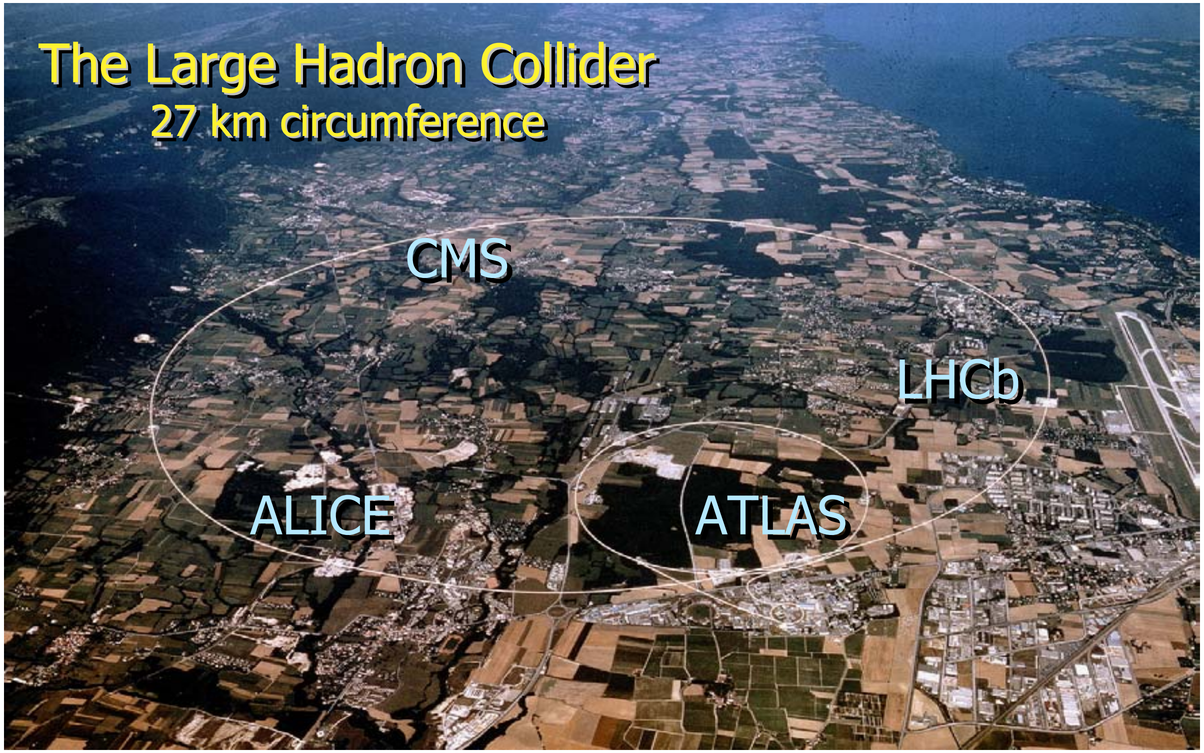
Readiness of the CMS and ATLAS experiments for the first collisions at LHC

Fabio Anulli

Roma, May 4th, 2009

Outline

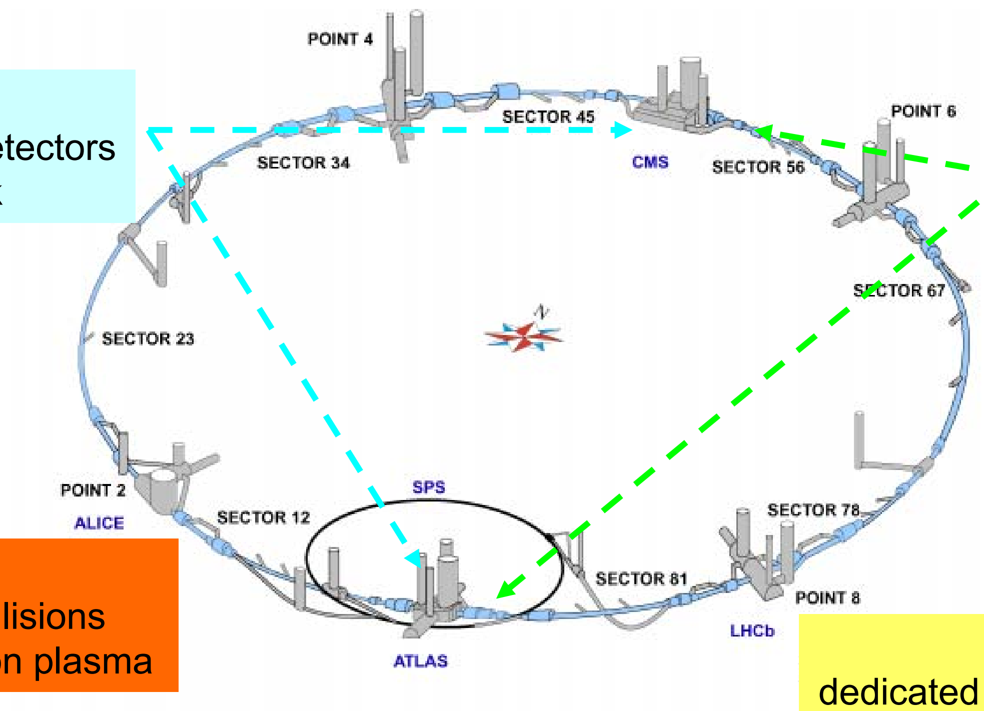
- LHC: plans toward beam collisions
- ATLAS: status and commissioning
- CMS: status and commissioning
- September 10-13, 2008: First beams in LHC
- Preliminary plans for super-LHC



The LHC project

pp collisions at $\sqrt{s}$ = 10-14 TeV ==> up to x7 Tevatron
High luminosity: $L_{design} = 10^{34}\ cm^{-2}\ s^{-1}$ ==> x100 Tevatron
Designed also for heavy ion collisions
First collision expected in November 2009!

CMS and ATLAS:
general purpose detectors
the topic of this talk

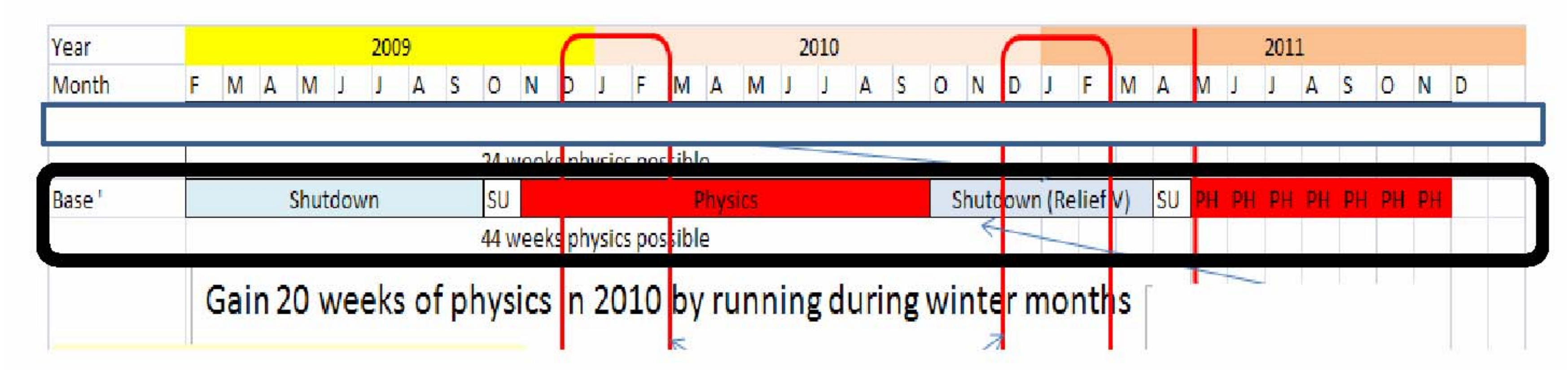


Two smaller experiments with very forward detector:
LHCf at P1
TOTEM at P5

ALICE:
ion-ion, p-ion collisions
study quark gluon plasma

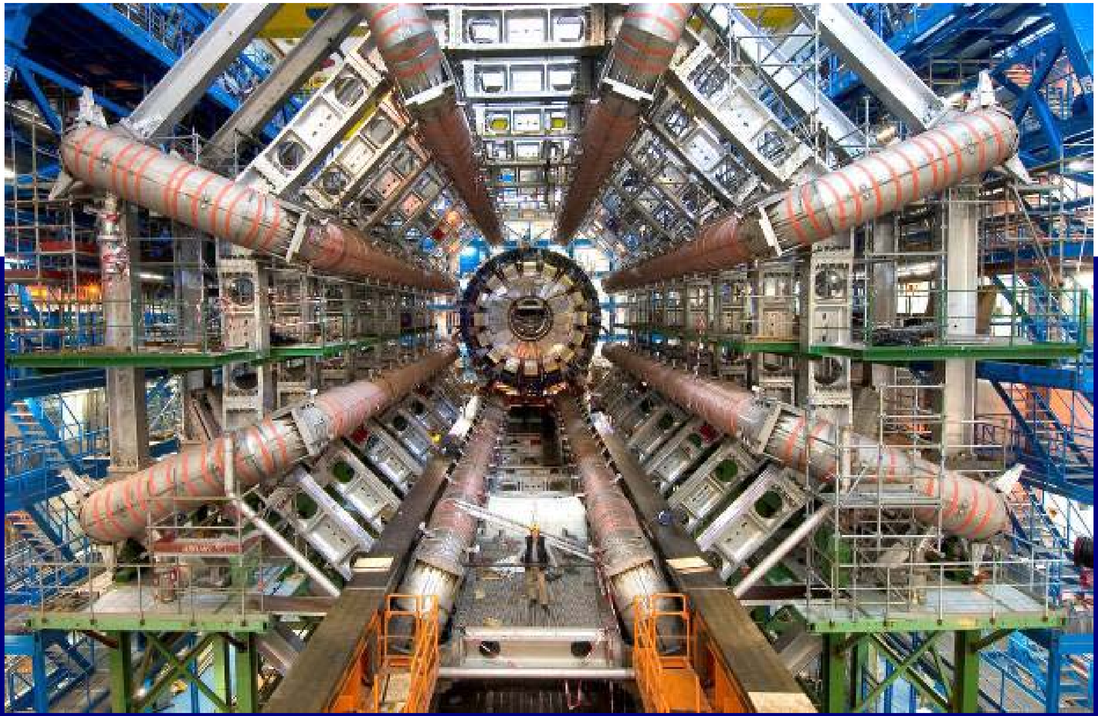
LHCb:
dedicated experiment to
B-physics and CP violation

LHC restart plan



- The machine will be cold by mid August, ready for first injected beam by second half of September
  - last refurbished magnet installed on April 30
- Physics run at 5 TeV until Autumn 2010
  - First physics run (~10 months long) at center of mass energy of 10 TeV
  - Heavy ion Pb-Pb collision toward the end of the run
- Then complete installation of additional extra pressure relief valves on remaining dipole cryostat (essential for maximum energy operation)
- Restart in Spring 2011 with increasing beam energies

ATLAS



COMPOSIZIONE DEL GRUPPO DI ROMA

Ricercatori:

A. De Salvo
A. Di Domenico
C. Dionisi
C. Bini
C. Luci
D. De Pedis
E. Petrolo
E. Pasqualucci
F. Anulli
F. La Cava
F. Marzano
G. Ciapetti
G. De Zorzi
L. Luminari
L. Zanello
L. Pontecorvo
M. Rescigno
L. Nisati
P. Bagnaia
P. Gauzzi
R. Vari
S. Gentile
S. Falciano
S. Giagu
S. Veneziano

TD/Assegnisti :

A. Di Girolamo
E. Solfaroli
F. Safai Tehrani
M. Verducci
S. Rosati
F. Pastore

Dottorandi:

S. Borroni
C. Maiani

Laureandi:

G. Artoni
P. Bagiacchi
M. Bettiol
V. Consorti
F. Lo Sterzo
L. Mazzaferro
M. Vanadia

Tecnici:

D. Anzellotti
G.Chiodi
R. Lunadei
E. Gennari
A. Ruggieri
D. Ruggieri

ATLAS Collaboration

37 Countries

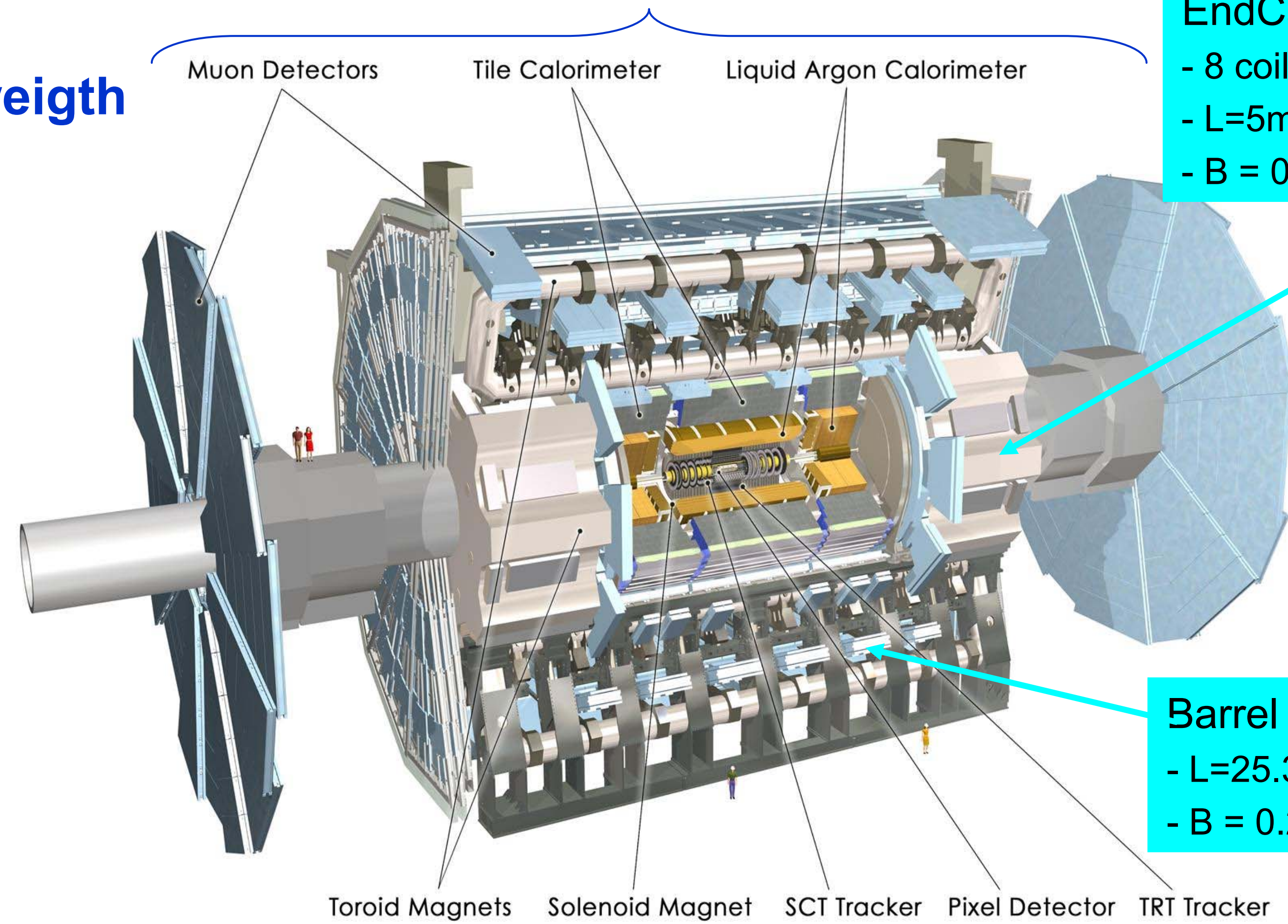
169 Institutions

>2500 Scientific Authors

total weigth
7000 T

45 m

24 m



EndCap Toroids
- 8 coils with common cryostat
- L=5m, $\varnothing_{outer}$ = 10.7m
- B = 0.2-3.5T (@20.5kA)

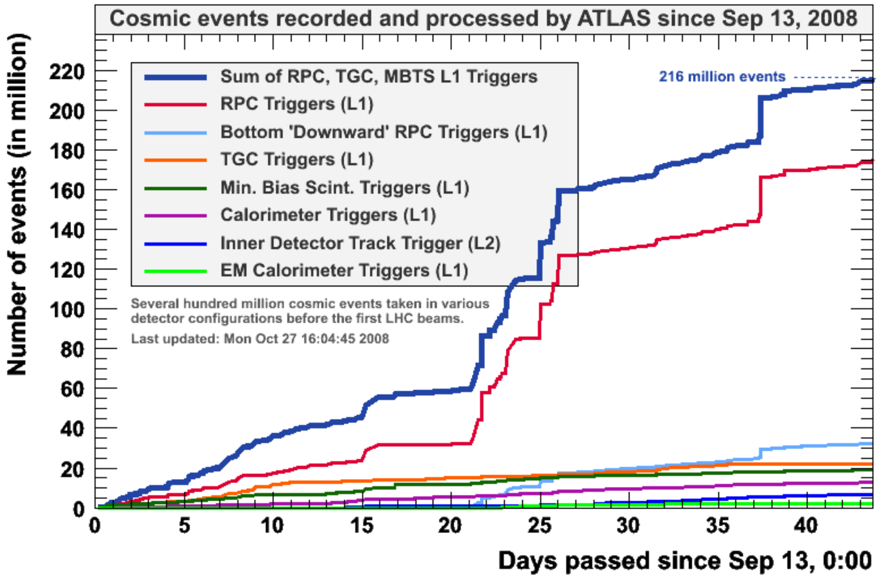
Barrel Toroid (8 coils)
- L=25.3m, $\varnothing_{outer}$ = 20m
- B = 0.2-2.5T (@20.5kA)

Detector Commissioning

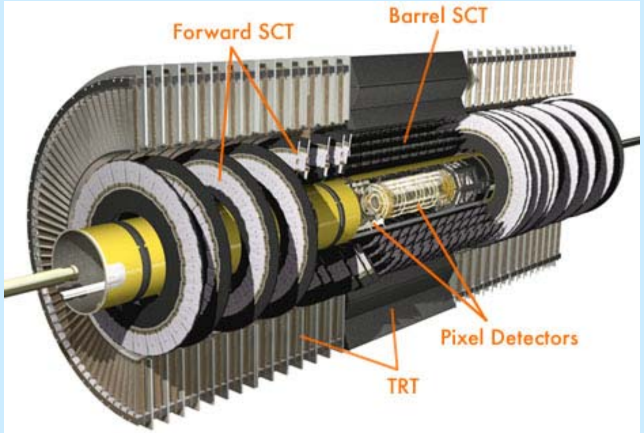
- Commissioning started in 2005 in parallel with detector assembling
- several cosmic ray runs periodically programmed
- from August 2009 should move in continuous run mode for preparation for collisions

- Test channel mapping and timing
- Determine dead and noisy channels
- Verify stability of hardware components during operation
- Gain experience in all aspects of detector operation and control, DAQ and analysis chain
- Obtain first calibration and alignment constants
- Develop and test monitoring tools
- Understand and improve detector performances

most of data collected in fall 2008, after LHC accident ==> 216M of selected cosmic ray events



Inner Detector and Calorimeters

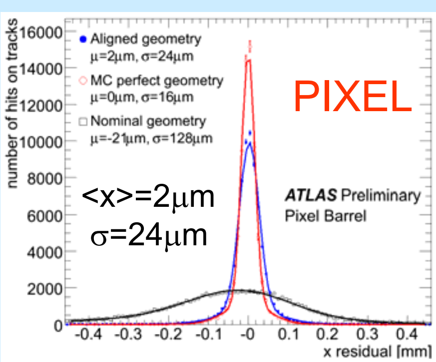


Operated inside the 2-T magnetic field

$\eta<2.5$ (TRT: $\eta<2.0$) $\sigma/p_T = (0.05\ p_T + 1)\%$

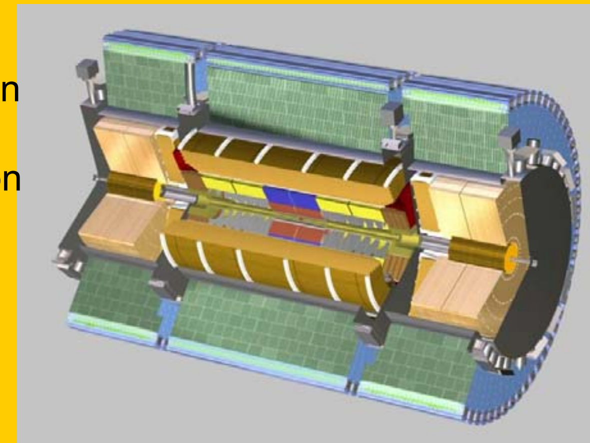
Pixel + Silicon micro-strips + Transition Radiation (both tracking and e/π ID)

- >97% of channels operational
- very few noisy channels



alignment of Barrel layers with cosmics. Reasonable agreement with MC

EMC:
- Pb-LAr, with accordion geometry
- Longitud. segmentation
- OK Calibration procedures
- Dead channels <1% (recoverable)



Hadronic Cal.
- Barrel: Fe + Sci.Tiles
- EndCap: Cu-LAr
- Forward: W-LAr
- Dead Channels <1.5% (mostly recoverable)

Electromagnetic energy resolution:

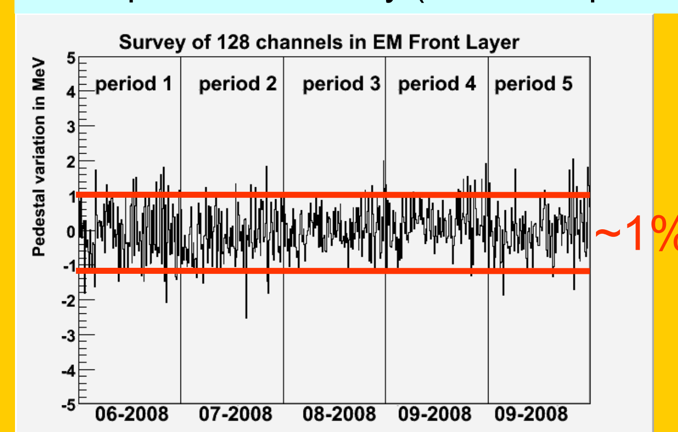
$$\sigma(E)/E = 10\%/\sqrt{E} \oplus 0.7\%$$

Hadronic energy resolution:

$$\sigma(E)/E = 50\%/\sqrt{E} \oplus 3\% \quad (\eta < 3.2)$$

$$\sigma(E)/E = 100\%/\sqrt{E} \oplus 10\% \quad (\eta > 3.1)$$

EMC pedestal stability (5 months period)



Muon spectrometer

Muon Trigger (for η<2.4)

End-cap Trigger:

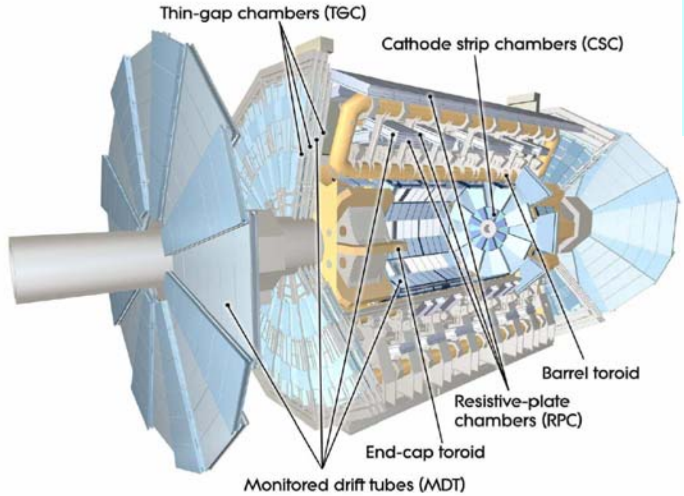
Thin Gap Chambers (TGC)

- 2D readout; σ_t < 10 ns
- 99.8% of chambers operational

Barrel Trigger:

Resistive Plate Chambers

- 2D readout
- σ_t ~ 2 ns
- >90% coverage (goal for 2009 95.5%)
- dead strips <2%
- hot strips <1%



stand-alone p_T measurement with precision chambers

- $\Delta p_T/p_T$ < 10% up to 1 TeV

EndCap:

Cathode strip Chambers (CSC)

Monitored Drift Tubes

~100% of chambers operational

Barrel:

Monitored Drift Tubes

- 99.8% of chambers operational
- dead ch: 0.1% (+1% recoverable)

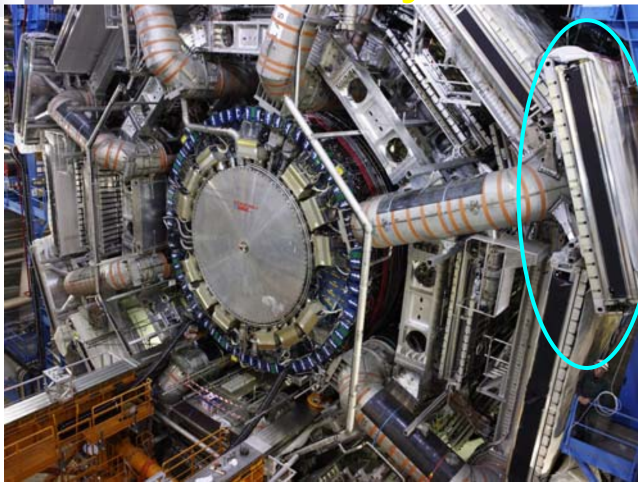
Muon Project Leader: L. Pontecorvo

Rome group activities in the muon project:

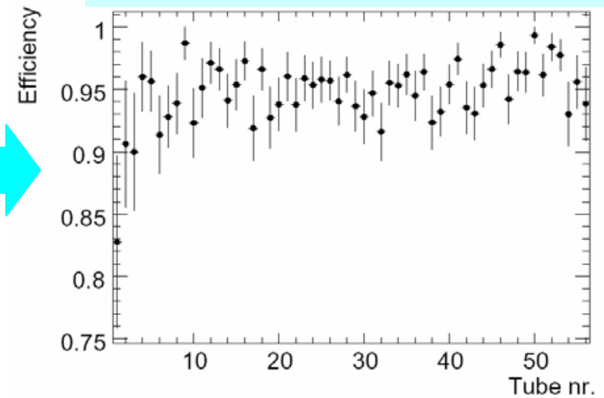
- MDT construction/test/commissioning (BIL chambers)
- MDT calibration (use the TIER2 in Rome)
- Barrel Level-1 trigger (design/implementation/commissioning)
  ==> system responsible: S. Veneziano
- High Level Trigger
- DAQ ==> responsible E. Pasqualucci

Other responsibilities:

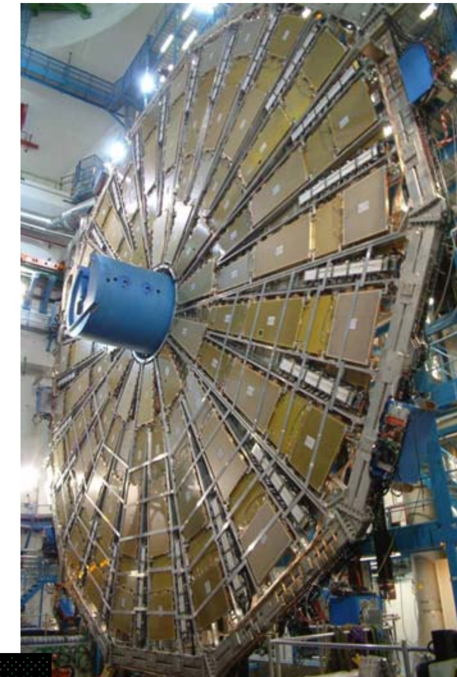
- Deputy Physics Analysis Coordinator (A. Nisati)
- Physics Analysis Tools (S. Giagu)



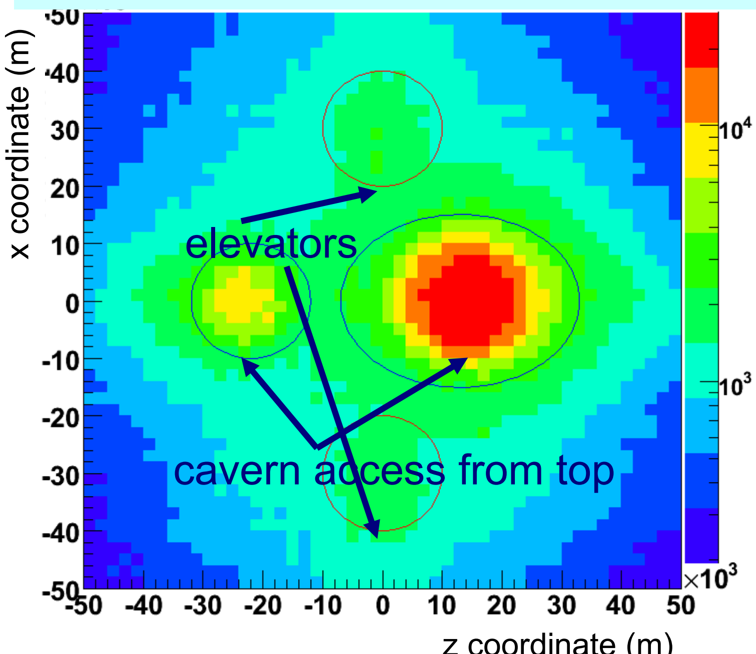
hit efficiency of a typical barrel chambers

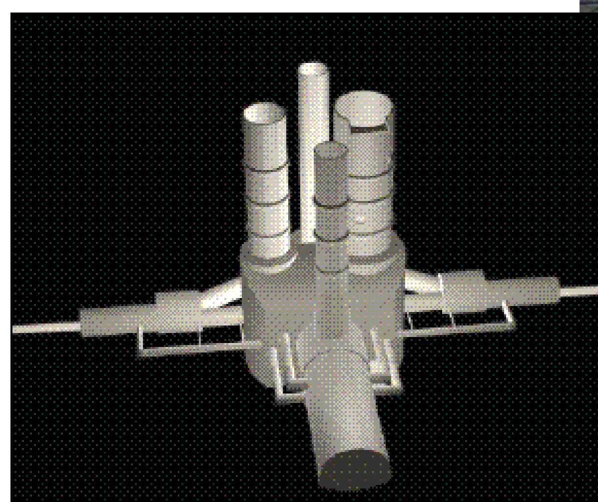


Big Wheel (TGC visibles)



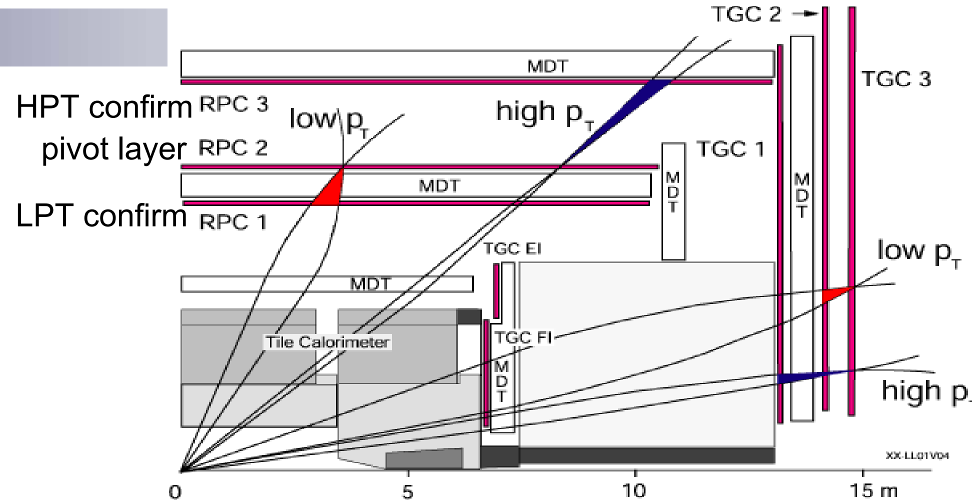
cosmic tracks reconstructed in the barrel RPC and projected onto cavern surface ==> “density map”





Barrel Level 1 Trigger

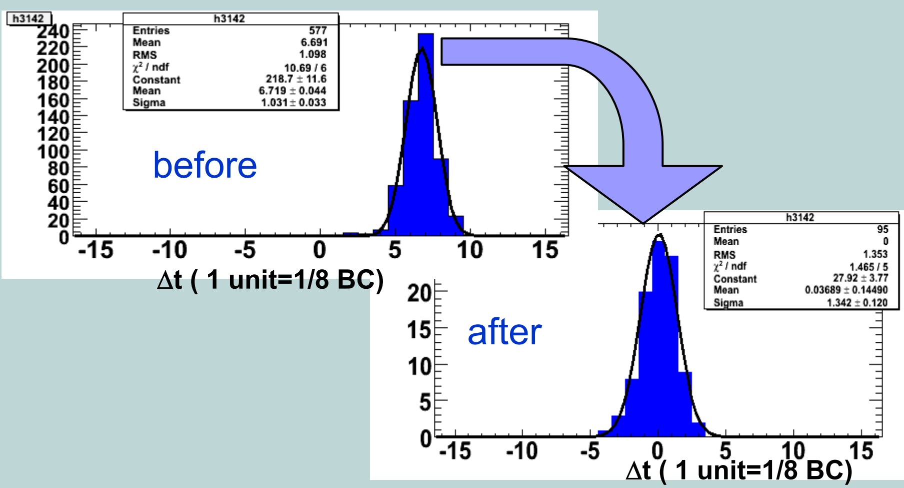
- Output rate for the whole trigger <75kHz, from the initial 1GHz
- Short latency; bunch crossing identification
- “Full” efficiency on rare new processes



Fast and high redundancy system

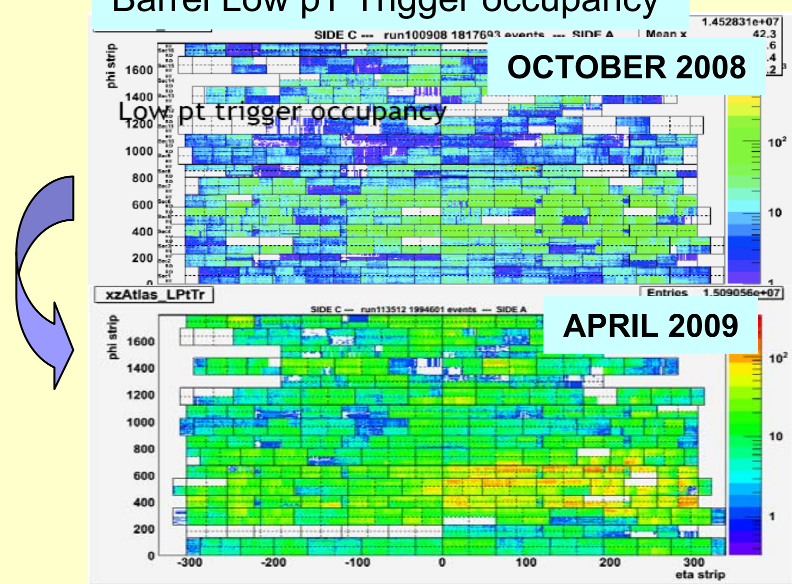
- Wide p_T-threshold range with 2 separate systems: **low p_T and high** p_T trigger
- Safe Bunch Crossing Identification
- Strong rejection of fake muons
- 1/8 BC interpolator to measure RPC timing hit

RPC time alignments within the same Trigger Tower from time difference between hits of different layers. Time is measured in 1/8 BC unit



Limited coverage during fall cosmic ray campaign.
Continuously improving, now almost OK.
Will reach full coverage for (new) LHC start-up

Barrel Low pT Trigger occupancy



High Level Trigger

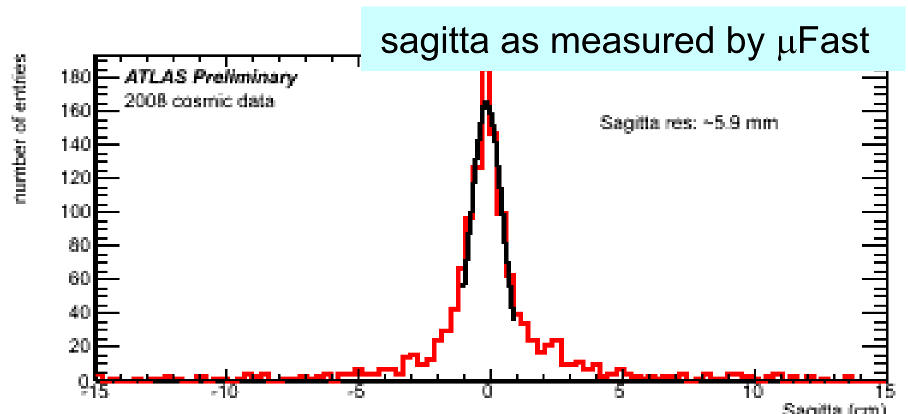
- The software ATLAS HLT trigger is realized in two main steps
  - Level 2
  - Event Filter
- Use information from all detectors within a Region Of Interest (ROI) individuated by the LVL1 trigger, to provide a high quality track measurement keeping the processing and decision time short

Level 2

- several algorithm developed partially serialized
  - μFast: track reco'ed in the MDT, fake μ rejection
  - μComb: combine μFast with ID track for better p_T meas.
  - μIso: select isolated muons from EW processes
  - μTile: identify muons from energy deposited in Hadcal

Event Filter

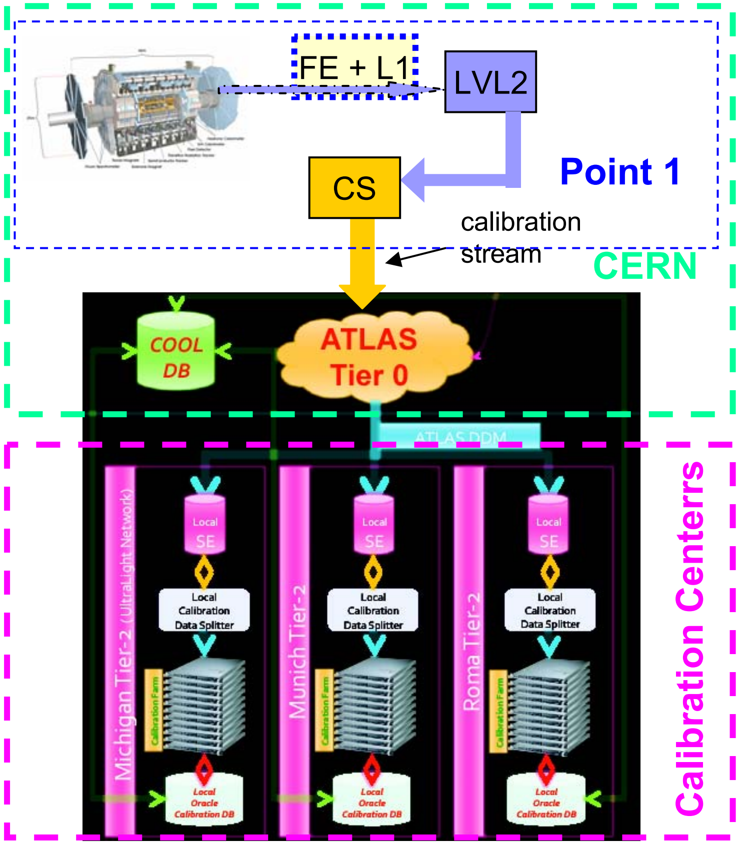
- final selection with improved p_T measurement
- record the full event on disk



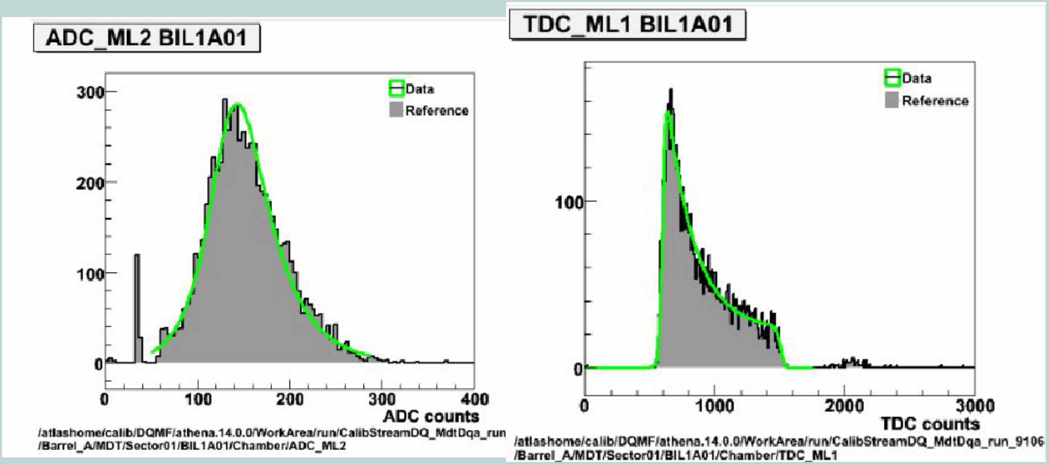
All magnets off (straight tracks). Chambers were not yet aligned, with clear effect on sagitta resolution

Barrel MDT calibration and DQM

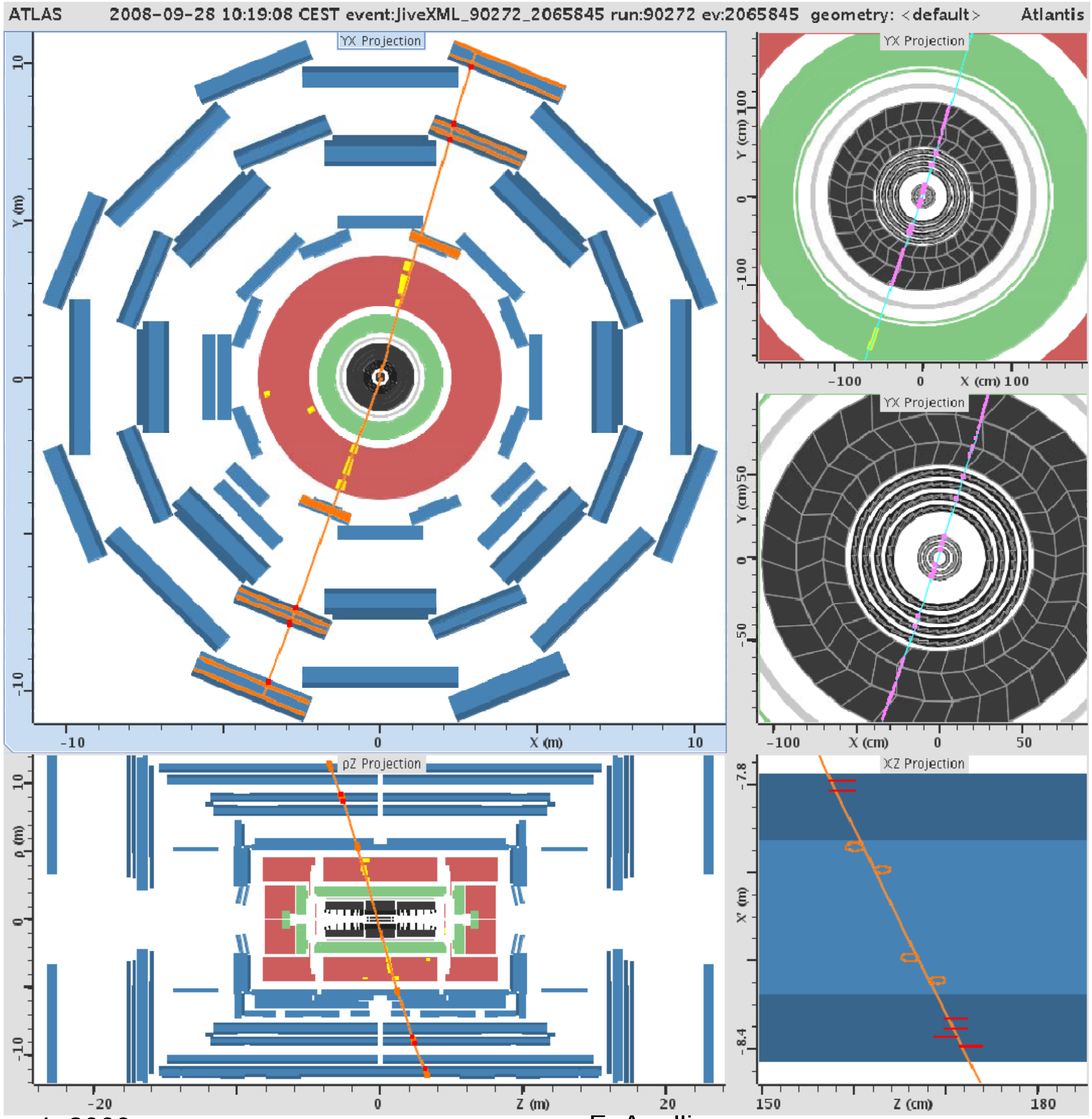
- 80–µm resolution on single hit is required in the coordinate orthogonal to B-field
- Accuracy in determination of detector alignment and of **drift time**
- *r-t* relations change with time because of many variables, making impossible to reach the required accuracy if not properly calibrated
- Daily determination of the *r-t* relation for each chambers and weekly computation of each tube require ~10^8 muon tracks per day!
- Not achievable using standard ATLAS Data Flow
- ==> need a dedicated data stream, extracted from the Level2 Trigger
- the system has been designed by the Rome group



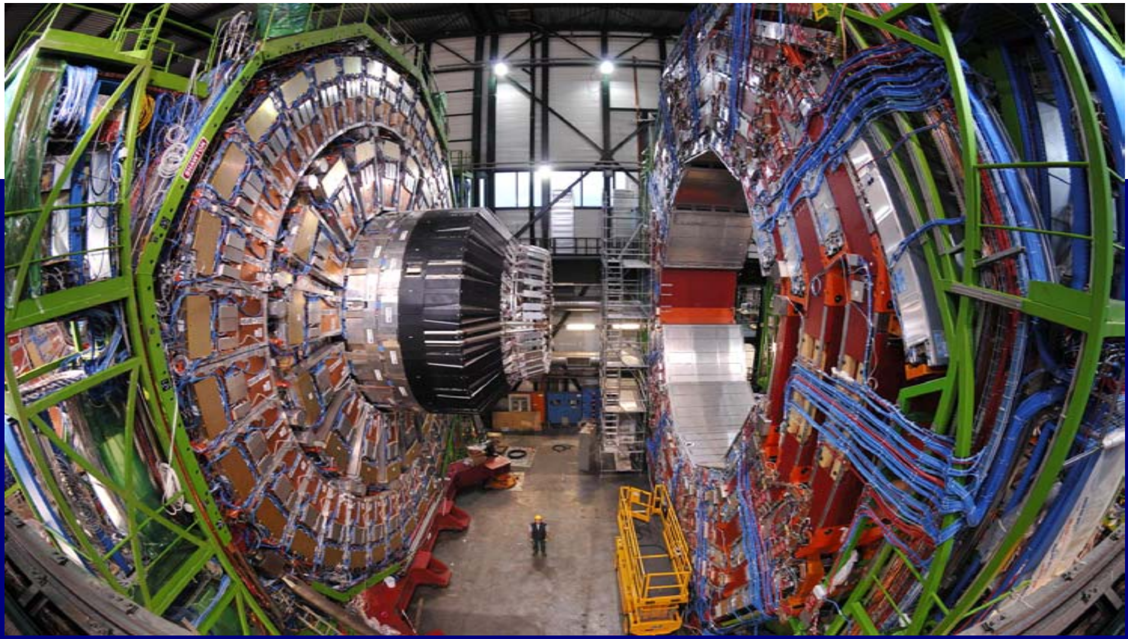
- at the T2 in Rome, the calibration stream is used also for Data Quality Monitor
- histograms of significant quantities are compared to references and an automatic decision about the quality is taken



Display of a cosmic ray event



CMS



COMPOSIZIONE DEL GRUPPO DI ROMA

Ricercatori:
L. Barone
F. Cavallari
D. del Re
M. Diemoz
E. Longo
G. Organtini
R. Paramatti
S. Rahatlou

Tecnici:
A. Bartoloni
I. Dafinei

TD/Assegnisti:
E. Di Marco
F. Safai Therani
C. Rovelli

Dottorandi:
D. Franci
A. Palma
F. Pandolfi

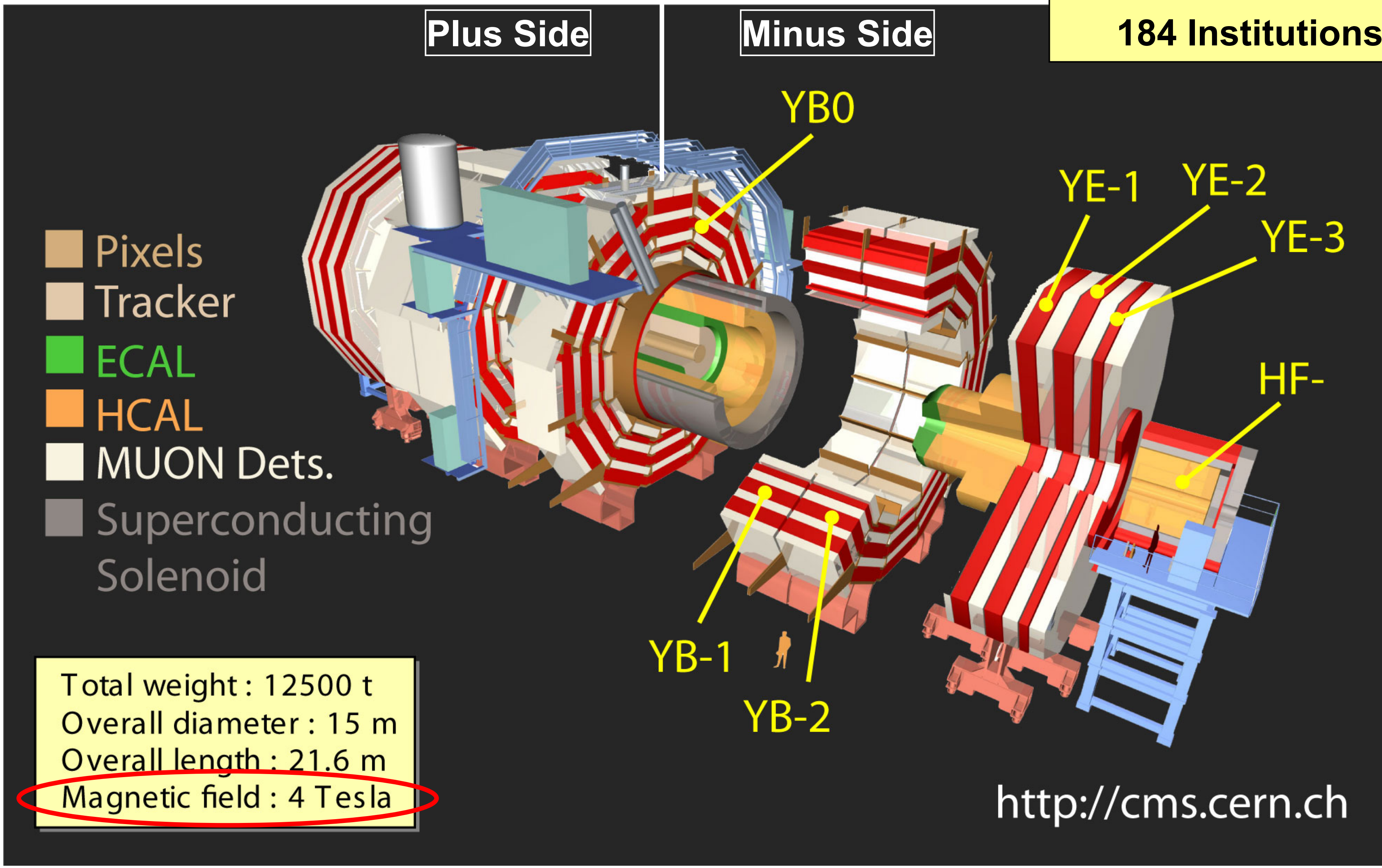
Laureandi:
M. Grassi

CMS detector layout

CMS

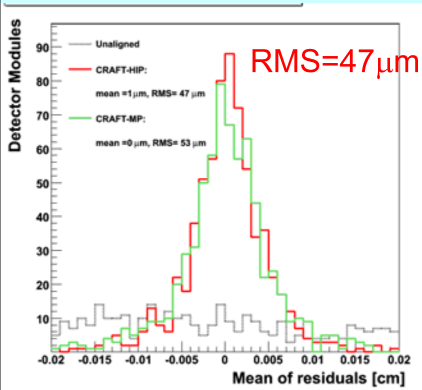
2930 Scientists

184 Institutions



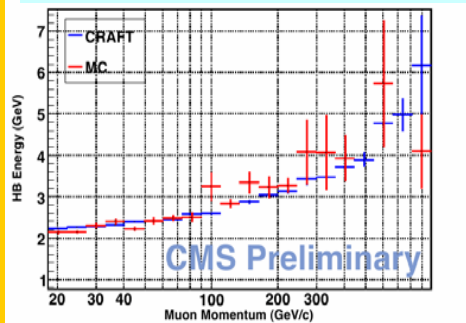
How does it work

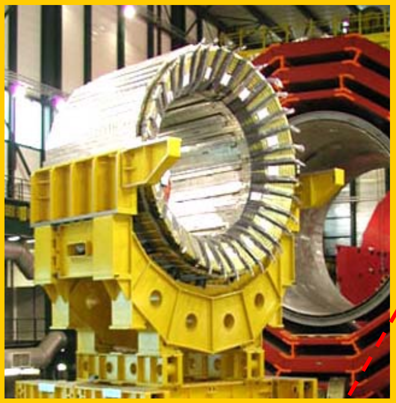
mean of residual distributions [cm] - PIXEL Barrel



full silicon detectors
pixel + microstrips
$\Delta p_T/p_T$ ~1-2%
~98% operational

HB response to muons.
HB energy: signal corrected for muon path legth

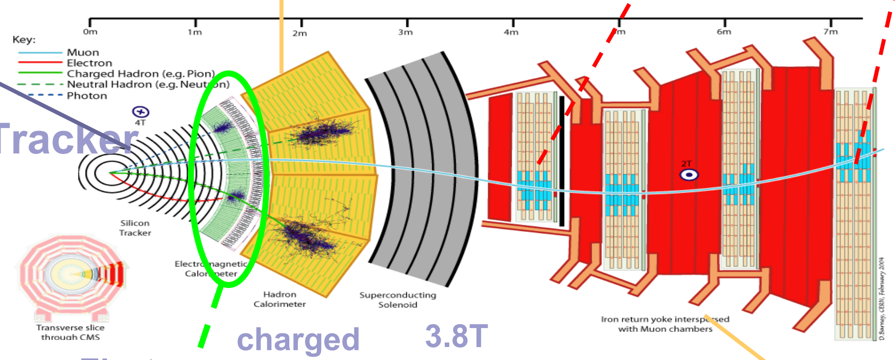




Barrel & EC: Brass/Fe +Scintillator
Fwd Cal: Steel + quartz fibers

$$\frac{\sigma(E)}{E} = \frac{85\%}{\sqrt{E}} + 8\% \quad \left(\frac{110\%}{\sqrt{E}} + 4\%\right)$$

$|\eta|<1.5$ $(1.3<\eta<3.0)$



Electrons
Photons

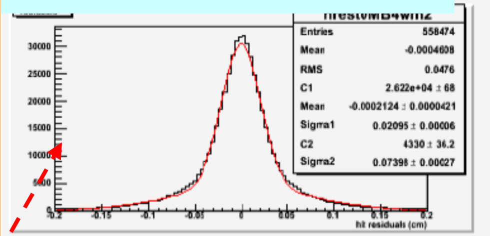
charged
Pions
Protons
Neutrons

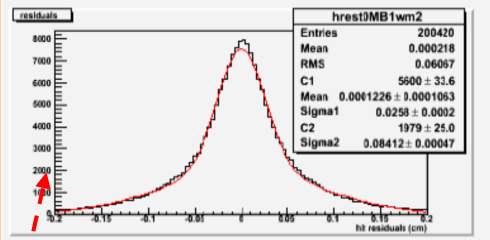
3.8T
Solenoid

Iron return
Muons

ECAL
ROME GROUP

Barrel DT residual

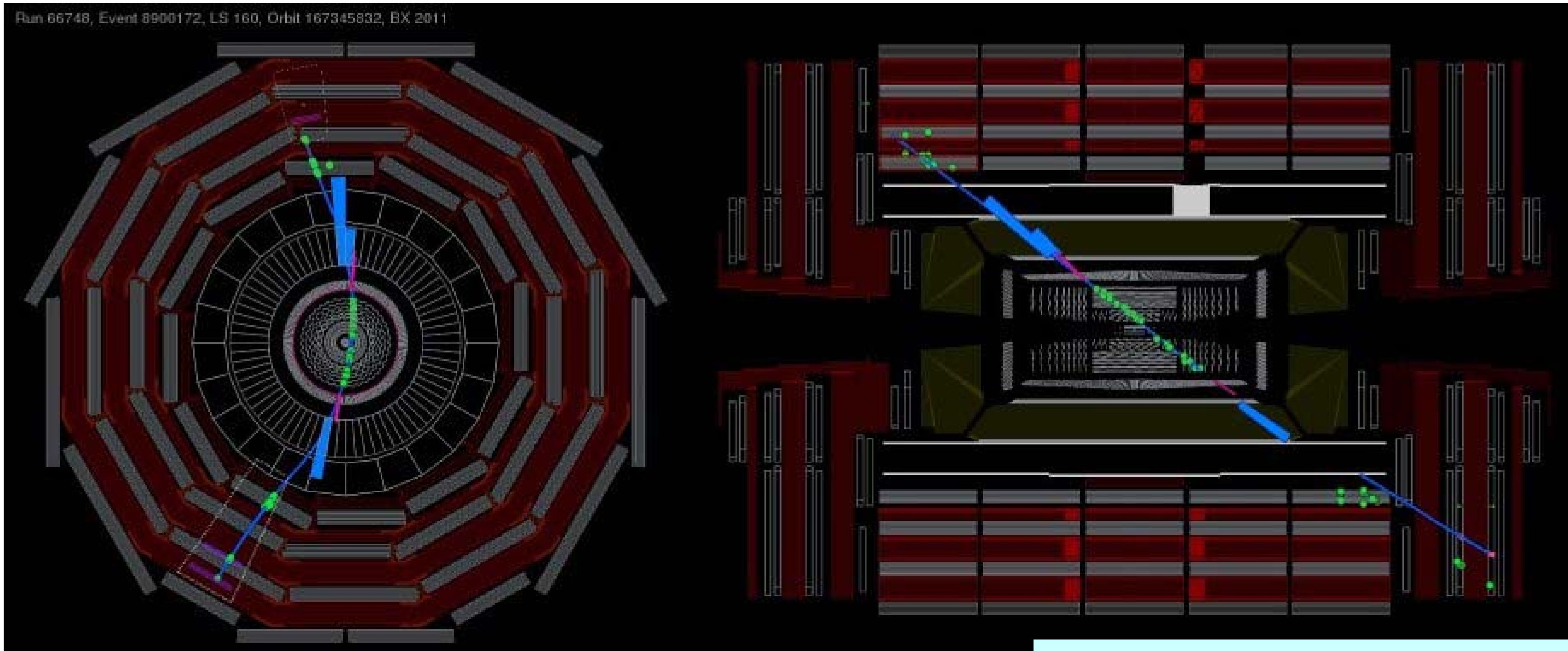




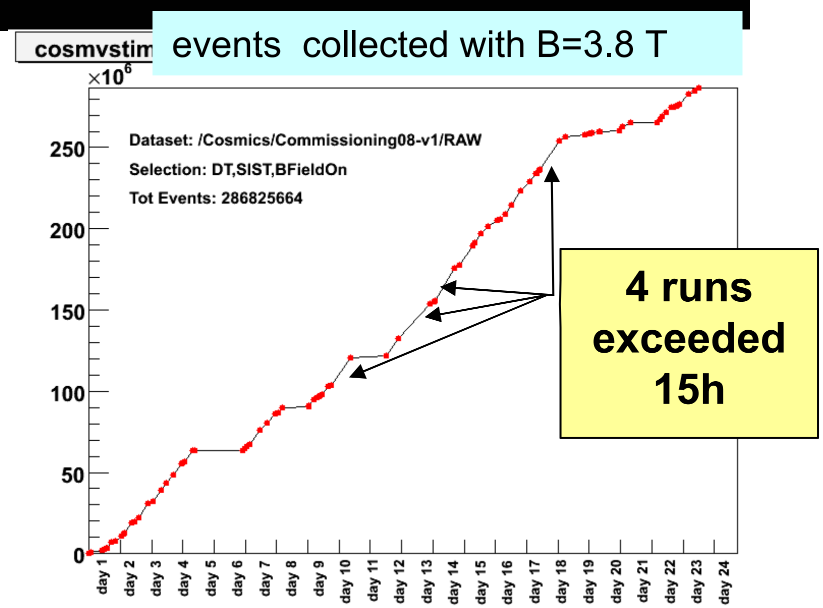
Barrel: Drift Tubes + RPC
EndCaps: CSC + RPC

Standalone resol.
9% @ 200GeV
15-40% @1TeV
Combined with tracker:
~5% @ 1 TeV

Cosmic Run at Four Tesla (CRAFT)



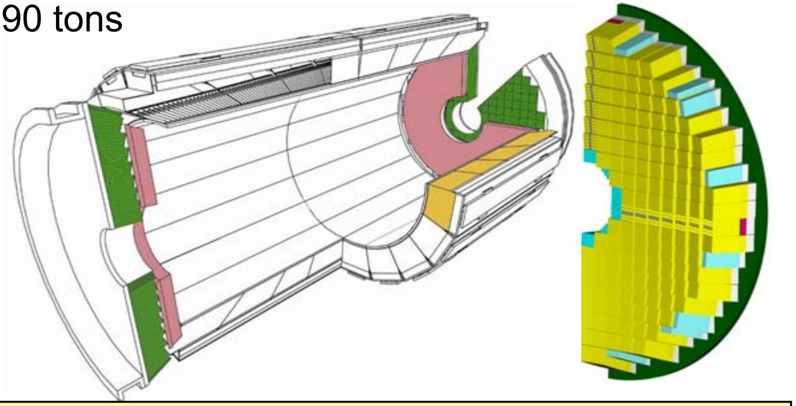
- CMS ran for 4 weeks continuously to gain operational experience
- Study effects of B field on detector components
- 370M cosmic events collected (290M with B = 3.8 T)
- good overall efficiency
- successful integration of all components

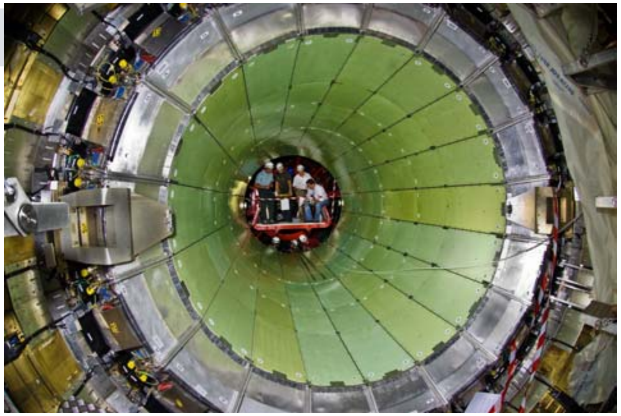


Electromagnetic Calorimeter

ECAL: Homogeneous crystal calorimeter

- $PbWO_4$ ~10 m^3, 90 tons





Barrel:
- $|\eta| < 1.48$
- 36 SuperModules
- 61200 crystals
- 2.2 x 2.2 x 23 cm^3

EndCaps:
- $1.48 < |\eta| < 3.0$
- 4 Dee's
- 14648 crystals
- 3 x 3 x 22 cm^3

Optimized for $H \to \gamma\gamma$ discovery, (SM Higgs with $m_H < 120$ GeV/c^2) with $\leq 10\ fb^{-1}$
==> goal $\sigma(E)/E \cong 0.5\%$ at high energies

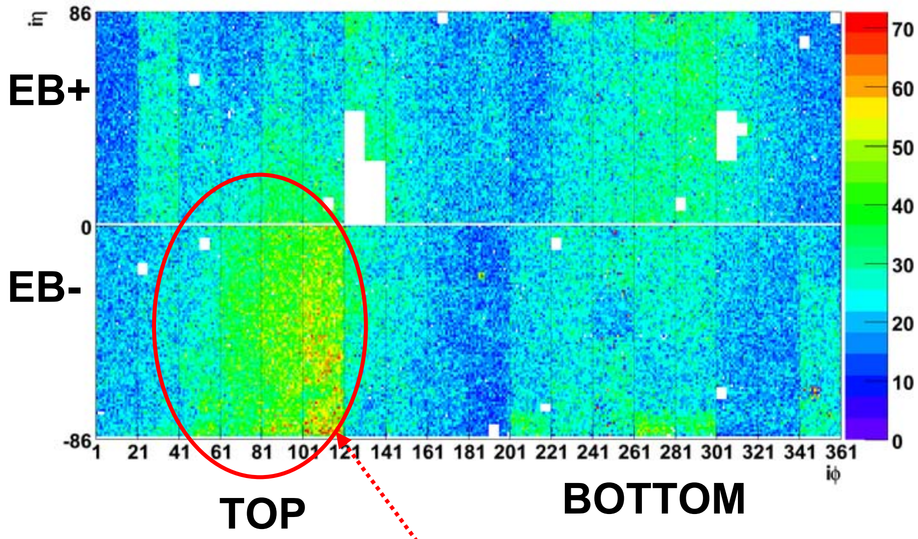
ECAL Deputy Project Manager: M. Diemoz

Rome group activities in the ECAL project:
- R&D/construction/test/commissioning (Barrel)
- HV: design/realization/monitoring
- Data Base (construction/configuration/condition)
- ECAL Calibration and Data Quality Monitoring
- Calibration at Tier2 Roma (physics calibration channels)

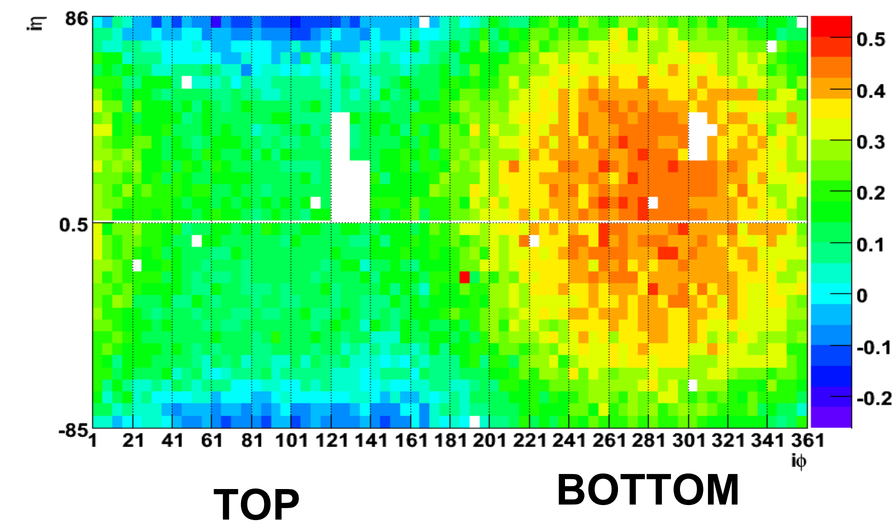
Rome group responsibilities :
- ECAL Editorial Board: E. Longo
- ECAL HV: E. Di Marco
- ECAL DQM: E. Di Marco
- ECAL Data Base: F. Cavallari
- ECAL calibration: R. Paramatti
- T2 Rome: L.M. Barone

Cluster occupancy and time

cluster occupancy (η vs ϕ map)



average cluster time (η vs ϕ map)

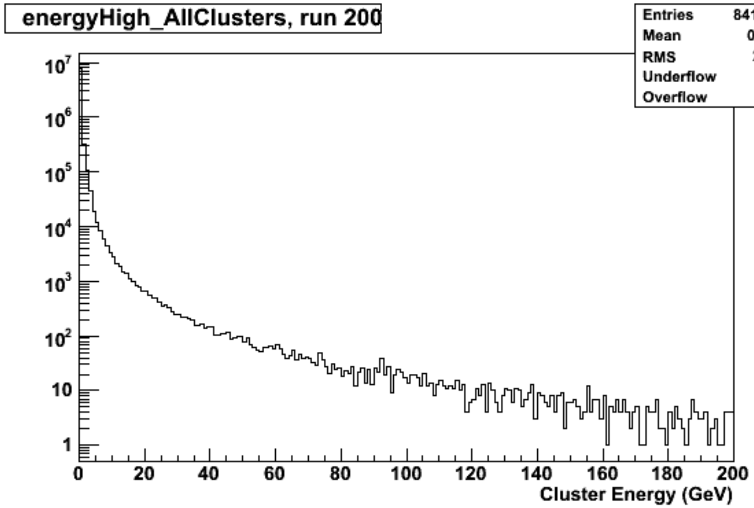


- Top and bottom regions more populated due to vertical cosmic rays flux
- excess in the top EB- region, in correspondence of the shaft
- white regions: masked towers
- some low voltage problems (being resolved)

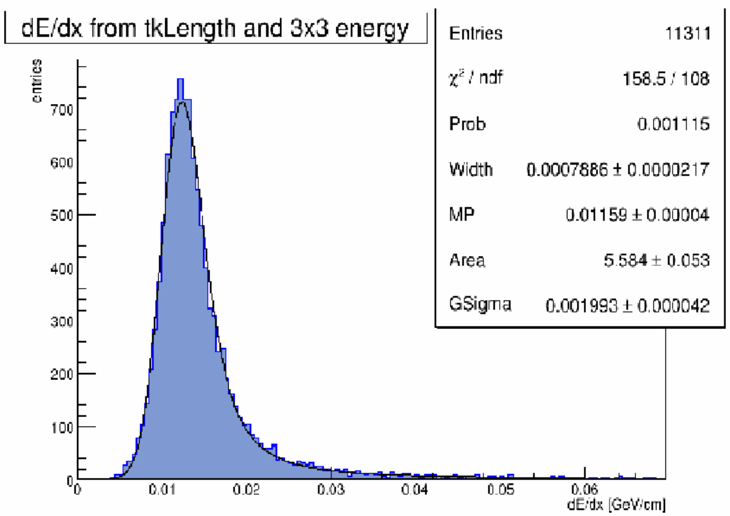
- Time measured in clock unit (25 ns) w.r.t. nominal setting for collisions
- Observed delays due to time of flight

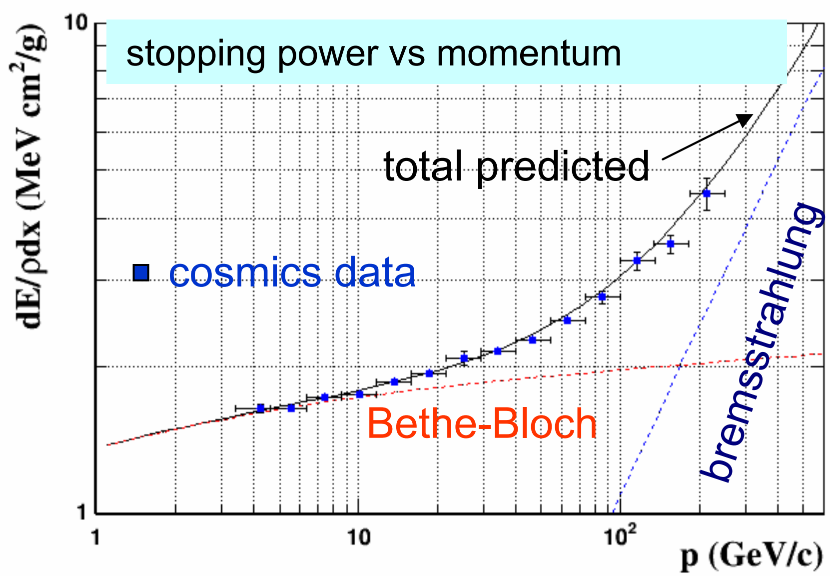
Energy spectrum

Energy deposited in the ECAL in cosmic runs.
APD gain set to 200 (x4 normal operation)



Corresponding measured de/dx.
tracks selected with the muon system





- Momentum from track reconstruction in ID
- Energy measured in the ECAL cluster matched to the track
- Very good agreement with expectations

==> both momentum end energy scale OK
==> simultaneous check of tracking reconstruction and crystals calibration
(performed with electron beams before installation)

ECAL energy calibration

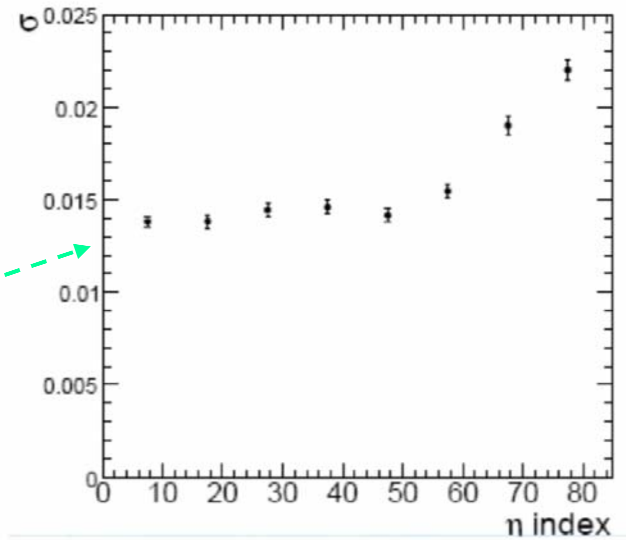
$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

- Energy resolution at high energies dominated by constant term
  ==> channel-to-channel intercalibration is essential
- Several steps and procedures
  - ¼ of Barrel calibrated with electron beams, σ/E ~0.3%
  - the rest of Barrel is being calibrated with cosmics: ~1.5-2.5% depending on η
  - EC calibrated at ~9% with light yield measurements

  } done
- calibration with beams
  - beam halo for EC ==> ~2-3%
  - $\pi^0 \rightarrow \gamma\gamma$, $Z \rightarrow ee$, and azimuthal symmetry of energy deposit of MB events

  } first data
- isolated electrons, $Z \rightarrow \mu\mu\gamma$ ⟶ longer term

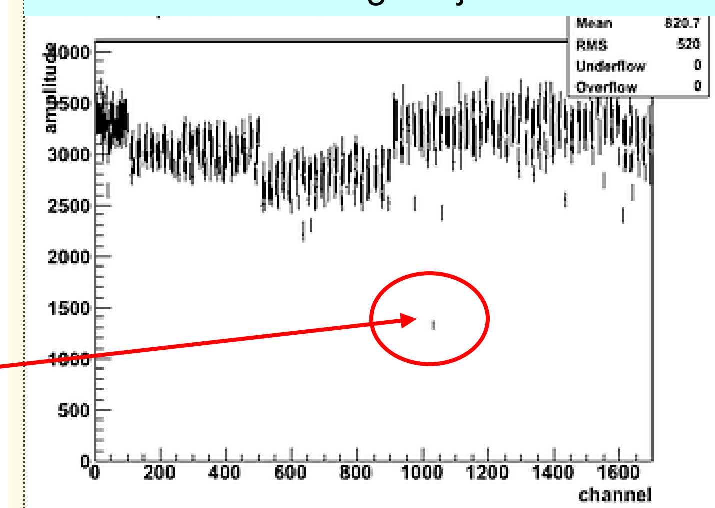
Barrel intercalibration *vs* η with cosmics



Control of crystal transparency with laser:

- crystal transparency reduced with time during LHC operation, recover in a few hours
- laser light injected into crystal, during LHC abort gaps
- get corrections to the crystals response
- spot problematic channels

monitoring of crystal response in a Barrel half-SM with laser light injection

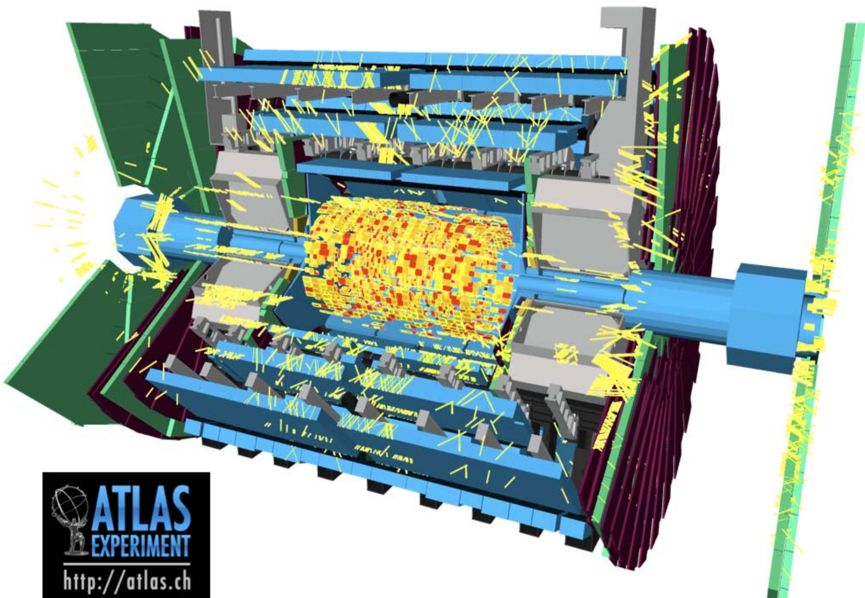


first beams in LHC

Not only cosmic rays….

BEAM SPLASH events recorded

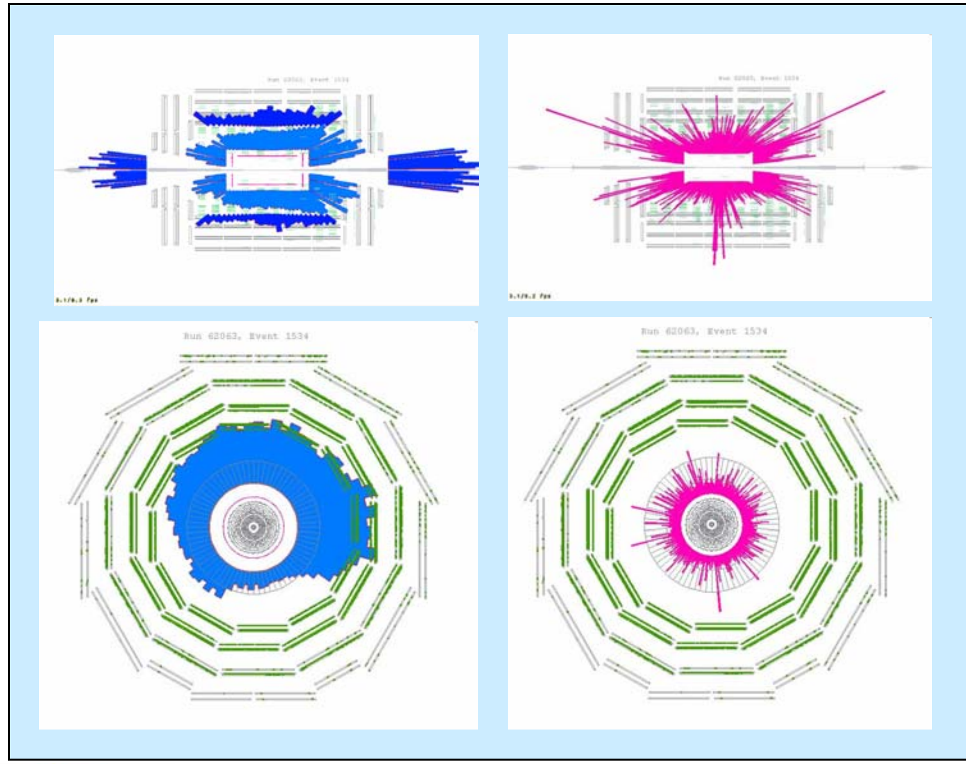
ATLAS offline event display

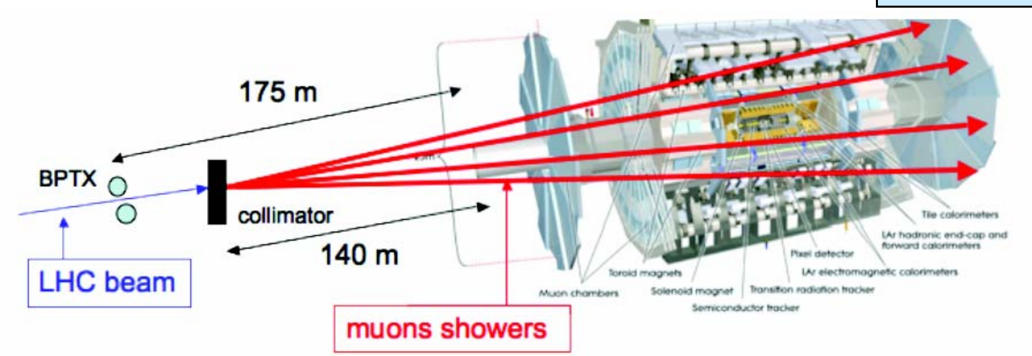


first beam event seen in ATLAS

10:19am on September 10, 2008

CMS event display



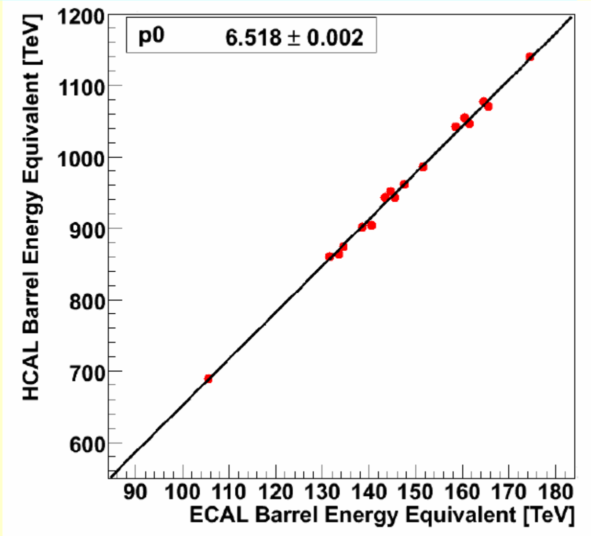


~2x10^9 protons on collimators located ~150m upstream

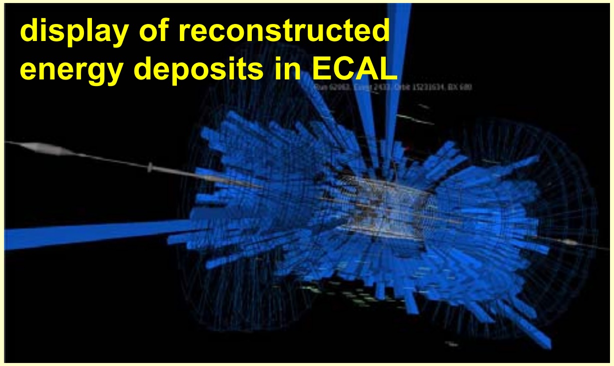
Example of use of single beam runs

CMS

total HCAL vs ECAL energy

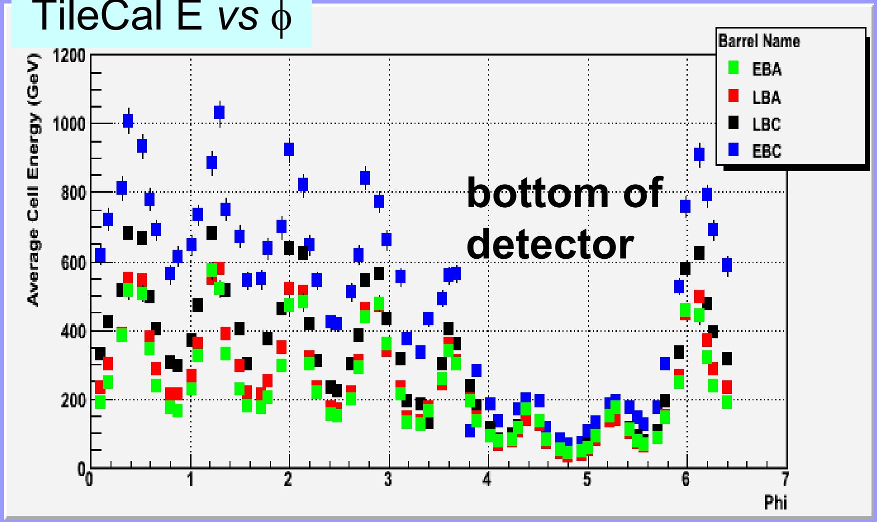


- check linearity of energy deposit in the calorimeters, from splash events



ATLAS

TileCal E *vs* ϕ



- Energy deposit in the Barrel TileCal from beam splash
- Note the 8-fold structure in phi corresponding to end-cap toroid coils
- Similar effect observed in EM LAr calorimeter

detector upgrades for S-LHC

LHC upgrade plan

- LHC designed for $L_{max}=10^{34}$ $cm^{-2}s^{-1}$
- Shutdown winter 2013-14: Phase-I
  - new Linac, brighter beam, ultimate current
  - new large-aperture focusing quadrupoles: β=55cm-->25cm
  - L_{max} = $3x10^{34}$ $cm^{-2}s^{-1}$
- 2018: long shutdown for Phase-II
  - new injectors + IR upgrade
  - L_{max} = 10^{35} $cm^{-2}s^{-1}$
  - major upgrade of the experiments

Goal: collect >3ab^{-1}
challenge: L_{max} = 10^{35} $\rightarrow$ ~300 minimum bias events/BC

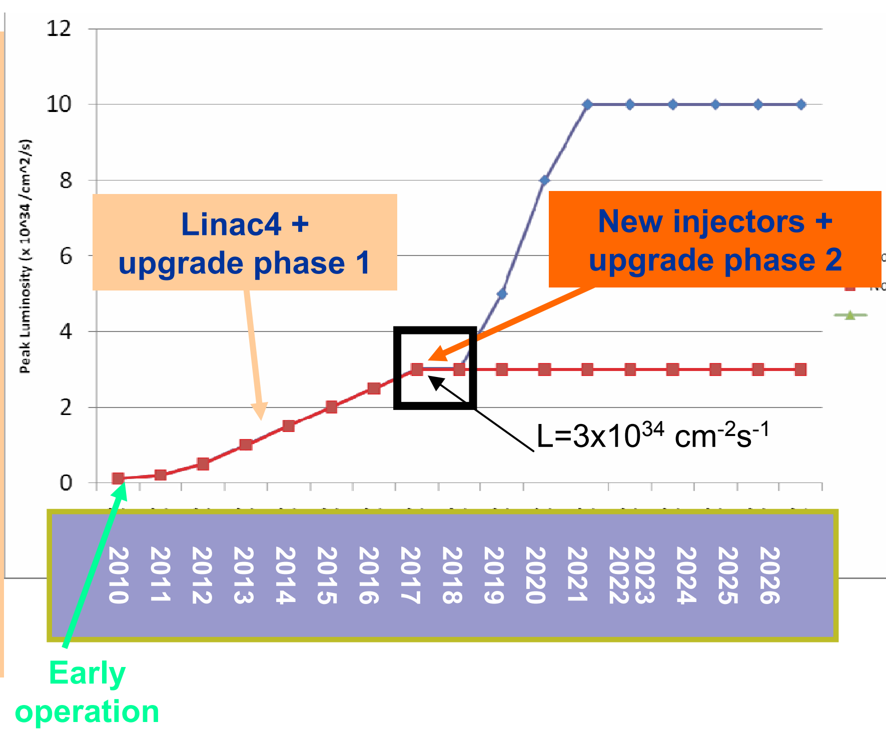
PHASE I

CMS

- replace pixel detector (4 layers)

ATLAS

- insert a new layer closer to beam pipe
- reinforce inner μ-station with a thin detector



PHASE II

CMS

- new Inner Tracker
- calorimeters: new electronic and part of photon detectors
- new trigger scheme
- μ-system OK

ATLAS

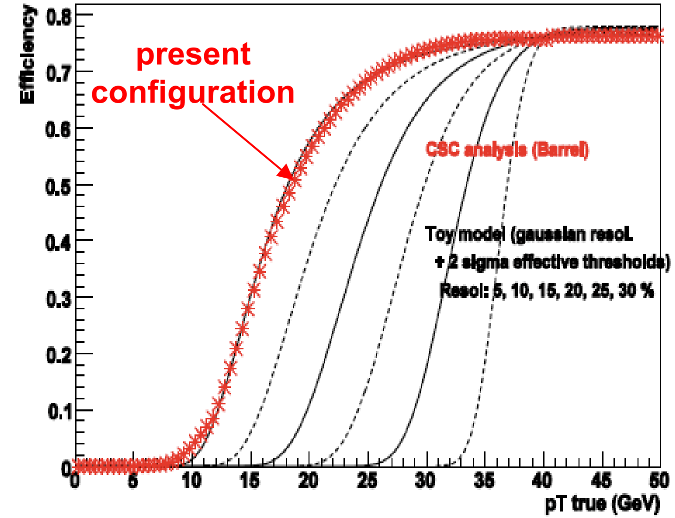
- new ID (all silicon)
- calorimeters: new electronic and possible replacement of Fwd-LAR
- μ-system and trigger to be largely upgraded : several technologies under study

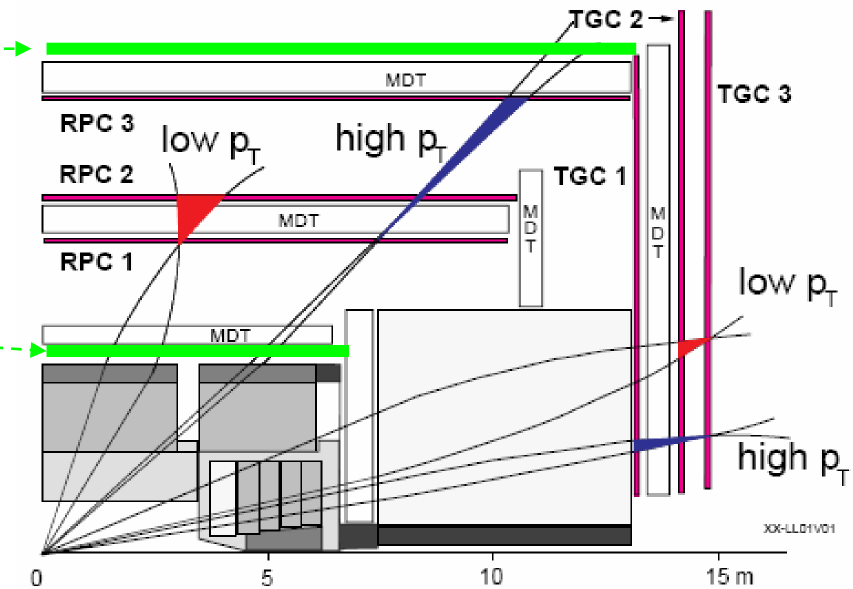
Phase-II: ATLAS muon system upgrades

- Aircore toroid does not provid shielding:
  - Severe problems in forward regions
  - ==> Replace Small Wheel, maybe inner part of Big Wheel, add shielding
  - Intervention needed also in the Barrel at least for triggering upgrade (threshold sharpening)
  - Study in progress by many groups

- Barrel upgrade for trigger threshold sharpening
  - presently trigger roads enlarged because of *pp* collision spread along *z*
  - ==>inclusive muon rates will be about 100 kHz @20 GeV and 50 kHz @40 GeV
  - adding a trigger layer at BI eliminate the collision spread
  - for 40GeV PT, outer layer cone size is reduced from ±1.5 to ±1 strip
  - under study also the addition of an extra layer on outer chambers

Trigger efficiency for p_T^{cut} = 40 GeV





Conclusions

- The LHC accident on September 19th, delayed of about one year the begin of this exciting adventure
- However the experiments are not sitting and waiting
- Installation and/or commissioning of all systems is being finalized
- Hundreds of millions of cosmic ray events have been collected
  - setting up/testing of:
    - the entire Trigger&DAQ chain
    - detector control and monitoring
    - calibration procedures
    - data quality
    - integration of the various subsystems
    - …..

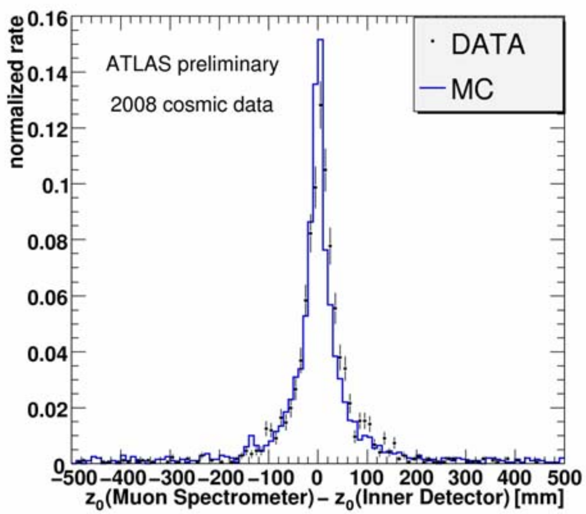
- All experiments are on track to be fully operational for the first collisions that will be provided by LHC at the end of the year
- The search for the unknown can begin!

BACKUP SLIDES

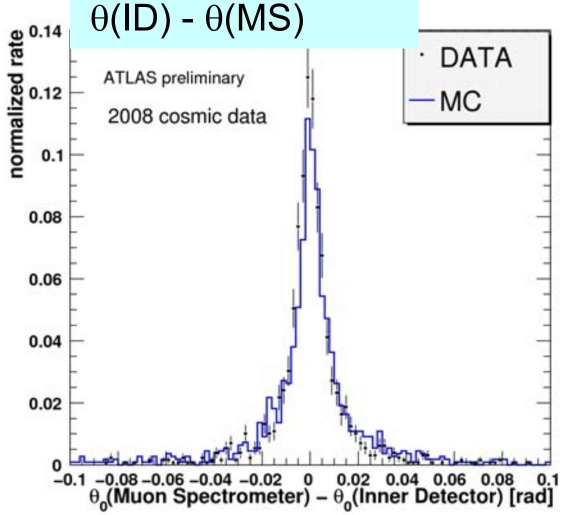
combined performance from cosmics

- compare fitted parameters of tracks reconstructed in the ID and in the MS (standalone)
- reasonable agreement with MC

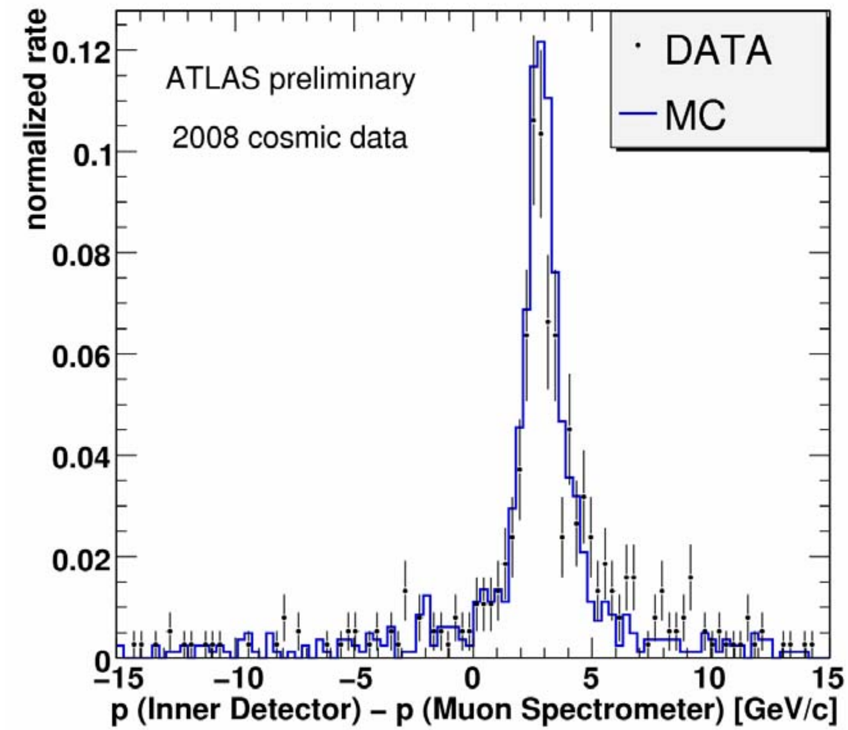
z_0(ID) - z_0(MS)



θ(ID) - θ(MS)



p(ID) - p(MS) for bottom sectors



Δp between ID and MS gives a measurement of energy absorbed by the calorimeters
==> it averages at ~3 GeV