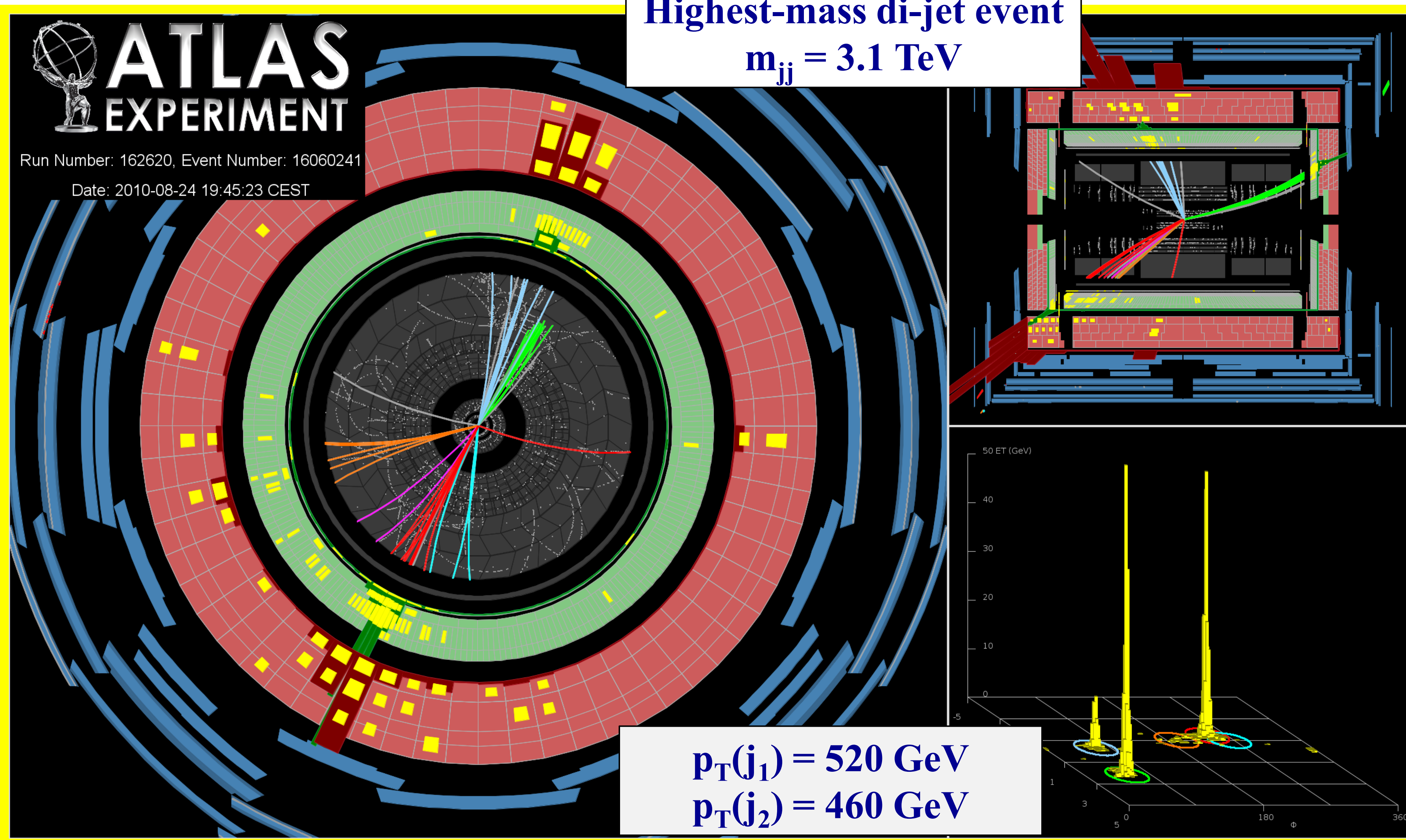
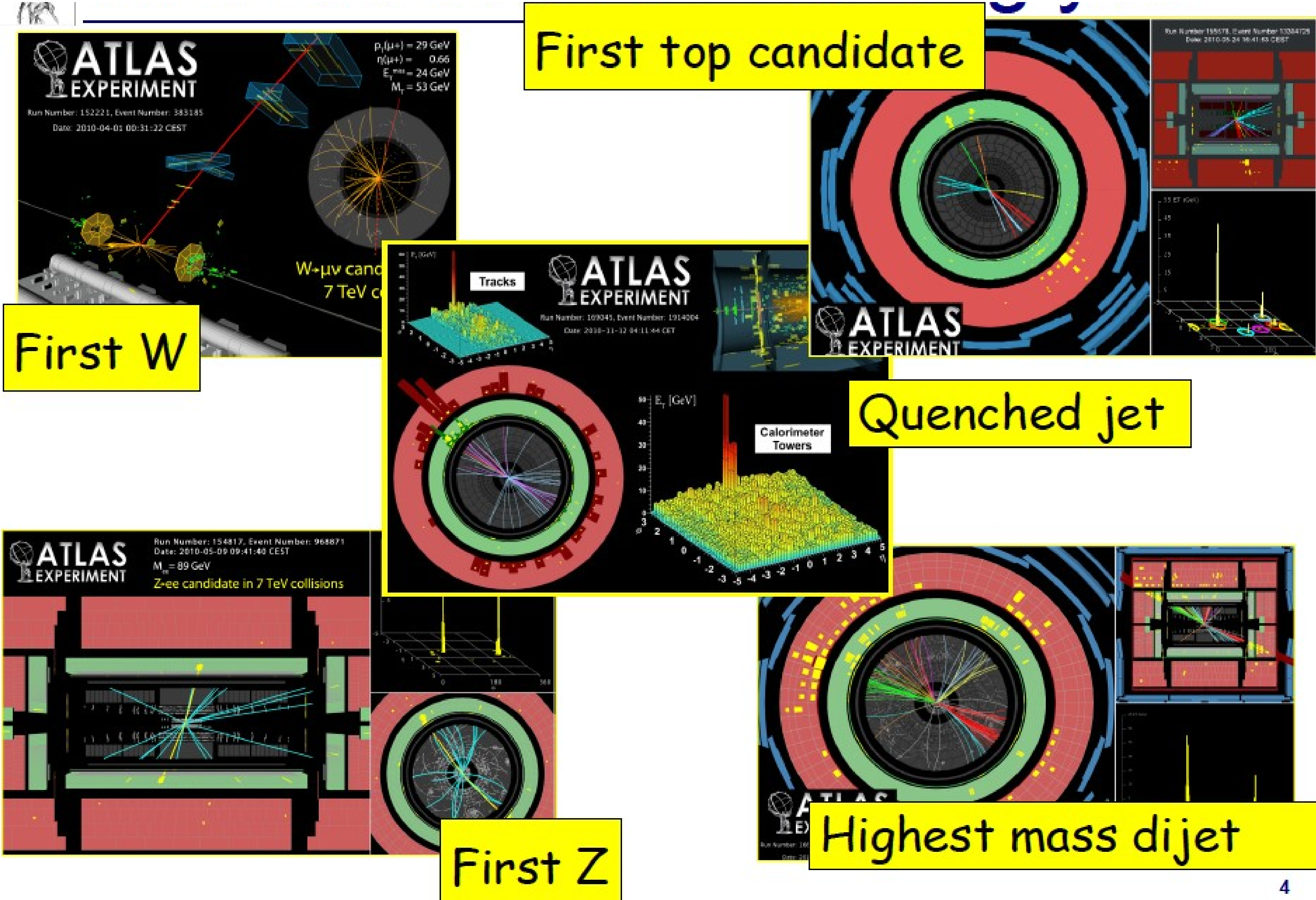
ATLAS: highlights from 2010 LHC run



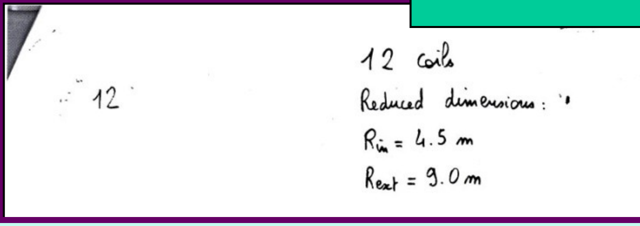
Highest-mass di-jet event
m_{jj} = 3.1 TeV

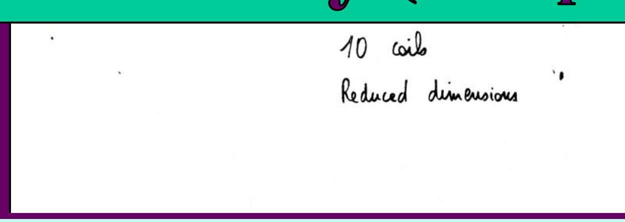
$p_T(j_1)$ = 520 GeV
$p_T(j_2)$ = 460 GeV

From 1984 to now: 2010 has been an exciting year!



ATLAS history (a snapshot)





- 1984: LHC is born as a concept
- 1987-88: first LHC detector ideas (very shy!)
- 1989: detector R&D starts
- 1992, 1994: Letter of Intent, Technical Proposal
- 1996: ATLAS approved by CERN DG and Research Board
- 1997: construction starts
- 2003: installation in the underground cavern
- 2008: installation completed; cos ... ector
- November 2009: first ... d

And ...

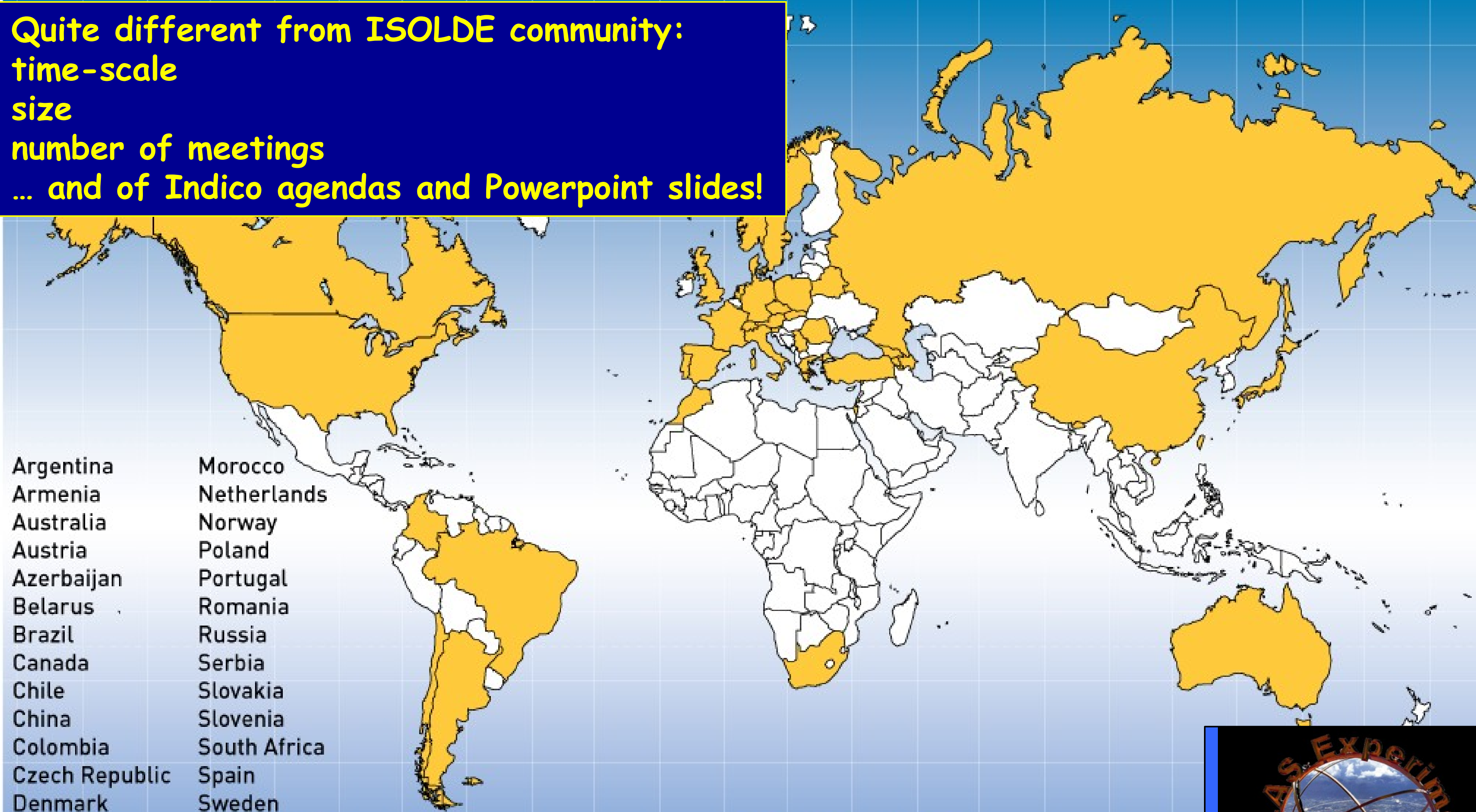
15 ye... ctivities, 20 years of simulations of detector perfor... nd physics potential, 8 years of world-wide computing data challenges,

17 Technical Design Reports , education and outreach ...

20 years of technological, human and financial efforts of a world-wide scientific community

~ 3000 scientists from 174 Institutions from 38 Countries

Quite different from ISOLDE community:
time-scale
size
number of meetings
… and of Indico agendas and Powerpoint slides!

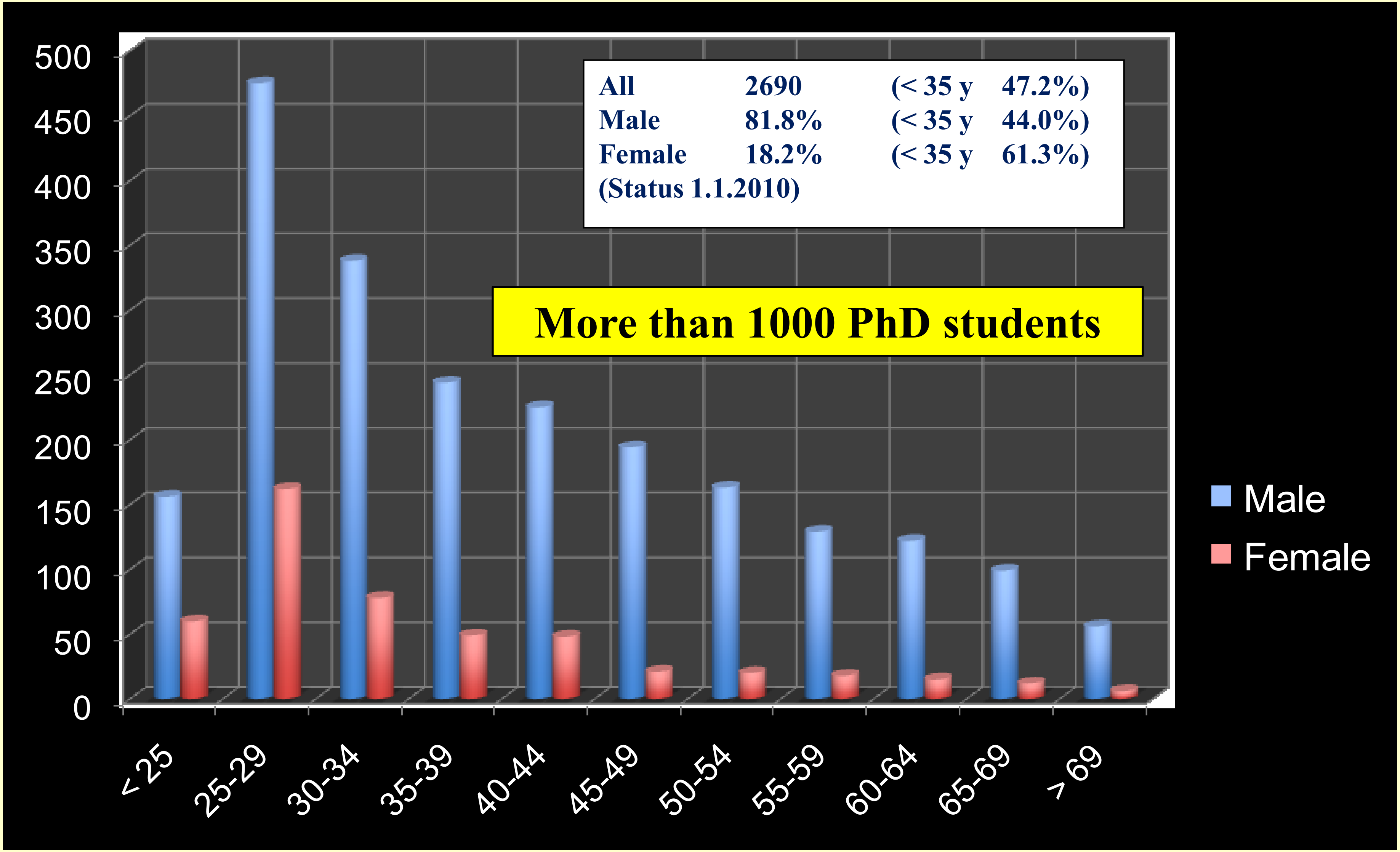


Argentina	Morocco
Armenia	Netherlands
Australia	Norway
Austria	Poland
Azerbaijan	Portugal
Belarus	Romania
Brazil	Russia
Canada	Serbia
Chile	Slovakia
China	Slovenia
Colombia	South Africa
Czech Republic	Spain
Denmark	Sweden
France	Switzerland
Georgia	Taiwan
Germany	Turkey
Greece	UK
Israel	USA
Italy	CERN
Japan	JINR

ATLAS Collaboration

ATLAS Experiment

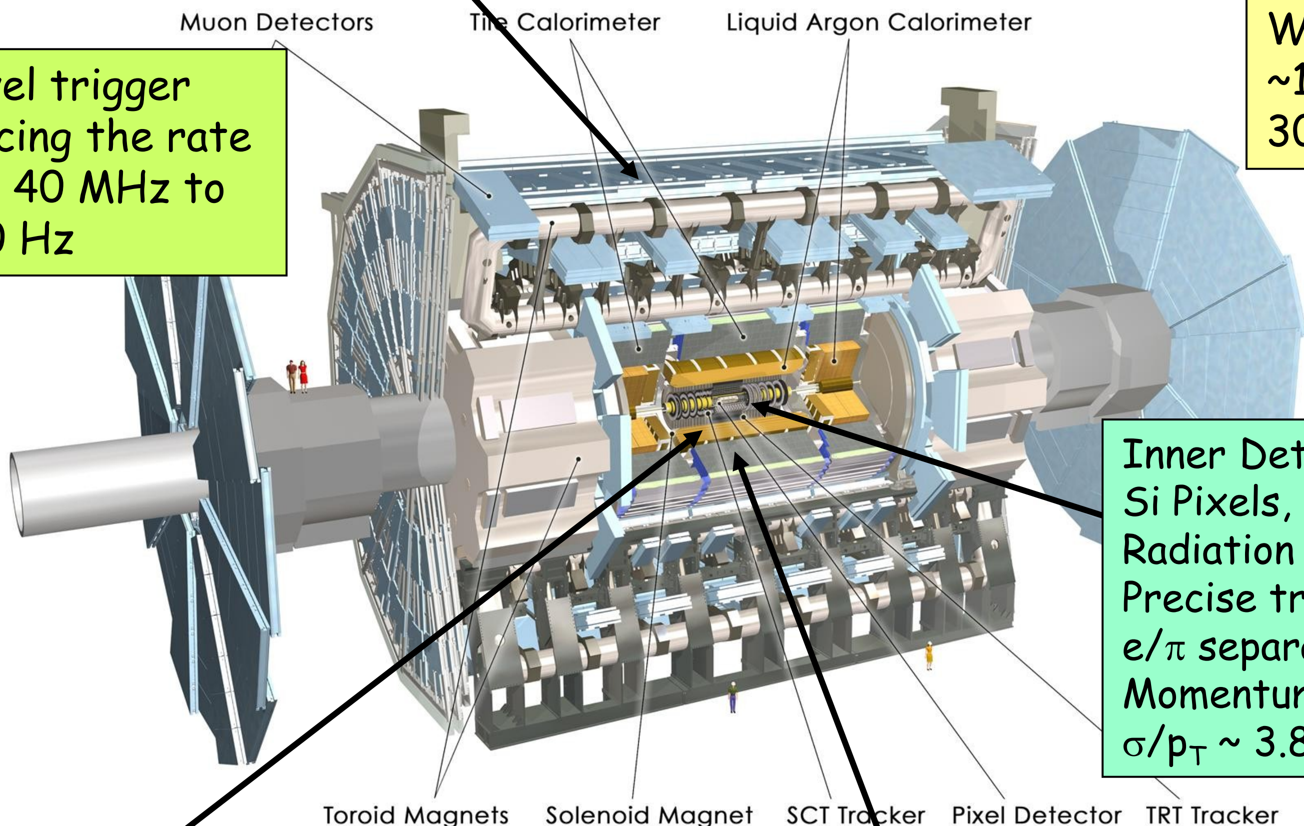
Age distribution of the ATLAS population



Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to E_μ ~ 1 TeV

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

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



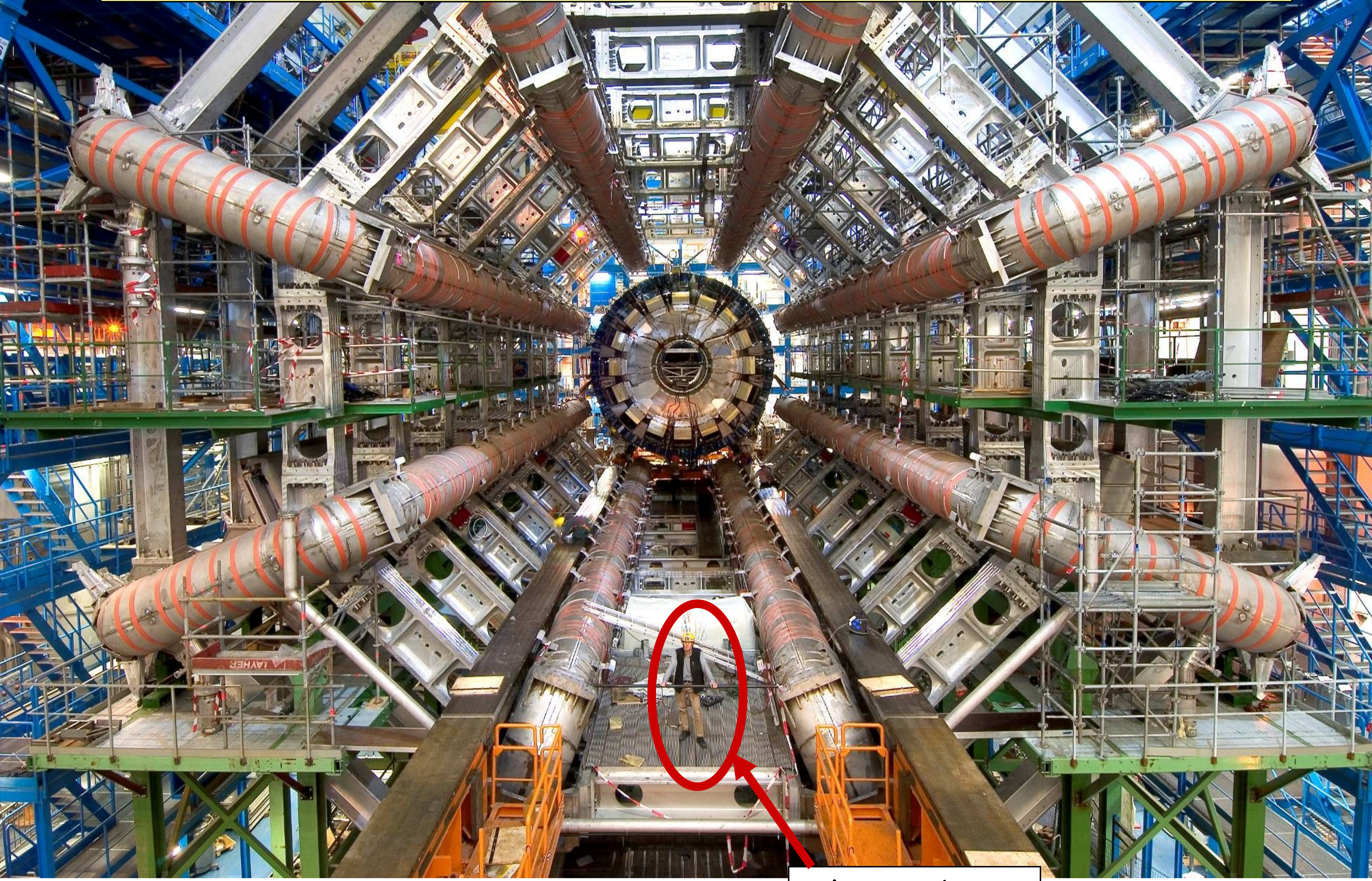
Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing,
e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T(\mathrm{GeV}) \oplus 0.015$

EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

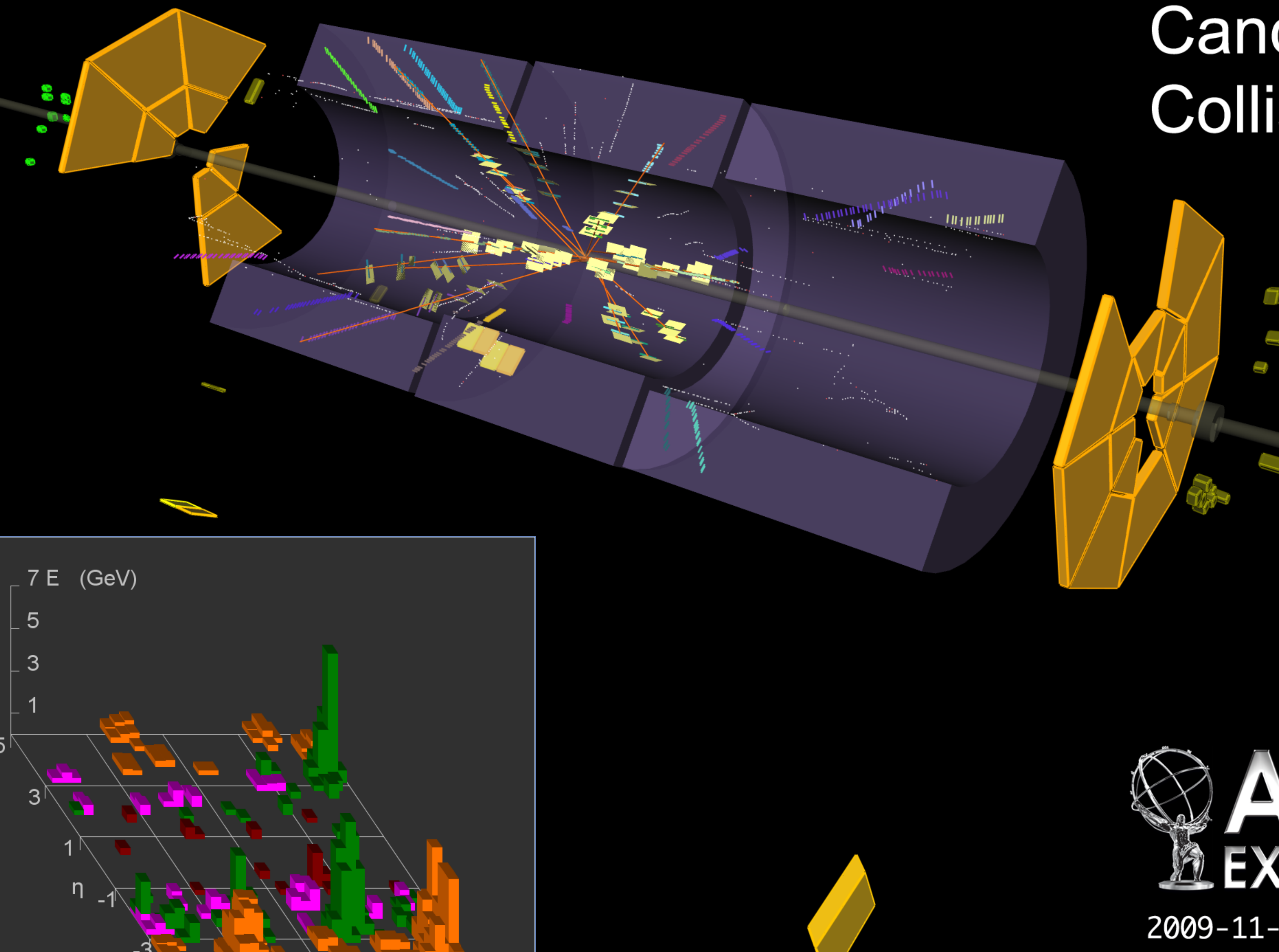
HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

ATLAS cavern (-100 m) in June 2003

October 2005: Barrel toroid magnet system in place



June 2008: installation completed → closure of the LHC beam pipe inside the ATLAS cavern



Candidate Collision Event

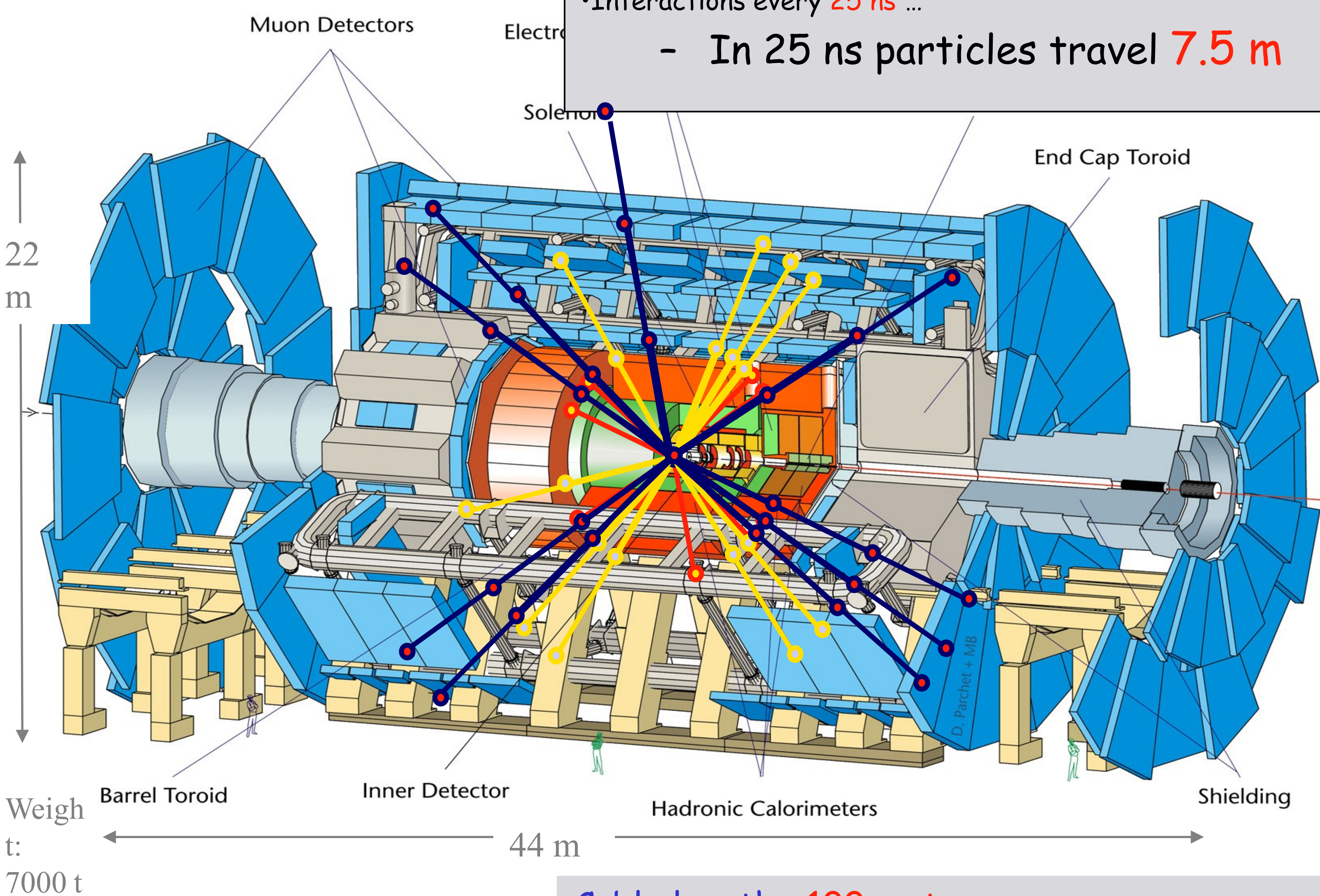
ATLAS EXPERIMENT

2009-11-23, 14:22 CET

Physics at the LHC: the environment

Time-of-flight

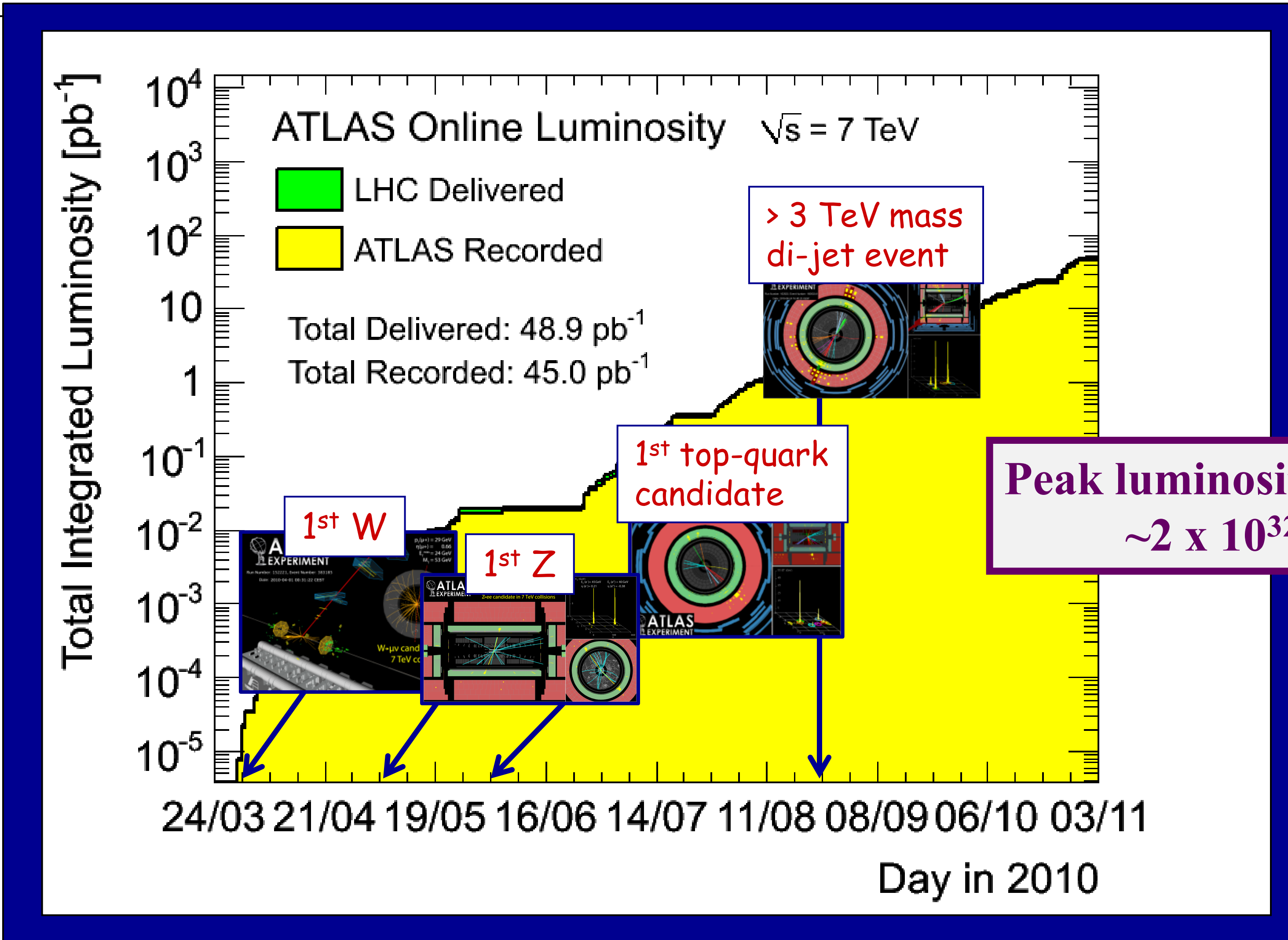
- Interactions every 25 ns …
  - In 25 ns particles travel 7.5 m



Cable length ~100 meters …

- In 25 ns signals travel 5 m

Integrated luminosity vs time
(from first √s =7 TeV collisions on 30 March until end of the pp run)



Peak luminosity in ATLAS: ~2 x 10^{32} cm^{-2} s^{-1}

Total recorded luminosity : 45 pb^{-1}

Data-taking efficiency (recorded/delivered luminosity): ~ 92 %

Detector operation: live channels and data quality

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.4%
SCT Silicon Strips	6.3 M	99.2%
TRT Transition Radiation Tracker	350 k	98.0%
LAr EM Calorimeter	170 k	98.5%
Tile calorimeter	9800	97.3%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	98.6%

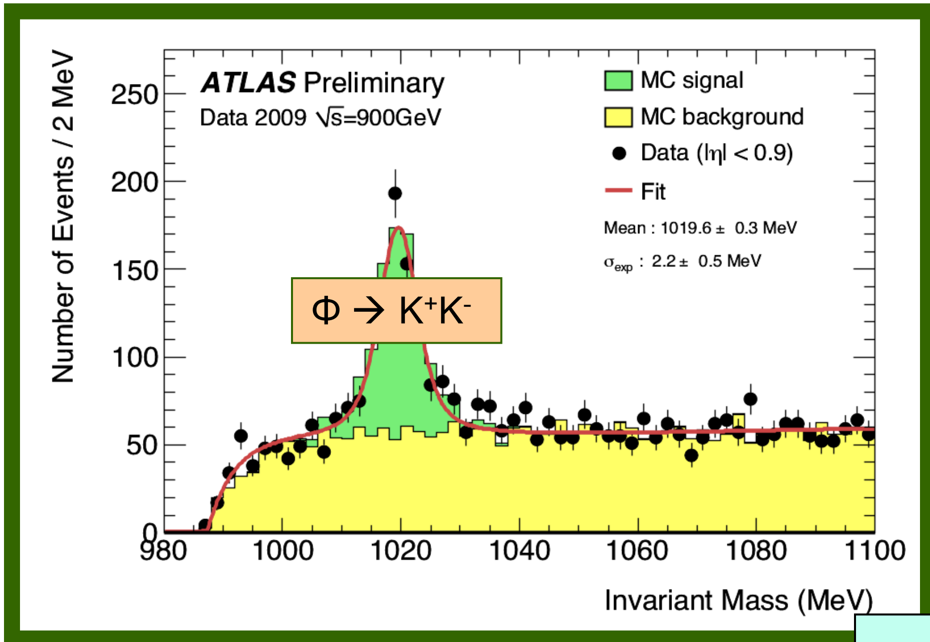
Total fraction of good quality data (green "traffic light")

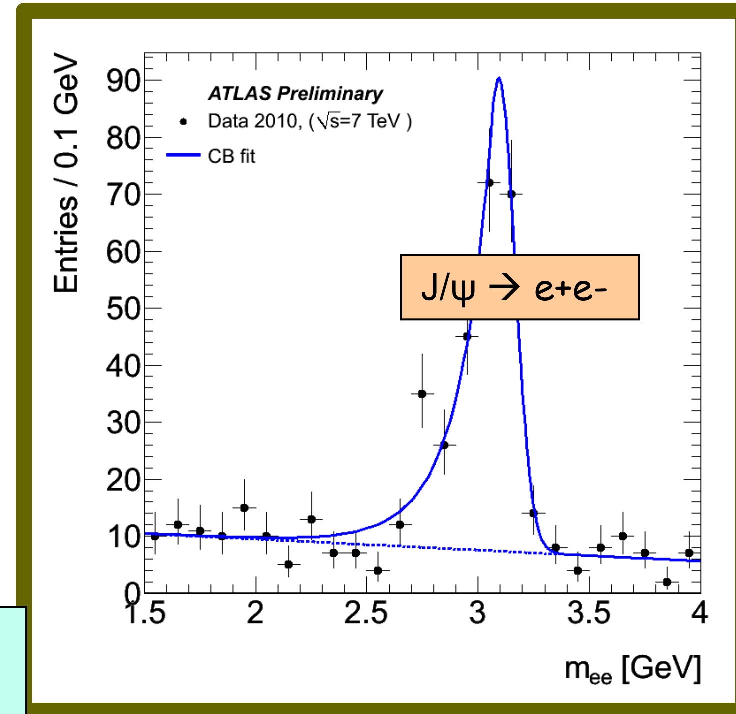
Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	TGC	CSC
99.9	99.1	100	93.6	98.7	99.0	99.7	100	99.8	99.9	100

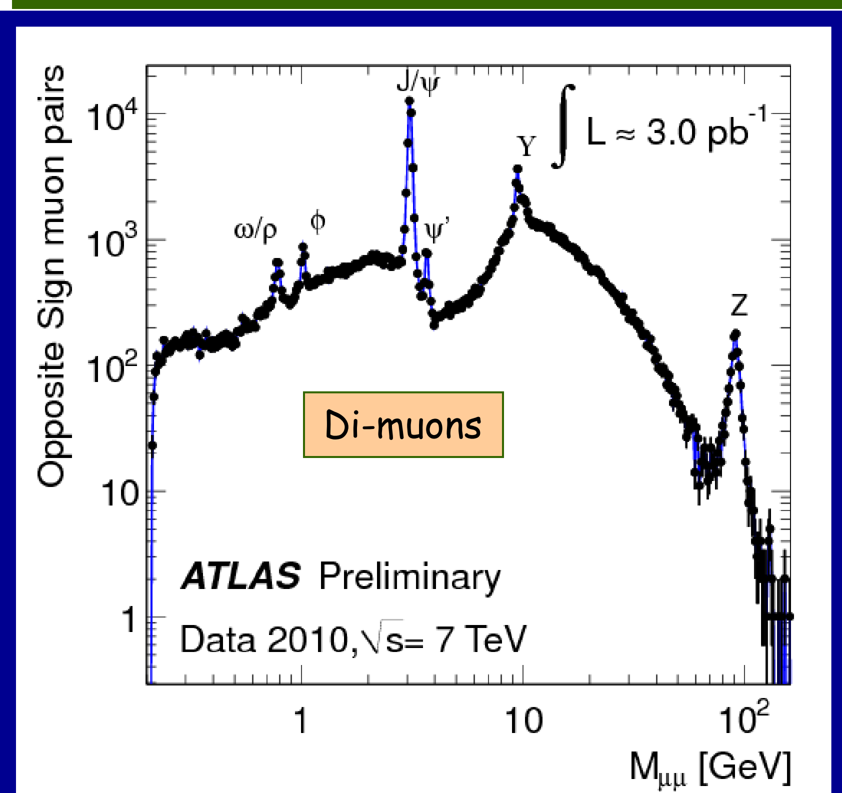
Luminosity weighted relative fraction (in %) of good quality data delivery by the ATLAS systems during 2010 stable beams at $\sqrt{s}$=7 TeV, between March 30th and August 30th, and after switching the tracking detectors fully on.

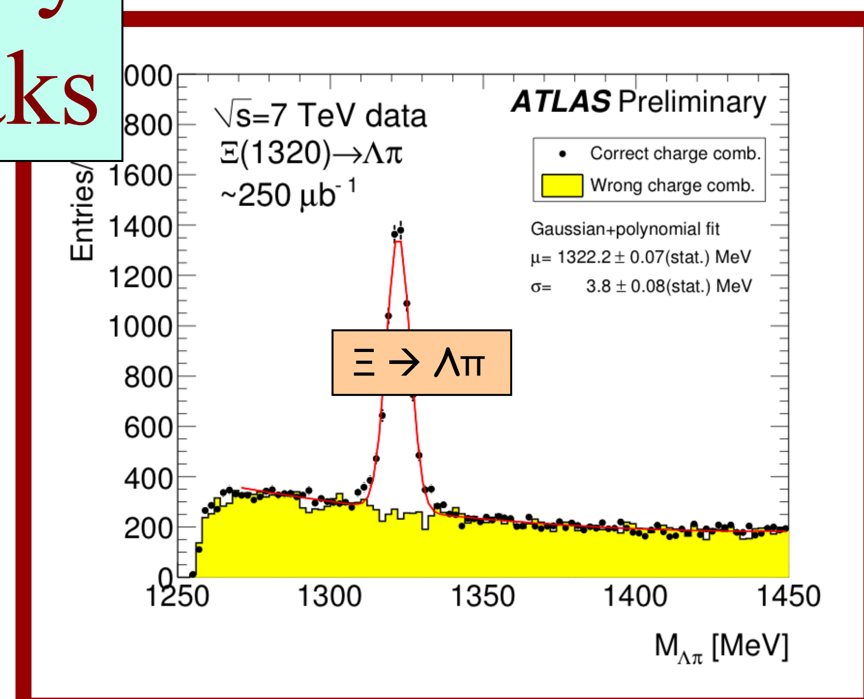
Few percent losses in EM calorimeter due to sporadic noise bursts and HV trips (conservative, being improved)

Early peaks


ATLAS Preliminary
Data 2009 √s=900GeV
MC signal
MC background
Data (|η| < 0.9)
Fit
Mean : 1019.6 ± 0.3 MeV
σexp : 2.2 ± 0.5 MeV
Φ → K+K-
Number of Events / 2 MeV
Invariant Mass (MeV)


ATLAS Preliminary
Data 2010, (√s=7 TeV)
CB fit
J/ψ → e+e-
Entries / 0.1 GeV
mee [GeV]

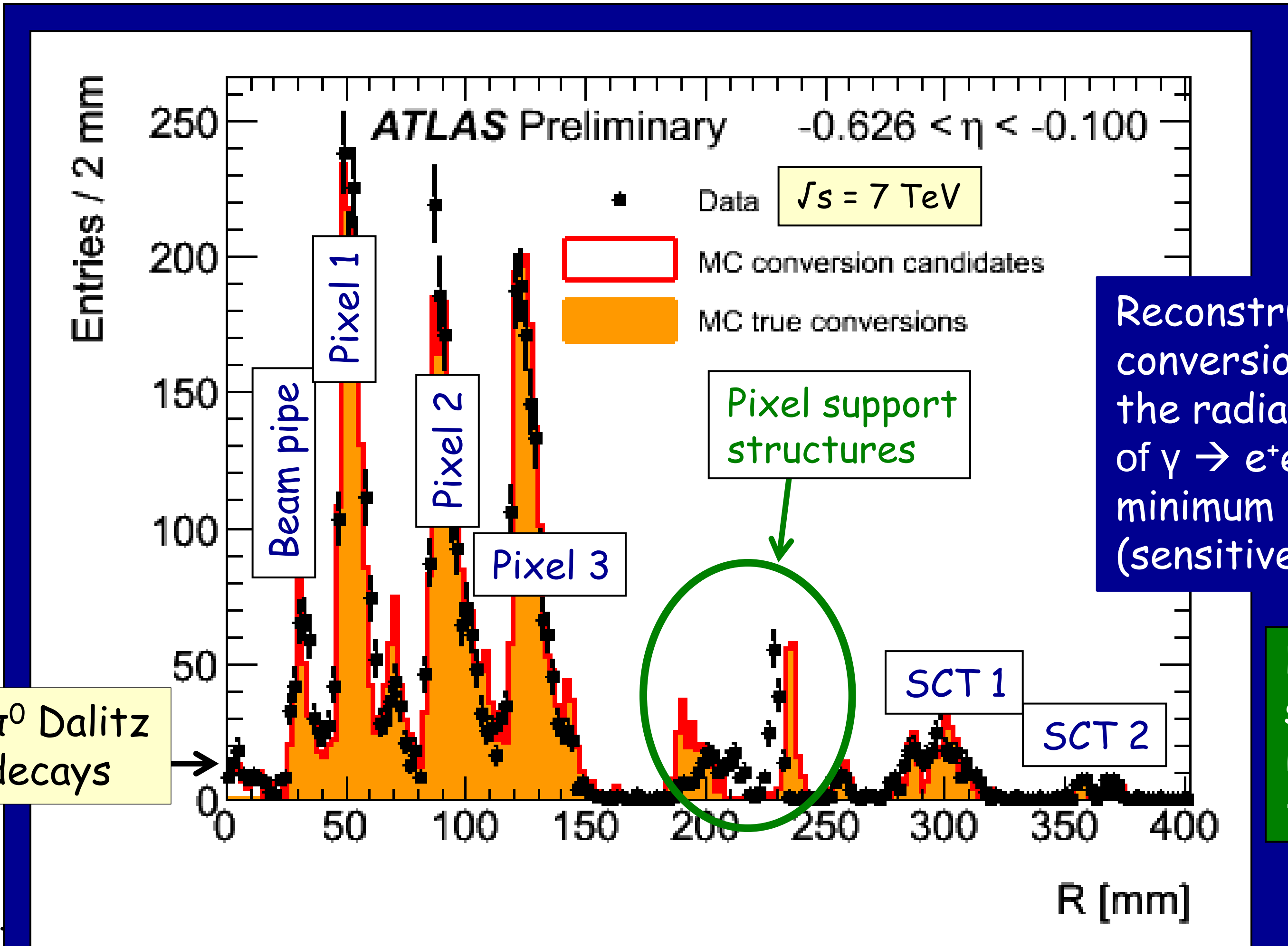

∫ L ≈ 3.0 pb-1
J/ψ
ω/ρ
φ
ψ'
Υ
Z
Di-muons
ATLAS Preliminary
Data 2010, √s= 7 TeV
Opposite Sign muon pairs
Mμμ [GeV]


√s=7 TeV data
Ξ(1320)→Λπ
~250 μb-1
ATLAS Preliminary
Correct charge comb.
Wrong charge comb.
Gaussian+polynomial fit
μ= 1322.2 ± 0.07(stat.) MeV
σ= 3.8 ± 0.08(stat.) MeV
Ξ → Λπ
MΛπ [MeV]

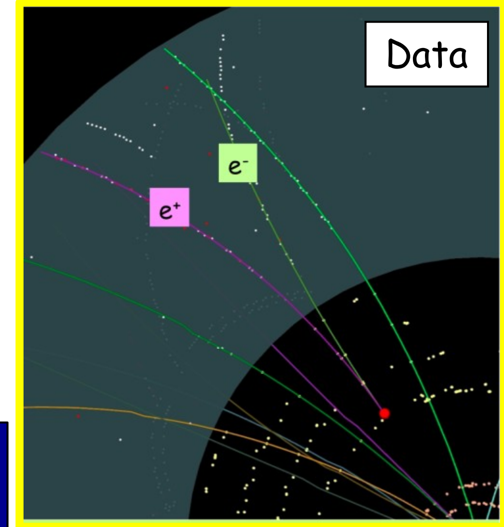
Mapping the Inner Detector material with $\gamma \rightarrow e^+e^-$ conversions and hadron interactions

… and using data to find geometry imperfections in the simulation

Goal is to know material to better than 5% (e.g. for W-mass measurement)
Present understanding: at the level of ~ 10%

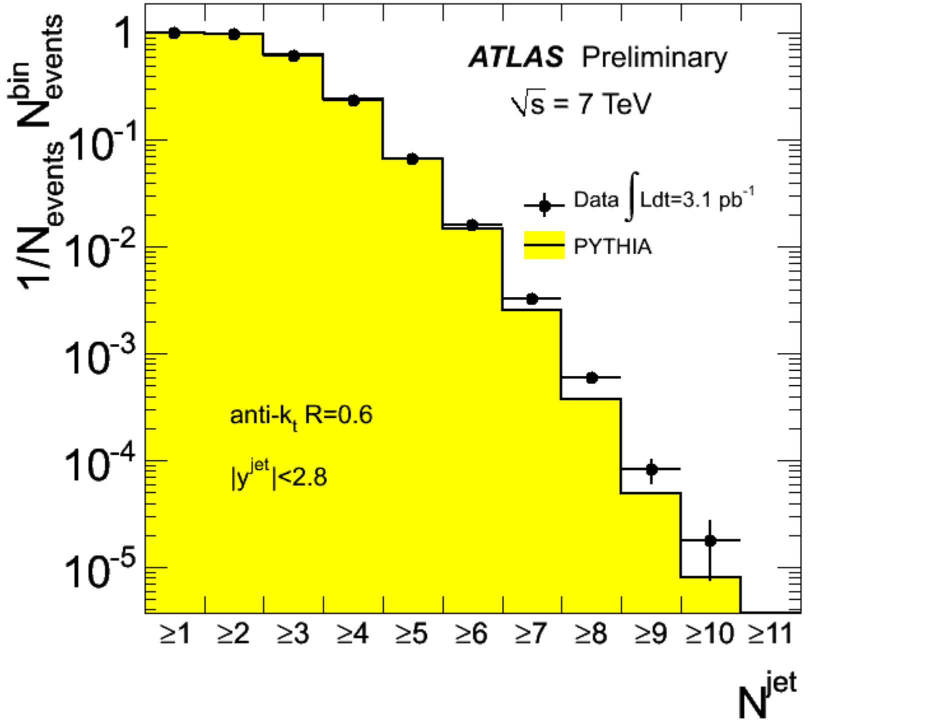


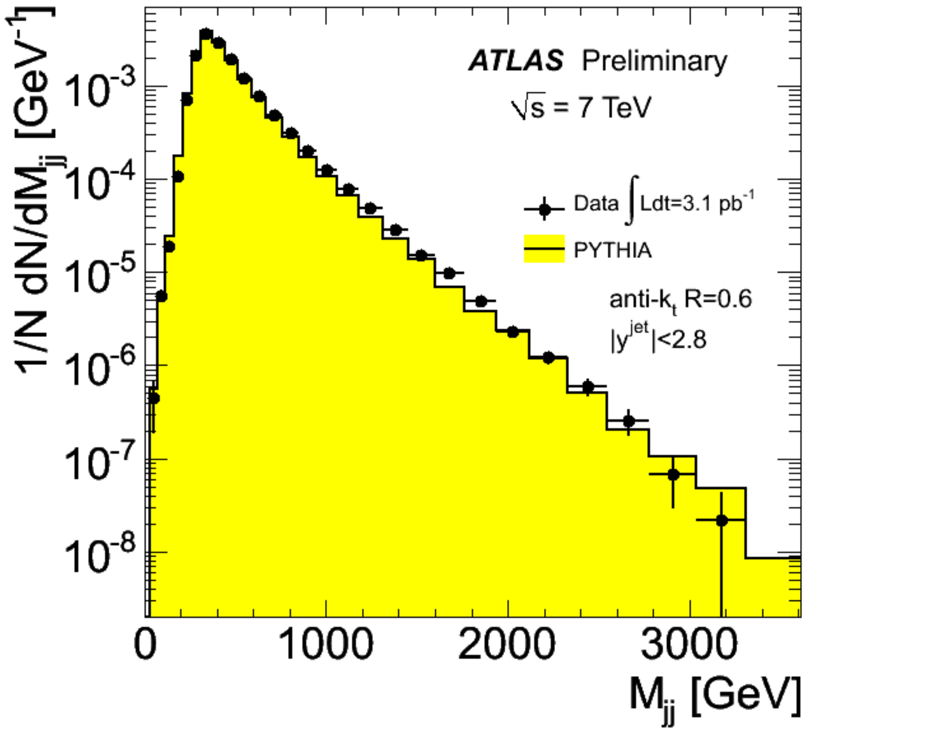
Reconstructed conversion point in the radial direction of $\gamma \rightarrow e^+e^-$ from minimum bias events (sensitive to X_0)



Data show that Pixel supports are displaced in the simulation
→ now fixed

Jets: energy scale now calibrated to < 5%

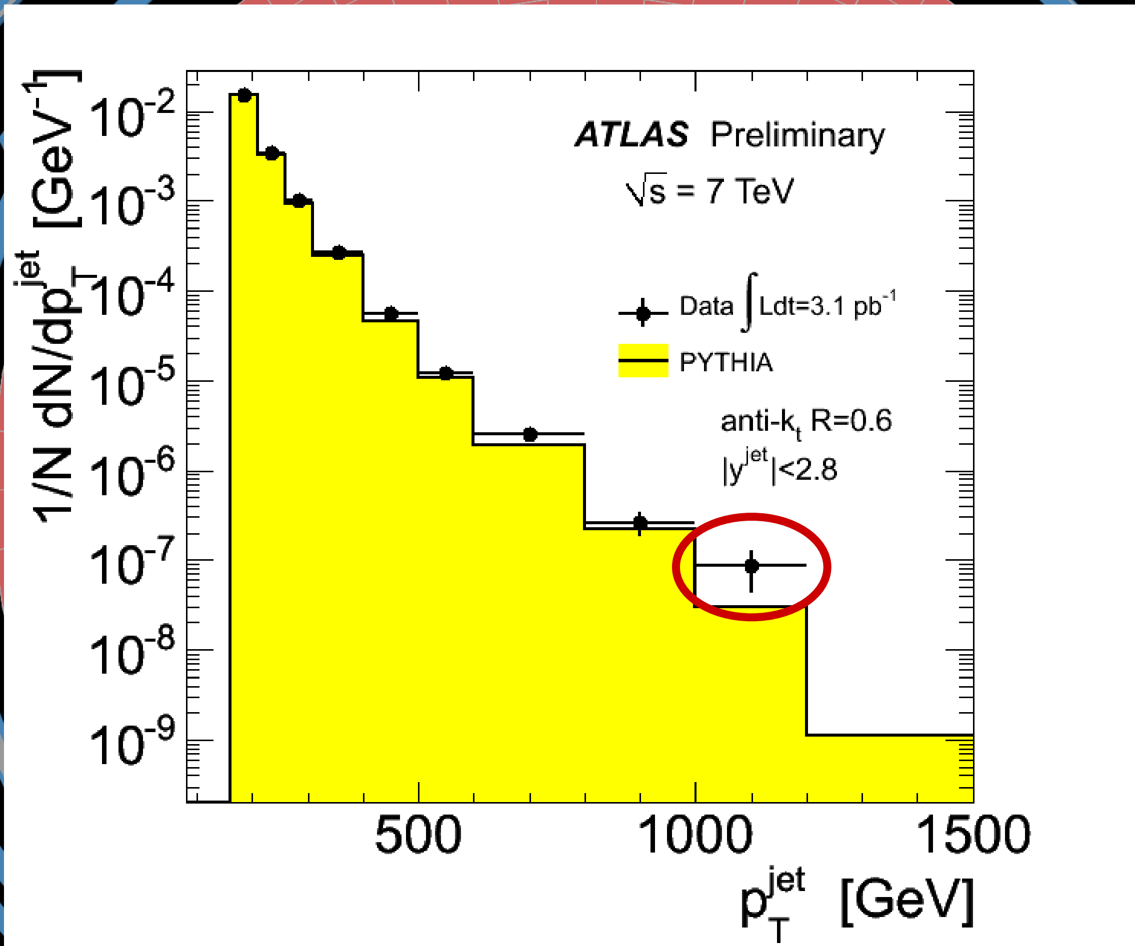


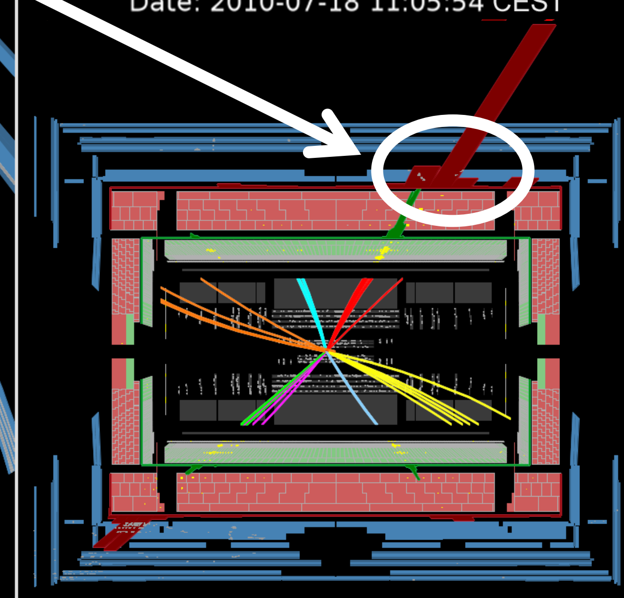


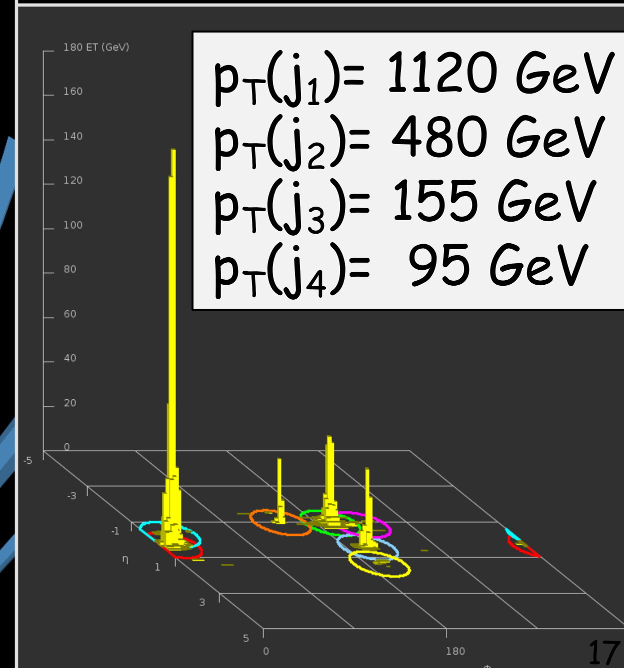
Leading jet p_T > 160 GeV, other jets p_T > 30 GeV

Observed event with hardest jet in first ~ 3 pb^{-1}

p_T (jet) > 1.1 TeV





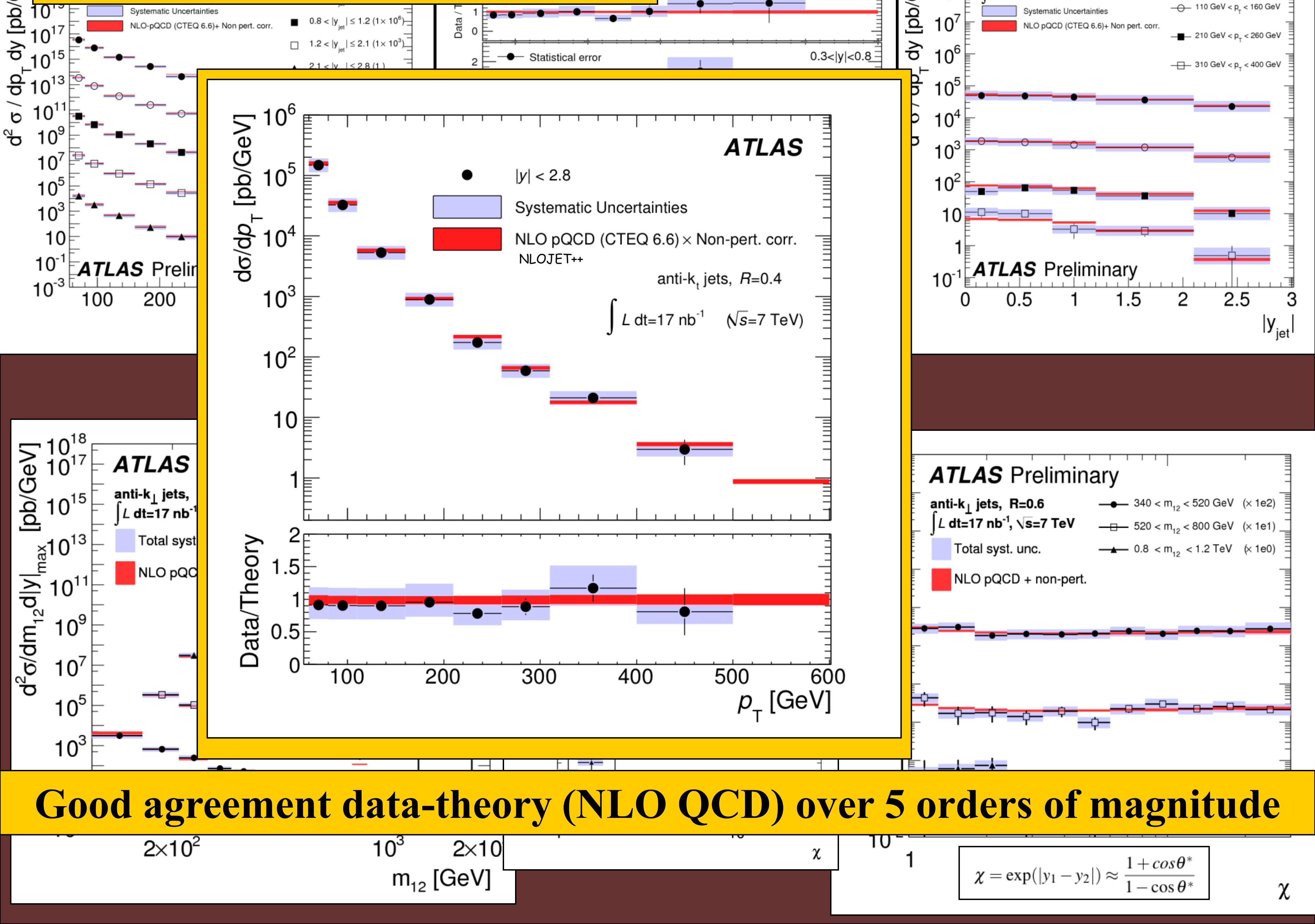


$p_T(j_1)$= 1120 GeV
$p_T(j_2)$= 480 GeV
$p_T(j_3)$= 155 GeV
$p_T(j_4)$= 95 GeV

ATLAS EXPERIMENT

Event display shows uncalibrated energies

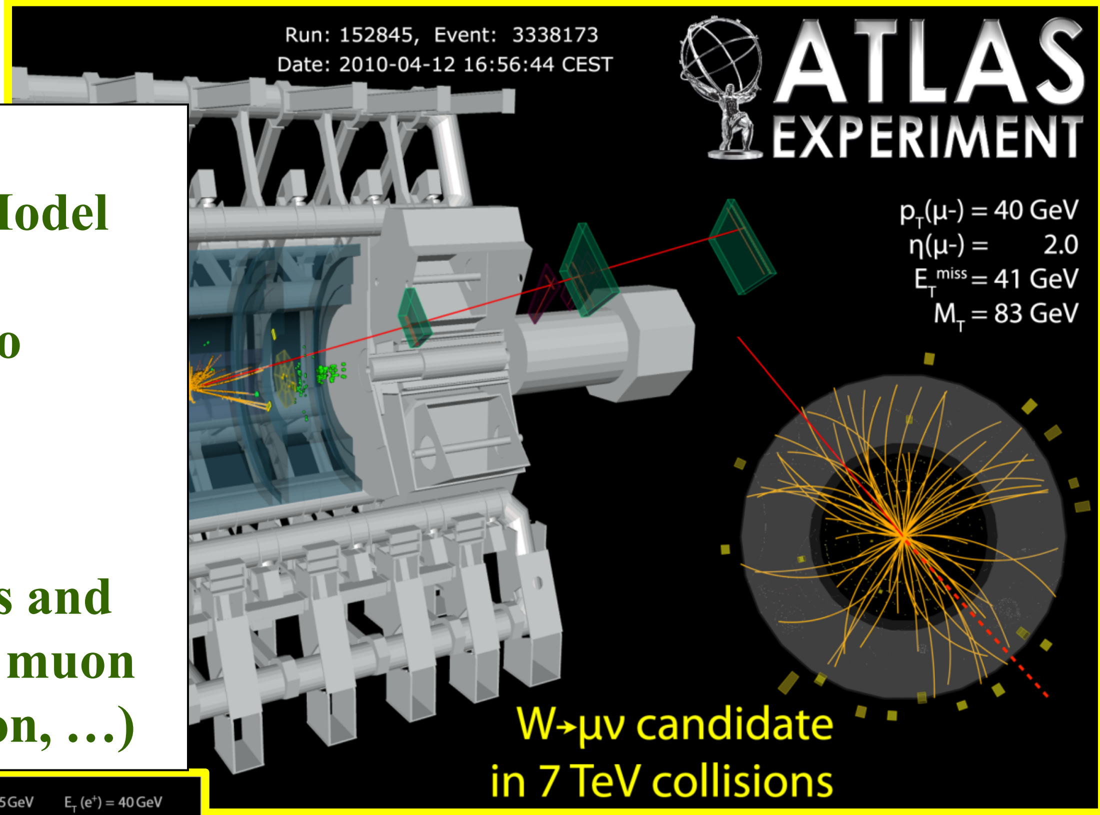
Inclusive jet cross-section

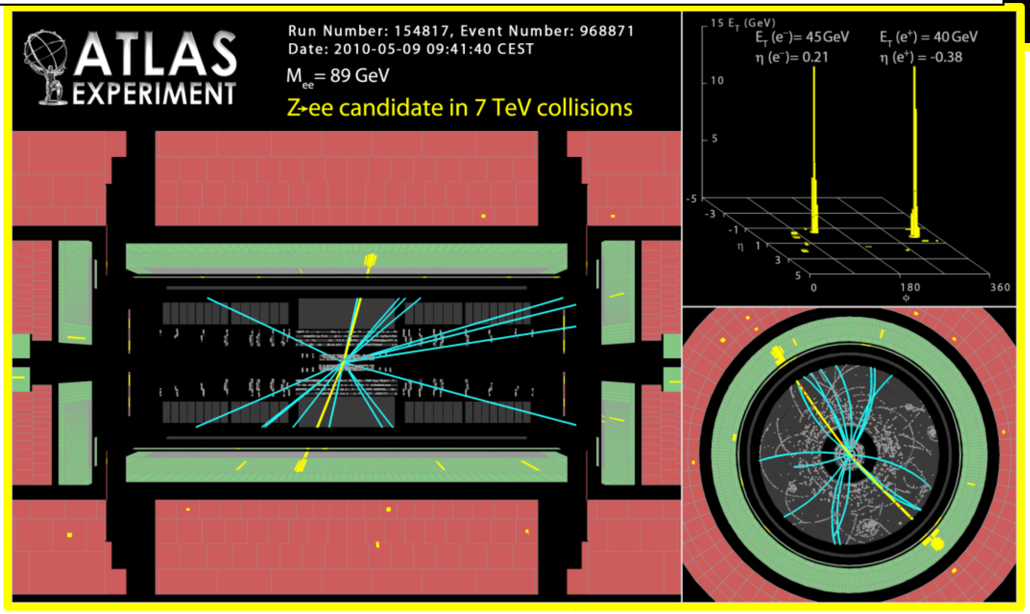


Good agreement data-theory (NLO QCD) over 5 orders of magnitude

W and Z physics

- Fundamental milestones in the "rediscovery" of the Standard Model at $\sqrt{s}$ = 7 TeV
- Among dominant backgrounds to searches for new physics
- Z → ll is gold-plated process to calibrate the detector to ultimate precision (E and p scales and resolutions in EM calo, tracker, muon spectrometer; lepton identification, …)

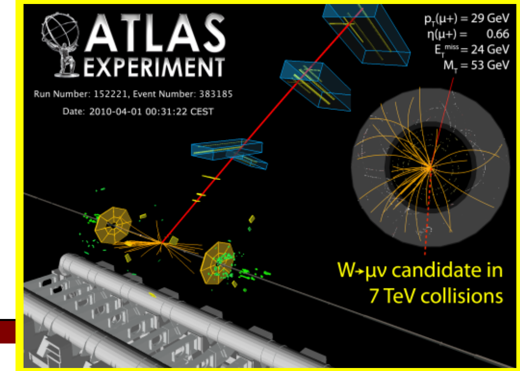


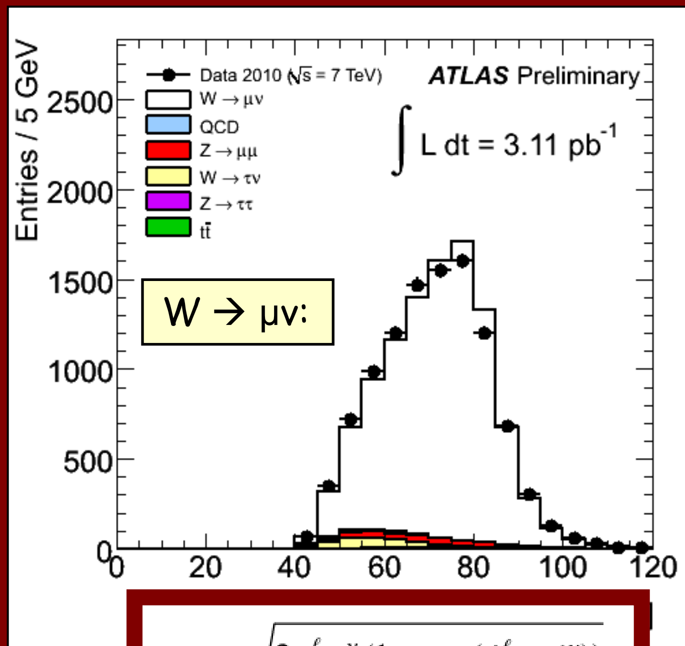


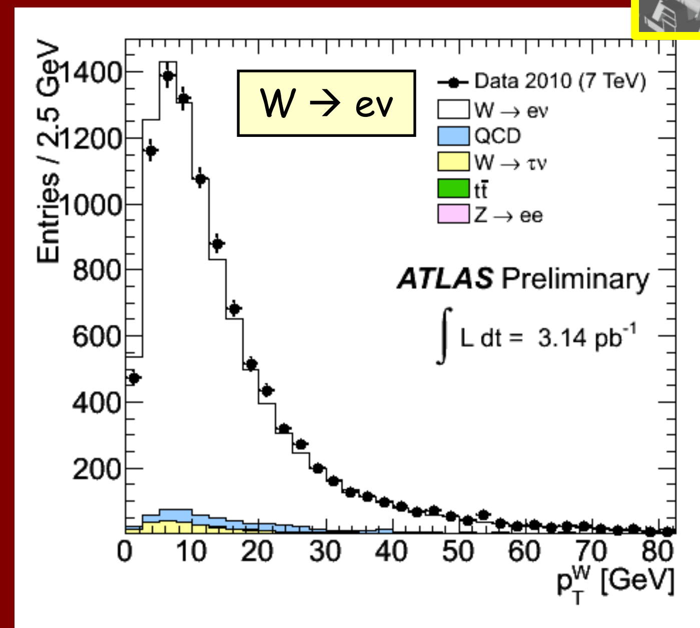
In the full data sample recorded this year:

~ 300k W→ μν, eν events

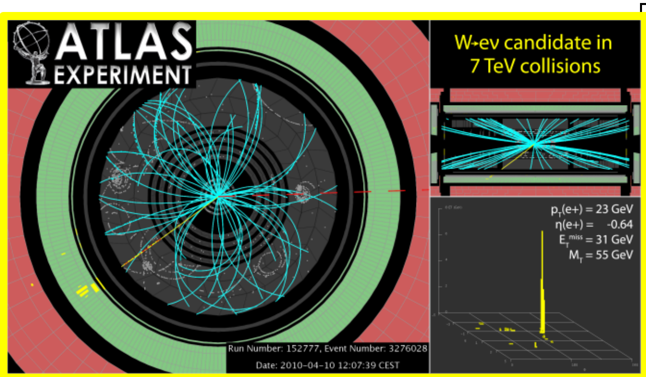
~ 30k Z → μμ, ee events



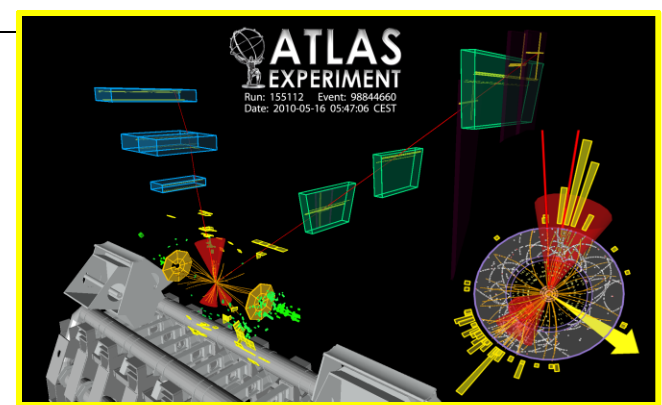




$$m_T = \sqrt{2 p_T^{\ell} p_T^{\nu} (1 - \cos(\phi^{\ell} - \phi^{\nu}))}$$

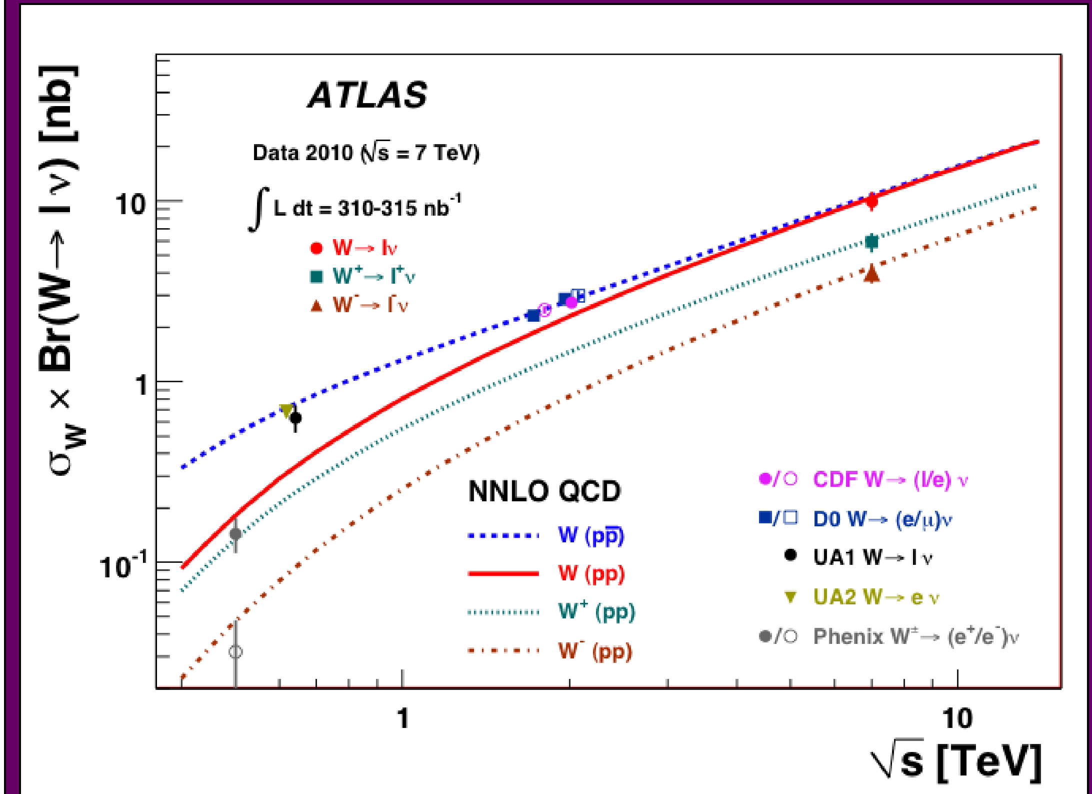


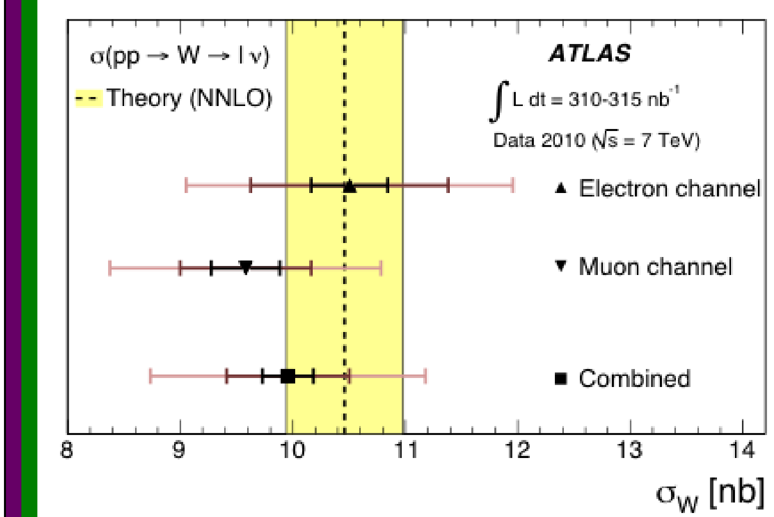
Only ~ 50 times less than the Tevatron experiments

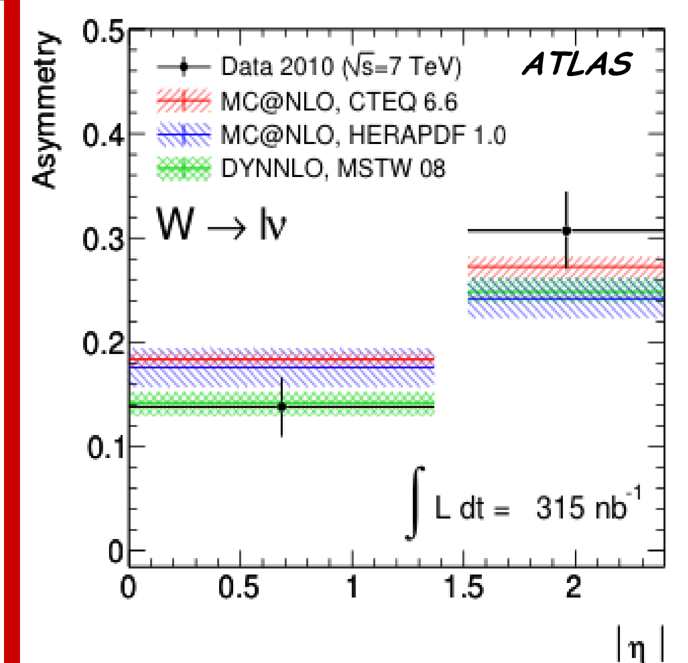


W cross-section and asymmetry measurements

σ (W → lν) = 9.96 ± 0.23 (stat) ± 0.5 (syst) ± 1.1 (lumi) nb





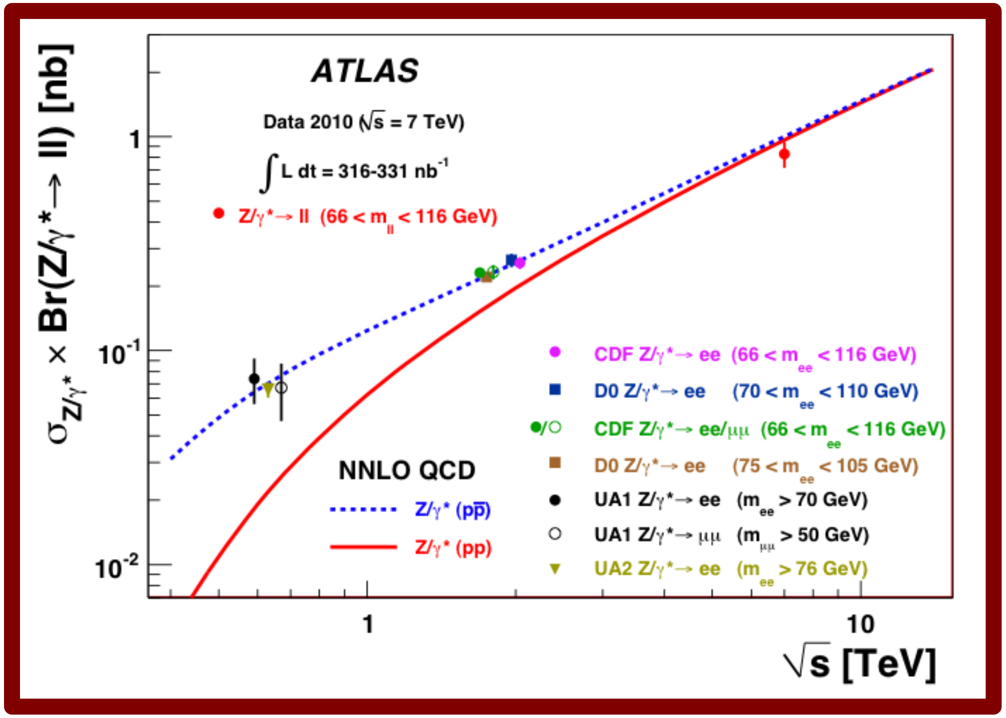


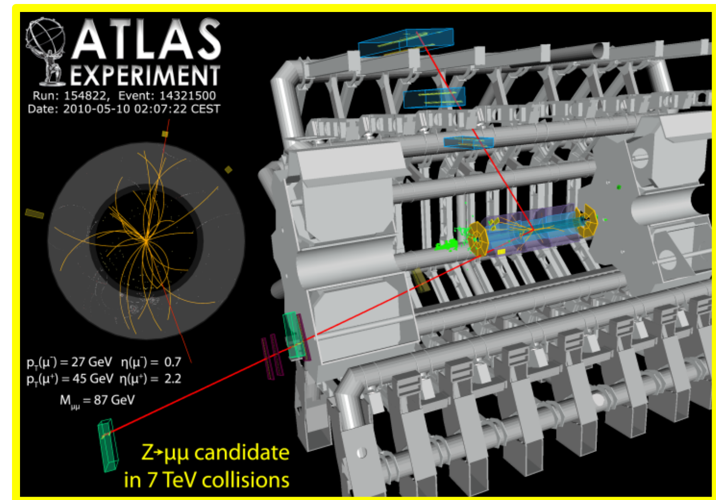
$$A = \frac{\sigma(W \to l^+\nu) - \sigma(W \to l^-\nu)}{\sigma(W \to l^+\nu) + \sigma(W \to l^-\nu)} \neq 0$$

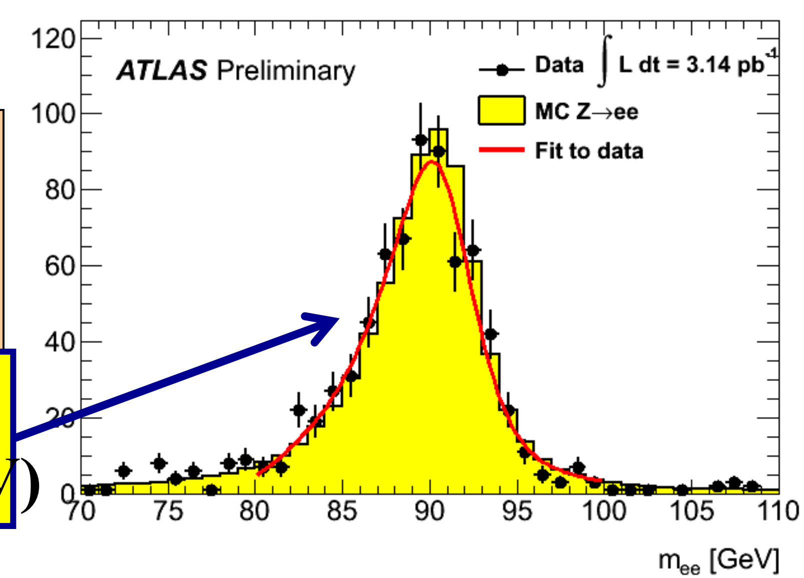
ATLAS:
A = 0.20 ± 0.02 (stat) ± 0.01 (syst)

Z cross-section

σ (γ*/Z→ ll) = 0.82 ± 0.06 (stat) ± 0.05 (syst) ± 0.09 (lumi) nb







Measured Z peaks: Z → μμ
90.9 ± 0.1 GeV
(MC: 91.3 GeV)

Z → ee experimental mass resolution:
1.59 ± 0.04 GeV (MC: 1.40 ± 0.01 GeV)

Top-quark candidates

$\sigma(t\bar{t}) \cong 160$ pb at $\sqrt{s} = 7$ TeV

lepton + jets channel
$tt \rightarrow bW\,bW \rightarrow bl\nu\,bjj$
$\sigma \sim 70$ pb

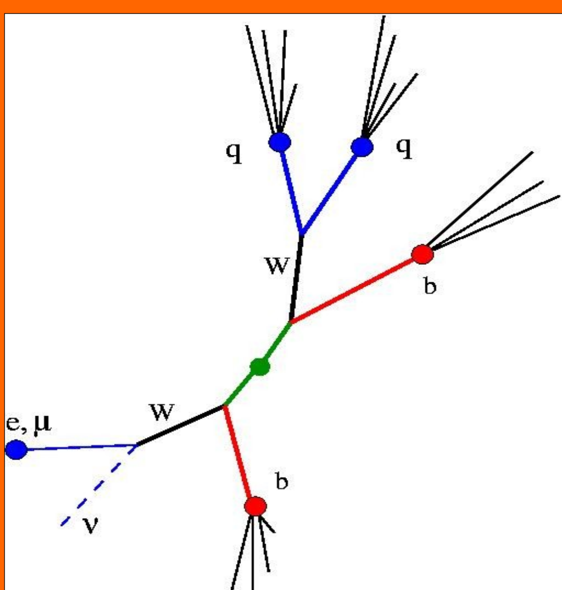
1 isolated lepton $p_T > 20$ GeV
$E_T^{miss} > 20$ GeV, $E_T^{miss} + m_T > 60$ GeV
≥ 4 jets $p_T > 25$ GeV
≥ 1 b-tag jet

Acceptance x efficiency ~ 15%

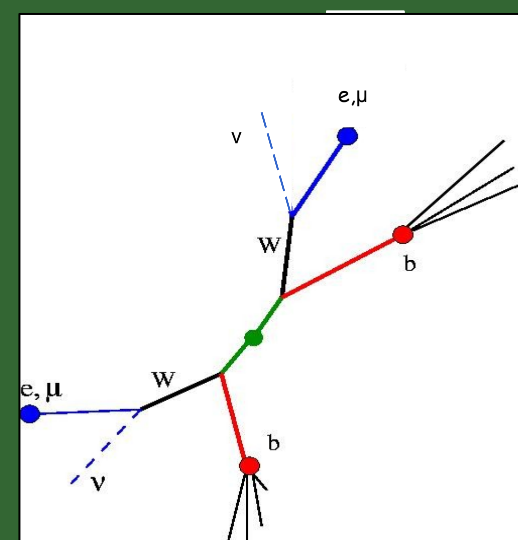
2-lepton channel
$tt \rightarrow bW\,bW \rightarrow bl\nu\,bl\nu$
$\sigma \sim 10$ pb

2 opposite-sign leptons: ee, eμ, μμ
both leptons $p_T > 20$ GeV
≥ 2 jets $p_T > 20$ GeV
ee: $E_T^{miss} > 40$ GeV $|M(ee)-M_Z| > 5$ GeV
μμ: $E_T^{miss} > 30$ GeV $|M(\mu\mu)-M_Z| > 10$ GeV
eμ: $H_T = \Sigma E_T$ (leptons, jets) > 150 GeV

Acceptance x efficiency ~ 25%



In the full data sample recorded this year: ~ 600 top events (only ~ 7 times less than at the Tevatron)

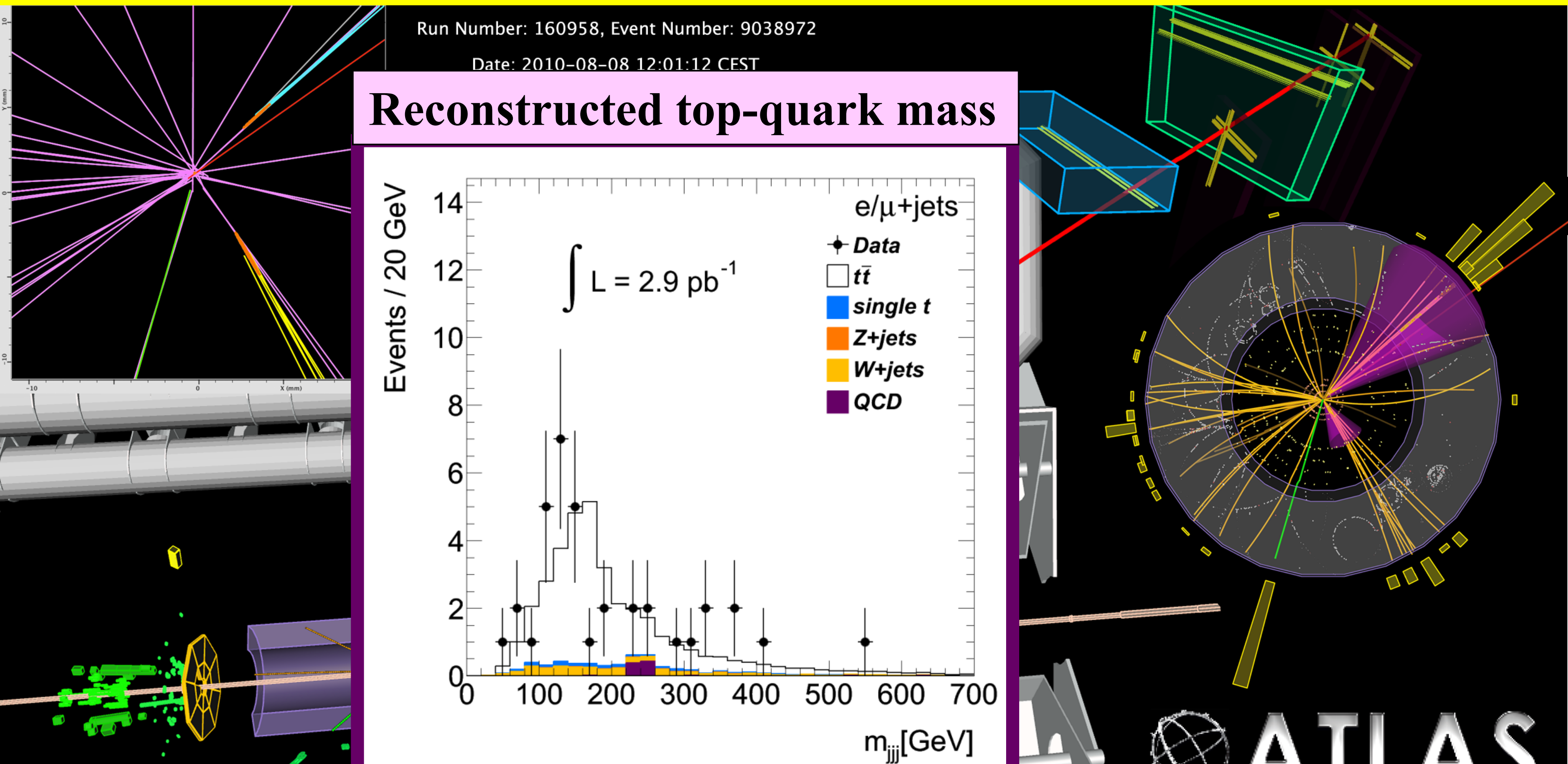


A gold-plated tt → beν bμν candidate

$p_T(\mu)$= 51 GeV $p_T(e)$=66 GeV p_T (b-tagged jets) = 174, 45 GeV E_T^{miss} = 113 GeV

Secondary vertices:

- Distance from primary vertex: 4 mm, 3.9 mm
- Vertex mass : ~2 GeV, ~ 4 GeV



The era of top-quark physics at the LHC has started

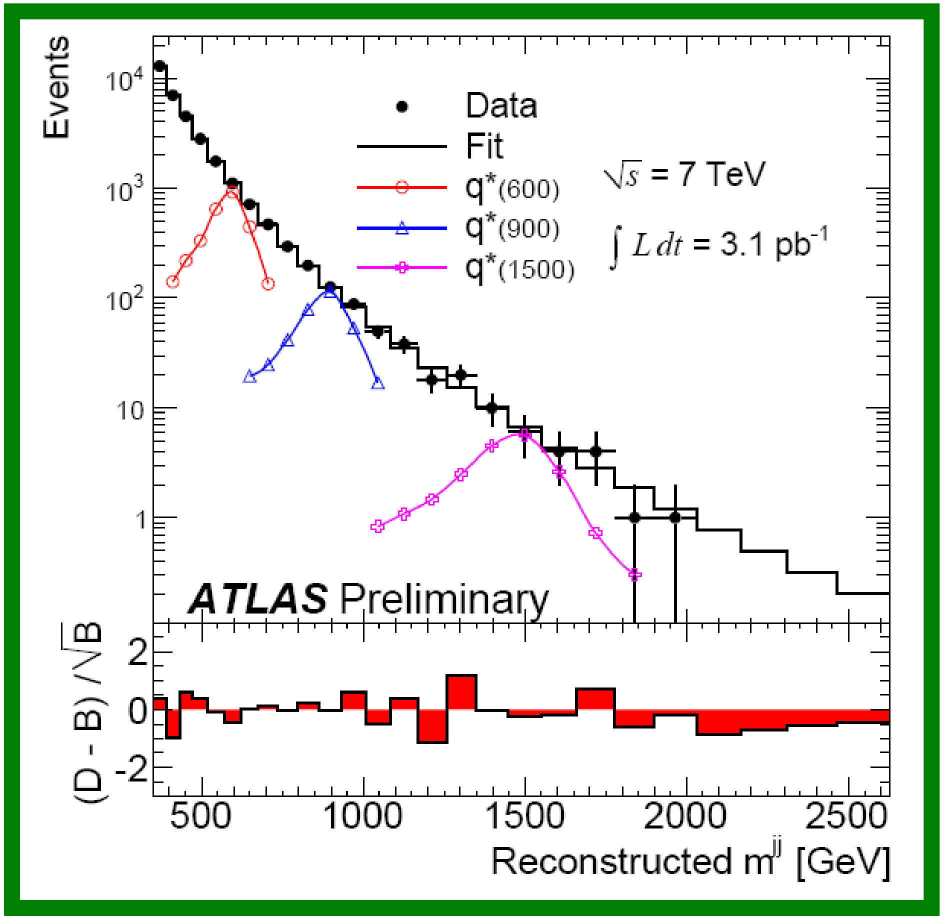
Searches for new physics: start to exceed the Tevatron reach

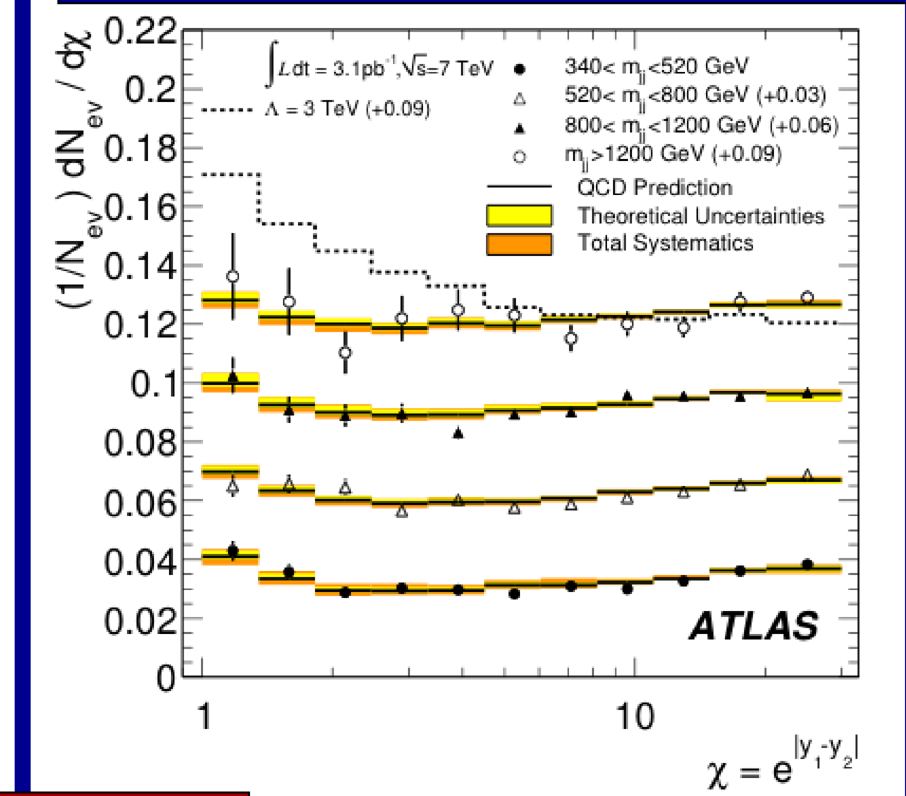
Look for di-jet resonances in the measured M(jj) distribution

Look for deviations from QCD in the measured di-jet angular distributions

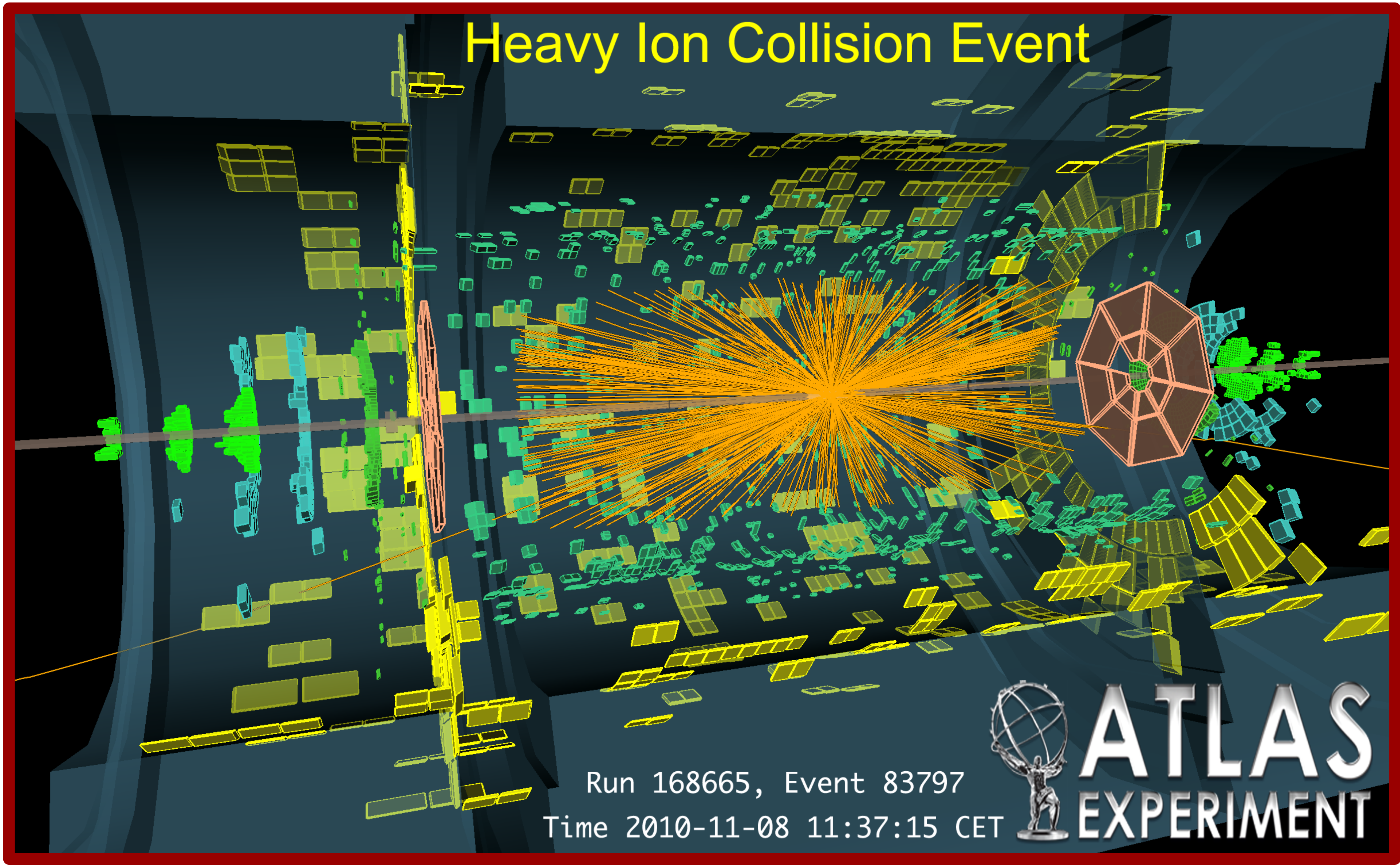
$$\chi = \exp(|y_1 - y_2|) = \frac{1 + \cos\vartheta^*}{1 - \cos\vartheta^*}$$

- QCD: χ distribution ~ flat
- Quark sub-structure: excess at low χ



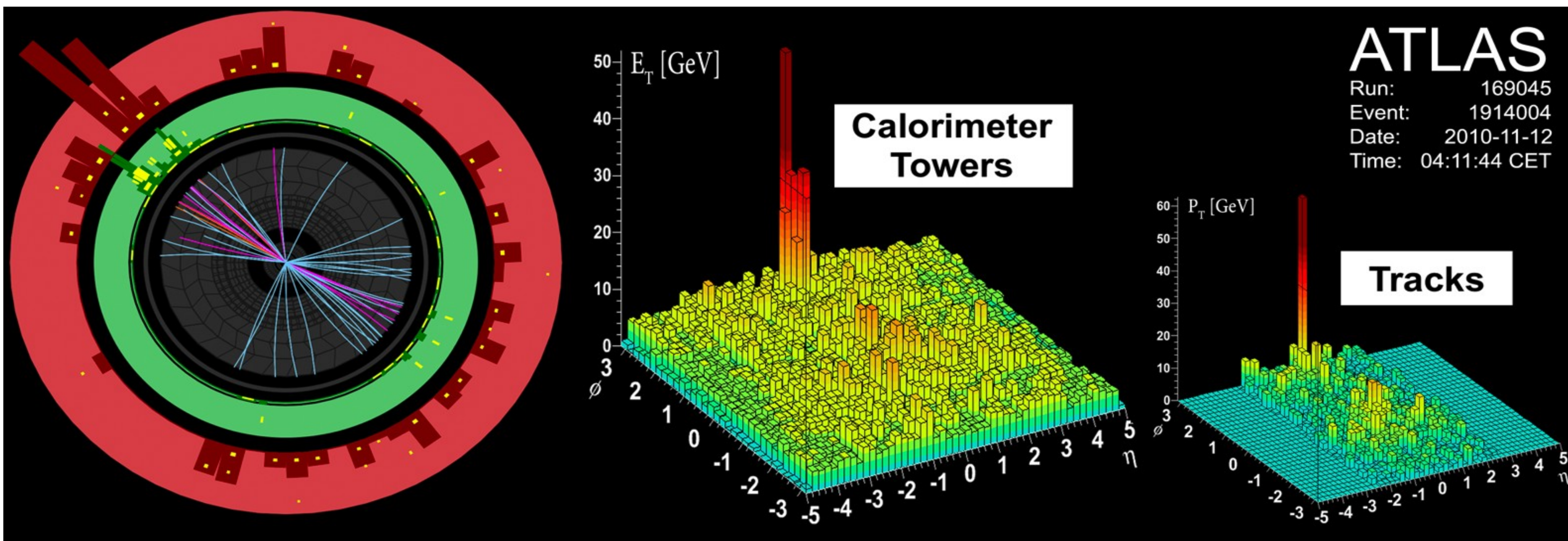


ATLAS: m(q*)>1.5 TeV ← ~ 0.5 TeV beyond the Tevatron reach → **ATLAS: Λ > 3.4 TeV**



> 1100 reconstructed tracks with p_T > 1 GeV

Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions with the ATLAS Detector



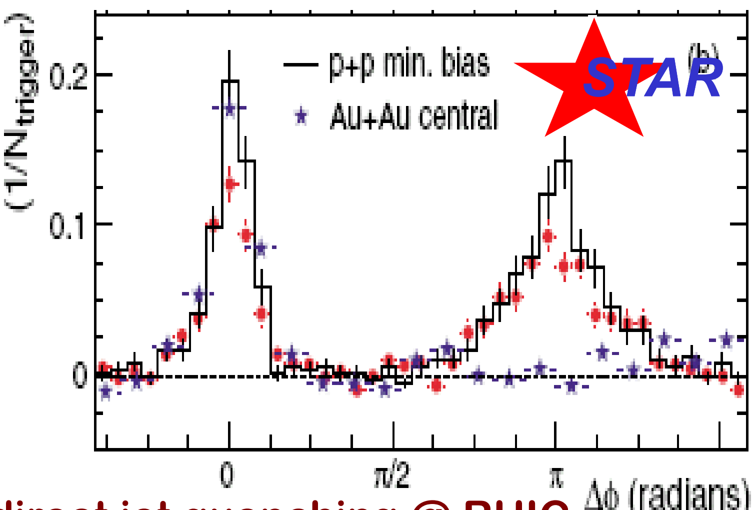
The paper: arXiv:1011.6182

Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS Detector at the LHC

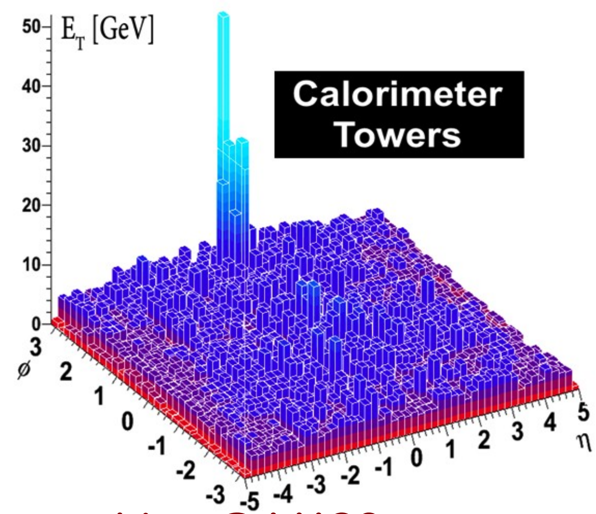
G. Aad *et al.* (The ATLAS Collaboration)*

Using the ATLAS detector, observations have been made of a centrality-dependent dijet asymmetry in the collisions of lead ions at the Large Hadron Collider. In a sample of lead-lead events with a per-nucleon center of mass energy of 2.76 TeV, selected with a minimum bias trigger, jets are reconstructed in fine-grained, longitudinally-segmented electromagnetic and hadronic calorimeters. The underlying event is measured and subtracted event-by-event, giving estimates of jet transverse energy above the ambient background. The transverse energies of dijets in opposite hemispheres is observed to become systematically more unbalanced with increasing event centrality leading to a large number of events which contain highly asymmetric dijets. This is the first observation of an enhancement of events with such large dijet asymmetries, not observed in proton-proton collisions, which may point to an interpretation in terms of strong jet energy loss in a hot, dense medium.

– Paper submitted on Nov 25, accepted by PRL



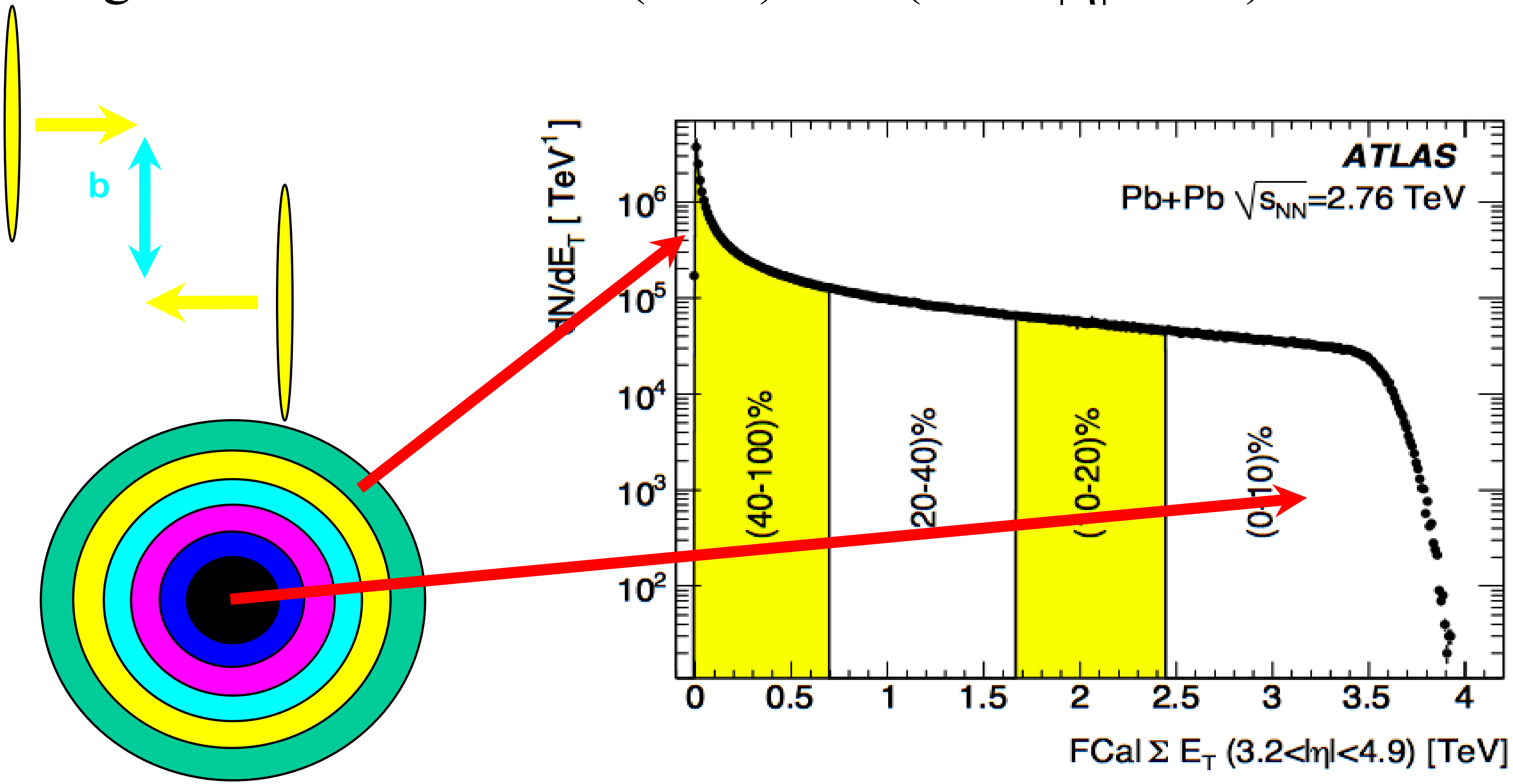
Indirect jet quenching @ RHIC



Direct quenching @ LHC?

Minimum-bias, centrality

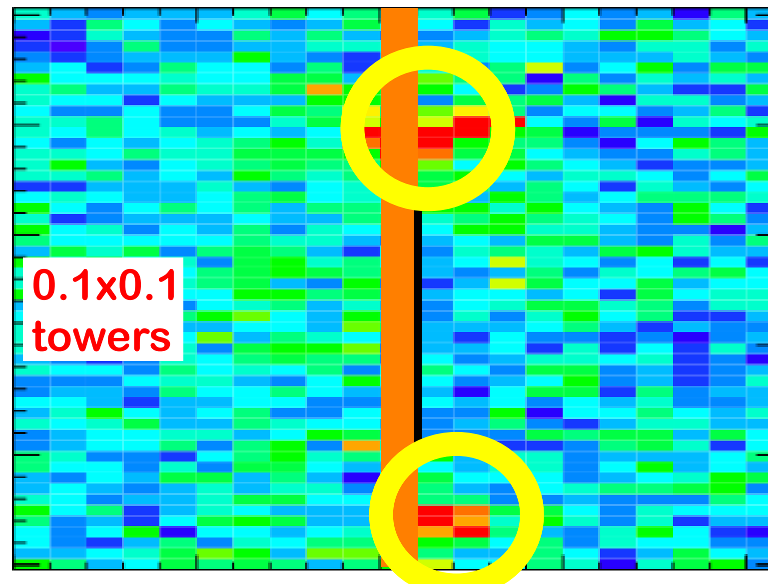
- Triggers: minimum-bias trigger scintillators, ZDC
- Characterise centrality by percentiles of total cross-section using forward calorimeter (FCal) ΣE_T ($3.2 < |\eta| < 4.9$)



Jet reconstruction

– Take maximum advantage of ATLAS segmentation

- Underlying event estimated and subtracted for **each longitudinal layer** and for 100 slices of $\Delta\eta = 0.1$
  – $$E_{T\,sub}^{cell} = E_T^{cell} - \rho^{layer}(\eta) \times A^{cell}$$
- ρ is energy density estimated event-by-event
  – From average over $0 < \varphi < 2\pi$



– Avoid biasing ρ due to jets

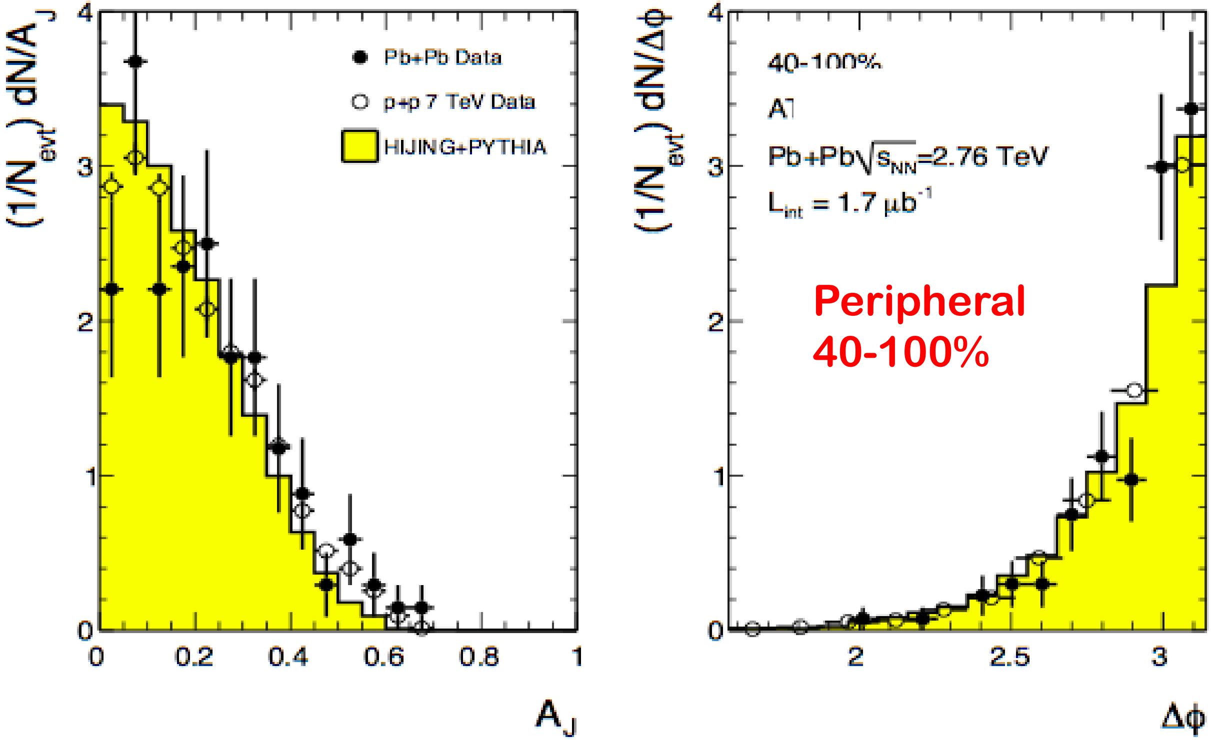
- Using anti-kt jets:
  – Exclude cells from ρ if

$$D = E_{T\,max}^{tower} / \langle E_T^{tower} \rangle > 5$$

- Cross check
  – Sliding Window algorithm

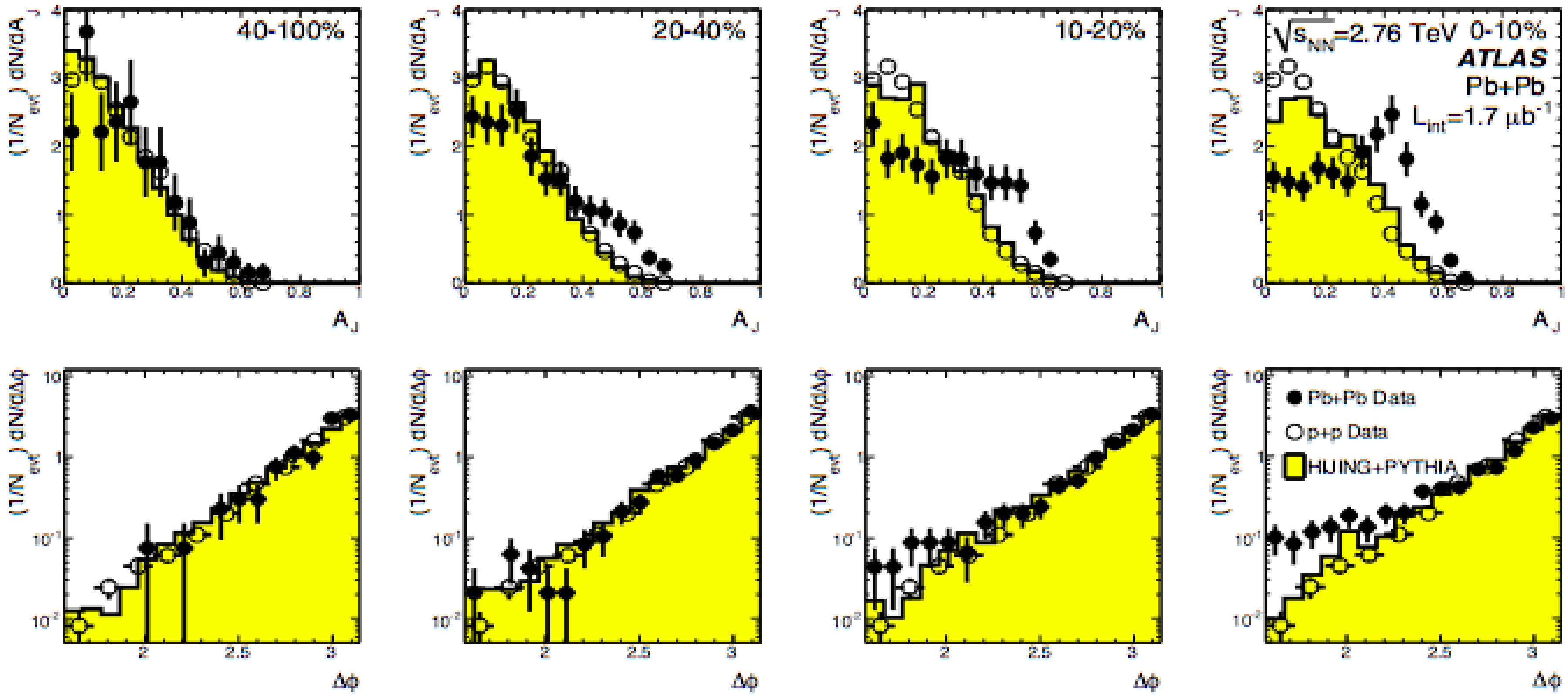
NO jet removal on basis of D, or any other quantity

Dijets: comparison to p+p, HIJING + PYTHIA



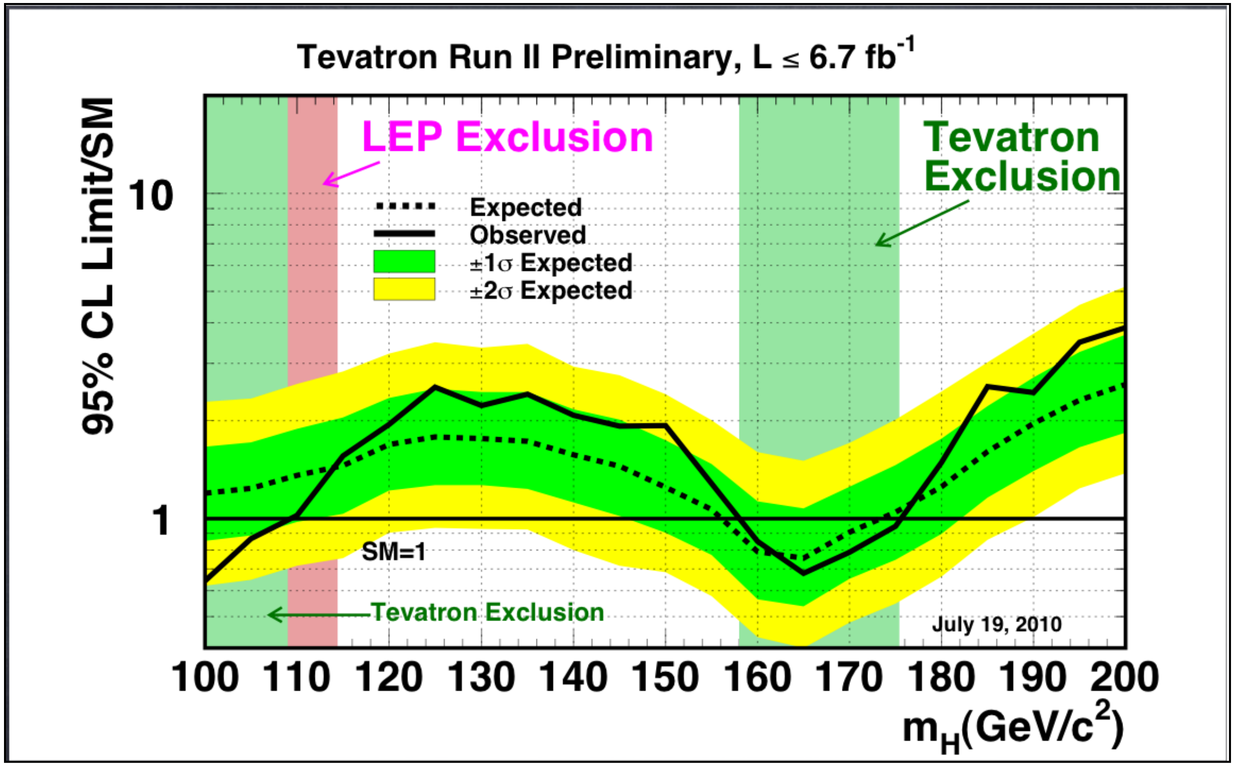
– Pb+Pb di-jet asymmetry (A_J), azimuthal separation ($\Delta\varphi$)
  - Compare to p+p data
  - And PYTHIA (7 TeV) dijet events embedded in HIJING
    – No HIJING quenching, flow added in afterburner
– Data agrees with p+p, MC in peripheral Pb+Pb.

Full centrality range: paper plots



- For more central collisions, see:
  - Reduced fraction of jets with small asymmetry
  - Increased fraction of jets with large asymmetry
    - For all centralities, Δφ strongly peaked at π
    - Possible small broadening in central collisions

Expectations for SM Higgs boson and comparison with Tevatron



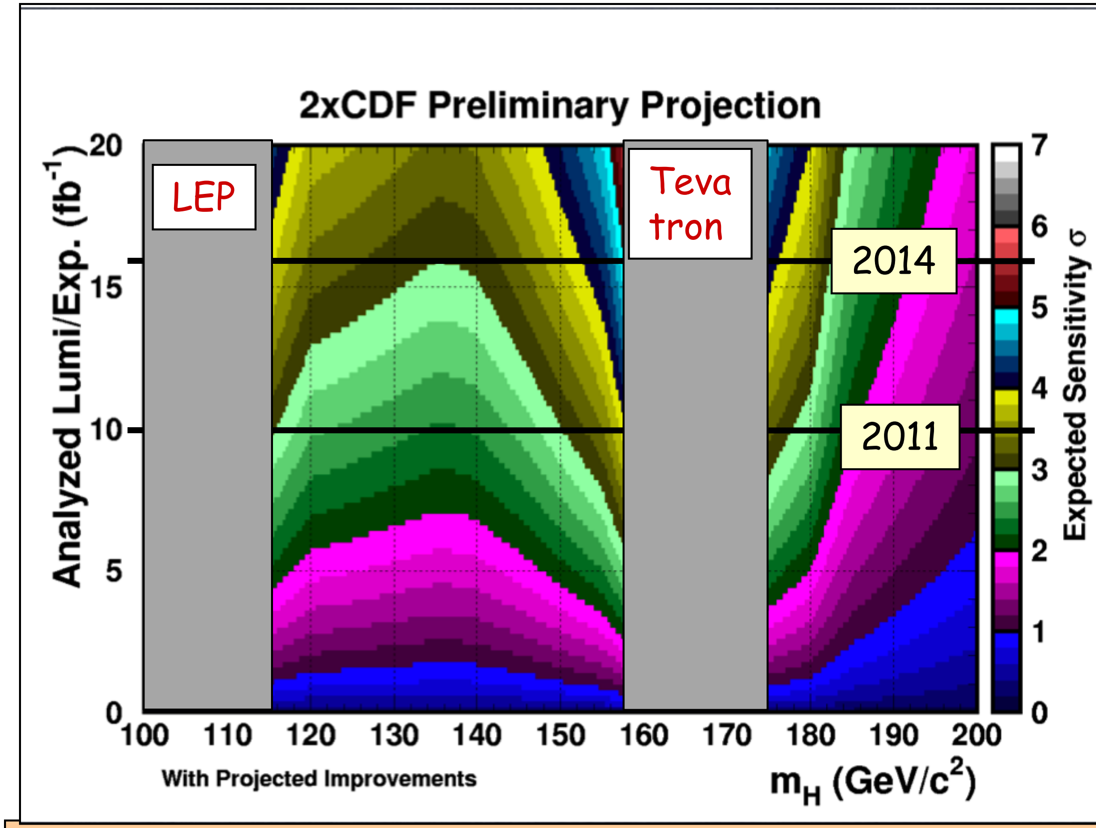
✓ Tevatron today: ~ 9 fb^{-1} delivered; ~ 6 fb^{-1} analysed

✓

✓ Present exclusion: 158< m_H< 175 GeV

✓ For m_H~115 GeV (most difficult region at LHC): sensitivity is 1.5 x SM

✓ Outstanding accelerator performance, very sophisticated and mature analyses
→ impressive achievement, beyond what one might have expected!



Future prospects at the Tevatron (include projected analysis improvements)

- ❑ Tevatron delivers ~ 2.5 fb^{-1} / year (~80% "analyzable" by CDF, D0)
- ❑ 2011: ~ 10 fb^{-1} analysable:
  - -- full region below 185 GeV could be excluded at 96% C.L.
  - -- 3σ evidence for m_H=115 GeV

  with analysis improvements
- ❑ 2014 (if Tevatron run extended for 3 more years): ~ 16 fb^{-1} analyzable:
  - -- 3σ evidence up to m_H ~ 180 GeV
  - -- ~ 4σ evidence for m_H=115 GeV

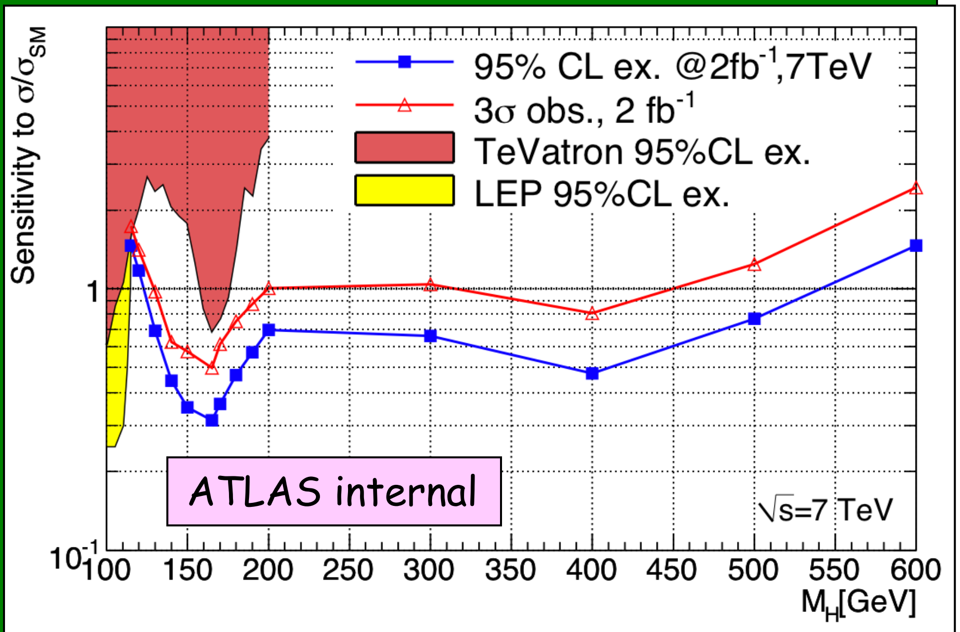
  with analysis improvements

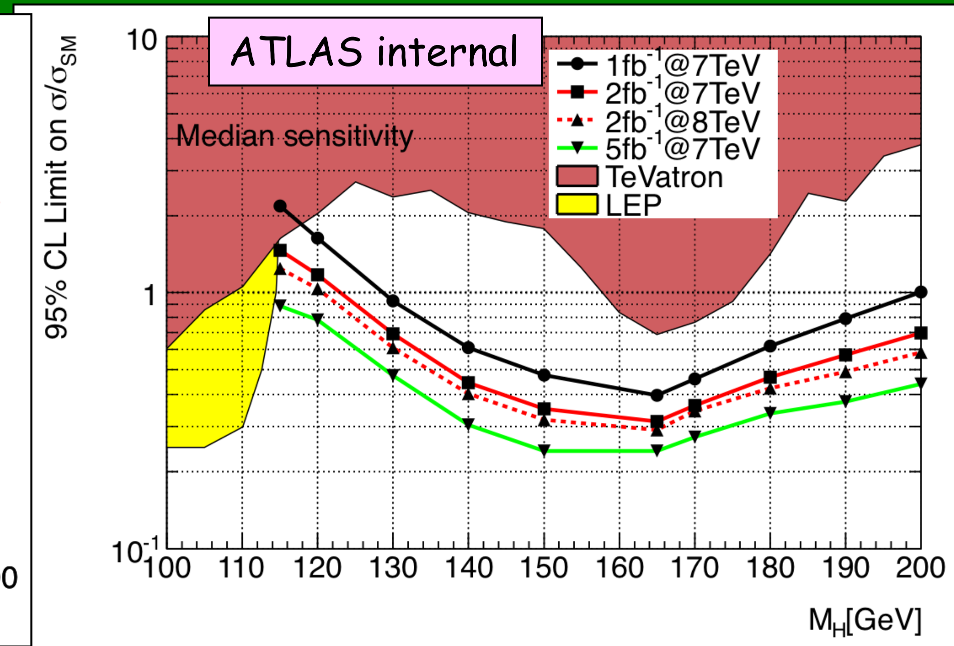
Note: most difficult region: m_H~ 135 GeV

ATLAS sensitivity by end 2011

ATLAS internal → to become public in a few weeks

Note: -- curves show sensitivity of one experiment
-- conservative: simple cut-based analyses





LHC is complementary to Tevatron: more powerful at high masses, weaker at low masses

- ❑ With 1 fb^{-1} per experiment and combining ATLAS+CMS:
  - -- could exclude 123 $< m_H <$ 540 GeV at 95% C.L.
  - -- 3σ evidence over 130 $< m_H <$ 450 GeV
- → extend sensitivity to higher masses than Tevatron
- → cover $m_H \sim$ 135 GeV where Tevatron is weakest
- ❑ Expected analysis improvements might allow exclusion down to $m_H \sim$ 115 GeV (otherwise would need 2.5 fb^{-1} per experiment) → hard to compete with Tevatron

Note: with 2.5 fb^{-1} per experiment: LHC has 3σ evidence down to ~ 120 GeV → Tevatron and LHC together could reach 3σ over almost full mass range 115-450 GeV

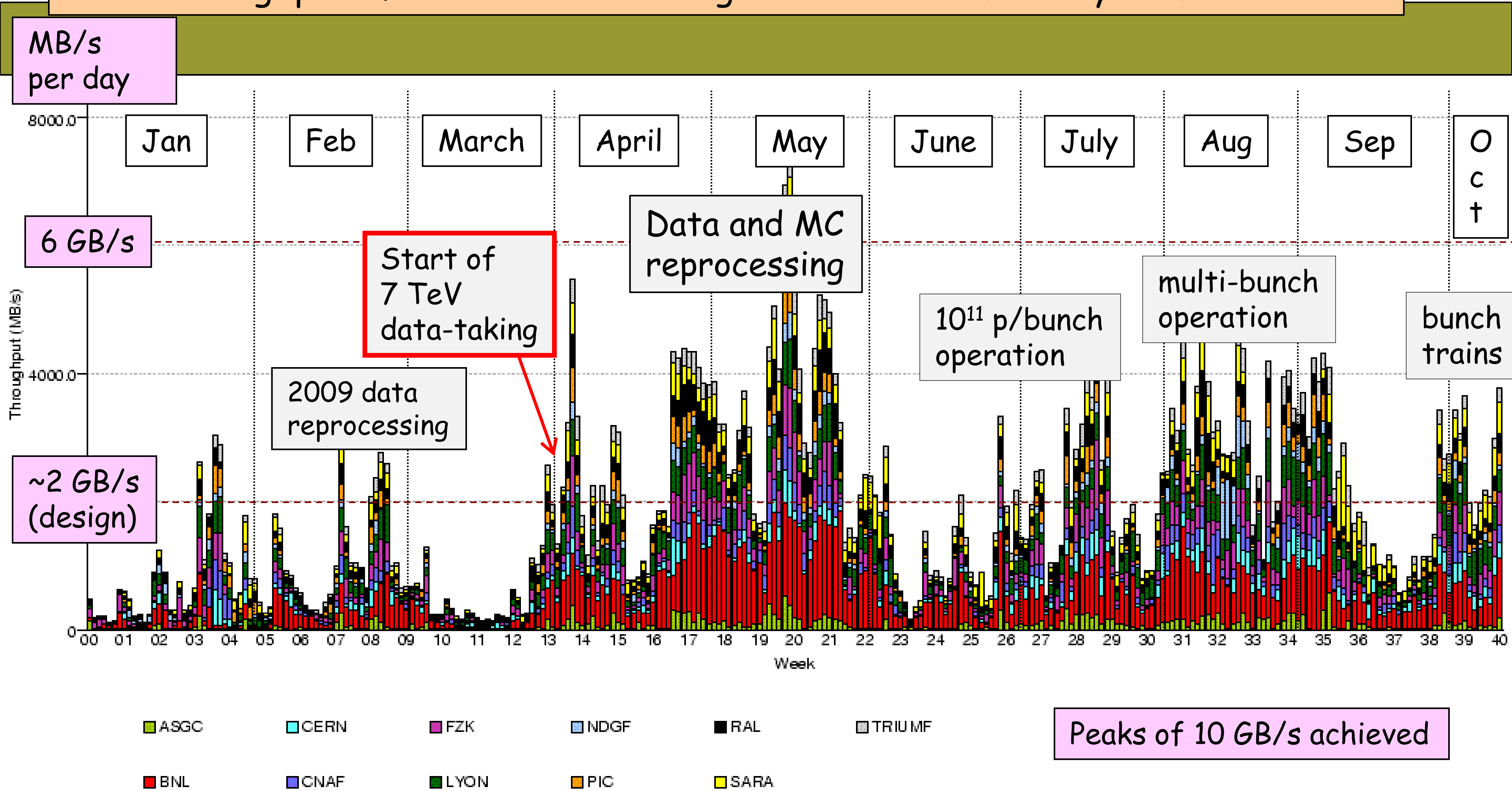
Spares

Computing infrastructure and operation

ATLAS wLCG world-wide computing: ~ 70 sites
(including CERN Tier-0, 10 Tier-1s, ~ 40 Tier-2 federations)

Worldwide data distribution and analysis

Total throughput of ATLAS data through the Grid: 1st January → mid October



Grid-based analysis in Summer 2010: > 1000 different users; > 15M analysis jobs

The excellent Grid performance has been crucial for fast release of physics results.
E.g.: ICHEP: the full data sample taken until Monday was shown at the conference on Friday