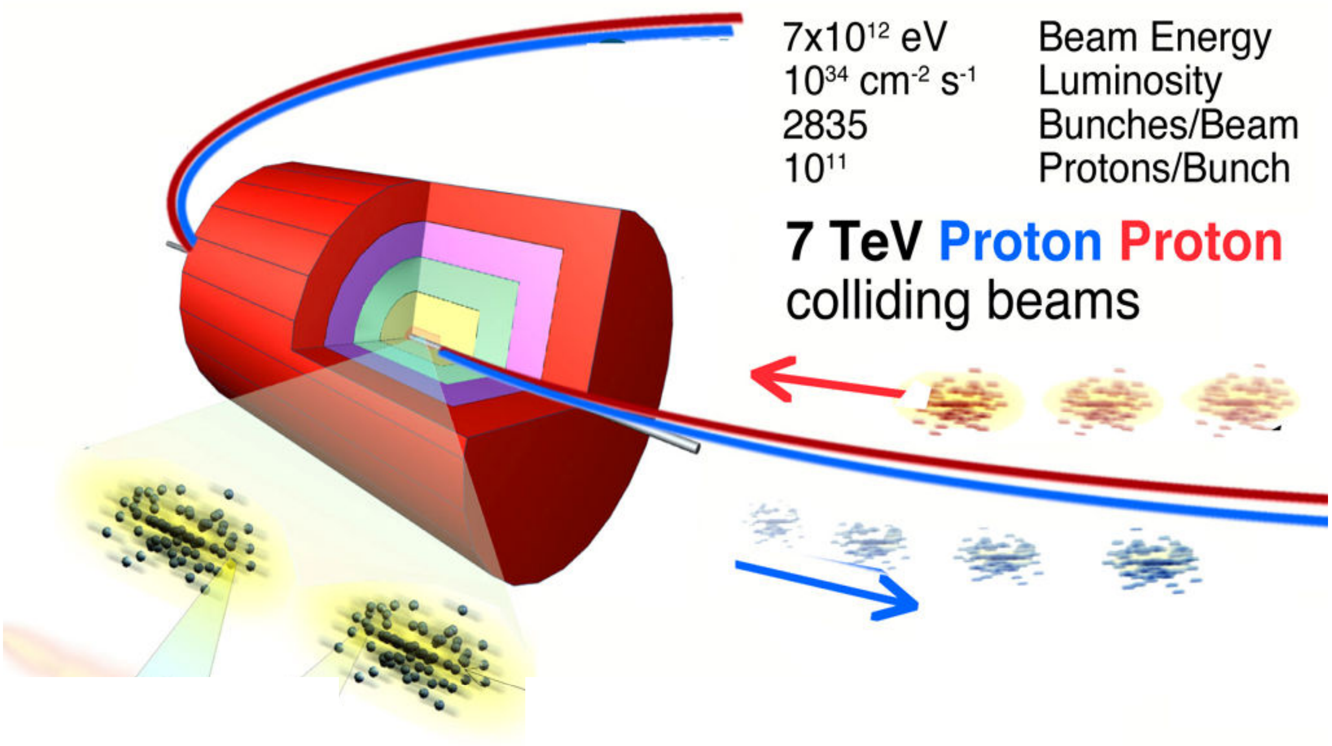


Installation, Commissioning and Startup of ATLAS & CMS Experiments

Collider Luminosity

The event rate R that we measure in a collider is proportional to the interaction cross section σ_{int} and the factor of proportionality is called the *luminosity*

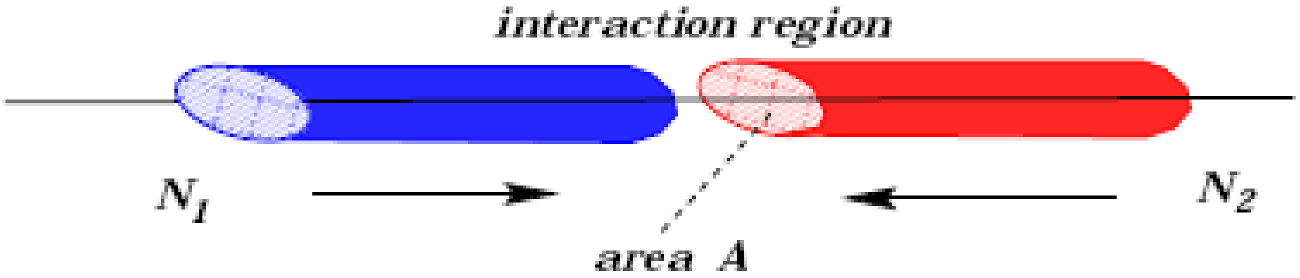
$$R = \mathscr{L}\sigma_{\text{int}} \; .$$

If two bunches containing n_1 and n_2 particles collide with frequency f, the luminosity is

$$\mathscr{L} = f\frac{n_1 n_2}{4\pi\sigma_x\sigma_y}$$

COLLIDER

PHYSICS



`http://pdg.lbl.gov/` ACCELERATOR PHYSICS OF COLLIDERS

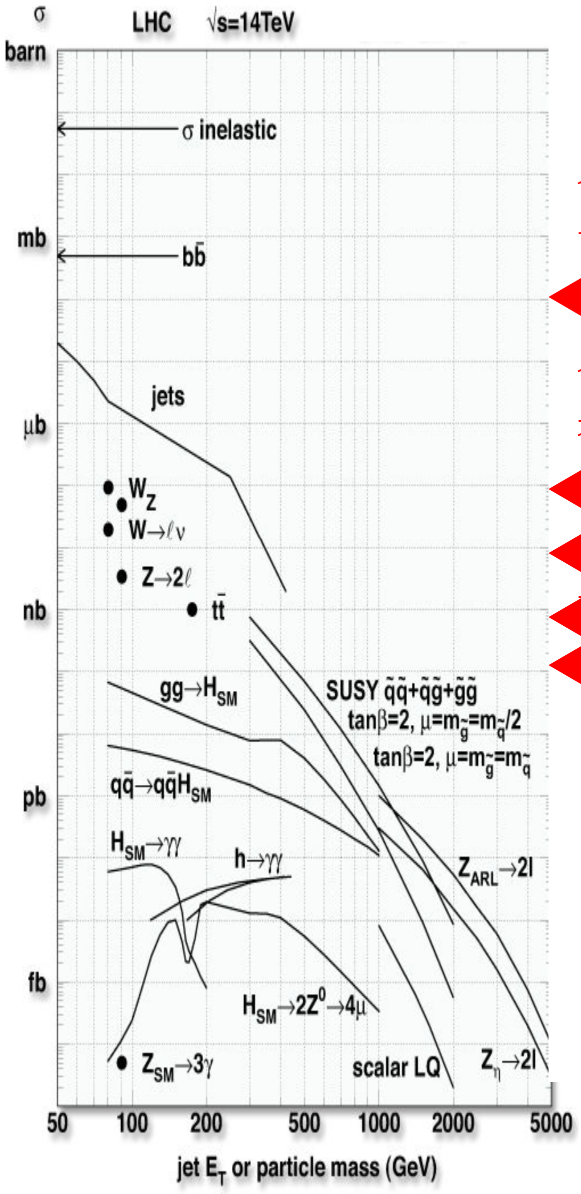
Collider Luminosity

Luminosity is measured in units of length^{-2} * time^{-1}

Typical collider values are in the range of

$10^{30\pm\text{units}}\ \text{cm}^{-2}\ \text{sec}^{-1}$

Search for new phenomena at LHC



10^{28} Startup

1 event/s

10^{31} First months

10^{32} First year

1 event/s

10^{33} Good machine

1 event/s

10^{34} Design Lumi

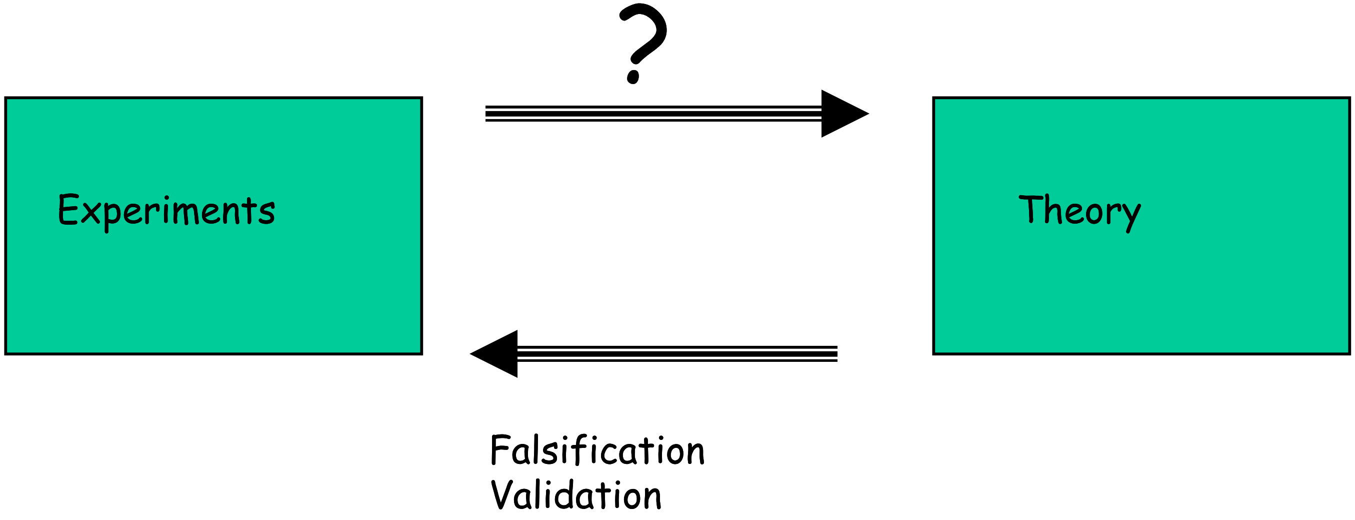
1 event/s

1 event/s

Luminosity is like money: the more you have the better

How do we measure these phenomena ?

How physicists go from the "basic ideas of measuring some quantities" to the "design and constructions and operation of large scale experiments".



?

Experiments

Theory

Falsification
Validation

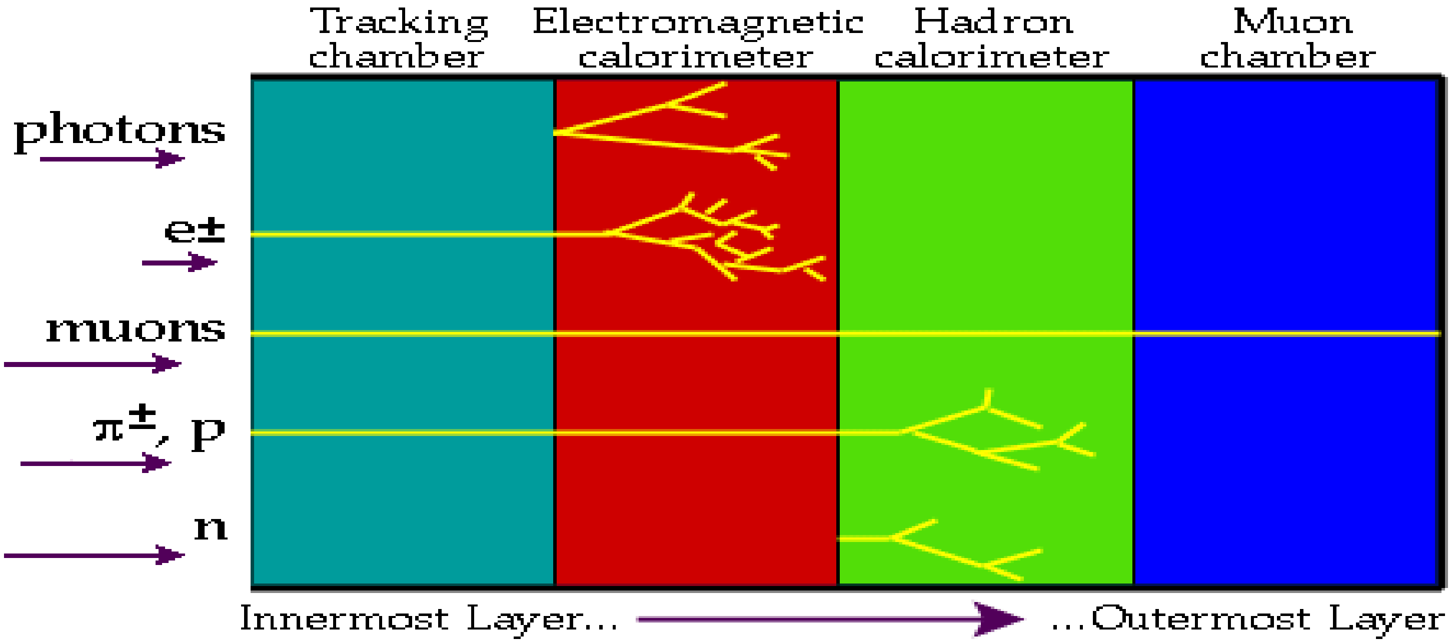
Theory and Experiments

- Exp: Particles have masses: …..why ?
- Theo: Mass is given by the interaction with the Higgs field
- Exp: Find the Higgs Boson

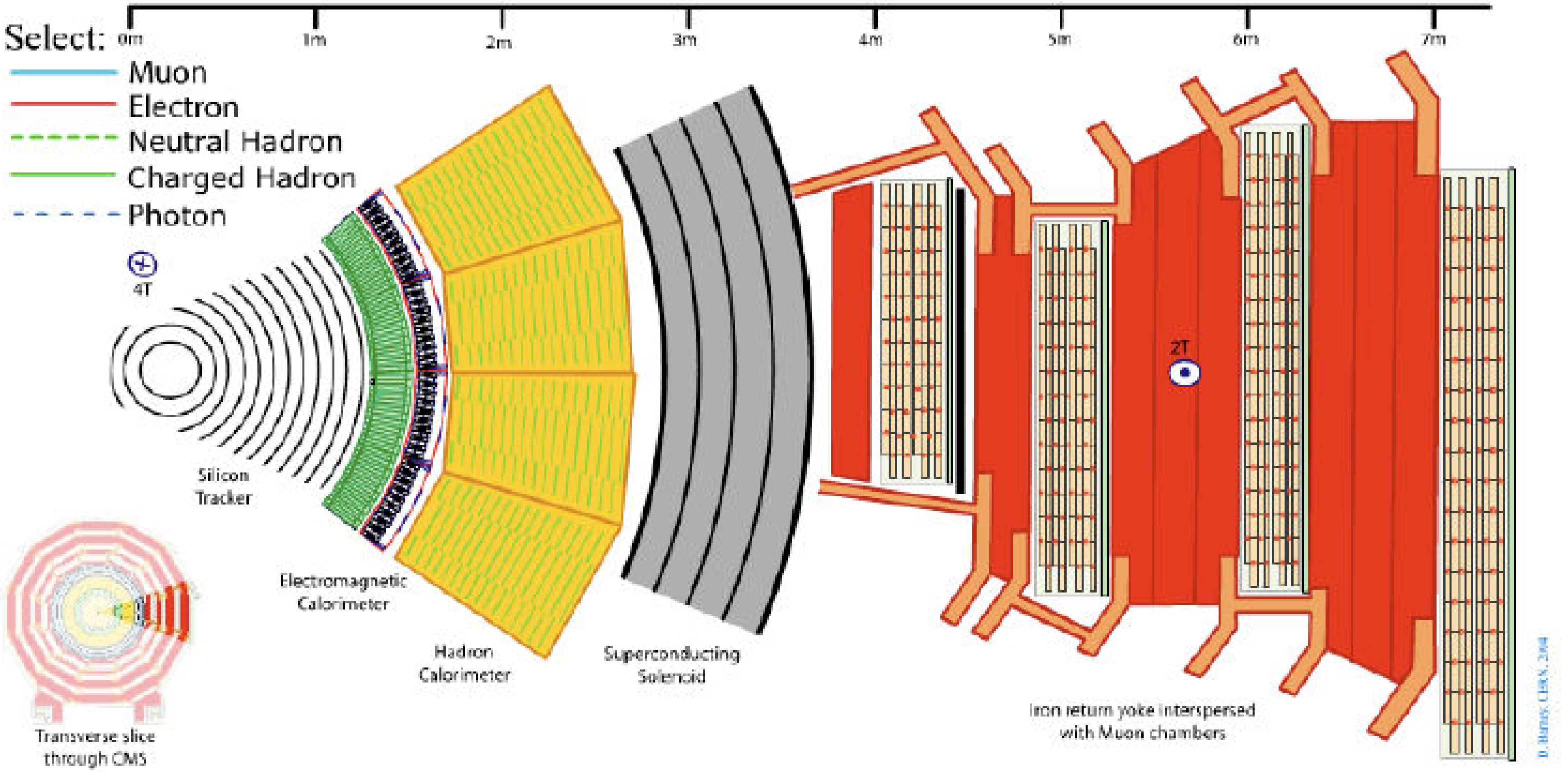
- Exp: There are 3 Forces: ……why ?
- Theo: Super Symmetry unifies the Forces
- Exp: Find the signals of Super Symmetry

Basic detector

New physics will be detected by the production of NEW PARTICLES. These particles will disintegrate in very short time (10^{-24} s) and we will detect their decay products. The particles that we will detect are particles with "long-life-time". The LHC detectors are designed to record the largest possible amount of information about these final state particles.

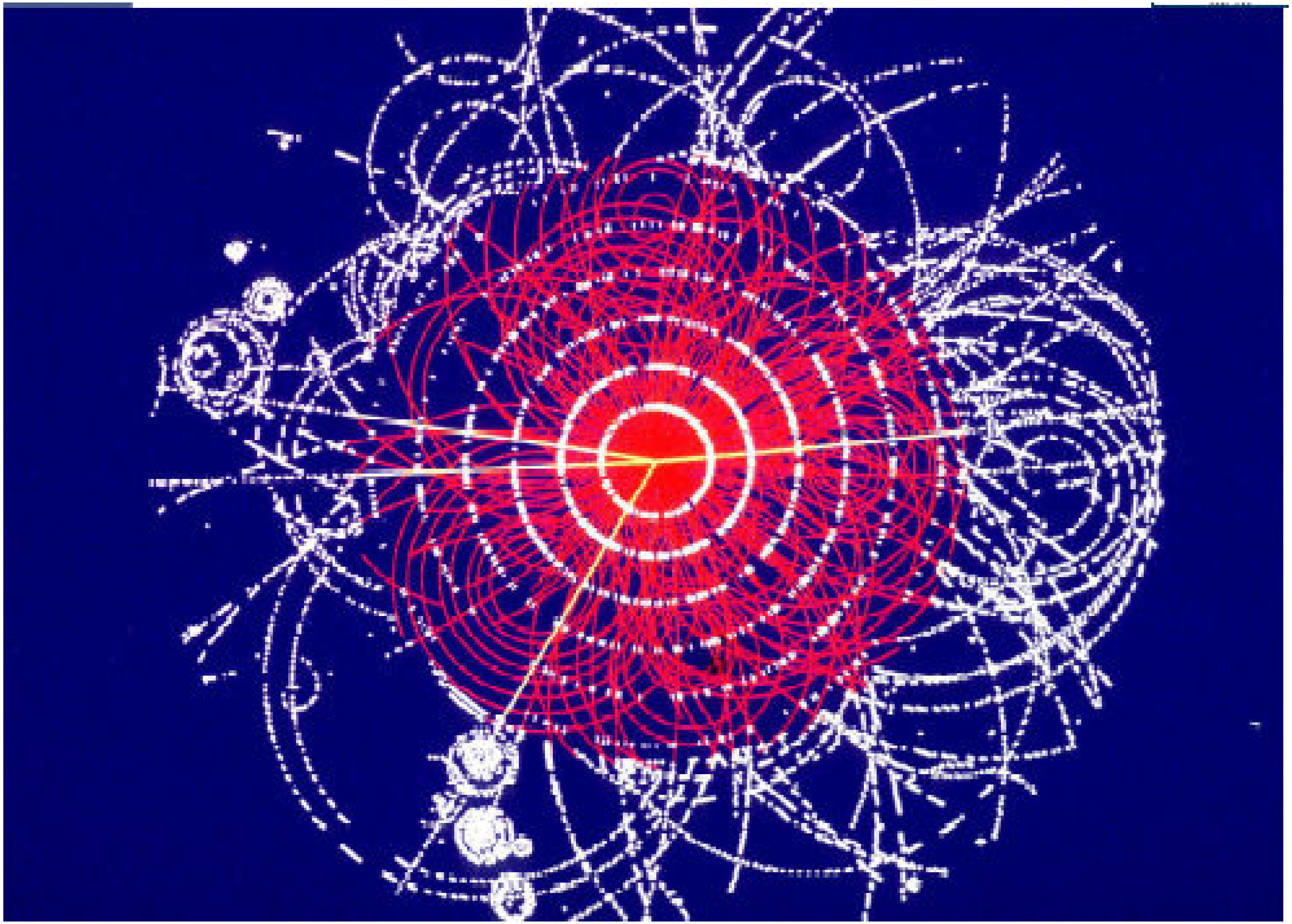


CMS SLICE



http://cms.web.cern.ch/cms/Resources/Website/Media/Videos/Animations/files/CMS_Slice.swf

Simulation of an Higgs Boson decay in ATLAS



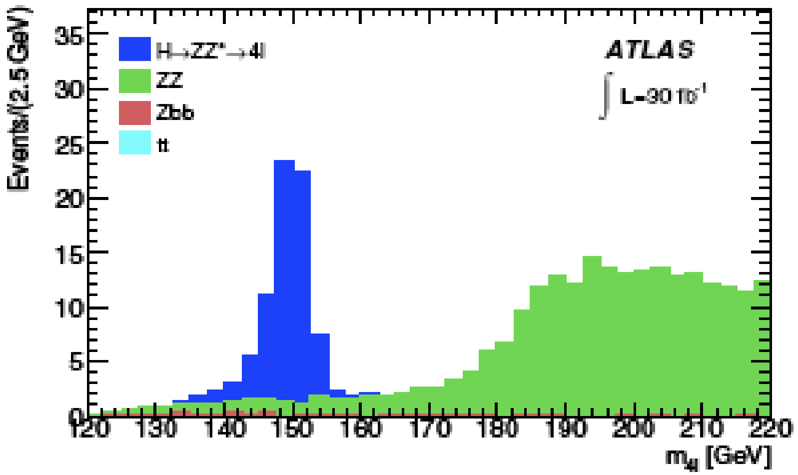
$H \rightarrow ZZ \rightarrow \mu\mu ee$

Detecting the Higgs Boson

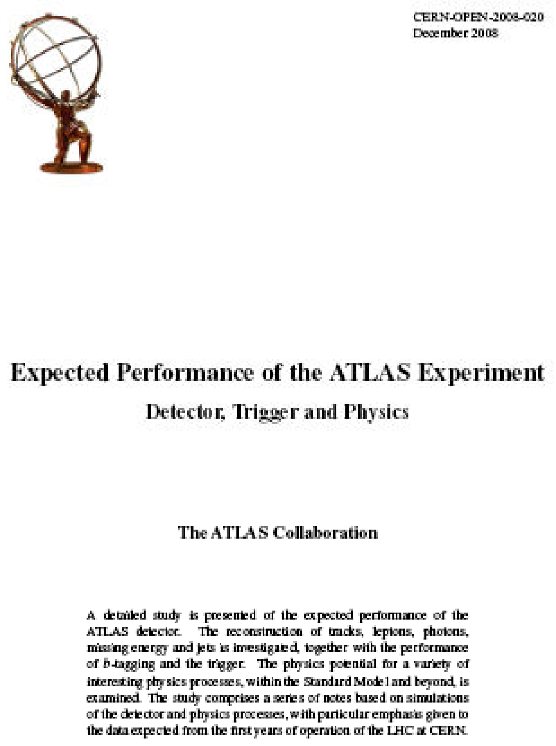
- IF the Higgs boson exists
- IF LHC gives large Luminosity for long time
- IF you have built a performing detector
- IF you have been able to record the events at high rate
- IF you are able to reconstruct correctly the events
- IF you have aligned and calibrated your detector
- IF you have understood your muon and electron identification
- IF you are able to run the detector under stable conditions for long time

- ……. then …… after years of hard work

30fb^{-1} 1year at L= 10^{33} cm^{-2} s^{-1}



ATLAS and CMS Physics Program



CERN-OPEN-2008-020
December 2008

Expected Performance of the ATLAS Experiment

Detector, Trigger and Physics

The ATLAS Collaboration

A detailed study is presented of the expected performance of the ATLAS detector. The reconstruction of tracks, leptons, photons, missing energy and jets is investigated, together with the performance of *b*-tagging and the trigger. The physics potential for a variety of interesting physics processes, within the Standard Model and beyond, is examined. The study comprises a series of notes based on simulations of the detector and physics processes, with particular emphasis given to the data expected from the first years of operation of the LHC at CERN.

http://cdsweb.cern.ch/record/1125884?ln=en

IOP PUBLISHING JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS

J. Phys. G: Nucl. Part. Phys. 34 (2007) 995–1579 doi:10.1088/0954-3899/34/6/S01

CMS Physics Technical Design Report,
Volume II: Physics Performance

The CMS Collaboration

Received 3 January 2007
Published 20 April 2007
Online at stacks.iop.org/JPhysG/34/995

Abstract

CMS is a general purpose experiment, designed to study the physics of pp collisions at 14 TeV at the Large Hadron Collider (LHC). It currently involves more than 2000 physicists from more than 150 institutes and 37 countries. The LHC will provide extraordinary opportunities for particle physics based on its unprecedented collision energy and luminosity when it begins operation in 2007.

The principal aim of this report is to present the strategy of CMS to explore the rich physics programme offered by the LHC. This volume demonstrates the physics capability of the CMS experiment. The prime goals of CMS are to explore physics at the TeV scale and to study the mechanism of electroweak symmetry breaking—through the discovery of the Higgs particle or otherwise. To carry out this task, CMS must be prepared to search for new particles, such as the Higgs boson or supersymmetric partners of the Standard Model particles, from the start-up of the LHC since new physics at the TeV scale may manifest itself with modest data samples of the order of a few fb^{-1} or less.

The analysis tools that have been developed are applied to study in great detail and with all the methodology of performing an analysis on CMS data specific benchmark processes upon which to gauge the performance of CMS. These processes cover several Higgs boson decay channels, the production and decay of new particles such as Z' and supersymmetric particles, B_s production and processes in heavy ion collisions. The simulation of these benchmark processes includes subtle effects such as possible detector miscalibration and misalignment. Besides these benchmark processes, the physics reach of CMS is studied for a large number of signatures arising in the Standard Model and also in theories beyond the Standard Model for integrated luminosities ranging from 1 fb^{-1} to 30 fb^{-1}. The Standard Model processes include QCD,

http://www.iop.org/EJ/abstract/0954-3899/34/6/S01/

production and decay of the Higgs particle is studied for many observable decays, and the precision with which the Higgs boson properties can be derived is determined. About ten different supersymmetry benchmark points are analysed using full simulation. The CMS discovery reach is evaluated in the SUSY parameter space covering a large variety of decay signatures.

0954-3899/07/060995+585$30.00 © 2007 IOP Publishing Ltd Printed in the UK 995

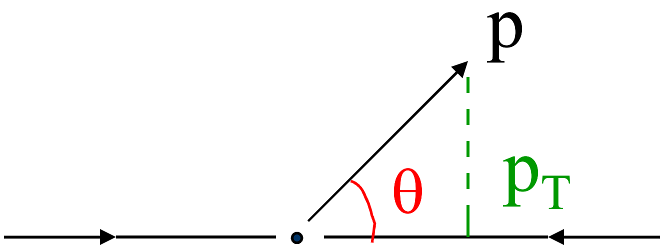
What can be done at the beginning ?

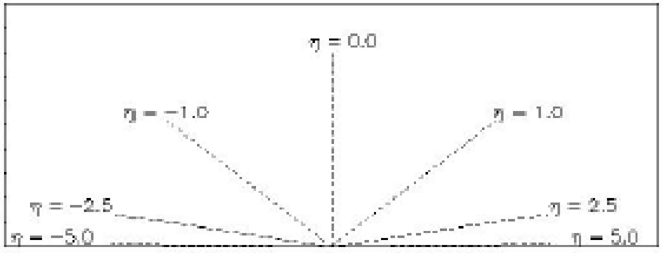
LHC first data from Fall 2009…..

100 pb^{-1} = 6 months at 10^{31} cm^{-2} sec^{-1}
at 50% efficiency we may collect several 100 pb^{-1} during the first LHC run

Channels (examples)	**Events to tape for 100 pb-1**	**Total statistics from previous Colliders**
W→μν	~10^6	~10^4 LEP ~10^6 TEVA.
Z→μμ	~10^5	~10^5 TEVATRON
tt →Wb Wb → μν+X	10^4	10^4 TEVATRON
SUSY ~ mass 500 GeV	10^2	----

Hadronic Collider variables





$$\boxed{p_T = p \sin\theta}$$

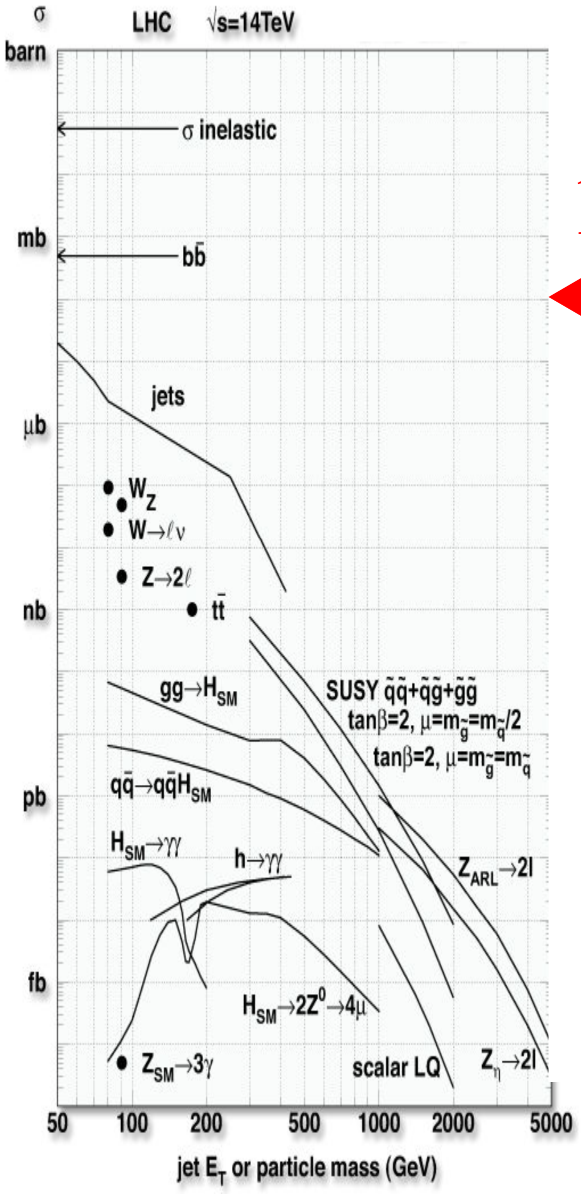
Pseudorapidity:

$\theta = 90^{\circ} \rightarrow \eta = 0$

$\theta = 10^{\circ} \rightarrow \eta \cong 2.4$

$\theta = 170^{\circ} \rightarrow \eta \cong -2.4$

First DAYS

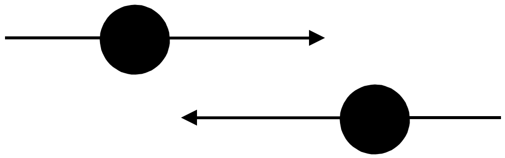


10^{28} Startup

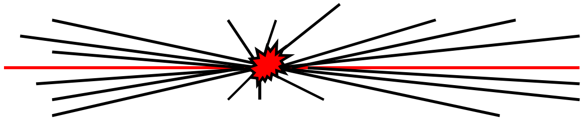
1 event/s

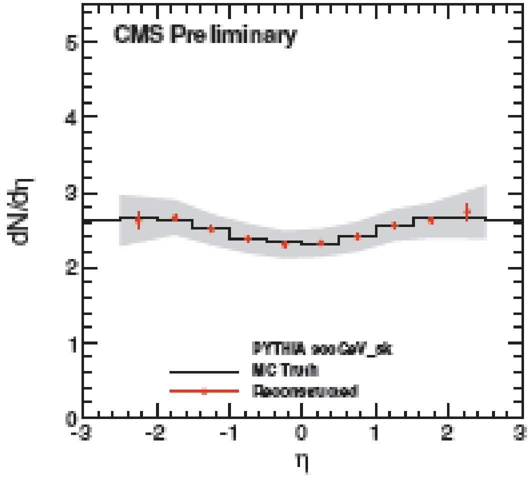
Minimum Bias Events

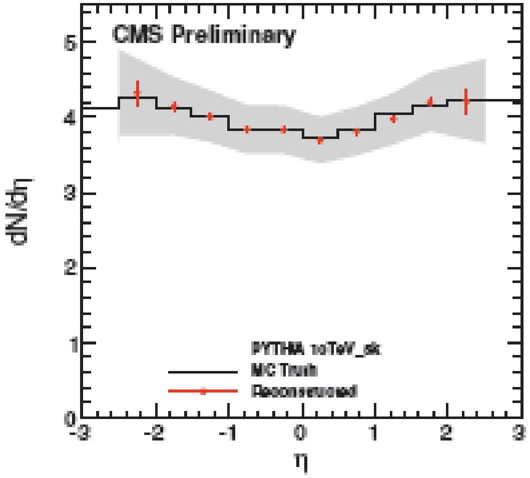
Most interactions are due to collisions at large distance between incoming protons where protons interact as " a whole " → small momentum transfer ($\Delta p \approx \hbar / \Delta x$) → particles in final state have large longitudinal momentum but small transverse momentum (scattering at large angle is small)



Minimum bias events





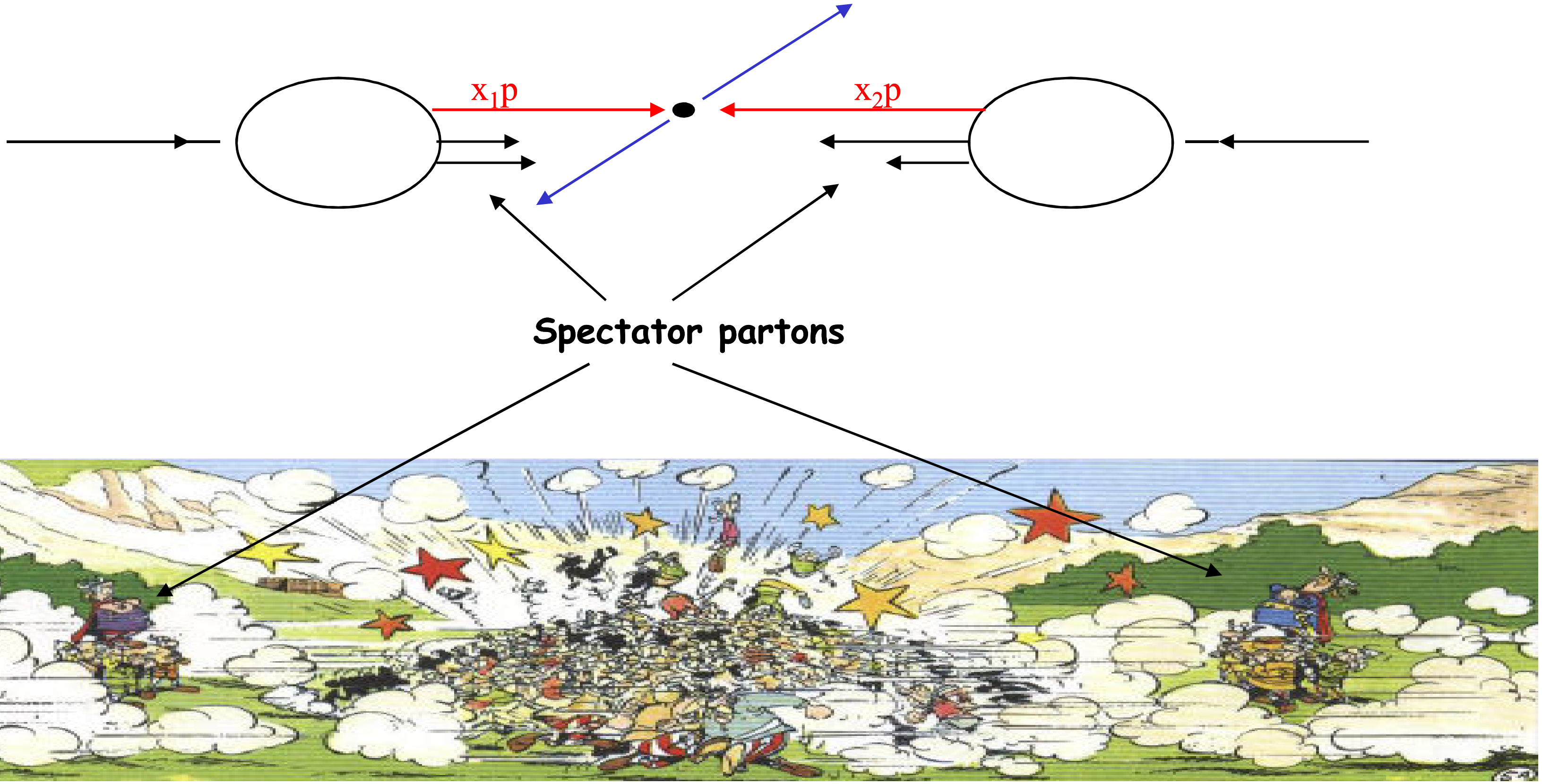


50 mb^{-1}

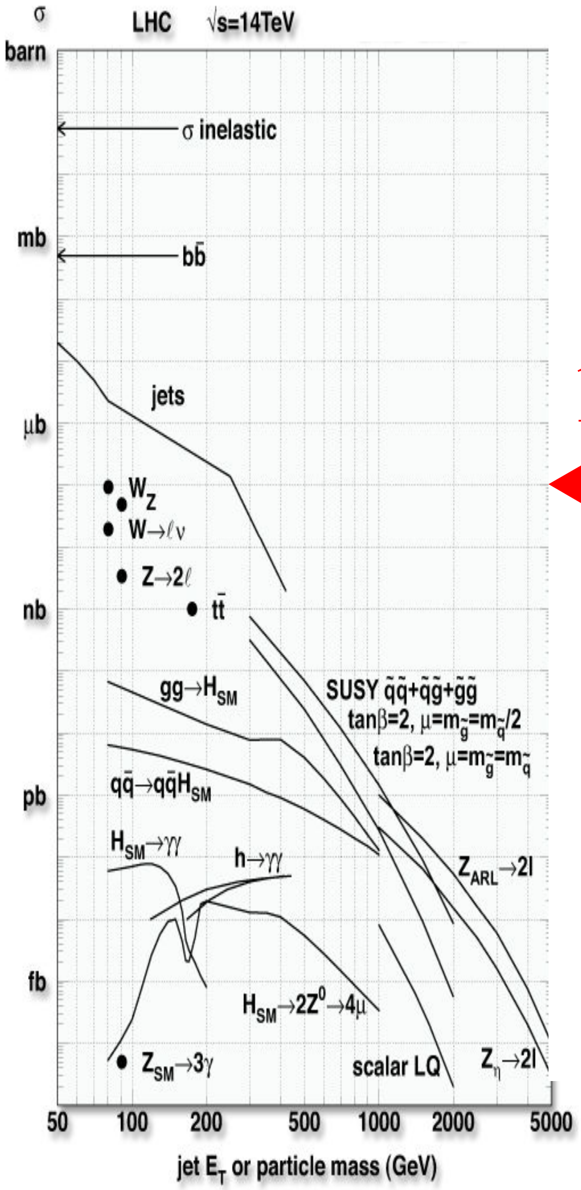
few seconds of data taking

Hard scattering

Monochromatic proton beam can be seen as beam of quarks and gluons with a wide band of energy. Occasionally hard scattering (“ head on”) between constituents of incoming protons occurs.



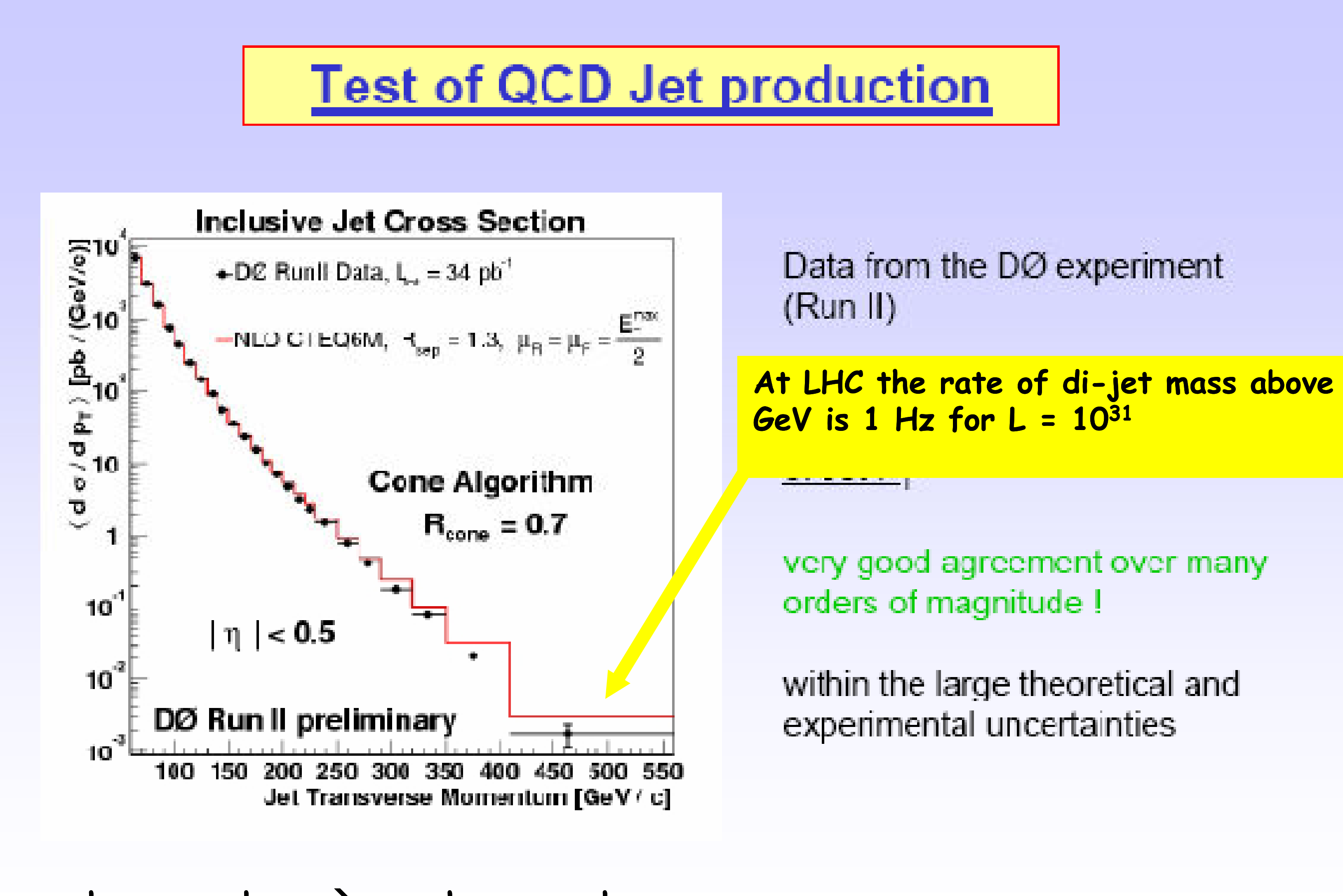
First weeks



10^{31} Startup

1 event/s

JET Production



Test of QCD Jet production

Data from the DØ experiment (Run II)

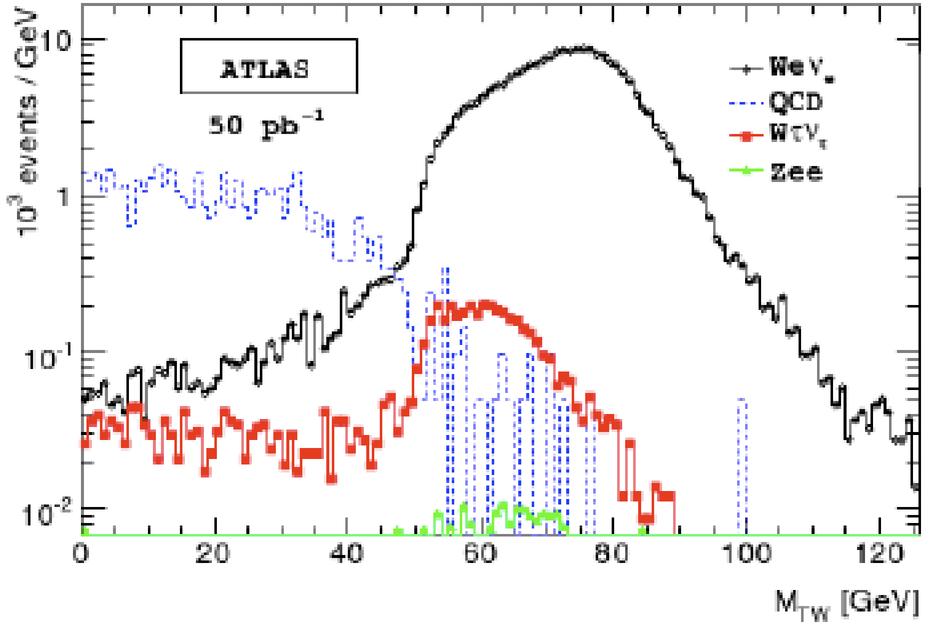
very good agreement over many orders of magnitude !

within the large theoretical and experimental uncertainties

At LHC the rate of di-jet mass above 500 GeV is 1 Hz for L = 10^{31}

parton+parton → parton+parton
parton can be gluon, quark, anti-quark

W and Z production



U-quark +anti-d quark -→ W → e ν

few weeks at 10^{32} cm^{-2} sec^{-1}

Can we do physics since the beginning ?

not likely !

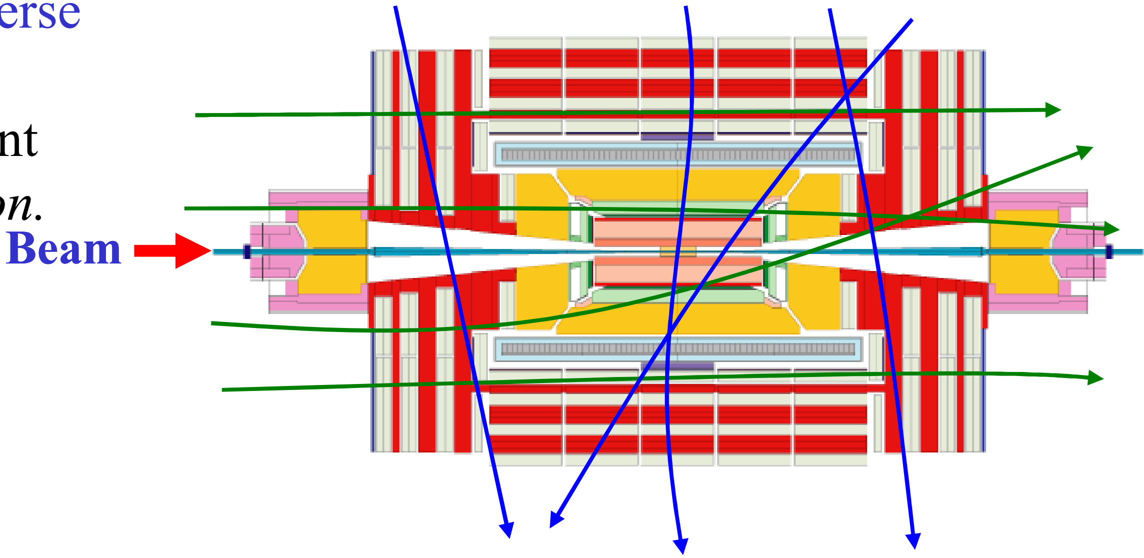
first ….we must
understand the detector

“Pre-Collision Physics Structures”

Cosmic Muons

High energetic muons that traverse the detector vertically

→particular useful for alignment and calibration - *barrel region.*

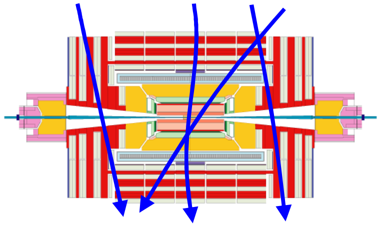


Beam Halo Muons

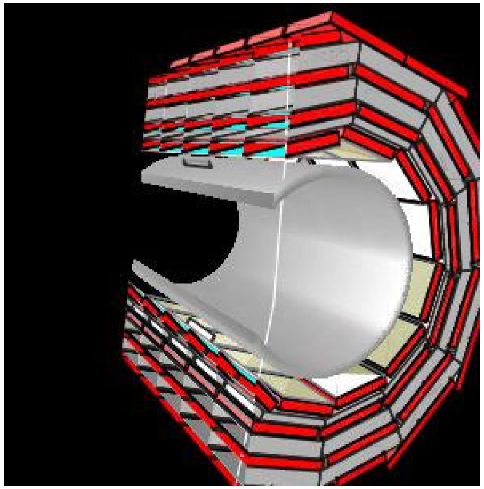
Machine induced secondary particles that cross the detector almost horizontally

→particular useful for alignment and calibration - *endcap region.*

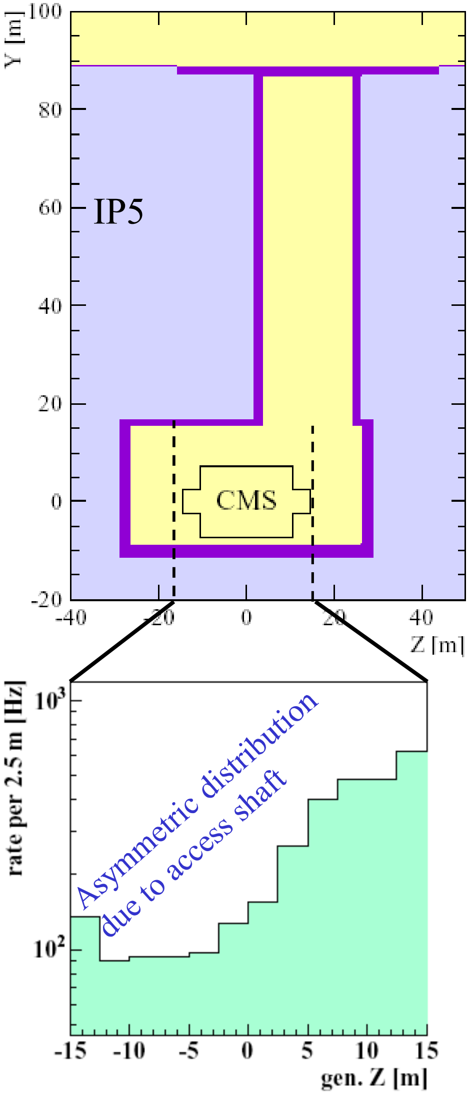
Cosmic Muons



Substantial Rates
for E_{μ}>10 GeV

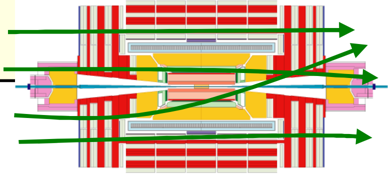


$N_{HIT}\geq 1$	Rate[Hz]
CMS tot	**~1800**
Muon only	**~1800**
calorimeter	**~ 700**
tracker	**~ 60**

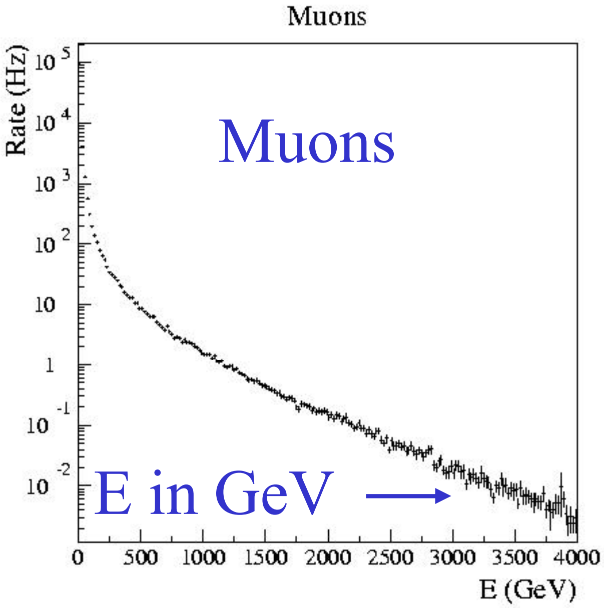


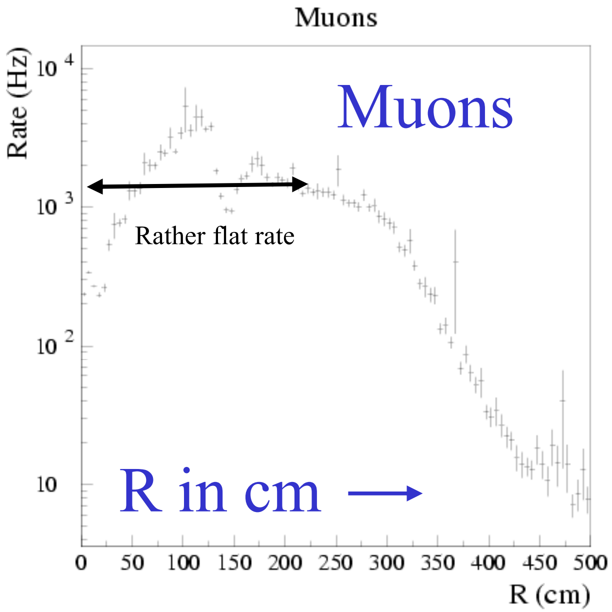
Cosmic Muons:
Special Topology (traverse whole detector) makes them very attractive for various commissioning activities (e.g. alignment, operational experience with high energetic muons, etc …

Beam Halo Muons



⇒**Beam halo muons are machine induced secondary particles and cross the detector almost horizontally. Thus leaving essentially signals in the endcaps.**



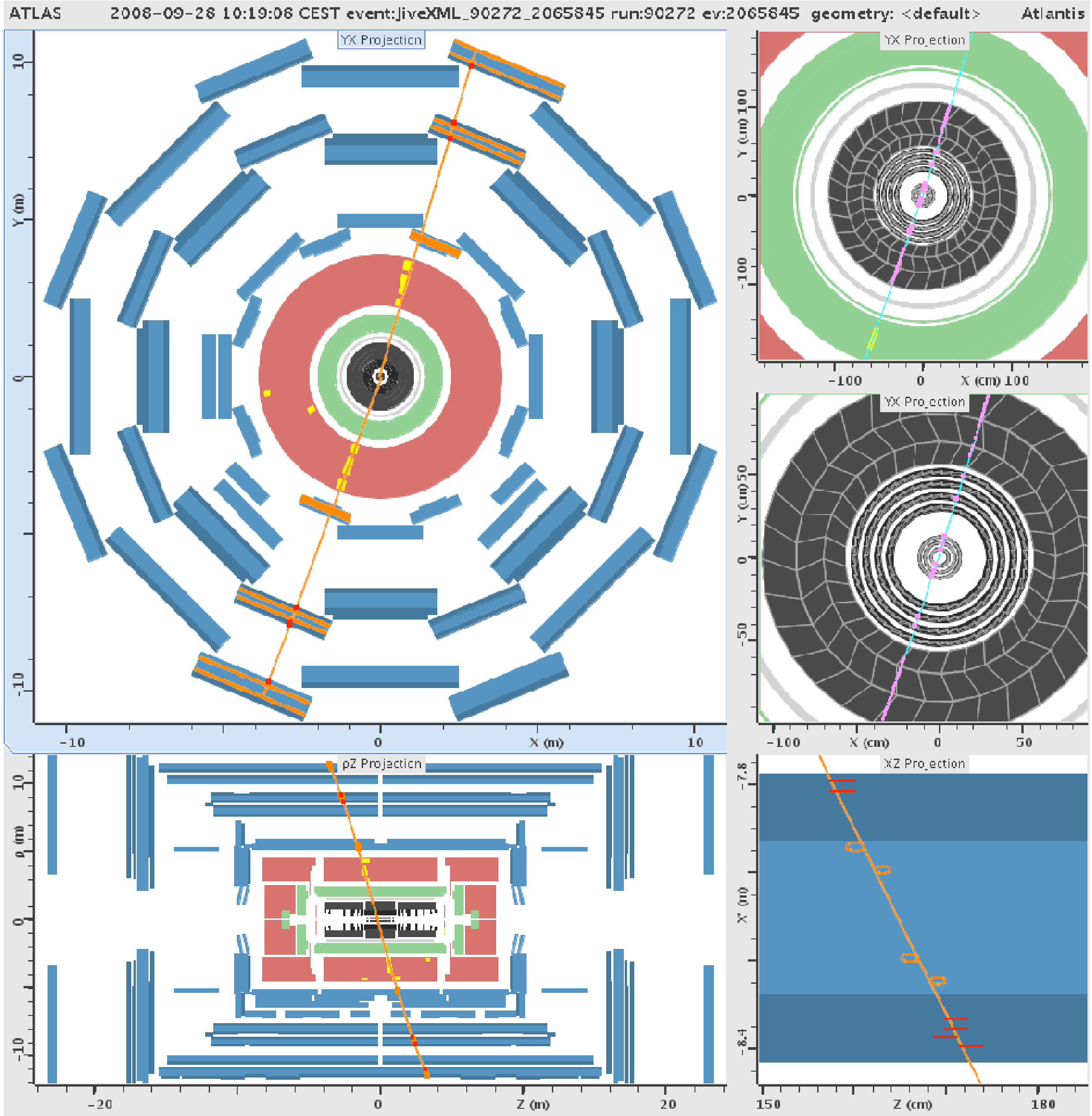


Substantial Expected Rates for E_μ>100 GeV

⇒Very interesting for several commissioning efforts of the endcap regions

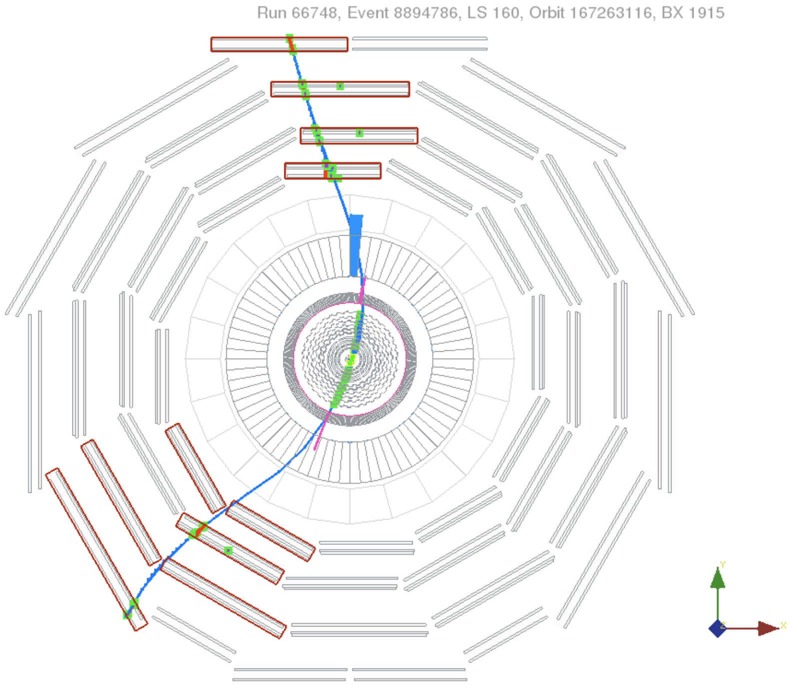
$N_{HIT}\geq 1$	[Hz]
CMS tot	**~1000**
Muon	**~ 800**
Calo.	**~ 800**
tracker	**~ 200**

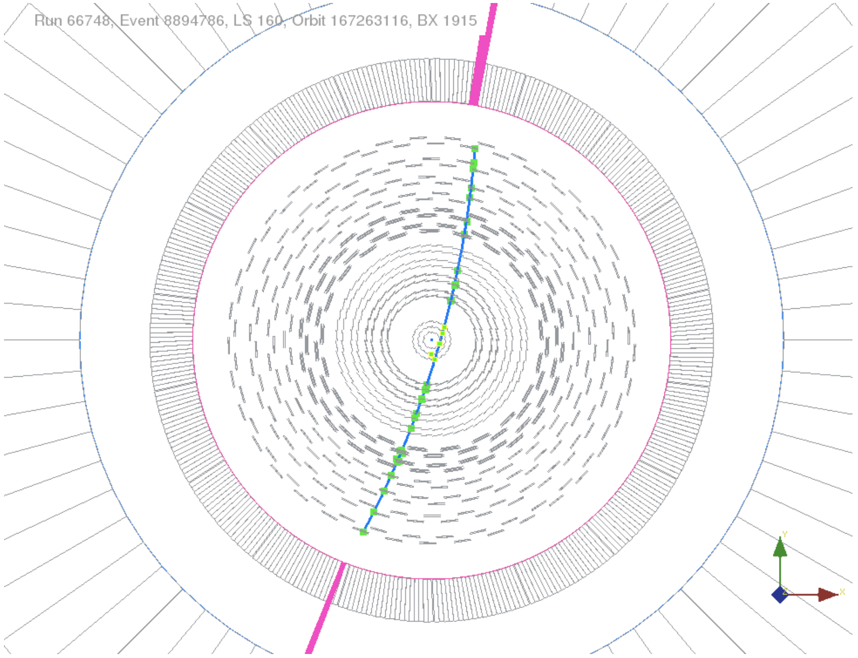
ATLAS COSMIC EVENT



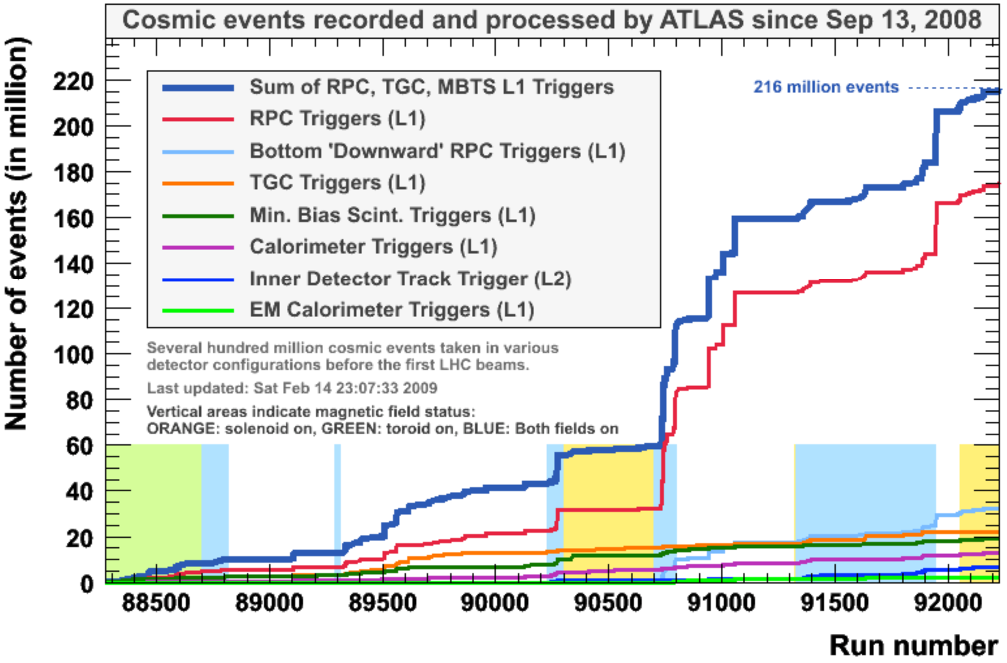
ATLAS 2008-09-28 10:19:06 CEST event:JiveXML_90272_2065845 run:90272 ev:2065845 geometry: <default> Atlantis

CMS COSMIC EVENT





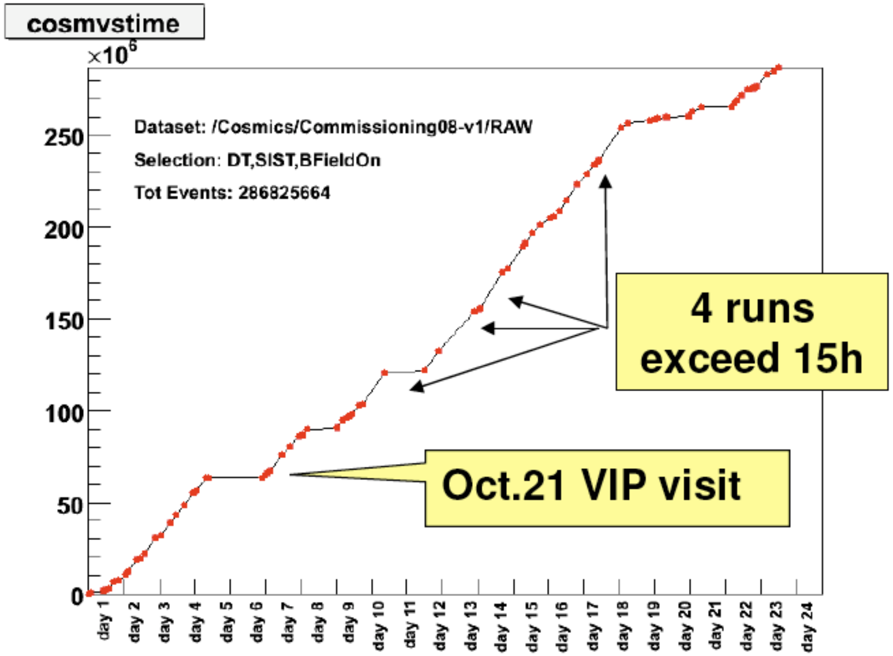
ATLAS and CMS COSMIC RUN


Cosmic events recorded and processed by ATLAS since Sep 13, 2008

Several hundred million cosmic events taken in various detector configurations before the first LHC beams.

Last updated: Sat Feb 14 23:07:33 2009

Vertical areas indicate magnetic field status:
ORANGE: solenoid on, GREEN: toroid on, BLUE: Both fields on

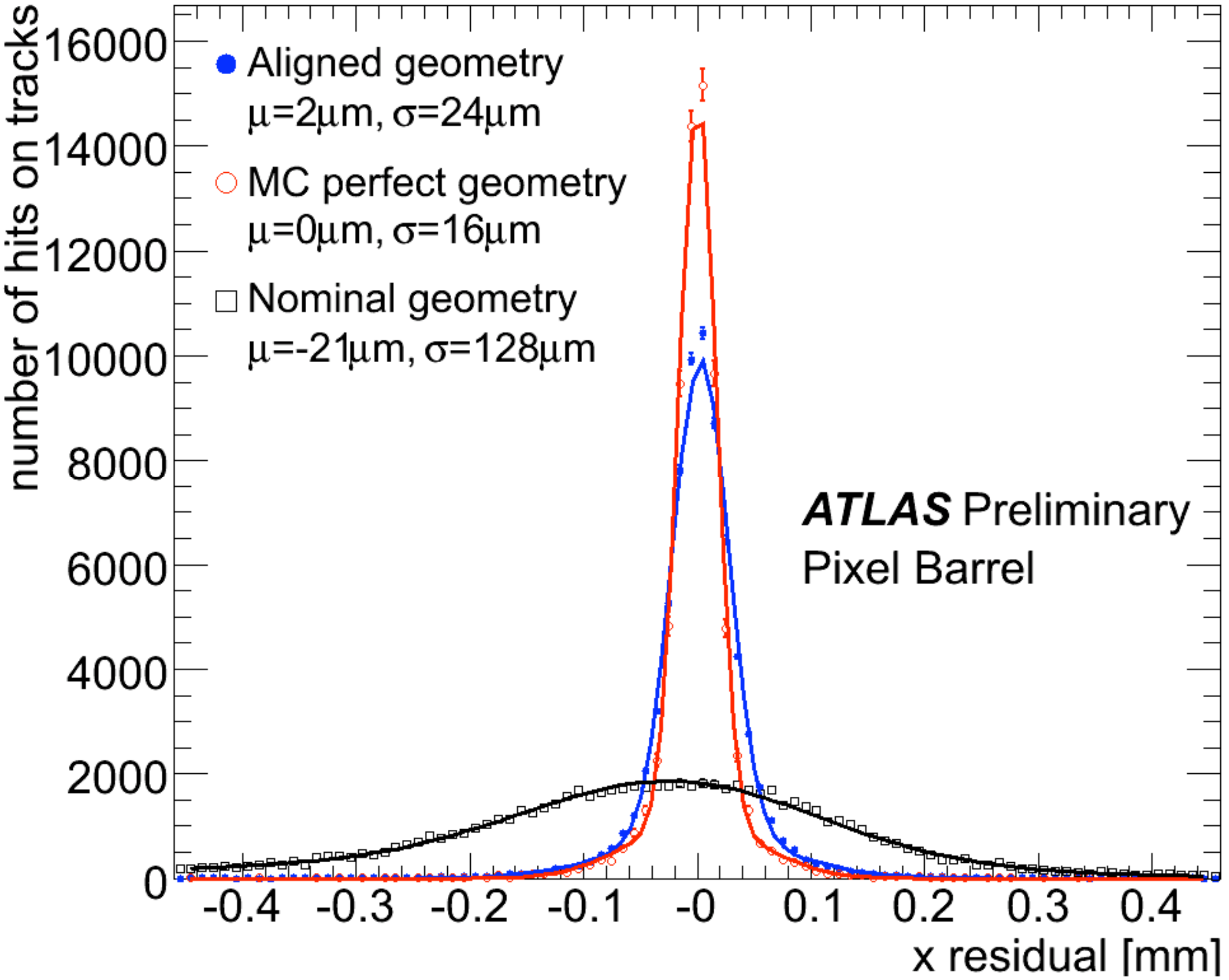

cosmvstime

Dataset: /Cosmics/Commissioning08-v1/RAW
Selection: DT,SiST,BFieldOn
Tot Events: 286825664

4 runs exceed 15h

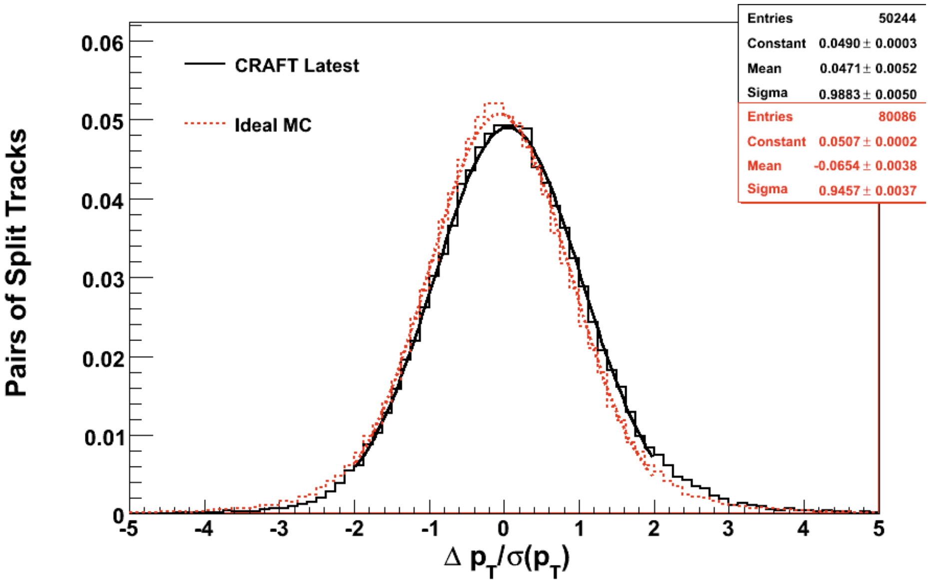
Oct.21 VIP visit

ALIGNMENT

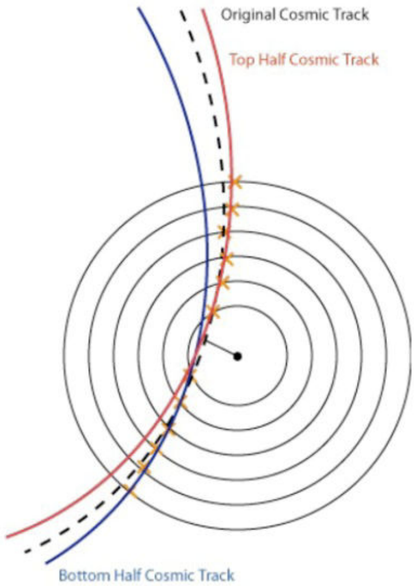


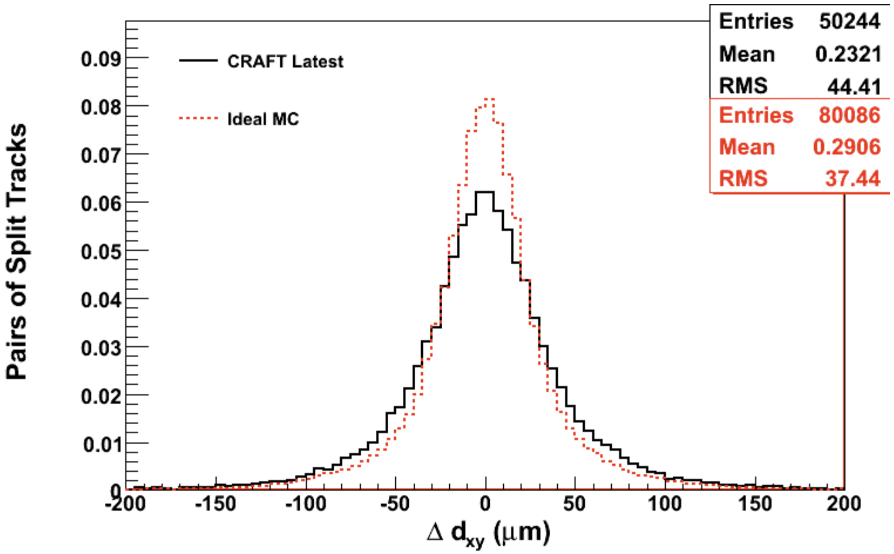
● Aligned geometry
μ=2μm, σ=24μm
○ MC perfect geometry
μ=0μm, σ=16μm
☐ Nominal geometry
μ=-21μm, σ=128μm
ATLAS Preliminary
Pixel Barrel
number of hits on tracks
0
2000
4000
6000
8000
10000
12000
14000
16000
-0.4
-0.3
-0.2
-0.1
-0
0.1
0.2
0.3
0.4
x residual [mm]

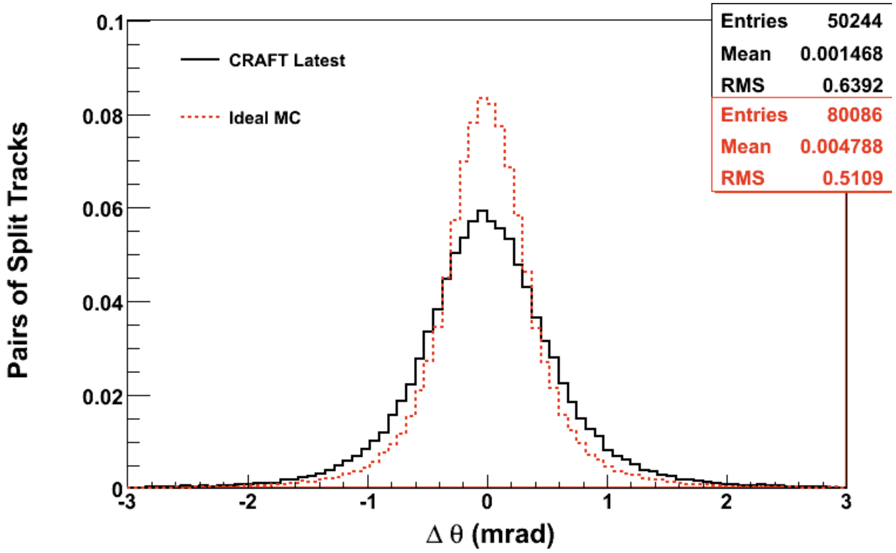
TRACKER RESOLUTION



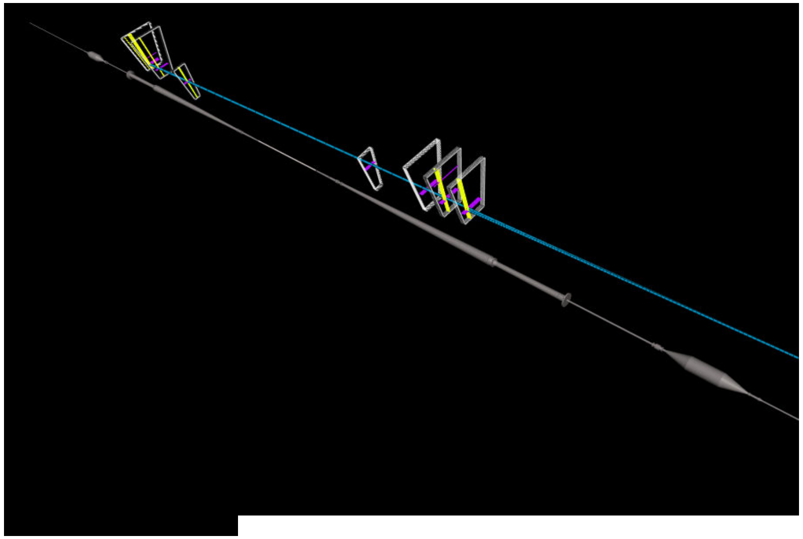
CMS

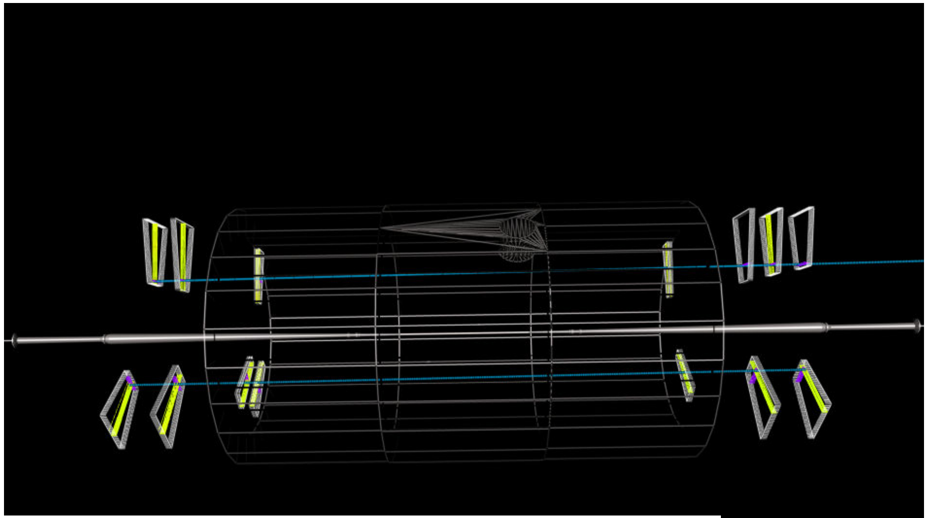


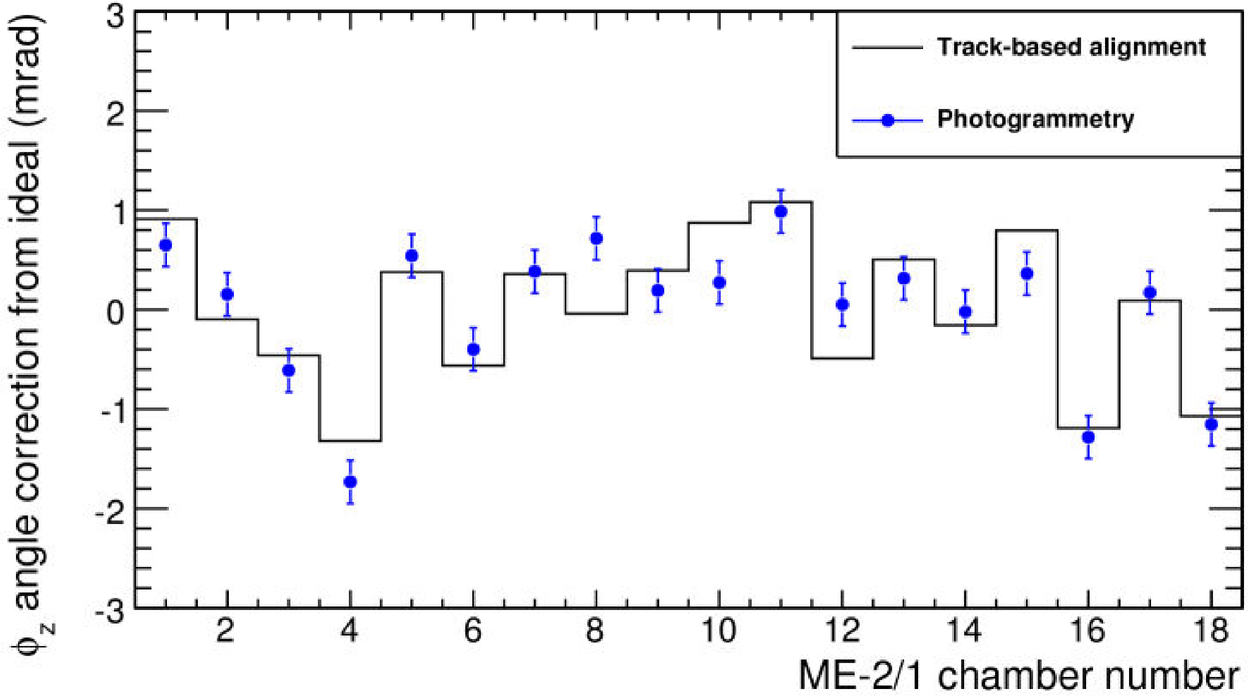




BEAM HALO MUONS IN CMS

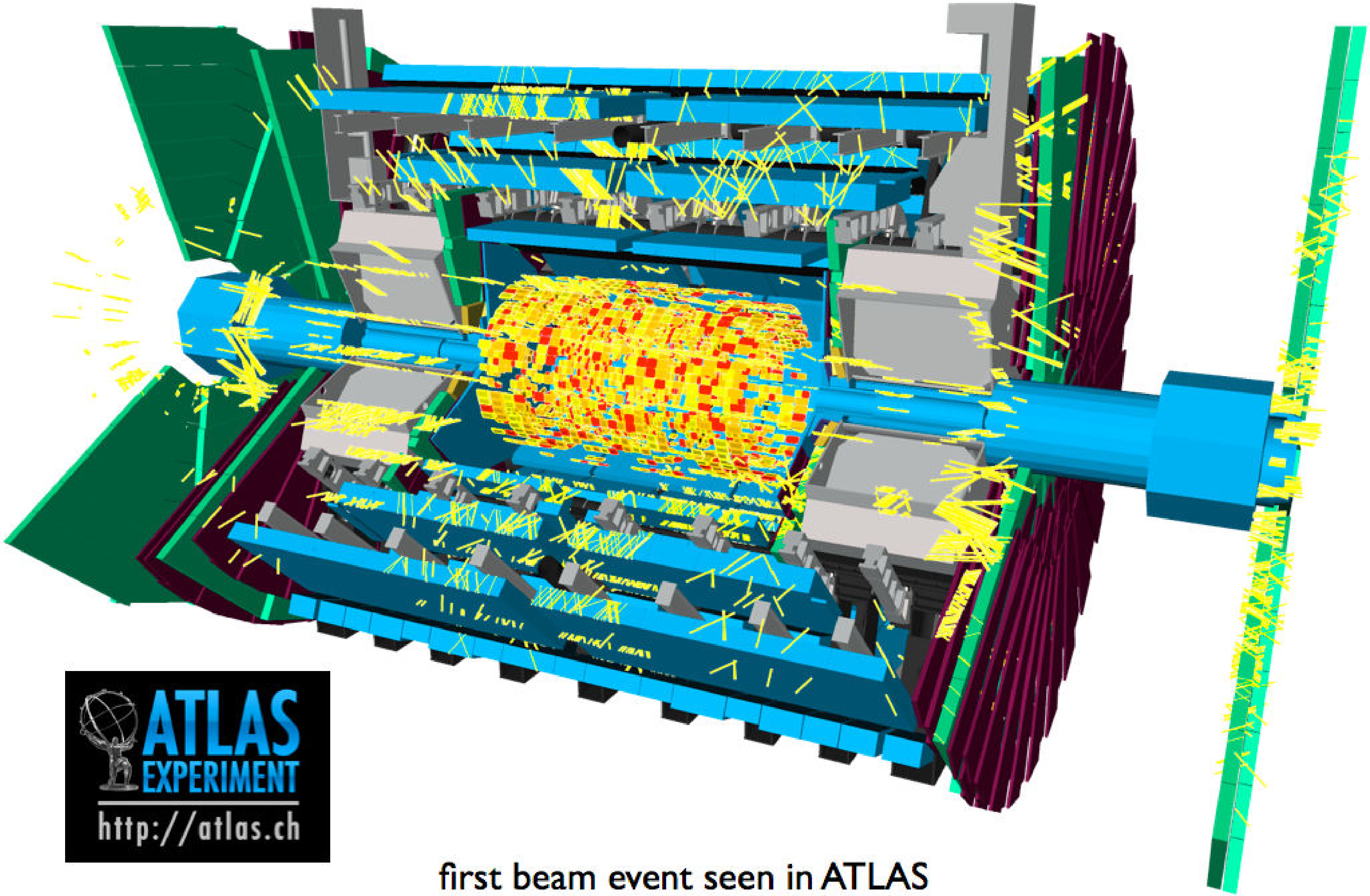






BEAM SPLASH EVENTS

During a test, one bunch of ~10^9 protons at 450 GeV was dumped on a collimator few hundreds meters upstream of the detectors producing ~ 10^6 muons (average energy 30 GeV) traversing the detector at the same time

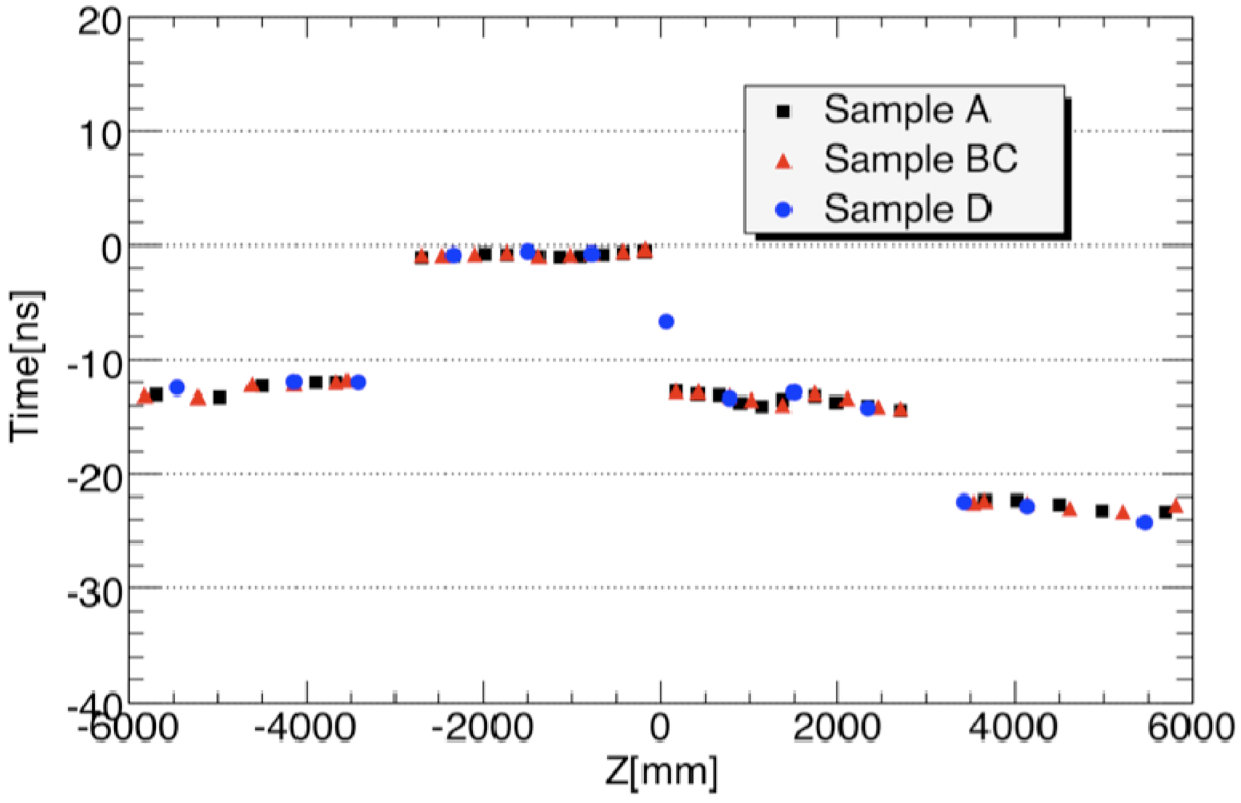


ATLAS EXPERIMENT
http://atlas.ch

first beam event seen in ATLAS

Timing of ATLAS TILE CAL

Each group was calibrated in time with laser



The visible discontinuities at Z= 0, ± 3000 mm are due to the uncorrected time differences between the four TileCal partitions. This data provided the opportunity to correct this discontinuity.

CONCLUSIONS

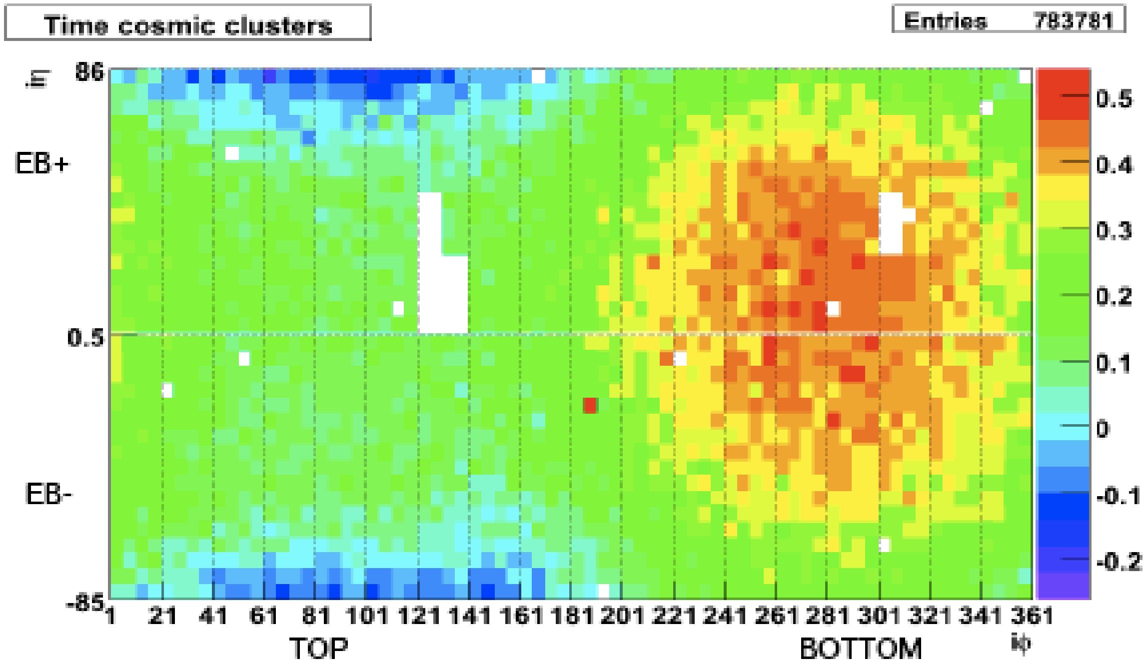
ATLAS and CMS arrived well prepared to the first rendezvous with the beam on the 10th of September 2008. Unfortunately it lasted only few days. Nonetheless the beam halo and beam splash events have been extremely useful to perform first calibrations

Since then the experiments have collected few hundred millions of cosmic rays that have been used for commissioning and have substantially improved the calibration of the detectors.

In July/August ATLAS and CMS will be again in run with cosmic rays preparing for the second rendezvous with the LHC beam, and this time it will be forever !

CMS ECAL TIMING

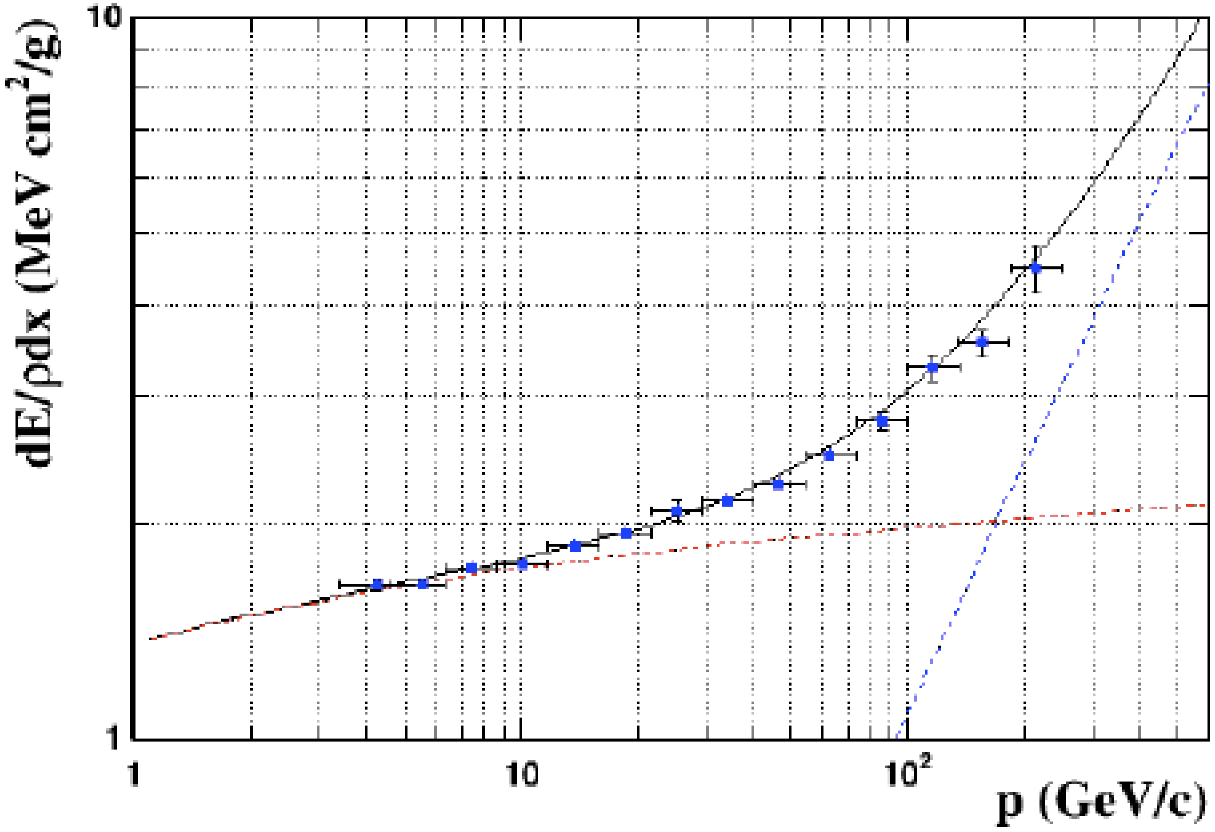
The figure shows the average time associated with clusters in ECAL barrel, in cosmic runs with magnetic field and and APD gain set to 200 (x4 the LHC conditions). The data sample is the same as the one used for the occupancy plot, but for timing only clusters with seed energy exceeding 100 MeV are used. Time is measured in clock units (25 ns) with respect to the nominal settings for collisions. Clusters in the bottom are seen later with respect to the top part as a result of the time of flight of the cosmic rays.



STOPPING POWER IN CMS CRYSTALS

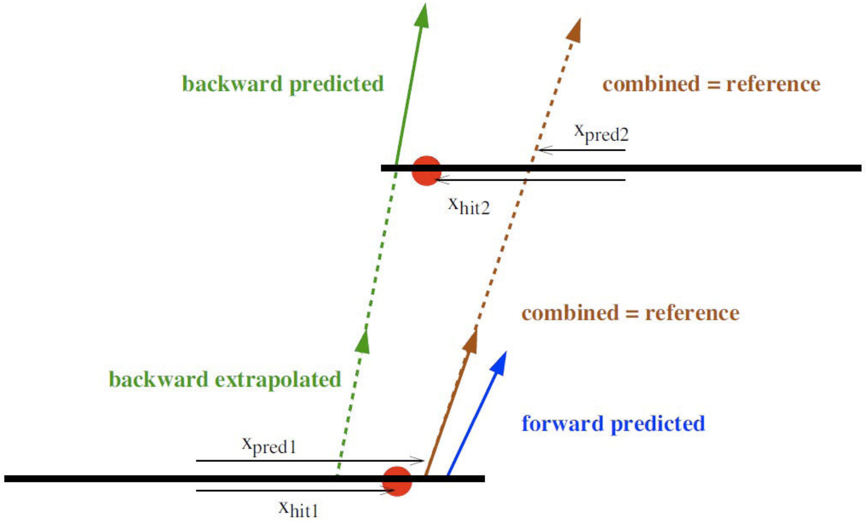
The figure shows the stopping power of cosmic muons traversing ECAL as a function of the muon momentum as measured in the tracker. In ECAL the energy deposit is measured by the cluster energy matched to the track; the track length is estimated from track propagation inside ECAL crystals. Loose selection on the distance of closest approach of the track to the centre of CMS is applied. Experimental data (dots) are compared to the total stopping power (dE/d x) in $PbWO_4$ (black continuous line). The dashed lines are the contributions due to collision loss (red) and bremsstrahlung radiation (blue). Data are displayed in the momentum range where sufficient number of events survive the selections. Errors on the vertical scale are statistical only; error bars on the momentum represent the bin width.

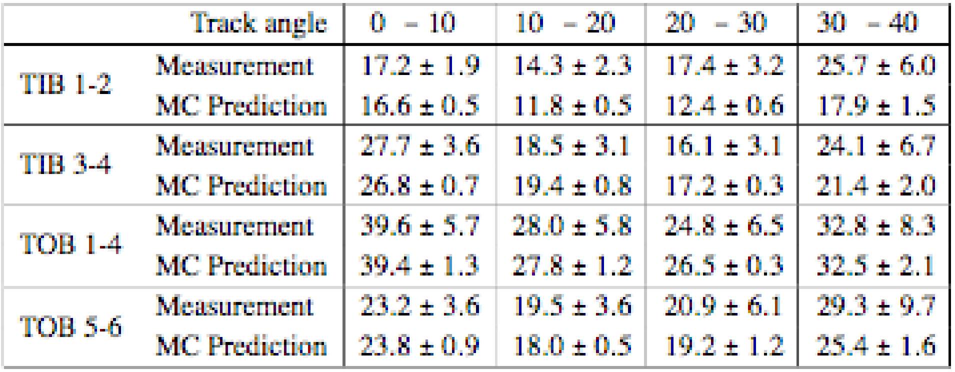
Results indicate the correctness of the tracker momentum scale and of the energy scale in ECAL calibrated with electron at test beams.



Strip Tracker Hit resolution

- Strip hit resolution in TIB and TOB (after alignment)
  - From comparison of measured and predicted differences of hit positions in region of overlap of two modules in a same detector layer





	Track angle	0 – 10	10 – 20	20 – 30	30 – 40
TIB 1-2	Measurement	17.2 ± 1.9	14.3 ± 2.3	17.4 ± 3.2	25.7 ± 6.0
	MC Prediction	16.6 ± 0.5	11.8 ± 0.5	12.4 ± 0.6	17.9 ± 1.5
TIB 3-4	Measurement	27.7 ± 3.6	18.5 ± 3.1	16.1 ± 3.1	24.1 ± 6.7
	MC Prediction	26.8 ± 0.7	19.4 ± 0.8	17.2 ± 0.3	21.4 ± 2.0
TOB 1-4	Measurement	39.6 ± 5.7	28.0 ± 5.8	24.8 ± 6.5	32.8 ± 8.3
	MC Prediction	39.4 ± 1.3	27.8 ± 1.2	26.5 ± 0.3	32.5 ± 2.1
TOB 5-6	Measurement	23.2 ± 3.6	19.5 ± 3.6	20.9 ± 6.1	29.3 ± 9.7
	MC Prediction	23.8 ± 0.9	18.0 ± 0.5	19.2 ± 1.2	25.4 ± 1.6

Hit resolution measured on CRAFT data and predicted by the model in the Monte Carlo Simulation, for the different local track angles