

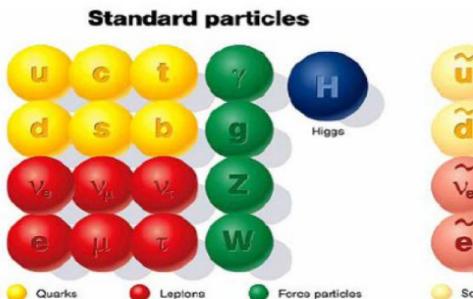


Search for R-parity violating SUSY and long lived particles with the ATLAS detector

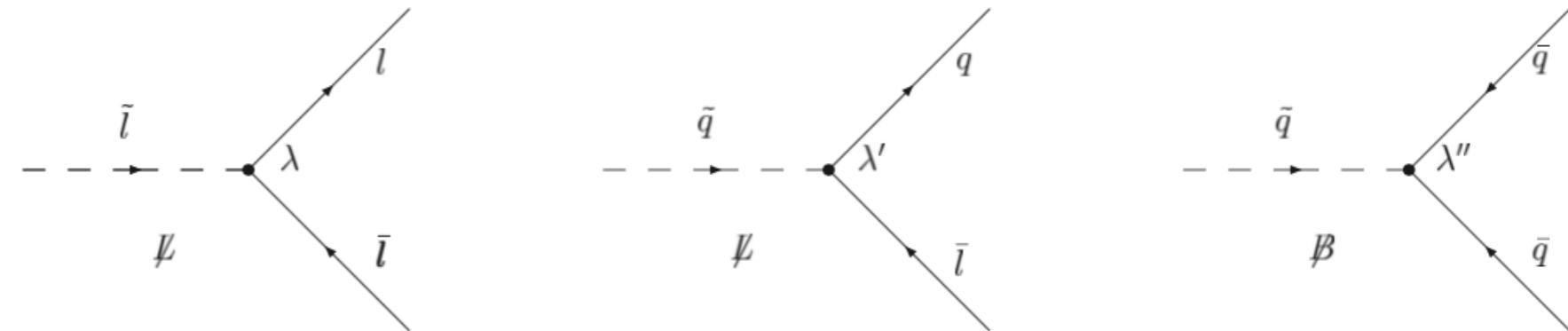
N. Bernard
University of Massachusetts, Amherst
DIS 2017



RPV SUSY

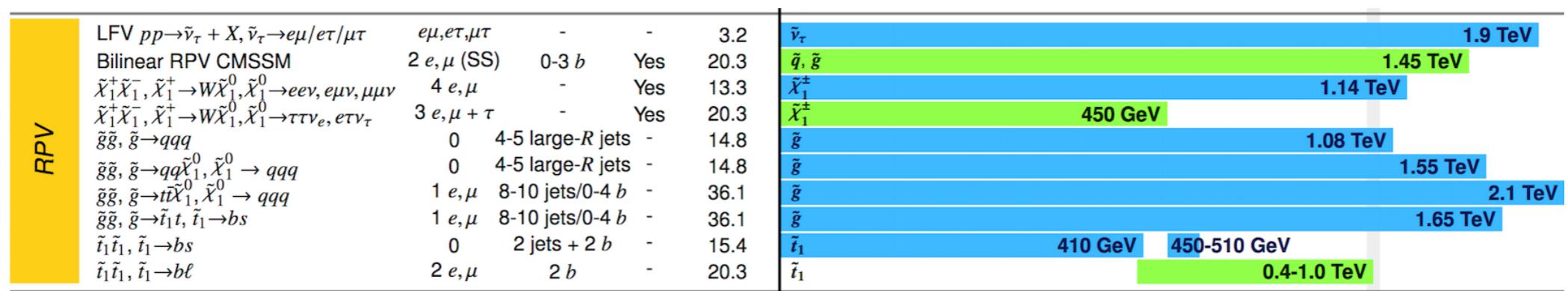


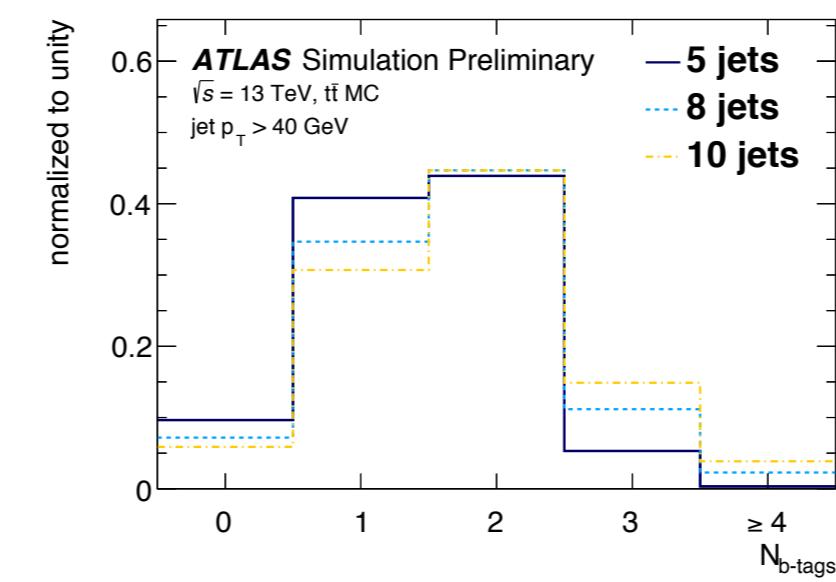
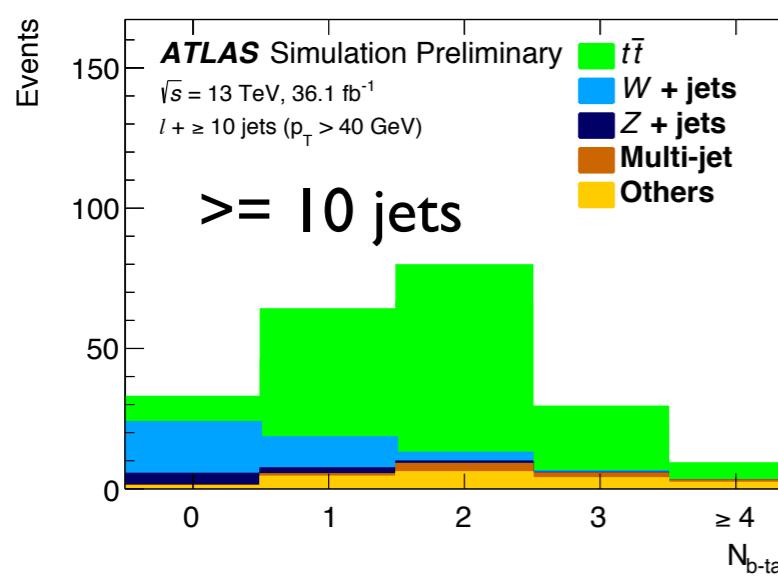
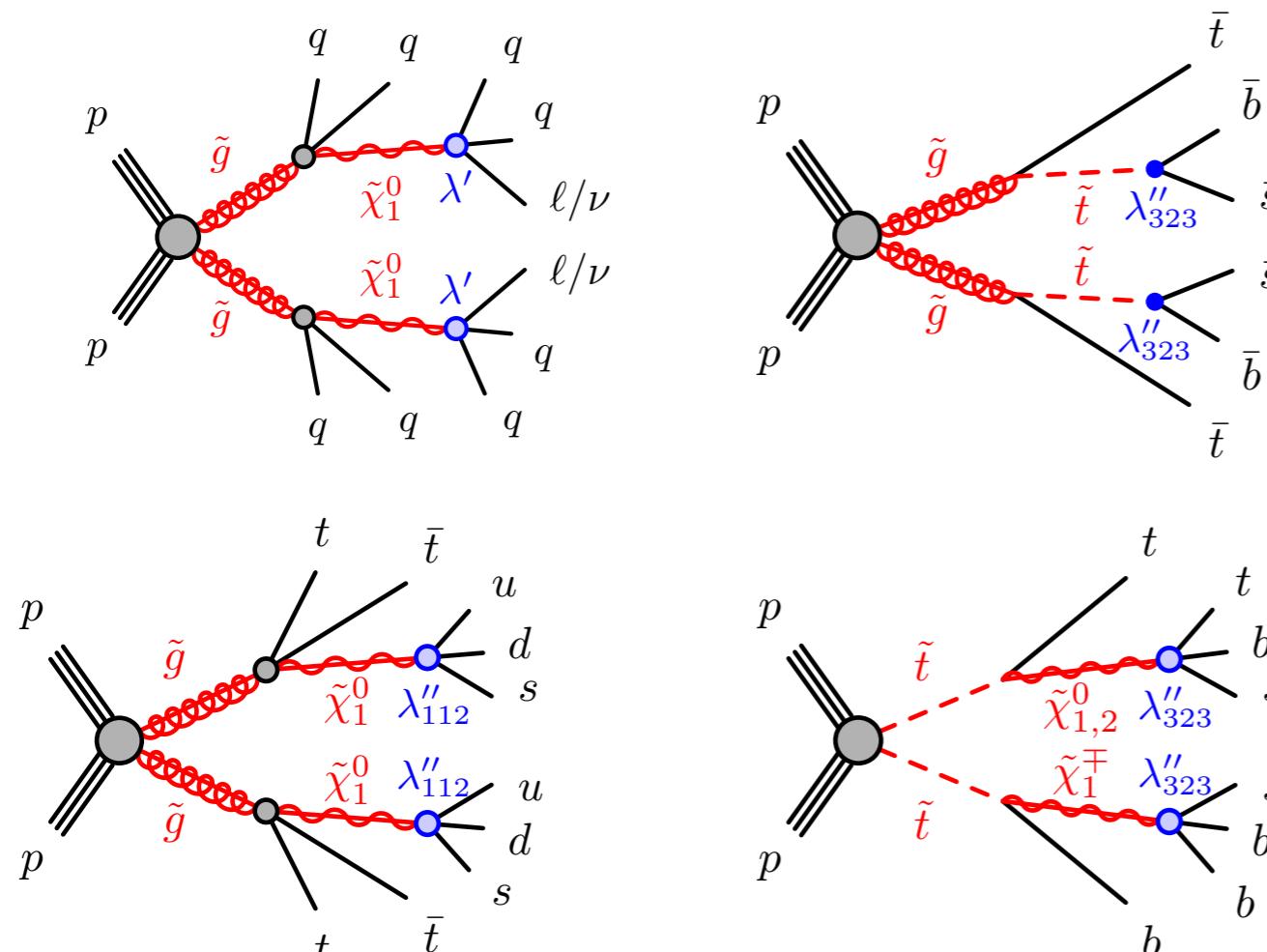
$$R = (-1)^{3B+L+2S}$$



- For SM particle: $R = +1$
- For SUSY particle: $R = -1$

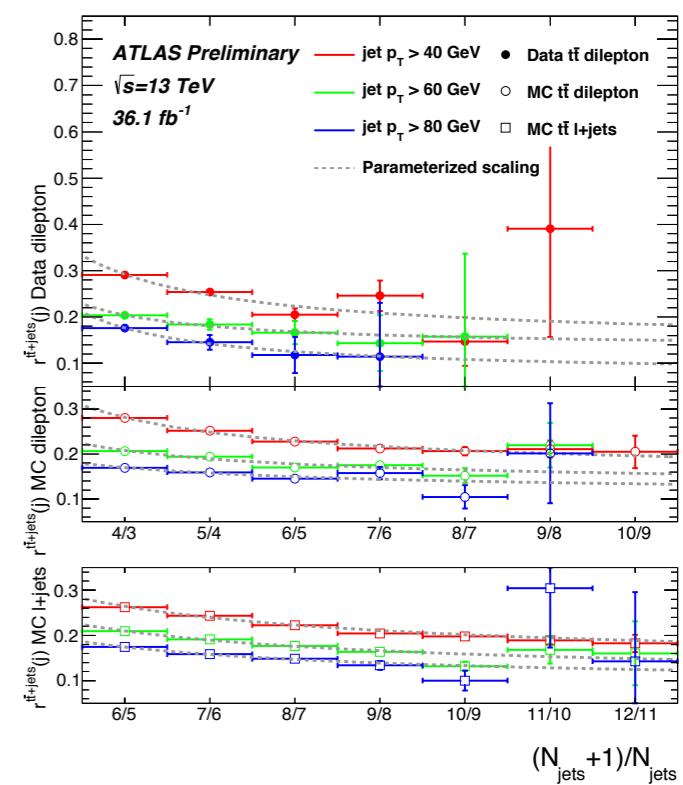
- Precision SM measurements support baryon and lepton number conservation, yet some MSSM couplings do not.
- R-parity is an additional symmetry placed on MSSM that forbids such couplings generically.
- Precision SM measurements rule out some RPV SUSY couplings, but collider searches are needed to cover full parameter space.





ATLAS-CONF-2017-013

- single lepton / large jet multiplicity
- 0-4+ bjets
- dominant bkgd: $t\bar{t}$, $W/Z + \text{jets}$
- data driven bkgd estimate:
 - find b jet multiplicity templates at lower jet multiplicities
 - extrapolate to high jet multiplicity using scaling parameterization



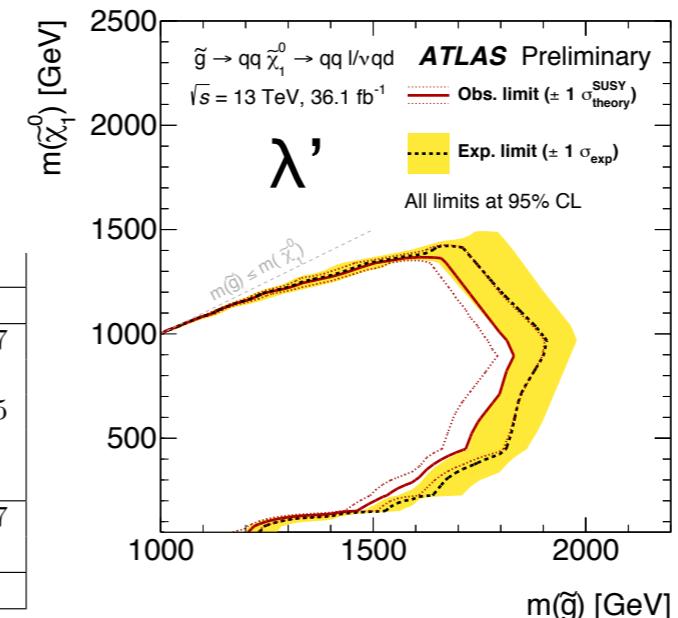
Lepton and high jet multiplicity (cont...)



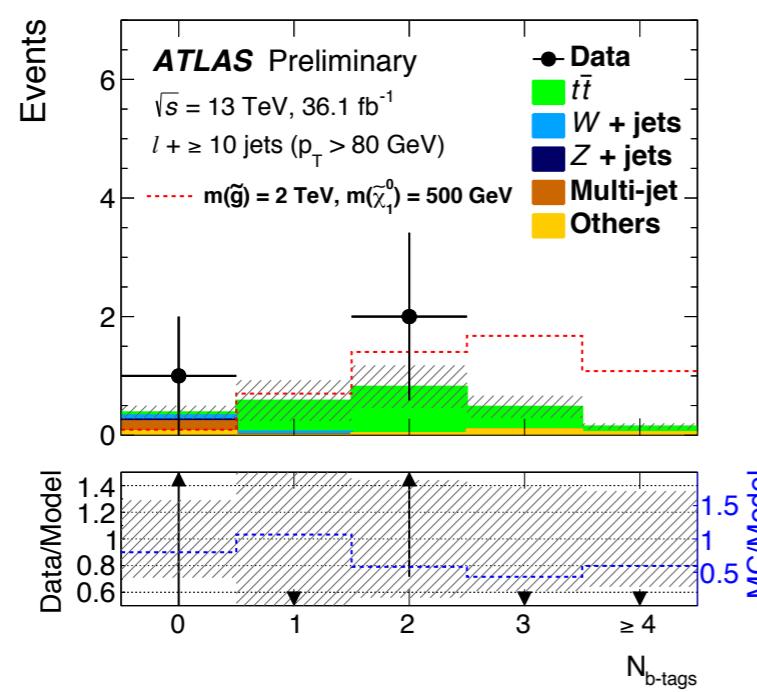
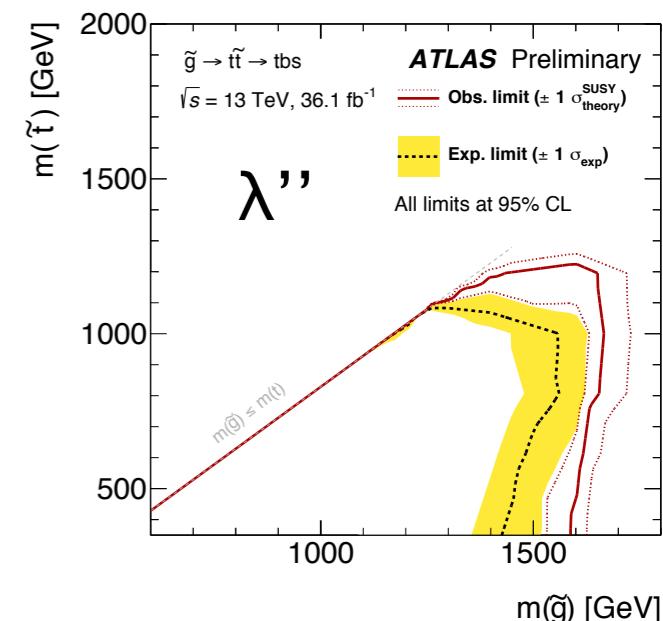
- no excess is seen
- limits set in various 2D mass planes.

Process	≥ 8 jets		≥ 9 jets		≥ 10 jets	
	0b	≥ 3 b	0b	≥ 3 b	0b	≥ 3 b
$t\bar{t}$ +jets	4.0 ± 1.7	15.7 ± 2.3	0.44 ± 0.21	2.7 ± 0.7	0.06 ± 0.04	0.38 ± 0.27
W +jets	9.0 ± 2.9	0.18 ± 0.07	1.2 ± 0.7	0.02 ± 0.02	0.05 ± 0.07	< 0.01
Others	2.3 ± 0.9	2.4 ± 0.7	0.16 ± 0.05	0.45 ± 0.15	0.06 ± 0.03	0.14 ± 0.05
Z +jets	1.7 ± 0.5	0.06 ± 0.02	0.23 ± 0.14	0.03 ± 0.01	0.02 ± 0.03	< 0.01
Multijet	0.8 ± 0.4	< 0.01	0.30 ± 0.15	< 0.01	0.16 ± 0.08	< 0.01
Total Bkd.	17.8 ± 2.9	18.4 ± 2.2	2.3 ± 0.9	3.2 ± 0.7	0.35 ± 0.13	0.52 ± 0.27
Data	21	14	3	1	1	0
$p_0 (\sigma)$	0.27 (0.6)	0.5 (0)	0.34 (0.4)	0.5 (0)	0.18 (0.9)	0.5 (0)

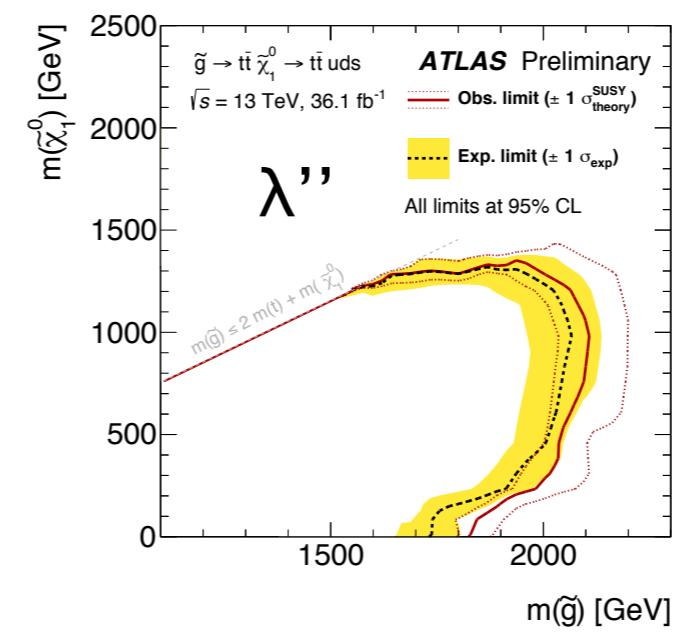
gluino \rightarrow neutralino



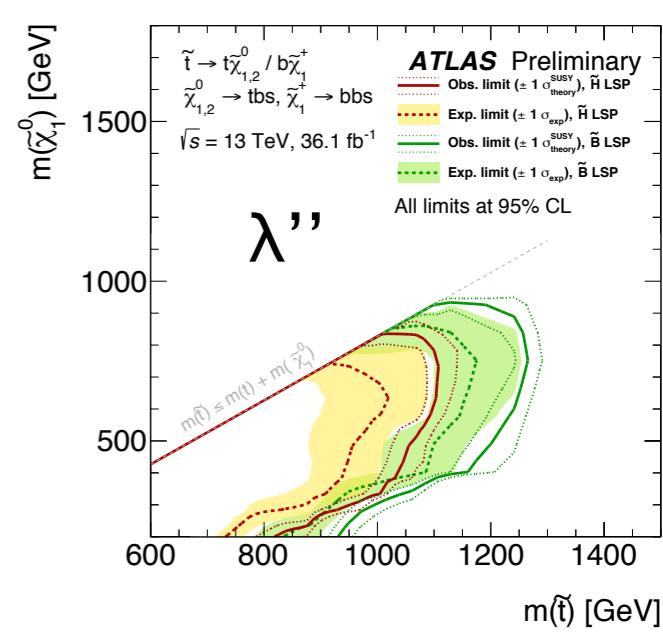
gluino \rightarrow stop

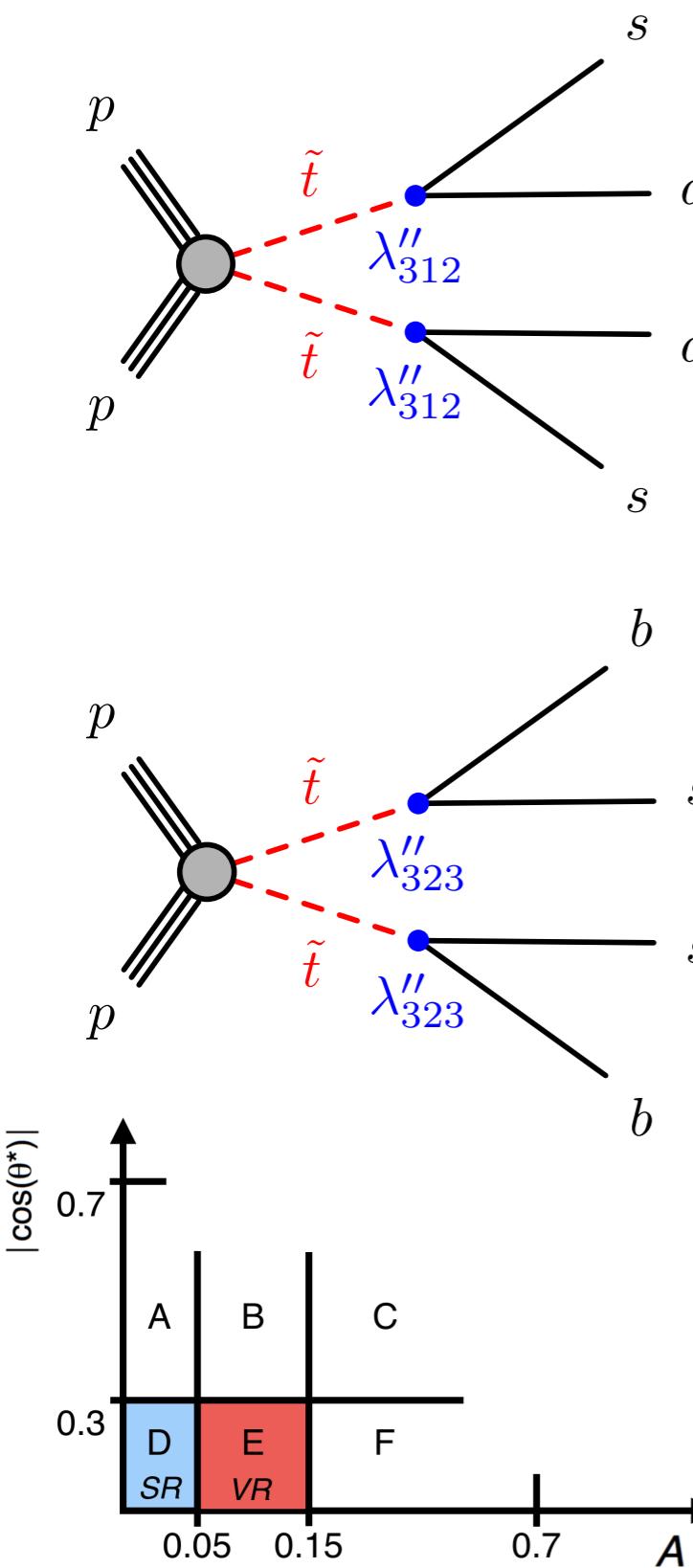


gluino \rightarrow neutralino

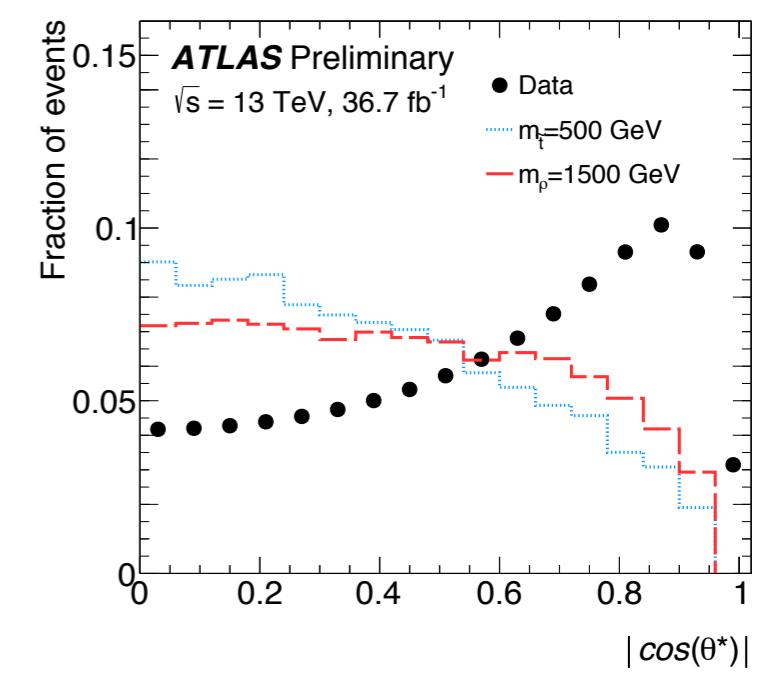
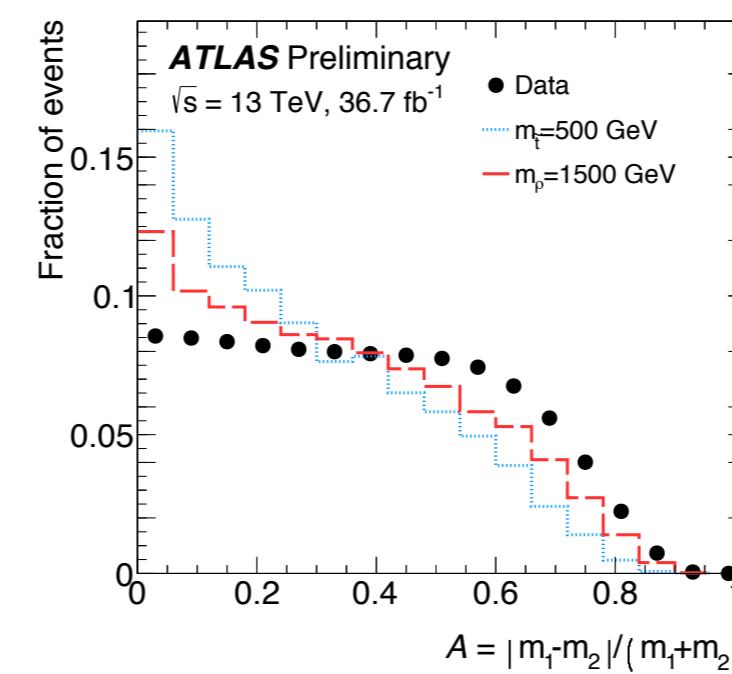


stop \rightarrow neutralino

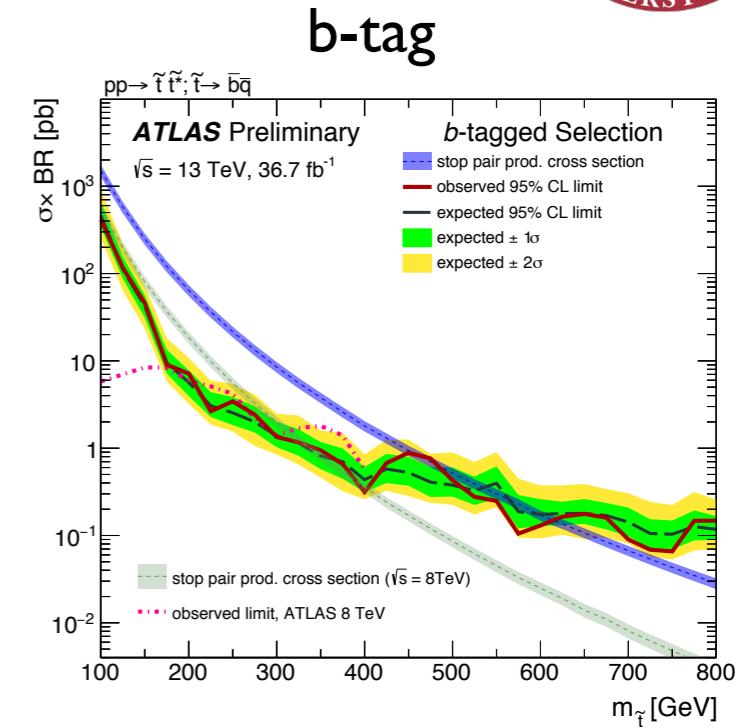
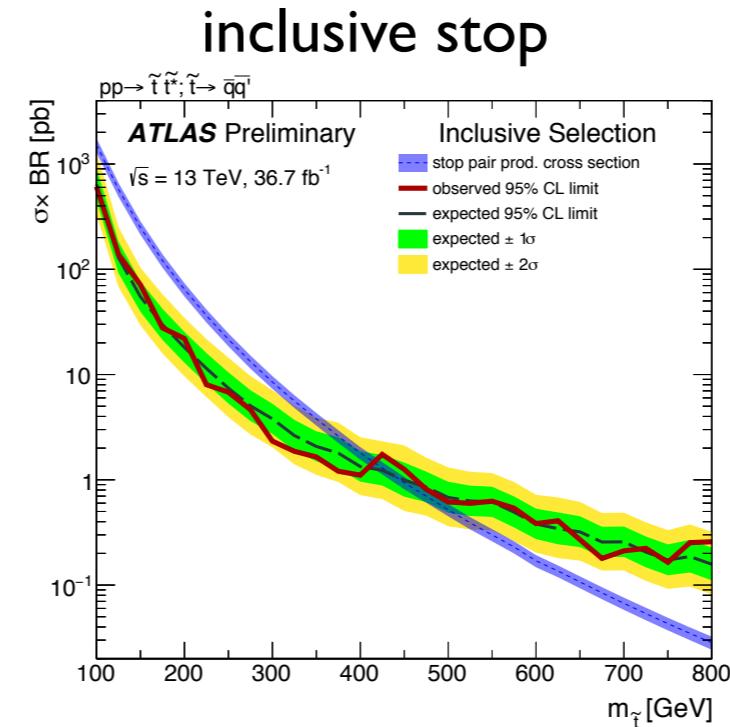



ATLAS-CONF-2017-025

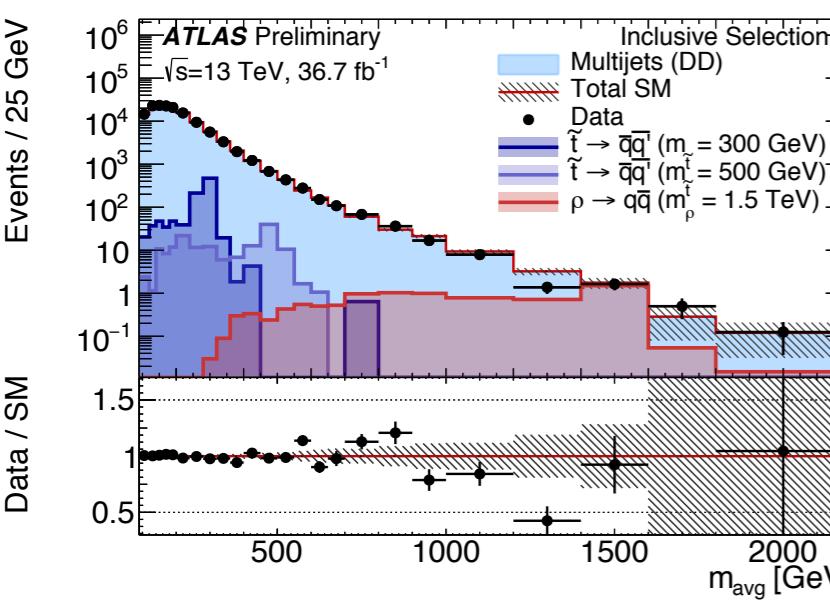
- two jet pairs formed from ΔR_{\min}
- m_{avg} of jet pairs is used as discriminating variable
- use ABCD method with \mathcal{A} and $|\cos(\theta^*)|$
- Background: QCD (data driven)



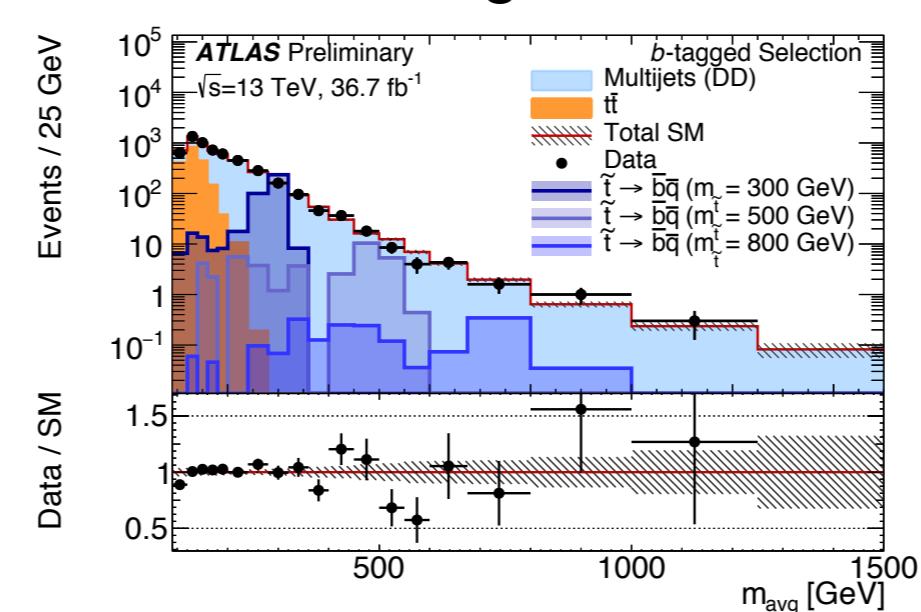
- no excess is seen
- limits set for both inclusive/b-tag stop selections, as well as inclusive coloron model



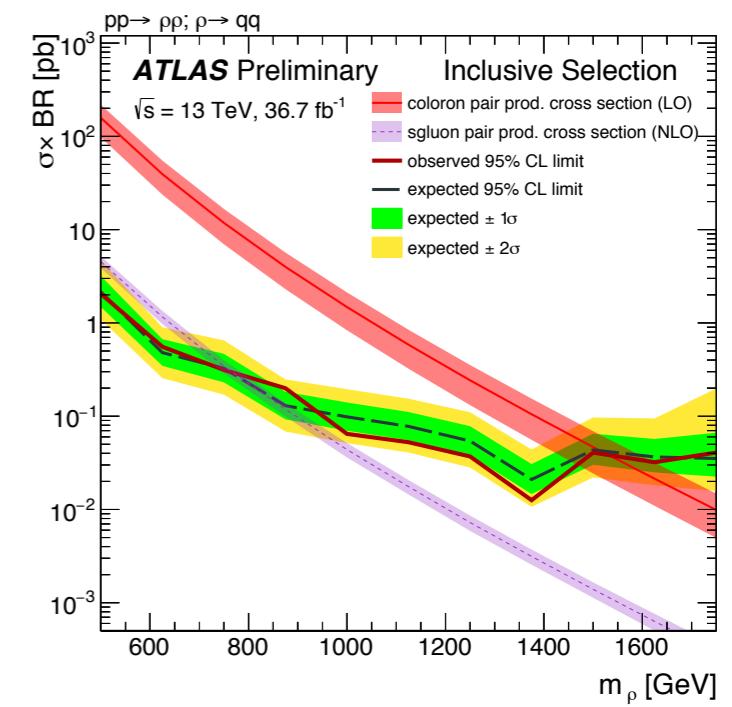
inclusive



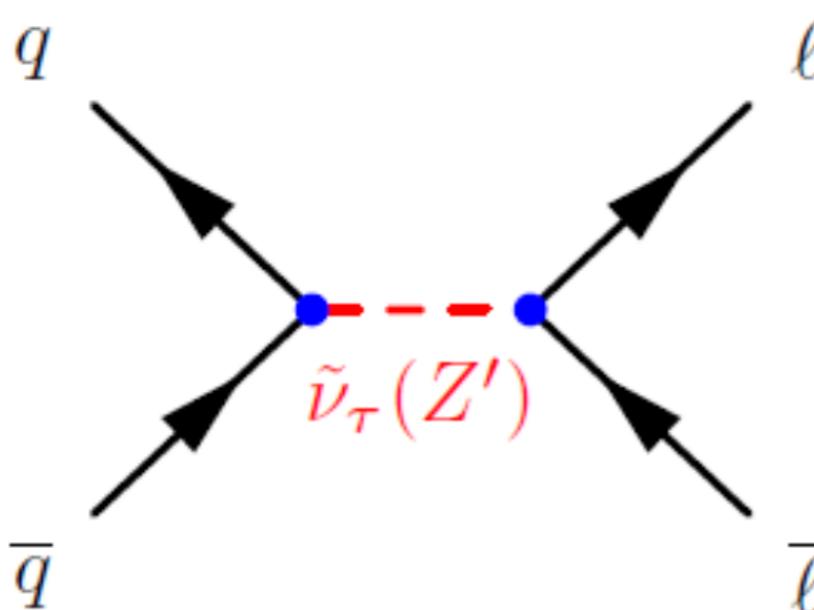
b-tag



inclusive coloron

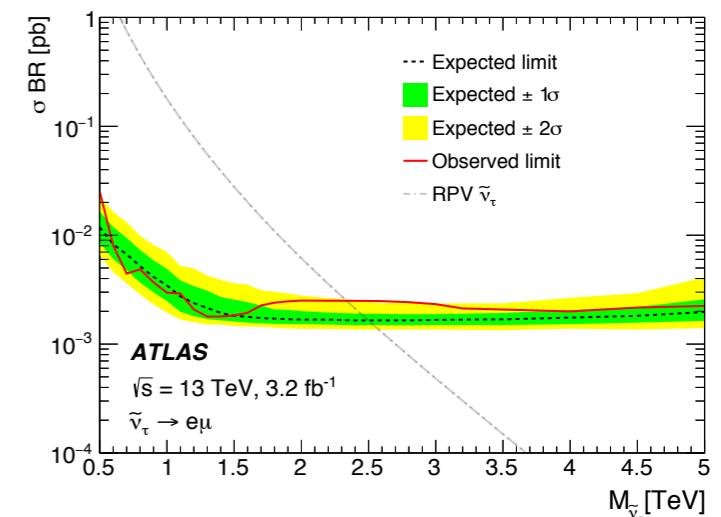
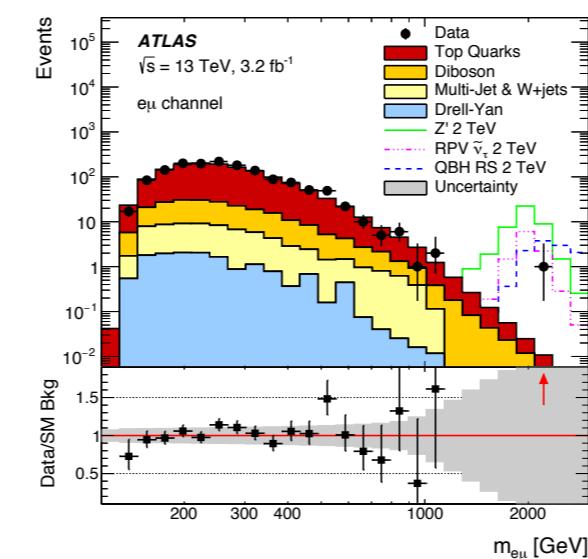


Eur. Phys. J. C76 (2016) 541



- 2 isolated leptons
- different flavor/charge
- Background:
 - WW, ttbar, single top, Z+jets
 - fake lepton (W+jet, QCD)

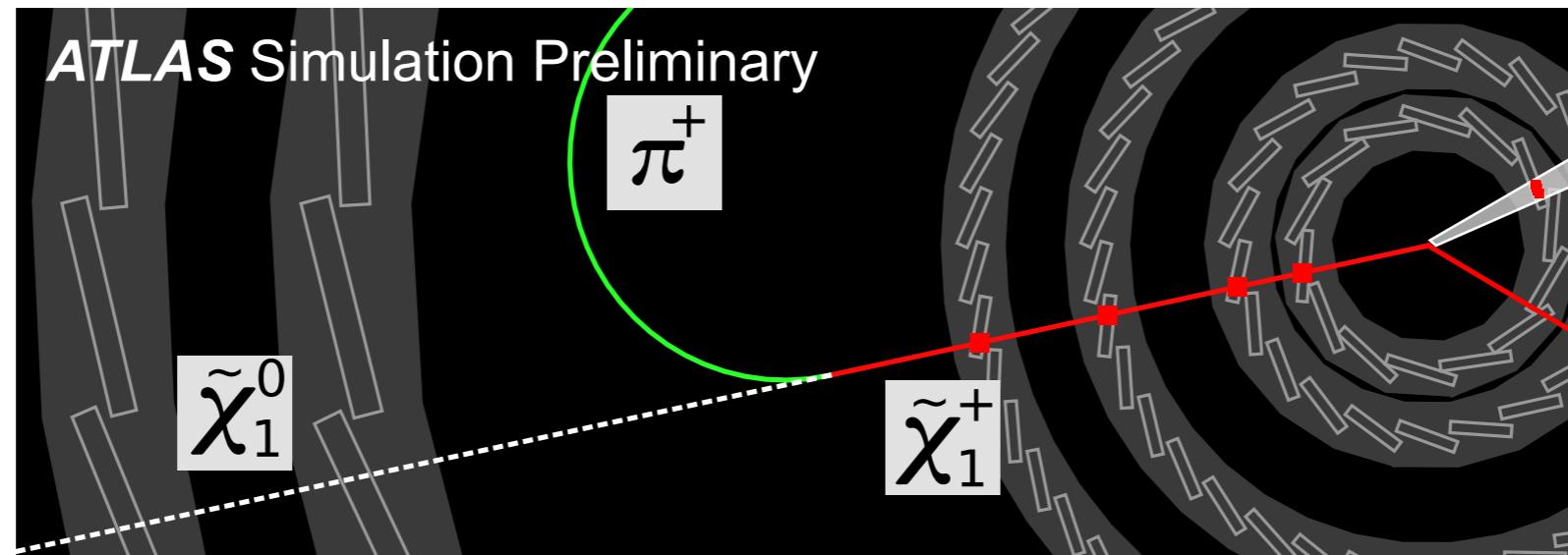
$\nu \rightarrow e\mu$



Process	$m_{e\mu} < 600$ GeV	$m_{e\mu} > 600$ GeV
Top quark	1190 ± 140	22 ± 5
Diboson	159 ± 17	4.9 ± 0.9
Multi-jet and $W+jets$	55 ± 11	2.7 ± 1.7
$Z/\gamma^* \rightarrow \ell\ell$	14.5 ± 2.0	0.18 ± 0.04
Total SM background	1410 ± 150	30 ± 7
SM+ Z' ($M_{Z'} = 2$ TeV)	-	75 ± 13
SM+ $\tilde{\nu}_\tau$ ($M_{\tilde{\nu}_\tau} = 2$ TeV)	-	40 ± 8
SM+QBH RS $n = 1$ ($M_{th} = 2$ TeV)	-	44 ± 9
Data	1463	25

(a) $e\mu$ channel

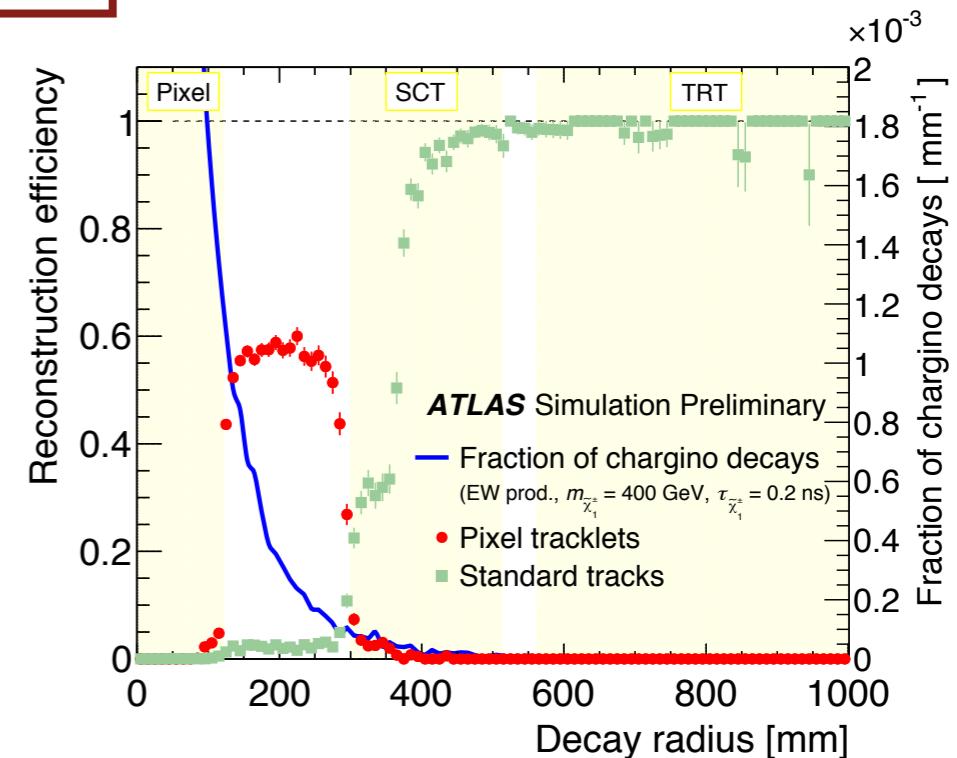
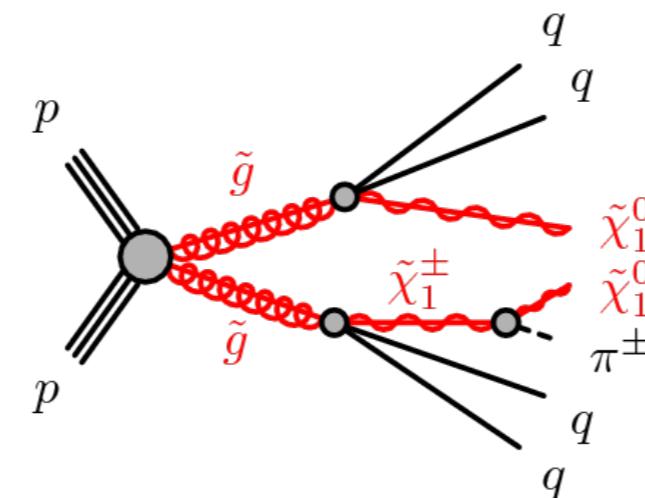
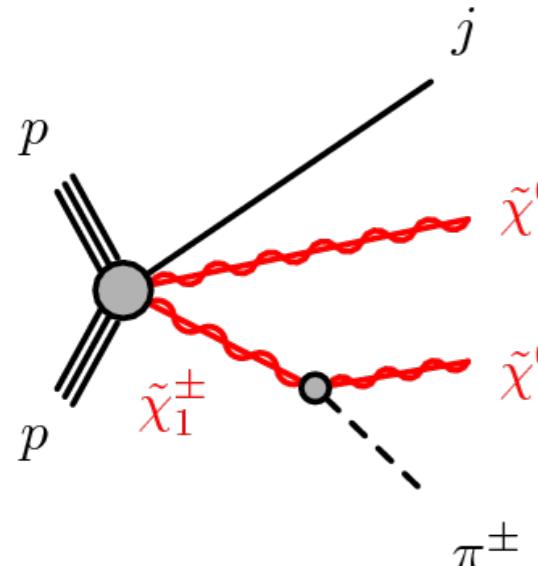
Model	Expected Limit [TeV]			Observed Limit [TeV]		
	$e\mu$	$e\tau$	$\mu\tau$	$e\mu$	$e\tau$	$\mu\tau$
Z'	3.2	2.7	2.6	3.0	2.7	2.6
RPV SUSY $\tilde{\nu}_\tau$	2.5	2.1	2.0	2.3	2.2	1.9
QBH ADD $n = 6$	4.6	4.1	3.9	4.5	4.1	3.9
QBH RS $n = 1$	2.5	2.2	2.1	2.4	2.2	2.1



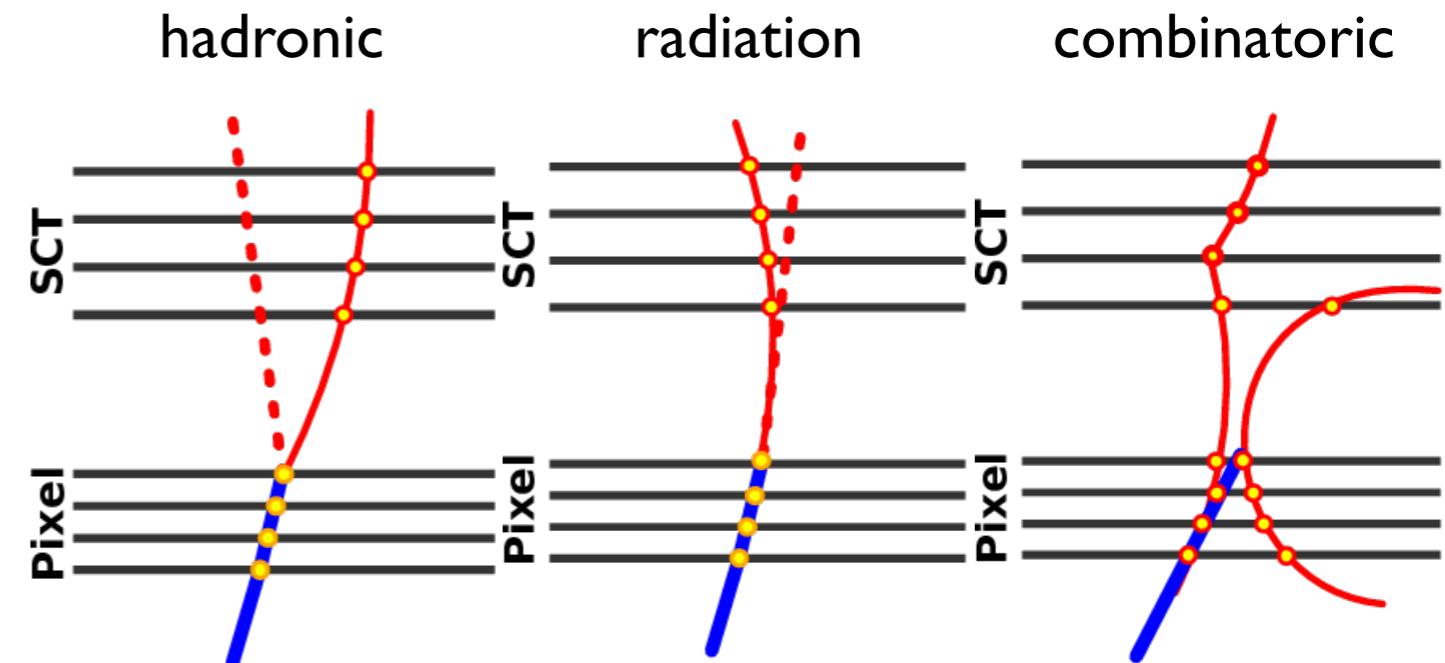
- There is no reason to expect most BSM particles to have negligible lifetime (i.e. prompt)
- non-negligible lifetimes arise from:
 - Small couplings, heavy mediators, small mass splittings, etc...
 - for example wino-like LSP scenarios favor long-lived charginos with lifetimes of a fraction of a ns
 - semi-stable decays inside the detector typically require non-standard analyses

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
	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
	Stable, stopped \tilde{g} R-hadron	0	1-5 jets	Yes	27.9	\tilde{g} 850 GeV
	Stable \tilde{g} R-hadron	trk	-	-	3.2	\tilde{g} 1.58 TeV
	Metastable \tilde{g} R-hadron	dE/dx trk	-	-	3.2	\tilde{g} 1.57 TeV
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0 \rightarrow \tilde{\tau}(\tilde{e}, \tilde{\mu}) + \tau(e, \mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$ 537 GeV
	GMSB, $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 440 GeV
	$\tilde{g}\tilde{g}, \tilde{\chi}_1^0 \rightarrow ee/\mu\nu/\mu\mu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$ 1.0 TeV
	GGM $\tilde{g}\tilde{g}, \tilde{\chi}_1^0 \rightarrow Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$ 1.0 TeV

ATLAS-CONF-2017-017



- look for high pT partial track in ID
- IBL allows for pixel tracklets
- SM Background:
 - hadronic decay, photon emission, combinatoric
- smear standard tracks to reproduce pixel tracklet pT spectrum
- fit and extrapolate pT spectra

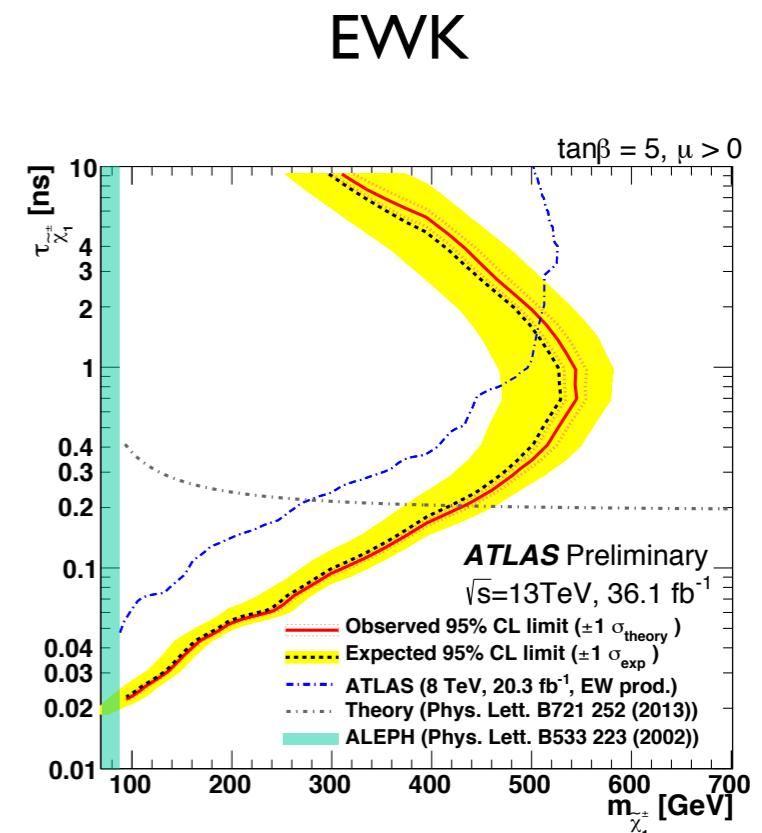
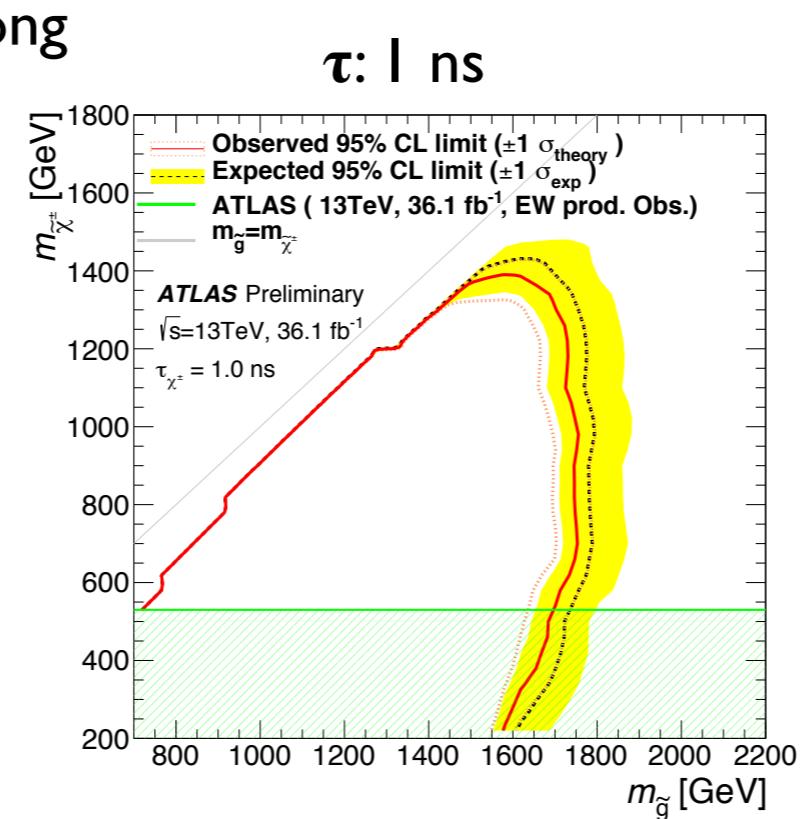
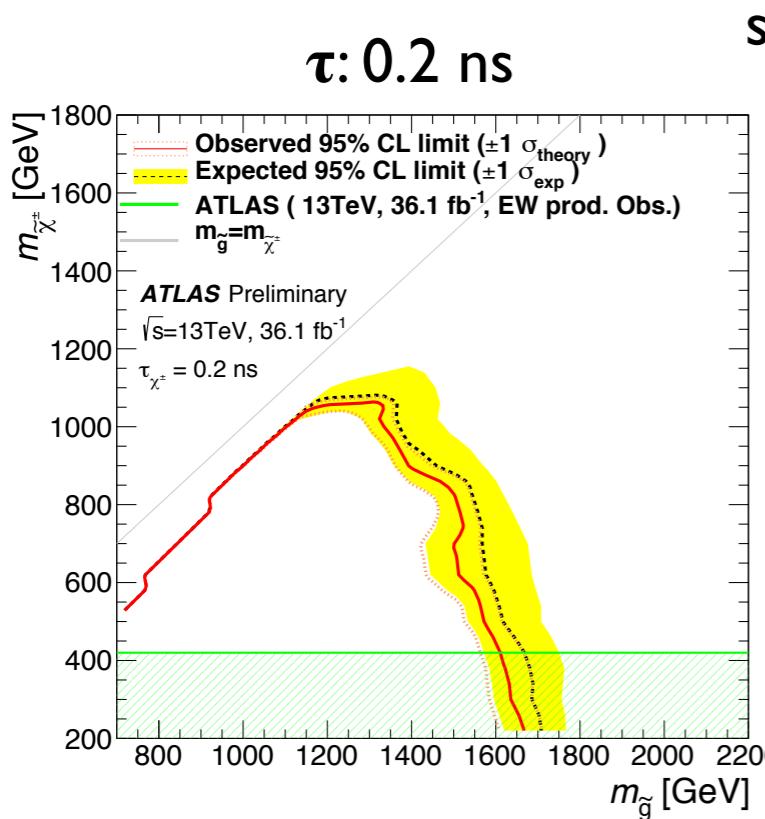


Disappearing track (cont...)



- no excess is seen
- limits set for both strong and electroweak production

	High E_T^{miss} region $(m_{\tilde{\chi}_1^\pm}, \tau_{\tilde{\chi}_1^\pm}) = (400 \text{ GeV}, 0.2 \text{ ns})$	Electroweak channel $(m_{\tilde{g}}, m_{\tilde{\chi}_1^\pm}, \tau_{\tilde{\chi}_1^\pm}) = (1600 \text{ GeV}, 500 \text{ GeV}, 0.2 \text{ ns})$	Strong channel
	Number of observed events with $p_T > 100 \text{ GeV}$		
Observed		9	2
	Number of expected events with $p_T > 100 \text{ GeV}$		
Hadron+electron background	6.1 ± 0.6		2.08 ± 0.35
Muon background	0.1549 ± 0.0022		0.0385 ± 0.0005
Fake background	5.5 ± 3.3		0.0 ± 0.8
Total background	11.8 ± 3.1		2.1 ± 0.9
Expected signal	10.4 ± 1.7		4.1 ± 0.5
CL _b	0.39		0.702
Observed $\sigma_{\text{vis}}^{95\%} [\text{fb}]$	0.22		0.14
Expected $\sigma_{\text{vis}}^{95\%} [\text{fb}]$	0.24 ^{+0.10} _{-0.07}		0.11 ^{+0.06} _{-0.04}



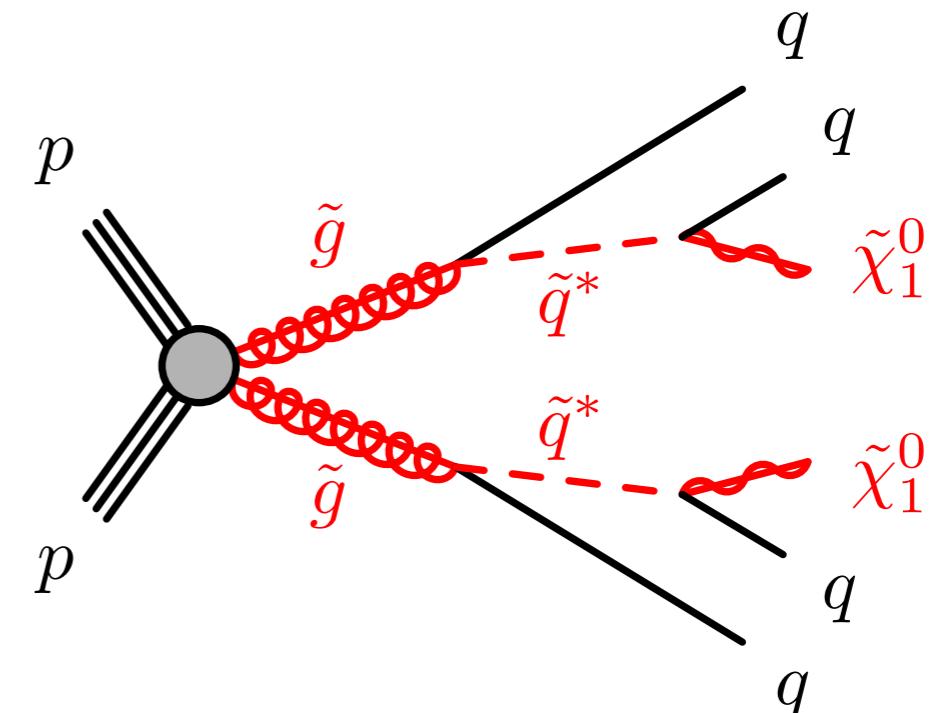


Displaced multi-track vertices

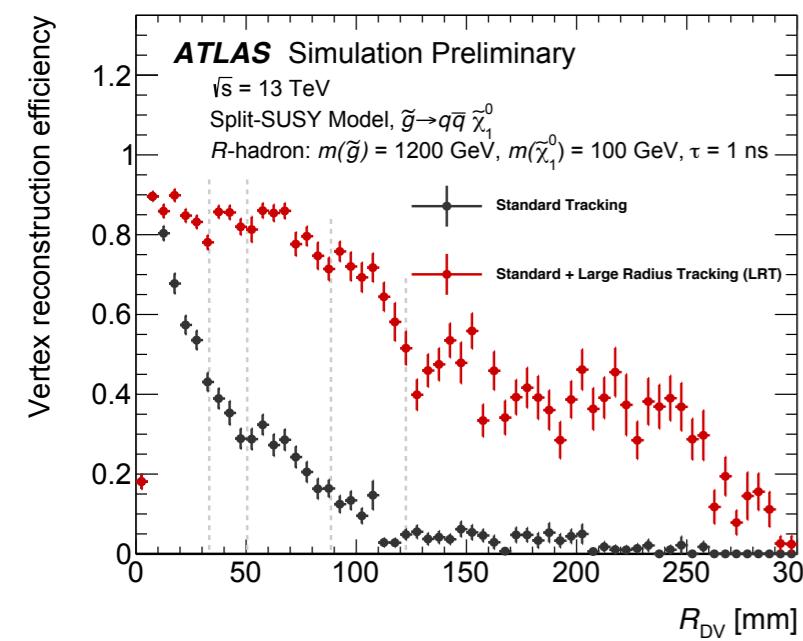


ATLAS-CONF-2017-026

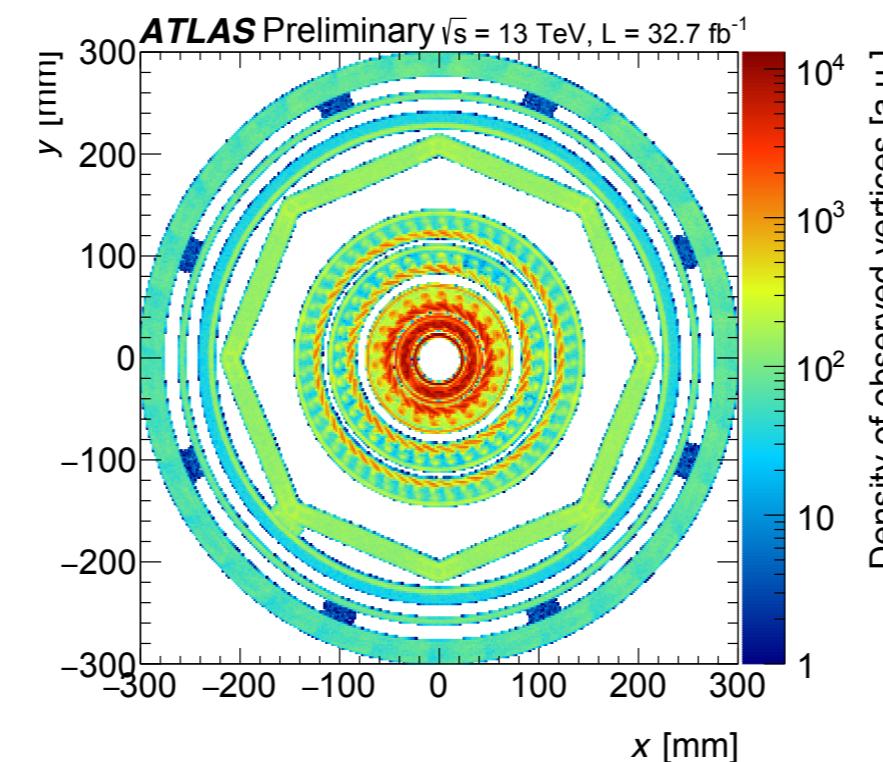
- re-run ID tracking with loosened IP constraints
- low background:
 - hadronic interactions
 - random track crossing
 - merged vertices
- uses data-driven methods to predict all backgrounds



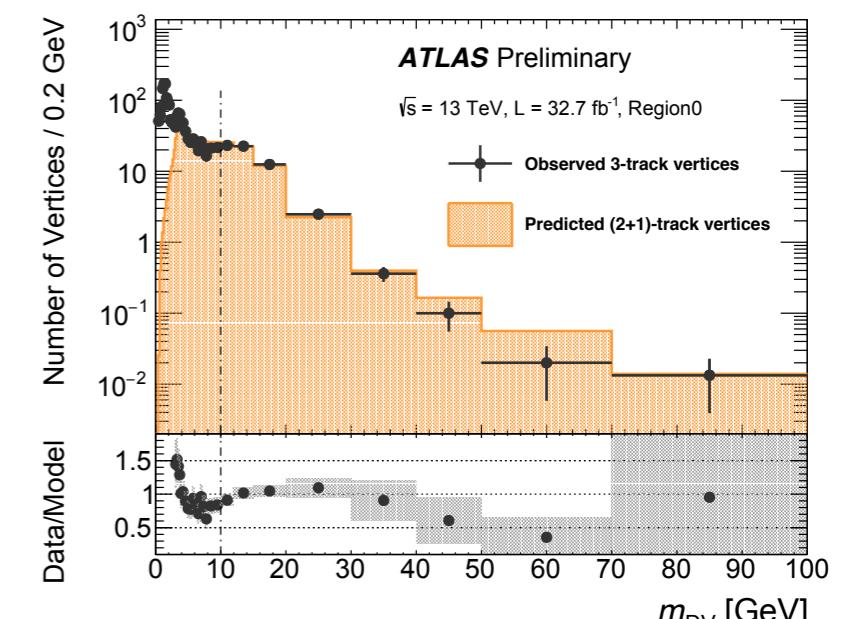
reco. eff.



material veto



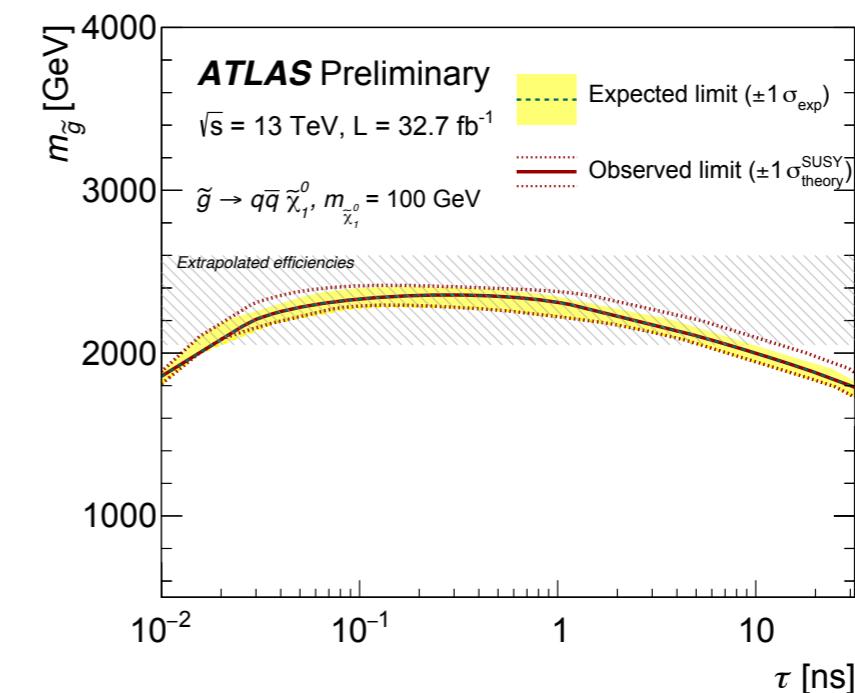
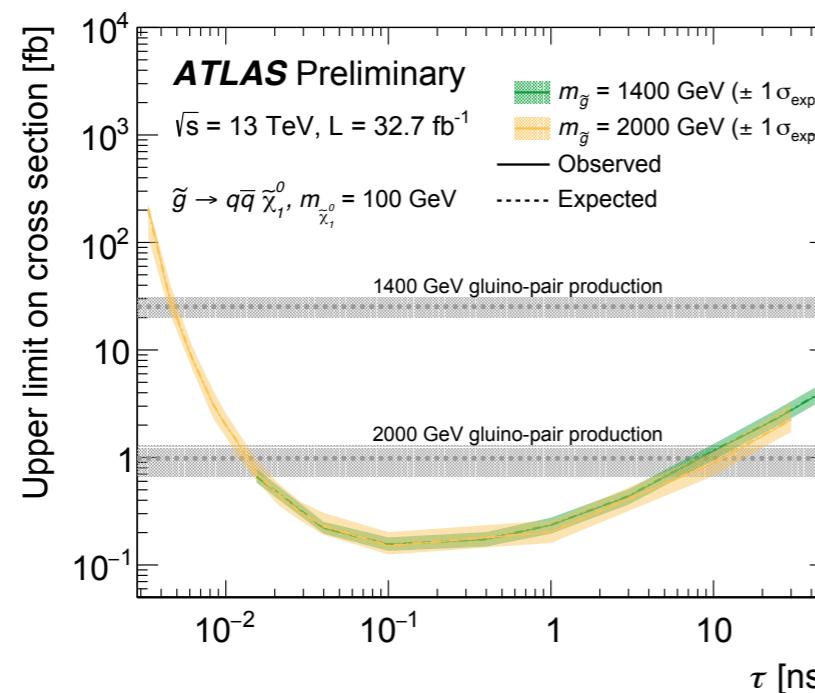
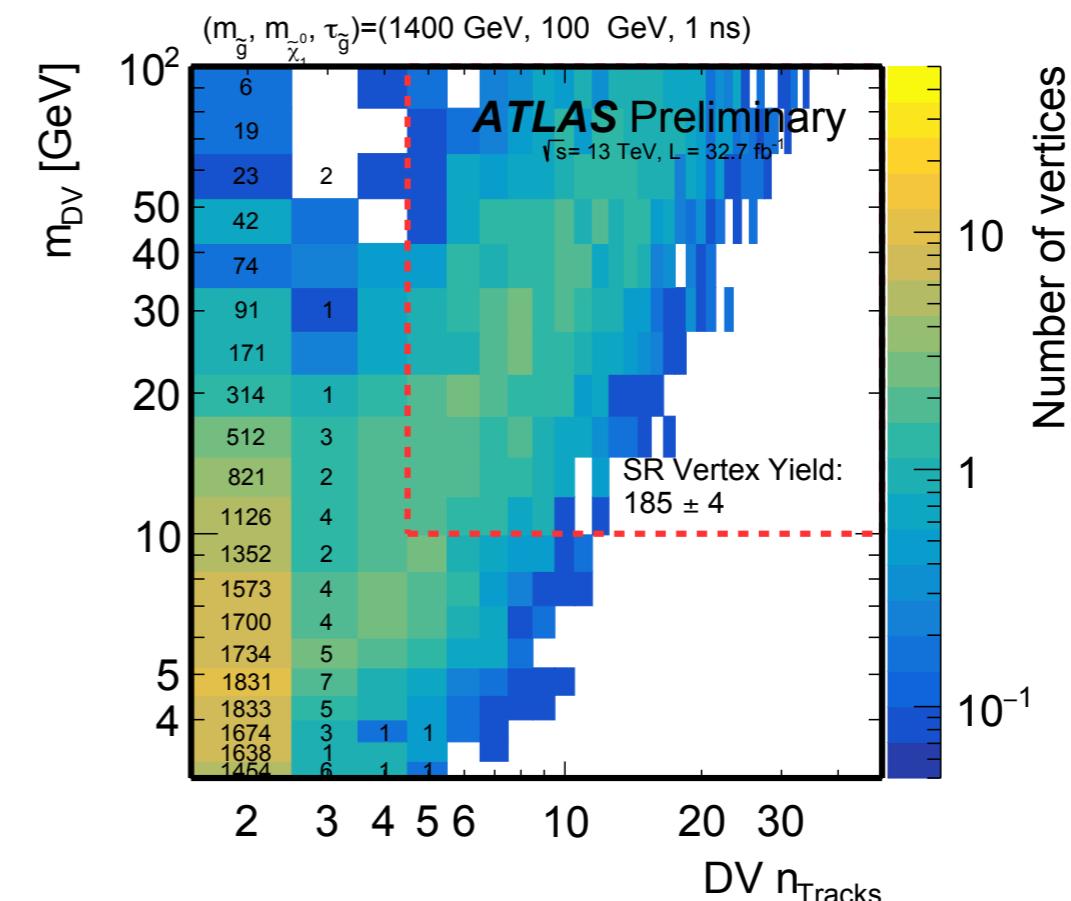
combinatoric crossing



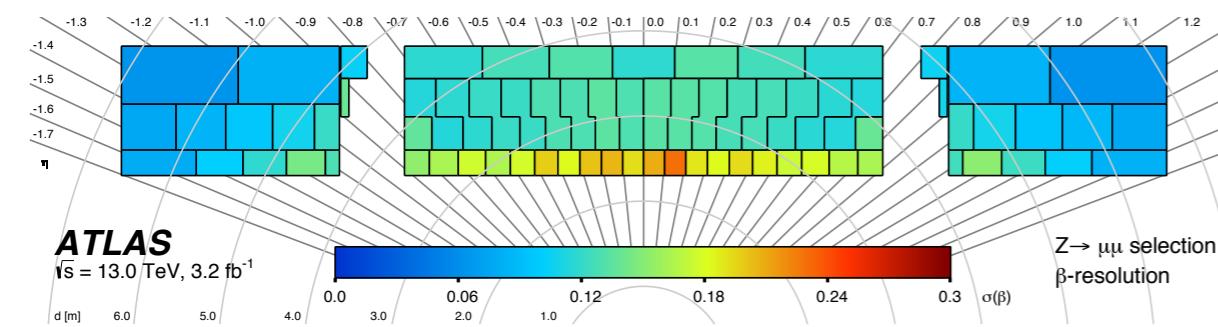
Displaced multi-track vertices (cont...)



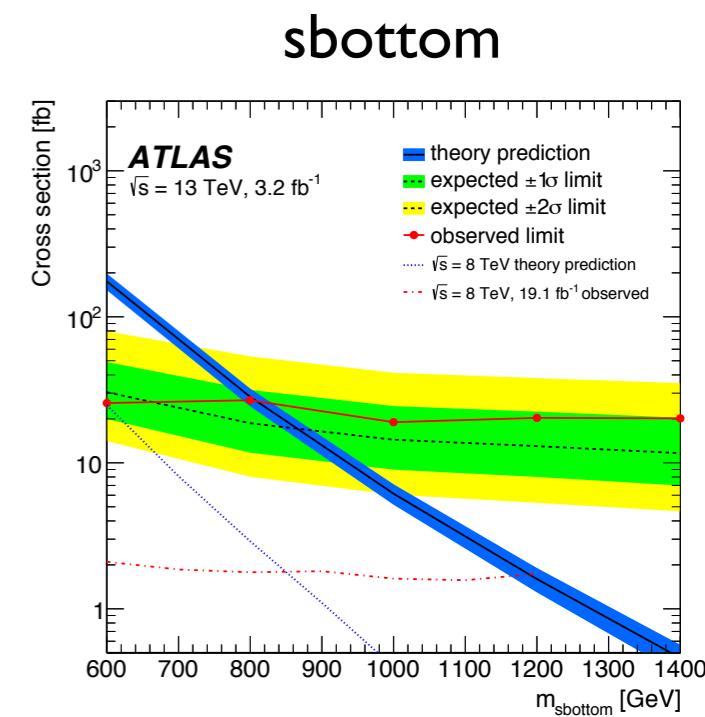
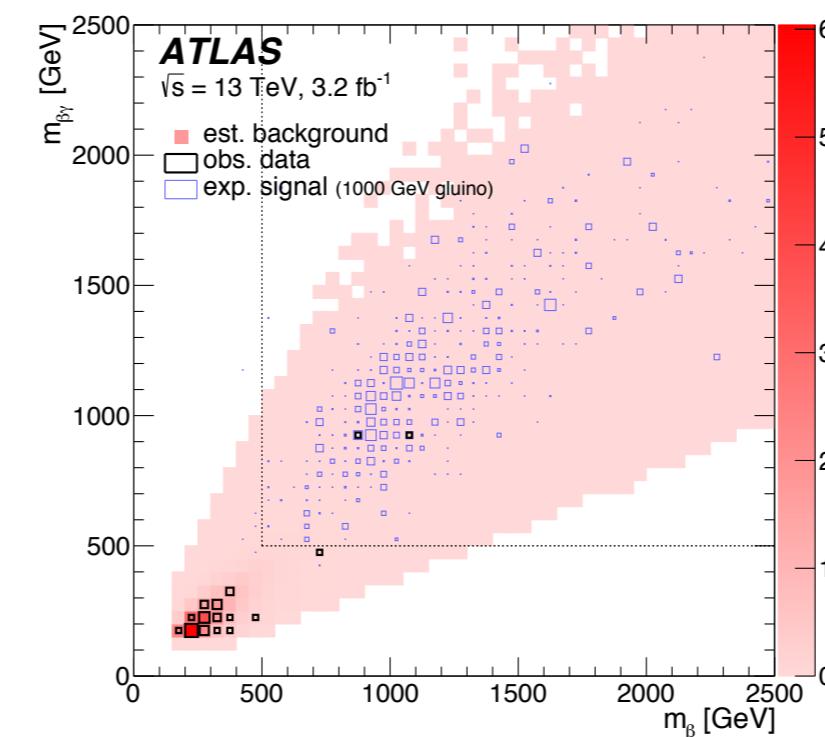
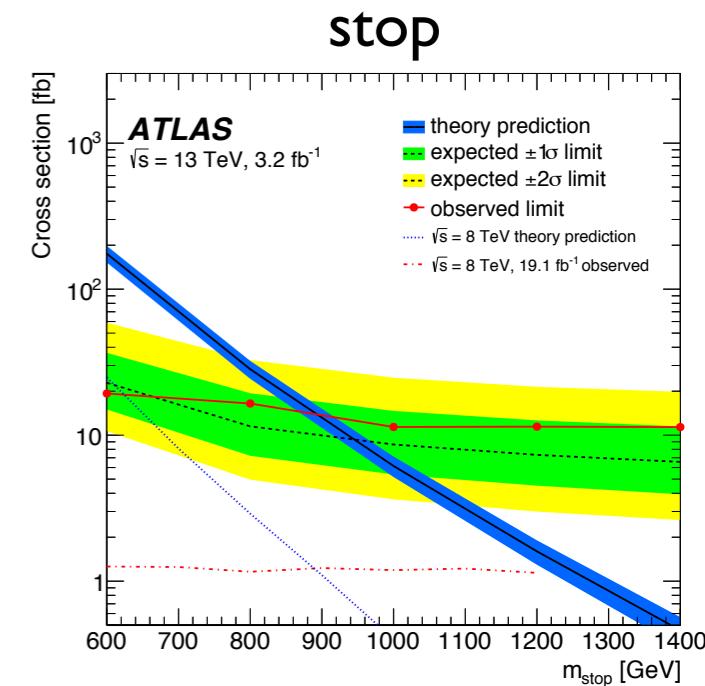
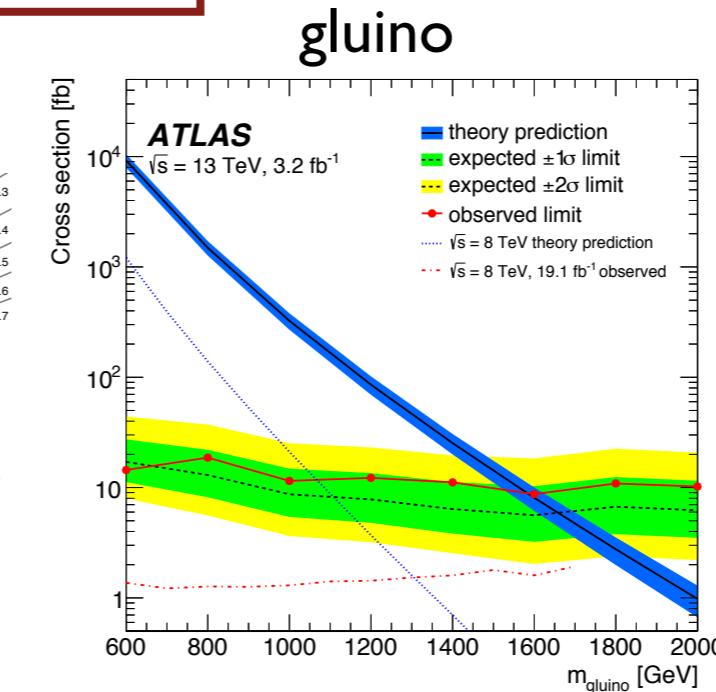
- no excess is seen
- limits set as function of neutralino τ , and in τ -gluino mass plane

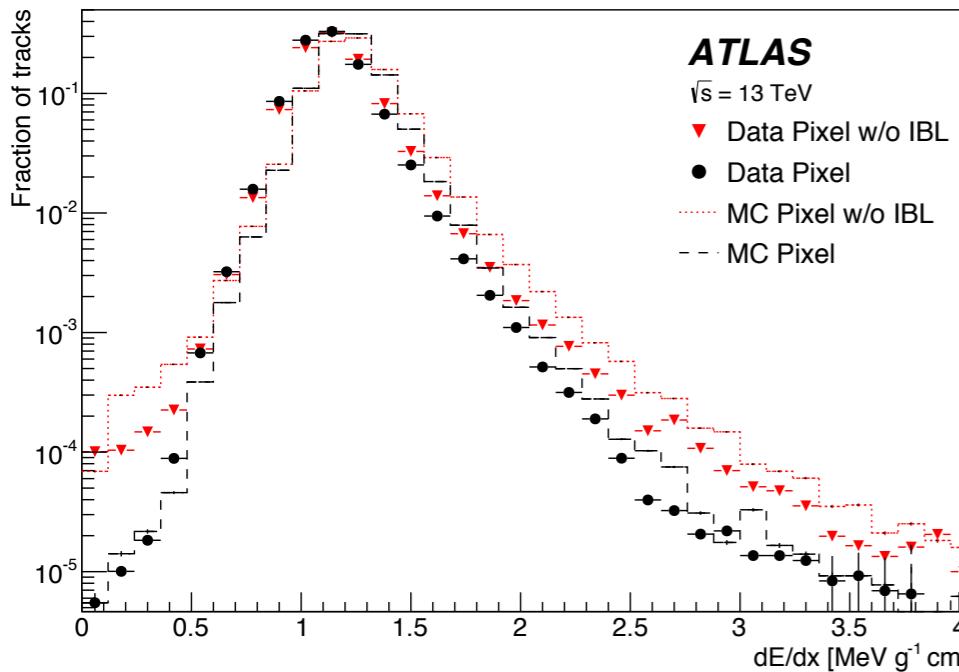


Physics Letters B 760 (2016), pp. 647-665



- R-hadron mass from p and $\beta/\beta\gamma$ measurements
- $\beta\gamma$ from dE/dx measurement in silicon pixel
- β from time-of-flight in tile calorimeter
- data-driven bkgd estimate (pdf of $p, \beta, \beta\gamma$ in sideband randomly sampled)
- Background:
 - large dE/dx track (i.e. cosmic muon or $Z \rightarrow \mu\mu$)

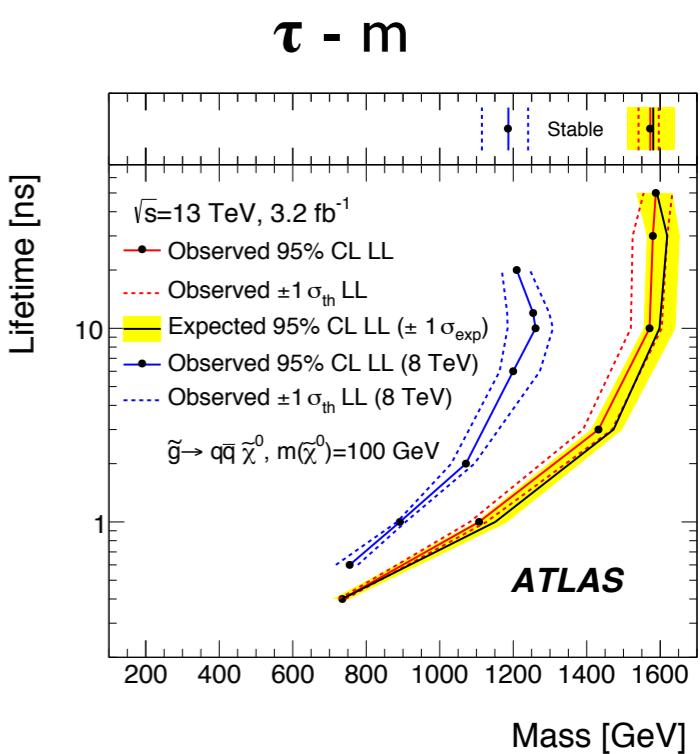
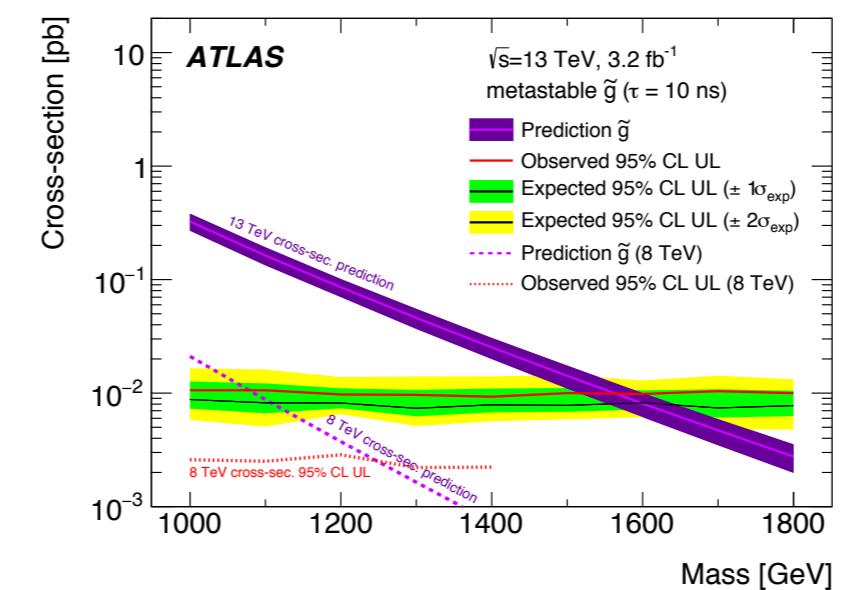
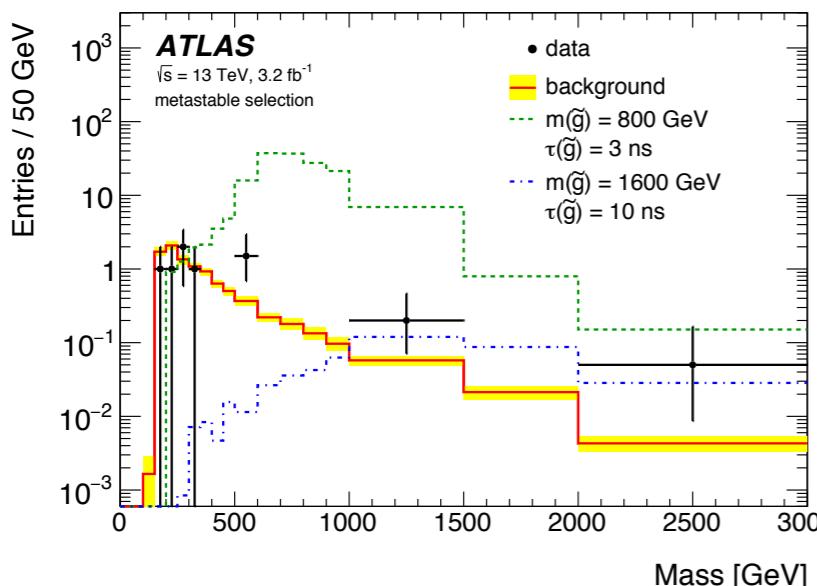


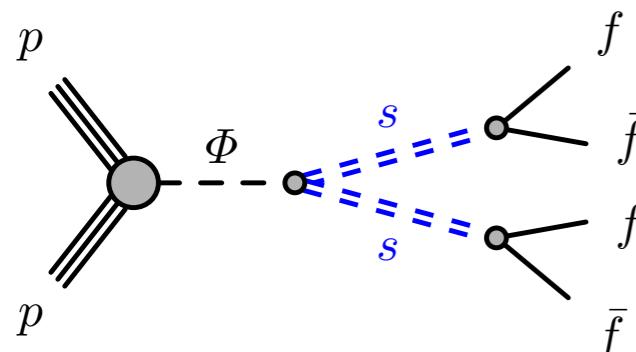


Phys. Rev. D 93, 112015 (2016)

- R-hadron mass from ionization energy left in silicon
- IBL layer narrows dE/dx distribution
- data-driven bkgd estimation
- Background:
 - jets/leptons with large ionization
 - overlapping tracks

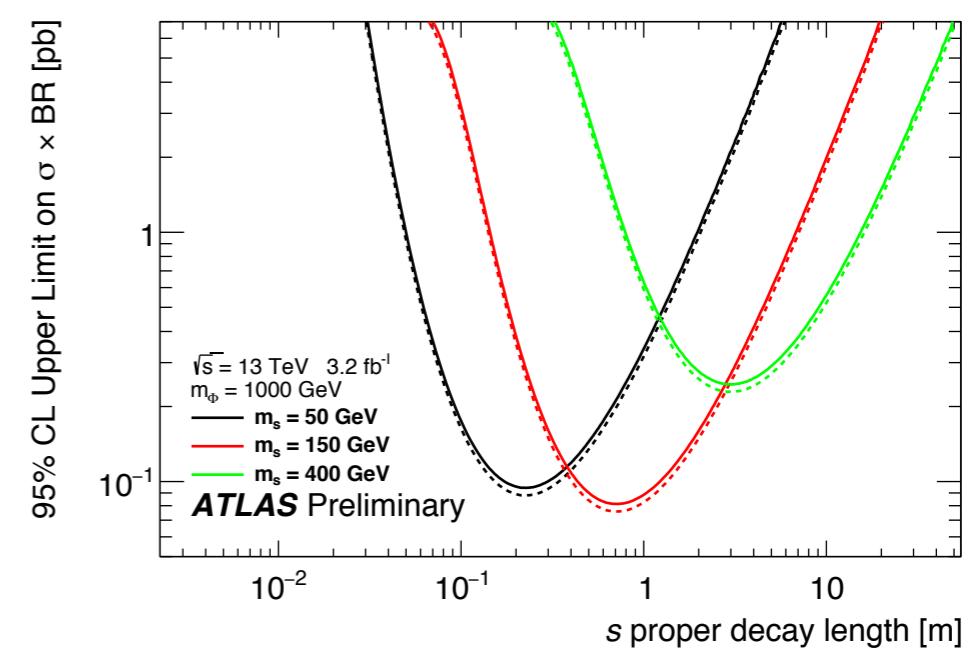
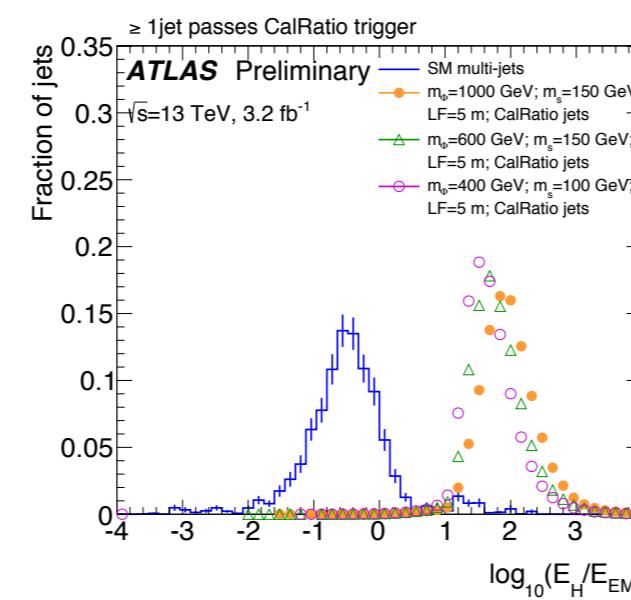
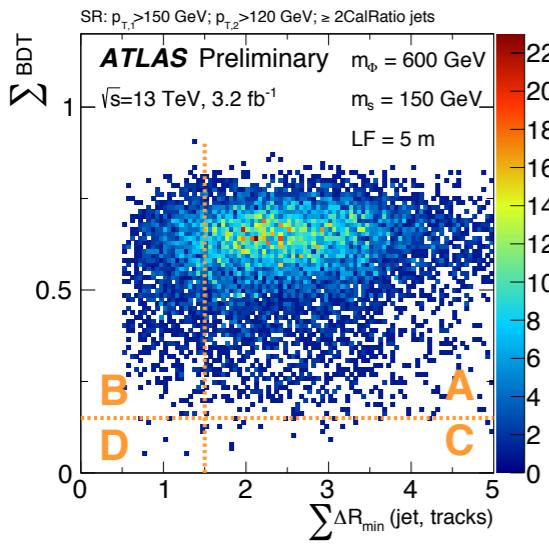
Selection region	Background exp.	Data
Metastable R -hadron	$11.1 \pm 1.7 \pm 0.7$	11
Stable R -hadron	$17.2 \pm 2.6 \pm 1.2$	16



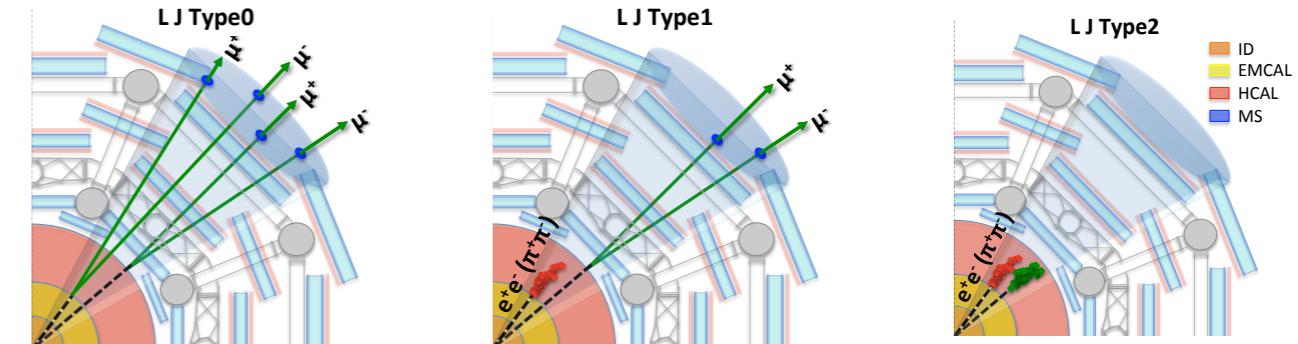
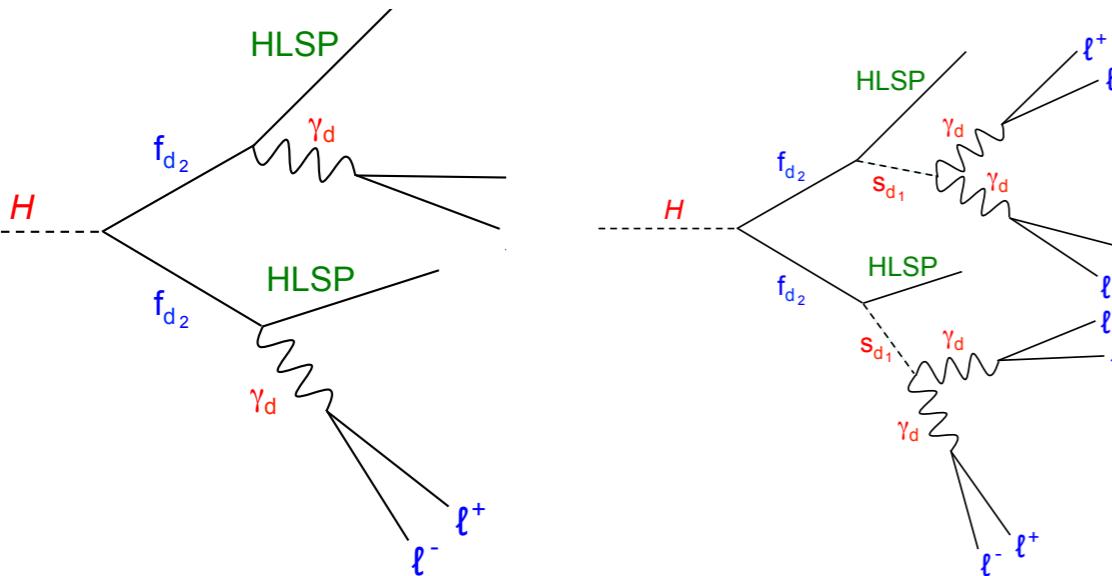


- dedicated cal-ratio trigger
- BDT selects signal based on jet $\log(E_H/E_{EM})$, etc...
- 2 cal-ratio jets passing BDT
- Background:
 - Non-collision bkgd, QCD multijet

Region	A	B	C	D	Estimated A = BC/D
SR : $p_{T,1} > 150 \text{ GeV}; p_{T,2} > 120 \text{ GeV}$:					
$\sum \text{BDT boundary} = 0.15$	24	16	39	34	18.0 ± 6.3
VR : $p_{T,1} > 140 \text{ GeV}; 80 \text{ GeV} < p_{T,2} < 120 \text{ GeV}$:					
$\sum \text{BDT boundary} = 0.2$	15	14	84	77	15.3 ± 4.7
$\sum \text{BDT boundary} = 0.15$	42	38	57	53	40 ± 10
$\sum \text{BDT boundary} = 0.1$	72	64	27	27	60 ± 19

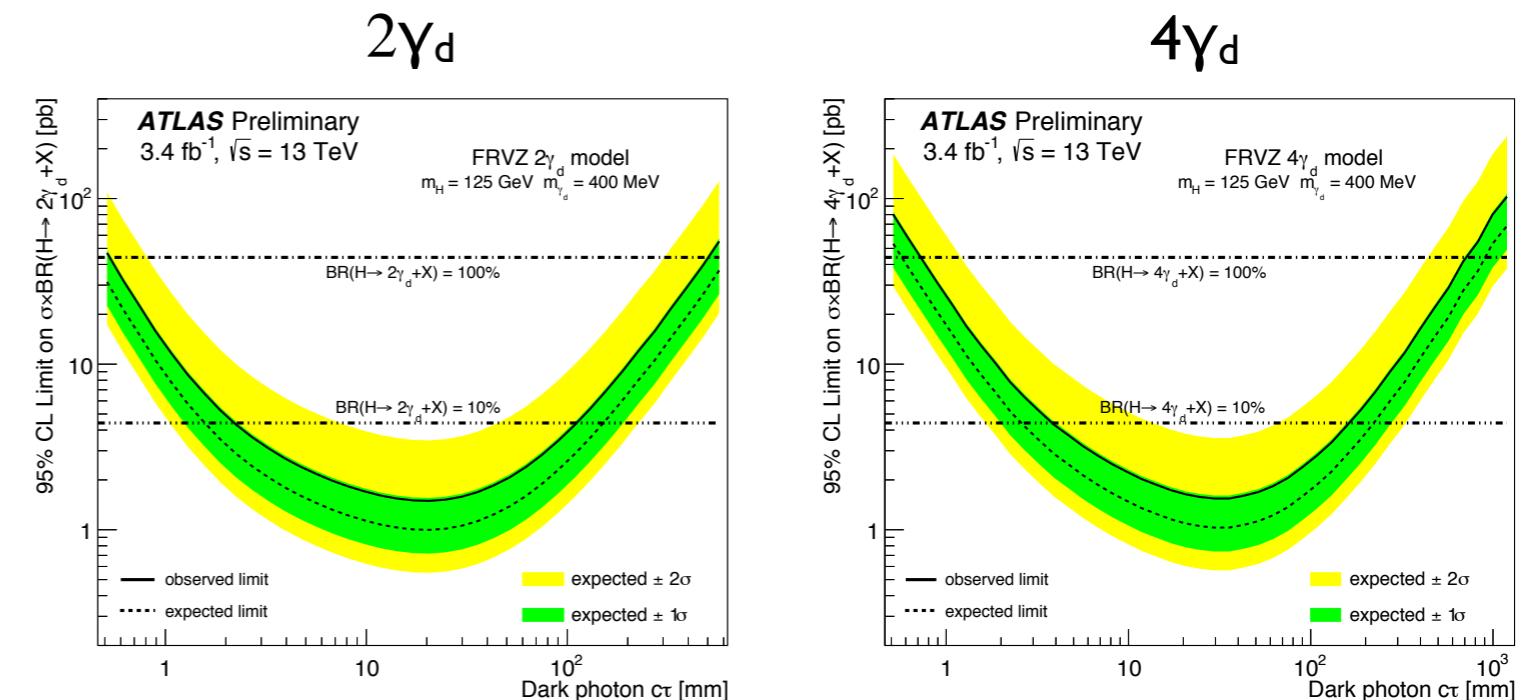


ATLAS-CONF-2016-042



Category	Observed events	Expected background
All events	285	$231 \pm 12 \text{ (stat)} \pm 62 \text{ (syst)}$
Type2-Type2 excluded	46	$31.8 \pm 3.8 \text{ (stat)} \pm 8.6 \text{ (syst)}$
Type2-Type2 only	239	$241 \pm 41 \text{ (stat)} \pm 65 \text{ (syst)}$

- low mass γ_d leaves collimated decay products.
- dedicated HLT narrowscan muon trigger
- ABCD method removes background (LJ iso - $\Delta\phi$)
- Background:
 - QCD, cosmic muons, Non-collision bkgd





Conclusion



- RPV SUSY and long lived particle searches are crucial for maximizing the ATLAS program's sensitivity to BSM physics.
- Such analyses are often difficult and require non-standard techniques, but there are already numerous interesting results for Run II.
- These results have chipped away at the relevant parameter spaces, but there is still a lot of space left!