ATLAS Results (2)

Corrinne Mills
(Harvard University && the ATLAS Collaboration)

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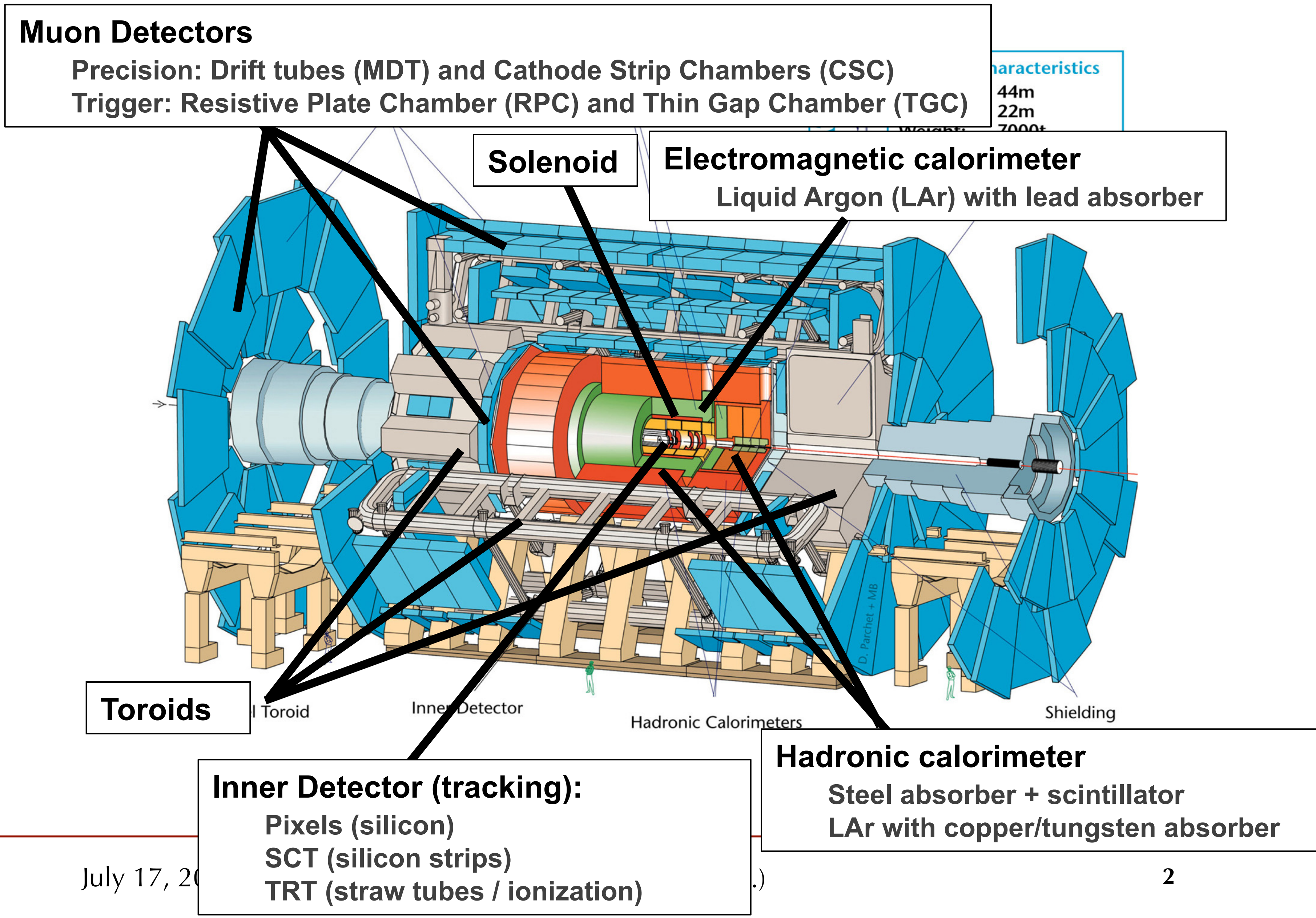
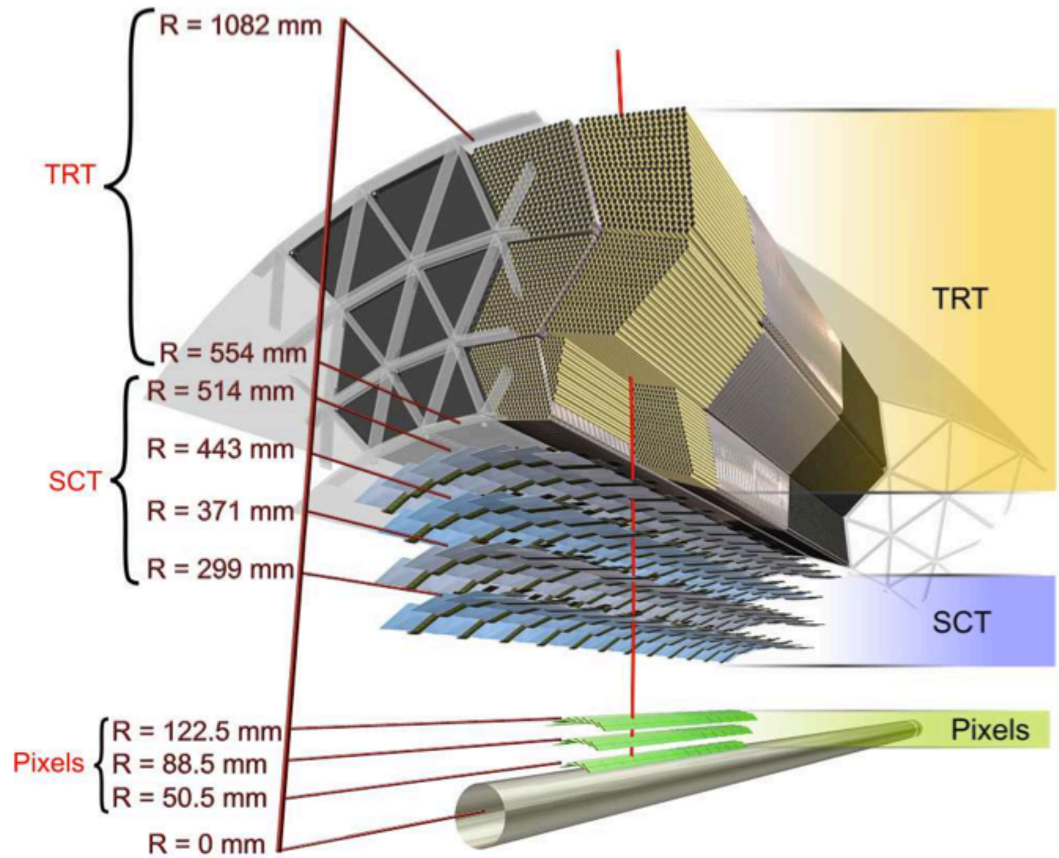
The ATLAS Detector



The Atlas Detector, in Numbers

- Precision tracking to $|\eta| = 2.5$, $R < 1.1$ m, $0 < |z| < 3.5$ m
- 7 layers of 3d spacepoints from semiconductor tracking,
  - → *3 pixel layers, SCT is 4 double-layers (small-angle stereo)*
- TRT is 4 mm diameter straw tubes (Xe), providing 36 additional R-φ (or z-φ) points
- ~100M readout channels

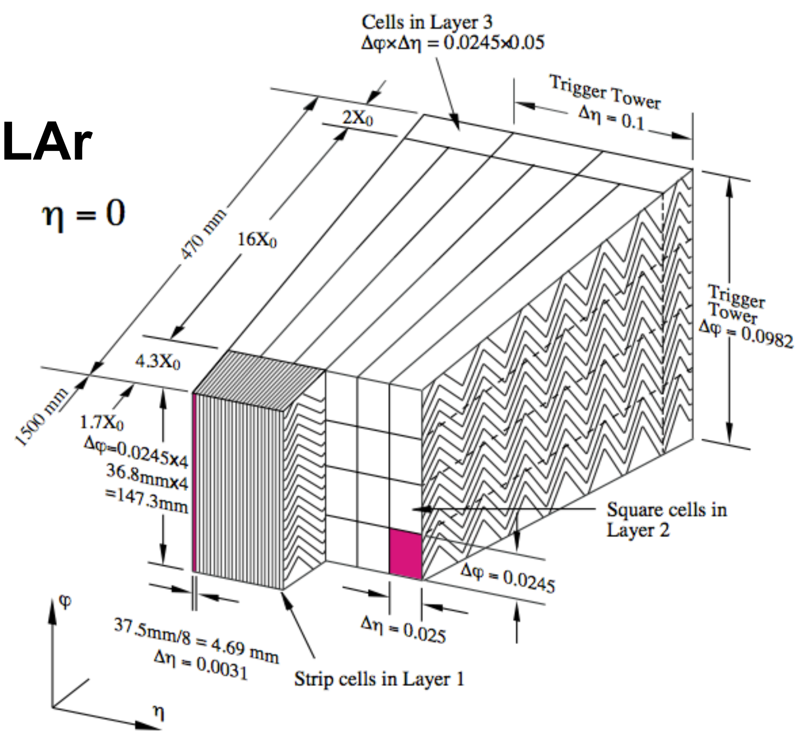


The Atlas Detector, in Numbers

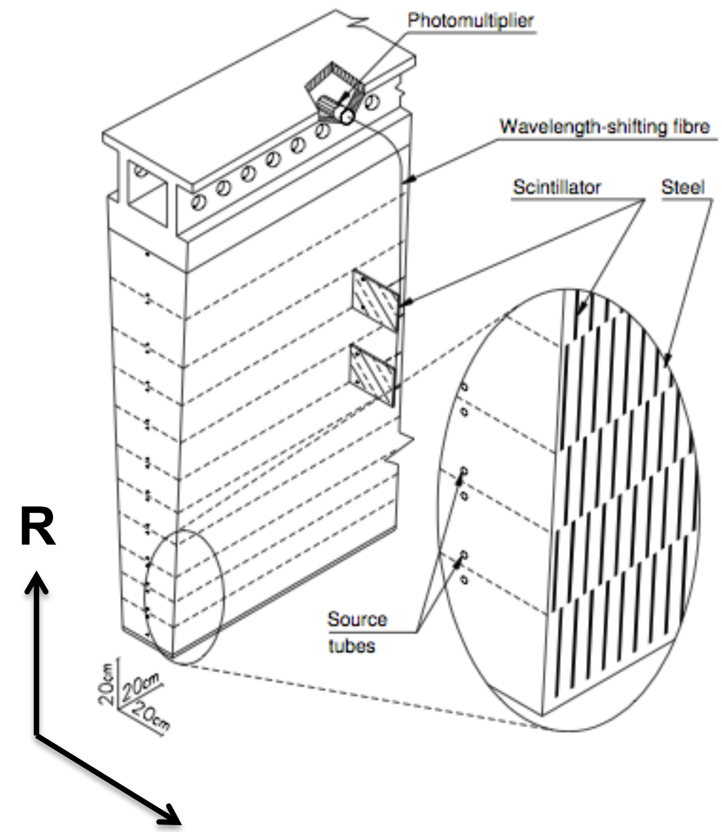
- Calorimetry
  - → *LAr barrel from 1.5 < R < 2m, 22 X_0 deep*
  - → *10 λ (interaction lengths) active, >11 total*
  - → *HCAL from 2.3 < R < 4.3 m, 7.4λ by itself*
  - → *total coverage to almost |η| = 5*

LAr

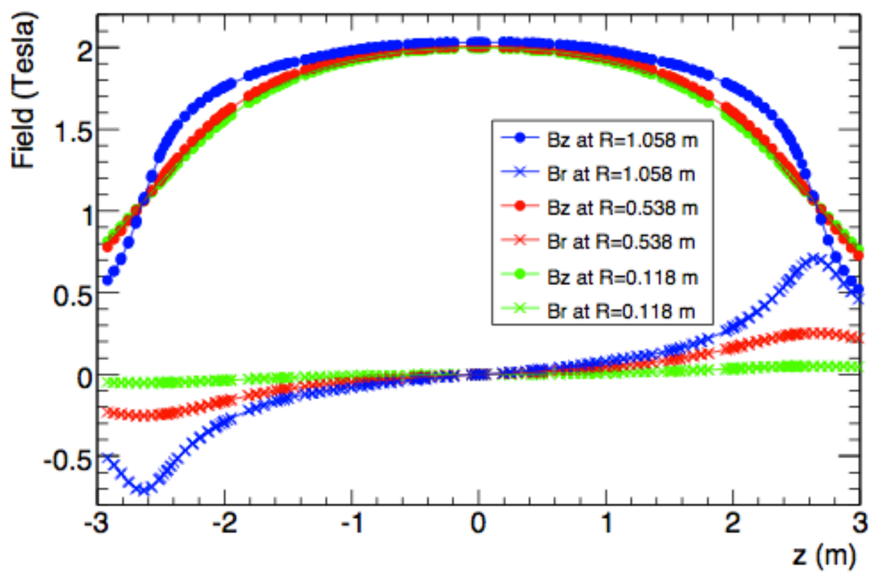
η = 0

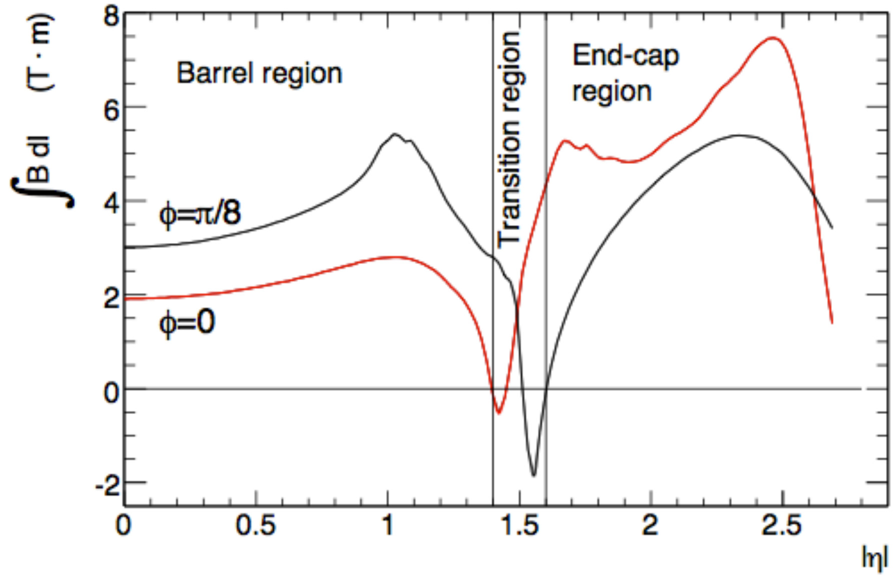


TileCal (HCAL)



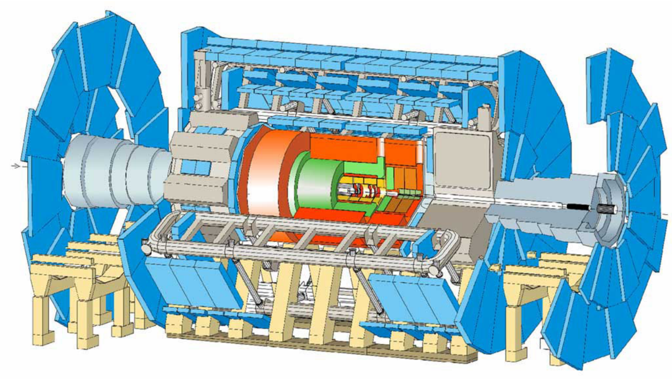
The Atlas Detector, in Numbers





- Magnets
  - → *Solenoid field 2T, Toroid field bending power $1 < \int B{\cdot}dl < 7.5$ T· m*
- Muons
  - → *Three MDT planes measure R-z using 3mm diameter tubes (Ar/CO_2)*
    - Nominal single-hit precision 80 μm
  - → *Forward precision by CSC (MWPC strip-wire-strip) $2 < |\eta| < 2.7$*
    - Designed to be functional at expected rates of > 150 Hz/cm^2
  - → *RPC and TGC: fast 2d spacepoints for triggering and second (phi) coordinate*

The ATLAS Trigger System



Level One (hardware)
limited info, calo + muon
(55 kHz (design: 75 → 100**))**

triggers

Region of Interest Builders

Level Two (software)
full granularity, partial readout
(3.5 → **4 kHz)**

triggers

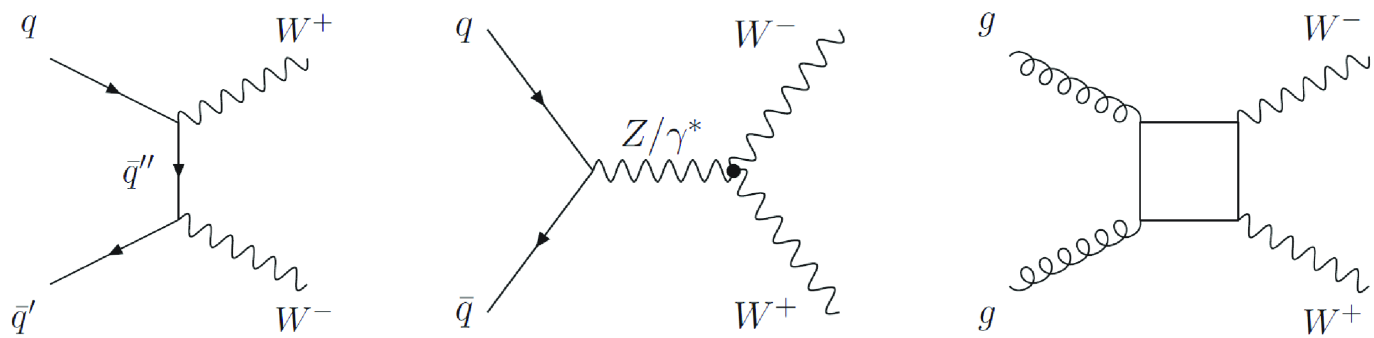
Event Builder

Event Filter (software)
full granularity, full readout
(200 → **400 Hz)**

triggers

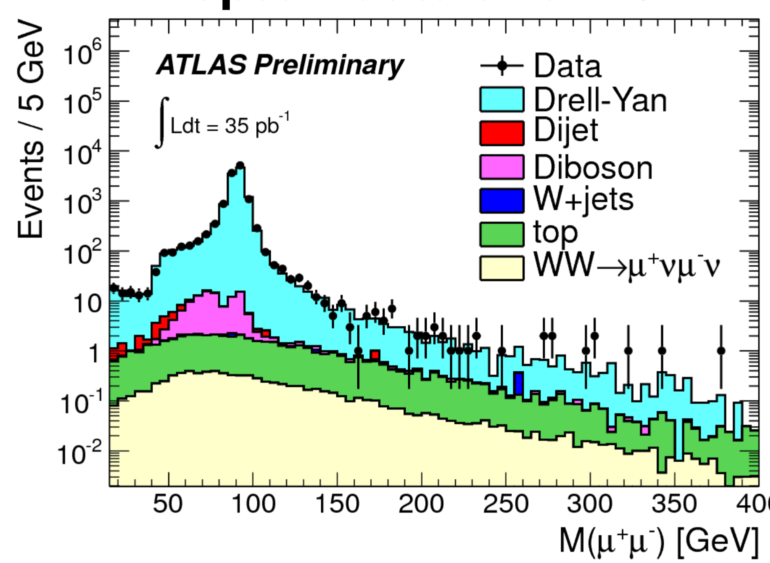
to tape

Dibosons: WW→lνlν

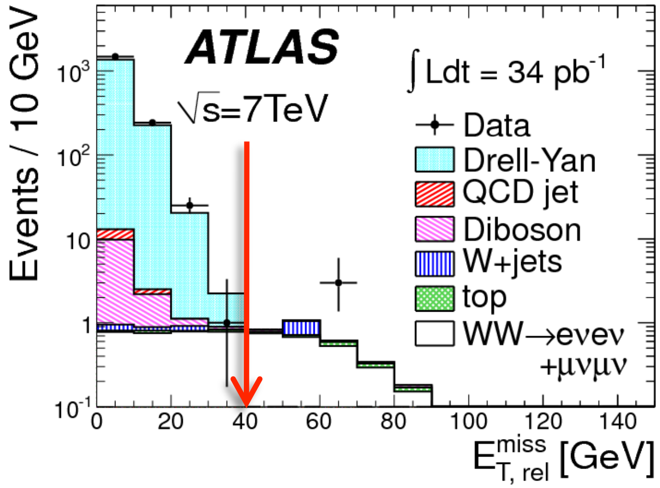


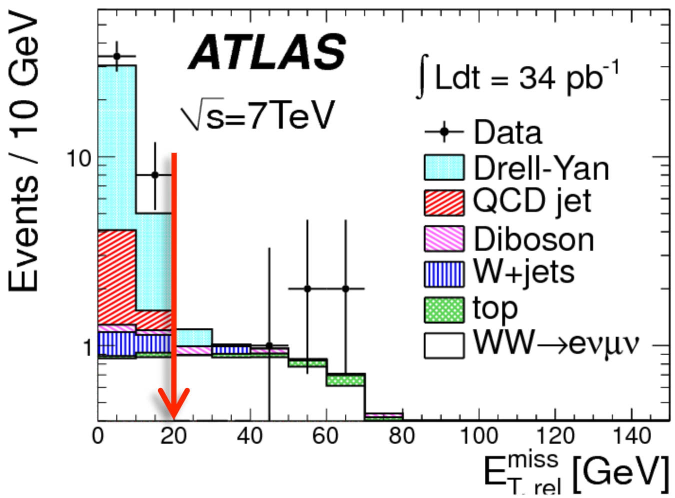
- Start from events with two opposite-charge leptons (e^+e^-, $e^\pm\mu^\mp$, or $\mu^+\mu^-$)
- Veto Z candidates ($|M_{ll}$ - $M_Z| < 10$ GeV)

Dilepton data and BG



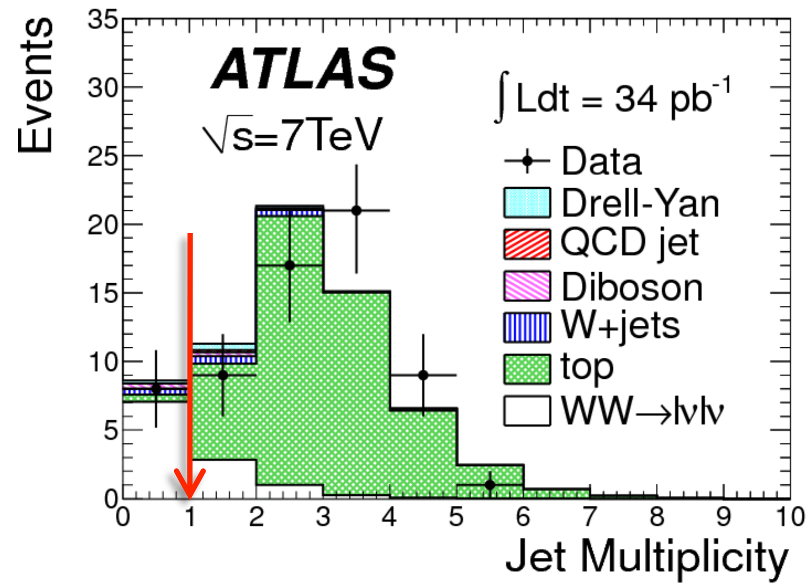
$WW \rightarrow l\nu l\nu$





Final state neutrinos:

- $E_T^{miss}{}_{rel}$ threshold rejects events where E_T^{miss} points at an object

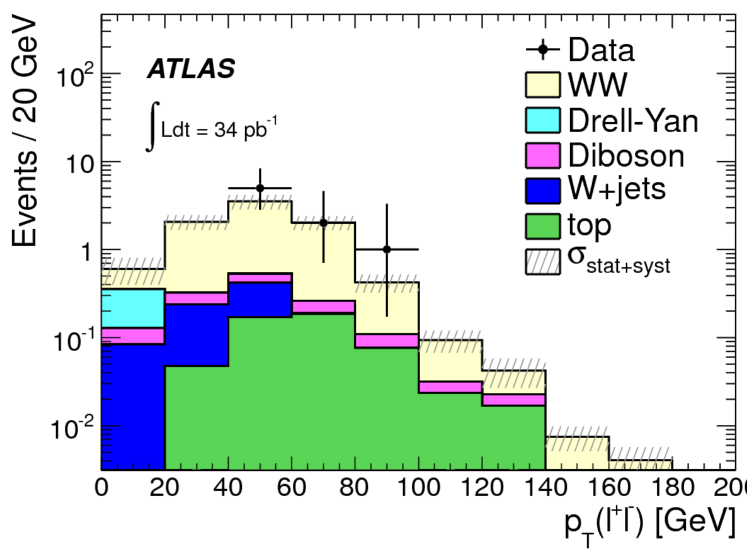


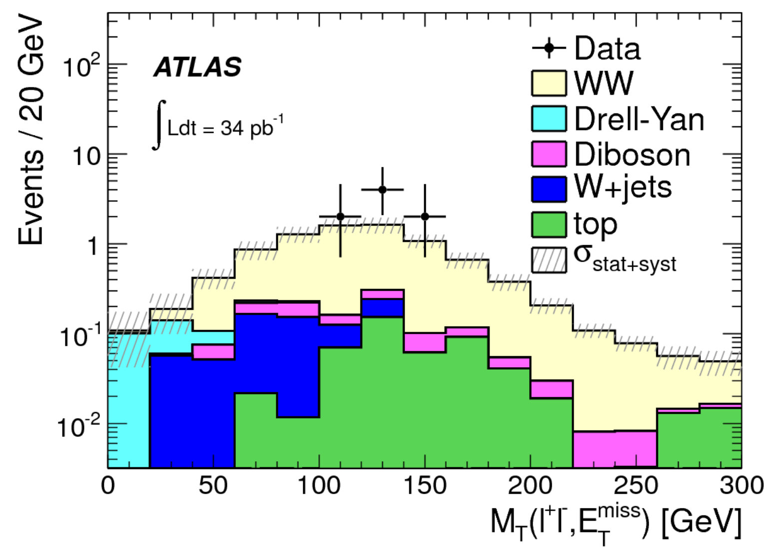
ttbar background ⇒ jet veto

$$E_{\mathrm{T,rel}}^{\mathrm{miss}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} \times \sin(\Delta\phi) & \text{if } \Delta\phi < \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi \geq \pi/2 \end{cases}$$

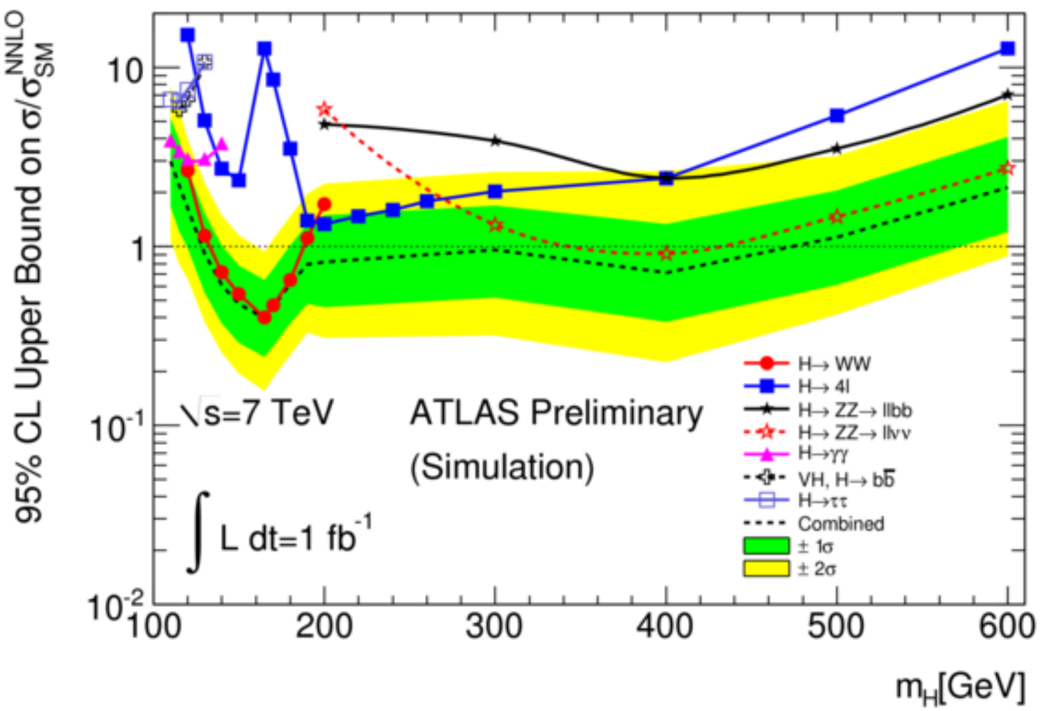
WW cross section

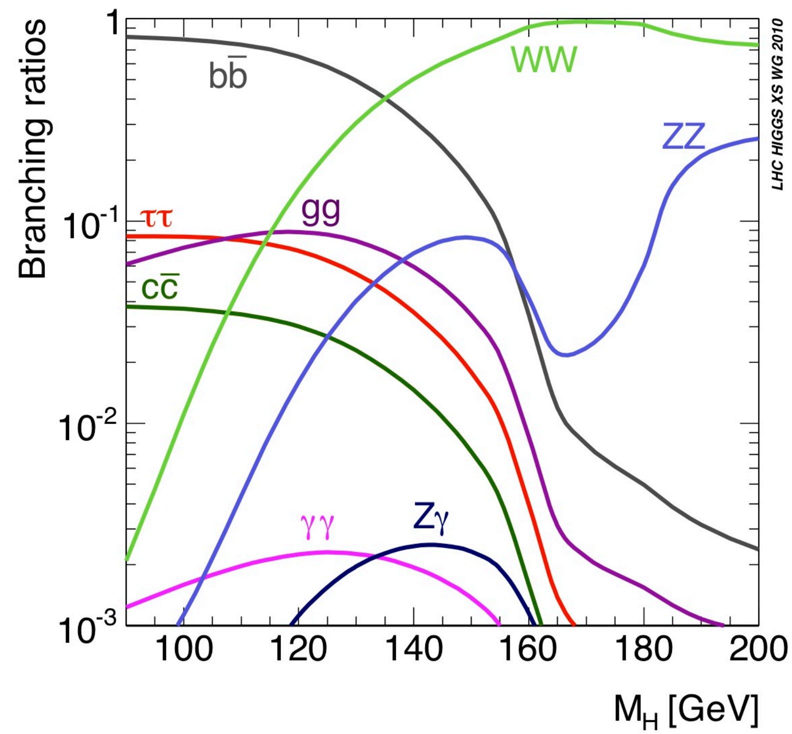
- Standard Model inclusive cross section 44 ± 3 pb
- Observe 8 candidates (1 ee, 2 eμ, 5 μμ) over predicted background of 1.7 ± 0.4 (stat) ± 0.4 (sys)
  - → *observation has 3σ significance*
  - → *measure cross section 41_{-16}^{+20} (stat) ± 5 (syst) ± 1 (lumi) pb*



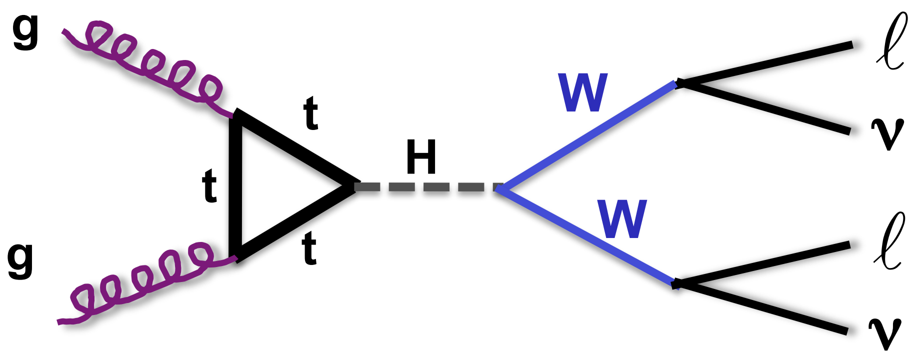


Sensitivity to Standard Model Higgs

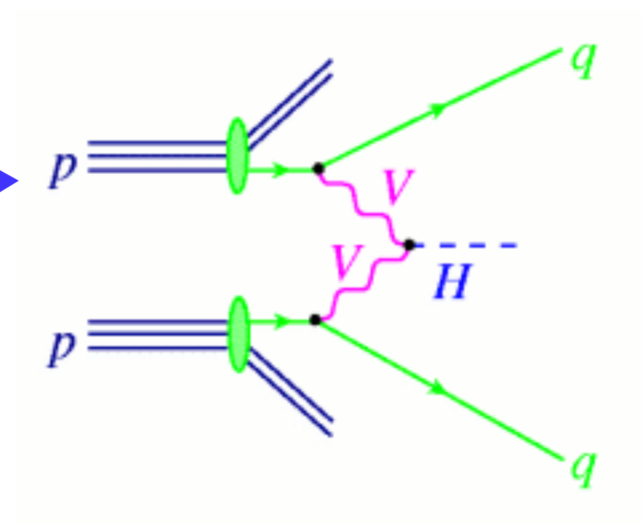




$H \rightarrow WW \rightarrow l\nu l\nu$



- Search separately in 0, 1, 2 jet events
  - → *different backgrounds*
  - → *2-jet has sensitivity to VBF*
- Signature: 2 charged leptons + E_T^{miss}
- Backgrounds: WW, Z/γ^*, ttbar, W+jets
  - → *data-driven estimates*

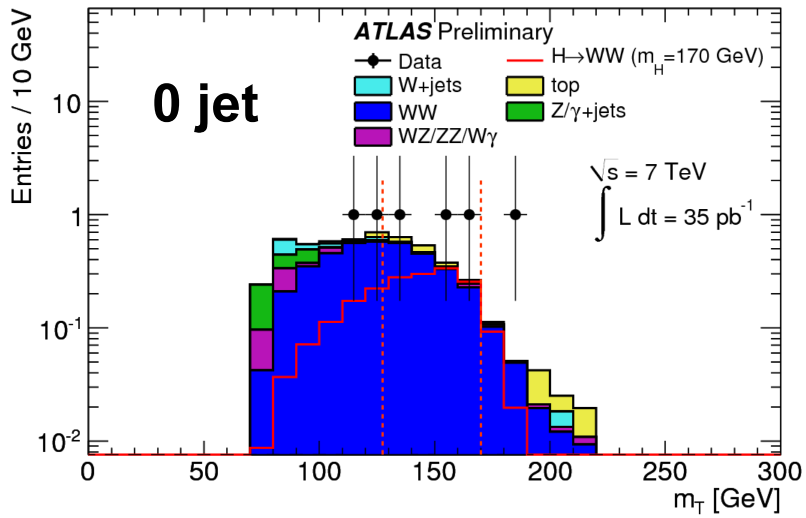


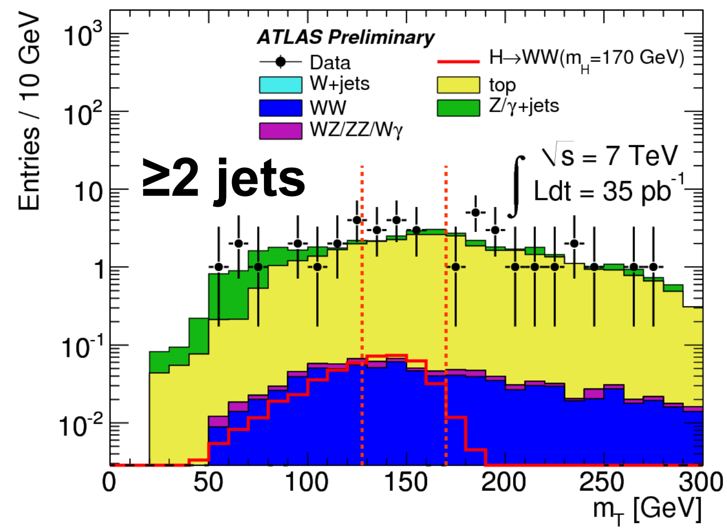
$H \rightarrow WW \rightarrow l\nu l\nu$

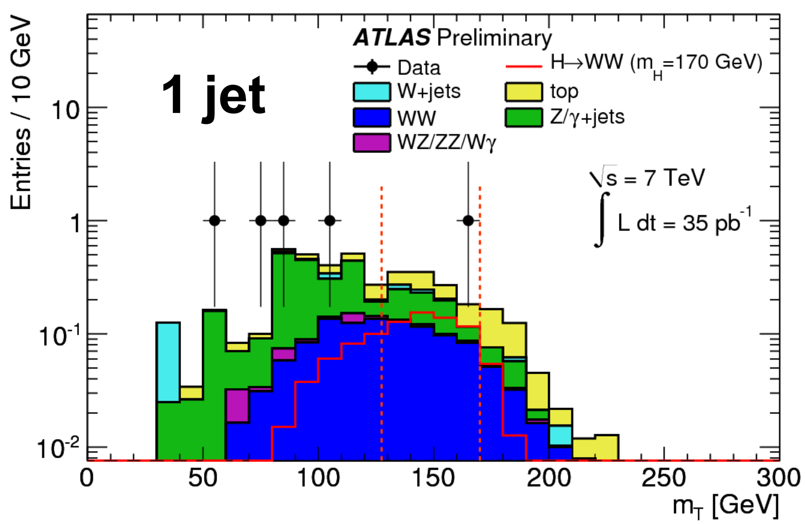
- Again, start from events with two isolated opposite-charge leptons (e, μ)
  - → *$p_T > 20$ (leading), $p_T > 15$ (subleading)*
- DY vetos (same flavor only)
  - → *Veto Z candidates ($|M_{ll} - M_Z| > 10$ GeV)*
  - → *Veto Υ, low-mass ($M_{ll} > 15$)*
- $E_T^{miss} > 30$
- Higgs kinematics: scalar WW spin correlations
  - → *$\Delta\varphi(ll) > 1.3$ (1.8)* ***for $m_H < 170$ ($m_H > 170$)*** ← **low mass (high mass) optimizations**

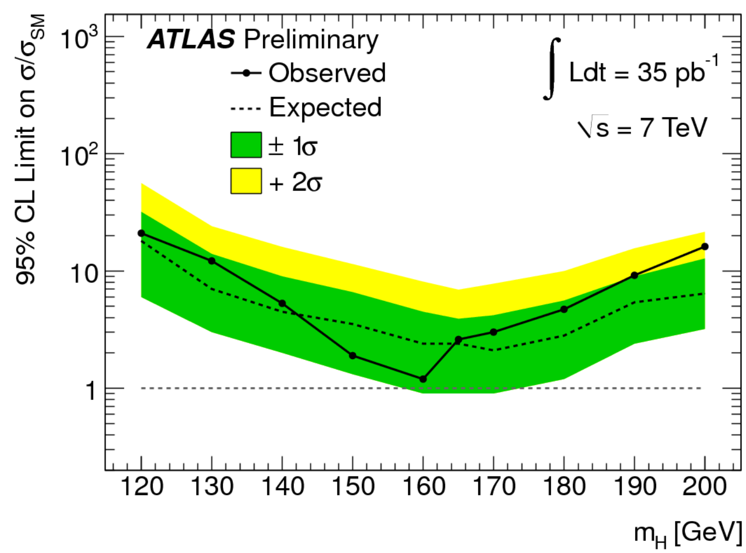
0 jet	**1 jet**	**≥ 2 jets**
$p_T(ll) > 30$ GeV	b-jet veto	$\Delta\eta(jj) > 3.8$ and $\eta_1 * \eta_2 < 0$
$m_{ll} < 50$ (65)	$\|M_{\tau\tau} - M_Z\| < 25$ GeV	$m(jj) > 500$
$0.75\ m_H < m_T < m_H$	tot $p_T < 30$	$m(ll) < 80$
		+ 1 jet cuts

$H \rightarrow WW \rightarrow l\nu l\nu$?

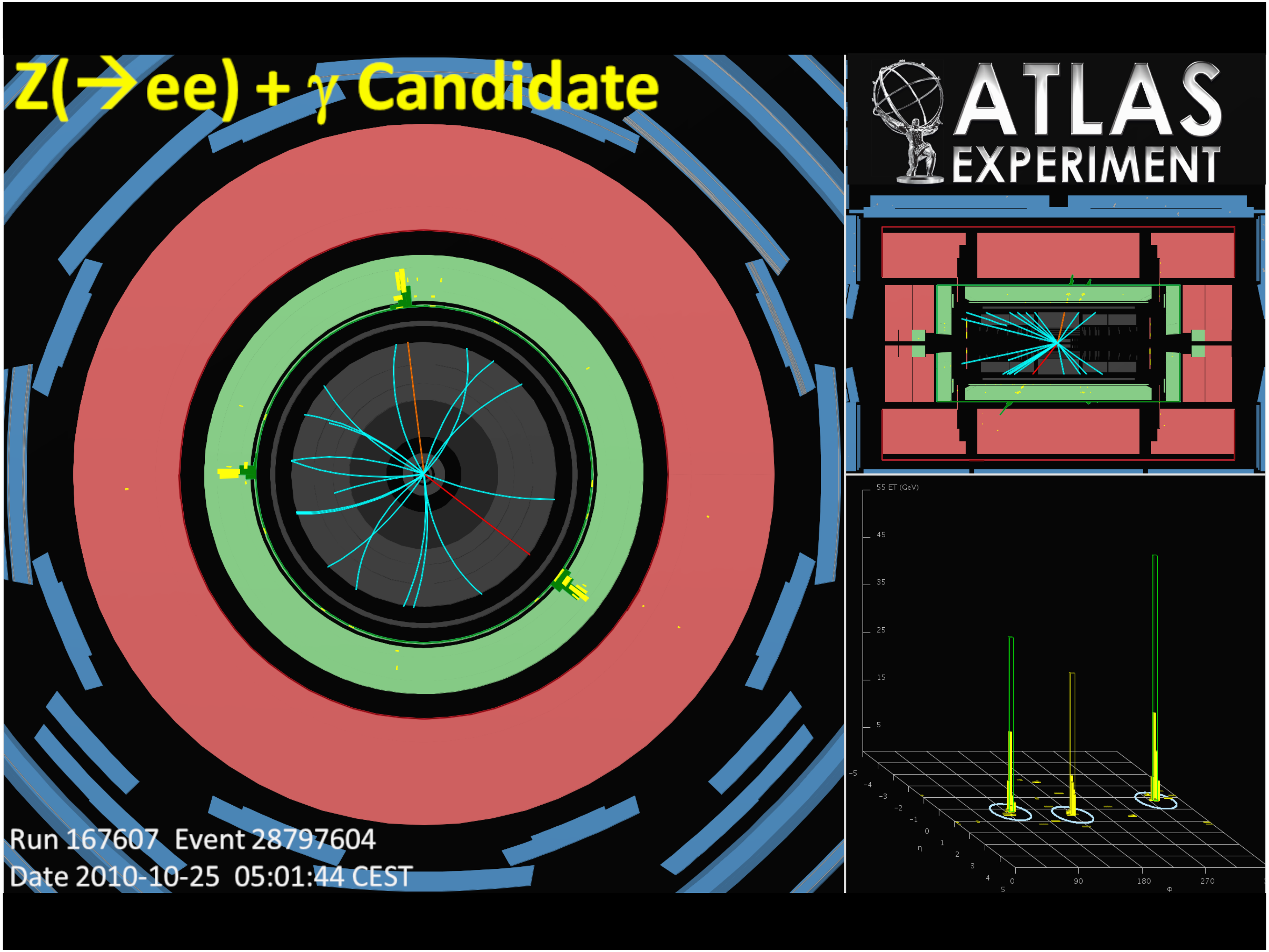




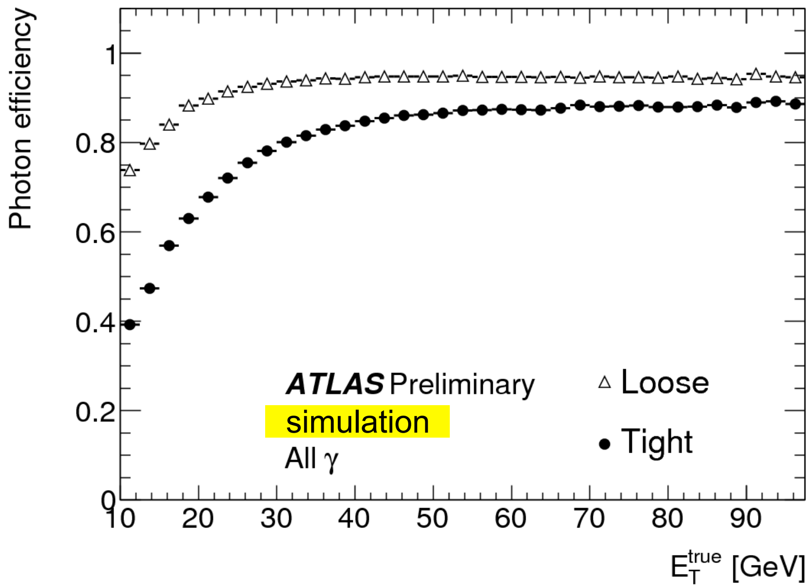


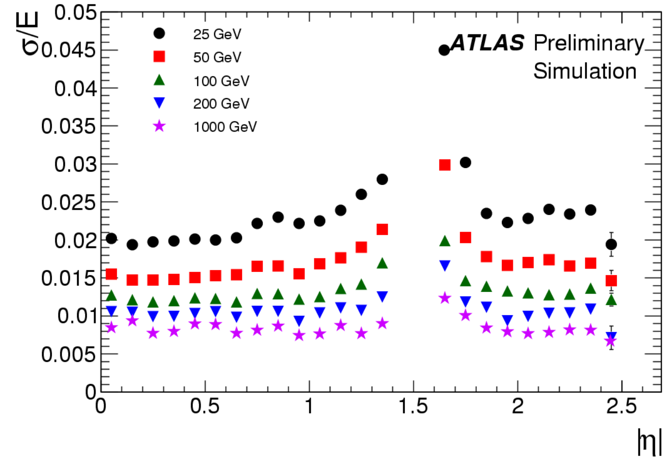


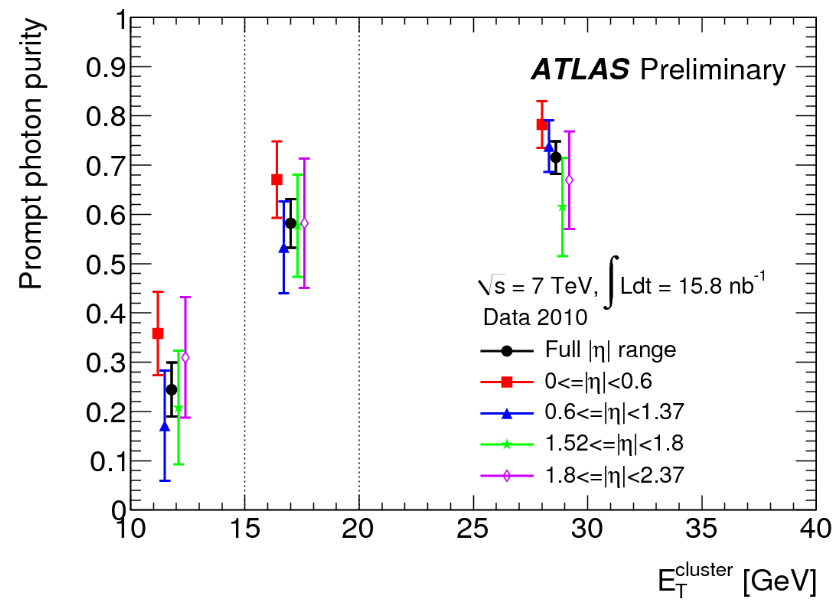
$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{\mathrm{miss}})^2 - (\mathbf{P}_T^{\ell\ell} + \mathbf{P}_T^{\mathrm{miss}})^2}$$


Z(→ee) + γ Candidate
ATLAS
EXPERIMENT
Run 167607 Event 28797604
Date 2010-10-25 05:01:44 CEST
55 ET (GeV)
45
35
25
15
5
η
Φ
0
90
180
270

Photons in ATLAS



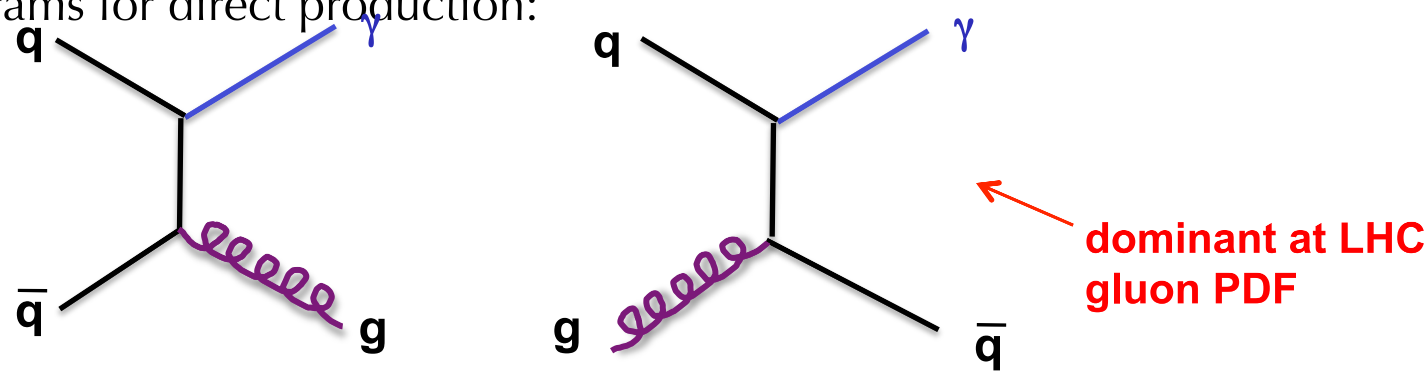




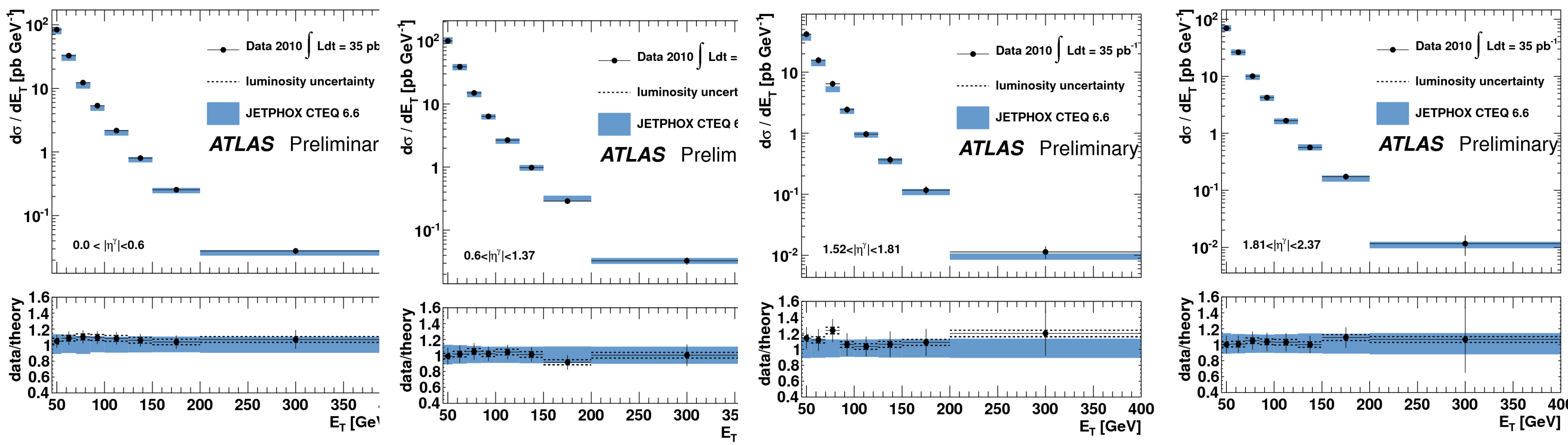
- δE/E ~ 1-2% like electrons
- "few%" systematics from MC
  - → *extra material, cross talk between calo. cells*
- cross check with data/MC comparisons
- purity = true/all

Prompt photons

- Measure the cross section for isolated photons (including direct and fragmentation contributions)
  - → *Isolated = energy in a cone of 0.4 < 3 GeV describe a bit more, talked about in dir. photon alg*
  - → *$45 < E_T^\gamma < 400$*
- Experimental challenges
  - → *No good control sample to calibrate efficiencies*
  - → *Large backgrounds from π^0 and $\eta \rightarrow \gamma\gamma$ decays*
- Constrain PDFs and test pQCD
- Diagrams for direct production:



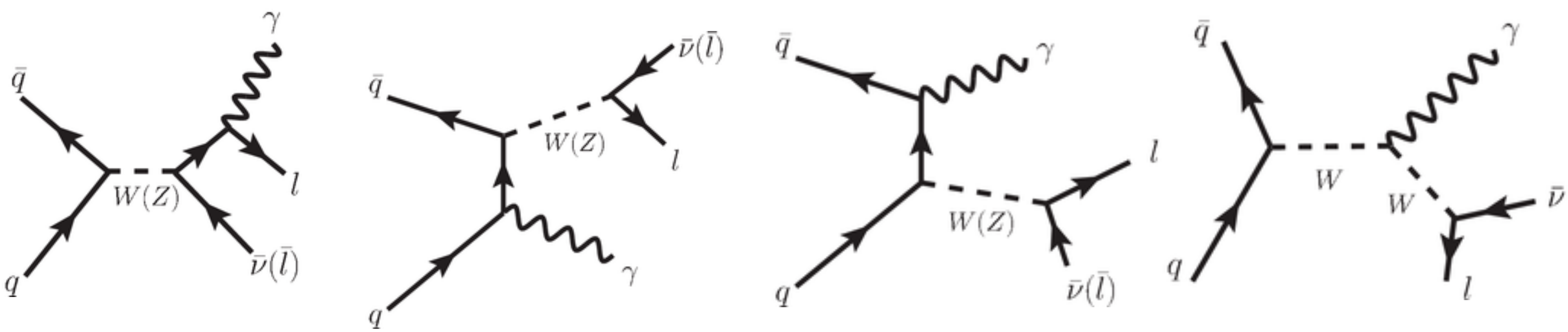
Isolated photons vs. photon E_T



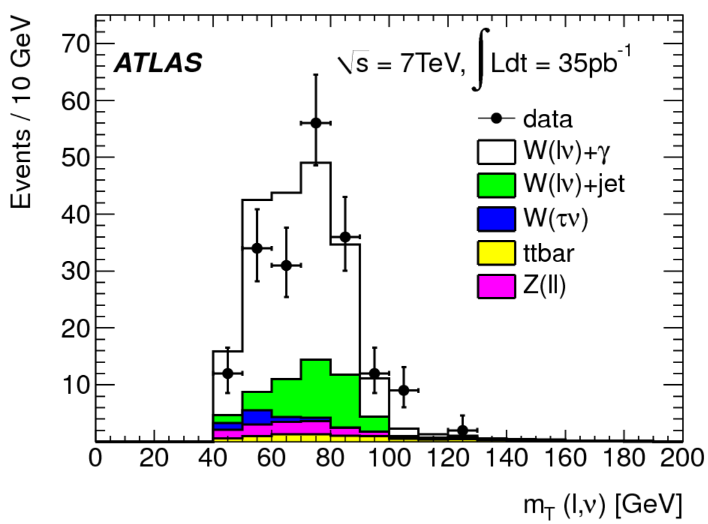
2010 result, 36 pb^{-1}

from ATLAS-CONF-2011-058, update of http://arxiv.org/abs/arXiv:1012.4389

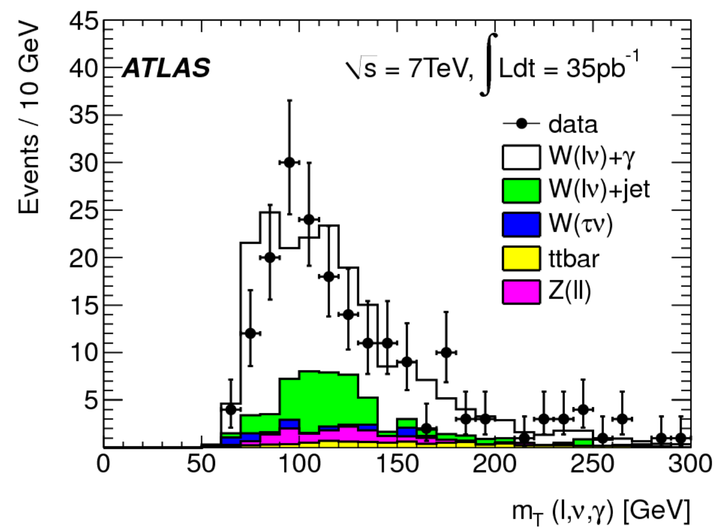
Dibosons: Wγ



$\bar{q}$
q
$W(Z)$
γ
l
$\bar{\nu}(\bar{l})$
$\bar{q}$
q
$W(Z)$
$\bar{\nu}(\bar{l})$
l
γ
$\bar{q}$
q
γ
$W(Z)$
l
$\bar{\nu}(\bar{l})$
$\bar{q}$
q
W
W
γ
$\bar{\nu}$
l

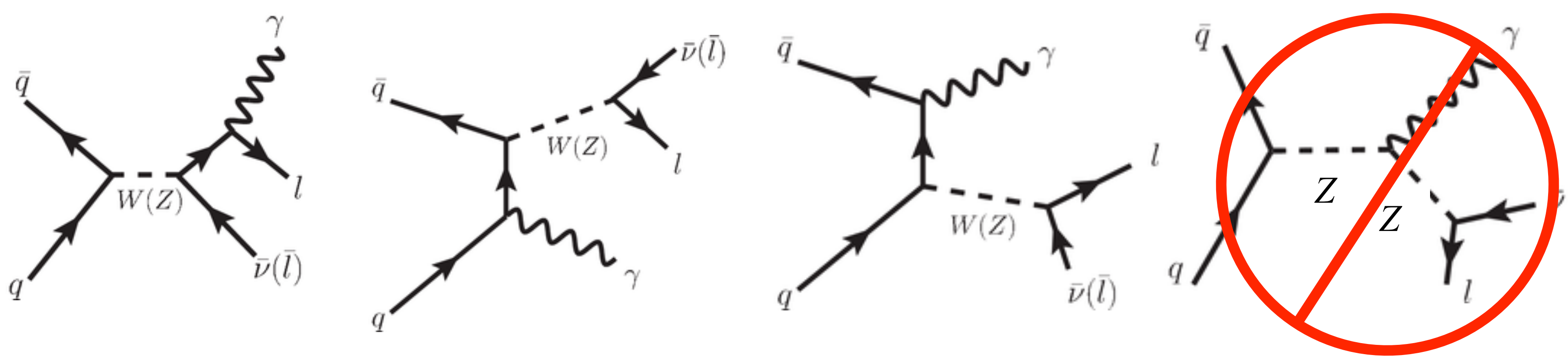


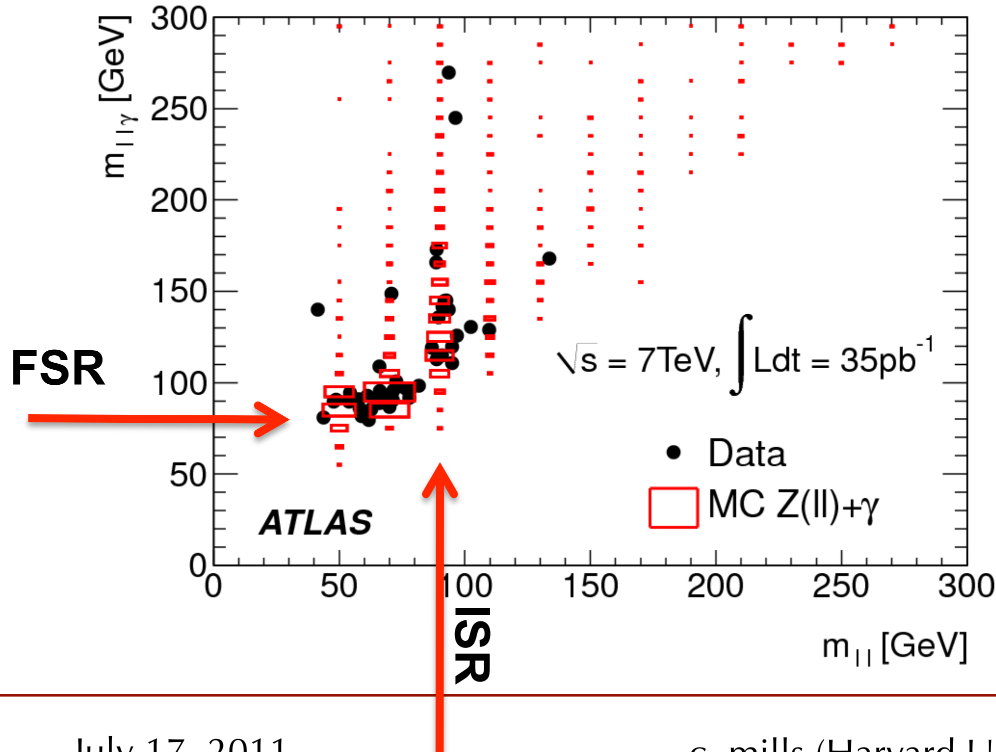
ATLAS
√s = 7TeV, ∫Ldt = 35pb⁻¹
data
W(lν)+γ
W(lν)+jet
W(τν)
ttbar
Z(ll)
Events / 10 GeV
0 20 40 60 80 100 120 140 160 180 200
10 20 30 40 50 60 70
m_T (l,ν) [GeV]

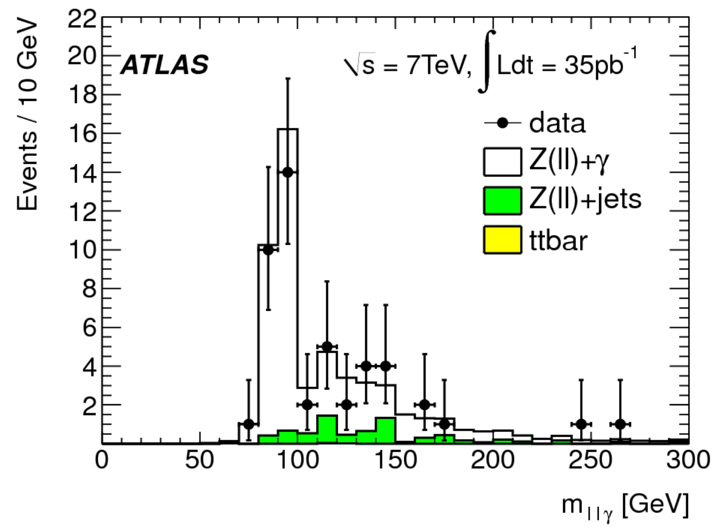


ATLAS
√s = 7TeV, ∫Ldt = 35pb⁻¹
data
W(lν)+γ
W(lν)+jet
W(τν)
ttbar
Z(ll)
Events / 10 GeV
0 50 100 150 200 250 300
5 10 15 20 25 30 35 40 45
m_T (l,ν,γ) [GeV]

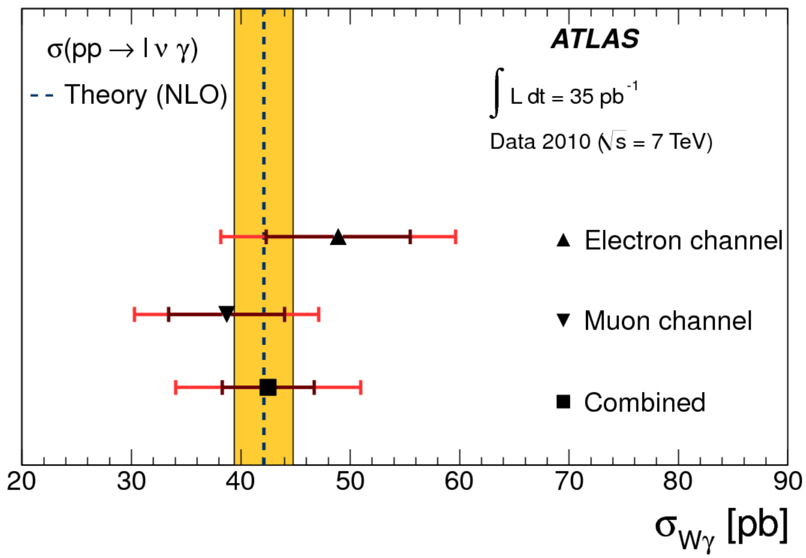
Dibosons: $Z\gamma$

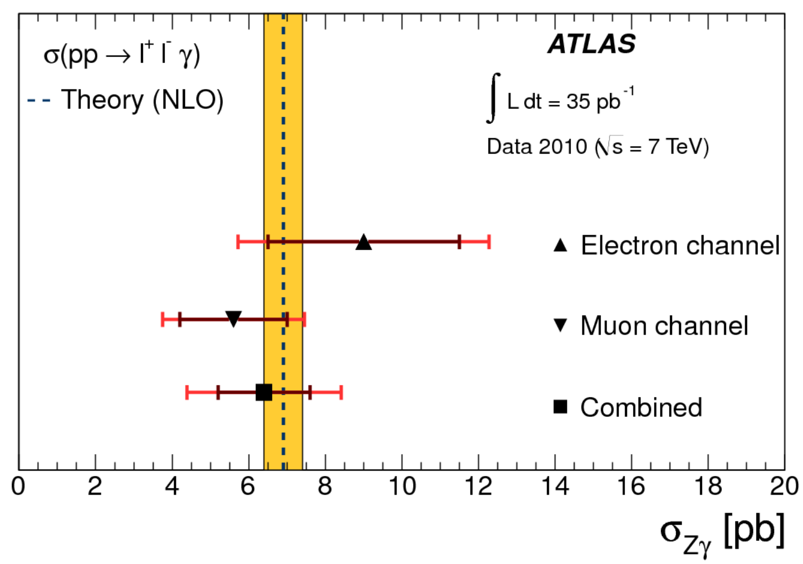


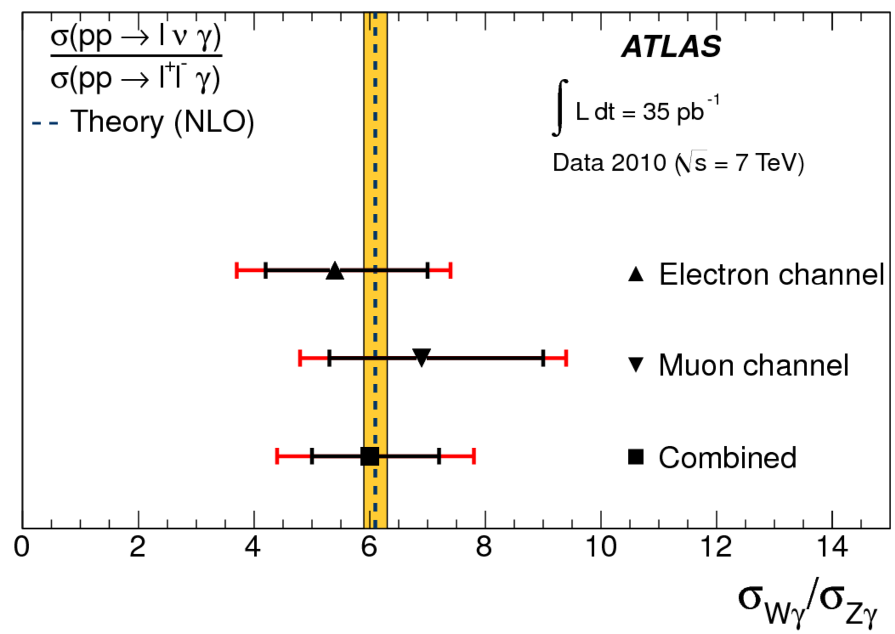




Diboson: $W\gamma/Z\gamma$

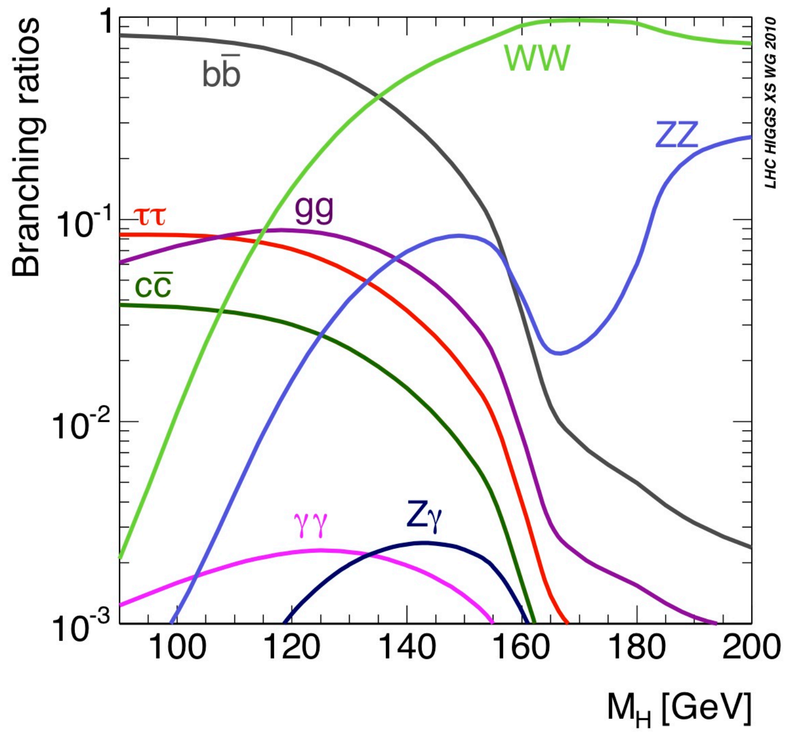






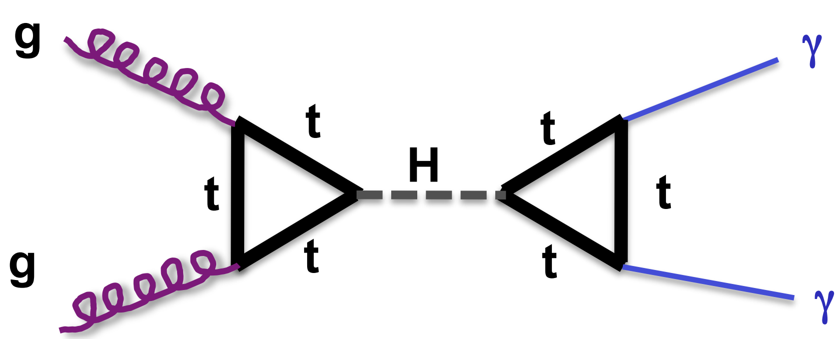
The Case for $H \rightarrow \gamma\gamma$

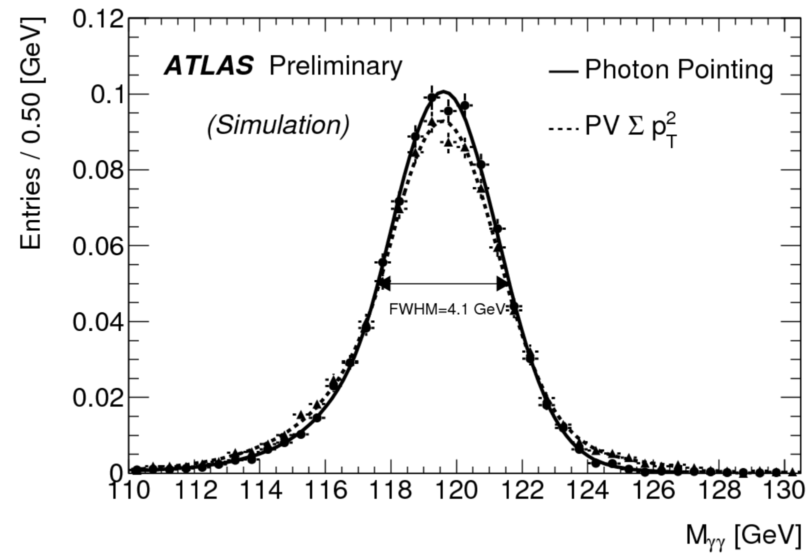
- Energy resolution and S/B make this a compelling channel in spite of the (Standard Model) branching fraction



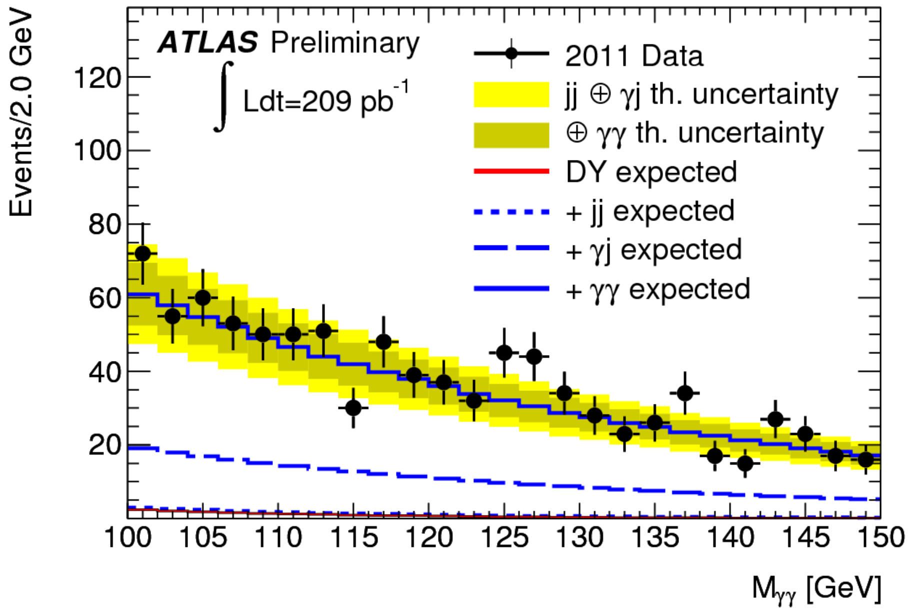
$H \rightarrow \gamma\gamma$

- 209 pb-1, ET thresholds 40,25, ~99% efficient diphoton trigger
- Background from γγ (mostly), γj, jj
- Mγγ depends on getting the right primary vertex
  - → *Photon pointing: exploit depth segmentation and fine granularity of innermost compartment*
- $M_{\gamma\gamma}$ resolution = 13%



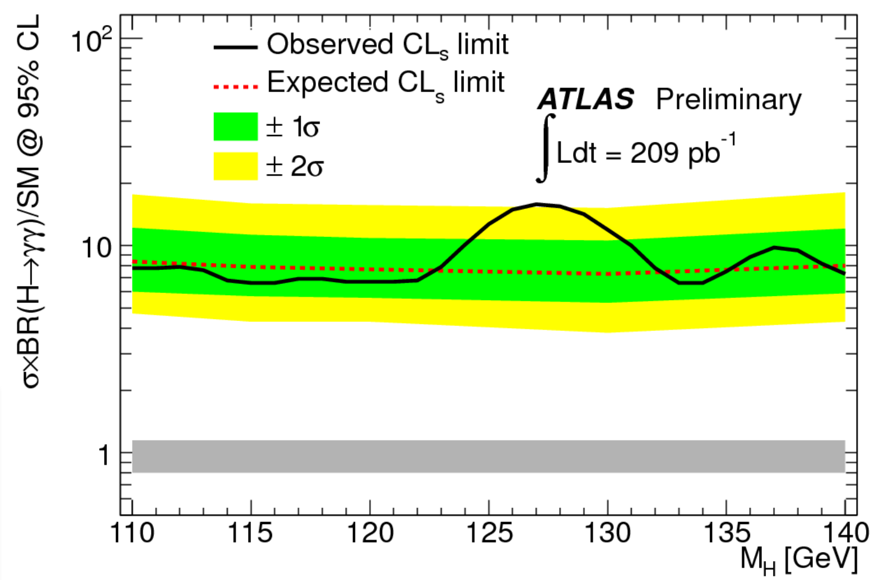


$H \to \gamma\gamma$



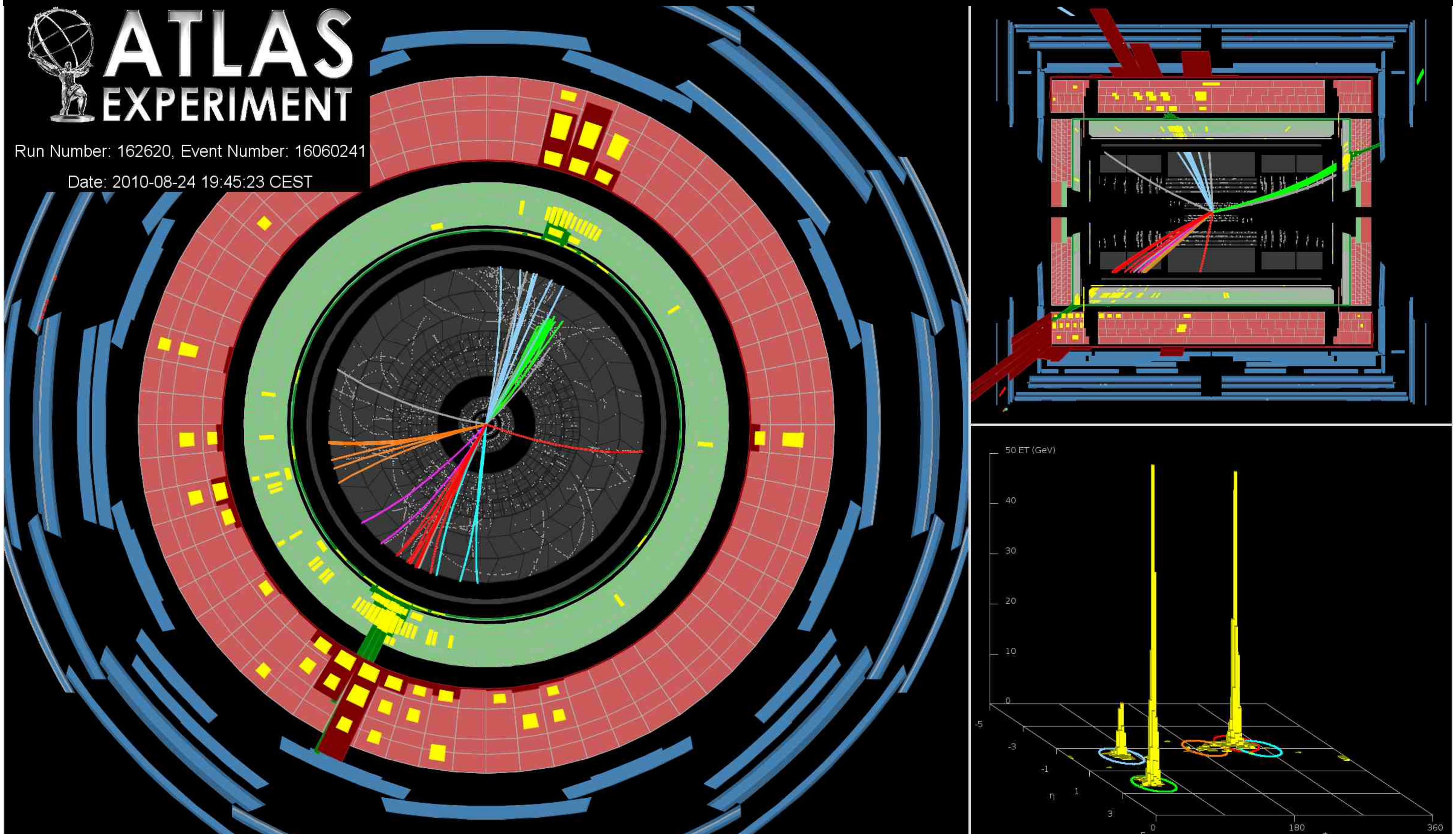
Here's the data and the SM background predictions…

…and the resulting limits, just below 10x the SM xsec



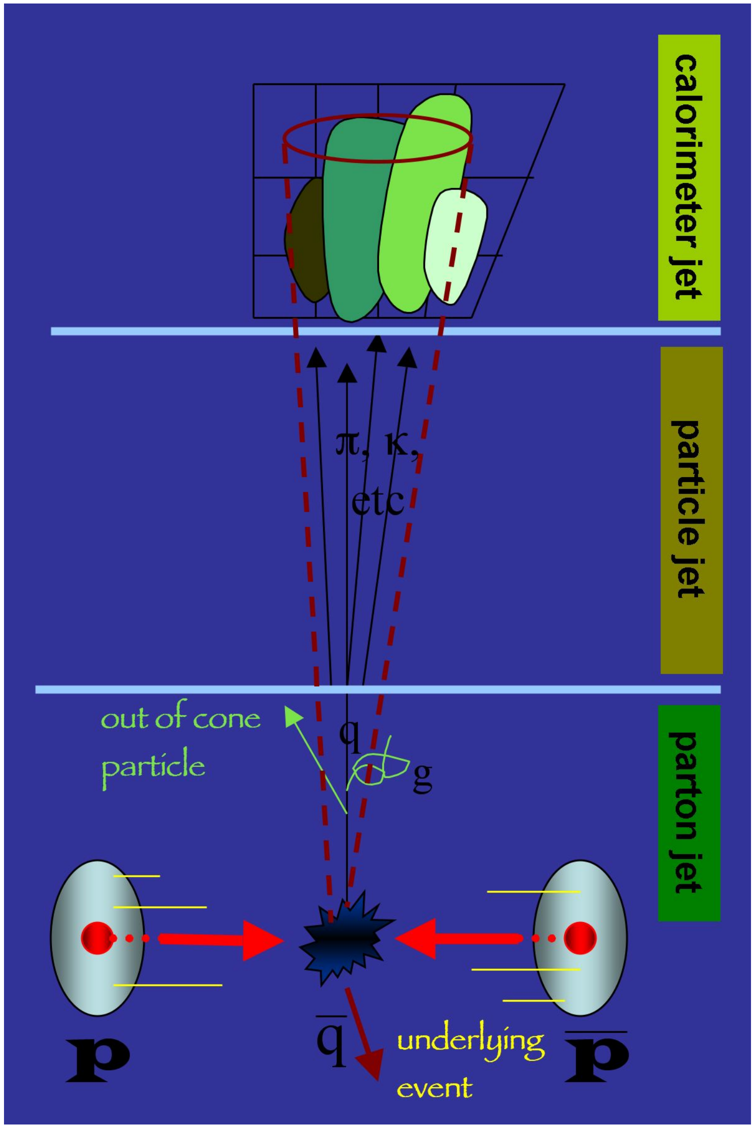
p-value is 2%
30% probability of such an excess in mass range considered

Jets

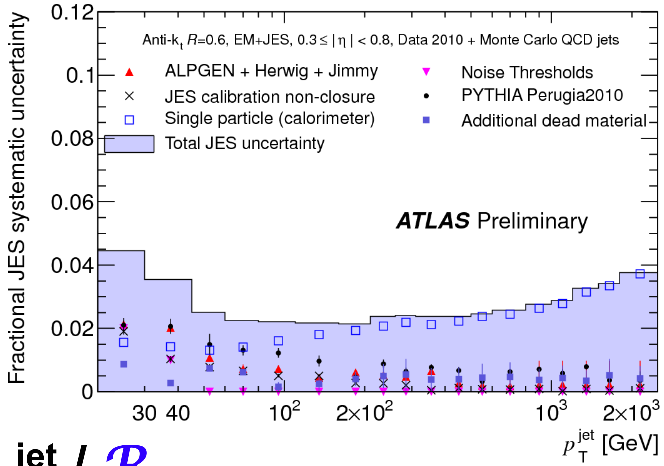

ATLAS
EXPERIMENT
Run Number: 162620, Event Number: 16060241
Date: 2010-08-24 19:45:23 CEST
50 ET (GeV)
40
30
20
10
0
-5
-3
-1
η
1
3
5
0
180
360
Φ

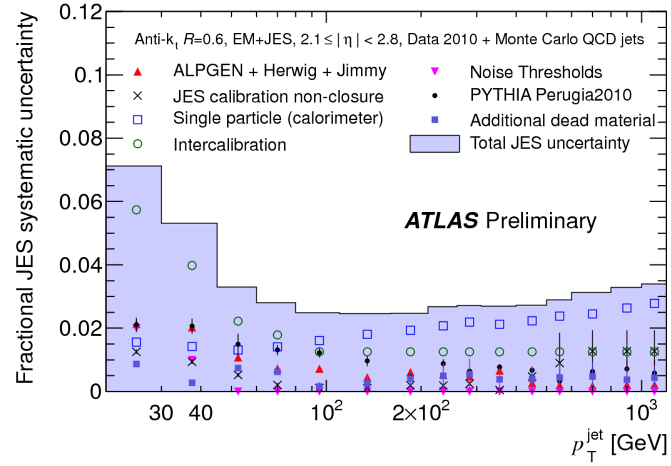
Jet Energy Scale

- Correct for
  1. *pileup / underlying event*
  2. *origin (not 0,0,0 but 0,0,z_0)*
  3. *from EM scale to hadronic scale*
     - non-compensation
     - detector non-uniformity
     - dead material and leakage
     - lost energy "out-of-cone" and soft
- By means of
  1. *avg/area/vertex from minbias data*
  2. *max p_T^2 vertex*
  3. *particle jet – reco jet comparison in MC (will ultimately use data)*
- All-MC, cross-checked with data

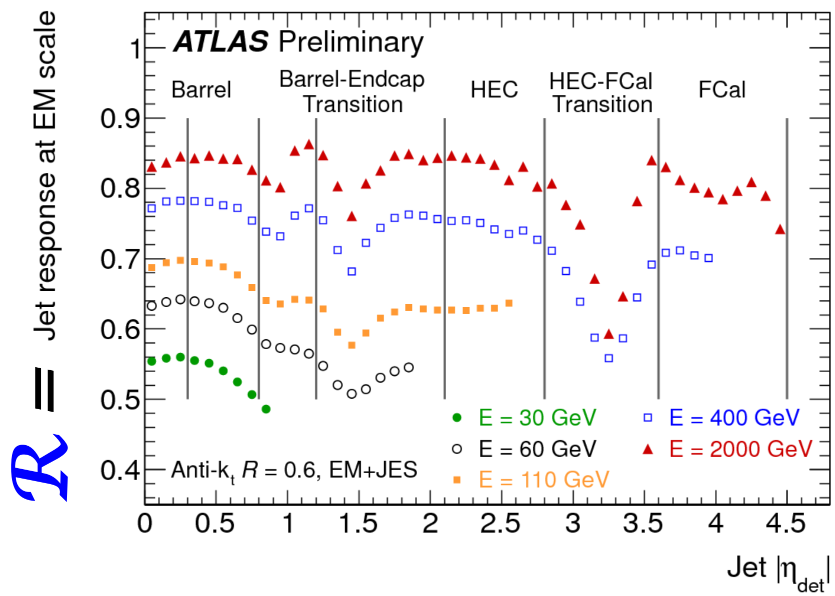


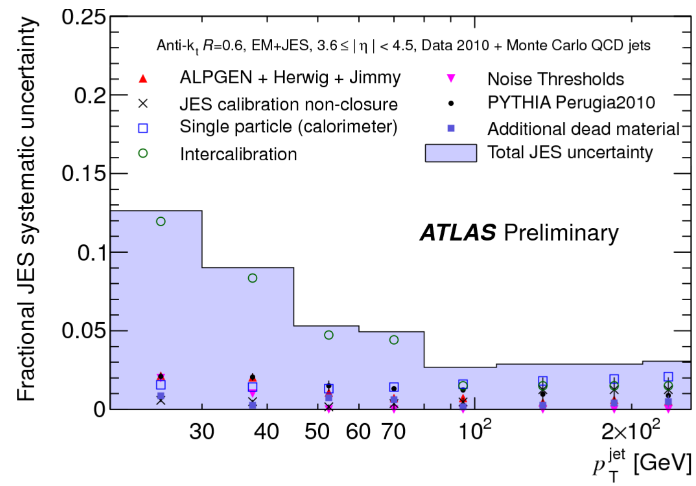
Jet Energy Scale





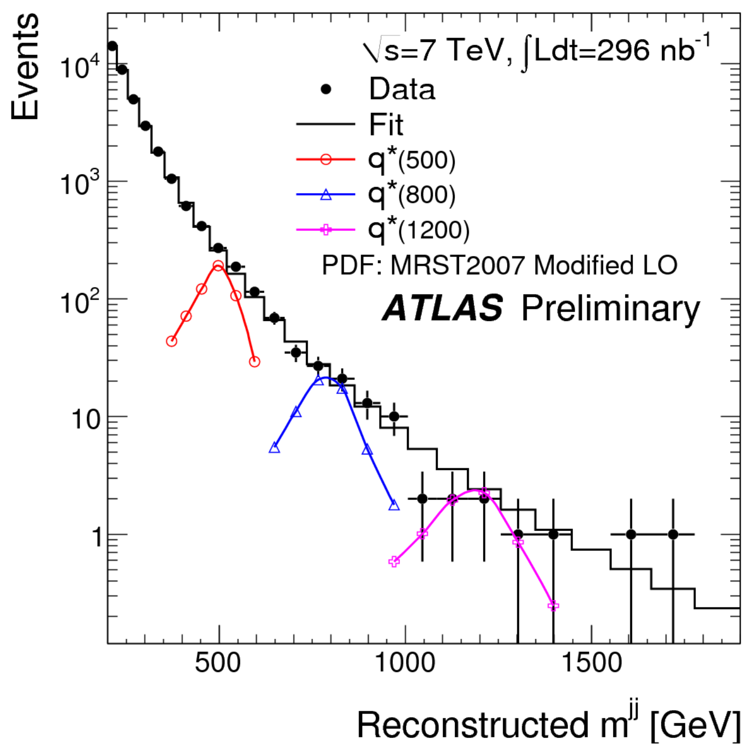
$$E_T^{jet} = E_T^{jet} / \mathcal{R}$$

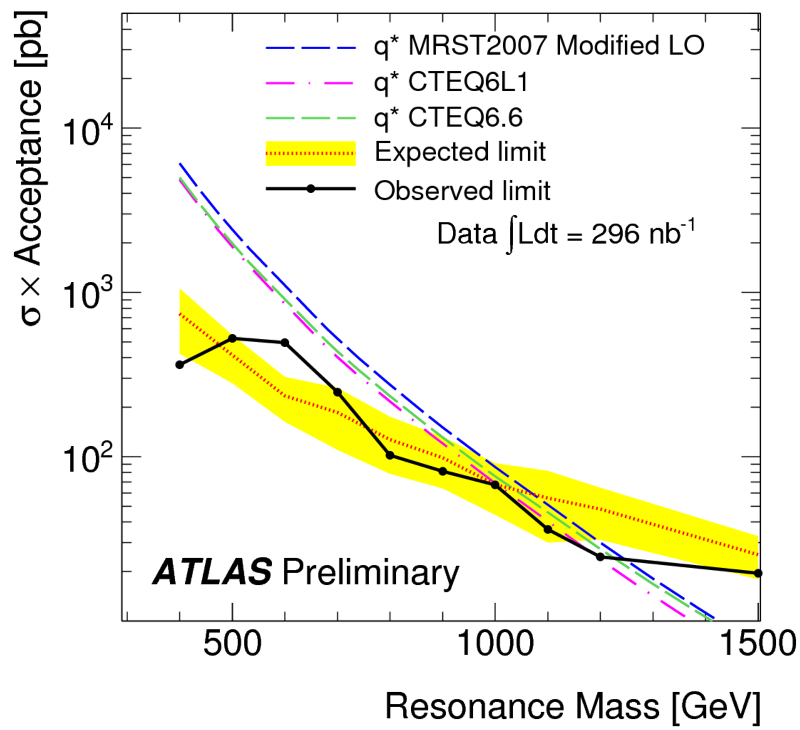




Jet-driven Searches

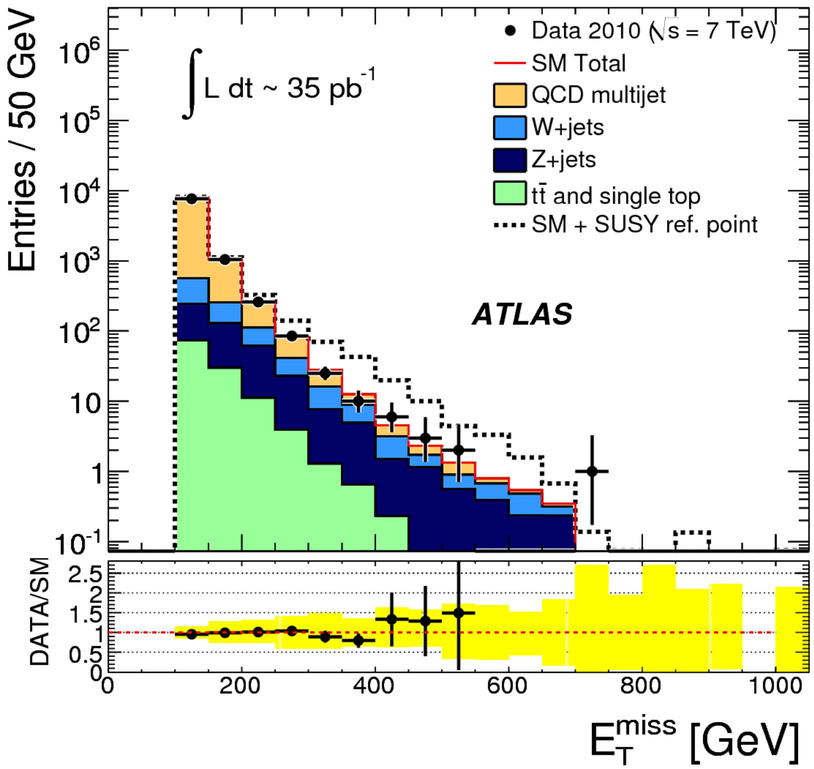
- First data – q* resonance searches





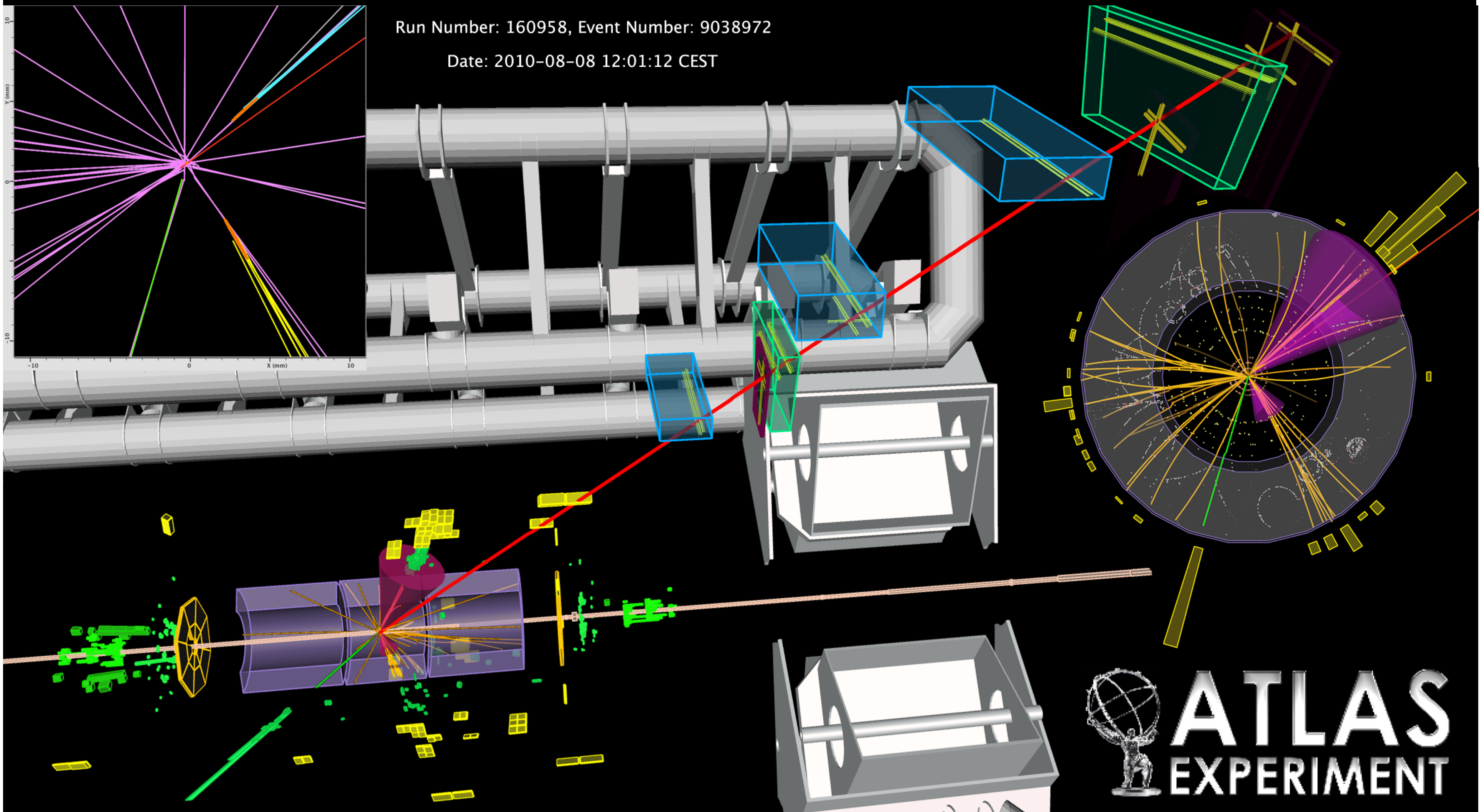
Jet-driven Searches

- The most generic SUSY search: jets+MET
  - → *Call it a "search for squarks and gluinos"*
  - → *Most generically, dark matter search*



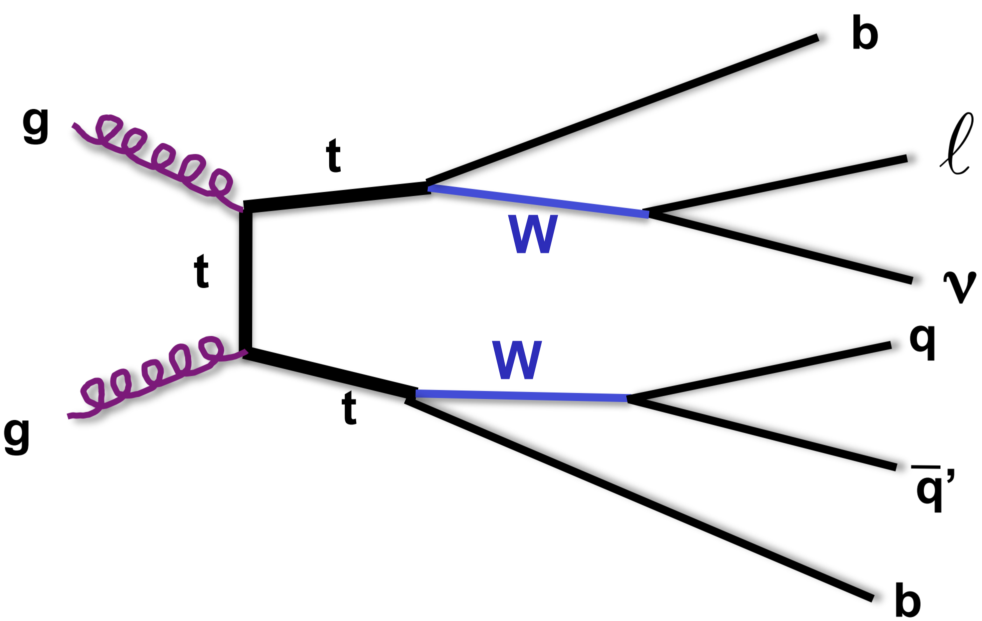
ETmiss for ≥ 2 jet events
Exclude 500-800 GeV gluino (depends on assumptions)

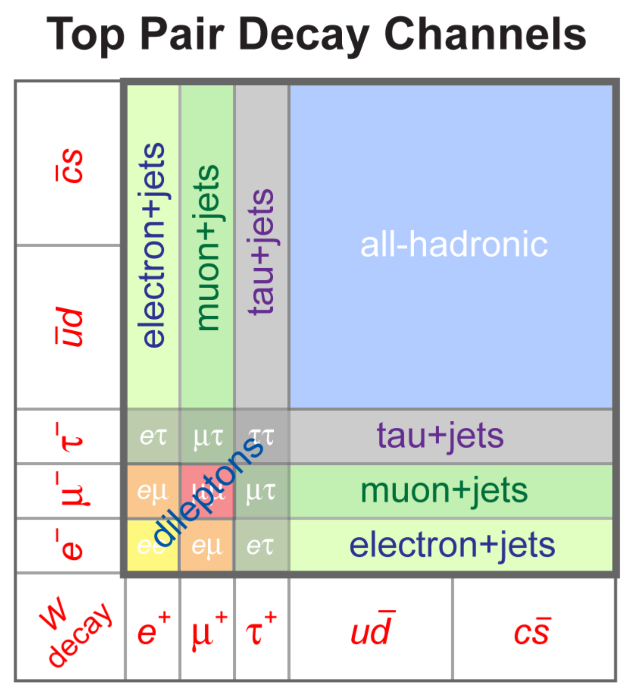
the top quark



And then there's the top quark

- Most massive fundamental particle m_t = 173.1 ±1.3 GeV
- Complex final state
  - → *Leptons, jets, and MET, together at last*
  - → *Including jets from b quarks*



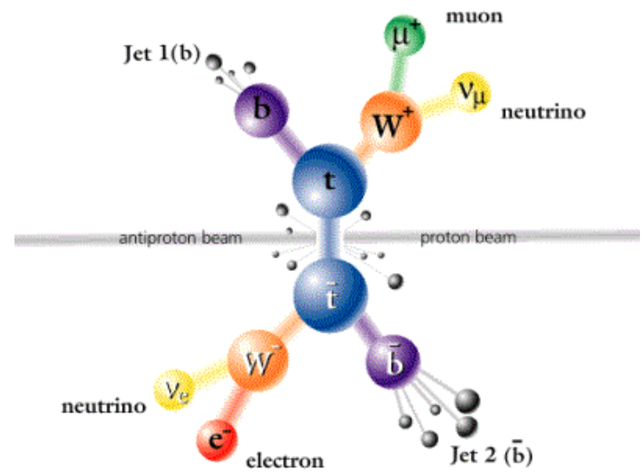


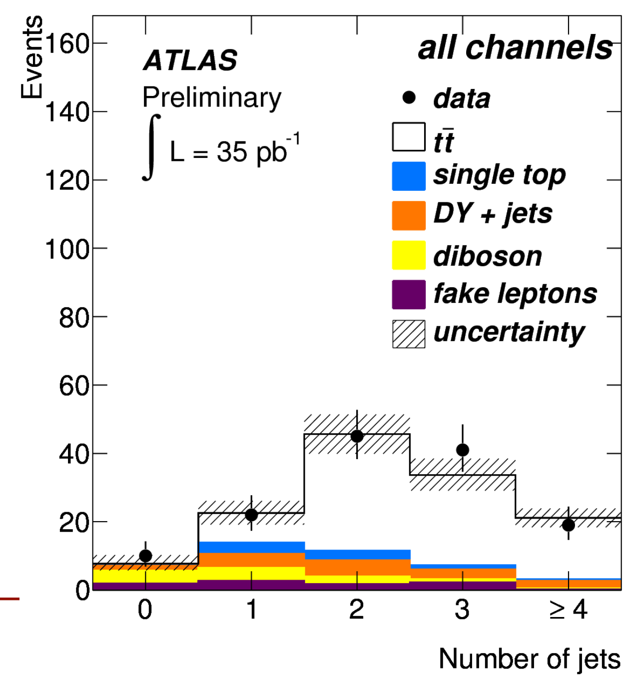
Dilepton ttbar cross section

- Final state: 2 leptons (e/μ), E_T^{miss}, ≥ 2 jets
  - → *Opposite-sign ee, eμ, or μμ with E_T (p_T) > 20 e (μ), isolated*
  - → *Anti-k_T jets with R = 0.4 and E_T > 20 and $|\eta| < 2.5$*
  - → *E_T^{miss} > 40 and $|m_{ll}-m_Z|$ > 10 in ee, μμ channels*
- 105 candidates in 35 pb^{-1}
  - → *expect 100.6 = 79.0 signal + 21.6 bg*
- Combined result

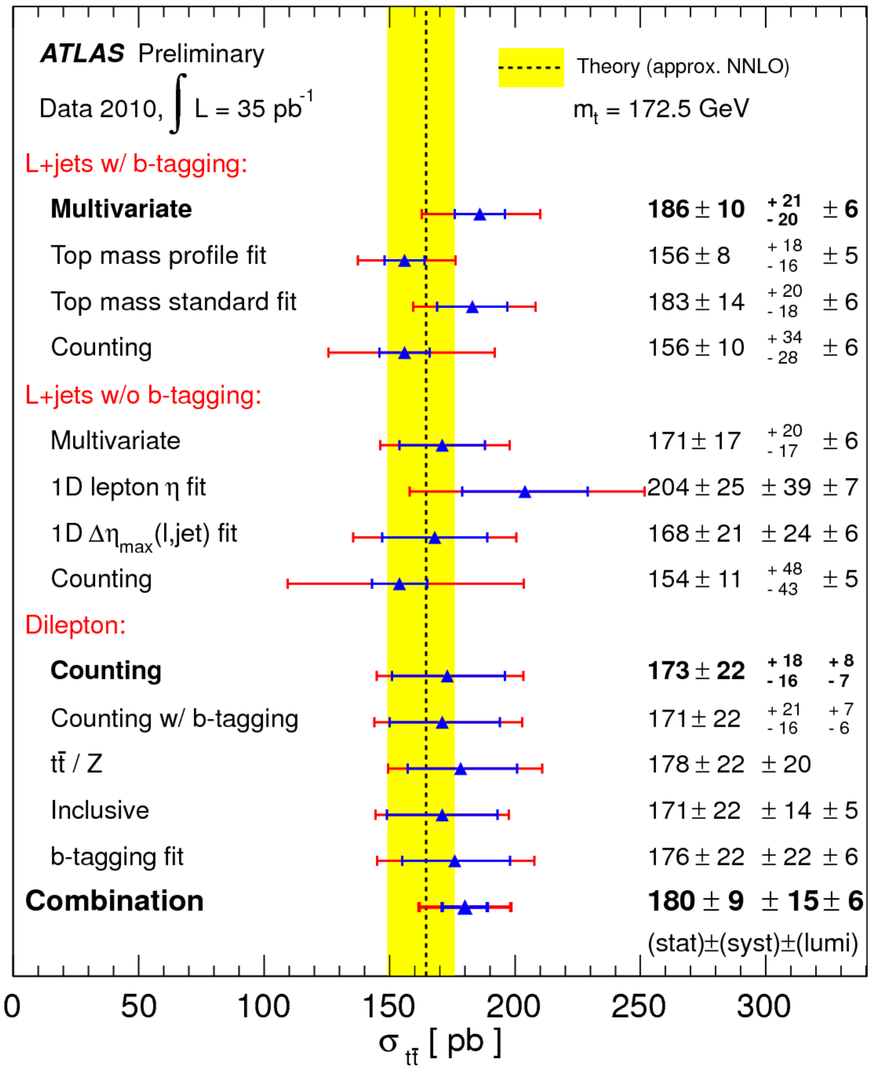
173 ± 22(stat.) $_{-16}^{+18}$ (syst.) $_{-7}^{+8}$ (lum.) pb

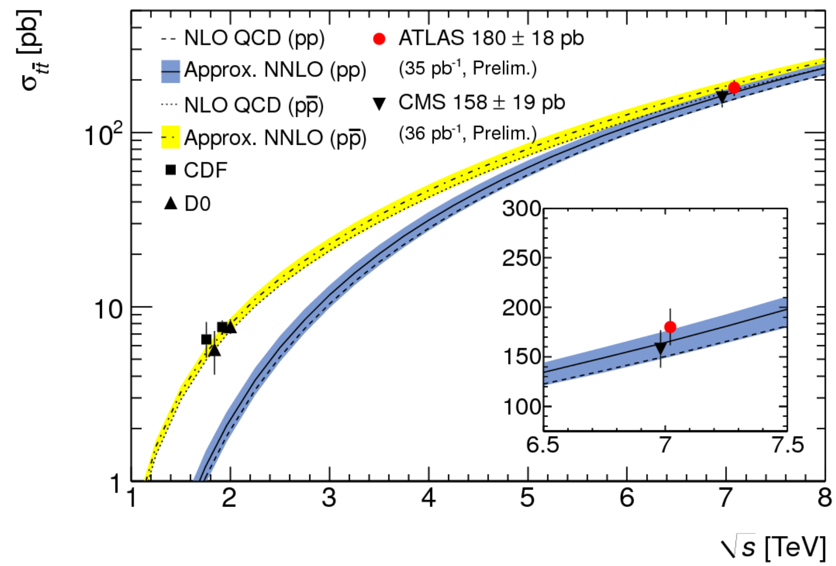
- Theory prediction: 165_{-16}^{+11} pb for m_t = 172.5
- kinematic cleverness





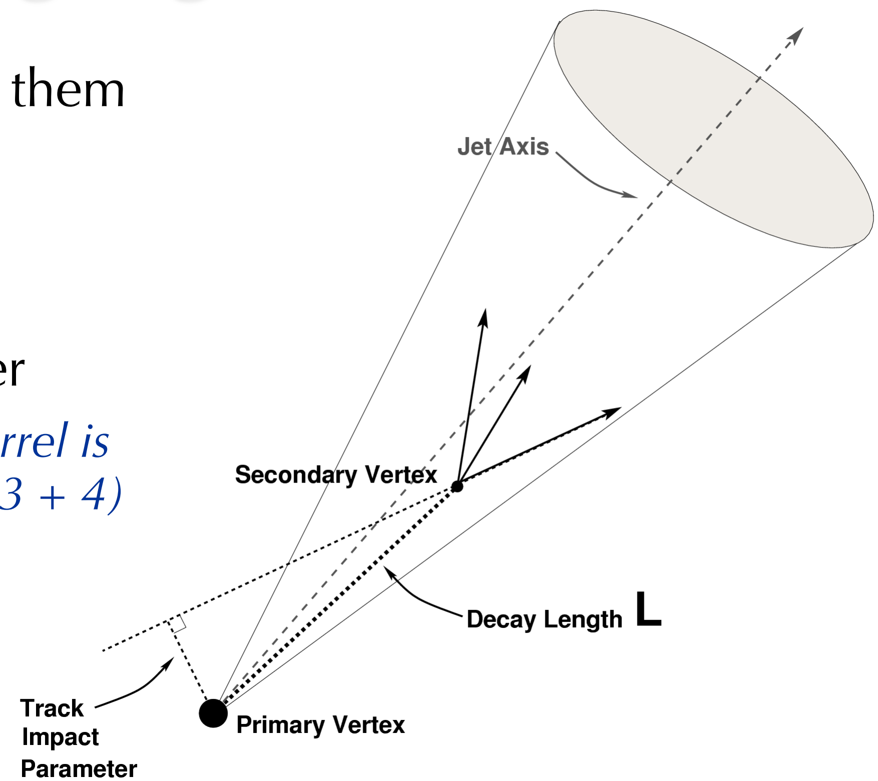
ttbar Cross Section





b-jet tagging

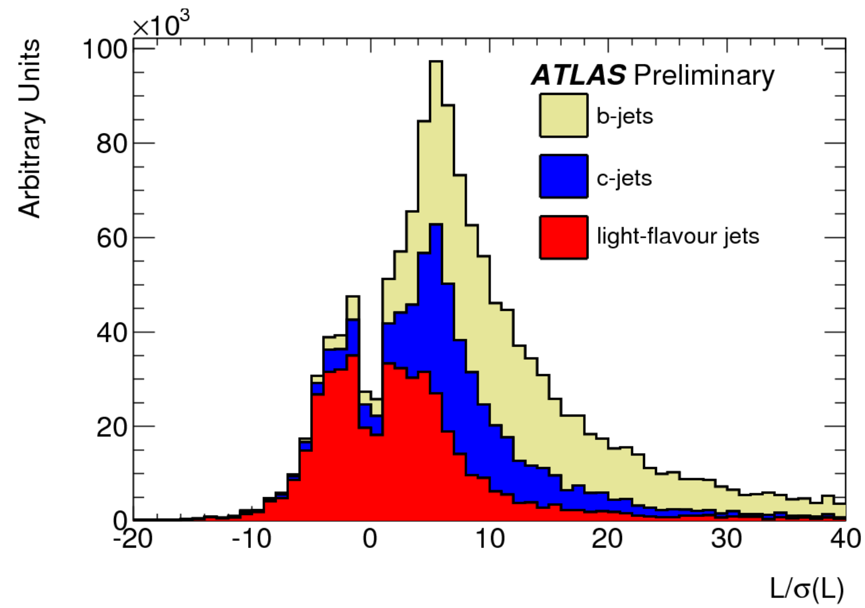
- Exploit b properties that distinguish them from light-quark jets…
  - → *in this case, τ_b ~ 1.5 ps*
- …and excellent resolution of tracker
  - → *intrinsic accuracy of R-φ hits in barrel is 10 μm (17 μm) in pixels (SCT) x (3 + 4) measurement layers*
- Detect via displaced vertices
  - → *Reconstruct of displaced vertex*
  - → *Soft leptons also possible, but more challenging*
  - → *"SV0" algorithm commissioned before other displaced vertex algs due to robustness*



b-jet tagging

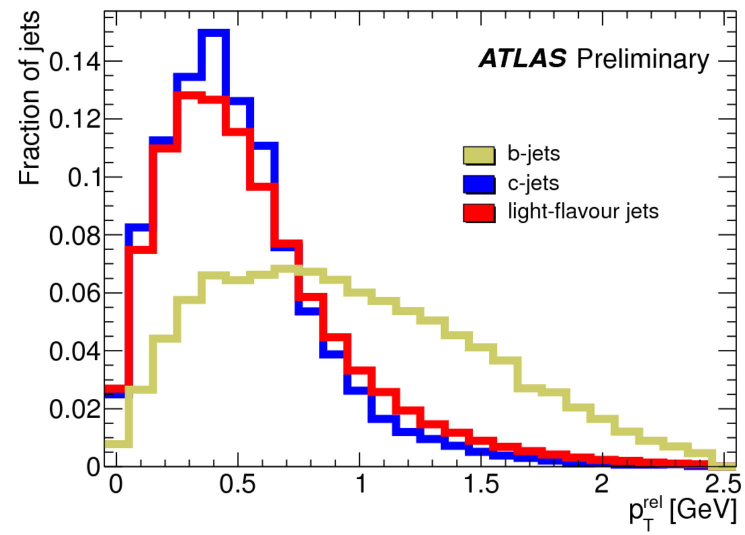
1. *Associate "high-quality" (see below) tracks to jet*
2. *Reconstruct significantly displaced 2-track vertices*
3. *Remove "V_0": K_0^s, Λ_0, γ conversion (based on mass)*
4. *Remove vertices at R = {pixels}*
5. *Merge 2-track vertices and iteratively remove tracks with largest χ^2 until fit prob. > 0.001, $M_{vtx} < 6$ GeV, $\chi^2_{max} < 7$*
6. *Cut on signed decay length signficance $L/\sigma(L) > 5.72$*

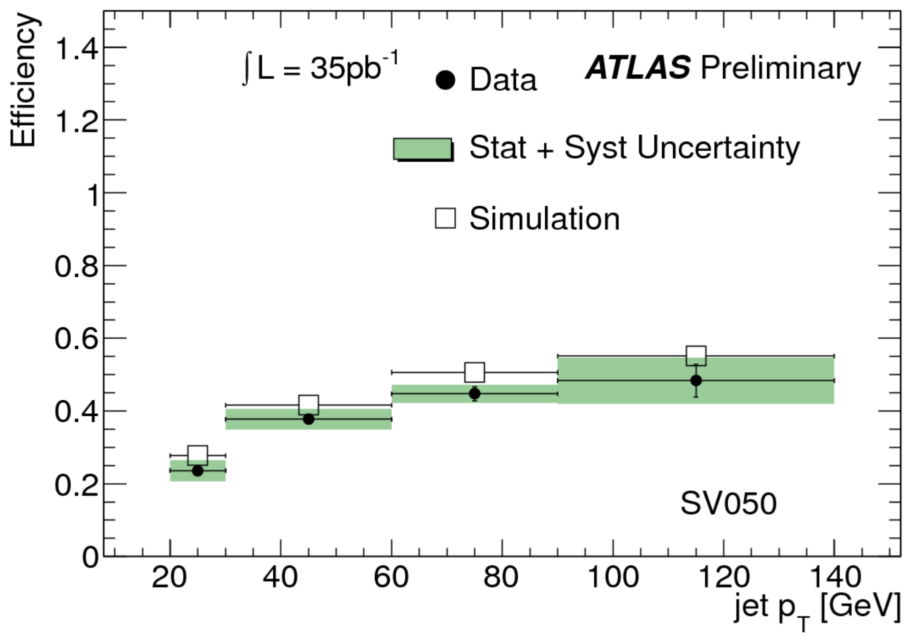
	Selection
p_T	> 0.5 GeV
d_0^{PV}	< 2 mm
$z_0^{PV} \sin\theta$	< 2 mm
$\sigma(d_0^{PV})$	< 1 mm
$\sigma(z_0^{PV})$	< 5 mm
χ^2/ndof	< 3
Number of Pixel hits	≥ 2
Number of SCT hits	≥ 4
Number of Pixel+SCT hits	≥ 7

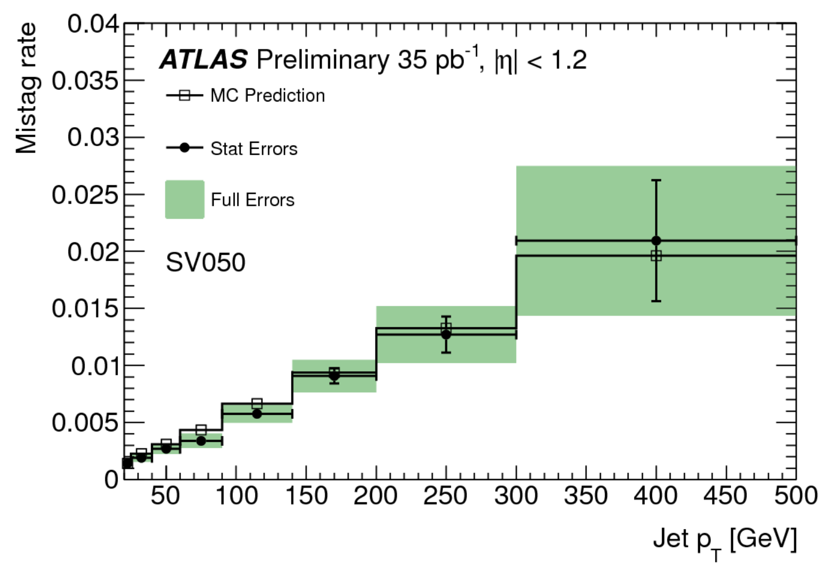


b-jet tagging

- Tagging efficiency:
  - → *p_T^{rel} uses presence of soft muon in jet*
  - → *Mass of b gives it a "kick" relative to jet*







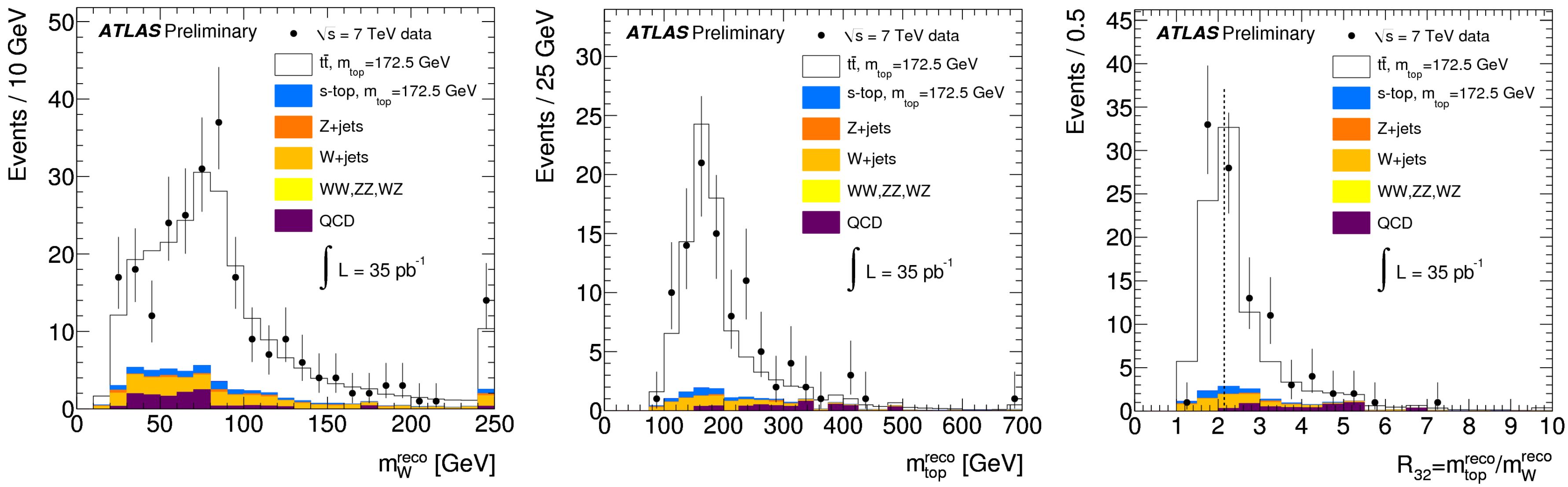
top mass: sample definition

- world avg $\mathbf{m_t}$ **= 173.1 ±1.3 GeV** BUT **δ(JES)/JES** ≥ **2**%
- signature: charged lepton + ETmiss + ≥ 4 jets
  - → *isolated e (or μ) with $p_T > 20$*
    - for μ, isol includes ΔR > 0.4 to nearest jet
  - → $E_T^{miss} > 35$ *(20)*
  - → $m_T^W > 40$ $((E_T^{miss} + m_T^W) > 60)$
  - → *anti-k_T jets with $R = 0.4$ with $p_T > 25$ & $|\eta| < 2.5$*
  - → *at least one jet b-tagged using SV0*
    - reject event if two b-tagged jets assigned to had. top
  - → $60 < mjj < 100$
- Leaves 155 candidates, with S/B ~ 5.5
- Hadronic top: pick 3 jets with max Σp_T (vector sum)
- Hadronic W: two untagged, or min ΔR, jets

$$R_{32} = \frac{m_{\text{top}}^{\text{reco}}}{m_W^{\text{reco}}}$$

35 $\mathbf{pb^{-1}}$ 2010 data

top mass



$$R_{32} = \frac{m_{\text{top}}^{\text{reco}}}{m_W^{\text{reco}}}$$

- world avg $\mathbf{m_t}$ **= 173.1 ±1.3 GeV** (sub-% level!)
- BUT **δ(JES)/JES** ≥ **2**%
- Stat. uncertainty is largest single uncertainty, JES still leading systematic

35 pb^{-1} 2010 data

Template Method

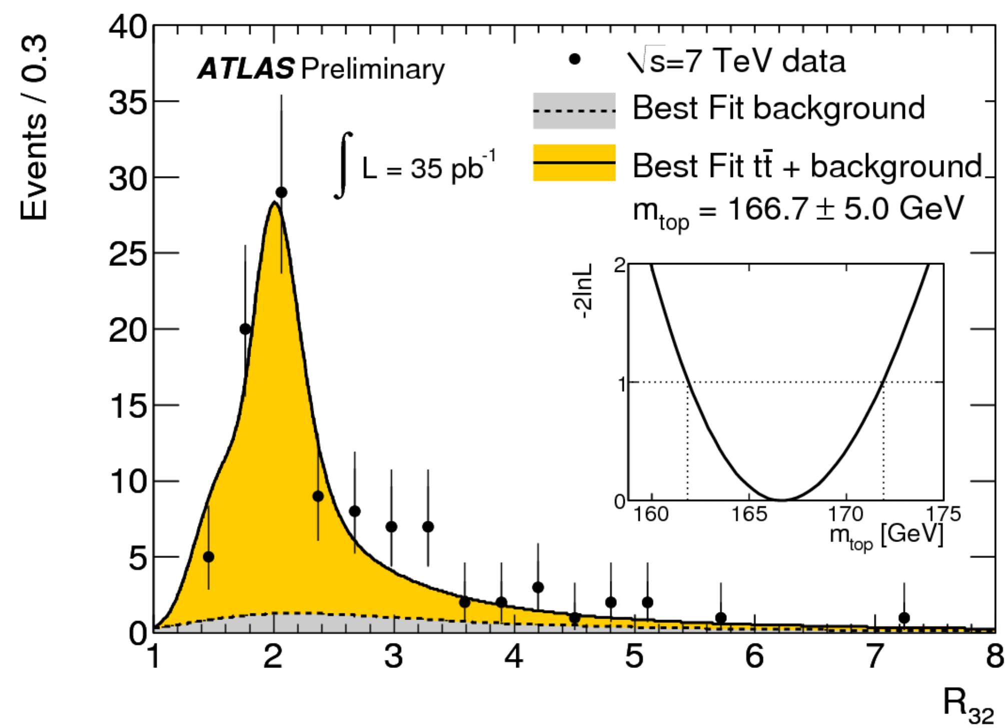
$$\mathcal{L}(R_{32}|m_{top}) = \mathcal{L}_{shape}(R_{32}|m_{top}) \times \mathcal{L}_{n_s+n_b} \times \mathcal{L}_{bkg} ,$$

$$\mathcal{L}_{shape}(R_{32}|m_{top}) = \prod_{i=1}^{N} \frac{n_s \cdot P_{sig}(R_{32}|m_{top})_i + n_b \cdot P_{bkg}(R_{32})_i}{n_s + n_b} ,$$

$$\mathcal{L}_{n_s+n_b} = \frac{e^{-(n_s+n_b)} \cdot (n_s + n_b)^N}{N!} ,$$

$$\mathcal{L}_{bkg} = \exp\left\{ -\frac{(n_b - n_b^{pred})^2}{2\sigma_{n_b^{pred}}} \right\} .$$

- Signal templates from MC
- BG templates from MC
- Single likelihood, extract m_t as linear function of the parameters



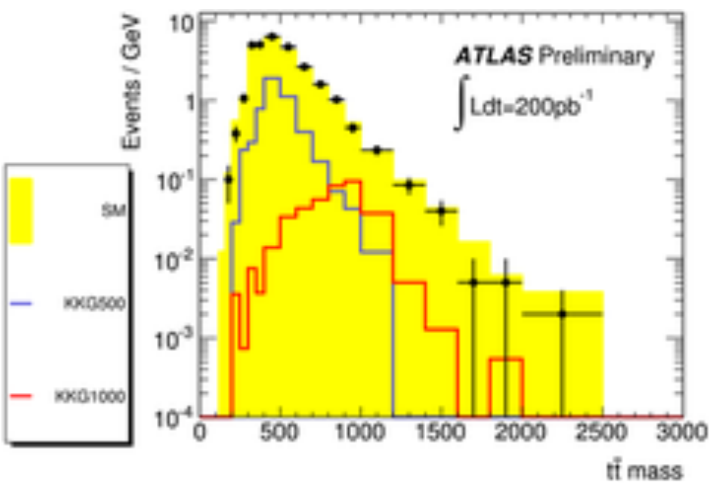
Searching for Exotica in ttbar

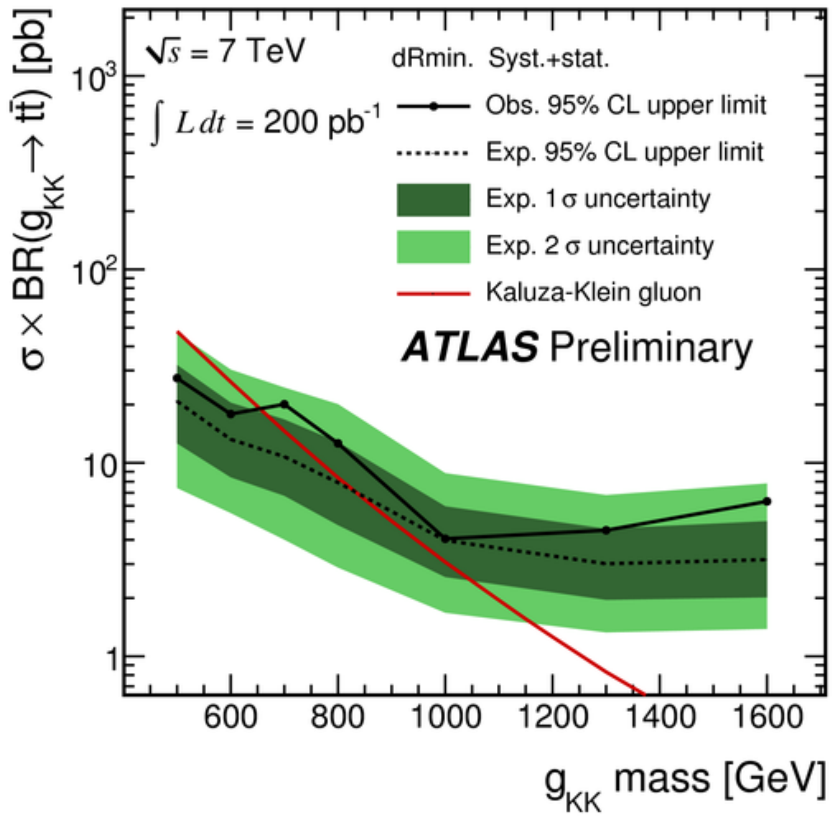
Large m_t trying to tell us something about TeV-scale physics?

Resonant production of ttbar?

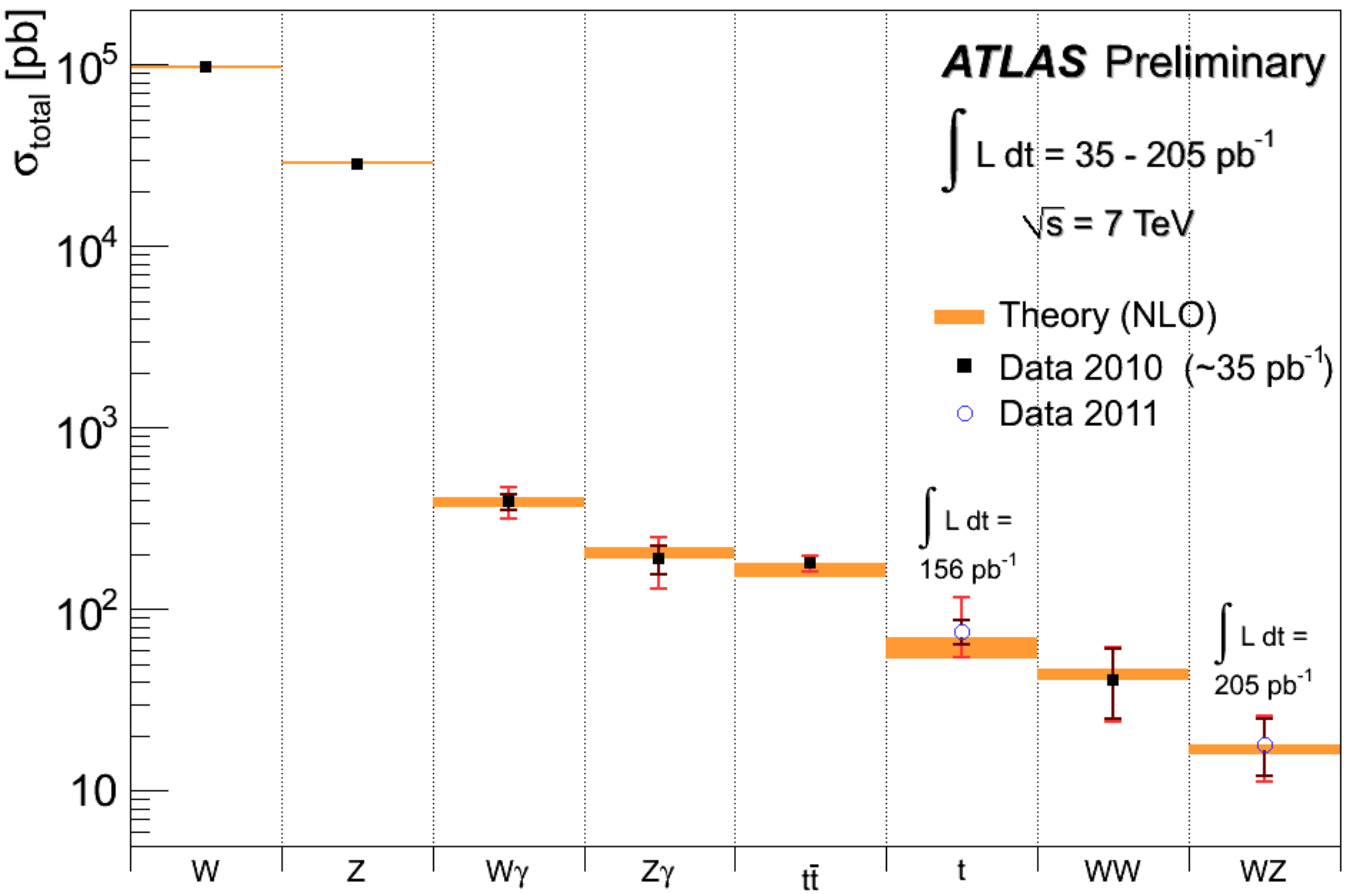
Select lepton+jets events

Solve for p_z^ν using W mass constraint





Searching for rarer processes



here there be tigers… we hope

Summary

- I've barely skimmed the surface of what's being done
- Flood of new results, many based on 1 fb^{-1}, going public now
  - → *ATLAS public results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic*
- Up to maybe 4 fb^{-1} by the end of the year
  - → *unexplored phase space*

Backup

LHC design parameters

Quantity	number
Circumference	26 659 m
Dipole operating temperature	1.9 K (-271.3°C)
Number of magnets	9593
Number of main dipoles	1232
Number of main quadrupoles	392
Number of RF cavities	8 per beam
Nominal energy, protons	7 TeV
Nominal energy, ions	2.76 TeV/u (*)
Peak magnetic dipole field	8.33 T
Min. distance between bunches	~7 m
Design luminosity	10^{34} cm^{-2} s^{-1}
No. of bunches per proton beam	2808
No. of protons per bunch (at start)	1.1×10^{11}
Number of turns per second	11 245
Number of collisions per second	600 million

(*) Energy per nucleon

From http://cdsmedia.cern.ch/img/CERN-Brochure-2009-003-Eng.pdf

Fact Sheet

- 1 event ~ 1 MB ESD, 150 kB AOD
- 75 → 50 ns bunch spacing this spring
  - → *25 ns under discussion but unlikely for pp colliding beams before 2012*
- Current data volume is ~ 400 MBytes/hour
- We will keep the raw for 3~4 week (~ TBytes) and then delete them