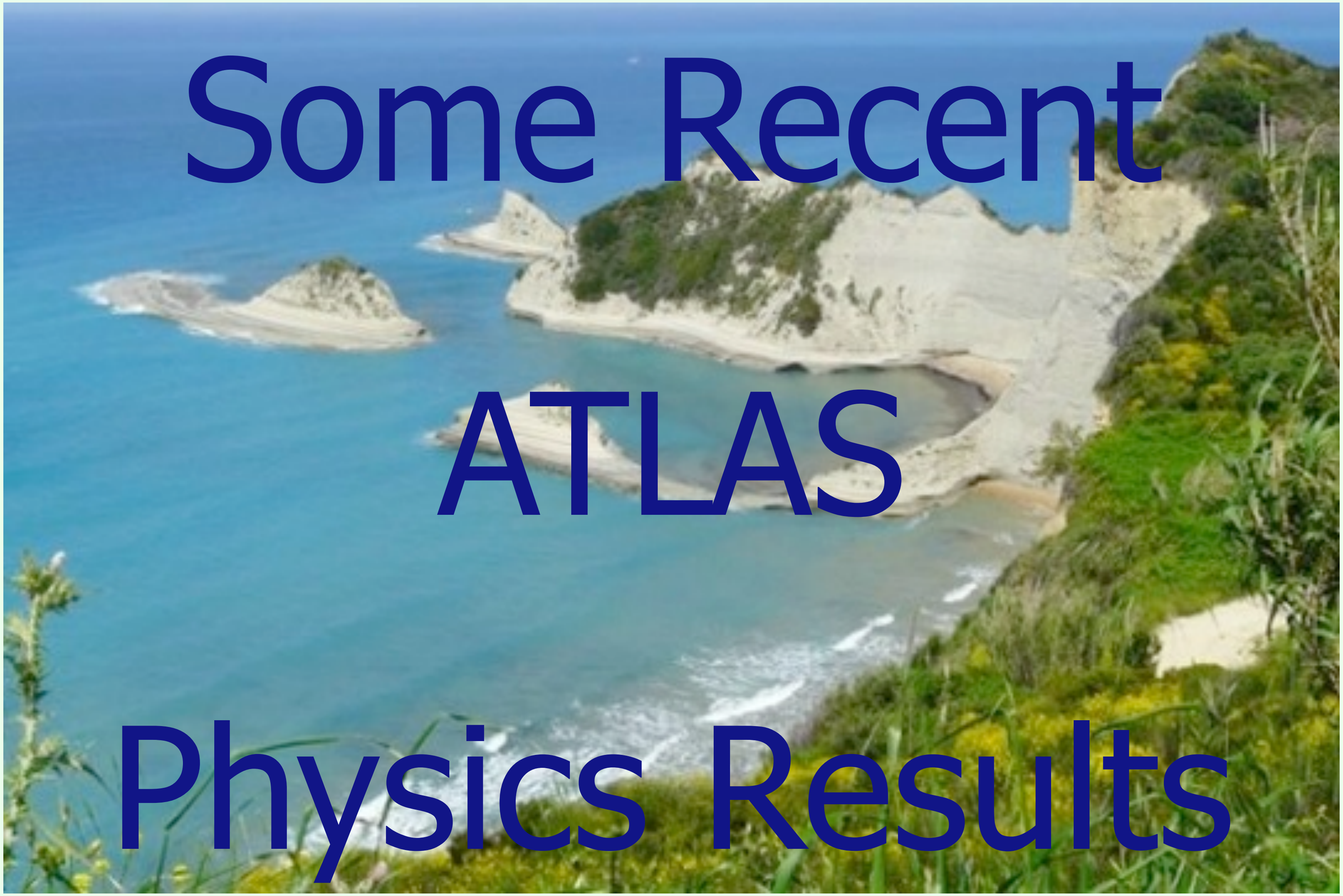
Some Recent ATLAS Physics Results



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Corfu Summer Institute
31 August 2010

Presentation

I. LHC start & ATLAS Operation
II. Jets & Limit on Q*
III. ETmiss & first SUSY search
IV. W&Z and M_W prospect
V. Conclusions

What is not presented

Detailed detector commissioning, performance & operation

Particle identification (electrons, muons, photons, …..)

Evidence for prompt photon production (cf Louis Fayard's presentation)

Soft Physics

Top

Even more uncovered topics

Credits

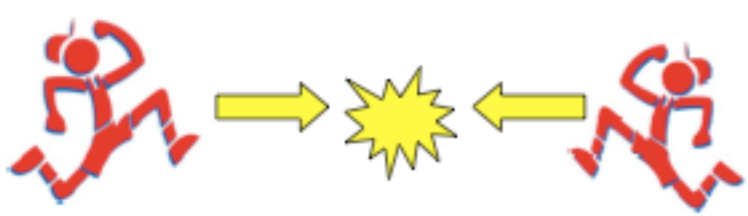
- I was inspired by the lectures/presentations prepared by
  - Fabiola Gianotti, Pascal Pralavorio, Tancredi Carli, Jim Virdee, Louis Fayard, Beate Heinemann, Ariel Schwartzman, Laurent Serin, …..

- Most of results presented today are from ATLAS CONFerence Notes prepared for ICHEP & HCP conferences and available at https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/RESULTS/summer2010.html

pp collisions at √s = 7 TeV

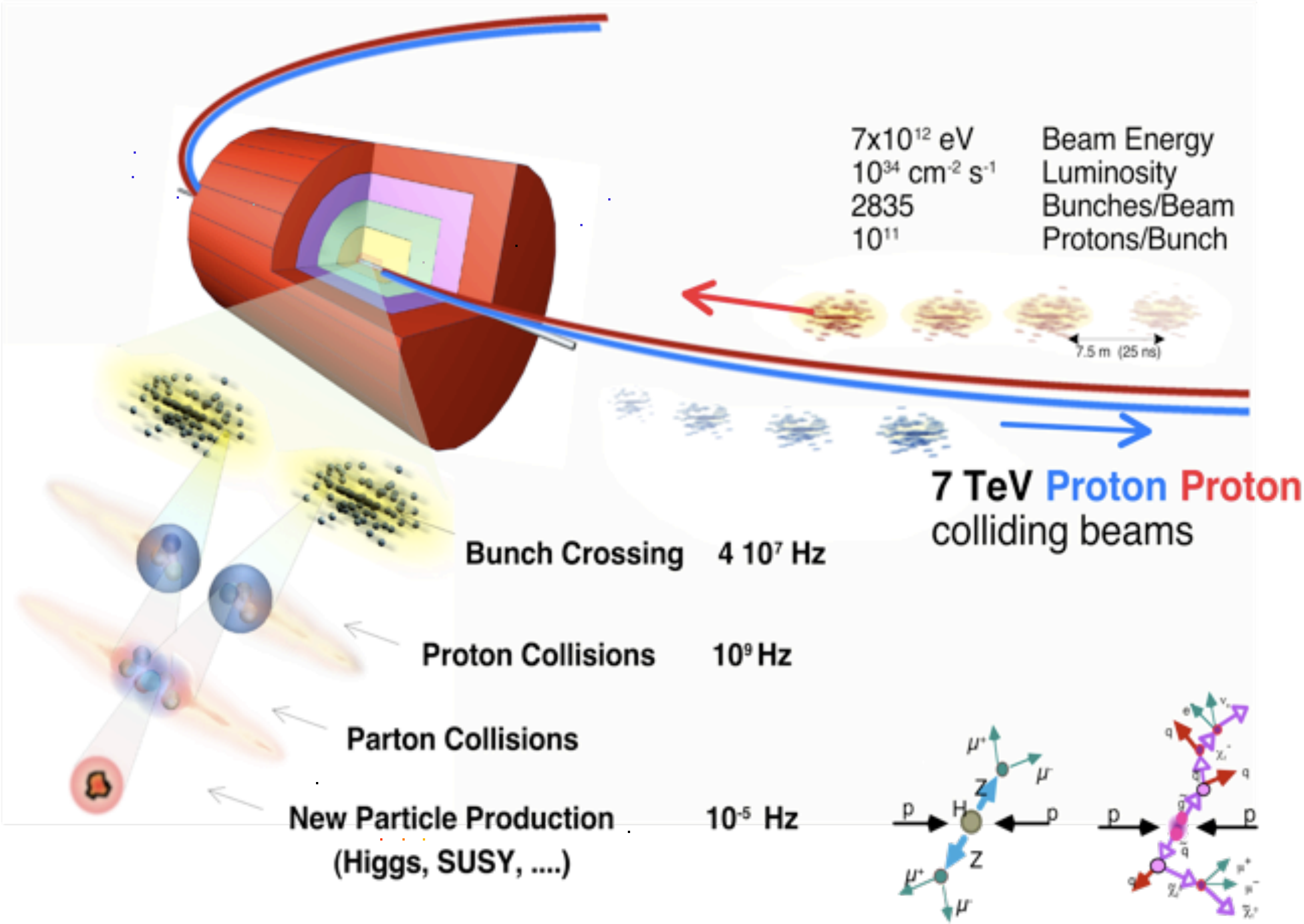
- Why a hadron collider when
  - Hadrons are complicated objects
    - the elementary process is then not known (quark, gluons)
    - the kinematics of the interaction not fully constraint
    - pollution by other components (underlying event)
- But
  - Can reach higher energies

Lepton Collider
(collision of two point-like particles)



Hadron collider
(collision of ~50 point-like particles)

[Karl Jakobs]



Selection of 1 event in 10,000,000,000,000

J. Virdee

From cosmic muons to collisions: LHC

	LHC design	LHC 2009-2011	Tevatron
$\sqrt{s}$	14 TeV	0.9, 2.1, 7 TeV	1.96 TeV
Number of bunches	2808	2-400 (40)	36
Bunch spacing	25 ns	75-150 ns?	396 ns
Energy stored in beam	360 MJ	2 MJ for 40 bunches	1 MJ
Peak Luminosity	10^{33}-10^{34} $cm^{-2}s^{-1}$	10^{28}-10^{33} $cm^{-2}s^{-1}$(10^{31})	$3 \cdot 10^{32}$ $cm^{-2}s^{-1}$
$\int \mathcal{L} \cdot dt$- one year	10-100 evts/fb	0.1-1 evts/fb (3 evts/pb)	~2 evts/fb

- With nominal parameters: LHC is a factor ~1000 more powerful than Tevatron
  - Energy: $E_{LHC} = 7 \cdot E_{Tevatron}$
  - Luminosity: $L_{LHC} = 3\text{-}30 \cdot L_{Tevatron}$
  - Physics cross sections factor 10-1000 larger
- First collisions at 7 TeV were collected on 30.03.2010
  - Generous harvest since then

Cross-section Measurement

Number of selected evts

Number of background evts

$$\sigma = \frac{N_{obs.} - N_B}{\varepsilon \times \mathcal{L}}$$

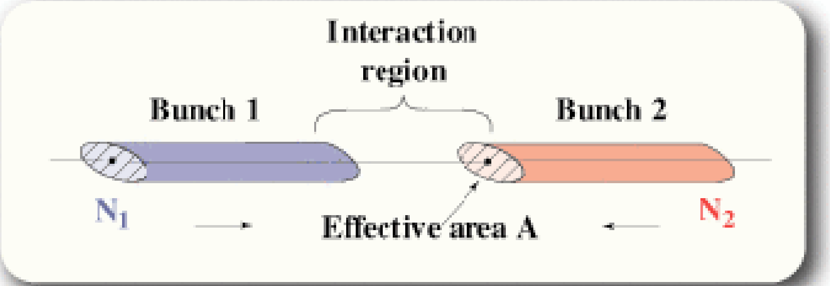
Selection efficiency

Luminosity

Collider luminosity $\mathcal{L}$

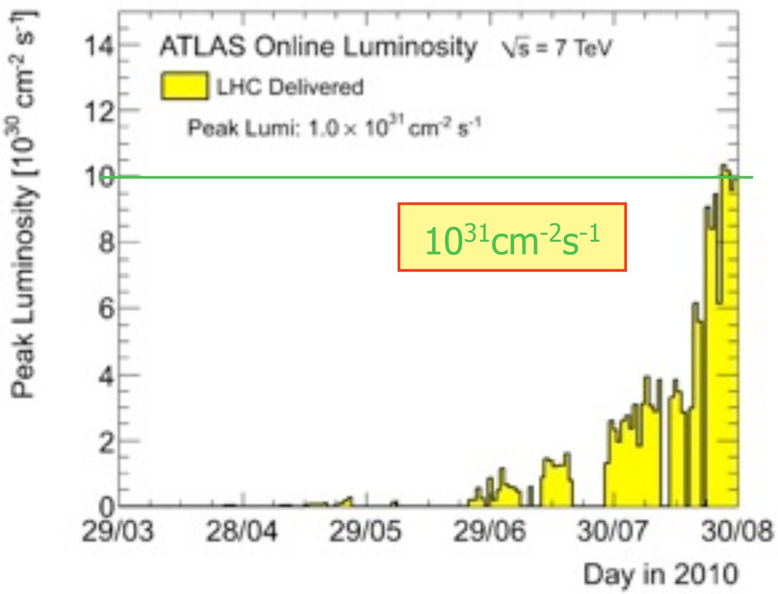
- Luminosity is given by the beam optics:

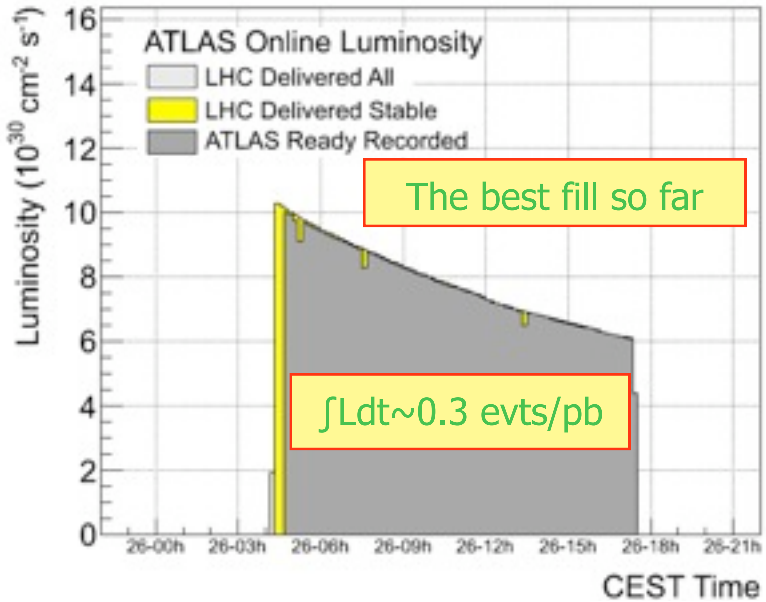
$$\mathcal{L} = \frac{N_1 N_2 f}{A_{\mathrm{eff}}}$$



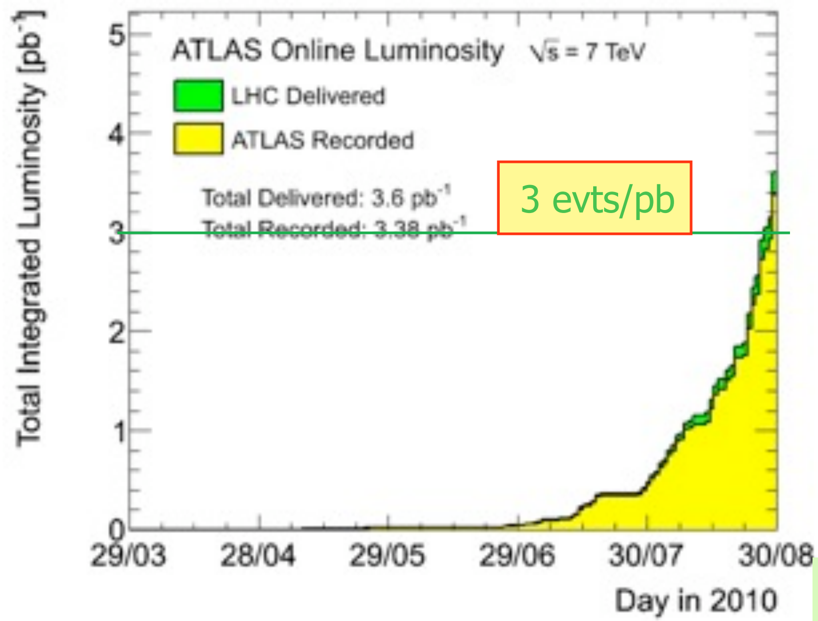
- $N_{events} = \mathcal{L} \times \sigma$
  - Experiments count the number of events
  - $\mathcal{L}$ has to be known to be able to measure cross sections
    - Best estimate of $\mathcal{L}$ is given today by the measurement of the LHC beam currents: ±11%
    - Dedicated detectors, measuring events from known cross-sections will be used and ultimately provide a measurement of the luminosity to ±2-3%
      - ALFA detector to measure elastic p-p scattering at small angle being installed
    - Physics processes with well calculated cross-sections

Luminosity so far with pp collisions at $\sqrt{s}$ = 7 TeV



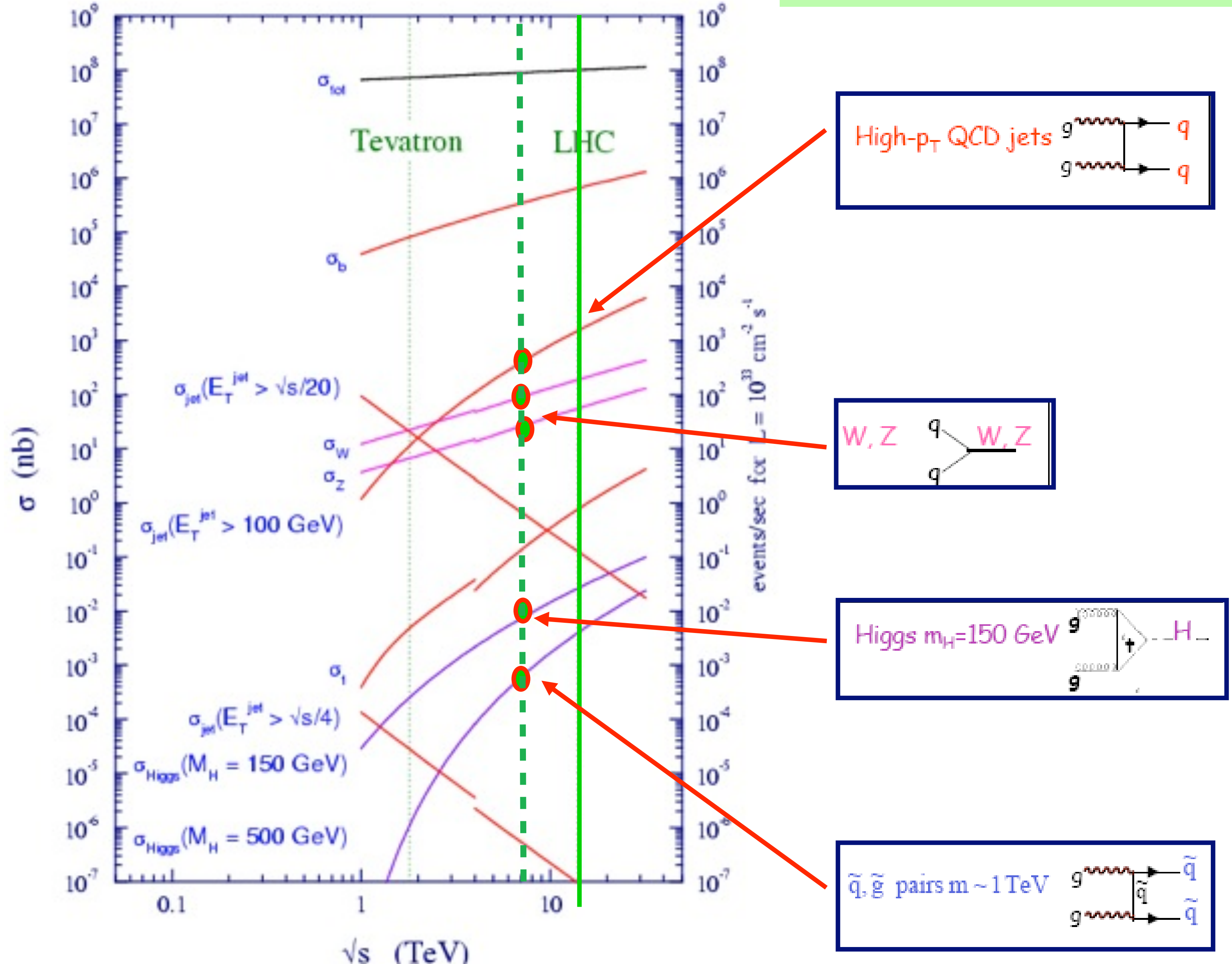


Needs to take into account data taking efficiency ~95%

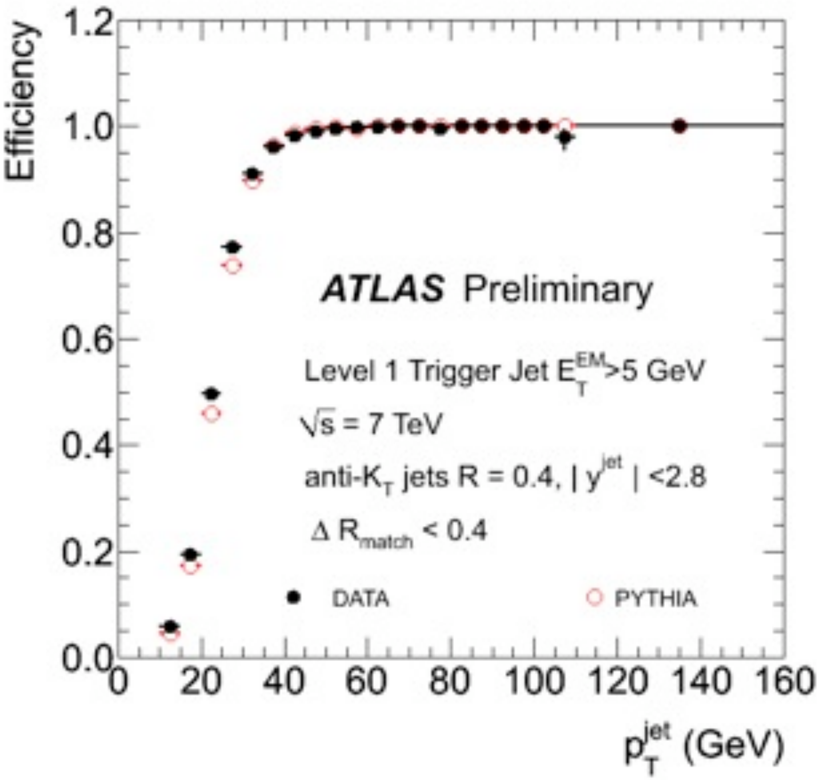


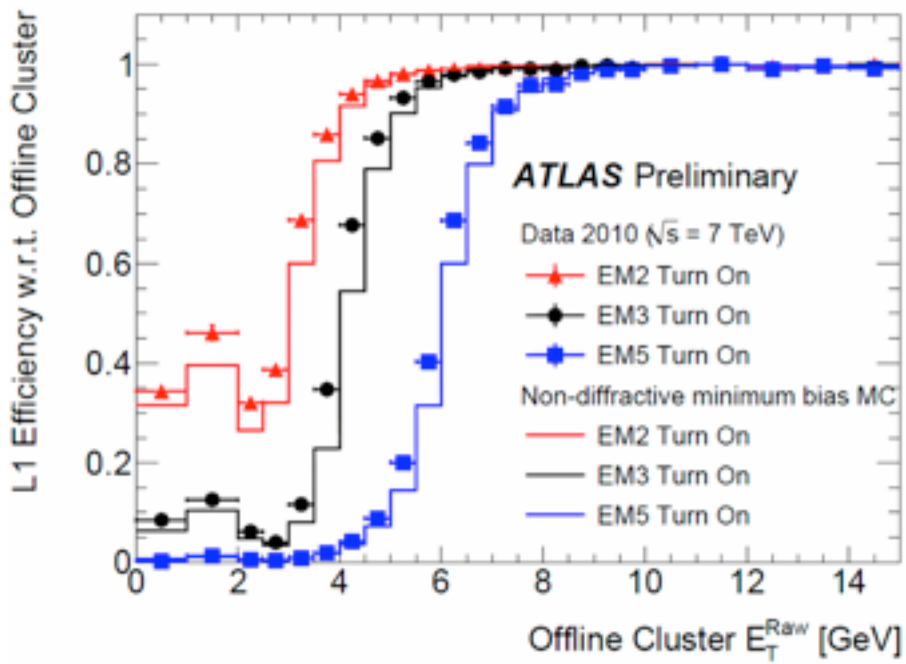
Very fast progress
1 fill today =
all data collected between April & July
(on Sunday: >430nb^{-1} recorded)

Cross-sections -> Triggering



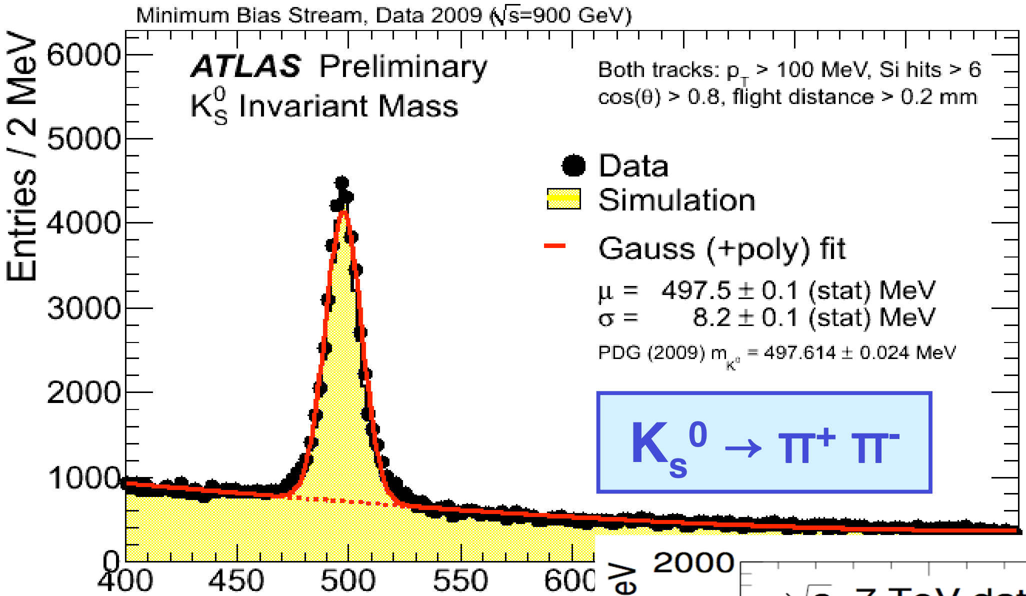
Triggering in pp collisions at √s = 7 TeV

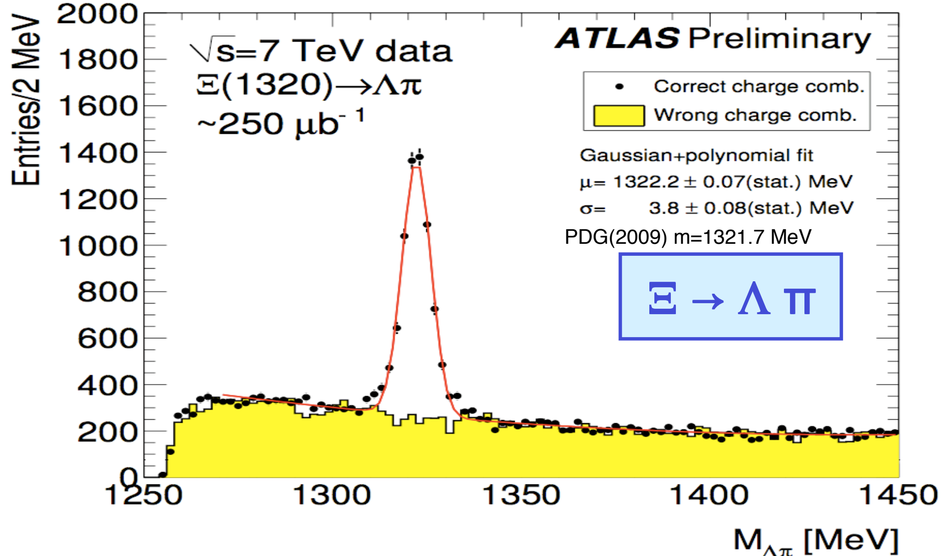


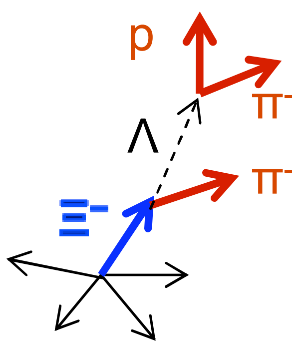


Track momentum scale

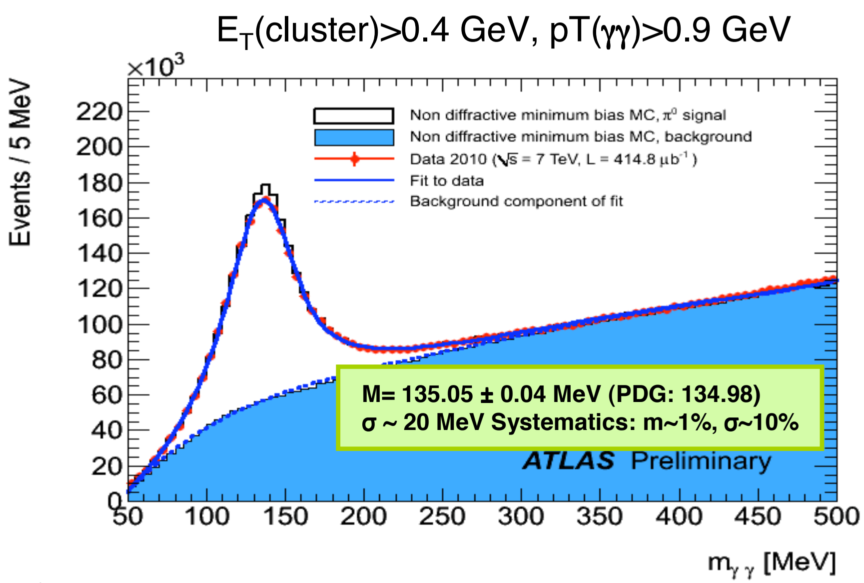
- Precise measurement of magnetic field (2006)
  - Momentum scale known to a few ‰ in low p_T range

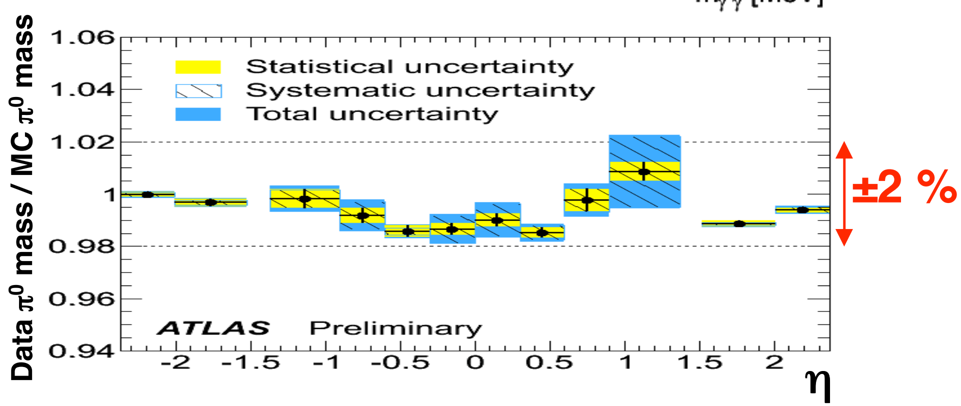


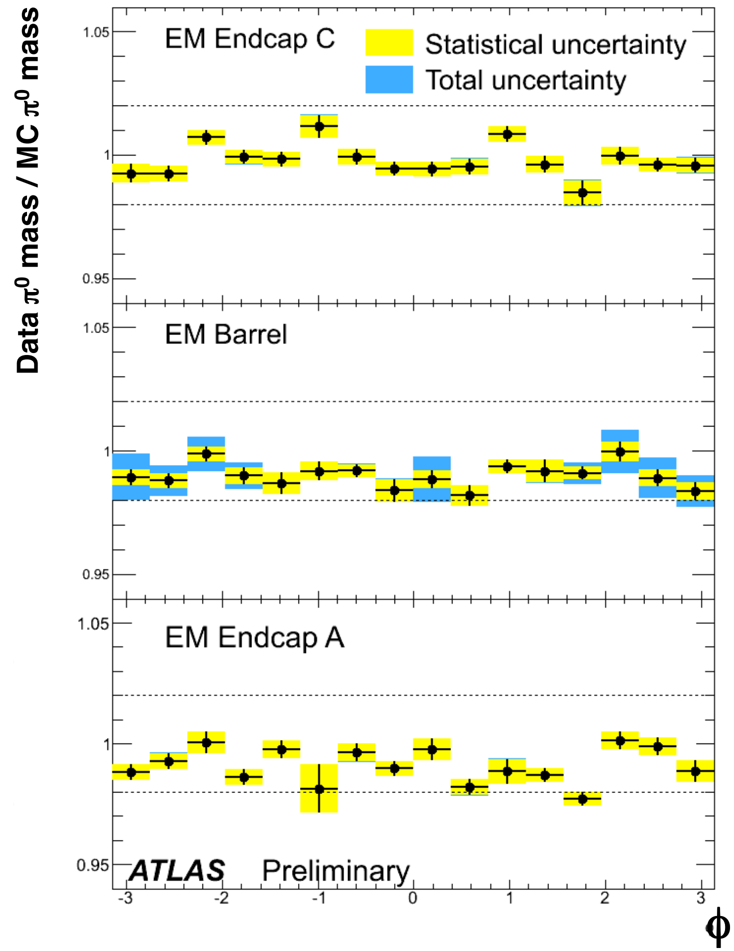




Electromagnetic Calorimeter Performance: π^0



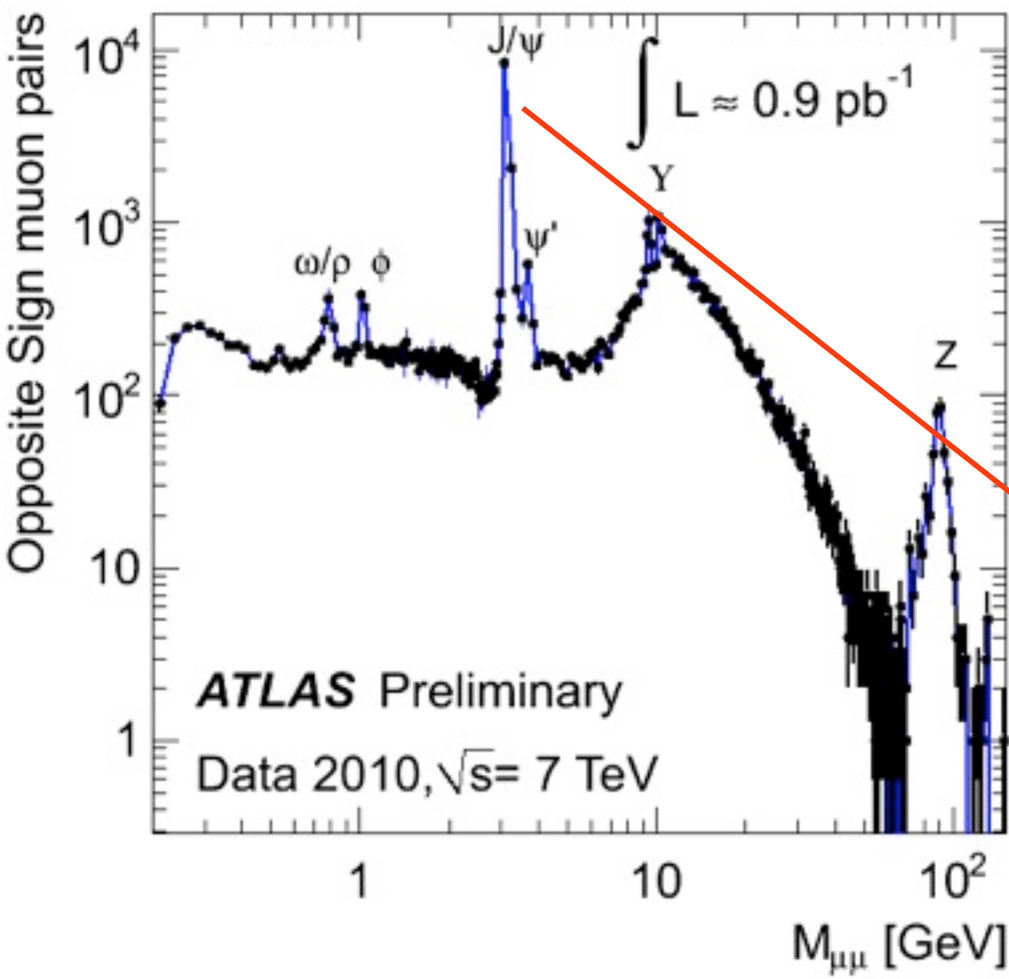


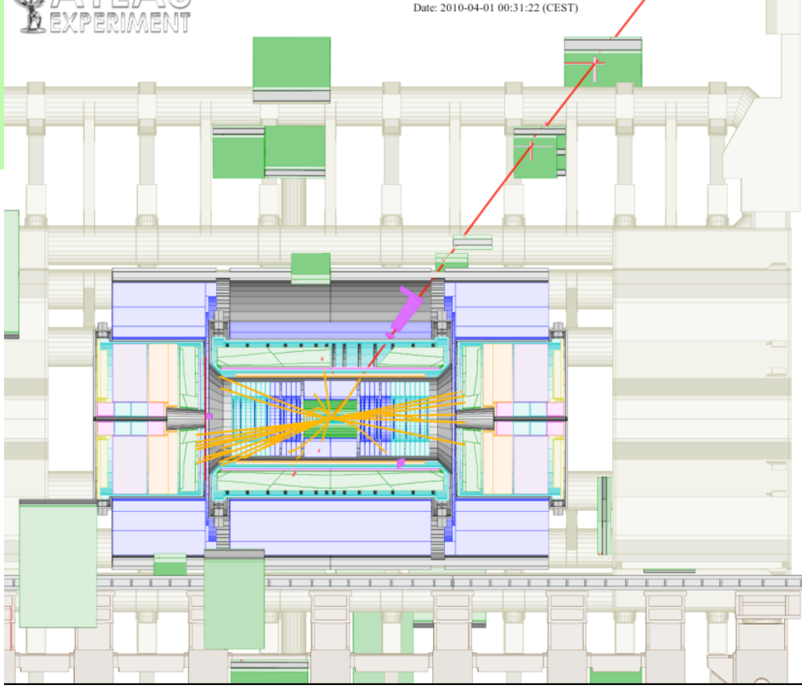


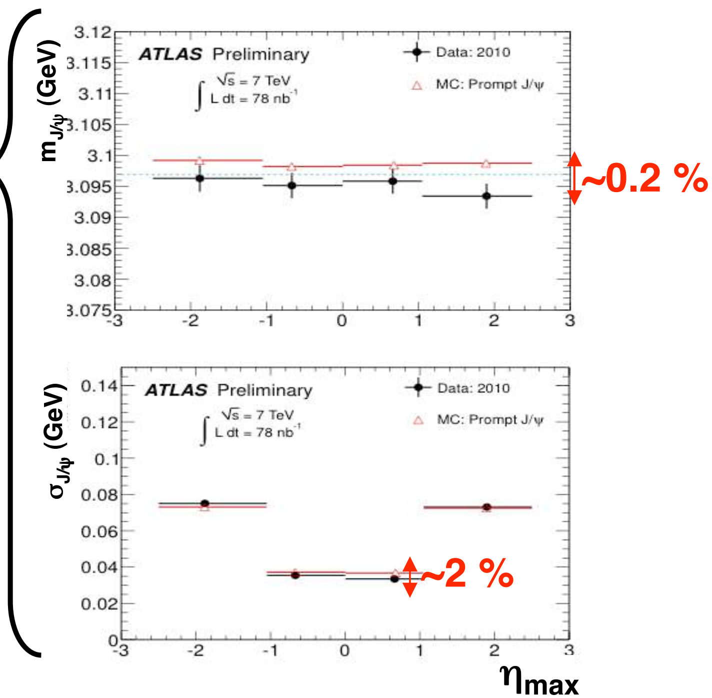
First check of energy scale over η: ±2%

EM calorimeter response uniformity in φ: <0.7 %

Muon Performance

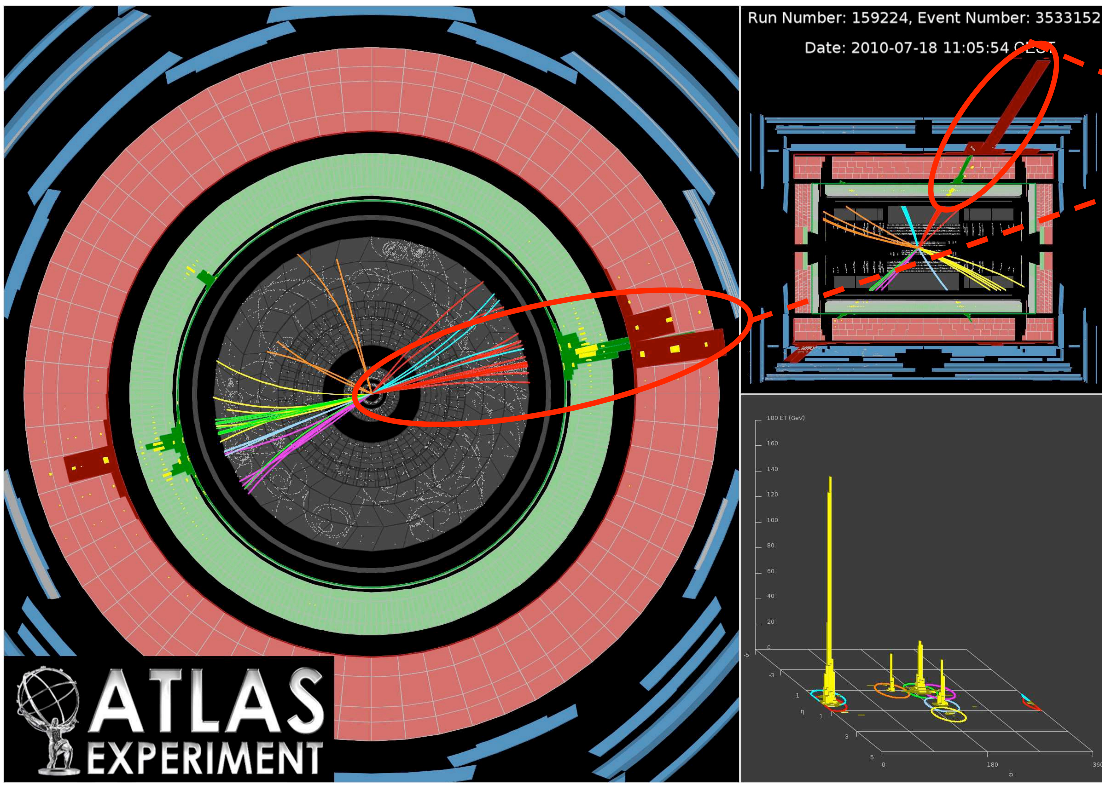






Jets in ATLAS

- Reconstruction in ATLAS
    - 3D calorimeter clusters + anti-k_T algorithm (R=0.4, 0.6)



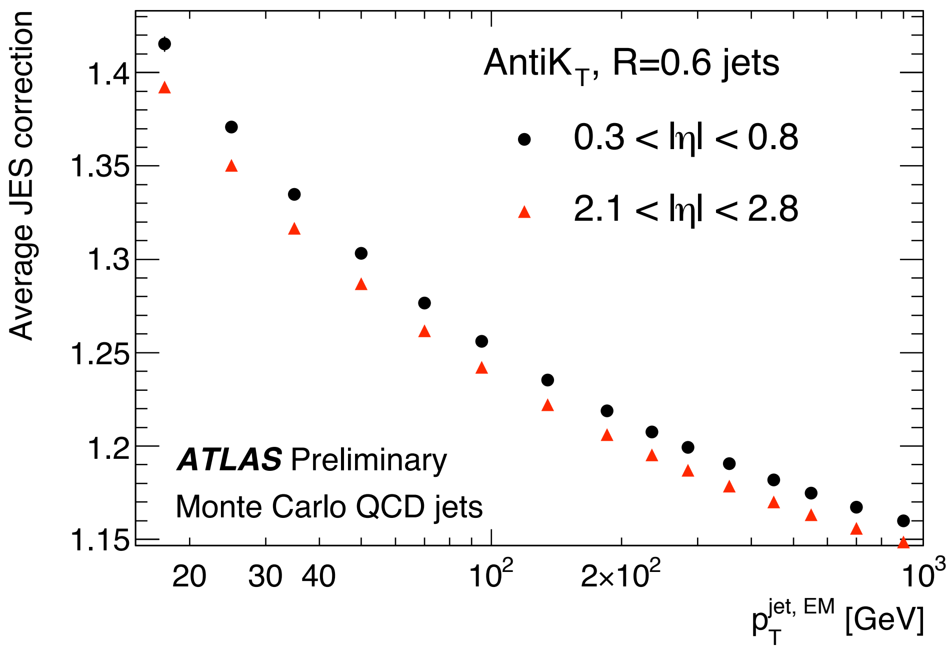
Highest jet p_T ~ 1.12 TeV in central detector region

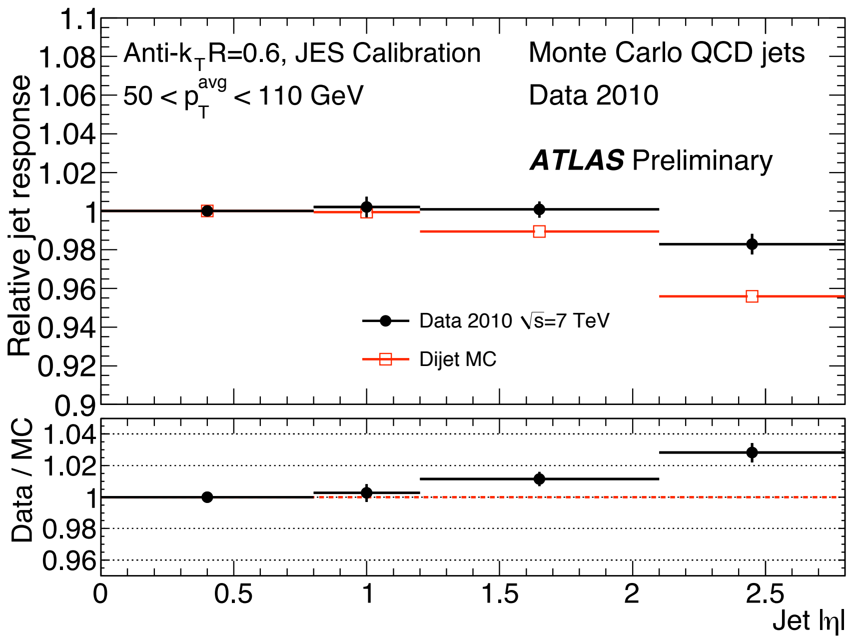
4 jets in this event:

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

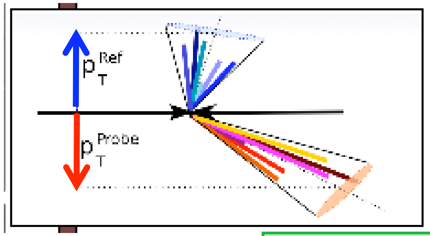
Jet Energy Scale

- Need to account for
  - Calorimeter non-compensation
  - Energy losses in inactive regions of the detector (des material)
  - Particles which are not totally contained in the calorimeter
  - Particles that fall out of the reconstructed jets but are included in the truth jet
  - Inefficiencies in calorimeter clustering and jet correction





- Explot jet p_T balance to
  - inter-calibrate central-forward jets



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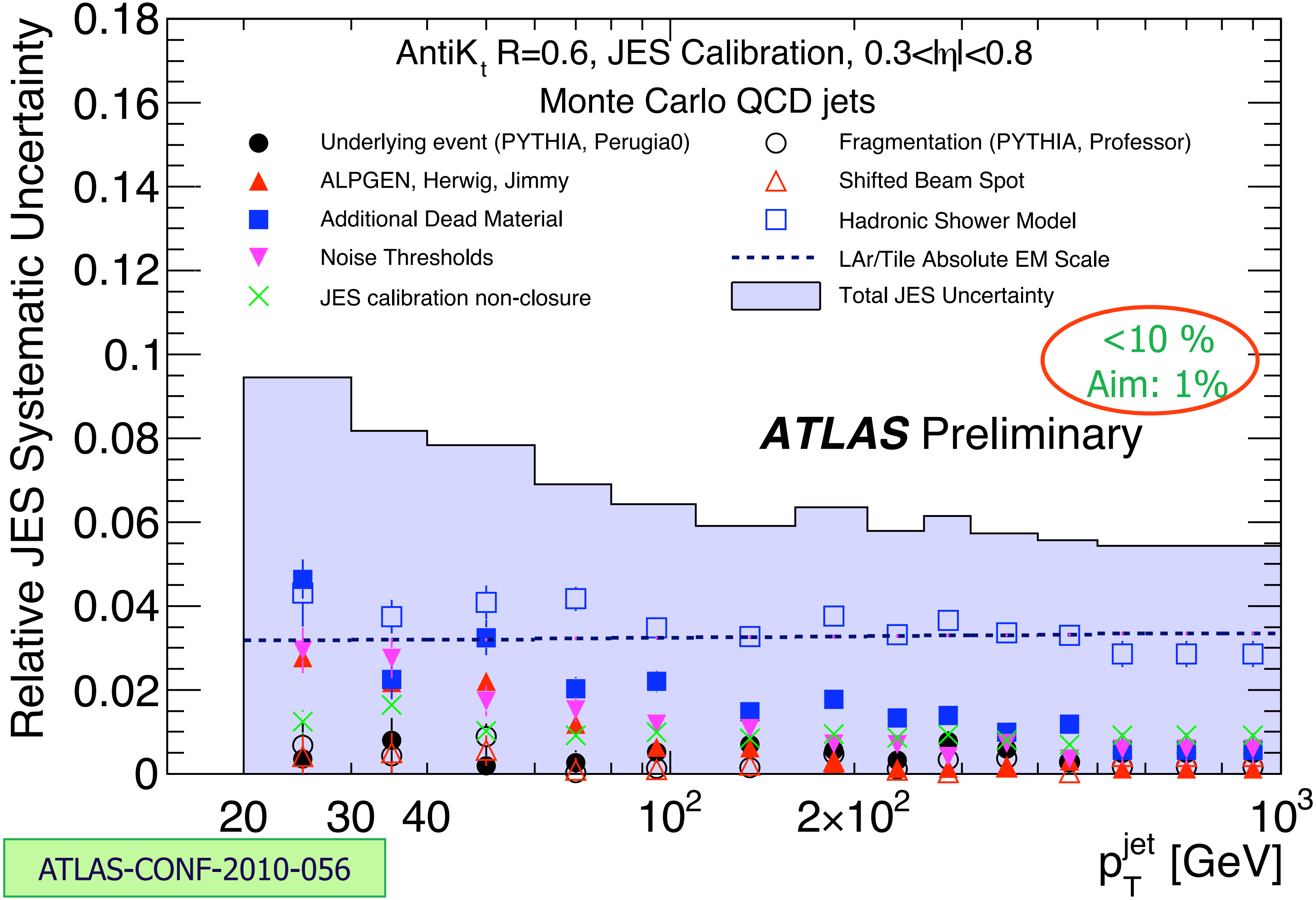
Relative Jet Energy Scale Systematic Uncertainty



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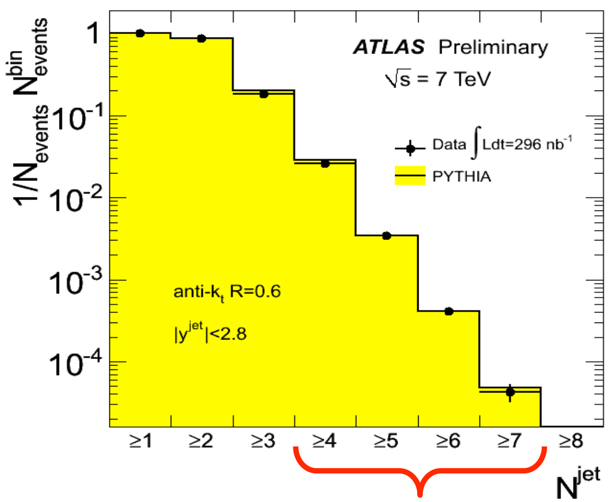
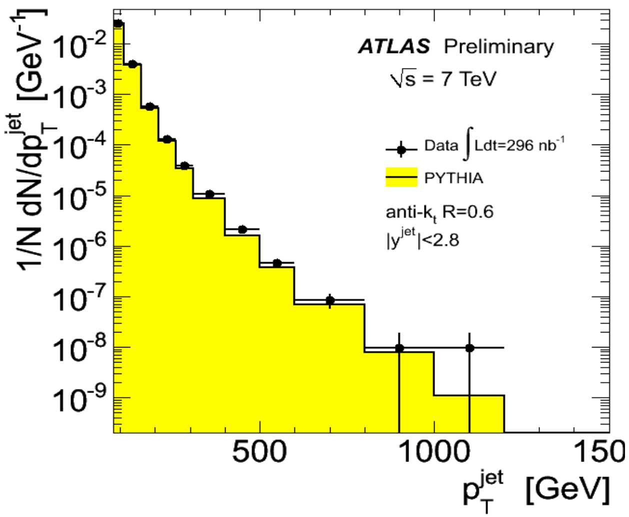
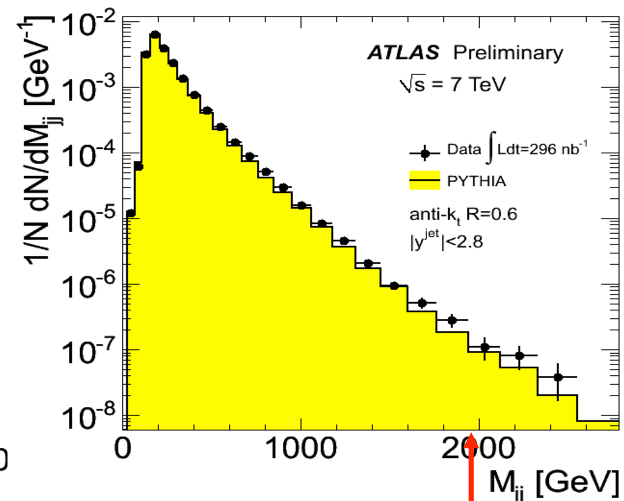
Jets Physics

- Statistics presented at ICHEP conference
  - p_T^{jet}>80 GeV (and sub-leading jets p_T^{jet}>40 GeV) & $|y^{jet}|$<2.8
  - Only show statistical errors



Few Top candidates in !





Tevatron √s=1.96 TeV !!

Start to probe new phase space

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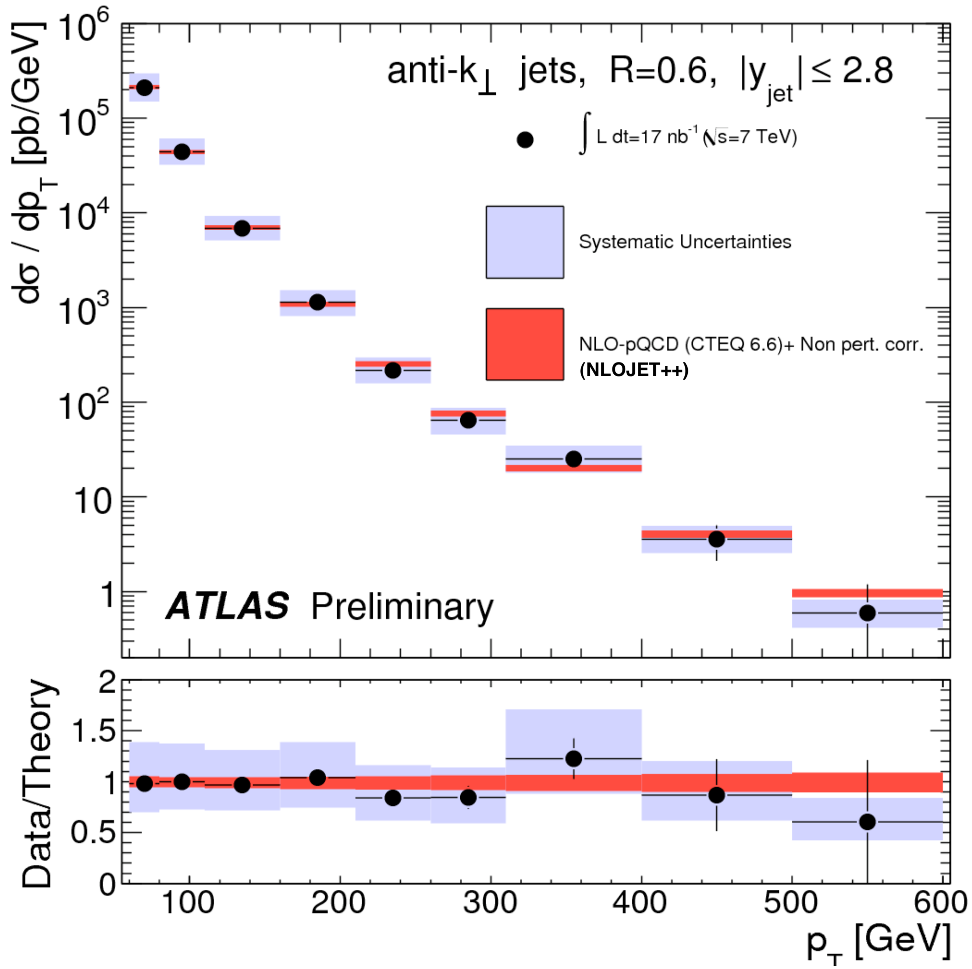
Inclusive Jet Differential cross-section

Inclusive Jet Differential cross-section



- Inclusive Jet Cross-Section (~Tevatron x 100)
  - Restricted to 17nb-1 (no pile-up contamination), P_T^{jet}>60 GeV, $|y_{jet}|$<2.8
  - Correct measured jets to particle level using parton-shower MC (Pythia, Herwig):
    - Compare to NLO pQCD prediction corrected from hadronisation and underlying event
  - Theoretical uncertainty on σ (PDF, α_s, scale)
    - 10% over measurable p_T range, y~0
    - increase to 30-40% at |y|~2.8
  - Experimental uncertainty on σ
    - 30-40% dominated by Jet Energy Scale
    - 11% from luminosity not included

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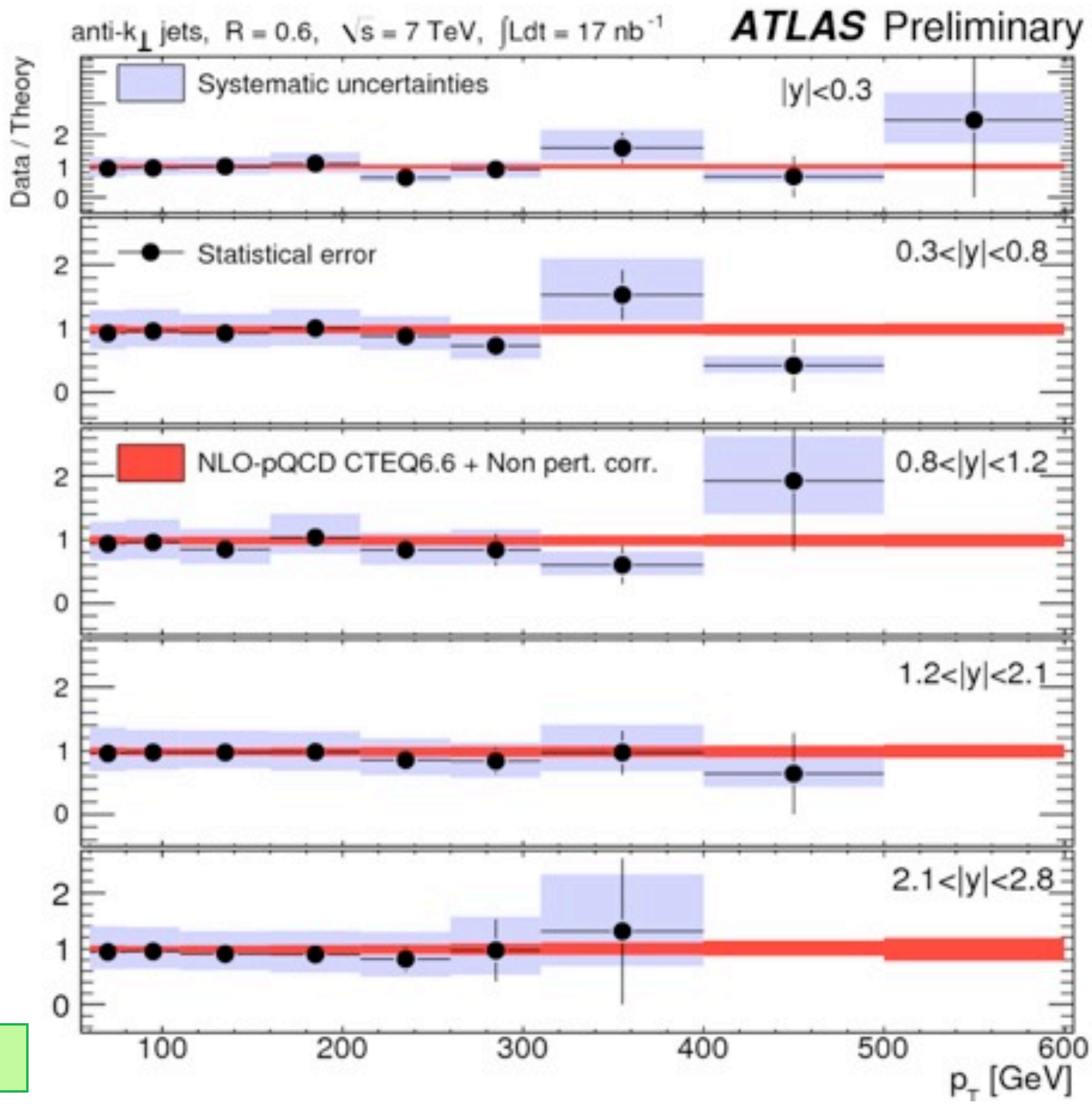
Jets: Theory vs Data vs pT



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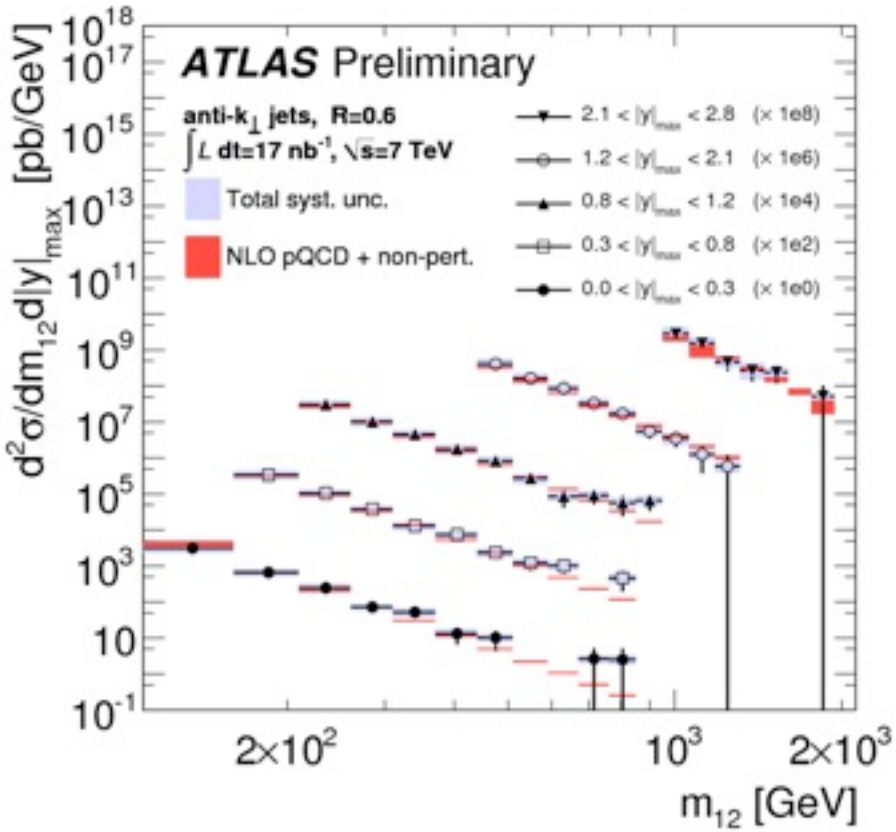
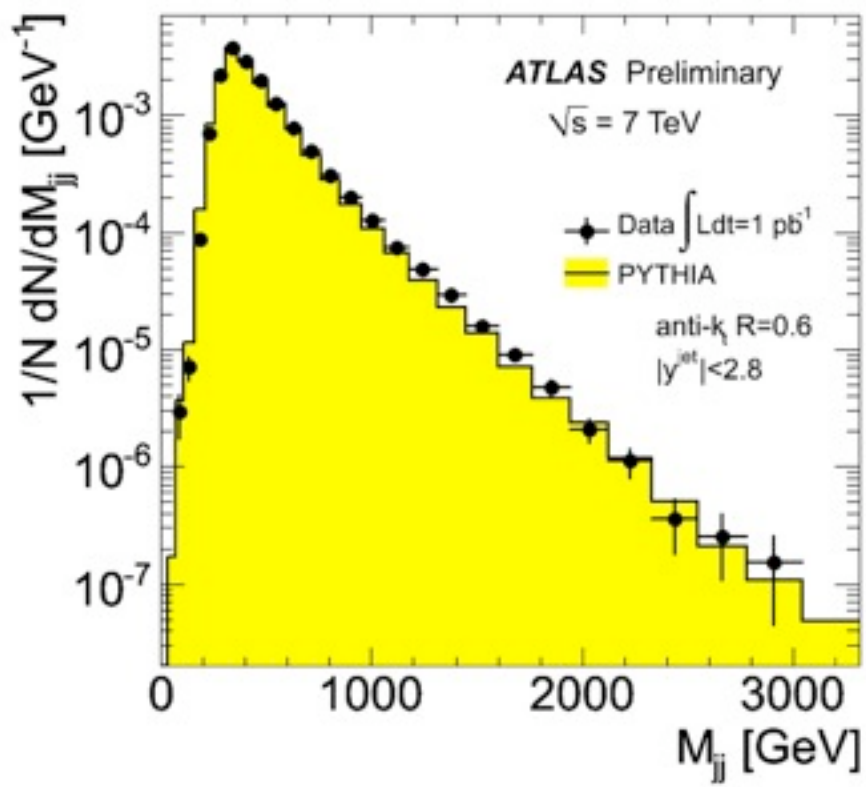
Jet-Jet mass





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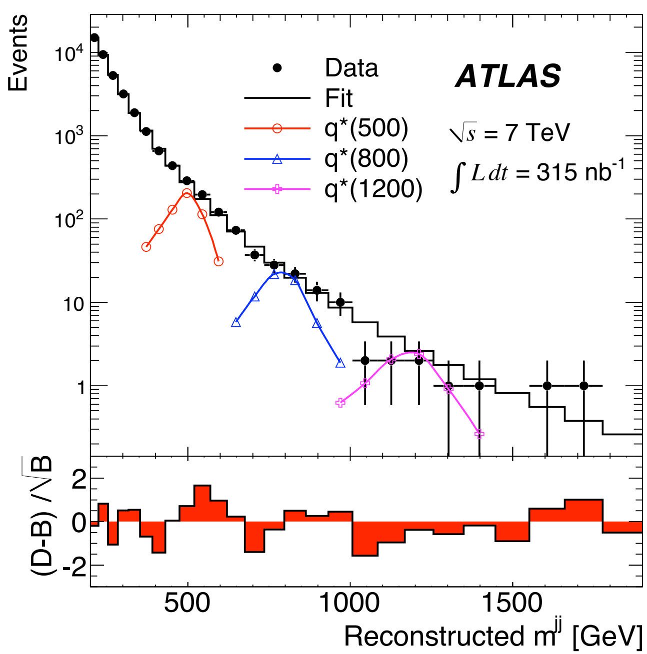
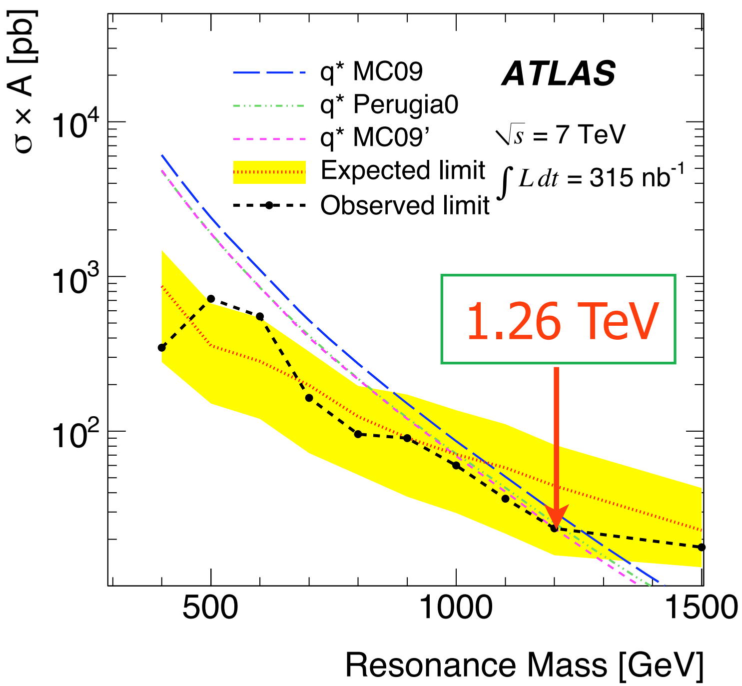
Search for new resonances

- Search for excited quarks ($q^* \to jj$) over 315 nb^{-1}
  - Signal is searched as a deviation from a smooth monotonic function
  - Systematics considered: luminosity, JES, background fit
- To enhance $S/\sqrt{B}$: $p_T^{j1}>80$ GeV, $P_T^{j2}>30$ GeV, $|y^j|<2.5$ & $|\Delta y|<1.3$



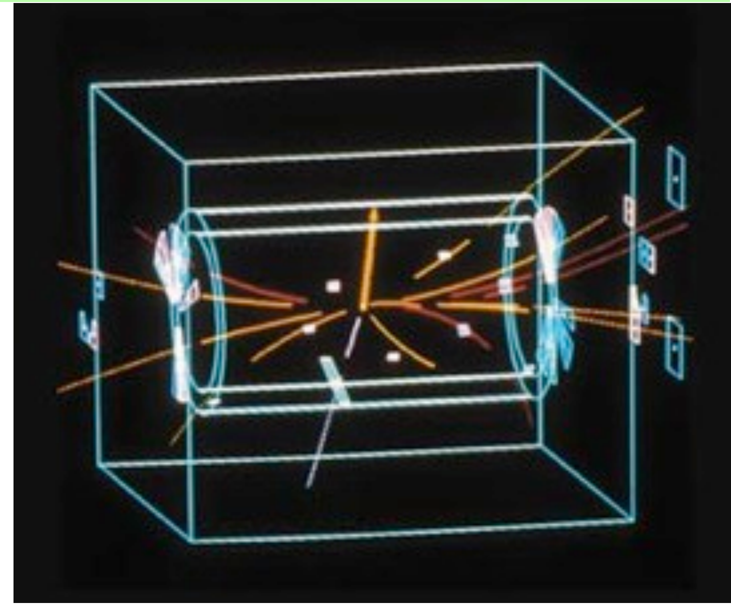


0.4<M(q*)<1.26 TeV excluded at 95% CL (CDF latest result 0.26<M(q*)<0.87 TeV

Submitted to PRL - arXiv:1008.2461v1 [hep-ex] 14 Aug 2010

Missing Transverse Energy

- E_T^{miss}
  - Important variable: measures the transverse momentum carried by neutrinos (or any non interacting particle)
  - Very sensitive to noise in the detector



$$\not{E}_{x,y}^{\mathrm{Calo}} = -\sum_{\mathrm{TopoCells}} E_{x,y}.$$

Electrons | Photons | Taus | Jets | Muons | Unused TopoClusters

↓

Go back to constituent Calorimeter Cells → apply overlap removal at Cell level → Cell calibration weights dependent on the object → add them to calculate partial terms

↓

MET_RefEle + MET_Refγ + MET_RefTau + MET_RefJet + MET_RefMuo + MET_CellOut

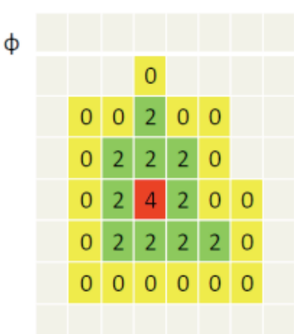
+ MET_Cryo + MET_Muon = MET_RefFinal

Missing Transverse Energy

From MB events where E_T^{miss}~0

Measured across the whole calorimeter (200 k cells), $|\eta|<4.9$

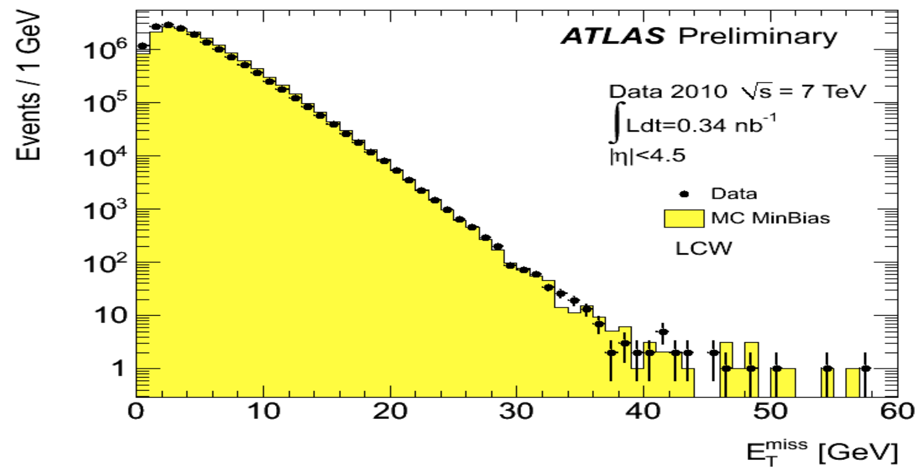
Use noise suppression



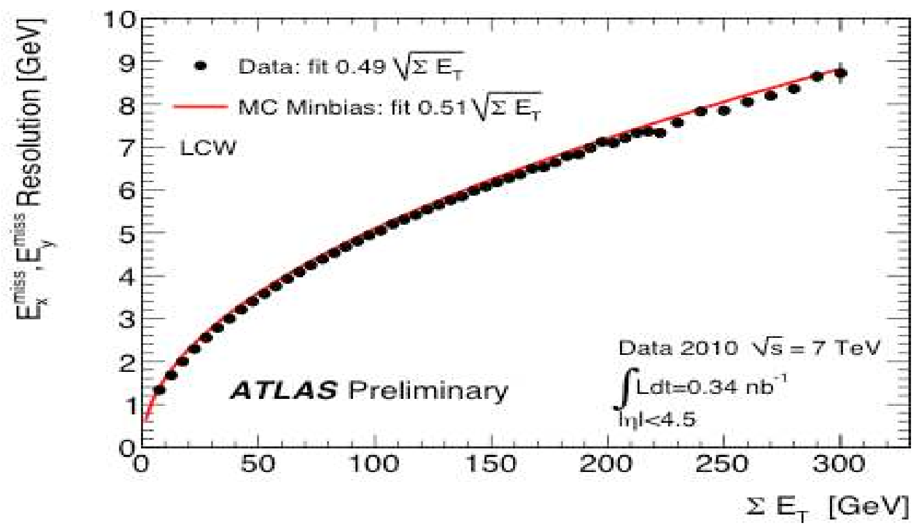
Seed: $|E_{cell}|>4\sigma$

Neighbors: $|E_{cell}|>2\sigma$

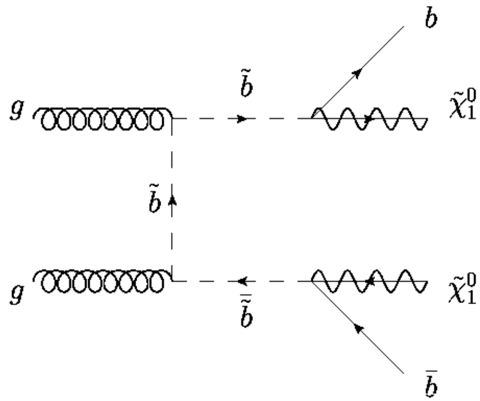
Nearest neighbors: $|E_{cell}|>0\sigma$

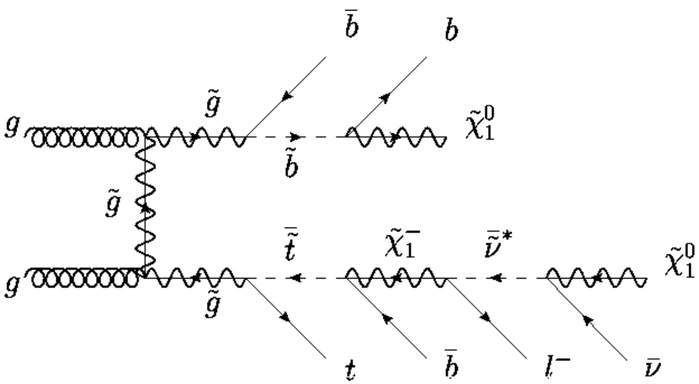


No tails

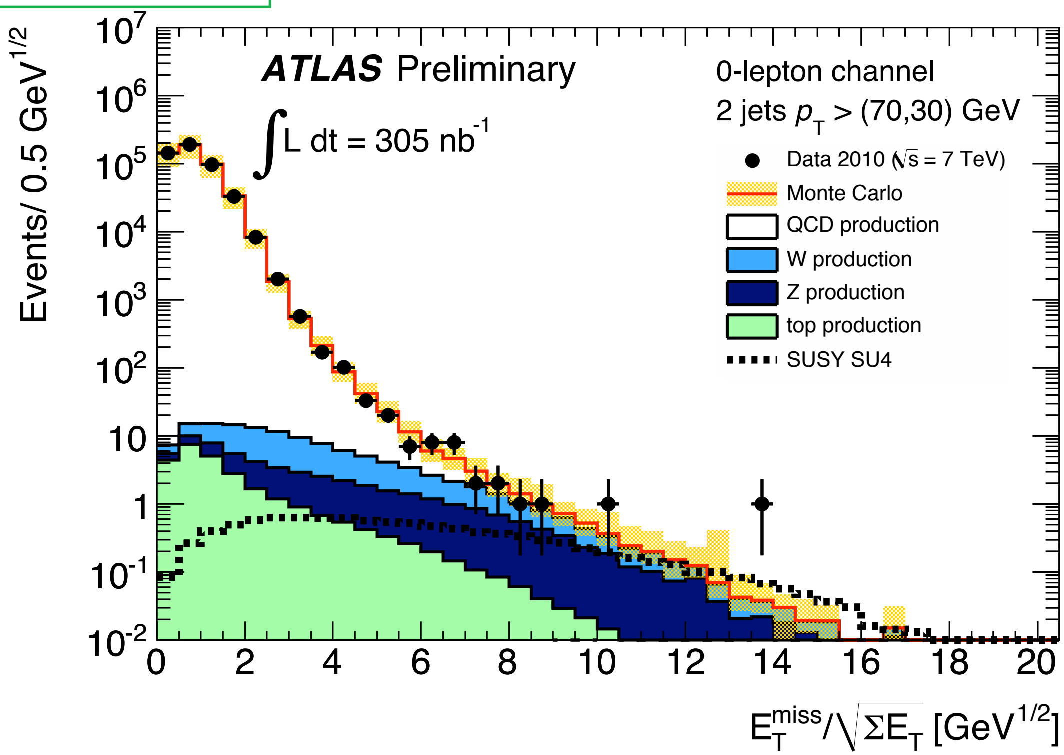


SUSY search





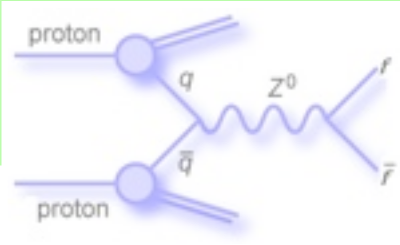
- Two high p_T jets (70-30 GeV)
- No lepton
- At least one b-tagged jet ($L/\sigma(L)>6$)



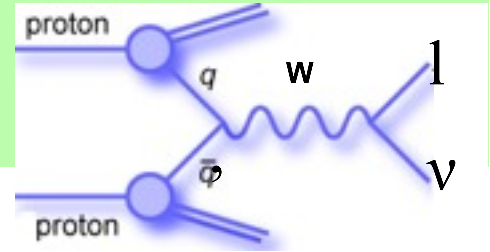
ATLAS-CONF-2010-079

Electroweak Physics

- Current Electroweak theory thoroughly tested (and never “broken”) until now (LEP, Hera, TeVatron, μ & neutron magnetic moments,…)
  - Better than ‰
- Aim at LHC:
  - Finally break it!
  - Deeper understanding to:
    - tighten indirect constraints
    - find deviations
  - Detector calibration



Z & W productions



- Z production
  - $15 \cdot 10^6$ evts in one year at $d\mathcal{L}/dt = 10^{33}$ evts/cm^2/s
  - $q\bar{q}$ annihilation
  - $x_q \cdot x_{\bar{q}} \sim 4 \cdot 10^{-5}$
  - $p_L = 0.5 \cdot \sqrt{s} \cdot (x_q - x_{\bar{q}})$
- Z decay
  - To 2 energetic fermions of opposite charge
  - 70% are quark pairs
    - jet-jet distributions are dominated by QCD background
  - Study lepton pairs: cleaner
    - electrons
    - muons
    - taus

- W production
  - $\sigma_Z \sim 10 \cdot \sigma_W$
  - $\sigma_{W^+} > \sigma_{W^-}$ (quark content of the proton)
  - W^+ peaked at high rapidity; W^- in central rapidity
- W decay
  - 32% to one energetic fermion & one neutrino
  - 68% to two quarks

W→eν

- E_T(e)> 20 GeV, |η|<2.47
- Loose electron ident.

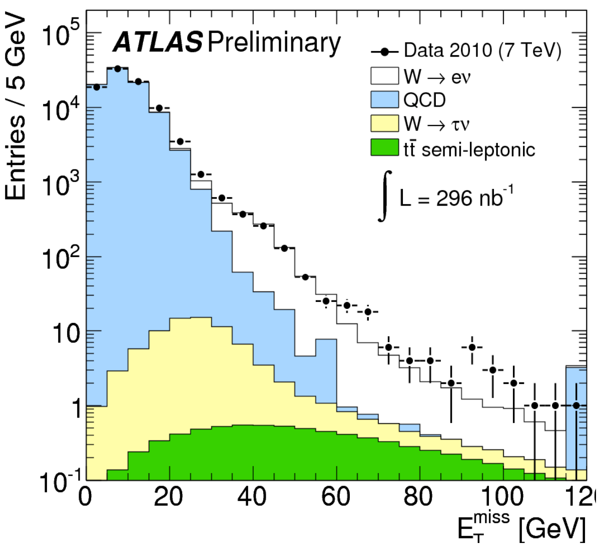
→

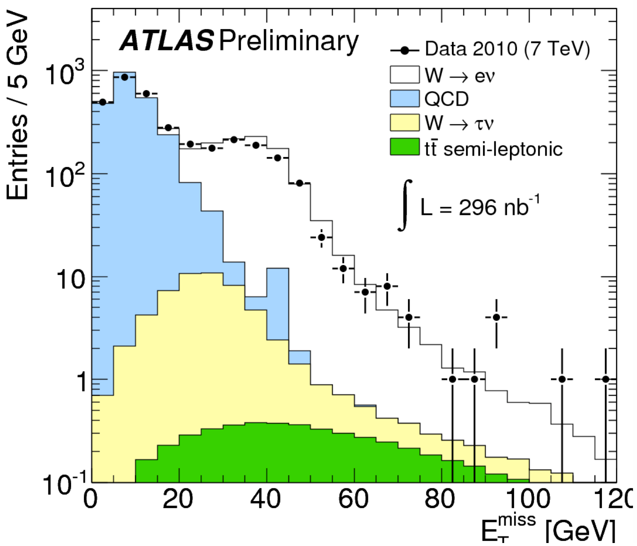
+
- Tight electron ident.

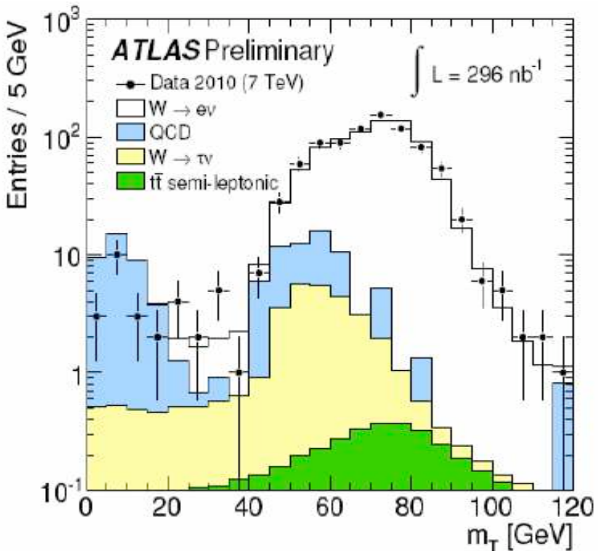
→

+
- E_T^{miss} > 25 GeV

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

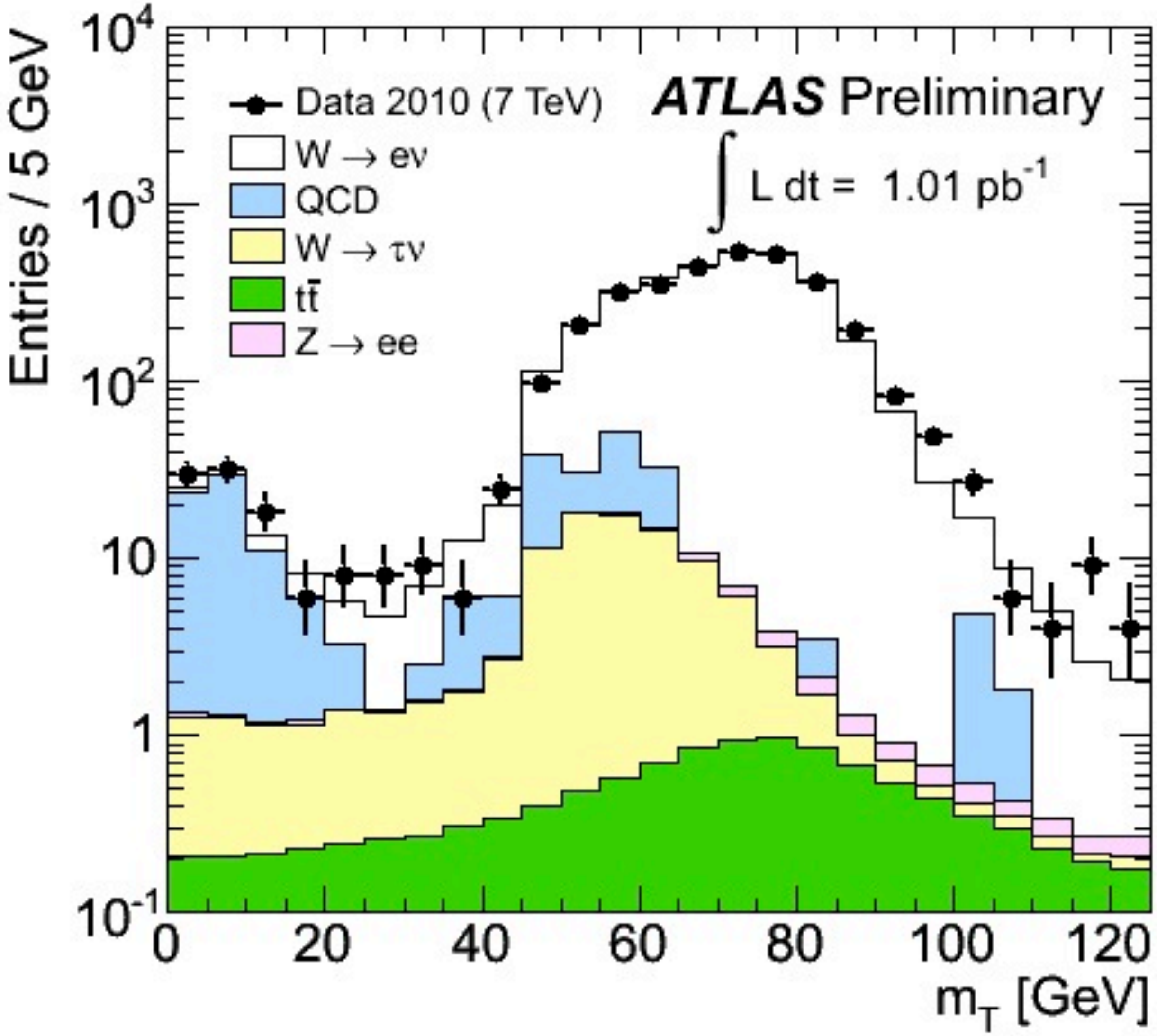






- Good agreement data/MC (shape)
- **815 W→eν** events (mT>40 GeV) with a high S/B

M_T with $\int Ldt=1.01pb^{-1}$ with E_T^{miss} cut



W→μν

- pT(μ)>15 GeV, |η|<2.4
- |ΔpT (ID-MS)| < 15 GeV
- |Zμ-Zvtx|<1 cm

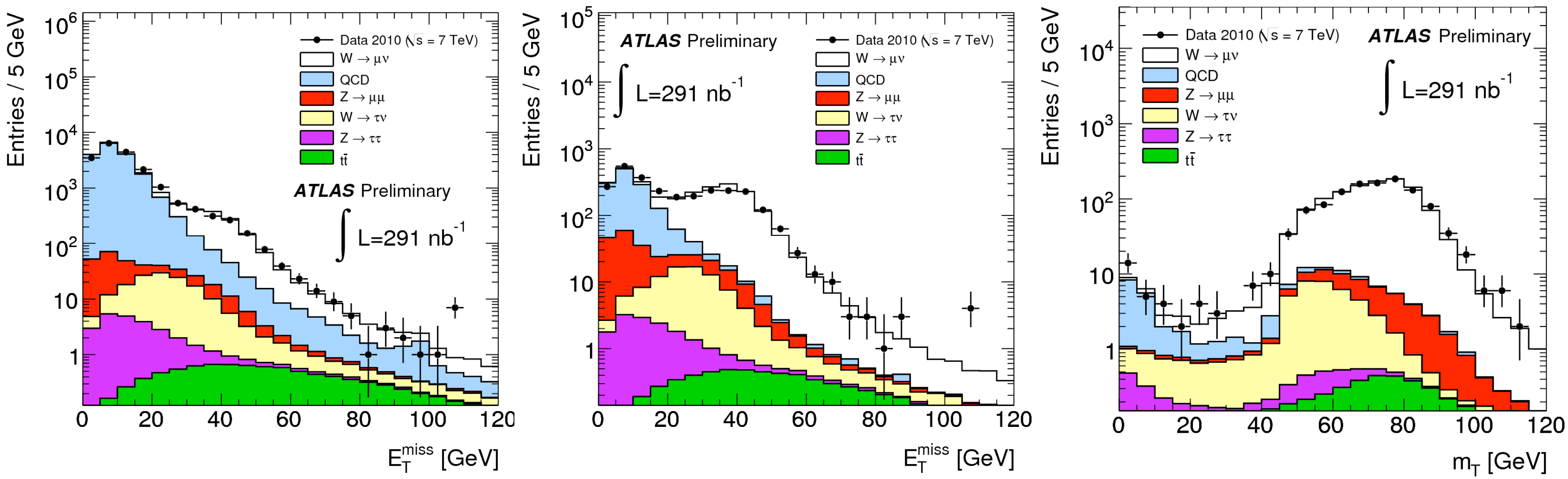
→

+
- pT (μ)> 20 GeV
- $\Sigma p_T(ID)/p_T < 0.2$

→

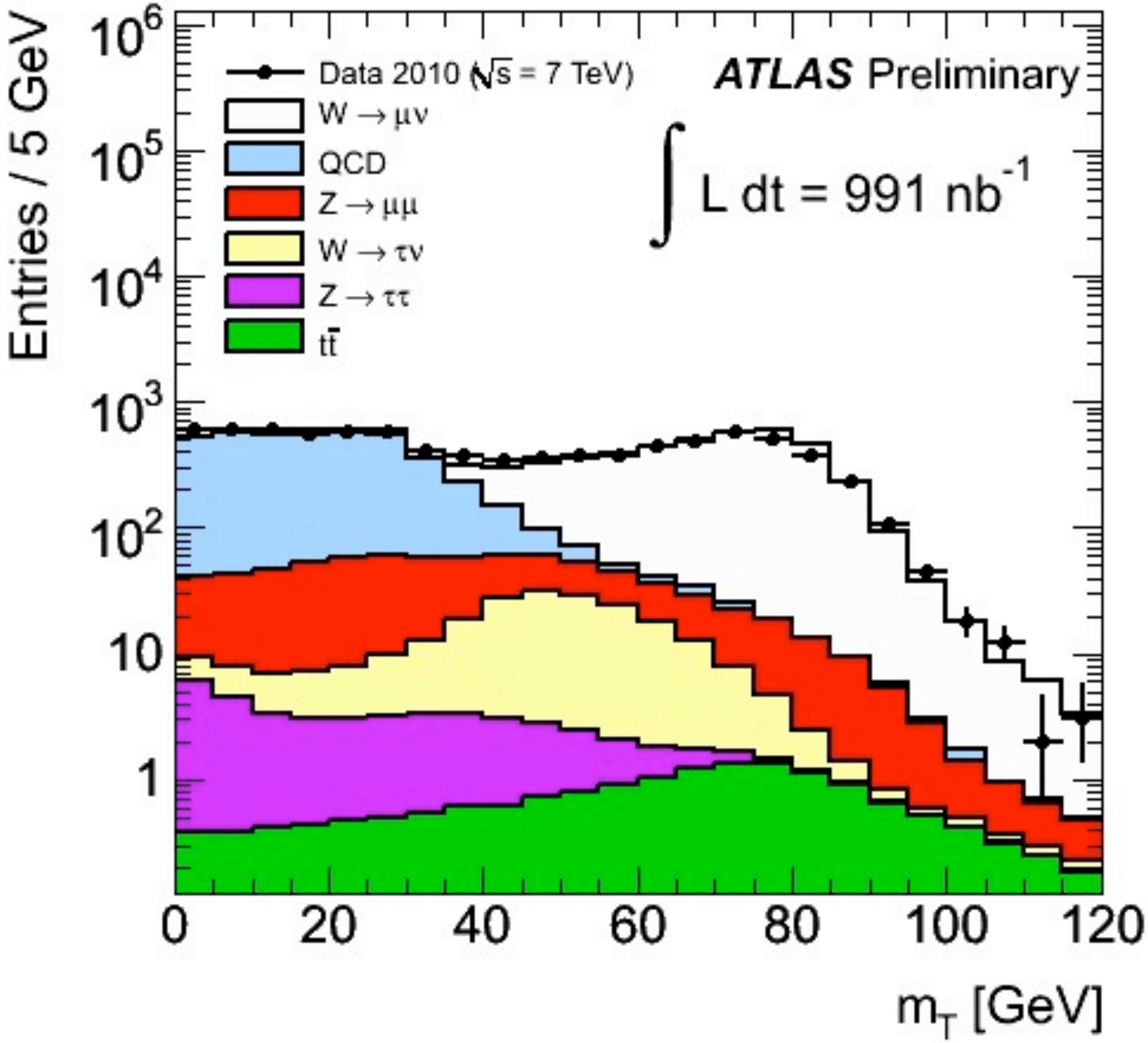
+
- $E_T^{miss} > 25$ GeV

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



- Good agreement data/MC (shape)
- **1111 W→μν** events (mT>40 GeV) with a high S/B

M_T with $\int Ldt=0.991\ pb^{-1}$ with E_T^{miss} cut



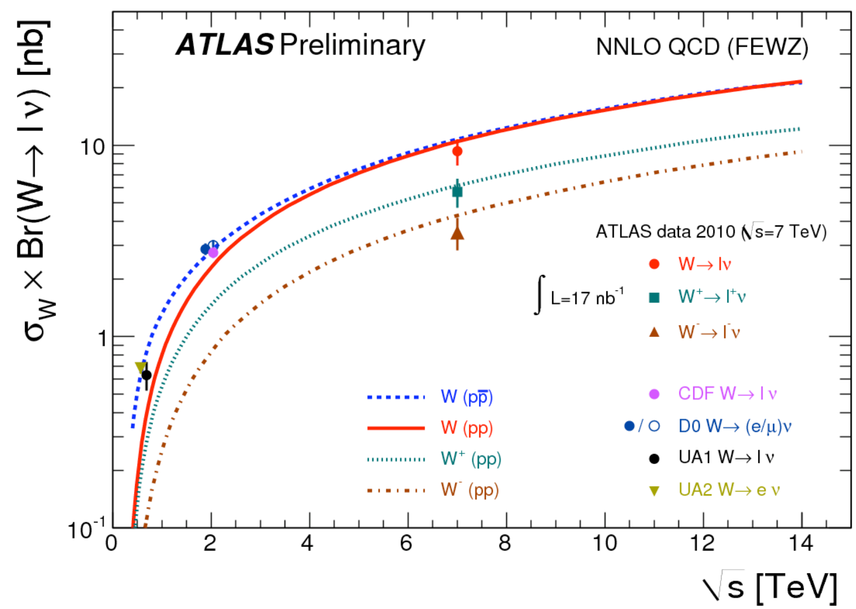
W cross-section - 17 nb^{-1}

46(72) W→eν (μν)

- MC geometrical and kinematic acceptance: A_W~ 47±1.5%
- Systematics on reconstruction efficiency (C_W):

$$\sigma(W \to l\nu) = \frac{N_W^{sig}}{A_W C_W L_{\text{int}}}$$

Uncertainty	Electron	Muon
Trigger	<0.5%	4%
Material effect	4%	--
Identification	6%	4%
E Scale+Resolution	2%	4%
E_T^{miss} Scale+Resolution	2%	2%
Total	8%	7%
C_W	(65.6±5.3)%	(81.4±5.6)%

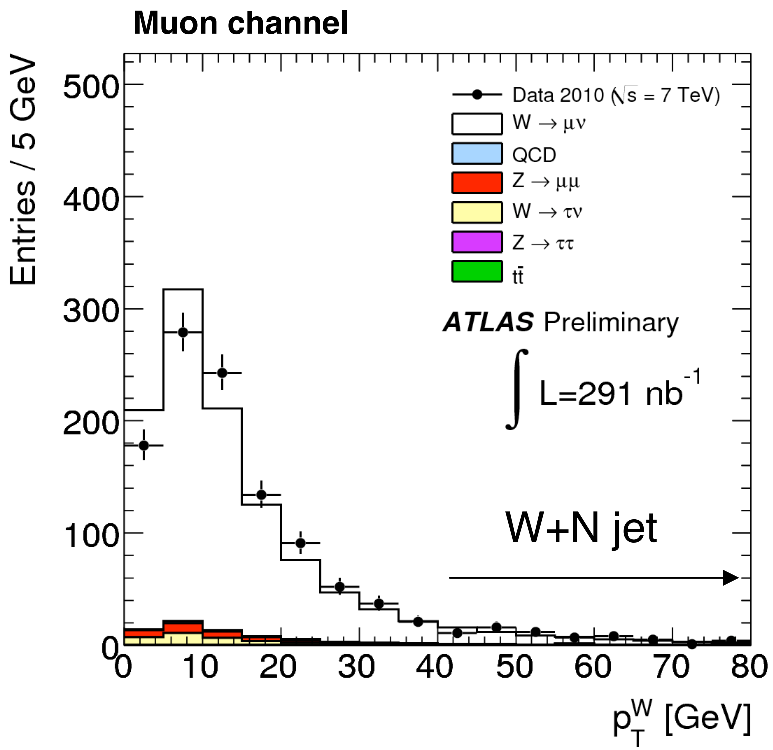


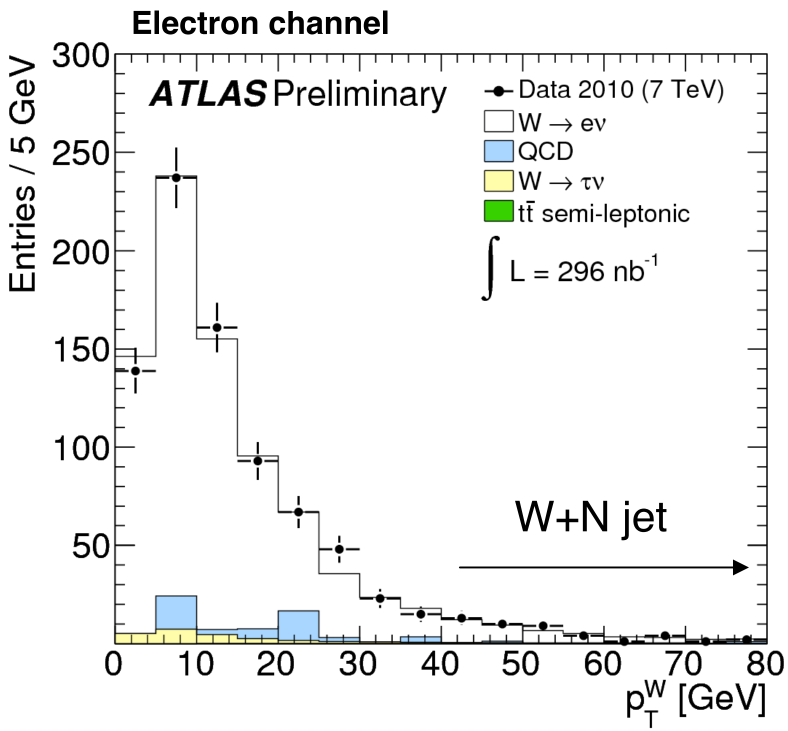
σ(W→lν) = 9.3 ± 0.9(stat) ± 0.6(syst) ± 1.0 (lumi) nb

σ_{SM} (W→lν) =10.5 ± 0.4 nb

Dominated by luminosity systematics

W transverse momentum





Good agreement data/MC (shape) for the **1926** W →lν events

W asymmetry

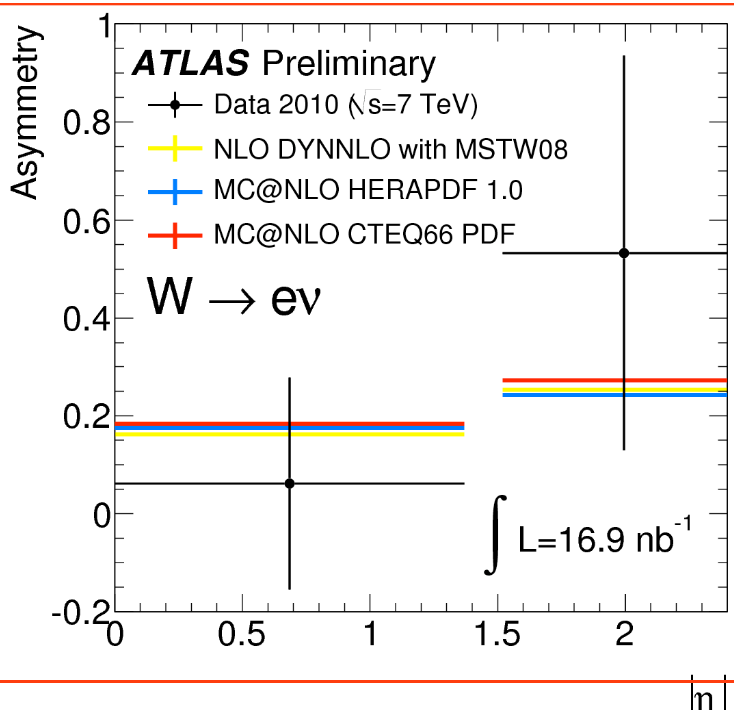
Asymmetry (A): Difference in W^+/W^- production

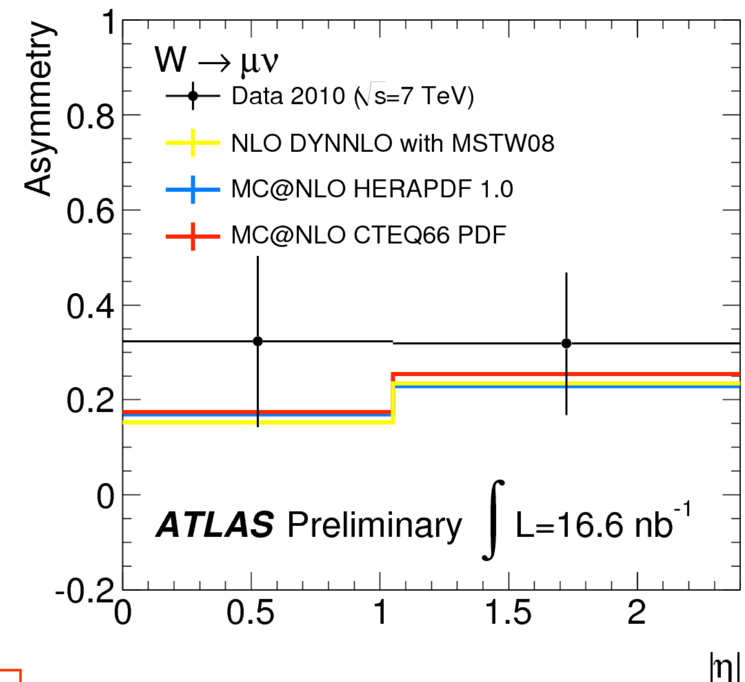
$$A = \frac{\sigma(W \to \ell^+\nu) - \sigma(W \to \ell^-\nu)}{\sigma(W \to \ell^+\nu) + \sigma(W \to \ell^-\nu)} \neq 0$$

- Most systematics cancel in the ratio
- Sensitive to valence quarks distributions ($x \sim 10^{-3}$-10^{-1})
  - A vs η to distinguish between PDF

$A(W \to e\nu) = 0.21 \pm 0.18\ (\text{stat}) \pm 0.01\ (\text{syst})$
$A(W \to \mu\nu) = 0.33 \pm 0.12\ (\text{stat}) \pm 0.01\ (\text{syst})$

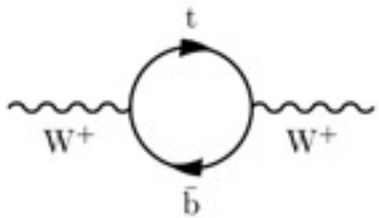
NNLO theory prediction: A~0.2

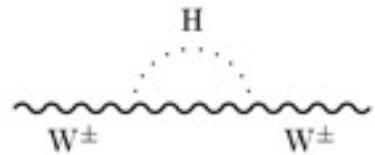




Statistically limited up to a few pb^{-1}

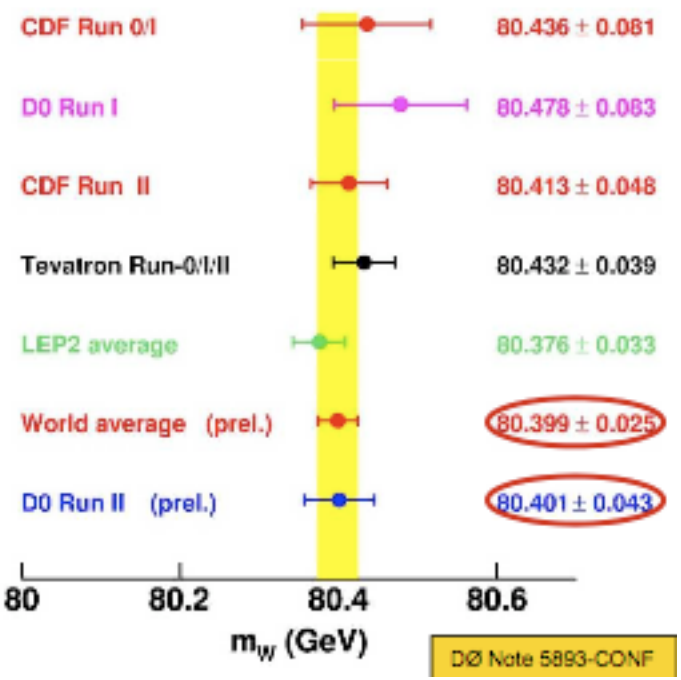
W Mass Measurement





$$M_W = 4\sqrt{\frac{\pi^2\alpha^2}{2G_F^2}}\,\frac{1}{\sin\theta_W(1-\Delta R)}$$

$$M_{top}^2, \log M_H$$



0. 3‰

World average: M_W = 80399 ± 25 MeV

ATLAS aims at a measurement of M_W with a precision of ~10 MeV.

0. 1‰

Measuring M_W

- Aim at $2 \cdot 10^{-4}$ precision on the energy scale (going from M_Z to M_W) i.e. 10 MeV at 50 GeV:
  - Electronics noise in strips compartment of LAr calorimeter
  - ~2 ADC counts in the middle compartment
  - A change of 0.01 degree of LAr temperature
  - Effect of empty Bunch Crossings ?
    - The protons packets are not uniformly distributed inside the LHC
    - Effect of pile-up is different depending on the packet
    - Careful treatment of this effect is necessary
- Many (careful) steps have to be taken to reach the goal
  - Z^0 to fix the energy scale at ~ M_Z/M_W
  - Detector acceptance
  - Description of variables by MC (templates)
  - ….

W Mass Measurement

15 pb^{-1}

Method	p_T (e) [MeV]	p_T (μ) [MeV]	m_T (e) [MeV]	m_T (μ) [MeV]
δM_W (stat.)	120	106	61	57
δM_W (scale)	110	110	110	110
δM_W (resol)	5	5	5	5
δM_W (tails)	28	<28	28	<28
δM_W (eff.)	14	-	14	-
δM_W (recoil)	-	-	200	200
δM_W (bkg)	3	3	3	3
δM_W (PDF)	25	25	25	25

p_T leptons $\delta M_W = 110 \text{ (stat)} \oplus 114 \text{ (exp.)} \oplus 25 \text{ (PDF) MeV}$

Transverse mass M_T $\delta M_W = 60 \text{ (stat)} \oplus 230 \text{ (exp.)} \oplus 25 \text{ (PDF) MeV}$

High Statistic Measurement of M_W

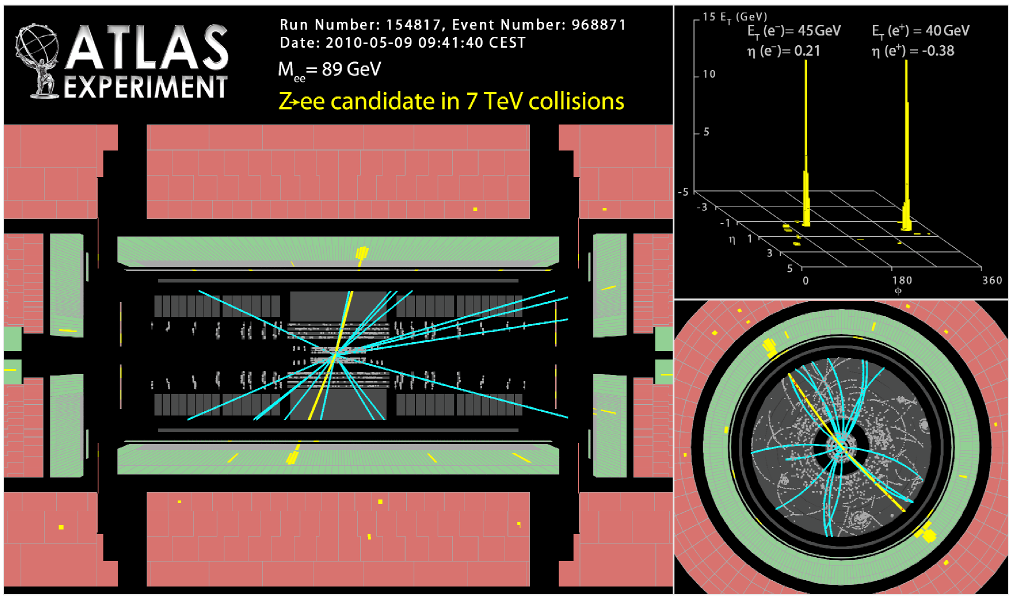
- With $1fb^{-1}$: expect to reach ~10 MeV
  - 45 10^6 W boson per leptonic channel
  - 4.5 10^6 Z boson per leptonic channel
- Examples of systematic studies:
  - Experimental
    - Lepton energy scale, linearity, resolution
    - Reconstruction efficiency
  - Theory
    - W distribution, y^W, p_T^W
    - FSR
  - Environment
    - Underlying event
    - Pile-up
    - Background

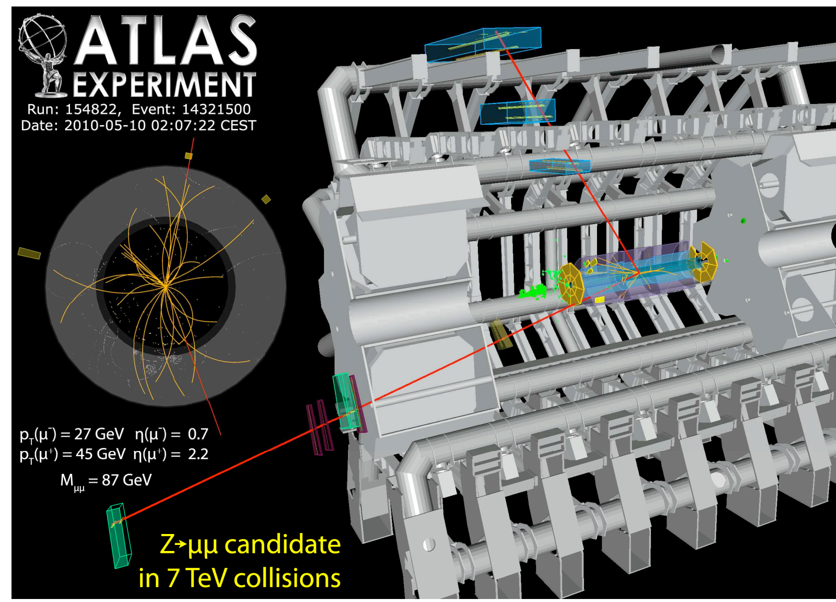
W Mass: Ultimate Measurement

source	effect	δm_W (MeV)
Theoretical model	Γ_W	0.5
	y_W	1
	p_{tW}	3
	QED radiation	<1
Lepton measurement	linearity and scale	4
	resolution	1
	efficiency	3 (e); <1 (μ)
Backgrounds	$W \rightarrow \tau\nu$	0.4
	$Z \rightarrow l\,(l)$	0.2
	$Z \rightarrow \tau\tau$	0.1
	Jet events	0.5
Pile-up and UE		<1 (e); ~0 (μ)
Beam crossing angle		<0.1
total		~7

One channel (e) and one study (p_T)

Z cross-section measurement

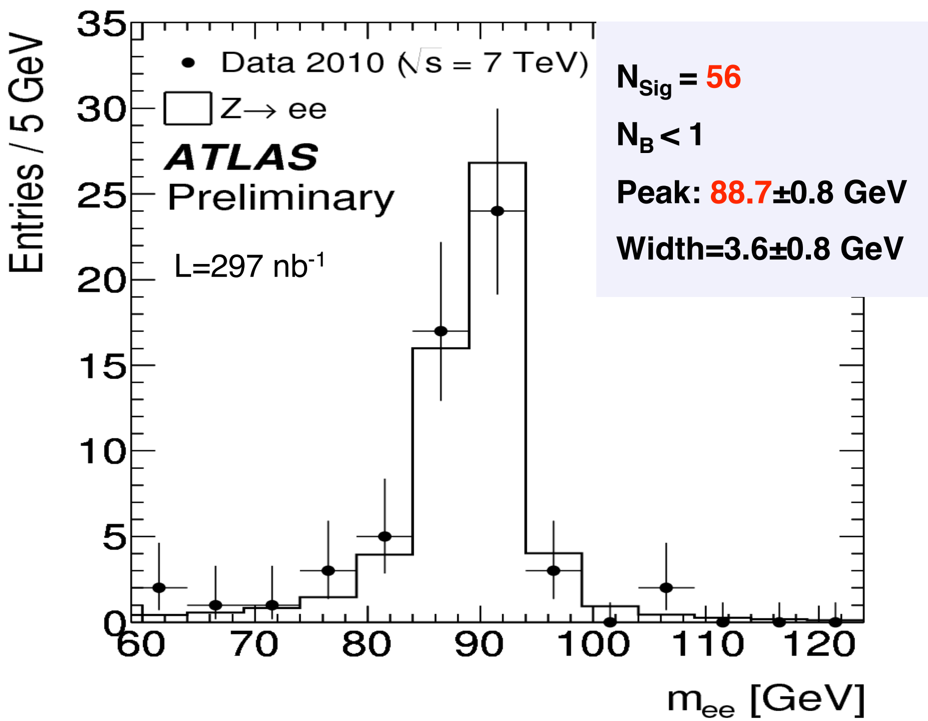


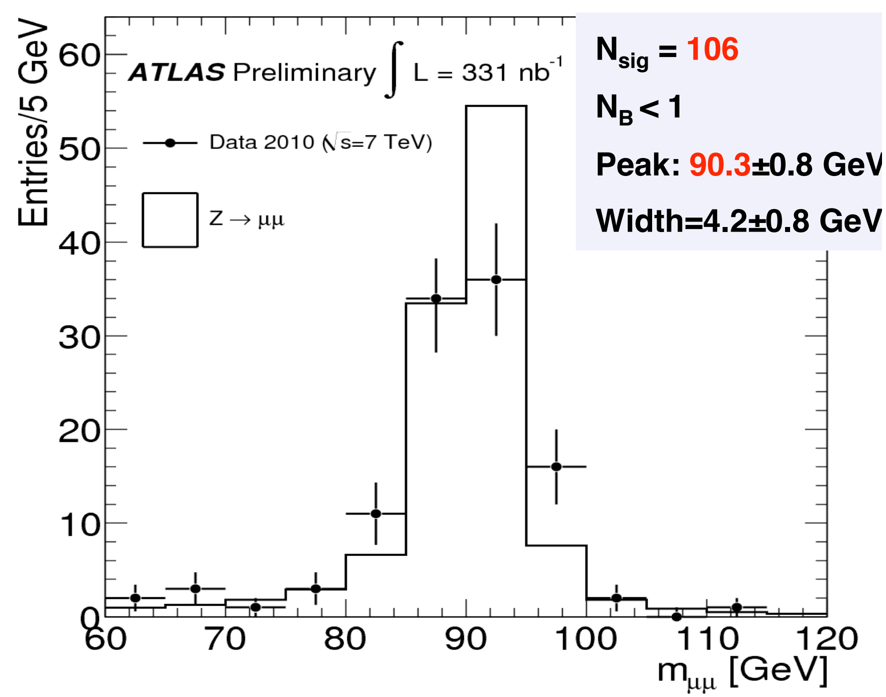


Z→ll Physics

~300 pb^{-1} of data - MC normalized to data

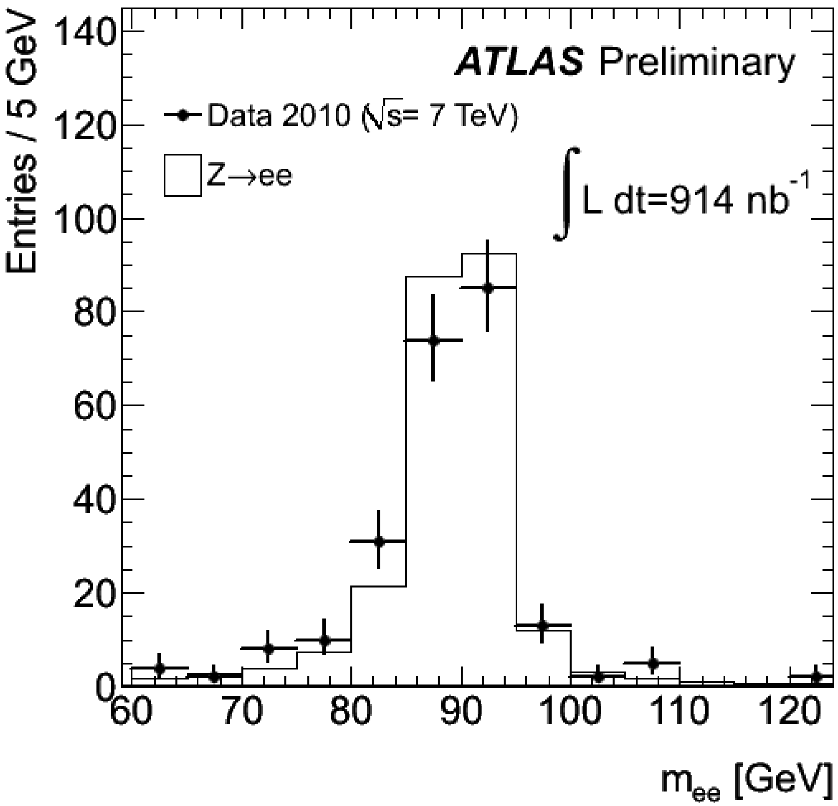
- From 2 opp. sign leptons (p_T>20 GeV, |η|<2.4)
- Similar lepton identification as for W (somewhat relaxed)

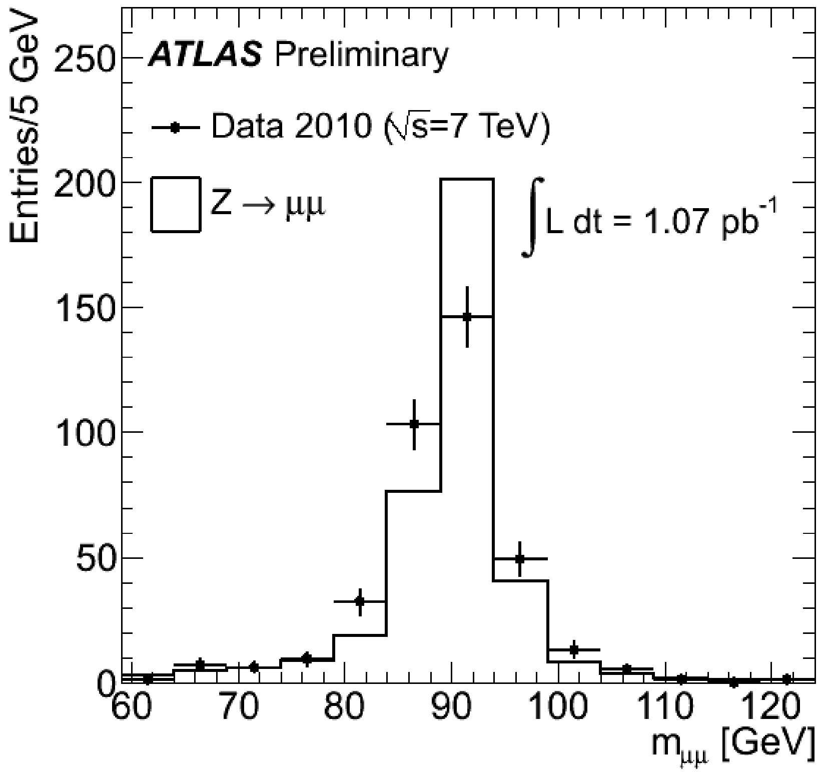




162 very clean Z→ll (l=e,μ) events observed

Recently Updated M_{ll} Plots - ~1pb^{-1}





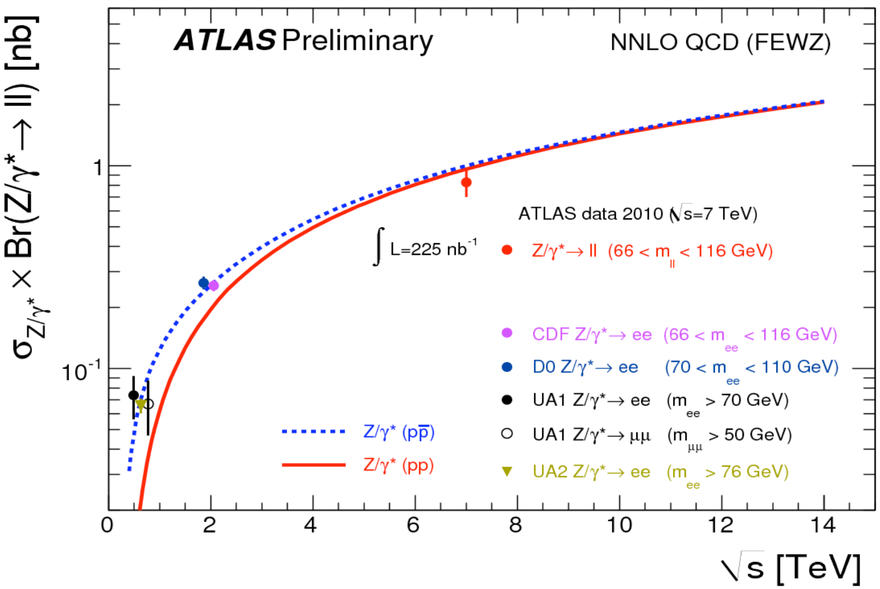
Z cross-section - 225 nb^{-1}

46(79) Z→ee (μμ)

- MC geometrical and kinematic acceptance: A_Z~ 46.5±1.4%
- Systematics on reconstruction efficiency (C_Z):

$$\sigma(Z/\gamma^* \to ll) = \frac{N_Z^{sig}}{A_Z C_Z L_{int}}$$

Uncertainty	Electron	Muon
Trigger	<0.5%	2%
Identification	10%	7%
Material effect	8%	--
E Scale+Resolution	2%	1%
Pile-up	2%	--
Total	14%	7%
C_Z	(64.5±9.0)%	(79.7±5.3)%



$\sigma(Z/\gamma^* \to ll)$ = 0.83 ± 0.07(stat) ± 0.06(syst) ± .09 (lumi) nb

σ_{SM} ($Z \to ll$) = 0.99 ± 0.04 nb

Combined measurement dominated by luminosity systematics at 225nb^{-1}

Conclusions

- LHC has been operating for 5 months at $\sqrt{s}$ = 7 TeV
  - As of Monday 30.08.2010, 3.4 pb^{-1} of p-p collisions have been collected by ATLAS, with a data taking efficiency of ~95%
  - $10^{31}cm^{-2}s^{-1}$ was reached during August
- Plan is to reach $10^{32}cm^{-2}s^{-1}$ before LHC switches to heavy ions in October
- The detector is functioning well
  - One decade of testbeam analysis
  - Detailed commissioning while awaiting for beam
  - MC description is already at the ~10% level
- The first results give a good taste of the physics potential ahead of us