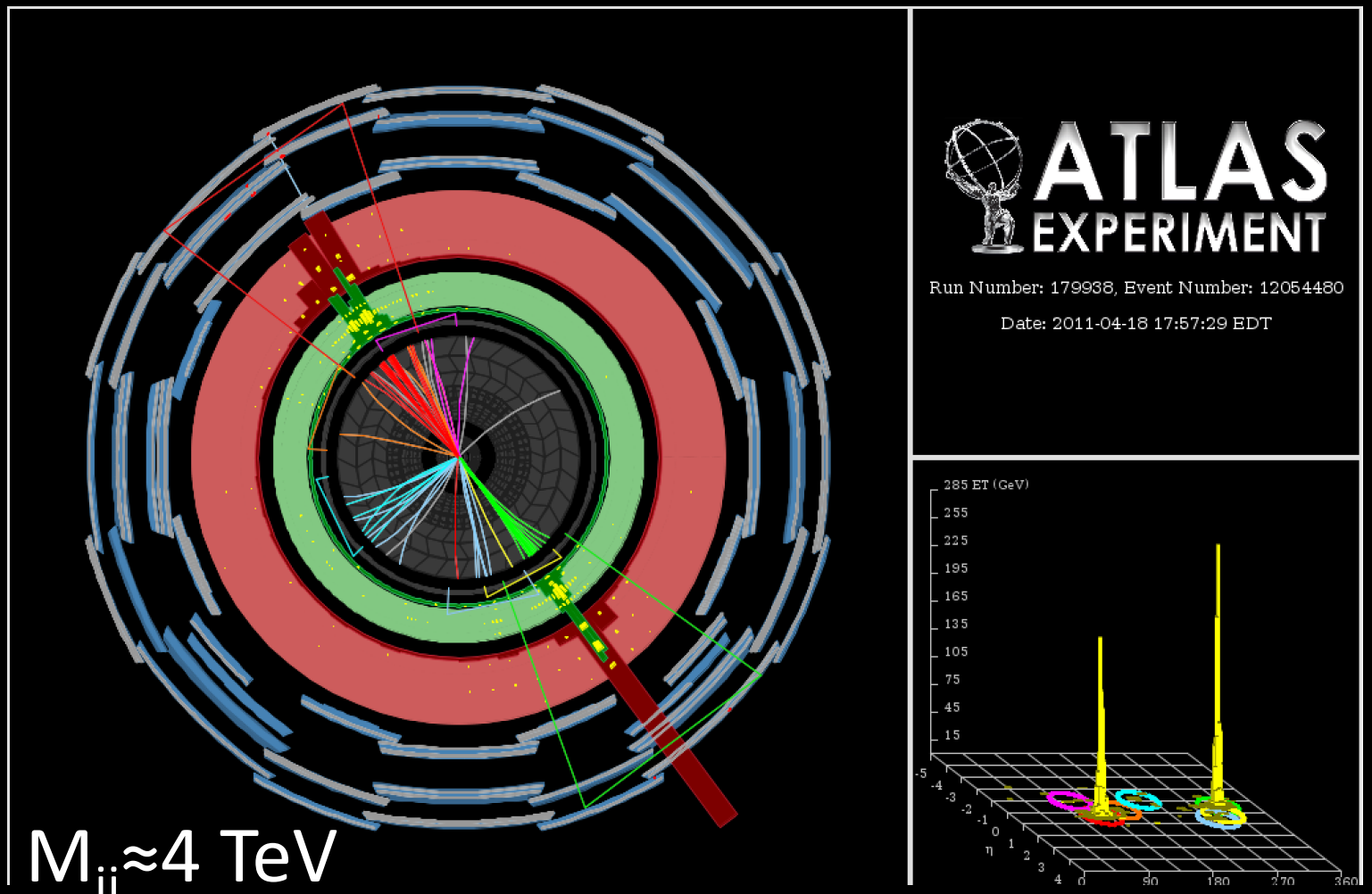
ATLAS Status and Results



Beate Heinemann

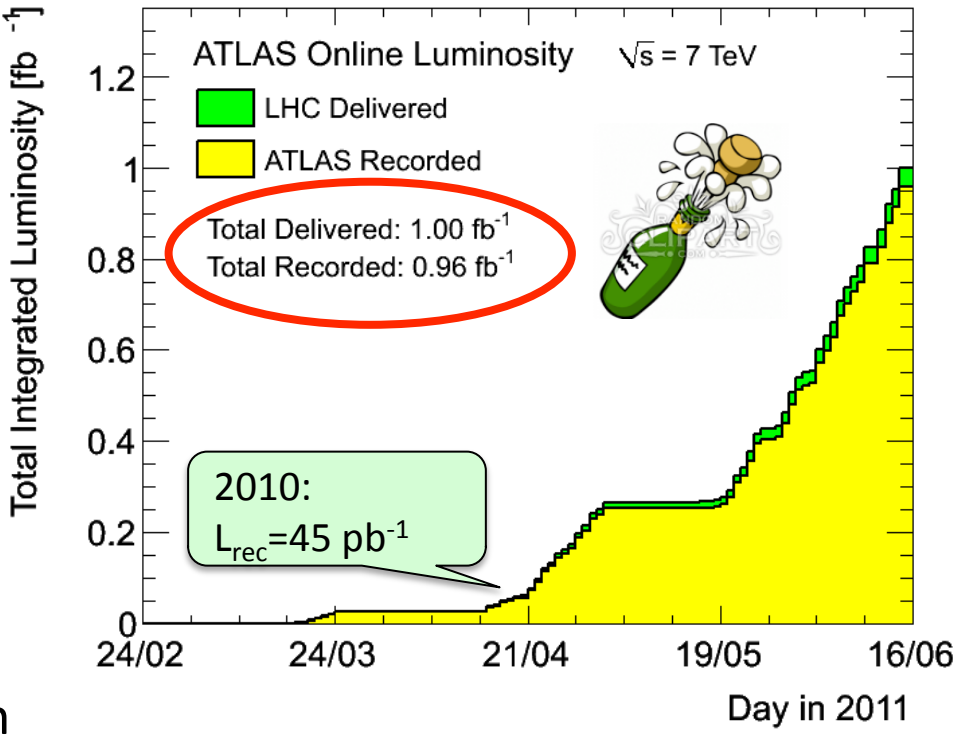
UC Berkeley and Lawrence Berkeley National Laboratory

on behalf of the ATLAS Collaboration

LHCC, CERN, June 15th

2011 Luminosity and Data Taking

- ATLAS is recording the amazing amount of LHC data efficiently: **1.0 fb^{-1} delivered by LHC**
  - 95.8% data-taking efficiency
  - Inefficiency due to:
    - Turn-on at start of stable beams: 1.6%
    - Deadtime: 2.6%
  - Uncertainty on luminosity: 4.5%
    - Will improve with recent vdM scan data
- Quality of data generally very high
  - LAr calorimeter DataQuality inefficiency will largely be recovered in reprocessing by Fall 2011



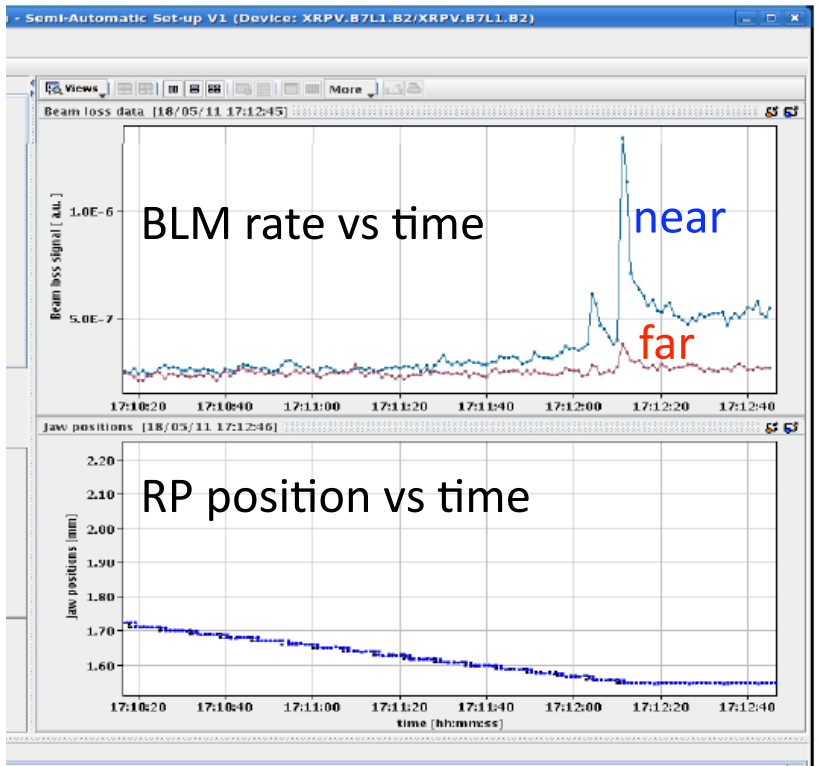
Inner Tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.5	100	89.3	92.7	94.3	99.5	100	99.5	100	99.9	98.5	97.9

Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at √s=7 TeV between March 13th and June 6th (in %). The inefficiencies in the LAr calorimeter will partially be recovered in the future. The magnets were not operational for a 3-day period at the start of the data taking.

ATLAS Subdetectors

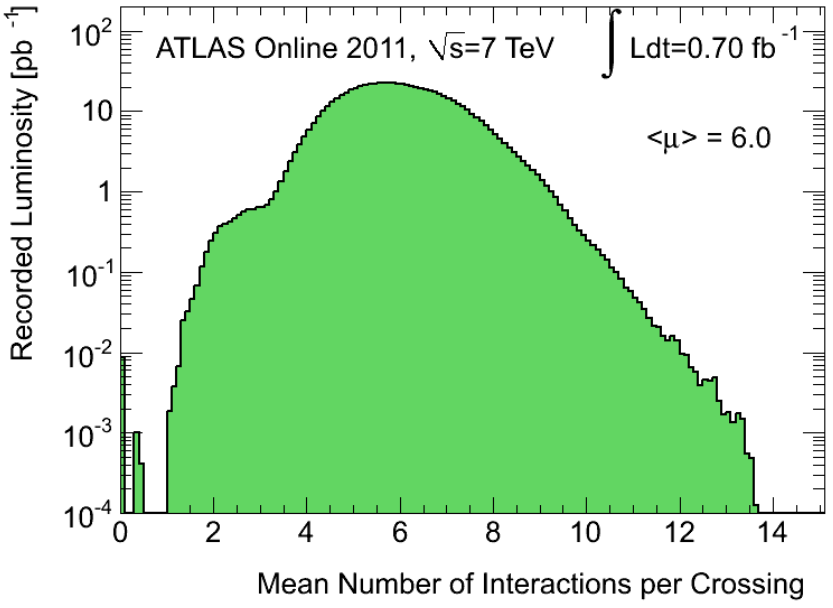
- **All ATLAS subdetectors work well**
  - Coverage 96.9-100%
    - On April 30th lost 0.4% of LAr barrel EM: hope to recover during technical stop in early July
- **ALFA roman pot detector commissioning progressing well**
  - Tracks observed regularly in garage position
  - Recent scraping run successful
    - All RP stations moved to 5σ from beam (1.5-2.0mm)

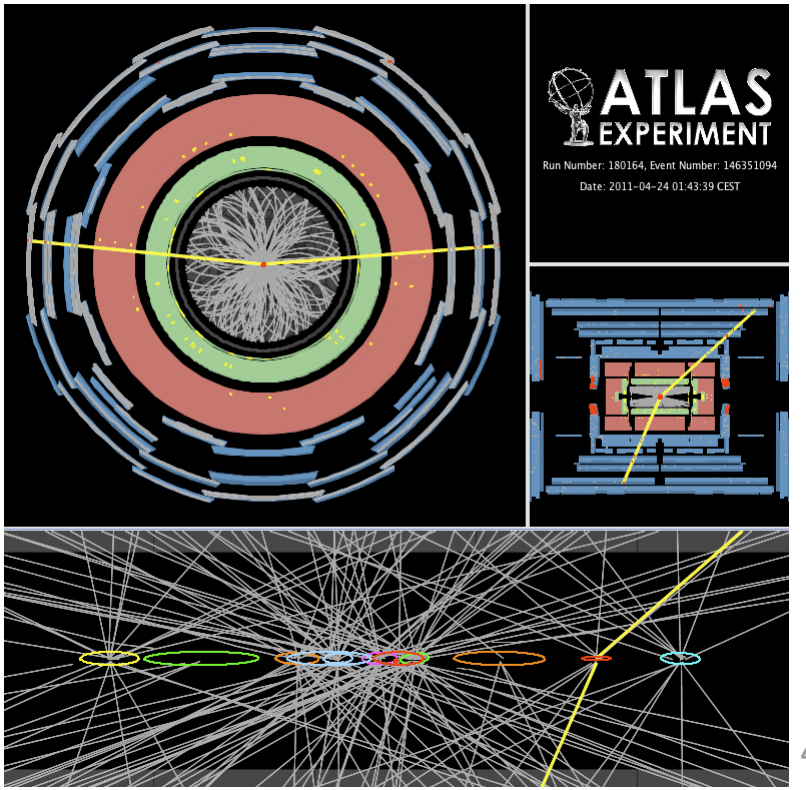
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	96.9%
SCT Silicon Strips	6.3 M	99.1%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.5%
Tile calorimeter	9800	97.9%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo 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	99.8%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	98.4%



Pileup

- **The pileup in 2011 is on average <μ>=6 interactions per crossing**
  - Significantly higher than 2010
    - And than originally anticipated in early LHC running
  - Tails up to 14 interactions per crossing
    - Due to some bunches with much higher currents
- **Causes challenge for physics analyses and software**
  - Detailed simulation models both the <μ> and the bunch train structure
    - Reweighted according to data <μ> distribution
  - Software performance significantly improved to accommodate Tier0 resources (reco time 11-13s/event)
  - Physics performance reasonably unaffected
    - Jet energy scale uncertainty temporarily increased for low p_T jets



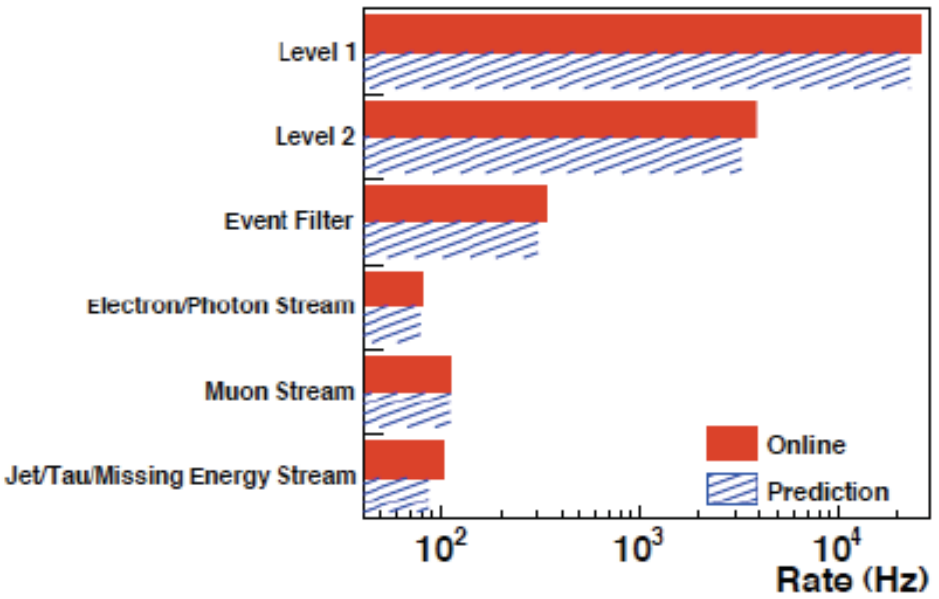


Trigger Menu in 2011

- Trigger menu kept stable for primary triggers
  - Primary triggers are never prescaled
  - Supplement by supporting and monitoring triggers
    - Increased fraction in early 2011 runs and at end of runs
- Typical Rates:
  - L1: 60 kHz, L2: 5 kHz, EF: 300-400 Hz
    - EF output rate constrained by offline resources
  - Can predict rates with ~20% accuracy
- Performance of trigger well understood
  - Detailed paper on 2010 data in preparation

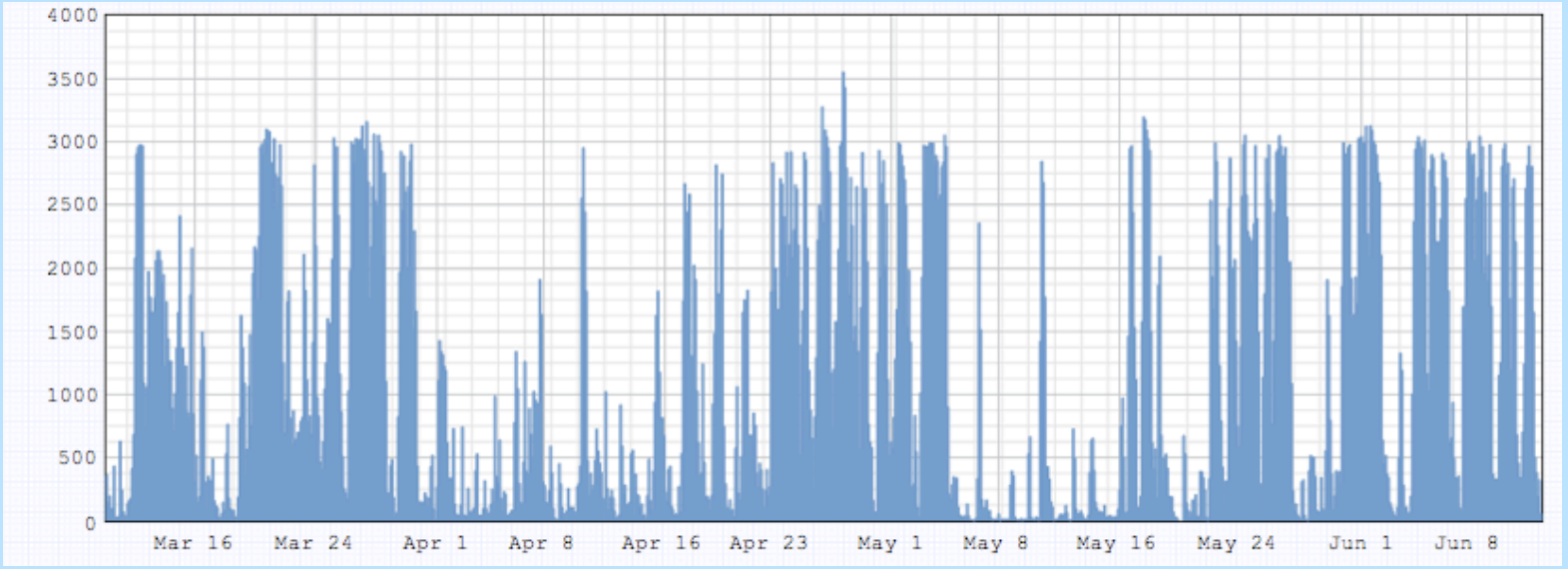
Unprescaled trigger rates at $L=1x10^{33}$ $cm^{-2}s^{-1}$

trigger	L1 item	L1 Rate (Hz)	EF Rate (Hz)
E20_medium	EM14	8500	50
2e12_medium	2EM7	5700	1
g80_loose	EM30	700	3
2g20_loose	2EM14	750	2
mu18	MU10	5300	40
2mu10	2MU10	100	1
xe60	XE40	300	4
J180	J75	200	6
Tau29medium_xe35	TAU11_XE20	3800	6
Tau16_e15	TAU6_EM10	7500	6
J75_xe45	J50_XE20	500	10



Data Processing

Number of jobs running at the Tier0 versus time

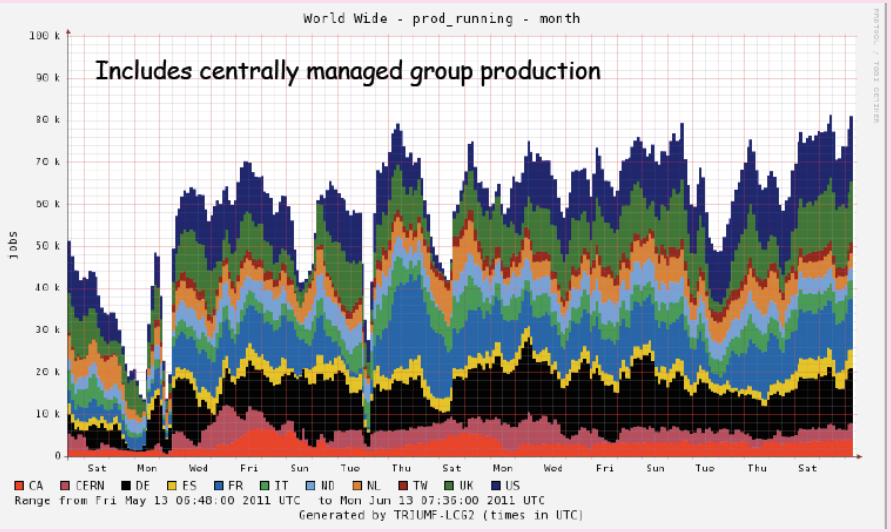


March 10th

June 12th

- Tier0 capacities sufficient to cope with current data volume
  - At current values of pileup
- Tier1 and Tier2 centres process ~70k jobs per day
  - Includes centralized analysis ntuple production

Processing at Tier1's and Tier2's



Physics Results

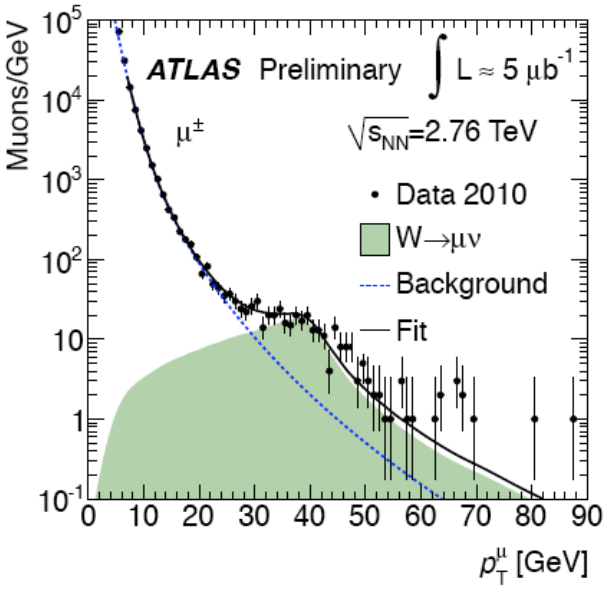
- Public results:
  - **Submitted papers** on collision data: **38**
    - About 20 drafts in final review stage
  - **Conference notes** provide thorough documentation of preliminary results: **192**
    - 102 in 2010
    - 90 in 2011

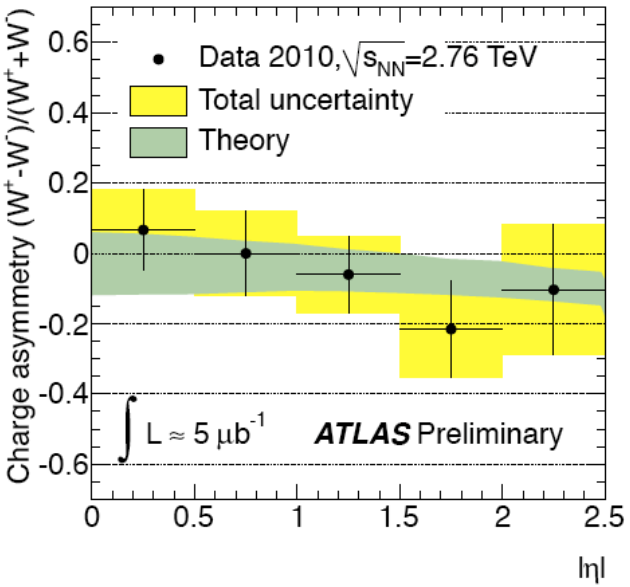
- Today will focus on selected results primarily obtained since the last LHCC meeting
  - Will highlight results obtained with early 2011 data

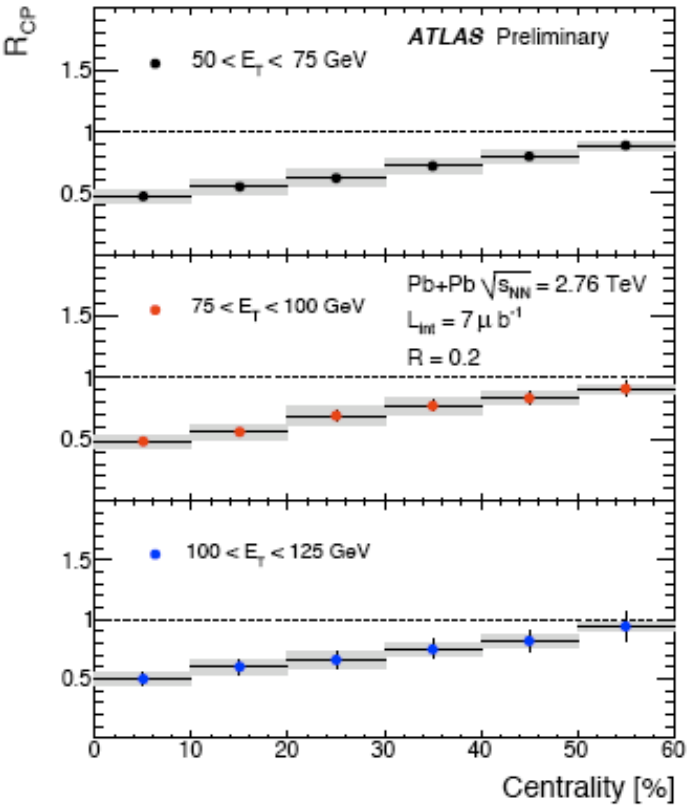
Pb-Pb Collisions

ATLAS-CONF-2011-079
ATLAS-CONF-2011-078
ATLAS-CONF-2011-075
ATLAS-CONF-2011-074

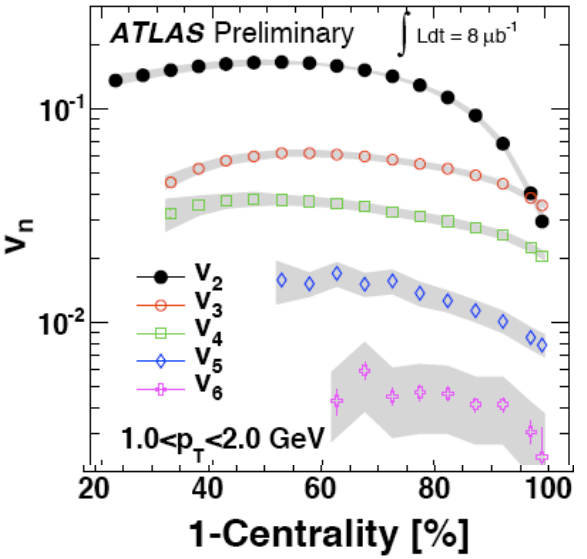
Some Highlights from Quark Matter 2011







- First steps towards probing **nuclear pdf's via $W^{\pm}$ production**
  - Observe 399^{+36}_{-38} $W^{\pm}$ candidates
- More **in-depth studies *of jet quenching***
  - Ratio of jet rate in central vs peripheral collisions ~0.5 independent of leading jet E_T
- Detailed studies of coefficients of **elliptic and higher order flow**

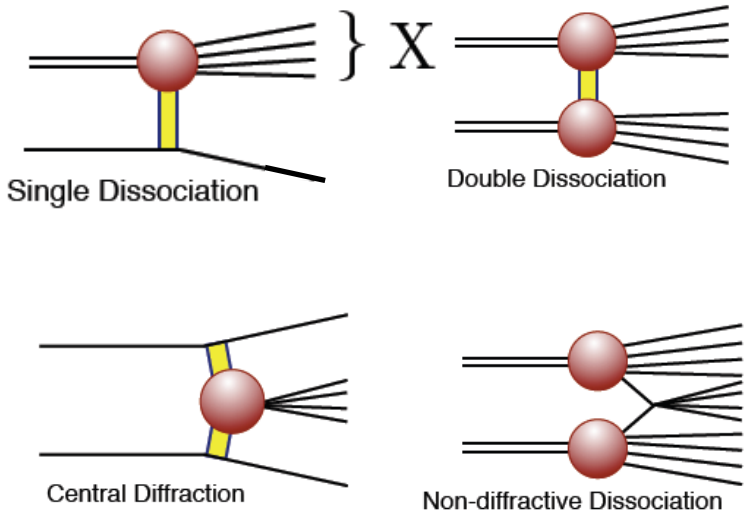


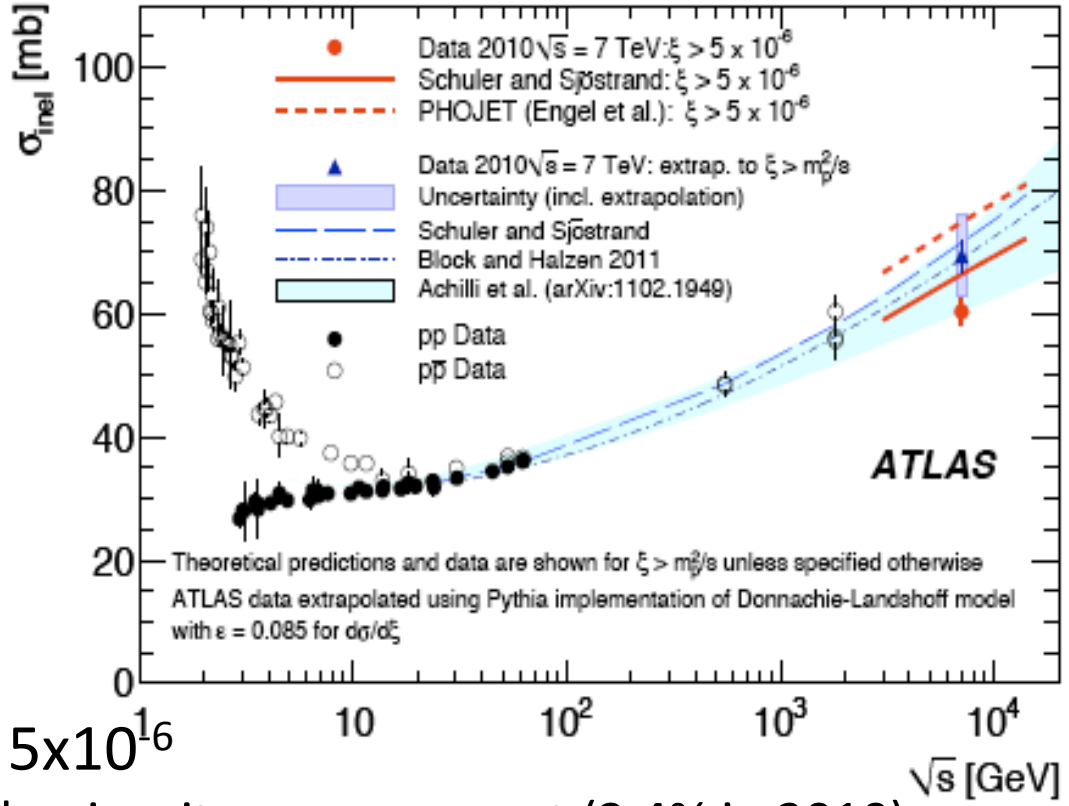
The Strong Interaction

Inelastic pp Cross Section

ATLAS-CONF-2011-011
arXiv: 1104.0326

- Hot topic at hadron colliders since the 1960's
- Inelastic cross section at 7 TeV measured using just 20 μb^{-1} of data (2nd run recorded in 2010)
  - Uses MBTS detector to detect events: defines acceptance ($\xi > 5 \times 10^{-6}$)

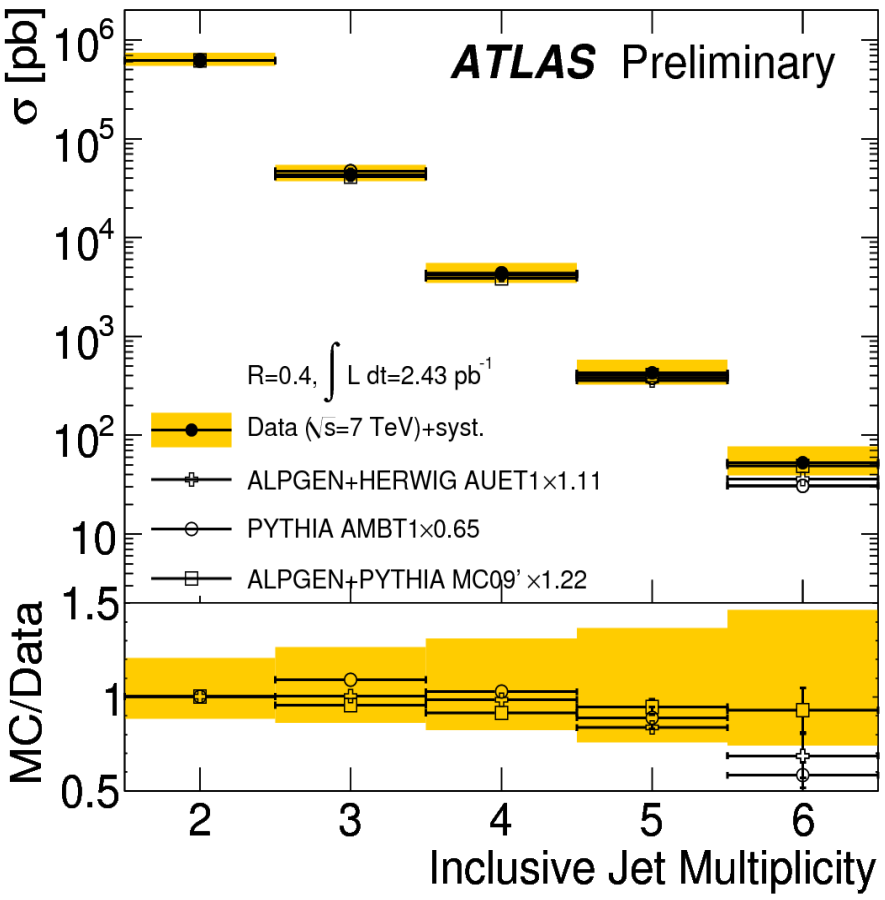


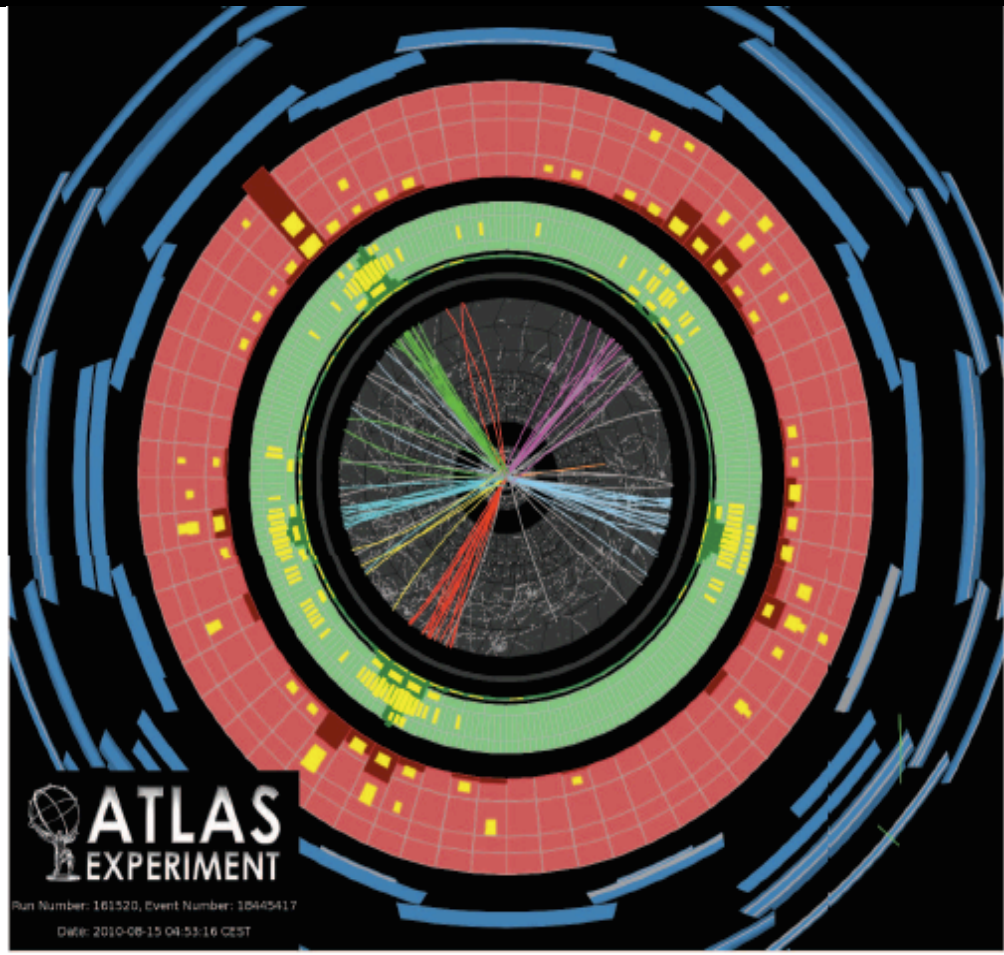


- Precision 3.5% for $\xi = M_X^2/s > 5 \times 10^{-6}$
  - Dominated by uncertainty on luminosity measurement (3.4% in 2010)
  - Larger uncertainty on full cross section due to model-dependence of extrapolation (use Donnachie-Landshoff model for $d\sigma/d\xi$)
- ALFA will provide complementary measurement

Multi-Jet Production

ATLAS-CONF-2011-043



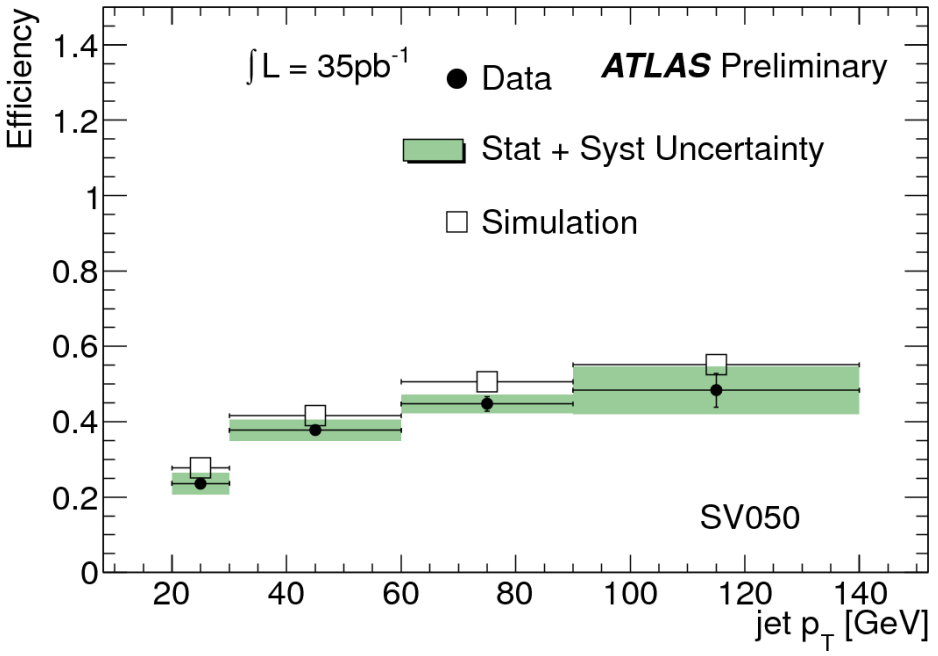


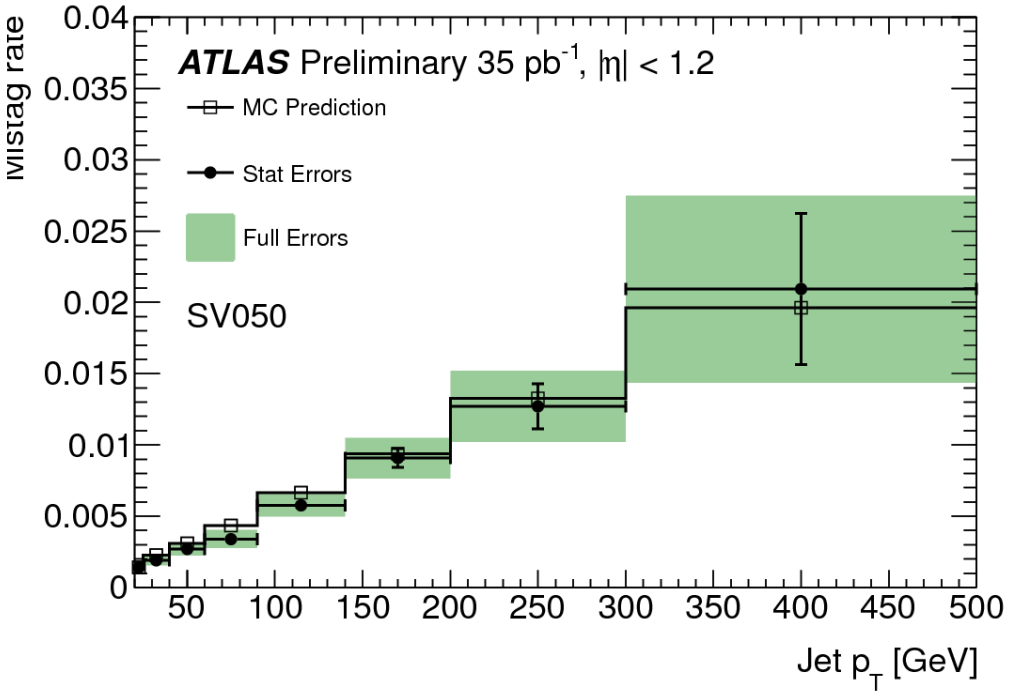
- Require at least 2 jets:
  - Leading jet P_T>80 GeV, all others require P_T>60 GeV
- Cross section measured up to 6 hard jets
  - Observe good agreement with ME and PS MC's (amazingly!)
- Excellent news for multi-jet searches for new physics (e.g. SUSY)

Heavy Quarks

Tracking and b-tagging

- B-tagging performance measured with 3 complementary methods for several taggers:
  - $p_T^{rel}(\mu)$, D*+μ, top
  - Consistent results
- Mistag rate also well controlled
- Understanding and calibration of advanced taggers in progress

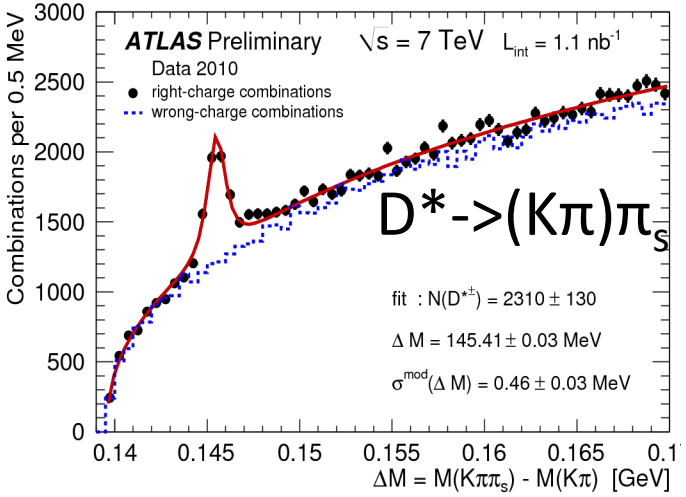


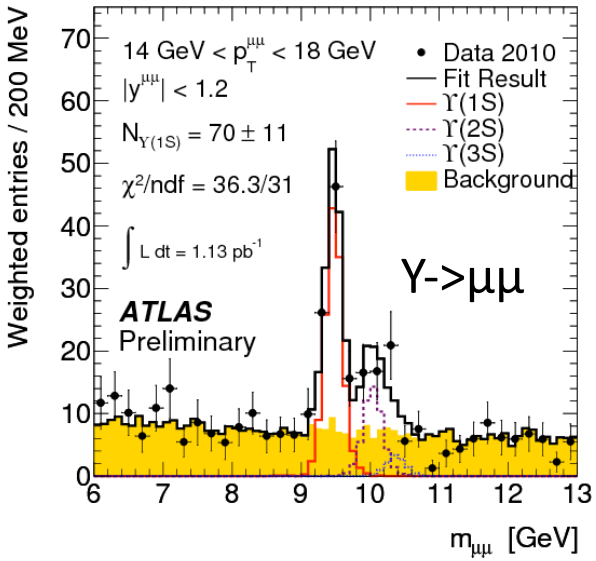


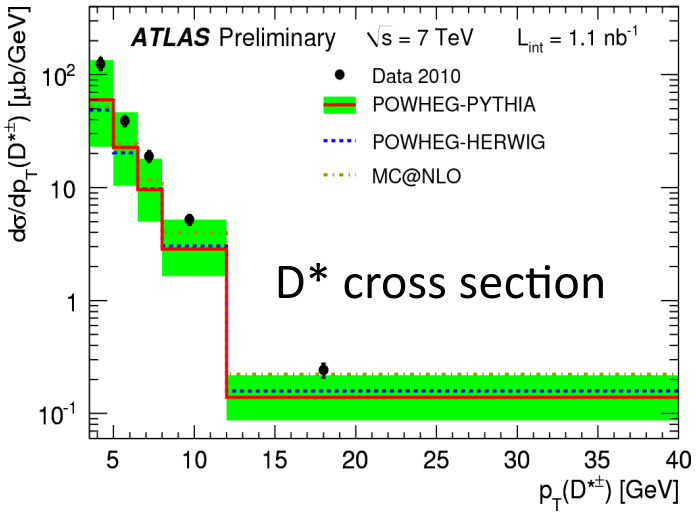
- Tracking p_T cut was increased to 400 MeV in 2011
  - Mainly affects vertexing but well understood

ATLAS-CONF-2011-089

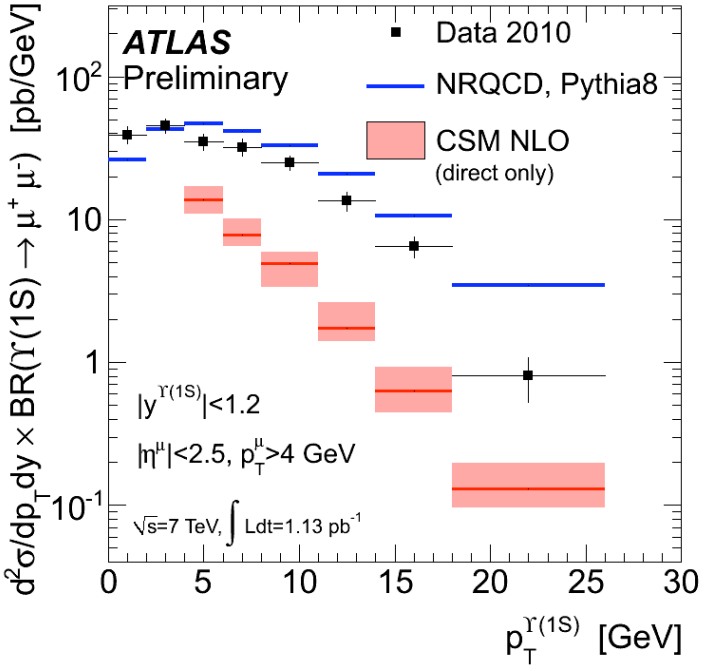
Charm and Bottom Meson Production







- **D* and D± meson cross sections measured in minimum bias events**
  - Typical exp. uncertainty 10%
  - Agreement with theory reasonable within large theory errors
- **Production of Υ(1S) mesons measured in restricted kinematic range**
  - $p_T(\mu)>4$ GeV, $|\eta(\mu)|<2.5$
  - Reasonable agreement with NRQCD (Pythia8)
  - CSM NLO falls short by ~factor 10

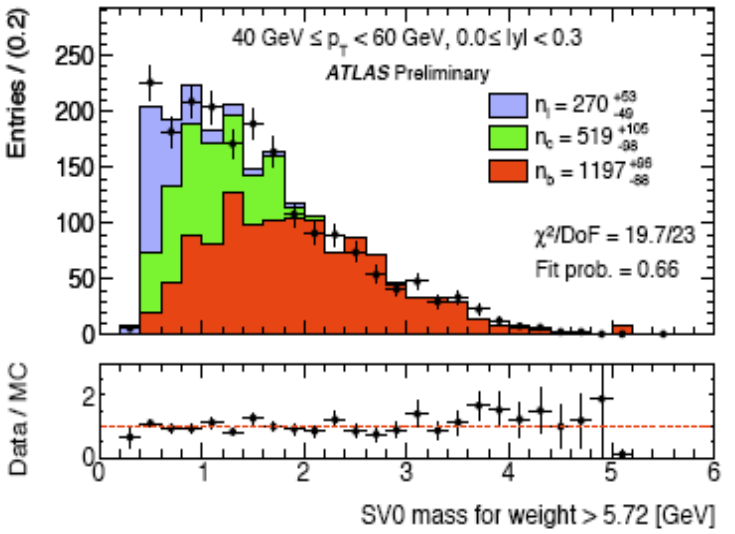


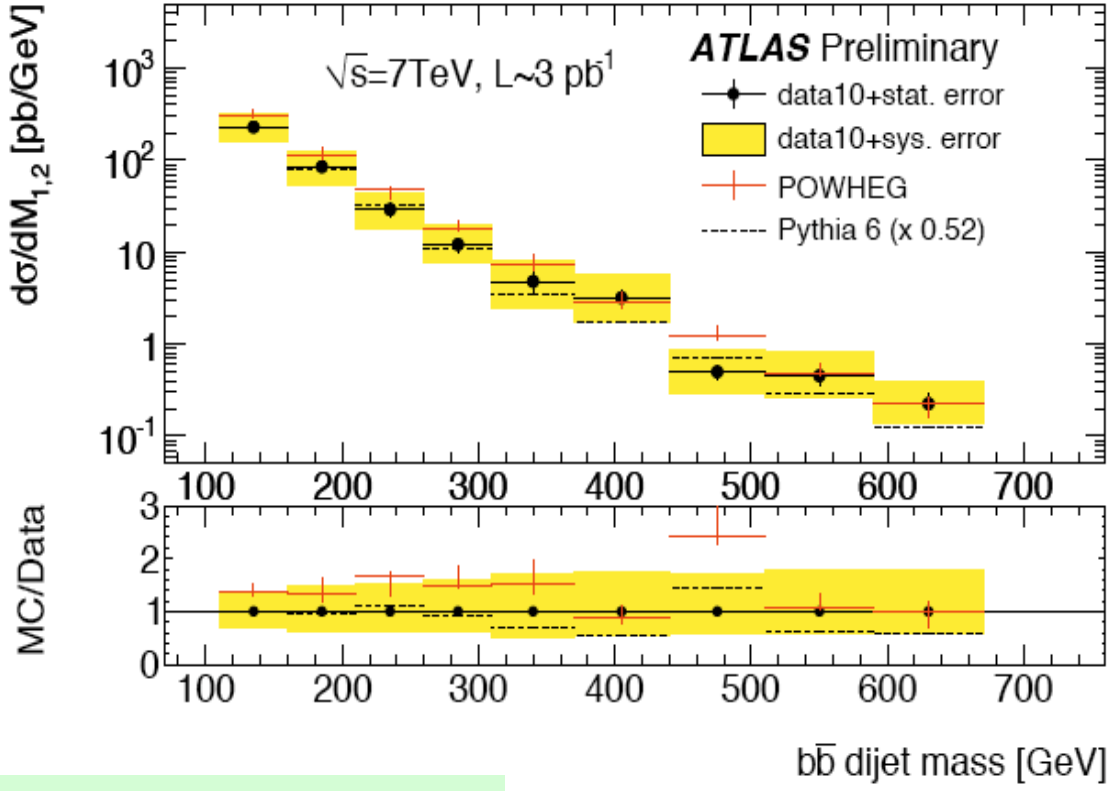
ATLAS-CONF-2011-017

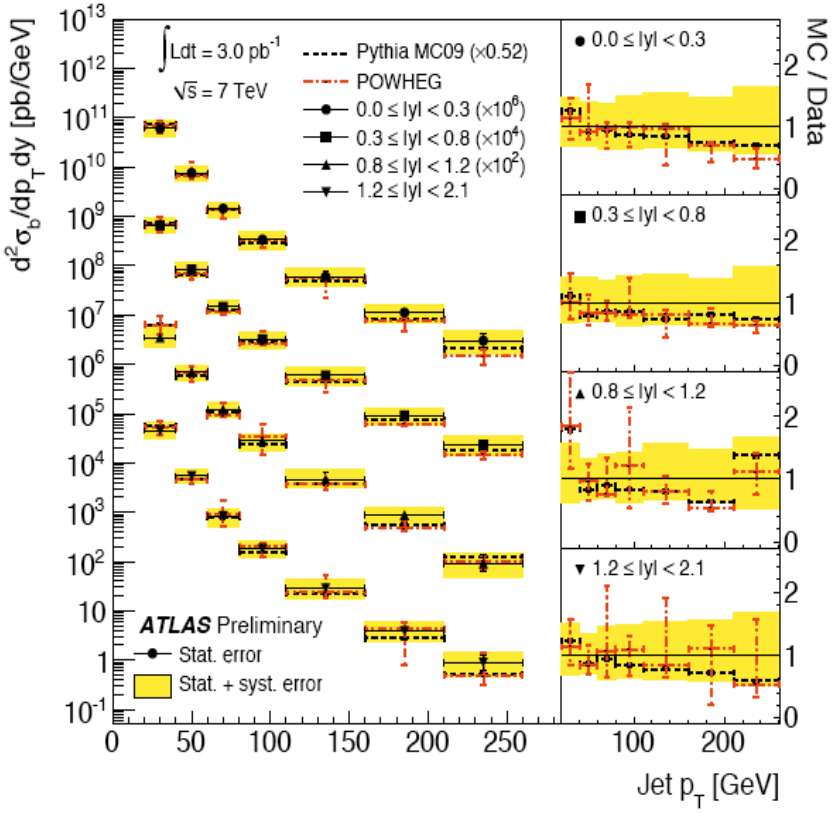
J/ψ cross section shown previously Nucl. Phys. B (arXiv:1104.3038)

b-jet Production Cross Section

- σ measured with two methods:
  - Secondary vertex mass
  - p_T^{rel} of muon
- Results compare well with predictions

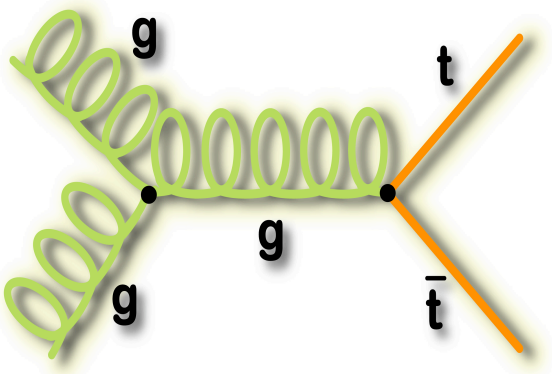




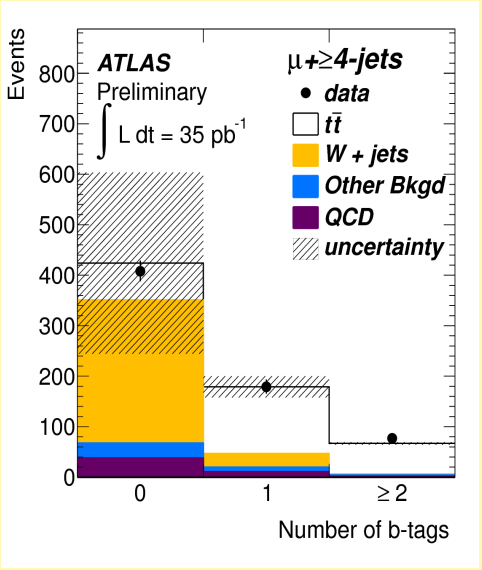


ATLAS-CONF-2011-057

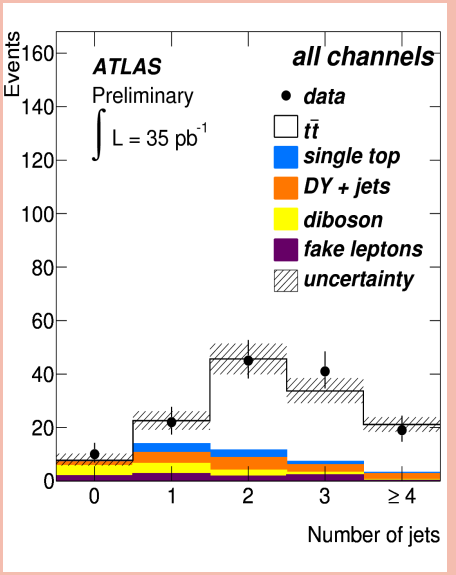
Top Quark Pair Production

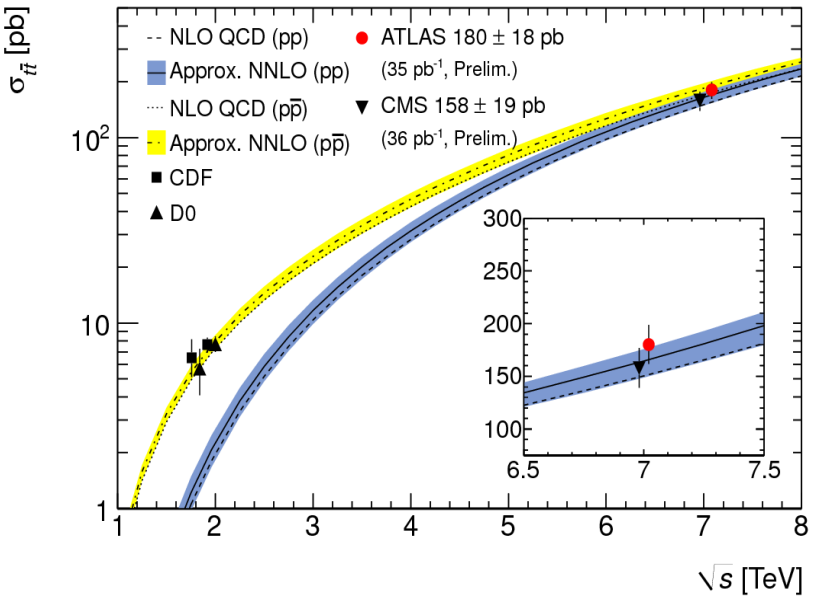


Lepton+jets:



Dilepton





- **Cross section measured in variety of channels with different techniques**
  - Lepton+jets: with and w/o b-tagging
  - Dileptons: with and w/o b-tagging
- Result: **σ_{tt} = 180 ± 18 pb**
  - 10% precision similar to theoretical precision

ATLAS-CONF-2011-023
ATLAS-CONF-2011-034
ATLAS-CONF-2011-035
ATLAS-CONF-2011-066

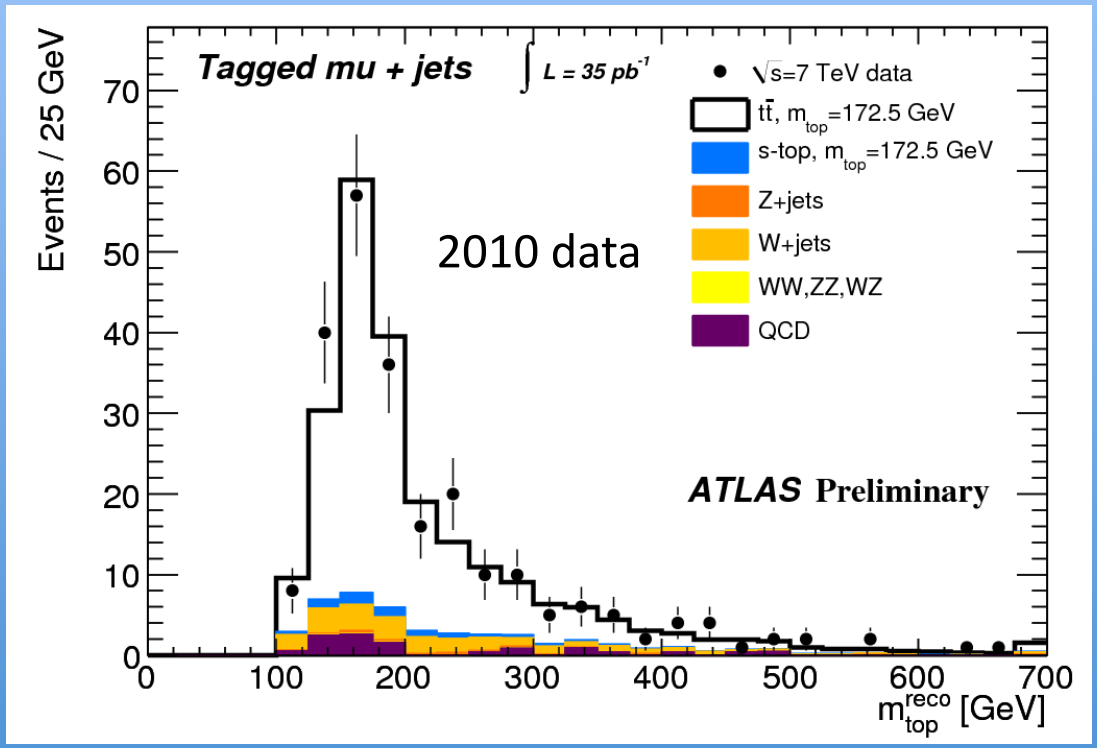
Top Quark Mass

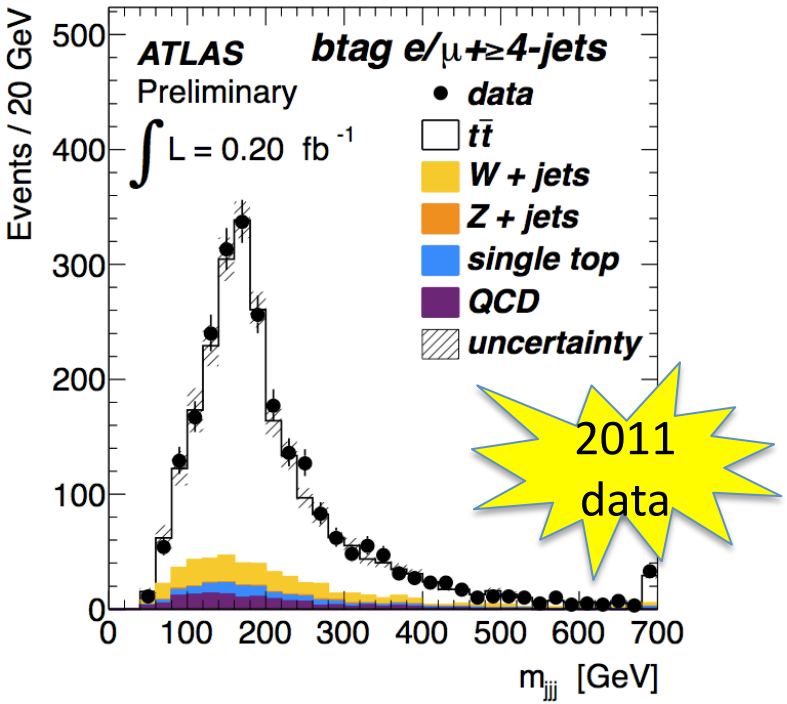
ATLAS-CONF-2011-033
ATLAS-CONF-2011-054

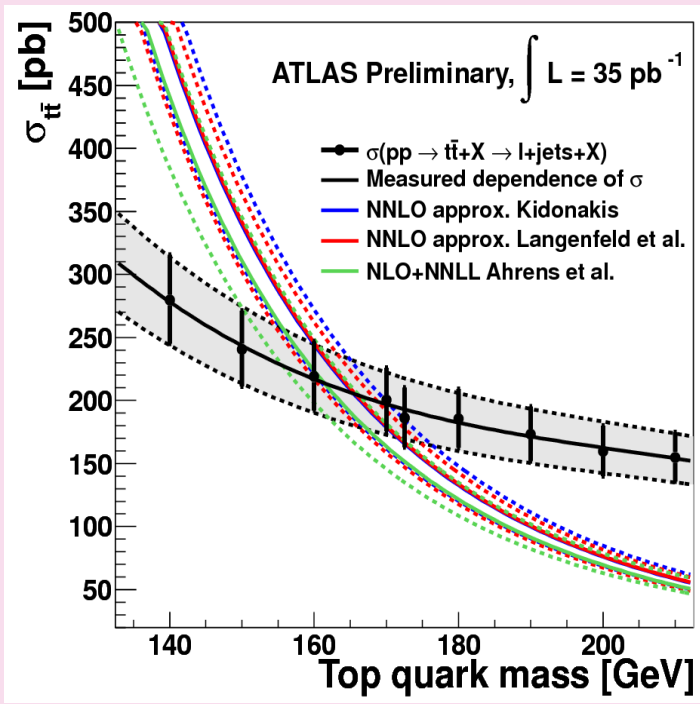
Via explicit reconstruction (2010 data):

$\Delta m_{top}/m_{top}$=3.7%

not yet competitive with Tevatron (but consistent)

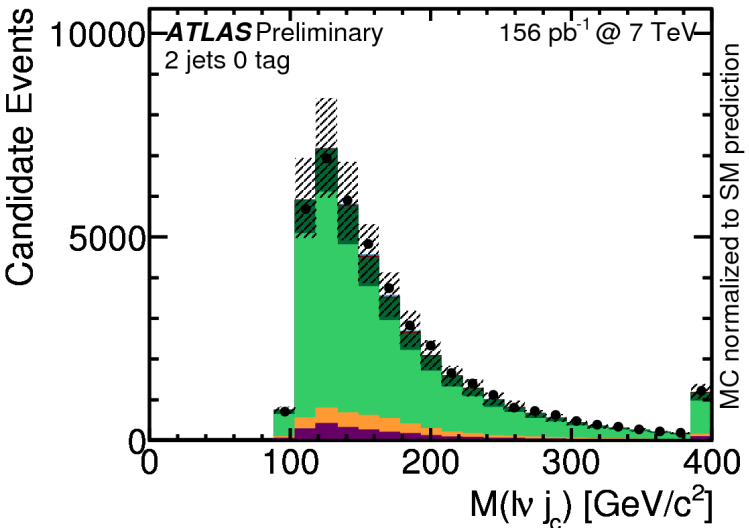


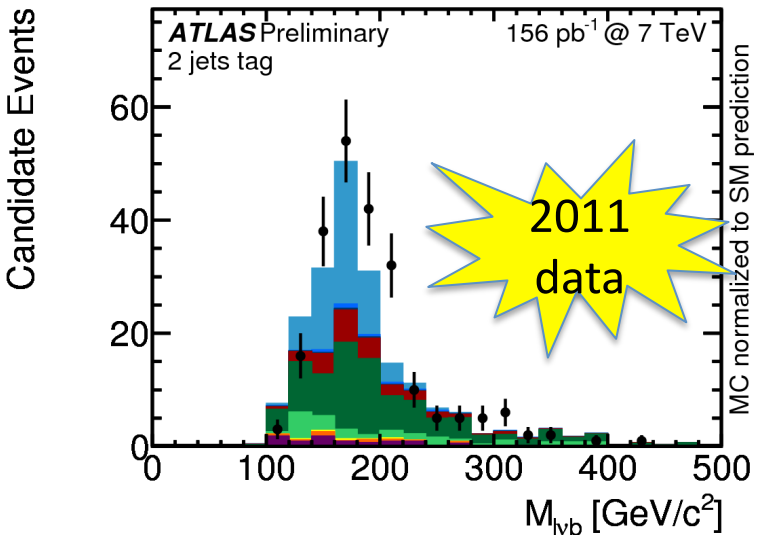


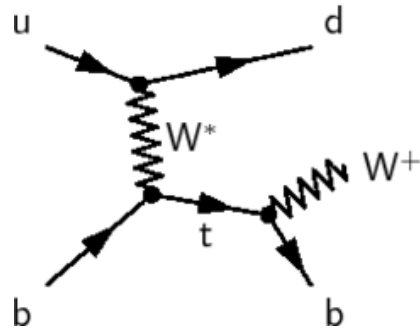


- σ_{tt} also constrains top mass
  - Directly sensitive to the pole mass
  - Uncertainty: **$\Delta m_{top}/m_{top}$=4.5%**

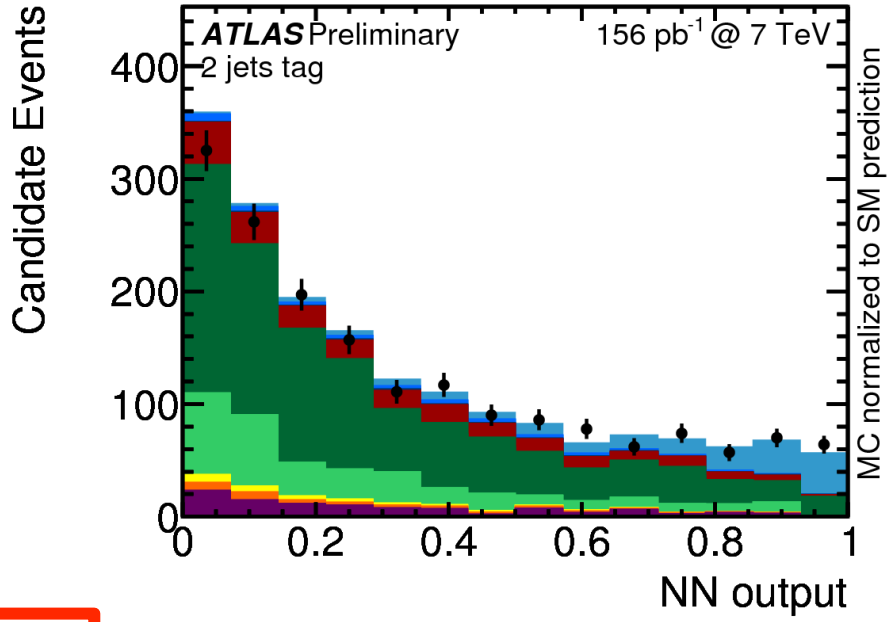
Single Top Quark Production







- Selection:
  - 1 lepton, E_T^{miss}, 1 b-jet, 1 other jet
  - Two analyses
    - Cut-based analysis using 6 variables
    - Neural network
- Signal significance: **6.3σ**
  - Observe 134 events
  - Expect 124.4±23.7 (66.4±19.6 signal)
- Cross section:



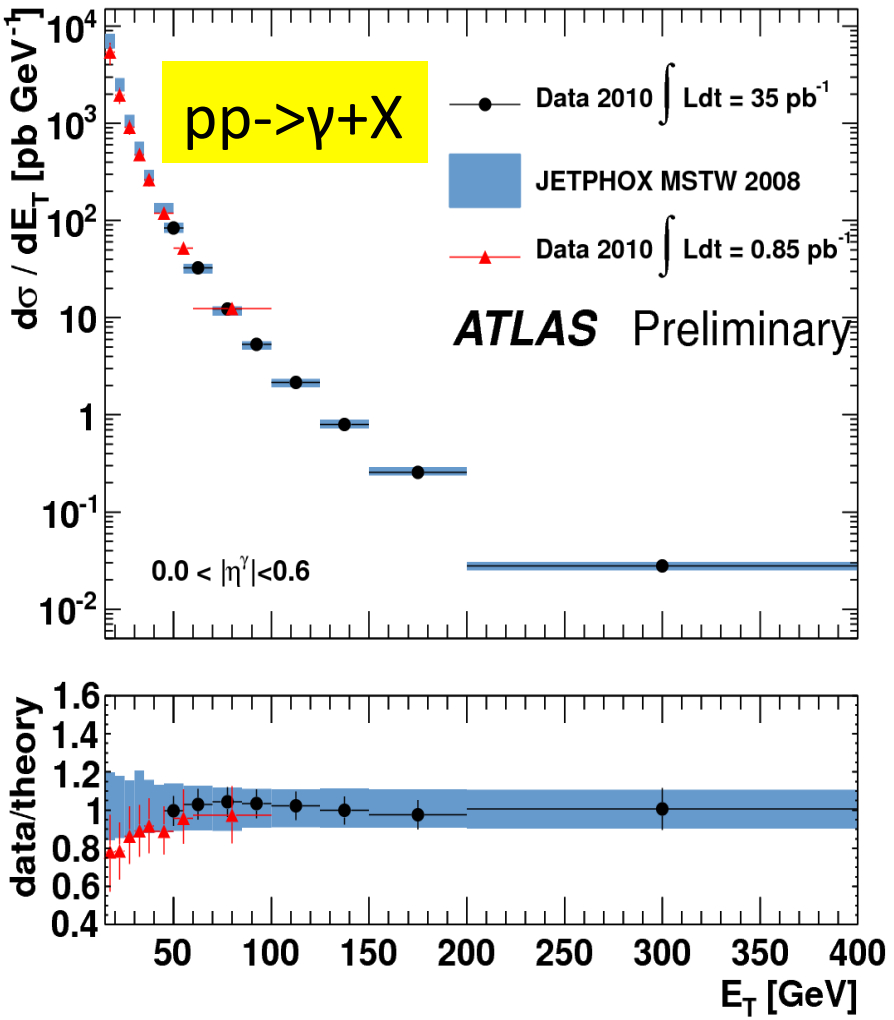
$$\sigma_t = 76^{+41}_{-21}\ \text{pb}$$

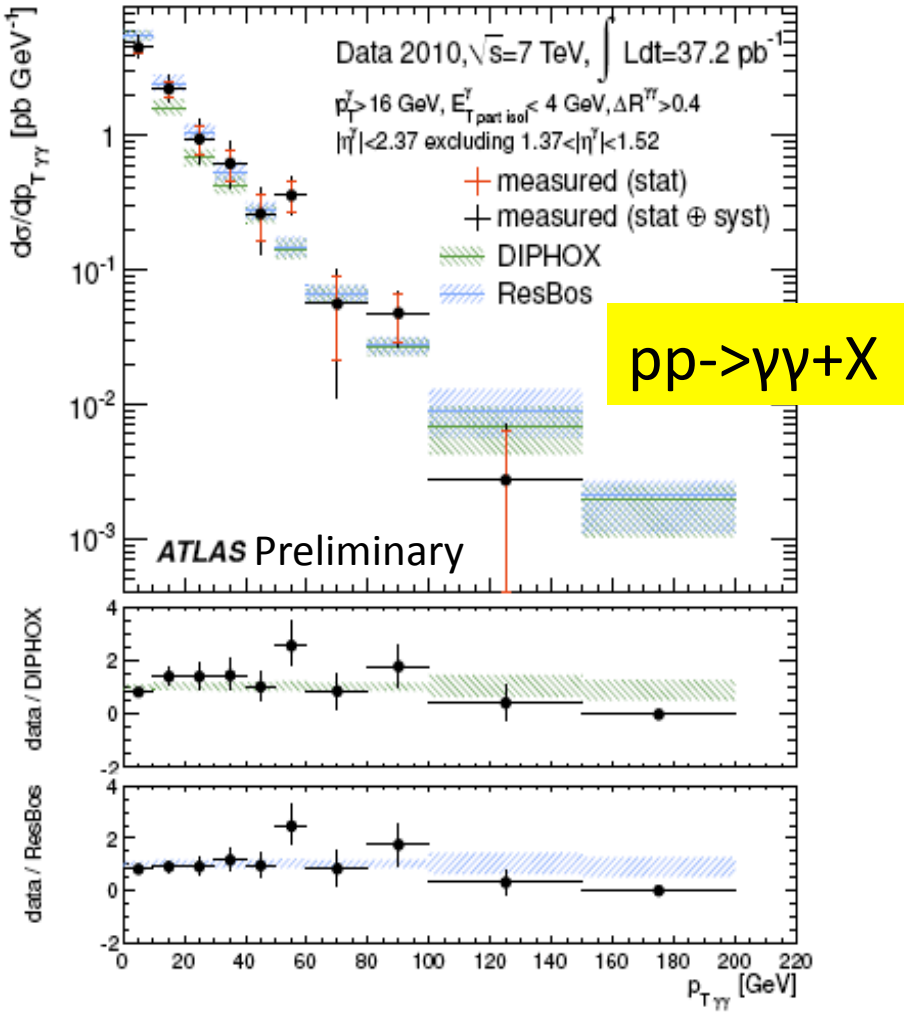
Consistent result obtained with cut-based measurement

ATLAS-CONF-2011-088

Electroweak Bosons

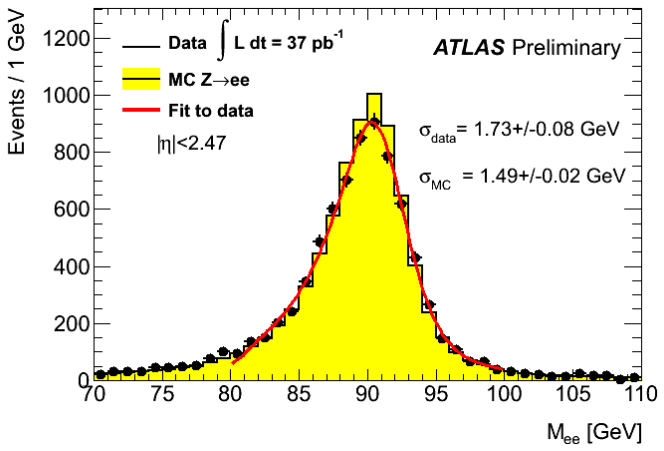
Direct Photon Cross Sections

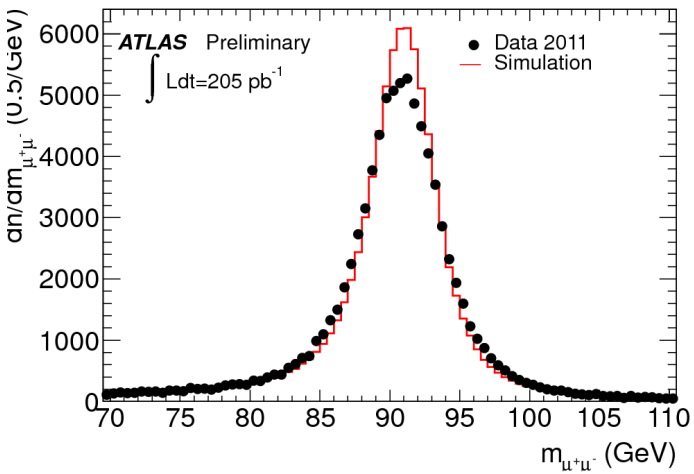


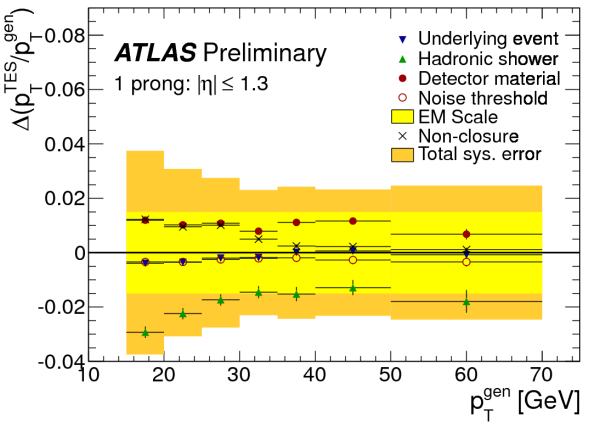


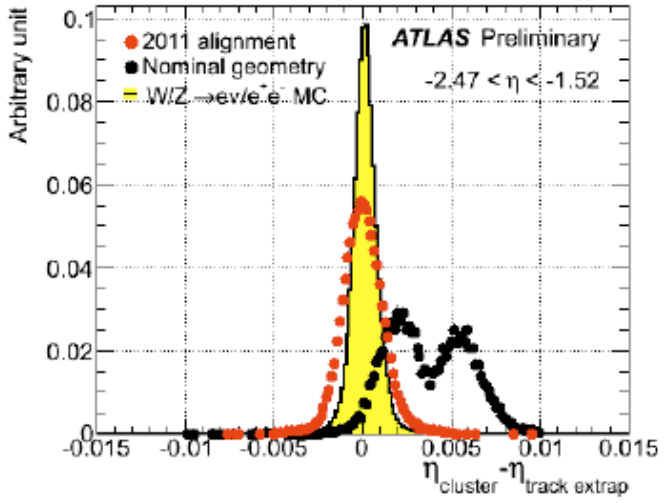
- Uses both converted and unconverted photons
  - Main background are π^0's and η's:
  - Photon purity is 88% (98%) at E_T^{γ}=50 (100) GeV
- Data agree well with predictions over 5 orders of magnitude

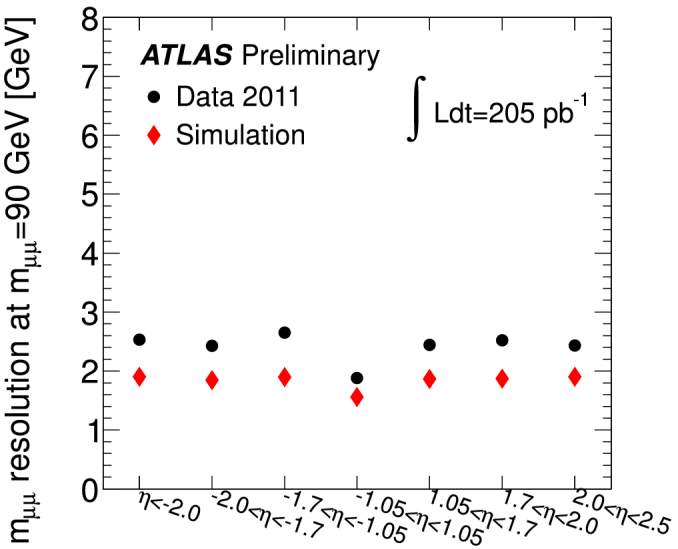
Understanding of Leptons

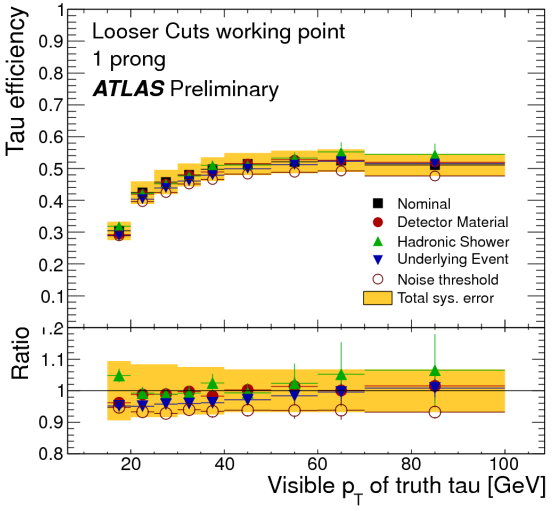






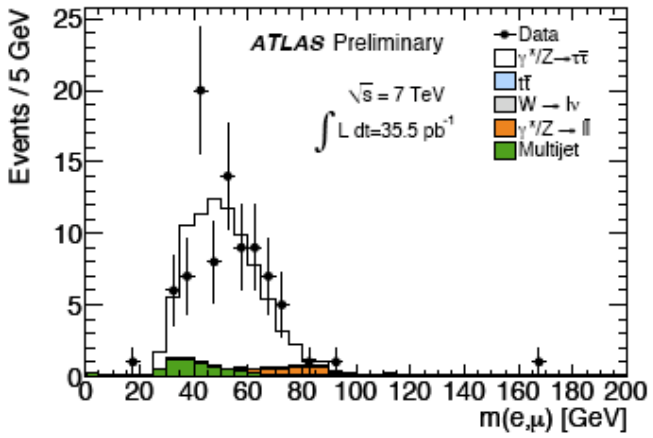


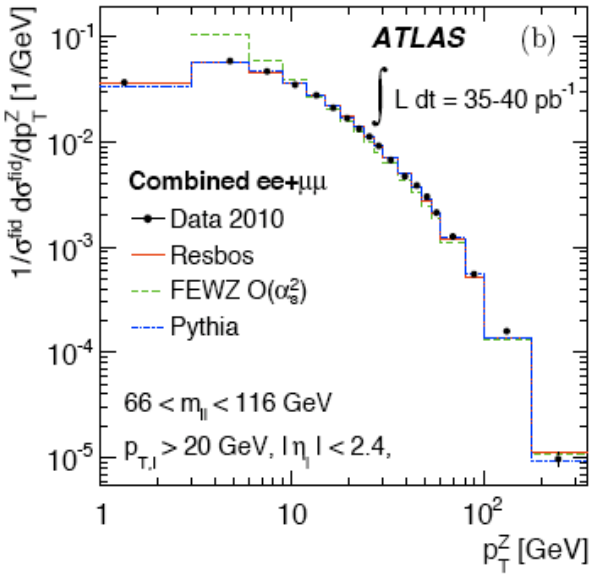


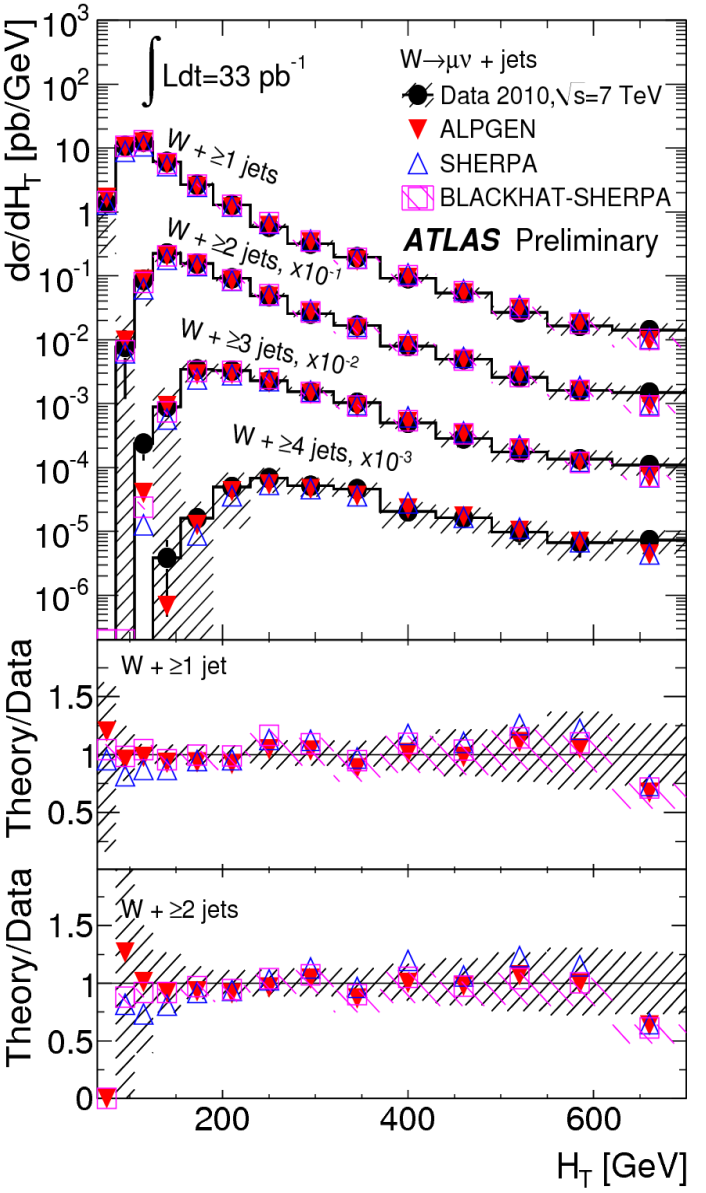


- Electrons, muons and τ's well understood
  - Improvements due to ID and LAr alignments
  - Expect further improvements in Inner Detector and Muon Spectrometer alignment for upcoming reprocessing

W and Z Boson Cross Sections





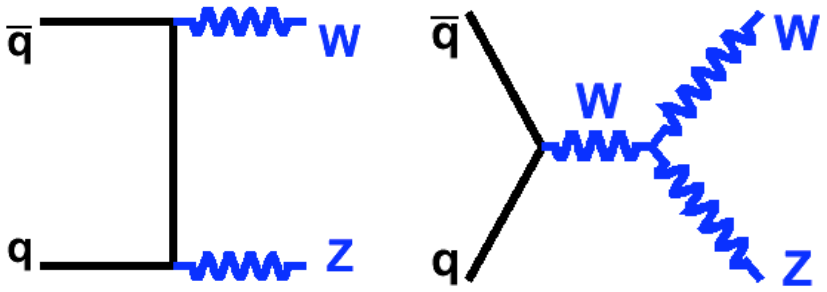


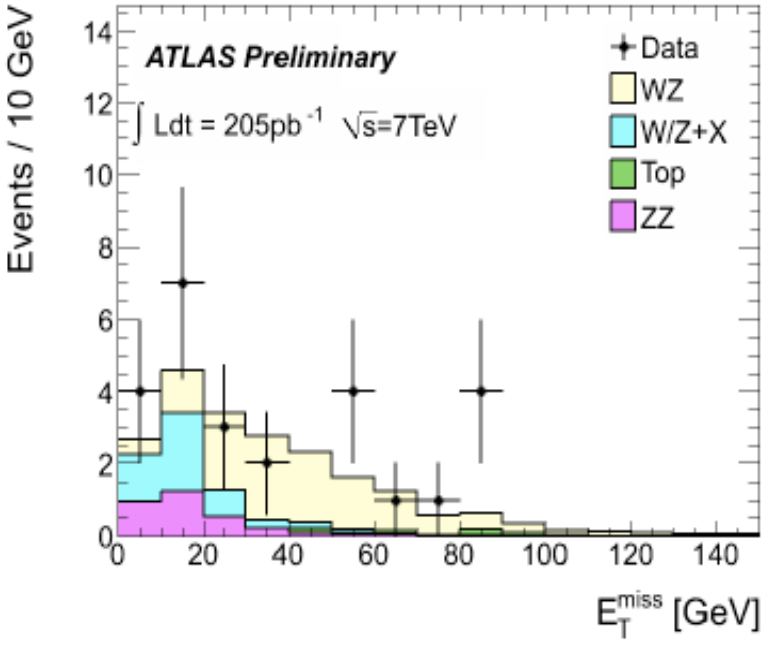
- **Inclusive σ(W) and σ(Z) measurements achieved precision of 5%**
  - Dominated by uncertainties on luminosity and acceptance (pdf's)
- **Z->ττ cross section measured with 11% uncertainty**
- **New measurement of differential Z p_T spectrum up to 350 GeV**
  - Falls by 3.5 orders of magnitude
  - Data impressively well described by most MC generators
- **W and Z + jet production also impressively well described by predictions**

ATLAS-CONF-2011-042
ATLAS-CONF-2011-060

WZ->lllν Production

2011 data





- Event selection
  - 3 leptons p_T>15 GeV
    - Leading e (μ) p_T>25 (20) GeV
  - E_T^{miss}>25 GeV
  - Dilepton mass consistent with Z
  - $m_T(l_3, E_T^{miss})$>20 GeV
- Very pure signal: S/B=4.8

	# of events
expected background	2.0 ± 0.7
expected WZ signal	9.1 ± 1.3
observed	12

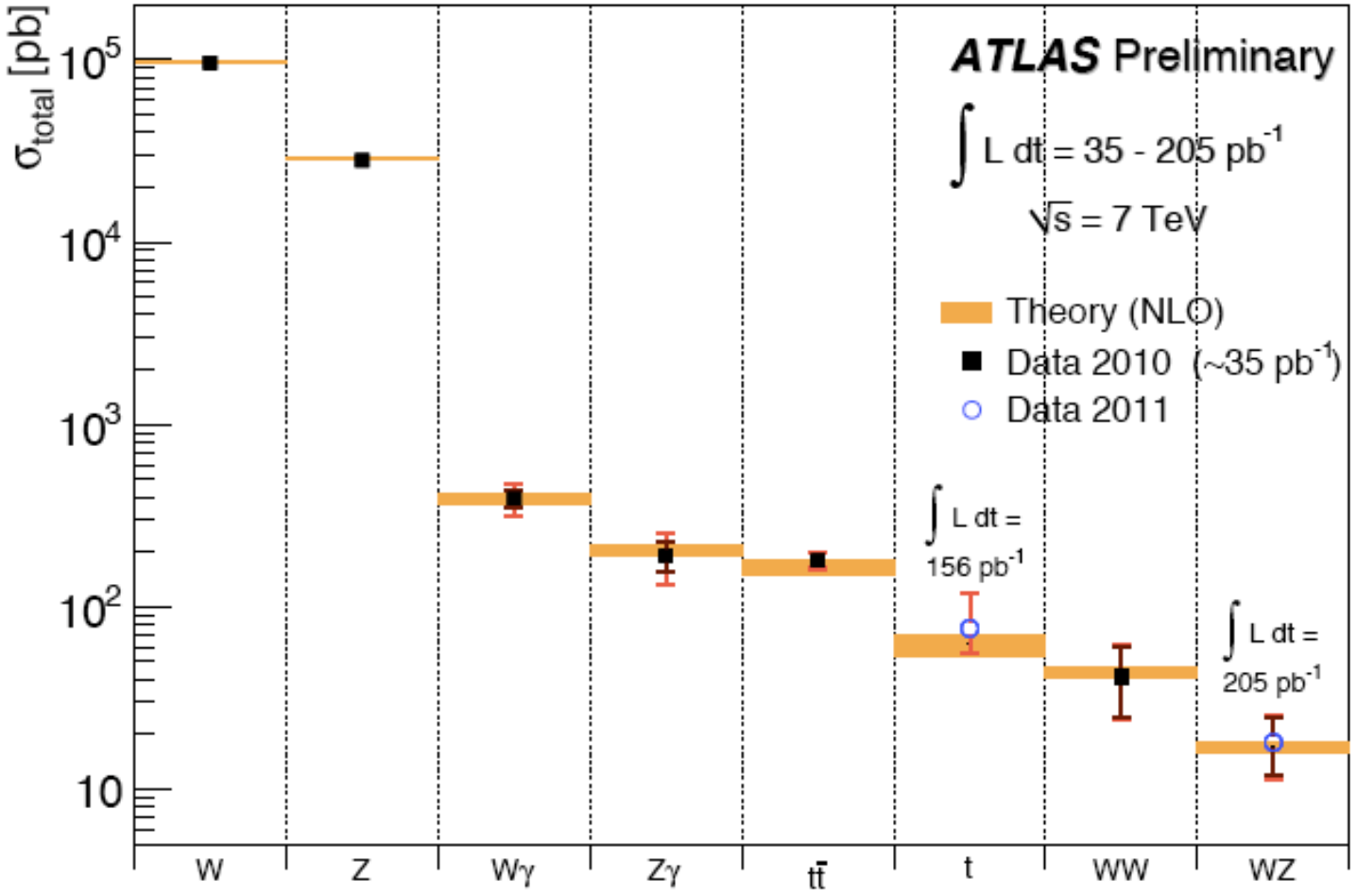
$$\sigma_{WZ}^{tot} = 18^{+7}_{-6}(\text{stat})\ ^{+3}_{-3}(\text{syst})\ ^{+1}_{-1}(\text{lumi})\ \text{pb}$$

Consistent with Prediction of

$$16.9^{+1.2}_{-0.8}\ \text{pb}$$

ATLAS-CONF-2011-084

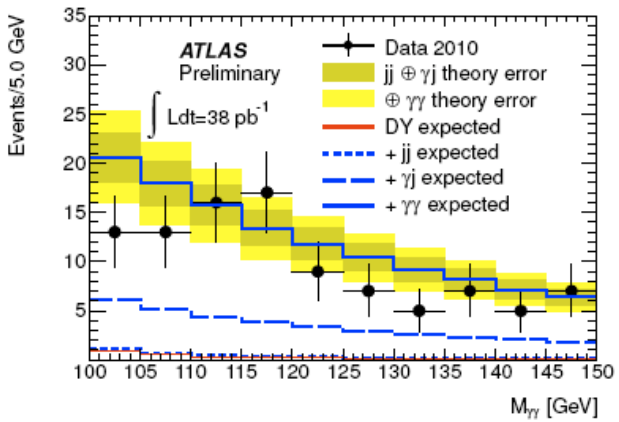
Summary of Electroweak Boson and Top Quark Cross Sections

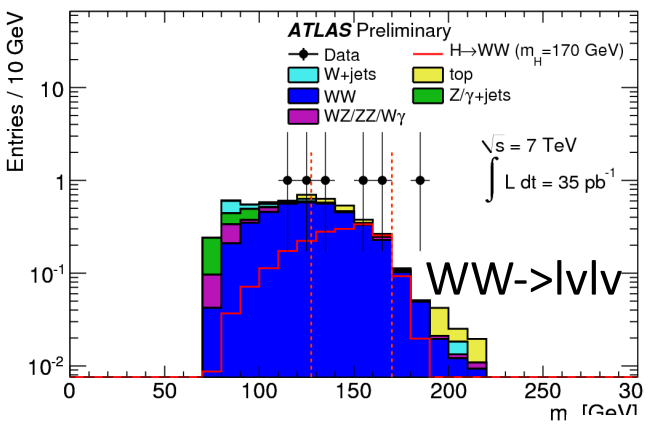


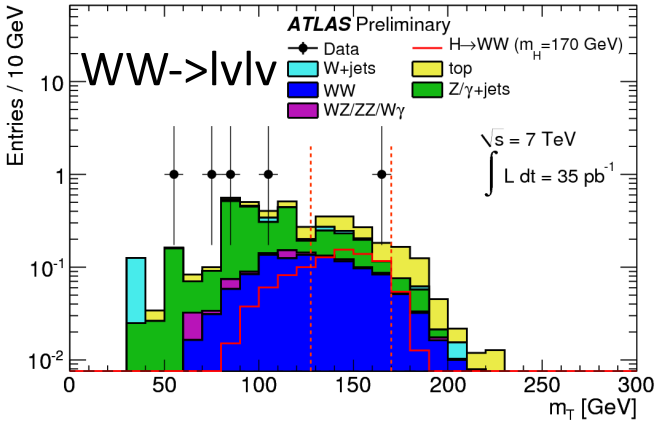
- All measurements agree with SM expectation (so far)
- Measuring cross sections of ~10 pb

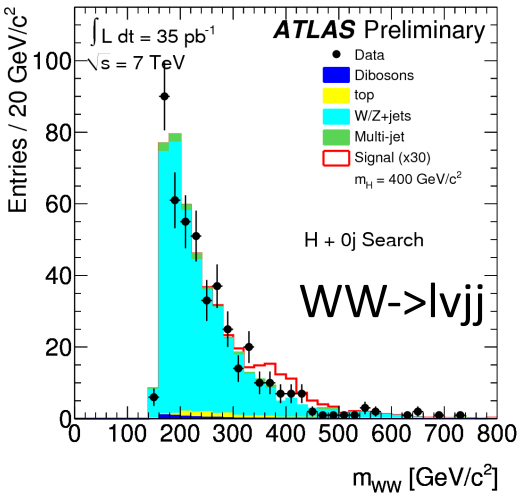
Searching for the Higgs Boson

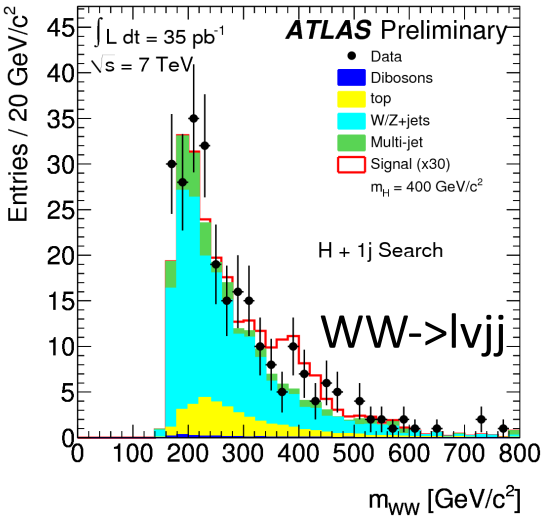
2010 Higgs Search Results

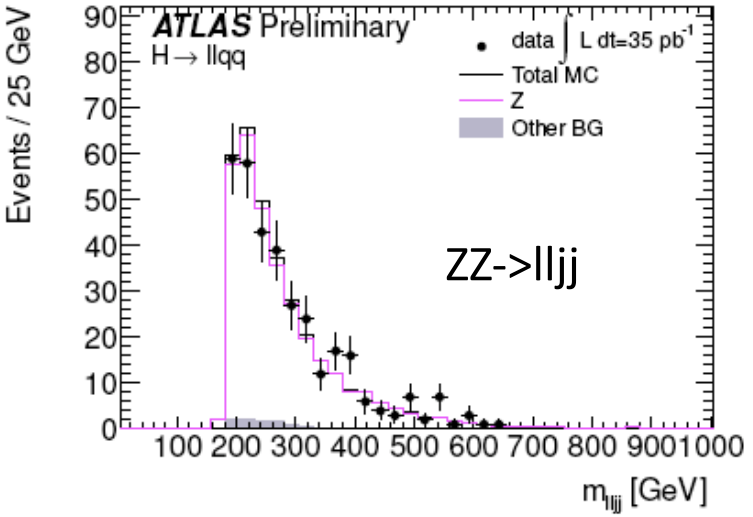




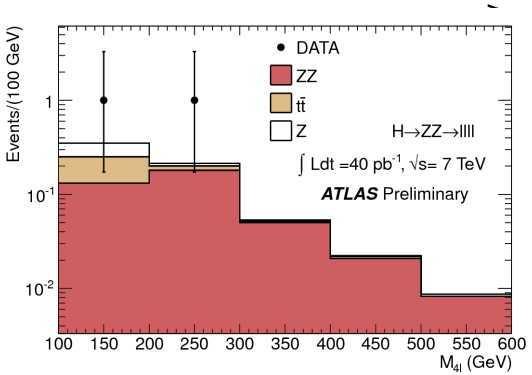


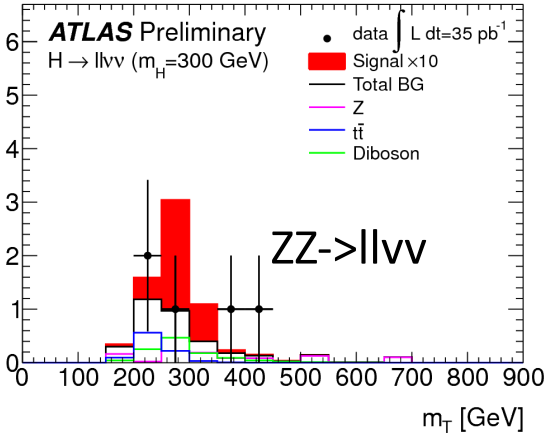




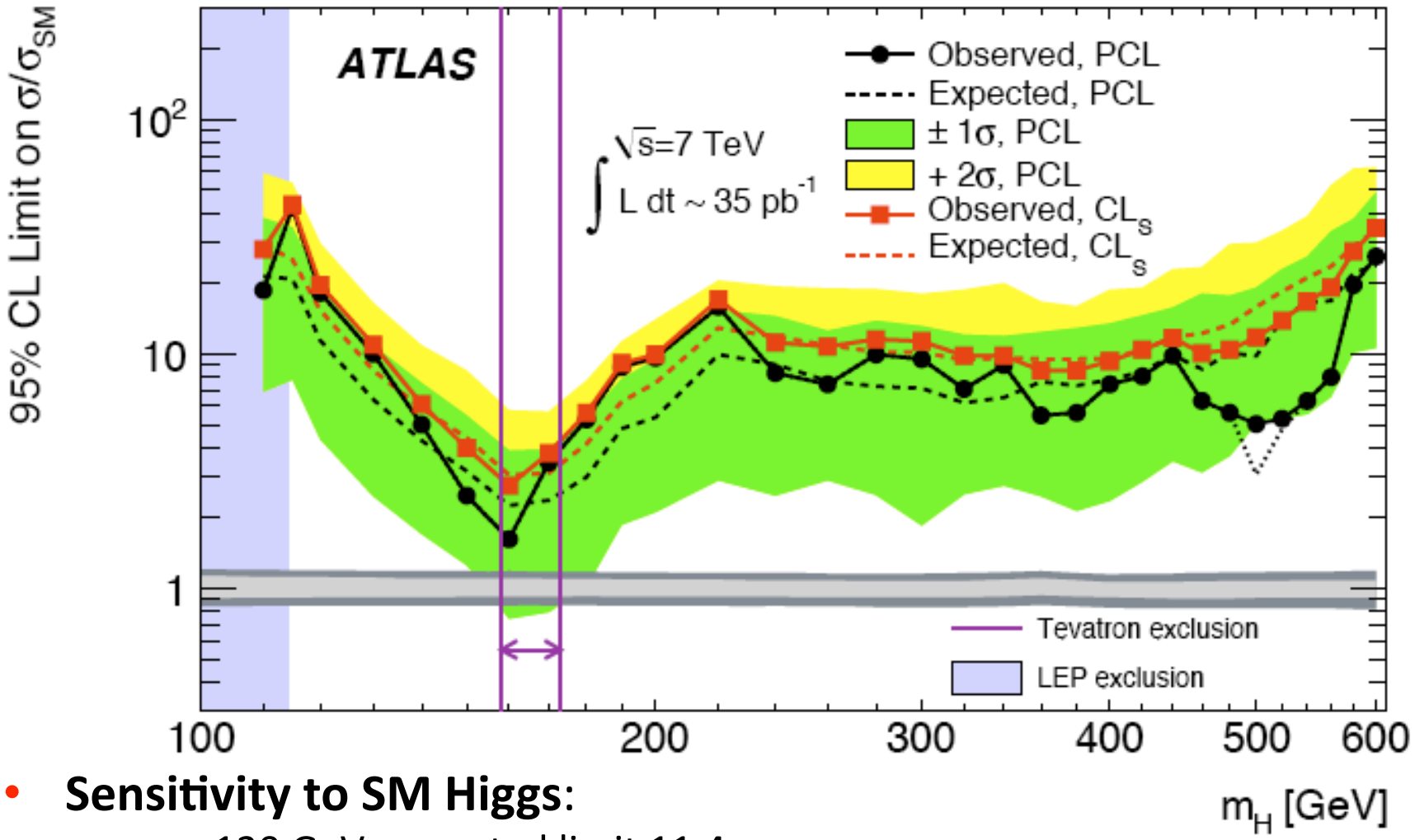


- 2010 data analyses complete
  - H->γγ
  - H->WW: both lvlv and lvjj
  - H->ZZ: llll, llvv and ll jj
- All analyses simple/cut-based
  - Room for improvement!





Combined Limit for 2010 Data on SM Higgs Cross Section

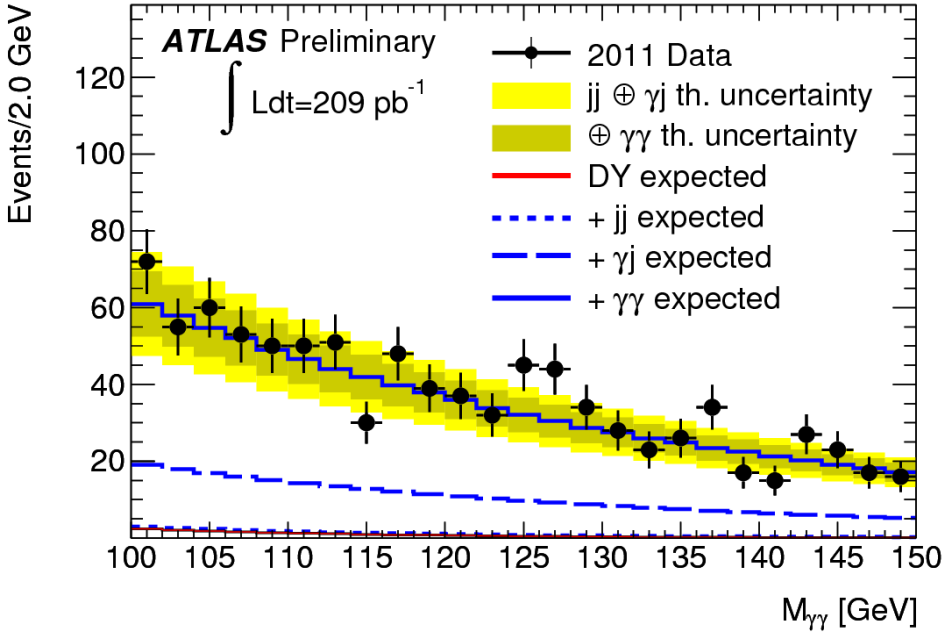


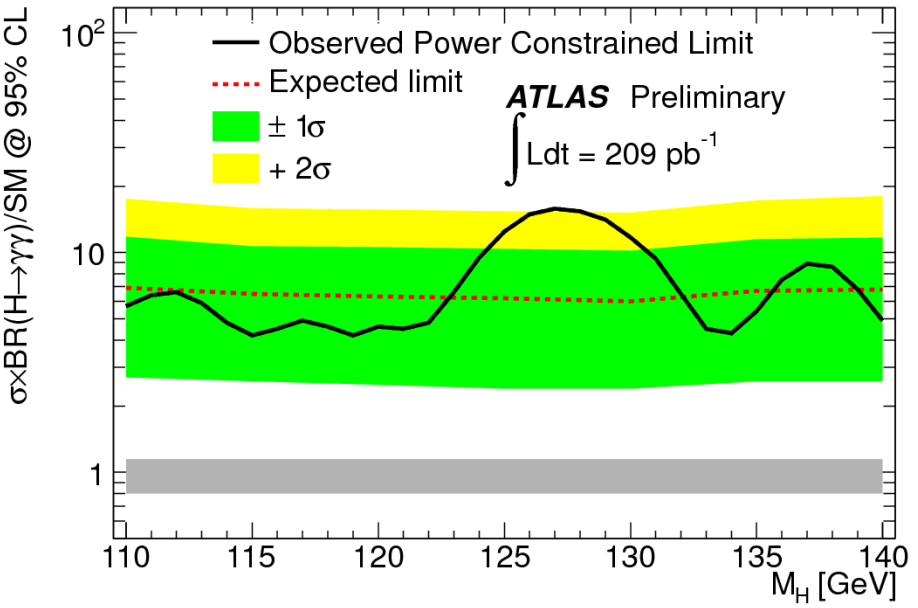
- **Sensitivity to SM Higgs**:
  - m_H=120 GeV: expected limit 11.4 x σ_{SM}
  - m_H=160 GeV: expected limit 2.3 x σ_{SM}
  - m_H=300 GeV: expected limit 7.2 x σ_{SM}
- **Exclude 140<m_H<185 GeV in models with 4th generation**
  - Assuming no other new physics is present
  - Expected exclusion 136<m_H<208 GeV

arXiv:1106.2748

H->γγ

2011 data





- **Di-photon events selected**
  - $E_T(\gamma_1)$>40 GeV, $E_T(\gamma_2)$>25 GeV, isolation cut <5 GeV
  - Background normalized from a-priori MC estimates (cross-checked in data)
- **No significant peak observed in mass spectrum**
  - Limit obtained by fitting for peak + exponential
    - independent of background estimate
- **Expected constraint on the Higgs cross section <7x SM expectation**
  - Observed constraint varies between 5x and 17x the SM cross section
  - Even with no improvements to analysis expect to **reach ~1.6 x σ_{SM} with 4 fb^{-1}**

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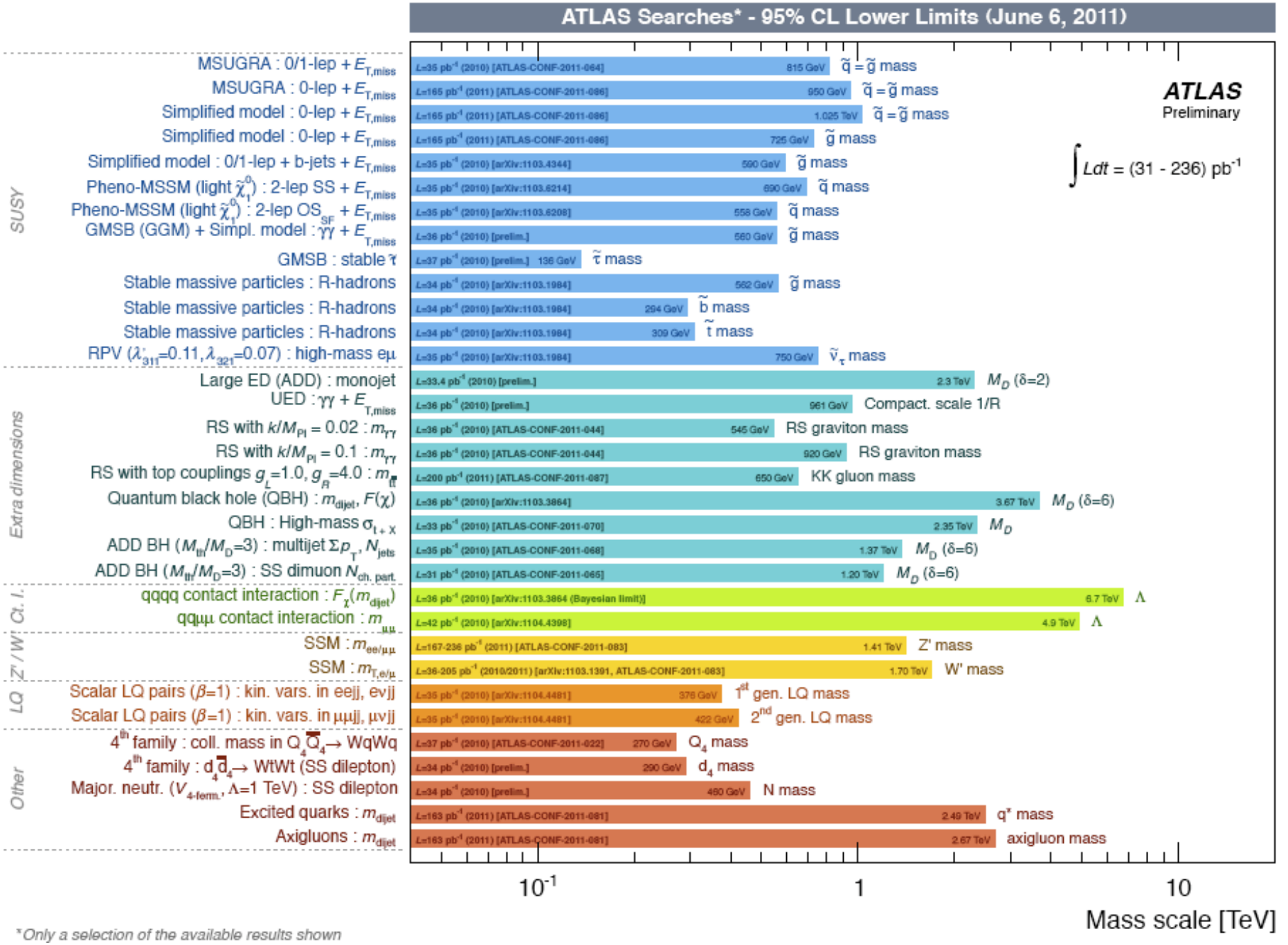
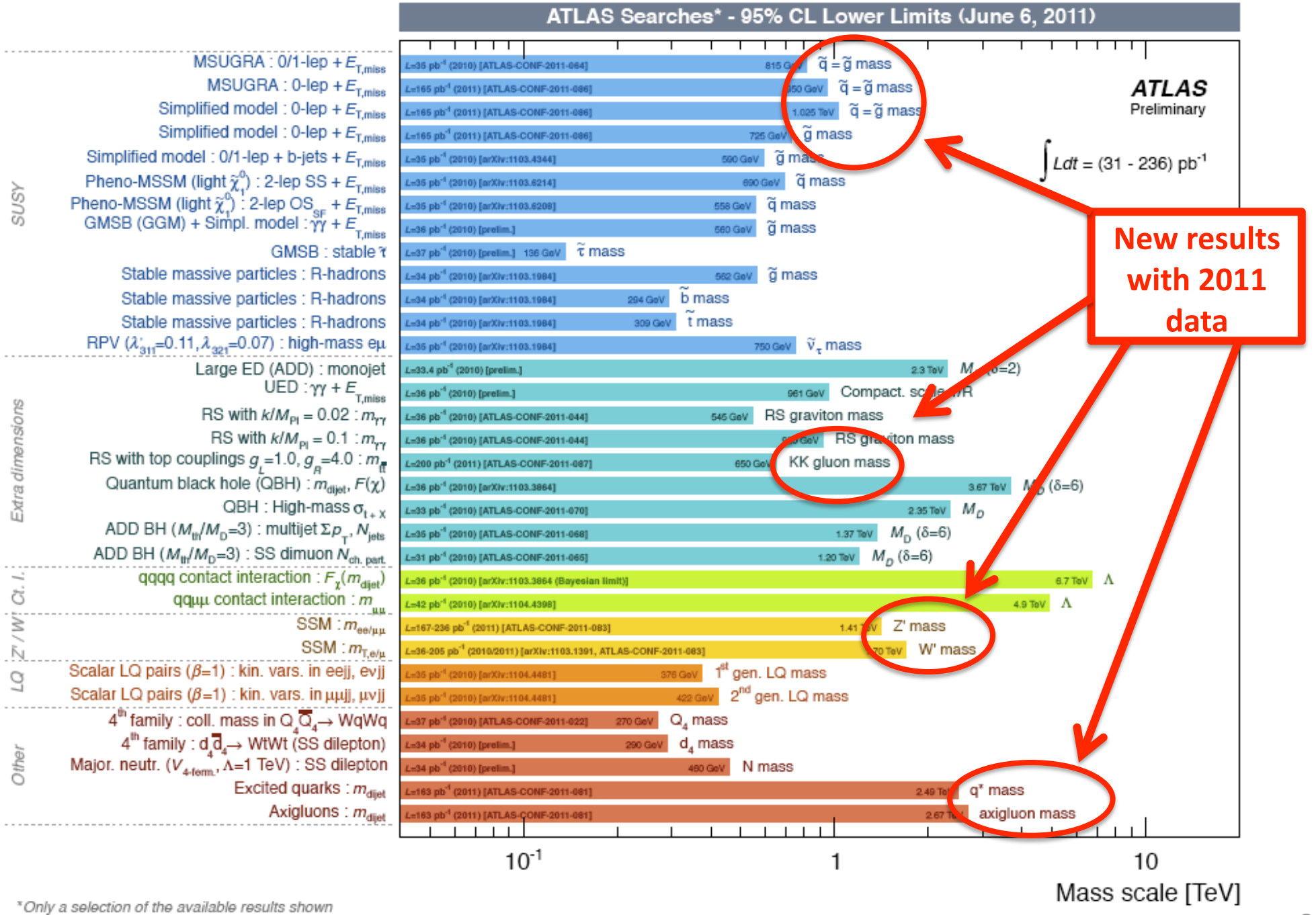
Physics Beyond the Standard Model



*Only a selection of the available results shown

Physics Beyond the Standard Model

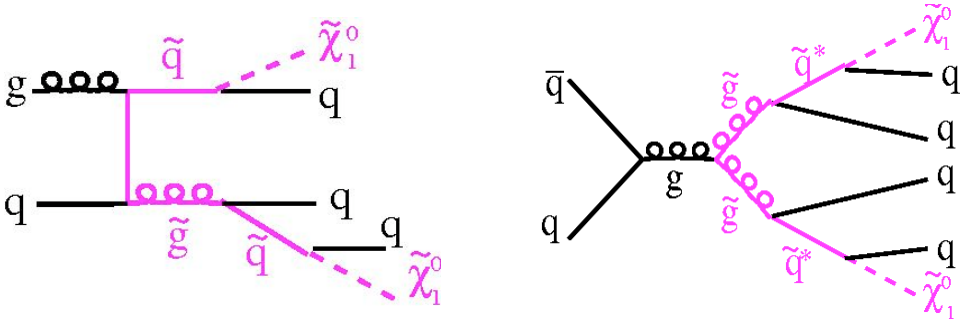


New results with 2011 data

*Only a selection of the available results shown

SUSY: E_t^{miss} + jets + 0 or 1 lepton

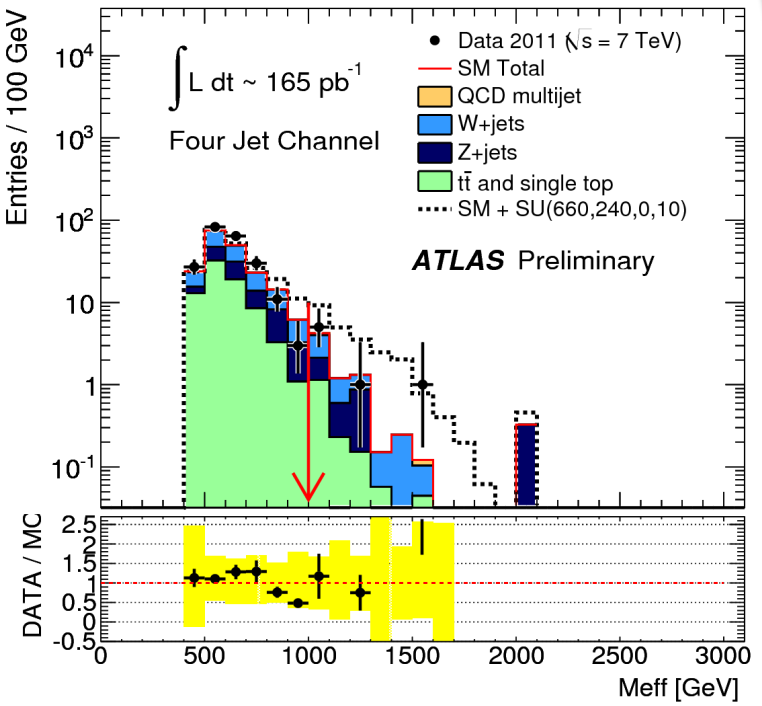
2011 data

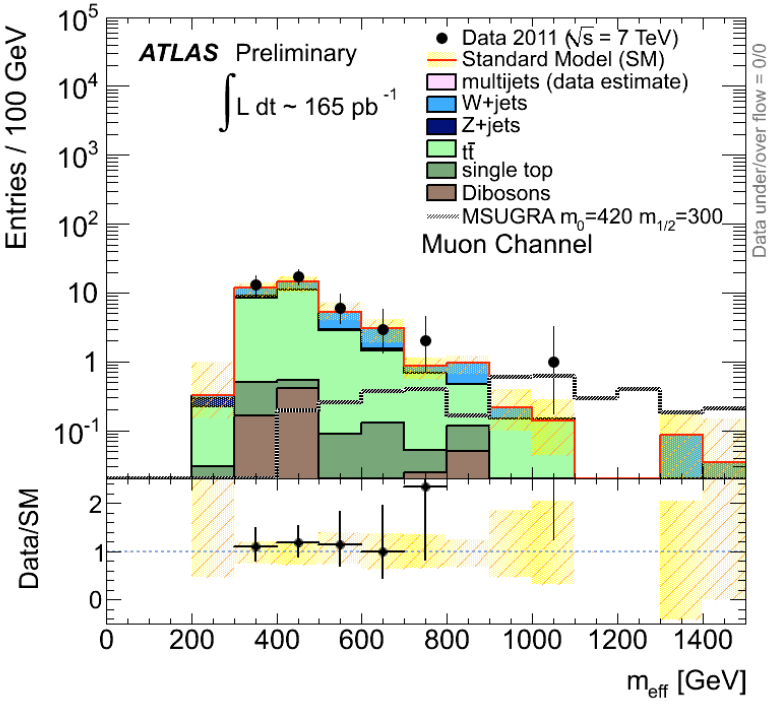


- Classic searches for events with multi-jets amd E_T^{miss}
  - Various jet multiplicities
  - 0 vs 1 lepton selection

Data vs Background Expectation

Analysis channel	expected	observed
≥2 jets+0 leptons	12.1±2.8	10
≥3 jets+0 leptons	10.1±2.4	8
≥4 jets+0 leptons	7.3±1.7	7
≥3 jets+1μ	12.2±3.8	12
≥3 jets+1e	14.5±5.2	10

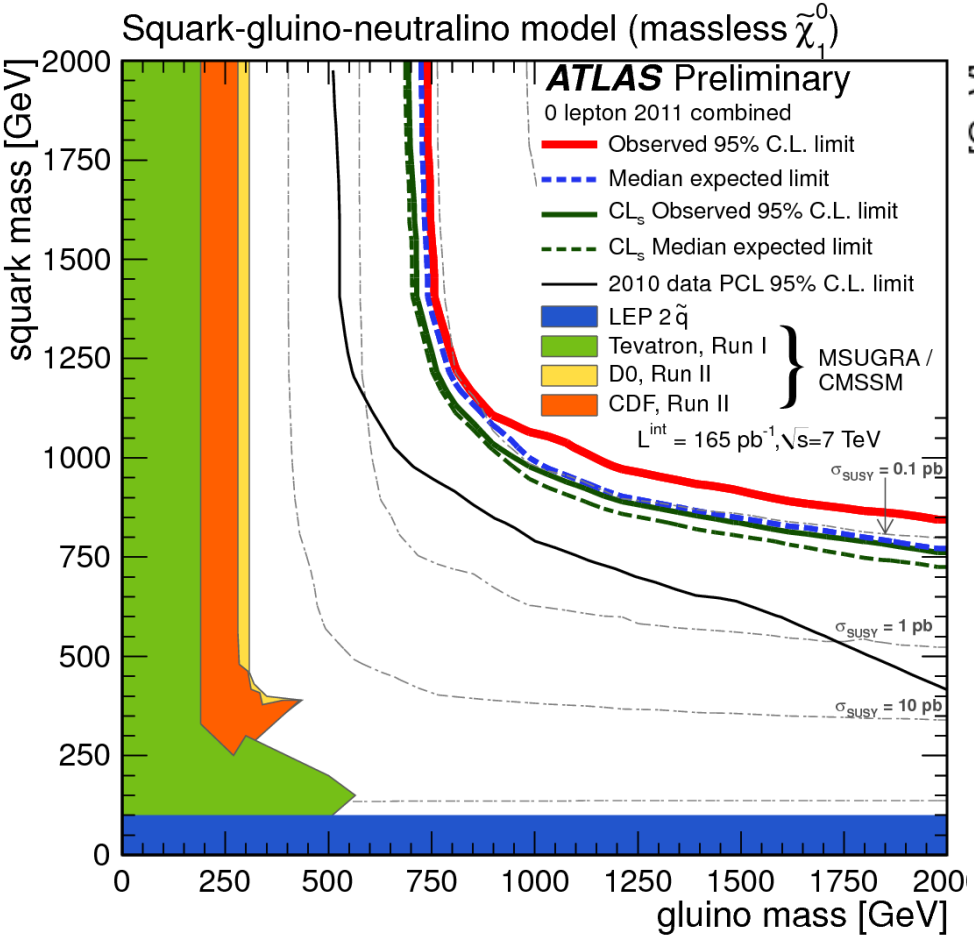


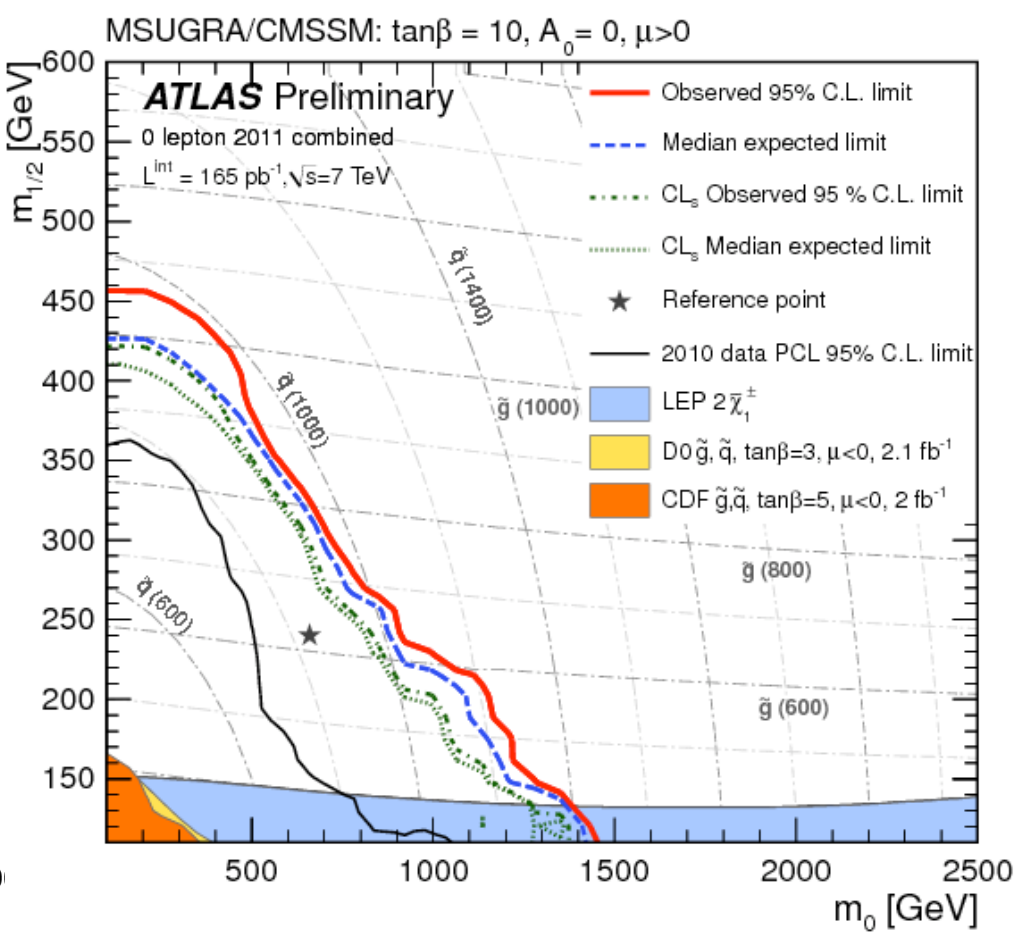


ATLAS-CONF-2011-086, ATLAS-CONF-2011-090

SUSY Interpretation

2011 data



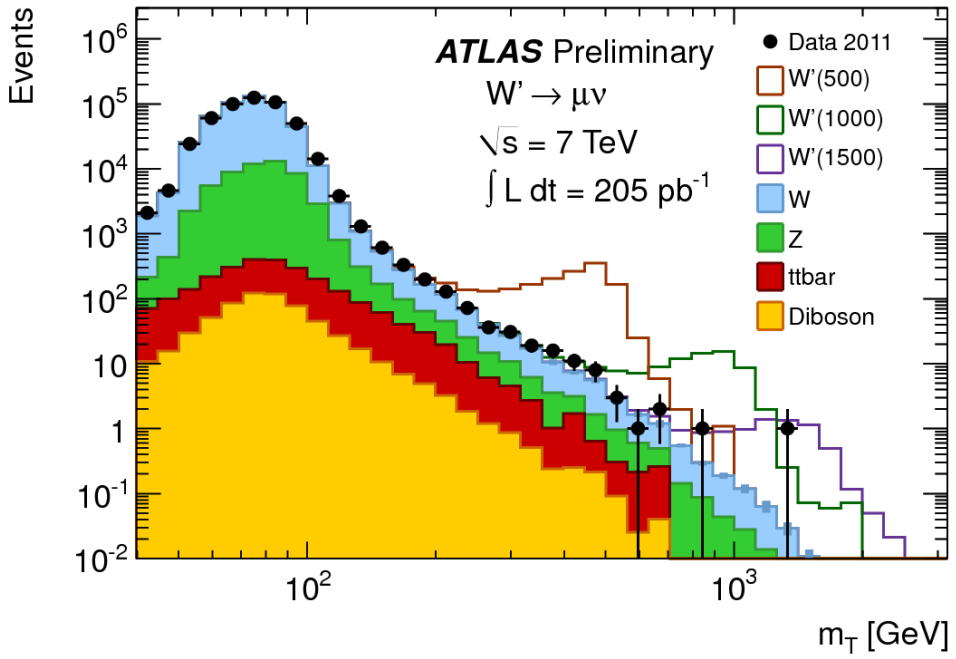


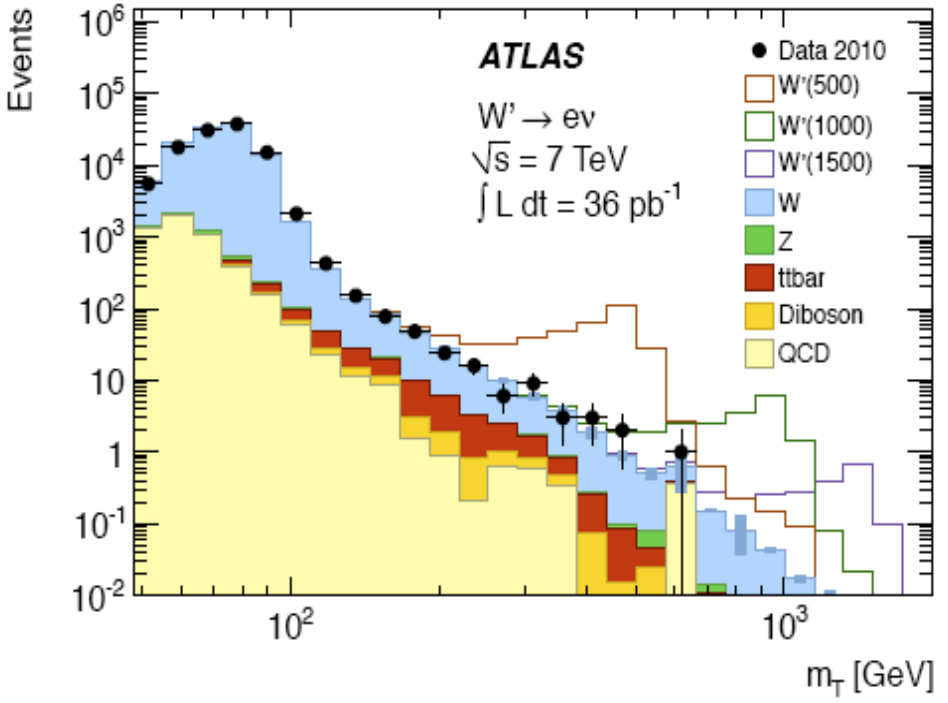
- Data probe squark/gluino cross sections of about **0.1 pb**
- Data challenge squark and gluino masses of ~1 TeV
  - **725 GeV** for gluino regardless of squark mass
  - **1025 GeV** for m($\tilde{g}$)=m($\tilde{q}$) in simplified model [m($\tilde{\chi}_1^0$)=0]
  - **950 GeV** in mSugra/CMSSM model [m($\tilde{\chi}_1^0$)≈m($\tilde{g}$)/6≈160 GeV]

W' searches

2011 data

- Selection of lepton p_T>25 GeV, E_T^{miss}>25 GeV
- For each W' mass require m_T>M(W')/2





- **Data consistent with background expectation**
  - Use data to constrain W' bosons
- **Exclude m(W')<1.7 TeV for SM couplings**
  - combining eν and μν decay modes

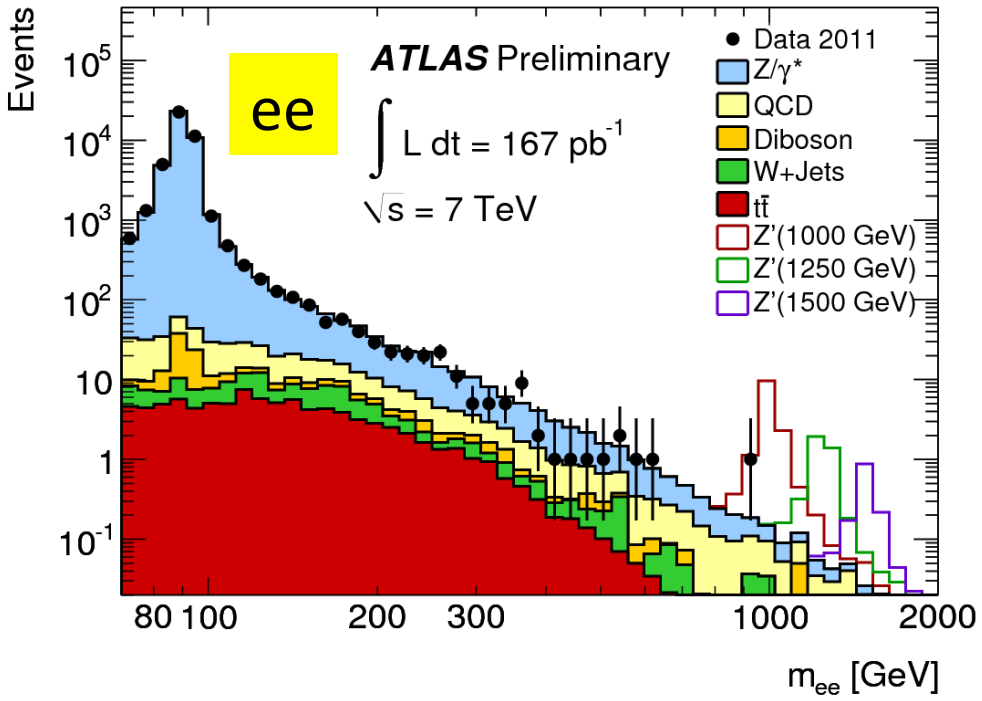
ATLAS-CONF-2011-082

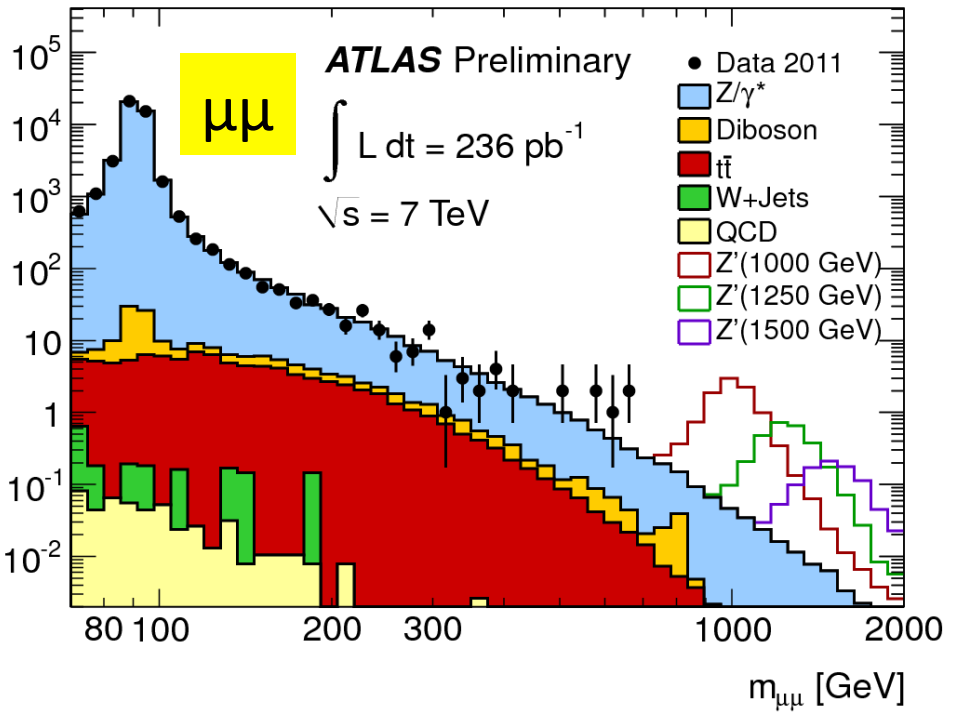
Z' Searches in Dilepton Decay

2011 data

ATLAS-CONF-2011-083

- **Search for peak in invariant mass of high P_T dilepton pairs**

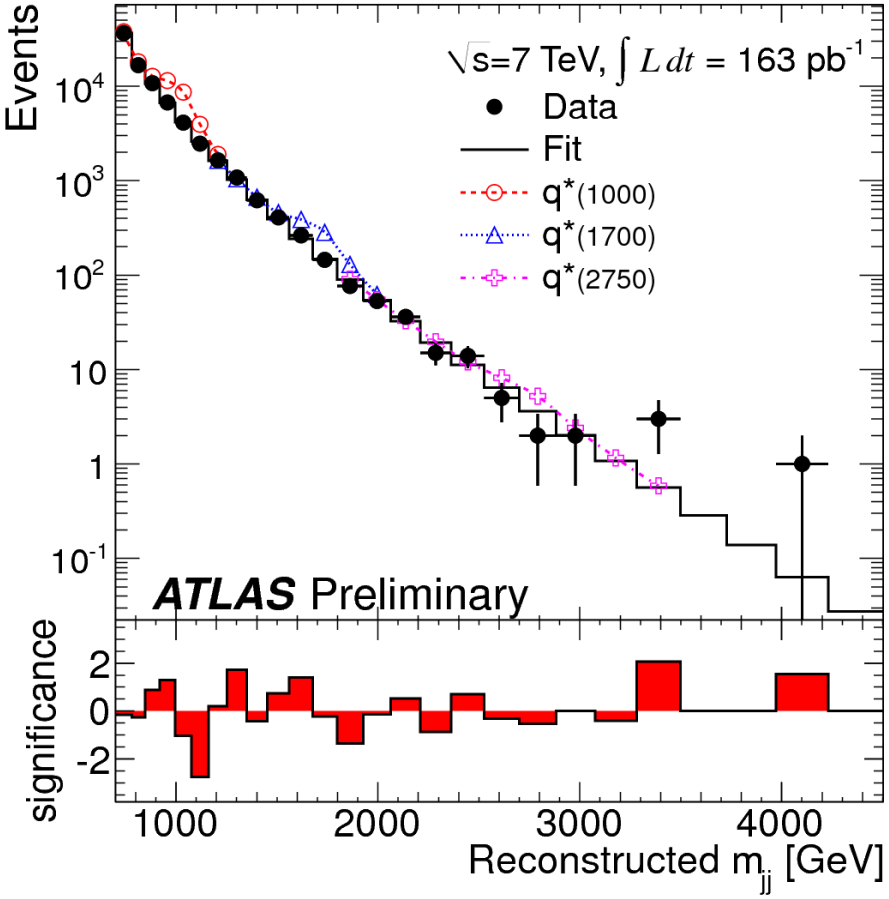


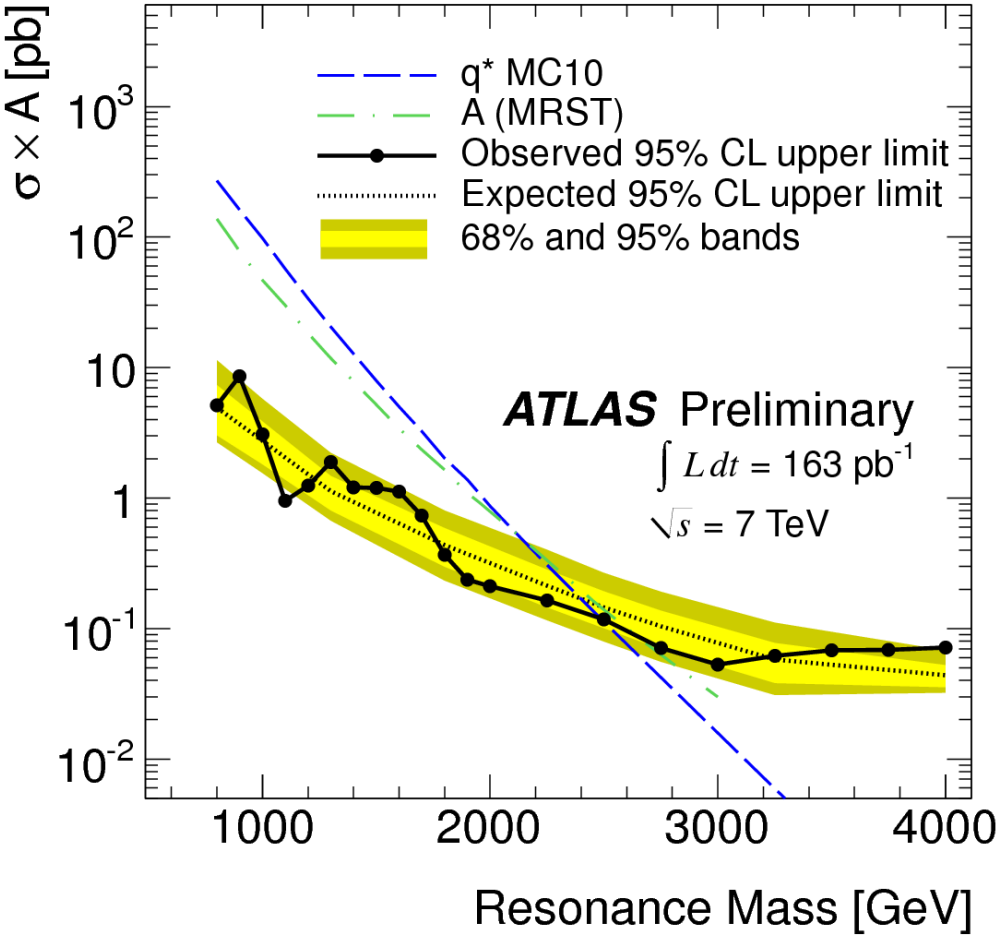


- **Data in good agreement with SM expectation**
  - No evidence for any peak structure
  - Use data to derive limits on Z' in various models
- **Exclude m(Z')<1.44 TeV with SM couplings** (ee and μμ combined)
  - Now clearly beyond Tevatron limits
  - Limits range between 1.15 and 1.29 TeV for E6 inspired models

Dijet Resonance

2011 data





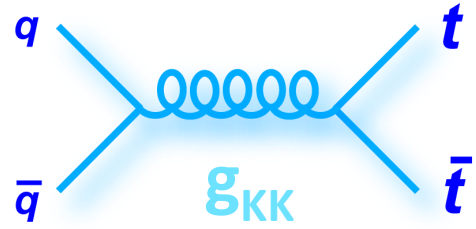
- **Dijet resonance search with 2011 data**
  - No bump-like structure found
- Excludes excited quarks with **0.8<M(q*)<2.5 TeV** and axigluons with **0.8<M(A)<2.67 TeV**

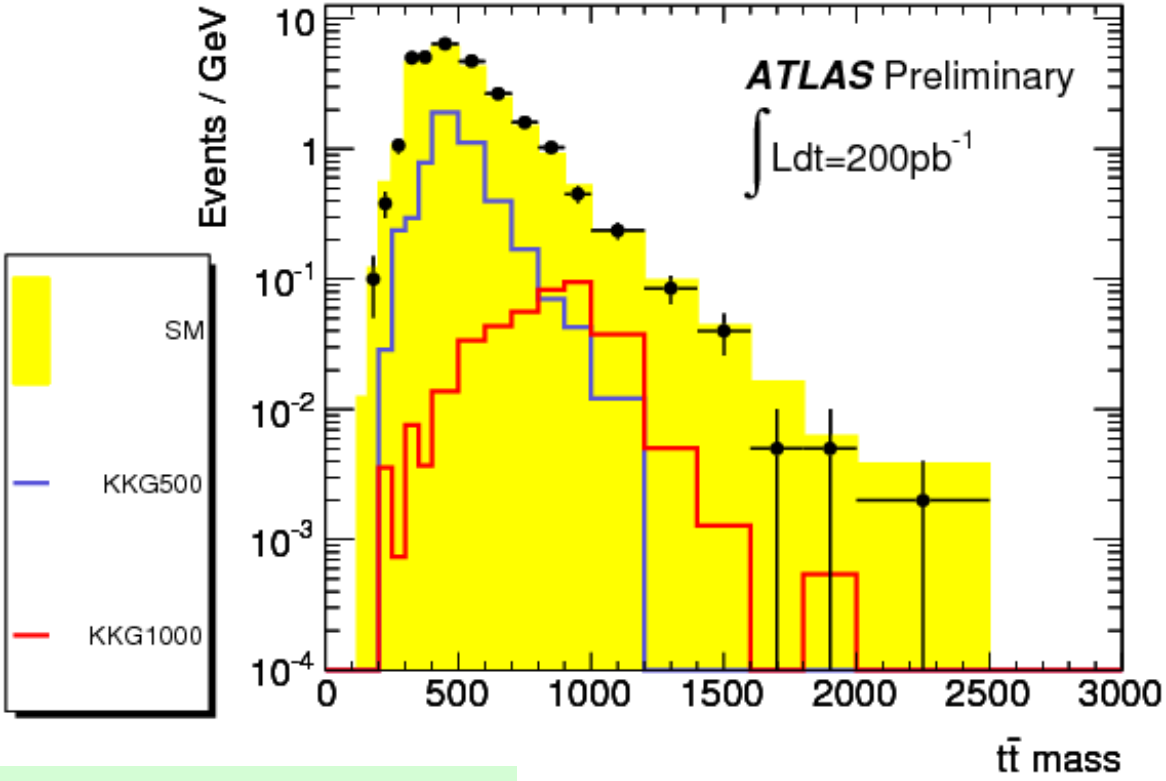
ATLAS-CONF-2011-081

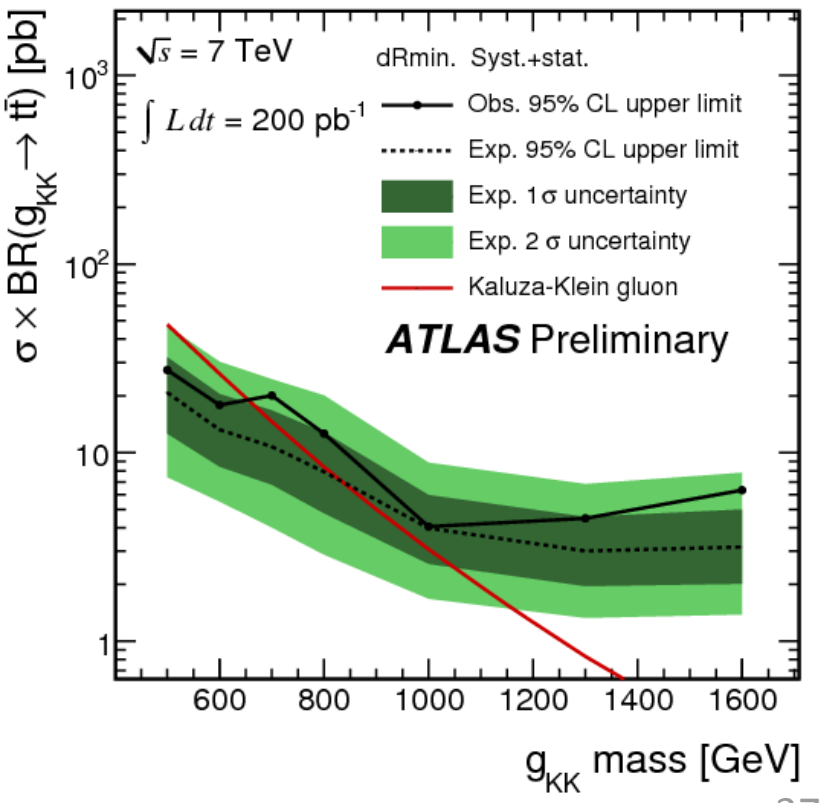
Resonant Top Pair Production

2011 data

- Same base event selection as cross section measurement in lepton+jets channel
- Data consistent with SM expectation
- **Sensitive to cross sections of about 10 pb**
  - Exclude Kaluza-Klein (KK) gluon with $M(g_{KK})<680$ GeV
  - Not yet sensitive to leptophobic Z' model







ATLAS-CONF-2011-087

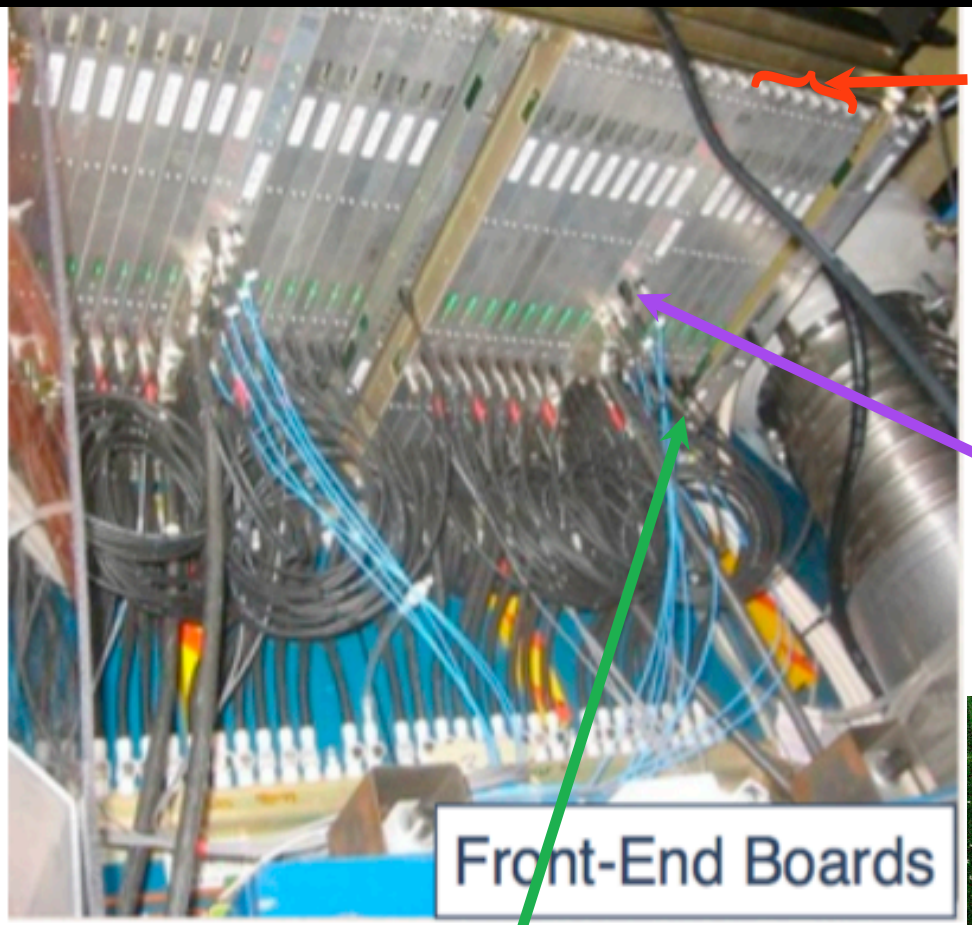
Concluding Remarks

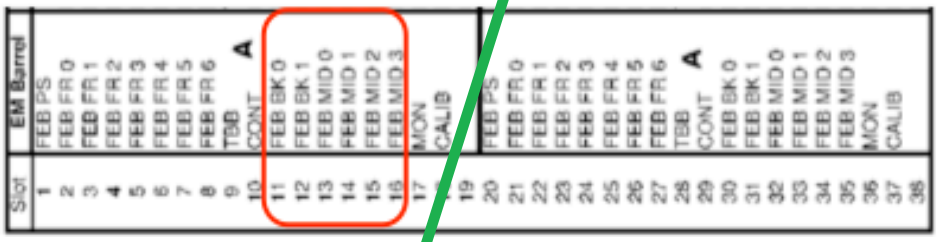
- **ATLAS is operating very well: collects, triggers, processes and analyses data delivered by LHC efficiently**
  - 1 fb^{-1} of data collected (ε=95.8%)
  - Many analyses already available with early 2011 dataset
    - Best demonstration of excellent performance of detector calibration, software, computing and fast analysis turnaround time
    - Excellent progress being made on understanding large pileup in 2011
- **Many new physics results since March 2011**
  - Continue to probe (ever more deeply) the strong and electroweak sectors of the Standard Model in new energy regime
  - New in-depth studies of the hot medium in Pb-Pb collisions
  - Closing in on the Standard Model Higgs boson
  - Searches for new physics truly probe TeV scale in many signatures
    - No deviation from SM found yet though => hope for this to change!
- **Looking forward to multi-fb^{-1} dataset this year**

The ATLAS collaboration deeply thanks the LHC for the outstanding accelerator performance!!

Backup Slides

LAr Calorimeter Incident: April 30th 7:45 am





TTC connectors

6 Frontend Boards and one calibration board lost TTC signal on 30.04.2011

4 FEBs Layer 2 (~$20X_0$),

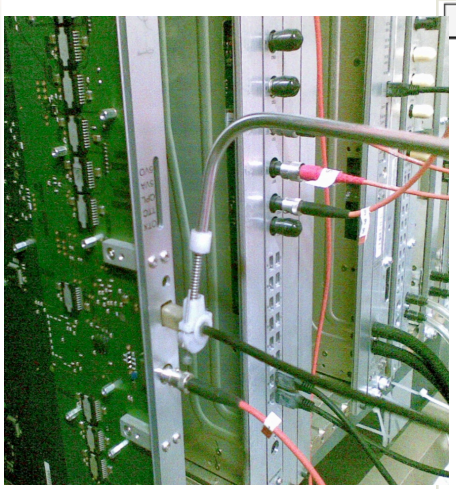
2 FEBs Layer 3 (a few X_0)

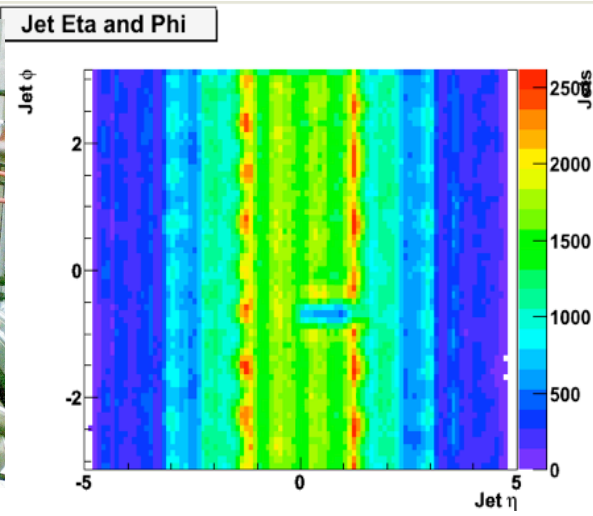
$-0.84<\phi<-0.64$ - $0<\eta<1.4$

Failure probably due to a burnt fuse on the **controller board**

Preparation of the repair during beg. of July Technical Stop ongoing

Review of controller board spec. ongoing

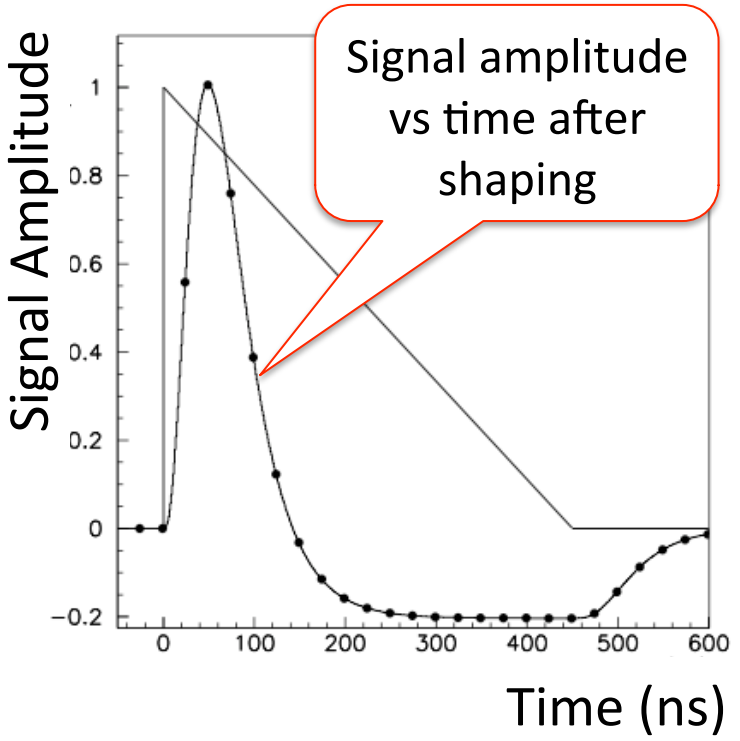


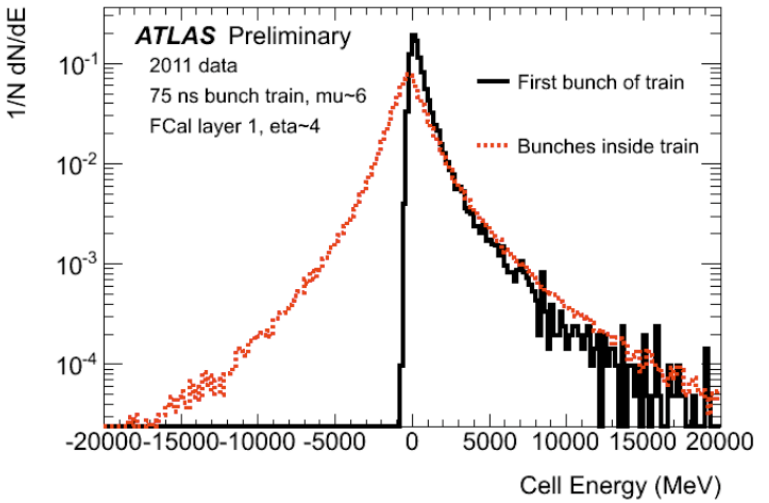


Impact on analyses mitigated by usage of tracking and other calorimeter layers

Impact of Pileup on Reconstruction

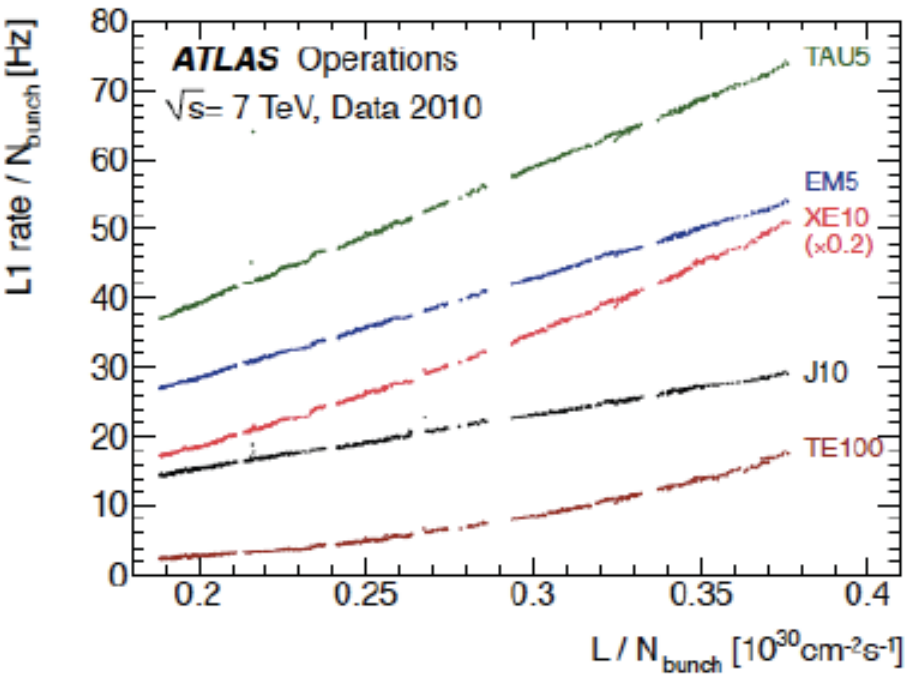
- **Significant impact on calorimeter reconstruction since LAr drift time is 400 ns**
  - Thus LAr calorimeter "sees" the previous 8 interactions (at 50ns bunch spacing)
    - Signal shape is bipolar to cancel on average for 25ns running
    - We call these previous interactions "out-of-time pileup noise"
  - Impact on physics
    - Depends on <μ> and position in bunch train
    - Increase in systematic uncertainty for low p_T jets w.r.t. 2010
      - Up to 7% at p_T<50 GeV in forward region
      - No impact for p_T>100 GeV
- **No appreciable impact on physics performance of ID tracking or muon reconstruction**

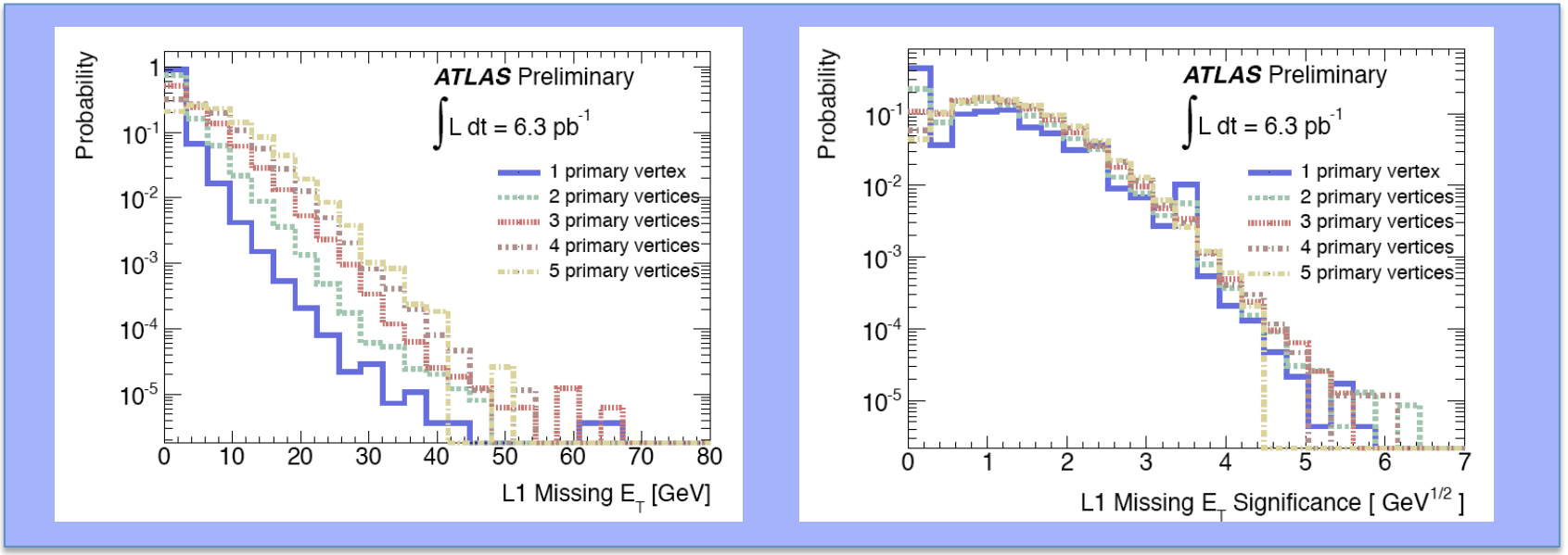




New: Missing Et Significance Trigger

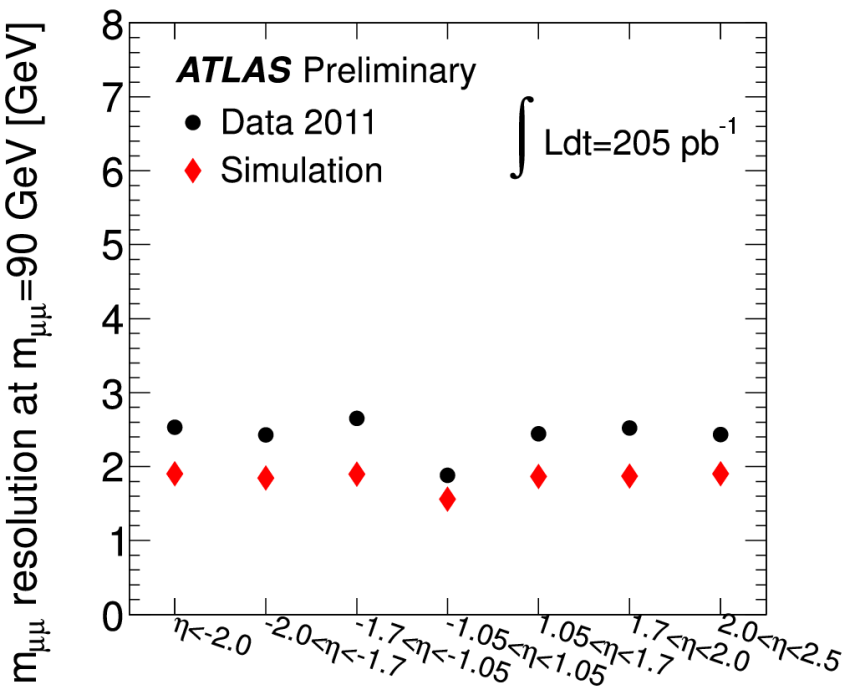
- L1 rates of SumET and MET triggers grows non-linearly with Luminosity
  - Sensitive to pileup
- Developed new trigger "Missing ET significance"
  - MEtSig=MEt/sqrt(SumEt)
  - Insensitive to pileup

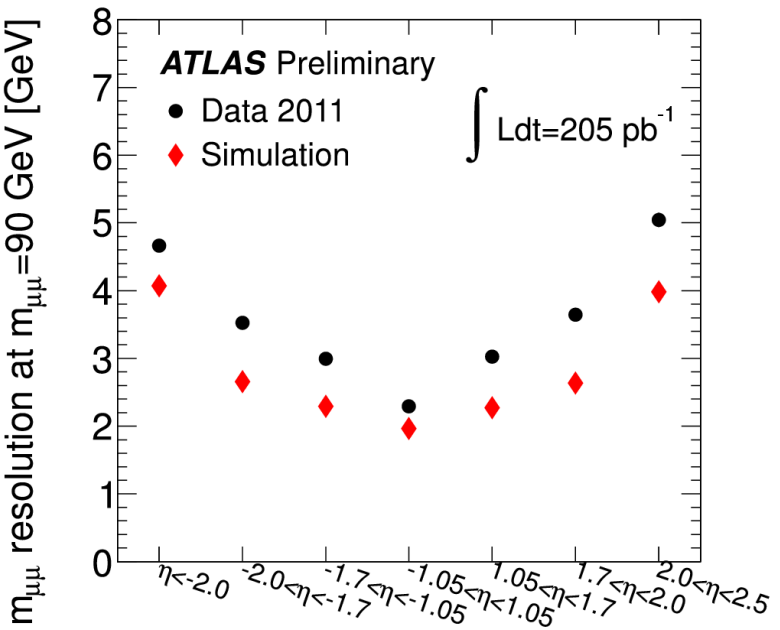




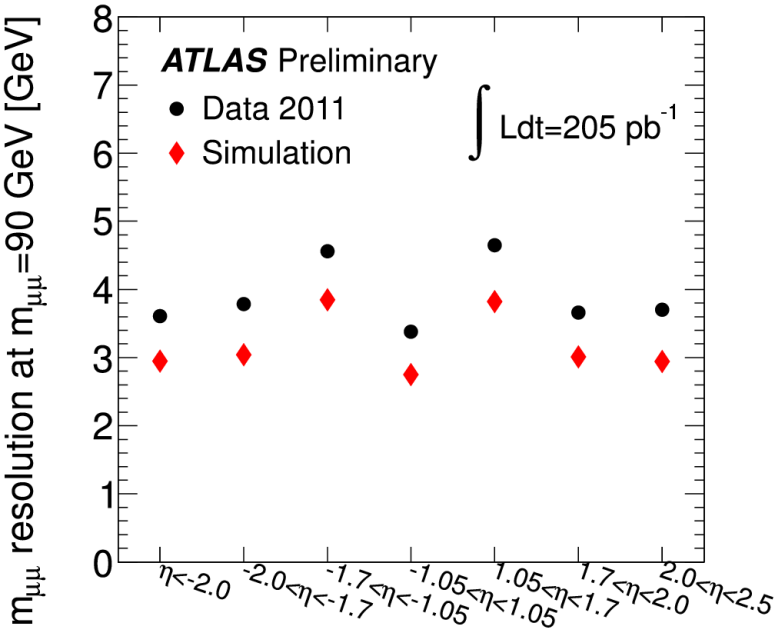
Adds flexibility particularly for tau and SUSY triggers

Muon Momentum Resolution

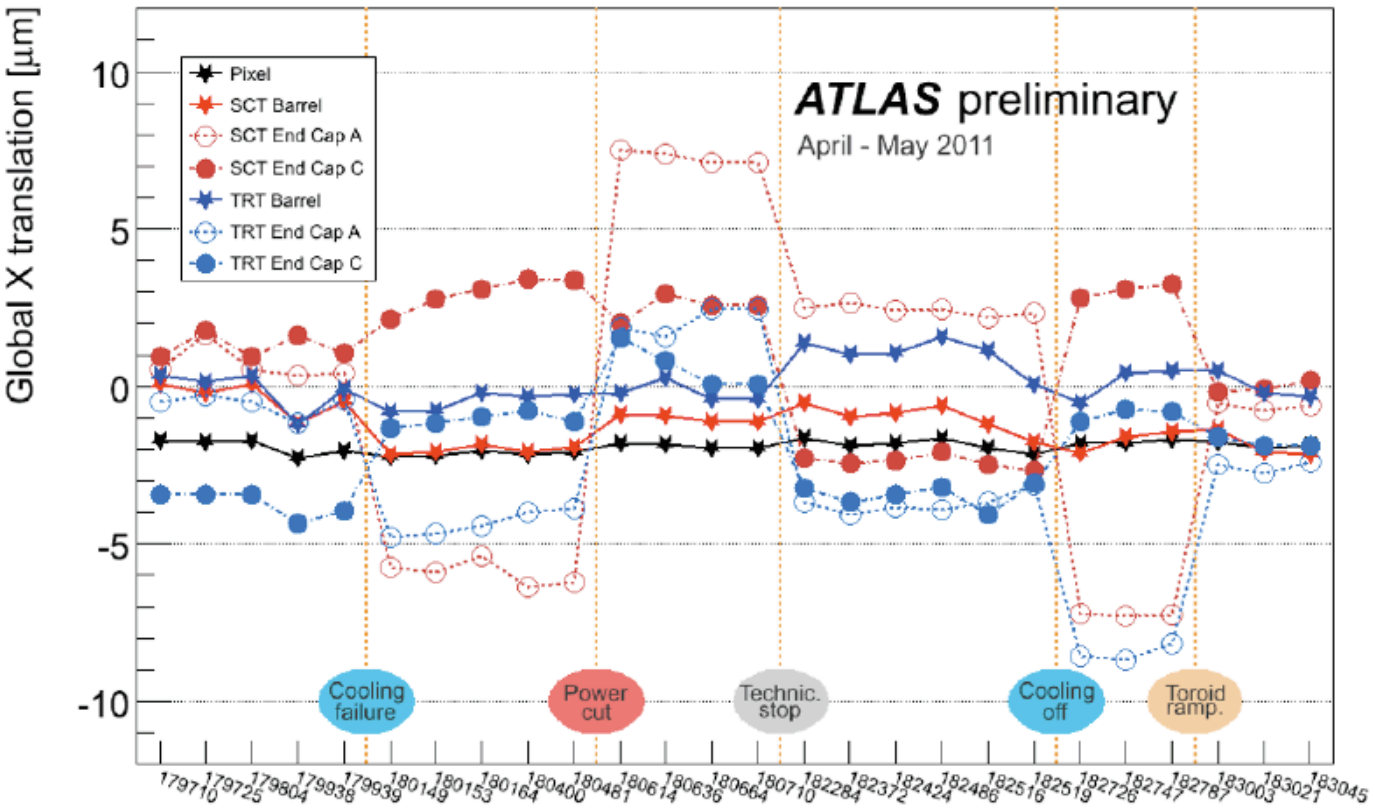




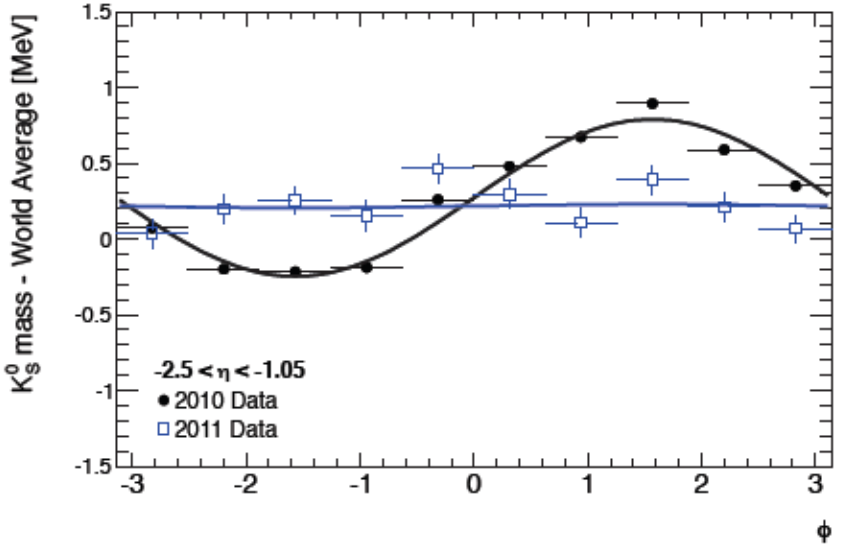
- Z mass resolution ~20% worse in data compared to ideal alignment
- Expect improvements for reprocessing campaign
  - Available for analyses in Fall 2011



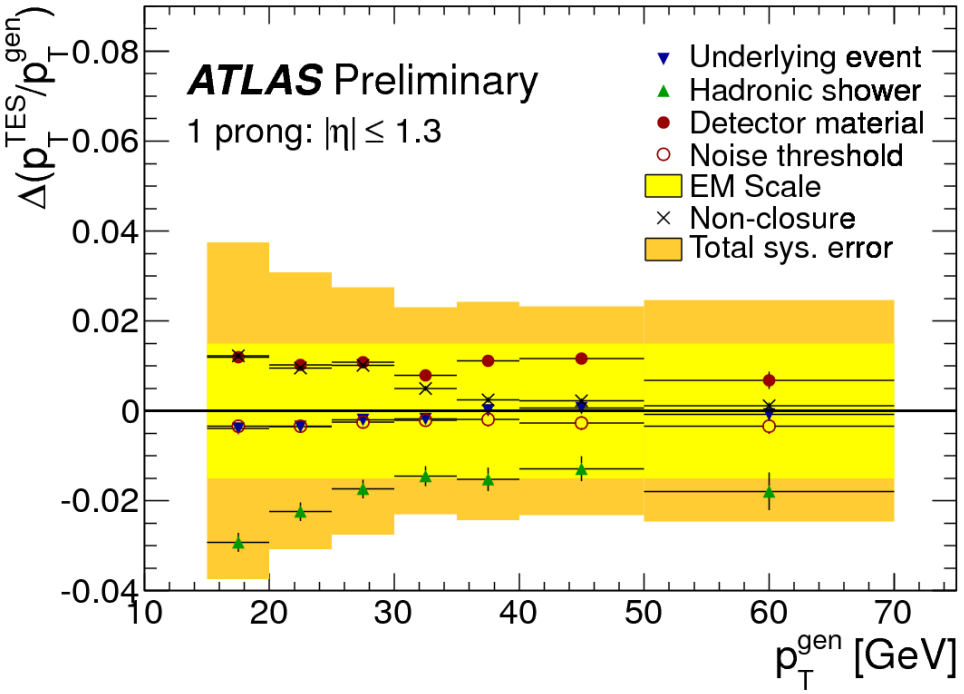
Inner Detector Alignment

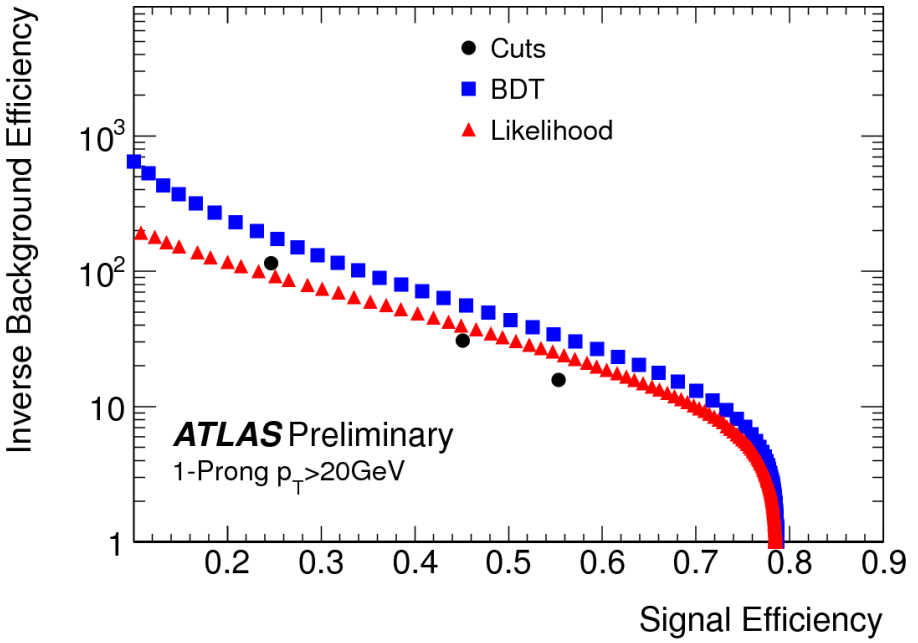


- Movements of up to 8 μm during interventions
  - Otherwise stable
- Recently corrected observed tilt between solenoid and ID

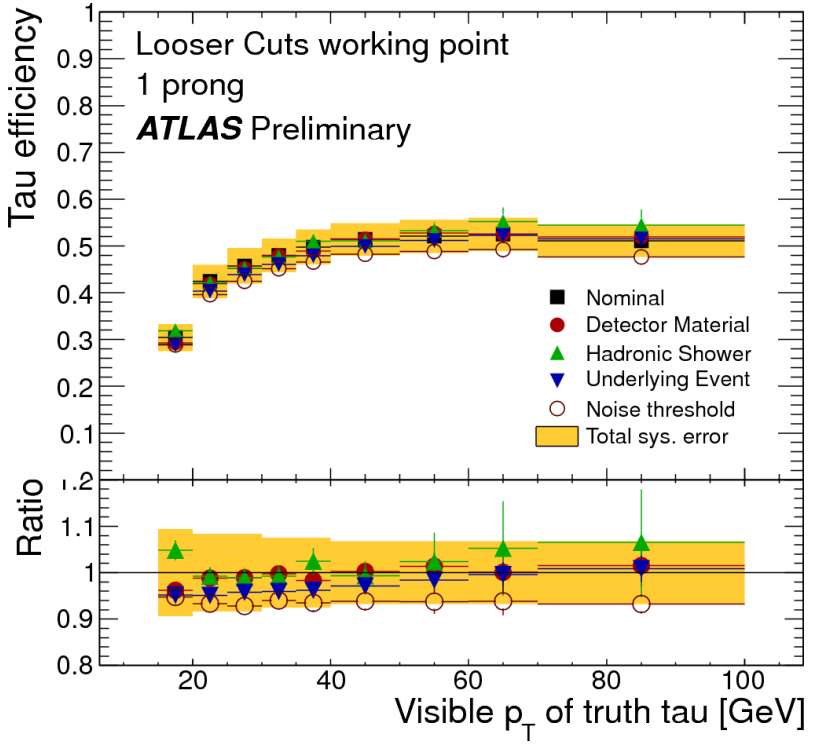


Understanding of τ-leptons

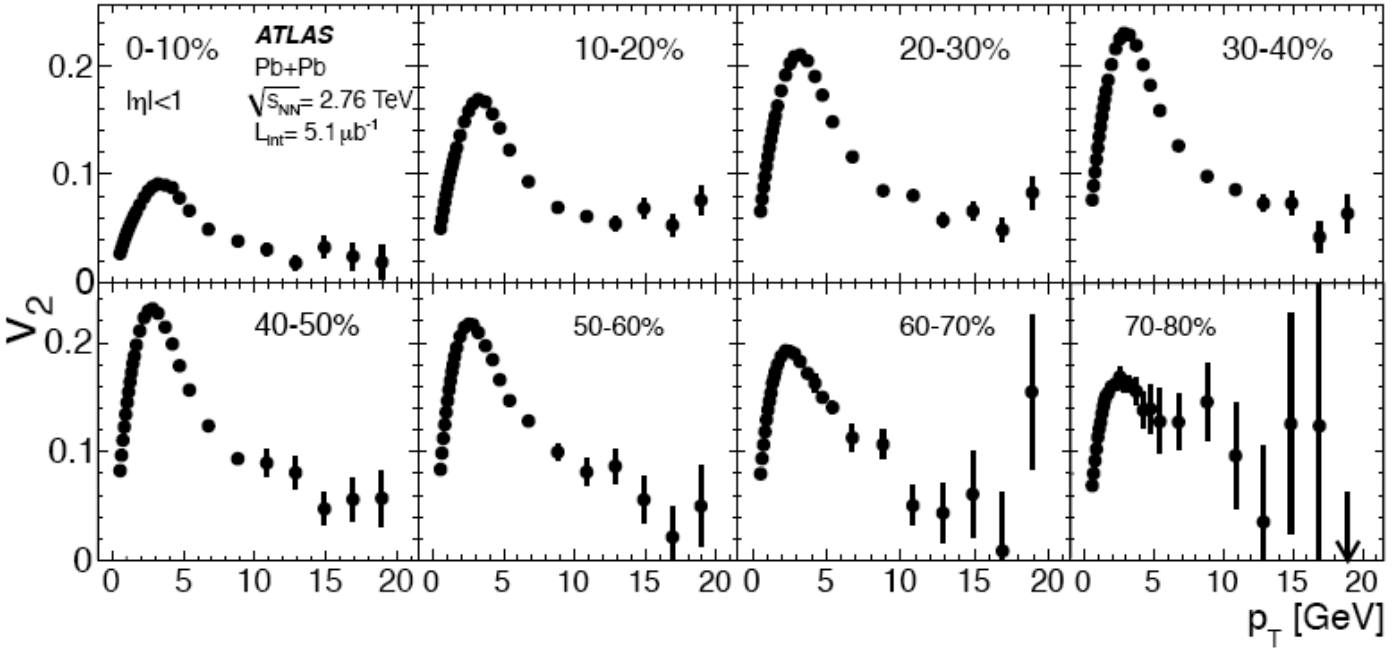




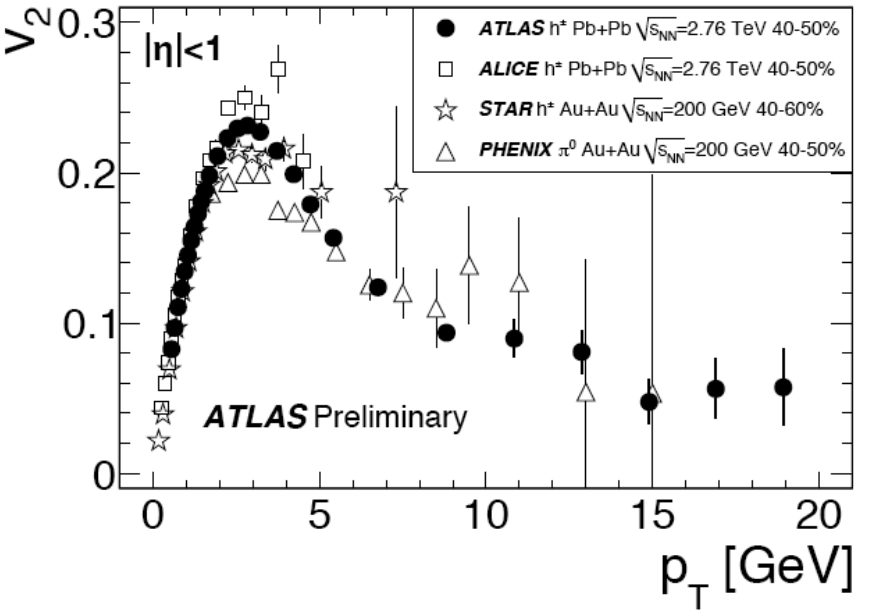
- Tau energy scale understood to within ~2-4%
- Efficiency understood to within 6-10%



Elliptic Flow

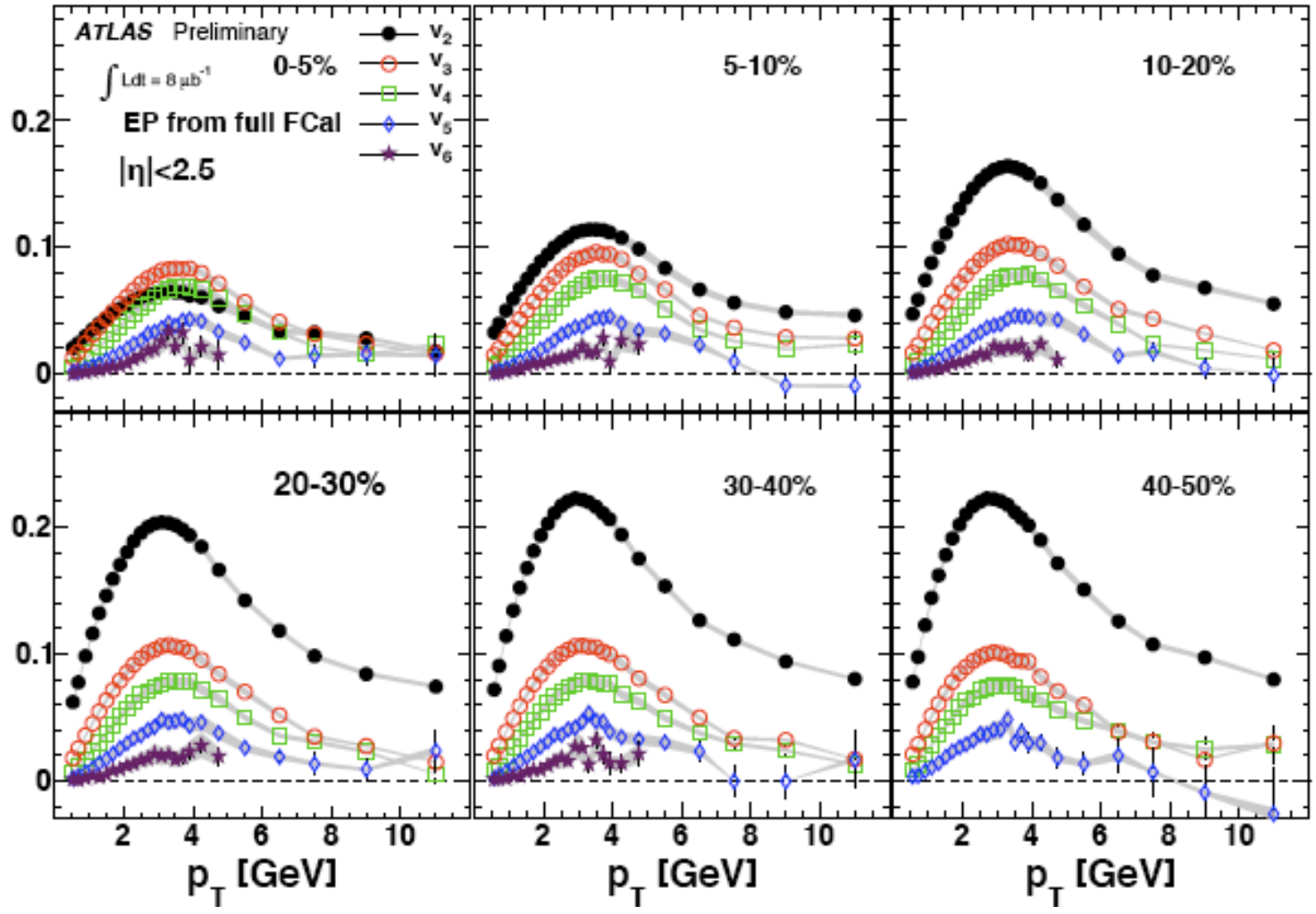


- No significant dependence of shape on centrality
- Appears to scale at fixed centrality
- No significant dependence versus |η|



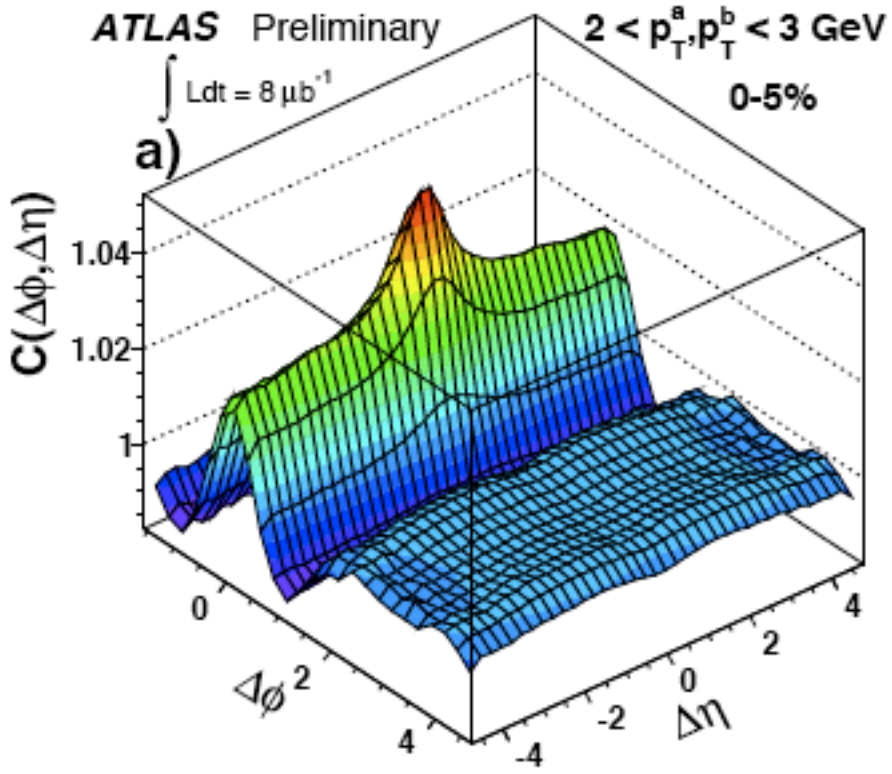
Elliptic and Higher Order Flow

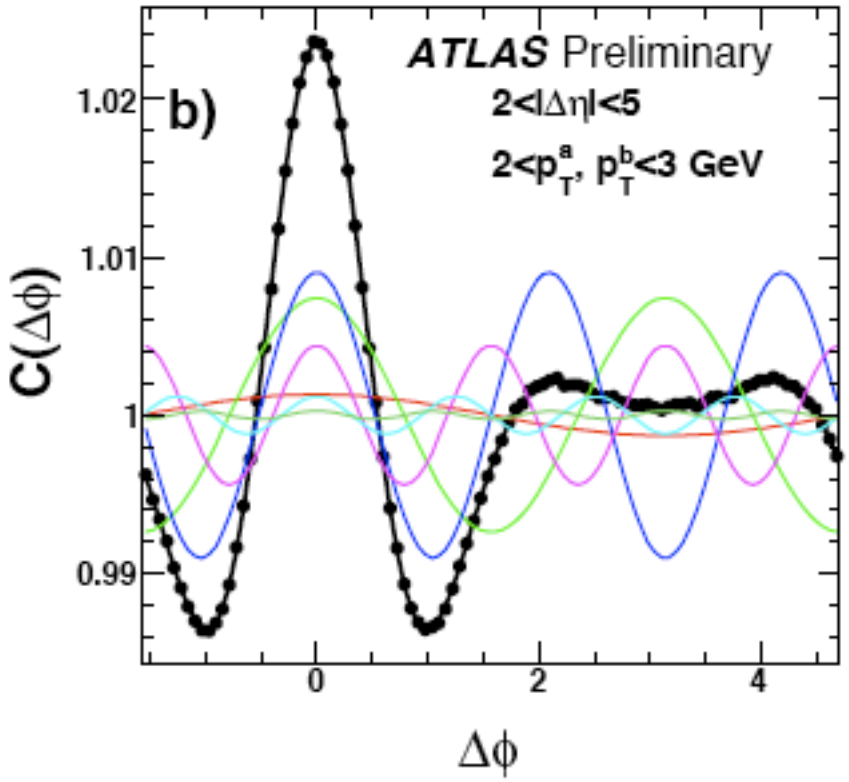
$$dN/d\phi \propto 1 + 2\sum_{n=1}^{\infty} v_n(p_T)\cos\left(n\left(\phi - \Psi_n\right)\right)$$



- v_2 depends on centrality
- Higher order coefficients nearly independent of centrality

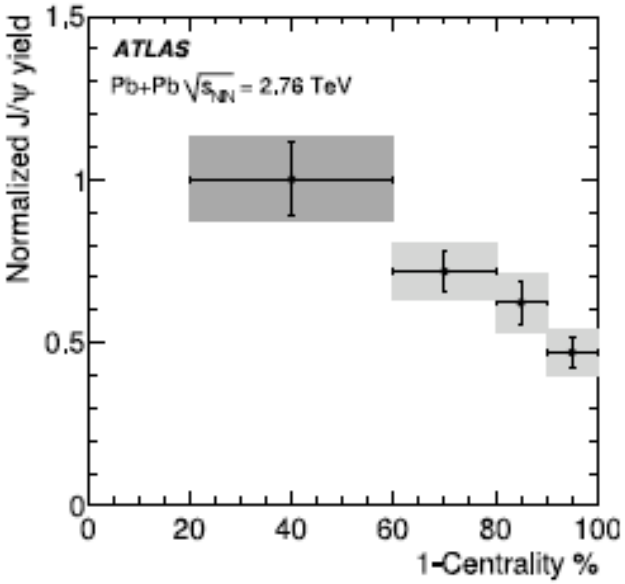
Two-Particle Correlations

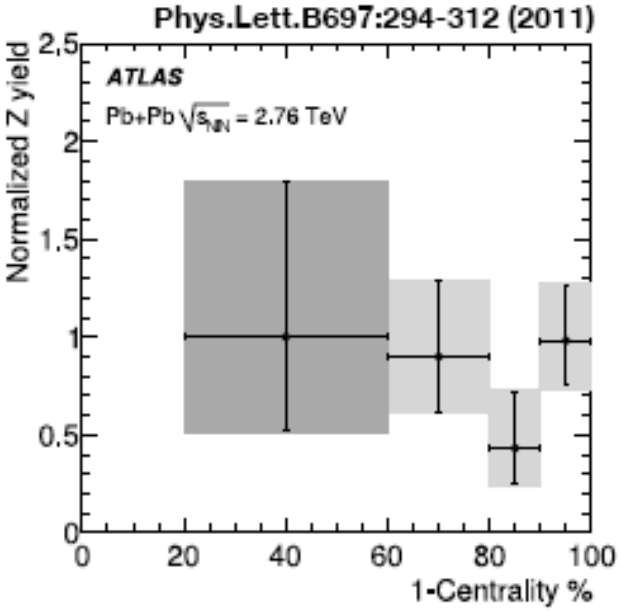


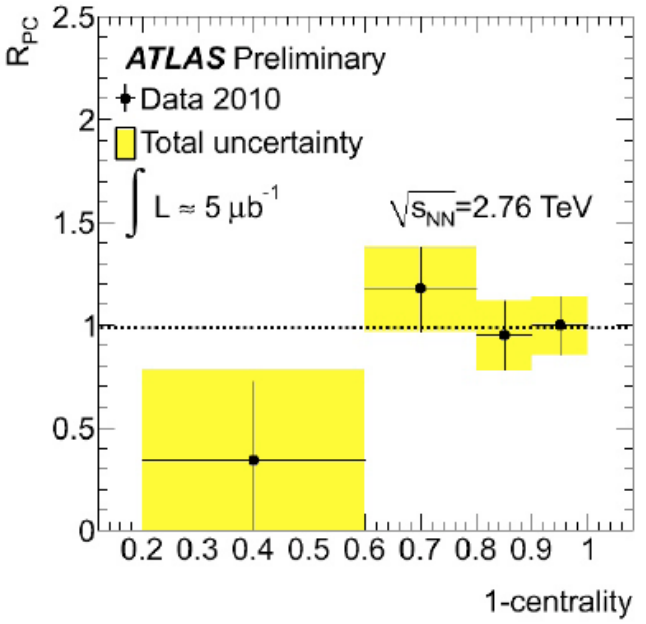


- Detailed measurements of 2-particle correlations
- For most central events data consistent with $v_3 > v_2$

Centrality dependence of high p_T probes

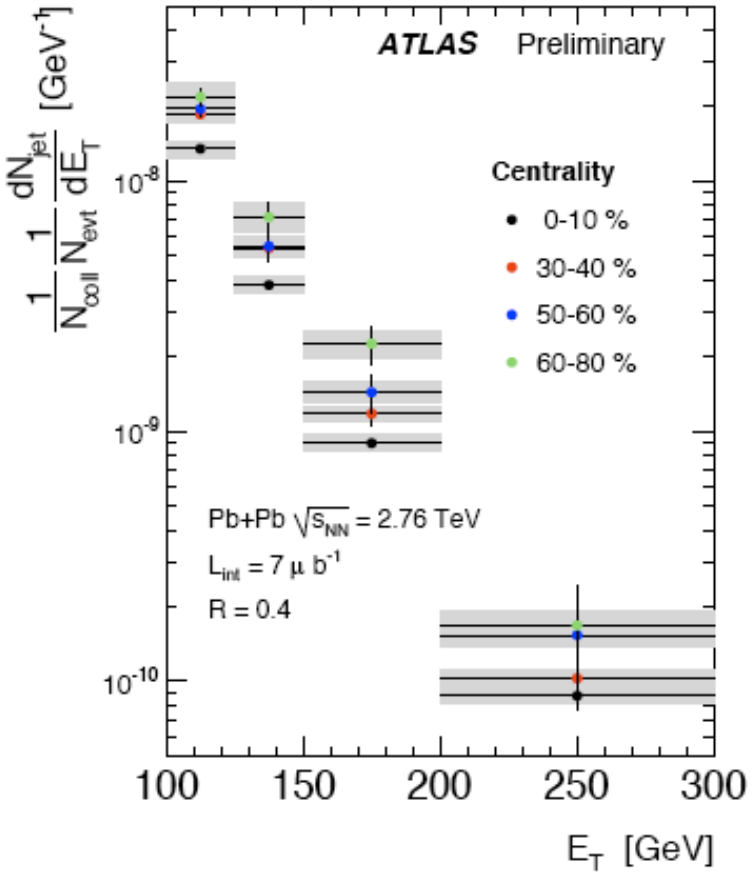


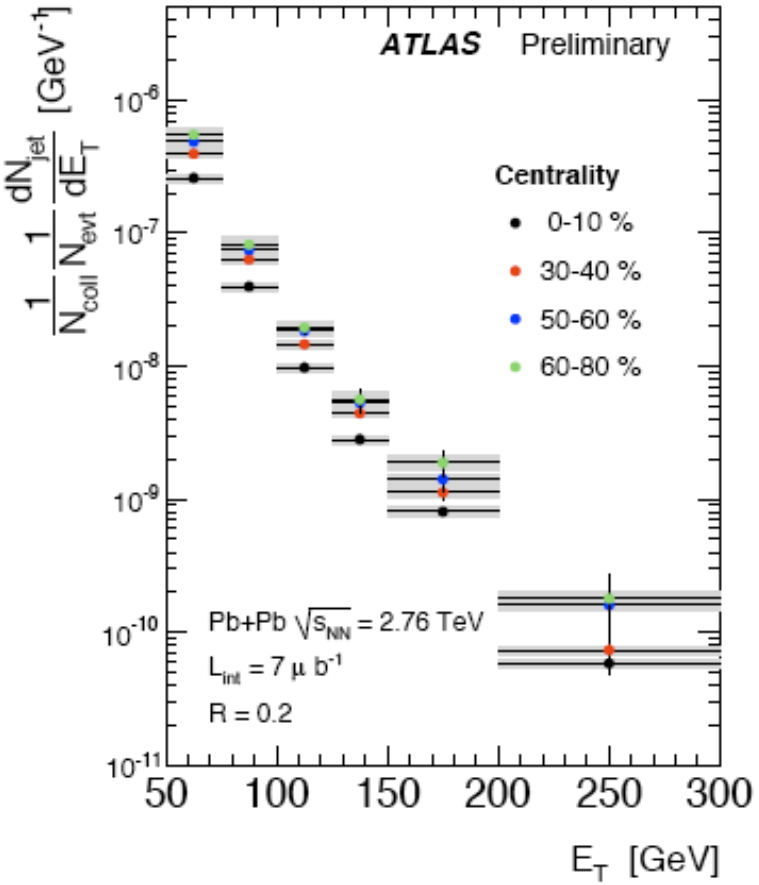




- Indication of J/psi suppression for central events
- W and Z bosons consistent with no suppression

Normalized Jet Yields in Pb-Pb Collisions





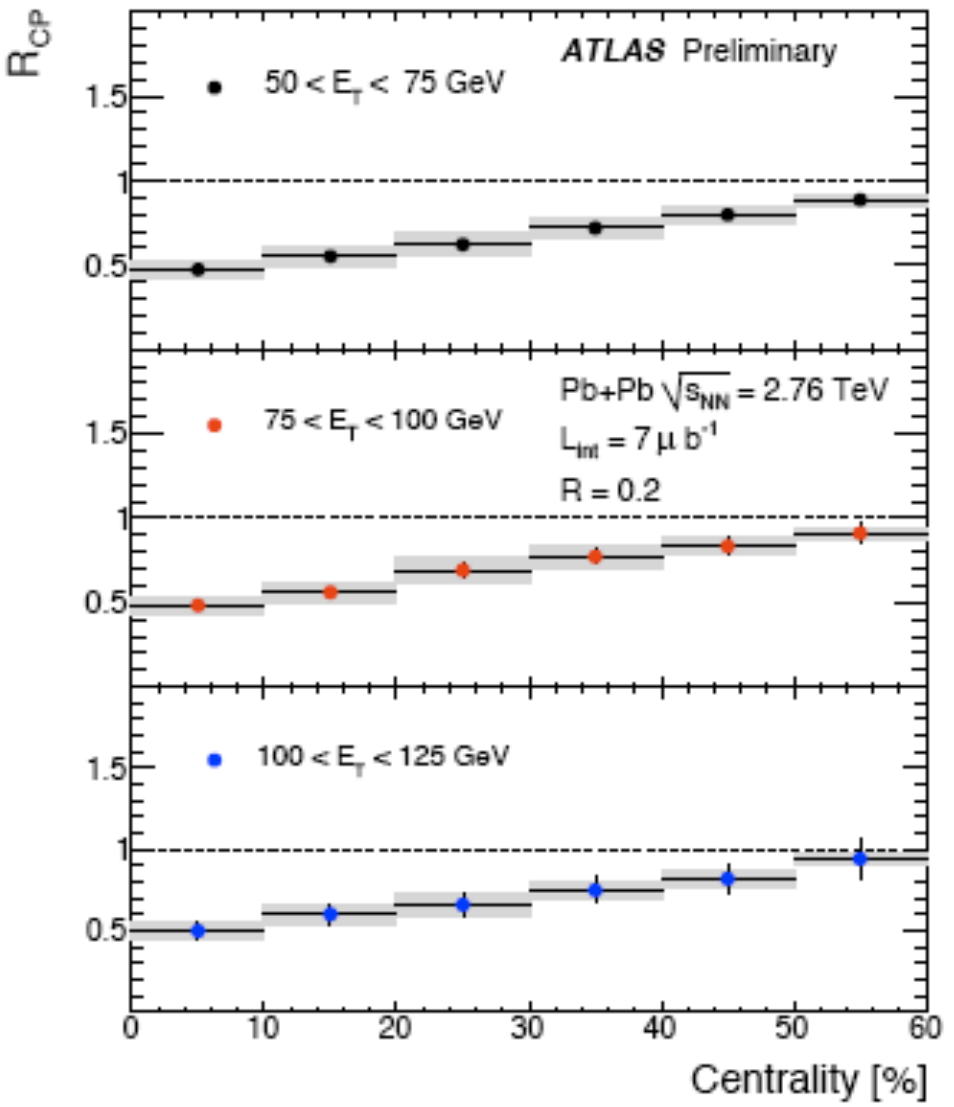
- Jet cross sections measured in Pb-Pb collisions for
  - Different centrality bins
  - Various p_T bins
- Relatively less jets observed in central events
  - Qualitatively consistent with jet quenching

Jets in Pb-Pb Collisions

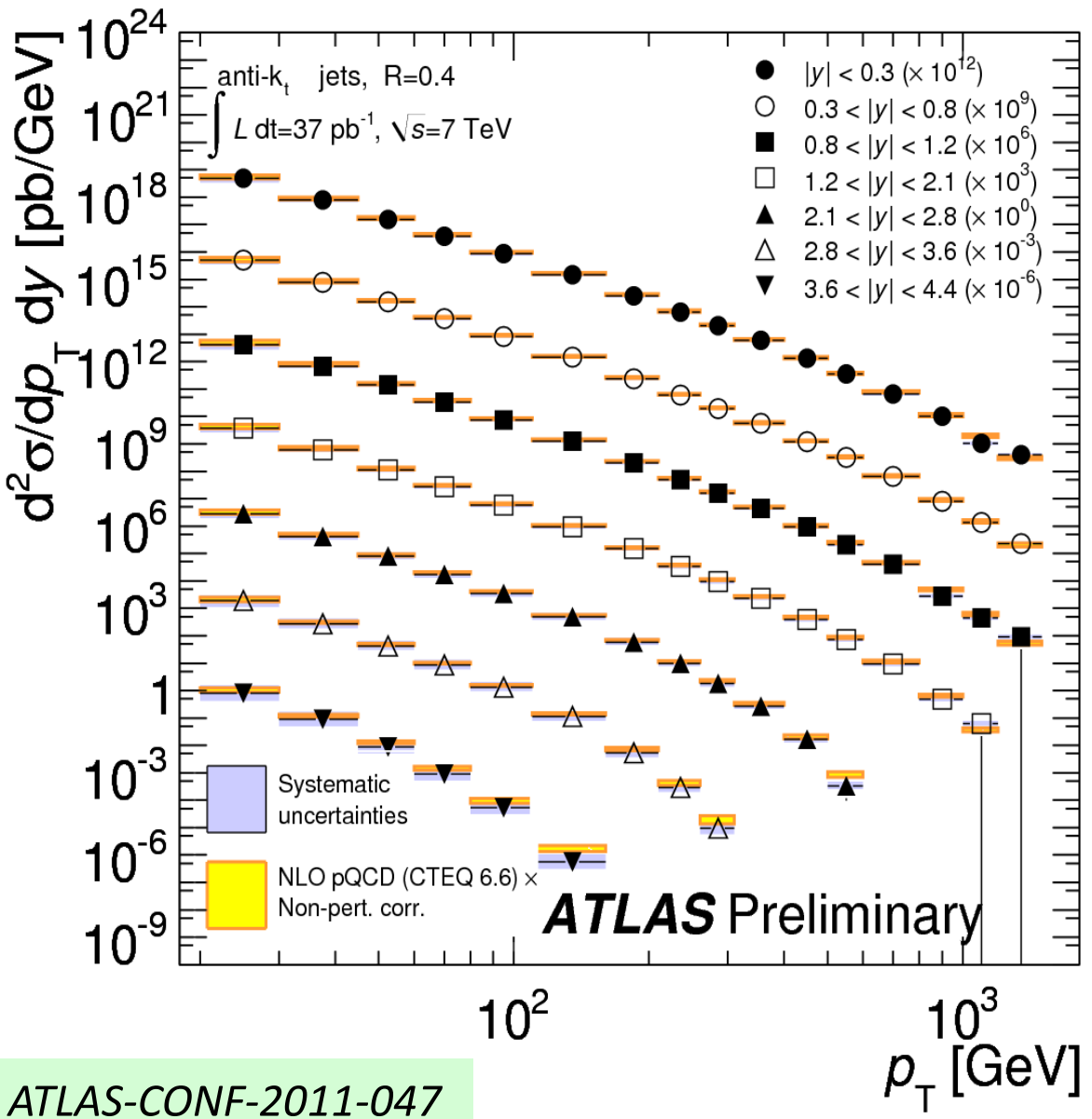
- Evaluating jet suppression in more details since initial observation end of 2010

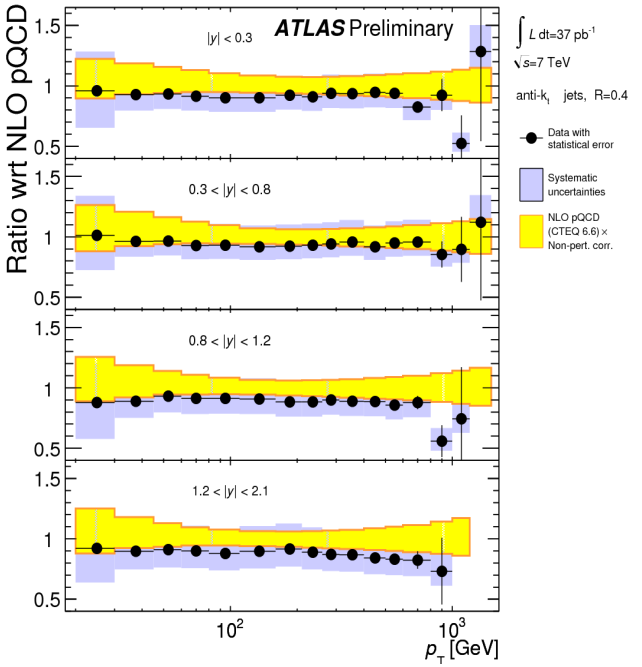
$$R_{CP} = \frac{\frac{1}{N_{coll}^{cent}} E\frac{d^3N^{cent}}{dp^3}}{\frac{1}{N_{coll}^{periph}} E\frac{d^3N^{periph}}{dp^3}}$$

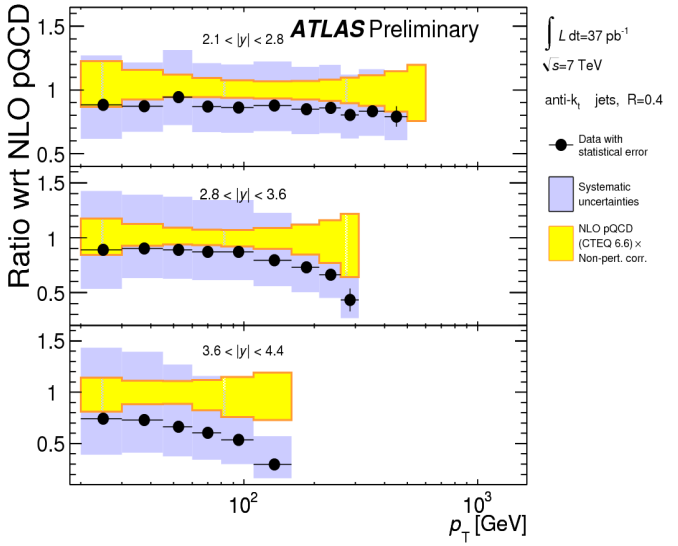
- Data tend to R_{CP}=0.5 in most central events
  - Effect ~independent of E_T(jet)
- Consistent results with cone sizes of 0.2 and 0.4 obtained



Inclusive Jet Production







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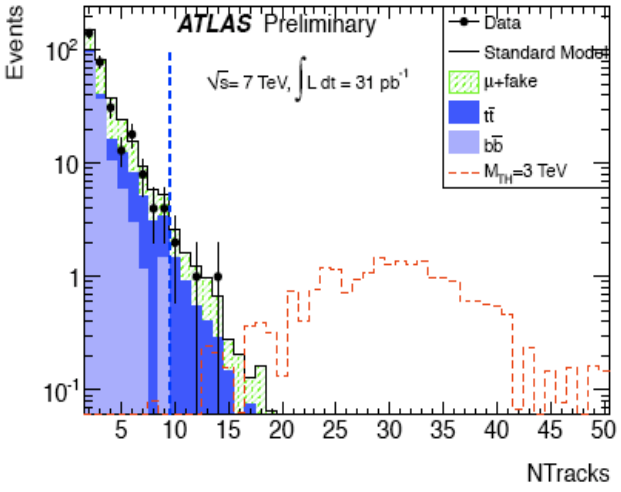
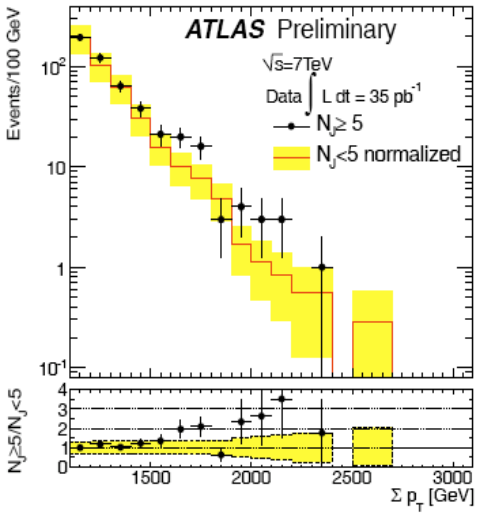
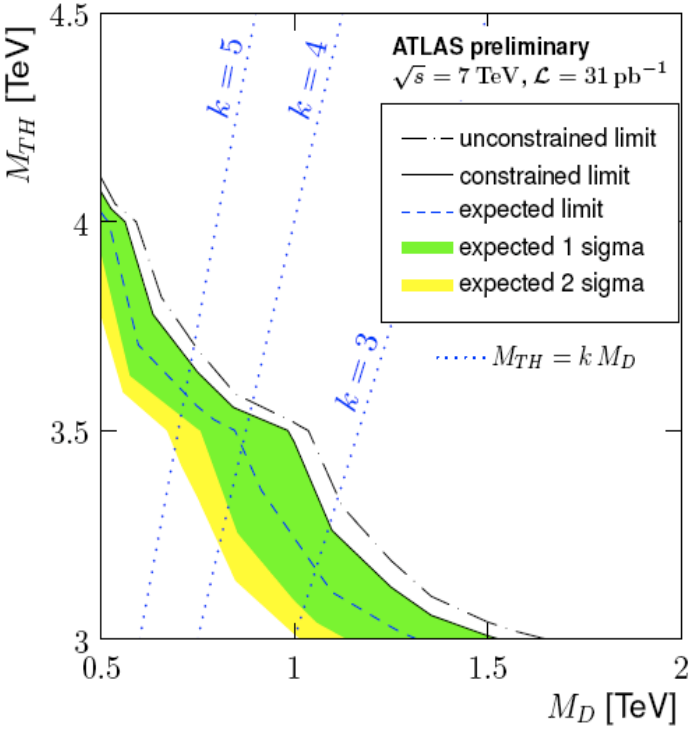
Impressive achievement of both Data and Theory!

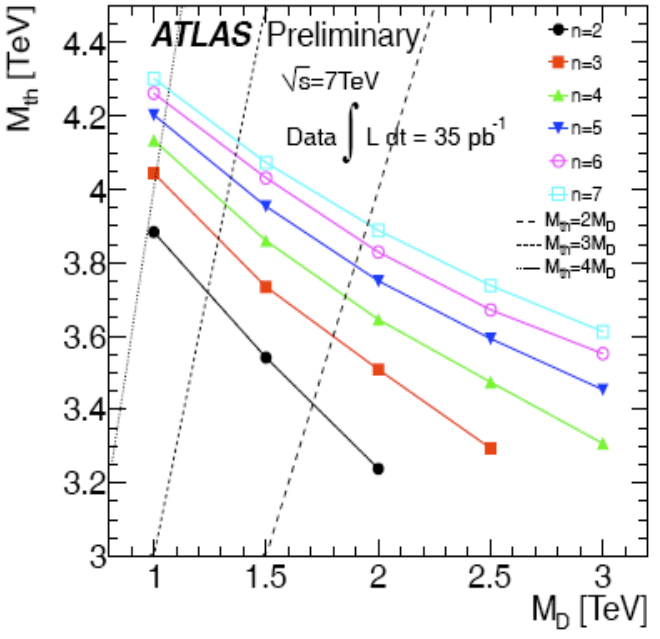
Search for Micro Black Holes







- **Search for strong gravity effects in several channels**
  - $\mu^{\pm}\mu^{\pm}$ + 10 tracks with p_T>8 GeV
  - >=5 high p_T jets
- **Data consistent with background**
  - Place limits in parameter space, probe
    - M_D up to 3 TeV
    - M_{TH} up to 4.5 TeV

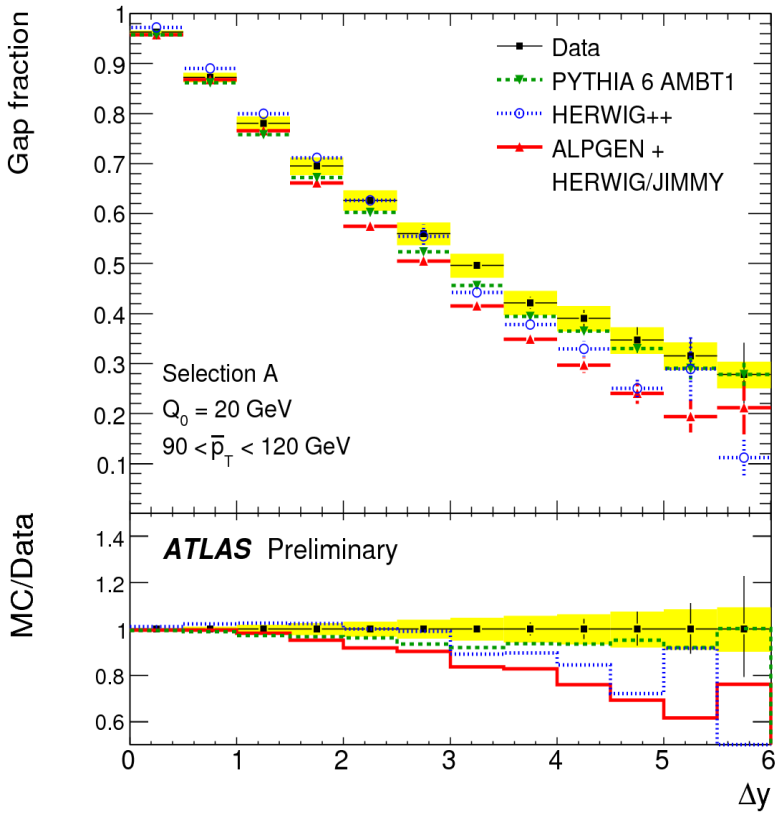


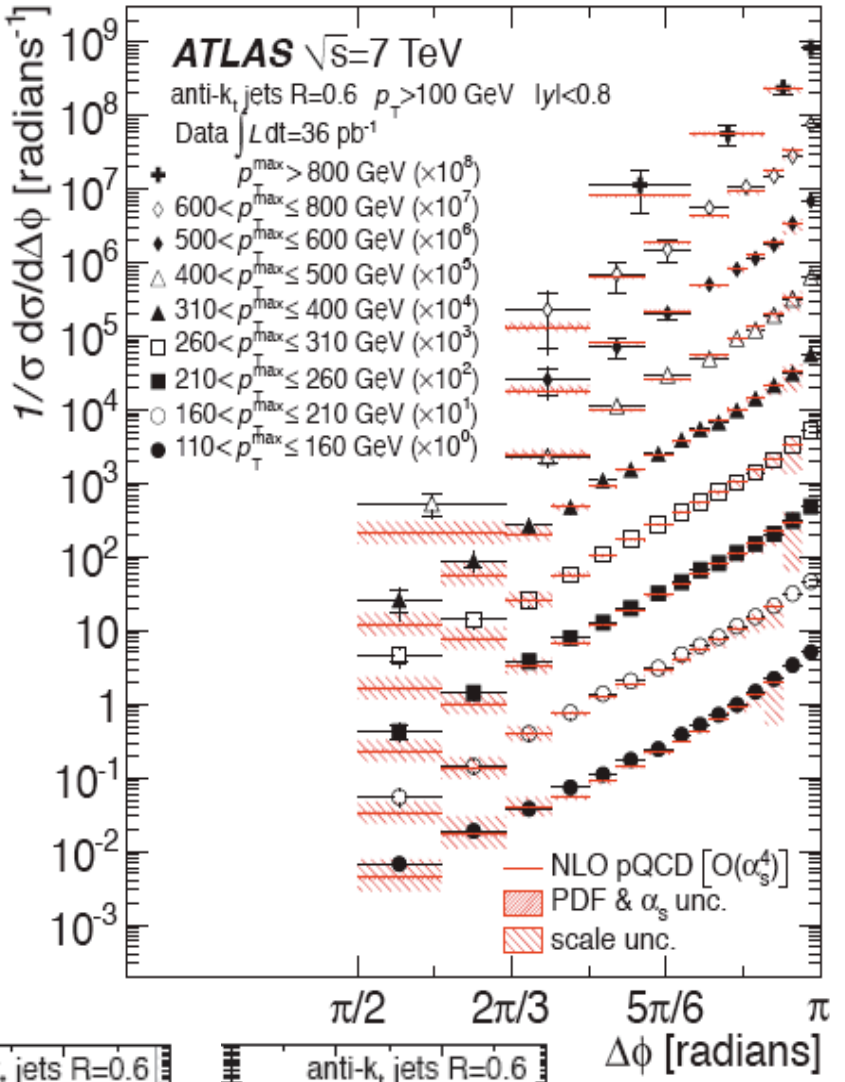
ATLAS-CONF-2011-065

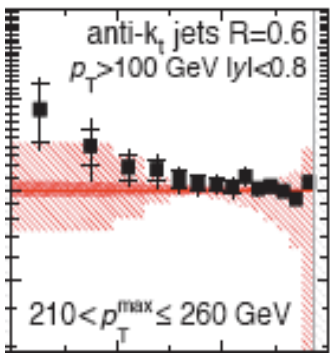
Di-Jets

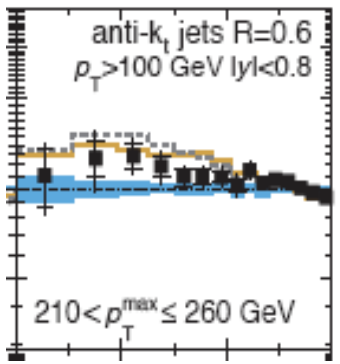
ATLAS-CONF-2011-038
arXiv: 1102.2696 (submitted to PRL)

- Previously reported inclusive jet cross section based on full 2010 dataset
- More exclusive jet measurements now available
  - Dijets separated by a rapidity gap
  - Δϕ between jets
- MC generators reproduce data quite well
  - NLO calculation also where available

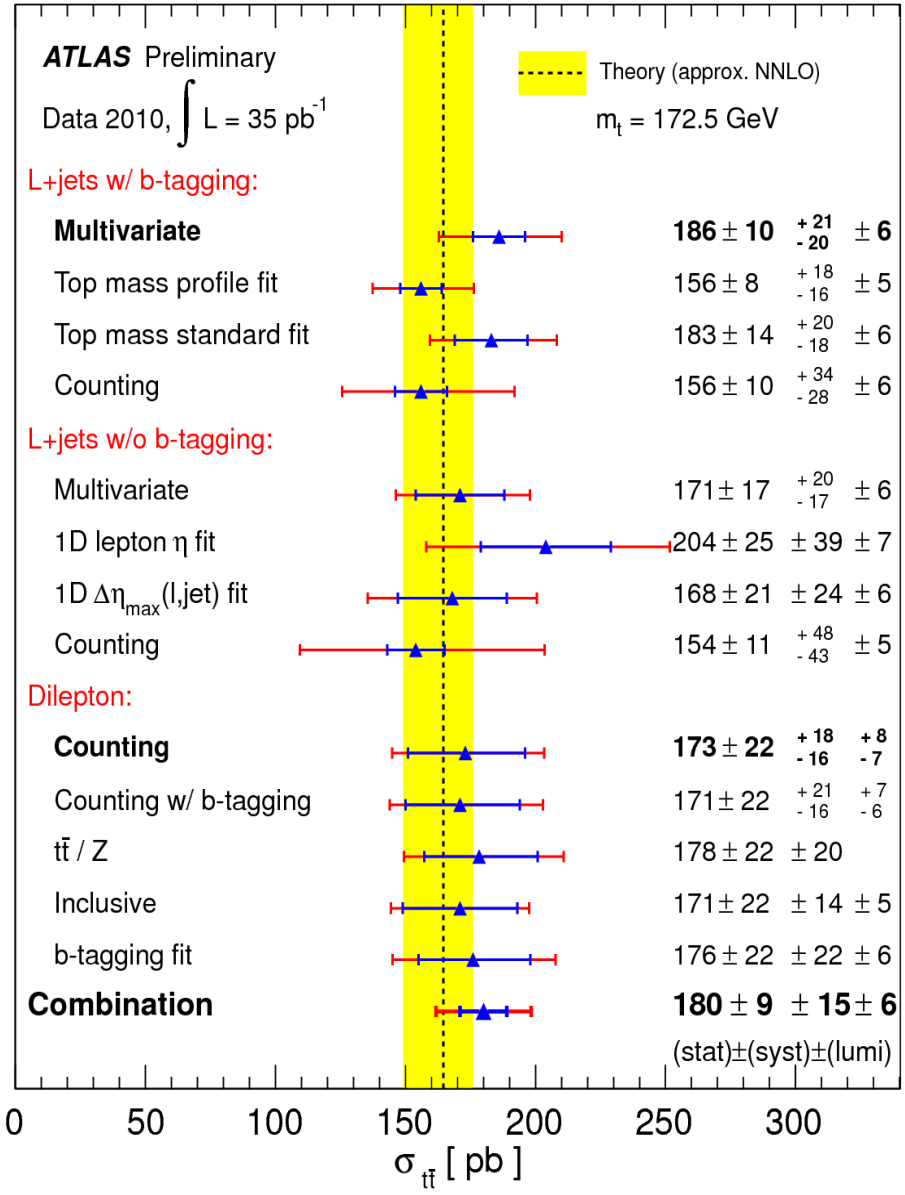


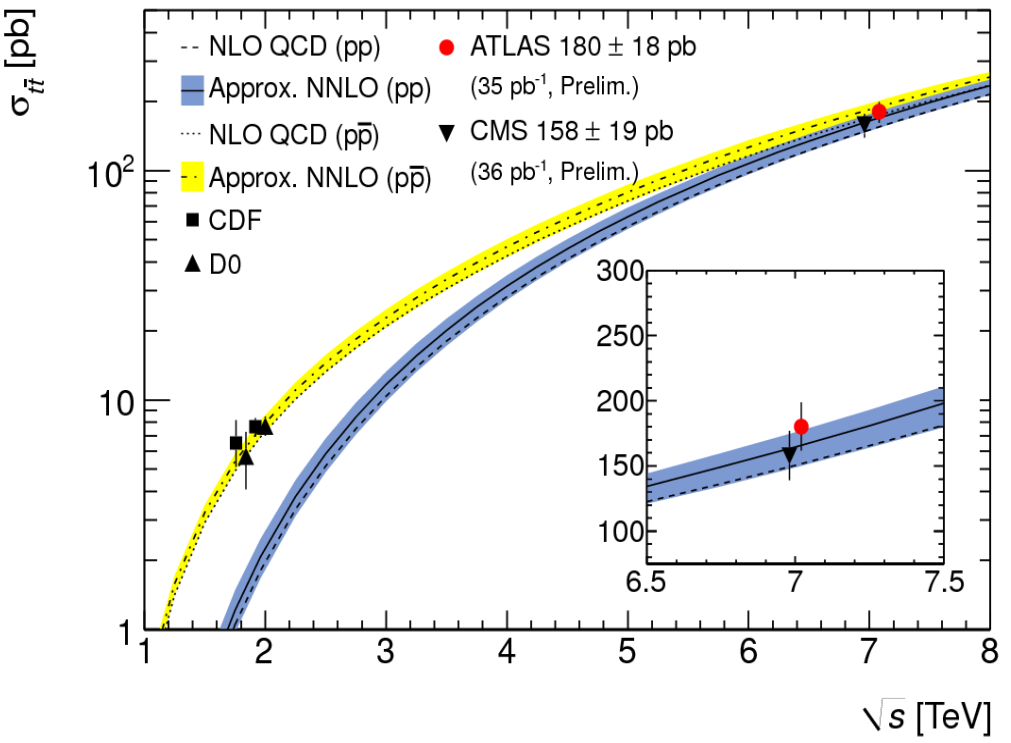






Summary of σ(tt) Measurements





- Cross sections consistent among different techniques and decay modes

$\Delta\sigma_{tt}/\sigma_{tt}=10\%$

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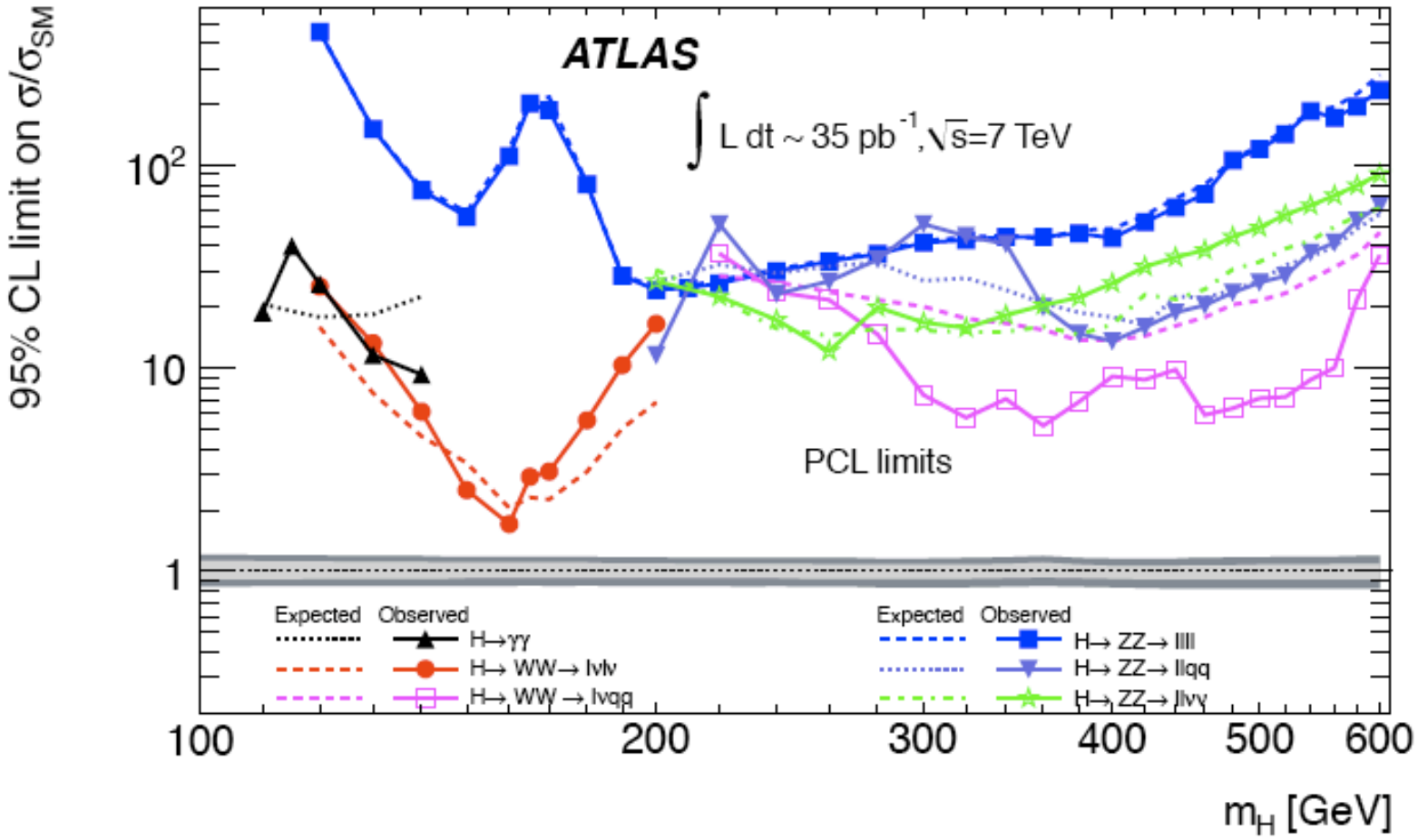
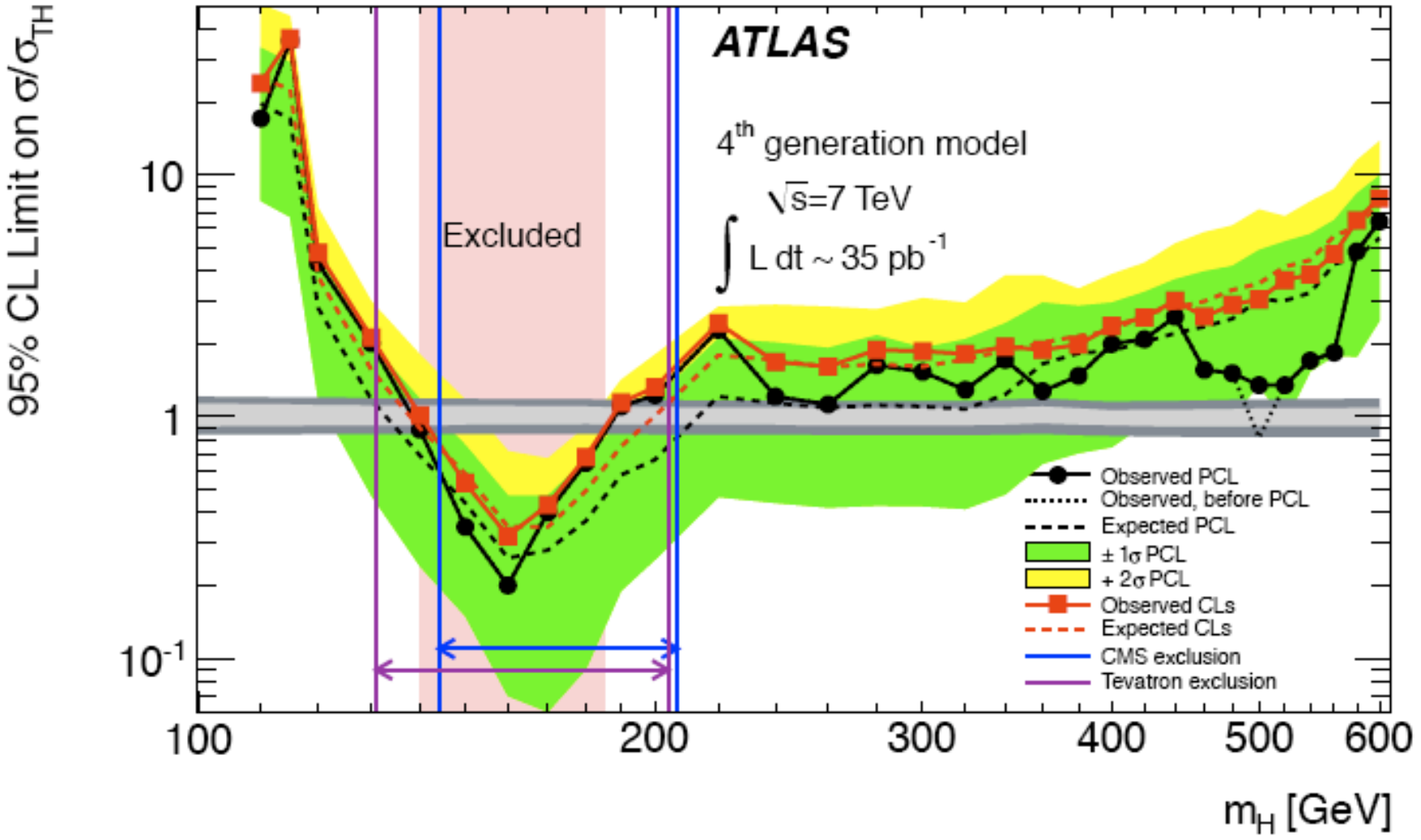
Combined limit based on 2010 data



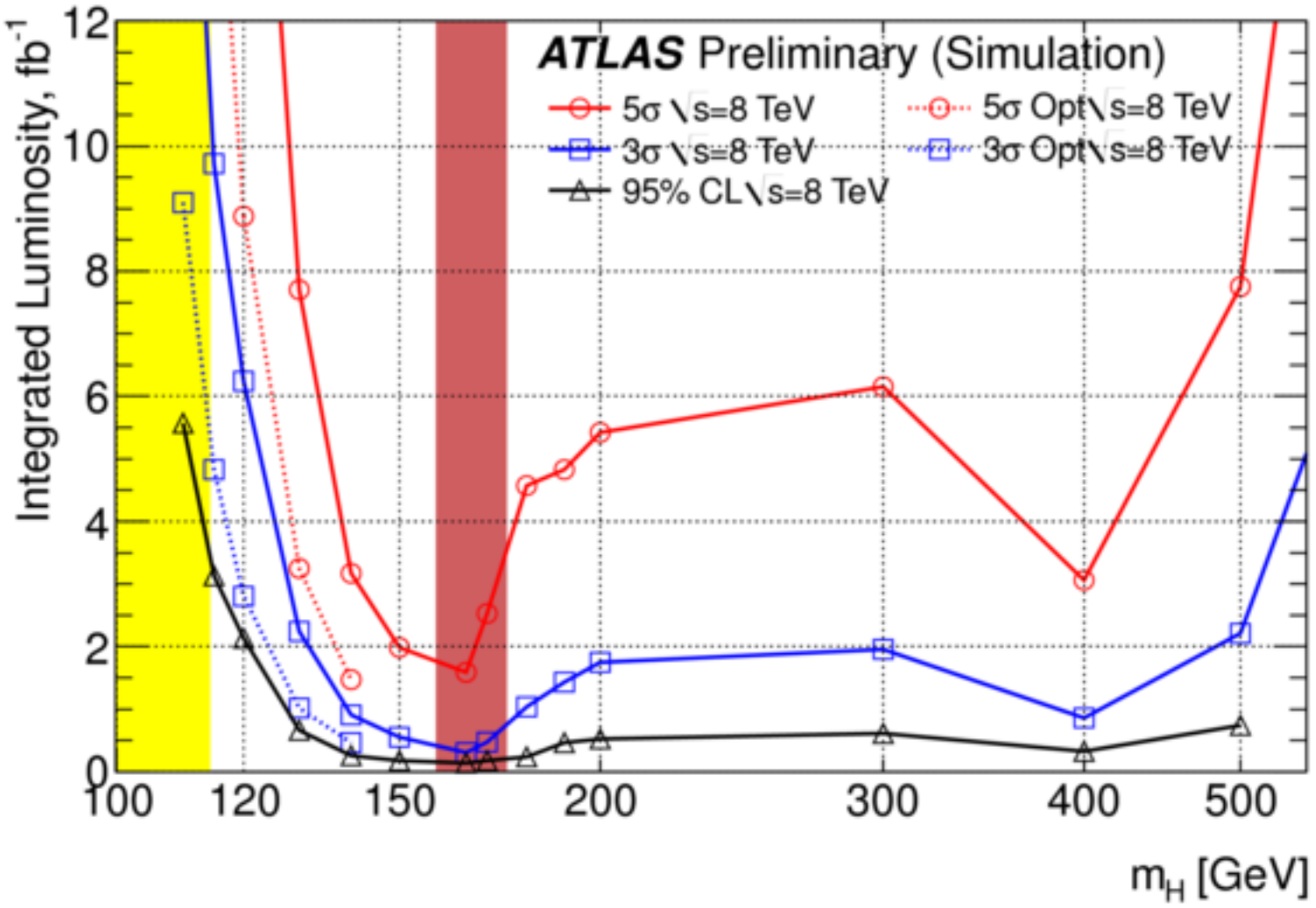
- Low mass: H->γγ and H->WW->lνlν contribute most
- High mass: strongest constraints from H->WW->lνjj, H->ZZ->ννll and H->ZZ->lljj
  - H->ZZ->4 leptons will improve most as nearly background free: sensitivity ~L and not √L as for most others

Combined Limit: 4th generation model



- Exclude Higgs in models with 4th generation for $140<m_H<185$ GeV
  - Expected exclusion 136-208 GeV
  - Similar to exclusions achieved by Tevatron and CMS
  - Assumes that no other new physics is present

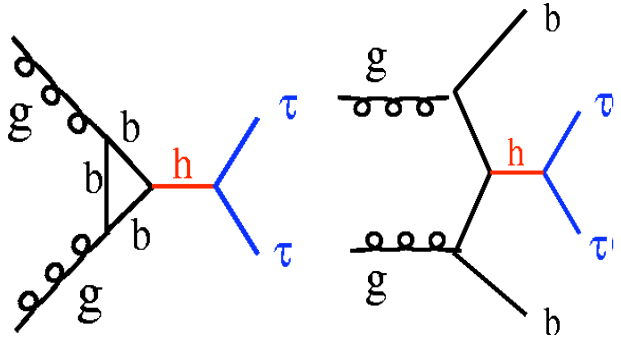
Luminosity Required for Higgs Boson Discovery



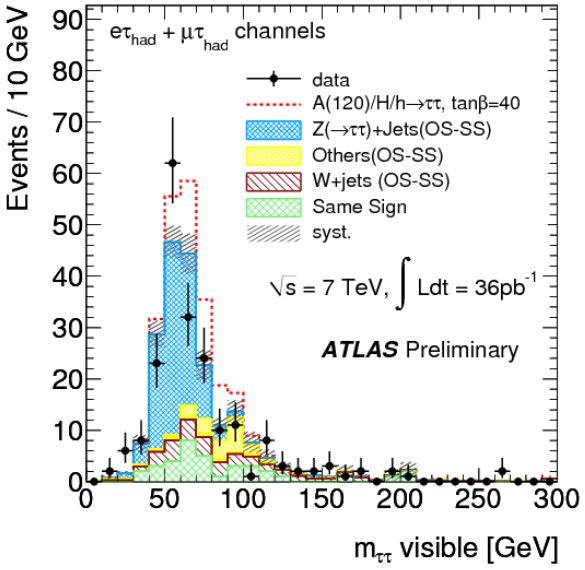
- 95% exclusion with 5 fb^{-1} for full mass range
- 3σ evidence possible for most of the mass range with 5 fb^{-1}

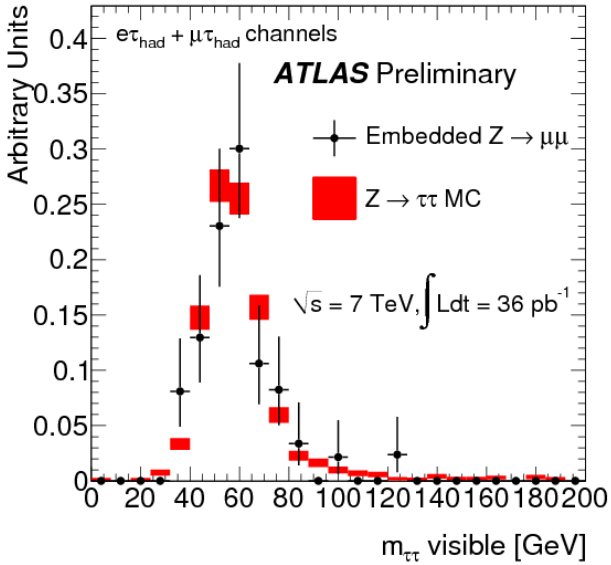
Higgs in Supersymmetry (MSSM)

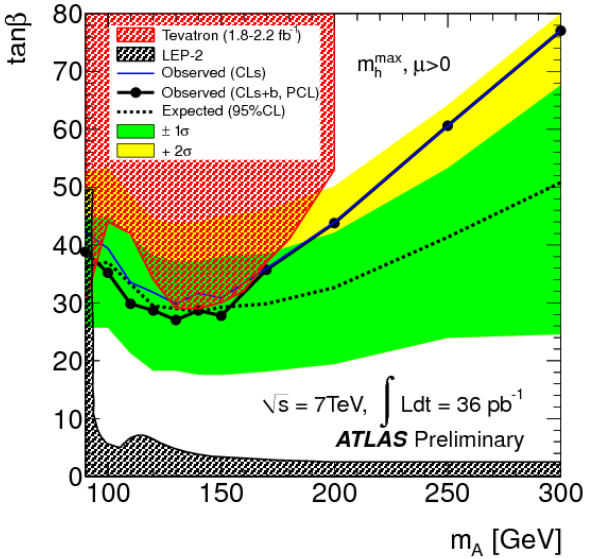
- **Parameter tanβ=<H_u>/<H_d>**
  - **3 Neutral Higgs Bosons: A, H, h**
    - At high tanβ: BR(A->ττ)≈10%
    - At least 2 of neutral states degenerate
  - **Cross section: σ(A) tan²β**



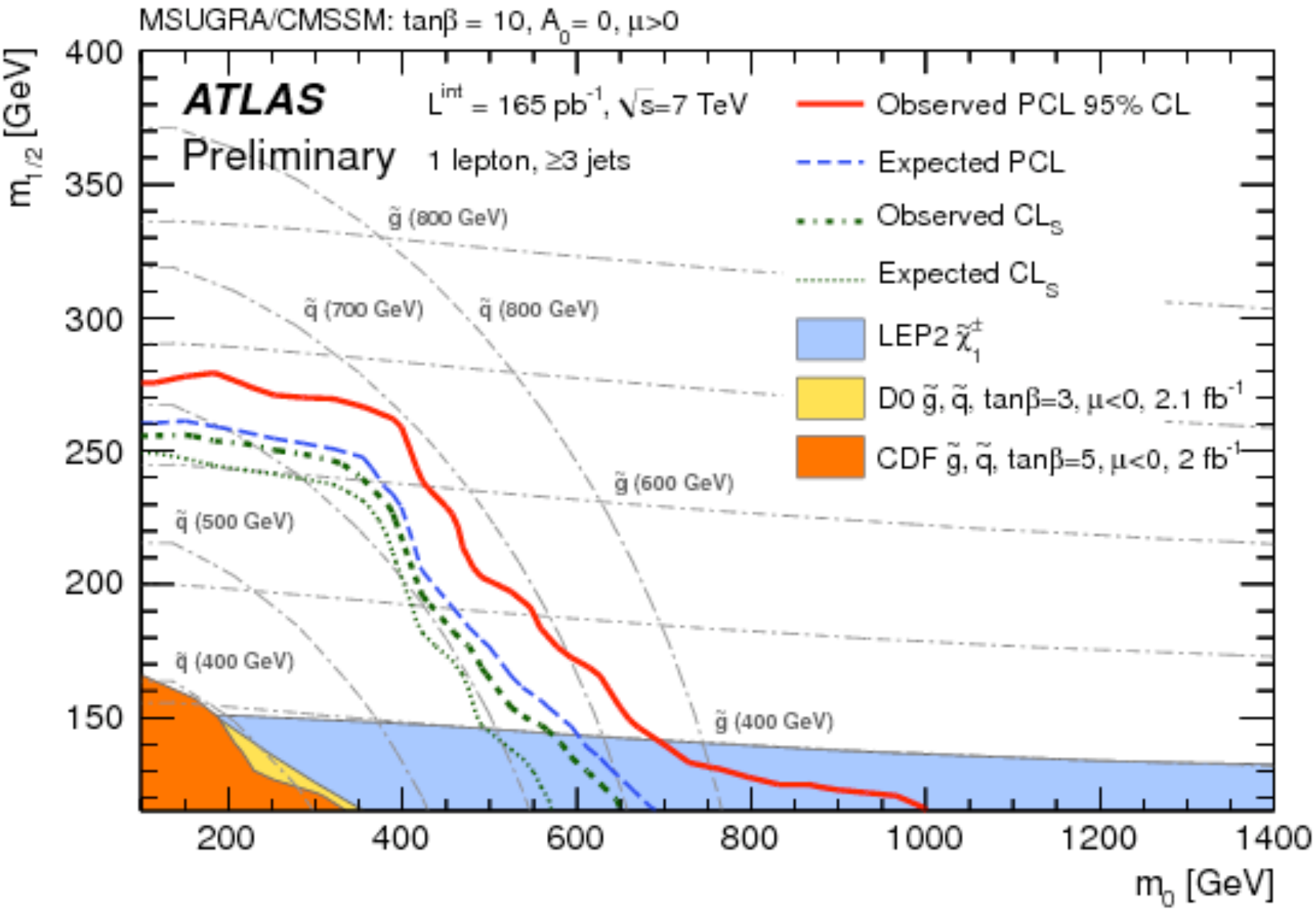
- **Analyse di-tau decays using 3 channels: τ_h+μ, τ_h+e, μ+e**
  - Identification efficiency for τ checked with data-embedding technique
- **Data agree well with background estimate**
  - Exclude tanβ>30 for m_A≈150 GeV



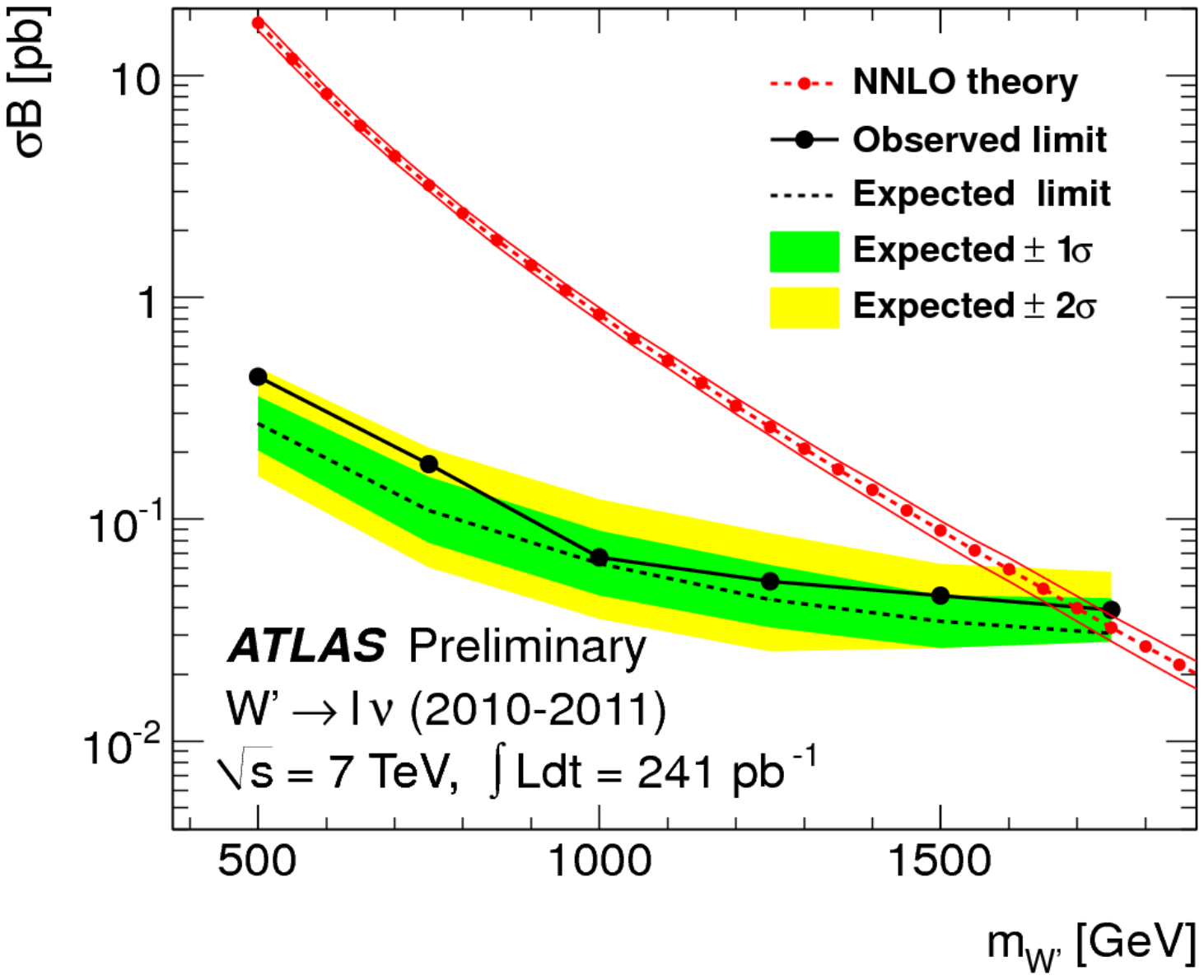




Exclusion from SUSY 1-lepton analysis



Limit on W’ bosons



- Exclude W’ bosons with SM coupling up to **1.70 TeV** at 95% CL

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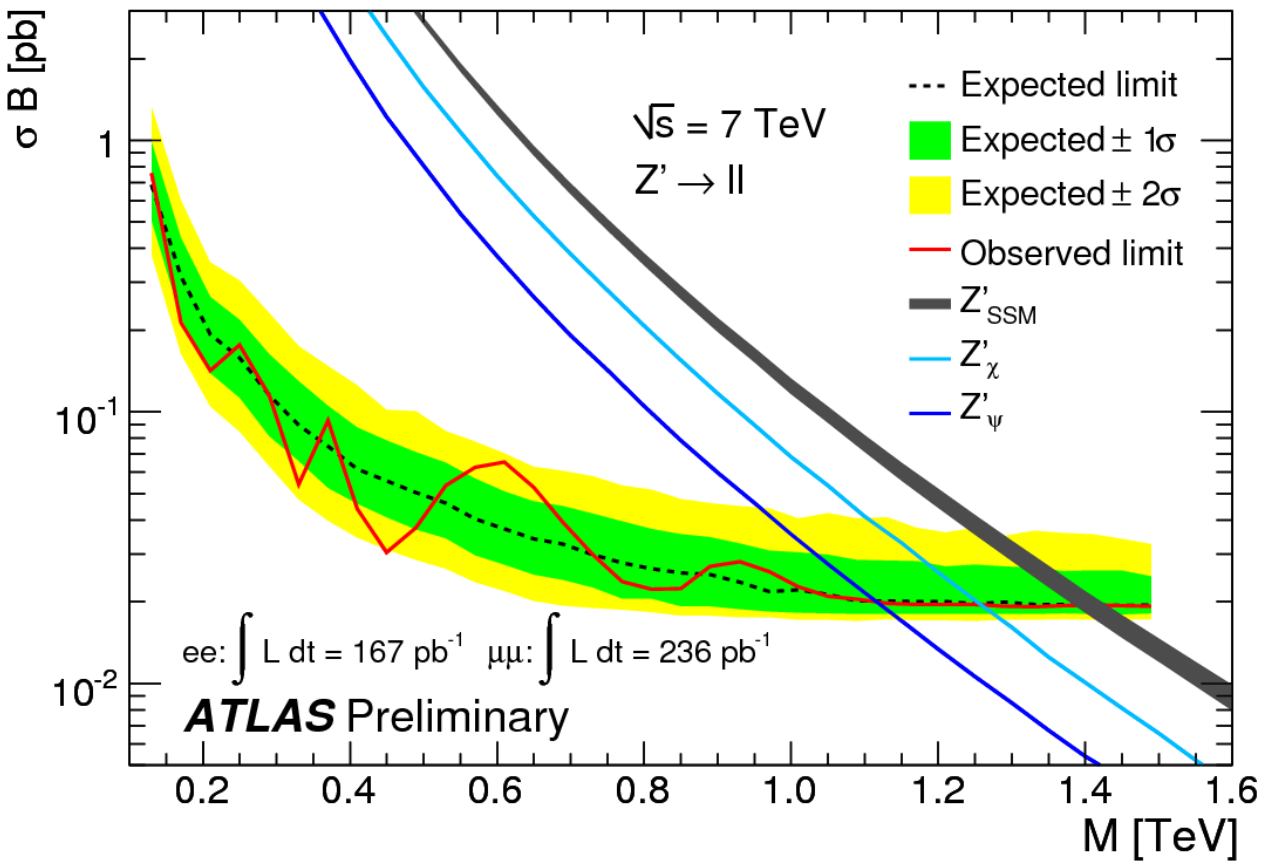
Limits on Z' Bosons



	95% exclusion on Z' in SSM [TeV]
ee	1.275
μμ	1.222
ee+μμ	1.442

Model	Z'_{ψ}	Z'_{N}	Z'_{η}	Z'_{I}	Z'_{S}	Z'_{χ}
Mass limit [TeV]	1.150	1.173	1.183	1.233	1.263	1.293

- With first 2011 data limits now approach 1.5 TeV

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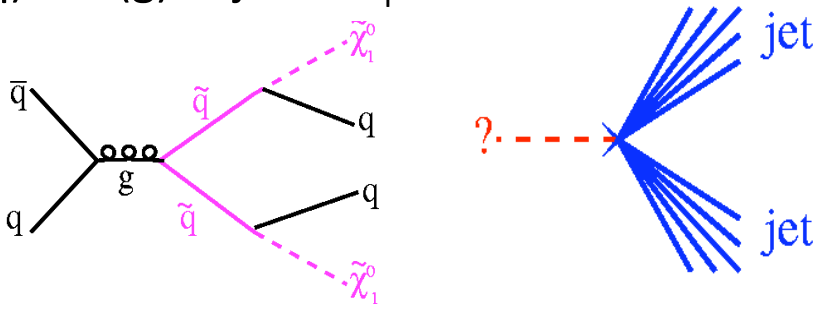
SUSY: E_t^{miss} and ≥2 jets Search

Selection cuts for 0-lepton analysis

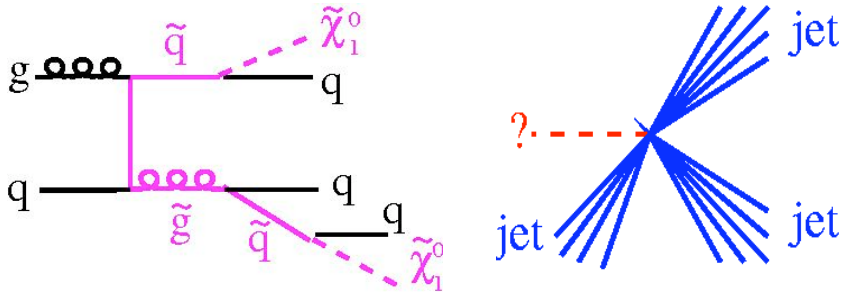
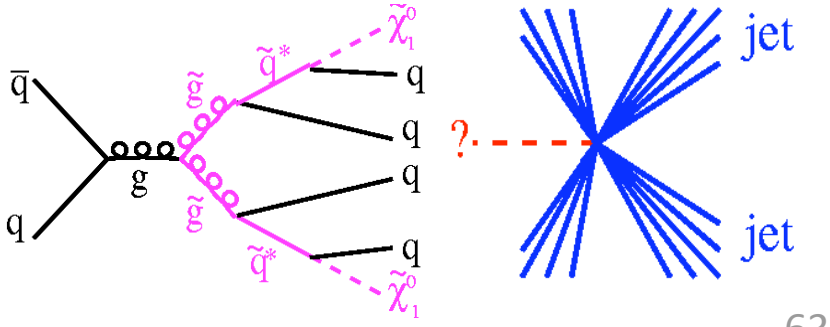
Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets
E_T^{miss} [GeV]	> 130	> 130	> 130
Leading jet p_T [GeV]	> 130	> 130	> 130
Second jet p_T [GeV]	> 40	> 40	> 40
Third jet p_T [GeV]	–	> 40	> 40
Fourth jet p_T [GeV]	–	–	> 40
$\Delta\phi(\text{jet}_i, E_T^{miss})_{min}$ $(i = 1, 2, 3)$	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25
m_{eff} [GeV]	> 1000	> 1000	> 1000

- Separate analysis performed with 1 lepton +≥3 jets
  - e or μ with p_T>25 GeV
  - 3 jets with p_T>60, 25, 25 GeV
  - E_T^{miss}>125 GeV
  - m_T>100 GeV
  - m_{eff}>500 GeV

m($\tilde{q}$)<<m($\tilde{g}$): 2 jets + E_T^{miss}



m($\tilde{q}$)≈m($\tilde{g}$): 3 jets + E_T^{miss}



m($\tilde{q}$)>>m($\tilde{g}$): 4 jets + E_T^{miss}