with 7 brand new results!

Searches for supersymmetry with electroweak and third generation squark production at ATLAS

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ATLAS CERN LHC Seminar
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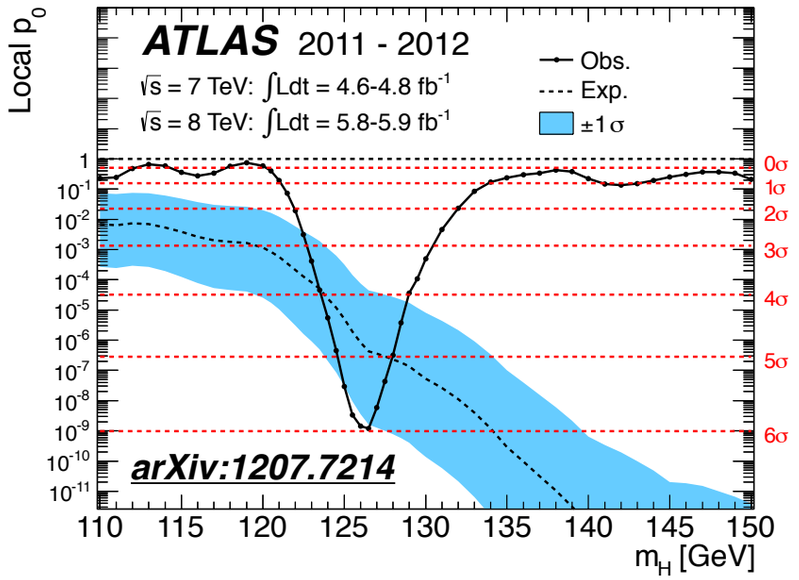
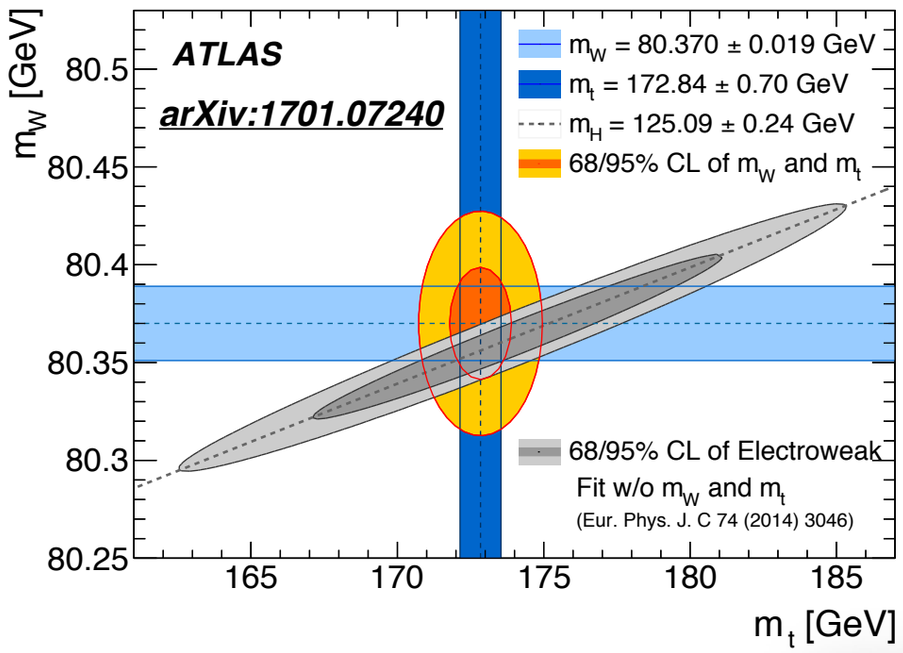
The Standard Model (SM)

- <u>The Standard Model:</u> The good, the bad and the ugly



… with the discovery of the Higgs boson, all free parameters of the SM have been measured…



m_W w/in ~10 MeV
Γ_Z w/in ~1 MeV
$\sin^2\theta_{eff}^{\ell}$ w/in $O(10^{-4})$

not a single doubt that <u>SM</u> has been <u>extremely successful</u>, <u>but…</u>

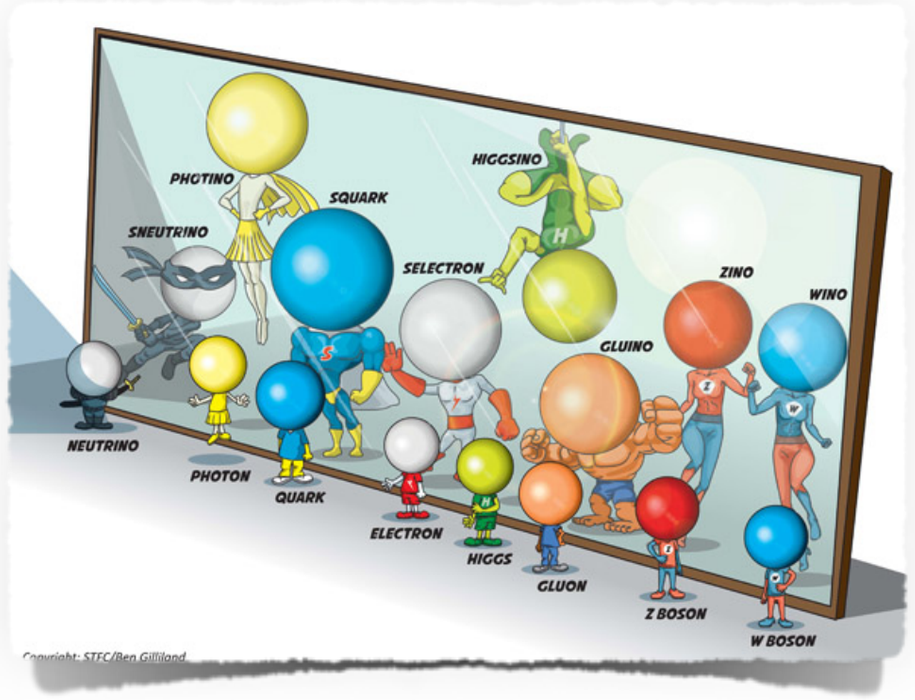
- Quadratically divergent Δm_H^2
- What is this dark matter anyways?
- Accelerated expansion of the Universe
- Where is my anti-matter gone?
- …

Beyond SM physics

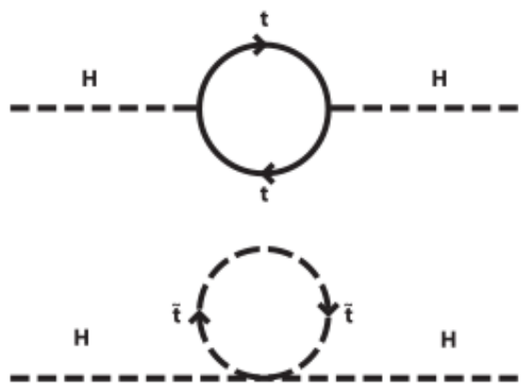
Supersymmetry (SUSY)

- SUSY : A framework, many realizations - not magic

- **Space-time symmetry** that postulates a partner particle to each SM particle whose spin differs by one-half unit



- Loop corrections from SUSY particles **cancel quadratic divergences**: m_H is saved!?



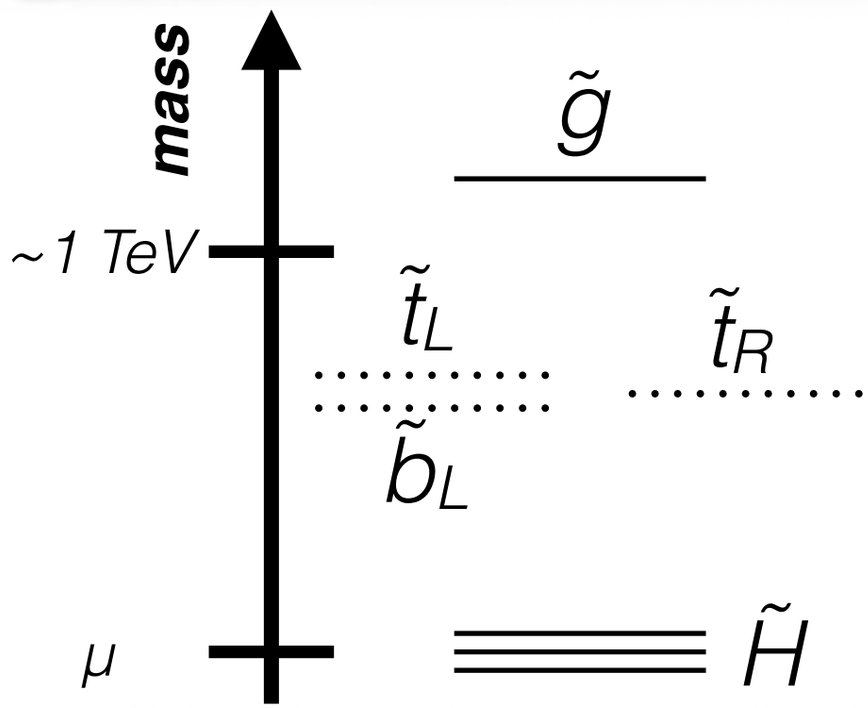
- If R-parity conserved lightest SUSY particle (**LSP**) is a **dark matter candidate**

R-parity : $(-1)^{3(B-L)+2s}$
+1 for SM and -1 for SUSY

Where are these *sparticles*?

What about Naturalness?

- We know that SUSY must be a broken symmetry
- Implications of many other experimental measurements:
  - Cosmological constraints on the dark matter relic density
  - Higgs related measurements (mass, BRs etc.)
- **Natural** SUSY scenarios typically favor:



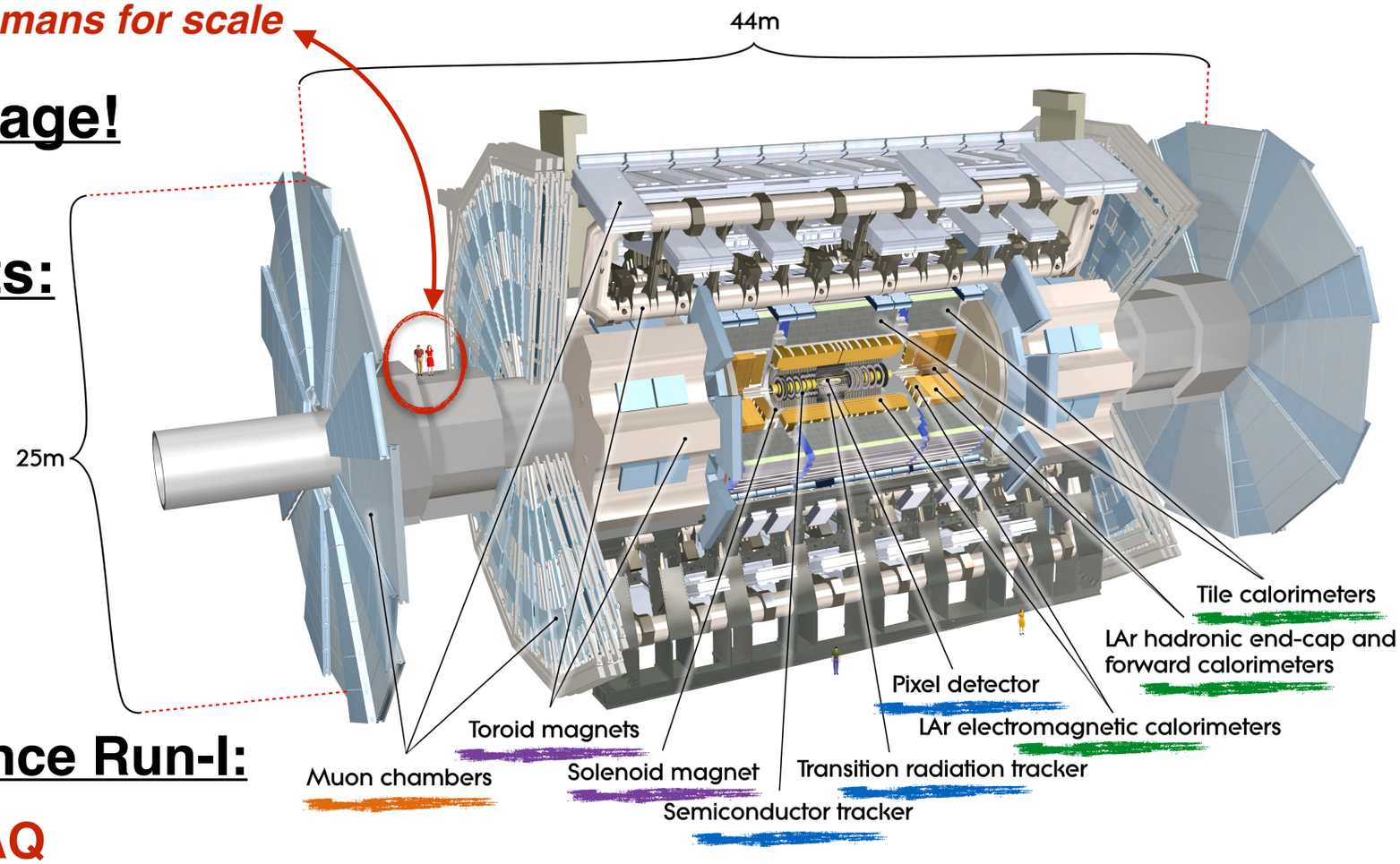
All in all fairly *natural* SUSY can still be out there!

The ATLAS Detector

EU sized anatomically modern humans for scale

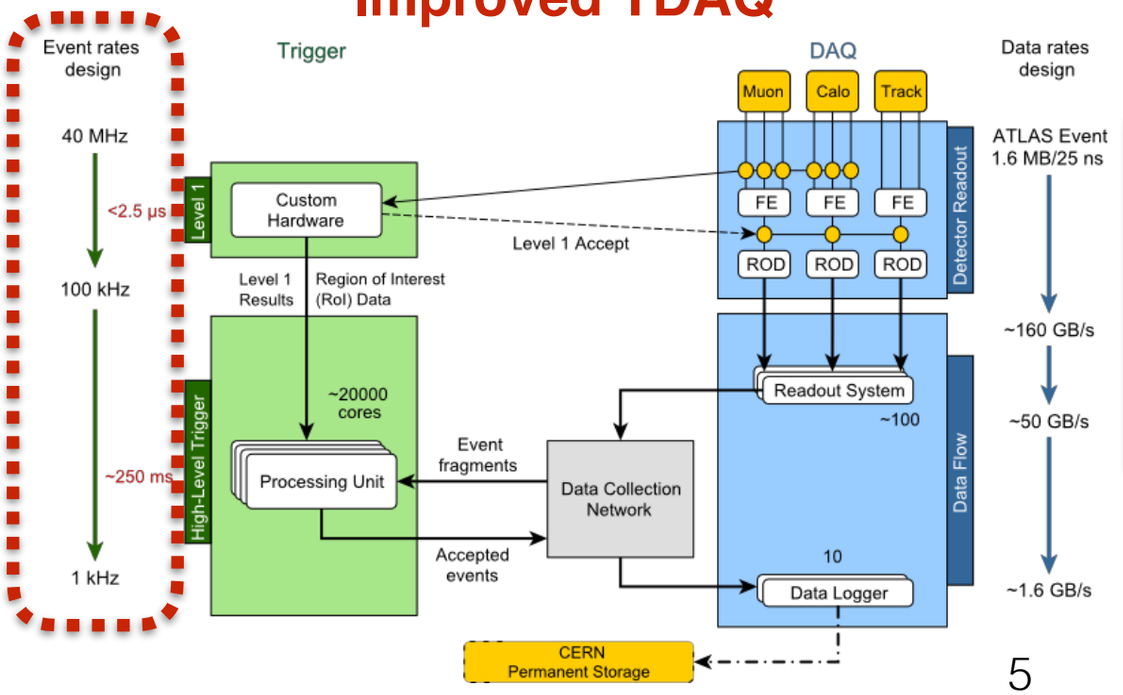
- **Approximate 4π coverage!**

- **Four main components:**
  - **Inner tracker**
  - **Calorimeters**
  - **Muon Spectrometer**
  - **Magnets**

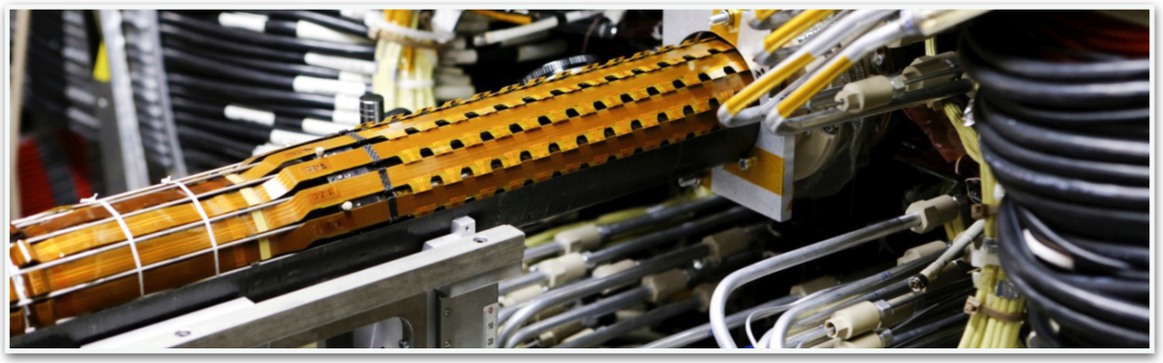


- **Many improvements since Run-I:**

Improved TDAQ



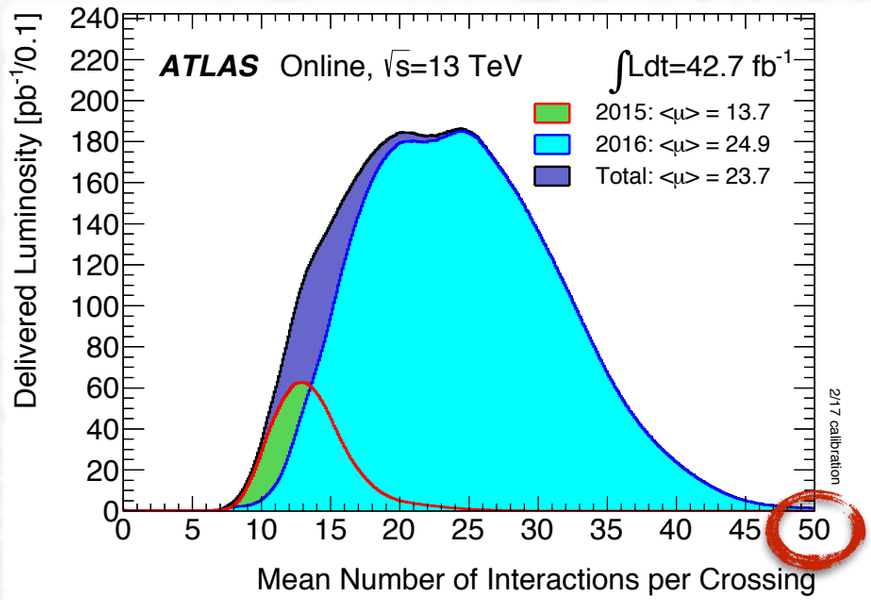
The new innermost (4th) pixel layer (IBL)

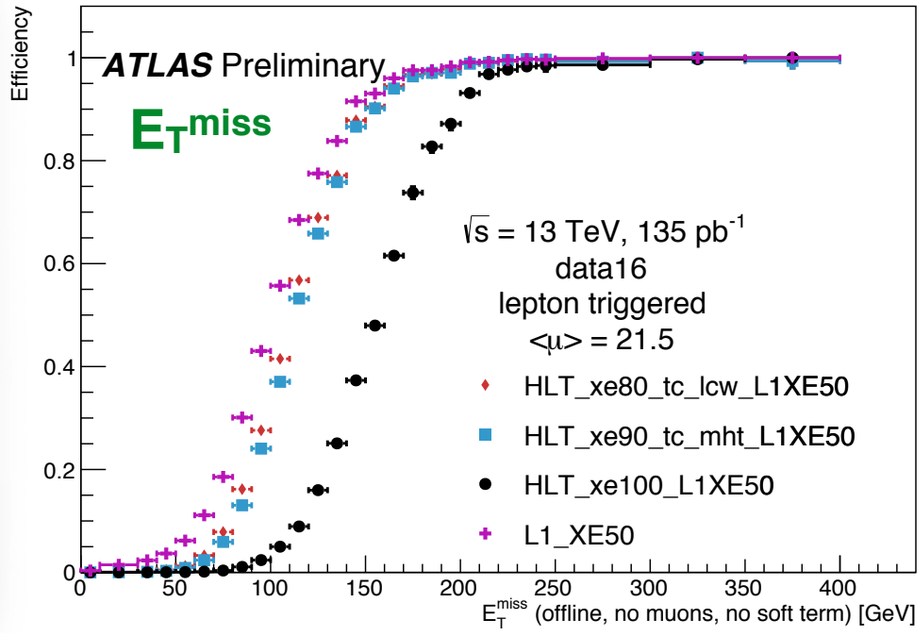


Improved Event Data Model, optimized reconstruction and analysis framework, and many more

Data-taking and Performance

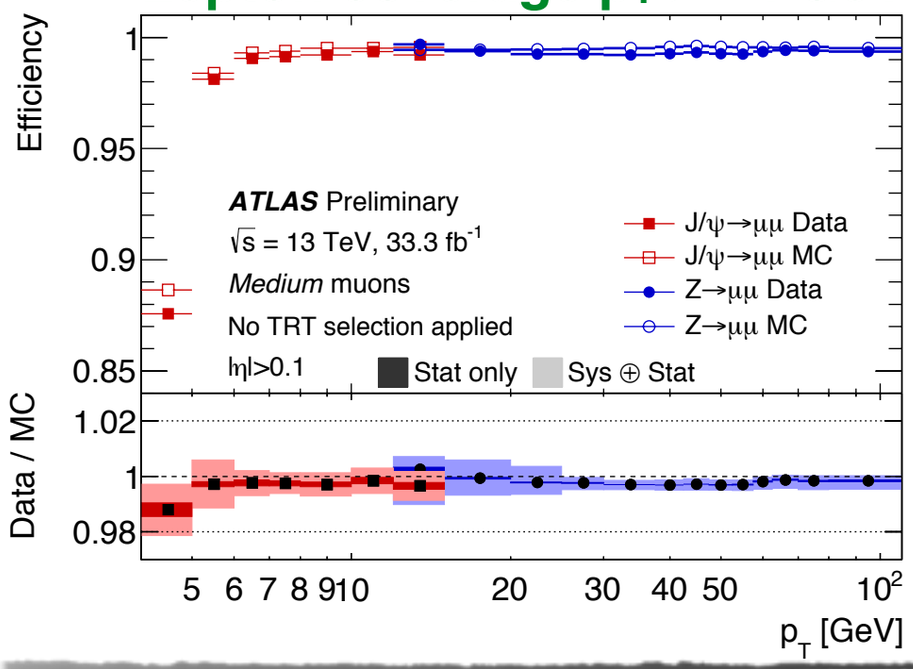
LHC Delivered 42.7 fb^{-1} → **ATLAS Recorded** 39.5 fb^{-1} (92.4%) → ***Good*** **for SUSY** 36.1 fb^{-1} (91.4%)





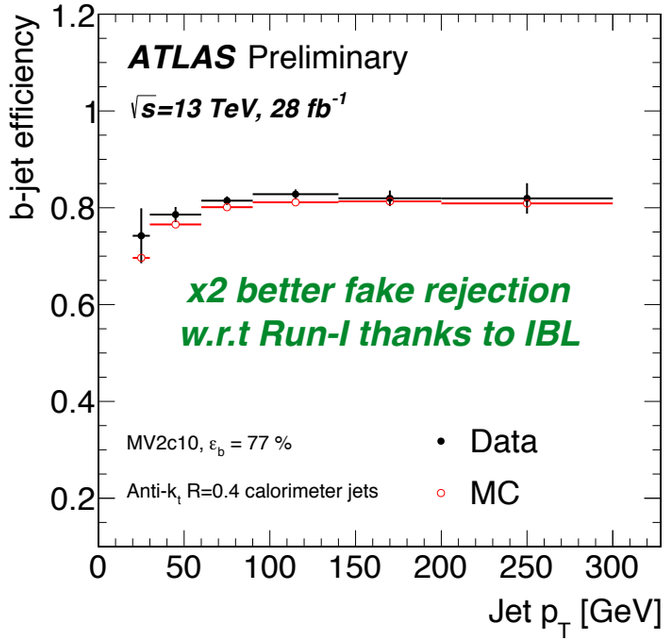
Trigger

Lepton coverage p_T > ~4 GeV



MUON-2017-001

Flavor tagging



FTAG-2017-001

Reconstruction

See Moritz's *talk*

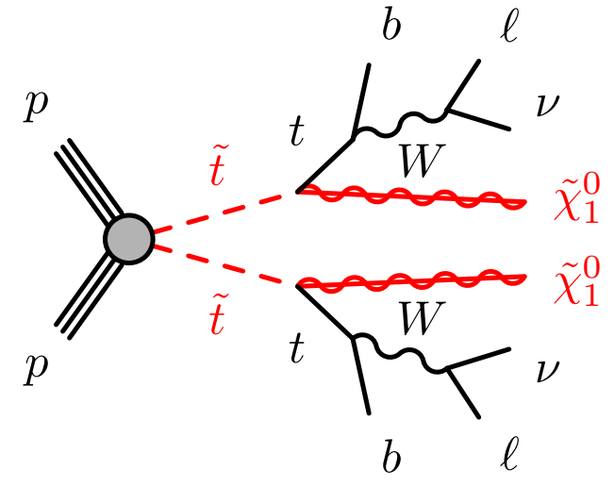
Signal Models and Search Optimization

Pick your favorite signal model:

Can explain a discrepancy in an existing analysis

Can extend the search coverage for a given particle

…



Typically Simplified Models are used in the search optimization:

Limited number of free parameters

Relatively easy to present results and provide information to the community

Typically assuming 100% branching ratios for the considered decay chains

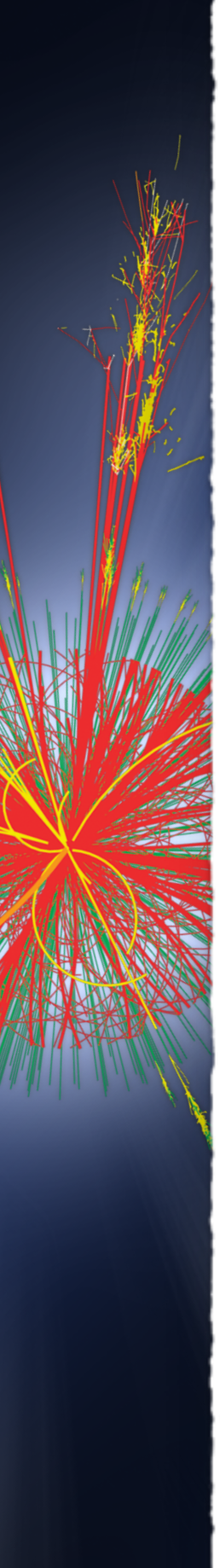
Lately full models (e.g. pMSSM) are also being used

Perform search optimization:

Discovery : Typically more inclusive *cut&count* signal regions (SRs)

Exclusion : Can be more elaborate involving *shape-fits*, *MVAs*, etc.

Discriminating Variables



complexity

Object counting, momenta, energies,
e.g. $N_{j/\ell/\gamma}$, $p_T^{j/\ell/\gamma}$, E_T^{miss}, …

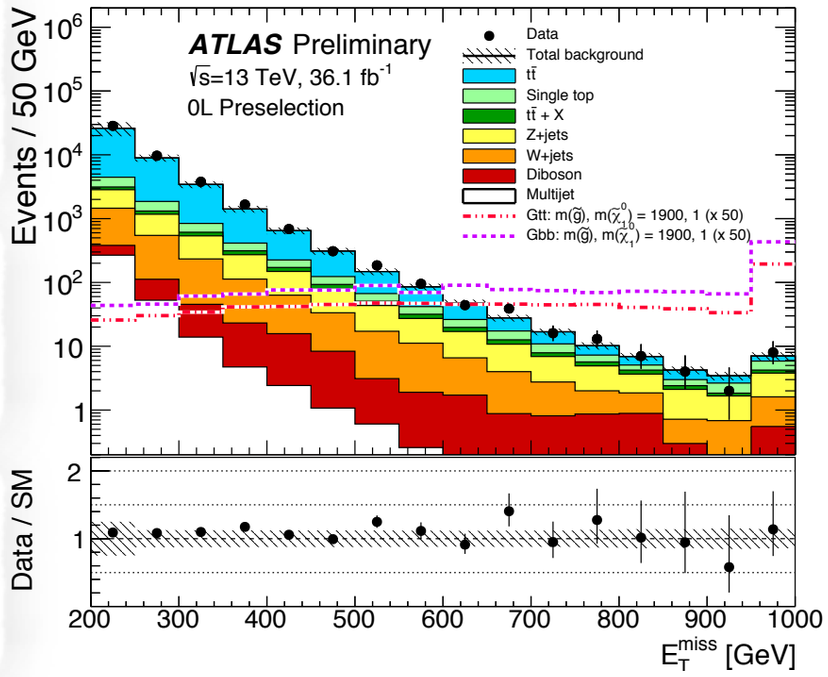
Scale variables,
e.g. $H_T = \Sigma p_T$, $m_{eff} = \Sigma p_T + E_T^{miss}$, …

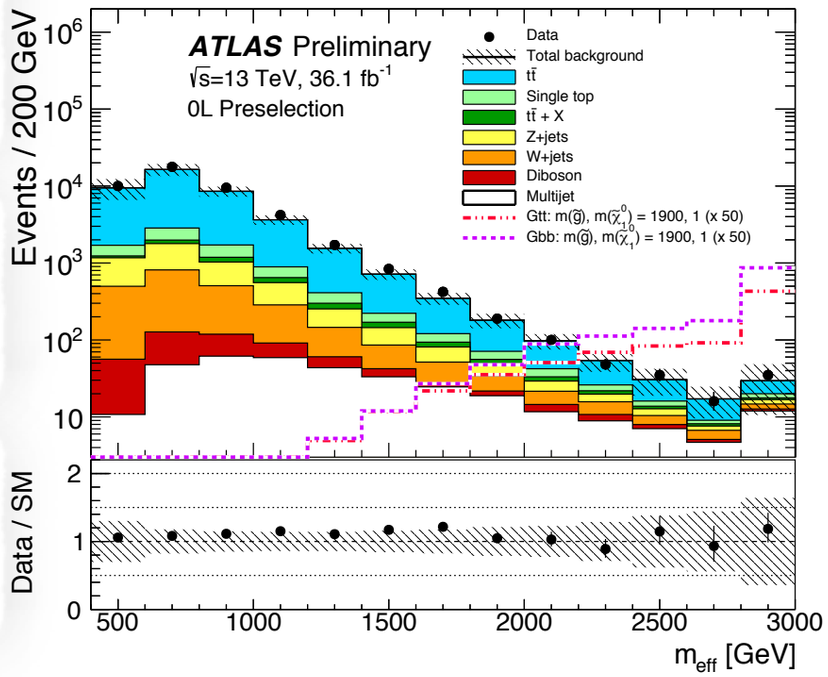
Angular variables,
e.g. $\Delta\phi(j, E_T^{miss})$, $\Delta R(\ell, j)$, …

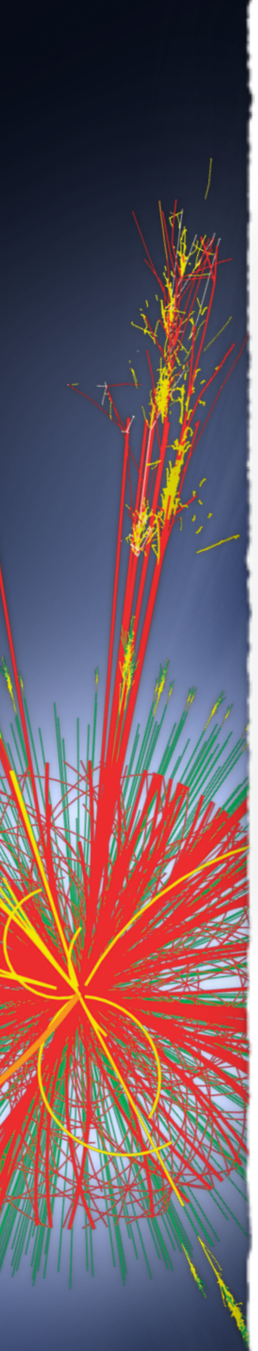
Mass variables,
e.g. $m_{\ell\ell}$, m_T^{ℓ} …

Hypothesis-based event variables,
e.g. (a)m_{T2} …

Newer more complex variables,
e.g. Recursive Jigsaw arxiv:1607.08307







Background Measurement and Systematics

Measure the background and systematic uncertainties:

(Semi-)Data-driven approaches when possible

Systematic uncertainties using ATLAS-wide performance group prescriptions

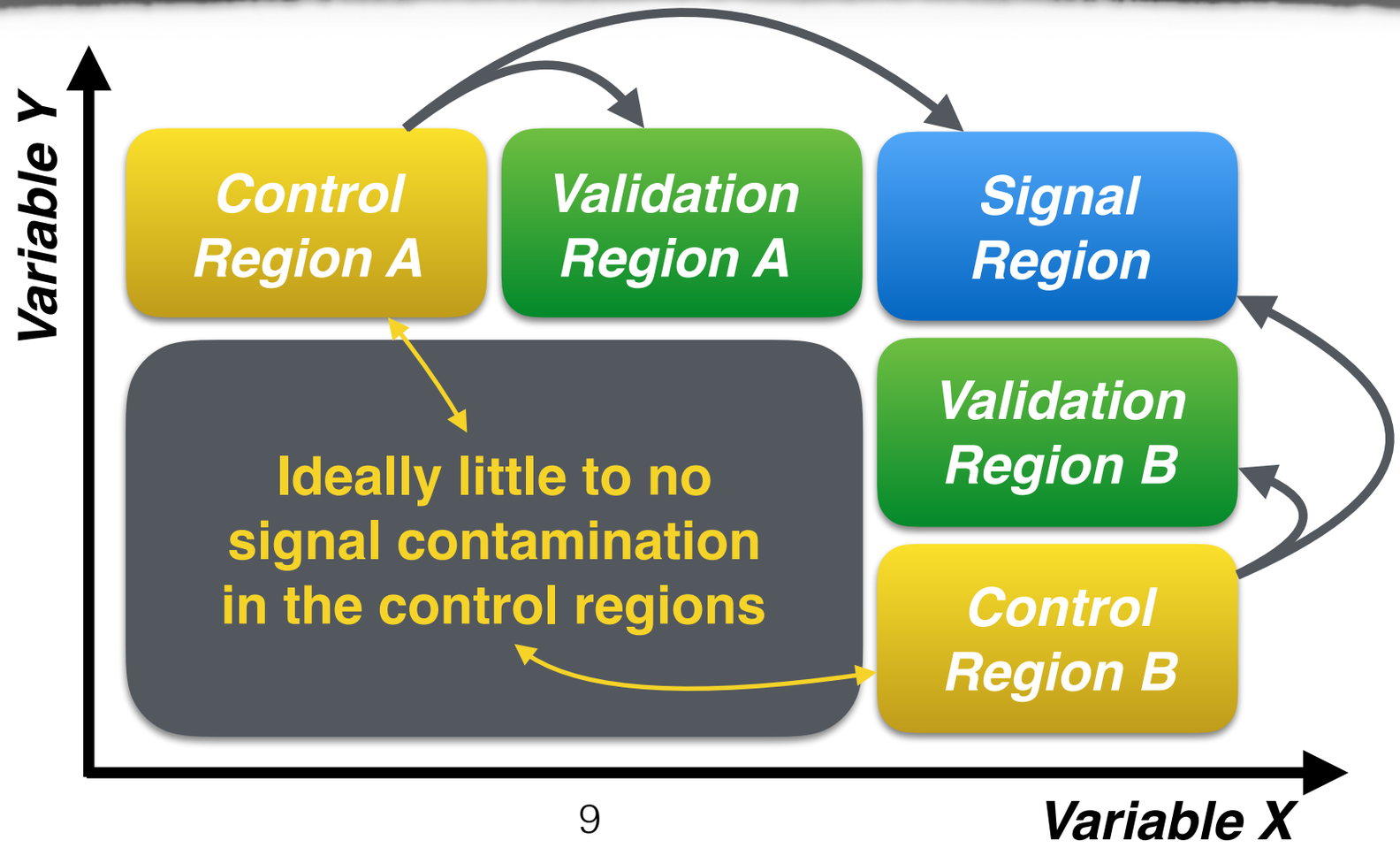
Typical SUSY background measurement approach:

For each important process define a representative control region (**CR**)

Fit the background to data simultaneously in all CRs to get the scale factors (SF)

Validate these SFs in the validation regions (**VR**) then use them in the **SRs**

Discovery limits using profiled likelihood fits avoiding constraining of systematics



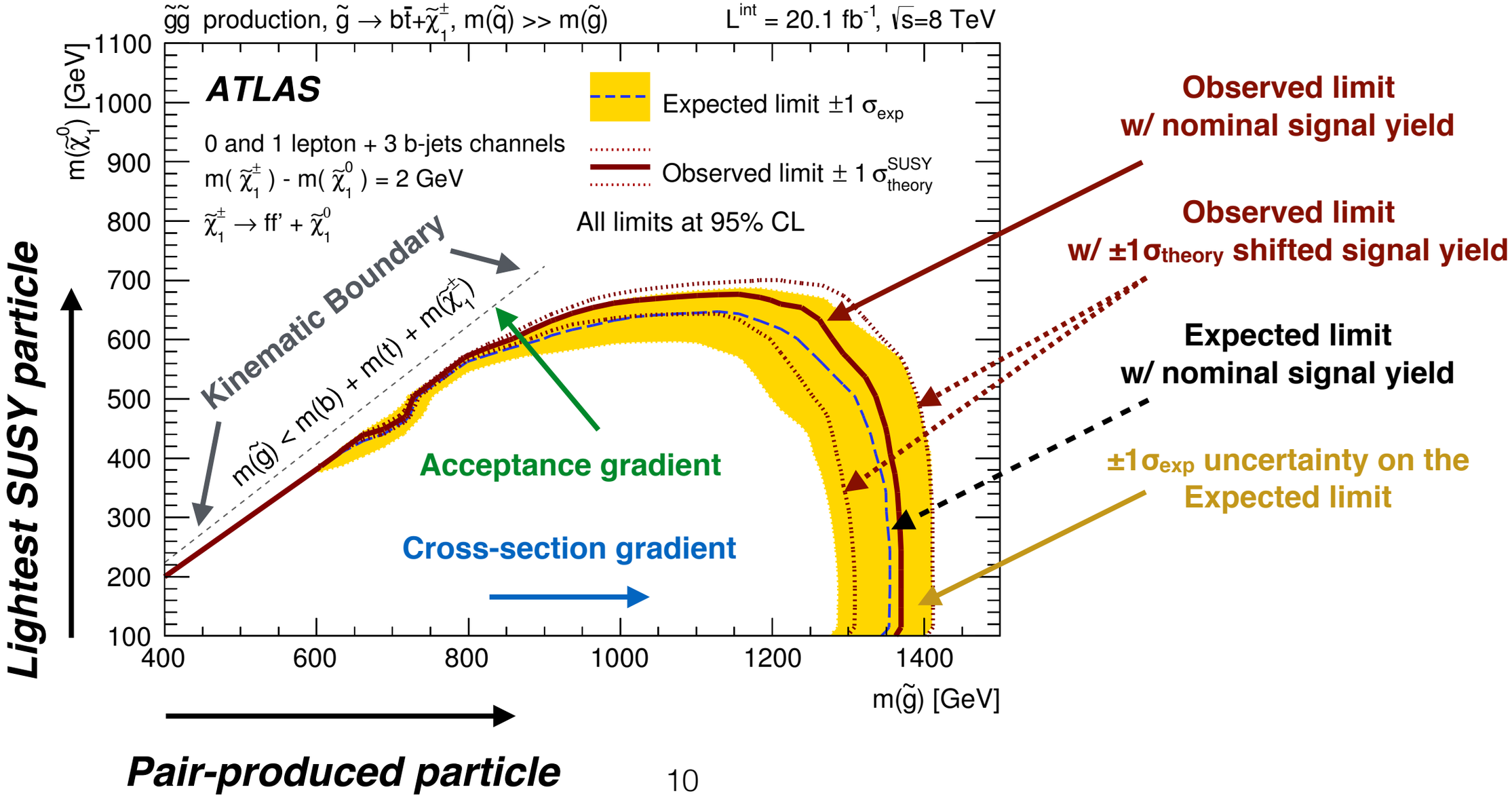
Statistical Interpretation of the Results

Statistical interpretation of results:

Consistency between data and background is quantified as a *p*-value

Model-dependent limits are set on signal strength/production cross-section

(Mainly presented on a 2-D mass-plane)



ATLAS SUSY Summary: May '17

ATLAS SUSY Searches* - 95% CL Lower Limits

May 2017

ATLAS Preliminary
$\sqrt{s}$ = 7, 8, 13 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt$[fb^{-1}]	Mass limit	$\sqrt{s}$ = 7, 8 TeV	$\sqrt{s}$ = 13 TeV	Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e, μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q}, \tilde{g}$	1.85 TeV	m($\tilde{q}$)=m($\tilde{g}$)	1507.05525
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{q}$	1.57 TeV	m($\tilde{\chi}_1^0$)<200 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	ATLAS-CONF-2017-022
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	3.2	$\tilde{q}$ 608 GeV		m($\tilde{q}$)-m($\tilde{\chi}_1^0$)<5 GeV	1604.07773
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{g}$	2.02 TeV	m($\tilde{\chi}_1^0$)<200	-022
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{g}$	2.01 TeV	m($\tilde{\chi}_1^0$)<200	-022
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e, μ	4 jets	-	36.1	$\tilde{g}$	1.825 TeV	m($\tilde{\chi}_1^0$)<400	-030
	$\tilde{g}\tilde{g}, \tilde{g}\to qqWZ\tilde{\chi}_1^0$	0	7-11 jets	Yes	36.1	$\tilde{g}$	1.8 TeV	m($\tilde{\chi}_1^0$) <40	-033
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	3.2	$\tilde{g}$	2.0 TeV		
	GGM (bino NLSP)	2 γ	-	Yes	3.2	$\tilde{g}$	1.65 TeV	$c\tau$(NLSP)<	
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$	1.37 TeV	m($\tilde{\chi}_1^0$)<950	
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	13.3	$\tilde{g}$	1.8 TeV	m($\tilde{\chi}_1^0$)>680 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	ATLAS-CONF-2016-066
	GGM (higgsino NLSP)	2 e, μ (Z)	2 jets	Yes	20.3	$\tilde{g}$ 900 GeV		m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV		m($\tilde{G}$)>1.8×10^{-4} eV, m($\tilde{g}$)=m($\tilde{q}$)=1.5 TeV	1502.01518
3rd gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	36.1	$\tilde{g}$	1.92 TeV	m($\tilde{\chi}_1^0$)<600 GeV	ATLAS-CONF-2017-021
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	36.1	$\tilde{g}$	1.97 TeV	m($\tilde{\chi}_1^0$)<200 GeV	ATLAS-CONF-2017-021
	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.37 TeV	m($\tilde{\chi}_1^0$)<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	36.1	$\tilde{b}_1$	950 GeV	m($\tilde{\chi}_1^0$)<420	-038
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e, μ (SS)	1 b	Yes	36.1	$\tilde{b}_1$	275-700 GeV	m($\tilde{\chi}_1^0$)<200	-030
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\tilde{\chi}_1^\pm$	0-2 e, μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$ 117-170 GeV	200-720 GeV	m($\tilde{\chi}_1^\pm$) = 2r	-2016-077
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e, μ	0-2 jets/1-2 b	Yes	20.3/36.1	$\tilde{t}_1$ 90-198 GeV	205-950 GeV	m($\tilde{\chi}_1^0$)=1 G	-2017-020
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet	Yes	3.2	$\tilde{t}_1$ 90-323 GeV		m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)	
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-600 GeV		m($\tilde{\chi}_1^0$)>150	
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e, μ (Z)	1 b	Yes	36.1	$\tilde{t}_2$ 290-790 GeV		m($\tilde{\chi}_1^0$)=0 G	-019
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+h$	1-2 e, μ	4 b	Yes	36.1	$\tilde{t}_2$ 320-880 GeV		m($\tilde{\chi}_1^0$)=0 GeV	2017-019
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	36.1	$\tilde{\ell}$ 90-440 GeV		m($\tilde{\chi}_1^0$)=0	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	36.1	$\tilde{\chi}_1^\pm$ 710 GeV		m($\tilde{\chi}_1^0$)=0, m	-039
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp/\tilde{\chi}_2^0, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu}), \tilde{\chi}_2^0\to\tilde{\tau}\tau(\nu\tilde{\nu})$	2 τ	-	Yes	36.1	$\tilde{\chi}_1^\pm$ 760 GeV		m($\tilde{\chi}_1^0$)=0, m	-035
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	36.1	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 1.16 TeV		m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)	-039
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	2-3 e, μ	0-2 jets	Yes	36.1	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 580 GeV		m($\tilde{\chi}_1^\pm$)=m(	-039
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e, μ, γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 270 GeV		m($\tilde{\chi}_1^\pm$)=m(	
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e, μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 635 GeV		m($\tilde{\chi}_2^0$)=m($\tilde{\chi}_3^0$), m($\tilde{\chi}_1^0$)	
	GGM (wino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	1 e, μ + γ	-	Yes	20.3	$\tilde{W}$ 115-370 GeV		$c\tau$<1 mm	
	GGM (bino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	2 γ	-	Yes	20.3	$\tilde{W}$ 590 GeV		$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	36.1	$\tilde{\chi}_1^\pm$ 430 GeV		m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)~160 MeV, $\tau(\tilde{\chi}_1^\pm)$=0.2 ns	ATLAS-CONF-2017-017
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^\pm$ 495 GeV		m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)~160 MeV, $\tau(\tilde{\chi}_1^\pm)$<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 850 GeV		m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	3.2	$\tilde{g}$ 1.58 TeV			1606.05129
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$ 1.57 TeV		m($\tilde{\chi}_1^0$)=100 GeV, τ>10 ns	1604.04520
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e}, \tilde{\mu})+\tau(e, \mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$ 537 GeV		10<tanβ<50	1411.67
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 440 GeV		1<$\tau(\tilde{\chi}_1^0)$<3 ns, SPS8 model	14
	$\tilde{g}\tilde{g}, \tilde{\chi}_1^0\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$ 1.0 TeV		7 <$c\tau(\tilde{\chi}_1^0)$< 740 mm, m($\tilde{g}$)=1.3 TeV	
	GGM $\tilde{g}\tilde{g}, \tilde{\chi}_1^0\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$ 1.0 TeV		6 <$c\tau(\tilde{\chi}_1^0)$< 480 mm, m($\tilde{g}$)=1.1 TeV	
RPV	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu, e\tau, \mu\tau$	-	-	3.2	$\tilde{\nu}_\tau$ 1.9 TeV		λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.45 TeV		m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\nu, e\mu\nu, \mu\mu\nu$	4 e, μ	-	Yes	13.3	$\tilde{\chi}_1^\pm$ 1.14 TeV		m($\tilde{\chi}_1^0$)>400GeV, $\lambda_{12k}\neq0$ (k = 1, 2)	-CONF-2016-075
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\nu_e, e\tau\nu_\tau$	3 $e, \mu+\tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 450 GeV		m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^\pm$), $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}, \tilde{g}\to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$ 1.08 TeV		BR(t)=BR(b)=BR(c)=	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^0, \tilde{\chi}_1^0\to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$ 1.55 TeV		m($\tilde{\chi}_1^0$)=800 Ge	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0, \tilde{\chi}_1^0\to qqq$	1 e, μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$ 2.1 TeV		m($\tilde{\chi}_1^0$)= 1	ATLAS-CONF-2017-013
	$\tilde{g}\tilde{g}, \tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$	1 e, μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$ 1.65 TeV		m($\tilde{\chi}$	ATLAS-CONF-2017-013
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$	0	2 jets + 2 b	-	15.4	$\tilde{t}_1$ 410 GeV 450-510 GeV			ATLAS-CONF-2016-022, ATLAS-CONF-2016-084
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\ell$	2 e, μ	2 b	-	36.1	$\tilde{t}_1$ 0.4-1.45 TeV		B	ATLAS-CONF-2017-036
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$ 510 GeV		m($\tilde{\chi}_1^0$) GeV	1501.01325

10^{-1} 1 2 **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

$\tilde{g}$ @ 2 TeV

$\tilde{t}/\tilde{b}$ @ 950 GeV

$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ @ 1 TeV

Please mind the assumptions!

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

New SUSY Results since Moriond EWK ‘17

- **Inclusive** searches for gluinos and squarks
  - ATLAS-CONF-2017-033 : 0 lepton (e/μ) + 7-11 jets
  - ATLAS-CONF-2017-030 : 2SS/3 leptons (e/μ)

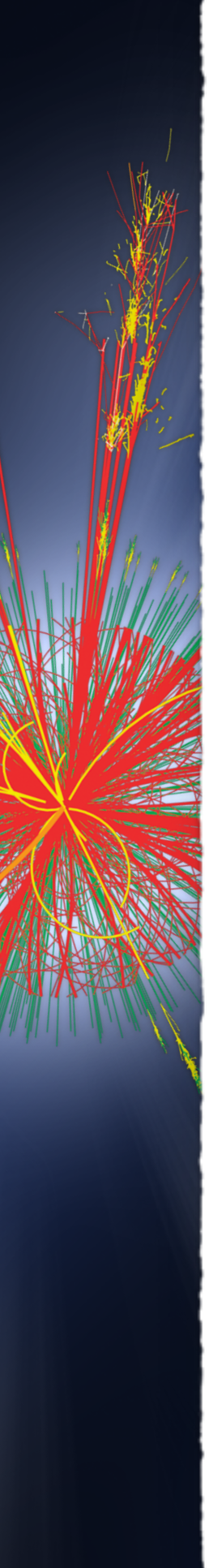
- Searches for direct production of **3rd generation squarks**:
  - ATLAS-CONF-2017-037 : Stop 1 lepton (e/μ)
  - ATLAS-CONF-2017-034 : Stop 2 leptons (e/μ)
  - ATLAS-CONF-2017-038 : Sbottom 2b + E_T^{miss}

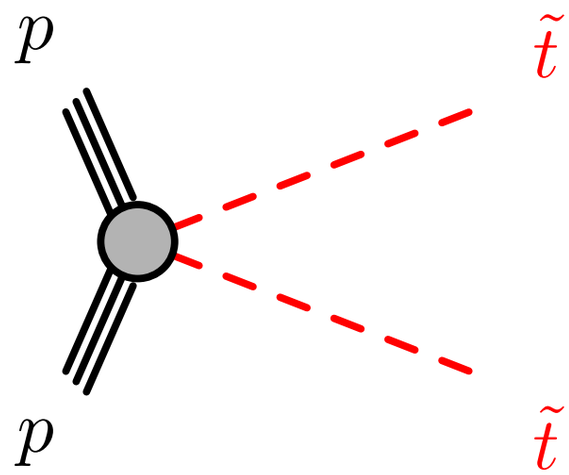
- Searches for direct production of **electro-weakinos**:
  - ATLAS-CONF-2017-039 : 2/3 leptons (e/μ)
  - ATLAS-CONF-2017-035 : ≥ 2 τ_{had}

- Searches for **RPV/Long-Lived** scenarios:
  - ATLAS-CONF-2017-036 : Stop B-L
  - ATLAS-CONF-2017-026 : Displaced vertices

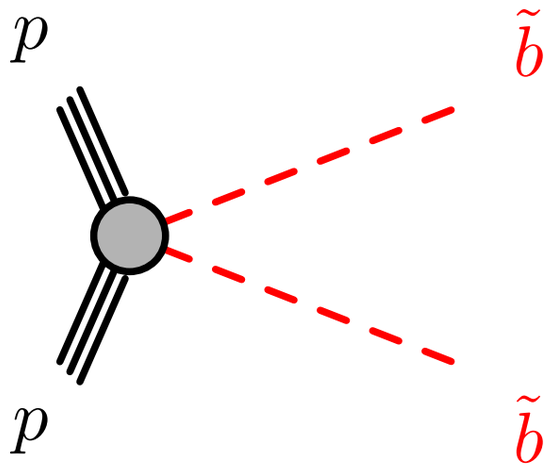
This talk

- **For all SUSY results, please visit:**
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

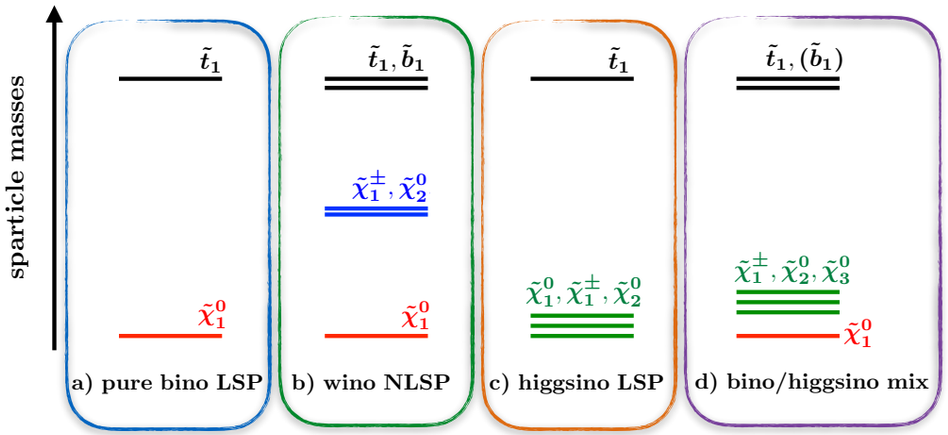




Direct 3rd Generation Production

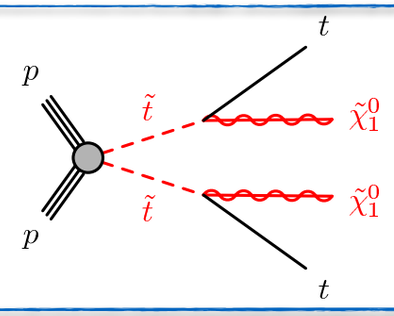


Signal Phenomenology in a Nutshell

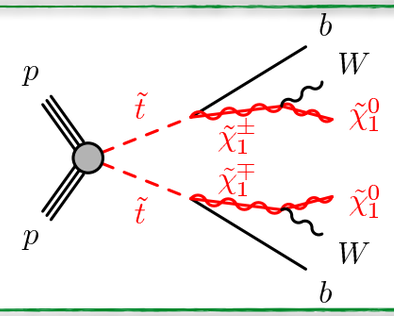


EW sector mass parameters :
M_1 (bino), M_2 (wino), μ (higgsino)

a) $|M_1| \ll |M_2, \mu|$
$\tilde{\chi}_1^0$ is **bino-like**
and *accessible*

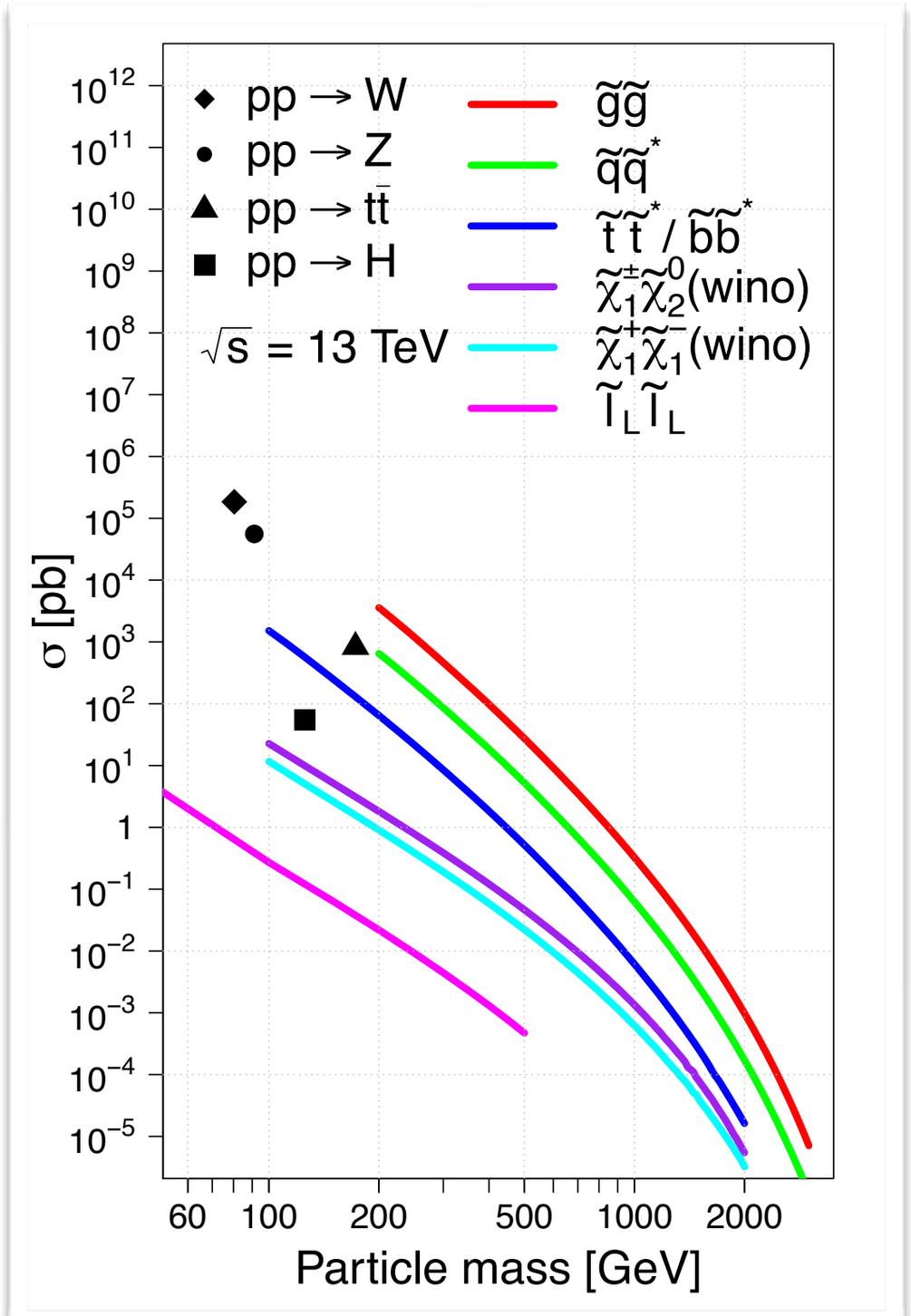


b) $|M_1, M_2| \ll |\mu|$
$\tilde{\chi}_1^0$ is **bino-like**
$\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ **wino-like**
$m(\tilde{\chi}_1^0) < m(\tilde{\chi}_1^\pm / \tilde{\chi}_2^0)$



c) $|M_1, M_2| \gg |\mu|$
$\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$
higgsino-like
and degenerate

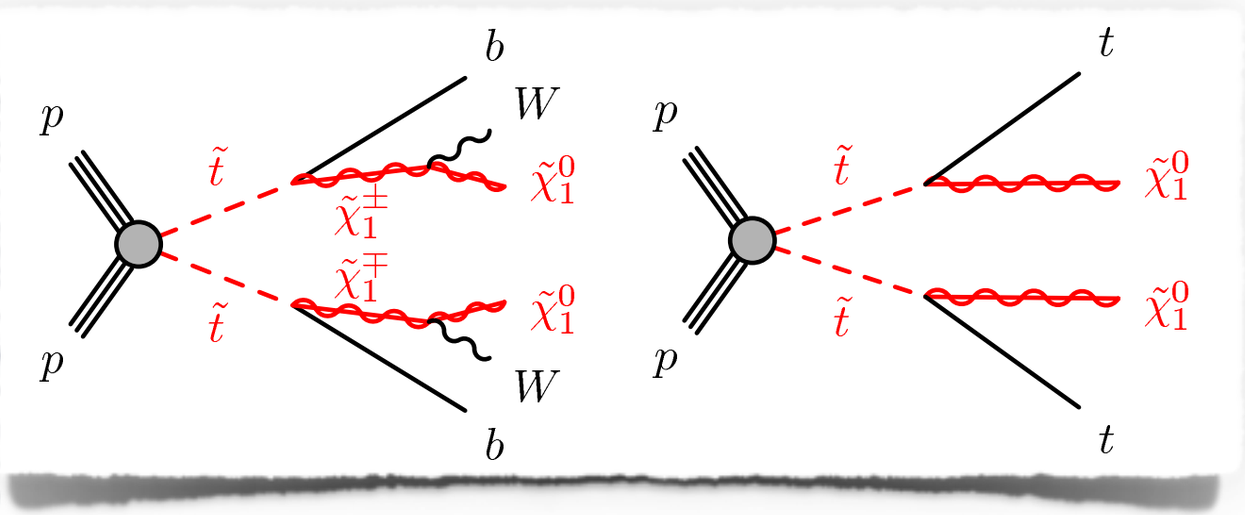
d) $|M_1, \mu| \ll |M_2|$
$\tilde{\chi}_1^0$ is **bino-like**
$\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$, $\tilde{\chi}_3^0$
higgsino-like
and degenerate

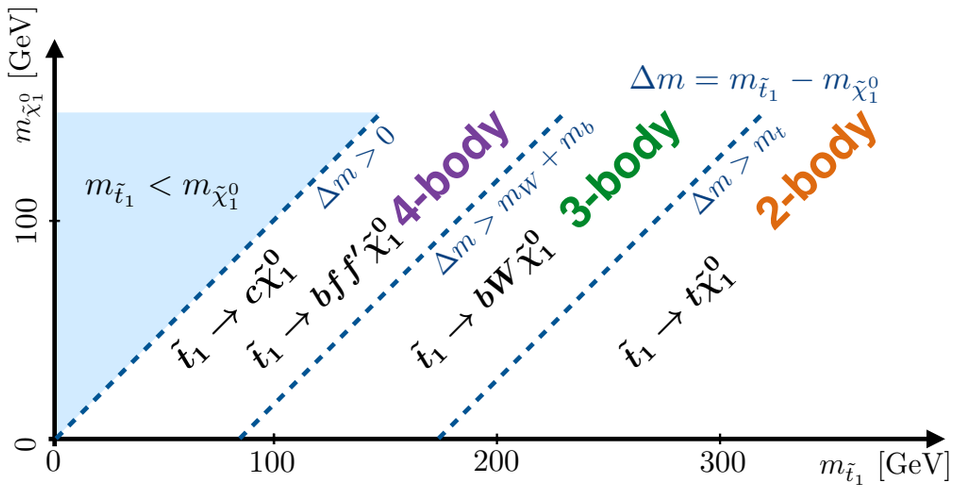


Composition dependent cross-sections

ATLAS-CONF-2017-037

Stop 1L : Overview





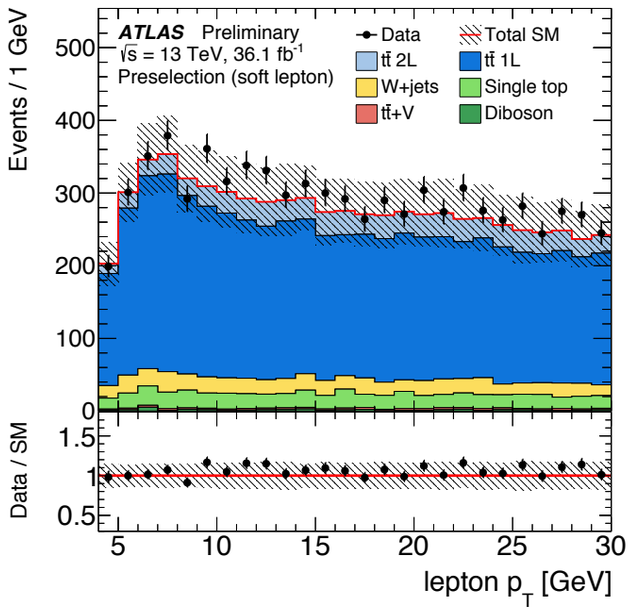
Search Strategy:

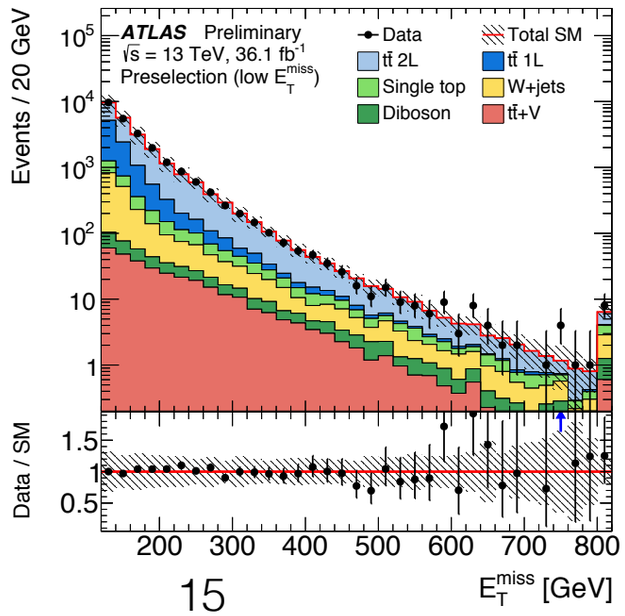
16 SRs targeting final states with 1 lepton (e/μ) + (b-)jets + E_T^{miss}

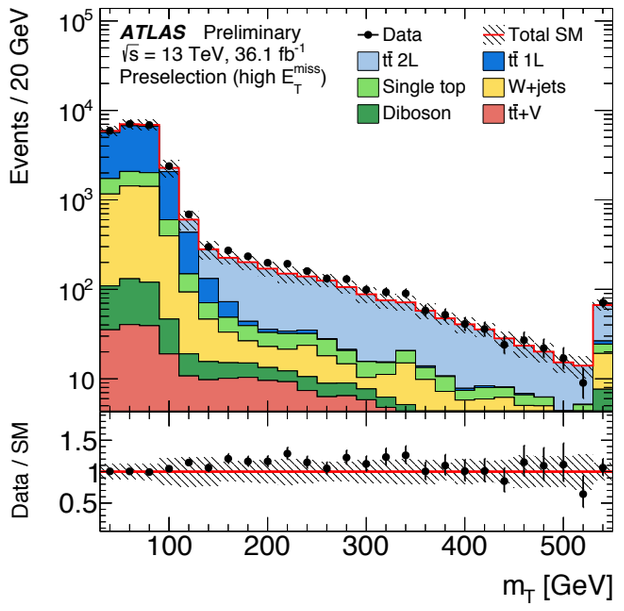
Four main scenarios : Pure bino LSP, wino NLSP, higgsino LSP, bino/higgsino mix

Three main final state topologies : soft-lepton, low-E_T^{miss}, and high-E_T^{miss}

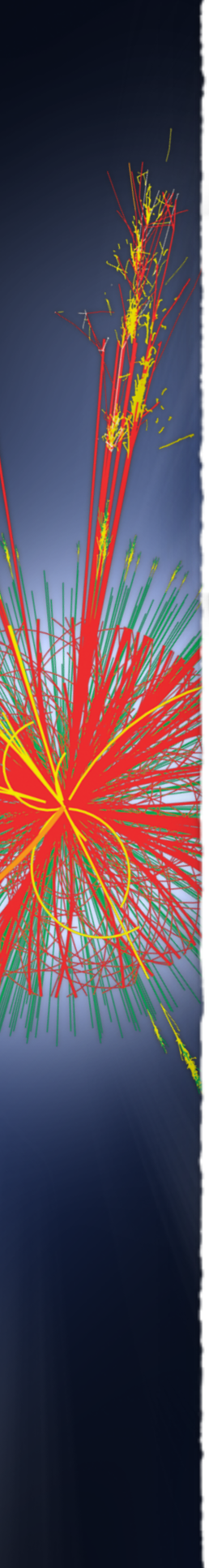
Main discriminants include m_T, E_T^{miss}, am_{T2}, p_T^W etc.

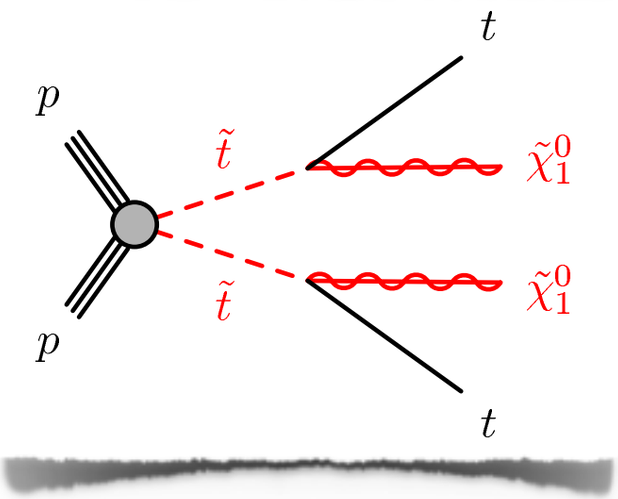






Stop 1L : Overview





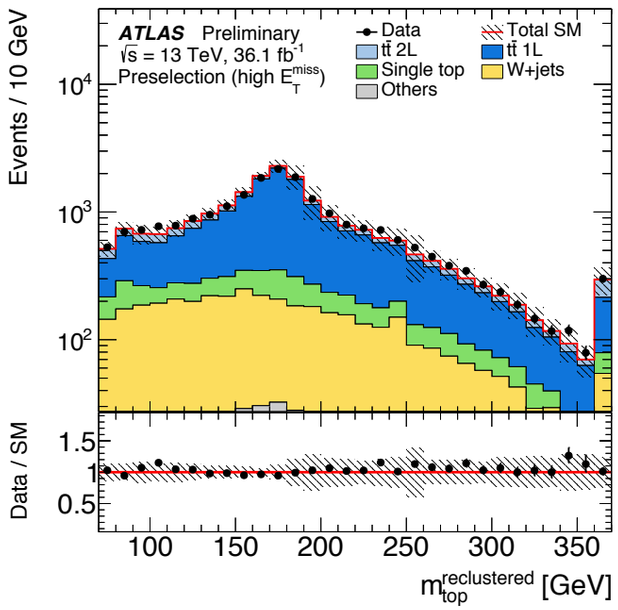
$\Delta m(\tilde{t},\tilde{\chi}_1^0) > m_t$: **2 SRs** including E_T^{miss} shape-fit

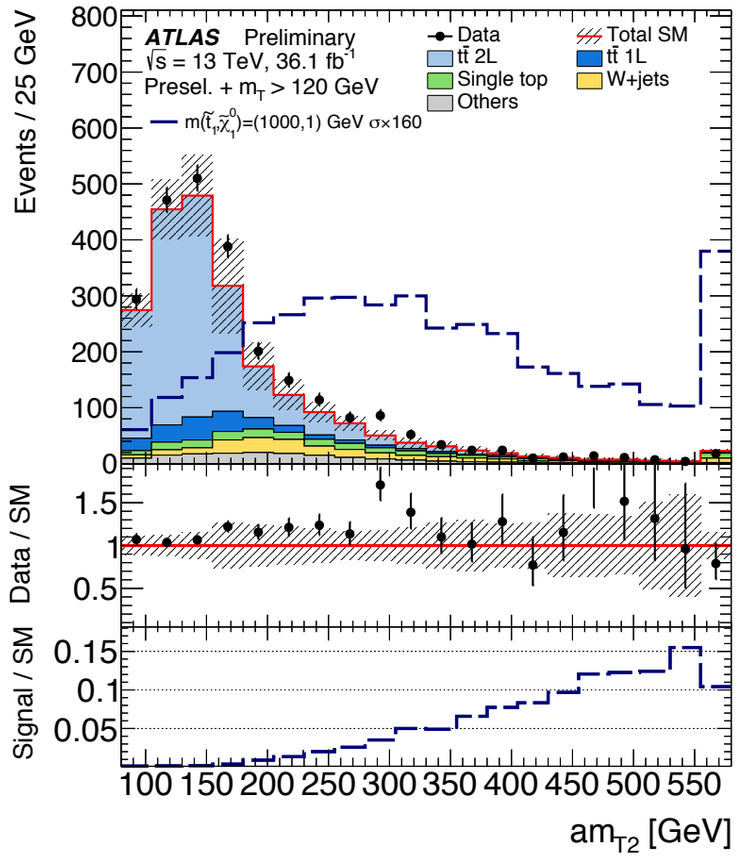
$\Delta m(\tilde{t},\tilde{\chi}_1^0) \sim m_t$: **3 SRs** BDTs using *recursive jigsaw*

$\Delta m(\tilde{t},\tilde{\chi}_1^0) < m_t$: **1 SR** asymmetric m_{T2} shape-fit

$\Delta m(\tilde{t},\tilde{\chi}_1^0) < m_W$: **1 SR** p_T^{ℓ}/E_T^{miss} shape-fit

Top reconstruction in
$\Delta m(\tilde{t},\tilde{\chi}_1^0) > m_t$





6 SRs targeting $\tilde{t}$ decays into $b\tilde{\chi}_1^{\pm}/t\tilde{\chi}_2^0$

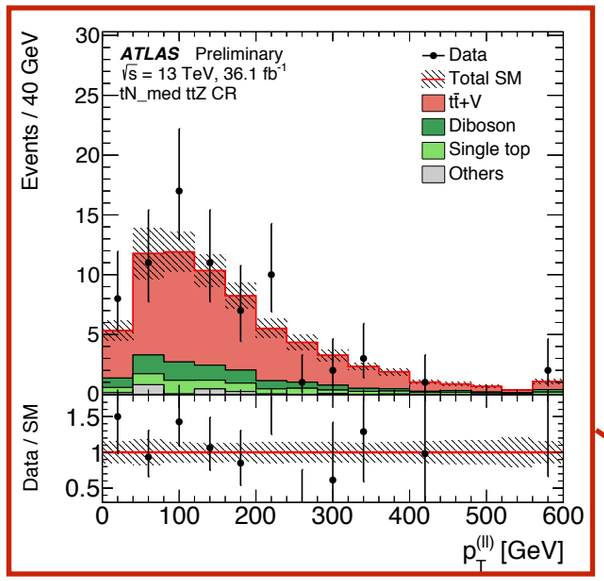
3 additional SRs targeting top-pair + dark matter production

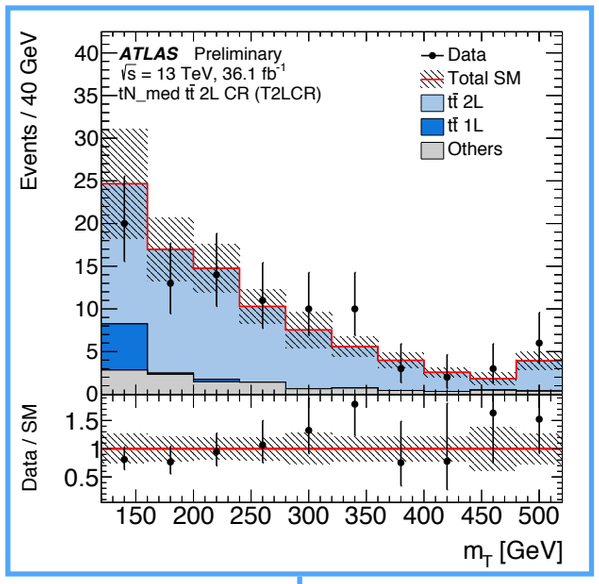
ATLAS-CONF-2017-037

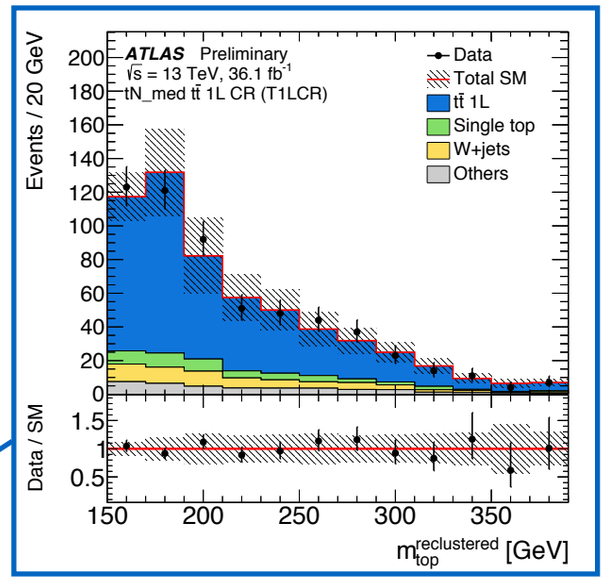
Stop 1L : Backgrounds

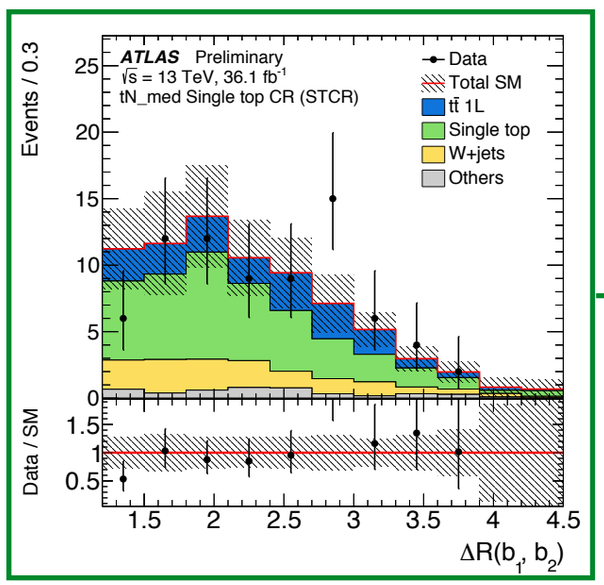
Dominant backgrounds estimated in up to 5 CRs per SR and validated in VRs

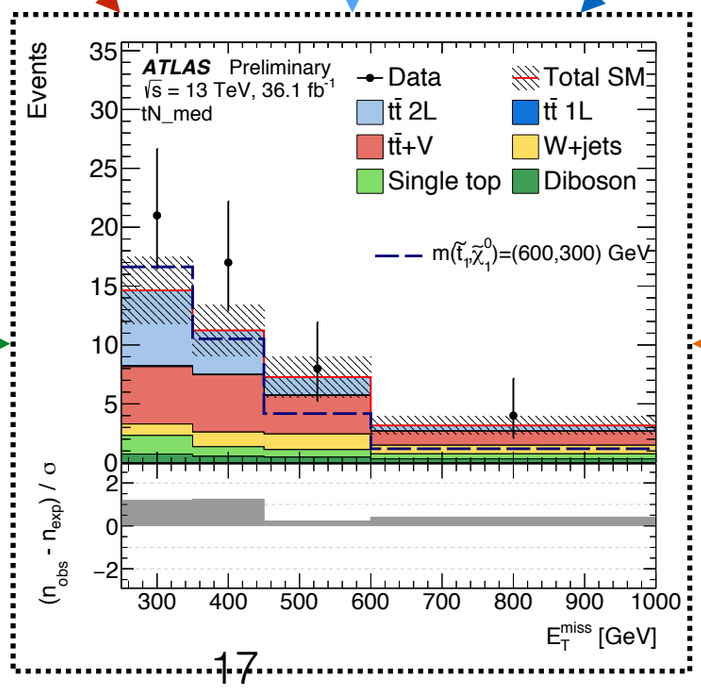
Total background systematics typically 20-30%

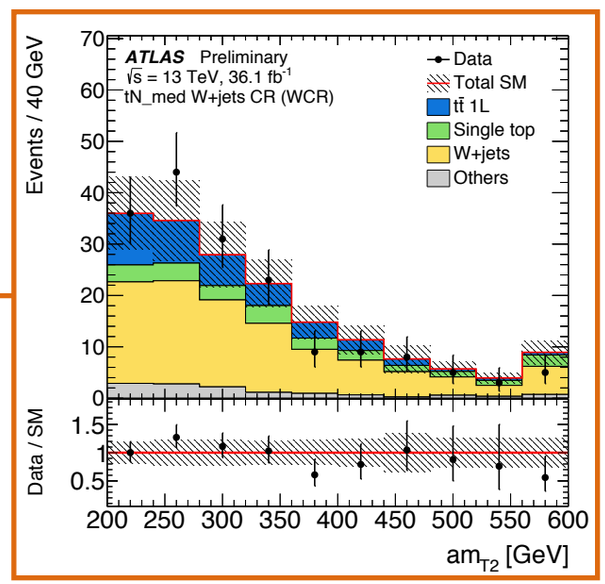








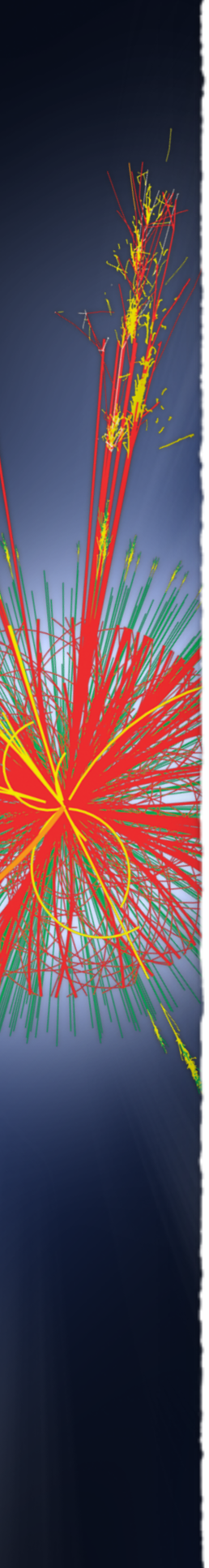


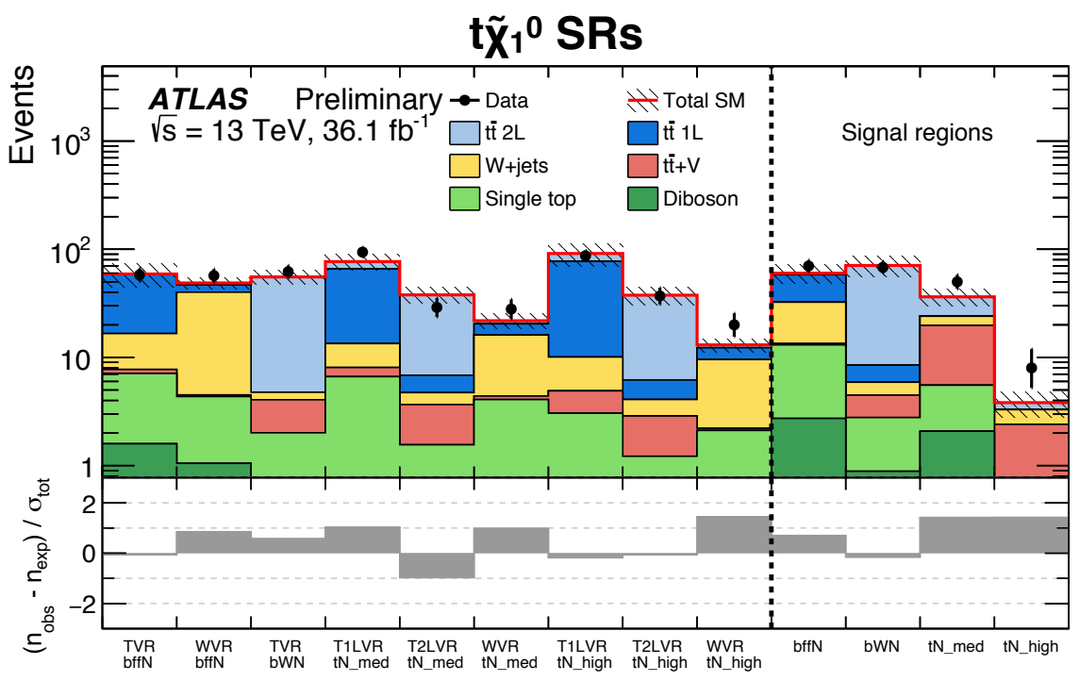


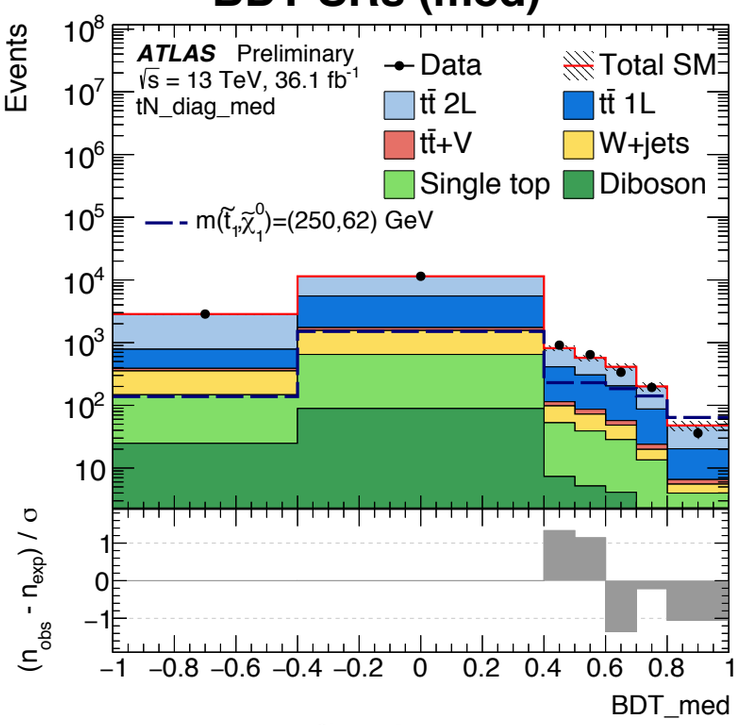
ATLAS-CONF-2017-037

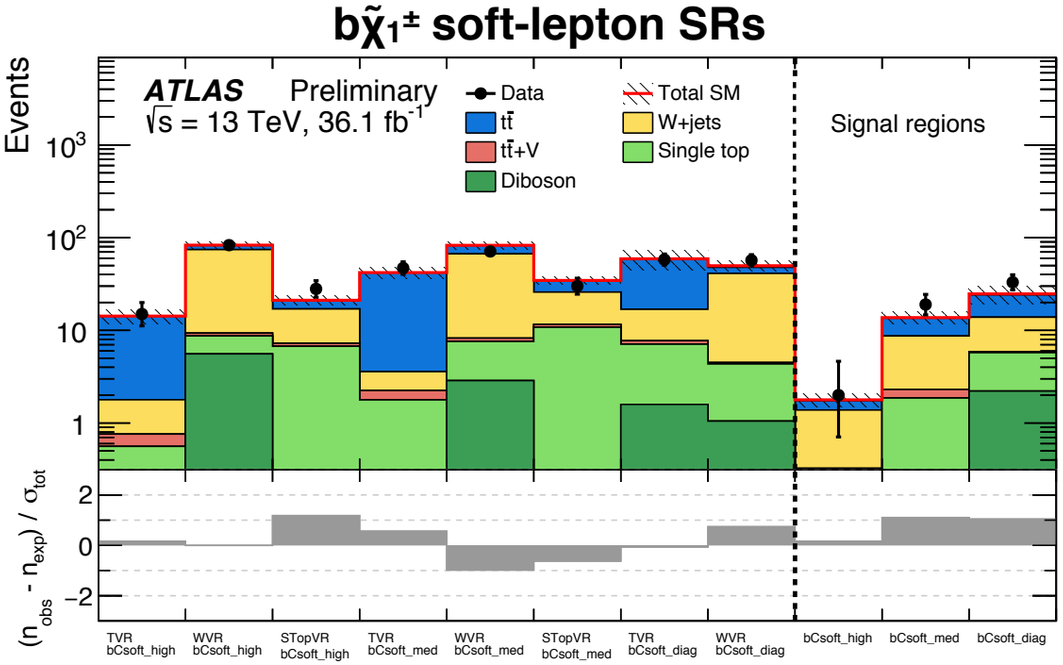
Stop 1L : Results

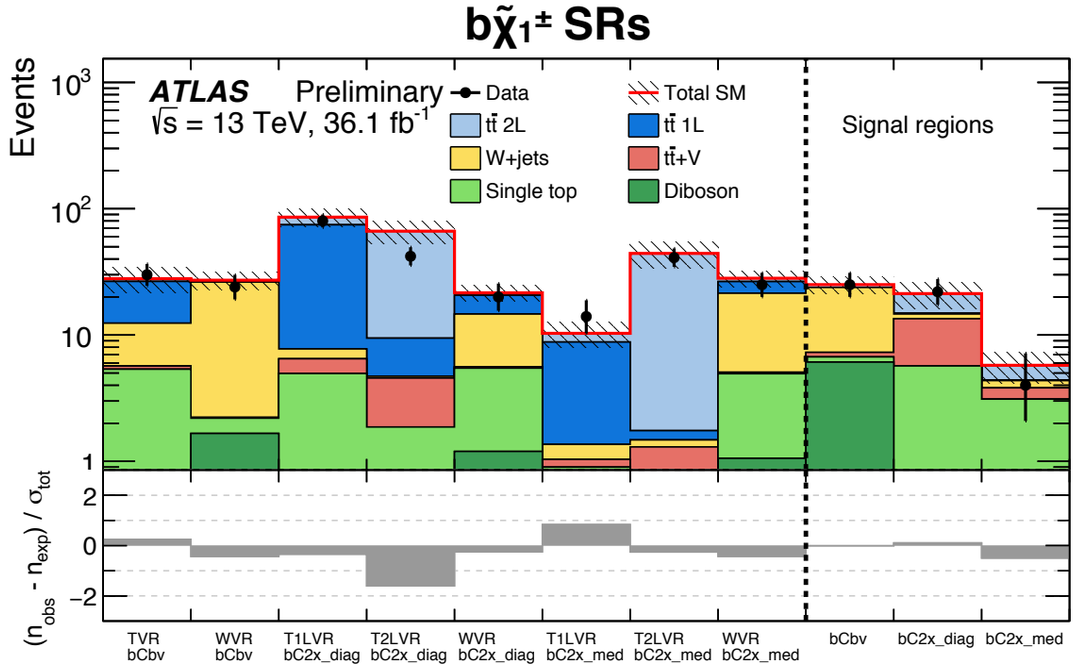
Overall good data-background agreement in all VRs and SRs





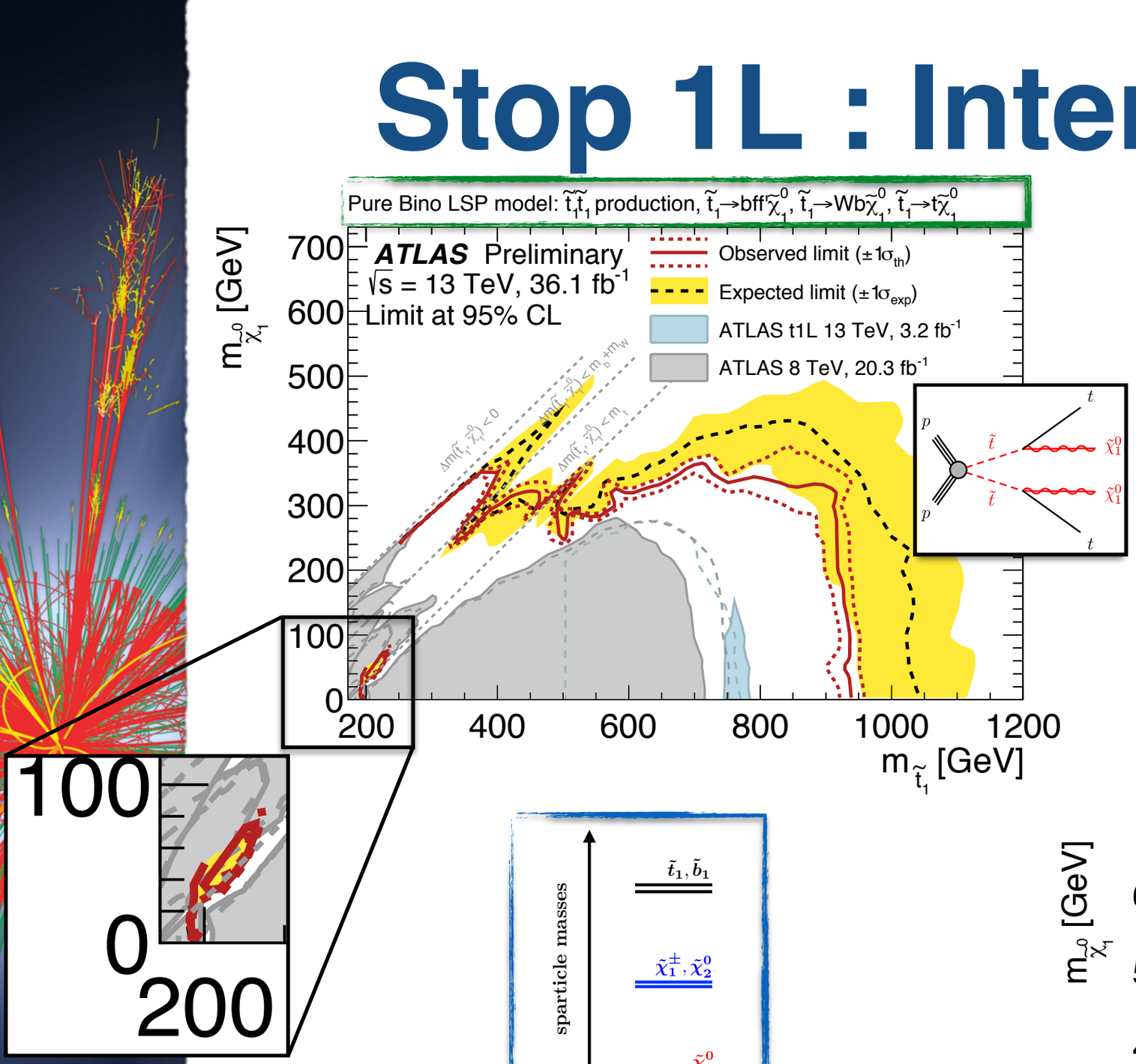


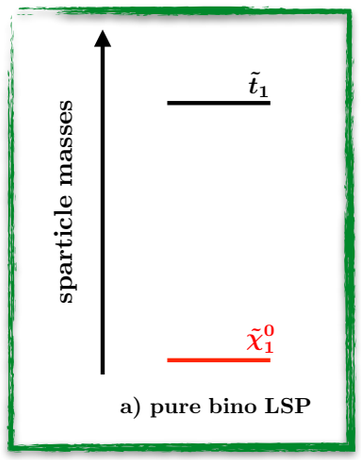




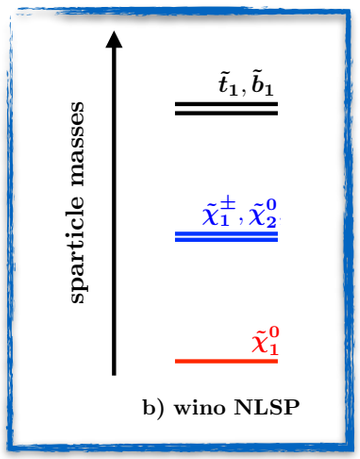
ATLAS-CONF-2017-037

Stop 1L : Interpretations

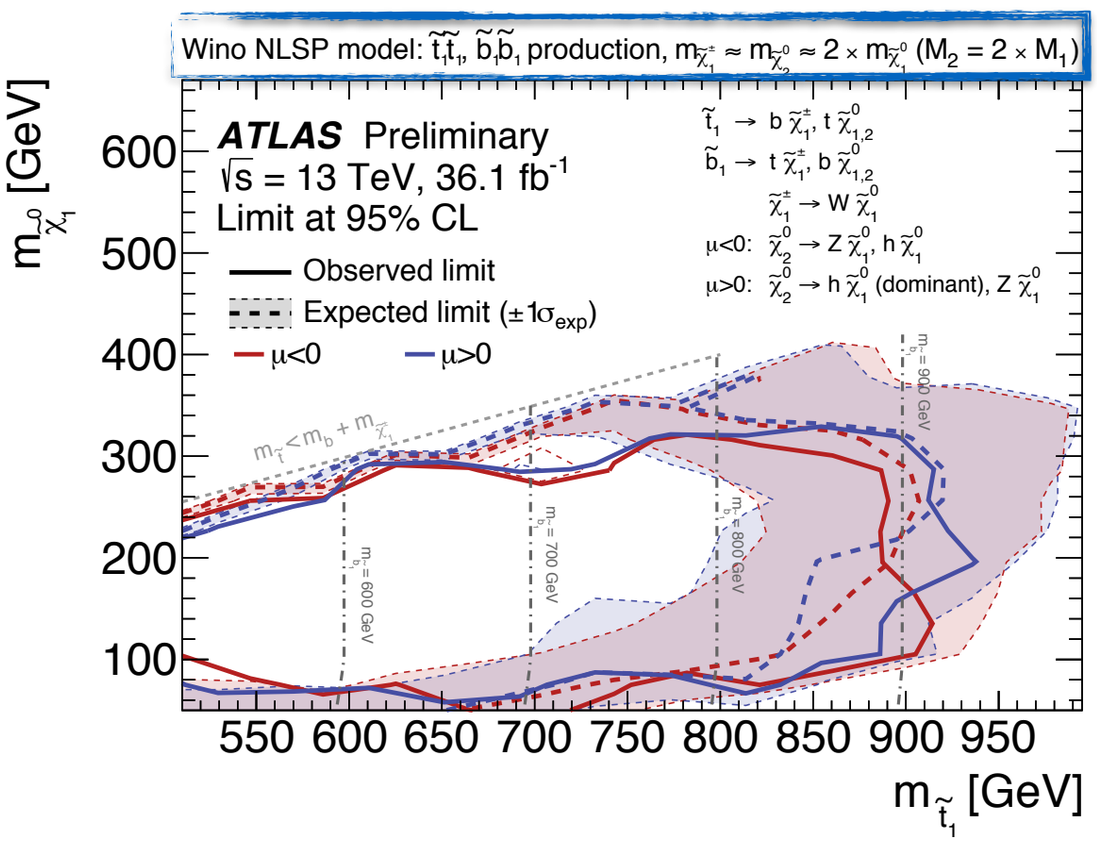




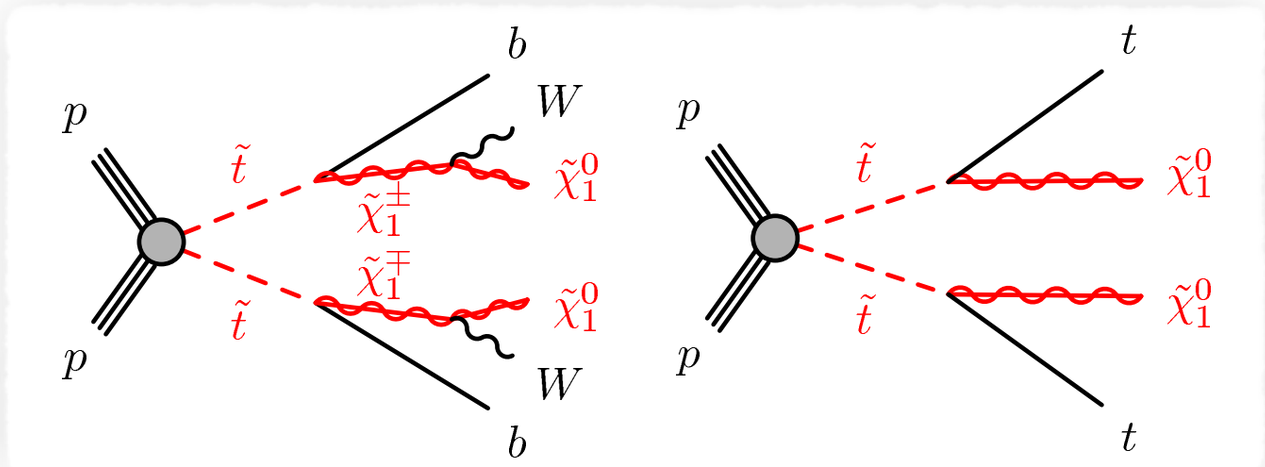
$\Delta m(\tilde{t},\tilde{\chi}_1^0) \sim m_t$ gap is almost closed up to $m(\tilde{t}) \sim 0.5$ TeV



$m(\tilde{t})$ as low as 600 GeV still survives in well-motivated models…



Stop 2L : Overview



Search Strategy:

6 SRs targeting final states with 2 leptons (e/μ) + (b-)jets + E_T^{miss}

Three main scenarios : Pure bino LSP, wino NLSP, bino/higgsino mix

Three main decay topologies : **2-body**, **3-body**, **4-body**

Main discriminants include $p_T^{\ell/j}$, E_T^{miss}, m_{T2}, $n_{b\text{-jets}}$ etc.

SRs in a nutshell:

2-body : **3 SR** for different $\Delta m(\tilde{t},\tilde{\chi}_1^0)$, includes m_{T2} shape-fit, also used for $b\tilde{\chi}_1^{\pm}$

3-body : **2 SRs** targeting $\Delta m(\tilde{t},\tilde{\chi}_1^0) \sim m_t/m_W$, uses *recursive jigsaw*

4-body : **1 SR** probing soft-leptons and large E_T^{miss}

ATLAS-CONF-2017-034

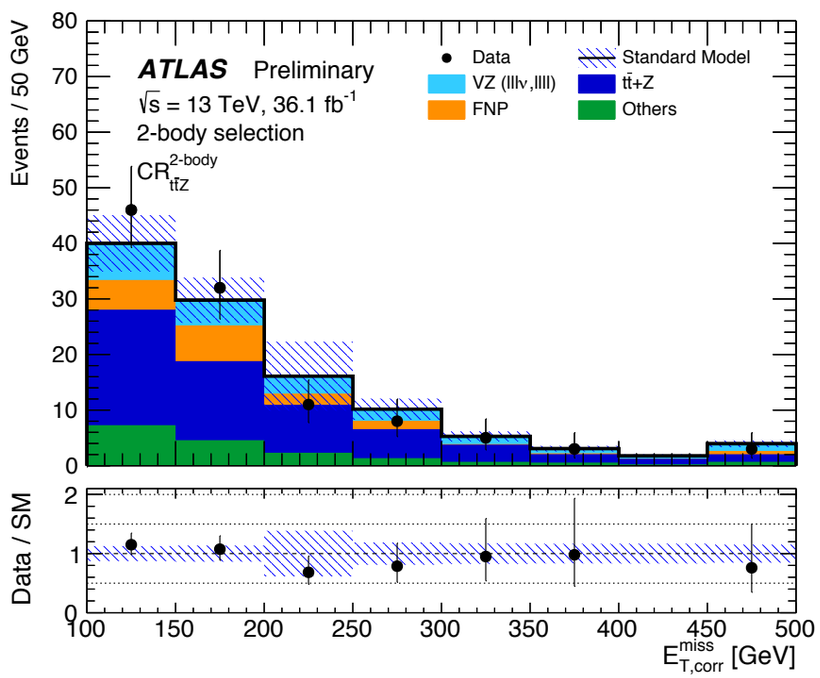
Stop 2L : Backgrounds

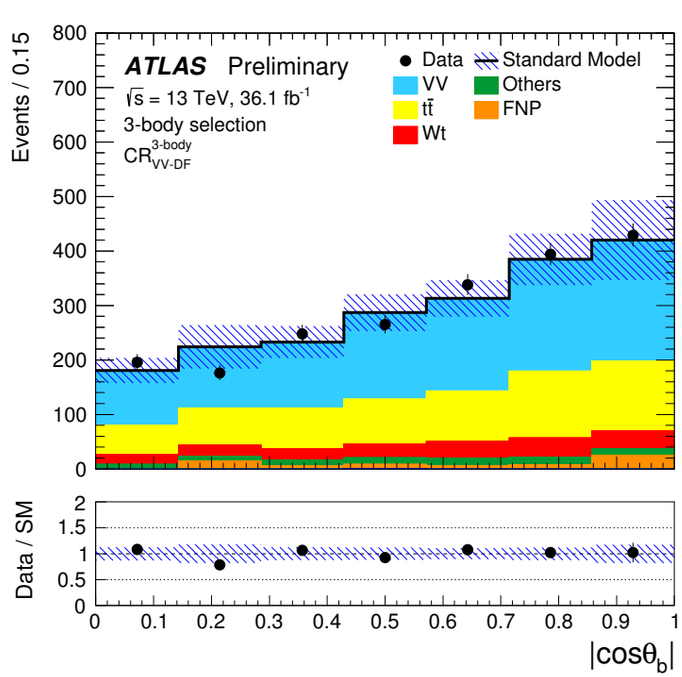
Dominant backgrounds estimated in CRs per SR

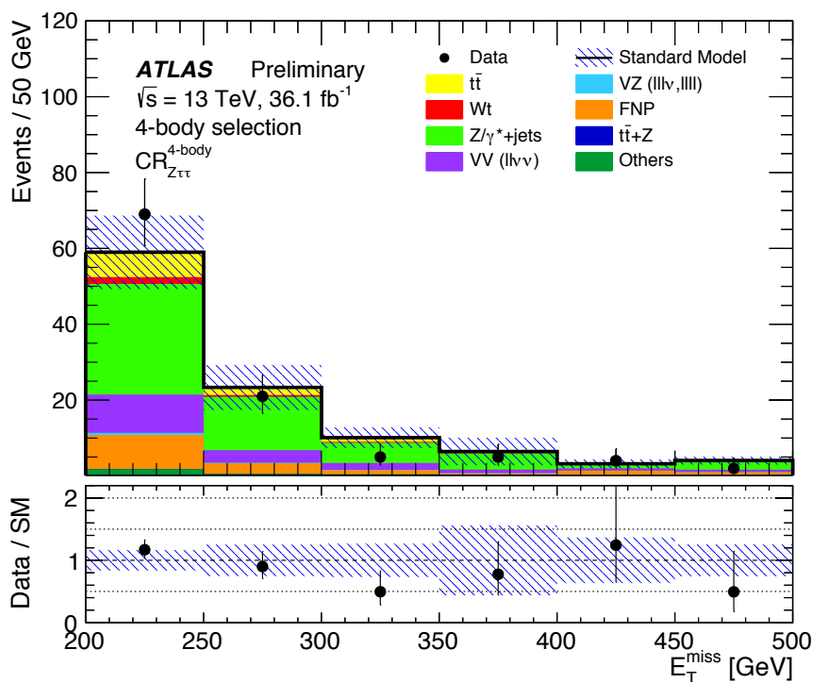
(**top-pair and VV** for all **SRs**, top-pair + *Z* for **2-body** and *Z*→ττ for **4-body**)

The **non-prompt background** is estimated **from data** using *Matrix Method*

Total background systematics typically 20-40%



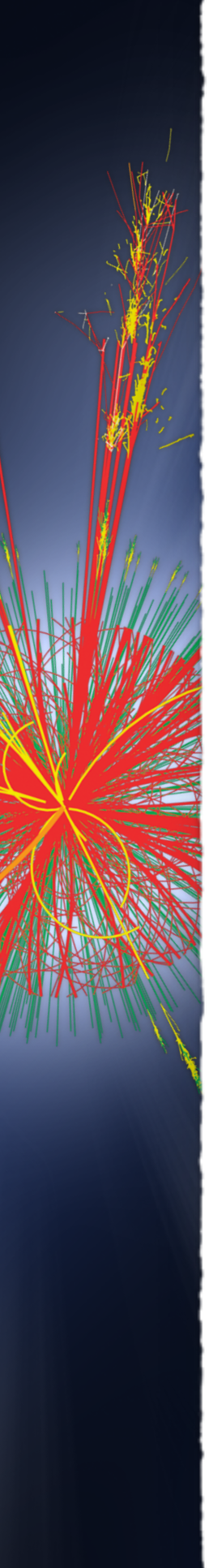


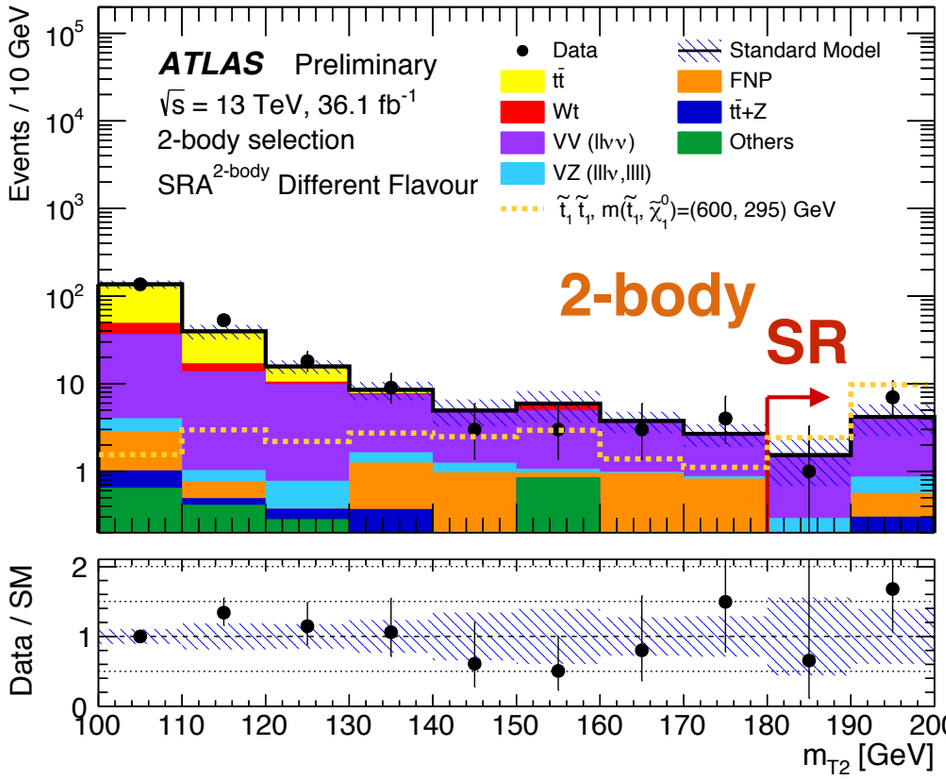


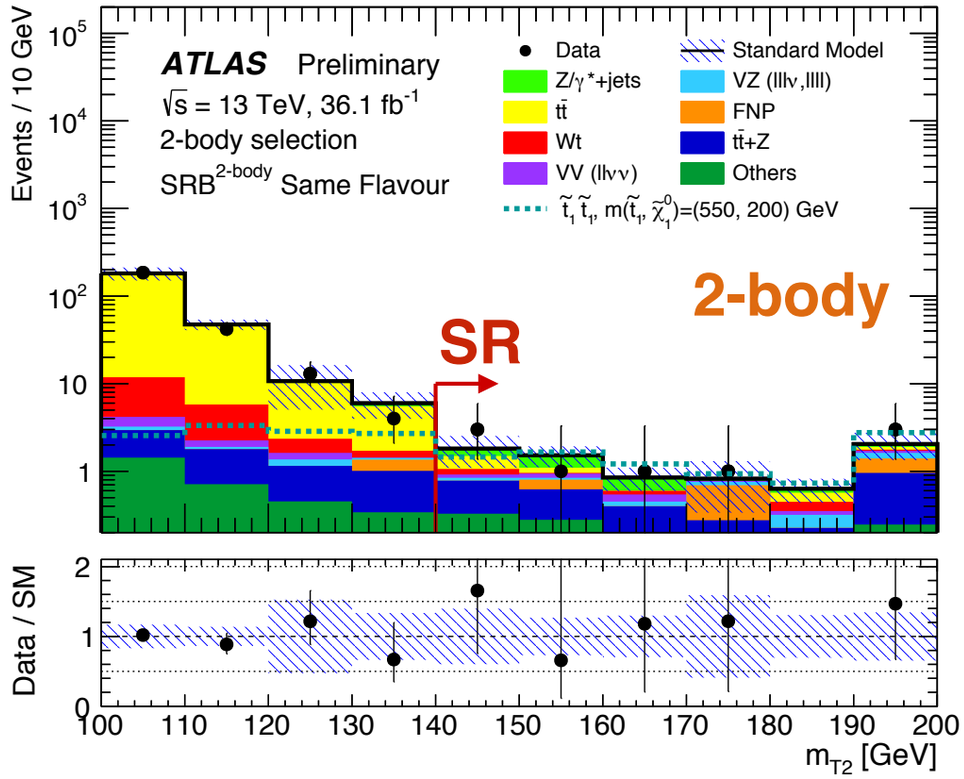
Backgrounds are further validated in dedicated VRs

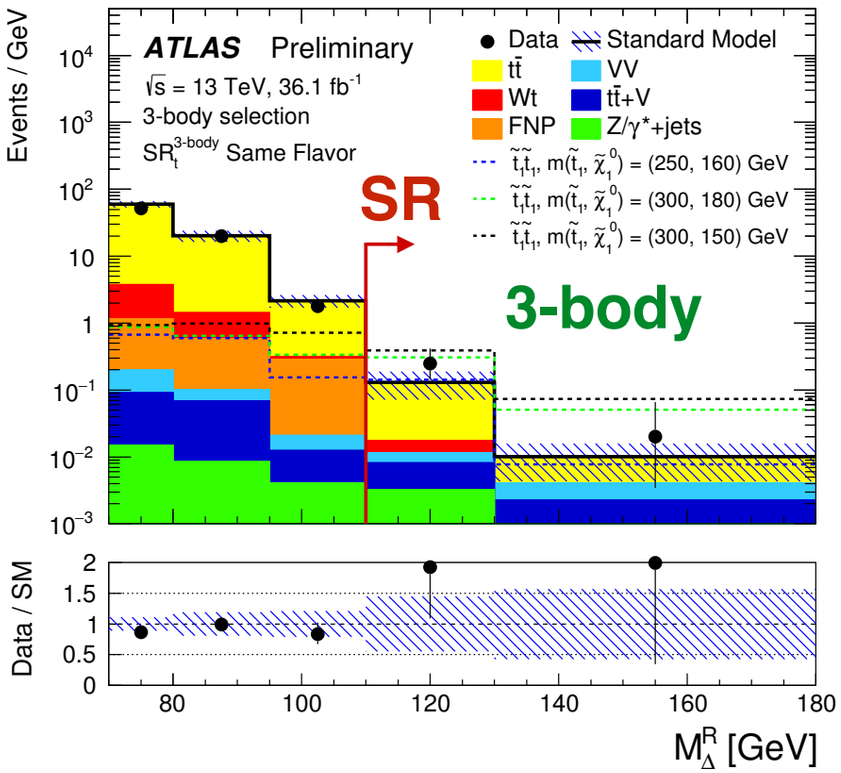
Stop 2L : Results

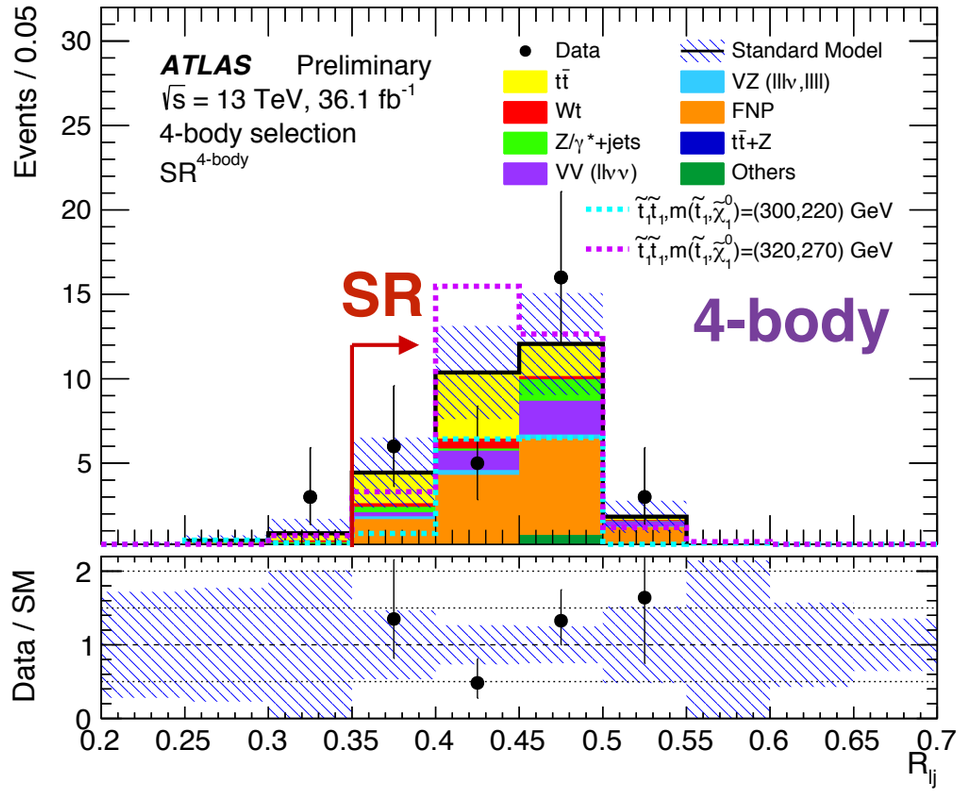
Good data-background agreement in all SRs





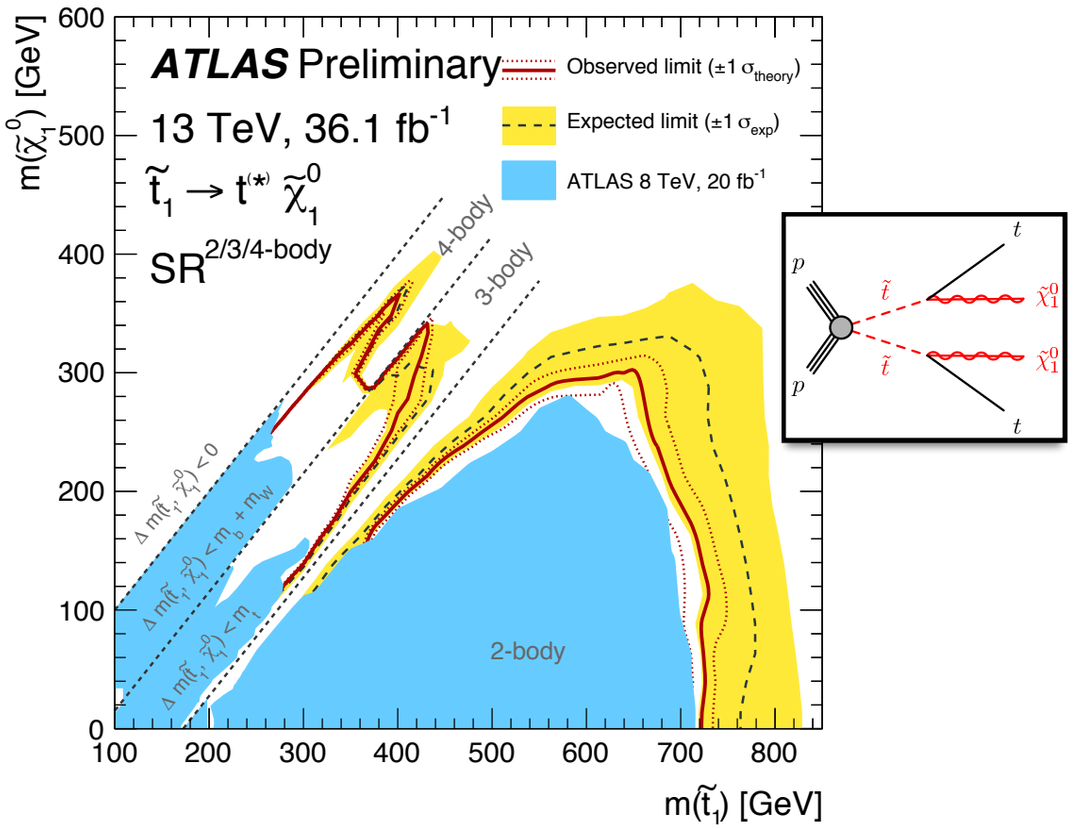


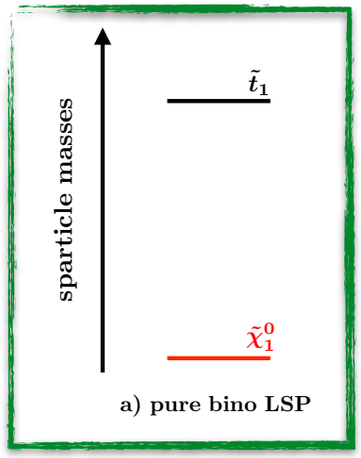




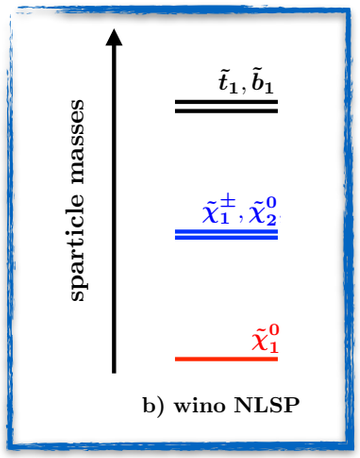
ATLAS-CONF-2017-034

Stop 2L : Interpretations

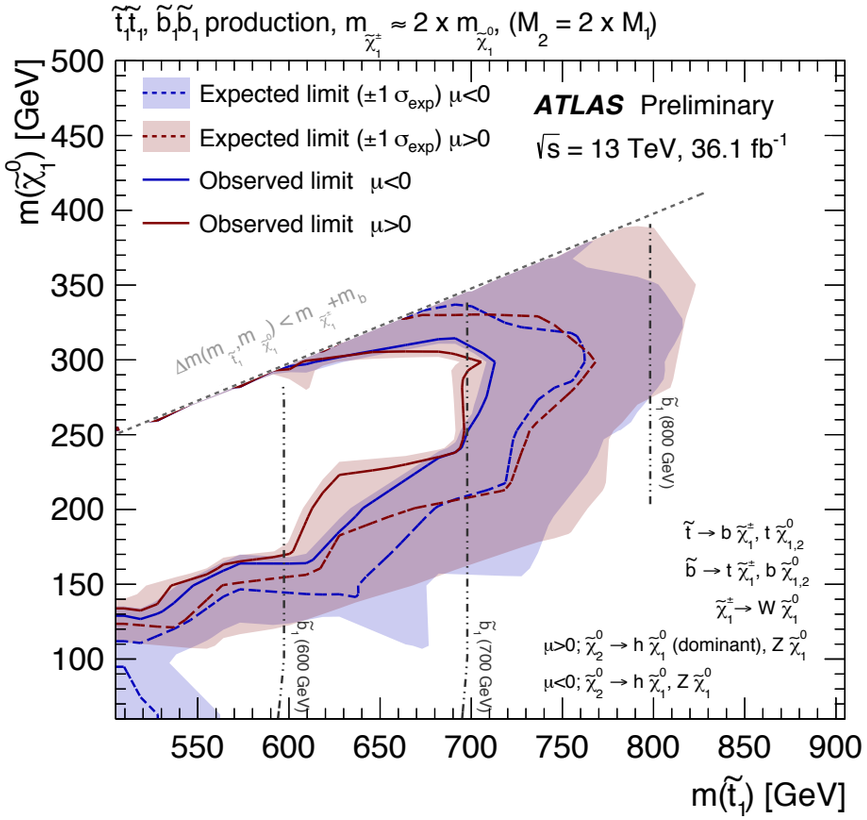




Significant boost in sensitivity for $\Delta m(\tilde{t},\tilde{\chi}_1^0) < m_t$



Strong unique sensitivity in low-$\Delta m(\tilde{t},\tilde{\chi}_1^0)$



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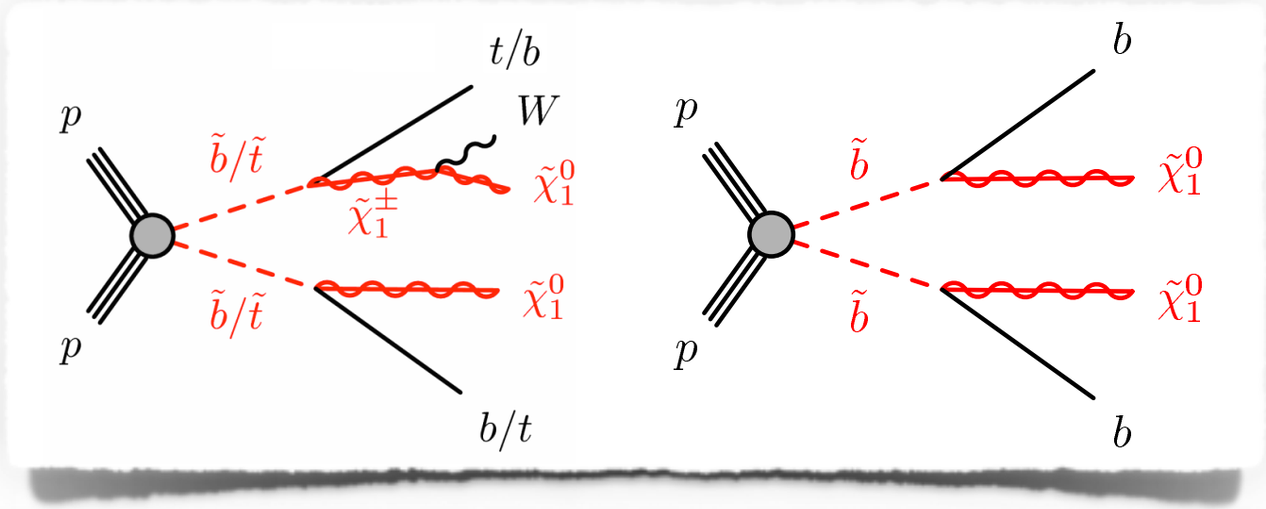
Sbottom : Overview



Search Strategy:

9 SRs targeting final states with 0/1 leptons (e/μ) + b-jets + E_T^{miss}

Two main scenarios : $b\tilde{\chi}_1^0$ (100%) : ***pure***, $b\tilde{\chi}_1^0$ (50%)+ $t\tilde{\chi}_1^\pm$ (50%) : ***mixed***

Two main decay topologies : 0 leptons for ***pure***, 1 lepton (tb) for ***mixed***

Main discriminants include E_T^{miss}, m_{eff}, m_{CT}, $m_T^{j\text{-}min}$, am_{T2} etc.

SRs in a nutshell:

b0L : **5 SR** for different $\Delta m(\tilde{b},\tilde{\chi}_1^0)$ from A (high-Δm) to C (low-Δm)

b1L : **4 SR** probing leptonic top decay and invisible *W* from $\tilde{\chi}_1^\pm$ decay

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Sbottom : Backgrounds

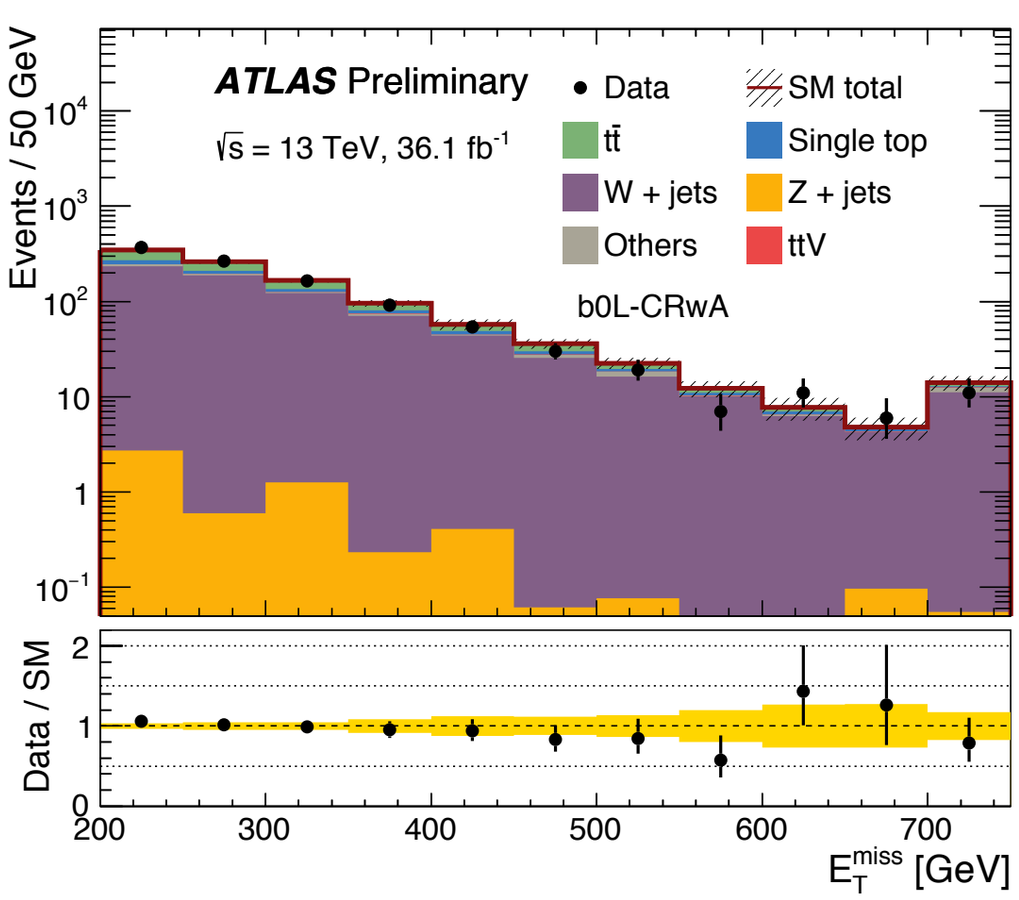
Dominant backgrounds estimated in CRs per SR

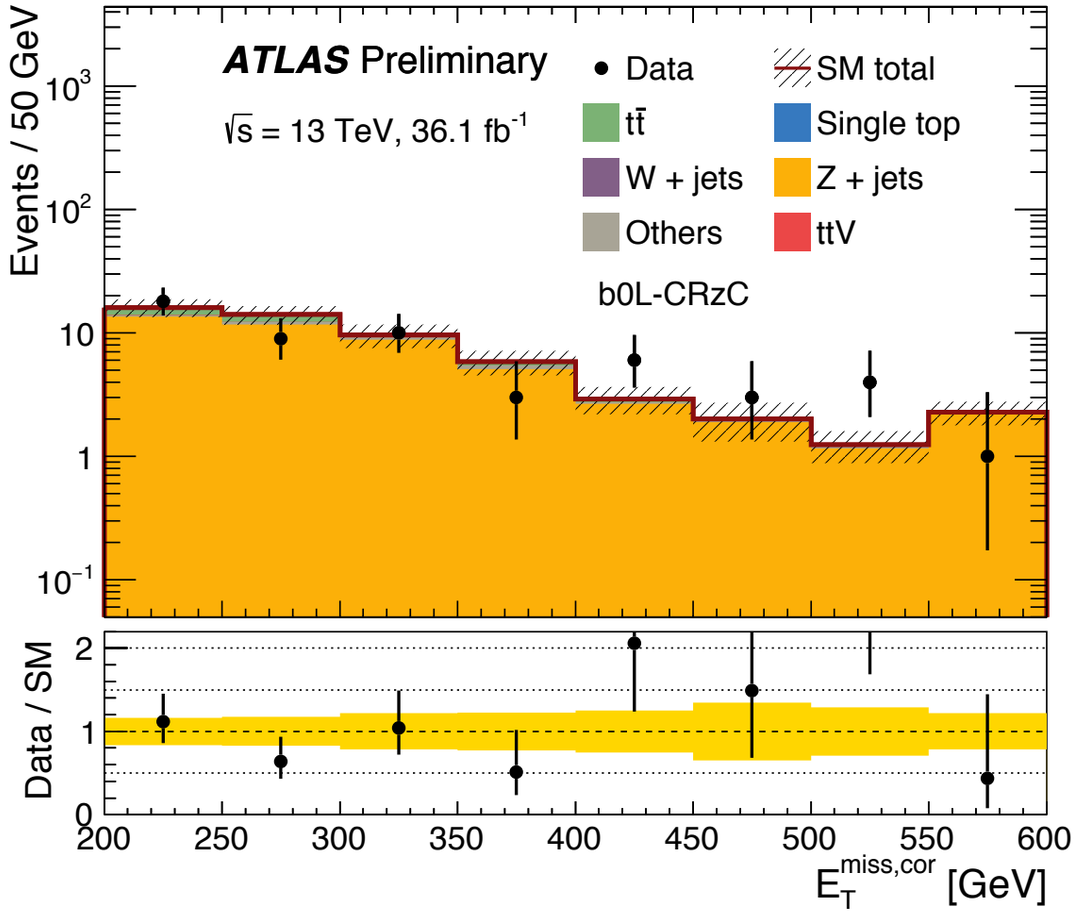
b0L : top-pair and *W*/*Z*+jets for all SRs, and single-top for SRA

b1L : top-pair and single-top for all SRs, and *W*+jets for SRB

The **multi-jet** background is estimated **from data** using the *Jet Smearing Method*

Total background systematics typically 20-30%





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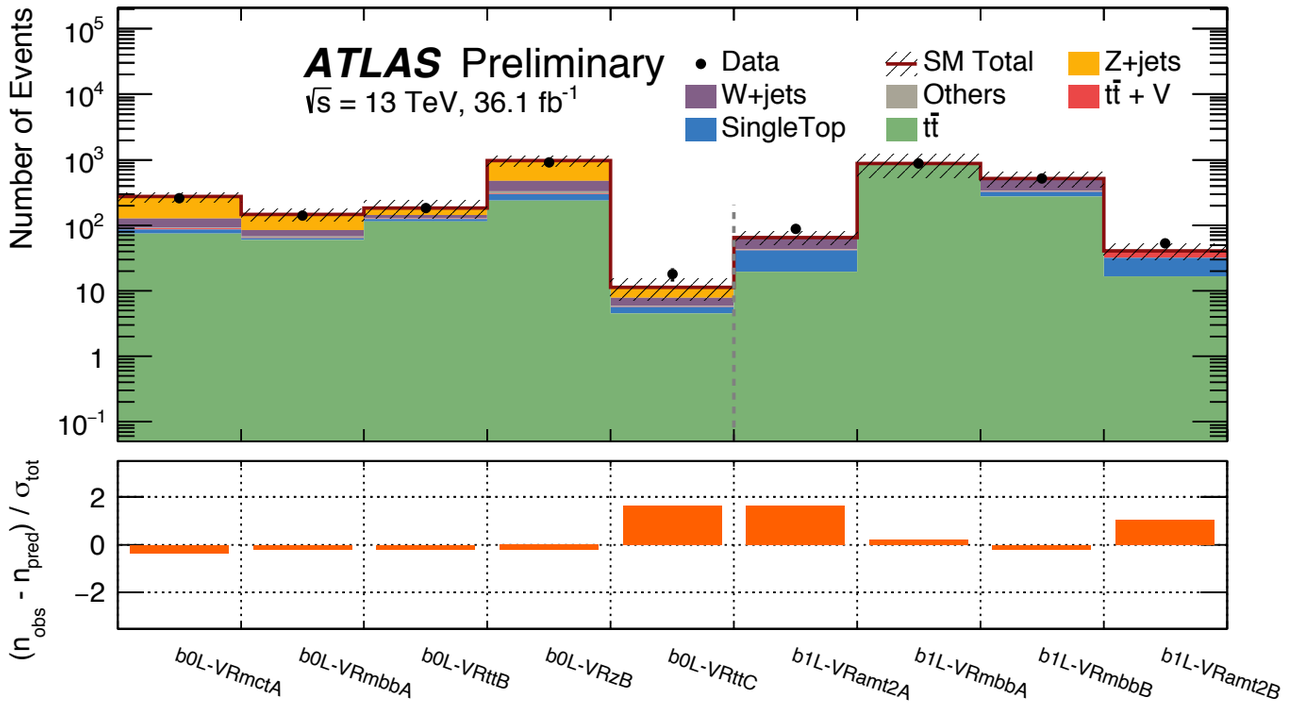
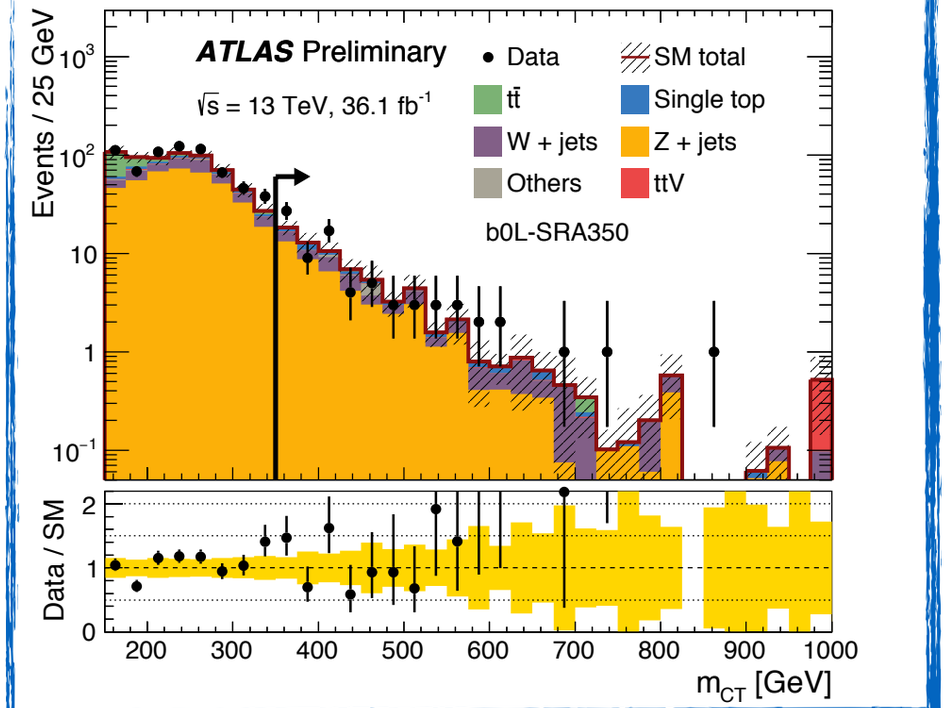
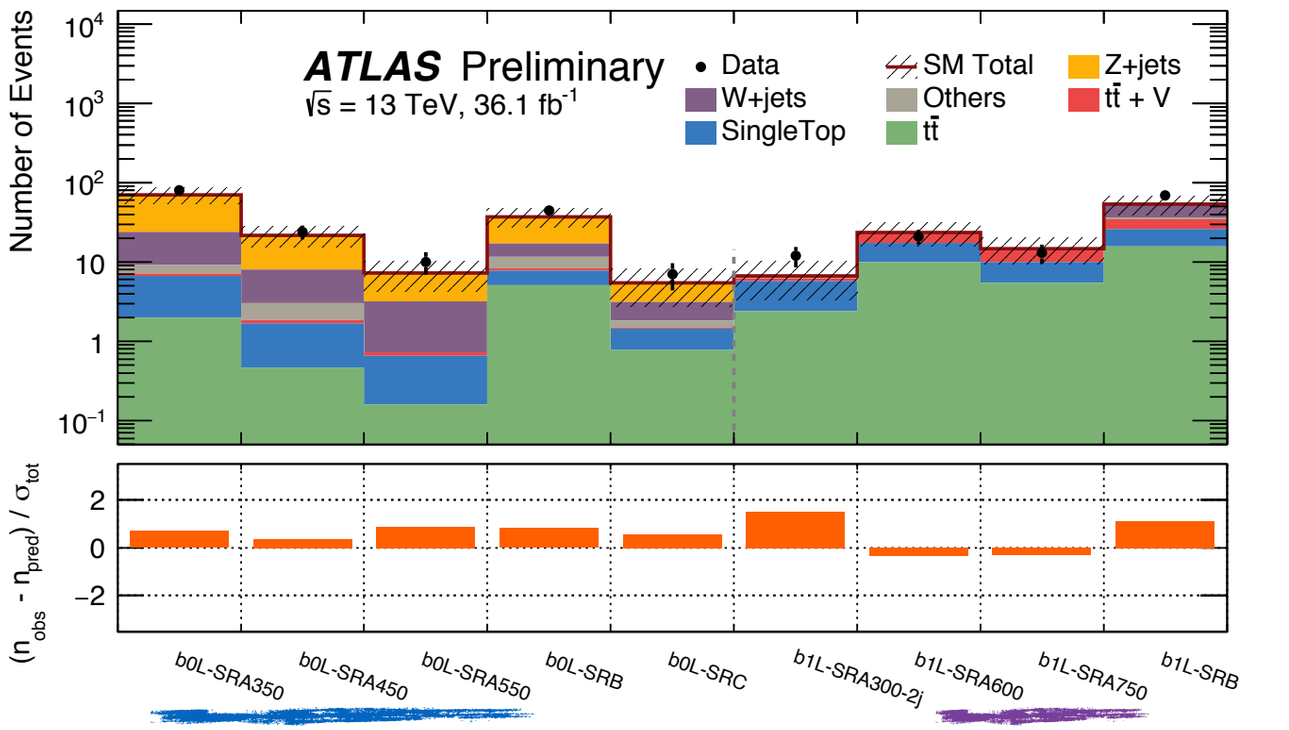
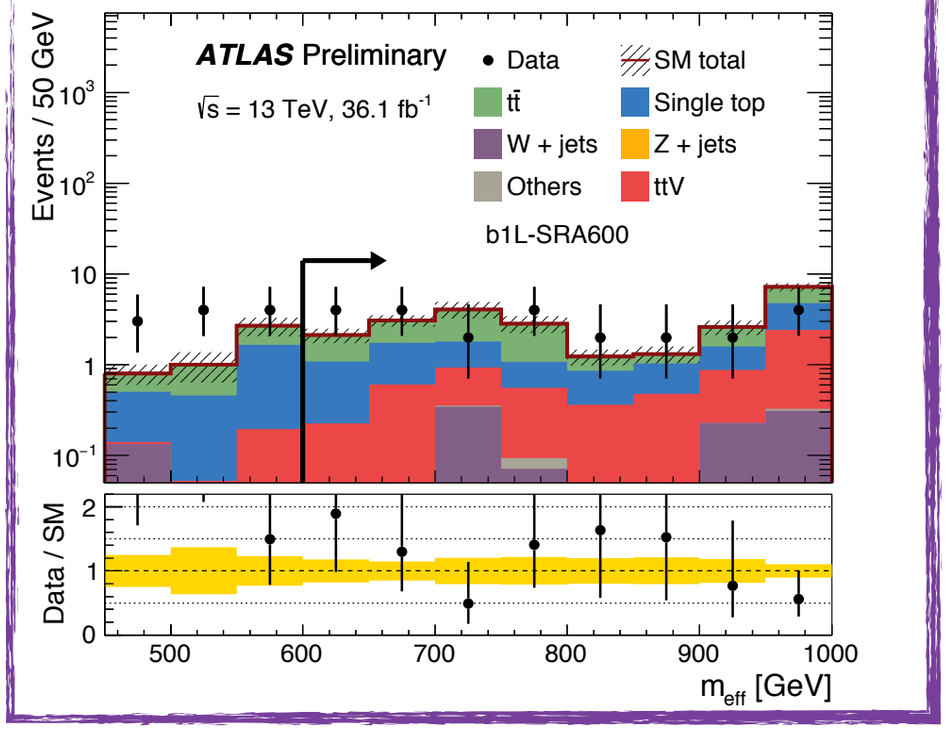
Sbottom : Results

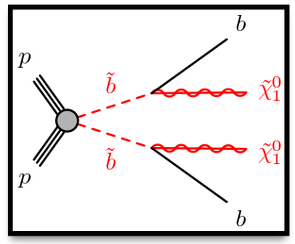


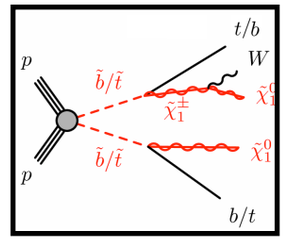


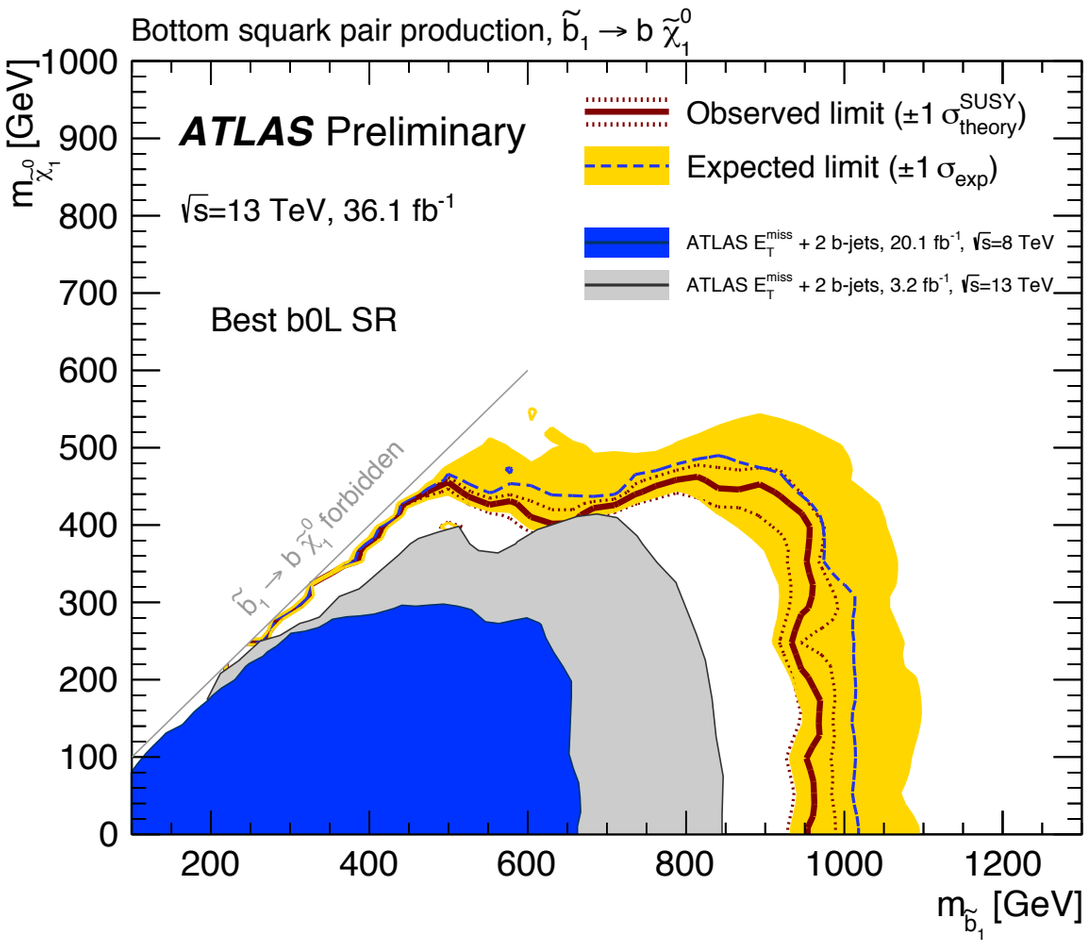


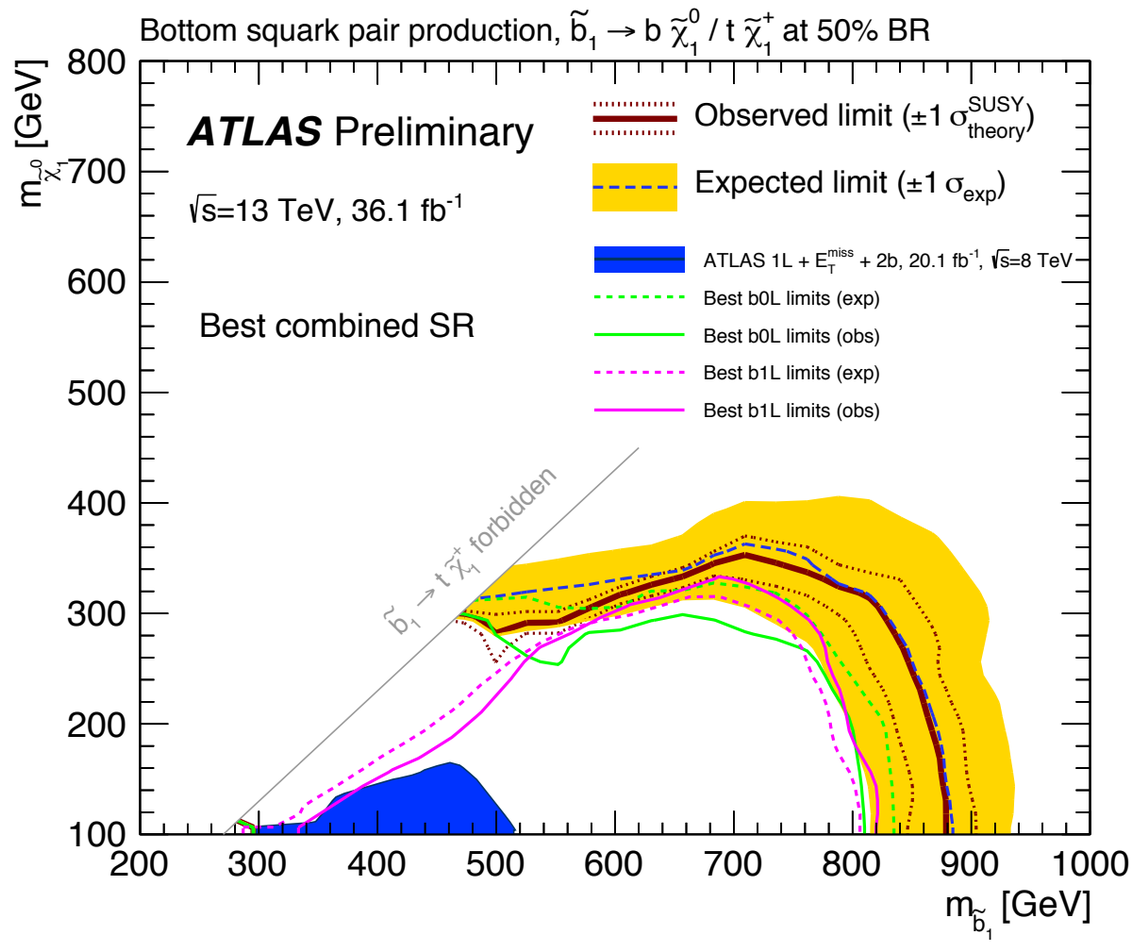


Sbottom : Interpretations





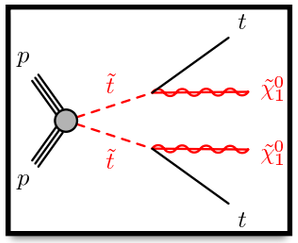


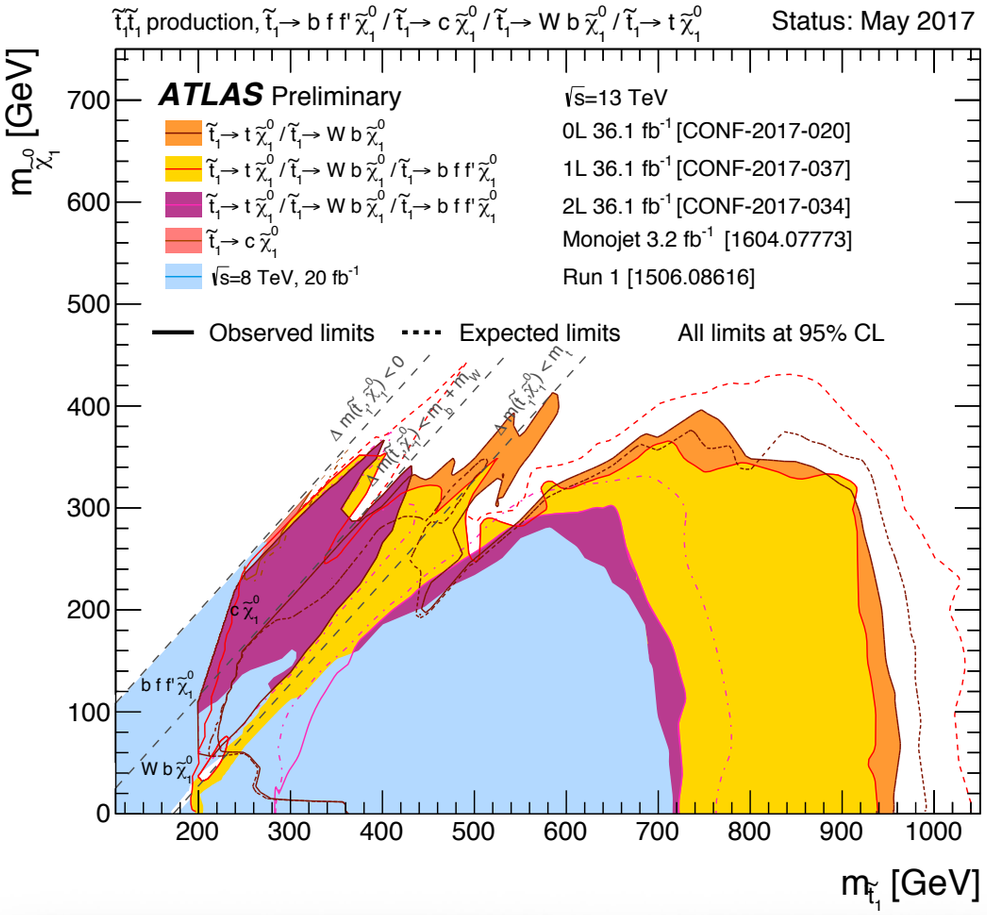


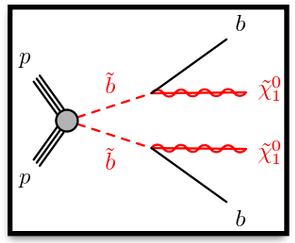
Extended sensitivity in both large mass-splitting and compressed topologies

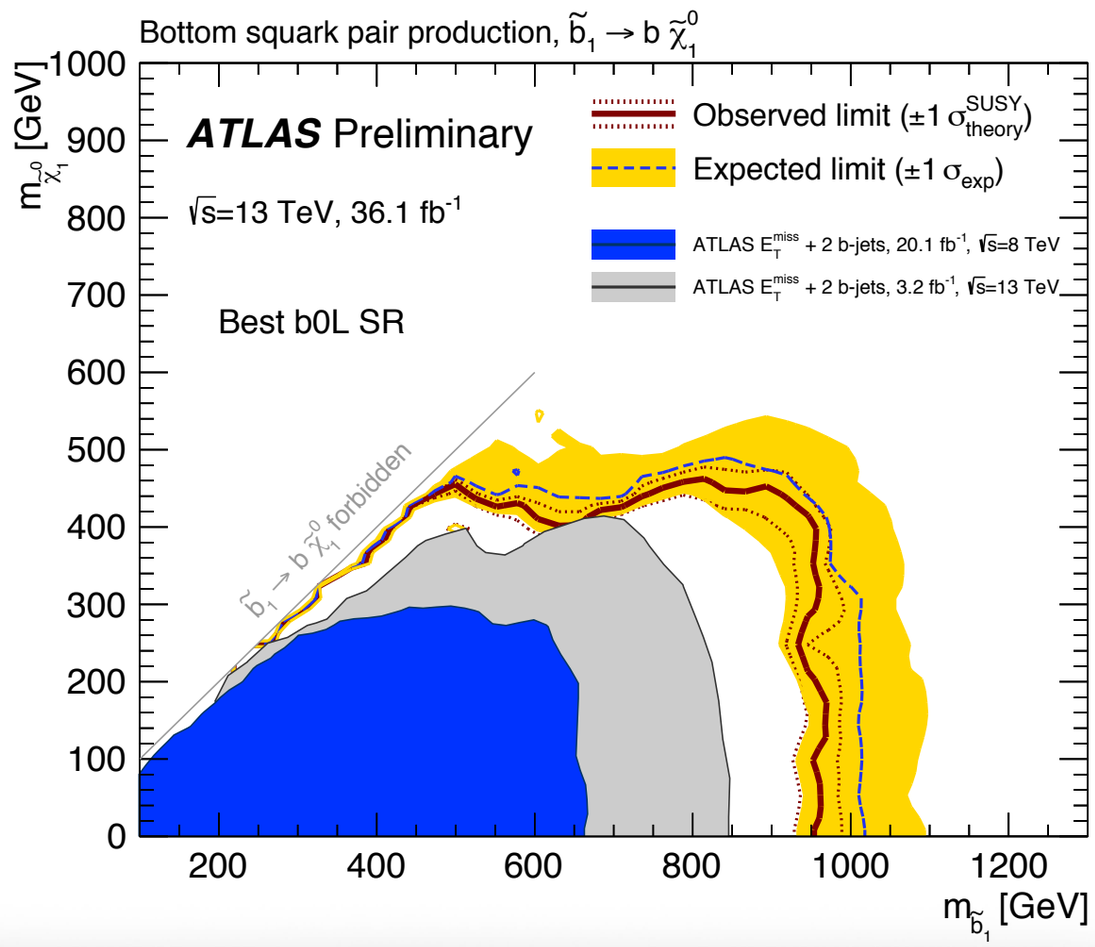
Significant sensitivity gain! Nice complementarity between b0L and b1L SRs

Summary of Direct 3rd Generation Production



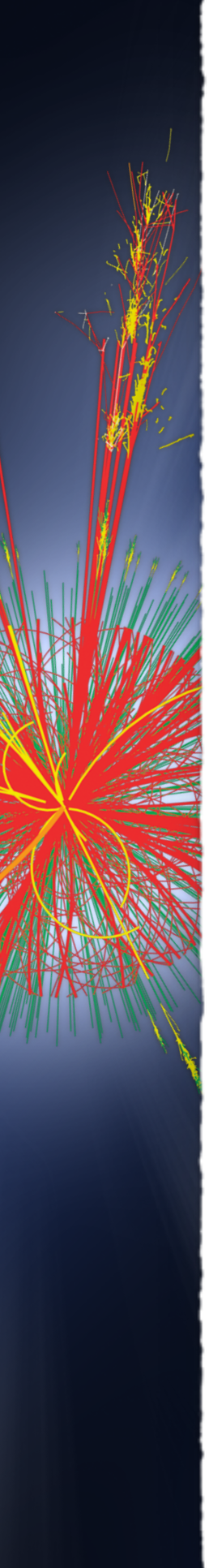


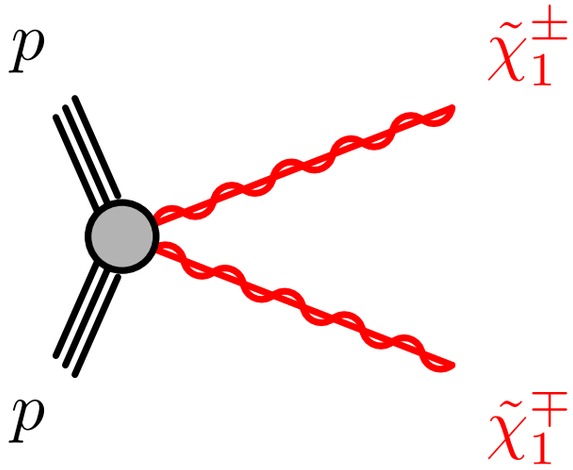


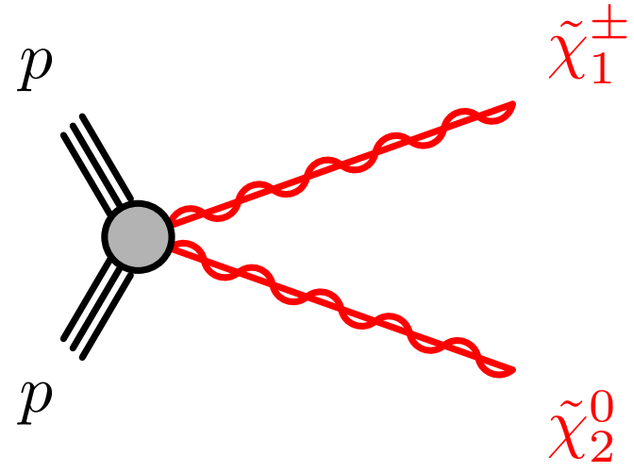


Stops w/ bino LSP : Improved sensitivity for $\Delta m(\tilde{t},\tilde{\chi}_1^0) \sim m_t$ and $\Delta m(\tilde{t},\tilde{\chi}_1^0) < m_W$

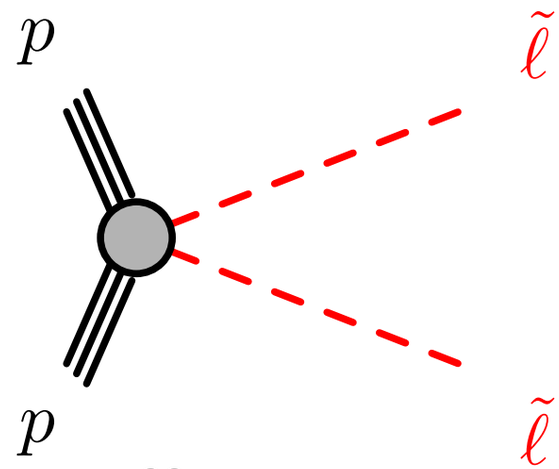
Sbottoms w/ bino LSP : Significant improvements in both low and high $\Delta m(\tilde{b},\tilde{\chi}_1^0)$



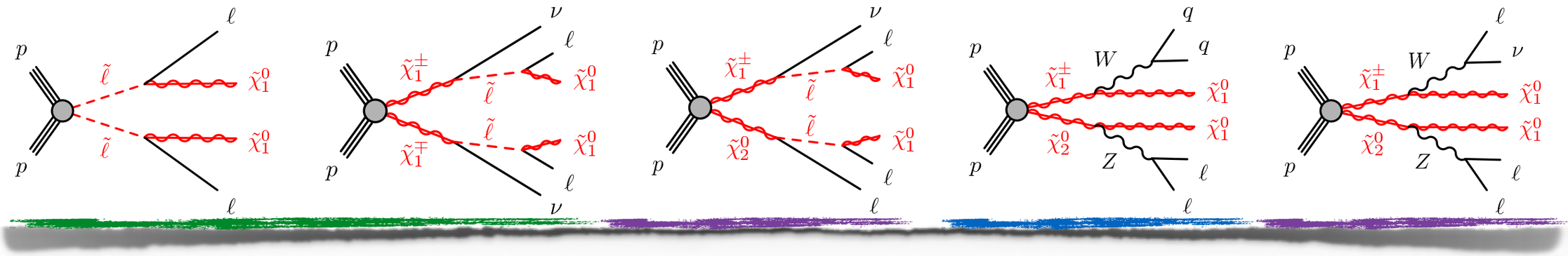




Direct Electroweak Production



2/3L : Overview



Search Strategy:

3 sets of SRs targeting final states with 2/3 leptons (e/μ) + (jets) + E_T^{miss}

Three main scenarios : $\tilde{\ell}\,\tilde{\ell}$, $\tilde{\chi}_1^+\,\tilde{\chi}_1^-$/ $\tilde{\chi}_1^{\pm}\,\tilde{\chi}_2^0$ via $\tilde{\ell}/\tilde{\nu}$, and $\tilde{\chi}_1^{\pm}\,\tilde{\chi}_2^0$ via *W/Z*

Three main final states : **2 leptons + 0 jets**, **2 leptons + jets**, and **3 leptons**

Main discriminants include E_T^{miss}, m_{T2}, $m_{\ell\ell}$, n_{jets}, RJ variables etc.

SRs in a nutshell:

2l + 0 jets : 2-D (m_{T2} - $m_{\ell\ell}$) shape-fit supported by inclusive SRs

2l + jets : Specifically targeting $\tilde{\chi}_1^{\pm}\,\tilde{\chi}_2^0$ via *W/Z* topology

3l : Multi-bin SRs targeting $\tilde{\chi}_1^{\pm}\,\tilde{\chi}_2^0$ via *W/Z* ($\tilde{\ell}/\tilde{\nu}$) with on(off)-shell $\ell^+\ell^-(\ell')$

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2/3L : Results

Background estimation:

2l + 0 jets : **top-pair and VV** from dedicated **CRs**

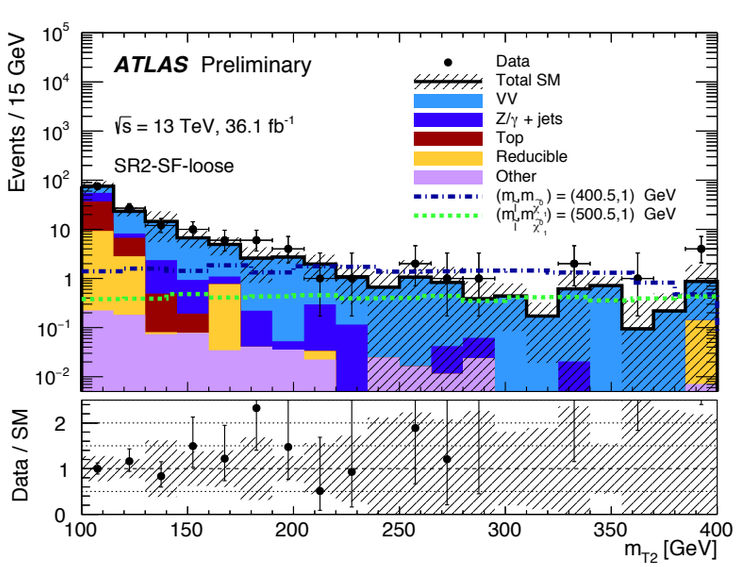
2l + jets : ***Z*+jets** from **data** using orthogonal γ+jets sample

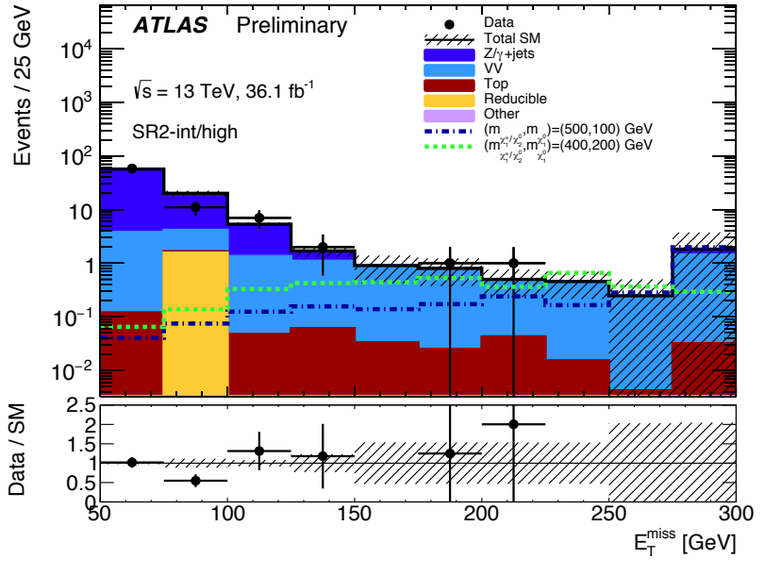
3l : **top-pair, VV, and single-top** from dedicated **CRs**,

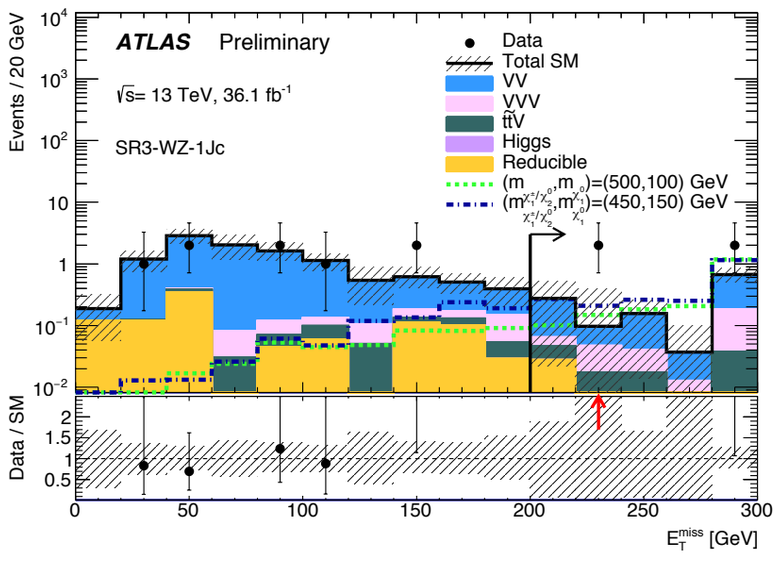
***Z*+jets/γ** from **data** using *Fake Factor Method*

The **non-prompt background** is estimated **from data** using *Matrix Method*

Total background systematics typically 20-50%





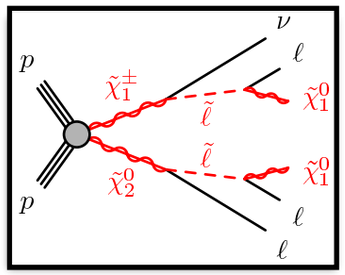


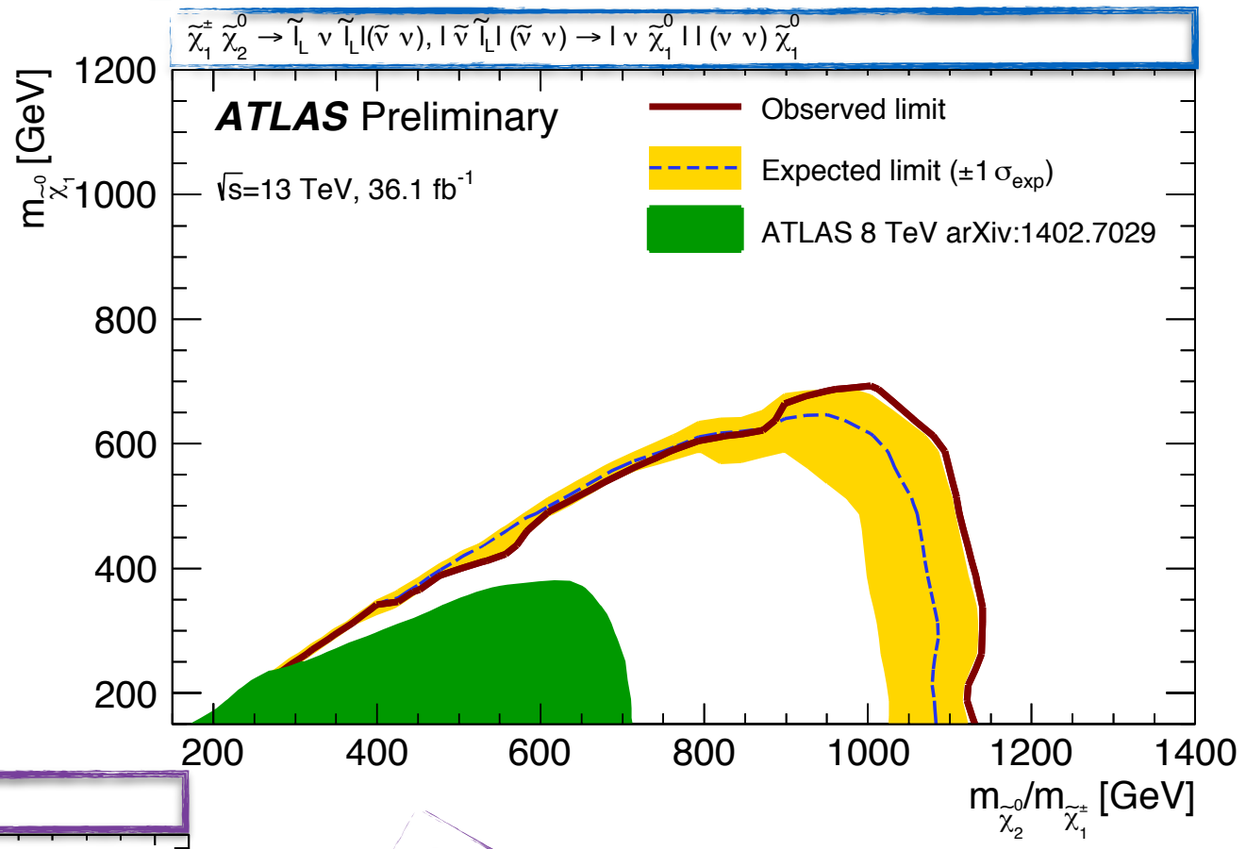
Good data-background agreement in all VRs/SRs

ATLAS-CONF-2017-039

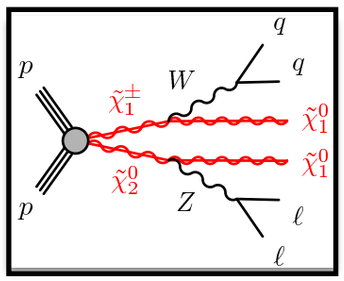
2/3L : Interpretations

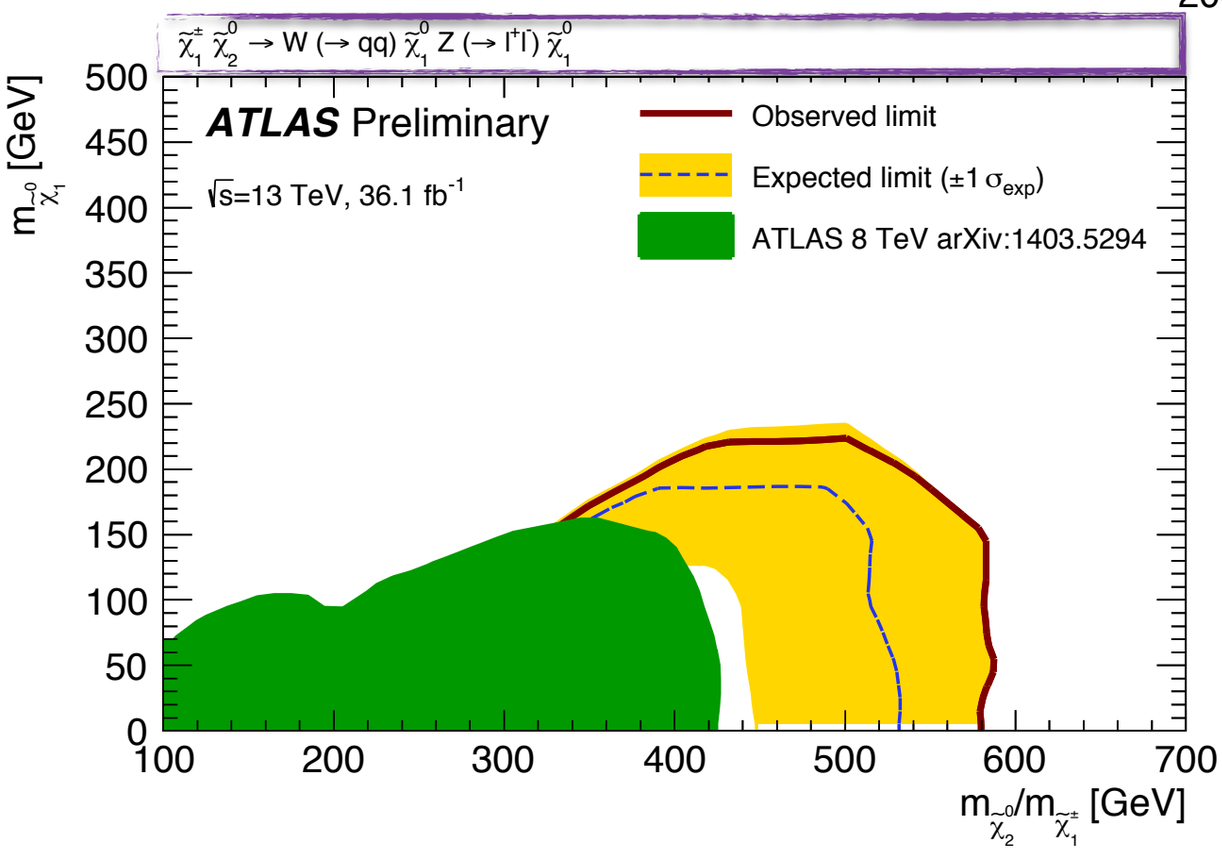
$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ sensitivity above 1 TeV!



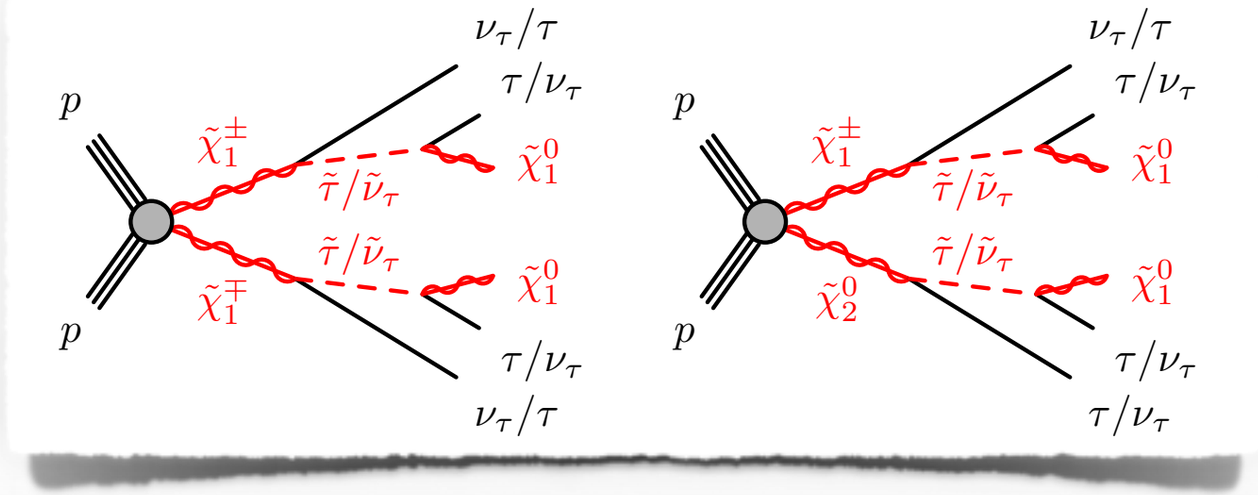


$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ sensitivity above 500 GeV!





≥2 τ_{had} : Overview



Search Strategy:

2 SRs targeting final states with ≥2 τ_{had} + E_T^{miss}

Two main scenarios : $\tilde{\chi}_1^+\tilde{\chi}_1^-$ via $(\tilde{\ell}_\tau/\tilde{\nu}_\tau)$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via $(\tilde{\ell}_\tau/\tilde{\nu}_\tau)$

One inclusive final state topology : ≥2 τ_{had} capturing both scenarios

Main discriminants include E_T^{miss}, m_{T2}, $m_{\tau\tau}$, $n_{b\text{-jets}}$ etc.

SRs in a nutshell:

SR-lowMass : Targets moderate $\Delta m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0,\tilde{\chi}_1^0)$ and m_{T2} > 70 GeV

SR-highMass : Targets large $\Delta m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0,\tilde{\chi}_1^0)$, m_{T2} > 70 GeV, and $m_{\tau\tau}$ > 110 GeV

Both SRs rely on *Z*/*b*-veto

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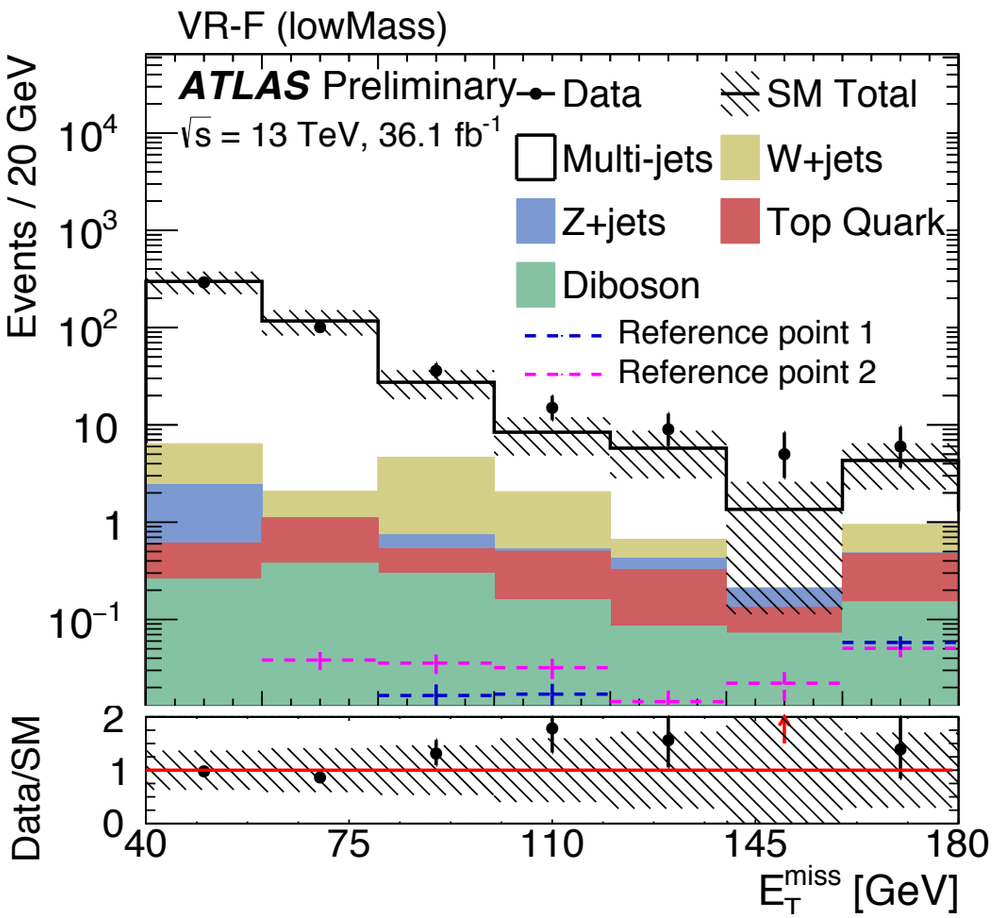
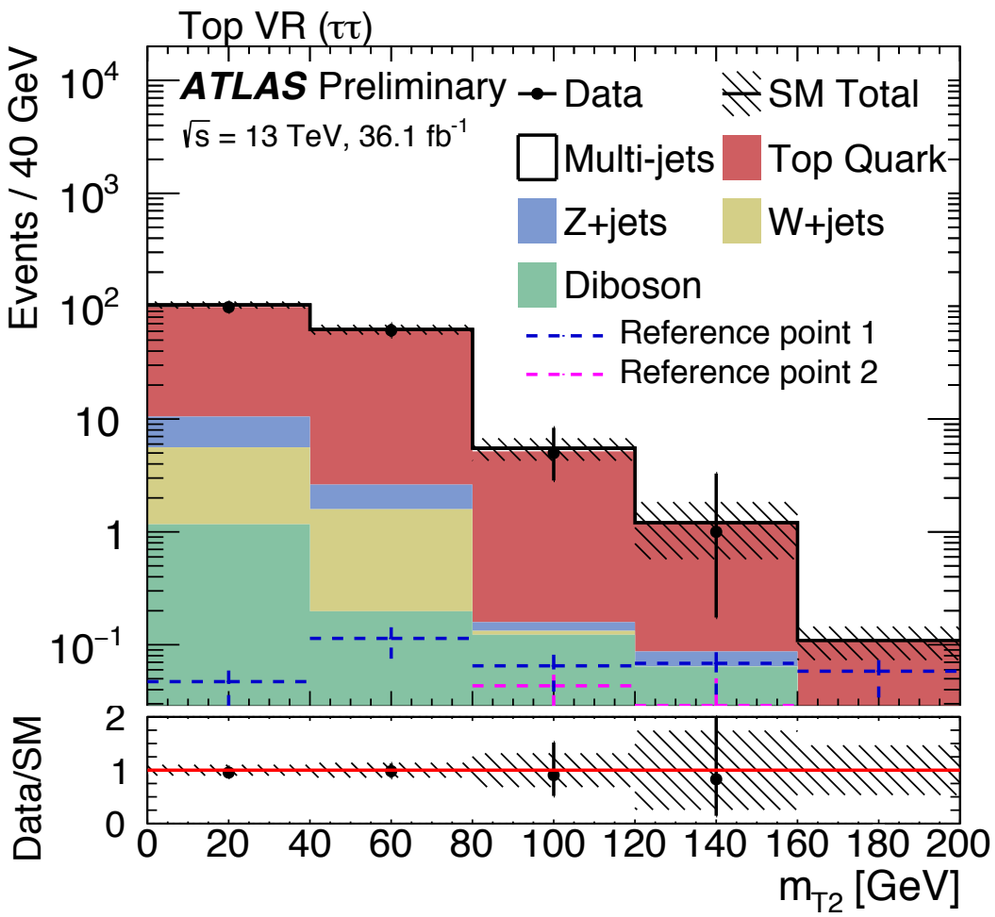
≥2 T_{had} : Backgrounds

The **multi-jet** background is estimated **from data** using the *ABCD Method*

W+jets from a dedicated CR using μτ sample

Total background systematics typically 35-40%





Good data-background agreement in VRs

Ref. point #1 : $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ w/ $m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0)$ = 600 GeV and $m(\tilde{\chi}_1^0)$ = 0 GeV

Ref. point #2 : $\tilde{\chi}_1^+\tilde{\chi}_1^-$ w/ $m(\tilde{\chi}_1^{\pm})$ = 600 GeV and $m(\tilde{\chi}_1^0)$ = 0 GeV

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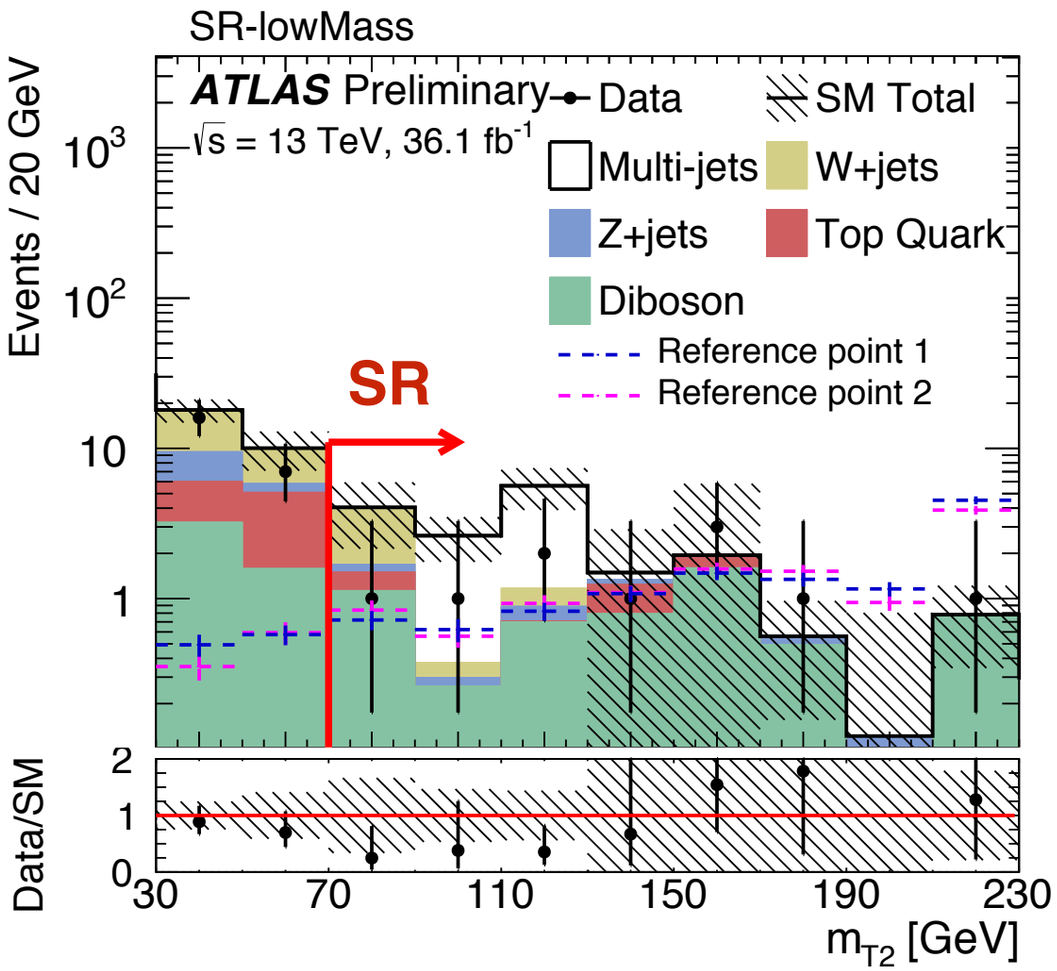
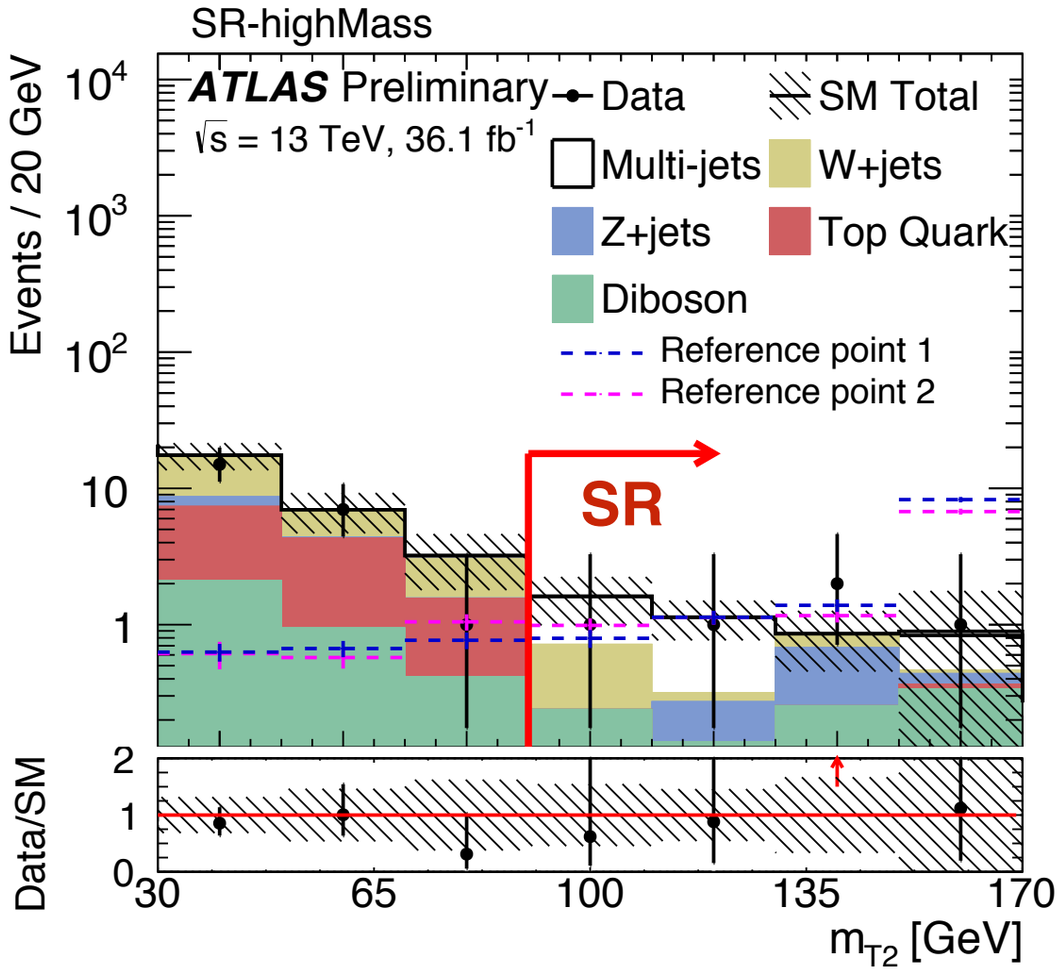
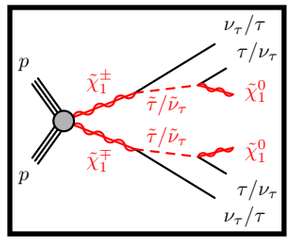
≥2 T_{had} : Results

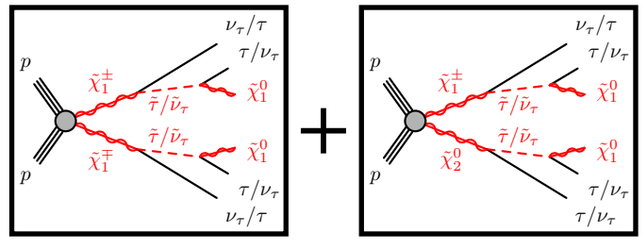


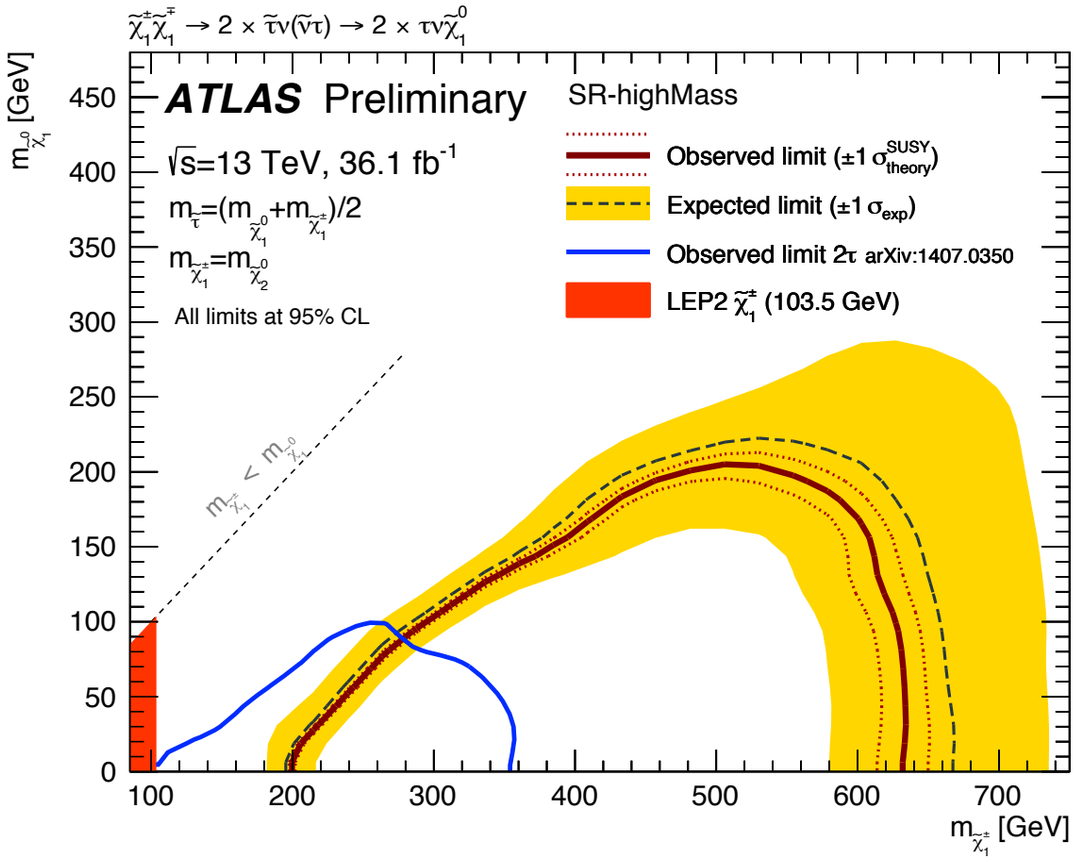


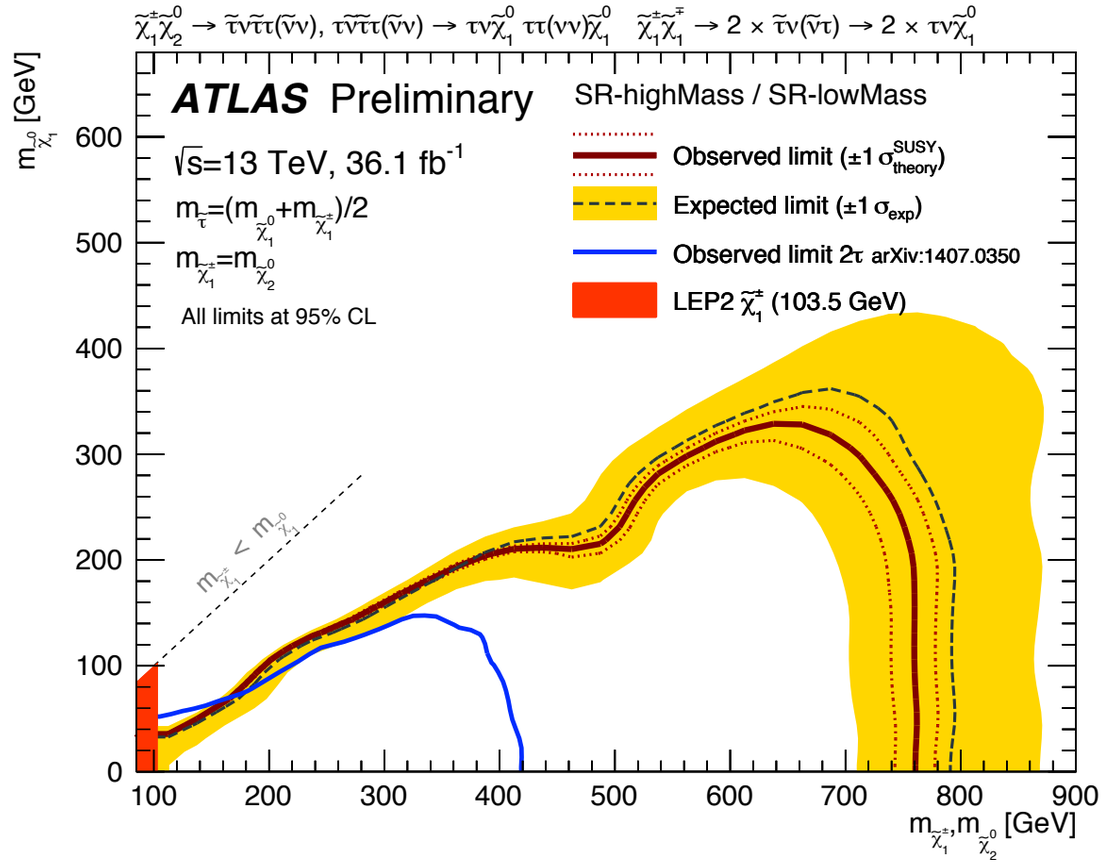
No excess over background expectations in the search regions

≥2 T_{had} : Interpretations







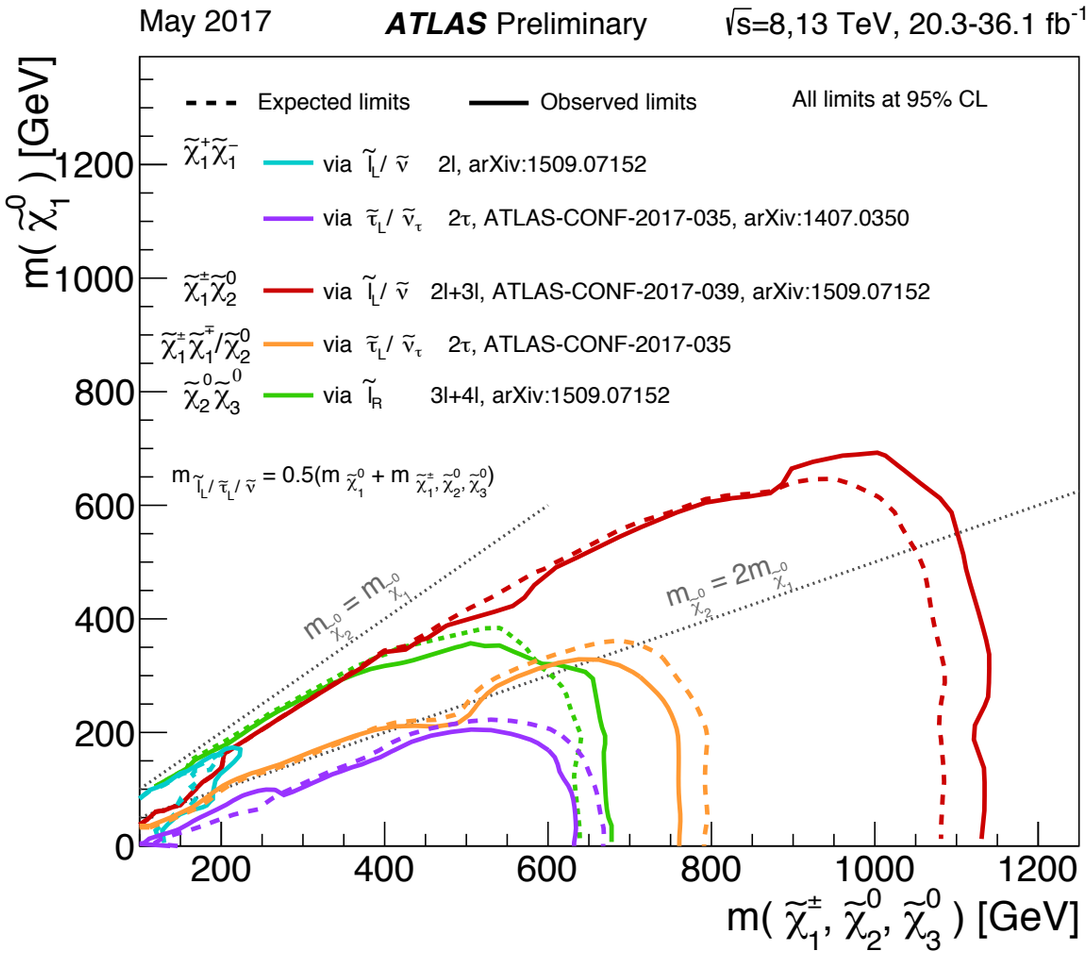


$\tilde{\chi}_1^+\tilde{\chi}_1^-$: Excluded $m(\tilde{\chi}_1^\pm)$ up to 630 GeV for $m(\tilde{\chi}_1^0) = 0$ GeV

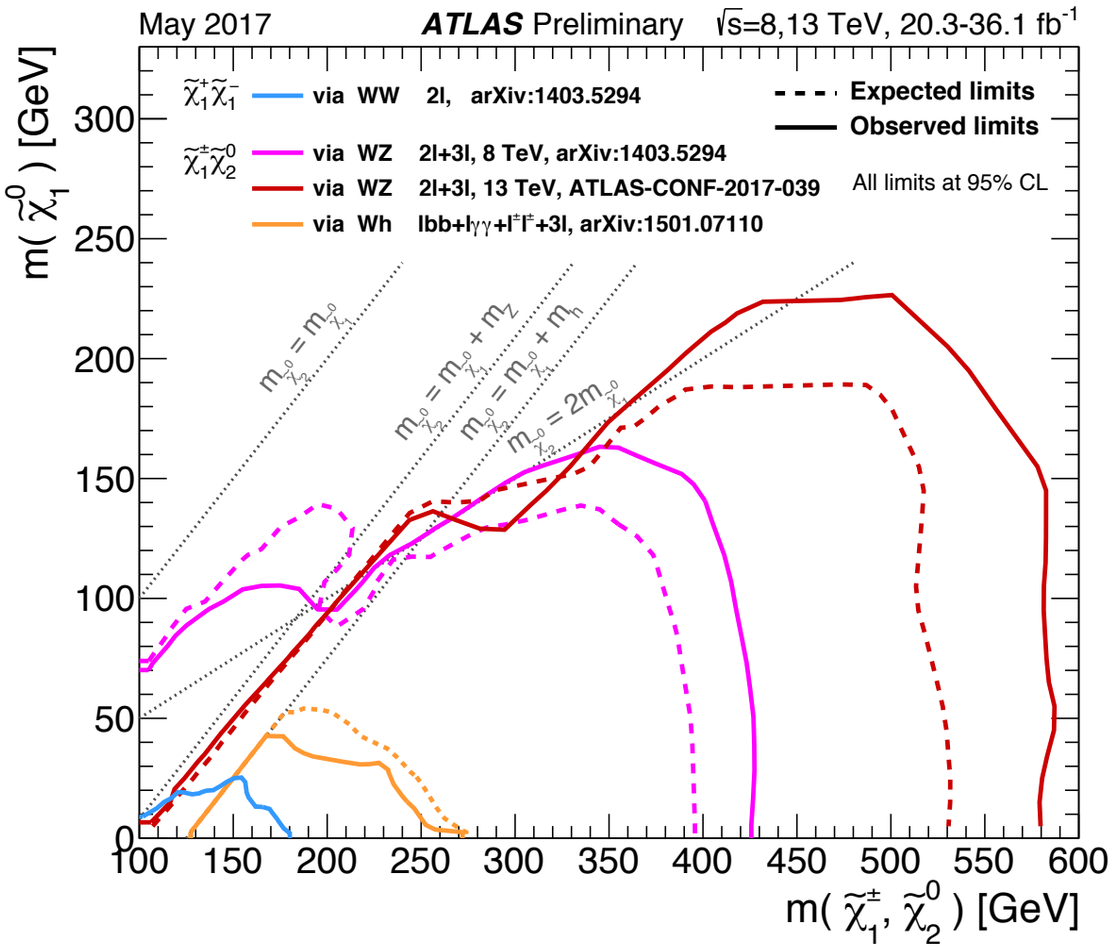
$\tilde{\chi}_1^+\tilde{\chi}_1^- + \tilde{\chi}_1^\pm\tilde{\chi}_2^0$: Excluded $m(\tilde{\chi}_1^\pm/\tilde{\chi}_2^0)$ up to 760 GeV for $m(\tilde{\chi}_1^0) = 0$ GeV

Summary of Direct Electroweak Production

$\tilde{\ell}/\tilde{\nu}$ mediated decays

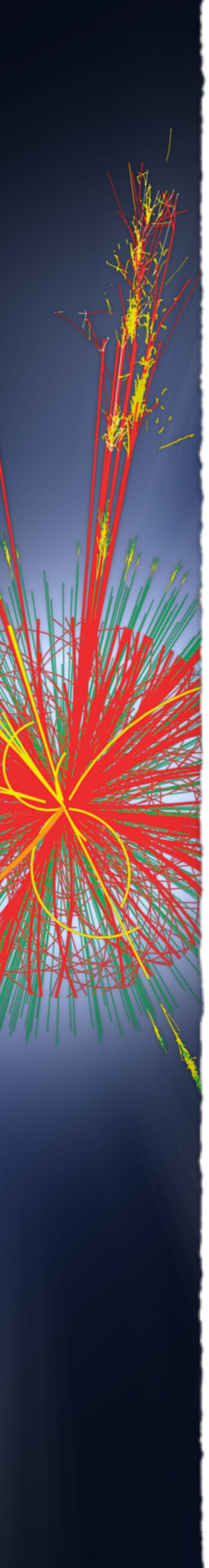


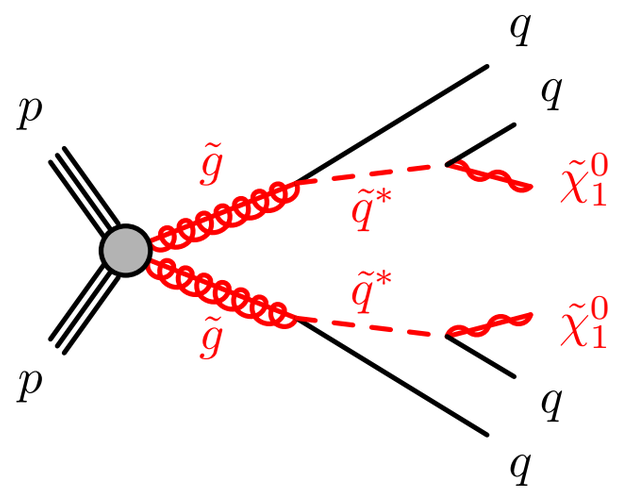
$W/Z/h$ mediated decays



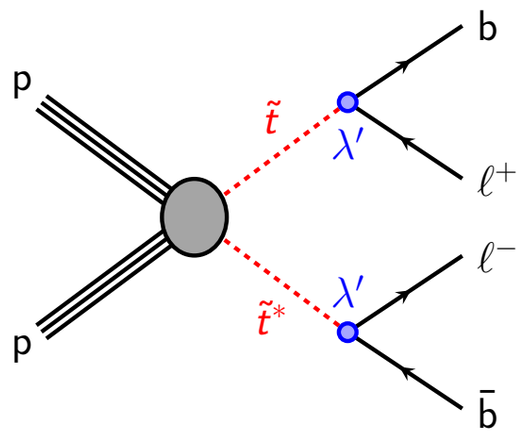
$\tilde{\ell}/\tilde{\nu}$ mediated decays : Sensitivity exceeding $m(\tilde{\chi}_1^\pm/\tilde{\chi}_2^0) = 1$ TeV!

W/Z/h mediated decays : Sensitivity exceeding $m(\tilde{\chi}_1^\pm/\tilde{\chi}_2^0) = 0.5$ TeV!

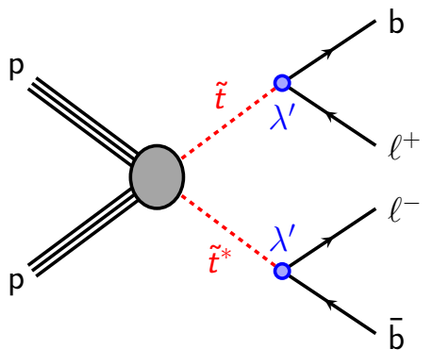




RPV/Long-Lived



Stop B-L : Overview



RPV motivated by a new subgroup $U(1)_{B-L}$ (baryon-lepton)

Stop (NLSP) decays into pairs of high-p_T *b*-quark and ℓ

Scan m($\tilde{t}$) and BR($\tilde{t} \rightarrow b$ + e/μ/τ)

Search Strategy:

2 SRs targeting final states with ≥2 leptons (e/μ) + ≥2 jets (≥1 *b*-jet)

SRs optimized assuming BR($\tilde{t} \rightarrow b$ + e) = BR($\tilde{t} \rightarrow b$ + μ) = 50%

Two main kinematic topologies : One for low and one for high m($\tilde{t}$)

Main discriminants include H_T, $n_{b\text{-jets}}$, m_{bl}, m_{ll}, m_{CT} etc.

SRs in a nutshell:

Choose *b*-*l* pairings by minimizing $m_{asym} = m_{bl}^0 - m_{bl}^1/(m_{bl}^0 + m_{bl}^1) < 0.2$

Require high-H_T (>1 TeV) and high-m_{ll} (> 300 GeV) to reduce background

SR800 requiring $m_{bl}^0 > 800$ GeV and **SR1100** requiring $m_{bl}^0 > 1.1$ TeV

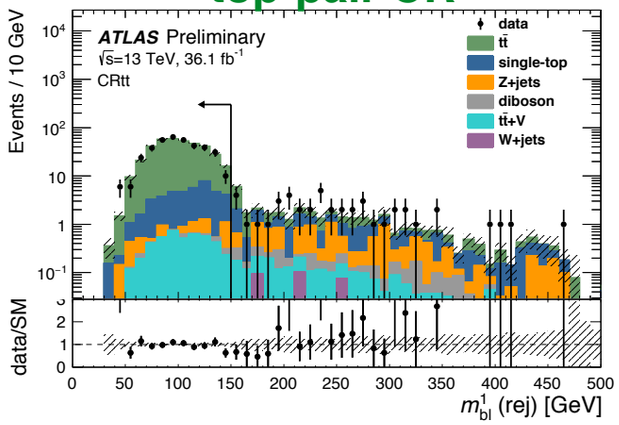
Stop B-L : Backgrounds

Dominant backgrounds estimated in CRs per SR

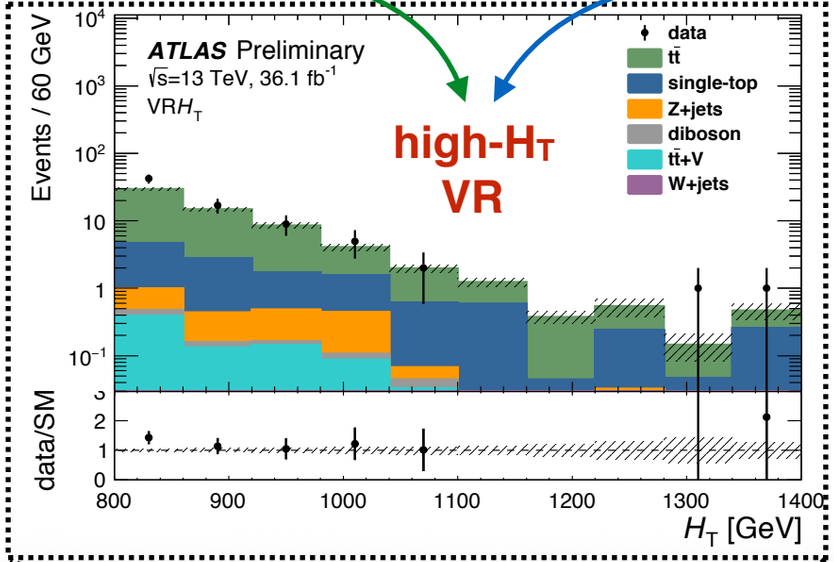
(**top-pair, single-top, and *Z*+jets**)

Total background systematics typically 20-50%

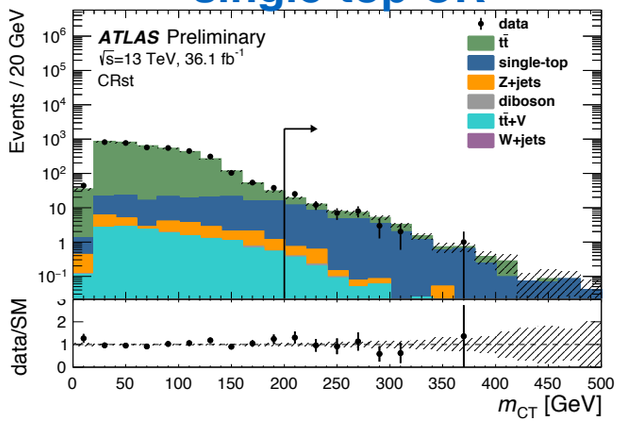
top-pair CR

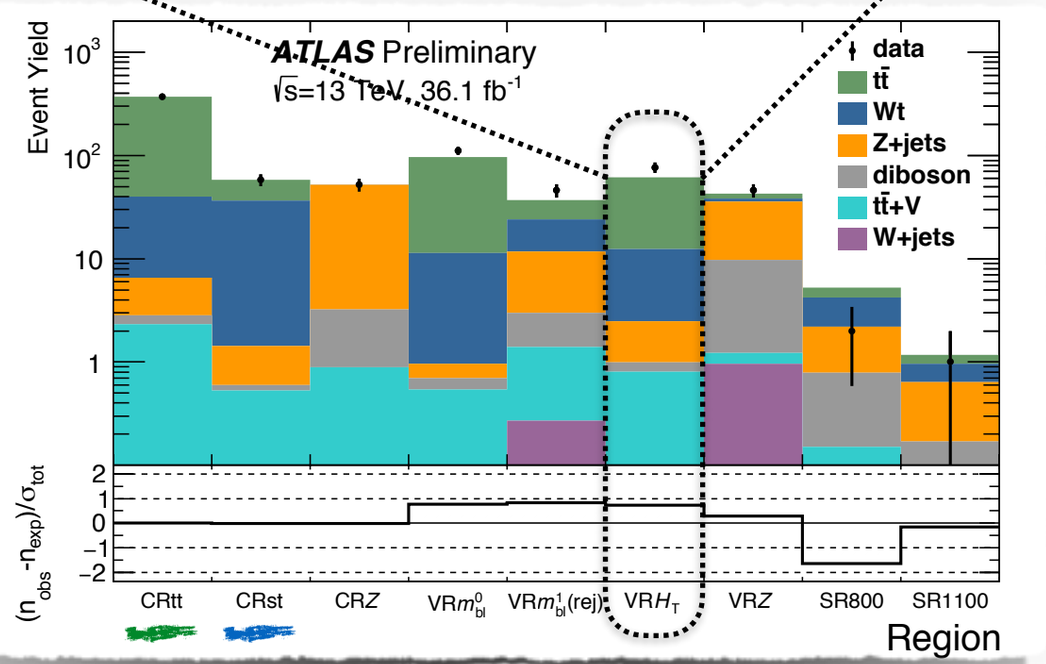


high-H_T VR



single-top CR





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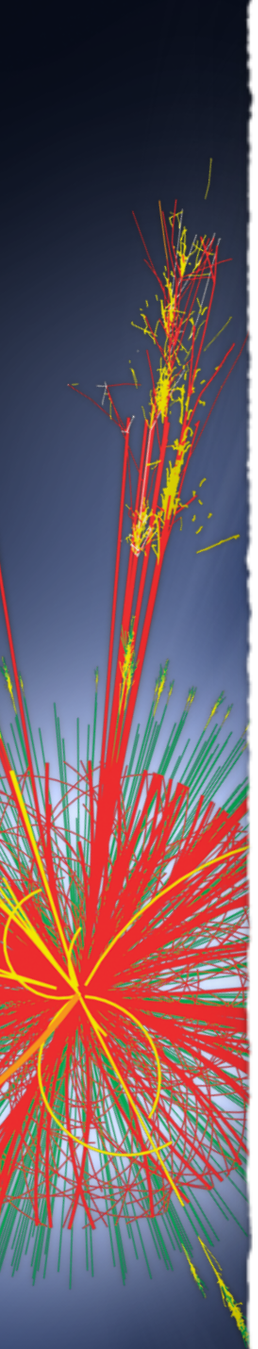
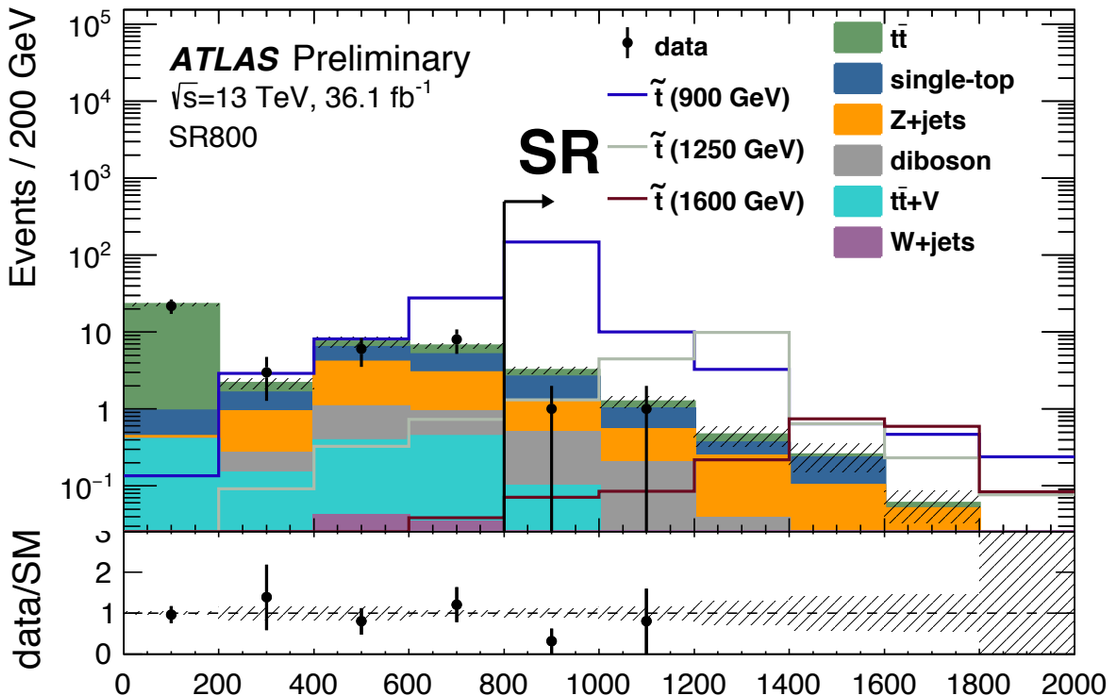
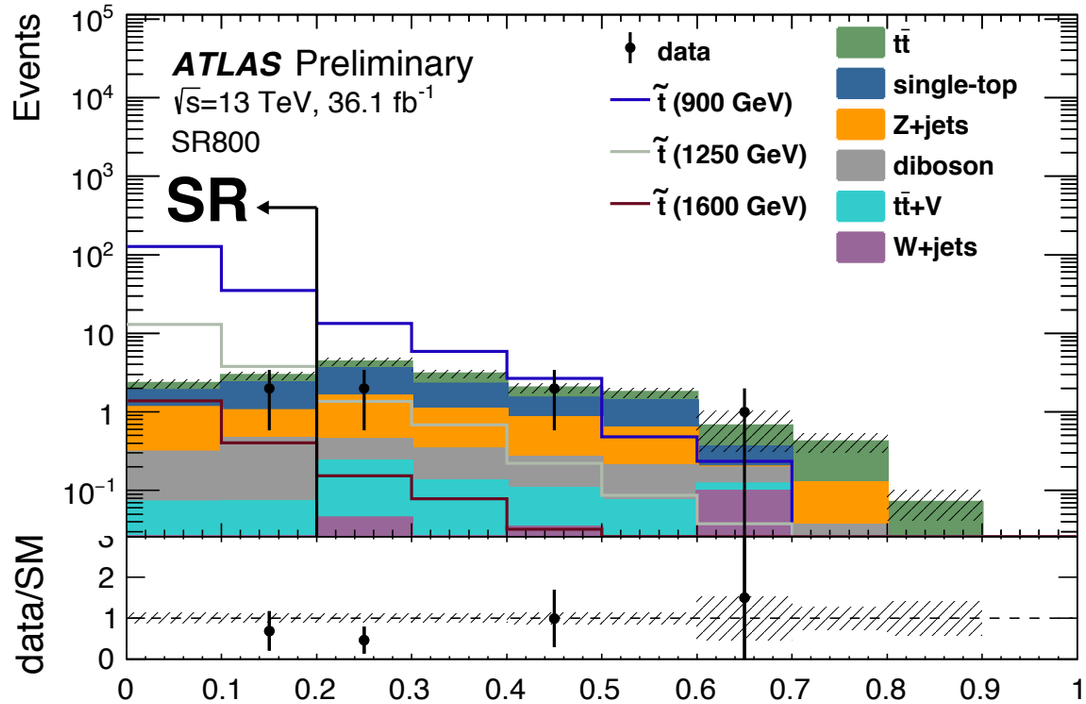
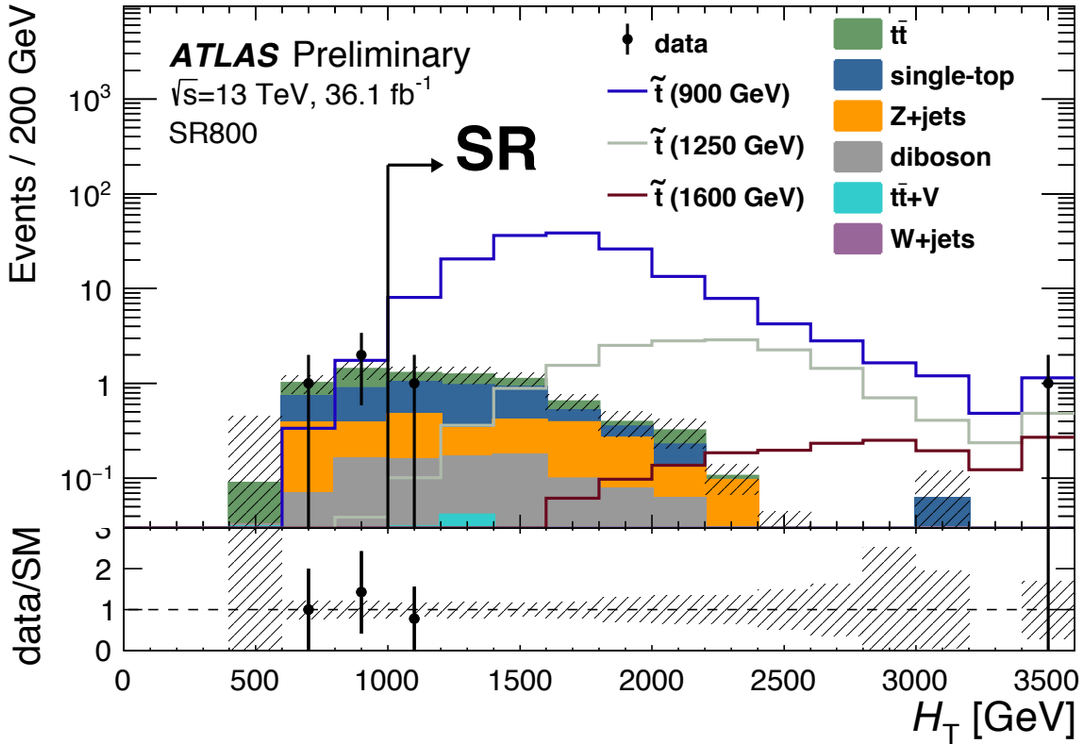
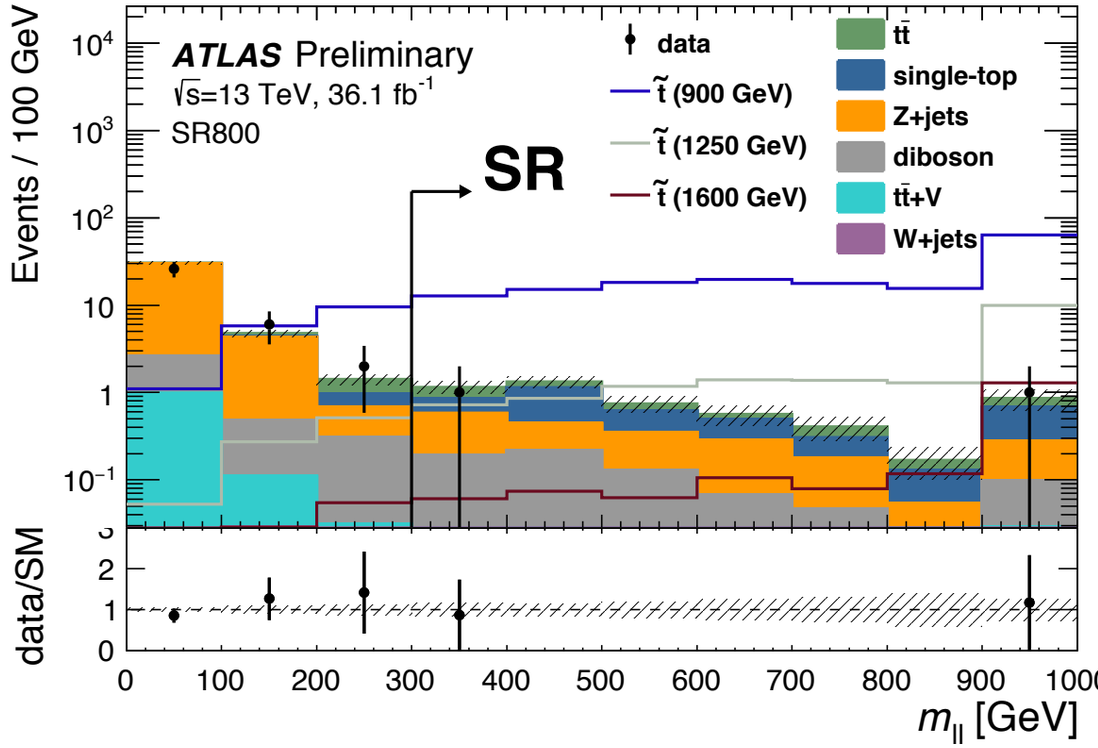
Stop B-L : Results











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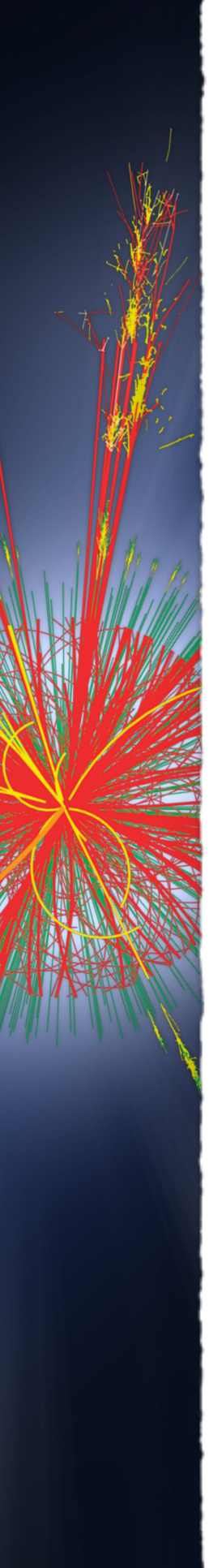
Stop B-L : Interpretations

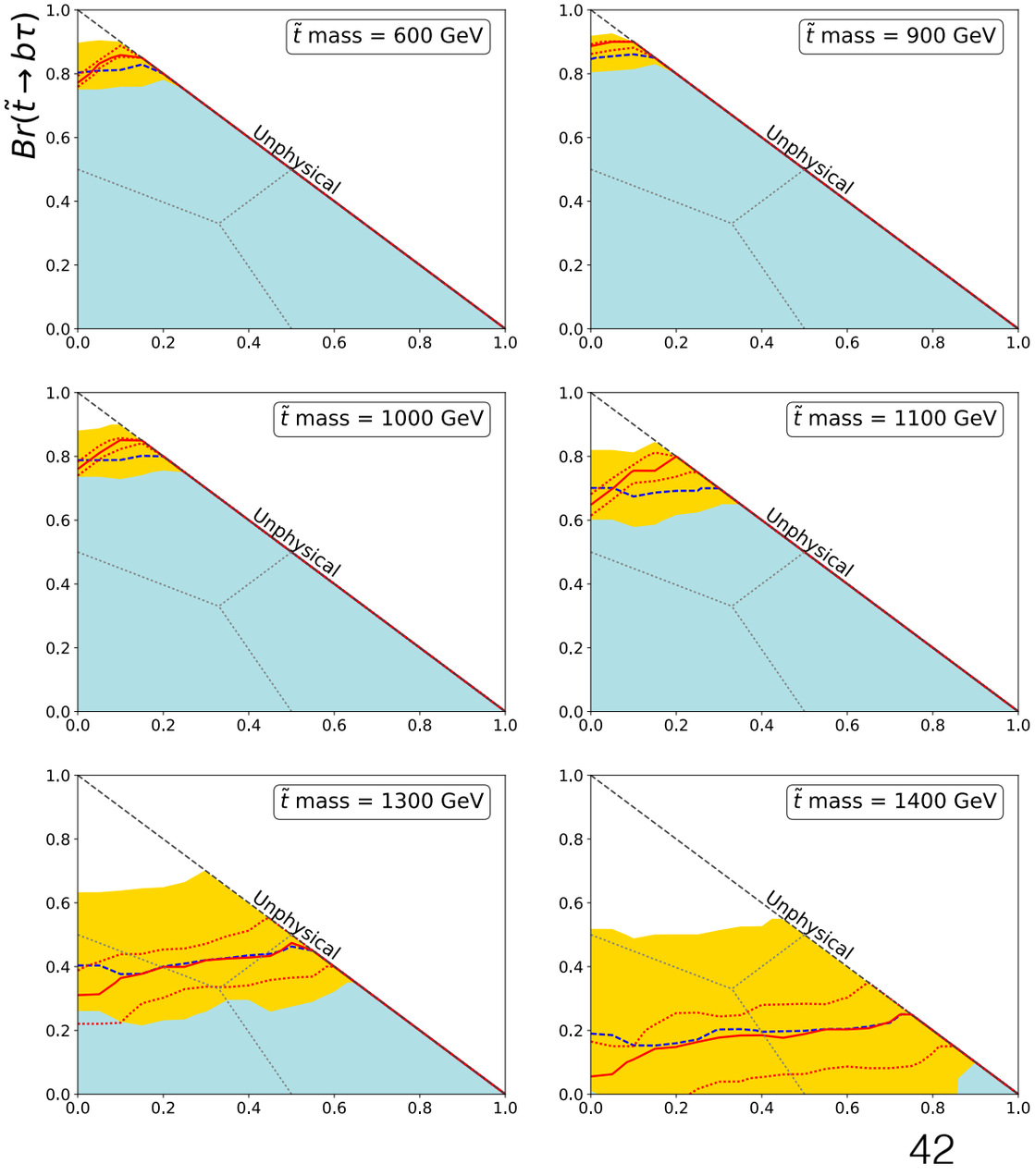


ATLAS Preliminary
$\sqrt{s} = 13$ TeV, 36.1 fb^{-1}

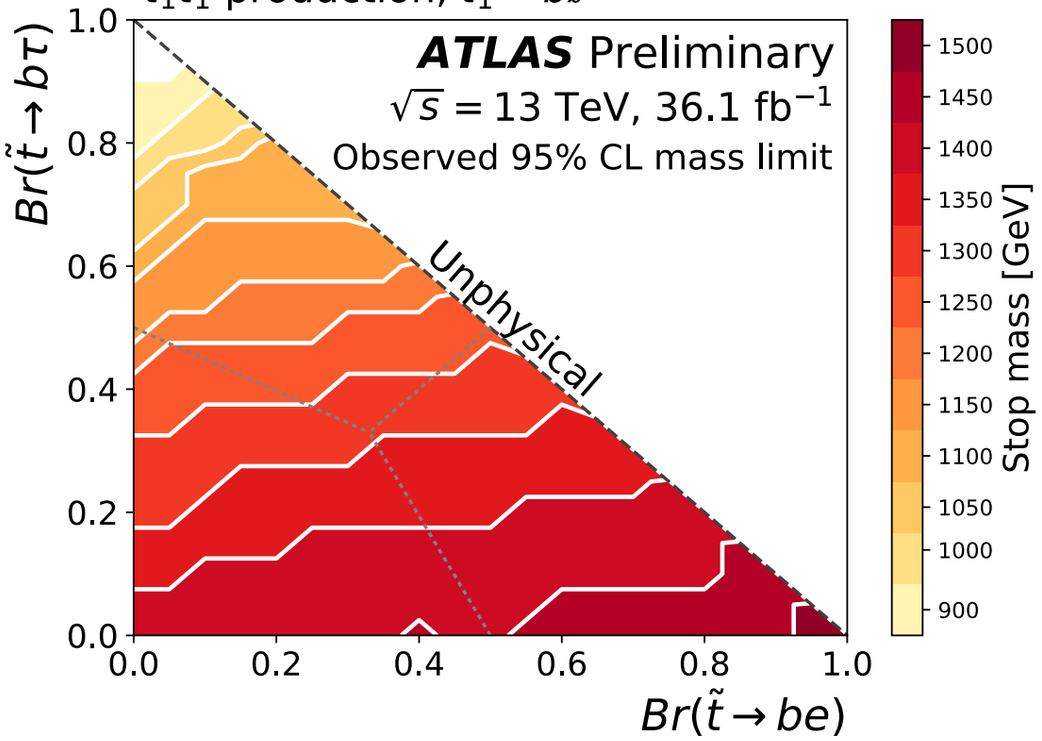
Observed limit ($\pm 1\sigma^{\text{SUSY}}_{\text{theory}}$)
Expected limit ($\pm 1\sigma_{\text{exp}}$)
All limits at 95% CL

Highest excluded m(t̃) for each BR scenario

$\tilde{t}\tilde{t}^*$ production, $\tilde{t} \to b\ell$



$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \to b\ell$



Excluded m(t̃) ∈ (0.6,1.5) TeV and up to 90% BR$_T$

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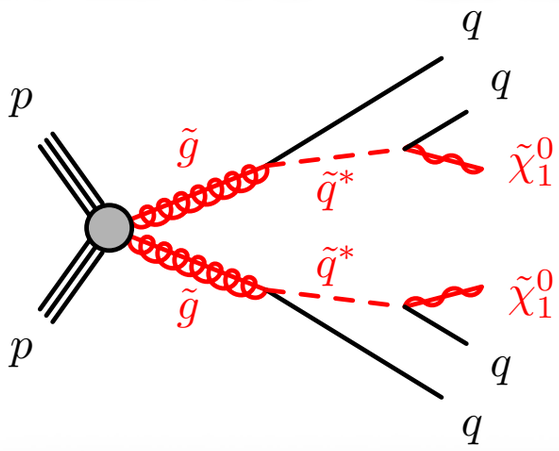
Displaced Vertices : Overview



Many SUSY models predict Long-Lived Particles (LLP)

Split SUSY : g̃ decays via highly off-shell q̃ → LL-g̃

LL-g̃ hadronizes to form the so-called *R*-hadrons

How would one search for them? Displaced Vertices (DV)

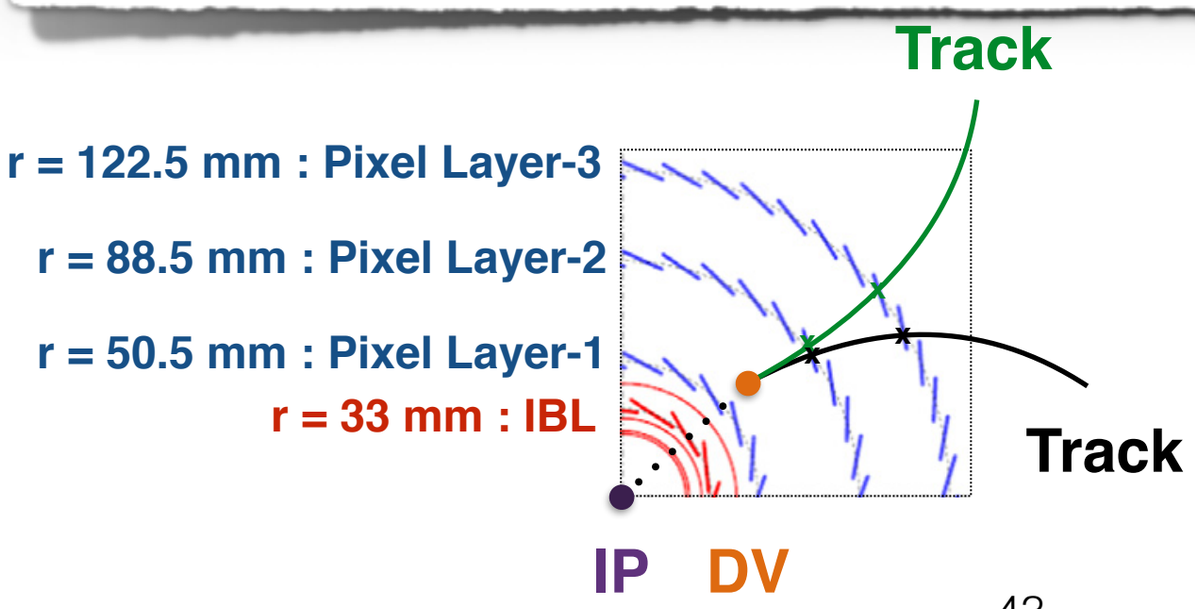
Search Strategy:

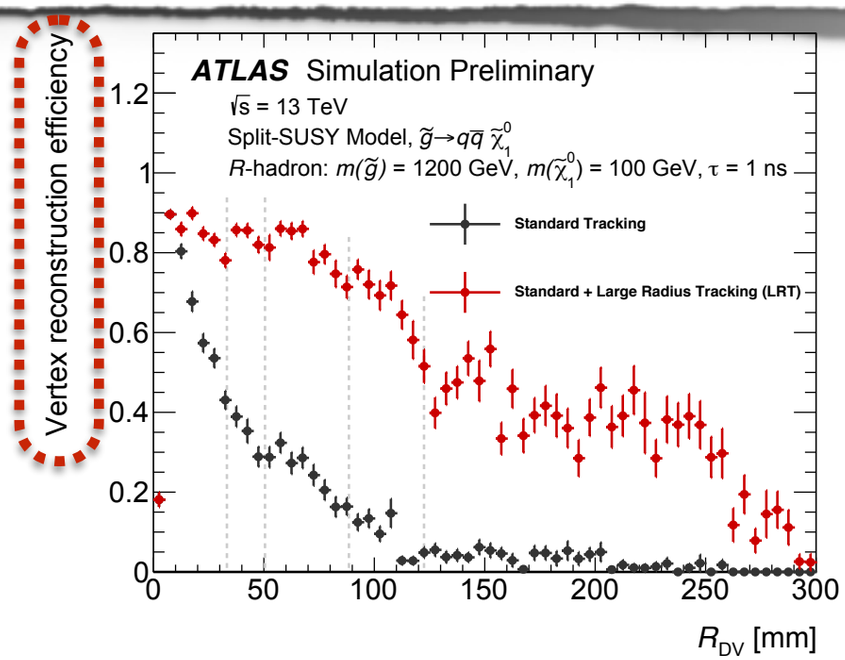
LLP may decay within tracking volume (away from interaction point - IP)

Default tracking and vertexing optimized for primary tracks from IP

Devise and utilize a special vertex/track reconstruction algorithm

Search for events w/ $n_{DV} \geq 1$ w/ $m_{DV} > 10$ GeV, $n_{trk} \geq 5$ and $E_T^{miss} > 250$ GeV



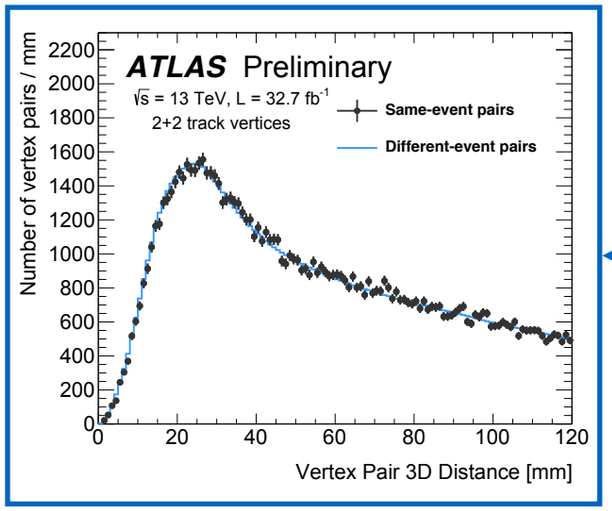


Displaced Vertices : Backgrounds

Three main backgrounds:

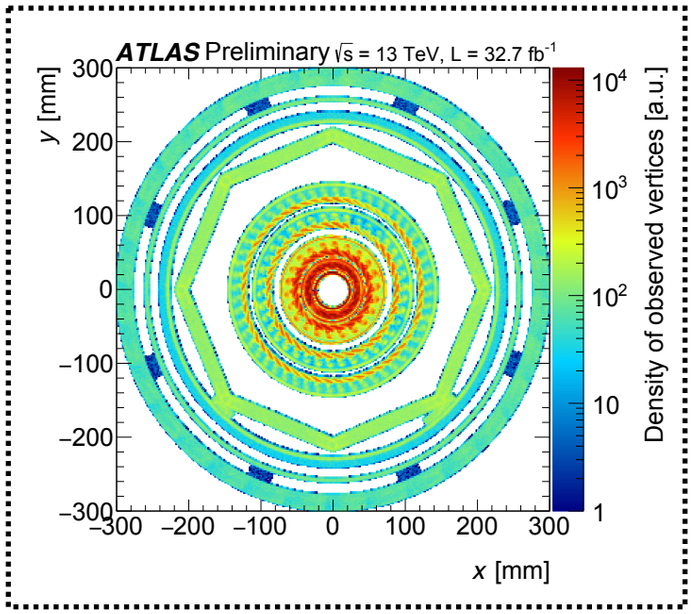
1. High Track-Multiplicity Hadronic Interactions:
   - Originating from hadronic interaction in material
   - Build material map using data to veto vertices

2. Merged Displaced Vertices:
   - Originating from vertex merging (within 1mm)
   - Estimated from data using a *template method*



i. Template from merging vertices in different events
ii. Normalize to same-event pairs in $d(v_1,v_2) > 1$ mm
iii. Extrapolate to $d(v_1,v_2) < 1$ mm to get the estimate in SR

Material map from data



3. Random Large-Angle Track Crossing
   - Originating from low-mass vertices crossed by an unrelated track
   - Add *pseudo-track* to *n*-track vertices from data in CR to create *n*+1-track *sample*
     - Pseudo-tracks coming multi-dimensional templates
   - Normalize the *n*+1-track prediction to real orthogonal *n*+1-track data (for *n*=2)

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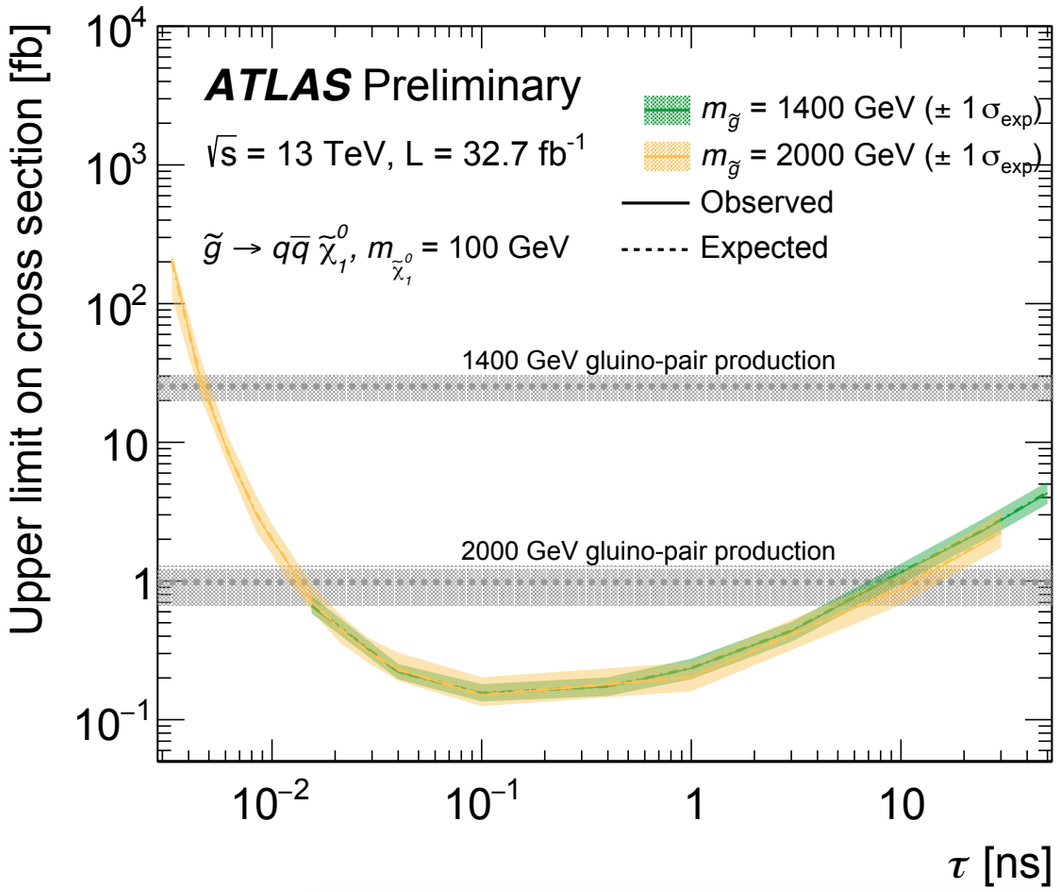
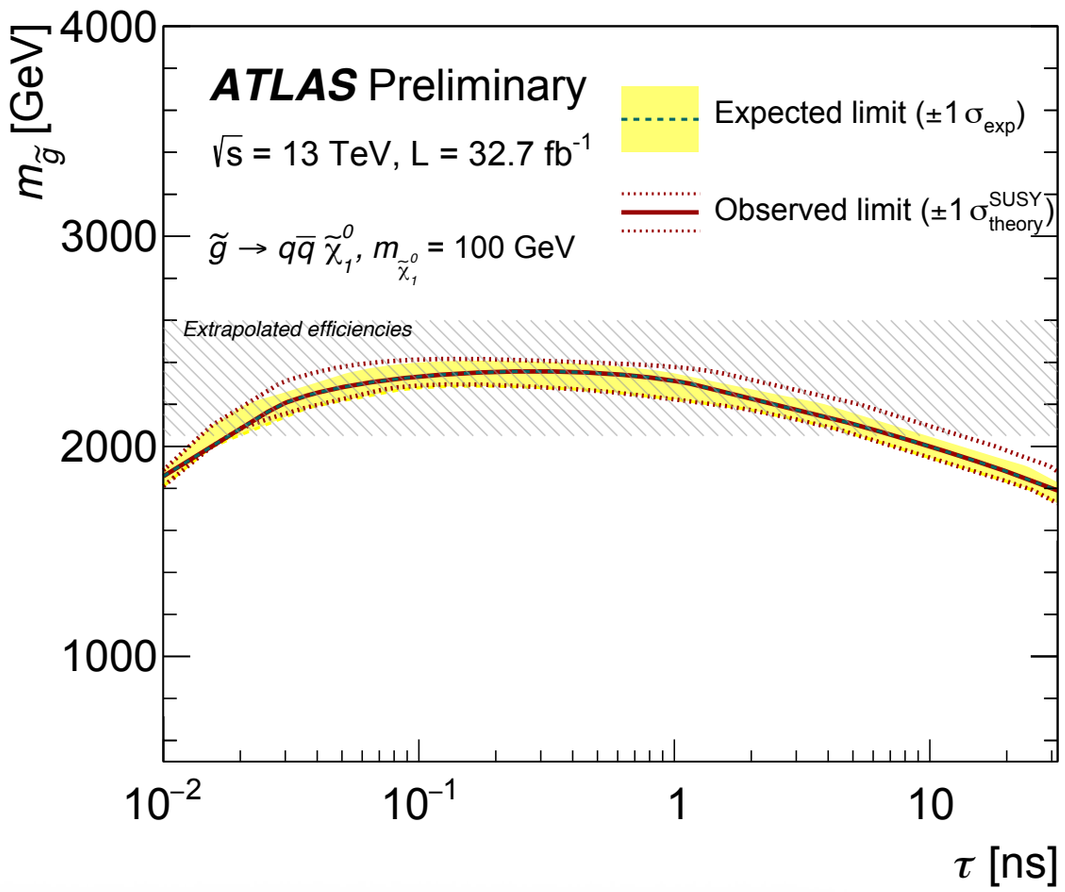
Displaced Vertices : Results

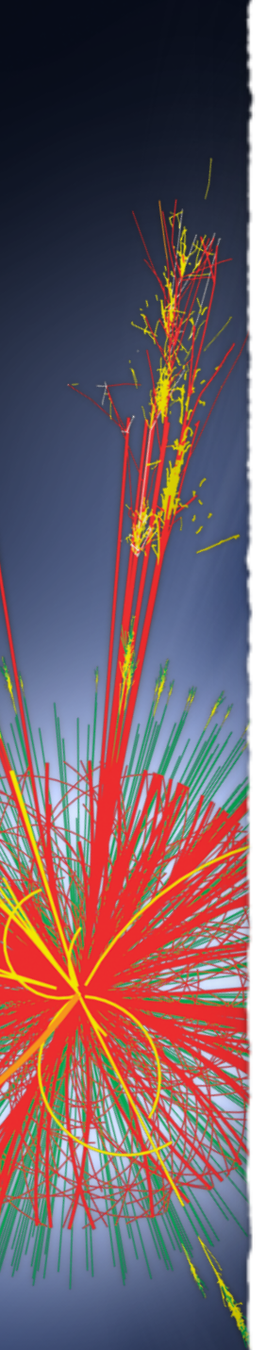
Background expectations are validated in VRs

The full SR selection has 0.02 ± 0.02 (expected) vs 0 (observed) events





Excluded m(g̃) ~ 2 to 2.3 TeV for m($\tilde{\chi}_1^0$) = 100 GeV and g̃ lifetimes between 0.02 and 10 ns



Conclusions and Outlook

- **Huge thanks to the accelerator team for the fantastic performance so far!**

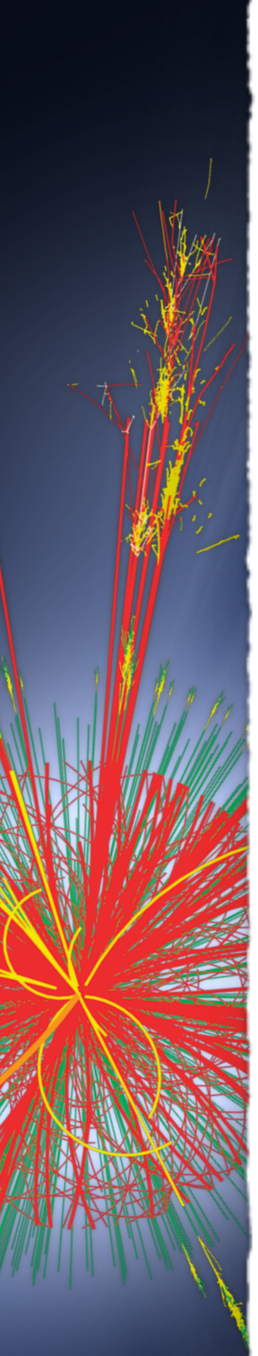
- **ATLAS** has just released **8 new SUSY results** for LHCP last week!
  - All using full 2015 + 2016 dataset of 36.1 fb^{-1} at $\sqrt{s}$ = 13 TeV (*except DV*)
  - Only a *small* fraction of the full list*

- Unfortunately no significant excess is observed (yet)
  - Although there is **significant boost in sensitivity** for all scenarios!

- Larger 2017 dataset will surely open up new possibilities
  - New scenarios, more complicated search techniques for increase sensitivity
  - Can probe lower cross-section processes and compressed mass-spectra

- **Stay tuned for more interesting results in the coming months!**

*https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults



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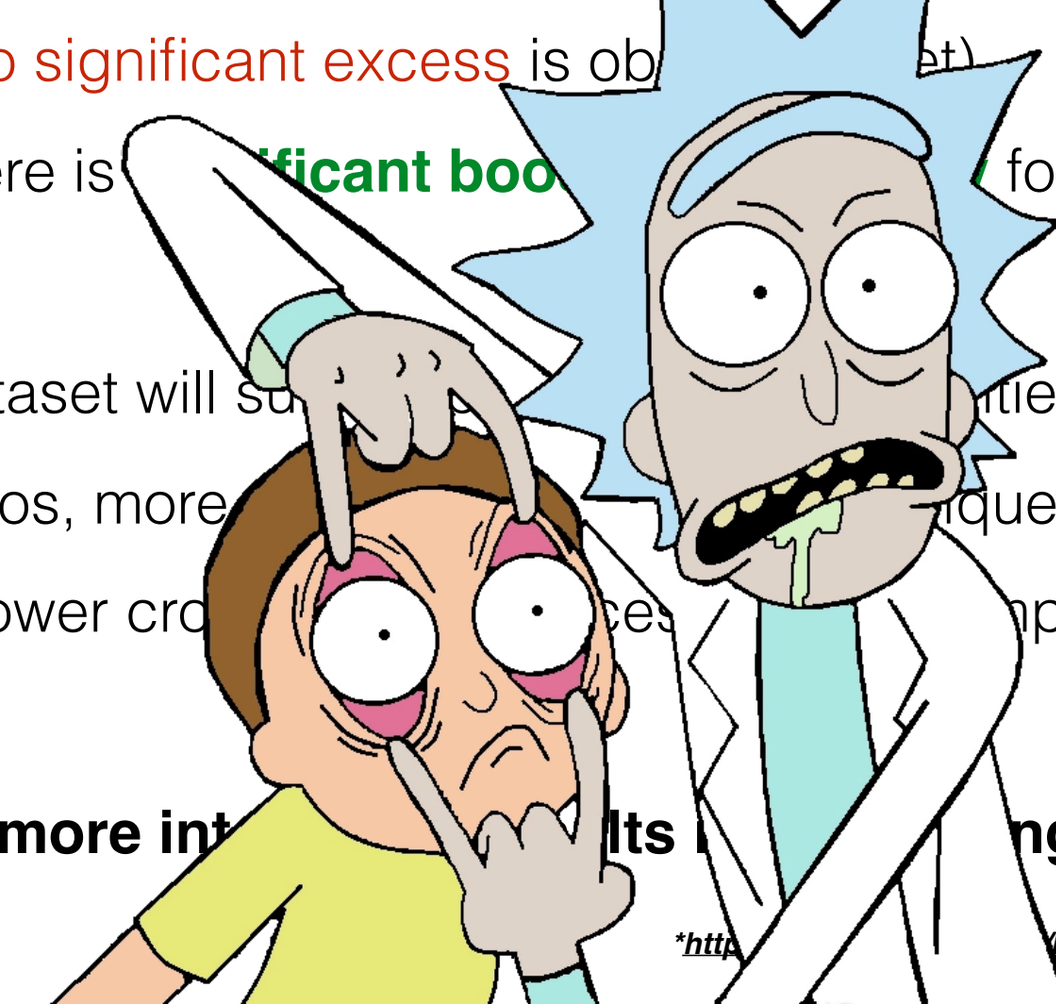

*http bin/view/AtlasPublic/SupersymmetryPublicResults