Measurement of the cosmic muon charge asymmetry in CMS

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Introduction

CMS experiment at CERN: ambitious physics program, from the measurement of Standard Model (SM) parameters to the discovery of new physics beyond the SM.

Potential of CMS to cover this physics programme: established by detailed studies based on simulated events (latest calculations, state-of-the-art Monte Carlo programs).

Since 2006, CMS has collected large amounts of data from cosmic ray muons, whose analysis has allowed for commissioning both the CMS detector and the reconstruction and analysis software.

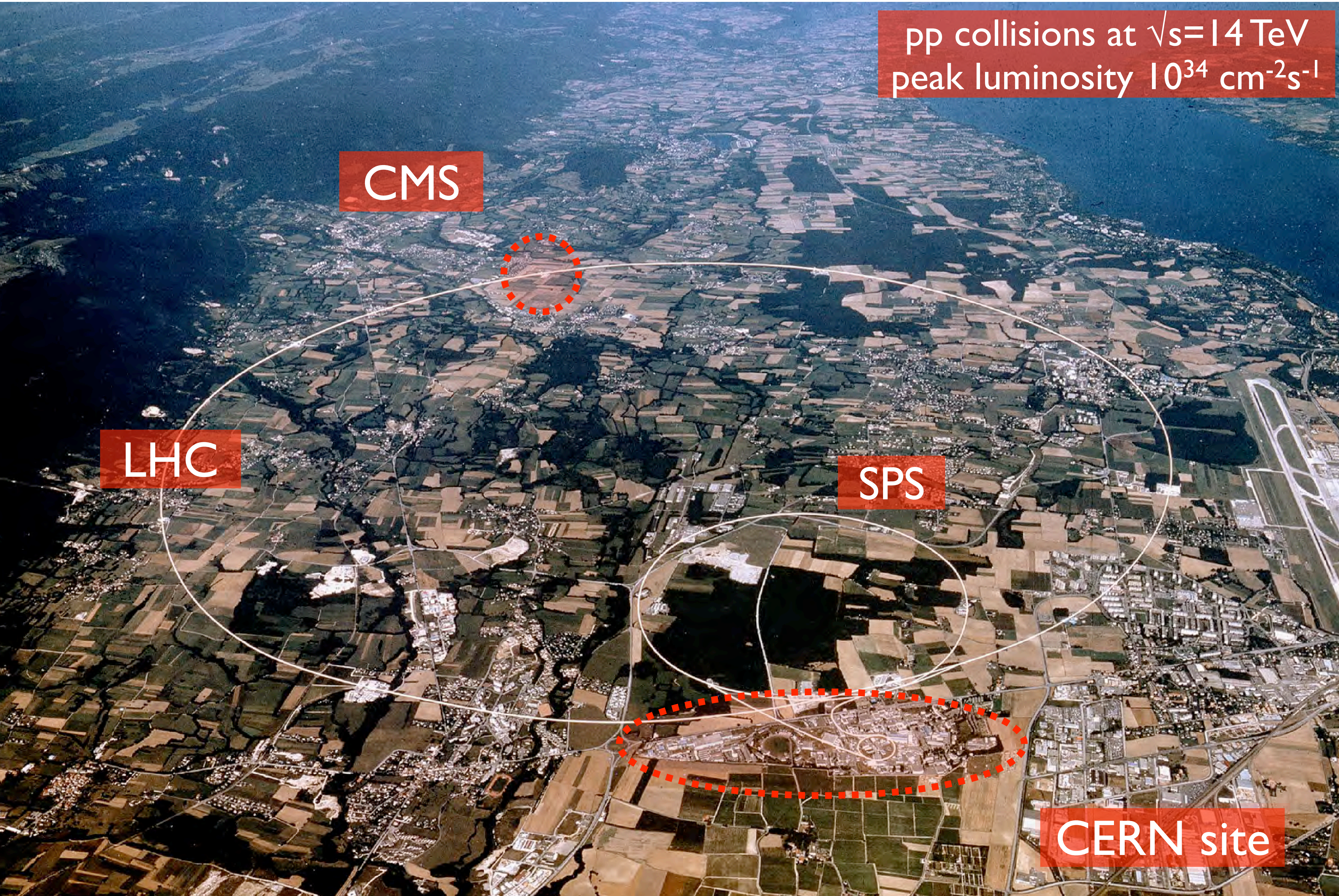
Introduction II

Measurement of the ratio of positive- to negative-charge cosmic muons, *charge asymmetry*, as a function of the muon momentum, using the data collected by CMS.

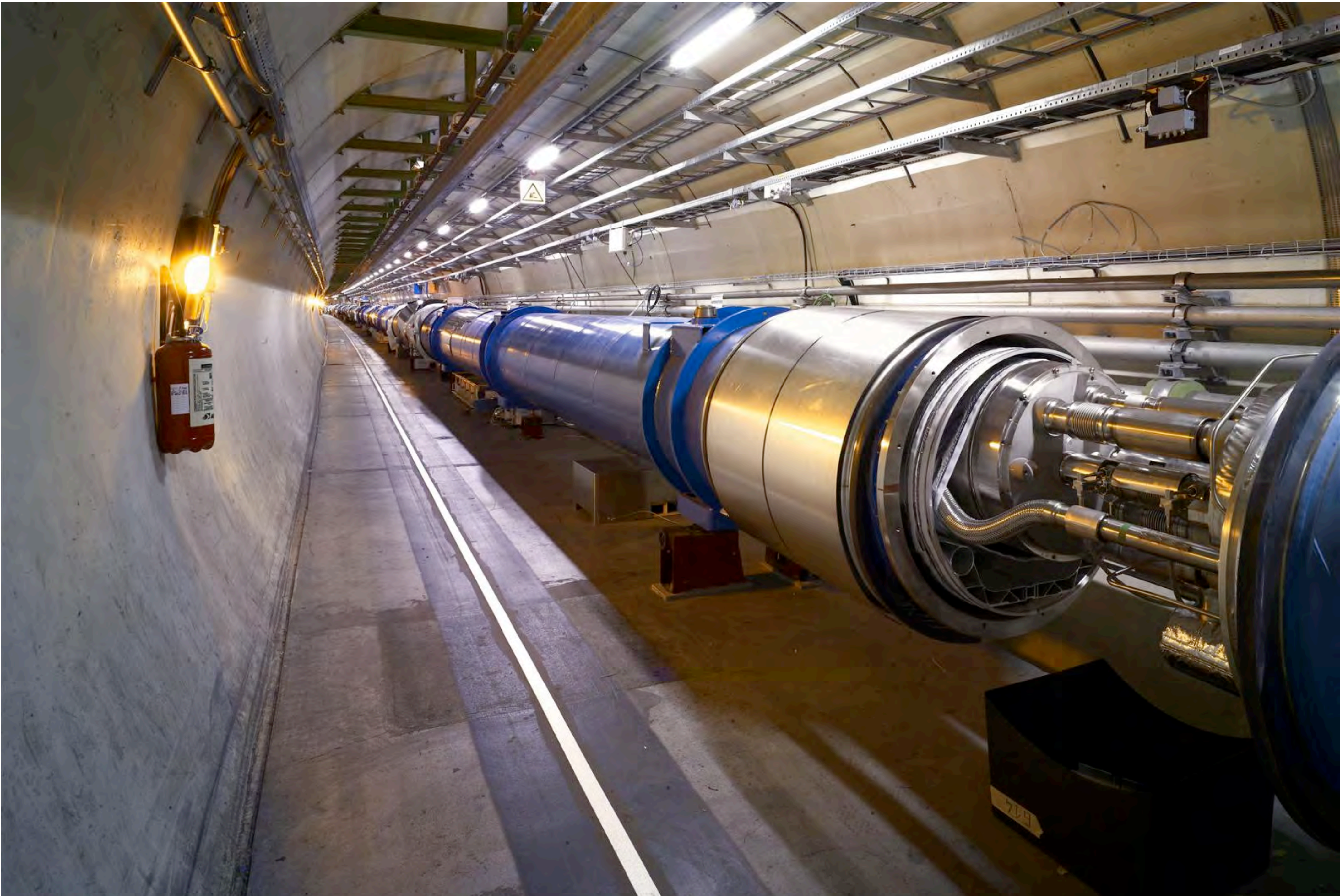
The analysis of cosmic muons is not part of the physics programme of CMS: it provides high quality measurements that probe the capabilities of our detector and reconstruction algorithms.

This is the first measurement of a physical parameter performed by the CMS experiment.

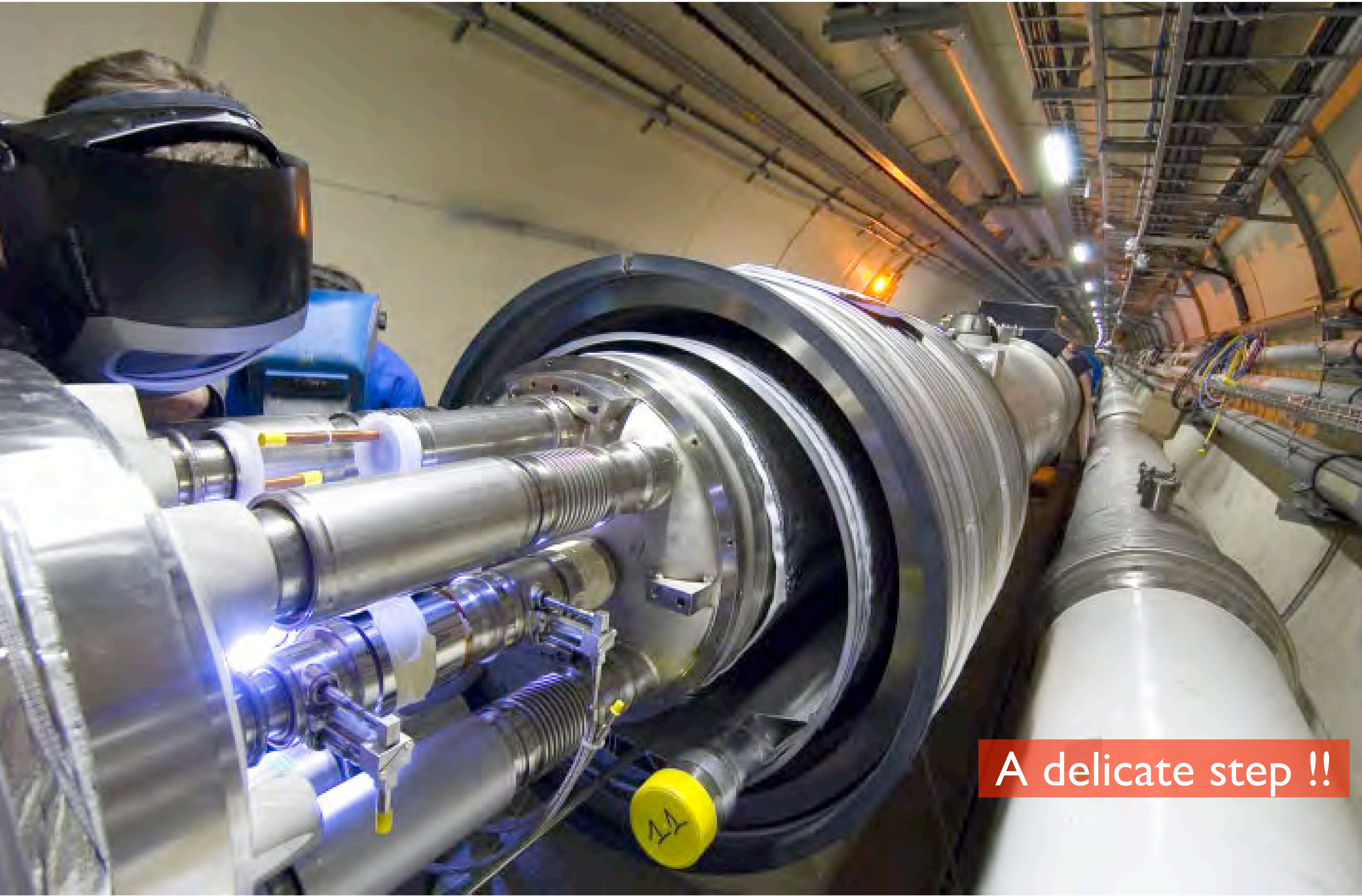
Setting the scene...



Large Hadron Collider



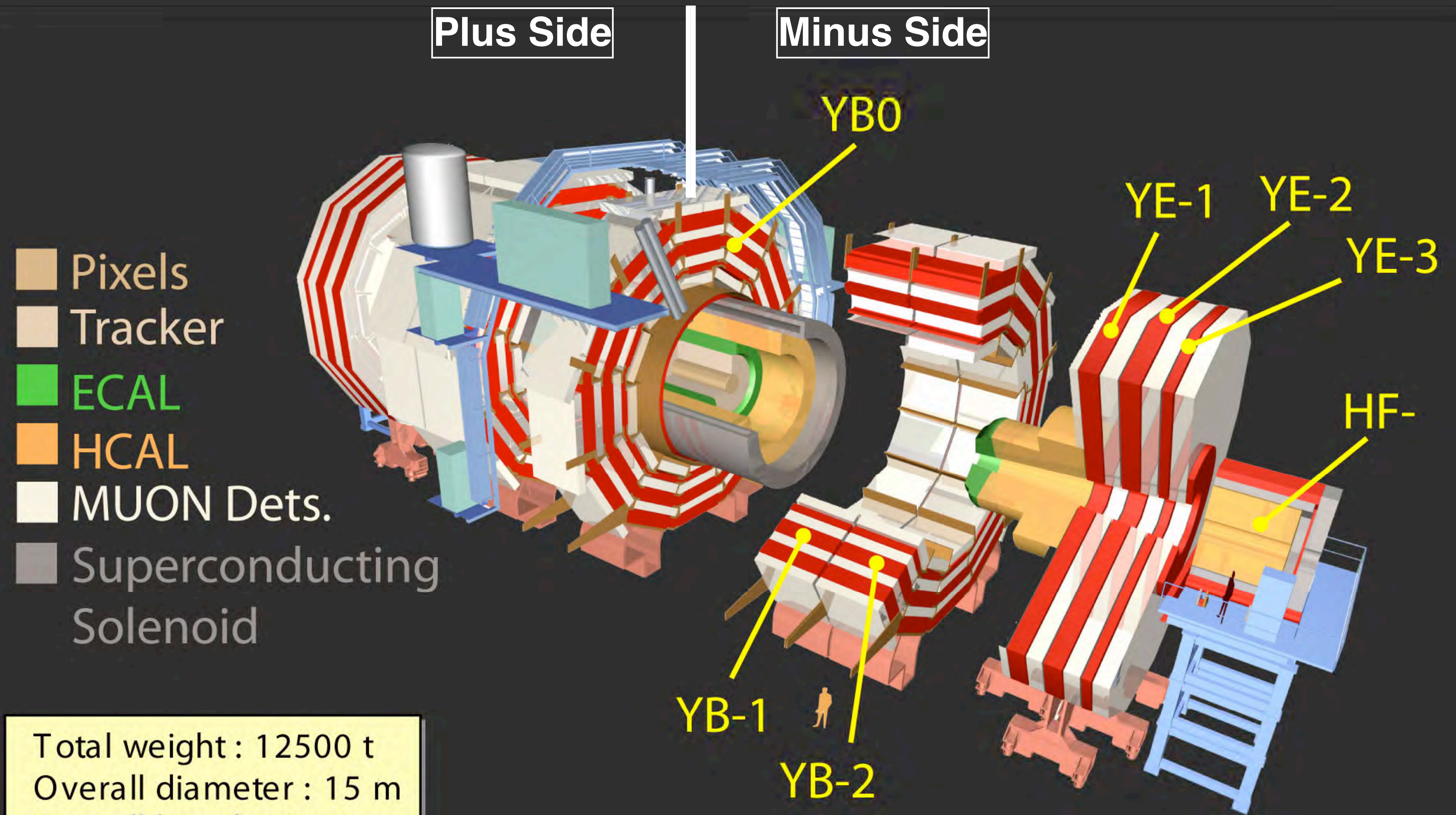
Connection of dipoles



Compact Muon Solenoid

- CMS is a huge 80 Mpixel "3D" (2x2D) digital camera (not impressive), spread over a 3700 m^3 volume, weighing 12500 Ton.
- Operating at B = 3.8 T, supplied by a super-conducting magnet (impressive).
- Very high precision in the pixel positions: from 20 to 200 μm.
- This camera works at 40 Mhz (this IS impressive too).

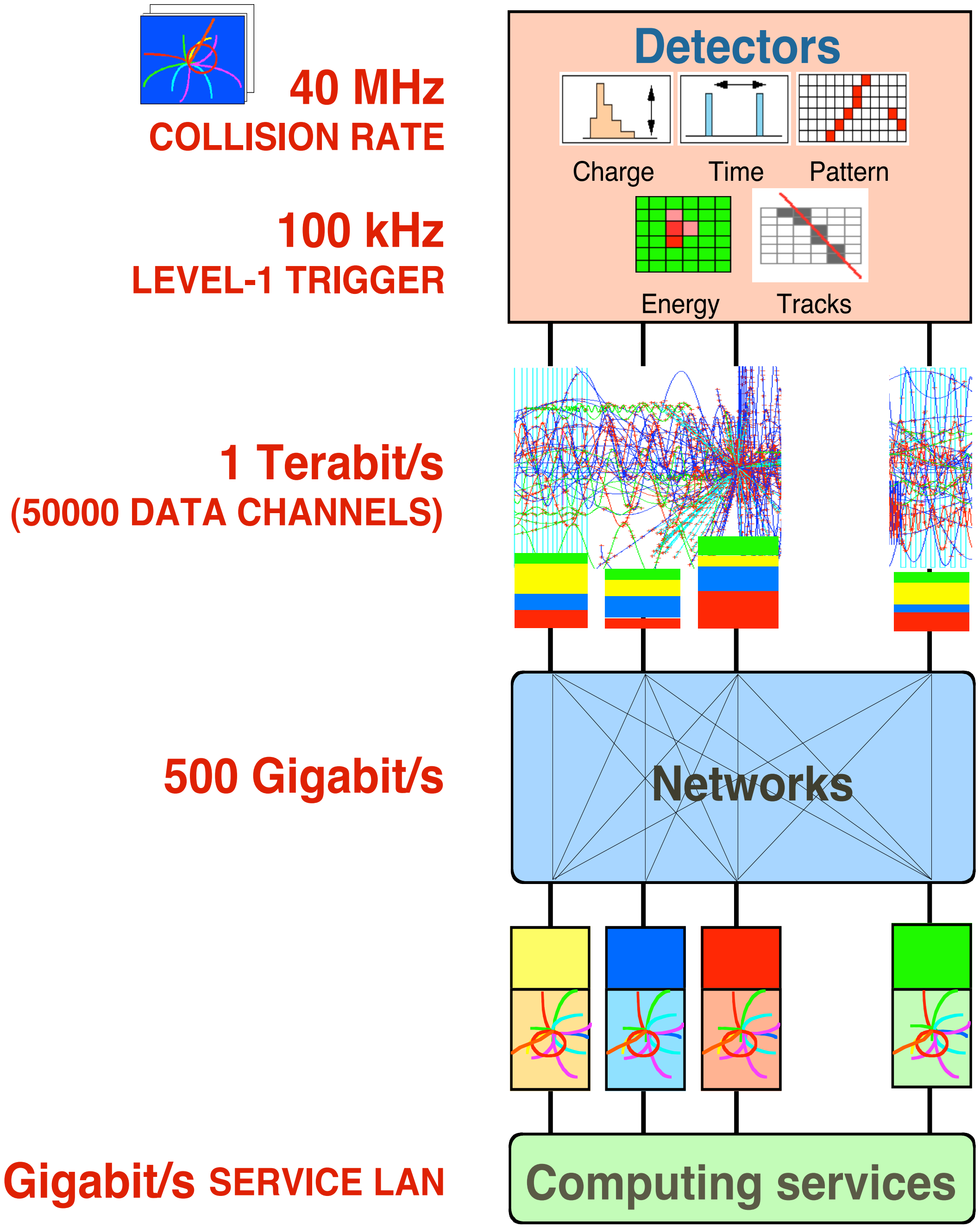
Schematic view of CMS



Total weight : 12500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

http://cms.cern.ch

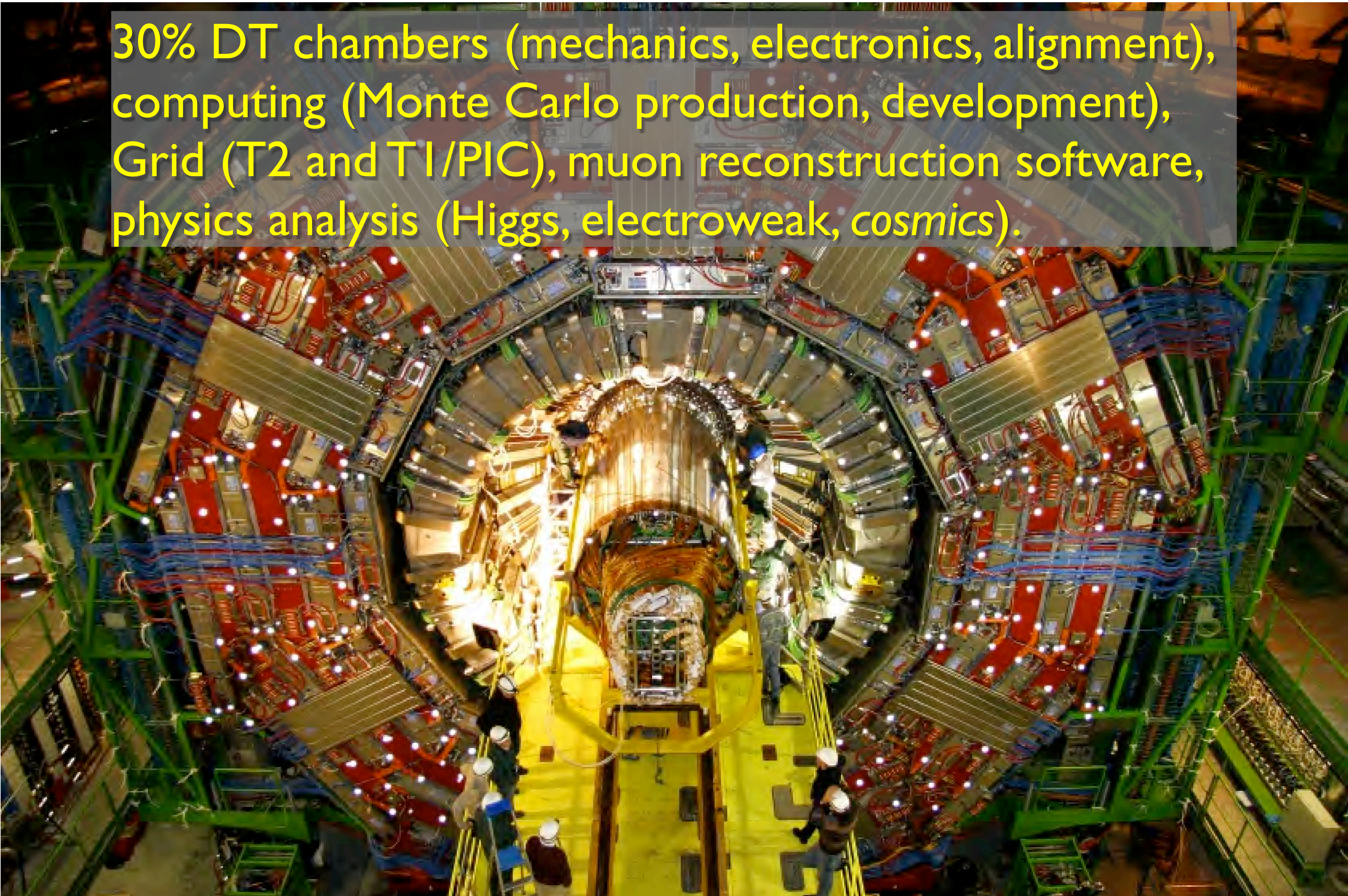
Data acquisition and trigger



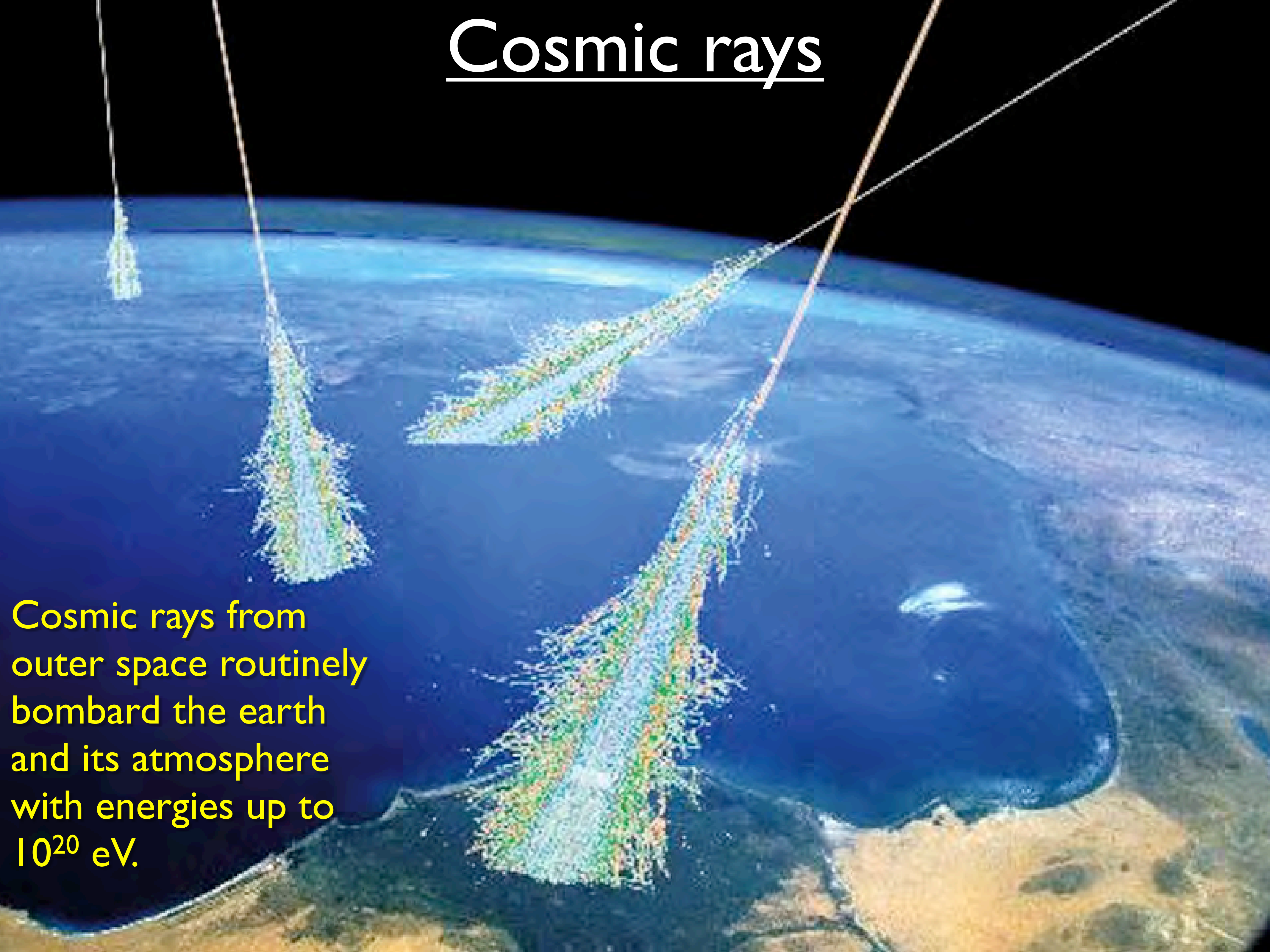
- Neither all the 80 Mpixel nor at 40 MHz go to "tape": 3 PB/s (Petabytes per second !!!)
- The trigger selects few hundred Hz of 1.5 MByte events, throughput ≈ 1 GB/s.
- At high luminosity, around 10 PB/year !!
- The trigger system is the *alma mater* of the experiment.

Contribution of CIEMAT

30% DT chambers (mechanics, electronics, alignment), computing (Monte Carlo production, development), Grid (T2 and T1/PIC), muon reconstruction software, physics analysis (Higgs, electroweak, *cosmics*).



Cosmic rays



Cosmic rays from outer space routinely bombard the earth and its atmosphere with energies up to 10^{20} eV.

Atmospheric Muons

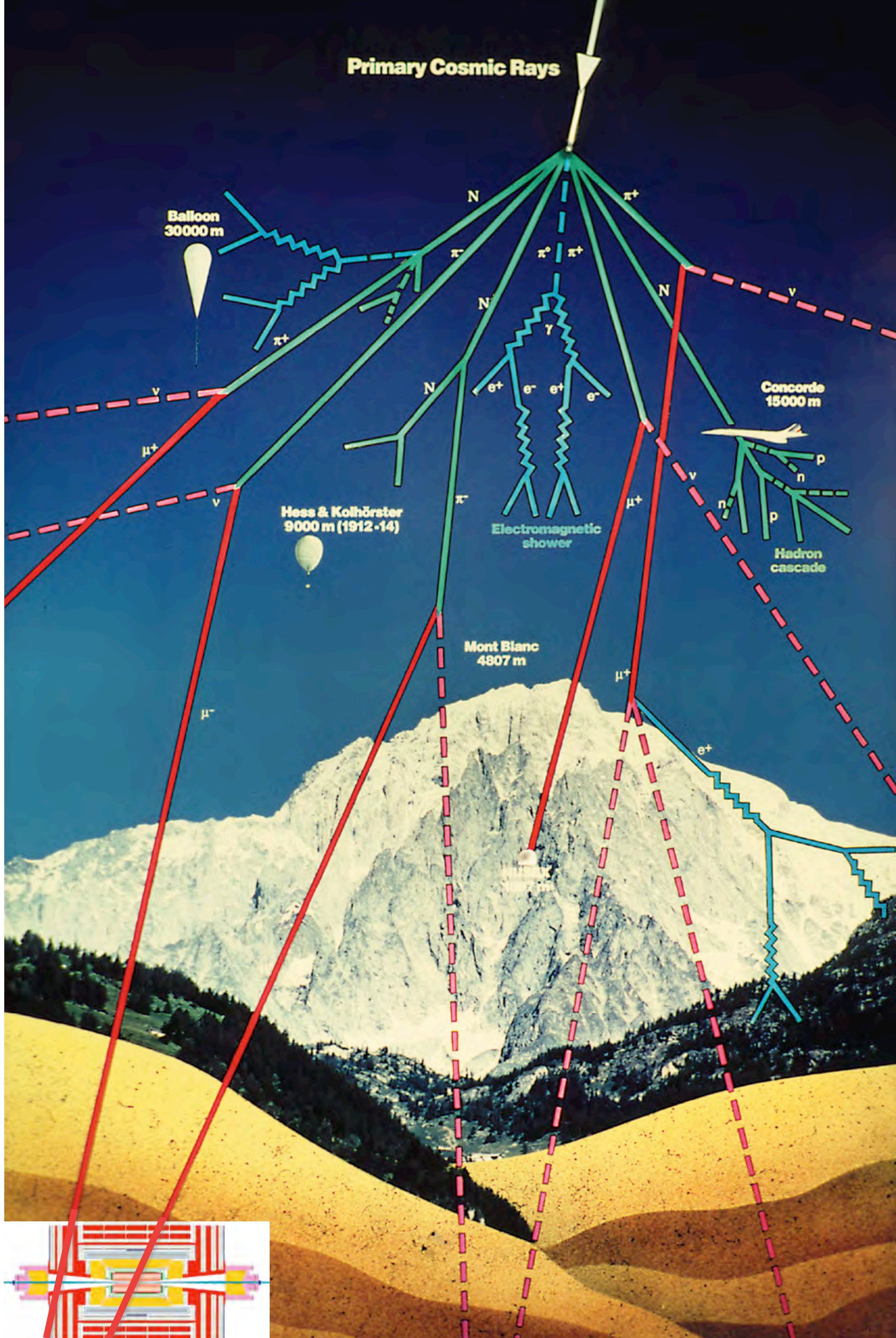
Stem from cosmic ray showers, produced via interactions of high-energy cosmic-ray particles (nuclei), entering the upper layers of the atmosphere, with air nuclei:

$(p, He, ..., Fe) \rightarrow$ hadrons, $e^{\pm}\gamma$

$(\pi^{\pm}, K^{\pm}) \rightarrow \mu^{\pm}\, \nu_{\mu}\, (\bar{\nu}_{\mu})$ and

$\mu^{\pm} \rightarrow e^{\pm}\, \nu_{e}\, \bar{\nu}_{\mu}\, (\bar{\nu}_{e}\, \nu_{\mu})$

Long-lived muons cross the overburden and reach CMS.



Cosmic muon charge ratio

Schreiner, Goodman (MINOS), arXiv:0706.0538v1 [hep-ex]

- Muon energy spectrum underground (vertical muons, $\cos\theta=1$):

$$\frac{[dN]}{[dE_\mu]} = A\left\{\frac{1}{1+\frac{1.1E_\mu\cos\theta}{\epsilon_\pi}} + \frac{0.054}{1+\frac{1.1E_\mu\cos\theta}{\epsilon_K}}\right\} \qquad A \equiv \frac{0.14E_\mu^{-2.7}}{\text{cm}^2\ \text{s sr GeV}}$$

- Both π and K contribute, ϵ is the energy where the probability of meson interaction and decay are equal: ϵ_π = 115 GeV and ϵ_K = 850 GeV.

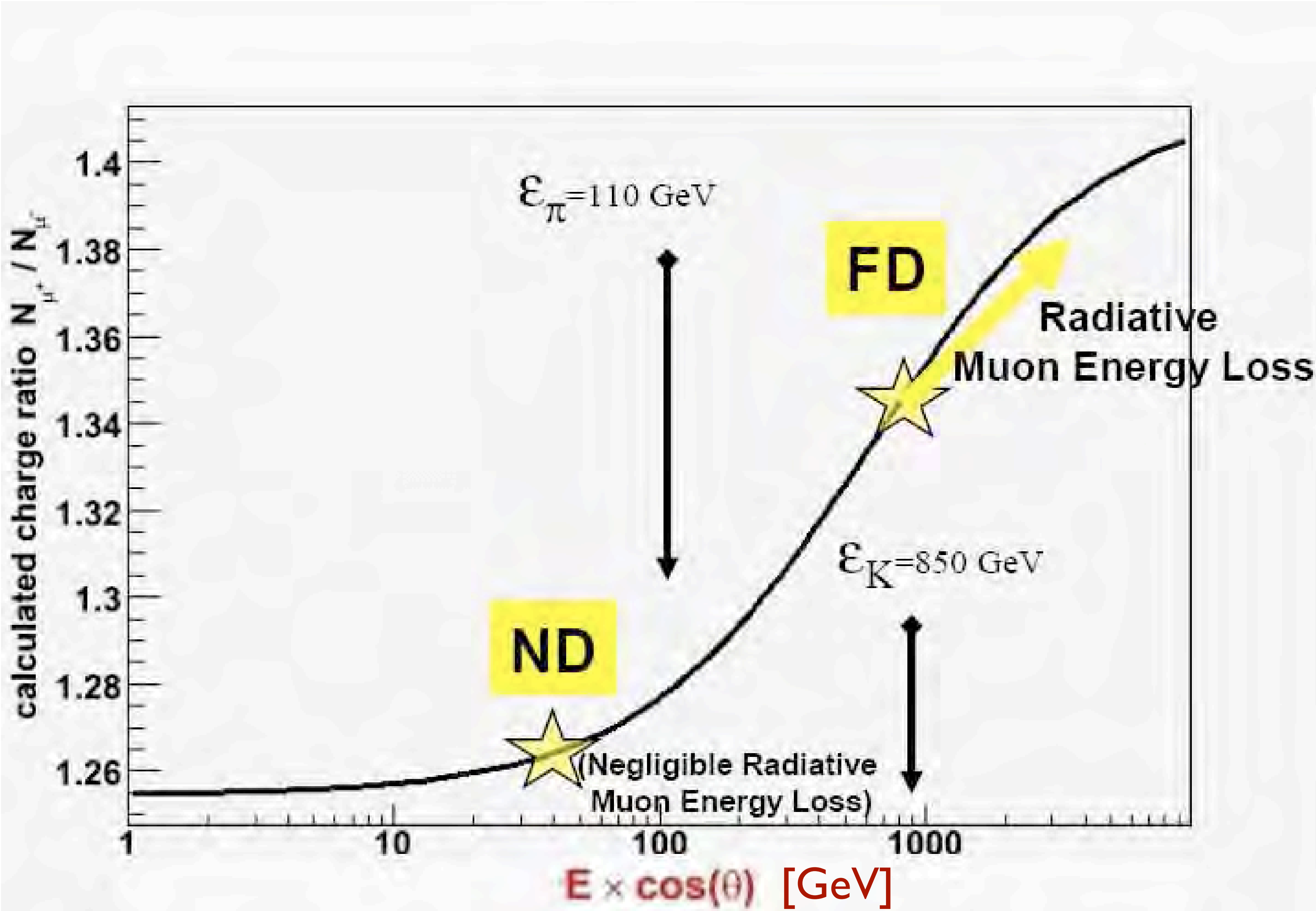
- Generalizing for μ^+ and μ^-, the measured charge ratio on surface is:

$$\frac{N^{\mu^+}}{N^{\mu^-}} = \left\{\frac{f_\pi}{1+\frac{1.1E_{\mu^+}\cos\theta}{115\ \text{GeV}}} + \frac{0.054\times f_K}{1+\frac{1.1E_{\mu^+}\cos\theta}{850\ \text{GeV}}}\right\} / \left\{\frac{1-f_\pi}{1+\frac{1.1E_{\mu^-}\cos\theta}{115\ \text{GeV}}} + \frac{0.054\times(1-f_K)}{1+\frac{1.1E_{\mu^-}\cos\theta}{850\ \text{GeV}}}\right\}$$

- From L3+C, f_π = 0.555(2) and f_K = 0.667(7). These values imply the muon charge asymmetry induced by π and K is

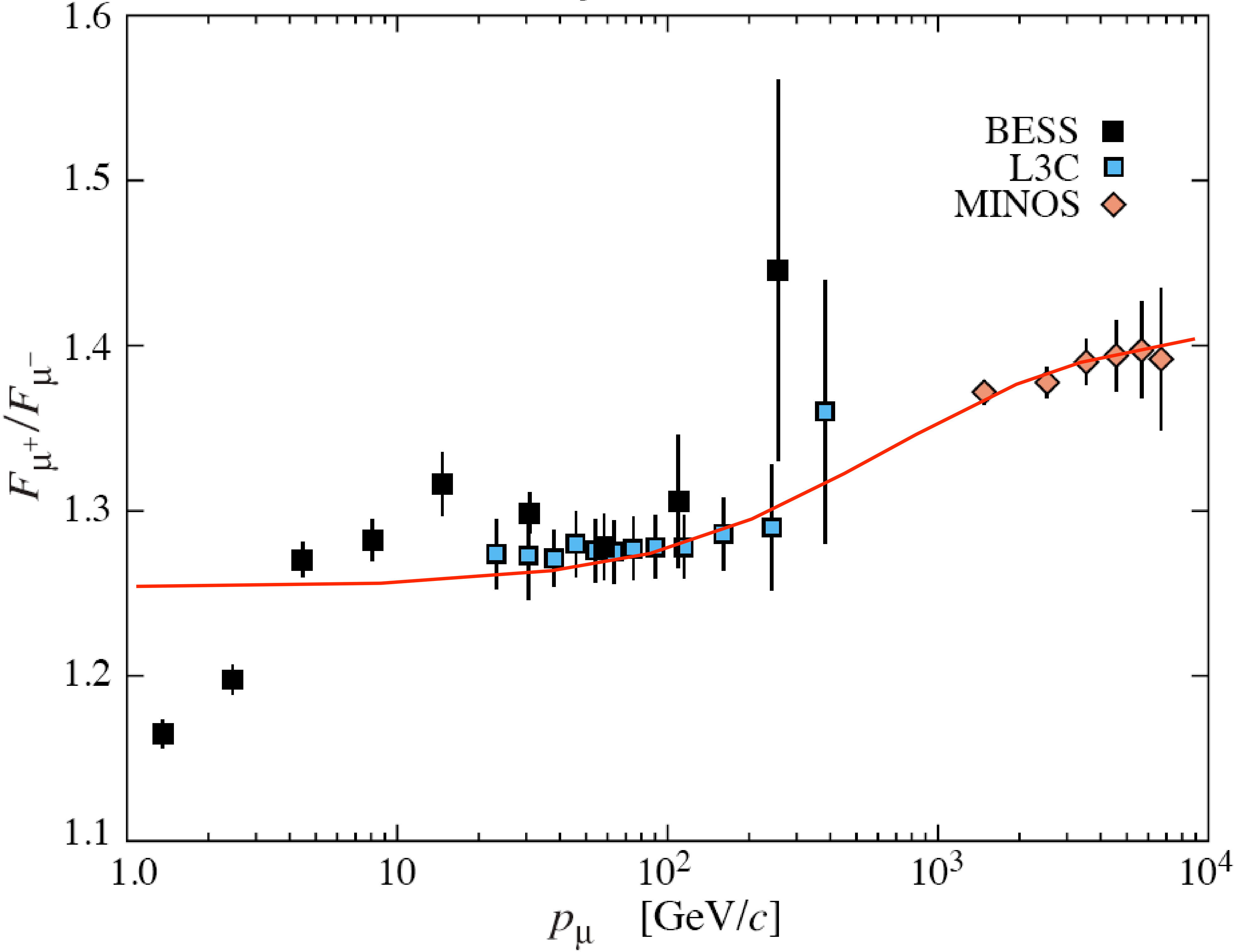
$$r_\pi = f_\pi / (1-f_\pi) = 1.25 \quad \text{and} \quad r_K = f_K / (1-f_K) = 2$$

Cosmic muon charge ratio



Schreiner, Goodman (MINOS), arXiv:0706.0538v1 [hep-ex]

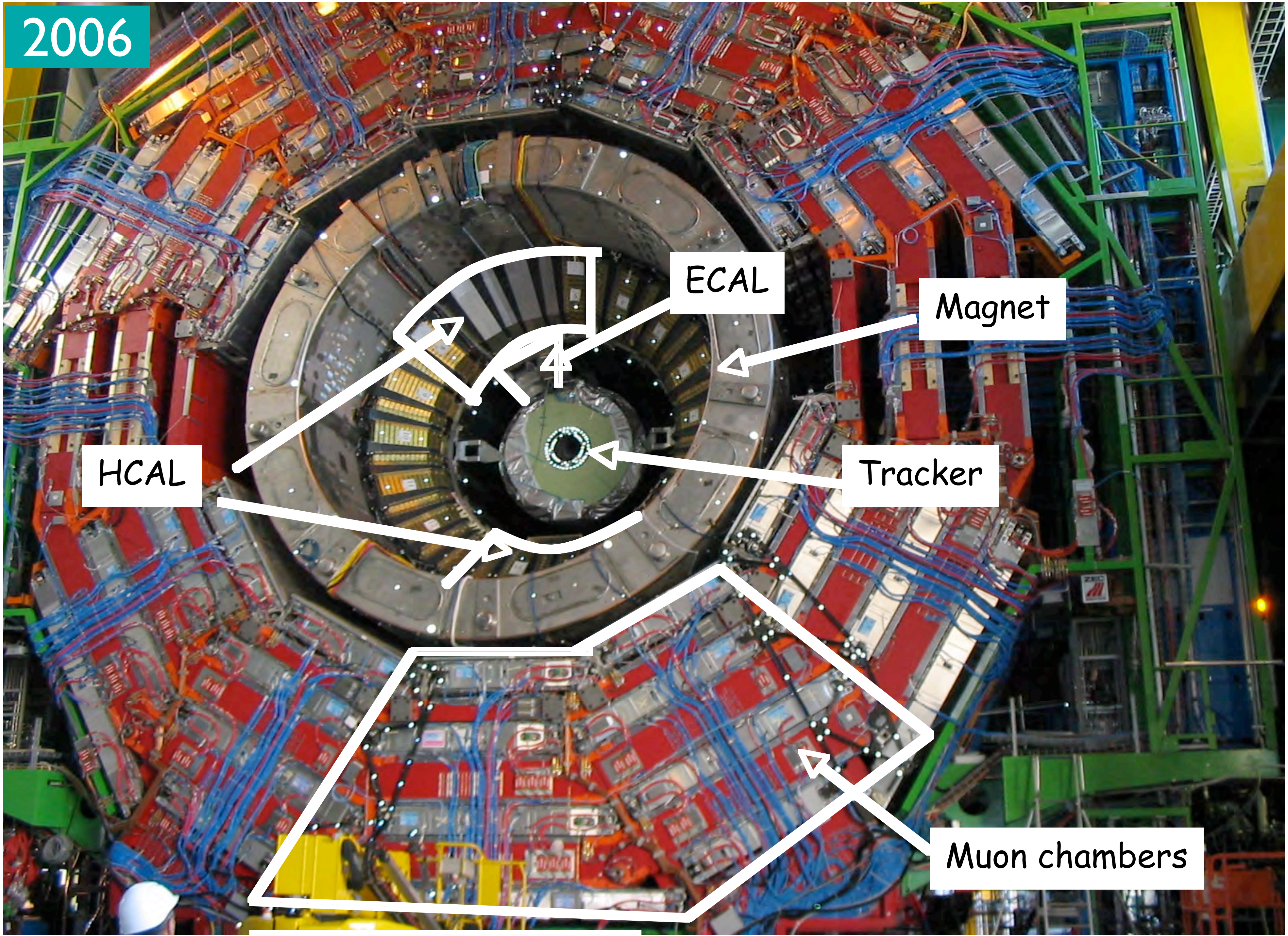
C. Amsler et al., Physics Letters B667, 1 (2008)



Measurement of the charge ratio in CMS

- In 2006, CMS is closed for the first time, on the *surface hall*.
- A major test of the magnet at 4 T is performed, the Magnet Test and Cosmic Challenge (MTCC):
  - testing and commissioning the superconducting magnet, measuring the magnetic field map,
  - data from cosmic muons are collected to test the whole system: detector, DAQ, alignment, event filtering and processing;
  - combined test of the sub-detectors available: 30° slice of CMS !!
- Use CMS data collected at the MTCC to perform a physics measurement: the cosmic muon charge asymmetry.

Experimental setup at MTCC

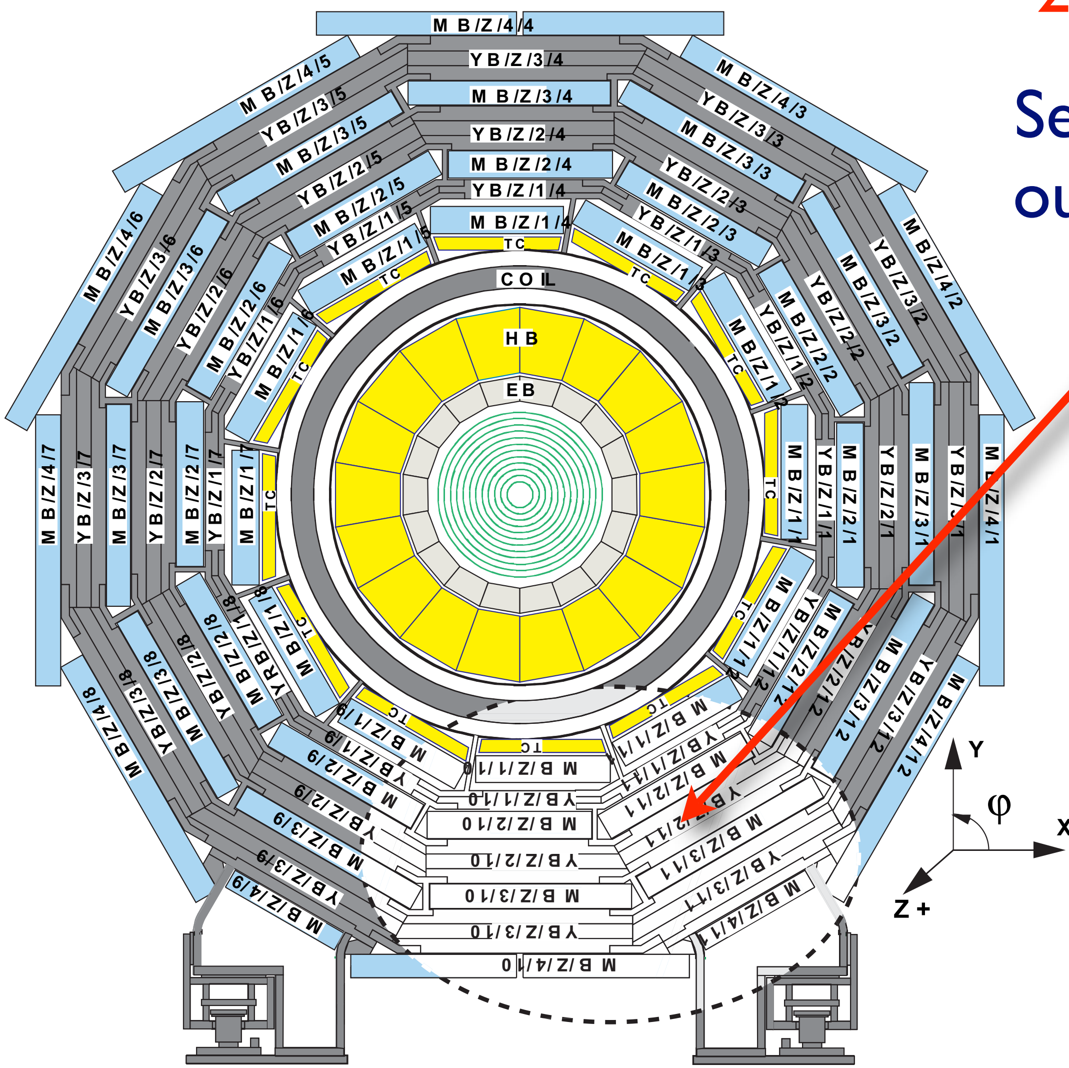


Schematic setup at MTCC

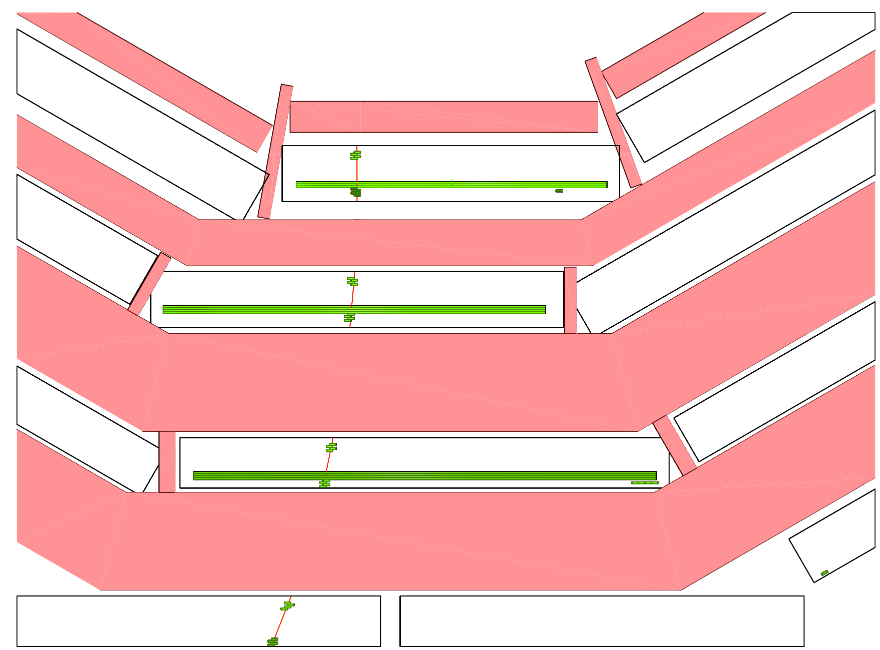
CMS detector on surface: high μ rate

25 Mevents on DTs, 15 M at B≥3.8 T

Sector 10 (sector 11 not used), in two out of five wheels (YB+1 and YB+2) of DT chambers



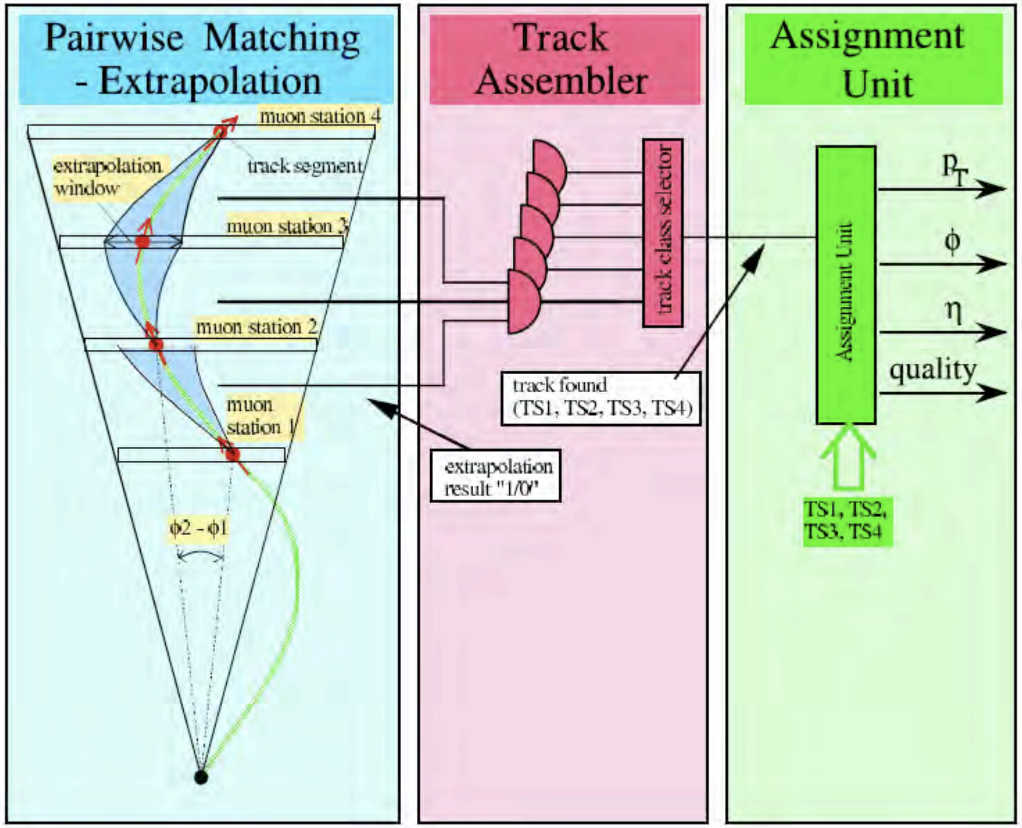
Barrel wheels YB+2 (S10, S11) and YB+1 (S10)



L1 muon trigger: DTTF

DT L1 muon trigger: creates good muon tracks from DT hits, sets muon trigger flag.

DTTF (DT track finder): sophisticated electronic system, finely segmented, creates muon tracks from DT segments (groups of hits) and assigns them physical parameters (p_T, ϕ, η). Best 4 tracks → Global Muon Trigger for further processing.



Performance: very high efficiency demonstrated at MTTC and CRAFT.

Designed, built and installed by the UAM group, the DTTF played a crucial role in the MTTC.

Data samples

Five runs with similar trigger conditions, ~ 9 M events.
Run at B=0 used for cross checks.

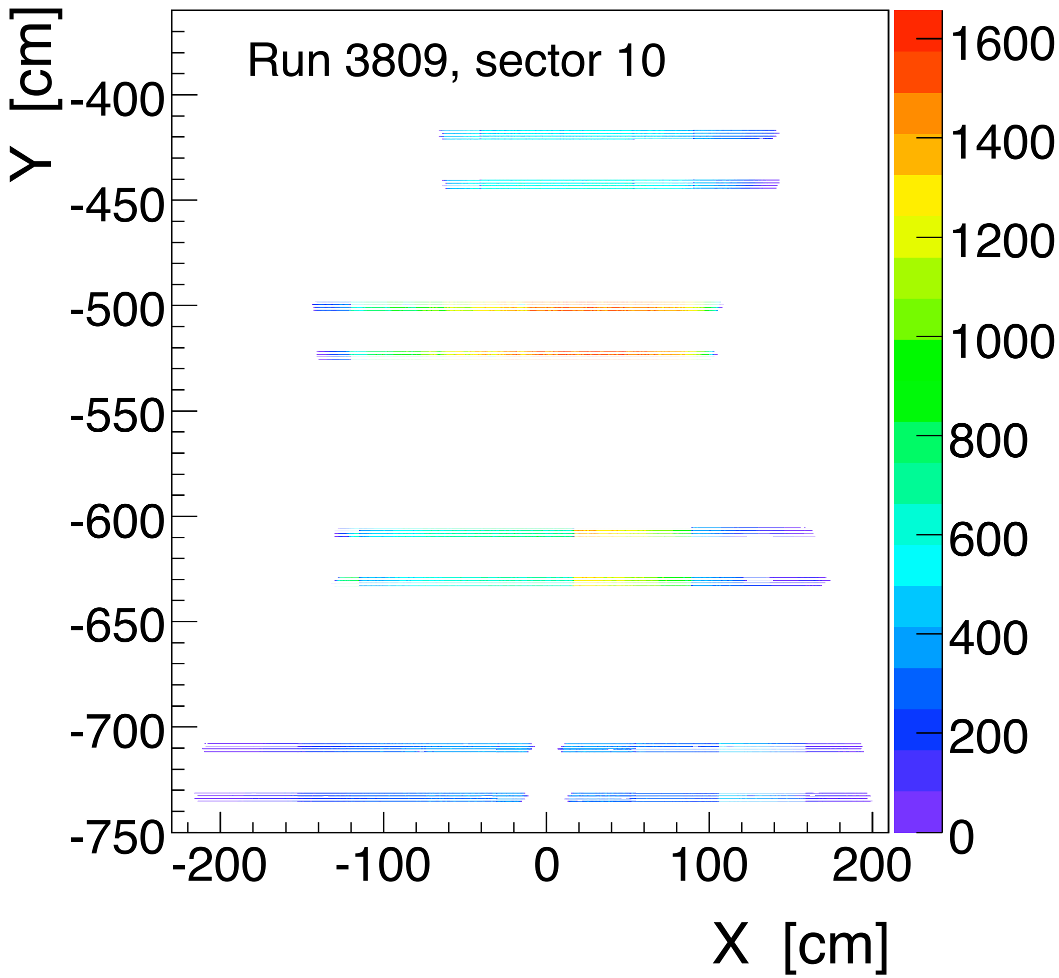
Run	B (T)	Trigger conditions	Events	DT trigger rate
2377	3.67	DT (MB2, MB3), CSC (first 160703 events); CSC, DT, RPC (from event 160704)	613 174	20 %
4045	3.8	DT (MB1, MB2, MB3) OR CSC	3 110 980	32 %
4406	4	DT (MB2, MB3) OR CSC	1 825 273	23 %
4407	4	DT (MB2, MB3) OR CSC	1 665 440	23 %
4409	4	DT (MB2, MB3) OR CSC	2 563 020	23 %
3809	0	any two DT chambers coincidence	611 407	99 %

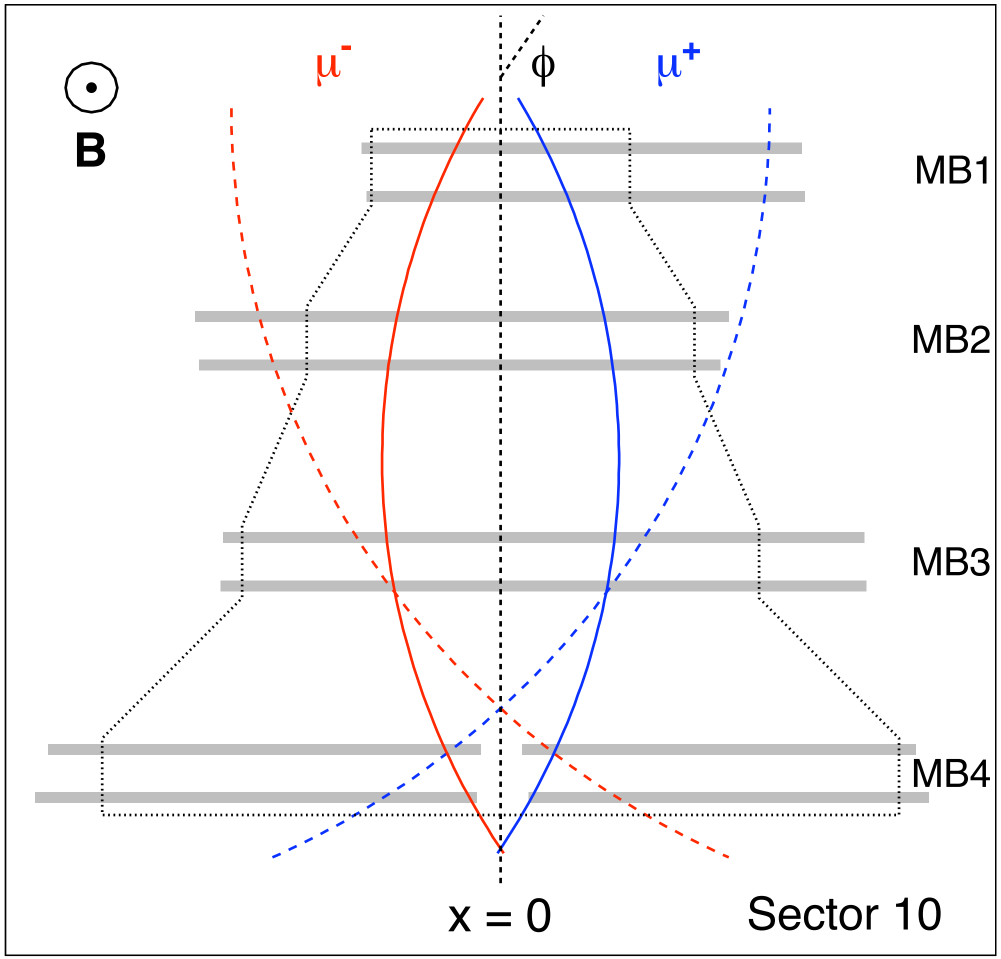
The DT trigger rate is normalized to the global trigger rate.

Symmetric fiducial geometry

Detector geometry asymmetric for μ^+ and μ^-: LR symmetry enforced

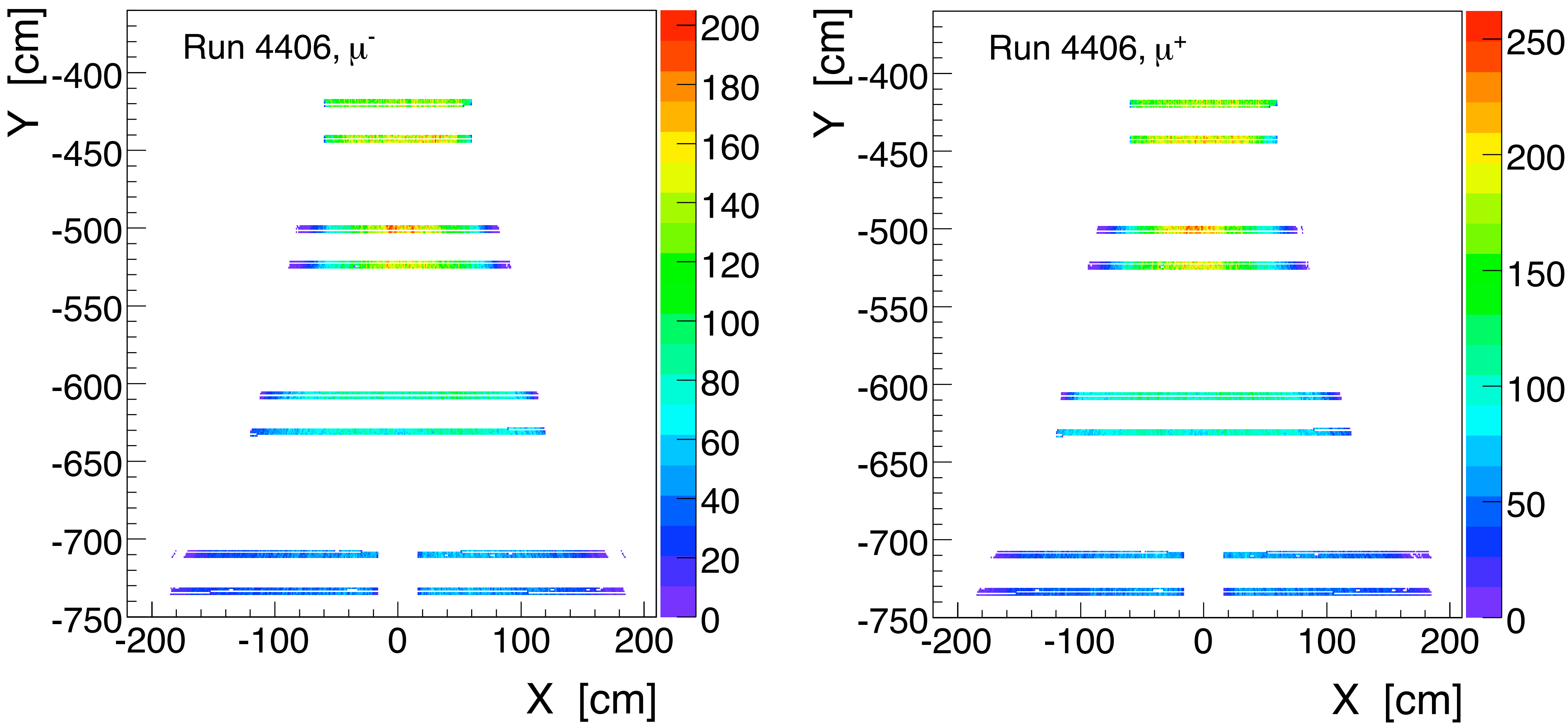
Key ingredient of the analysis (no MC efficiency corrections)





Event selection

Distribution of hits, global XY coordinate, after selection cuts (3 or 4 DT stations, sector 10, same wheel, p_T>3 GeV/c): illumination of DTs is LR symmetric



Selection efficiencies

PRESELECTION

Preselection		
Run	Events	Relative efficiency
2377	40 650	33 %
4045	280 165	28 %
4406	147 471	35 %
4407	135 209	35 %
4409	207 985	35 %
Total	811 480	29 %

Preselection, track quality criteria:

one muon track with ≥10 hits in DTs,
at least 6 in MB2 and MB3.

SELECTION

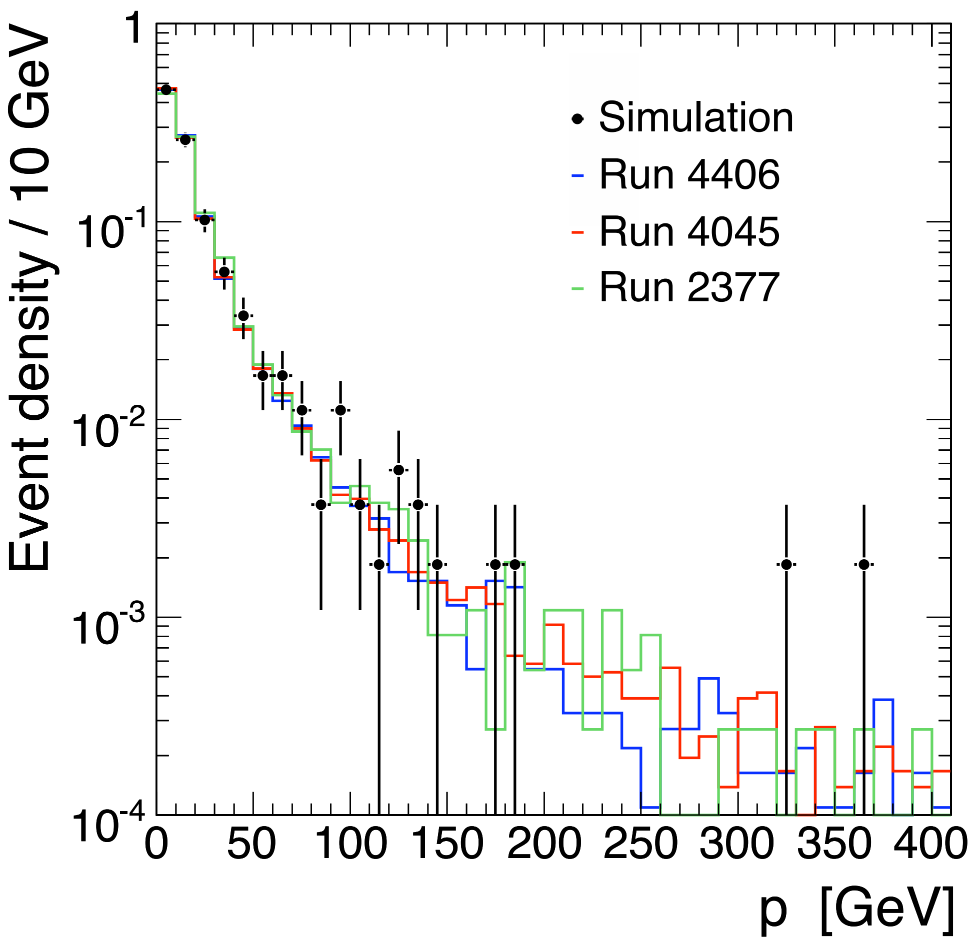
Selection			
Run	Events	Relative efficiency	Q/(Q+T)
2377	16 908	42 %	54.9 %
4045	123 916	44 %	78.5 %
4406	59 227	40 %	79.2 %
4407	54 028	40 %	79.2 %
4409	83 036	40 %	78.9 %
Total	337 115	42 %	77.6 %

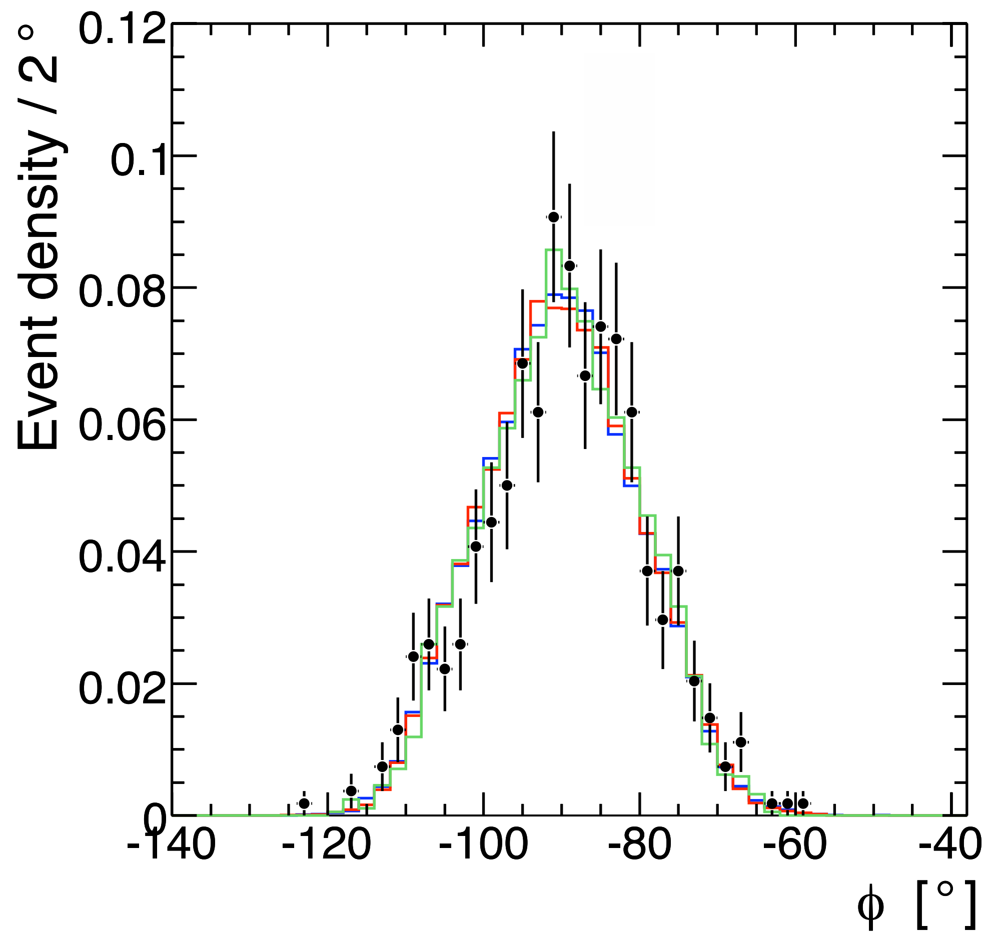
Selection, unbiased sample, high quality muons:

p_T>3 GeV/c,
3 or 4 segments in DTs, sector 10,
LR-symmetric fiducial region.

Distributions after selection

Track momentum and ϕ, after selection cuts are applied, for three data runs and for simulated events (very few).

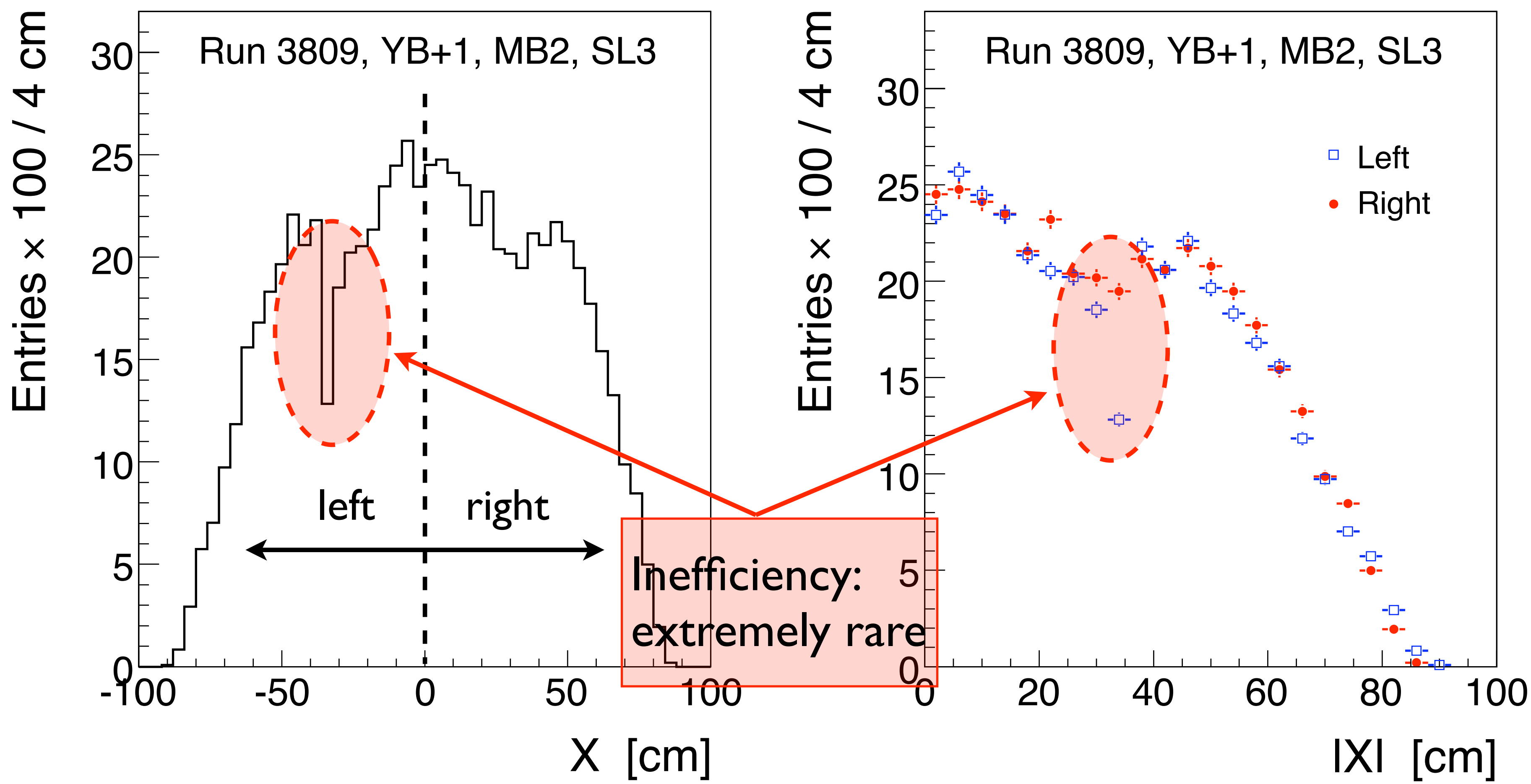




Detector performance

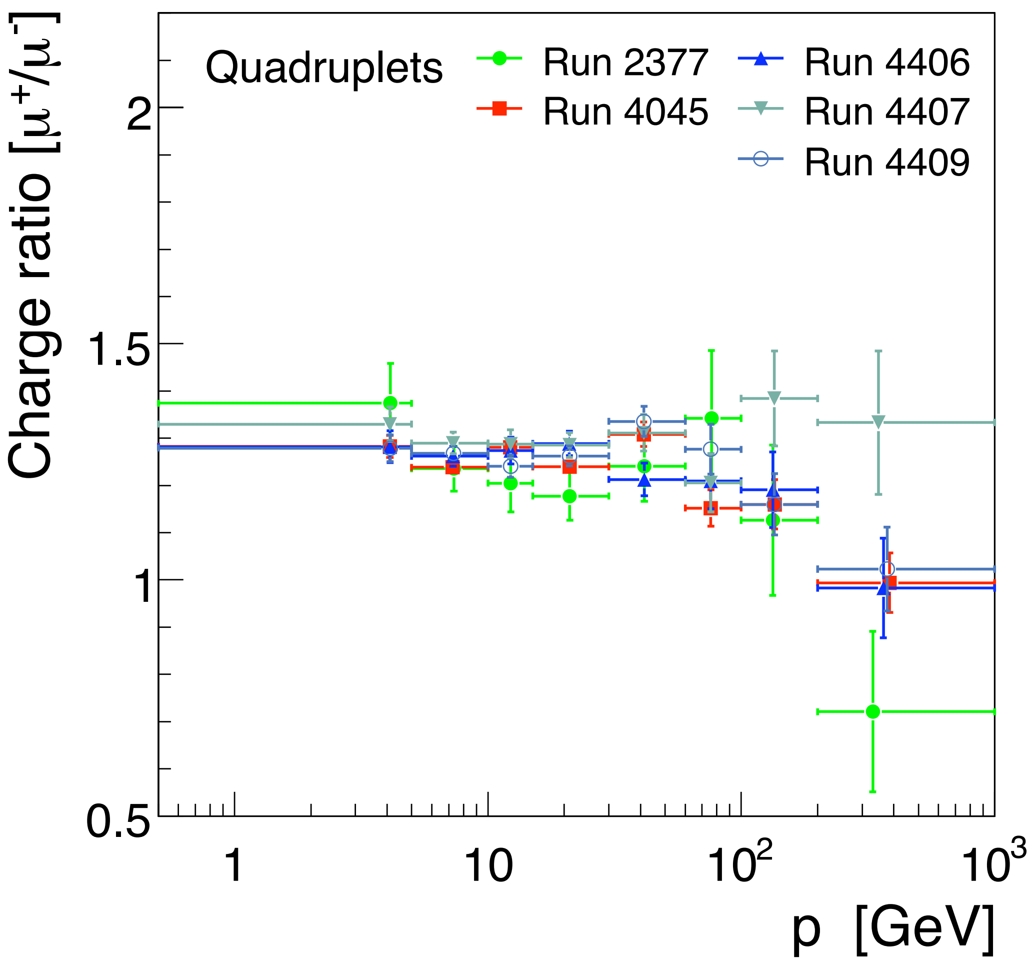
LR symmetry of the performance key of the analysis.

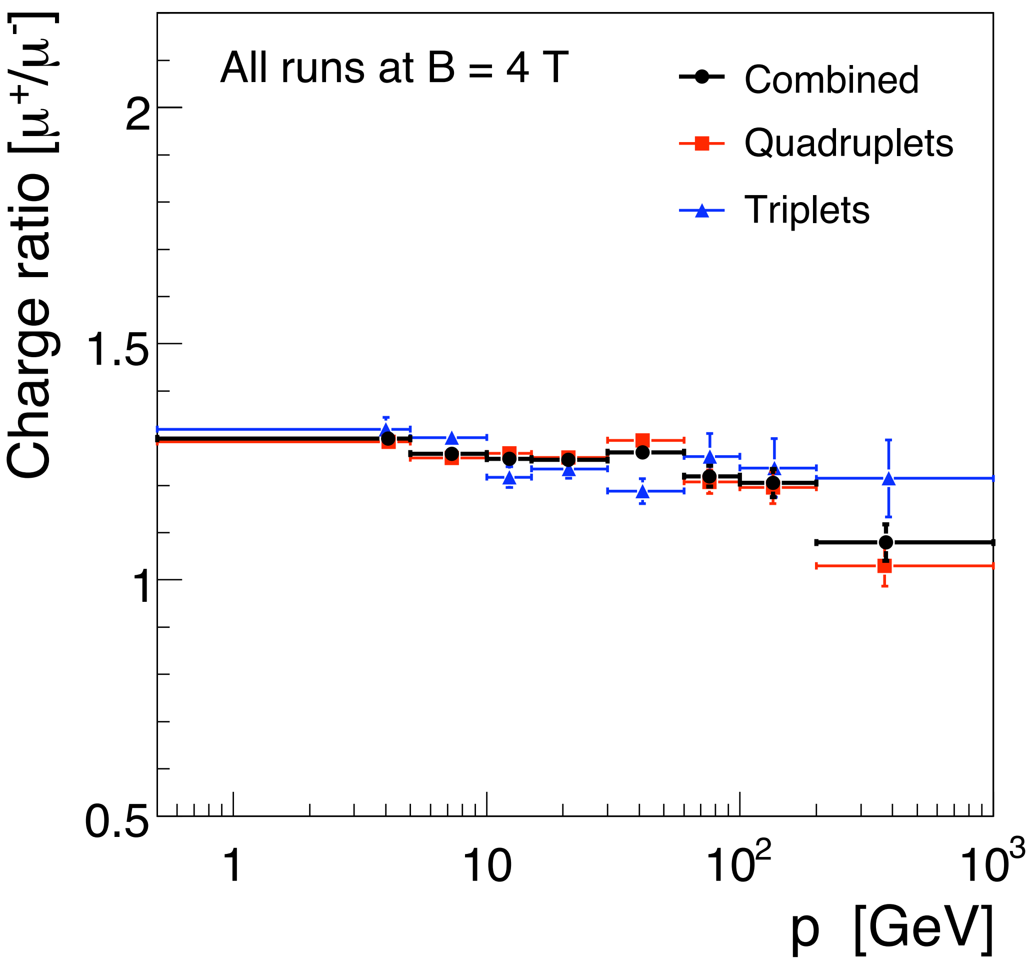
Distribution of hits in the fiducial geometry for one SL.
Data collected at B=0, independent of muon charge.



Consistency of the measurements

Measurements are consistent among runs and for different track qualities (number of 4D segments)

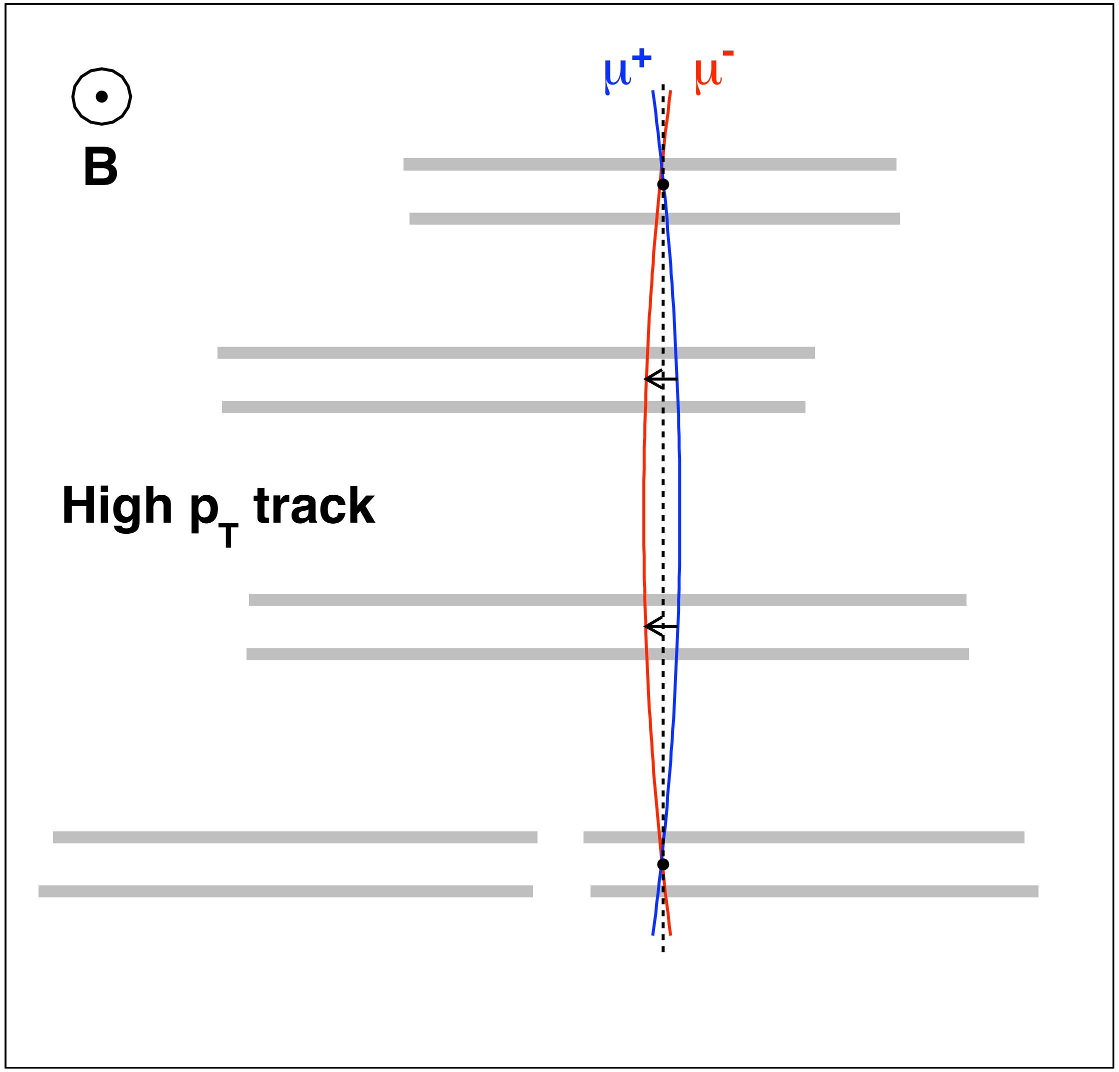




Misalignment induces bias

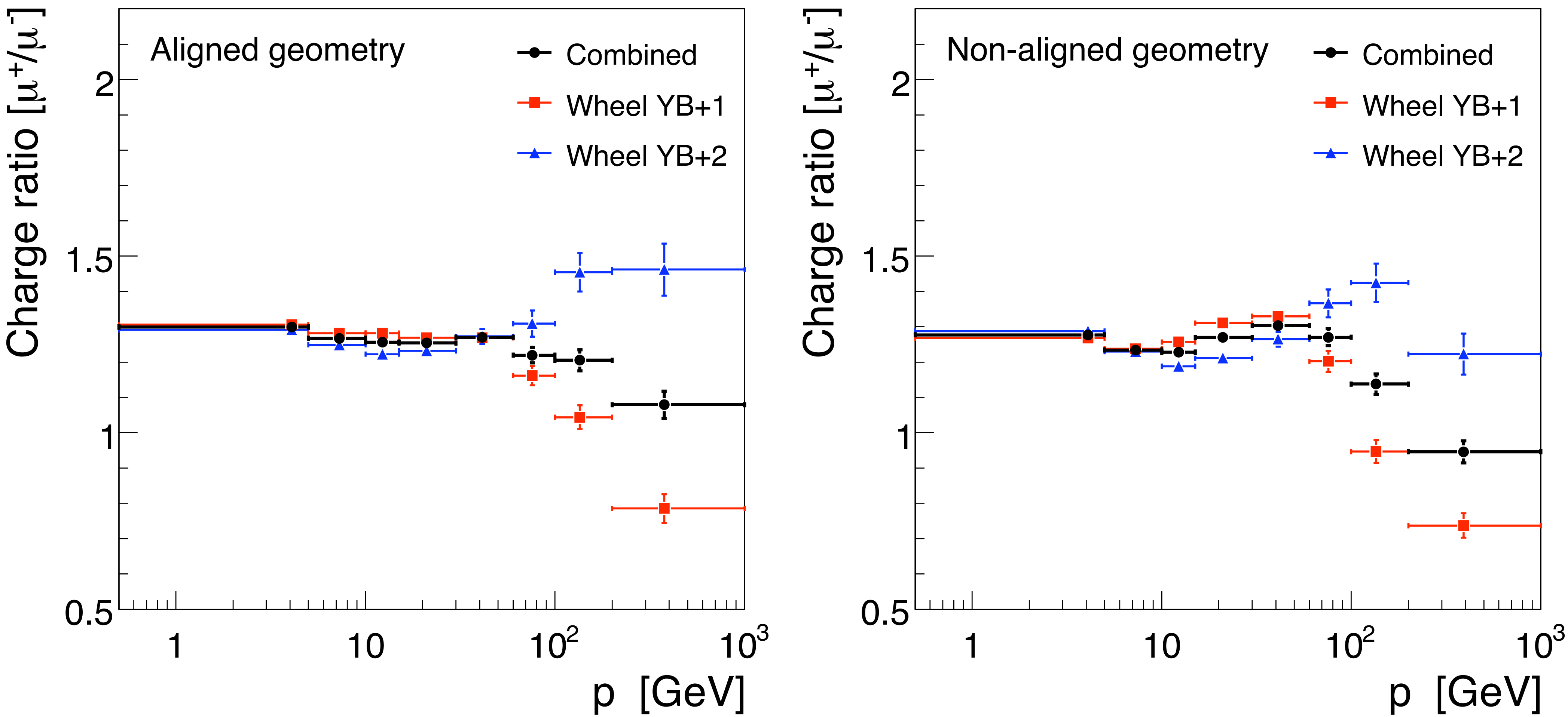
Deviation of the position of the chambers from their ideal position introduces a momentum-dependent bias in the momentum (charge) determination, antisymmetric for μ^+ and μ^-.

Most important systematic uncertainty, in particular at hight p_T.



Alignment corrections

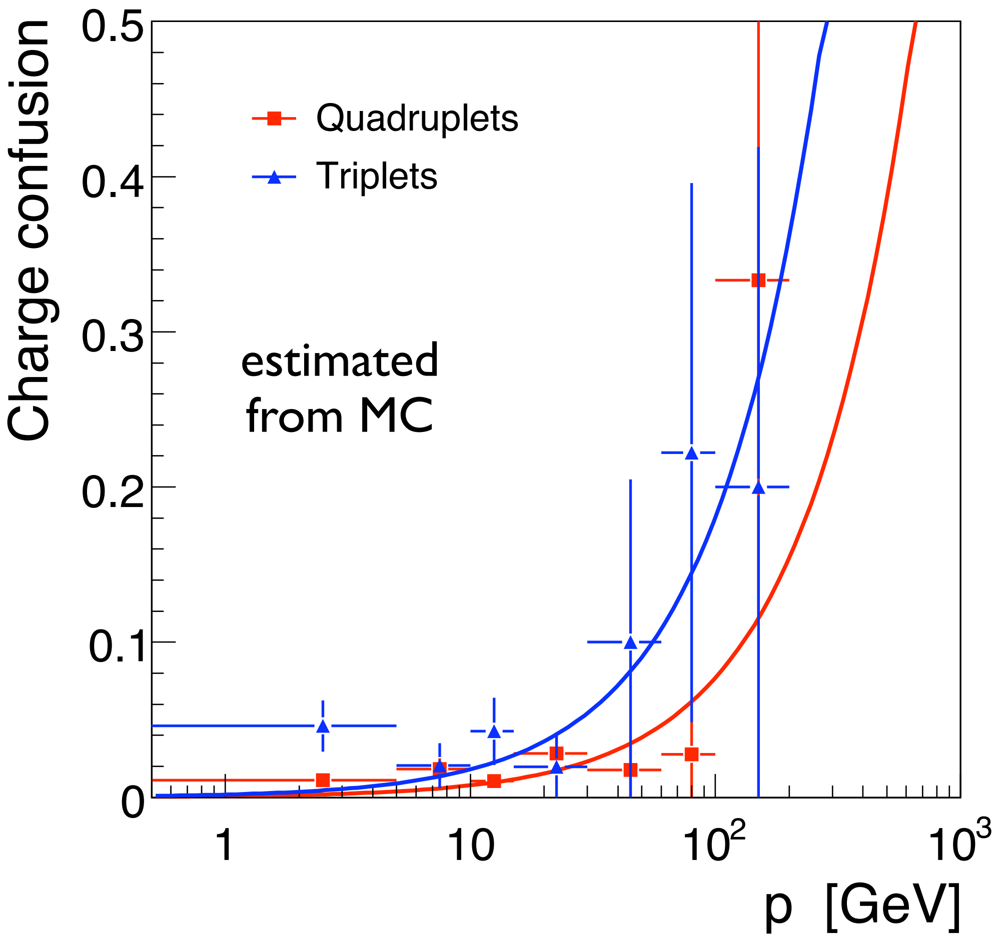
Alignment corrections from survey: large discrepancy between two wheels. Consistent with accuracy of parameters: toy MC.

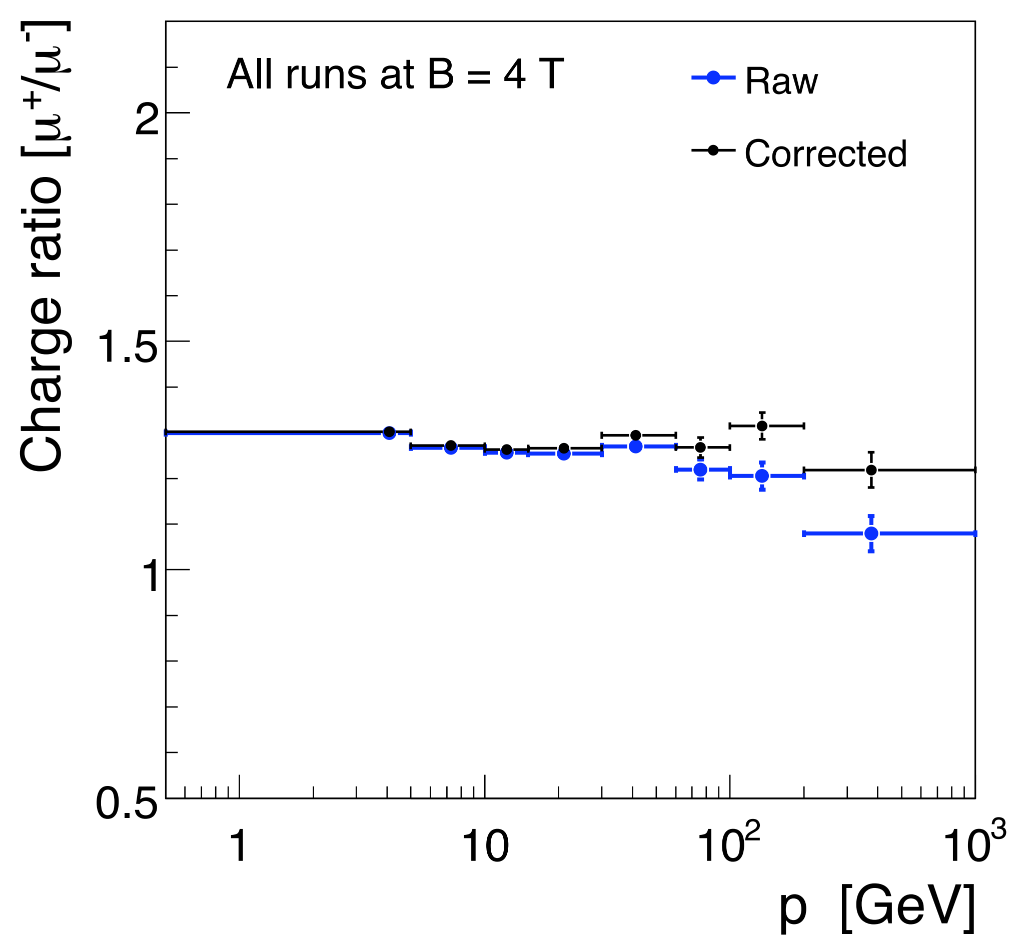


Charge misidentification

Limited detector resolution yields a momentum-dependent charge misidentification probability:

$$N_{\mu^\pm} = (1-C)\,N^\circ_{\mu^\pm} + C\,N^\circ_{\mu^\mp}, \quad R^\circ = \frac{R - C\,(1+R)}{1 - C\,(1+R)}.$$



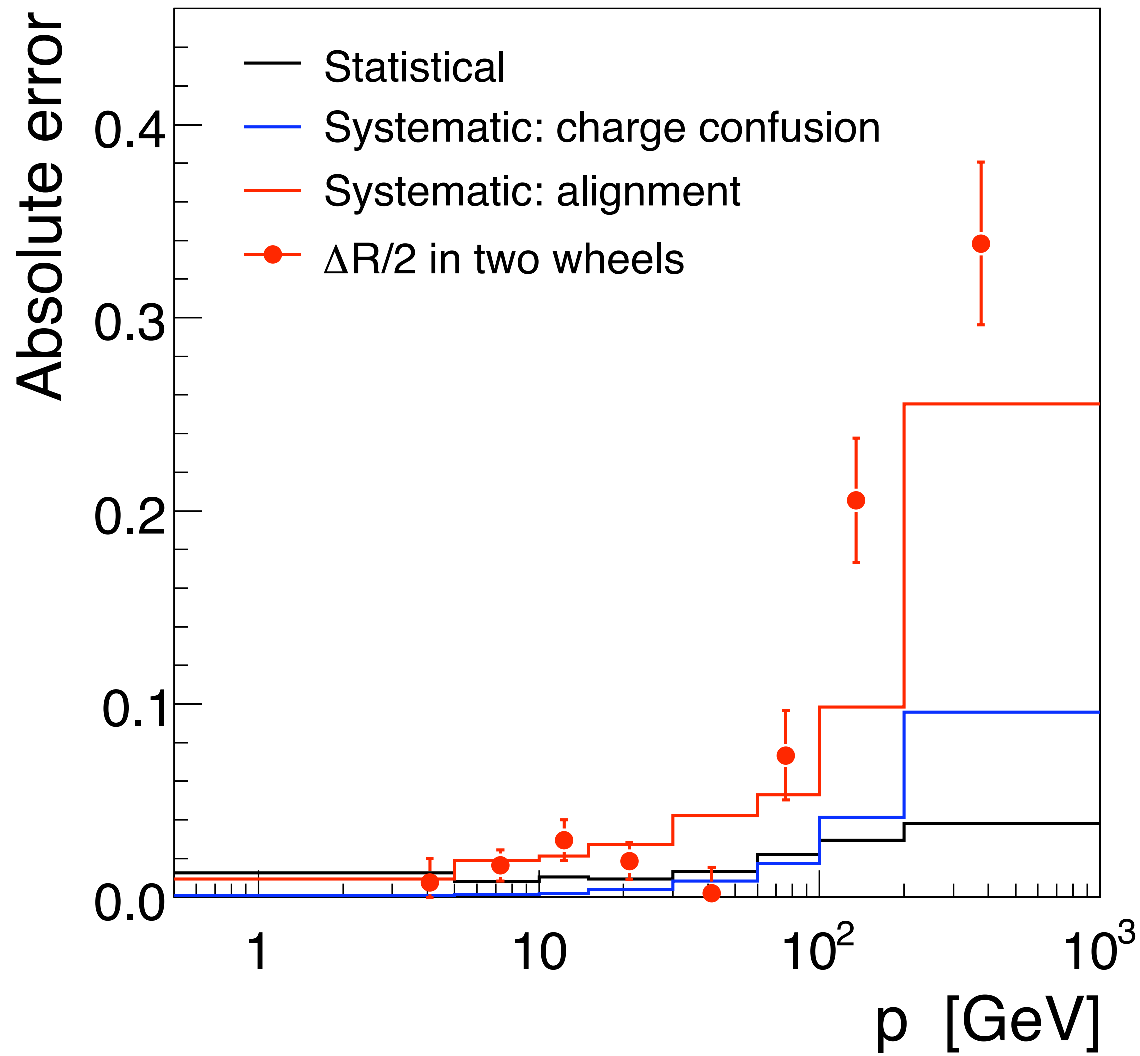


Systematic uncertainties

Systematic uncertainties significantly increase at p_T above 100 GeV/c.

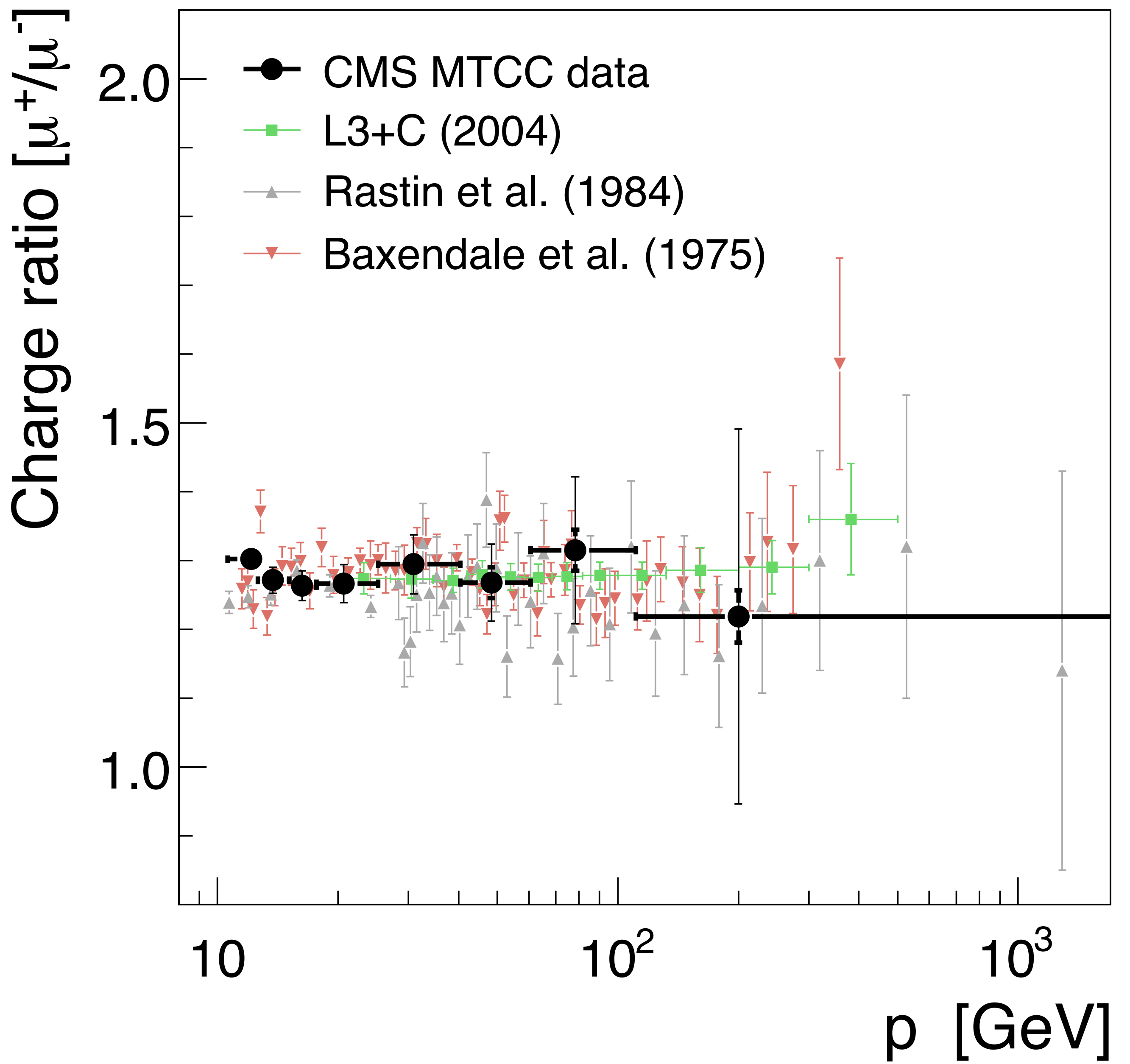
This is consistent with the resolution of the DT chambers, without the vertex constraint (unlike for pp collision data).

During normal operation of CMS, muon tracks *are* reconstructed with much higher accuracy and precision: tracker, vertex.



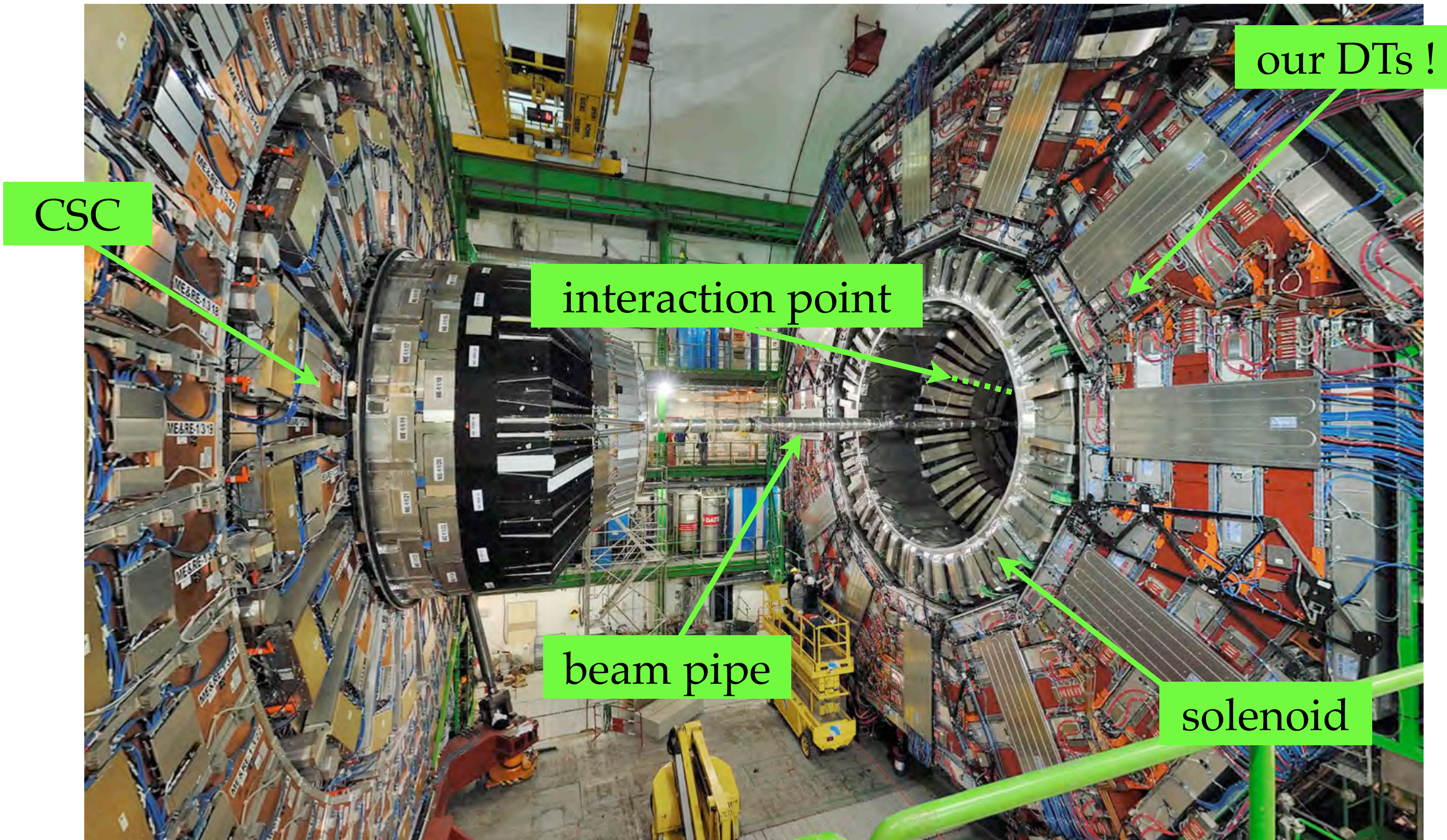
Measurement of R°

- The CMS result compares to results from other experiments.
- Large systematic uncertainties at high momentum.
- Ph.D. thesis of M. Aldaya, CMS NOTE 2008/016.

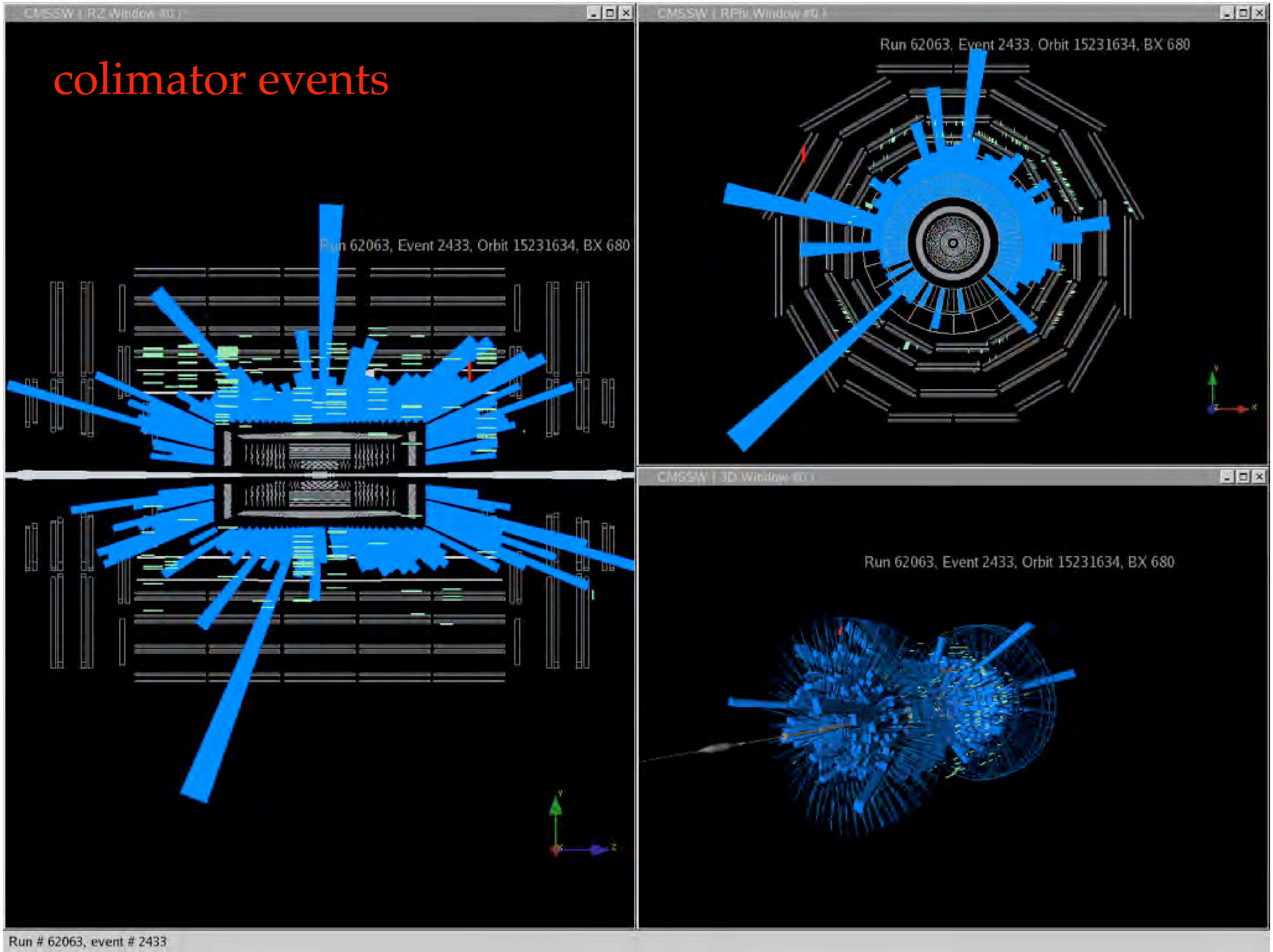


CMS today

Detector complete and installed in the P5 experimental area since Aug. '08



First LHC beams on Sep. 10



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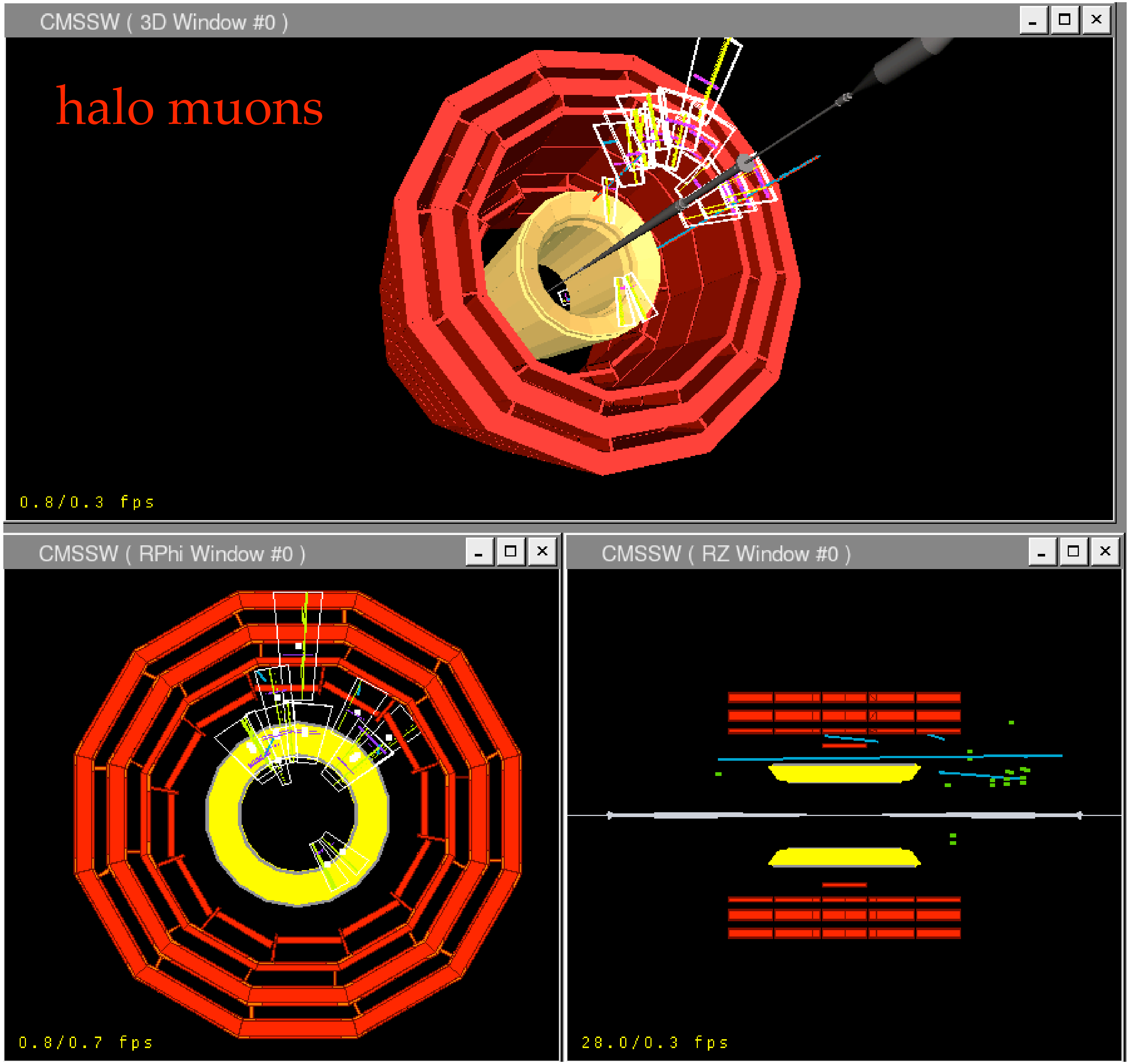
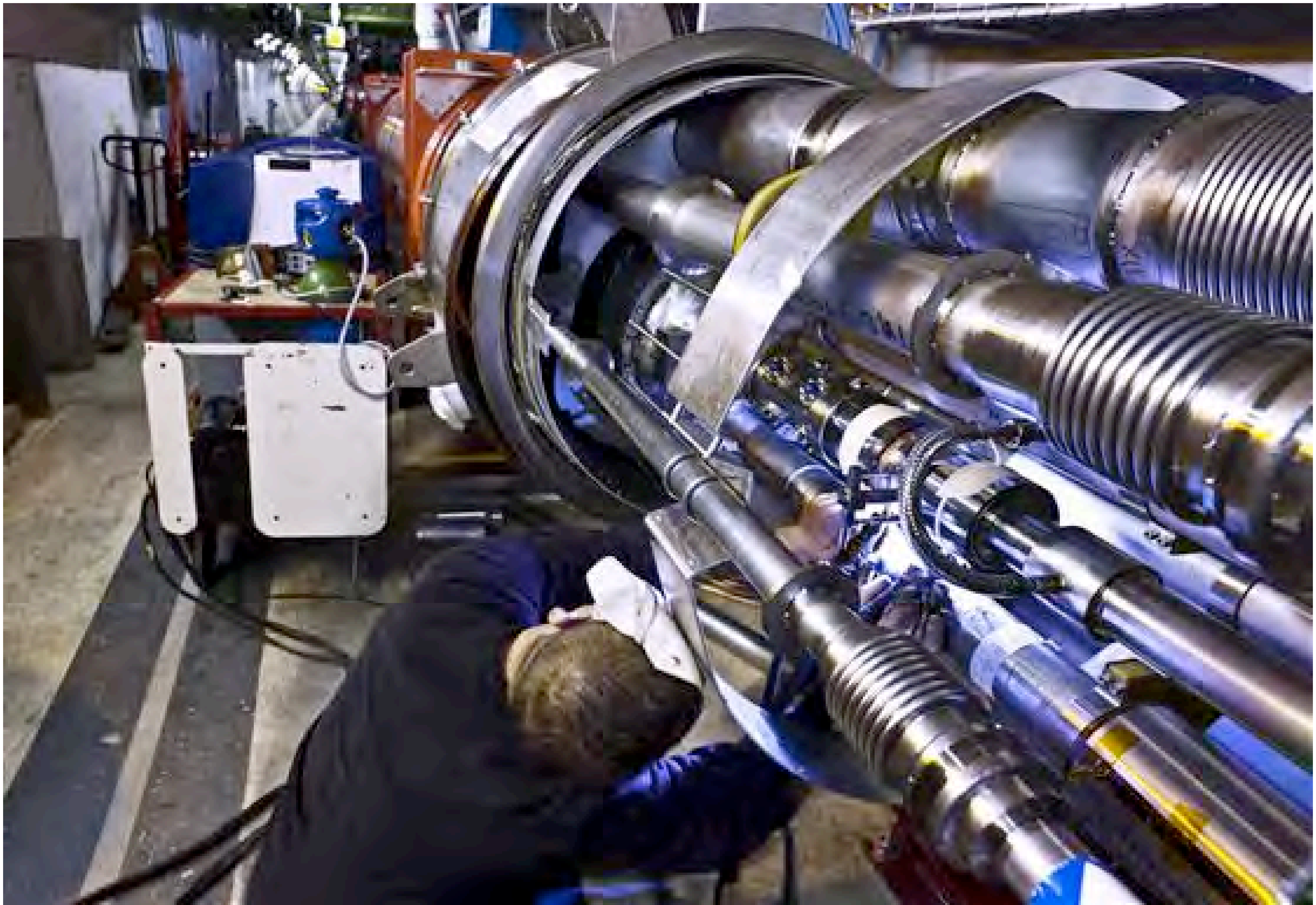


Incident at the LHC

Sep. 19: "faulty electrical connection between two of the accelerator's magnets. This resulted in mechanical damage and release of helium from the magnet cold mass into the tunnel".

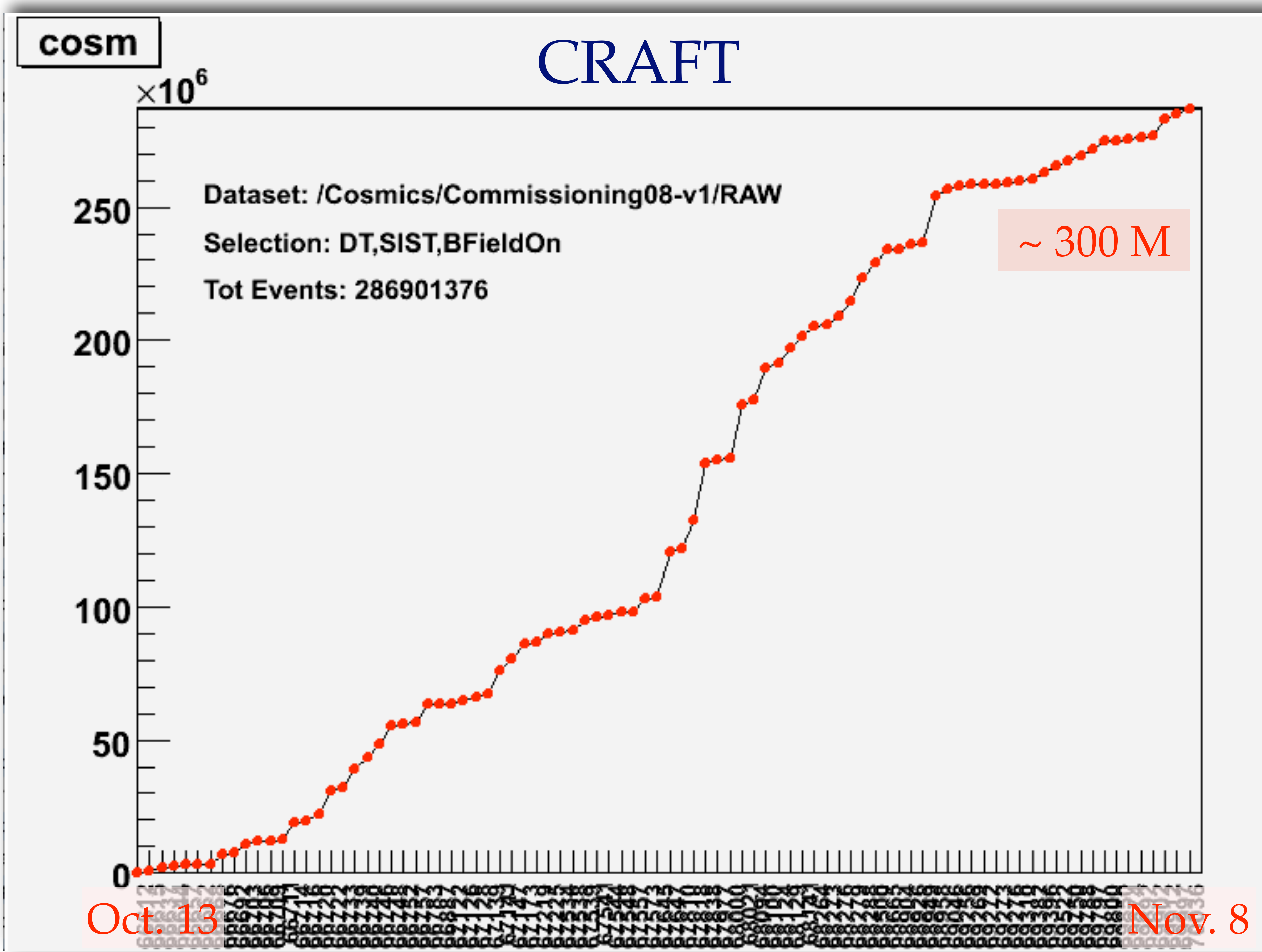
Repair work ongoing



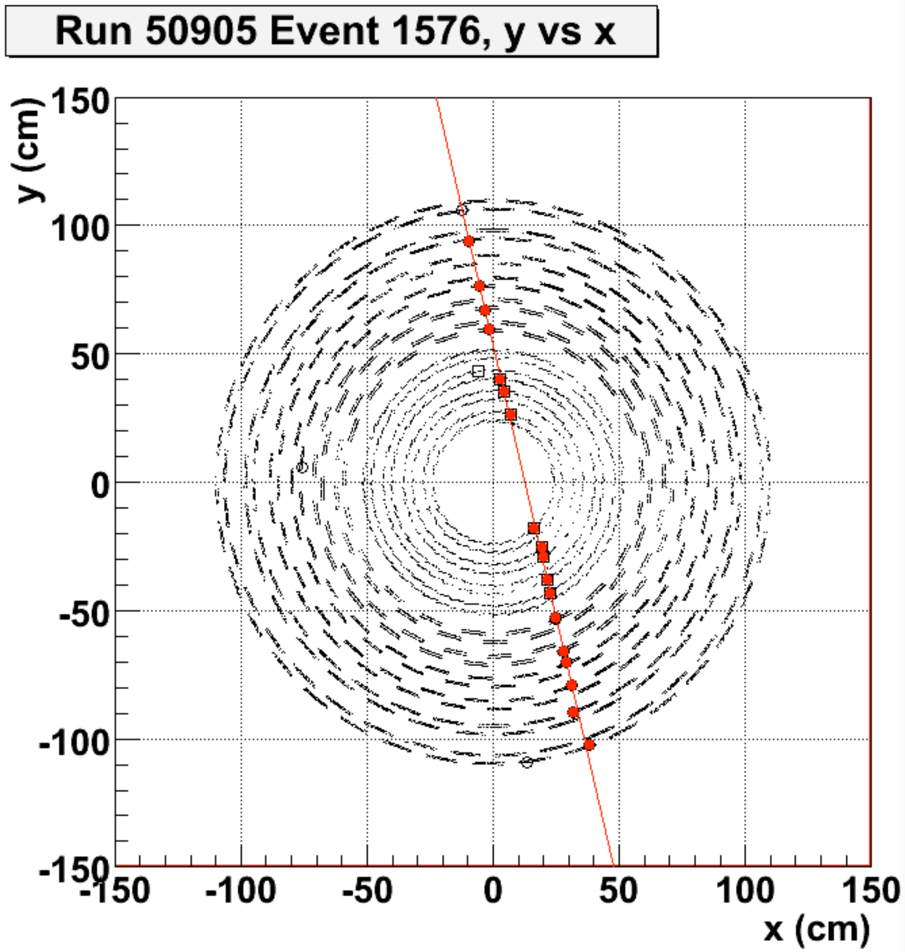
New plans of CMS

- LHC will restart on fall 2009...
- CMS closed and ready for beam September ’09.
- In the mean time, keep CMS alive, up and running:
  - commissioning of magnet, hardware (DAQ, L1, DQM) and software (HLT, reconstruction),
  - conditions workflows → alignment and calibration.
- Cosmic muon runs, with full detector operational.

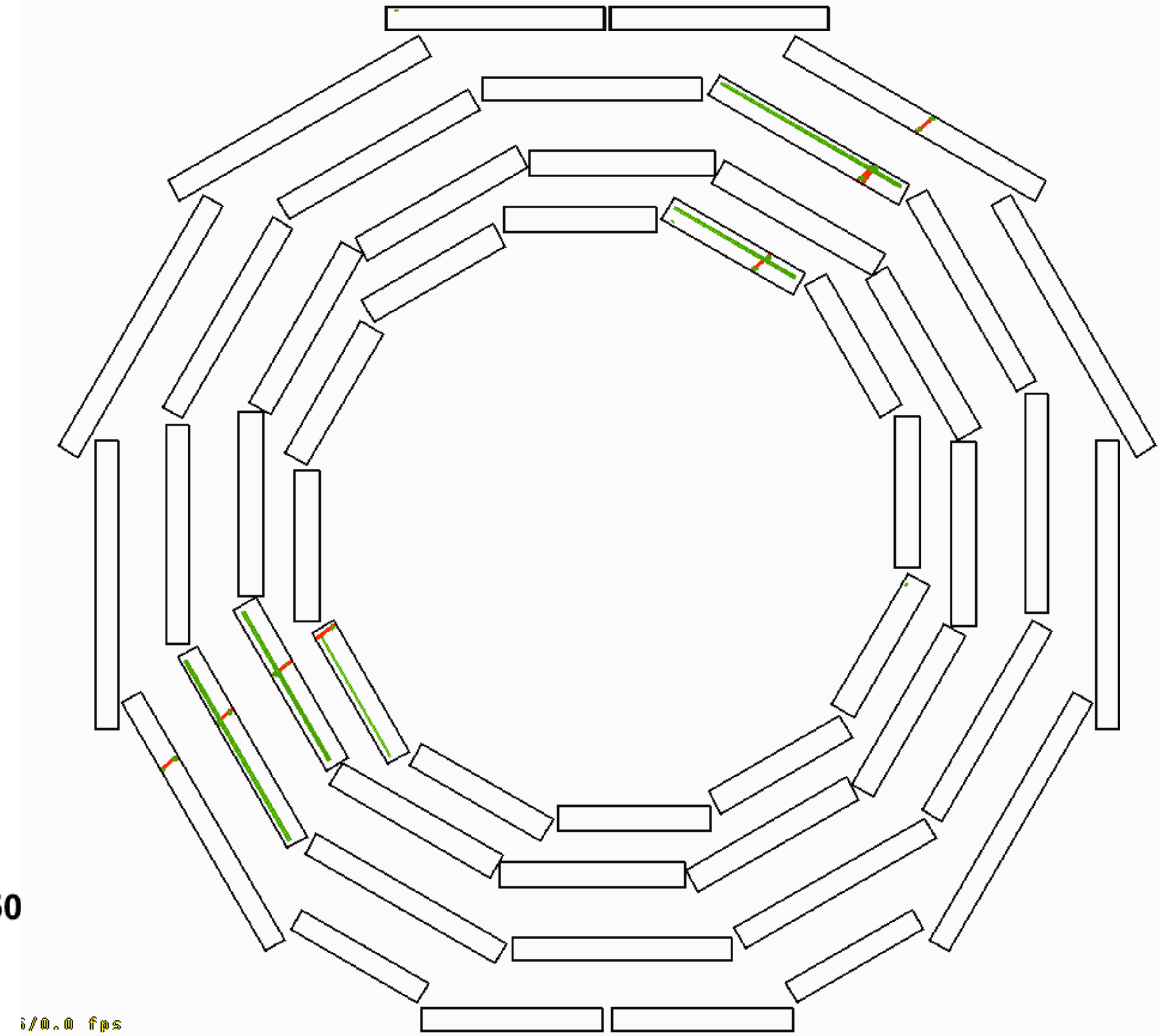
Cosmics run at 4 T



Cosmic muon events

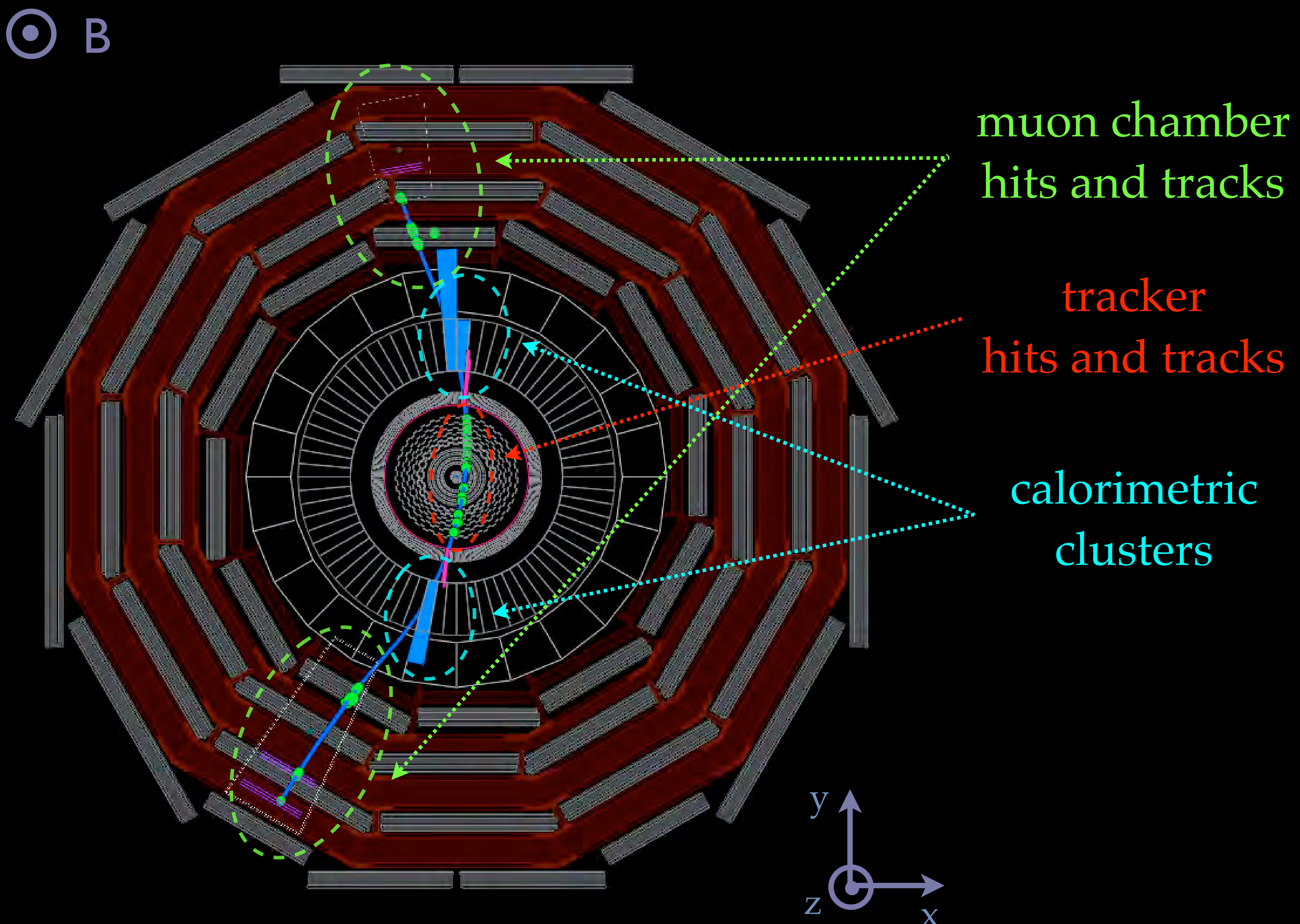


tracker



muon chambers

pp-like muon event



Conclusions from CRAFT

Useful lessons learned from CRAFT (can't make them public yet ☹). Publications (JINST) on detector performance and analysis expected end of summer.

Cosmic Muon Analysis group aims to publish the first CMS physics paper(s):

"measurement of the cosmic muon charge asymmetry"

("measurement of the absolute muon flux")

Conclusions

Current analyses of cosmic ray muons confirm the readiness of CMS for pp collision data, from data acquisition (DAQ) to end-user analysis. In particular, it endorses the capability of CMS to successfully covering its physics program.

Eagerly waiting for LHC to delliver pp collisions.