Search for Charginos and Sleptons in ATLAS

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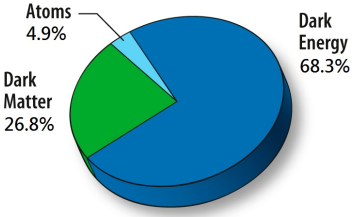
Why Beyond Standard Model Physics?

- SM is very successful theory
  - No significant tension with experiment
  - Predicts the widest range of physics phenomena
- SM in not a fundamental theory
  - Gravitation is not incorporated
  - Unknown origin of dark matter and dark energy
  - Hierarchy problem
  - Unknown origin of neutrino masses

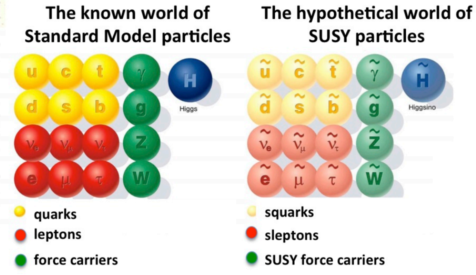


Beyond Standard Model

- Hierarchy problem can be solved for example by:
  - Supersymmetry:
    - Symmetry which leads to a new sets of the particles
    - Their contributions cancel out the contributions of the SM particles in the correction term of Higgs mass
  - Large extra dimensions:
    - Additional spacial dimensions cause the Planck scale to be much lower
- Dark Matter can be explained for example by:
  - Supersymmetry:
    - New quantum number: R-parity
    - If R-parity is conserved, LSP is stable and is a good dark matter candidate
  - Universal extra dimensions:
    - New quantum number: KK-parity
    - KK-parity conservation causes LKP is stable and is a good dark matter candidate

Supersymmetry

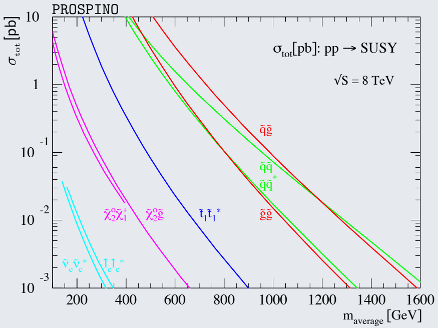
- Extends the Standard Model
- Each SM particle has at least one superpartner
- Superpartners have the same properties as their SM counterparts except for the spin that differs by 1/2
- SUSY is broken since superpartners have higher masses



- Provides solution for hierarchy problem
- If R-parity is conserved, provides a dark matter candidate

Supersymmetry

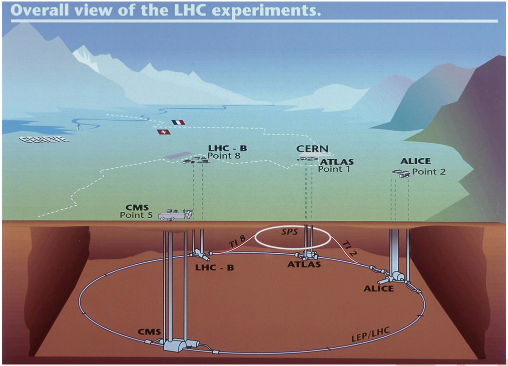
- Number of events at the LHC:
  $N = \mathscr{L} \times \sigma$
- Cross section depends on the masses and couplings of the SUSY particles
- SUSY searches were focused on strong production at the beginning of the LHC run
- SUSY weak production can be dominating at the LHC if squarks/gluinos are heavy and neutralinos/charginos are light



Cross sections for the production of various SUSY particles in $\sqrt{s} = 8$ TeV collisions at the LHC

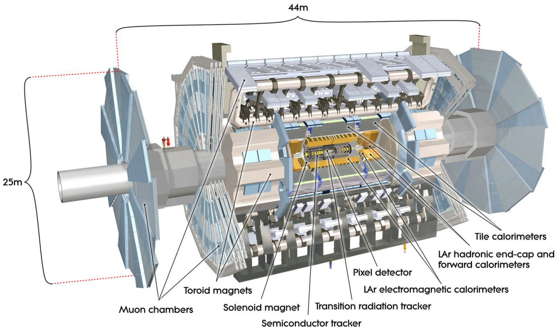
The Large Hadron Collider

- Collides protons collisions at:
  - $\sqrt{s} = 7$ TeV (2010-2011)
  - $\sqrt{s} = 8$ TeV (2012)
  - $\sqrt{s} = 13$ TeV (2015)
- Collisions every 50 ns (25 ns starting in 2015)
- Circumference: 26.7 km
- Four main experiments
  - ATLAS
  - CMS
  - ALICE
  - LHCb

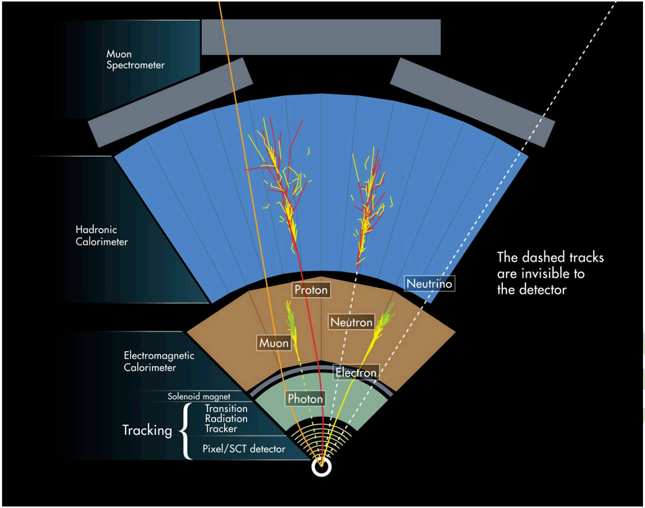


The ATLAS Detector

- A Toroidal LHC ApparatuS
- General purpose detector
- Detector characteristics
  - Width: 44 m
  - Diameter: 25 m
  - Weight: 7000 t
- Subdetectors
  - Inner Detector
  - Calorimeters
  - Muon Spectrometer

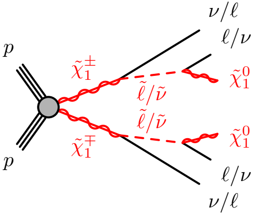


Particle Identification



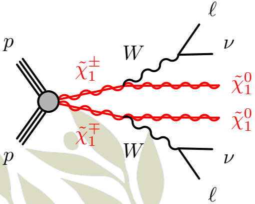
$$E_{\mathrm{T}}^{\mathrm{miss}} = \left| - \sum \mathbf{p}_{\mathrm{T}}^{e} - \sum \mathbf{p}_{\mathrm{T}}^{\mu} - \sum \mathbf{p}_{\mathrm{T}}^{j} - \ldots - \sum \mathbf{p}_{\mathrm{T}}^{\mathrm{uncl}} \right|$$

Search for Chargino and Slepton Pairs Directly Produced in ATLAS

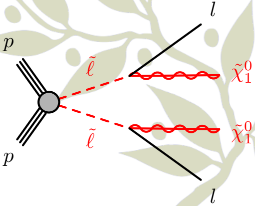


- *JHEP* 05 (2014) 071

- Signal signature
  - 2 leptons
  - $E_{\mathrm{T}}^{\mathrm{miss}}$
  - no final state jets



- Used the entire dataset recorded with dilepton triggers in 2012 (20.3 fb^{-1}) at $\sqrt{s} = 8$ TeV

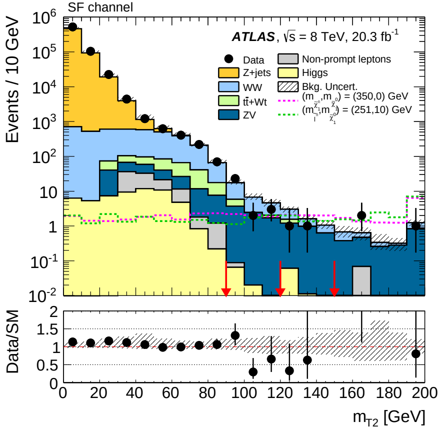


Signal Characteristic Observable

- The stransverse mass (m_{T2}) is defined to measure the transverse mass of the system of two particles decaying to a visible and an invisible particle
- Kinematic edge at the value of the mass of the system of two primary particles

$$m_{\mathrm{T2}} \leq (m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0}^2)/m_{\tilde{\ell}}$$

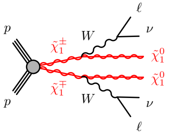
- SUSY signal events can have values of m_{T2} exceeding the W mass
- Used to suppress WW background

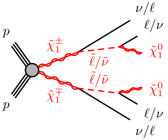


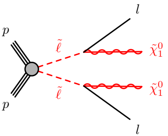
Standard Model Backgrounds

WW: WW and WWW processes	Suppressed by m_{T2} cut
ZV: Z+jets, ZW, ZZ, and Z+two vector bosons	Suppressed by veto on Z boson
Top: $t\bar{t}$, single t and t+vector boson processes	Suppressed by veto on jets
Fakes: mis-identified as electrons or isolated muons	Small
Higgs: Standard Model Higgs boson processes	Small

Signal Regions Definition







Criteria	SR-WW_a	SR-WW_b	SR-WW_c	SR-$m_{T2,90}$	SR-$m_{T2,120}$	SR-$m_{T2,150}$
Opposite sign lep.	✔					
Lepton flavour	ee, $e\mu$, $\mu\mu$					
$p_T^{\ell 1}$	> 35 GeV					
$p_T^{\ell 2}$	> 20 GeV					
$m_{\ell\ell}$	> 20 GeV					
Z veto { $\lvert m_{\ell\ell} - m_Z \rvert$	> 10 GeV					
Jet veto { signal central jets	$= 0$					
signal b-jets	$= 0$					
signal forward jets	$= 0$					
$p_T^{\ell\ell}$	> 80 GeV	–				
$E_T^{\mathrm{miss,rel}}$	> 80 GeV	–				
$m_{\ell\ell}$	< 120 GeV	< 170 GeV	–			
m_{T2}	–	> 90 GeV	> 100 GeV	> 90 GeV	> 120 GeV	> 150 GeV

Invariant mass of two body system

$$m_{1,2} = \sqrt{(E_1 + E_2)^2 - |\mathbf{p}_1 + \mathbf{p}_2|^2}$$

Calculation of ZV Background

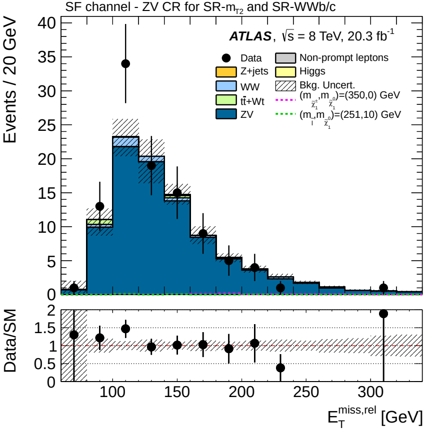
- ZV stands for Z+jets, ZW, ZZ and Z+two vector bosons

$$N^{\text{SR}}_{ZV} = N^{\text{SR}}_{ZV,\ \text{MC}} \times \mathcal{S}$$

where

$$\mathcal{S} = \frac{N^{\text{CR}}_{ZV,\ \text{data}} - N^{\text{CR}}_{\text{non-}Z,\ \text{MC}}}{N^{\text{CR}}_{ZV,\ \text{MC}}}$$

CR-ZV	
Opposite sign leptons	✔
Lepton flavour	ee, $\mu\mu$
$p_{\text{T}}^{\ell 1}$	$>$ 35 GeV
$p_{\text{T}}^{\ell 2}$	$>$ 20 GeV
$m_{\ell\ell}$	$>$ 20 GeV
$\lvert m_{\ell\ell} - m_Z \rvert$	$<$ 10 GeV
signal central jets	$= 0$
signal b-jets	$= 0$
signal forward jets	$= 0$
m_{T2}	$>$ 90 GeV



Scale factor $\mathcal{S} = 1.08 \pm 0.12$

Calculation of WW Background

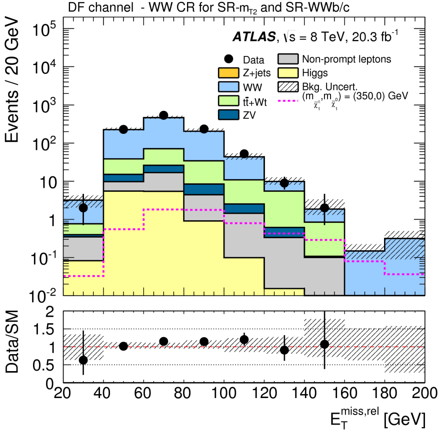
$$N^{\rm SR}_{WW} = N^{\rm SR}_{WW,\ \rm MC} \times \mathcal{S}$$

where

$$\mathcal{S} = \frac{N^{\rm CR}_{WW,\ \rm data} - N^{\rm CR}_{{\rm non}\text{-}WW,\ \rm MC}}{N^{\rm CR}_{WW,\ \rm MC}}$$

CR-WW	
Opposite sign leptons	✔
Lepton flavour	$e\mu$
$p_{\rm T}^{\ell 1}$	$>$ 35 GeV
$p_{\rm T}^{\ell 2}$	$>$ 20 GeV
$m_{\ell\ell}$	$>$ 20 GeV
signal central jets	$= 0$
signal b-jets	$= 0$
signal forward jets	$= 0$
$m_{\rm T2}$	[50, 90] GeV

- In agreement with the ATLAS measurement of the WW production cross section



Scale factor $\mathcal{S} = 1.14 \pm 0.05$

Top Background Estimation

$$N_{\text{Top}}^{\text{SR}} = N_{\text{Top, MC}}^{\text{SR}} \times \mathcal{S} \times C_{\mathcal{S}}$$

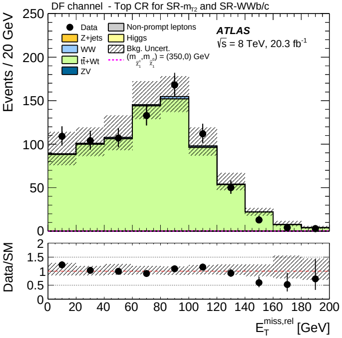
where

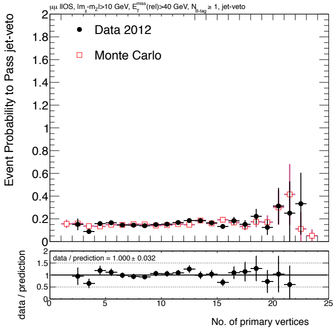
$$\mathcal{S} = \frac{N_{\text{Top, data}}^{\text{CR}}}{N_{\text{Top, MC}}^{\text{CR}}} \quad \text{and} \quad C_{\mathcal{S}} = \frac{\varepsilon_{\text{data}}^{\text{jet-veto}}}{\varepsilon_{MC}^{\text{jet-veto}}}$$

- $C_{\mathcal{S}}$ used to address potential difference in the jet-veto efficiency between data and MC

CR-Top	
Opposite sign leptons	✔
Lepton flavour	$e\mu$
$p_{\mathrm{T}}^{\ell 1}$	$>$ 35 GeV
$p_{\mathrm{T}}^{\ell 2}$	$>$ 20 GeV
$m_{\ell\ell}$	$>$ 20 GeV
signal central jets	$= 0$
signal b-jets	≥ 1
signal forward jets	$= 0$
m_{T2}	$>$ 70 GeV

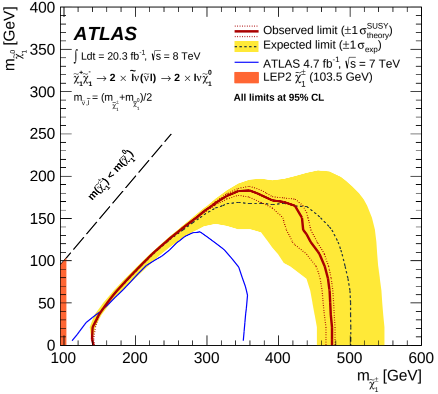
- Scale factor $\mathcal{S} = 1.02 \pm 0.04$



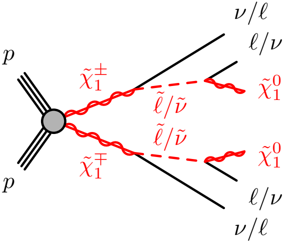


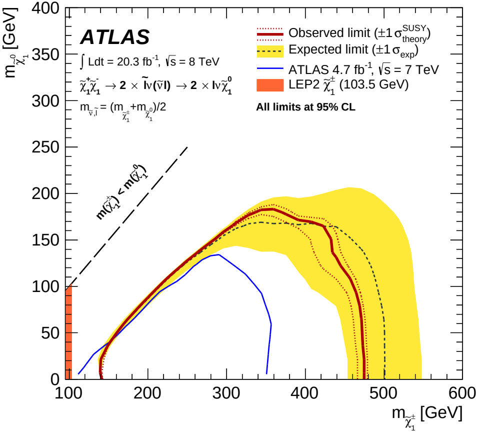
Exclusion Limits

- No significant excess over the expected Standard Model background observed
- Limits at 95% CL on chargino and slepton production derived
  - Dashed black line: expected limits
  - Solid red line: observed limits
  - Yellow band: experimental uncertainties on the expected limits
  - Dashed red lines: impact on the observed limits when the signal cross section is scaled up and down by 1σ of theoretical uncertainties



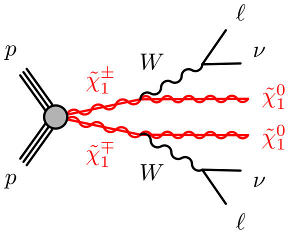
Exclusion Limits

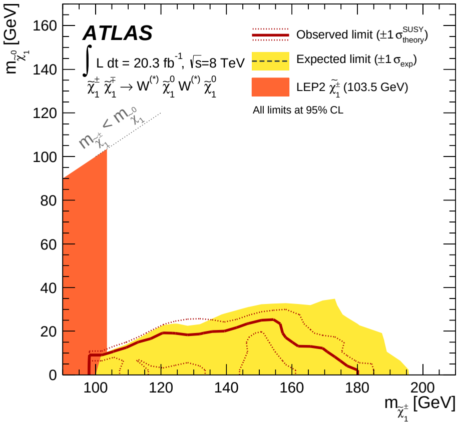




- Chargino mass between 140 GeV and 470 GeV is excluded for massless neutralino at 95% CL

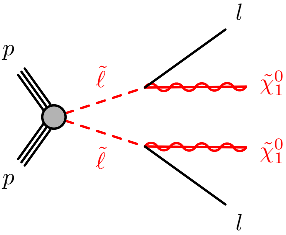
Exclusion Limits

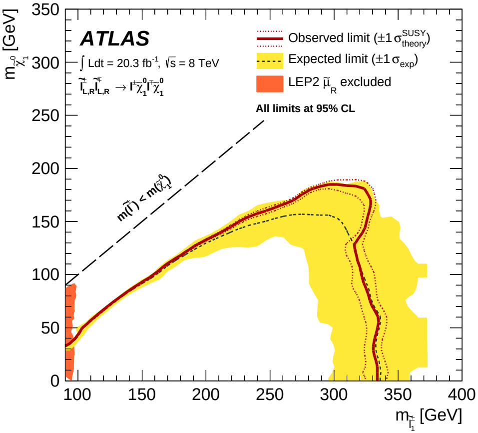




- Chargino mass between 100 GeV and 180 GeV is excluded for massless neutralino at 95% CL

Exclusion Limits

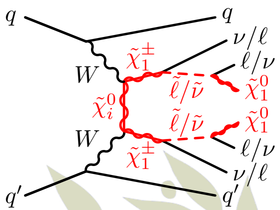




- A common value for left- and right-handed slepton mass between 90 GeV and 330 GeV is excluded for massless neutralino at 95% CL

Search for Chargino Pairs Produced via VBF in ATLAS

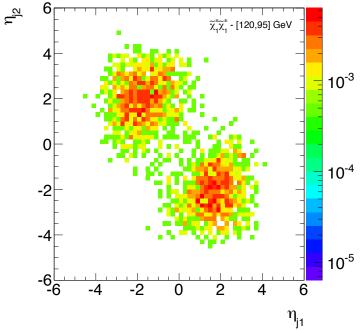
- Submitted to *Phys. Rev.* D arXiv:1509.07152 [hep-ex]
- Signal signature
  - 2 leptons
  - 2 jets
  - $E_{\mathrm{T}}^{\mathrm{miss}}$

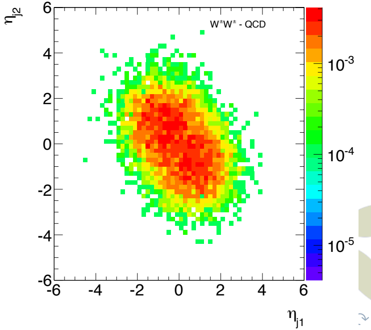


- VBF production of SUSY particles investigated for the first time in ATLAS
- If observed it would prove that the exchanged $\tilde{\chi}_i^0$ is a Majorana particle
- Targeting scenarios with small mass differences $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$
- Used the entire dataset recorded with $E_{\mathrm{T}}^{\mathrm{miss}}$ triggers in 2012 (20.3 fb^{-1}) at $\sqrt{s} = 8$ TeV

Signal Characteristic Observable

- Lepton Observables
  - Dilepton invariant mass ($m_{\ell\ell}$)
  - Stransverse mass (m_{T2})
- Jet Observables
  - Dijet invariant mass (m_{jj})
  - Jet transverse momentum (p_{T}^{j})
  - $|\Delta\eta|$ between two leading jets ($|\Delta\eta_{jj}|$)
- Missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$)





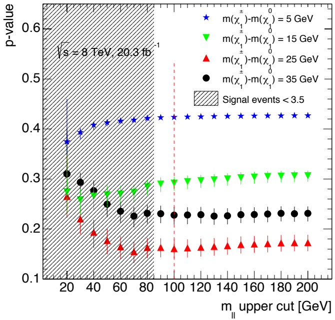
Standard Model Backgrounds

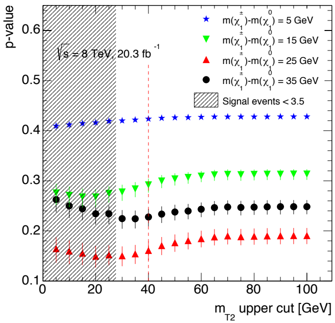
Fakes: mis-identified as electrons or isolated muons	Suppressed by lepton isolation
Diboson: WW, WZ and ZZ processes	Suppressed by $\|\Delta\eta_{jj}\|$ cut
Top: single t and $t\bar{t}$+vector boson processes	Suppressed by veto on b-jet
Charge flip: events with electron with misidentified charge	Small
Higgs: Standard Model Higgs boson processes	Small

Signal Region Optimisation

- Figure of merit:
  - p-value
  - at least 3.5 signal events

	Signal Region	
	Same sign leptons	✔
	Lepton flavour	ee, $\mu\mu$, $e\mu$
	$E_{\mathrm{T}}^{\mathrm{miss}}$	$>$ 120 GeV
	signal b-jets	$=$ 0
Small mass gap signature	p_{T}^{e} (p_{T}^{μ})	$>$ 7 (5) GeV
Small mass gap signature	$m_{\ell\ell}$	$<$ 100 GeV
Small mass gap signature	m_{T2}	$<$ 40 GeV
Small mass gap signature	$p_{\mathrm{T}}^{\ell\ell}/E_{\mathrm{T}}^{\mathrm{miss}}$	$<$ 0.4
VBF signature	signal light + forward jets	$\geq$ 2
VBF signature	p_{T}^{j1}	$>$ 95 GeV
VBF signature	$\lvert\Delta\eta_{jj}\rvert$	$>$ 1.6
VBF signature	$\eta_{j1}\cdot\eta_{j2}$	$<$ 0
VBF signature	m_{jj}	$>$ 350 GeV
VBF signature	$p_{\mathrm{T}}^{j1}/E_{\mathrm{T}}^{\mathrm{miss}}$	$<$ 1.9
VBF signature	$p_{\mathrm{T}}^{\ell\ell}/p_{\mathrm{T}}^{jj}$	$<$ 0.35





Diboson Background Estimation

- Simulated with LO generator (Sherpa) and normalised with NLO cross section using PowhegBox (WW) and VBFNLO (WZ)
- The LO Sherpa samples are normalised to yield the same number of events in the fiducial region as the NLO generator
- Fiducial region is a region as close to the signal region as possible

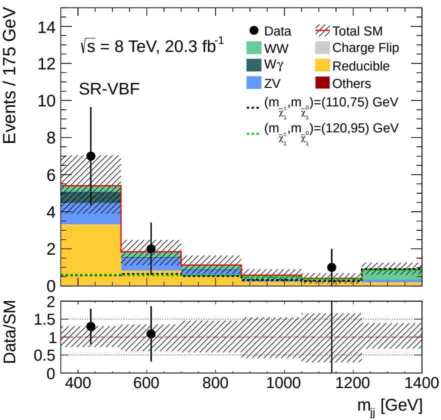
$$\sigma^{\mathrm{NLO}}_{\mathrm{extrap}} = \frac{\sigma^{\mathrm{NLO,fid}}_{\mathrm{PB/VBFNLO}}}{A_{\mathrm{Sherpa}}} \quad \text{where} \quad A_{\mathrm{Sherpa}} = \frac{N^{\mathrm{fid}}}{N^{\mathrm{all}}}$$

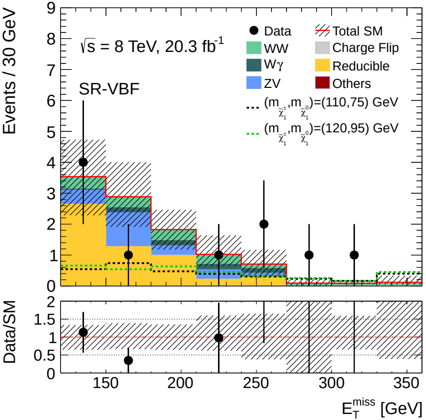
Process	$\sigma^{\mathrm{LO}}_{\mathrm{Sherpa}}$ [fb]	$\sigma^{\mathrm{NLO}}_{\mathrm{extrap}}$ [fb]
$WWjj$ EWK	27.6	21.4 $\pm$ 1.7
$WWjj$ QCD	16.1	10.8 $\pm$ 3.0
$WZjj$ EWK	82.1	85.2 $\pm$ 1.4
WZ QCD	9740	11530 $\pm$ 1580

- Theoretical uncertainty is assigned to the predicted NLO values
  - Generator, PDF, scale, parton showering
- ZZ background is small and estimated using LO Monte Carlo

Results

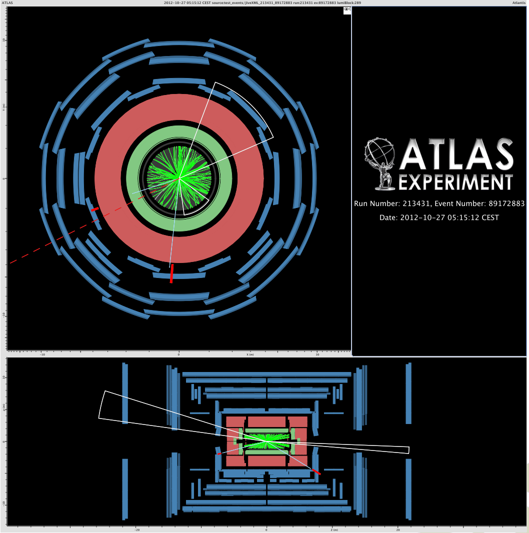
- Good agreement between observed data and estimated background
- The uncertainty band represents the total statistical and systematic uncertainty on the Monte Carlo prediction





Event Display

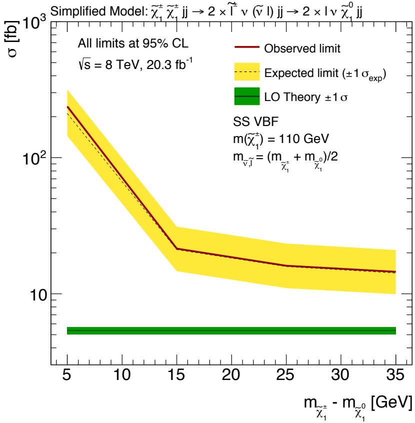
- Event display of one VBF signal-like collision event in ATLAS data from October 27, 2012
- $p_T^{\mu 1} = 19$ GeV, $p_T^{\mu 2} = 7$ GeV
- $p_T^{j1} = 146$ GeV, $p_T^{j2} = 31$ GeV
- m_{jj}=1.2 TeV
- E_T^{miss}= 130 GeV

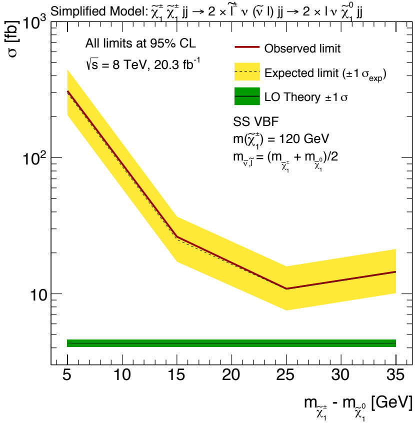


Exclusion Limits

- No significant excess over the expected Standard Model background observed
- The 95% CL upper limit on the cross section for same sign $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ pair production via VBF is set with respect to the mass difference $m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0}$

$m_{\tilde{\chi}_1^{\pm}} = 110$ GeV | $m_{\tilde{\chi}_1^{\pm}} = 120$ GeV





Conclusions & summary

- Supersymmetry is a theory that can address some of the shortcomings of the Standard Model
- Electroweak production of supersymmetric particles can be dominating at the LHC if squarks/gluinos are heavy and neutralinos/charginos are light
- No significant excess over the expected Standard Model background is observed
- Limits on the masses of charginos and sleptons are set at 95% CL
- Upper limit on the cross section for same sign $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ pair production via VBF is set with respect to the mass difference $m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0}$ at 95% CL
- The LHC Run II data will allow to study the wider range of parameter space and provide the sensitivity to SUSY production via VBF