Discovery Physics at the LHC, Kruger 2014
5 December 2014

ADELAIDE UNIVERSITY AUSTRALIA

"Brussels, Belgium" (1932) Henri Cartier-Bresson

Searches for Supersymmetry at ATLAS

Lawrence Lee
for the ATLAS Collaboration

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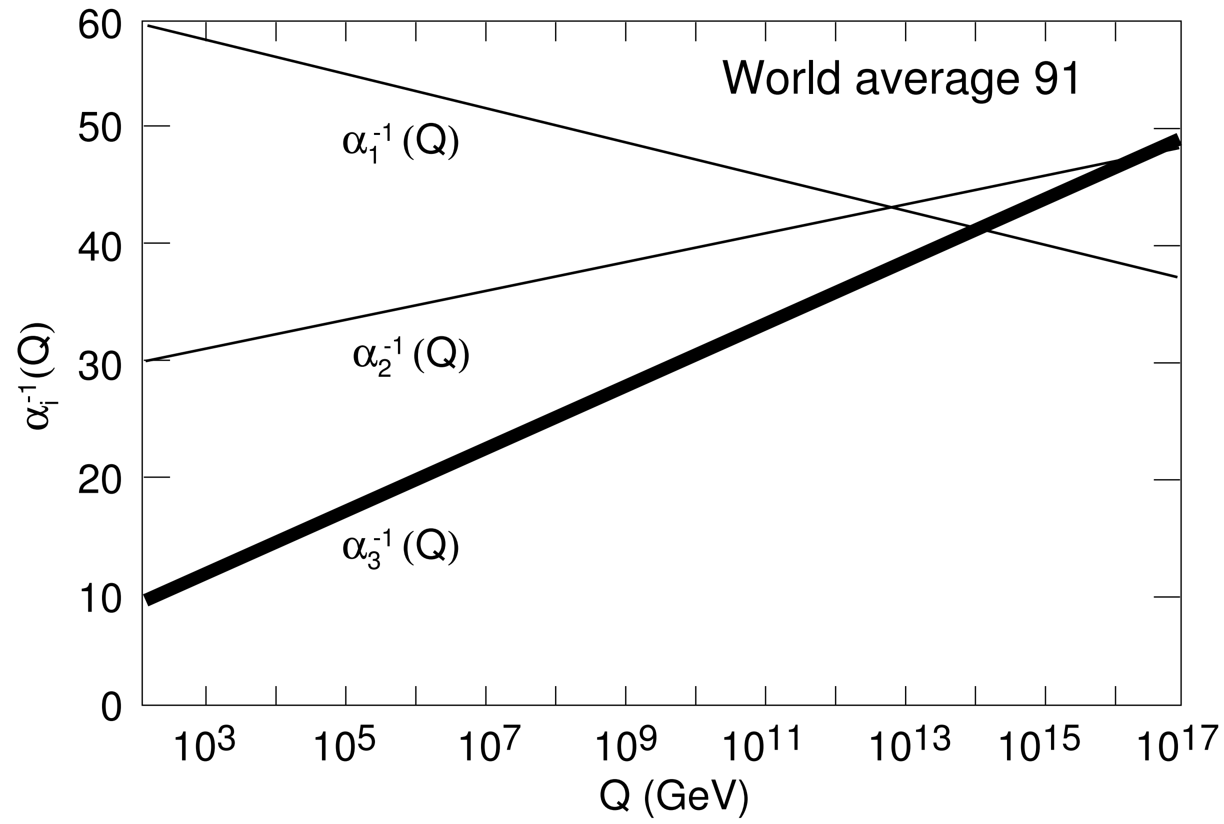
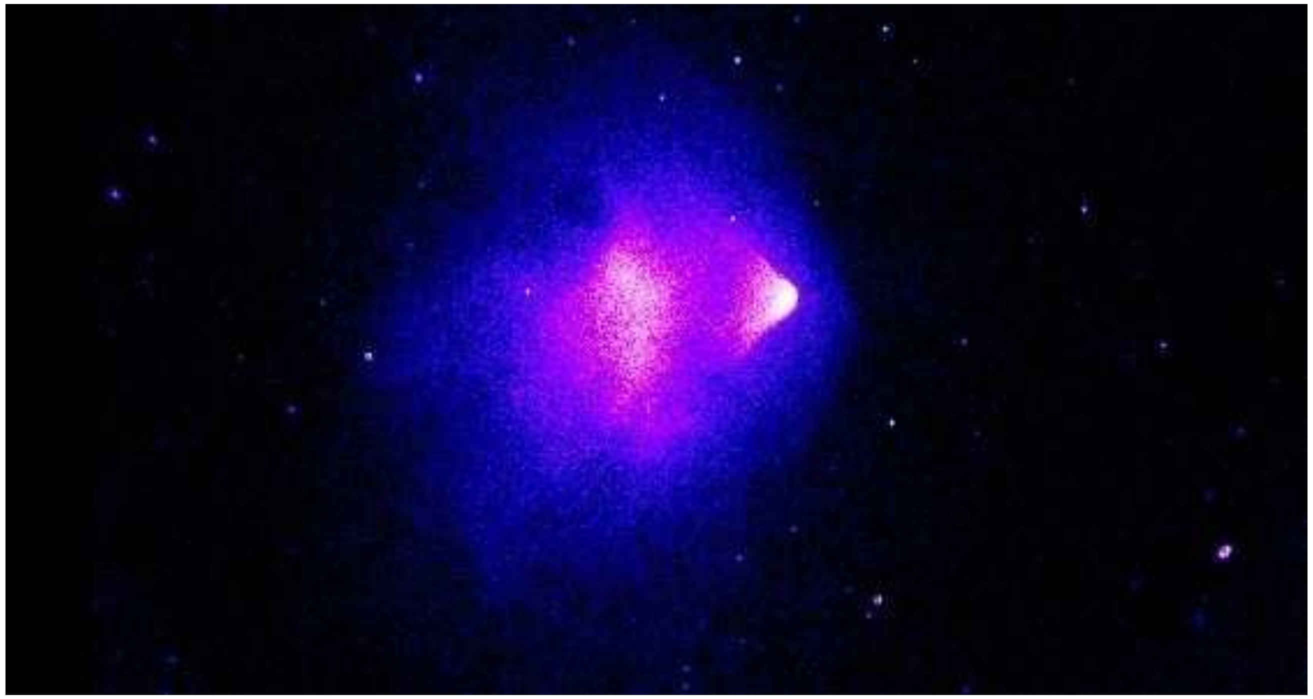
What are the triangles telling us here?

$$\Delta m_H^2 \sim \Lambda_{UV}^2 + ...$$





The State of SUSY at ATLAS

- A weak-scale supersymmetry deflates the naturalness problem by protecting the Higgs mass from UV scales
  - Provides new partners to SM particles
  - Potential Dark Matter candidates
  - Potential to unify the coupling constants
- No direct evidence for SUSY after decades of searching
- Goal is to probe what’s left of the allowed SUSY parameter spaces

The State of SUSY at ATLAS

ATLAS has many results in the search for

Inclusive Strongly-Produced Squarks & Gluinos

Third Generation Squarks

Electroweak-Produced Particles

R-Parity Violating Models

Long-Lived Particles

Indirect Searches for Particles

The State of SUSY at ATLAS

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Indirect Searches for Particles

Will highlight some new results across this spectrum today

Inclusive Search for Squarks and Gluinos ≥1 Lepton, Jets, MET

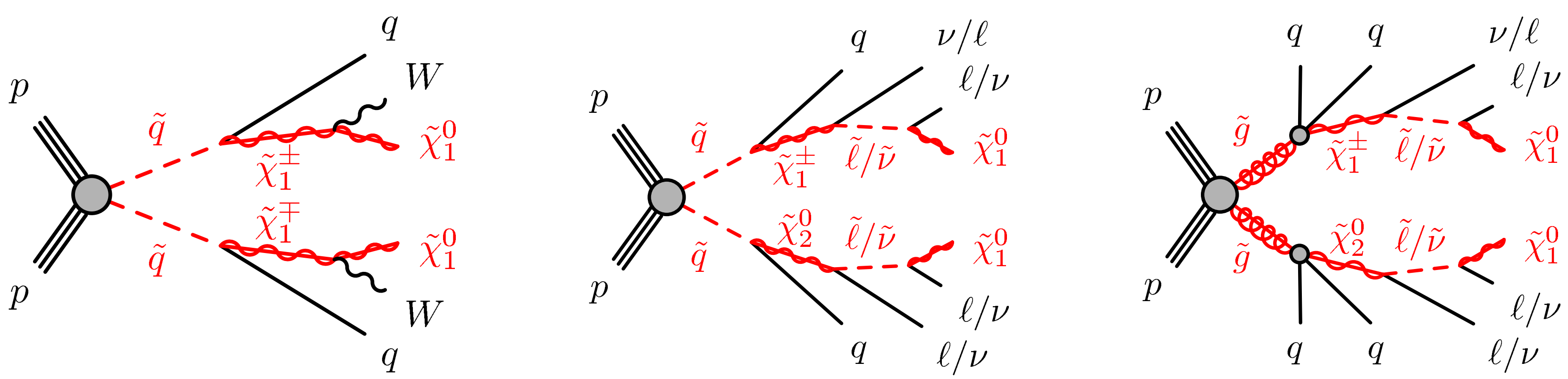
- Start with the most likely place to find SUSY – Strongly produced squarks and gluinos
- Most likely *way* to find it – General, inclusive searches
  - ≥ 1 Lepton, Jets, Missing E_T
  - 3 Classes of Signal Regions
    - Statistical combinations for certain models

1 Hard Lepton
(>25 GeV)
Mid-High Mass Splittings

1-2 Soft Leptons
(~6-25 GeV)
Compressed Spectra

2 Hard Leptons
(>14/10 GeV)
Using event-level topological observables
(Razor prescription)

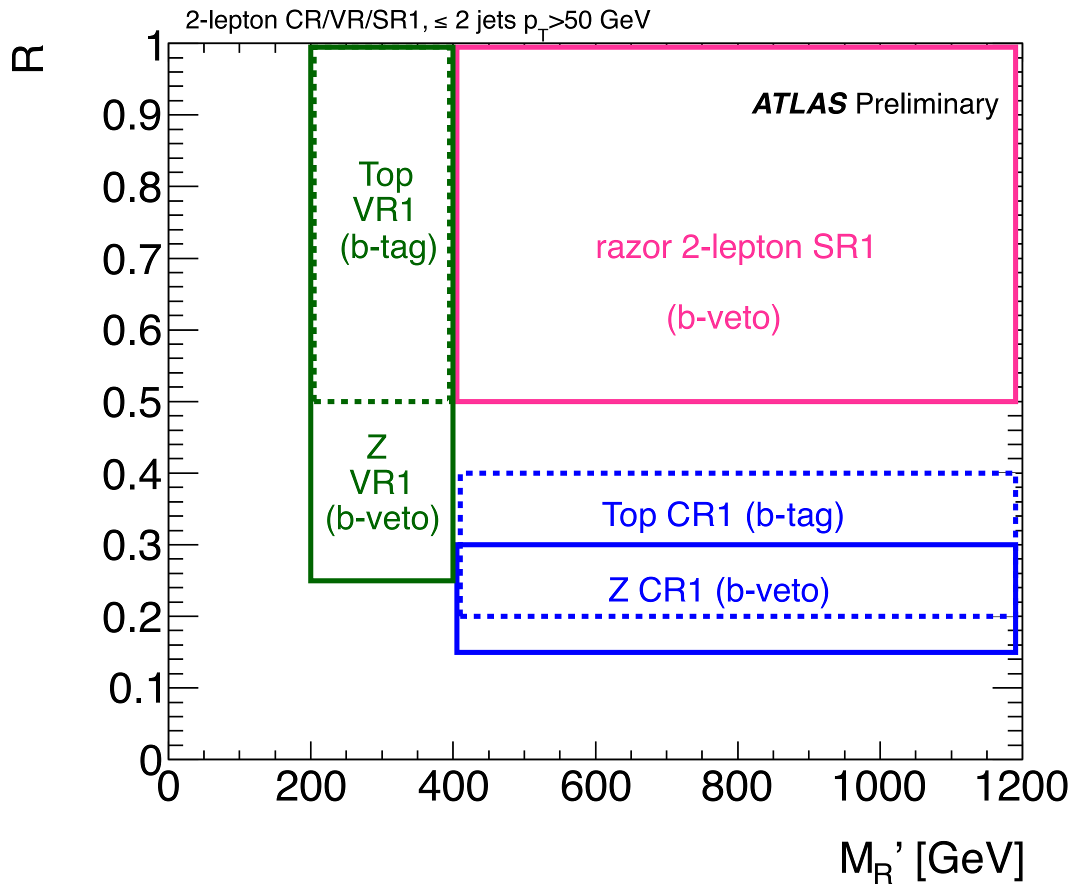
e.g.

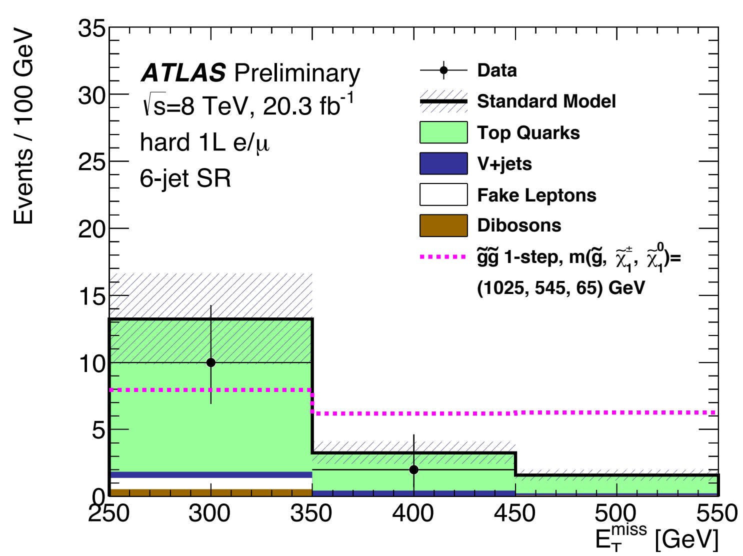


Paper Forthcoming

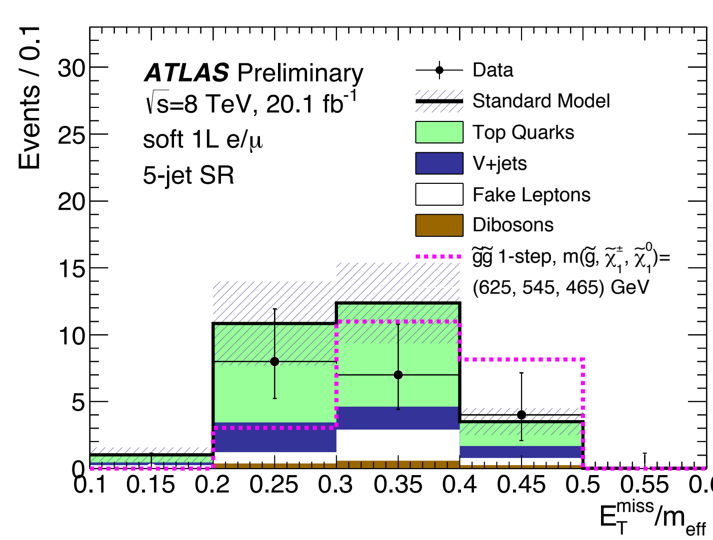
Inclusive Search for Squarks and Gluinos ≥1 Lepton, Jets, MET

- Sensitive to a wide array of BSM models with final observables
  - Single Hard Lepton: m_{Eff} or MET
  - 1-2 Soft Lepton: MET/m_{Eff}
  - Dilepton: Razor Variable M'_R
- Control/Validation/Signal Regions used in background estimation
- No deviation from the Standard Model prediction observed

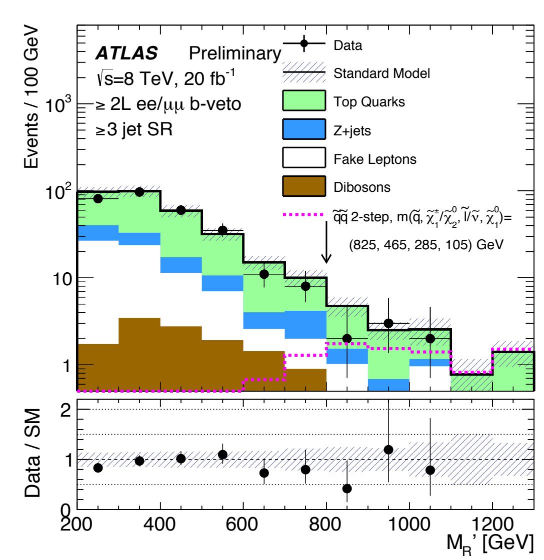




One Hard Lepton



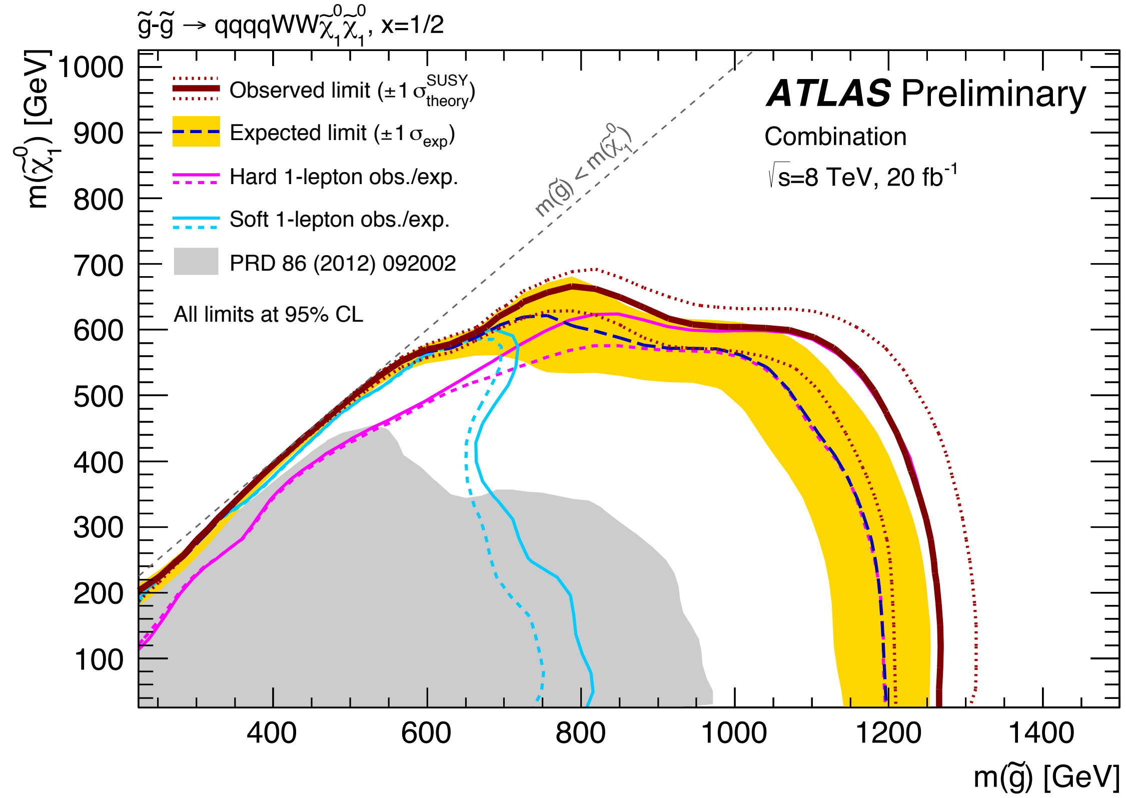
One Soft Lepton

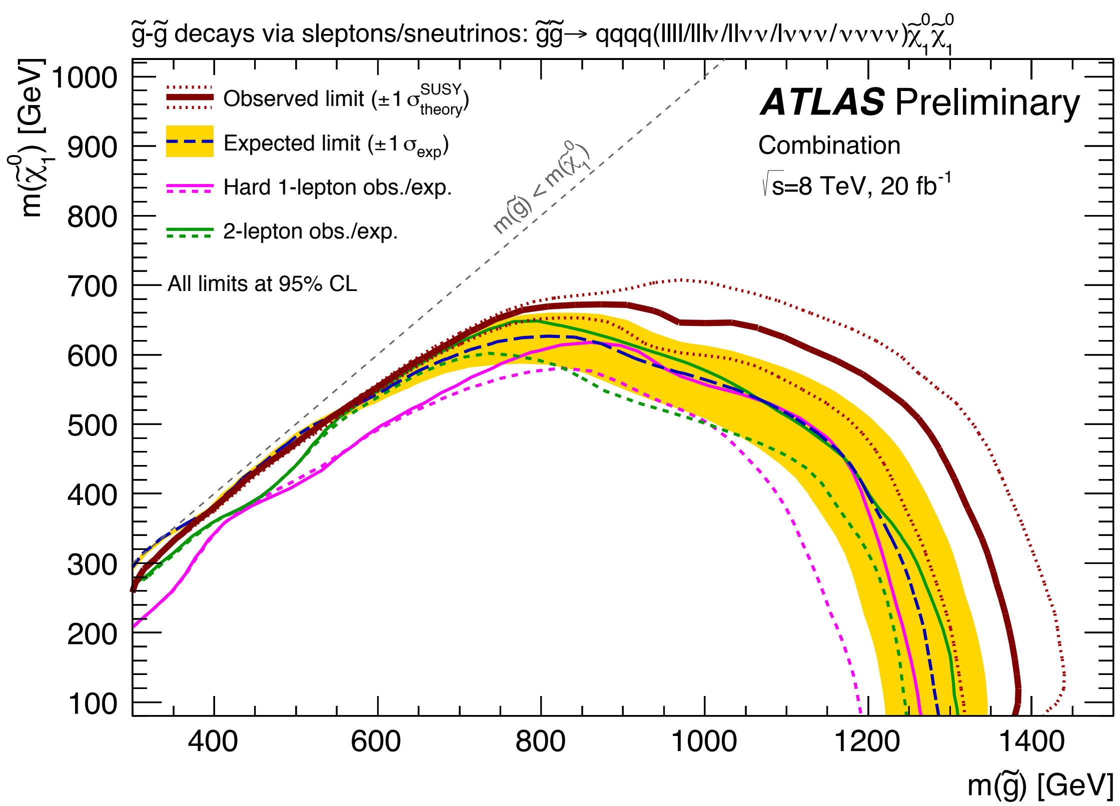


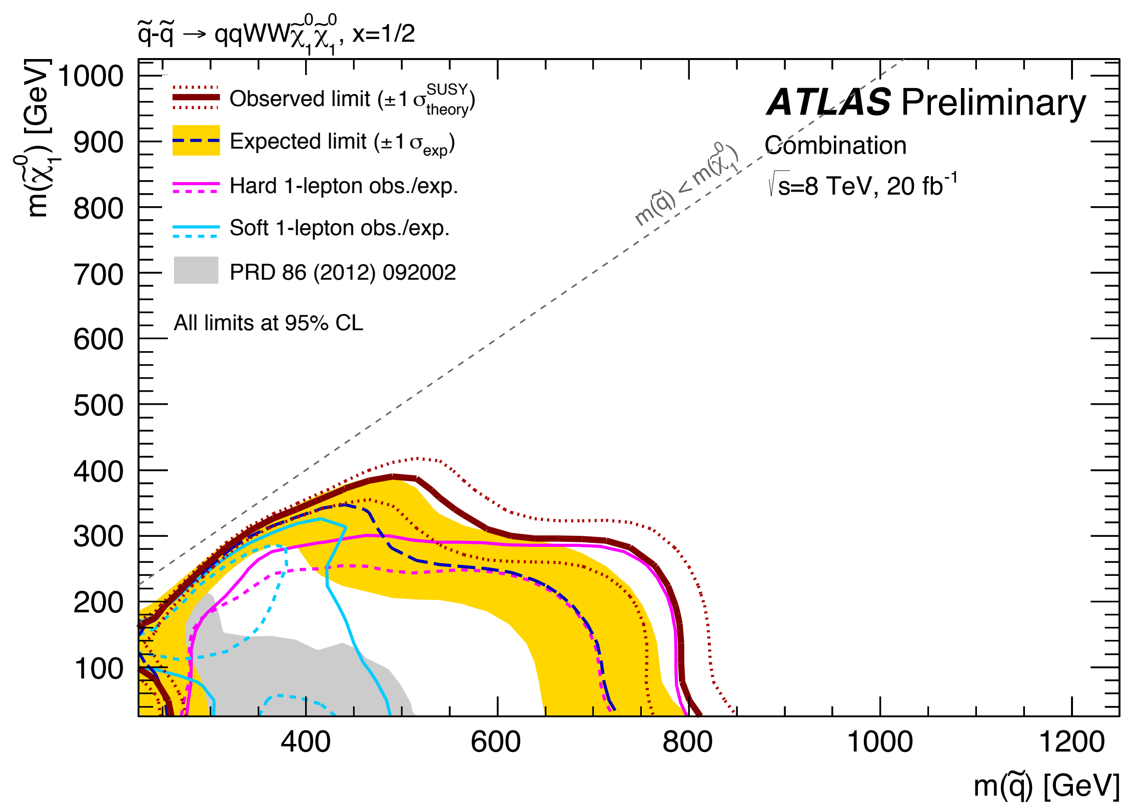
Two Hard Leptons

Inclusive Search for Squarks and Gluinos
≥1 Lepton, Jets, MET

- Statistical combinations of multiple channels
- Strong production of squarks and gluinos with decays via W's, sleptons, and sneutrinos excluded up to
  - gluino masses of ~1.2-1.4 TeV
  - squark masses of ~800 GeV

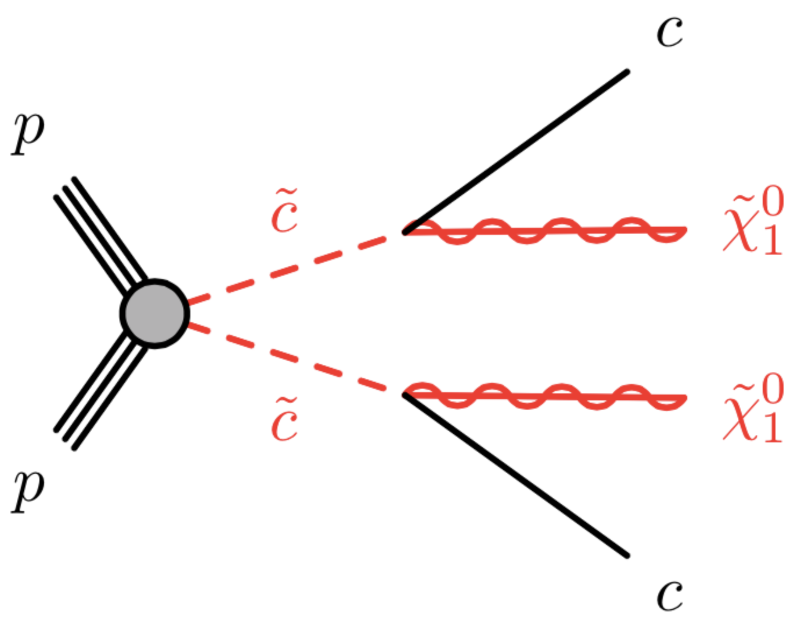






Scharm Search with Charm Tagging

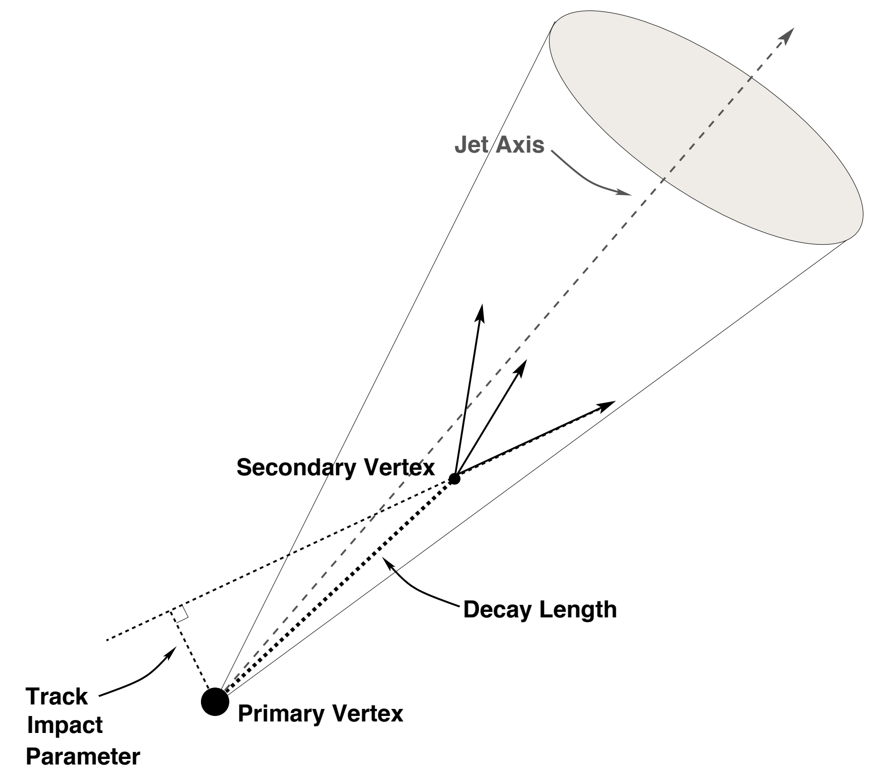
- If the scalar charm partner is lighter than the other squarks, this could be one of the few ways to find SUSY
- Finding scharm pair production is a challenge with many SM dijet+MET sources
  - Introduce charm-optimized lifetime jet taggers to reduce backgrounds
- Search for a signature of two charm tags plus high MET
  - First dedicated search for scharm pair production

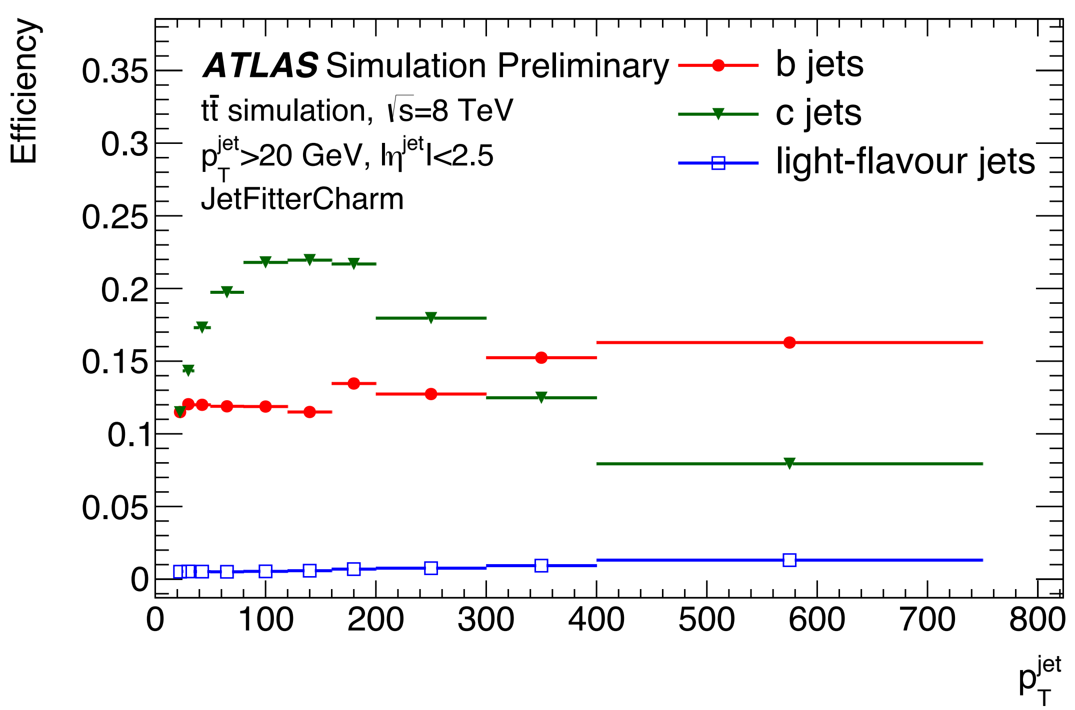


ATLAS-CONF-2014-062

Charm Tagging

- Analogous to BTagging, charm tagging looks for the displaced decay of a D hadron within a jet
- Multivariate Tagger calibrated in data with ttbar (b efficiency) and D* events (c efficiency)
- 2D probability cuts, simultaneously rejecting light quark or gluon jets and B jets





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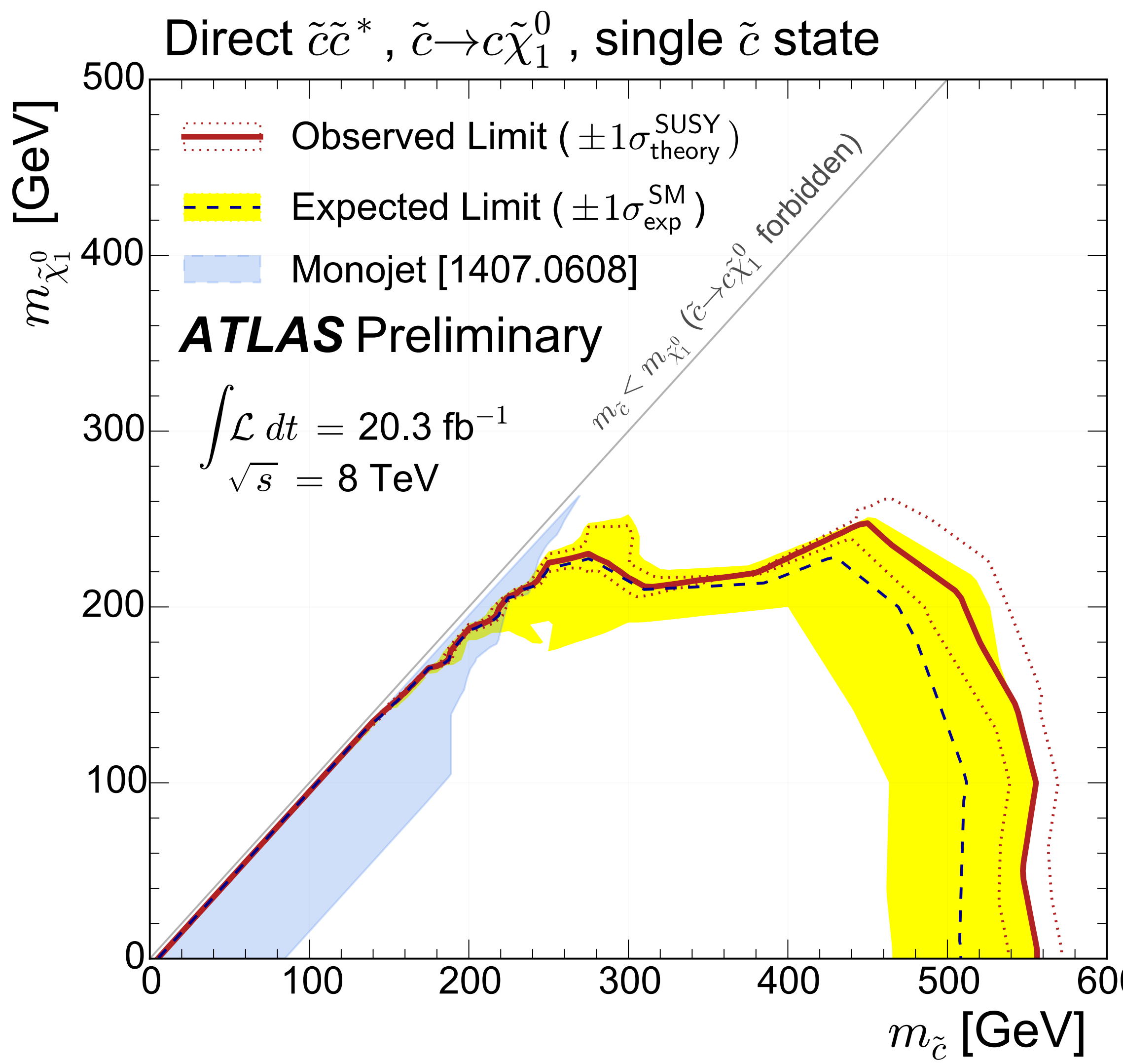
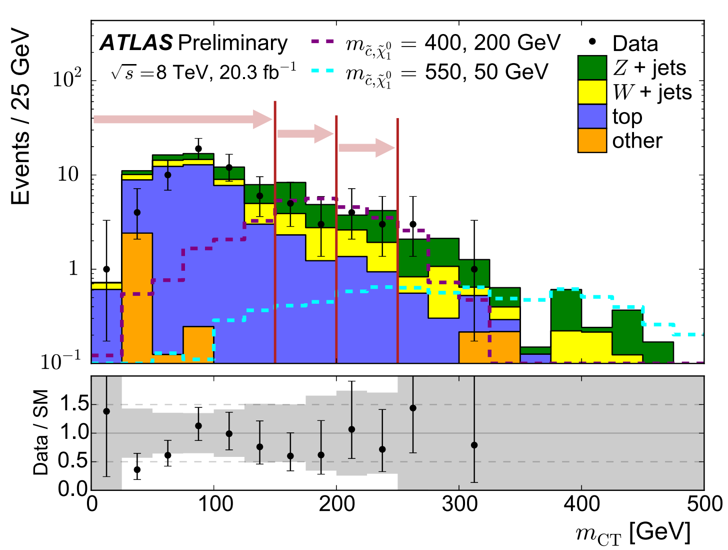
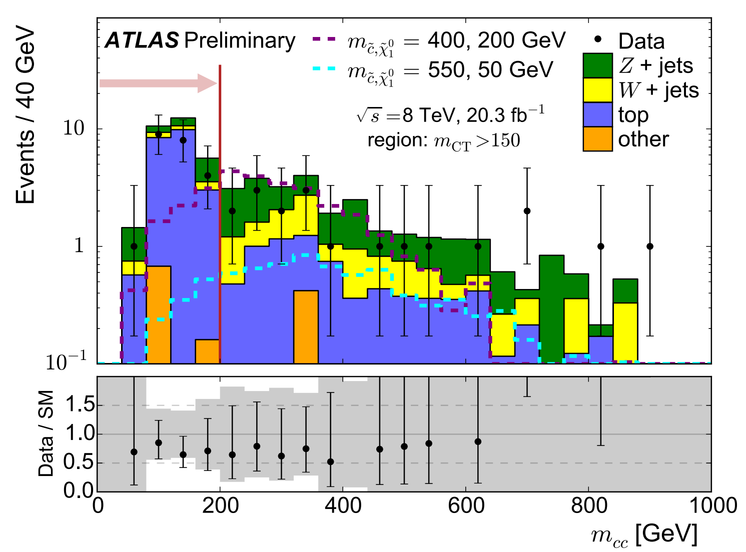
Scharm Search Results

- Control Regions are reasonably modeled, constrain final fit
- Signal Regions
  - MET > 150 GeV (Events triggered on MET)
  - 2 c-tagged jets above [130, 100] GeV
  - Δphi(MET,jets) > 0.4
  - MET/m_{Eff} > 0.25
  - m_{CT} > {150, 200, or 250} GeV to kill most backgrounds
  - m_{CC} > 200 GeV rejects ttbar and Z+jets
- No deviation from the Standard Model prediction observed







- Scharm masses are excluded up to ~500 GeV for a neutralino mass less than 200 GeV
- Complementary analyses provide sensitivity to various regions of this plane

ATLAS-CONF-2014-062

ATLAS-CONF-2014-063

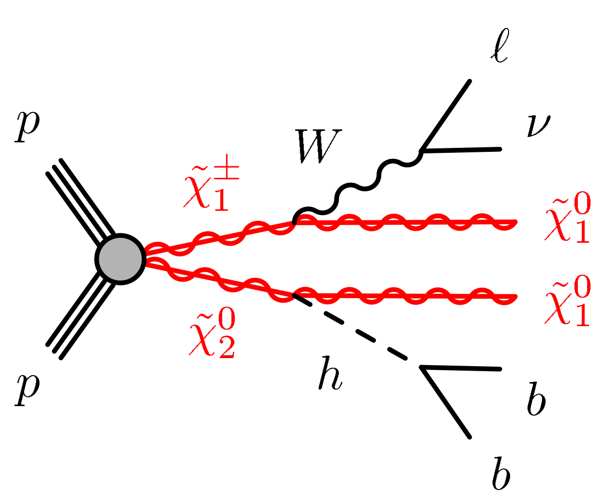
Chargino and Neutralino Production

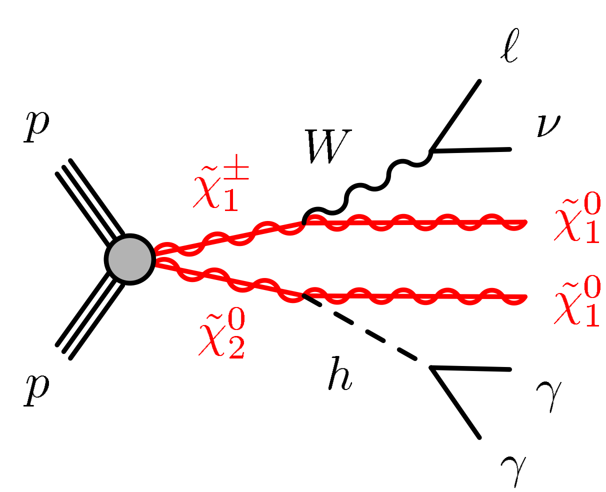
- Probe electroweak production of chargino+neutralino
- Chargino decay via W
- Neutralino decay via 125 GeV Higgs
- 3 Channels for different Higgs decays
  - Each analysis independent with individual techniques
  - Orthogonal signal regions allow for statistical combination of results

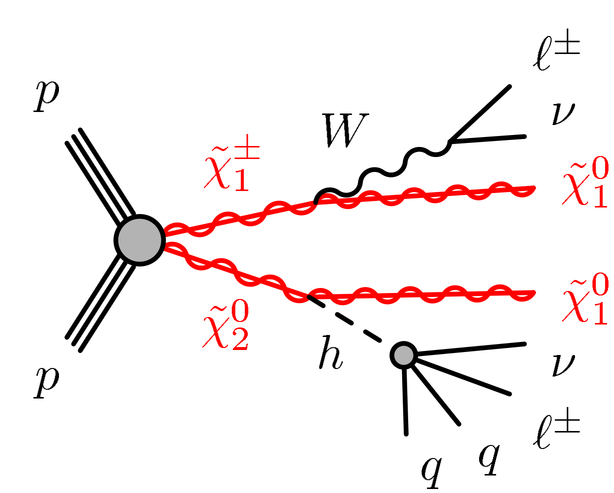
Lepton+bb
with H→bb

Lepton+γγ
with H→γγ

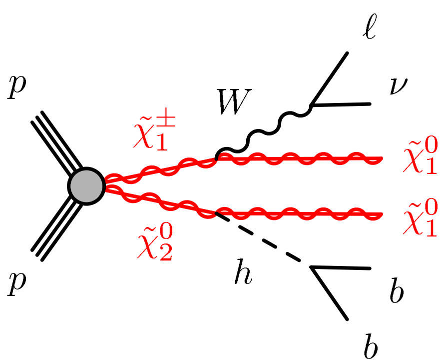
Same-sign Dilepton
with H→WW



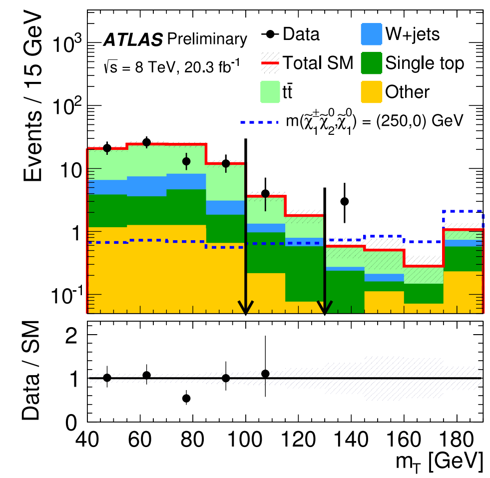




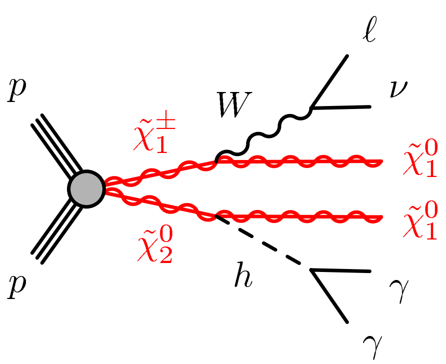
Chargino and Neutralino Production



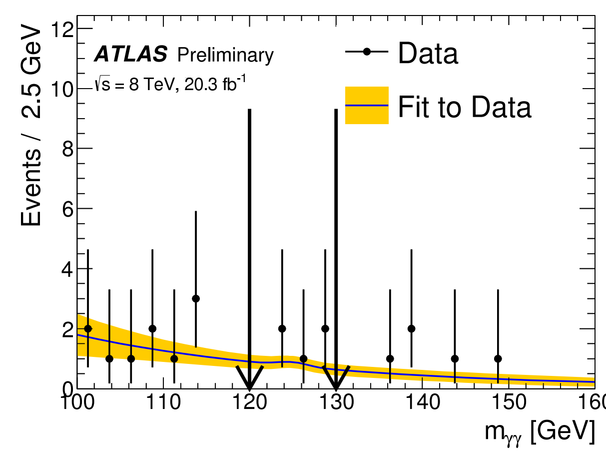
- **lbb Channel**
  - ttbar and W+Jets normalization from dedicated CRs



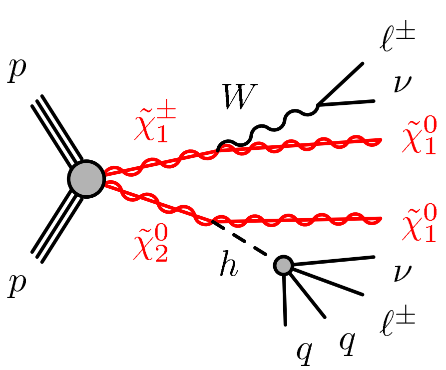
	SRℓbb-1	SRℓbb-2	SRℓbb-1	SRℓbb-2
	$105 < m_{bb} < 135$		m_{bb} sidebands	
Observed events	4	3	14	10
SM expectation	6.0 ± 1.3	2.8 ± 0.8	13.1 ± 2.4	8.8 ± 1.7
$t\bar{t}$	3.8 ± 1.2	1.4 ± 0.7	8.0 ± 2.4	3.1 ± 1.4
W + jets	0.6 ± 0.3	0.2 ± 0.1	2.7 ± 0.5	1.7 ± 0.3
Single top	1.3 ± 0.4	0.7 ± 0.4	1.9 ± 0.6	2.5 ± 1.1
Other	0.3 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	1.5 ± 0.2



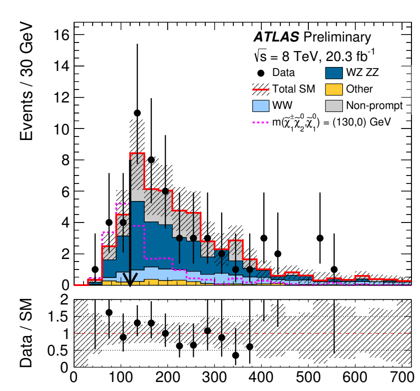
- **lγγ Channel**
  - Unbinned fit to $m_{\gamma\gamma}$
  - Non-Higgs BG from sidebands, Higgs from MC



	SR$\ell\gamma\gamma$-1	SR$\ell\gamma\gamma$-2
Observed events	1	5
SM expectation	1.6 ± 0.4	3.3 ± 0.8
Non-Higgs	0.6 ± 0.3	3.0 ± 0.8
Wh	0.85 ± 0.02	0.23 ± 0.01
Zh	0.04 ± 0.01	0.02 ± 0.01
$t\bar{t}h$	0.14 ± 0.01	0.02 ± 0.01

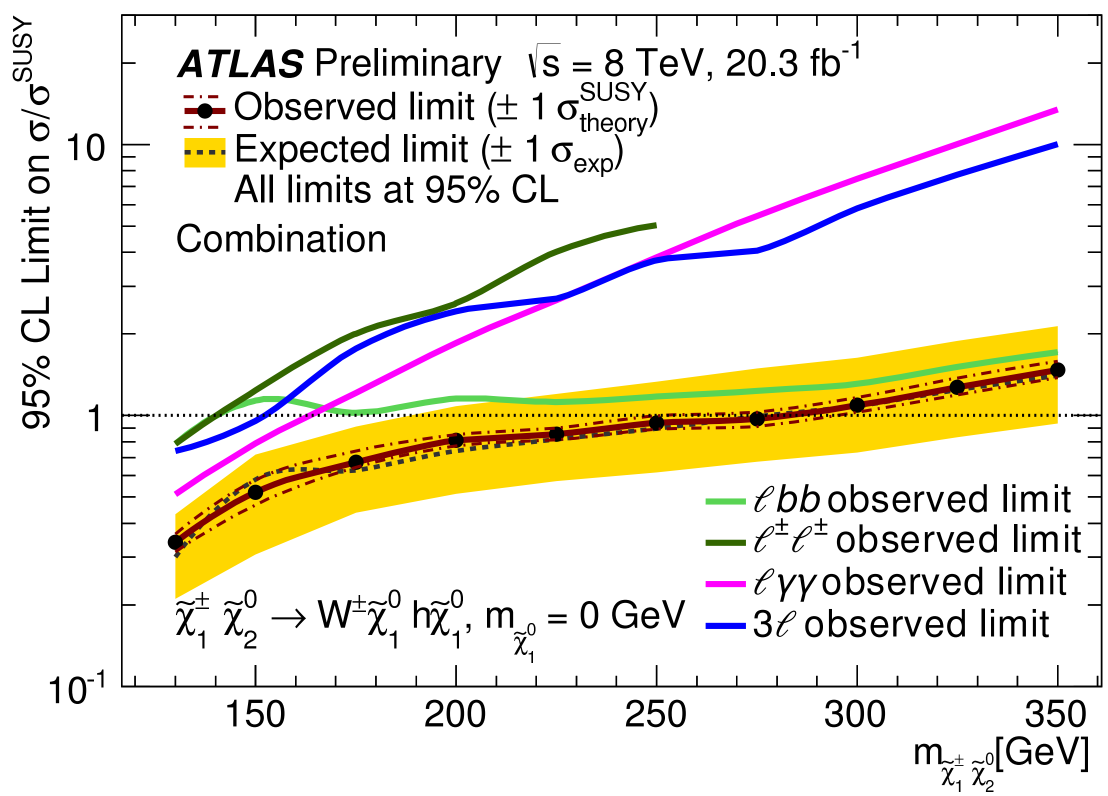


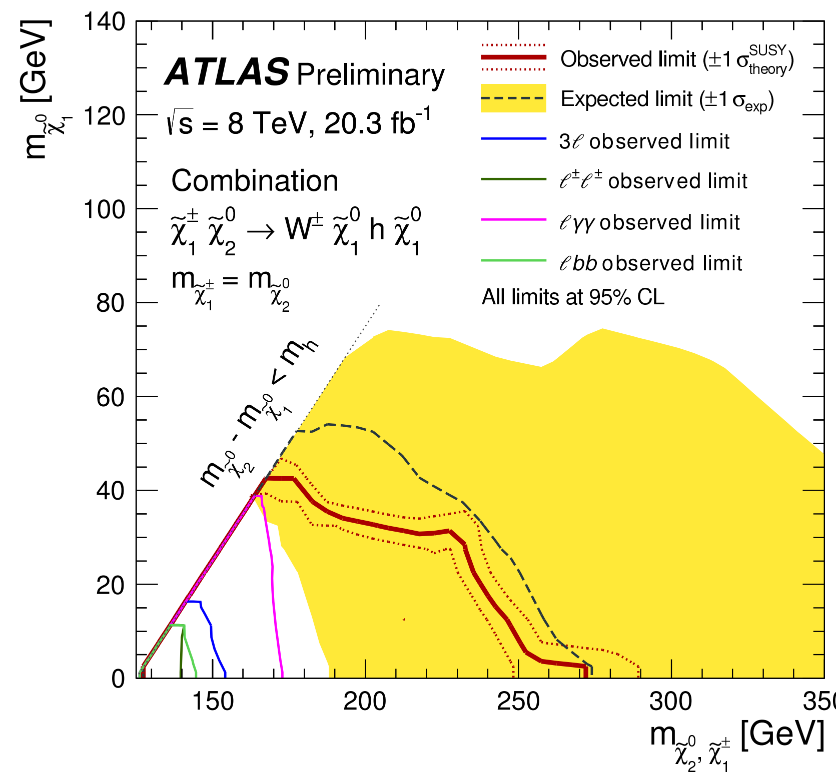
- **Same-Sign Dilepton Channel**
  - Use partially reconstructed Higgs mass in m_{ljj}



	SRee-1	SRee-2	SR$\mu\mu$-1	SR$\mu\mu$-2	SR$e\mu$-1	SR$e\mu$-2
Observed events	2	1	6	4	8	4
SM expectation	6.0 ± 1.2	2.8 ± 0.8	3.8 ± 0.9	2.6 ± 1.1	7.0 ± 1.3	1.9 ± 0.7
Non-prompt	3.4 ± 1.0	1.6 ± 0.5	0.00 ± 0.20	0.3 ± 0.4	3.0 ± 0.9	0.48 ± 0.28
WZ, ZZ	2.2 ± 0.6	0.7 ± 0.4	3.4 ± 0.8	1.8 ± 0.9	3.3 ± 0.8	1.1 ± 0.5
WW	0.33 ± 0.31	0.22 ± 0.23	0.24 ± 0.29	0.4 ± 0.5	0.4 ± 0.4	0.23 ± 0.26
Other	0.13 ± 0.13	0.31 ± 0.31	0.14 ± 0.14	0.06 ± 0.06	0.19 ± 0.17	0.09 ± 0.08

Chargino and Neutralino Production





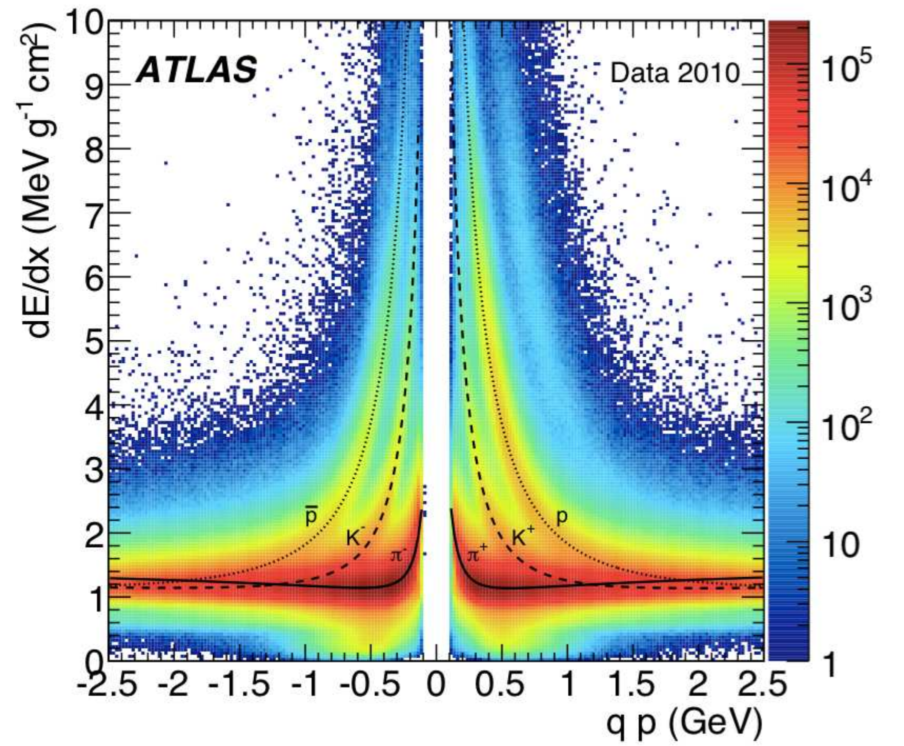
- No deviation from the Standard Model prediction observed
- Results from channels statistically combined
  - Also combined with published 3-Lepton search – JHEP 04 (2014)169
- Neutralino$_1$ LSP sensitivity from lγγ
- Chargino$_1$/Neutralino$_2$ NLSP sensitivity from lbb channel

Model Independent Limits

	$\langle\sigma_{\rm vis}\rangle^{95}_{\rm obs}$ [fb]	$S^{95}_{\rm obs}$	$S^{95}_{\rm exp}$	CL_B	p_0
SRℓbb-1	0.26	5.3	$6.3^{+3.4}_{-2.0}$	0.28	0.50
SRℓbb-2	0.27	5.5	$5.1^{+2.6}_{-1.4}$	0.56	0.43
SR$\ell\gamma\gamma$-1	0.18	3.6	$4.1^{+2.0}_{-0.7}$	0.25	0.50
SR$\ell\gamma\gamma$-2	0.34	7.0	$5.9^{+2.0}_{-1.2}$	0.75	0.19
SR$\ell\ell$-1	0.51	10.4	$10.9^{+3.8}_{-3.1}$	0.51	0.50
SR$\ell\ell$-2	0.51	10.3	$8.1^{+3.3}_{-1.5}$	0.72	0.32

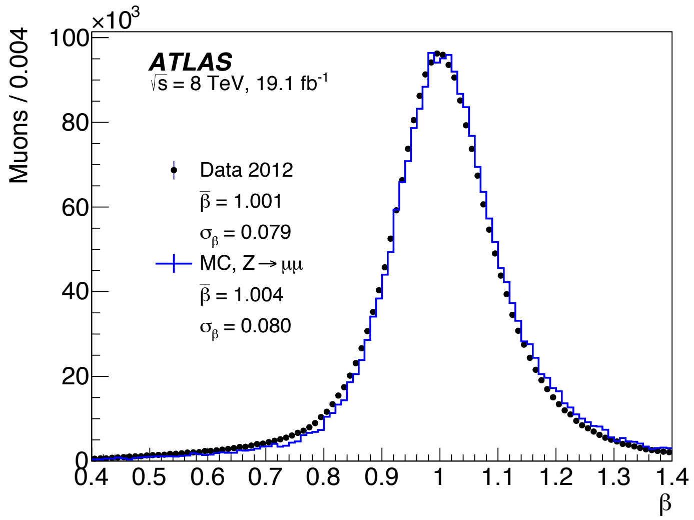
Long-Lived Particles

- ATLAS has several searches involving long-lived particles
- This one - Looking for massive charged particles that are measurably slower than the speed of light
    - Motivated by many BSM models, splitSUSY, GMSB, UED, etc
    - Can pass through layers of pixel detector and can be identified by exotic Bethe-Bloch contours
        - Gives βγ measurement (Range of 0.2-1.5 with 20% resolution)
    - Or can be found with precise timing in calorimeter and muon system
        - Gives β measurement

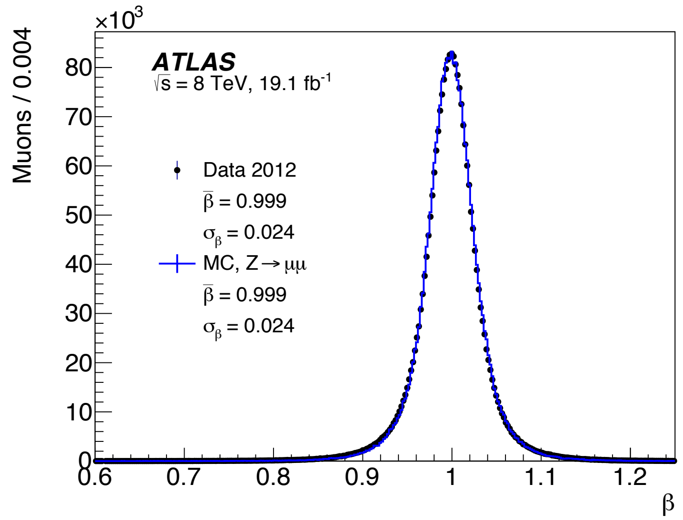


Pixel dE/dx measurement

Calo-Only



Calo+Muon System

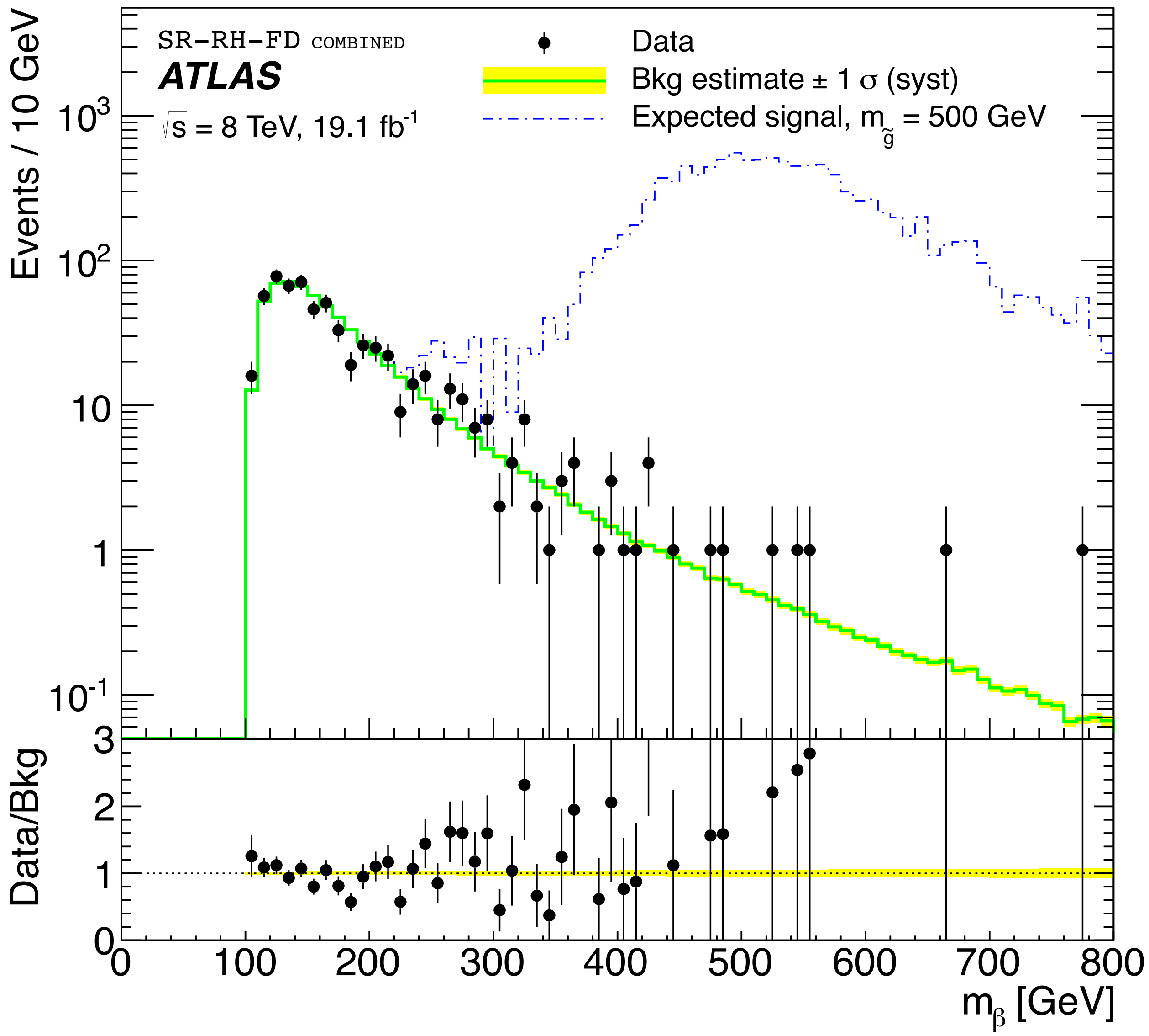


Long-Lived Particles

- Analysis Observables

$$m_\beta = p/\beta, m_{\beta\gamma} = p/\beta\gamma$$

- Sensitivity to
  - Long-lived charged sleptons (GMSB, leptoSUSY)
  - Stable charginos
  - Stable R-Hadrons (SUSY bound states in e.g. splitSUSY)
- Backgrounds mostly composed of mismeasured muons
  - Estimated by random pairings of candidate p and β (or βγ) in mass calculation
  - p and β measurements are independent and uncorrelated
- No deviation from the Standard Model prediction observed



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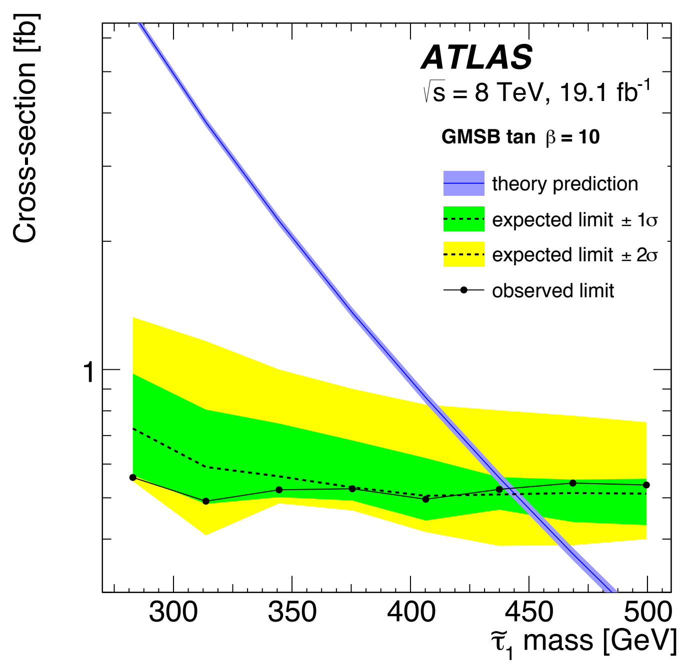
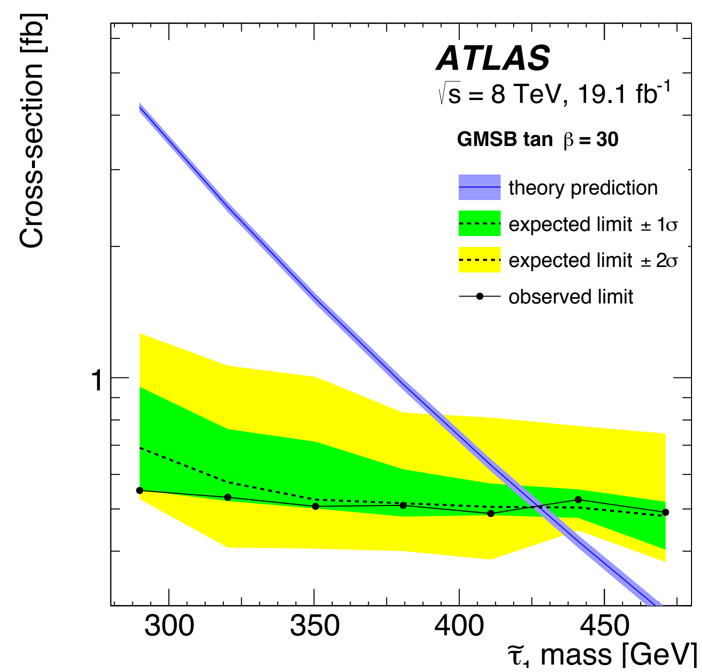
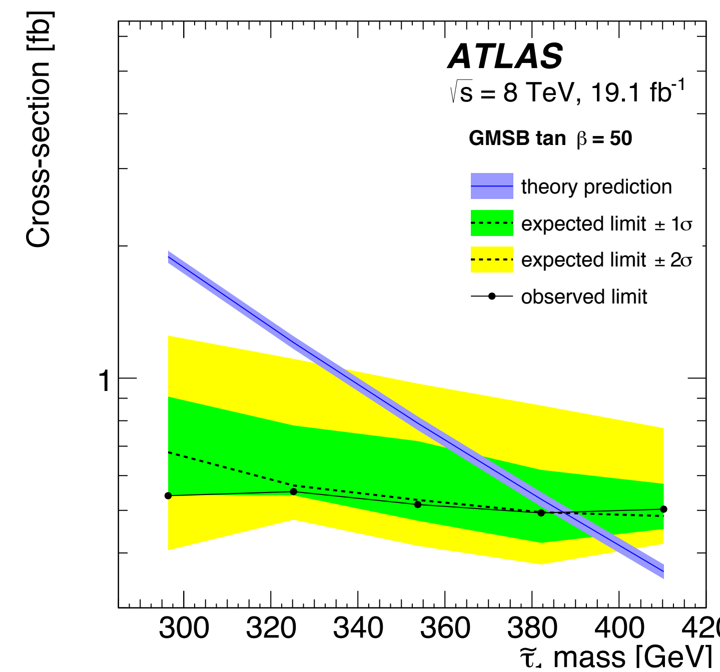
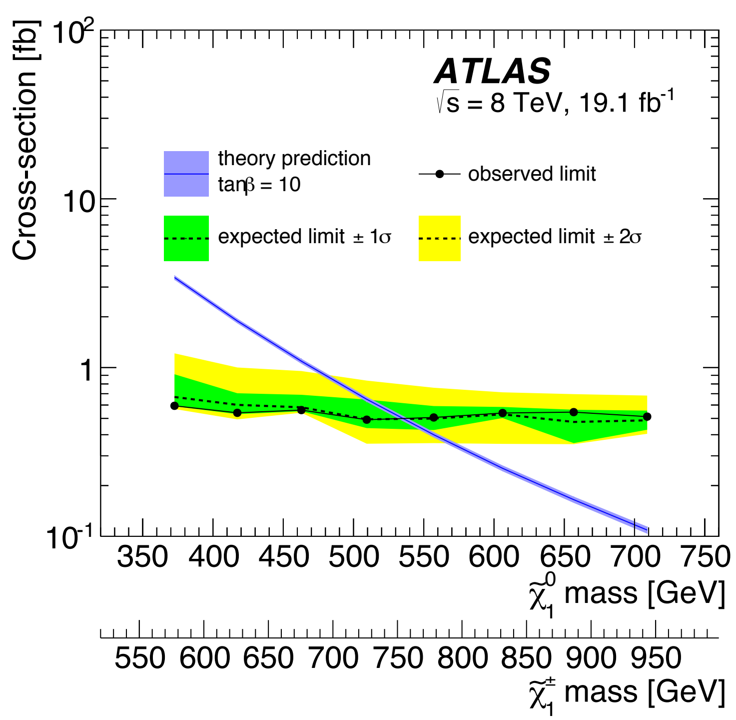
Long-Lived Particles - Long-Lived Stau Results





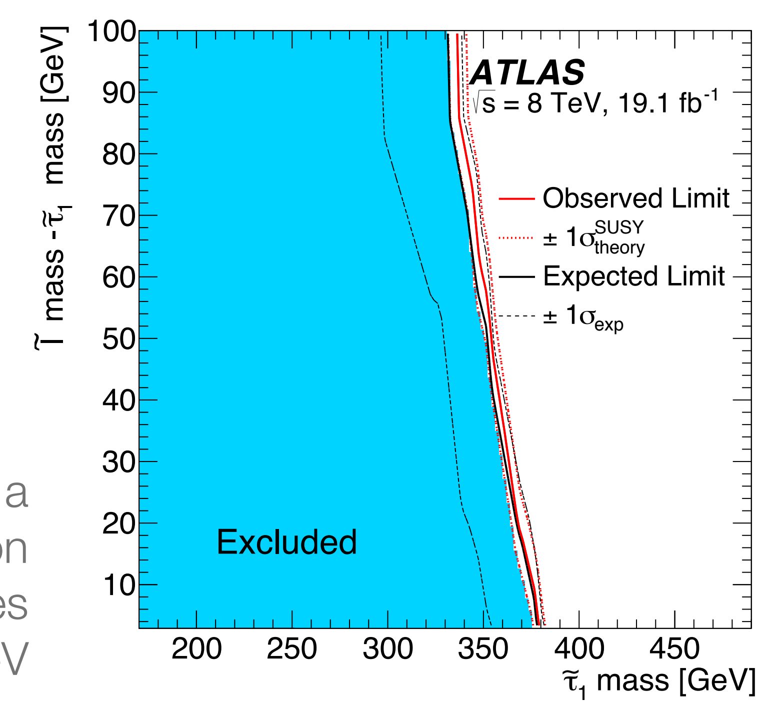




Limits placed on long-lived staus in GMSB models excluding masses up to ~380-440 GeV for various values of tanβ

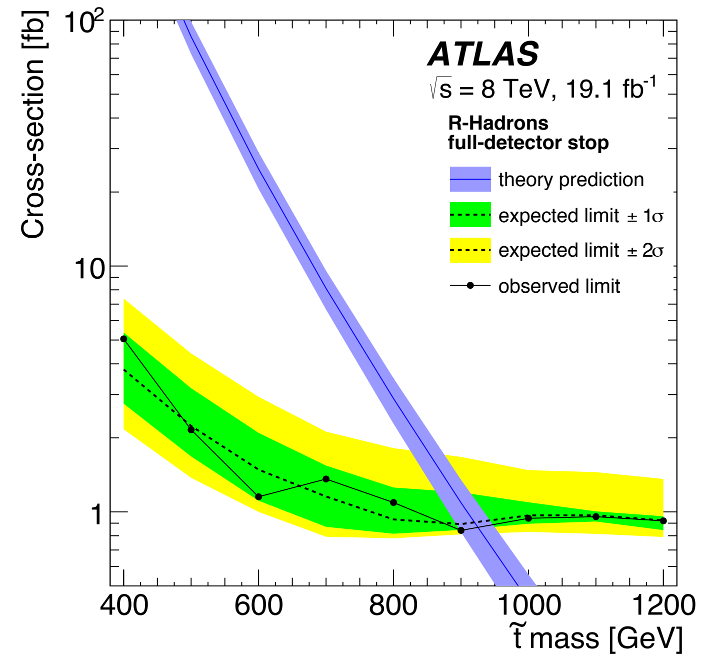
And in a GMSB context, these are used as limits on the neutralino and chargino masses

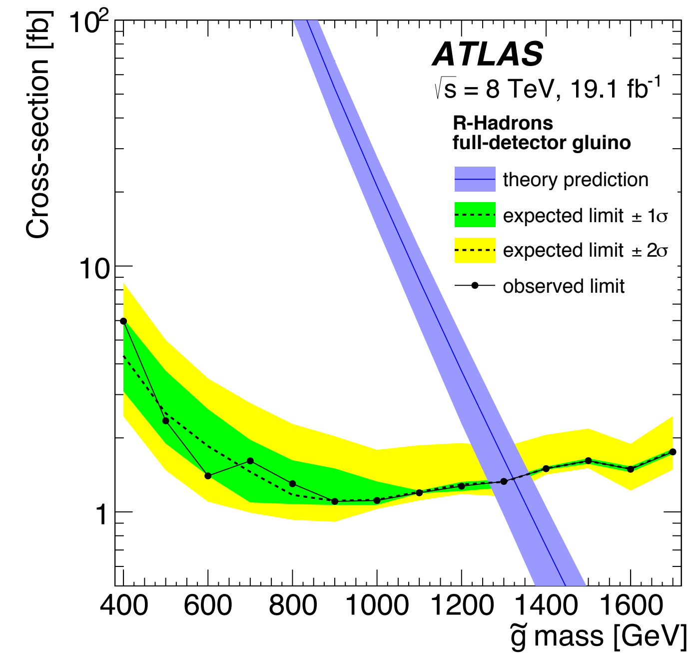
Results also interpreted as limits on a simplified direct slepton production model, excluding long-lived stau masses up to ~350 GeV

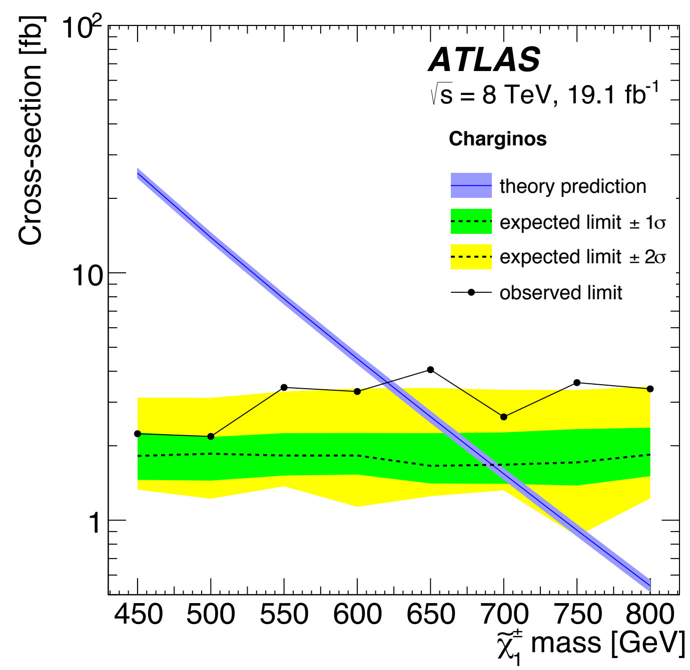


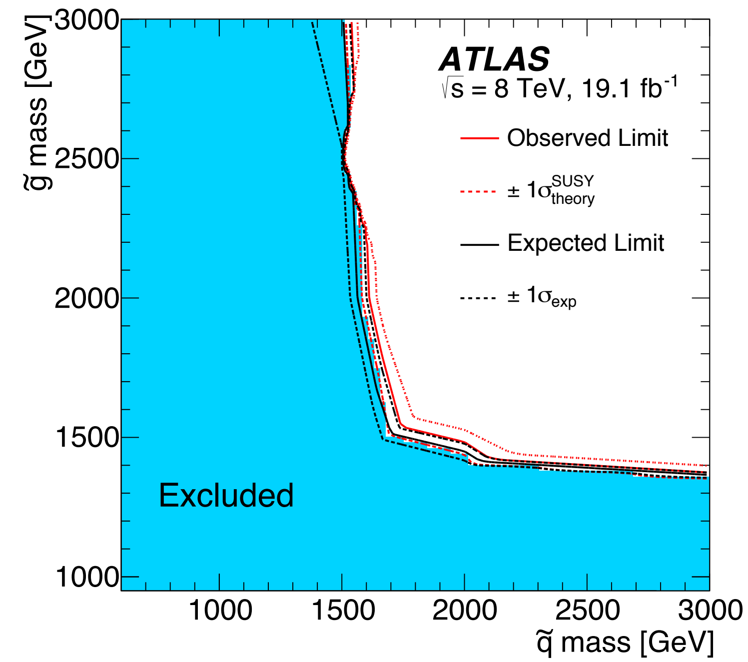
Long-Lived Particles - Other Results

- Limits placed on R-Hadron and long-lived Chargino models
  - Stop-R-Hadron masses excluded up to ~880 GeV
  - Gluino-R-Hadron masses excluded up to ~1250 GeV
  - Long-lived Chargino masses excluded up to ~620 GeV
- Limits placed in squark and gluino mass plane for LeptoSUSY models as well



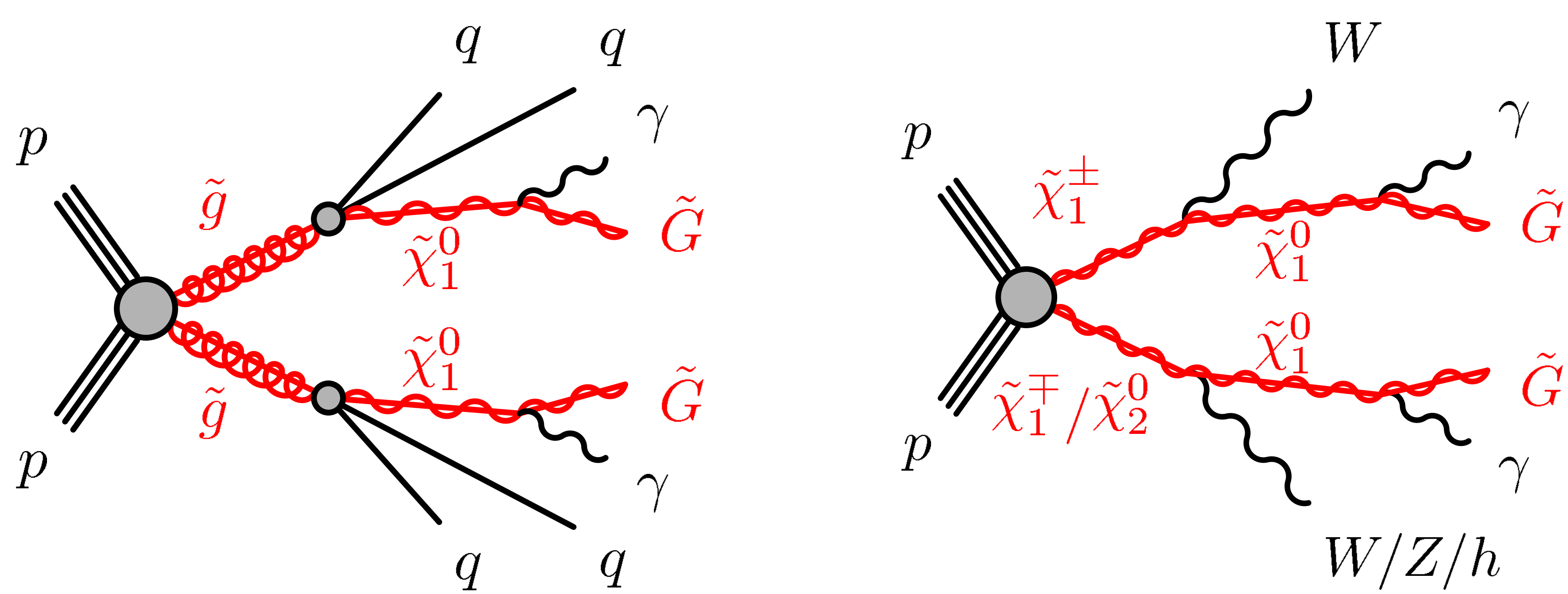






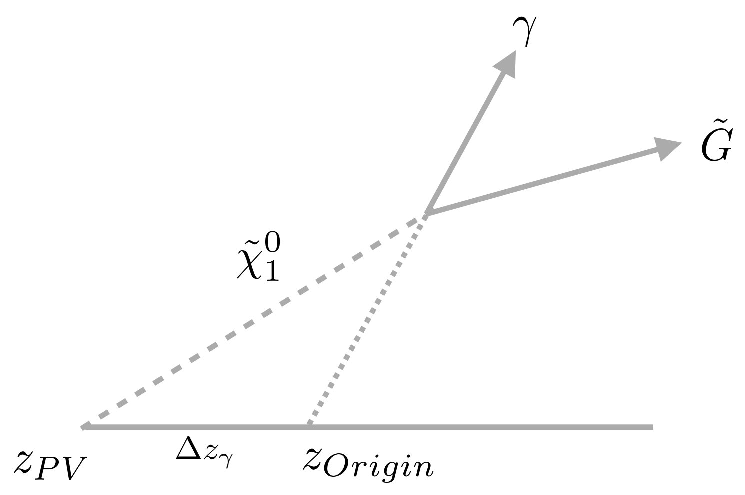
Non-Pointing Photons

- Models with long-lived particles decaying to photons
- Two non-pointing photons + Missing Transverse Energy
- Interpreted in GMSB (SPS8) models
    - Gravitino LSP, Neutralino NLSP

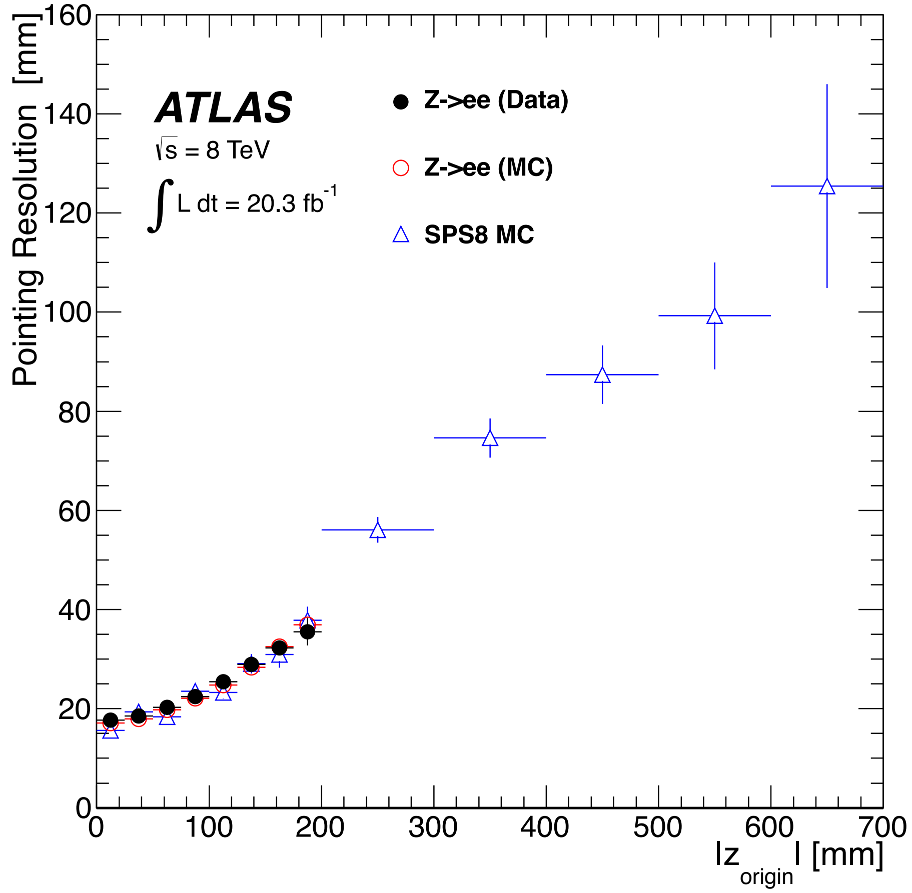


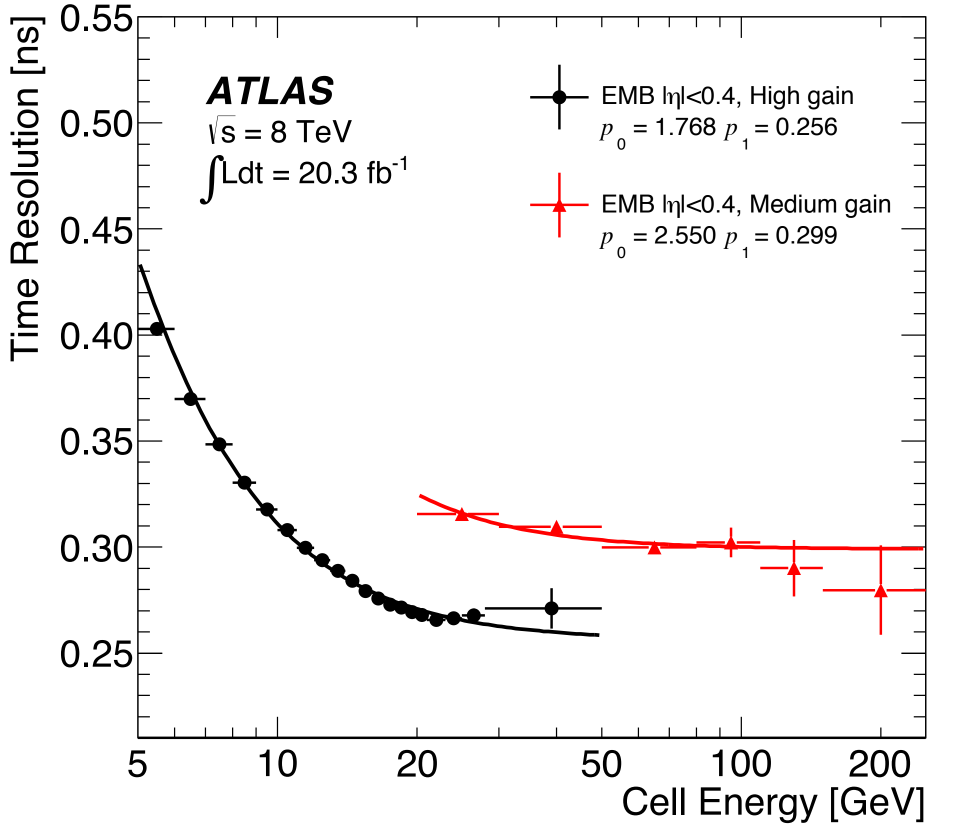
arXiv:1409.5542

Non-Pointing Photons



- High-granularity EM calorimeter gives
  - z_{origin} : Distance along beam axis between detector origin and projected photon 4-vector
- Excellent timing resolution of LAr calo gives
  - t_γ : Arrival time of EM shower
  - Resolution ~300 ps is largely from collision spread of ~220 ps
- Resolution validated in data with Z→ee





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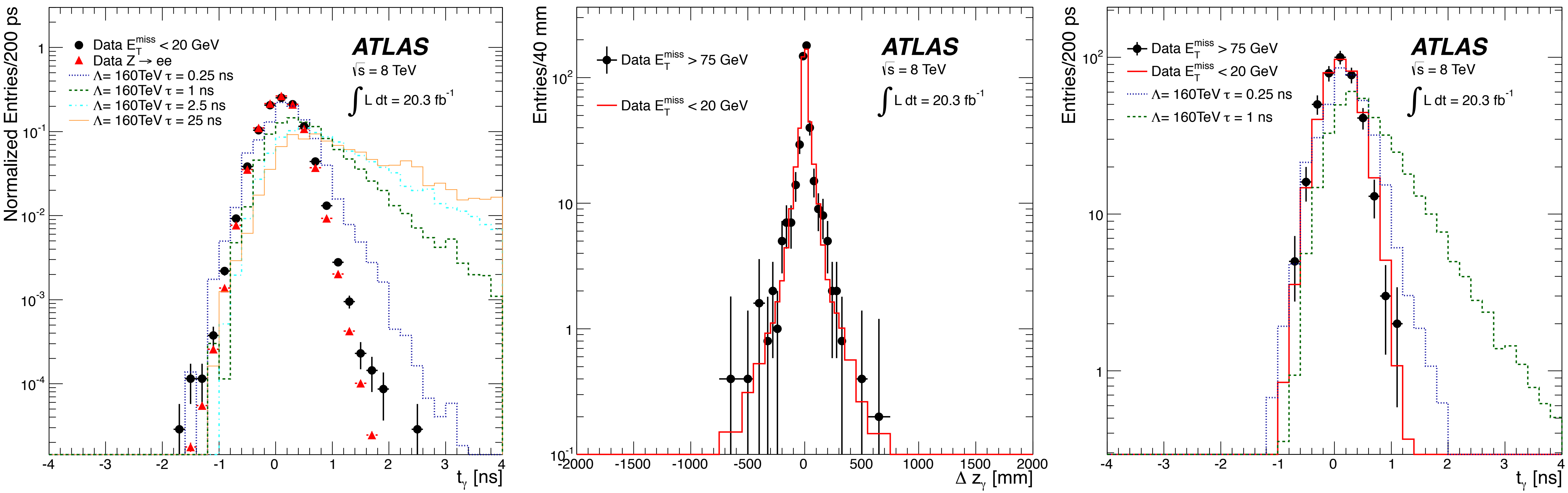
Non-Pointing Photons



Low MET Control Regions and $Z \to ee$ calibration regions show good agreement in t_γ

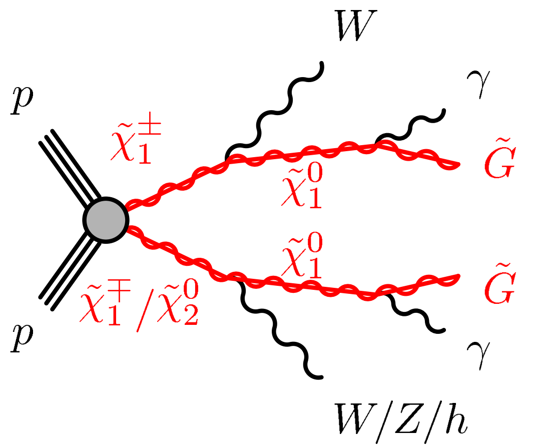
Signal Region with MET > 75 GeV

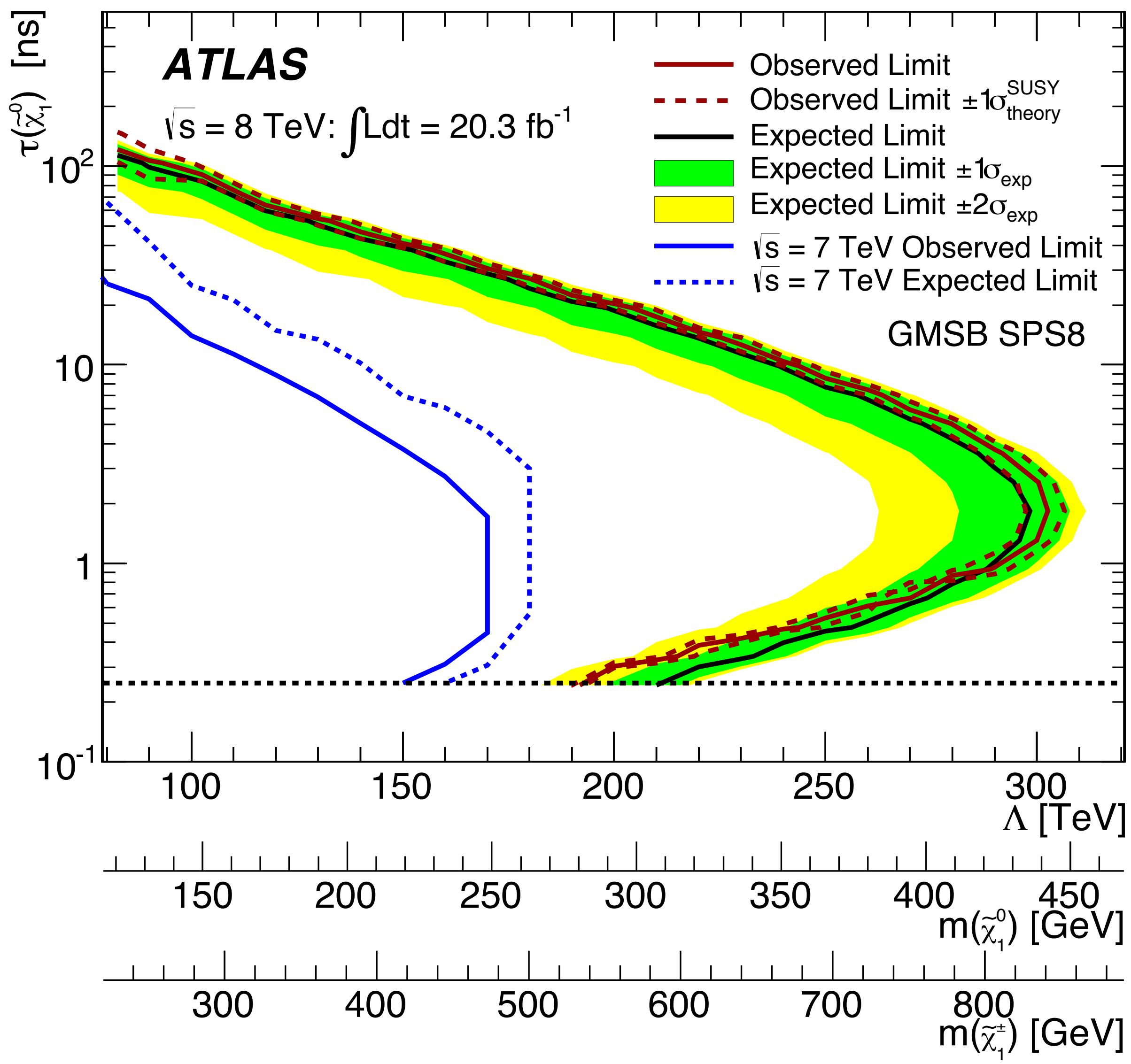
Final fits in t_γ distributions

No deviation from the Standard Model prediction observed

arXiv:1409.5542

Non-Pointing Photons

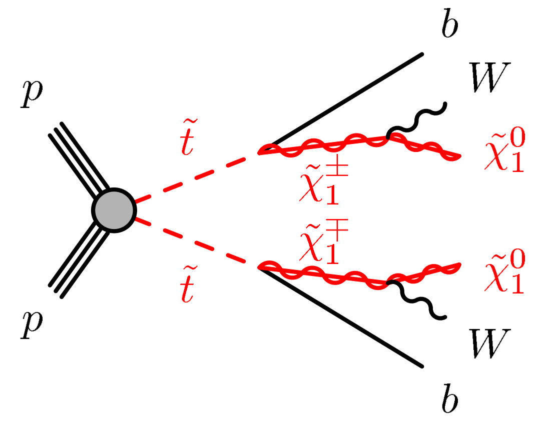




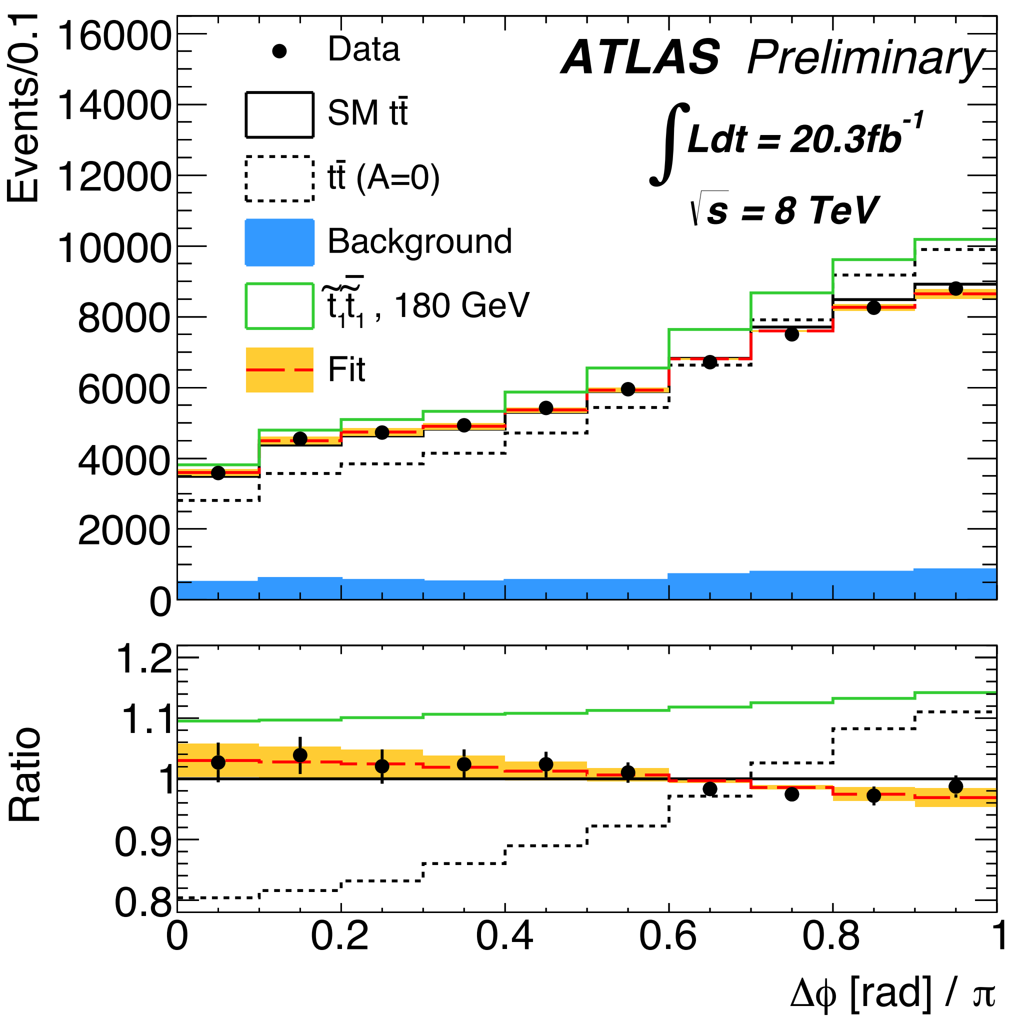
In the SPS8 benchmark, a large range of neutralino lifetimes are excluded for SUSY breaking scales up to a few hundred TeV

arXiv:1409.5542

Stop Limits from Top-Spin Correlation Measurement

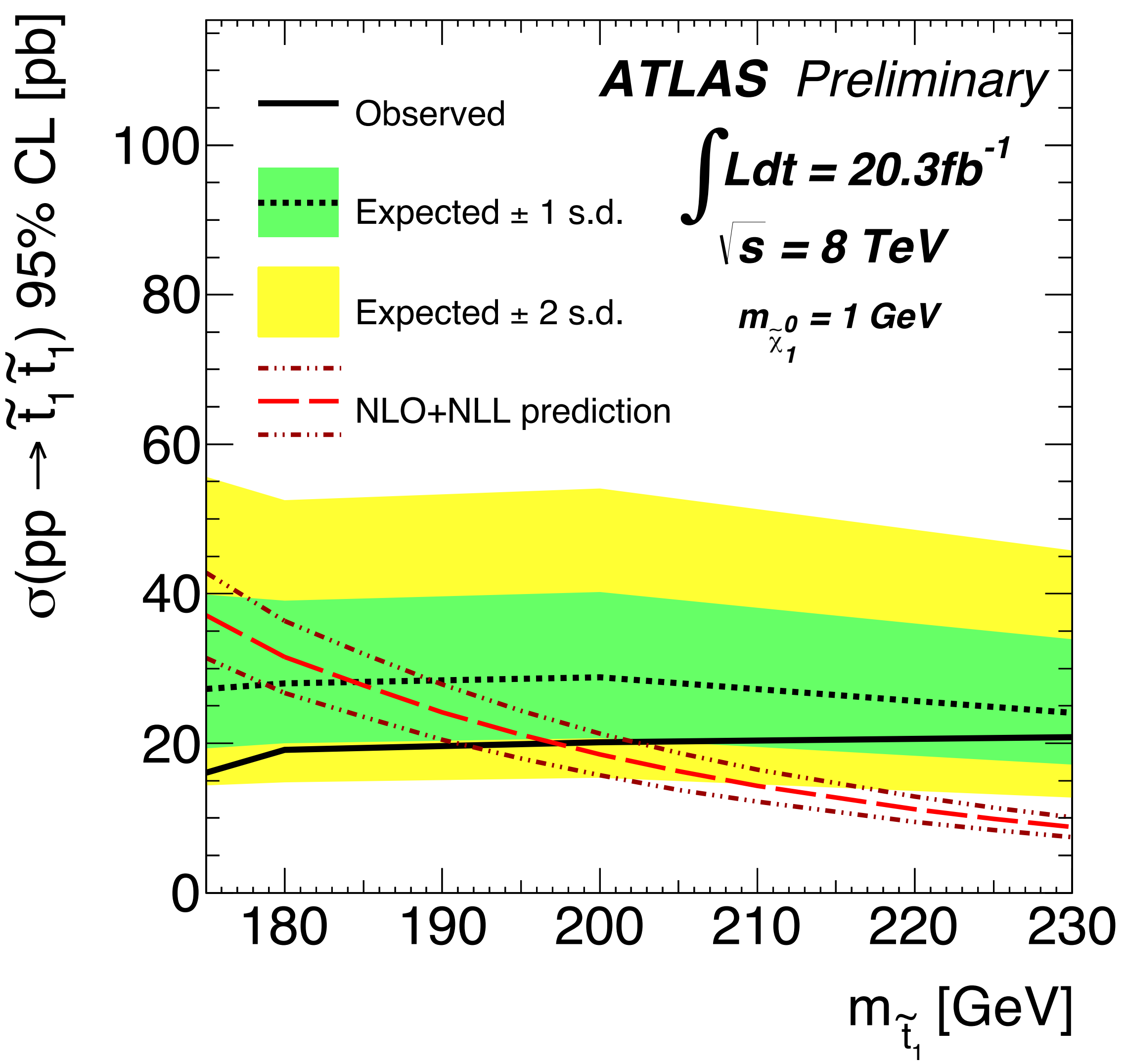


- SM top-spin correlation measurement
- Measurement of the azimuthal angle between charged leptons in dileptonic top pair events
- Measured asymmetry $A_{helicity}$ = 0.38 ± 0.04 (SM Prediction = 0.318±0.005)
- Sensitive to stop pair contributions when the stop mass is near the top mass



ATLAS-CONF-2014-056

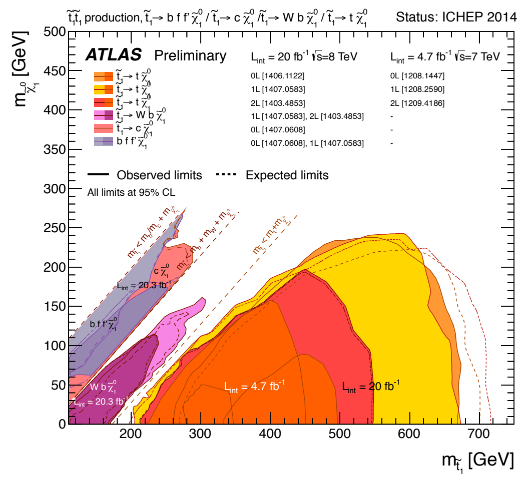
Stop Limits from Top-Spin Correlation Measurement



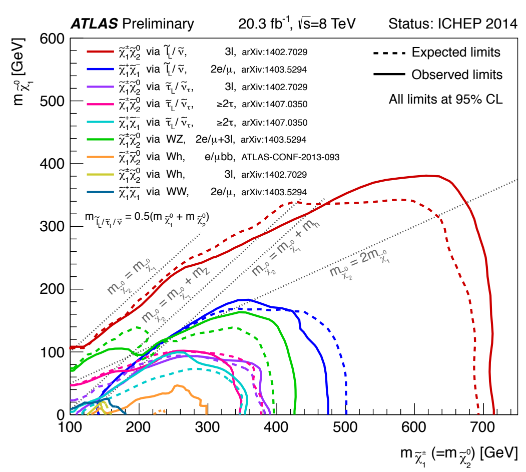
- No evidence of stop contribution is found
- Assuming massless LSPs and 100% branching fraction for stop to top + LSP
- Stop masses between m_t and 191 GeV have been excluded at 95% CL

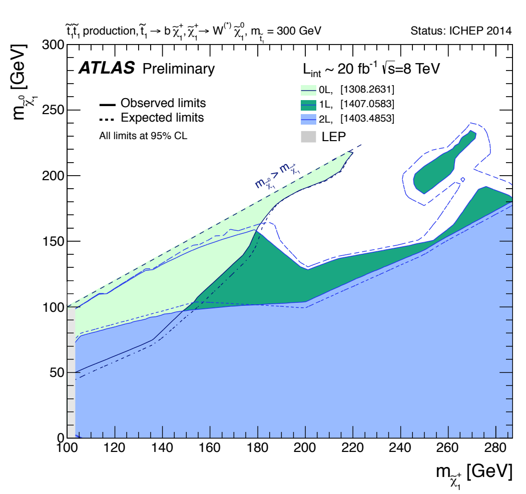
ATLAS-CONF-2014-056

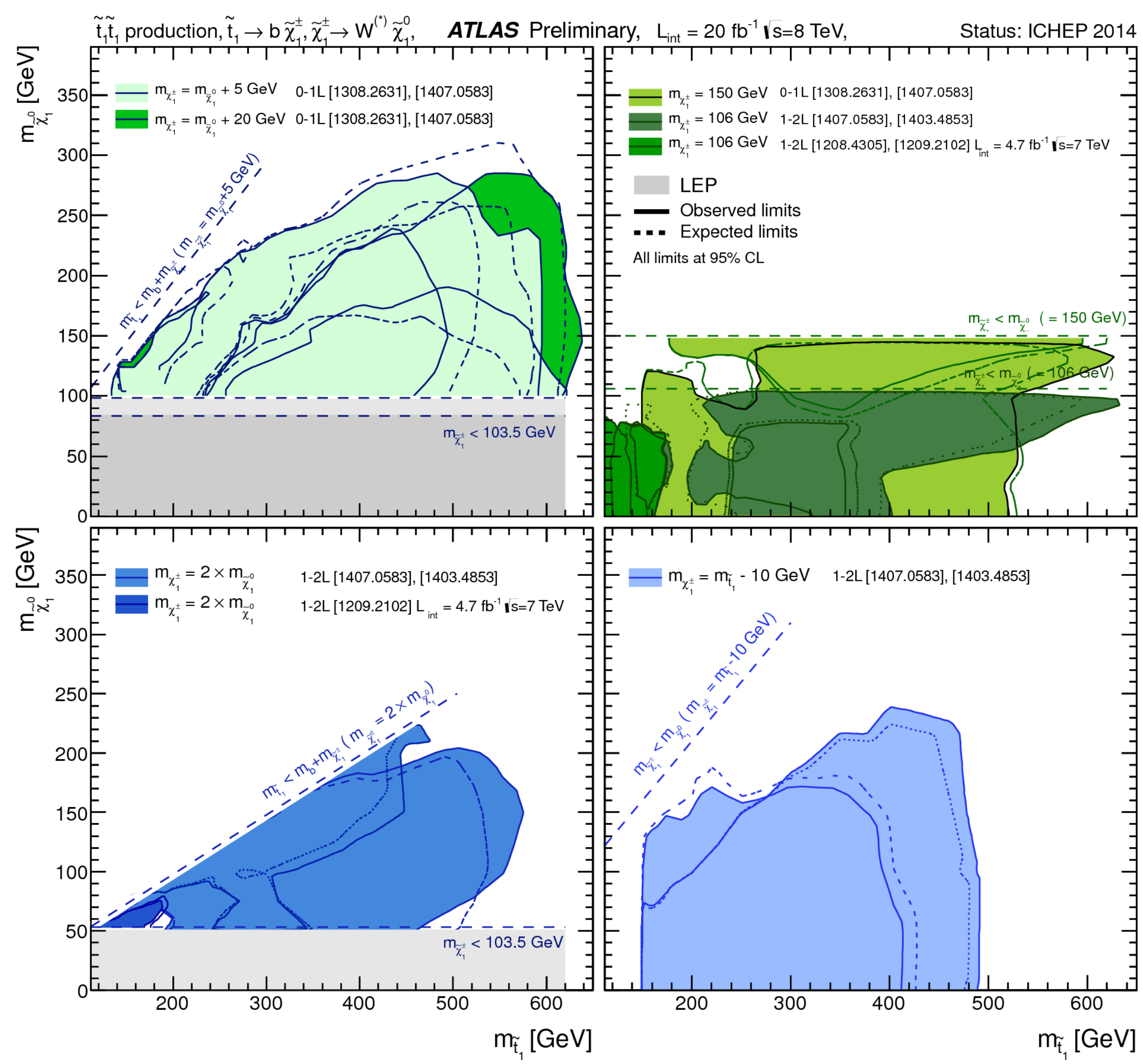
The State of SUSY at ATLAS

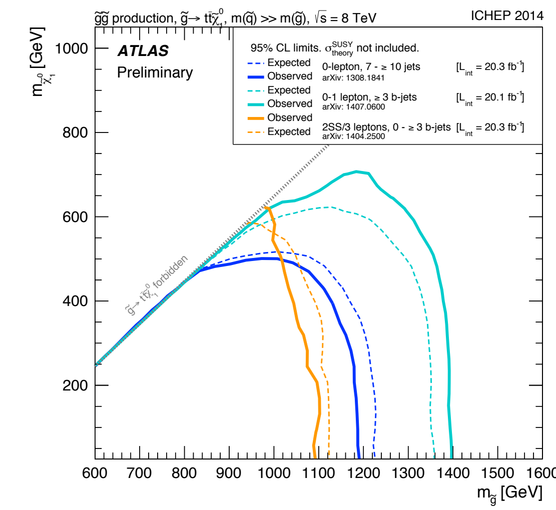


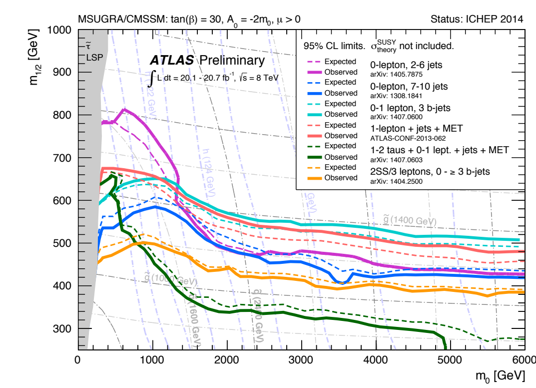
Of course we have yet to find SUSY

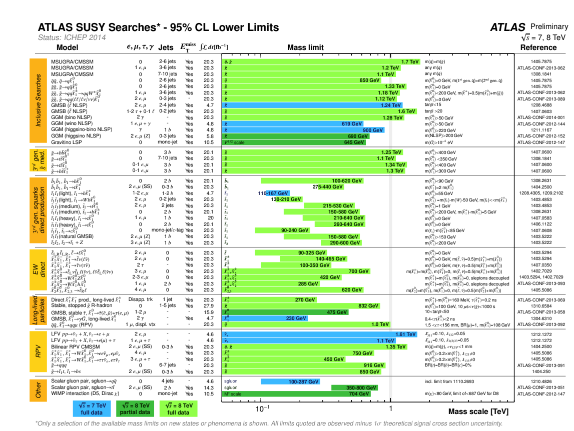












The State of SUSY at ATLAS

Of course we have yet to find SUSY

Many results from many channels trying to be as inclusive as possible

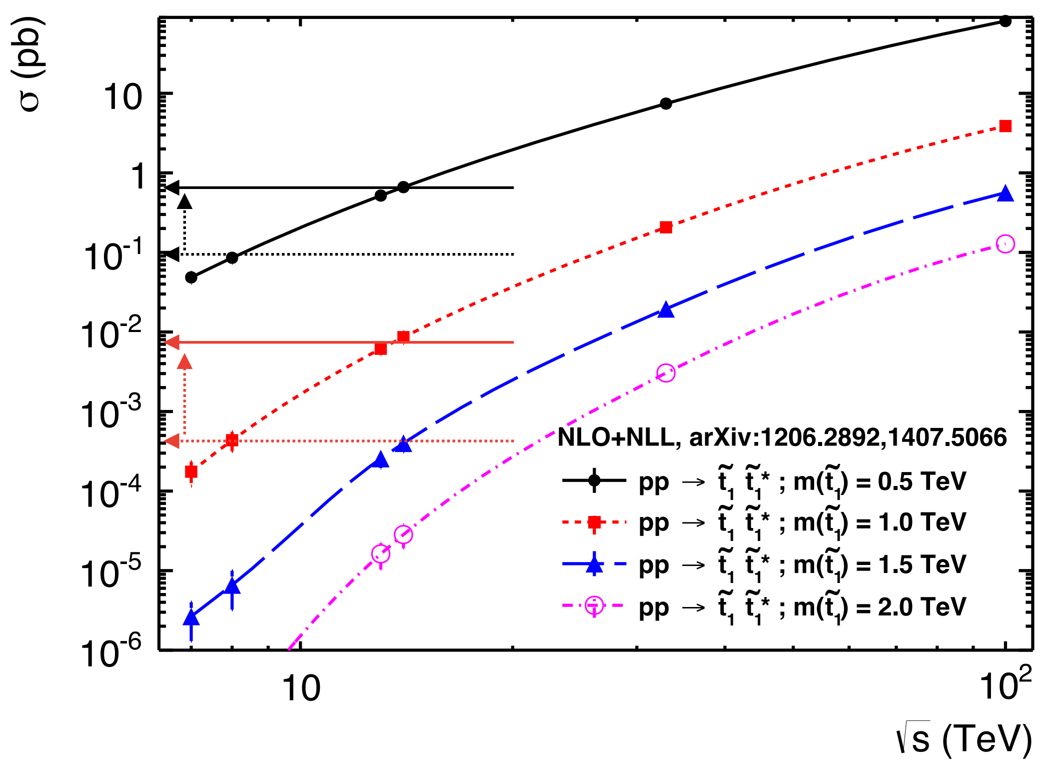
For details visit
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

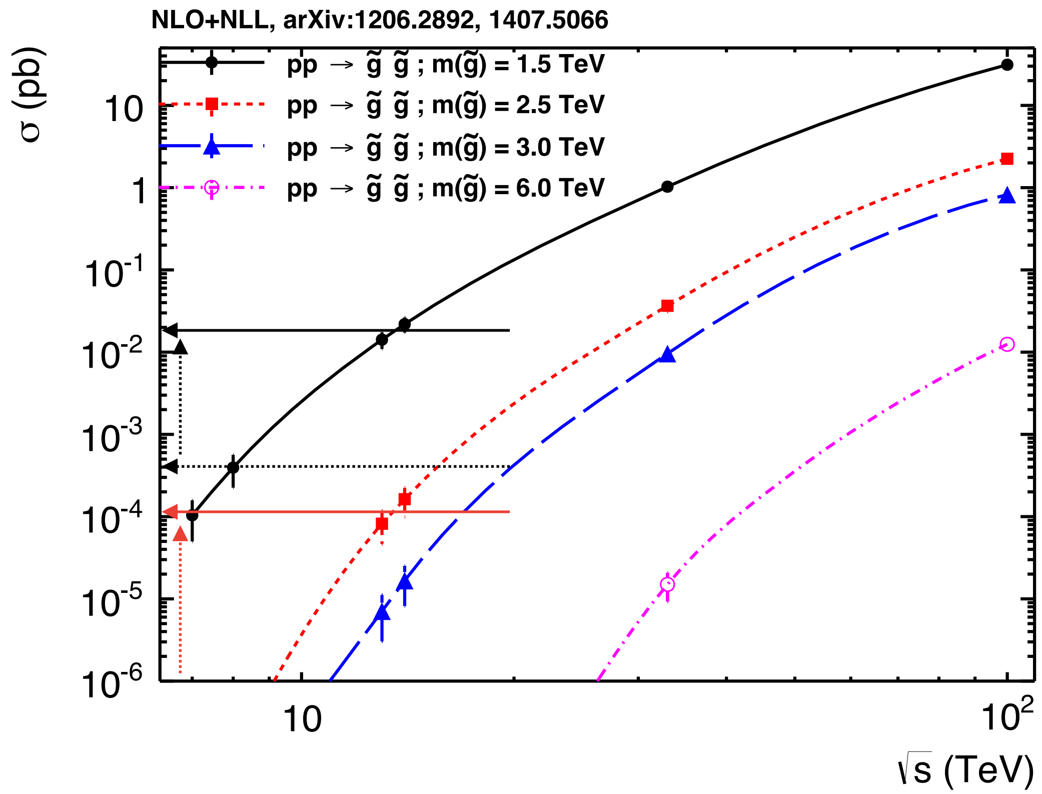
Our goal is discovery and all these exclusions aren't going to stop us

The State of SUSY at ATLAS

Of course we have yet to find SUSY

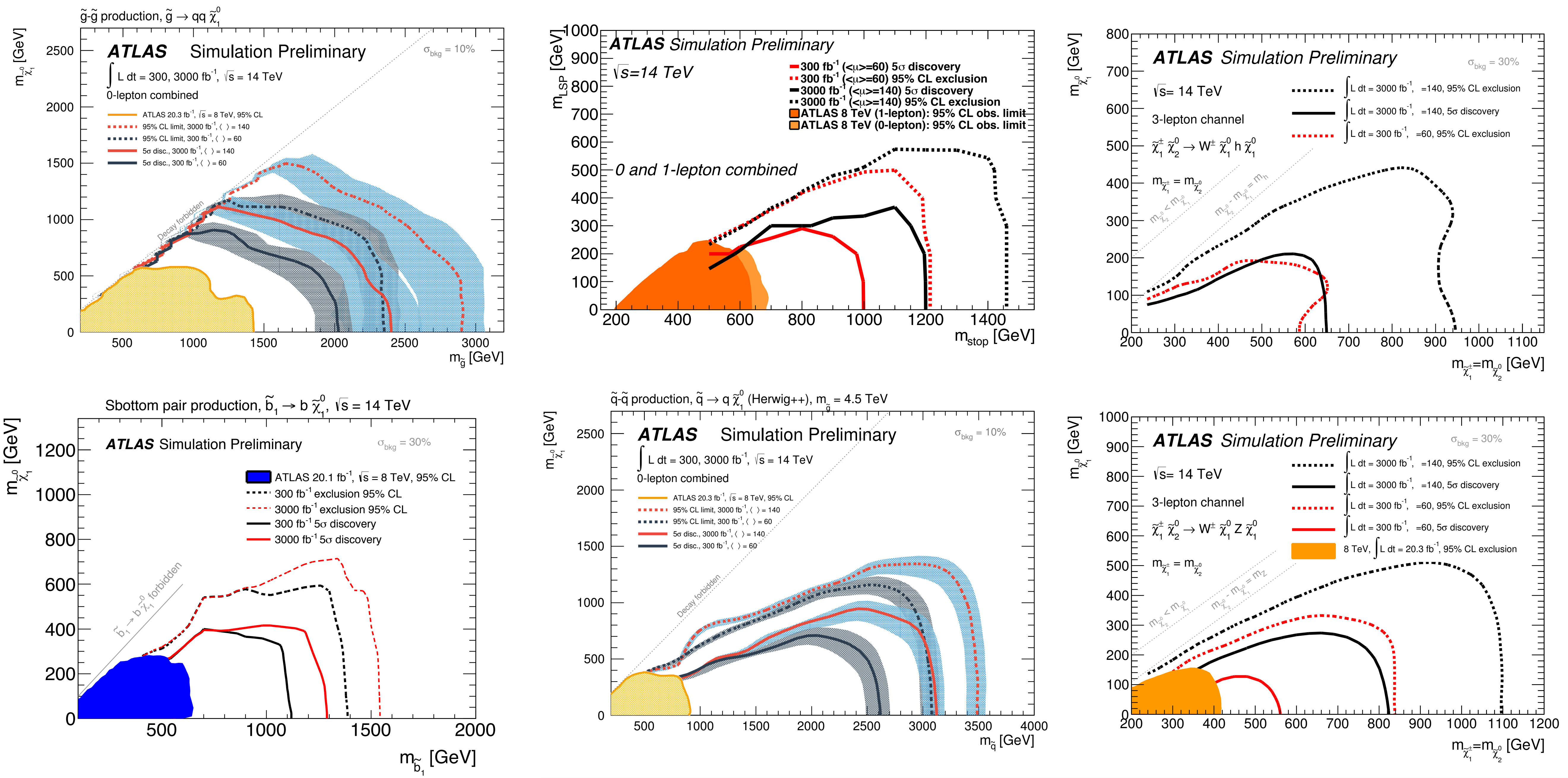
But we have a new machine about to turn on





The State of SUSY at ATLAS

And earlier in the week Philip Clark presented the prospects for the further future



“Above all, I craved to seize the whole essence, in the confines of one single photograph, of some situation that was in the process of unrolling itself before my eyes.”

–Henri Cartier-Bresson

But many more photographs will be needed to see the “whole essence” we hope exists


Thanks


Backup

Fine Print

Limits are determined at 95% CL using a CL_S profile likelihood ratio in the asymptotic limit using nuisance parameters to account for theoretical and experimental uncertainties

PDF and scale uncertainties are taken as theory uncertainties on the signal cross section

All mass limits are with respect to the NLO+NLL signal cross-sections *minus 1 sigma*

Some limits are on simplified models assuming 100% branching fractions

The most common side effects may include loss of faith in SUSY, increased theoretical complexity, and in rare cases, death.

Inclusive Search for Squarks and Gluinos ≥1 Lepton, Jets, MET

- 1 Hard Electron: Electron (24 GeV) + MET (35 GeV) Trigger
- 1 Hard Muon: Muon (24 GeV) + Jet (65 GeV) + MET (40 GeV)
- 2 Hard Leptons: Combination of single- and dilepton triggers
  - Leading lepton in SF events p_T>14 GeV
  - Leading lepton in OF events p_T>10(18) GeV for electron (muon)
- Soft Lepton Channels: MET (80 GeV) Trigger
- Events require ≥[2-6] Jets

$$m_T = \sqrt{2p_T^{\ell} E_T^{miss}(1 - \cos[\Delta\phi(\vec{\ell}, \vec{p}_T^{miss})])}$$

$$m_{eff}^{inc} = \sum_{i=1}^{N_\ell} p_{T,i}^{\ell} + \sum_{j=1}^{N_jet} p_{T,j} + E_T^{miss}$$

$$m_{eff}^{excl} = \sum_{i=1}^{N_\ell} p_{T,i}^{\ell} + \sum_{\text{3 leading jets}} p_{T,j} + E_T^{miss}$$

Razor Variables

- The so-called Razor variables (1006.2727) are an attempt to handle the missing degrees of freedom in events with weakly interacting particles
  - Organize jets in the event into two “mega-jets”
  - The rest frame of these mega-jets is constructed – “R” Frame
  - Define

$$M'_R = \sqrt{(j_{1,E} + j_{2,E})^2 - (j_{1,L} + j_{2,L})^2}$$

$$M_T^R = \sqrt{\frac{|\vec{E}_{\mathrm{T}}^{\mathrm{miss}}|(|\vec{j}_{1,\mathrm{T}}| + |\vec{j}_{2,\mathrm{T}}|) - \vec{E}_{\mathrm{T}}^{\mathrm{miss}} \cdot (\vec{j}_{1,\mathrm{T}} + \vec{j}_{2,\mathrm{T}})}{2}}$$

$$R = \frac{M_T^R}{M'_R}$$

  - R peaks low for most SM processes and is uniform in [0,1] for SUSY signals

Scharm Search Signal Region Yields

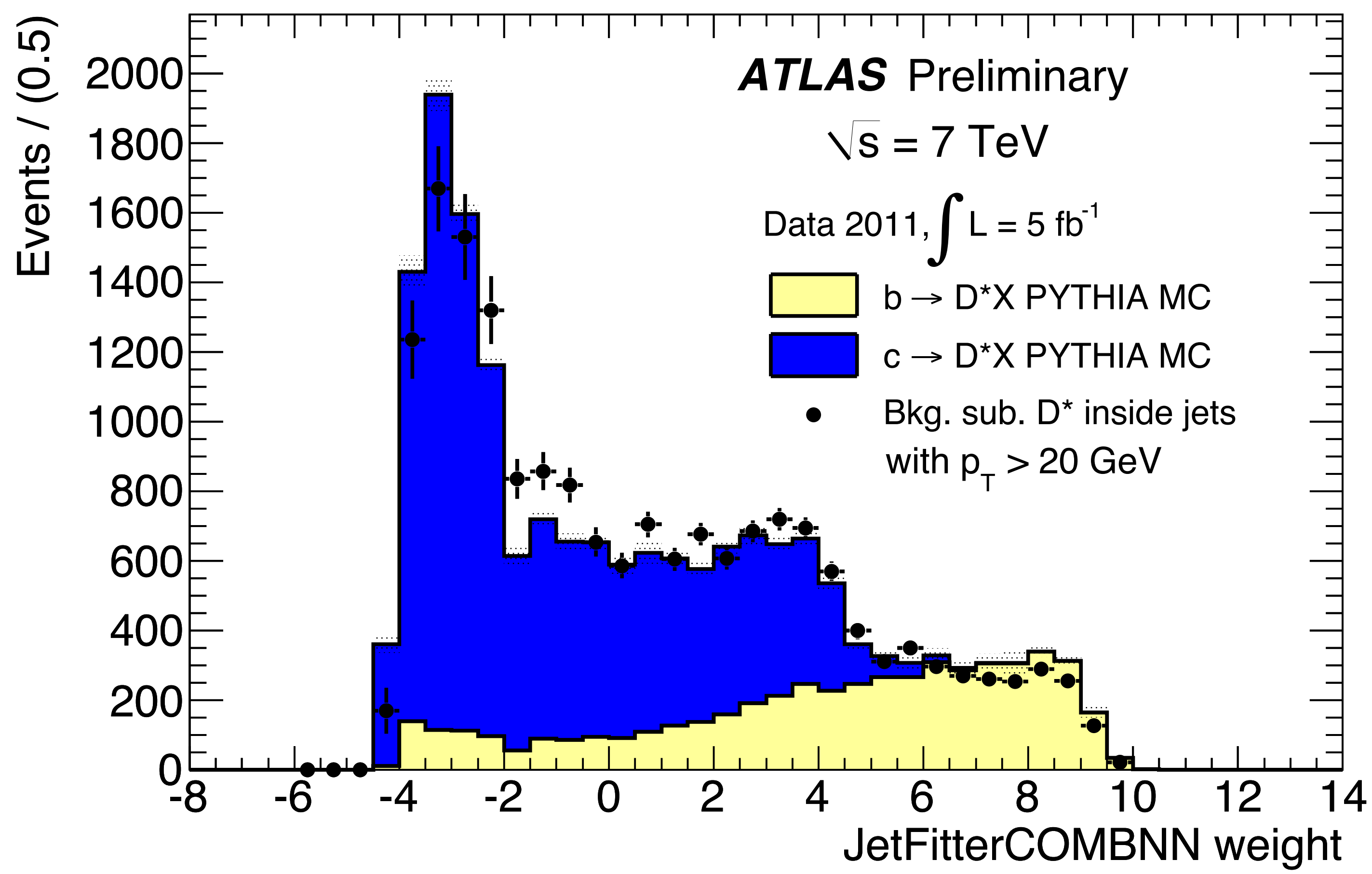
- Multiple Signal Regions
- Control regions to constrain Z, top, and W contributions to the total background
- No significant deviation from the Standard Model prediction is found

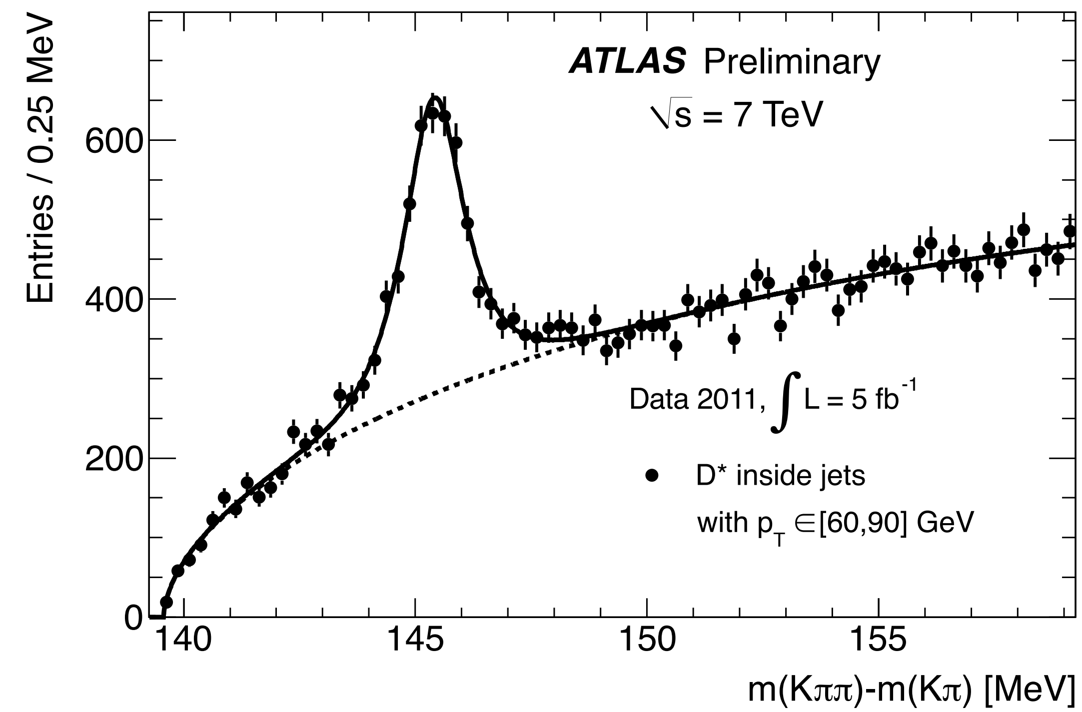
m_{CT} (GeV)	>150	>200	>250
Top	7.4 ± 2.7 (7.1)	3.9 ± 1.6 (3.7)	1.6 ± 0.7 (1.5)
Z+jets	14 ± 3 (13)	7.7 ± 1.7 (7.0)	4.3 ± 1.2 (3.9)
W+jets	7.2 ± 4.5 (7.4)	4.1 ± 2.6 (4.2)	1.9 ± 1.2 (1.9)
Multijets	0.3 ± 0.3	0.2 ± 0.2	0.05 ± 0.05
Others	0.5 ± 0.3	0.4 ± 0.3	0.4 ± 0.3
Total	30 ± 6	16 ± 3	8.2 ± 1.9
Data	**19**	**11**	**4**

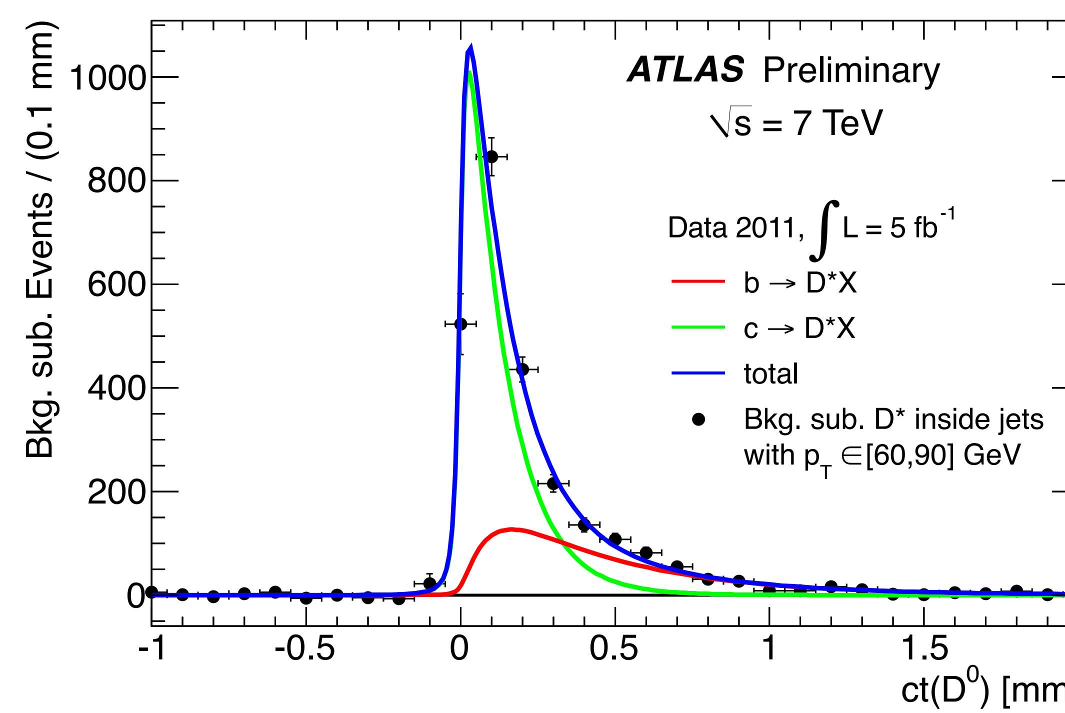
- Jet + MET Trigger Used
  - Fully efficient with MET > 150 GeV and $p_{T,j1}$ > 130 GeV

Charm Efficiency Calibration

- Select a pure sample of c jets at the D* peak to calibrate charm tagging efficiency in data







Chargino and Neutralino Production

- lbb Channel
  - Single lepton trigger, fully efficient when for lepton p_T > 25 GeV
- lγγ Channel
  - Diphoton trigger, threshold for (sub)leading photon energy at (25)35 GeV
- Same-sign Dilepton Channel
  - Dilepton trigger, threshold for (sub)leading (14)25 GeV in lepton p_T

Long-Lived Particles - Signal Regions

- Single Muon Trigger when assuming LLP escapes detector
  - p_T threshold of 24 GeV
- Missing E_T Triggers
  - Thresholds between 60-80 GeV depending on channel

Search	Signal regions	LLP mass [GeV]	N_{cand}	Momentum [GeV]	$\lvert\eta\rvert$	E_T^{miss} [GeV]	β	$\beta\gamma$
Sleptons	SR-SL-2C	175–510	2	$p_T > 70$	< 2.5		< 0.95	consistency
	SR-SL-1C	175–510	1	$p_T > 70$	< 2.5		< 0.85	consistency
Charginos	SR-CH-2C	100–800	2	$p_T > 70$	< 2.5		< 0.95	consistency
	SR-CH-1LC	100–800	1	$p_T > 70$	< 1.9	$> 100^{***}$	< 0.95	consistency
	SR-CH-1C	100–800	1	$p_T > 70$	< 1.9		< 0.85	consistency
R-hadrons	SR-RH-MA	400–1700	≥ 1	$p > 140$–200^{*}	< 1.65		< 0.88–0.74	< 2.3–1.15
	SR-RH-FD	400–1700	≥ 1	$p > 140$–200^{*}	$< 1.65^{**}$		< 0.88–0.74	< 2.3–1.15

$^{*}\Delta R_{\text{jet},p_T>40\text{GeV}} > 0.3$, $\Delta R_{\text{track},p_T>10\text{GeV}} > 0.25$ ** only for ID+CALORIMETER candidates $^{***}\Delta\phi_{\text{LLP},E_T^{\text{miss}}} > 1.0$

	$\tilde{\tau}_1$ mass [GeV]	345	407	469
SR-SL-2C	Minimum m_β requirement [GeV]	240	270	320
	Expected signal	12.5	5.1	2.1
	Efficiency	0.28±0.01	0.29±0.01	0.28±0.01
	Estimated background	0.43±0.05	0.25±0.03	0.10±0.01
	Observed	0	0	0
SR-SL-1C	Minimum m_β requirement [GeV]	240	280	320
	Expected signal	8.5	3.5	1.5
	Efficiency	0.19±0.01	0.20±0.01	0.21±0.01
	Estimated background	49±5	27±3	15±1
	Observed	47	28	20
	Cross-section limit [fb]	0.52	0.50	0.54

	$\tilde{\chi}_1^{\pm}$ mass [GeV]	500	600	700
SR-CH-2C	Minimum m_β requirement [GeV]	350	420	480
	Expected signal	16.9	4.9	1.5
	Efficiency	0.061±0.003	0.054±0.002	0.047±0.002
	Estimated background	0.053±0.006	0.018±0.003	0.008±0.001
	Observed	0	0	0
SR-CH-1LC	Minimum m_β requirement [GeV]	300	330	420
	Expected signal	35.0	10.7	3.3
	Efficiency	0.126±0.006	0.118±0.005	0.109±0.005
	Estimated background	29.6±0.3	21.1±0.3	8.6±0.3
	Observed	37	31	12
SR-CH-1C	Minimum m_β requirement [GeV]	340	430	450
	Expected signal	9.21	2.95	0.99
	Efficiency	0.033±0.002	0.033±0.002	0.032±0.002
	Estimated background	14.14±0.67	4.85±0.21	3.91±0.16
	Observed	14	6	6
	Cross-section limit [fb]	2.18	3.31	2.62

Long-Lived Particles - Systematics

	GMSB		LeptoSUSY	
Source	SR-SL-1C	SR-SL-2C	SR-SL-1C	SR-SL-2C
Signal size – theory	5	5	1–54	1–54
Signal efficiency				
· Trigger efficiency	3.2	3.2	3.1	3.1
· ISR	≤0.5	≤0.5	≤0.5	≤0.5
· Pixel dE/dx calibration	1.1	1.1	1.1	1.1
· β timing calibration	1.0	2.0	1.0	2.0
Total signal efficiency	3.6	4.0	3.5	3.9
Luminosity	2.8	2.8	2.8	2.8
Background estimate	10–12	8.3–9	10–12	8.3–9

		Charginos		R-hadrons
Source	SR-CH-1C	SR-CH-1LC	SR-CH-2C	SR-RH-MA & SR-RH-FD
Signal size – theory	8.5	8.5	8.5	15–56
Signal efficiency				
· Trigger efficiency	3.4	3.4	3.4	≤2.4
· ISR	≤1.0	≤1.0	≤1.0	≤9
· Pixel dE/dx calibration	1.1	1.1	1.1	1.1
· β timing calibration	1.0	1.0	2.0	≤3.6
· Offline $E_{\mathrm{T}}^{\mathrm{miss}}$ scale	5.6–7.6	2–4.2		
Total signal efficiency	6.8–8.5	4.3–5.7	4.2	≤10.2
Luminosity	2.8	2.8	2.8	2.8
Background estimate	3.5–6.8	4	8.7–20	3–15

Stop Limits from Top-Spin Correlation Measurement

- Exactly two OS leptons - Full efficient single-lepton trigger
  - Electrons: p_T > 25 GeV, |eta| < 2.47
  - Muons: p_T > 25 GeV, |eta| < 2.5
- ≥2 Jets with pT above 25 GeV, |eta| < 2.5
- ≥1 BTag with 70% efficient tagger
- SF events require MET > 30 GeV, m_{ll} > 15 GeV, $|m_{ll}-m_Z|$ > 10 GeV
- emu events require $\sum p_T$ (jets, leptons) > 130 GeV

Non-Pointing Photons

- Diphoton trigger with threshold on (sub)leading photon energy of (25)35 GeV
- Low MET control regions
- Signal region with MET > 75 GeV
  - Exclusion fits in t_γ distributions

TABLE IV. Summary of relative systematic uncertainties that affect the normalization of the signal yield. The last row summarizes the relative uncertainty on the theoretical cross section, and is treated separately, as explained in the text.

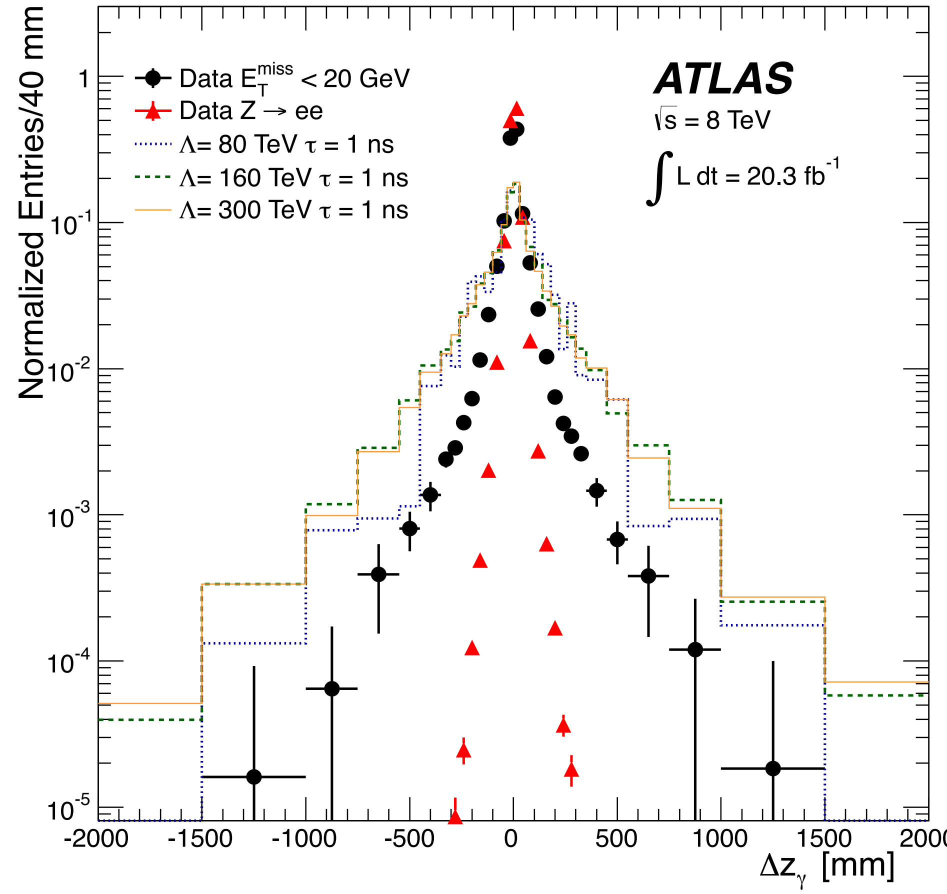
Source of uncertainty	Value [%]
Integrated luminosity	$\pm$ 2.8
Trigger efficiency	$\pm$ 2
Photon E_T scale/resolution	$\pm$ 1
Photon identification and isolation	$\pm$ 1.5
Non-pointing photon identification	$\pm$ 4
E_T^{miss} reconstruction	$\pm$ 1.1
Signal MC statistics	$\pm$ (0.8–3.6)
Signal reweighting	$\pm$ (0.5–5)
Signal PDF and scale uncertainties	$\pm$ (9–14)

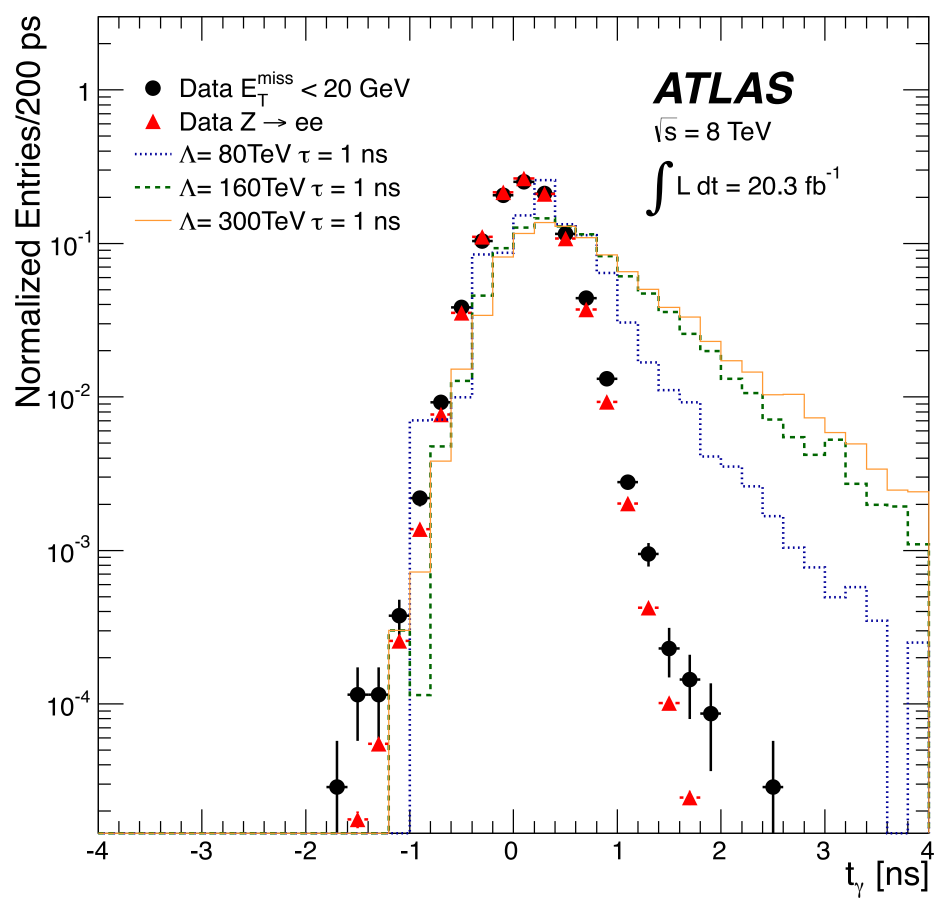
TABLE II. Values of the optimized ranges of the six $|\Delta z_\gamma|$ categories, for both low and high NLSP lifetime (τ) values.

NLSP	Range of $\|\Delta z_\gamma\|$ values for each category [mm]					
Lifetime	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5	Cat. 6
$\tau < 4$ ns	0 – 40	40 – 80	80 – 120	120 – 160	160 – 200	200 – 2000
$\tau > 4$ ns	0 – 50	50 – 100	100 – 150	150 – 200	200 – 250	250 – 2000

TABLE III. Values of the optimized ranges of the six t_γ bins, for both low and high NLSP lifetime (τ) values.

NLSP	Range of t_γ values for each bin [ns]					
Lifetime	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6
$\tau < 4$ ns	−4.0 – +0.5	0.5 – 1.1	1.1 – 1.3	1.3 – 1.5	1.5 – 1.8	1.8 – 4.0
$\tau > 4$ ns	−4.0 – +0.4	0.4 – 1.2	1.2 – 1.4	1.4 – 1.6	1.6 – 1.9	1.9 – 4.0





Non-Pointing Photons