LHC is back !!

- The year 2008/2009 saga in few slides
- First collisions in ATLAS detector.
- Physics goals in next months

Large part based on presentations by S. Meyers and A. Hoecker shown at the meeting CERN, „LHC, week 1", 26 November 2009.
http://indico.cern.ch/conferenceDisplay.py?confId=74907

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

Situation as of October 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

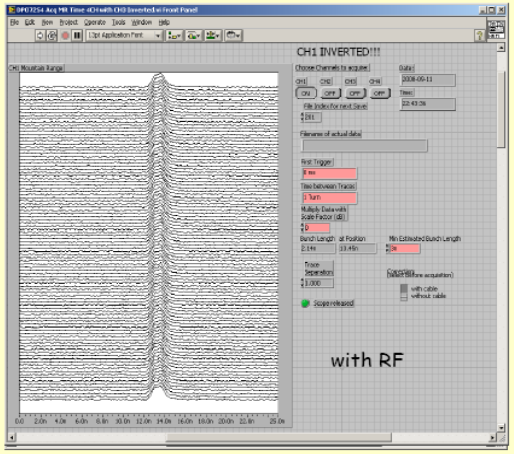
Many tests (orbit, dump,…)

Sept 12:

Measure horizontal beam profile with wire scanner

Evening: transformer failure pt8 replacement + recovery

Continue with machine checkout (without beam)



Problem in Sector 34

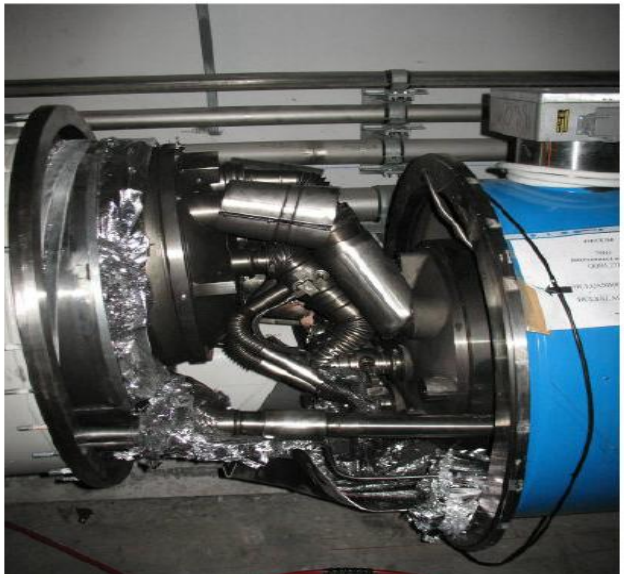
Friday, Sept 19

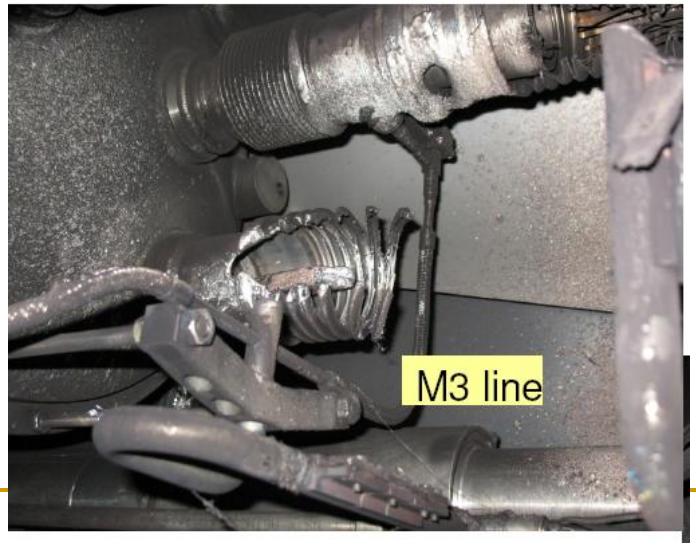
- Commissioning without beam of final sector for 5 TeV operation
- Faulty electrical connection between two magnets
- Leading to large helium leak into the tunnel
- Sector has to be warmed up (started, takes several weeks) before diagnosis and repair can start, then cool down again (several weeks)

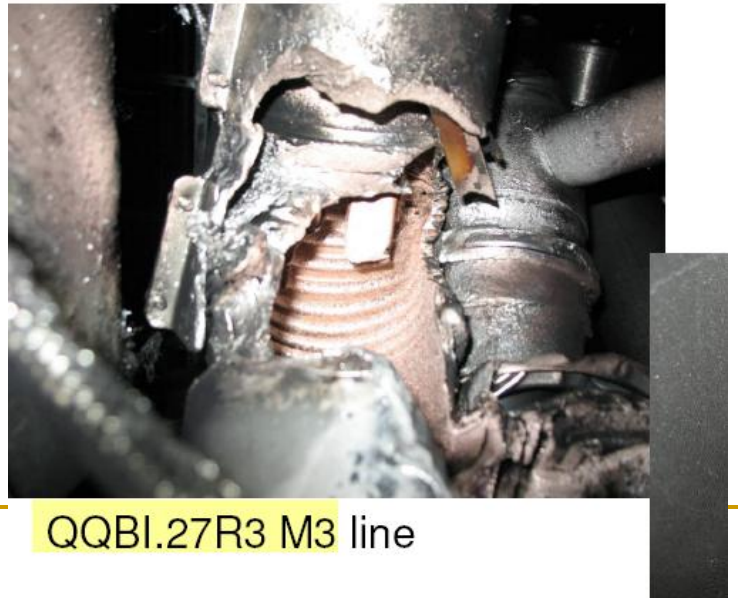
  → runs into winter shutdown
- Restart of accelerators spring 2009 – LHC beams to follow

LHC damages

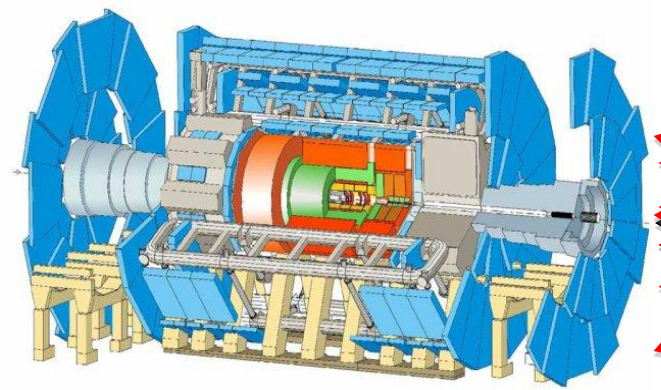
S.Myers
CERN December 2009

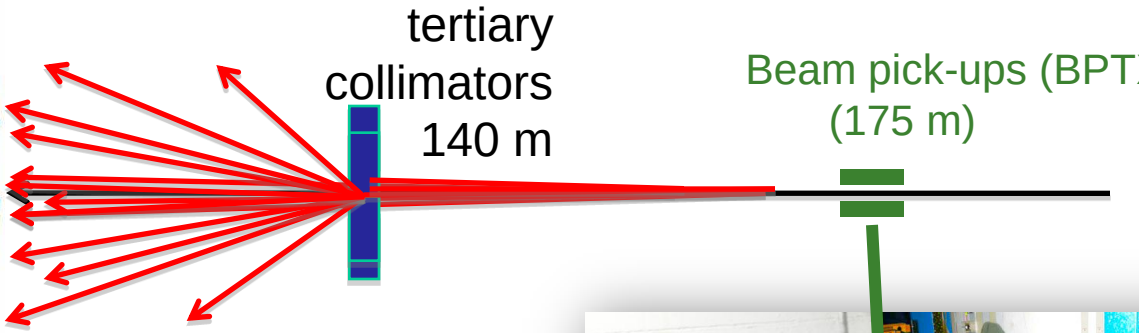


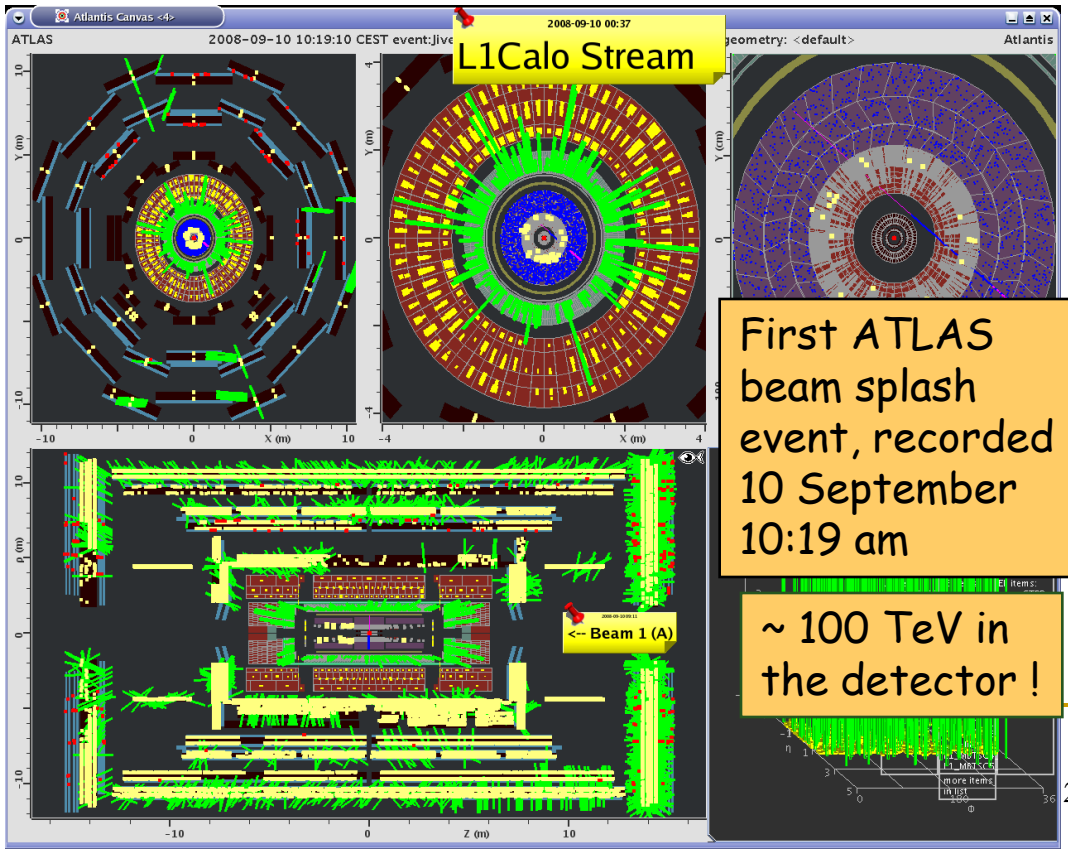




Beam bunches (2×10^9 protons at 450 GeV) stopped by (closed) collimators upstream of experiments → "splash" events in the detectors (debris are mainly muons)



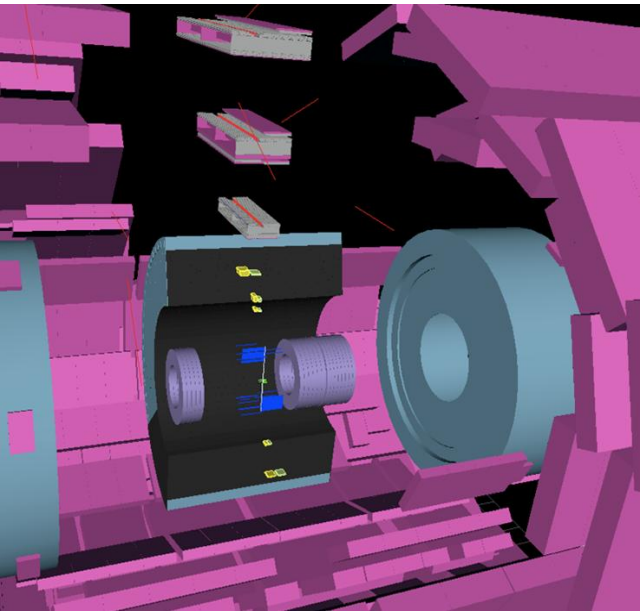




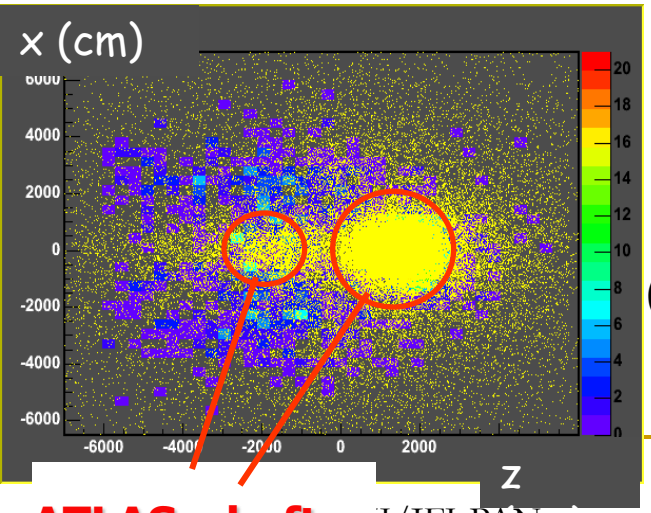
First ATLAS beam splash event, recorded 10 September 10:19 am

~ 100 TeV in the detector !

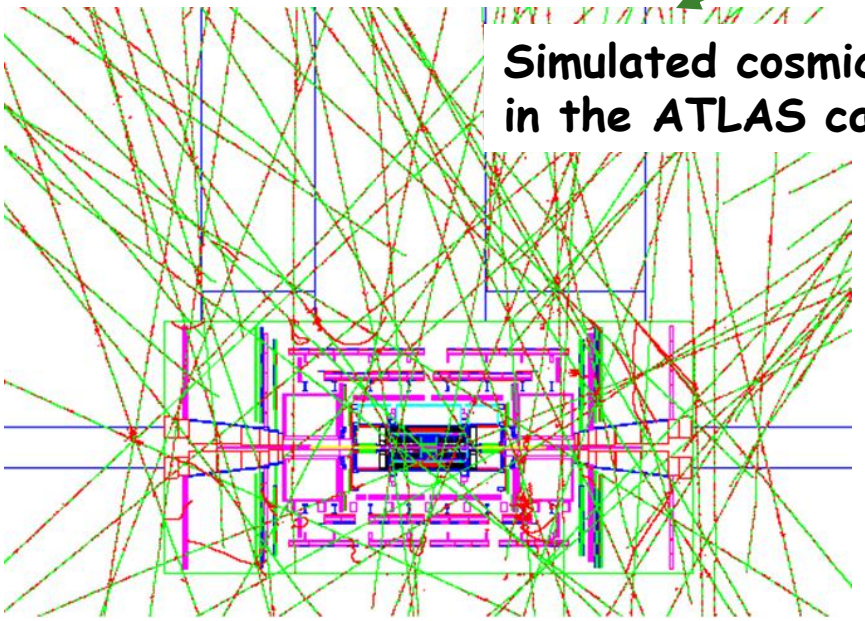
Cosmic Muons in ATLAS



Real Cosmic Event



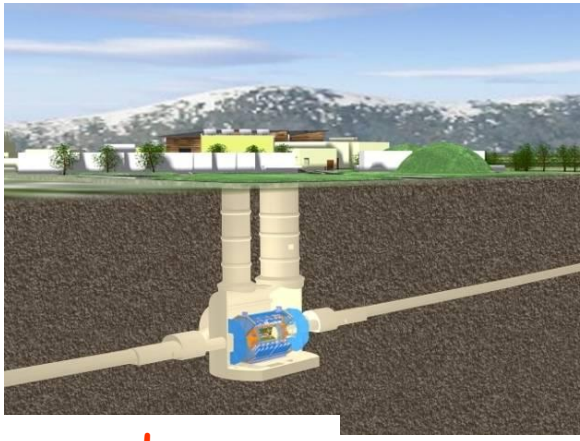
10 ms



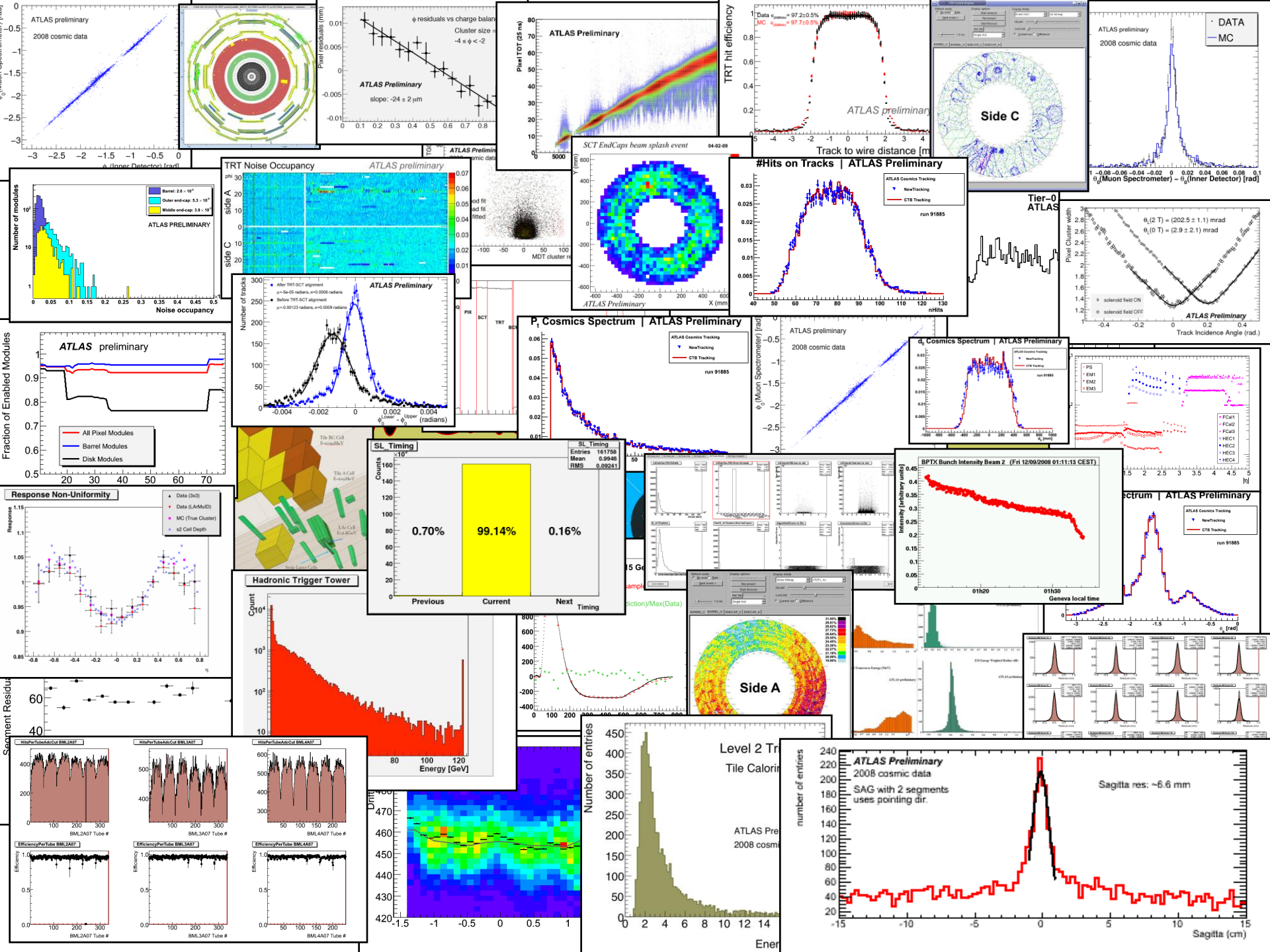
Simulated cosmics flux in the ATLAS cavern

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

(Calorimeter trigger also available)



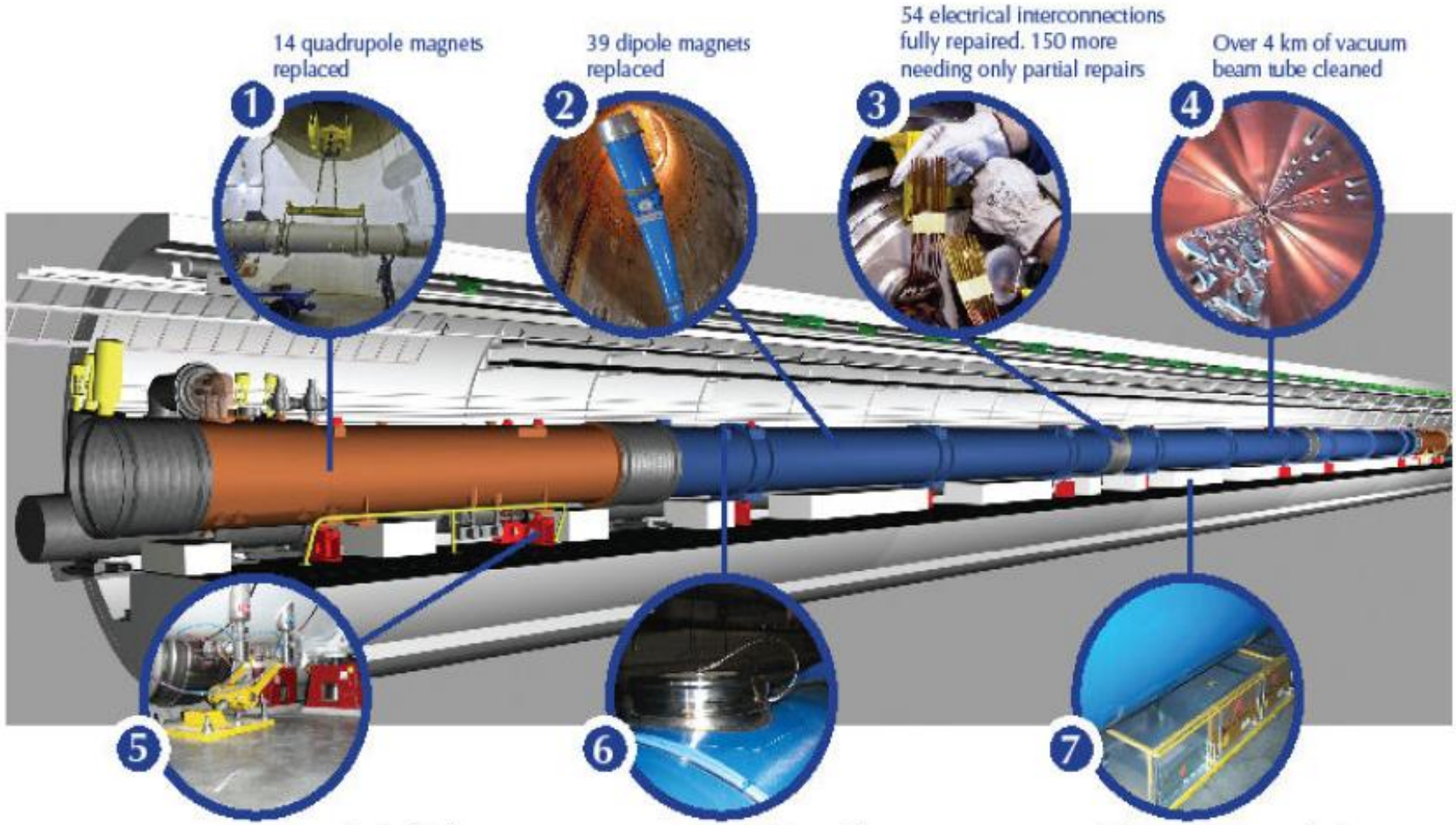
Rate ~100 m below ground:
~ O(15 Hz) crossing Inner Detector


ATLAS preliminary
2008 cosmic data
ATLAS Preliminary
TRT Noise Occupancy
ATLAS preliminary
side A
side C
Number of modules
ATLAS PRELIMINARY
Noise occupancy
ATLAS Preliminary
Number of tracks
ATLAS preliminary
Fraction of Enabled Modules
All Pixel Modules
Barrel Modules
Disk Modules
Response Non-Uniformity
Data (3x3)
Data (LArMuID)
MC (True Cluster)
s2 Cell Depth
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]
ATLAS Preliminary
Pixel ToT (25 ns)
Pixel residuals (mm)
slope: -24 ± 2 μm
Cluster size = 1
-4 ≤ ϕ < -2
TRT hit efficiency
Track to wire distance [m]
Side C
Side A
SCT EndCaps beam splash event
04-02-09
X (mm)
Y (mm)
#Hits on Tracks | ATLAS Preliminary
ATLAS Cosmics Tracking
NewTracking
CTB Tracking
run 91885
nHits
P_t Cosmics Spectrum | ATLAS Preliminary
d_0 Cosmics Spectrum | ATLAS Preliminary
DATA
MC
Tier–0
ATLAS
Pixel Cluster width
Track Incidence Angle (rad.)
solenoid field ON
solenoid field OFF
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 cosmi
Number of entries
Ener
ATLAS Preliminary
2008 cosmic data
SAG with 2 segments
uses pointing dir.
Sagitta res: ~6.6 mm
Sagitta (cm)
number of entries

Phase 1 +2

S.Myers
CERN November 2009

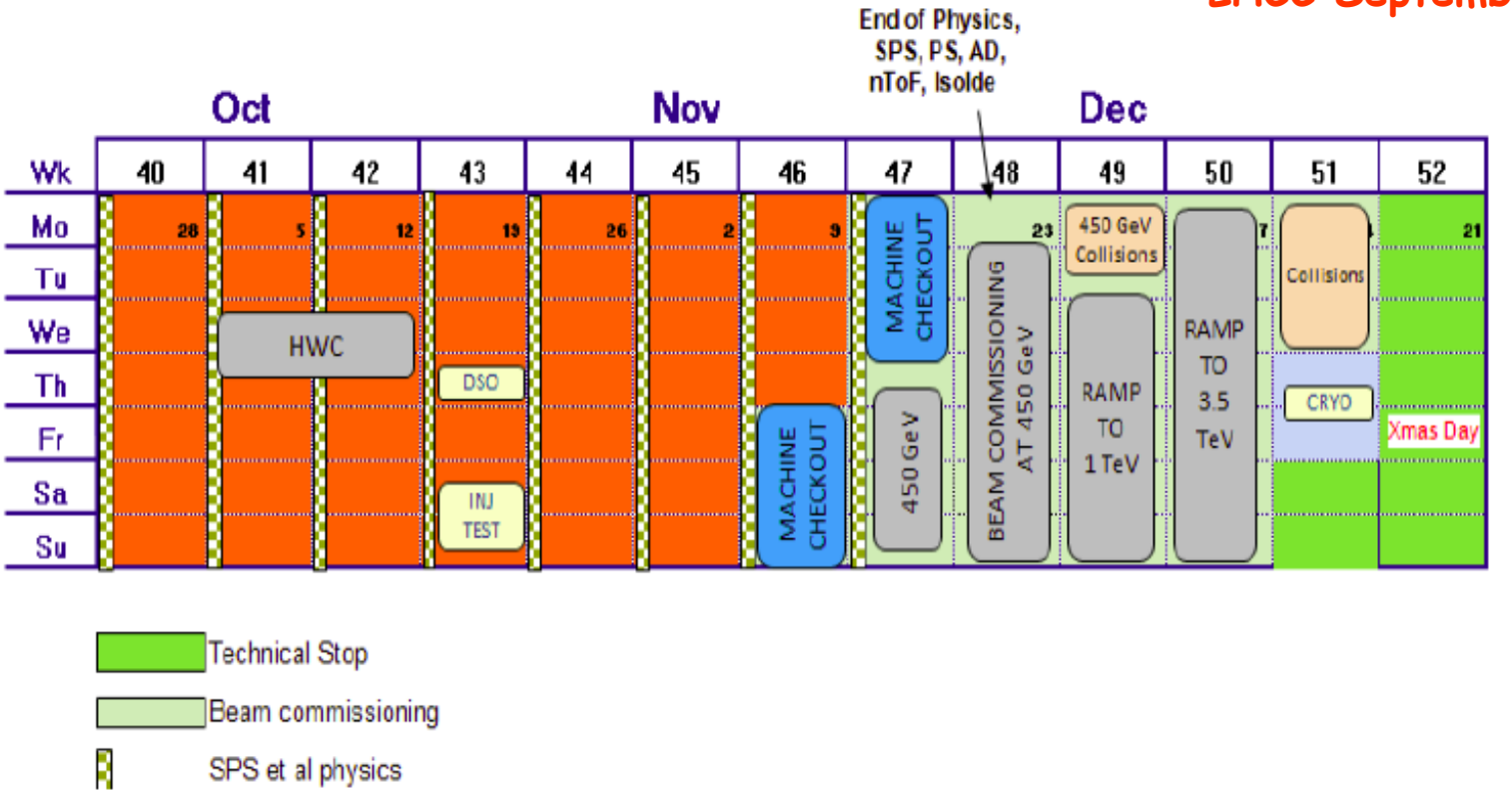
The LHC repairs in detail



+ cryogenics!

LHC running scenario in 2009

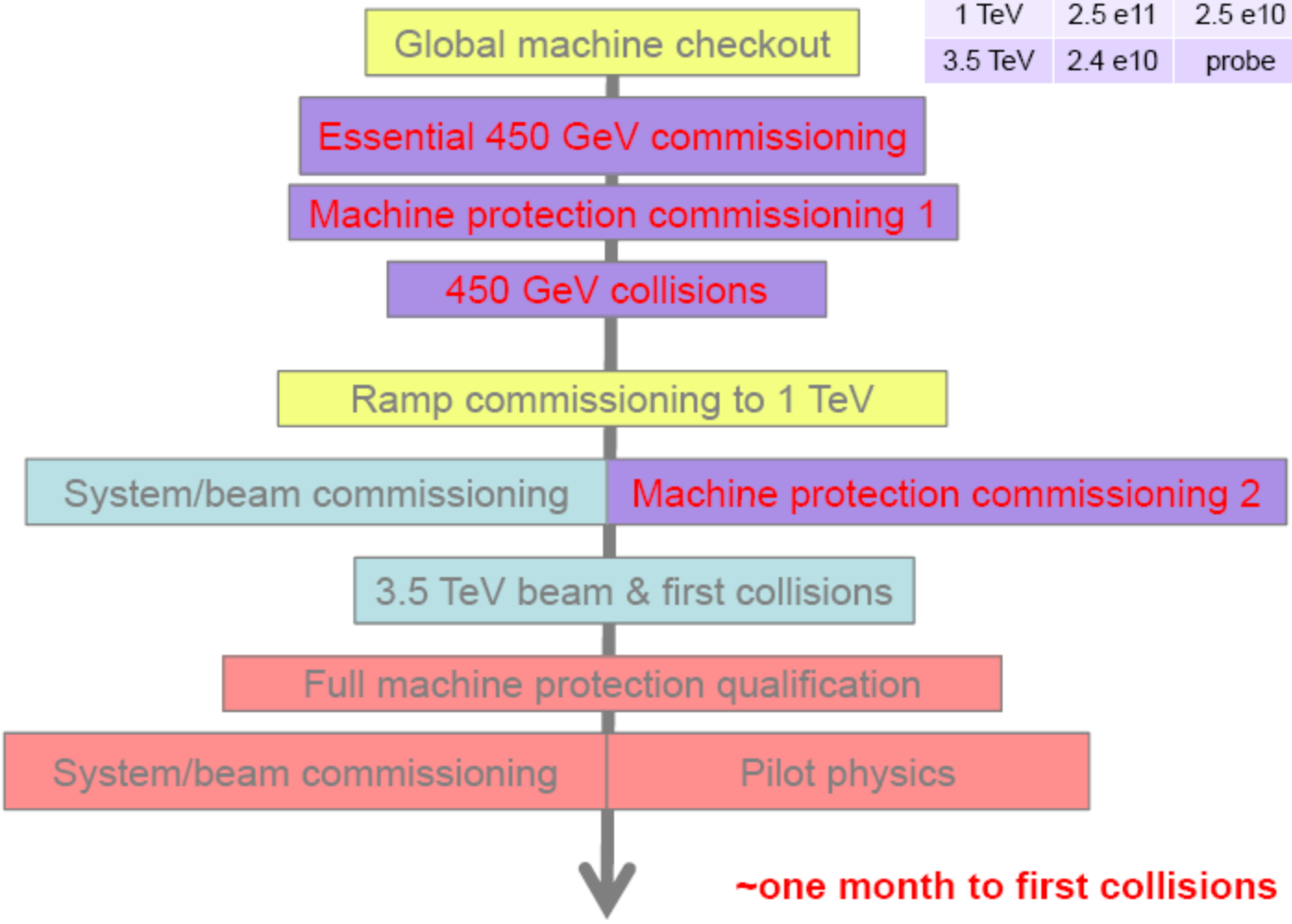
S.Myers
LHCC September 2009



- All dates approximate…
- Reasonable machine availability assumed

LHC beam commissioning

Energy	Safe	Very Safe
450	1 e12	1 e11
1 TeV	2.5 e11	2.5 e10
3.5 TeV	2.4 e10	probe



49

S.Myers
LHCC September 2009

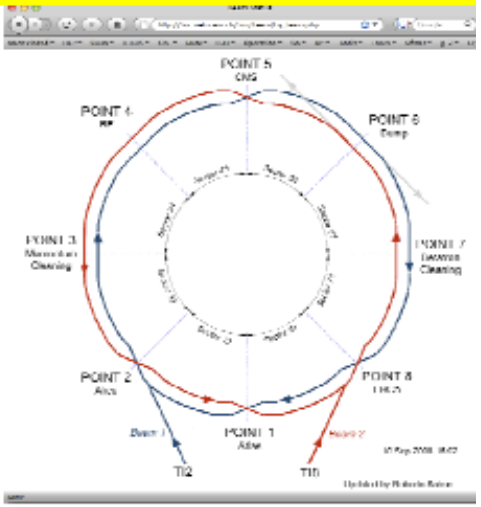
Friday November 20

18:30 Beam 1

- 19.00 beam through CMS (23, 34, 45)
  - beam1 through to IP6 19.55 Starting again injection of Beam1
  - corrected beam to IP6, 7, 8, 1
- 20.40 Beam 1 makes 2 turns

2h10 for 27km: 12.5km/h average speed

  - Working on tune measurement, orbit, dump and RF
  - Beam makes several hundred turns (not captured)
    - Integers 64 59, fractional around .3 (Qv trimmed up .1)
- 20.50 Beam 1 on beam dump at point 6
- 21.50 Beam 1 captured



22:15 Beam2

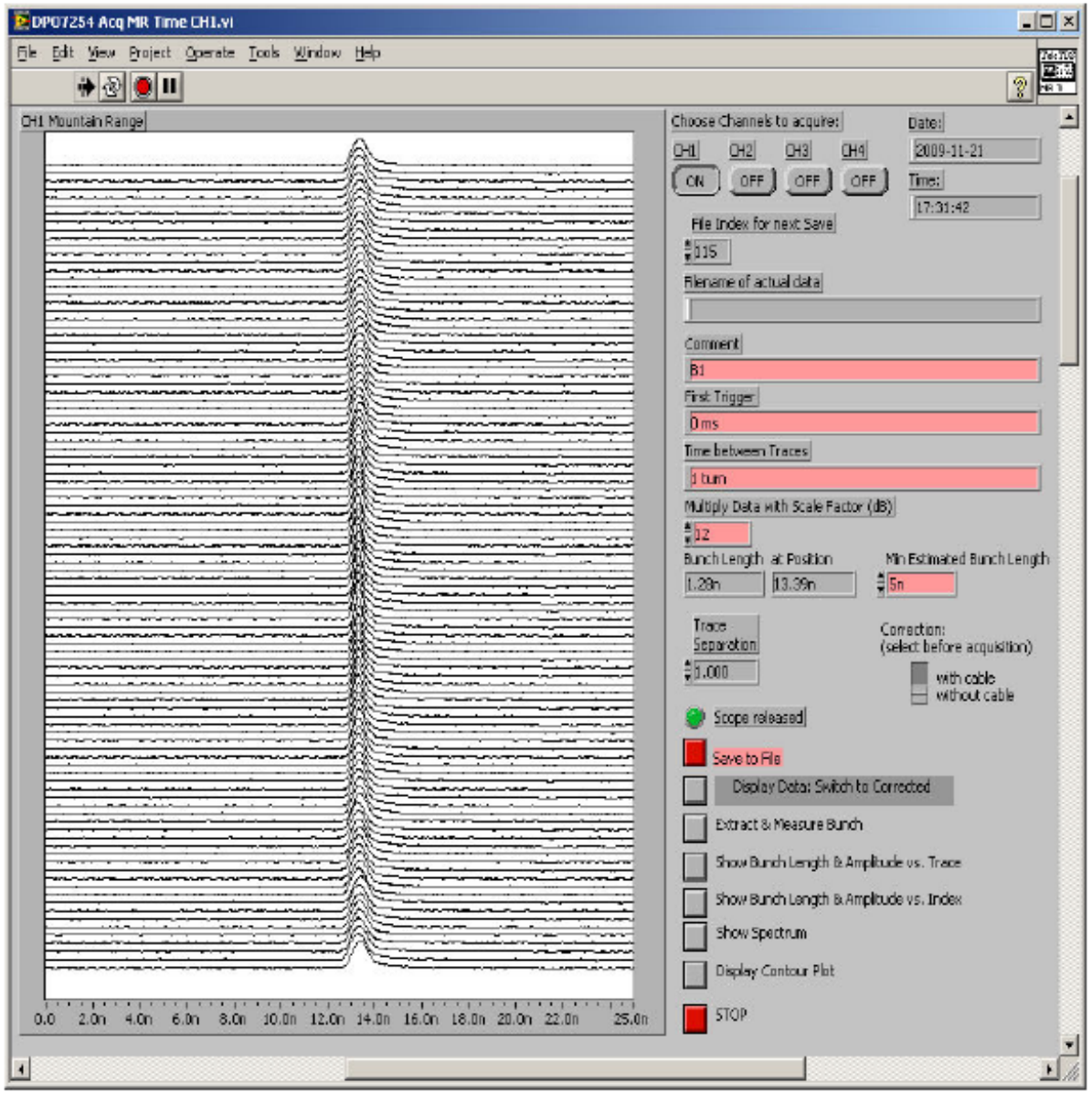
- 23.10 Start threading Beam2
  - Round to 7 6 5 2 1
- 23.40 First Turn Beam2

1h25 for 27km: a bit faster

  - Working on tune measurement, orbit, dump and RF
  - Beam makes several hundred turns (not captured)
    - Integers 64 59, fractional around .3 (Qv trimmed up .05)
- 24.10 Beam 2 captured

LHC is back!!!

S.Myers
CERN December 2009



Beam is circulating and stable

- magnets
- power supplies
- vacuum
- RF
- cryogenics
- all infrastructure
- optics
- injection

ATLAS

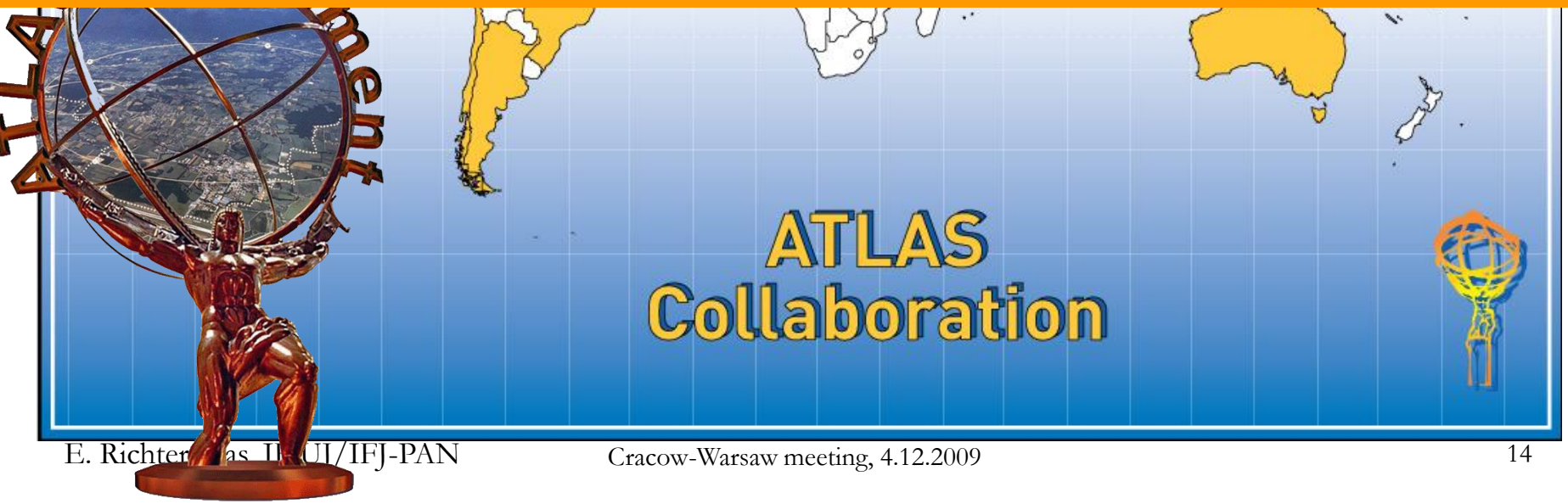
Beams and first collisions

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

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

~2800 physicists (800 PhD students) from 169 Institutions/Universities, 37 countries, 5 continents

Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Brasil Cluster, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, CERN, Chinese Cluster, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, UT Dallas, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, RUPHE Morocco, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Olomouc, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Regina, Ritsumeikan, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, Southern Methodist Dallas, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Würzburg, Yale, Yerevan

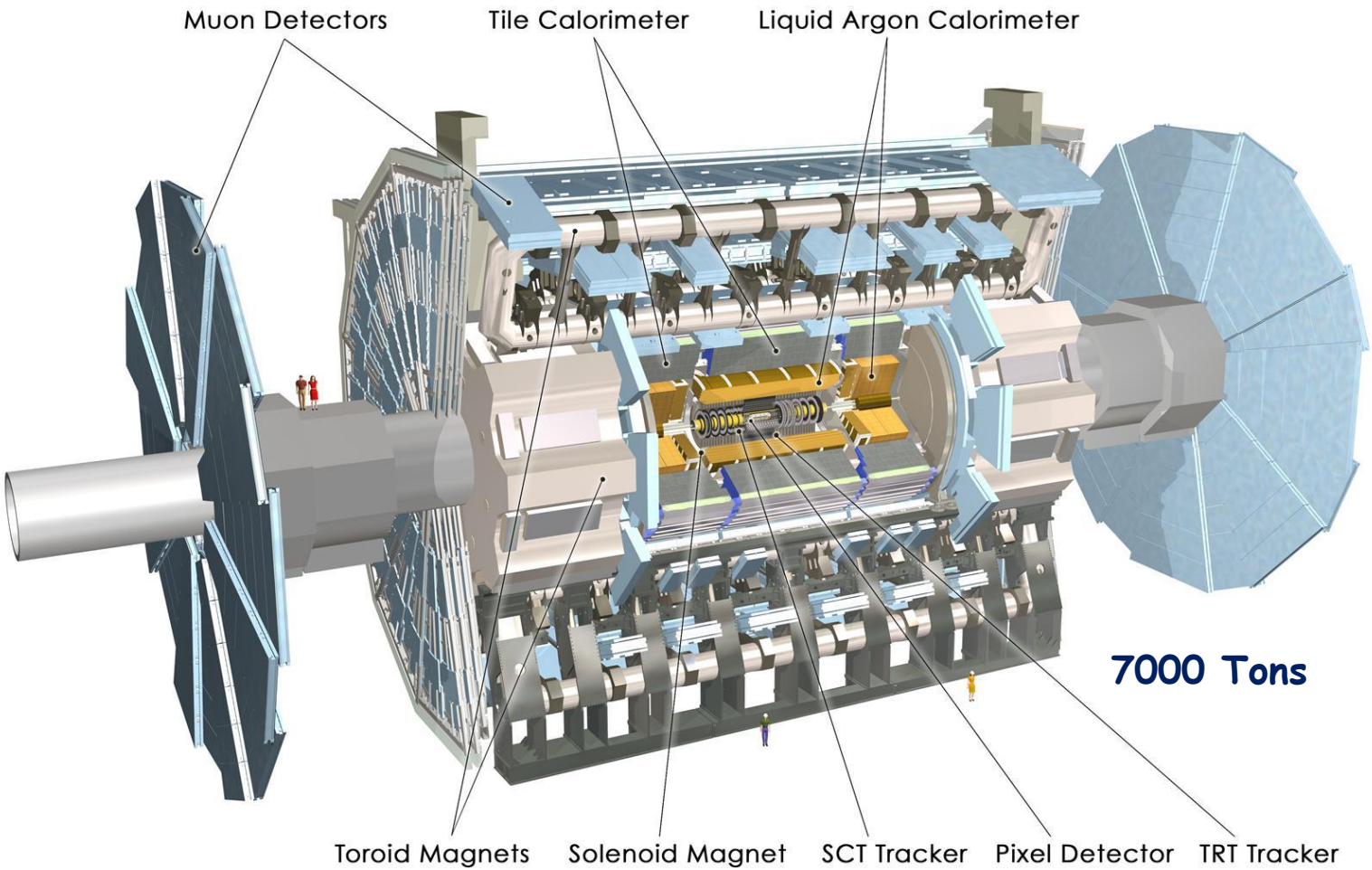


ATLAS Detector

45 m

ATLAS superimposed to the 5 floors of building 40

24 m



Nov 20 – 23: beam history from ATLAS perspective

Friday, November 20:

~ 20:30h: beam-1 threading → 6 beam splashes to ATLAS

~ 22:30h: beam-2 threading → 7 beam splashes to ATLAS

Saturday, 21 November:

~ 1h: beam-2 splashes to ATLAS → 27 events (side C)

~ 4h: beam-1 splashes to ATLAS → 26 events (side A)

Sunday, 22 November:

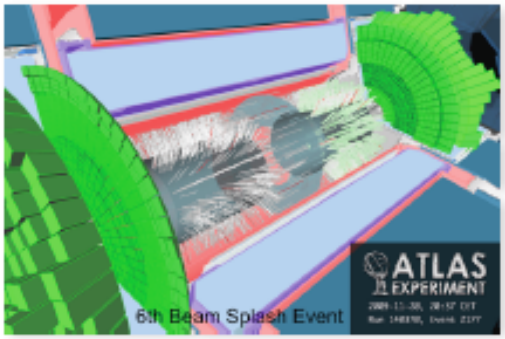
~ 6h: 15 splash events to test beam abort by BCM → successful

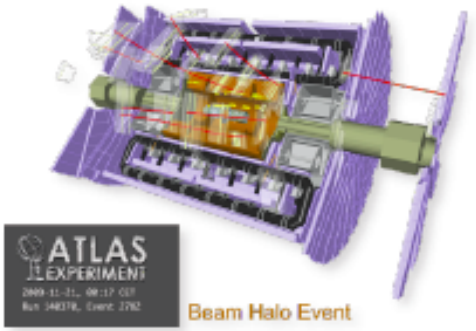
Monday 23 November:

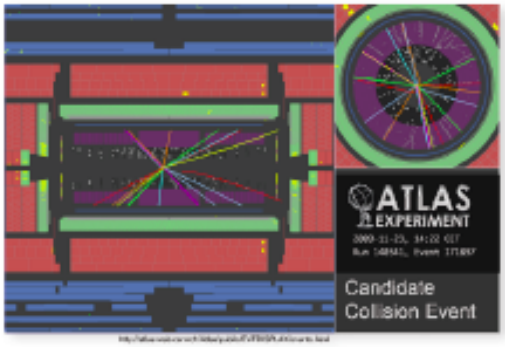
~ 6:30: last series of splashes to ATLAS→ 25 events (side C)

~ 13:30: two beams injected for collisions at IP1 and IP5

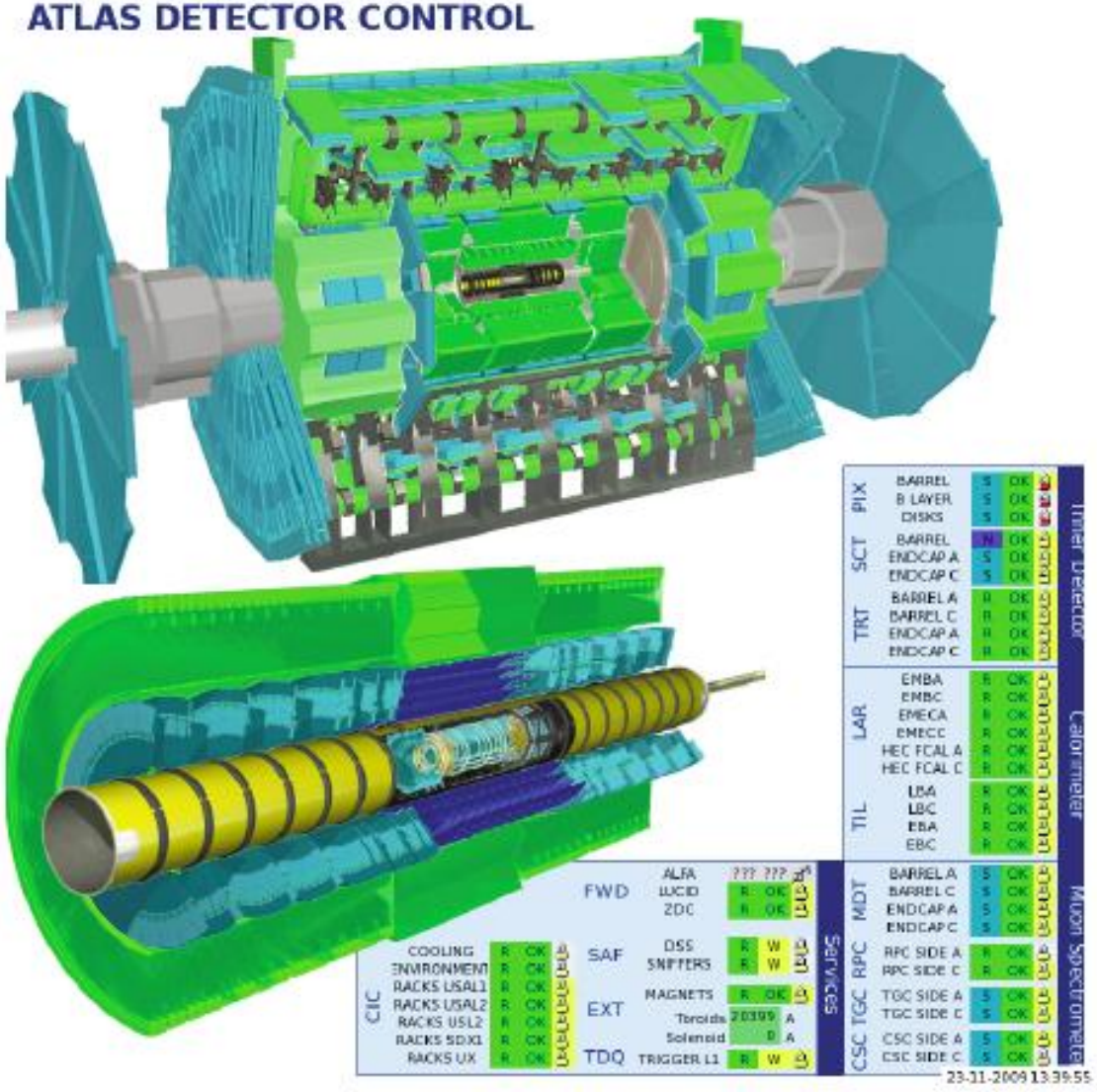
~ 14:22: first ATLAS collision event seen







Detector fully operational



Setup for beam commissioning

- Pixel off
- SCT (standard bias voltage 150 V)
  - 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 ON
- No solenoid field, toroids ON

CSC running in separate DAQ partition for rate tests

1st Beam Splash from Beam-2

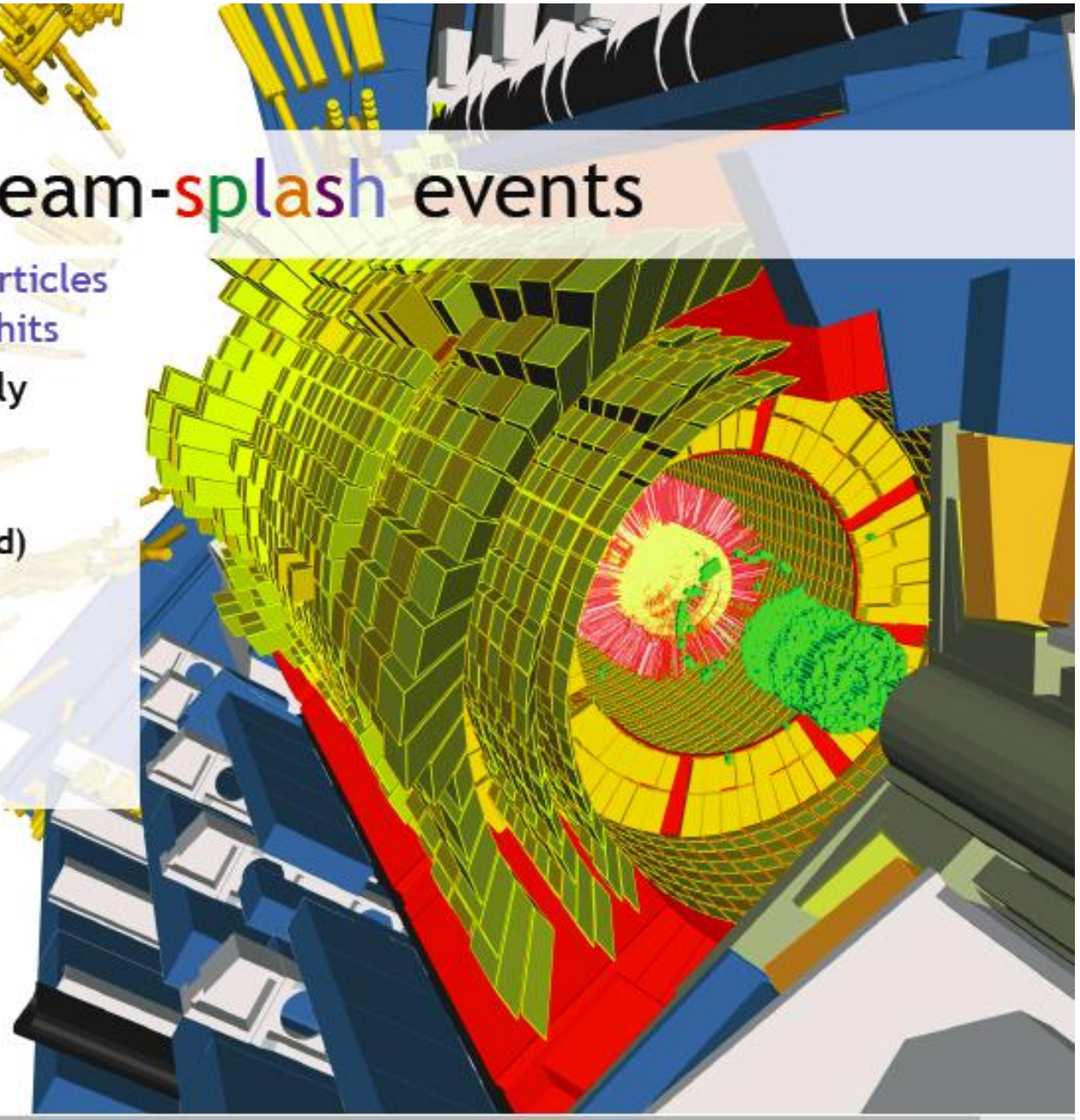
Beam-splash events

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

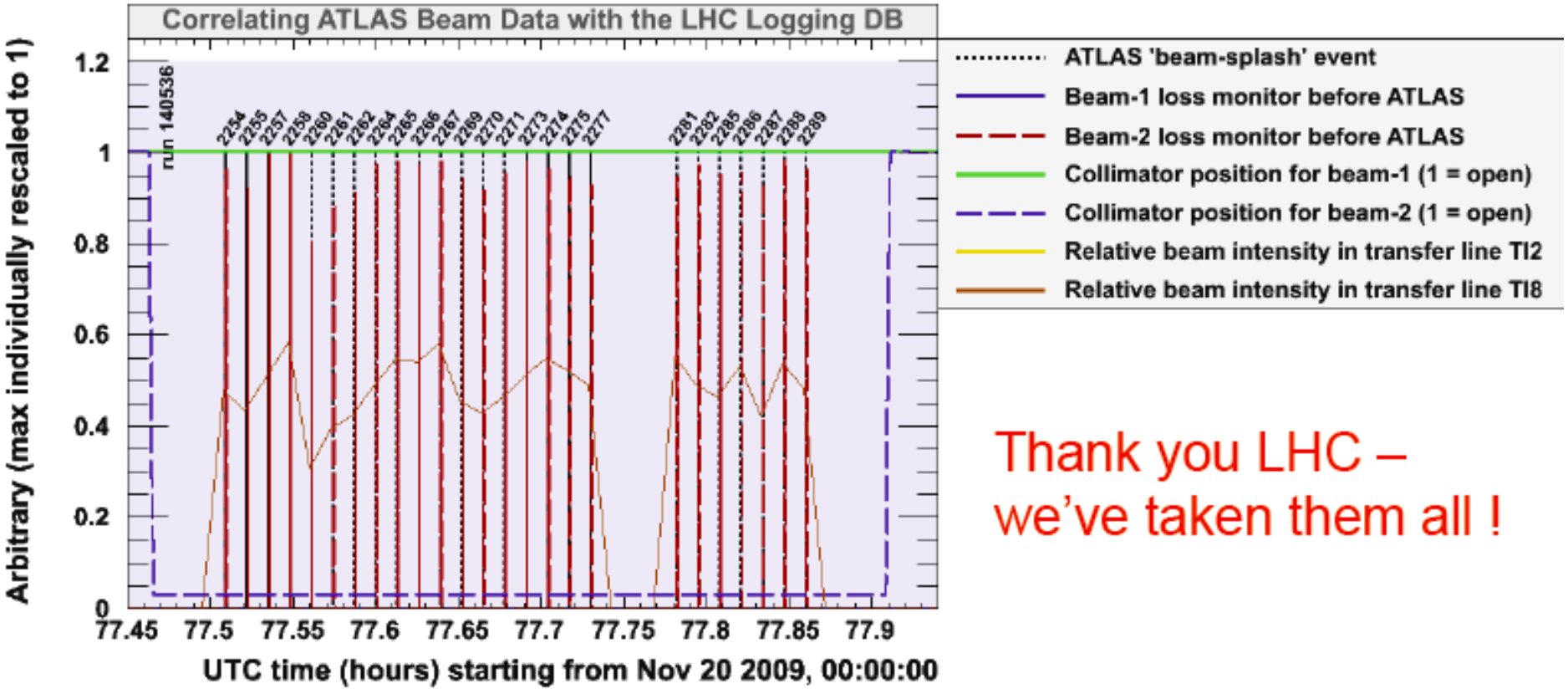


Proudly presents …

Indeed … why do it again ?

Timing and beam-abort tests!

- Triggering on splashes: ATLAS received and triggered on 106 splashes

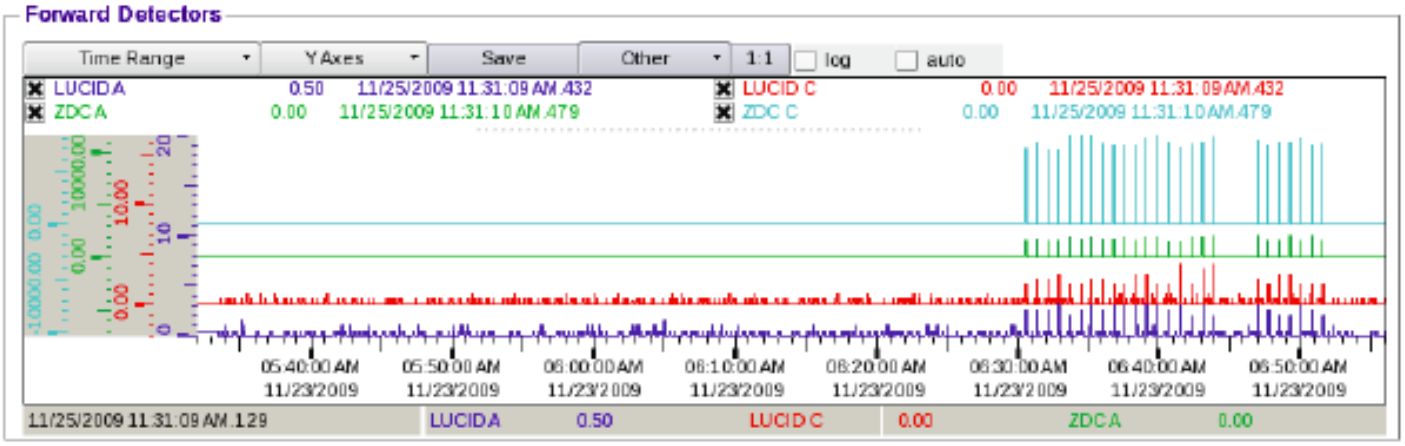


Thank you LHC –
we've taken them all !

Indeed … why do it again ?

Timing and beam-abort tests!

Beam splash events also measured by ATLAS very forward detectors (LUCID $z = \pm 17$ m and ZDC $z = \pm 140$ m)



ZDC C

ZDC A

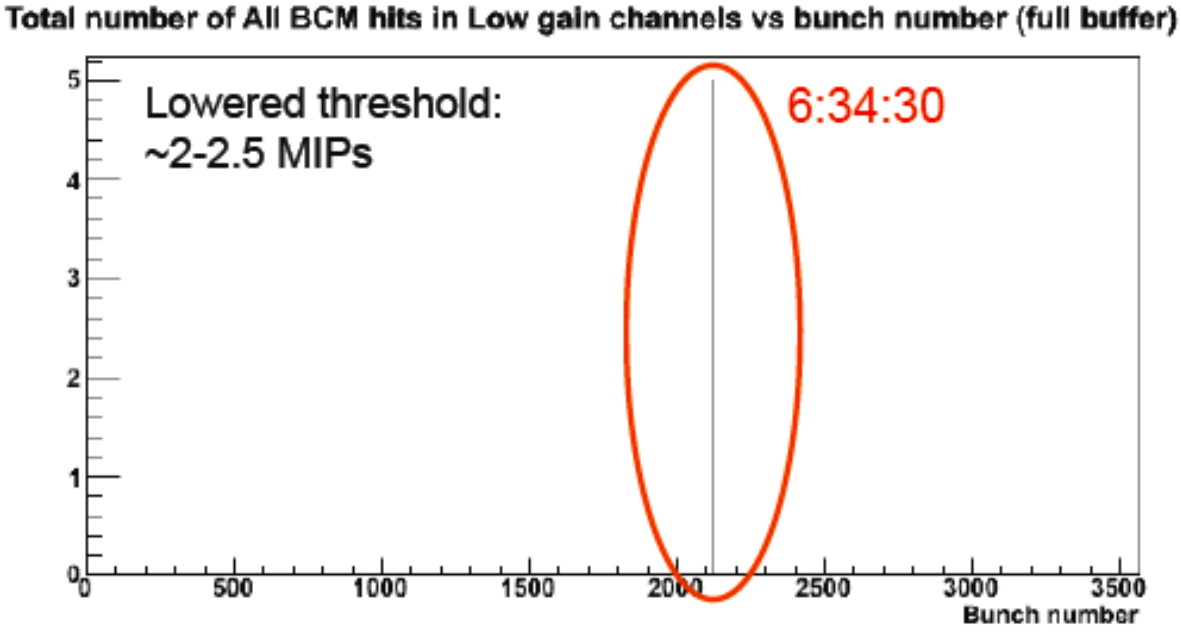
LUCID A

LUCID C

Indeed … why do it again ?

Timing and beam-abort tests!

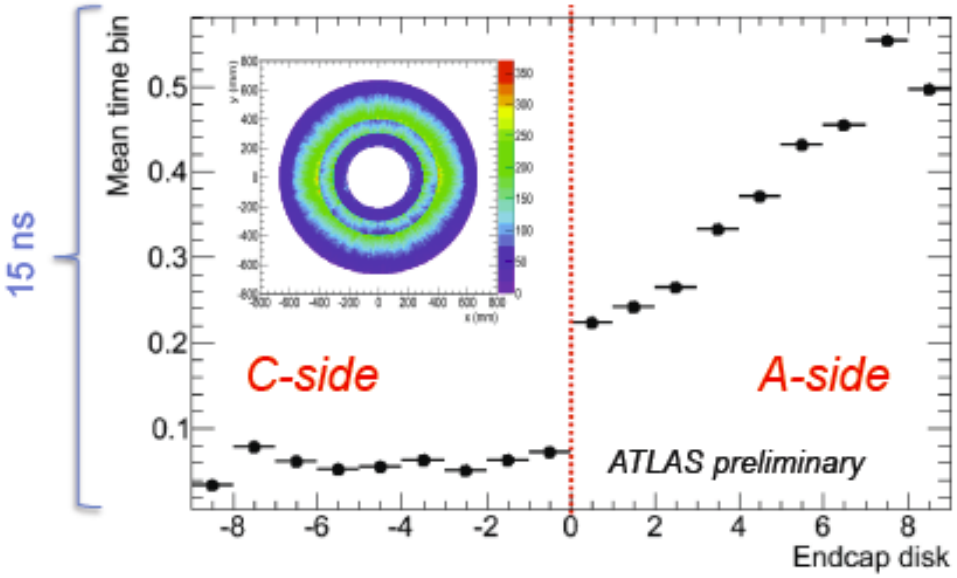
Beam abort test using dedicated diamond Beam Condition Monitors was successfully conducted on Sun, 22 Nov at 6:34, and no fake abort!



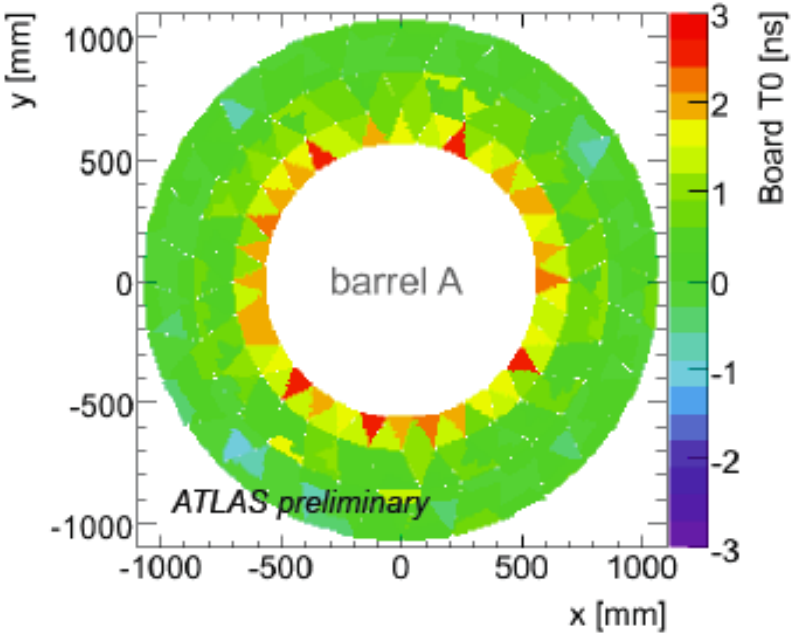
Timing studies with beam-splash events (Inner Detector)

- Inner tracking systems:
  - SCT already well timed-in from cosmics and known cable lengths (better than 2 ns)
  - TRT boards timed-in to better than 2 ns

Beam-1 arriving from A-side: timing as collisions for C-side, but wrong for A-side



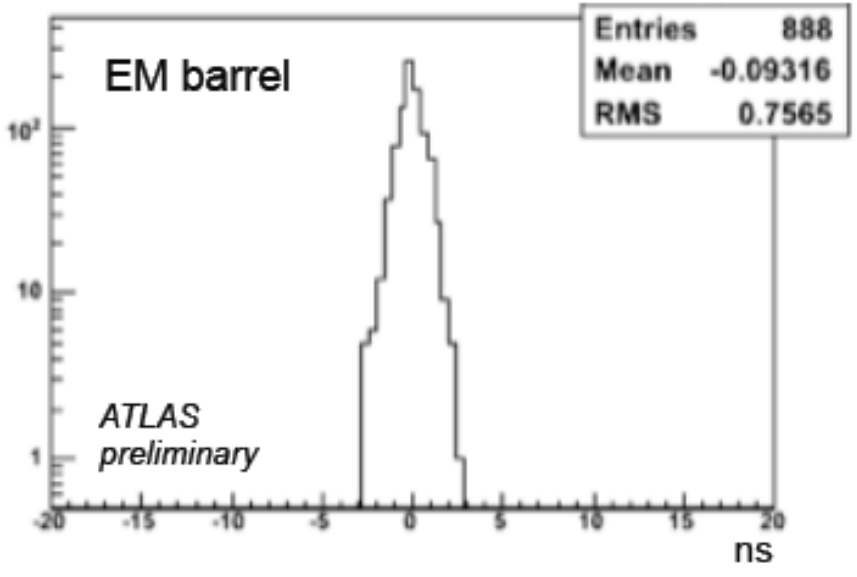
TRT Barrel: plot made with collision timing
→ sensitive to ToF effect on Inner Boards !



Timing studies with beam-splash events (Calorimeter & Muons)

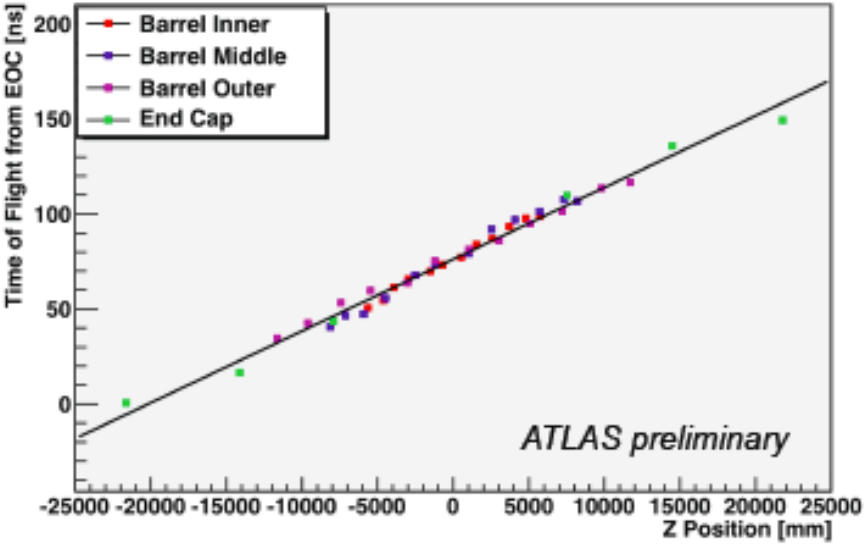
LAr Timing:

After 2008 beam-splash data taking and analysis of many millions of cosmics events, timing good within a few ns



MDT Timing:

Synchronize all chambers at a given z using the synchronous front of splash particles and the very large particle flux



Timing studies with beam-splash events (Calorimeter & Muons)

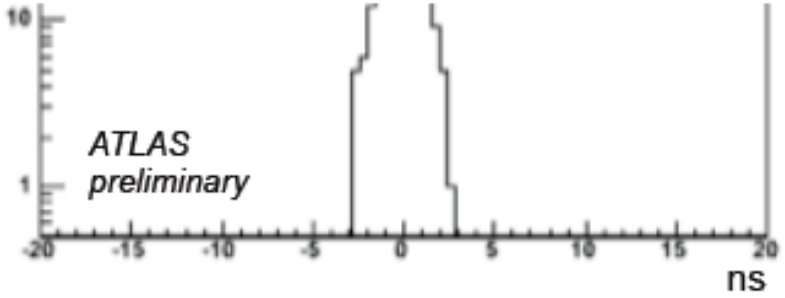
LAr Timing:

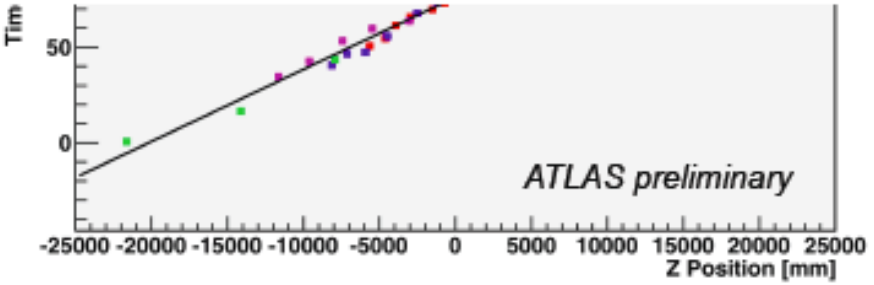
After 2008 beam-splash data taking and analysis of many millions of cosmics events, timing good within a few ns

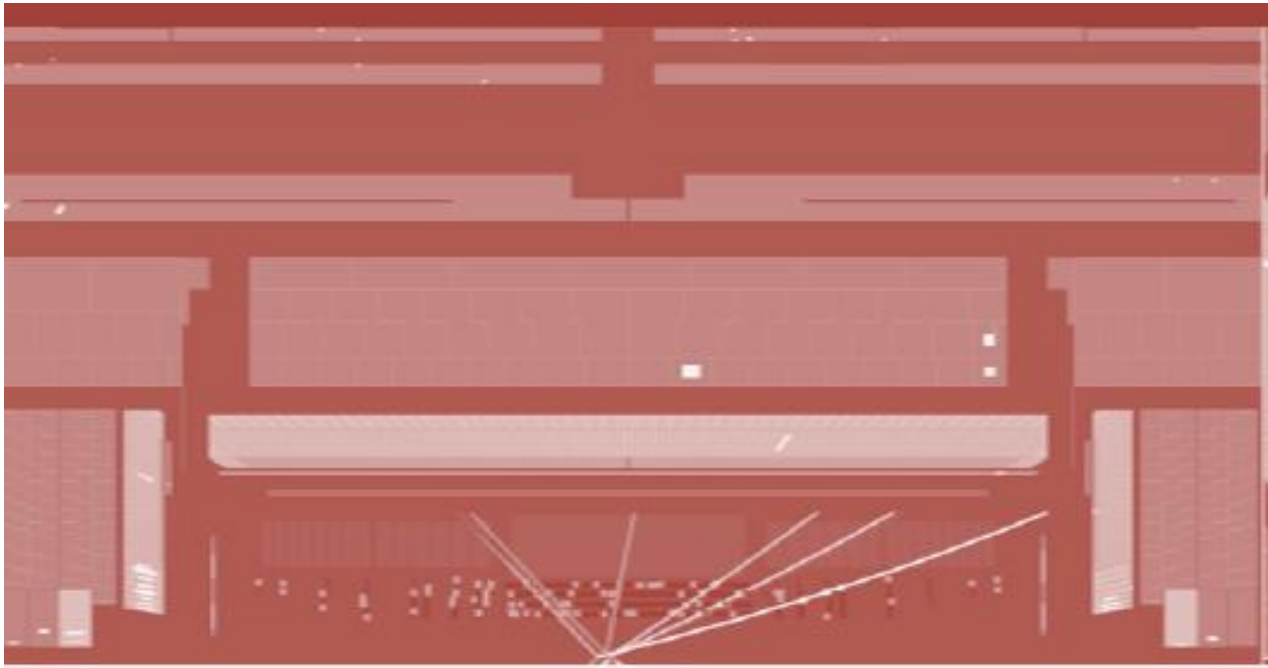
MDT Timing:

Synchronize all chambers at a given z using the synchronous front of splash particles and the very large particle flux

ATLAS now well timed in for collisions

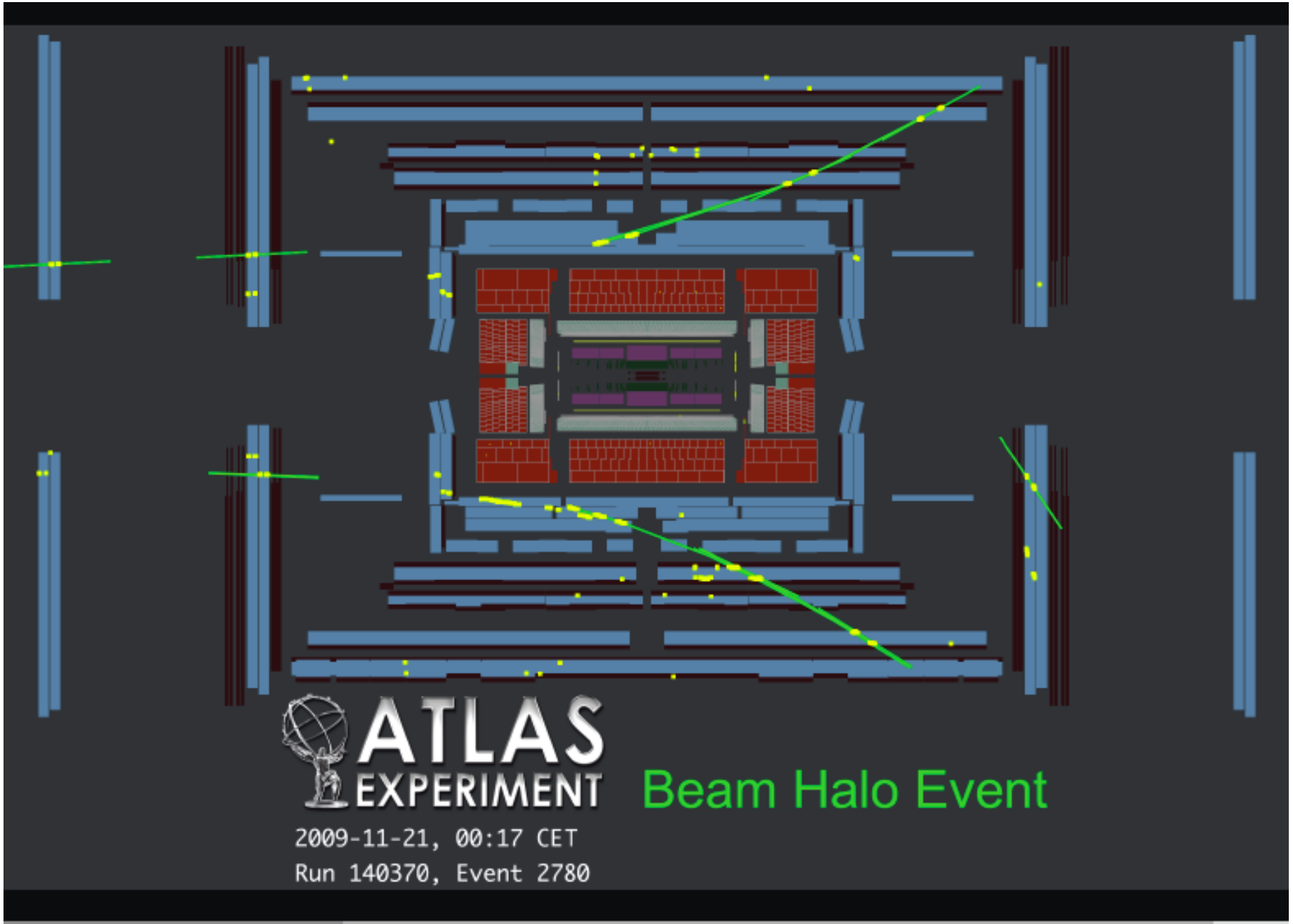




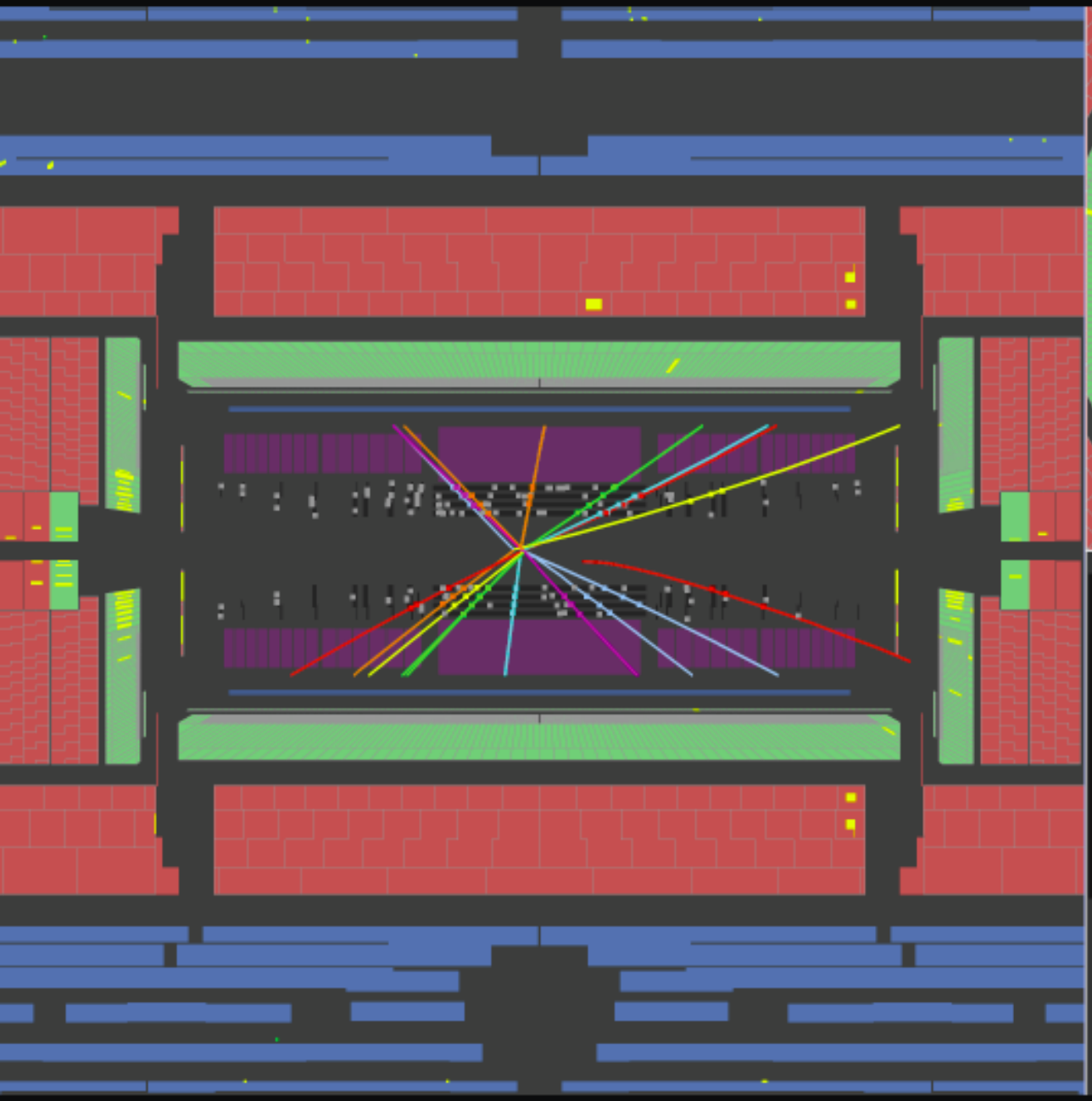


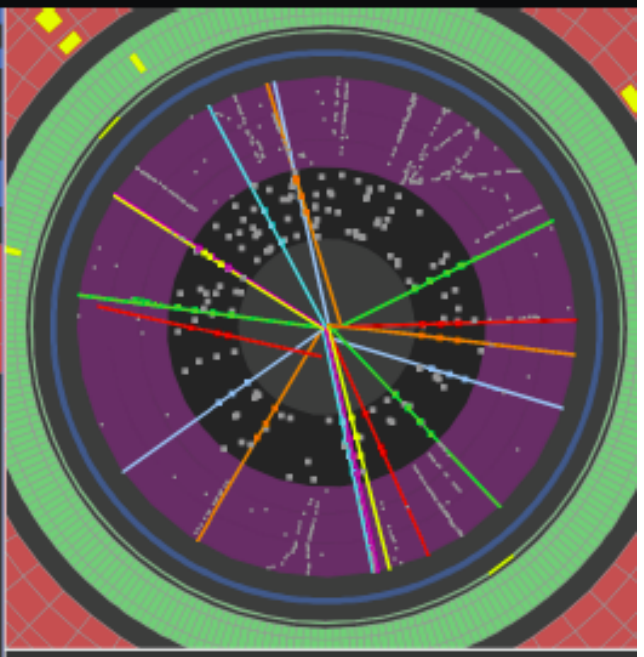
Single beam, two beams,
two synchronised beams,
colliding beams, **collisions** ?

Candidate
Collision Event


ATLAS
EXPERIMENT
Beam Halo Event
2009-11-21, 00:17 CET
Run 140370, Event 2780

We were lucky - shortly after colliding beams were announced, at 14:22 an interesting event appeared on our screens





ATLAS EXPERIMENT

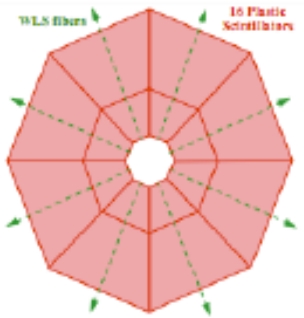
2009-11-23, 14:22 CET

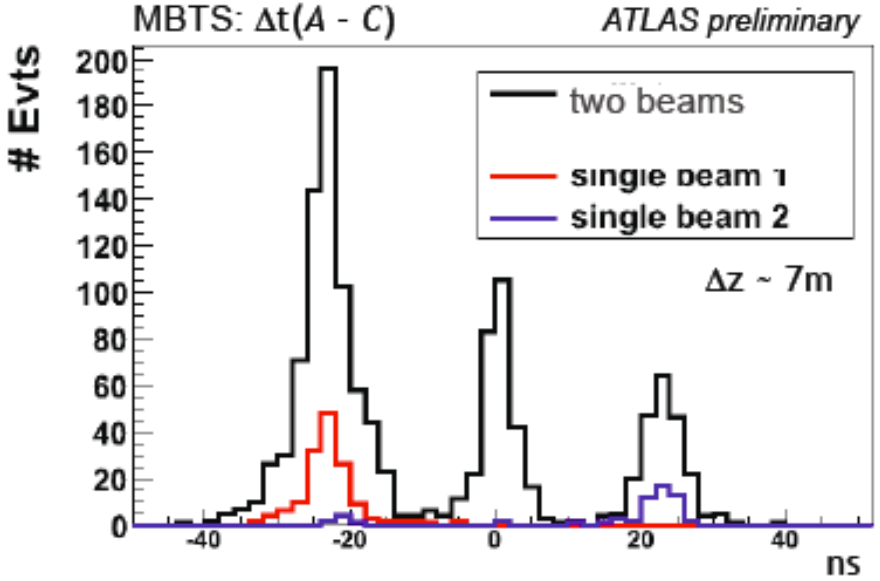
Run 140541, Event 171897

Candidate Collision Event

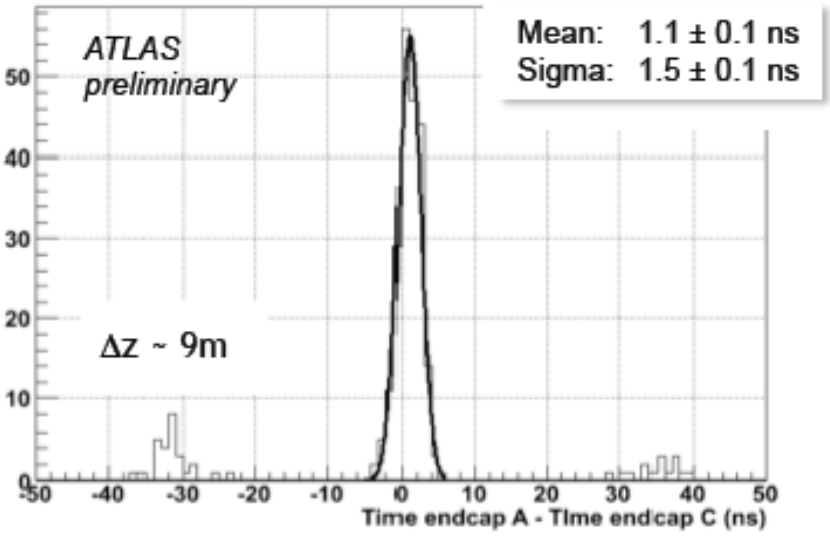
Two beams in the machine, how to detect a collision event?

- Trigger synchronized with beam pickup signals (suppresses cosmics)
- Separation of beam-related backgrounds and collisions via timing measurements on *A* and *C* sides of ATLAS (ToF)
  - Use minimum bias scintillators (MBTS) in forward regions (use also multiplicity)
  - Use precise Liquid-argon endcap calorimeter timing





LAr calorimeter:
Δt(*A* - *C*)

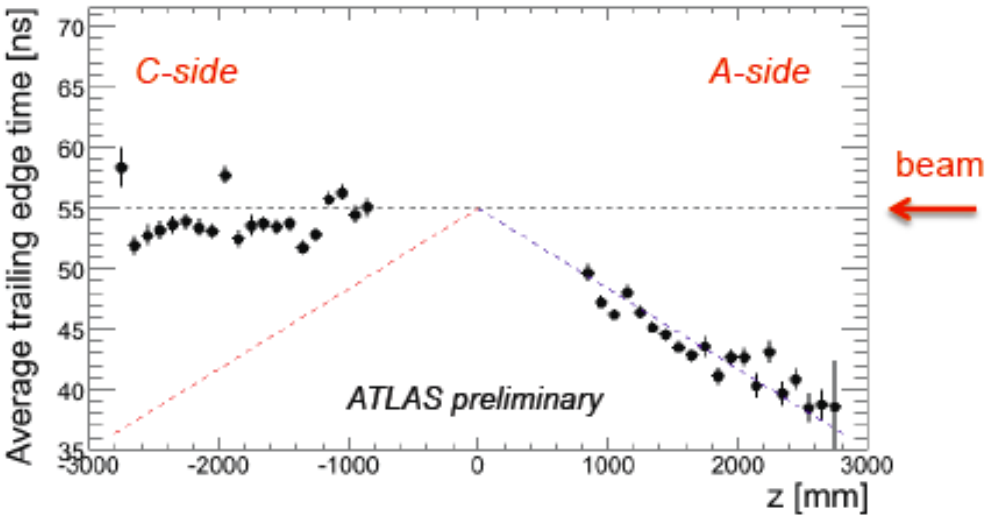


Two beams in the machine, how to detect a collision event?

- Can also use TRT timing

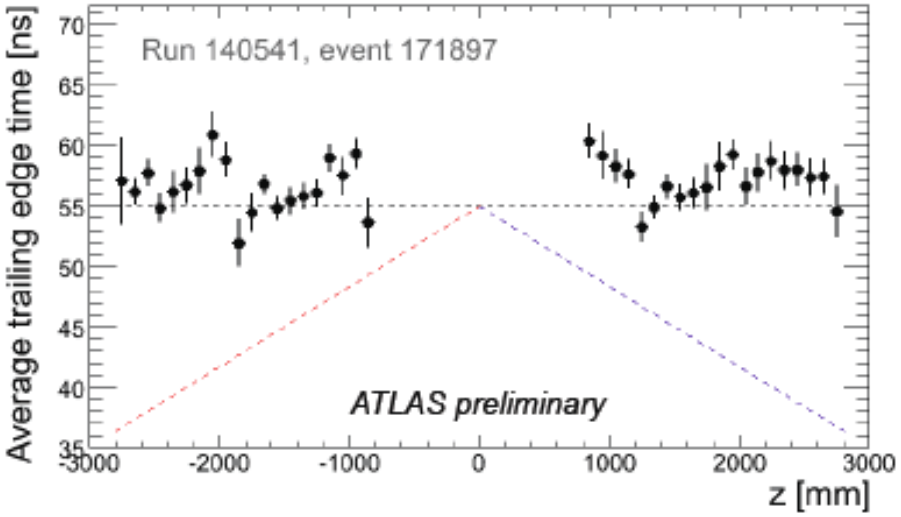
A beam-related background event coming from beam-1 (A-side)

→ timing is "wrong" for A-side

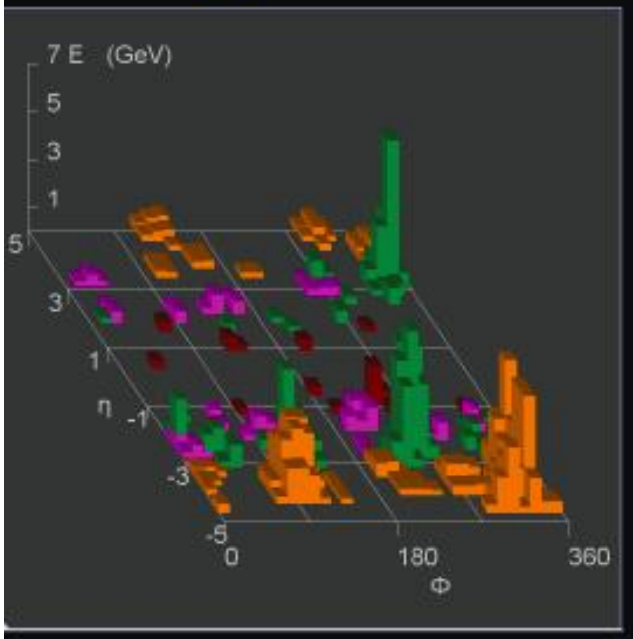


A collision event

→ timing is collision-like on both sides



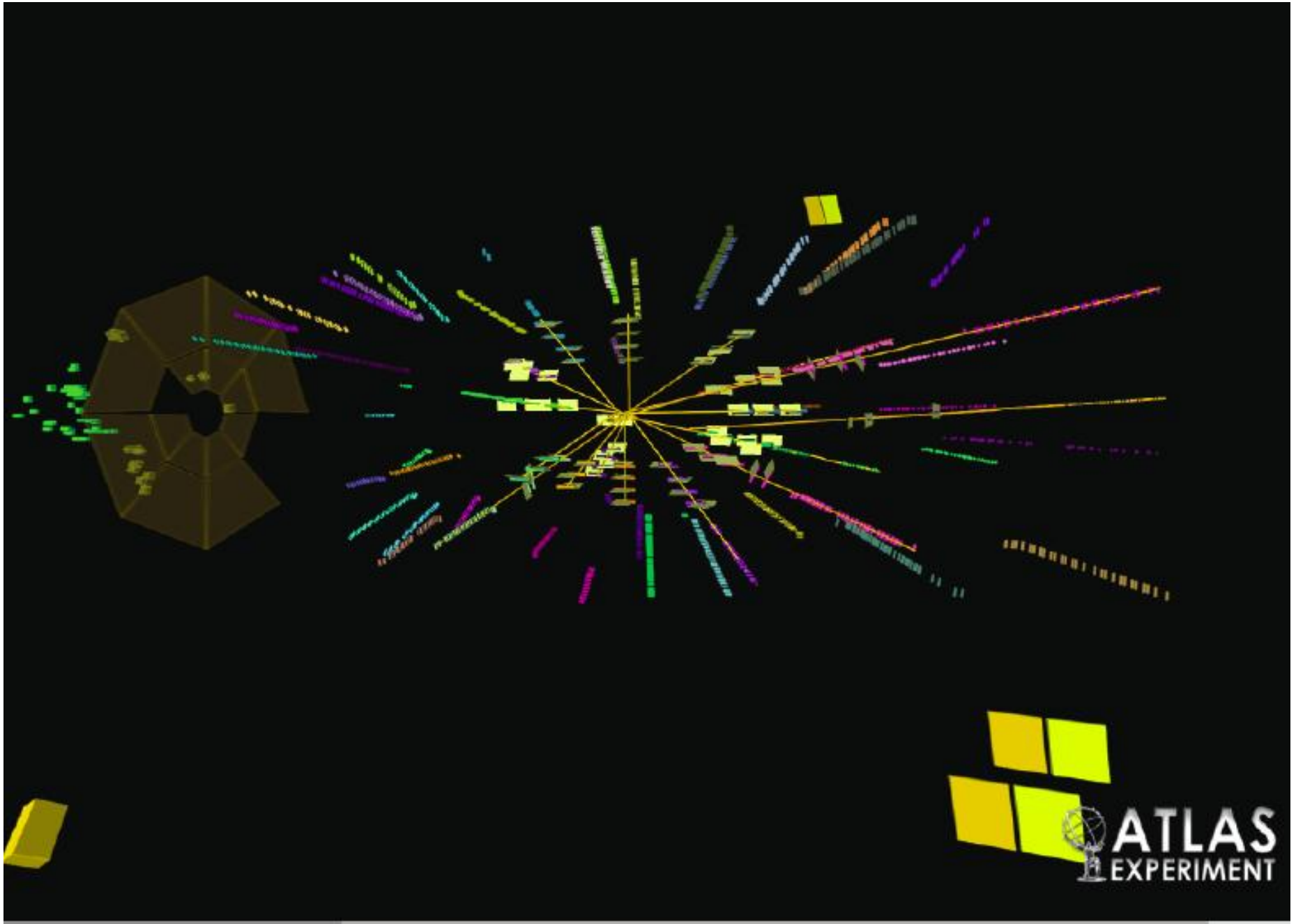
Candidate Collision Event



ATLAS EXPERIMENT

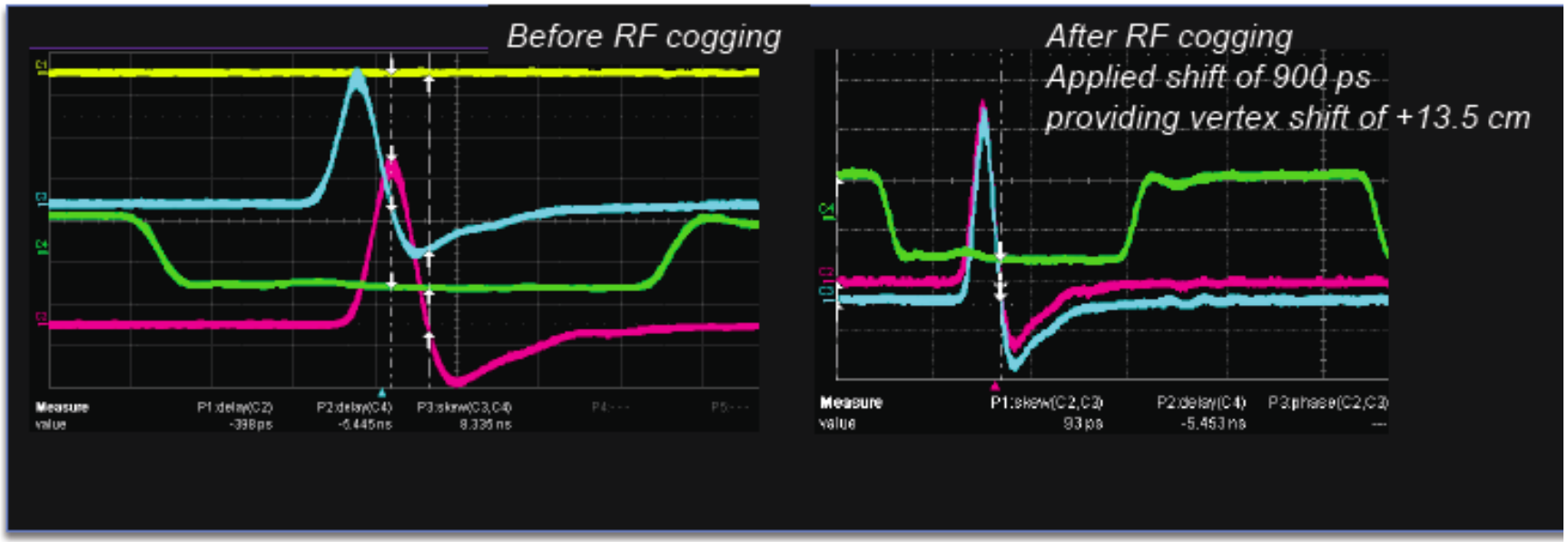
2009-11-23, 14:22 CET
Run 140541, Event 171897

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


ATLAS
EXPERIMENT

Can we prove that our background separation works?

- The ATLAS beam pickups showed a phase inconsistency of 900 ps causing the primary vertex to be shifted by −13.5 cm in *z*
- Based on this information, at around 14:50, the LHC operators performed an RF cogging to correct the *z* positioning of the beam spot at IP1

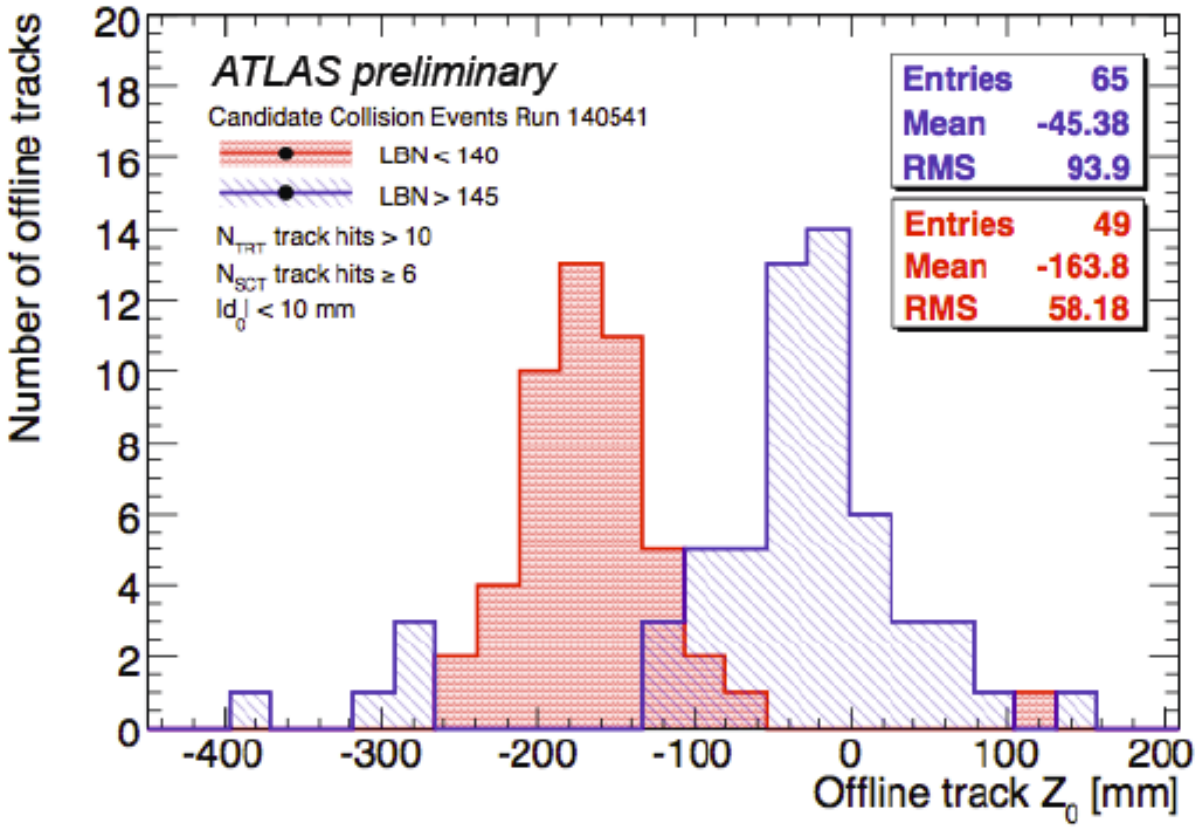


Beam pickup scope shots, beam 1 & 2

Bunches stable within 20 ps (RMS) !

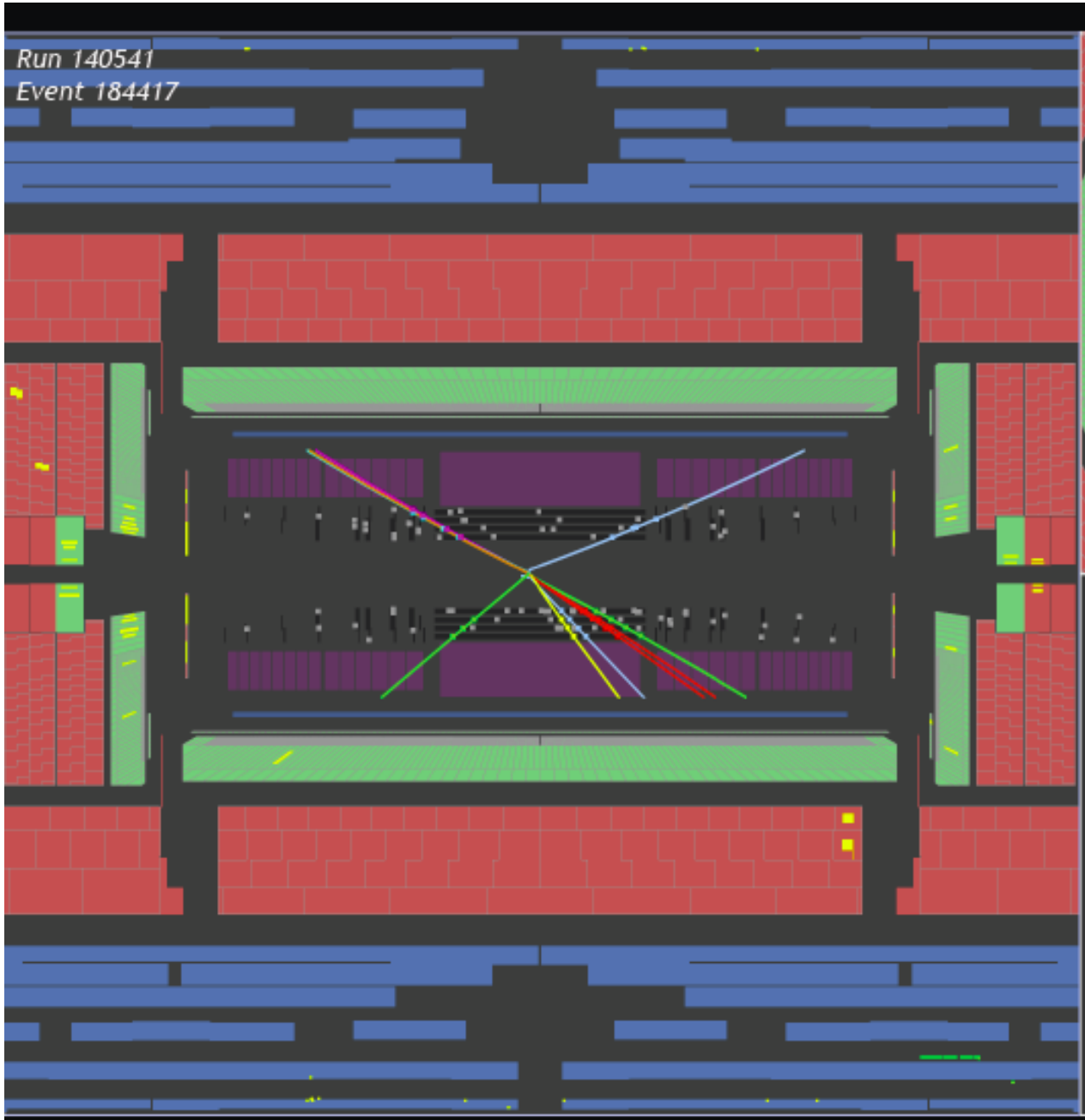
Can we prove that our background separation works?

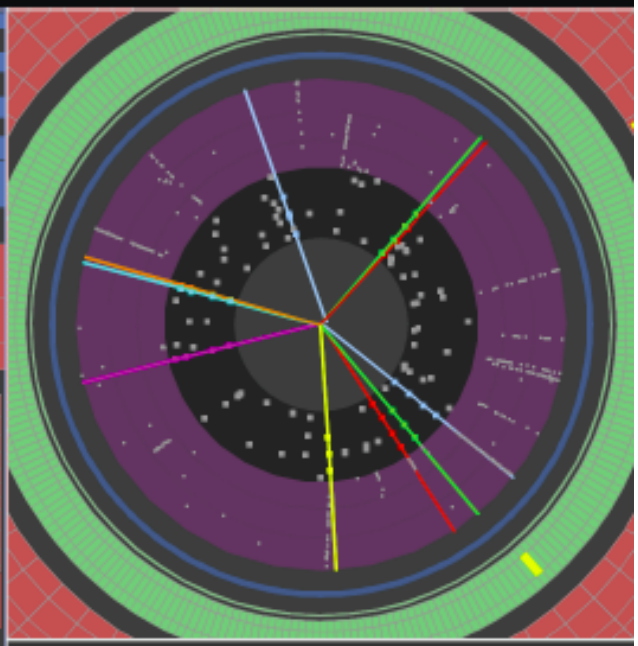
- ATLAS has taken data before and after the RF cogging
- Must observe shift in z_0 of tracks if indeed we select collision events!



Track z_0 distribution of collision candidate events taken **before** and **after** RF cogging

Observed shift: +12 cm

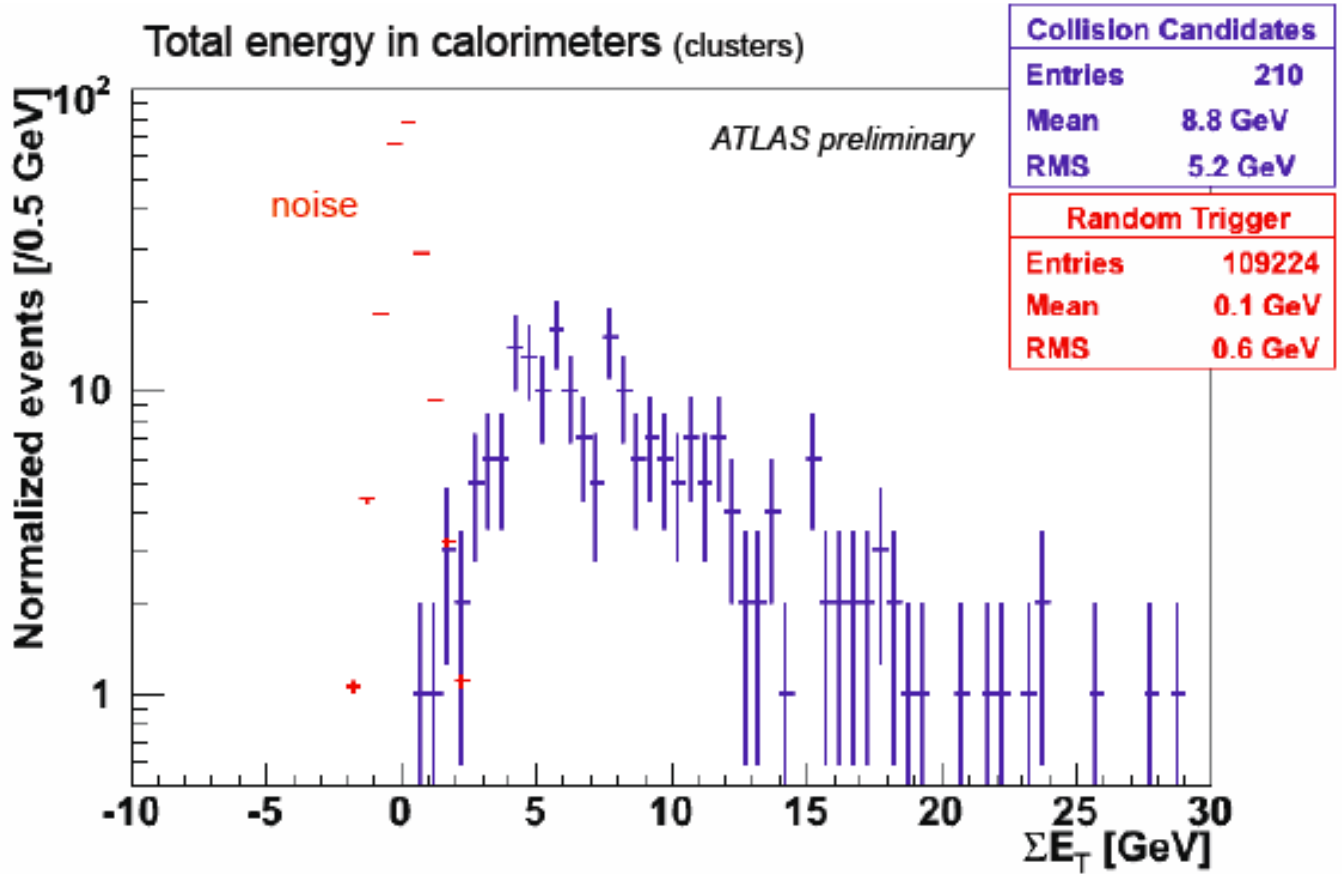




Looking at properties of collision events

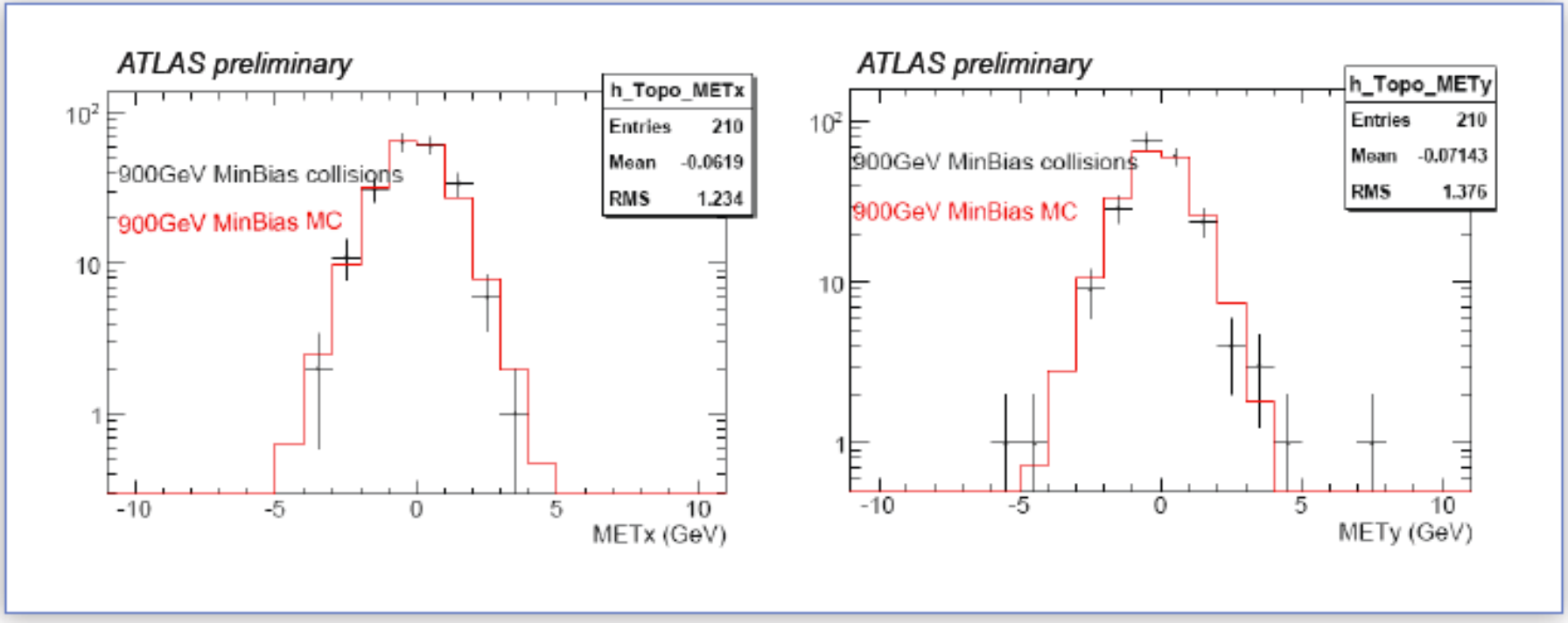
Properties of collision events

- Sum of calorimeter transverse energy compared to random events



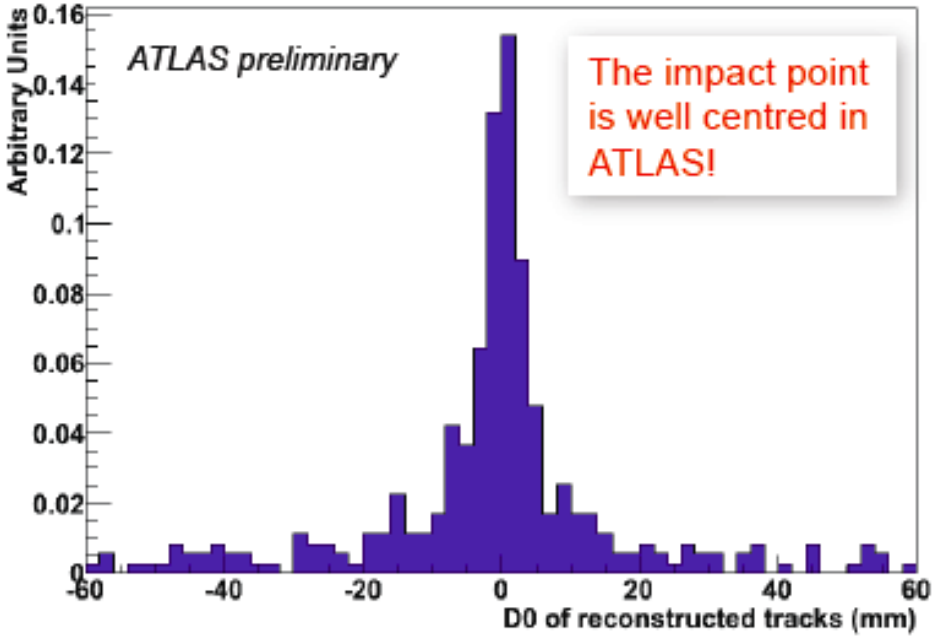
Properties of collision events

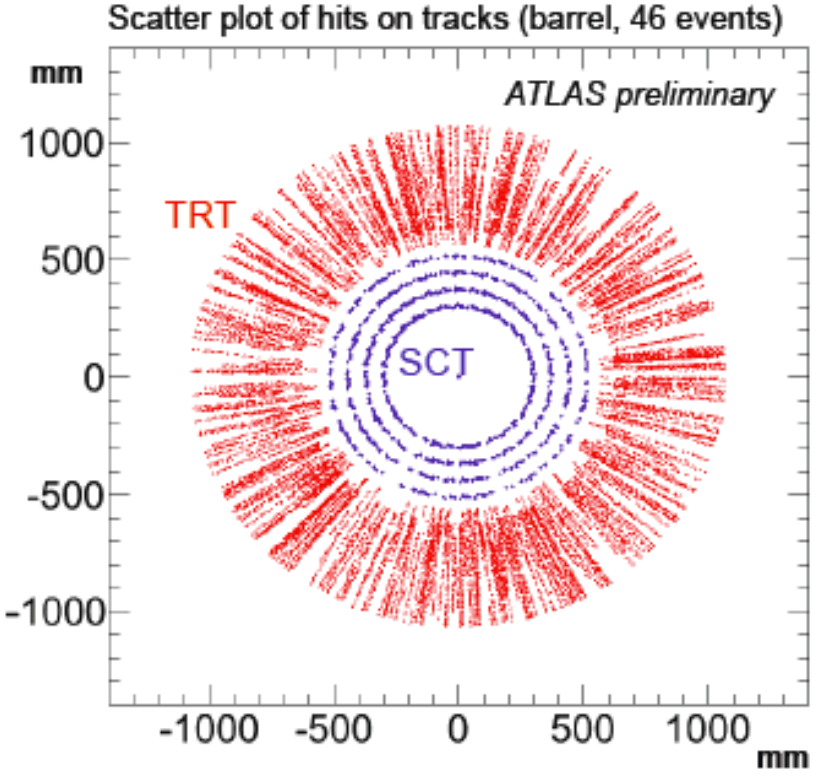
- Missing transverse energy components compared to 900 GeV minimum bias Monte Carlo (solenoid field ON)



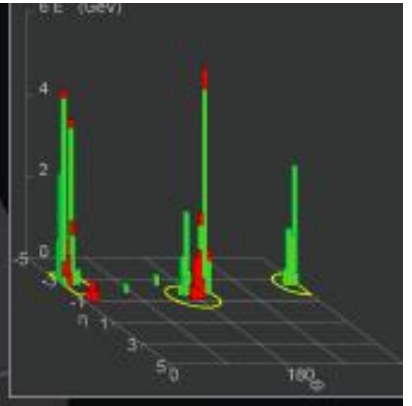
Tracking (challenging w/o Pixel, limited SCT and solenoid field off!)

- Without solenoid field no separation of tracks by momenta
- Fit impact parameter in a "silver-plated" sample with SCT >= 20 V and number of SCT hits >= 6 (46 events)





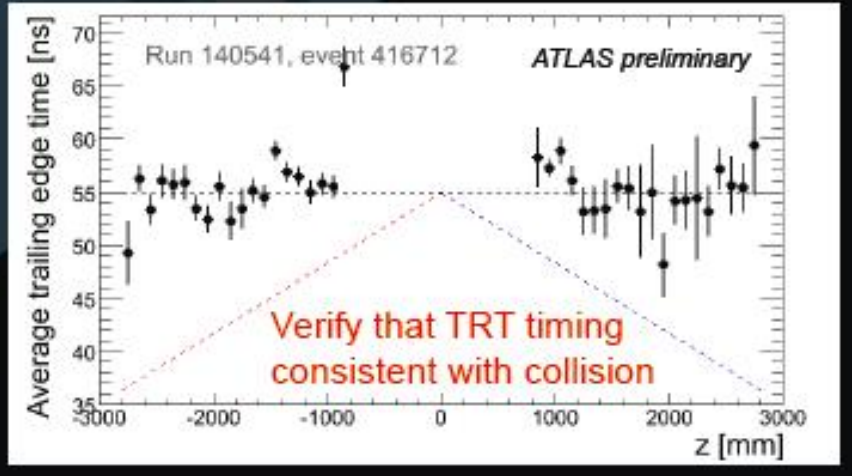
A di-jet candidate



Run 140541
Event 416712

Two jets back-to-back in ϕ, both with (uncalibrated) E_T ~ 10 GeV,
η of −1.3 and −2.5,
~ no missing E_T

Triggered by MBTS A/B in time, several hits
Also triggered by L1Calo EM3



How much luminosity did we collect? Naïve estimate

- With a tight calorimeter-based timing selection, cross-checked by the MBTS and TRT ToF measurements, we have identified 197 golden collision candidates from run 140541 of Nov 23
- We separate this sample into 2 parts (afternoon=A, evening=B) of different beam conditions
- From Monte Carlo (solenoid field on) we find that the selection efficiency, including trigger, for inelastic and diffractive minimum bias events is about 70%
- Using as total minimum bias cross section of 58 mb (40 mb inelastic, 12/6 mb SD/DD):

Sample	Number of events	DAQ duration	Average rate	Average inst. luminosity	Integrated luminosity
A	61	54 mins	0.03 Hz	0.5×10^{24} cm^{-2} s^{-1}	1.5 mb^{-1}
B	136	46 mins	0.07 Hz	1.2×10^{24} cm^{-2} s^{-1}	3.4 mb^{-1}

Cross checks:
- Assuming that ε=0% for SD and DD → increases luminosity by 10%
- change inelastic cross section to 34 mb → increases luminosity by 15%

Final words …

ATLAS welcomes the beams - experiment and collaboration are ready for physics!

What I did not mention: the data acquisition system, prompt reconstruction and the worldwide data distribution worked smoothly with collision and the huge beam splash events.

First collisions at 900 GeV have been recorded, and were a phase transition for ATLAS.

We are looking forward to lots more data, with the solenoid field on.

Again, thanks to the LHC team for a spectacular restart !

Plans till the end of 2009

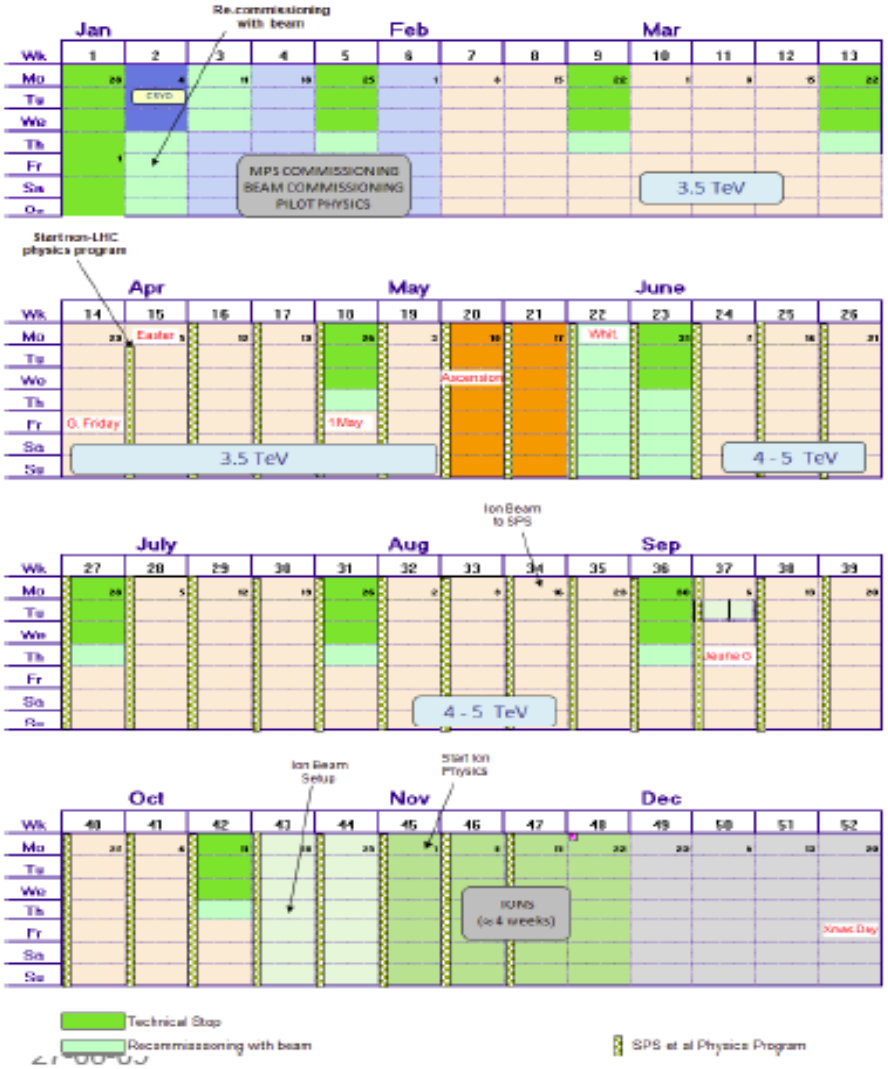
- This weekend, 5-7 December, collisions with 450GeV beams, expect to collect about 1mln of minimum bias events
- Decide on 7-th December on schedule for next week
  - Continue with 450 GeV beams for next few days
  - Ramp energy to 1.18 TeV /beam
  - Few shifts of collisions with 1.18 TeV beams
- LHC beam OFF on 17-th December

Physics at 900 GeV

	14 TeV	900 GeV
Total LHC inelastic (NSD) σ	70 mb	40 mb
Total LHC bb cross section	500 μb	25 μb
jet p_T>15GeV $\lvert\eta\rvert$<2.5		24 μb
Min bias $\rightarrow \mu 6(5)$ X $\lvert\eta_\mu\rvert$<2.5	10000 nb	1400 nb
b-jet p_T>15GeV $\lvert\eta\rvert$<2.5		370 nb
jet p_T>50 GeV $\lvert\eta\rvert$<2.5		45 nb
bb $\rightarrow \mu 6(5)$ X $\lvert\eta_\mu\rvert$<2.5	4000 nb	60 nb
bb $\rightarrow \mu 6(5)\ \mu 3$ X $\lvert\eta_\mu\rvert$<2.5	200 nb	2 nb
pp $\rightarrow \Upsilon$ ($\mu 6(5)$ $\mu 3$) $\lvert\eta_\mu\rvert$<2.5	9 nb	1.7 nb
pp $\rightarrow$ J/ψ ($\mu 6(5)\ \mu 3$) X $\lvert\eta_\mu\rvert$<2.5	28 nb	1 nb
b-jet p_T>50 GeV $\lvert\eta\rvert$<2.5		0.63 nb
bb $\rightarrow$ J/ψ ($\mu 6(5)\ \mu 3$) X $\lvert\eta_\mu\rvert$<2.5	7 nb	0.1 nb

Assuming ~ 1 nb^{-1} @ 900 GeV (3 days at 10^{28} with 30% efficiency):
→collect ~20k jets, ~100 b-jets, few tens of muons, very few electrons

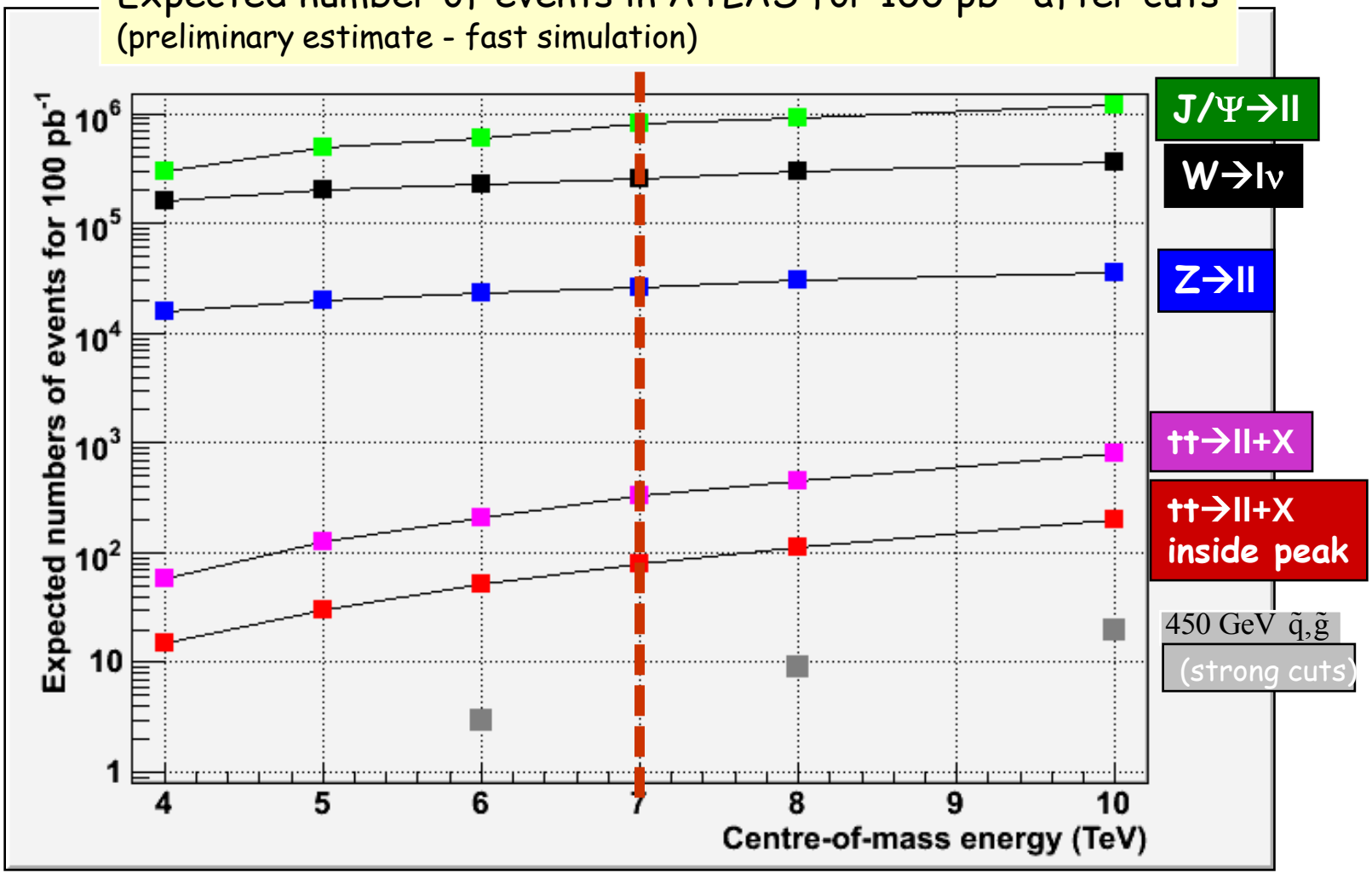
LHC 2010 – very draft



- **2009**:
  - 1 month commissioning
- **2010**:
  - 1 month pilot & commissioning
  - 3 month 3.5 TeV
  - 1 month step-up
  - 5 month 4 - 5 TeV
  - 1 month ions

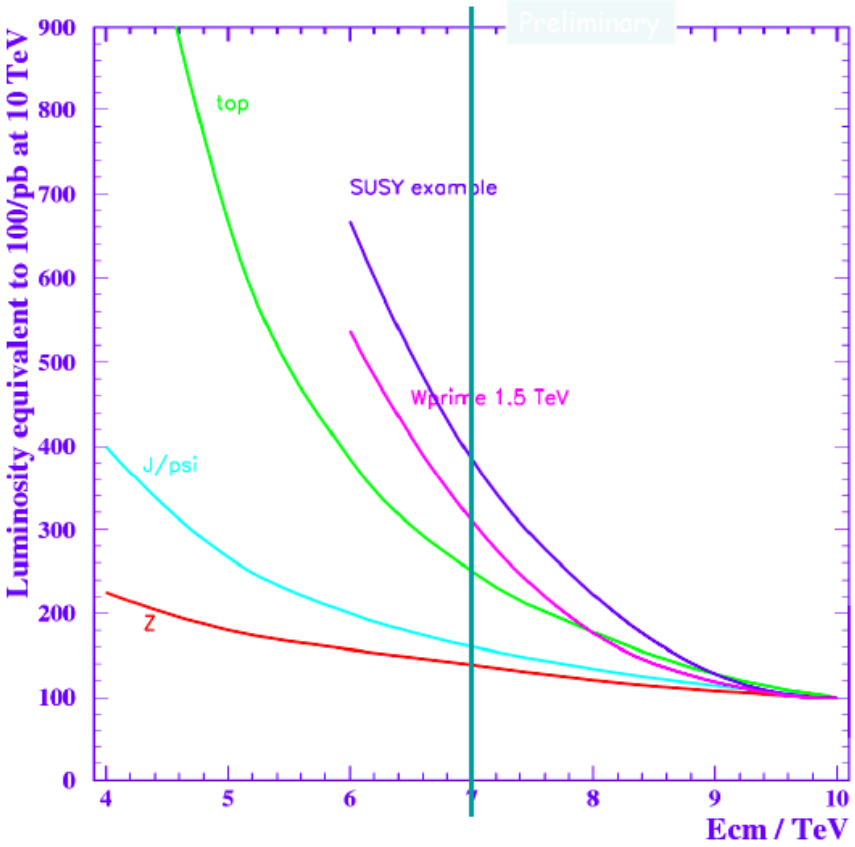
S.Myers
LHCC September 2009

Expected number of events in ATLAS for 100 pb^{-1} after cuts
(preliminary estimate - fast simulation)



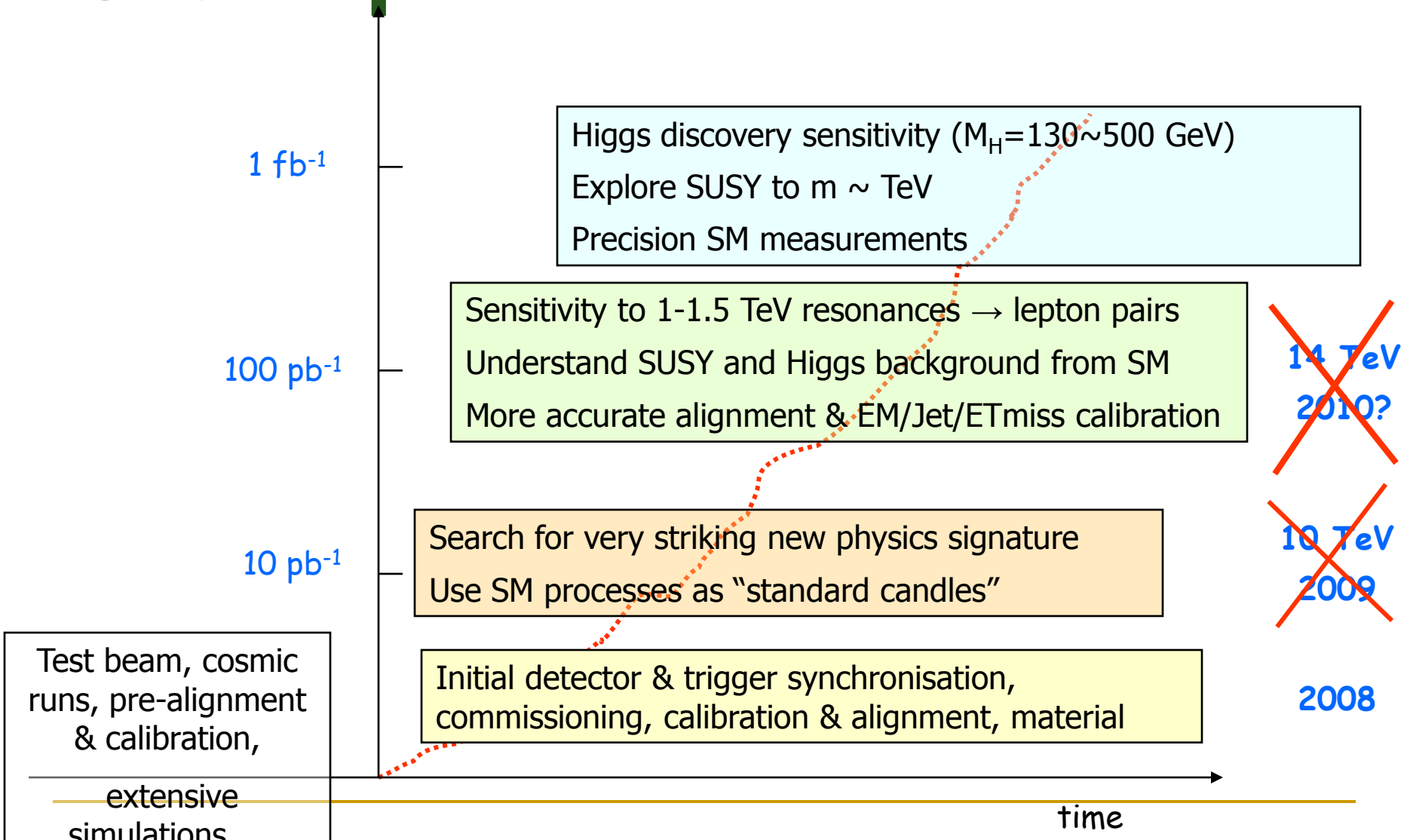
At sqrt(s) = 7 TeV and 200-300 pb^{-1}: LHC has discovery potential beyond Tevatron reach for some scenarios
(~ 1 TeV Z', ~450 GeV SUSY, …)

Physics with reduced centre-of-mass energy



Collisions: a physics Roadmap

Situation as of December 2009



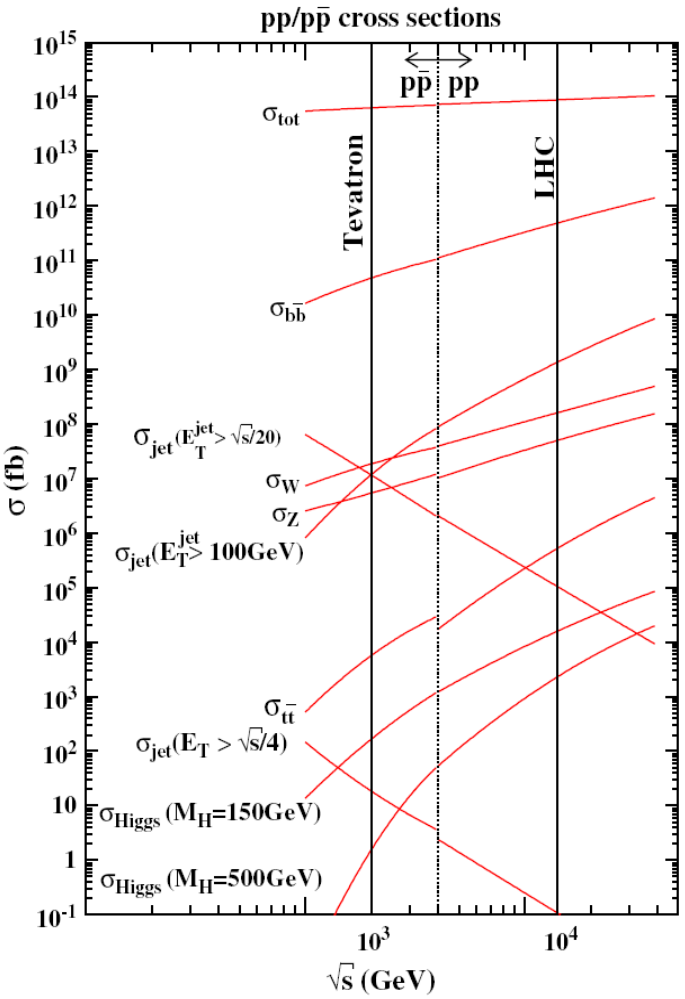
… and a final toast !

SPARES

The first 10 pb^{-1}

1 pb^{-1} is ~3 days of data at 10^{31} cm^{-2}s^{-1}, with 30% efficiency

Process	Events (10 pb^{-1})
minimum bias	~ ∞
W→eν	10^5
Z→ee	10^4
tt	10^3
Higgs (130 GeV)	10
Gluinos (1 TeV)	1



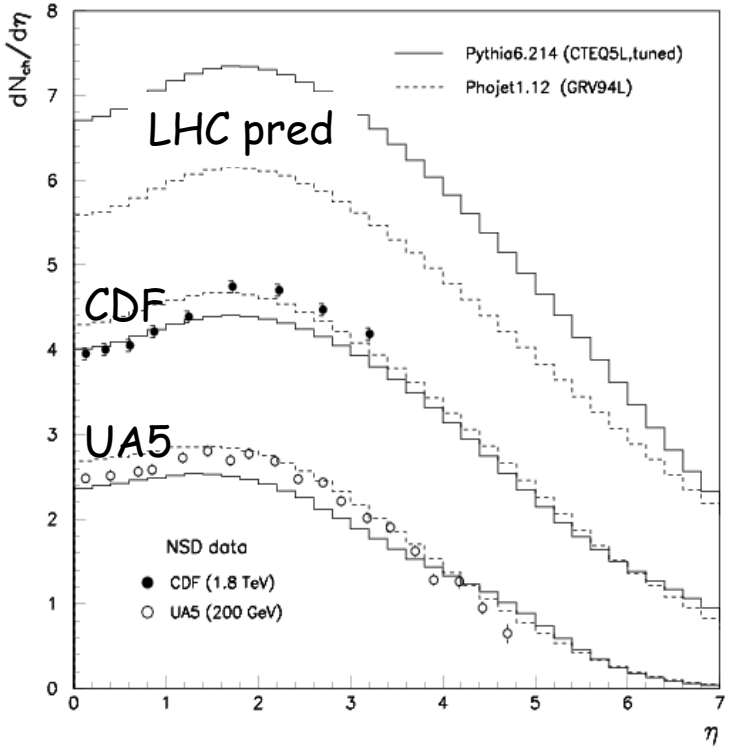
Focus:

1. Establish SM signals
2. Use them for detector calibration („tag and probe")
3. Tune MC
4. Perform basic cross section measurements

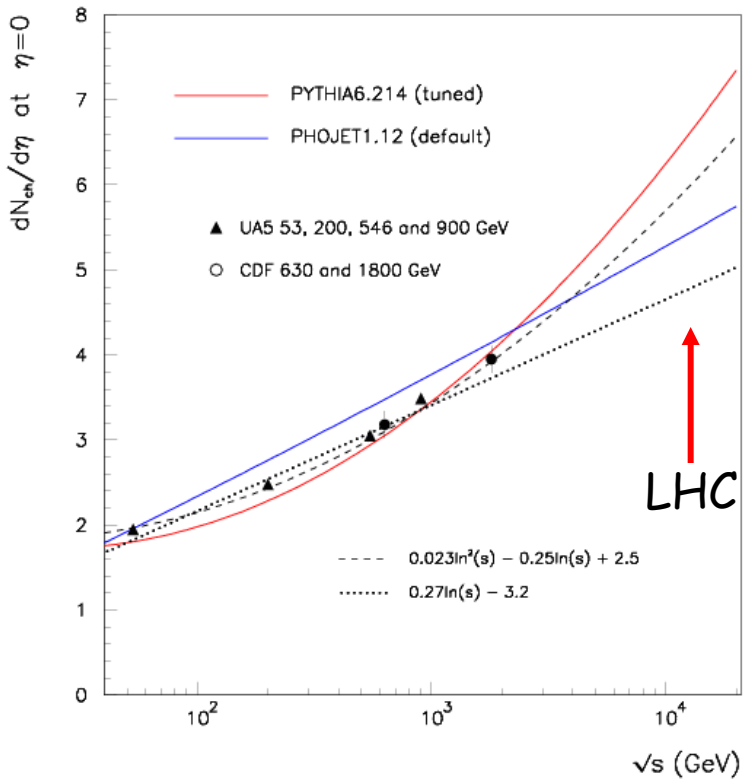
Examples →

Minimum bias

Charged particle density



Charged particle density at $\eta = 0$

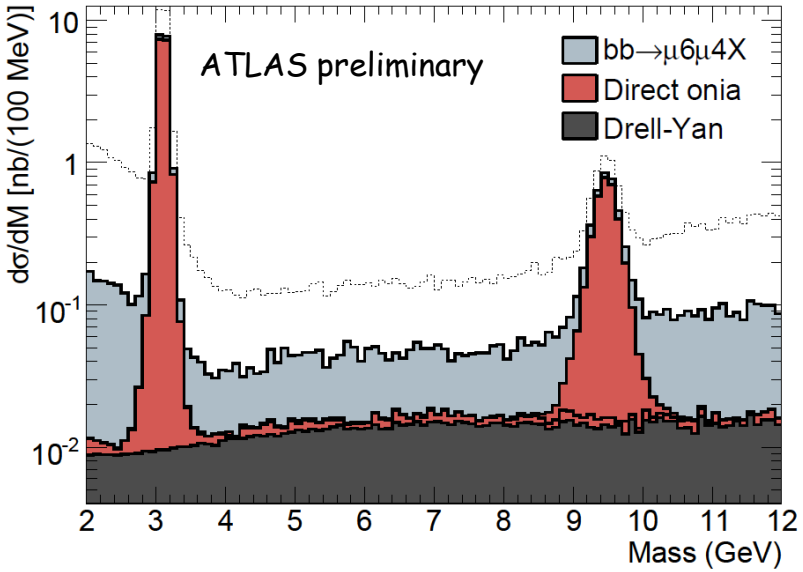


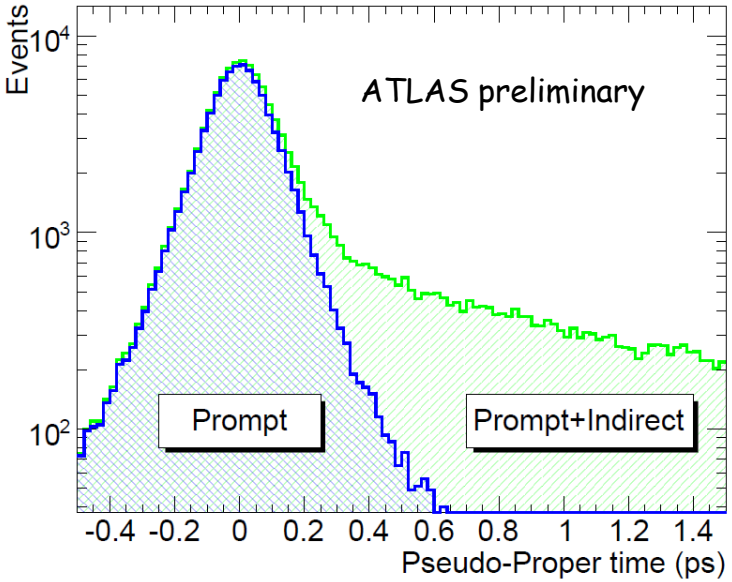
Energy dependence of dN/dη ?
Vital for tuning Underlying Event model
Important for all analyses
Only requires a few thousand events.

- PYTHIA models favour $\ln^2(s)$;
- PHOJET suggests a $\ln(s)$ dependence.

J/Ψ

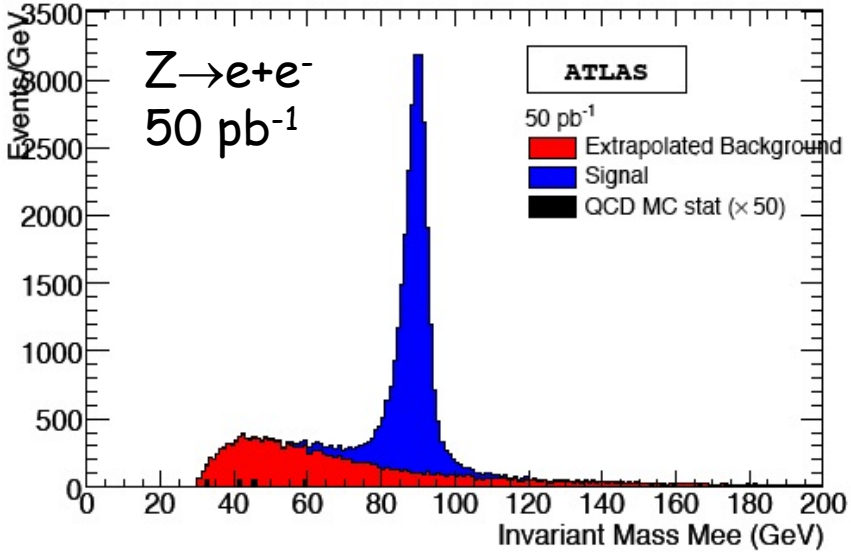
High cross-section
Very useful for tracking / muon tuning and data quality
O(10k) J/Ψ → μμ per pb^{-1}
Measurements also feasible with very little data...

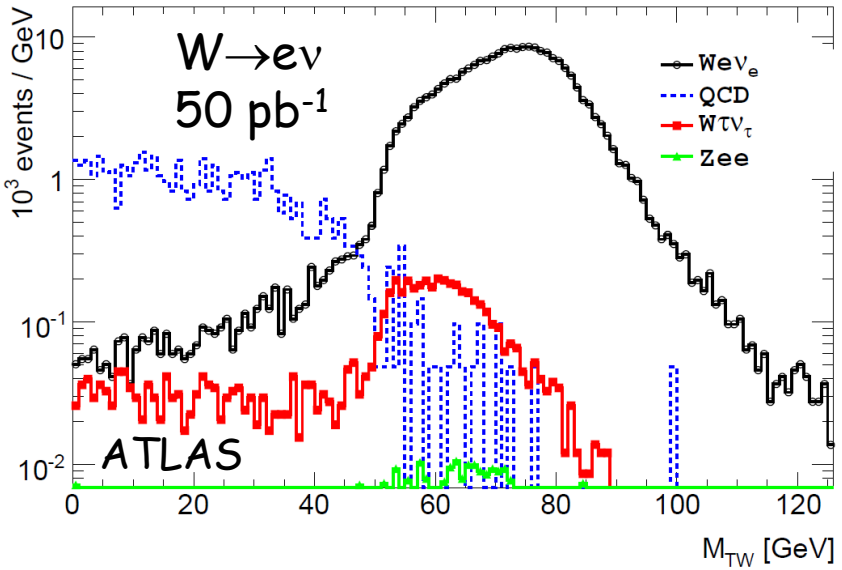




With 1 pb^{-1} could already measure
R = σ(bb->J/Ψ)/σ(pp->J/Ψ)
with <5% statistical precision
provided: muon trigger working;
tracking understood well enough

W/Z in leptonic modes





25 k $Z \rightarrow ee$ for 50 pb^{-1}

clean signatures, high statistics

Quickly dominated by systematics

Initial precision of W/Z cross sections 4-5%

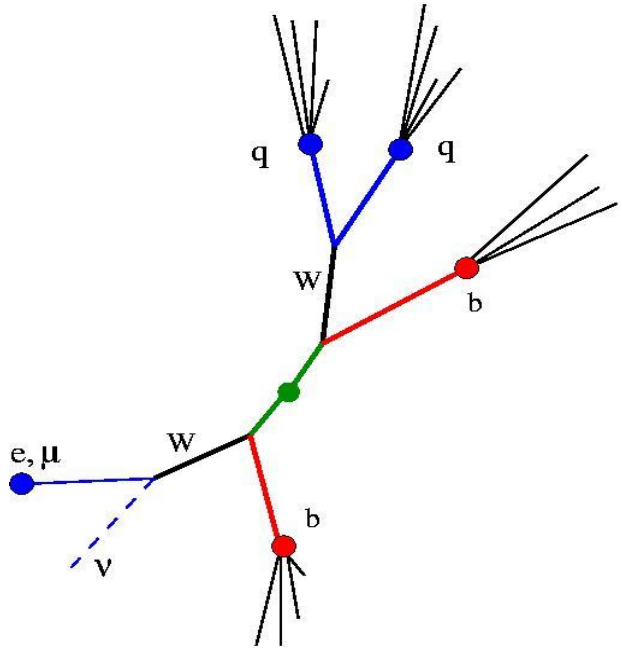
$\sigma(W \rightarrow l\nu)$ ~20nb, $\sigma(Z \rightarrow ll)$ ~2nb

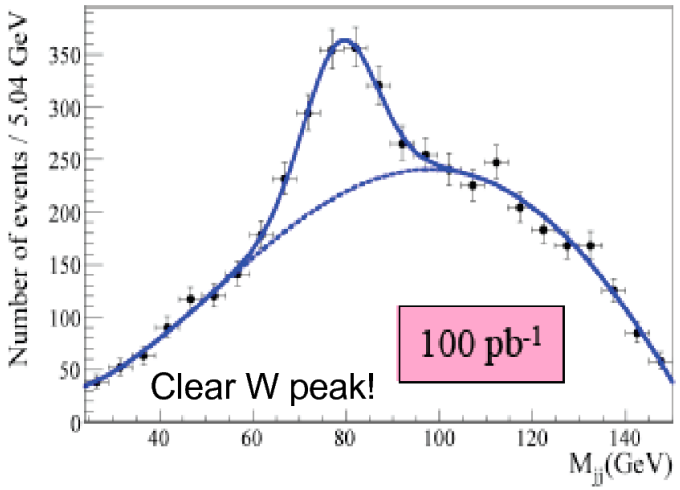
Differential NNLO calculations, <2% theoretical error on acceptance

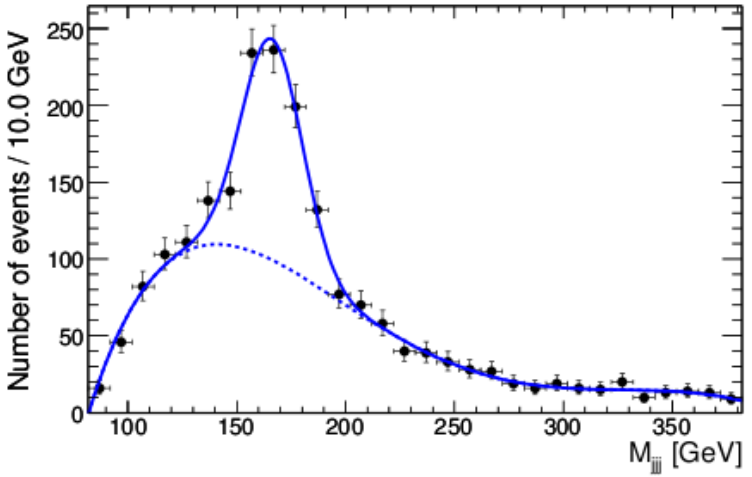
Top

Top (tt) NLO cross-section
at 14 TeV ~ 830 pb (Tevatron ~ 7 pb)
Invaluable channel for data-driven calibration

- can select without b-tags
- commission b tagging
- general performance
- calibrate the light jet energy scale with W→jj

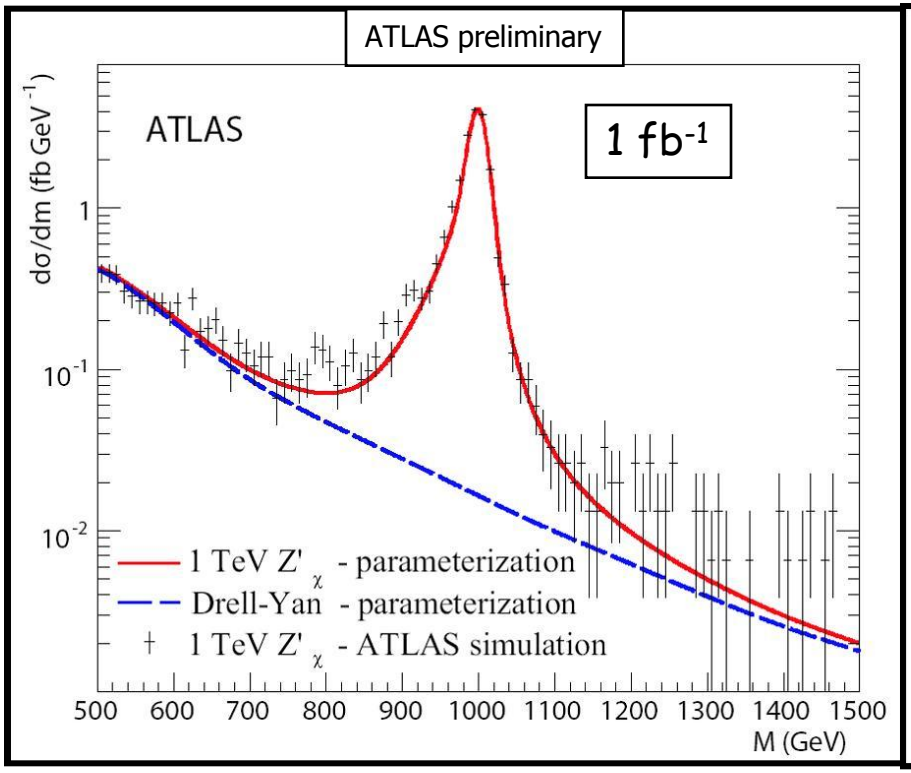


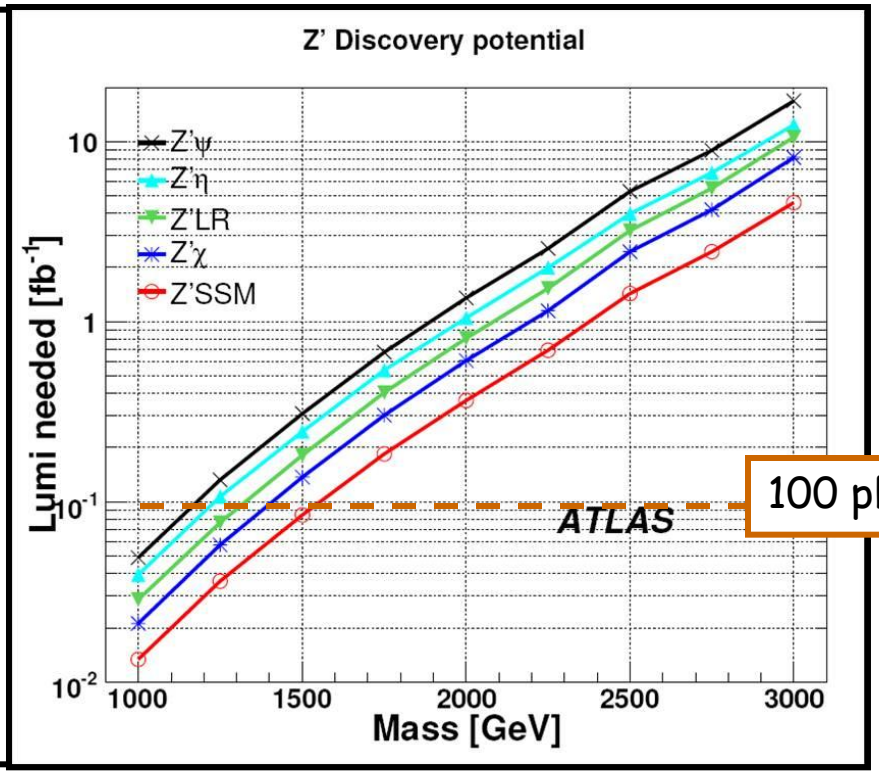




Early discovery: a narrow resonance decaying into e^+e^-?

Various models predict heavy resonances decaying to leptons





- signal is (narrow) mass peak on top of small Drell-Yan background
- with 100 pb^{-1} large enough signal for discovery up to m ~ 1.5 TeV
  $\sigma(10\ \text{TeV}) \sim \frac{1}{2}\ \sigma(14\ \text{TeV})$
- ultimate calorimeter performance not needed