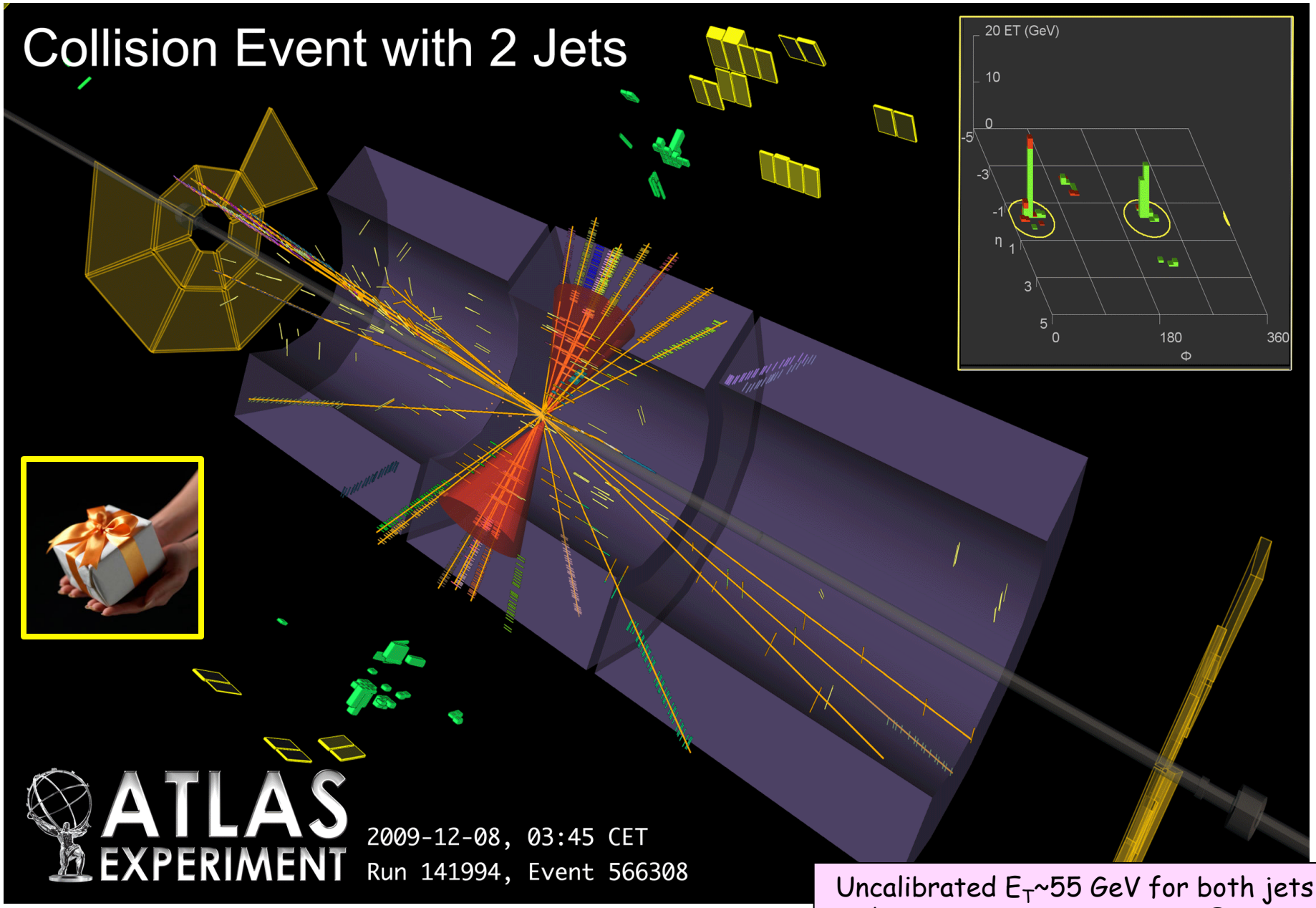
ATLAS through "first light"

Minute Particulars & Hidden Symmetries
Chris Quigg Symposium
FNAL, 14-15 December 2009

Fabiola Gianotti (CERN)

Collision Event with 2 Jets



Uncalibrated E_T~55 GeV for both jets
Both jets at η= -0.2 ; ~ no missing E_T

Few milestones of a spectacular project …

1984 : First studies for a high-energy pp collider in the LEP tunnel

I meet Chris for the first time on … paper (EHLQ, i.e. the `Bible' !)

1989 : Start of SLC and LEP e^+e^- colliders

1993 : SSC is cancelled

1994 : LHC approved by the CERN Council

1995 : Top-quark discovery at the Tevatron

1996 : Construction of LHC machine and experiments start

1999 : I meet Chris by E-mail

2000 : End of LEP2

I meet Chris in person for the first time at the APS

2003 : Start of LHC machine and experiments installation

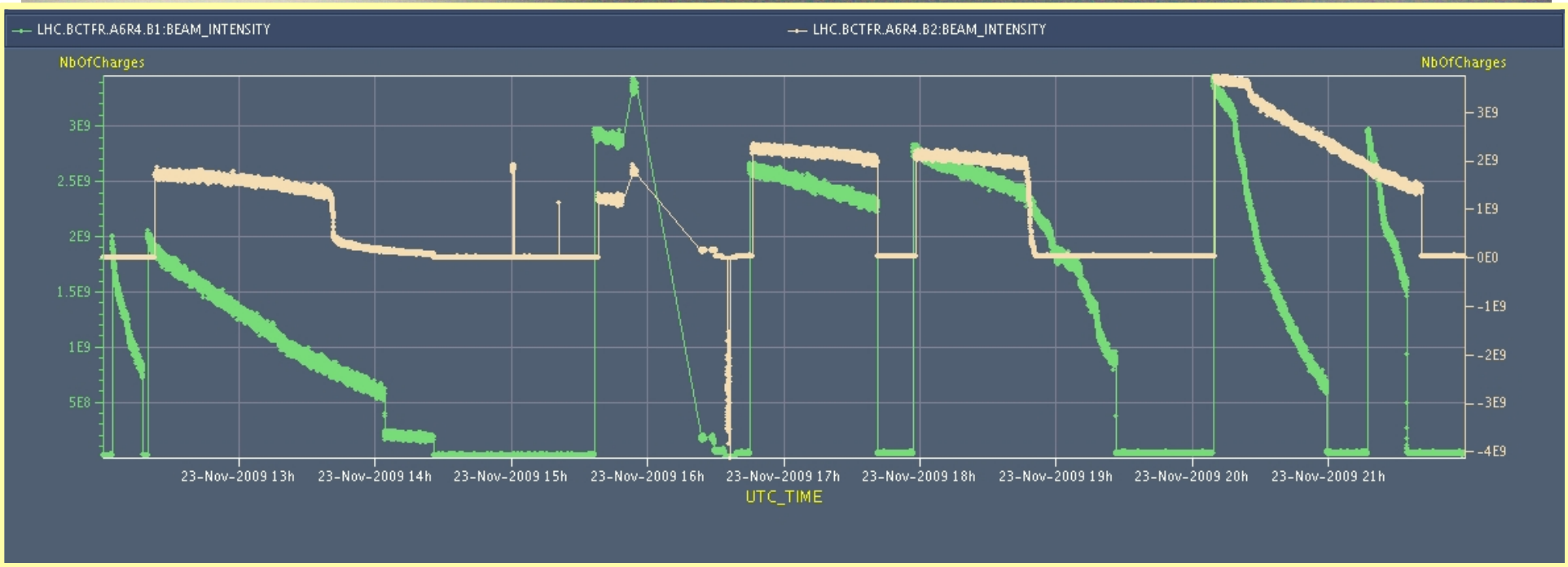
2009 : First LHC collisions

Date: Thu, 09 Sep 1999 11:45:30 -0600 (CST)
From: Chris Quigg <quigg@fnal.gov>
To: gianotti@mail.cern.ch
Subject: Re: LEP2 young physicists

Many thanks. I had the pleasure of watching your first summer student lecture on the web last week (and I will look at the others when I have a moment to breathe). I was very pleased with the motivation you presented to them--the big picture, and not just the shorthand of finding the Higgs boson. It is very important that we share the excitement and importance of the LHC experiments with the next generation and with the world, and I thought you did it beautifully. It made me very happy.
Best wishes, Chris

… and of a great friendship that honours me

Since 20 November: a fantastic crescendo of events ….



1st Beam Splash from Beam-2

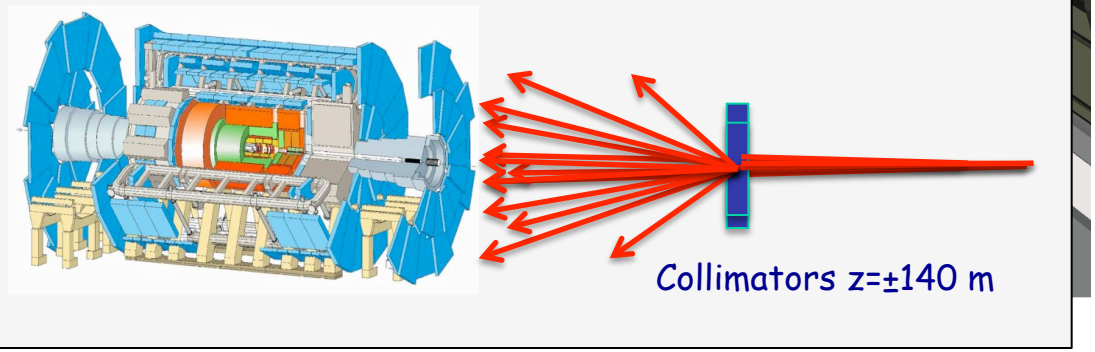
Friday 20 November: first circulating beams
→ATLAS collects ~ 100 splash events

Avalanche of scattered particles from beam on collimators

Detectors fully lit, typically

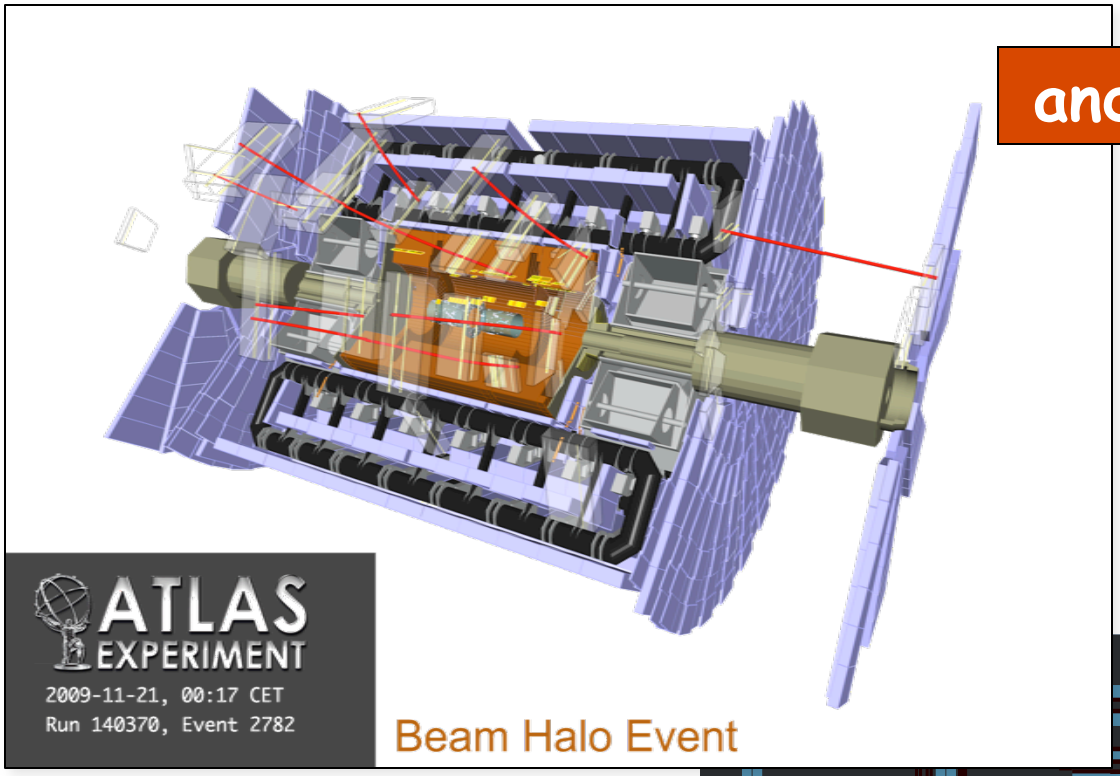
- 300,000 SCT hits
- 350,000 TRT hits
- 3000 TeV calo energy sum
- 490,000 MDT hits
- 320,000 RPC hits
- 65,000 TGC hits

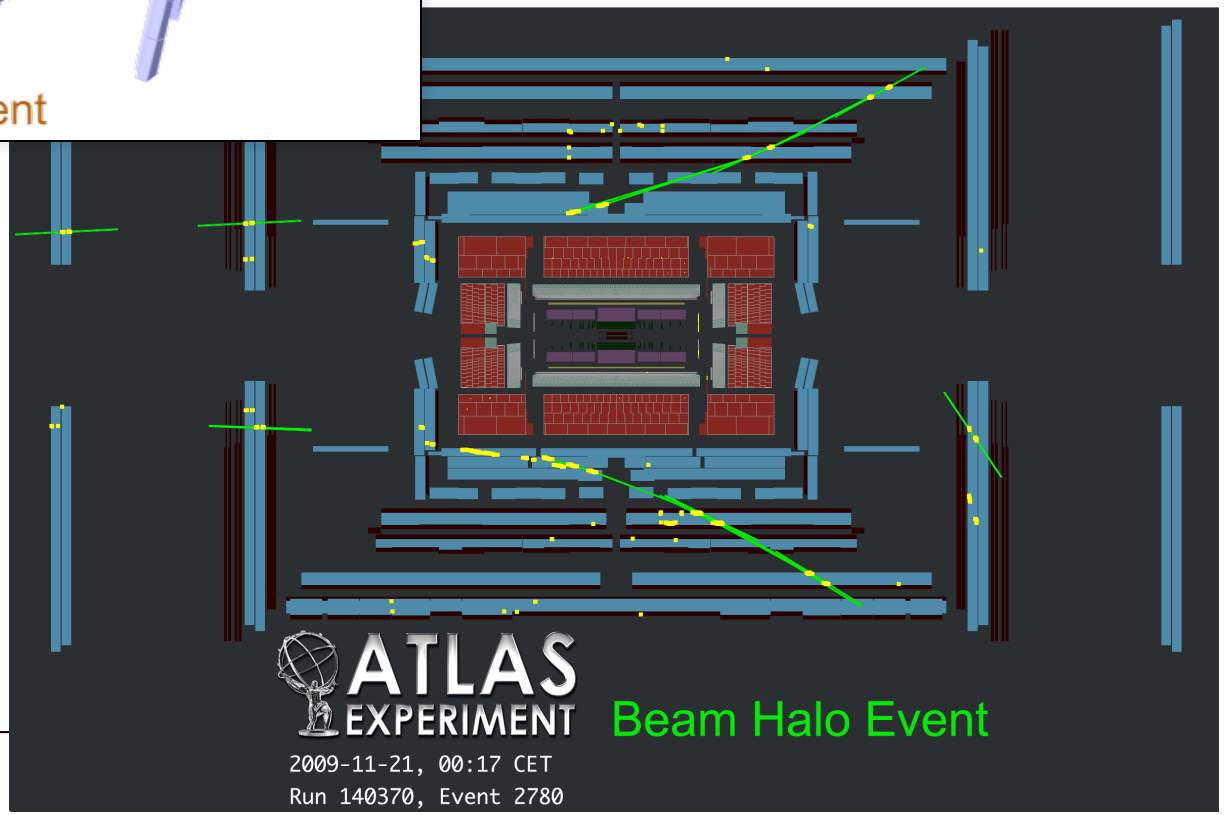
2009-11-20, 23:32 CET
Run 140370, Event 2666



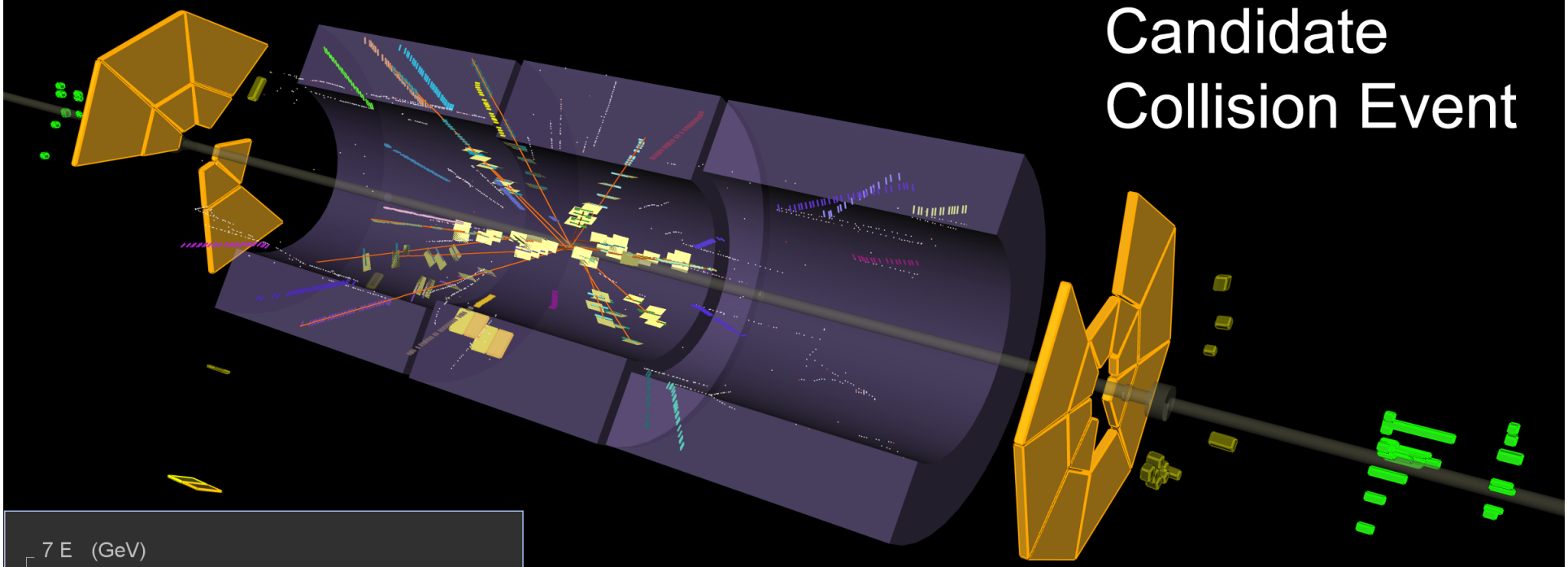
F. Gianotti, FNAL, 14/12/2009

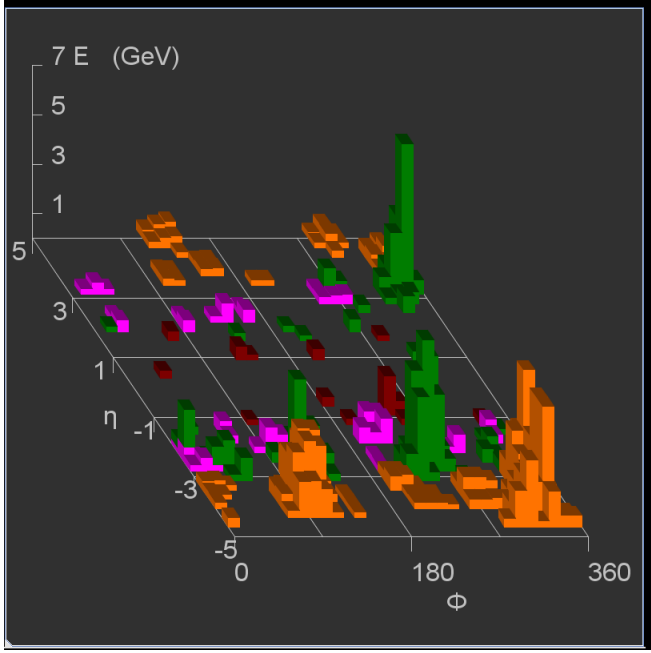
and plenty of beam halos…





Monday 23 November: first collisions !
→ ATLAS records ~ 200 collision events (first one observed @14:22)



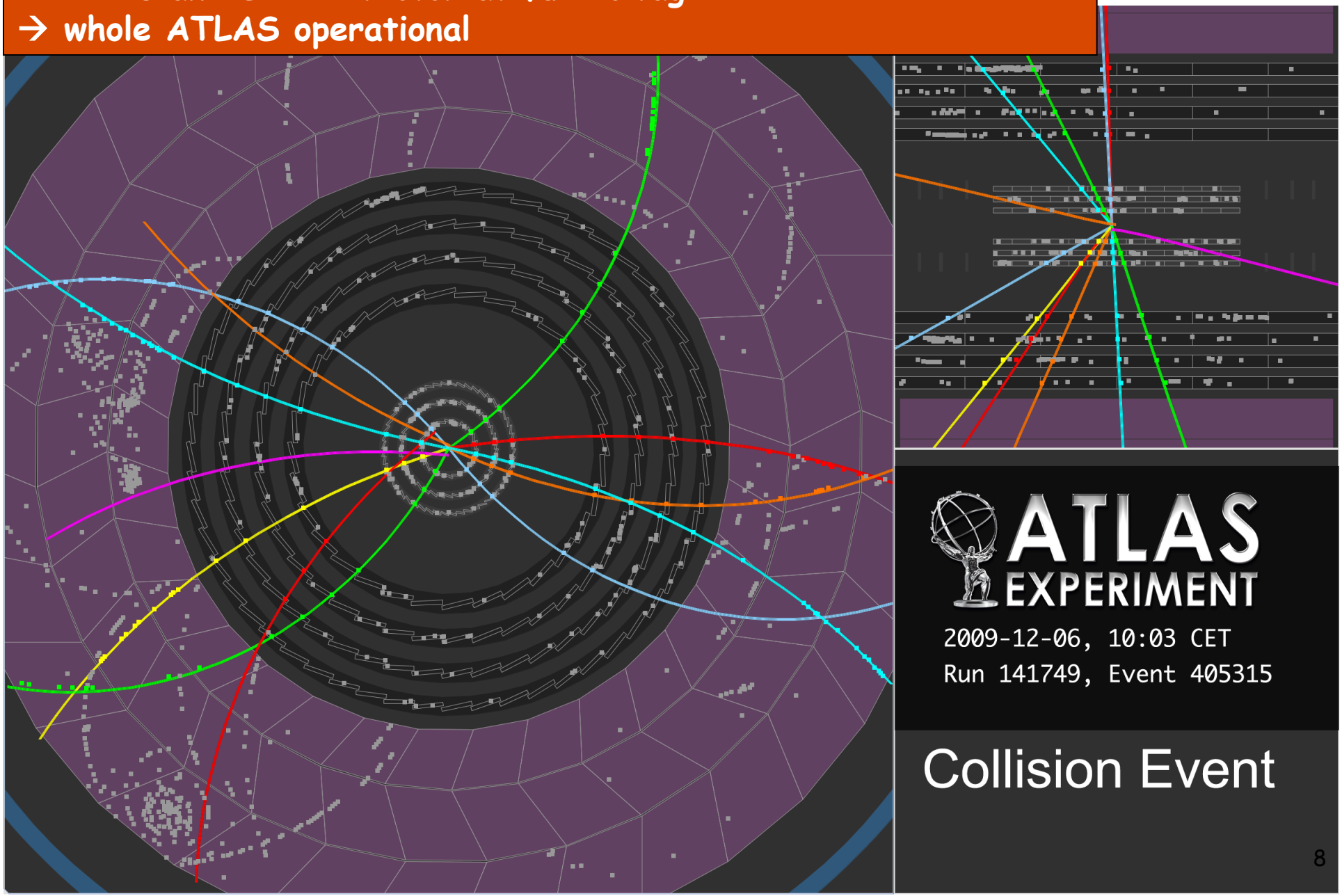


ATLAS EXPERIMENT

2009-11-23, 14:22 CET
Run 140541, Event 171897

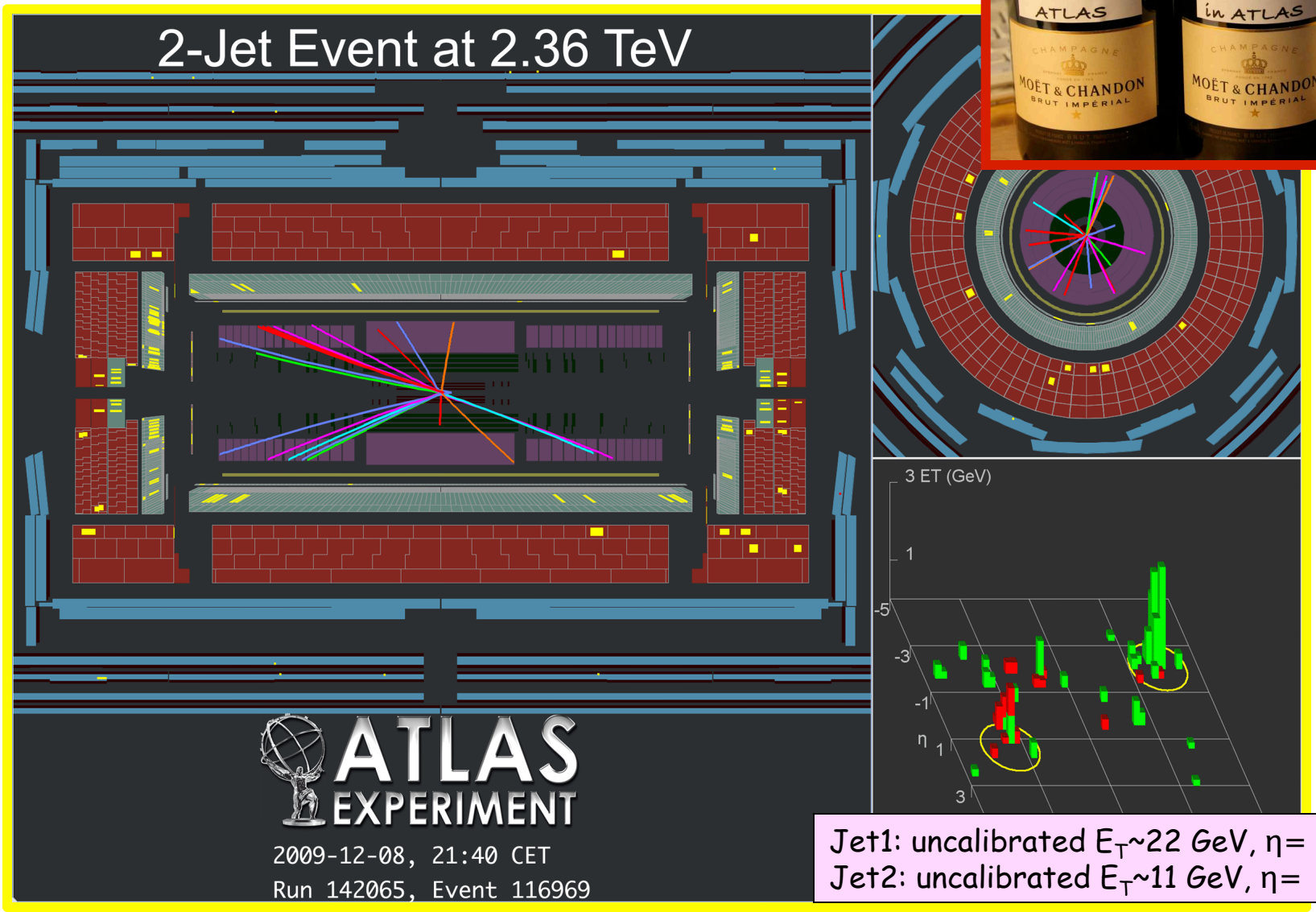
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

Sunday 6 December: machine protection commissioning concluded
→ stable beams for the first time
→ Pixels and SCT detector at full voltage
→ whole ATLAS operational



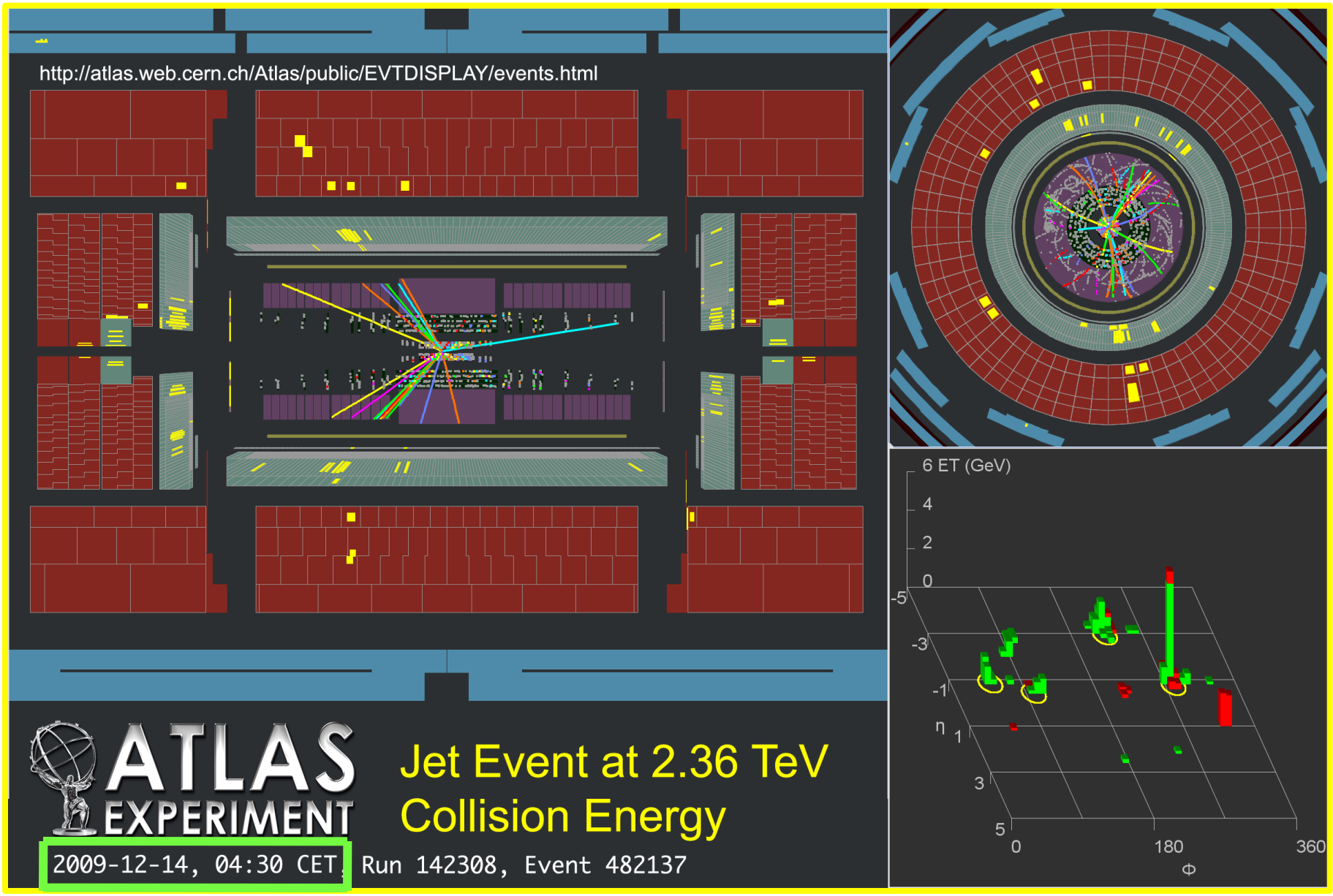
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

Tuesday 8 December:
~ 3 minutes of collisions at √s = 2.36 TeV
→ ATLAS collects ~ 120 events

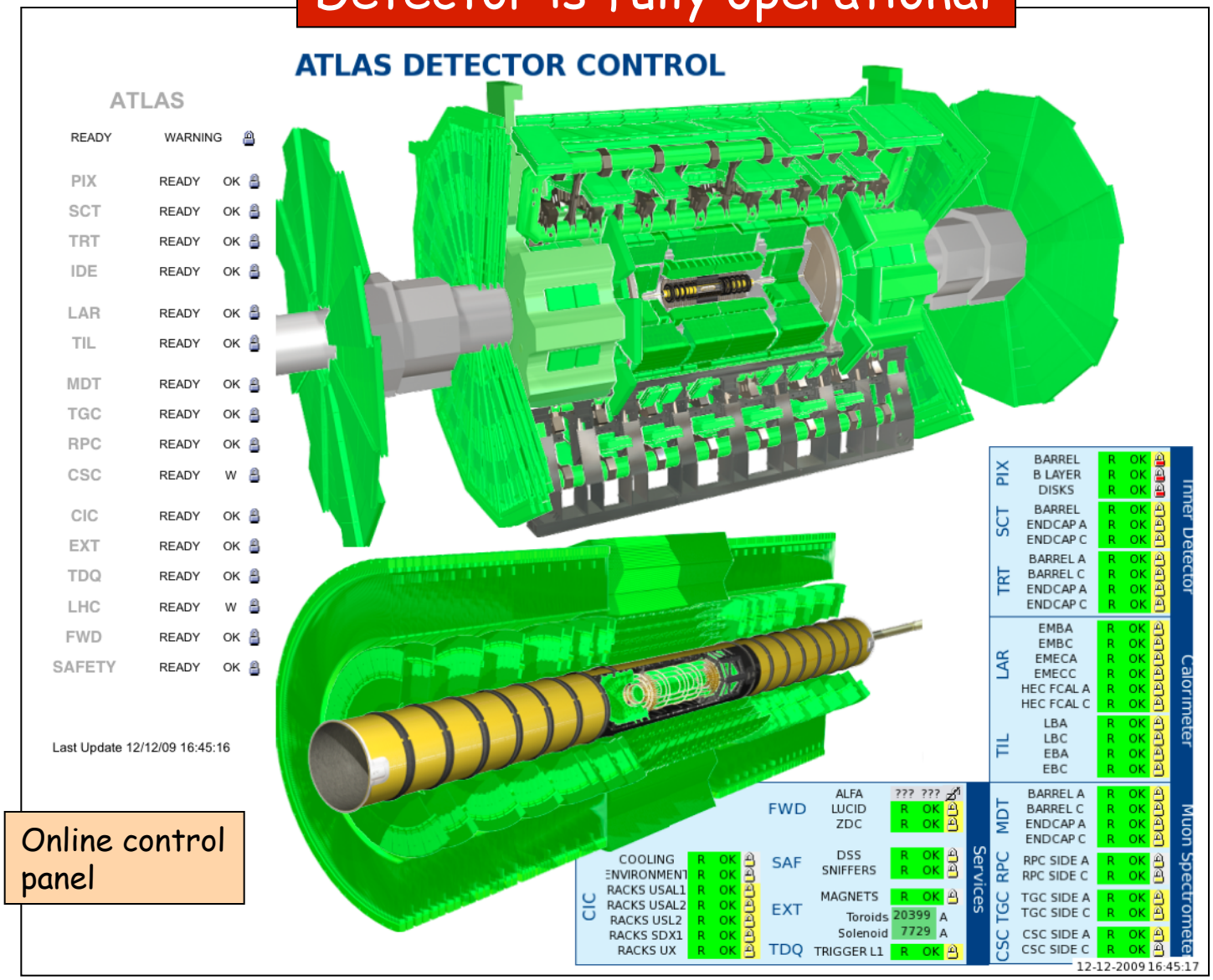


Jet1: uncalibrated E_T~22 GeV, η= -2.1
Jet2: uncalibrated E_T~11 GeV, η= 1.4

Monday 14 December 3h-6h am CET:
Collisions at √s = 2.36 TeV
→ ATLAS collects ~ 12k events at flat top



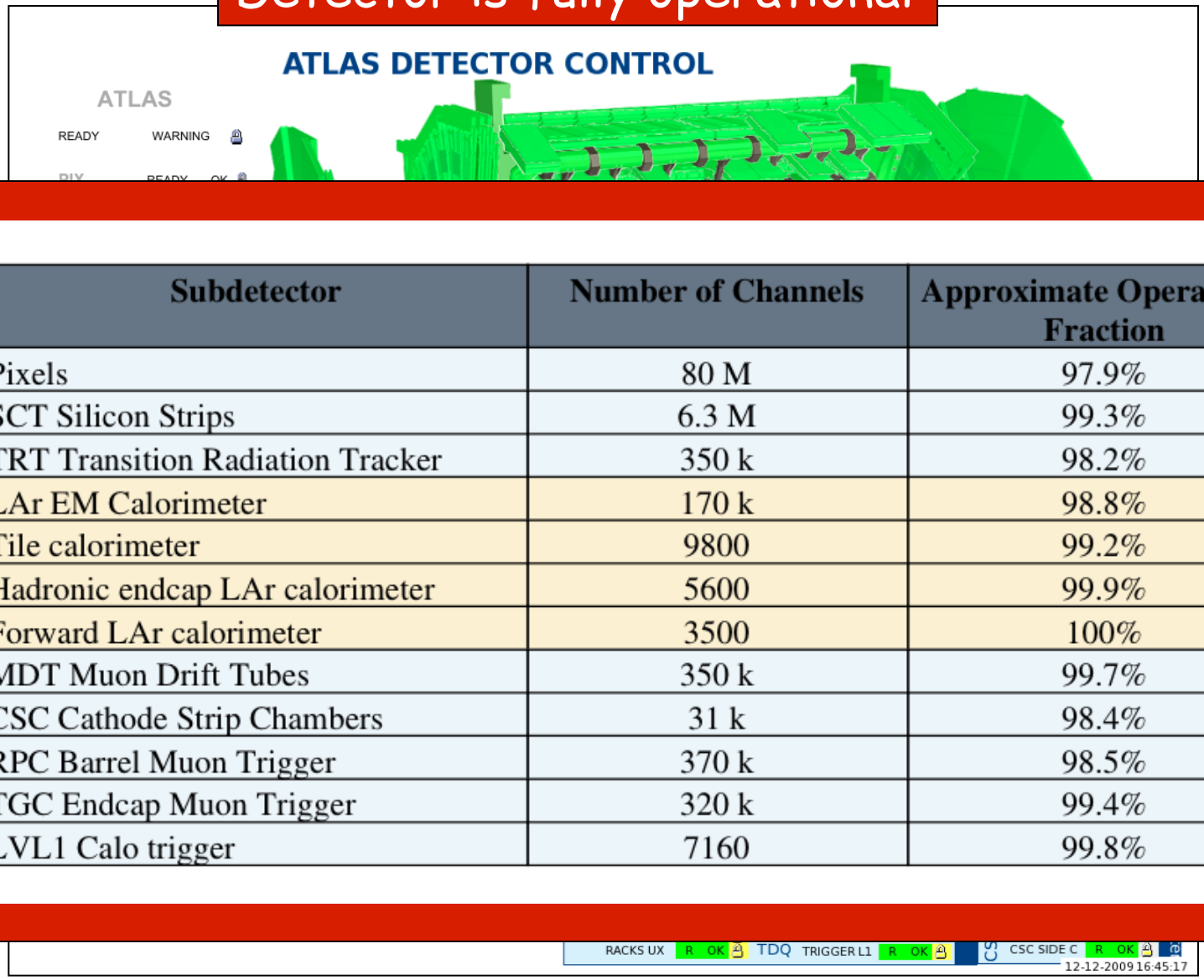
Detector is fully operational



Online control panel

- Pixels and SCT at nominal voltage only with stable beams
- Solenoid and/or toroids off in some periods
- Muon CSC chambers running in separate partition for rate tests

Detector is fully operational



Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.9%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	98.2%
LAr EM Calorimeter	170 k	98.8%
Tile calorimeter	9800	99.2%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.4%
RPC Barrel Muon Trigger	370 k	98.5%
TGC Endcap Muon Trigger	320 k	99.4%
LVL1 Calo trigger	7160	99.8%

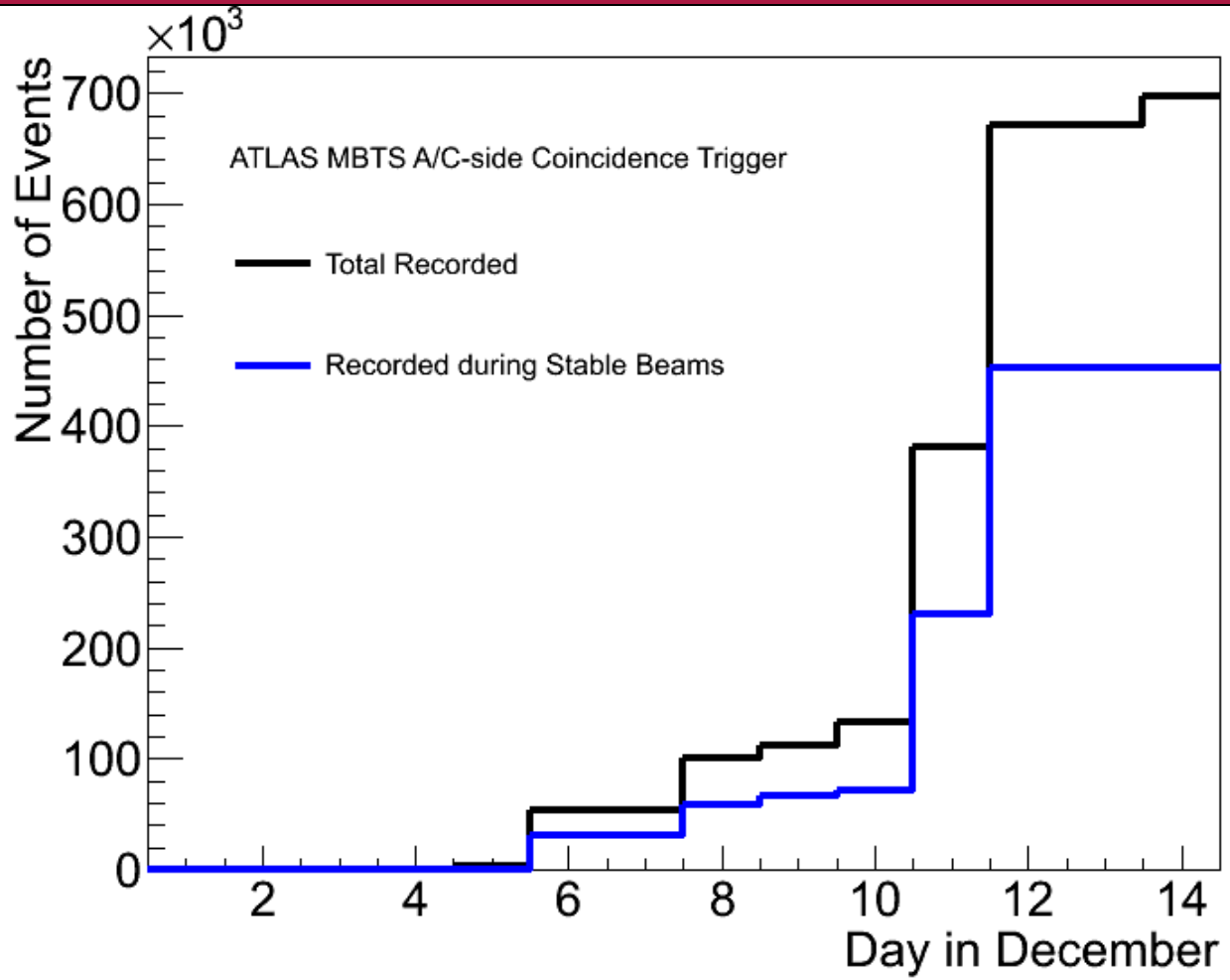
- Pixels and SCT at nominal voltage only with stable beams
- Solenoid and/or toroids off in some periods
- Muon forward chambers (CSC) running in separate partition for rate tests

Total number of collisions recorded: ~700k

- ~450k with stable beams → tracker fully on
- ~ 12k at $\sqrt{s}$=2.36 TeV flat top (Monday, 14 December, 3h-6h AM)

Recorded integrated luminosity with stable beams: ~ 10 μb^{-1}

Max peak luminosity seen by ATLAS : ~ 5 x 10^{26} cm^{-2} s^{-1}

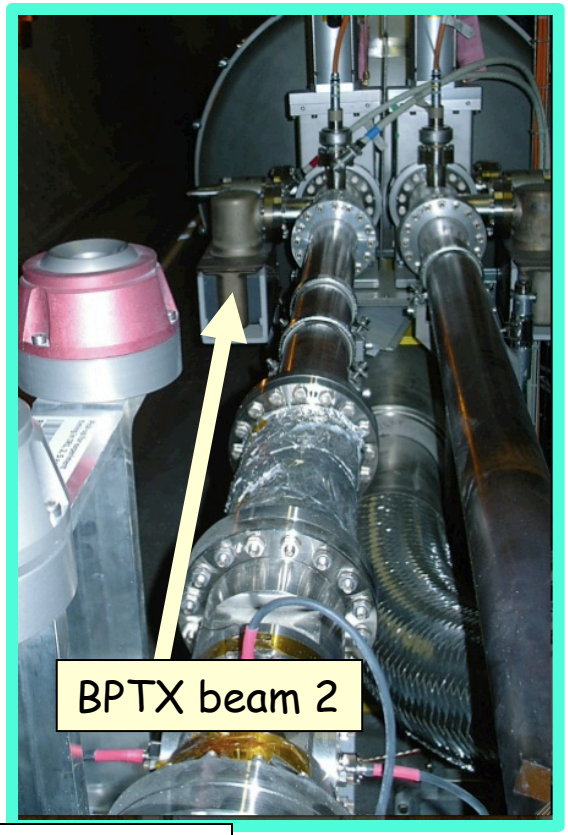


How do we select collision events (rejecting beam-halo, beam-gas, cosmics) ?

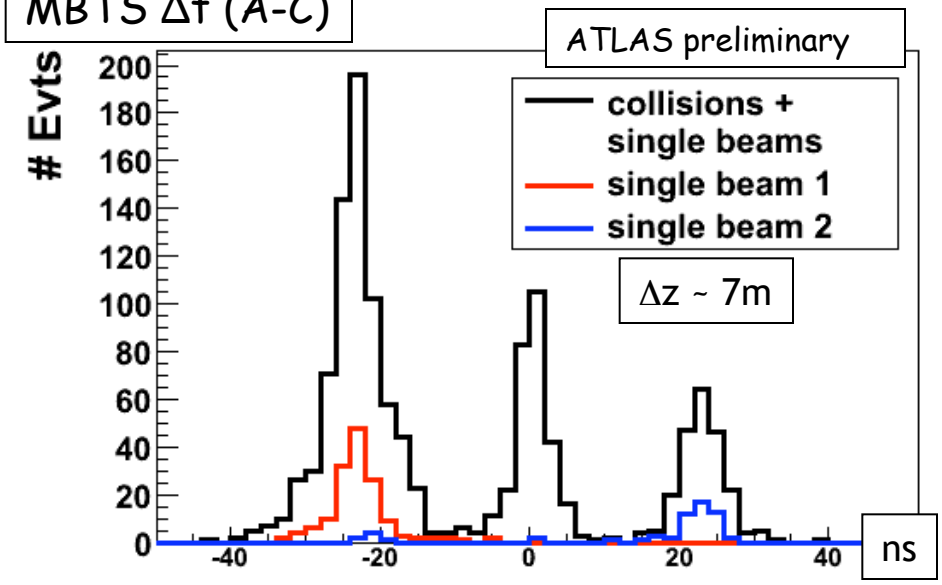
Level-1 trigger based on:

- "Minimum-bias scintillator counters" (MBTS) located at both sides (A and C side) of the collision (Z=± 3.5 m, in front of the end-cap calorimeters)
- in coincidence with beam pickups located at Z= ± 175 m

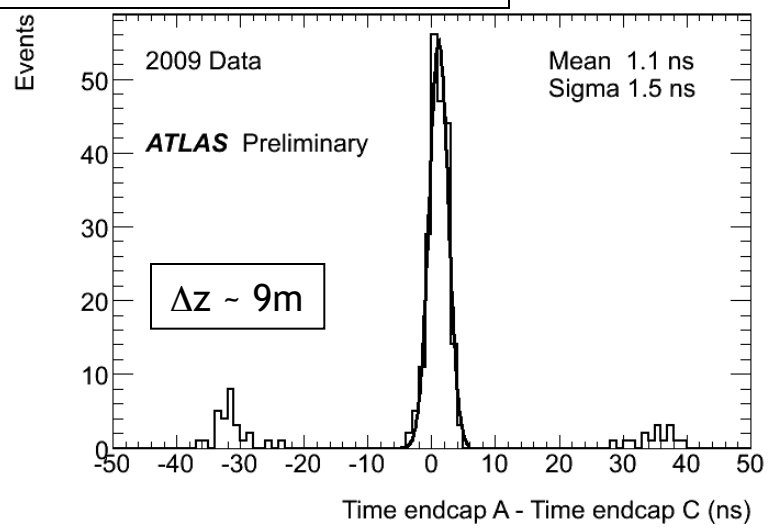
Level-1 interaction rate: up to ~ 20 Hz



MBTS Δt (A-C)

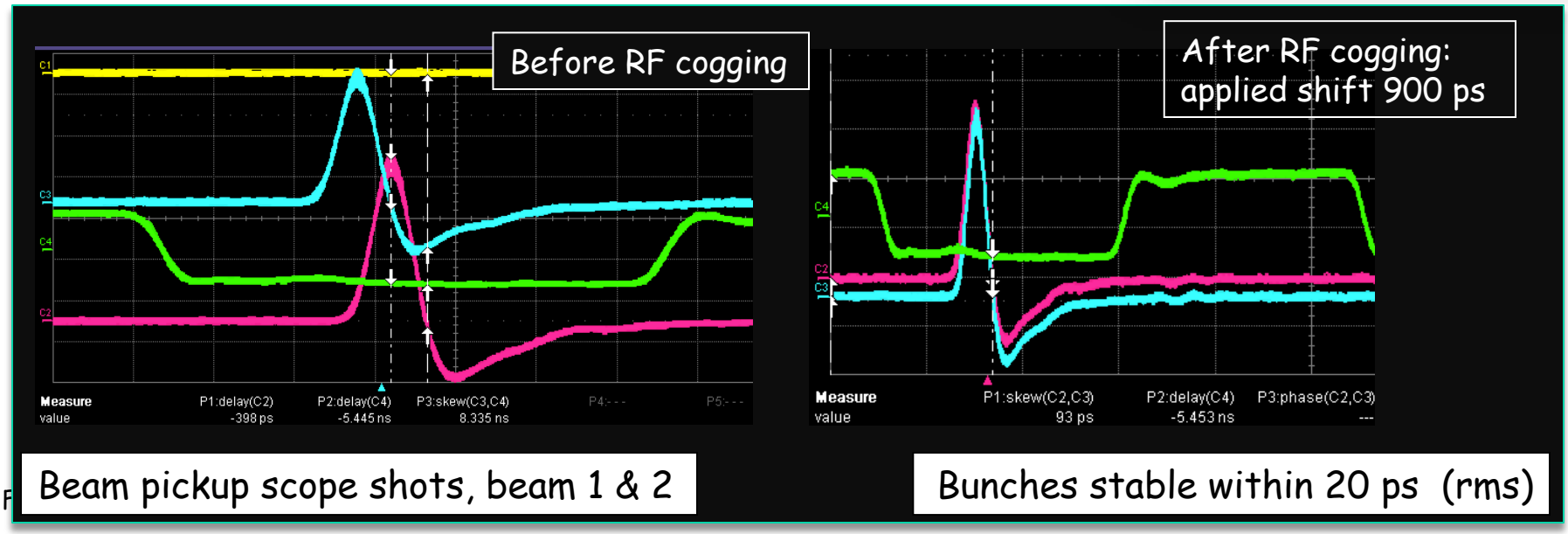


LAr calorimeter Δt (A-C)



Examples of early optimization work …
and "handshake" between
ATLAS and LHC operation team

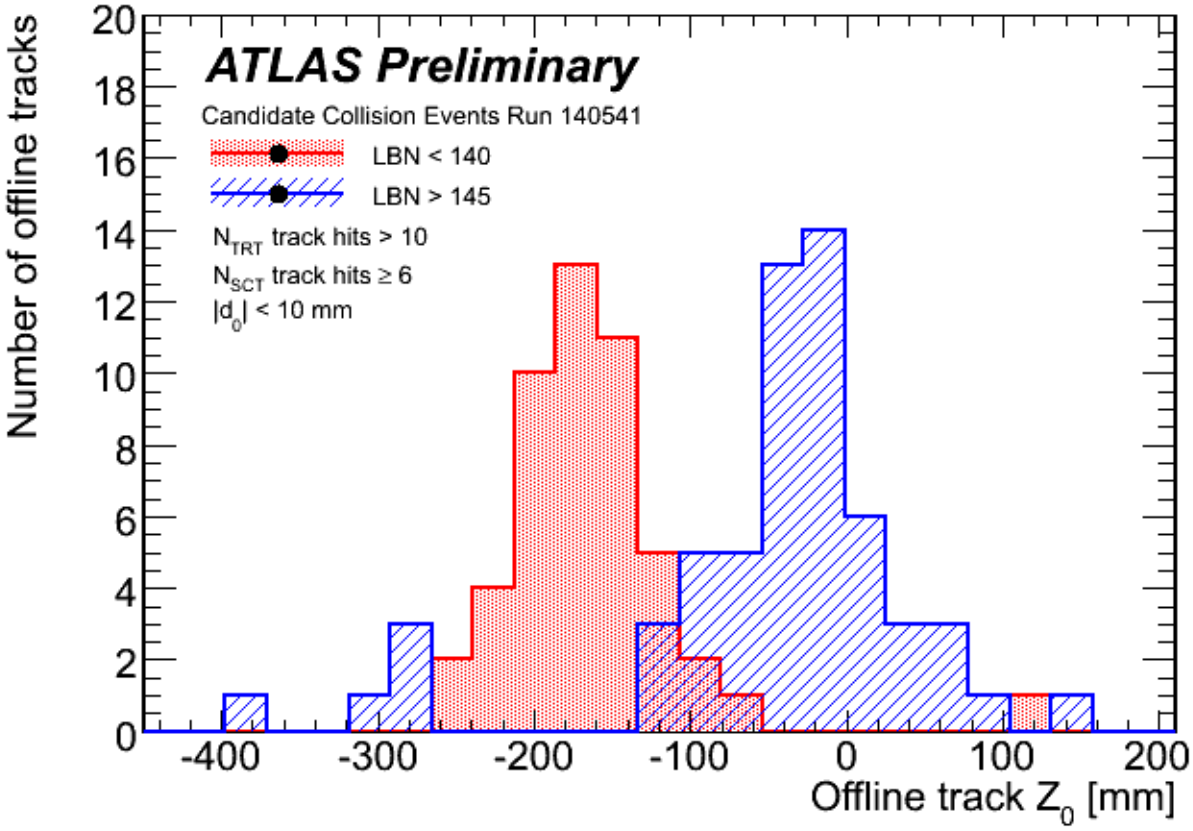
First collision events on 23 November:
ATLAS beam pickups showed phase shift of
900 ps, causing the primary vertex
to be shifted by -13.5 cm in Z → based on this
information, the machine team corrected the RF cogging



Beam pickup scope shots, beam 1 & 2

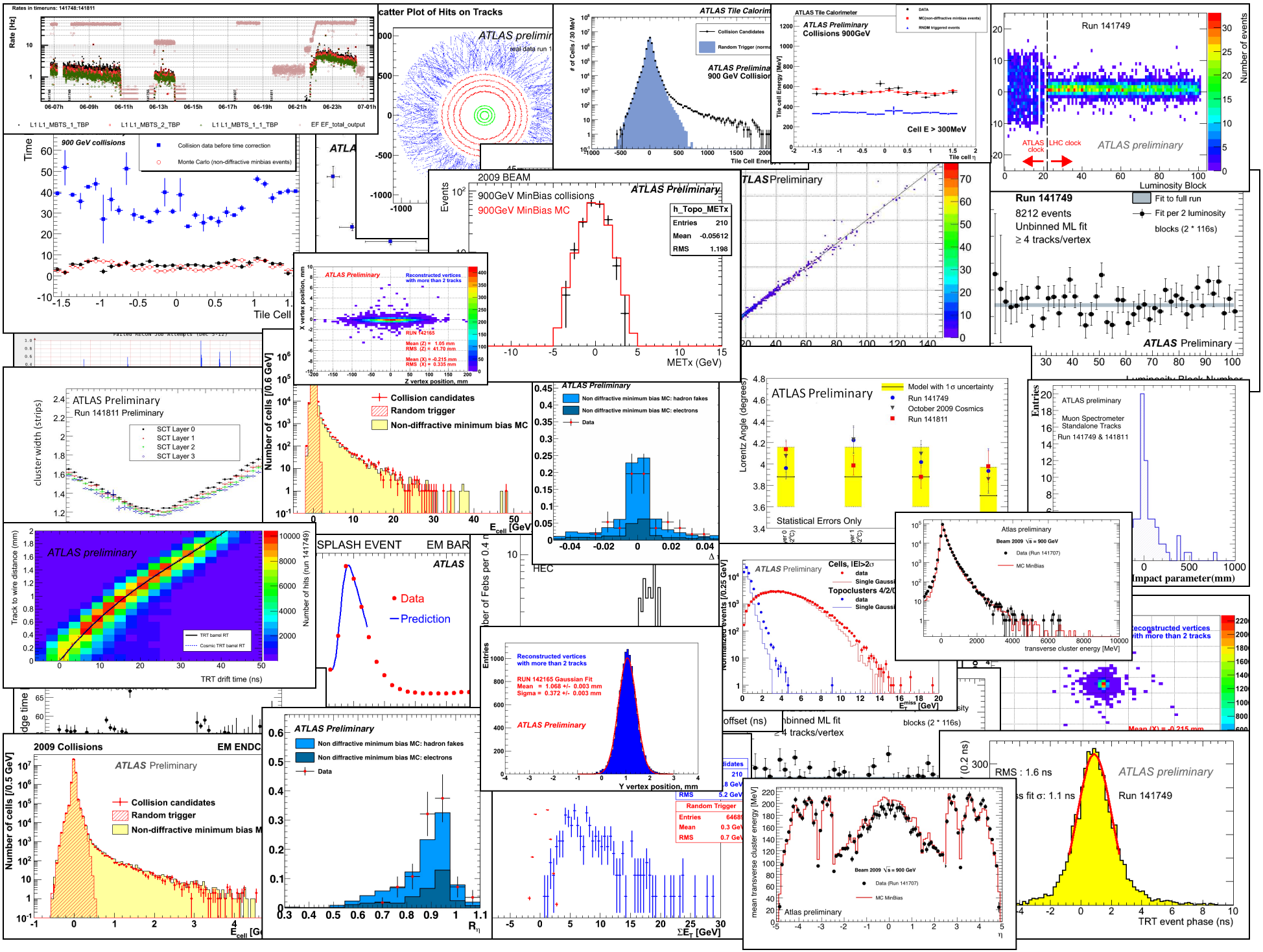
Bunches stable within 20 ps (rms)

Track *Z* distribution of collision candidate events as obtained before and after RF cogging. Observed shift: ~ +12 cm



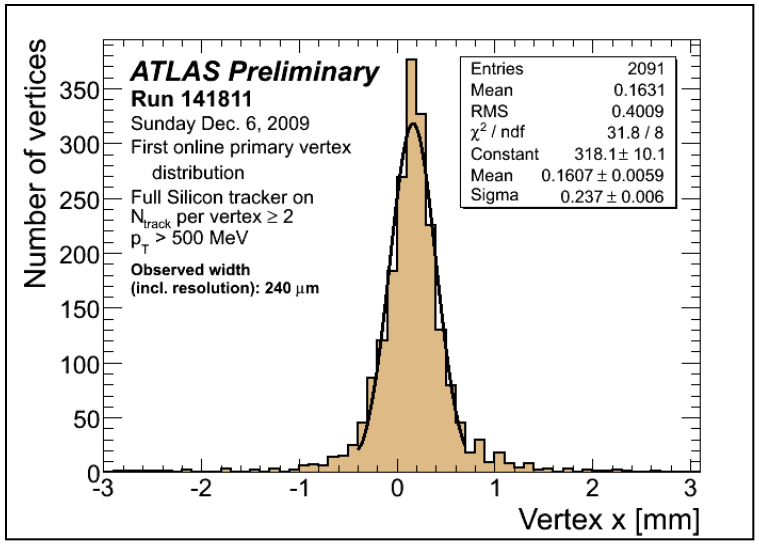
Note: beams were not yet stable → Pixels off and SCT at reduced voltage

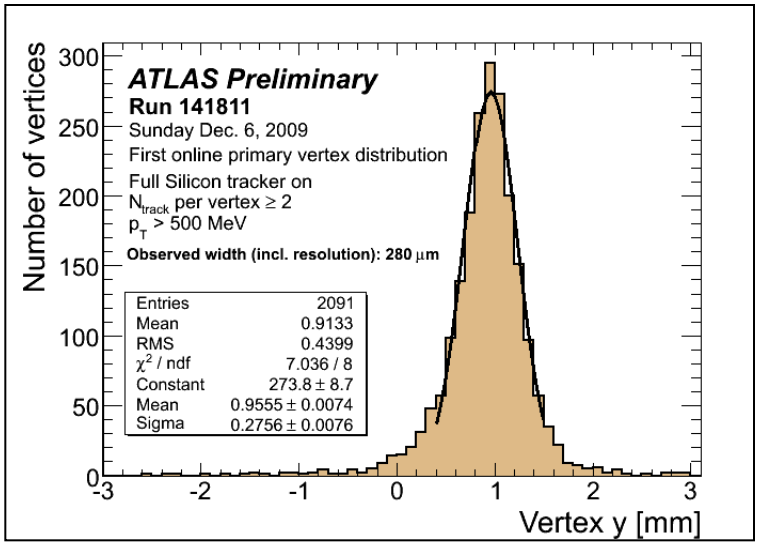
In the following: few examples from large amount of detector performance results obtained in just a few days ….

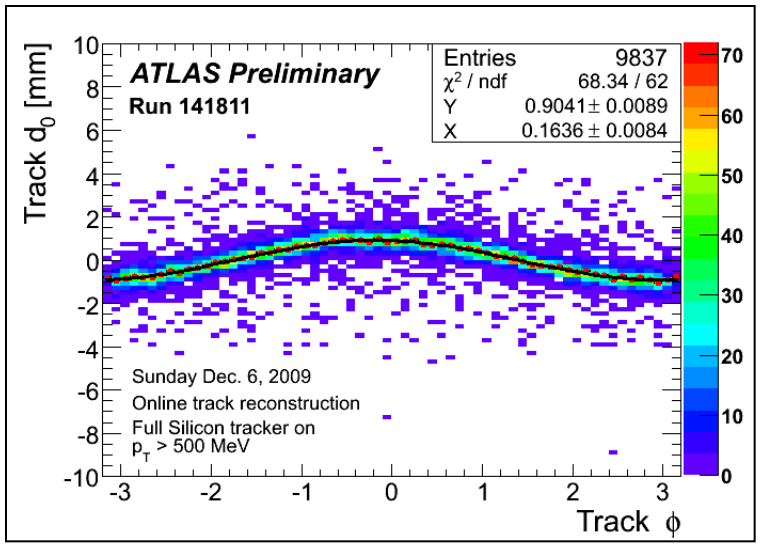

Rates in timeruns: 141748:141811
Rate [Hz]
L1 L1_MBTS_1_TBP
L1 L1_MBTS_2_TBP
L1 L1_MBTS_1_1_TBP
EF EF_total_output
900 GeV collisions
Collision data before time correction
Monte Carlo (non-diffractive minbias events)
Time
Tile Cell
ATLAS preliminary
real data run 1
2009 BEAM
900GeV MinBias collisions
900GeV MinBias MC
ATLAS Preliminary
h_Topo_METx
Entries 210
Mean -0.05612
RMS 1.198
METx (GeV)
Events
ATLAS Tile Calorimeter
Collision Candidates
Random Trigger (noise)
ATLAS Preliminary
900 GeV Collisions
# of Cells / 30 MeV
Tile cell Energy [MeV]
Tile cell η
ATLAS Tile Calorimeter
ATLAS Preliminary
Collisions 900GeV
DATA
MC(non-diffractive minbias events)
RNDM triggered events
Cell E > 300MeV
Run 141749
ATLAS clock
LHC clock
ATLAS preliminary
Luminosity Block
Number of events
ATLAS Preliminary
Reconstructed vertices with more than 2 tracks
RUN 142165
Mean (Z) = 1.05 mm
RMS (Z) = 41.70 mm
Mean (X) = -0.215 mm
RMS (X) = 0.335 mm
X vertex position, mm
Z vertex position, mm
ATLAS Preliminary
Run 141749
8212 events
Unbinned ML fit
≥ 4 tracks/vertex
Fit to full run
Fit per 2 luminosity blocks (2 * 116s)
ATLAS Preliminary
ATLAS Preliminary
Run 141811 Preliminary
SCT Layer 0
SCT Layer 1
SCT Layer 2
SCT Layer 3
cluster width (strips)
Number of cells [/0.6 GeV]
Collision candidates
Random trigger
Non-diffractive minimum bias MC
E_cell [GeV]
ATLAS Preliminary
Non diffractive minimum bias MC: hadron fakes
Non diffractive minimum bias MC: electrons
Data
Δ
ATLAS Preliminary
Model with 1σ uncertainty
Run 141749
October 2009 Cosmics
Run 141811
Lorentz Angle (degrees)
Statistical Errors Only
ATLAS preliminary
Muon Spectrometer Standalone Tracks
Run 141749 & 141811
Entries
Impact parameter(mm)
ATLAS preliminary
Track to wire distance (mm)
Number of hits (run 141749)
TRT barrel RT
Cosmic TRT barrel RT
TRT drift time (ns)
SPLASH EVENT
EM BAR
ATLAS
Data
Prediction
HEC
ber of Febs per 0.4
ATLAS Preliminary
Cells, |E|>2σ
data
Single Gaussi
Topoclusters 4/2/0
data
Single Gaussi
Normalized events [/0.25 GeV]
E_T^miss [GeV]
Atlas preliminary
Beam 2009 √s = 900 GeV
Data (Run 141707)
MC MinBias
transverse cluster energy [MeV]
Reconstructed vertices with more than 2 tracks
RUN 142165 Gaussian Fit
Mean = 1.068 +/- 0.003 mm
Sigma = 0.372 +/- 0.003 mm
ATLAS Preliminary
Entries
Y vertex position, mm
offset (ns)
≥ 4 tracks/vertex
blocks (2 * 116s)
Mean (X) = -0.215 mm
2009 Collisions
EM ENDC
ATLAS Preliminary
Collision candidates
Random trigger
Non-diffractive minimum bias M
Number of cells [/0.5 GeV]
E_cell [G
ATLAS Preliminary
Non diffractive minimum bias MC: hadron fakes
Non diffractive minimum bias MC: electrons
Data
R_η
Random Trigger
Entries 64685
Mean 0.3 GeV
RMS 0.7 GeV
ΣE_T [GeV]
mean transverse cluster energy [MeV]
Beam 2009 √s = 900 GeV
Data (Run 141707)
MC MinBias
Atlas preliminary
RMS : 1.6 ns
fit σ: 1.1 ns
ATLAS preliminary
Run 141749
TRT event phase (ns)

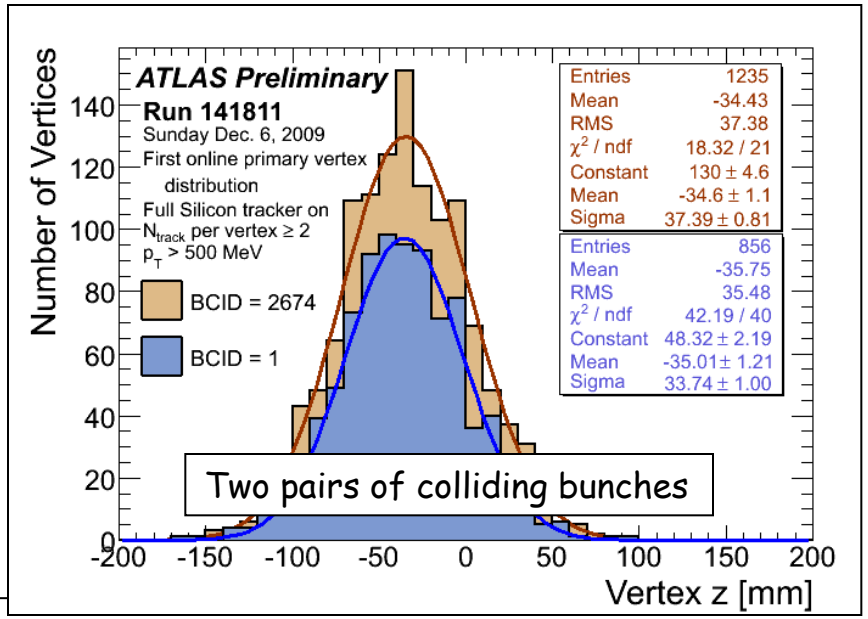
Online determination of the primary vertex and beam spot using the Level-2 trigger algorithms

High-Level Trigger running with > 150 chains



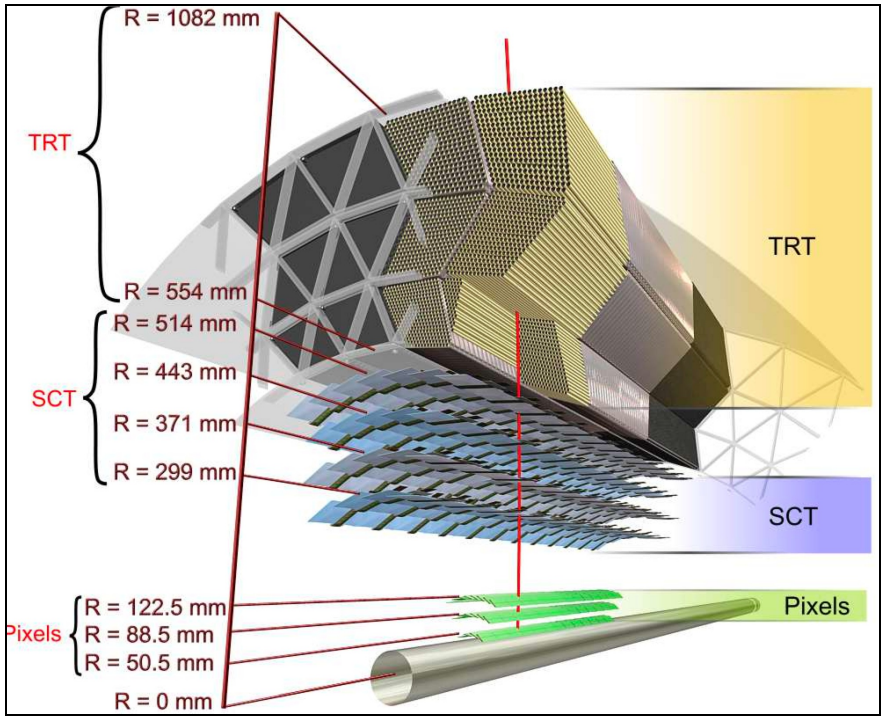


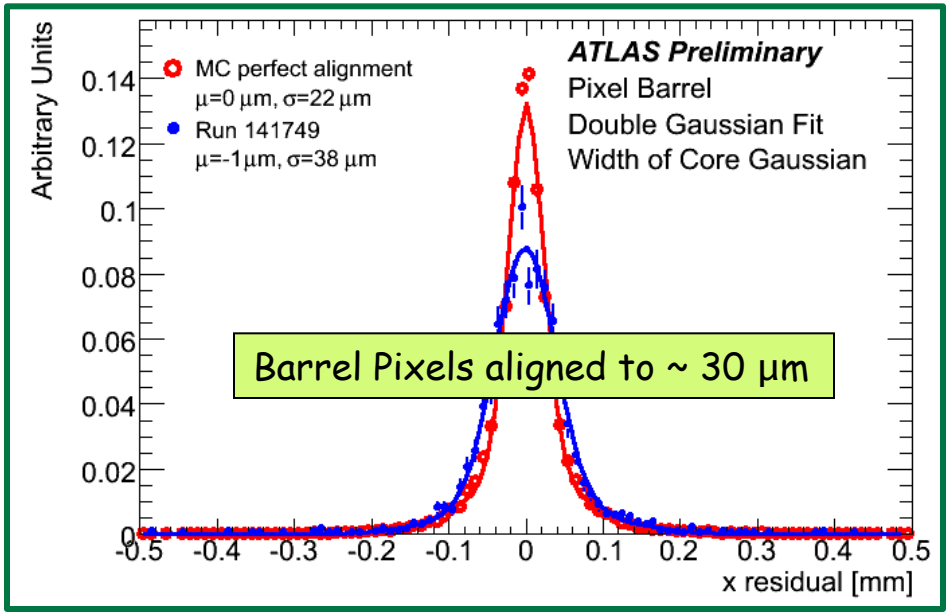


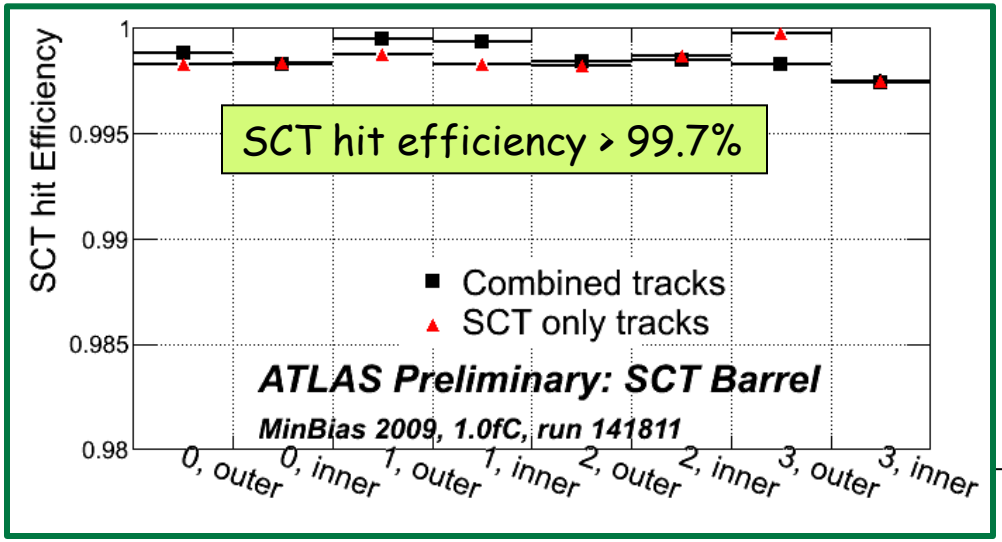


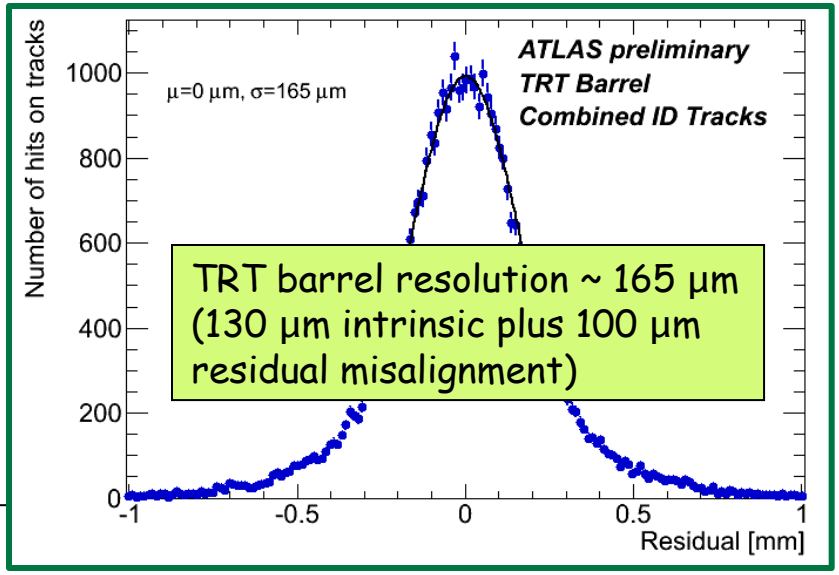
Tracking

Thanks to huge work done with cosmics …





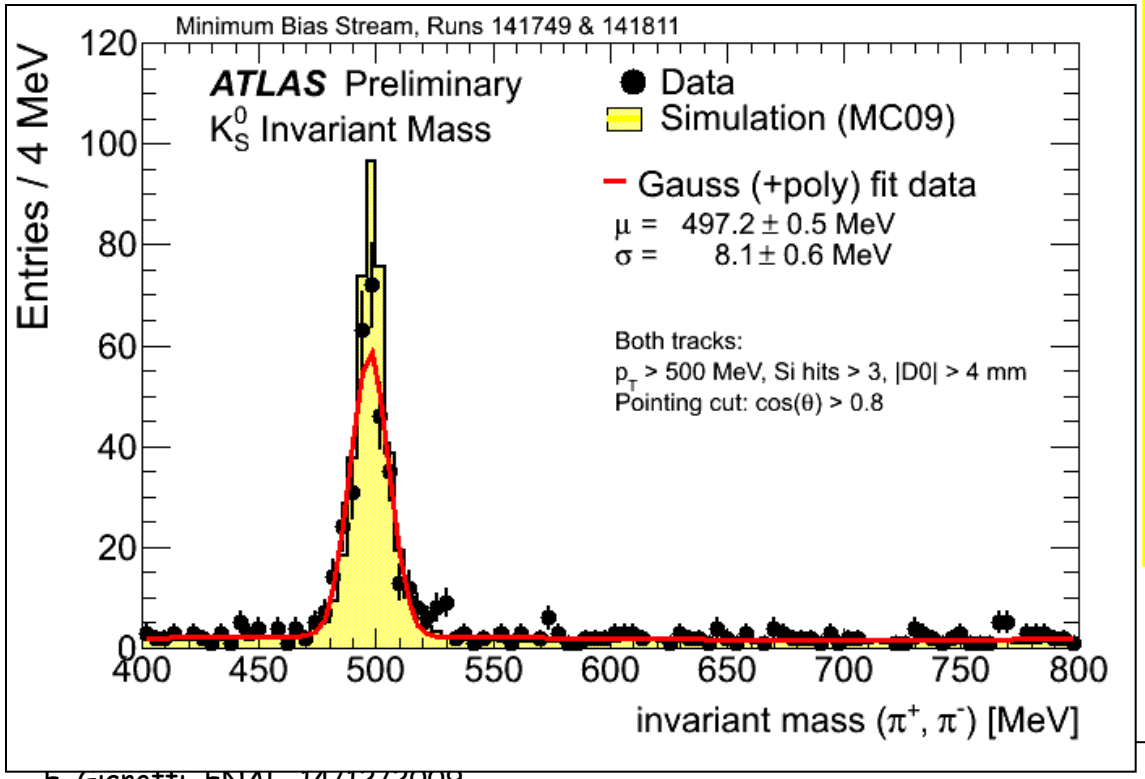


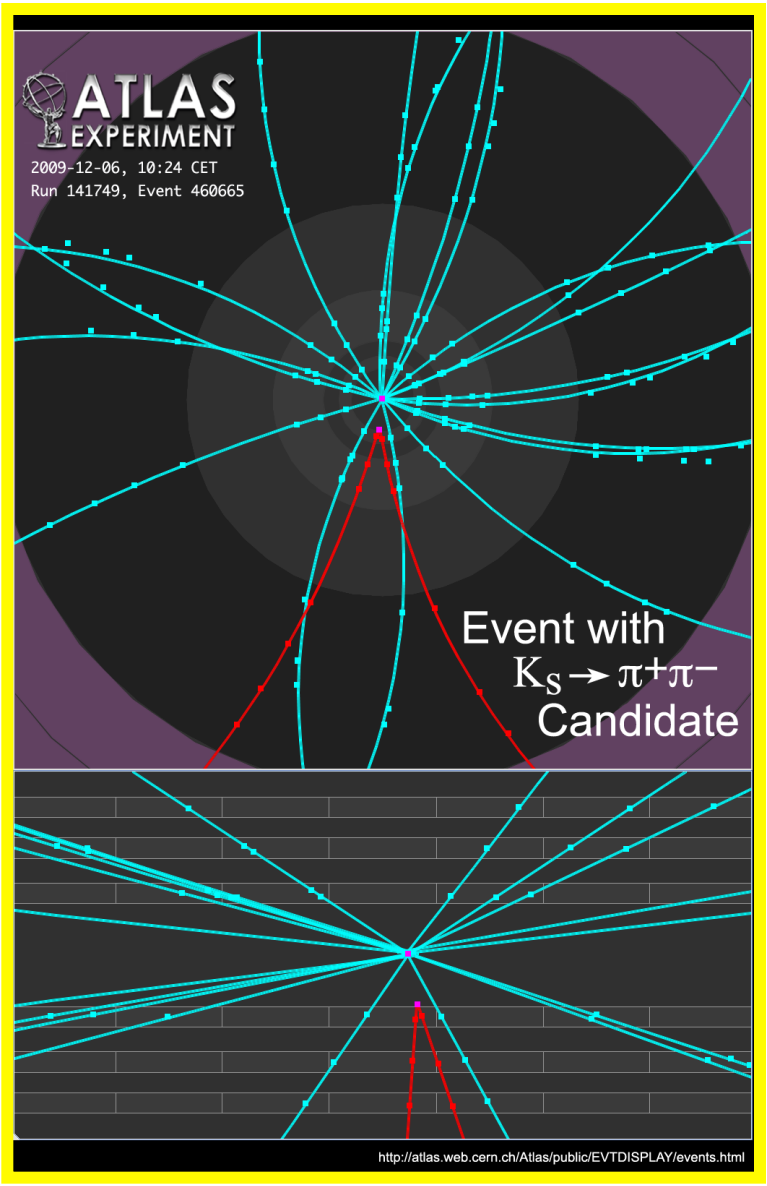


$K^0_s \rightarrow \pi^+\pi^-$

2 opposite-sign tracks:
- p_T >500 MeV
- originating from common vertex
- impact parameter d_0 > 4 mm
- momentum sum along flight direction

Data and MC normalized to the same area

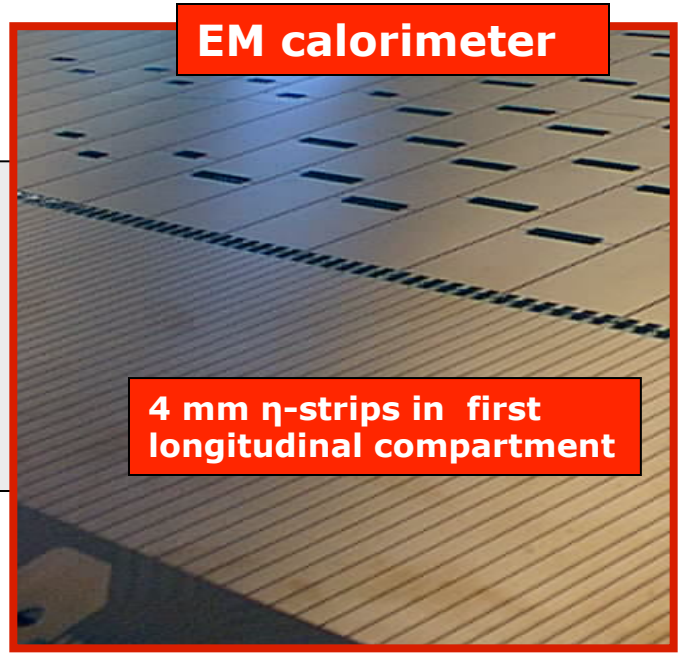


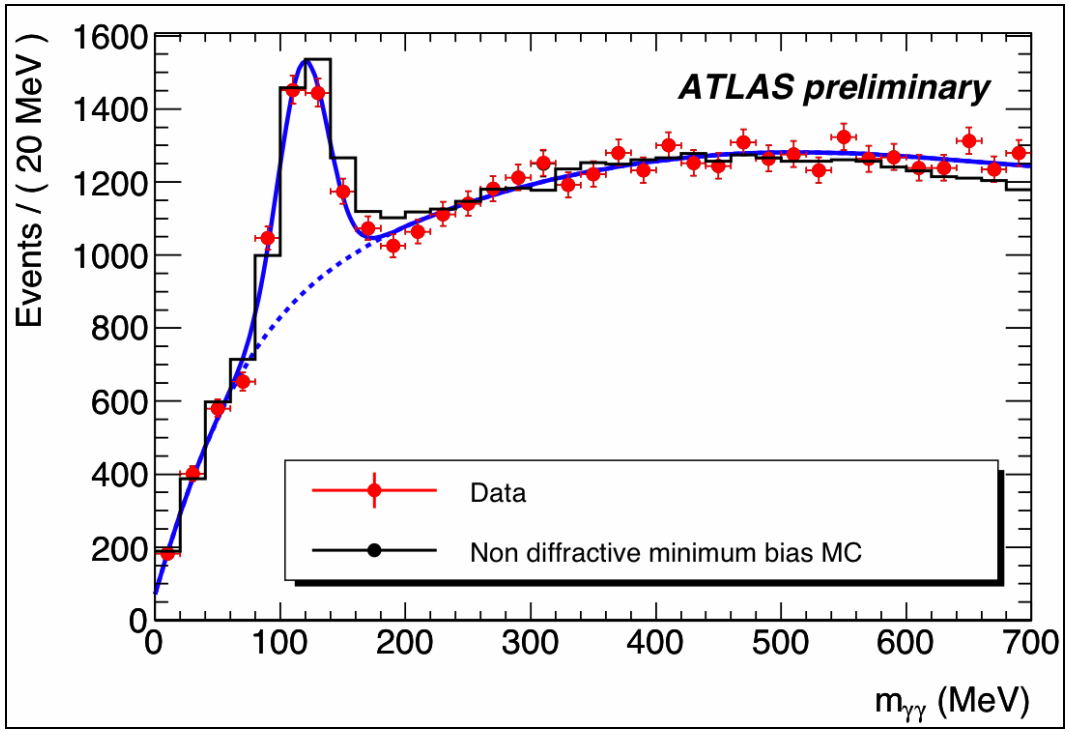


$\pi^0 \rightarrow \gamma\gamma$

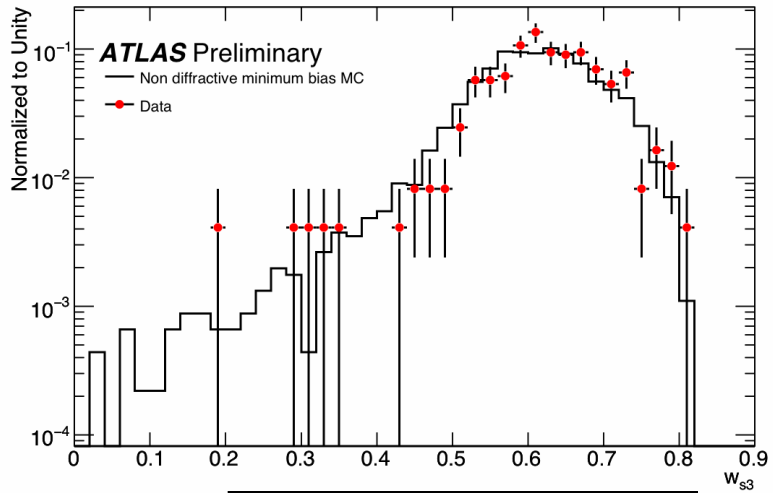
- 2 photons with $E_T(\gamma) > 300$ MeV
- $E_T(\gamma\gamma) > 900$ MeV
- shower shapes compatible with photons

All combinations plotted.
No correction for upstream dead material (~ 2.5 X_0 at η=0)
Data and MC normalised to the same area



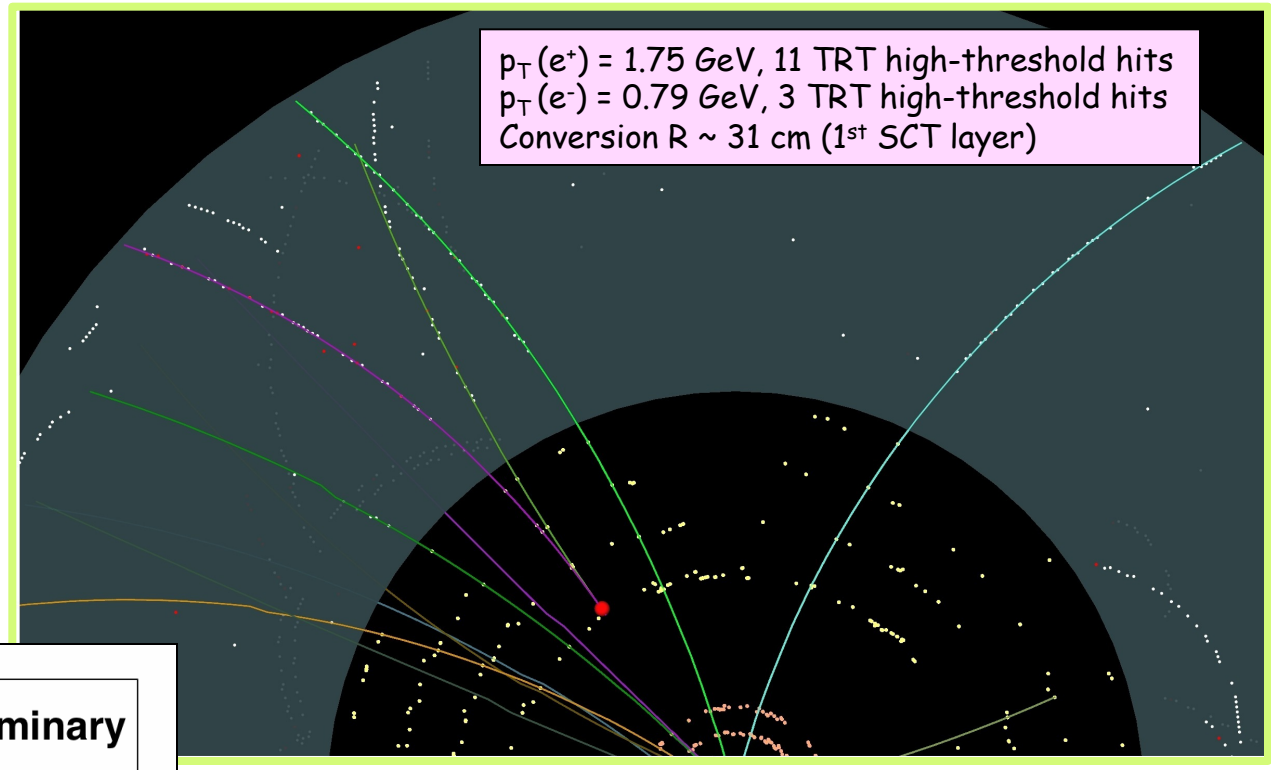


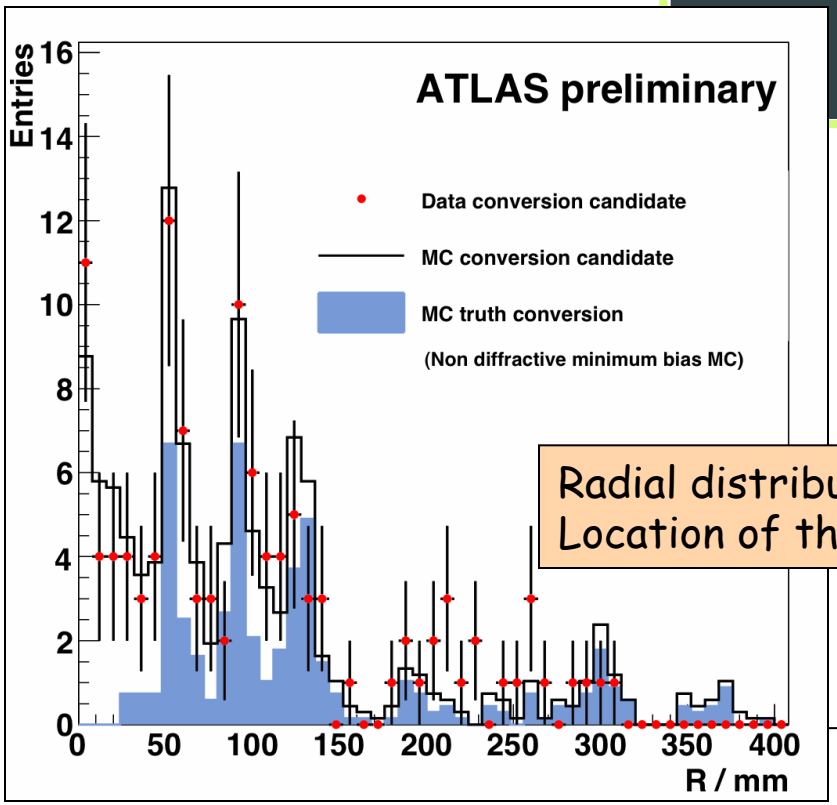
Very good data-MC agreement for (very soft !) photon showers



Shower width (strip unit)

$\gamma \rightarrow e^+e^-$ conversions

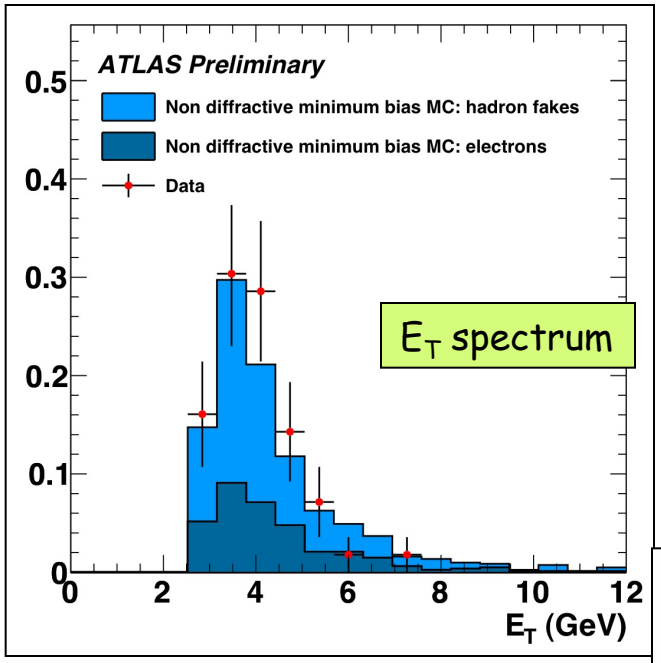




Radial distribution of conversions occurring in Si layers.
Location of the pixels layers at R=50, 90, 120 mm is clearly visible

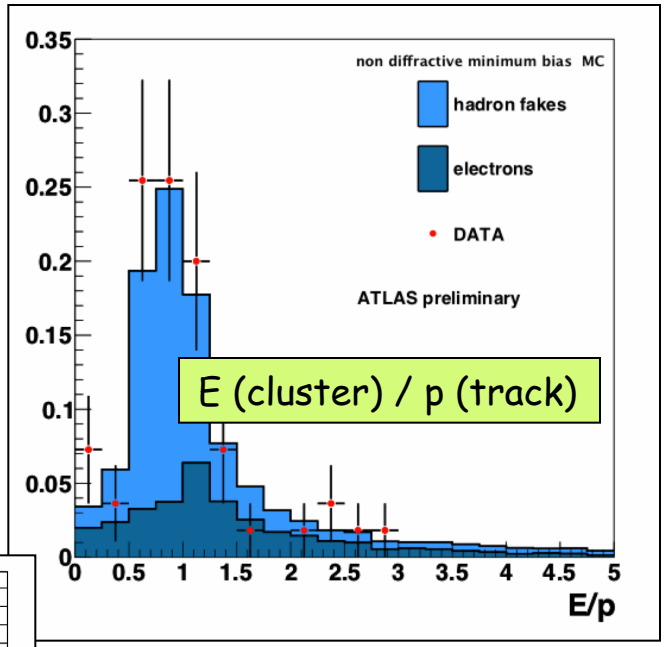
Electron candidates

EM clusters E_T > 2.5 GeV matched to a track
→ 47 candidates in 20000 minimum-bias events
Data and MC normalised to the same area



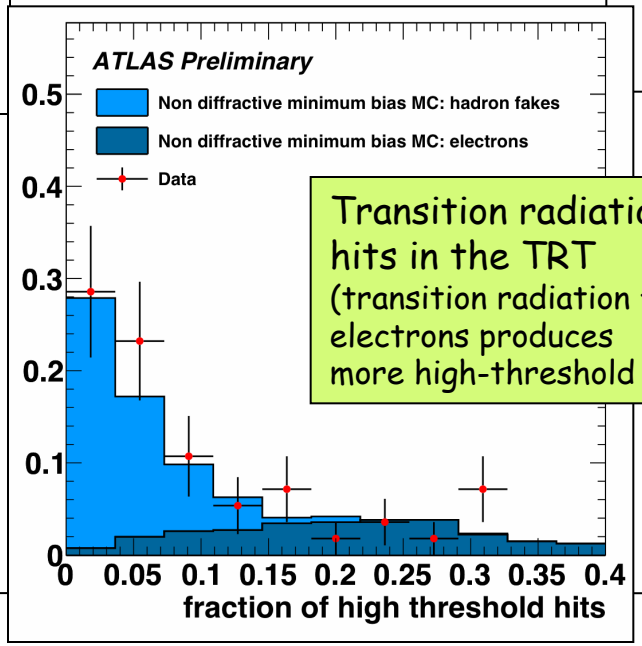
E_T spectrum

According to MC:
- Sample dominated by hadron fakes
- Most electrons from γ-conversions



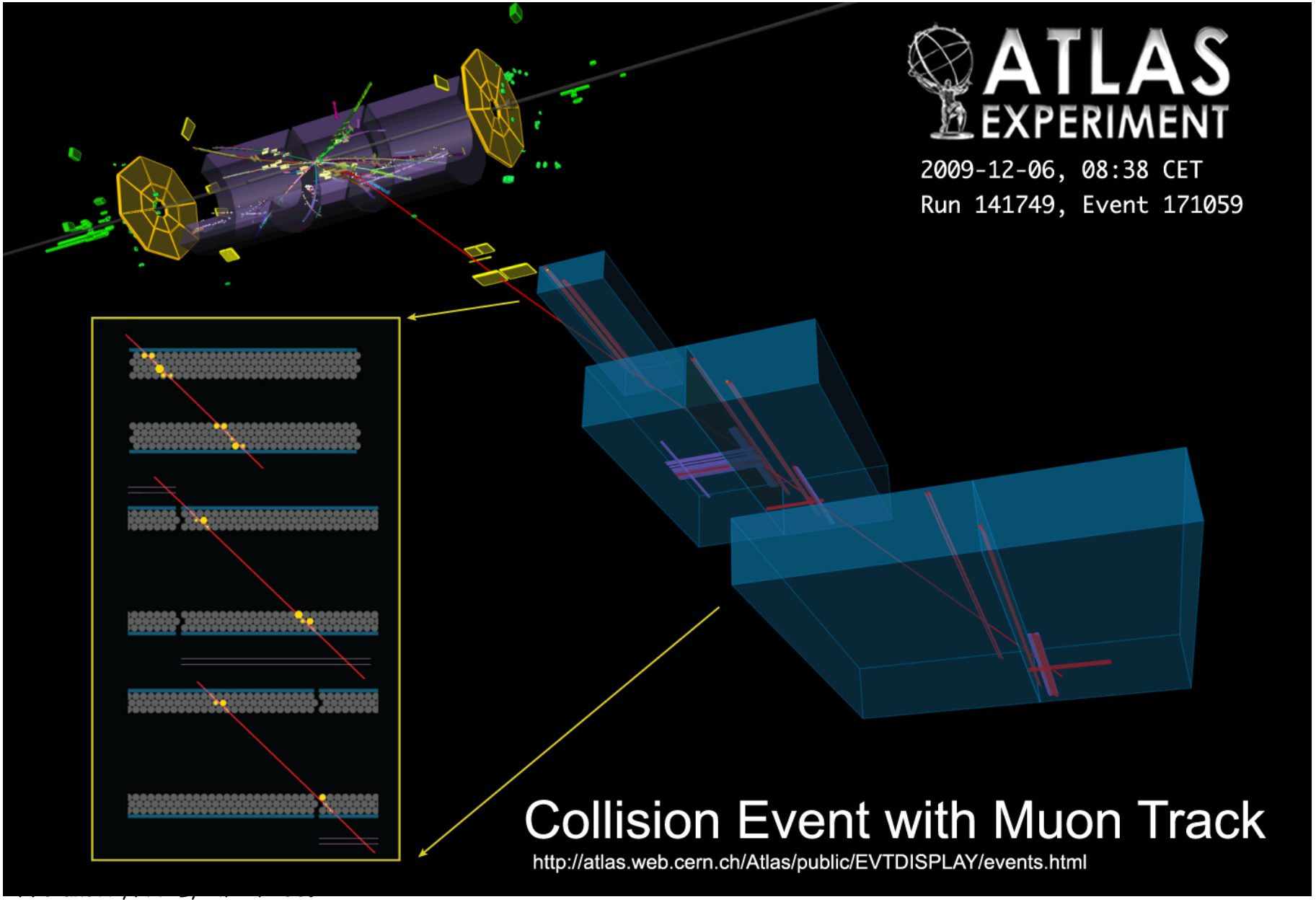
E (cluster) / p (track)

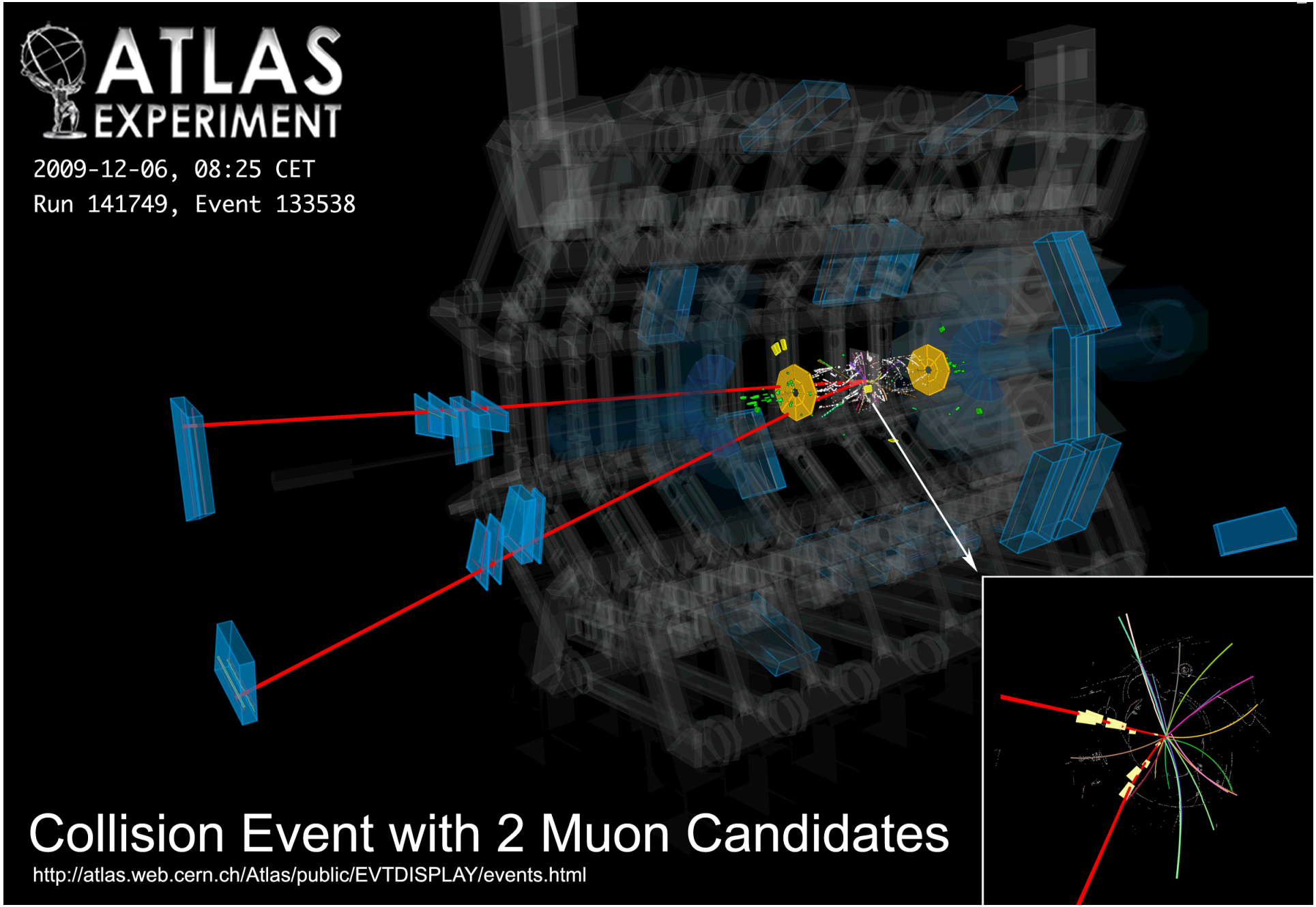
Very good data-MC agreement for (soft !) electrons and hadrons

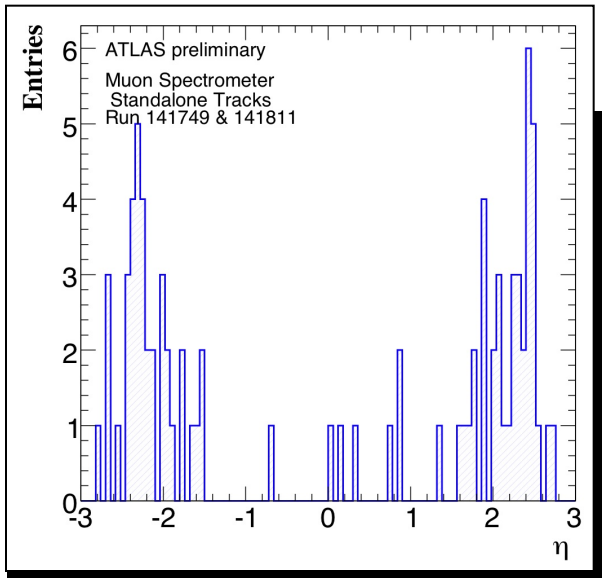


Transition radiation hits in the TRT
(transition radiation from electrons produces more high-threshold hits)

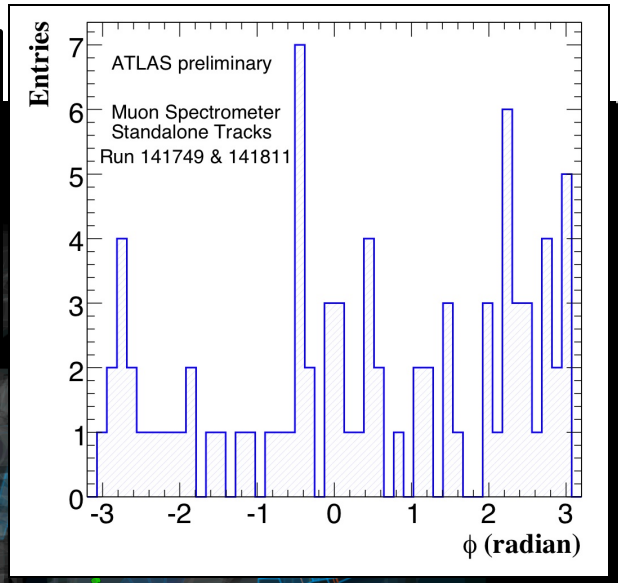
Muon candidates

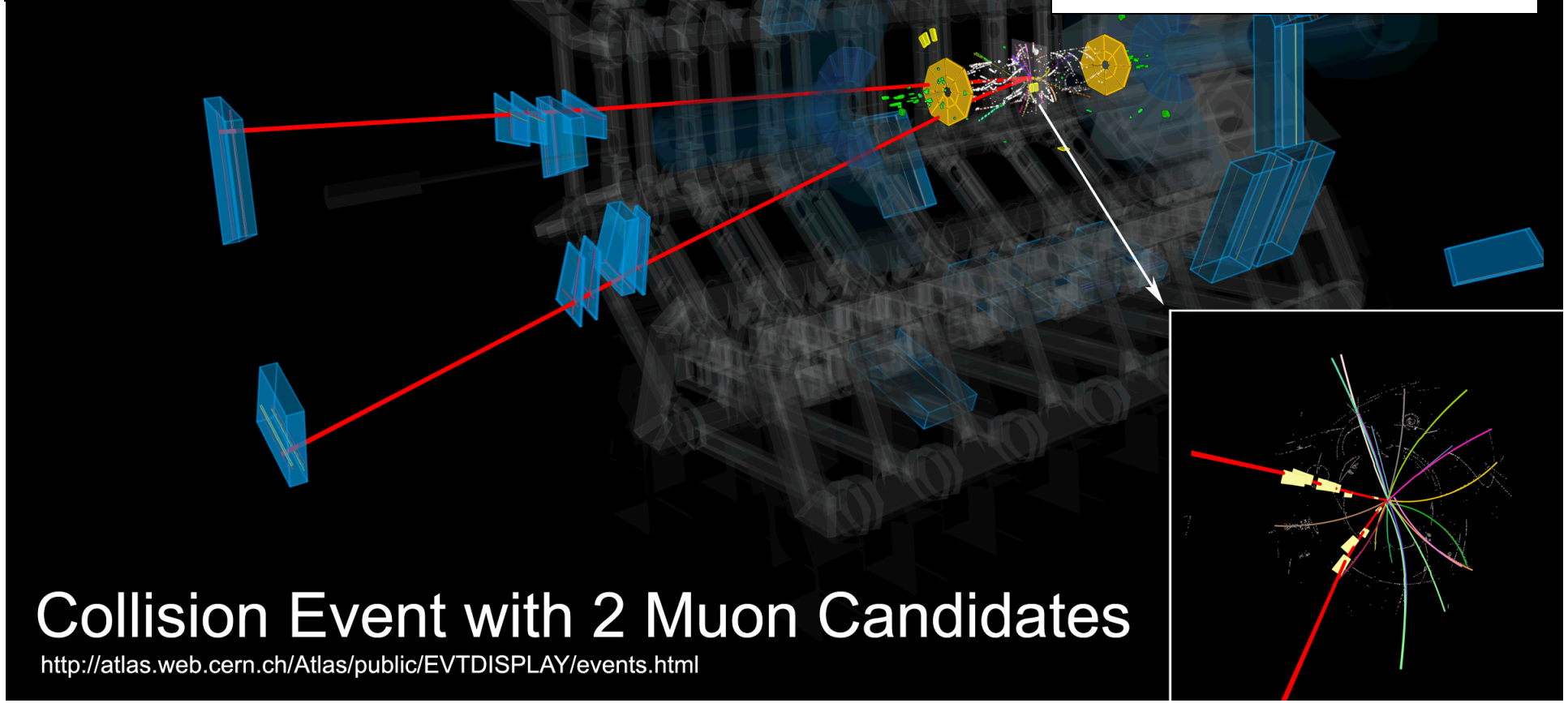



ATLAS
EXPERIMENT
2009-12-06, 08:25 CET
Run 141749, Event 133538
Collision Event with 2 Muon Candidates
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html



η and φ distributions of (very low momentum p ~ 3 GeV) muon candidates are compatible with particles produced in the collisions (mainly coming from K/π decays)

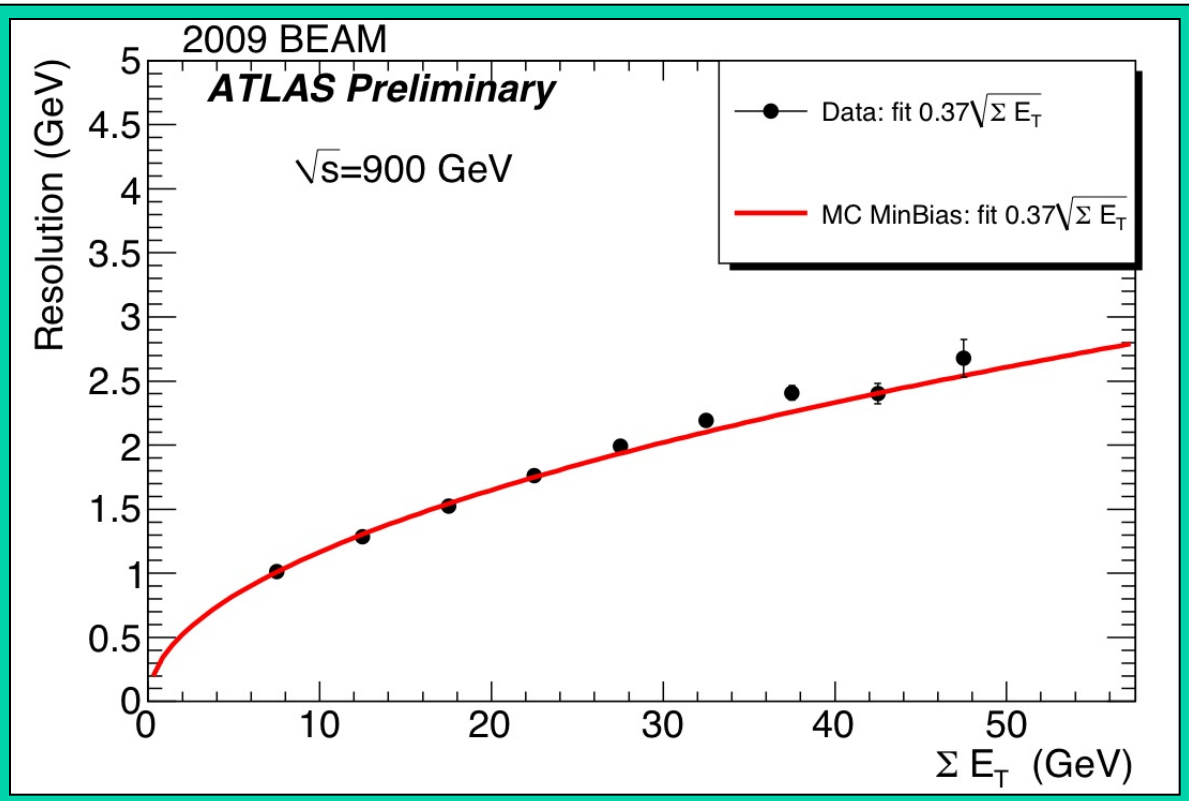




Collision Event with 2 Muon Candidates

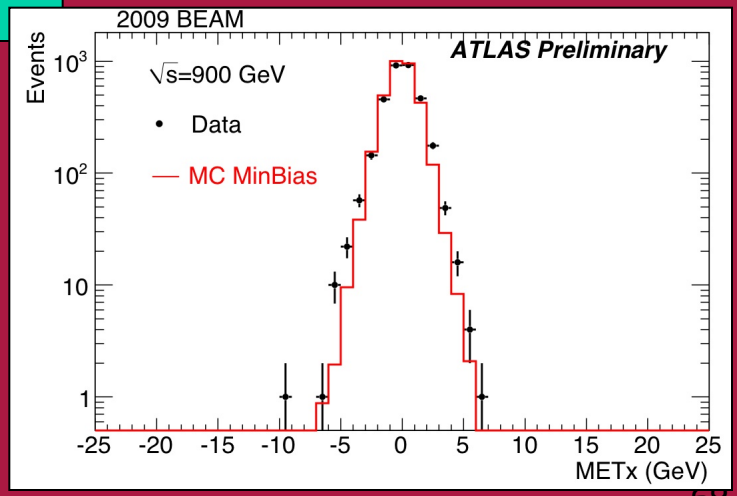
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

Missing transverse energy resolution



Energy resolution of the two components (METx, METy) of the missing E_T vector vs the total transverse energy in the calorimeters

- Measurement over full calorimeter coverage, $|\eta| < 5$, ~ 200000 cells
- Calculated using clusters at EM-scale
- Noise contribution (from random triggers): 0.5 GeV



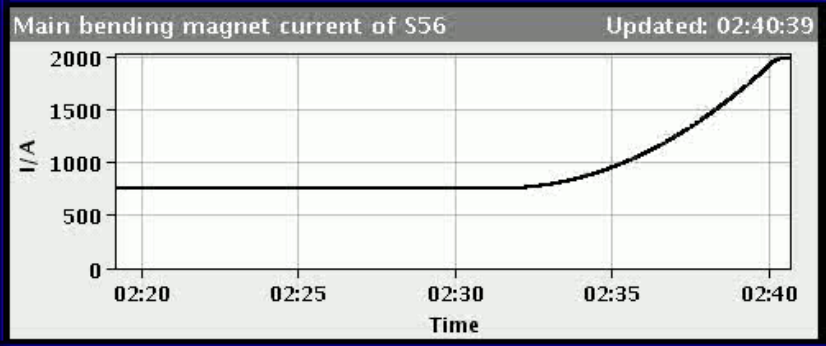
VLC media player

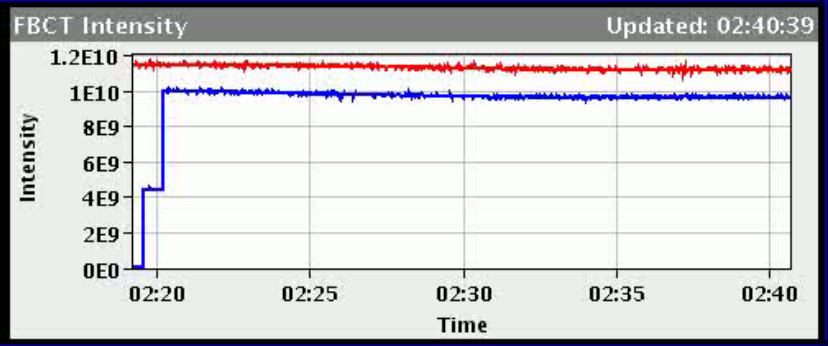
File View Settings Audio Video Navigation Help

LHC Page1 Fill: 916.0 E: 1180 GeV 14-12-2009 02:40:39

BEAM SETUP: RAMP

Energy:	1180 GeV	I(B1):	0.00e+00	I(B2):	7.80e+09





Many thanks to the accelerator team for the outstanding machine performance, for the impressive progress over a few days of operation, and for the excellent interactions with the experiments

Comments 14-12-2009 02:33:04 :

Expts: can go back to LHC clocks

ramping up

filling schema: bucket 1 and 17851 in B1

filling schema: bucket 1 and 8911 in B2

SMP Flags

Channel Link Status

Global Beam Per

Setup Beam

Beam Presenc

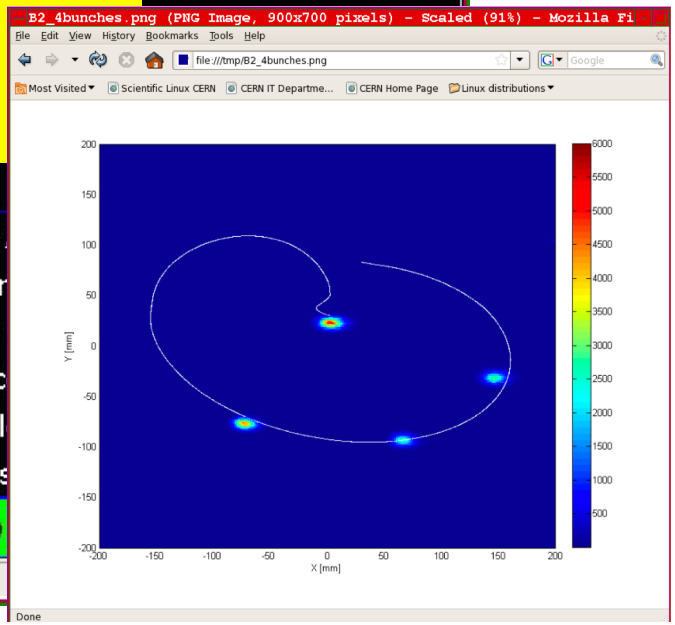
Moveable Devices All

Stable Beams

LHC Operation in CCC : 77600, 70480

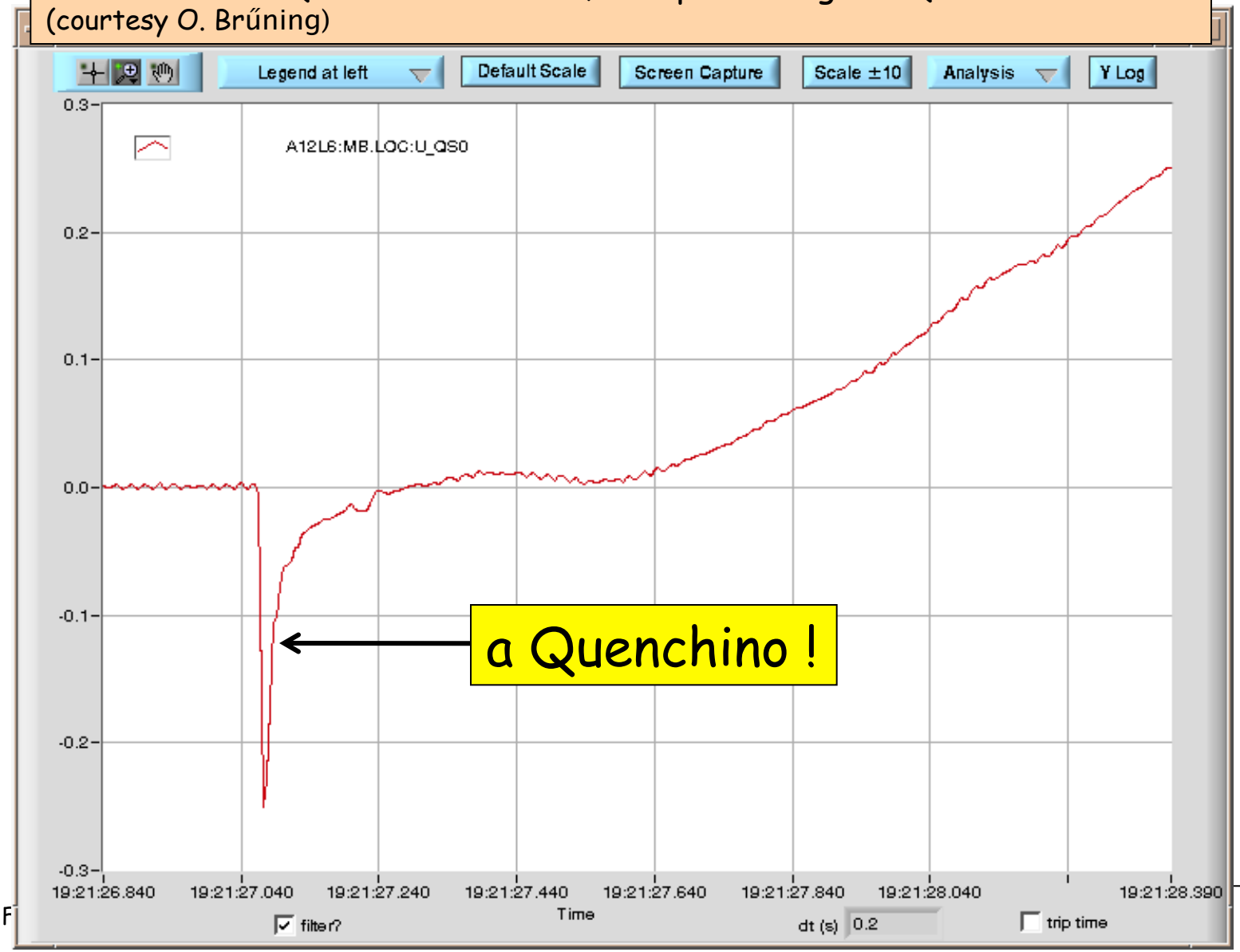
PM Status B1 ENABLED

0:00:00 / 0:00: x1.00 "LHC Page 1"

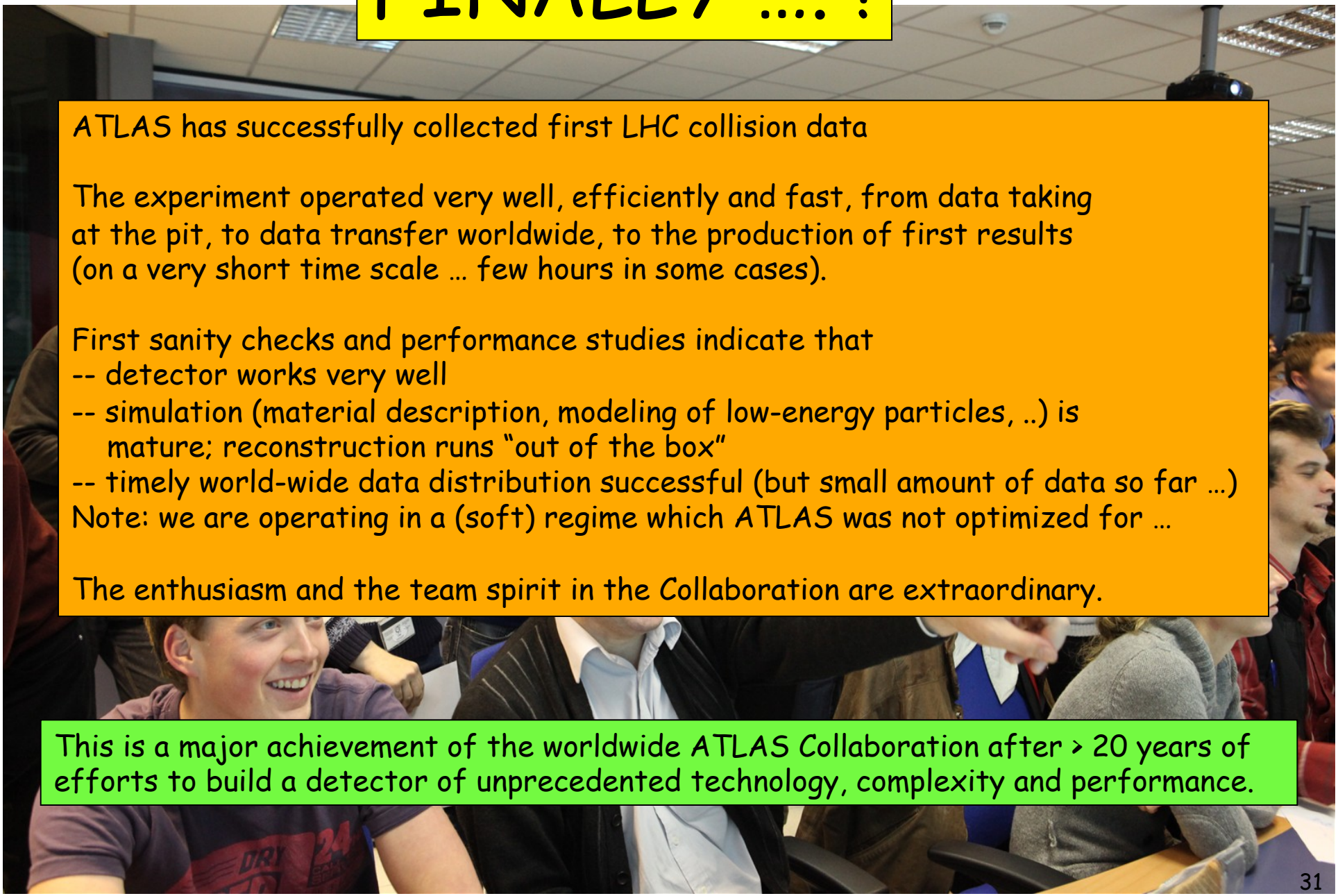


They even gave us first SUSY signals …

Beam Induced Quench 20.11.2009, 7:30pm: voltage in QPS of sector 56
(courtesy O. Brűning)



FINALLY …. !



ATLAS has successfully collected first LHC collision data

The experiment operated very well, efficiently and fast, from data taking at the pit, to data transfer worldwide, to the production of first results (on a very short time scale … few hours in some cases).

First sanity checks and performance studies indicate that
-- detector works very well
-- simulation (material description, modeling of low-energy particles, ..) is mature; reconstruction runs "out of the box"
-- timely world-wide data distribution successful (but small amount of data so far …)
Note: we are operating in a (soft) regime which ATLAS was not optimized for …

The enthusiasm and the team spirit in the Collaboration are extraordinary.

This is a major achievement of the worldwide ATLAS Collaboration after > 20 years of efforts to build a detector of unprecedented technology, complexity and performance.

What's next ?

Chris Quigg

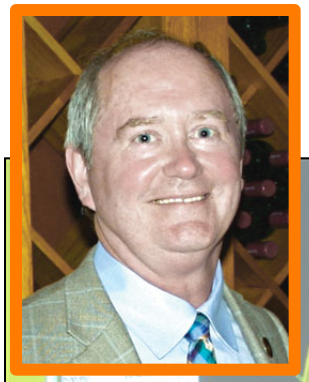
In a decade or two, we can hope to . . .

- Understand electroweak symmetry breaking
- Observe the Higgs boson
- Measure neutrino masses and mixings
- Establish Majorana neutrinos ($\beta\beta_{0\nu}$)
- Thoroughly explore CP violation in B decays
- Exploit rare decays (K, D, . . .)
- Observe neutron EDM, pursue electron EDM
- Use top as a tool
- Observe new phases of matter
- Understand hadron structure quantitatively
- Uncover the full implications of QCD
- Observe proton decay
- Understand the baryon excess
- Catalogue matter and energy of the universe
- Measure dark energy equation of state
- Search for new macroscopic forces
- Determine GUT symmetry
- Detect neutrinos from the universe
- Learn how to quantize gravity
- Learn why empty space is nearly weightless
- Test the inflation hypothesis
- Understand discrete symmetry violation
- Resolve the hierarchy problem
- Discover new gauge forces
- Directly detect dark-matter particles
- Explore extra spatial dimensions
- Understand the origin of large-scale structure
- Observe gravitational radiation
- Solve the strong CP problem
- Learn whether supersymmetry is TeV-scale
- Seek TeV-scale dynamical symmetry breaking
- Search for new strong dynamics
- Explain the highest-energy cosmic rays
- Formulate the problem of identity

. . . learn the right questions to ask . . .

. . . and rewrite the textbooks!

Thanks, Chris, for being a continuous source of inspiration for generations of experimentalists, and such a wonderful scientist and exquisite friend



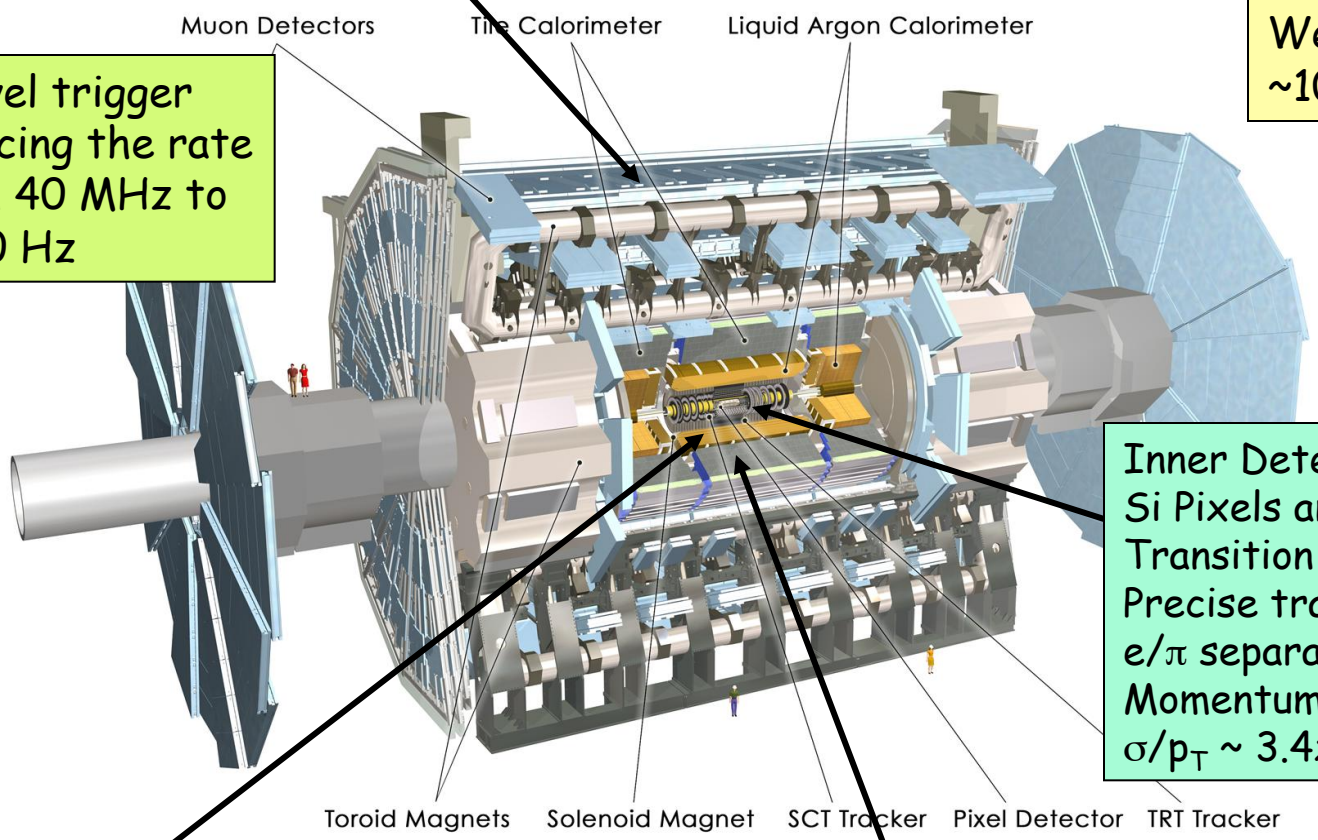
Buon compleanno, caro Chris !

Back-up

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based chambers
Muon trigger and measurement with momentum resolution < 10% up to E_μ ~ TeV

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels

3-level trigger reducing the rate from 40 MHz to ~200 Hz

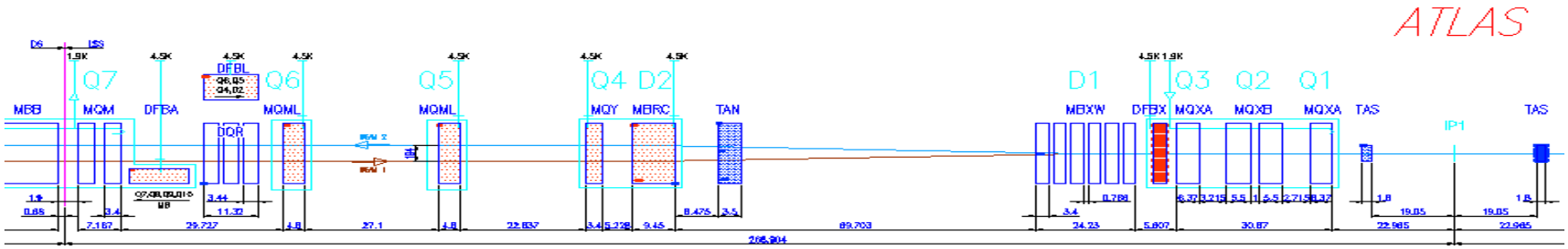


Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels and strips (SCT) +
Transition Radiation straws
Precise tracking and vertexing,
e/π separation (TRT).
Momentum resolution:
$\sigma/p_T \sim 3.4\times10^{-4}\ p_T(\mathrm{GeV}) \oplus 0.015$

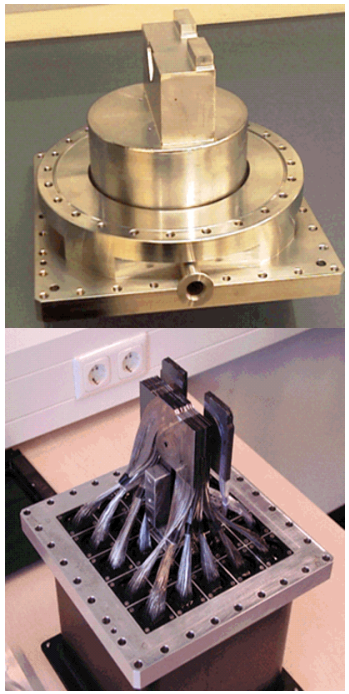
EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: ~ 1% at 100 GeV, 0.5% at 1 TeV

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Tilecal Fe/scintillator (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

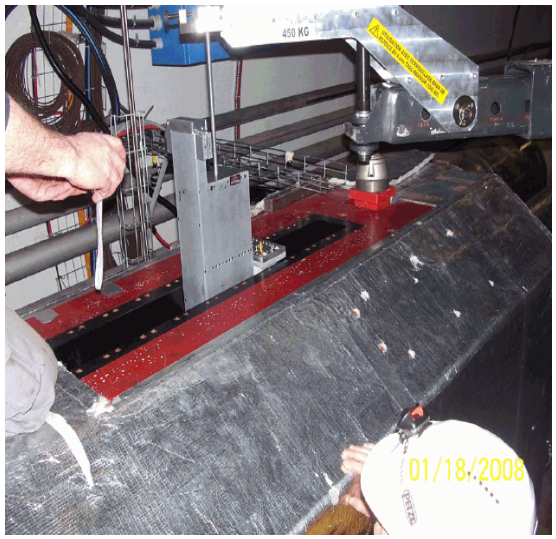
Forward detectors



ALFA at 240 m



ZDC at 140 m



Zero Degree Calorimeter
(Data taking in 2009)

LUCID at 17 m

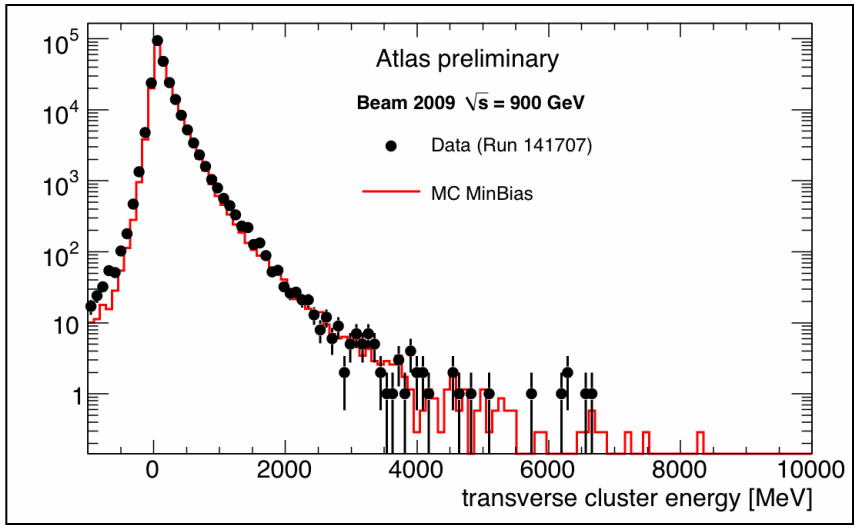
Luminosity Cerenkov Integrating Detector
(Phase 1 operational since 2008)

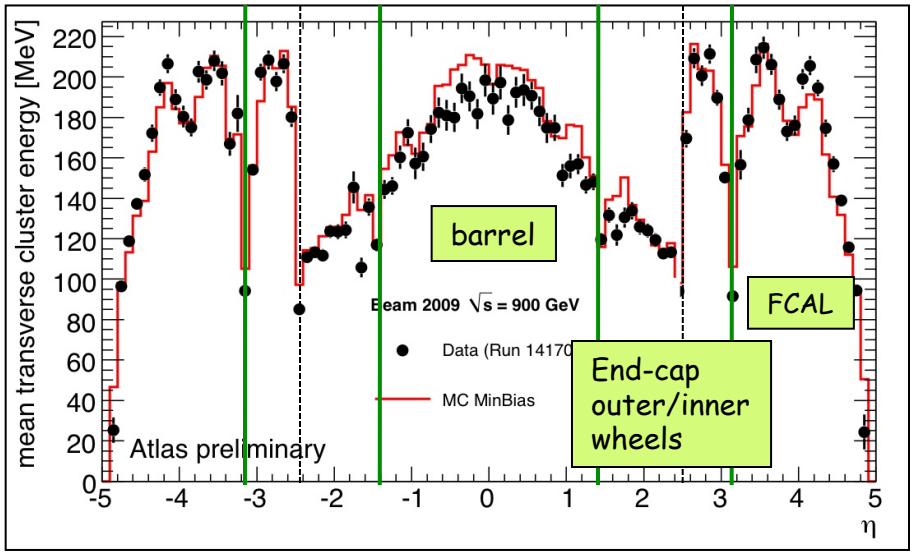
ALFA: Absolute Luminosity for ATLAS
(Installation in 2010)

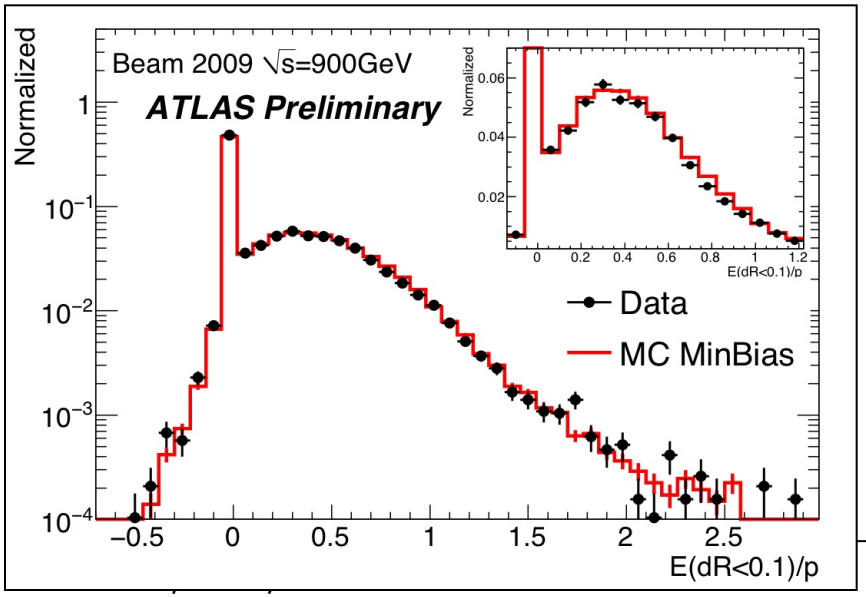
LoI for Forward Proton detectors at 220 and 420 m (AFP): ongoing ATLAS review

Energy flow in calorimeters …

Uncalibrated clusters
(topological clusters with noise suppression)



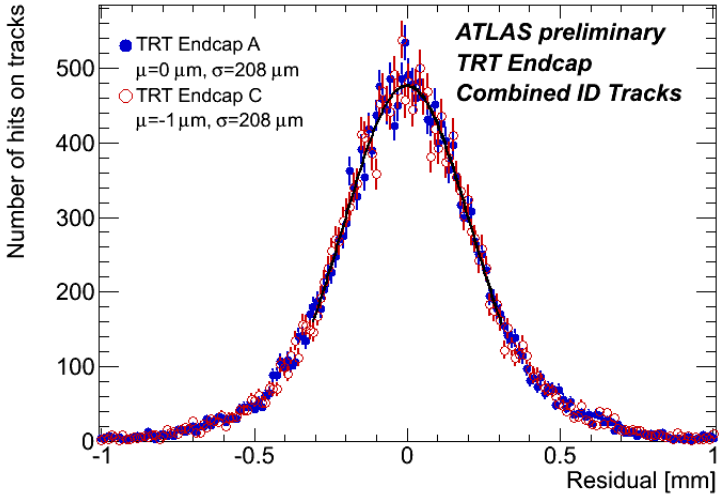




$$\frac{E(\text{calorimeter})}{p(\text{tracker})}$$

for isolated tracks with $|\eta| < 0.8$
and $0.5 < p_T < 10$ GeV (average ~ 0.8 GeV)
Cluster energy at EM scale

Excellent agreement data-MC at such low energies indicates very good description of material in simulation and G4 shower modeling


TRT Endcap A
μ=0 μm, σ=208 μm
TRT Endcap C
μ=-1 μm, σ=208 μm
ATLAS preliminary
TRT Endcap
Combined ID Tracks
Number of hits on tracks
Residual [mm]
0
100
200
300
400
500
-1
-0.5
0
0.5
1