Physics Program

of the experiments at

Large Hadron Collider

Lecture 2

First pp collisions

in ATLAS detector

LHC parameters

Beam energy	7 TeV
Design Luminosity	$10^{34}\,cm^{-2}s^{-1}$
Bunch spacing	25 ns
Particles/Bunch	10^{11} x 2808 bunches
SC Dipoles	1232, 15 m, 8.33T
Stored Energy	350 MJ/Beam

LHCb

ATLAS

CMS

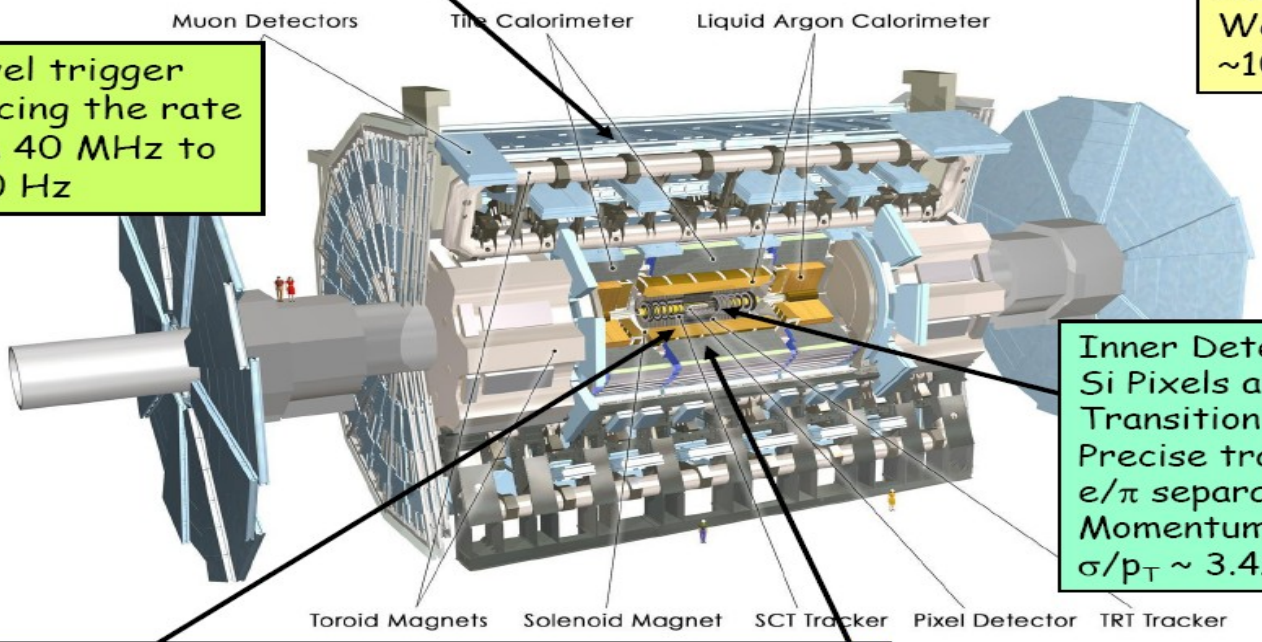
ALICE

The ATLAS Detector

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: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

September 2008

First beams - September 10, 2008

First beams - in ATLAS...

After Sept 10

Successful continuation of commissioning with beam

(low intensity, 10^9 protons)

Sept 11:

Switched on RF for beam 2 circulating beam for 10 min

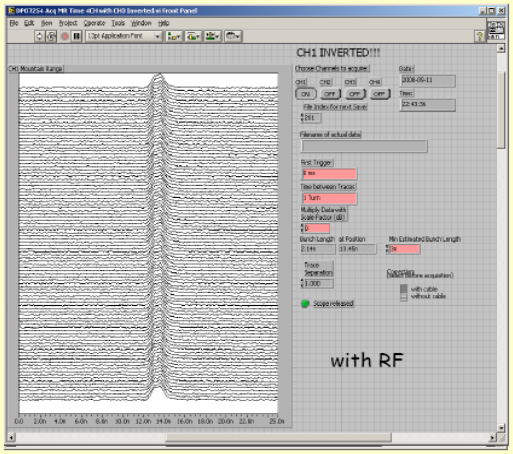
Many tests (orbit, dump,...)

Sept 12:

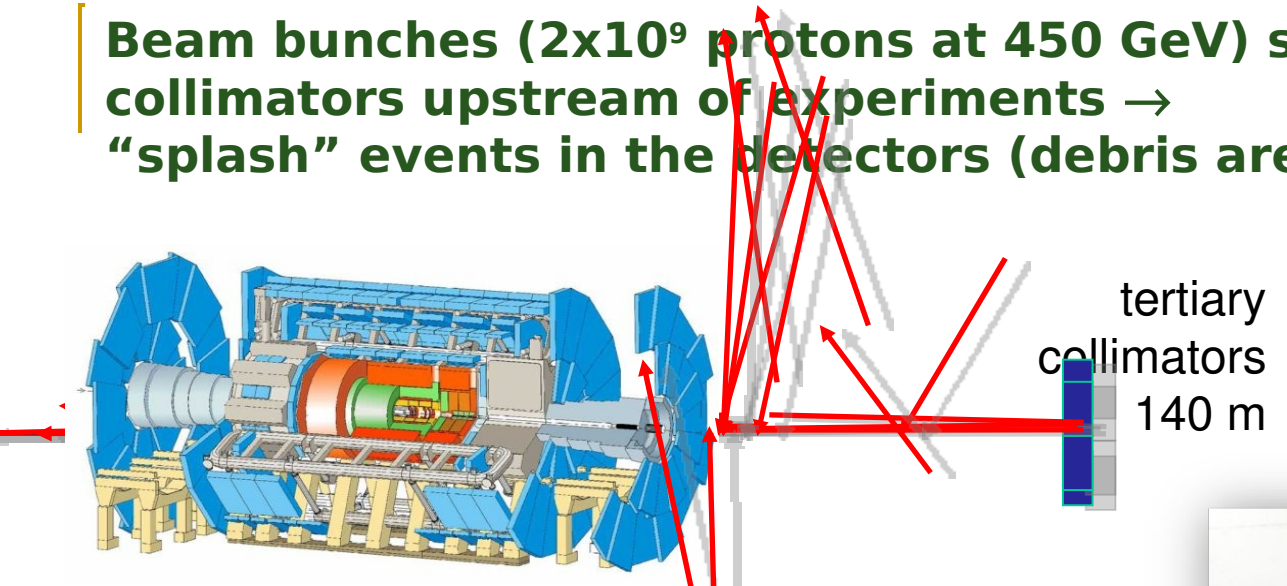
Measure horizontal beam profile with wire scanner

Evening: transformer failure pt8 replacement + recovery

Continue with machine checkout (without beam)

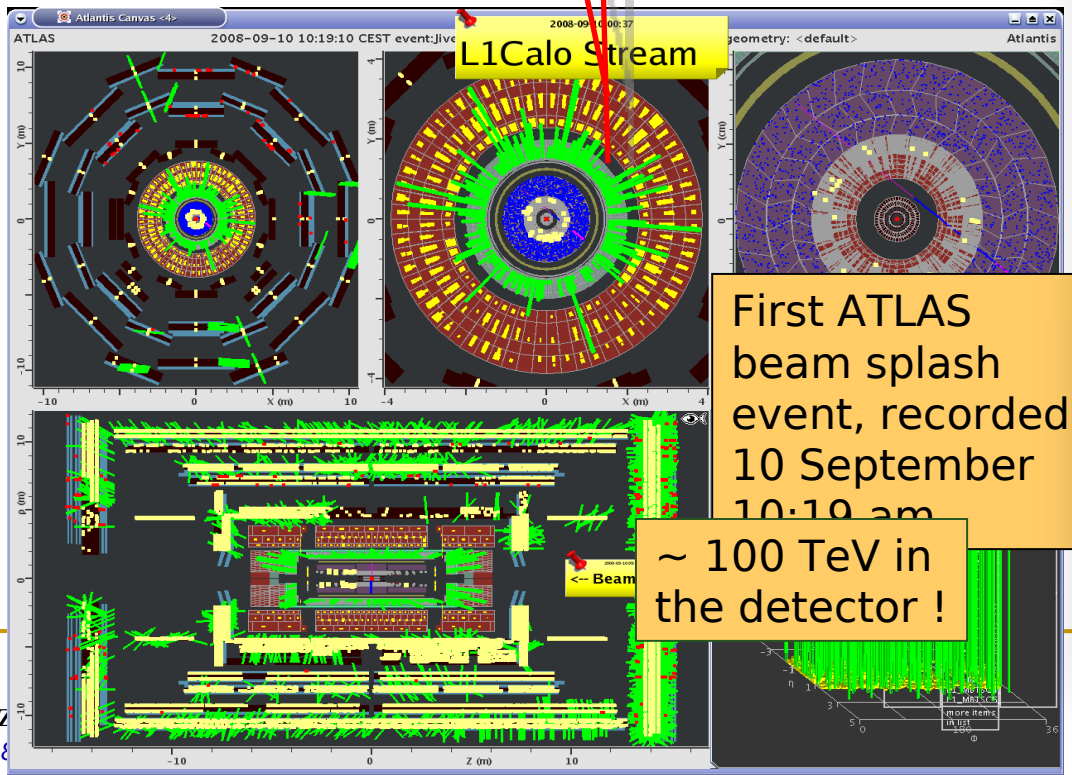


Beam bunches (2x10⁹ protons at 450 GeV) stopped by (closed) collimators upstream of experiments →
"splash" events in the detectors (debris are mainly muons)



tertiary collimators 140 m

Beam pick-ups (BPTX) (175 m)



First ATLAS beam splash event, recorded 10 September 10:19 am

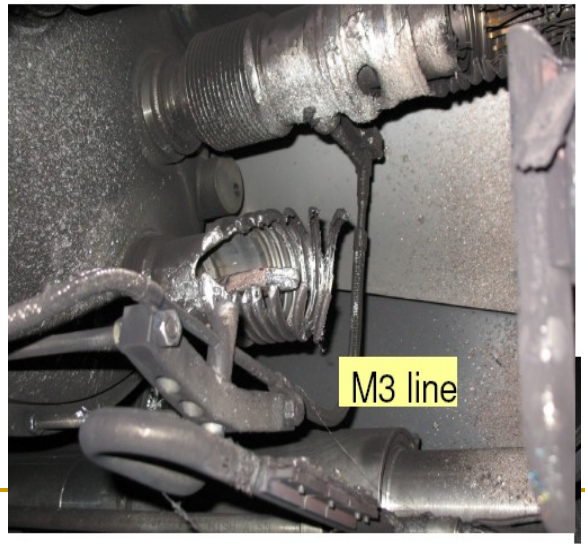
~ 100 TeV in the detector !

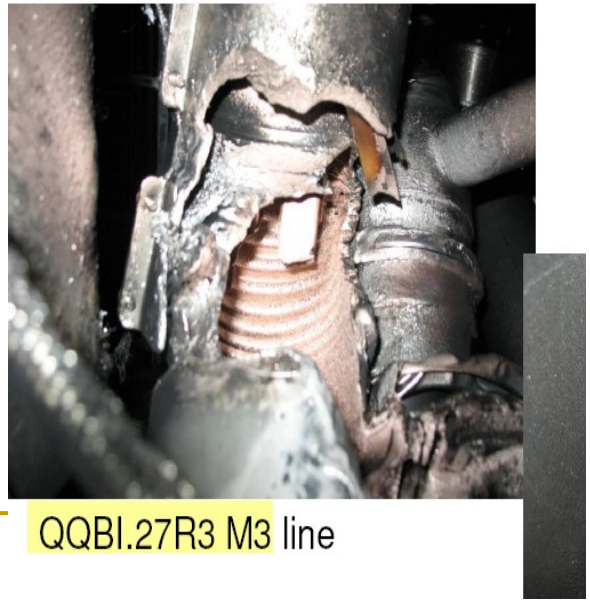
LHC damages

Problem in Sector 34

Friday, Sept 19

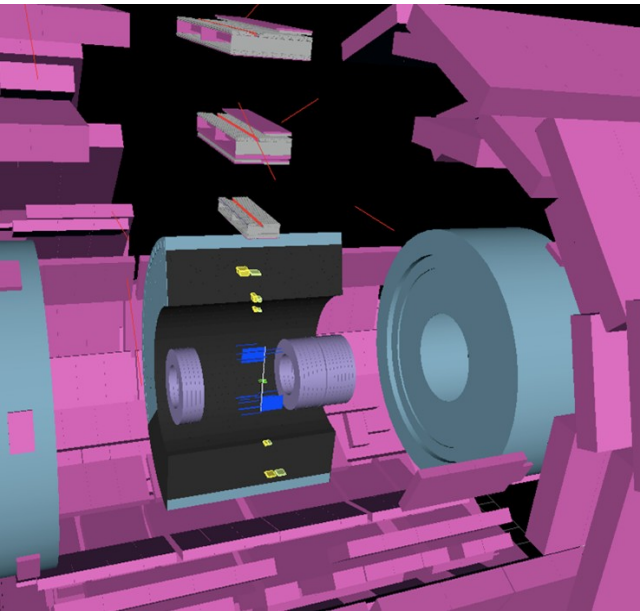
- Commissioning without beam of final sector for 5 TeV operation
- Faulty electrical connection between two magnets
- Leading to large helium leak into the tunnel
- Sector has to be warmed up (started, takes several weeks) before diagnosis and repair can start, then cool down again (several weeks)
  → runs into winter shutdown
- Restart of accelerators spring 2009 – LHC beams to follow



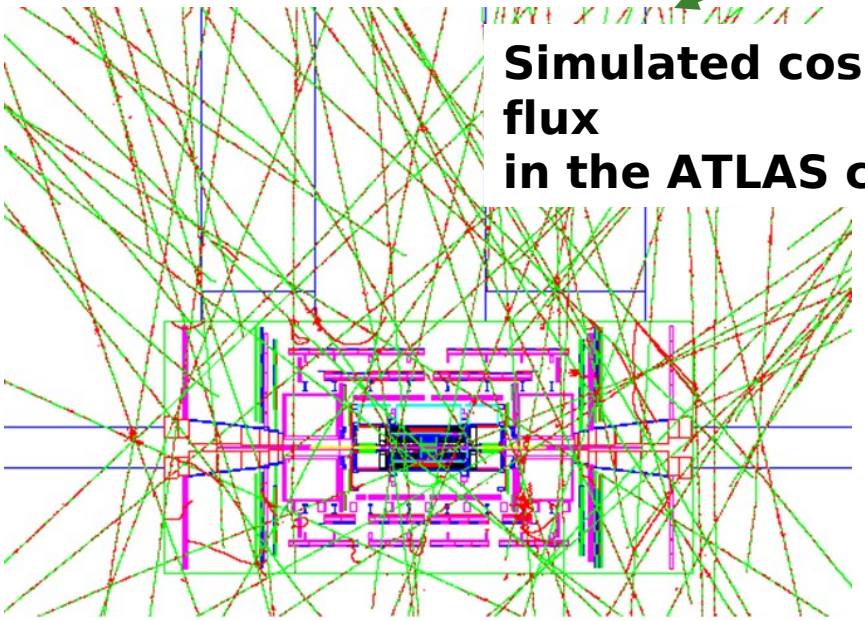


QQBI.27R3 M3 line

Cosmic Muons in ATLAS

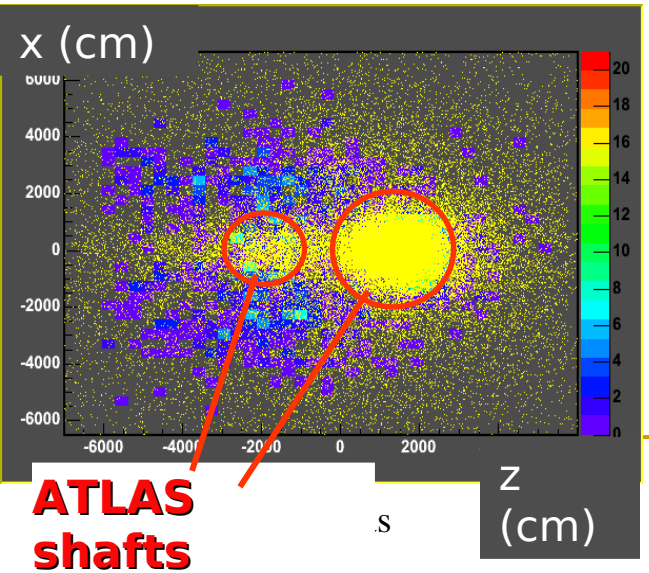


10 ms



Simulated cosmics flux in the ATLAS cavern

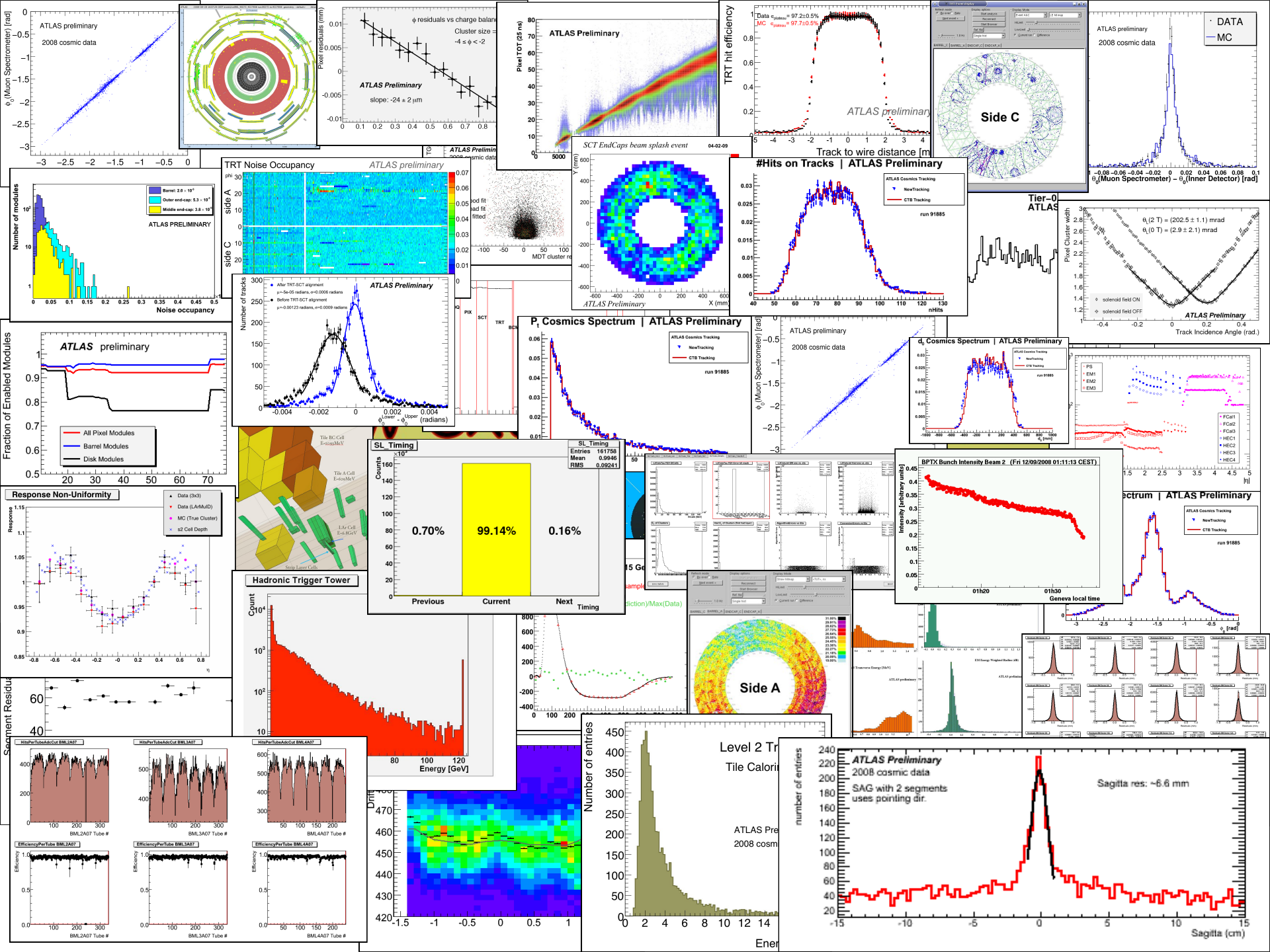
Real Cosmic Event



Muon impact points extrapolated to surface as measured by Muon Trigger chambers (RPC)

(Calorimeter trigger also

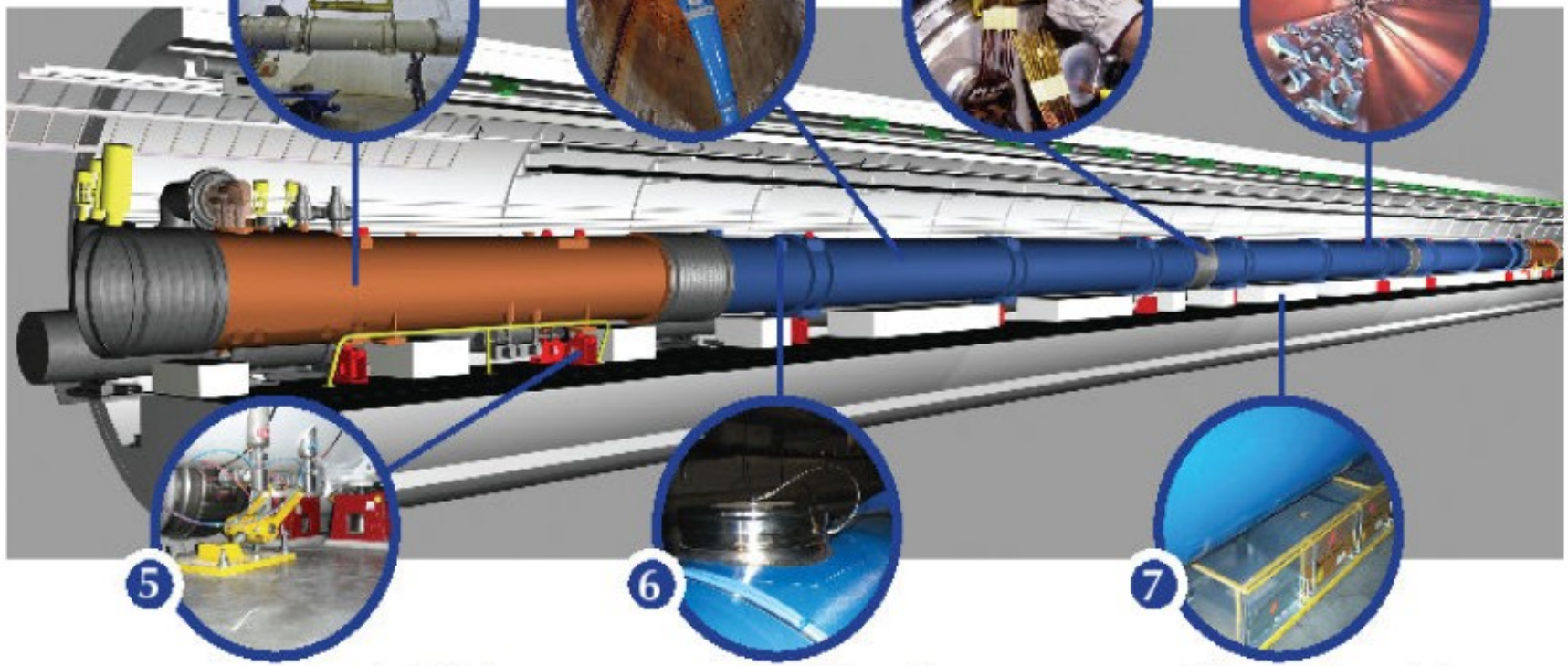
Rate ~100 m below ground:
~ O(15 Hz) crossing Inner Detector


ATLAS preliminary
2008 cosmic data
ATLAS Preliminary
ATLAS preliminary
TRT Noise Occupancy
side A
side C
Number of modules
Noise occupancy
ATLAS PRELIMINARY
Number of tracks
ATLAS Preliminary
SCT EndCaps beam splash event
#Hits on Tracks | ATLAS Preliminary
Track to wire distance [m]
TRT hit efficiency
Side C
Side A
DATA
MC
Pixel Cluster width
Track Incidence Angle (rad.)
ATLAS preliminary
Fraction of Enabled Modules
All Pixel Modules
Barrel Modules
Disk Modules
P_t Cosmics Spectrum | ATLAS Preliminary
d_0 Cosmics Spectrum | ATLAS Preliminary
Response Non-Uniformity
SL_Timing
Entries 161758
Mean 0.9946
RMS 0.09241
0.70%
99.14%
0.16%
Previous
Current
Next
Timing
Hadronic Trigger Tower
Count
Energy [GeV]
BPTX Bunch Intensity Beam 2 (Fri 12/09/2008 01:11:13 CEST)
Intensity [arbitrary units]
Geneva local time
Level 2 Tr
Tile Calori
ATLAS Pre
2008 cosm
Number of entries
Ener
ATLAS Preliminary
2008 cosmic data
SAG with 2 segments
uses pointing dir.
Sagitta res: ~6.6 mm
number of entries
Sagitta (cm)

Phase 1 +2

S.Myers
CERN November 2009

The LHC repairs in detail



+ cryogenics!

ATLAS

Beams and first collisions

Andreas Hoecker (CERN) **on behalf of the ATLAS Collaboration**

CERN seminar "LHC, week 1", Nov 26, 2009

1st Beam Splash from Beam-2

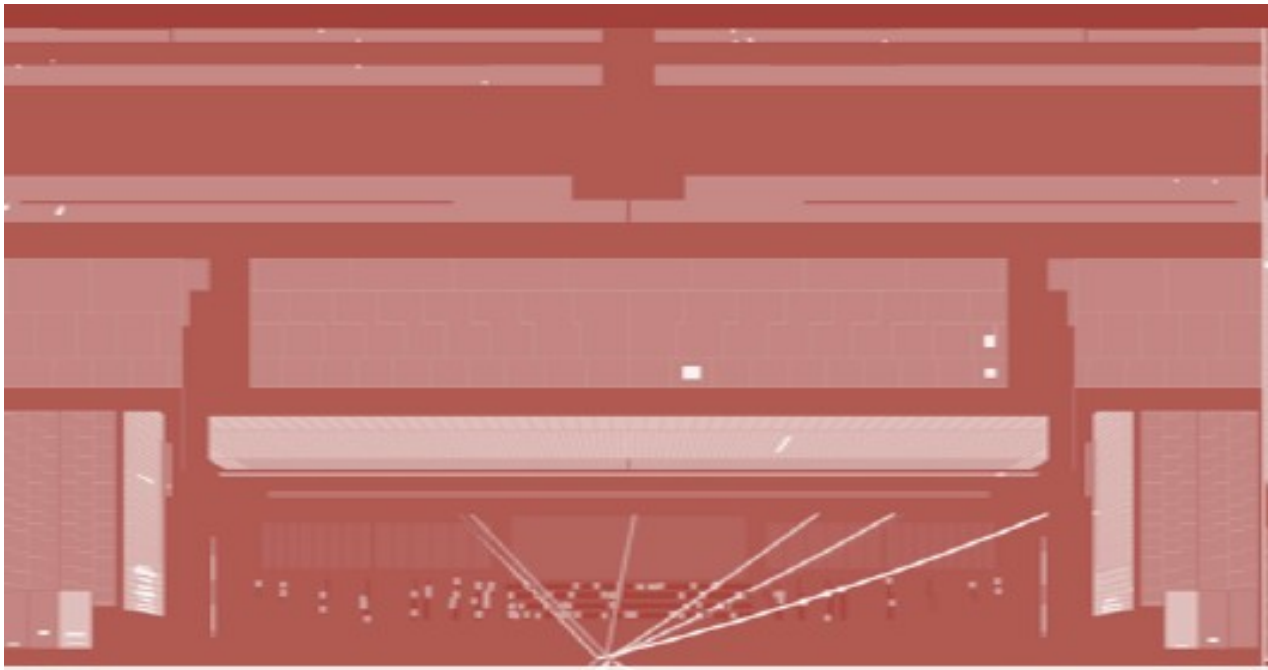
Beam-splash events

Avalanche of scattered particles from beam-on-collimator hits

Detectors fully lit, typically

- 300,000 SCT hits
- 350,000 TRT hits (~all passing high-threshold)
- 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

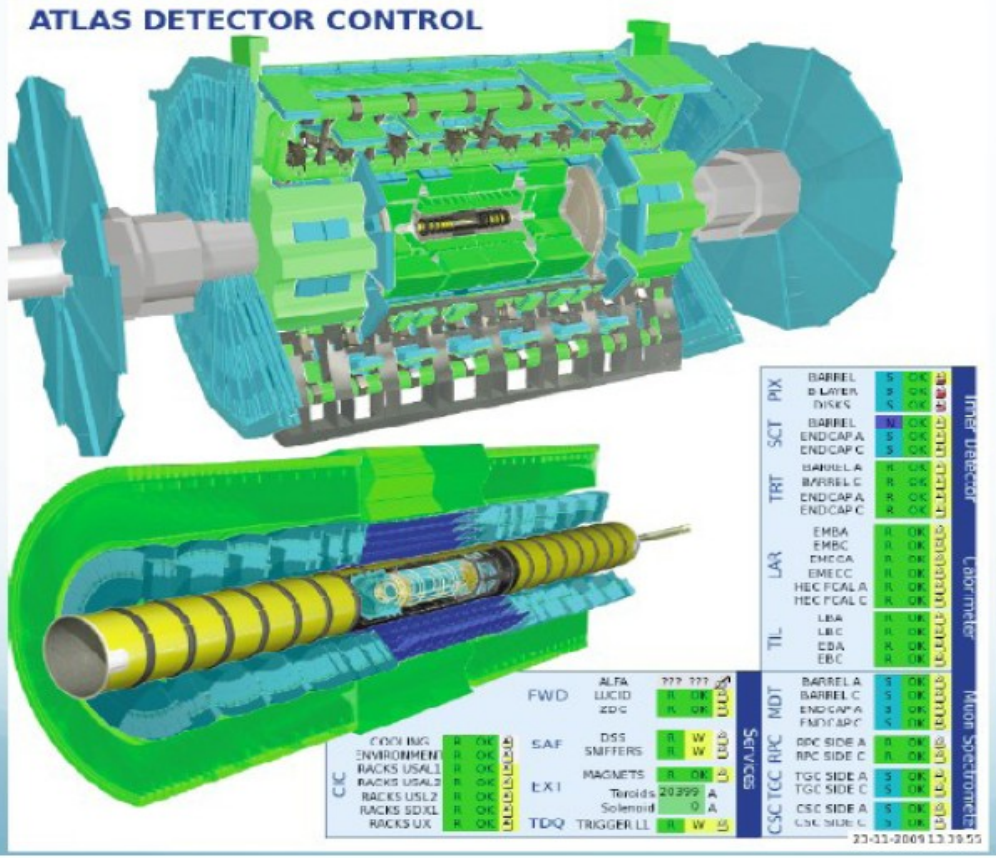


Single beam, two beams,
two synchronised beams,
colliding beams, **collisions** ?

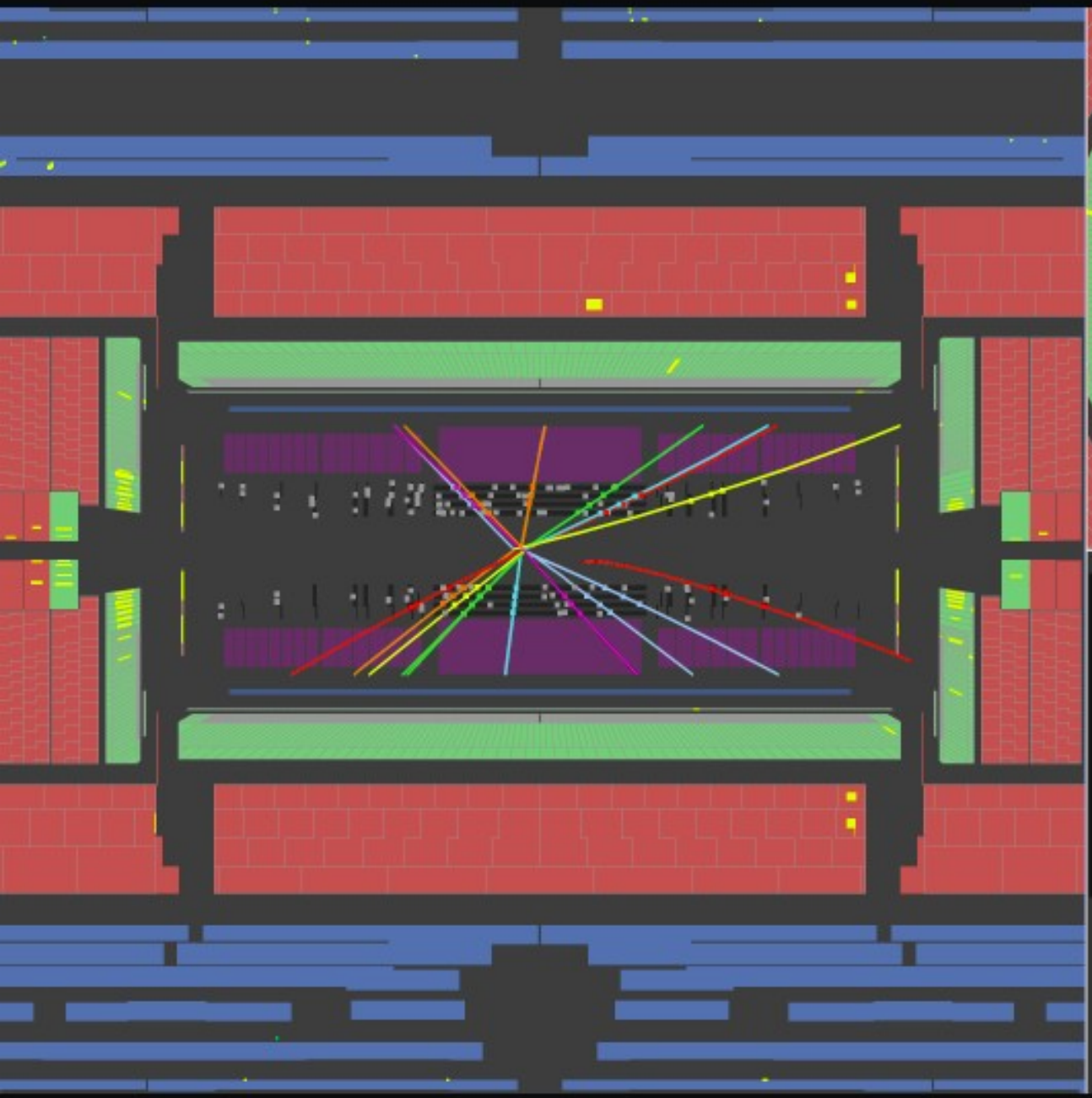
Candidate
Collision Event

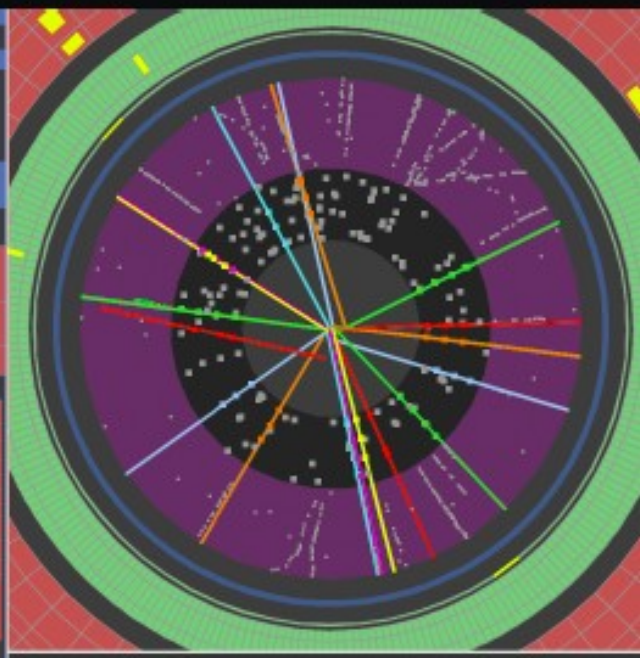
Status for first collision

After a vast multi-year programme of cosmic ray data taking and system commissioning ...



- Pixel - off (no stable beam)
- SCT - standby
  - Standby V is 20 V → ~50% hit efficiency (increases with incidence angle)
  - Barrel and endcap increased to 50V for short stable beam periods during collisions
  - Barrel voltage sometimes lower than 20V for beam set up (eg. splash events)
- All other systems (Muon system, Calorimeters, TRT, Forward detectors) on
- Trigger and DAQ ready
- Solenoid off, toroids on
- Waiting for beam ...





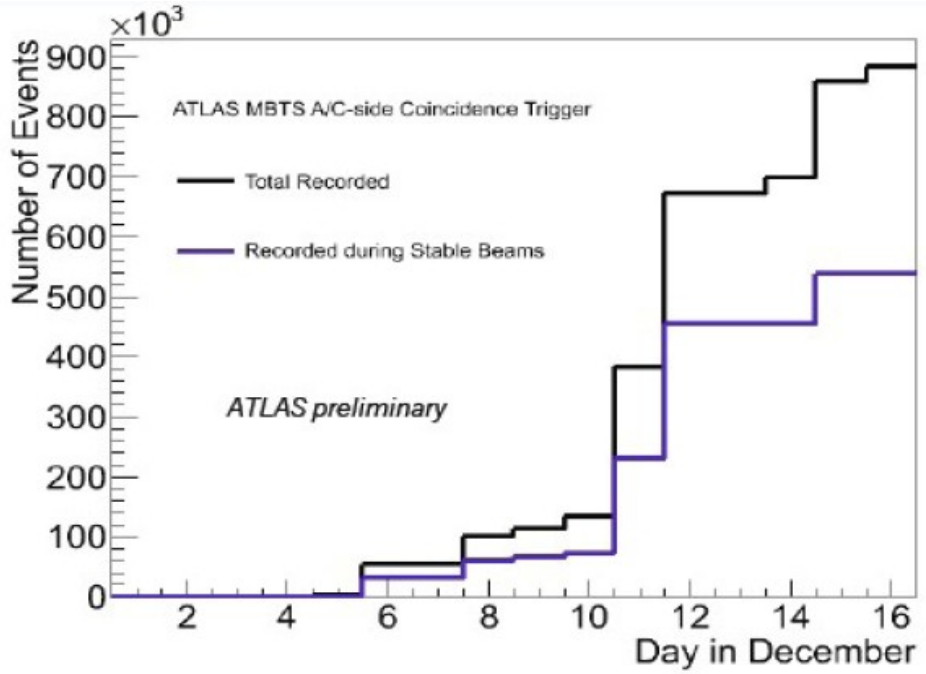
ATLAS EXPERIMENT

2009-11-23, 14:22 CET

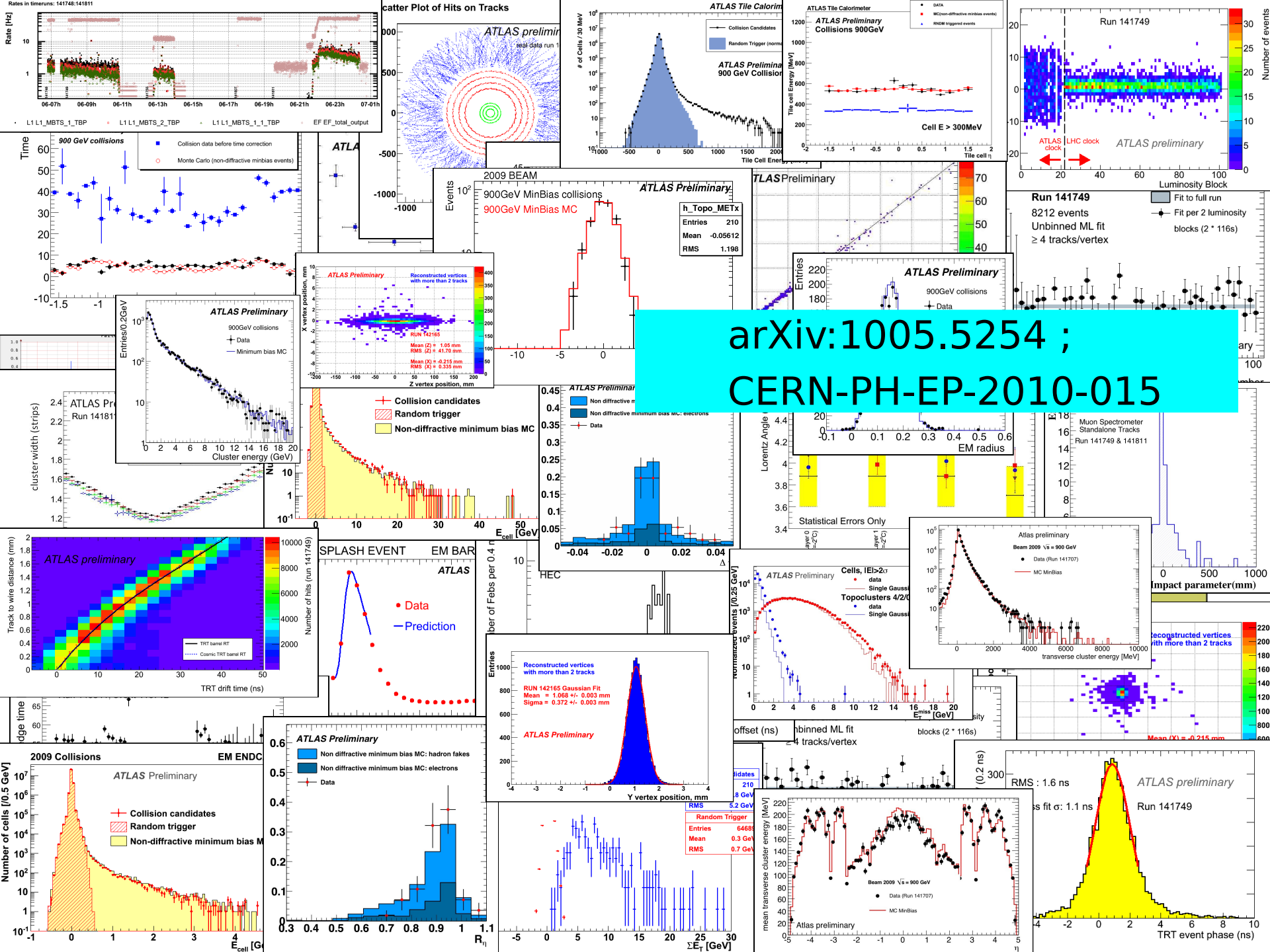
Run 140541, Event 171897

Candidate Collision Event

Luminosity recorded with 900 GeV and 2.36 TeV

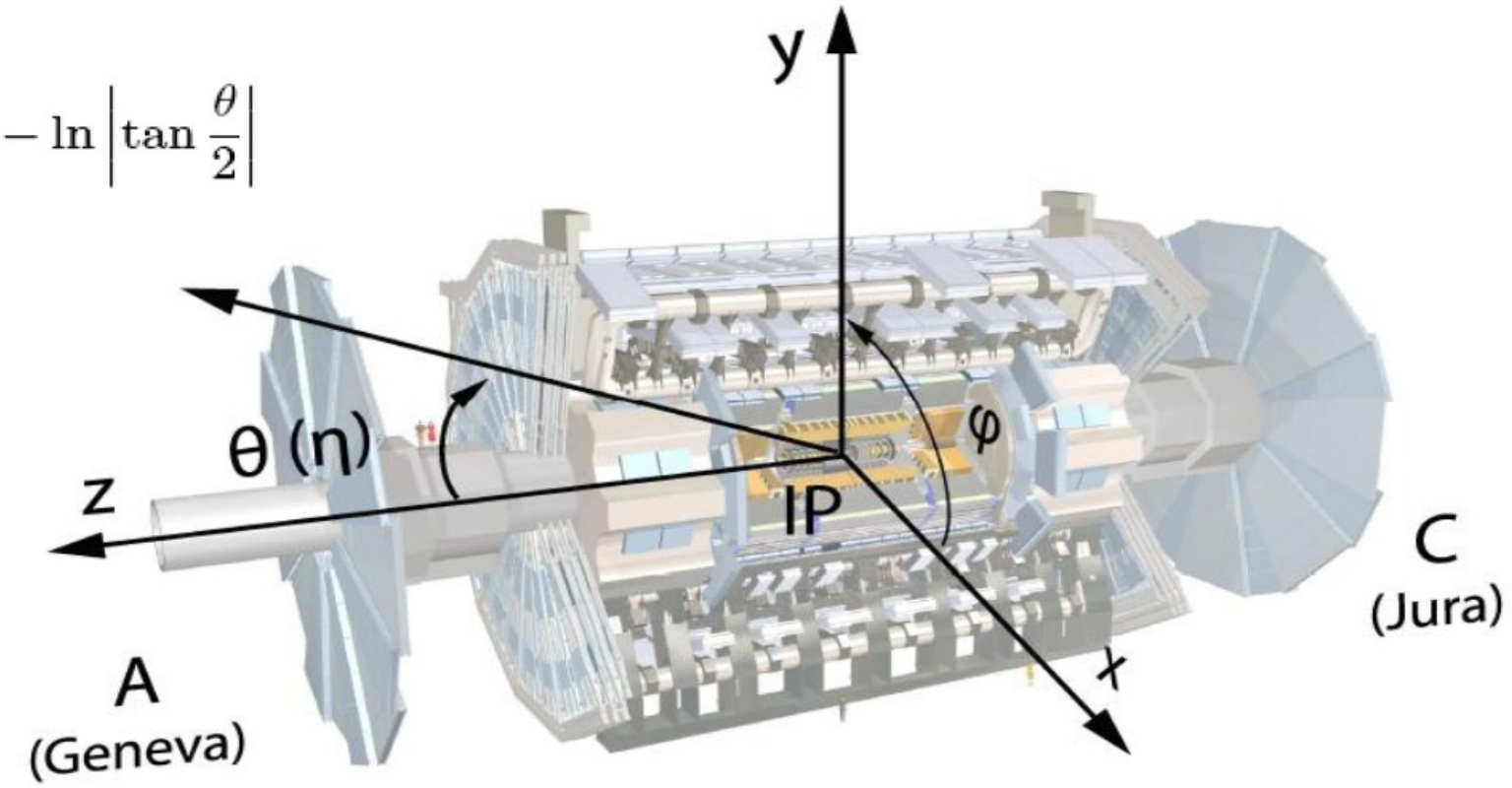


- Total number of collisions recorded: ~880k
  - ~540k with stable beams → Tracker fully on
  - ~34k at $\sqrt{s}$=2.36 TeV
- Recorded integrated luminosity with stable beams: ~ 11 μb^{-1}
- Max peak luminosity seen by ATLAS : ~ 7 x 10^{26} cm^{-2} s^{-1}

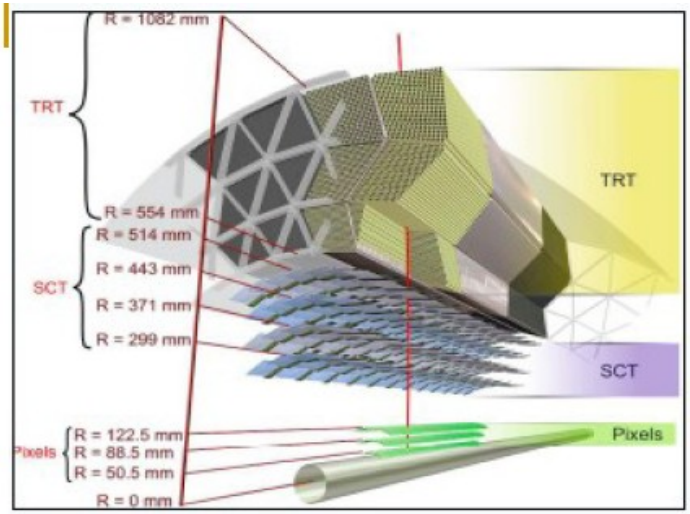

arXiv:1005.5254 ;
CERN-PH-EP-2010-015

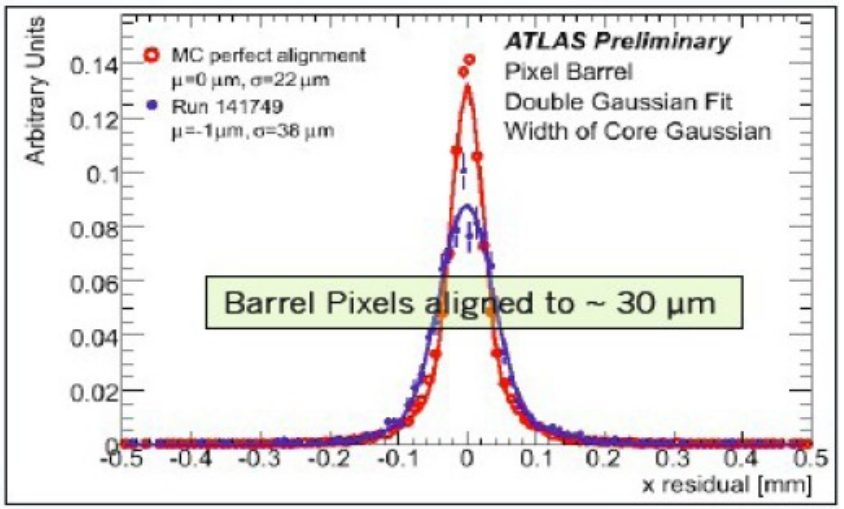
Kinematics

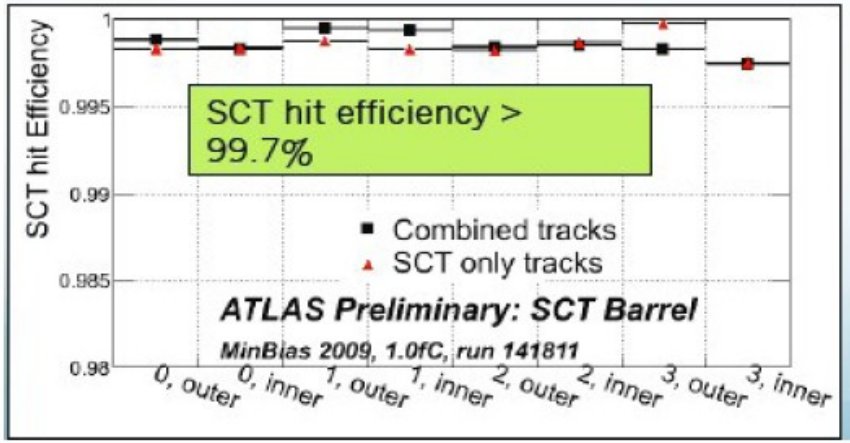
$$\eta = -\ln\left|\tan\frac{\theta}{2}\right|$$

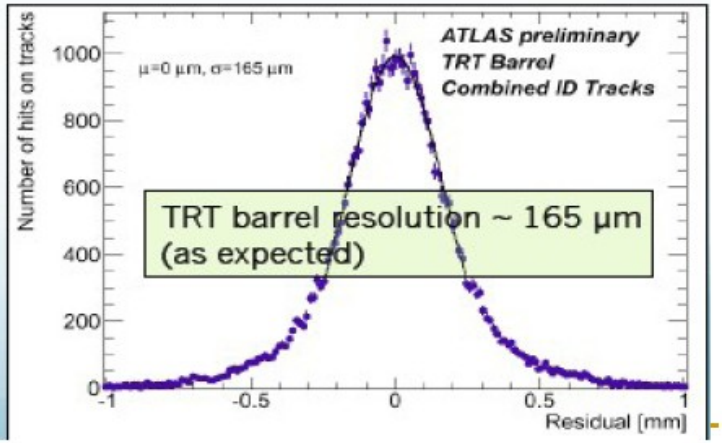


Tracking

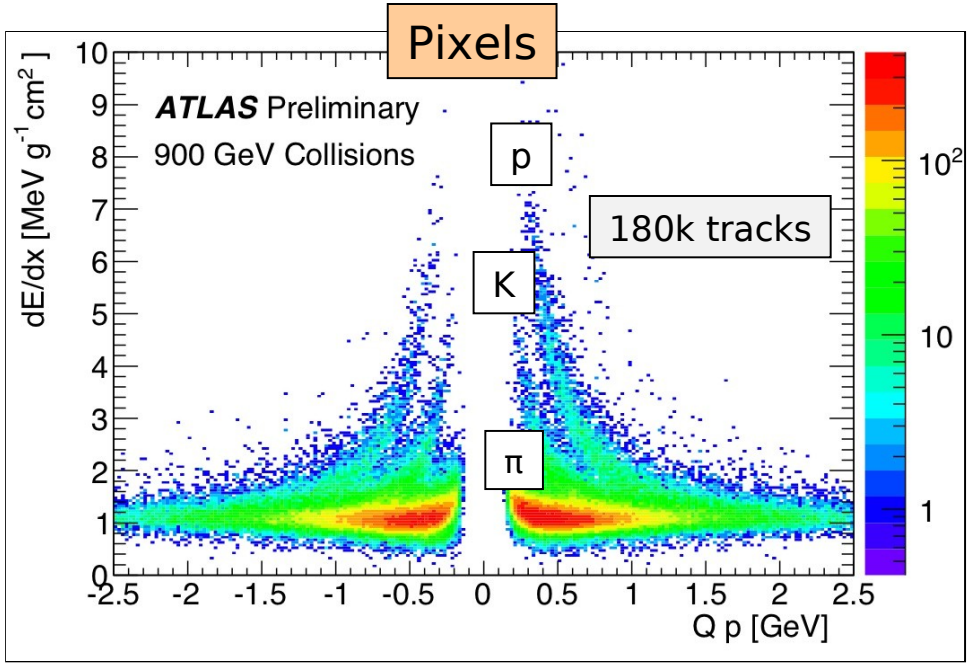

R = 1082 mm
TRT
R = 554 mm
R = 514 mm
R = 443 mm
SCT
R = 371 mm
R = 299 mm
R = 122.5 mm
Pixels
R = 88.5 mm
R = 50.5 mm
R = 0 mm
TRT
SCT
Pixels

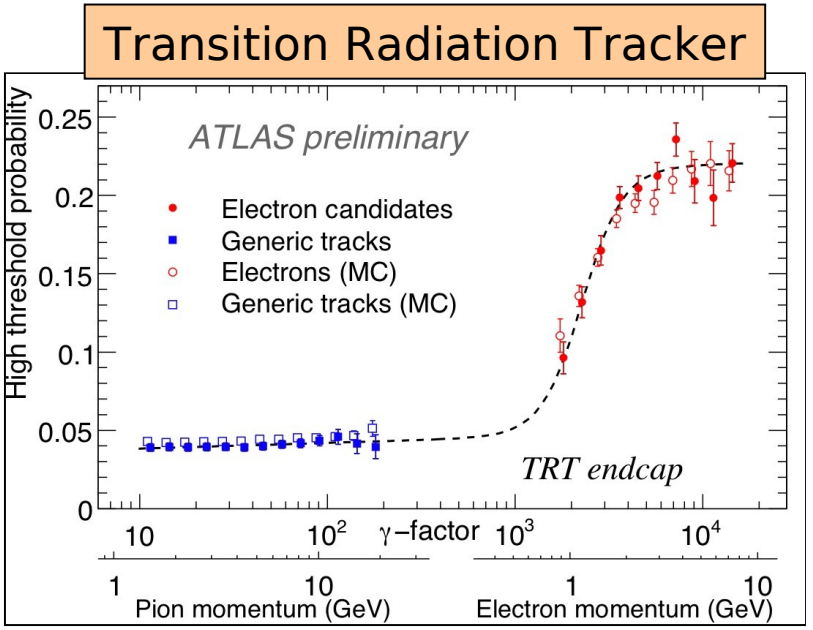

Arbitrary Units
MC perfect alignment
μ=0 μm, σ=22 μm
Run 141749
μ=-1μm, σ=38 μm
ATLAS Preliminary
Pixel Barrel
Double Gaussian Fit
Width of Core Gaussian
Barrel Pixels aligned to ~ 30 μm
x residual [mm]


SCT hit Efficiency
SCT hit efficiency > 99.7%
Combined tracks
SCT only tracks
ATLAS Preliminary: SCT Barrel
MinBias 2009, 1.0fC, run 141811
0, outer
0, inner
1, outer
1, inner
2, outer
2, inner
3, outer
3, inner


Number of hits on tracks
μ=0 μm, σ=165 μm
ATLAS preliminary
TRT Barrel
Combined ID Tracks
TRT barrel resolution ~ 165 μm (as expected)
Residual [mm]

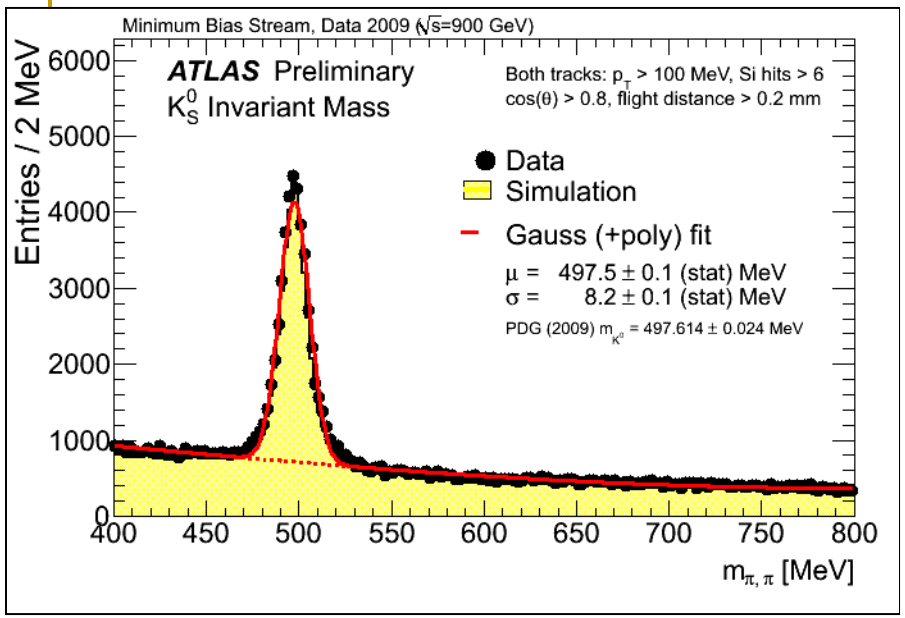
Particle identification in Inner Detector

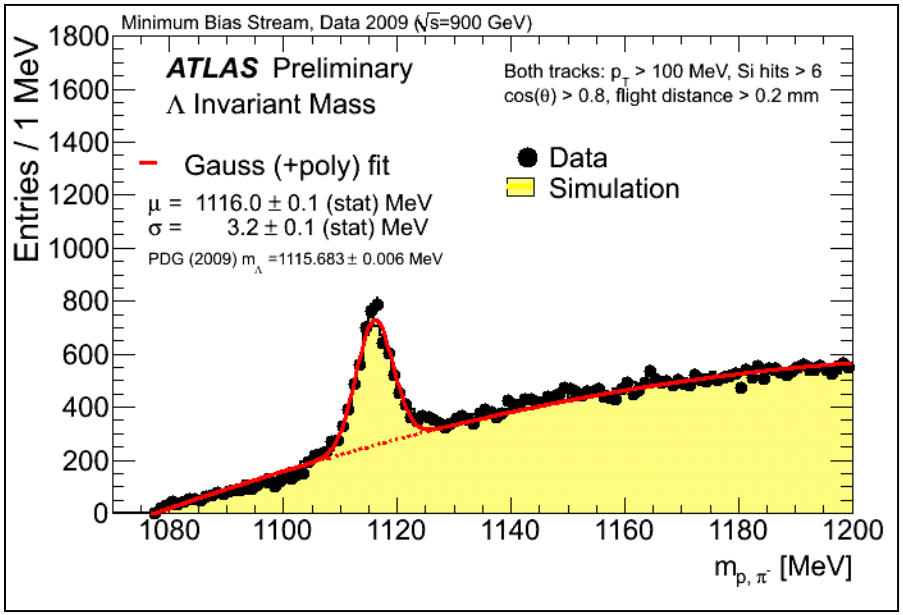


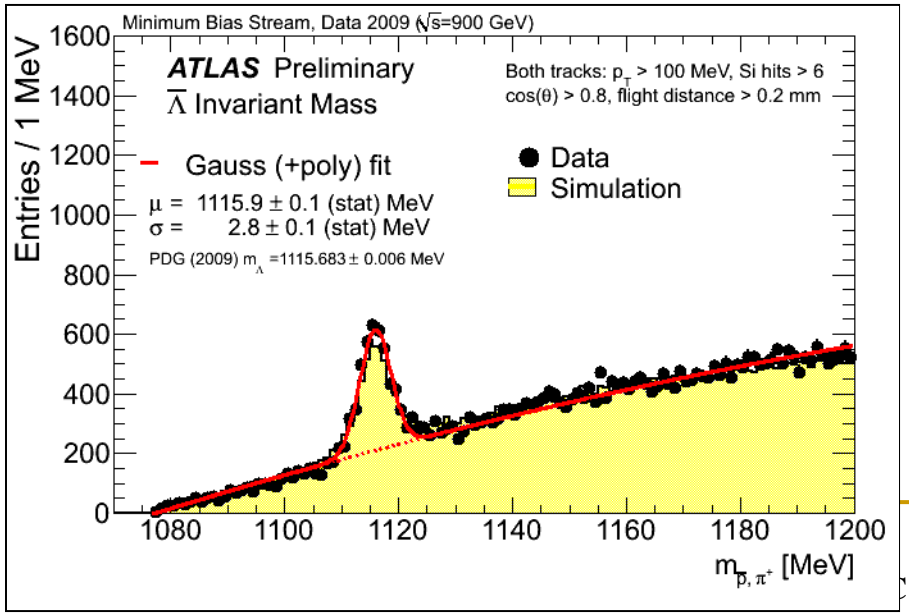


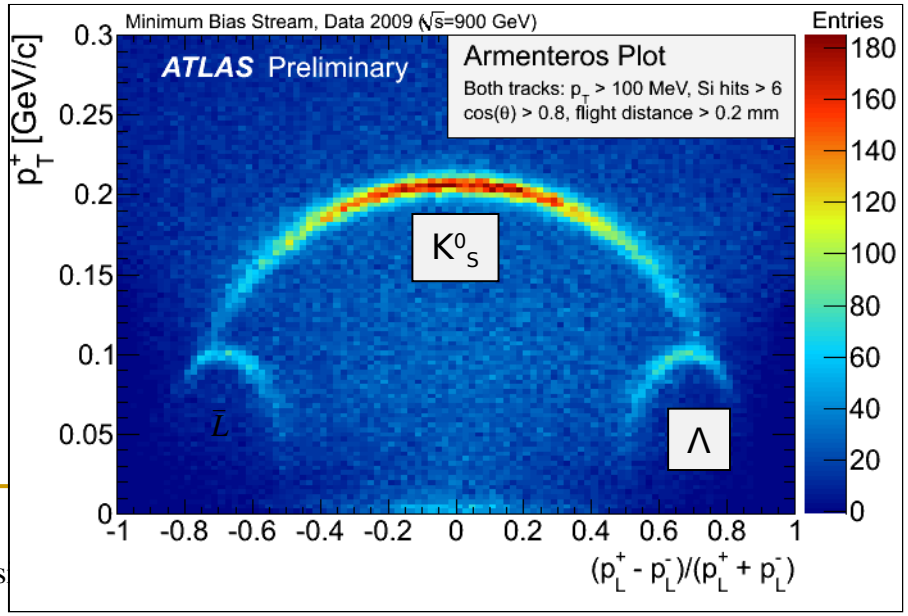
Transition radiation intensity is proportional to particle relativistic factor $\gamma = E/mc^2$. Onset for $\gamma \sim 10$

p_T (track) > 100 MeV
MC signal and background normalized independently









phys

Identifying Kaons

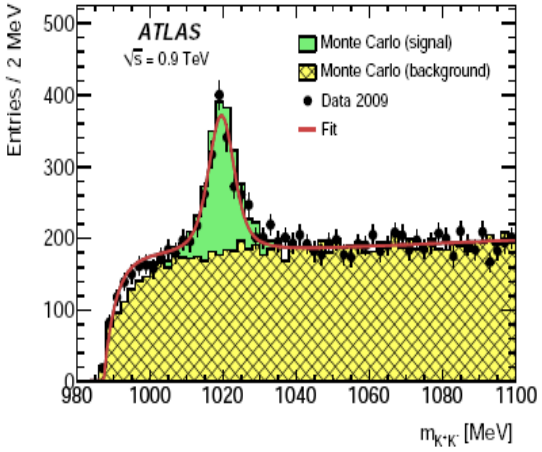


Figure 11: The measured and simulated mass spectra of K^+K^- pairs. The ϕ peak is fitted with a Breit-Wigner with a fixed width convoluted with a Gaussian. Both kaons must be identified through the dE/dx measurement.

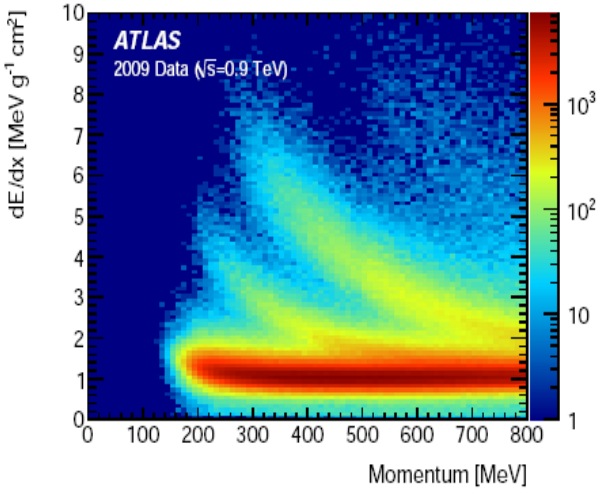
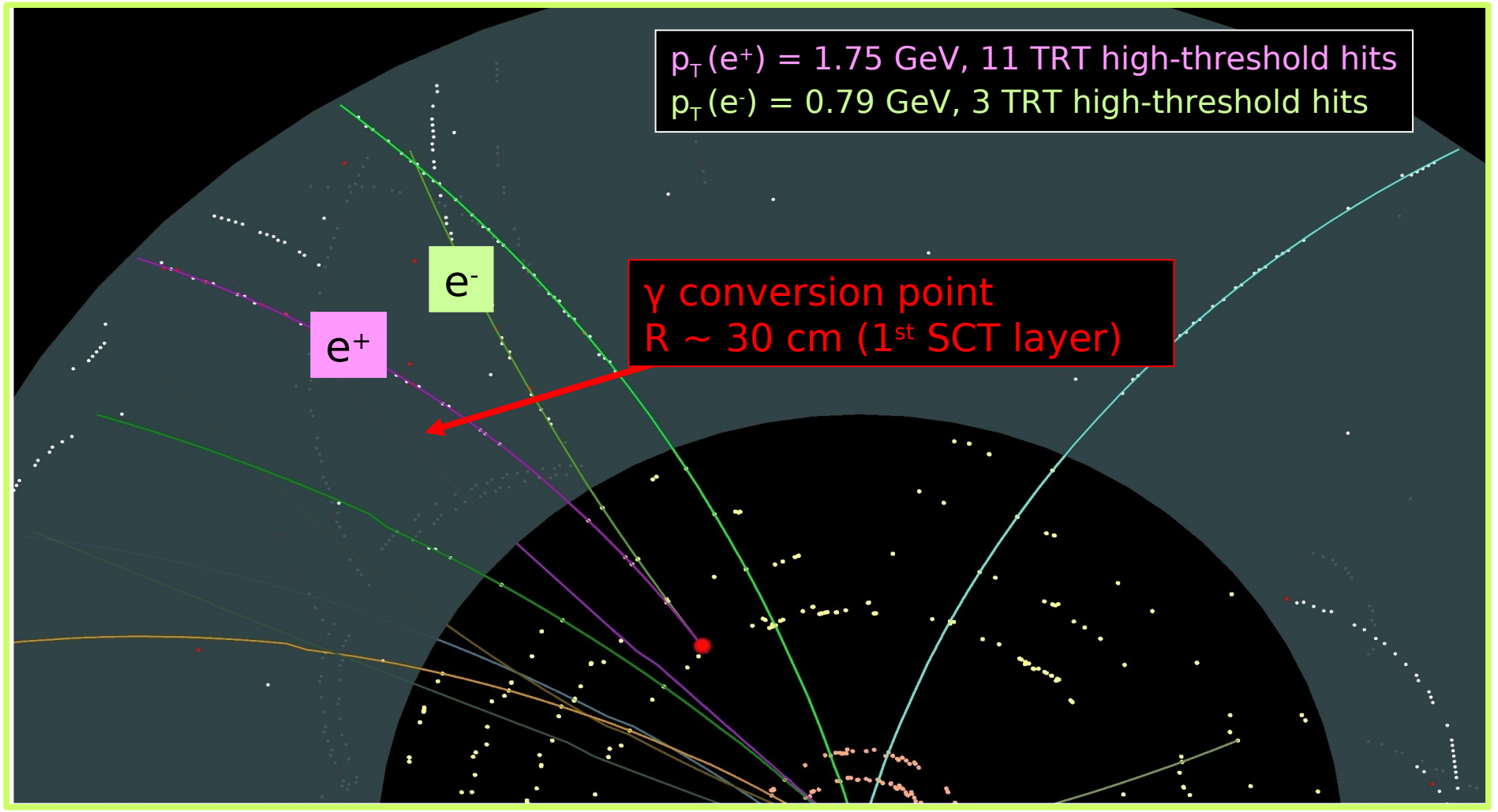


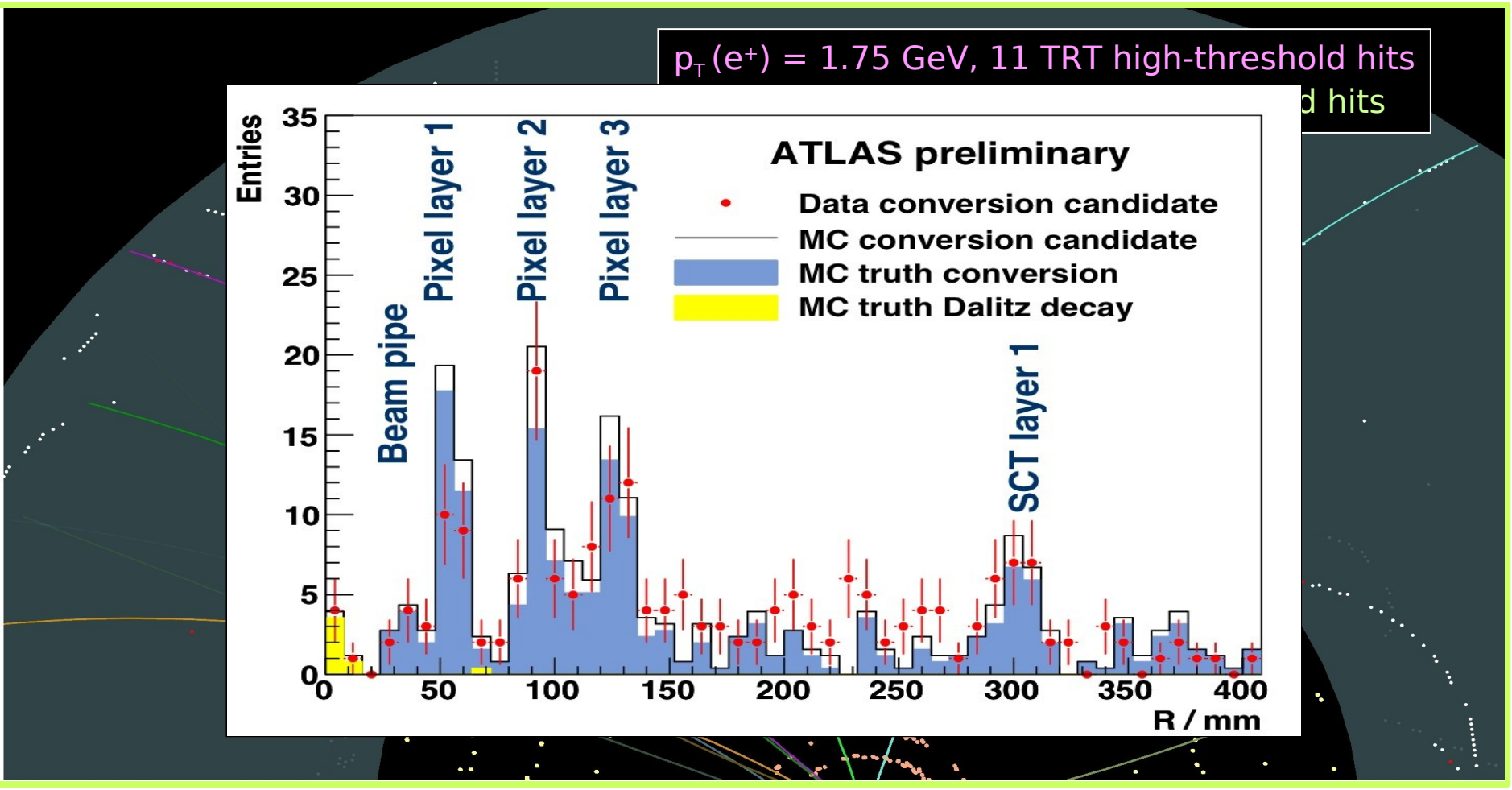
Figure 10: The dE/dx measured in data as a function of momentum.

- Charge particles with $200 < p_T < 800$ MeV with dE/dx tag.
- Mass in agreement with PDG value.

γ→ e^+e^- conversions

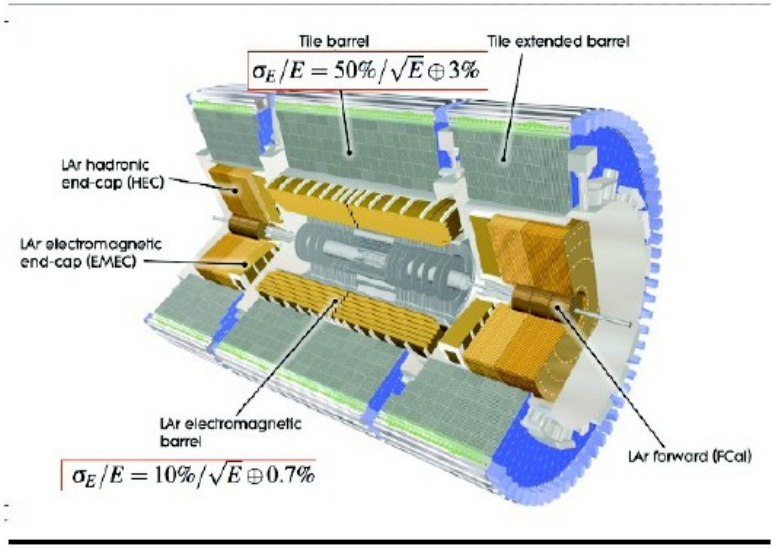


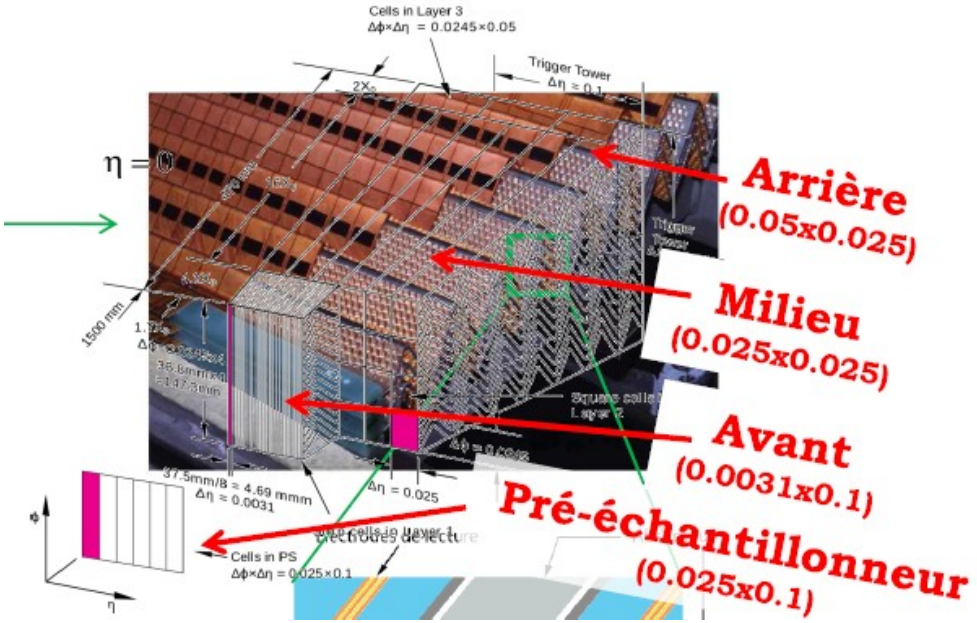
γ→ e+e- conversions



Calorimetry

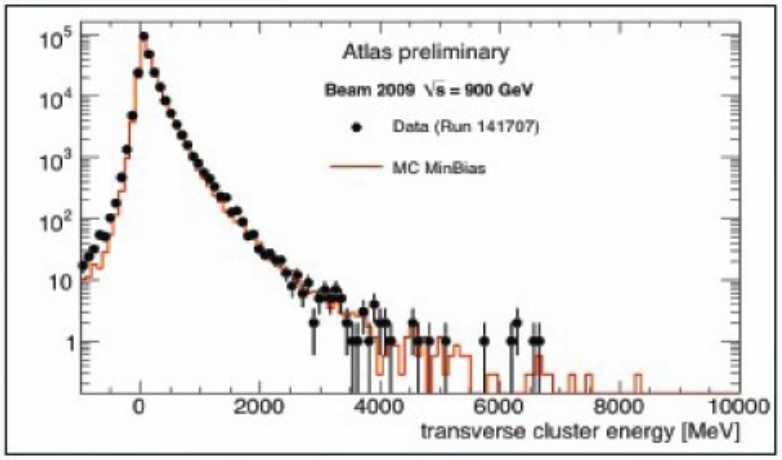
Barrel EM

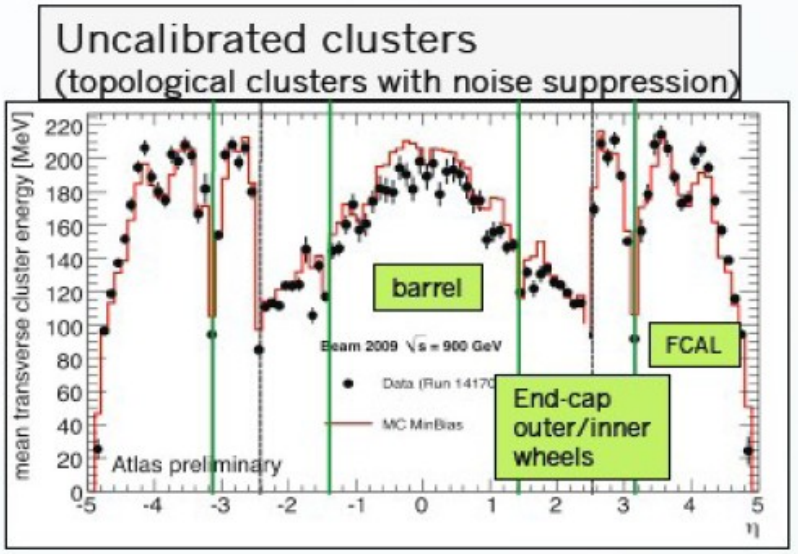




- LAr electromagnetic calorimeter
  - Barrel: $|\eta| < 1.475$
  - EndCap: $1.375 < |\eta| < 3.2$
- Hadronic calorimeter
- Tile calorimeter: $|\eta| < 1.7$
- LAr endcap calorimeter: $1.5 |\eta| < 3.2$

Energy flow in calorimeters

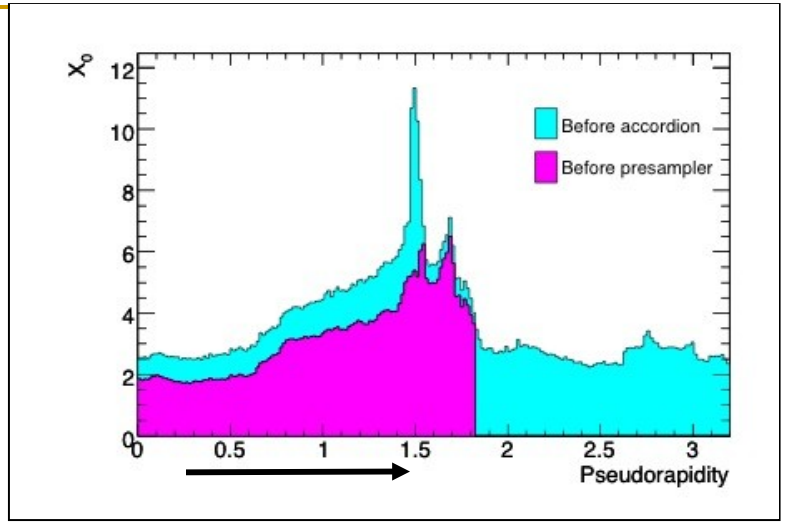


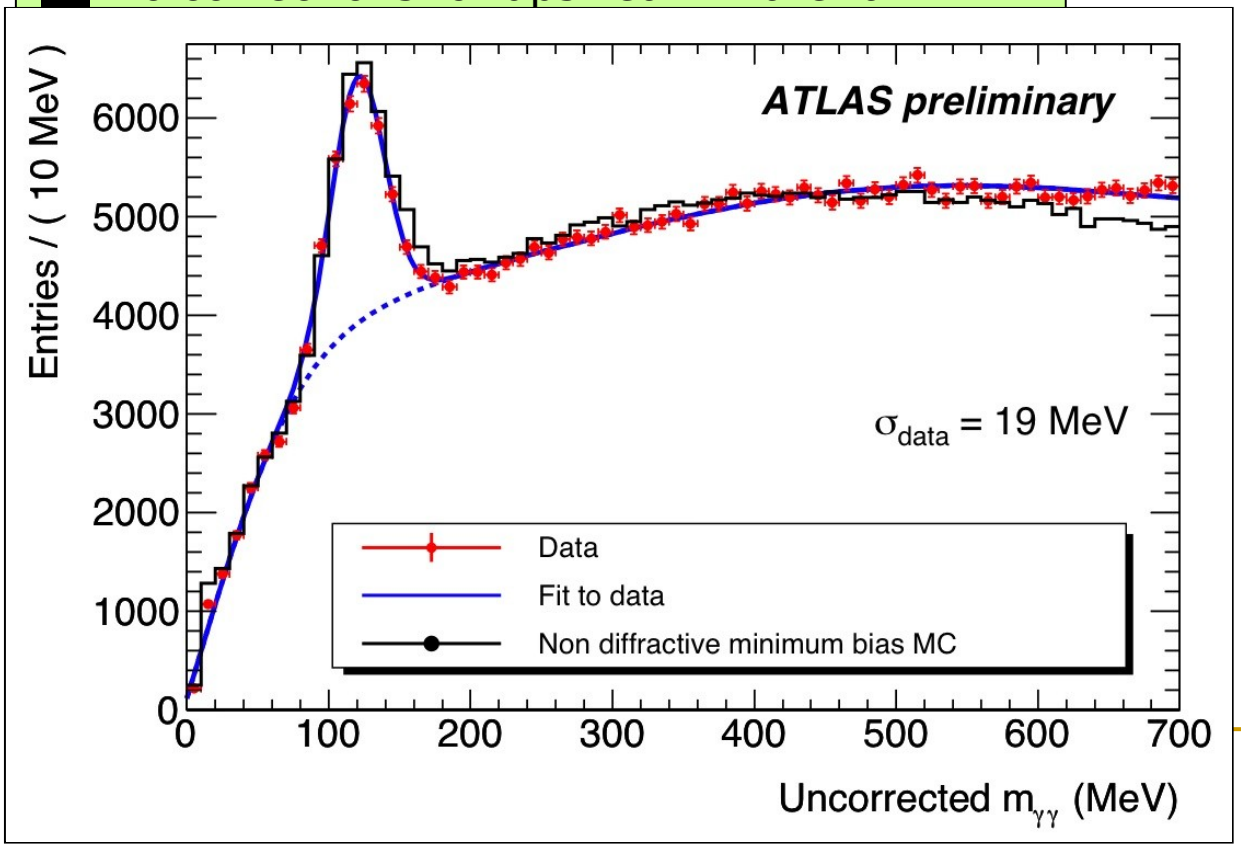


➔ Excellent agreement data-MC at such low energies indicates very good description of material in simulation and G4 shower modeling

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

- 2 photon candidates with $E_T(\gamma) > 300$ MeV
- $E_T(\gamma\gamma) > 900$ MeV
- Shower shapes compatible with photons
- No corrections for upstream material



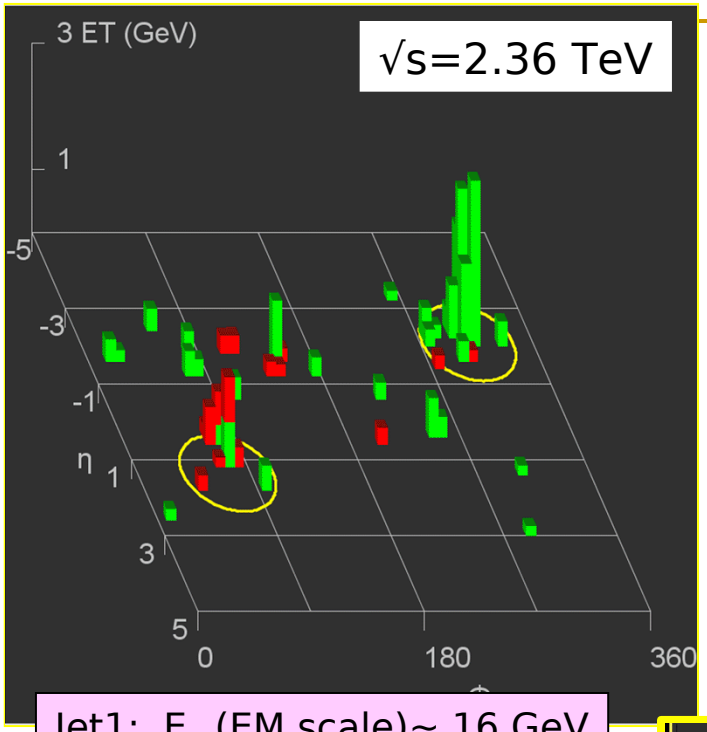


Note: soft photons are challenging because of material in front of EM calorimeter (cryostat, coil):
~ 2.5 X_0 at η=0

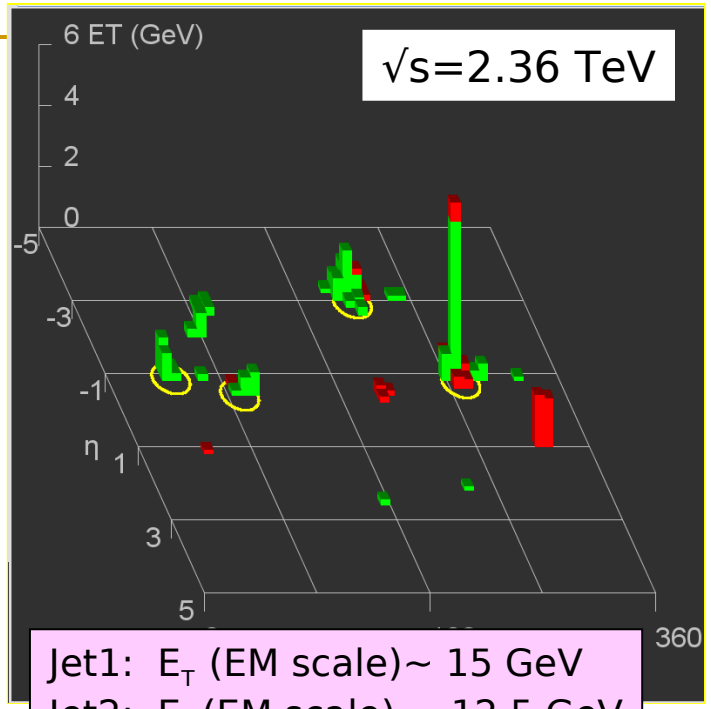
Data and MC normalised to the same area

26

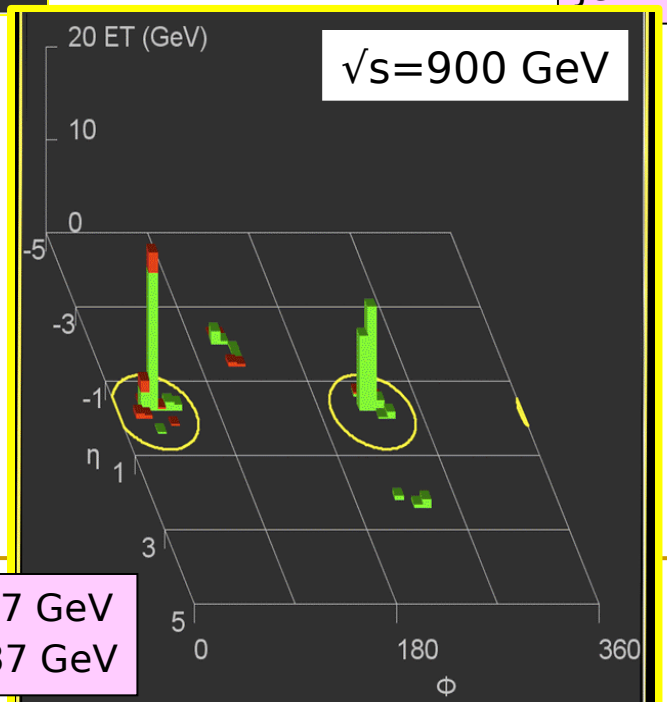
Jets



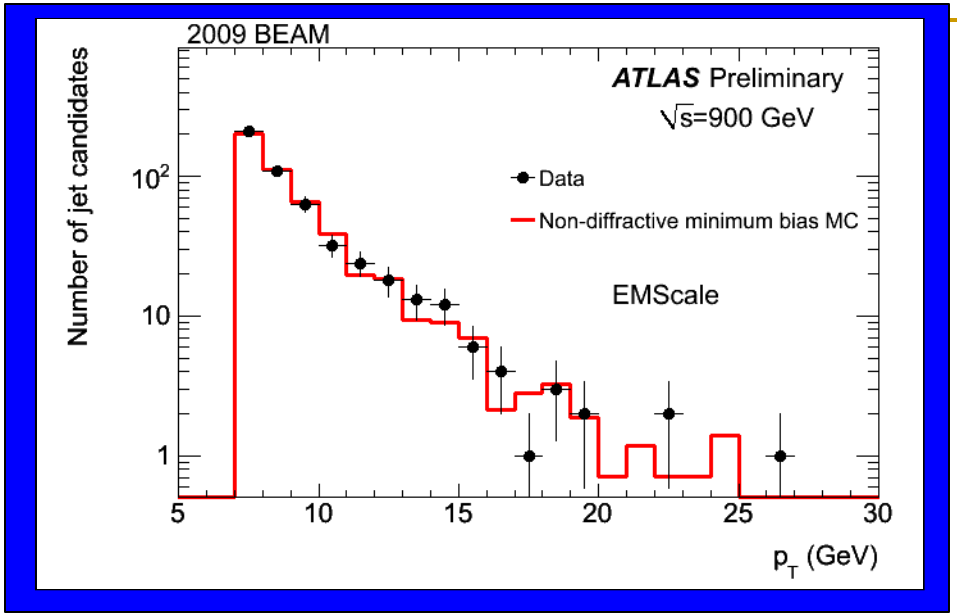
Jet1: E_T (EM scale)~ 16 GeV
Jet2: E_T (EM scale) ~ 6 GeV

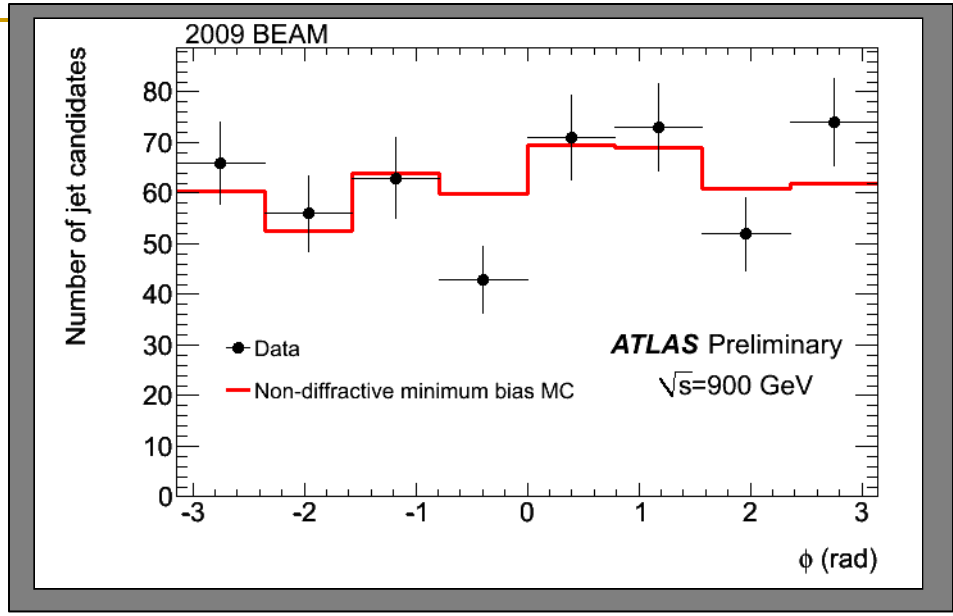


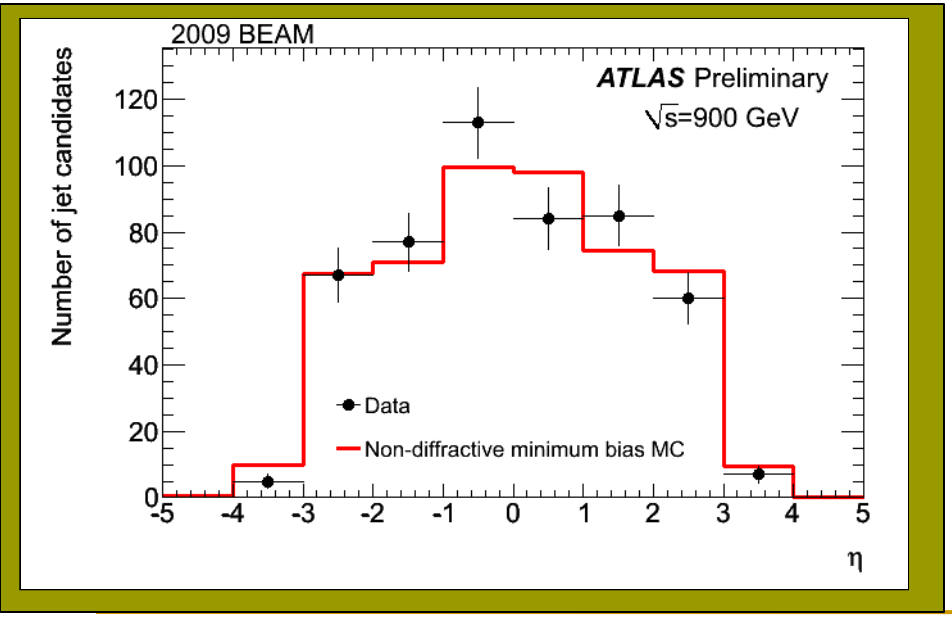
Jet1: E_T (EM scale)~ 15 GeV
Jet2: E_T (EM scale) ~ 12.5 GeV

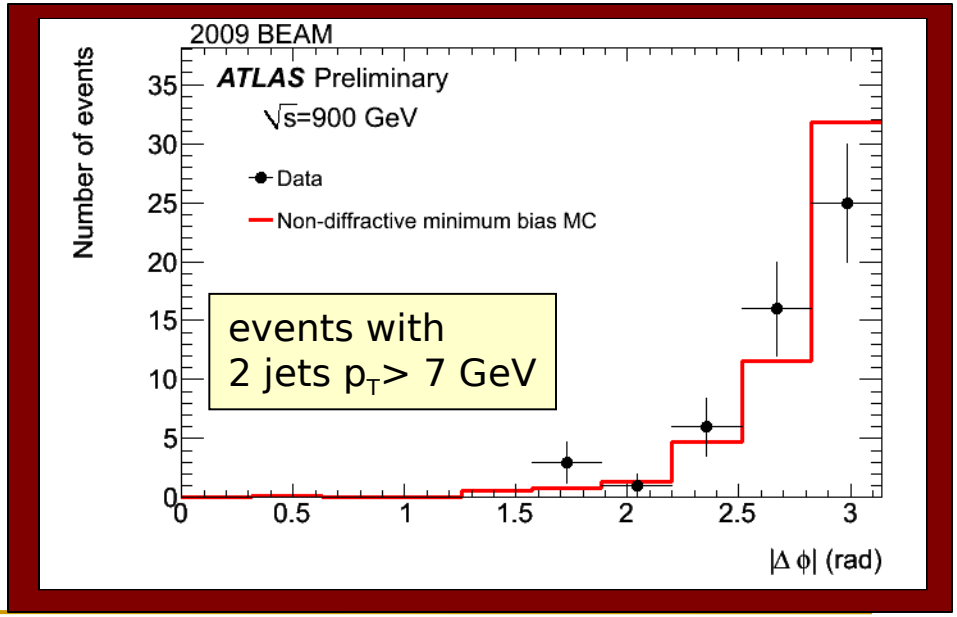


Jet1: E_T (EM scale)~ 37 GeV
Jet2: E_T (EM scale) ~ 37 GeV







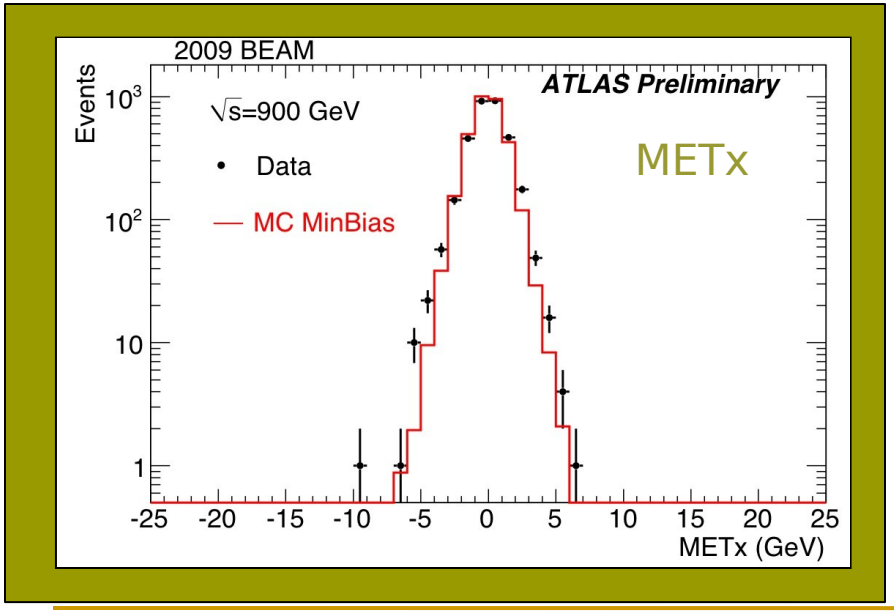


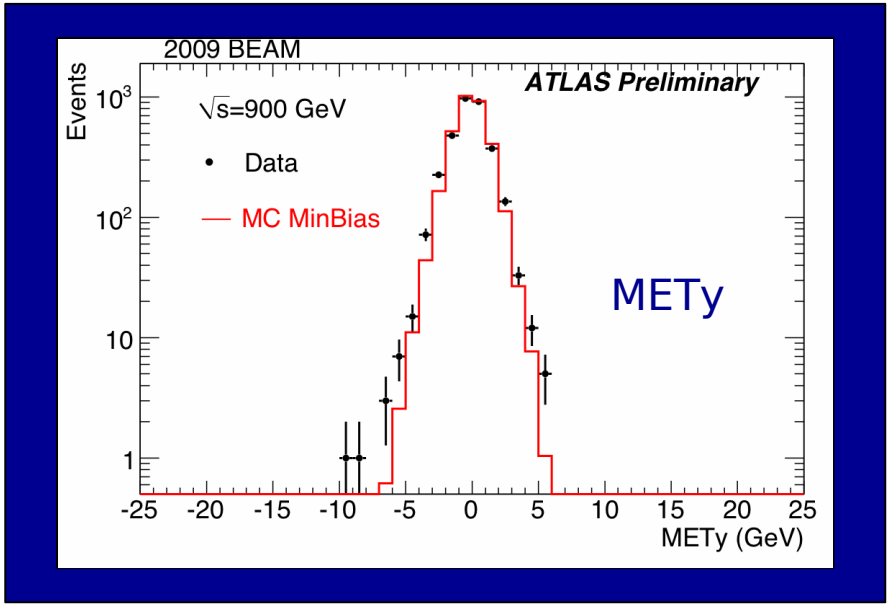
Uncalibrated EM scale
Monte Carlo normalized to number of jets or events in data

Missing transverse energy

- Sensitive to calorimeter performance (noise, coherent noise, dead cells, mis-calibrations, cracks, etc.) and backgrounds from cosmics, beams, …
- Measurement over full calorimeter coverage (360^0 in φ, $|\eta| < 5$, ~ 200000 cells)

METx / METy indicate x/y components of missing E_T vector



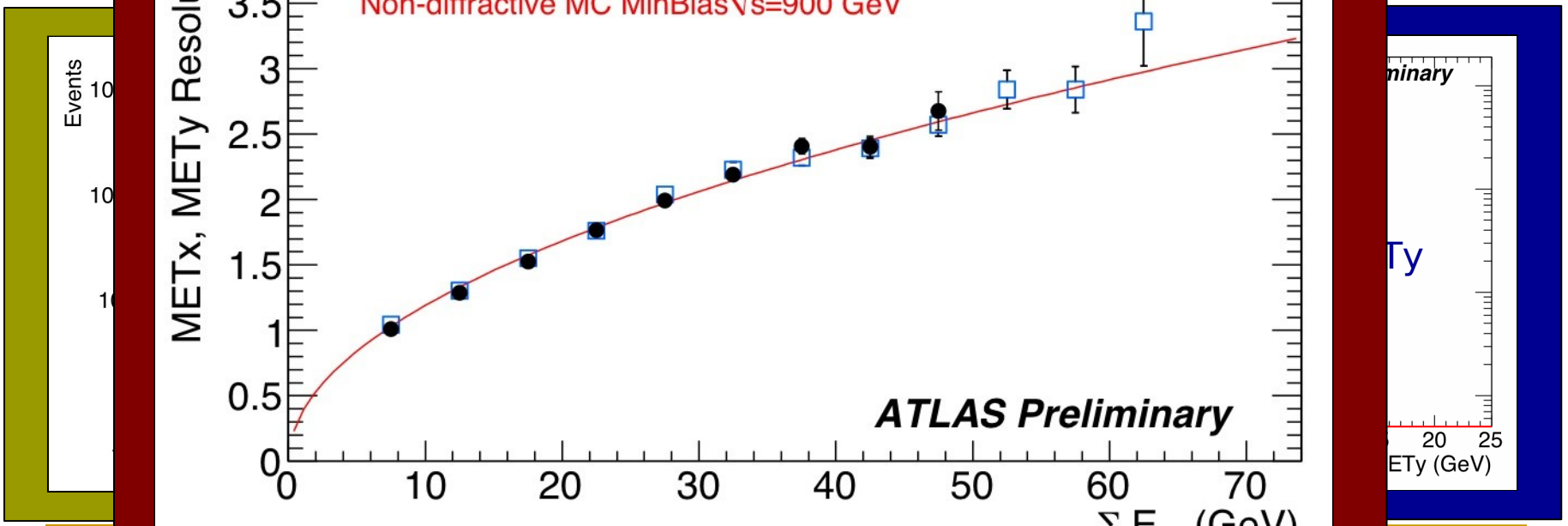


Missing transverse energy

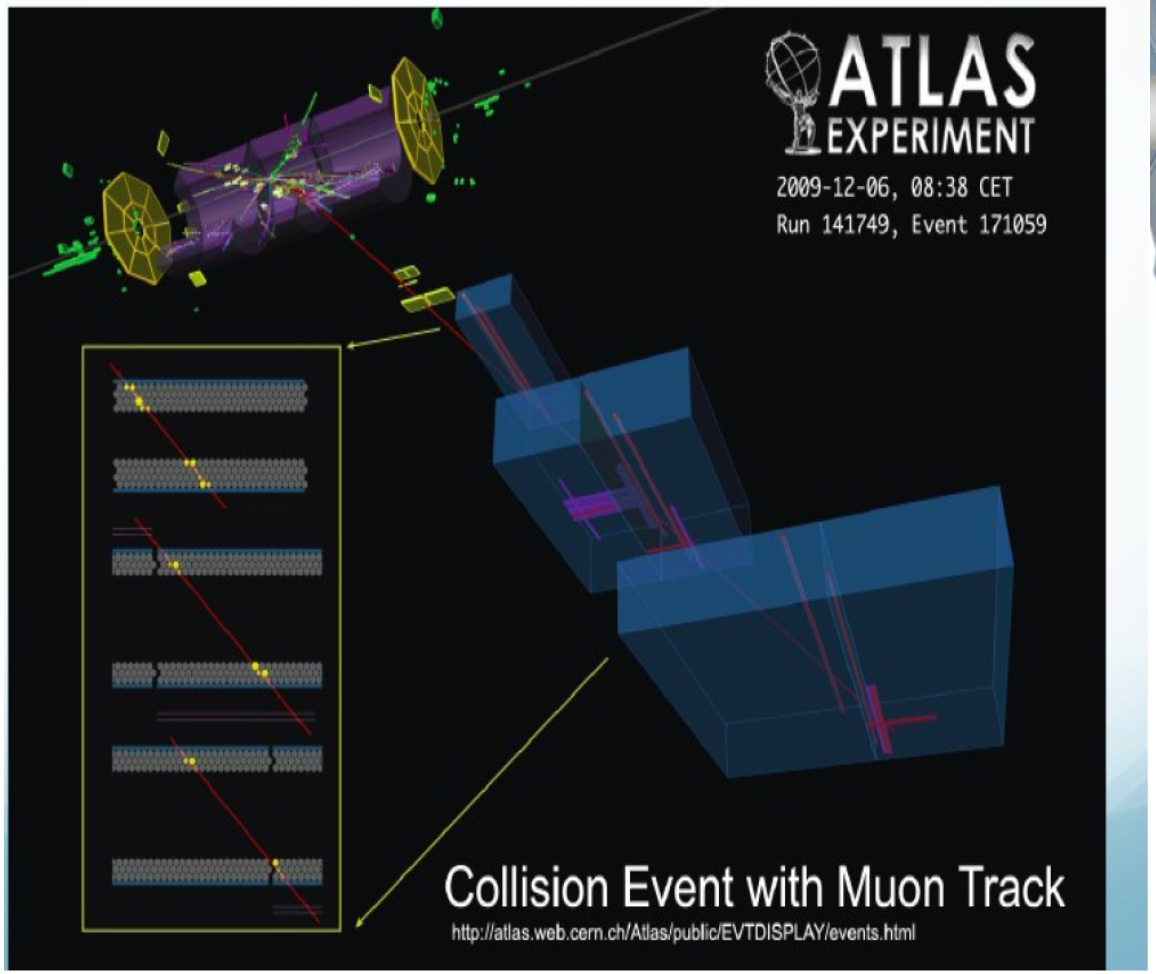
- Sensitive to calorimeter performance (noise, coherent noise, dea
  cra
- Me

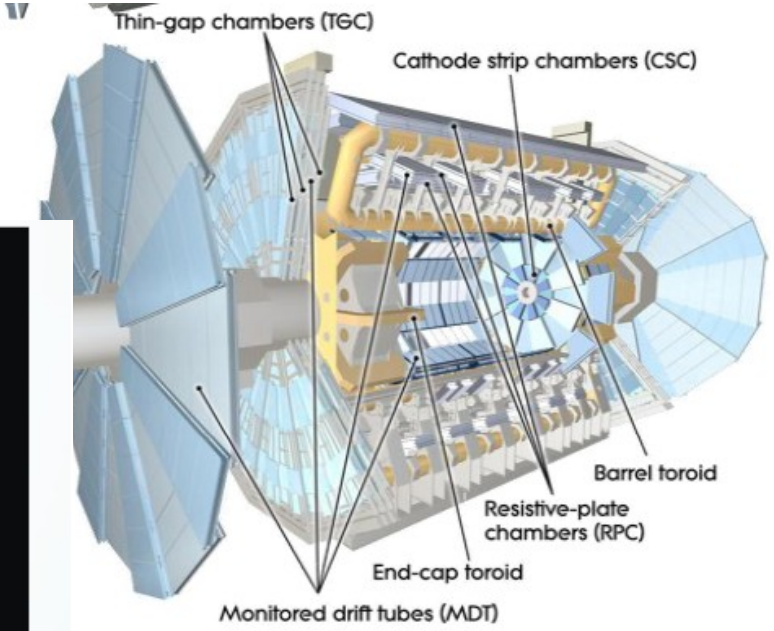
00 cells)

T vector



Muons


ATLAS
EXPERIMENT
2009-12-06, 08:38 CET
Run 141749, Event 171059
Collision Event with Muon Track
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html


Thin-gap chambers (TGC)
Cathode strip chambers (CSC)
Barrel toroid
Resistive-plate chambers (RPC)
End-cap toroid
Monitored drift tubes (MDT)

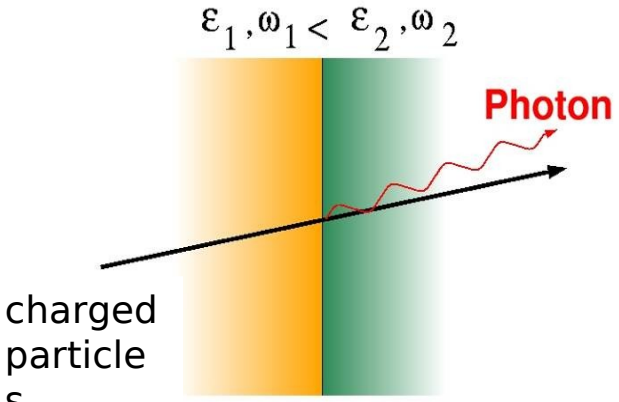
Summary

- Based on the 2009 datasets ATLAS has published
  - XX conference notes (winter conferences)
  - Performance paper:
    - arXiv:1005.5254 ; CERN-PH-EP-2010-015
  - Physics paper: “Charged-particle multiplicities in pp interactions at s = 900 GeV measured with the ATLAS detector at the LHC”
    - arXiv:1003.3124; CERN-PH-EP-2010-004

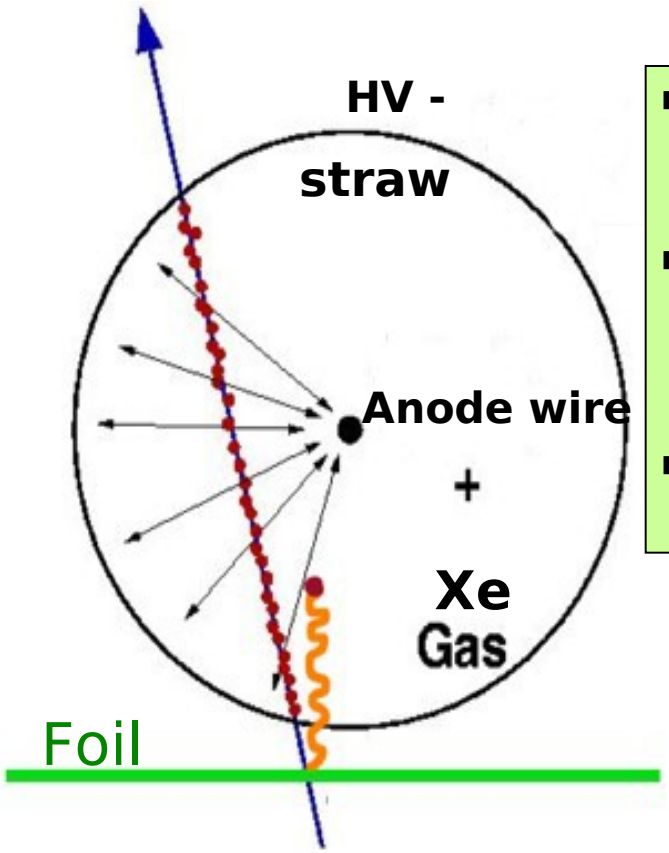
      Phys. Lett. B 688 (2010) 21-42

BACKUP SLIDES

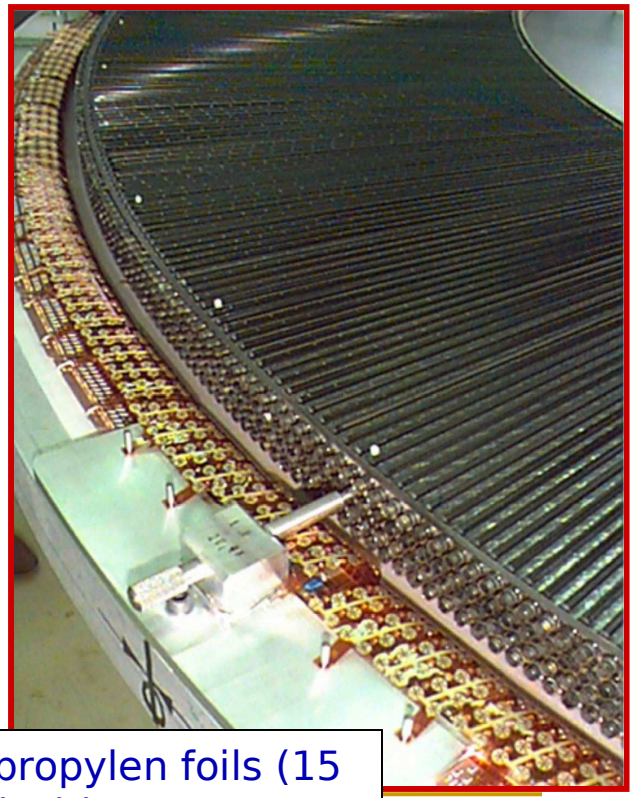
The Transition Radiation detector (TRT)



Transition radiation is emitted whenever a relativistic charged particle traverses the border between two media with different dielectric constants.
TR intensity is proportional to the particle γ -factor
$\rightarrow$for a given particle momentum p, electrons emit more TR than pions $\rightarrow$TR detectors used for particle identification

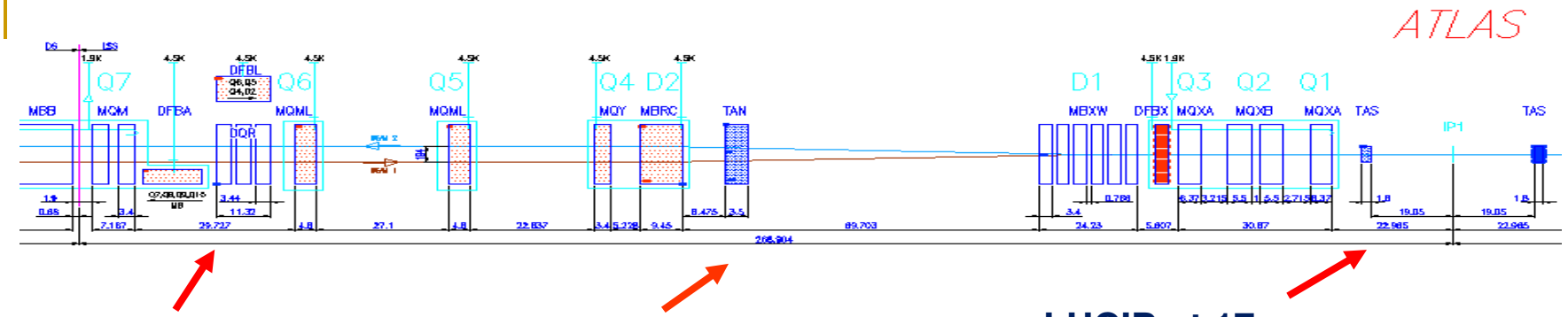


- Energy of TR photons (proportional to ε_1-ε_2): ~ 10-30 keV (X-rays)
- Many crossings of polypropylene foils (radiator) to increase TR photons
- Xenon as active gas for high X-ray absorption

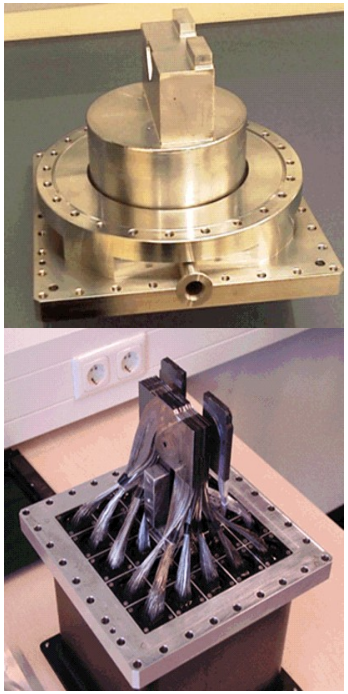


Radiator: Polypropylen foils (15 μ) interleaved with straws

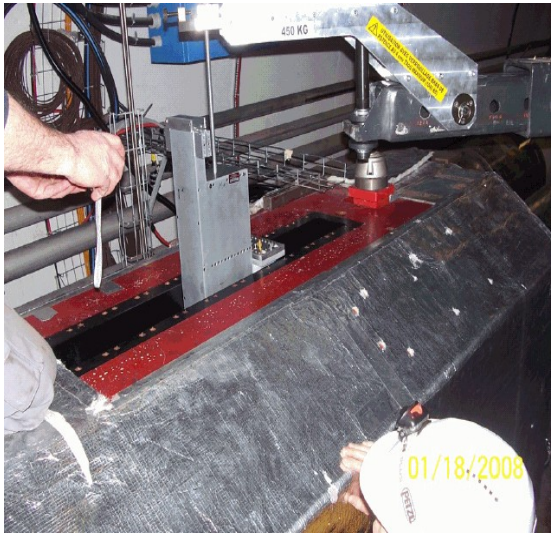
Forward detectors



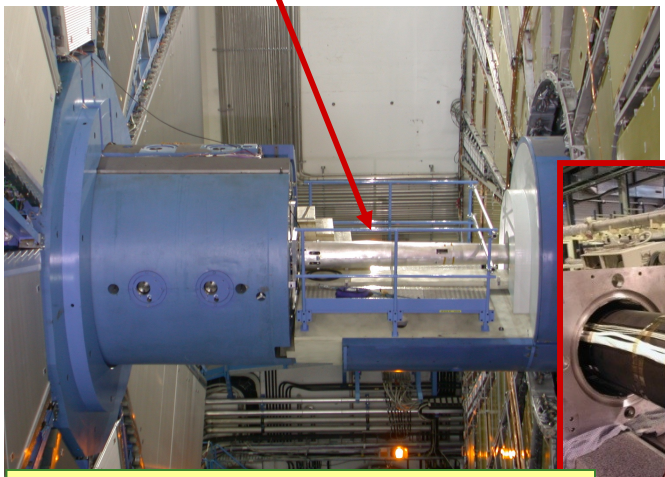
ALFA at 240 m

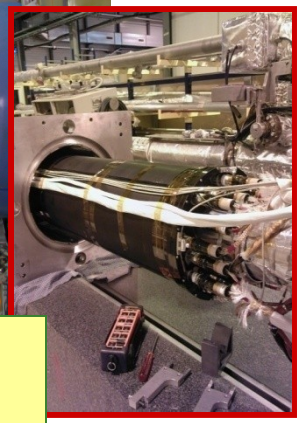


ZDC at 140 m



LUCID at 17 m





Zero Degree Calorimeter
(Data taking in 2009)

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