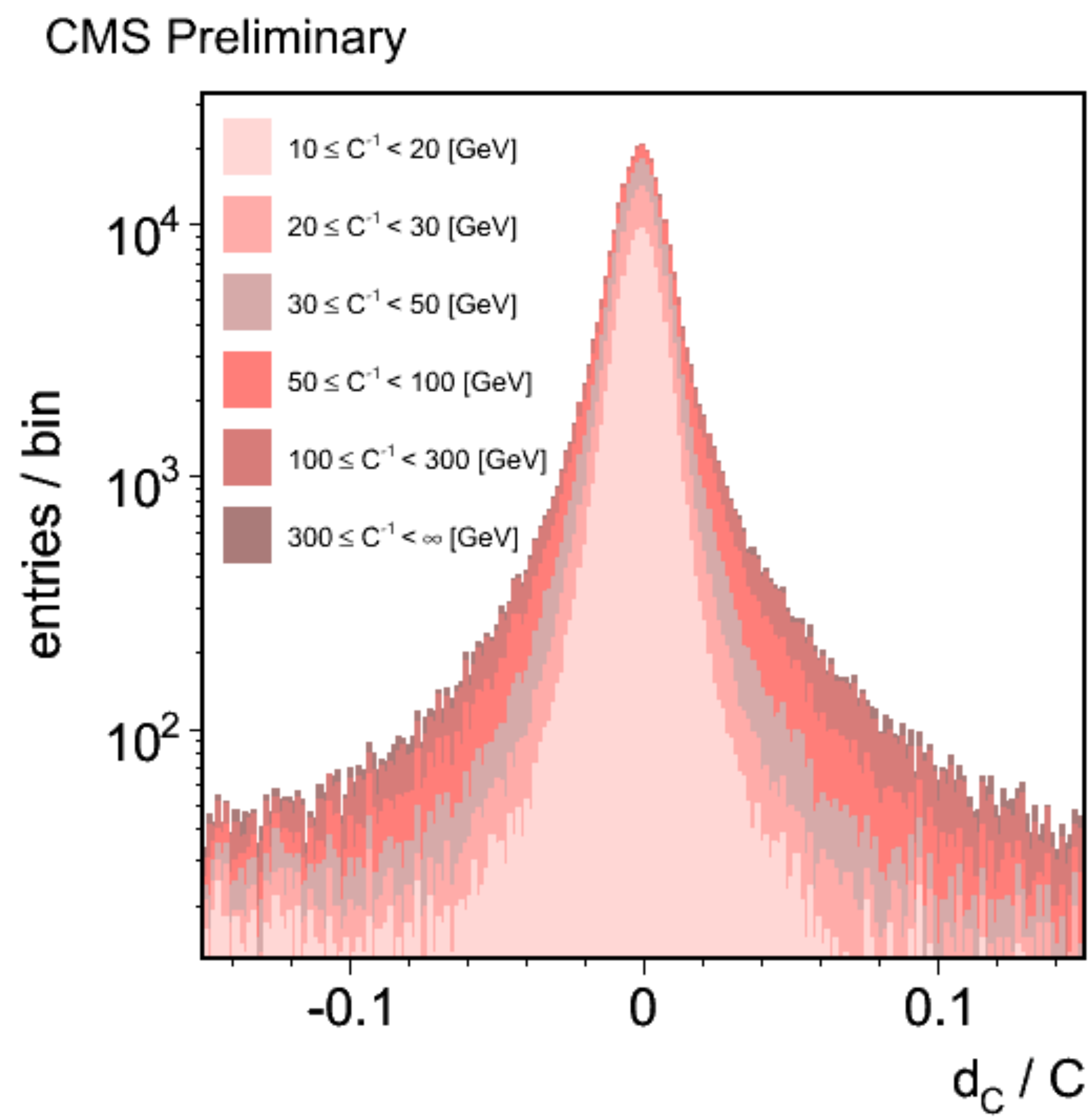
- compare DT charge with that from the tracker
  - fraction below 5% up to *pt = 500 GeV*

2-leg analysis

- completely data-driven approach
  - no Monte Carlo correction involved
  - however Monte Carlo can help to validate technique
- based on the **Tracker** information
- measure the charge ratio vs average *curvature*
  - $\boldsymbol{C} \equiv 1/2 \cdot (q^{up} / pt^{up} + q^{low} / pt^{low})$
- measure the resolution from *curvature* difference
  - $\boldsymbol{d_C} \equiv 1/2 \cdot (q^{up} / pt^{up} - q^{low} / pt^{low})$
- performance closer to that from LHC reconstruction
  - handle on goodness of TeV LHC tracks

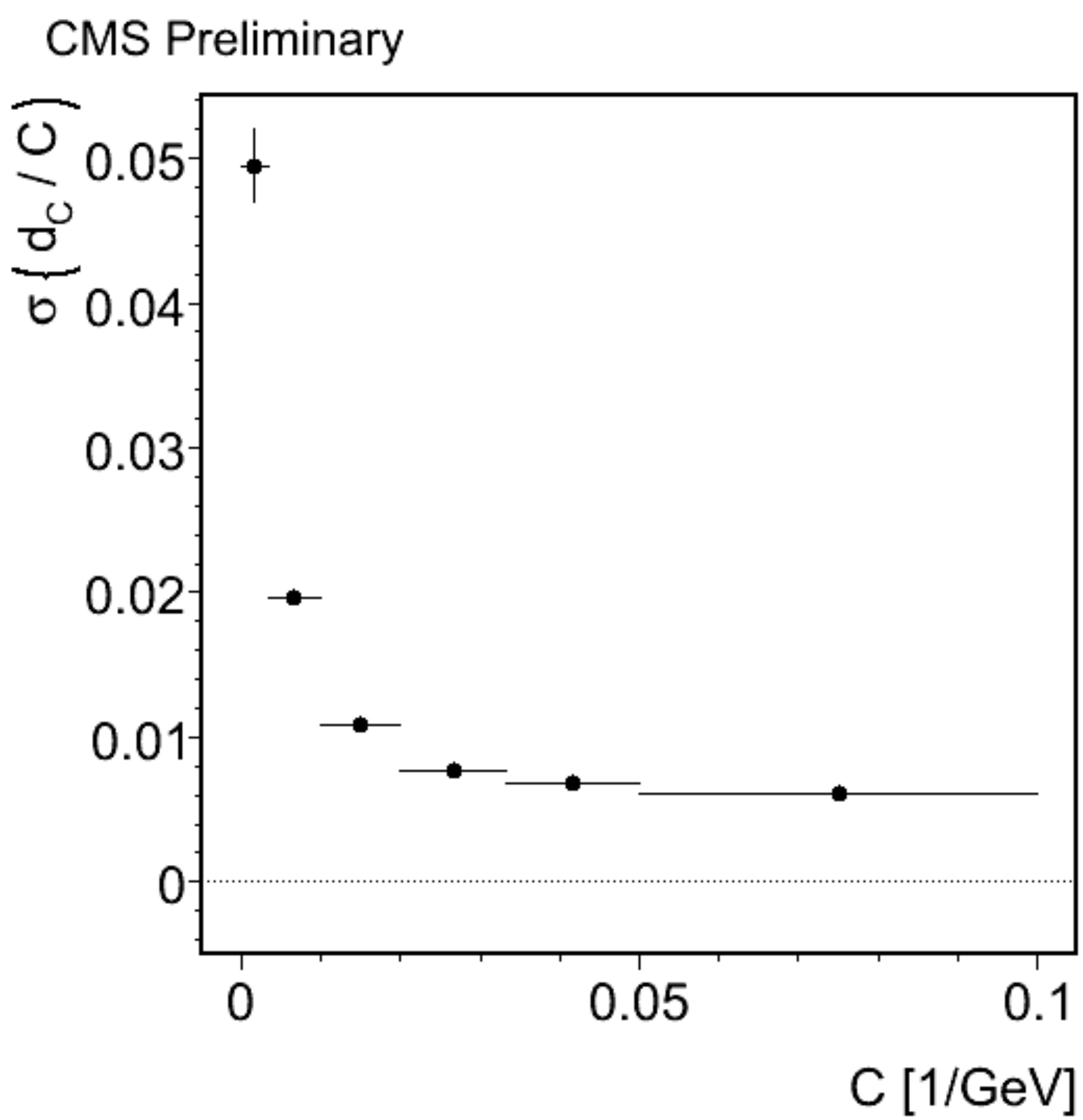
curvature and resolution





- curvature (left) and resolution (right) after selection
  - darker red corresponds to higher transverse momentum $pt \equiv 1 / |C|$
  - can see resolution getting worse with increasing *pt*

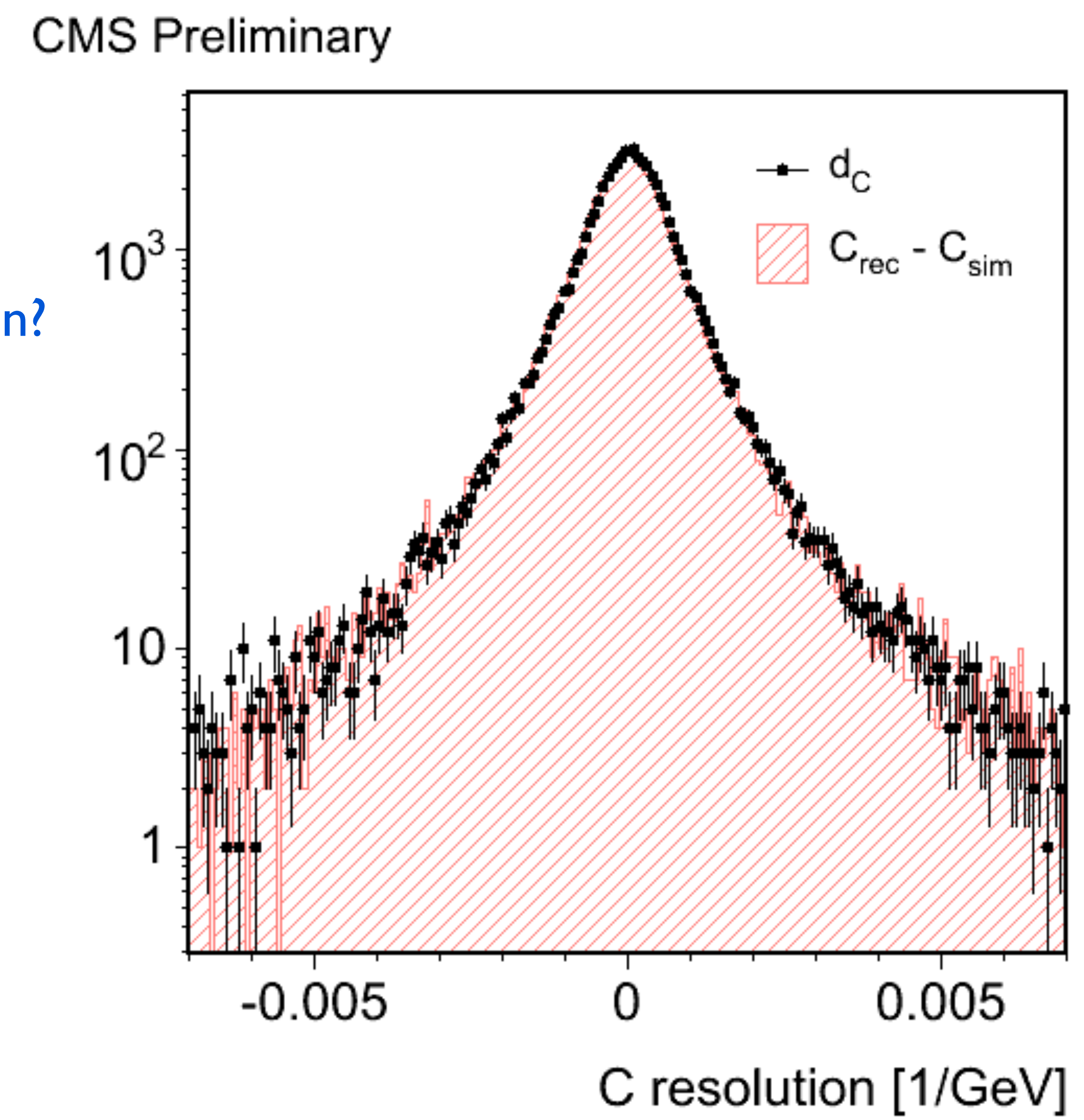
2-leg resolution



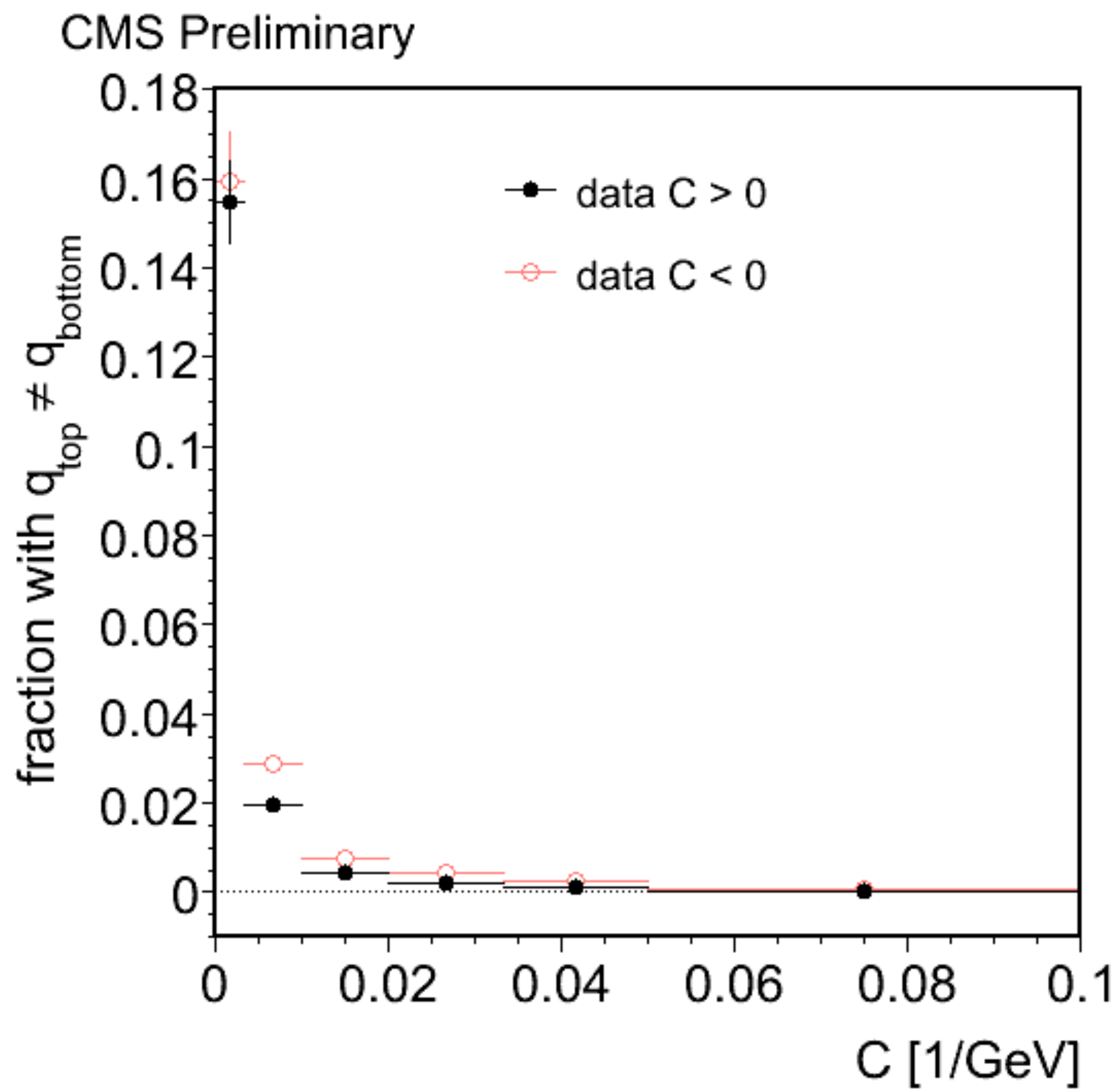
- Gaussian fits of d_C/C core
  - excellent resolution, below 5% in all the curvature spectrum

check d_C with MC

- d_C
  - data-driven resolution estimator
  - how well it reproduces the true resolution?
- compare with true resolution
  - true resolution = $C_{rec} - C_{sim}$
  - rec ➠ reconstructed
  - sim ➠ simulated
- excellent agreement :-)



2-leg charge study



- fraction below 3% for *pt < 300 GeV*

systematics

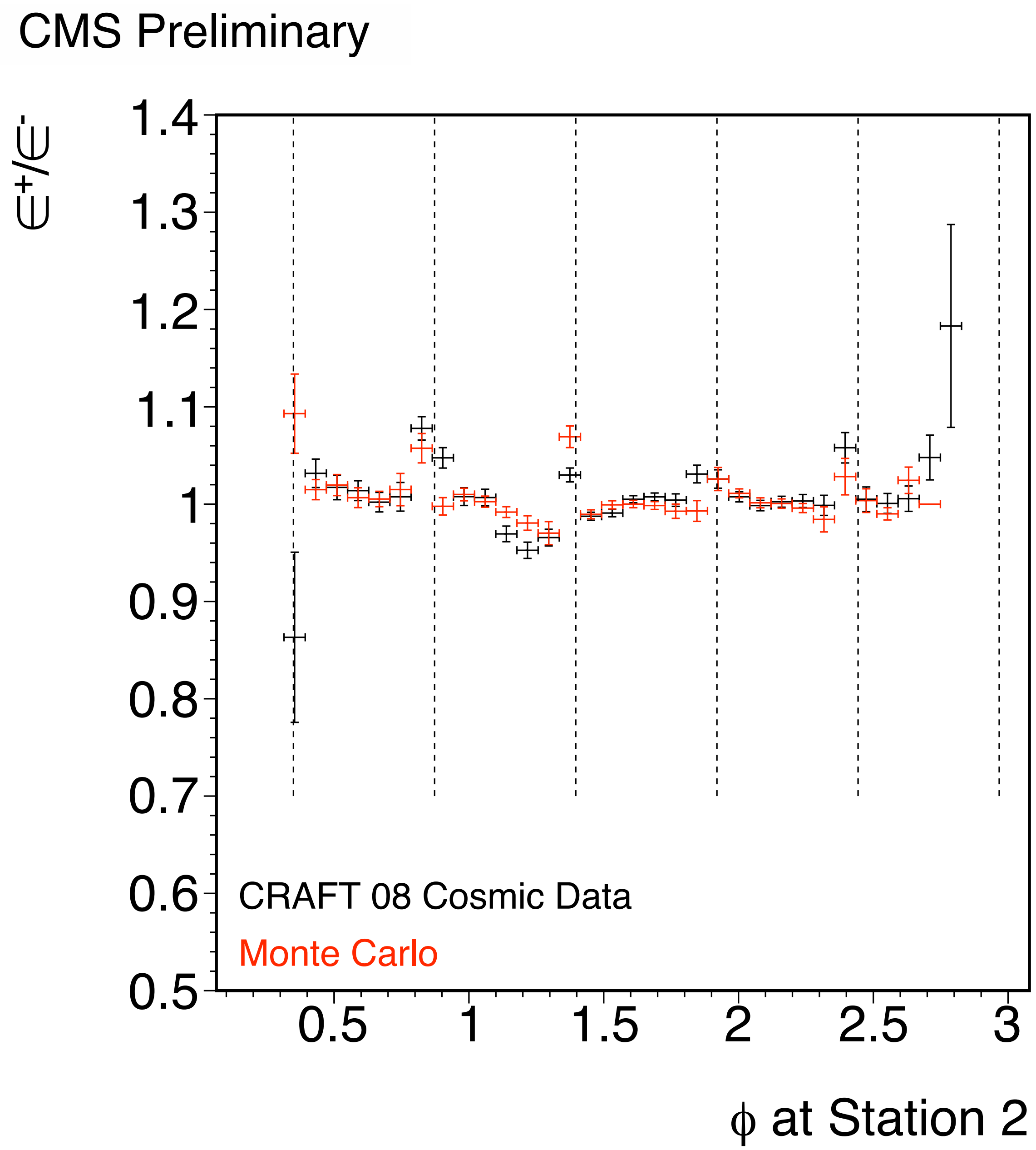
- selection
  - the goal was selecting high quality muons without introducing any bias
  - we have checked the impact of removing each cut
  - systematic uncertainty ≤ 1% in all *pt* range
- resolution function
  - splitting a cosmic muon in two legs provides a fully data-driven approach
  - from MC, d_C is an excellent proxy of the curvature resolution
- wrong tracker-muon matching
  - sometimes the tracker track is matched to the wrong muon
  - it affects less than 0.02% of the selected events

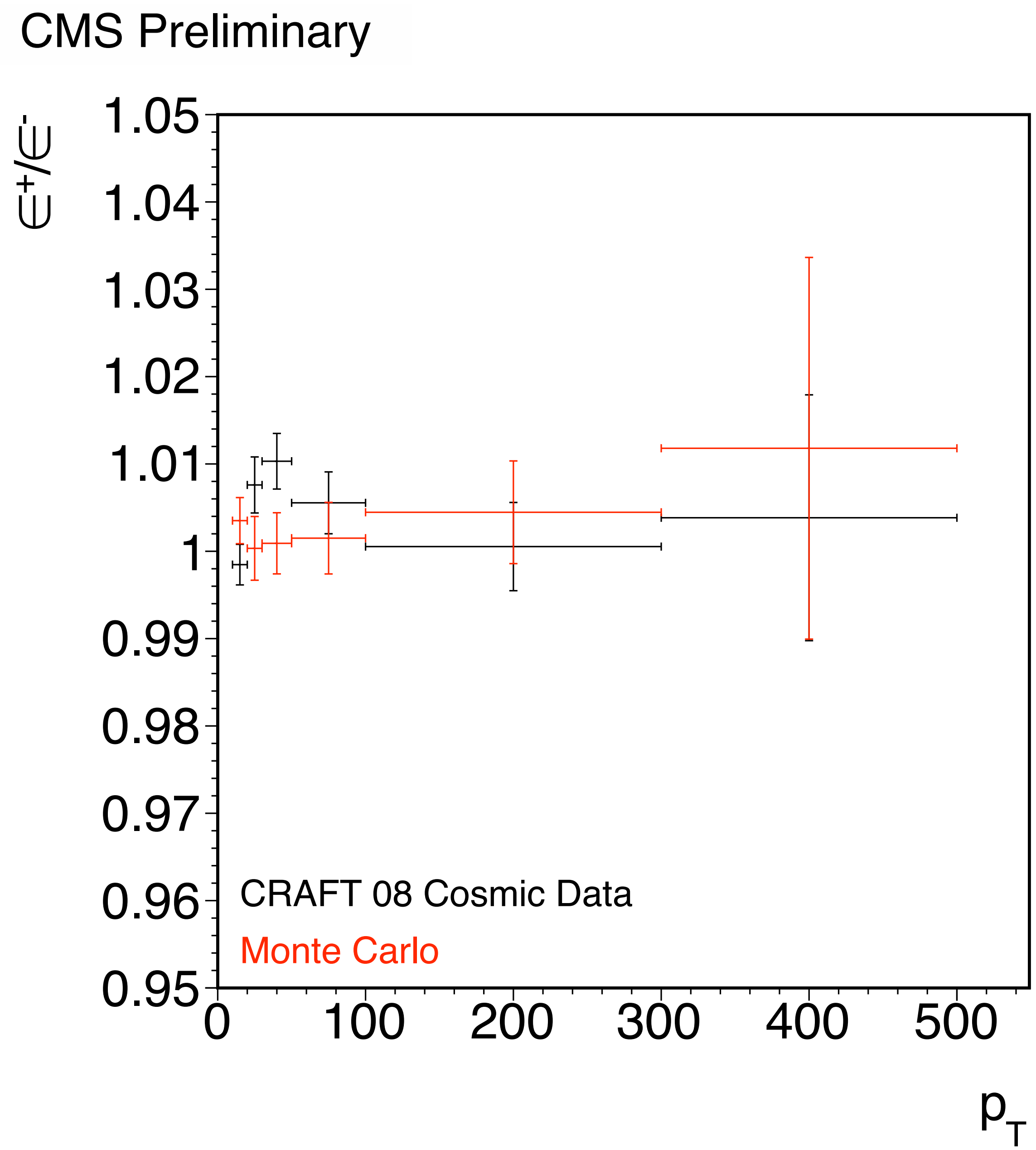
- magnetic field
  - the *B field* in the tracker region was known with great precision (<0.1%) before CRAFT
  - more complex field in the iron layers of the return yoke (muon spectrometer)
    see back up slides
    - harder to measure / model
  - with CRAFT we probed for the first time the *B field* in the iron of the yoke directly
    - comparing tracker *pt* with muon *pt* ➠ the momentum scales were found to be different
  - after several studies ➠ highly improved field map
  - compare the effect of different field maps in the analysis ~ 3% at high *pt*
- trigger
  see next slides
- alignment
  - curvature sensitive to muon, tracker and muon-tracker relative alignments
  - impact of different alignments up to 5% at high *pt*

trigger efficiency ratio *(1)*

- different trigger efficiency for positive and negative muons?
- trigger efficiency definition
  - **denominator** - there's a reconstructed muon in the bottom half of CMS with $\Delta\phi$*(reconstructed, trigger) < 0.2* and there's a reconstructed muon in the top half
    tag
  - **numerator** - denominator condition & the reconstructed muon in the top half of CMS satisfies $\Delta\phi$*(reconstructed, trigger) < 0.2*
    probe
- ϕ measured at DT Station 2 (DT trigger ϕ)
- efficiencies agree
  see next slide
  - for positive and negative muons
  - for data and MC

trigger efficiency ratio *(2)*





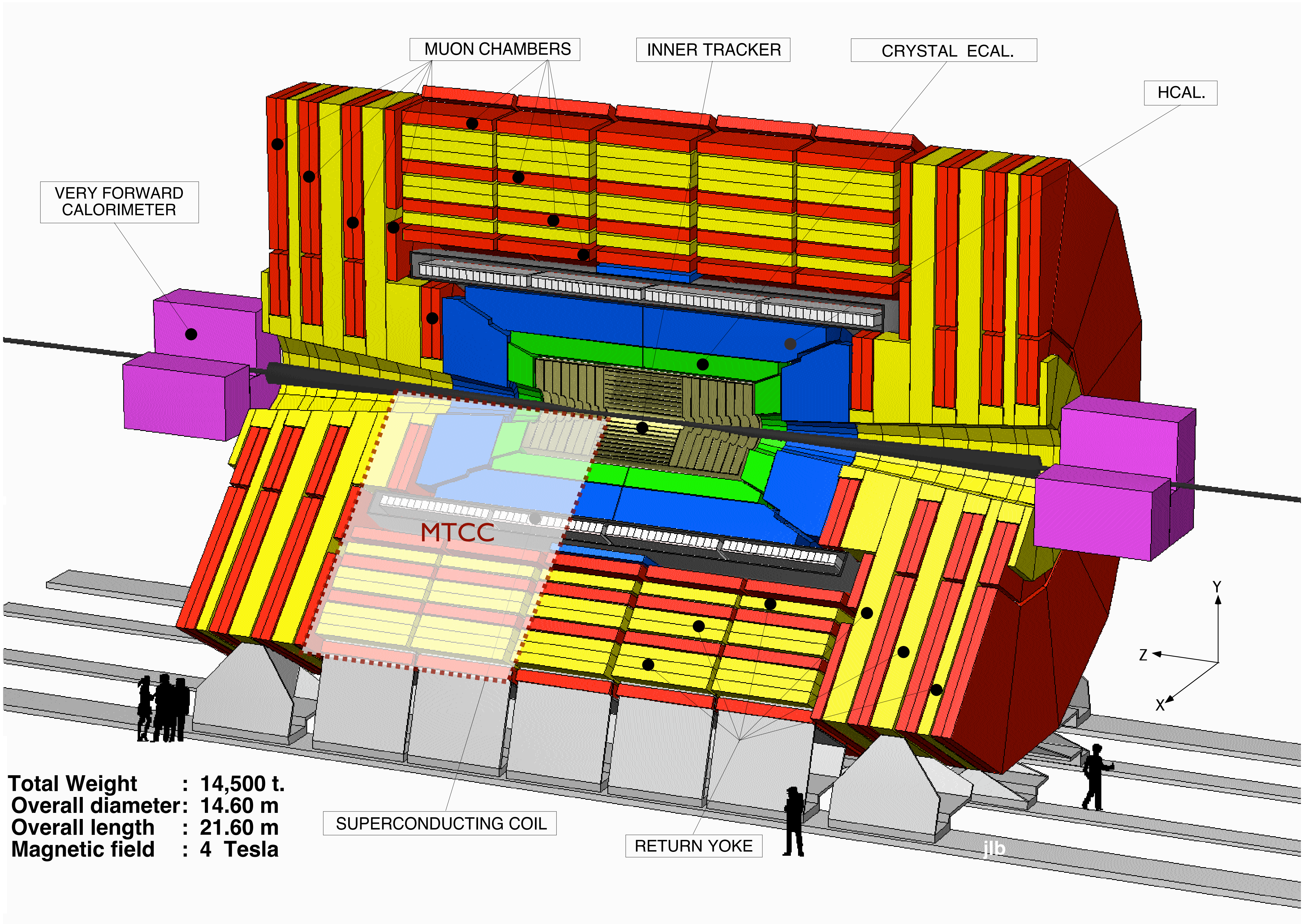
- efficiency ratio vs ϕ (left) and *pt* (right)
- structure agrees with chamber edges (left)

conclusions

- CRAFT 08 has been an excellent workbench
  - improved understanding of CMS magnetic field map
  - improved muon, tracker, and muon-tracker relative alignments
  - achieved excellent momentum resolution up to high *pt* values
- for the charge ratio
  - both analyses have gathered high quality muons after an unbiased selection
  - the *2-leg* analysis is fully data-driven, with the resolution proxy checked on MC
  - trigger has been studied in detail finding no bias towards a given charge
- CRAFT 08 charge ratio result coming soon
  - unfold charge ratio from CMS center to Earth's surface
  - finish systematic studies

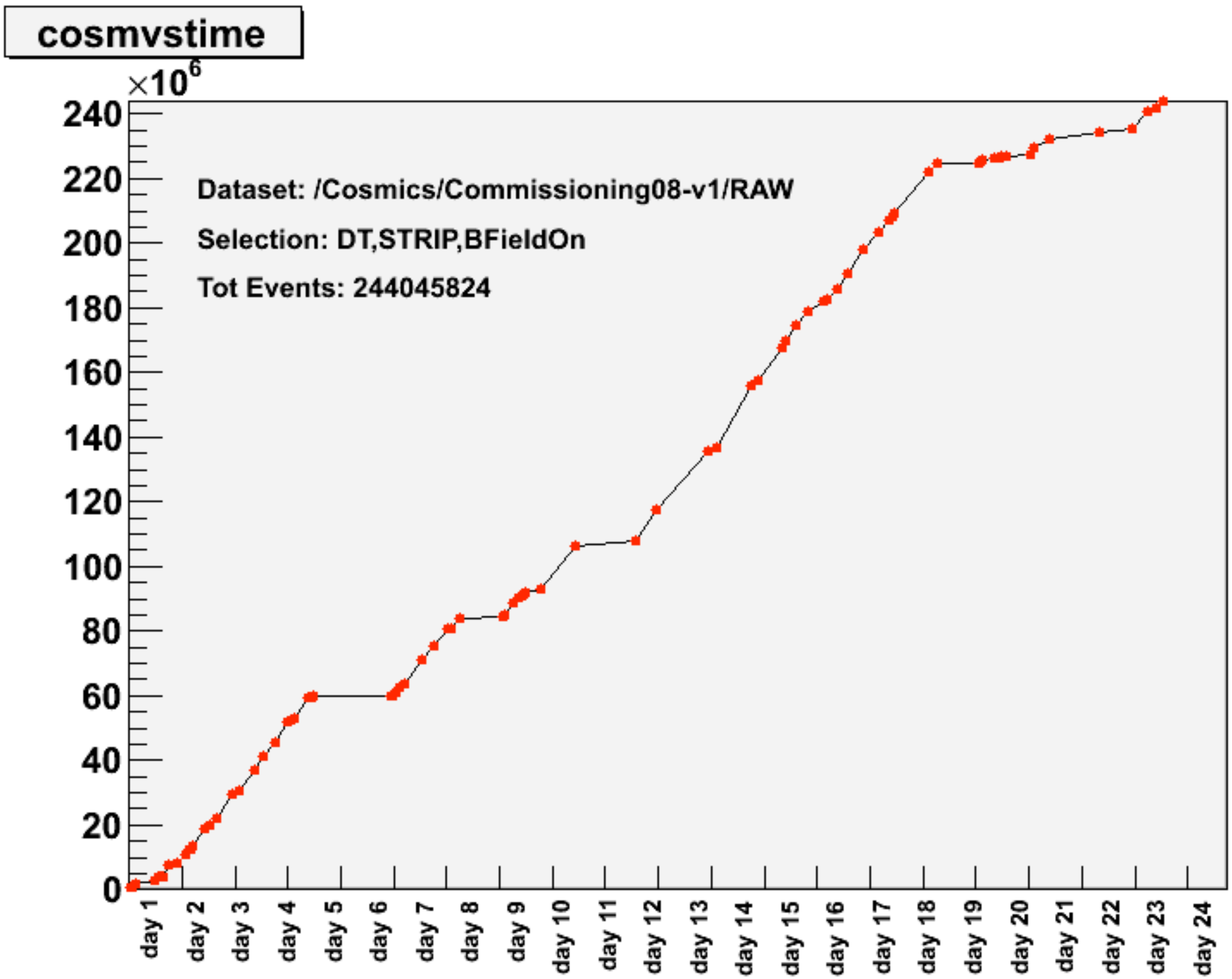
back up

CMS
Compact Muon Solenoidal Detector for LHC



Total Weight : 14,500 t.
Overall diameter: 14.60 m
Overall length : 21.60 m
Magnetic field : 4 Tesla

data volume


cosmvstime
×10^6
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220
200
180
160
140
120
100
80
60
40
20
0
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Selection: DT,STRIP,BFieldOn
Tot Events: 244045824
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day 2
day 3
day 4
day 5
day 6
day 7
day 8
day 9
day 10
day 11
day 12
day 13
day 14
day 15
day 16
day 17
day 18
day 19
day 20
day 21
day 22
day 23
day 24

B field map