SUSY searches with ATLAS new results for ICHEP

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Executive summary

We haven't found it

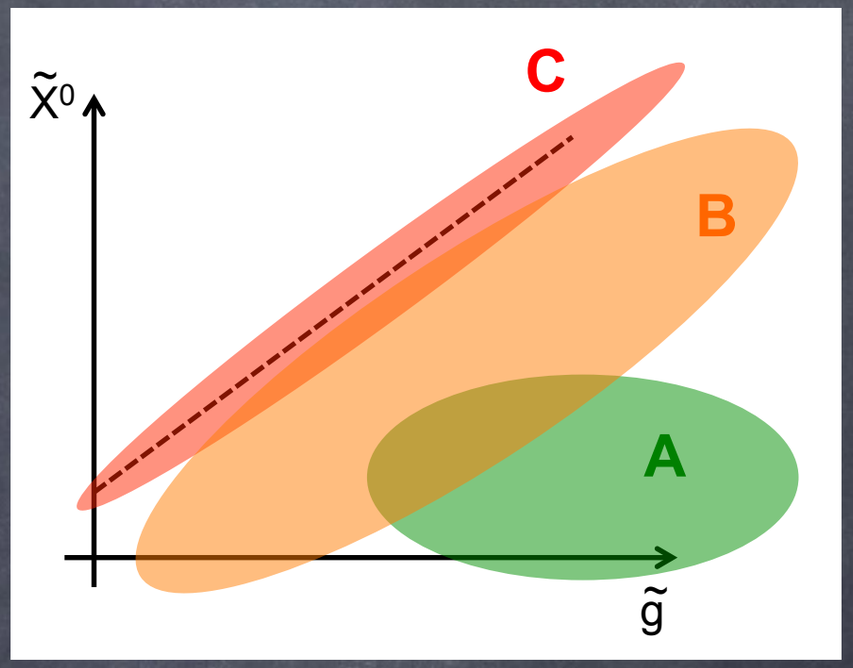
let me elaborate on that...

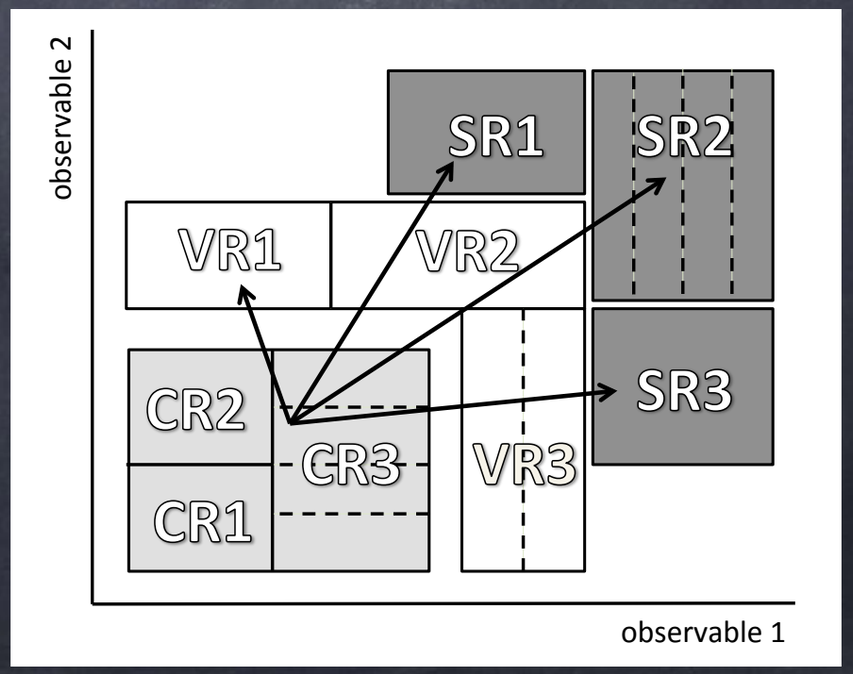
scope of the talk

- Focusing on new results released for ICHEP, that cover a large fraction (but not all) of ATLAS SUSY searches.
- All with 13 to 15 fb-1 of 13 TeV data. Many thanks for the LHC for the fantastic performances !
- All results can be found at https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

A typical ATLAS susy search

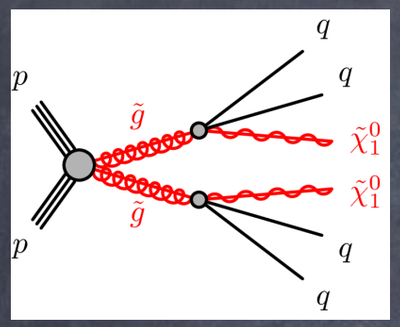
- Signal selection targeting a specific production/decay mode (simplified model)
- Optimized for best discovery significance in a single 1-bin selection (SR). To cover different mass hierarchies, this typically results in a few overlapping SRs for each final state.
- Background estimate :
  - Irreducible backgrounds estimated using control region (CR) data as a constraint and MC to extrapolate from CR to SR in a likelihood fit.
  - Reducible background (fake/non isolated leptons, E_T^{Miss} from jet mismeasurement) from data.
  - Use only well modelled variable in CR => SR extrapolations ! Validation regions (VR) used to check the assumptions in the background estimate and the CR => SR variable modelling.



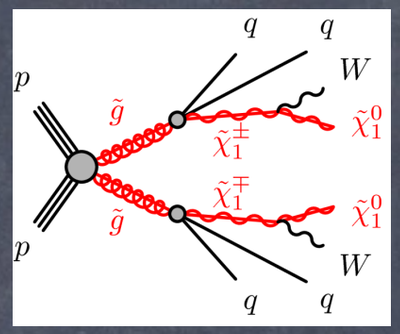


gluinos and squark searches

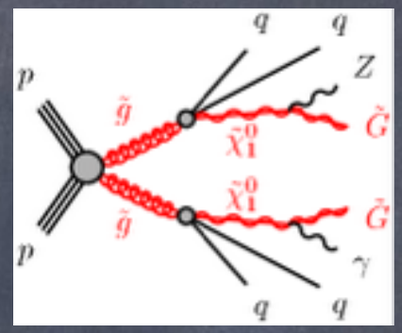
gluino direct

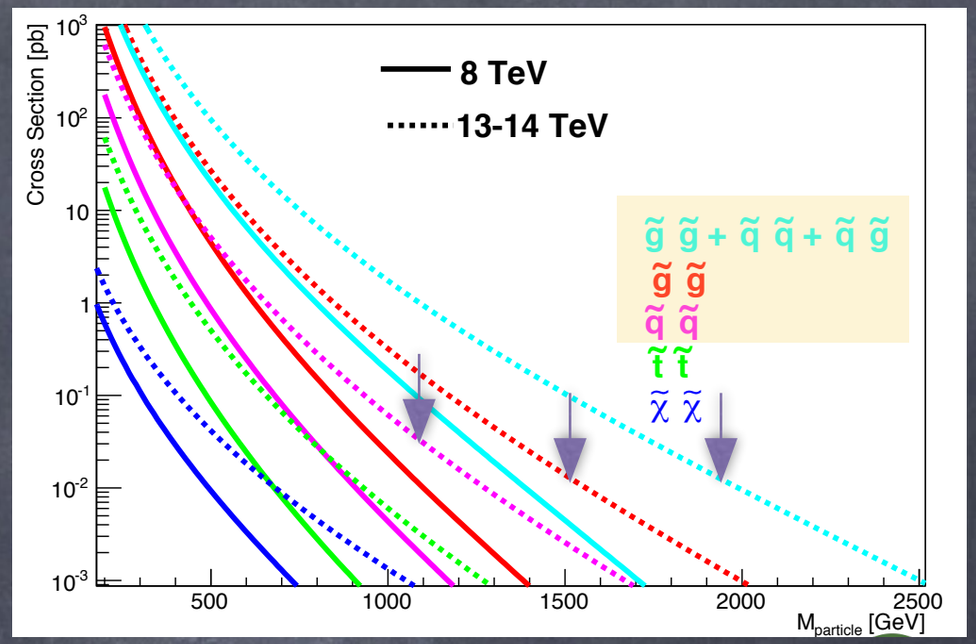


gluino 1-step (W)

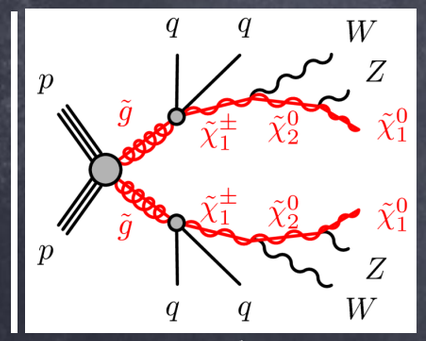


gluino 1-step (Z)

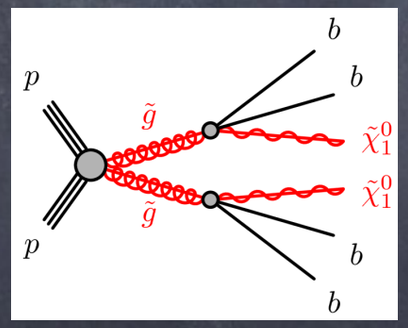




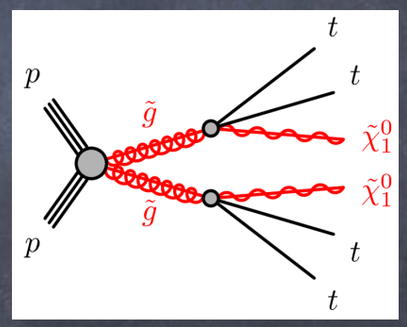
gluino 2-step



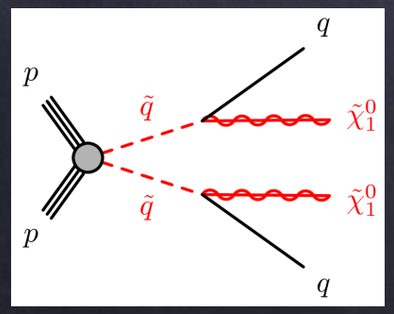
gluino via b



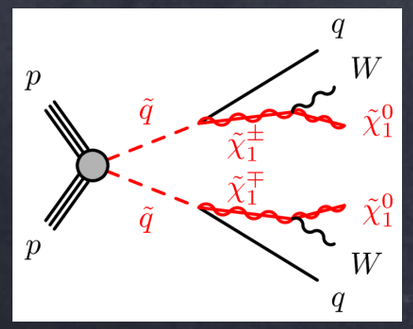
gluino via t



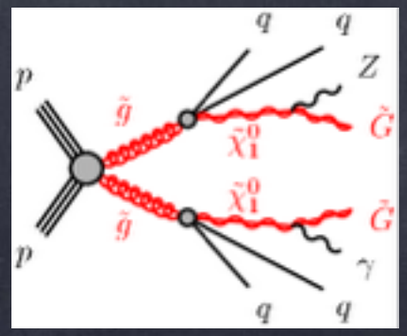
squark direct



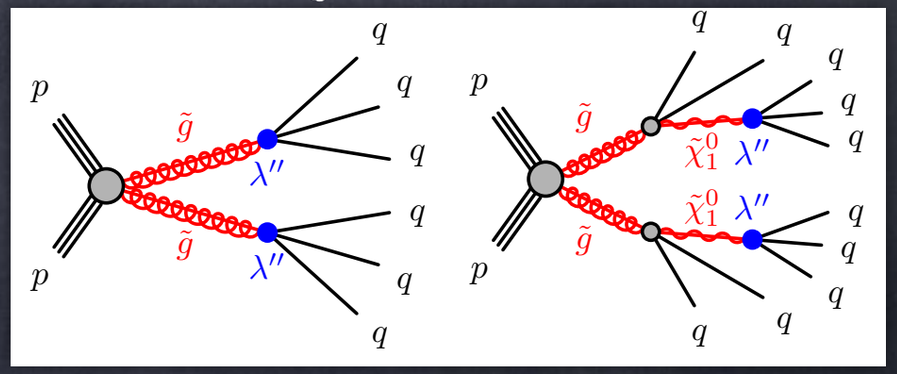
squark 1-step



gluino GMSB



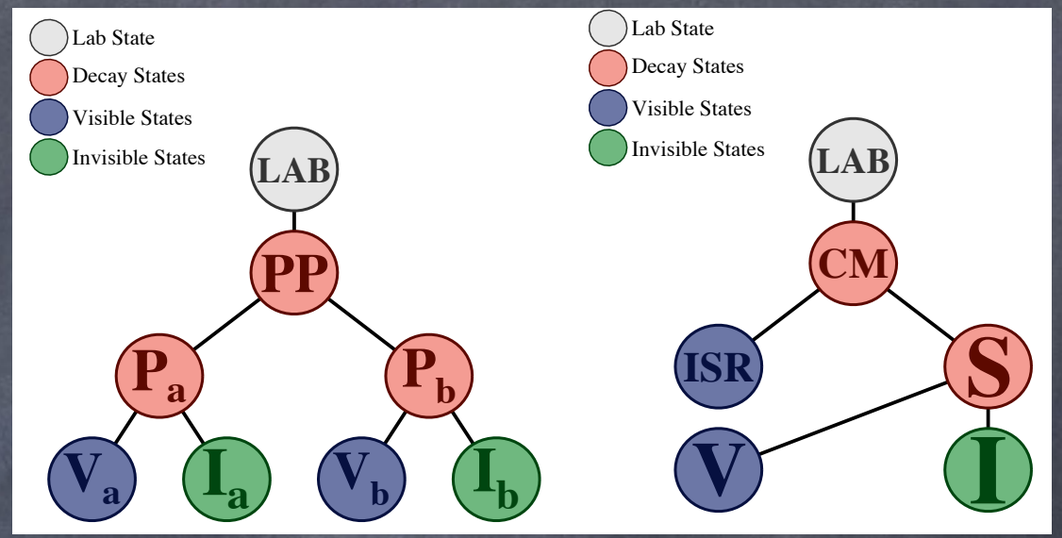
gluino RPV

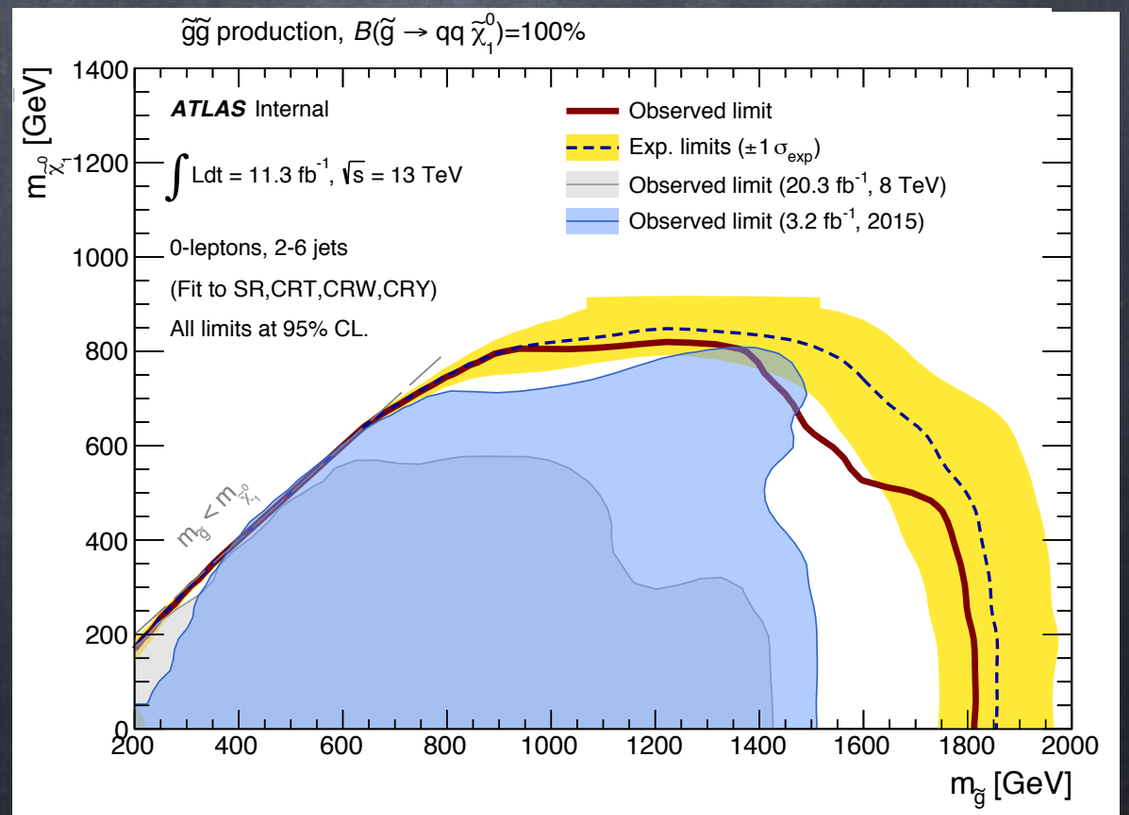


ATLAS-CONF-2016-078

0 lepton + 2-6 jets + MET

- No electron or muon, 2-6 jets, MET > 200 GeV. Two sets of selections with similar sensitivity :
  - Effective mass ($\sum p_T^{jets}$ +MET)
  - RJigsaw variables: decompose an event assuming a decay topology; compute invisible momenta by minimizing each hemisphere mass; all momenta of decay tree available for selection (mass-sensitive scale variables, angles for compressed topologies)
- Main backgrounds normalized in 1 lepton, gamma+jets, and multijet control regions
- No excess, limits improve by a few hundred GeV

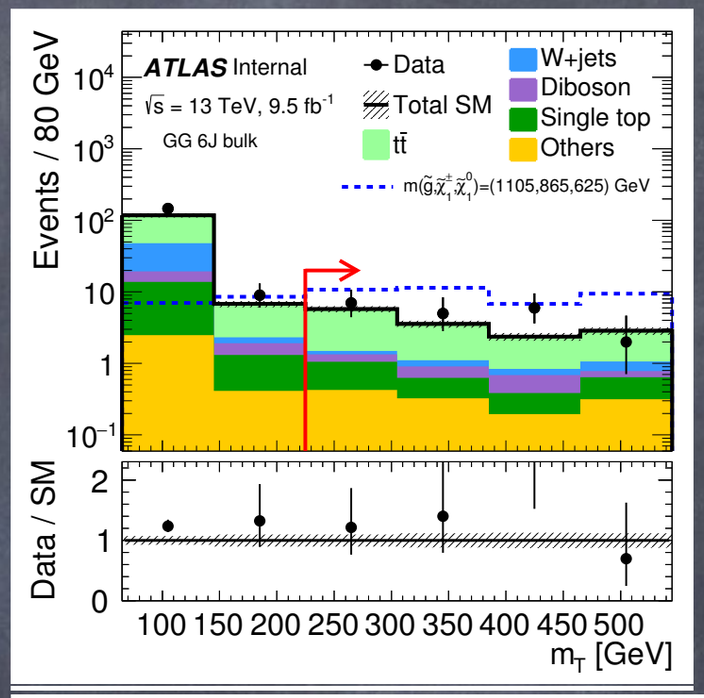


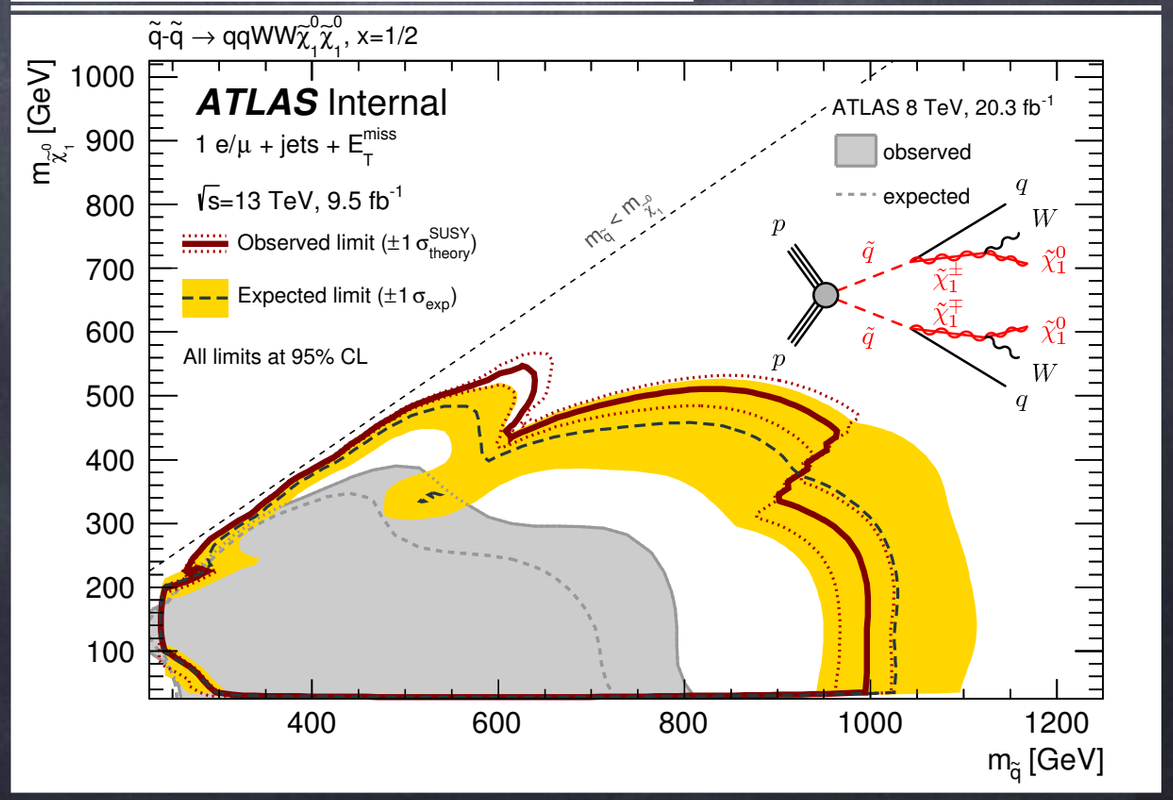


ATLAS-CONF-2016-054

1 lepton + 2-6 jets + MET

- 1L+jets+MET, targeting 1-step decays with a variety of mass hierarchies
- MET triggered, one soft (6-35 GeV) or hard (> 35 GeV) lepton, 2 to 6 jets
- Dominant W+jets and ttbar background normalized to control regions with low mT and aplanarity
- No excess, improved limits

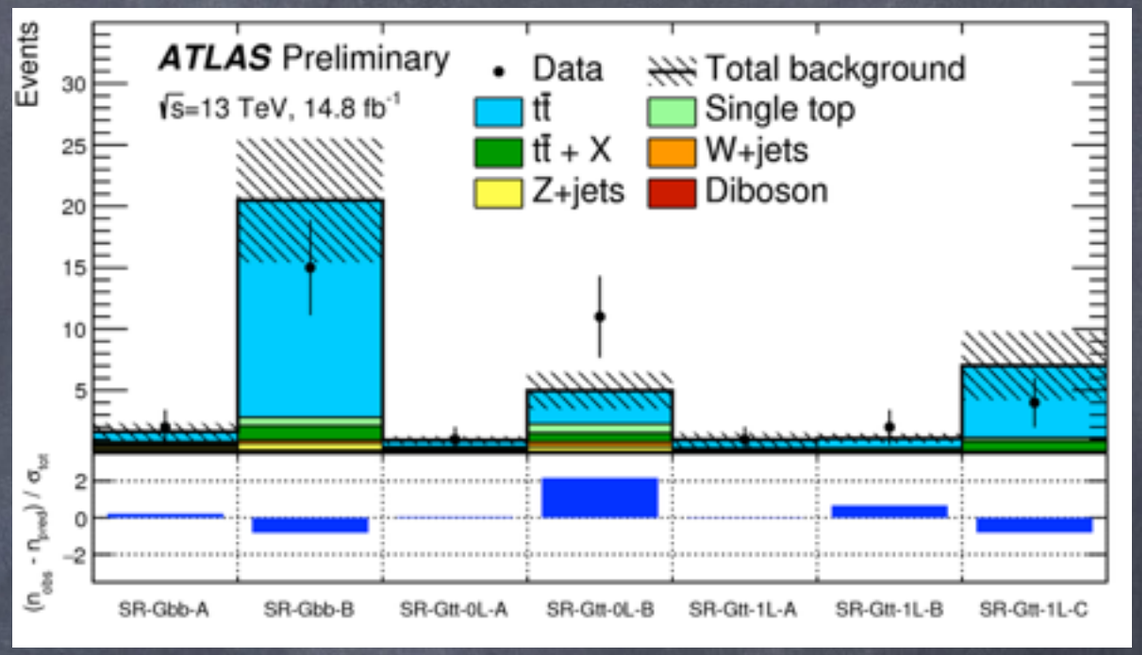


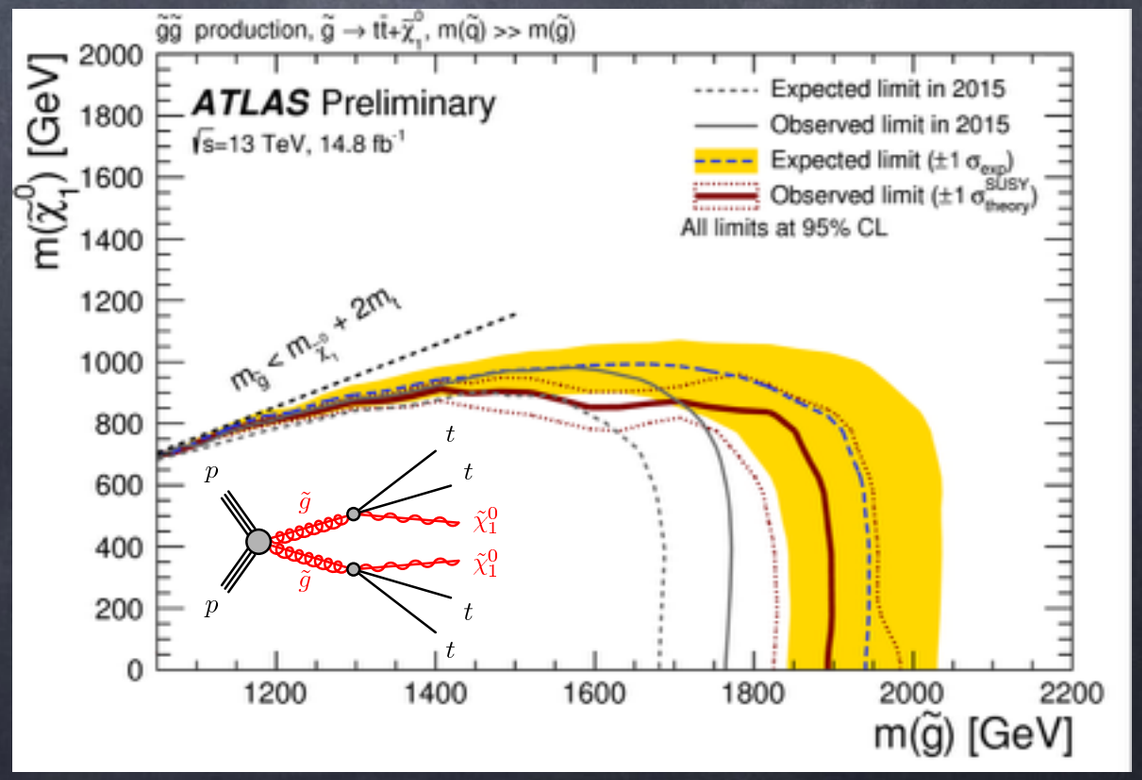


ATLAS-CONF-2016-052

0/1 leptons+3 b-jets+MET

- 0/1L+3 bjets+MET, targeting gluino decays via stop/sbottom
- $t\bar{t}$+HF normalized to control selection with same b-jet multiplicity, robust against mismodelings of heavy flavor cross section
- No excess, improved limits (expected improves by 200 GeV, observed only a bit because of small 2015 deficit and 2016 excess)

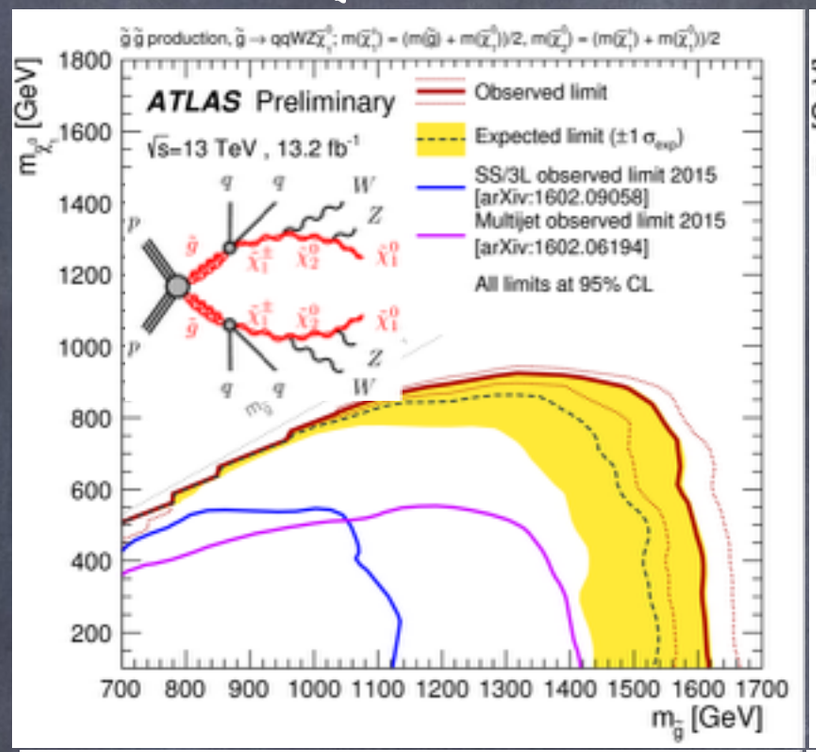


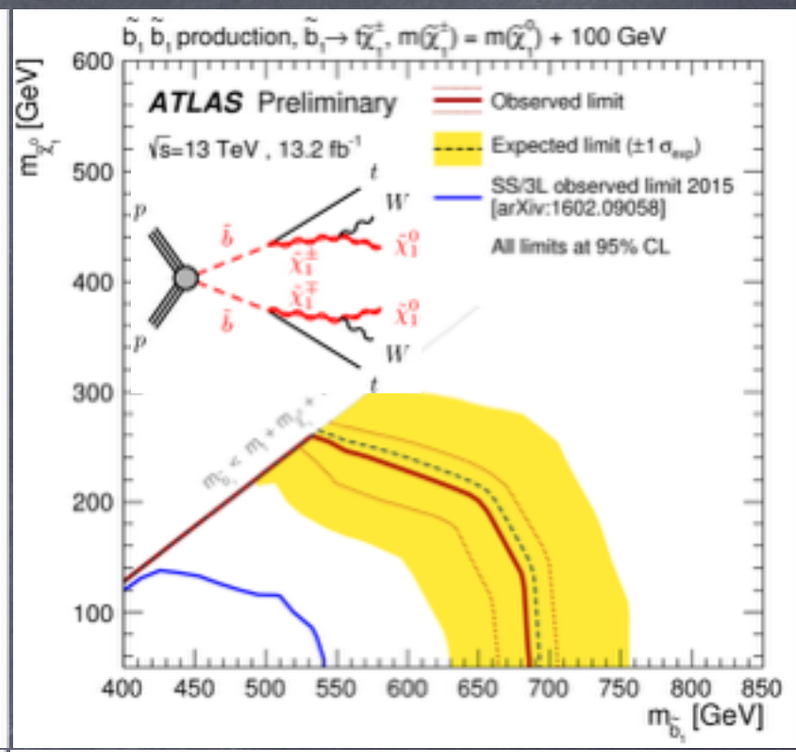


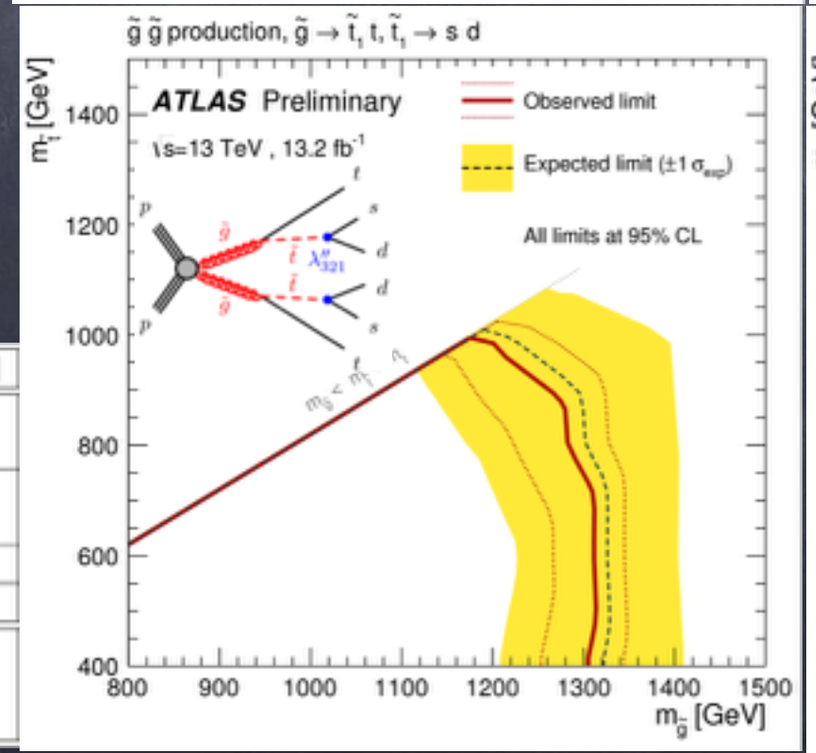
ATLAS-CONF-2016-037

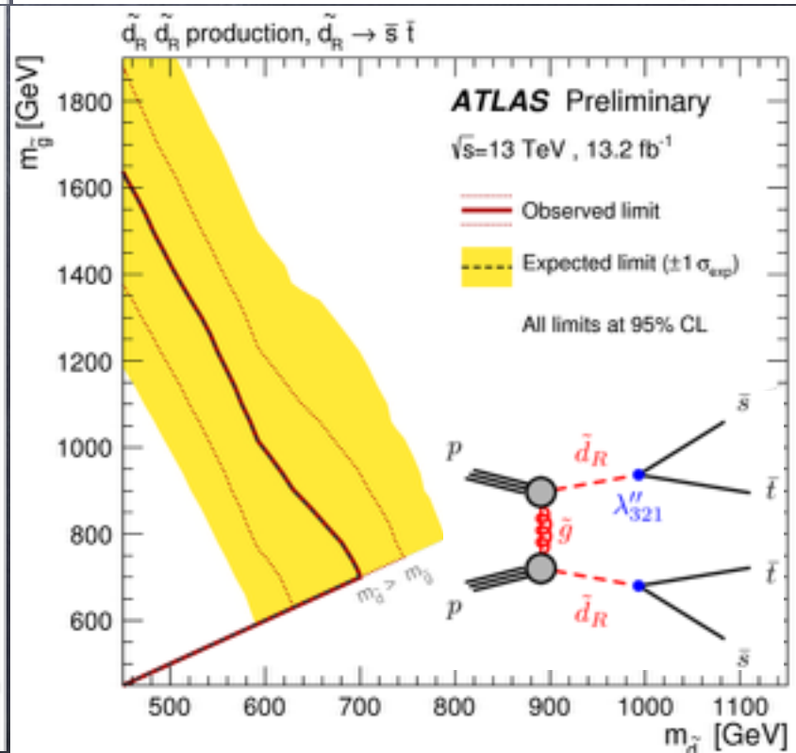
SS/3 leptons

- majorana gluinos or long cascade decays can give SS leptons, low SM background
- relax or remove MET cut : compressed spectra and RPV targets
- backgrounds : data driven charge flips and fake leptons, MC based rare SM processes (with validation region)







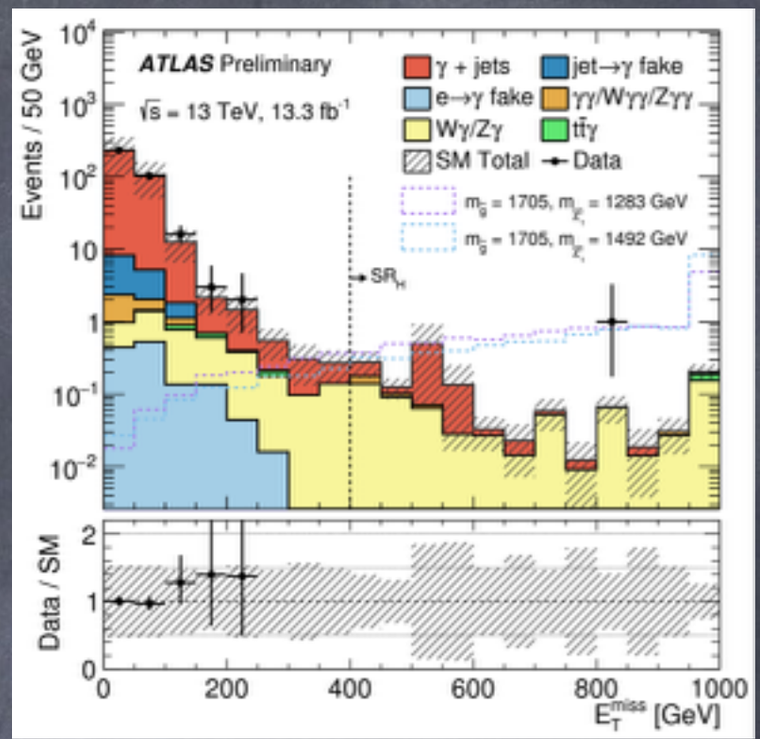


Signal region	$N_{\text{lept}}^{\text{signal}}$	$N_{b\text{-jets}}^{20}$	N_{jets}	$p_{\text{T,jets}}$ [GeV]	$E_{\text{T}}^{\text{miss}}$ [GeV]	m_{eff} [GeV]
SR3L1	≥ 3	$= 0$	≥ 4	40	> 150	-
SR3L2	≥ 3	$= 0$	≥ 4	40	> 200	> 1500
SR0b1	≥ 2	$= 0$	≥ 6	25	> 150	> 500
SR0b2	≥ 2	$= 0$	≥ 6	40	> 150	> 900
SR1b	≥ 2	≥ 1	≥ 6	25	> 200	> 650
SR3b	≥ 2	≥ 3	≥ 6	25	> 150	> 600
SR1b-DD	≥ 2	≥ 1	≥ 4	50	-	> 1200
SR3b-DD	≥ 2	≥ 3	≥ 4	50	-	> 1000
SR1b-GG	≥ 2	≥ 1	≥ 6	50	-	> 1800

ATLAS-CONF-2016-066

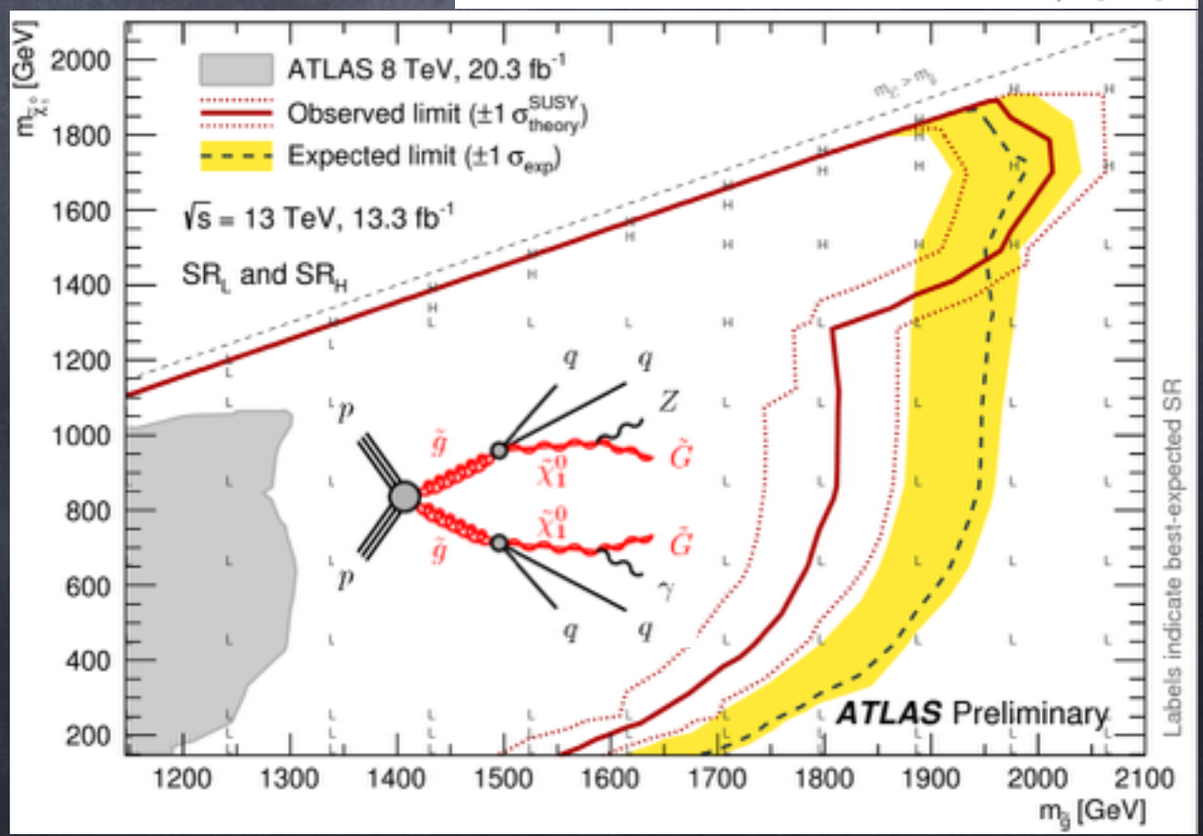
photon+jets+MET

- targeting neutralino NSLP decaying to gravitino and photons, with non-100% branching ratios
- low background signature. Wγ, ttγ, γ+jets normalized in control regions.
- No excess, limits (400 GeV improvement over run1)



SRL/SRH target light/heavy neutralino

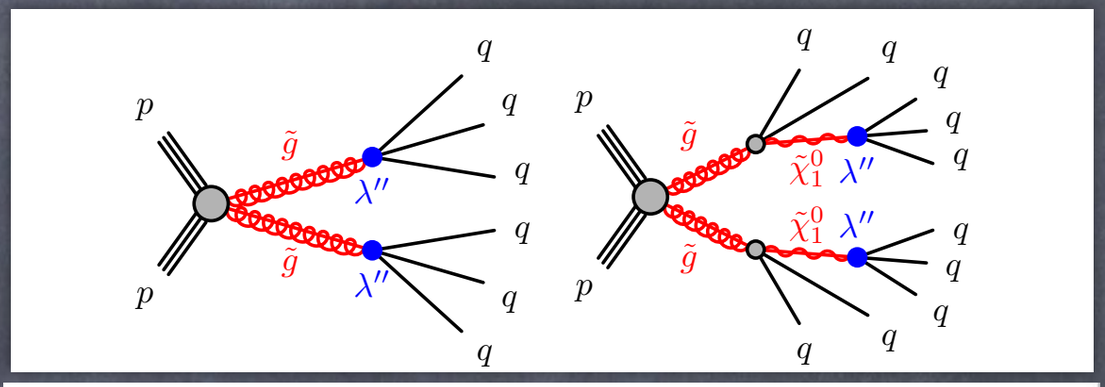
	SR_L	SR_H
N_{photons}	> 0	> 0
$p_T^{\text{leading}-\gamma}$	> 145 GeV	> 400 GeV
N_{leptons}	0	0
N_{jets}	> 4	> 2
$\Delta\phi(\text{jet}, E_T^{\text{miss}})$	> 0.4	> 0.4
$\Delta\phi(\gamma, E_T^{\text{miss}})$	> 0.4	> 0.4
E_T^{miss}	> 200 GeV	> 400 GeV
m_{eff}	> 2000 GeV	> 2000 GeV
R_T^4	< 0.90	-

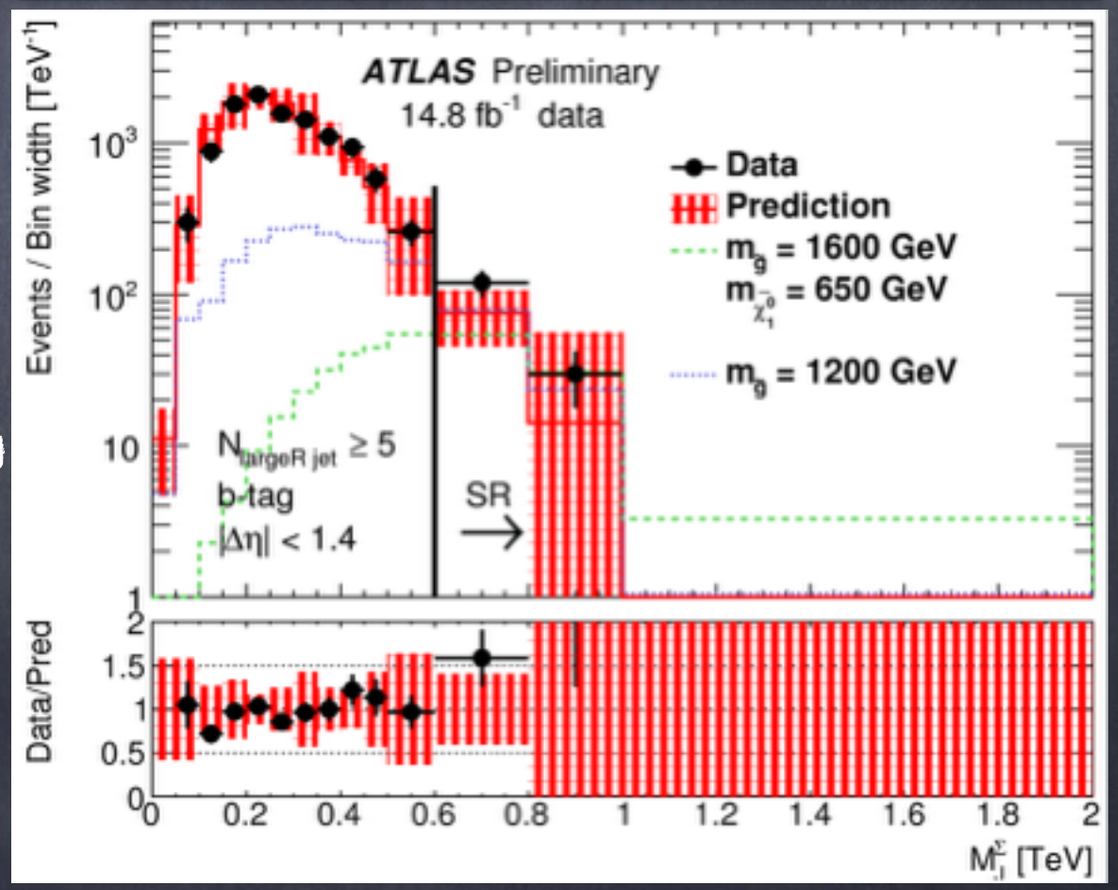


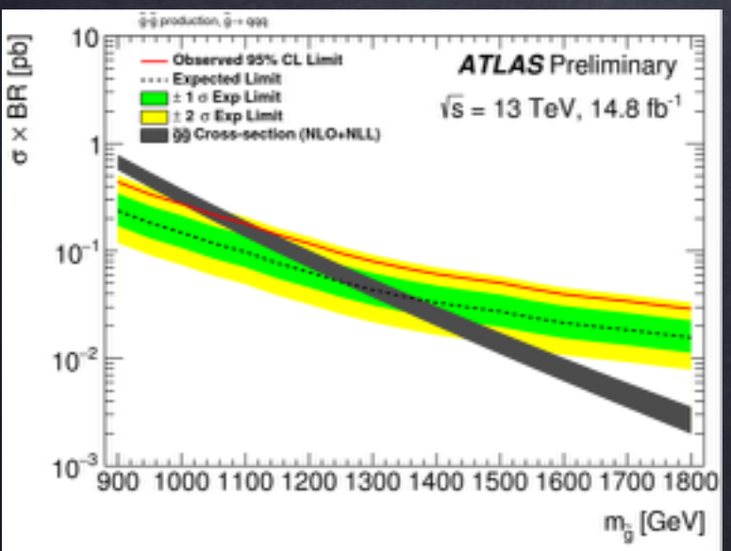
ATLAS-CONF-2016-057

RPV multijet

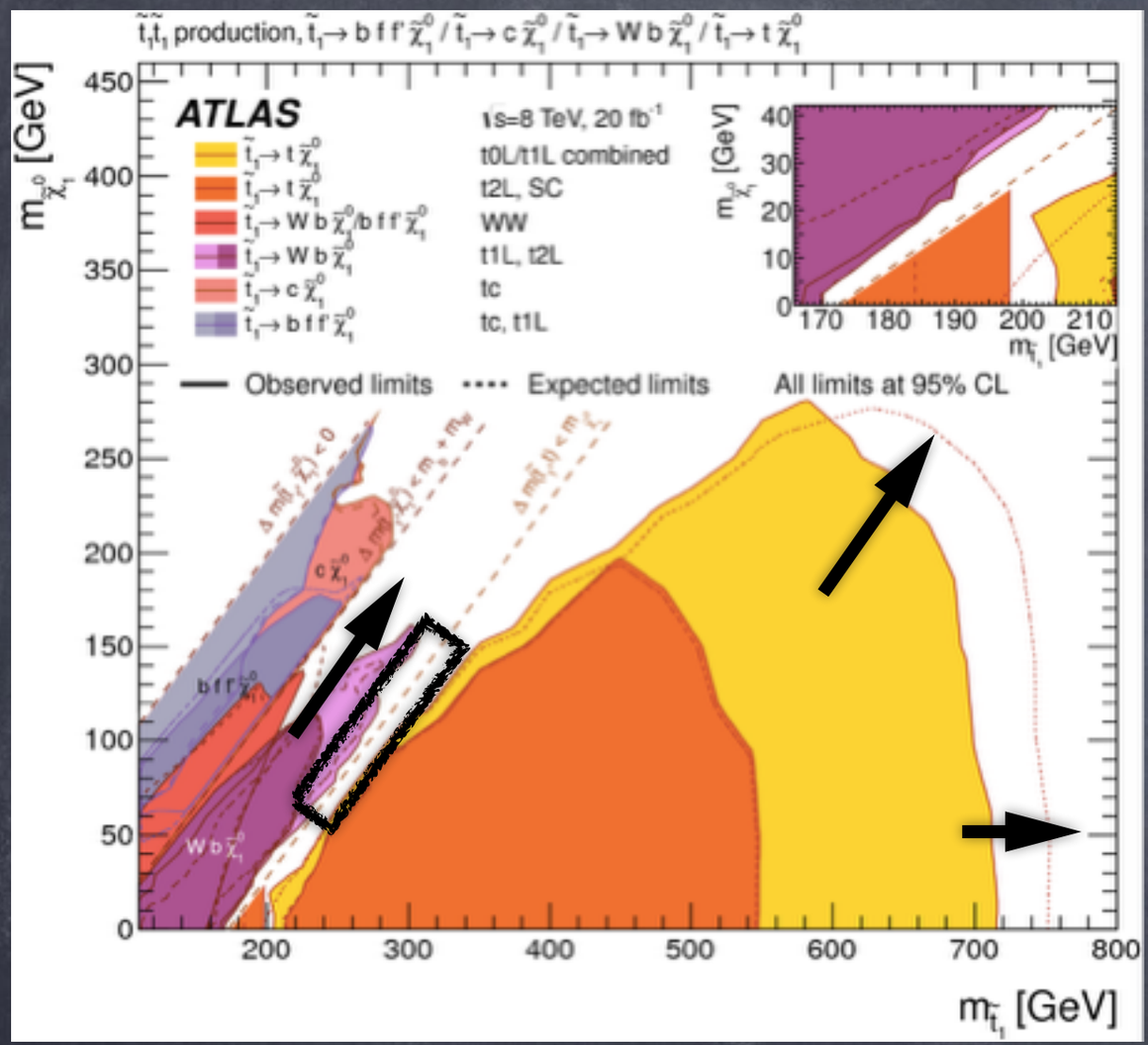
- no MET makes search more difficult
- key observable is sum of large-R jet masses
- background mass template built in data control regions, MC only used in closure tests
- Limits between 1000-1550 GeV depending on model







third generation squarks



Run 1 summary plot (stop direct decays)

Targets of ICHEP analyses

- heavy stop to top neutralino (boosted top, hard MET)
- stealth stop diagonal (ISR+tt+MET, MET/pTISR peaks at mc/mt)
- 3-body stop decays (bWχ°)
- stop via chargino to bWχ°
- stop via stau to gravitino
- stop2 to stop1 Z
- stop RPV decays in two jets
- sbottom via chargino (shown before)

not updated : sbottom direct decays

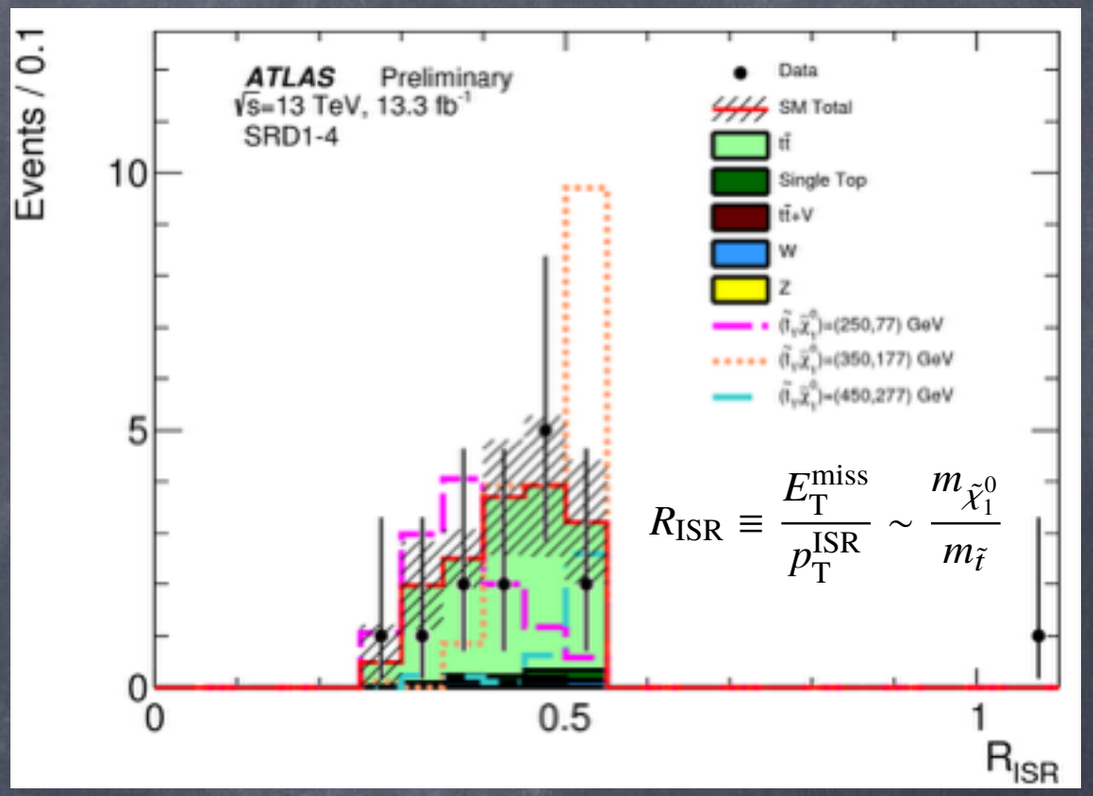
Channels

- 0L+bjets+MET
- 1L+bjets+MET
- 2L+bjets+MET
- Z+3rd lepton+b-jets+MET
- taus+bjets+MET
- 2x2 jets

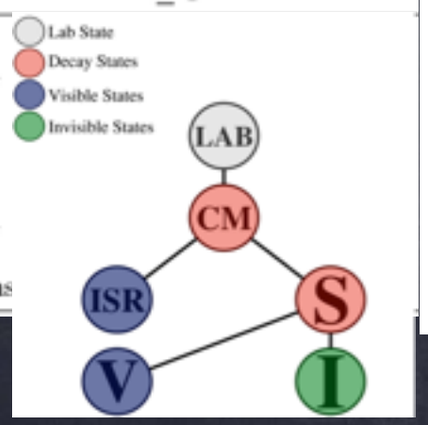
ATLAS-CONF-2016-077

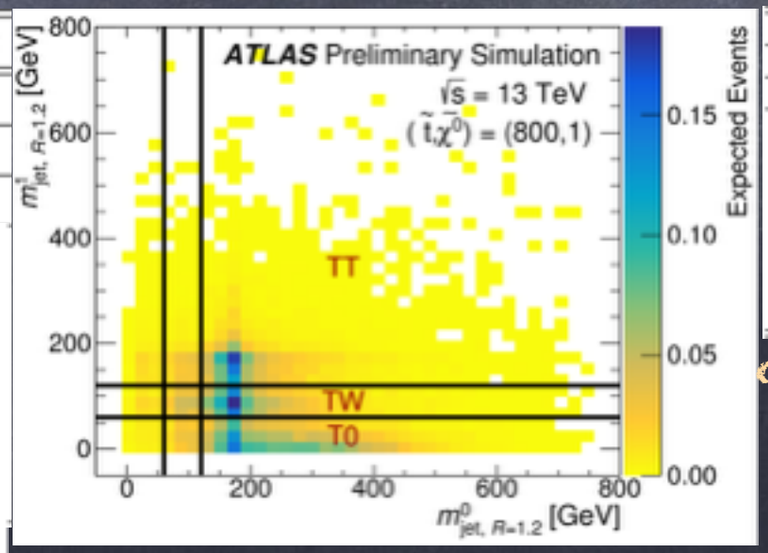
stop 0L channel

- 6 sets of SR, for heavy stop (direct and 1-step decays), stealth stop and Dark Matter + ttbar in fully hadronic channel
- Stealth stop selection : Jigsaw reconstruction
- Heavy stop with boosted top categories. Combine TT,TW,T) for discovery p-value assuming benchmark point signal ratios between categories



Variable	SRD1	SRD2	SRD3	SRD4	SRD5	SRD6	SRD7	SRD8
min R_{ISR}	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
max R_{ISR}	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75
b-tagged jets	≥ 2				≥ 1			
N_{jet}^S	≥ 5							
p_T^{ISR}	> 400 GeV							
$p_T^{b\text{-tag},S}$	> 40 GeV							
$p_T^{jet\,4,S}$	> 50 GeV							
M_T^S	> 300 GeV							
$\Delta\phi_{ISR}$	> 3.0 radians							





	SRA-TT	SRA-TW	SRA-T0
Observed	8	5	16
Total SM	5.2 ± 1.4	5.7 ± 1.6	11.3 ± 2.6
$t\bar{t}$	$0.78^{+0.84}_{-0.78}$	0.60 ± 0.34	1.13 ± 0.79
W + jets	0.48 ± 0.19	0.54 ± 0.18	1.13 ± 0.31
Z + jets	1.83 ± 0.55	3.0 ± 1.2	6.7 ± 2.1
$t\bar{t}+W/Z$	1.03 ± 0.33	0.84 ± 0.26	1.29 ± 0.57
Single top	$0.45^{+0.53}_{-0.45}$	$0.34^{+0.40}_{-0.34}$	$0.88^{+0.97}_{-0.88}$
Dibosons	0.62 ± 0.44	0.31 ± 0.20	0.18 ± 0.14
Multijets	$0.02^{+0.05}_{-0.02}$	$0.01^{+0.02}_{-0.01}$	$0.02^{+0.05}_{-0.02}$

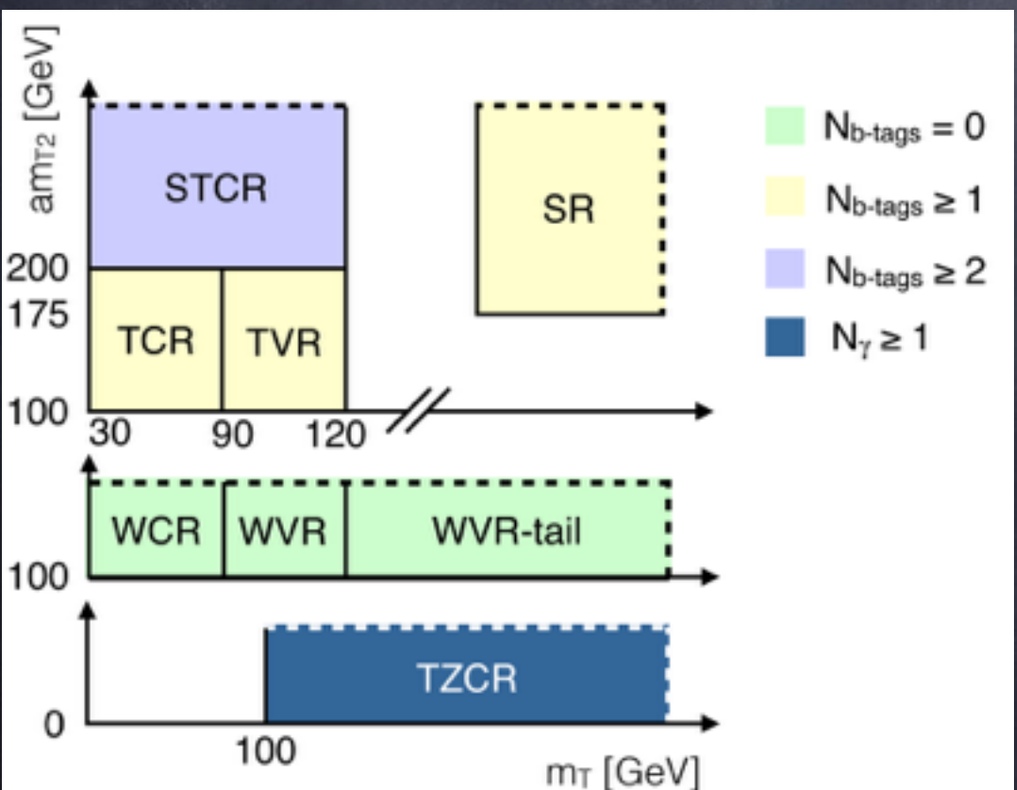
combined p-value = 0.10

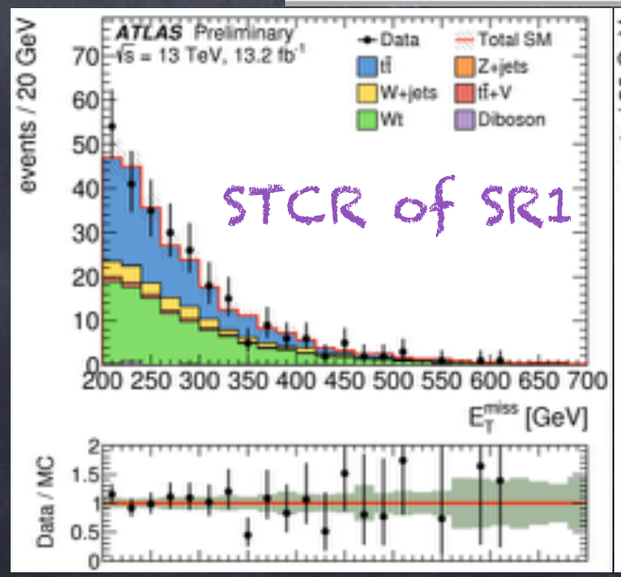
ATLAS-CONF-2016-050

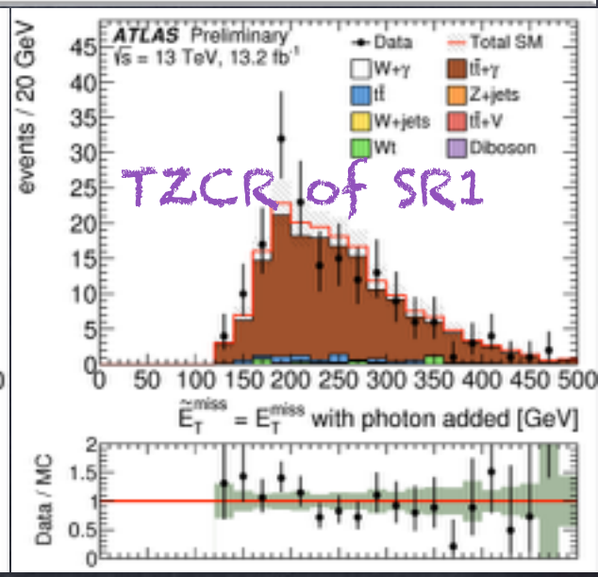
stop 1L channel

- targeting DM, heavy stop (direct and 1-step decays)
- 1 lepton, 4 jets, b-jets, high MT and dedicated selections for each target
- W+jets, ttbar, single top normalized in low MT control regions. ttZ normalized with ttgamma control region.

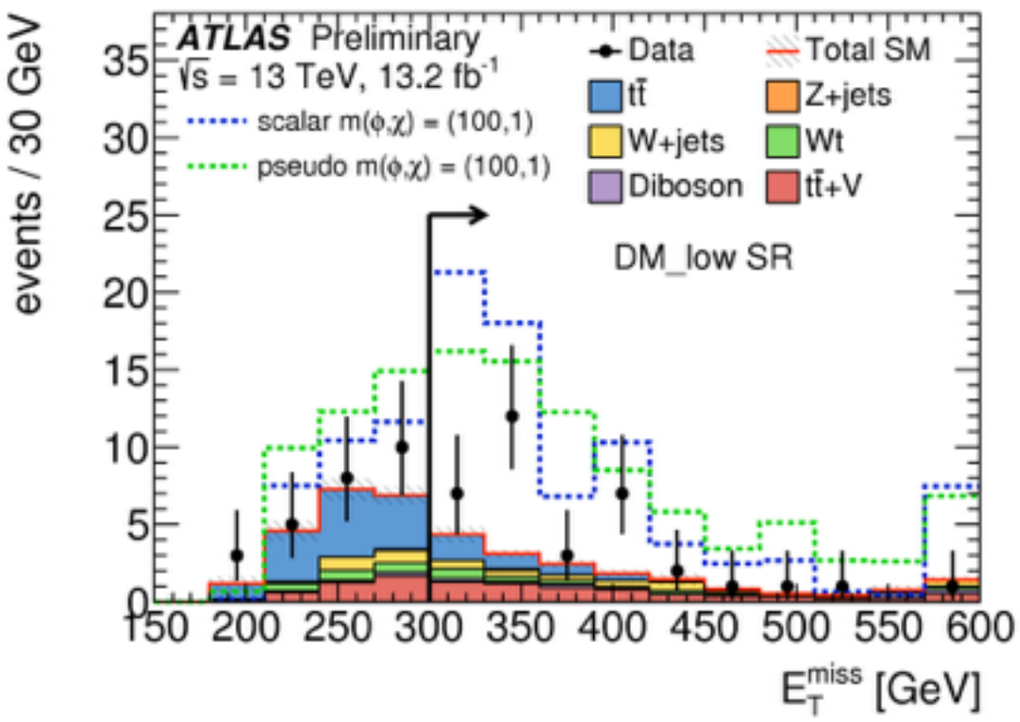
Common event selection			
Trigger	E_T^{miss} trigger		
Lepton	exactly one signal lepton (e, μ), no additional baseline leptons		
Jets	at least two signal jets, and $\lvert\Delta\phi(\text{jet}_i, \vec{p}_T^{miss})\rvert > 0.4$ for $i \in \{1,2\}$		
Hadronic τ veto*	veto events with a hadronic τ decay and $m_{T2}^{\tau} < 80\,\text{GeV}$		
Variable	SR1	tN_high	
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$	
Jet $p_T >$ [GeV]	(80 50 40 40)	(120 80 50 25)	
E_T^{miss} [GeV]	> 260	> 450	
$E_{T,\perp}^{miss}$ [GeV]	–	> 180	
$H_{T,sig}^{miss}$	> 14	> 22	
m_T [GeV]	> 170	> 210	
am_{T2} [GeV]	> 175	> 175	
topness	> 6.5	–	
m_{top}^{χ} [GeV]	< 270	–	
$\Delta R(b, \ell)$	< 3.0	< 2.4	
Leading large-R jet p_T [GeV]	–	> 290	
Leading large-R jet mass [GeV]	–	> 70	
$\Delta\phi(\vec{p}_T^{miss}, 2^{nd}\text{large-R jet})$	–	> 0.6	
Variable	bC2x_diag	bC2x_med	bCbv
Number of (jets, b-tags)	$(\geq 4, \geq 2)$	$(\geq 4, \geq 2)$	$(\geq 2, = 0)$
Jet $p_T >$ [GeV]	(70 60 55 25)	(170 110 25 25)	(120 80)
b-tagged jet $p_T >$ [GeV]	(25 25)	(105 100)	–
E_T^{miss} [GeV]	> 230	> 210	> 300
$H_{T,sig}^{miss}$	> 14	> 7	> 16
m_T [GeV]	> 170	> 140	> 200
am_{T2} [GeV]	> 170	> 210	–
$\lvert\Delta\phi(\text{jet}_i, \vec{p}_T^{miss})\rvert (i = 1)$	> 1.2	> 1.0	> 2.0
$\lvert\Delta\phi(\text{jet}_i, \vec{p}_T^{miss})\rvert (i = 2)$	> 0.8	> 0.8	> 0.8
Leading large-R jet mass [GeV]	–	–	[70, 100]
$\Delta\phi(\vec{p}_T^{miss}, \ell)$	–	–	> 1.2
Variable	DM_low	DM_high	
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$	
Jet $p_T >$ [GeV]	(60 60 40 25)	(50 50 50 25)	
E_T^{miss} [GeV]	> 300	> 330	
$H_{T,sig}^{miss}$	> 14	> 9.5	
m_T [GeV]	> 120	> 220	
am_{T2} [GeV]	> 140	> 170	
$\min(\Delta\phi(\vec{p}_T^{miss}, \text{jet}_i))$ $(i \in \{1-4\})$	> 1.4	> 0.8	
$\Delta\phi(\vec{p}_T^{miss}, \ell)$	> 0.8	–	

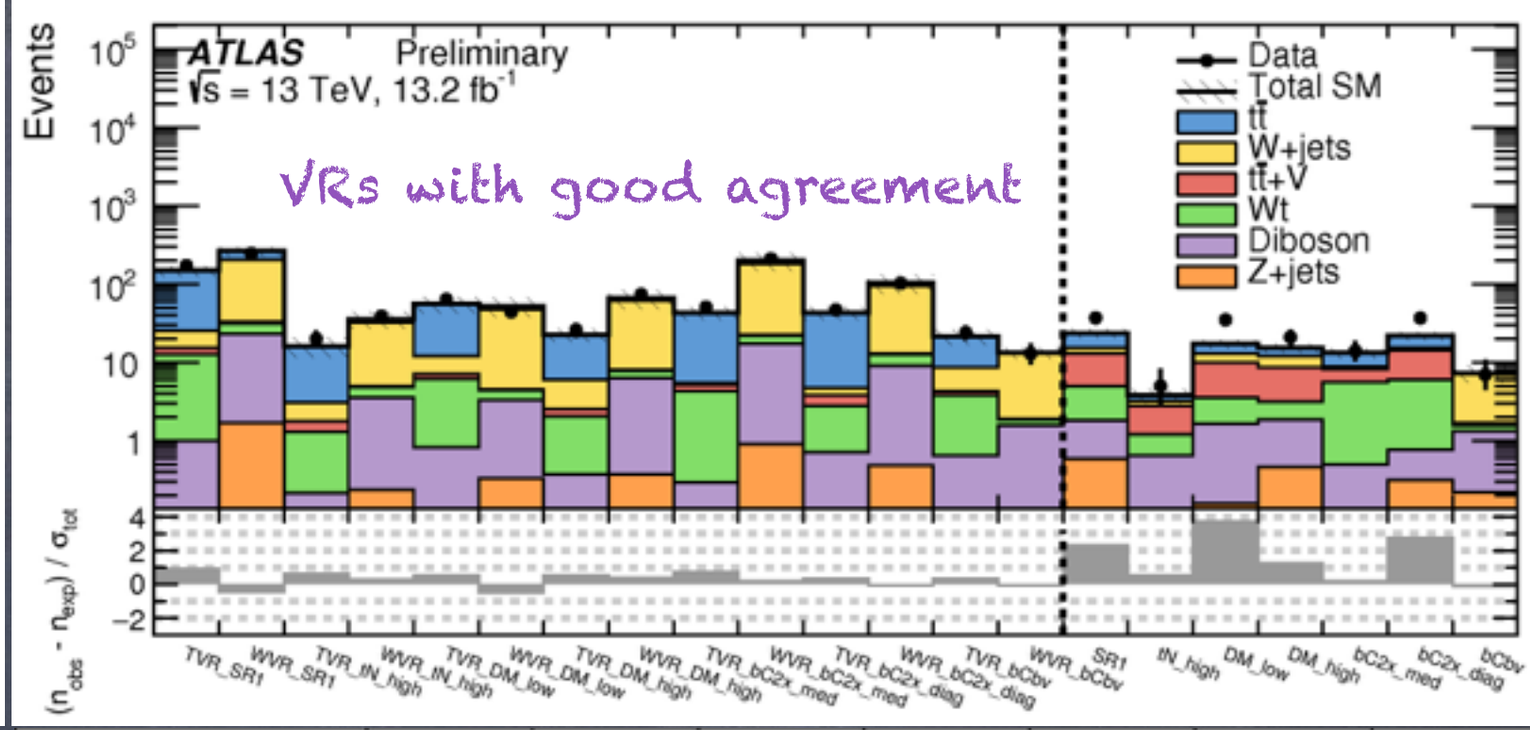






stop 1-lepton results





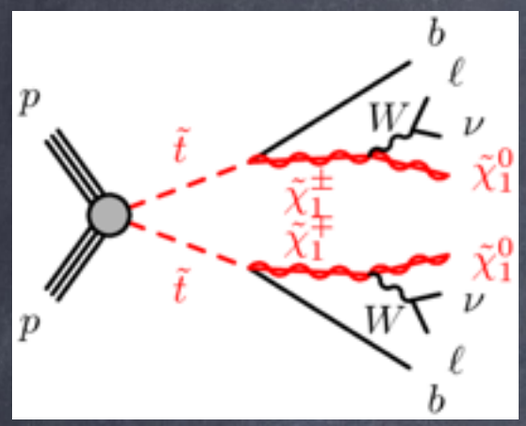
Signal region	SR1	tN_high	bC2x_diag	bC2x_med	bCbv	DM_low	DM_high
Observed	37	5	37	14	7	35	21
Total background	24 ± 3	3.8 ± 0.8	22 ± 3	13 ± 2	7.4 ± 1.8	17 ± 2	15 ± 2
$t\bar{t}$	8.4 ± 1.9	0.60 ± 0.27	6.5 ± 1.5	4.3 ± 1.0	0.26 ± 0.18	4.2 ± 1.3	3.3 ± 0.8
W+jets	2.5 ± 1.1	0.15 ± 0.38	1.2 ± 0.5	0.63 ± 0.29	5.4 ± 1.8	3.1 ± 1.5	3.4 ± 1.4
Single top	3.1 ± 1.5	0.57 ± 0.44	5.3 ± 1.8	5.1 ± 1.6	0.24 ± 0.23	1.9 ± 0.9	1.3 ± 0.8
$t\bar{t} + V$	7.9 ± 1.6	1.6 ± 0.4	8.3 ± 1.7	2.7 ± 0.7	0.12 ± 0.03	6.4 ± 1.4	5.5 ± 1.1
Diboson	1.2 ± 0.4	0.61 ± 0.26	0.45 ± 0.17	0.42 ± 0.20	1.1 ± 0.4	1.5 ± 0.6	1.4 ± 0.5
Z+jets	0.59 ± 0.54	0.03 ± 0.03	0.32 ± 0.29	0.08 ± 0.08	0.22 ± 0.20	0.16 ± 0.14	0.47 ± 0.44
$t\bar{t}$ NF	1.03 ± 0.07	1.06 ± 0.15	0.89 ± 0.10	0.95 ± 0.12	0.73 ± 0.22	0.90 ± 0.17	1.01 ± 0.13
W+jets NF	0.76 ± 0.08	0.78 ± 0.08	0.87 ± 0.07	0.85 ± 0.06	0.97 ± 0.12	0.94 ± 0.13	0.91 ± 0.07
Single top NF	1.07 ± 0.30	1.30 ± 0.45	1.26 ± 0.31	0.97 ± 0.28	–	1.36 ± 0.36	1.02 ± 0.32
$t\bar{t} + W/Z$ NF	1.43 ± 0.21	1.39 ± 0.22	1.40 ± 0.21	1.30 ± 0.23	–	1.47 ± 0.22	1.42 ± 0.21
p_0 (σ)	0.012 (2.2)	0.26 (0.6)	0.004 (2.6)	0.40 (0.3)	0.50 (0)	0.0004 (3.3)	0.09 (1.3)
$N^{\text{limit}}_{\text{non-SM}}$ exp. (95% CL)	$12.9^{+5.5}_{-3.8}$	$5.5^{+2.8}_{-1.1}$	$12.4^{+5.4}_{-3.7}$	$9.0^{+4.2}_{-2.7}$	$7.3^{+3.5}_{-2.2}$	$11.5^{+5.0}_{-3.4}$	$9.9^{+4.6}_{-2.9}$
$N^{\text{limit}}_{\text{non-SM}}$ obs. (95% CL)	26.0	7.2	27.5	9.9	7.2	28.3	15.6

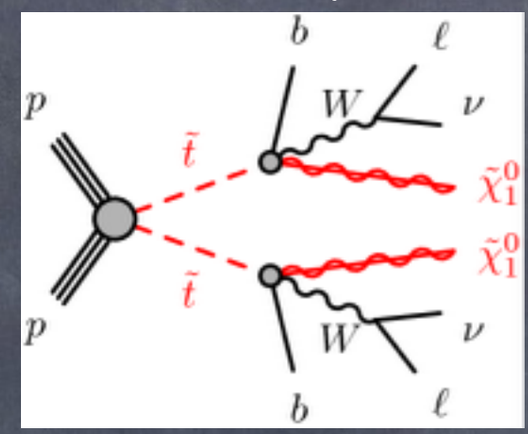
- Some excess in three (overlapping) signal regions, designed for chargino decays (bC2x_diag) direct decays (SR1) and DM+ttbar (DMlow) with relatively low mass scales/splitting
- 3.3 sigma local is the largest excess

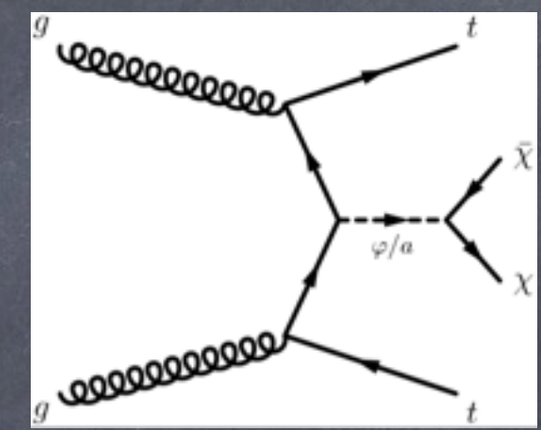
keep calm and wait for more data

ATLAS-CONF-2016-076

stop 2L



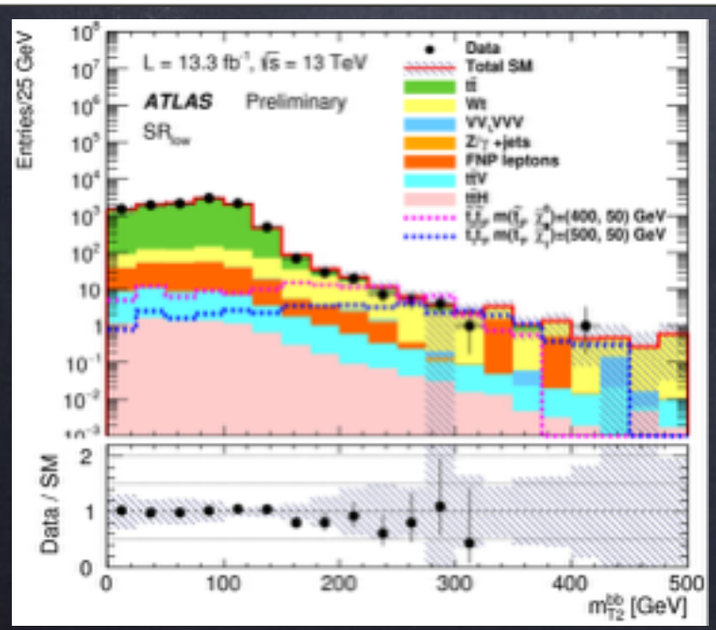


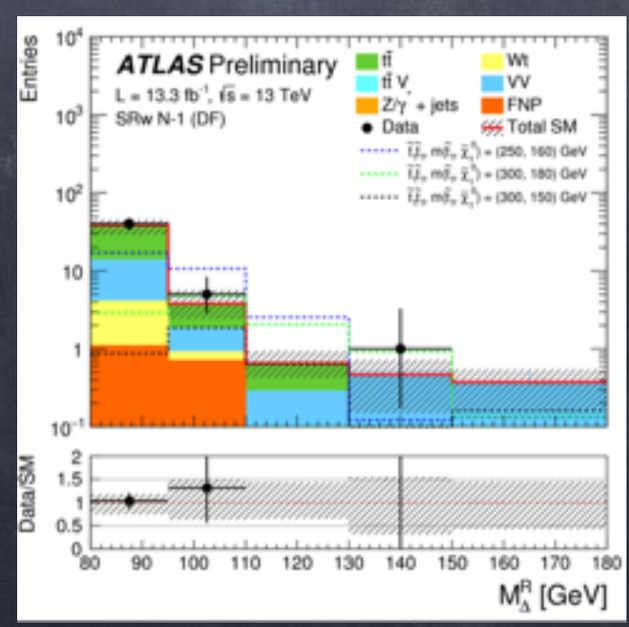


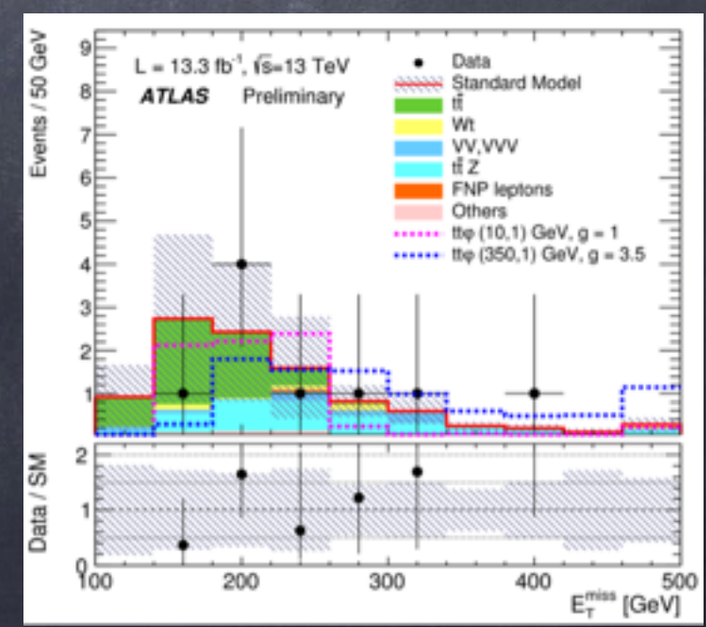
Variable	SR^{hadMT2}_{Low}	SR^{hadMT2}_{High}
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV] (SF only)	>20	>20
b-jet multiplicity	2	2
m^{bb}_{T2} [GeV]	>220	>220
p_T^{lep1} [GeV]	<120	<120
$E^{bl}_{T,min}$ [GeV]	-	>180

Common selection		
Lepton flavour	SF, DF	
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV] (SF only)	>10	
R_{PT}	>0.5	
$1/\gamma_{R+1}$	>0.8	
$\Delta\phi^R_\beta$	> 0.85 $\lvert\cos\theta_b\rvert$ + 1.8	
Region specific	SR^{3-body}_W	SR^{3-body}_t
b-jet multiplicity	= 0	> 0
M^R_Δ [GeV]	> 95	> 110

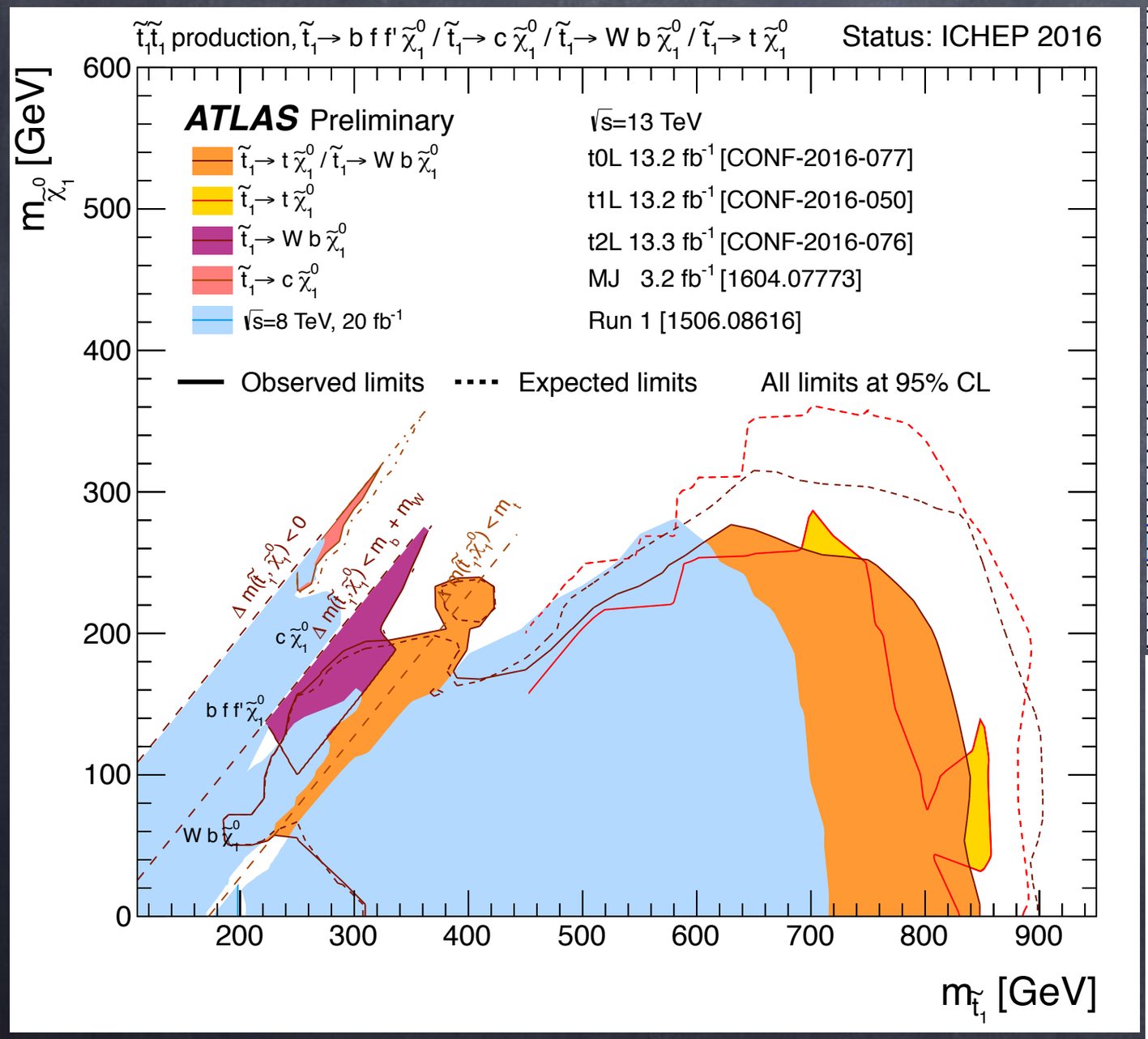
Variable	DM-SRL	DM-SRH
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV] (SF only)	>20	>20
b-jet multiplicity	> 0	> 0
$\Delta\phi_{boost}$	< 1.0	< 1.0
m^{ll}_{T2} [GeV]	>120	>120
E_T^{miss} [GeV]	> 180	> 260

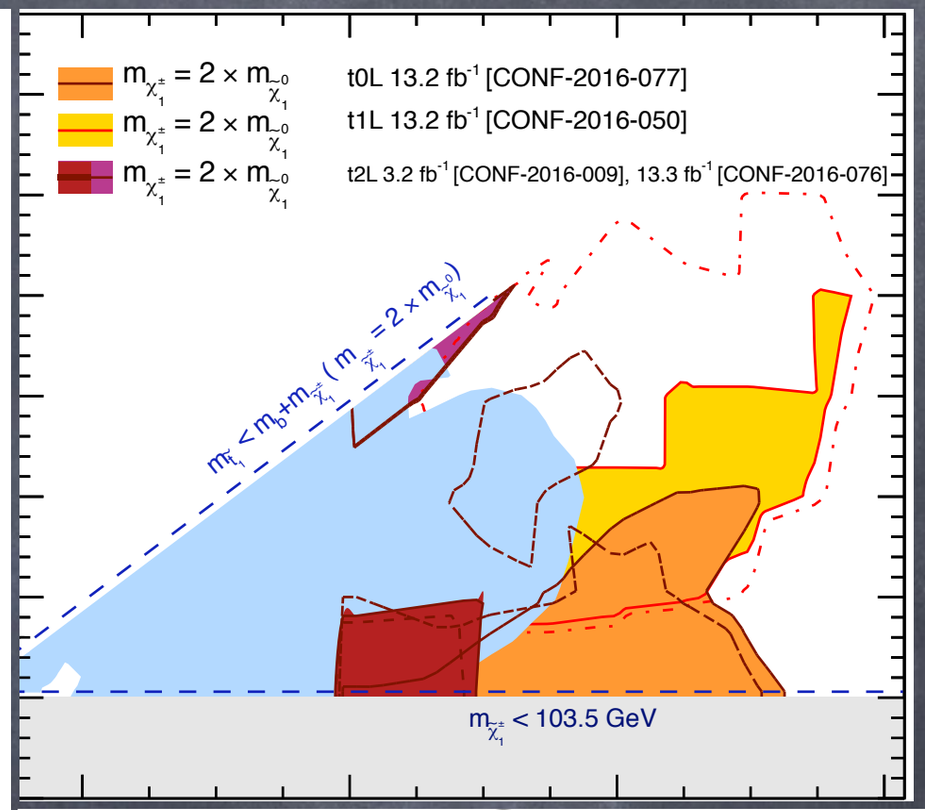


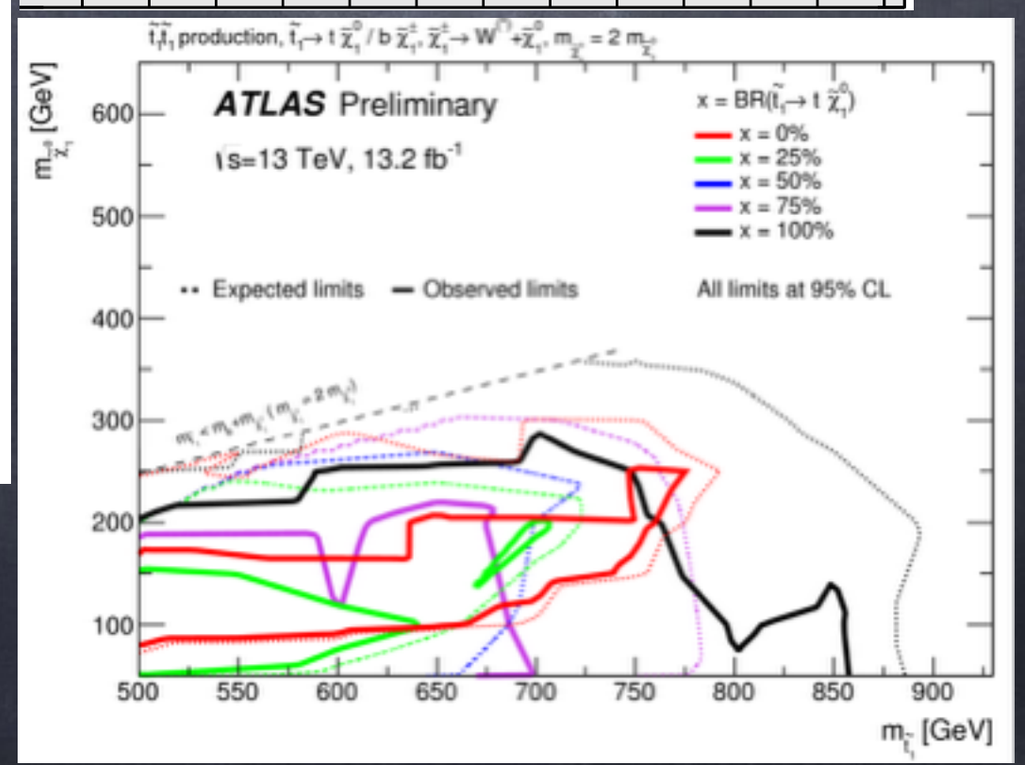




Limits...


$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \to b f f' \tilde{\chi}_1^0$ / $\tilde{t}_1 \to c \tilde{\chi}_1^0$ / $\tilde{t}_1 \to W b \tilde{\chi}_1^0$ / $\tilde{t}_1 \to t \tilde{\chi}_1^0$
Status: ICHEP 2016
ATLAS Preliminary
$\sqrt{s}$=13 TeV
$\tilde{t}_1 \to t \tilde{\chi}_1^0$ / $\tilde{t}_1 \to W b \tilde{\chi}_1^0$ t0L 13.2 fb^{-1} [CONF-2016-077]
$\tilde{t}_1 \to t \tilde{\chi}_1^0$ t1L 13.2 fb^{-1} [CONF-2016-050]
$\tilde{t}_1 \to W b \tilde{\chi}_1^0$ t2L 13.3 fb^{-1} [CONF-2016-076]
$\tilde{t}_1 \to c \tilde{\chi}_1^0$ MJ 3.2 fb^{-1} [1604.07773]
$\sqrt{s}$=8 TeV, 20 fb^{-1} Run 1 [1506.08616]
Observed limits
Expected limits
All limits at 95% CL
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]
$\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) < 0$
$\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) < m_b + m_W$
$\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) < m_t$
$c \tilde{\chi}_1^0$
$b f f' \tilde{\chi}_1^0$
$W b \tilde{\chi}_1^0$

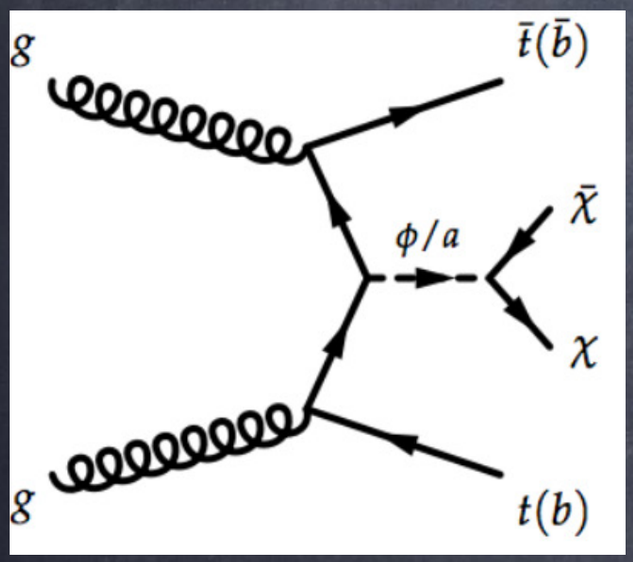

$m_{\tilde{\chi}_1^\pm} = 2 \times m_{\tilde{\chi}_1^0}$ t0L 13.2 fb^{-1} [CONF-2016-077]
$m_{\tilde{\chi}_1^\pm} = 2 \times m_{\tilde{\chi}_1^0}$ t1L 13.2 fb^{-1} [CONF-2016-050]
$m_{\tilde{\chi}_1^\pm} = 2 \times m_{\tilde{\chi}_1^0}$ t2L 3.2 fb^{-1} [CONF-2016-009], 13.3 fb^{-1} [CONF-2016-076]
$m_{\tilde{t}_1} < m_b + m_{\tilde{\chi}_1^\pm}$ ($m_{\tilde{\chi}_1^\pm} = 2 \times m_{\tilde{\chi}_1^0}$)
$m_{\tilde{\chi}_1^\pm} < 103.5$ GeV


$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \to t \tilde{\chi}_1^0$ / $b \tilde{\chi}_1^\pm$, $\tilde{\chi}_1^\pm \to W^{(*)} + \tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^\pm} = 2 m_{\tilde{\chi}_1^0}$
ATLAS Preliminary
$\sqrt{s}$=13 TeV, 13.2 fb^{-1}
$x = BR(\tilde{t}_1 \to t \tilde{\chi}_1^0)$
x = 0%
x = 25%
x = 50%
x = 75%
x = 100%
Expected limits
Observed limits
All limits at 95% CL
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]

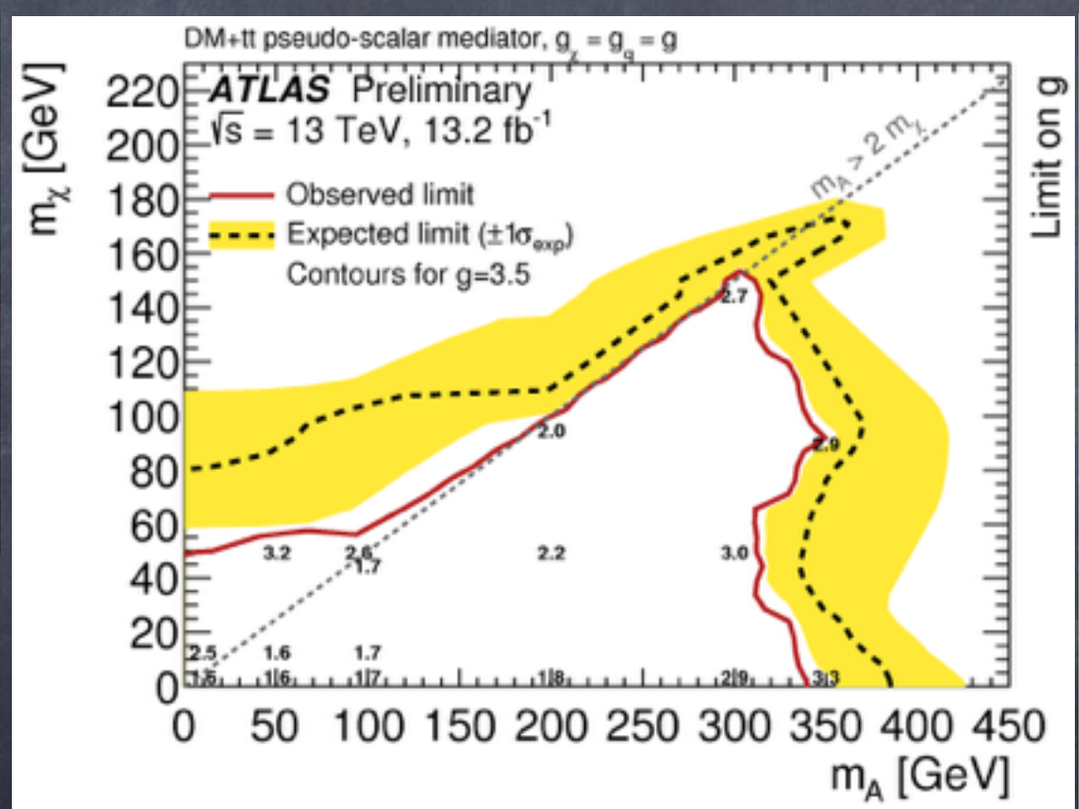
Dark Matter interpretations

- The stop 0L, 1L, 2L notes also contain selections targeting DM production in the same final state (with comparable sensitivities)

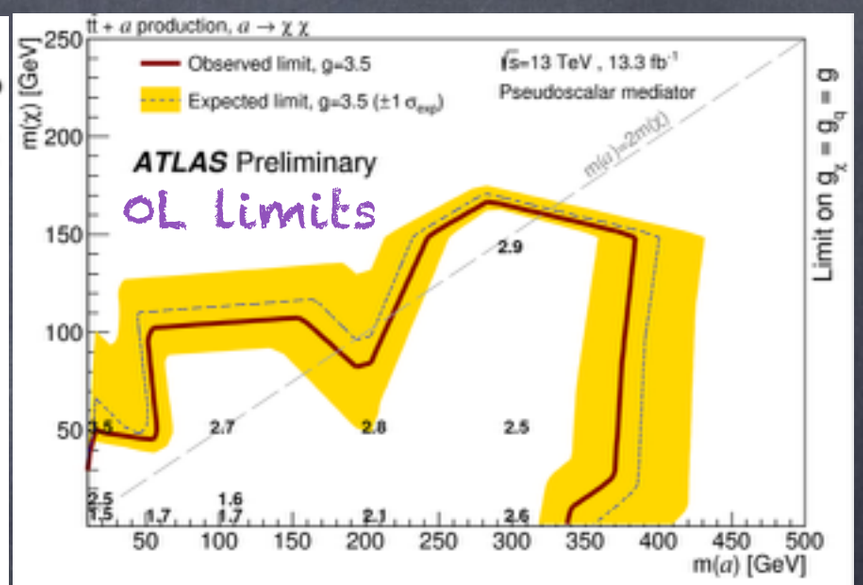
- on-shell mediator lighter than 350 GeV excluded for maximum g=3.5 coupling. Probing couplings down to 1.7 at lower mass.

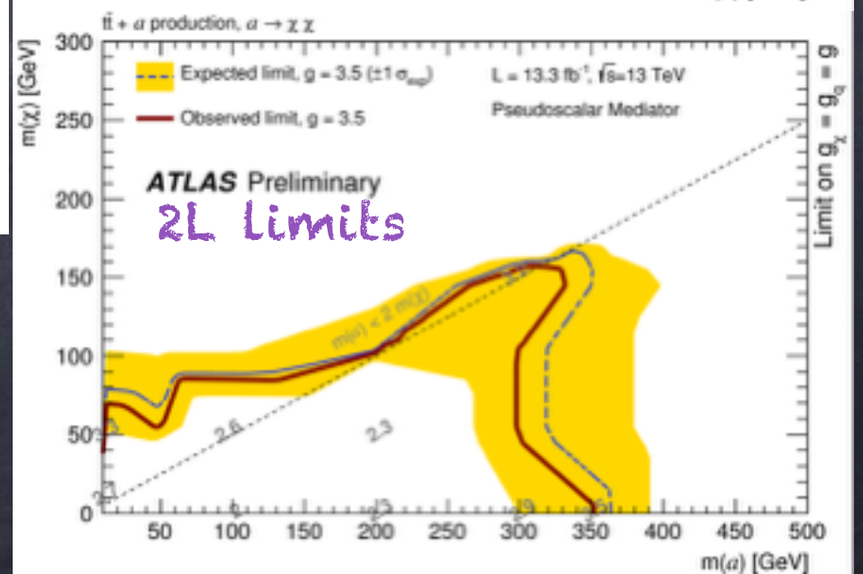


scalar or pseudo scalar mediator (similar sensitivity)



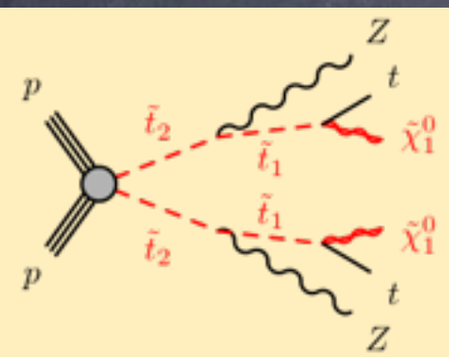
1L limits





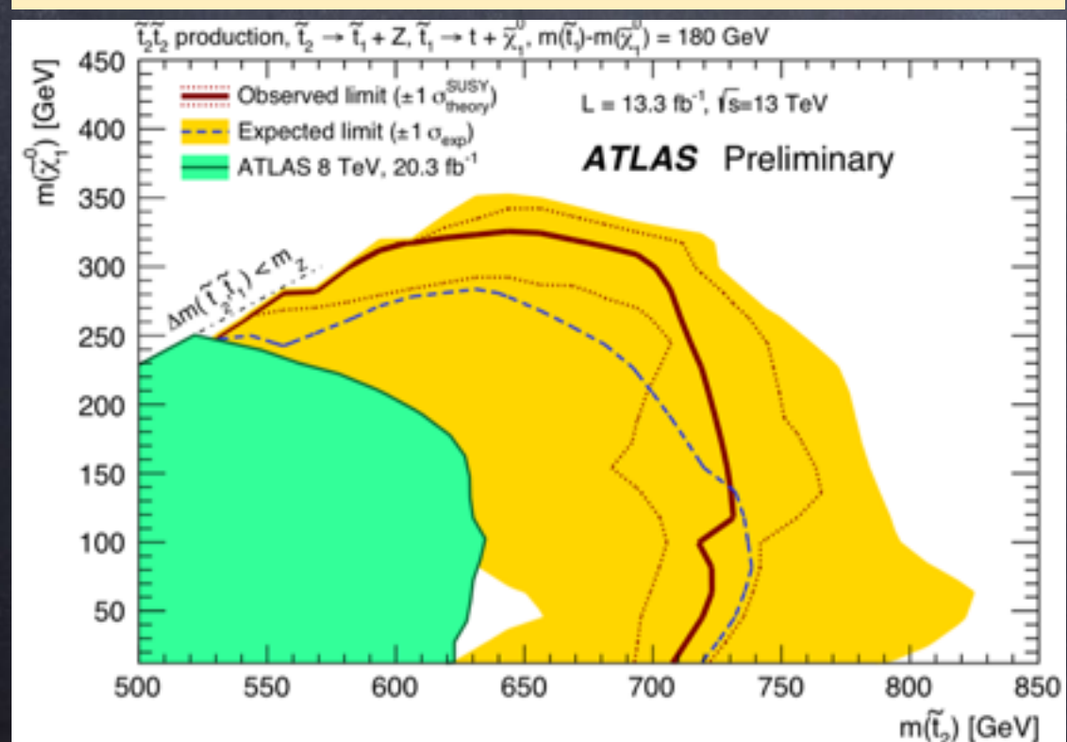
ATLAS-CONF-2016-038
ATLAS-CONF-2016-048

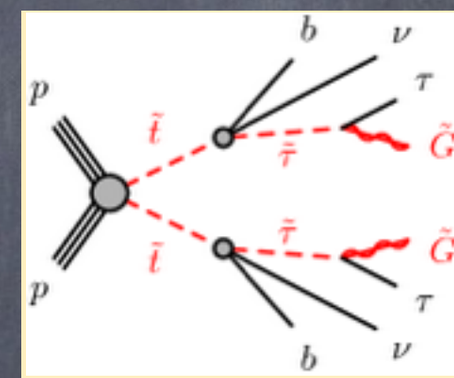
3-lepton and 2-tau stop



- fix stop1 mass to $m(\chi^0)+m(t)$
- Look for stop2

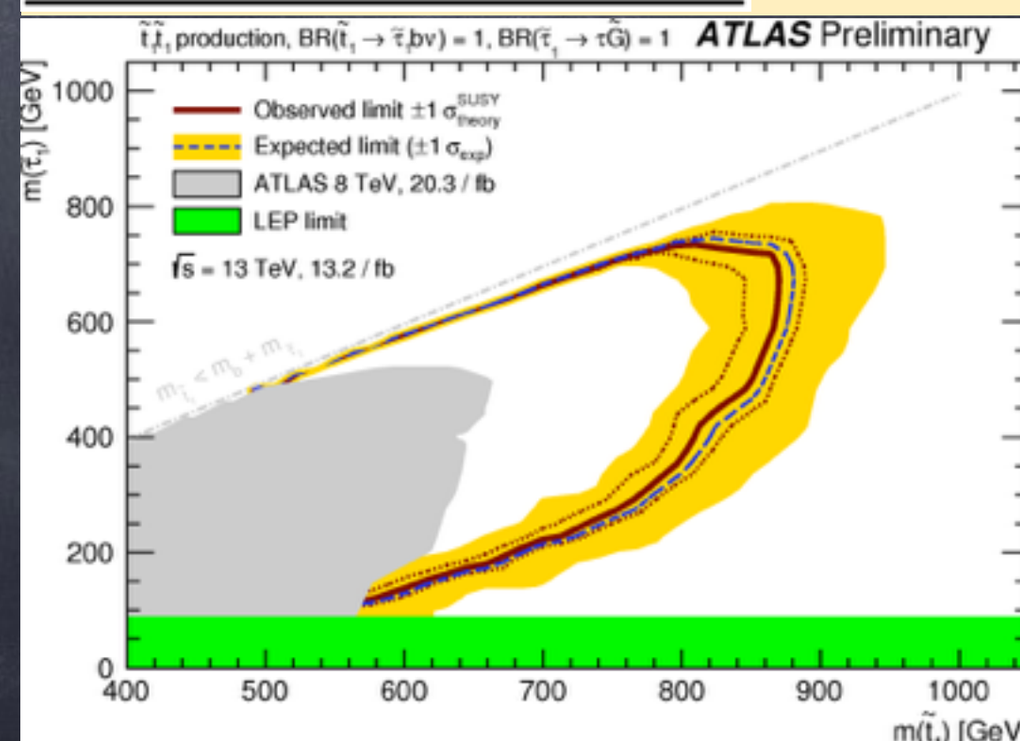
Var/Region	SRL	SRH	SRE
$m_{\ell\ell}$ [GeV]	76.2–106.2	76.2–106.2	76.2–106.2
Leading lepton p_T [GeV]	> 40	> 40	> 40
Leading jet p_T [GeV]	> 60	> 100	> 80
n_{b-jets}	≥ 1	≥ 1	≥ 1
n_{jets}	≥ 6	≥ 5	≥ 5
E_T^{miss} [GeV]	> 100	> 100	> 100
$p_T^{\ell\ell}$ [GeV]	–	> 200	> 100





- 2t, 2b, MET, using lep-had channel

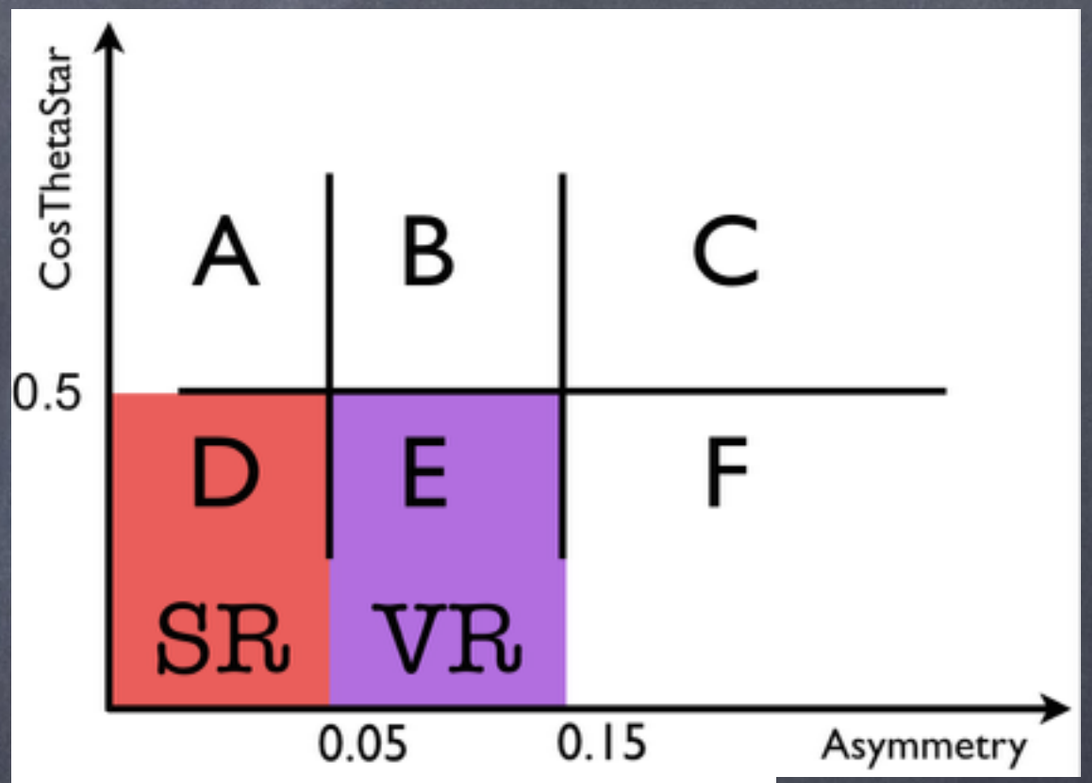
Variable	SR requirement
$N_{b\text{-jet}}$	≥ 1
E_T^{miss}	$> GeV180$
$p_T(\tau)$	$> GeV70$
$m_{T2}(\ell,\tau)$	$> GeV100$

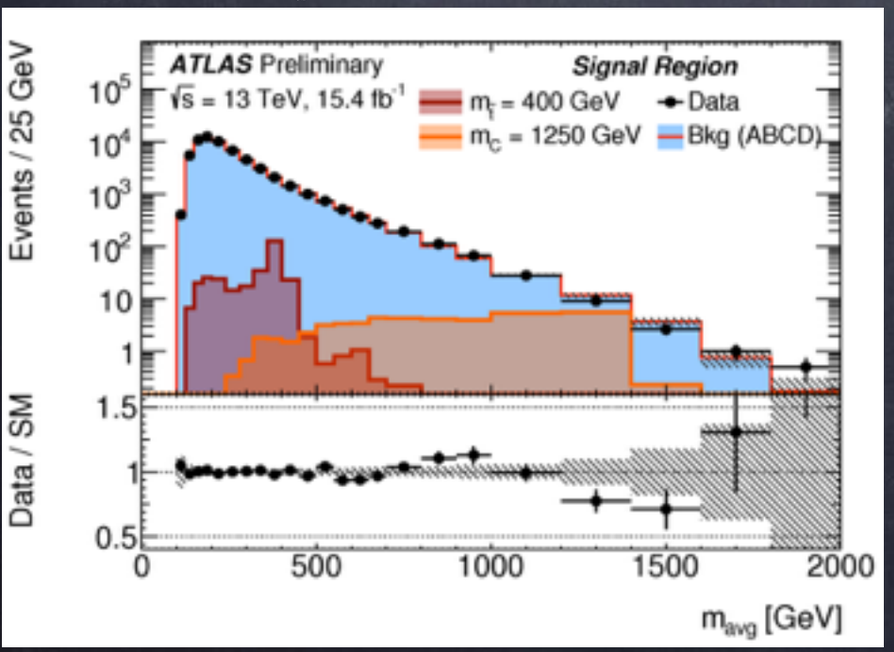


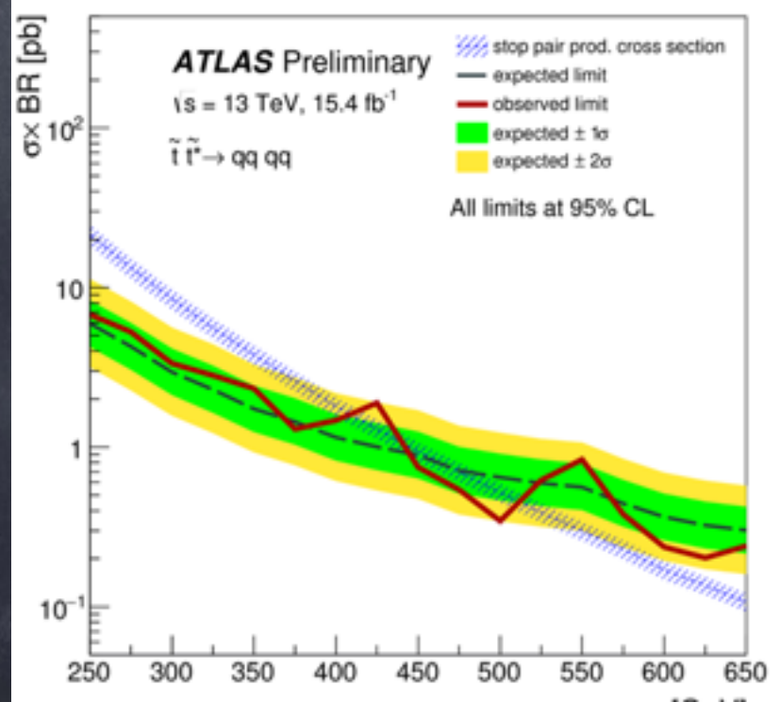
ATLAS-CONF-2016-084

stop RPV (2x2 jets)

- Target stop decay in two jets (no b-tagging, flavor agnostic)
- Select 4 jets with pT>120 GeV, forms 2 pairs according to ΔR, cut on mass asymmetry and angle with beam line of the two resonances
- ABCD method for background estimate (multijet)

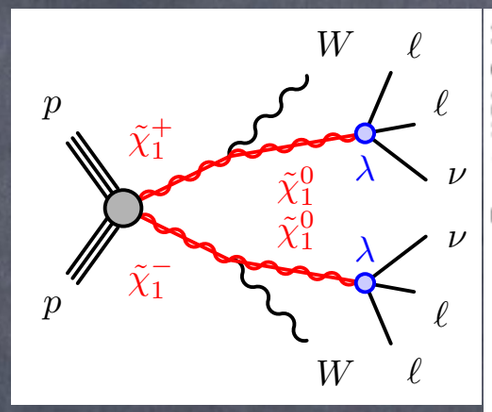


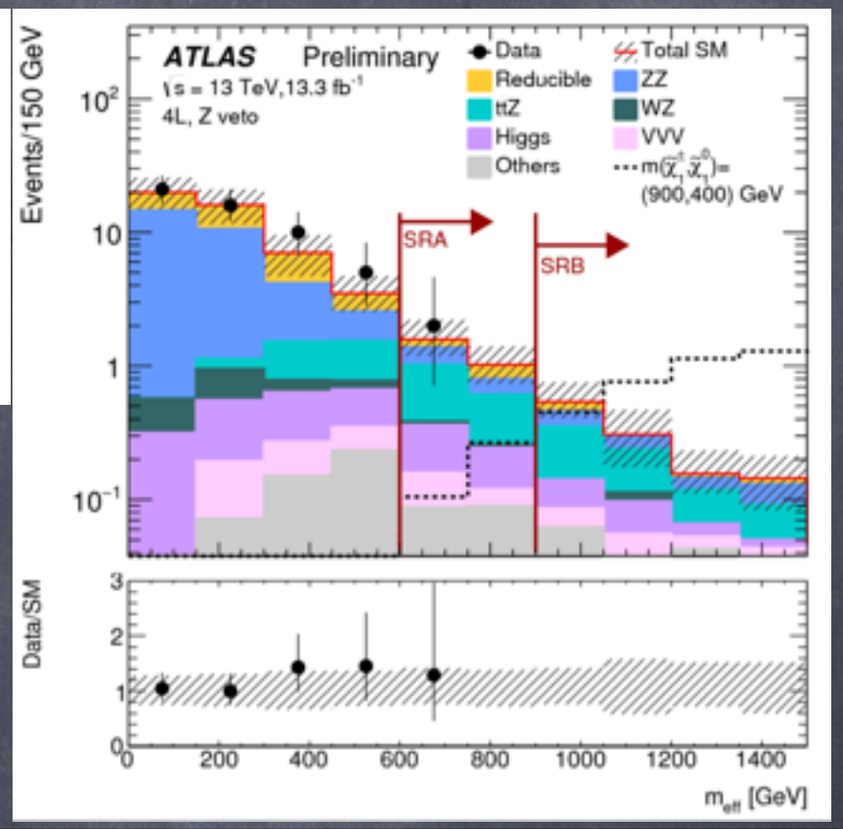




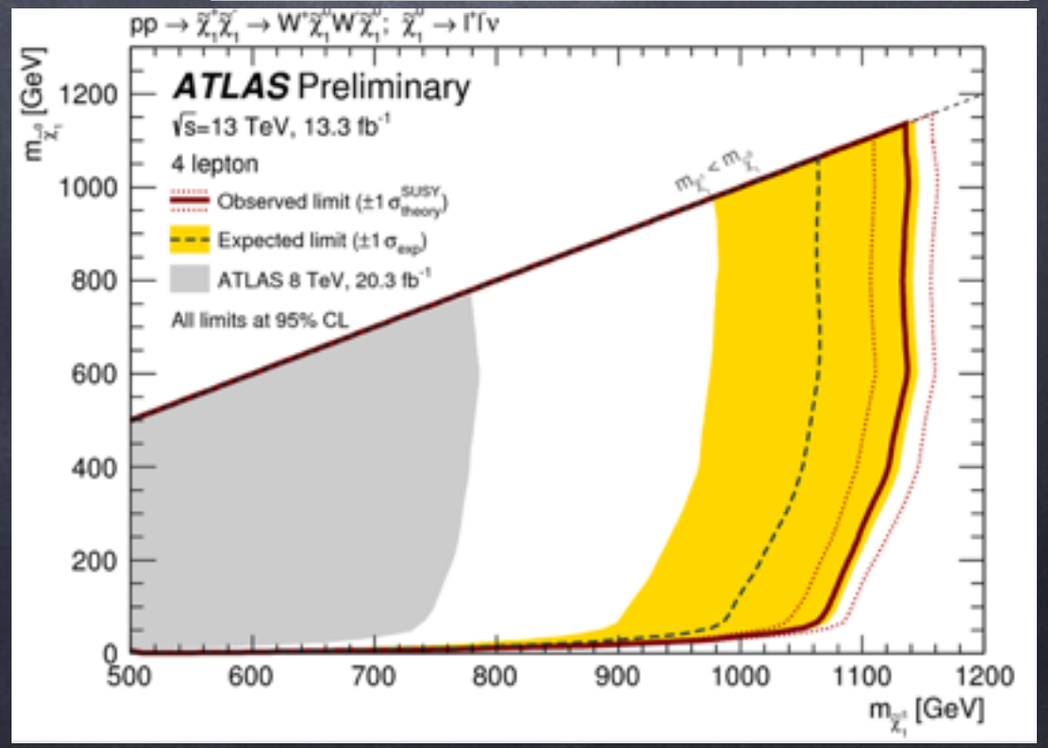
ATLAS-CONF-2016-075

4 lepton search





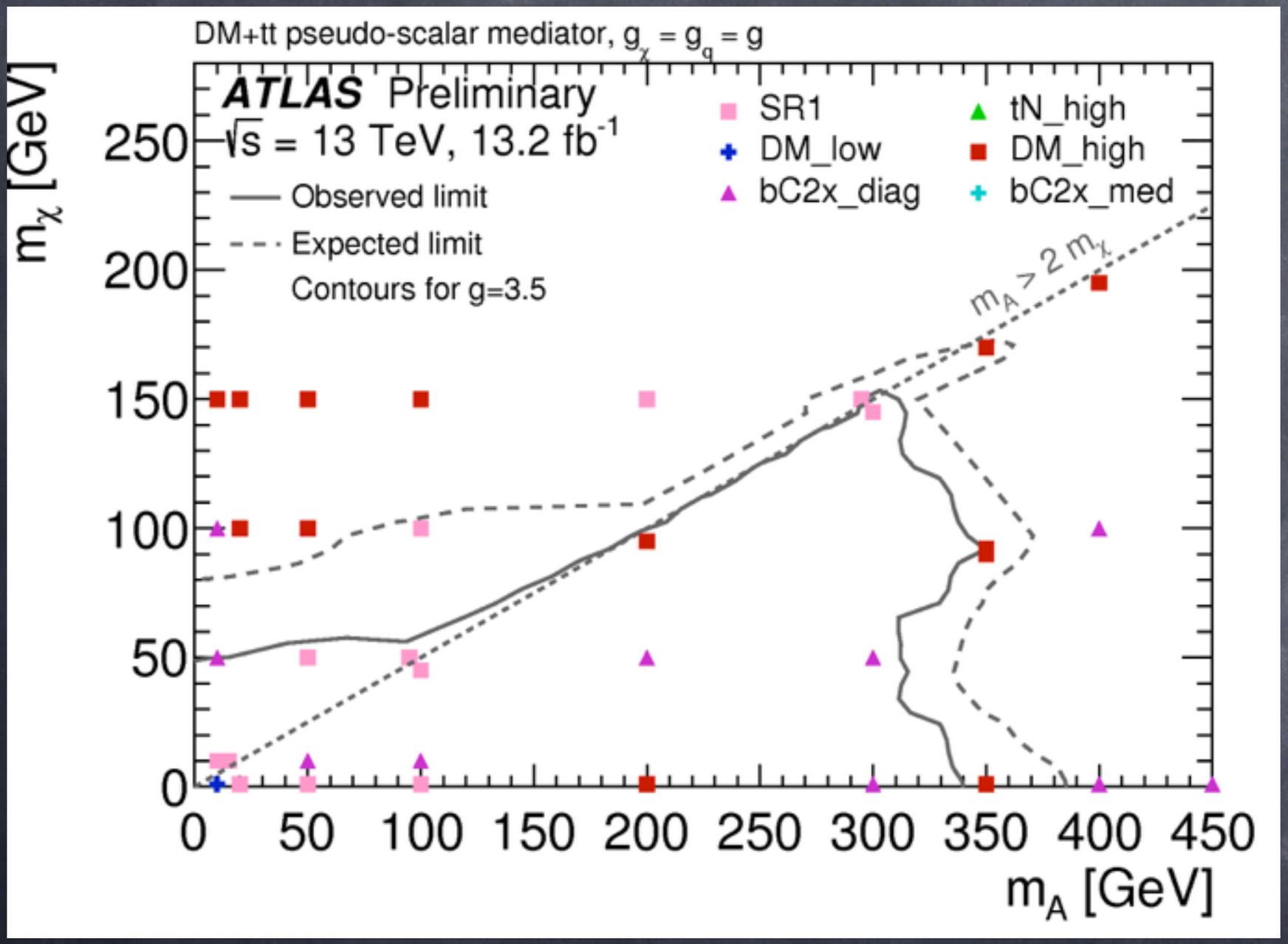
- Four (off-Z) leptons and Meff > 600/900 GeV
- Clean and relatively model independent selection, sensitive to many BSM. Interpreted in the context of leptonic RPV decay of EWKinos.
- Fake background from data loose lepton selection, scaled with tight/loose probabilities



conclusions/outlook

- 13 ATLAS analysis targeting SUSY released for ICHEP significantly improving sensitivity
- More searches in preparation - stay tuned !
- Looking forward to more data

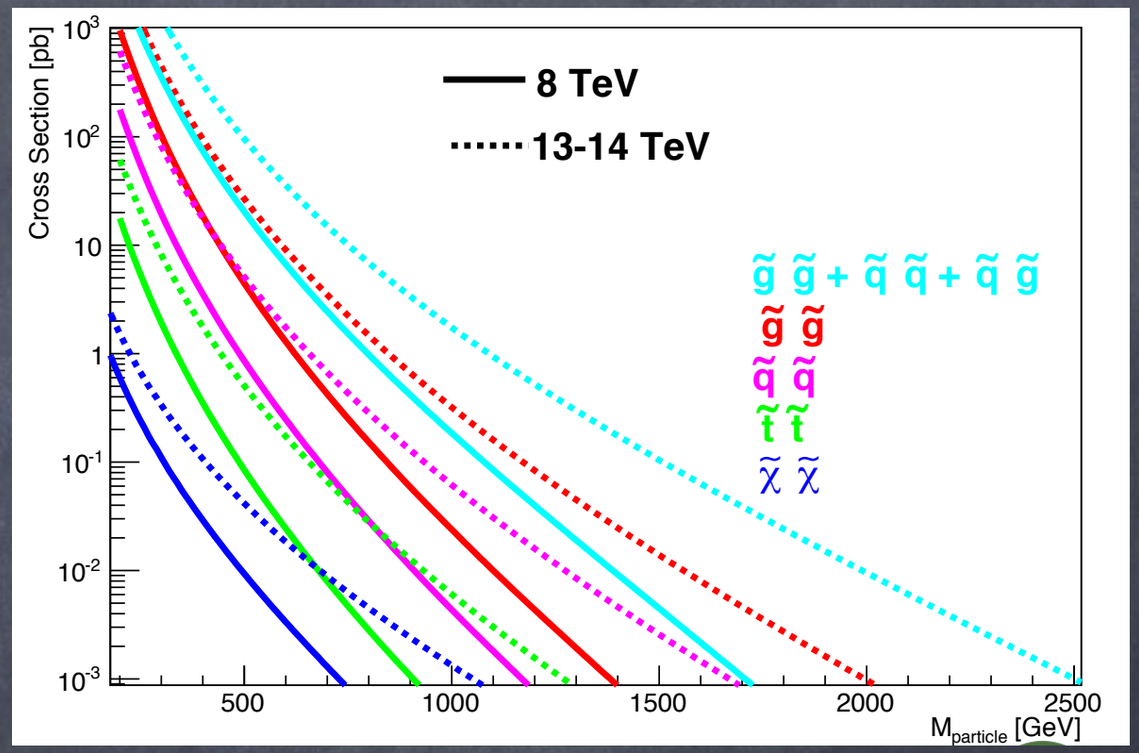
backup



- For every point, the SR with the best expected sensitivity is used
- DM_low, which has the largest excess, is the best SR only for the (10,1) point
- For most low mass region, SR1 and bC2c_diag which have also a mild excess are best

SUSY signatures

- R-parity conservation, pair production with two invisible particles in the final state
  - strong production of squarks and gluinos : high cross section/mass scale, jets and missing ET.
  - third generation squarks: same as above, but lower cross section/mass scale, b-tagging, focused effort/analysis techniques
  - electroweak production: low cross section/mass scale, typical (but not only) signature many leptons, missing ET, no jets.
- RPV signatures: no MET but high jet multiplicity (jets or leptons depending on couplings) and resonances
- Long Lived particles: model independent searches for "stable" coloured/charged particles and particles decaying inside detector



- Focus of 2015 paper was heavy squarks to profit from center of mass energy
- With more luminosity, we are getting sensitive to electroweak production and compressed spectra