Standard Model Physics and Higgs Searches at the LHC

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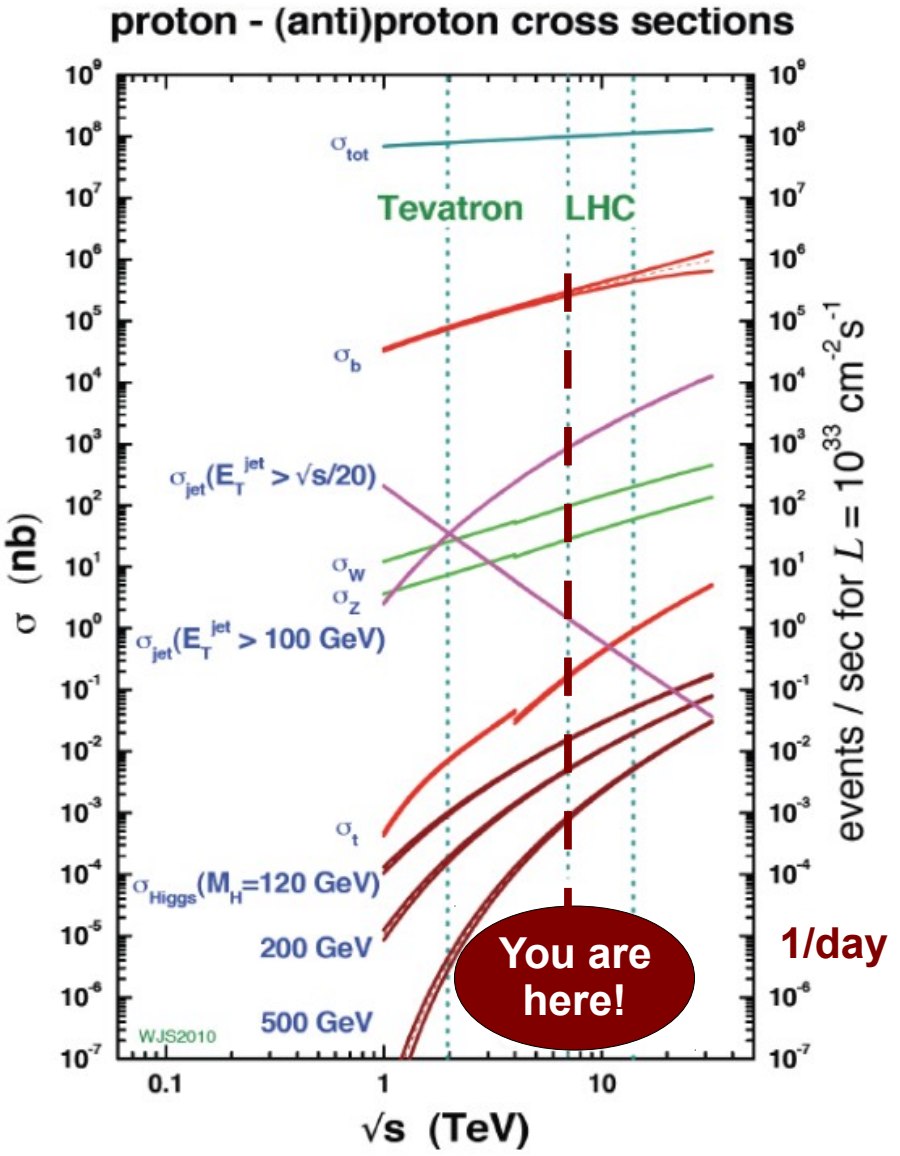
for the
ATLAS & CMS Collaboration

Outline

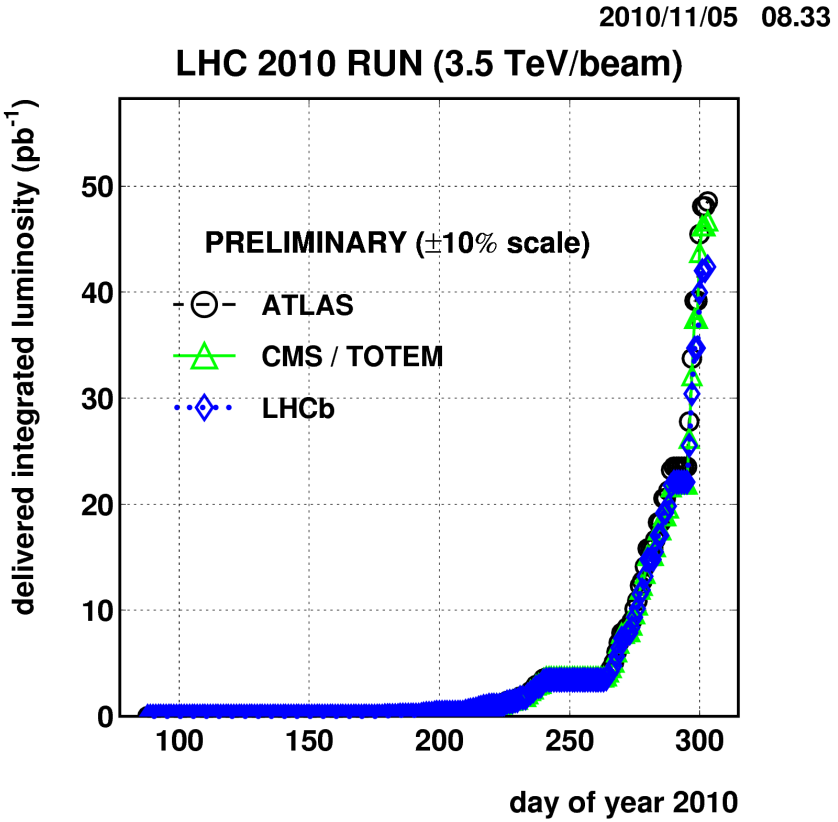
- **Introduction**
  - LHC Performance
  - ATLAS and CMS Performance
- **Selected Physics Results**
  - Heavy Ion
  - **Jet Production**
  - **Vector Bosons**
  - **Top Quark Physics**
  - **Higgs Boson Searches**
- **Conclusion**

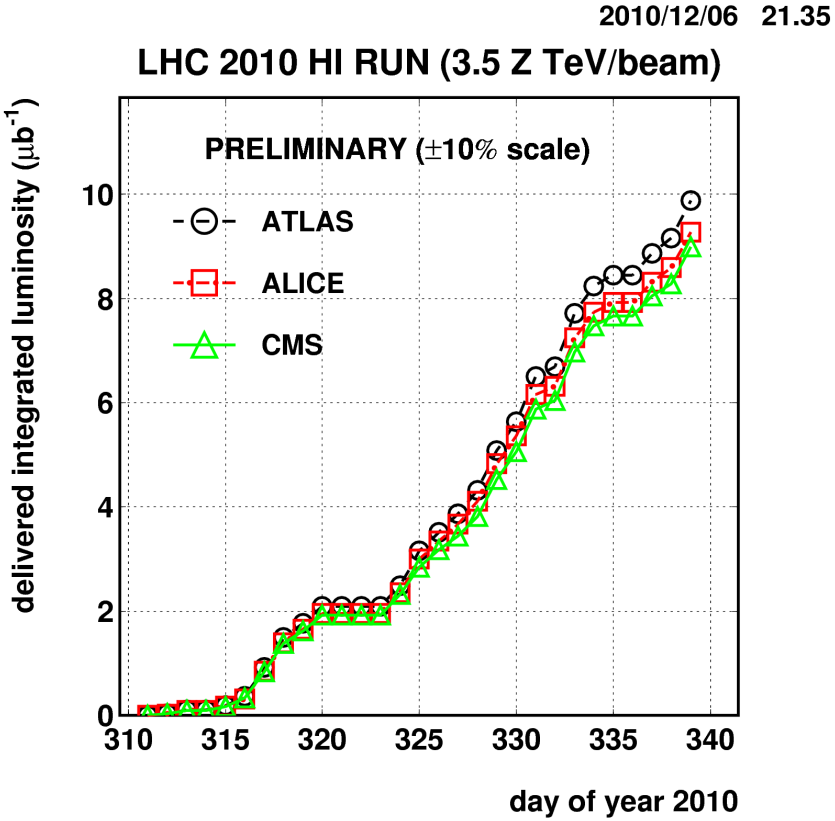


LHC Performance in 2010

- 2010 pp @ 7 TeV: ~ 47pb^{-1} delivered, L = 2x10^{32} cm^{-2}s^{-1}
- 2010 PbPb: ~ 10μb^{-1} delivered

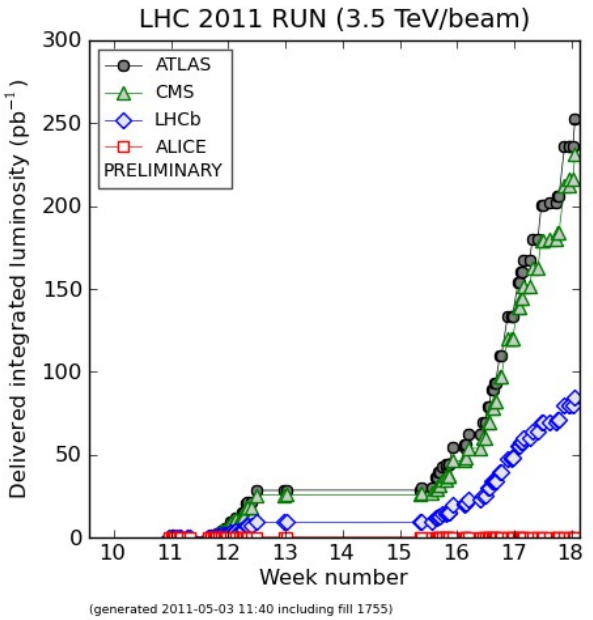
Physics shown here based on 2010 data!

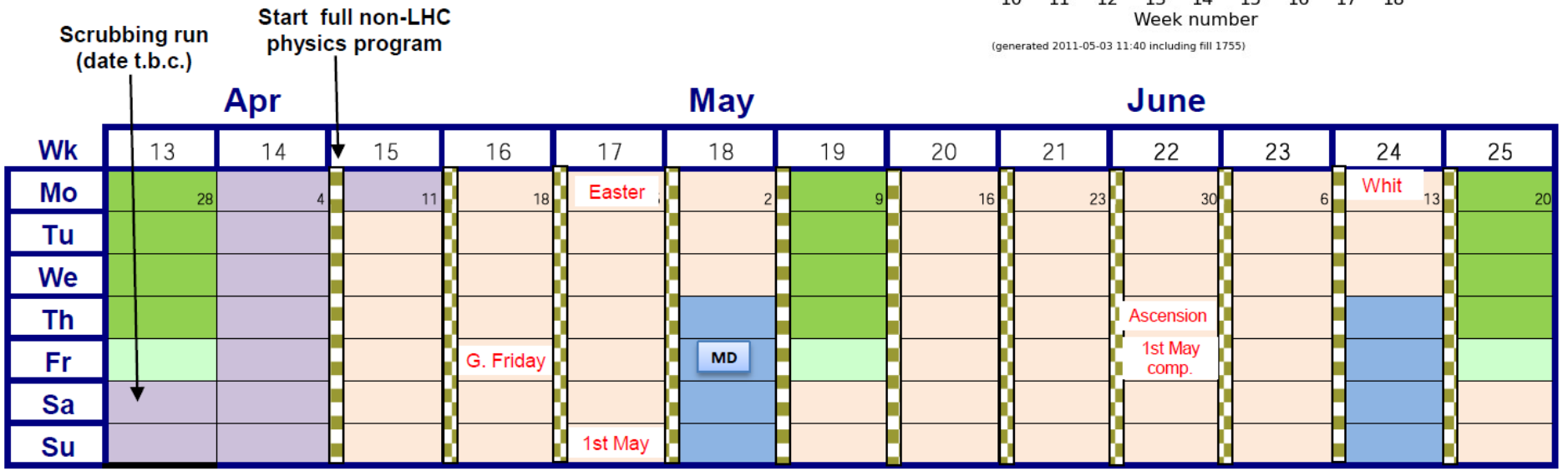




LHC Performance in 2011

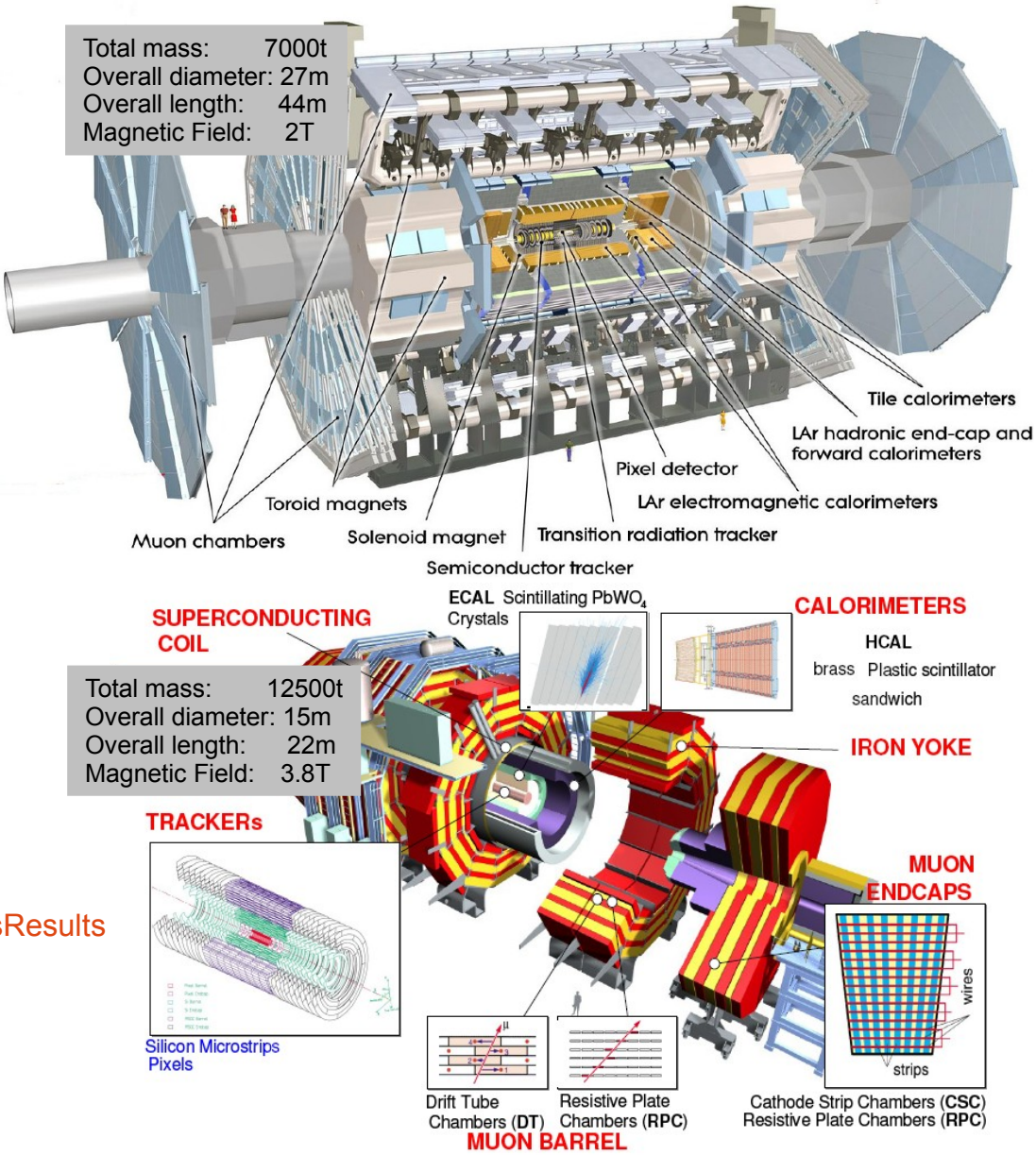
- 2011 pp @ 7 TeV: ~ 230pb^{-1} delivered
- L = 8.4*10^{32} cm^{-2}s^{-1}
- 768 bunches, 10^{14} protons per beam
- 50ns bunch spacing
- Increased pile-up
- We will soon talk about fb^{-1}'s



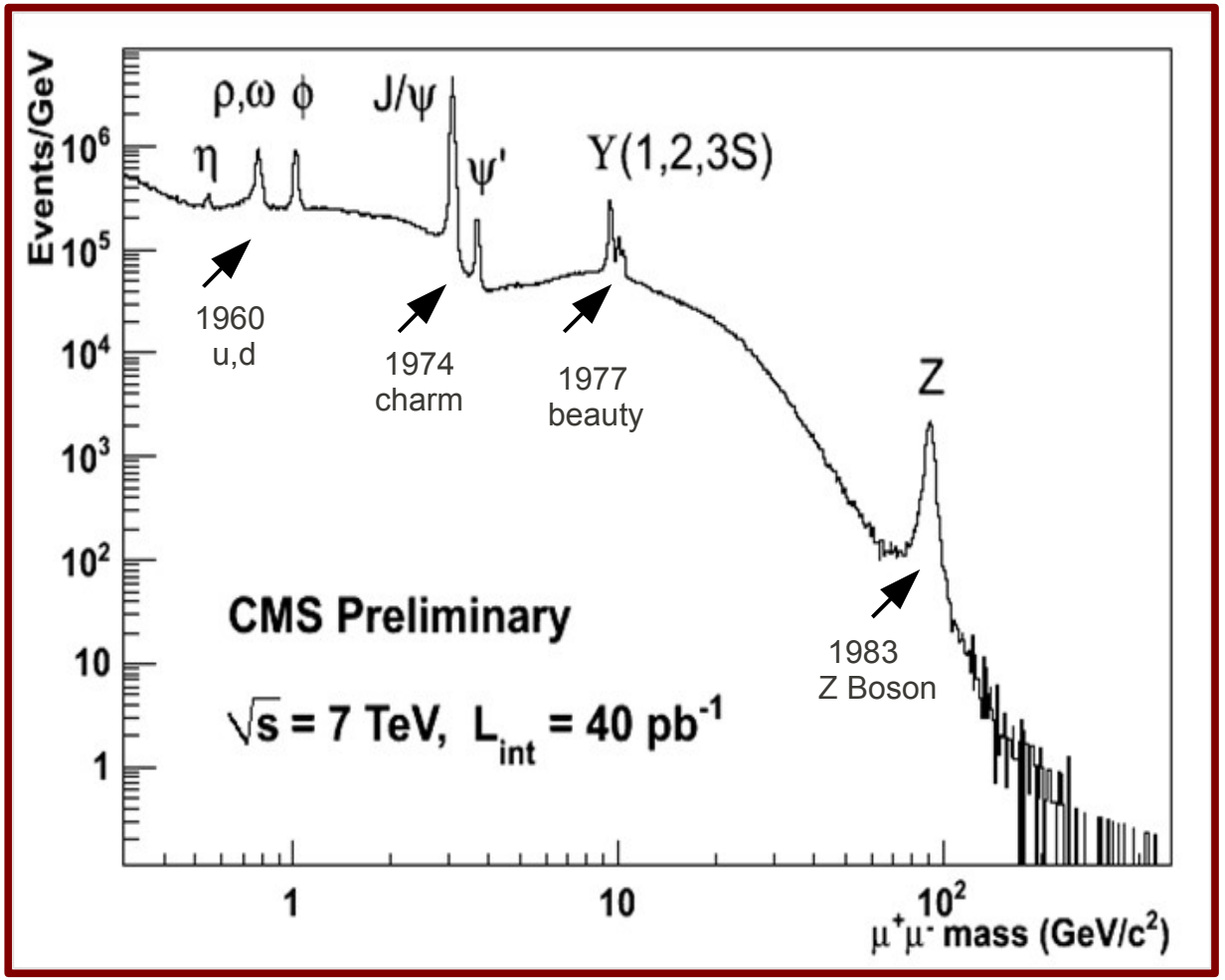


ATLAS and CMS Performance

- Operational fraction per sub-detector ~ 99%
- Overall data taking efficiency ~92%
- Improved uncertainty on pp luminosity measurement ~4%
- Detector performance is approaching expectation
- Many, many, many physics results
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

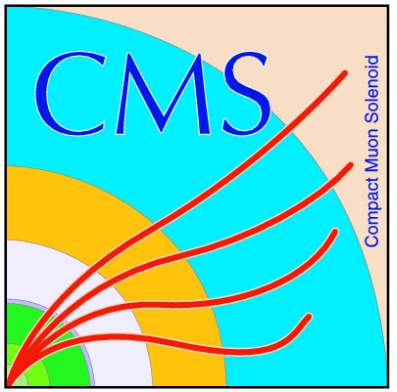


Re-Discovery of SM in 2010 Data



ATLAS and CMS
Standard Model Physics and Higgs Searches
Pheno 2011

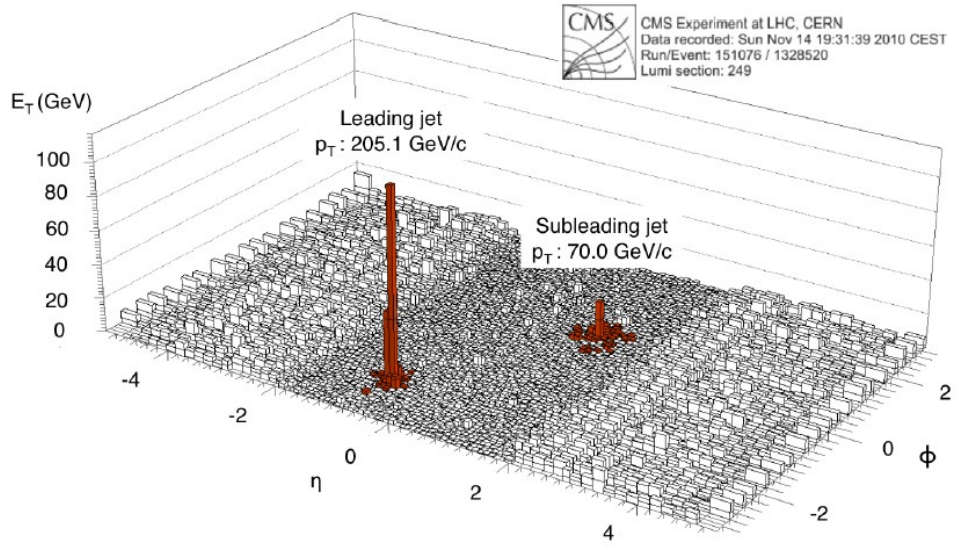
- Chad Suhr: Top cross section and mass measurement at ATLAS
- Frank Siegert: Monte Carlo tuning with ATLAS data
- Srivas Prasas: W/Z and di-boson results from ATLAS
- Paola Giovannini: Jet and photon results from ATLAS
- Yaquan Fang: Standard Model Higgs Searches with ATLAS
- Borge Kile Gjelsten: SUSY Higgs searches with ATLAS
- Adam Everett: Recent EWK results from CMS
- Sinjini Sen Gupta: Recent results on jet physics
- Simon Marie E De Visscher: Recent heavy-flavor results
- Lara Iglesias: Higgs searches with CMS
- Hans Holger Enderle: Recent top results
- Jessica Leonard: Inclusive vector boson production cross section

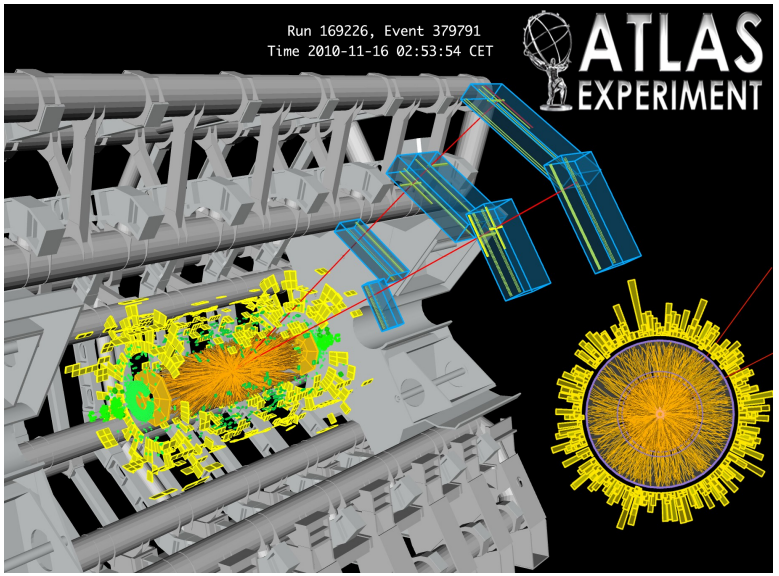


Can only show highlights here!

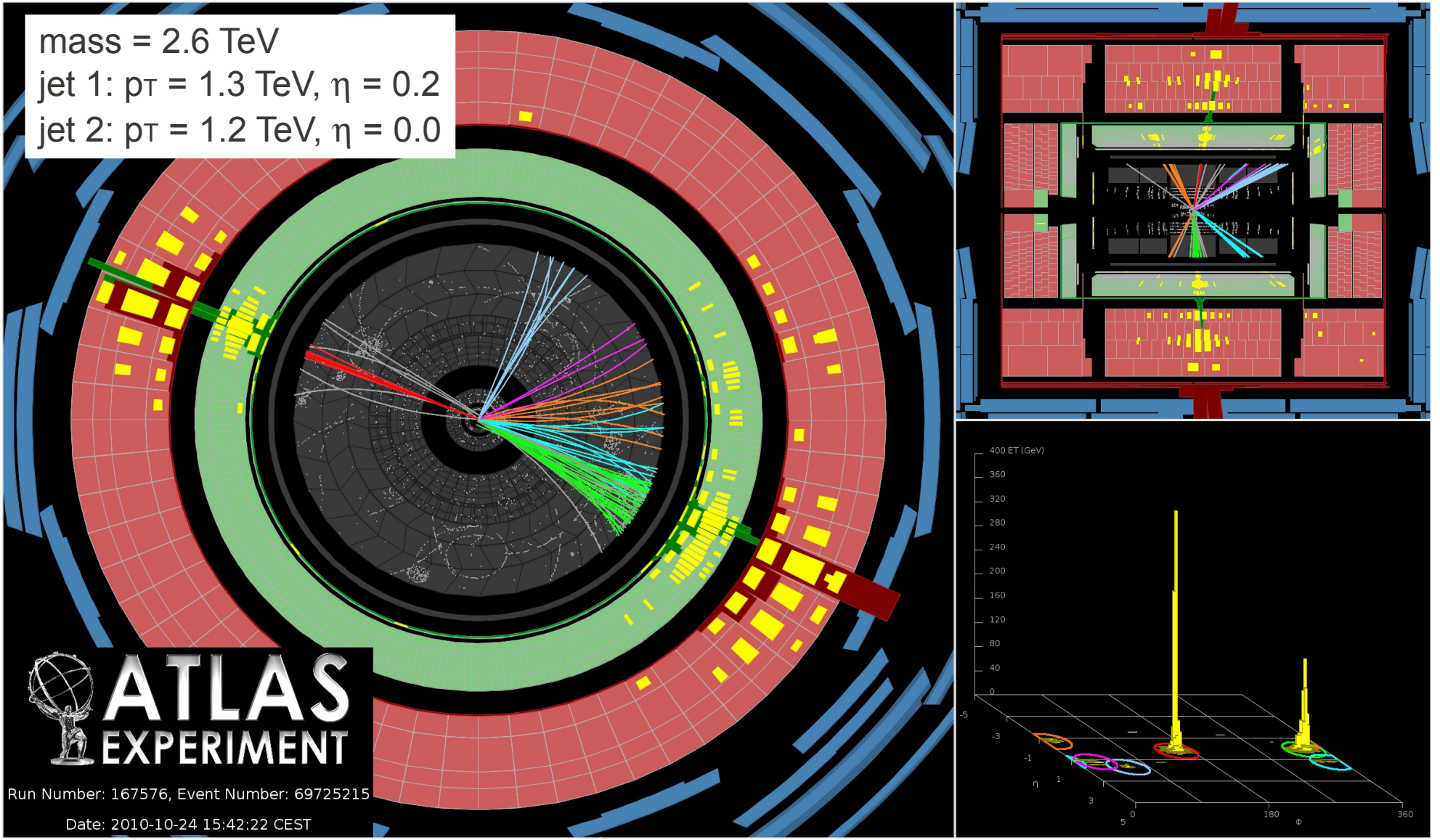
Heavy Ion Results

- **ATLAS & CMS: Heavy Ion detectors**
  - Calorimeter with large coverage
  - Muon spectrometer with large coverage
  - Tracking for pT > ~500 MeV
- Measurements so far
  - Global and collective phenomena
  - Charge particle multiplicity
- Observation of
  - **Jet quenching**
  - **Z boson production**
  - J/ψ yield suppression
- Experiments are preparing more results for QM 2011
- Details on HI physics by Peter Jacobs



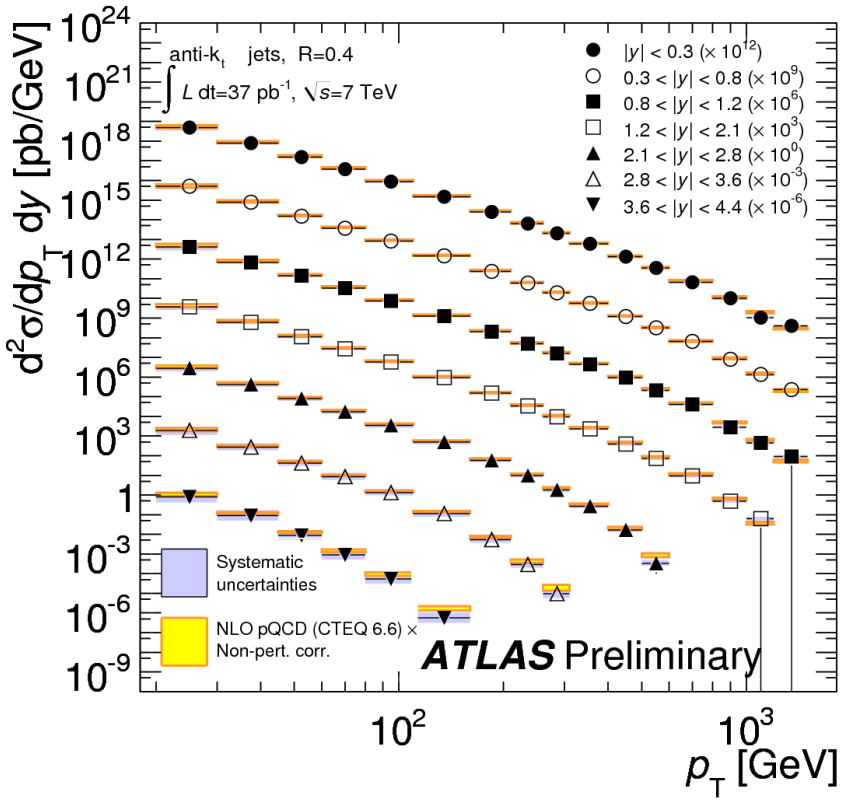


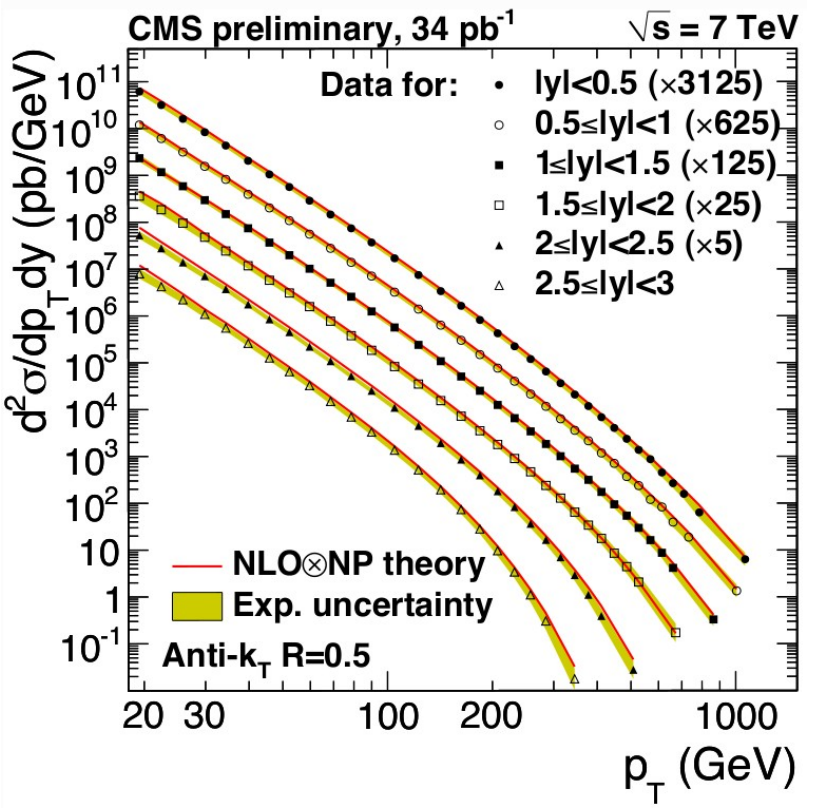
Jet Physics


mass = 2.6 TeV
jet 1: pT = 1.3 TeV, η = 0.2
jet 2: pT = 1.2 TeV, η = 0.0
ATLAS
EXPERIMENT
Run Number: 167576, Event Number: 69725215
Date: 2010-10-24 15:42:22 CEST
400 ET (GeV)
360
320
280
240
200
160
120
80
40
0
-5
-3
-1
1
3
η
0
180
360
Φ

Inclusive Jet Production

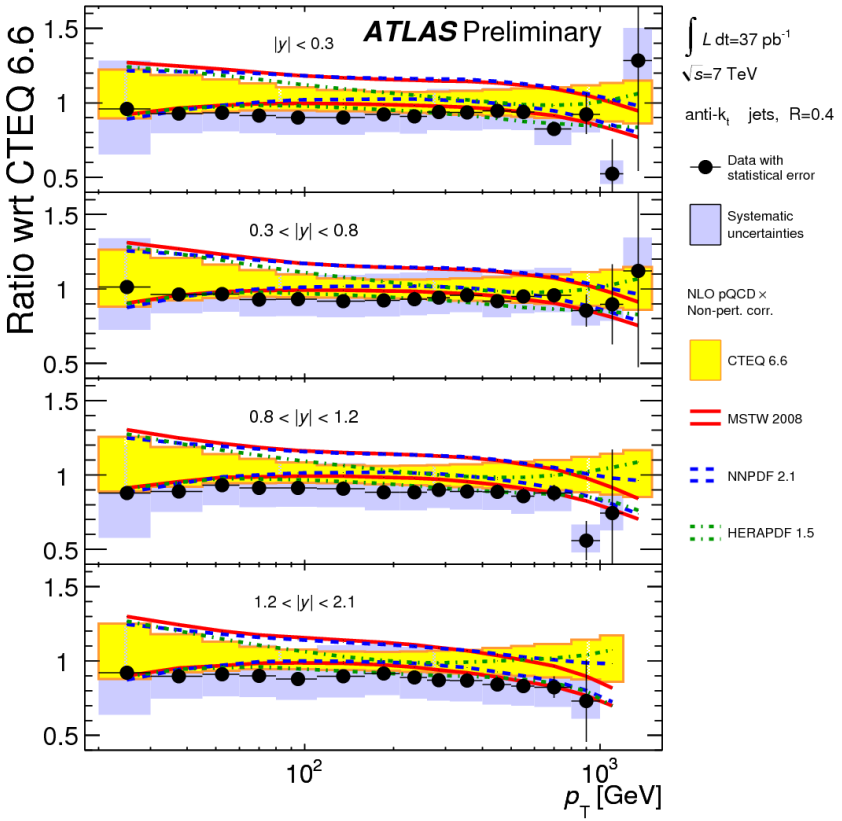
- Measured jet p_T from 18 GeV -1.5 TeV
- Corrected to particle level
- Inclusive jet spectra in agreement with NLO pQCD calculation to non-perturbative corrections
- Test perturbative QCD cross section predictions over 10 orders of magnitude

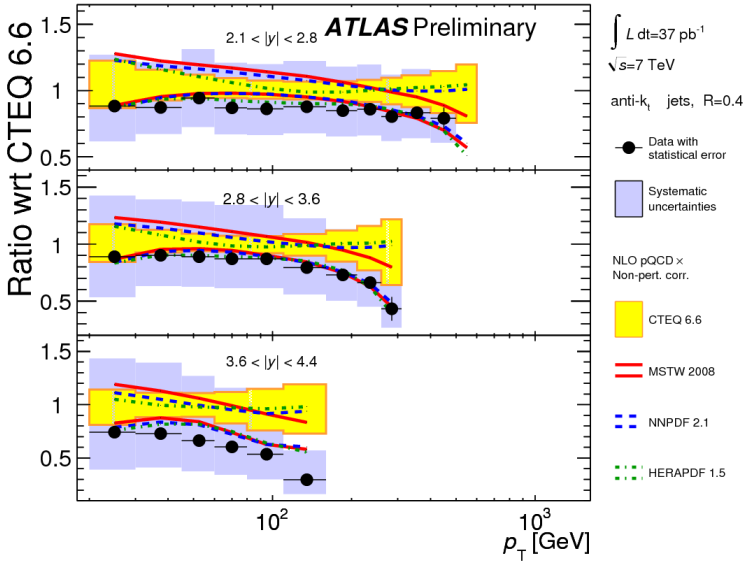




Inclusive Jet Production

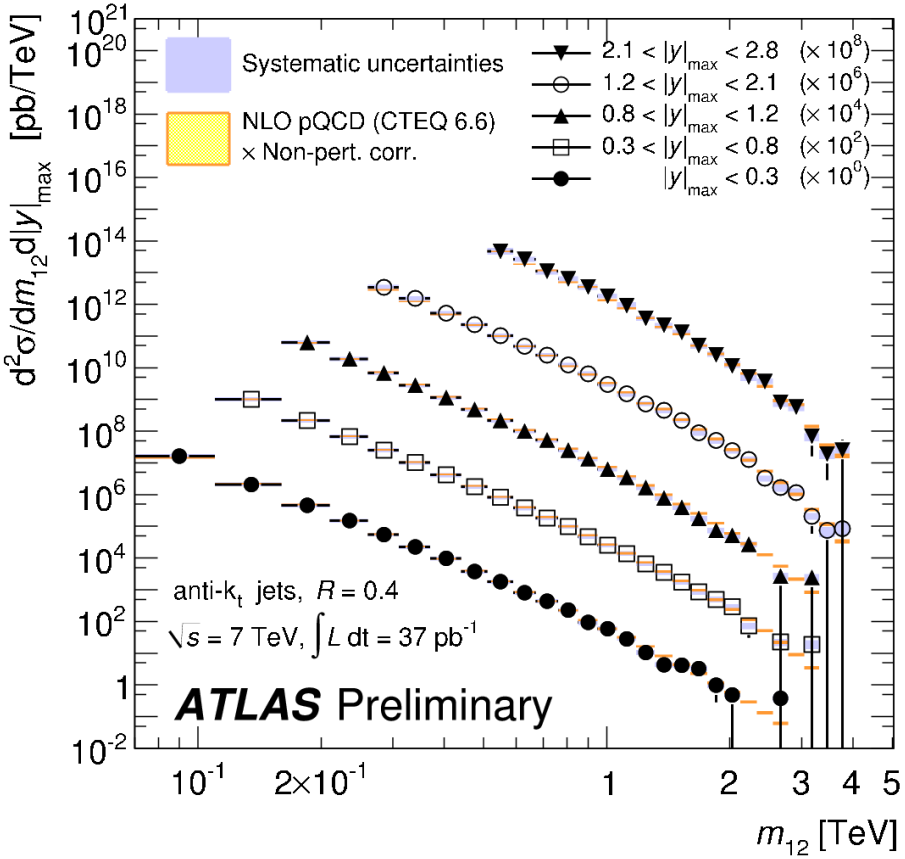
- Systematic uncertainties range from 50% at low pT to 20%
  - Unfolding of detector effects; jet energy scale dominates
- Theoretical uncertainty typically 10-20%
- Comparisons with different PDFs

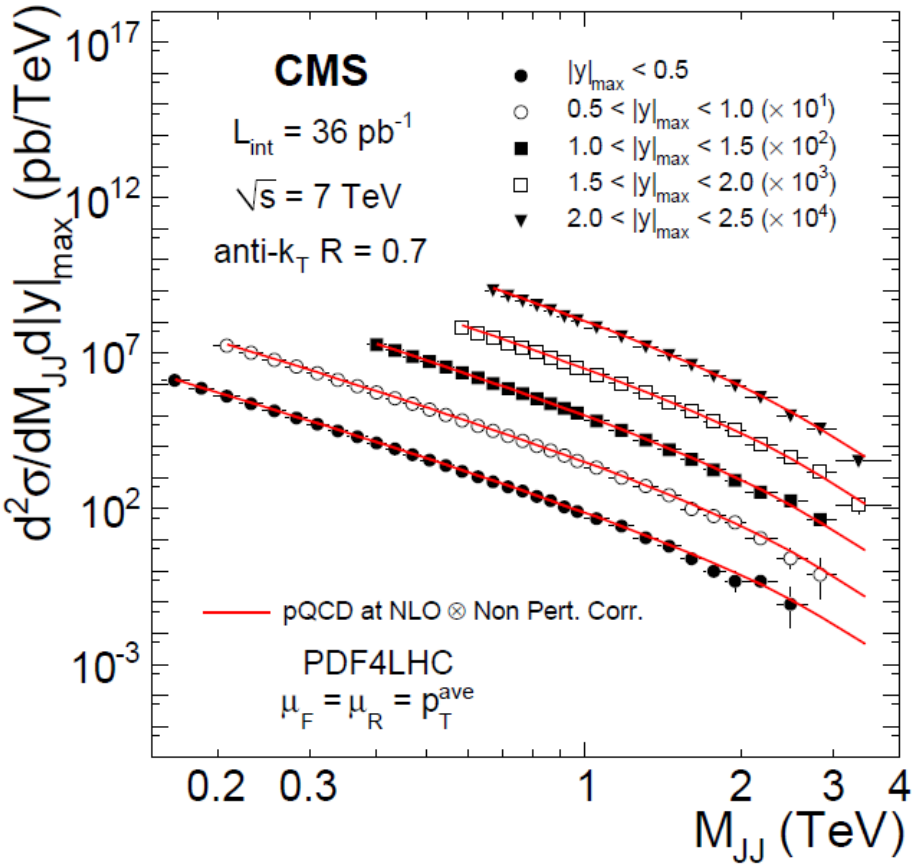




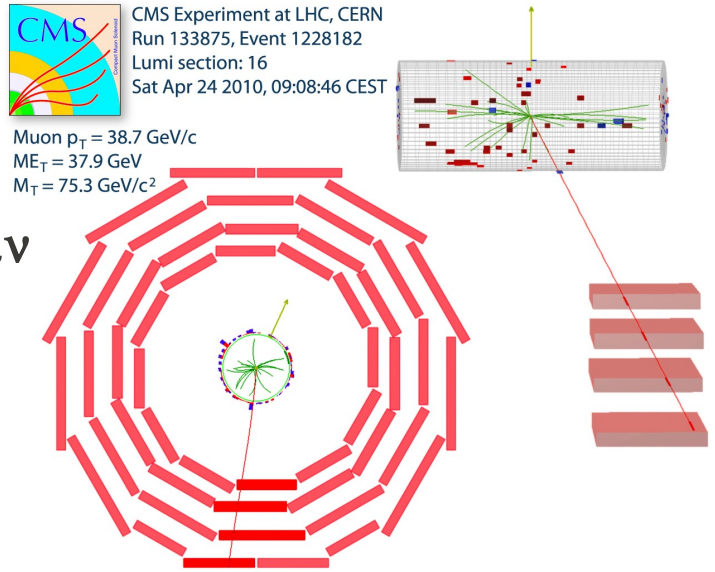
Di-Jet Cross Sections

- Di-jet spectrum tested up to masses of 4 TeV
- Data agrees well with prediction (NLO pQCD + non-perturbative corrections)
- Experimental uncertainty dominated by jet energy scale
- PDF generally largest theoretical uncertainty

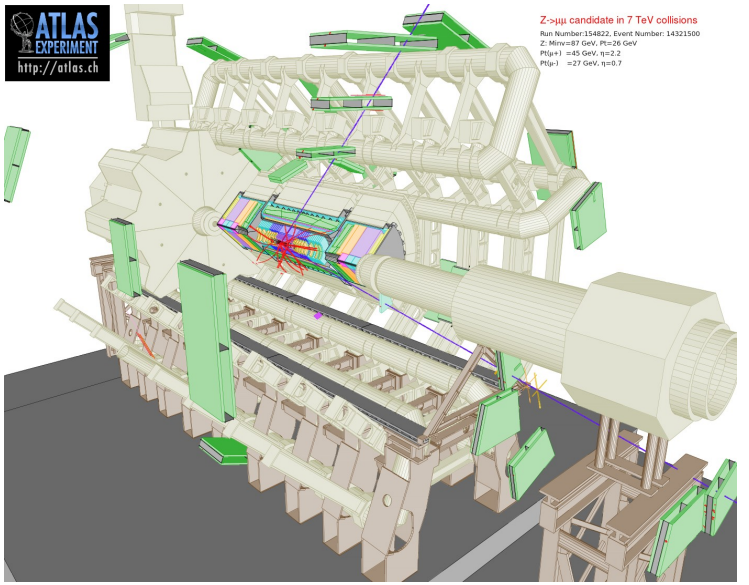




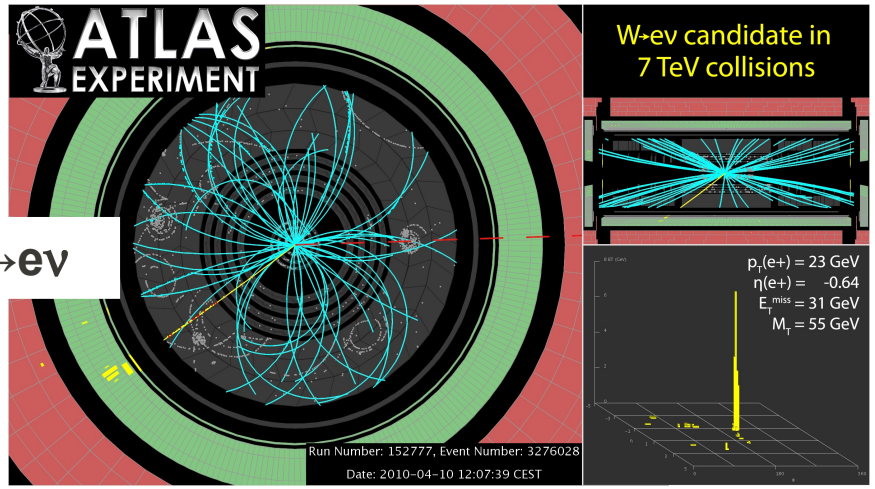
LHC Standard Candles



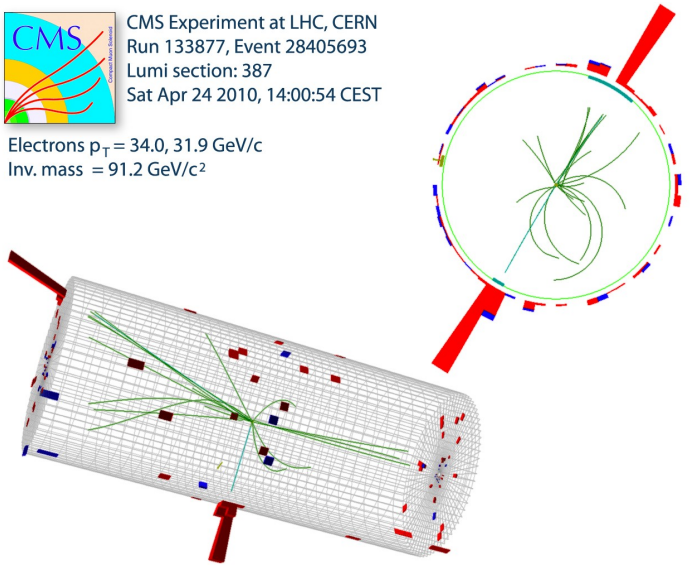
$W \rightarrow \mu\nu$



$Z \rightarrow \mu\mu$



$W \rightarrow e\nu$

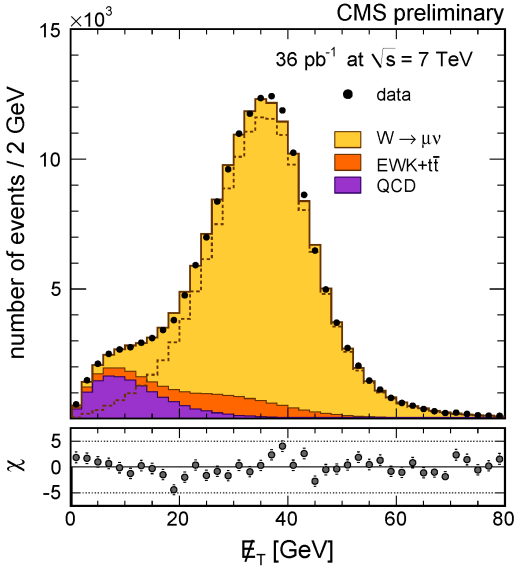


$Z \rightarrow ee$

LHC Standard Candles

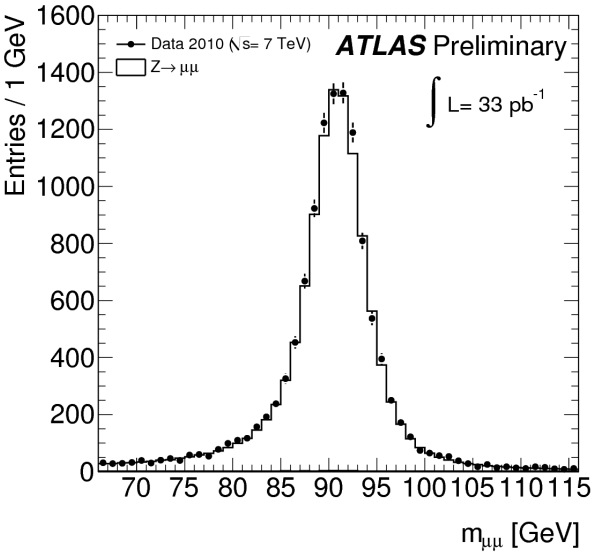
W→μν

~120000 evts



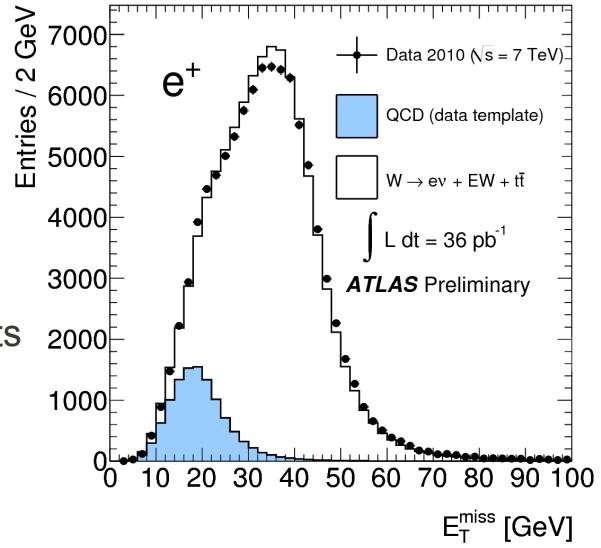
Z→μμ

~10000 evts



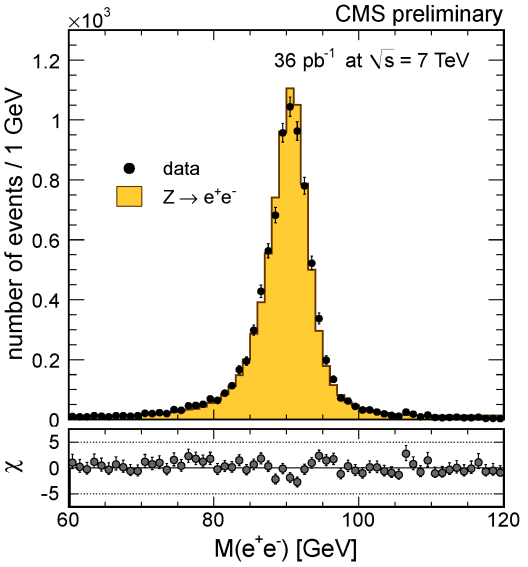
W→eν

~120000 evts



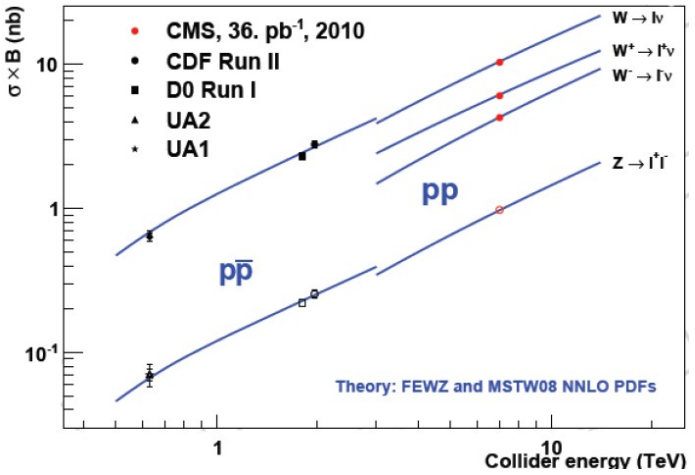
Z→ee

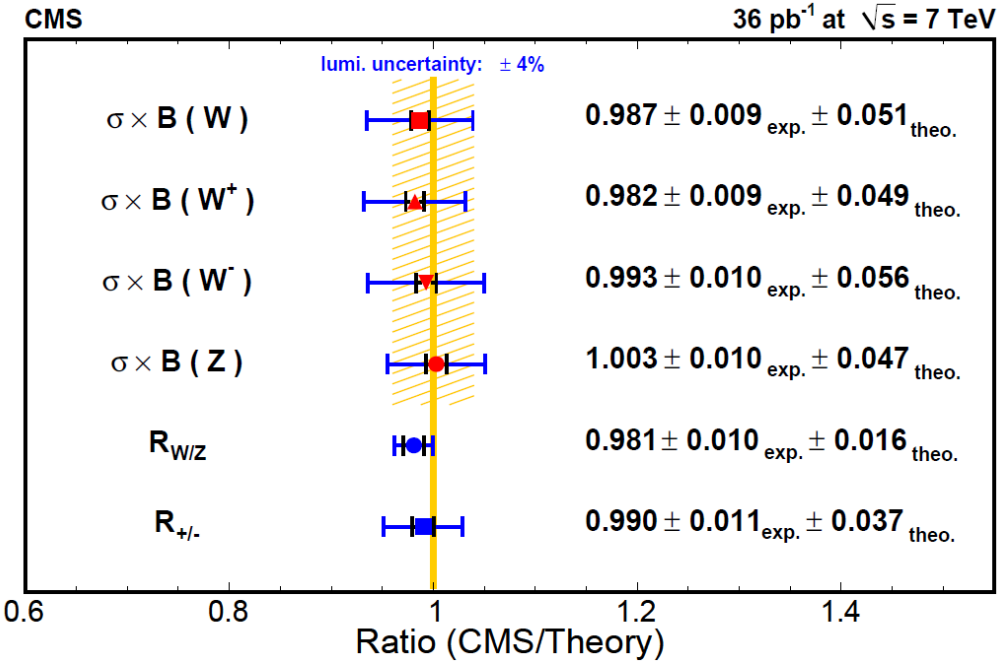
~10000 evts

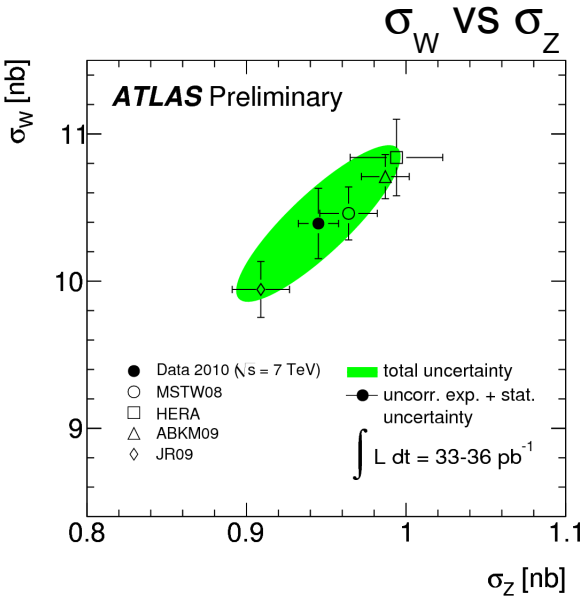


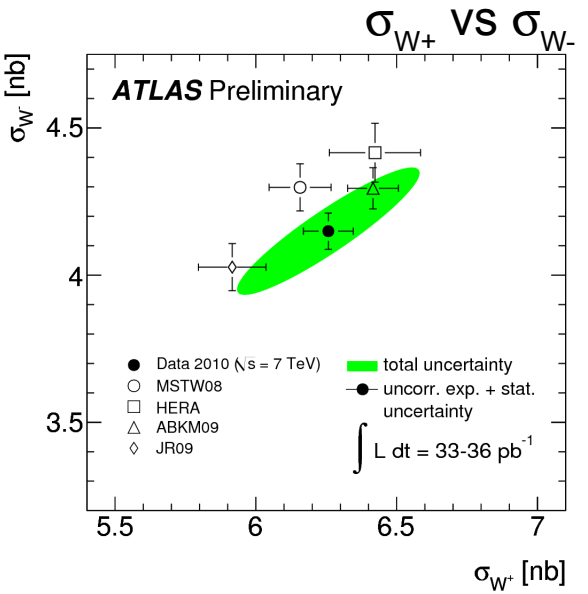
Vector Boson Production

- Results consistent with NNLO calculations (qQCD+PDF)
- ~1% experimental uncertainty
- 4% luminosity largest uncertainty









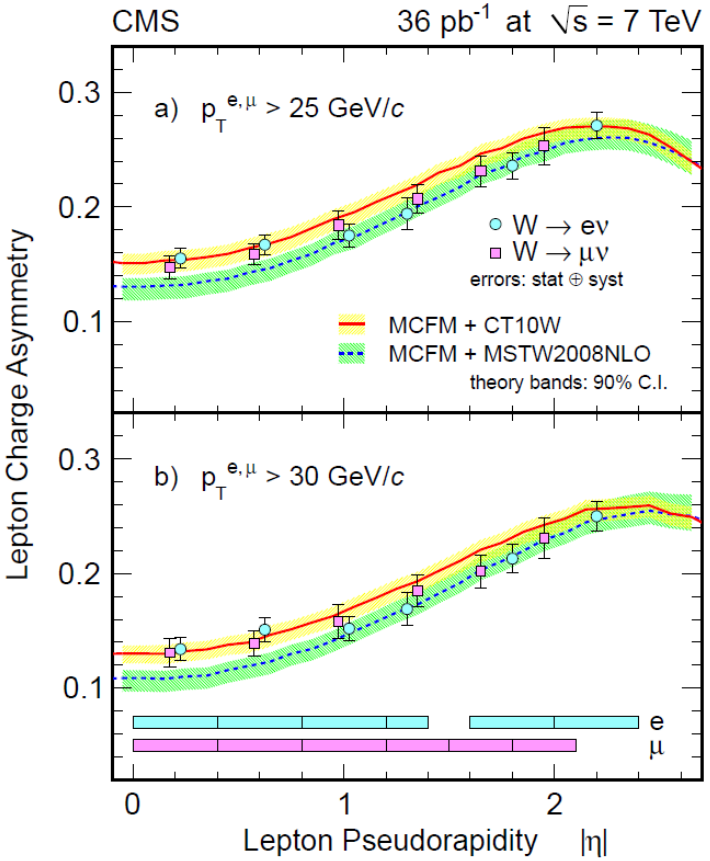
Lepton Charge Asymmetry

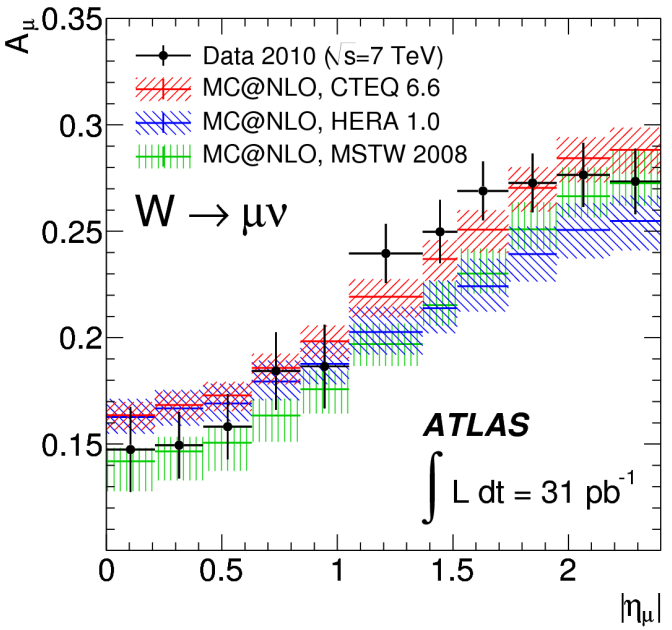
- Measured with electrons and muons
- ATLAS and CMS selected different phase space
- Electron channel allows larger η coverage; charge confusion due to bremsstrahlung more challenging
- Results provide strong new constraints on PDFs

$$\frac{\sigma(W^+)}{\sigma(W^-)} = 1.43 \pm 0.05$$

Experimental quantity :

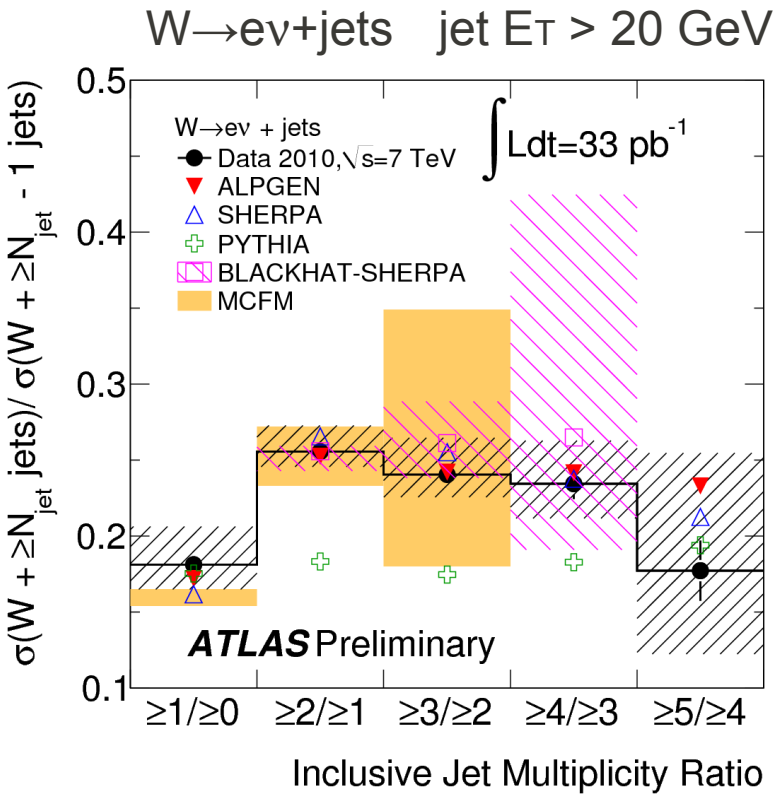
$$\mathcal{A}(\eta) = \frac{d\sigma/d\eta(W^+ \to \ell^+\nu) - d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \to \ell^+\nu) + d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}$$

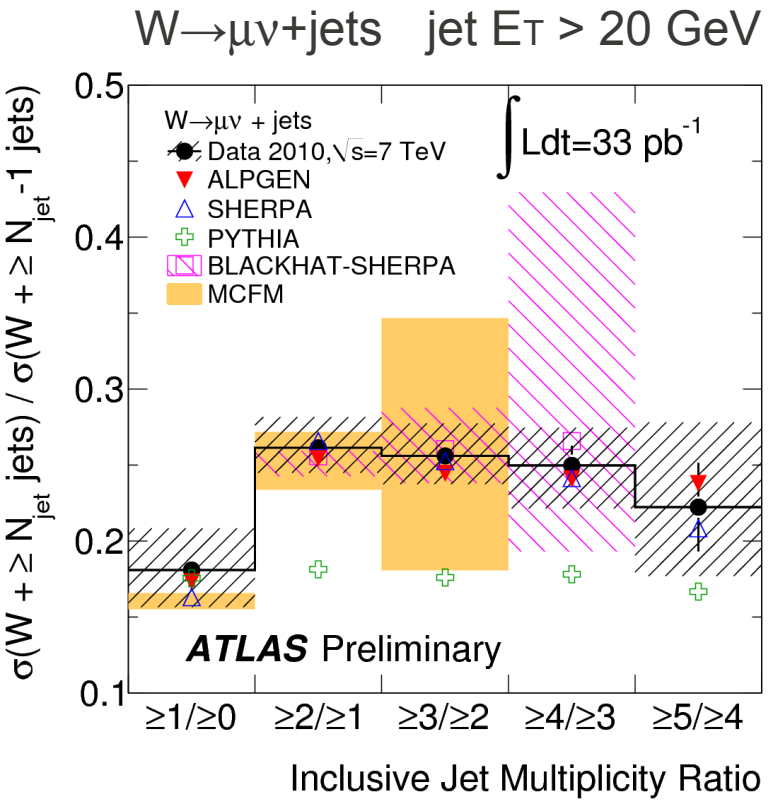




Vector Bosons Plus Jets

- Major background for top, Higgs & new physics
- ATLAS & CMS report inclusive rates and double differential cross sections
- Results compared to particle level predictions
- Agreement with ME generators





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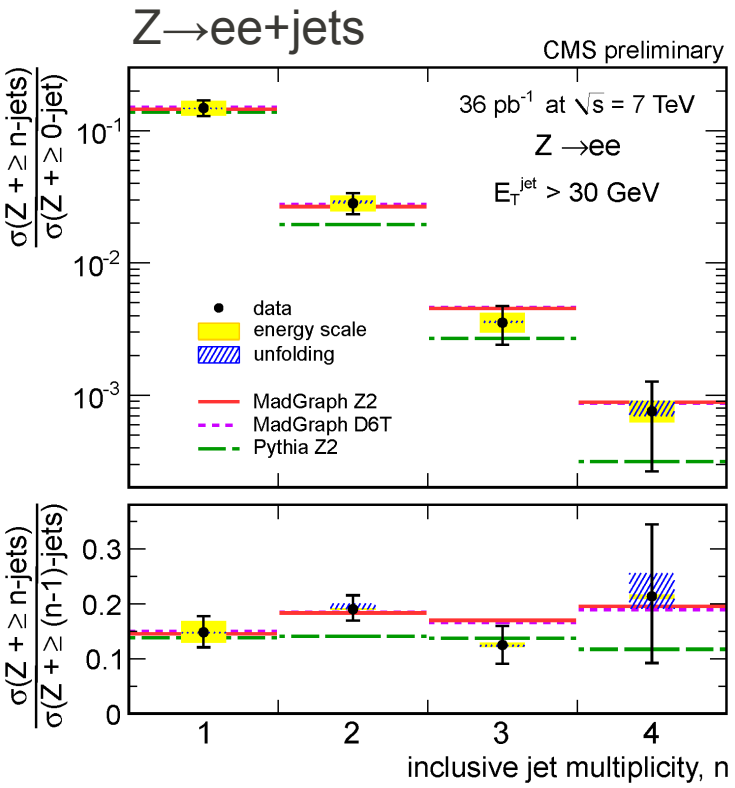
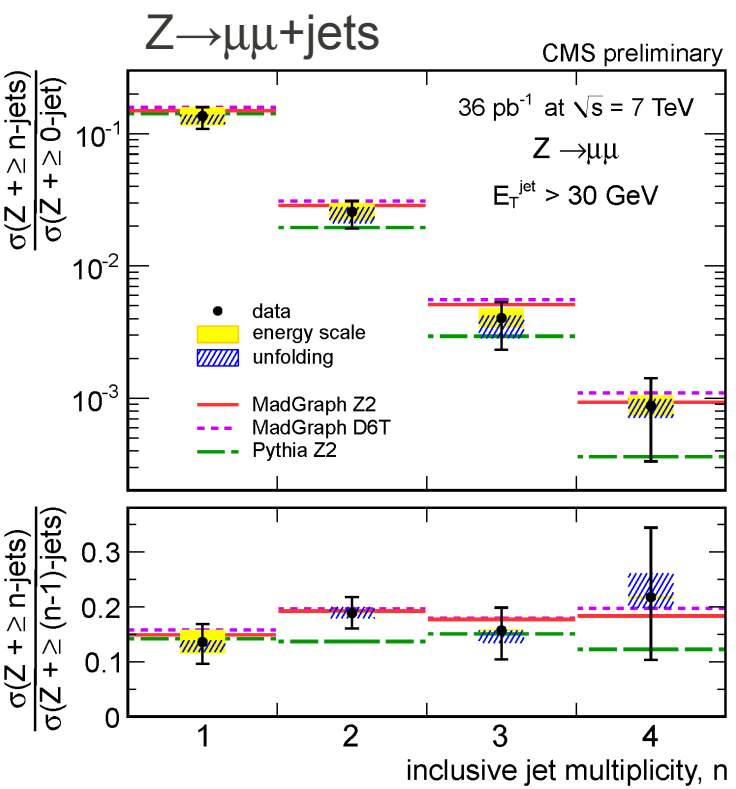
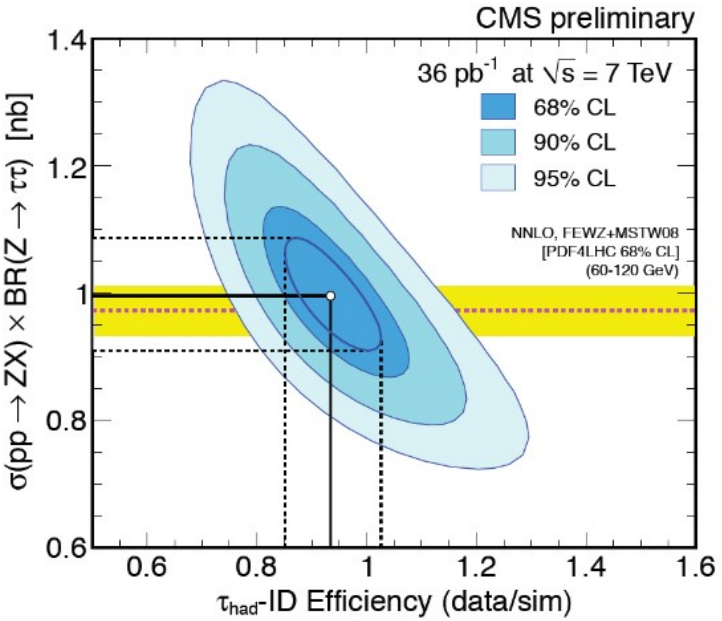
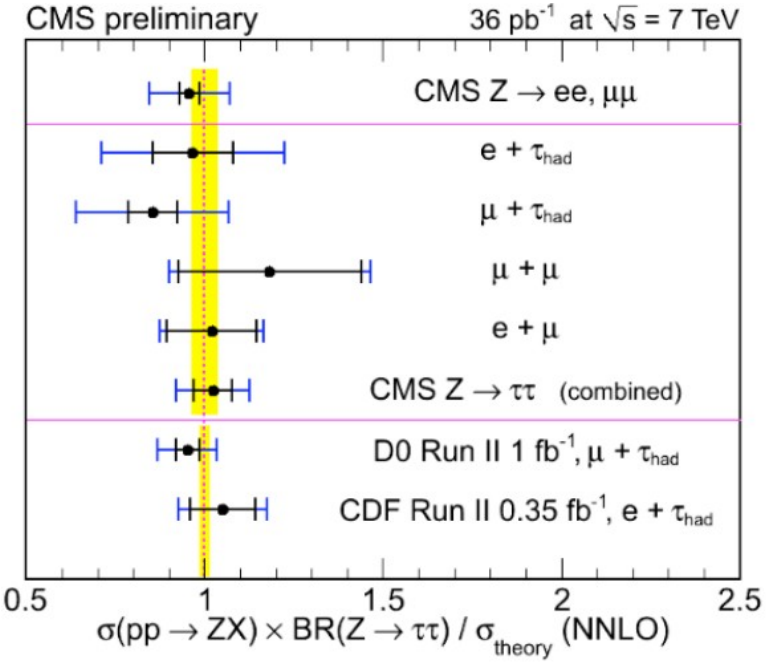




W & Z to Tau Decays

- Establish hadronic tau as tool for many new physics search, in particular Higgs
- CMS uses reconstruction of individual decay modes
- ATLAS traditional cone algorithm



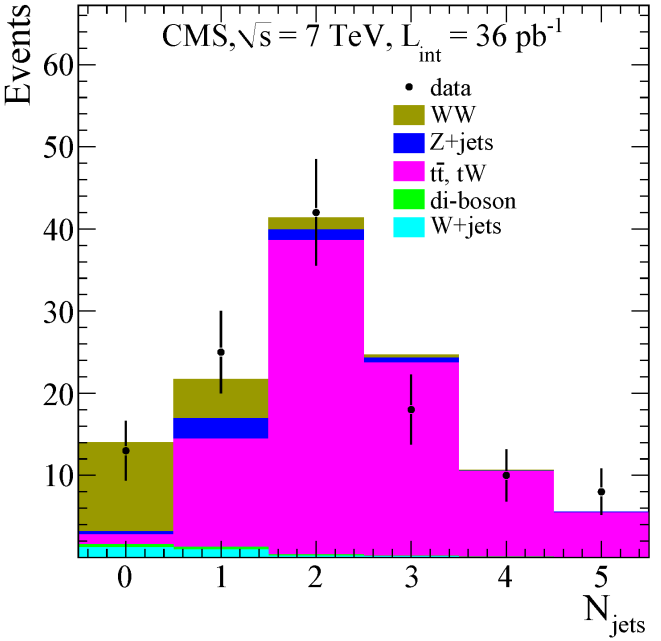


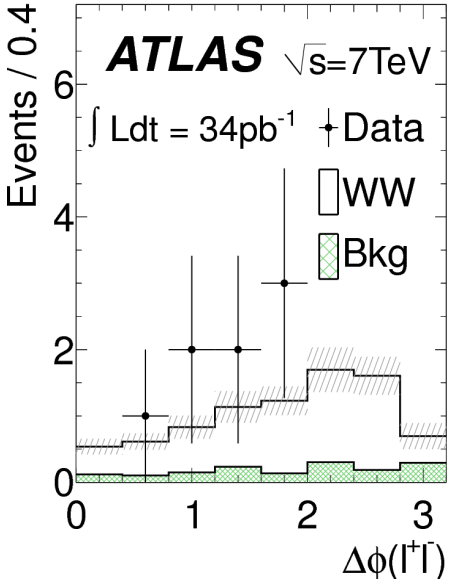
Combined:

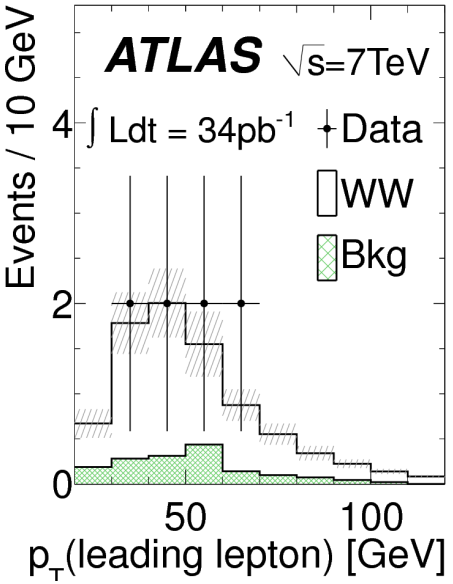
$\sigma \bullet BR(Z/\gamma^* \rightarrow \tau^+\tau^-) = 1.00 \pm 0.05\ (stat.) \pm 0.08\ (sys.) \pm 0.04\ (lumi.)\ nb$

Vector Boson in Pairs

- WW production
  - Shares final state with H→WW search. Groundwork for Higgs search.
  - Top quarks major background
  - Cross section measured in agreement with SM
    - ATLAS: **N_{obs} = 8**, N_{bkg} = 1.7
    - CMS: **N_{obs} = 13**, N_{bkg} = 3.3
  - Dominated by statistical uncertainty
  - Limits on triple gauge couplings (TGC)

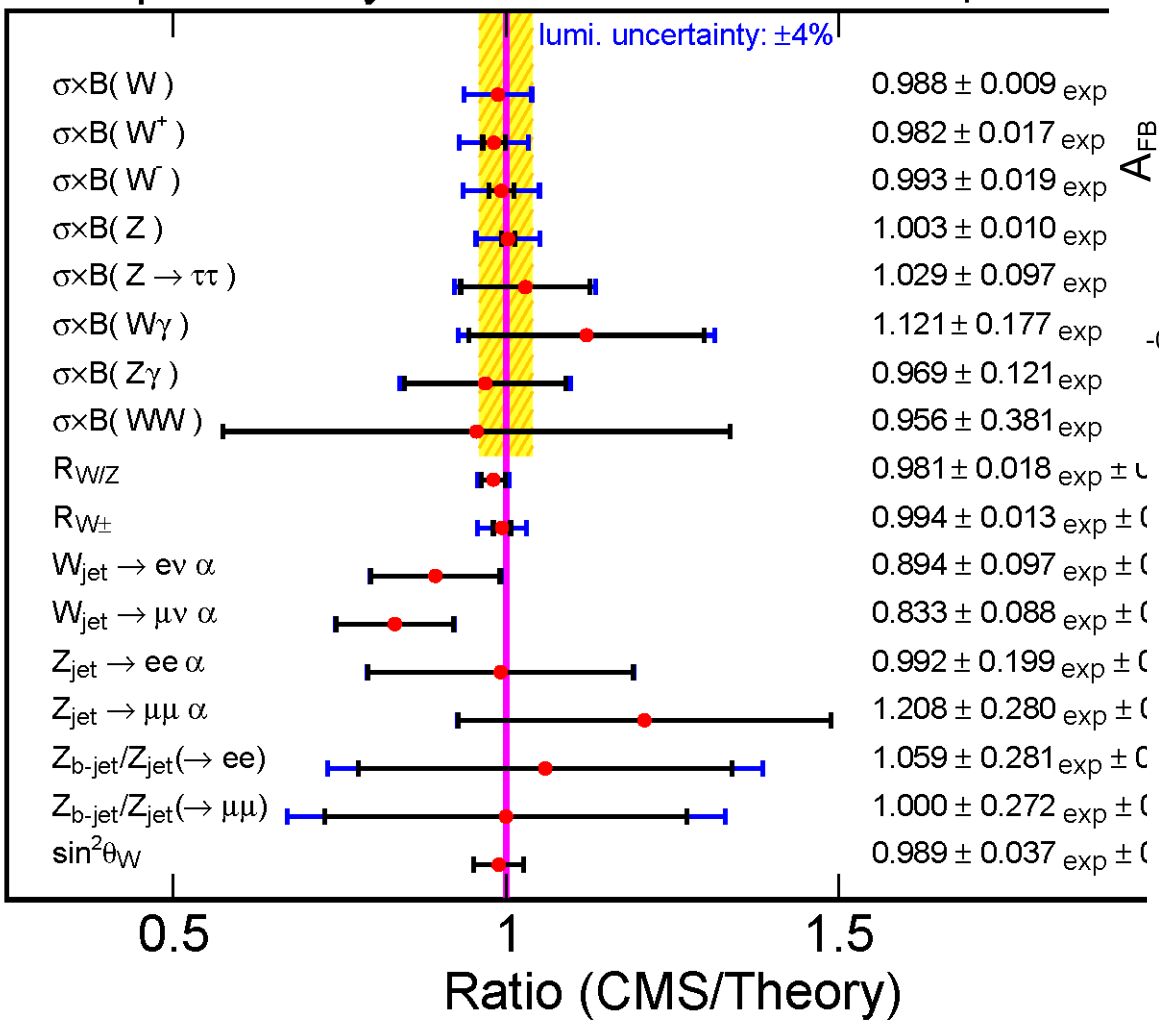


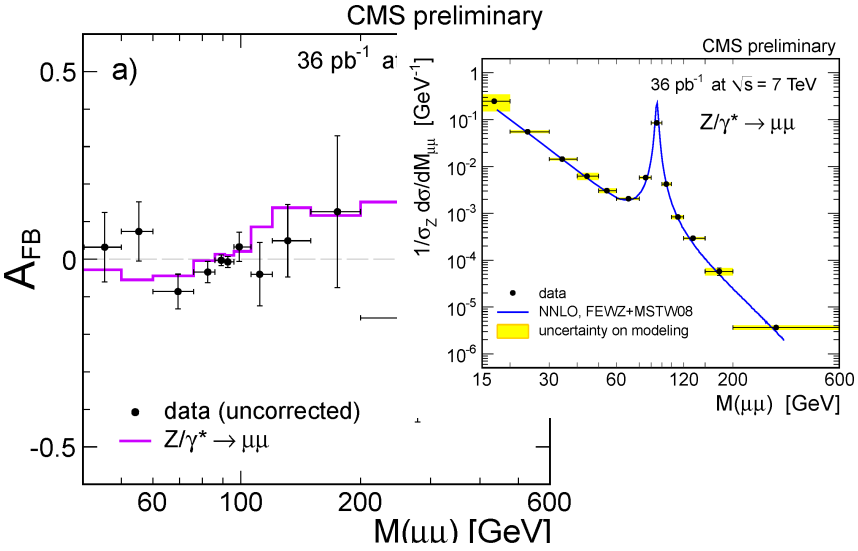


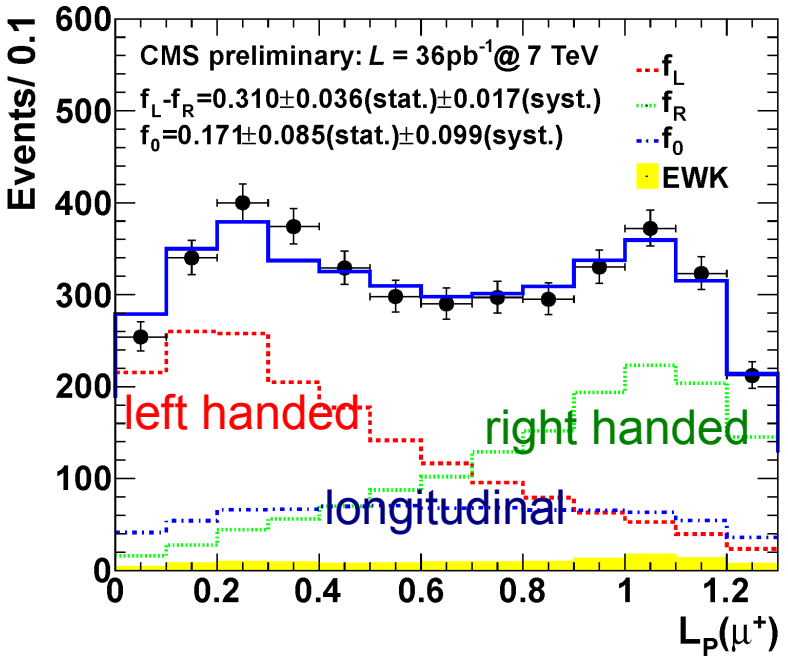


	σ_{WW} (pb)
ATLAS	$40\ ^{+20}_{-16}$ (stat)
CMS	41 ± 15.3 (stat)
Theory	43 ± 2

More Results with W and Z's

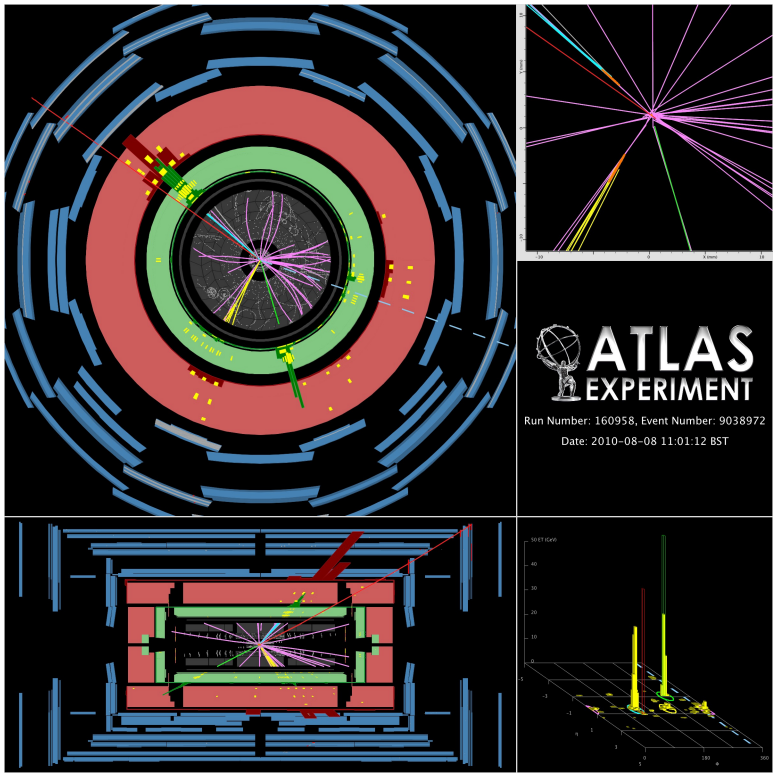






Top Quark Physics

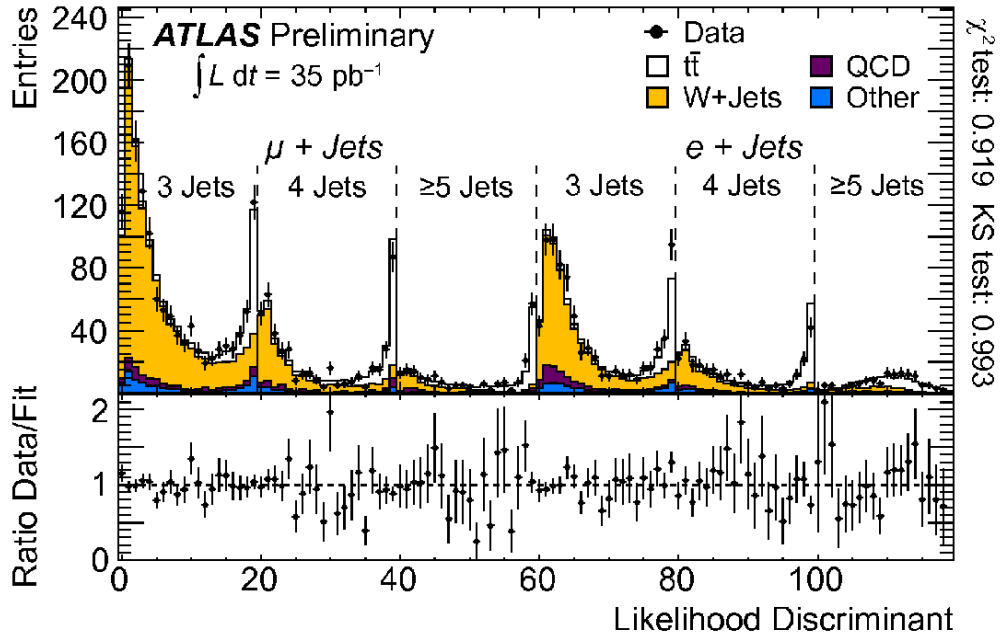
- LHC is a factory of top quarks
  - Cross section ~160pb
- Multiple final states used in measurements
  - di-lepton
  - lepton+jets
  - lepton+jets+b-tag
- Top quark measurements use most physics objects
  - Leptons
  - Jets and missing ET
  - Primary and secondary vertex (b-tagging) reconstruction
- Systematic uncertainties usually dominated by
  - JET/MET energy scale
  - b-tagging efficiency
- Top quark used as standard candle and is main background to many searches

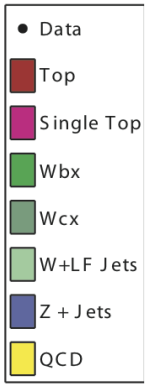


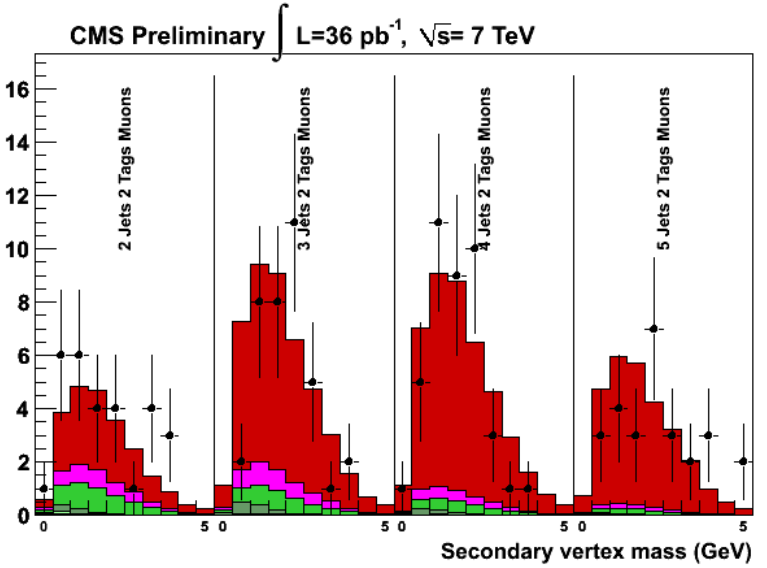
top candidate: e μ 2b

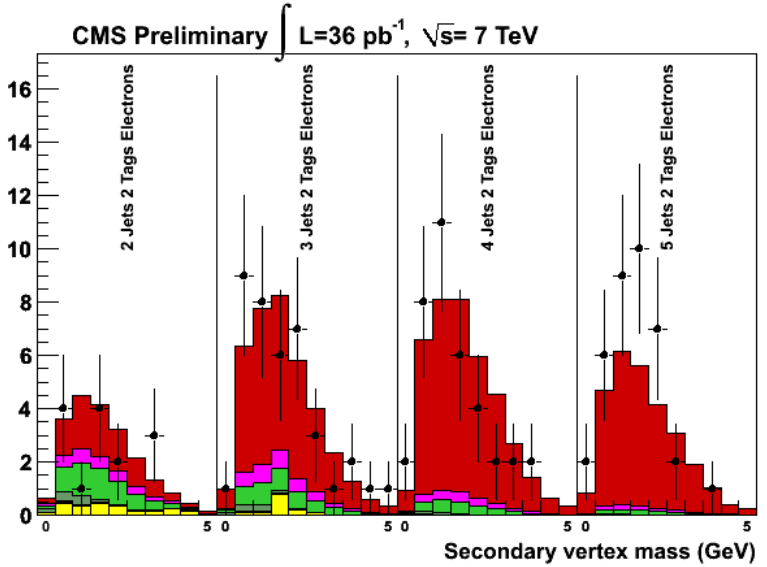
Top Quark Cross Section

- Lepton + jets channel with b tagging
  - Clean signal observed
  - ATLAS
    - Profile likelihood fit of multivariate discriminant
      - lepton η, jet momenta, aplanarity, b-tag weight
  - CMS
    - Binned likelihood with secondary vertex mass in categories of jets and jets with b-tag



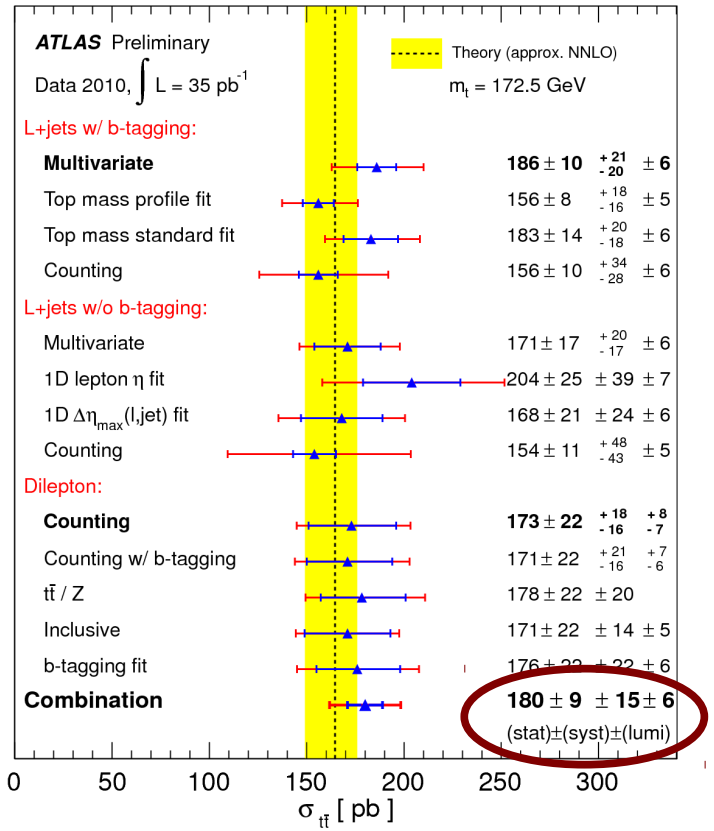


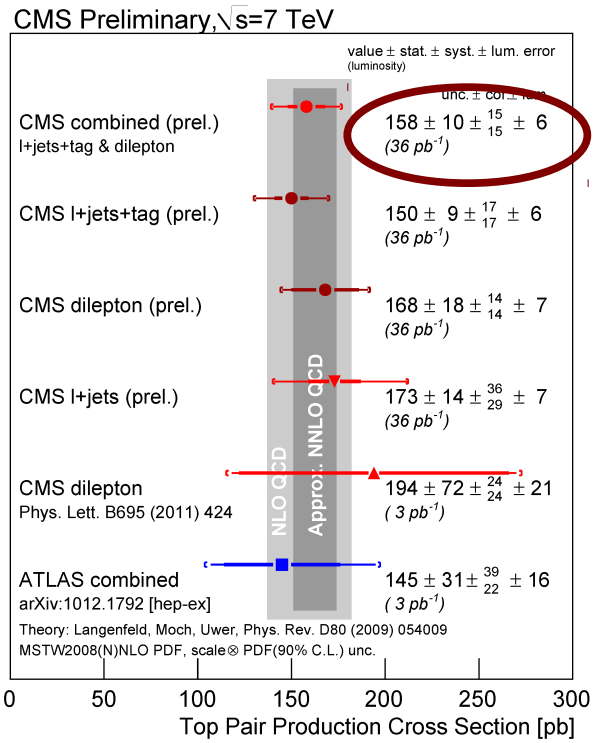


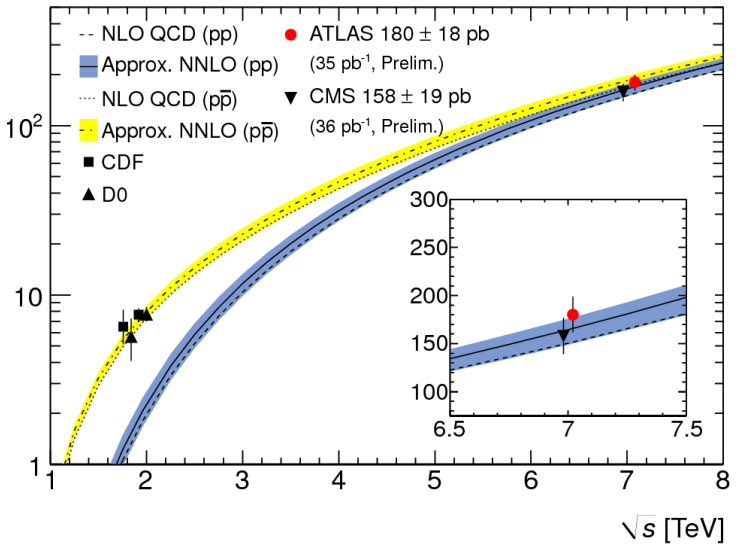


Top Quark Cross Section

- Measured in lepton+jets and di-lepton channels
- SM, ATLAS and CMS in agreement
- Experimental uncertainty in the 10% range, same order as theoretical prediction

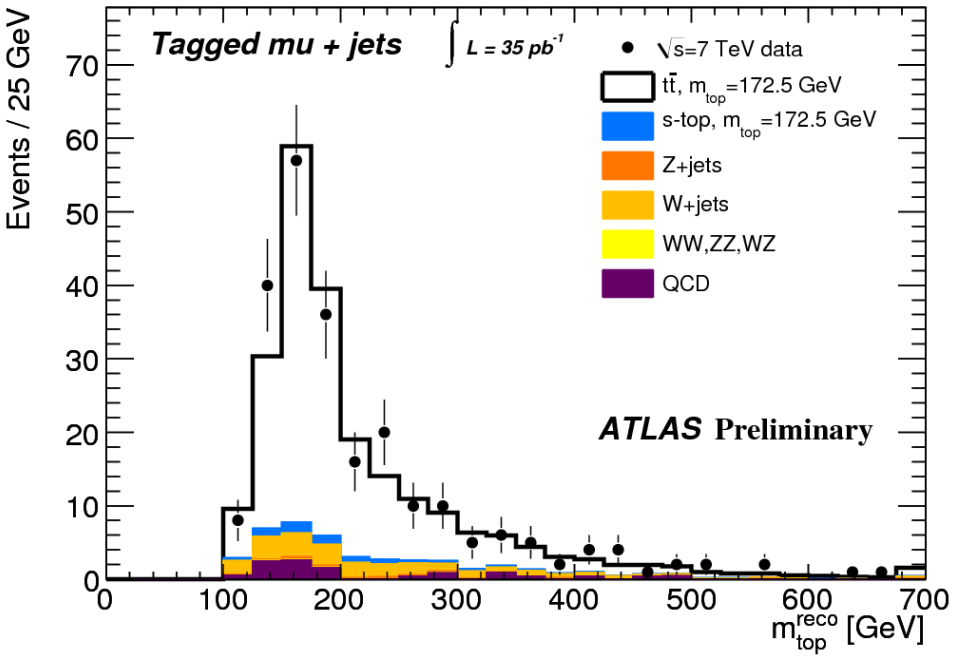


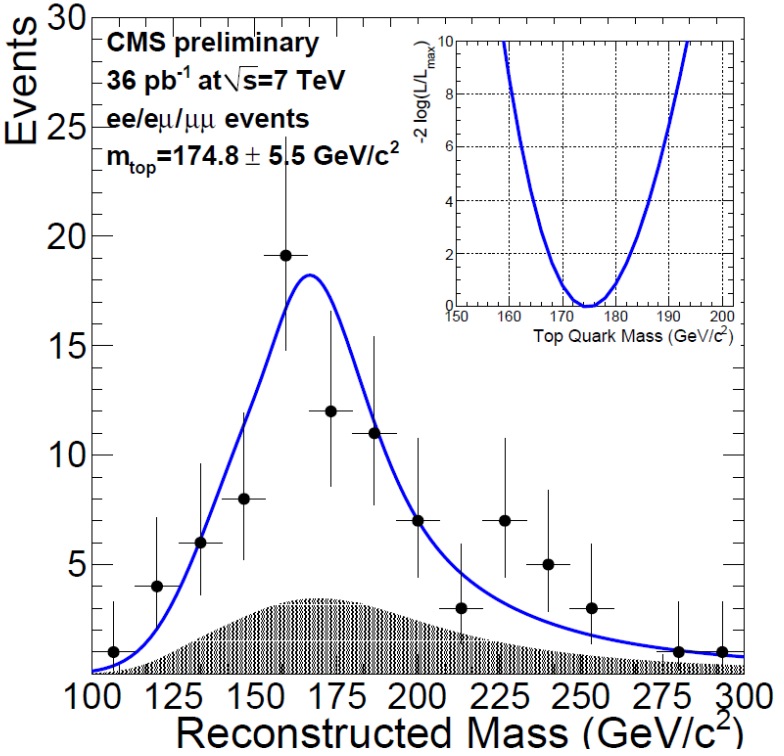




Top Quark Properties

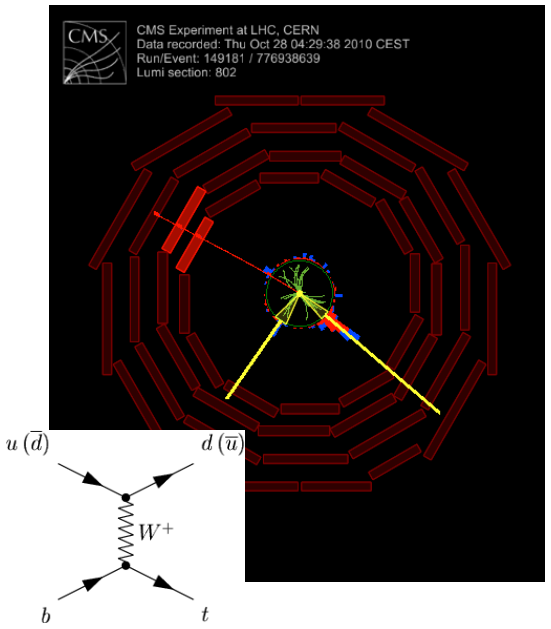
- Early top mass measurements
  - ATLAS: lepton+jet channel (m_{top} = 169 ± 4.0 ± 4.9 GeV)
  - CMS: two measurement in di-lepton channel (m_{top} = 175.5 ± 4.6 ± 4.6 GeV)
  - Uncertainties in the 5 GeV range
  - Consistent with Tevatron measurements
- Others: W polarization, search for FCNC, top pair charge asymmetry

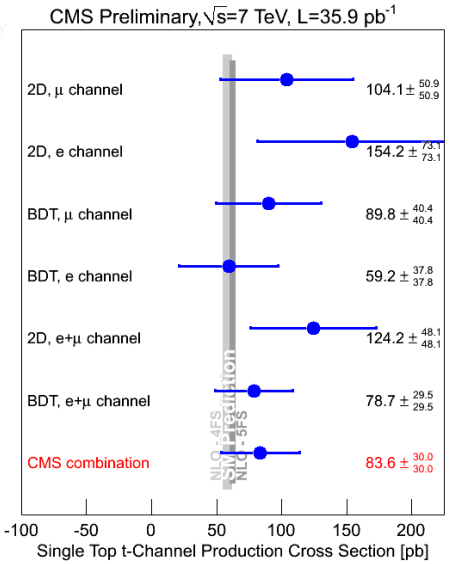


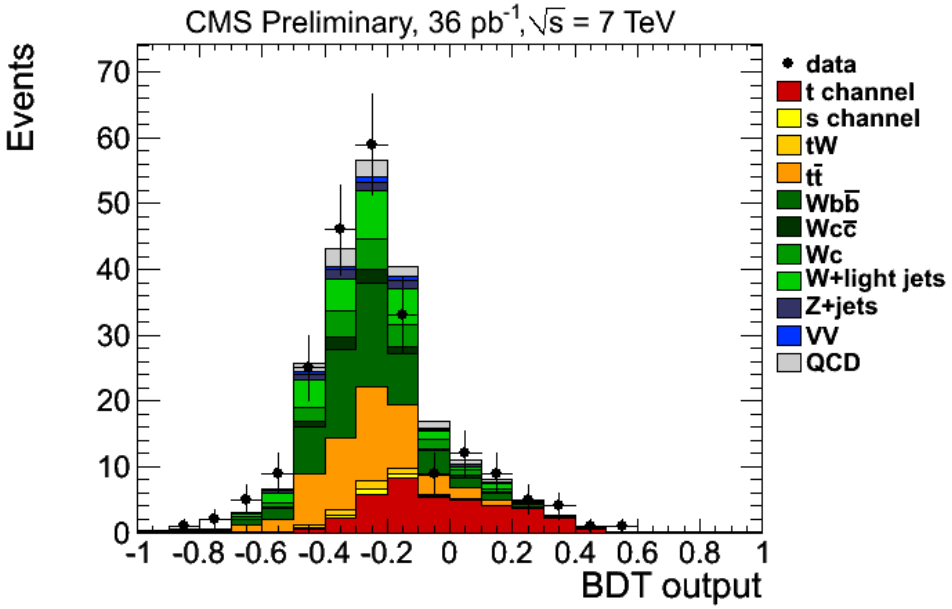


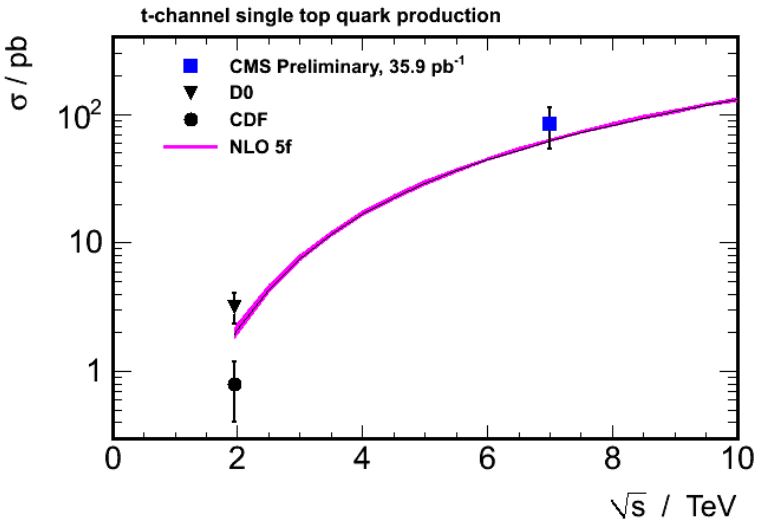
Single Top Quarks

- First observation of single top t-channel production at the LHC from CMS
- $\sigma = 86.3 \pm 30$ pb by CMS
- $\sigma = 53\ ^{+46}_{-36}$ pb by ATLAS
- Cross sections in agreement with expectation
- Signature: lepton + E_T^{miss} + b-jet + jet
- Small signal extracted from large background with multivariate analysis technique



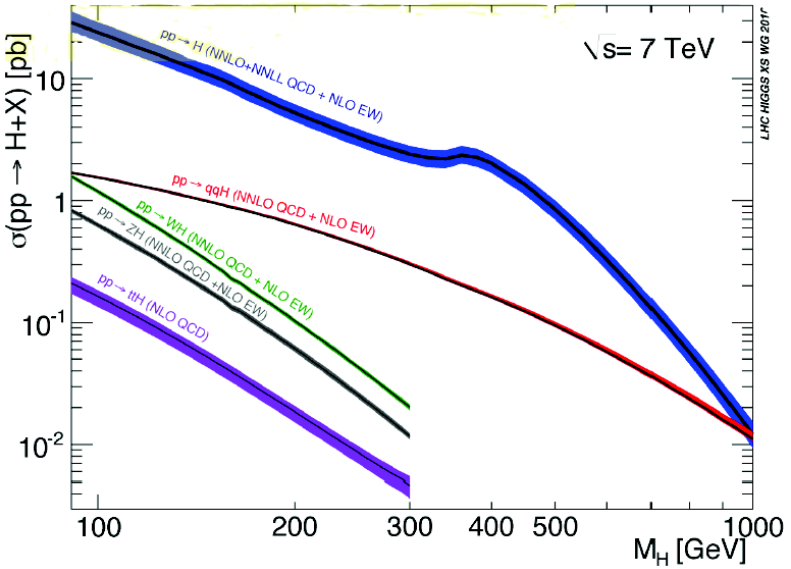


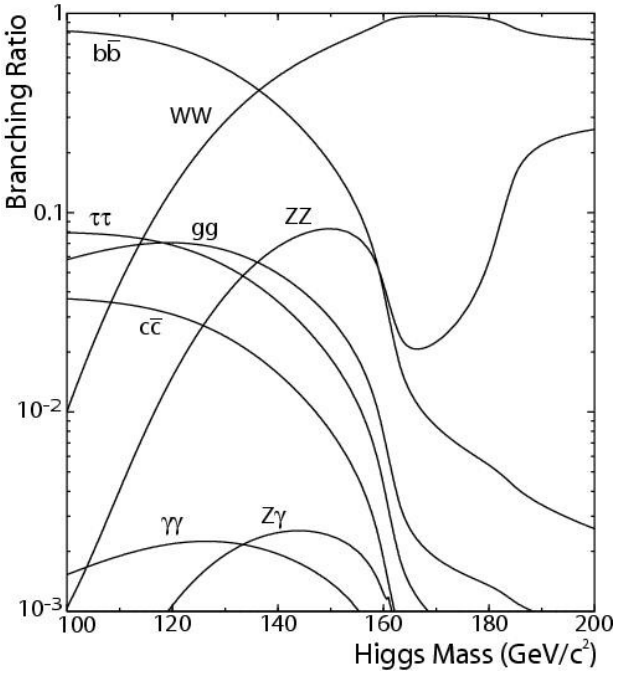




Higgs Searches at the LHC

- Combined effort by ATLAS, CMS and theory
  "Handbook of LHC Higgs Cross Sections"
  arXiv:1101.0593





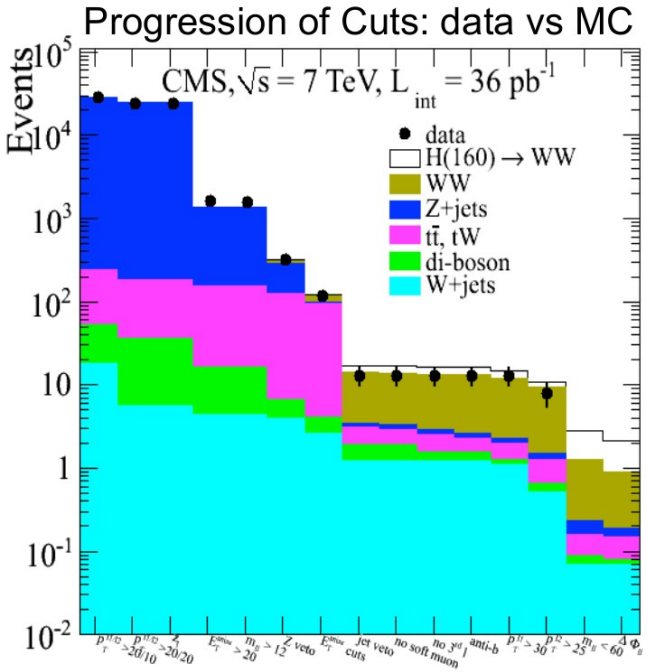
Channels included	≈ Mass range (GeV)	Status, Comments
H→ γγ	115-150	Challenging.
VBF H→ ττ	115-145	Results with 2010 data. Breaking new ground
VH, H→bb (highly boosted)	115-125	
VH, H→WW→lνjj	130-200	Results with 2010 data. Work horse for 120-200 GeV, large yield
H→WW→2l2ν + 0/1 jets	120-600	
VBF H→WW→2l2ν	130-500	
H→ZZ→4l	120-600	The golden channel. Low bkgr but low yield
H→ZZ→2l2ν	200-600	Major bkgr is diboson and top. Profits from jet, MET reco and good b-tagging
H→ZZ→2l2b	300-600	

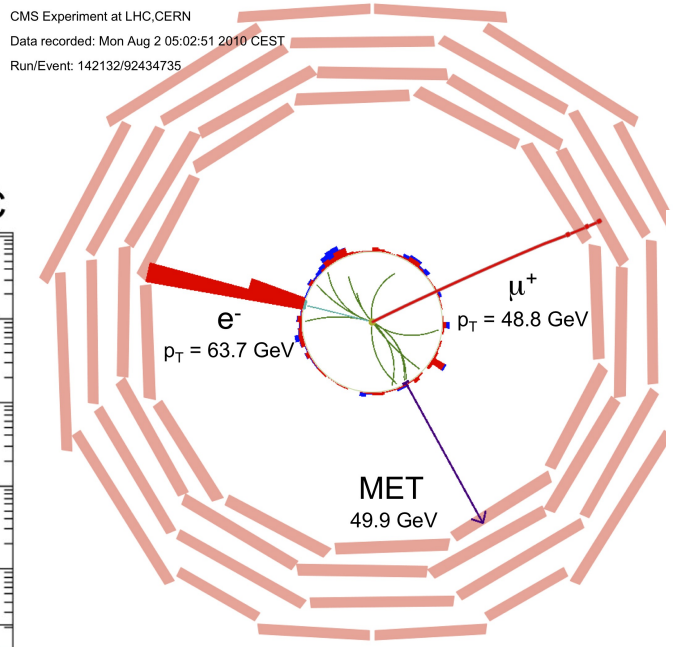
modified from K. Hoepfner

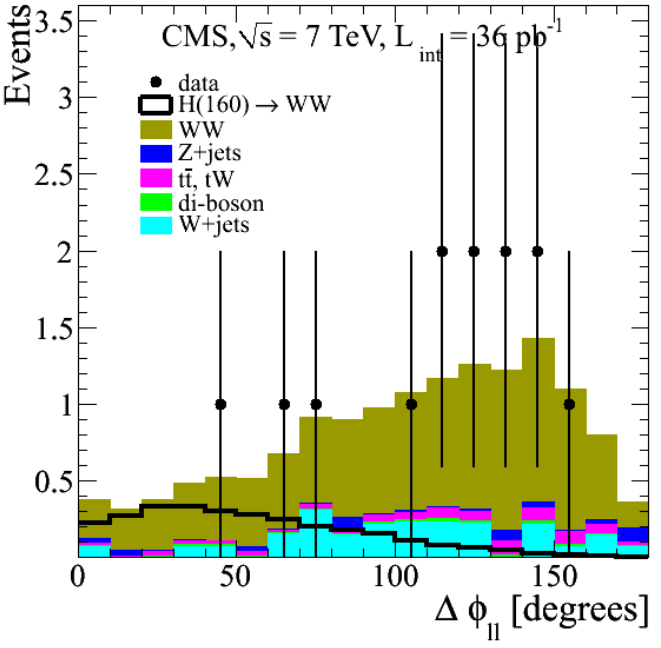
- Event yields can be modified and additional channels are possible in models beyond the SM
  - Modified particle content can change production or decay of the Higgs boson (e.g. 4th generation models)
  - Higgs sector is modified
    - Two Higgs doublet models (2HDM)
    - More complex models

Higgs → WW

- H→WW→2l2ν : most significant analysis over large mass range
- Multiple analysis techniques deployed
- ATLAS and CMS with similar performance







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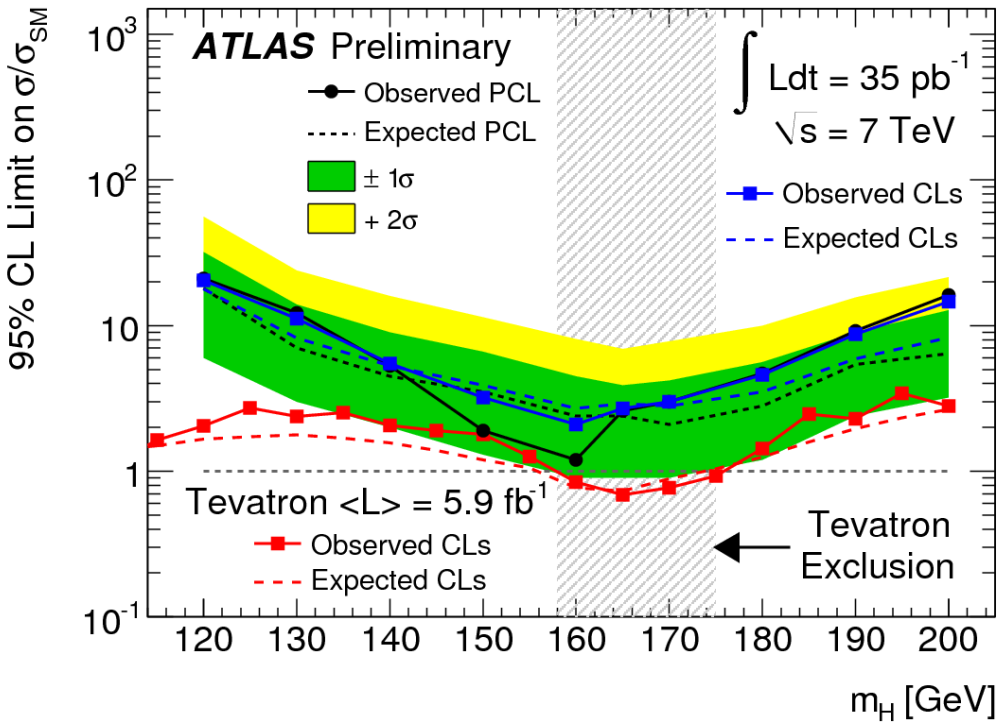
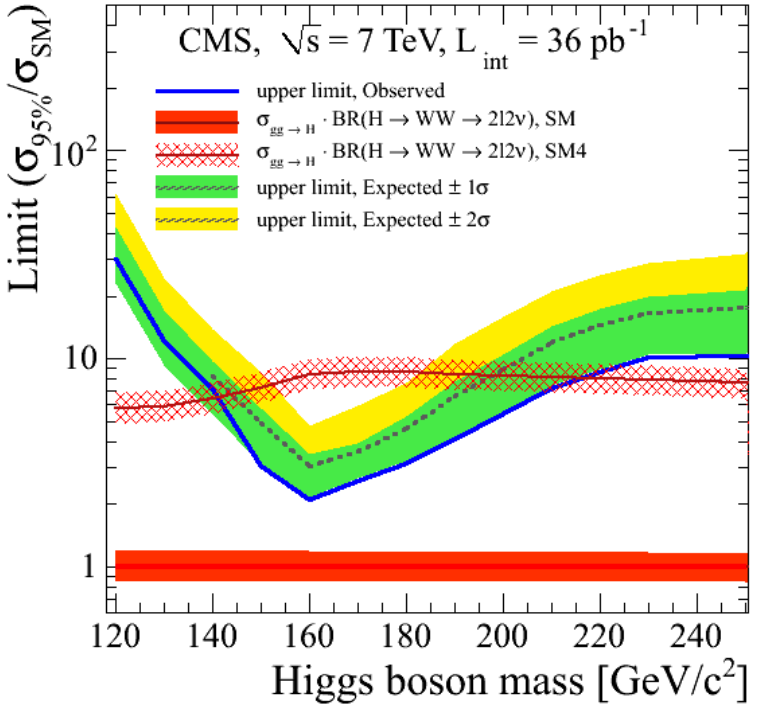
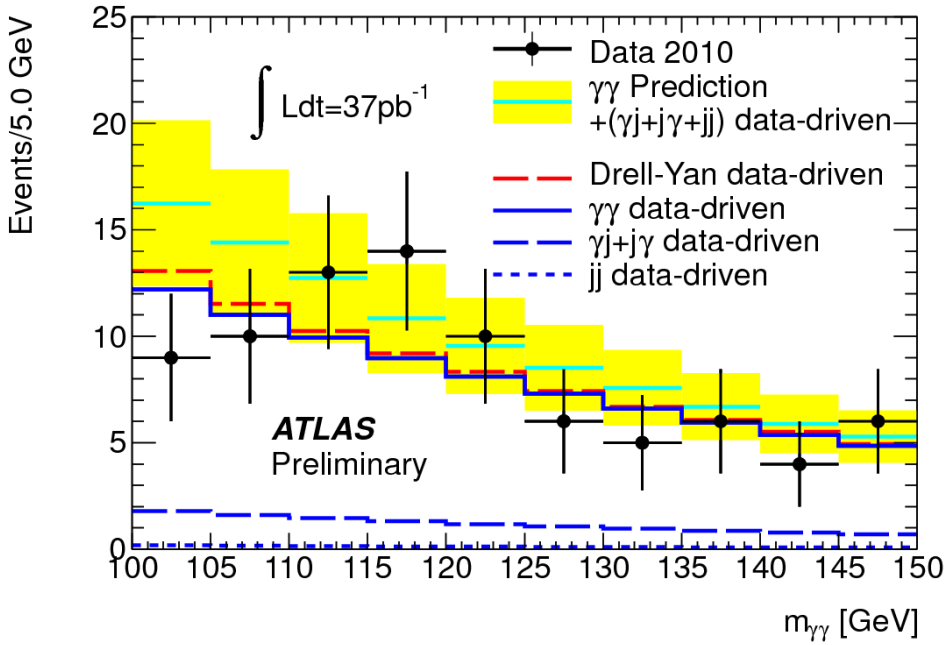
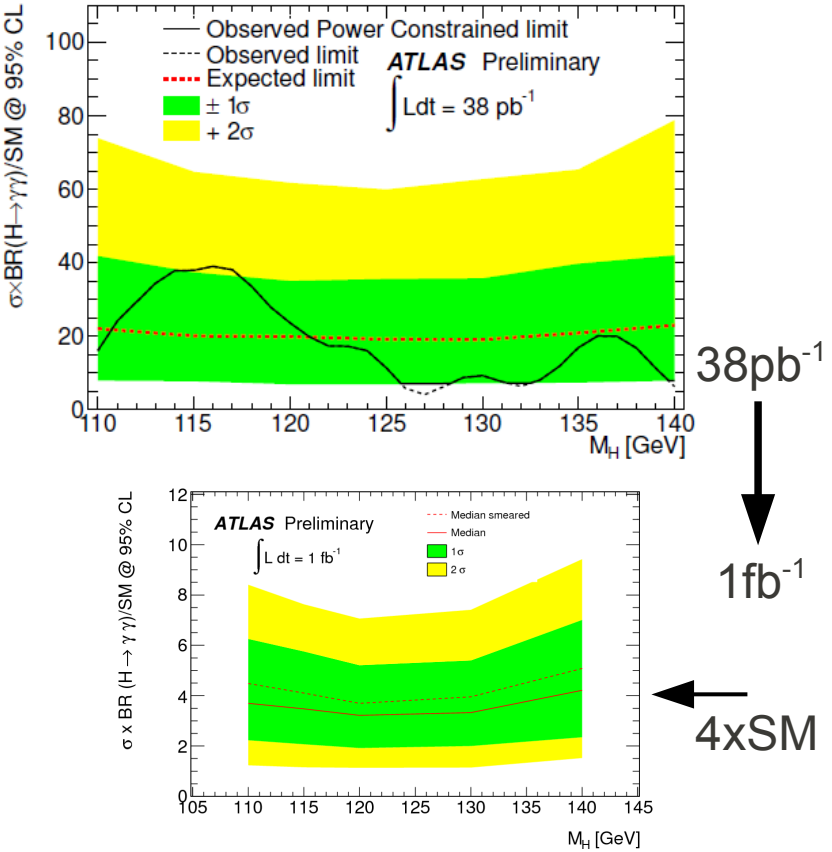




Higgs → γγ

- Very exciting channel. No signal observed yet.
- Mass range 110-140 GeV
- Measurement of background and estimation of sensitivity from ATLAS





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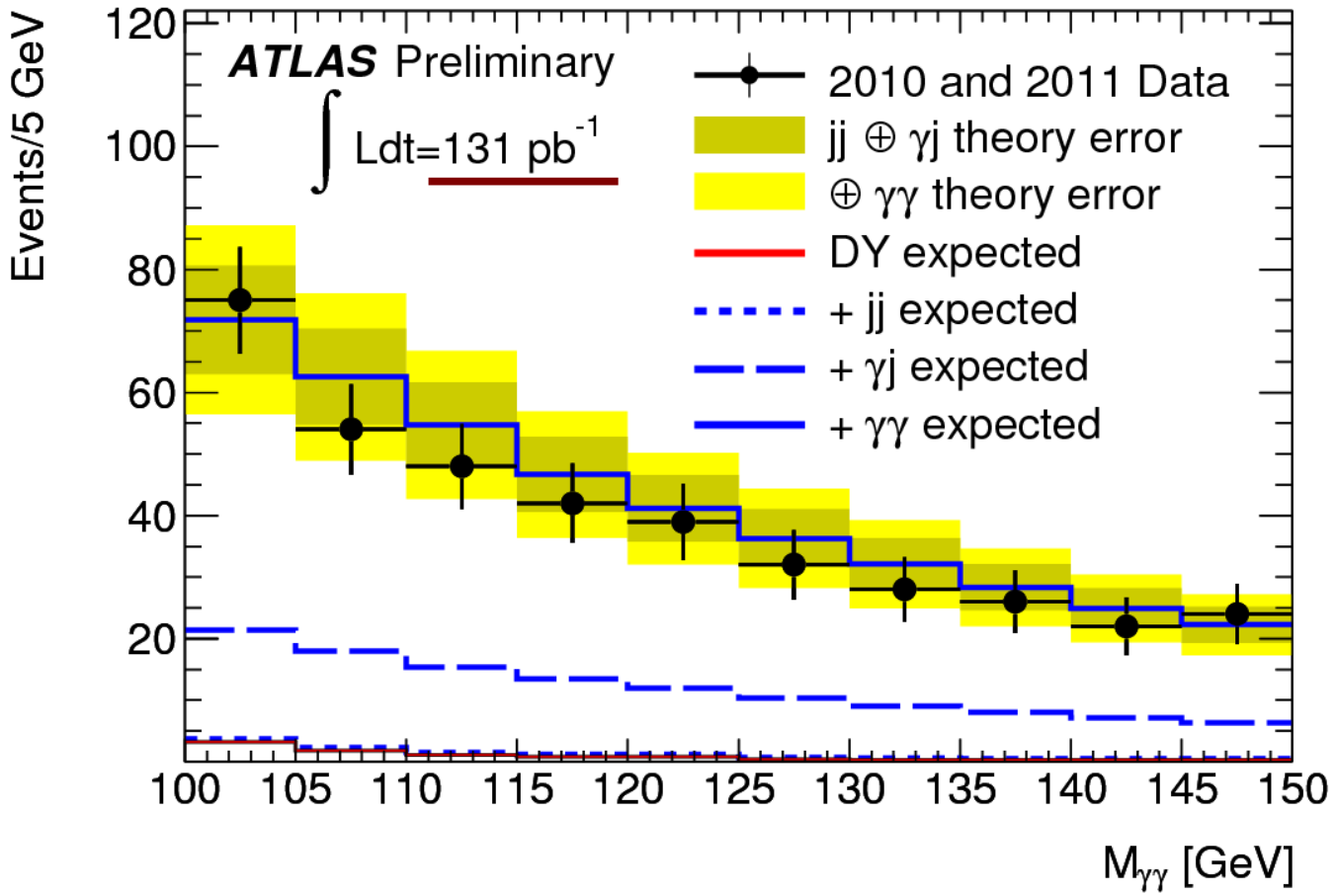
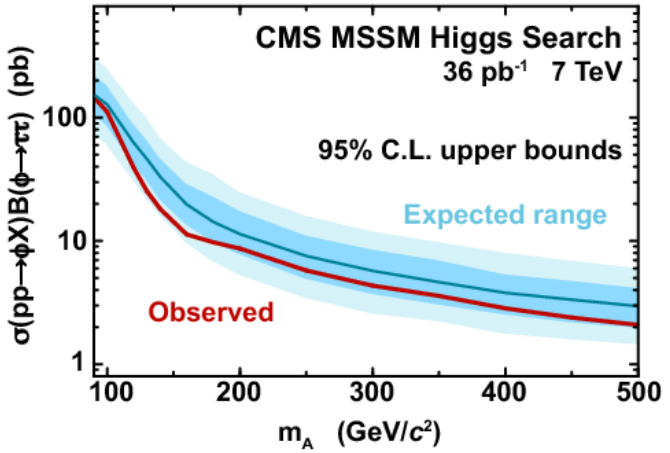
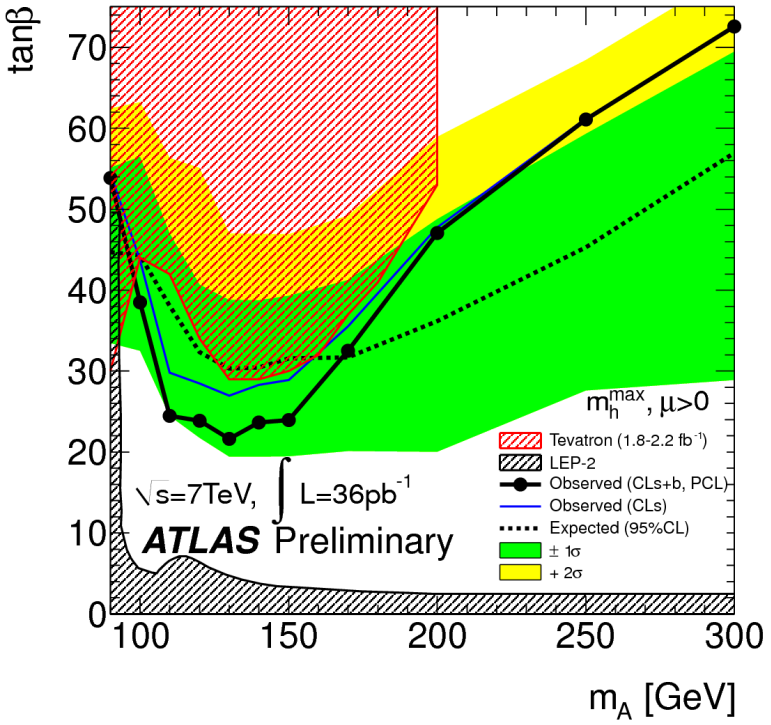
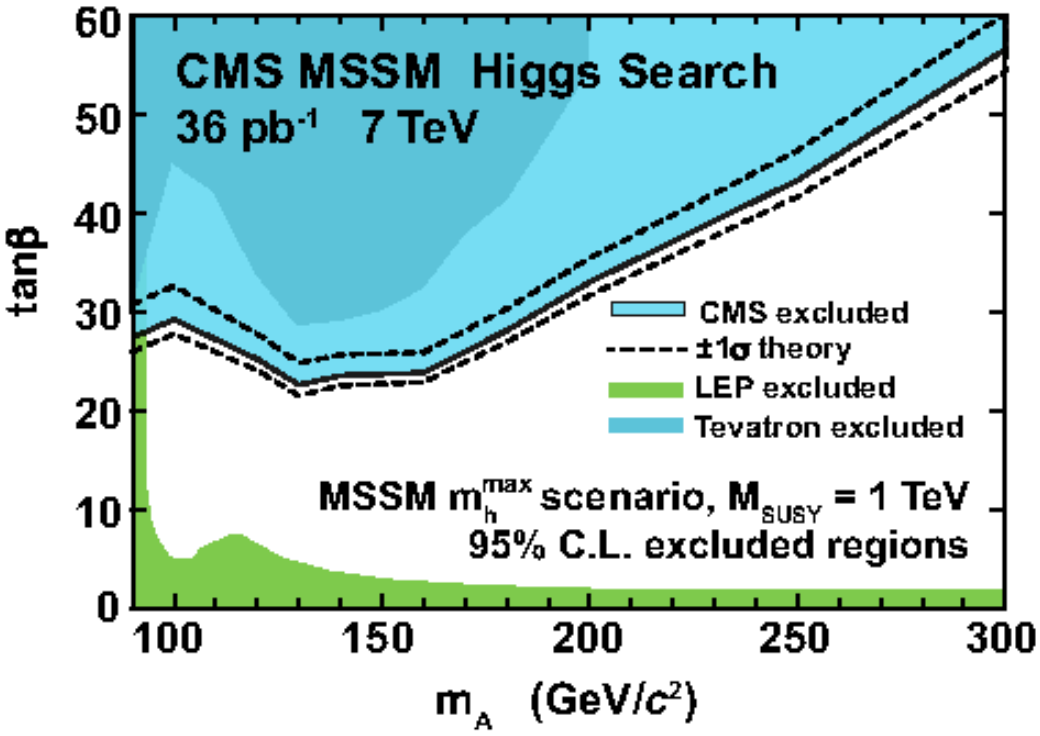


Higgs → ττ

- Studied τμ+τhad, τμ+τe and τe+τhad channels
- No excess observed in di-τ mass spectrum
- Z boson production irreducible background
- Limits on cross section and MSSM [tanβ,mA] exclusion
- ATLAS & CMS breaking new grounds!

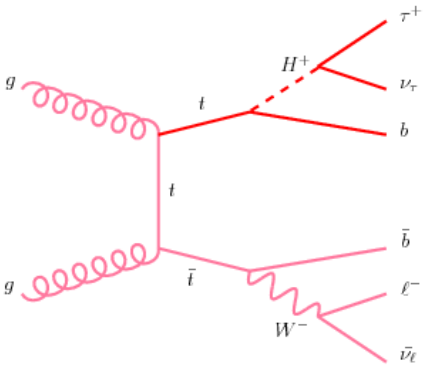


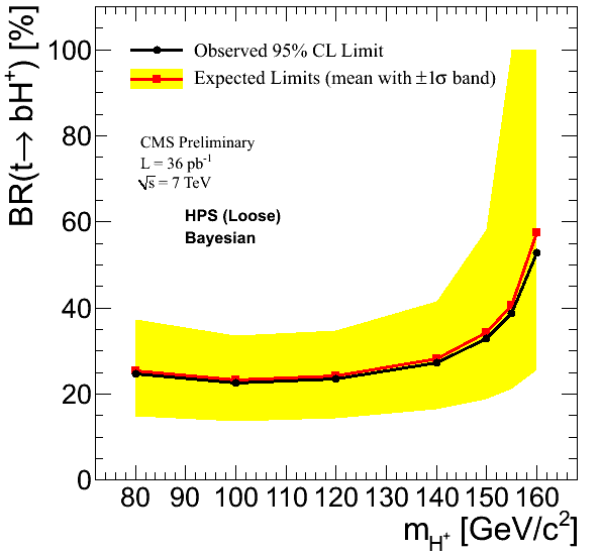




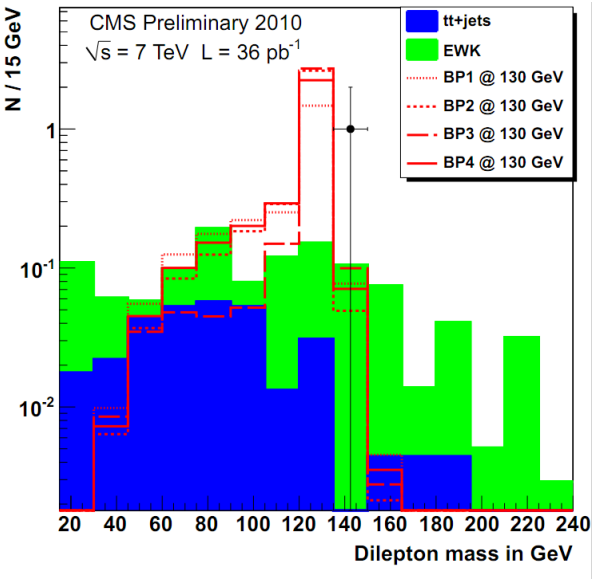
Charged and Doubly Charged Higgs

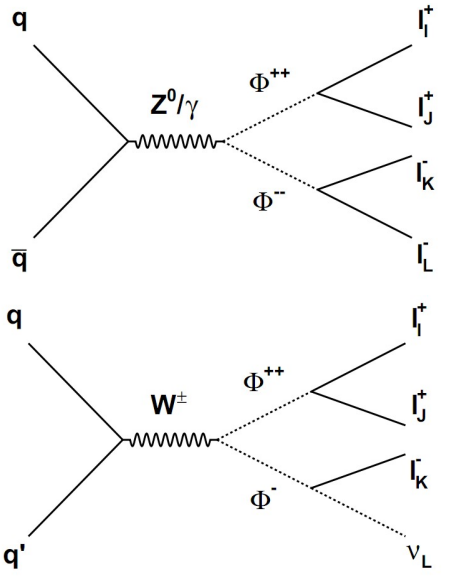
- **Charged Higgs**
  - Explore top decays. No deviation from expectation observed.
  - Limit on BR(t→H⁺b)
  - Limits comparable to Tevatron results





- **Doubly Charged Higgs**
  - Search in 3 or 4 lepton (e,μ,τ) final states
  - No excess observed
  - 95% CL on Φ^{++} for several scenarios
    - $m_{\Phi^{++}} < 154$ GeV for BR ($\Phi^{++}\rightarrow e\mu$) = 100%
    - $m_{\Phi^{++}} < 156$ GeV for BR ($\Phi^{++}\rightarrow \mu\mu$) = 100%
    - $m_{\Phi^{++}} < 144$ GeV for BR ($\Phi^{++}\rightarrow ee$) = 100%
    - $m_{\Phi^{++}} < 116$-131 GeV for benchmark points

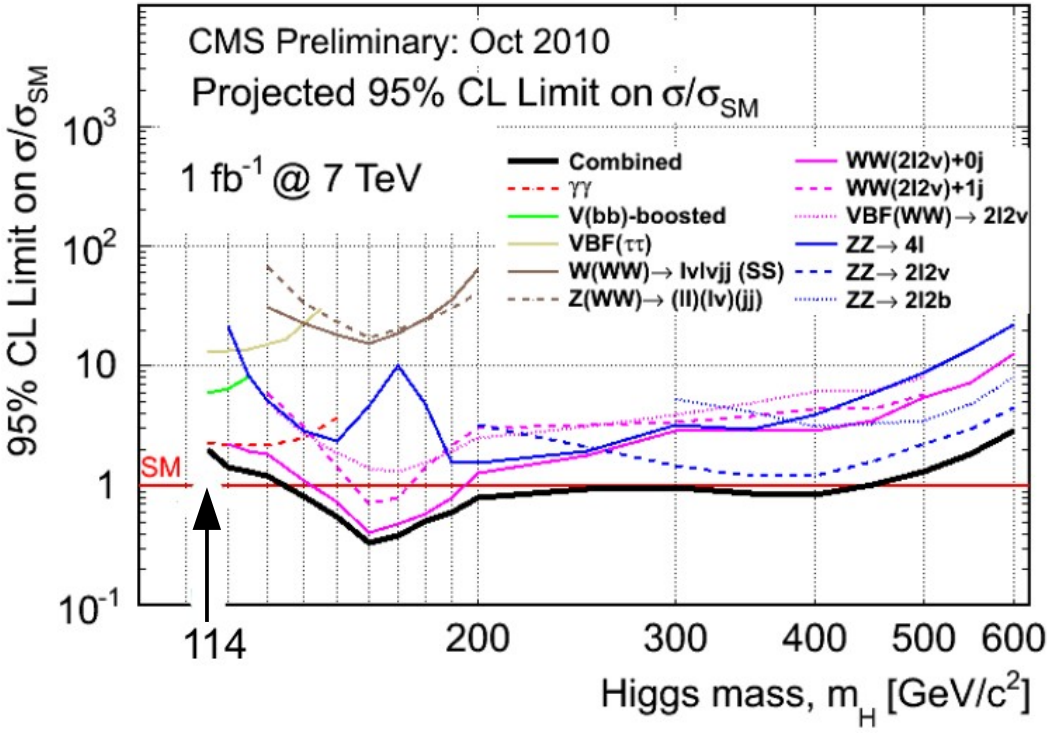




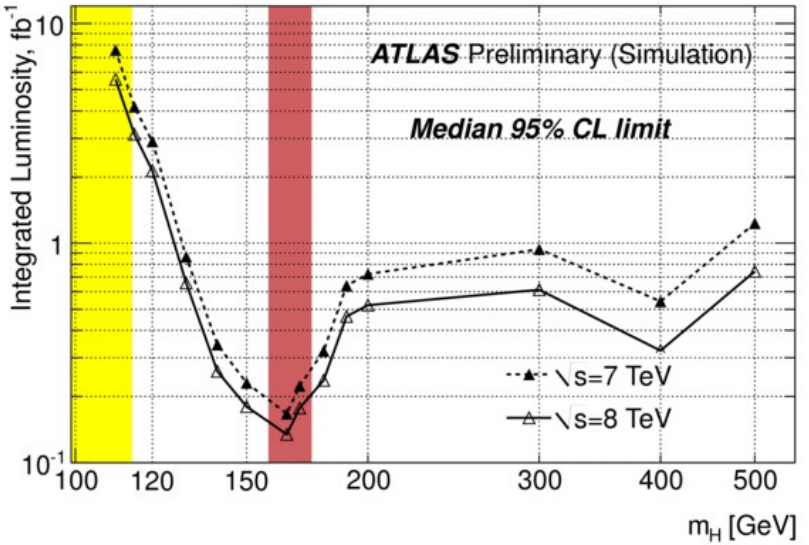
SM Higgs Prospects for Exclusion

- If SM Higgs does not exist, exclusion possible in 2011
- Region below m_H = 125 GeV extremely challenging

How much can we exclude with 1fb^{-1}?

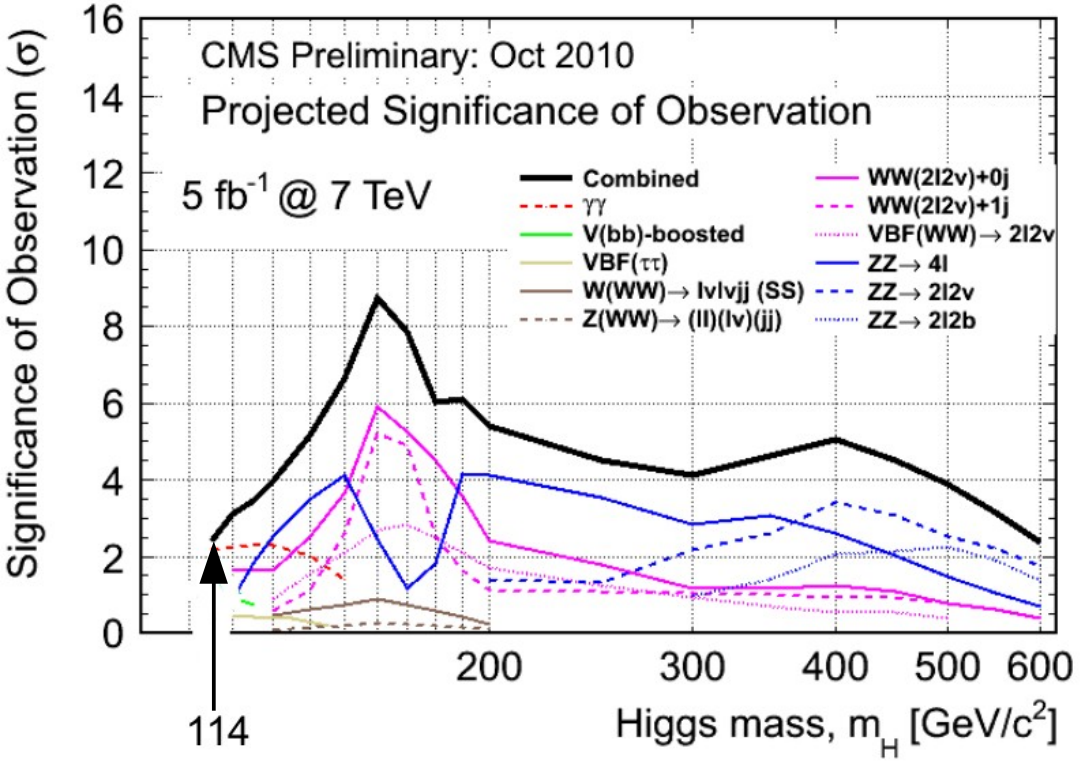


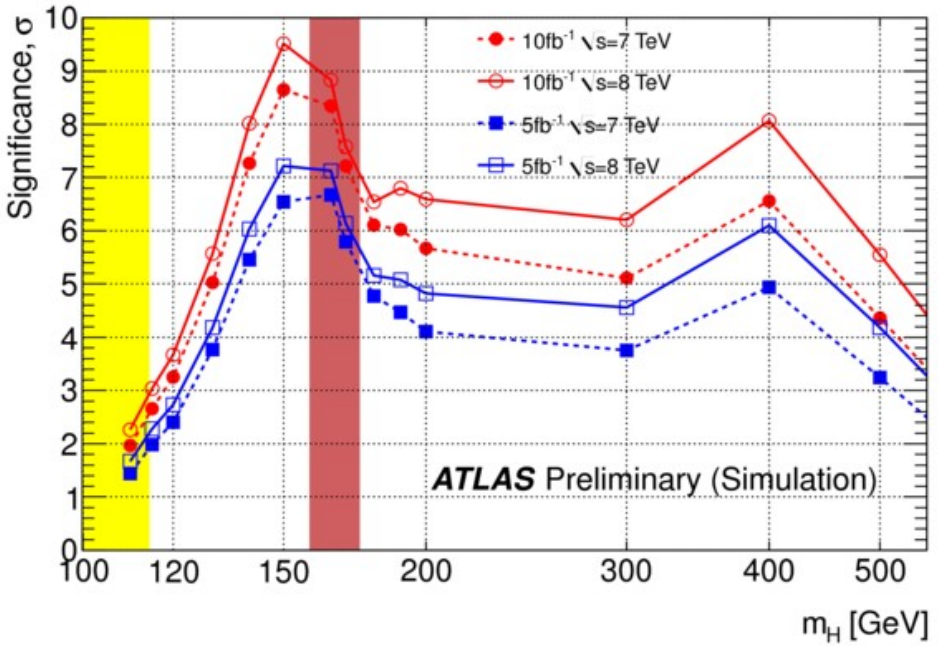
How much data is needed to exclude?



SM Higgs Prospects for Discovery

- If SM Higgs exist, discovery possible in 2011 (in limited mass range)
- Region below m_H = 125 GeV extremely challenging





Conclusion

- With 2010 data ATLAS & CMS produced an impressive set of Standard Model measurements at 7 TeV for QCD, W, Z and top
- Very quick turn-around of data by experiments
- First precision measurements
- Prospects for Higgs searches are very promising
- Baseline set for many searches for new physics

Discussed in the next talk by George Redlinger

- Fasten your seatbelt. Already ~230pb^{-1} collected per experiment

- Many interesting results not included. See complete list and references at
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults