Highlights from LHC & ATLAS

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ATLAS

BROOKHAVEN NATIONAL LABORATORY

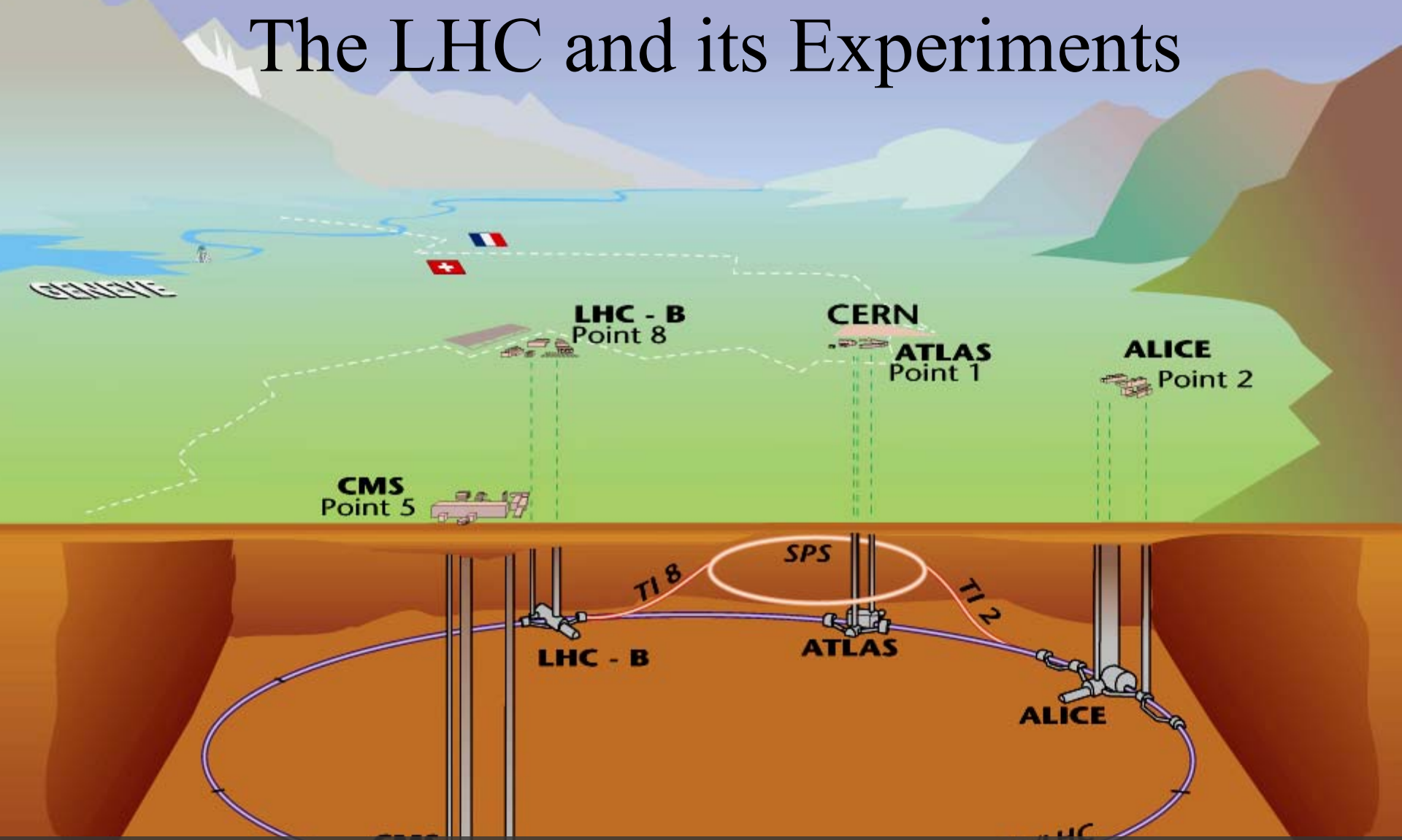
LHC Theory Initiative, BNL, October 07 2010

March 30 2010 – ATLAS control room

7 TeV collisions in ATLAS!

The LHC

The LHC and its Experiments



- ~16.5 mi circumference, ~300 feet underground
- 1232 superconducting twin-bore Dipoles (49 ft, 35 t each)
- Dipole Field Strength 8.4 T (13 kA current), Operating Temperature 1.9K
- Beam intensity 0.5 A (2.2 10^{-6} loss causes quench), 362 MJ stored energy

Instantaneous Luminosity

$$L = \frac{N^2 k_b f}{4\pi\sigma_x\sigma_y} F = \frac{N^2 k_b f \gamma}{4\pi\varepsilon_n \beta^*} F$$

Goal:
$>10^{32}$ cm^{-2}s^{-1},
1/fb in 2011

Parameters to "play" with:

- Number of particles per bunch N } **Intensity**
- Number of bunches per beam k_b } **Intensity**
- Relativistic factor (E/m_0) γ **Energy**
- Normalised emittance ε_n
- Beta function at the IP β^* } **Interaction Region**
- Crossing angle factor F } **Interaction Region**
  - Full crossing angle θ_c
  - Bunch length σ_z
  - Transverse beam size at the IP σ^*

$$F = 1/\sqrt{1+\left(\frac{\theta_c\sigma_z}{2\sigma^*}\right)^2}$$

<u>PDG 2010</u>: So to achieve high luminosity, **all one has to do** is make high population bunches of low emittance to collide at high frequency at locations where the beam optics provides as low values of the amplitude functions as possible.

What we don't want to see…

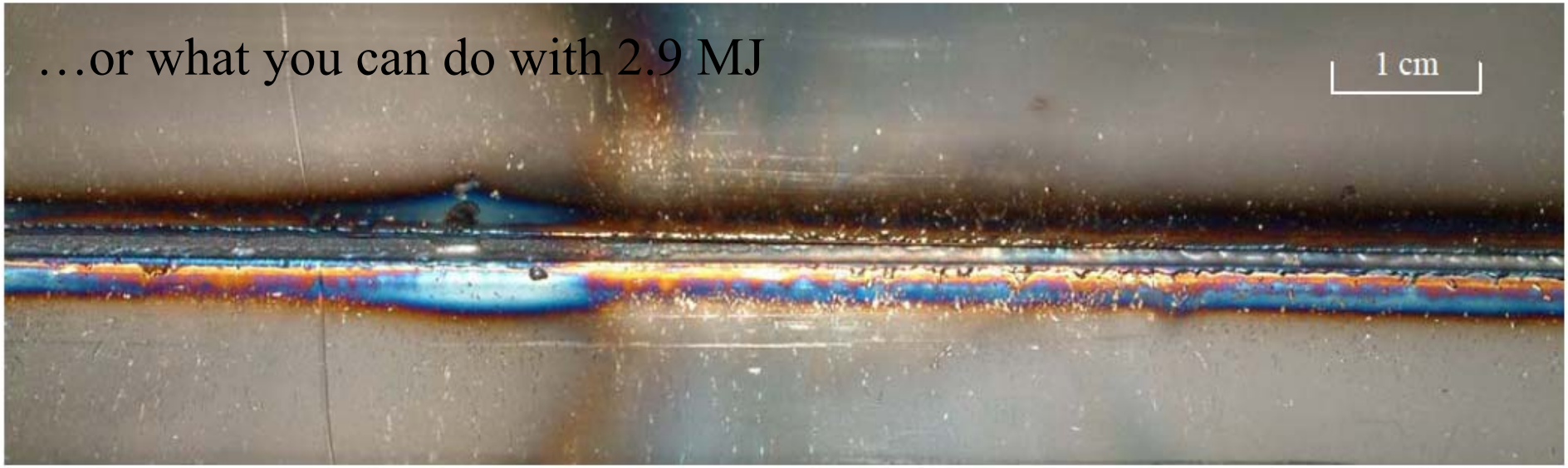
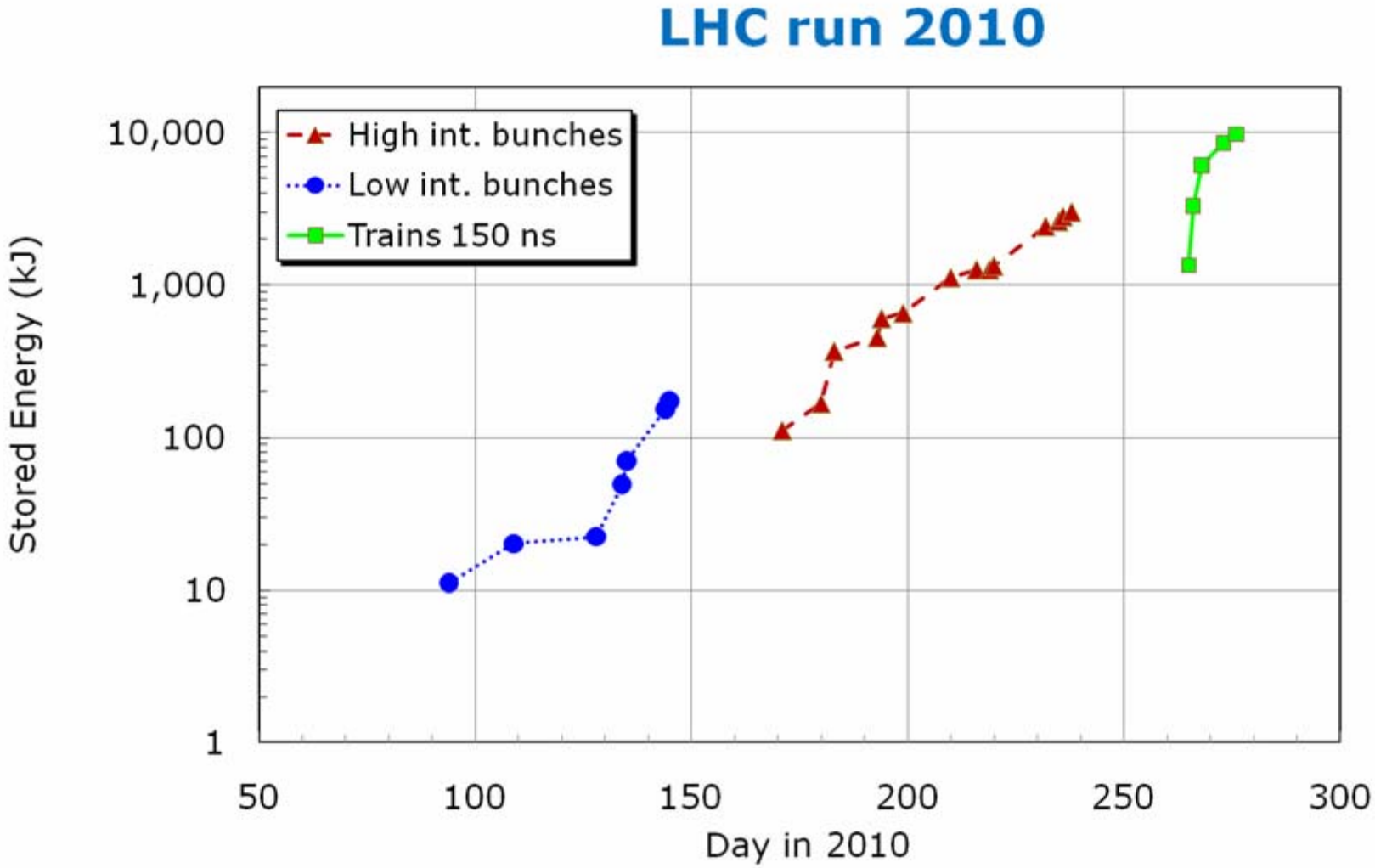


Figure 4. Damage observed on the inside of the vacuum chamber, on the beam impact side. A groove approximately 110 cm long due to removed material was clearly visible, starting at about 30 cm from the entrance.

World record of stored energy is 2-3 MJ (TEVATRON, SPS, HERA). Obtained after years of operation…

careful stepwise increase in intensity through the year with each step up in intensity to be followed by an extended running period…

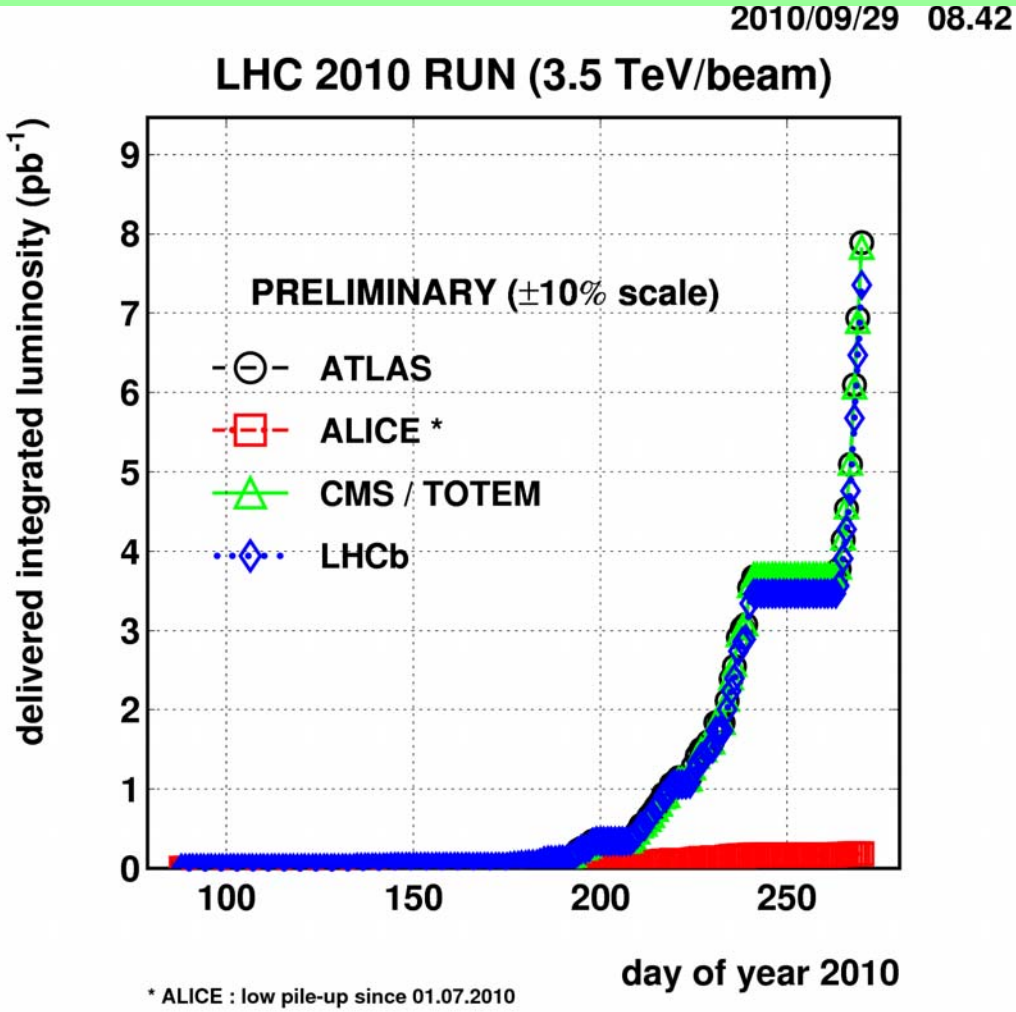
Stored Energy Evolution



Current record: ~ 10 MJ @ peak (~ Tevatron x 5!)

Destructive intensity even at injection!

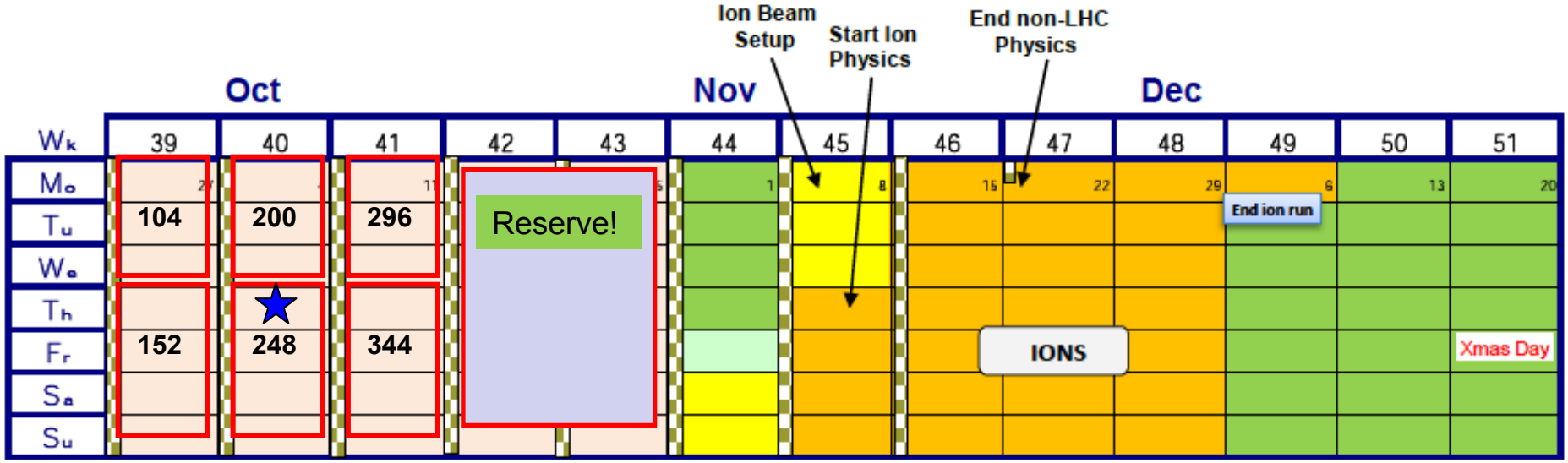
Integrated Luminosity Evolution



Current integrated luminosity > 10/pb

A fill with 100 bunches delivers 1/pb in ~12 hours

“The Plan”



Steve Myers’ plan

- Assuming we manage to follow this plan, by end of W41 we should collect another ~20-25 pb^{-1}.
- If the reserve is used for physics, with 6 fills per week it is possible to collect ~40 pb^{-1} more since for ≥ 350 b fills deliver ~3-4 pb^{-1} / 12 hour.

Outlook 2011

Possible gains in luminosity:

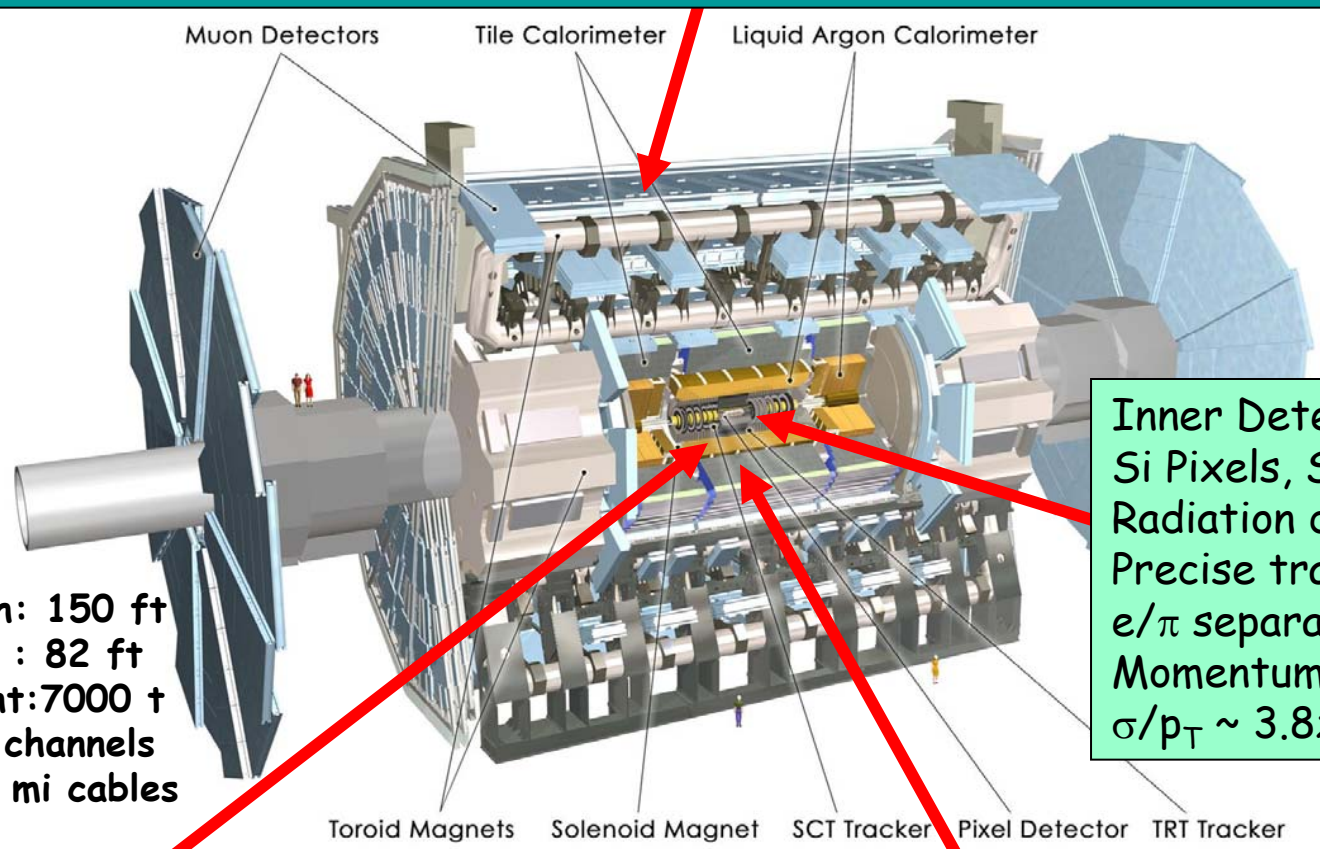
- 75/50 ns trains x 2-3
- $\beta^* = 2$ m x 1.7
- Lower emittance x 1.3
- Bunch charge to 1.3×10^{11} p x 1.4

Total x 6-9

! Total intensity may be limited by collimation or lifetime considerations – we may not gain the full factor !

ATLAS

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



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:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T(\mathrm{GeV}) \oplus 0.015$

Length: 150 ft
Ø : 82 ft
Weight: 7000 t
~10^8 channels
~2000 mi cables

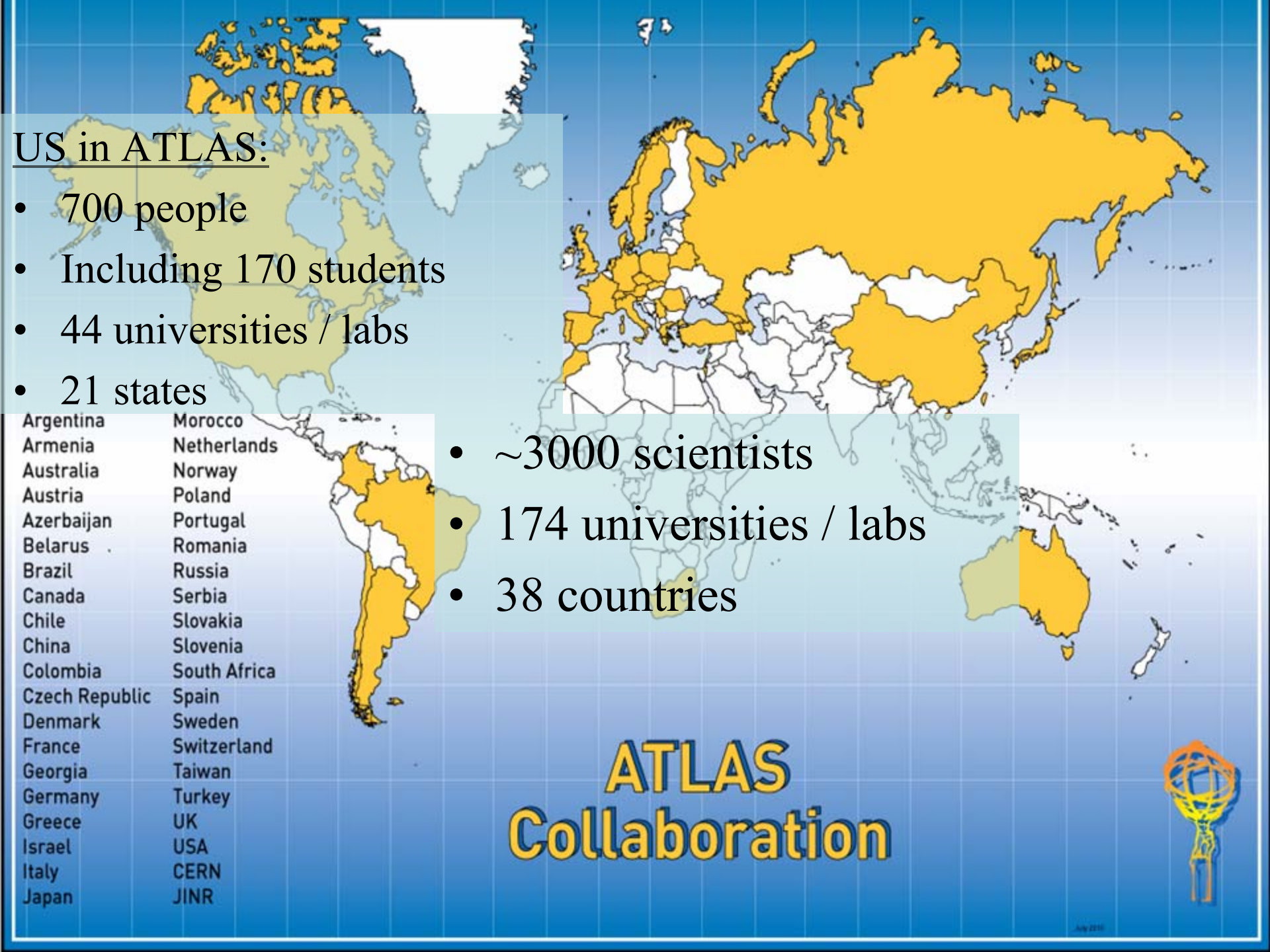
EM calorimeter: Pb-LAr Accordion
e/γ trigger, ID and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

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

US in ATLAS:

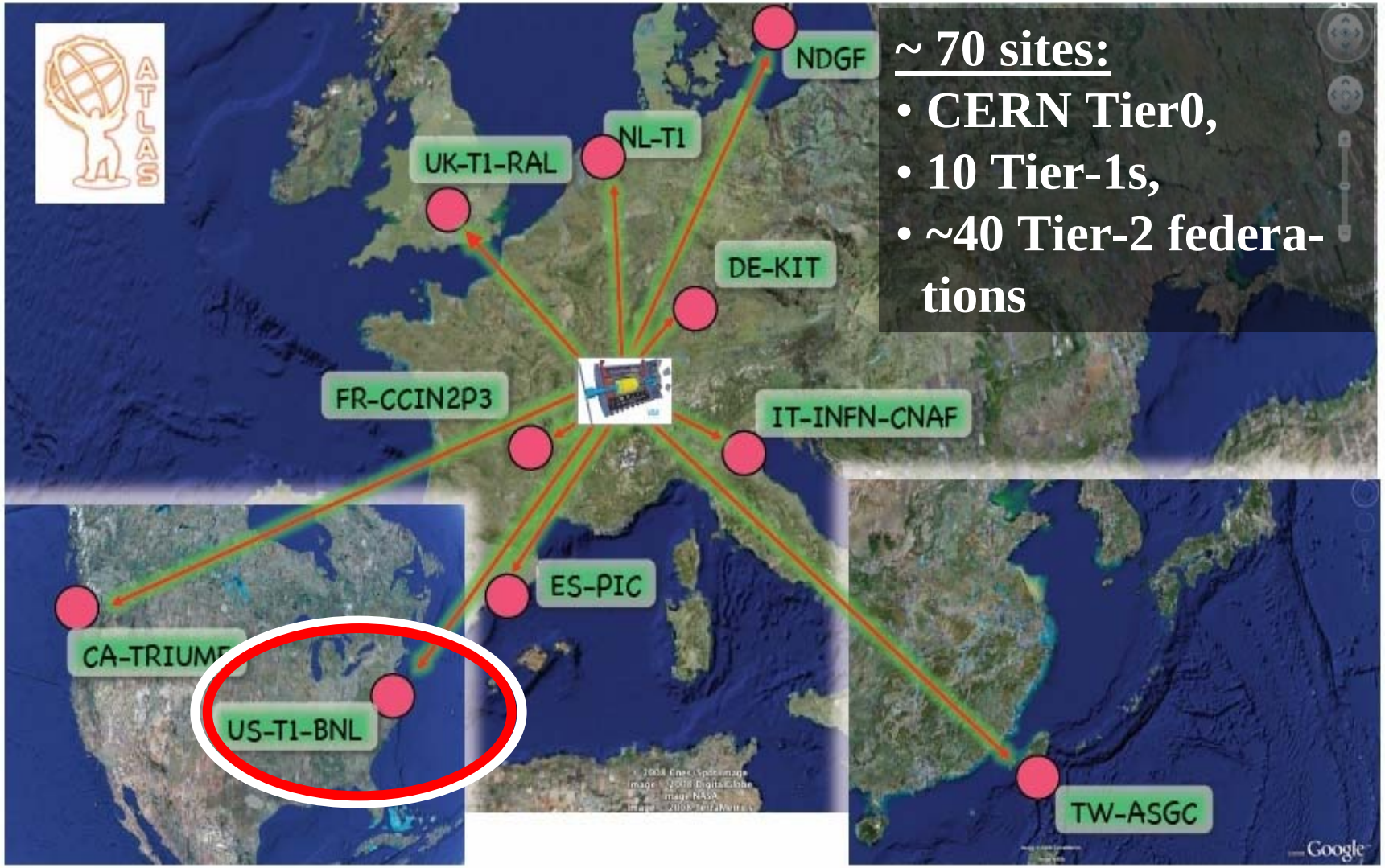
- 700 people
- Including 170 students
- 44 universities / labs
- 21 states

- ~3000 scientists
- 174 universities / labs
- 38 countries



ATLAS World-Wide Computing Grid

~10 TB/day, 1 PB/yr recorded data



~ 70 sites:

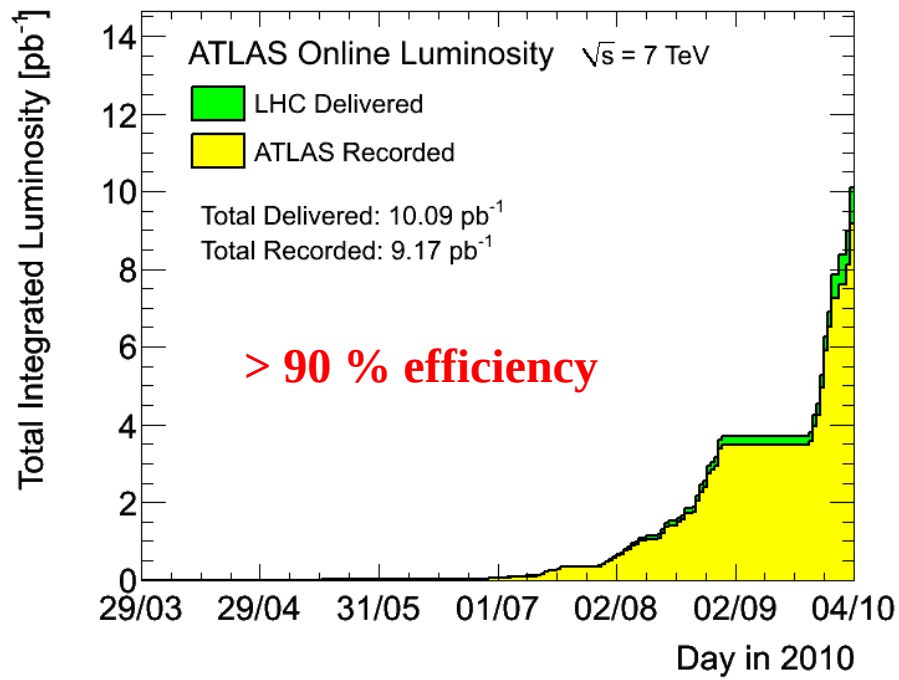
- **CERN Tier0,**
- **10 Tier-1s,**
- **~40 Tier-2 federations**

ATLAS Detector Performance

Detector Status

Subdetector	# Channels	% operational
Pixels	80 M	97.3%
SCT Silicon Strips	6.3 M	99.2%
TRT	350 k	97.1%
LAr EM Calorimeter	170 k	98.1%
Tile calorimeter	9800	96.9%
Hadr. endcap LAr cal.	5600	99.9%
Forward LAr cal.	3500	100%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trig.	370 k	99.5%
LVL1 Muon TGC trig.	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Ch.	31 k	98.5%
RPC Barrel Muon Ch.	370 k	97.0%
TGC Endcap Muon Ch.	320 k	98.6%

Data Taking Efficiency



Data Quality

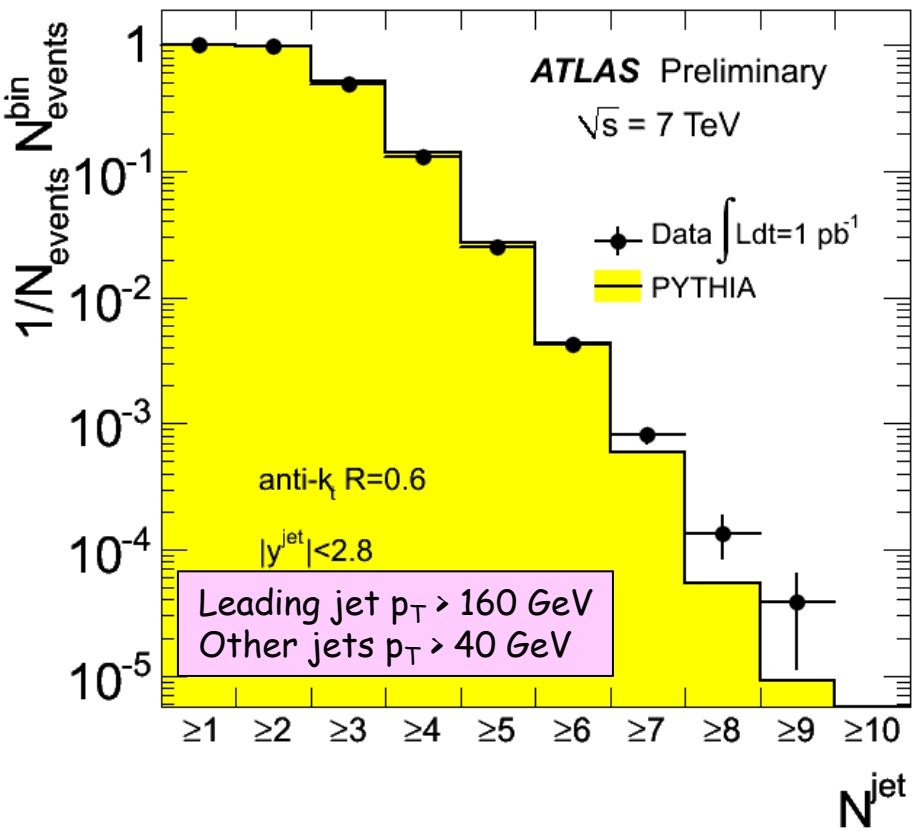
Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	TGC	CSC
96.7	97.5	100	93.8	98.8	99.0	99.7	98.6	98.5	98.6	98.5

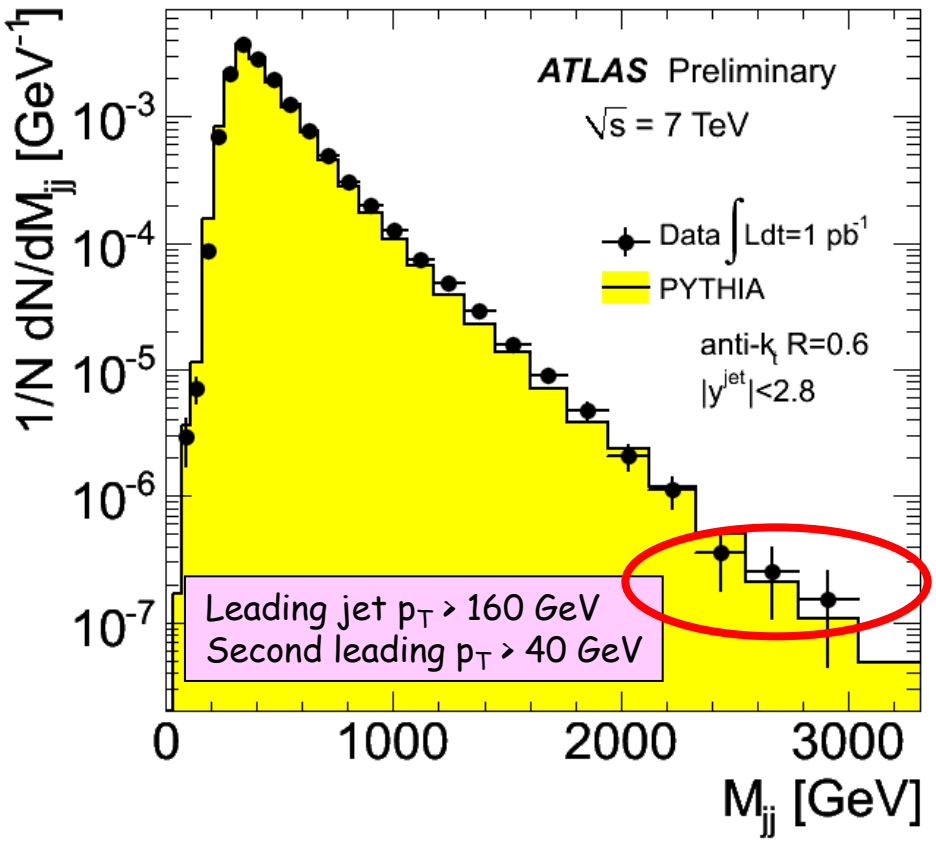
Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams at √s=7 TeV between March 30th and August 30th (in %)

(Si, μ losses due to HV ramping)

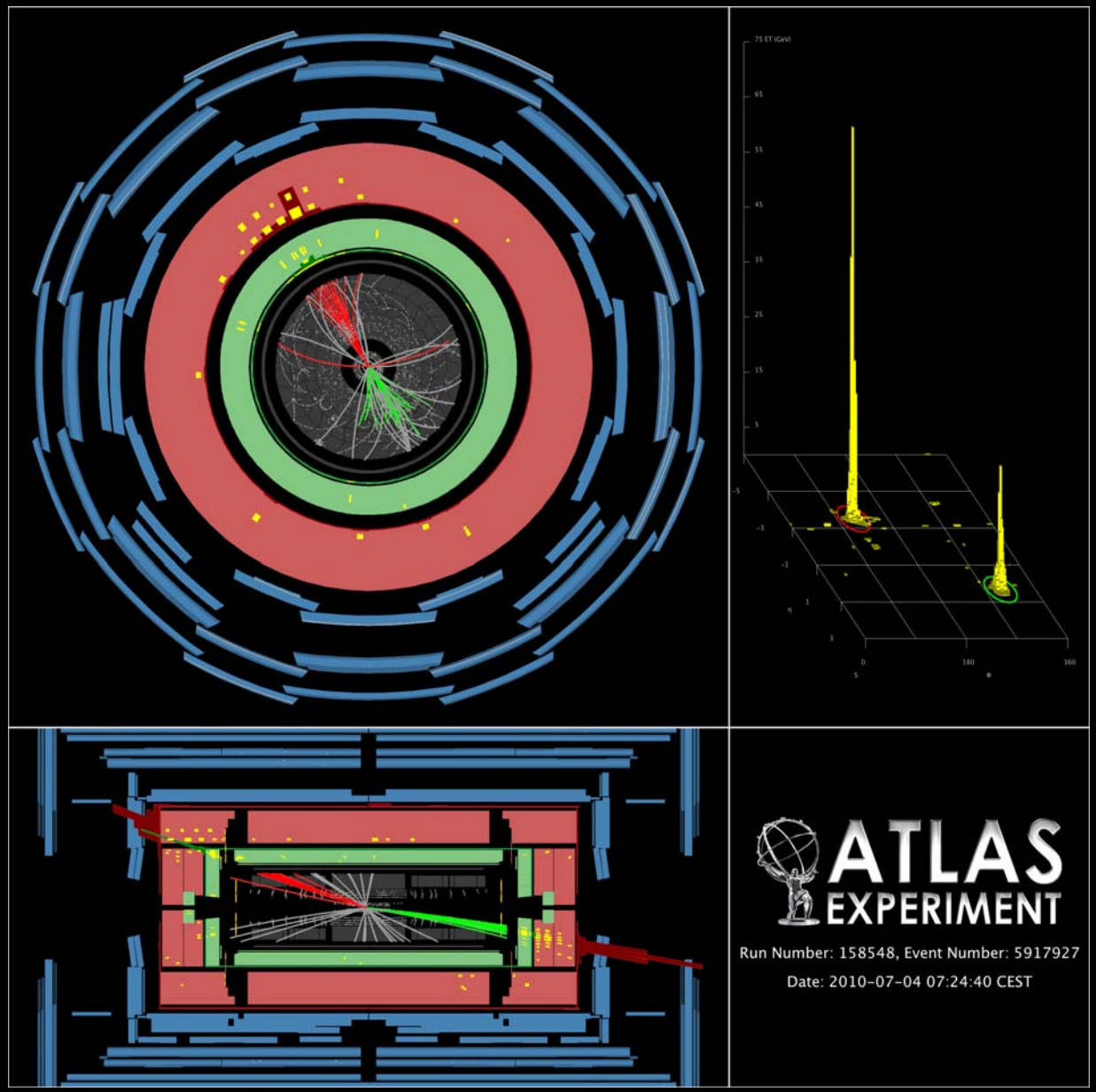
Jets

Shape comparisons between data and PYTHIA MC:
(distributions normalized to unity, only stat. uncertainties)





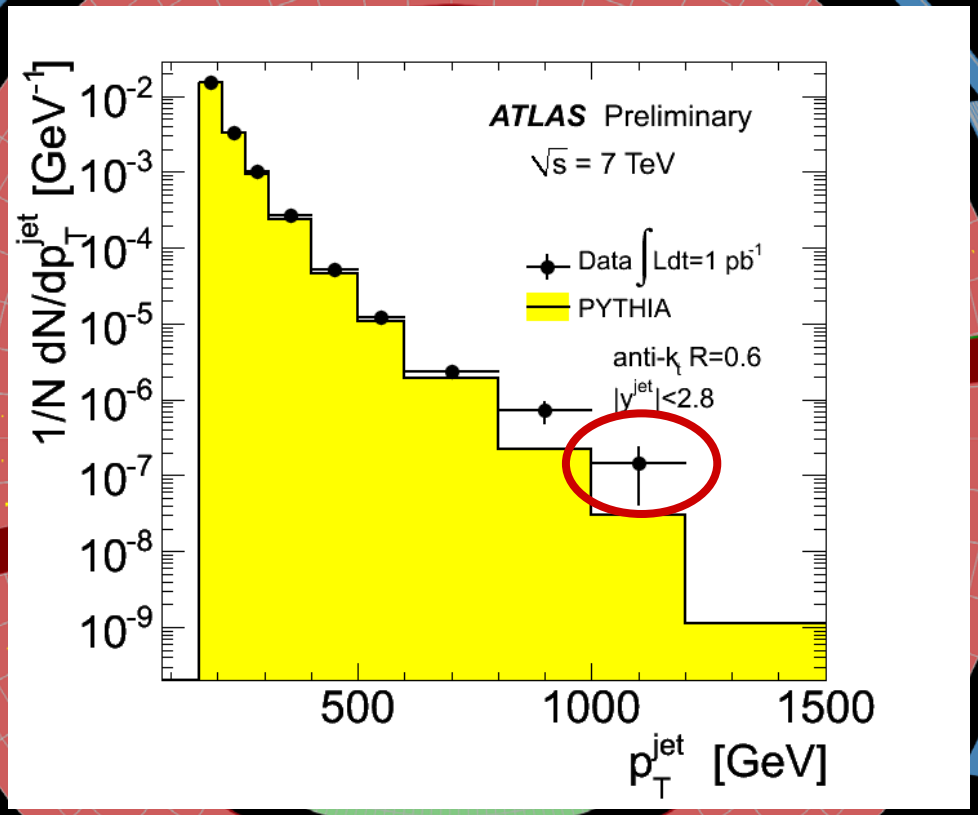
High mass dijet event

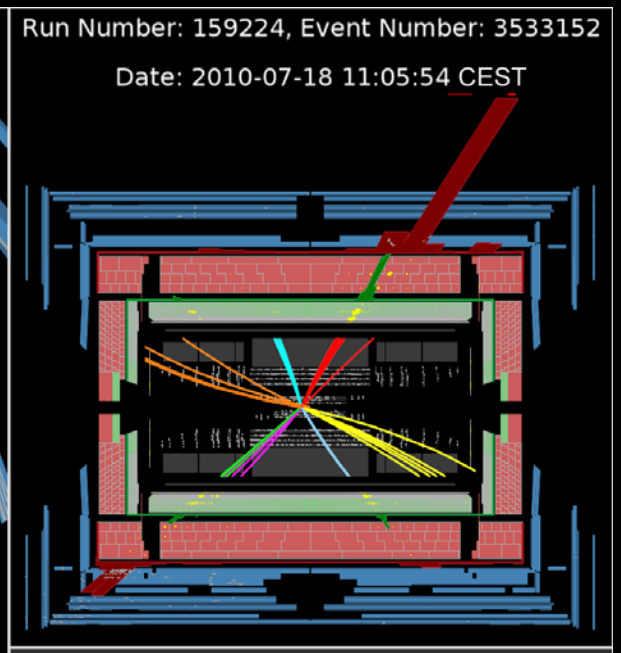


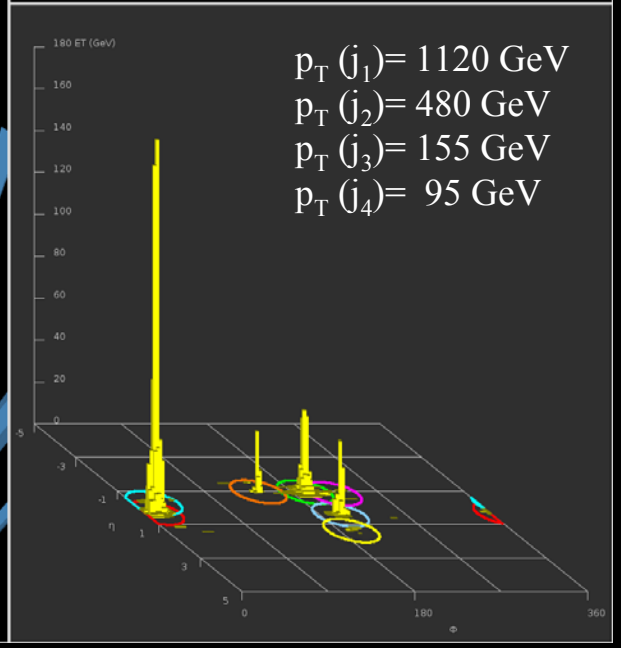
M_{jj} = 2.55 TeV
p_T (j_1)=420 GeV
p_T (j_2)=320 GeV

No other jet > 20 GeV

Hardest jet so far: $p_T > 1.1$ TeV





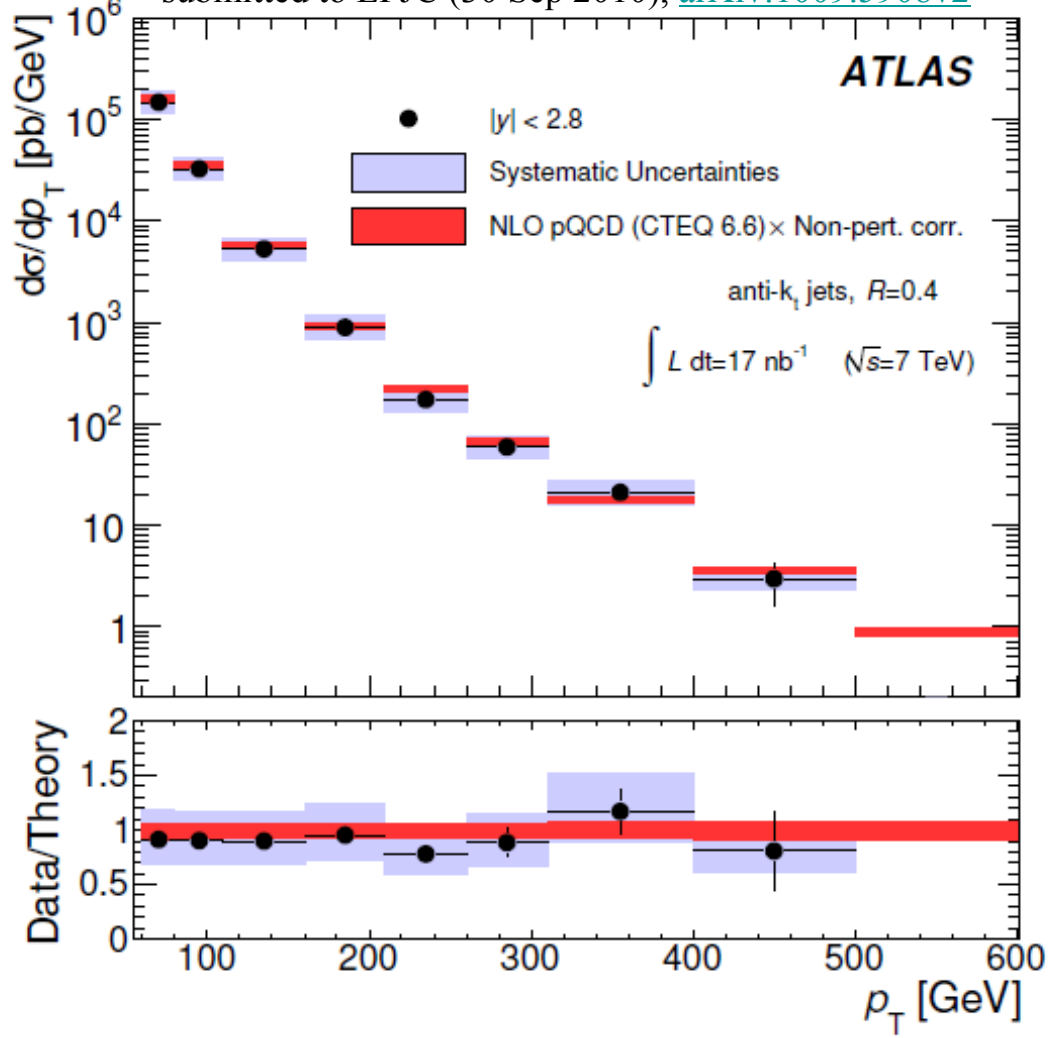


ATLAS EXPERIMENT

Inclusive jet differential cross section

- Measured jets corrected to particle-level using parton-shower MC (Pythia, Herwig): justified by detailed comparison studies and good agreement with data
- Results compared to NLO QCD prediction after corrections for hadronization and underlying event
- Theoretical uncertainty: ~20% (up to 40% at large $|y_j|$) from variation of PDF, α_s, scale (μ_R, μ_F)
- Experimental uncertainty: ~30-40% dominated by Jet E-scale (known to ~7%)
- Luminosity (11%) not included

submitted to EPJC (30 Sep 2010), arXiv:1009.5908v2

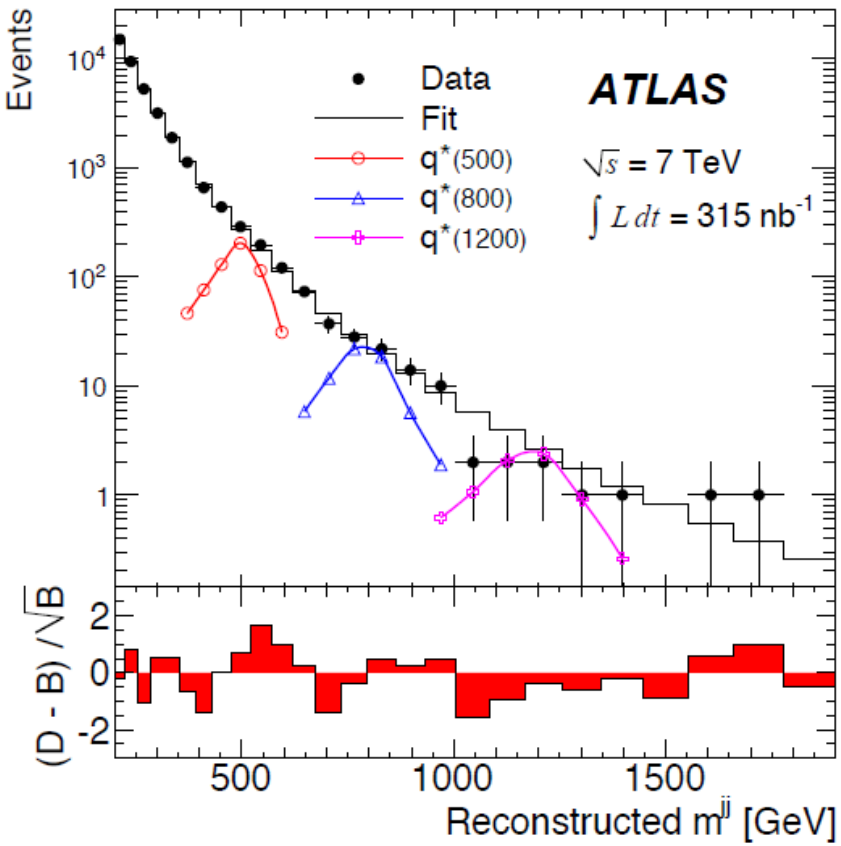


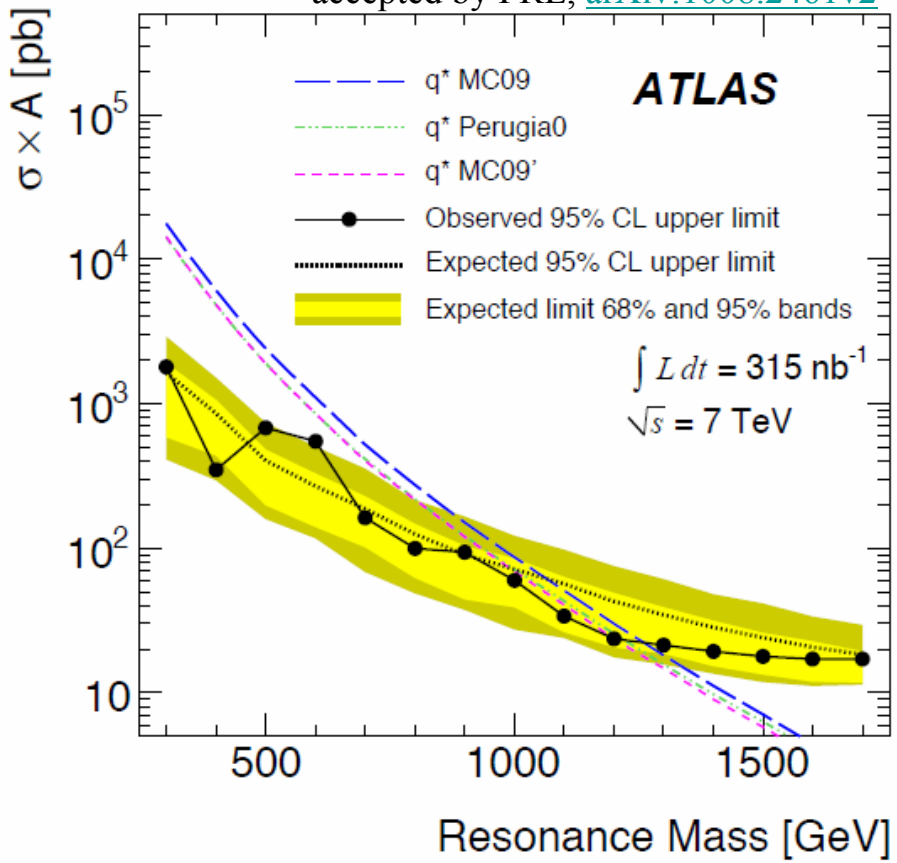
Good data-NLO QCD agreement over 5 orders of magnitude

Search for excited quarks: q*→ jj

- Search for resonance in dijet-mass: none observed
- Exp. systematic uncertainties included: lumi, JES (dominant), BG fit, …

Latest published limit:
CDF: 260 < M (q*) < 870 GeV
accepted by PRL, arXiv:1008.2461v2





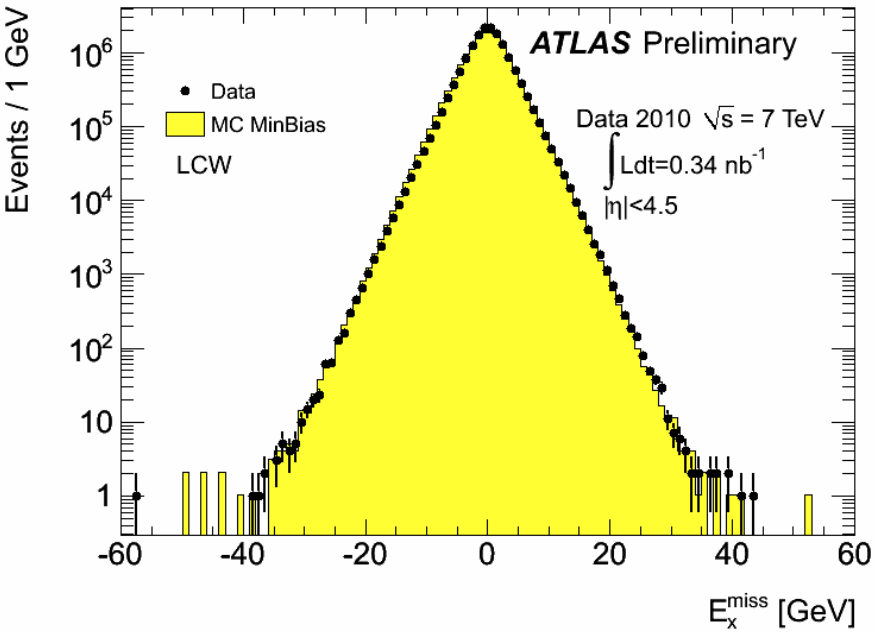
Using default ATLAS MC tune: 0.30 TeV < M (q*) < 1.26 TeV excluded @ 95% CL

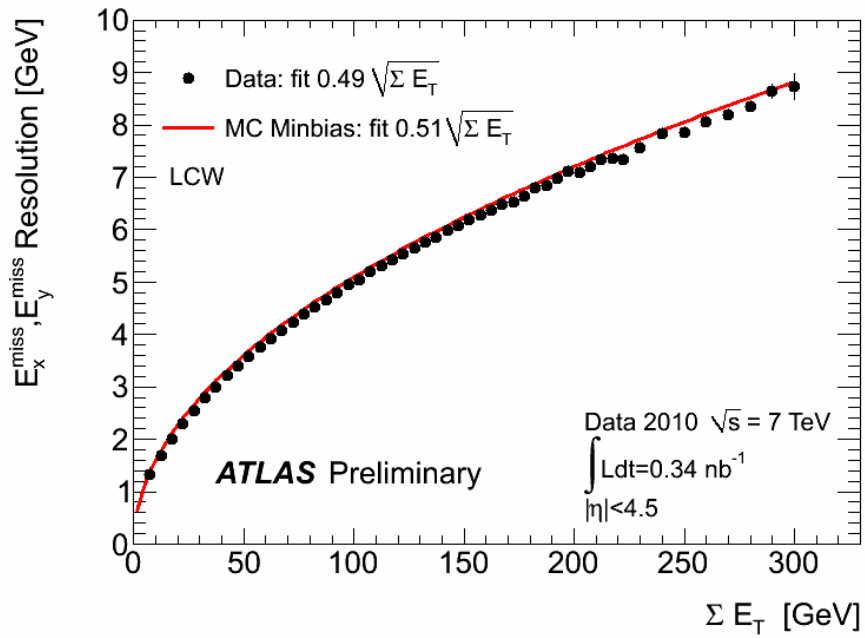
Missing E_T (MET)

Calorimeter-based MET: Sensitive to

- calorimeter performance ((coherent)noise, dead cells, mis-calibs, cracks, etc.)
- cosmics and beam-related backgrounds

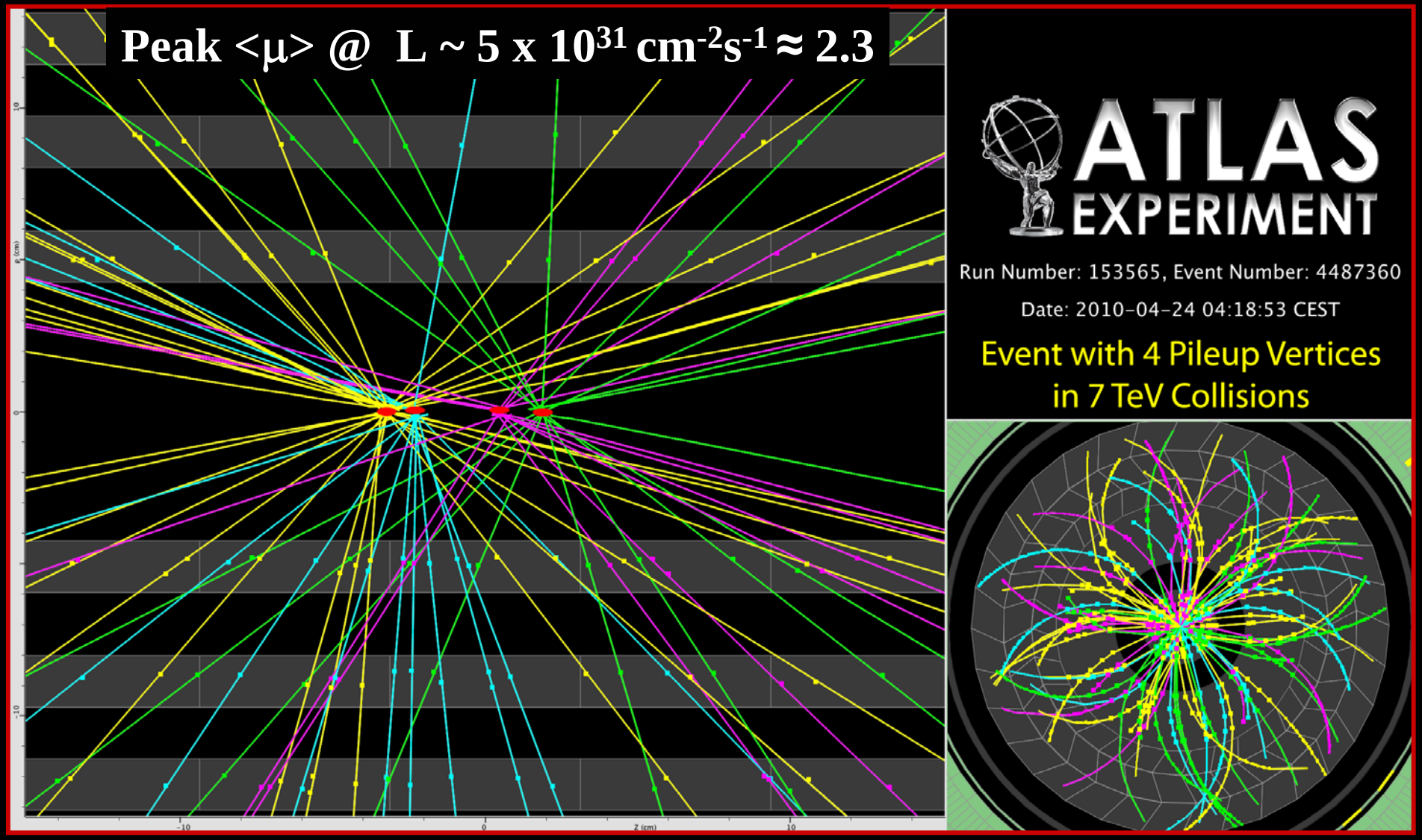
ATLAS-CONF-2010-057





MET calibration well under control !

The other side of high luminosity…



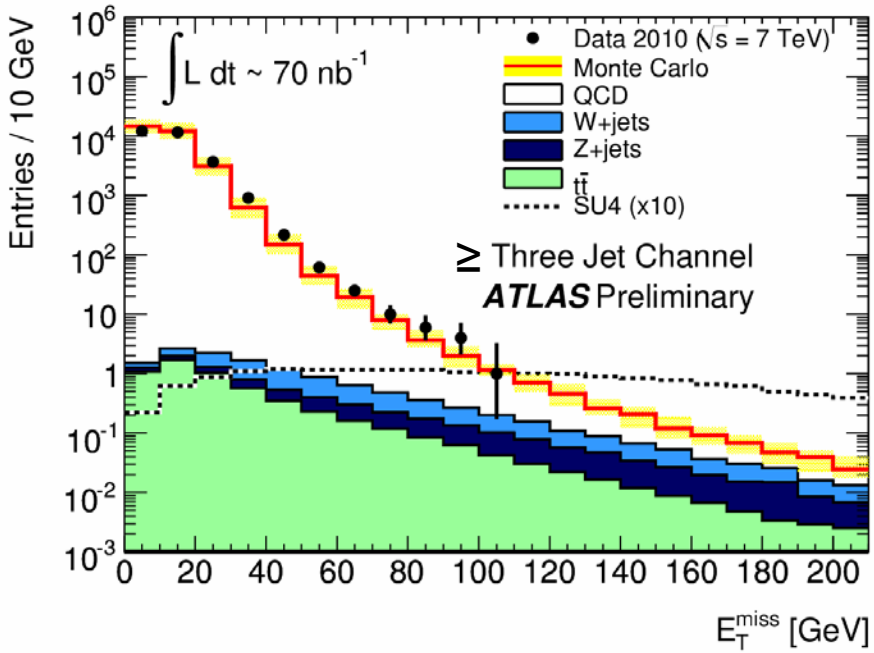
~ 10-45 tracks with p_T >150 MeV per vertex

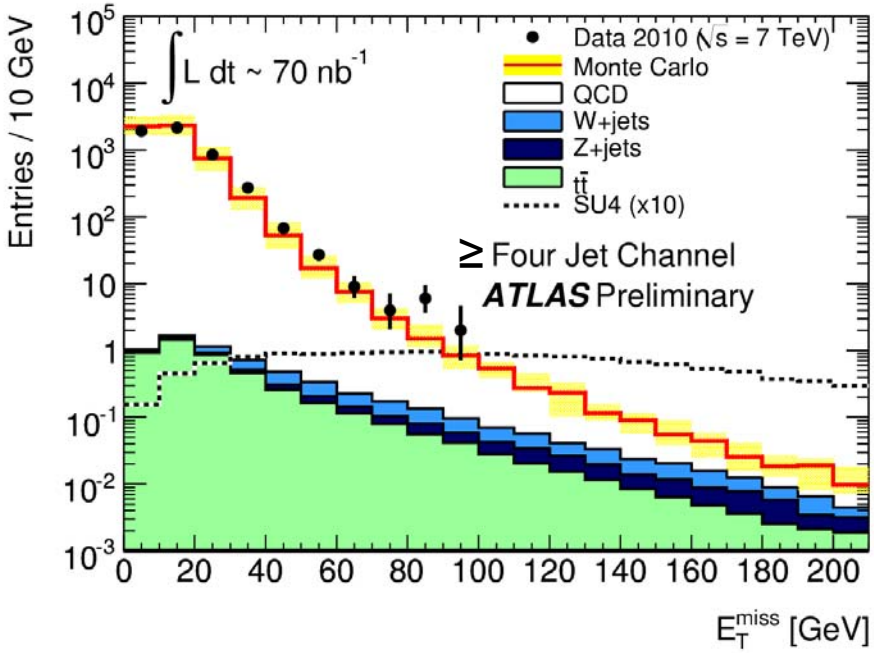
Vertex z-positions : -3.2, -2.3, 0.5, 1.9 cm (vertex resolution better than ~200 μm)

Jets + MET

Select events with MET > 40 GeV, (sub-) leading jets > (30) 70 GeV, ΔΦ(MET,jet) cuts, NO leptons, …

ATLAS-CONF-2010-065



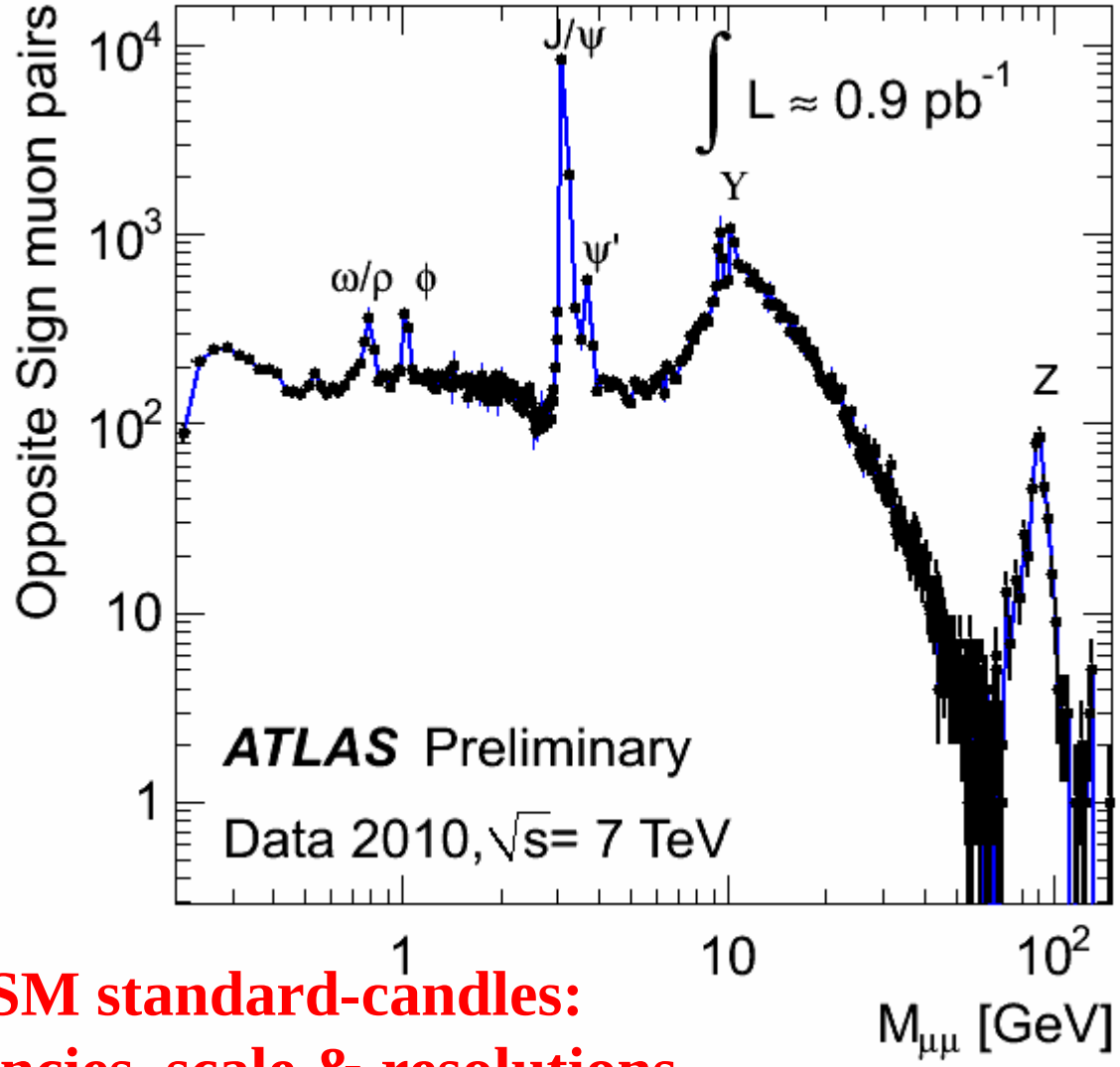


- Reasonable agreement wrt. Standard Model prediction found
- Larger datasets will provide sensitivity for new physics (mSUGRA example above)

Muons

Di-muon invariant mass spectrum:

- LVL1 muon trigger with $p_T \sim 6$ GeV threshold
- 2 opposite-sign muons reconstructed by combining tracker and muon spectrometer
- both muons with $|z|<1$ cm from primary vertex



Rediscovering the SM standard-candles:
=> trigger & ID efficiencies, scale & resolutions

Electrons

Electron reco / ID:

-energy from calibrated cluster

-angles from track

3 levels of ID:

-loose (basic shower shape & track)

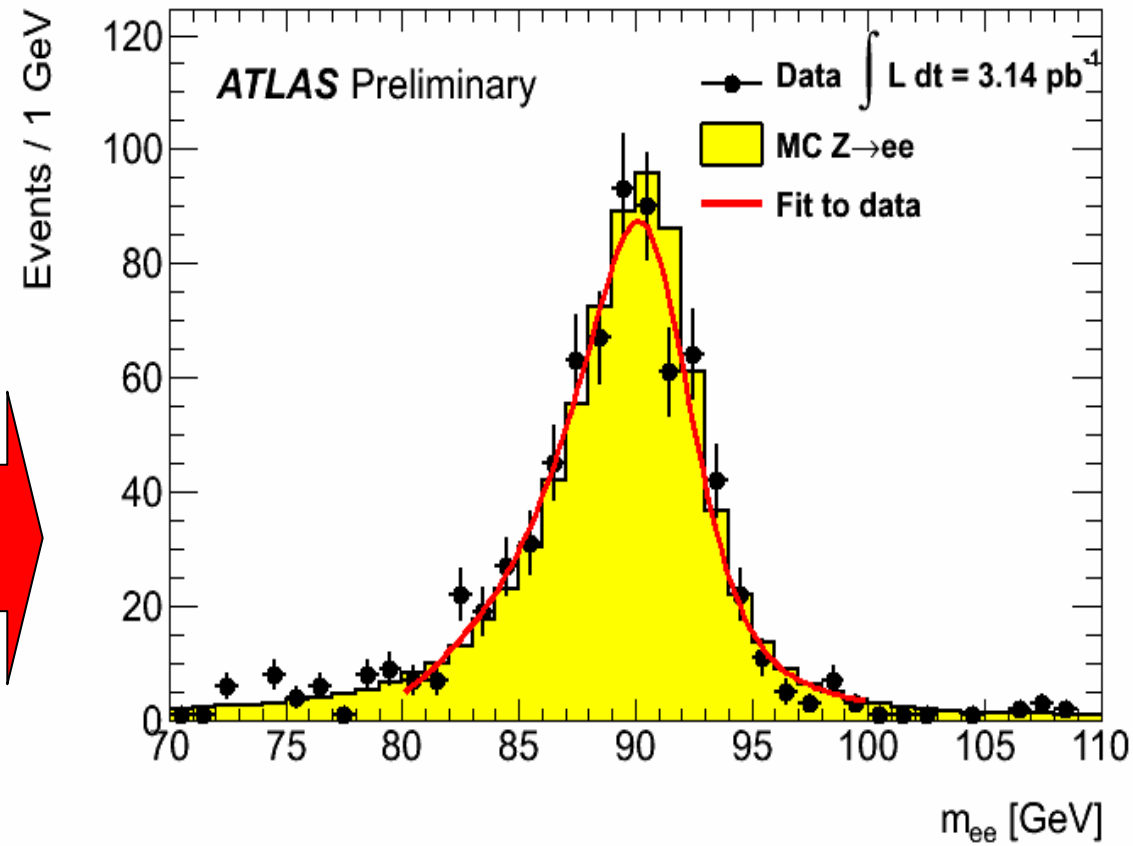
-medium: refined shower shape, pixel hit,…

-tight: track match, TRT, E/P

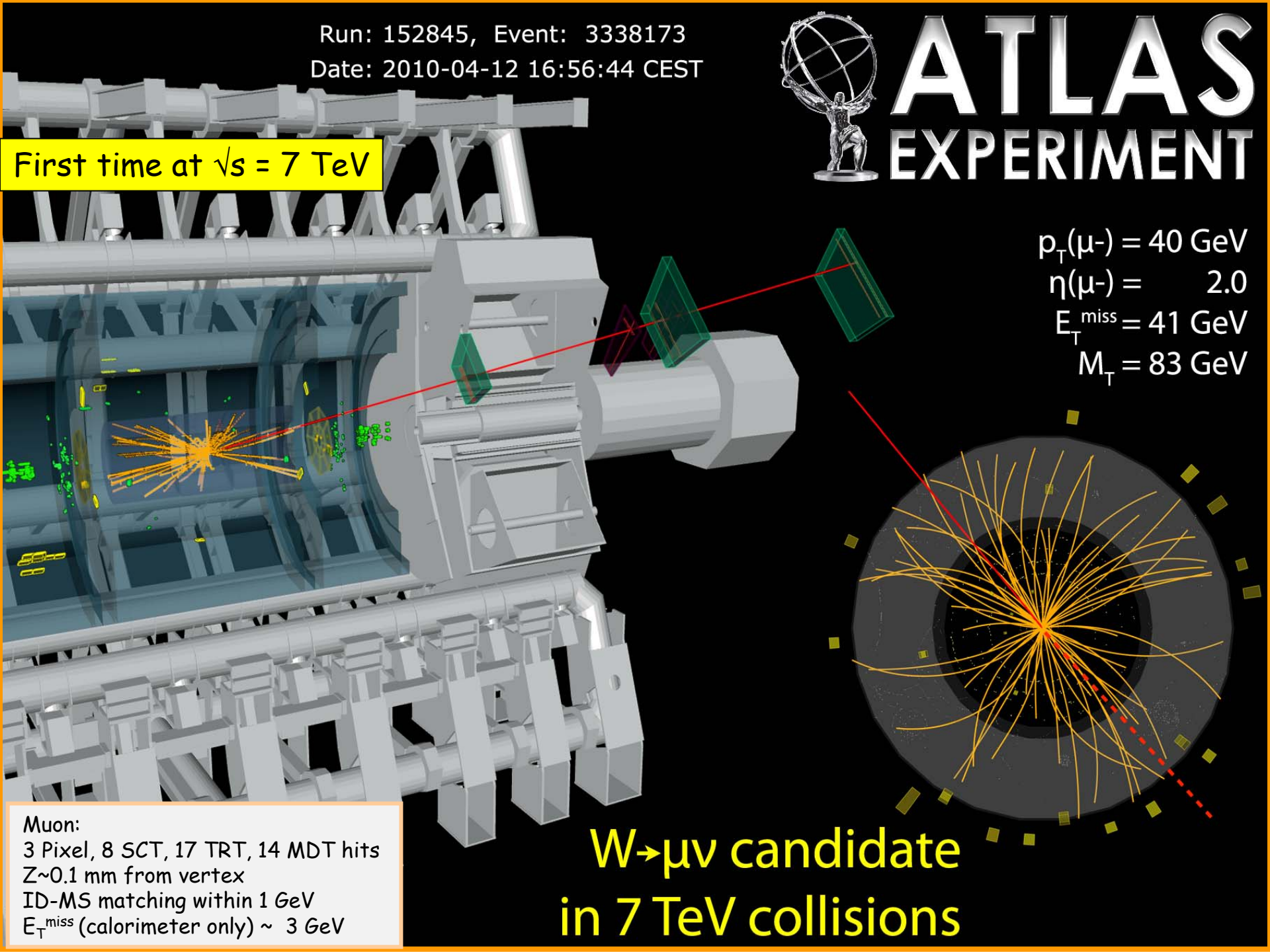
Tight (>20 GeV)rejection/jets up to 10^5

ATL-COM-PHYS-2010-734

- Two opposite sign EMs
- $E_T > 20$ GeV
- $|\eta| < 2.47$ ($\neg$crack $1.37 < |\eta| < 1.52$)
- "Medium" ID quality
- M_{ll} in [80,100] GeV



Determine the electromagnetic energy scale


Run: 152845, Event: 3338173
Date: 2010-04-12 16:56:44 CEST
ATLAS EXPERIMENT
First time at √s = 7 TeV
$p_T(\mu-) = 40$ GeV
$\eta(\mu-) = 2.0$
$E_T^{miss} = 41$ GeV
$M_T = 83$ GeV
Muon:
3 Pixel, 8 SCT, 17 TRT, 14 MDT hits
Z~0.1 mm from vertex
ID-MS matching within 1 GeV
E_T^{miss} (calorimeter only) ~ 3 GeV
W→μν candidate
in 7 TeV collisions

W production cross-section

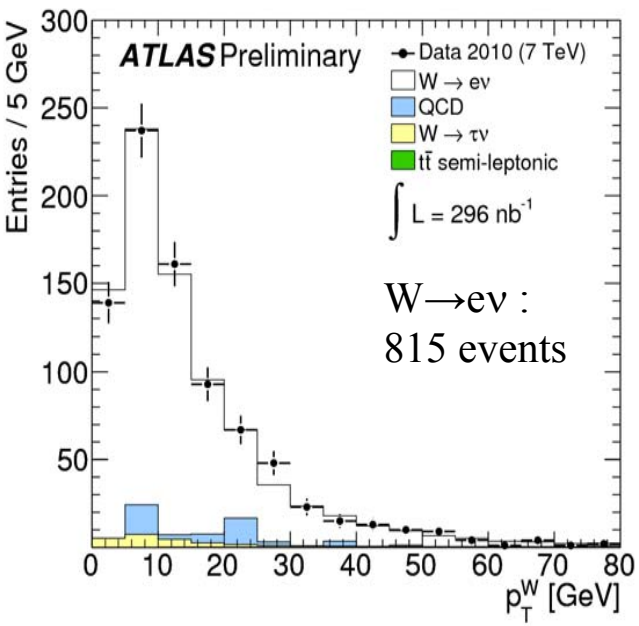
W→eν:

- $E_T(e) > 20$ GeV, $|\eta|<2.47$
- tight electron identification criteria
- $E_T^{miss} > 25$ GeV
- transverse mass $m_T > 40$ GeV

➢Acceptance x efficiency : ~ 30%

➢Main background: QCD jets

➢Expected S/B: ~ 20



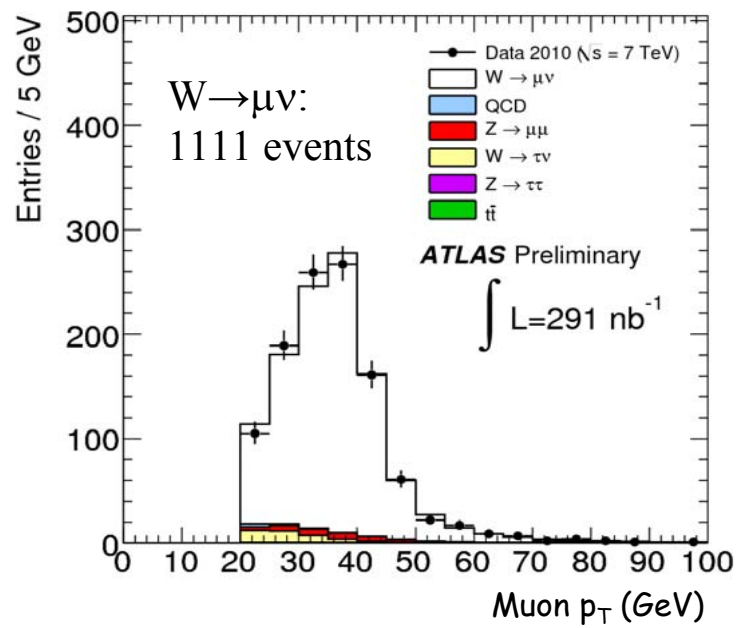
W→μν:

- $p_T(\mu) > 20$ GeV, $|\eta|<2.4$, $|\Delta p_T^{ID-MS}| < 15$ GeV
- isolated; $|Z_\mu - Z_{vtx}|<1$ cm
- $E_T^{miss} > 25$ GeV
- transverse mass $m_T > 40$ GeV

➢Acceptance x efficiency: ~ 40%

➢Main background: Z→μμ and QCD

➢Expected S/B ~ 20



W production cross-section

σ (W $\rightarrow$ eν) = 8.5 ± 1.3 (stat) ± 0.7 (syst) ± 0.9 (lumi) nb
σ (W $\rightarrow$ $\mu\nu$) = 10.3 ± 1.3 (stat) ± 0.8 (syst) ± 1.1 (lumi) nb

(based on first 17 nb^{-1})

σ (W $\rightarrow$ lν) = 9.3 ± 0.9 (stat) ± 0.6 (syst) ± 1.0 (lumi) nb

σ^{NNLO} (W $\rightarrow$ lν) = 10.46 nb per family

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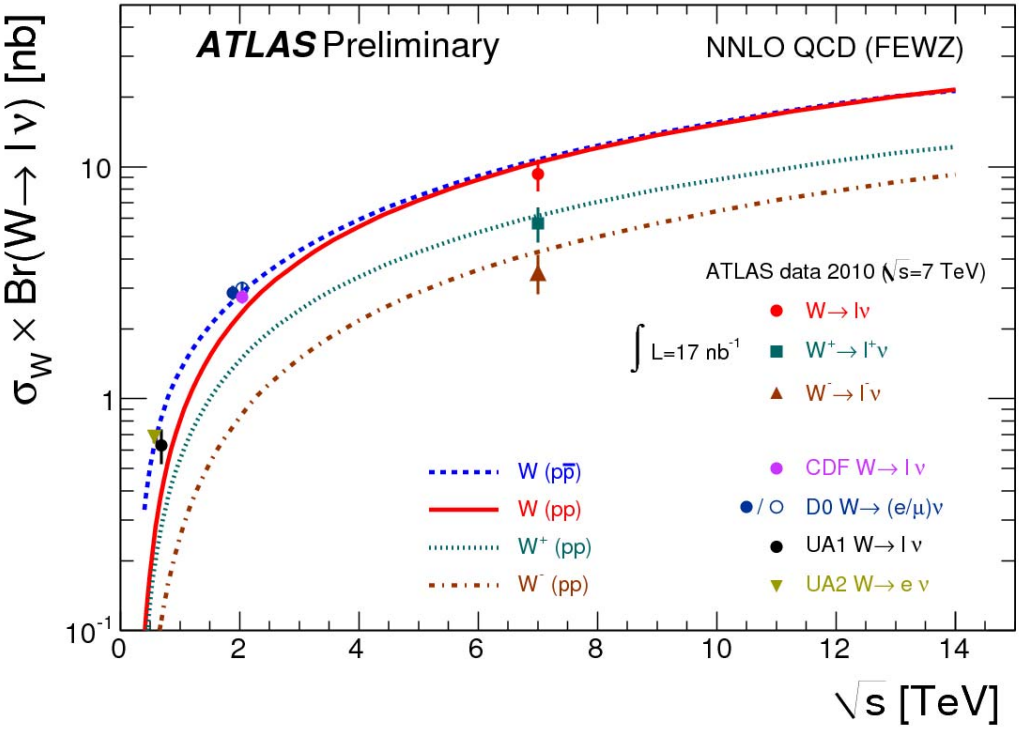


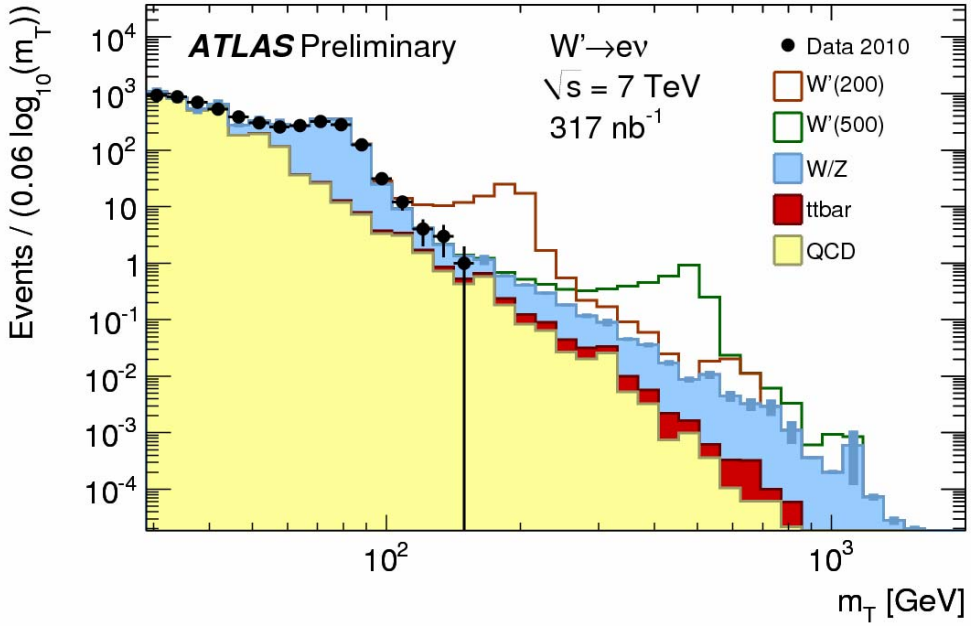
Dominant experimental uncertainties:
e: identification efficiency
μ: trigger and reconstruction efficiency

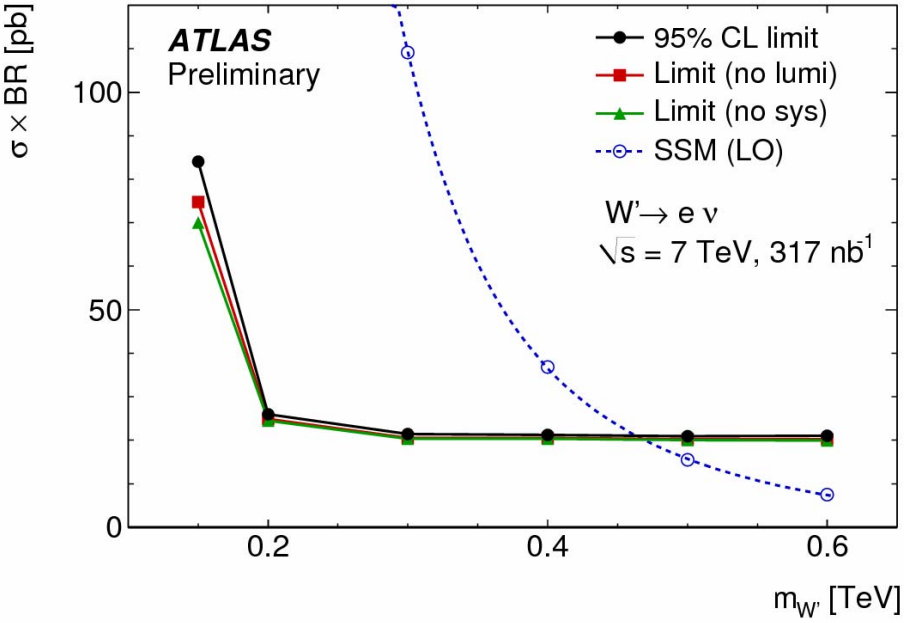
Constrain PDFs through W$^+$, W$^-$ rates

W' search

Search for Sequential Standard Model (SSM)W′ in eν channel:

ATLAS-CONF-2010-089





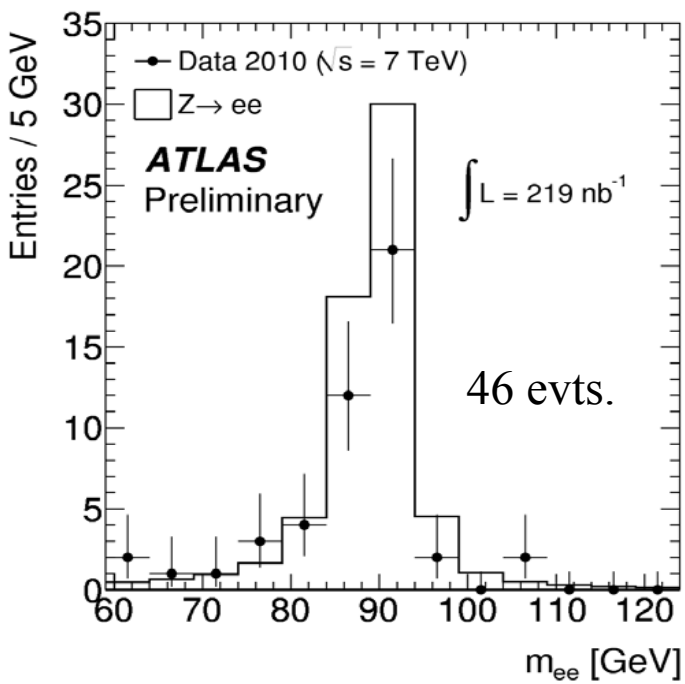
$m_{W'}$ < 465 GeV excluded @ 95% CL

Z production cross-section

Z→ee:

- 2 opposite-sign electrons
- $E_T > 20$ GeV, $|\eta|<2.47$
- medium electron identification criteria
- $66 < M(e^+e^-) < 116$ GeV

➢ Acceptance x efficiency : ~ 30%
➢ Main background: QCD jets
➢ Expected S/B ~ 100



Z→μμ:

- 2 opposite-sign muons
- $p_T > 20$ GeV, $|\eta|<2.4$, $\Delta p_T^{\text{ID-MS}}| < 15$ GeV
- isolated; $|Z_\mu - Z_{vtx}|<1$ cm
- $66 < M(\mu^+\mu^-) < 116$ GeV

➢ Acceptance x efficiency: ~ 40%
➢ Main background: tt, Z→ ττ
➢ Expected S/B > 100

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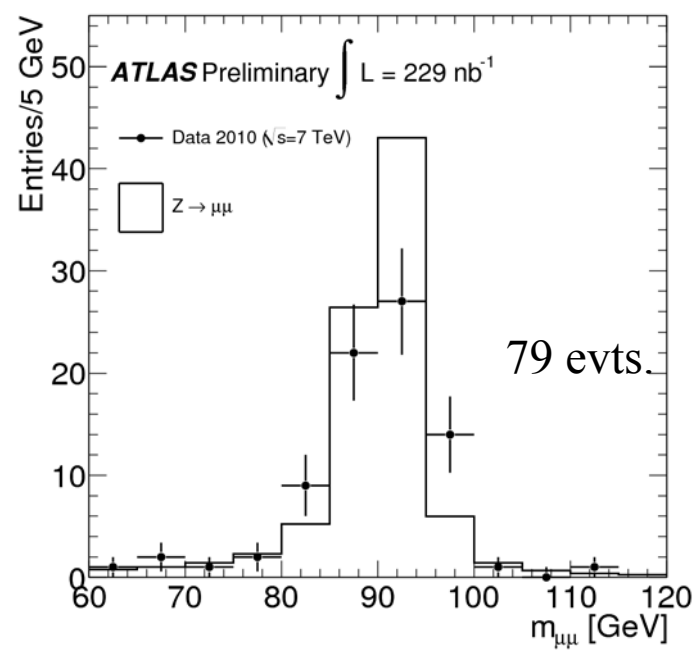
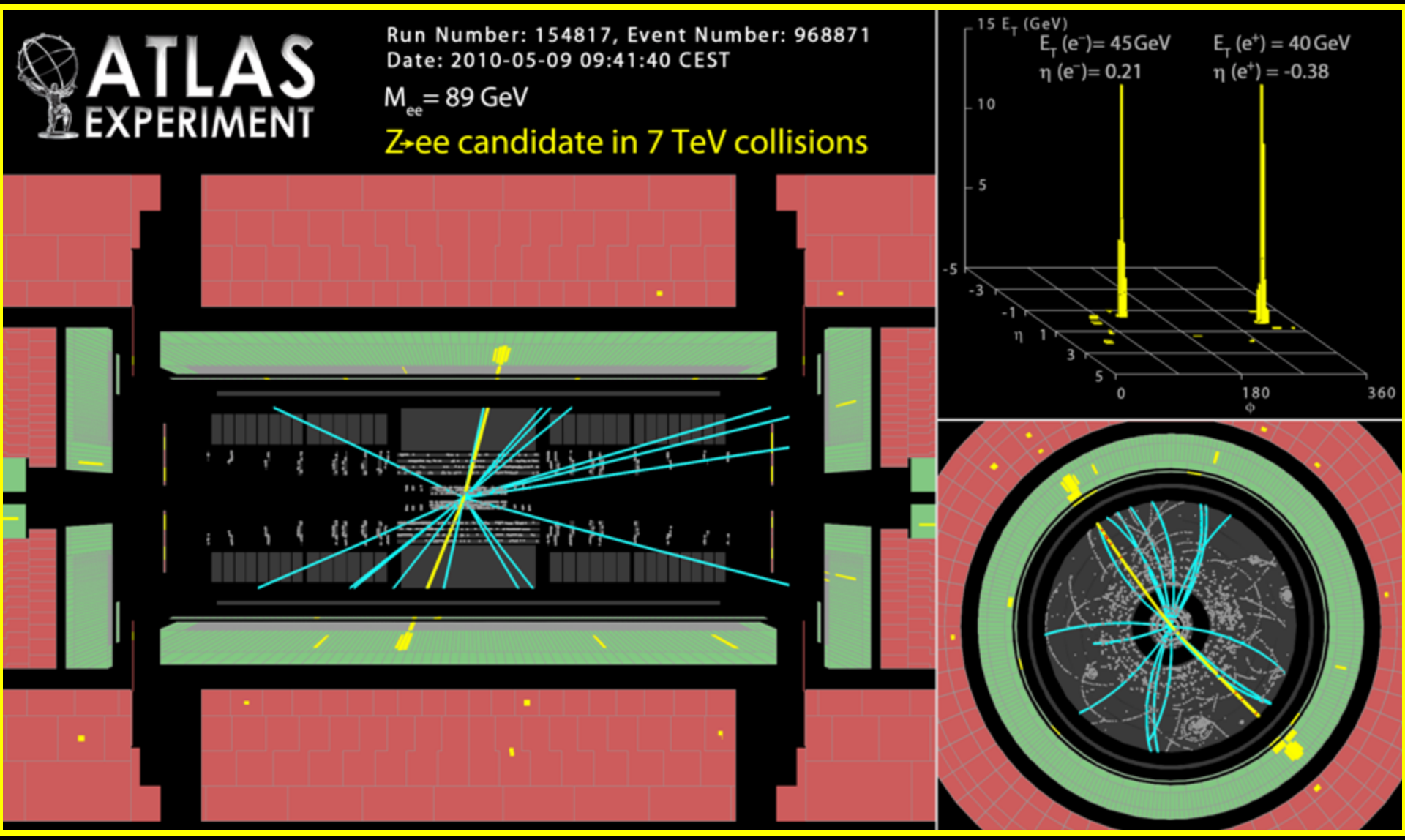
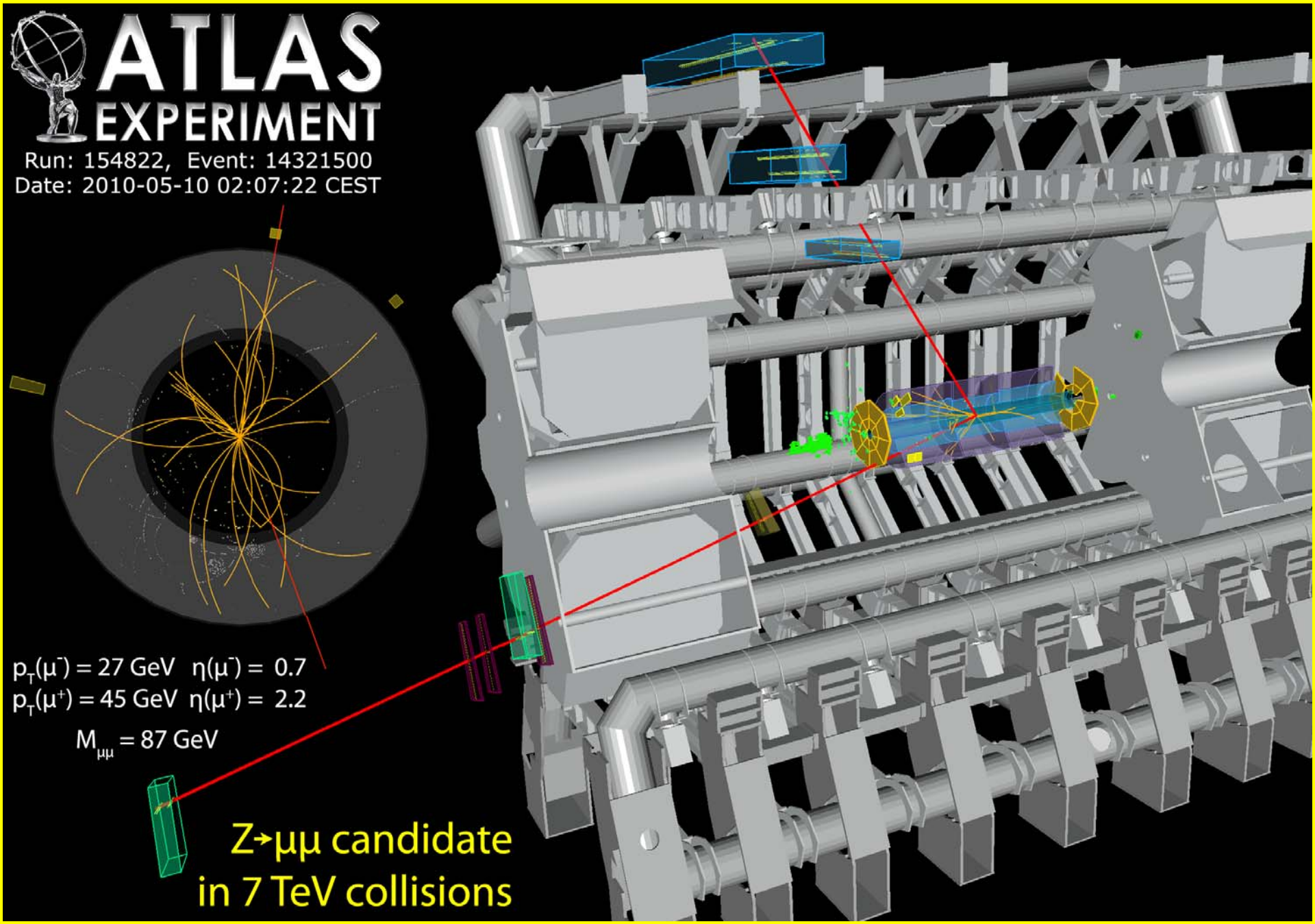



ATLAS EXPERIMENT
Run Number: 154817, Event Number: 968871
Date: 2010-05-09 09:41:40 CEST
M_{ee} = 89 GeV
Z→ee candidate in 7 TeV collisions
15 E_T (GeV)
E_T (e^-)= 45 GeV
η (e^-)= 0.21
E_T (e^+) = 40 GeV
η (e^+) = -0.38
10
5
-5
-3
-1
η
1
3
5
0
180
360
φ

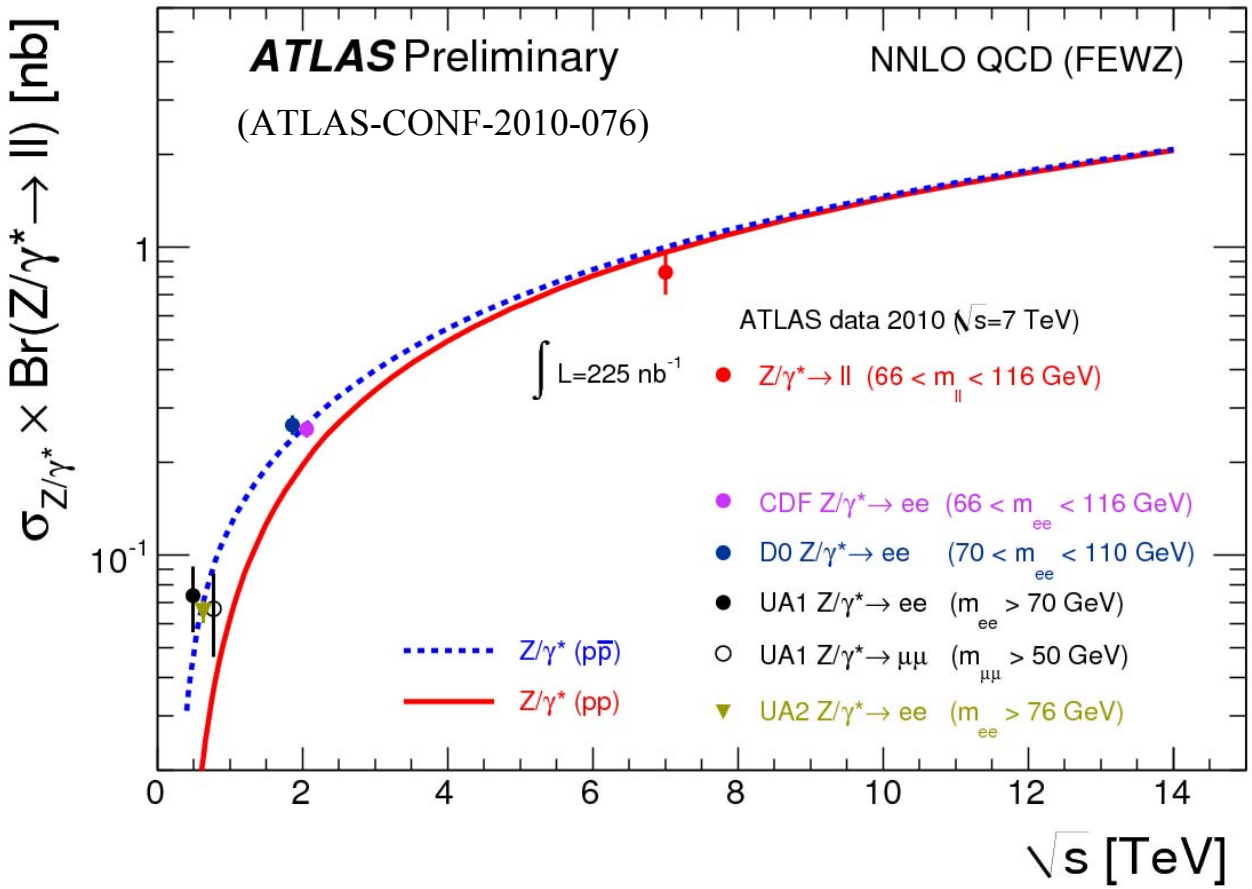

ATLAS
EXPERIMENT
Run: 154822, Event: 14321500
Date: 2010-05-10 02:07:22 CEST
$p_T(\mu^-) = 27$ GeV $\eta(\mu^-) = 0.7$
$p_T(\mu^+) = 45$ GeV $\eta(\mu^+) = 2.2$
$M_{\mu\mu} = 87$ GeV
Z→μμ candidate
in 7 TeV collisions

Z production cross-section

$\sigma(Z \rightarrow ee) = 0.72 \pm 0.11$ (stat) ± 0.10 (syst) ± 0.08 (lumi) nb
$\sigma(Z \rightarrow \mu\mu) = 0.89 \pm 0.10$ (stat) ± 0.07 (syst) ± 0.10 (lumi) nb

$\sigma(Z \rightarrow ll) = 0.83 \pm 0.07$ (stat) ± 0.06 (syst) ± 0.09 (lumi) nb

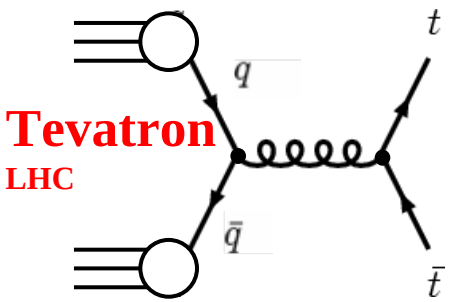
$\sigma^{NNLO}(\gamma^*/Z \rightarrow ll) \sim 0.99$ nb / family for $M(ll) > 60$ GeV



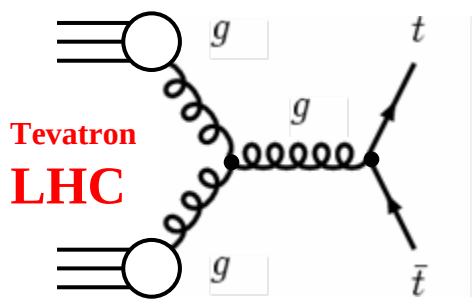
Dominant experimental uncertainty:
lepton reconstruction and identification

Top Quark Production & Decay

- Main **production** of Top Quarks – via strong interaction in *pairs*:



+



Theoretical expectation:

$$\sigma_{t\bar{t}} = (163\ ^{+11}_{-10})\ \text{pb}$$

Kidonakis, arXiv:1009.4935v1

m_t=173 GeV, $\sqrt{s}$ = 7 TeV

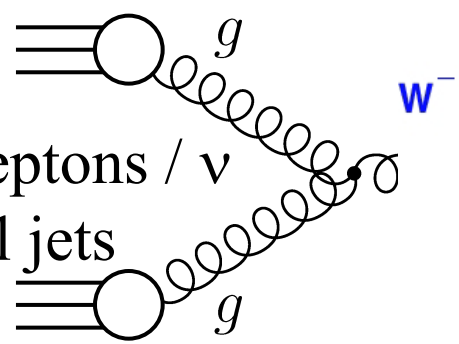
- SM Top **decay** ≈100% Wb

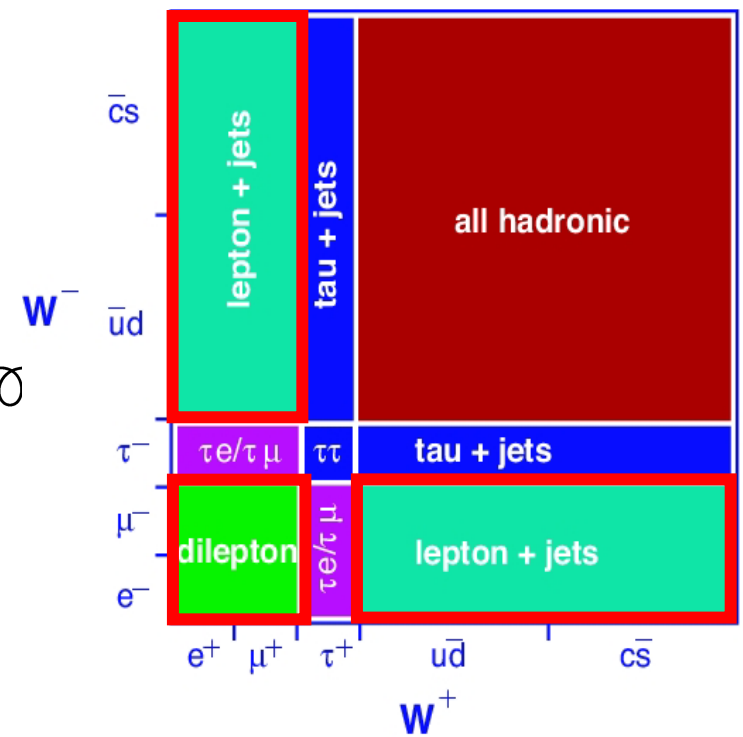
⇒ W decay modes determine final states

⇒ 2 b-jets

⇒ Up to two charged leptons / ν

⇒ Up to four additional jets





Selection of top-candidates

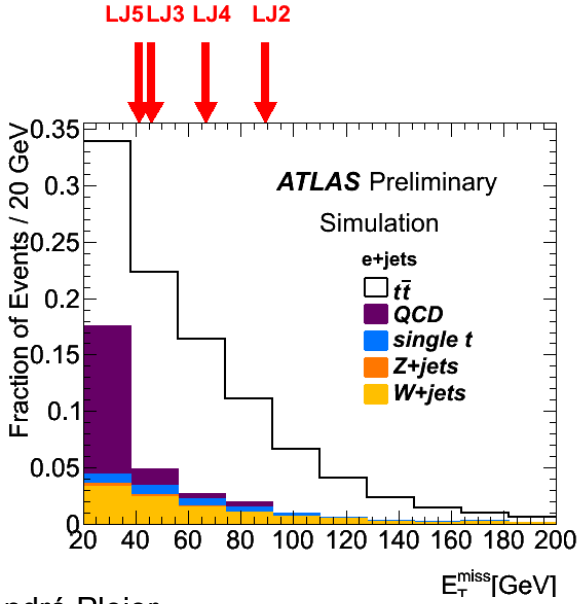
lepton + jets channel (σ ~ 70 pb):

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

➢Acceptance x efficiency ~ 30%

➢Expect ~ 5 signal events (280/nb data sample)

Observed: 7 candidates (4 e+j, 3 μ+j)



ATLAS-CONF-2010-063

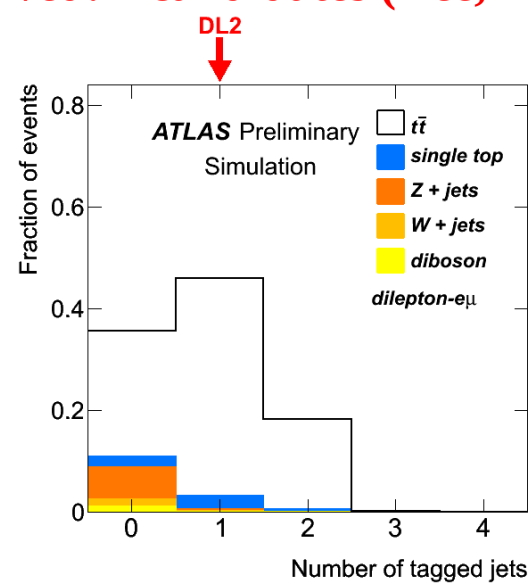
dilepton channel (σ ~ 10 pb)

- 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

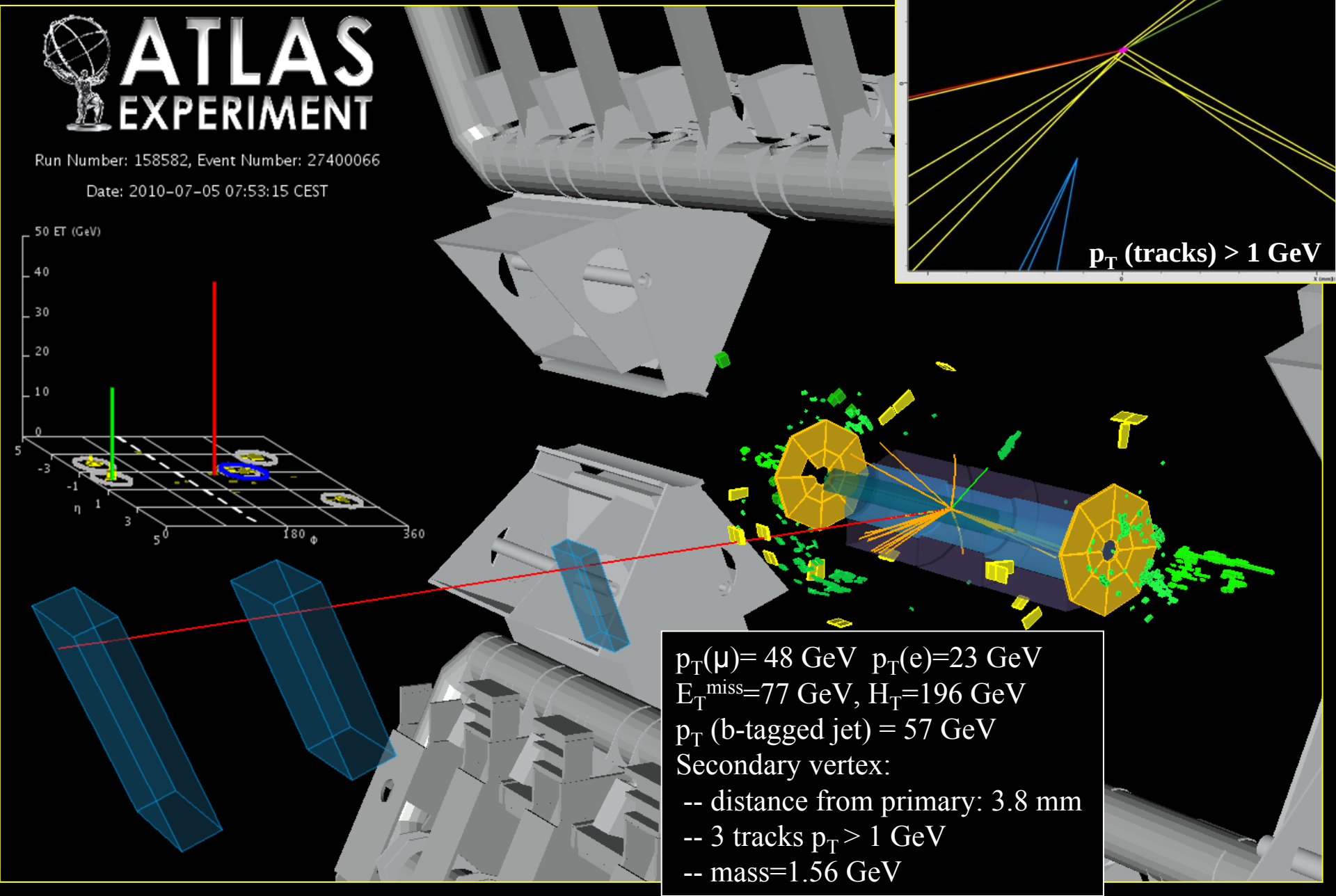
➢Acceptance x efficiency ~ 25%

➢Expect ~ 0.7 signal events (280/nb data sample)

Observed: 2 candidates (1 ee, 1eμ)



eμ candidate event



$p_T(\mu)$= 48 GeV $p_T(e)$=23 GeV
E_T^{miss}=77 GeV, H_T=196 GeV
p_T (b-tagged jet) = 57 GeV
Secondary vertex:
-- distance from primary: 3.8 mm
-- 3 tracks p_T > 1 GeV
-- mass=1.56 GeV

Summary

LHC:
•Increased luminosity by ~100000 in ½ year!
•Well on track for 50/pb in 2010, 1/fb in 2011.

ATLAS:
•Good detector performance
•Rich physics program – only a glimpse today!
•More information: see ATLAS Public Results page

The LHC era has only just begun!

Thanks to R. Bailey, F.Gianotti, M. Lamont, S. Myers, J. Wenninger for their slide-material and a few thousand scientists, engineers & technicians making these results possible…

Outlook: ATLAS @ LHC
???
Higgs?!
VV
Top
? ?
V+Jets
Calibration