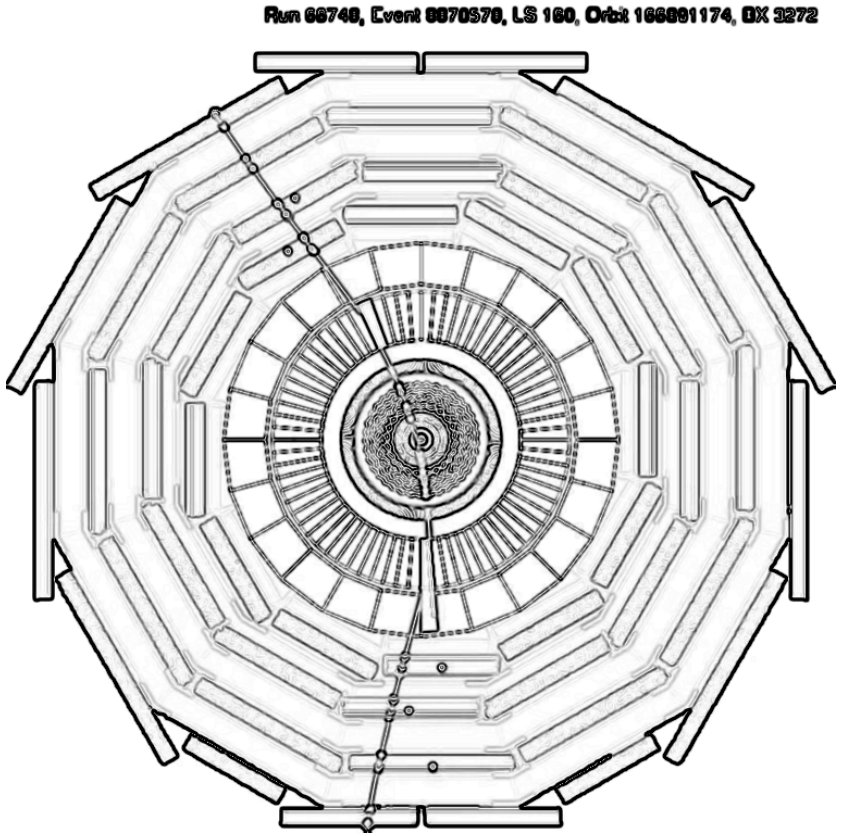
μ, e, τ Commissioning with Cosmics



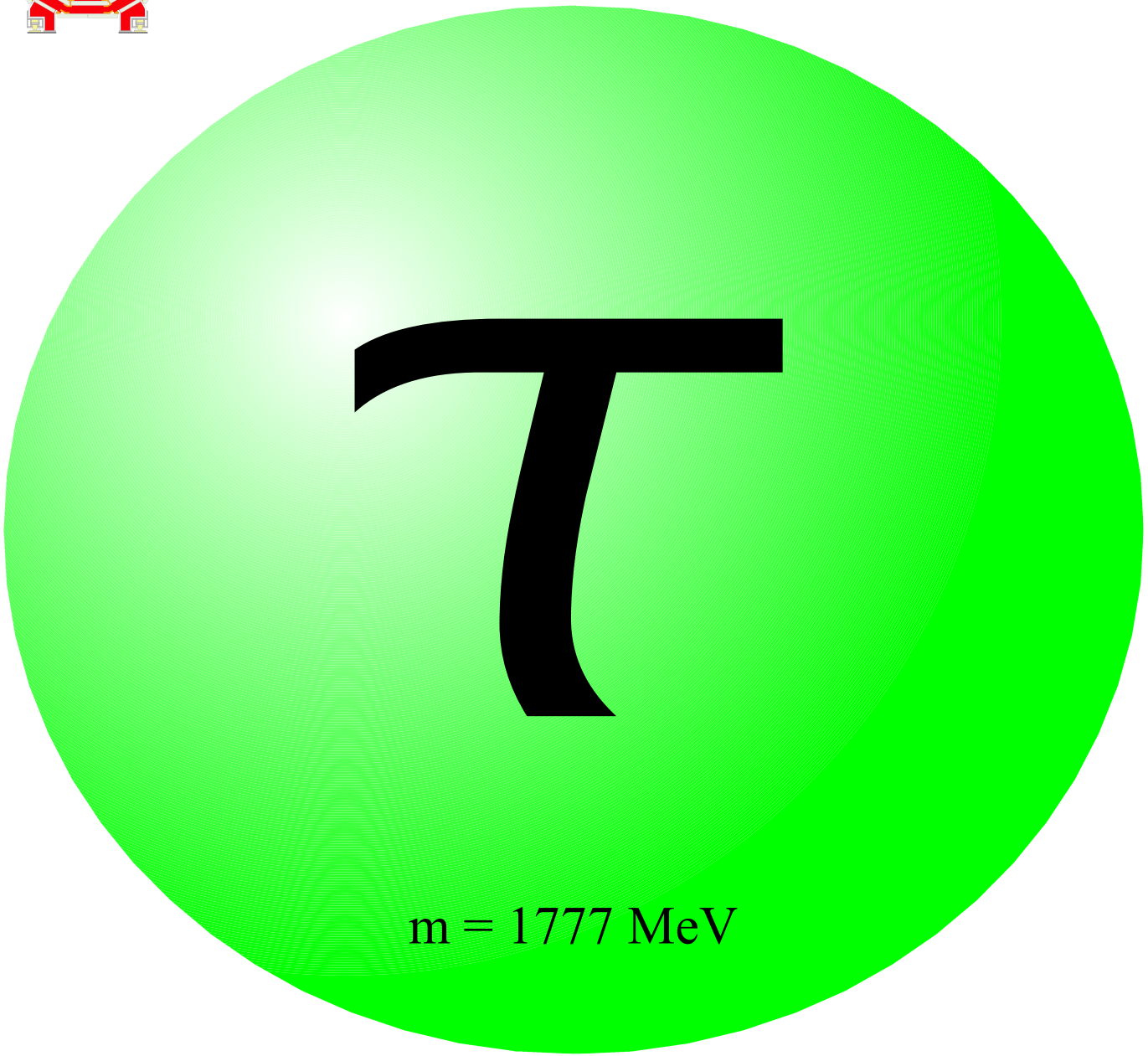
XX Hadron Collider Physics Symposium
16-20 November 2009
Evian (France)

Outline:

- Introduction to CMS and lepton identification
- Commissioning of **basic ingredients** for lepton reconstruction and identification
- Commissioning of lepton reconstruction and identification **algorithms**

Riccardo Bellan
(CERN)
for the CMS Collaboration

Charged Leptons in the Standard Model

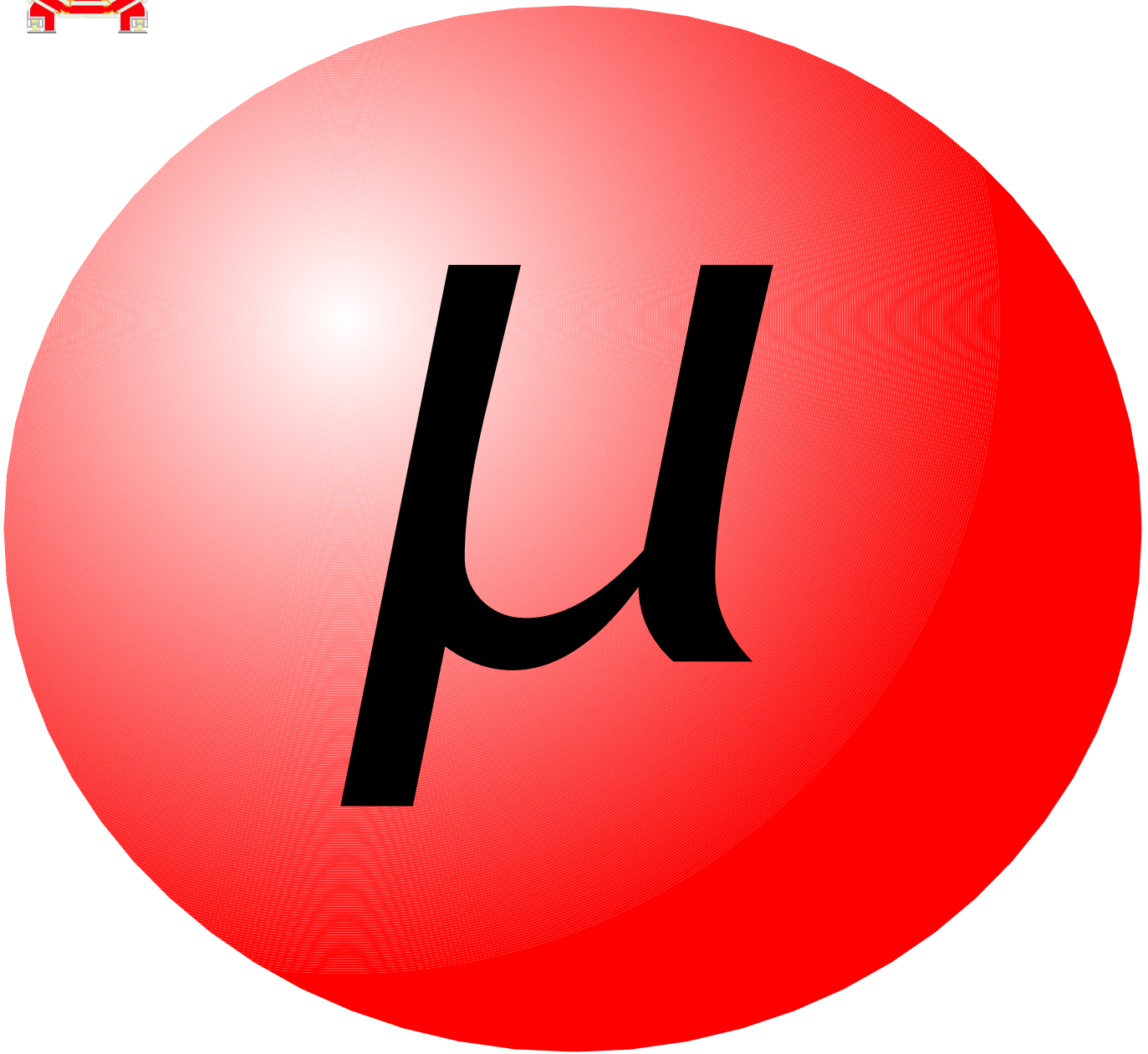


m = 106 MeV

e

m = 0.5 MeV

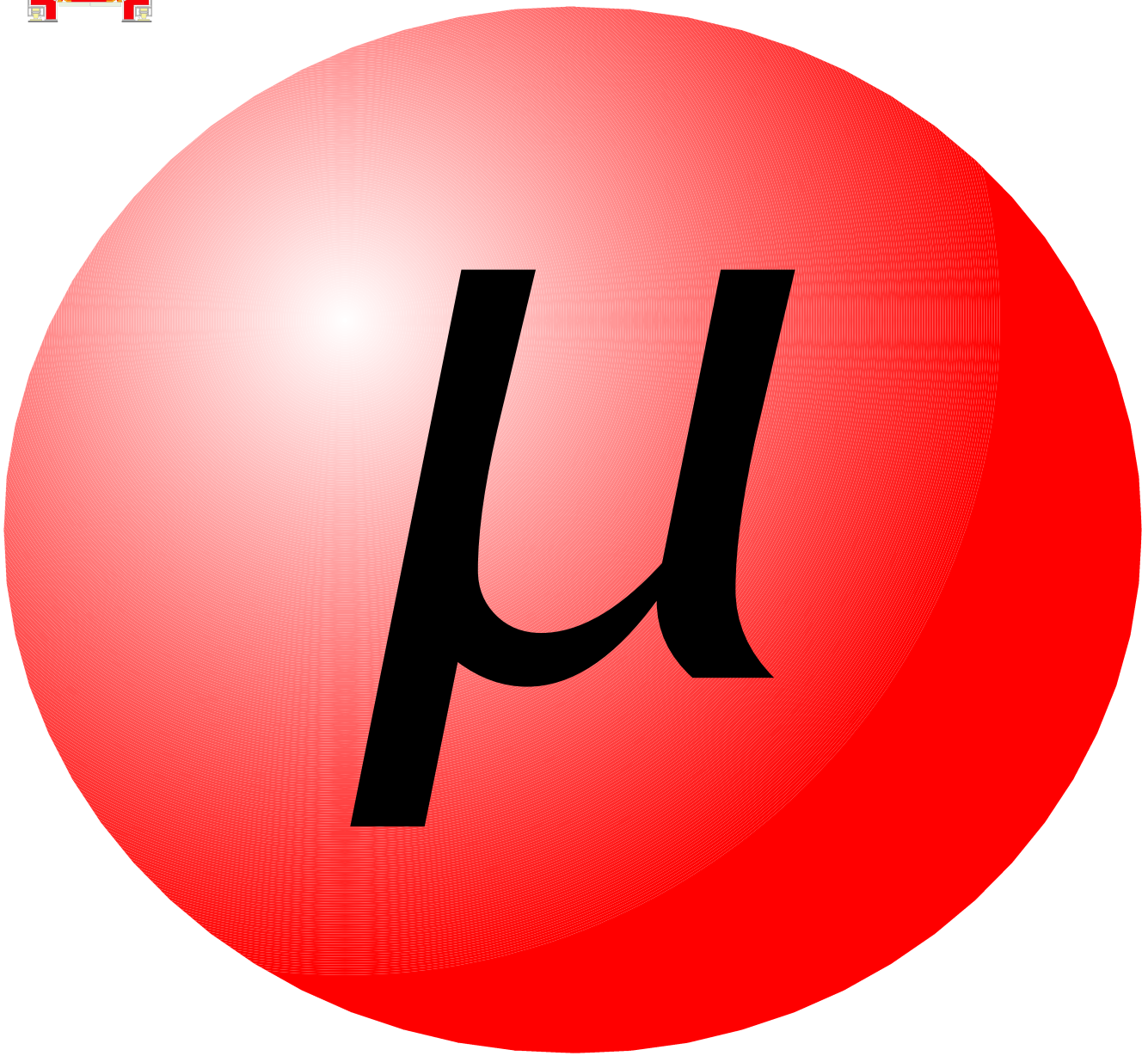
Relative Contents in this Talk



e

τ

...With Radiative Corrections...



The CMS Detector

SUPERCONDUCTING COIL

CALORIMETERS

ECAL Scintillating $PbWO_4$ Crystals

HCAL Plastic scintillator brass sandwich

Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

IRON YOKE

TRACKERs

Silicon Microstrips
Pixels

MUON ENDCAPS

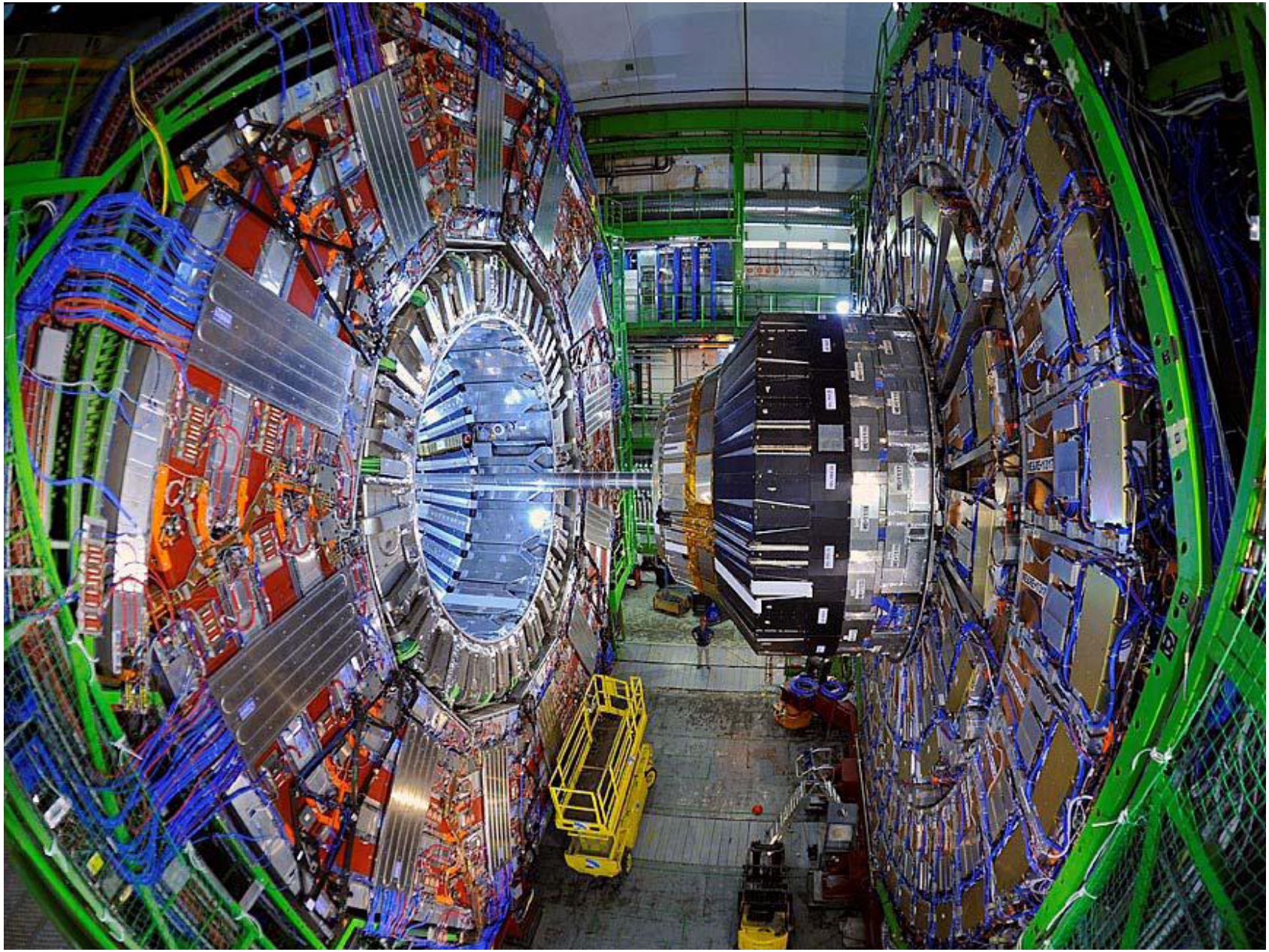
MUON BARREL

Drift Tube Chambers (**DT**)

Resistive Plate Chambers (**RPC**)

Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

The CMS Detector



The Cosmic Data Taking Champaign

Independent subdetectors commissioning

2006

Aug 2006: Magnet Test/Cosmic Challenge

- Test&mapping of magnet at 4T on surface, global data taking with a fraction of each CMS subdetector

2007

Lowering into cavern;
Underground global runs

- increasing fraction of CMS integrated

End heavy lowering →

Tracker ready →

2008

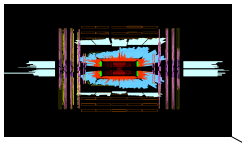
May-Aug 08: Weekly "global runs" + Cosmic Runs At Zero Tesla (**CRUZET**)

- Entire CMS integrated; 300 M events, B off

Sep 08: First beams

- Beam splash events; beam halo

2009



HCP2009 →

Oct 08: Cosmic Run at Four Tesla (**CRAFT**)

- Run 24/7 for extended period
- 270M events, full detector, nominal B field
- 25 papers in preparation

First H → 4μ (??)

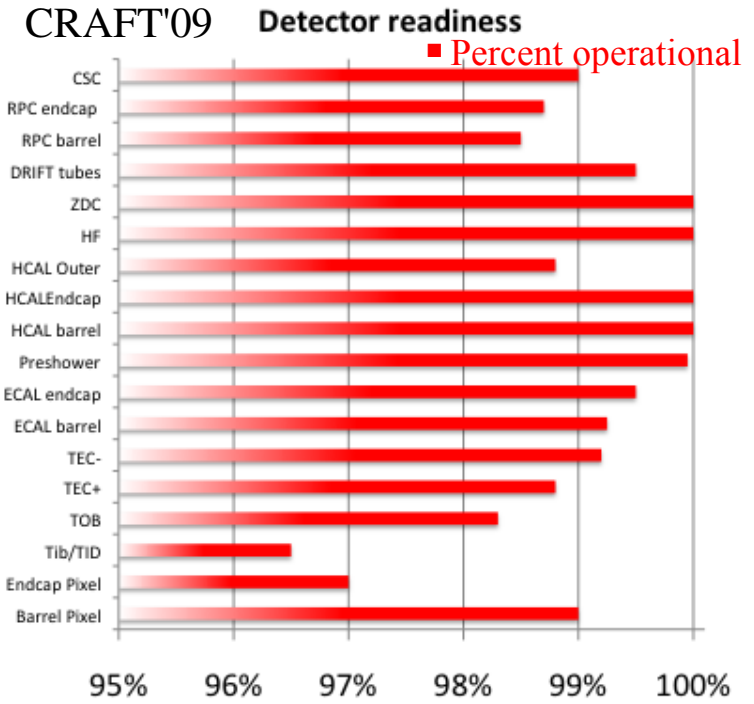
t

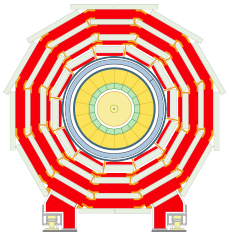
Aug 09: **CRAFT 09**

- 300M events

Integrated commissioning with cosmics

- Learn how to operate detectors
- Study detector response and performance
- Exercise & develop alignment, calibration etc.
- Discover and fix problems

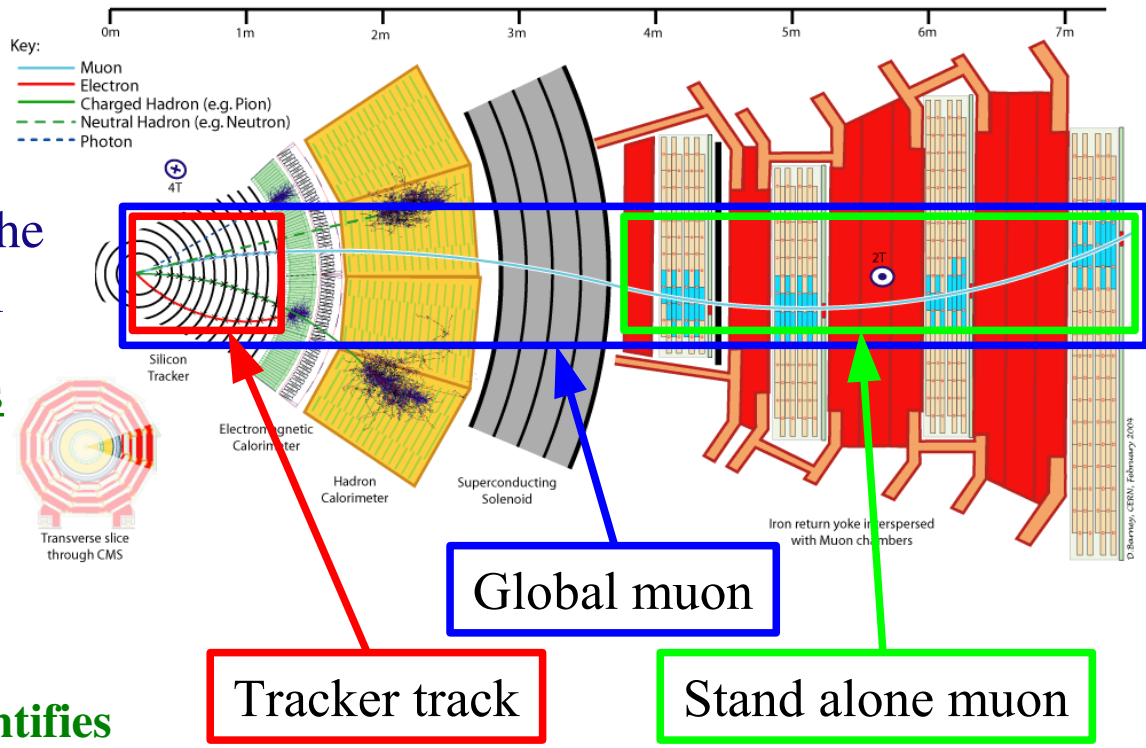




Few Basic Concept About Lepton Reconstruction and identification in CMS

Muon Reconstruction and Identification

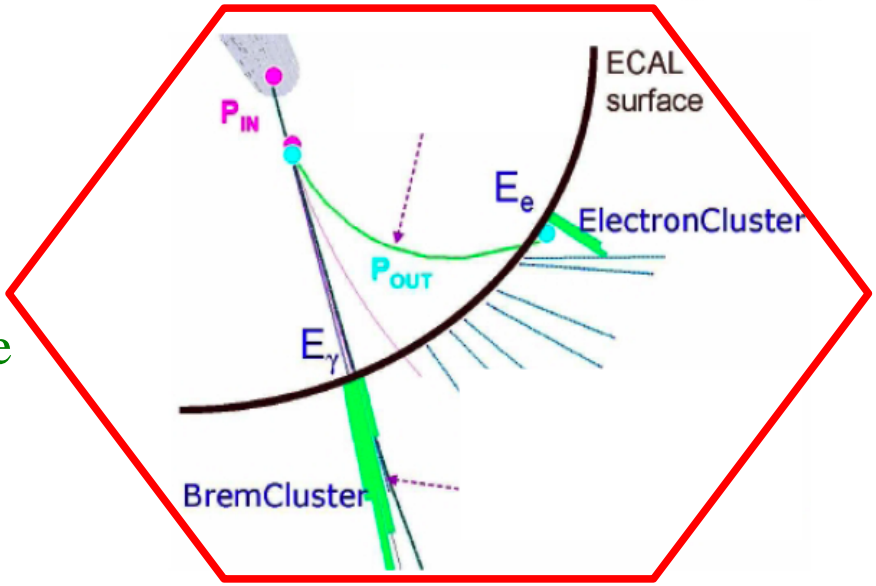
- *Two* complementary approaches for a unique collection of muons
  - **Stand alone muon based** (outside-in)
  - **Tracker based** (inside-out)
- Both are based on the reconstruction of the segments and rechits in the muon system
  - the outside-in approach fits all muon hits and search for a compatible tracker track to **build a global muon**
  - the inside-out, instead, try to match the tracks in the tracker with the muon segments and on compatibility basis **identifies the tracker tracks which are muons**
    - By product, a set of muon identification variables are computed

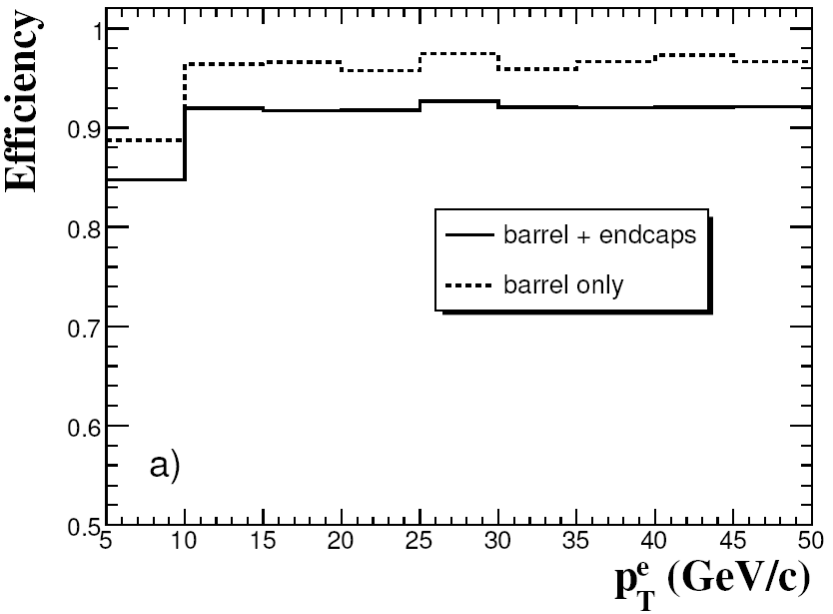


- The two algorithms are such that **cooperate** after they have individually performed their choices (e.g., an high quality muon will have the information from both the strategies)

Electron Reconstruction and Identification

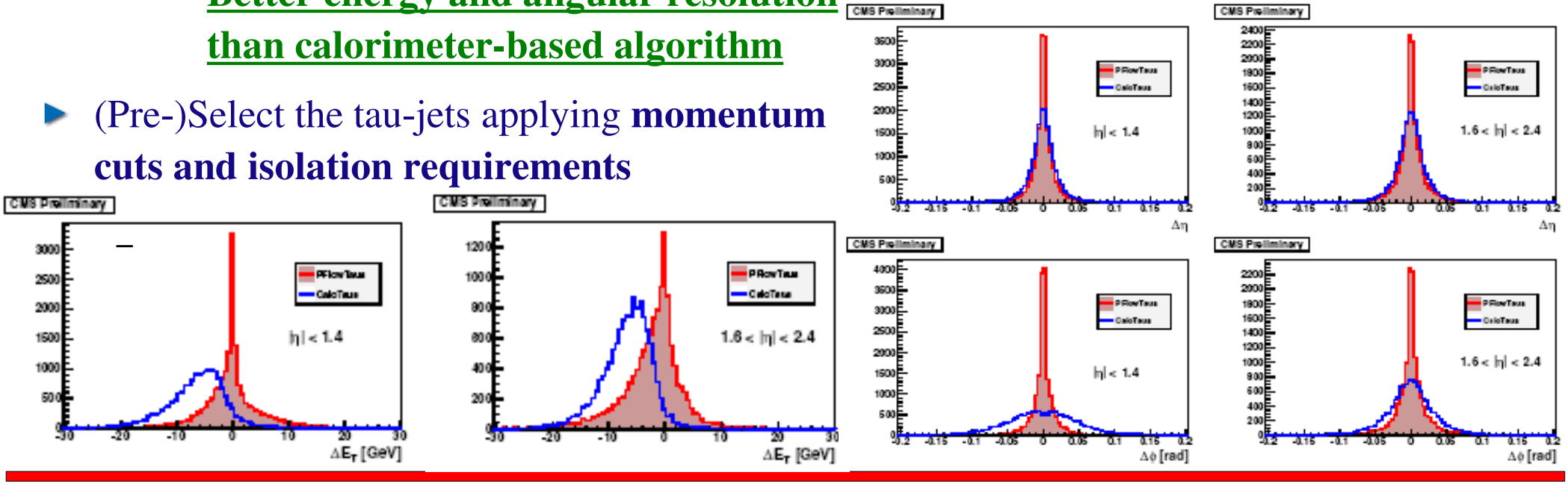
- **Reconstruction**:
  - *Start form ECAL cluster* and then **match it with the tracker seeds** (with loose criteria)
  - **Build the tracks from matched seeds** with loose chi2, electron hypothesis for energy loss, final fit with Gaussian Sum Filter
  - On-going studies on track seeded approaches, to increase efficiency for low pT electrons (<10 GeV)
- **Identification**:
  - 10^3-10^5 rejection power needed against jets (depending on physics analysis)
  - For start-up cut based approach, as it is more robust, later multivariate technique will be applied
  - Further rejection against jets can be achieved using *isolation* cuts in tracker, ECAL and HCAL

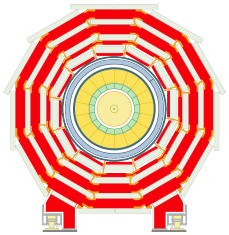




Tau Identification in CMS

- Tau is reconstructed in *hadronic channel* (main products are γ and charged pions)
  - 1 prong ($1\ \pi^{\pm} + n\ \pi^{0}$) ~50%, 3 prongs ($3\ \pi^{\pm} + n\ \pi^{0}$) ~ 15%
- Tau reconstruction and identification is based on **particle flow technique** (PF)
  - All reconstructed particle in the event (including charged pions and photons) from any possible hadronic tau decay products, are clustered into jets using a cone algo
    - PF-tau reconstruction is based on **tracker and ECAL**
    - **Better energy and angular resolution than calorimeter-based algorithm**
- (Pre-)Select the tau-jets applying **momentum cuts and isolation requirements**

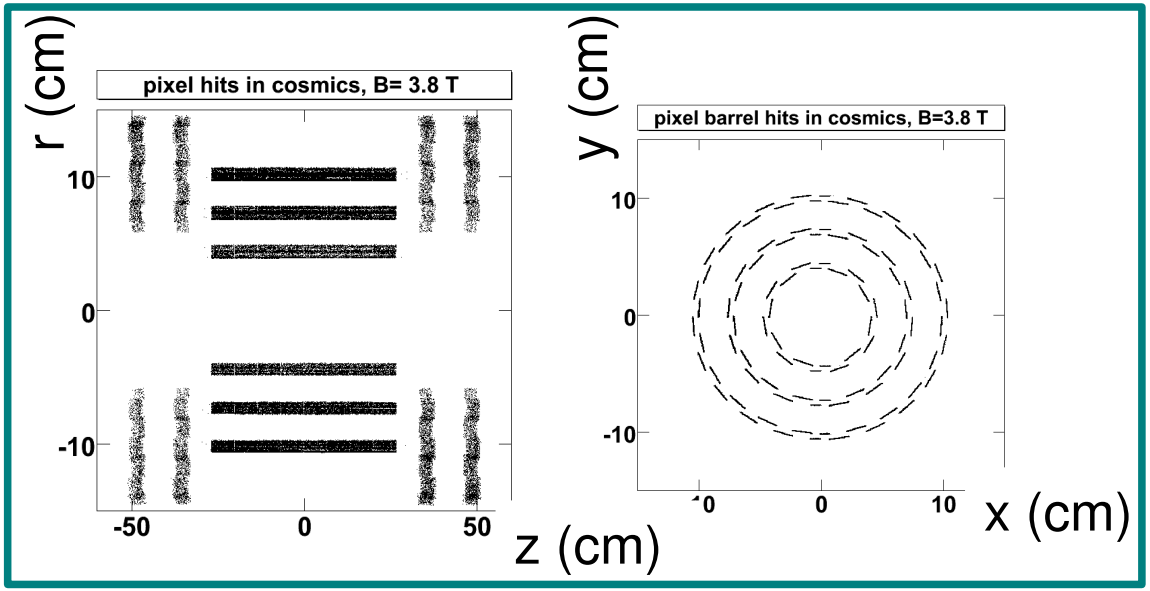


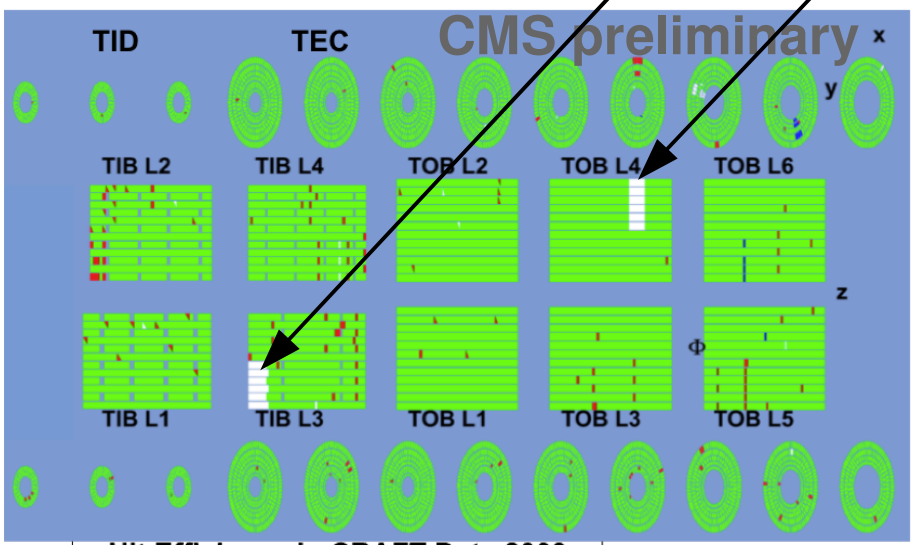


Commissioning of Basic Ingredients for Lepton Reconstruction and Identification

Tracker Availability in 2009

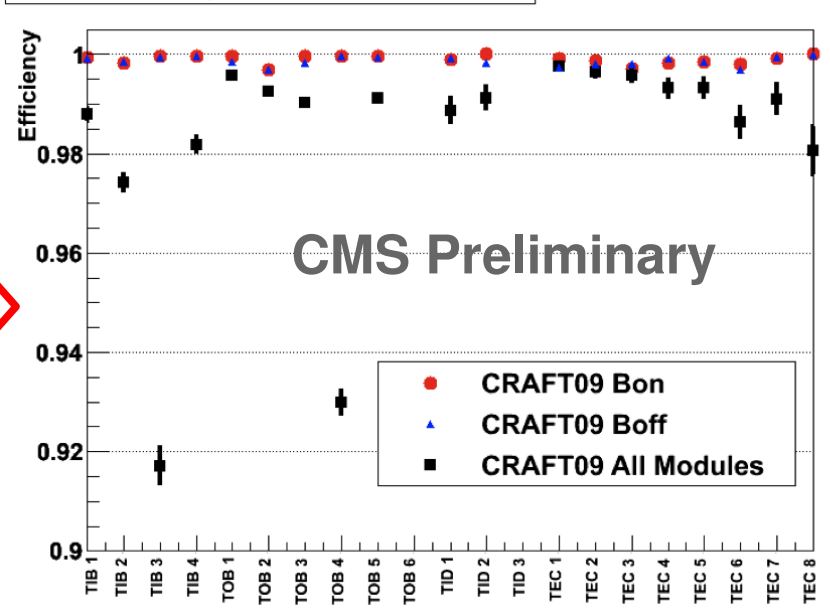
- Si pixel : 98.5%
- Si strip : 98.1%





Efficiency in the various layer of the Si tracker

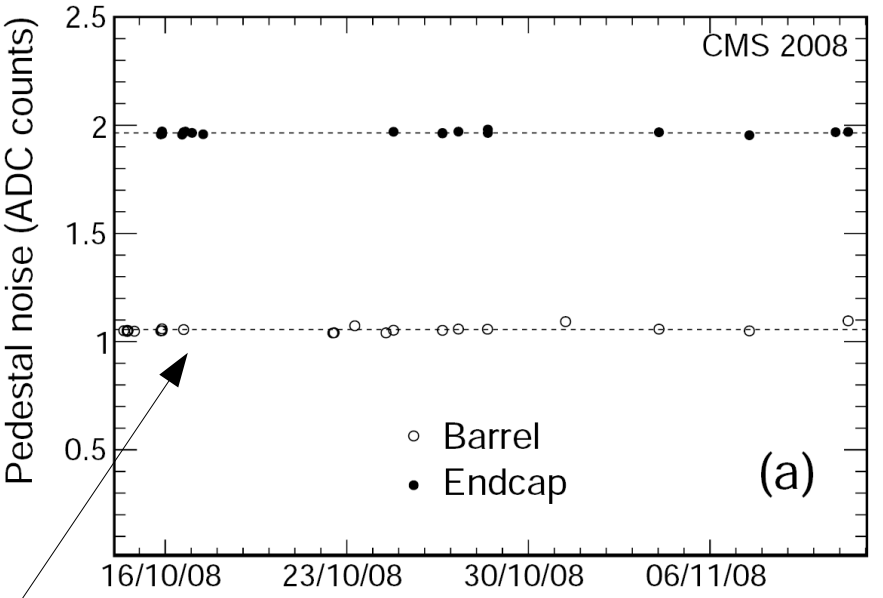
- Tracks are searched for without considering the layer under investigation.
- Track is extrapolated into layer under investigation
- A hit is searched for in the expected region
- Efficiency including faulty modules: **~98.1%**
- Efficiency excluding known faulty modules: **99.9%**

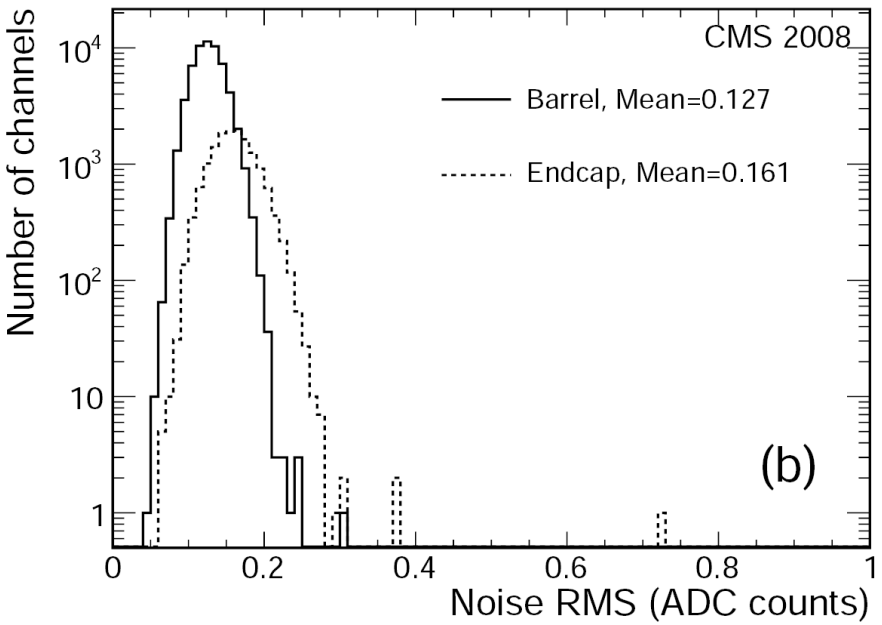


ECAL Pedestal Noise Stability

- Electronic noise monitored in several dedicated runs
  - Per-channel noise level
  - 0 and 3.8 T, for the barrel APD Gains G50 and G200
    - Points are perfectly aligned

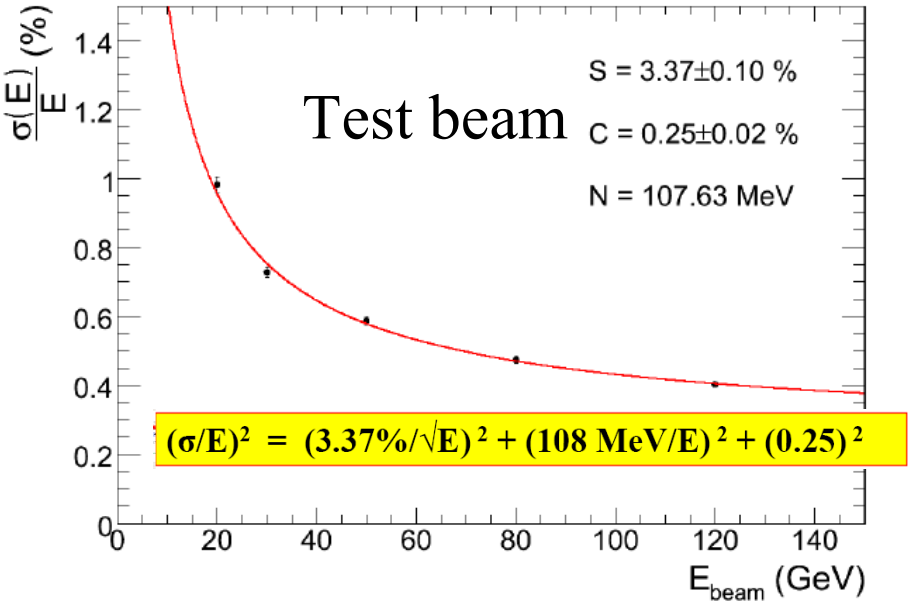
    → **<u>the noise does not depend on Magnetic field nor APD gain</u>**
- For the barrel, the average value of the noise in energy equivalent units correspond to roughly **40 MeV/channel** (APD G50)



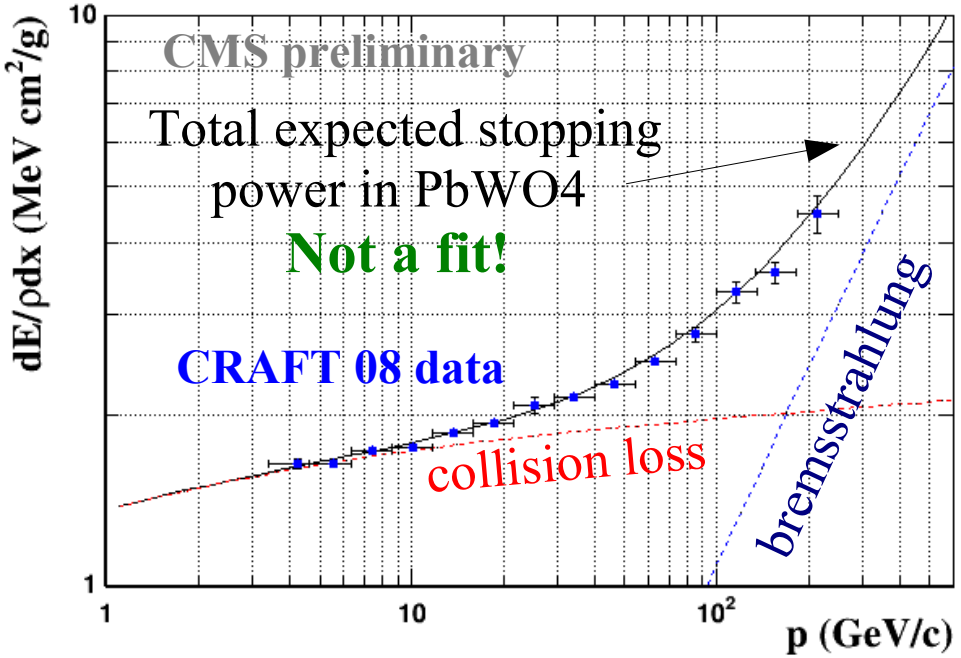


ECAL Pre-Calibration Constant

- Check the **goodness of the calibration** constant calculated with test beam
  - 9 Barrel SuperModules (SM) studied with electron beam in the energy range 15-230 GeV
  - **Constant term in energy resolution better than 0.5%**
  - **Noise is at ~40 MeV level per channel**



- **Stopping power** of cosmic muons traversing ECAL VS muon momentum from tracker
  - Loose selection on the distance of closest approach of the track to the centre of CMS
  - Errors on the vertical scale are stat only; error bars on the momentum represent the bin width
  - Results indicate the **correctness** of the tracker momentum scale and of the energy scale in ECAL calibrated with electron at test beams



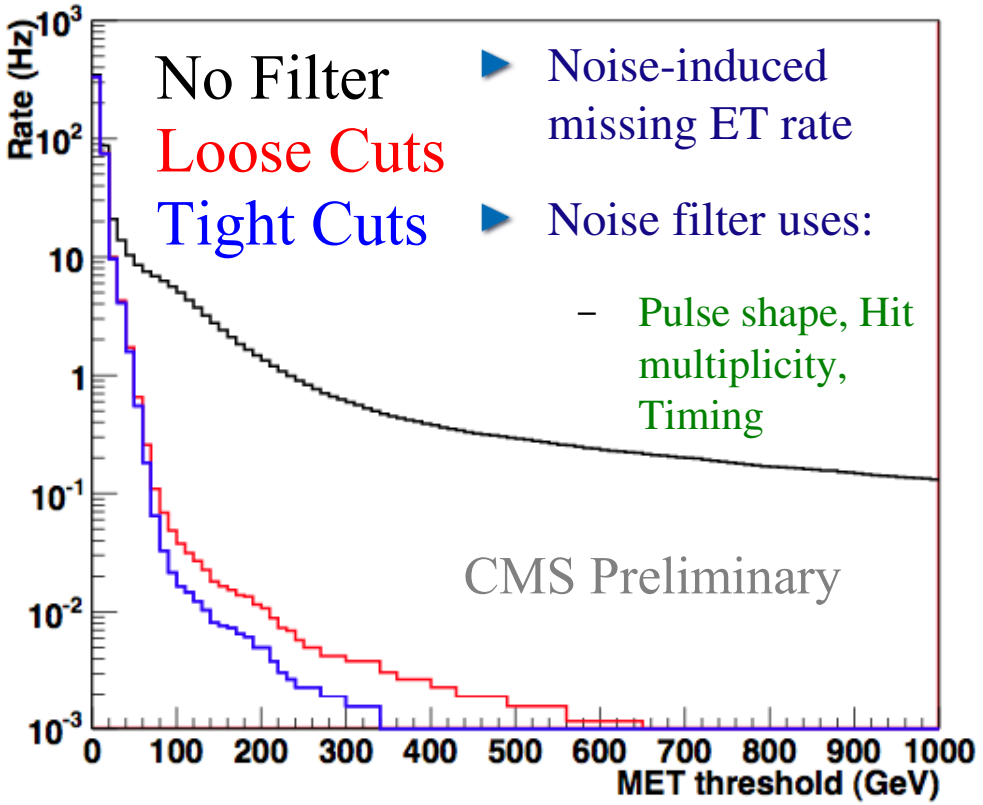
HCAL Noise and Response

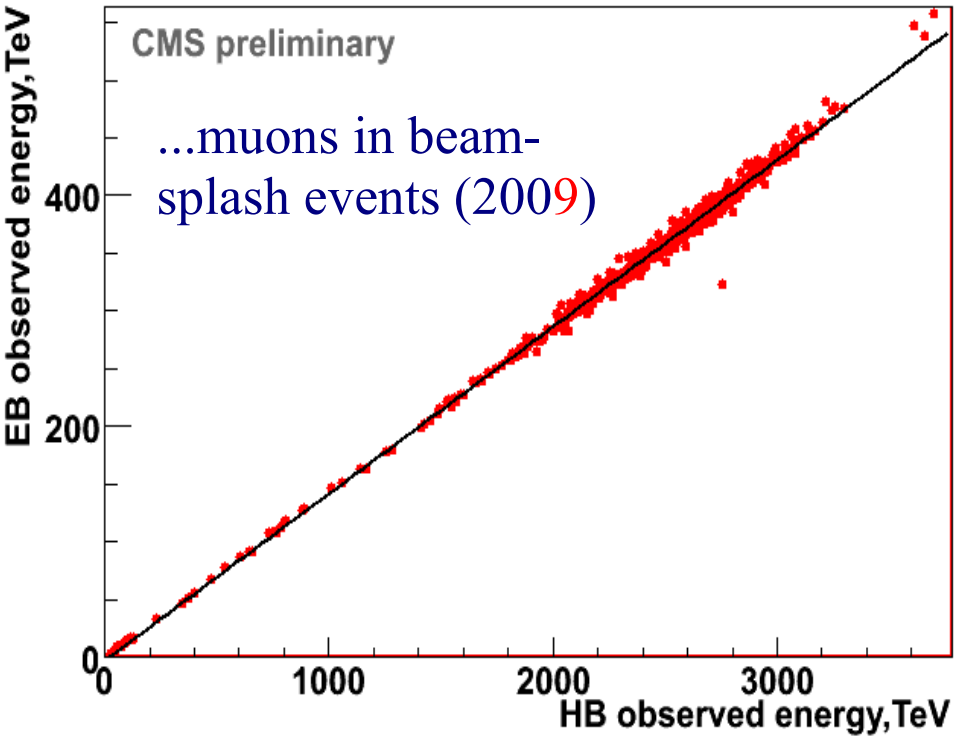
HPD Noise Rates*	0 T	3.8 T
CRAFT 08†	0.27 Hz	0.29 Hz
CRAFT 09	0.14 Hz	0.16 Hz

R109049

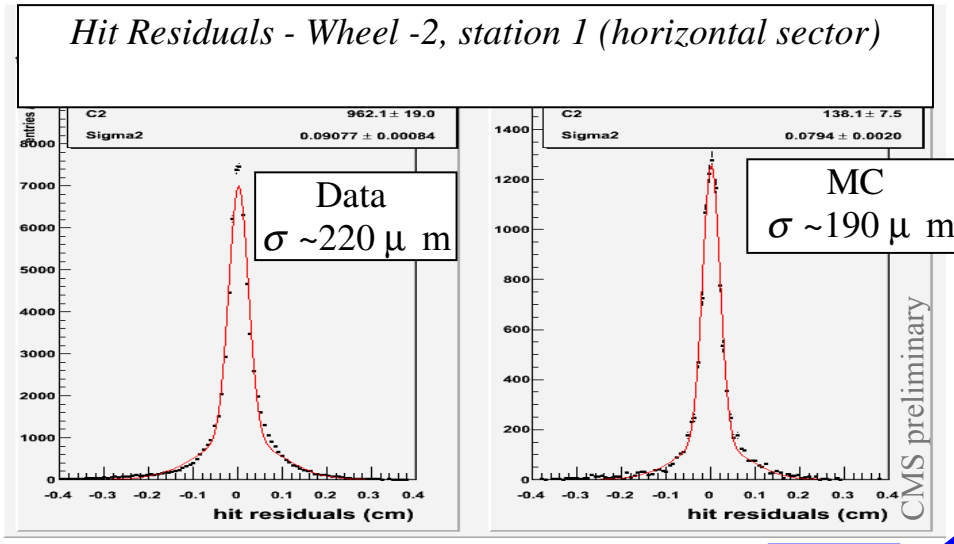
* HPD mean noise rate in HB/HE for a 50 fC threshold (10 GeV)
† 7 noisiest HPDs are not included, and were replaced during shutdown

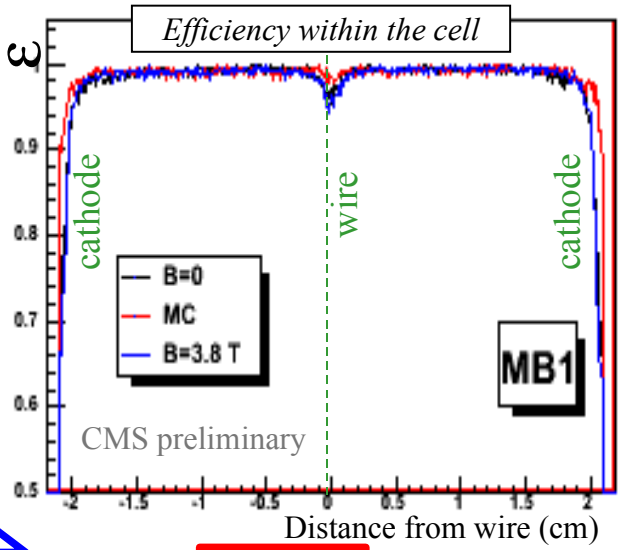
HPD noise reduced by factor ~2 in CRAFT09 vs. CRAFT08 (for a 50 fC - 10 GeV threshold)
Replaced noisiest HPDs during shutdown





Drift Tube and RPC



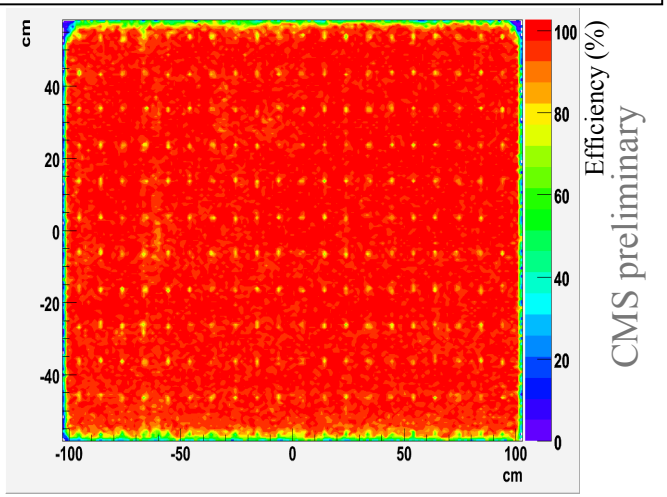


- Average cell efficiency: 98.4%
- Hit residuals 200-260 μ m
  - reasonable agreement with MC

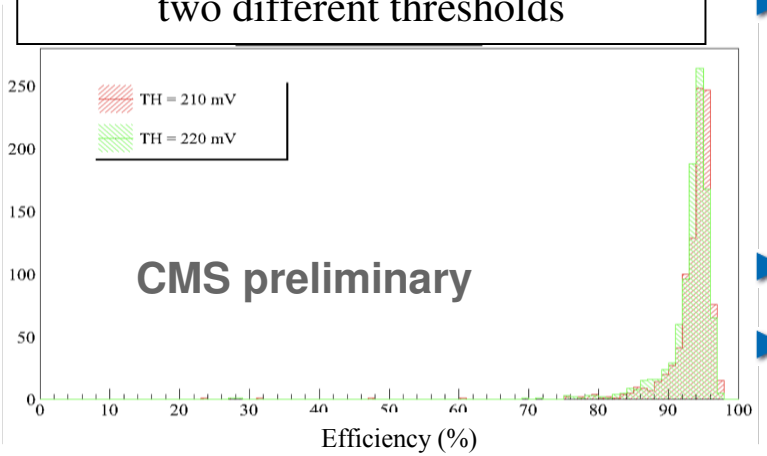
DT

RPC

"Muongraphy" of one barrel chamber

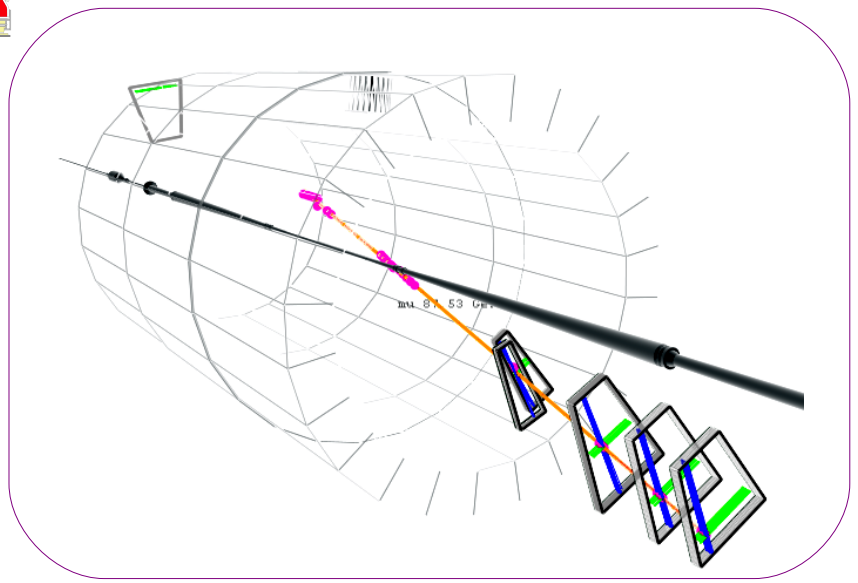


Efficiency distributions at 9.3 kV for two different thresholds

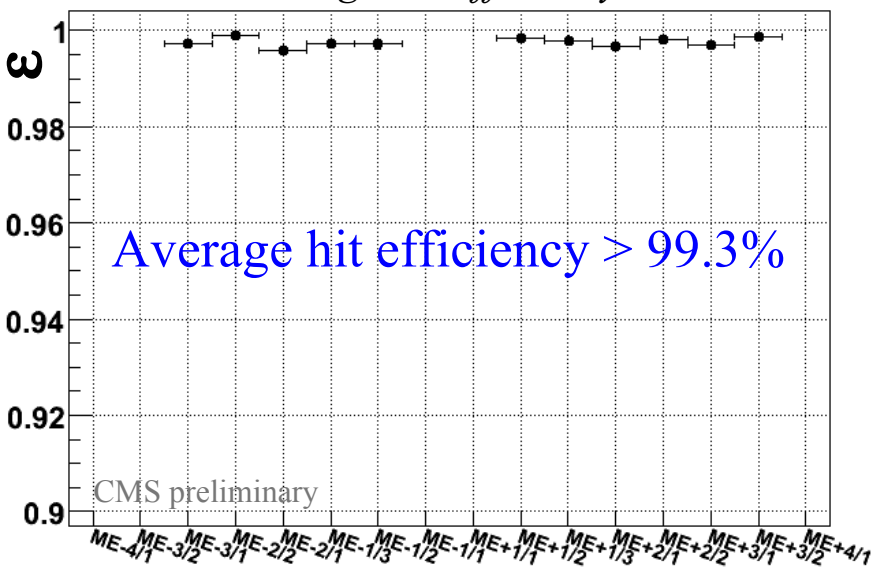


- Efficiency above 90%
  - estimated from extrapolation of DT segments
- Noise below 1 Hz/cm²
- r-ϕ resolution 1.1 cm

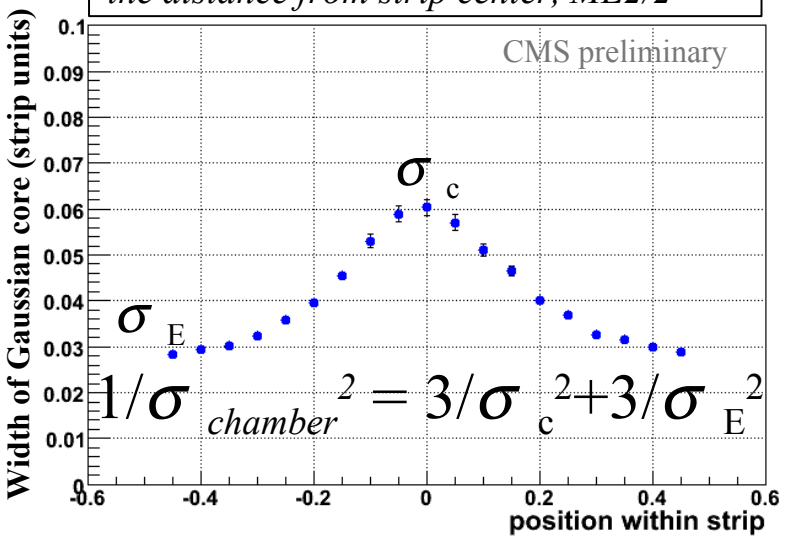
CSC Craft Data



Single hit efficiency

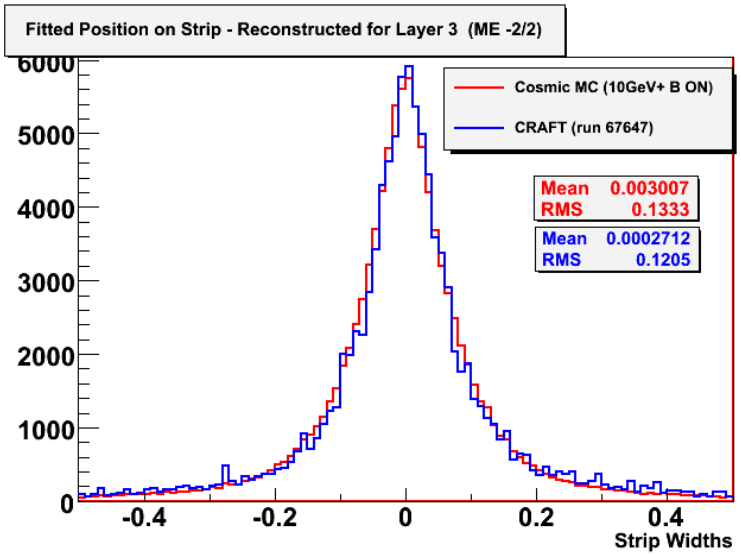


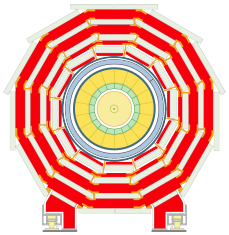
Single hit Resolution as a function of the distance from strip center, ME2/2



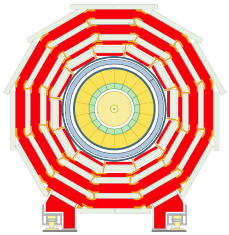
Chamber resolution: ~160 μm

- ~50-55 μ m in ME1/1
- Single Hit resolution better at edge of strips (charge sharing)
  - Strips are staggered layer-by-layer

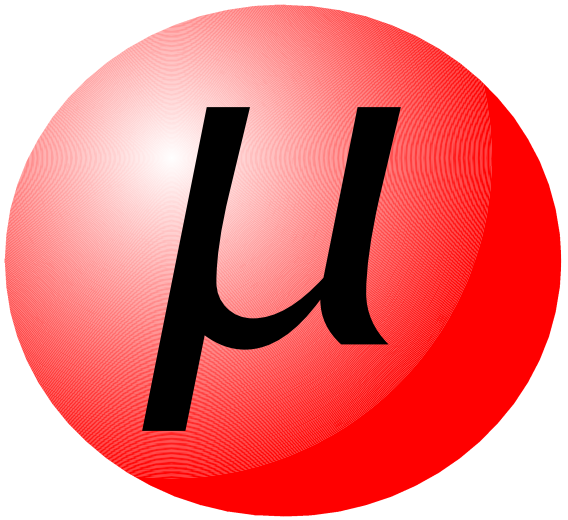




Commissioning of Lepton Reconstruction and Identification Algorithms



Commissioning of Lepton Reconstruction and Identification Algorithms

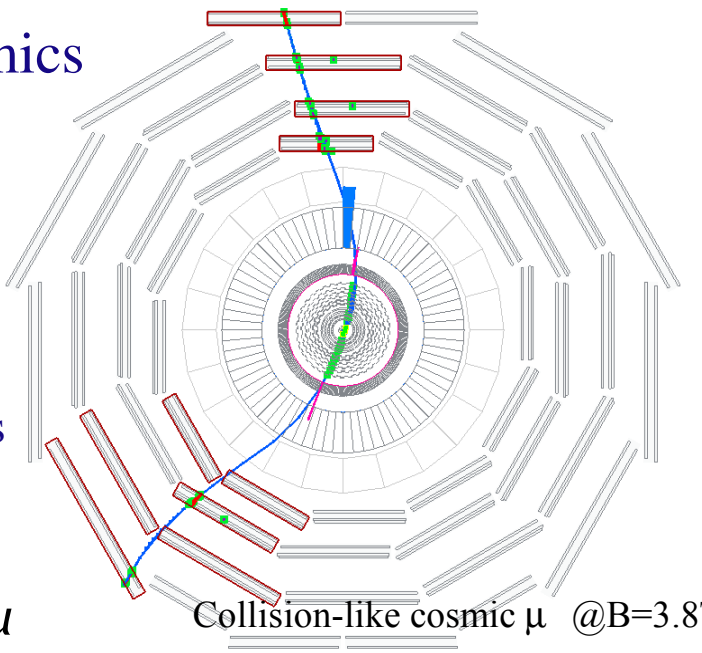


e τ

Cosmic Muon Reconstruction

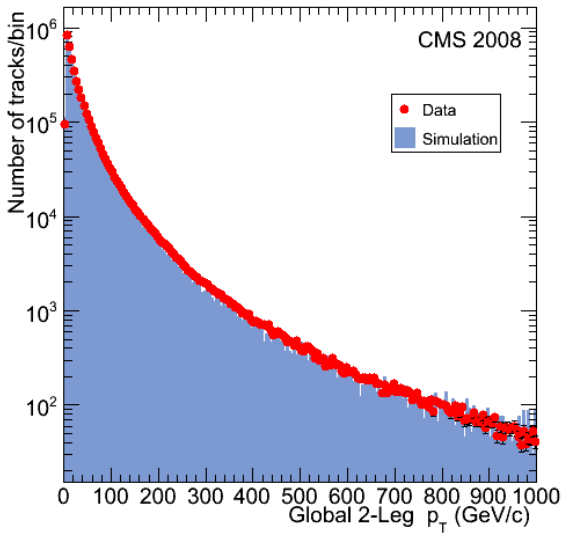
Many handles to probe the system performance with cosmics

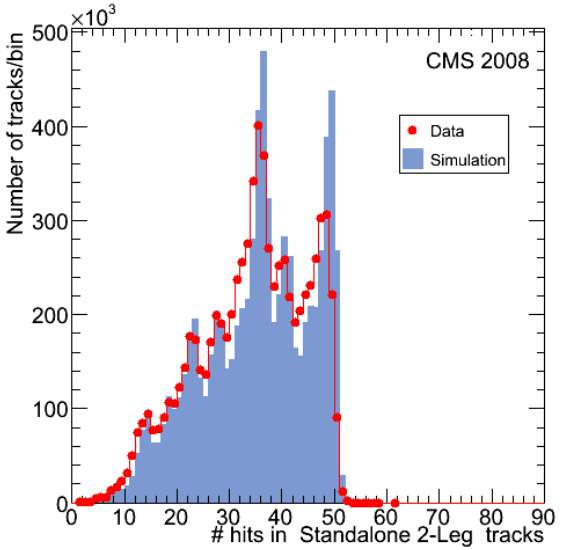
- Redundancy of tracker-only, stand-alone, combined fits
- Comparison of "top" and "bottom" legs
  - "IP-Pointing" muons mimic collision tracks
  - "1-leg" fit of top+bottom together also possible (provides best possible resolution)

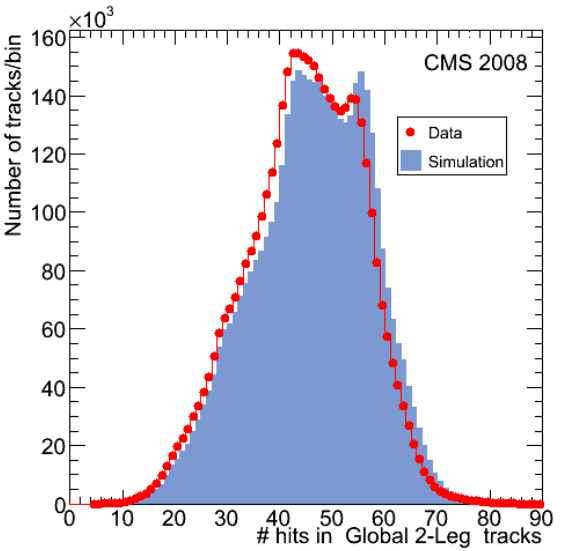


Collision-like cosmic μ @B=3.8T

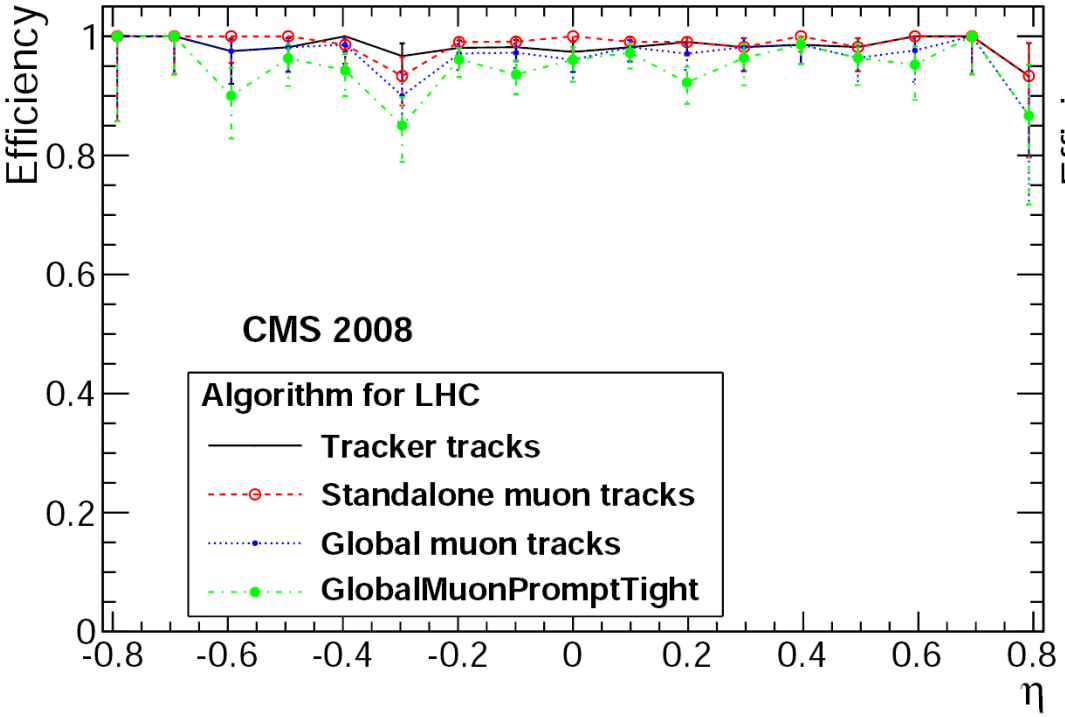
Data-Simulation comparisons for (loosely) pointing μ

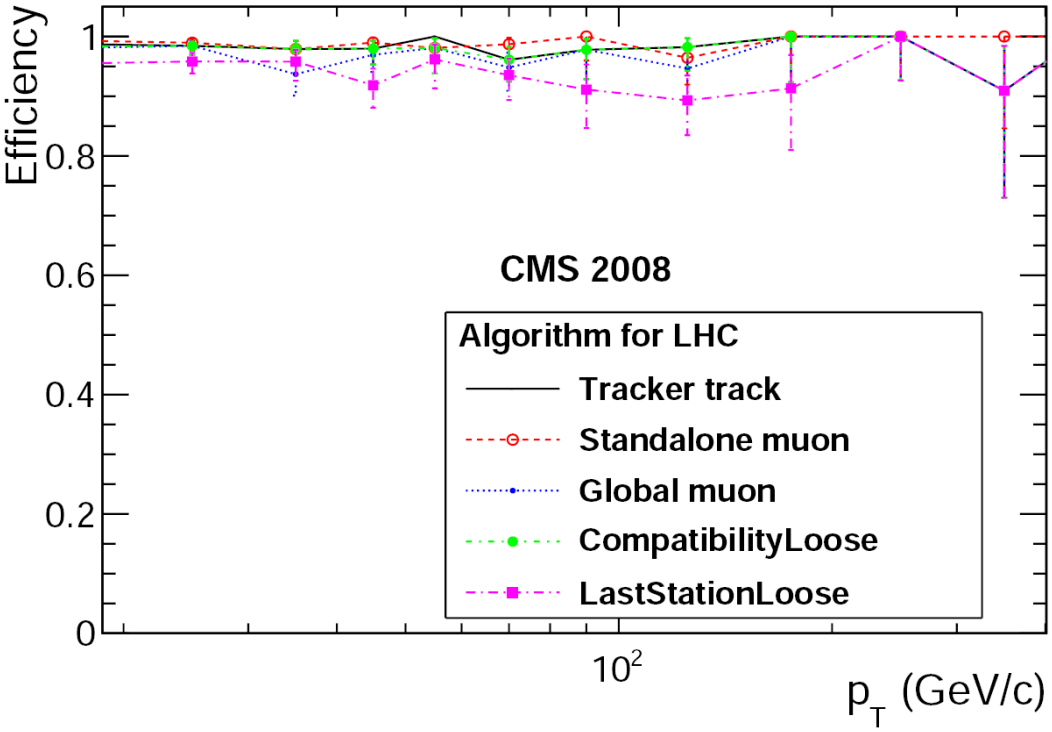






LHC Reconstruction on CRAFT'08 Data

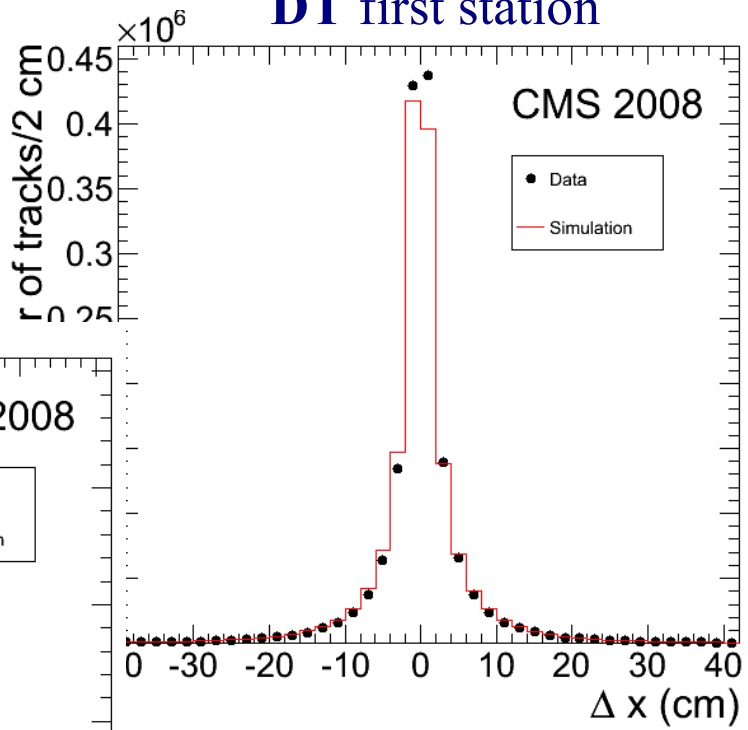




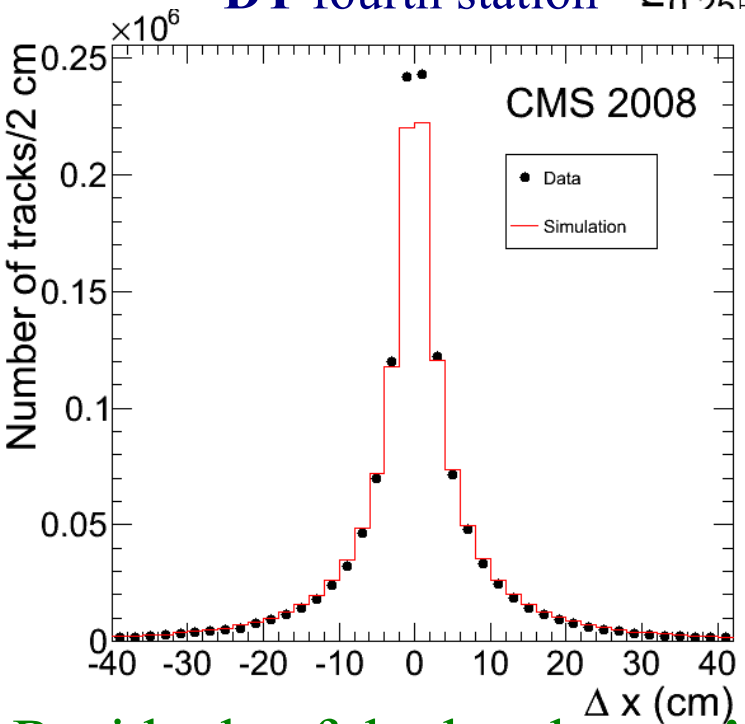
- LHC like reconstruction efficiency in CRAFT '08 data
  - Evaluated tagging the muon on one half of the detector and probing the other half
- Tag muons have been requested to be pointing:
  - |d0| < 10 cm, |dz| < 20 cm

Muon ID Variables

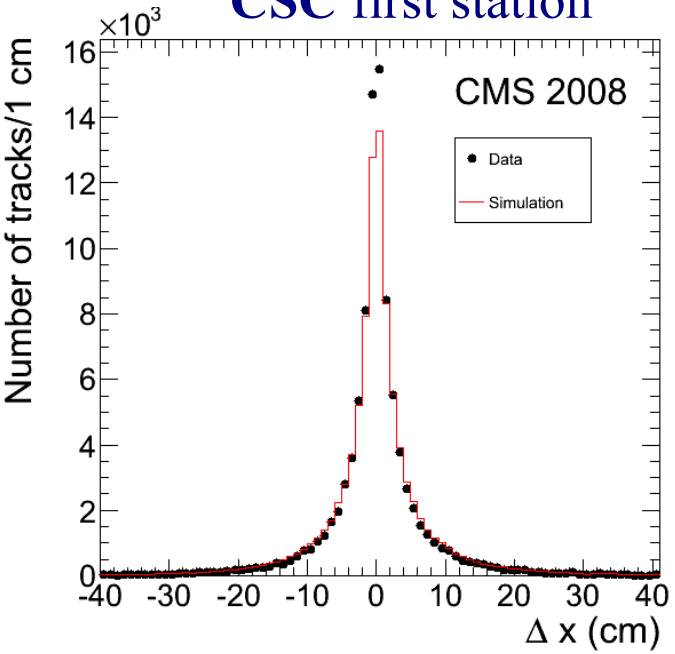
DT first station



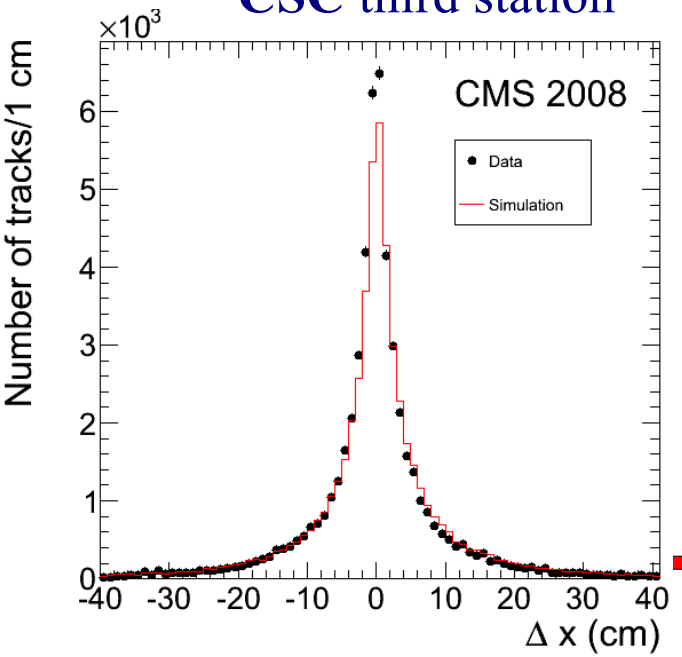
DT fourth station



CSC first station

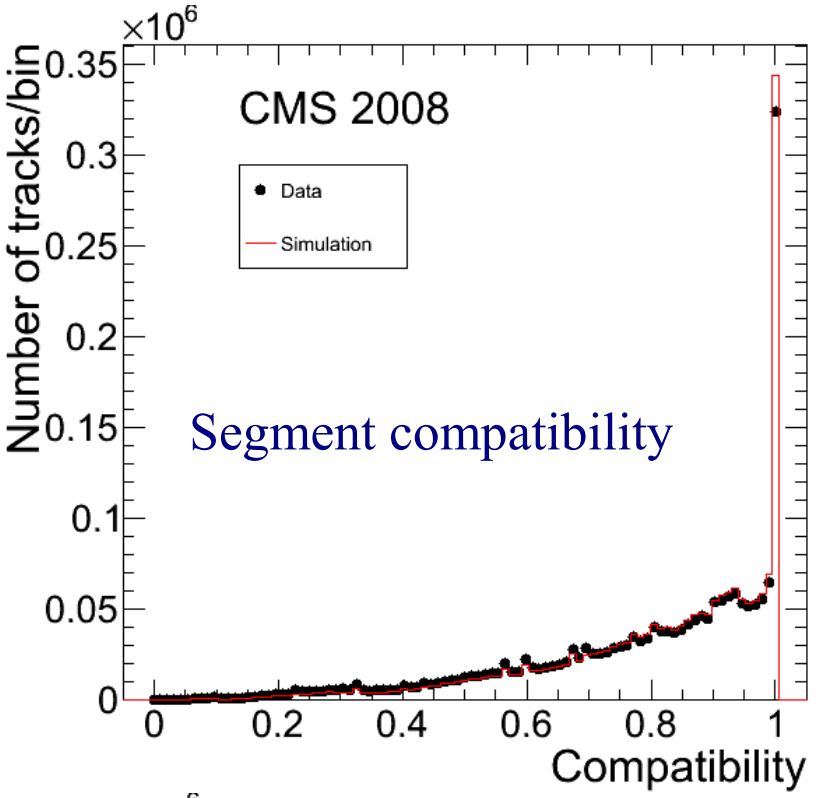


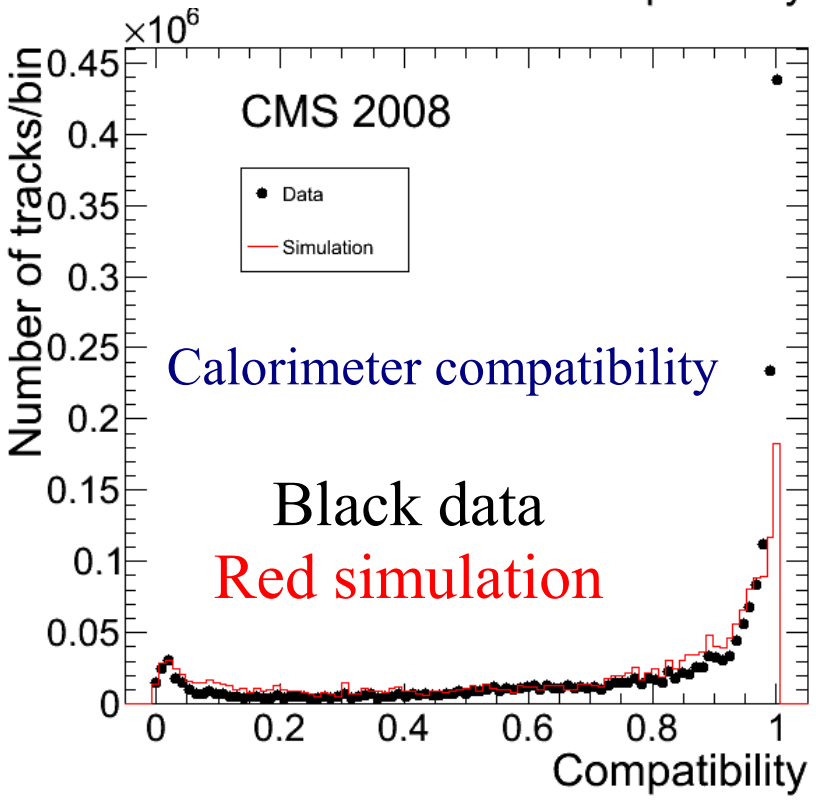
CSC third station

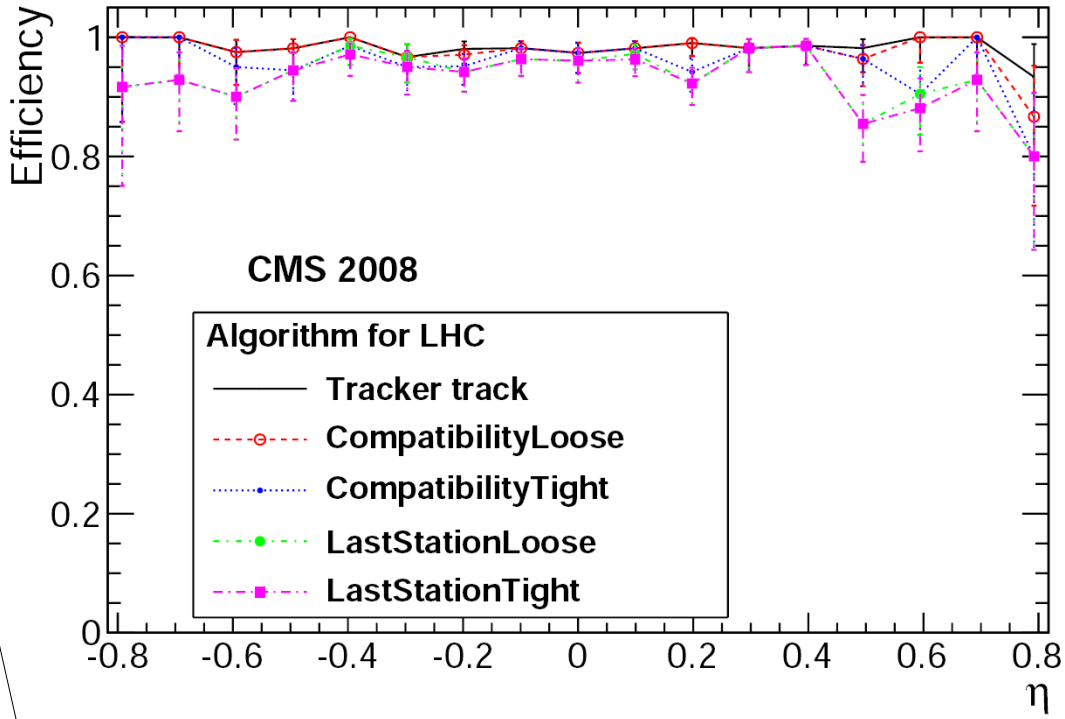


Residuals of the local **x variable,** of tracker track extrapolated to the relevant muon chambers and the matched segments

Muon ID in CRAFT'08

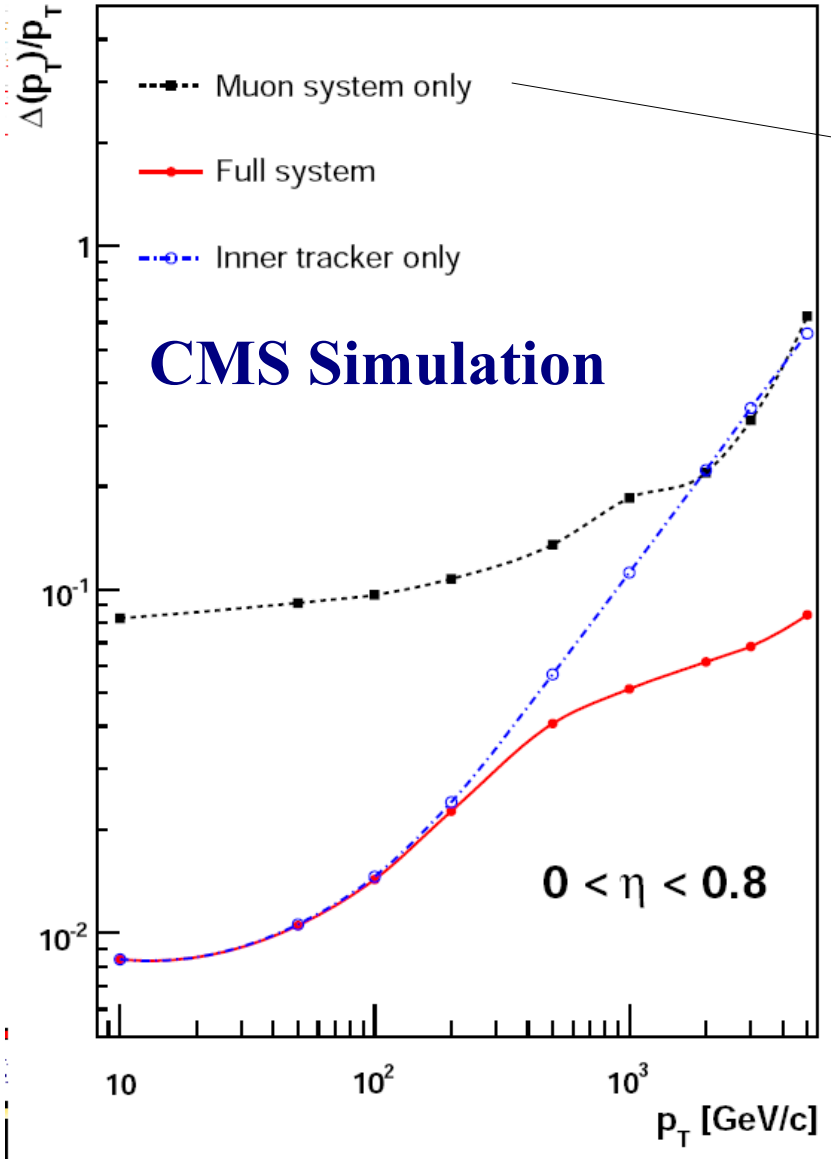




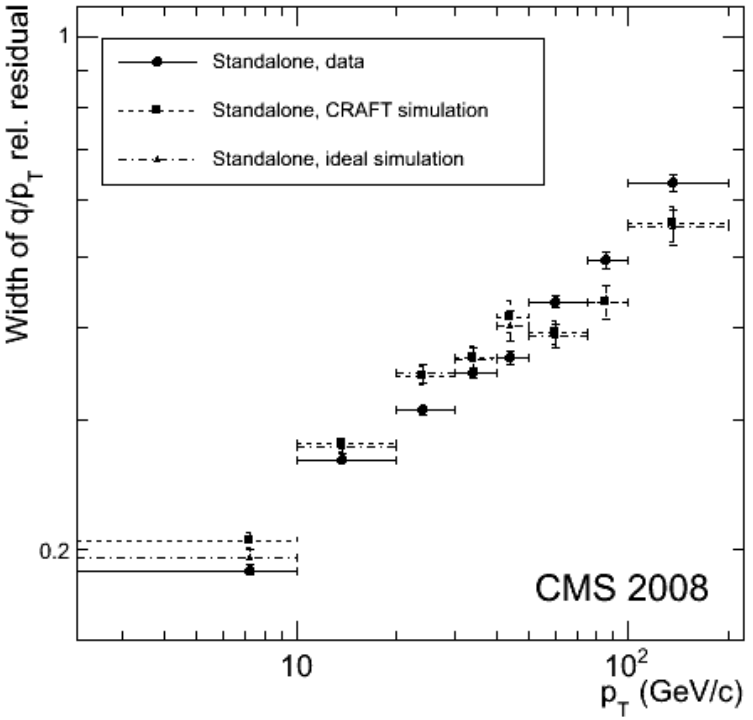


- Two possibilities to identify a Tracker muon as a muon candidate
- Compatibility Based selections:
  - **CompatibilityLoose** and **CompatibilityTight**
- Cut Based (on previous slide variables)
  - **LastStationLoose** and **LastStationTight**

Muon pT Resolutions



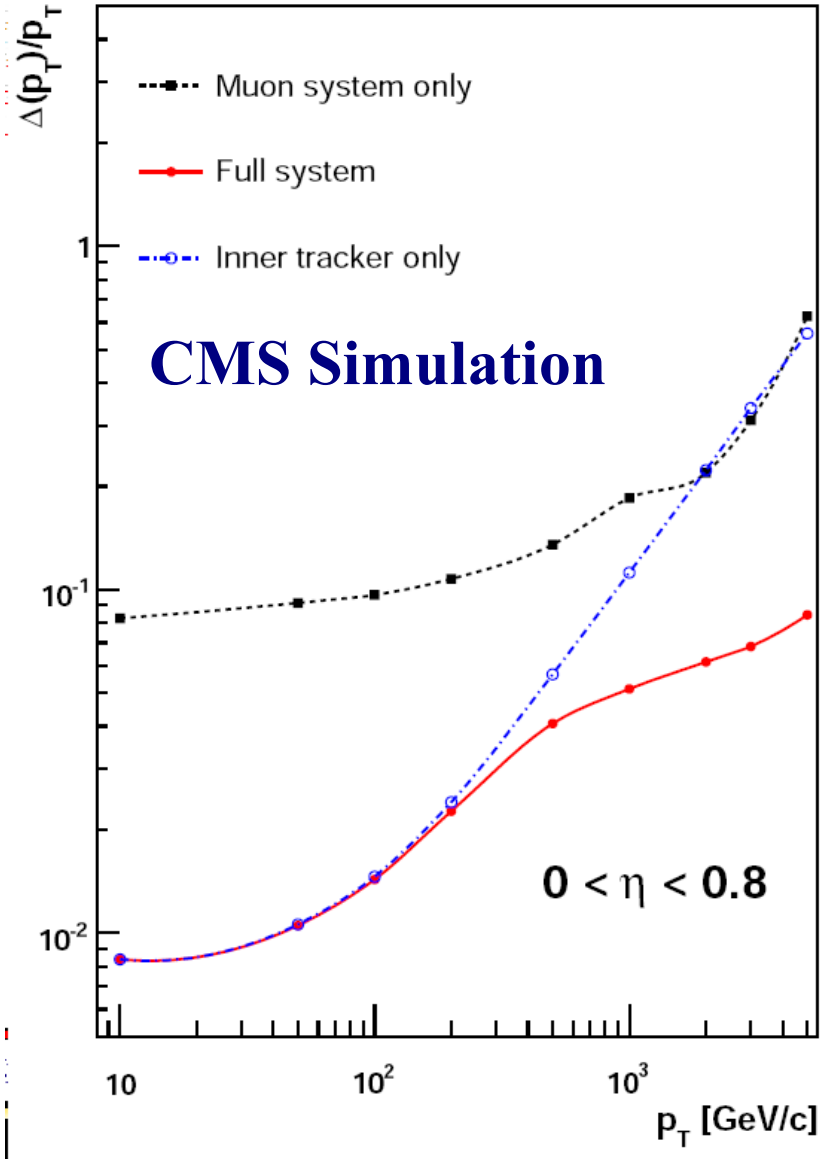
CRAFT '08 data



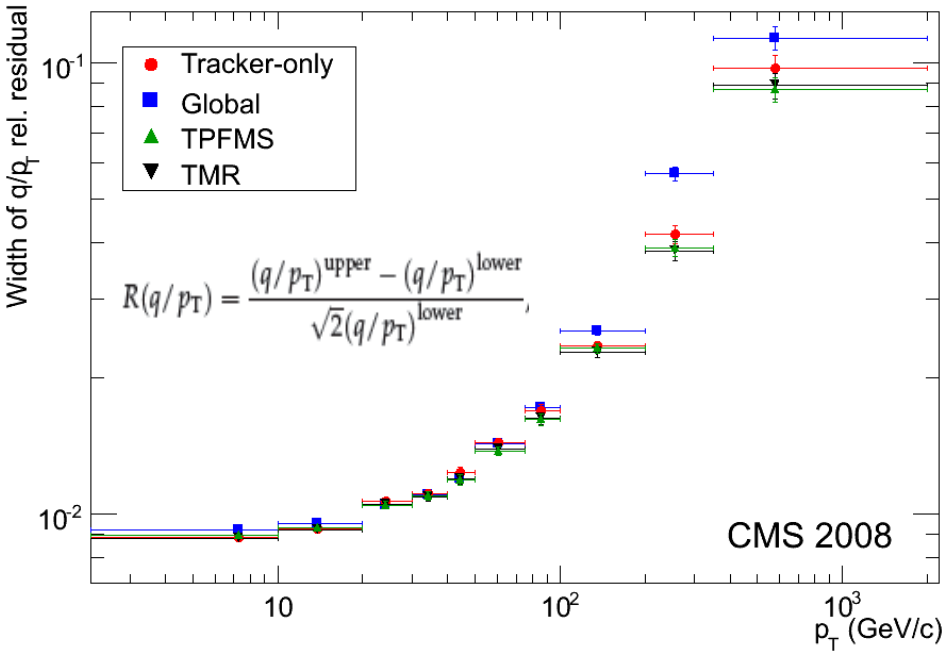
Measure the **stand alone muon reconstruction resolution** using the measurement in the *tracker as reference* (one order of magnitude better)

No vertex constraint in data...

Muon pT Resolutions



CRAFT '08 data

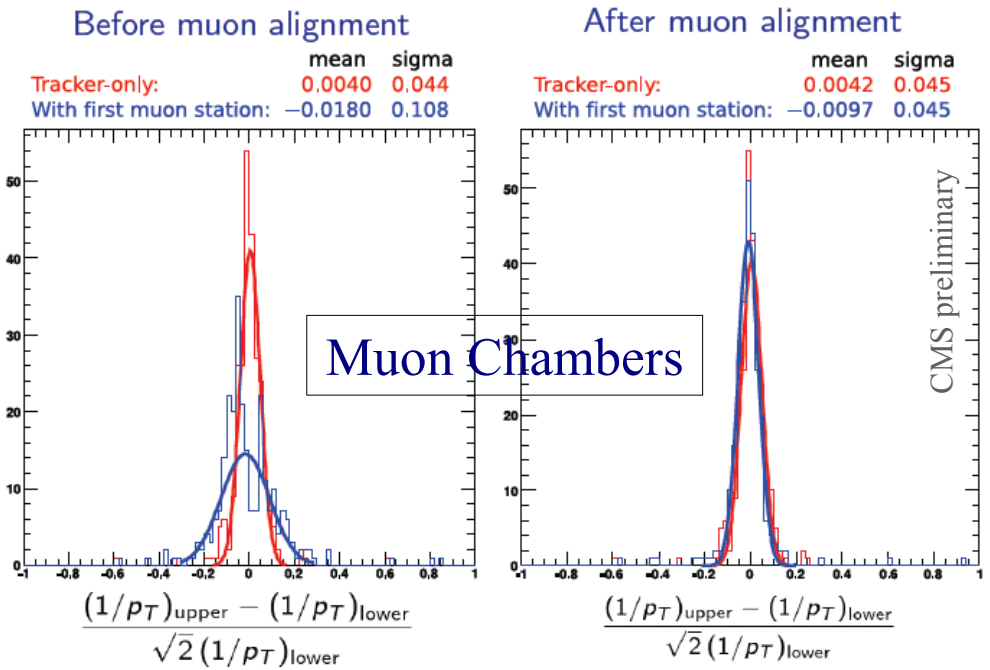


▲ TPFM = Tracker Plus First Muon Station

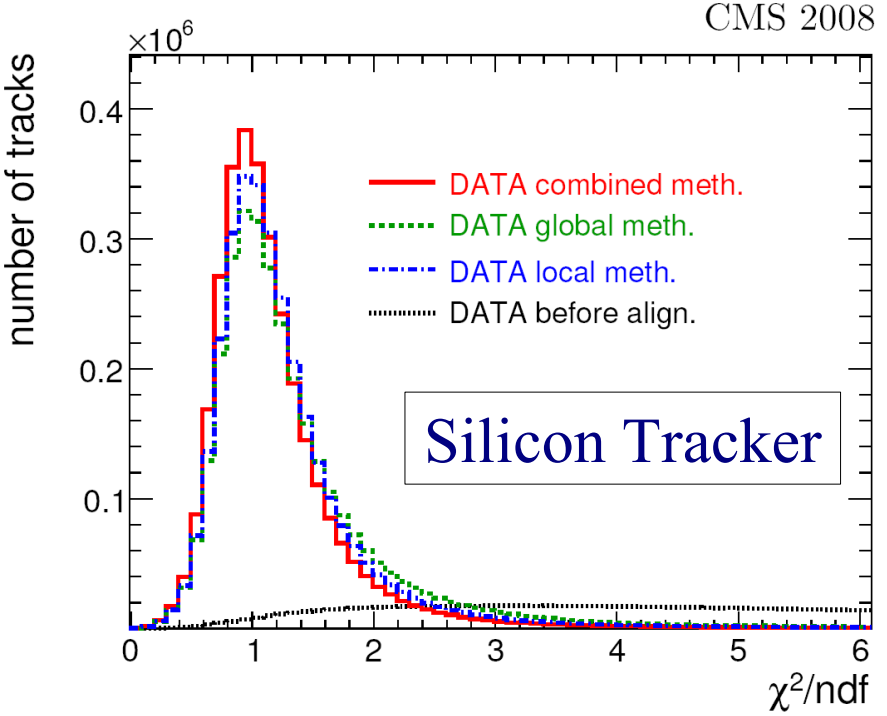
▼ TMR = Truncated Mean Reconstructor
(pick up Tracker or TPFM on chi2 basis)

Specialized combined fits exceed resolution of silicon tracker alone thanks to accuracy of alignment reached with CRAFT tracks

Alignment



Muon Chambers

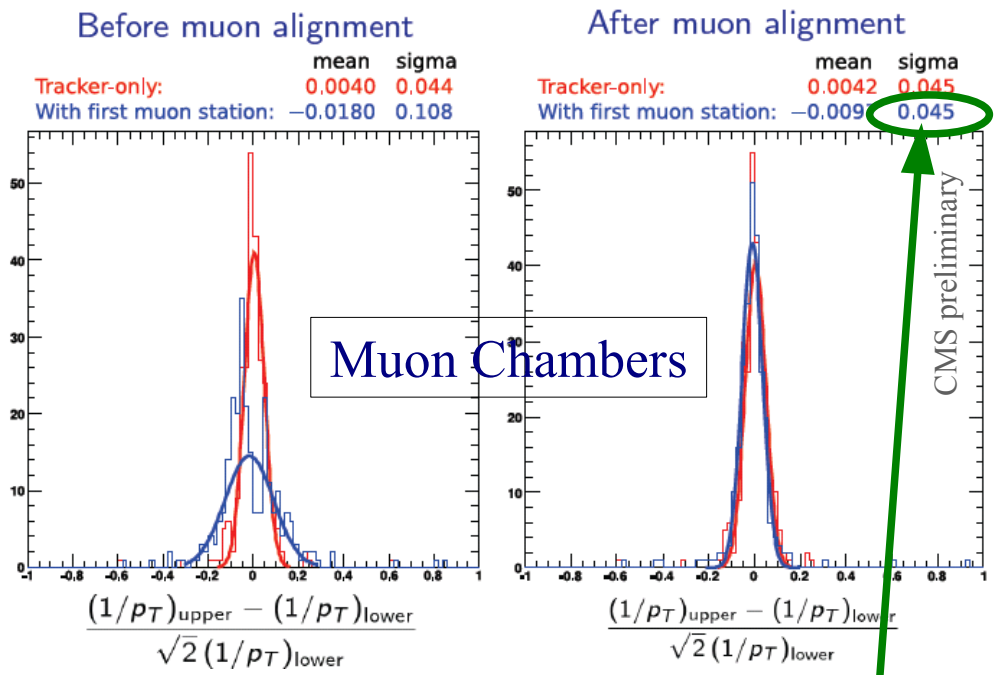


Silicon Tracker

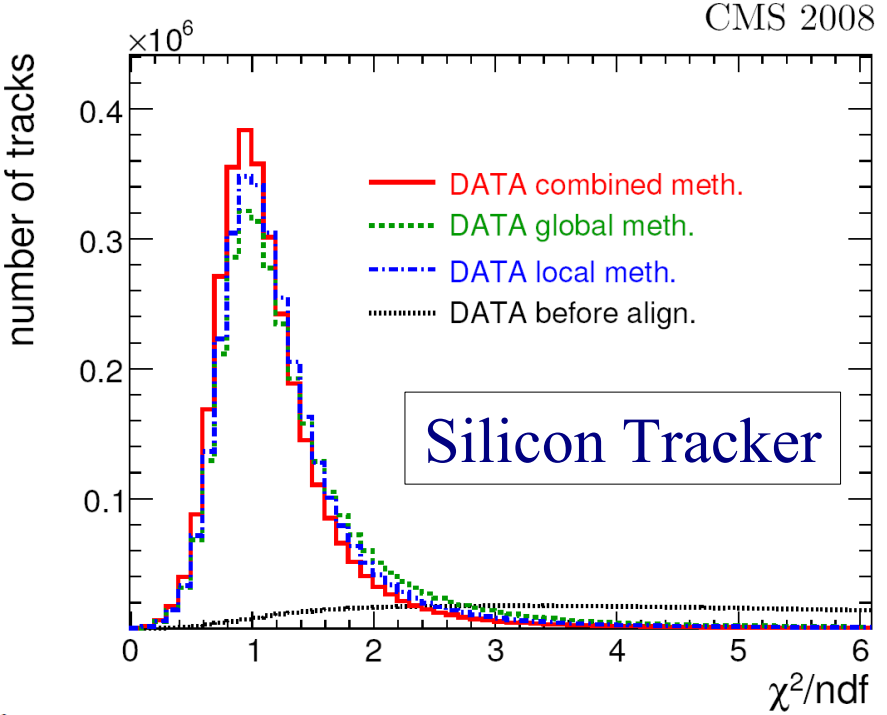
Collision-like cosmics, $p > 200$ GeV before and after CRAFT alignment with tracks

Alignment

CMS 2008



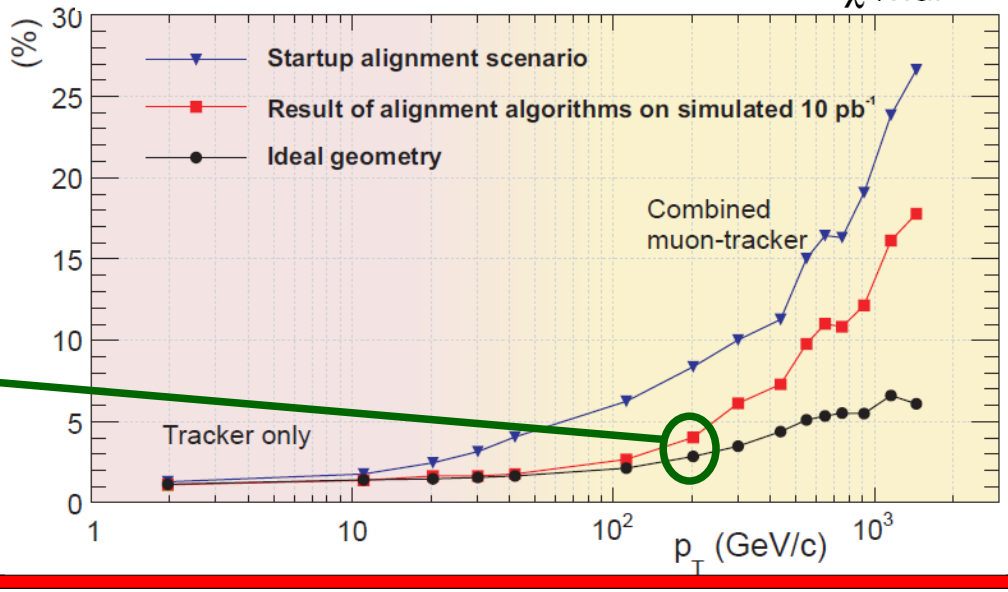
Muon Chambers



Silicon Tracker

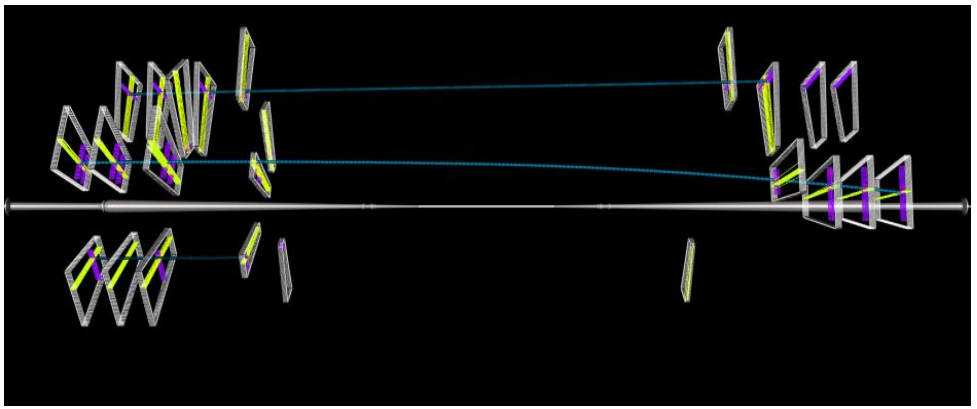
Collision-like cosmics, $p > 200$ GeV before and after CRAFT alignment with tracks

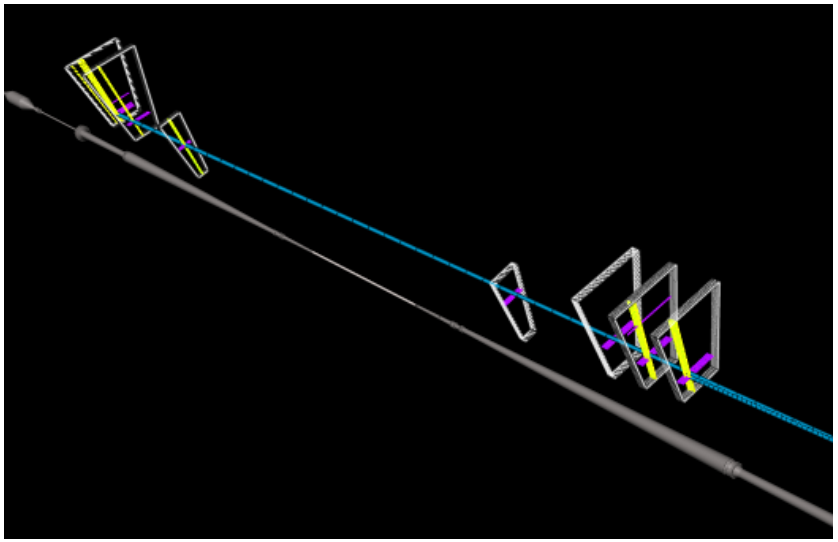
Reaching the level of alignment expected **after 10/pb of data**... *before* the first collisions!



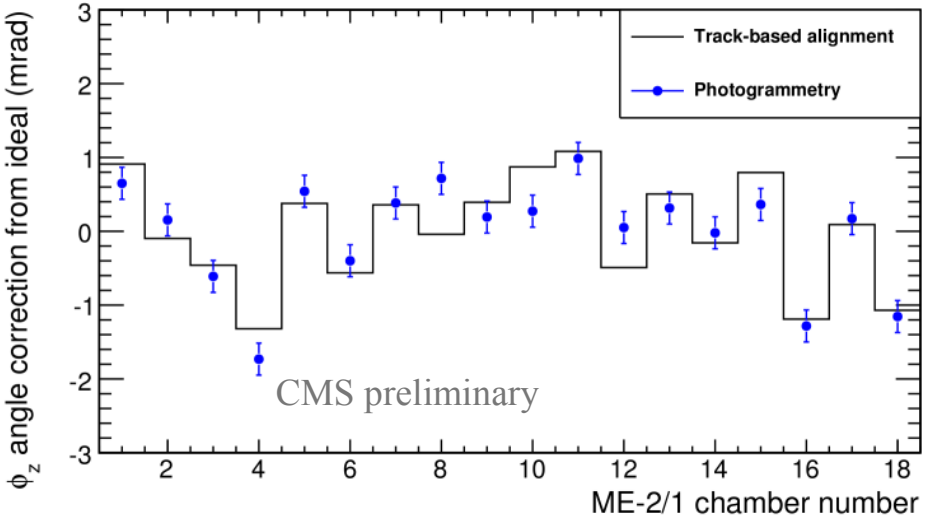
CSC: Beam Halo

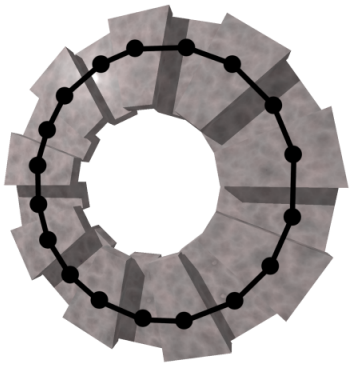
Beam halo reconstructed promptly on Sep, 10,2008!

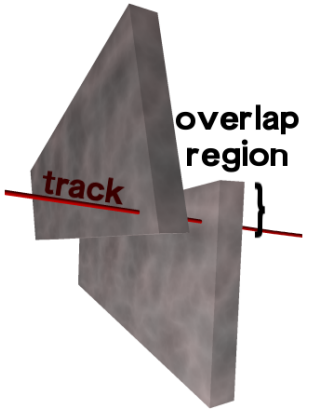




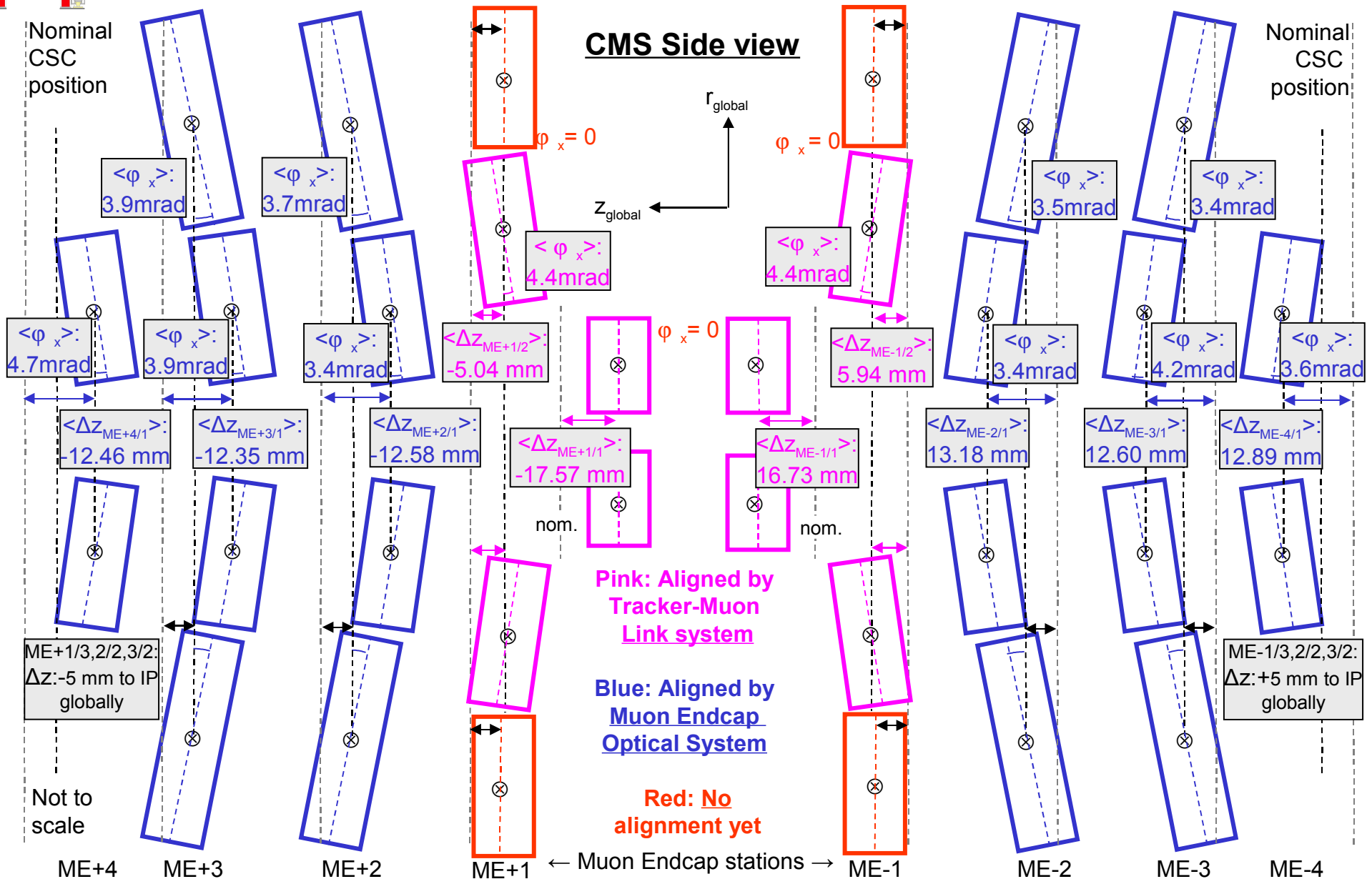
Chamber rotation alignment with 9' of beam halo, compared to photogrammetry







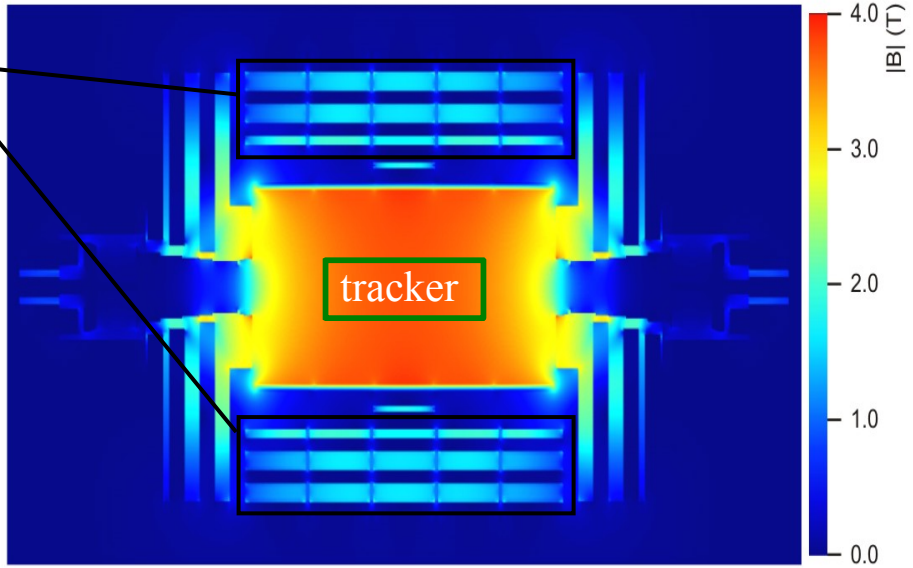
Muon Endcaps Hardware Alignment



Magnetic Field Map

Measurement of the B field in the yoke by comparison of measured track bending to prediction from track extrapolation

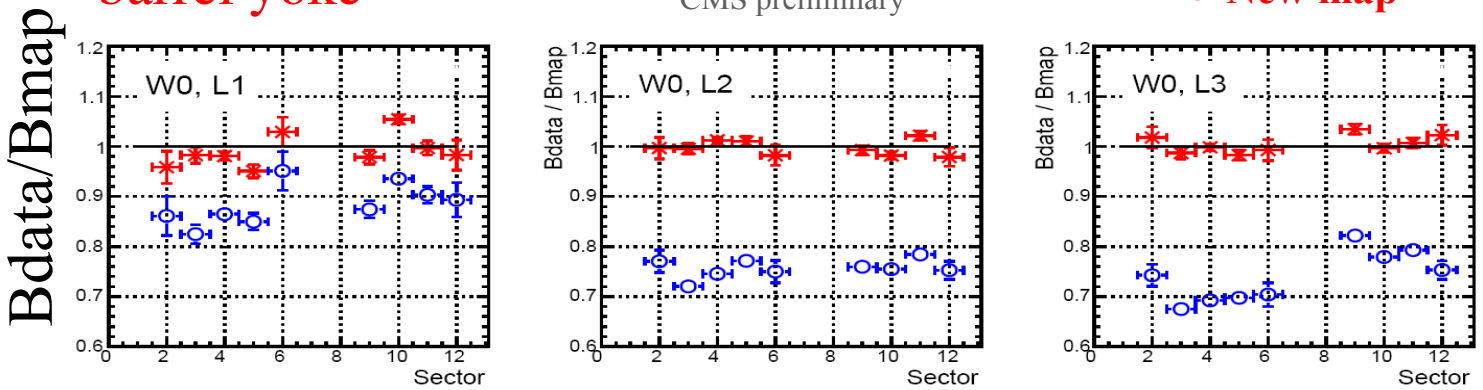
- **Using the tracker track as a reference** (field within the solenoid mapped to better than 0.5%, in 2006)
- Revealed a problem in the field map
- updated map + calibration with data reproduces bending to ~3% in the barrel yoke



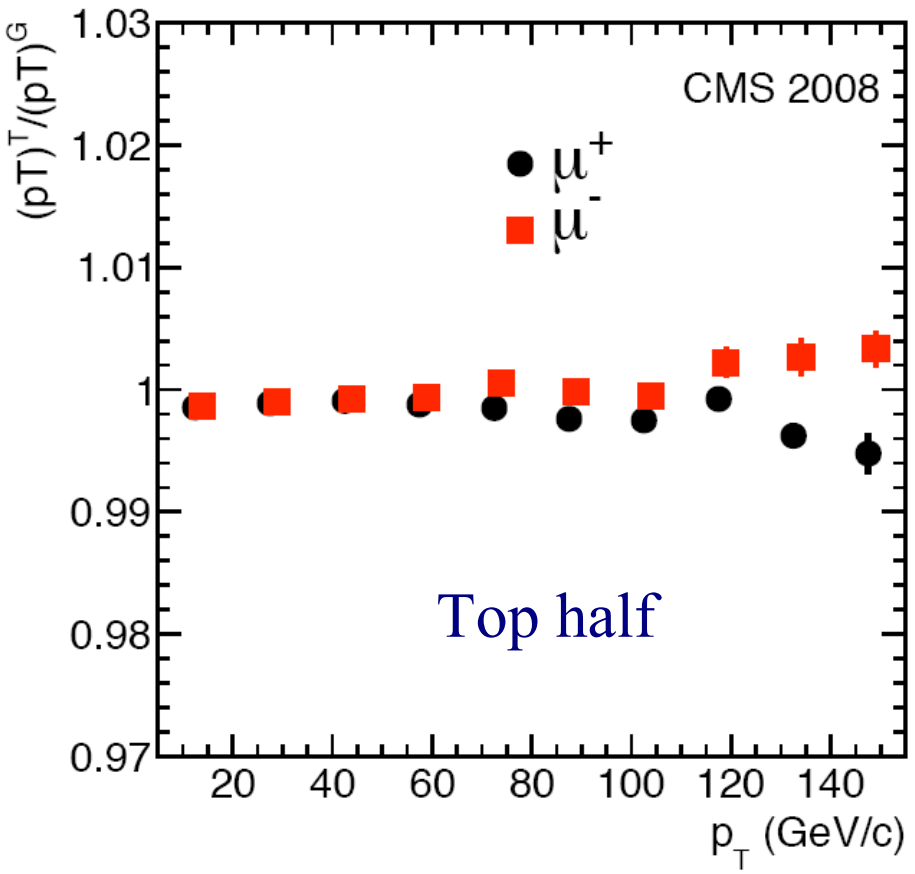
• **Old map**

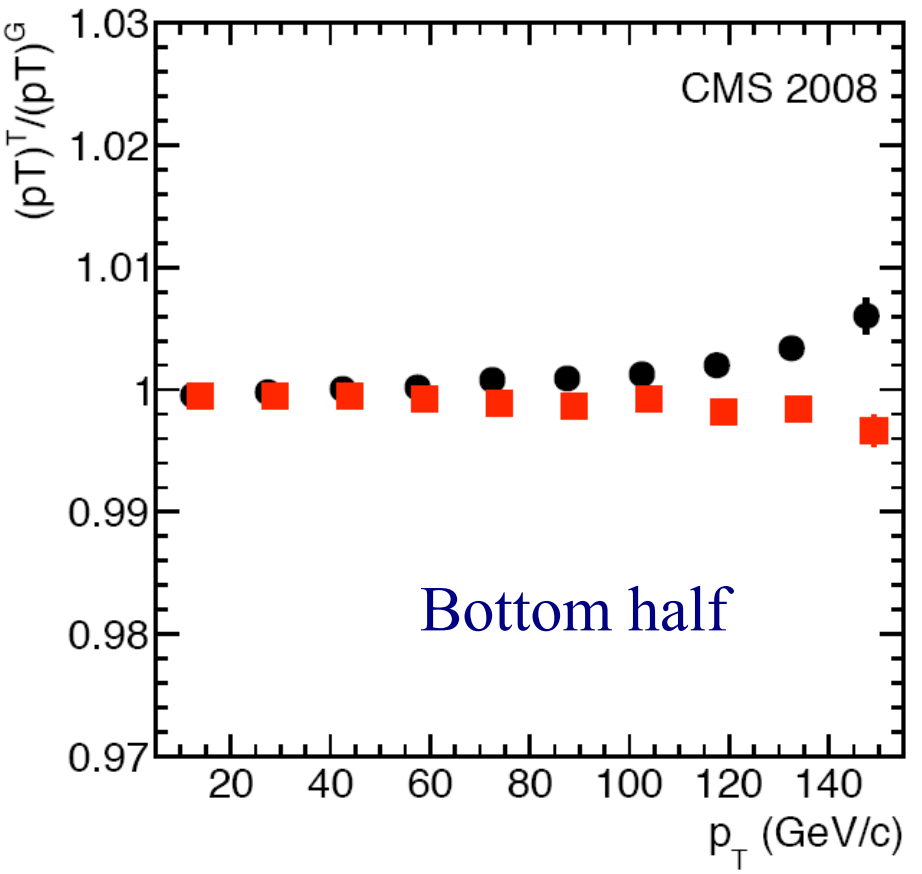
○ **New map**

CMS preliminary



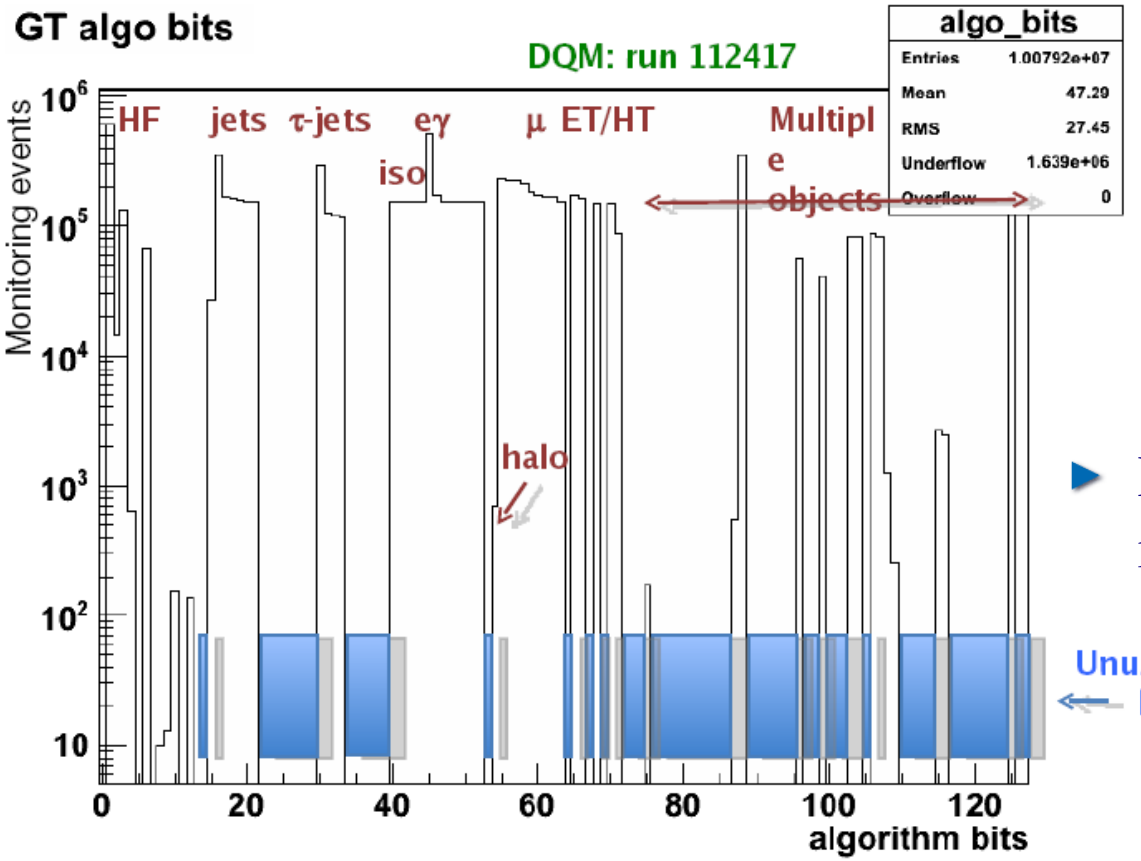
Systematics in Muon Reconstruction





- Comparison of **Tracker (T)** and **Global muon (G)** pT
  - Sensitive to systematic effects due to the scale of the magnetic field and to unaccounted shifts or rotations of the muon system w.r.t. the tracker
- **Systematics are below 1%**

L1 Trigger

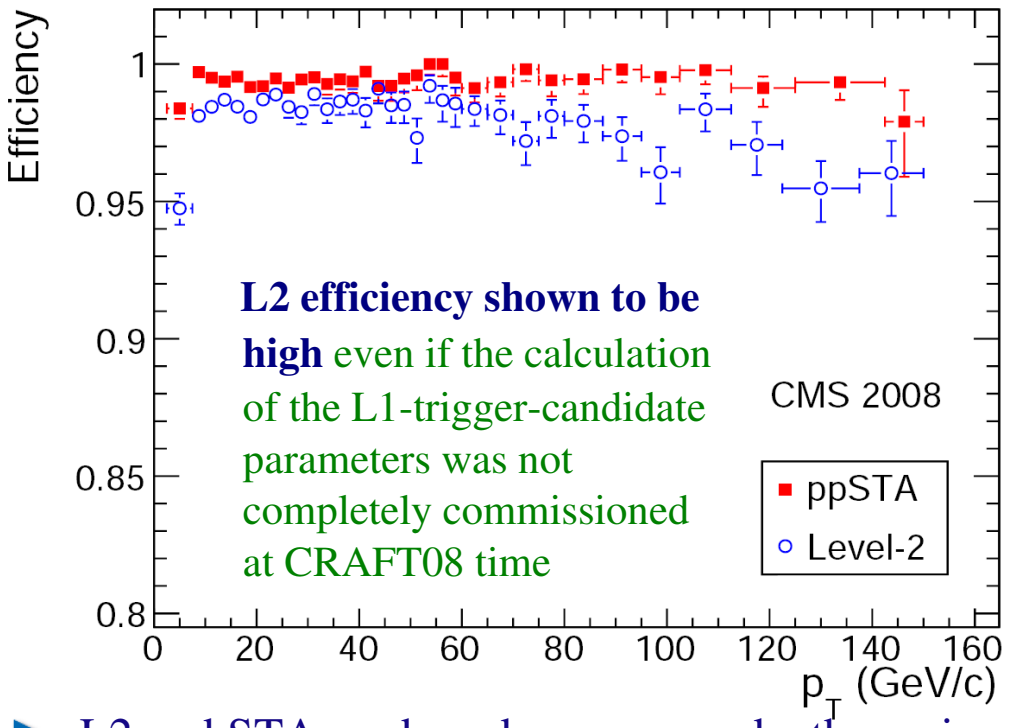


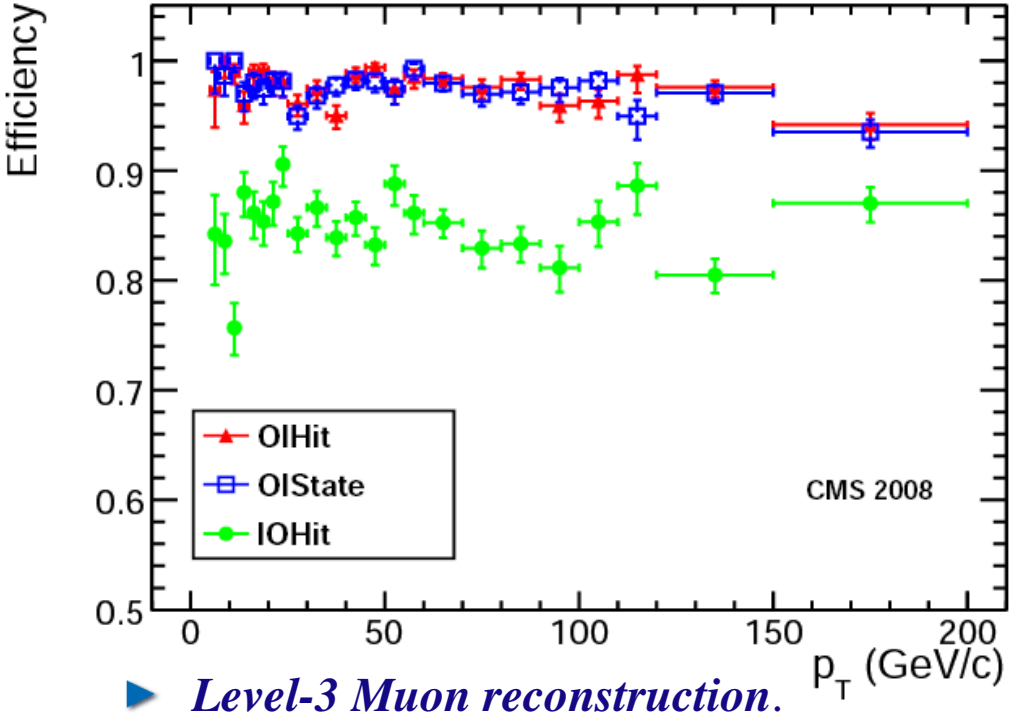
Trigger	Cosmics setup	LHC setup
All muon	295 Hz	82 Hz
DT	225 Hz	45 Hz
CSC	60 Hz	3 Hz
RPC barrel	150 Hz	58 Hz
RPC endcap	1.5 Hz	0.8 Hz

- Run 112417 has a " LHC" like muon trigger

- Some calorimeter low-threshold triggers (eg 1GeV, jet 10GeV, tau jet 10GeV, HF min bias) are more populated than muon triggers due to their slightly higher rate
  - these triggers are included in the menu deliberately to study the noise behavior of the calorimeters and to catch maximum of muon-induced signals e.g. for synchronization

Muon High Leve Trigger





- L2 and STA are based on same code, the main difference is the seeding step: L1 for the on-line reconstruction, internal for the off-line reconstruction
  - For this comparison, no vertex constraint is applied
- Tag in upper hemisphere, probe at the bottom
  - R = 10cm, |z| =30 cm

- ***Level-3 Muon reconstruction***. Currently, 3 types of seeding:
- **IOHit**: inside-out hit-based (relies on pixels), **OIHit**: outside-in hit-based. Use the tracker seeds, build them in inner/outer layers
- **OIState**: outside-in state-based. Uses the L2 as seed

Summary

- The CMS Collaboration put **a lot of resources** in the commissioning with cosmics
- The system was **extensively** and **successfully** stressed and tested
  - Over than 1 billion of cosmics events recorded and processed
- **This strategy**, in terms of detector/software/computing understanding, **payed off**
- **"Commissioning of leptons" is in a good shape**
- The improved understanding of alignment, tracking, and experience with calorimeters provide **a good start for electron and tau commissioning with collisions**
- The **muon reconstruction and identification look great** and in a fairly advanced stage of commissioning
- We have done everything with cosmics we could think off (see the additional slides), and **really we need the collisions for the next step**!

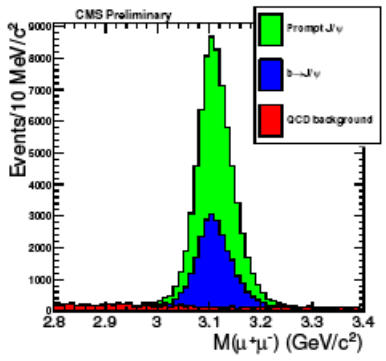
Conclusion

We "*should*" be ready for physics with leptons!

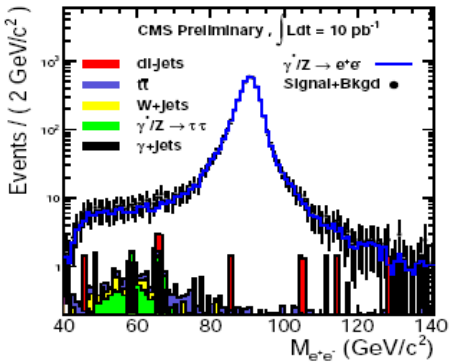
0 10 20 30 40 50 60 70 80 90 100 110 120 130

$\int \mathcal{L}dt\ (\mathrm{pb}^{-1})$

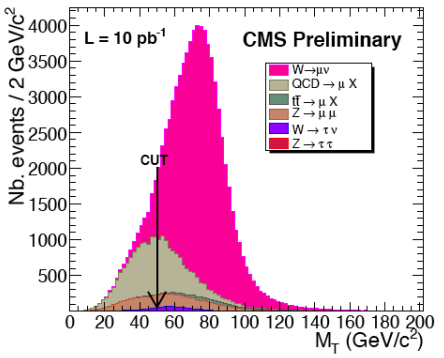
J/ψ & Y resonances (few pb^{-1})



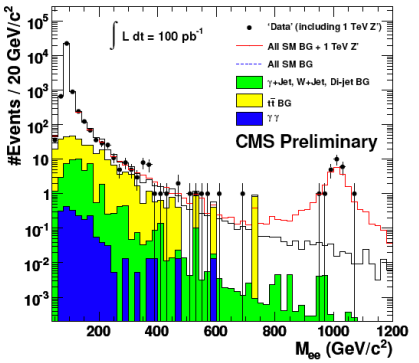
Z peak (10pb^{-1})

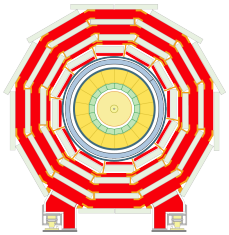


W cross-section measurement



Look @ DY spectrum beyond $M_{\mu\mu} > 700$ GeV/c^2





More Information

The Cosmic Data Taking Champaign

Independent subdetectors commissioning

2006

Aug 2006: Magnet Test/Cosmic Challenge

- Test&mapping of magnet at 4T on surface, global data taking with a fraction of each CMS subdetector

2007

Lowering into cavern;

Underground global runs

- increasing fraction of CMS integrated

End heavy lowering →

Tracker ready →

2008

May-Aug 08: Weekly "global runs"
+ Cosmic Runs At Zero Tesla (CRU

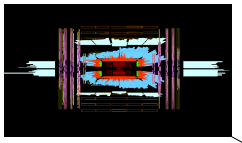
- Entire CMS integrated; 300 M events

Sep 08: First beams

- Beam splash events; beam halo

Oct 08: Cosmic Run at Four Tesla (C

- Run 24/7 for extended period
- 270M events, full detector, nominal I
- 25 papers in preparation



2009

HCP2009 →

First H → 4μ (??)

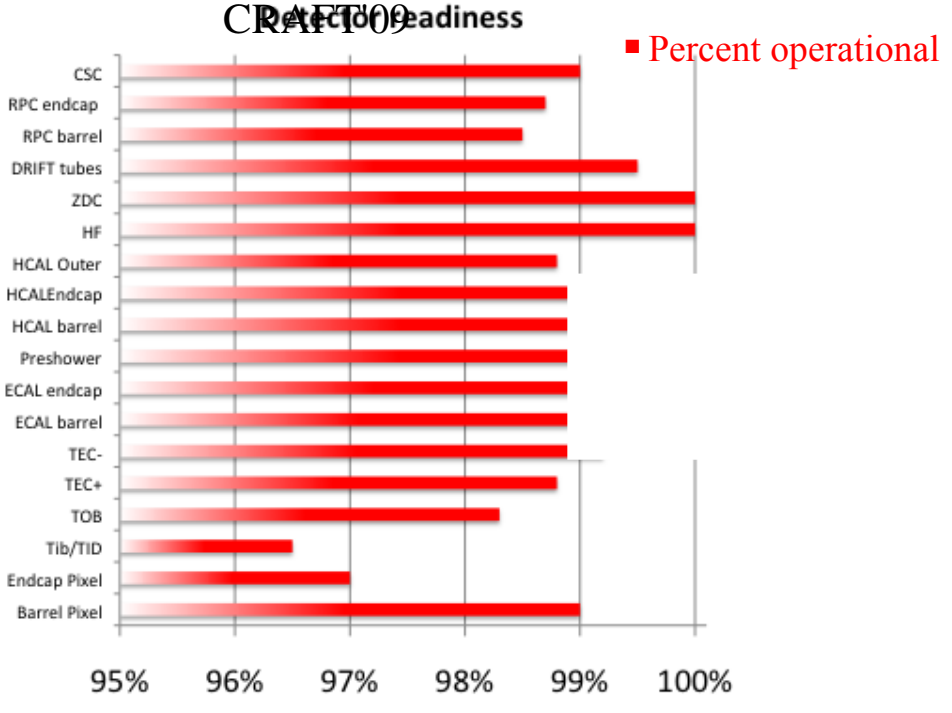
t

Aug 09: **CRAFT 09**

- 300M events

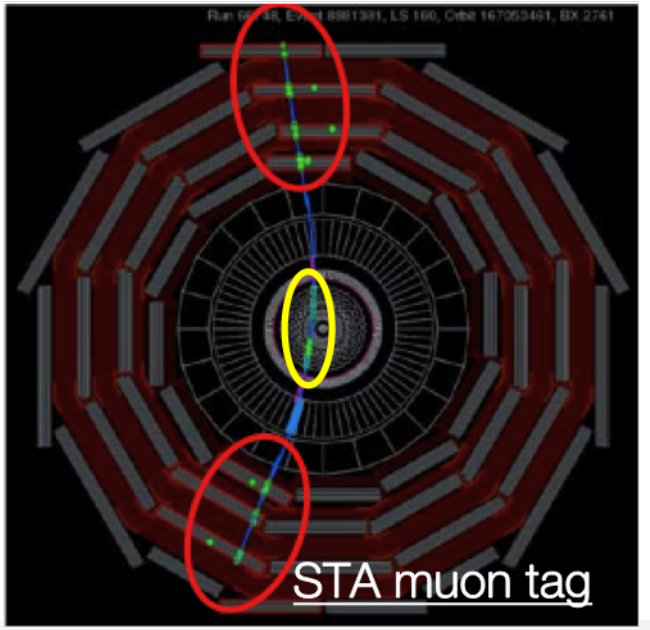
Integrated commissioning with cosmics

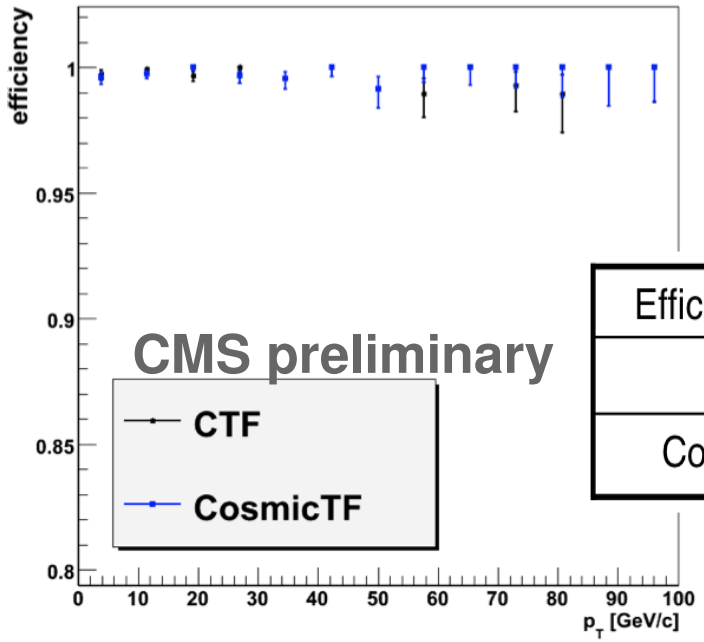
- Learn how to operate detectors
- Study detector response and performance
- Exercise & develop alignment, calibration etc.
- Discover and fix problems



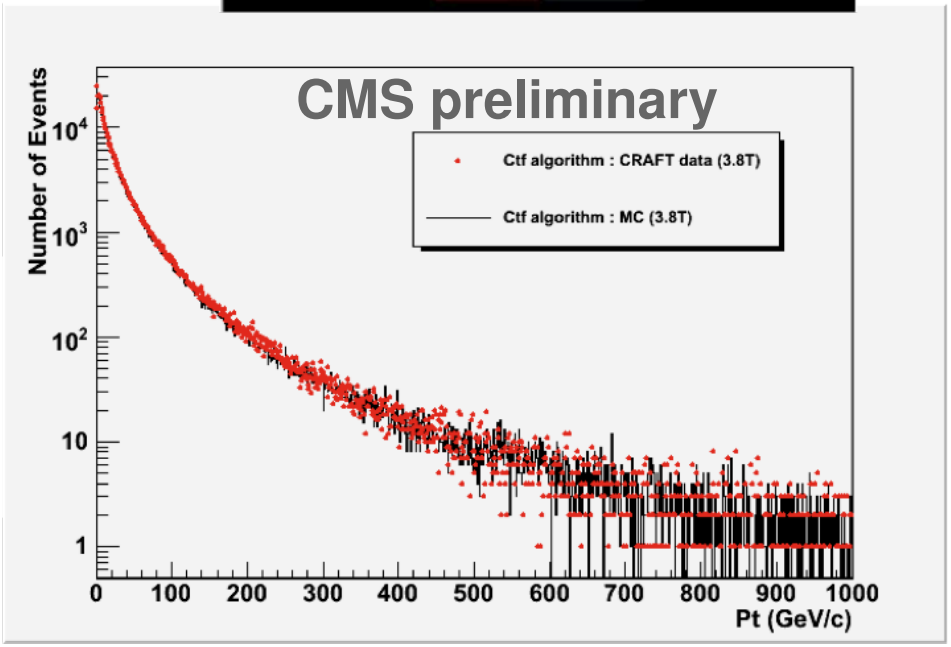
Efficiency to Find a Track in the Tracker

- Tag an event with muon with tracks from the muon chambers
- 2 track-finders
  - **Combinatorial Track Finder** (will be used in collisions)
  - **Cosmic Track Finder** (simple algorithm tailored for single muon tracks provides cross check)

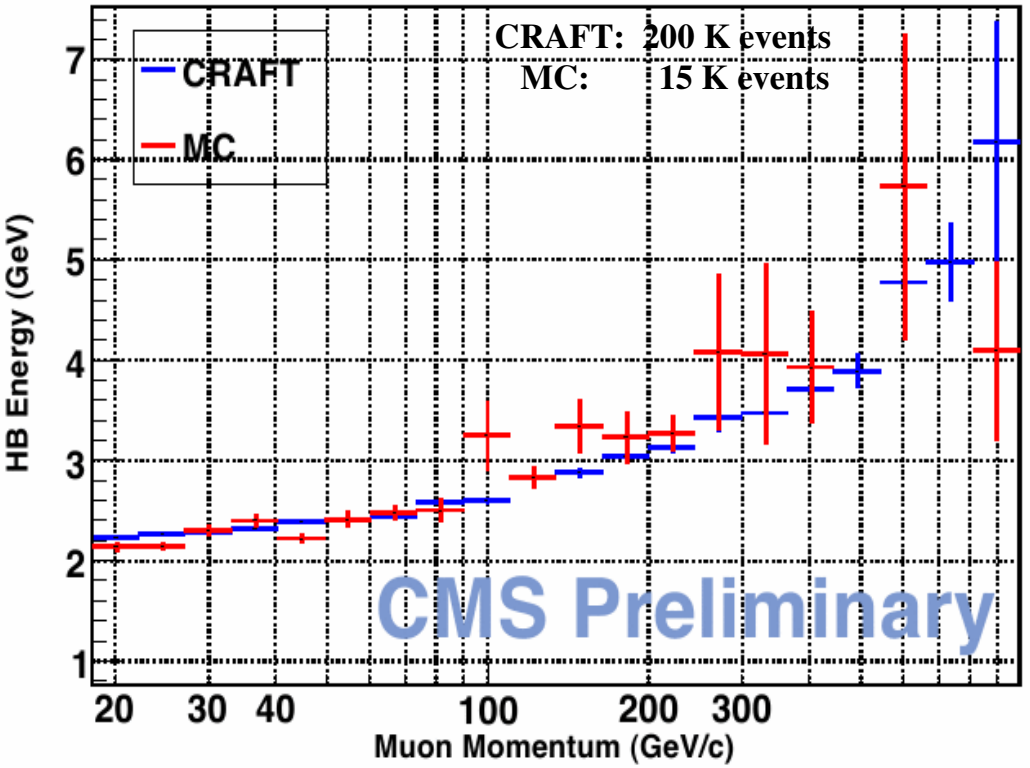


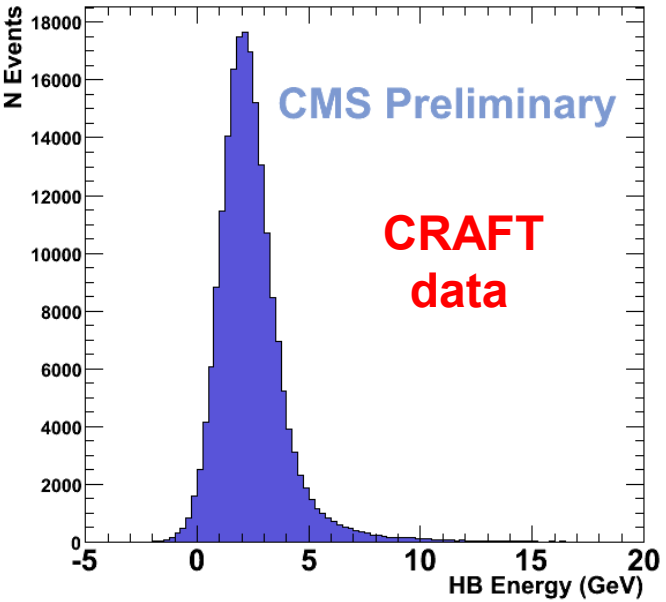


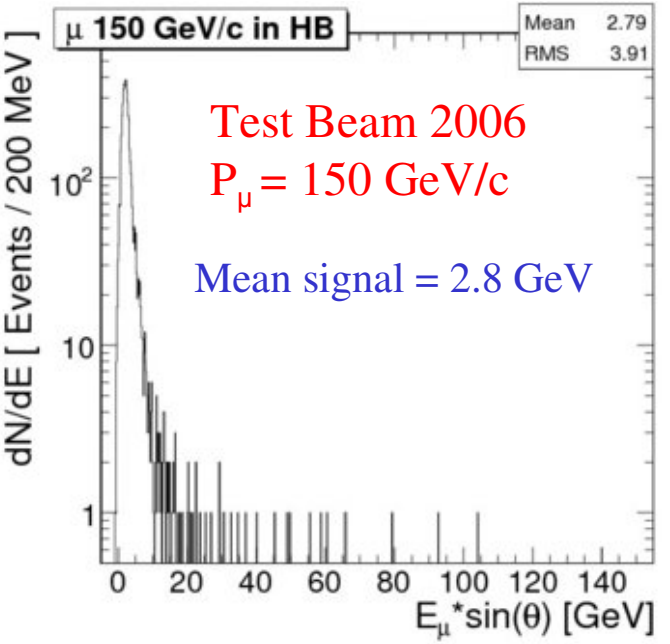
Efficiency (%)	CRAFT 09
CTF	99.8±0.1
CosmicTF	99.8±0.1



HCAL Barrel Response to Muons





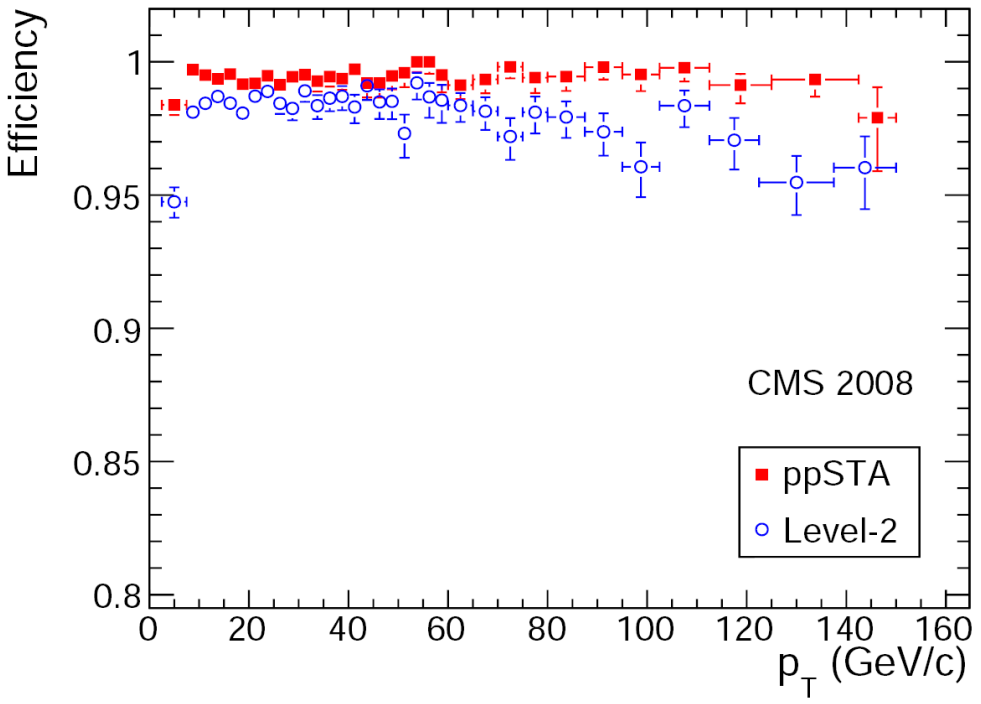


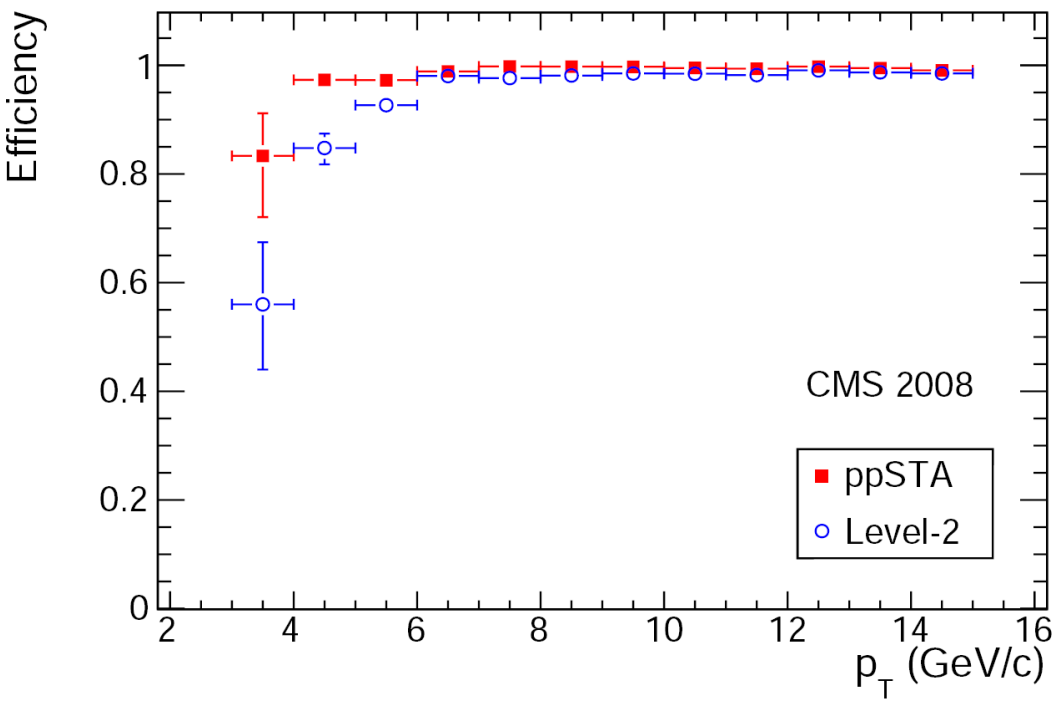
Event selection:

- Muon track matching in DT and Tracker
- $20 < P_\mu < 1000$ GeV

HB energy: signal from HB towers corrected for muon path length in HB

L2 Muon Trigger

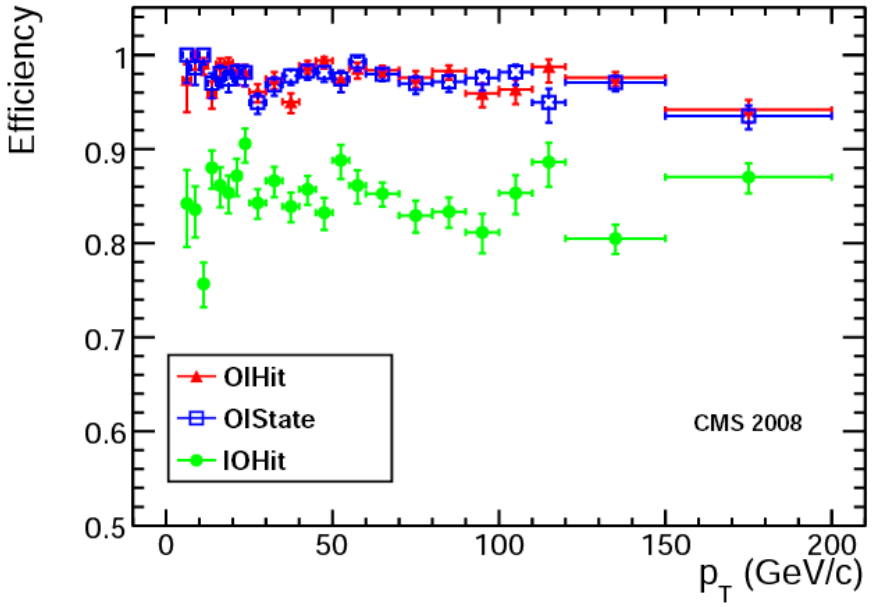


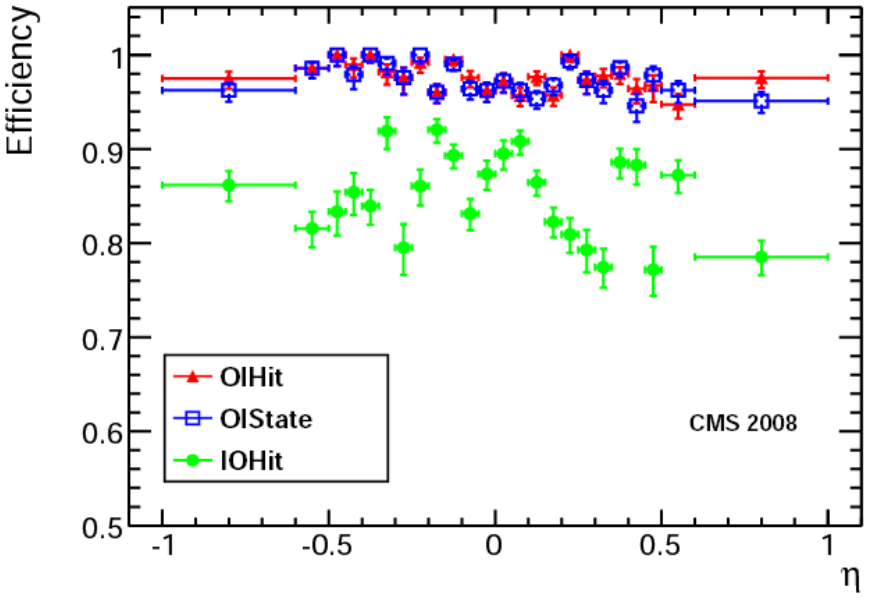


- L2 and STA are based on same code, the main difference is the seeding step: L1 for the on-line reconstruction, internal for the off-line reconstruction
  - For this comparison, no vertex constraint is applied
- Tag in upper hemisphere, probe at the bottom
  - R = 10cm, |z| =30 cm

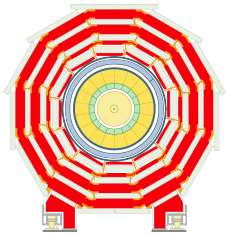
- **L2 efficiency shown to be high** even if the calculation of the L1-trigger-candidate parameters was not completely commissioned at CRAFT08 time

L3 Muon Trigger



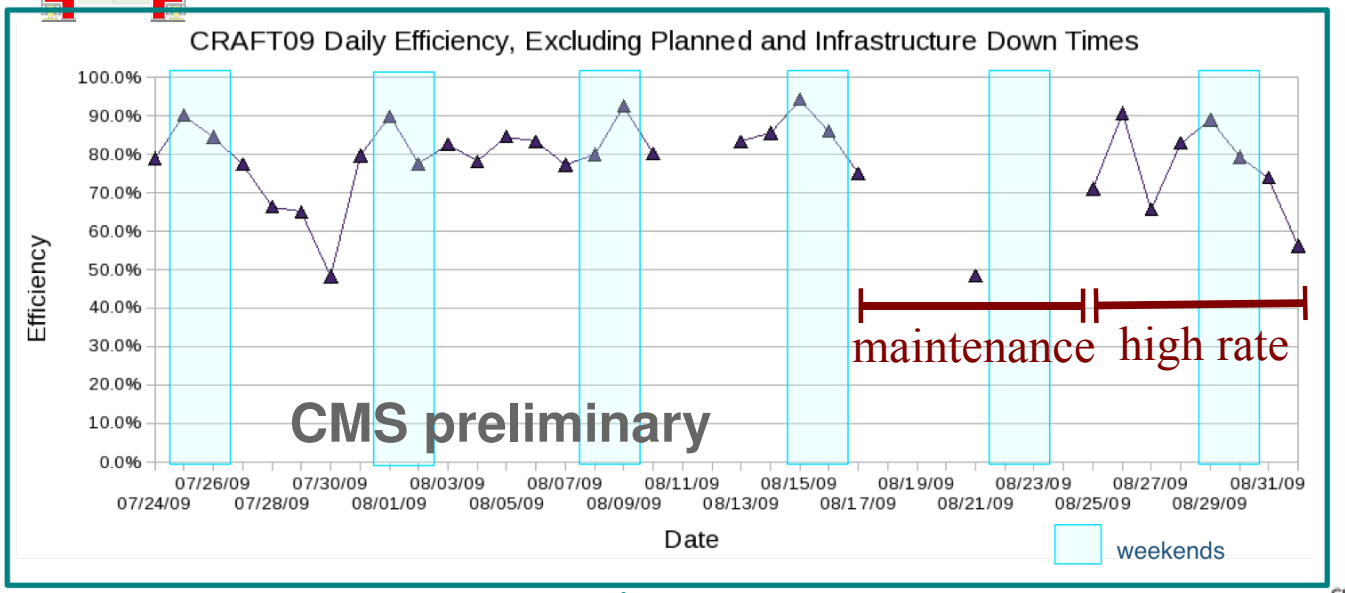


- ***Level-3 Muon reconstruction*** consists of 3 steps: seeding, trajectory building and global matching (includes refitting). Currently, 3 types of seeding:
- **IOHit**: inside-out hit-based (relies on pixels), **OIHit**: outside-in hit-based
  - Use the tracker seeds, build them in inner/outer layers
- **OIState**: outside-in state-based
  - Uses the L2 as seed for the trajectory building

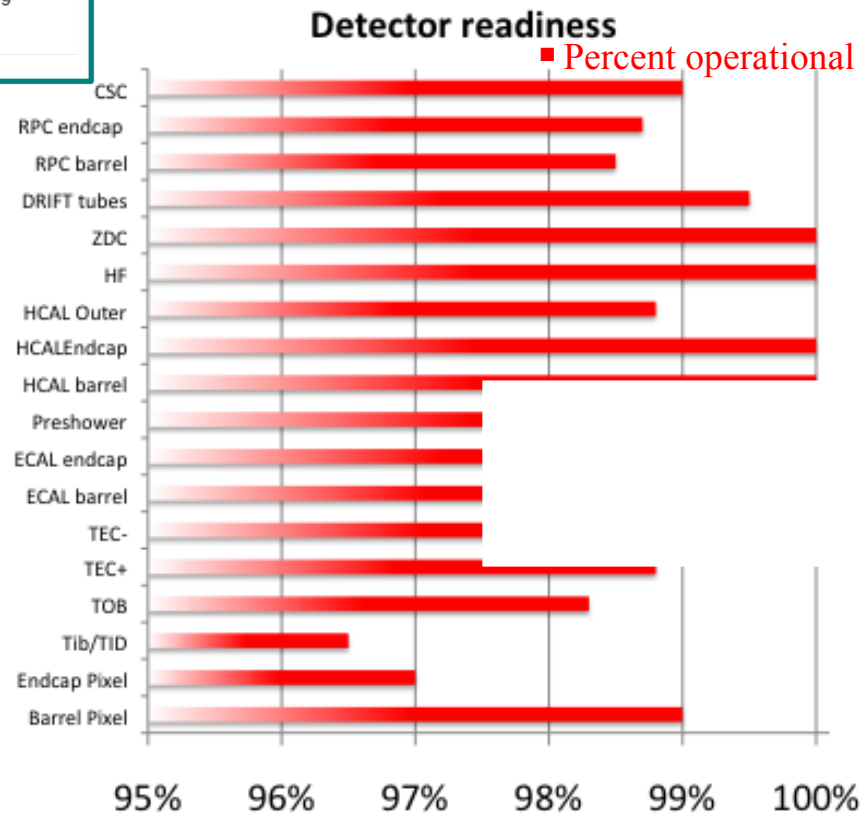


...Additional (More) Information

Data Taking Efficiency and Detector Readiness



Readiness of the sub-detectors after CRAFT09 and for collision data is **> 96 %**



Average efficiency from 24th July to 1st September: 71%

> 80% without disruptions or scheduled testing periods

Noticeably higher efficiency during weekends

The Cosmic Data Taking Champaign

Independent subdetectors commissioning

2006

Aug 2006: Magnet Test/Cosmic Challenge

- Test&mapping of magnet at 4T on surface, global data taking with a fraction of each CMS subdetector

2007

Lowering into cavern;
Underground global runs

- increasing fraction of CMS integrated

End heavy lowering →

Tracker ready →

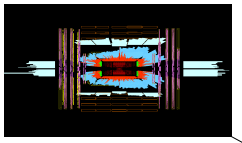
2008

May-Aug 08: Weekly "global runs"
+ Cosmic Runs At Zero Tesla (**CRUZET**)

- Entire CMS integrated; 300 M events, B off

Sep 08: First beams

- Beam splash events; beam halo



HCP2009 →

2009

Oct 08: Cosmic Run at Four Tesla (**CRAFT**)

- Run 24/7 for extended period
- 270M events, full detector, nominal B field
- 25 papers in preparation

Aug 09: **CRAFT 09**

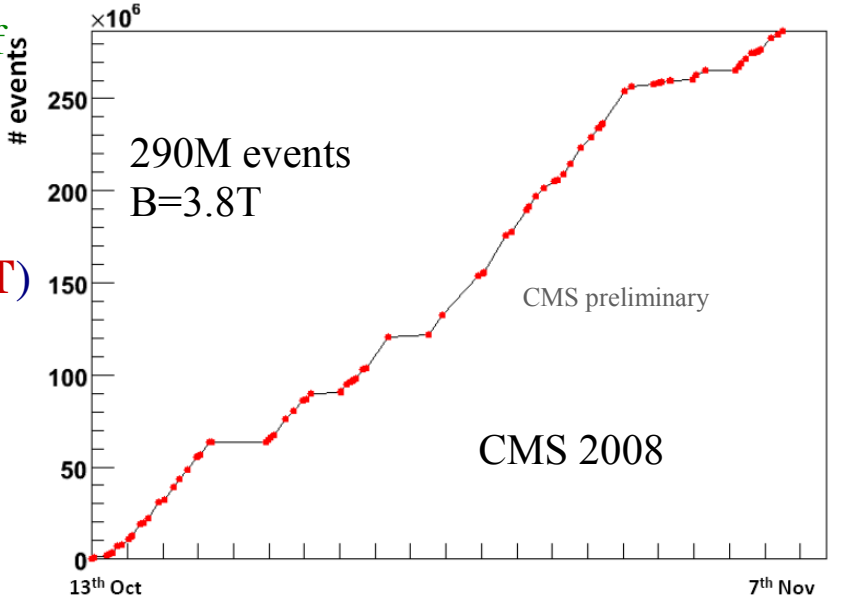
- 300M events

First H → 4μ (??)

t

Integrated commissioning with cosmics

- Learn how to operate detectors
- Study detector response and performance
- Exercise & develop alignment, calibration etc.
- Discover and fix problems

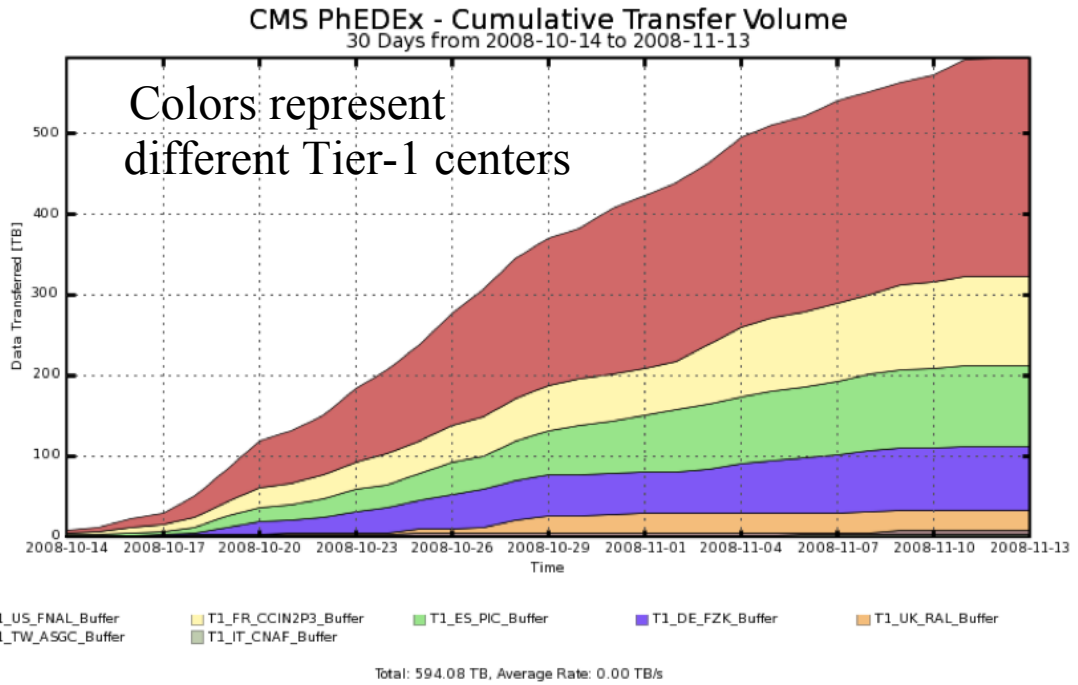


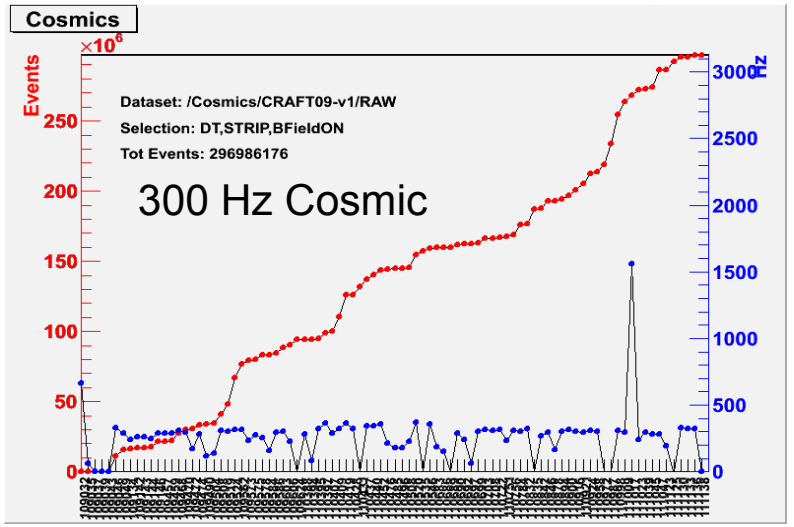
Trigger Setup

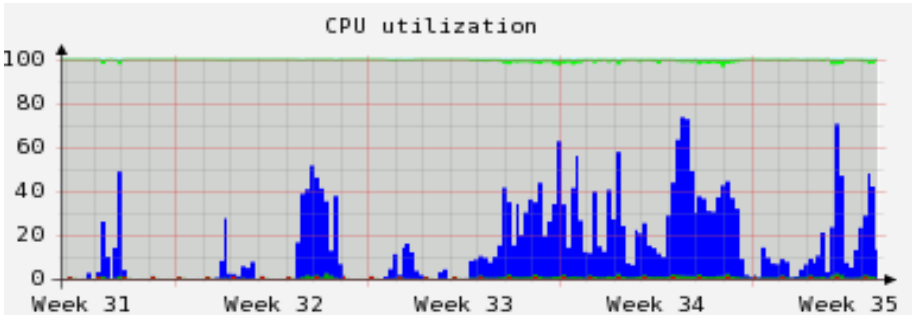
- Cosmics setup:
  - Trigger on full acceptance
  - DT trigger – any coincidence between two stations in the same or neighboring sector
  - CSC trigger – any segment in one station
  - RPC trigger – open roads but slightly pointing
- " LHC" setup:
  - Trigger only on bottom half of muon detectors (avoid timing ambiguity top/bottom)
  - DT trigger – as before but with pointing roads
  - CSC trigger – coincidence of two stations with pointing roads
  - RPC trigger – as before (LHC like tightly pointing roads were not available!)

- The difference in RPC rates is only due to switch to bottom half only
- The difference between DT and RPC rates in the Cosmics setup is due to more selective RPC trigger towards pointing tracks – this is then opposite in the "LHC"-like setup where DT is more tight
- Difference between CSC and RPC endcap in " LHC" like is due to smaller acceptance of RPC endcap ($|eta| < 1.5$)
- Plots show stability of muon trigger components (absence of noise etc) which improved since CRAFT08 – e specially in the RPC case
- Gaps in the left plot are due to problems with 2 CSC FEDs, on the right ECAL FED problem after going to 50 kHz random triggers - recovered

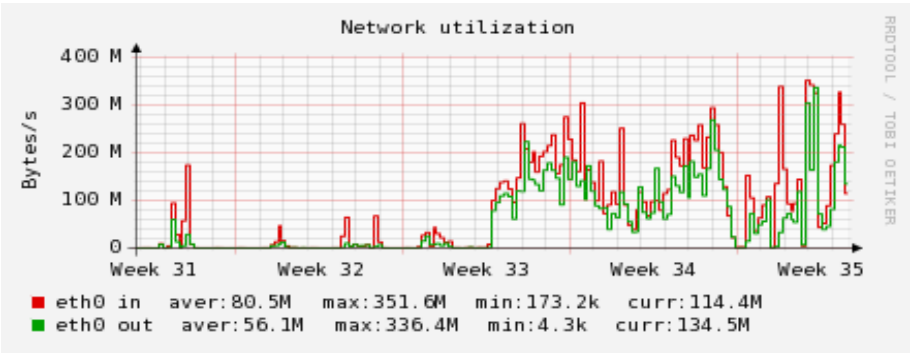
Data Transferred During CRAFT 09



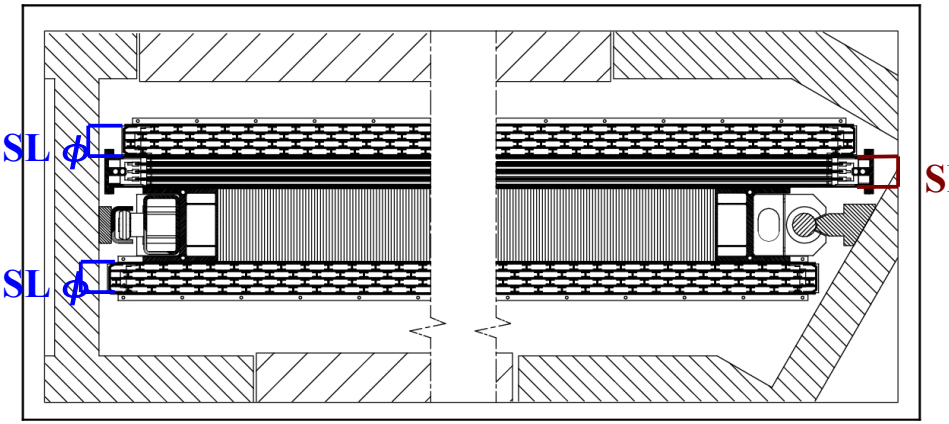




- **Intense** utilisation of the T0 CPUs
- Sustained transfer rate during all CRAFT period: mean transfer rate **~180MB/s**, peak above **300 MB/s**



The CMS muon system



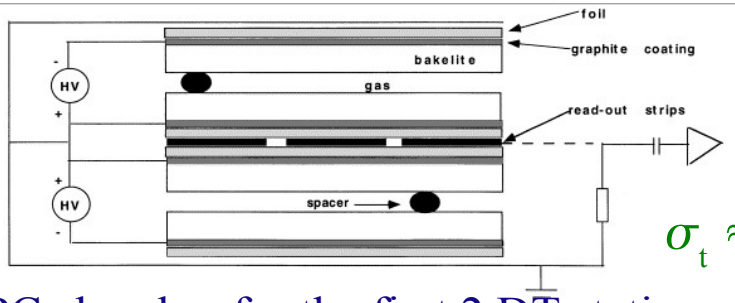
3 Super Layer (2ϕ and 1θ) for the first 3 stations

2 Super Layer (2ϕ) for the last station

4 Layer for each Super Layer

DT

$\sigma_x \approx 200\ \mu m$

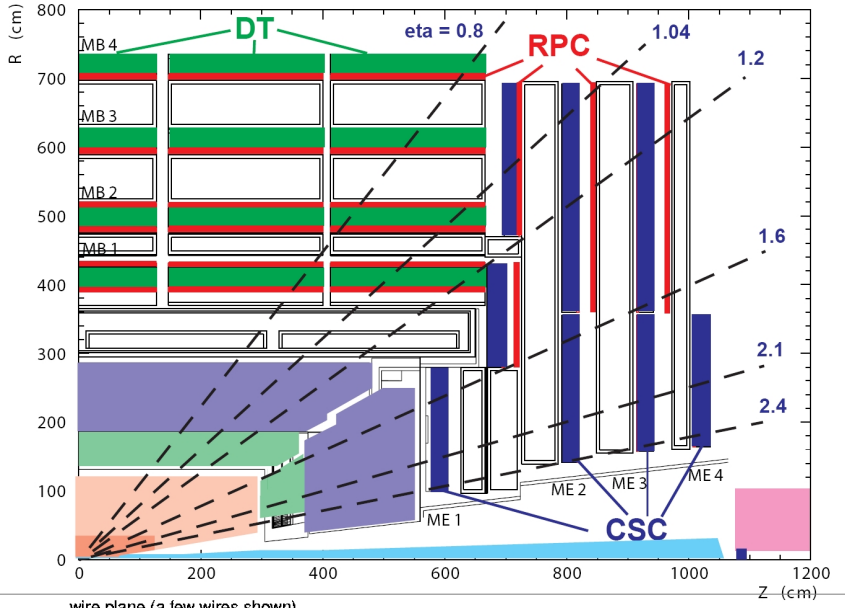


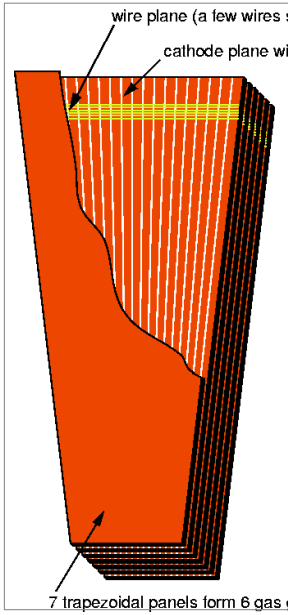
2 RPC chamber for the first 2 DT stations

1 RPC chamber for the last 2 DT stations and for the CSC chamber till $|\eta|<1.6$

RPC

$\sigma_t \approx 2$ ns





CSC

6 gaps (Layers) for each camber

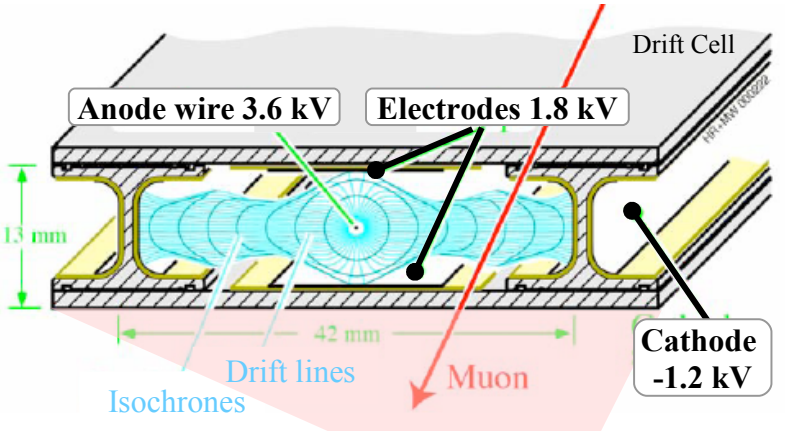
1 wire plane and 1 cathode plane with strips

$\sigma_x \approx 100\text{-}240\ \mu m$

Barrel (letal < 1.2) : Drift Tubes (DT)

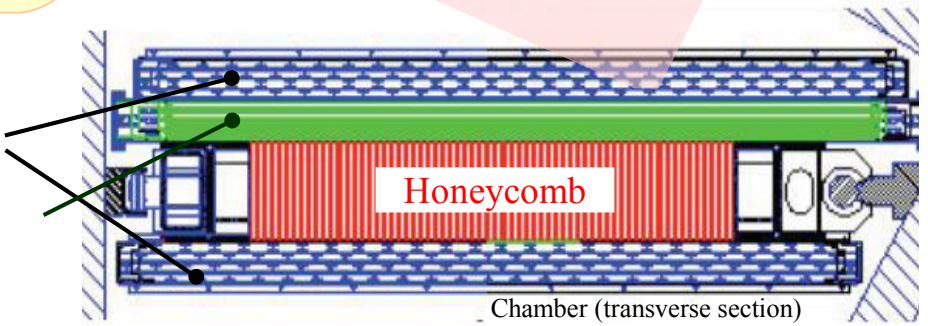
Basic element: 4.2 cm drift cells

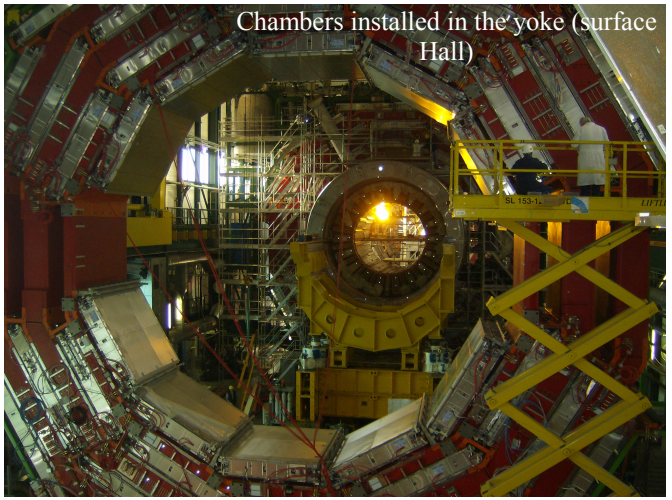
- Ar/CO_2 (85/15)%
- field shaping with strip electrodes
- Long drift time (380 ns)
- almost uniform drift velocity (V_d ~ 55 μ m/ns)
- Cell resolution ~200 μ m



Chambers made of staggered cell layers:

- (4+4) layers in the bending coordinate (ϕ)
- 4 layers measuring *z* (θ) (except in outermost station)
- Self-triggering, with BX id



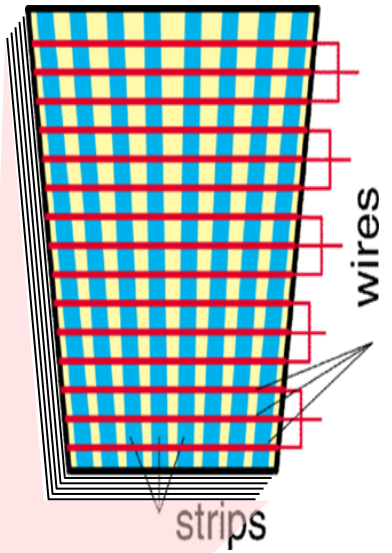


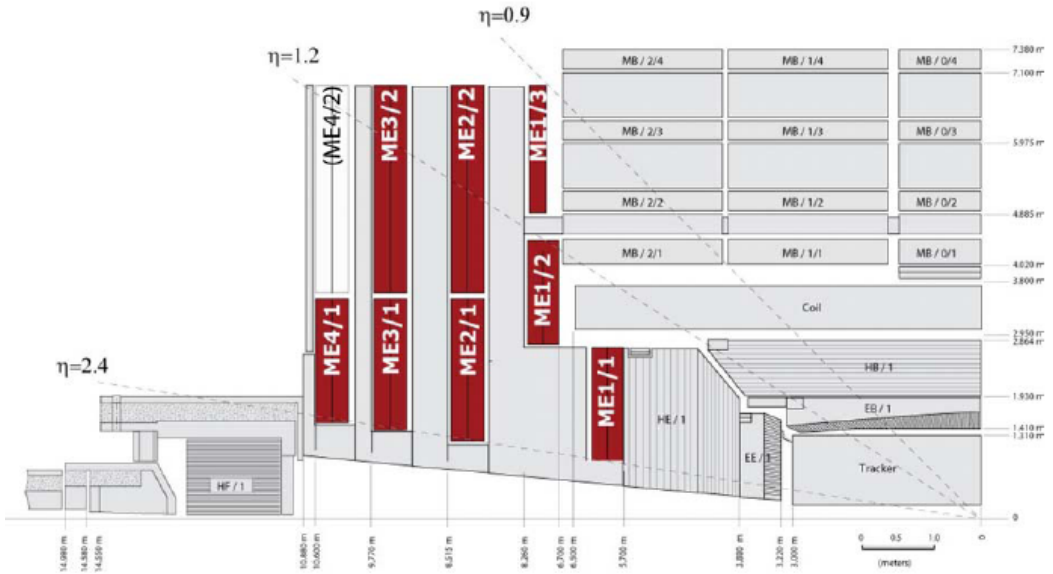
Total: 250 chambers, 172k wires

Endcaps (0.9 < |η| < 2.4): CSCs

MWPC chambers with cathode strip readout

- 6 layers per chamber, 9.5 mm gap, $Ar/CO_2/CF_4$ (40/50/10)%
- Fast response from wire groups
  - BX id; radial (coarse) coordinate
- Bending coordinate (ϕ) measured by centroid on strips
  - Strip pitch 8.4-16 mm
- Design resolution of ~150 μ m/chamber
  - 75 μ m in ME 1/1 that operate in a critical region (less spaced, tilted wires; smaller strips; smaller gap)

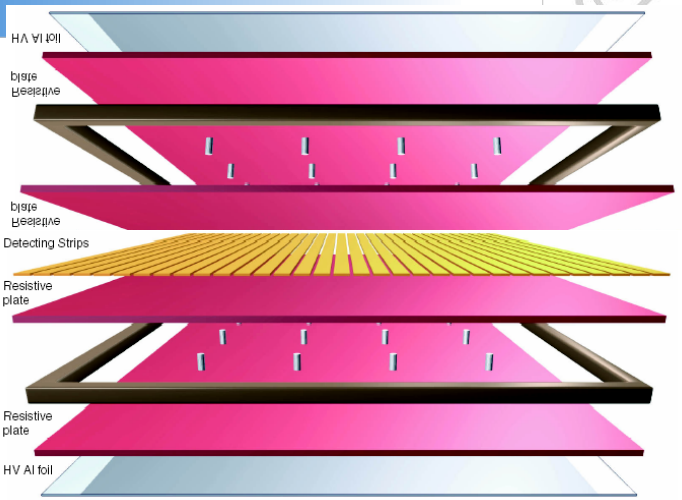




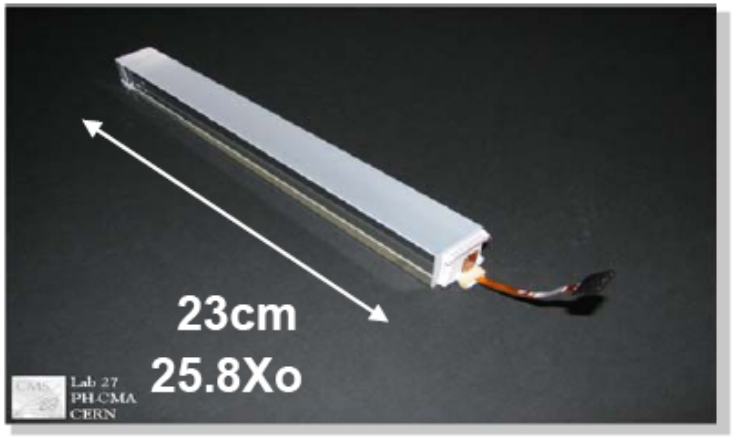
Total 468 chambers,
400 k channels

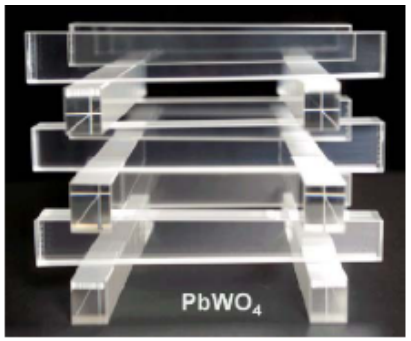
RPC (Resistive Plate Chambers)

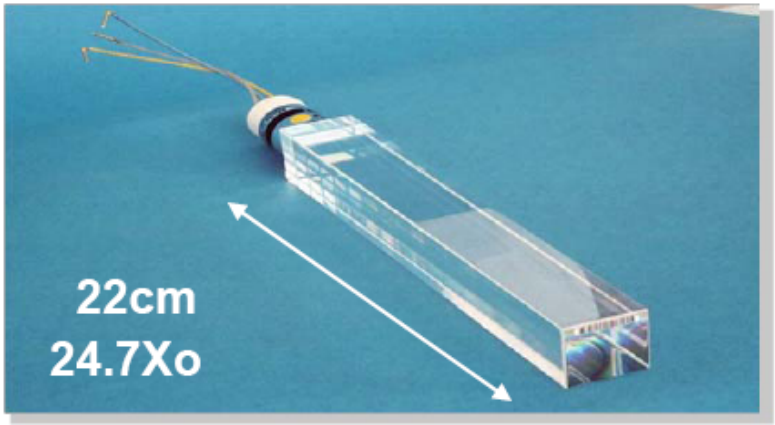
- Double-gap, avalanche mode
  - to cope with hit rates up to ~1KHz/cm^2
- $C_2H_2F_4$/iso-$C4H_{10}$/SF_6 (96.2/3.5/0.3)%; closed loop
- Strips measure bending coordinate (ϕ)
  - ~1 cm resolution
- Fast response; very good timing resolution (~3ns)
  - unambiguous BX id at L1
- Trigger with pattern comparator



Barrel: 6 layers, 480 chambers
Endcaps ($|\eta| < 1.6$) :3 layers, 432 chambers
160K total channels







$PbWO_4$ Producers:
BTCP (Bogoroditsk, Russia)
SIC (Shanghai, China)

- EB crystal, tapered
34 types, ~(2.6x2.6 cm² at rear)x23cm
- Two avalanche photodiodes (APD), 5x5 mm² each, QE ~75%, Temperature coeff.: -2.4%/° C

- EE crystal, tapered 1 type, (3x3 cm² at rear)x22cm
- Vacuum phototriodes (VPT), more rad hard than diodes; gain 8 -10 (B=3.8T), Q.E. ~20% at 420nm

Properties:

Homogeneous medium

Fast light emission	~80% in 25 ns
Short radiation length	X_0 = 0.89 cm
Small Molière radius	R_M = 2.10 cm
Emission peak	425nm

Reasonable radiation resistance to very high doses

Light yield (23cm)	100 γ/Mev

Challenges:

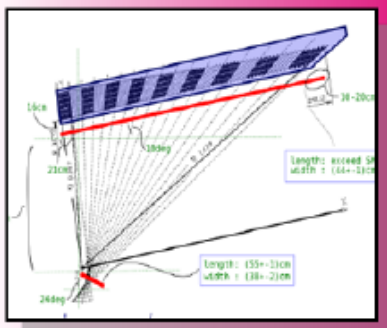
Crystal LY temperature dependence -2.2%/°C
Need excellent thermal stability (±0.05 °C)

Formation/decay of colour centres
Need precise light monitoring system

Low light yield (1.3% NaI)
Need photodetectors with gain in magnetic field

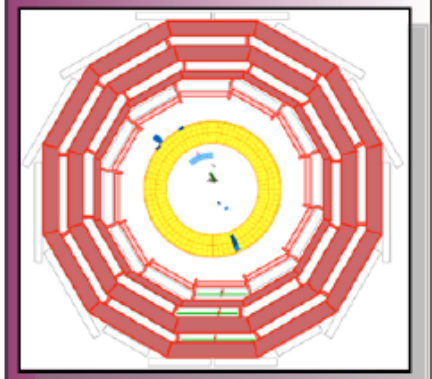
ECAL Road to Collisions

2006-2007:
Commissioning & calibration of each SM with cosmics on surface

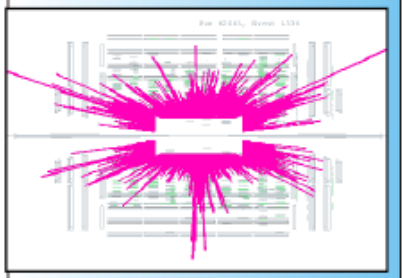


2006:
H4 Test Beam: 9 SM calibrated; H2 Combined Test Beam: ECAL&HCAL

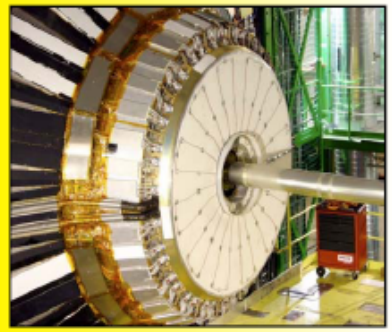
2006:
2 SM tested with B-field on surface (MTCC)



2008:
Endcap Installation; Commissioning with cosmics and first beam in-situ



2009:
Installation of Preshower and commissioning of Endcap trigger

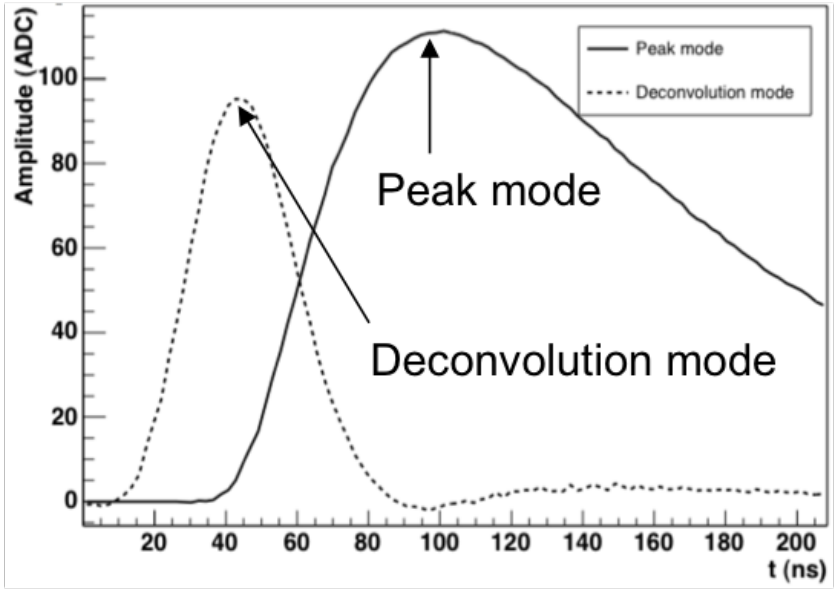


2007:
Individual signoff of each SM during installation in P5; H4 EE Test Beam

2006 2007 2008 2009

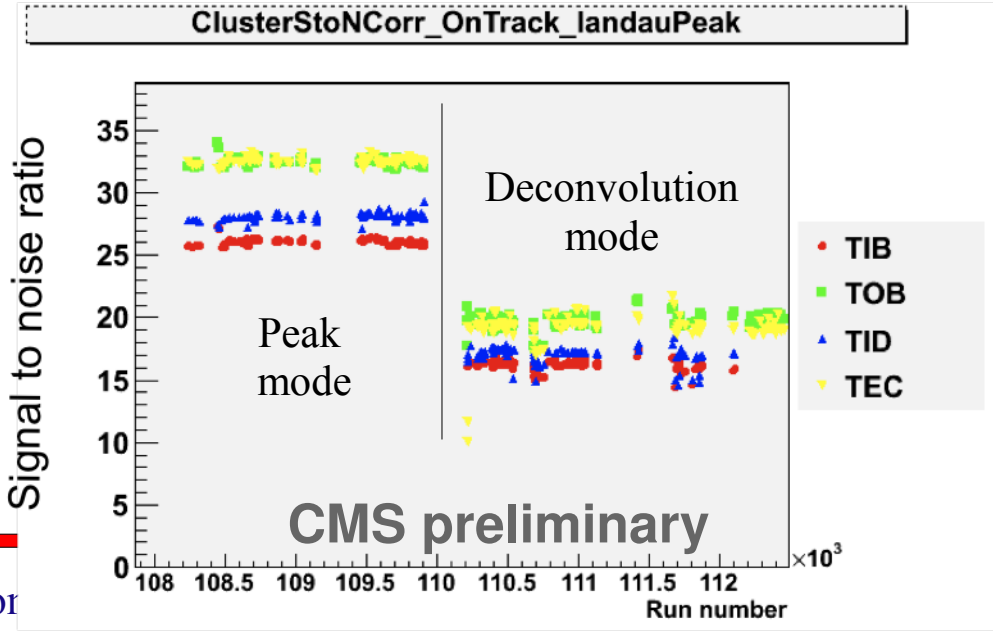
Tracker Readout in Deconvolution Mode

APV Pulse shape



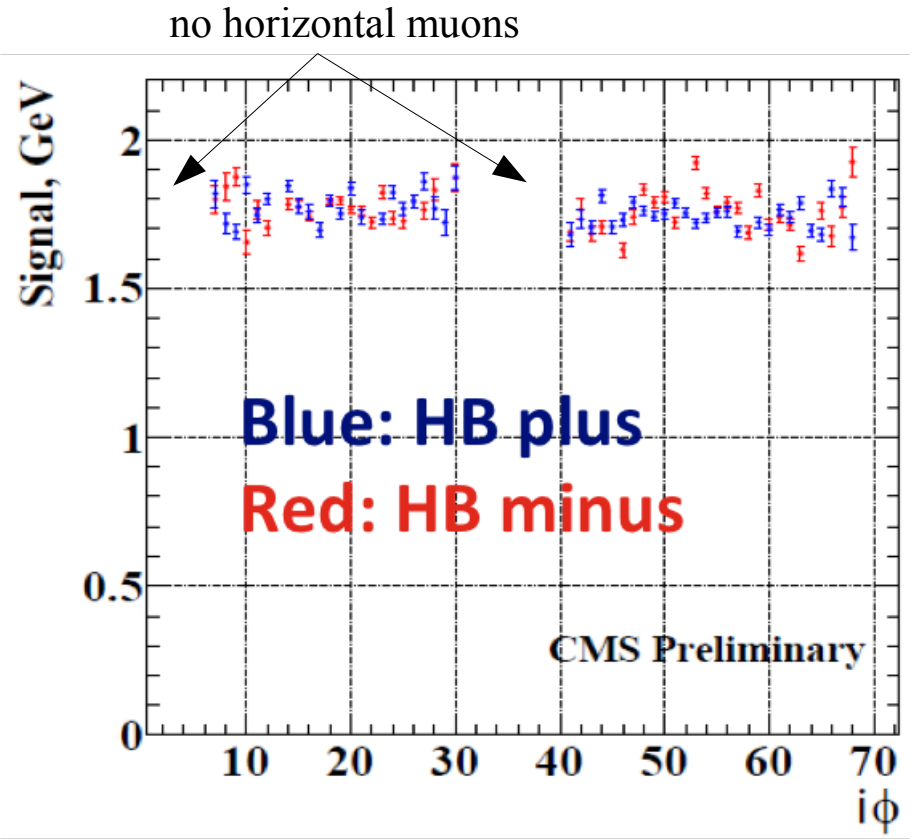
- Comparison to Peak mode
  - Noise 1.5 x higher
  - Signal 0.9 x lower
- These values agree with expectation

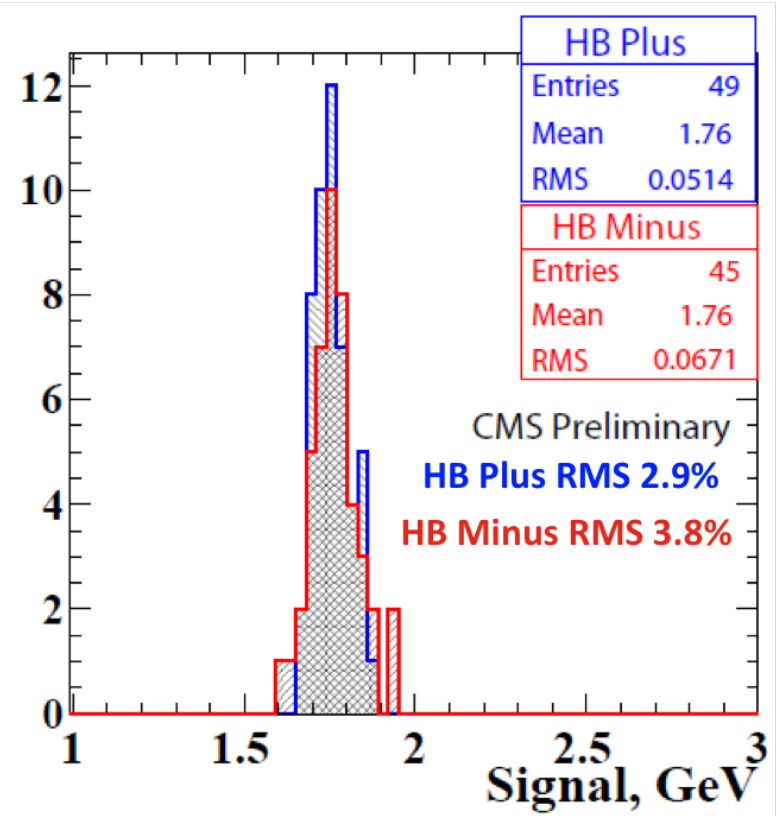
- Deconvolution mode used in CRAFT 2009
- A digital filter: build weighted analog sum of three samples at amplifier output. For given amplifier this sum is equivalent to integral over delta function representing charge injection.
- In practice this is equivalent to having a faster amplifier (less sensitive to pileup), without the disadvantages of more electronic noise, power dissipation, crosstalk...
- This mode is foreseen for collisions



HCAL Barrel Response to Muons

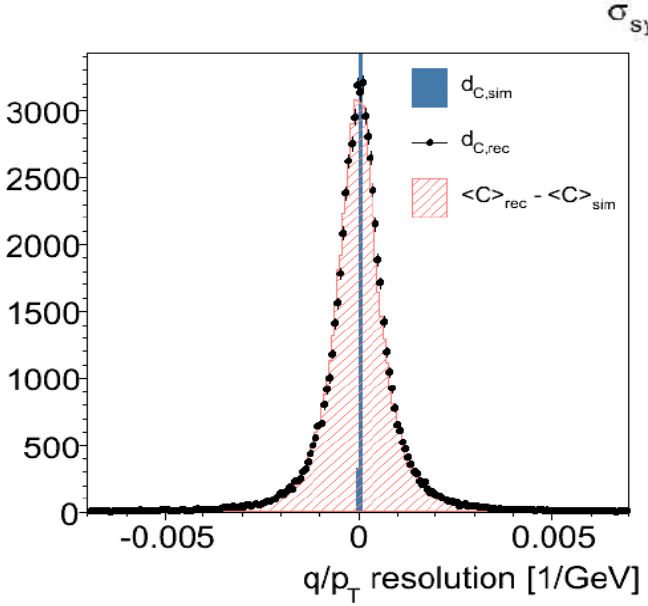
- Extrapolate tracks from tracker to inner and outer HCAL radii
  - Pμ = 5...100 GeV/c and some quality cuts
  - Correct for path length in HCAL
  - Normalize response to 25 GeV/c muon (using a fit to a measured dE/dx curve)



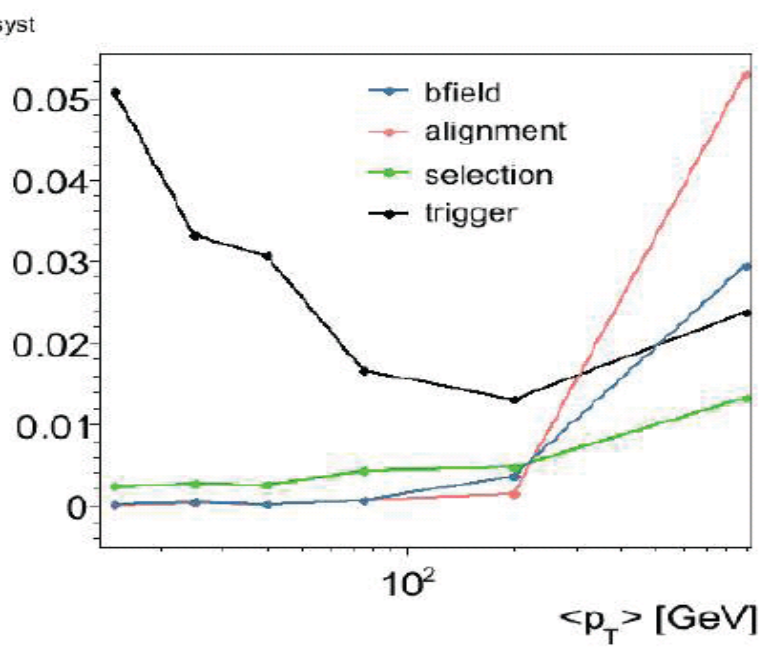


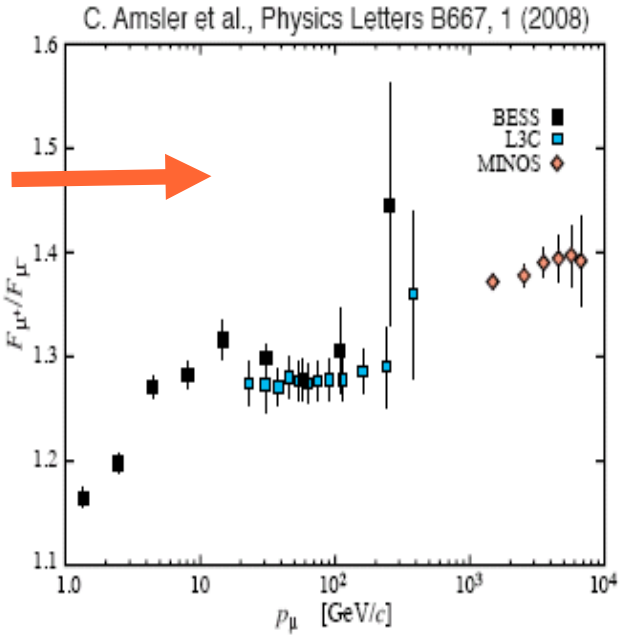
Some Physics with Cosmics

- Many analyses ongoing
  - Charge ratio measurement, Muon flux estimation, determination of cosmic rays background, muon bundles and showering studies, ...
- Making good progress:



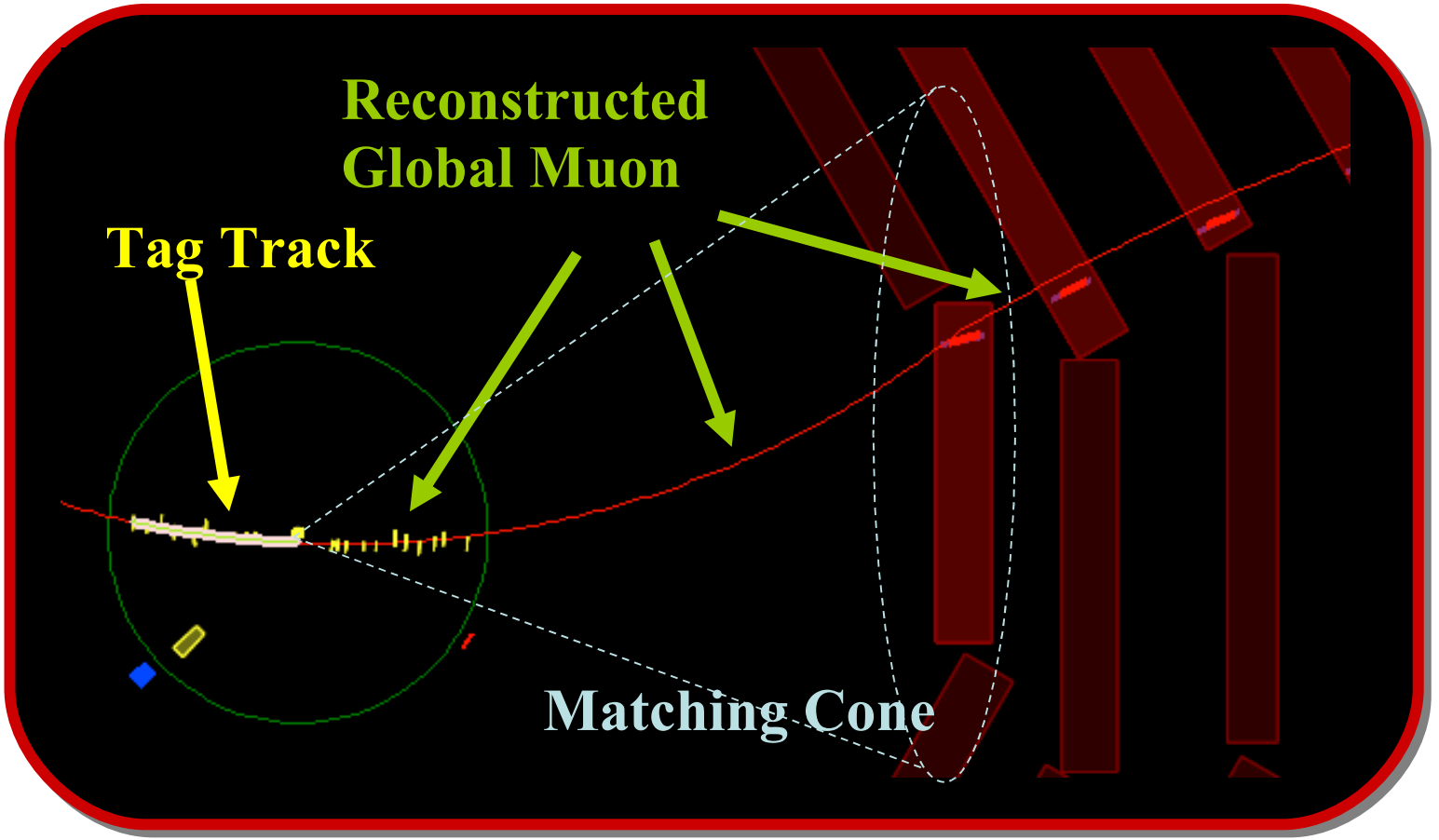
verifying (on MC) data-based method to extract resolution...



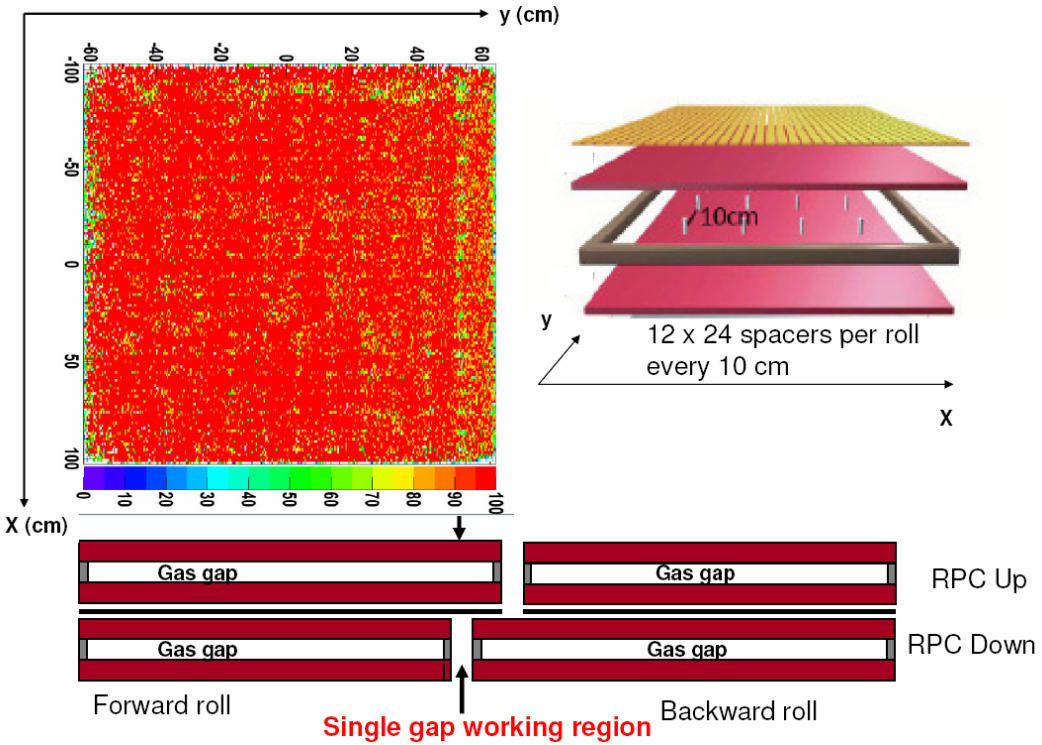


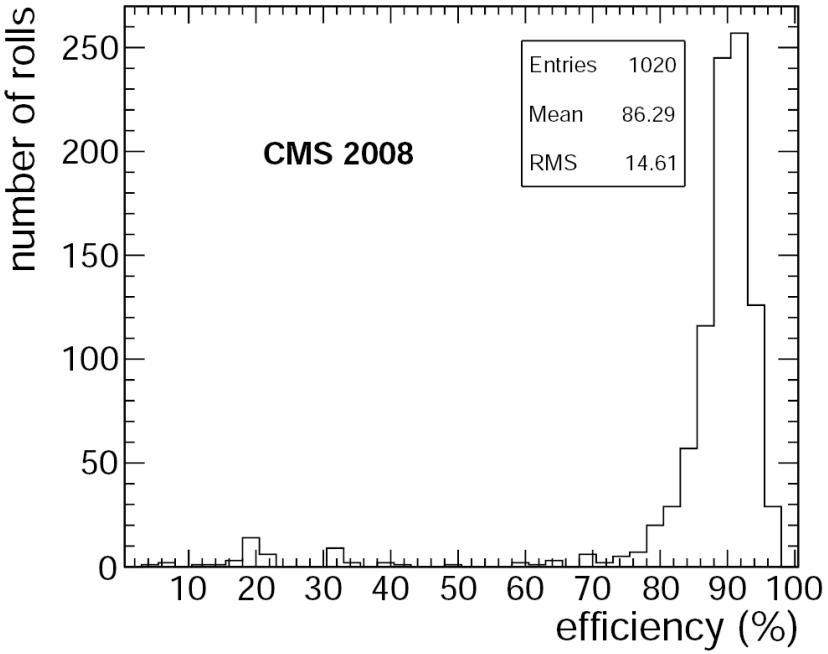
Systematic uncertainty on charge ratio (in progress)

Reconstruction Efficiency in CRAFT Data



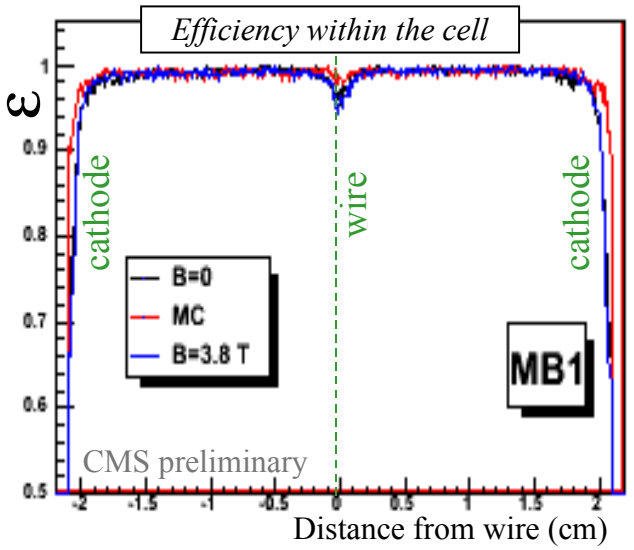
RPC Efficiency in CRAFT 08

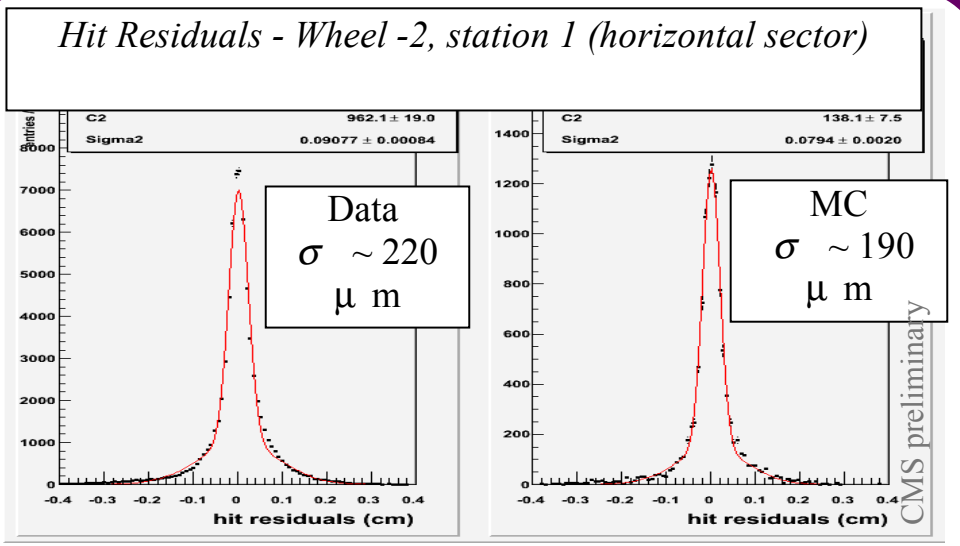




Drift Tube

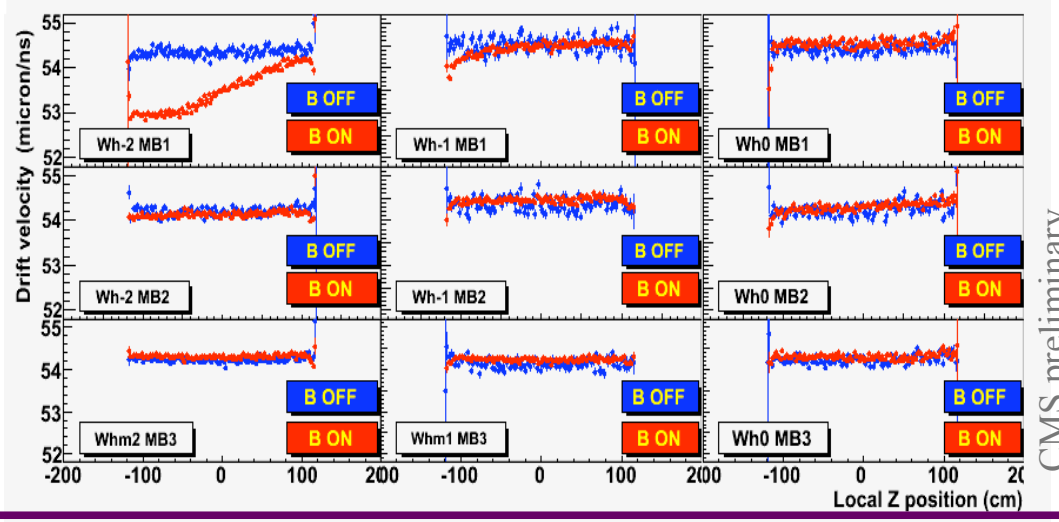
Average cell efficiency: 98.4%





Hit residuals between 200-260 μ m

– reasonable agreement with MC



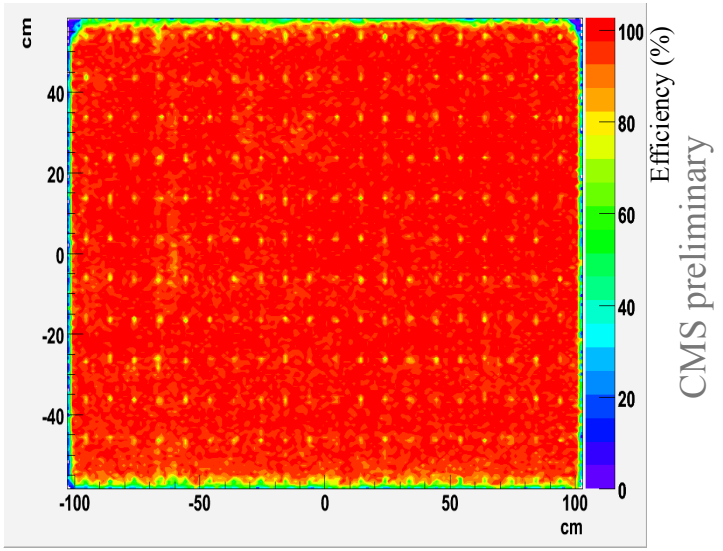
Fringe field effect on drift velocity

- V_d measured using the mean timer method from drift times in 3 consecutive staggered layers
- Measured the (expected) effect of stray field, esp. in innermost stations on outer wheels; below 3%

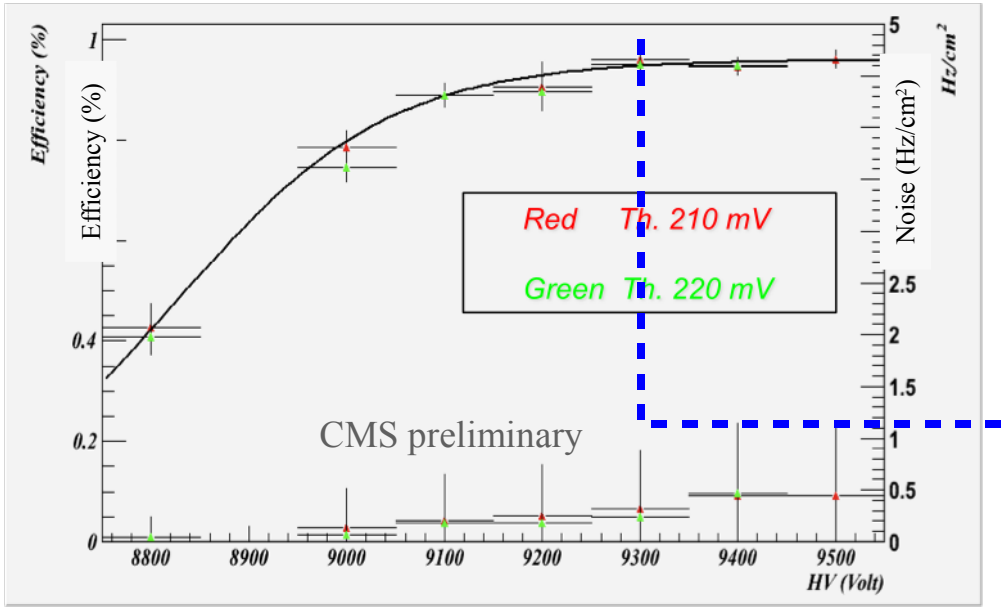
RPC (CRAFT09 Data)

- Efficiency above 90%
  - estimated from extrapolation of DT segments
- Noise below 1 Hz/cm^2
- r-ϕ resolution 1.1 cm

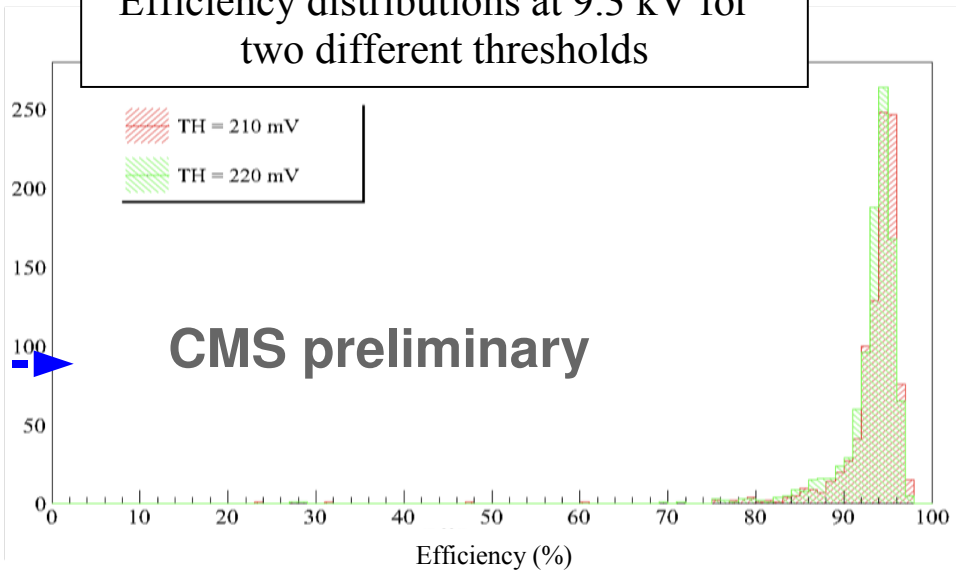
"Muongraphy" of one barrel chamber



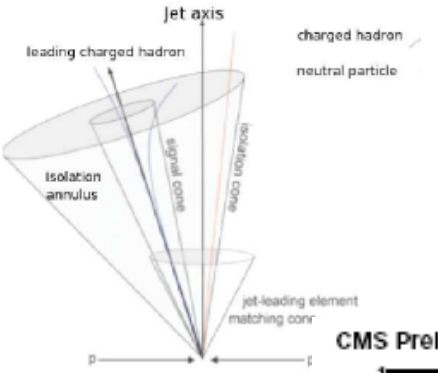
HV scan for noise and efficiency at 2 thresholds (1 barrel chamber)



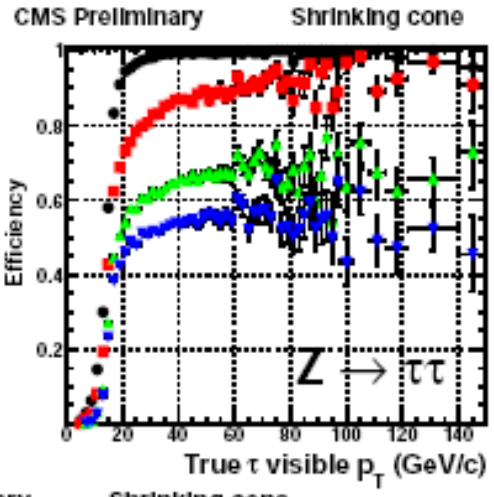
Efficiency distributions at 9.3 kV for two different thresholds

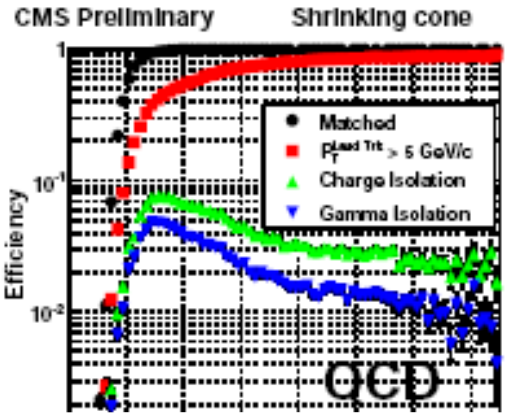


Tau Identification in CMS (II)

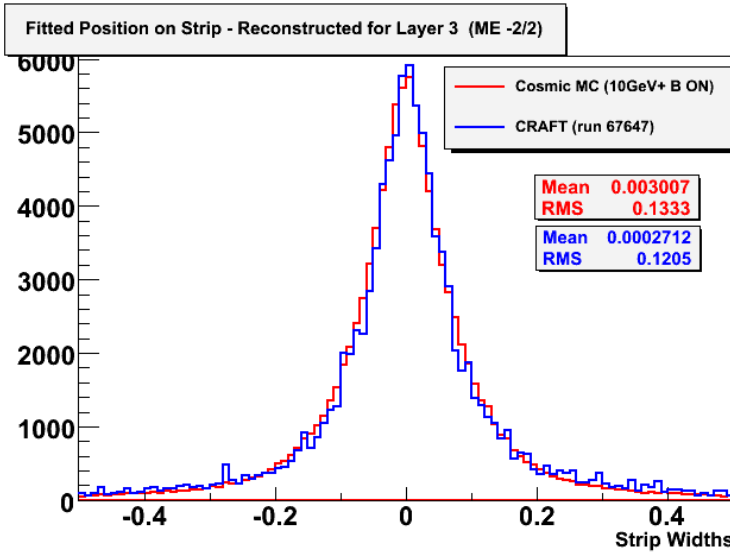


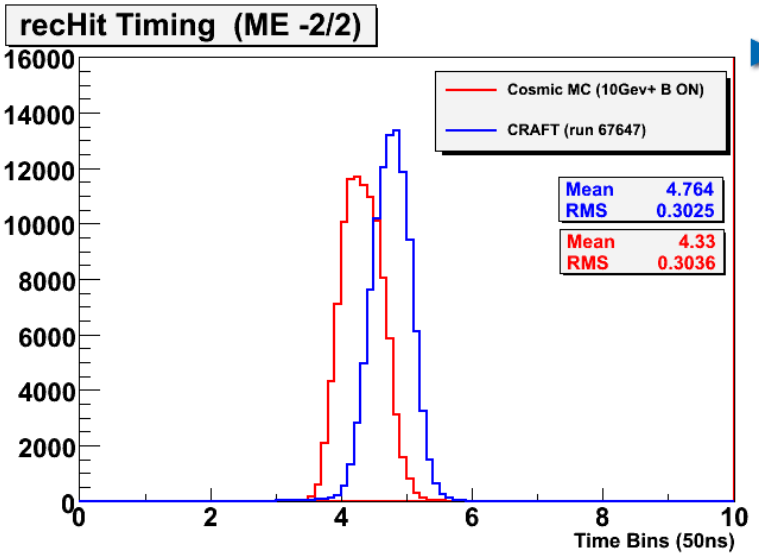
- On the contrast to for electrons and muons, taus identification strongly depends on the type of analysis in which taus are involved. Therefore the tau identification is performed in two stages
- A *pre-selection* which serves as a common basis for all final state with taus
  - **pT cut on each tau-jet candidate**, at least a charged hadron with pT > 5 GeV should be into a cone of 0.1 around the jet direction
  - An **isolation** cone is built around the leading track (highest-momentum charged hadrons). No tracks with pT>1 GeV nor photon with ET larger than 1.5 GeV
    - Isolation cone is ET dependent (5/ET)
- *Sophisticated tau id algorithms*, suitable and tunable for each individual physics analyses

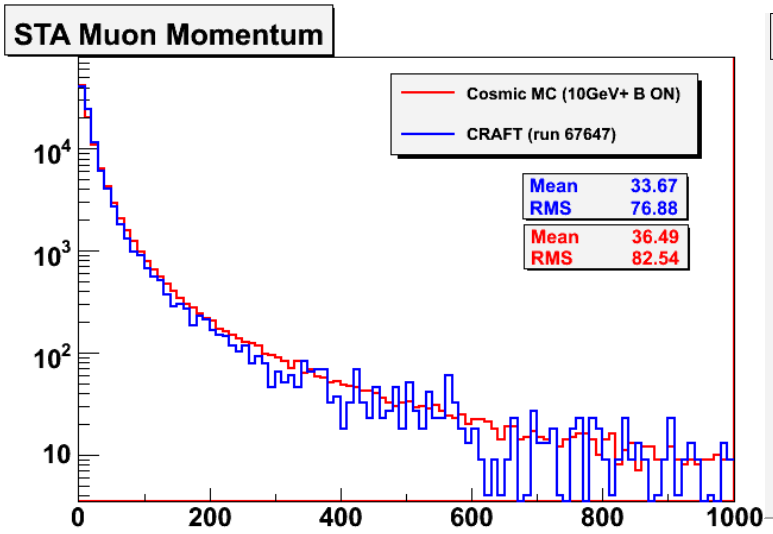


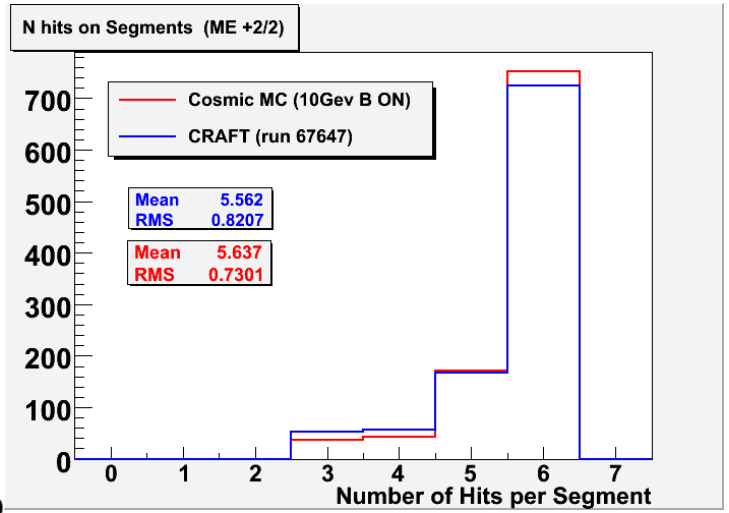


Data-Simulation Comparisons of Cosmic Muons in Endcaps



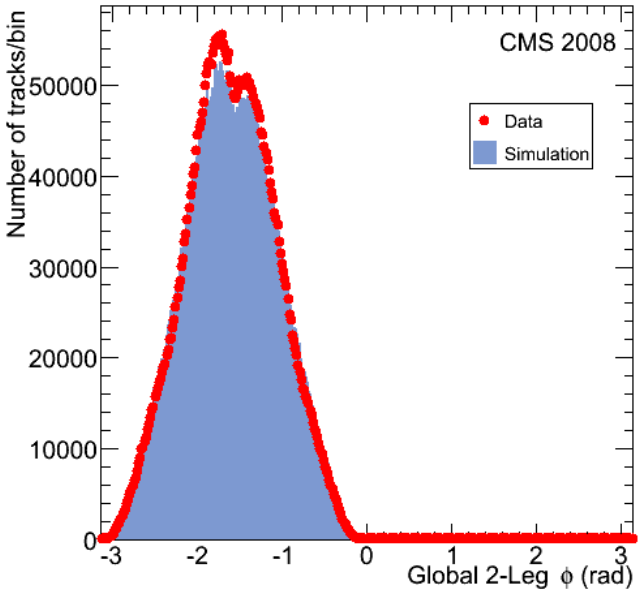


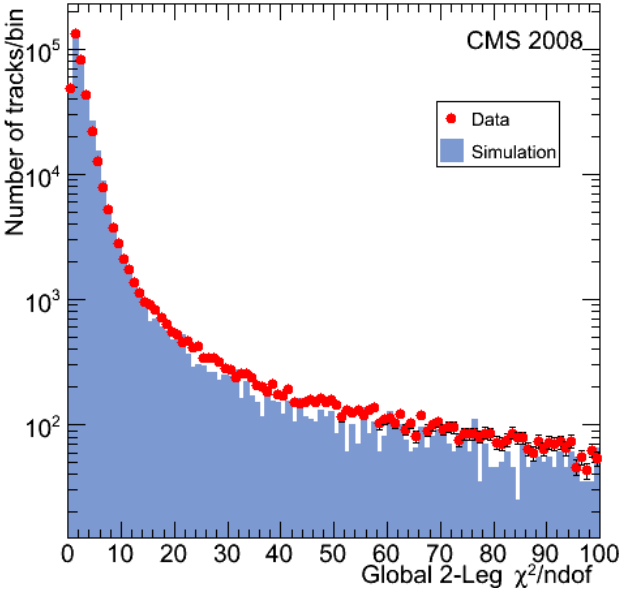


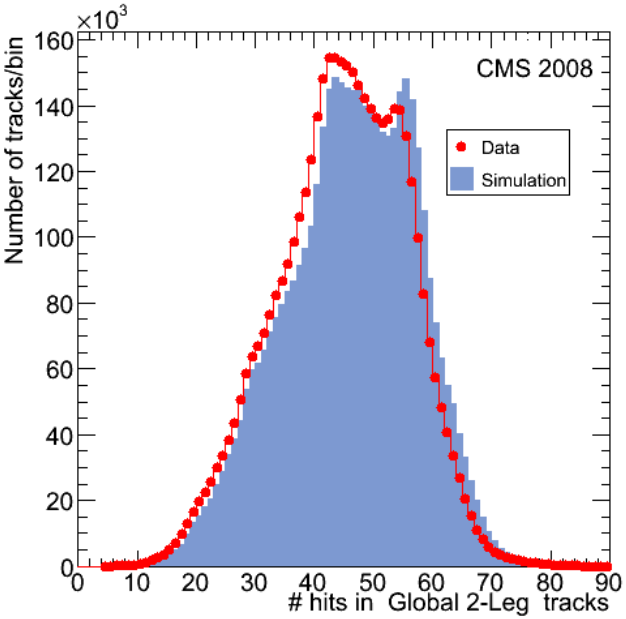


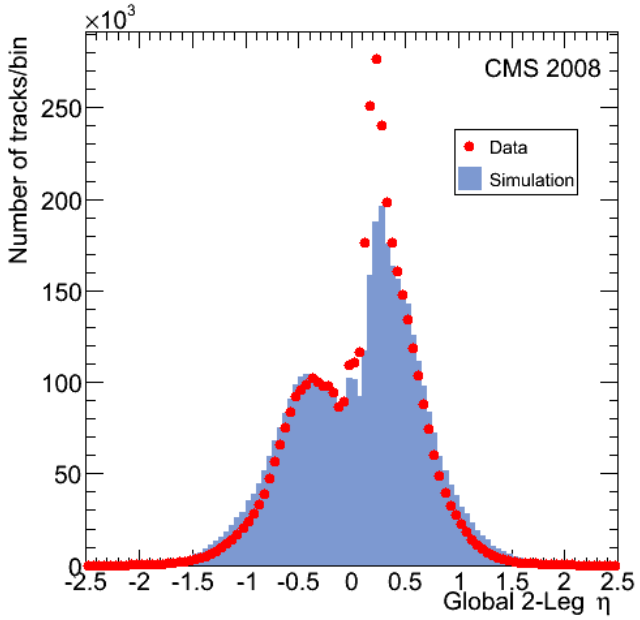
- CSC simulation does not model exact (and somewhat arbitrary) start time of recorded pulses, but does reproduce width and does have pulses in time window
- Wide angular spread of cosmic muons can lead to tracks registering only 3/6 layers

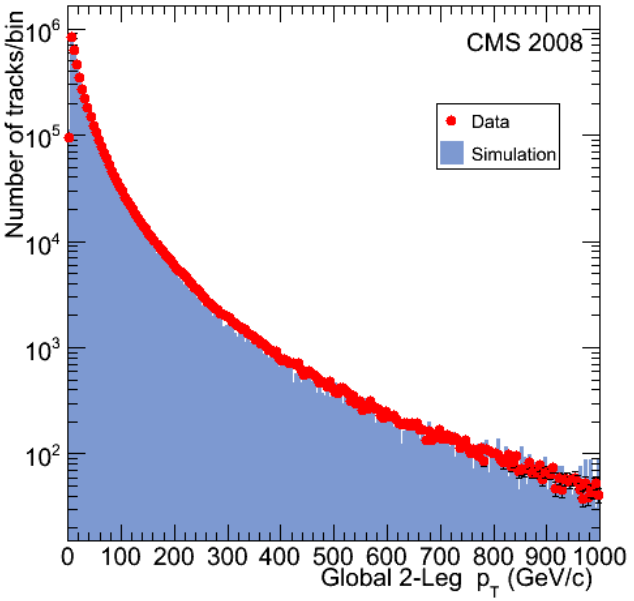
Global Muon Variables

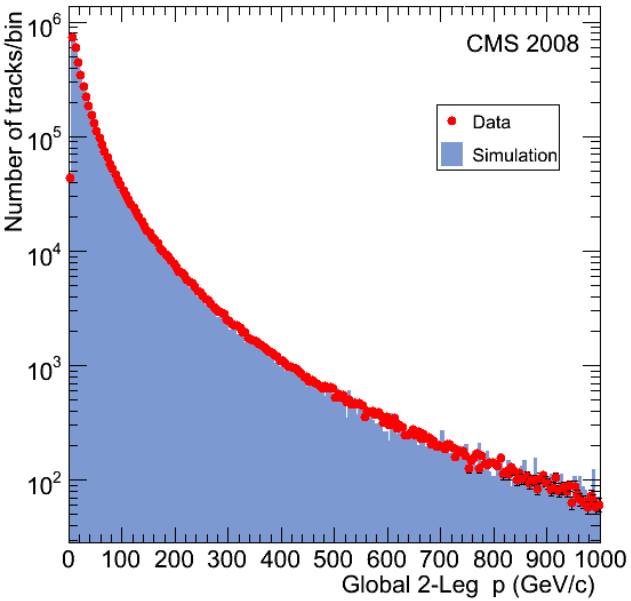




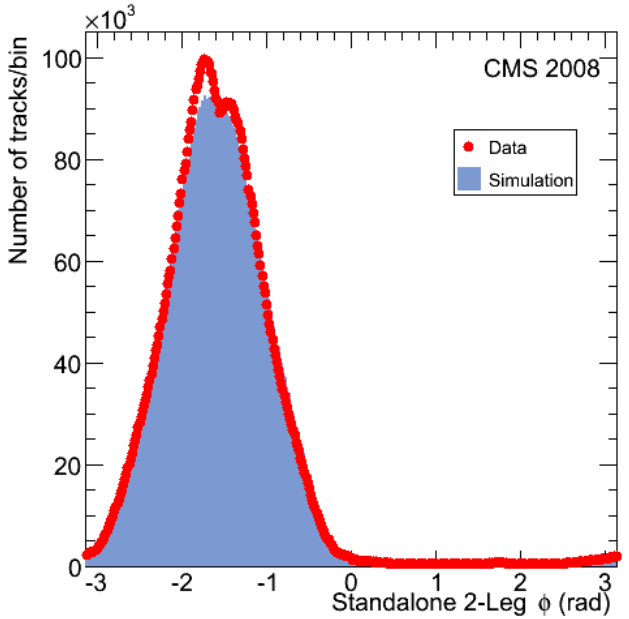


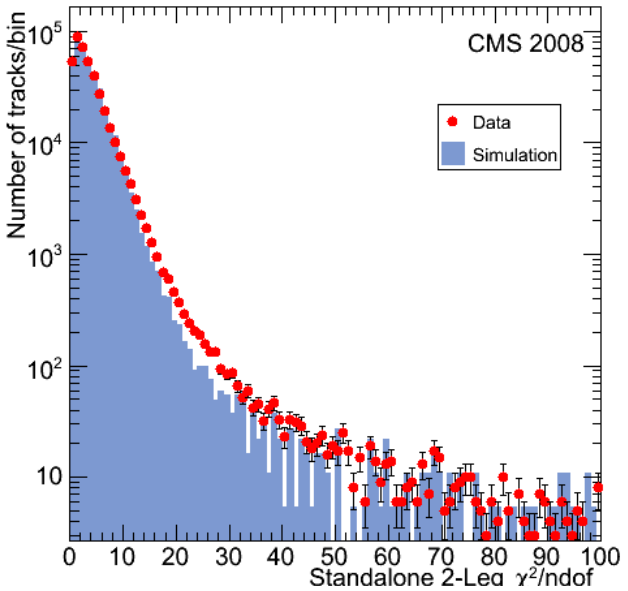


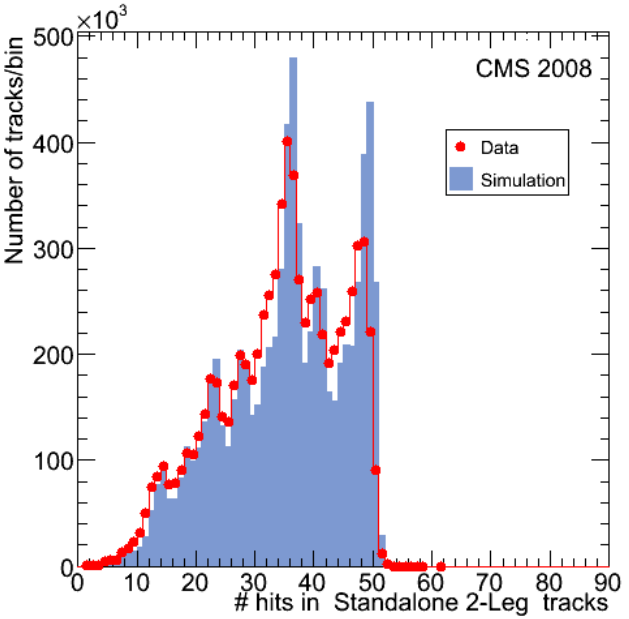


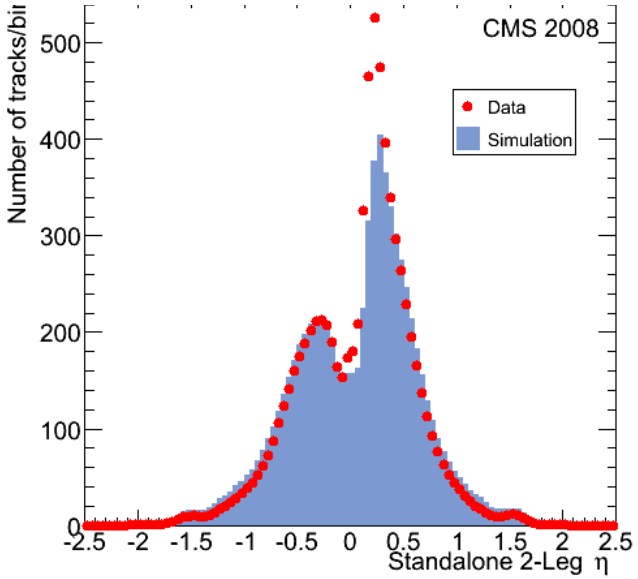


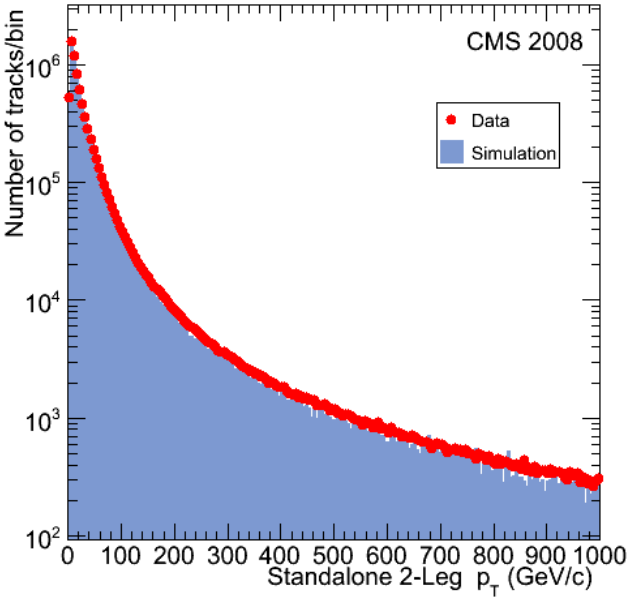
STA Muon Variables



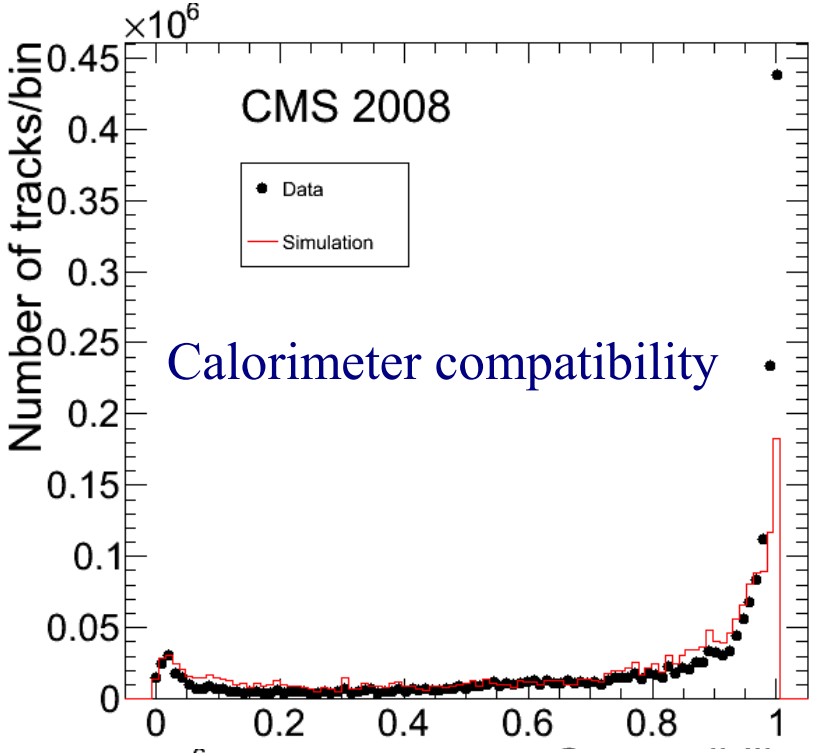


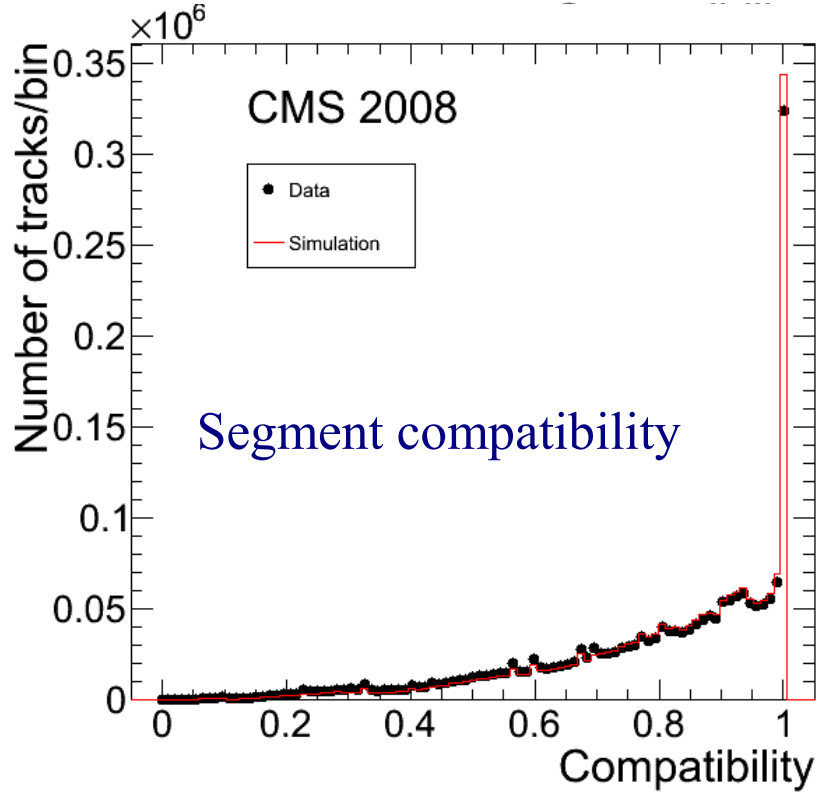






Muon ID in CRAFT'08

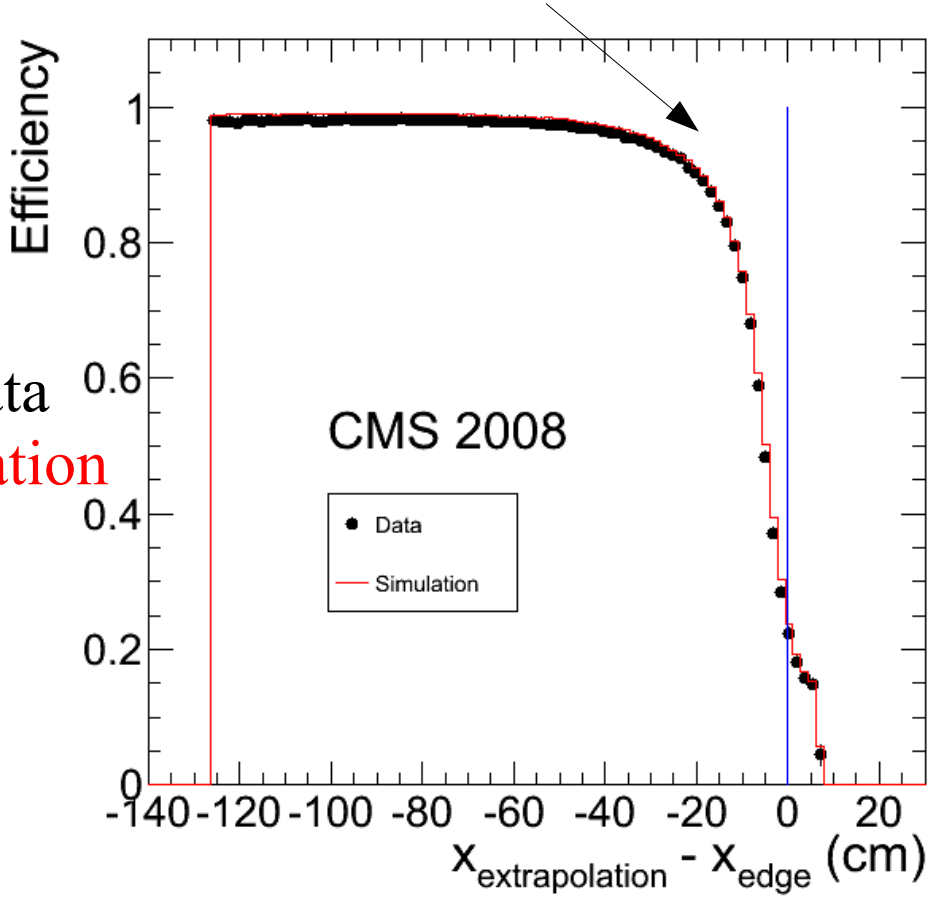




Efficiency of a successful track-to-segment match (in the DT sys) as a function of the propagated track position and the nearest chamber edge

Black data

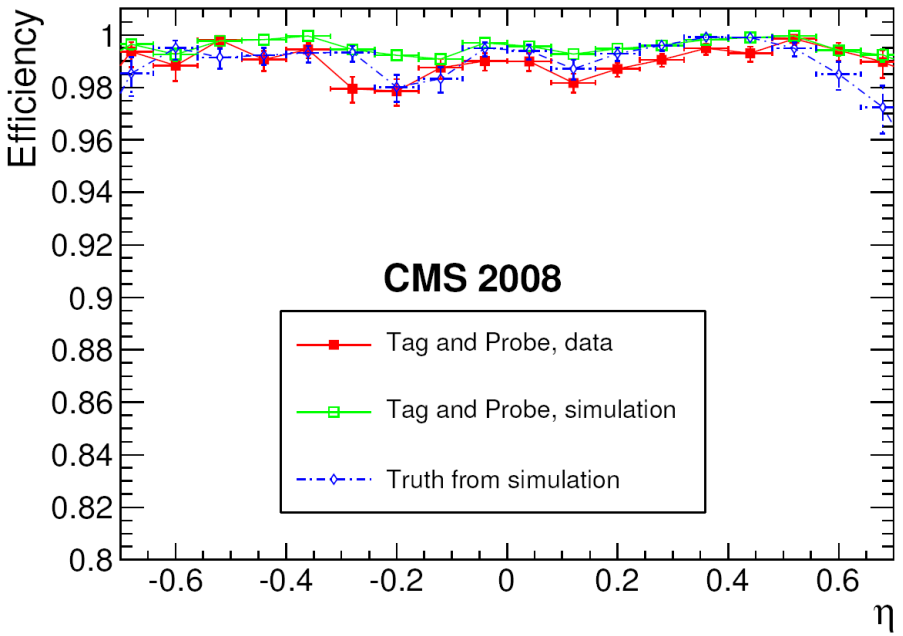
Red simulation

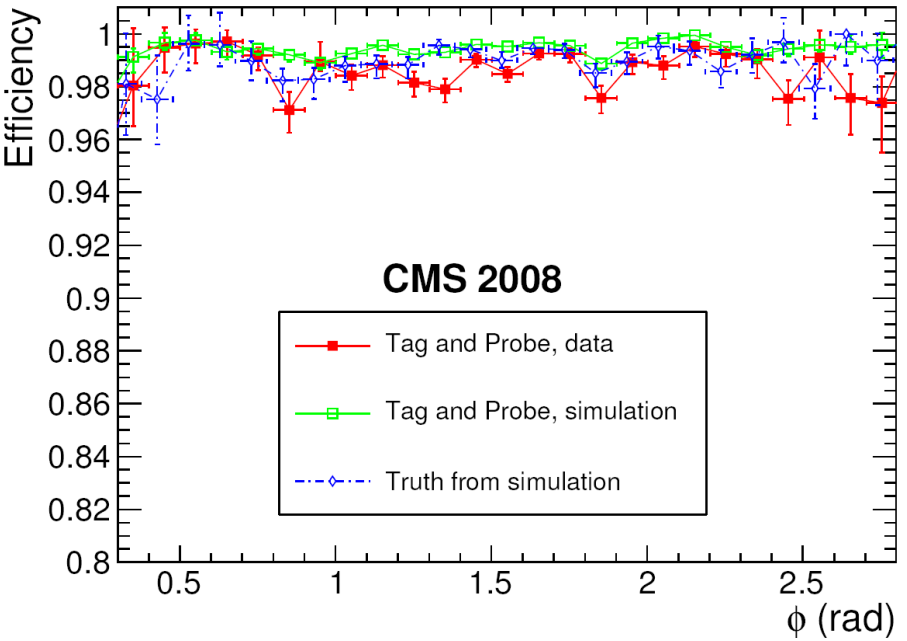


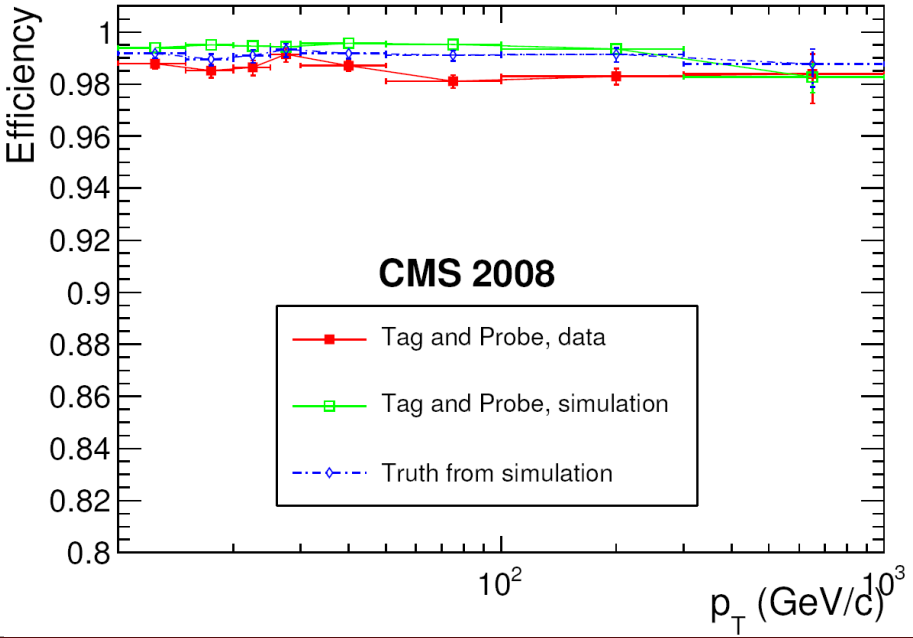
(distance is assumed negative when the propagated state is within the segment's chamber)

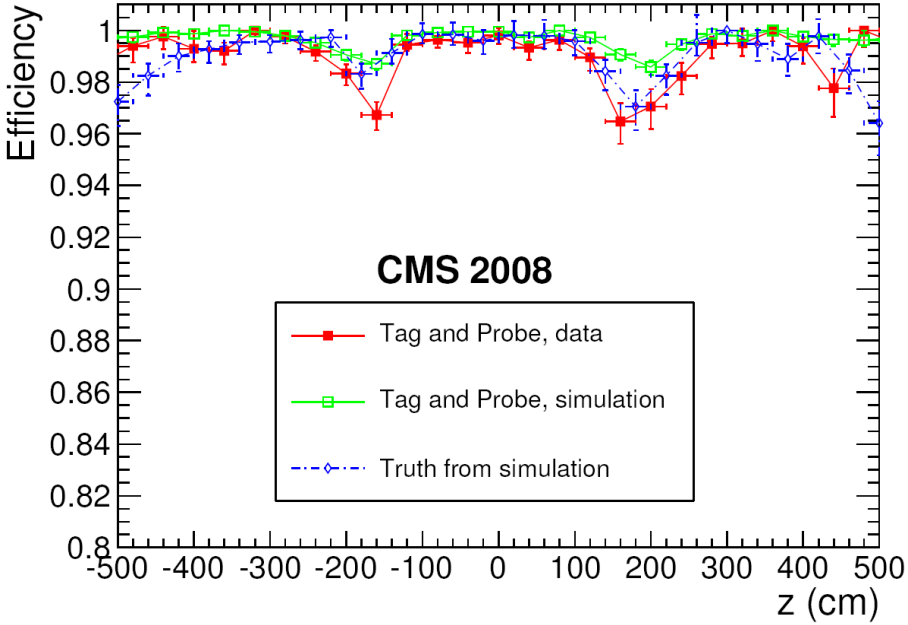
Dedicate Cosmic Muon Reconstruction

1-leg Stand-alone muon

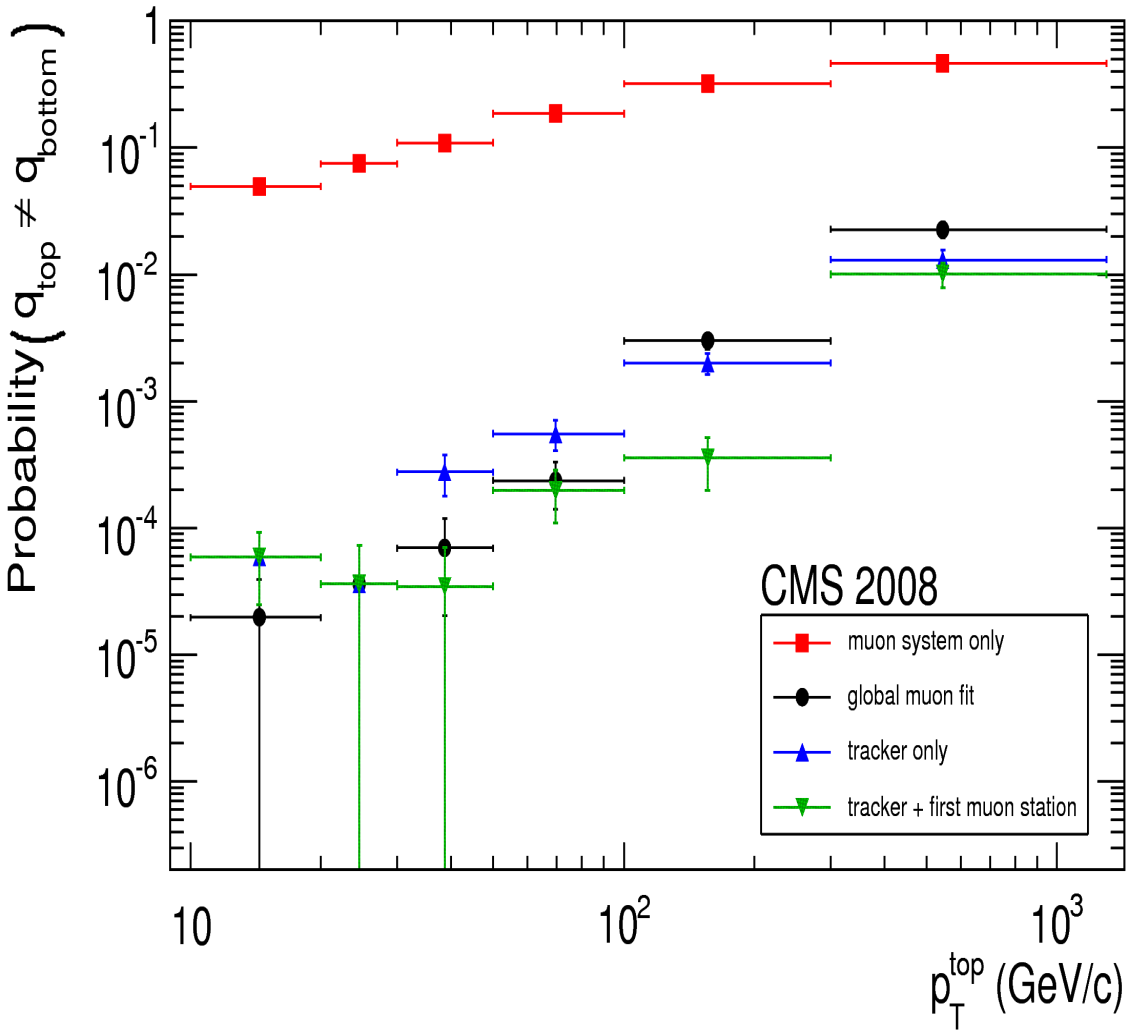








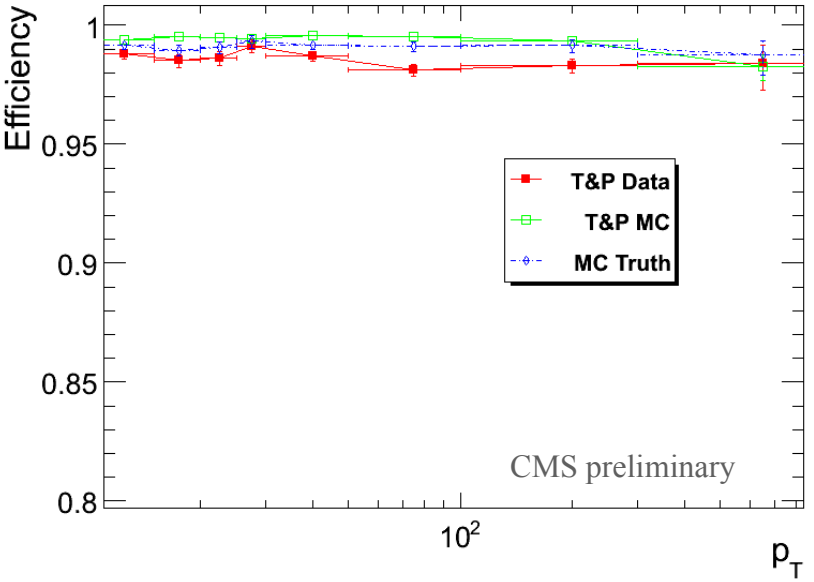
Charge Mis-Assignment probability

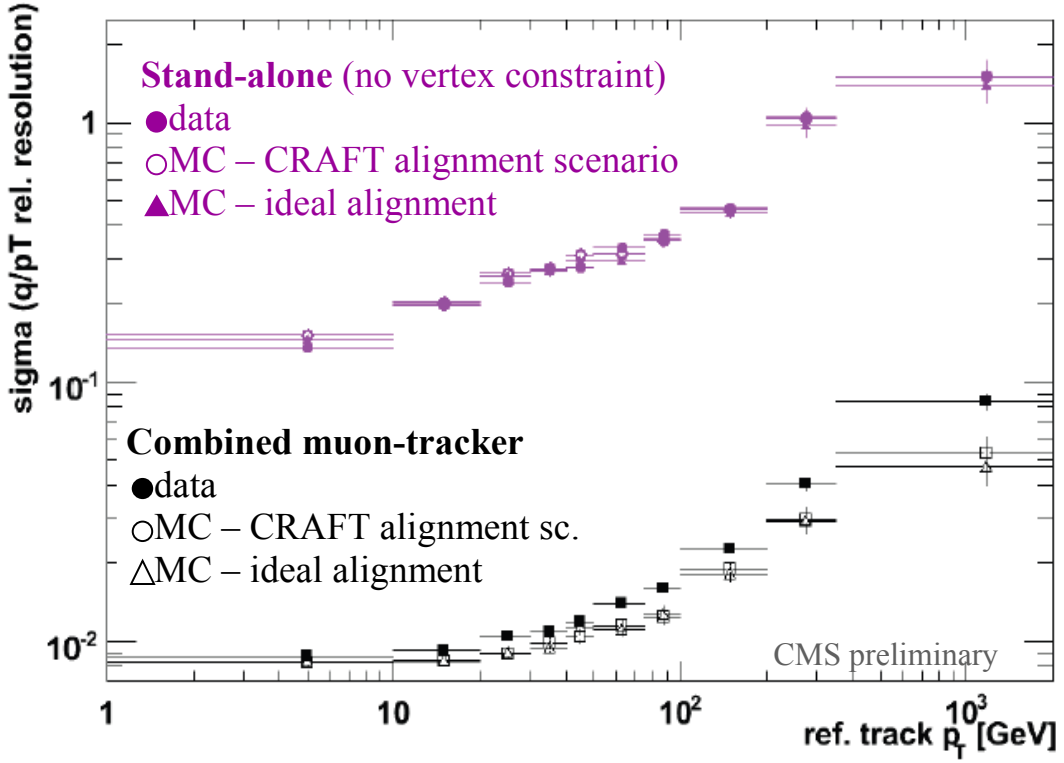


Resolutions on Cosmics

Stand-alone reconstruction efficiency

- For 1-leg reconstruction, given trigger and a good-quality tracker track (tag)
- >98%; well described by MC





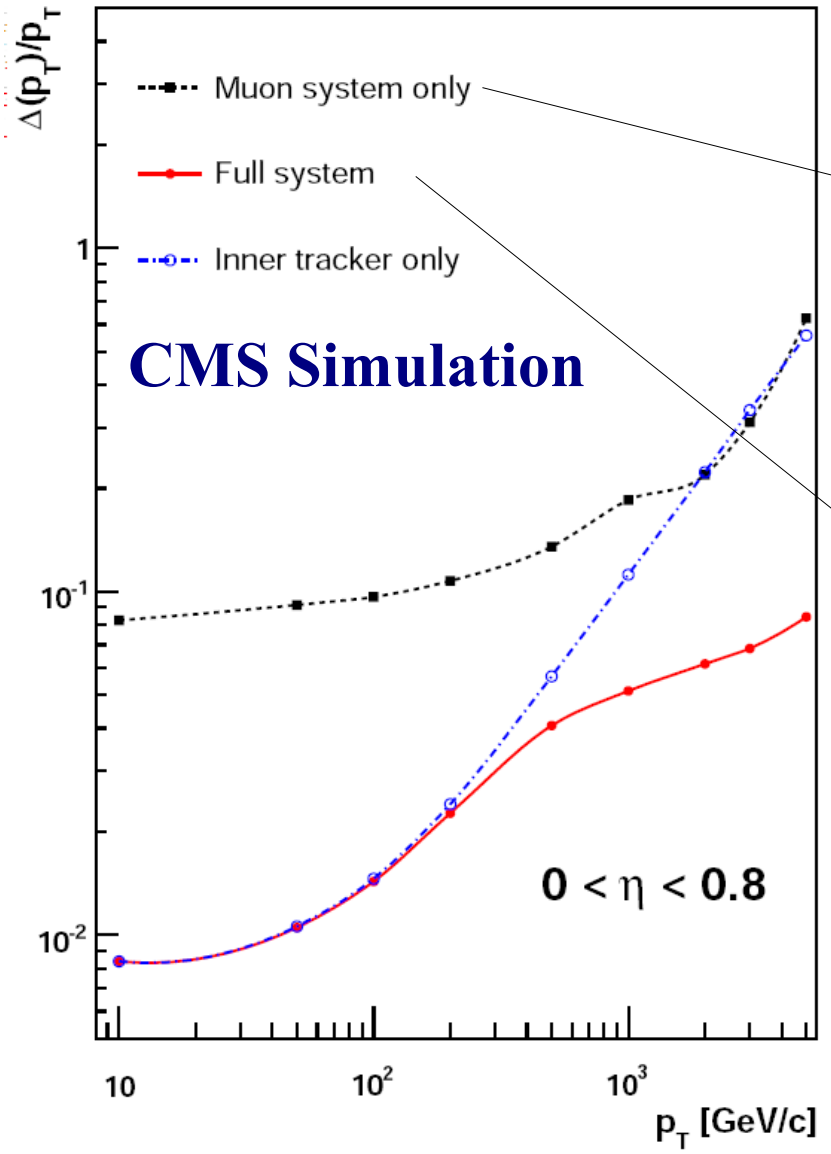
Resolution for collision-like cosmics

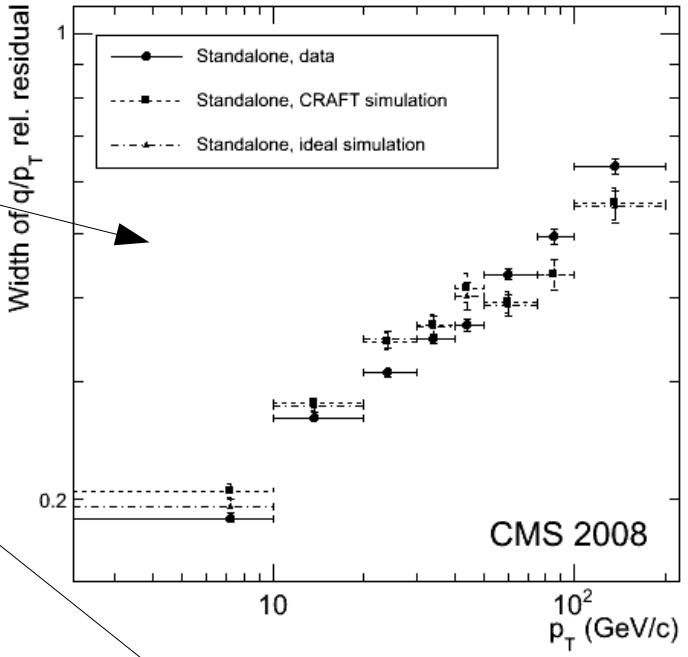
- By comparison of top and bottom legs:

$$R(q/p_T) = \frac{(q/p_T)^{\text{upper}} - (q/p_T)^{\text{lower}}}{\sqrt{2}(q/p_T)^{\text{lower}}},$$

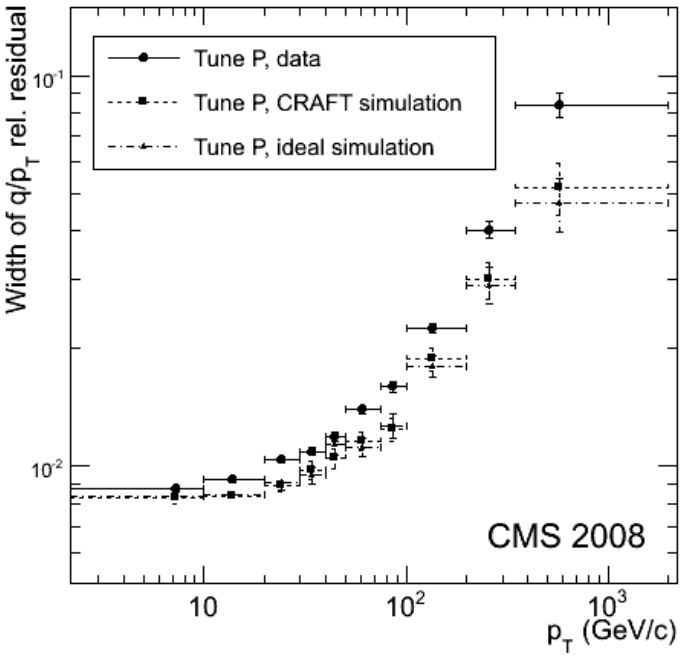
- Good agreement with MC
  - MC misalignment scenario slightly too optimistic at high p_T

Muon pT Resolutions

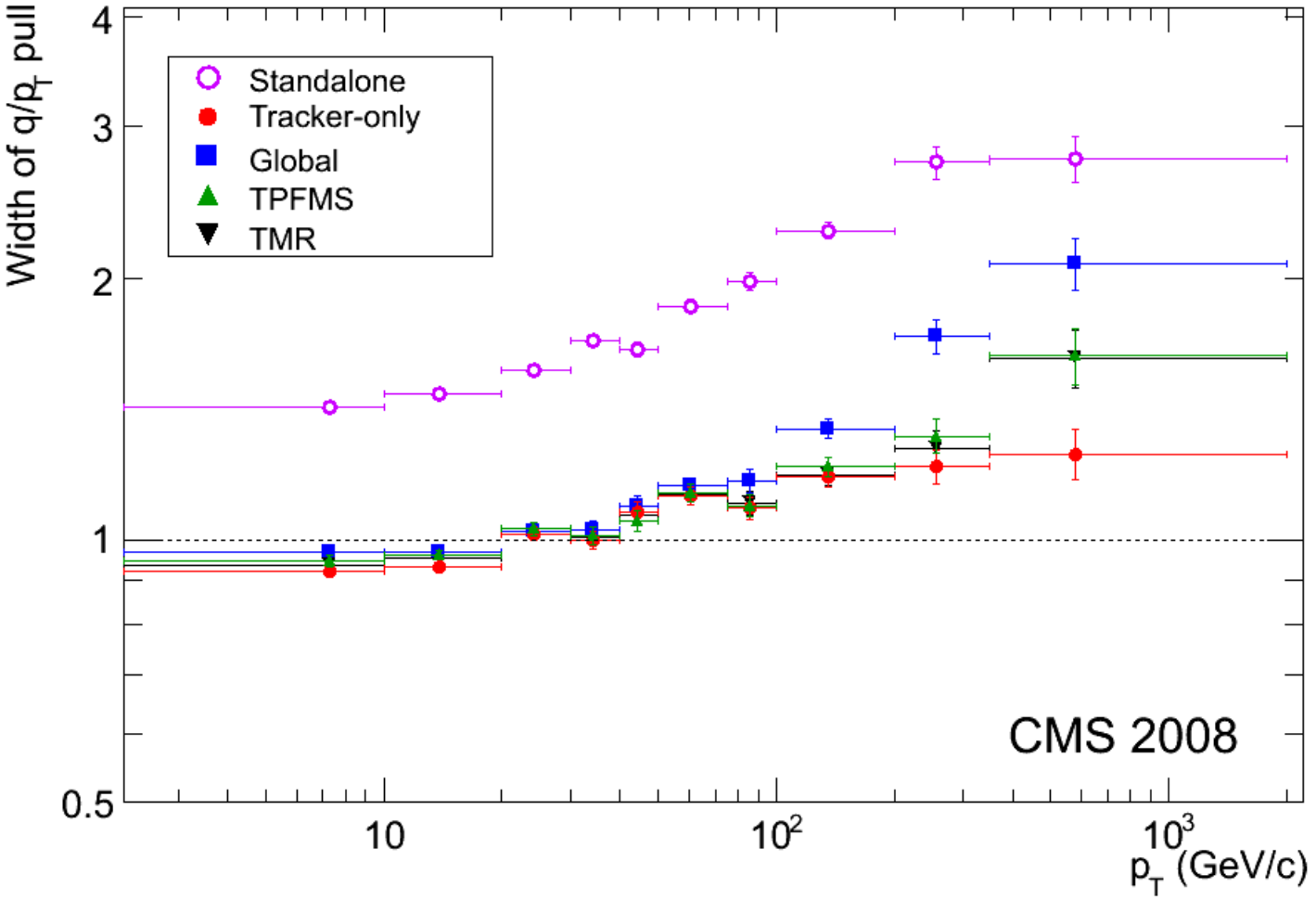




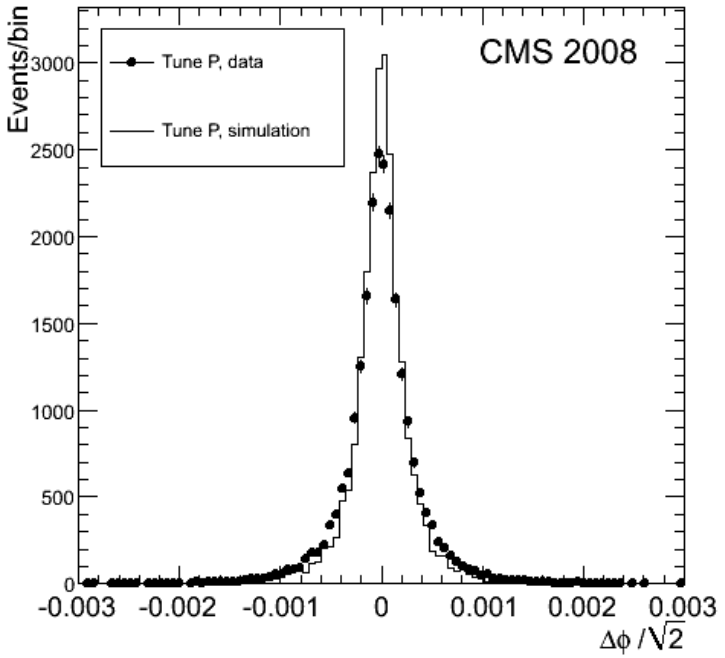
CRAFT '08 data

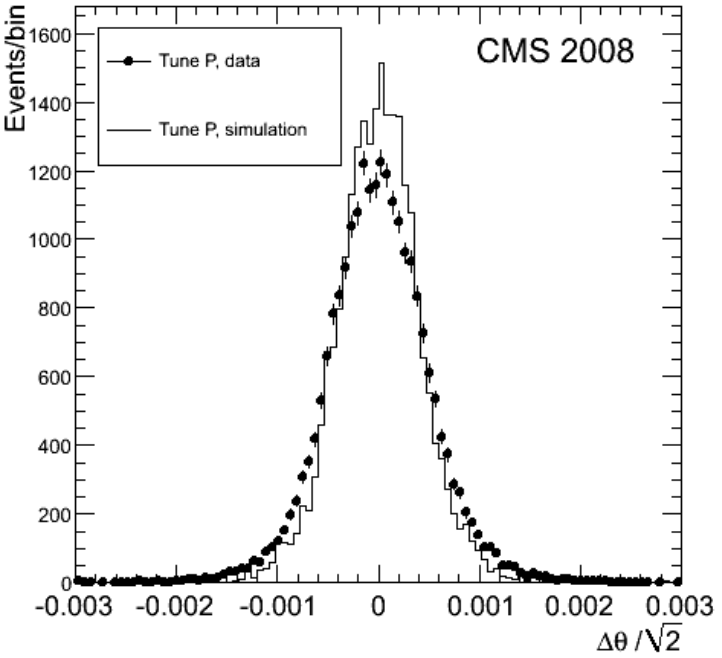


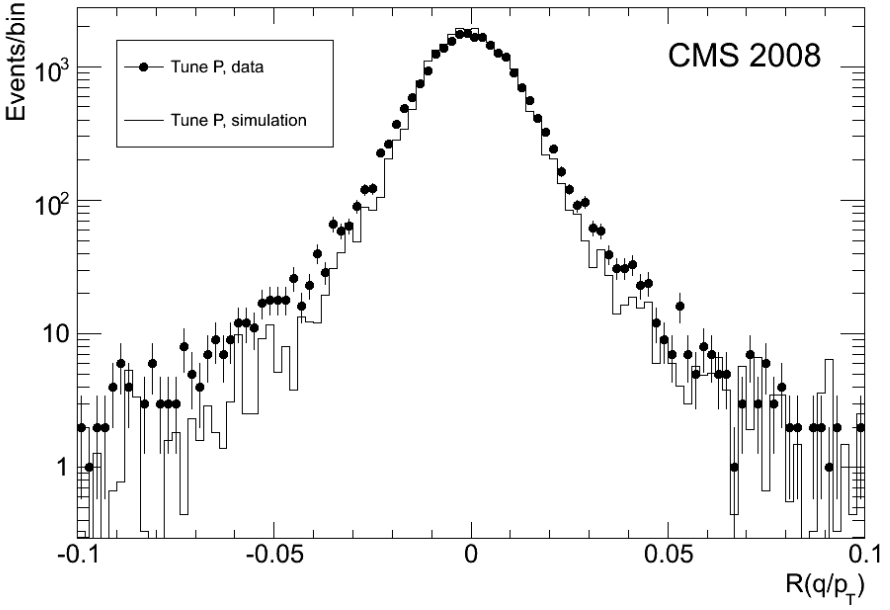
Pull Transverse Momentum



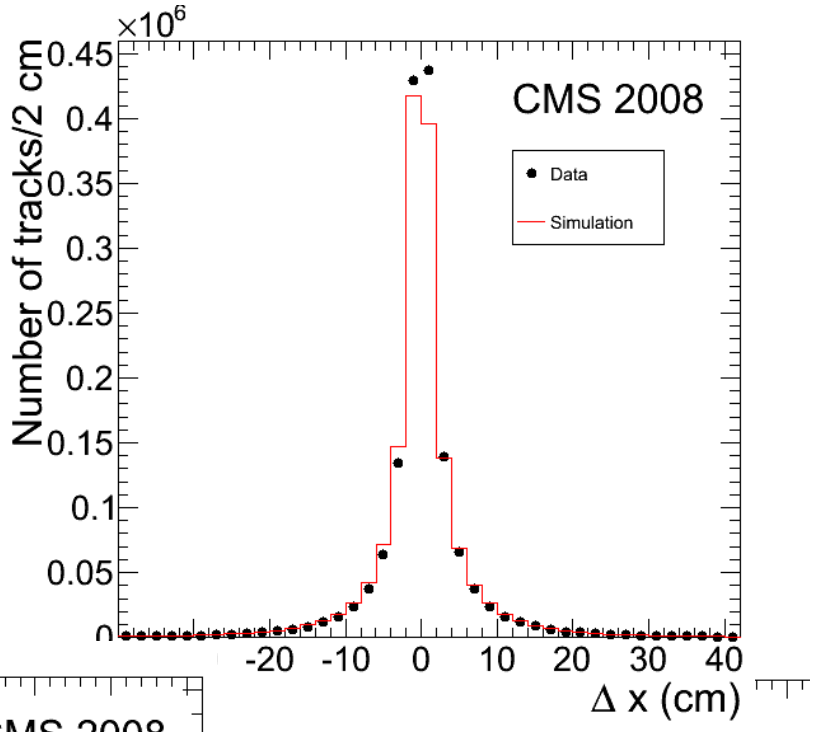
GLB Resolutions (CRAFT 08)

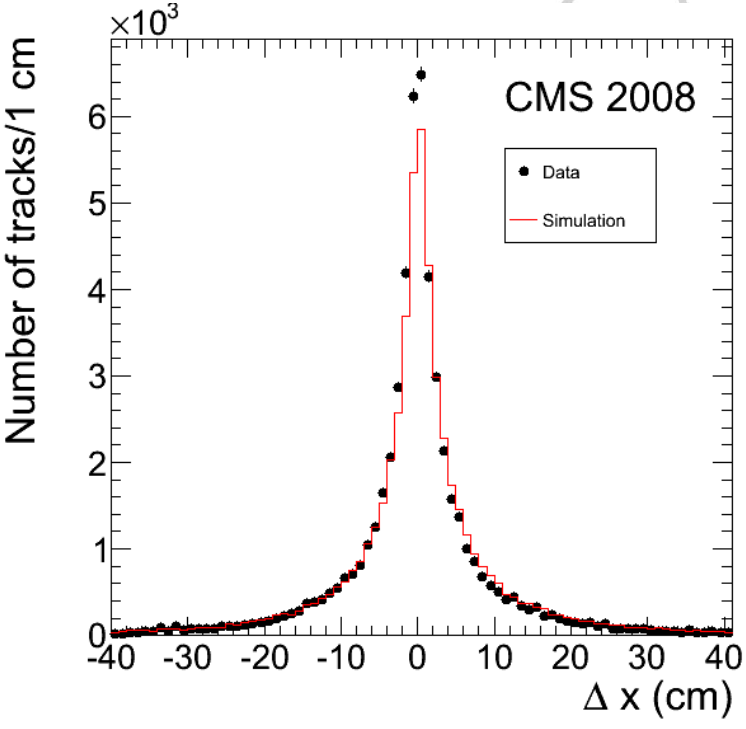


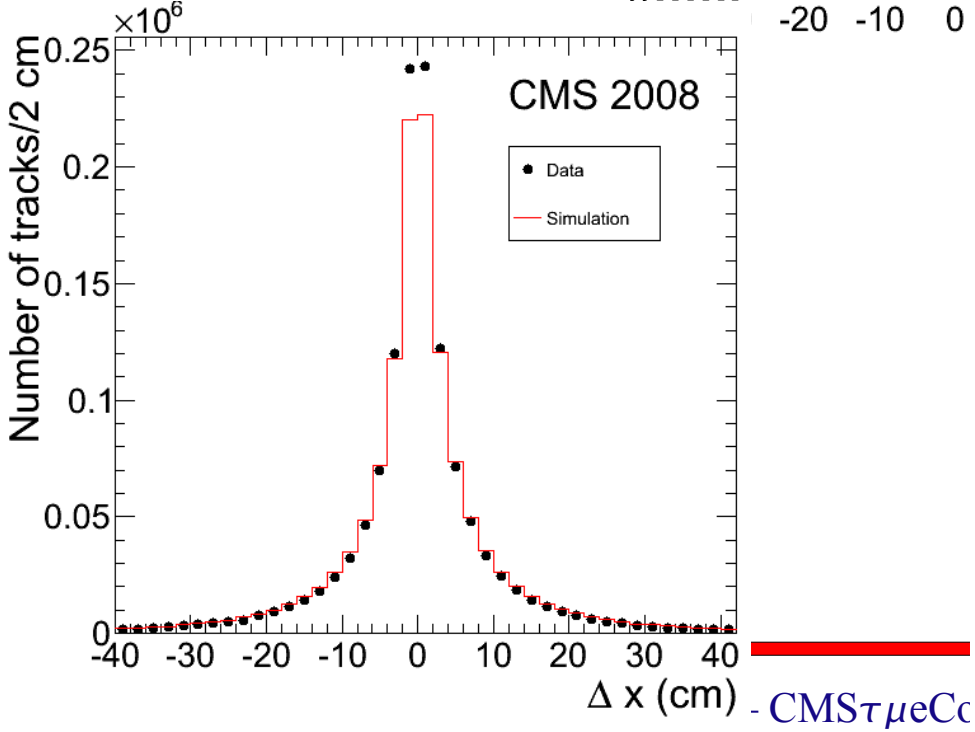


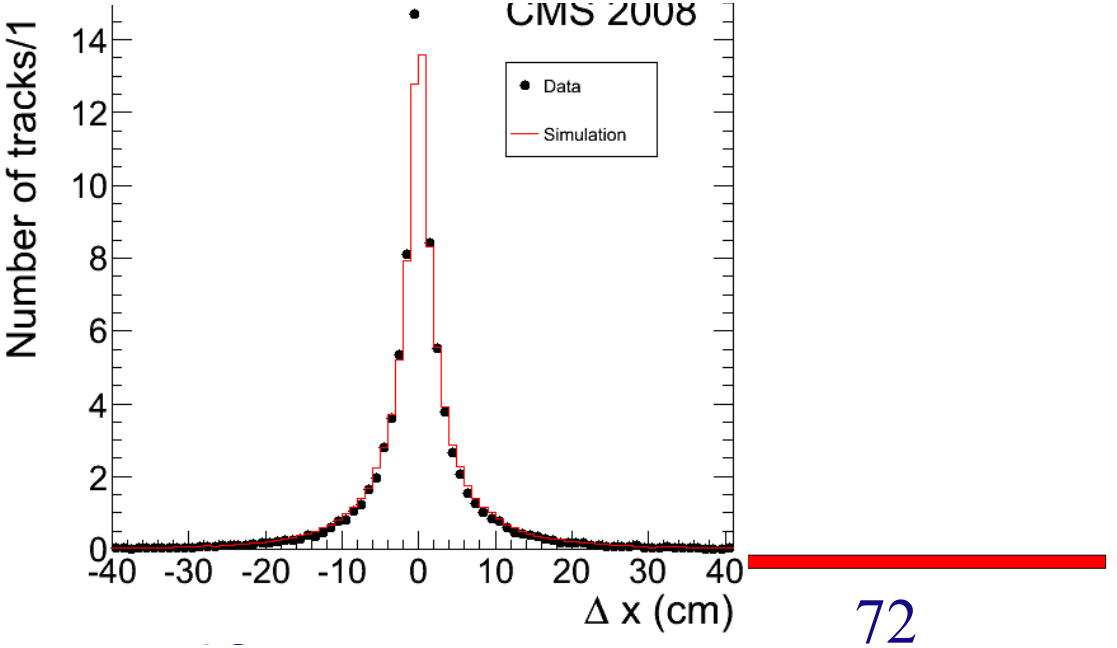


Tracker Track Extrapolation – Residuals with CSC Segments

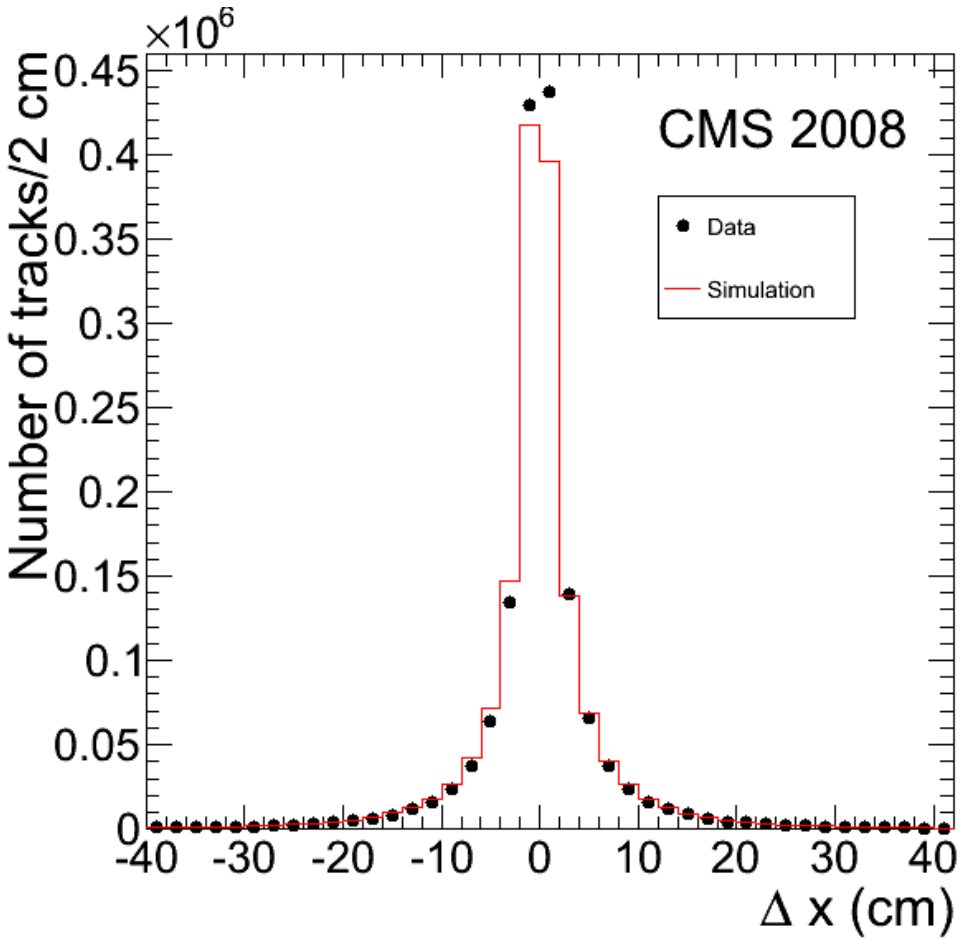


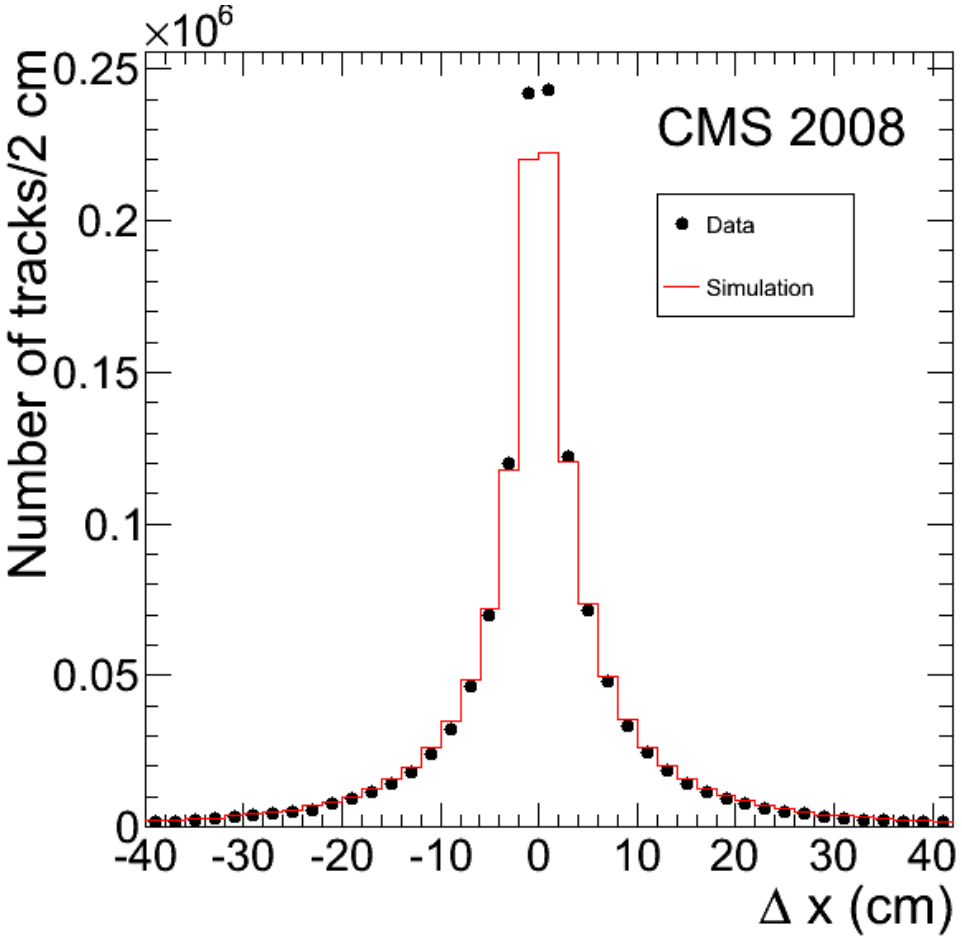






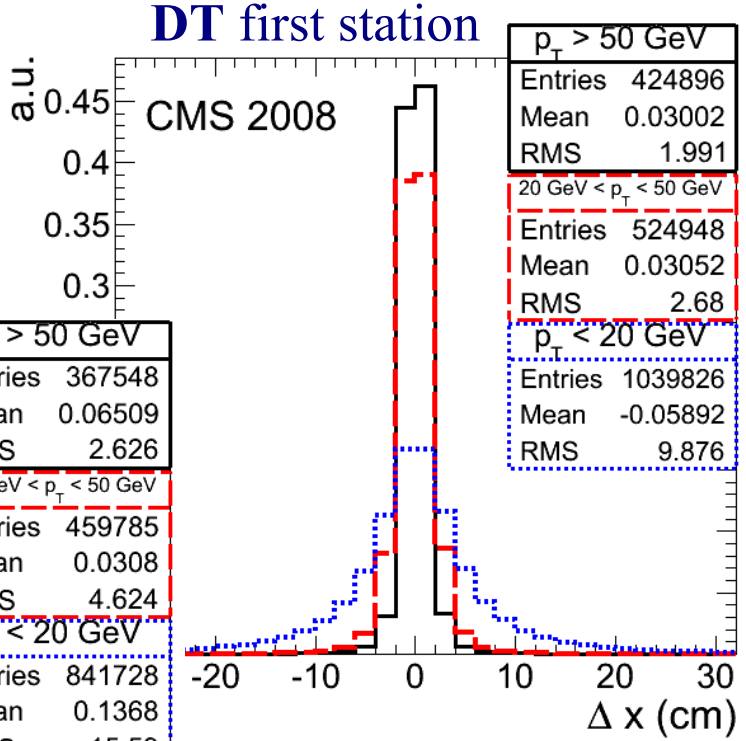
Tracker Track Extrapolation – Residuals with DT Segments



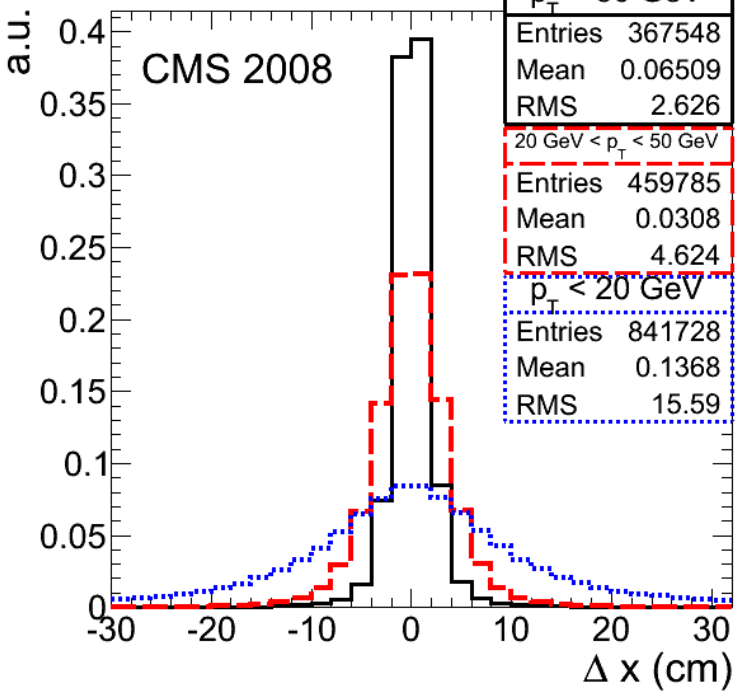


Muon ID Variables

DT first station

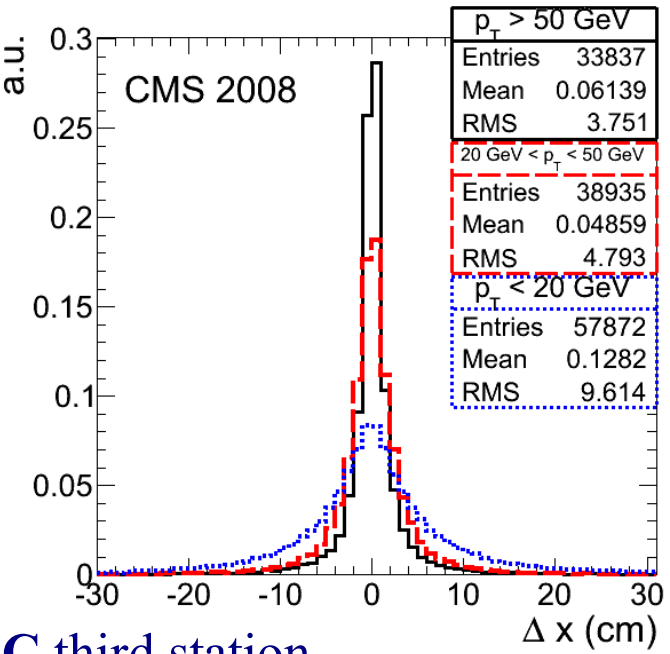


DT fourth station

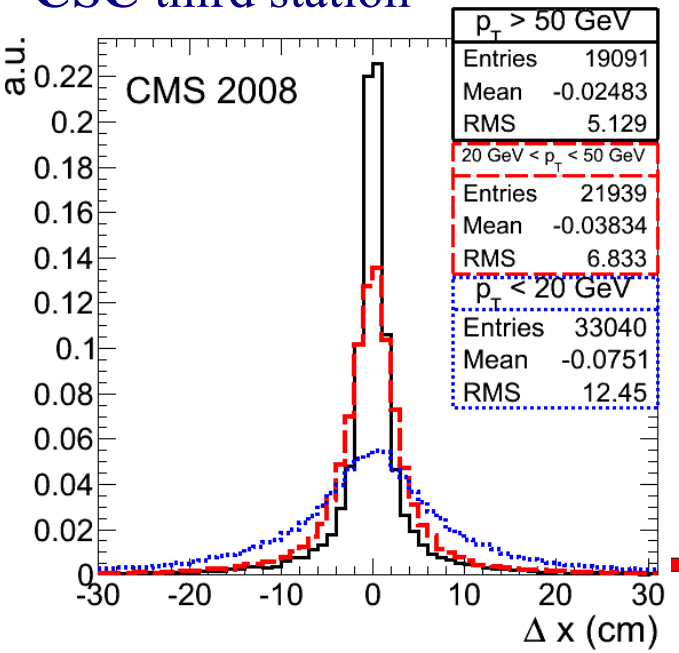


above 50 GeV
20-50 GeV
below 20 GeV

CSC first station



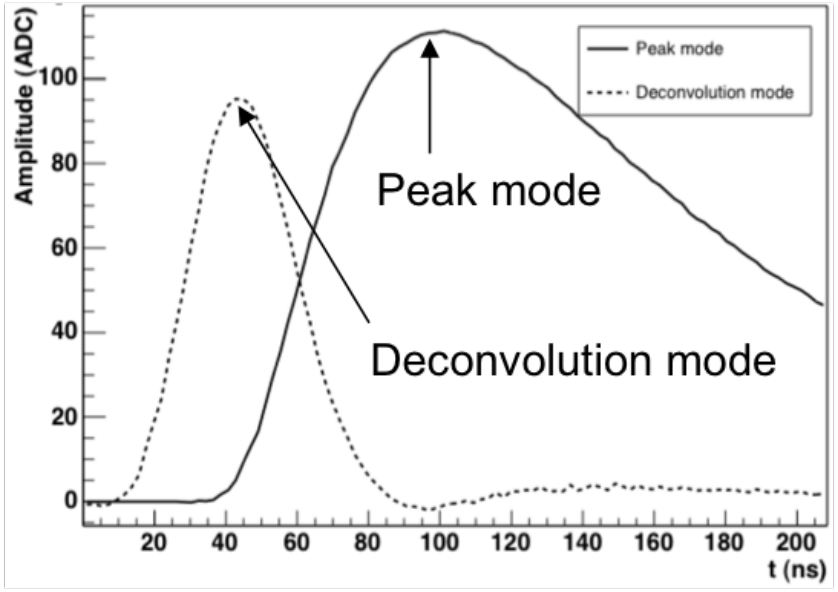
CSC third station



Residuals of the local **x variable,** of tracker track extrapolated to the relevant muon chambers and the matched segments

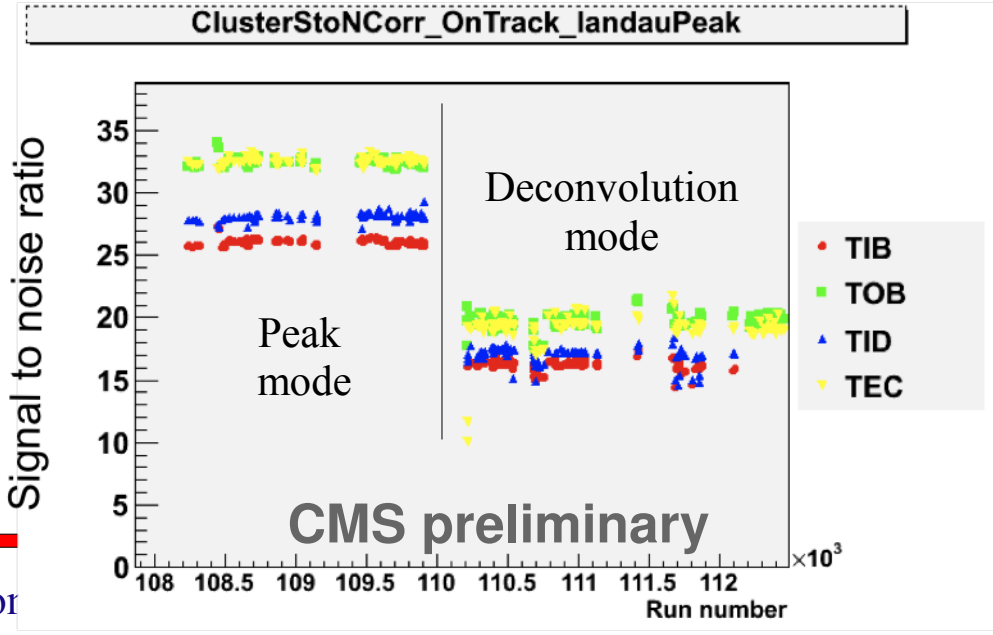
Tracker Readout in Deconvolution Mode

APV Pulse shape

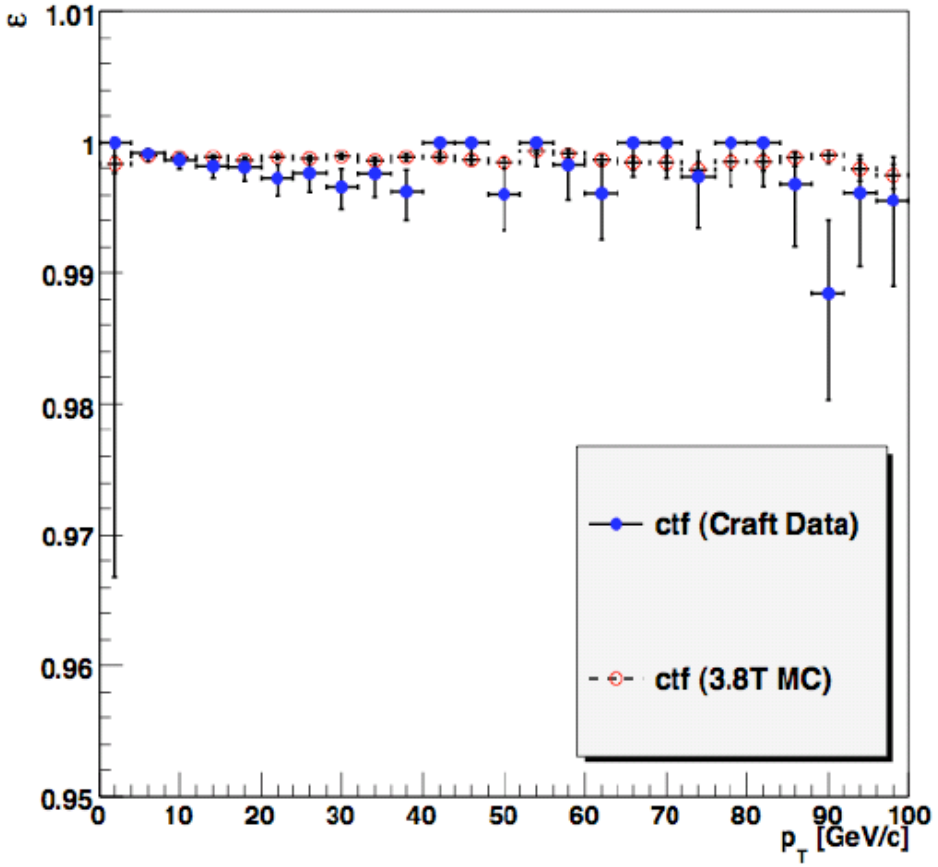


- Comparison to Peak mode
  - Noise 1.5 x higher
  - Signal 0.9 x lower
- These values agree with expectation

- Deconvolution mode used in CRAFT 2009
- A digital filter: build weighted analog sum of three samples at amplifier output. For given amplifier this sum is equivalent to integral over delta function representing charge injection.
- In practice this is equivalent to having a faster amplifier (less sensitive to pileup), without the disadvantages of more electronic noise, power dissipation, crosstalk...
- This mode is foreseen for collisions



Tracker Track Efficiency (CRAFT08)



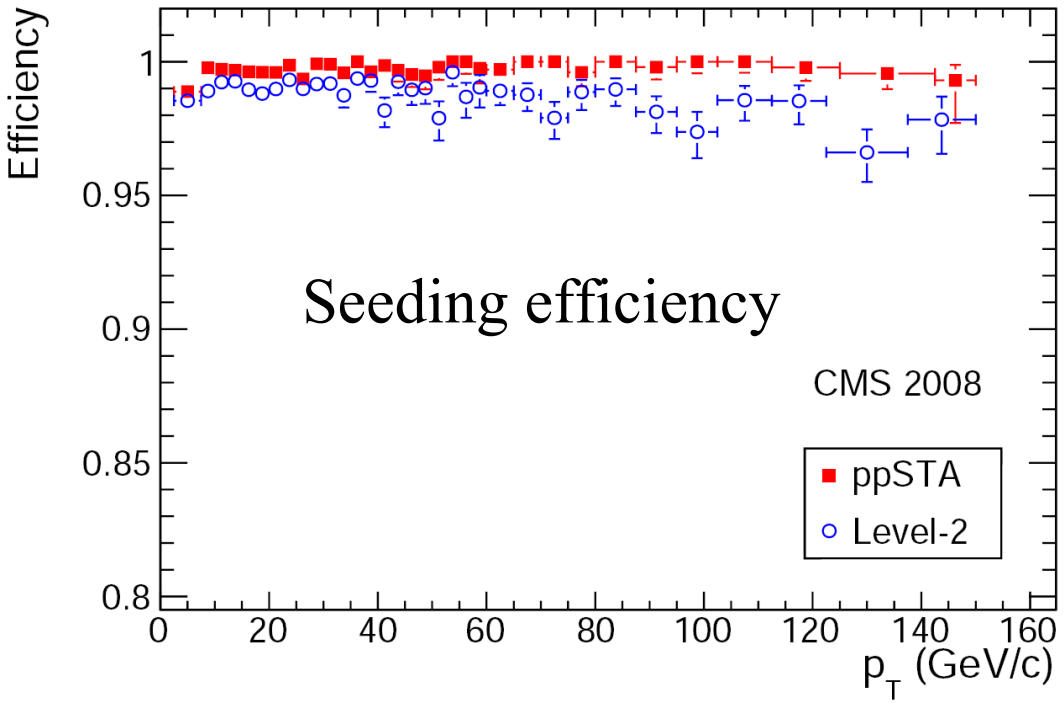
Efficiency (%)	Data	MC
CKF	99.5±0.1	99.9±0.1
CosTF	99.3±0.1	99.7±0.1
RS	99.1±0.1	99.6±0.1

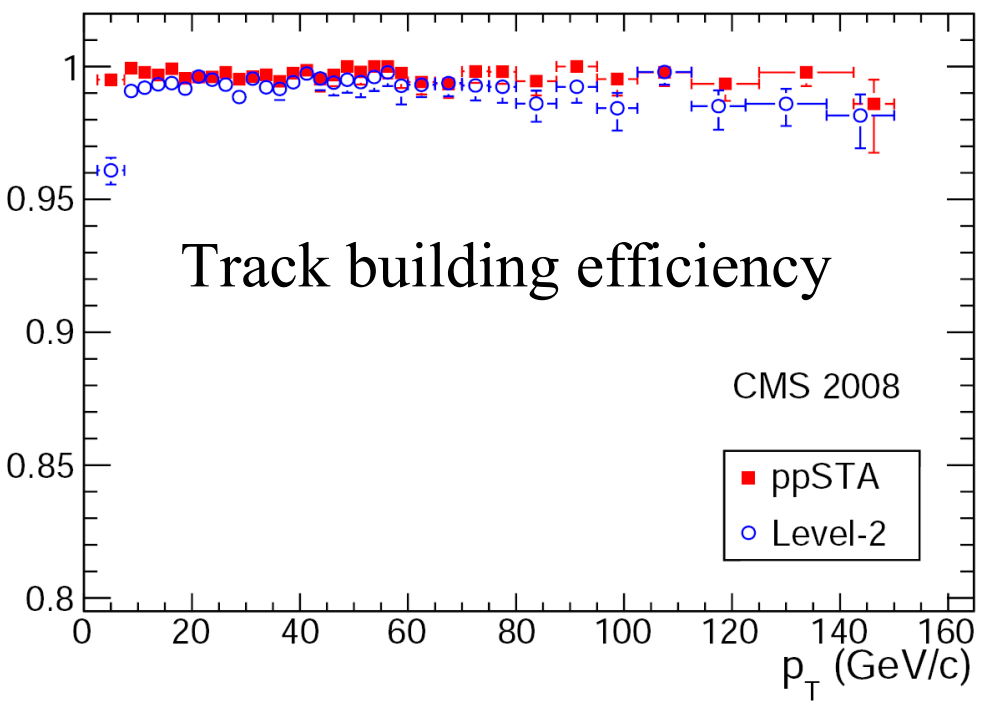
Cut on Stand Alone Tracks

|d0| < 30cm, |dZ| < 30cm

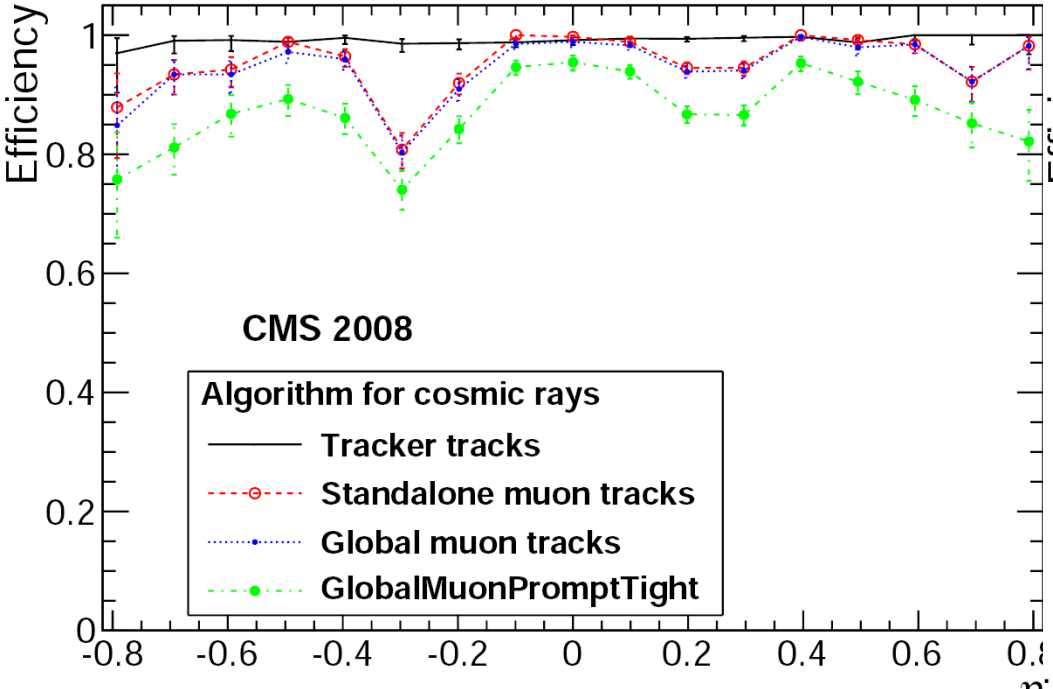
|eta| < 1; 0.5 < | phi| < 2.5

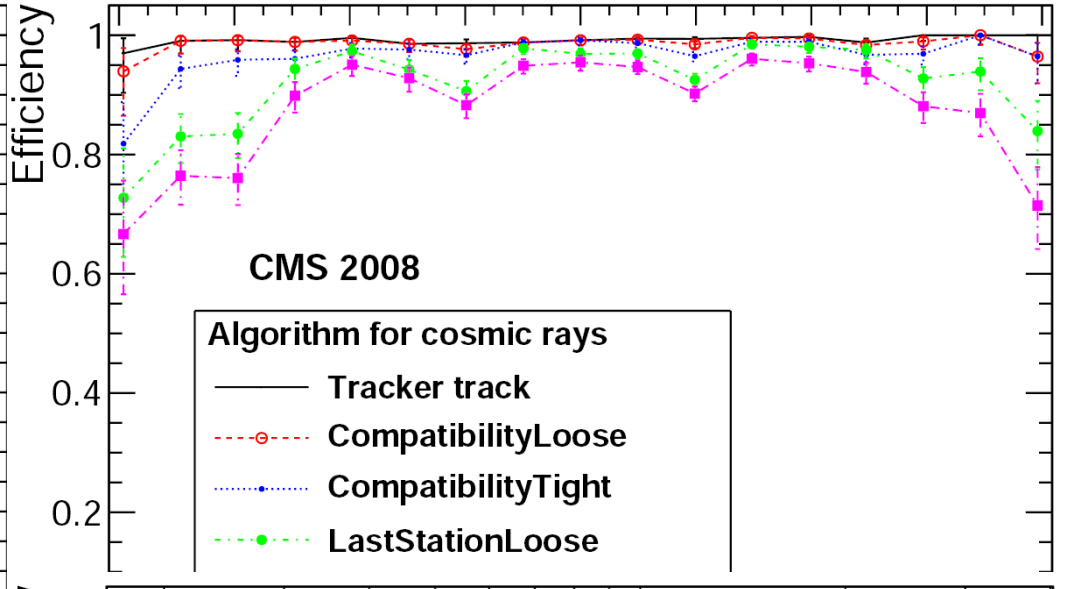
L2 Muon Trigger

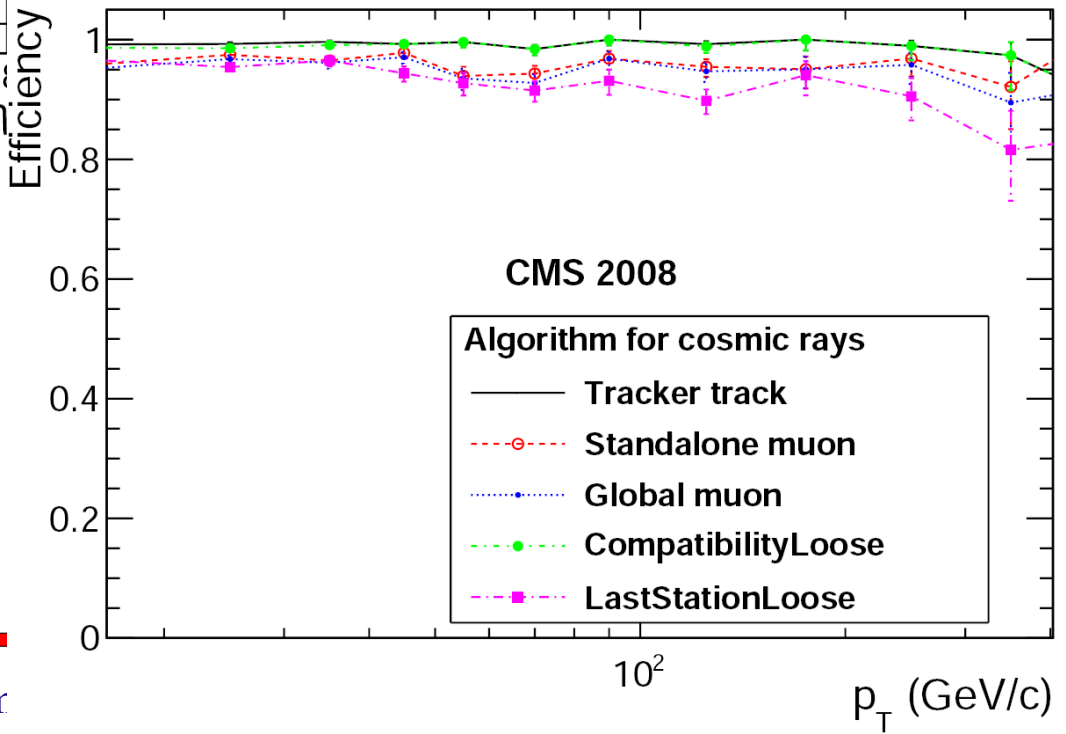




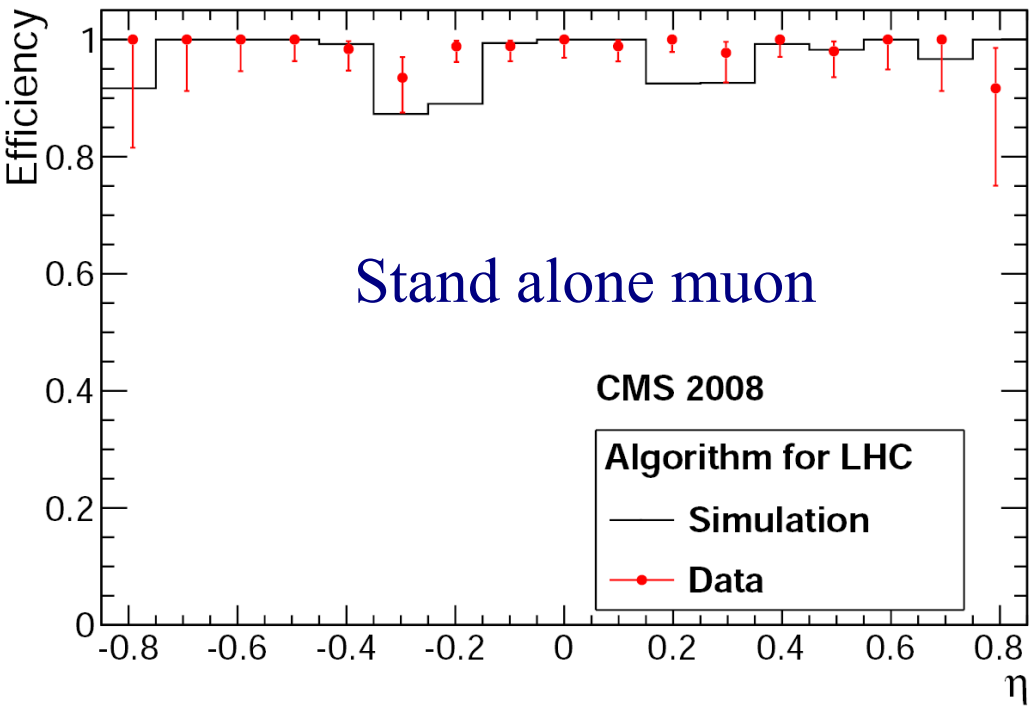
Muon Reconstruction&Identification Efficiency (Cosmic-dedicated algorithms)

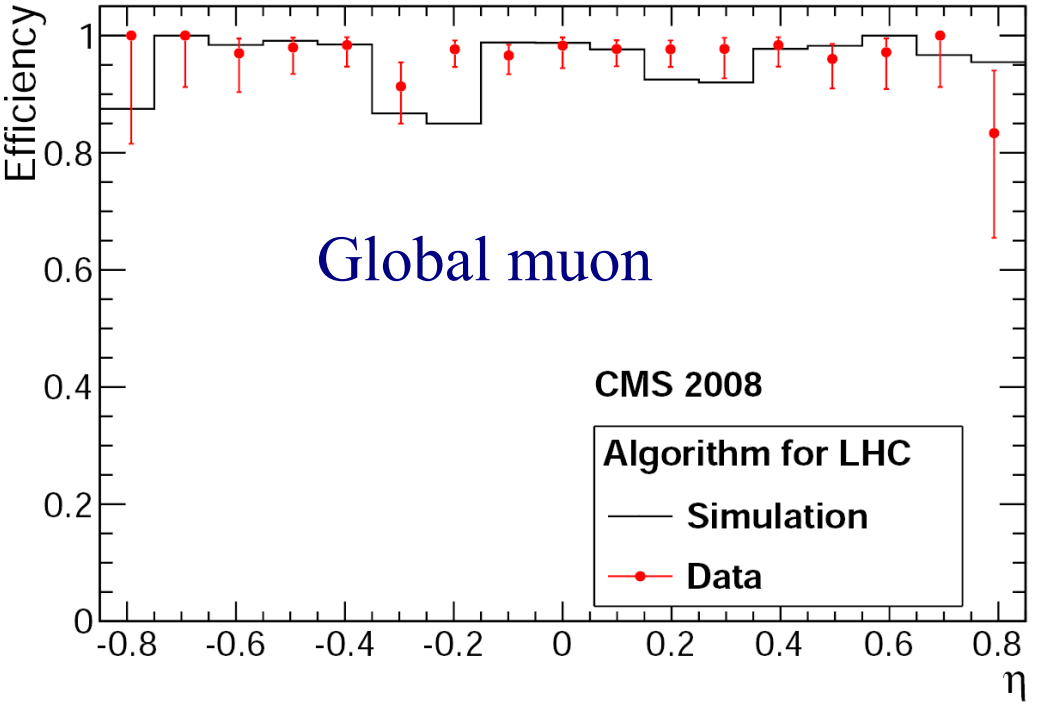






Data-MC Comparison for LHC Algorithms



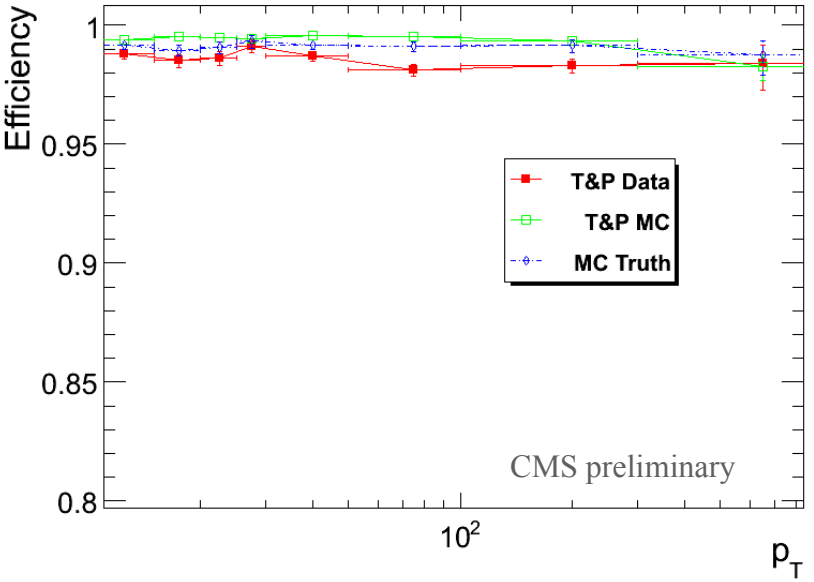


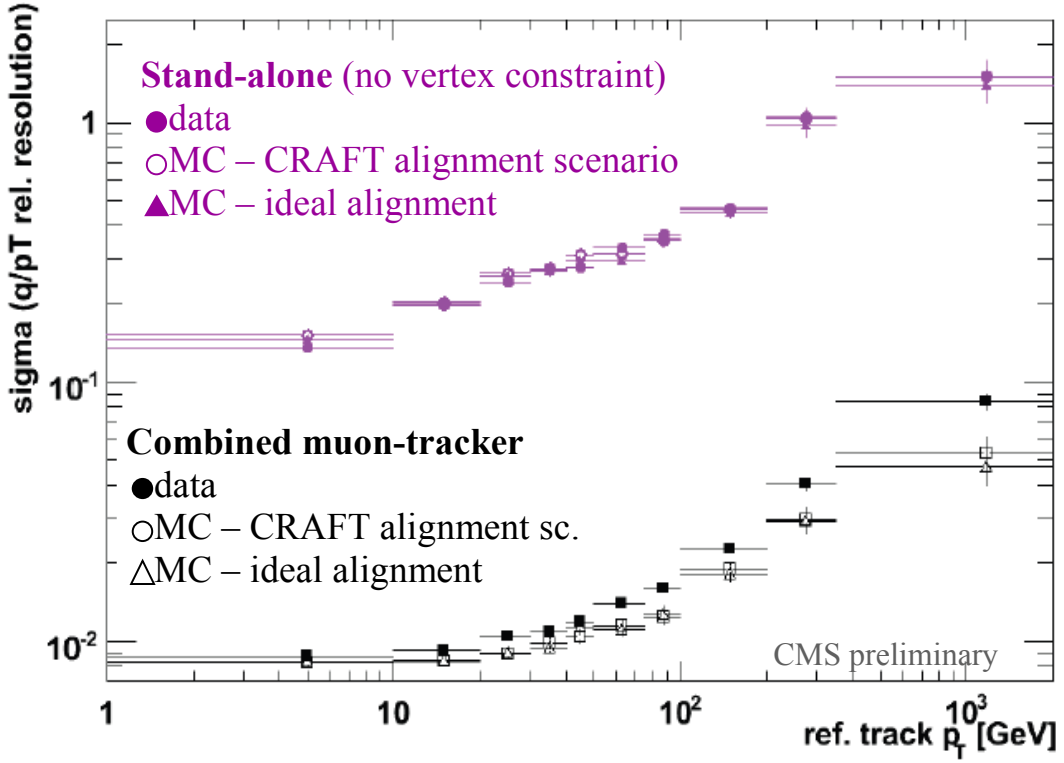
- Efficiencies of muon reconstruction algorithms dedicated for collisions in cosmic data and in p-p simulation

Resolutions on Cosmics

Stand-alone reconstruction efficiency

- For 1-leg reconstruction, given trigger and a good-quality tracker track (tag)
- >98%; well described by MC



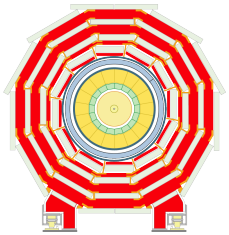


Resolution for collision-like cosmics

- By comparison of top and bottom legs:

$$R(q/p_T) = \frac{(q/p_T)^{\text{upper}} - (q/p_T)^{\text{lower}}}{\sqrt{2}(q/p_T)^{\text{lower}}},$$

- Good agreement with MC
  - MC misalignment scenario slightly too optimistic at high p_T

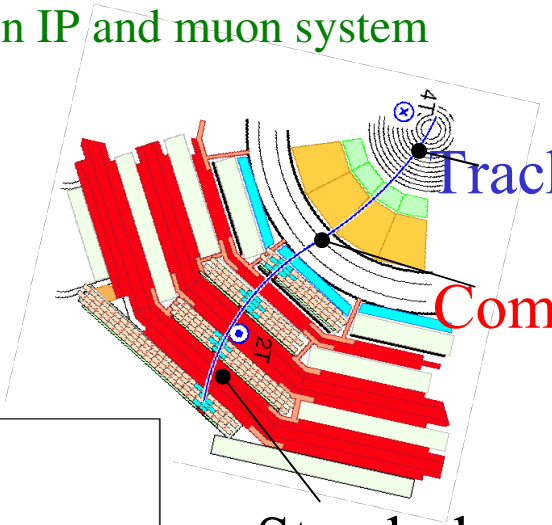


Particle Flow

- The particle-flow algorithm aims at providing a global event description at the level of individually reconstructed particles
- The reconstructed and identified individual particle list includes muons, electrons, photons, charged hadrons, stable and unstable neutral hadrons
- The complete list of particles may then be used to derive composite physics object, such as clustering into jets

Muon Track Reconstruction

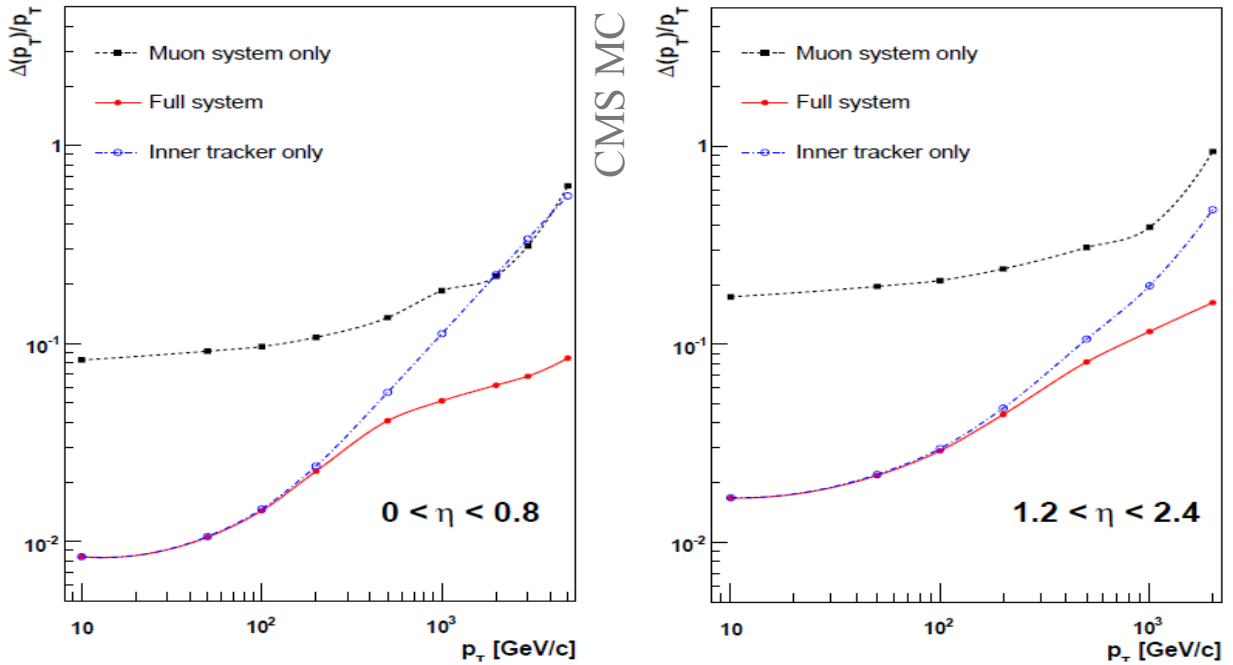
- The muon spectrometer provides a "stand-alone" measurement
  - independent from the inner tracker
  - for collision muons, can profit of large $\int B\mathrm{d}L$ between IP and muon system (vertex constraint)
- Inner tracker dominates resolution up to 200 GeV
  - Due to multiple scattering in the iron
- Above 200 GeV, improvement from combined muon-tracker fit



Tracker track

Combined fit

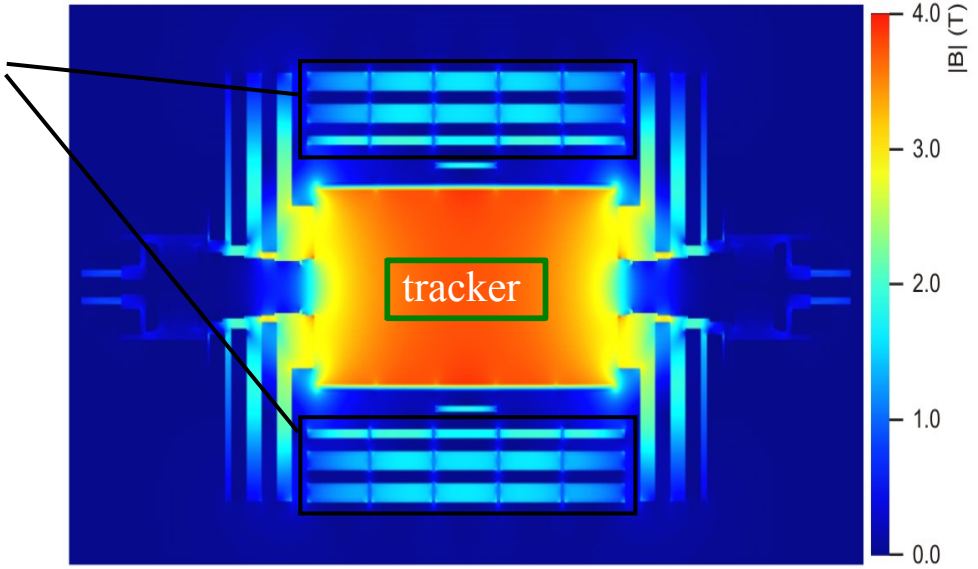
Stand-alone muon track

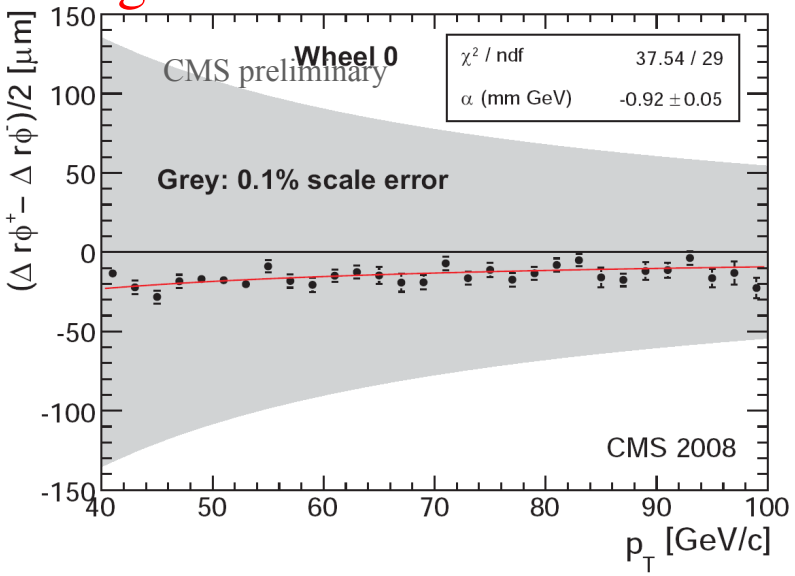


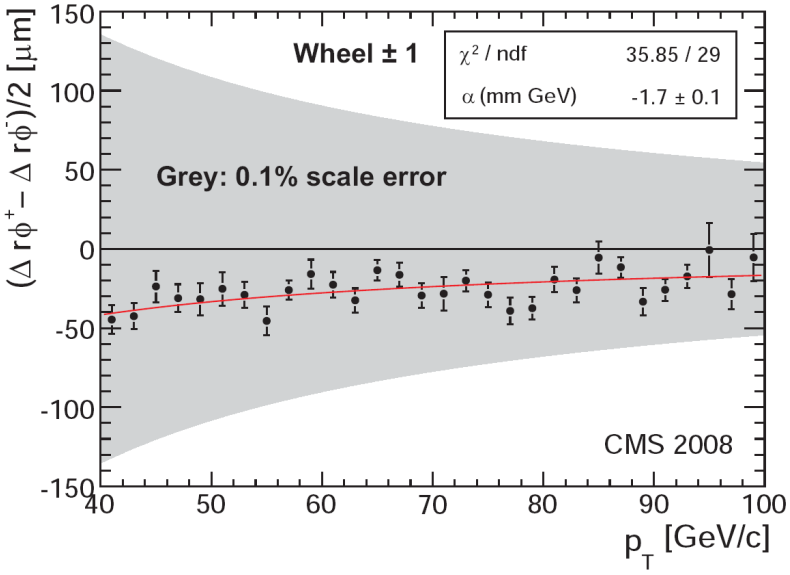
Magnetic Field Map

Measurement of the B field in the yoke by comparison of measured track bending and prediction from track extrapolation

- **Using the tracker track as a reference** (field within the solenoid mapped to better than 0.5% in 2006)
- Revealed a problem in the field map
- updated map + calibration with data reproduces bending to ~3% in the barrel yoke







Trigger Setup

- Cosmics setup:
  - Trigger on full acceptance
  - DT trigger – any coincidence between two stations in the same or neighboring sector
  - CSC trigger – any segment in one station
  - RPC trigger – open roads but slightly pointing
- " LHC" setup:
  - Trigger only on bottom half of muon detectors (avoid timing ambiguity top/bottom)
  - DT trigger – as before but with pointing roads
  - CSC trigger – coincidence of two stations with pointing roads
  - RPC trigger – as before (LHC like tightly pointing roads were not available!)

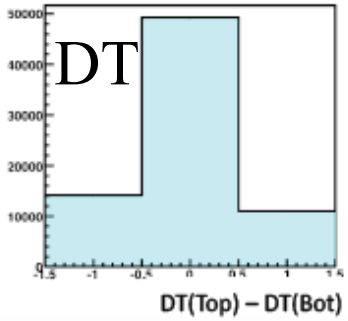
- The difference in RPC rates is only due to switch to bottom half only
- The difference between DT and RPC rates in the Cosmics setup is due to more selective RPC trigger towards pointing tracks – this is then opposite in the "LHC"-like setup where DT is more tight
- Difference between CSC and RPC endcap in " LHC" like is due to smaller acceptance of RPC endcap ($|eta| < 1.5$)
- Plots show stability of muon trigger components (absence of noise etc) which improved since CRAFT08 – e specially in the RPC case
- Gaps in the left plot are due to problems with 2 CSC FEDs, on the right ECAL FED problem after going to 50 kHz random triggers - recovered

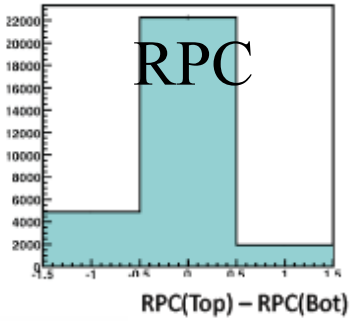
L1 Muon Trigger

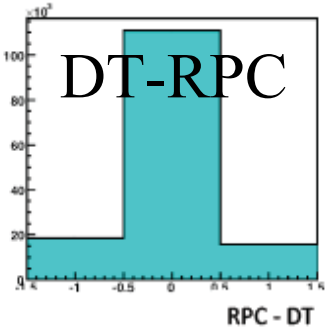
Relative Synchronization

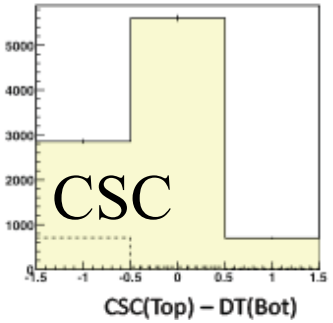
- Same BX id >90%
- life will be easier with collisions (expected 99%)

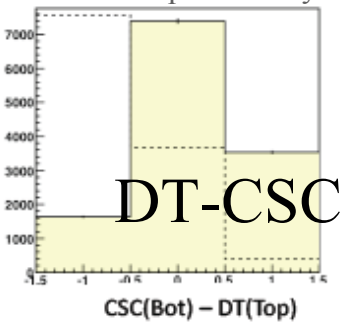
CMS preliminary









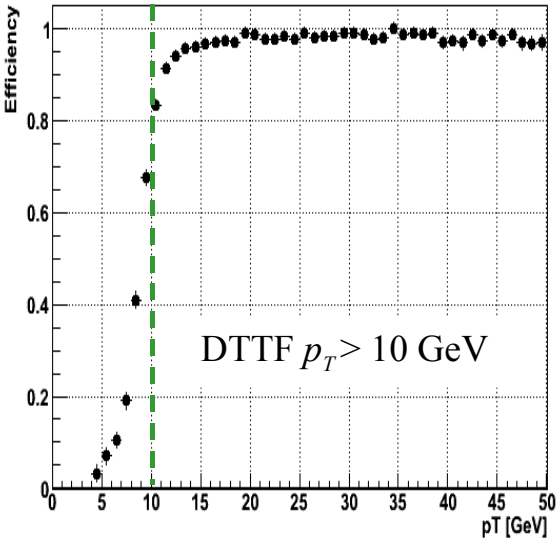


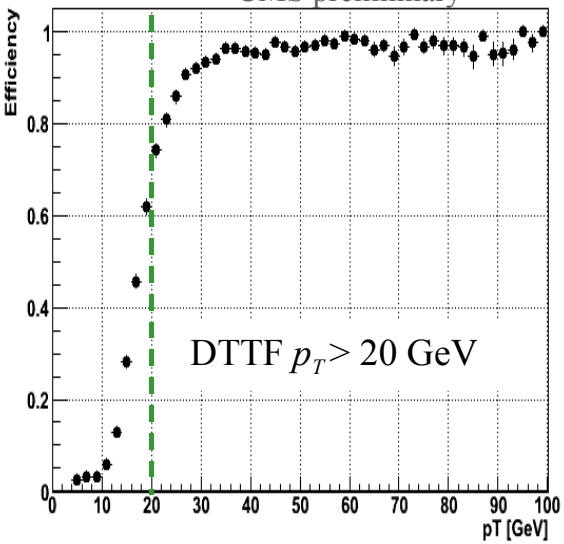
L1 and HLT menus deployed
System throttled to 100 kHz

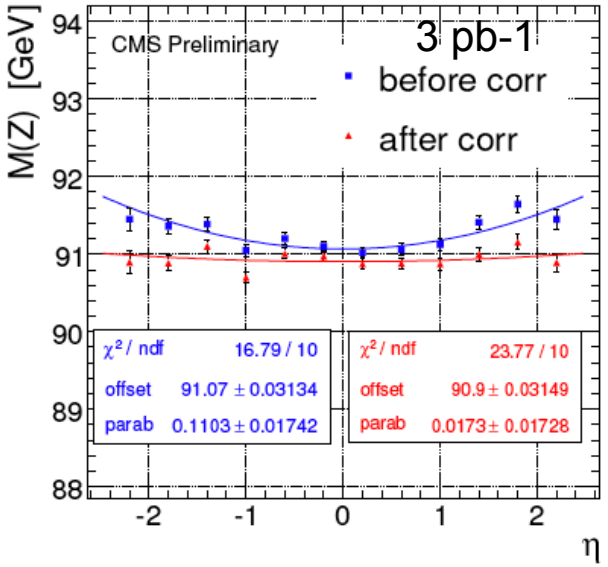
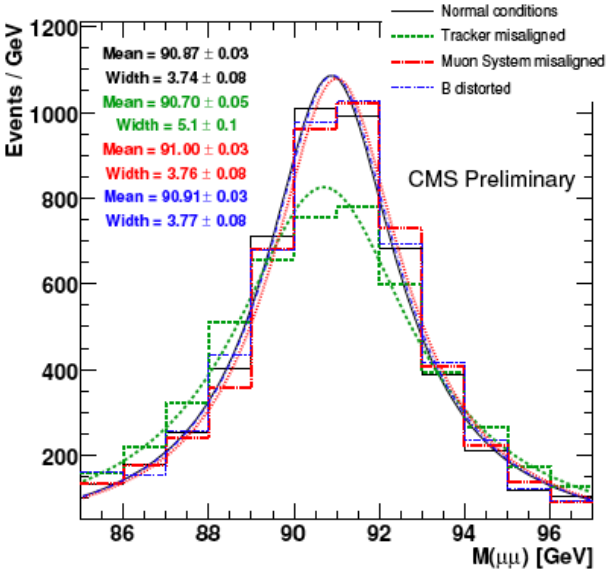
DT track finder turn-on curves

- Collision-like cosmics, bottom sectors, p_T given by tracker track

CMS preliminary





Lepton Commissioning with Early Data

- Understand lepton **trigger**
- Understand building blocks of lepton **reconstruction**
- Detector **calibration & alignment**
- **Electromagnetic & momentum scale**
- **Comparison with MC**: ID variables for signal and backgrounds, efficiencies, fakes, material budget