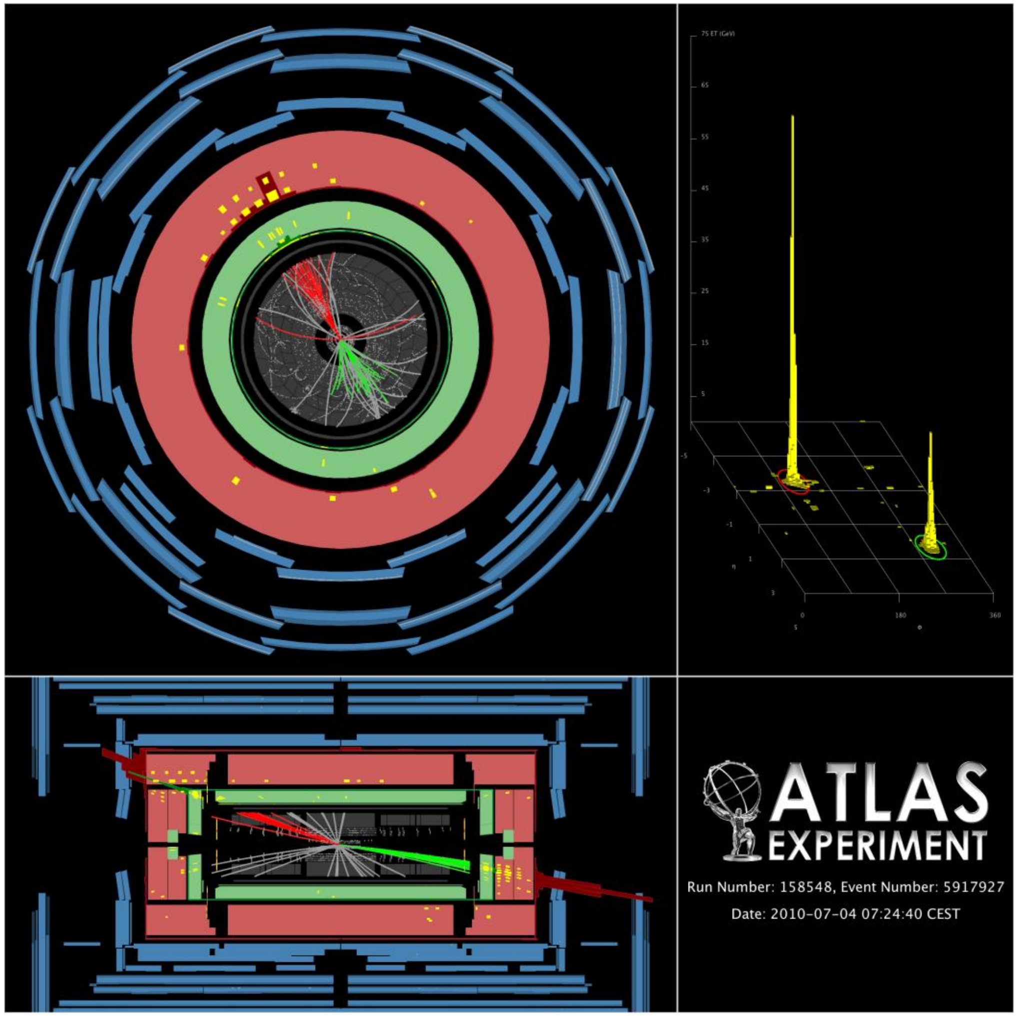
A (Distressingly Incomplete) Subset of ATLAS Results



ATLAS of the Americas
9 August 2010

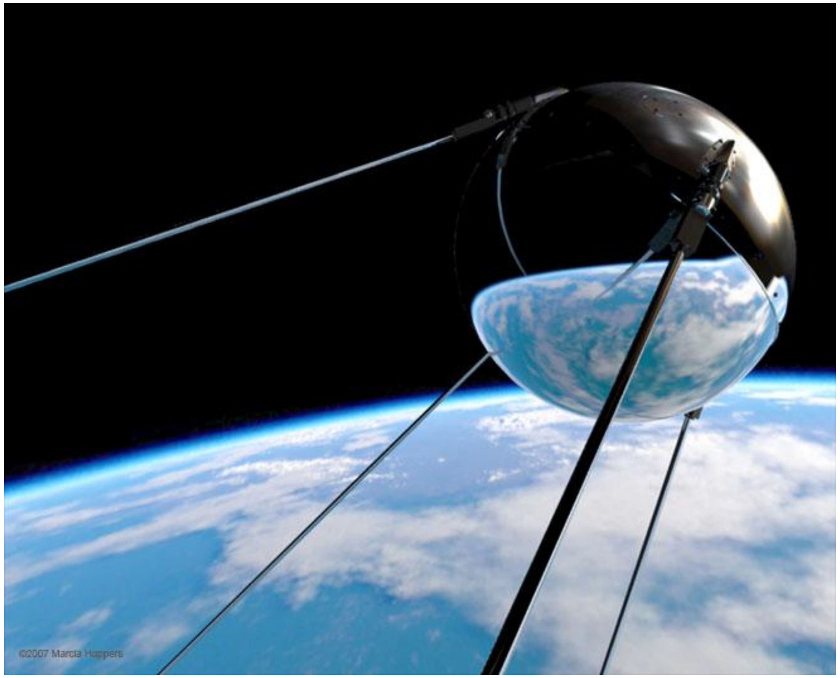
Tom LeCompte/ANL

LHC Status – Where We Are Today

Today, the LHC has delivered a few hundred inverse nanobarns, out of a target of 30 fb^{-1}.

This is typical of large accelerators – having the luminosity increase over time means that most of the data comes late in the run.

To put these numbers in perspective, if the ultimate target is putting a man on the moon (380,000 km), we've made it about as far as low earth orbit.

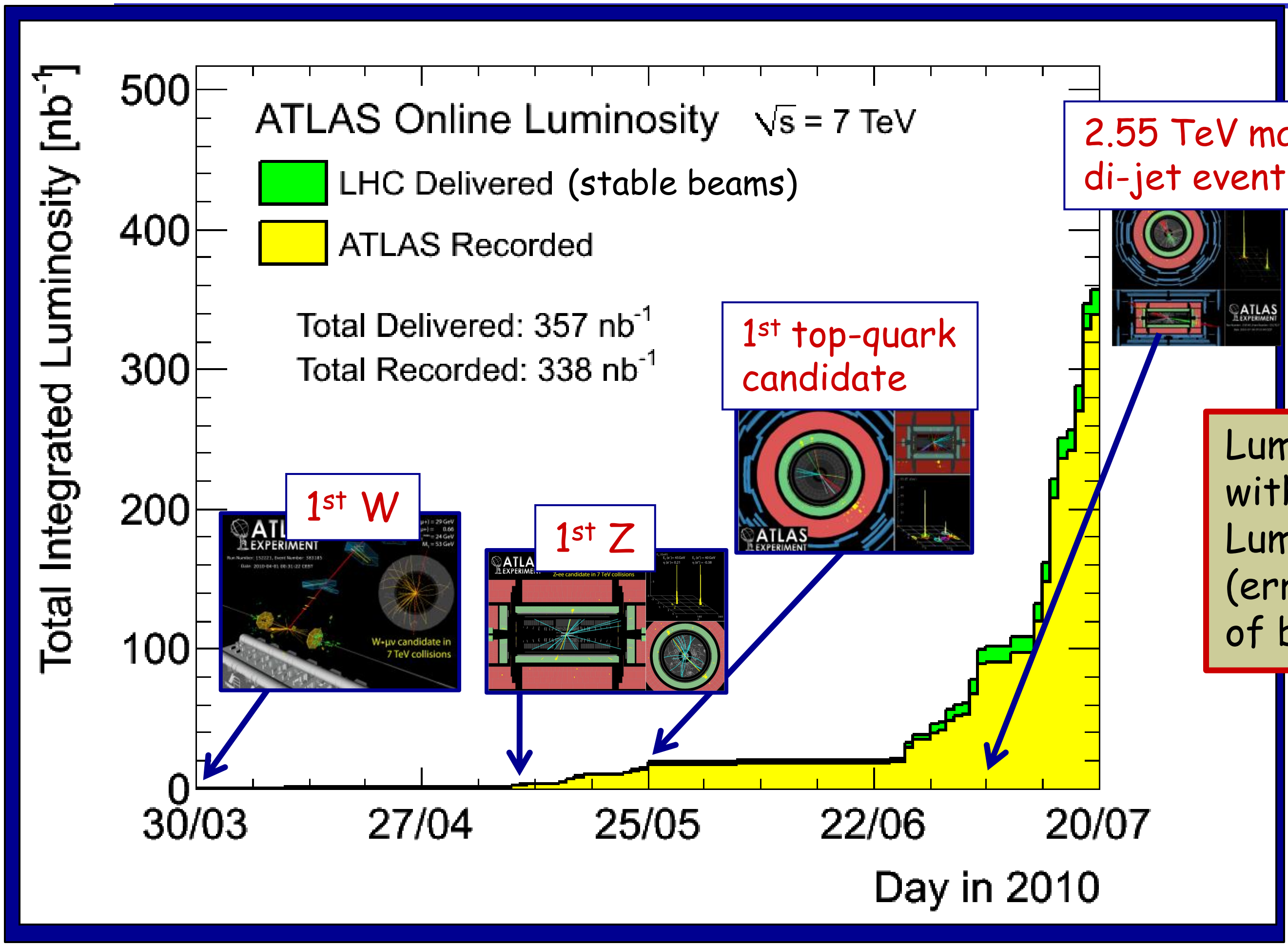


Just as we learned a lot in the early days of the space program, we're learning a lot now.

I hope to show you some of what we have learned during this talk.

Integrated luminosity vs time

(from first √s =7 TeV collisions on 30 March to beginning of ICHEP on 22 July)



Show at ICHEP by Fabiola

Luminosity detectors calibrated with van der Meer scans. Luminosity known today to 11% (error dominated by knowledge of beam currents)

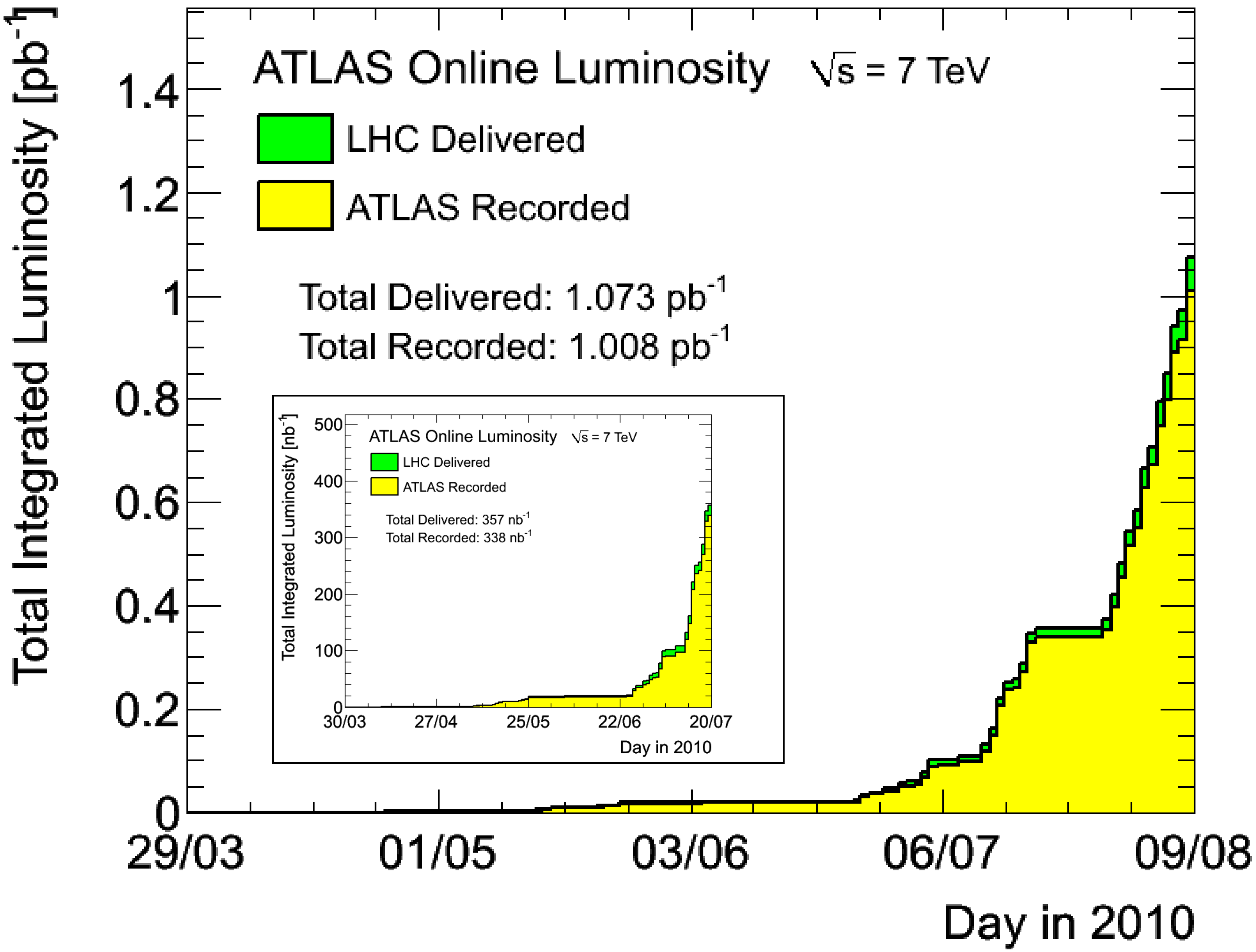
Peak luminosity in ATLAS $L \sim 1.6 \times 10^{30}\ cm^{-2}\ s^{-1}$

Overall data taking efficiency: 95%

(includes time lost to ramp up Silicon detectors to nominal voltage after stable beams are declared)

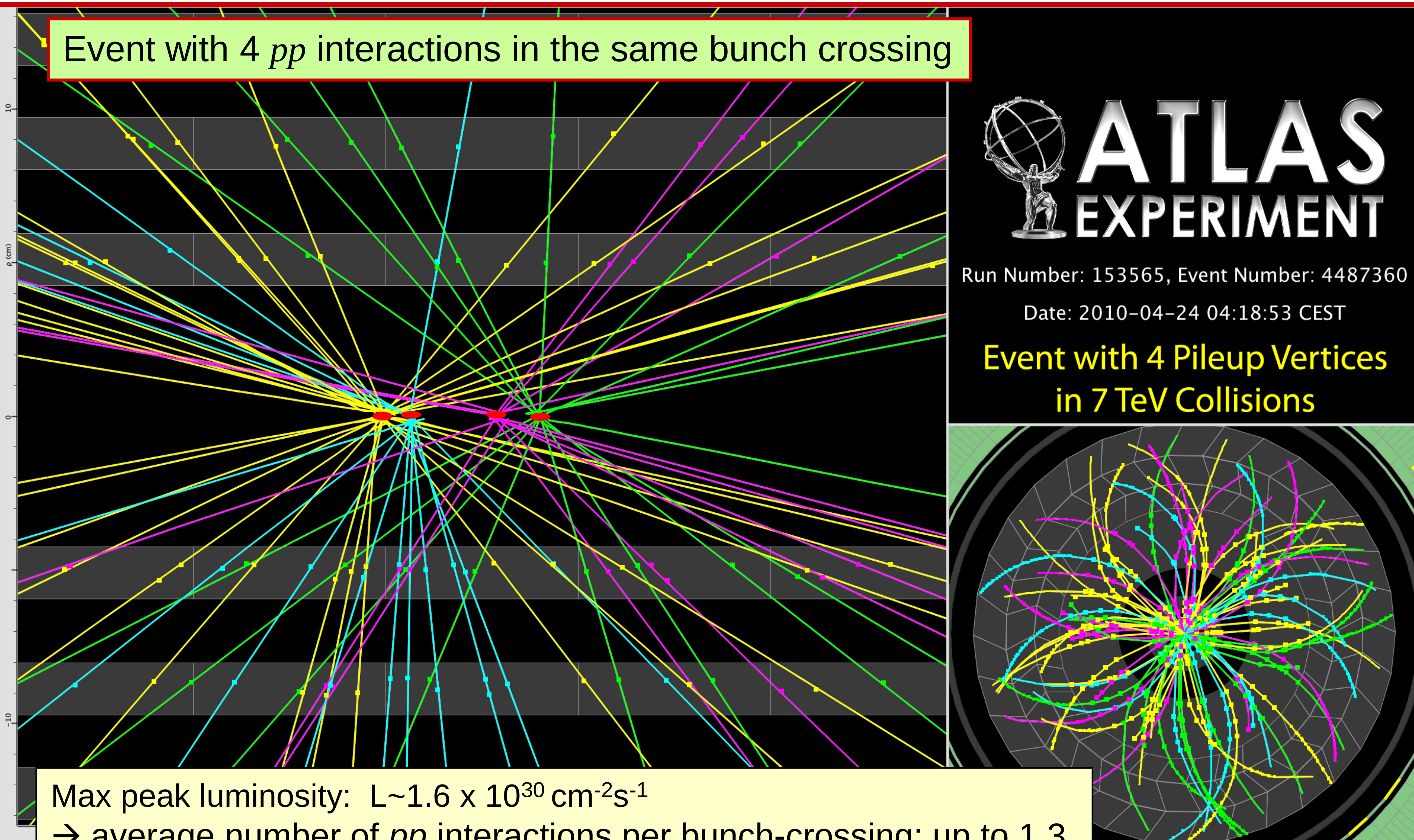
Results presented here based in many cases on whole data sample recorded until the beginning of ICHEP

Then and Now



ATLAS Online Luminosity √s = 7 TeV
LHC Delivered
ATLAS Recorded
Total Delivered: 1.073 pb-1
Total Recorded: 1.008 pb-1
Total Integrated Luminosity [pb-1]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
29/03
01/05
03/06
06/07
09/08
Day in 2010
ATLAS Online Luminosity √s = 7 TeV
LHC Delivered
ATLAS Recorded
Total Delivered: 357 nb-1
Total Recorded: 338 nb-1
Total Integrated Luminosity [nb-1]
500
400
300
200
100
0
30/03
27/04
25/05
22/06
20/07
Day in 2010

The New Normal



Max peak luminosity: L~1.6 x 10^{30} $cm^{-2}s^{-1}$
→ average number of *pp* interactions per bunch-crossing: up to 1.3
→ “pile-up” (~40% of the events have > 1 pp interaction per crossing)

Physics results and highlights of detector combined performance

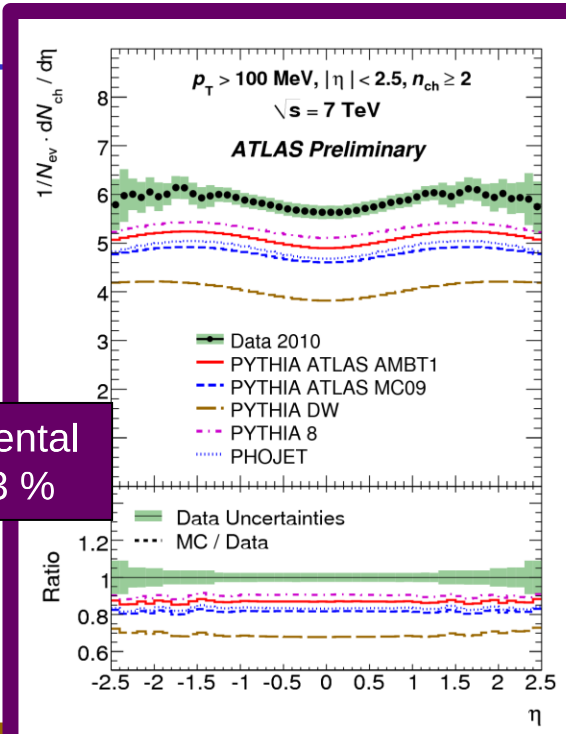
- A few examples
  - -- Soft QCD
  - -- Jets
  - -- J/ψ and di-muon resonances
  - -- W/Z
  - -- Top-quark [candidates, for now]
  - -- First searches for New Physics

- ATLAS' strategy - detailed ongoing work to lay the foundation for solid physics measurements

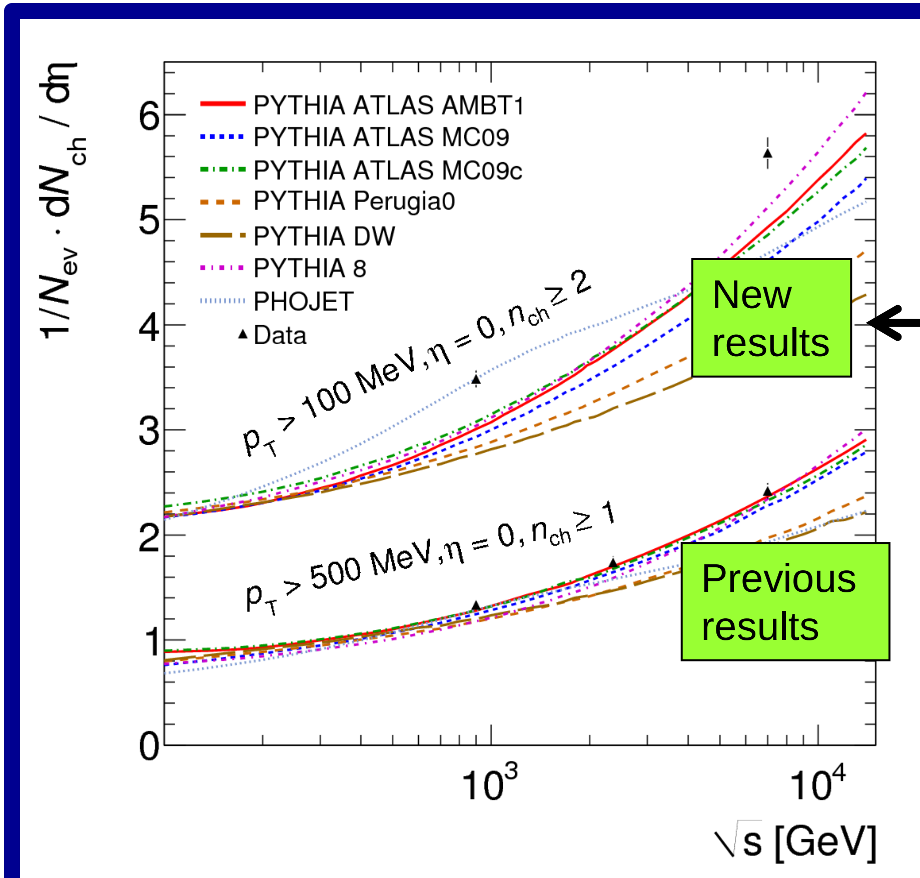
Particle multiplicities and momentum spectra in pp minimum-bias events

Soft QCD

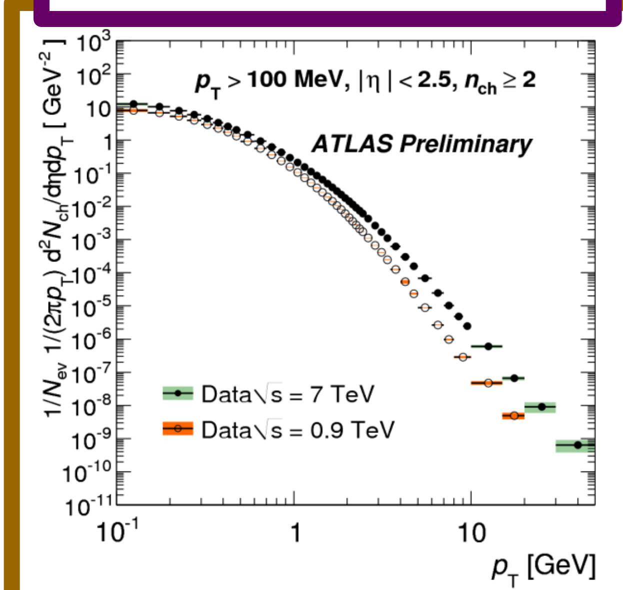
- ❑ Measured over a well-defined kinematic region: ≥ 2 charged particle with p_T > 100 MeV, $|\eta|$ <2.5
- ❑ No subtraction for single/double diffractive components
- ❑ Distributions corrected back to hadron level
- → High-precision minimally model-dependent measurement
- → Provides strong constraints on MC models



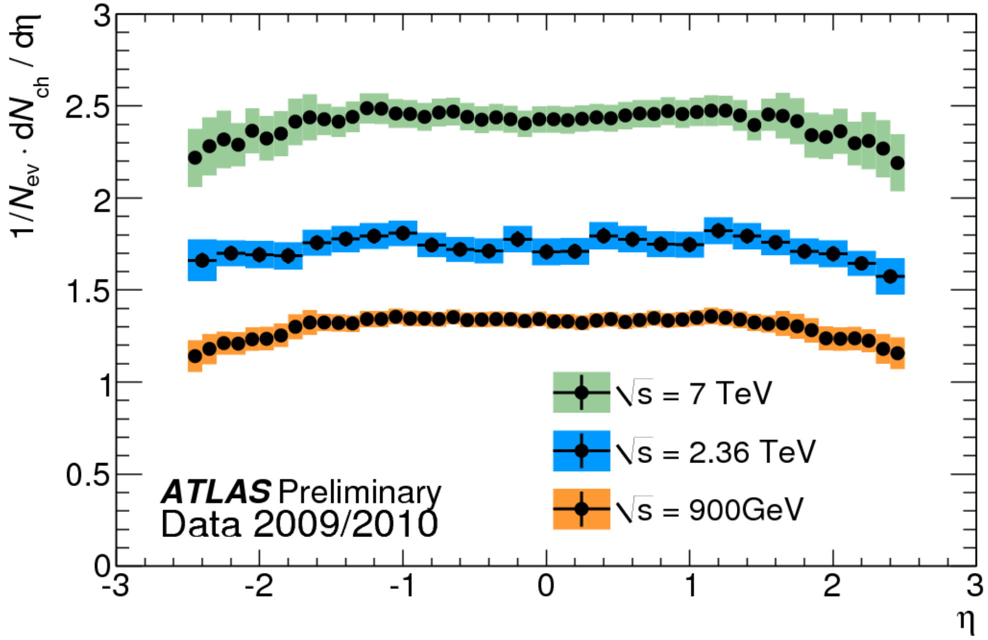
Experimental error: < 3 %



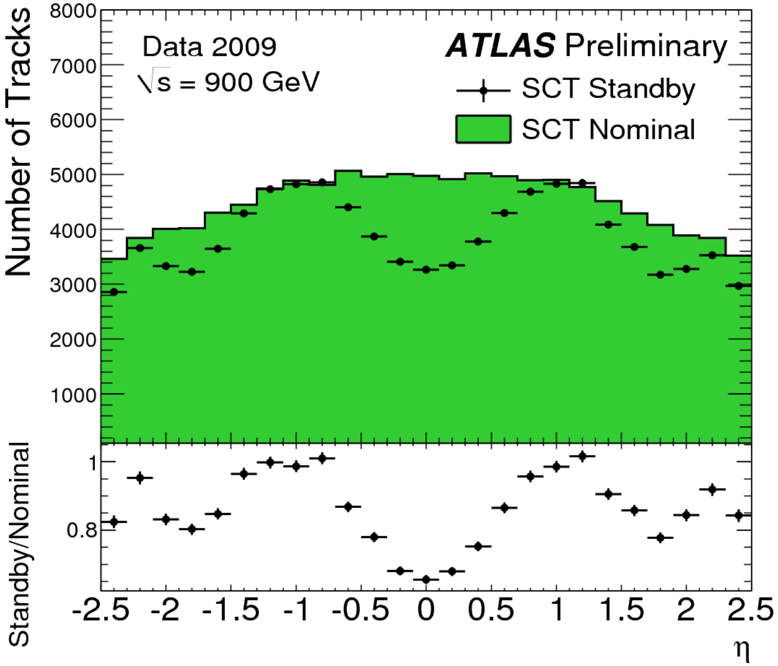
lower p_T
→ larger diffractive component
→worse description by models



A Fun Soft QCD Footnote



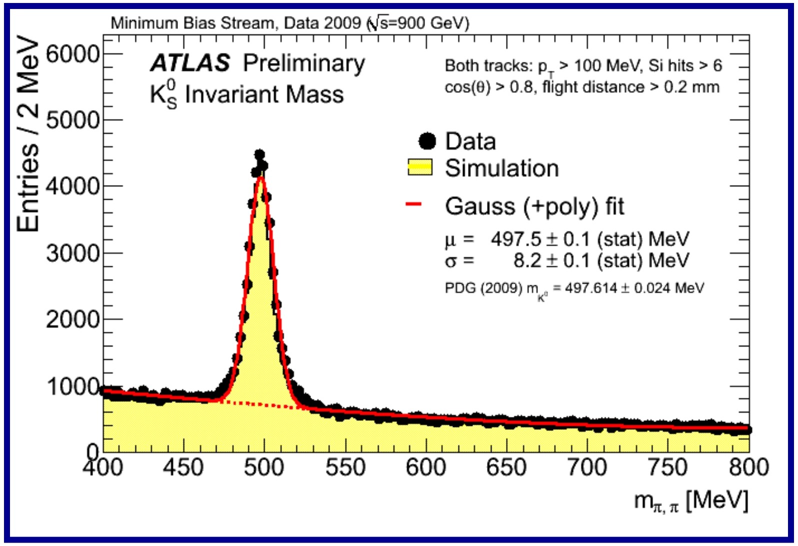
I really like the 2.36 TeV minimum bias analysis



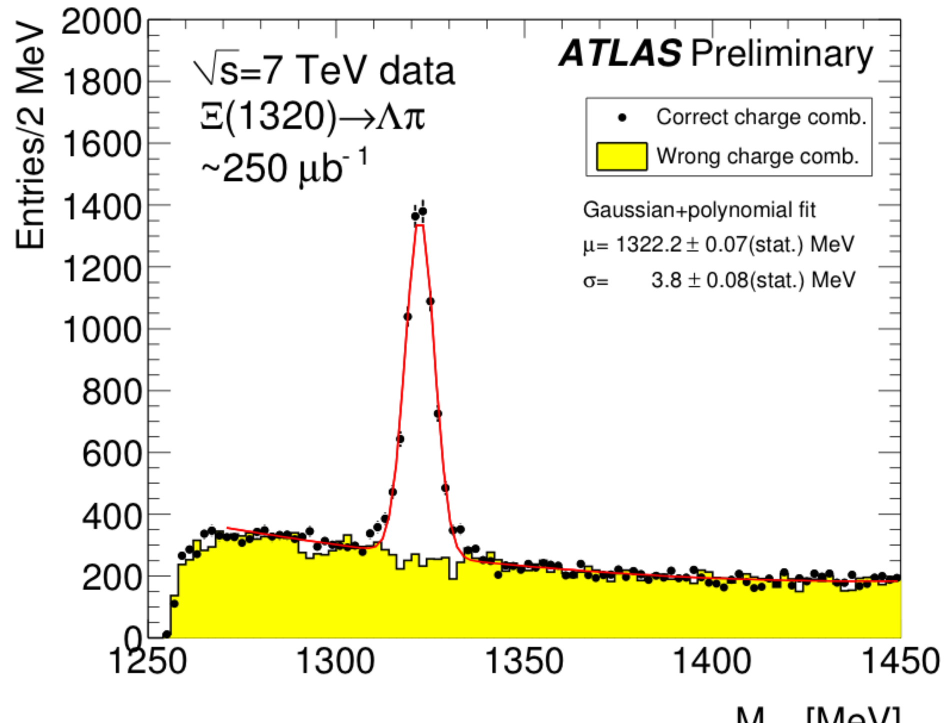
Because it was done with data taken with the SCT at standby.

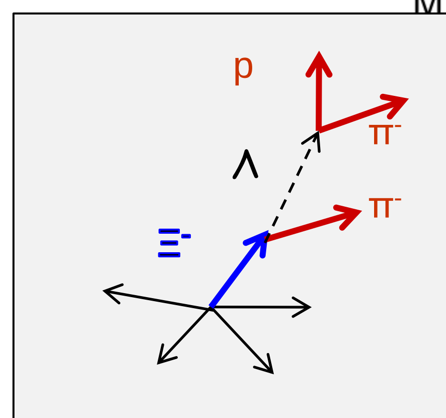
(remember, stable beams were never declared at 2.36 TeV)

ID: from early observation of peaks to complex decays



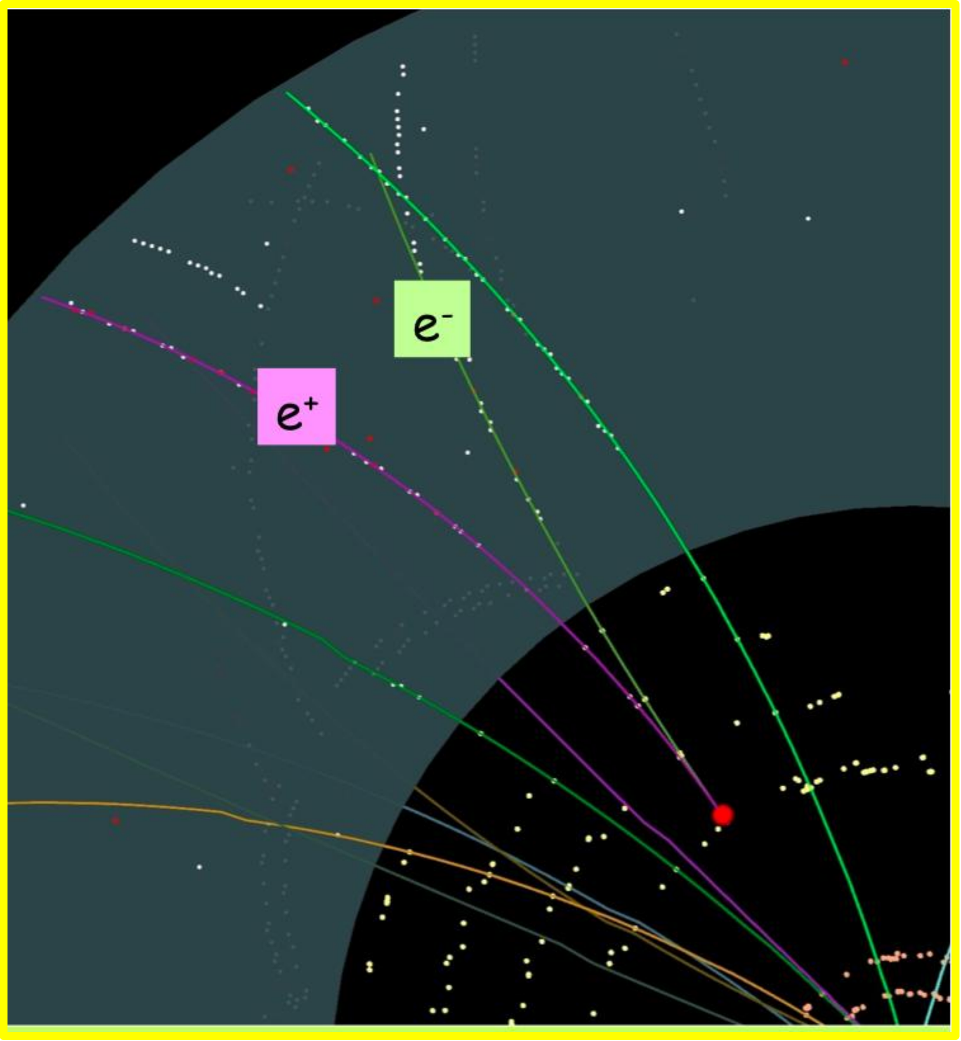
Early $K^0_s \rightarrow \pi^+\pi^-$ observed in Dec 2009, few days after first collisions



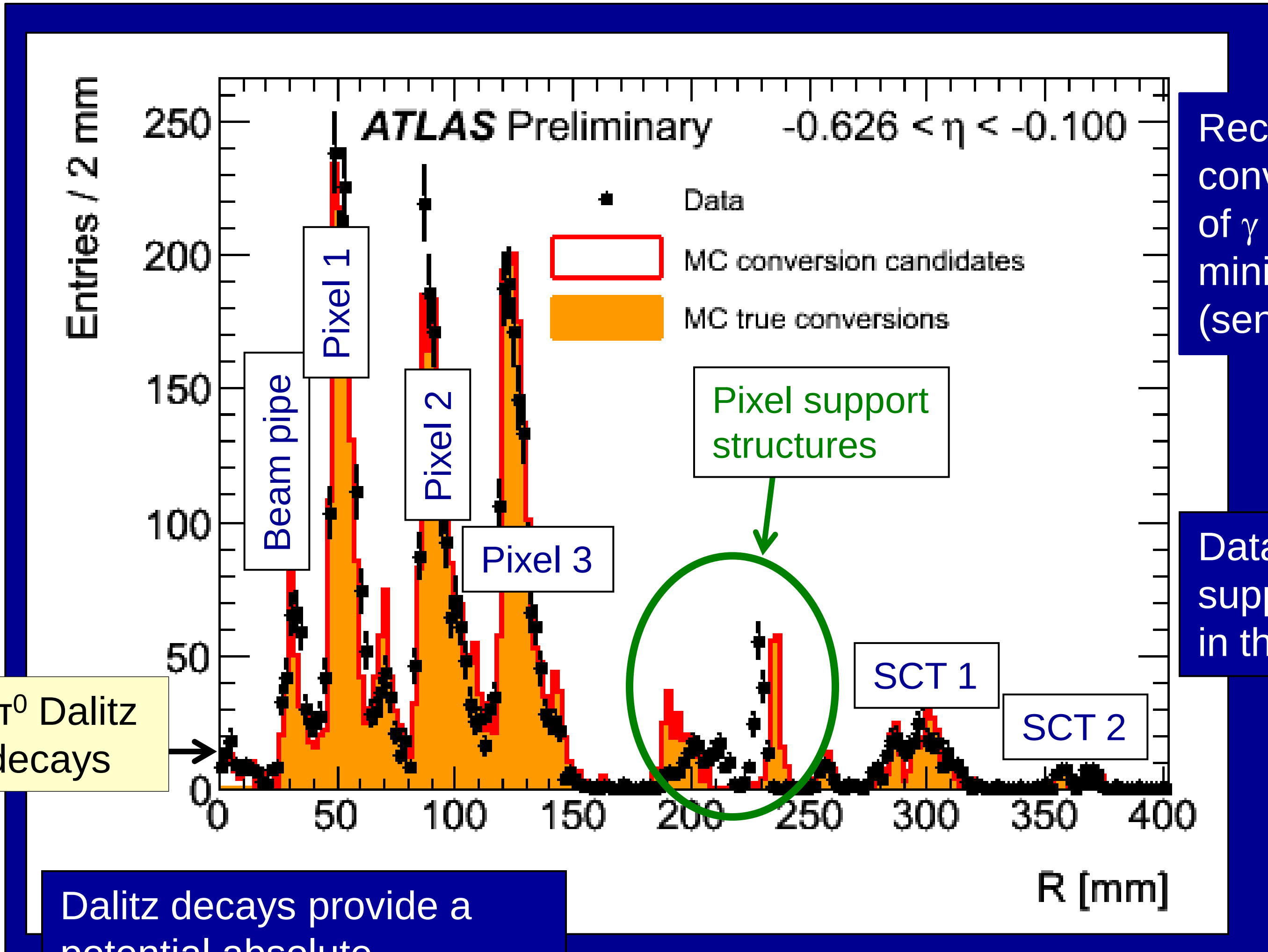


Mapping the Material

- Today:
  - We know the material to within about 10%
- Goal:
  - Get better than 5%, using several different methods to overconstrain the system
- Our tools:
  - Conversions
  - Hadronic Interactions



Reconstructed Conversions



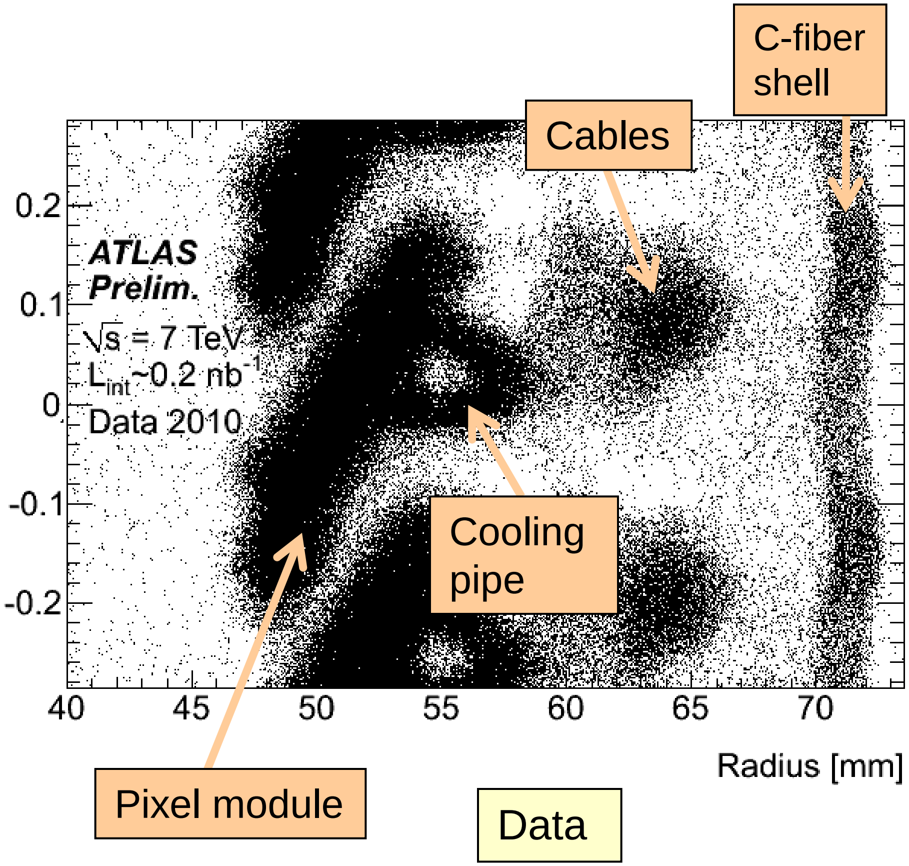
π^0 Dalitz decays

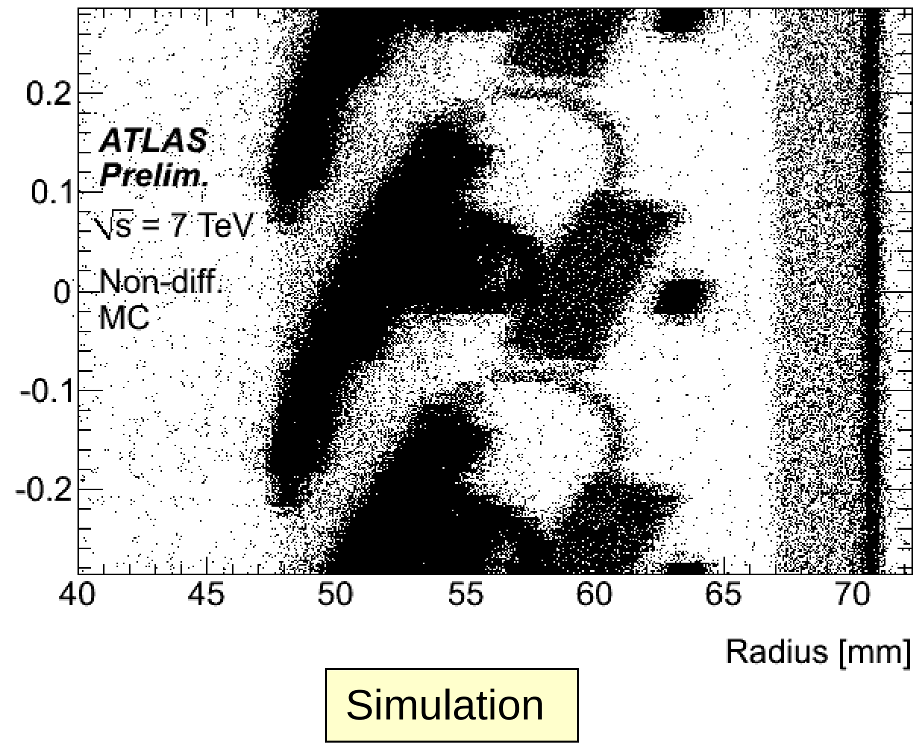
Reconstructed conversion radius of $\gamma \rightarrow e^+e^-$ from minimum bias events (sensitive to X_0)

Data show that Pixel supports are displaced in the simulation

Dalitz decays provide a potential absolute normalization.

Reconstructed Secondary Hadronic Interactions

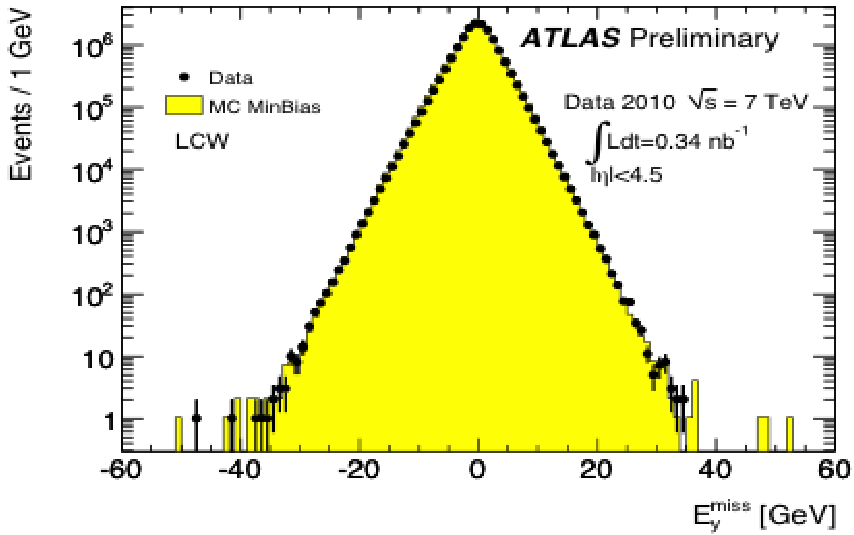




This technique is sensitive to interaction length instead of radiation length.

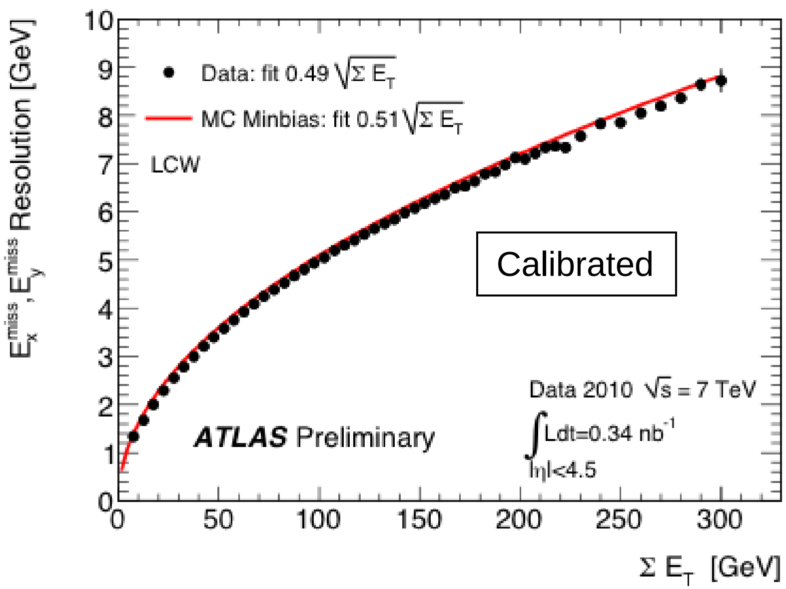
- ❑ Vertex mass veto applied against γ → ee, K_S^0 and Λ
- ❑ Vertex (R, Z) resolution ~ 250 μm (R <10 cm) to ~1 mm

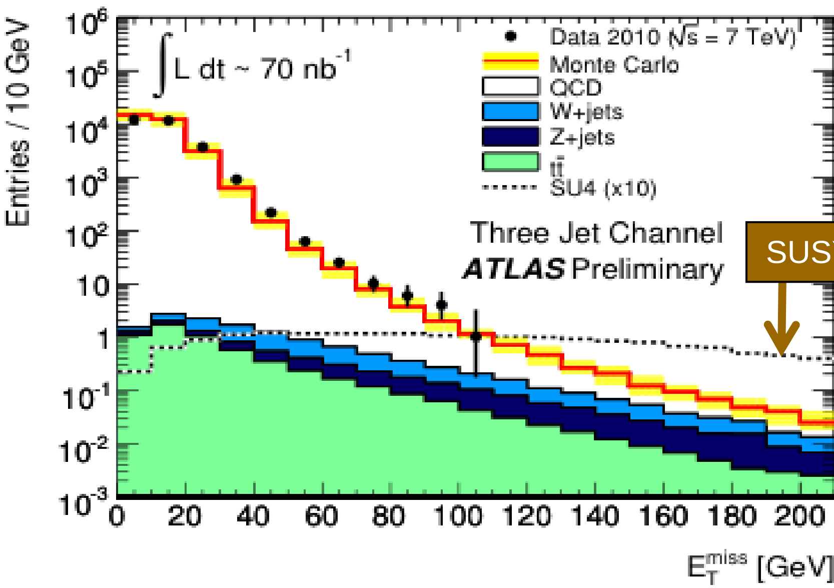
Missing transverse energy in the calorimeters



Start with the basic missing ET distributions…

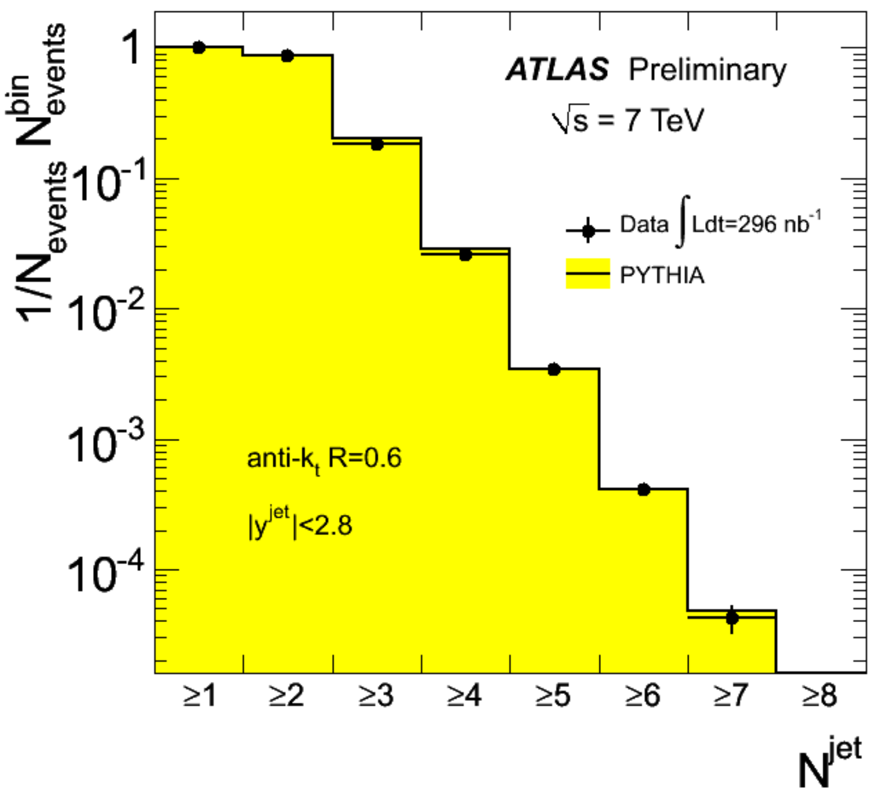
…and apply it in (e.g.) SUSY searches: events with ≥ 3 high-pT jets

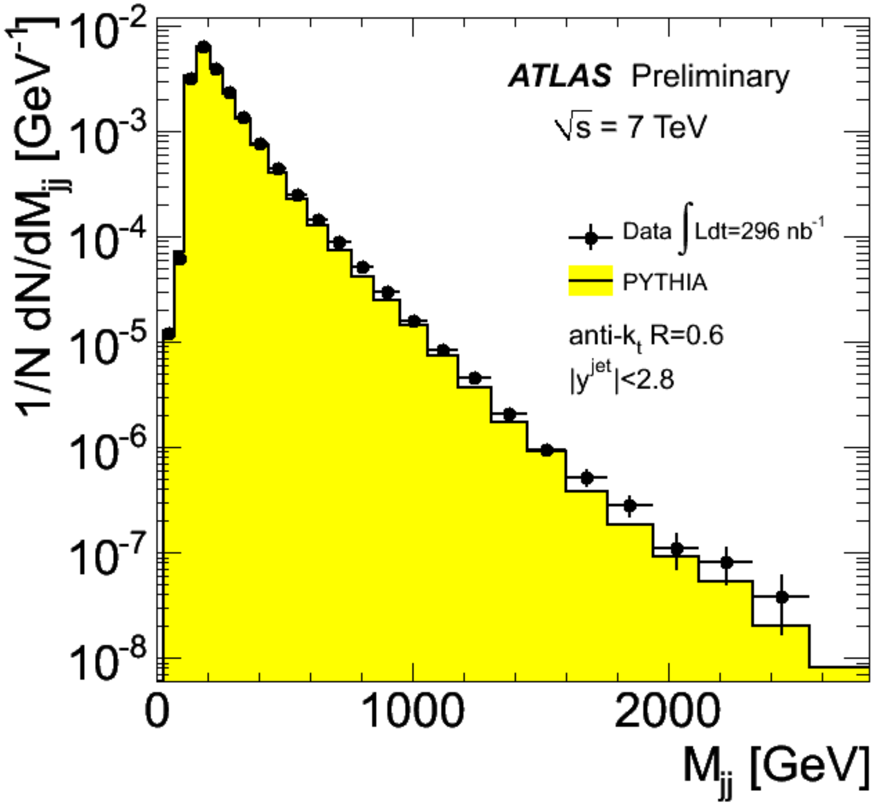




SUSYx10

Inclusive Jet Measurements (I)

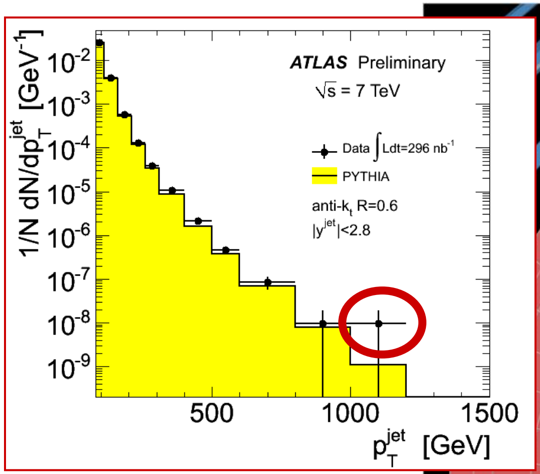


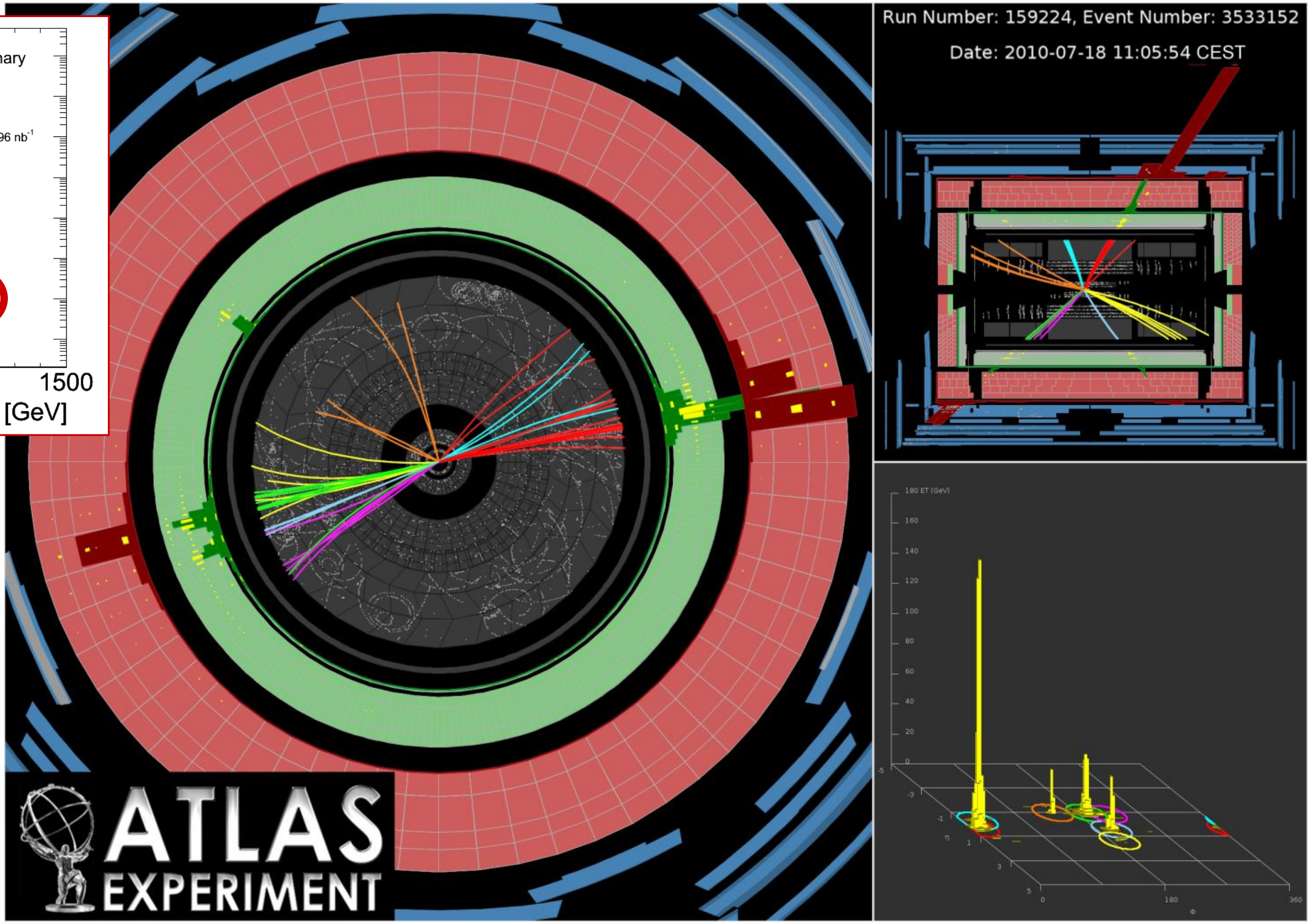


Shape comparisons between data and Pythia (distributions normalized to unity)
It's good but (more than) a little mysterious that Pythia does as well as it does.

Leading jet p_T > 80 GeV
Second leading p_T > 40 GeV

Our Most Energetic Jet (As of Two Weeks Ago)





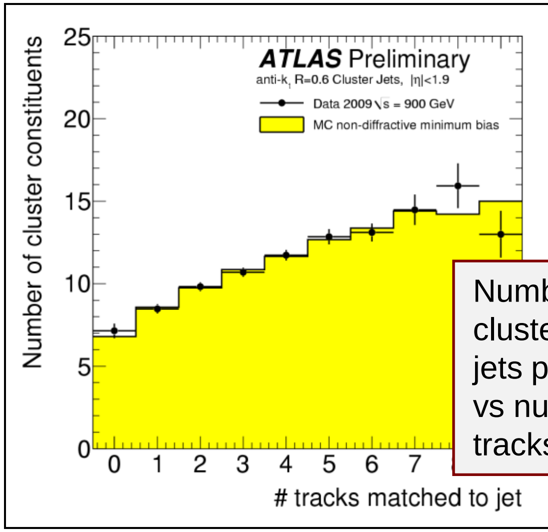
p_T (j_1)= 1.12 TeV

p_T (j_2)= 480 GeV

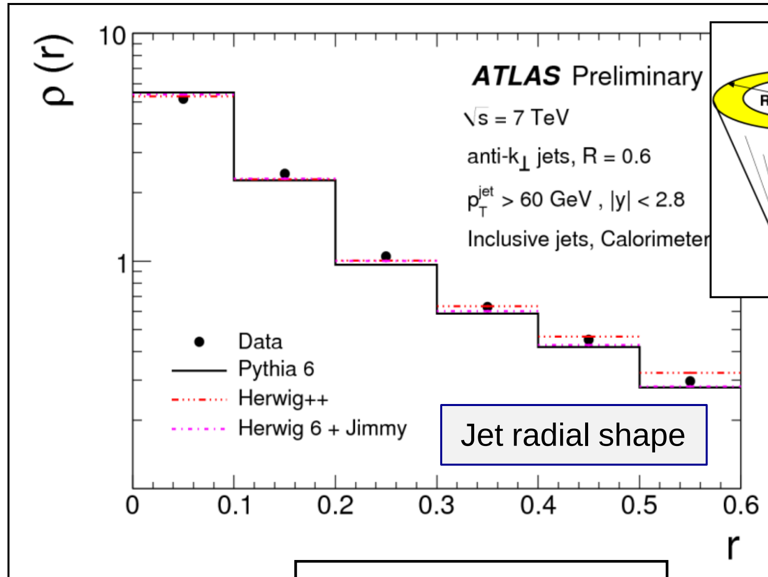
p_T (j_3)= 155 GeV

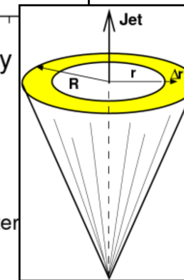
p_T (j_4)= 95 GeV

Looking at Jets in (Much) More Detail



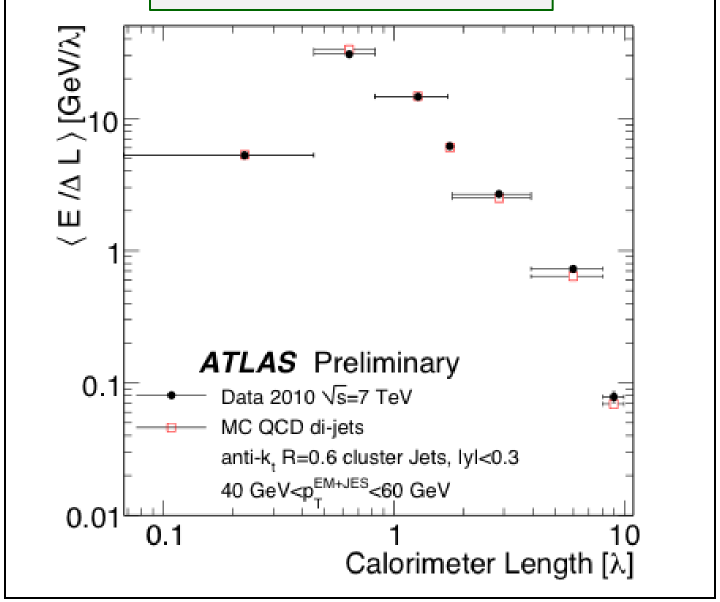
Number of clusters in jets p_T>7 GeV vs number of tracks



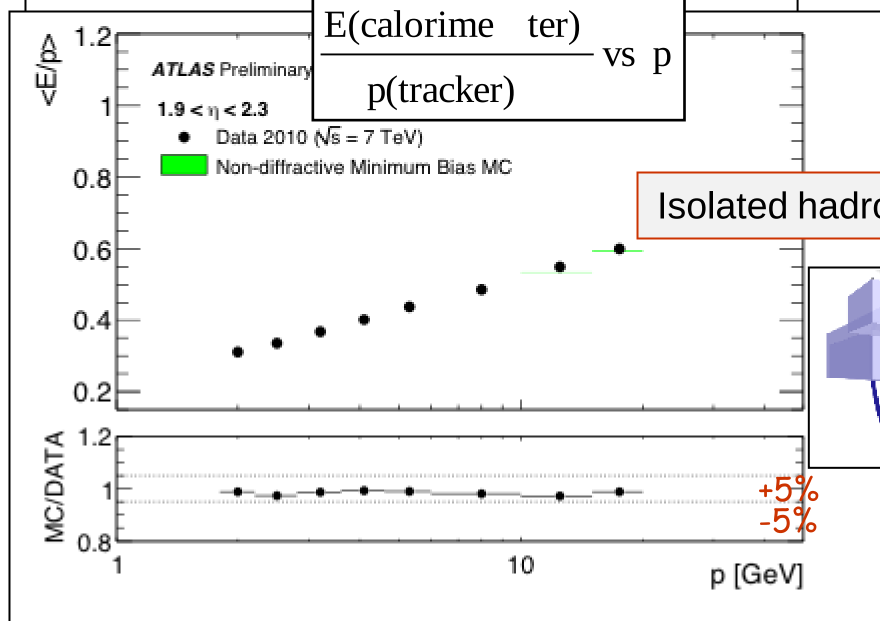


Jet radial shape

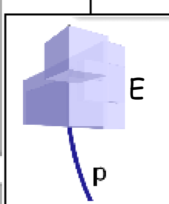
Longitudinal jet profile



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

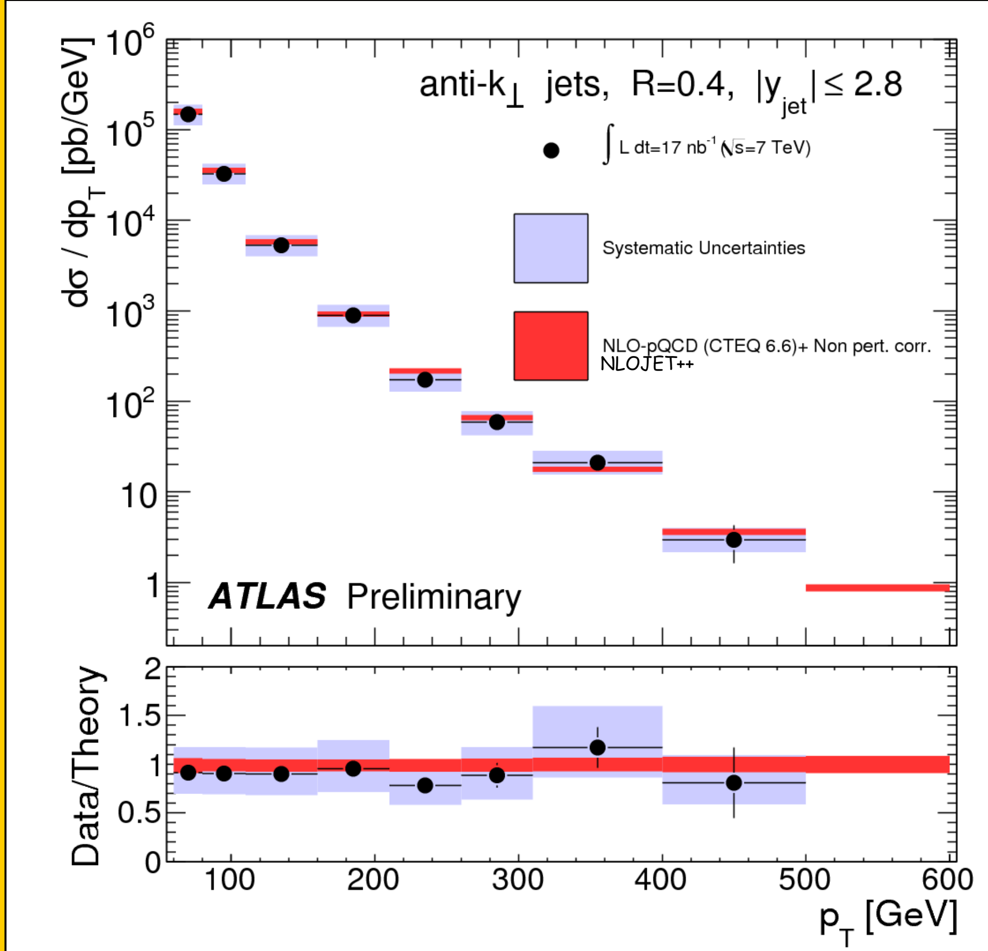


Isolated hadrons



Inclusive Jet Cross Section

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

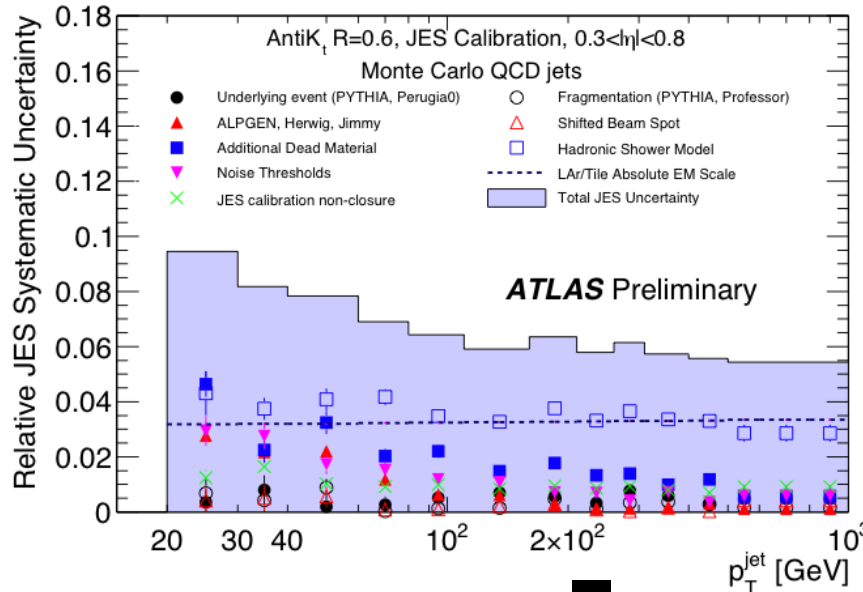


Good agreement with QCD over (only) 5 orders of magnitude

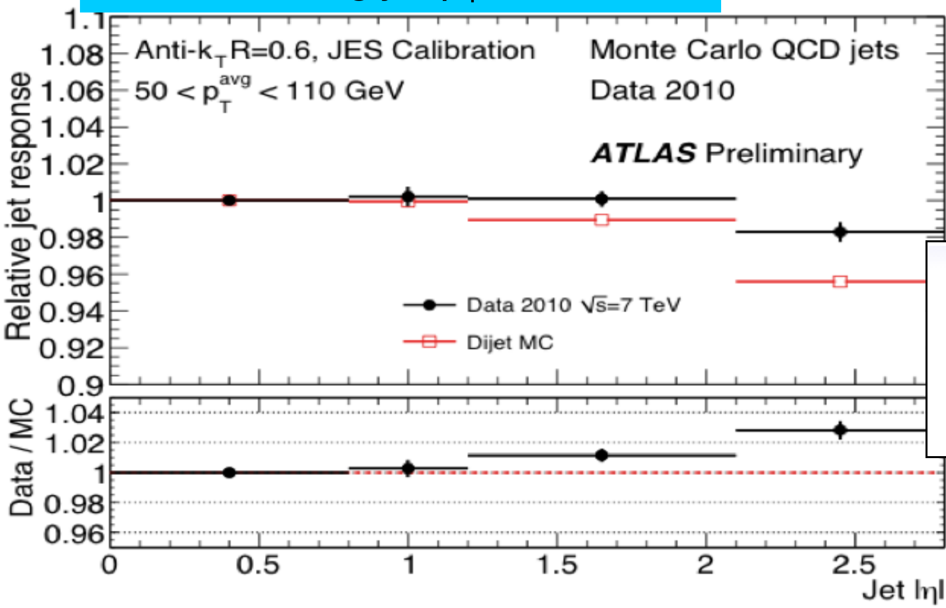
JES Uncertainty

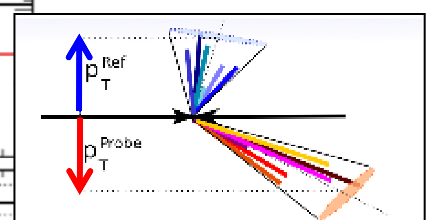
Jet momenta corrected (for calorimeter non-compensation, material, etc.) using η/p_T-dependent calibration factors derived from MC (need ~ 1 pb-1 for in-situ gamma/jet)

- ❑ Builds on detailed foundation work to understand main ingredients by comparing MC/data (see before)
- ❑ Many sources of systematic uncertainties studied in detail



Inter-calibration central-forward checked using jet p_T-balance





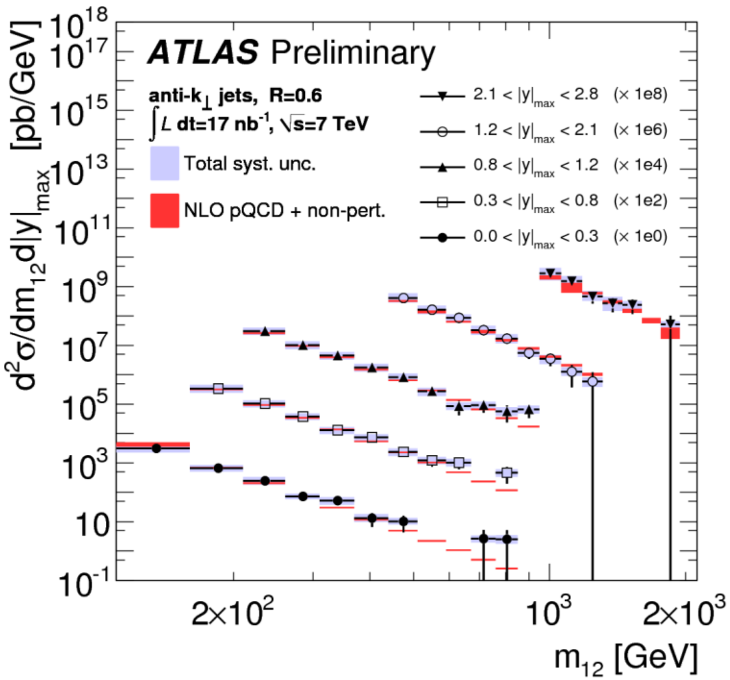
Today JES known to : ~ 7%

Ultimate goal: ~1%

Tom LeCompte, ANL

Other Jet Measurements

Di-jet cross-section vs mass



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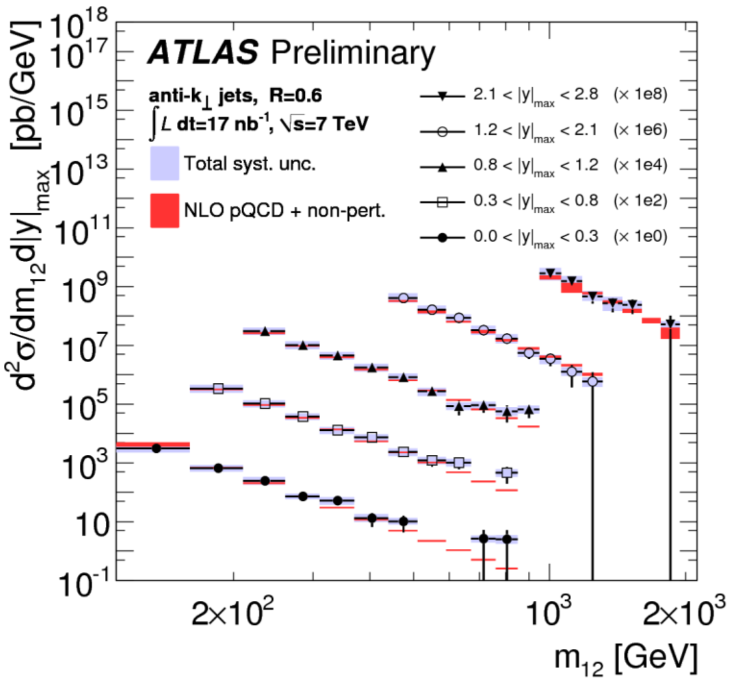
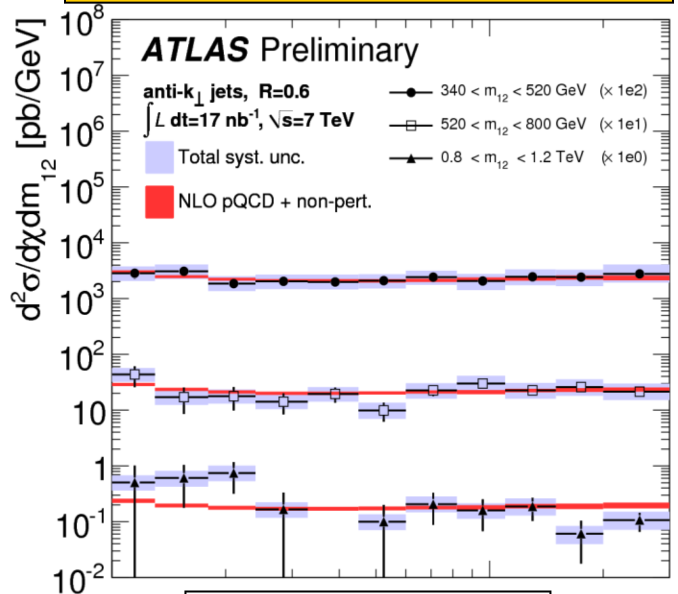


Di-jet cross-section vs angle



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

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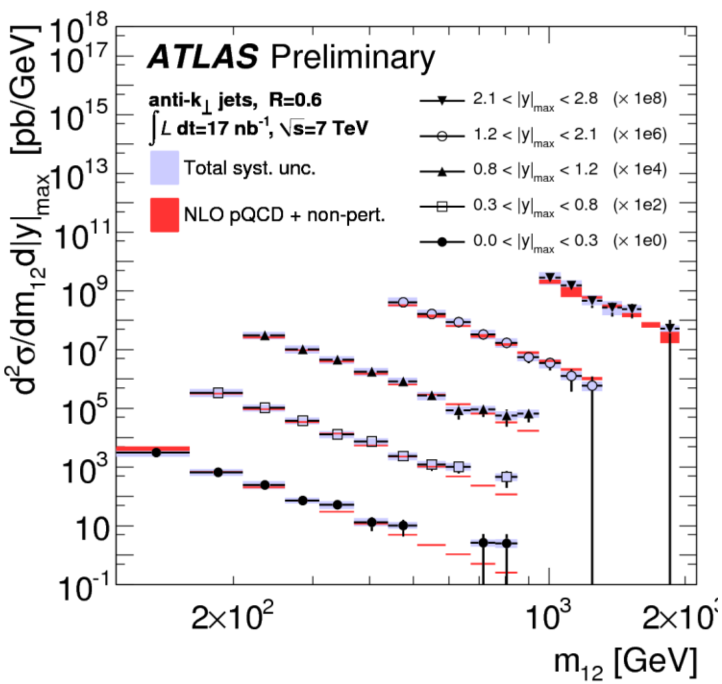

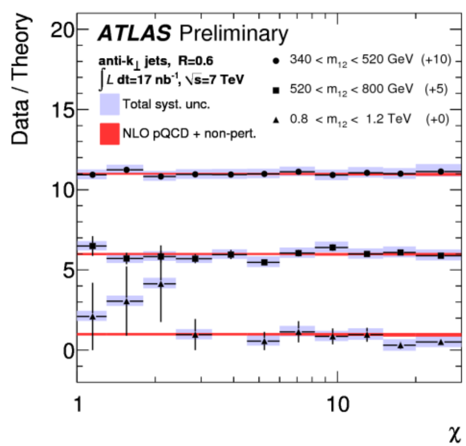

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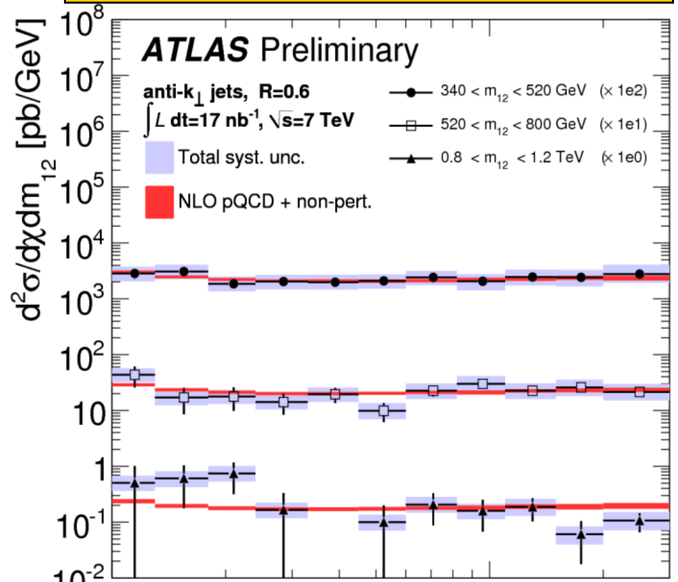

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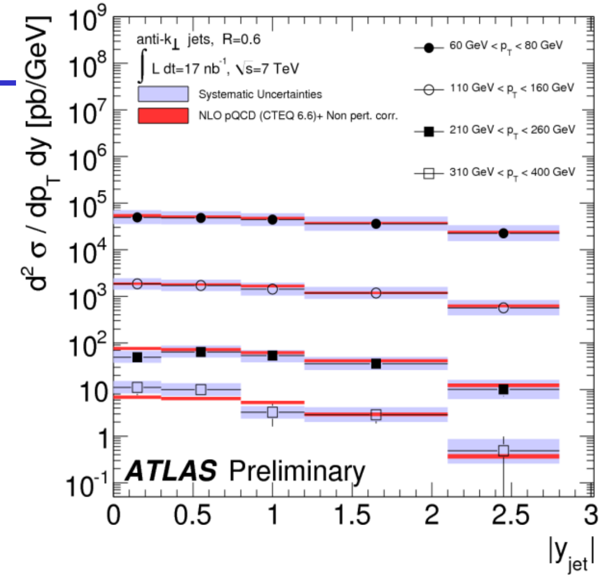

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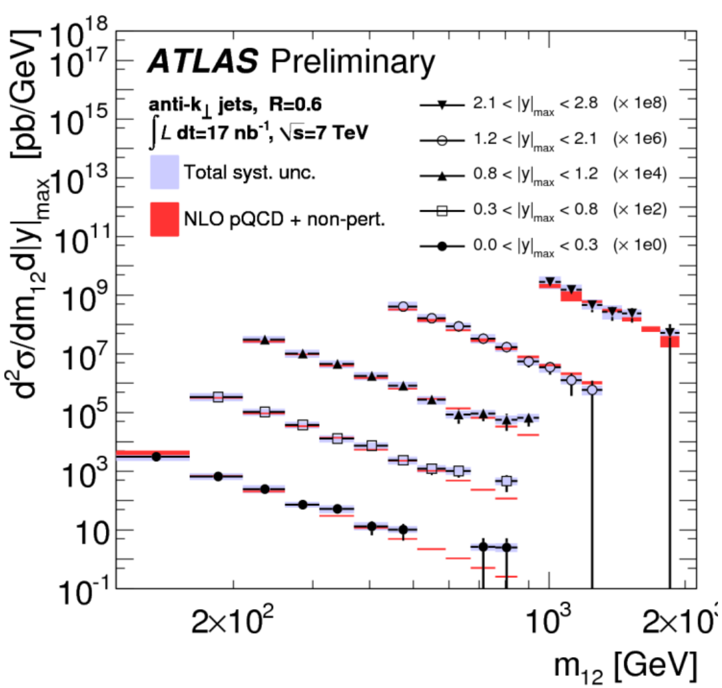

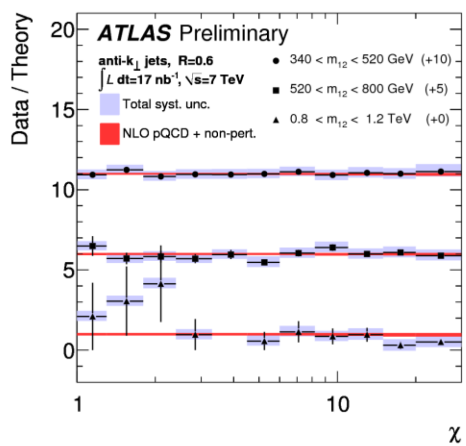

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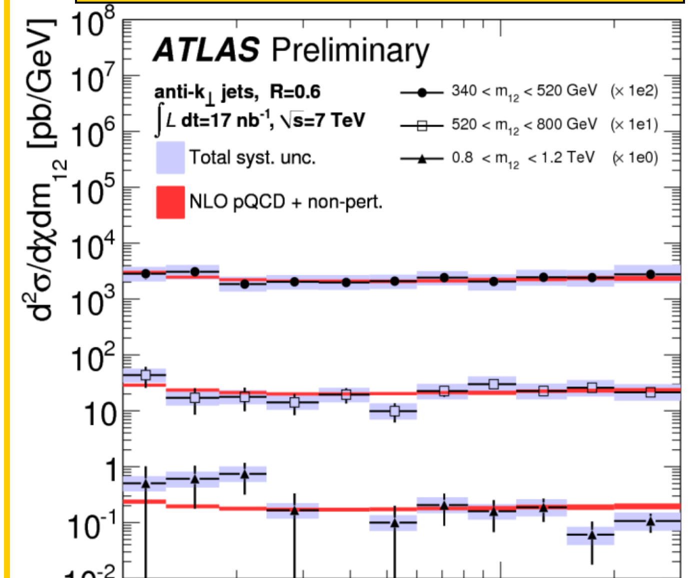

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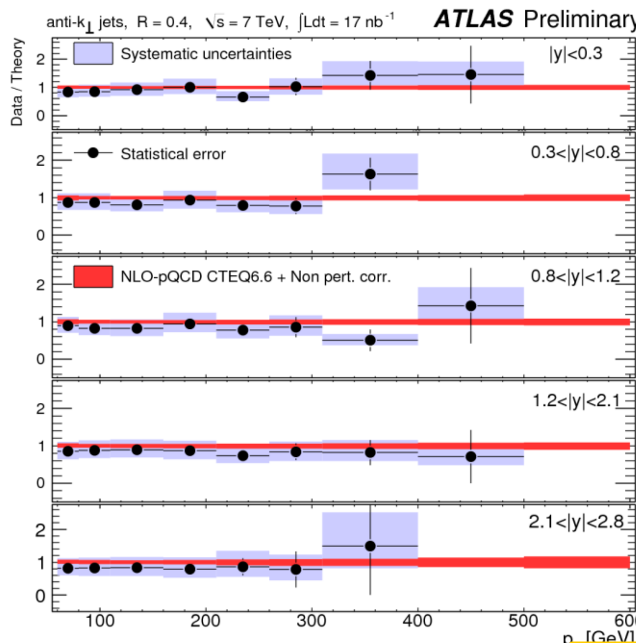
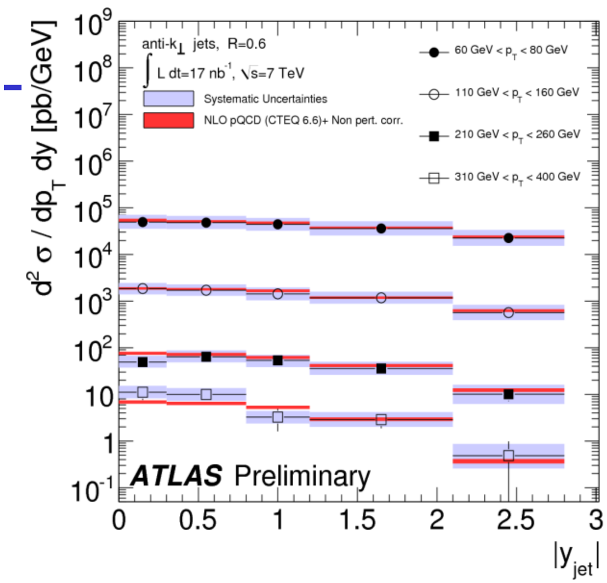
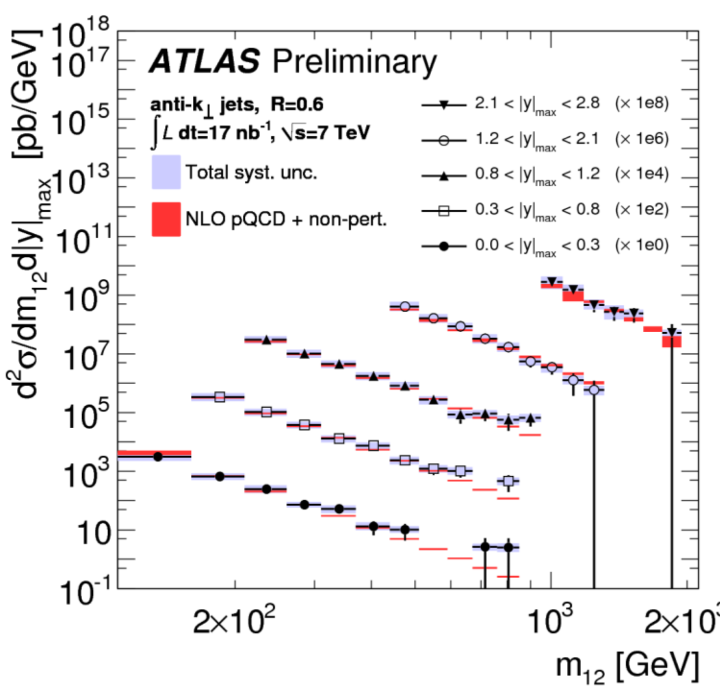
χ

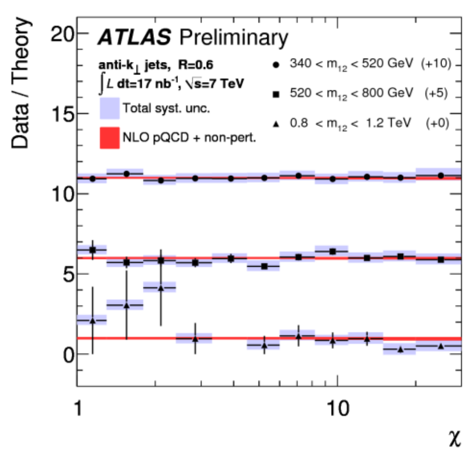
Other Jet Meası





Di-jet cross-section vs mass





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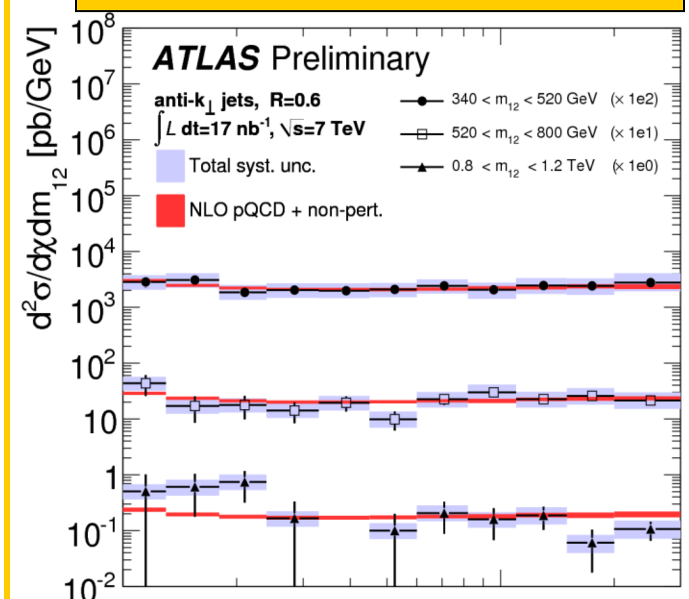

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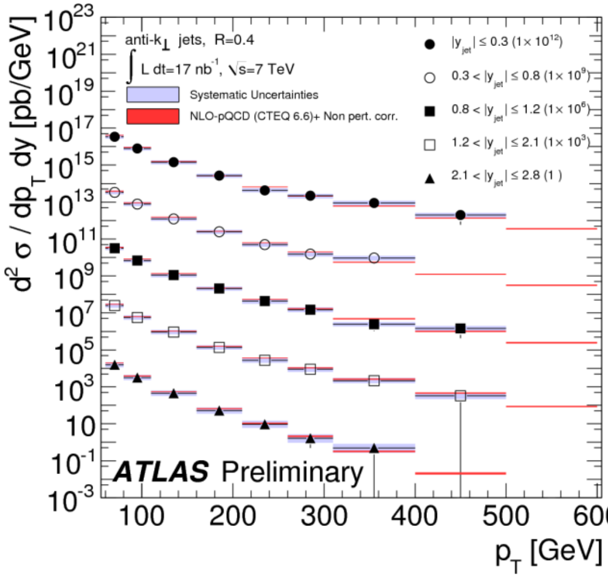
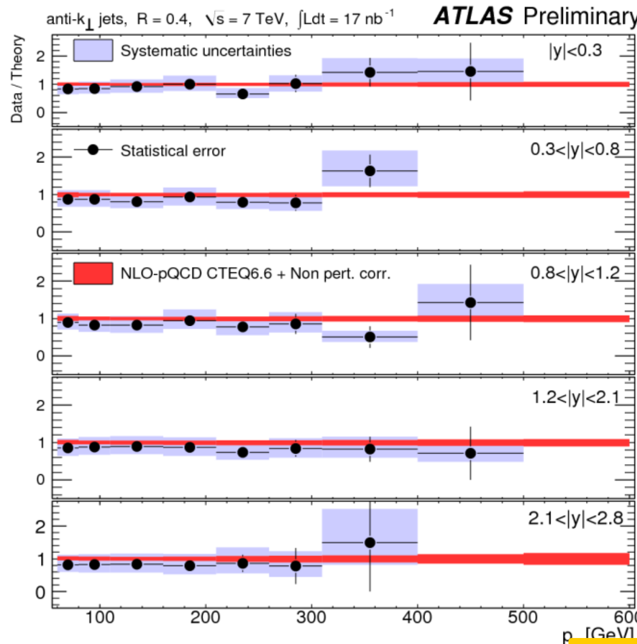
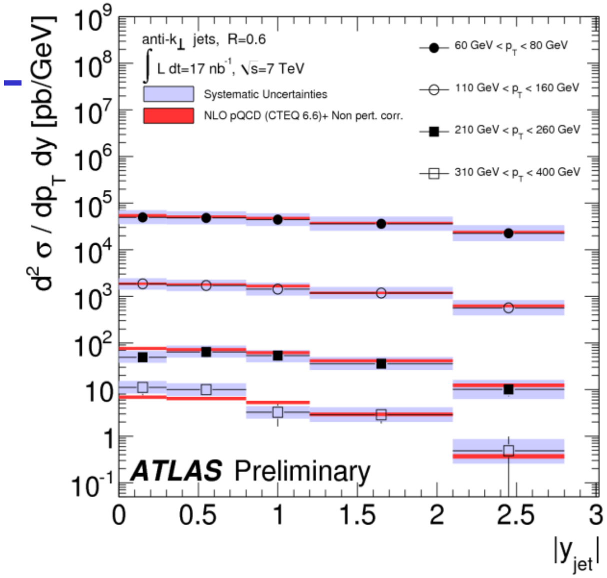
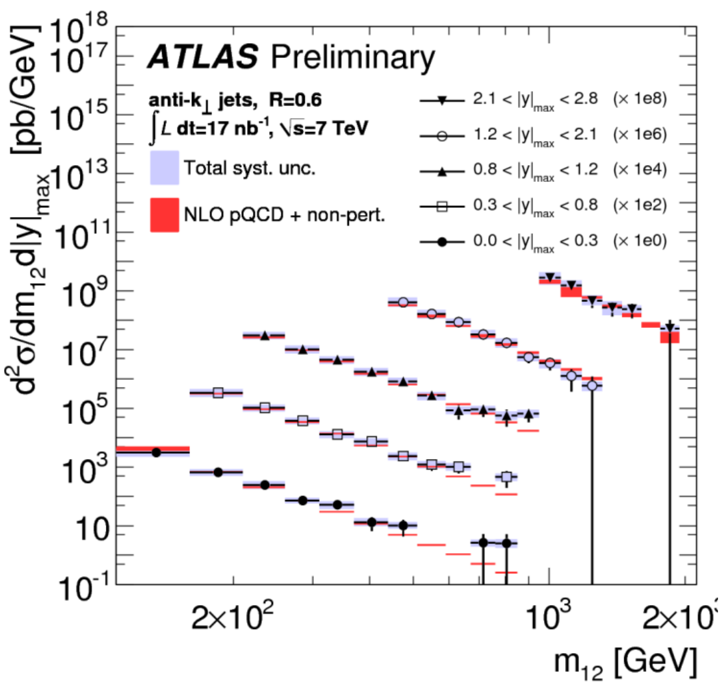


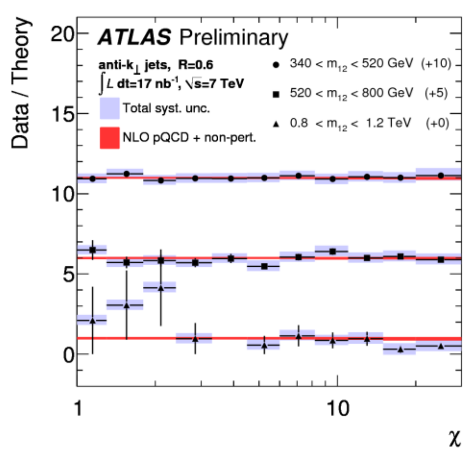


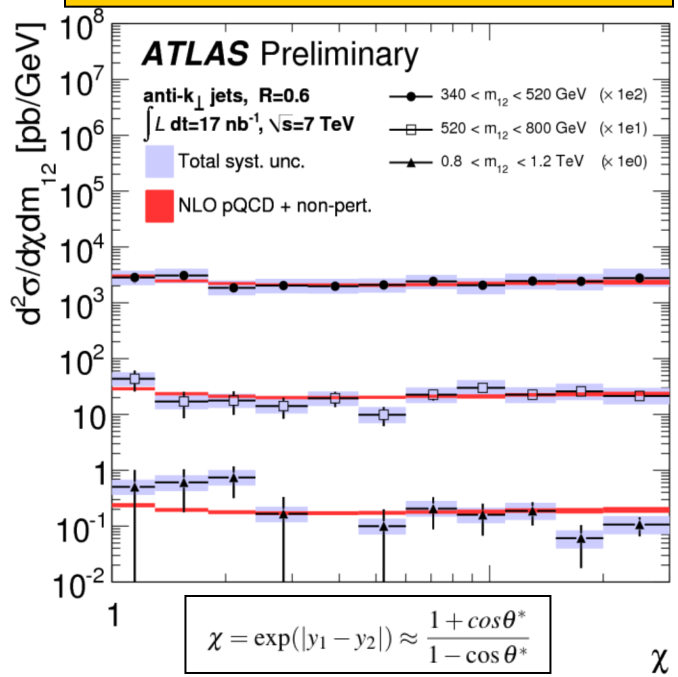


Di-jet cross-section vs mass

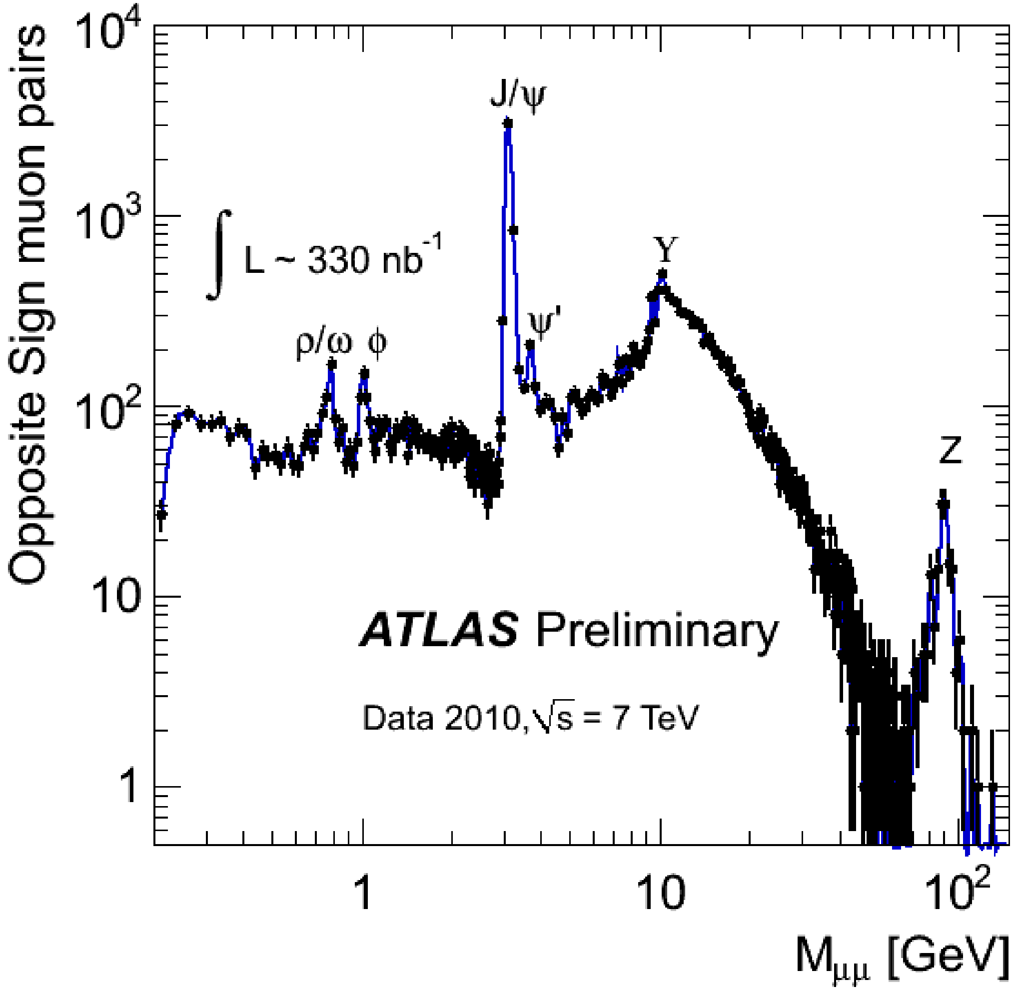
Di-jet cross-section vs angle







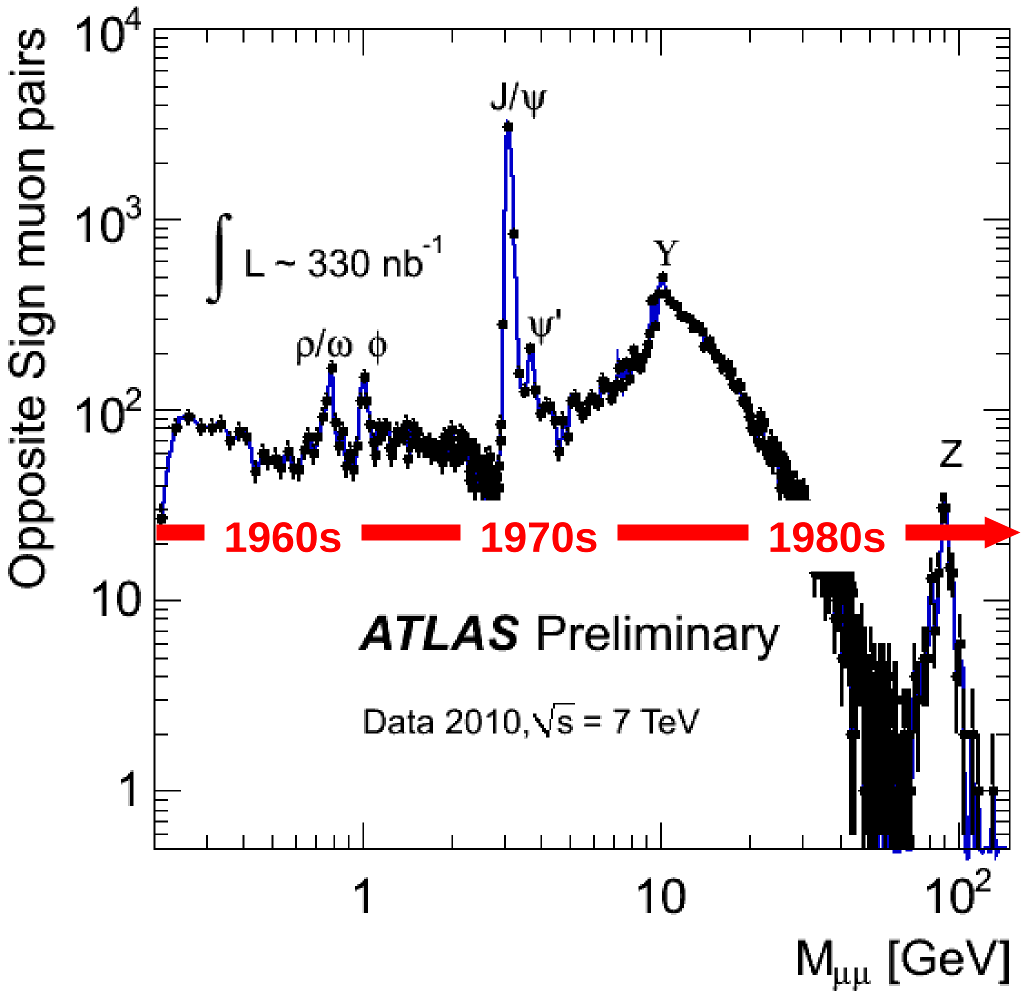
Dimuon Resonances



Simple analysis:

- LVL1 muon trigger with $p_T \sim 6$ GeV threshold
- 2 opposite-sign primary muons reconstructed by combining tracker and muon spectrometer

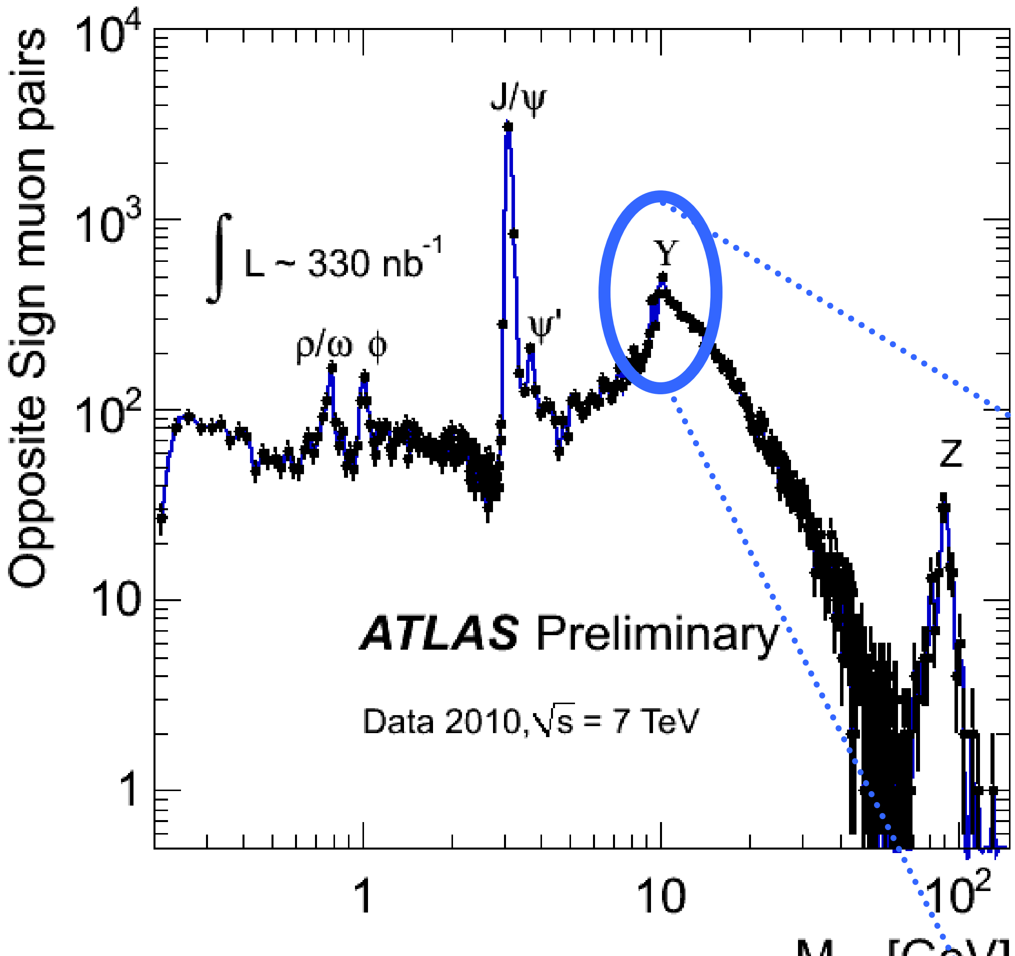
Dimuon Resonances



Simple analysis:

- LVL1 muon trigger with p_T ~ 6 GeV threshold
- 2 opposite-sign primary muons reconstructed by combining tracker and muon spectrometer

Dimuon Resonances



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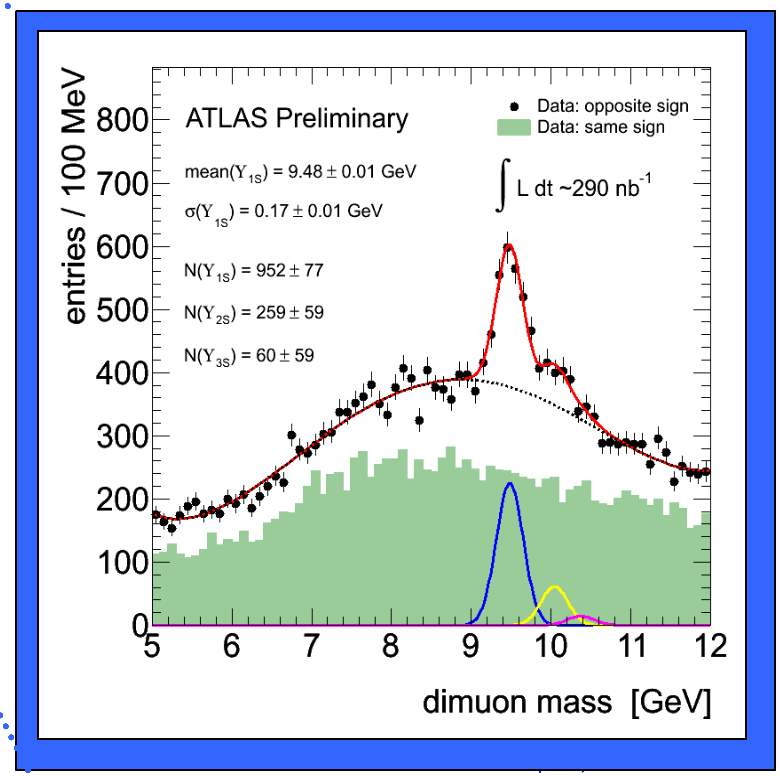
- ❑ LVL1 muon trigger with p_T ~ 6 GeV threshold
- ❑ 2 opposite-sign primary muons reconstructed by combining tracker and muon spectrometer

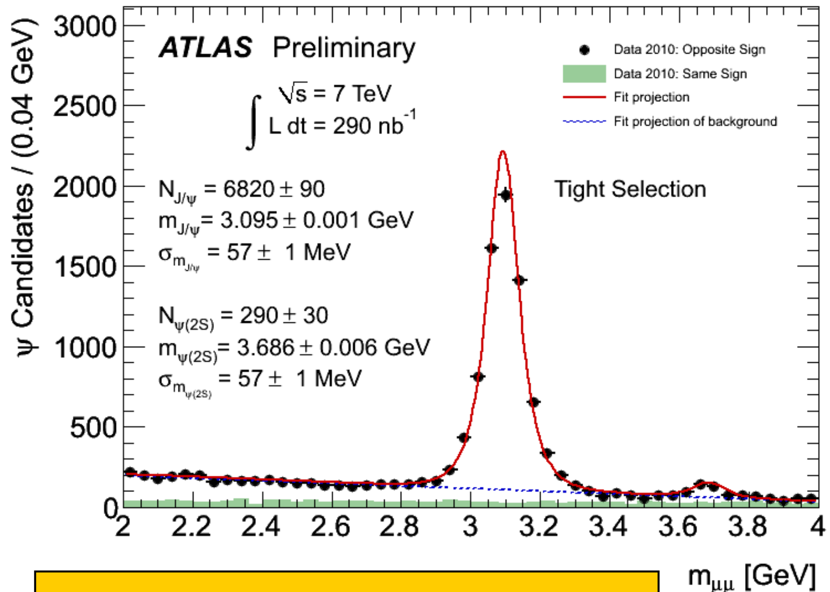


- ❑ Looser selection: includes also muons made of Inner Detector tracks + Muon Spectrometer segments
- ❑ Distances between resonances fixed to PDG values; Υ(2S), Υ(3S) resolutions fixed to Υ(1S) resolution

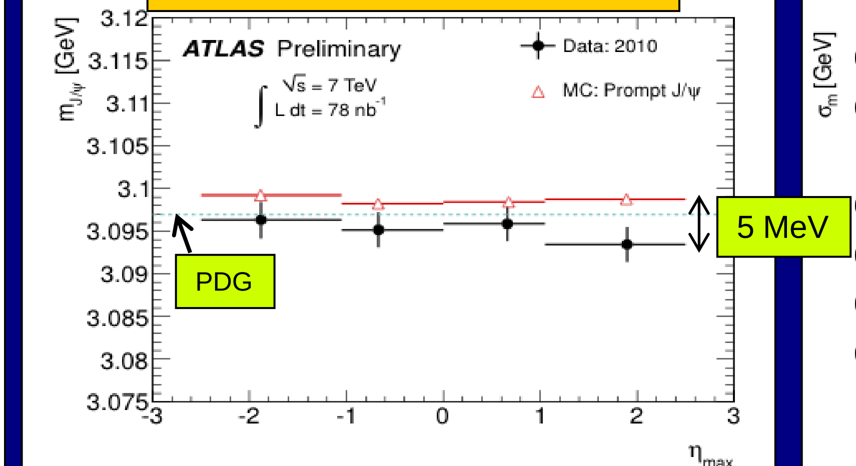
J/ψ in the Dimuon Channel

J/ψ reconstruction uses the muon spectrometer to identify ID tracks that are muons from which we form combinations.

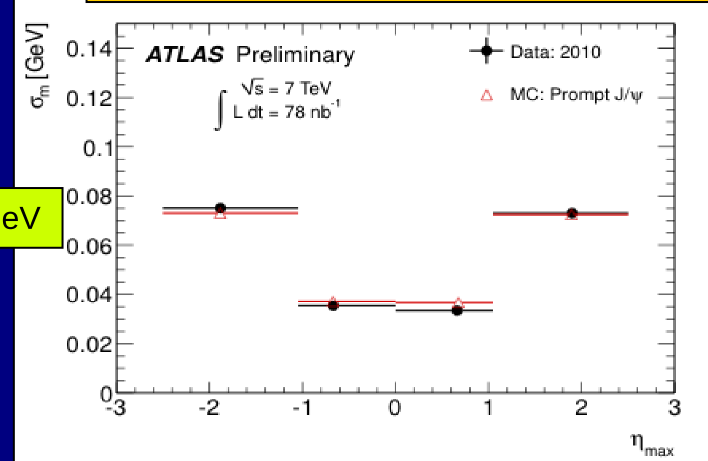
From J/ψ mass peak and resolution reconstructed in the Inner Detector: absolute momentum scale known to ~ 0.2% and momentum resolution to ~2 % in the ~few GeV region



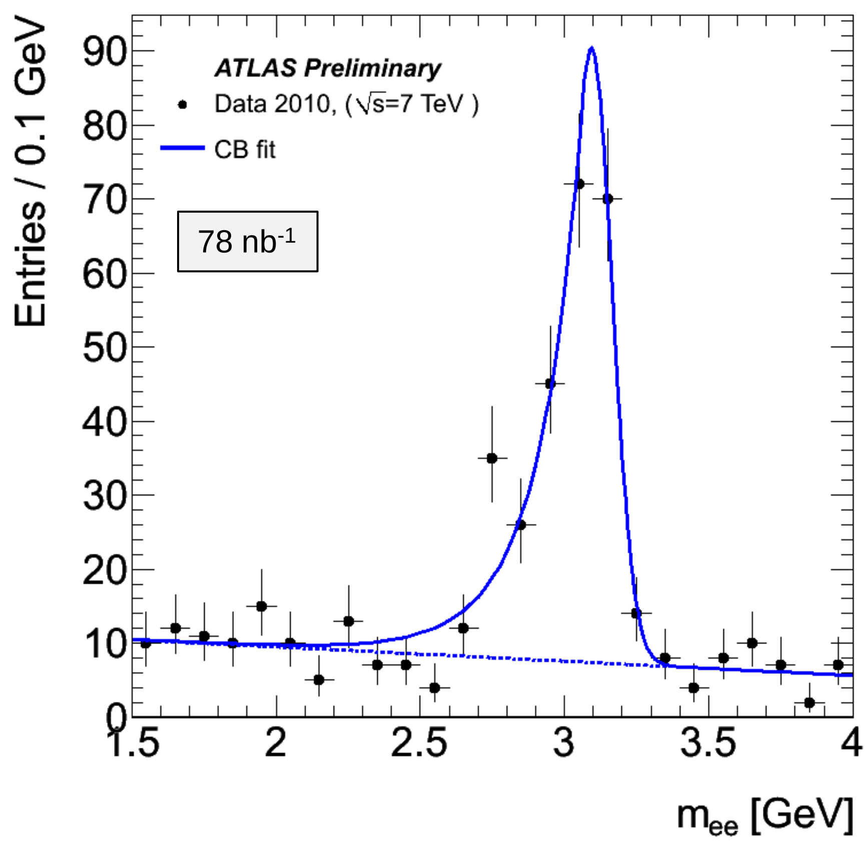
J/ψ mass peak vs muon η



J/ψ mass resolution vs muon η



J/ψ into electrons

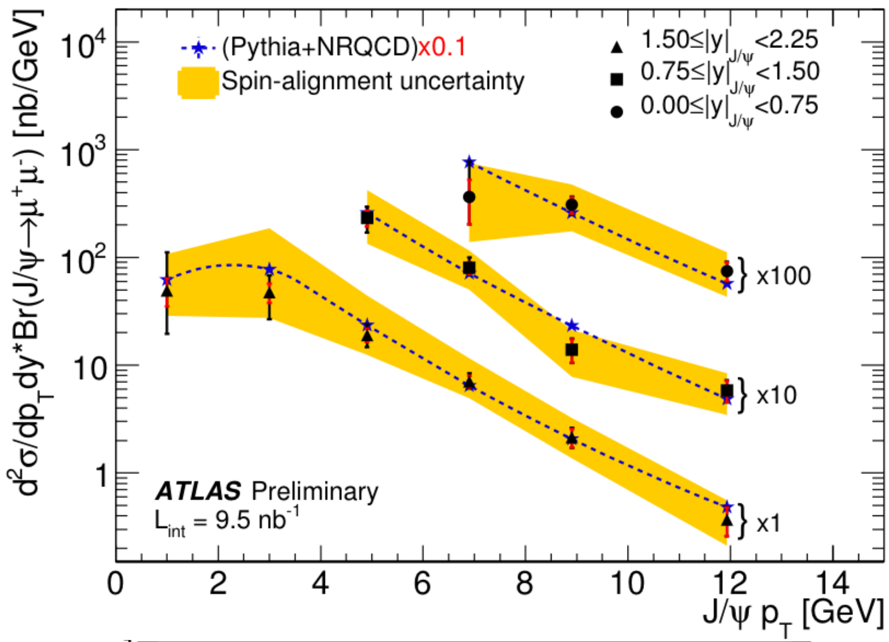


Signal	: 222 ± 11 events
Background	: 28 ± 2 events
Mass peak	: 3.09± 0.01 GeV
Mass resolution	: 0.07 ± 0.01 GeV

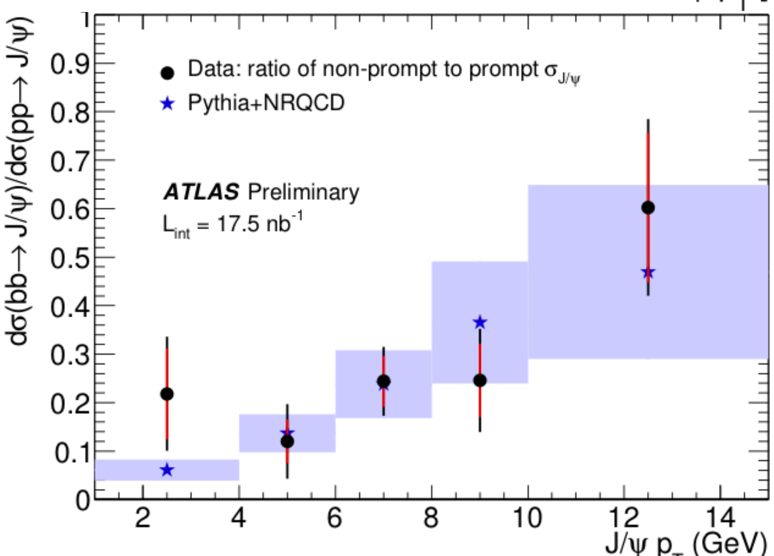
Requirements:

- 2 EM clusters matched to tracks
- p_T ($e^{\pm}$ tracks) > 4, 2 GeV
- track quality, calo shower shapes
- key handle: large transition radiation in TRT
- invariant mass from track parameters after Brem recovery (GSF)

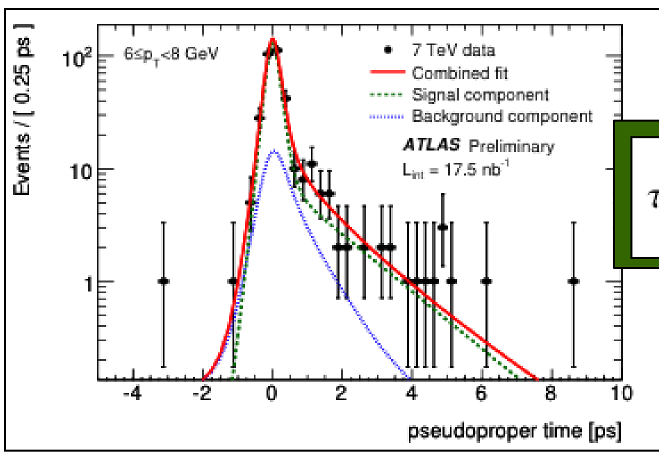
J/ψ Production



- ❑ Measured over |y (J/ψ)|<2.25, down to p_T (J/ψ)~ 1 GeV in forward region (p larger → higher acceptance)
- ❑ Pythia (Color Octet Model): good agreement in shape
- ❑ Uncertainty dominated by (unknown) spin-alignment



- ❑ From fit of proper decay time in inclusive J/ψ sample.
- ❑ Many uncertainties cancel in the ratio

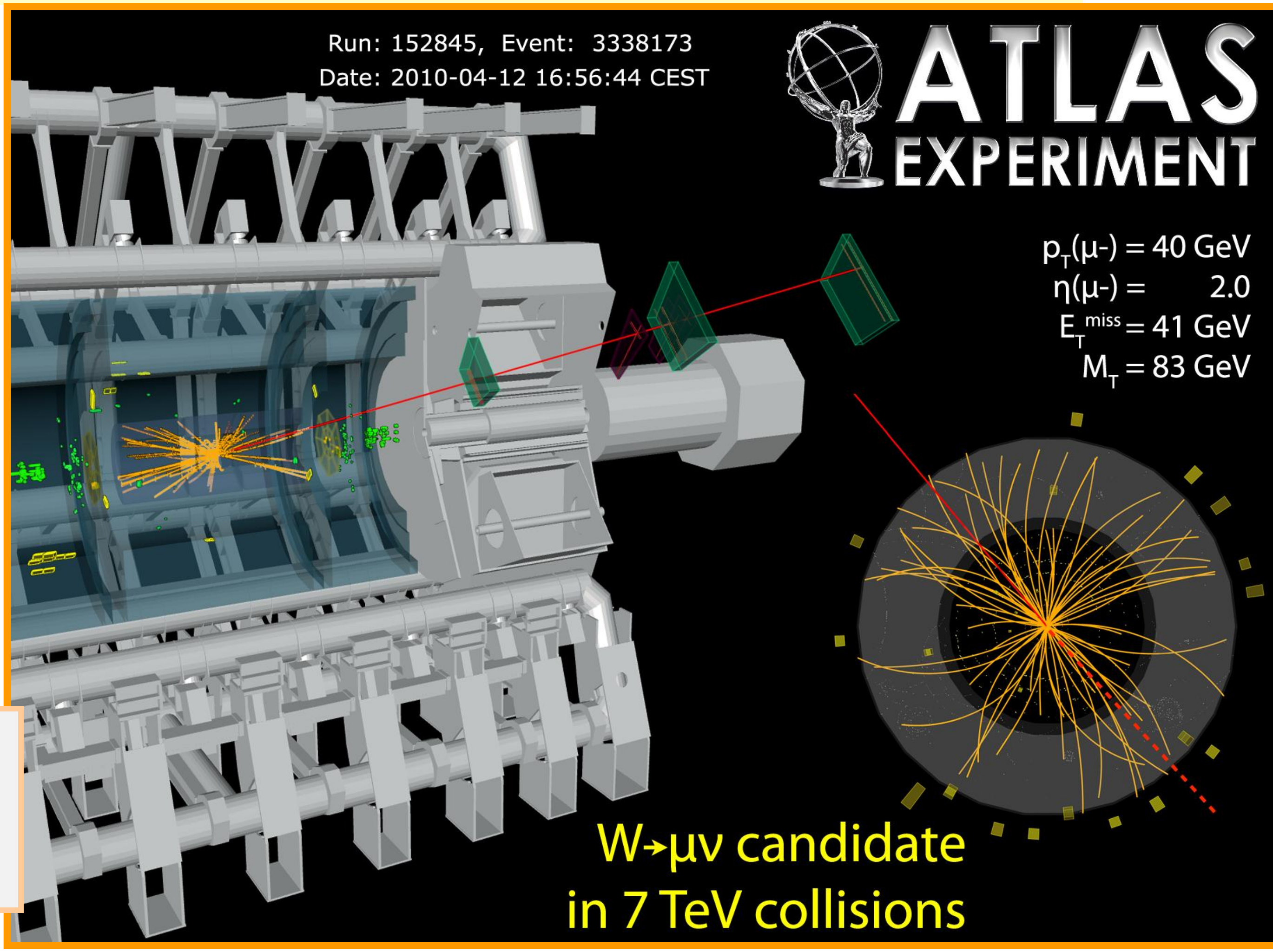


$$\tau = \frac{L_{xy}\, m(J/\psi)}{p_T(J/\psi)}$$

W and Z Physics

- Fundamental milestones in the "rediscovery" of the Standard Model at √s = 7 TeV
- Powerful tools to constrain PDF's and to understand ATLAS

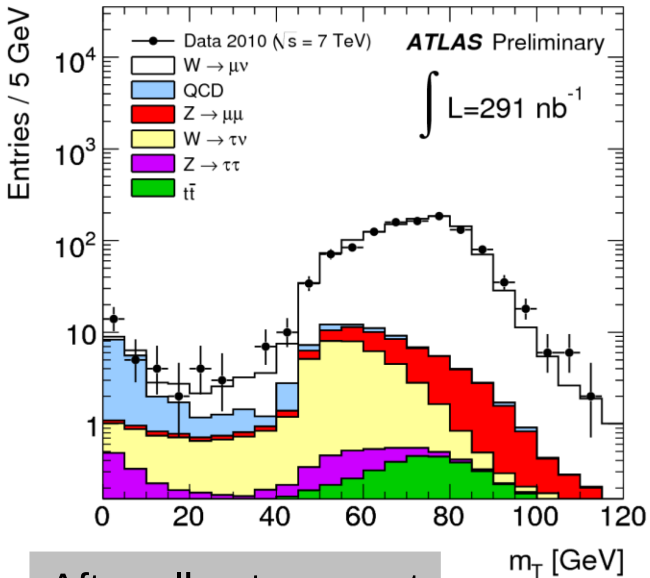
We all have favorite W's – this is mine.



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

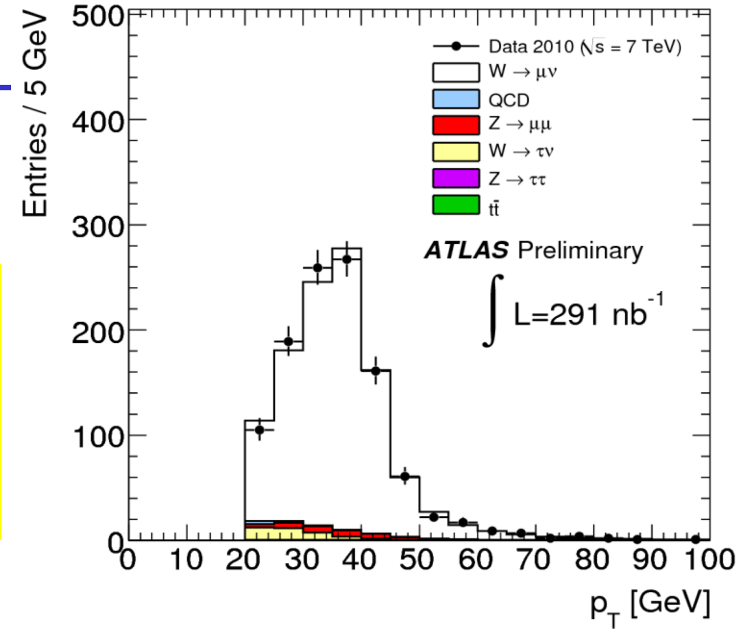
~300 nb^{-1}s of Ws

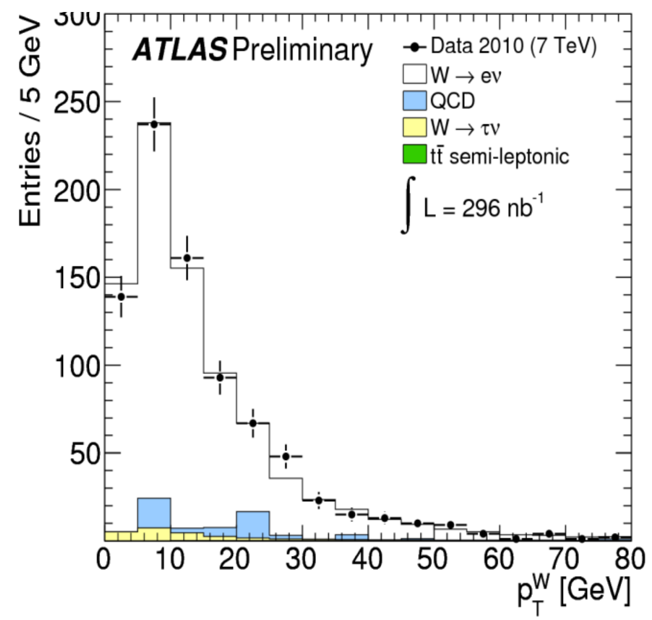
$$m_T = \sqrt{2 p_T^{\ell} p_T^{\nu} (1 - \cos(\phi^{\ell} - \phi^{\nu}))}$$



After all cuts except missing E_T

After all cuts
W→ eν (296 nb^{-1}): 815 events
W→ μν (291 nb^{-1}): 1111 events





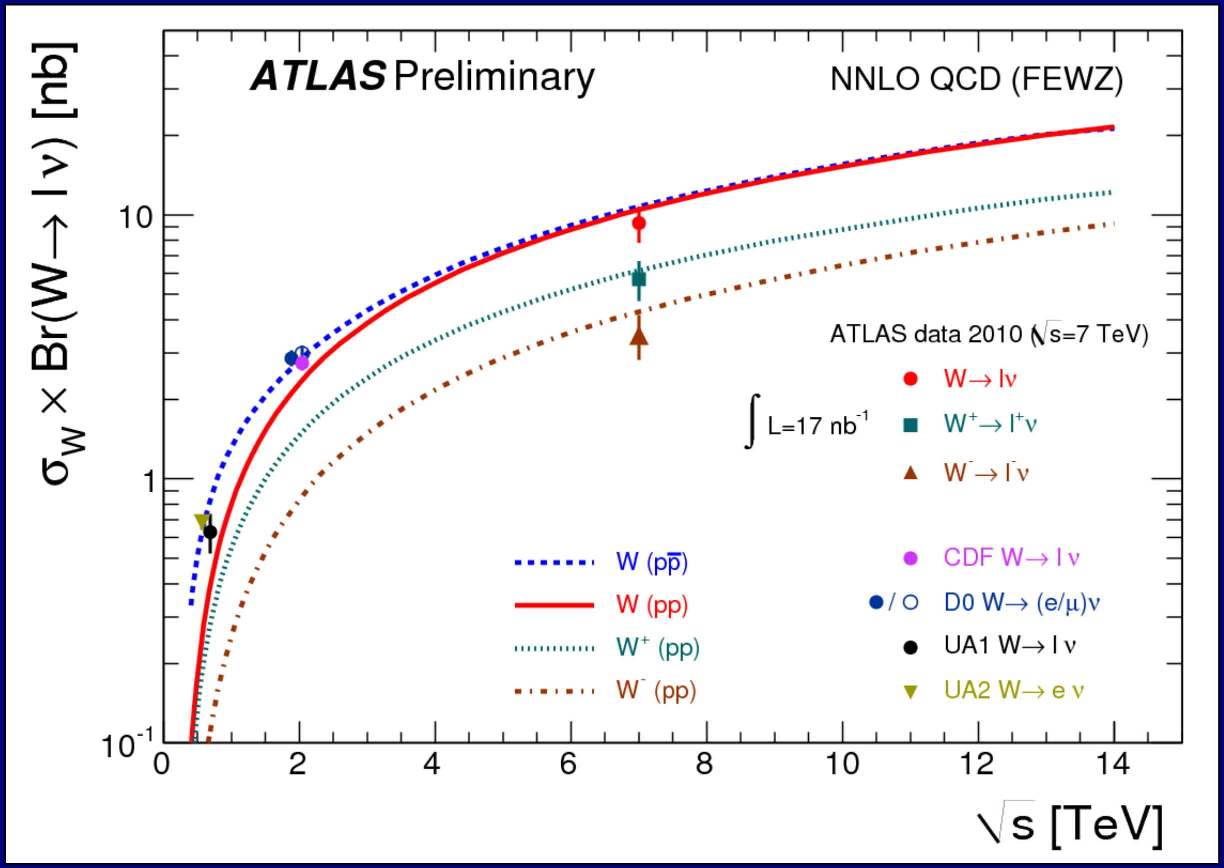
Work to determine systematic uncertainties (missing E_T …) in the presence of pile-up ongoing
→W cross-section measurements shown here are based on first 17 nb^{-1} (recorded at lower instantaneous luminosity)

W Cross-Section

σ (W → lν) = 9.3 ± 0.9 (stat) ± 0.6 (syst) ± 1.0 (lumi) nb

σ (W → eν) = 8.5 ± 1.3 (stat) ± 0.7 (syst) ± 0.9 (lumi) nb
σ (W → μν) = 10.3 ± 1.3 (stat) ± 0.8 (syst) ± 1.1 (lumi) nb

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



118 events:
47 W→ eν
72 W→ μν

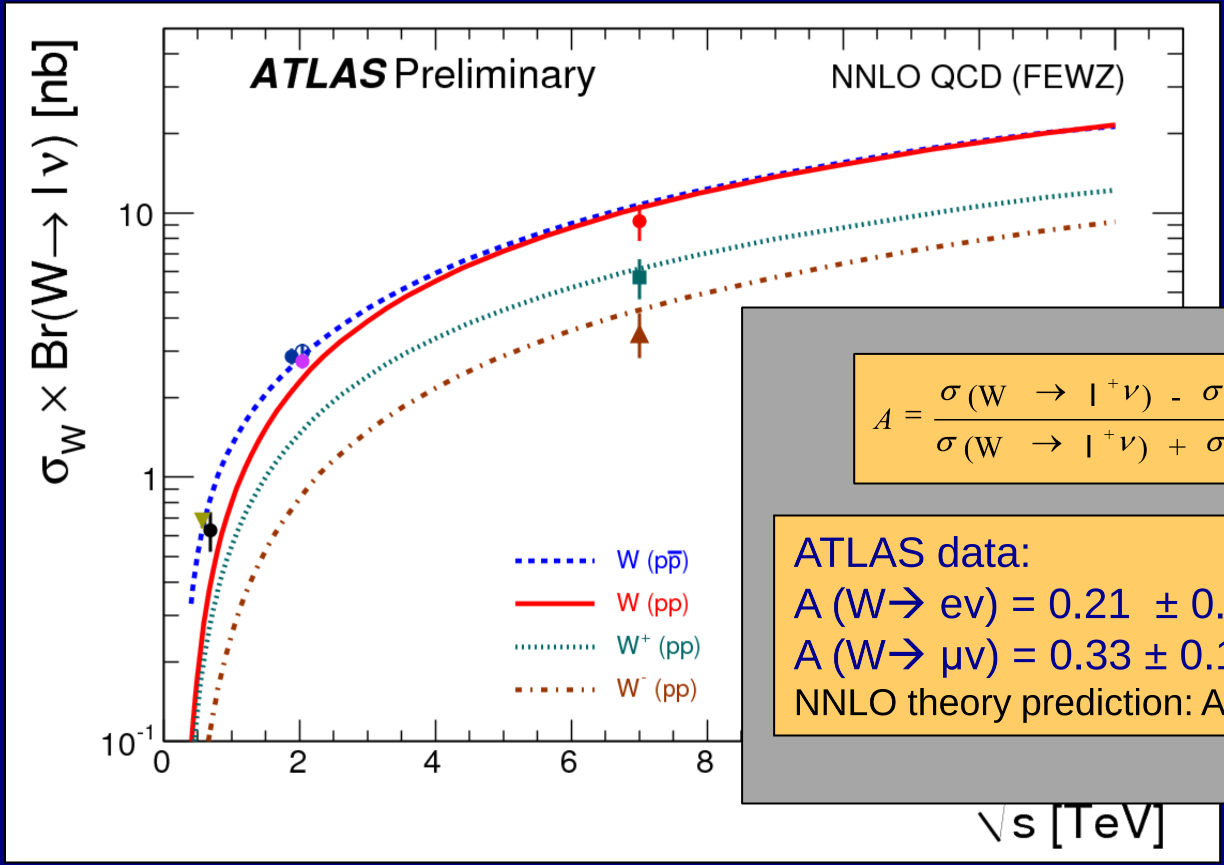
W Cross-Section and Asymmetry

σ (W → lν) = 9.3 ± 0.9 (stat) ± 0.6 (syst) ± 1.0 (lumi) nb

σ (W → eν) = 8.5 ± 1.3 (stat) ± 0.7 (syst) ± 0.9 (lumi) nb
σ (W → μν) = 10.3 ± 1.3 (stat) ± 0.8 (syst) ± 1.1 (lumi) nb

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

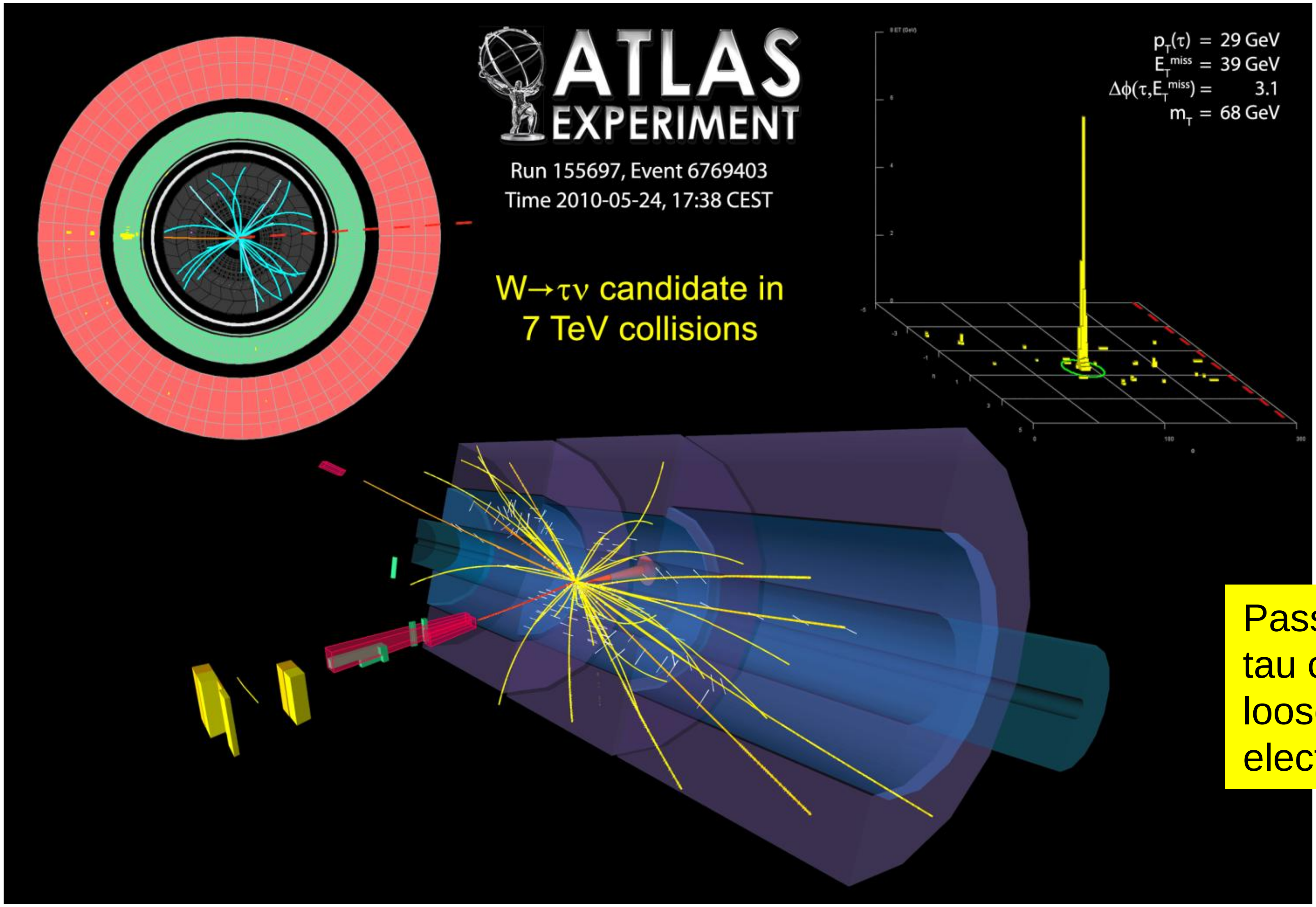
118 events:
47 W→ eν
72 W→ μν



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

ATLAS data:
A (W→ eν) = 0.21 ± 0.18 (stat) ± 0.01 (syst)
A (W→ μν) = 0.33 ± 0.12 (stat) ± 0.01 (syst)
NNLO theory prediction: A=0.2

And Maybe Even Some Taus



Passes tightest tau cuts; fails loosest electron cuts.

This channel has substantially more background, so
it's difficult to tell event-by-event if this is a real tau or background.

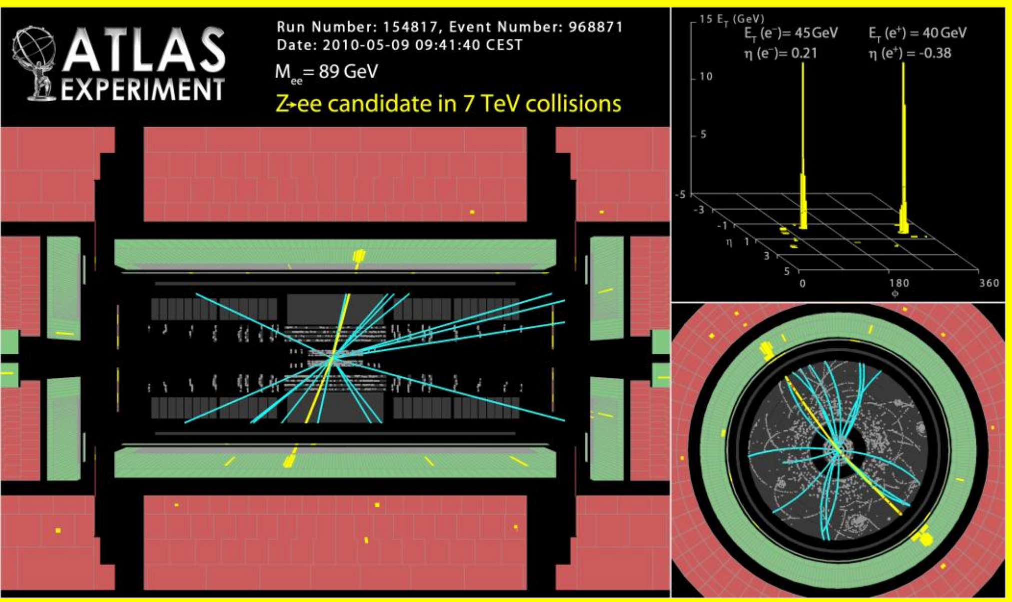
Moving on to the Z

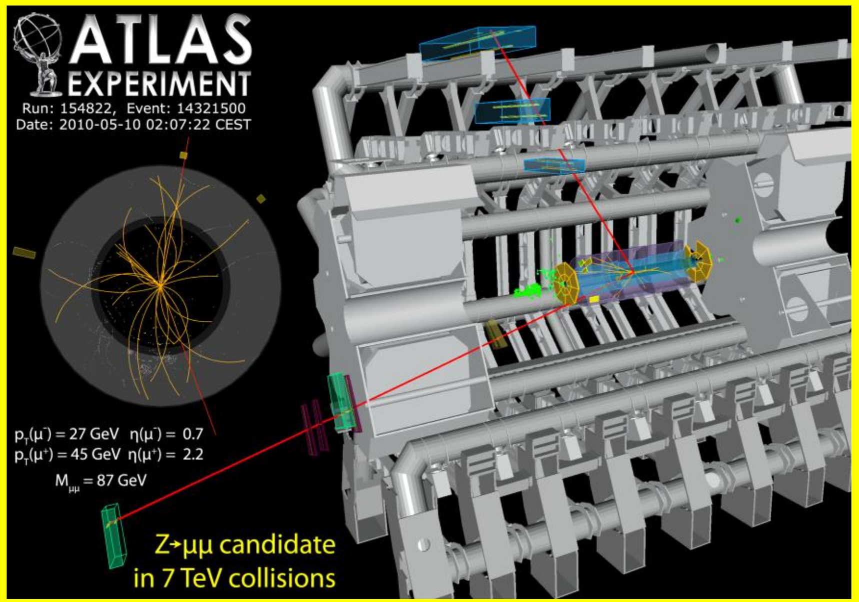
Main selections : Z → ee
- 2 opposite-sign electrons
- E_T > 20 GeV, $|\eta|<2.47$
- medium electron identification criteria
- 66 < M (e^+e^-) < 116 GeV

Total efficiency : ~ 30%
Main background: QCD
S/B ~ 100

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

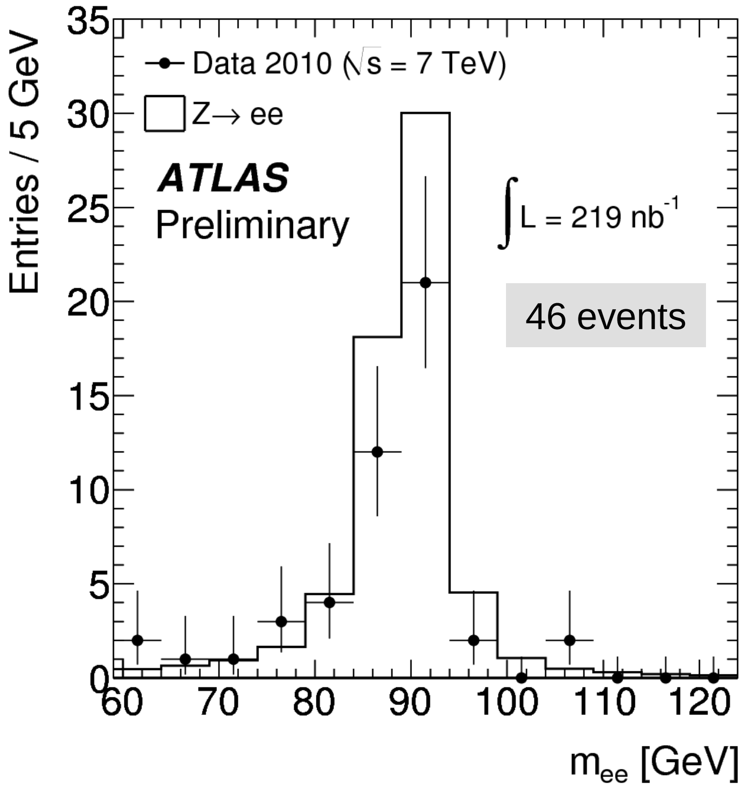
Total efficiency: ~ 40%
Main background: tt, Z→ ττ
S/B ~ 400

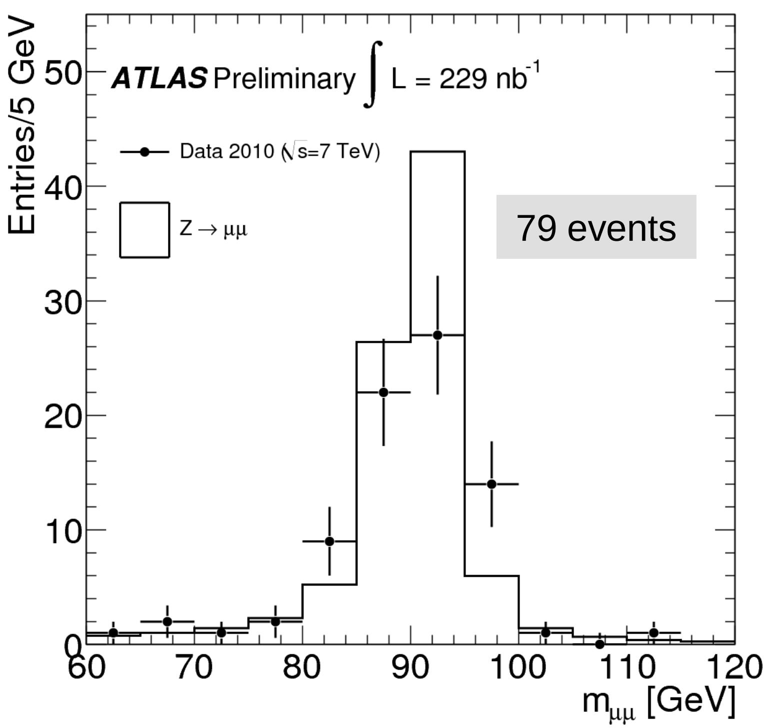




~300 nb^{-1}s of Zs

We have an incontrovertible Z signal, with an expected background level of 2/3 of an event.





Nevertheless, we still have some work to do (alignment, intercalibration, etc.) to get to ATLAS' design resolution.

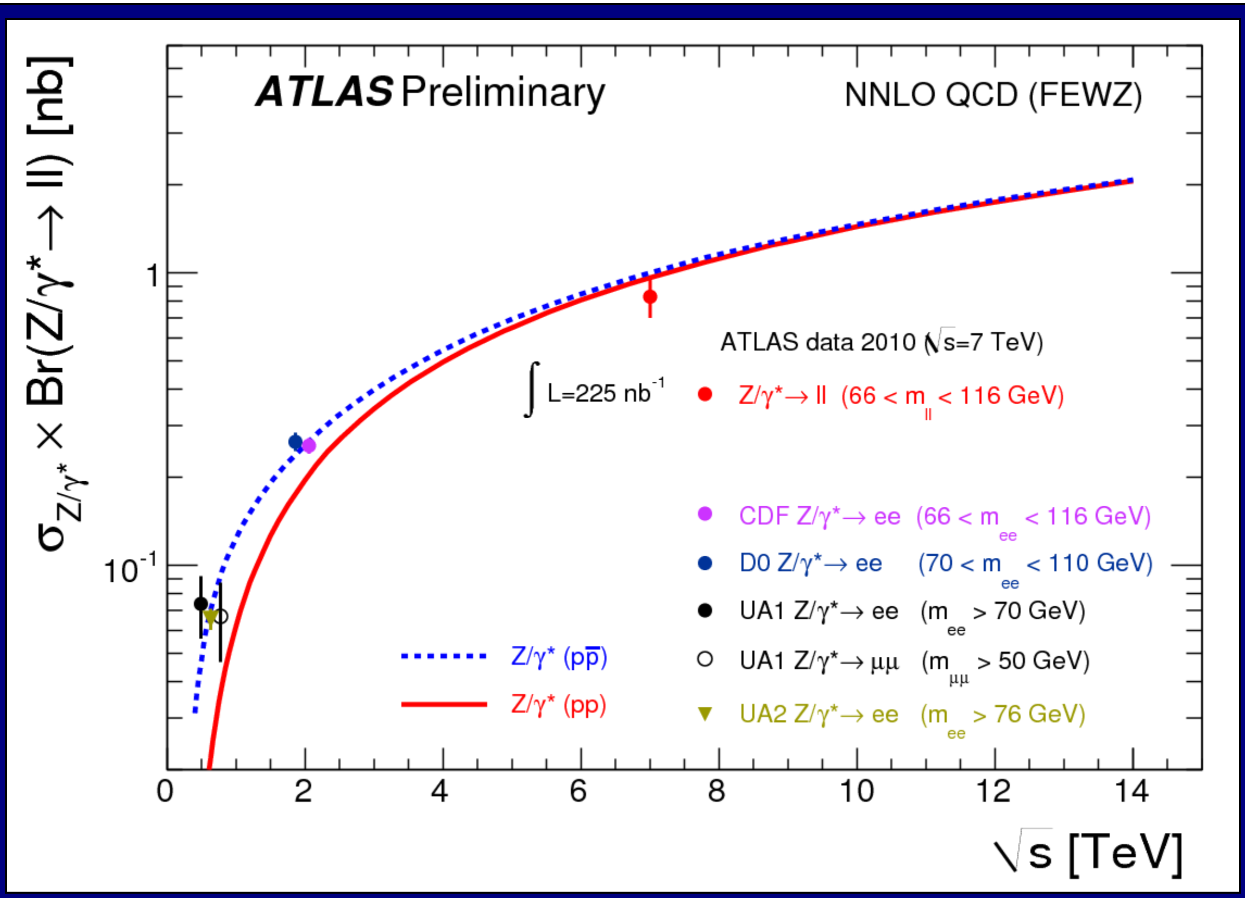
Z Cross-Section

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

$\sigma\ (Z \rightarrow ee) = 0.72 \pm 0.11\ \text{(stat)} \pm 0.10\ \text{(syst)} \pm 0.08\ \text{(lumi) nb}$

$\sigma\ (Z \rightarrow \mu\mu) = 0.89 \pm 0.10\ \text{(stat)} \pm 0.07\ \text{(syst)} \pm 0.10\ \text{(lumi) nb}$

Dominant experimental uncertainties: lepton reconstruction and identification.



125 events:
46 Z→ ee
79 Z→ μμ

Top Quarks

lepton + jets channel
tt → bW bW → blν bjj
σ ~ 60 pb

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

2-lepton channel
tt → bW bW → blν blν
σ ~ 6 pb

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

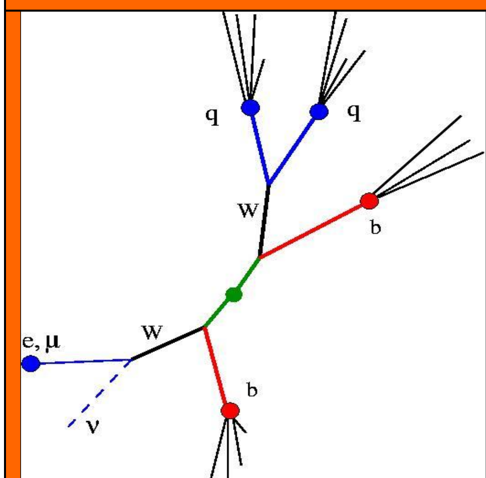
Acceptance x efficiency ~ 30%

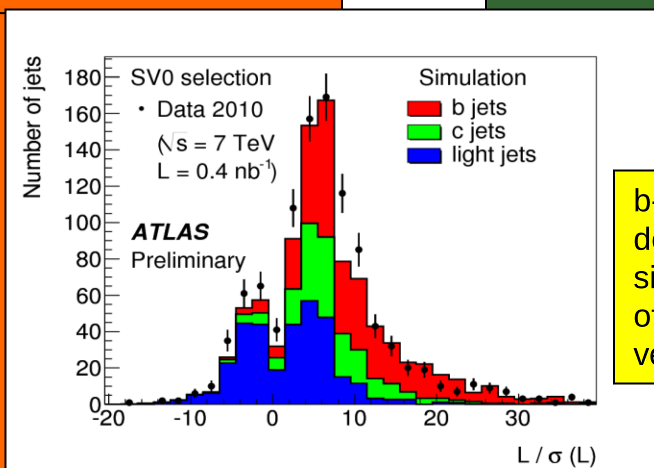
Expect ~ 5 signal events

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

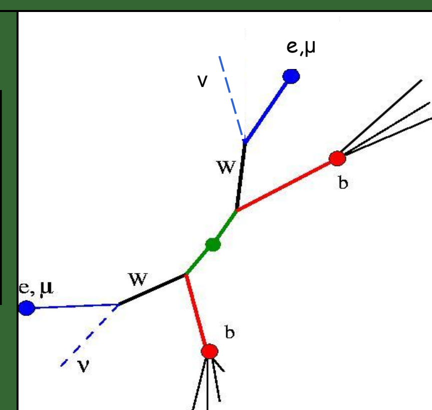
Acceptance x efficiency ~ 25%

Expect ~ 0.5 signal events





b-tagging:
decay length significance of secondary vertex



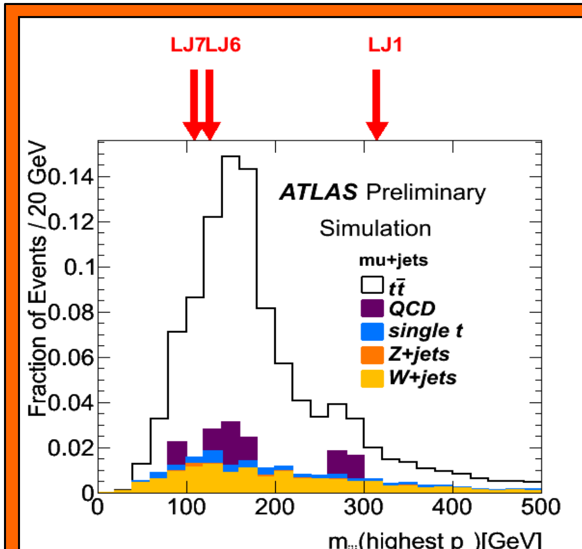
Our Nine Candidates

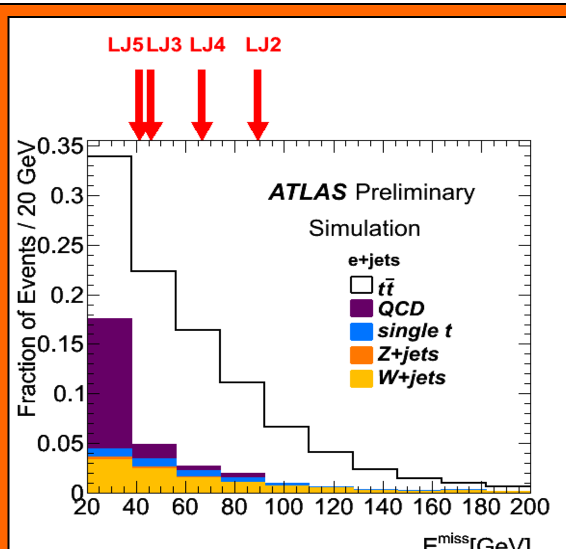
2 dilepton

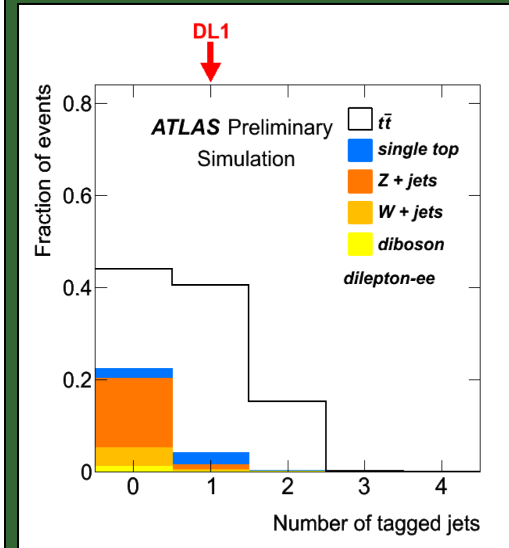
ID	Run number	Event number	Channel	p_T^{lep} (GeV)	E_T^{miss} (GeV)	H_T (GeV)	#jets $p_T > 20$ GeV	#b-tagged jets
DL1	155678	13304729	ee	55.2/40.6	42.4	271	3	1
DL2	158582	27400066	$e\mu$	22.7/47.8	76.9	196	3	1

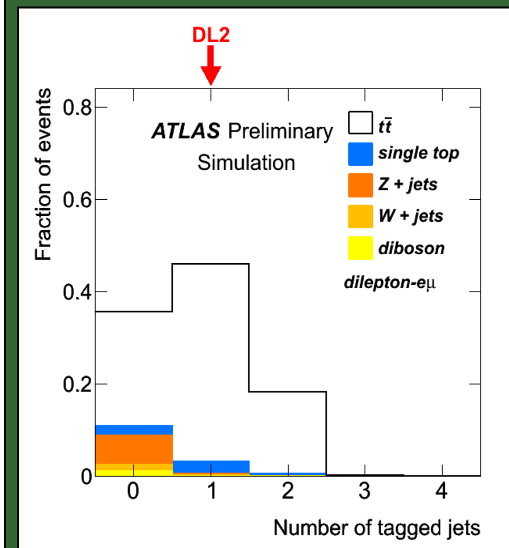
7 lepton + jets

ID	Run number	Event number	Channel	p_T^{lep} (GeV)	E_T^{miss} (GeV)	m_T (GeV)	m_{jjj} (GeV)	#jets $p_T > 20$ GeV	#b-tagged jets
LJ1	158801	4645054	μ+jets	42.9	25.1	59.3	314	7	1
LJ2	158975	21437359	e+jets	41.4	89.3	68.7	106	4	1
LJ3	159086	12916278	e+jets	26.2	46.1	62.6	94	4	1
LJ4	159086	60469005	e+jets	39.1	66.7	102	231	4	1
LJ5	159086	64558586	e+jets	79.3	43.4	86.7	122	4	1
LJ6	159224	13396261	μ+jets	29.4	65.4	64.1	126	5	1
LJ7	159224	13560451	μ+jets	78.7	40.0	83.7	108	4	1

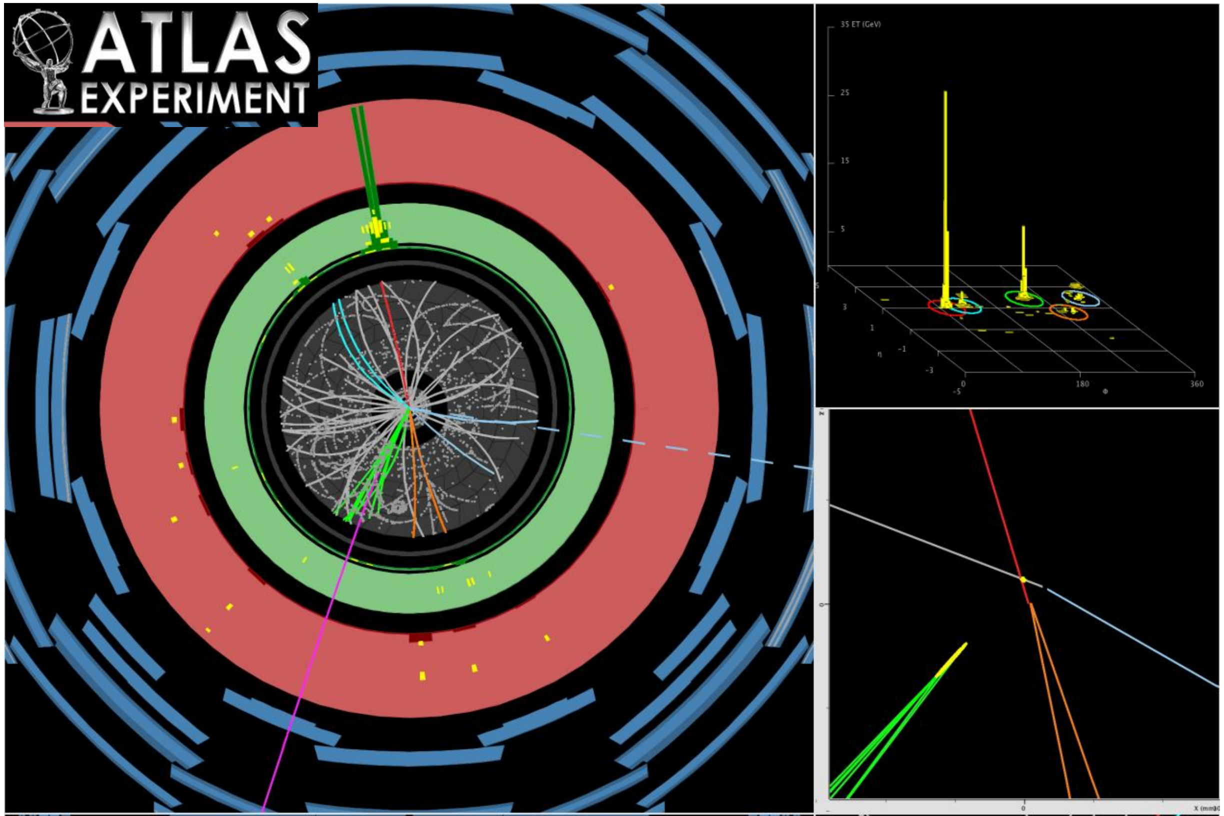


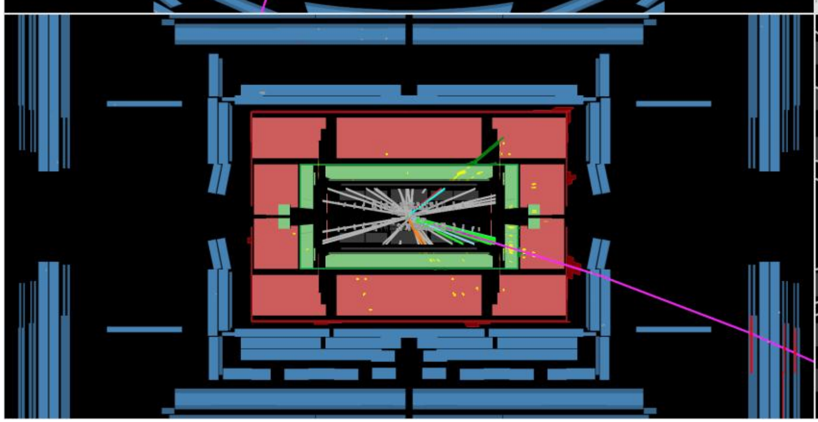






One Lepton+Jets Candidate (LJ5)





$p_T(e)$=79 GeV E_t^{miss} = 43 GeV

m_T (“W→eν”)= 87 GeV

p_T (b-tagged jet) = 91 GeV

M (jjj)= 122 GeV

Secondary vertex:

-- distance from primary: 5 mm

-- 6 tracks p_T > 2 GeV

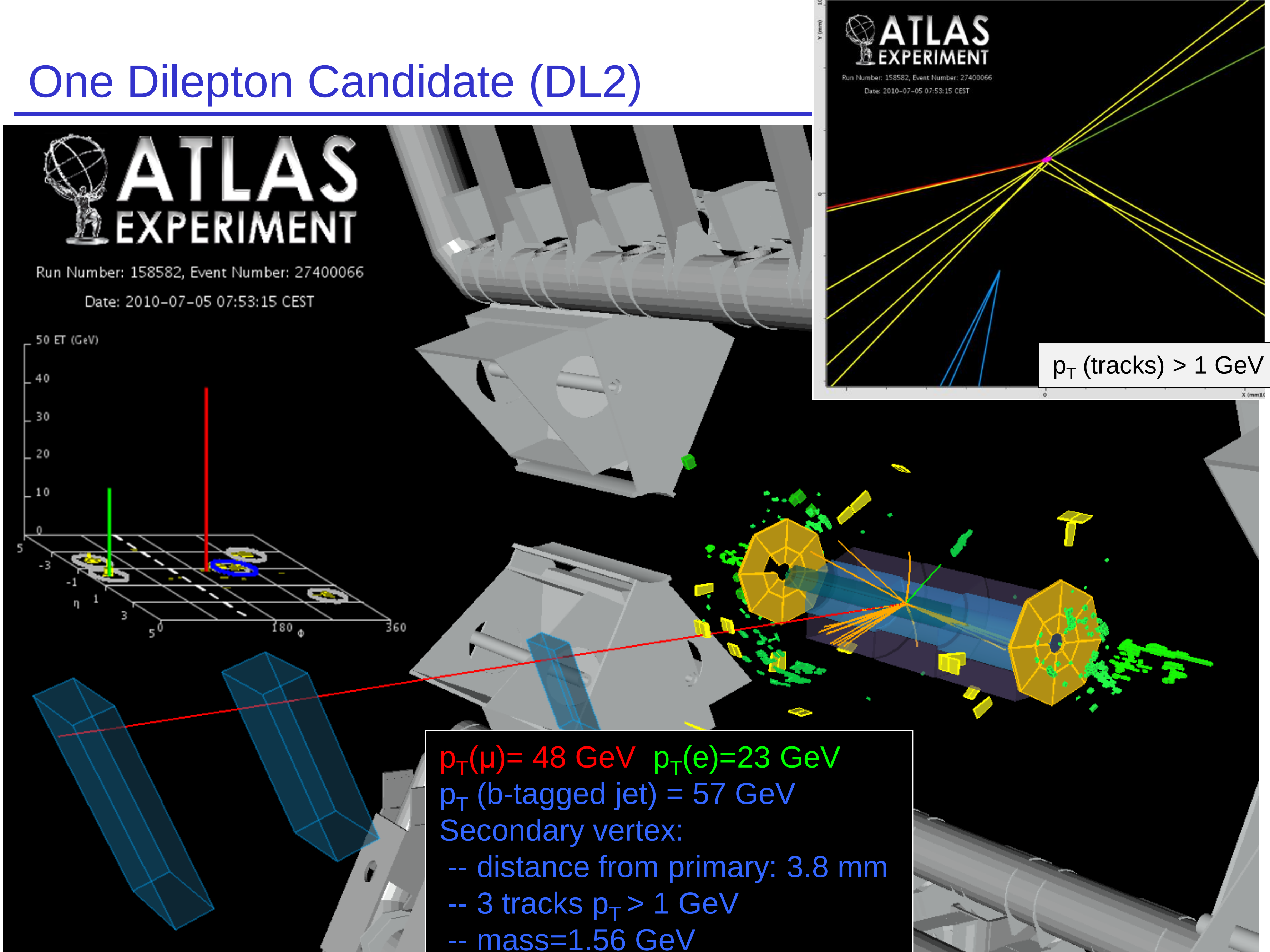
-- mass=3.8 GeV

This event has a number of top-like features.

Nevertheless, we cannot say with certainty any particular event is signal or background.

This event also has a second primary vertex. All the high p_T objects come from the same interaction point.

One Dilepton Candidate (DL2)



$p_T(\mu)$= 48 GeV $p_T(e)$=23 GeV

p_T (b-tagged jet) = 57 GeV

Secondary vertex:

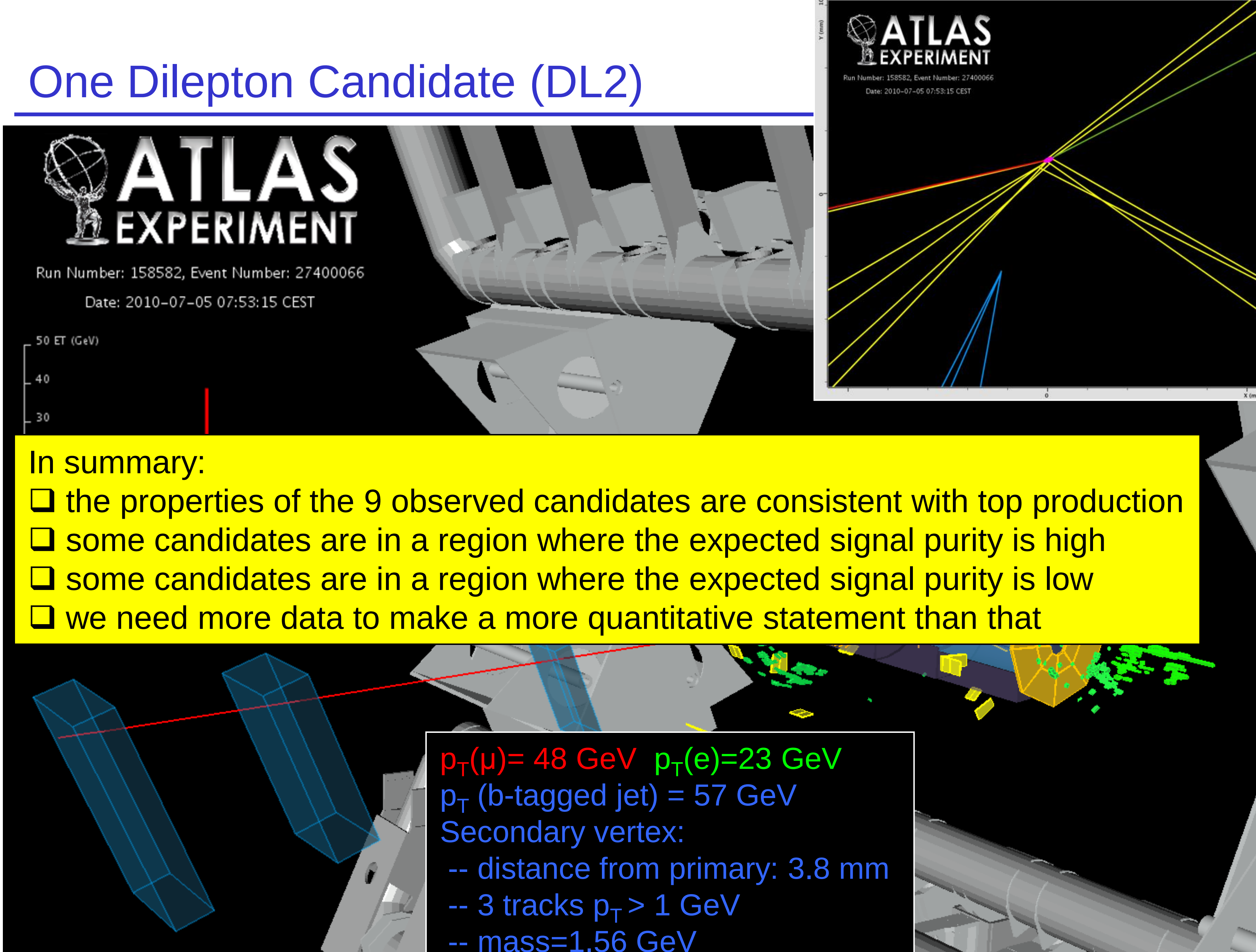
-- distance from primary: 3.8 mm

-- 3 tracks p_T > 1 GeV

-- mass=1.56 GeV

E_T^{miss}=77 GeV, H_T=196 GeV

One Dilepton Candidate (DL2)



In summary:

- ❑ the properties of the 9 observed candidates are consistent with top production
- ❑ some candidates are in a region where the expected signal purity is high
- ❑ some candidates are in a region where the expected signal purity is low
- ❑ we need more data to make a more quantitative statement than that

$p_T(\mu)$= 48 GeV $p_T(e)$=23 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
E_T^{miss}=77 GeV, H_T=196 GeV

Searches for New Physics

- While everything I have shown you is interesting and solid science (that is leading or has led to publications) that's not why we built ATLAS

- ATLAS was built to search for new particles and new phenomena

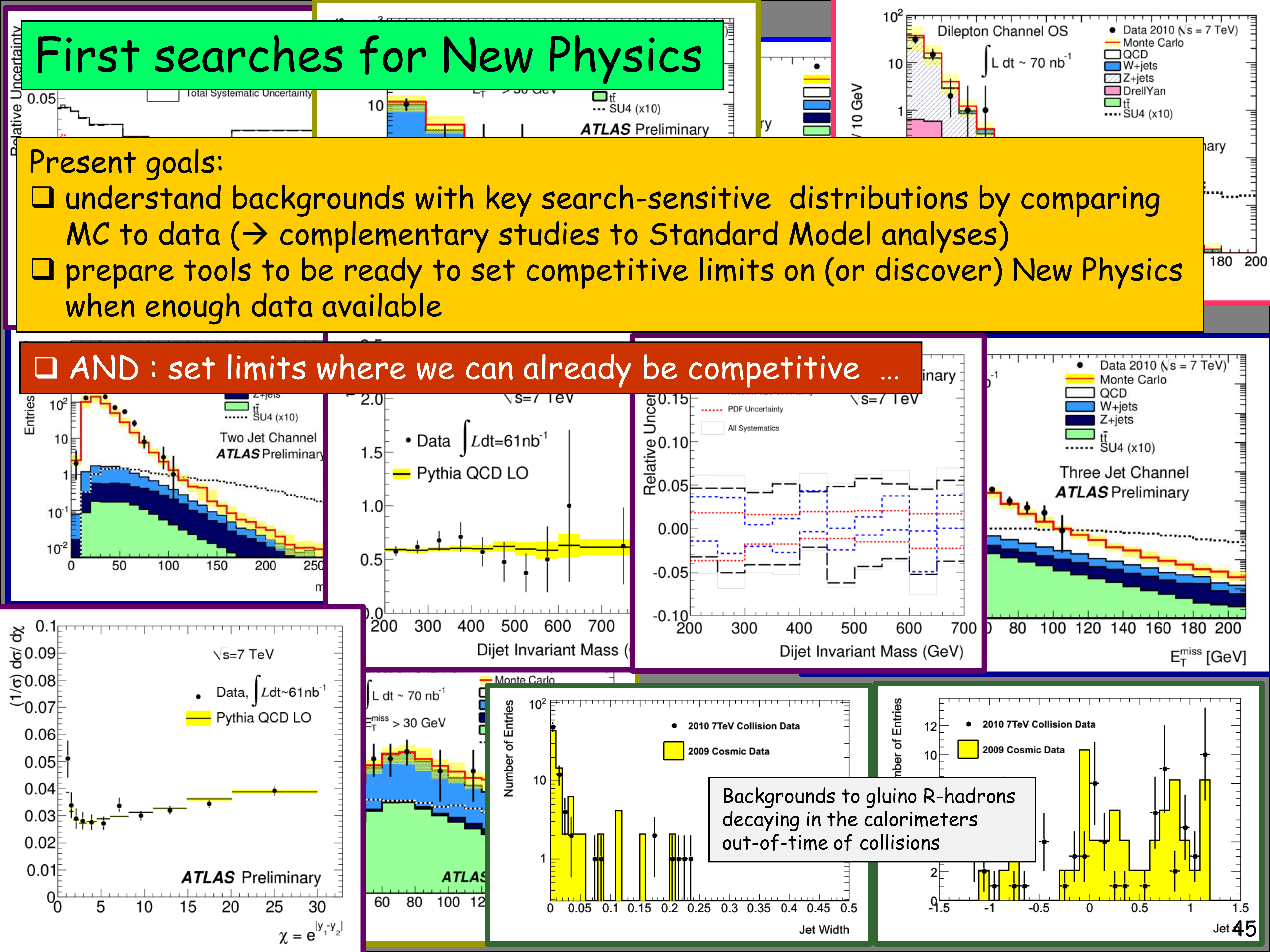
- It's hard to make a better slide showing where we are than what Fabiola showed at ICHEP:

First searches for New Physics

Present goals:

- understand backgrounds with key search-sensitive distributions by comparing MC to data (→ complementary studies to Standard Model analyses)
- prepare tools to be ready to set competitive limits on (or discover) New Physics when enough data available

- AND : set limits where we can already be competitive …



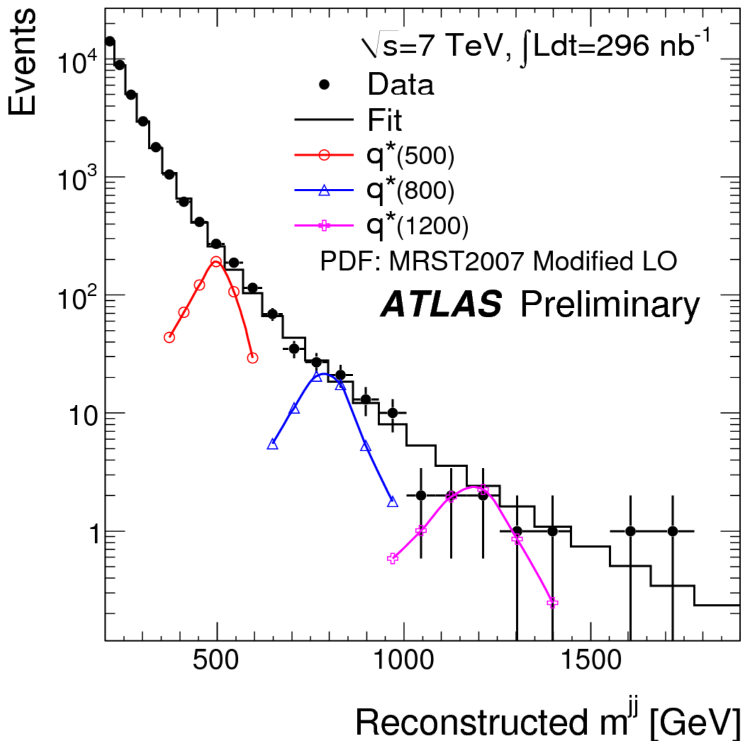
Backgrounds to gluino R-hadrons decaying in the calorimeters out-of-time of collisions

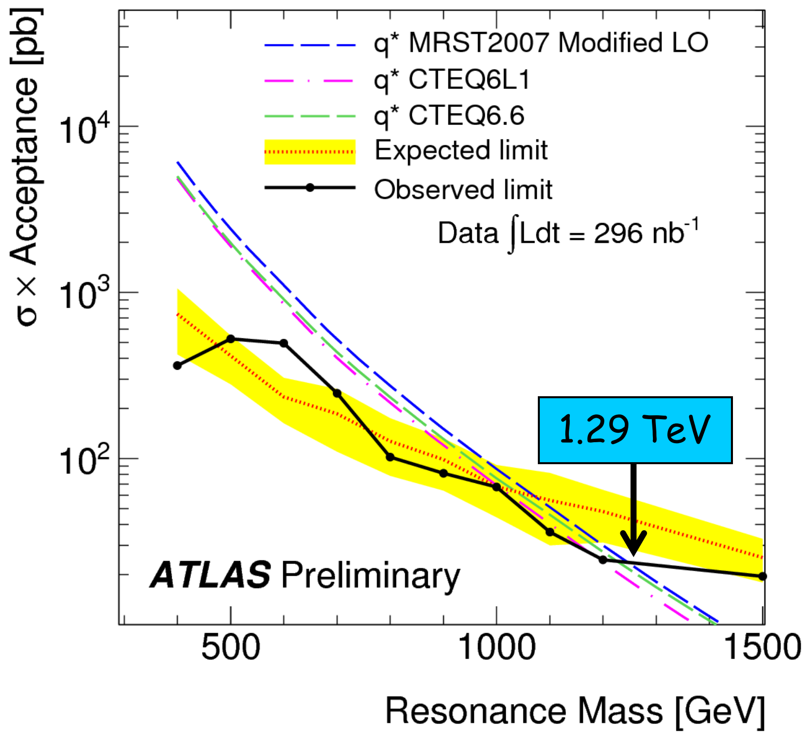
Searches for excited quarks: q* → jj

Looked for di-jet resonance in the measured m(jj) distribution
→ spectrum compatible with a smoothly falling function → no bumps

Latest published limit:
CDF: 260 < M (q*) < 870 GeV

400 GeV < M (q*) < **1.29 TeV** excluded at 95% C.L.





- ❑ Experimental systematic uncertainties included: luminosity, JES (dominant), background fit, ..
- ❑ Impact of different PDF sets studied → with CTEQ6L1: 400 < M (q*) < 1180 GeV

Conclusions

- It took only four months for ATLAS to go from taking its first 7 TeV collisions to producing science
- Much of this is presently Standard Model…
  – Soft QCD,Jets, Quarkonium, Electoweak and Top
- …but searches are now starting to move into unexplored territory
  – m(q*) > 1.29 TeV is our first example