Overview of ATLAS physics results at ICHEP2010

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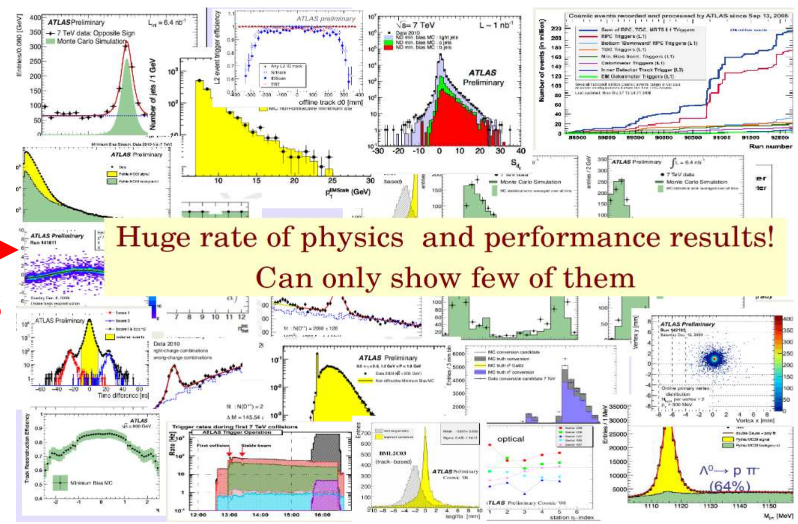
On Behalf of the ATLAS Collaboration

ATLAS Control Room : First Beams (20 November 2009)

8 months …

… of sleepless nights

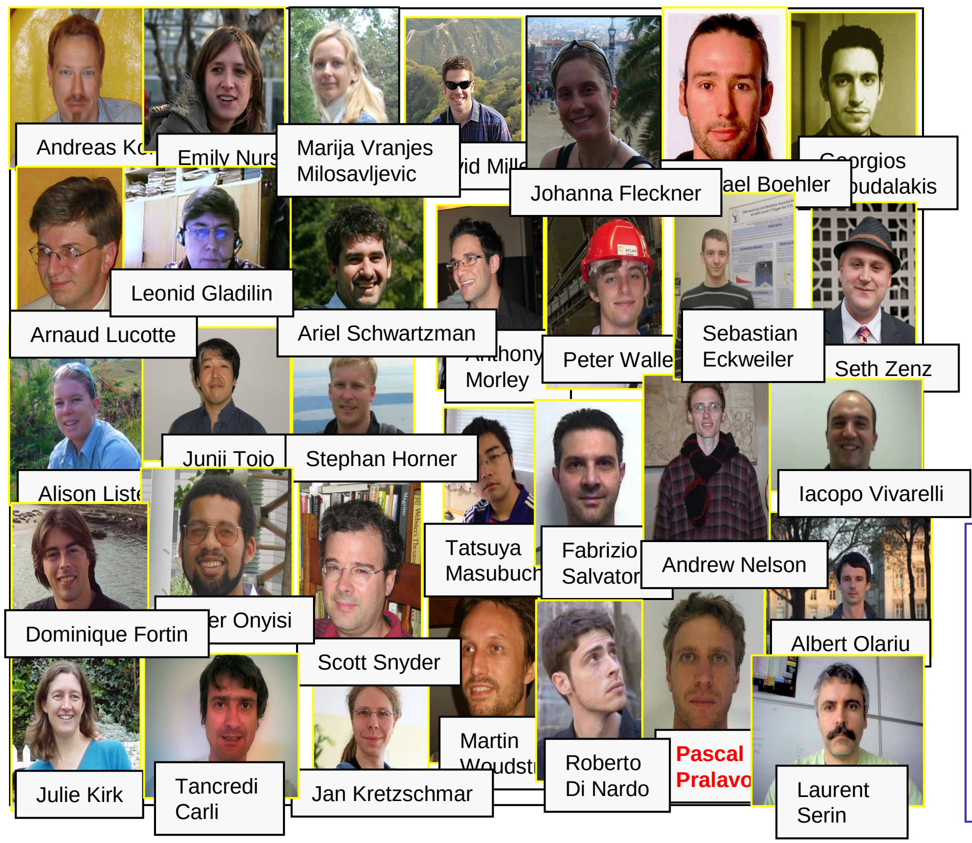
ICHEP Conference: First physics results (22-28 July 2010)



LPCC, CERN, August 2010

ATLAS at ICHEP

- 21 talks in parrallel sessions, 10 posters + 1 plenary talk



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Outline of the talk

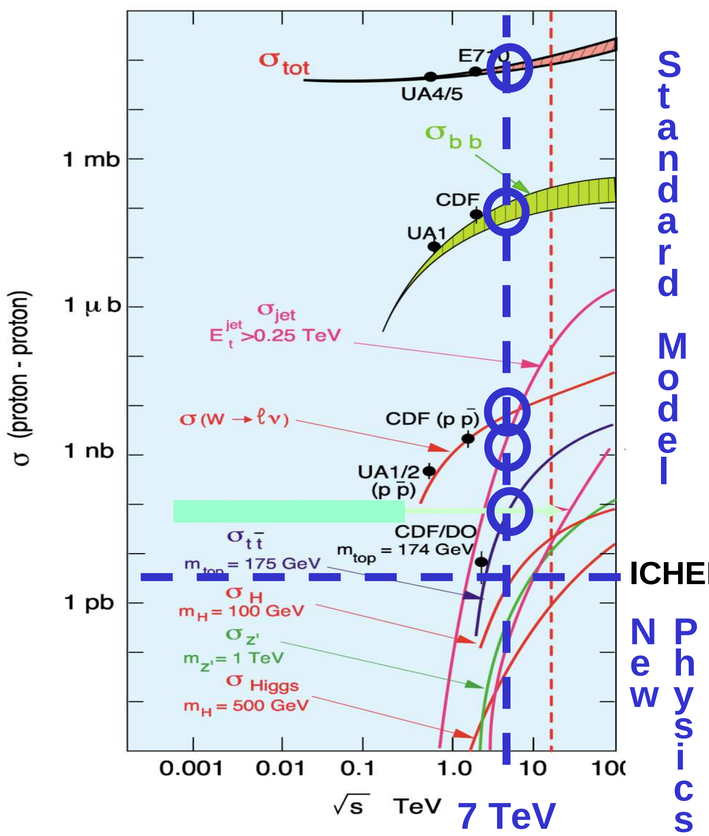
- **Generalities**
- **Glimpse of systematics from Object reconstruction**
- **Physics results (J/psi, W, Z, jet cross-sections, top, …)**
- **Conclusions**

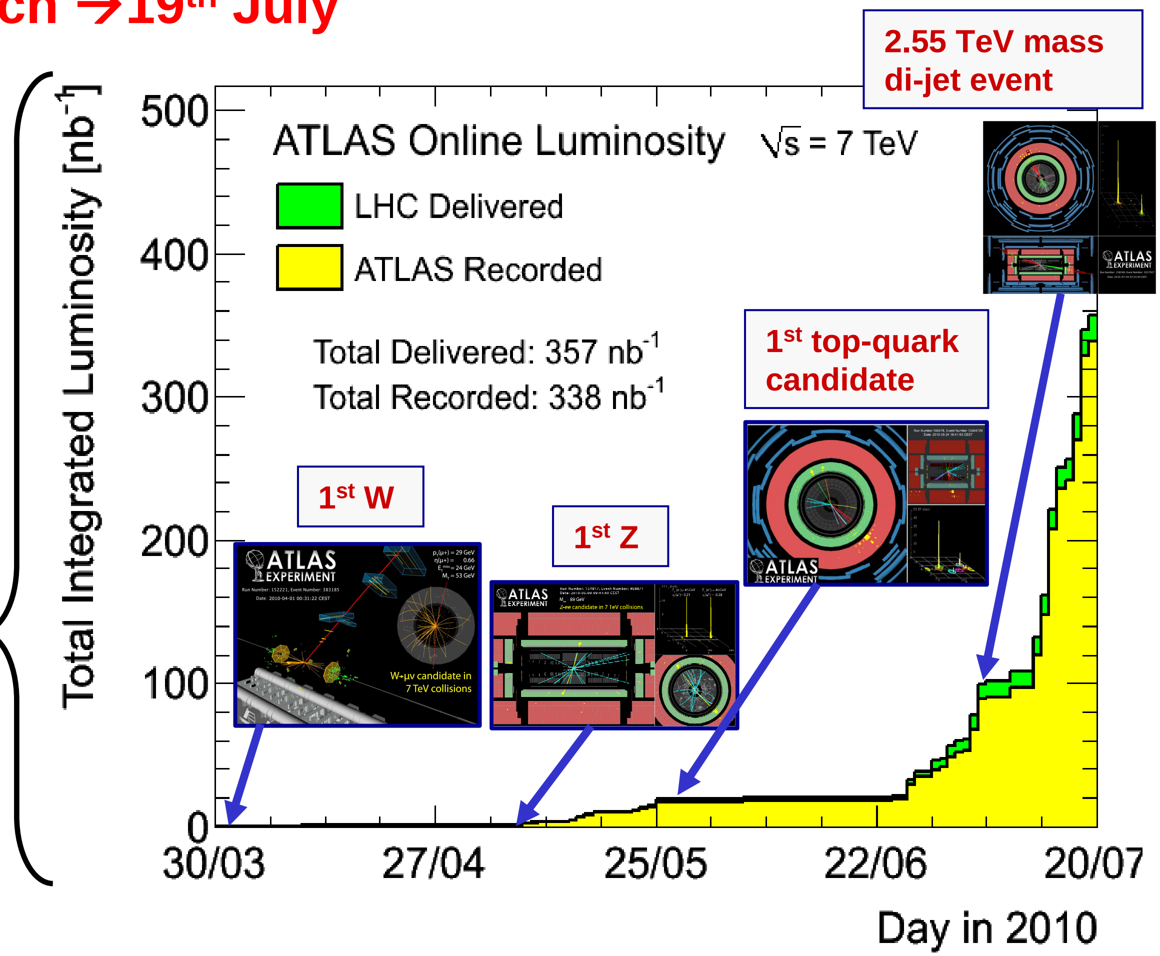
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/RESULTS/summer2010.html

A huge effort from the ATLAS Collaboration (50 CONF Notes !)

Data at √s=7 TeV (1)

❑ **ICHEP data: From 30th March → 19th July**

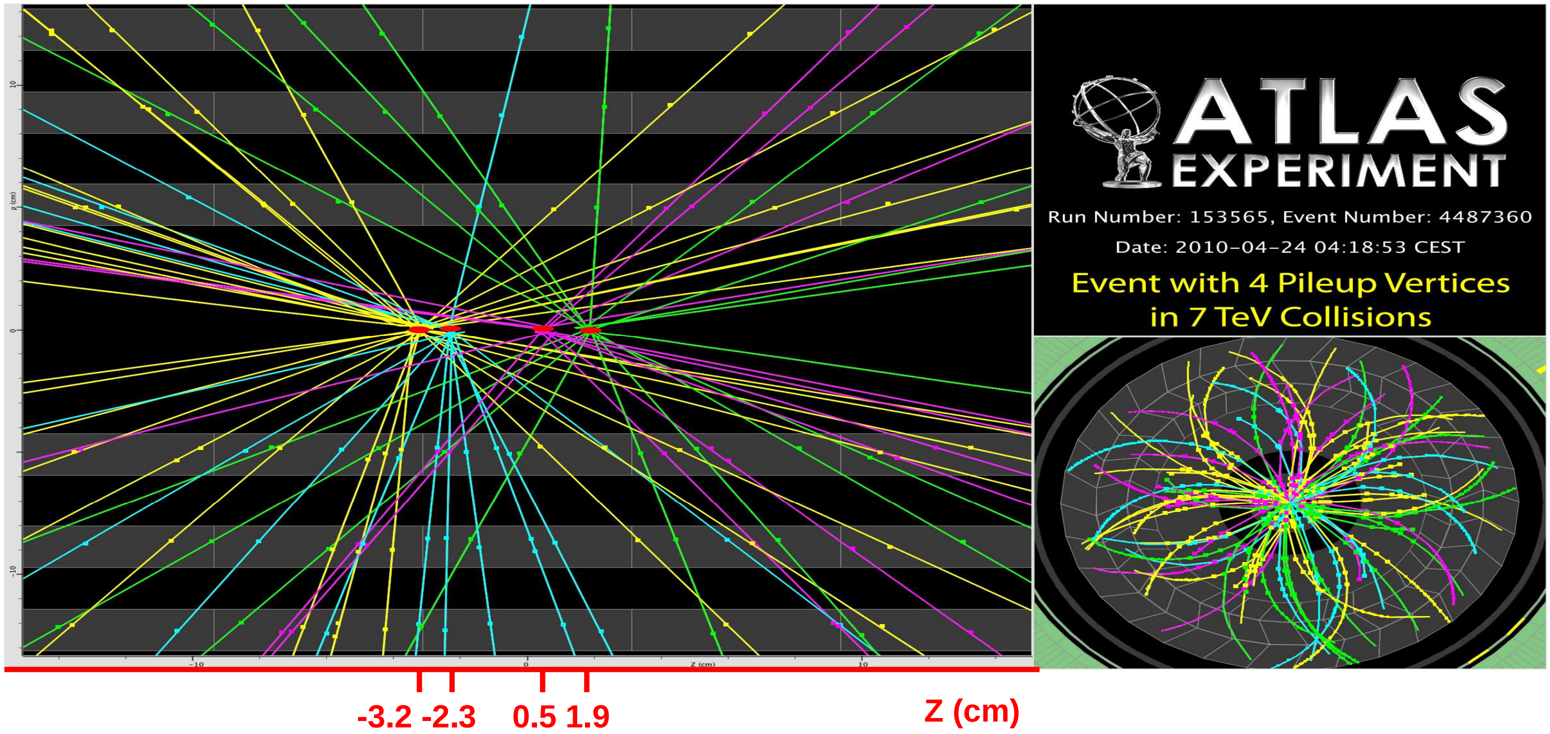




95% Overall data taking eff. (detector >97% operationnal) → 338 nb^{-1} to analyse

Data at √s=7 TeV (2)

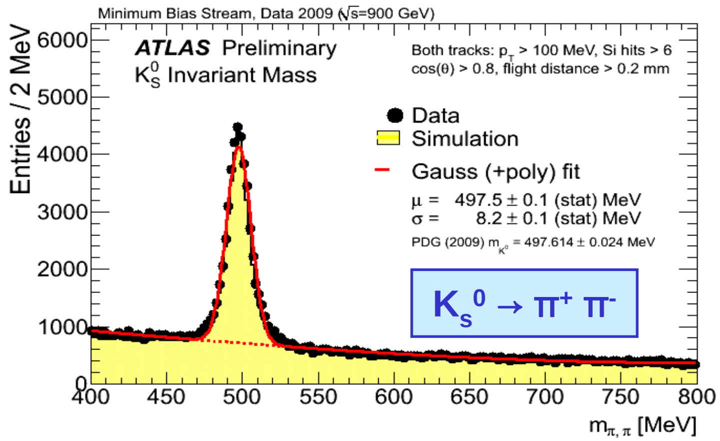
- **40% of event have > 1 pp interaction per crossing**
  - Example : 4 pp interactions in one bunch crossing
    - ➔ 10-45 tracks p_T>150 MeV per vertex

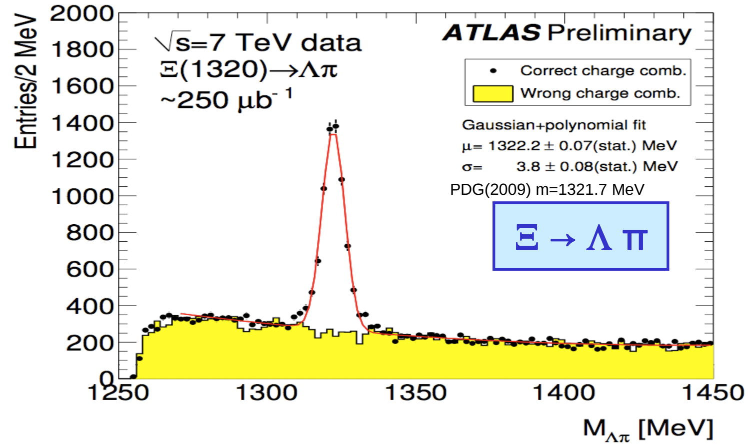


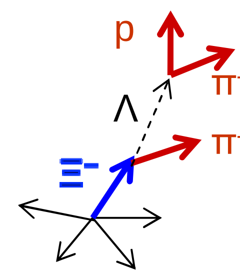
In average 1.3 pp collision per bunch crossing ➔ Analysis more complex

Track momentum scale

❑ At low pT : from early peaks and cascade decays

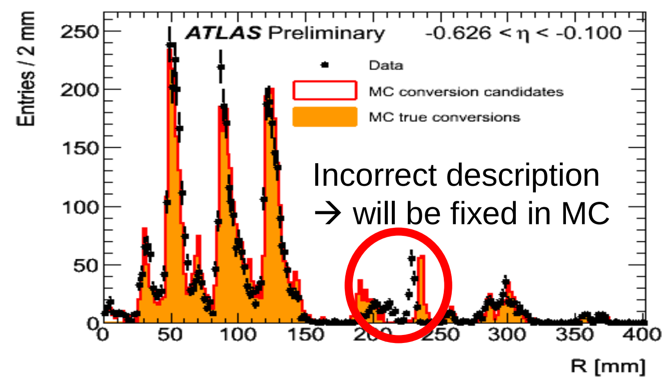






❑ Knowledge of Inner Detector Material

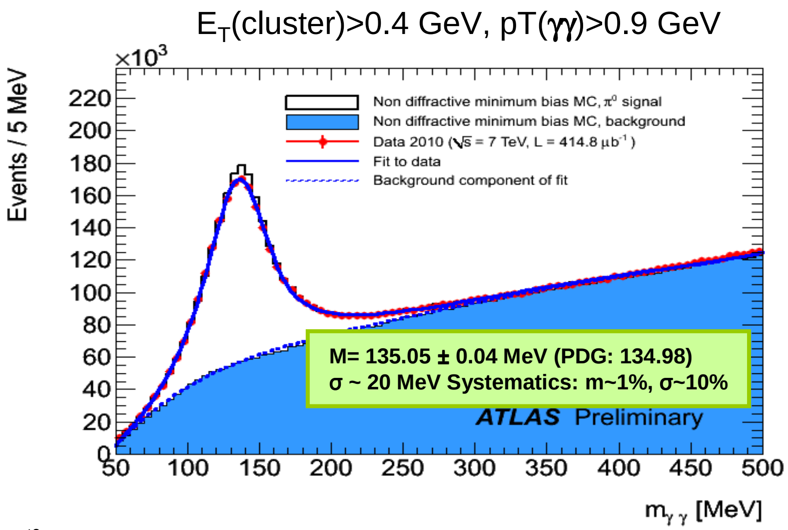
- Looked at using $\gamma \rightarrow ee$ conversion and hadronic interaction secondary vertices
- Found some discrepancies data-MC
- Today ~10% level. Ultimate goal: 1%

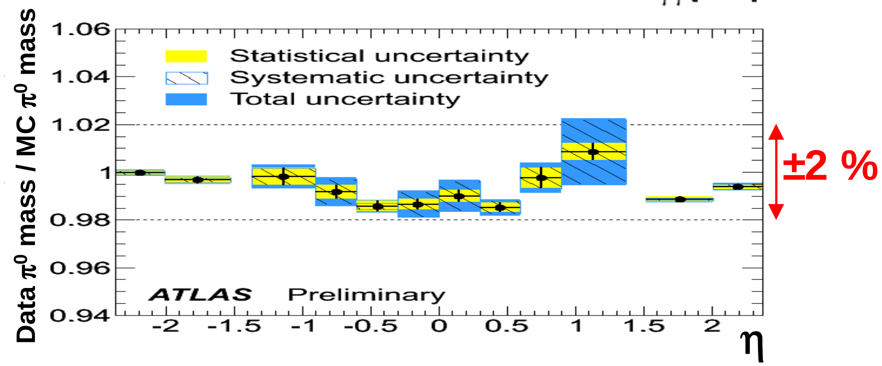


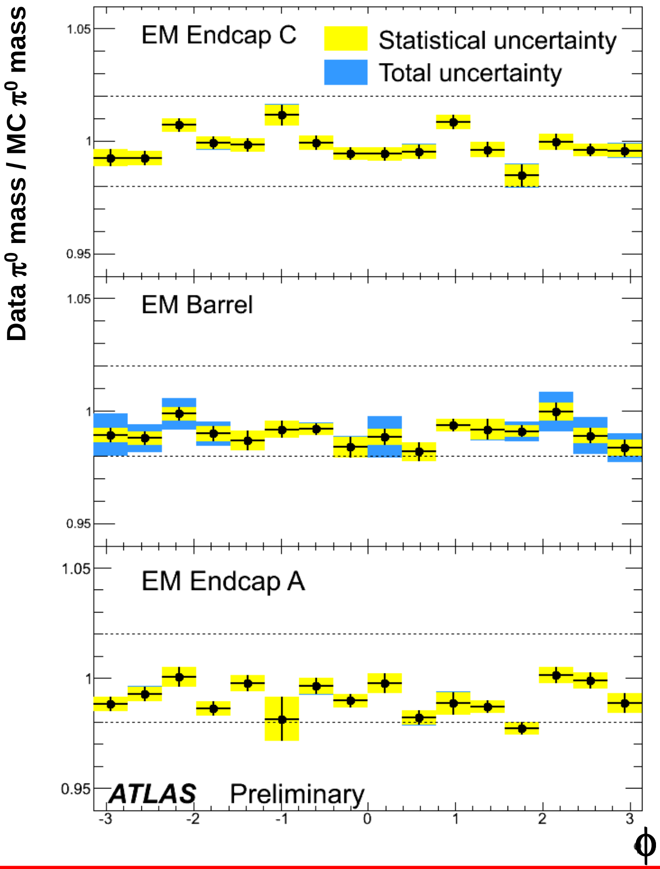
- **Momentum scale known to few permil in low pT range**
- **Inner Detector material known at 10%**

EM shower energy scale

- Taste of EM calorimeter uniformity with first million of $\pi^0 \rightarrow \gamma\gamma$





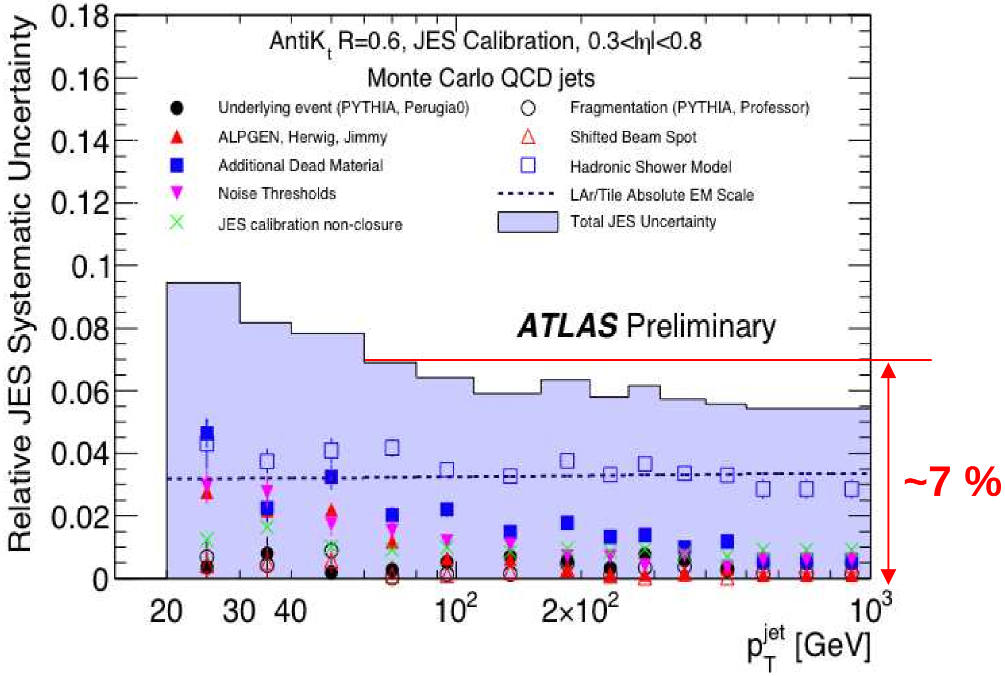


First check of energy scale over η (~ 2%) and EM calo response uniformity in φ (< 0.7%)

Jet Energy scale and E_T^{miss}

❑ Jet energy scale

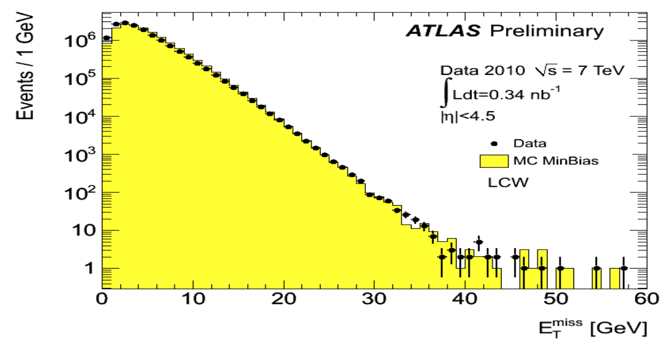
- Presently from MC (based on last 10 years)



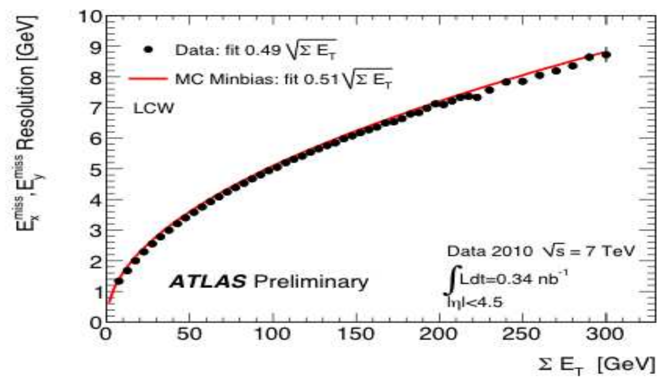
- Soon reduced with γ-jet balance (~1 pb^{-1})

❑ E_T^{miss} resolution and tails

- From Minimum Bias events (E_T^{miss}~0)
- Measured over full calorimeter coverage (360^0 in ϕ, |η|<4.5, ~200k cells)



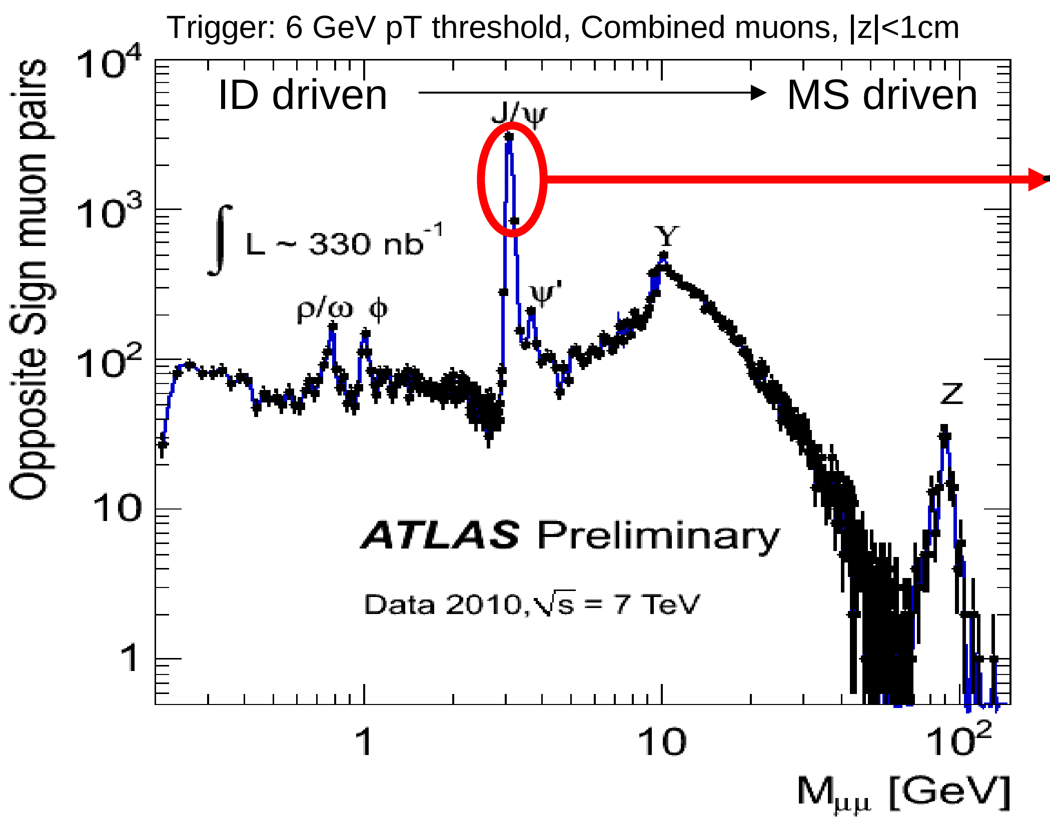
No tails

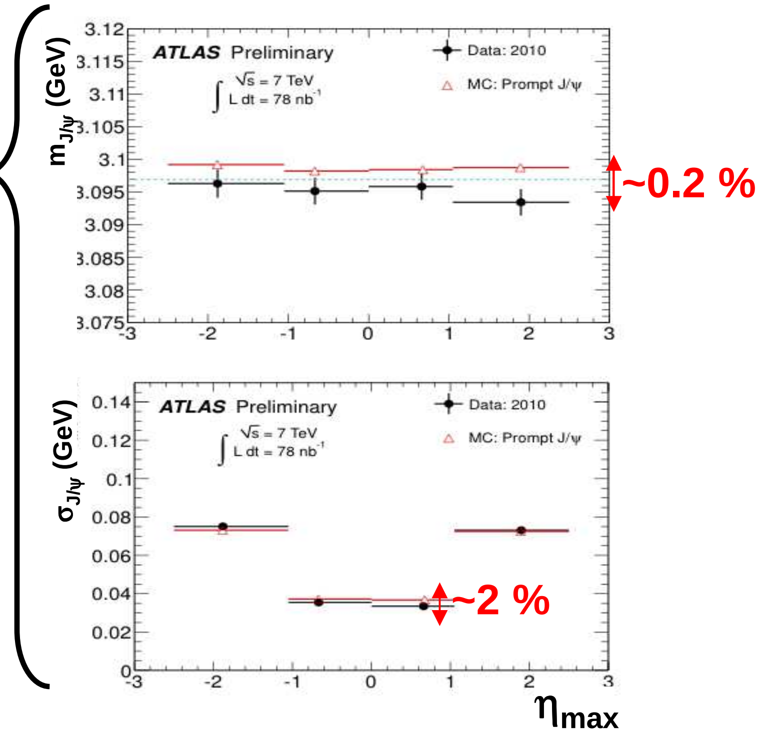


Jet Energy scale known to ~7% for pT>100 GeV. E_T^{miss} under control

Muon Reconstruction

- Combined Inner Detector (ID) + Muon Spectrometer (MS) measurement





Very good understanding at low pT (high pT needs more data)

Physics Results

- **Already good understanding of the detector/object …**
  1. Data-MC in fair agreement : most systematics for physics from MC
  2. Wherever possible, use data driven technics

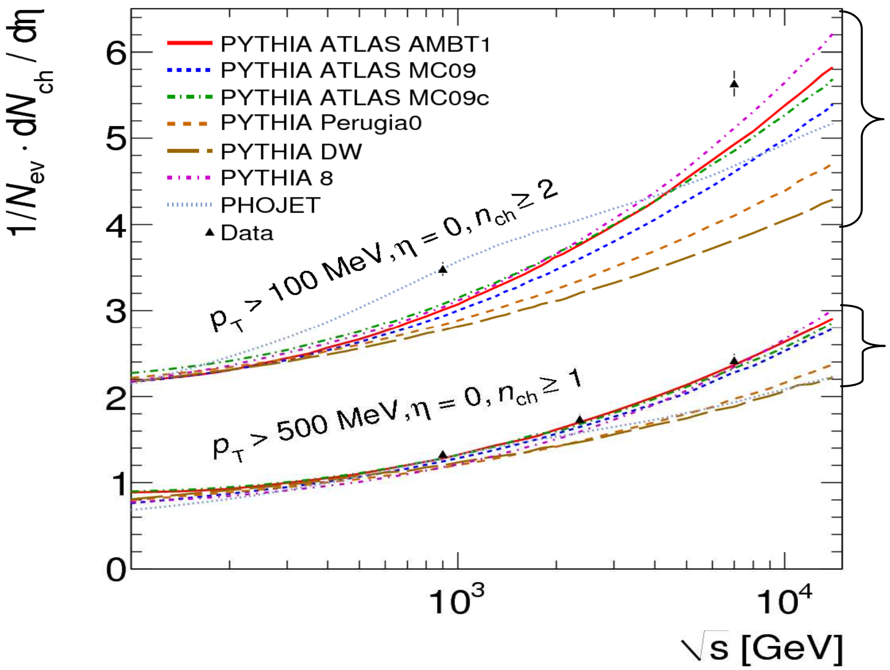
  → **Conservative estimate for physics measurements**

- **… allows first physics measurements (after 3.5 months at $\sqrt{s}$=7 TeV) !**
  1. Soft QCD: Charge particle multiplicities
  2. b and c physics: **$J/\psi \rightarrow \mu\mu$** cross-section and properties
  3. Hard QCD: Evidence of **prompt photon** and **single jet / dijet** cross-sections
  4. EW Physics: **W, Z** cross-sections and properties
  5. First **Top** candidates
  6. Very first searches beyond the SM : first limit beyond Tevatron reach !

Already a wide coverage of physics subjects !

Soft QCD

- **Soft hadronic activity must be well modeled for precise measurements**
  - To allow tuning of MC generator (in a region where physics is poorly known):
    - ✓ Correct back to hadron level, no subtraction of single/double diffractive component
    - ✓ Choose a well-defined kinematic region: ≥ 2 charged particles (p_T > 100 MeV, |η|<2.5)



New results (pT>100 MeV) :

➔ Measurement dominated by systematics ~2-3%

➔ Higher multiplicities in data compare to all MCs by 20-30%

Previous results (pT>500 MeV)

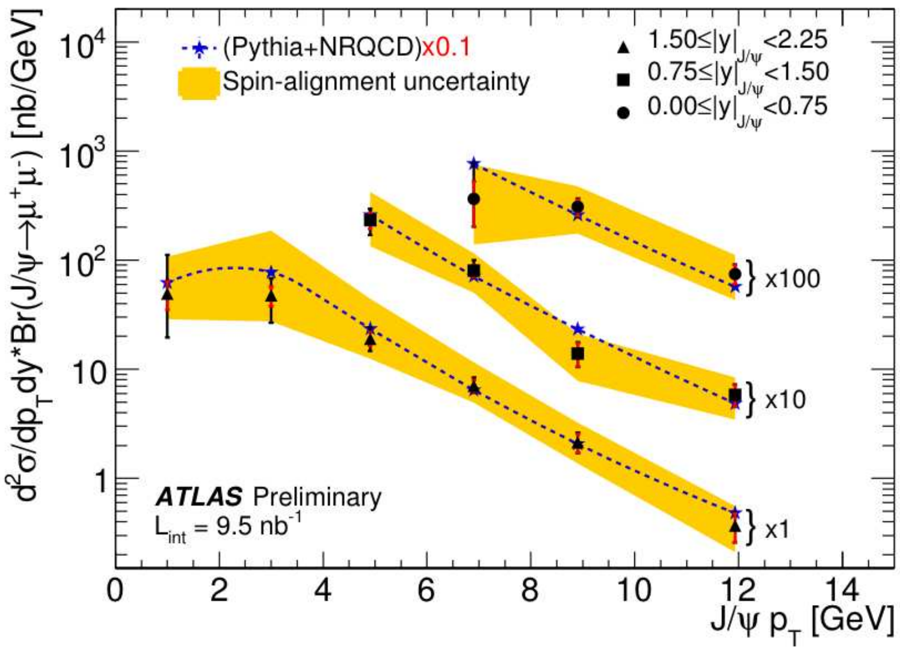
➔ Fair agreement with PYTHIA AMBT1-tune

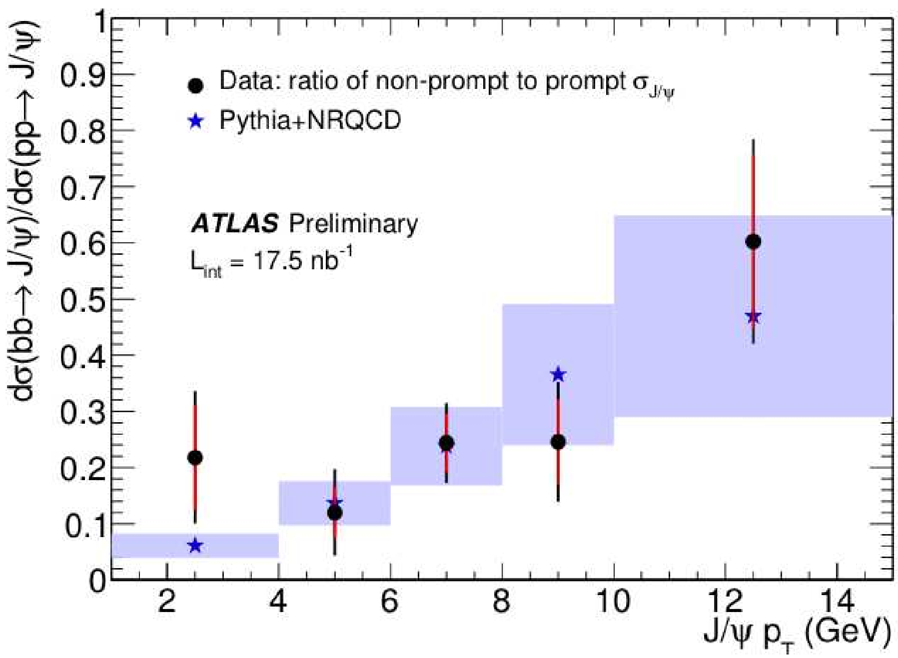
Continue active program to get agreement data-MC

J/ψ→μμ cross-section

❑ Probe J/ψ production mechanisms

- Differential cross-section in p_T and y bins
- Separate prompt J/ψ from others with: $\frac{L_{xy}\, m(J/\psi)}{p_T(J/\psi)}$.

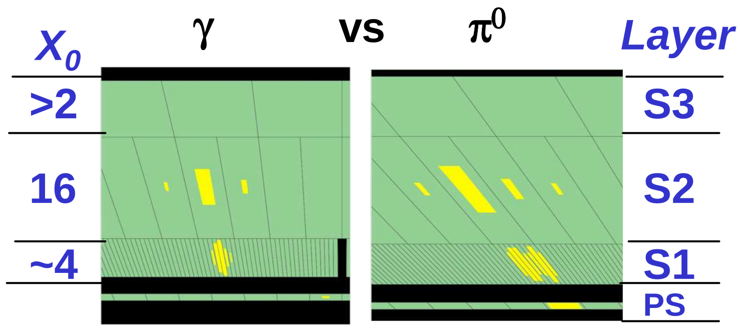


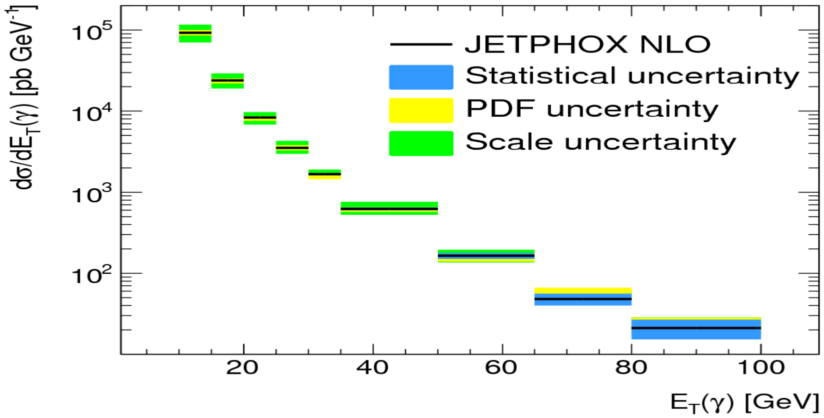


Comparison limited by theoritical uncertainties

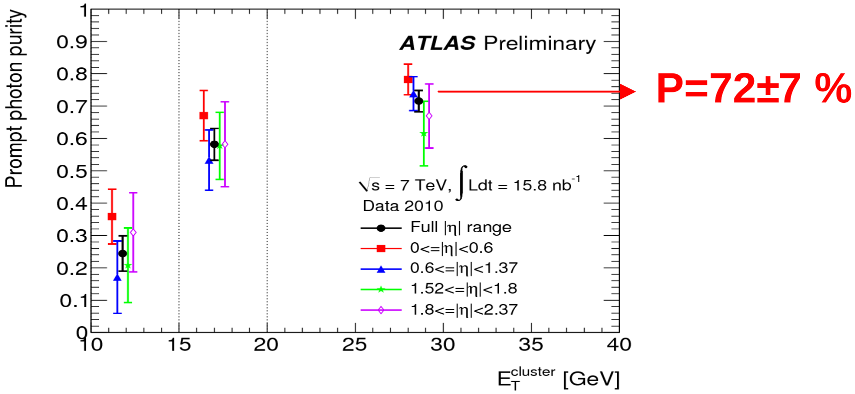
Evidence of prompt photon

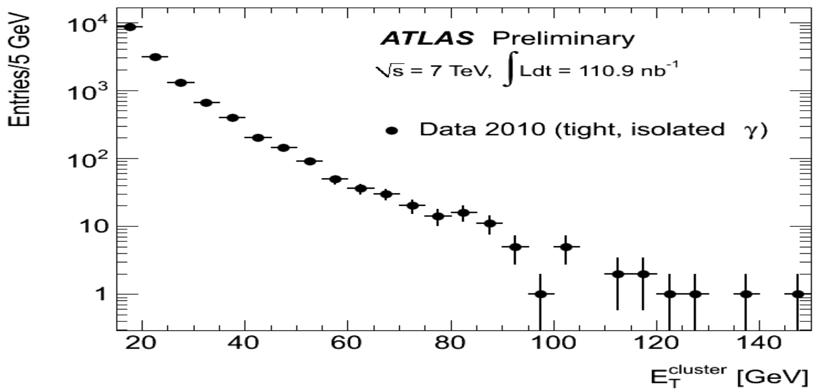
- **Possible in ATLAS with the fine granular EM calorimeter (π^0 rejection)**
  - Test perturbative QCD, constraint parton structure function (first step for H,G→γγ search)





2D [γ ID vs γ Isolation] side-band background subtraction



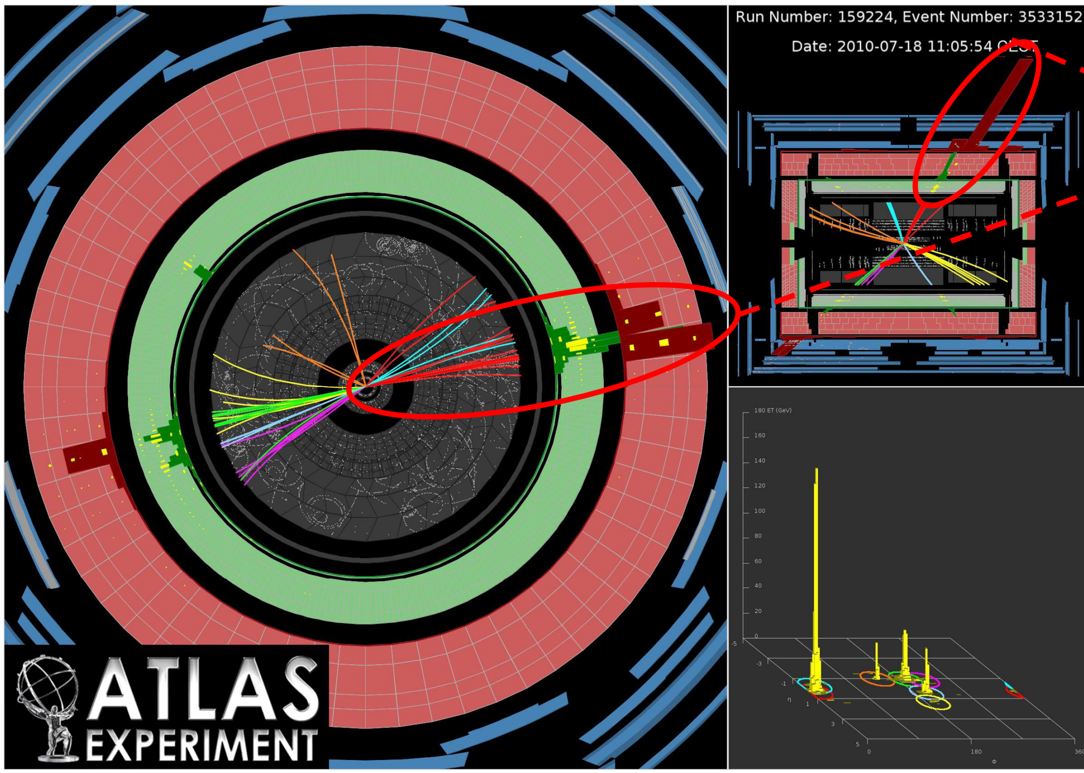


Observe ~ 40 prompt γ signal / nb with E_T>20 GeV with a good purity (~70%)

Jet physics (1)

❑ High pT jets abundantly produced at LHC

- Evidence of jet production shown 28 years ago in ICHEP Paris (p_T~60 GeV, Mjj~140 GeV) !
- In ATLAS: Jet = 3D calorimeter cluster + Anti-kt algorithm (R=0.4, 0.6)



Highest jet p_T ~ 1.12 TeV in central detector region

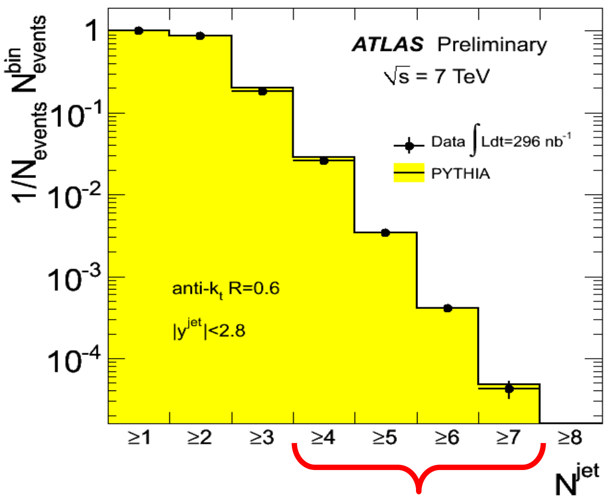
4 jets in this event:

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

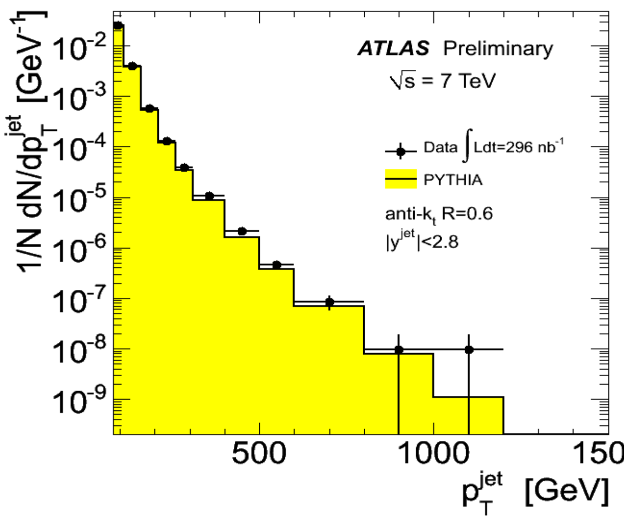
Jet physics (2)

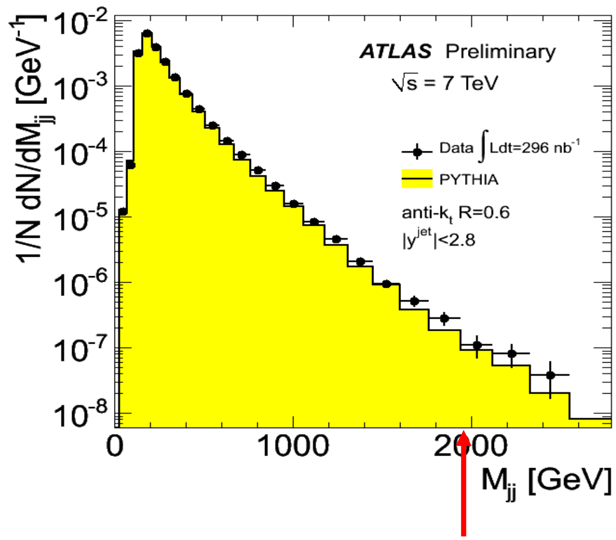
❑ Full ICHEP stat, MC normalised to data

- Main jet : p_T>80 GeV (and sub-leading jets: p_T>40 GeV) in $|y^{jet}|$<2.8
- Statistical error only



Few Top candidates in !





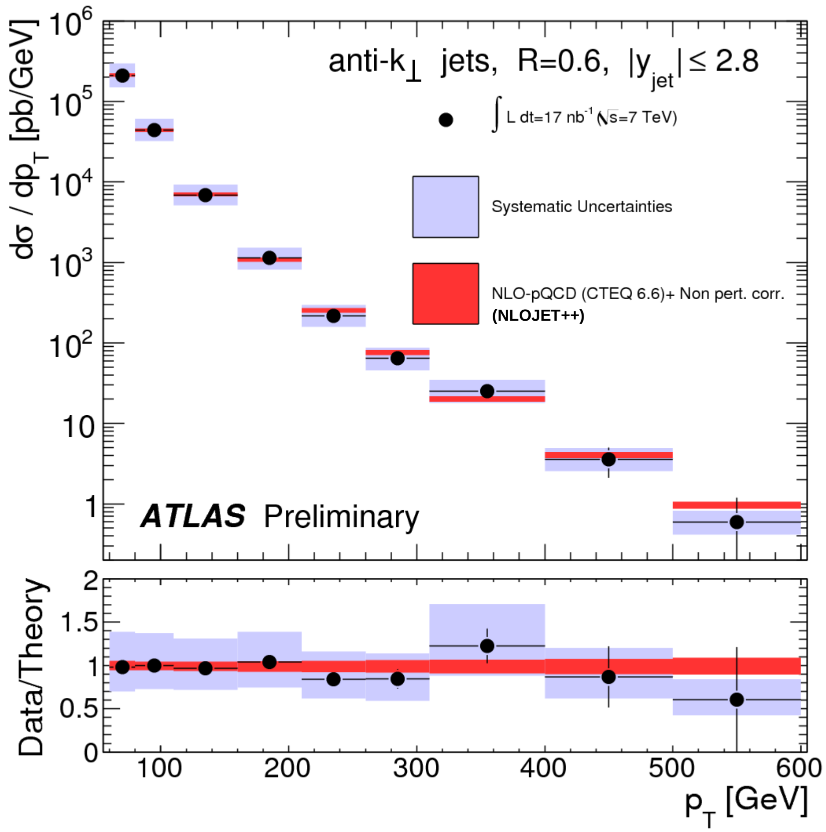
Tevatron √s=1.96 TeV !!

Already start to explore new phase space !

Jet physics (3)

❑ Inclusive jet cross-section (~Tevatron x 100)

- Restricted to 17 nb^{-1} (no pile-up contamination) and p_T^{jet}>60 GeV and $|y^{jet}|$<2.8
- Correct measured jets to particle level using parton-shower MC (Pythia, Herwig):
  ➔ Compare to NLO pQCD prediction corrected from hadronization and underlying event
- Theoritical uncertainties on σ (PDF, α_S, scale):
  ✓ **10%** over measurable p_T range y~0
  ✓ Increase to **30-40%** at |y|~2.8
- Experimental uncertainties on σ:
  ✓ **30-40%** dominated by Jet Energy Scale
  ✓ 11% from Luminosity not included

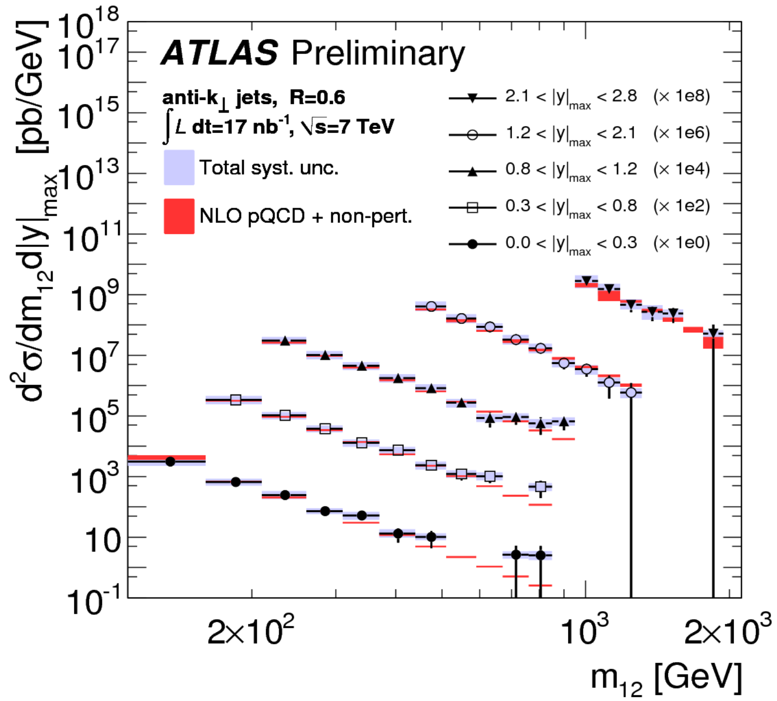


Good agreement data-MC over 5 orders of magnitude

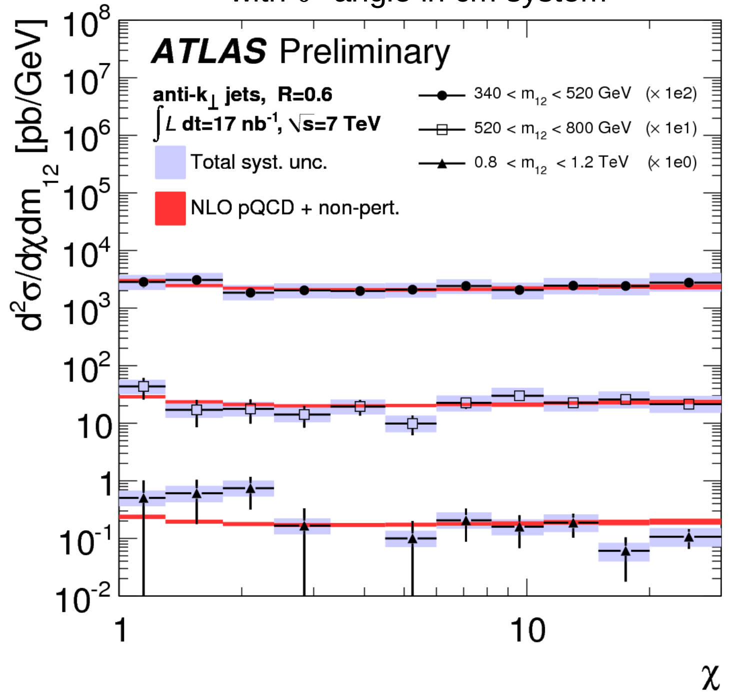
Jet physics (4)

❑ Dijet cross-section

- Main jet : p_T>60 GeV. Sub-leading jet: p_T>30 GeV



χ= exp(|y1-y2|) ~ (1+cos θ*)/(1-cos θ*)
with θ* angle in cm system



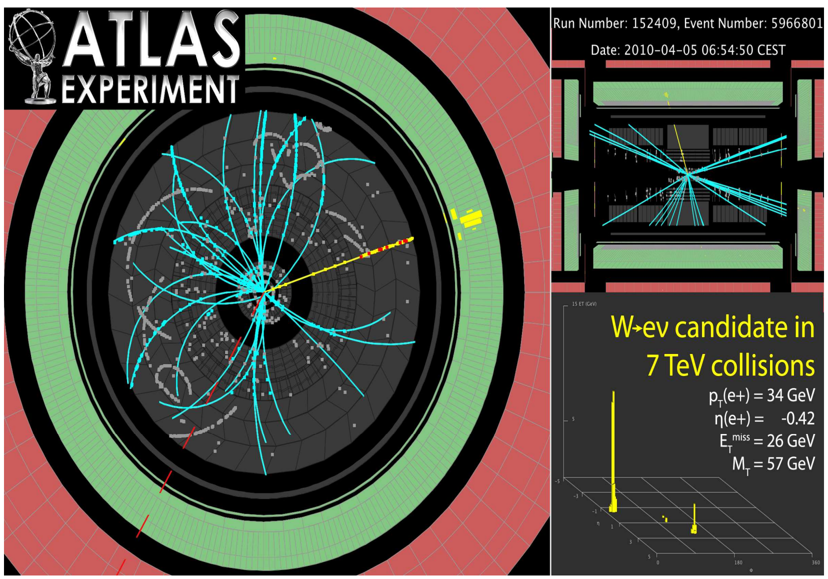
Good agreement data-MC in all rapidity and mass regions

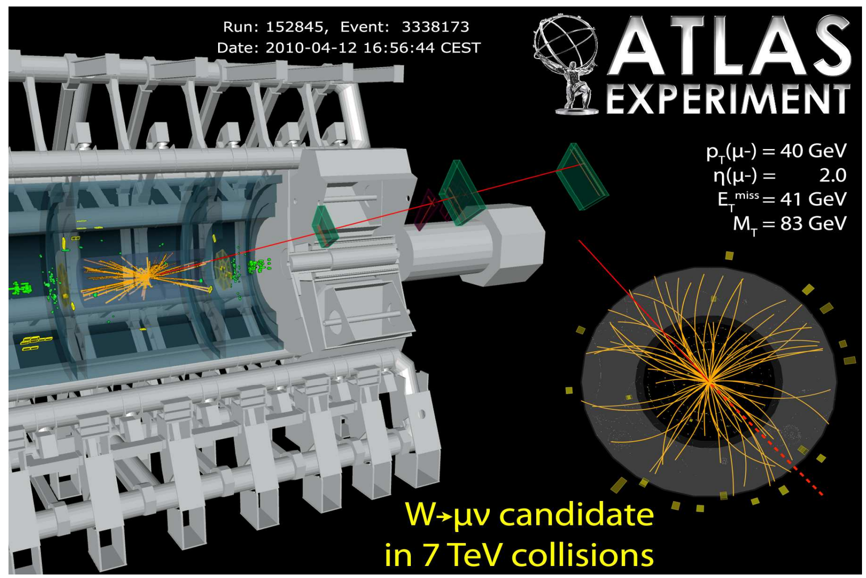
W→lν physics (1)

❑ Fundamental milestone in the rediscovery of the Standard Model

- W powerfull tool to constraints the PDF
- Among dominant source for New physics and top (W+4 jets)
- High statistics sources of pure high pT leptons

➔ EM calo calibration (E/p), Muon Spectrometer aligment / Toroidal field mapping





Very clean signatures !

W→lν physics (2)

❑ Electron channel (Full ICHEP stat, MC normalised to data)

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

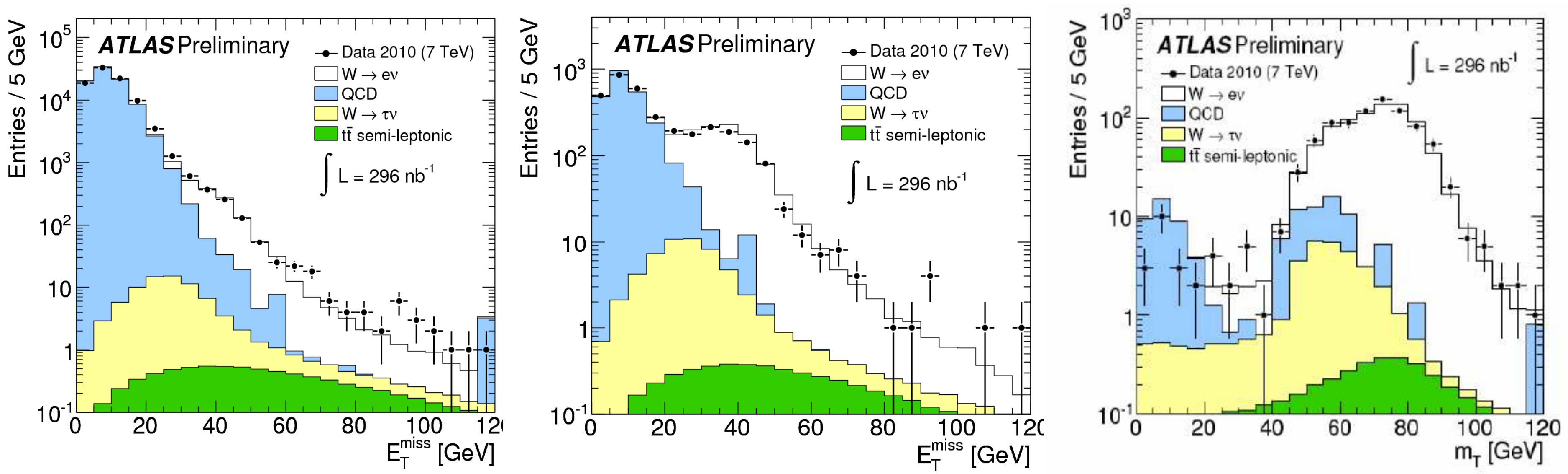
→ +

- Tight electron ident.

→ +

- 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)
- **815 W→eν** events (mT>40 GeV) with a high S/B

W→lν physics (3)

❑ Muon channel (Full ICHEP stat, MC normalised to data)

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

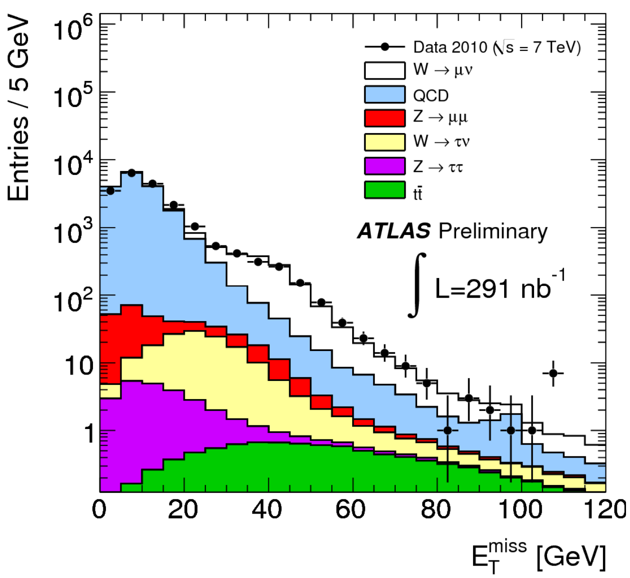
→ +

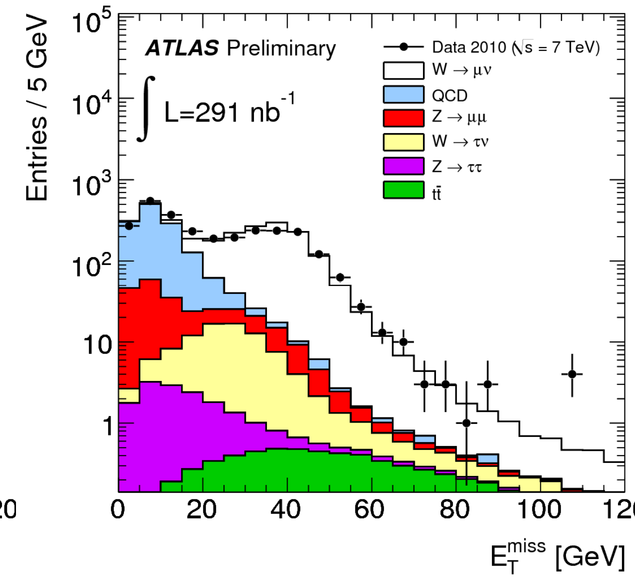
- pT (μ)> 20 GeV
- $\Sigma p_T(ID)/p_T < 0.2$

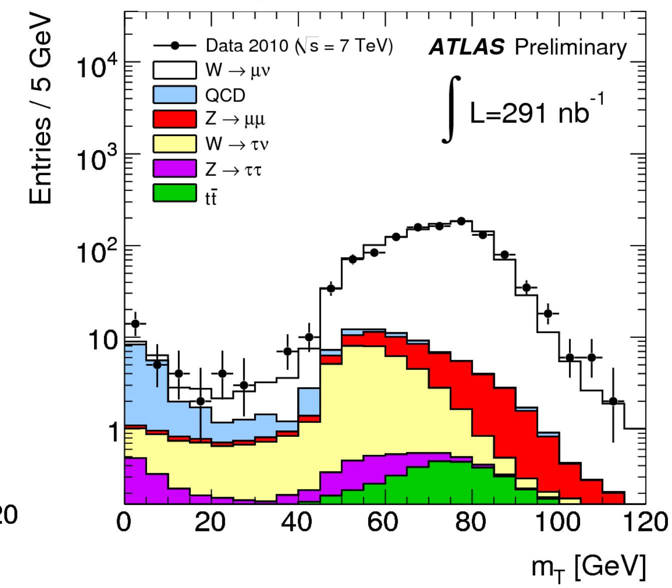
→ +

- $E_T^{miss} > 25$ GeV

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





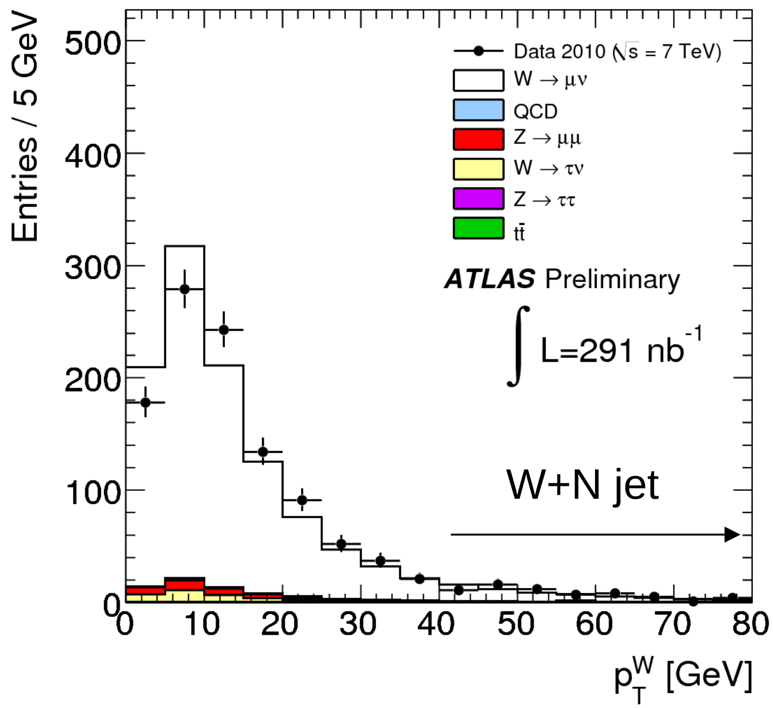


- Good agreement data/MC (shape)
- **1111 W→μν** events (mT>40 GeV) with a high S/B

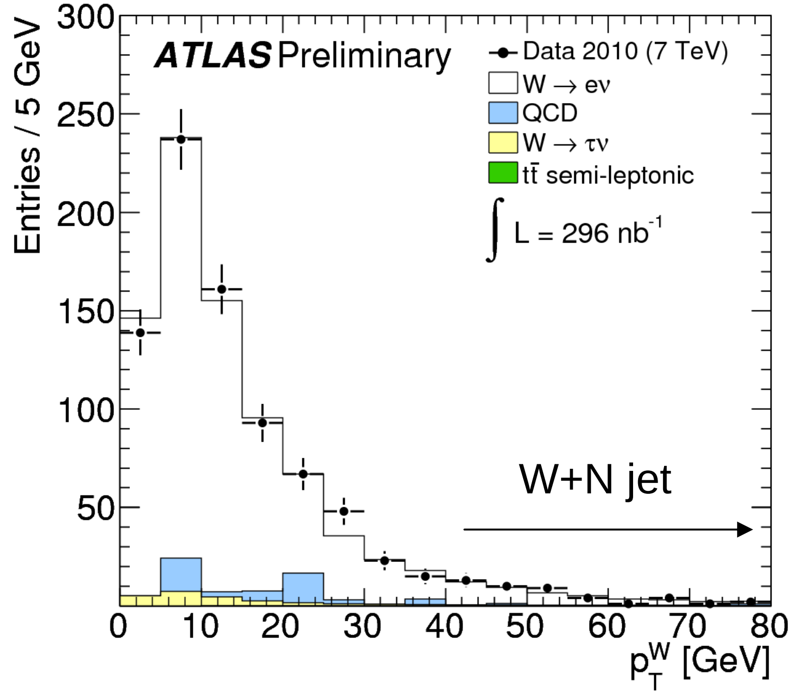
W→lν physics (4)

❑ **Kinematics of « Pure » W (Full ICHEP stat, MC normalised to data)**

Muon channel



Electron channel



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

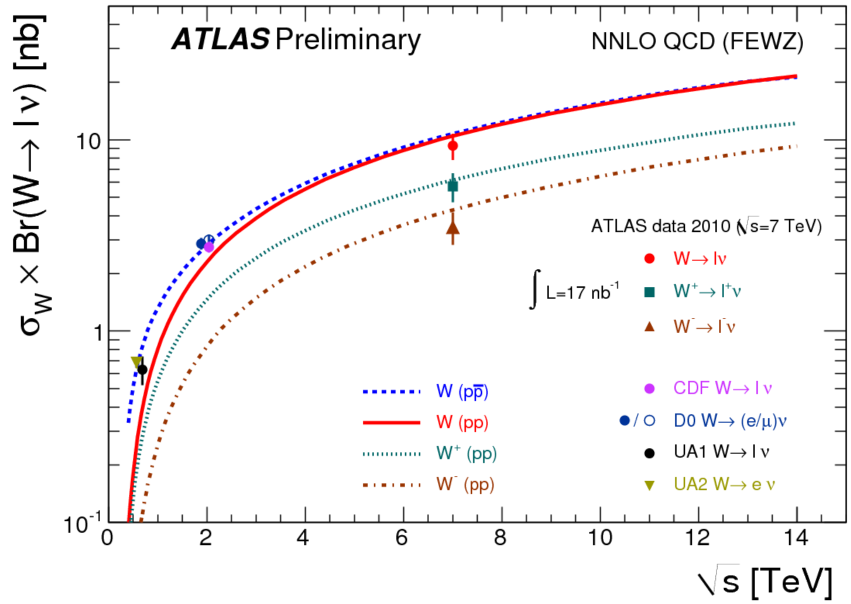
W→lν physics (5)

❑ Total cross-section measurement at L_{int}=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

- Compatible with Standard Model expectations (10.5±0.4 nb)
- Combined measurement dominated by luminosity systematics at 17 nb^{-1} !

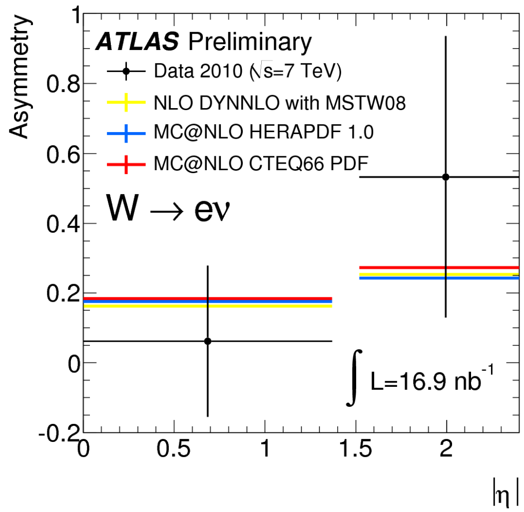
W→lν physics (6)

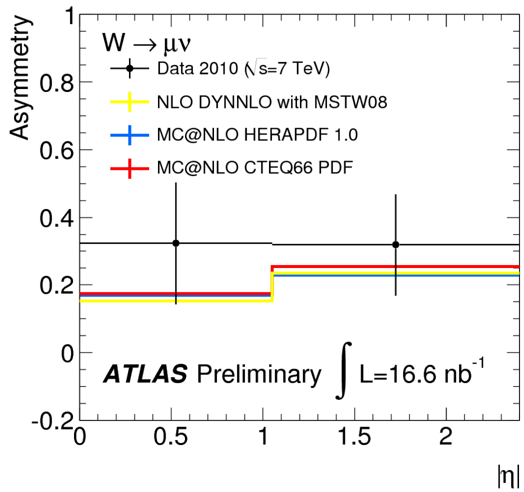
❑ Asymmetry (A) → Measured the difference in W+/W- production

- Most systematics cancel in the ratio
- Sensitive to valence quark distributions (x ~10^{-3}-10^{-1}) ➔ A vs η to distinguish between PDF

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

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



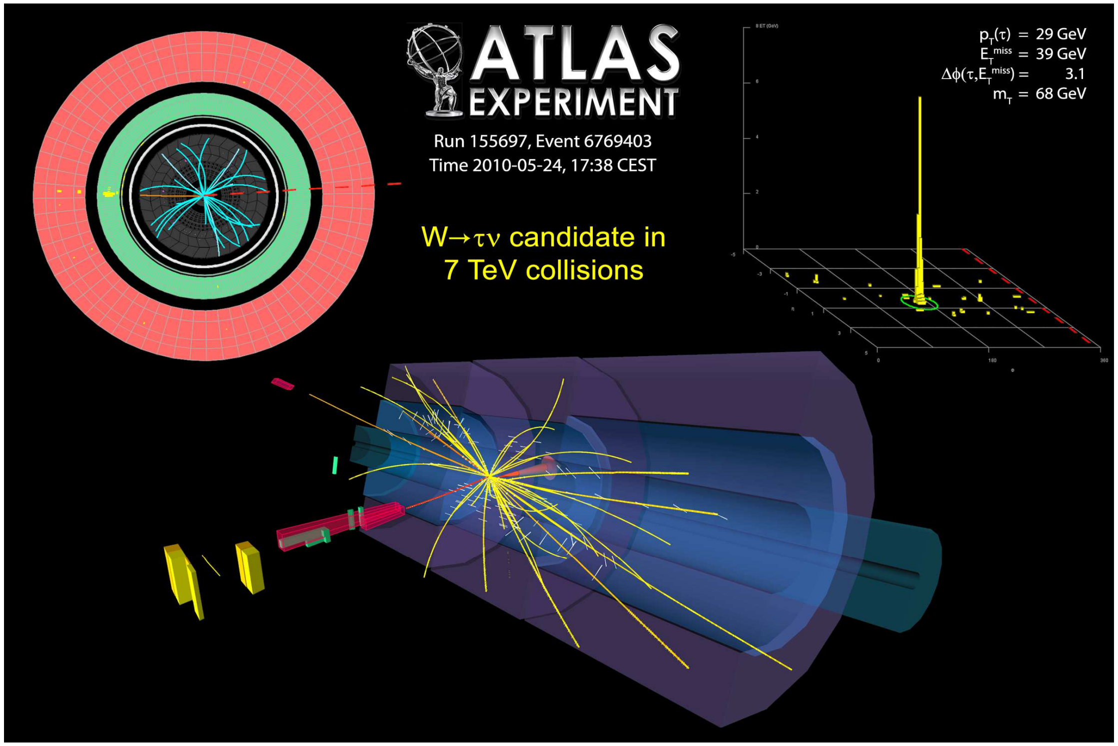


Statistically limited up to few pb^{-1}

W→lν physics (7)

❑ First candidate W→tau nu

- 1-prong tau-candidate (tight tau-selection cuts, fails loose e cuts)
- Second hardest track: p_T ~ 3 GeV

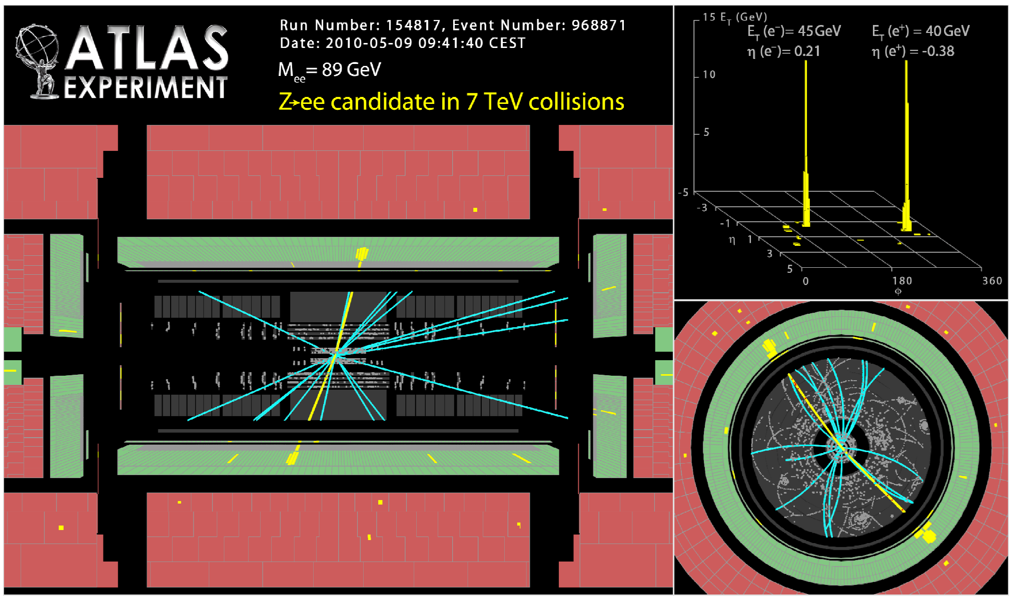


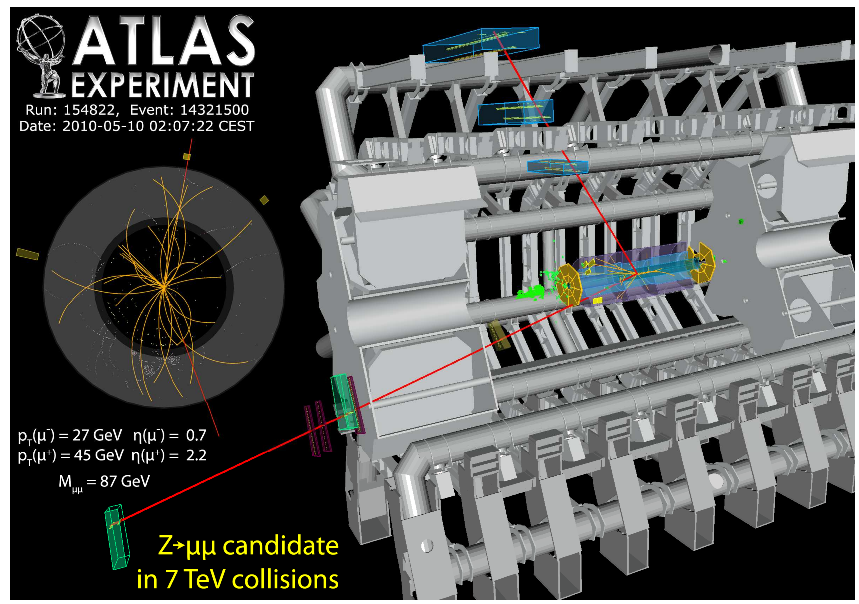
Harder to observe (softer spectrum and larger background)

Z→ ll physics (1)

❑ Another Standard Model Candel

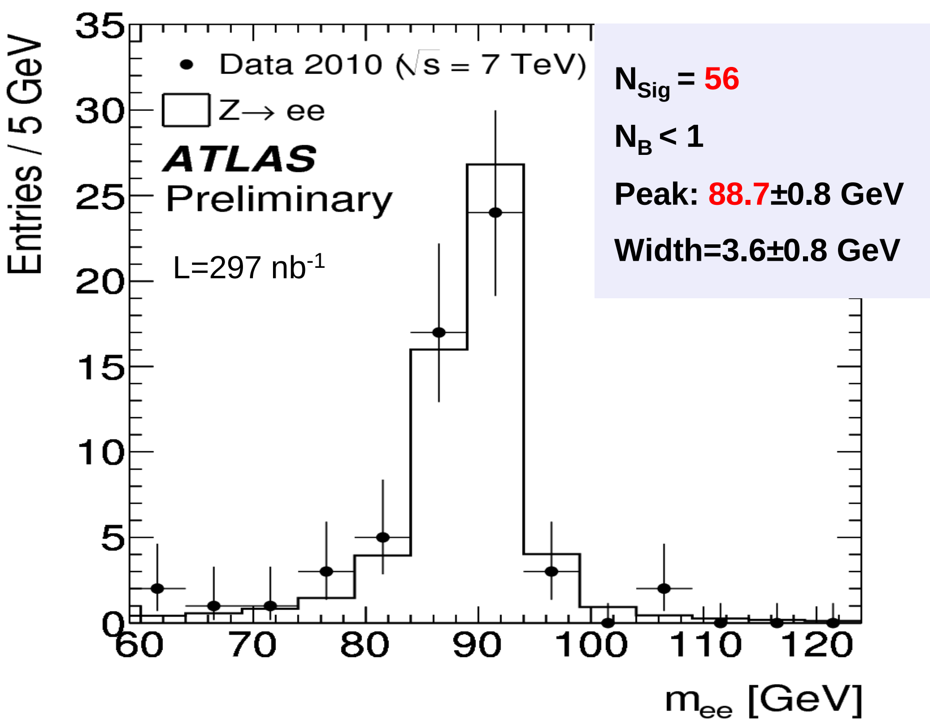
- Gold-plated channel to calibrate the detector to the ultimate precision
- Among dominant backgrounds for new physics

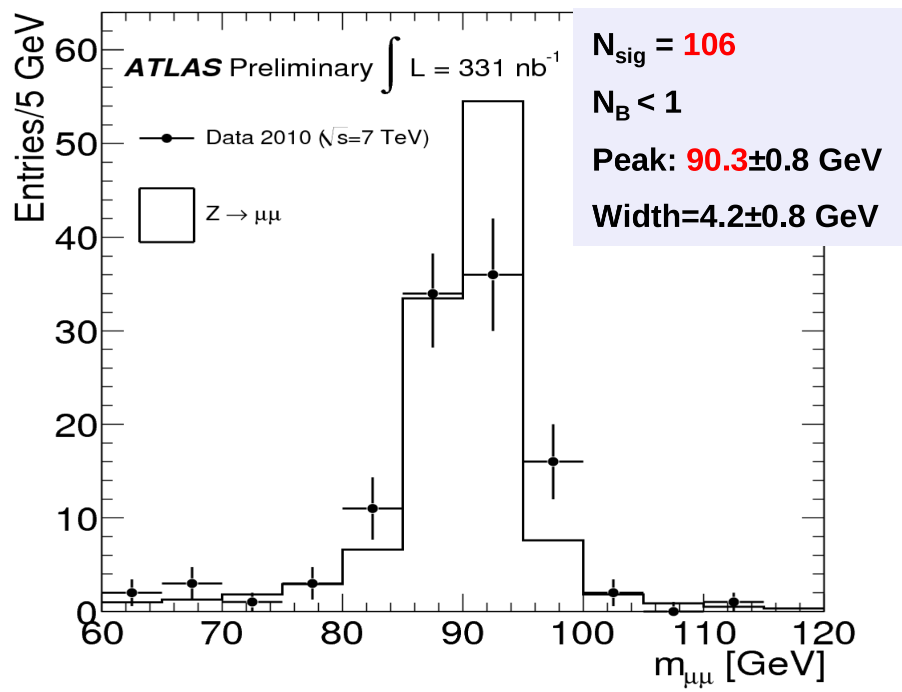




Z→ ll physics (2)

- **Full ICHEP stat, MC normalised to data**
  - From 2 opp. sign leptons (p_T>20 GeV, $|\eta|$<2.4)
  - Similar lepton identification as for W (somewhat relaxed)





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

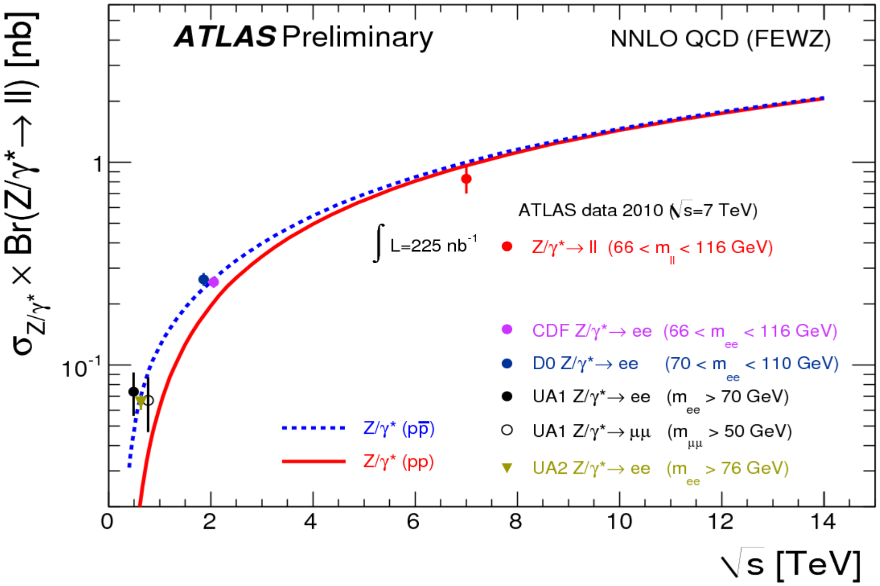
Z→ ll physics (3)

❑ Total cross-section measurement at L_{int}~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)%**

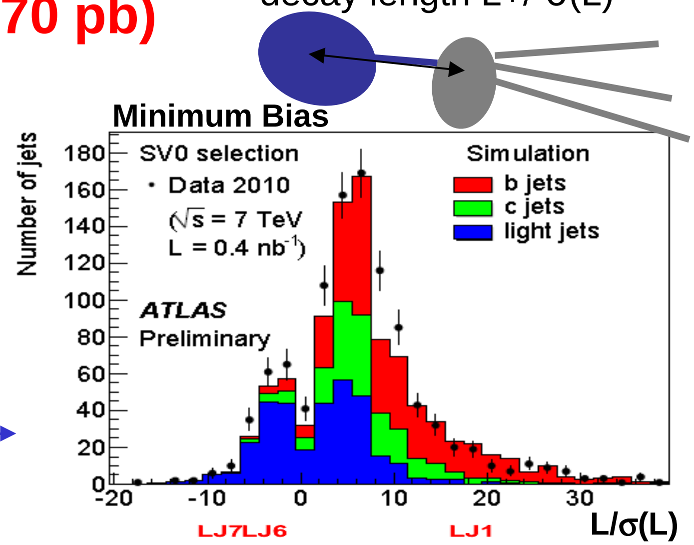


σ (Z/γ* → ll) = 0.83 ± 0.07 (stat) ± 0.06 (syst) ± 0.09 (lumi) nb

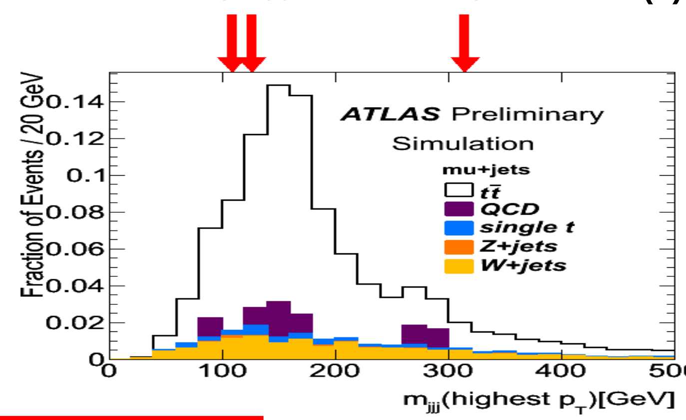
- Compatible with Standard Model expectations (0.99±0.04 nb)
- Combined measurement dominated by luminosity systematics at 225 nb^{-1} !

Top Candidates (1)

- **Lepton + jet channel: tt→Wb Wb →jjb lνb (σ~70 pb)**
  - A simple selection algorithm (Eff. ~ 30%)
    - ✓1 isolated lepton pT>20 GeV
    - ✓ E_T^{miss} > 20 GeV
    - ✓ ≥ 4 jets pT>20 GeV
    - ✓ ≥ 1 b-tag jet (L/σ(L)>5, ~50% eff.) →
    - →Full ICHEP stat: expect 5 events, get 7 !



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

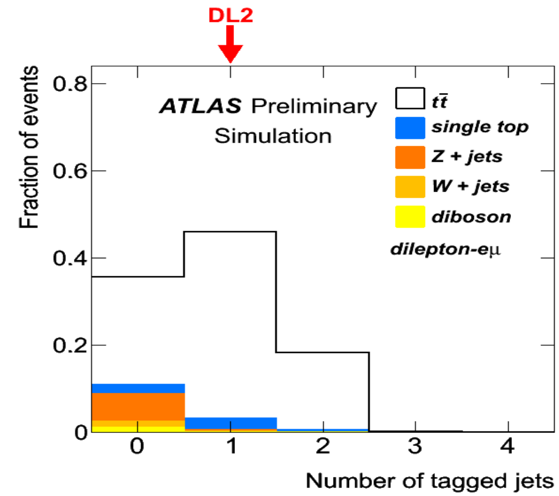


Several events in regions with signal purity is high

Top Candidates (2)

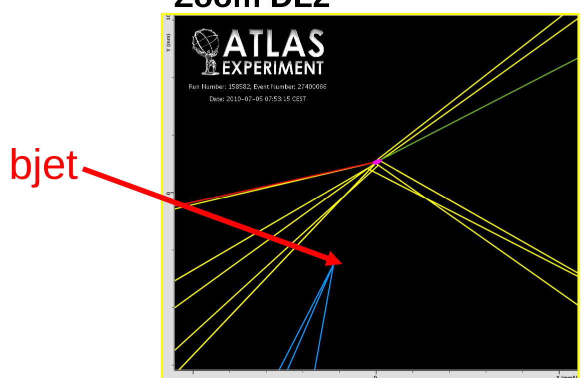
❑ Dilepton channel: tt→Wb Wb →lνb lνb (σ~10 pb)

- A simple selection algorithm (Eff. ~ 25%)
  - ✓ 2 opposite sign lepton (ee, eμ, μμ) pT>20 GeV
  - ✓ ee, eμ: E_T^{miss} > 30 GeV + Z veto. μμ: ΣE_T(lept.+jet)>150 GeV
  - ✓ ≥ 2 jets pT>20 GeV
  - ➔ Full ICHEP stat: expect 0.7 events, get **2** !

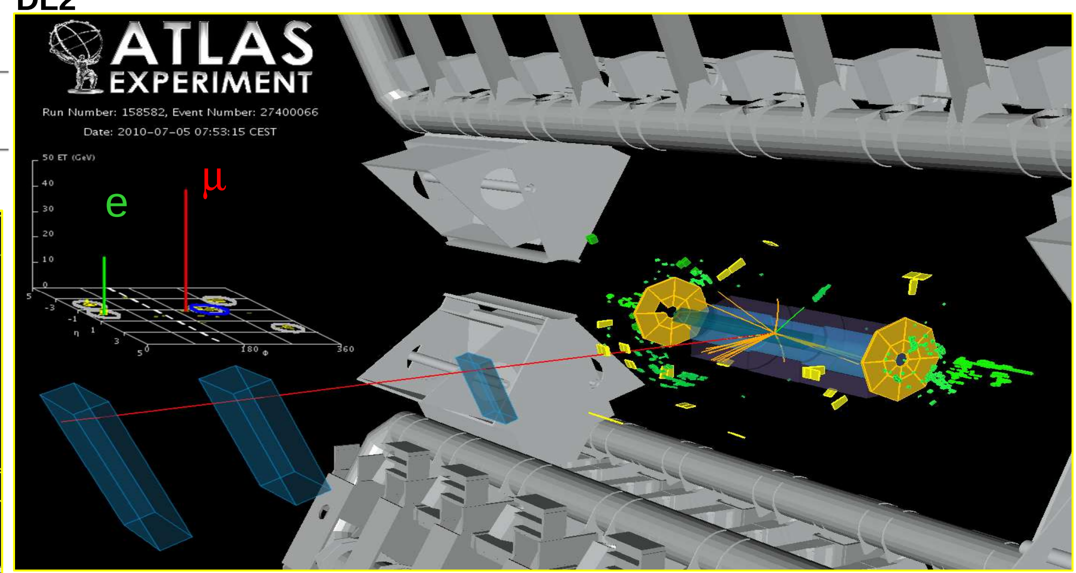


ID	Run number	Event number	Channel	p_T^{lep} (GeV)	E_T^{miss} (GeV)	H_T (GeV)	#jets $p_T > 20$ GeV	#b-tagged jets
DL1	155678	13304729	ee	55.2/40.6	42.4	271	3	1
DL2	158582	27400066	eμ	22.7/47.8	76.9	196	3	1

Zoom DL2



DL2

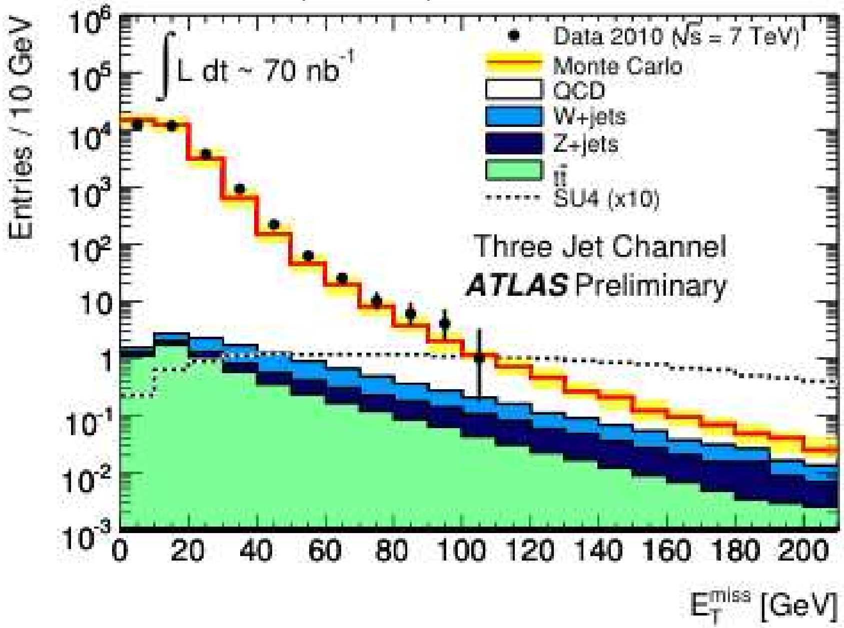


New Physics (1)

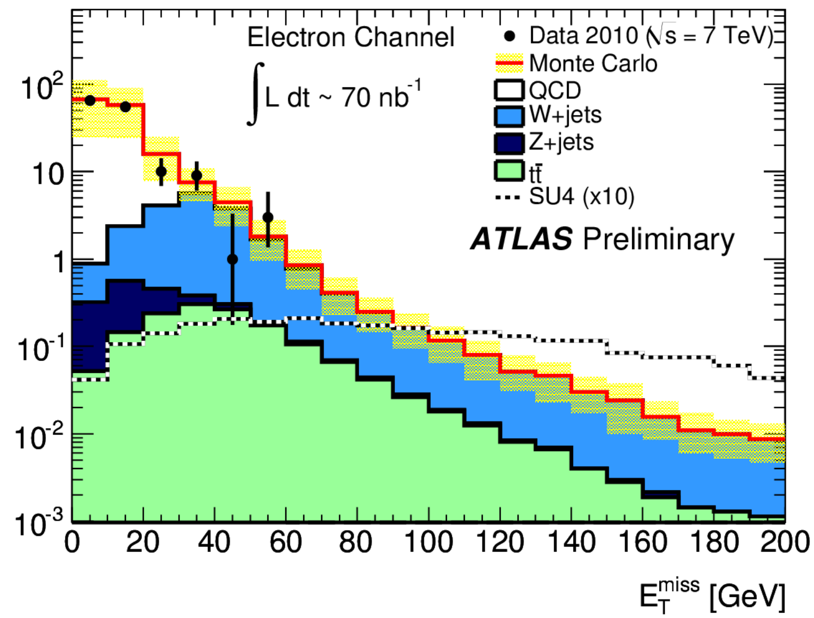
❑ First task: Understand backgrounds !

- Some examples in SUSY-like searches

Jets + E_T^{miss} channel:
≥ 3 high-p_T jets, p_T (j1) > 70 GeV



1 electron + Jets + ETmiss channel:
p_T (el) > 20 GeV, ≥ 2 high-p_T jets



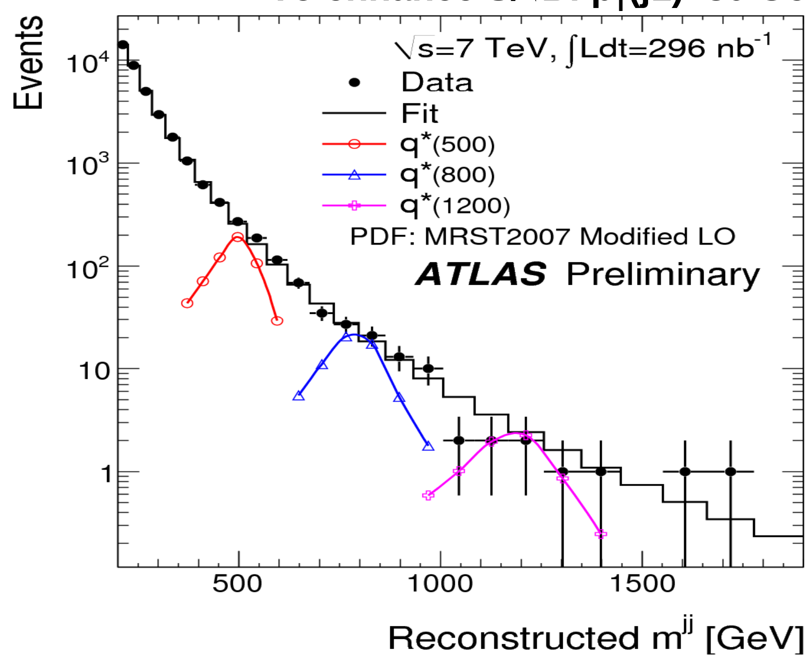
Meanwhile be prepared to set competitive limits with > 1pb^{-1} data

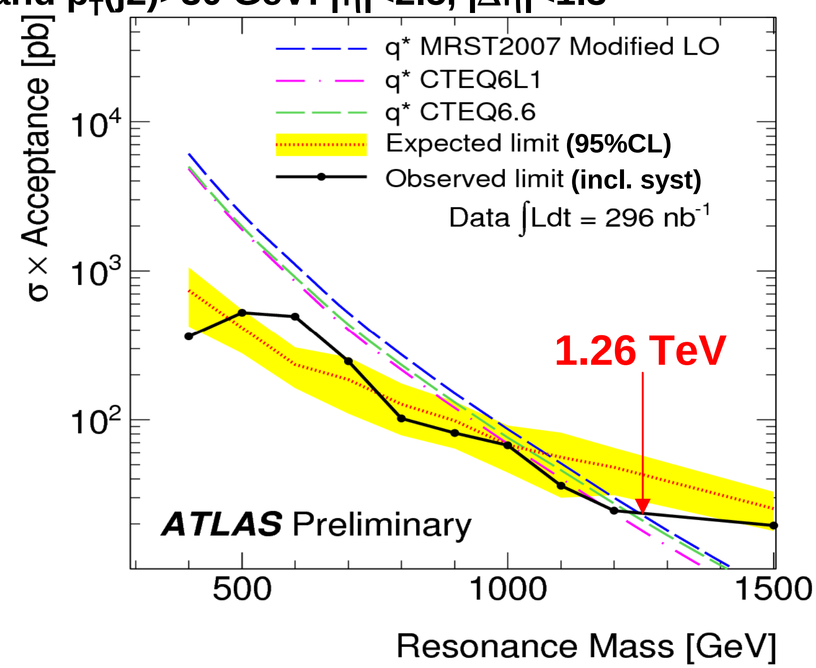
New Physics (2)

❑ Search for excited quarks (q*→jj) on full ICHEP data sample

- Signal is searched as deviation from smooth monotonic function
- Systematics considered: luminosity, Jet Energy scale, background fit

To enhance $S/\sqrt{B}$: $p_T(j1)>80$ GeV and $p_T(j2)>30$ GeV: $|\eta|<2.5$, $|\Delta\eta|<1.3$





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

Conclusions

- **The ATLAS detector takes maximum profit of 7 TeV run (~300 nb^{-1}) …**

  Thanks to LHC team !

  - High data taking efficiency (**95%**)
  - Detector already well understood over its full coverage (**~1-10 %** level) and working at **>97%**
  - Data available for physicists in very short time scale

- **… and produces many new/interesting physics results**
  - Analysing all available statistics for ICHEP:
    - ✓ 1 jet **p_T=1.1 TeV** and handfull of **M_{jj}>1.96 TeV**: entering an uncovered phase space !
    - ✓ **~2000** W→lν, **160** Z→ll (l=e,μ) + **9** top candidates
  - First W (Z), single and dijet **cross-section measurements** with 17 (225) nb^{-1} without pile-up:
    - ✓ In agreement with Standard Model prediction
    - ✓ Systematics dominated by lepton/jet reconstruction and luminosity
  - Searches for new physics on their way: first limit (q*) above Tevatron reach

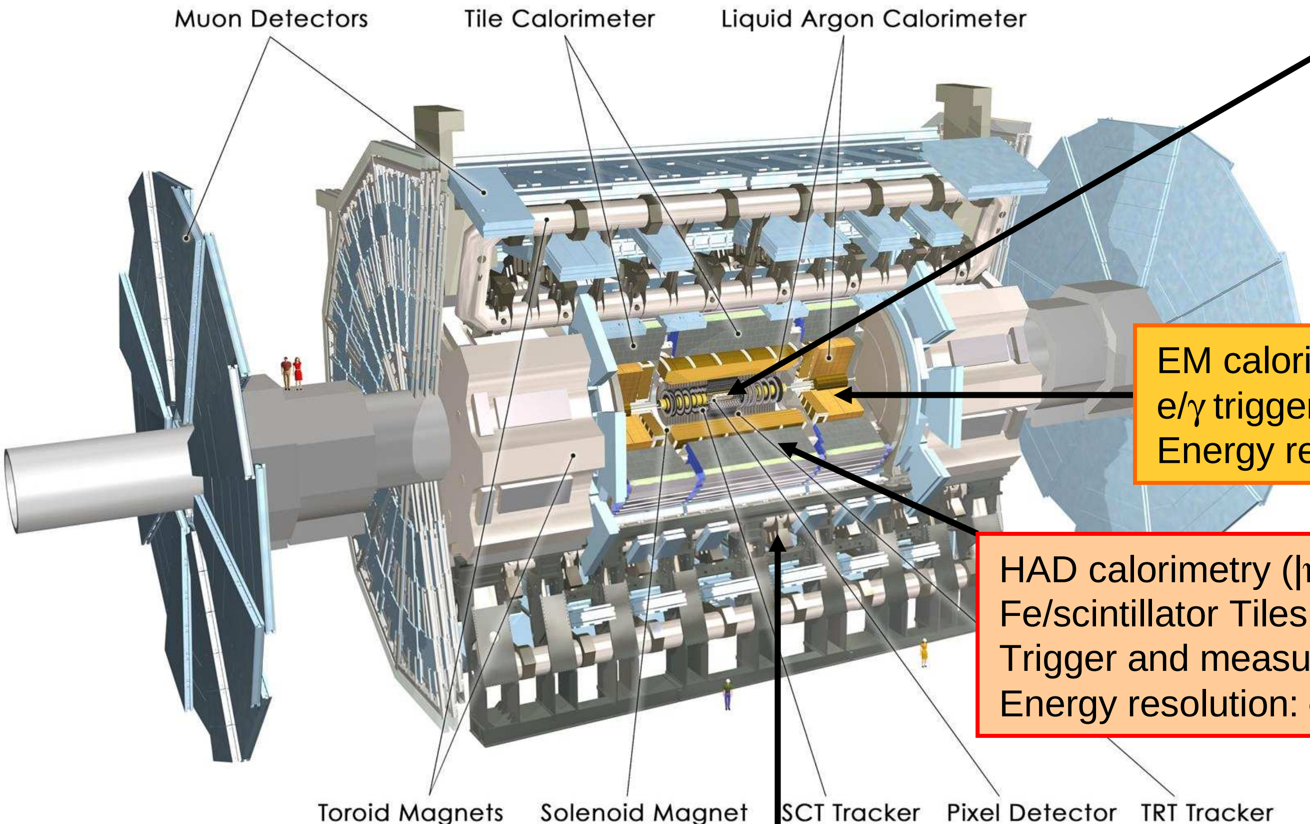
- **Today already have ~3 times more data: updates for HCP (23-27/08/2010)**

SPARES

The ATLAS detector

L ~ 46 m, ∅ ~ 22 m, 7000 tons
~10^8 electronic channels

Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws).
Precise tracking and vertexing, e/π separation.
Momentum resolution:
$\sigma/p_T \sim 0.04\%\ p_T (\text{GeV}) \oplus 1.5\%$



EM calorimeter: Pb-LAr Accordion.
e/γ trigger, identification and measurement
Energy resolution: $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.7\%$

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity.
Fe/scintillator Tiles (central), Cu/W-LAr (forward).
Trigger and measurement of jets and missing E_T.
Energy resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 3\%$

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

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

Detector status

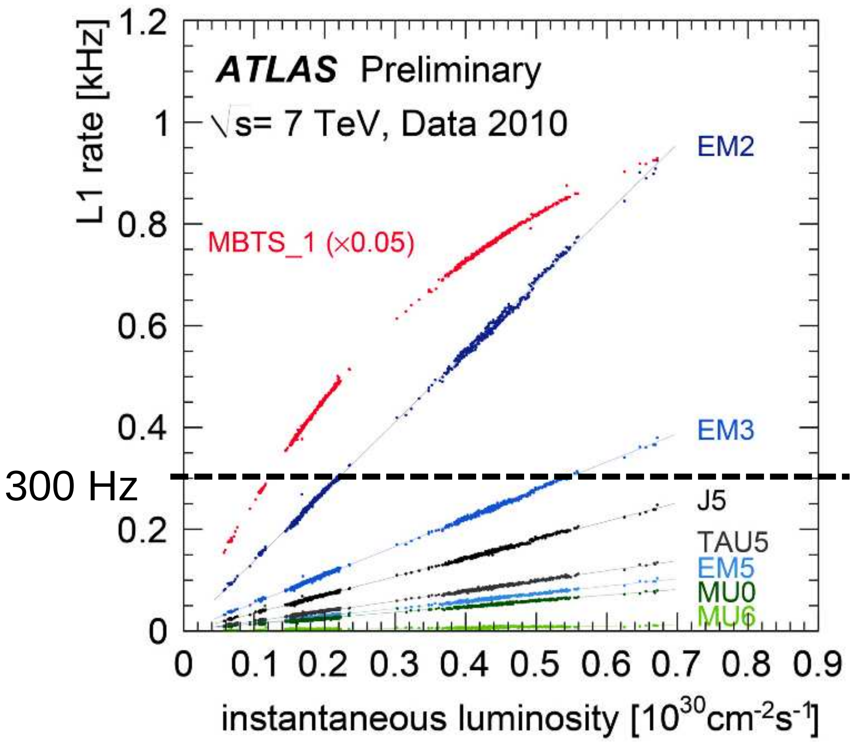
L ~ 46 m, ∅ ~ 22 m, 7000 tons
~10^8 electronic channels

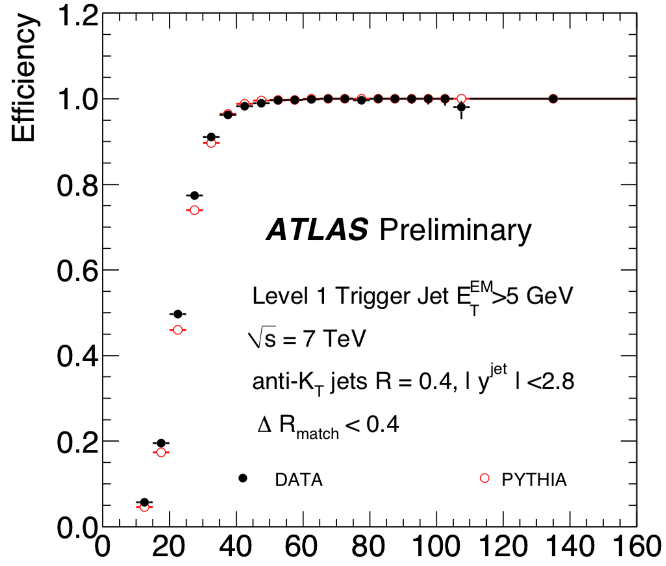
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.4%
SCT Silicon Strips	6.3 M	99.2%
TRT Transition Radiation Tracker	350 k	98.0%
LAr EM Calorimeter	170 k	98.5%
Tile calorimeter	9800	97.3%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo 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%

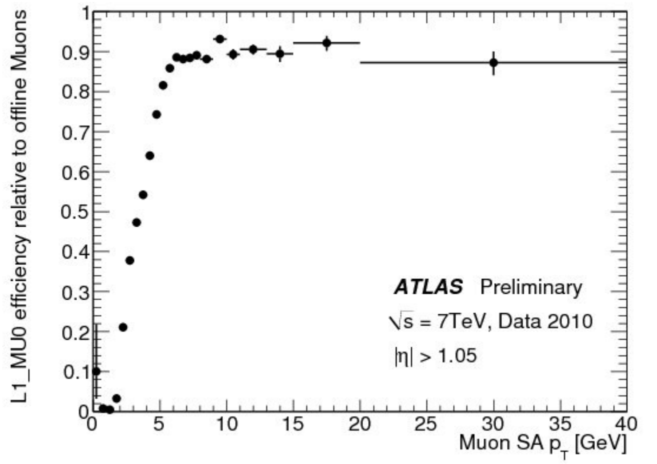
All subsystems operational at > 97%

ATLAS Trigger

- Key ingredient for physics analysis





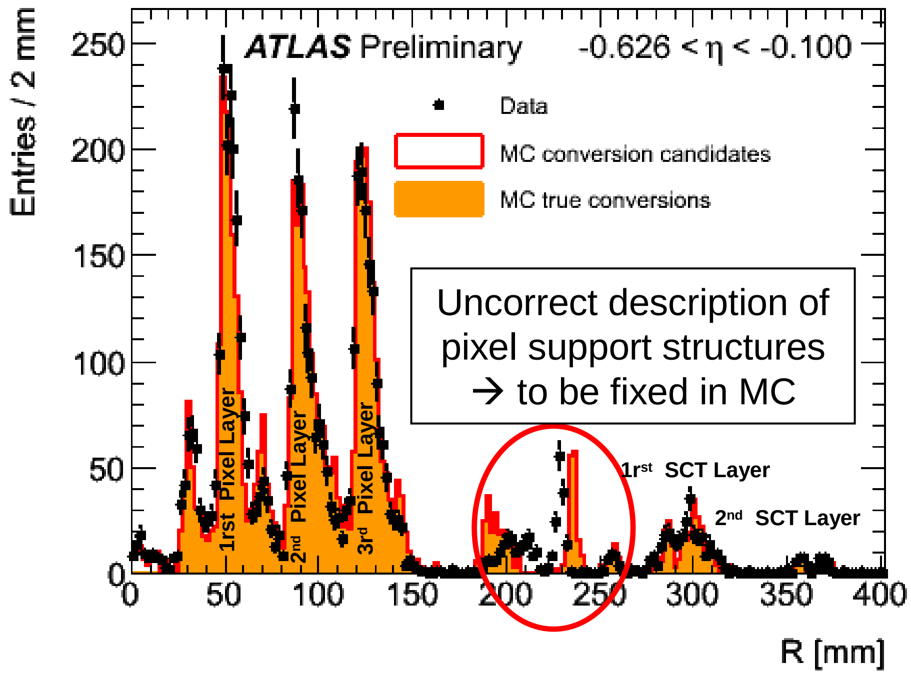


Inner Detector (2)

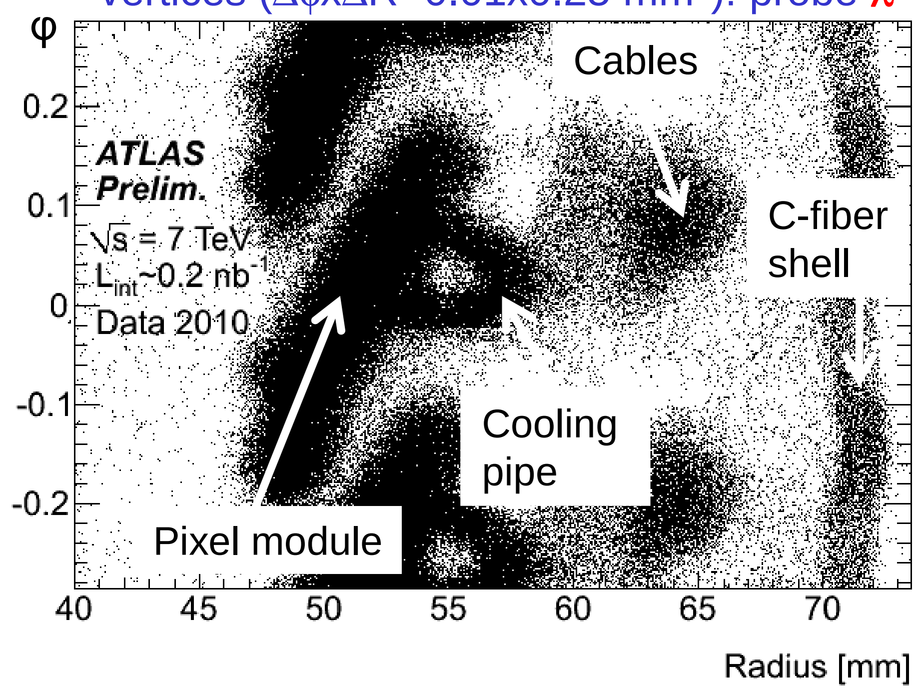
❑ Mapping Inner detector material (to improve simulation)

- Ultimate goal: know material budget to ~1% using complementary methods

Reconstruct $\gamma \rightarrow ee$ conversions : probe X_0



Reconstruct **hadronic interaction** secondary vertices ($\Delta\phi x \Delta R$=0.01x0.25 mm^2): probe λ

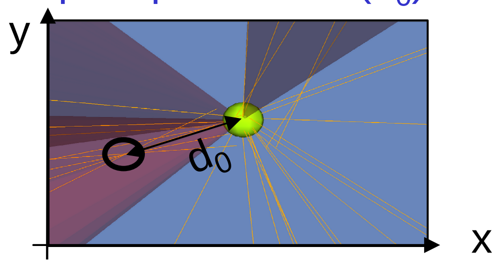


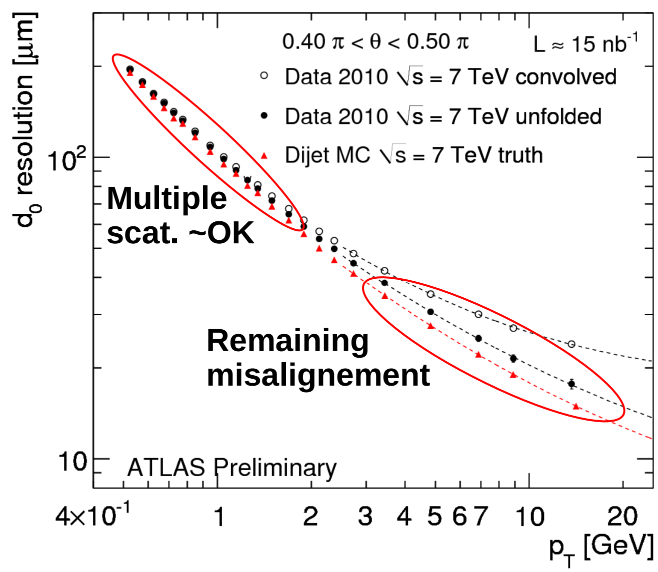
Present understanding of material at ~10%

Inner Detector (3)

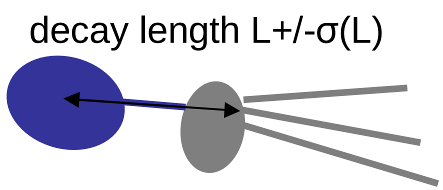
❑ Tagging b-jets

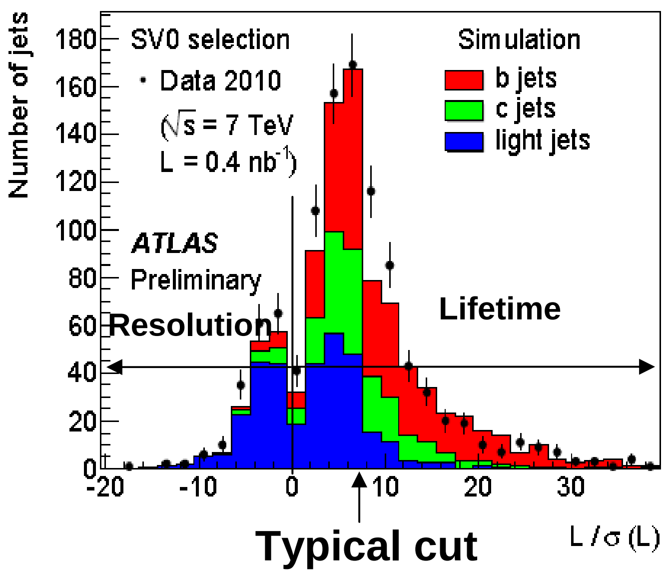
- Transverse Impact parameter (d_0) resolution





- Decay length significance





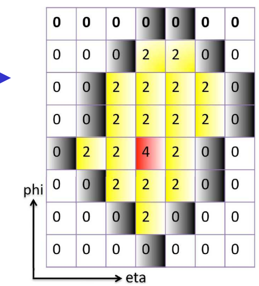
Encouraging agreement data/MC ➔ will start to use it for physics analysis

Jet Energy SCale

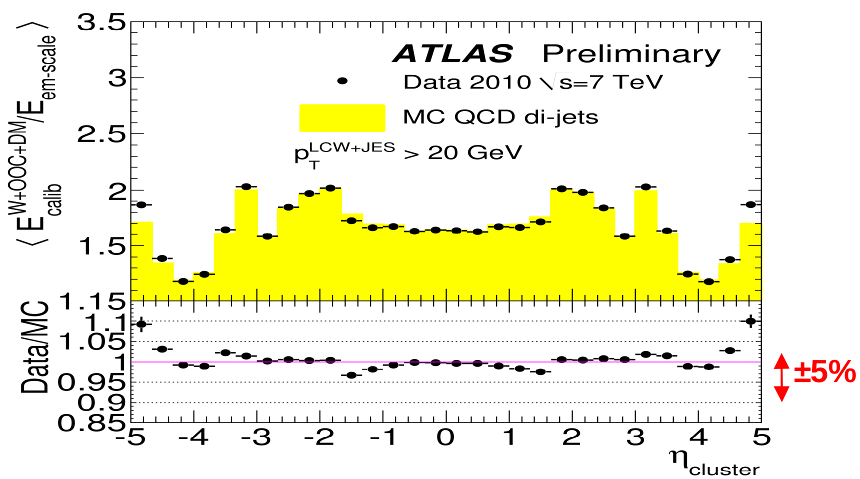
❑ Energy calibration for jet and Etmiss

- Define **3D cluster** : ~ particle level, suppress noise →
- Separate EM-like (e, γ, π^0) and HAD-like (π^+, n) with cluster moment
  - ✓ Apply weights (W) according to **cluster energy density**
- Correct for out of cone (OOC) and inner detector/cryostats material (DM)

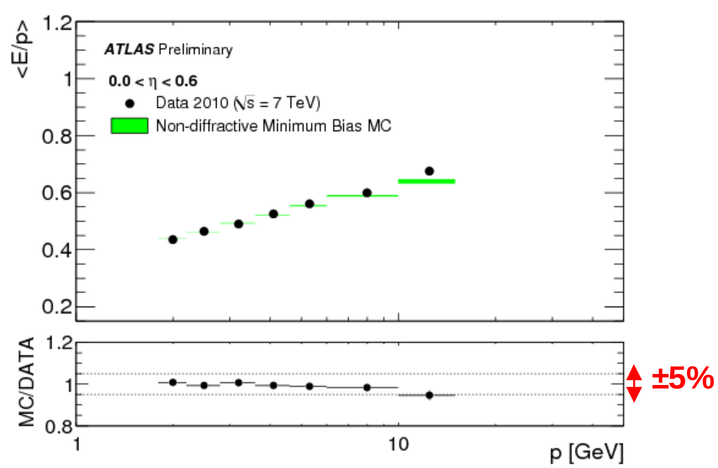
E/σ_{noise} map



Weight for 3D clusters entering jets (p_T>20 GeV)



E/p with single hadrons (|η|<2.3)



Agreement data-MC in ± 5% over the ~ full calorimeter coverage (|η|<4.5)!