Search for supersymmetry via resonant final states with the ATLAS detector

Junjie Zhu

University of Michigan

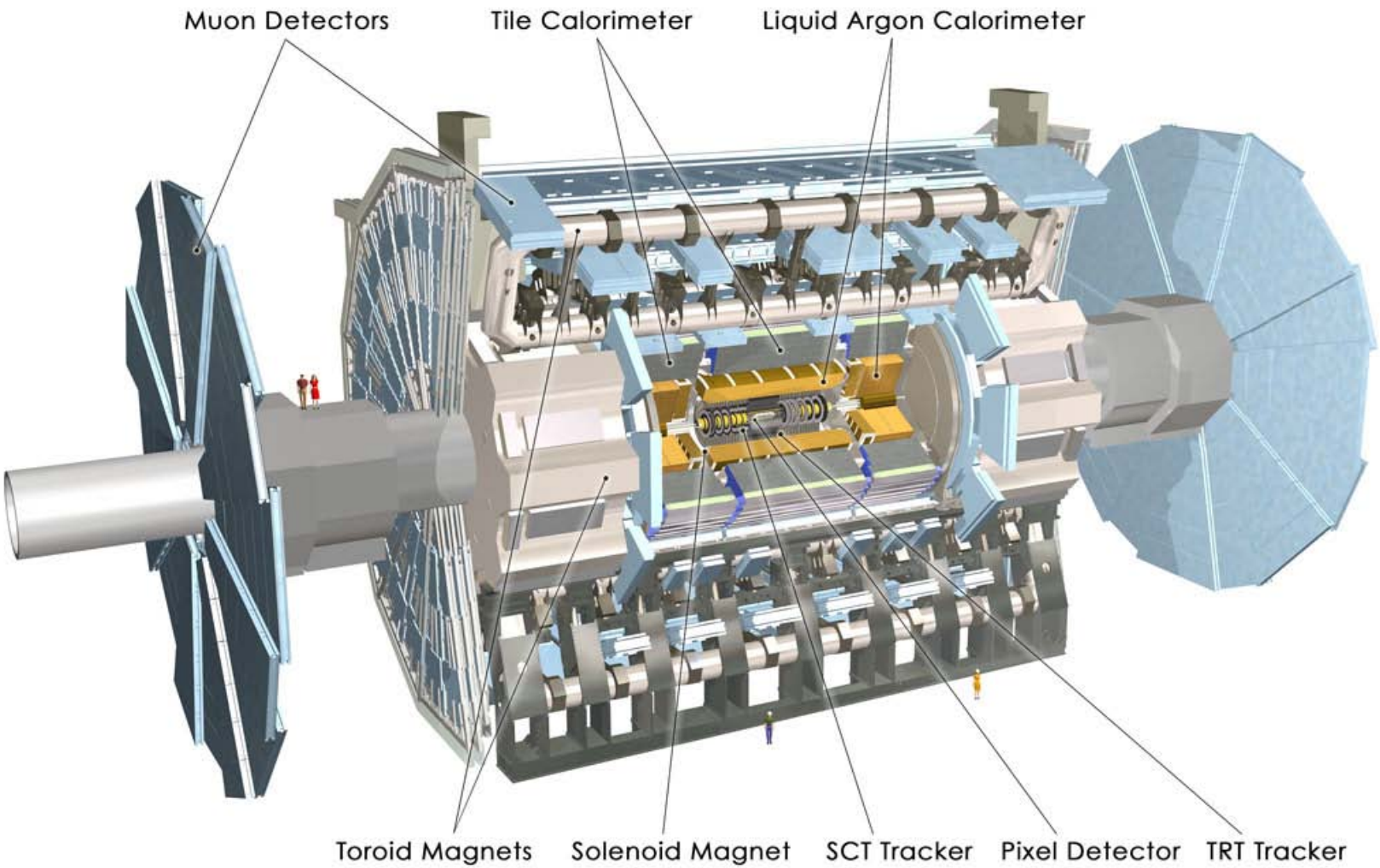
On behalf of the ATLAS Collaboration

SUSY 2011, Fermilab

Overview

- Introduction
- RPV sneutrino search in the $e\mu$ final state
- Scalar gluon search in the four jets final state
- Conclusion

ATLAS Detector



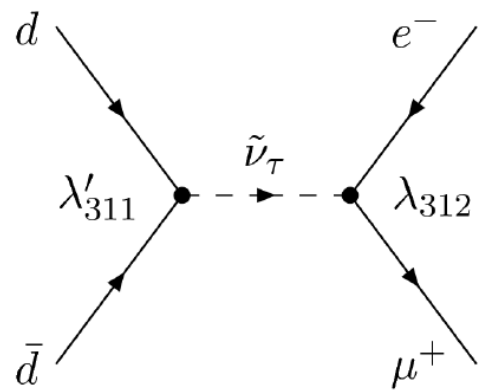
Introduction to RPV Sneutrino Search

- R-parity in SUSY: $R = (-1)^{3(B-L)+2S}$
  - SM particles have R = 1, SUSY particles have R = -1
- R-parity conservation → SUSY particles are produced in pair
- R-parity violation → lepton/baryon number violation, and singly-produced SUSY particles decaying to SM-only particles
- If B or L violations don't happen at the same, proton will still be stable
- R-parity violating SUSY:
  - automatically generates neutrino masses and mixings
  - provides a possible way to understand the anomalies related to b to s transition (Phys Rev D 78 015009, 2008)

Introduction to RPV Sneutrino Search

$$\mathcal{W}_{\not{R}_p} = \frac{1}{2}\varepsilon_{ab}\lambda_{ijk}\underline{\hat{L}_i^a\hat{L}_j^b\hat{E}_k} + \varepsilon_{ab}\lambda'_{ijk}\underline{\hat{L}_i^a\hat{Q}_j^b\hat{D}_k} + \frac{1}{2}\varepsilon_{\alpha\beta\gamma}\lambda''_{ijk}\hat{U}_i^\alpha\hat{D}_j^\beta\hat{D}_k^\gamma$$

- L, Q: doublet superfields of leptons and quarks
- E, U and D: singlet superfields of leptons, up and down type quarks
- λ: Yukawa couplings with i, j, k refer to fermion generation
- Search for RPV sneutrino production with lepton number violating decay
  - tau sneutrino → eμ (non-zero couplings λ'_{311}, λ_{312}, and tau sneutrino is the LSP)
  - eμ channel considered due to its clean detector signature and low SM bkgs
  - Tau sneutrinos used due to strong limits from other low energy experiments
- Previous limits (λ'_{311}<0.11, λ_{312}<0.07 assuming $M_{squark}=M_{slepton}$=100 GeV) obtained from tau lepton branching ratio measurements at low energy



No u-quarks involved in the initial state due to the LQD term in the superpotential

Tau Sneutrino

- $d\bar{d} \rightarrow \tilde{\nu}_\tau \rightarrow e\mu$ events are generated with Herwig plus Jimmy
- LO cross section (assuming λ'_{311}=0.11 and λ_{312}=0.07):
  - 153 pb for sneutrino mass of 100 GeV (0.34 pb at the Tevatron)
  - 0.03 pb for snuetrino mass of 1 TeV
- NLO-LO k-factor:
  - Decreases from 1.6 to 1.3 for sneutrino mass from 100 GeV to 1 TeV
- Detector signature for the tau sneutrino signal:
  - Isolated electron and muon with opposite sign charge
  - High eμ invariant mass
  - Narrow width (~1 GeV for 1 TeV tau sneutrino)
  - Nearly back-to-back in azimuthal direction
  - Low jet multiplicity
  - Low missing transverse energy

Event Selection

- L = 0.87 fb^{-1} (taken from March to June 2011)
- Triggered by a set of single electron and muon triggers
- Electron:
  - p_T>25 GeV
  - In the calorimeter fiducial region: $|\eta|<1.37$ or $1.52<|\eta|<2.47$
  - Isolated in the EM calorimeter
  - Pass the shower shape requirement
- Muon:
  - p_T>25 GeV, $|\eta|<2.4$
  - Reconstructed both in the inner tracker and in the muon spectrometer
  - Isolated in the inner tracker
- Exactly one electron and one muon in the event with opposite-sign charge
- No requirements placed on the number of jets and missing transverse energy (to make the search more generic)

Backgrounds

- Physics backgrounds (with real electron and muon in the final state):
  - $Z/\gamma^* \rightarrow \tau\tau$, top pair, single top, WW, WZ and ZZ
  - Estimated using MC simulation corrected for data/MC differences
- Instrumental backgrounds (mainly electron or(and) muon come from a jet or a photon):
  - $W/Z+\gamma$: estimated using MC simulation
  - QCD dijet, W/Z+jets: estimated using data-driven 4×4 matrix method
    - Define loose and tight lepton definitions
    - Apply on all events to get N_{TT}, N_{TL}, N_{LT}, N_{LL}
    - Determine efficiency (ε) and fake rate (f) for a lepton that has passed the loose definition to also pass the tight definition
    - Solve 4×4 matrix to get N_{RR}, N_{RF}, N_{FR}, N_{FF}

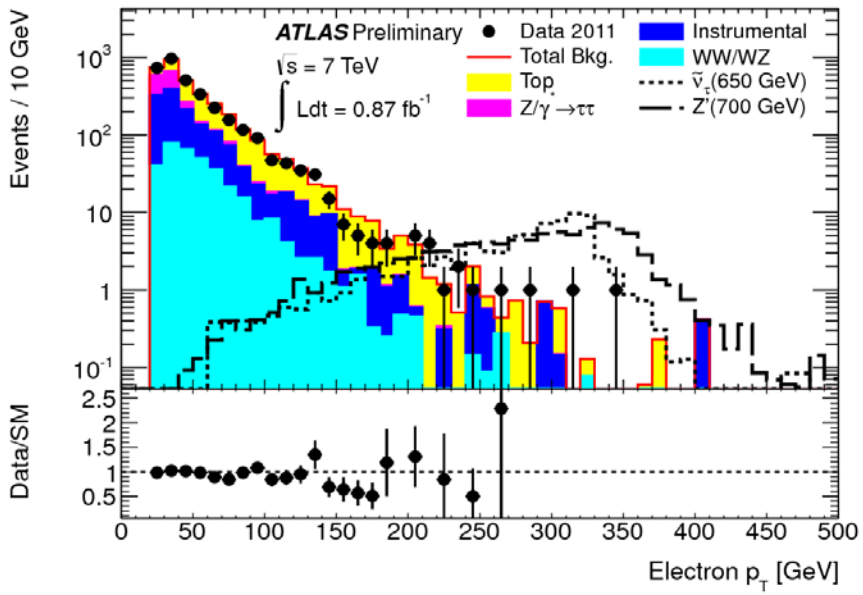
$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

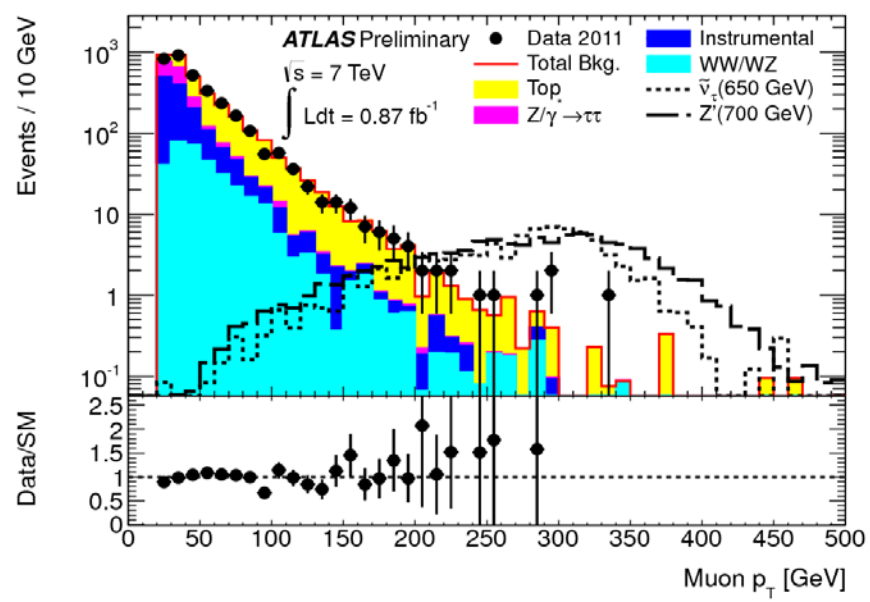
Data and MC predictions

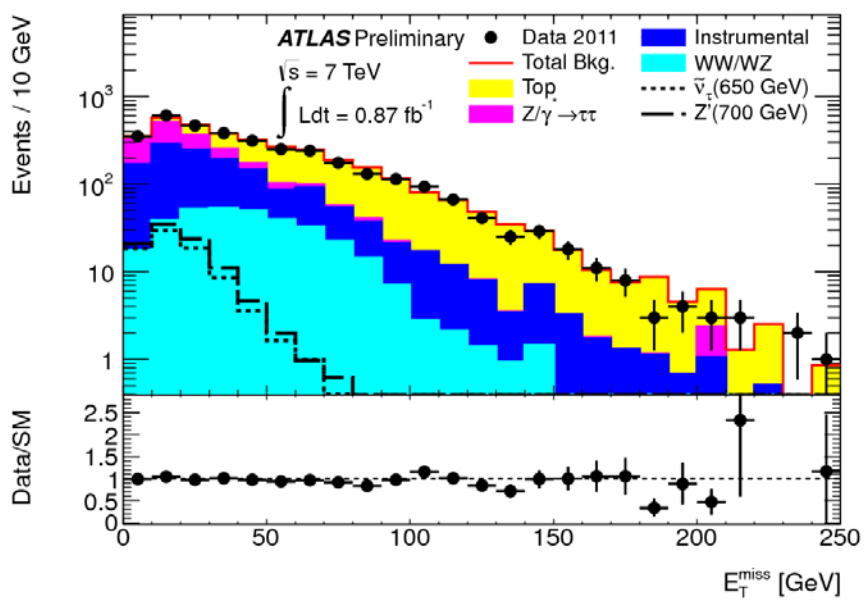
Process	Number of events
$Z/\gamma^* \to \tau\tau$	614 ± 53
$t\bar{t}$	1281 ± 168
WW	318 ± 24
Single top	125 ± 17
WZ	18.2 ± 1.9
$W/Z + \gamma$	67 ± 11
Jet instrumental background	984 ± 105
Total background	3408 ± 230
Data	3338

Good agreement between data and MC for all events

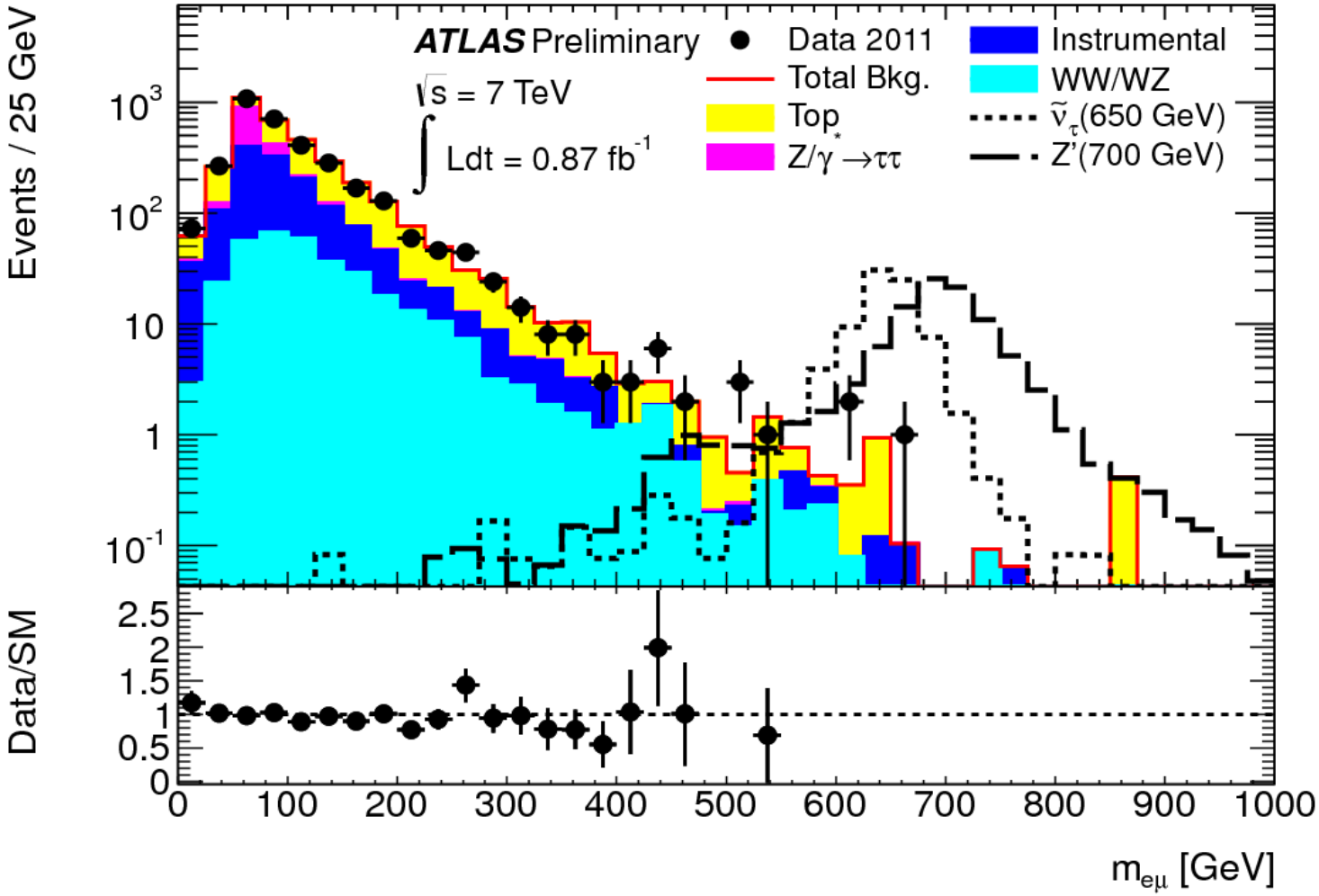
Data and MC predictions (I)





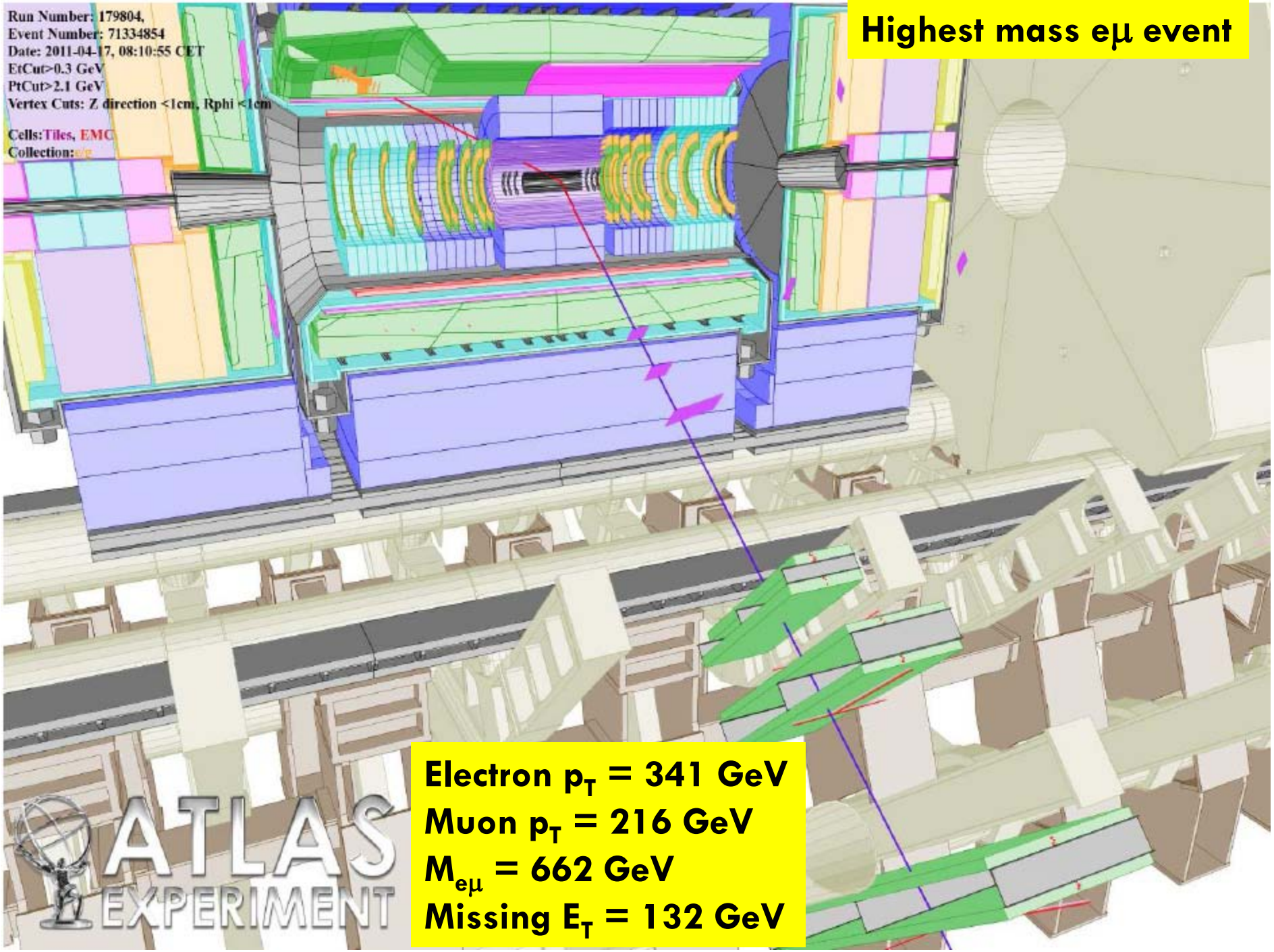


Data and MC predictions (II)



KS test probability: 56%

Data are consistent with the absence of a new physics signal


Run Number: 179804,
Event Number: 71334854
Date: 2011-04-17, 08:10:55 CET
EtCut>0.3 GeV
PtCut>2.1 GeV
Vertex Cuts: Z direction <1cm, Rphi <1cm
Cells:Tiles, EMC
Collection:
Highest mass eμ event
Electron p_T = 341 GeV
Muon p_T = 216 GeV
$M_{e\mu}$ = 662 GeV
Missing E_T = 132 GeV
ATLAS
EXPERIMENT

Data and MC predictions

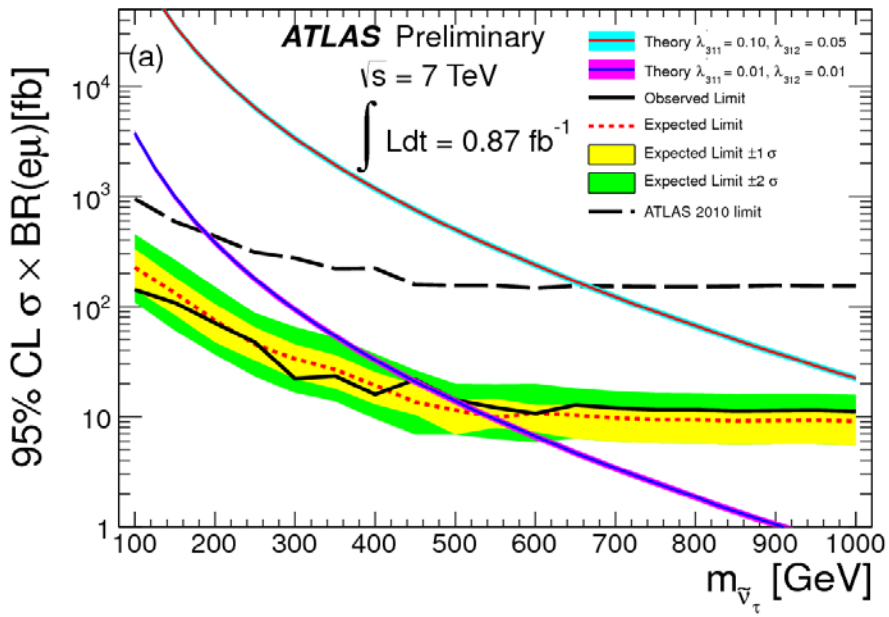
$m_{e\mu}$	Data	SM prediction
> 200 GeV	224	236 ± 21
> 250 GeV	119	111 ± 11
> 300 GeV	51	55 ± 6
> 350 GeV	29	30 ± 4
> 400 GeV	18	14.2 ± 2.2
> 450 GeV	9	8.2 ± 1.5
> 500 GeV	7	5.3 ± 1.1
> 550 GeV	3	3.4 ± 0.8
> 600 GeV	3	2.2 ± 0.7
> 650 GeV	1	0.9 ± 0.4
> 700 GeV	0	0.8 ± 0.4

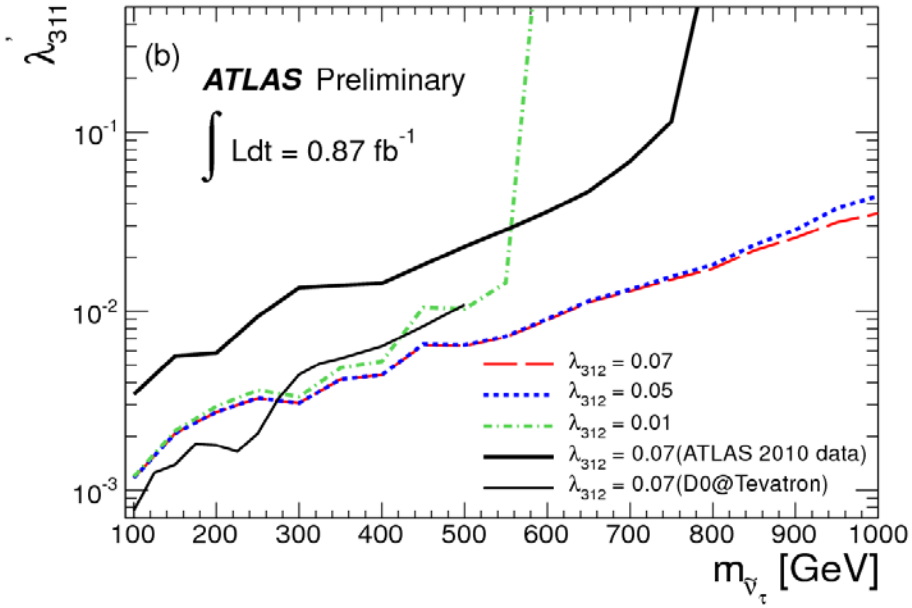
Good agreement between data and predictions for events with high eμ invariant mass

Systematics

Source	Fractional uncertainty (%)	Relations with backgrounds	Relation with signal
Luminosity	4.5%	related to all bkg samples	related
Trigger efficiency	1%	related to all bkg samples	related
Electron reco and ID efficiency	2%	related to all bkg samples	related
Muon reco and ID efficiency	1%	related to all bkg samples	related
$Z/\gamma^* \to \tau\tau$ cross section	5%	related to $Z/\gamma^* \to \tau\tau$ sample	unrelated
ZZ cross section	5%	related to ZZ sample	unrelated
WW cross section	5%	related to WW sample	unrelated
WZ cross section	7%	related to WZ sample	unrelated
$t\bar{t}$ cross section	12%	related to $t\bar{t}$ sample	unrelated
Wt cross section	12%	related to Wt sample	unrelated
$W\gamma$ cross section	10%	related to $W\gamma$ sample	unrelated
$Z\gamma$ cross section	10%	related to $Z\gamma$ sample	unrelated

Limits

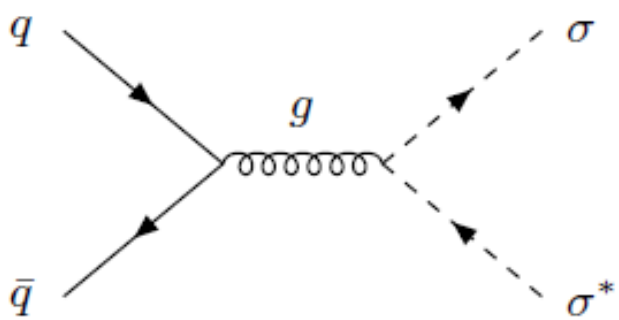




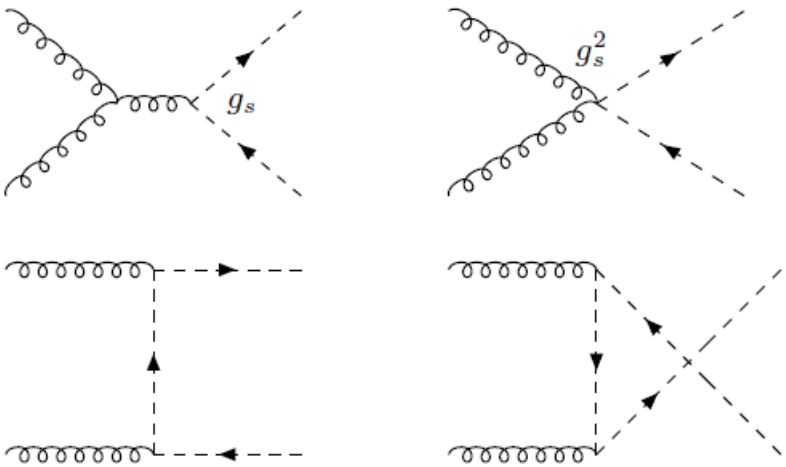
- Cross section limit: 130 fb at 100 GeV and 11 fb at 1 TeV
- Tau sneutrinos with a mass below 0.44 (0.65) TeV are excluded assuming λ'_{311}=0.01, λ_{312}=0.01 and λ'_{311}=0.10, λ_{312}=0.05
- The limits obtained extend 7 (14) times beyond the previous ATLAS results using 35 pb^{-1} of data (PRL 106, 251801, 2011)
- Limits on λ'_{311} are better than the D0 results for sneutrino mass > 270 GeV assuming λ_{312}=0.07

Introduction to Scalar Gluon Search

- Challenging to search for SUSY with fully hadronic final states without leptons and missing transverse energy
- Pair production of scalar gluon (sgluon) occurs in several models: MRSSM, the N=1/N=2 hybrid model, SM extension with new gauge group "hypercolor" etc
- Sgluon cross section implemented as an external process to PYTHIA based on the calculations from Phys Lett. B 672, 2009: σ=7.5 nb at 100 GeV, 100 pb at 225 GeV
- Pythia is then used to decay the sgluon to two jets



Quark annihilation

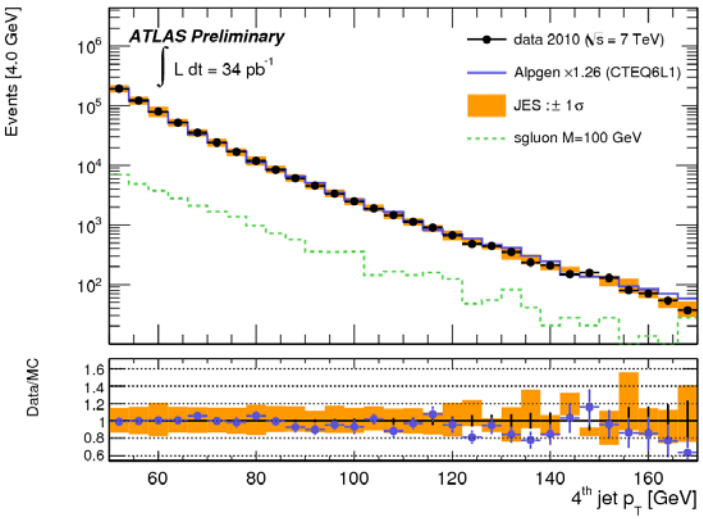


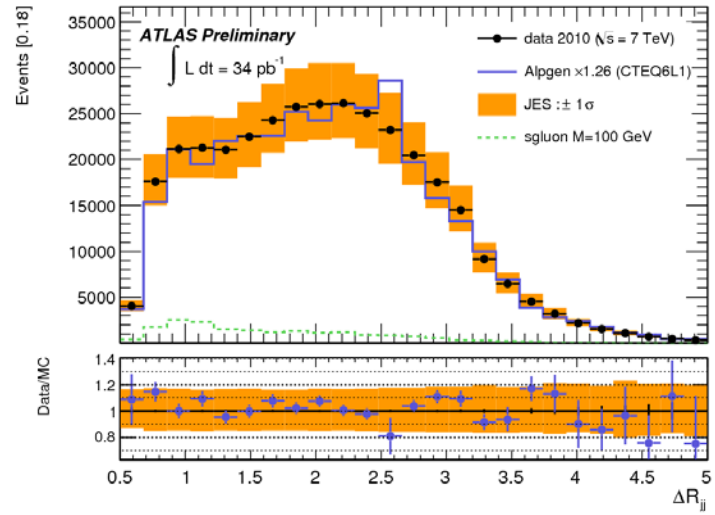
Gluon fusion

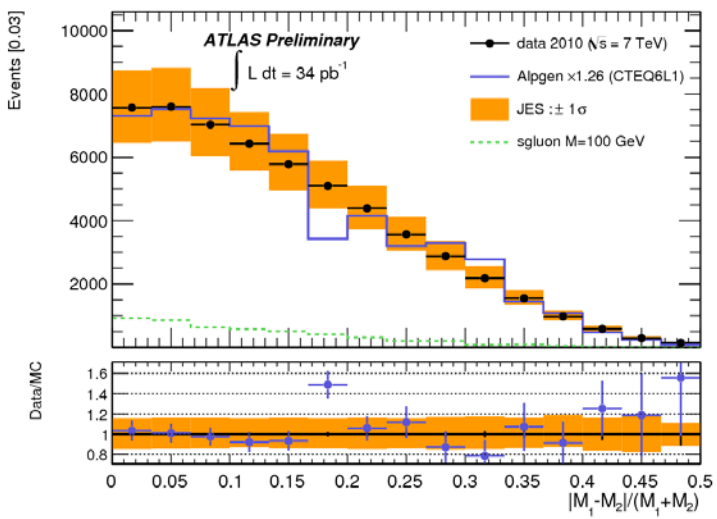
Event Selection

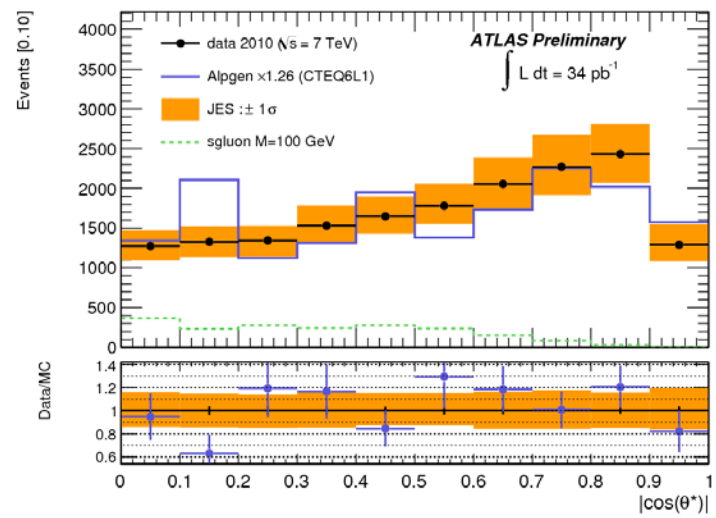
- L = 34 pb^{-1} (taken from March to October 2010)
- Trigger: at least four jets with $p_T > 5$ GeV
- At least four jets are required with $p_T > 0.55 \times M_{sgluon}$ (M_{sgluon} from 100 GeV to 200 GeV)
- Four highest p_T jets are paired by minimizing $|\Delta R_{pair1}-1|+|\Delta R_{pair2}-1|$ (due to the boost, the two jets from sgluon decays tend to have $\Delta R \approx 1$)
- Events are removed if a jet-jet-pairing has $\Delta R_{ij} > 1.6$
- Relative mass difference between the two pairs: $|M_1-M_2|/|M_1+M_2| < 7.5\%$
- Scattering angle of the sgluon in the four jets rest frame: $|\cos\theta^*| < 0.5$
  - Dominant QCD multijet backgrounds tend to be forward due to the exchange of t-channel gluon
  - Sgluon signal tends to be produced centrally

Data and MC Comparisons









QCD MC sample: ALPGEN + HERWIG + JIMMY

Good data/MC agreement observed, but large statistical uncertainty on the QCD MC simulation, need to use data driven method

Data-driven Background Estimation

- ABCD method with one signal region (A) and three background-dominated regions (B, C, D) → **$\cos\theta^*$** and **$|M_1-M_2|/(M_1+M_2)$** → (small correlation found for these two variables)

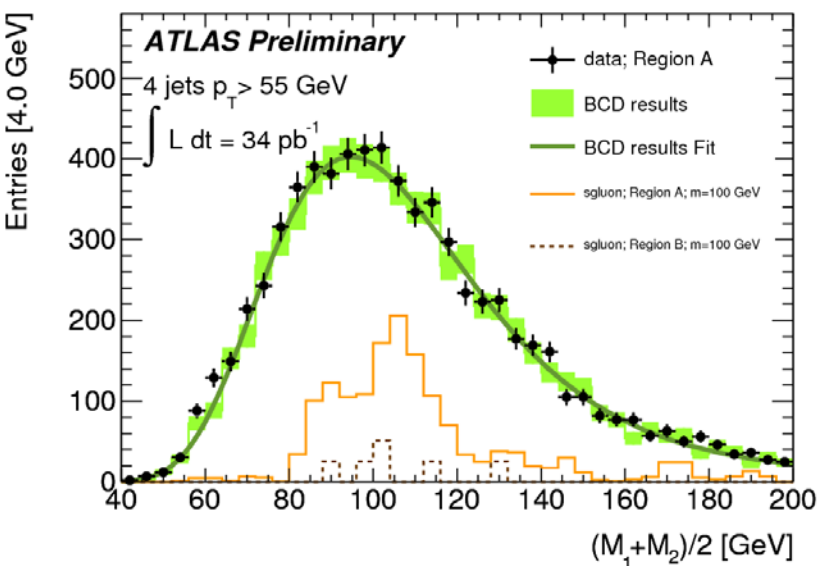
  Region A: $|\cos\theta^*| < 0.5$ and $|M_1-M_2|/(M_1+M_2) < 7.5\%$

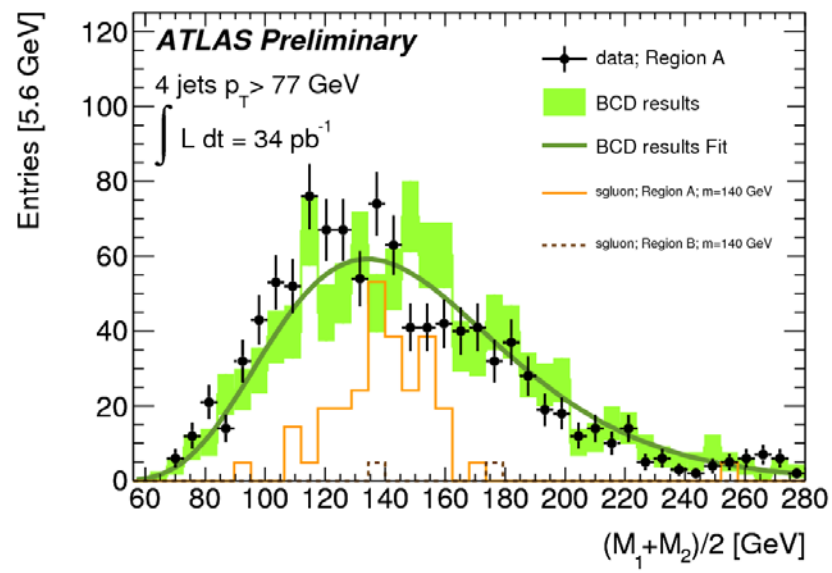
  Region B: $|\cos\theta^*| > 0.7$ and $|M_1-M_2|/(M_1+M_2) < 7.5\%$

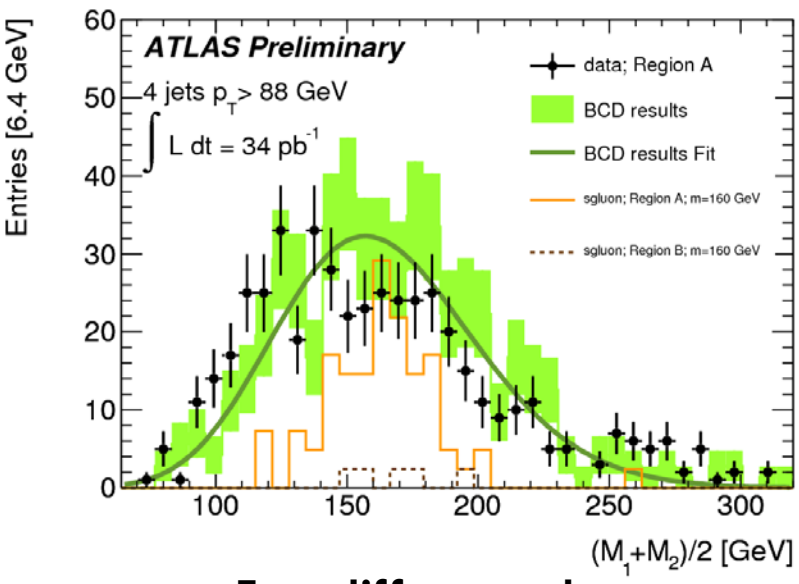
  Region C: $|\cos\theta^*| < 0.5$ and $|M_1-M_2|/(M_1+M_2) > 7.5\%$

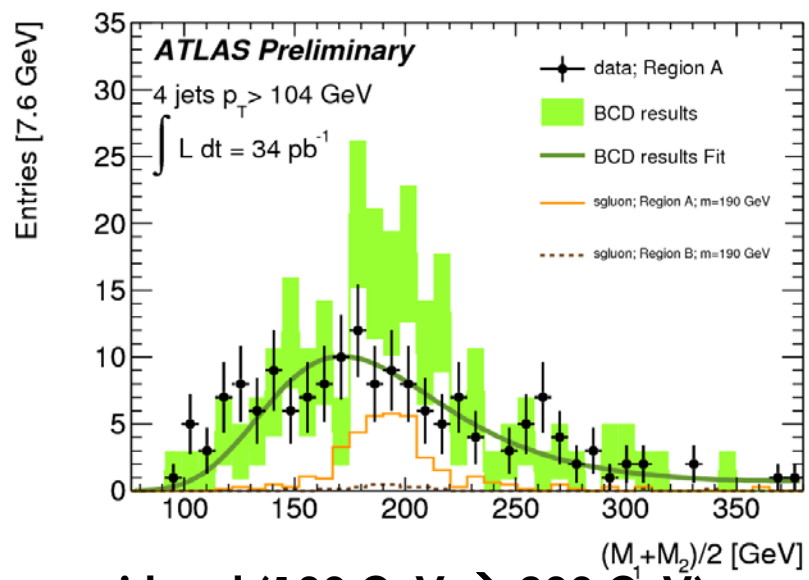
  Region D: $|\cos\theta^*| > 0.7$ and $|M_1-M_2|/(M_1+M_2) > 7.5\%$
- Shape of the background in signal region A is determined in region B (either from the original average reconstructed mass distribution or from a fit to the original distribution, $f(x) = (x-p1)^{p2}\, e^{-x\bullet p3-x2\bullet p4}$)
- Signal contamination in B, C and D regions are removed
- Normalization is derived from ratio of events in the control sample: $N_B \times N_C/N_D$
- ABCD method is applied to QCD MC simulation for validation

Data-driven Background Estimation







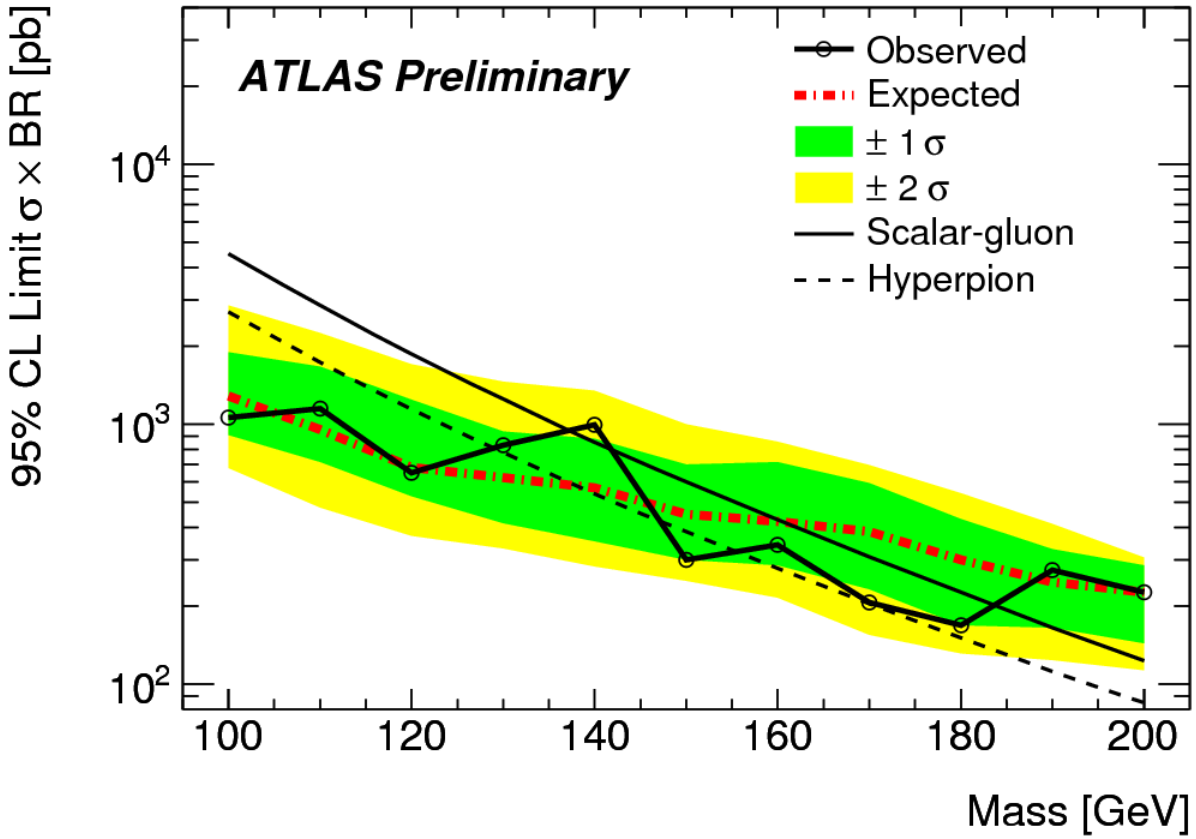


Four different sgluon mass points considered (100 GeV → 200 GeV)

Systematics

Source	Effect
JES	Signal peak center $\pm 2\%$ Signal efficiency $\pm 15\%$
JER	Signal peak width $\pm 10\%$
ABCD	Bkg prediction $\pm 1 - 10\%$
PDF	Signal efficiency $\pm 2\%$
L	Signal normalization $\pm 3.4\%$
MC stat.	Signal normalization in A(B,C,D) $\pm 5(16, 5, 16)\%$
Trigger	Signal normalization (eff $= 99\%$) $\pm 1\%$

Limits



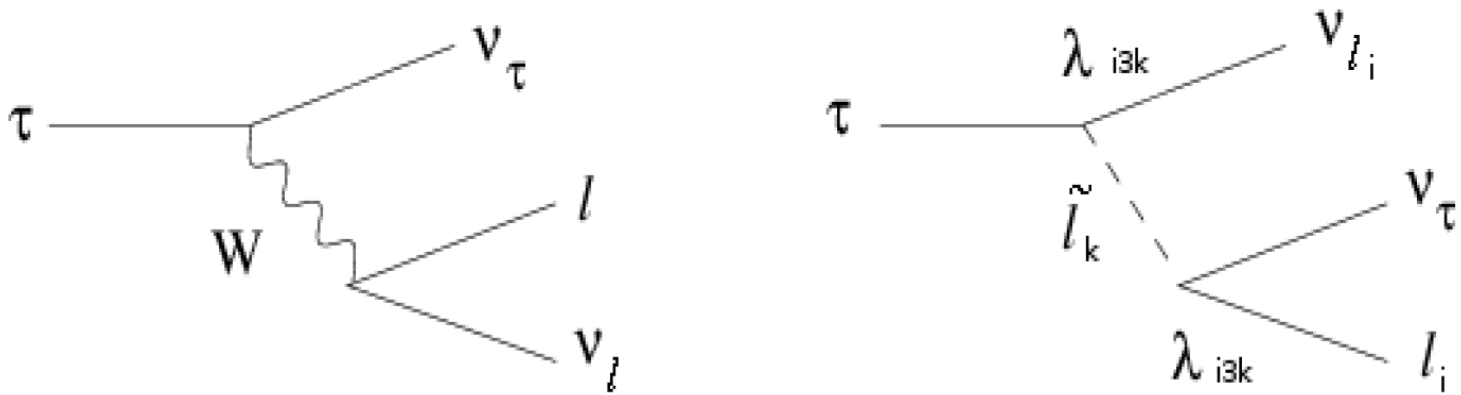
- Cross section limit: 1 nb at 100 GeV and 350 pb at 190 GeV
- Exclude sgluon with 100 < M < 185 GeV at 95% C.L. with a mass window of 5 GeV around 140 GeV

Conclusion

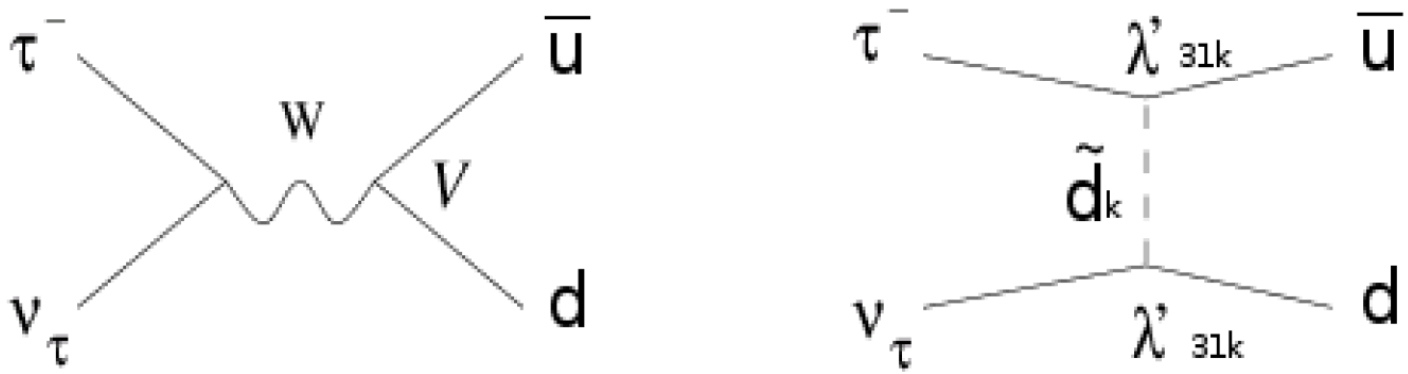
- Search for RPV tau sneutrino decaying to eμ (L = fb^{-1})
  - Good agreement between data and MC predictions for high invariant mass eμ events
  - Better limits set for sneutrino mass vs couplings
- Search for pair-produced scalar particles decaying to four-jets (L=34 pb^{-1}):
  - Good agreement between data and predictions for average reconstructed mass
  - First limits obtained for this search at low mass
- Continuing to analyze more data to search for SUSY at ATLAS

Backup

Tau branching ratio measurement



- Processes contributing to the measurement of λ_{312}



- Processes contributing to the measurement of λ'_{311}