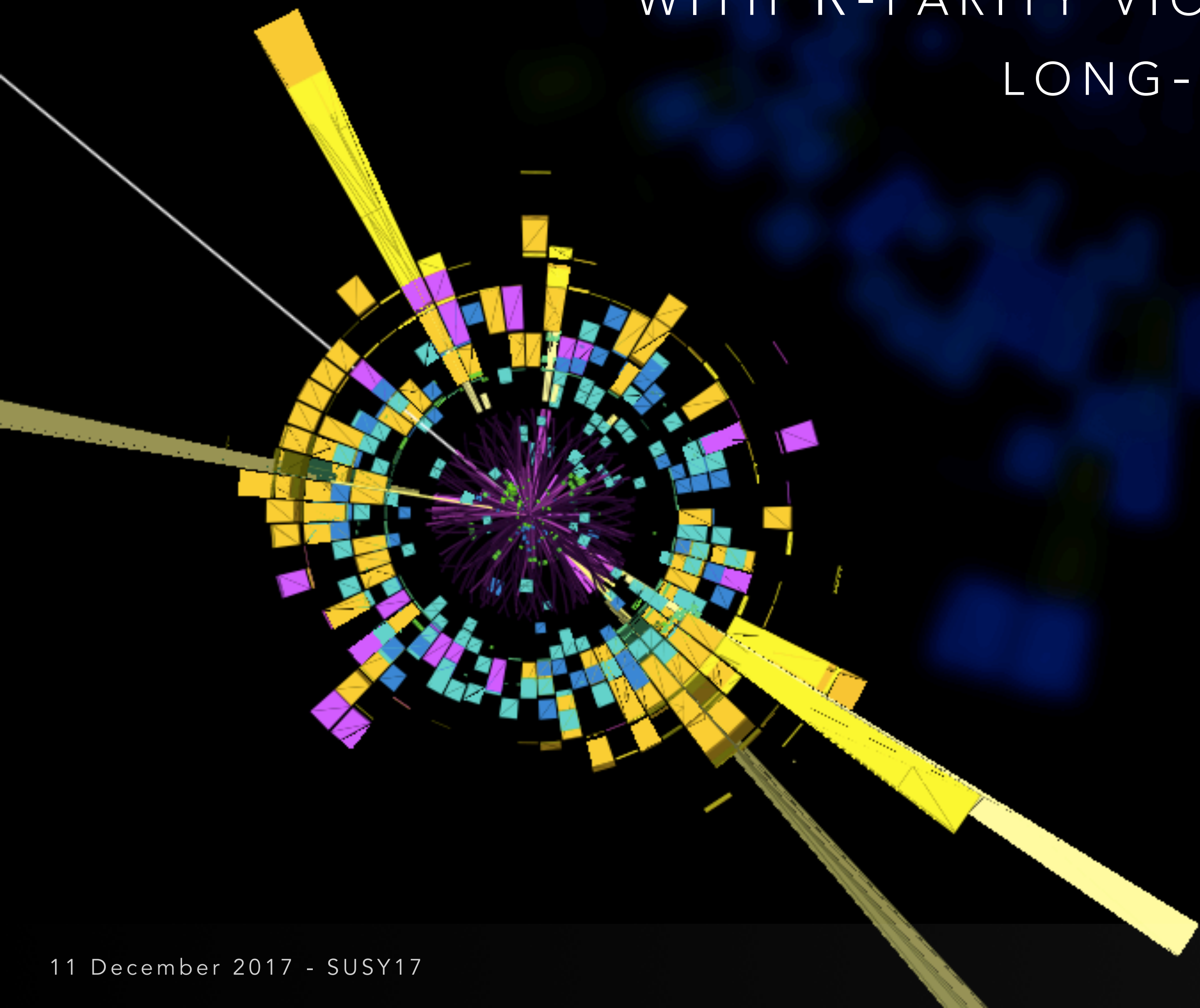
Searches for squarks and gluinos in scenarios with R-parity violating sparticle decays, or long-lived sparticles with ATLAS

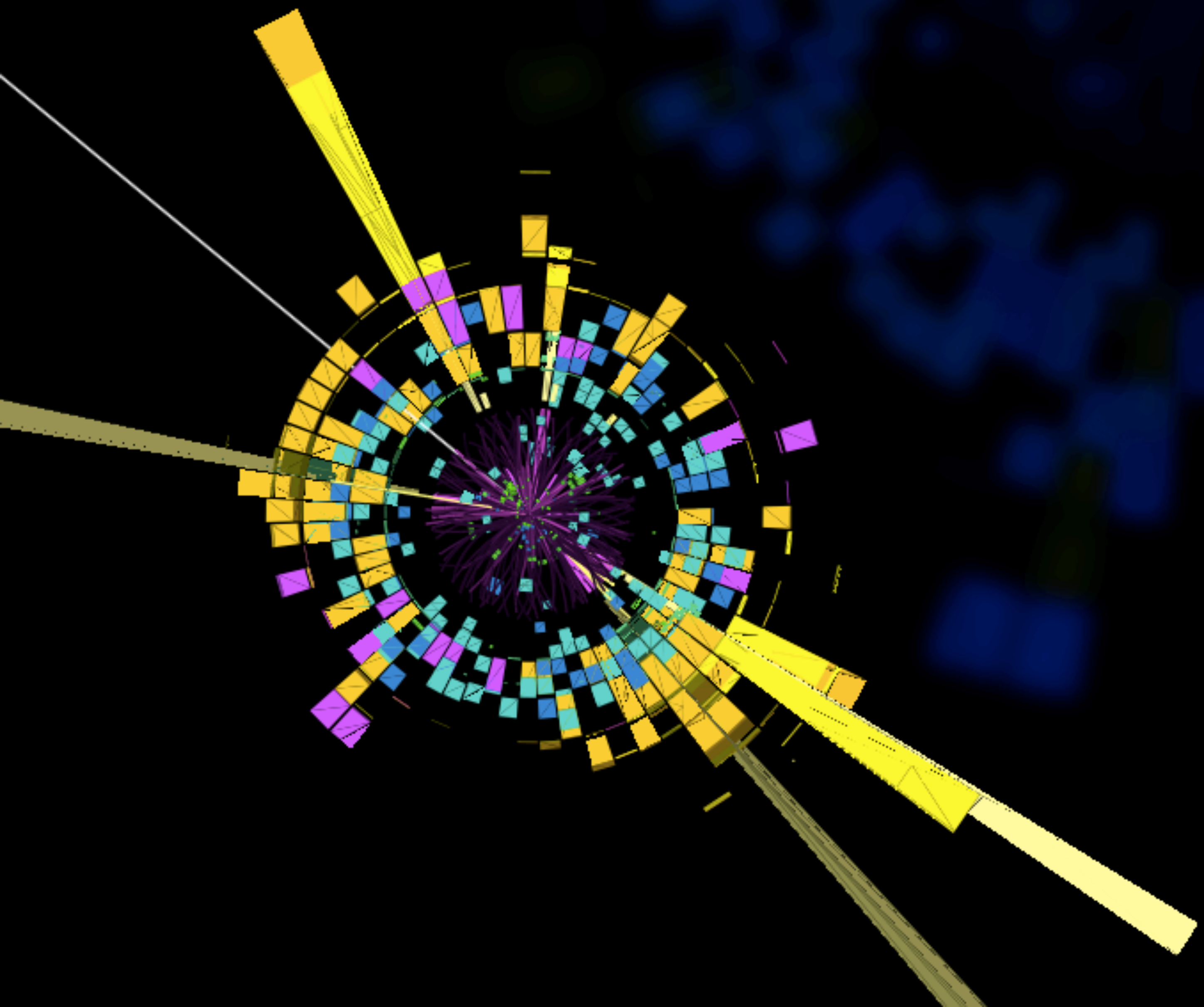
Lawrence Lee

On behalf of the ATLAS Collaboration



HARVARD UNIVERSITY

n.b. We haven’t found any evidence for SUSY



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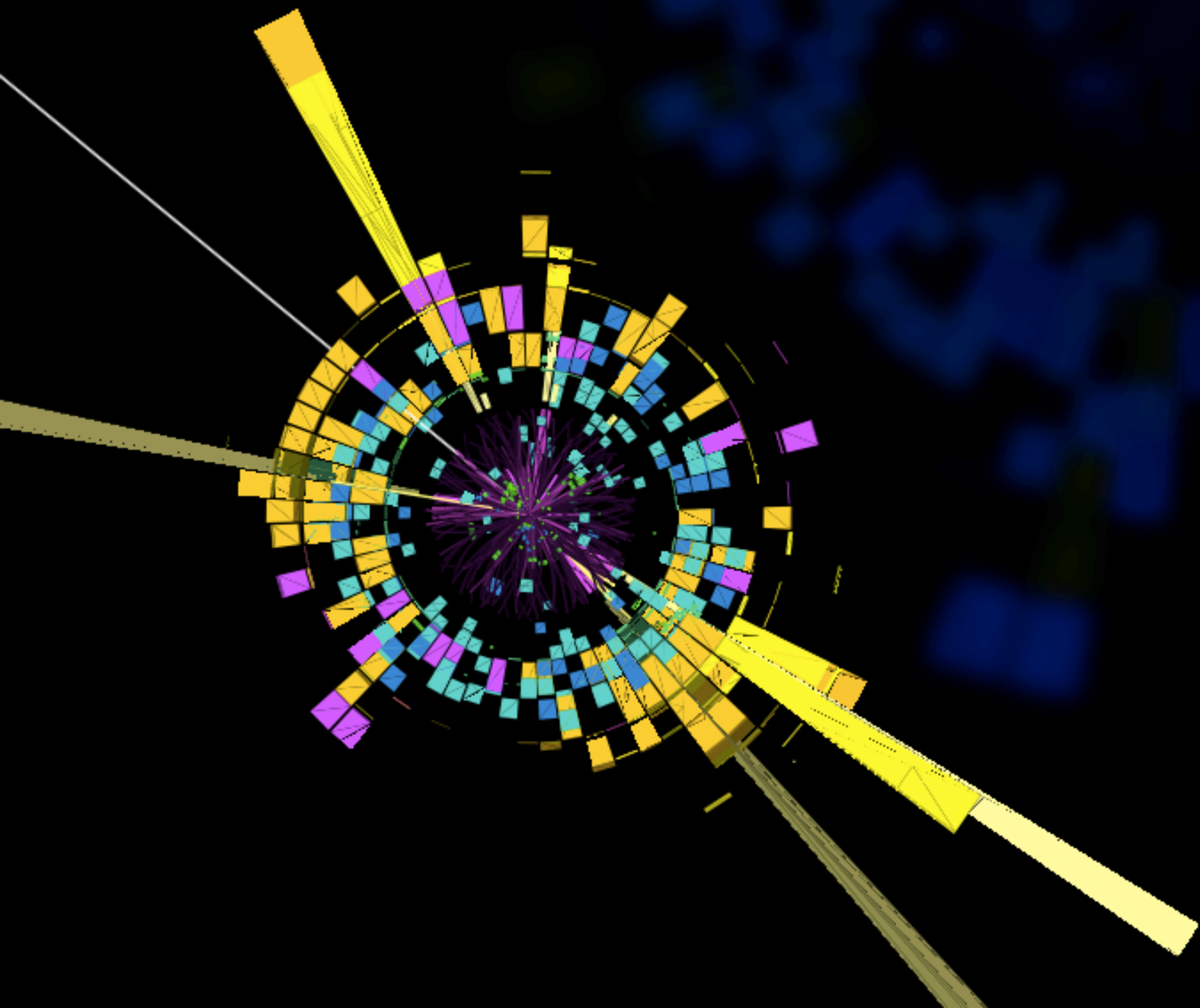


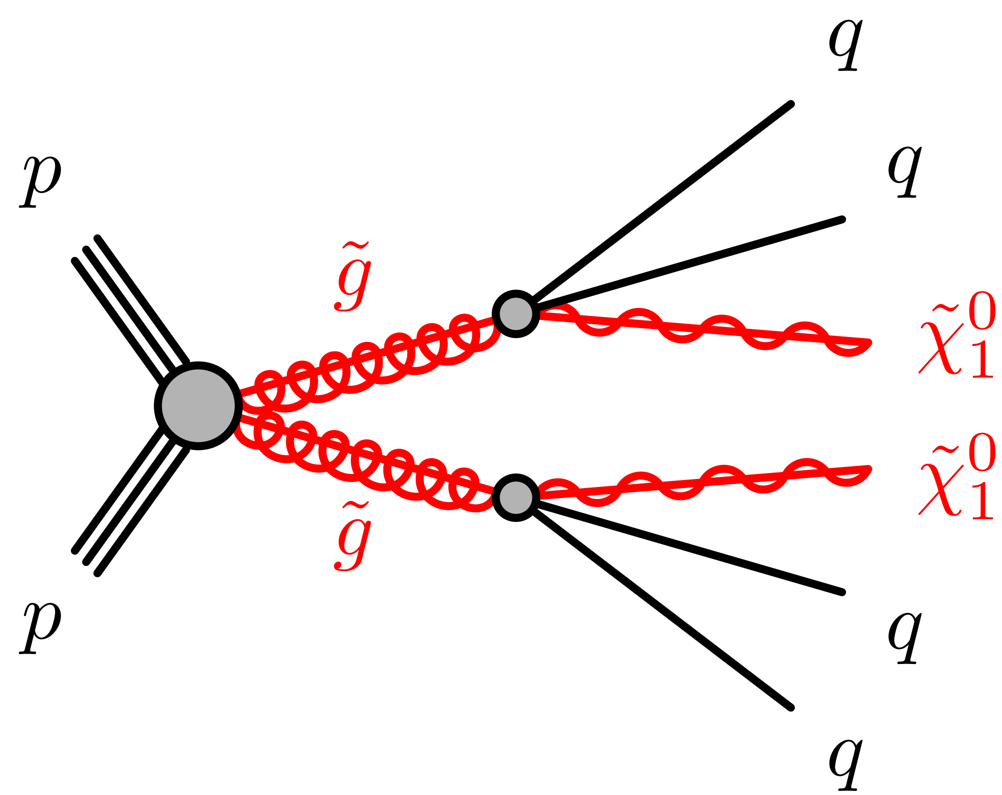
Why not?

Often assume:

Very massive squarks+gluinos

R-Parity Conservation

Trivial Sparticle Lifetimes



Look for very large Missing E_T

High momentum objects

Often assume:

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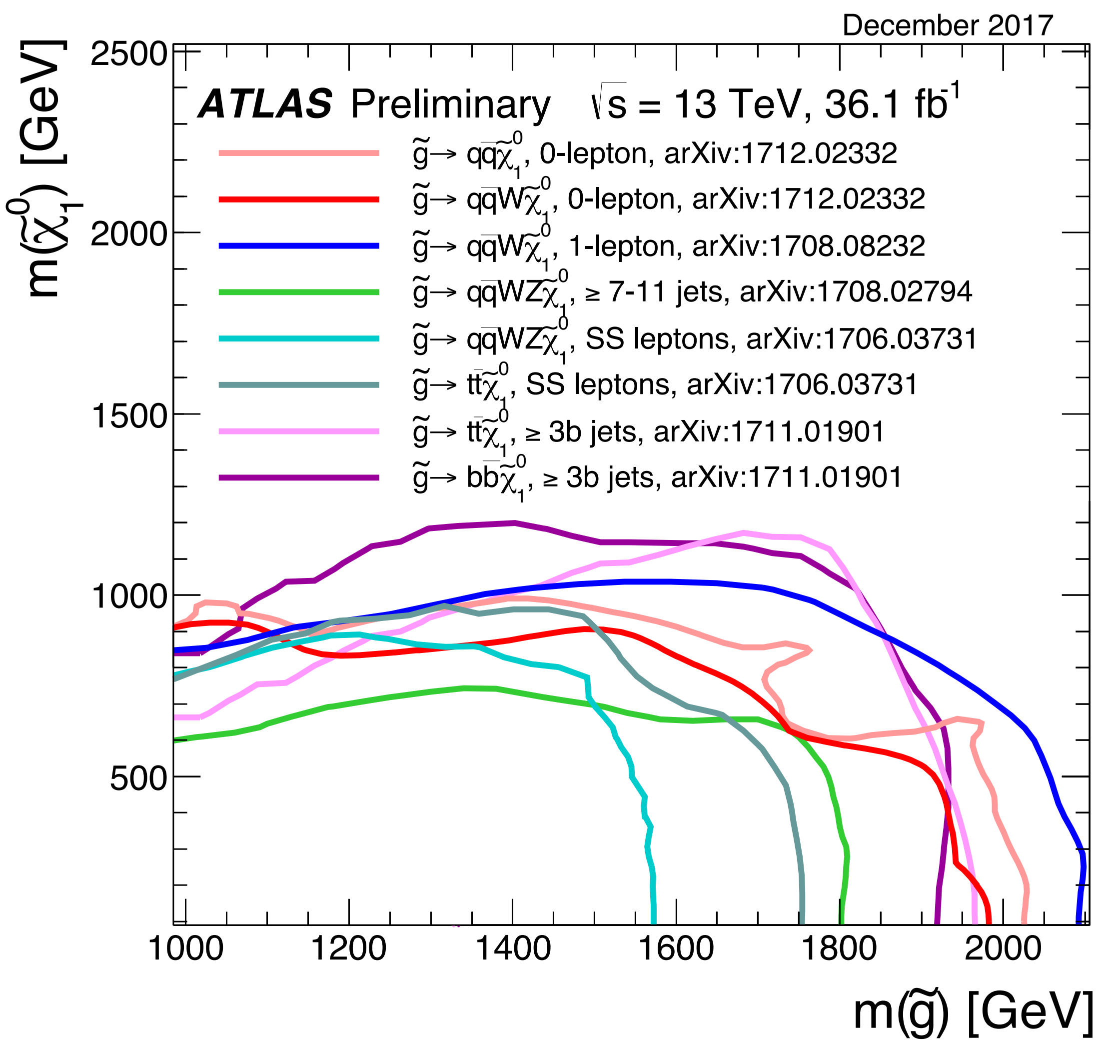
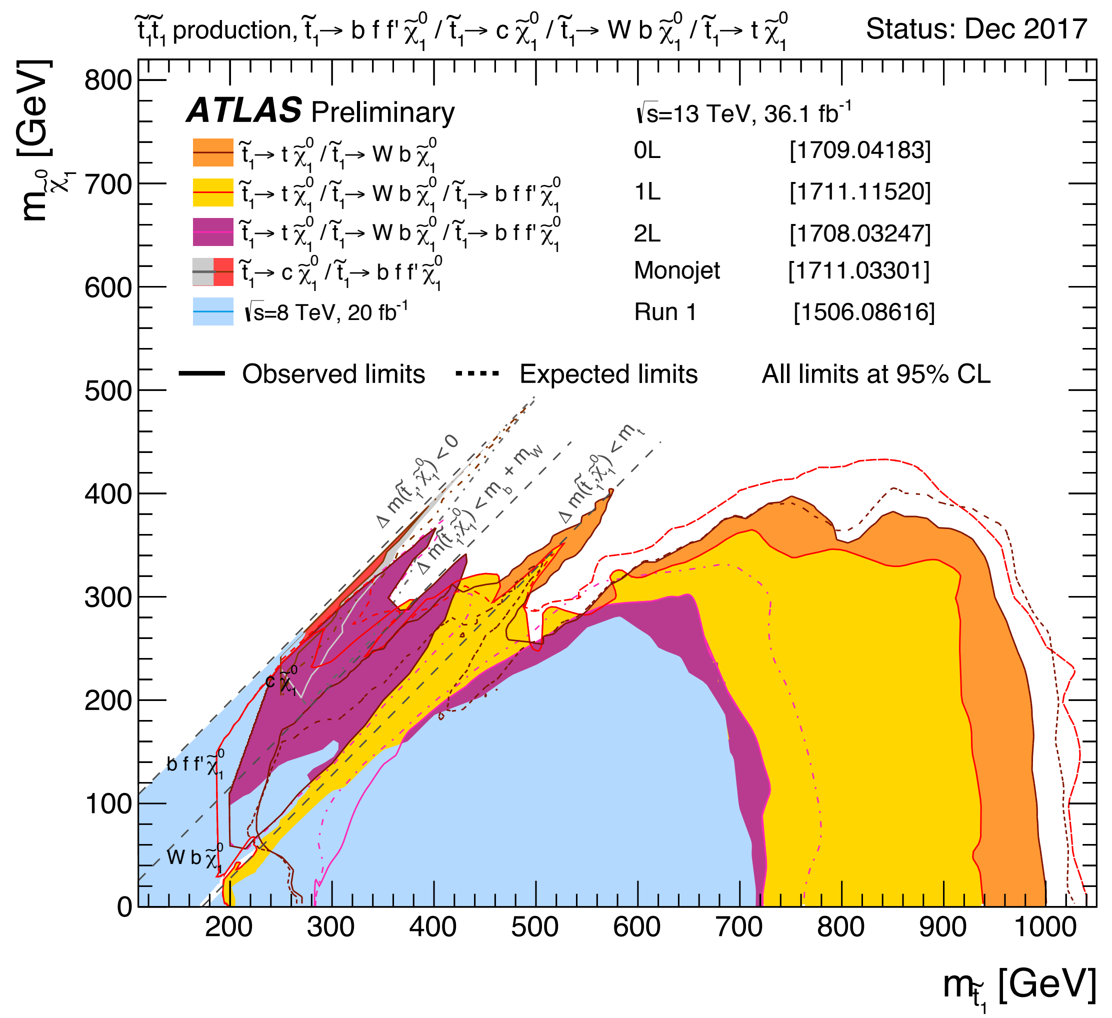
R-Parity Conservation

Trivial Sparticle Lifetimes





But we have a huge number of exclusions

and no SUSY discoveries

Maybe R-Parity Is Not Conserved?

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

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We often forbid them.

"SM conserves R at tree level, why shouldn't the MSSM?"

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No fundamental symmetry requires it…

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$$W_{RPV} = \underbrace{\mu_i H_u L_i + \frac{1}{2}\lambda_{ijk} L_i L_j E_k + \lambda'_{ijk} L_i Q_j D_k}_{\text{L Violating}} + \underbrace{\frac{1}{2}\lambda''_{ijk} U_i D_j D_k}_{\text{B Violating}}$$

Because of their coupling to Lepton superfields, these terms give rise to Missing E_T
→RPC Searches often have sensitivity

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L Violating

B Violating

Because of their coupling to Lepton superfields, these terms give rise to Missing E_T

→RPC Searches often have sensitivity

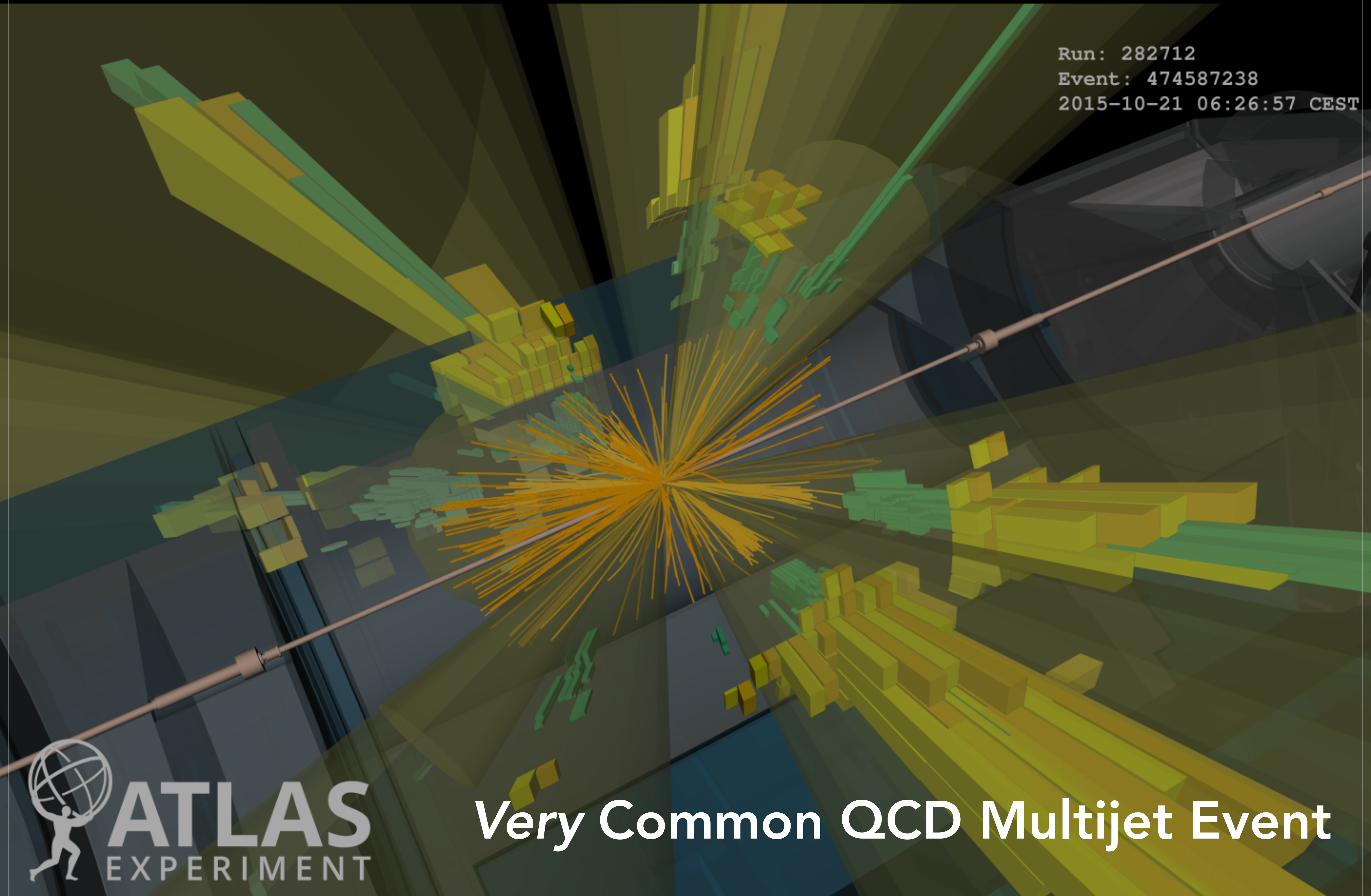
But these couplings give SUSY particle decays to quarks…

All hadronic signals at a QCD collider

$$W_{RPV} = \boxed{\mu_i H_u L_i + \frac{1}{2}\lambda_{ijk} L_i L_j E_k + \lambda'_{ijk} L_i Q_j D_k} + \boxed{\frac{1}{2}\lambda''_{ijk} U_i D_j D_k}$$

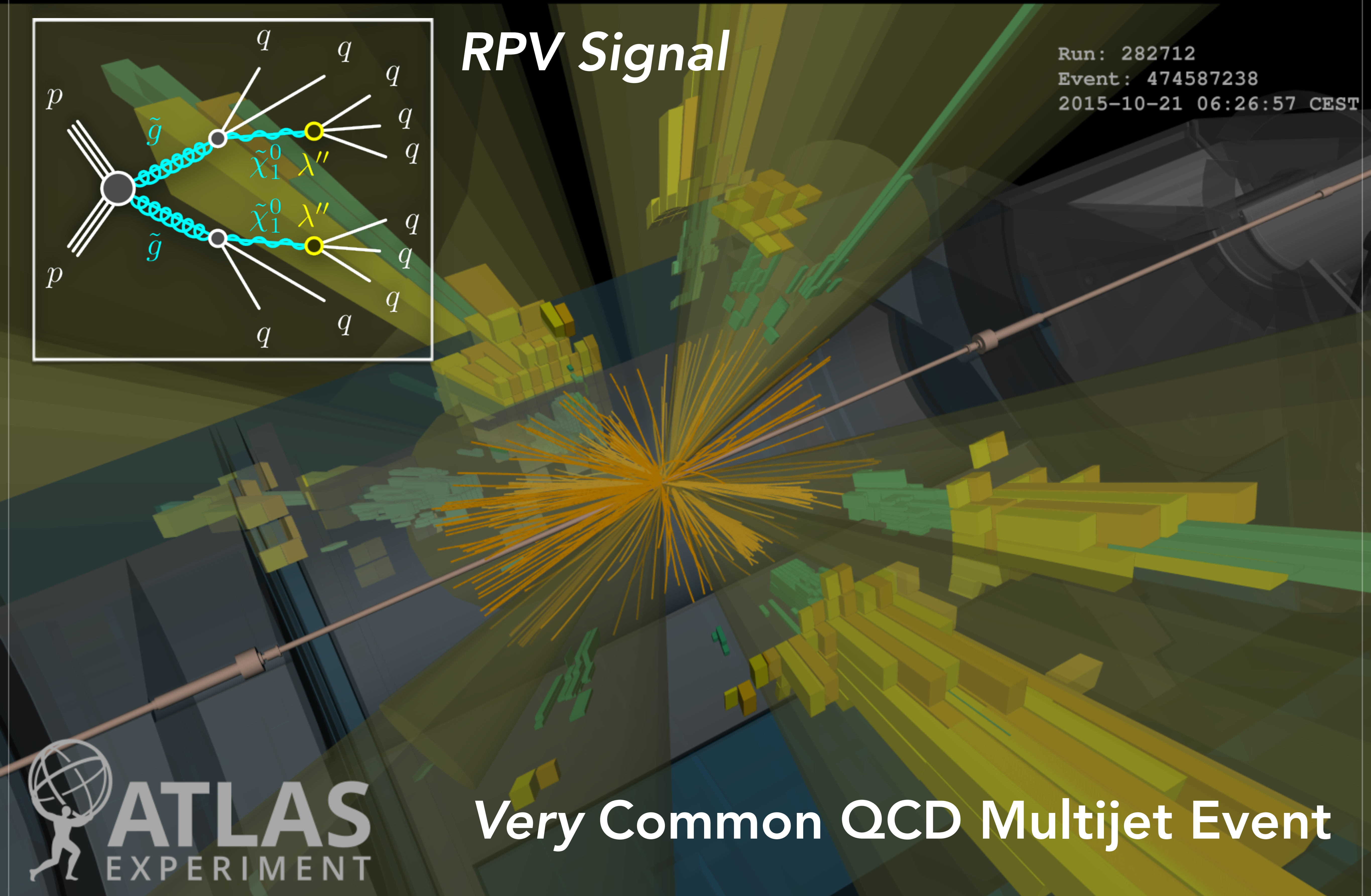
L Violating

B Violating



Very Common QCD Multijet Event

RPV Signal



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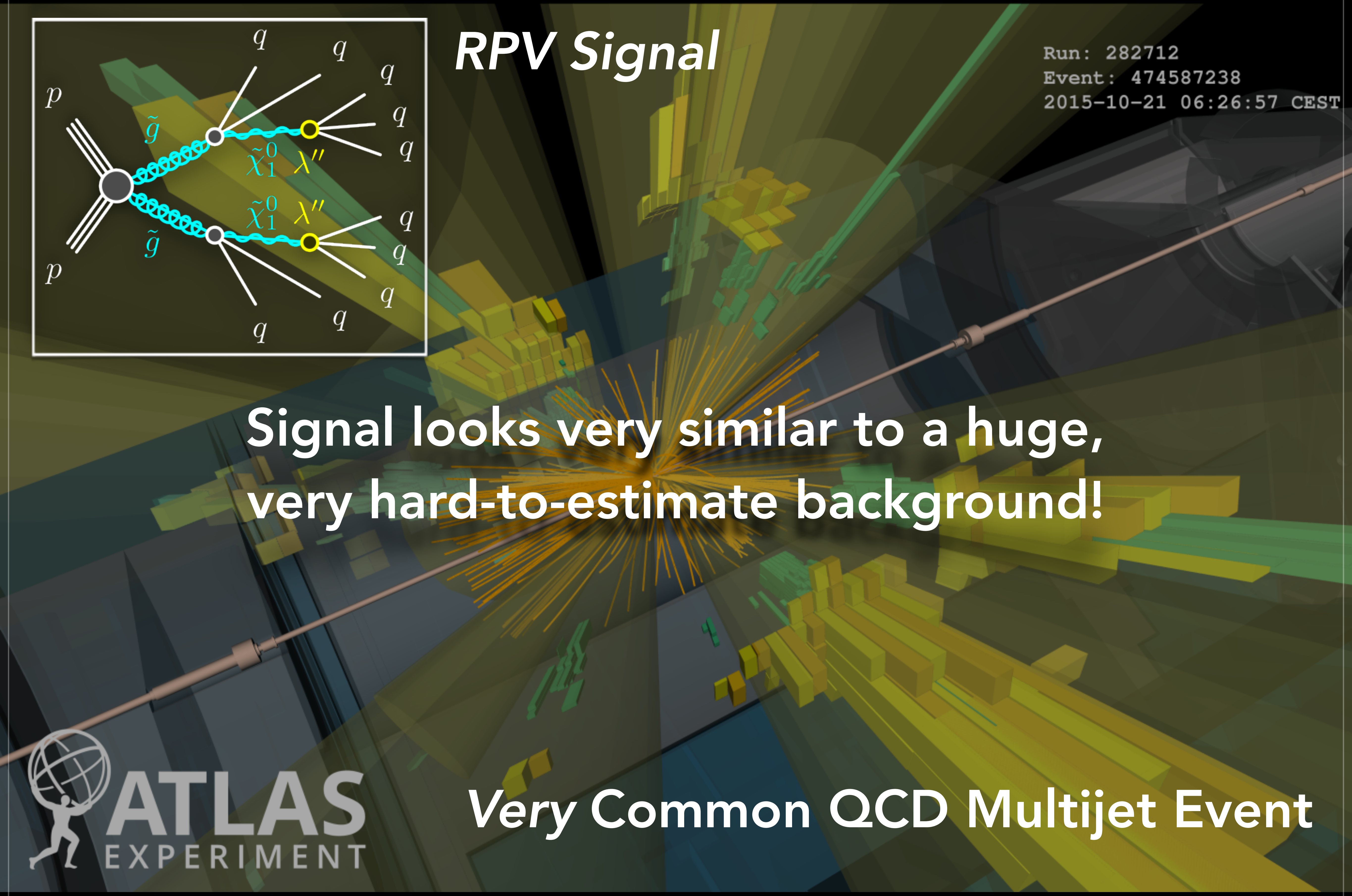
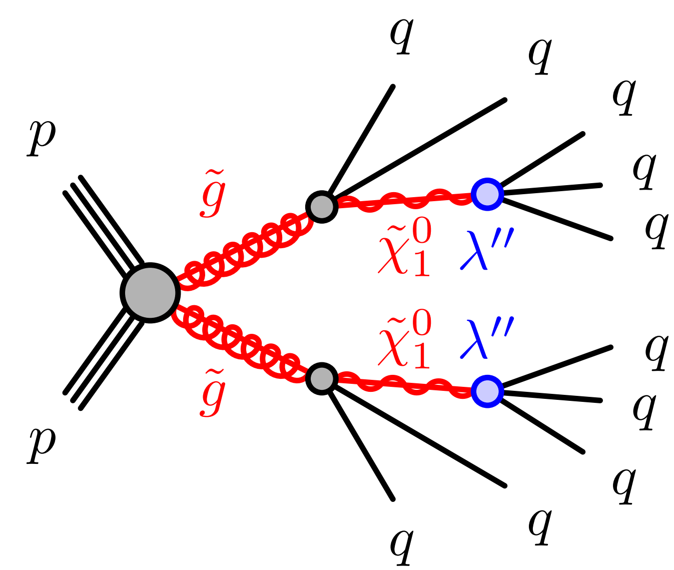


Signal looks very similar to a huge, very hard-to-estimate background!

Very Common QCD Multijet Event

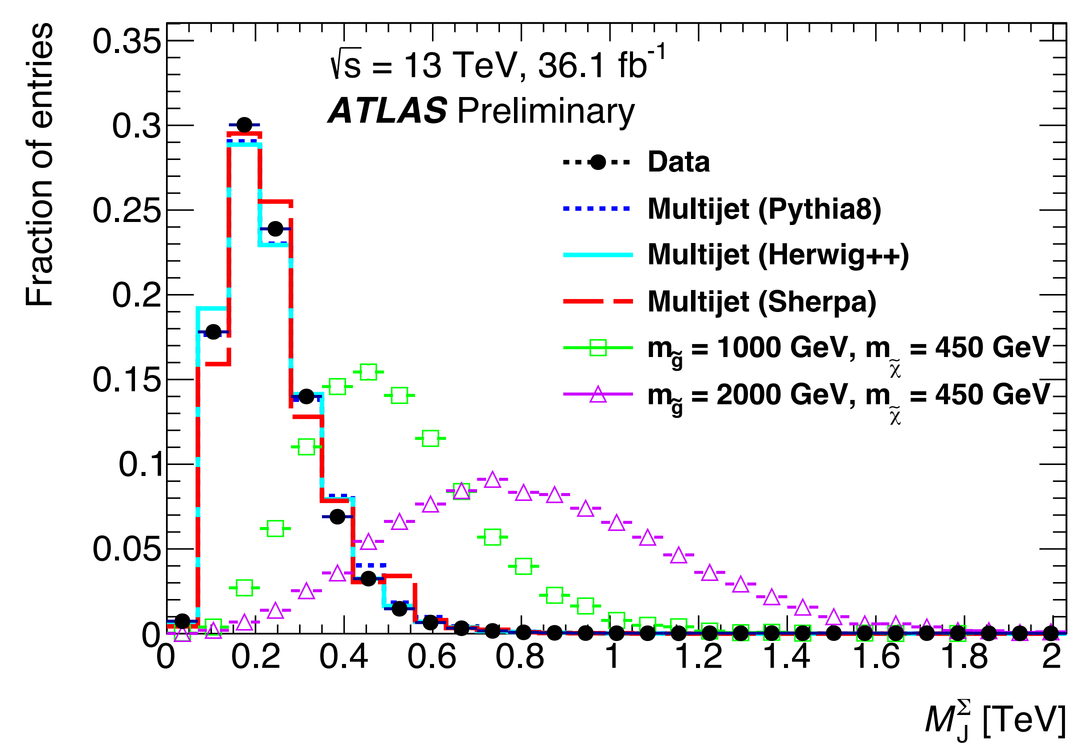
RPV MULTIJET SEARCH



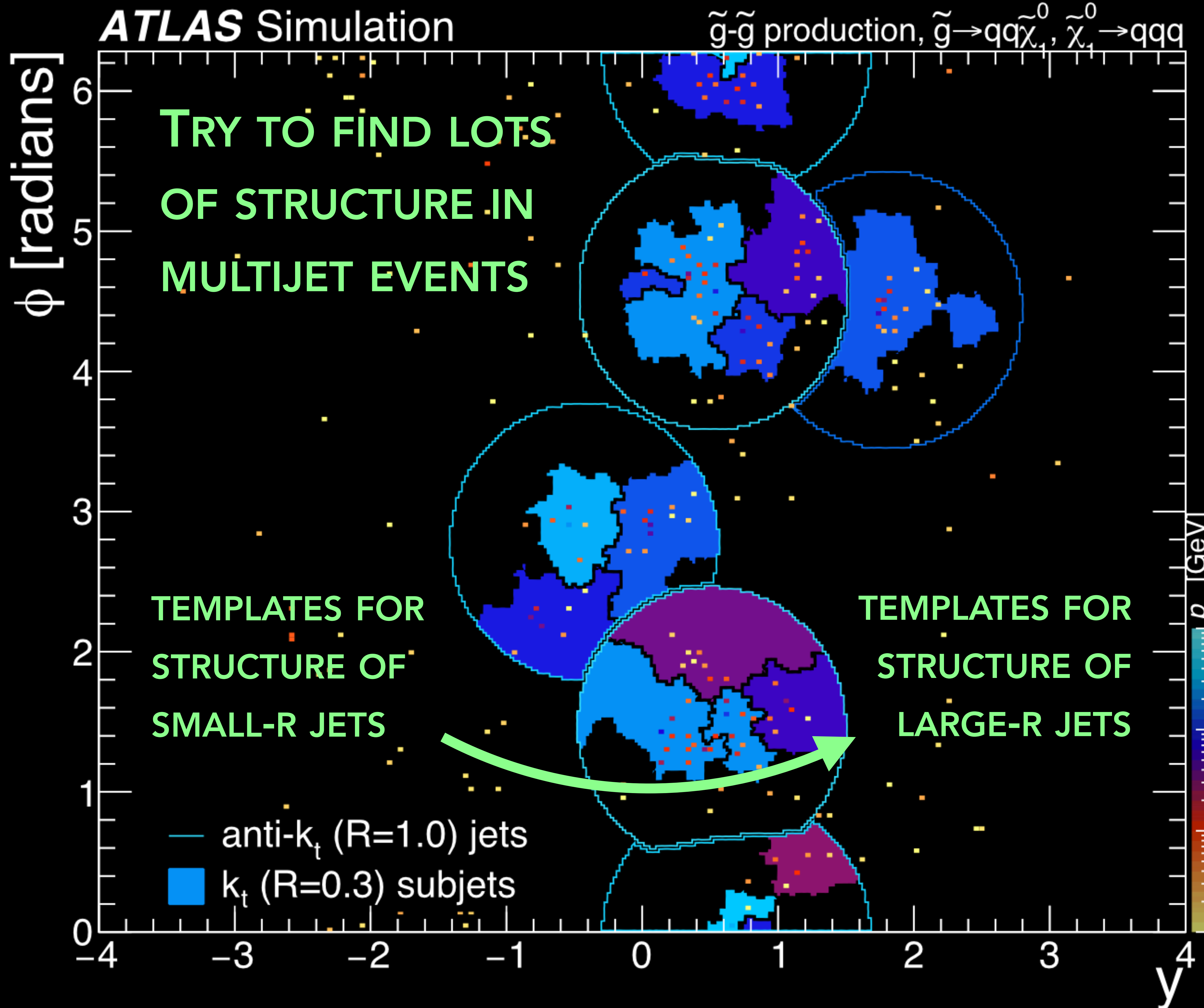
- To kill QCD multi jet backgrounds, construct composite mass variable out of Large-R jets

$$M_J^{\Sigma} = \sum_{p_T > 200\,\mathrm{GeV}, |\eta| \leq 2.0} m_j$$

- Scalar sum of masses
  - QCD: Small angle emissions
  - SUSY/BSM: Large angles → Event structure
- Regions w/ or w/o B-Tag for HF sensitivity



ATLAS SUSY-2016-22 (Submitted to Phys.Lett.B.)



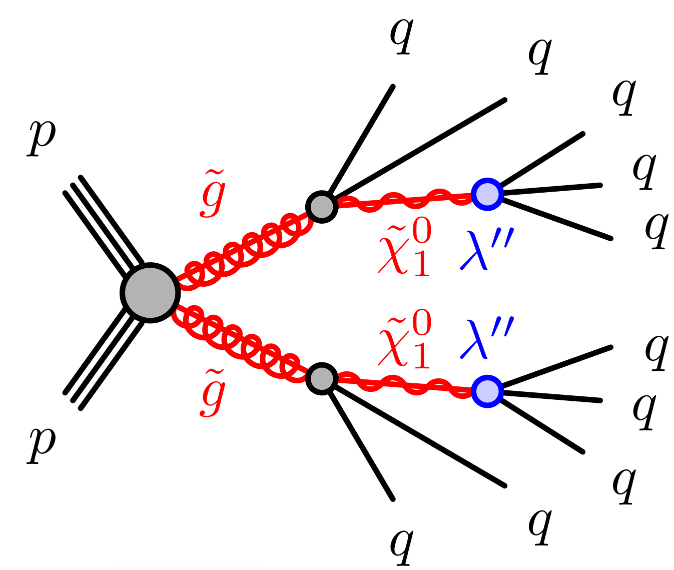
TRY TO FIND LOTS OF STRUCTURE IN MULTIJET EVENTS

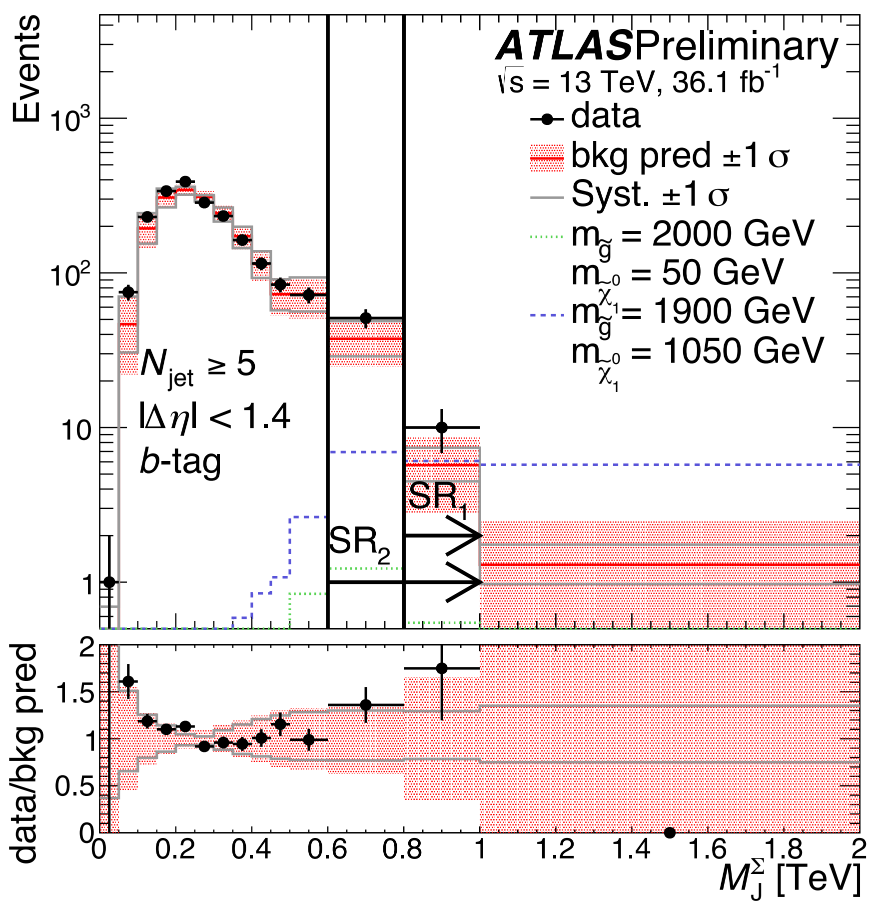
TEMPLATES FOR STRUCTURE OF SMALL-R JETS

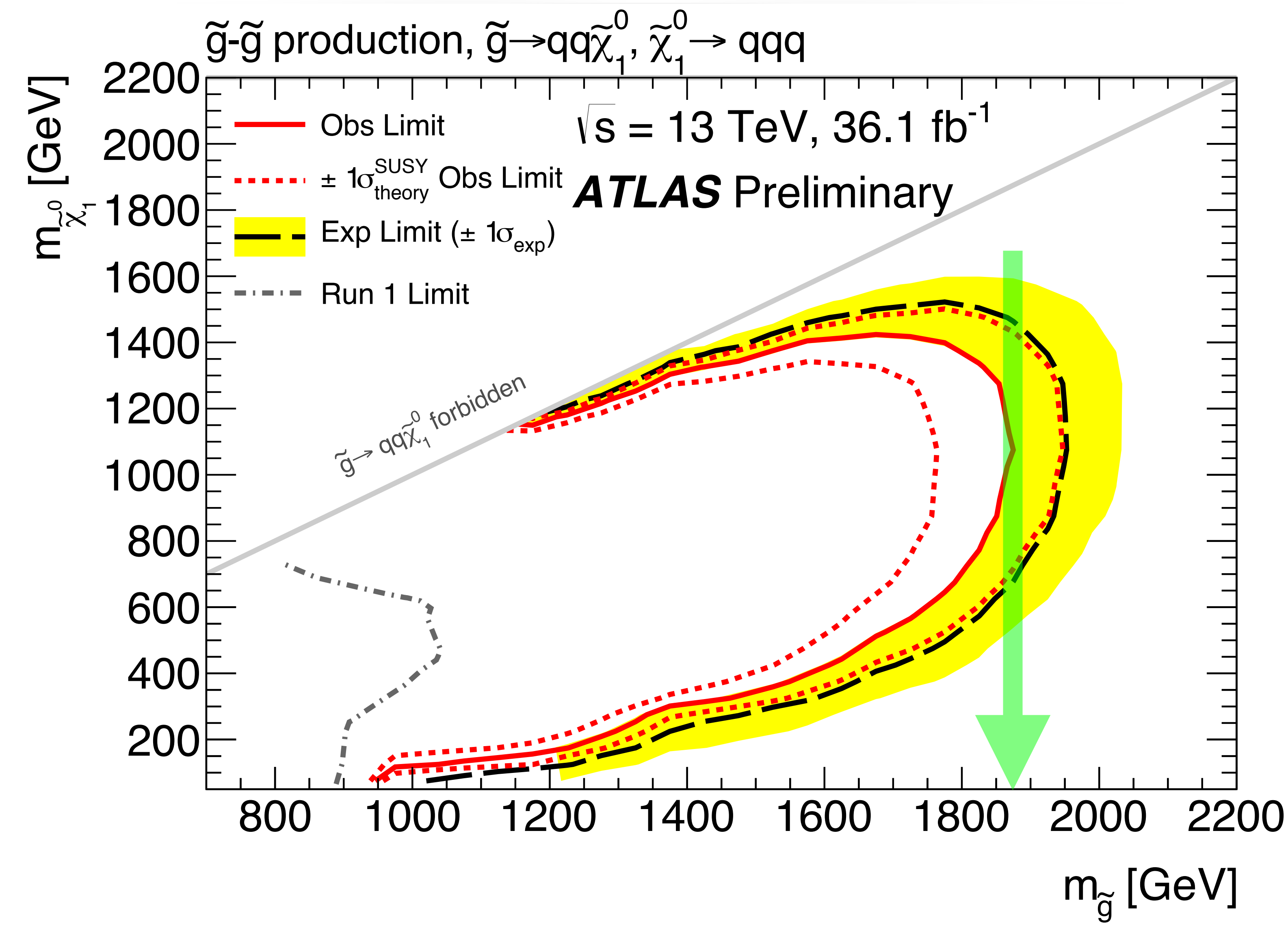
TEMPLATES FOR STRUCTURE OF LARGE-R JETS

No significant deviation from SM.

→ Very strict limits on gluino mass despite the multijet background!







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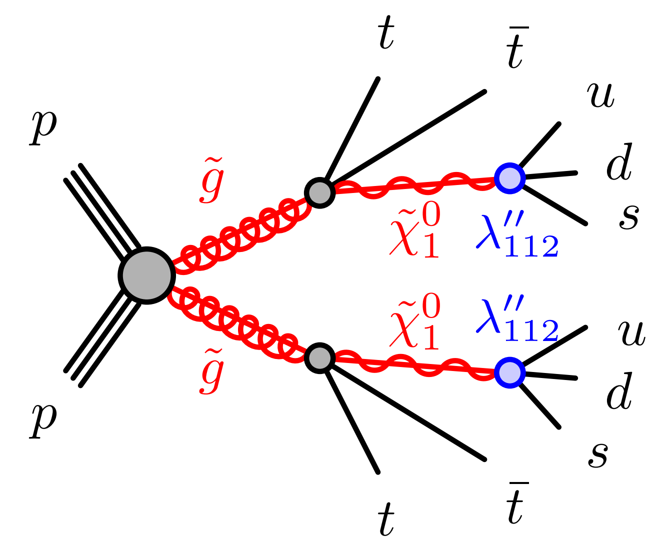
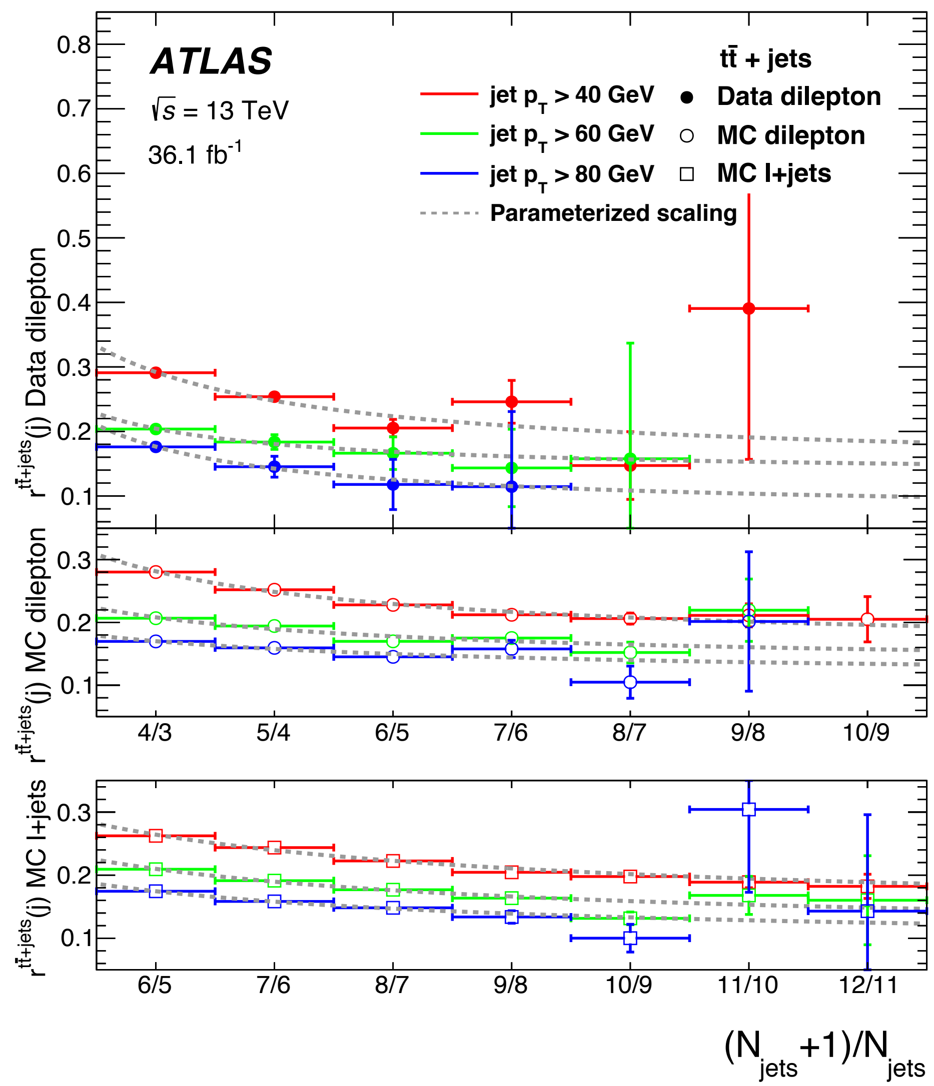
RPV MULTIJET+1L SEARCH



- If top-quarks in final state, or L-violating RPV
  - Very low MET + *Many* Jets + [***e*** or ***mu***]
  - Regions looking for 12 jets ($p_T \geq 40$ GeV)!
  - Or 10 jets ($p_T \geq 80$ GeV)
- Backgrounds from ttbar estimated from jet multiplicity scaling parametrization
  - Stair-case/Berends Scaling + Poisson Term

$$N_{j+1}^{t\bar{t}+\text{jets}} / N_j^{t\bar{t}+\text{jets}} \equiv r^{t\bar{t}+\text{jets}}(j) = c_0^{t\bar{t}+\text{jets}} + c_1^{t\bar{t}+\text{jets}} / (j + c_2^{t\bar{t}+\text{jets}})$$

- B-jet multiplicity distribution fit in SR



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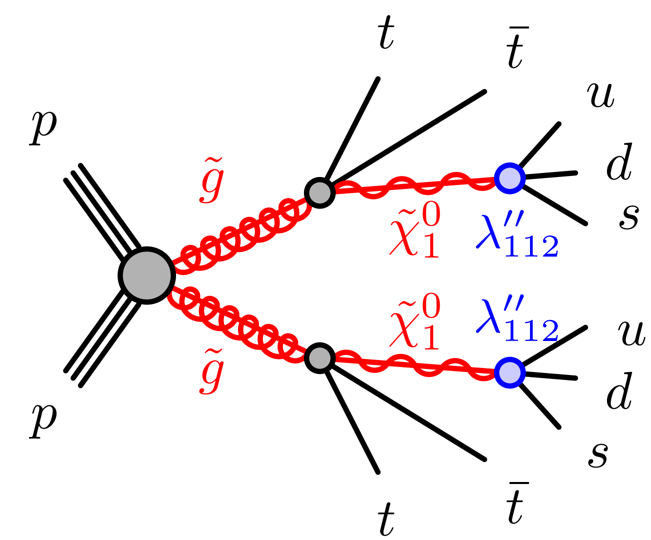
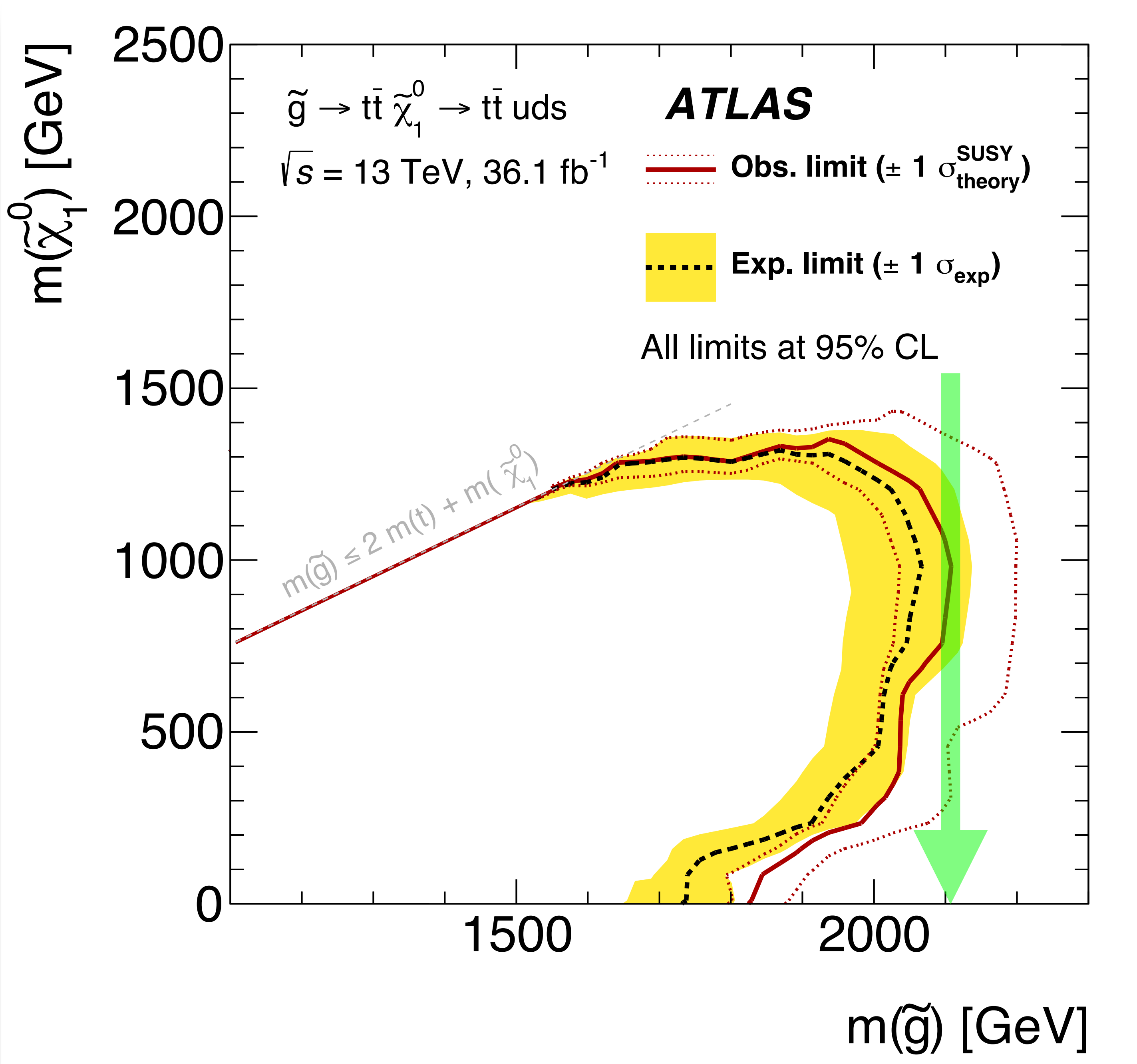
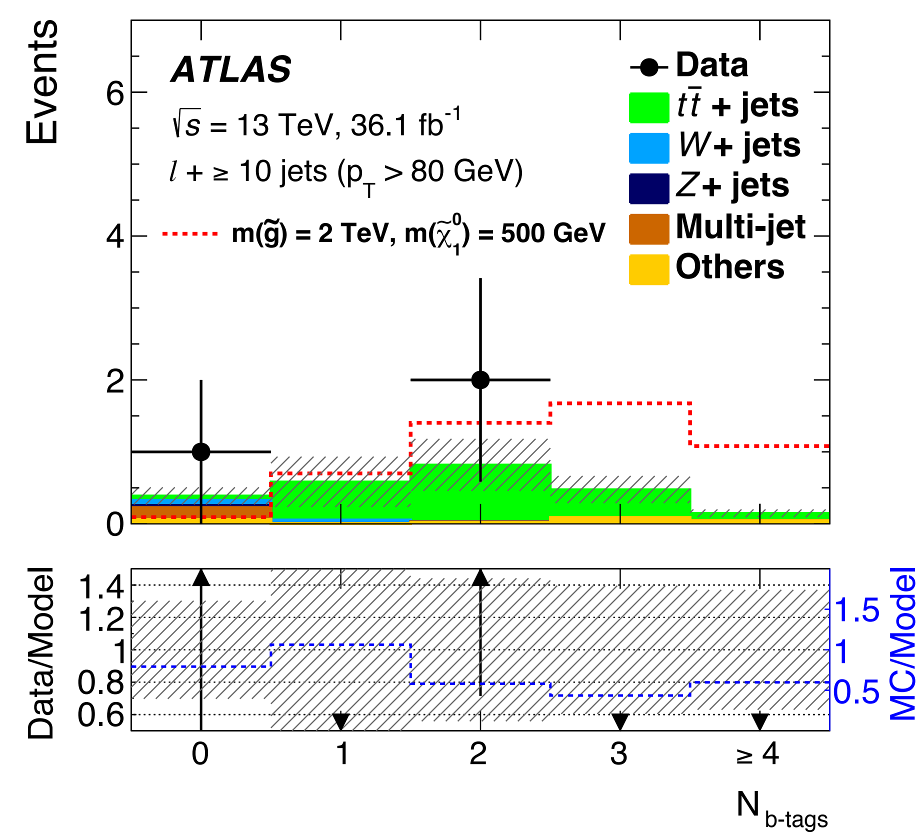
No significant deviation from SM.

→ *Very* strict limits on gluino mass despite complicated signature!







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Unfortunately RPV gluinos are probably not hiding there…
So that's depressing.

But what if another assumption has been wrong?

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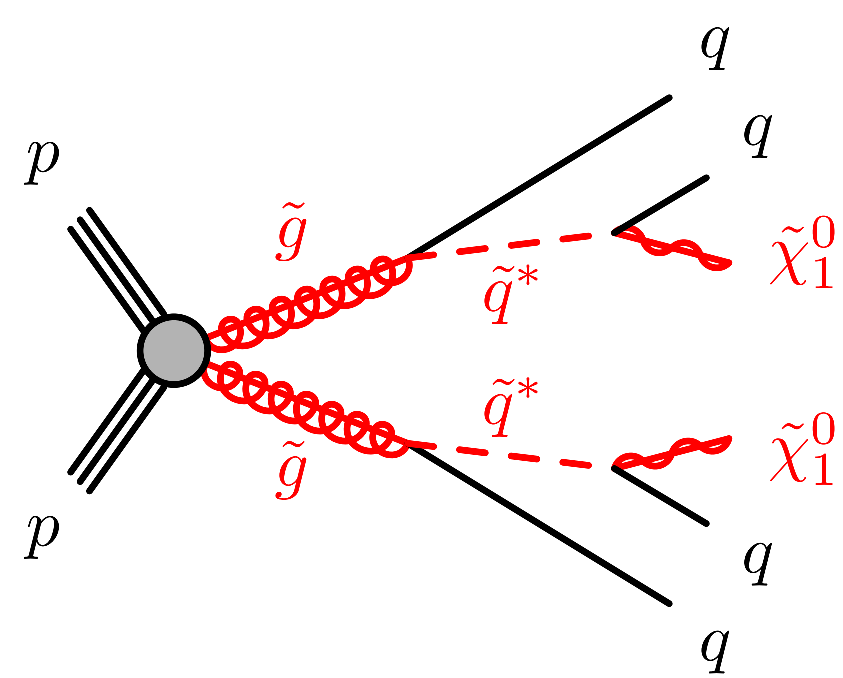
So that's depressing.

But what if another assumption has been wrong?

Many mechanisms for making long-lived sparticles!

(Squark mass ~ 1 PeV,
Gluino mass ~ TeV)

→ Gluino hadronizes to "R-Hadron" and decays within inner tracking detectors



e.g. Split SUSY:

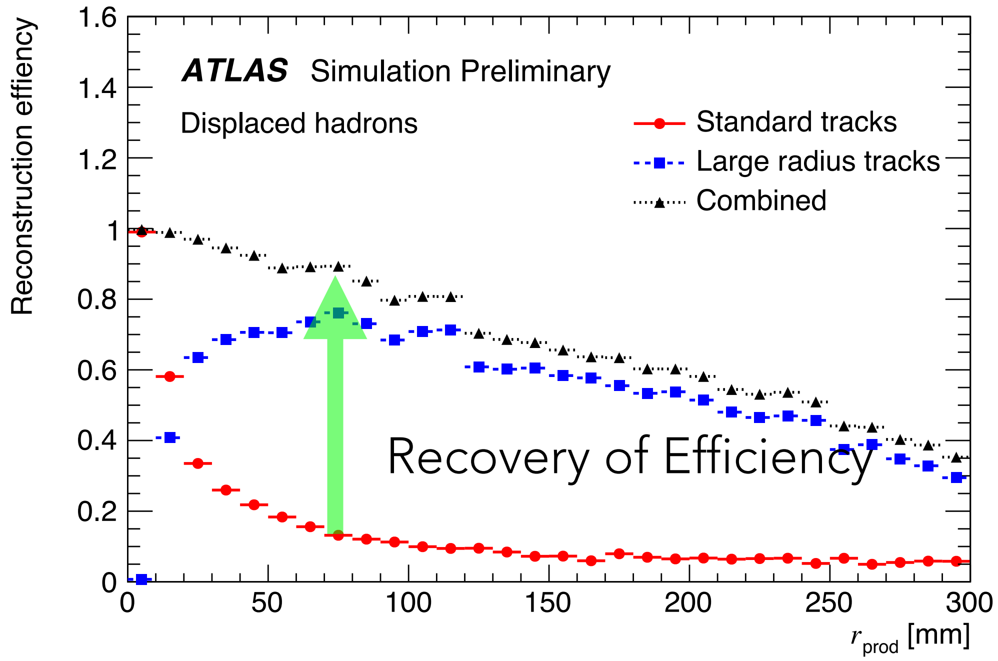
$$m_{\tilde{q}} \gg m_{\tilde{g}}$$

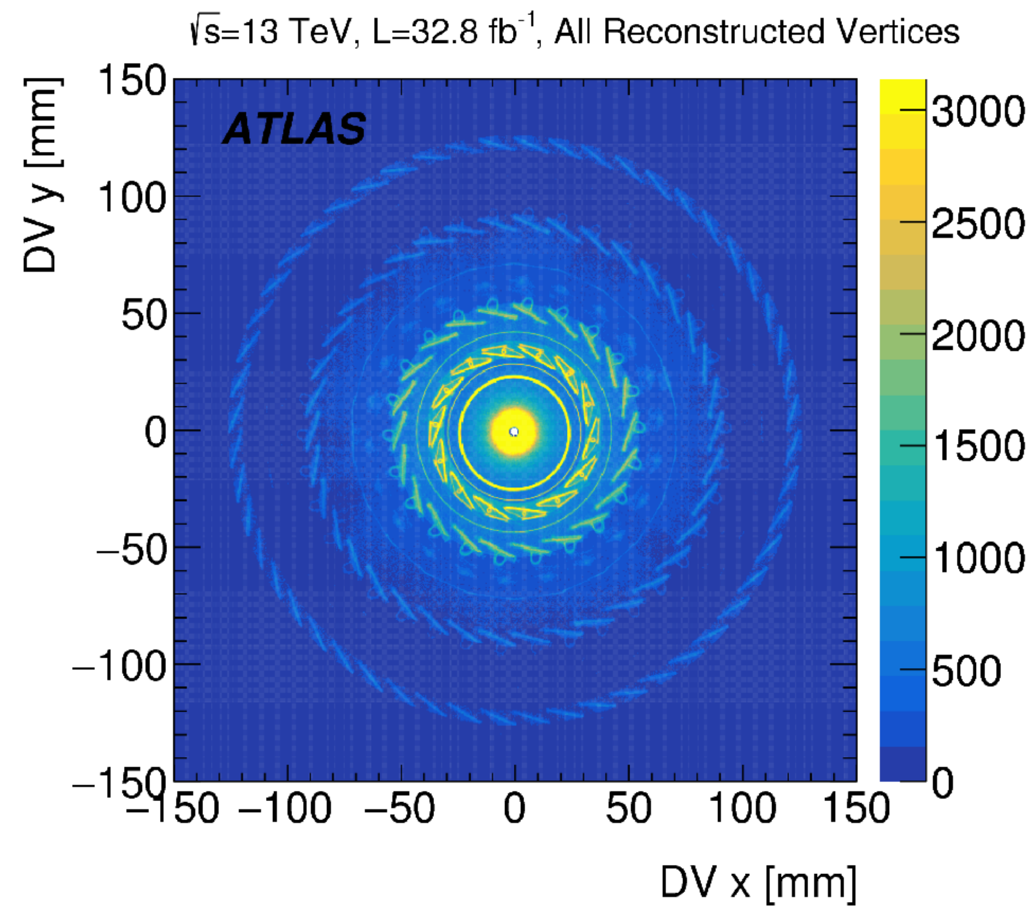
Macroscopic Lifetimes

Spectacular Displaced Signatures

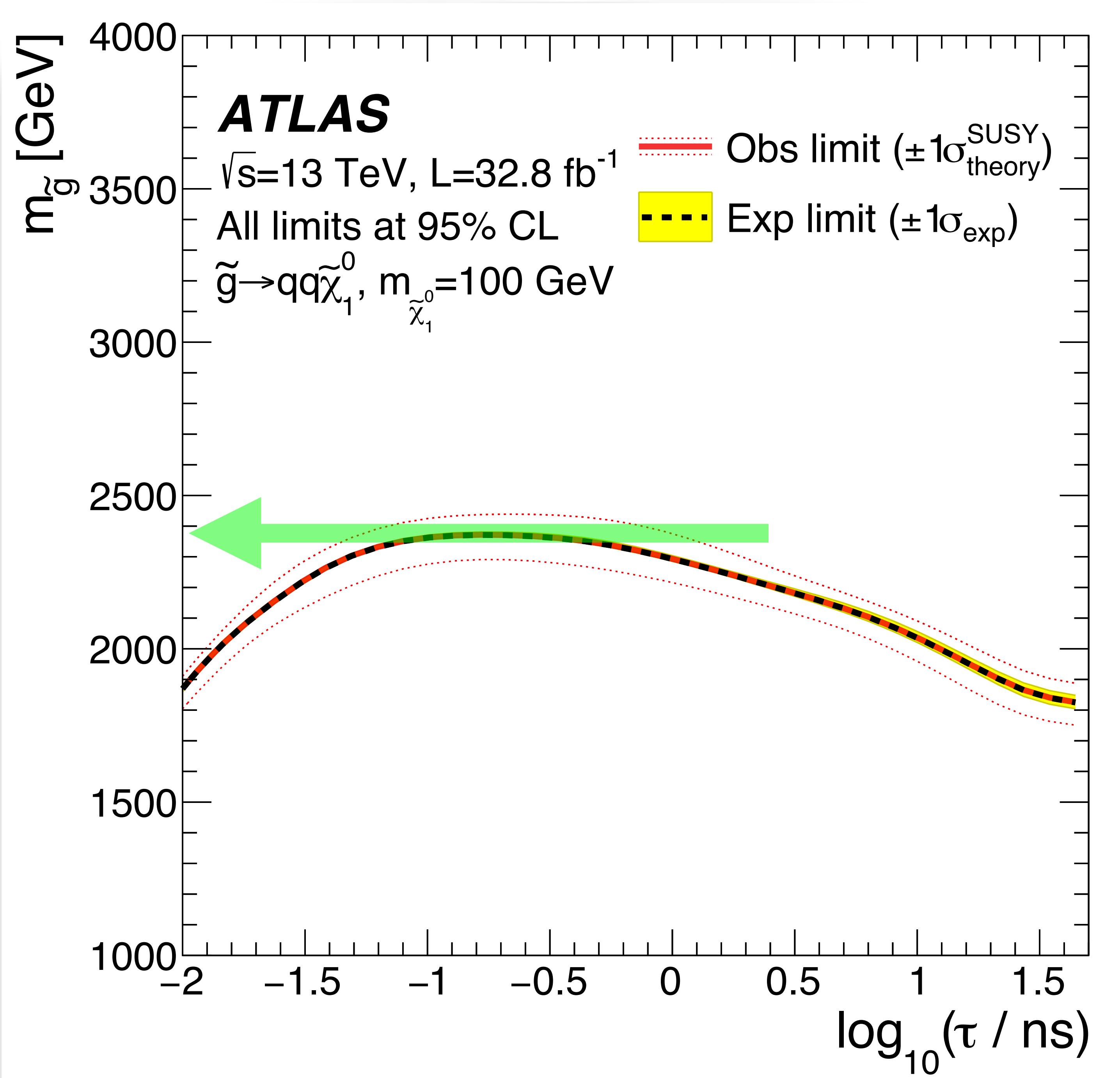
DISPLACED VERTEX + MET SEARCH

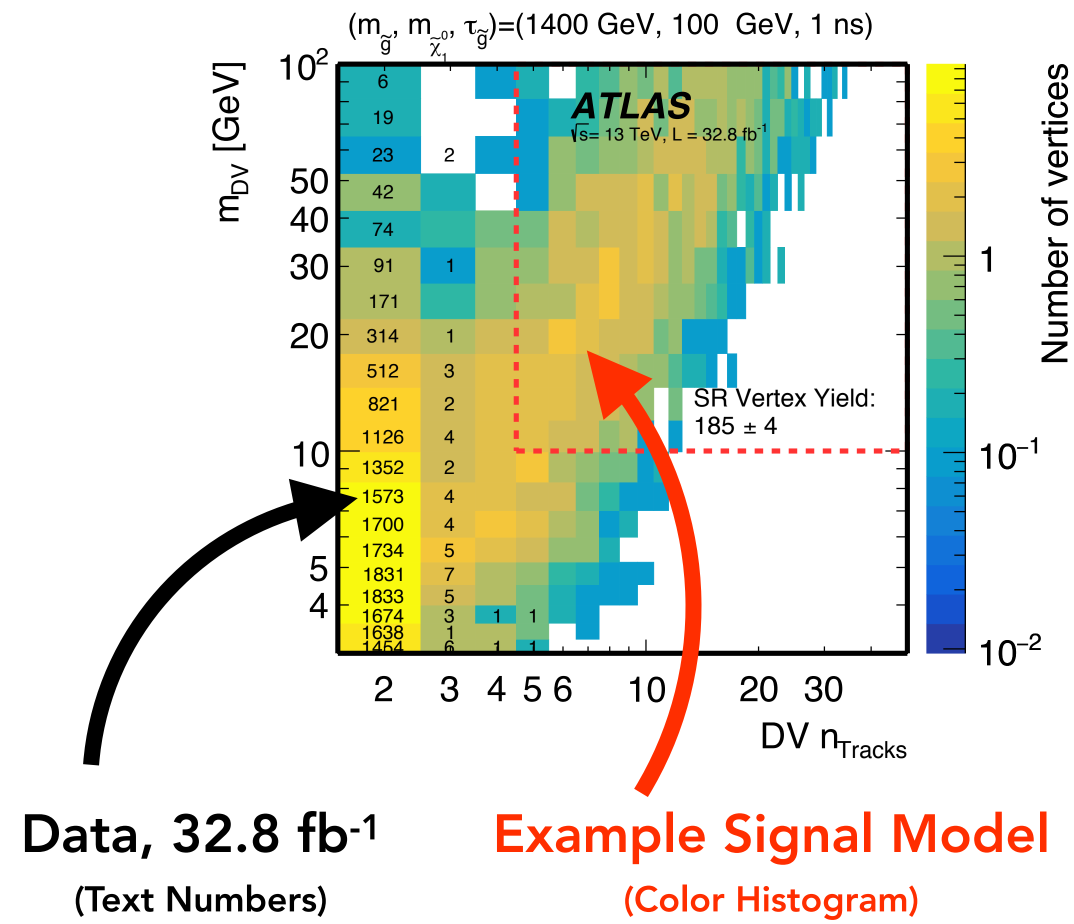
- Missing $E_T \geq 250$ GeV from neutralinos (or ISR for compressed spectra)
- Look for R-Hadron decay with Displaced Vertex:
  - Mass ≥ 10 GeV && Track Multiplicity ≥ 5
  - Roughly within pixel tracker volume
  - **Dedicated tracking and vertexing algorithms**
- No irreducible backgrounds. Purely instrumental.
  - High Mass Hadronic Interactions
  - Merged SM Vertices
  - Accidental High-Angle Track Crossing





ATLAS SUSY-2016-08 (Submitted to PRD)



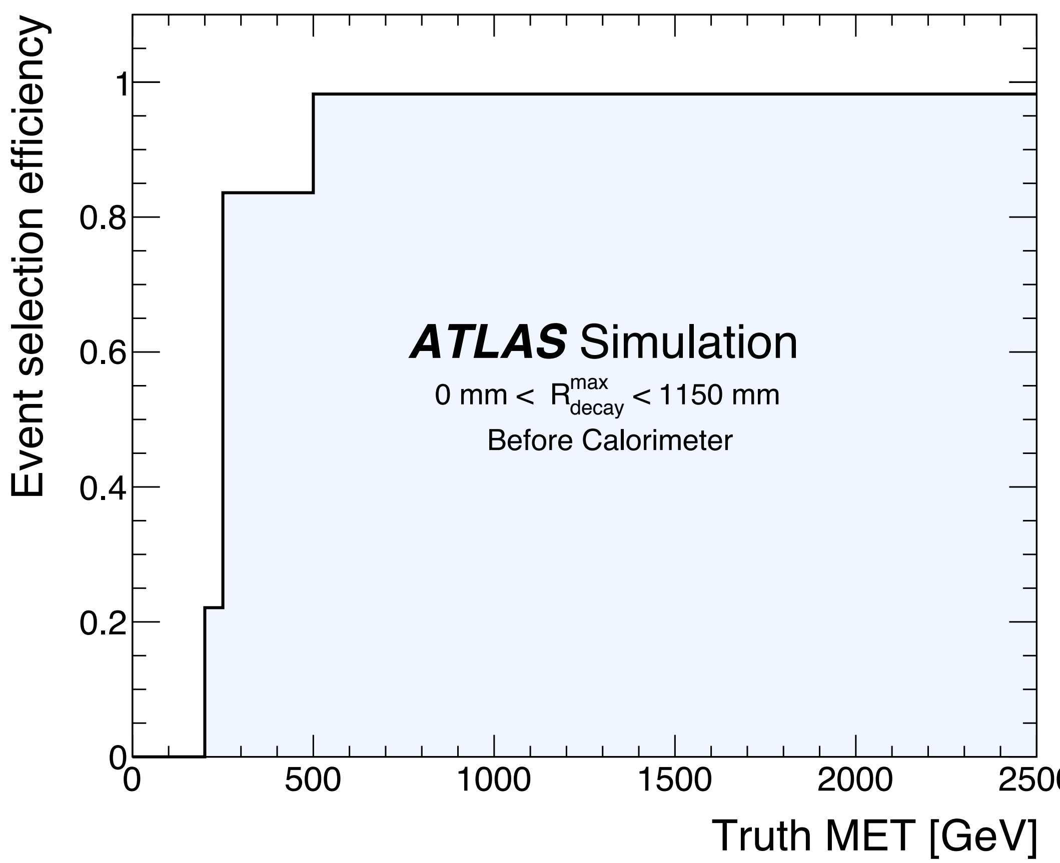


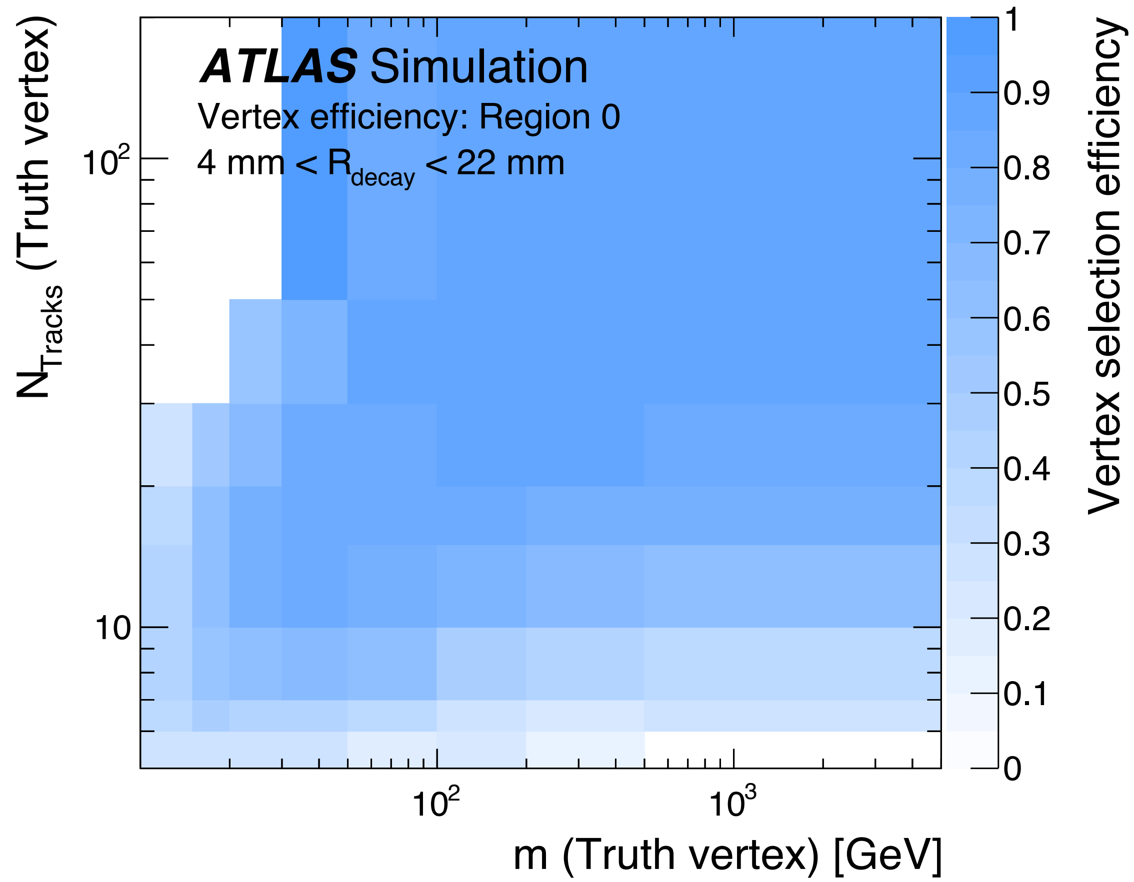
- Expected BG: 0.02 ± 0.02 Events
- Observed: 0 Events
- In absence of an excess, able to set limits on gluino masses to up ~2.37 TeV!
  - **The strictest limit on gluino mass of any search ever!**

ATLAS SUSY-2016-08 (Submitted to PRD)

We are trying to ease reinterpretations for long-lived particle searches.
Parametrized efficiencies on HEPData

We are making this a priority, so feedback from the theory community is very welcome! We want our information to be useful!





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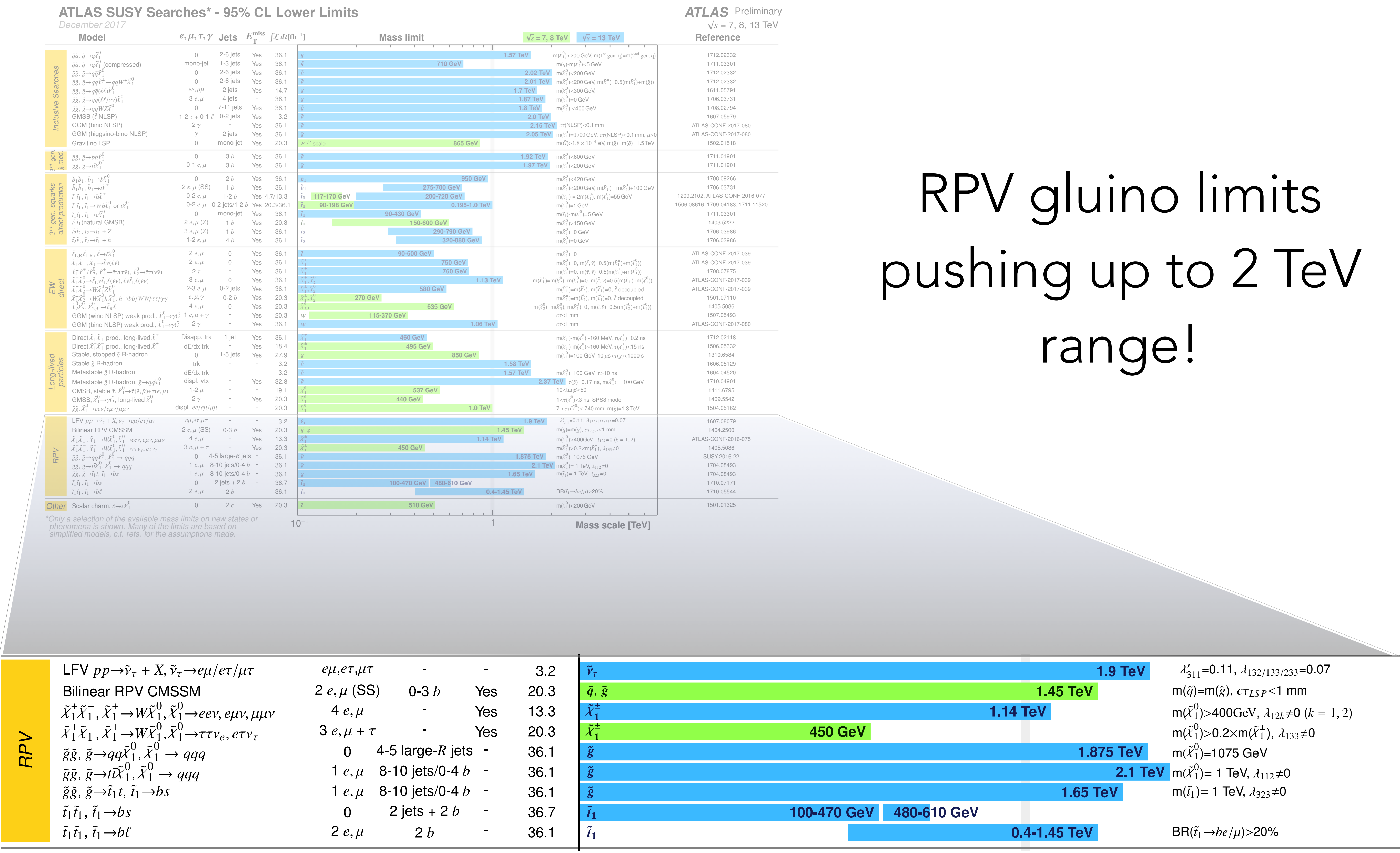
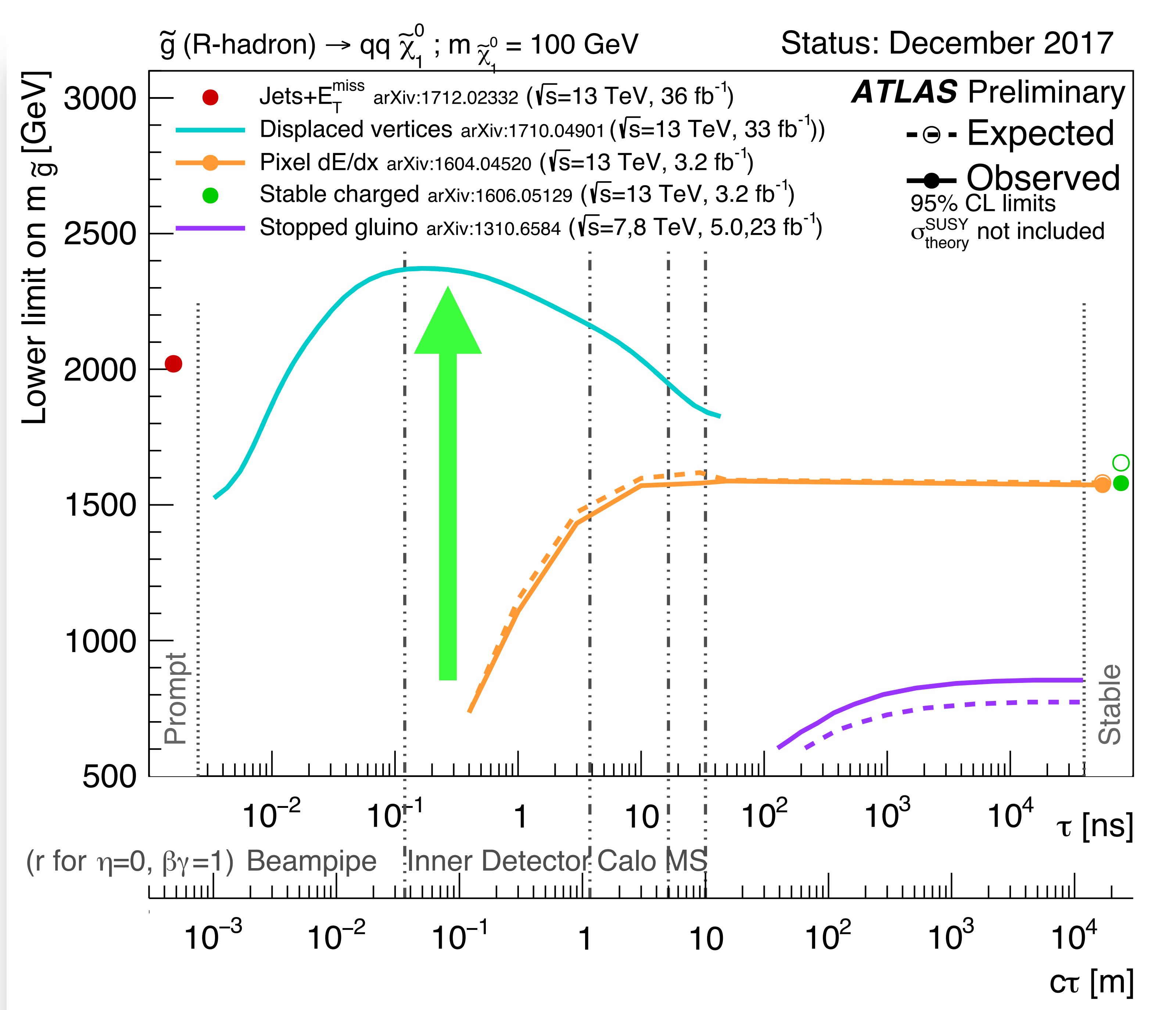


RPV gluino limits pushing up to 2 TeV range!

And LLP limits even higher to ~2.4 TeV!



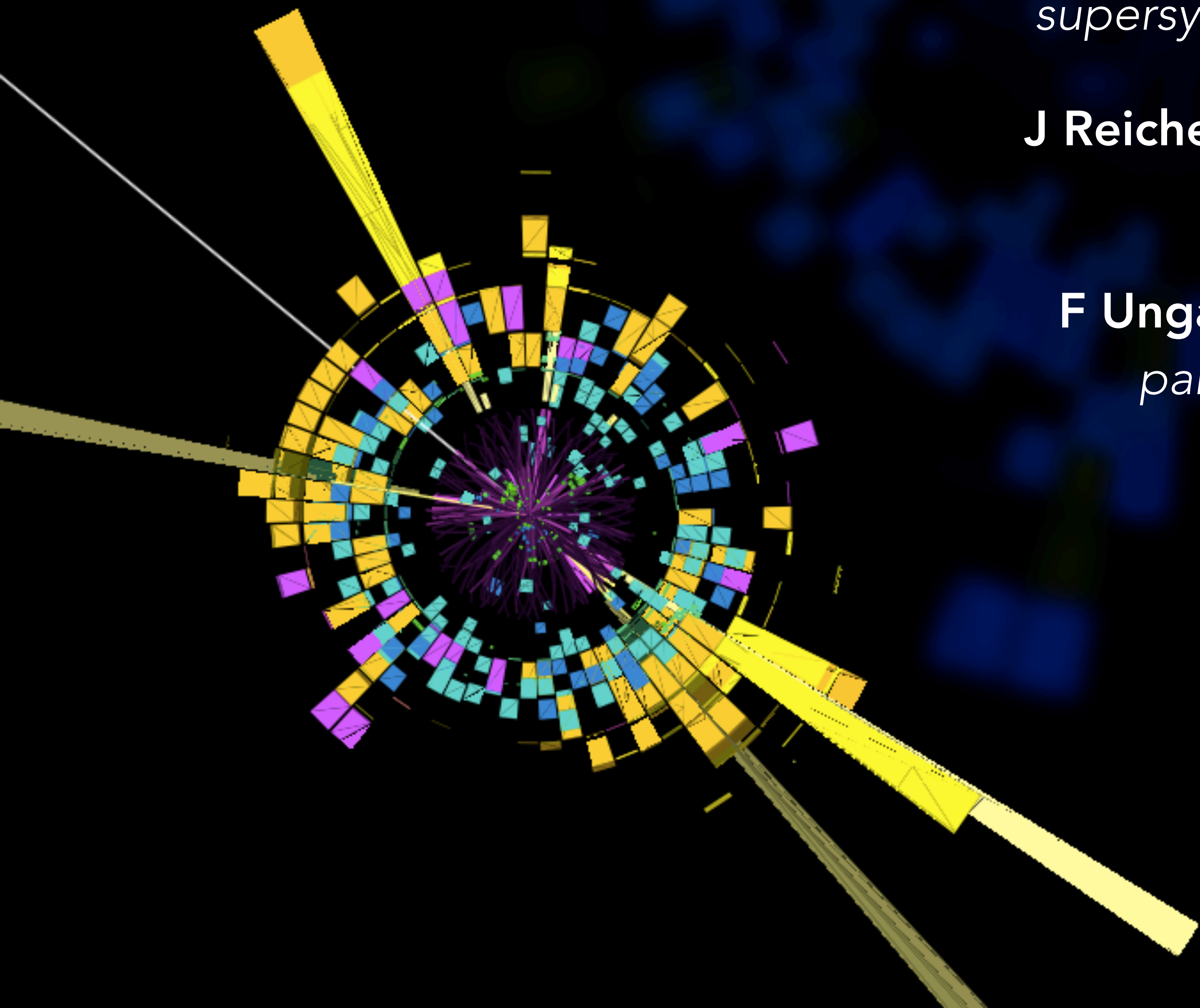
There's more to this story from ATLAS. See talks by:

B Hooberman: *SUSY searches with ATLAS*

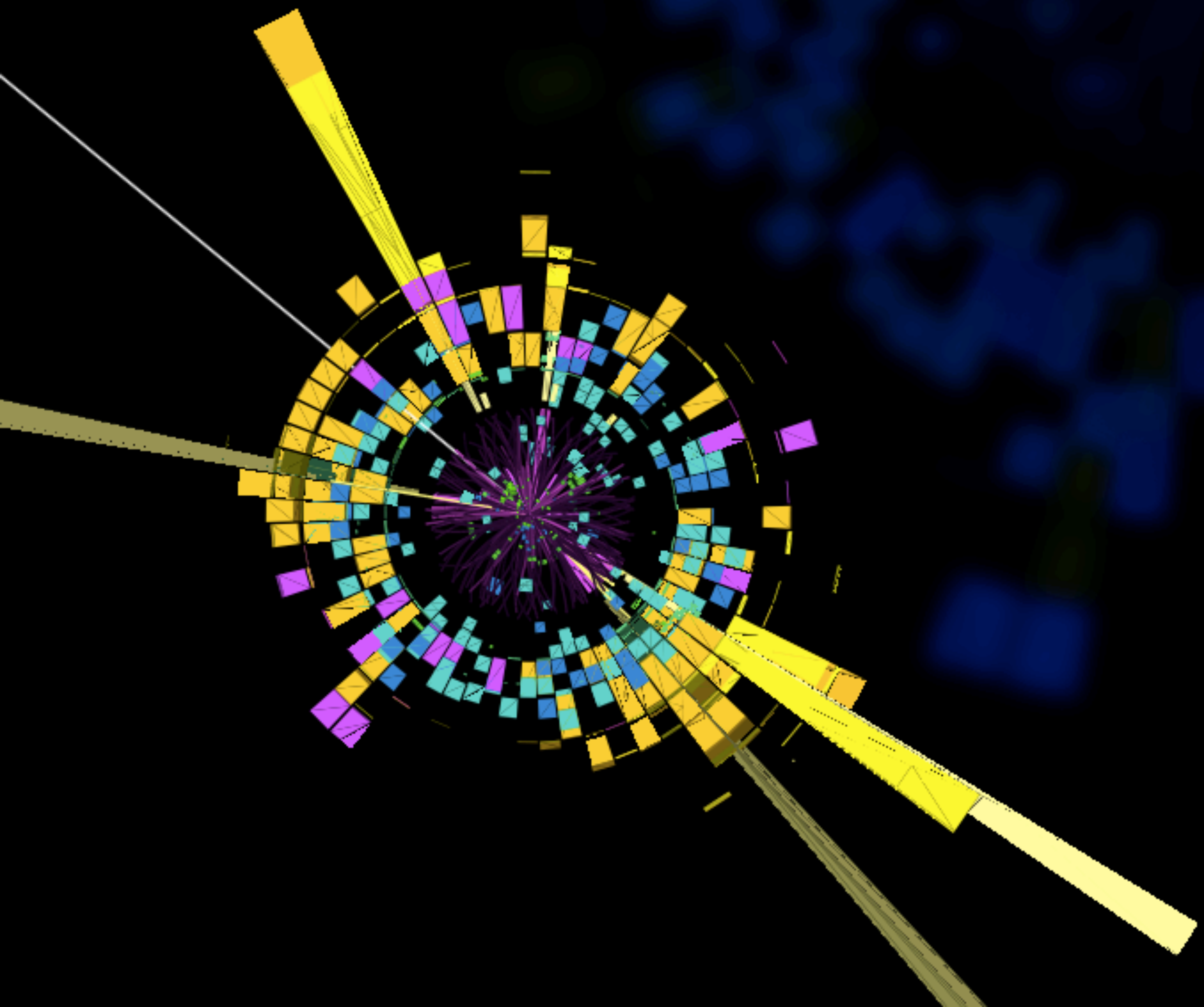
K Onogi: *Reconstruction techniques in supersymmetry searches in the ATLAS experiment*

J Reichert: *Search for compressed SUSY scenarios with the ATLAS detector*

F Ungaro: *Searches for stops in scenarios with R-parity violating sparticle decays, or long-lived sparticles with ATLAS*

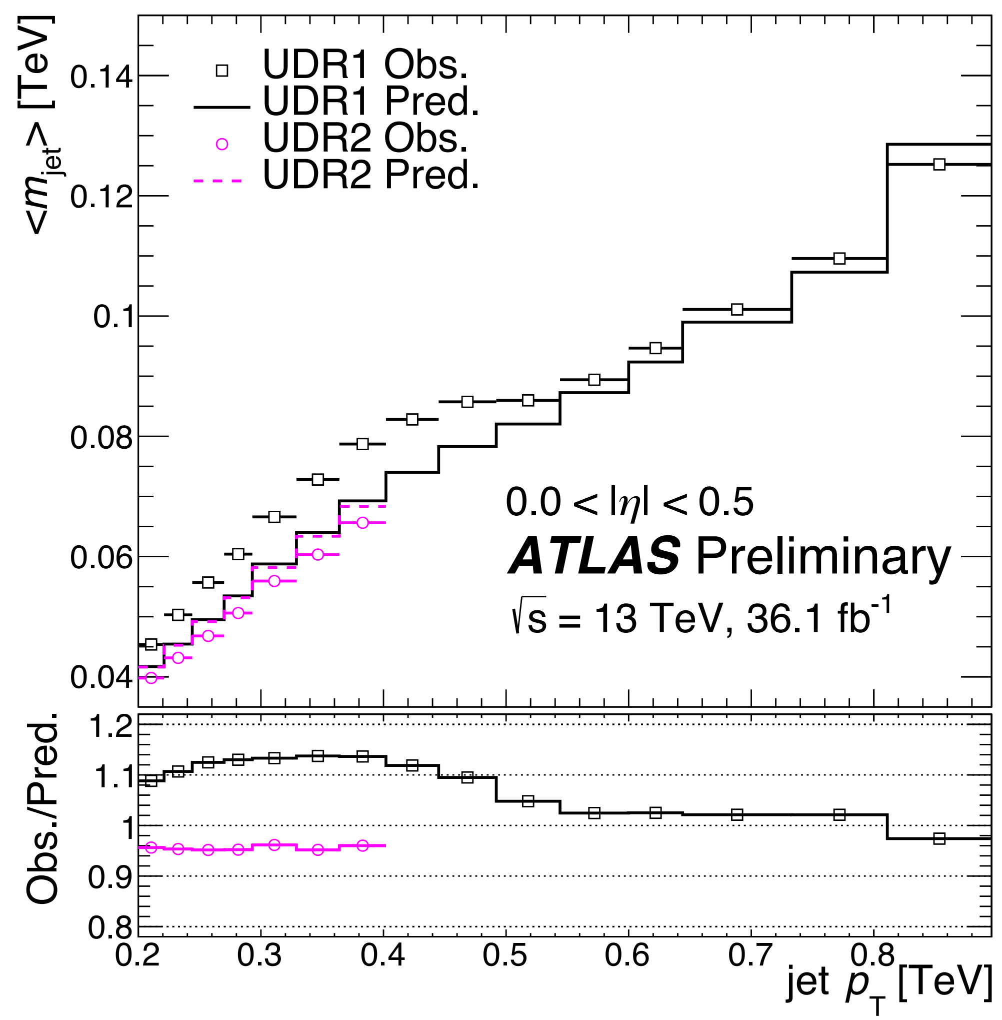


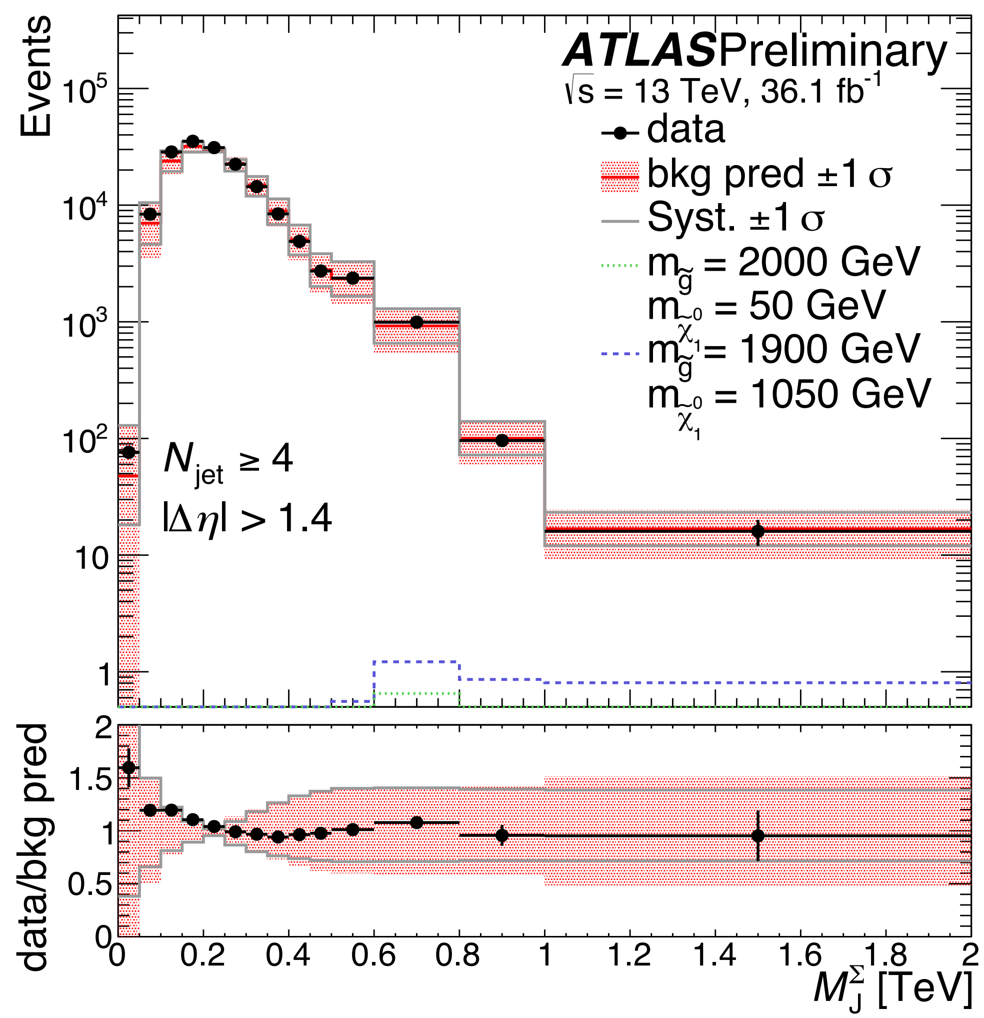
Thanks for your attention!



Additional RPV Multijet Material

		N_{jet} (p_T > 200 GeV)	b-tag	$p_{T,1}$	$\lvert\Delta\eta_{12}\rvert$	M_J^{Σ}
CR	3jCR	= 3	-	-	-	-
UDR	UDR1	= 2	-	> 400 GeV	-	-
	UDR2	= 4	-	< 400 GeV	-	-
VR	4jVR	≥ 4	-	> 400 GeV	> 1.4	-
	5jVR	≥ 5	-	-	> 1.4	-
	4jVRb	≥ 4	Yes	> 400 GeV	> 1.4	-
	5jVRb	≥ 5	Yes	-	> 1.4	-
SR	4jSR	≥ 4	-	> 400 GeV	< 1.4	> 1.0 TeV
	5jSR	≥ 5	-	-	< 1.4	> 0.8 TeV
	4jSRb	≥ 4	Yes	> 400 GeV	< 1.4	> 1.0 TeV
	5jSRb	≥ 5	Yes	-	< 1.4	> 0.8 TeV
		≥ 5	Yes	-	< 1.4	> 0.6 TeV





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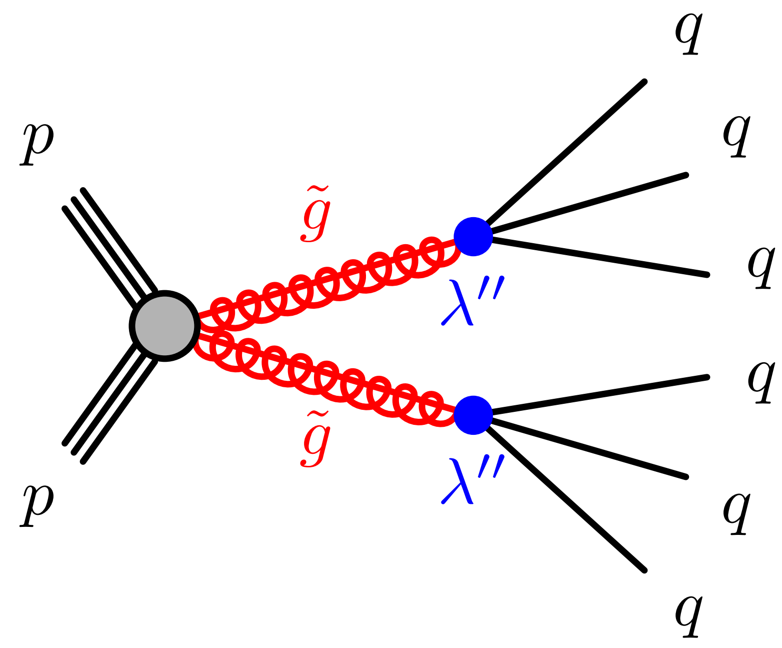
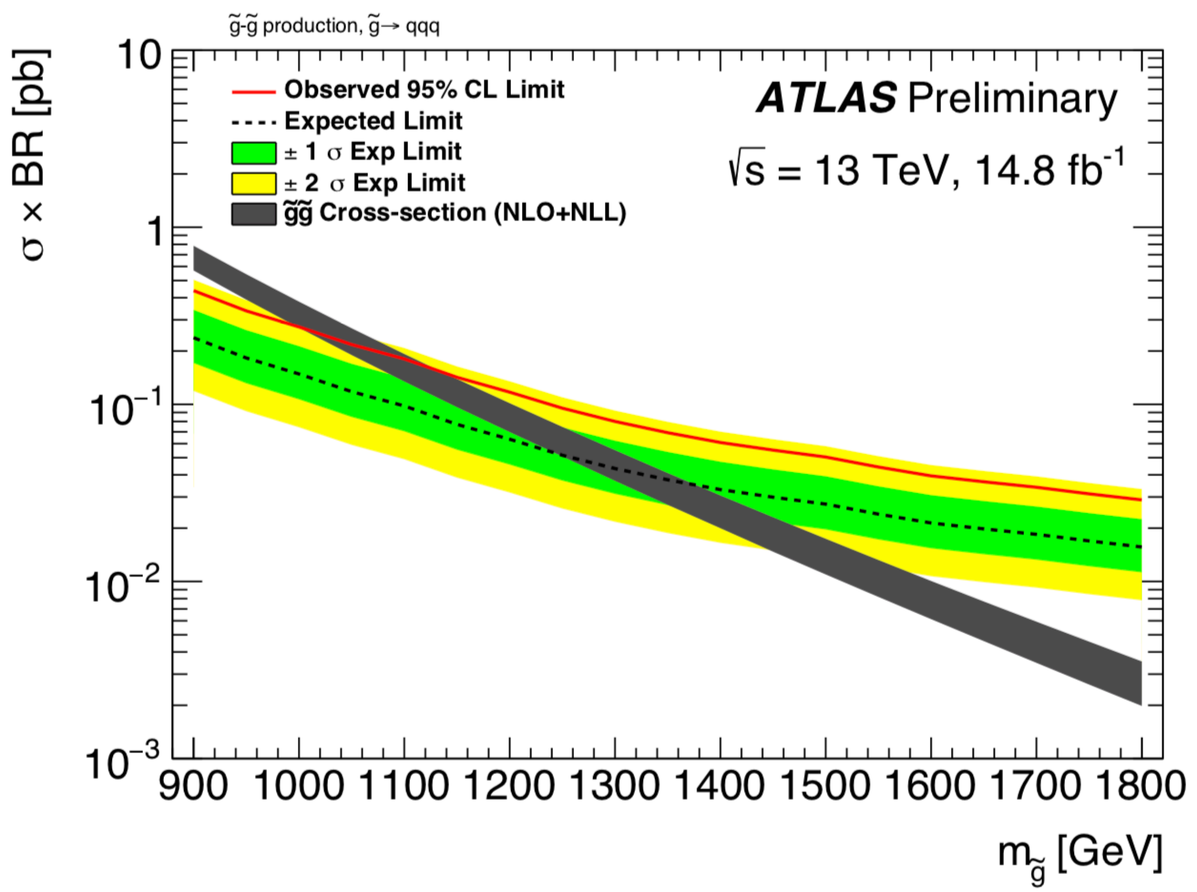
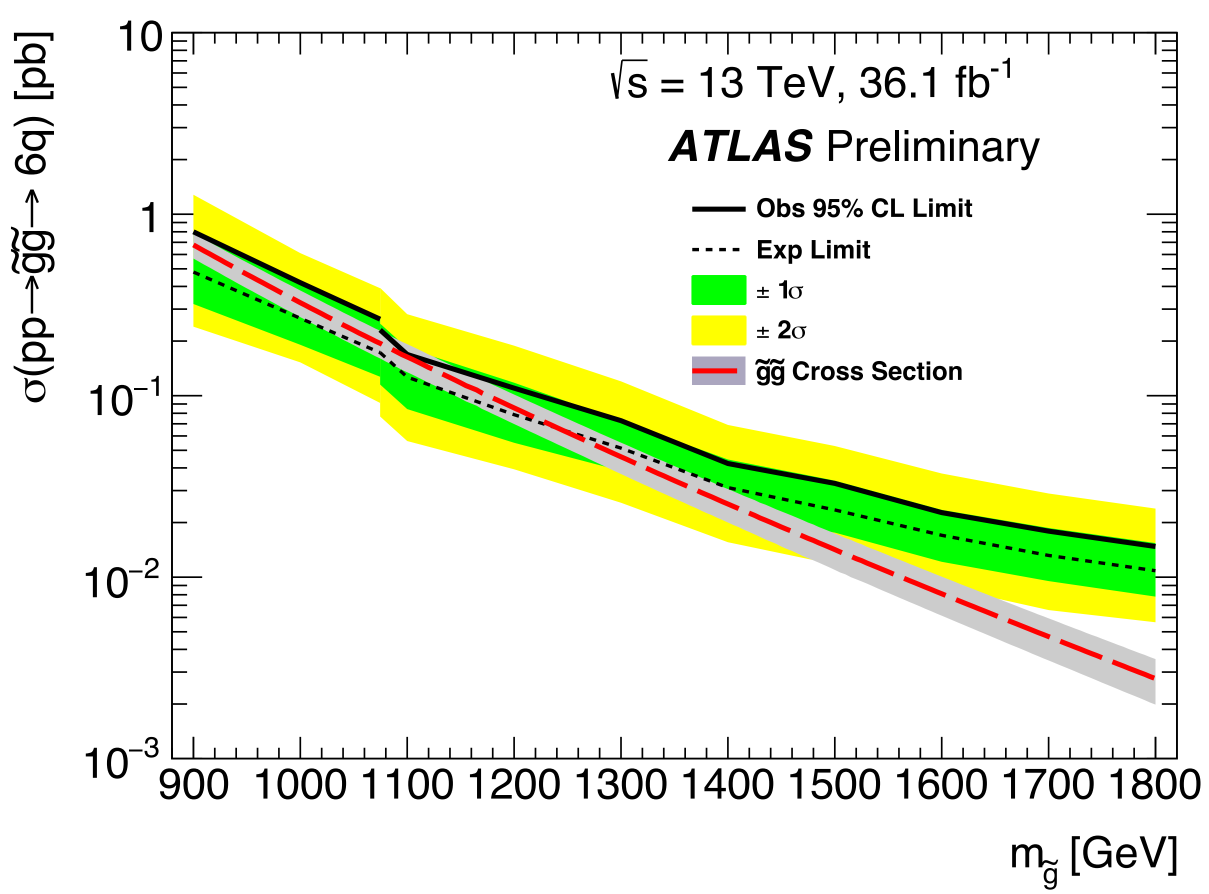


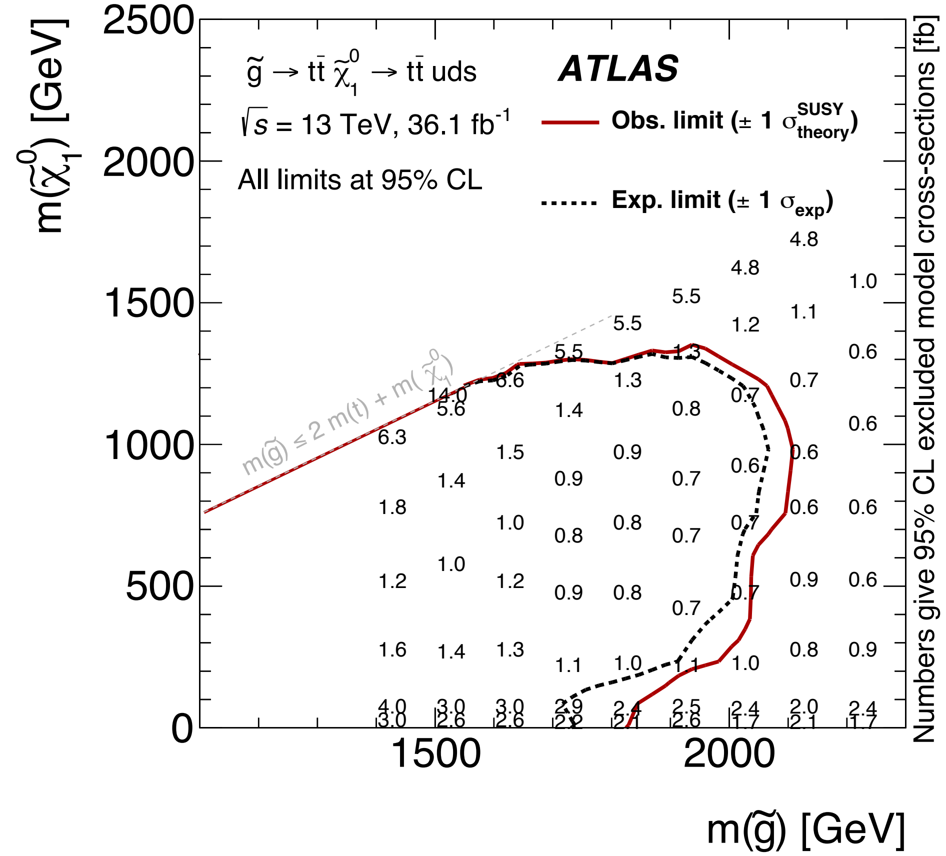
ICHEP 2016



SUSY 2017



Additional RPV Multijet+1L Material



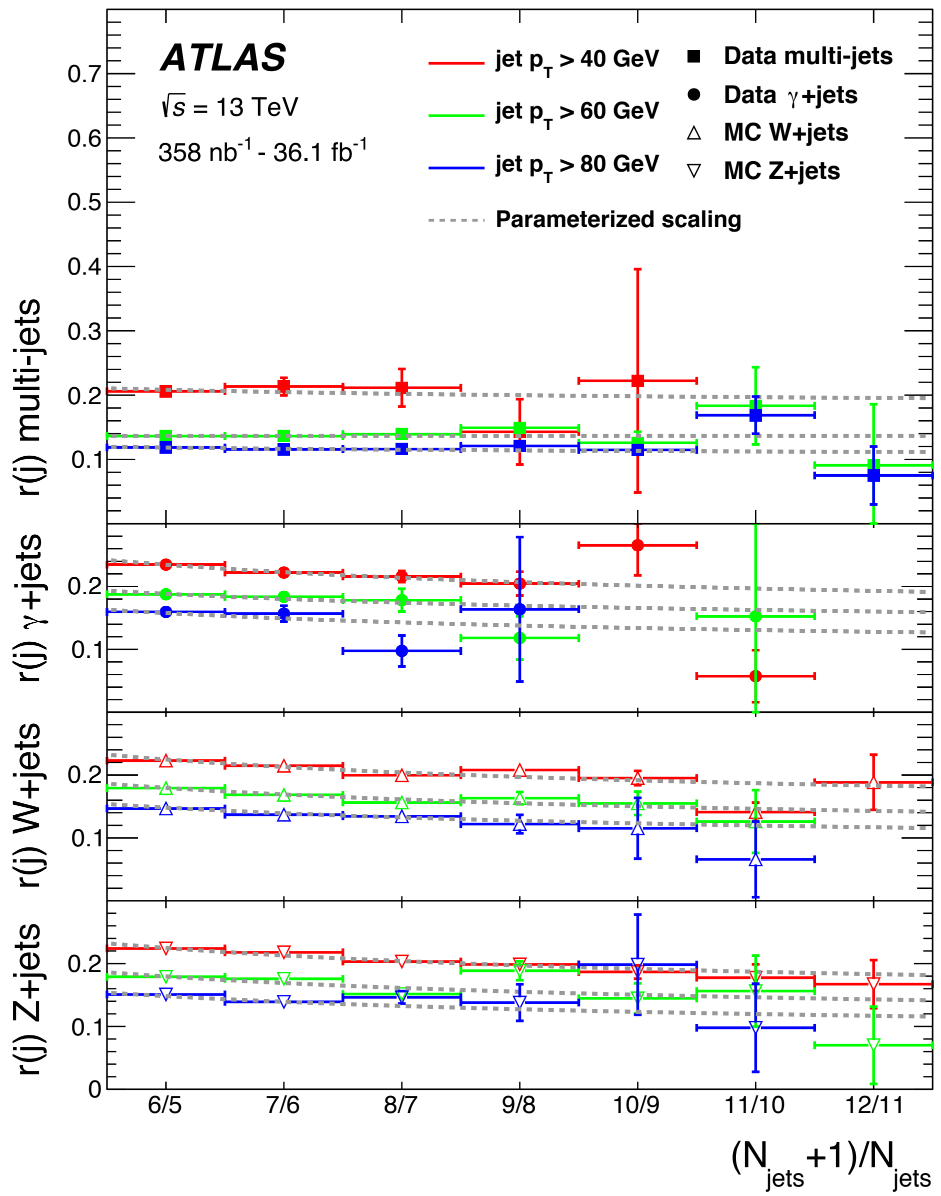
$\tilde{g} \to t\bar{t}\tilde{\chi}^0_1 \to t\bar{t}uds$ ($m_{\tilde{g}} = 2000$ $GeV, m_{\tilde{\chi}^0_1} = 941$ GeV)	N_{raw}			$N_{weighted}$			Total Eff.		
All Events	10000			10557.0			100.0 %		
Lepton trigger	5647			5713.4			54.1 %		
>= 1 baseline lepton	4360			4411.2			41.8 %		
>= 1 signal lepton	3535			3623.0			34.3 %		
>= 5 jets, $p_{\mathrm{T}} \geq 40$ GeV	3535			3580.9			33.9 %		
	jet $p_{\mathrm{T}} \geq 40$ GeV			jet $p_{\mathrm{T}} \geq 60$ GeV			jet $p_{\mathrm{T}} \geq 80$ GeV		
	N_{raw}	$N_{weighted}$	Total Eff.	N_{raw}	$N_{weighted}$	Total Eff.	N_{raw}	$N_{weighted}$	Total Eff.
$\geq$ 8 jets	3512	3556.6	33.7%	3397	3436.0	32.5%	3116	3152.8	29.9%
$\geq$ 9 jets	3438	3483.8	33.0%	3128	3177.1	30.1%	2533	2568.1	24.3%
$\geq$ 10 jets	3245	3271.5	31.0%	2599	2654.9	25.1%	1757	1785.9	16.9%
$\geq$ 11 jets	2814	2852.3	27.0%						
$\geq$ 12 jets	2246	2266.8	21.5%						
$\geq$ 8 jets, $\geq$ 3 b-tags	1907	2057.5	19.5%	1515	1675.8	15.9%	1164	1301.3	12.3%
$\geq$ 9 jets, $\geq$ 3 b-tags	1886	2035.8	19.3%	1447	1605.6	15.2%	1012	1114.9	10.6%
$\geq$ 10 jets, $\geq$ 3 b-tags	1809	1936.3	18.3%	1249	1384.2	13.1%	759	830.1	7.9%
$\geq$ 11 jets, $\geq$ 3 b-tags	1615	1735.0	16.4%						
$\geq$ 12 jets, $\geq$ 3 b-tags	1324	1419.5	13.4%						

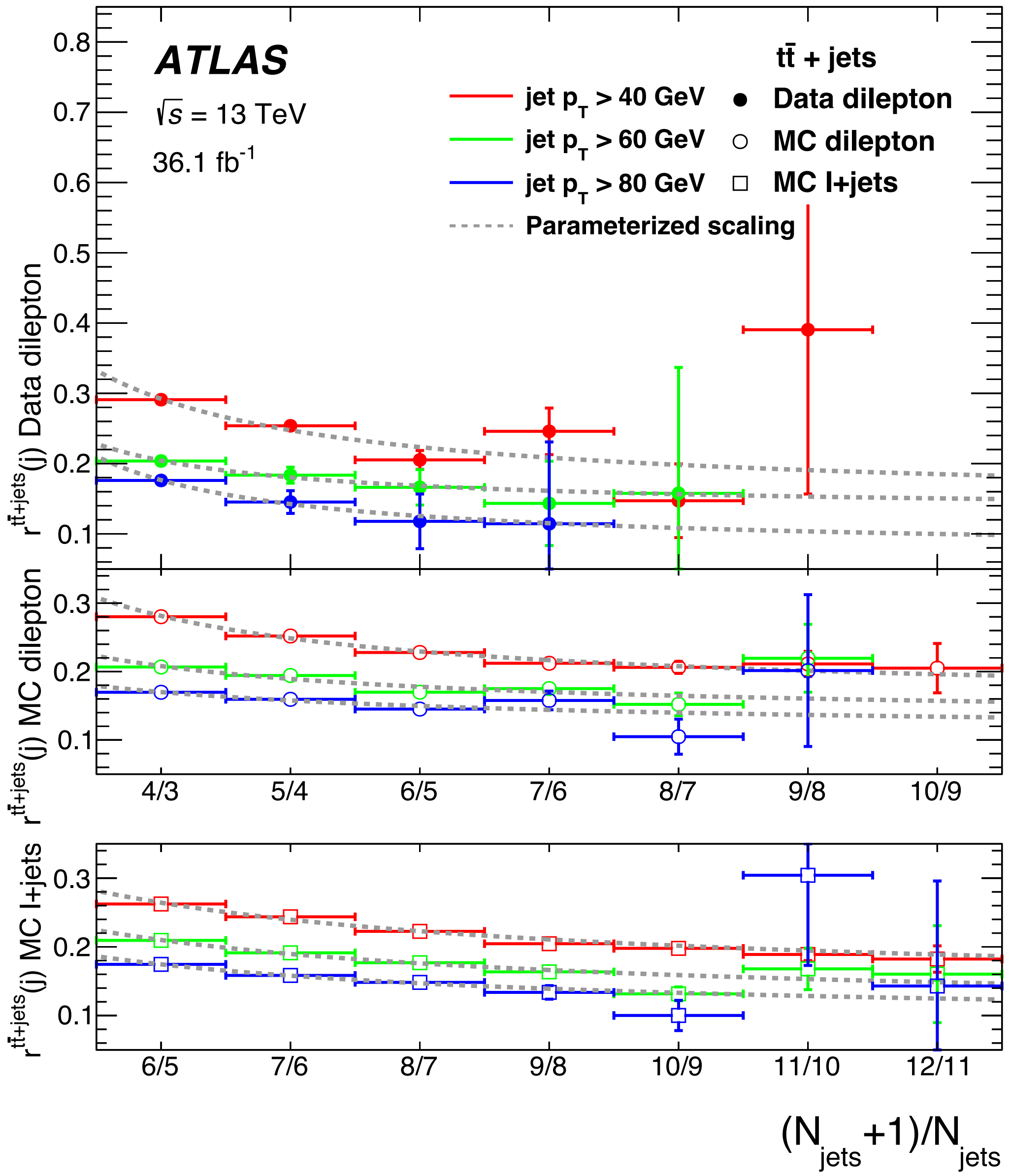
Additional RPV Multijet+1L Material

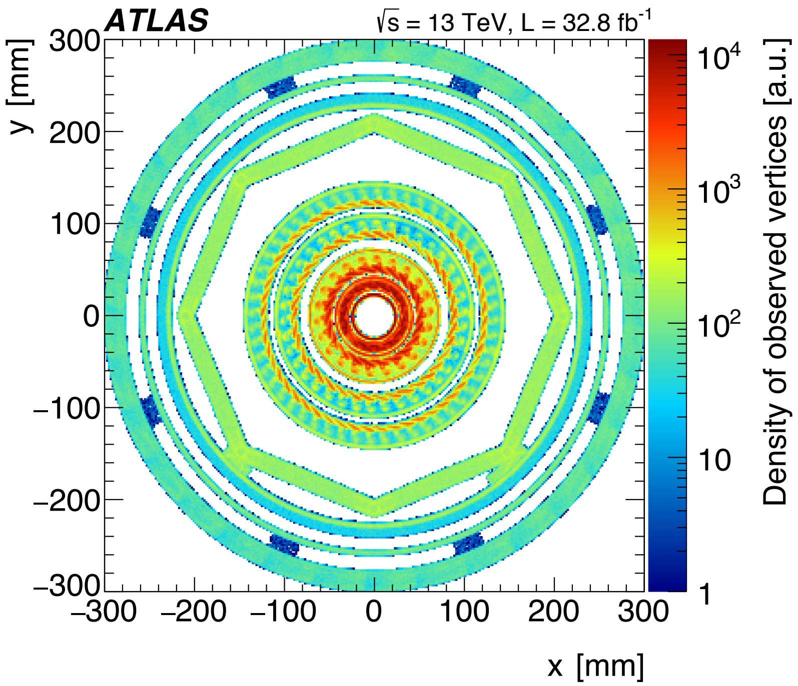
$$N_{j,b}^{t\bar{t}+\text{jets}} = N_j^{t\bar{t}+\text{jets}} \cdot f_{j,b},$$

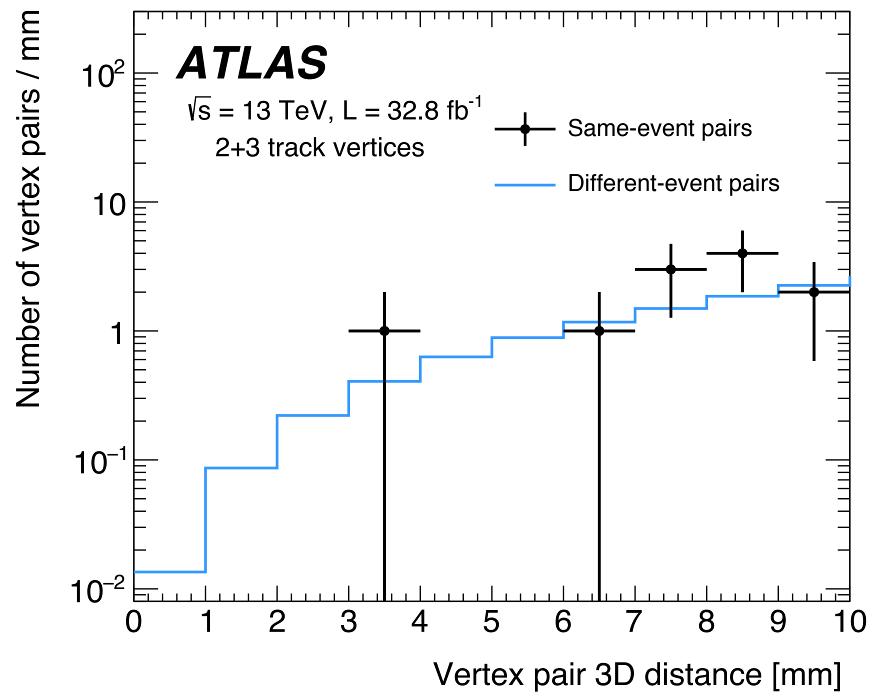
$$f_{(j+1),b} = f_{j,b} \cdot x_0 + f_{j,(b-1)} \cdot x_1 + f_{j,(b-2)} \cdot x_2,$$

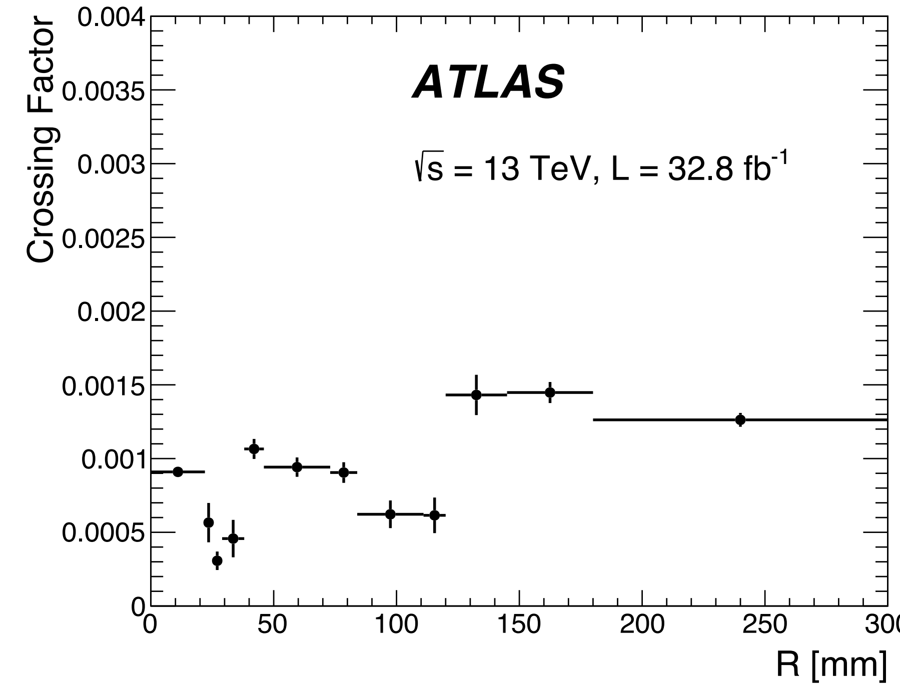
$$N_{j+1}^{t\bar{t}+\text{jets}} / N_j^{t\bar{t}+\text{jets}} \equiv r^{t\bar{t}+\text{jets}}(j) = c_0^{t\bar{t}+\text{jets}} + c_1^{t\bar{t}+\text{jets}} / (j + c_2^{t\bar{t}+\text{jets}}),$$









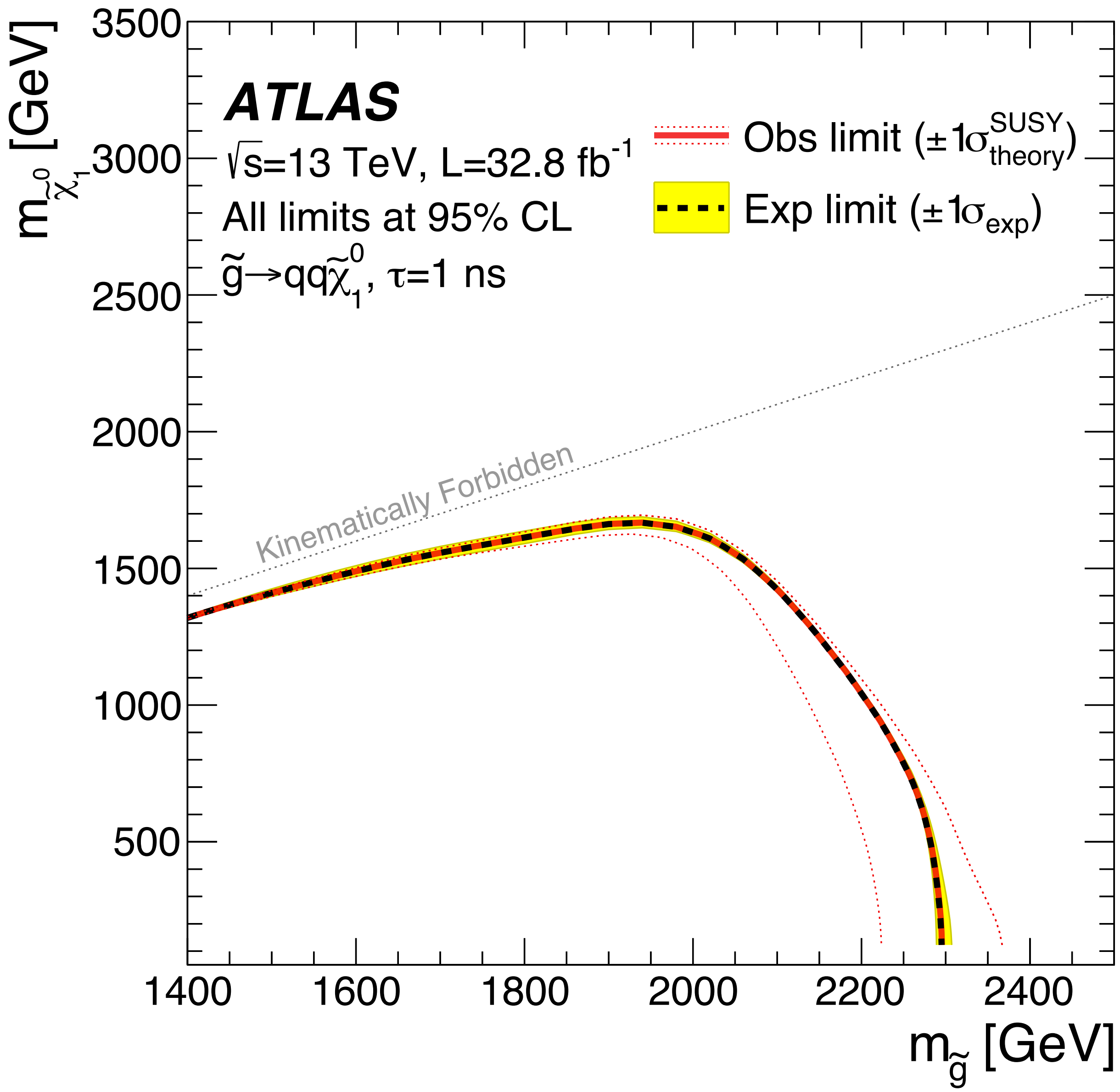


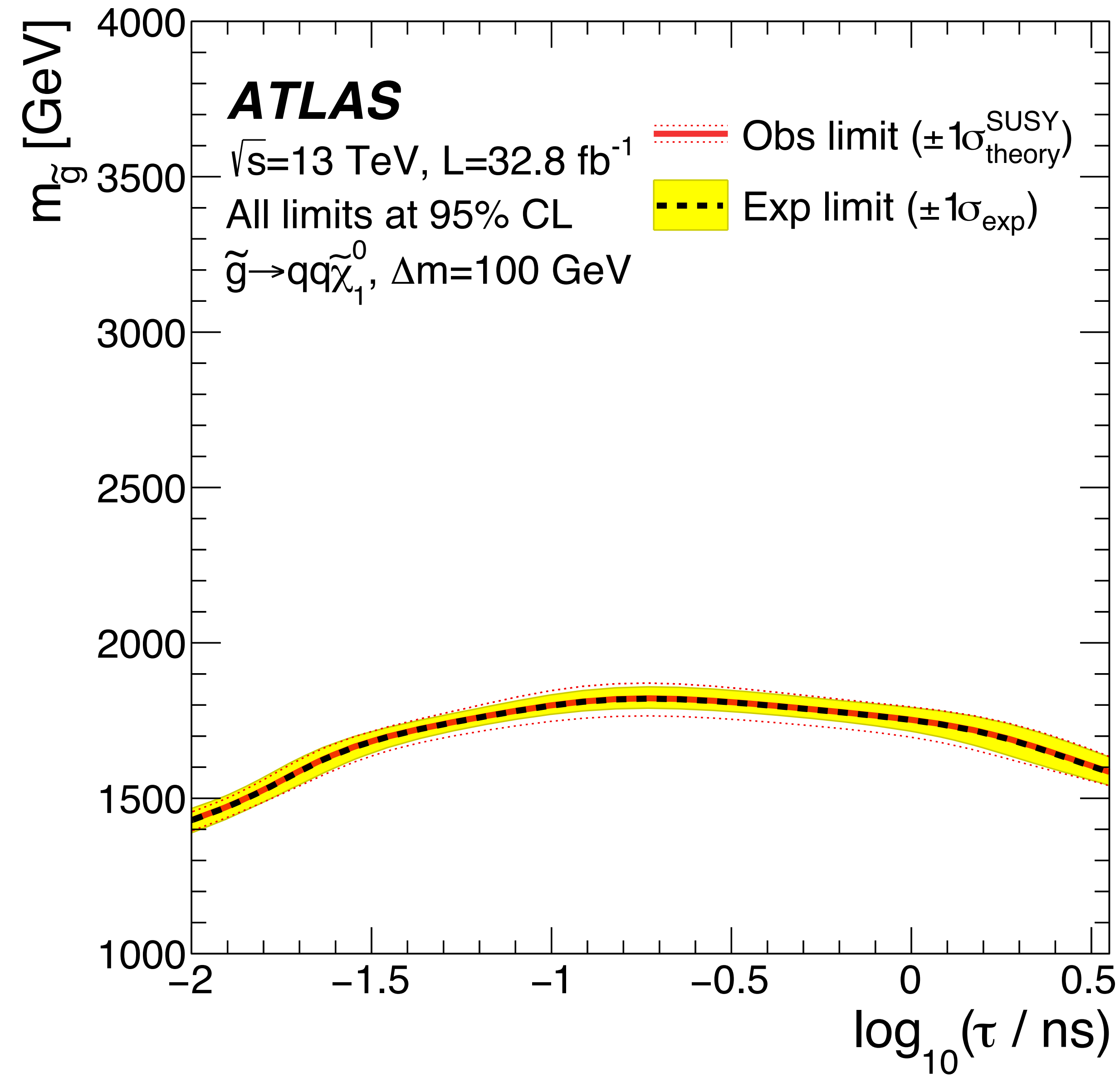
($m_{\tilde{g}}$ [GeV], $m_{\tilde{\chi}_1^0}$ [GeV], τ [ns])	(1400, 100, 1)	(2000, 100, 1)	(2000, 1800, 1)	(1400, 100, 0.1)
Initial Events	827	32	32	827
Trigger-based data reduction	826	32	27	827
Event cleaning	826	32	27	827
Good Runs List	826	32	27	827
Primary vertex	826	32	27	827
NCB veto	823	32	26	824
$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger	791	31	24	803
$E_{\mathrm{T}}^{\mathrm{miss}}$ filter	760	31	17	717
Offline $E_{\mathrm{T}}^{\mathrm{miss}}$	671	29	7	641
DV fiducial acceptance	620	28	6	625
DV fit quality	615	27	6	621
DV displacement	613	27	6	608
Material veto	493	22	5	544
Disabled module veto	480	22	5	541
DV track multiplicity	331	15	3	455
DV mass	305	14	2	442

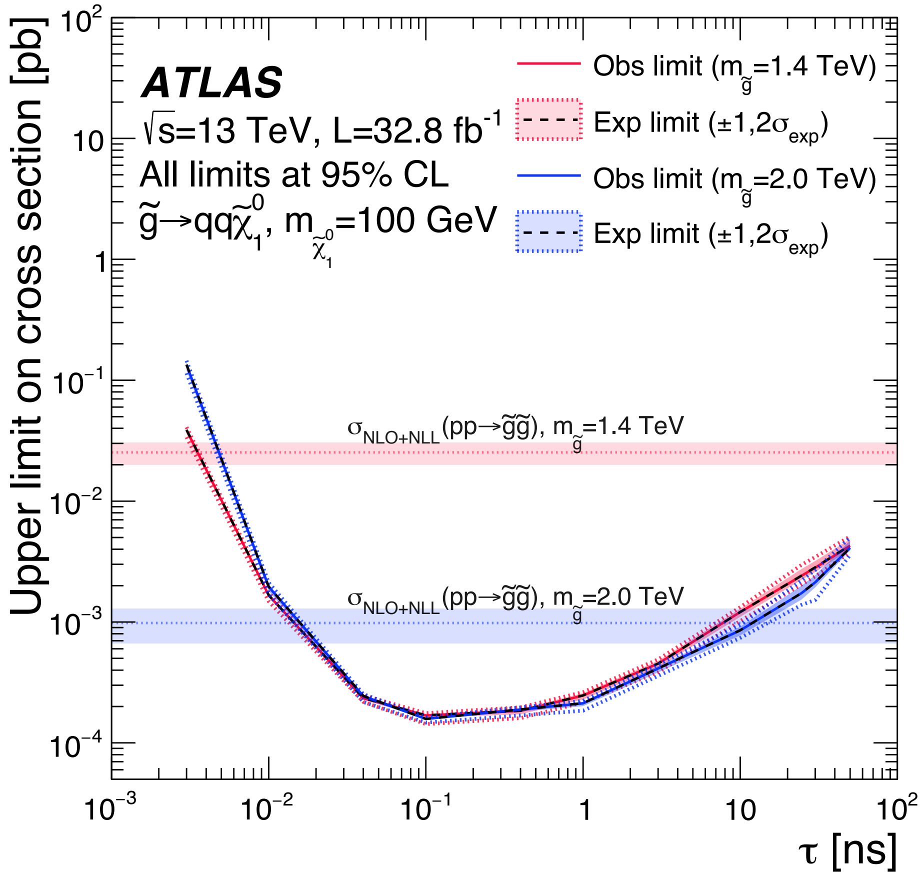
- Hadronic interactions killed by data-driven material map
- Merging of low mass vertices uses other-event spatial correlations
- Random crossing of a track with a vertex from a crossing probability defined in low n-track regions

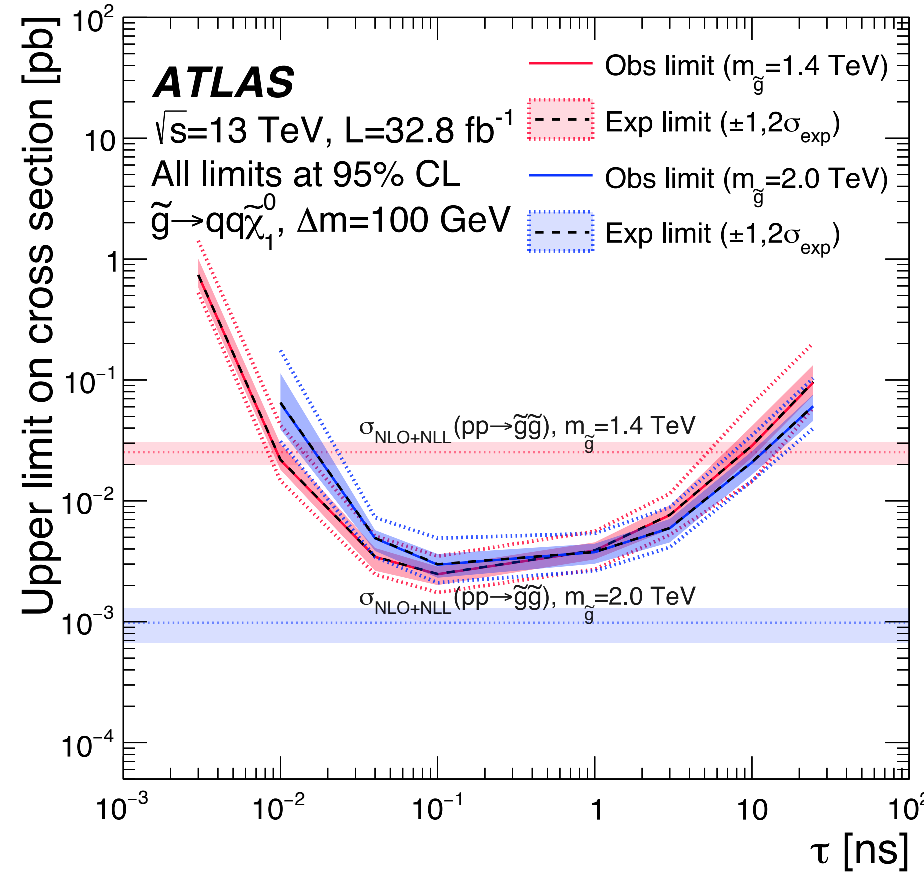
ATLAS SUSY-2016-08 (Submitted to PRD)

Additional DV+MET Exclusion Plots









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