

Searches for strong production of supersymmetric particles with the ATLAS detector

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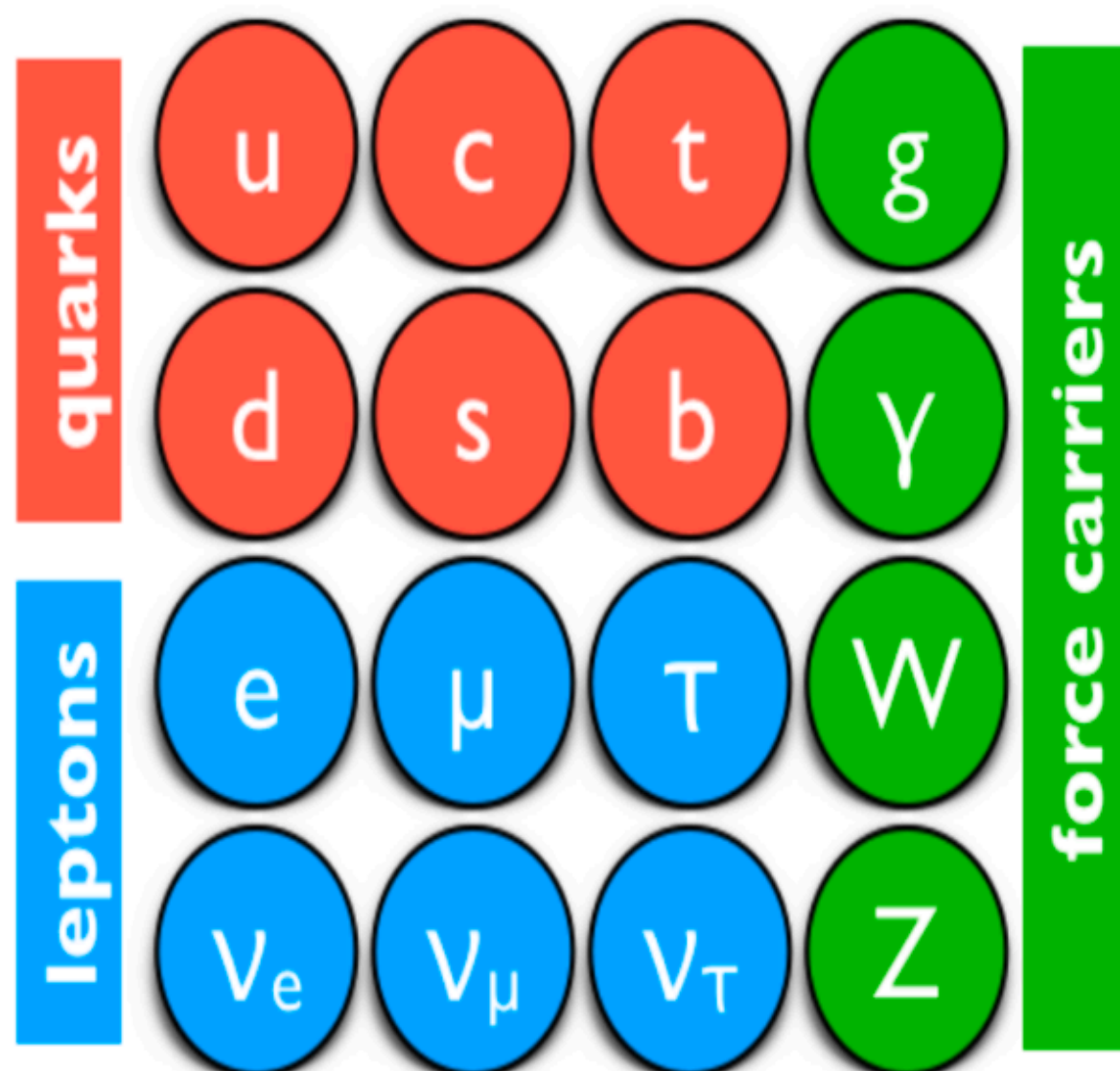
LLWI 2022 Conference



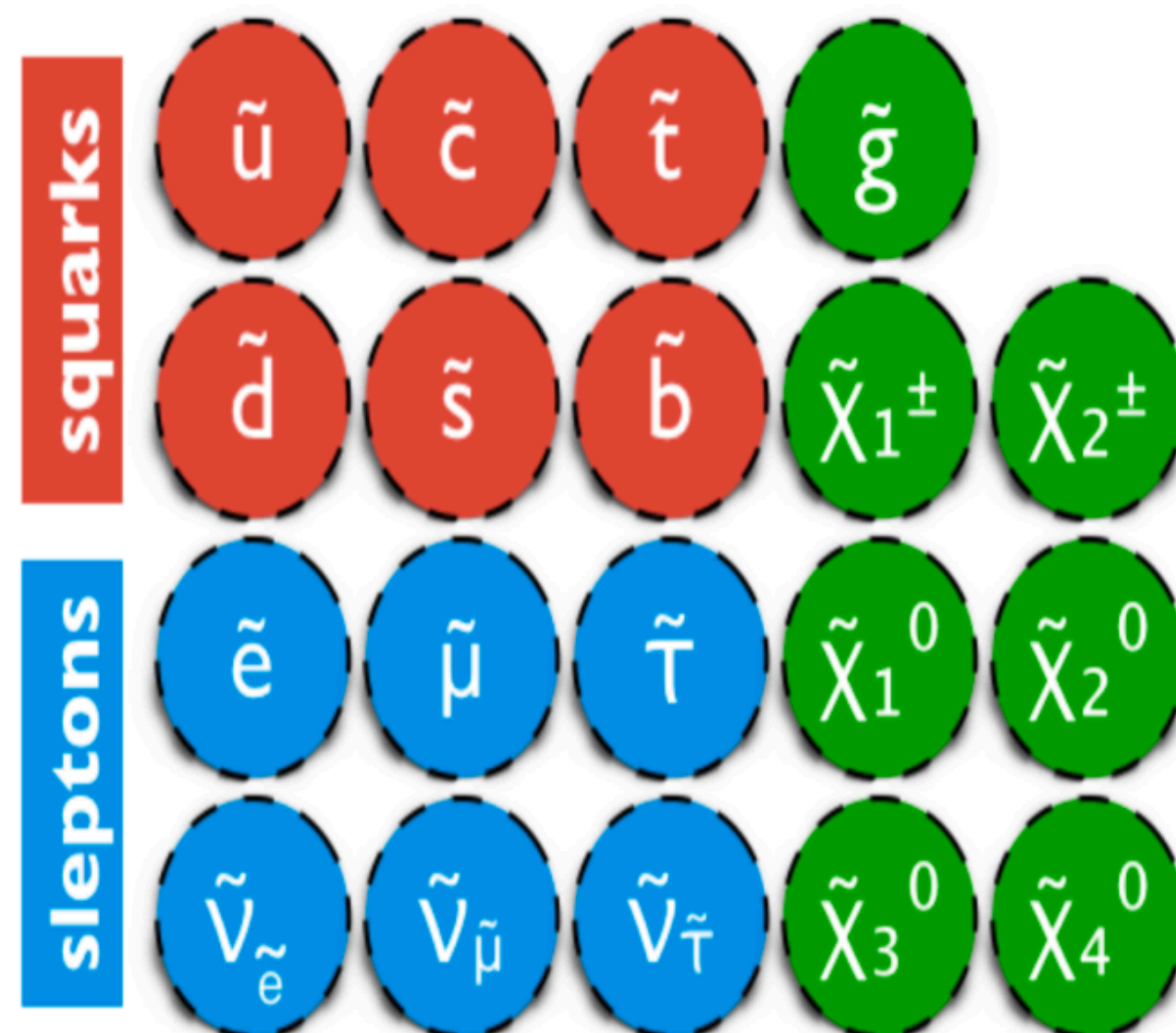
Introduction:

Supersymmetric particle content

Standard Model



Supersymmetry



higgs sector

(minimally extended)

$\tilde{\chi}$: combinations of the partners to the gauge bosons and higgs fields

- ★ Supersymmetry (SUSY): one of the most popular Standard Model (SM) extensions.
 - ★ Each SM particle has its own supersymmetric partner.
 - ★ Spin differing by 1/2
 - ★ Provides:
 - ★ a dark matter candidate (for R-parity conserving theory).
 - ★ the unification of fundamental forces at high energies.
 - ★ a solution to the fine-tuning problem of the Higgs mass.
- ★ SUSY searches at the LHC going on extensively.
 - ★ Strong production mechanism, as well as electroweak production.
- ★ Strong SUSY production:
 - ★ Higher xsec than the electroweak production.
 - ★ In general, search for high p_T particles and large missing transverse energy (E_T^{miss}).

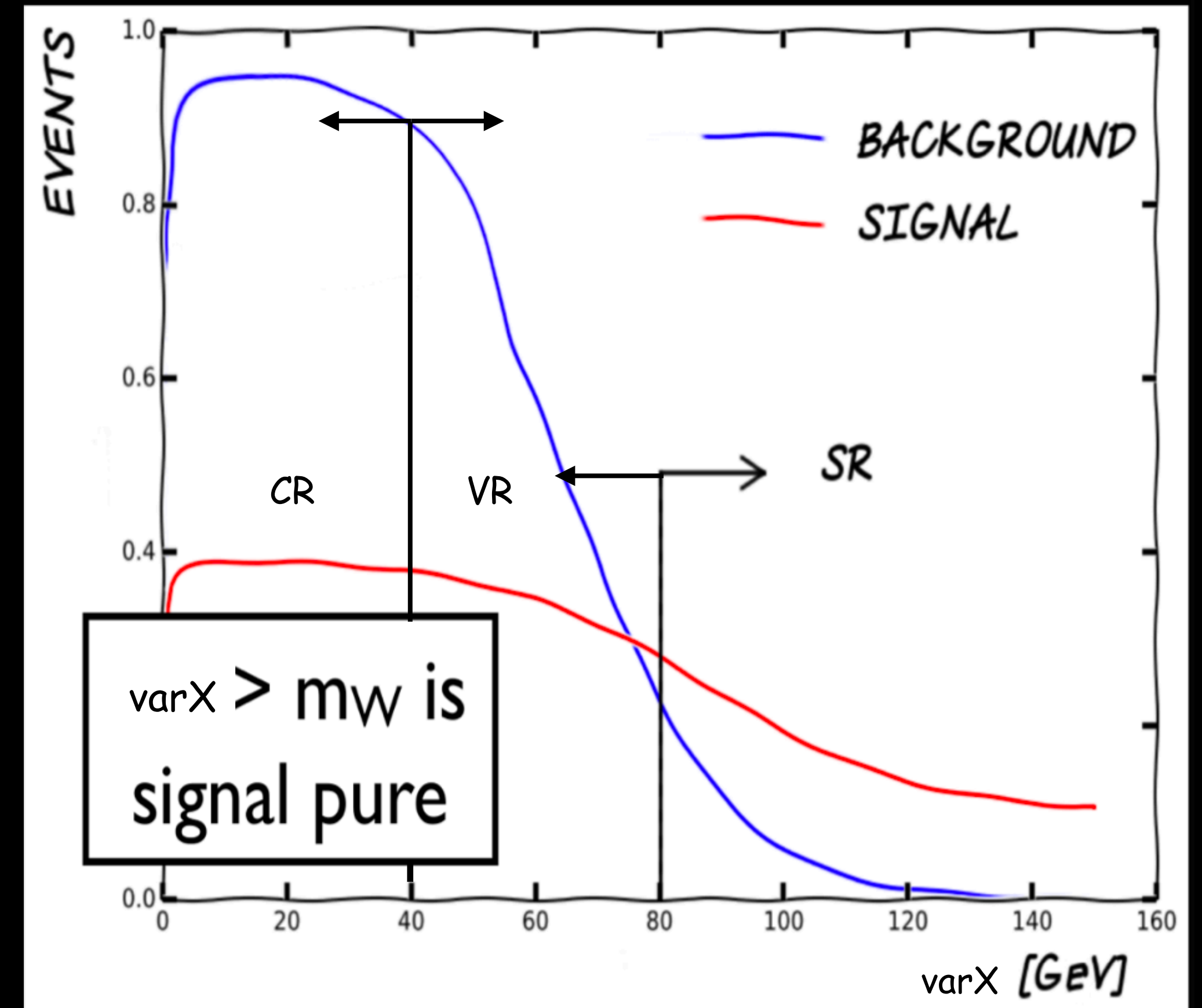
SUSY searches in a nutshell

Strategy:

- ★ Look for a region enriched with signal (SR)
 - ★ Selection requirement on observables enhancing the signal significance.
- ★ Estimate the background
 - ★ May be fully data-driven
 - ★ Partially data-driven where Control Regions (CR) are used to constrain the MC predictions
 - ★ Validate the background estimation in the Validation Regions (VR).

Blinding

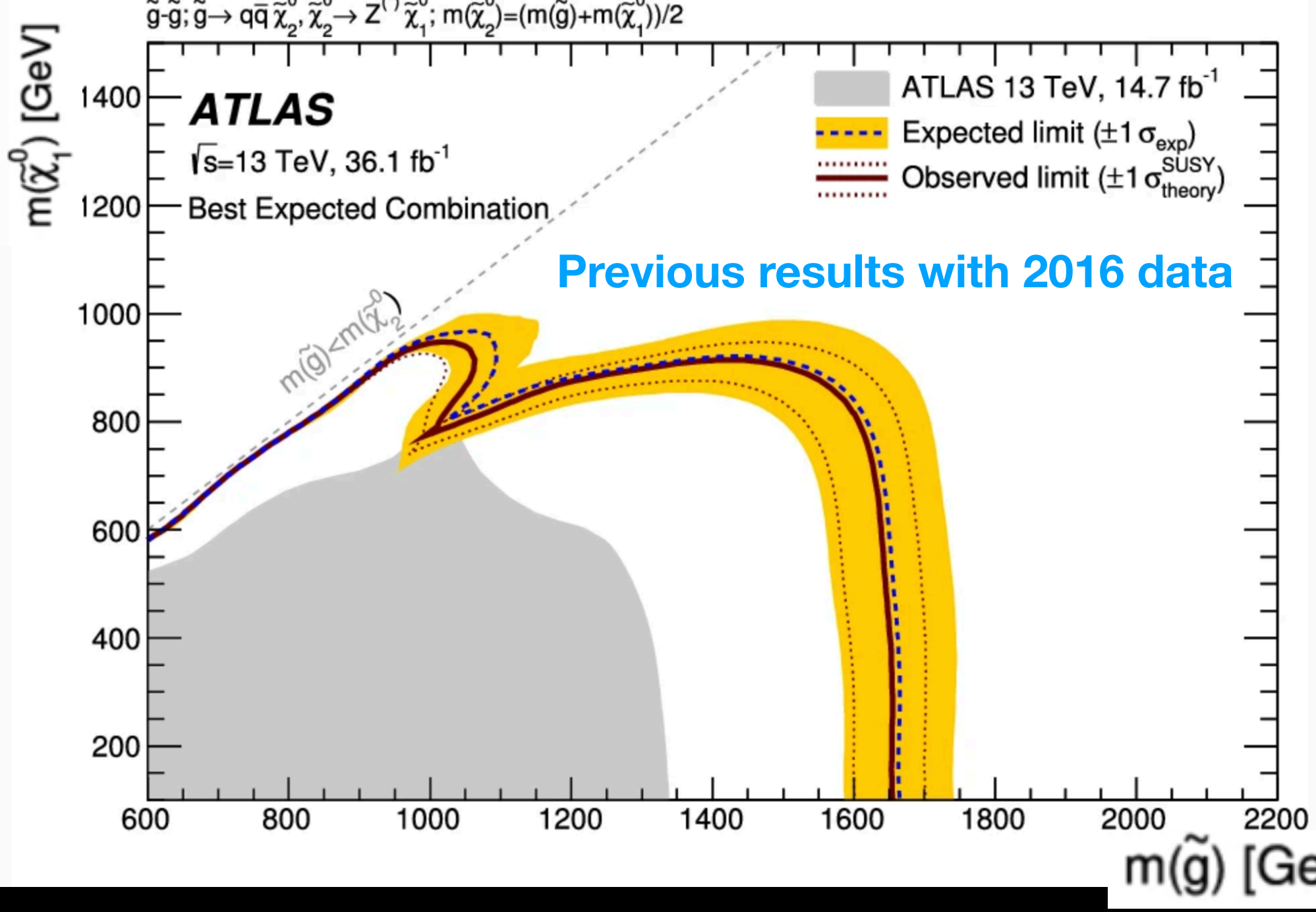
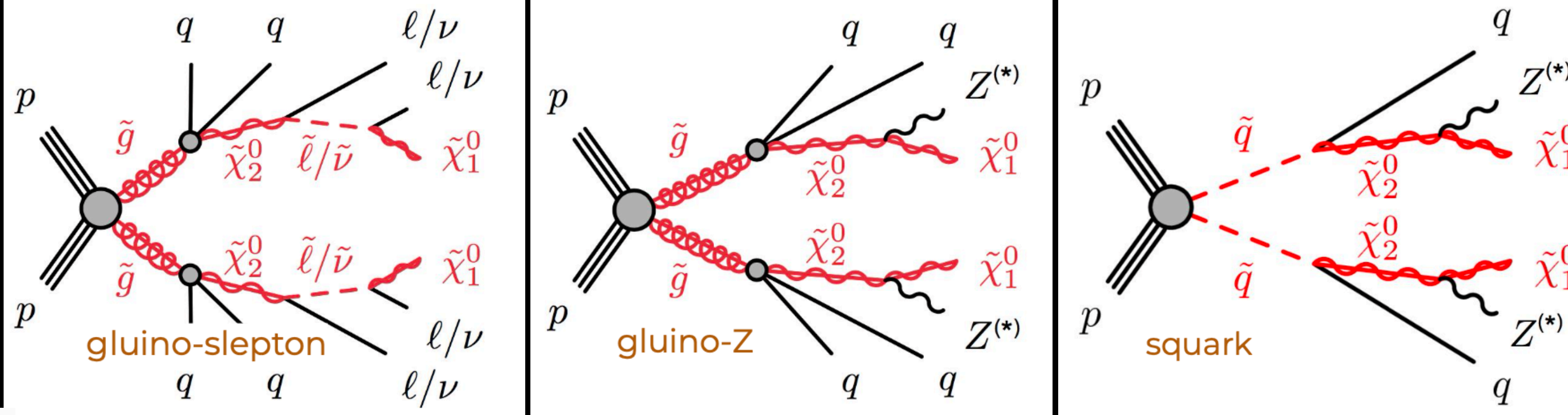
- ★ The data in SR are not looked at unless the background estimations are properly understood and validated.
- ★ Systematic uncertainties are understood.
- ★ Once satisfied with uncertainties, data in SR are looked at.
 - ★ Any significant excess of data over estimated background goes to test for discovery.
 - ★ No excess in data sets upper limits in SUSY xsec and parameters.



SUSY search with two leptons and two jets

SUSY-2018-05

- ★ Searches for strong production of SUSY
 - ★ Gluino pair production with decay via slepton
 - ★ Gluino pair production with decay via $Z^{(*)}$
 - ★ Squark pair production with decay via $Z^{(*)}$
 - ★ $\tilde{\chi}_1^0$ is the Lightest Supersymmetric Particle (LSP).



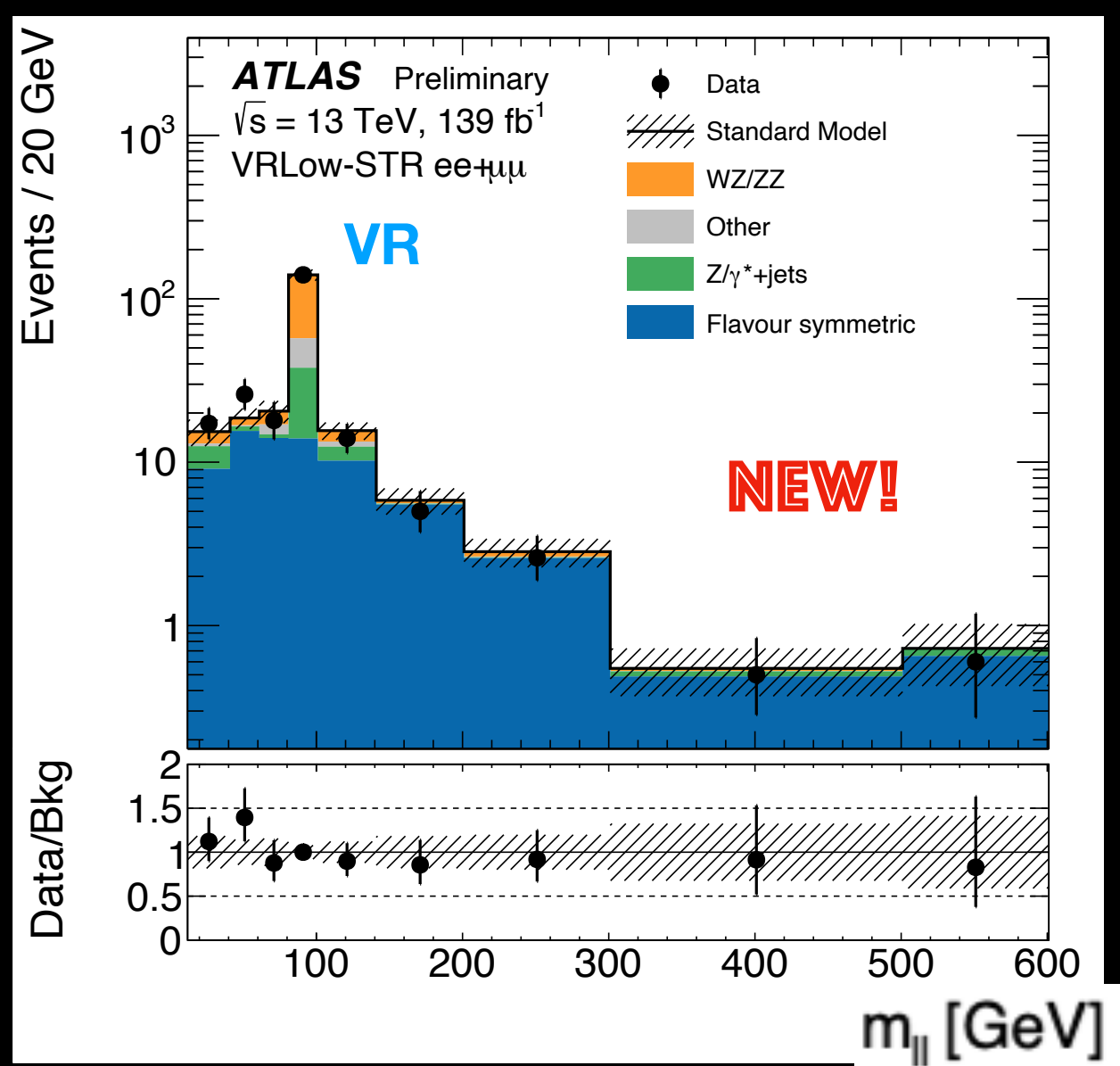
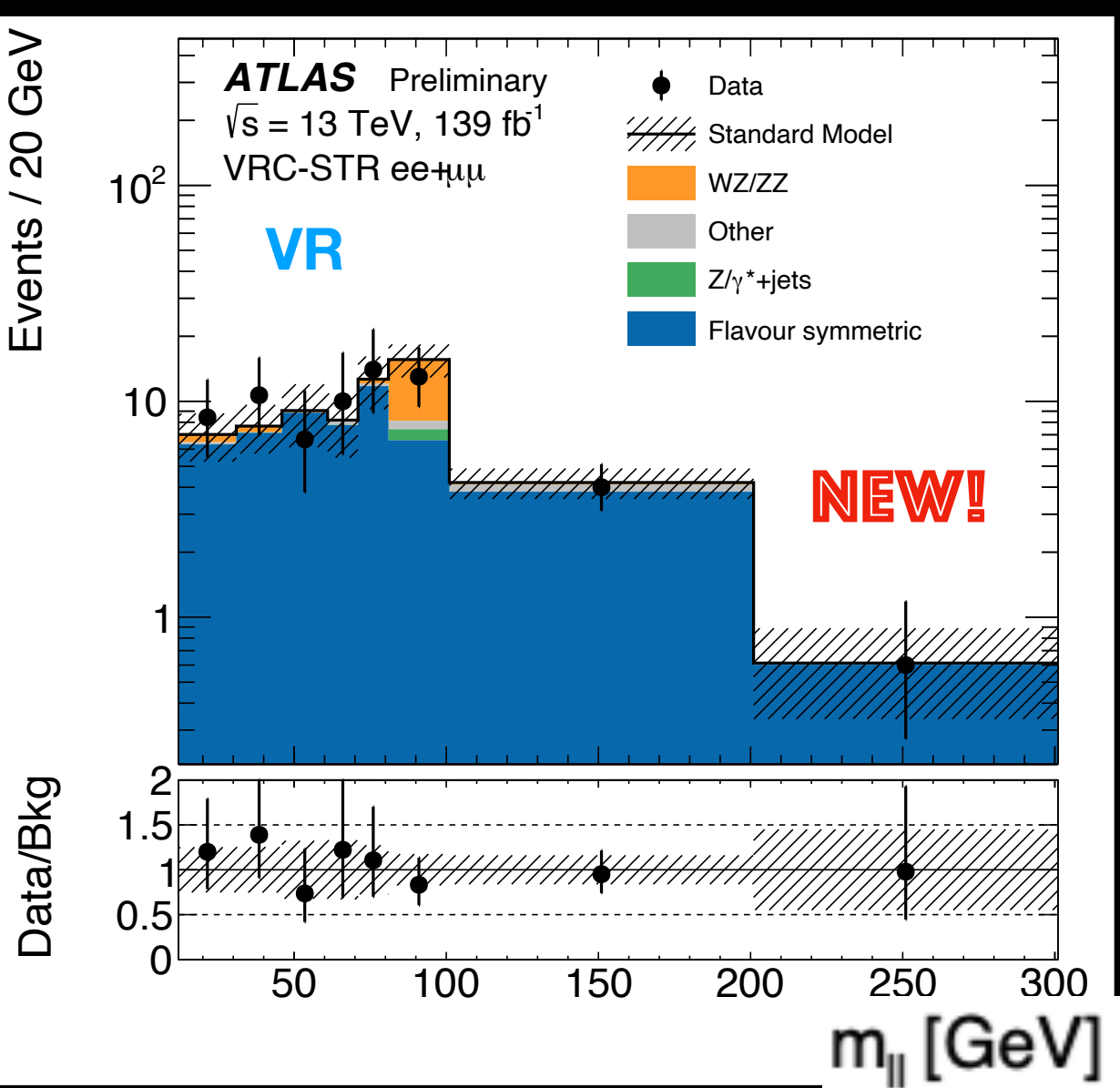
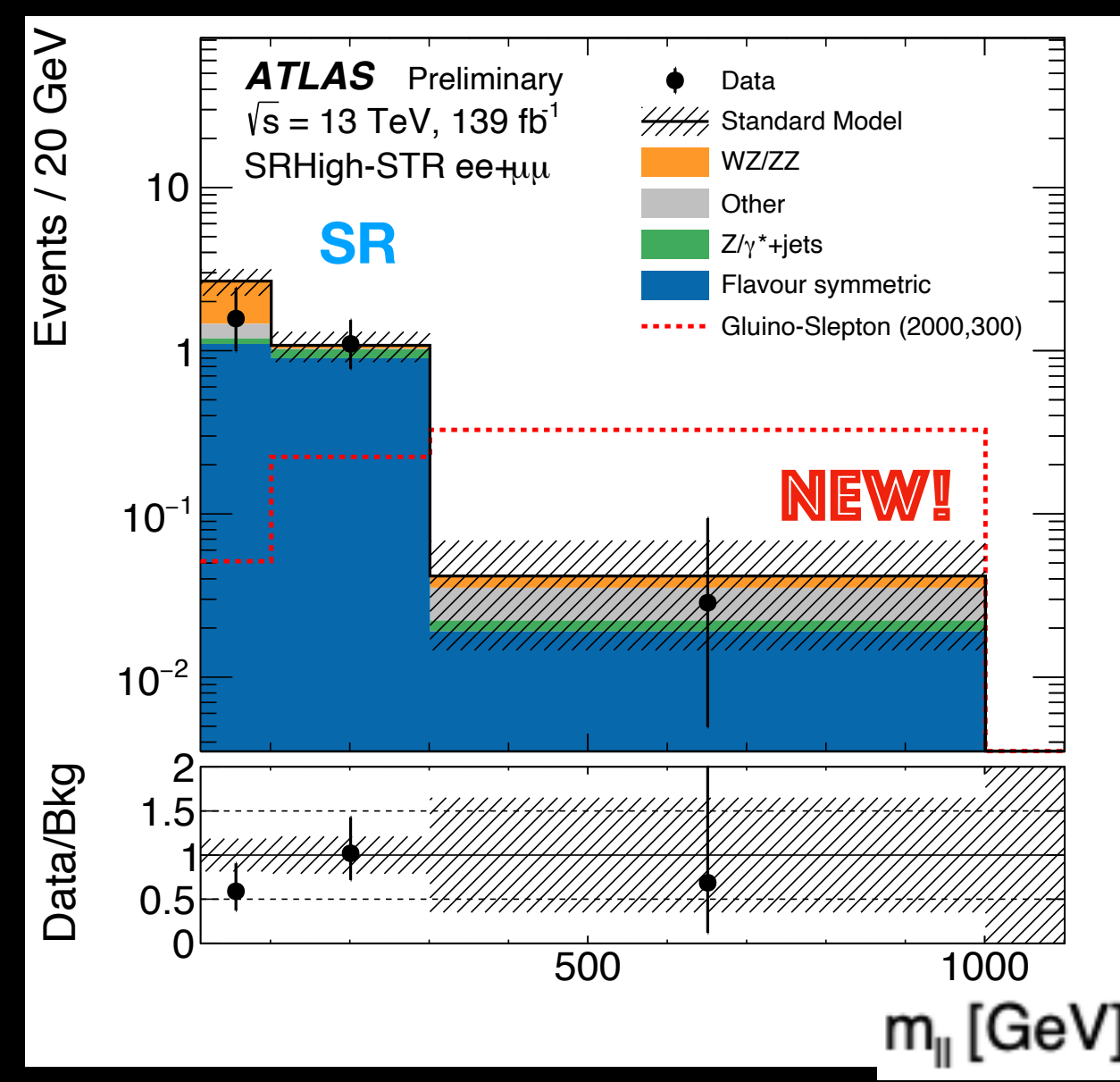
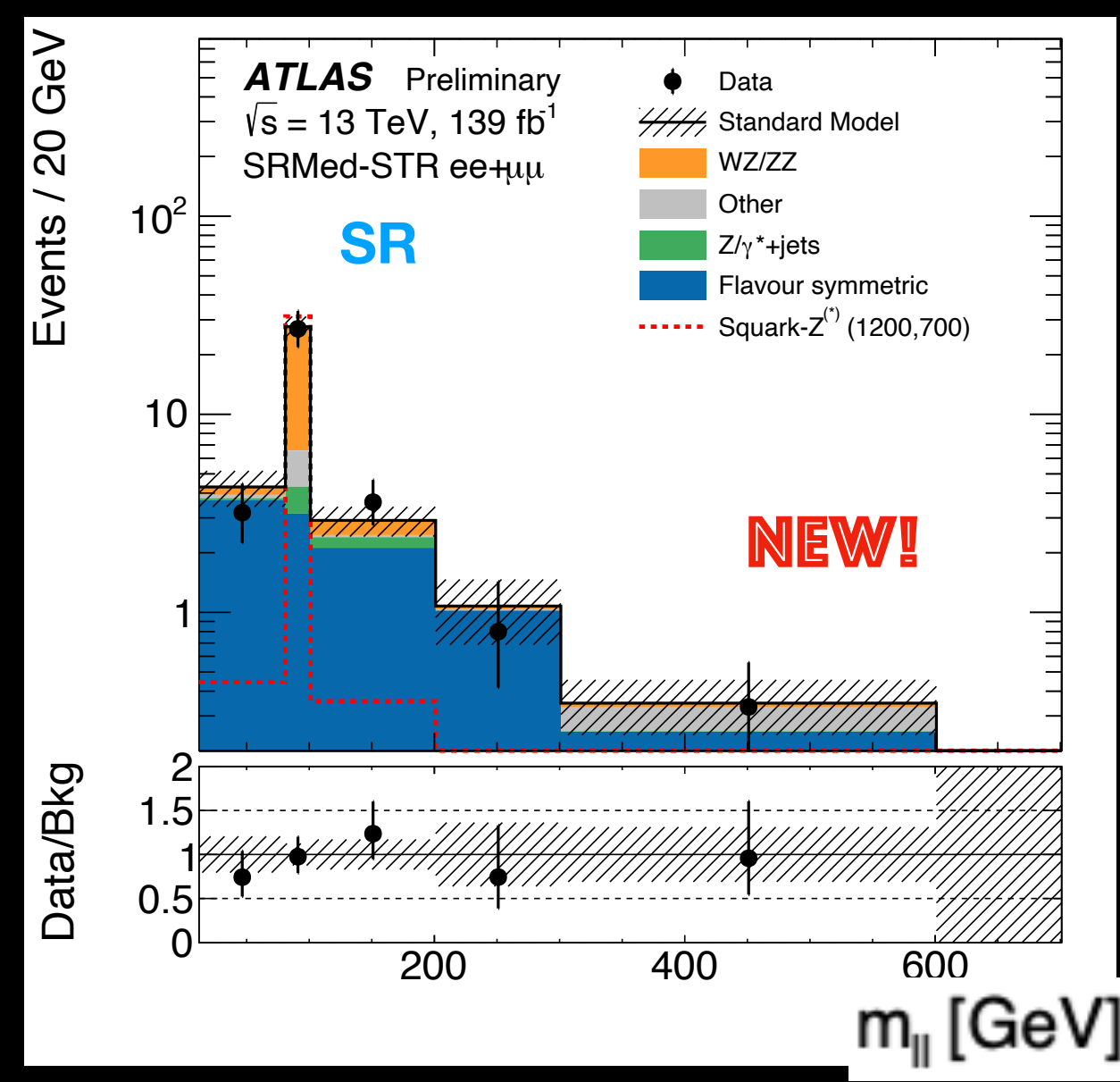
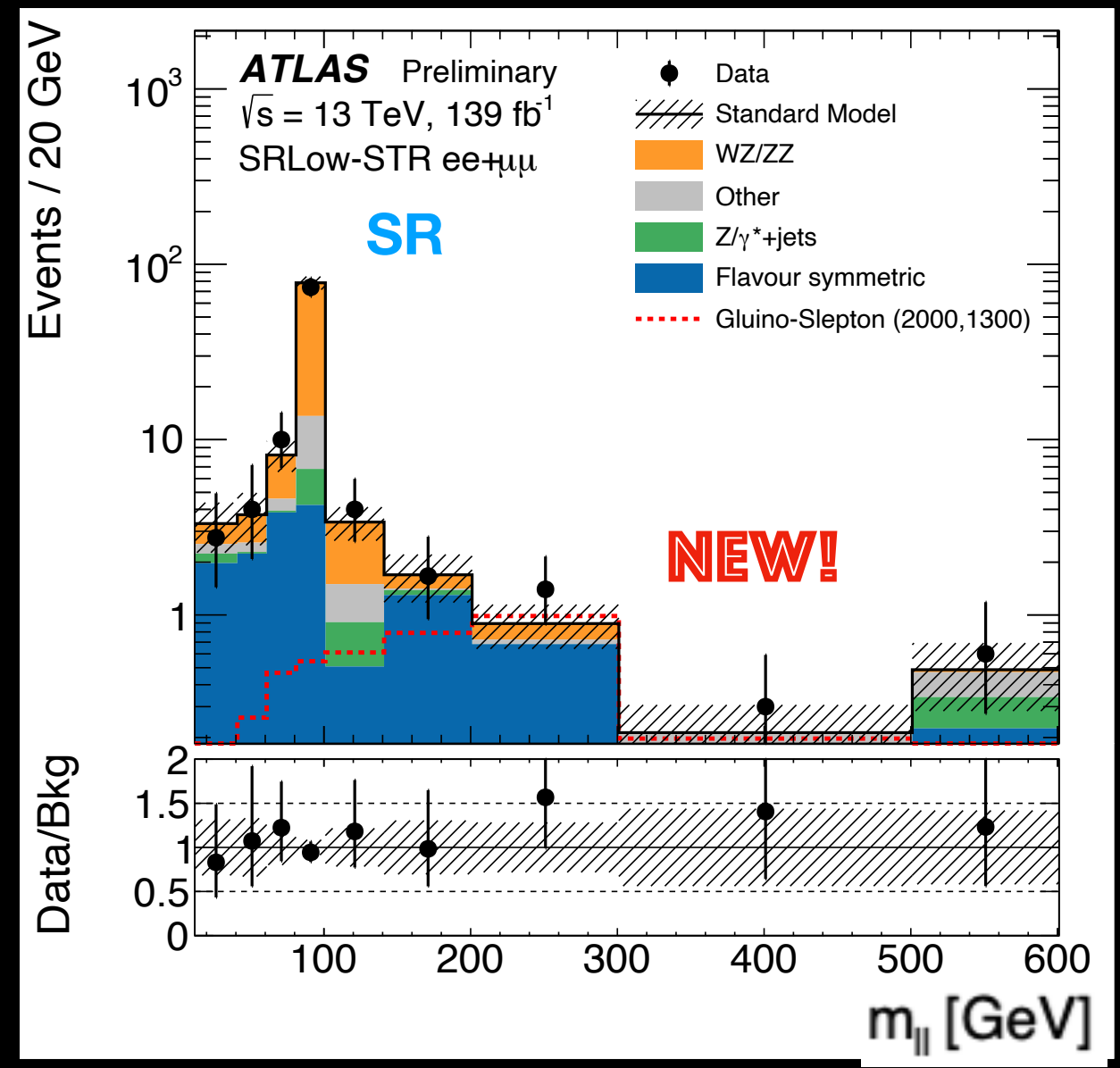
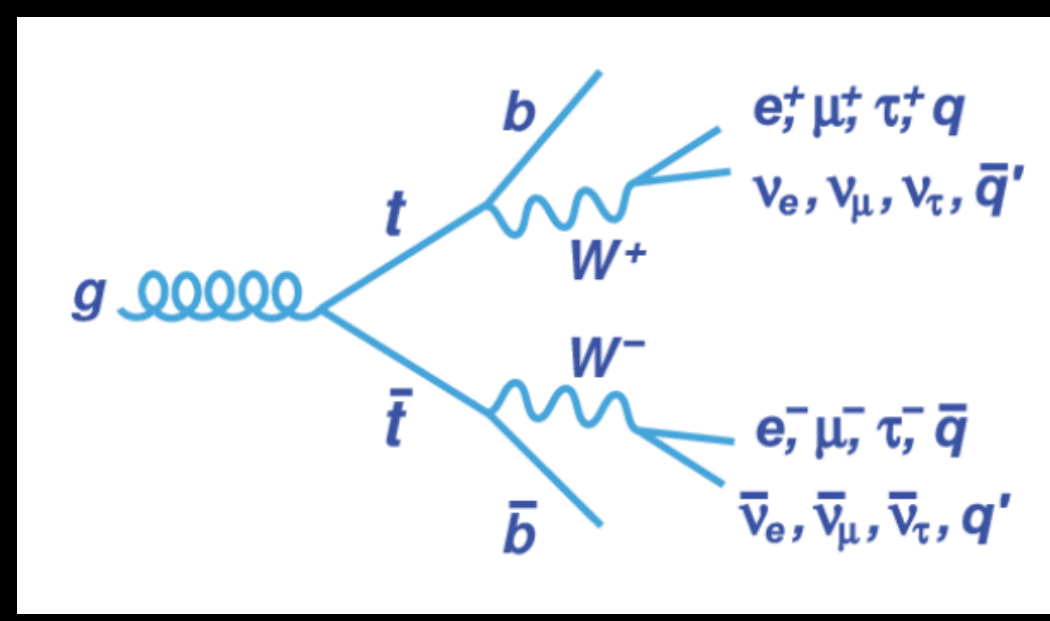
- ★ **Preselection:**
 - ★ Exactly two same flavor opposite sign electrons or muons with $p_T > 25$ GeV and two jets with $p_T > 30$ GeV.
- ★ For analysis with 139 fb $^{-1}$, signal regions require
 - ★ High $H_T > 250$ GeV to $H_T > 800$ GeV, where H_T is the scalar sum of jet p_T .
 - ★ High $E_T^{\text{miss}} (> 250$ GeV to > 300 GeV)
 - ★ Medium to high $m_{T2} (> 75$ GeV to > 100 GeV), m_{T2} being the extension of the transverse mass m_T for the case of two missing particles.
 - ★ On-shell Z regions require invariant mass within 81 GeV to 101 GeV.

Previous publication with 36.1 fb $^{-1}$: [Eur. Phys. J. C 78 \(2018\) 625](#)

Background estimation:

SUSY-2018-05

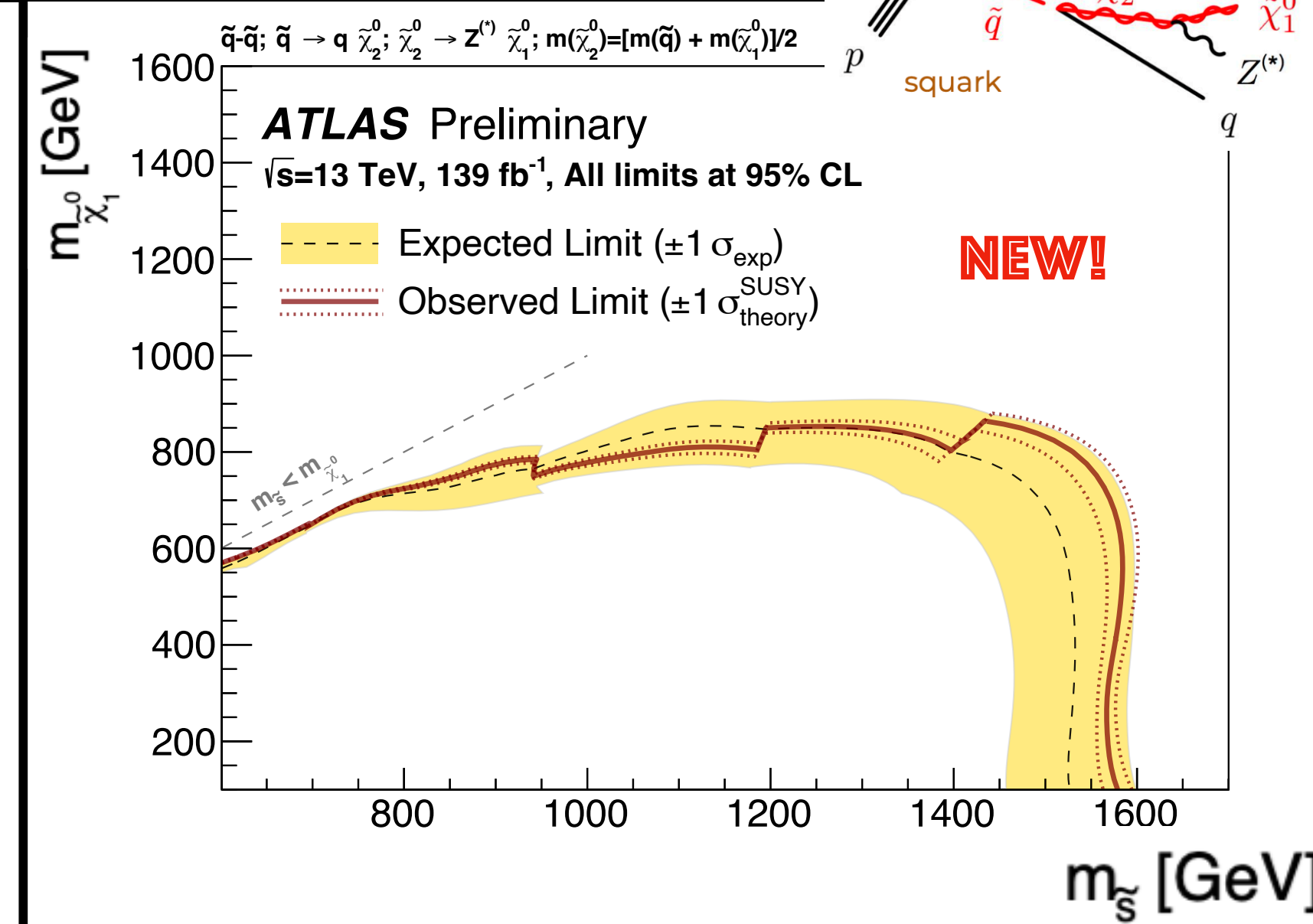
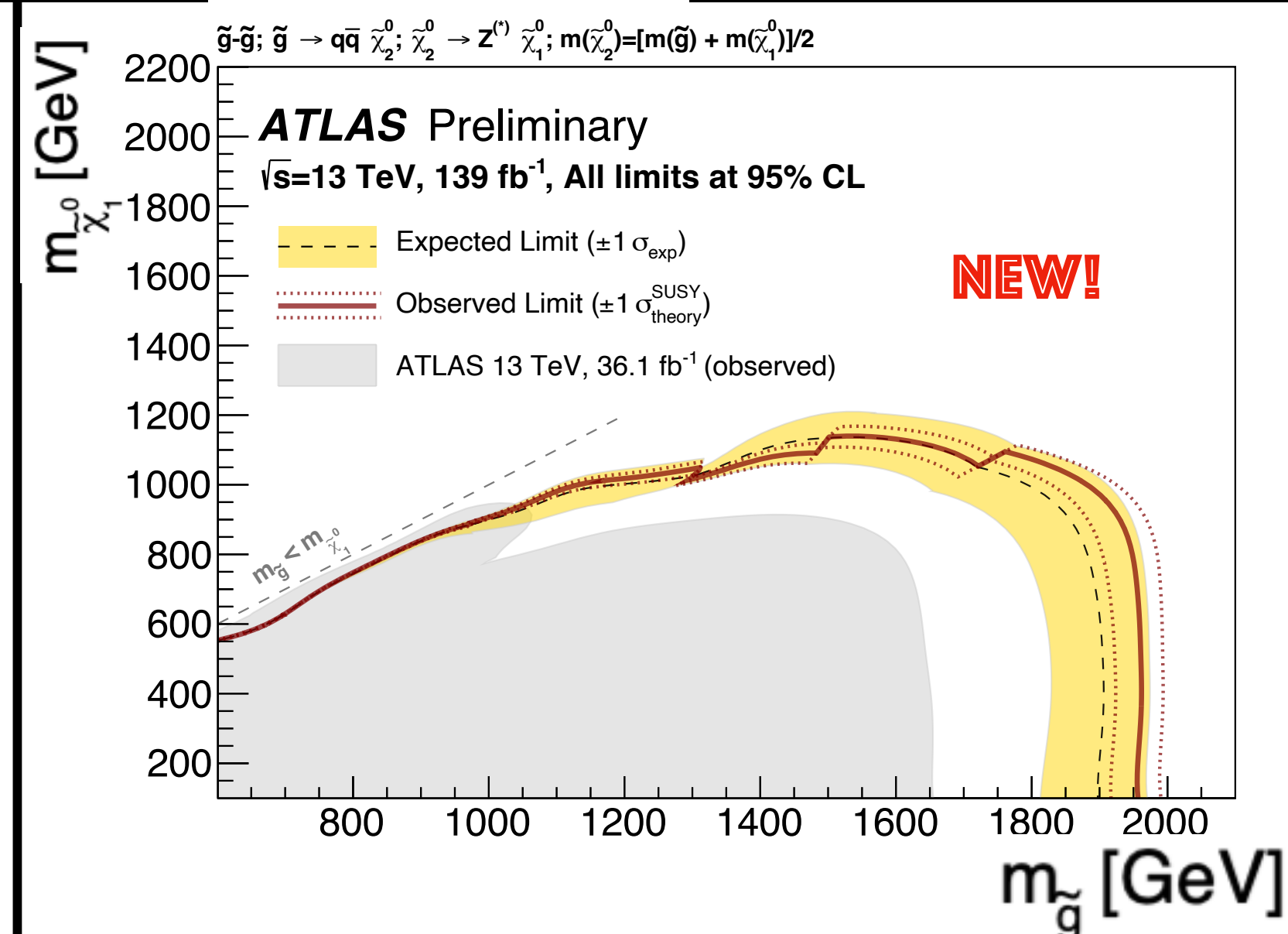
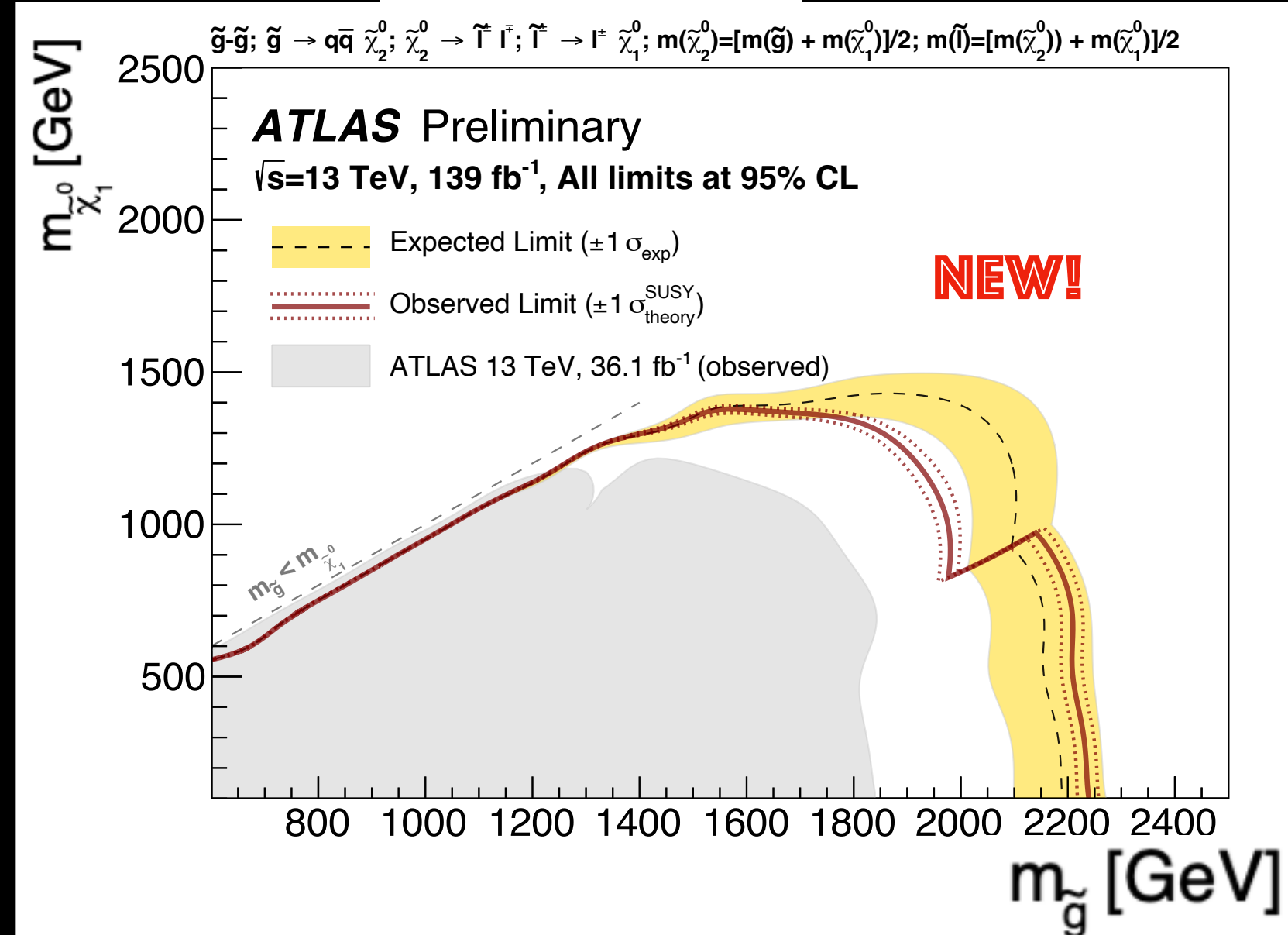
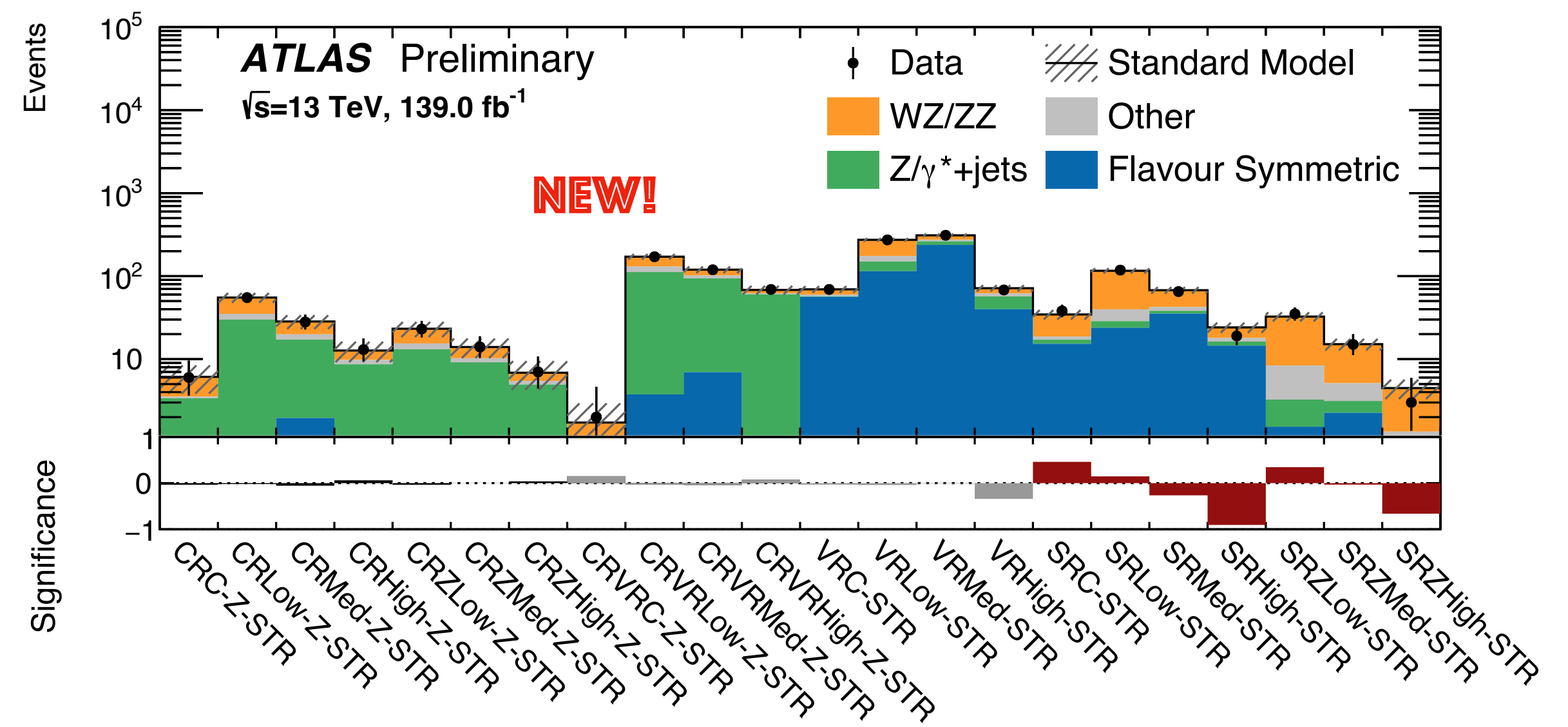
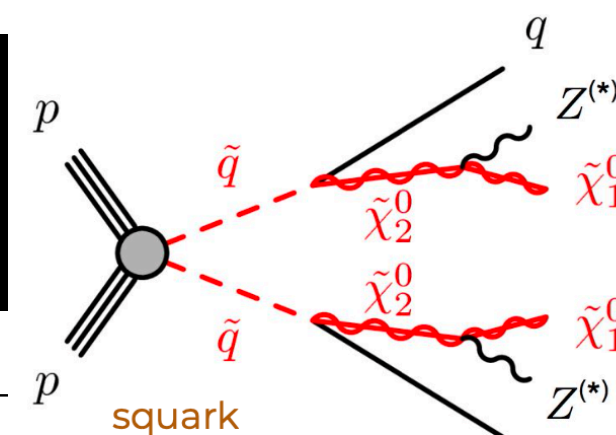
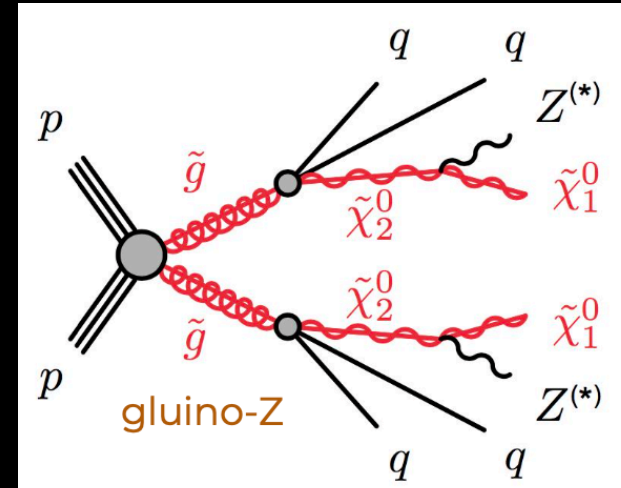
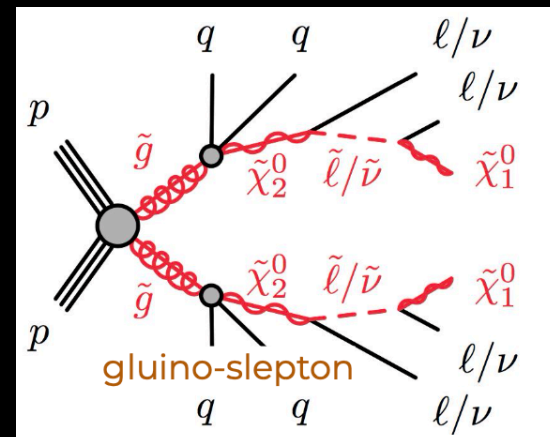
- ★ Background for strong searches:
 - ★ $Z \rightarrow \tau\tau, t\bar{t}, Wt$ and WW have independent leptonic decays.
 - ★ Estimated using Flavor Symmetry method from $e\mu$ events.
 - ★ Z+jets estimated from MC.
 - ★ CR region with $\Delta\phi_m = \text{minimum}(\Delta\phi(\text{jet}_{1,2}, E_T^{\text{miss}}) < 0.4$ used to normalize the MC estimate to data.
 - ★ Fakes/non-prompt leptons (for $W \rightarrow l\nu$, single top etc) estimated from matrix method.
 - ★ Rest (WZ/ZZ) are estimated from MC.



Interpretations:

SUSY-2018-05

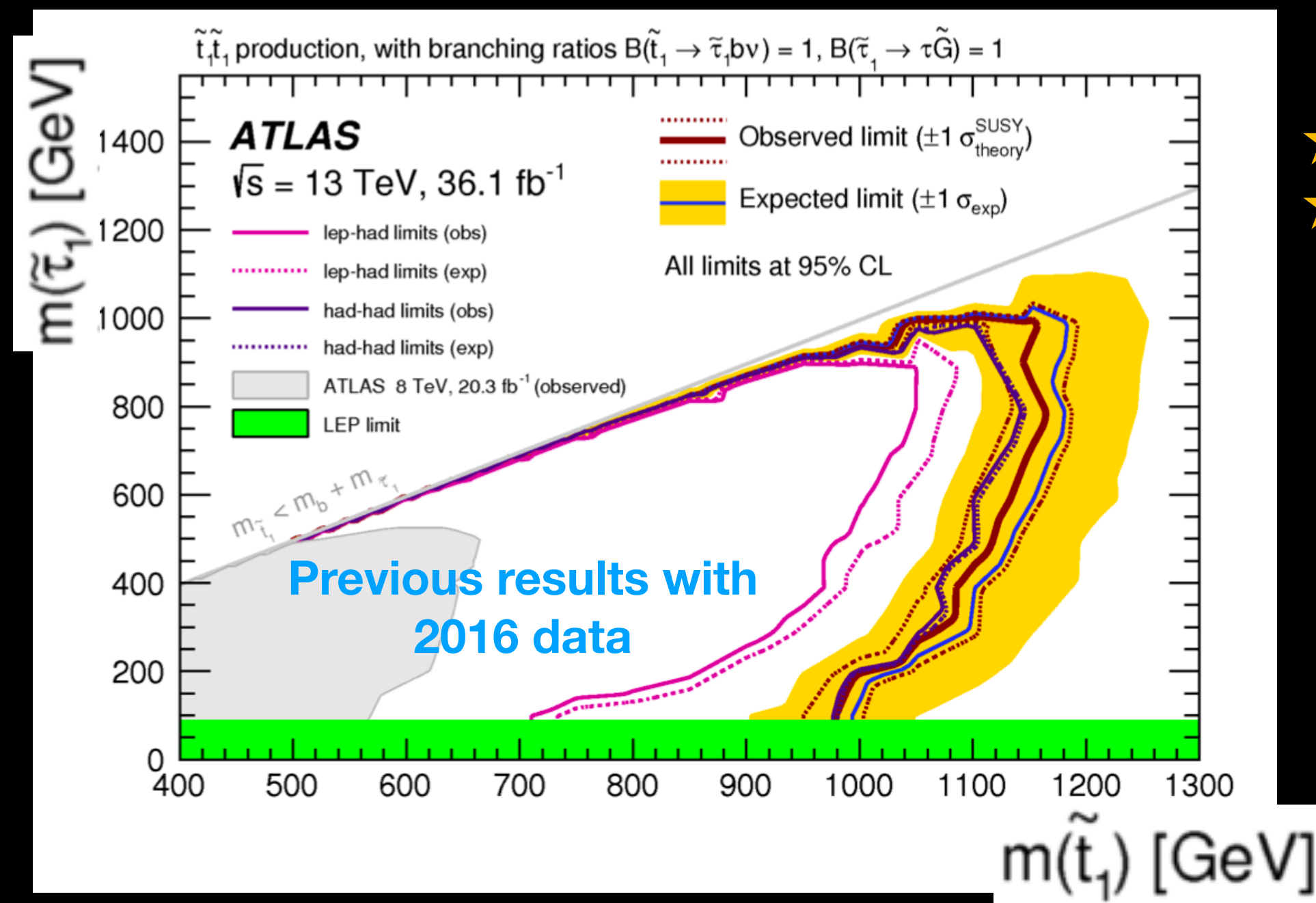
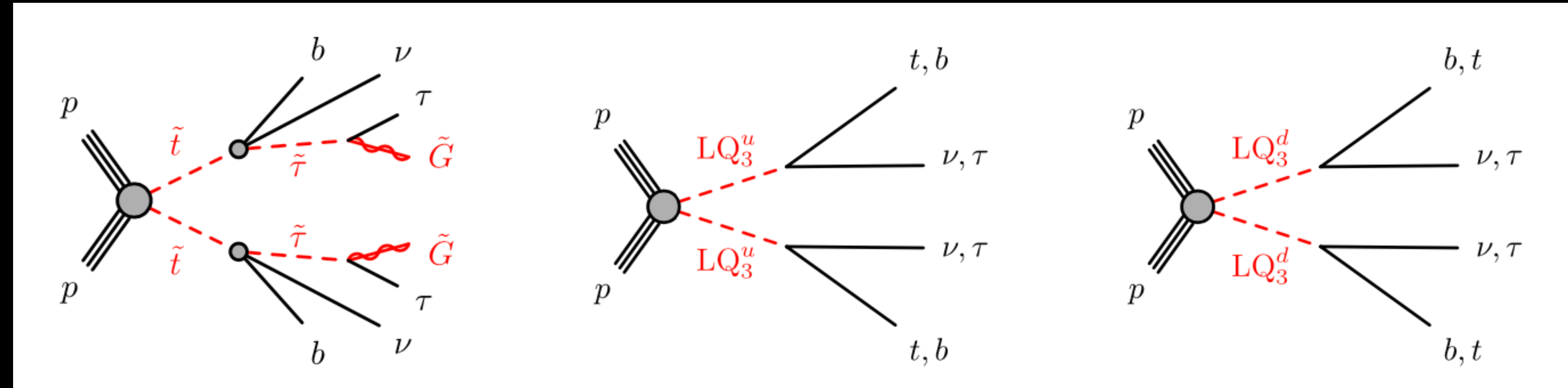
- ★ Used best expected SR per region of phase-space.
- ★ Sharp features come because of stitching of multiple SRs.
- ★ Artifact of changing between SRs



SUSY search with τ : Stop-stau signal

Phys. Rev. D 104, 112005

- ★ Direct pair production of stops
- ★ 3 body decay to b-quark, neutrino and a scalar tau ($\tilde{\tau}$)
- ★ $\tilde{\tau}$ decays to τ and \tilde{G} (LSP)



Previous result (Phys. Rev. D 98, 032008 (2018))

For present search

- ★ Focus on channels with hadronic τ -s
- ★ Two different regions of the parameter space
 - ★ Low to medium mass splitting: **2 τ SR**
 - ★ High p_T τ -s, high E_T^{miss} and relatively soft b-jets
 - ★ High mass splitting: **1 τ SR**
 - ★ High p_T b-jets, relatively soft τ and high E_T^{miss} .
- ★ **1 τ SR** has been optimized also for leptoquark search.

- ★ Previous result with **36.1 fb^{-1}** .
- ★ Two channels
 - ★ τ -s decay hadronically
 - ★ One τ decay hadronically and another leptonically.
- ★ Stop mass exclusion up to **1150 GeV**

Background estimation

Phys. Rev. D 104, 112005

★ Identification of τ

★ Used Recurrent Neural Network (RNN) [ATLAS-PHYS-PUB-2019-033]

★ Input: transverse and longitudinal impact parameters, ratio of EM energy and track momentum, mass of the track system, mass of the track+EM system etc

★ Signal regions:

★ 2τ channel

★ $E_T^{\text{miss}} > 280 \text{ GeV}$, $OS(\tau_1, \tau_2)=1$, $m_{T2}(\tau_1, \tau_2) > 70 \text{ GeV}$

★ 1τ channel

★ $E_T^{\text{miss}} > 280 \text{ GeV}$, $\sum m_T(b_1, b_2) > 700 \text{ GeV}$, $m_T(\tau) > 300 \text{ GeV}$

★ $S_T = p_T(\tau) + p_T(j_1) + p_T(j_2) > 800 \text{ GeV}$

★ Dominant background

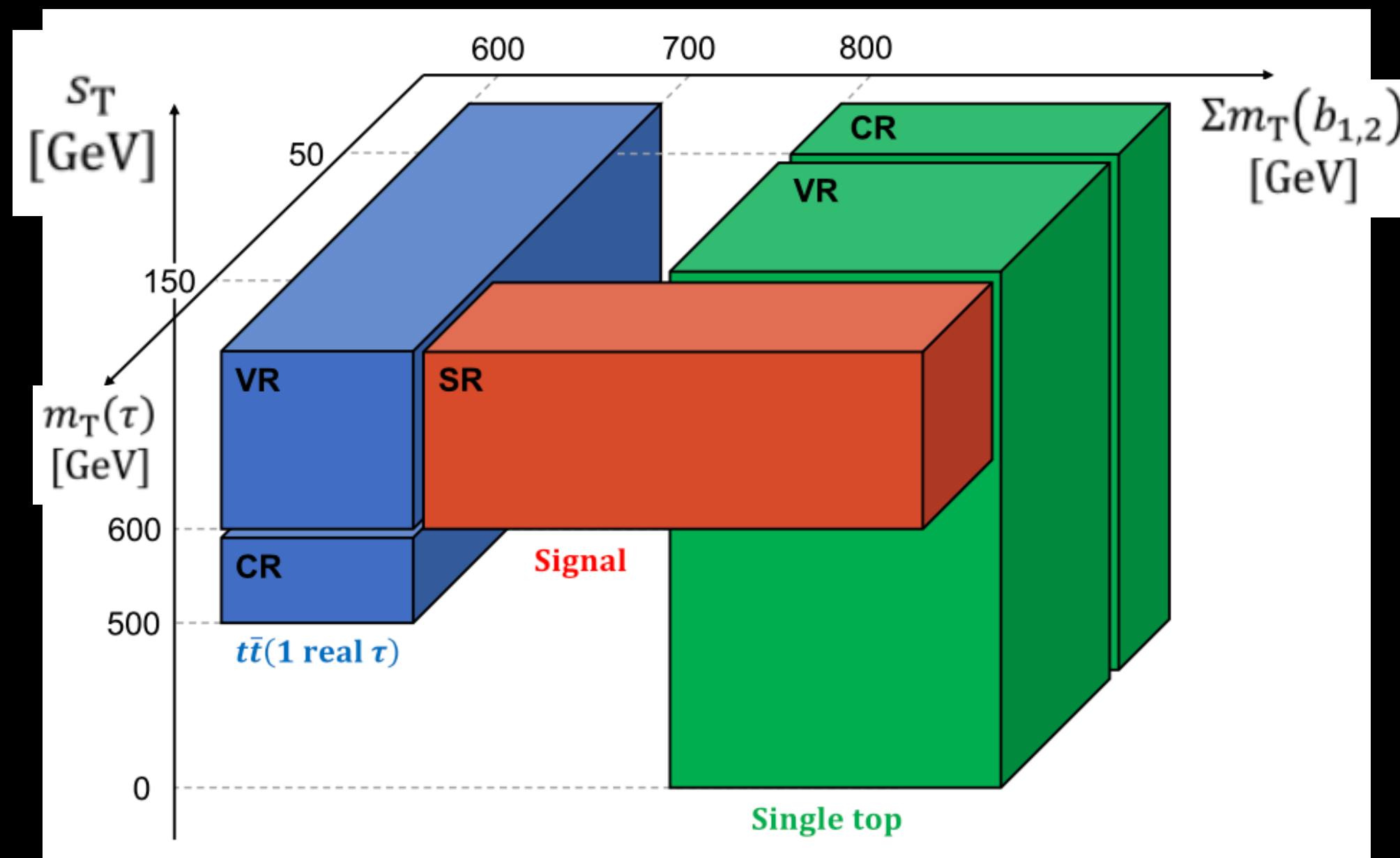
★ $t\bar{t}$ (2 real τ)

★ $t\bar{t}$ (1 real τ)

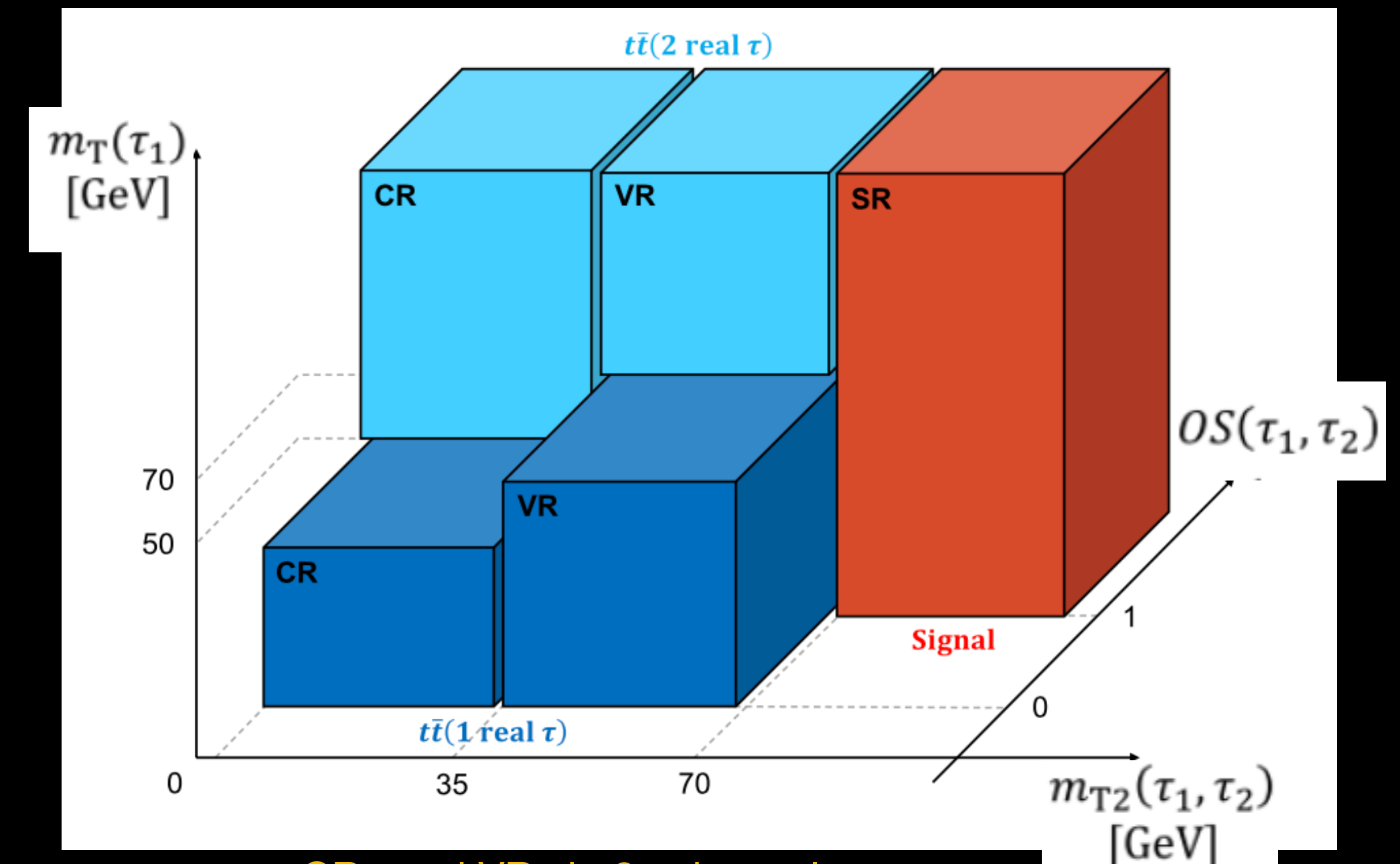
★ Single top (Wt)

★ Control and validation regions in both channels

★ QCD is negligible because of the high E_T^{miss} cut.



CRs and VRs in 1τ channel



CRs and VRs in 2τ channel

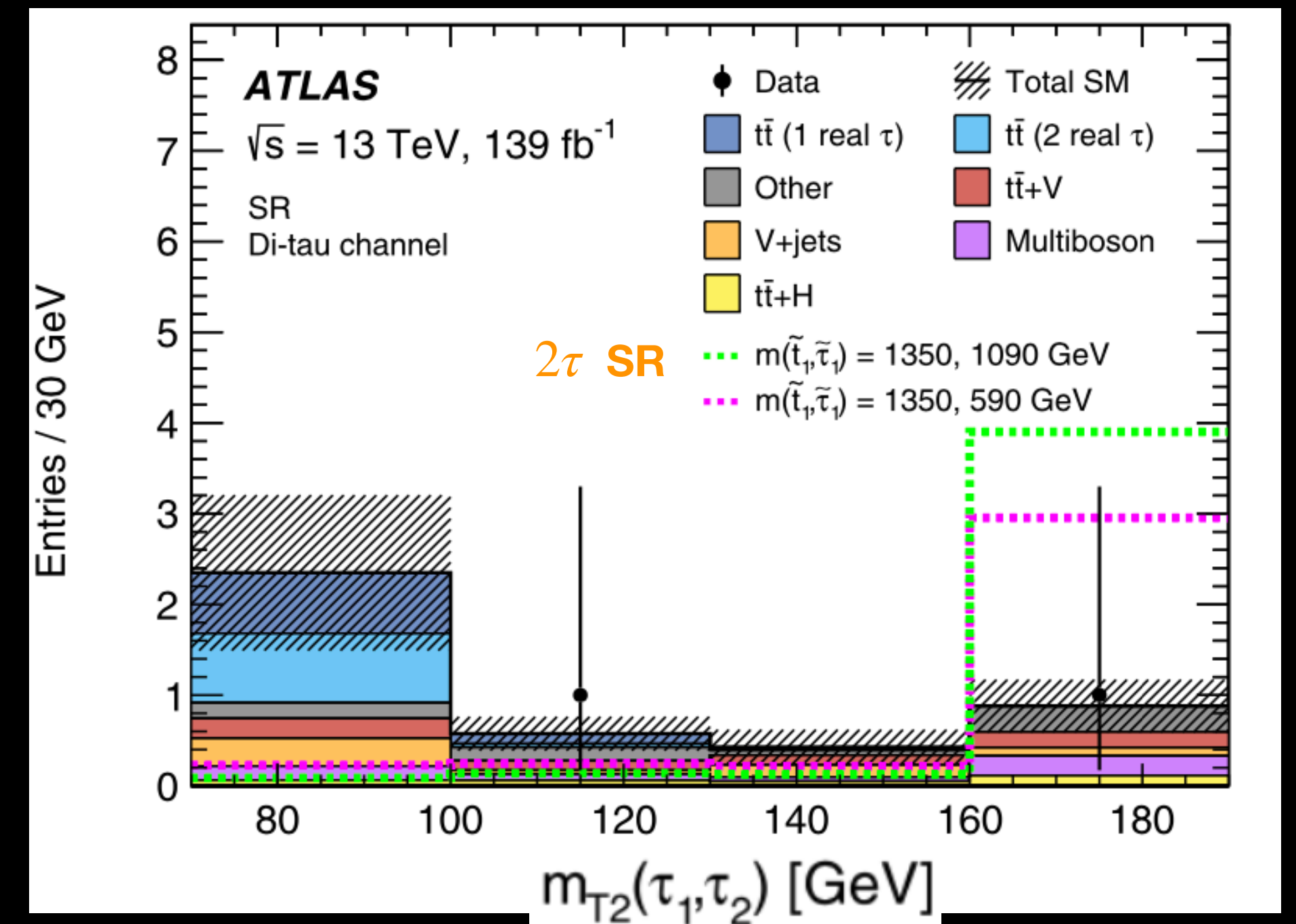
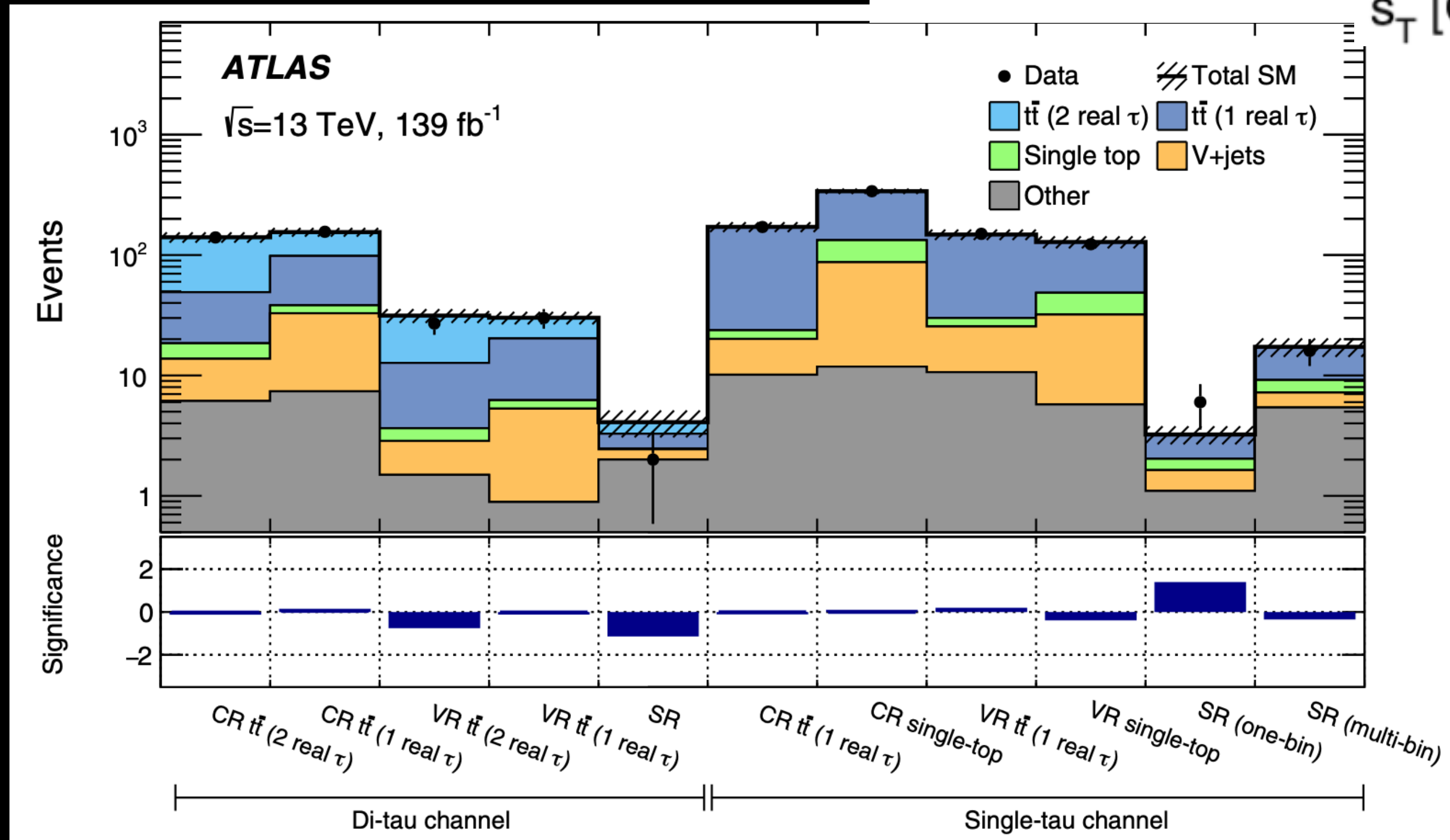
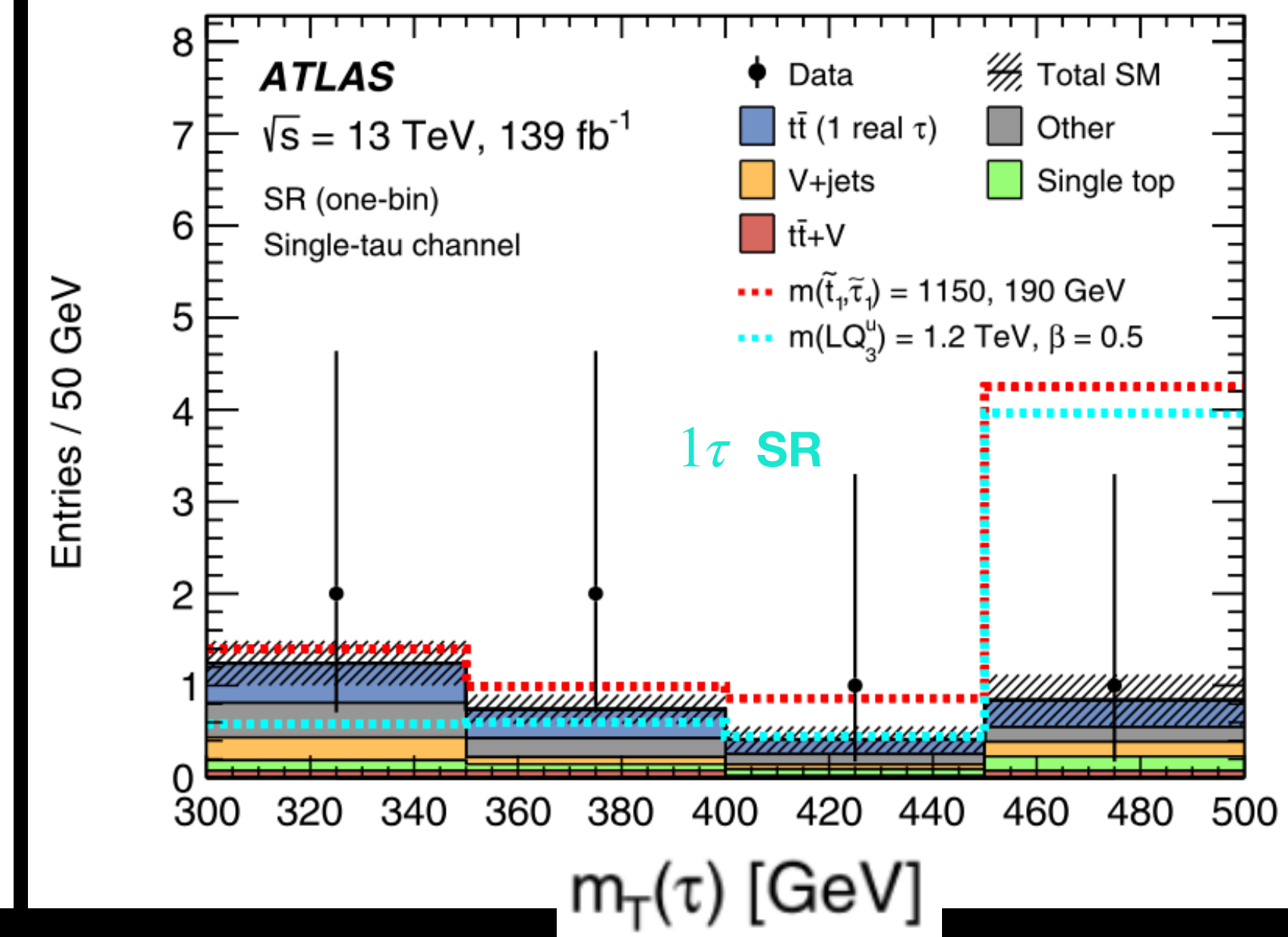
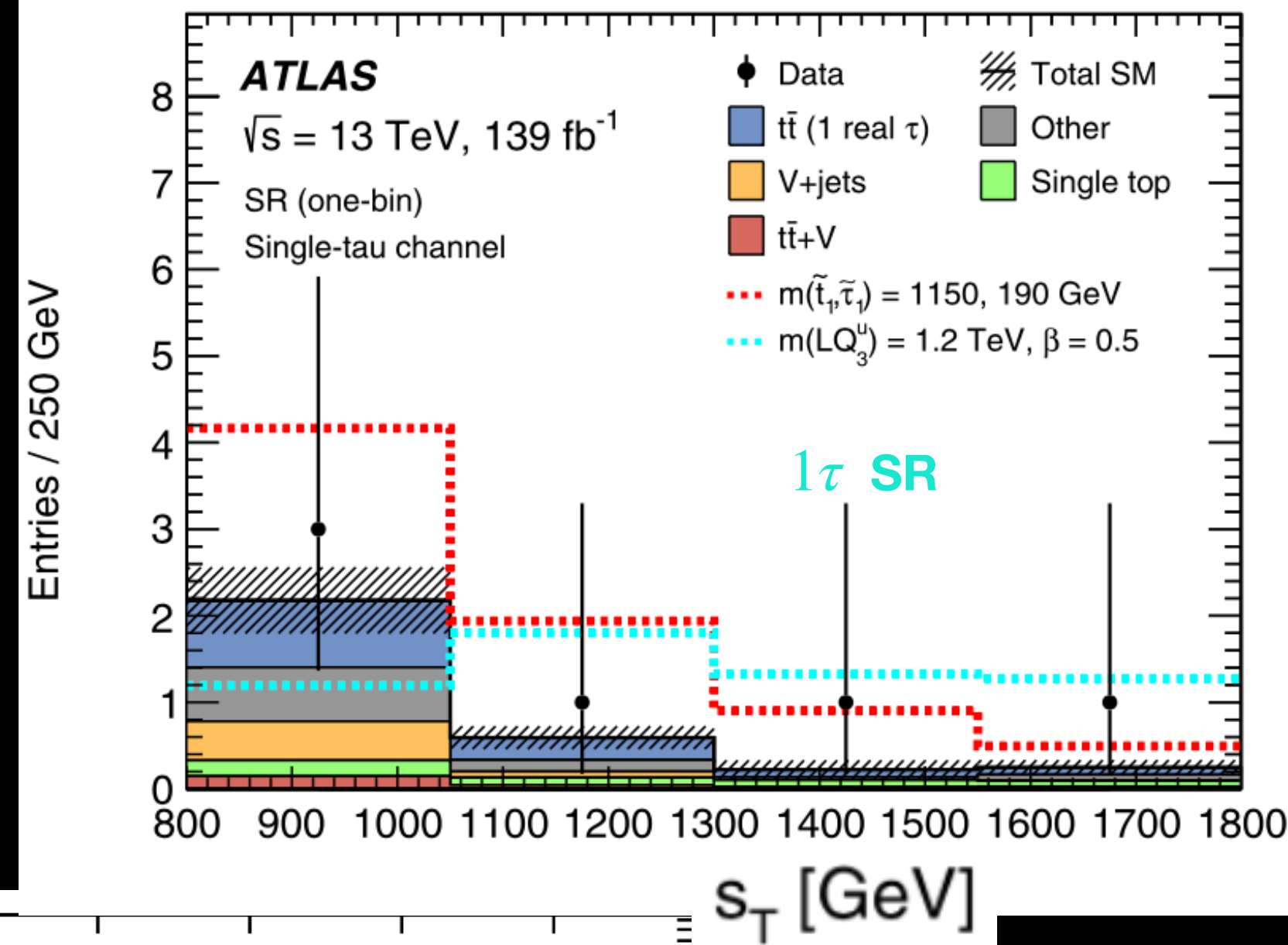
Results:

Phys. Rev. D 104, 112005

★ Over all good agreement for the extrapolation in

★ S_T and $\sum m_T(b_1, b_2)$ (1τ channel)

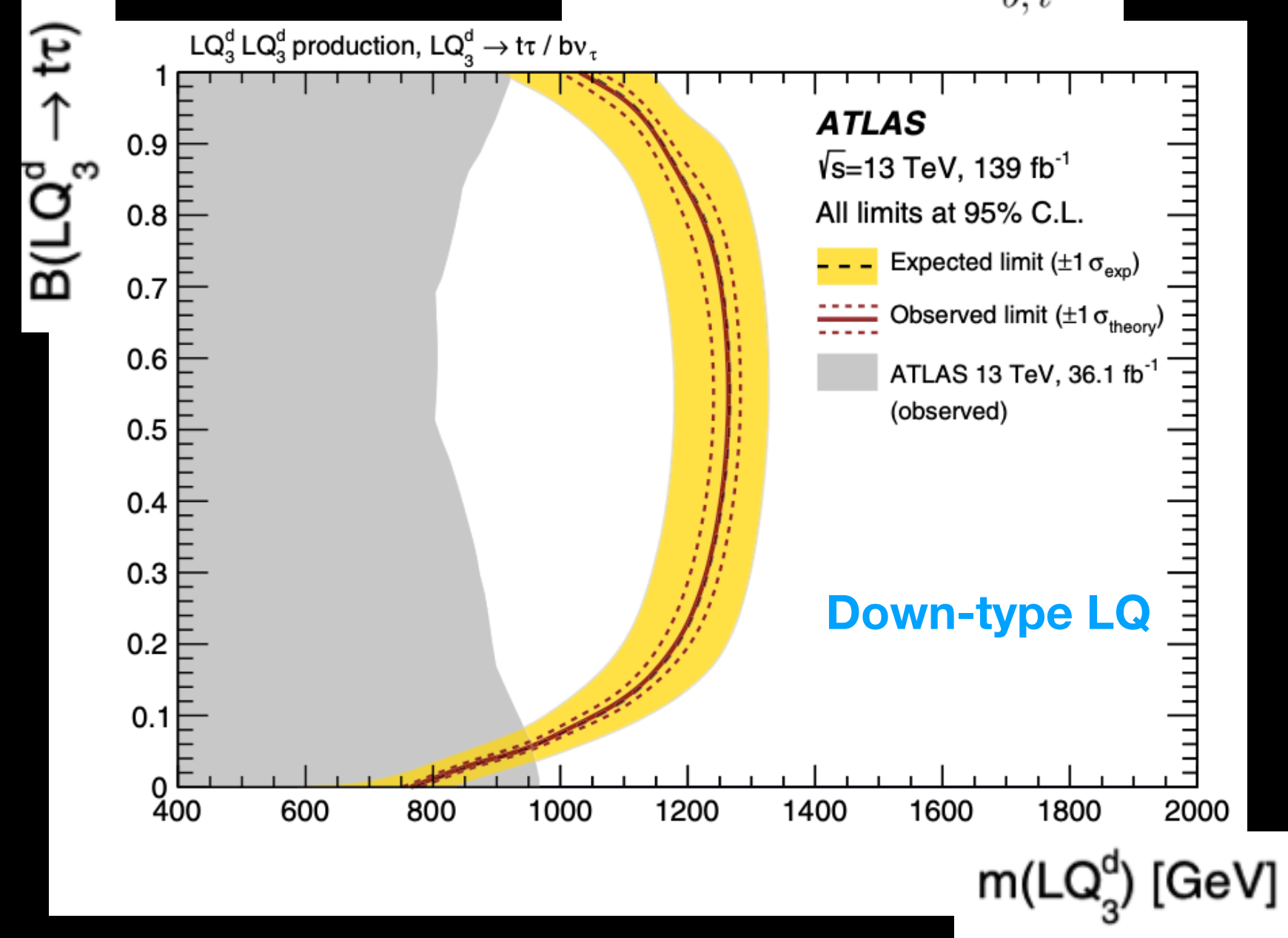
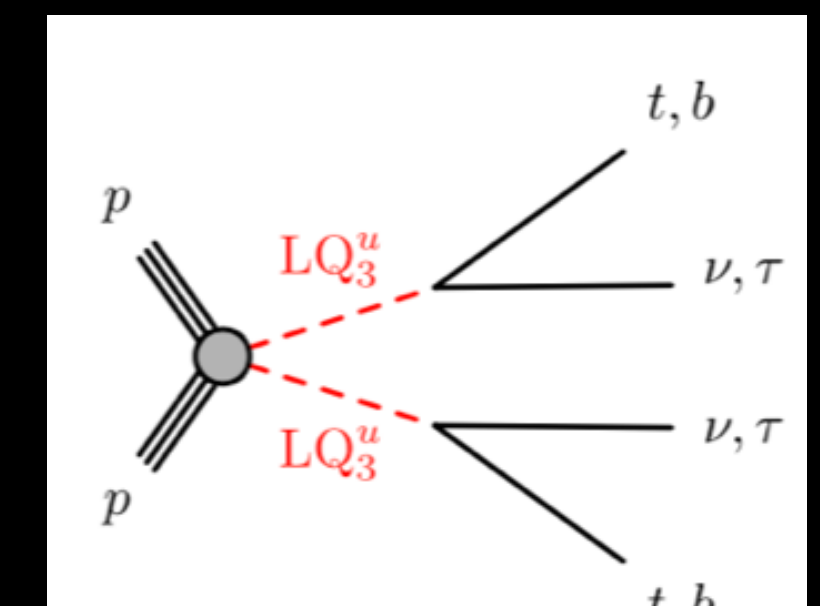
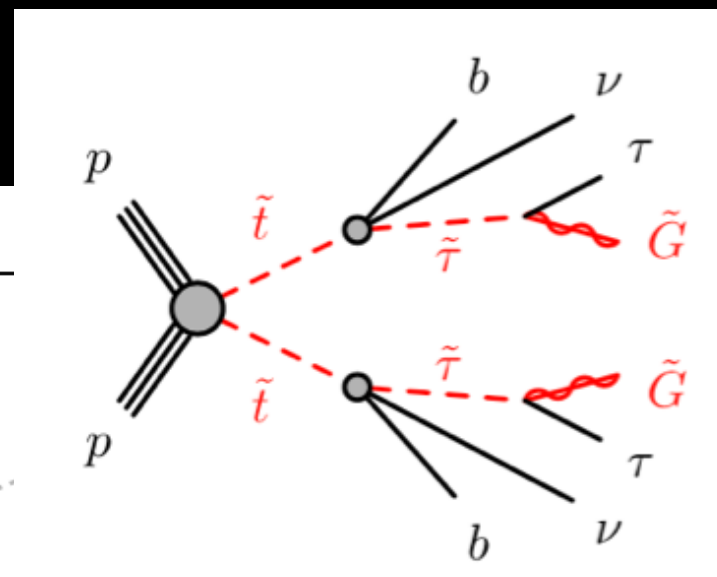
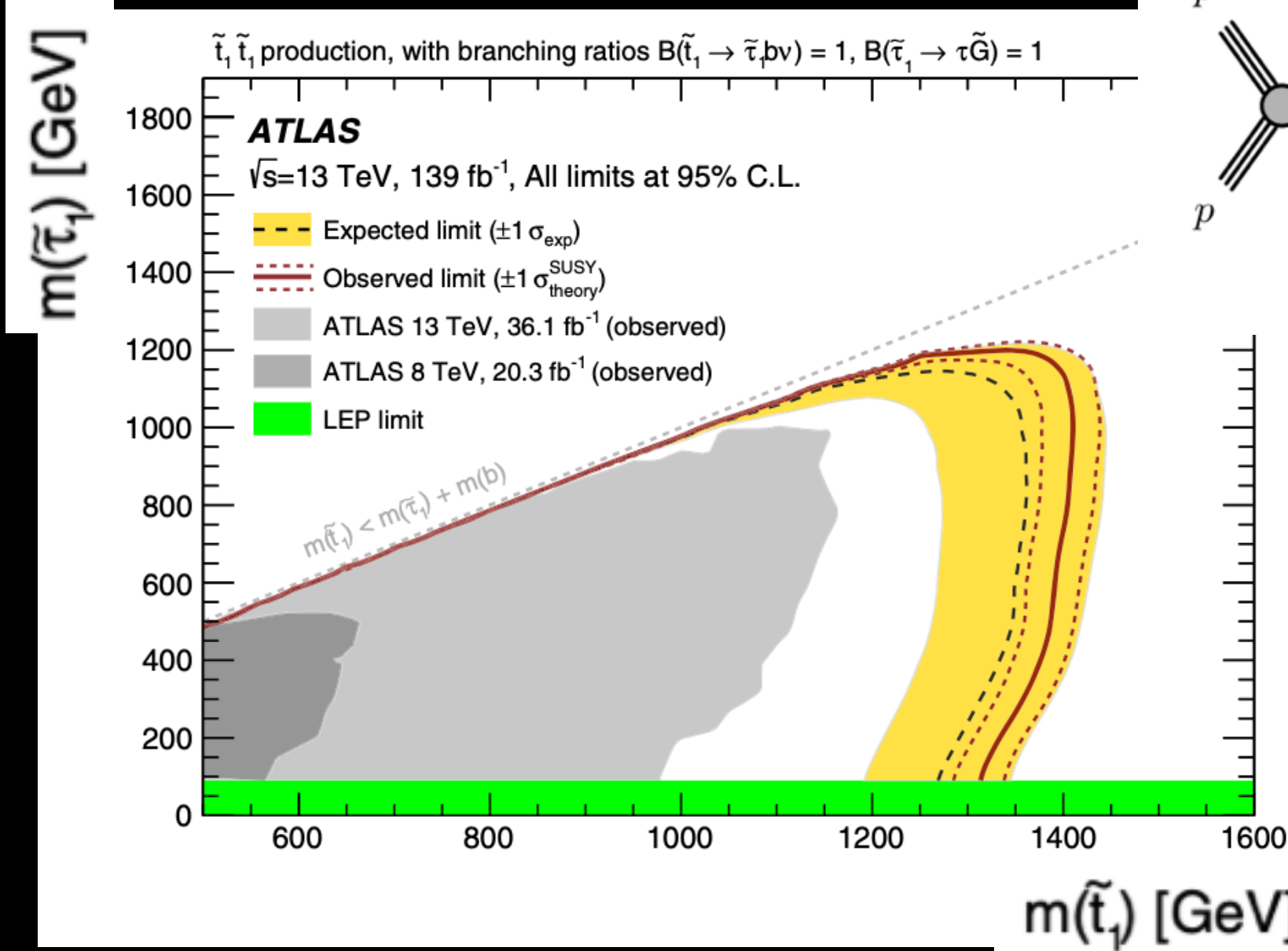
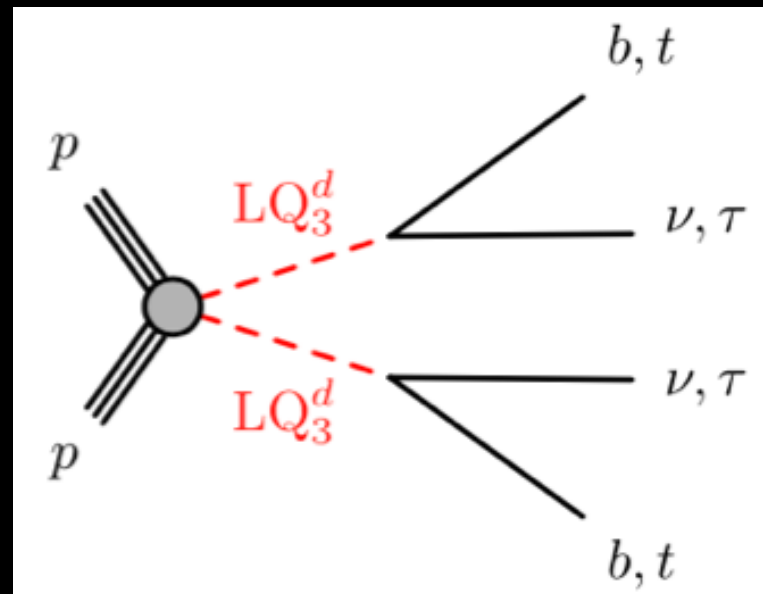
★ $m_{T2}(\tau_1, \tau_2)$ (2τ channel)



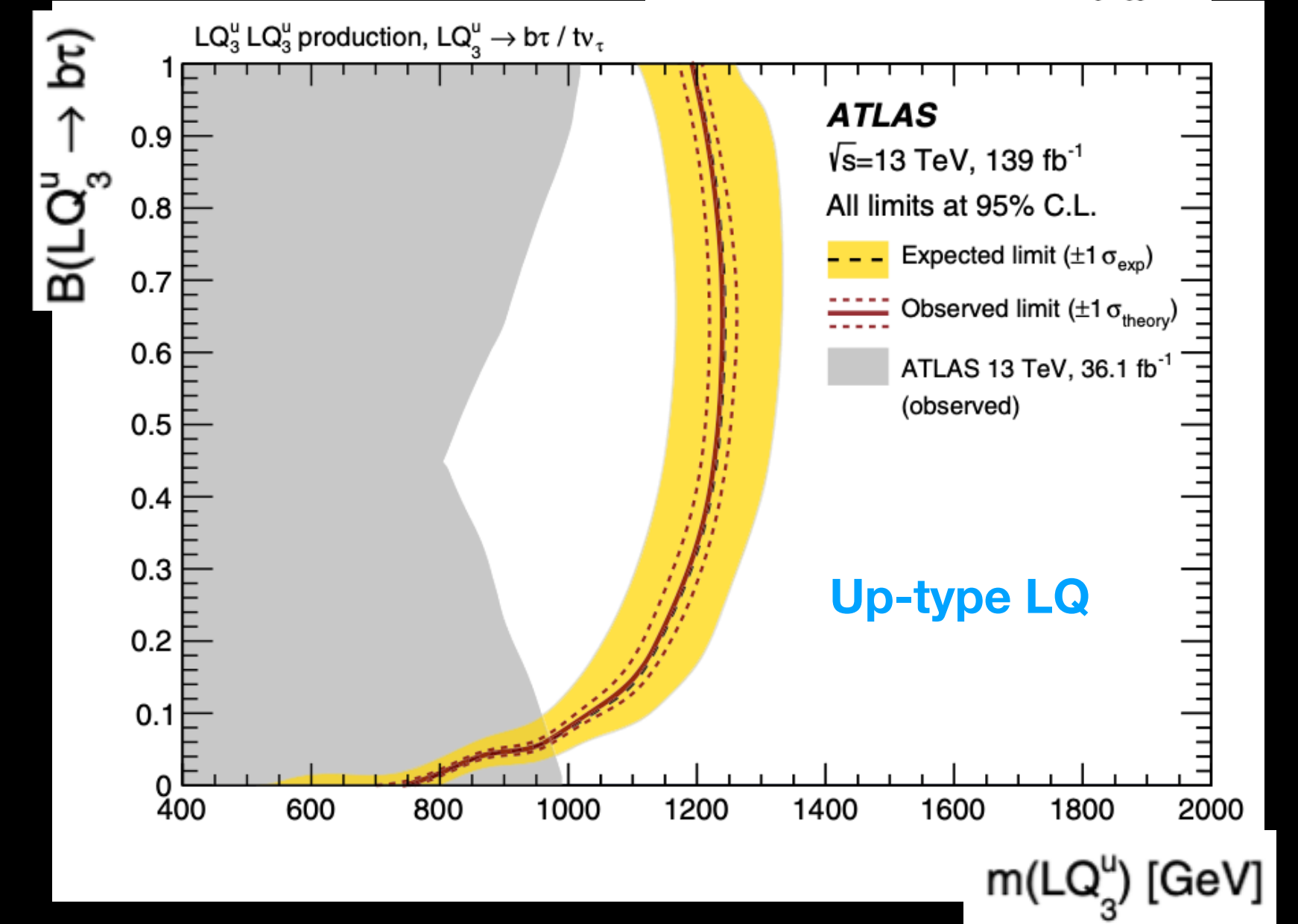
Interpretation:

Phys. Rev. D 104, 112005

★ Exclusion contours at the 95% confidence level for the stop-stau signal model



★ Exclusion contours at the 95% confidence level for the third generation scalar leptoquark model
 ★ Shown as a function of mass $m(LQ_3^{u/d})$ and the branching fraction $B(LQ_3^{u/d} \rightarrow ql)$.



SUSY searches with photon and E_T^{miss}

ATLAS-CONF-2021-028

- ★ Strong production of gluino pairs, decaying to photon, jets and E_T^{miss} .
- ★ The LSP is \tilde{G} , the Next to LSP is the $\tilde{\chi}_1^0$.

★ Background for this analysis:

	Real E_T^{miss}	Instrumental E_T^{miss}
Real photon	$Z(\nu\nu)\gamma, W\gamma, Z(\nu\nu)\gamma\gamma, t\bar{t}\gamma, W\gamma\gamma$	γ +jets, $\gamma\gamma, Z(l\bar{l}) + \gamma, Z(l\bar{l}) + \gamma\gamma$
Fake photon	W +jets, $Z(\nu\nu)$ +jets $t\bar{t}$	QCD multijets $Z(l\bar{l})$ +jets

★ Background with fake photons:

★ Data-driven fake rate

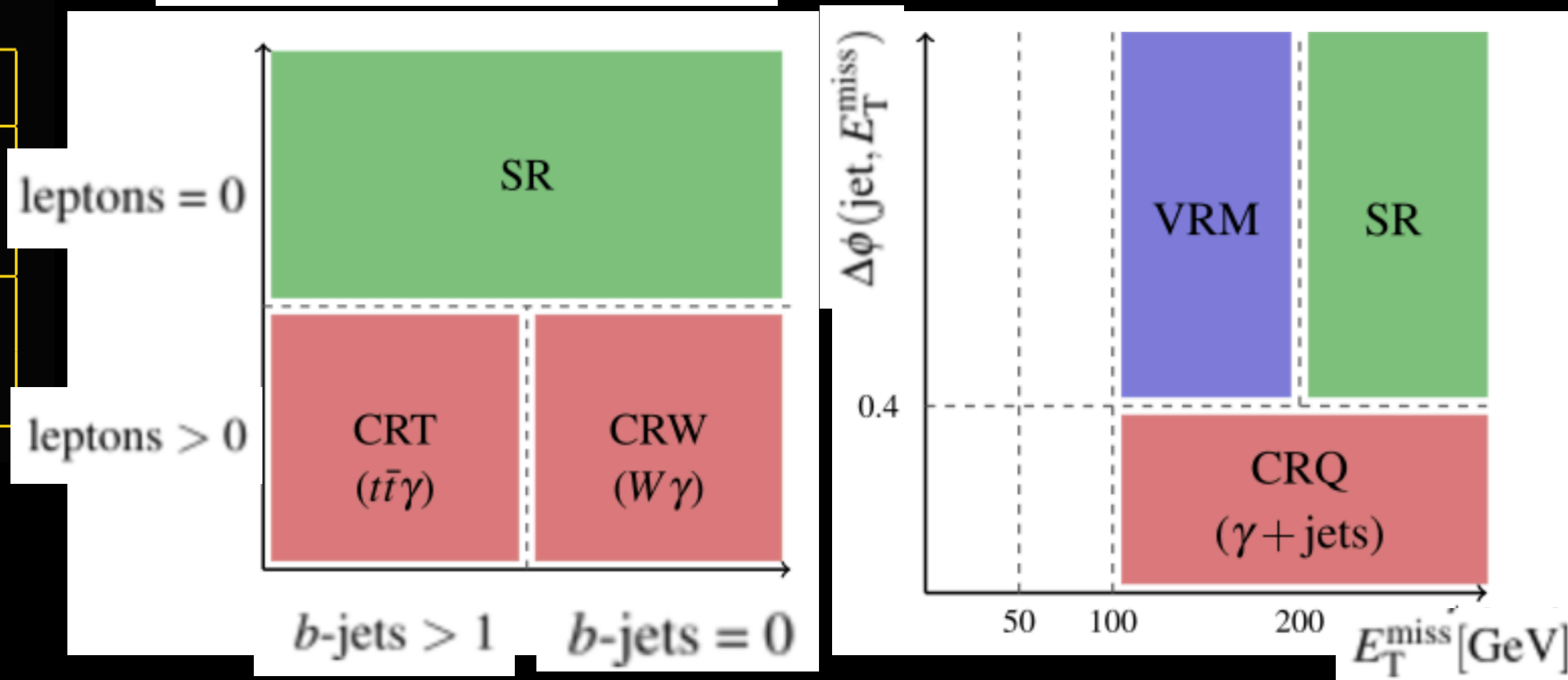
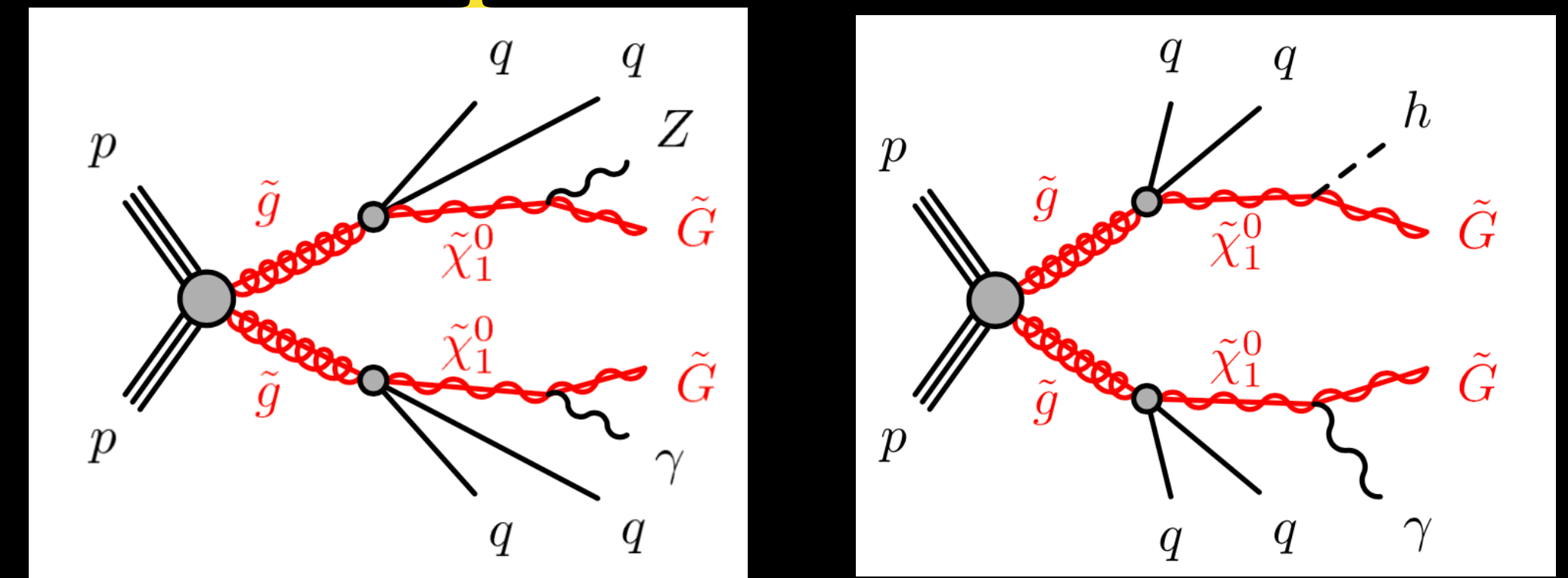
★ $e \rightarrow \gamma$ fakes

★ Based on data samples of $Z \rightarrow ee/e\gamma_{\text{fake}}$

★ The fake rate is determined as a function of p_T and η

★ $j \rightarrow \gamma$ fakes

★ Estimated using ABCD method in the photon ID/Isolation plane



★ Background with real photons:

★ Three control regions:

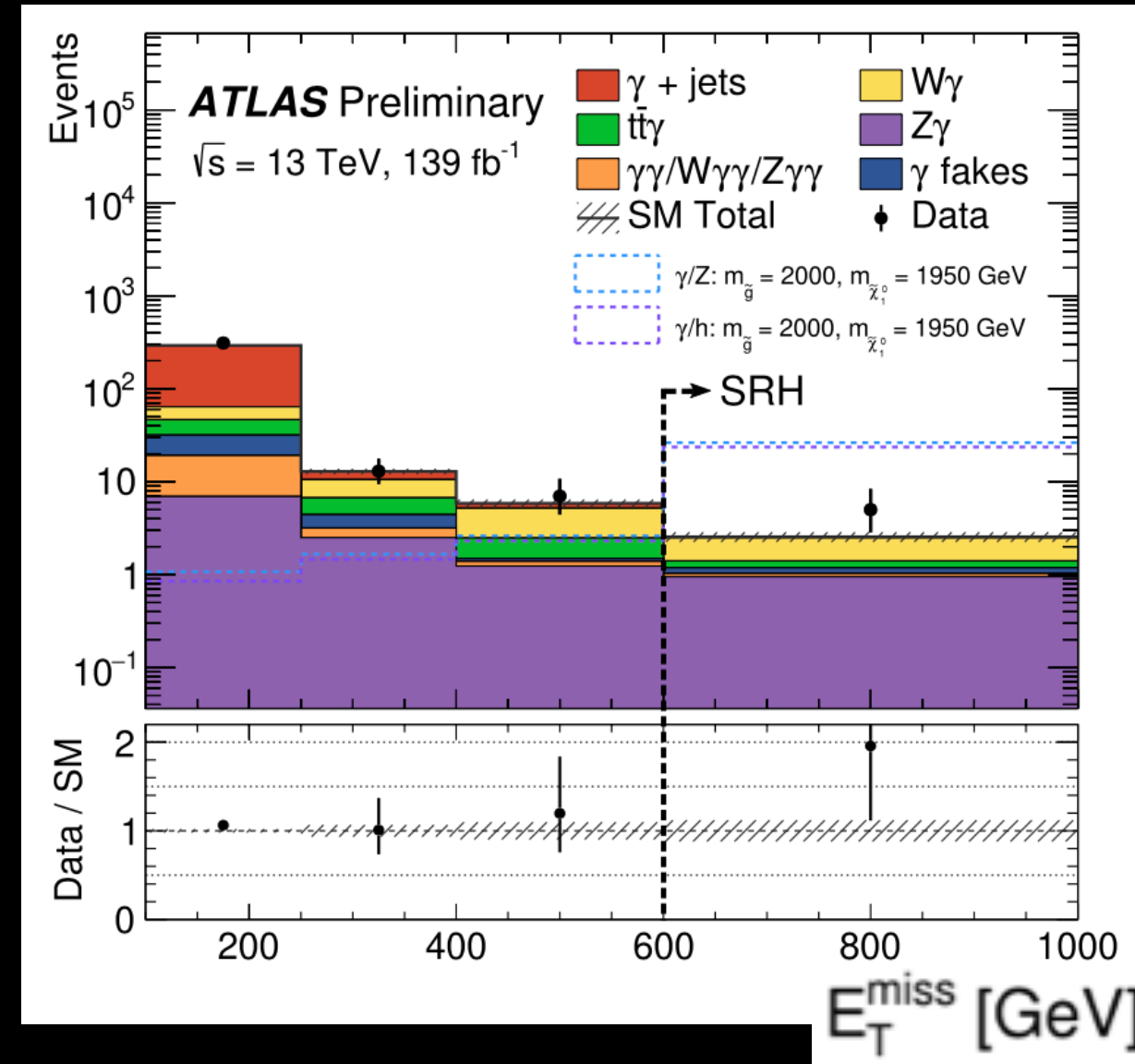
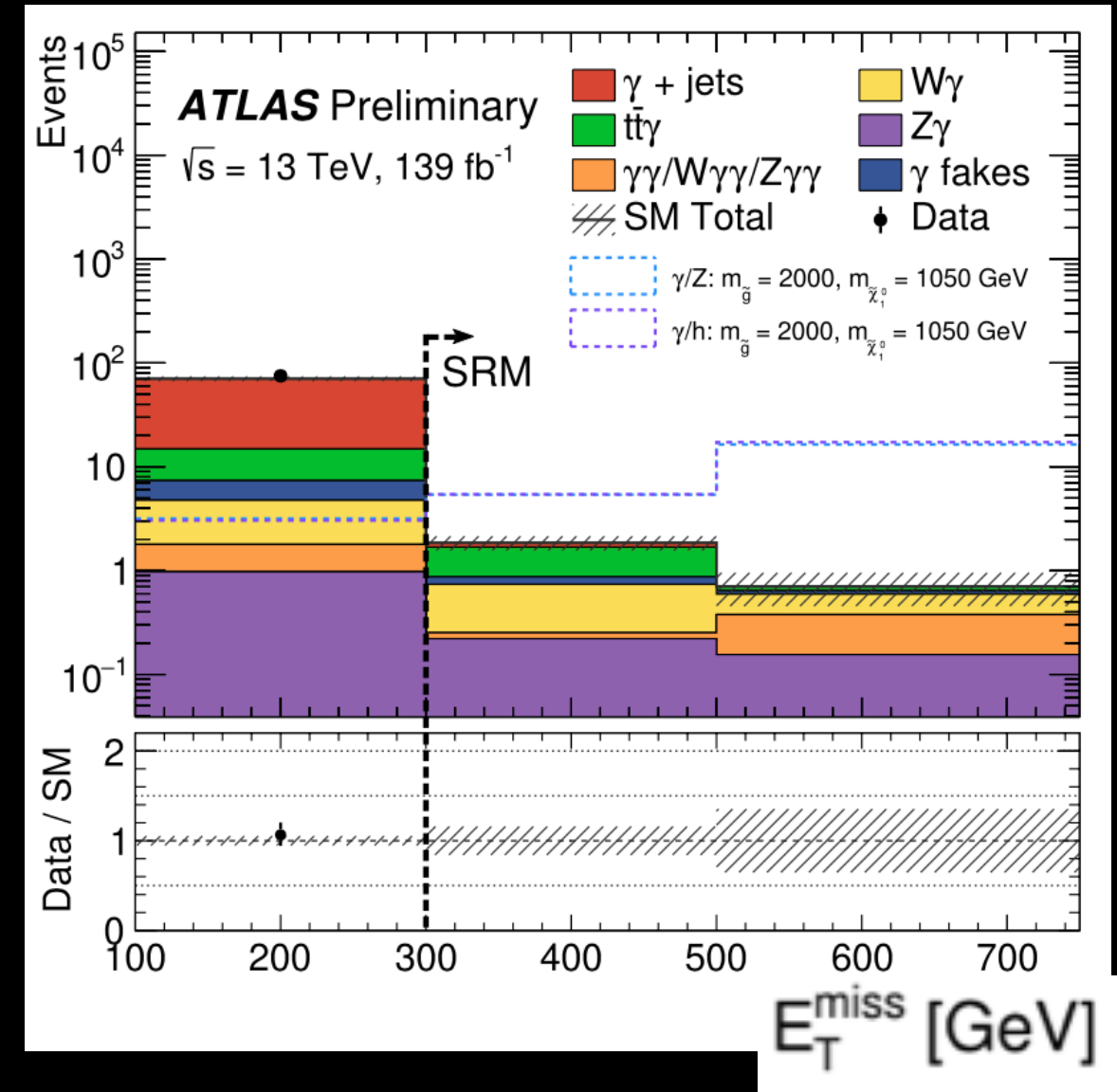
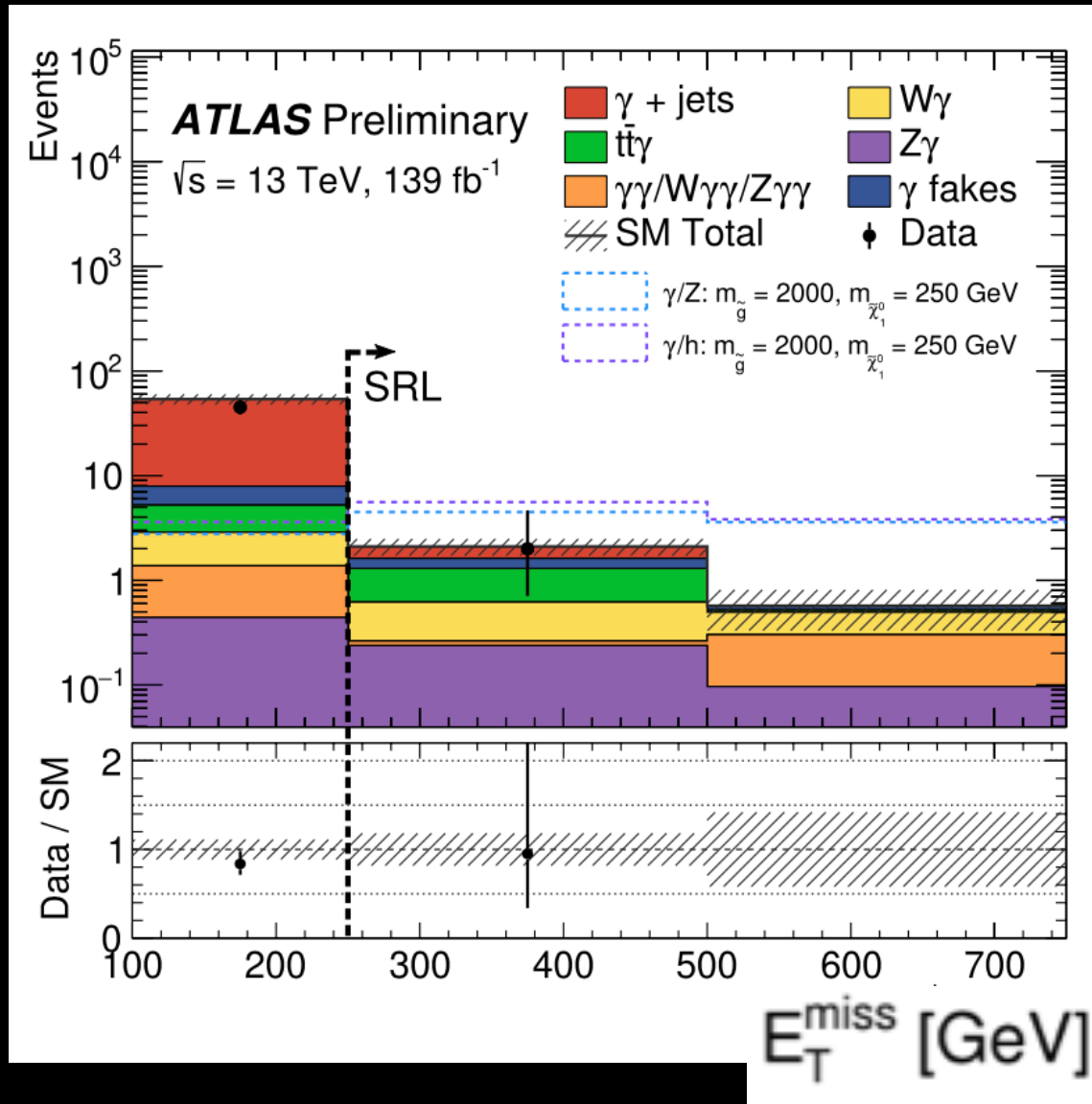
★ γ +jets constrained in CRQ

★ $W\gamma$ constrained in CRW

★ $t\bar{t}\gamma$ constrained in CRT

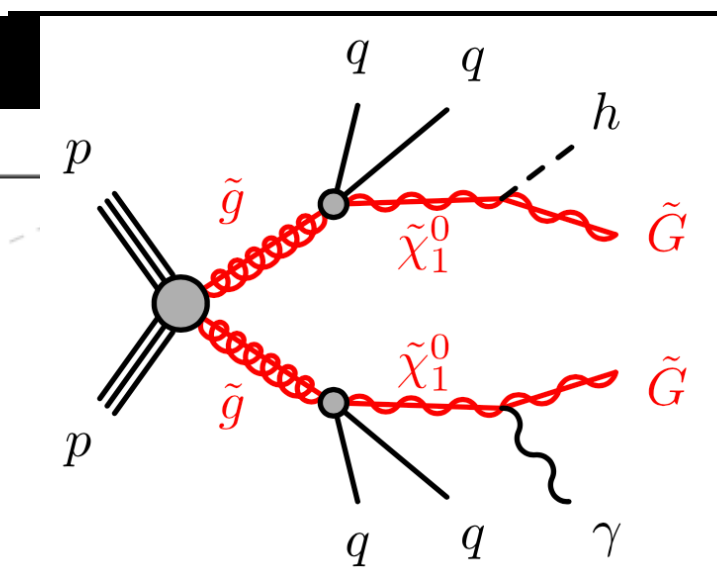
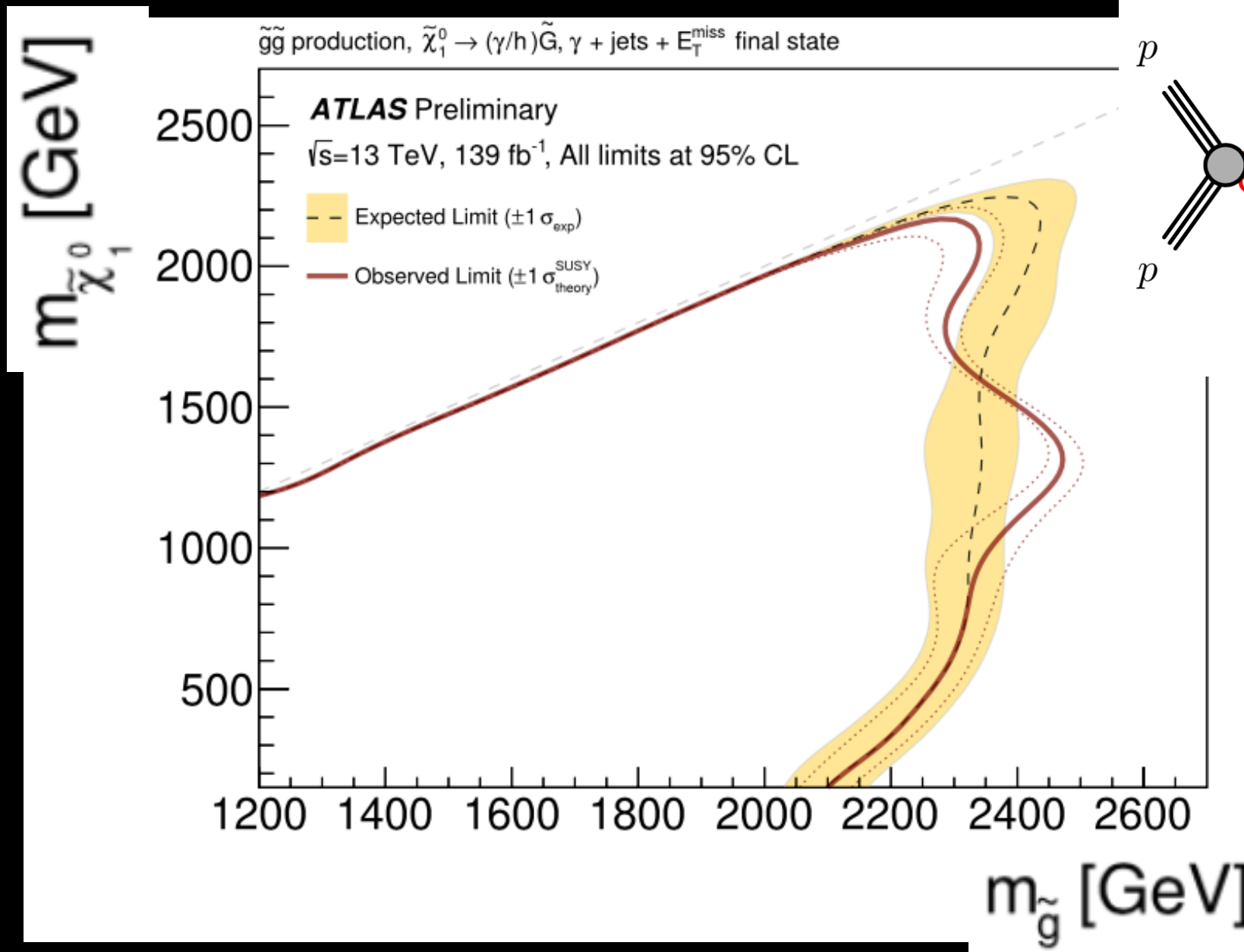
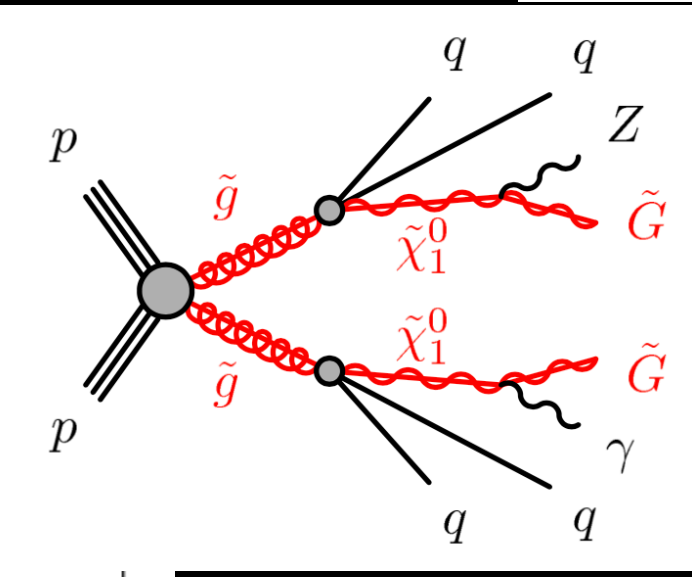
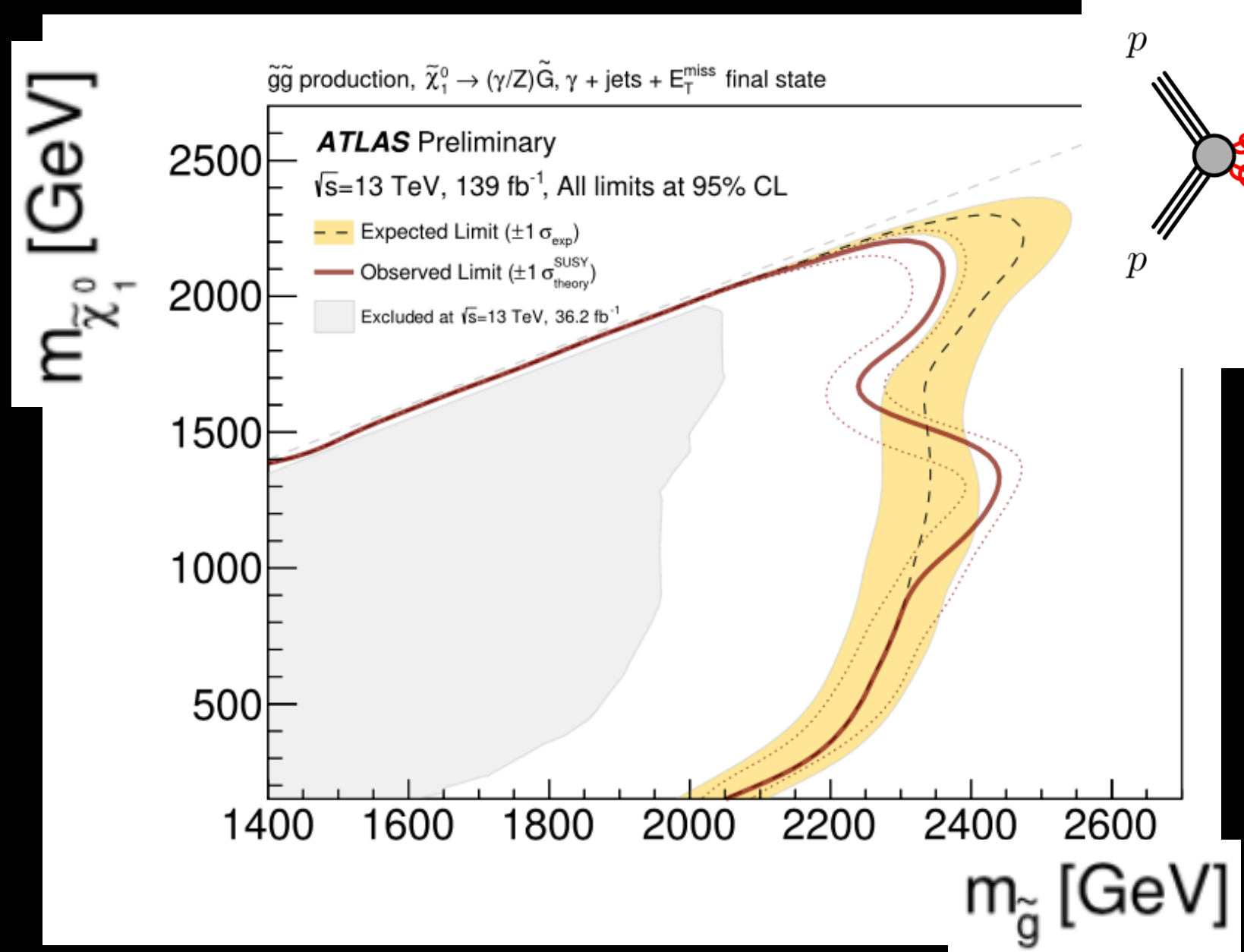
Results and interpretation

ATLAS-CONF-2021-028



★ No significant excess was observed

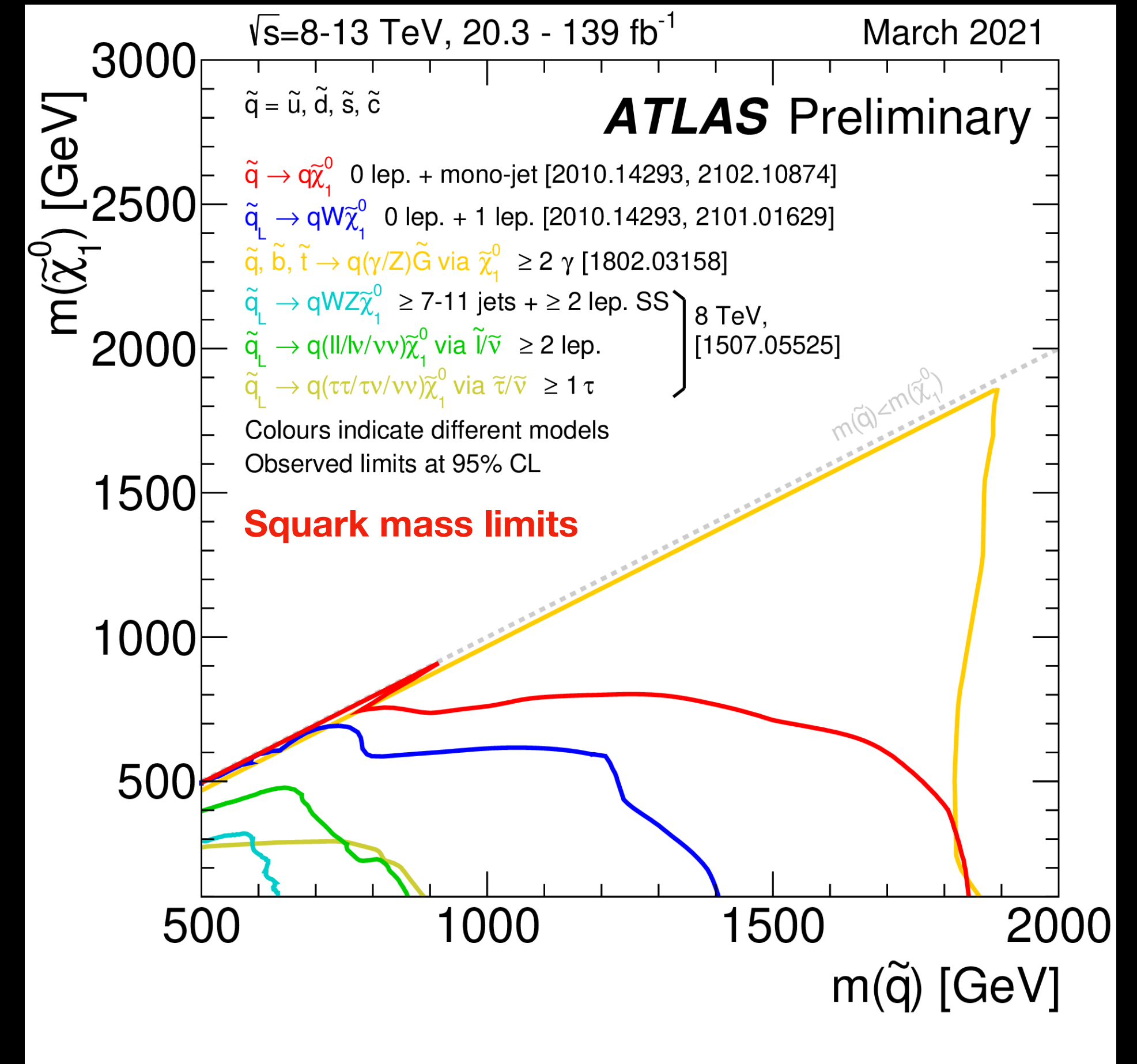
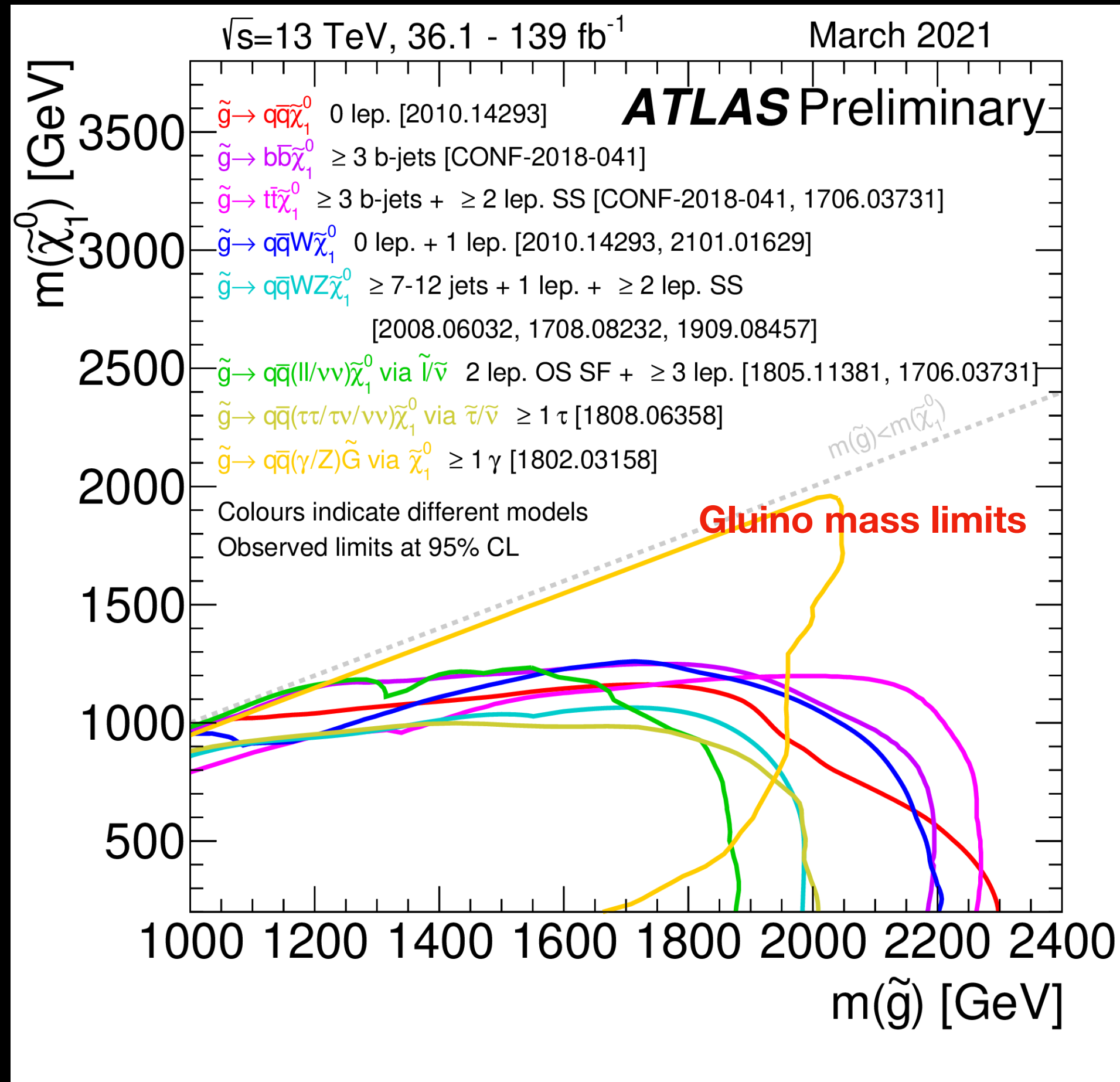
	SRL	SRM	SRH
Observed events	2	0	5
Expected SM events	2.67 ± 0.75	2.55 ± 0.64	2.55 ± 0.44
$t\bar{t}\gamma$	0.70 ± 0.18	0.87 ± 0.18	0.22 ± 0.05
$W\gamma$	0.55 ± 0.37	0.70 ± 0.42	1.08 ± 0.21
$\gamma + \text{jets}$	0.49 ± 0.29	0.17 ± 0.10	0.07 ± 0.01
$Z(\rightarrow \nu\nu)\gamma$	0.31 ± 0.11	0.35 ± 0.12	0.94 ± 0.28
$\gamma\gamma/W\gamma\gamma/Z\gamma\gamma$	0.23 ± 0.11	0.25 ± 0.10	0.08 ± 0.01
Fake photons from e	0.22 ± 0.08	0.04 ± 0.03	0.06 ± 0.04
Fake photons from jets	0.15 ± 0.09	0.14 ± 0.09	0.09 ± 0.07
$Z(\rightarrow \ell\ell)\gamma$	0.03 ± 0.03	0.03 ± 0.01	–



★ Interpretation on γh scenario
 ★ First limit in Run-2.

Conclusion

- ★ A brief overview of present SUSY searches from ATLAS experiment in strong production is shown here.
- ★ Very impressive and extensive search program.
- ★ There are plenty of analyses going on right now with Run-2 dataset (139 fb^{-1}).
- ★ Stay tuned for many interesting results.



Thank You

Bonus Slides

ATLAS SUSY Searches* - 95% CL Lower Limits

June 2021

ATLAS Preliminary

$\sqrt{s} = 13$ TeV

Summary of mass limits from ATLAS for all production mode

Model	Signature	$\int \mathcal{L} dt$ [fb ⁻¹]	Mass limit	Reference				
Inclusive Searches	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$	0 e, μ mono-jet	2-6 jets 1-3 jets	E_T^{miss} E_T^{miss}	139 36.1	\tilde{q} [1x, 8x Degen.] 1.0 1.85 \tilde{q} [8x Degen.] 0.9	$m(\tilde{\chi}_1^0) < 400$ GeV $m(\tilde{q}) - m(\tilde{\chi}_1^0) = 5$ GeV	2010.14293 2102.10874
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0$	0 e, μ	2-6 jets	E_T^{miss}	139	\tilde{g} 2.3 \tilde{g} Forbidden 1.15-1.95	$m(\tilde{\chi}_1^0) = 0$ GeV $m(\tilde{\chi}_1^0) = 1000$ GeV	2010.14293 2010.14293
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}W\tilde{\chi}_1^0$	1 e, μ	2-6 jets		139	\tilde{g} 2.2	$m(\tilde{\chi}_1^0) < 600$ GeV	2101.01629
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}(\ell\ell)\tilde{\chi}_1^0$	$ee, \mu\mu$	2 jets	E_T^{miss}	36.1	\tilde{g} 1.2	$m(\tilde{g}) - m(\tilde{\chi}_1^0) = 50$ GeV	1805.11381
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qqWZ\tilde{\chi}_1^0$	0 e, μ	7-11 jets	E_T^{miss}	139	\tilde{g} 1.97	$m(\tilde{\chi}_1^0) < 600$ GeV	2008.06032
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qqWZ\tilde{\chi}_1^0$	SS e, μ	6 jets	E_T^{miss}	139	\tilde{g} 1.15	$m(\tilde{g}) - m(\tilde{\chi}_1^0) = 200$ GeV	1909.08457
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\tilde{\chi}_1^0$	0-1 e, μ SS e, μ	3 b 6 jets	E_T^{miss}	79.8 139	\tilde{g} 2.25 \tilde{g} 1.25	$m(\tilde{\chi}_1^0) < 200$ GeV $m(\tilde{g}) - m(\tilde{\chi}_1^0) = 300$ GeV	ATLAS-CONF-2018-041 1909.08457
3 rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$	0 e, μ	2 b	E_T^{miss}	139	\tilde{b}_1 1.255 \tilde{b}_1 0.68	$m(\tilde{\chi}_1^0) < 400$ GeV 10 GeV $< \Delta m(\tilde{b}_1, \tilde{\chi}_1^0) < 20$ GeV	2101.12527 2101.12527
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_2^0 \rightarrow bh\tilde{\chi}_1^0$	0 e, μ 2 τ	6 b 2 b	E_T^{miss} E_T^{miss}	139 139	\tilde{b}_1 Forbidden 0.23-1.35 \tilde{b}_1 0.13-0.85	$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130$ GeV, $m(\tilde{\chi}_1^0) = 100$ GeV $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130$ GeV, $m(\tilde{\chi}_1^0) = 0$ GeV	1908.03122 ATLAS-CONF-2020-031
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	0-1 e, μ	≥ 1 jet	E_T^{miss}	139	\tilde{t}_1 1.25	$m(\tilde{\chi}_1^0) = 1$ GeV	2004.14060, 2012.03799
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$	1 e, μ	3 jets/1 b	E_T^{miss}	139	\tilde{t}_1 Forbidden 0.65	$m(\tilde{\chi}_1^0) = 500$ GeV	2012.03799
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{\tau}_1 b\nu, \tilde{\tau}_1 \rightarrow \tau\tilde{G}$	1-2 τ	2 jets/1 b	E_T^{miss}	139	\tilde{t}_1 Forbidden 1.4	$m(\tilde{\tau}_1) = 800$ GeV	ATLAS-CONF-2021-008
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 / \tilde{c}\tilde{c}, \tilde{c} \rightarrow c\tilde{\chi}_1^0$	0 e, μ 0 e, μ	2 c mono-jet	E_T^{miss} E_T^{miss}	36.1 139	\tilde{c} 0.85 \tilde{t}_1 0.55	$m(\tilde{\chi}_1^0) = 0$ GeV $m(\tilde{t}_1, \tilde{c}) - m(\tilde{\chi}_1^0) = 5$ GeV	1805.01649 2102.10874
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z/h\tilde{\chi}_1^0$	1-2 e, μ	1-4 b	E_T^{miss}	139	\tilde{t}_1 0.067-1.18	$m(\tilde{\chi}_2^0) = 500$ GeV	2006.05880
$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 e, μ	1 b	E_T^{miss}	139	\tilde{t}_2 Forbidden 0.86	$m(\tilde{\chi}_1^0) = 360$ GeV, $m(\tilde{t}_1) - m(\tilde{\chi}_1^0) = 40$ GeV	2006.05880	
EW direct	$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via WZ	Multiple ℓ /jets $ee, \mu\mu$	≥ 1 jet	E_T^{miss} E_T^{miss}	139 139	$\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$ 0.96 $\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$ 0.205	$m(\tilde{\chi}_1^0) = 0$, wino-bino $m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0) = 5$ GeV, wino-bino	2106.01676, ATLAS-CONF-2021-022 1911.12606
	$\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$ via WW	2 e, μ		E_T^{miss}	139	$\tilde{\chi}_1^\pm$ 0.42	$m(\tilde{\chi}_1^0) = 0$, wino-bino	1908.08215
	$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via Wh	Multiple ℓ /jets		E_T^{miss}	139	$\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$ Forbidden 1.06	$m(\tilde{\chi}_1^0) = 70$ GeV, wino-bino	2004.10894, ATLAS-CONF-2021-022
	$\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$ via $\tilde{\ell}_L/\tilde{\nu}$	2 e, μ		E_T^{miss}	139	$\tilde{\chi}_1^\pm$ 1.0	$m(\tilde{\ell}, \tilde{\nu}) = 0.5(m(\tilde{\chi}_1^\pm) + m(\tilde{\chi}_1^0))$	1908.08215
	$\tilde{\tau}\tilde{\tau}, \tilde{\tau} \rightarrow \tau\tilde{\chi}_1^0$	2 τ		E_T^{miss}	139	$\tilde{\tau}$ [$\tilde{\tau}_L, \tilde{\tau}_{R,L}$] 0.16-0.3 0.12-0.39	$m(\tilde{\chi}_1^0) = 0$	1911.06660
	$\tilde{\ell}_{L,R} \tilde{\ell}_{L,R}, \tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0$	2 e, μ $ee, \mu\mu$	0 jets ≥ 1 jet	E_T^{miss} E_T^{miss}	139 139	$\tilde{\ell}$ 0.7 $\tilde{\ell}$ 0.256	$m(\tilde{\chi}_1^0) = 0$ $m(\tilde{\ell}) - m(\tilde{\chi}_1^0) = 10$ GeV	1908.08215 1911.12606
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}/Z\tilde{G}$	0 e, μ 4 e, μ 0 e, μ	≥ 3 b 0 jets ≥ 2 large jets	E_T^{miss} E_T^{miss} E_T^{miss}	36.1 139 139	\tilde{H} 0.13-0.23 0.29-0.88 \tilde{H} 0.55 \tilde{H} 0.45-0.93	$BR(\tilde{\chi}_1^0 \rightarrow h\tilde{G}) = 1$ $BR(\tilde{\chi}_1^0 \rightarrow Z\tilde{G}) = 1$ $BR(\tilde{\chi}_1^0 \rightarrow Z\tilde{G}) = 1$	1806.04030 2103.11684 ATLAS-CONF-2021-022
Long-lived particles	Direct $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	E_T^{miss}	139	$\tilde{\chi}_1^\pm$ 0.66 $\tilde{\chi}_1^\pm$ 0.21	Pure Wino Pure higgsino	ATLAS-CONF-2021-015 ATLAS-CONF-2021-015
	Stable \tilde{g} R-hadron		Multiple		36.1	\tilde{g} 2.0		1902.01636, 1808.04095
	Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow qq\tilde{\chi}_1^0$		Multiple		36.1	\tilde{g} [$\tau(\tilde{g}) = 10$ ns, 0.2 ns] 2.05 2.4	$m(\tilde{\chi}_1^0) = 100$ GeV	1710.04901, 1808.04095
	$\tilde{\ell}\tilde{\ell}, \tilde{\ell} \rightarrow \ell\tilde{G}$	Displ. lep		E_T^{miss}	139	$\tilde{\ell}, \tilde{\mu}$ 0.7 $\tilde{\tau}$ 0.34	$\tau(\tilde{\ell}) = 0.1$ ns $\tau(\tilde{\ell}) = 0.1$ ns	2011.07812 2011.07812
RPV	$\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp / \tilde{\chi}_1^0, \tilde{\chi}_1^\pm \rightarrow Z\ell \rightarrow \ell\ell\ell$	3 e, μ			139	$\tilde{\chi}_1^\pm / \tilde{\chi}_1^0$ [BR(Z τ)=1, BR(Z e)=1] 0.625 1.05	Pure Wino	2011.10543
	$\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp / \tilde{\chi}_2^0 \rightarrow WW/Z\ell\ell\ell\nu\nu$	4 e, μ	0 jets	E_T^{miss}	139	$\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$ [$\lambda_{33} \neq 0, \lambda_{12k} \neq 0$] 0.95 1.55	$m(\tilde{\chi}_1^0) = 200$ GeV	2103.11684
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qq\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow qq\tilde{q}$		4-5 large jets		36.1	\tilde{g} [$m(\tilde{\chi}_1^0) = 200$ GeV, 1100 GeV] 1.3 1.9	Large λ'_{12}	1804.03568
	$\tilde{t}\tilde{t}, \tilde{t} \rightarrow t\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow tbs$		Multiple		36.1	\tilde{t} [$\lambda'_{323} = 2e-4, 1e-2$] 0.55 1.05	$m(\tilde{\chi}_1^0) = 200$ GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}, \tilde{t} \rightarrow b\tilde{\chi}_1^\pm, \tilde{\chi}_1^\pm \rightarrow bbs$		$\geq 4b$		139	\tilde{t} Forbidden 0.95	$m(\tilde{\chi}_1^0) = 500$ GeV	2010.01015
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow bs$		2 jets + 2 b		36.7	\tilde{t}_1 [qq, bs] 0.42 0.61		1710.07171
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow q\ell$	2 e, μ 1 μ	2 b DV		36.1 136	\tilde{t}_1 0.4-1.45 \tilde{t}_1 [$1e-10 < \lambda'_{23k} < 1e-8, 3e-10 < \lambda'_{23k} < 3e-9$] 1.0 1.6	$BR(\tilde{t}_1 \rightarrow be/b\mu) > 20\%$ $BR(\tilde{t}_1 \rightarrow q\mu) = 100\%, \cos\theta_t = 1$	1710.05544 2003.11956
$\tilde{\chi}_1^\pm / \tilde{\chi}_2^0 / \tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow tbs, \tilde{\chi}_1^\pm \rightarrow bbs$	1-2 e, μ	≥ 6 jets		139	$\tilde{\chi}_1^0$ 0.2-0.32	Pure higgsino	ATLAS-CONF-2021-007	

*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.

10⁻¹ 1 Mass scale [TeV]

Two leptons and two jets:

SUSY-2018-05

$$m_T^2(\vec{p}_{T,a}, \vec{p}_T^{\text{miss}}) = 2 \times (p_{T,a} \times E_T^{\text{miss}} - \vec{p}_{T,a} \cdot \vec{p}_T^{\text{miss}}),$$

$$m_{T2}^2 = \min_{\vec{x}_{T,1} + \vec{x}_{T,2} = \vec{p}_T^{\text{miss}}} [\max\{m_T^2(\vec{p}_{T1}, \vec{x}_{T,1}), m_T^2(\vec{p}_{T2}, \vec{x}_{T,2})\}],$$

Year	Type	Trigger	Comment
2015	ee	HLT_2e12_lhloose_L12EM10VH	
2015	$\mu\mu$	HLT_2mu10	
2015	$\mu\mu$	HLT_mu18_mu8noL1	
2015	$e\mu$	HLT_e17_lhloose_mu14	
2015	$e\mu$	HLT_e7_lhmedium_mu24	
2016	ee	HLT_2e15_lhvloose_nod0_L12EM13VH	except run 300540
2016	ee	HLT_2e17_lhvloose_nod0	run 300540 and from period D4
2016	$\mu\mu$	HLT_2mu10	period A
2016	$\mu\mu$	HLT_2mu14	from period B
2016	$\mu\mu$	HLT_mu20_mu8noL1	periods A-D3
2016	$\mu\mu$	HLT_mu22_mu8noL1	periods from D4
2016	$e\mu$	HLT_e17_lhloose_nod0_mu14	
2016	$e\mu$	HLT_e24_lhmedium_nod0_L1EM20VHI_mu8noL1	
2016	$e\mu$	HLT_e7_lhmedium_nod0_mu24	
2017	ee	HLT_2e17_lhvloose_nod0_L12EM15VHI	except periods B5-B8
2017	ee	HLT_2e24_lhvloose_nod0	
2017	$\mu\mu$	HLT_2mu14	
2017	$\mu\mu$	HLT_mu22_mu8noL1	
2017	$e\mu$	HLT_e17_lhloose_nod0_mu14	
2017	$e\mu$	HLT_e26_lhmedium_nod0_mu8noL1	
2017	$e\mu$	HLT_e7_lhmedium_nod0_mu24	
2018	ee	HLT_2e17_lhvloose_nod0_L12EM15VHI	
2018	ee	HLT_2e24_lhvloose_nod0	
2018	$\mu\mu$	HLT_2mu14	
2018	$\mu\mu$	HLT_mu22_mu8noL1	
2018	$e\mu$	HLT_e17_lhloose_nod0_mu14	
2018	$e\mu$	HLT_e26_lhmedium_nod0_mu8noL1	
2018	$e\mu$	HLT_e7_lhmedium_nod0_mu24	

Preselection	Lepton triggers						
Preselection	Lepton $p_T > 25$ GeV; == 2 leptons (baseline & signal) SF-OS						
Preselection	$m_{\ell\ell} > 12$ GeV						
Preselection	$p_T^{\ell\ell} > 40$ GeV						
Preselection	Jet $p_T > 30$ GeV; ≥ 2 jets						
Preselection	$\Delta\phi(\text{jet}_{1,2}, E_T^{\text{miss}}) > 0.4$						
Region	N_{jets}	H_T	E_T^{miss}	m_{T2}	$E_T^{\text{miss, sig}}$	$p_T^{\ell\ell}$	$m_{\ell\ell}$
SRC	-	> 250	> 250	> 90	> 10	< 100	-
SRLow	-	> 250	> 250	> 100	-	< 500	-
SRZLow	≥ 4	> 250	> 250	> 100	-	< 500	$81 < m_{\ell\ell} < 101^*$
SRMed	-	> 500	> 300	> 75	-	< 800	-
SRZMed	≥ 4	> 500	> 300	> 75	-	< 800	$81 < m_{\ell\ell} < 101^*$
SRHigh	-	> 800	> 300	> 75	-	-	-
SRZHigh	≥ 4	> 800	> 300	> 75	-	-	$81 < m_{\ell\ell} < 101^*$

Region	n_{jets}	H_T [GeV]	E_T^{miss} [GeV]	m_{T2} [GeV]	$S(E_T^{\text{miss}})$	$p_T^{\ell\ell}$ [GeV]	$\Delta\phi(\text{jet}_{1,2}, p_T^{\text{miss}})$	SF/DF	$m_{\ell\ell}$ [GeV]
Signal regions									
SRC	≥ 2	> 250	> 250	> 90	> 10	40-100	> 0.4	SF	> 12
SRLow	≥ 2	> 250	> 250	> 100	-	40-500	> 0.4	SF	> 12
\leftrightarrow SRZLow	≥ 4	> 250	> 250	> 100	-	40-500	> 0.4	SF	81-101
SRMed	≥ 2	> 500	> 300	> 75	-	40-800	> 0.4	SF	> 12
\leftrightarrow SRZMed	≥ 4	> 500	> 300	> 75	-	40-800	> 0.4	SF	81-101
SRHigh	≥ 2	> 800	> 300	> 75	-	> 40	> 0.4	SF	> 12
\leftrightarrow SRZHigh	≥ 4	> 800	> 300	> 75	-	> 40	> 0.4	SF	81-101

Two leptons and two jets: Flavor symmetry

$$N^{\text{est}} = \frac{1}{2} \cdot \left[\sum_i^{N_{e\mu}^{\text{data}}} \left(k_e(p_T^{i,\mu}, \eta^{i,\mu}) + k_\mu(p_T^{i,e}, \eta^{i,e}) \right) \cdot \alpha(p_T^{i,\ell_1}, \eta^{i,\ell_1}) \right. \\ \left. - \sum_i^{N_{e\mu}^{\text{MC}}} \left(k_e(p_T^{i,\mu}, \eta^{i,\mu}) + k_\mu(p_T^{i,e}, \eta^{i,e}) \right) \cdot \alpha(p_T^{i,\ell_1}, \eta^{i,\ell_1}) \right],$$

Electron vs Muon eff

ee/mm vs em trigger eff

- Corrections evaluated in a loose 2L2J region with data
- Non-FS processes subtracted off via MC

Uncertainties

- Statistics
- Non-closure tests in loose regions and SRs
 - 10% non closure syst.

Two leptons and two jets: Matrix method

- $N_{\text{pass}}^{\text{FNP}} = \frac{N_{\text{fail}} - (1/\epsilon_{\text{real}} - 1) \times N_{\text{pass}}}{1/\epsilon_{\text{FNP}} - 1/\epsilon_{\text{real}}}$
- Here ϵ_{real} is the efficiency for a real prompt lepton to pass the single lepton requirement and ϵ_{FNP} are the same for FNP leptons.
- ϵ_{real} obtained from MC, ϵ_{FNP} obtained from data using tag-and-probe method.

The Matrix Method (MM)

For event with two leptons the following matrix is used to estimate the **fake leptons** and **leptons from non-prompt sources** (FNP background)

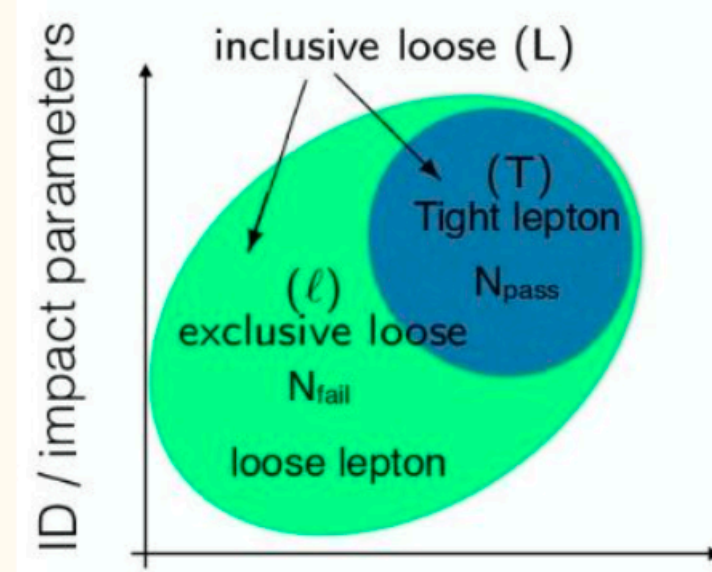
$$\begin{bmatrix} N_{TT} \\ N_{Tl} \\ N_{lT} \\ N_{ll} \end{bmatrix} = \begin{bmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1 (1 - r_2) & r_1 (1 - f_2) & f_1 (1 - r_2) & f_1 (1 - f_2) \\ (1 - r_1) r_2 & (1 - r_1) f_2 & (1 - f_1) r_2 & (1 - f_1) f_2 \\ (1 - r_1) (1 - r_2) & (1 - r_1) (1 - f_2) & (1 - f_1) (1 - r_2) & (1 - f_1) (1 - f_2) \end{bmatrix} \begin{bmatrix} N_{LL}^{RR} \\ N_{LL}^{RF} \\ N_{LL}^{FR} \\ N_{LL}^{FF} \end{bmatrix}$$

The measured number of events with two tight (TT), one tight and one loose (Tl, lT) and two loose (ll) leptons in the region of interest (i.e CR, VR, SR)

Notation:

The 1 and 2 subscripts refer to the two leptons (sorted after p_T)

T: lepton passes tight, **L**: lepton passes loose, **l**: lepton passes loose, but not tight



The final yields:

$$\begin{aligned} N_{TT}^{RR} &= r_1 r_2 N_{LL}^{RR} && \text{The real lepton background (from MC or other techniques)} \\ N_{TT}^{RF} &= r_1 f_2 N_{LL}^{RF} \\ N_{TT}^{FR} &= f_1 r_2 N_{LL}^{FR} && \text{The FNP background} \\ N_{TT}^{FF} &= f_1 f_2 N_{LL}^{FF} \end{aligned}$$

Stop-Stau Search

SUSY-2019-018

Di-tau preselection	Single-tau preselection
E_T^{miss} -trigger fired and $E_T^{\text{miss}} > 250$ GeV No light leptons (e/μ) At least two jets	
At least two hadronic tau leptons At least one b -tagged jet	Exactly one hadronic tau lepton At least two b -tagged jets

Variable	CR $t\bar{t}$ (2 real τ)	CR $t\bar{t}$ (1 real τ)	VR $t\bar{t}$ (2 real τ)	VR $t\bar{t}$ (1 real τ)	SR
E_T^{miss}	—	—	—	—	> 280 GeV
$OS(\tau_1, \tau_2)$	1	—	1	—	1
$m_{T2}(\tau_1, \tau_2)$	< 35 GeV	< 35 GeV	$[35, 70]$ GeV	$[35, 70]$ GeV	> 70 GeV
$m_{\text{vis}}(\tau_1, \tau_2)$	> 50 GeV	> 50 GeV	—	—	—
$m_T(\tau_1)$	> 50 GeV	< 50 GeV	> 70 GeV	< 70 GeV	—

Stop-Stau Search

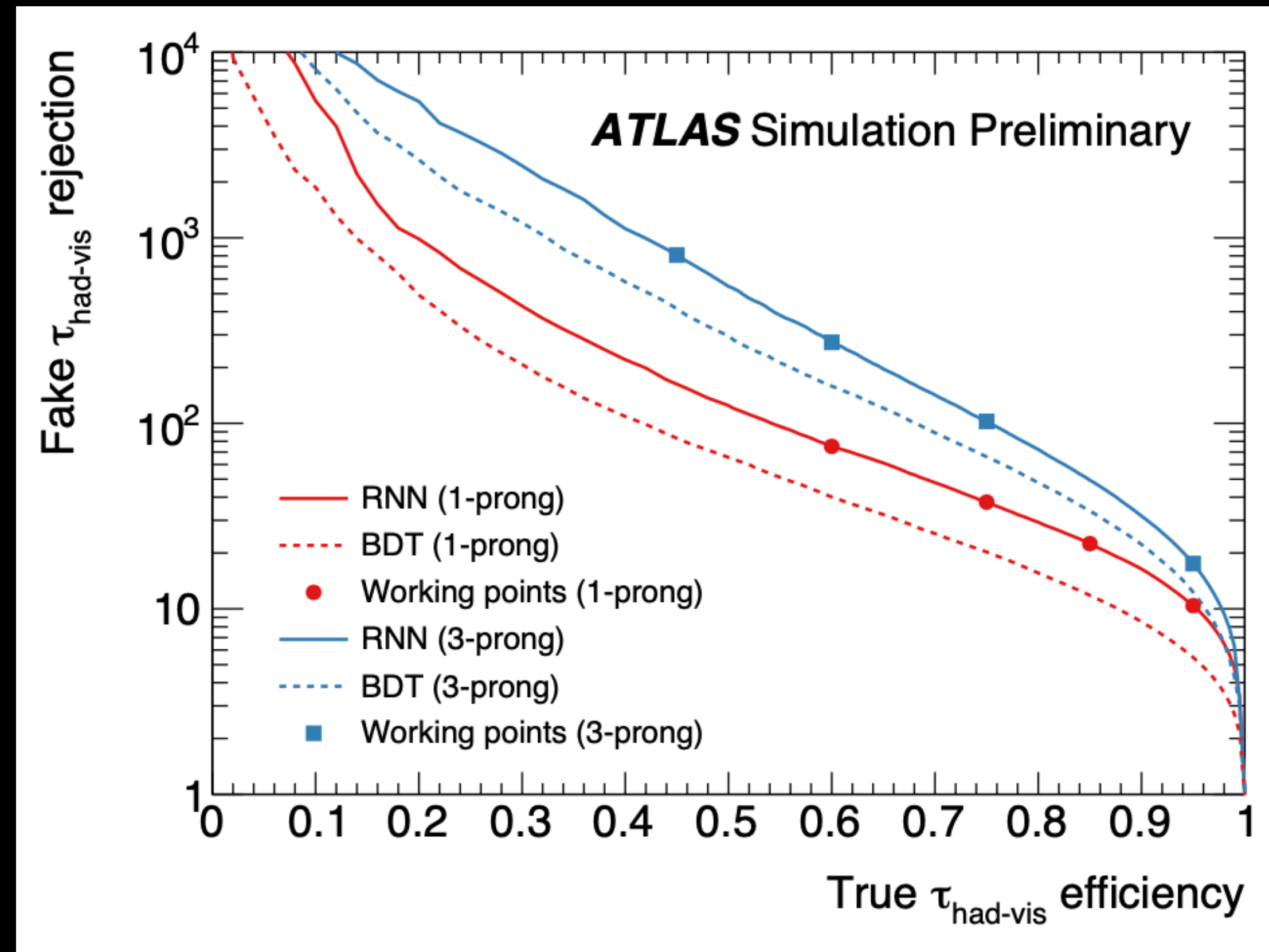
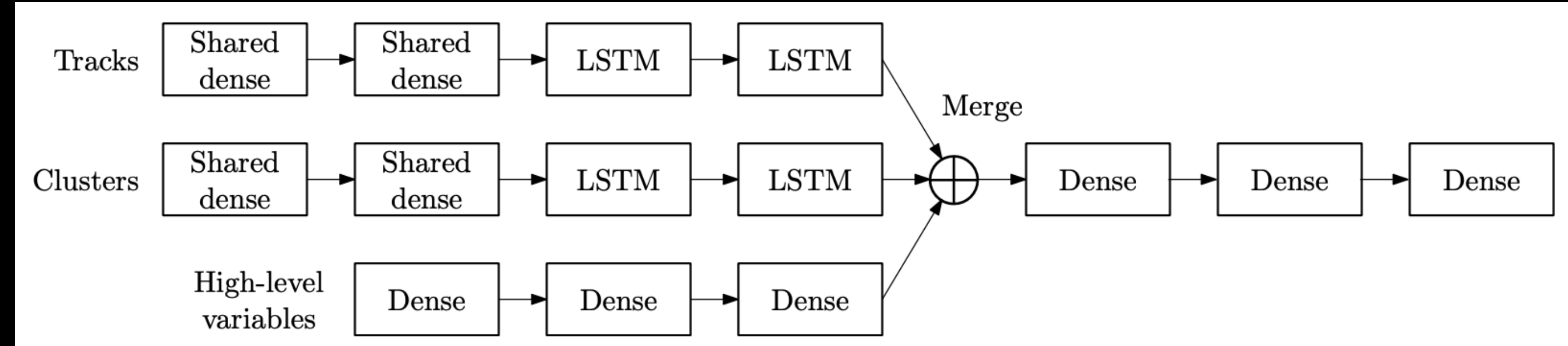
Variable	CR $t\bar{t}$ (1 real τ)	CR single top	VR $t\bar{t}$ (1 real τ)	VR single top	SR
E_T^{miss}	> 280 GeV	> 280 GeV	> 280 GeV	> 280 GeV	> 280 GeV
s_T	[500, 600] GeV	—	> 600 GeV	—	$> 800(600)$ GeV
$\sum m_T(b_{1,2})$	[600, 700] GeV	> 800 GeV	[600, 700] GeV	> 800 GeV	> 700 GeV
$m_T(\tau)$	—	< 50 GeV	—	[50, 150] GeV	$> 300(150)$ GeV
$p_T(\tau)$	—	> 80 GeV	—	> 80 GeV	— (binned)

Systematic uncertainty	Di-tau SR	Single-tau one-bin SR	Single-tau multi-bin SR
Total	25%	17%	17%
Jet-related	19%	4.2%	3.9%
Tau-related	4.7%	5.5%	4.3%
Other experimental	3.7%	1.0%	0.8%
Theoretical modeling	13%	17%	19%
MC statistics	12%	7.5%	4.4%
Normalization factors	8.8%	15%	16%
Luminosity	0.8%	0.5%	0.4%

Stop-Stau: τ RNN

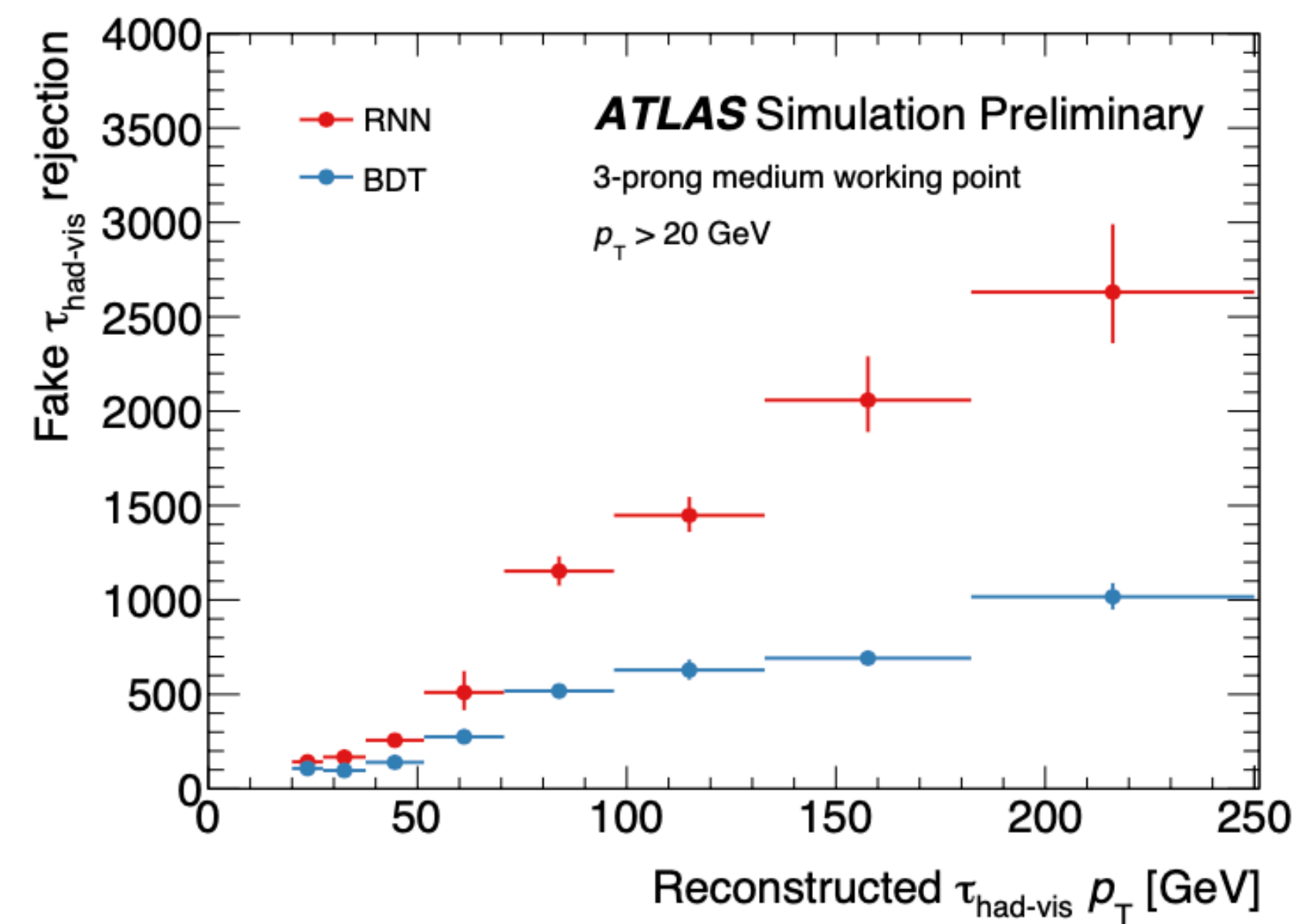
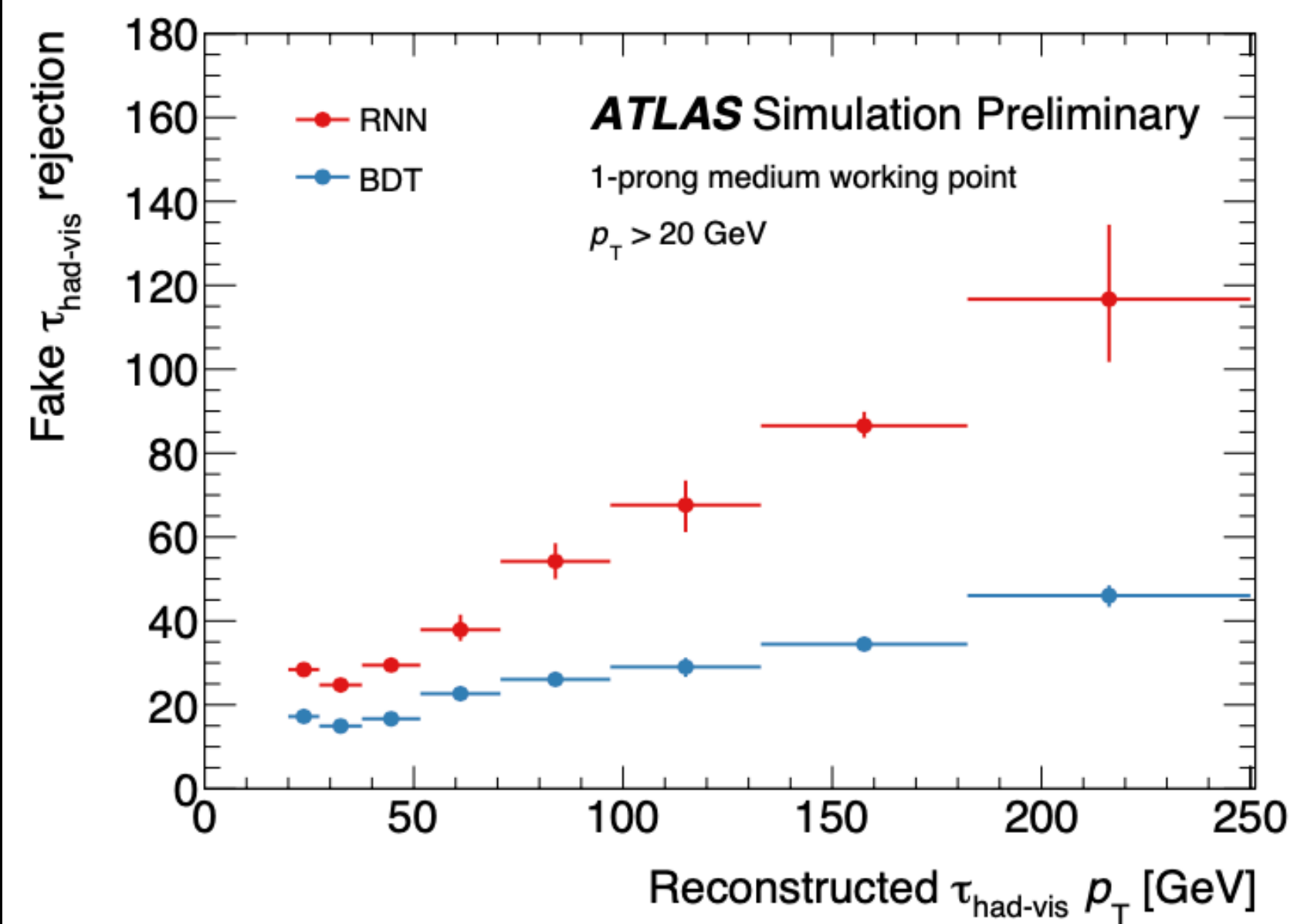
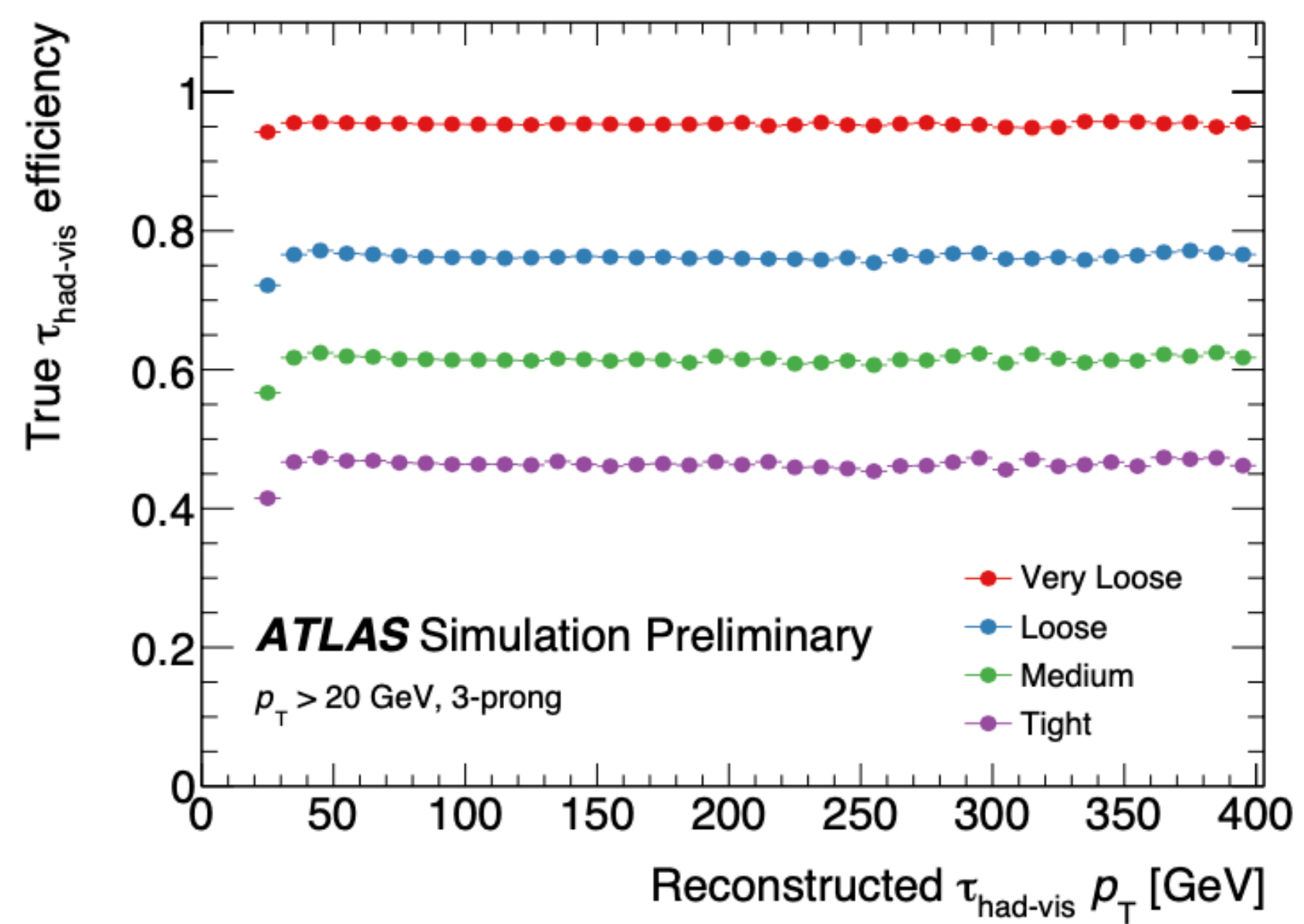
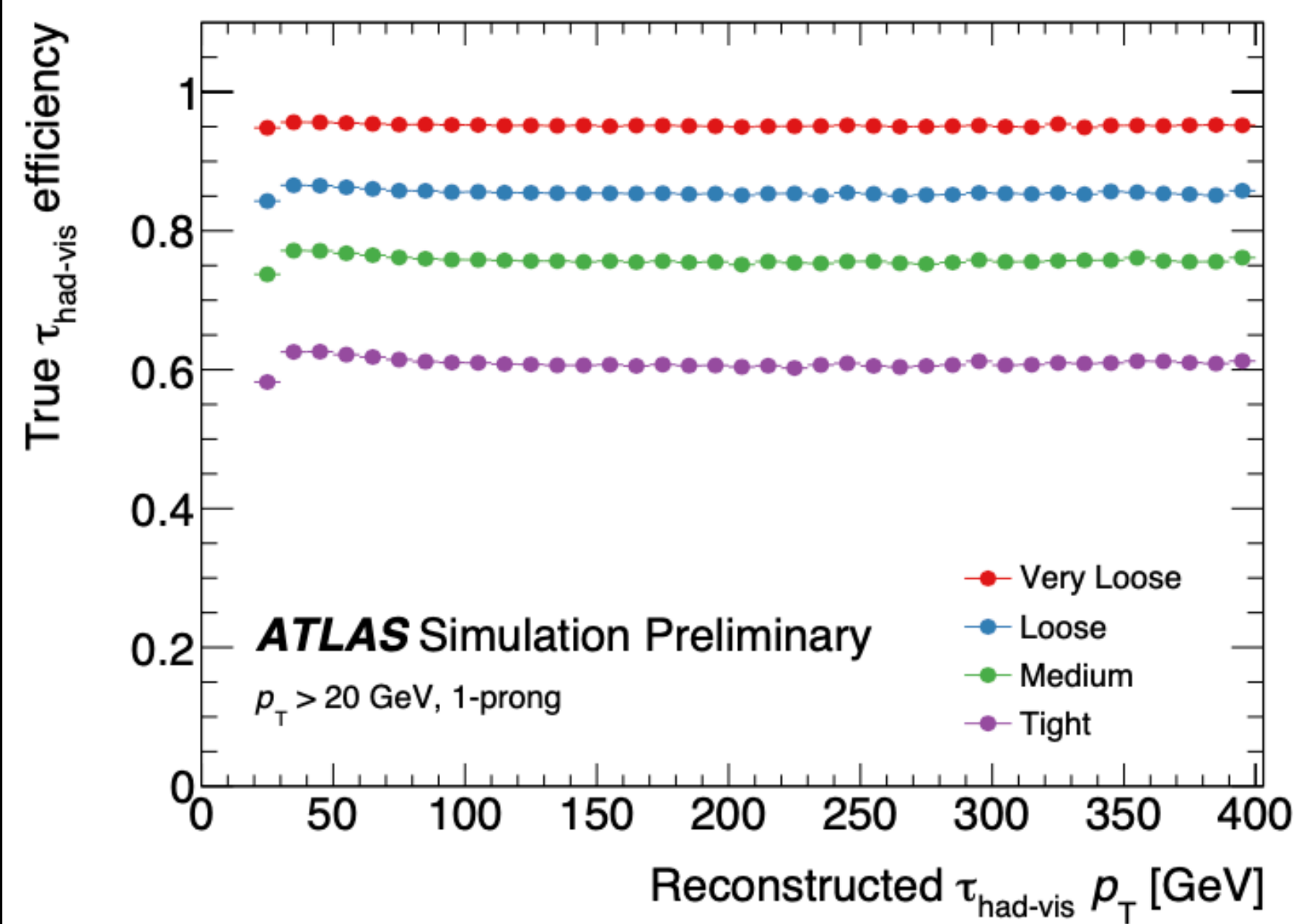
ATLAS-PHYS-PUB-2019-033

Observable	1-prong	3-prong
Track inputs		
seed jet	•	•
p_T^{track}	•	•
$\Delta\eta^{\text{track}}$	•	•
$\Delta\phi^{\text{track}}$	•	•
$ d_0^{\text{track}} $	•	•
$ z_0^{\text{track}} \sin \theta $	•	•
$N_{\text{IBL hits}}$	•	•
$N_{\text{Pixel hits}}$	•	•
$N_{\text{SCT hits}}$	•	•
Cluster inputs		
jet seed	•	•
p_T^{cluster}	•	•
E_T^{cluster}	•	•
$\Delta\eta^{\text{cluster}}$	•	•
$\Delta\phi^{\text{cluster}}$	•	•
λ_{cluster}	•	•
$\langle \lambda_{\text{cluster}}^2 \rangle$	•	•
$\langle r_{\text{cluster}}^2 \rangle$	•	•
High-level inputs		
$p_T^{\text{uncalibrated}}$	•	•
f_{cent}	•	•
$f_{\text{leadtrack}}^{-1}$	•	•
ΔR_{max}	•	•
$ S_{\text{leadtrack}} $	•	•
S_T^{flight}	•	•
$f_{\text{track}}^{\text{iso}}$	•	•
$f_{\text{EM}}^{\text{track}}$	•	•
$p_T^{\text{EM+track}}/p_T$	•	•
$m^{\text{EM+track}}$	•	•
m^{track}	•	•



Stop-Stau: τ RNN

ATLAS-PHYS-PUB-2019-033

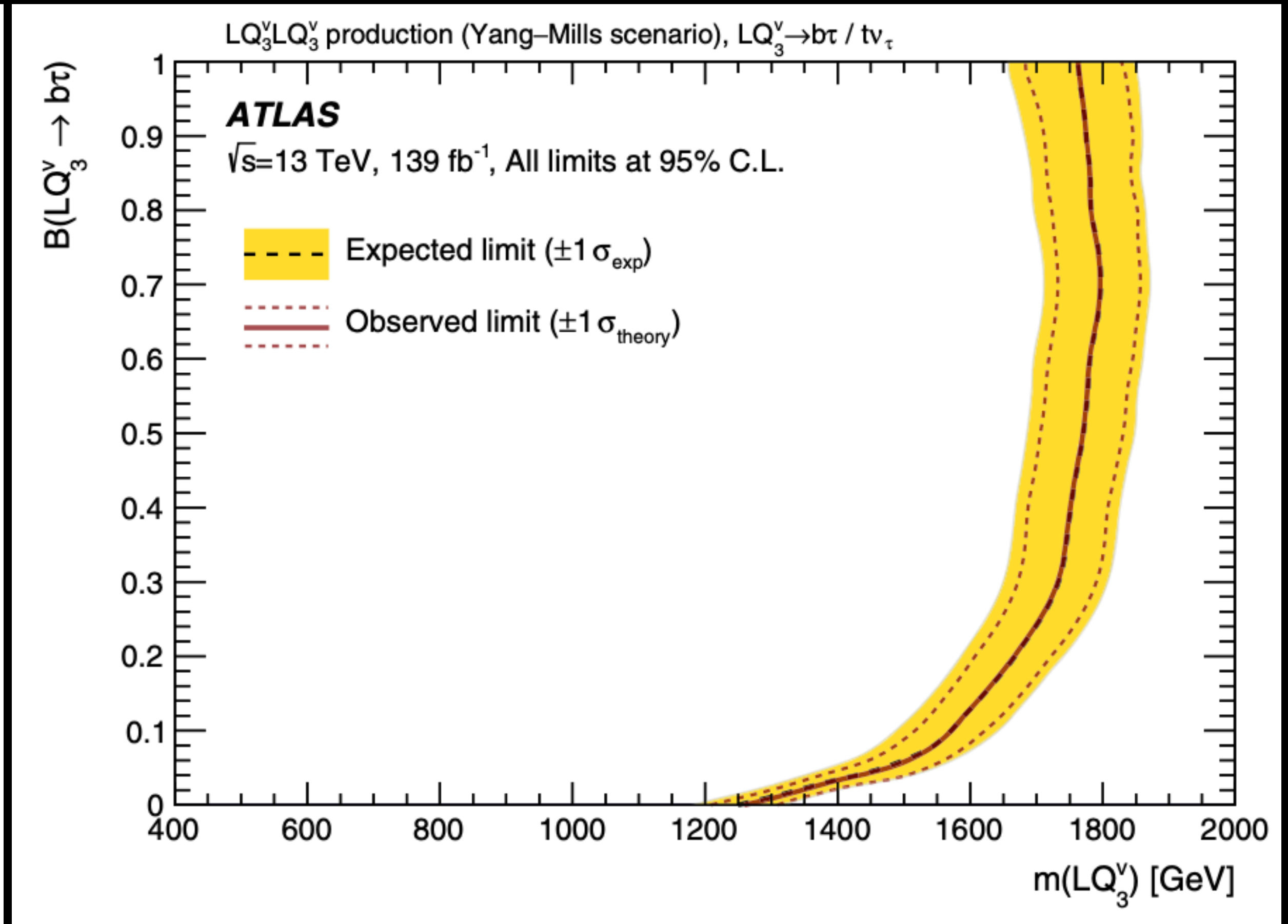
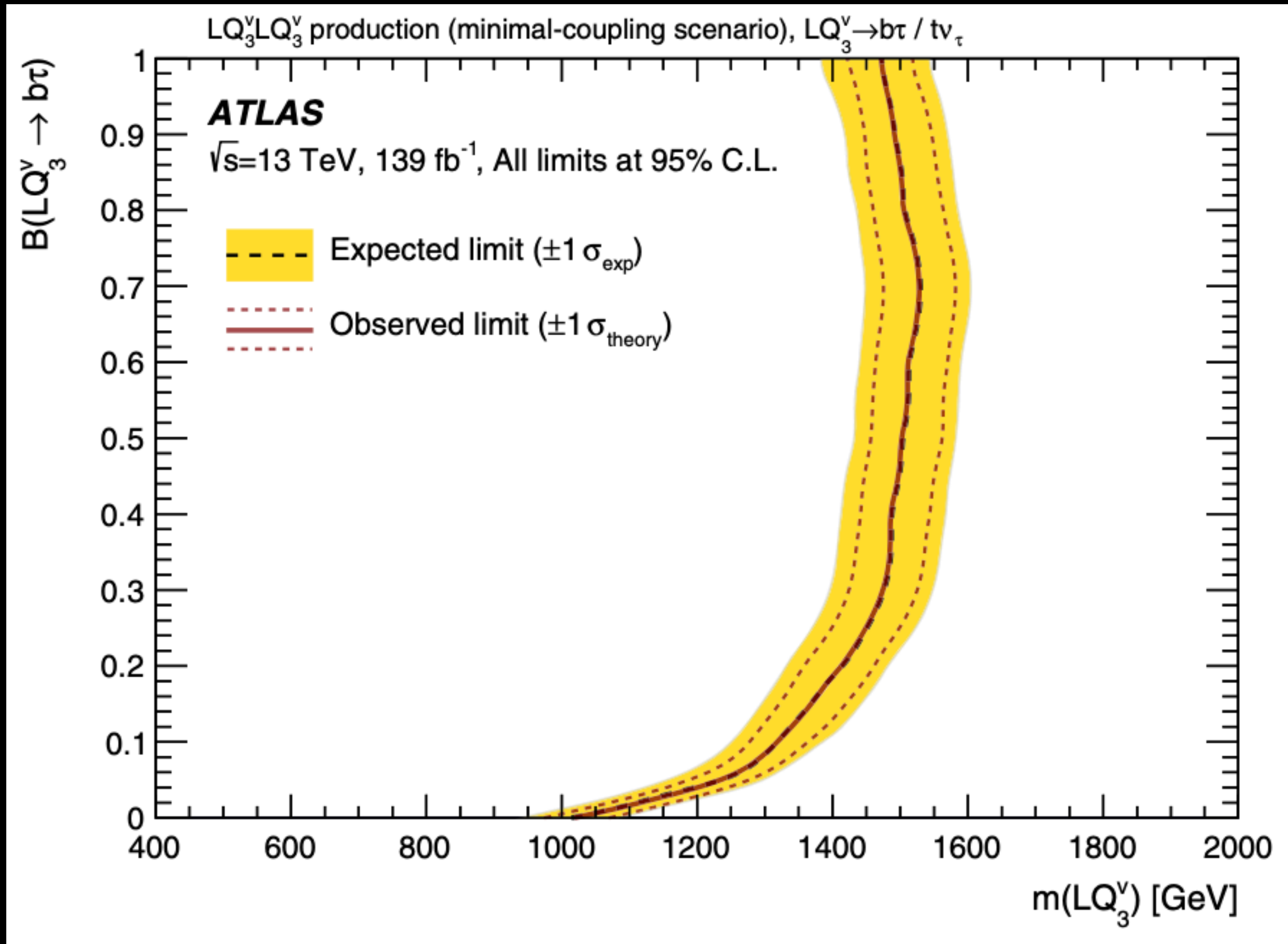


Stop-Stau

	Di-tau SR		Single-tau SR (one-bin)		Single-tau SR (binned in $p_T(\tau)$)					
					[50, 100] GeV		[100, 200] GeV		> 200 GeV	
Observed	2		6		8		6		2	
Total bkg.	4.1	± 1.0	3.23	± 0.55	10.1	± 1.8	5.1	± 1.1	2.05	± 0.64
$t\bar{t}$ (2 real τ)	0.81	± 0.71	—	—	—	—	—	—	—	—
$t\bar{t}$ (1 real τ)	0.82	± 0.27	1.20	± 0.30	4.8	± 1.2	2.69	± 0.88	0.64	± 0.29
$t\bar{t}$ -fake	0.51	± 0.15	0.69	± 0.15	2.83	± 0.87	0.66	± 0.17	0.185	± 0.072
Single top	0.03	$^{+0.10}_{-0.03}$	0.39	$^{+0.45}_{-0.39}$	0.85	$^{+0.86}_{-0.85}$	0.54	± 0.54	0.57	± 0.56
W + jets	0.08	$^{+0.11}_{-0.08}$	0.35	± 0.16	0.34	± 0.12	0.64	± 0.24	0.37	± 0.12
Z + jets	0.35	± 0.14	0.187	± 0.054	0.275	± 0.081	0.043	± 0.022	0.123	± 0.048
Multiboson	0.48	± 0.21	0.085	± 0.037	0.163	± 0.037	0.111	± 0.030	0.030	$^{+0.032}_{-0.030}$
$t\bar{t}$ + V	0.60	± 0.15	0.242	± 0.064	0.65	± 0.16	0.31	± 0.12	0.092	± 0.035
$t\bar{t}$ + H	0.28	$^{+0.29}_{-0.28}$	0.039	$^{+0.040}_{-0.039}$	0.10	± 0.10	0.060	$^{+0.061}_{-0.060}$	0.028	$^{+0.029}_{-0.028}$
Other top	0.122	± 0.067	0.043	± 0.022	0.096	± 0.074	0.091	± 0.049	0.0120	± 0.0084

Analysis region	$\langle A\epsilon\sigma \rangle_{\text{obs}}^{95}$ [fb]	S_{obs}^{95}	S_{exp}^{95}	CL_b	$p(s = 0)$	Z
Di-tau SR	0.03	4.1	$5.3^{+2.2}_{-1.5}$	0.18	0.50	0.0
Single-tau one-bin SR	0.06	8.2	$5.1^{+2.1}_{-1.3}$	0.91	0.08	1.37

Exclusion limit (vector leptoquark)



Photon + E_T^{miss}

ATLAS-CONF-2021-028

Single photon trigger with $p_T > 140$ GeV

	SRL	SRM	SRH
$N_{\text{photons}}^{\text{leading-}\gamma}$	≥ 1	≥ 1	≥ 1
p_T	> 145 GeV	> 300 GeV	> 400 GeV
N_{leptons}	0	0	0
N_{jets}	≥ 5	≥ 5	≥ 3
$\Delta\phi(\text{jet}, E_T^{\text{miss}})$	> 0.4	> 0.4	> 0.4
$\Delta\phi(\gamma, E_T^{\text{miss}})$	> 0.4	> 0.4	> 0.4
E_T^{miss}	> 250 GeV	> 300 GeV	> 600 GeV
H_T	> 2000 GeV	> 1600 GeV	> 1600 GeV
R_T^4	< 0.90	< 0.90	-

Regions	N_{photons}	$p_T^{\text{leading}\gamma}$ (GeV)	N_{leptons}	N_{jets}	$N_{b\text{-jets}}$	$\Delta\phi(\text{jet}, E_T^{\text{miss}})$	$\Delta\phi(\gamma, E_T^{\text{miss}})$	E_T^{miss} (GeV)	H_T (GeV)	R_T^4
CRQ	≥ 1	> 145	0	≥ 3	-	< 0.4	> 0.4	> 100	> 1600	-
CRW	≥ 1	> 145	≥ 1	≥ 1	0	> 0.4	-	[100, 200]	> 400	-
CRT	≥ 1	> 145	≥ 1	≥ 2	≥ 2	> 0.4	-	[50, 200]	> 400	-
VRL1	≥ 1	> 145	≥ 1	≥ 2	-	> 0.4	-	[50, 200]	> 800	-
VRL2	≥ 1	> 145	≥ 1	≥ 2	-	> 0.4	-	[50, 200]	> 1300	-
VRL3	≥ 1	> 145	≥ 1	≥ 2	-	> 0.4	-	> 200	[600, 1600]	-
VRL4	≥ 1	> 145	≥ 1	≥ 2	-	< 0.4	-	> 200	> 1100	-
VRQ	≥ 1	> 145	0	≥ 3	-	> 0.4	> 0.4	[100, 200]	> 1600	-
VRM1L	≥ 1	> 145	0	≥ 5	-	> 0.4	> 0.4	[100, 200]	> 1600	< 0.90
VRM2L	≥ 1	> 145	0	≥ 5	-	> 0.4	> 0.4	[150, 200]	> 1600	< 0.90
VRM1H	≥ 1	> 300	0	≥ 3	-	> 0.4	> 0.4	[100, 200]	> 1600	-
VRM2H	≥ 1	> 300	0	≥ 3	-	> 0.4	> 0.4	[150, 200]	> 1600	-
VRE	≥ 1	> 145	-	≥ 1	≥ 1	> 0.4	< 0.4	> 200	[100, 1600]	-

Photon + E_T^{miss}

	SRL [%]	SRM [%]	SRH [%]
Total (stat. + syst.) uncertainty	28	25	17
Statistical uncertainty	20	15	12
Jet energy scale and resolution	18	19	4.1
b-tagging calibration	3.2	4.3	3.6
Jet fakes	2.1	2.5	2.3
MC theory	3.6	3.1	10
Electron fakes	1.4	1.9	< 1
Electron/photon energy resolution and scale	5.5	1.1	4.1
Muon reconstruction and identification	2.6	1.8	< 1
Photon ID and isolation	2.6	2.1	1.1
Pile-up reweighting	< 1	1.2	1.0
E_T^{miss} soft-term scale and resolution	< 1	< 1	< 1

Photon + E_T^{miss}

	SRL	SRM	SRH
Observed events	2	0	5
Expected SM events	2.67 ± 0.75	2.55 ± 0.64	2.55 ± 0.44
$t\bar{t}\gamma$	0.70 ± 0.18	0.87 ± 0.18	0.22 ± 0.05
$W\gamma$	0.55 ± 0.37	0.70 ± 0.42	1.08 ± 0.21
γ + jets	0.49 ± 0.29	0.17 ± 0.10	0.07 ± 0.01
$Z(\rightarrow \nu\nu)\gamma$	0.31 ± 0.11	0.35 ± 0.12	0.94 ± 0.28
$\gamma\gamma/W\gamma\gamma/Z\gamma\gamma$	0.23 ± 0.11	0.25 ± 0.10	0.08 ± 0.01
Fake photons from e	0.22 ± 0.08	0.04 ± 0.03	0.06 ± 0.04
Fake photons from jets	0.15 ± 0.09	0.14 ± 0.09	0.09 ± 0.07
$Z(\rightarrow \ell\ell)\gamma$	0.03 ± 0.03	0.03 ± 0.01	–

Signal Region	N_{obs}	N_{exp}	$\langle \epsilon\sigma \rangle_{\text{obs}}^{95}$ [fb]	$\langle \epsilon\sigma \rangle_{\text{exp}}^{95}$ [fb]	S_{obs}^{95}	S_{exp}^{95}	$p_0(\mathbf{Z})$
SRL	2	2.67 ± 0.75	0.030	$0.034^{+0.019}_{-0.011}$	4.12	$4.7^{+2.6}_{-1.6}$	0.50 (0.00)
SRM	0	2.55 ± 0.64	0.018	$0.032^{+0.018}_{-0.011}$	2.56	$4.4^{+2.5}_{-1.6}$	0.50 (0.00)
SRH	5	2.55 ± 0.44	0.054	$0.034^{+0.019}_{-0.011}$	7.43	$4.7^{+2.6}_{-1.6}$	0.09 (1.36)