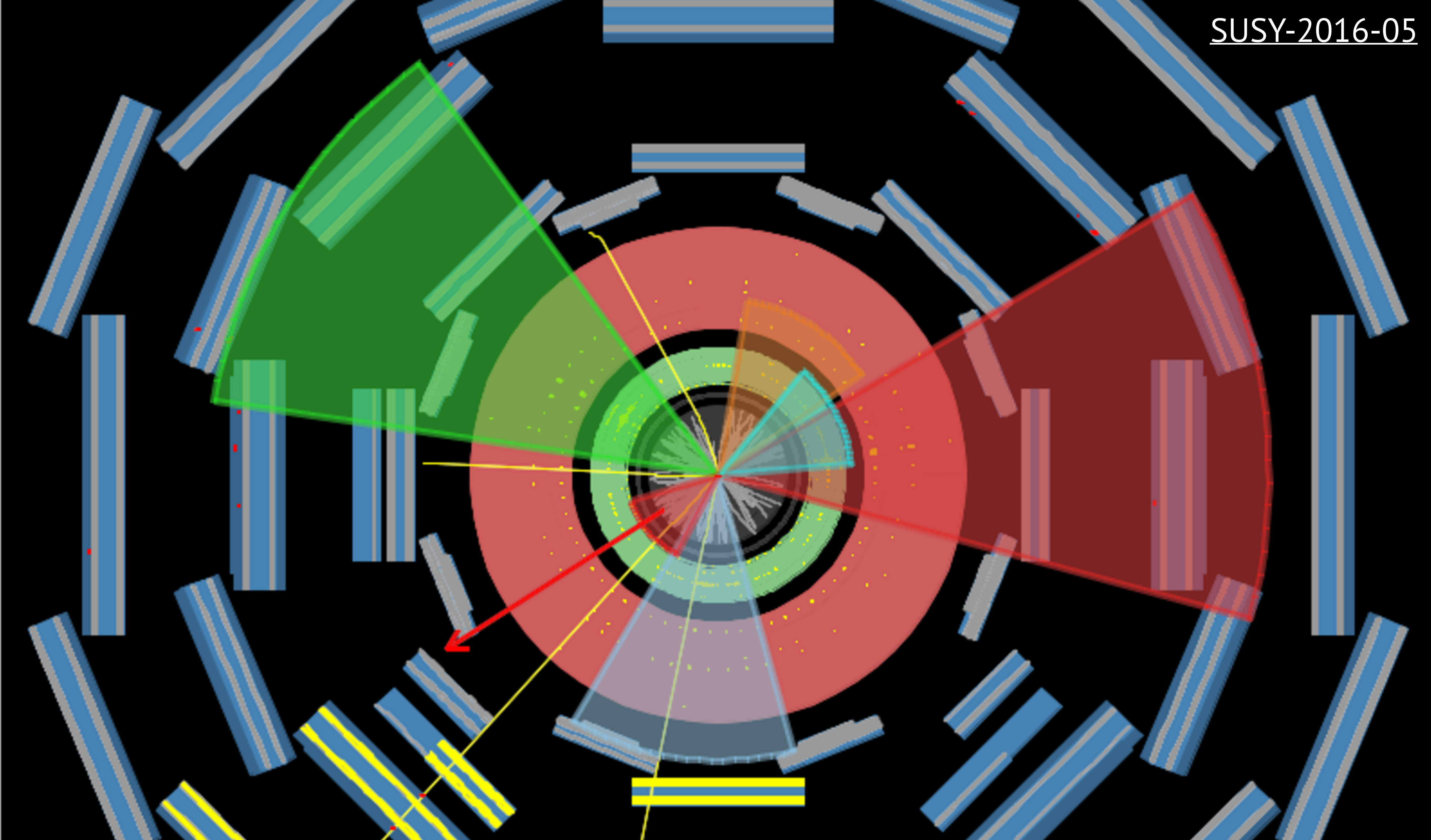
SUSY-2016-05



ATLAS searches for squarks and gluinos decaying to leptons

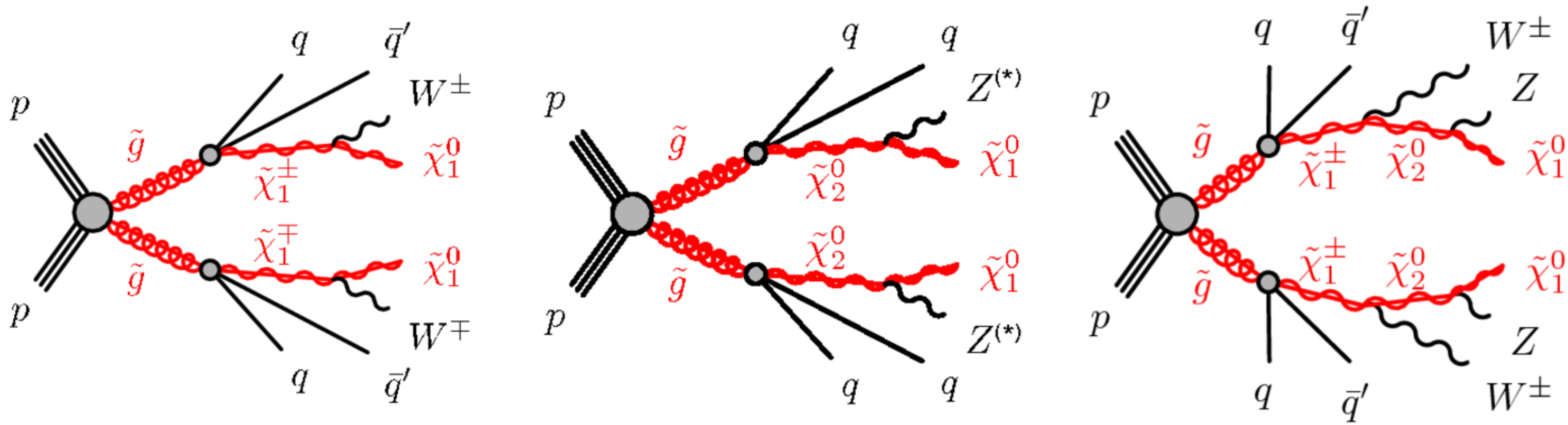
Tova Holmes, on behalf of the ATLAS Collaboration

SUSY 2017

12.11.2017

What do our SUSY signals look like?

- Small changes in models → different mass hierarchies
- Affects branching ratios for different final states
  - To cover all SUSY scenarios, need to look at all of them!



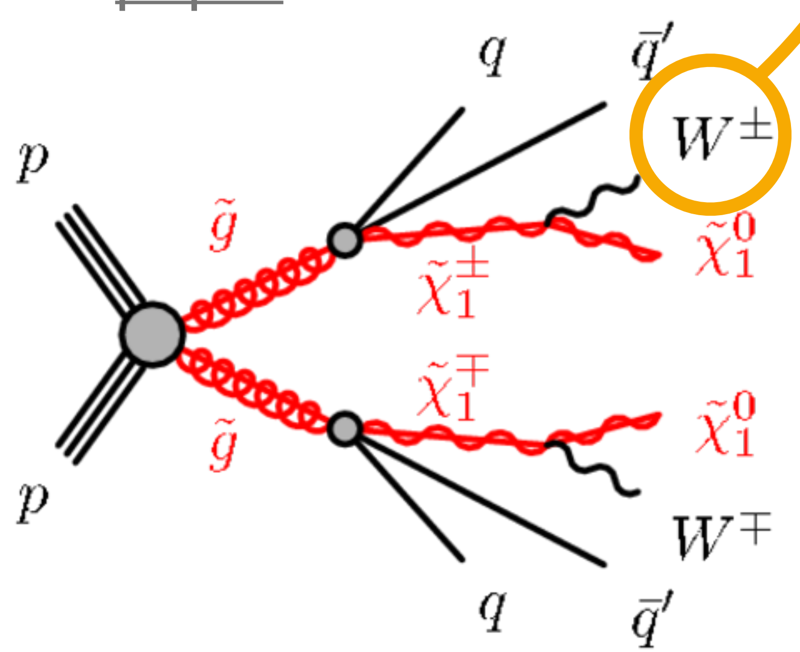
What do our SUSY signals look like?

- Divide into final states (number of leptons)
  - isolates types of backgrounds
  - allows for special variables and background estimates

1L

W decay to $\ell\nu$

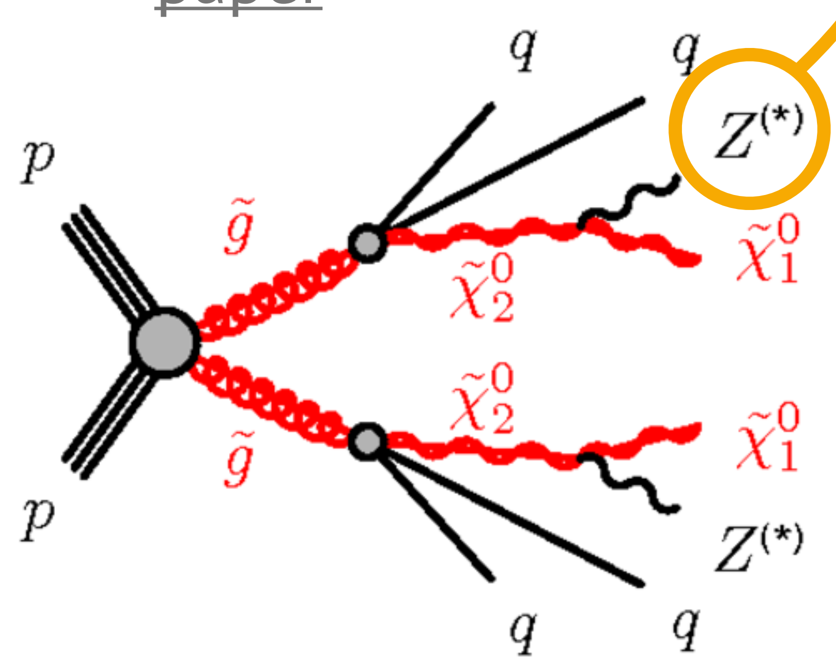
paper



2L

Z decay to $\ell\ell$

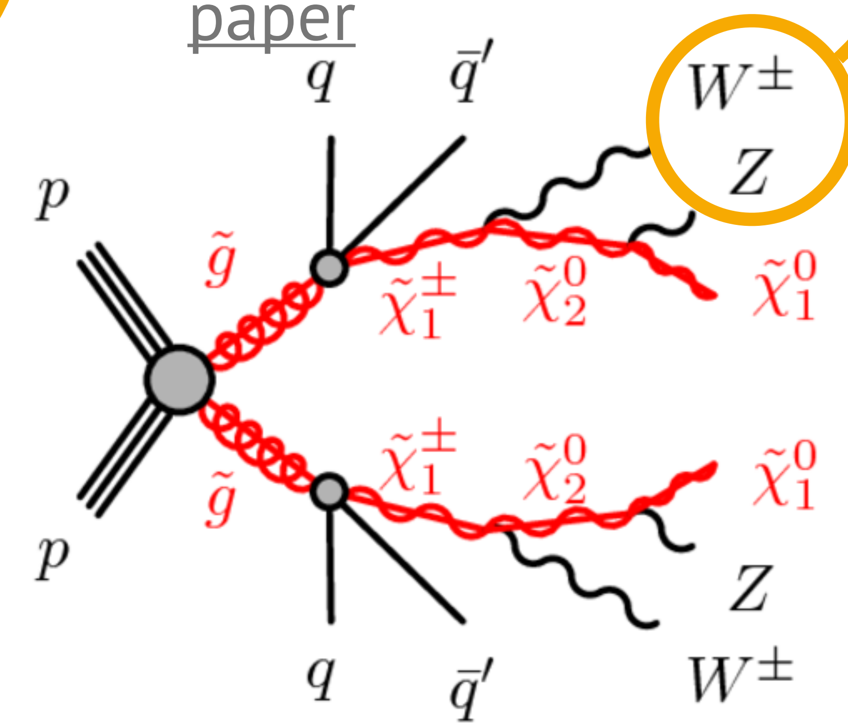
paper



3L

W+Z decay to $\ell\ell\ell\nu$

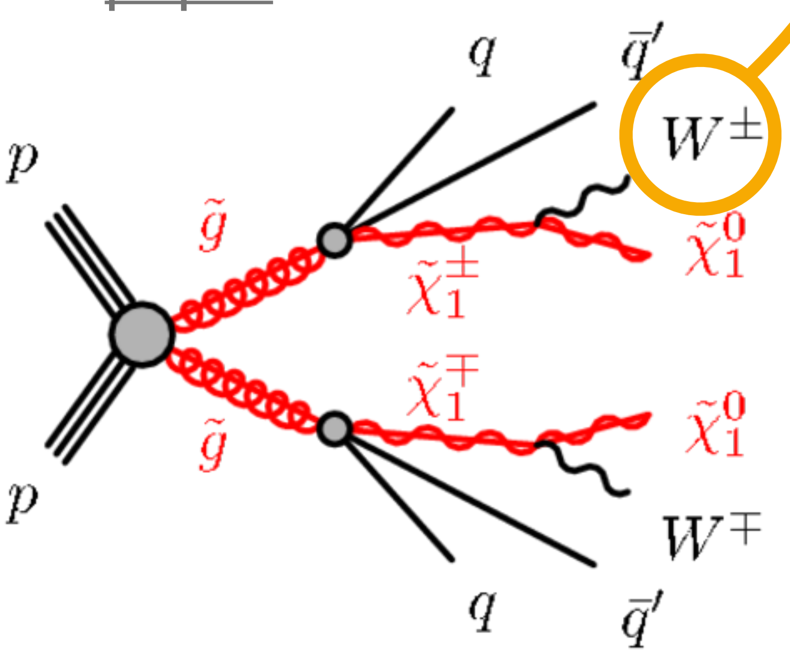
paper



1-Lepton Analysis

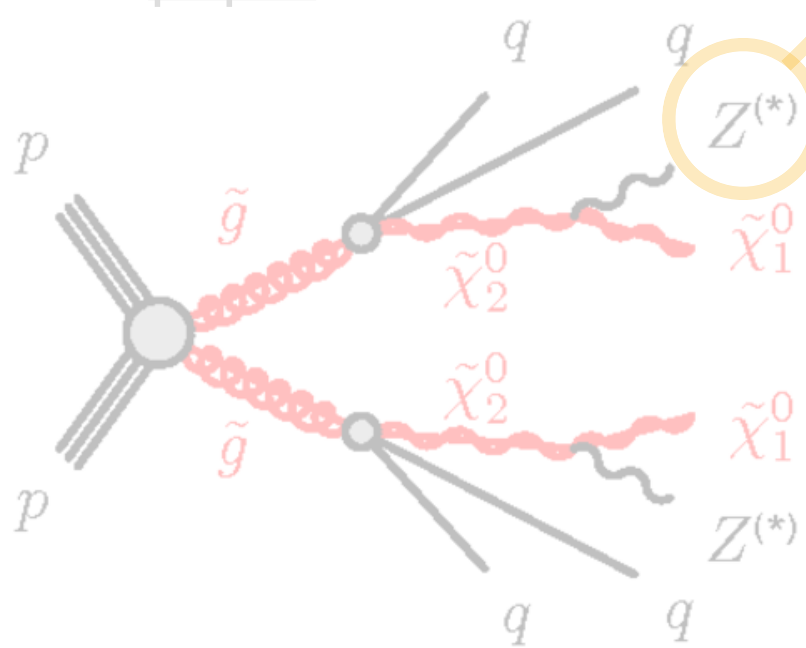
W decay to $\ell\nu$

paper



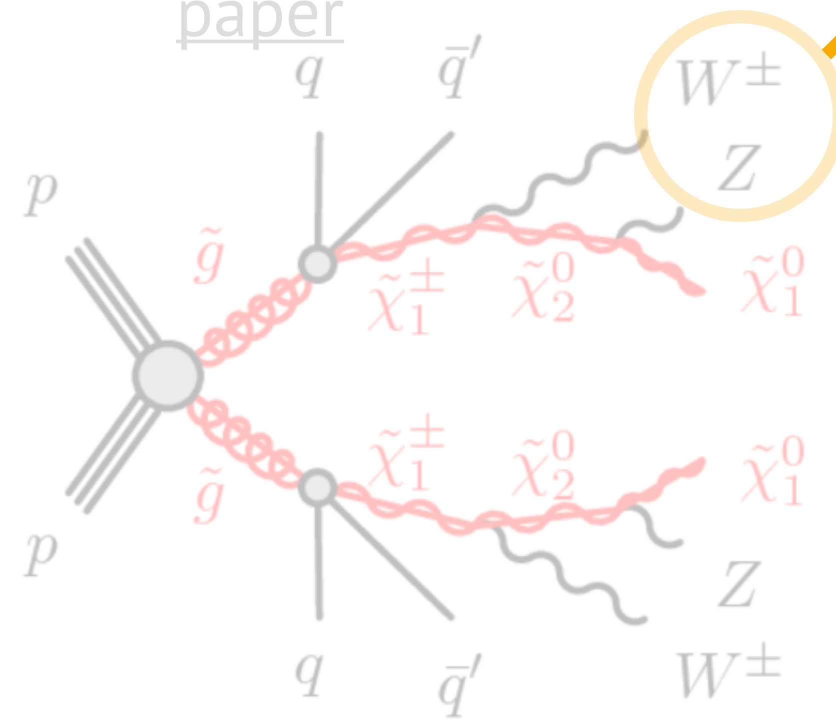
Z decay to $\ell\ell$

paper



W+Z decay to $\ell\ell\ell\nu$

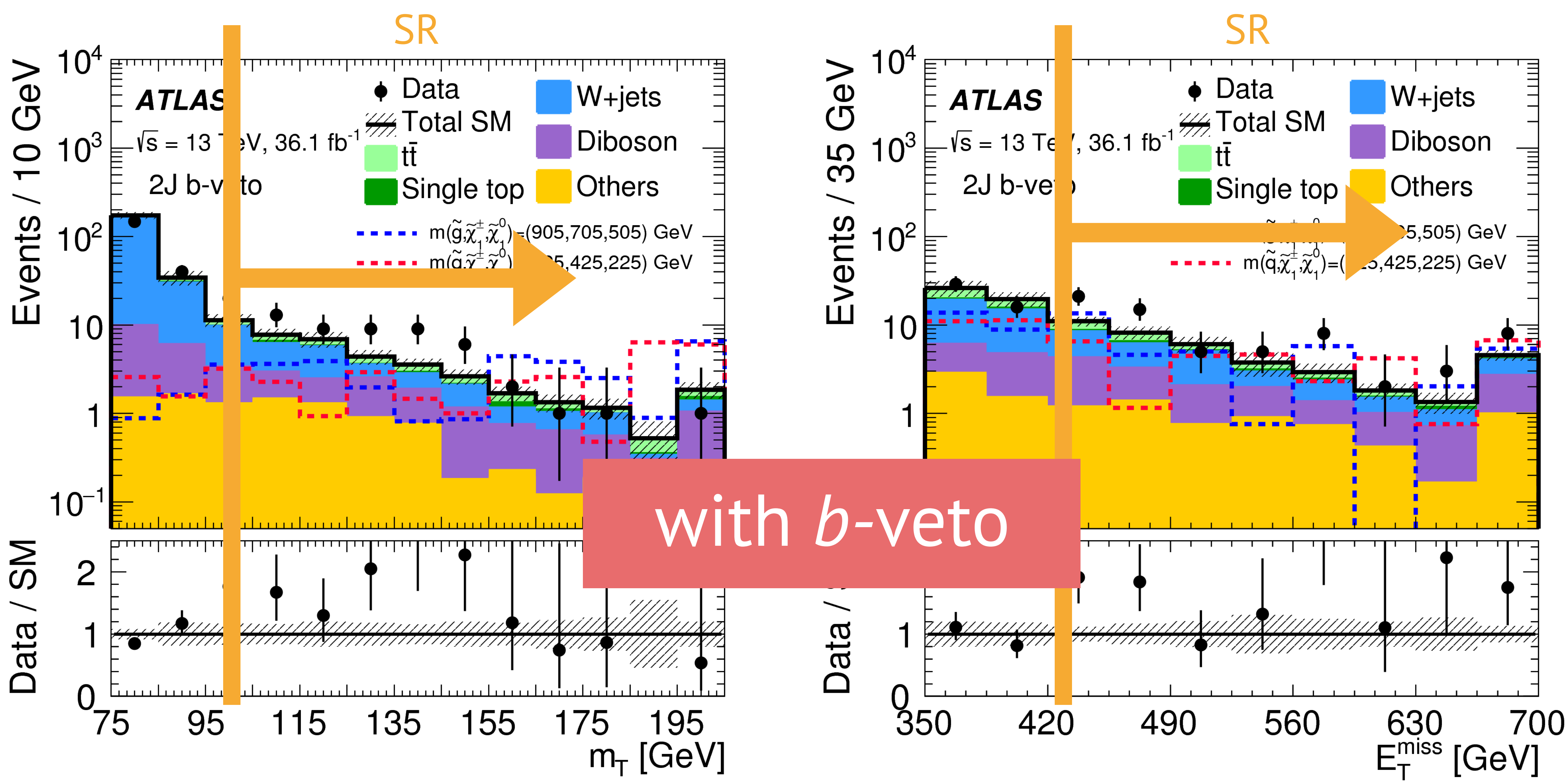
paper



What do the backgrounds look like?

1L

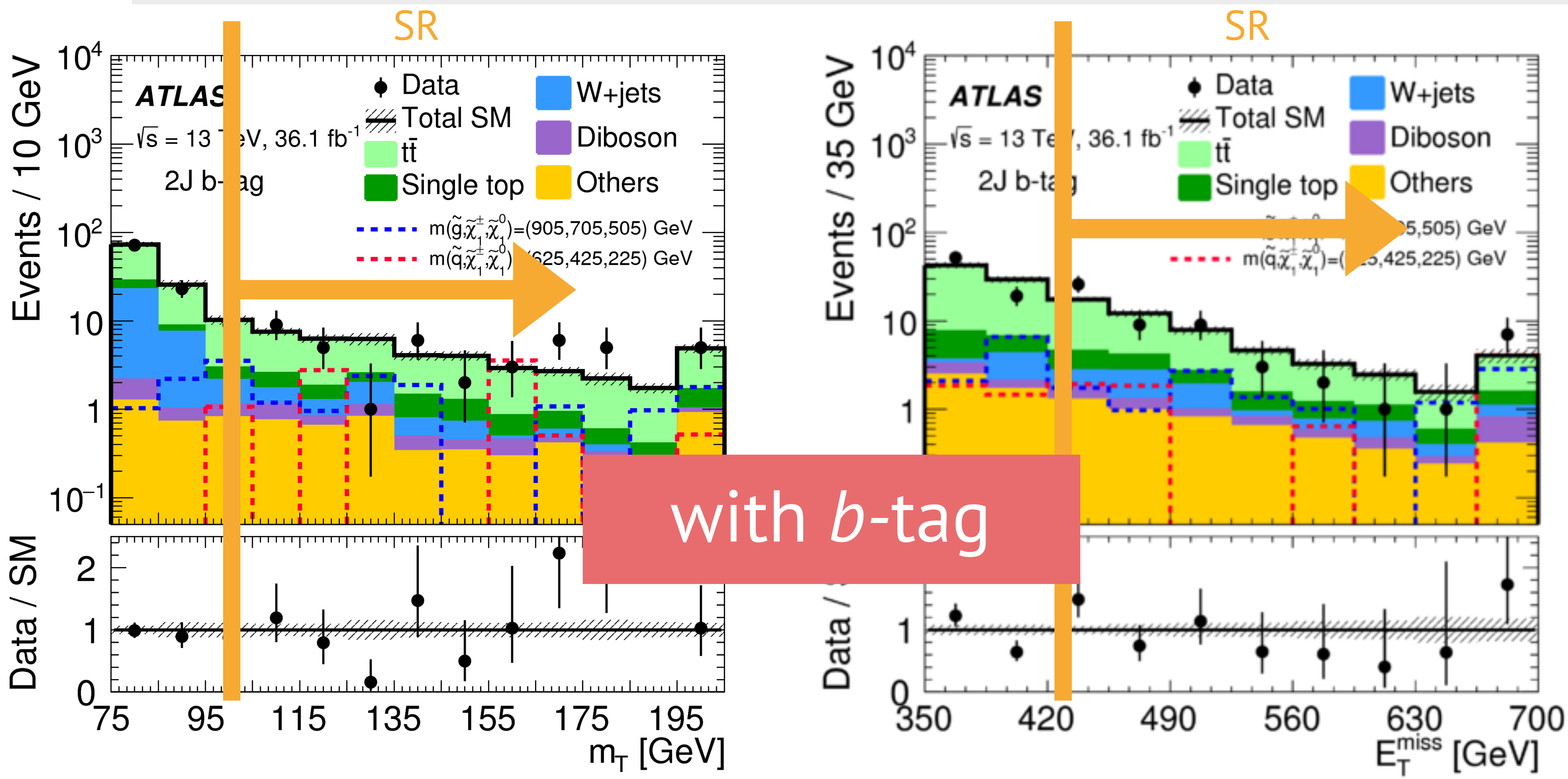
- W+jets produces 1L events with E_T^{miss}
- m_T is a proxy for the invariant mass of $\ell\nu$ from the W decay
  - $m_T > W$ mass reduces this background



What do the backgrounds look like?

1L

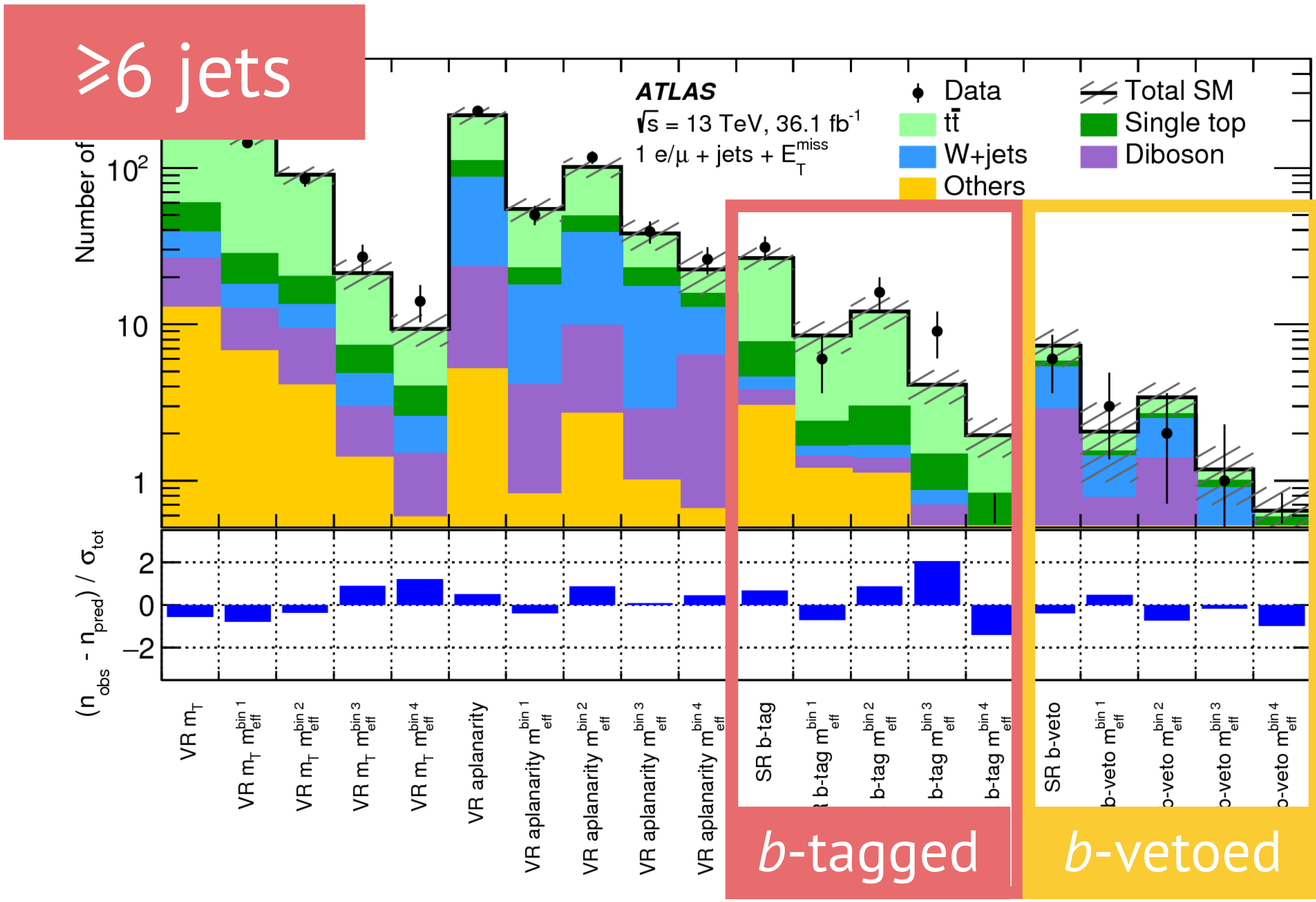
- When *b*-tagging, semi-leptonic *ttbar* is dominant
  - targets scenarios in which sparticles decay to third-generation quarks
- *ttbar* and *W*+jets backgrounds estimated using CRs at low m_{eff} (sum of E_T^{miss} and jet and lepton p_T)



Signal region specialization

1L

- Additional SRs targeting different numbers of jets (⩾2, 4-5, ⩾6, ⩾9)
  - optimized for different mass hierarchies and decay chains



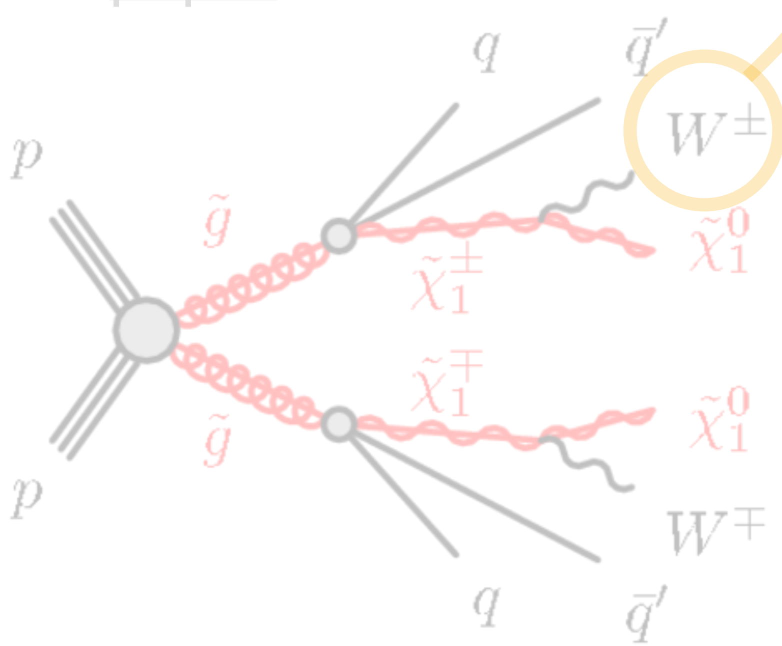
This region targets scenarios with high sparticle masses.

SR bins in m_{eff}

2-Lepton Analysis

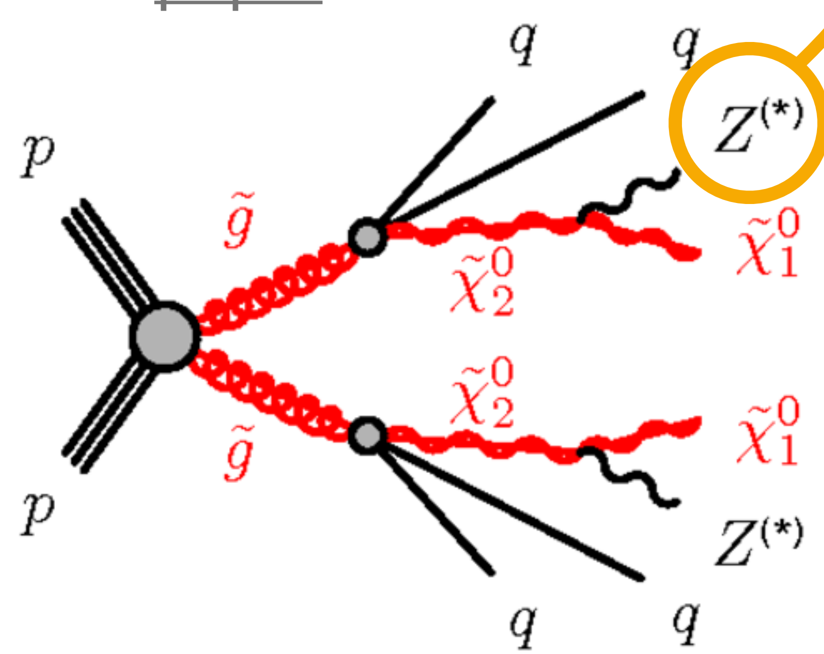
W decay to
ℓν

paper



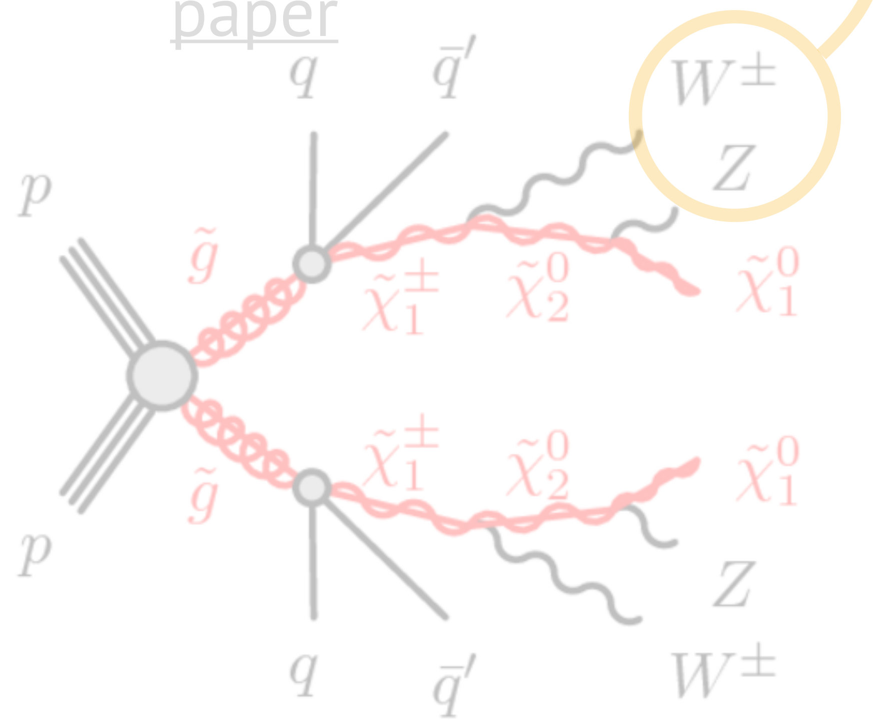
Z decay to
ℓℓ

paper



W+Z decay to
ℓℓℓν

paper

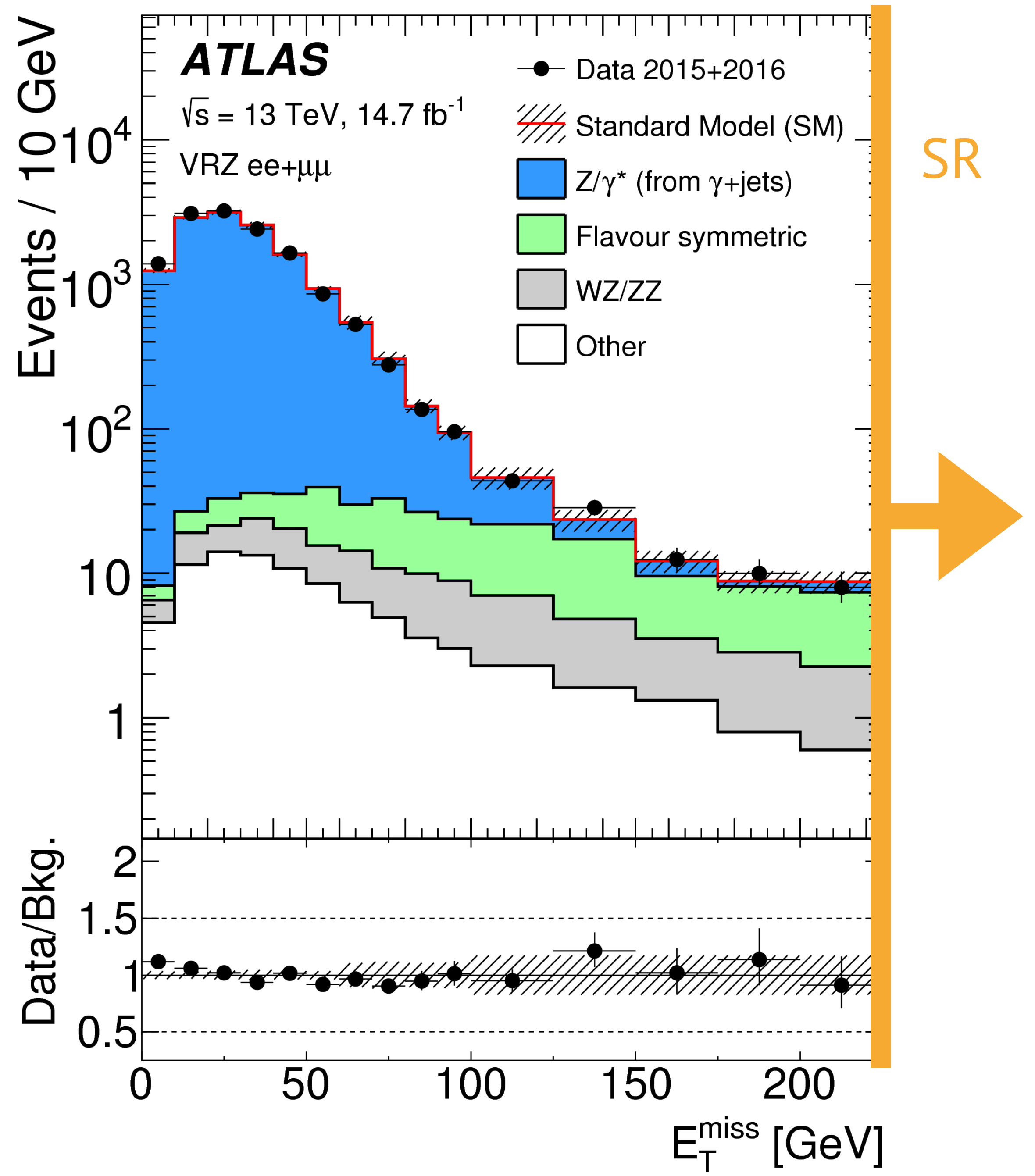


What do the backgrounds look like?

2L

- 2L events come primarily from Z+jets decays
  - no real E_T^{miss} → cut on this to reduce
  - a template method from photon+jets data is used to approximate

on-shell Z



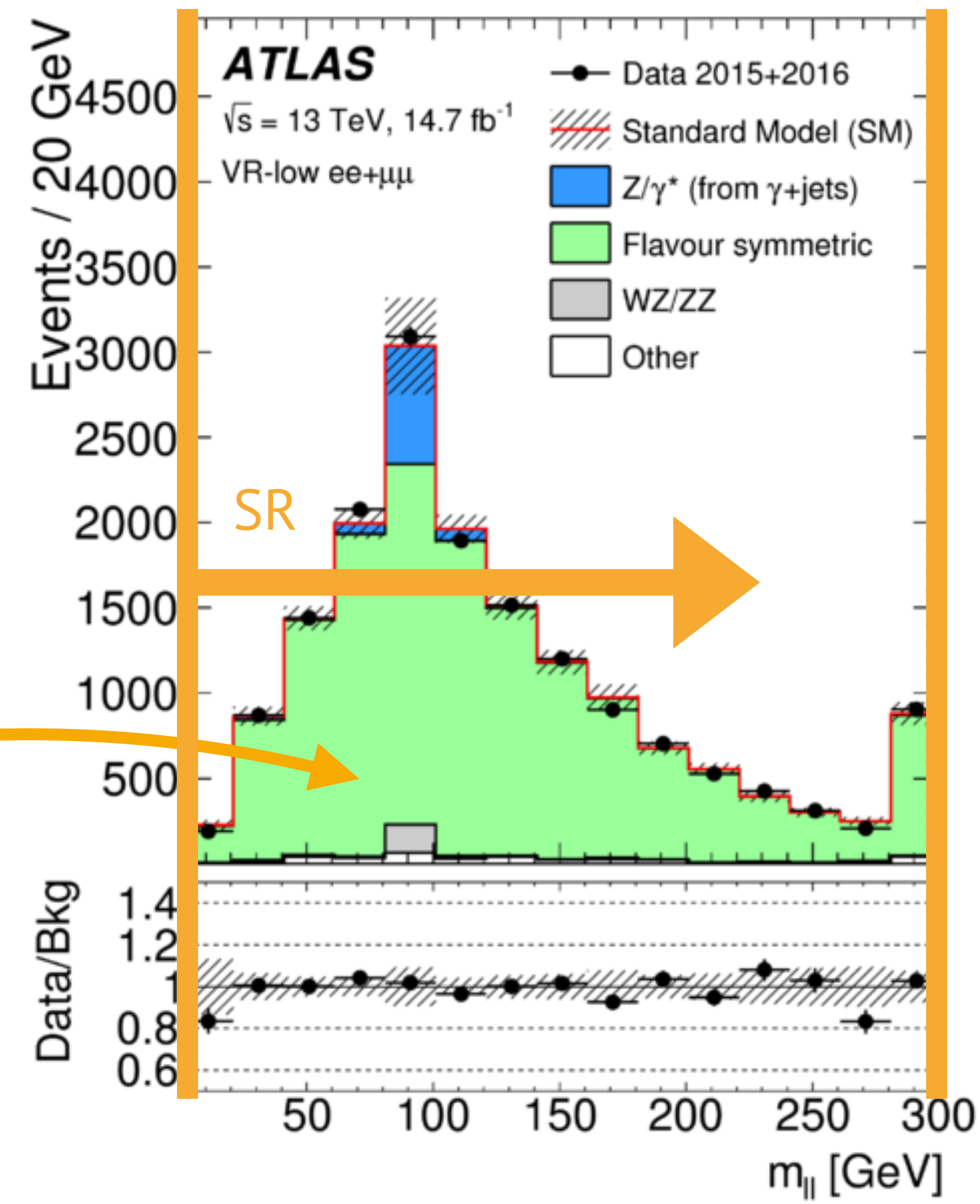
What do the backgrounds look like?

2L

- Away from the Z-peak, *ttbar* is the major contributor
  - like 1L case, background is difficult to reduce
  - exploit the flavor symmetric nature to estimate using *eμ* channel

Flavor symmetric backgrounds:
ttbar, WW, Z→ττ
-
all produce a pair of flavor-uncorrelated leptons
1 *ee* : 1 *μμ* : 2 *eμ*

off-shell *Z*

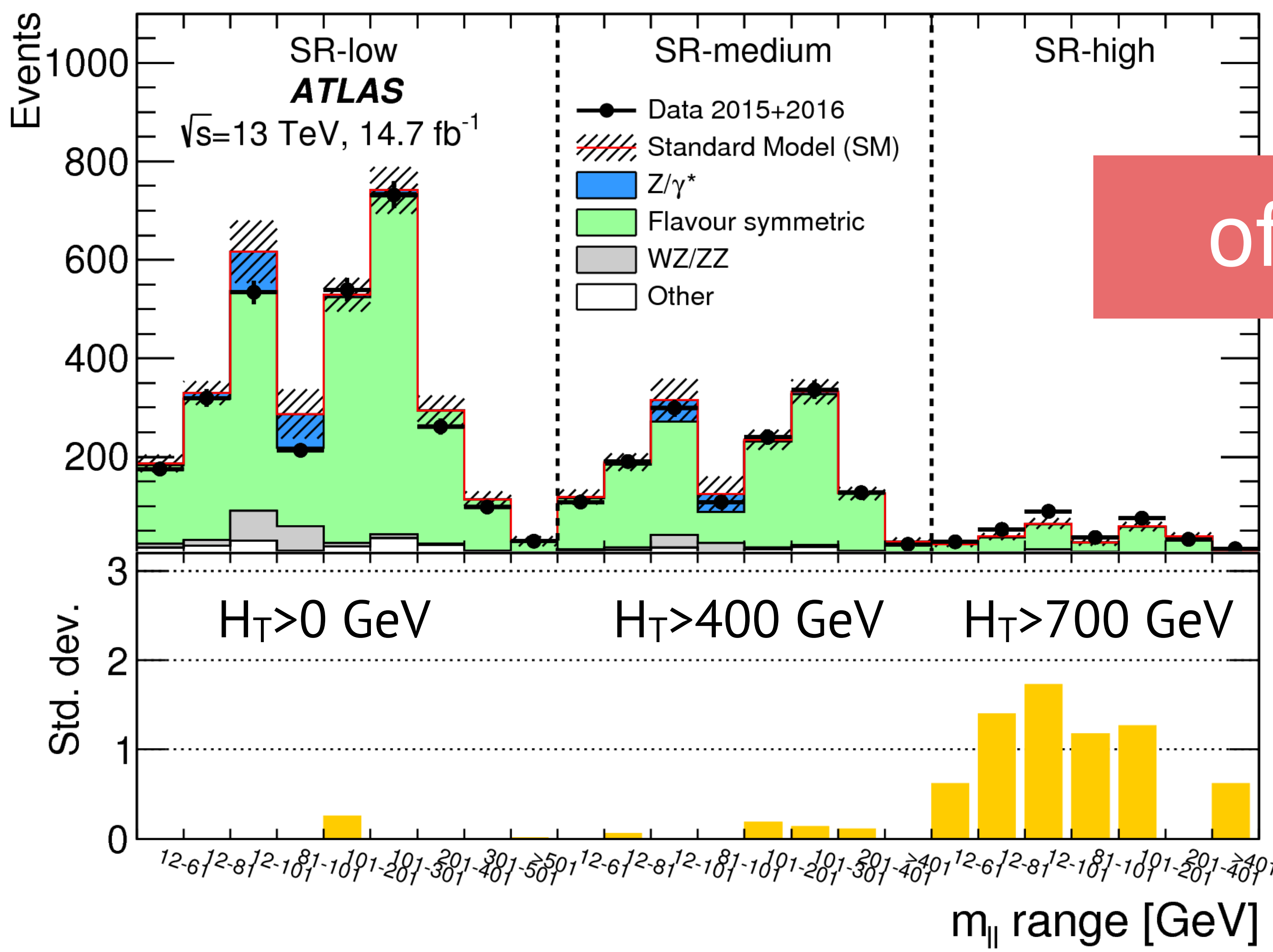


Signal region specialization

2L

- off-Z SRs target different mass splittings between gluino and neutralino

off-shell Z

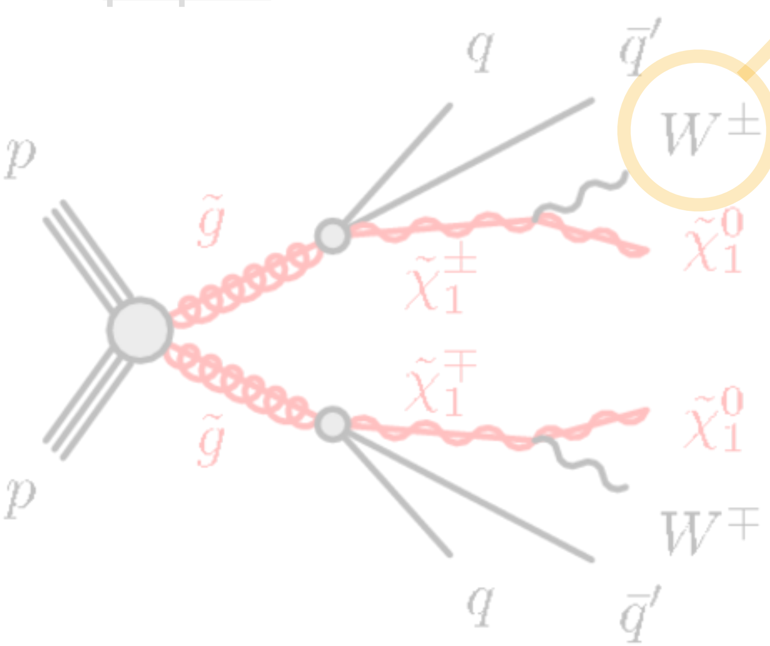


H_T:
scalar sum of p_T of jets and two leading leptons

3-Lepton Analysis

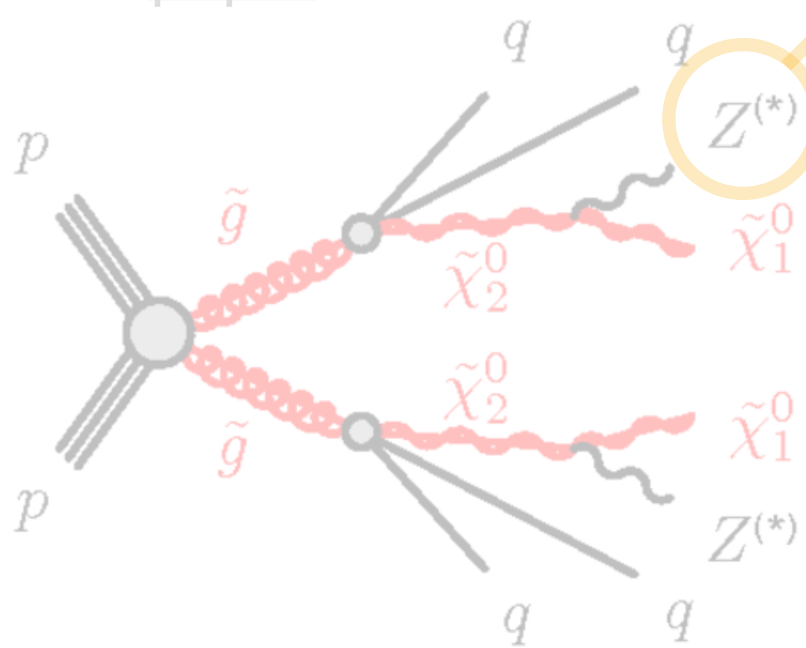
W decay to $\ell\nu$

paper



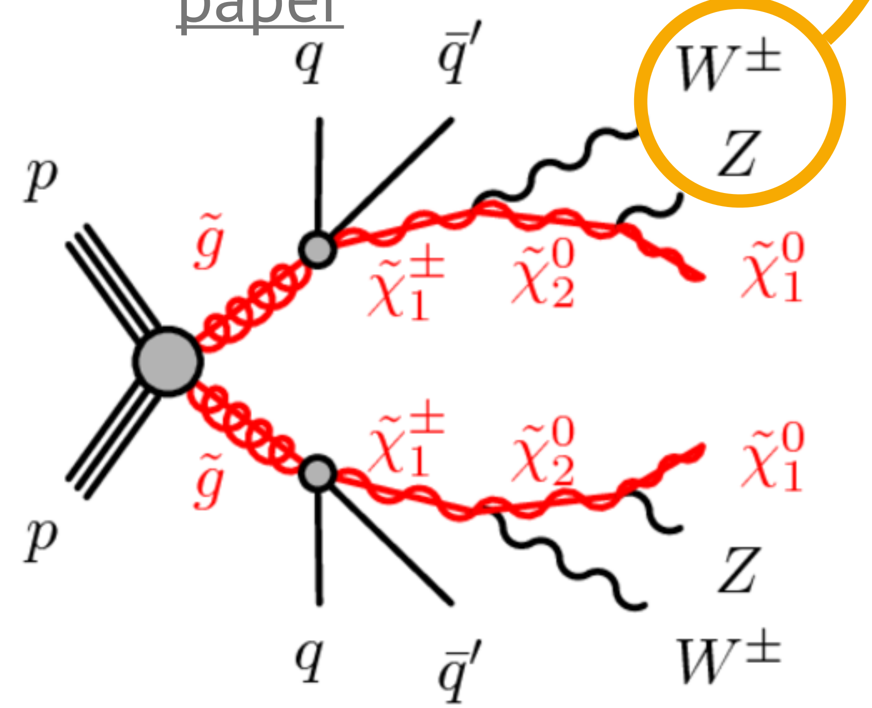
Z decay to $\ell\ell$

paper



W+Z decay to $\ell\ell\ell\nu$

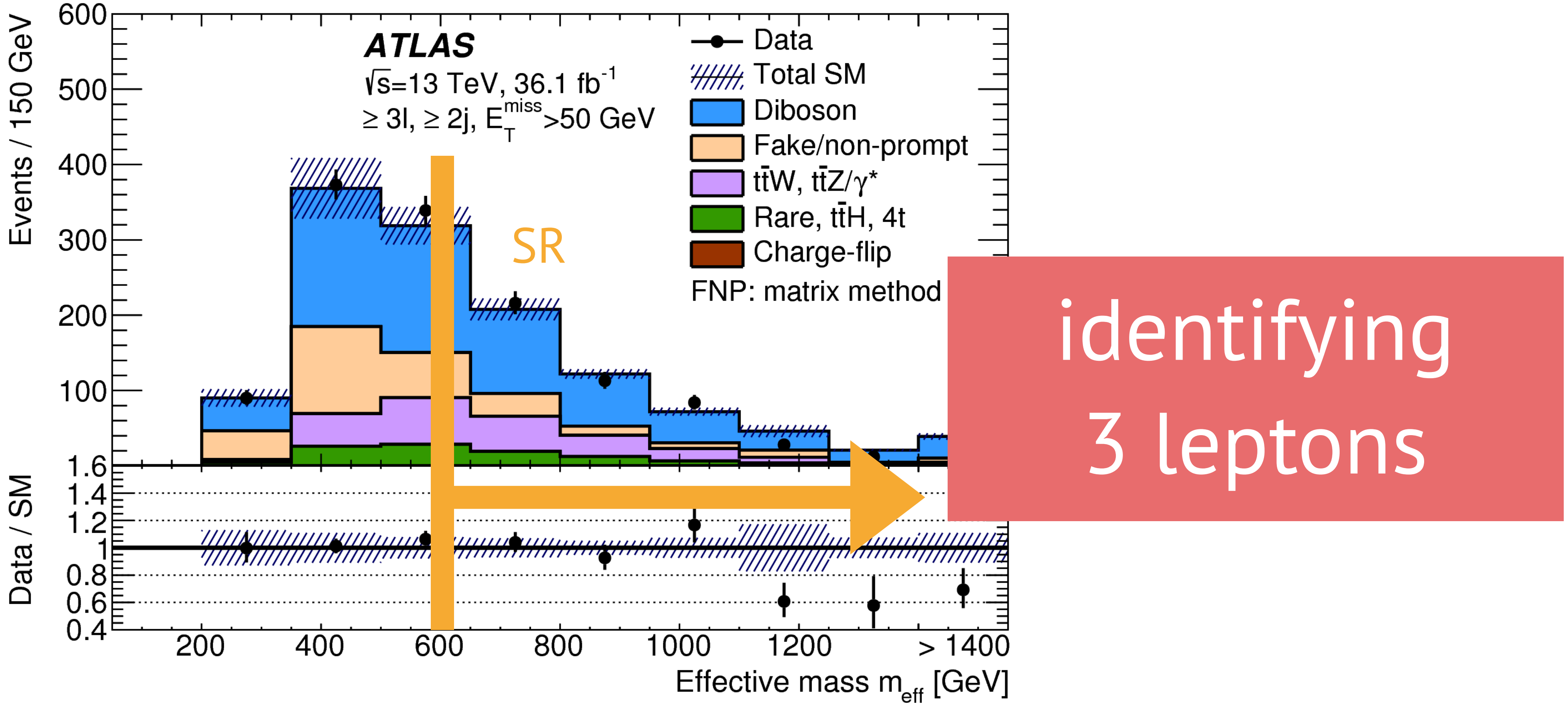
paper



What do the backgrounds look like?

3L

- Primary background is dibosons
  - WZ and ZZ events can both produce 3 real prompt lepton (+ E_T^{miss} for WZ)
  - E_T^{miss} and n_{jets} cuts reduce this background
- Estimated using MC with validation regions close to the SRs

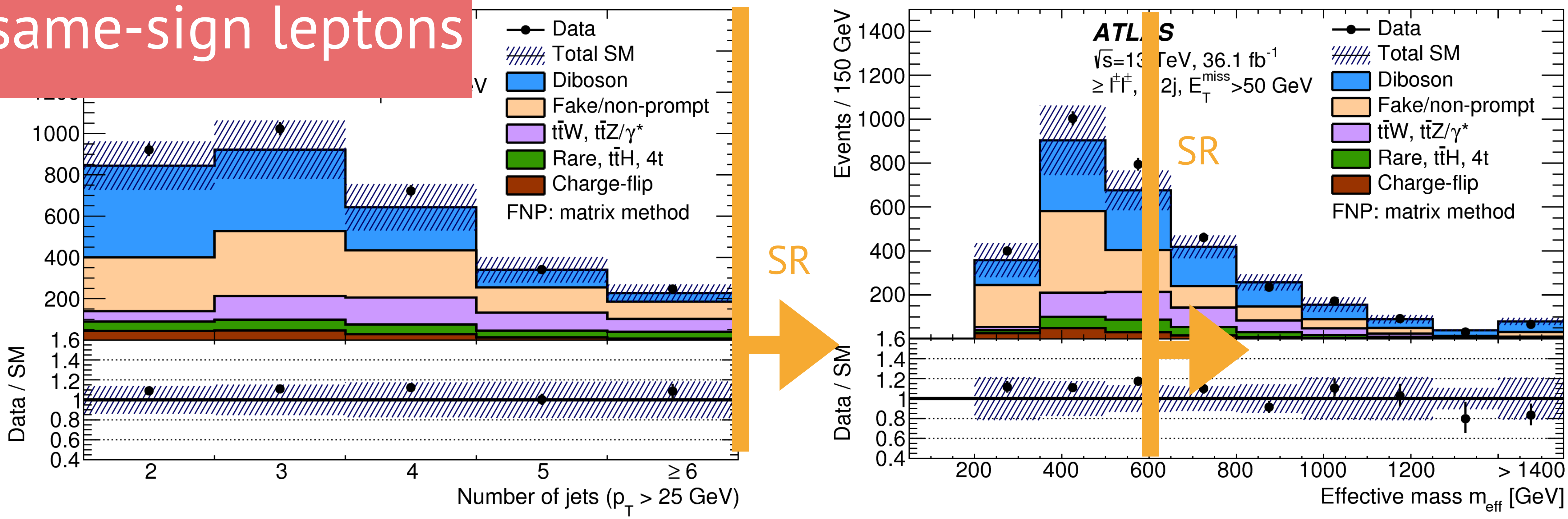


What do the backgrounds look like?

3L

- SM backgrounds for SS leptons are much lower than OS
  - main backgrounds dibosons and fake or non-prompt leptons in *t/W/Z* events
  - cuts on n_{jets} and E_T^{miss} reduce these backgrounds
- Fake leptons estimated from data using the matrix method

identifying 2 same-sign leptons

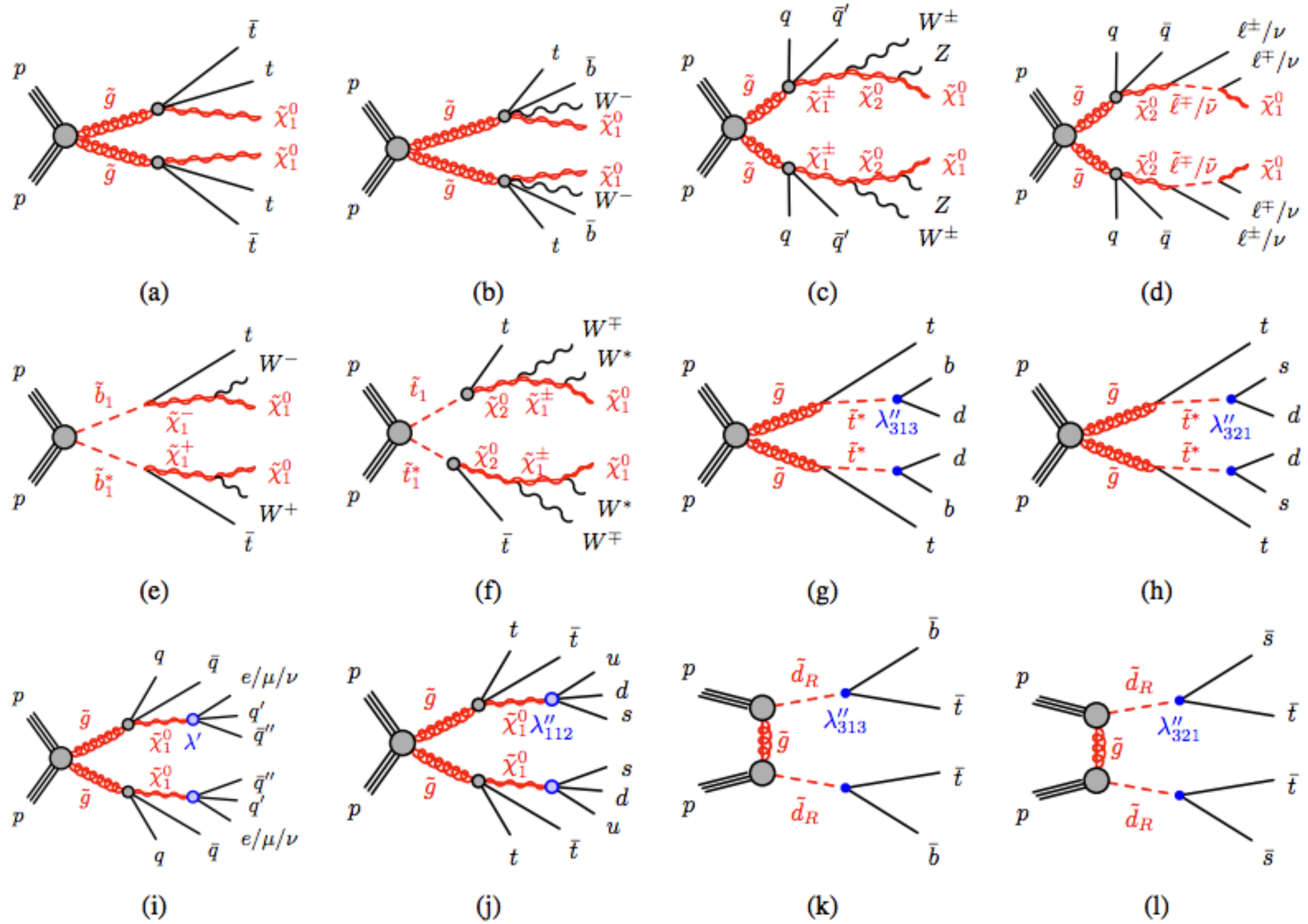


Signal region specialization

3L

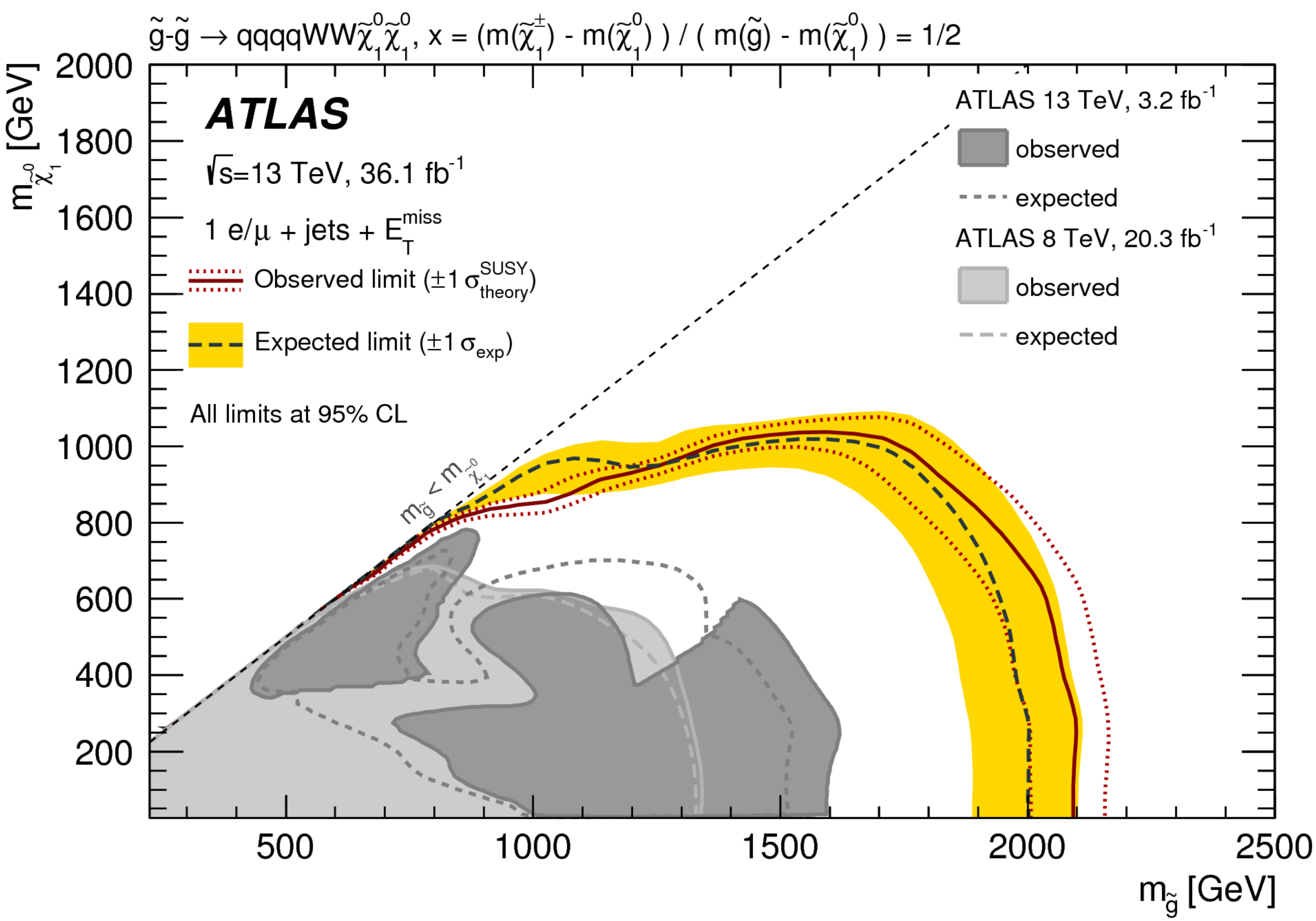
- Overall, the analysis has 19 SRs targeting 12 different processes!

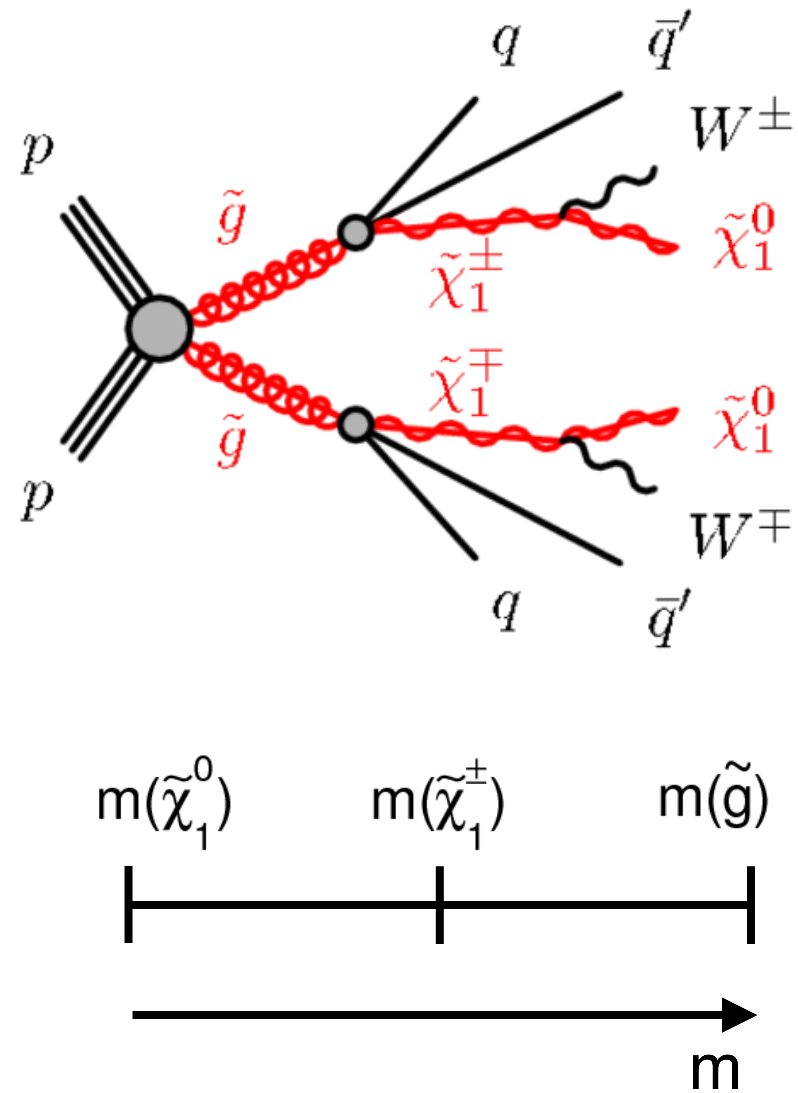
SRs optimized for number of leptons, jets, *b*-jets, E_T^{miss}, m_{eff}, and more!



1L Exclusions

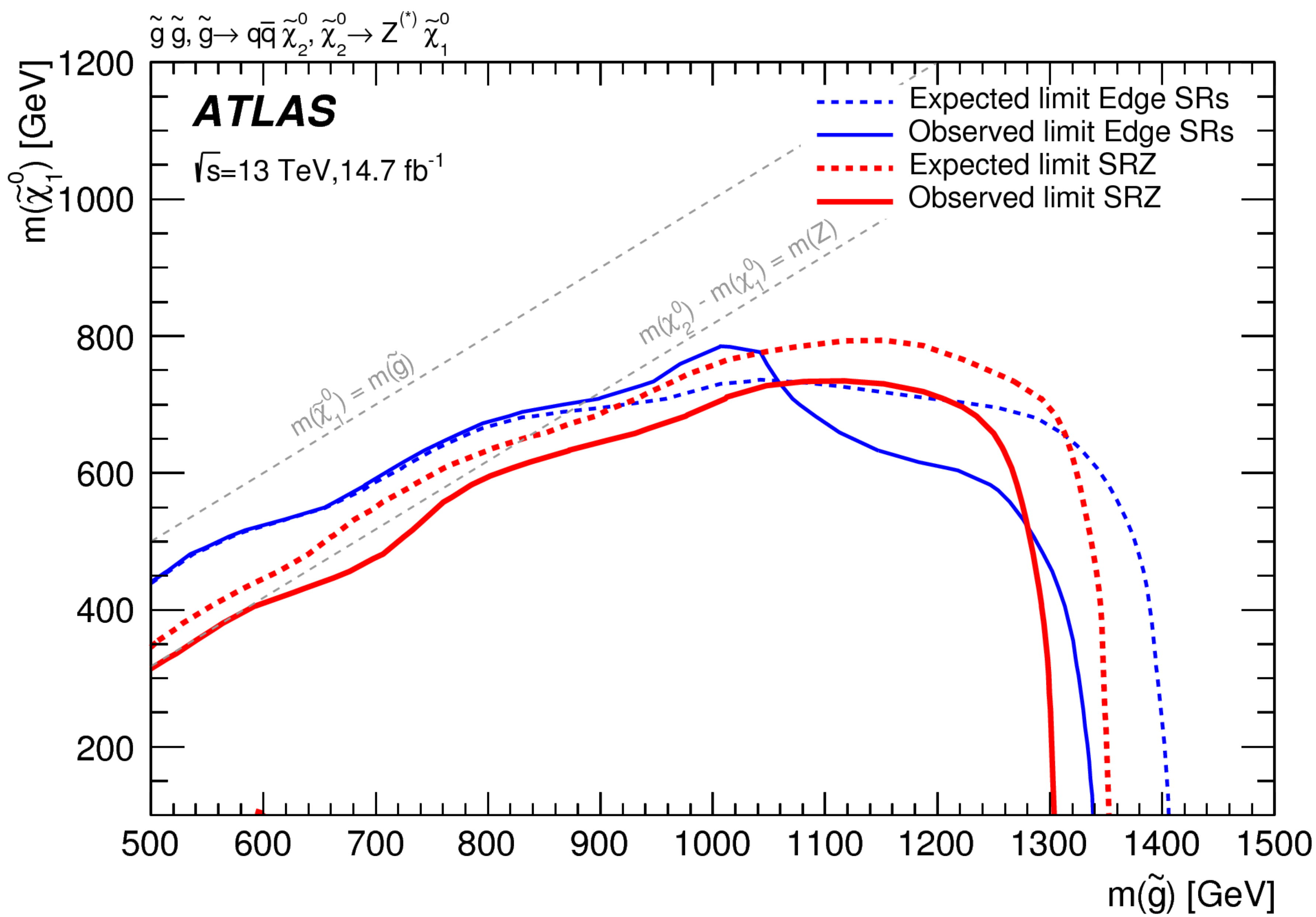
- excludes gluino masses up to 2.1 TeV, and squark masses up to 1.25 TeV
- excellent coverage even in the region of small neutralino-gluino Δm

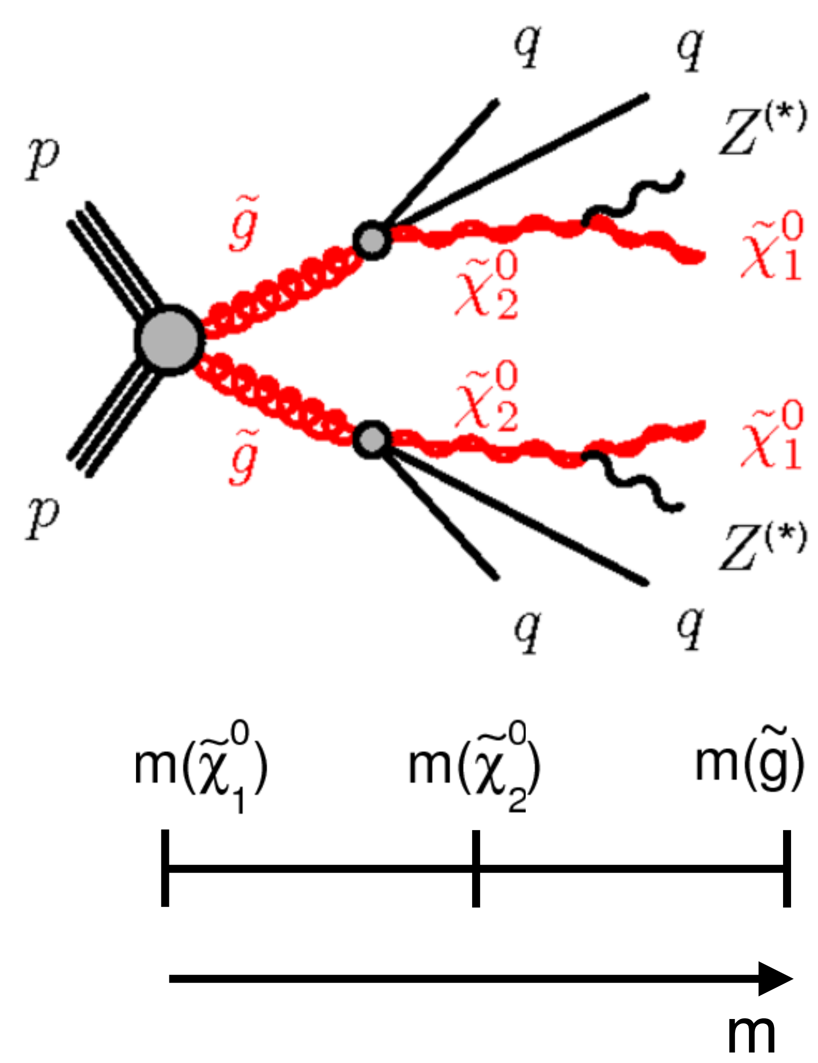




2L Exclusions

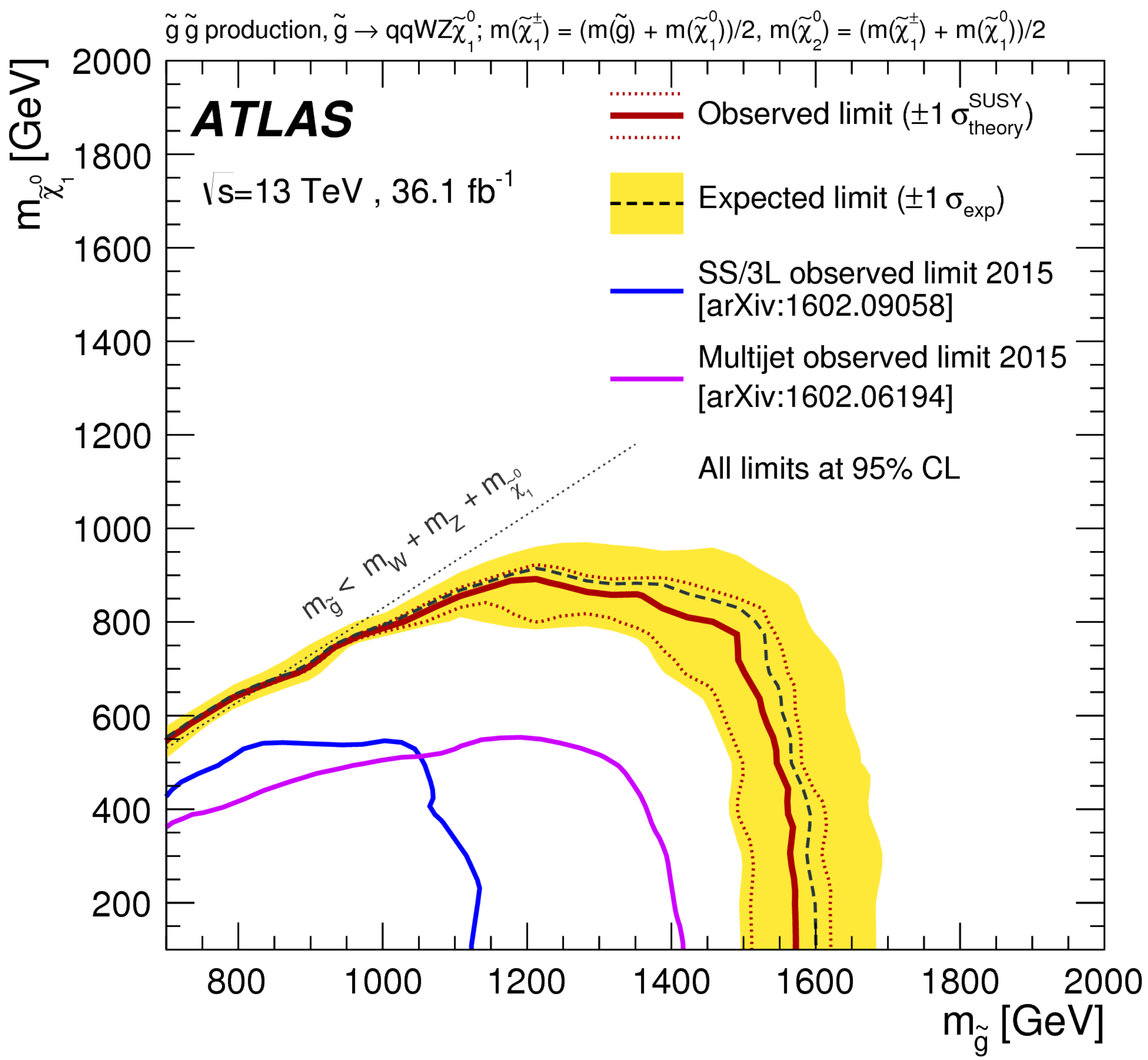
- excludes gluino masses up to 1.70 TeV, and squark masses up to 980 GeV
- still some uncovered space close to the diagonal

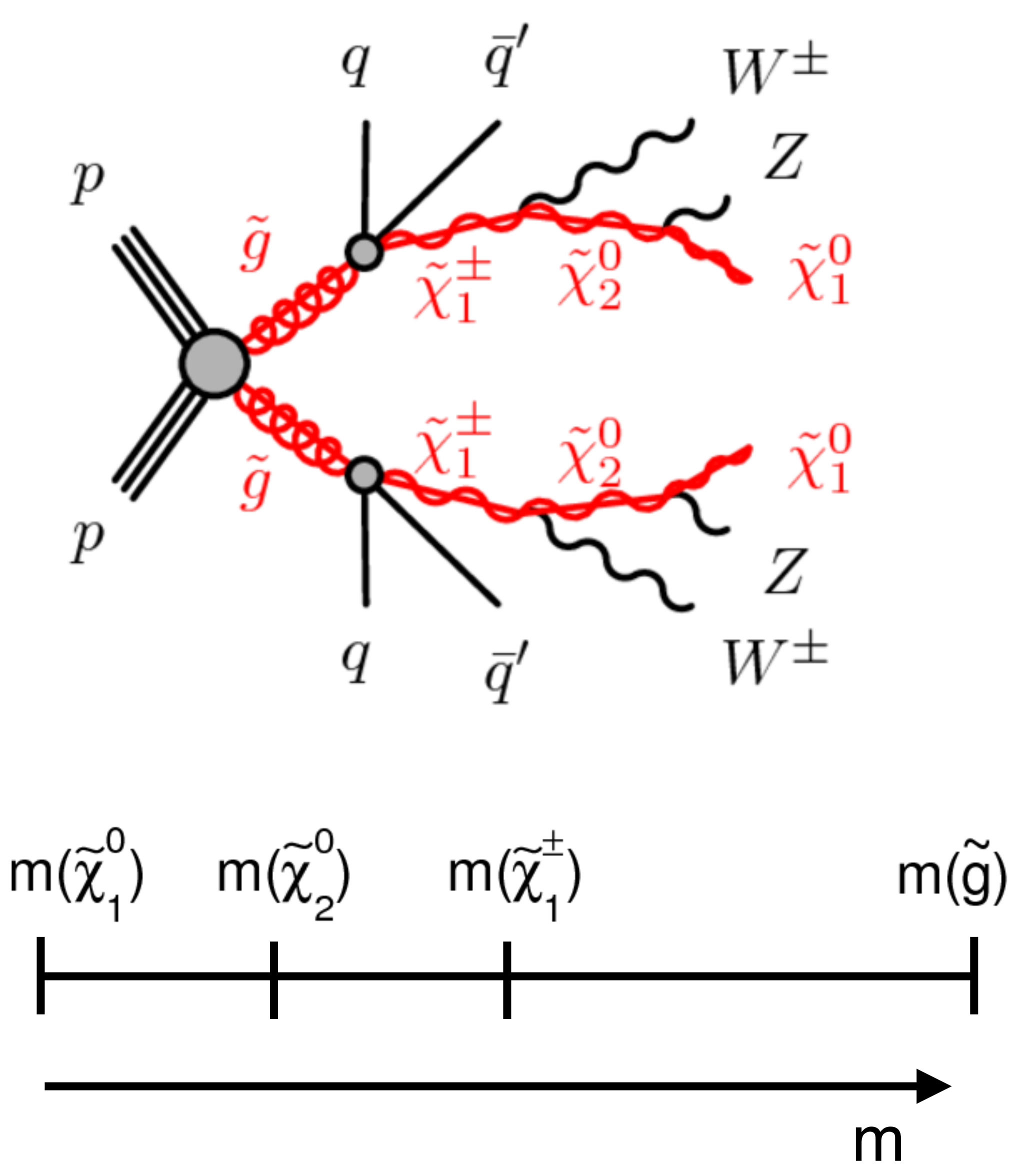




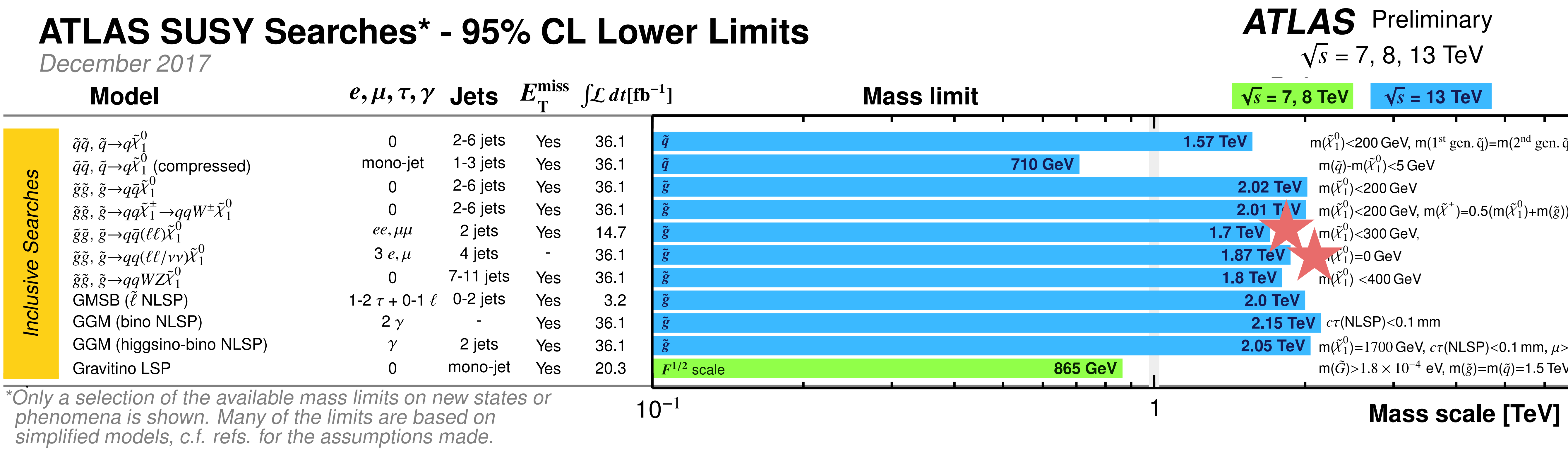
3L Exclusions

- excludes gluino masses up to 1.87 TeV, and squark masses up to 700 GeV (1.6 TeV in the model shown)
- large improvements over 2015 analyses

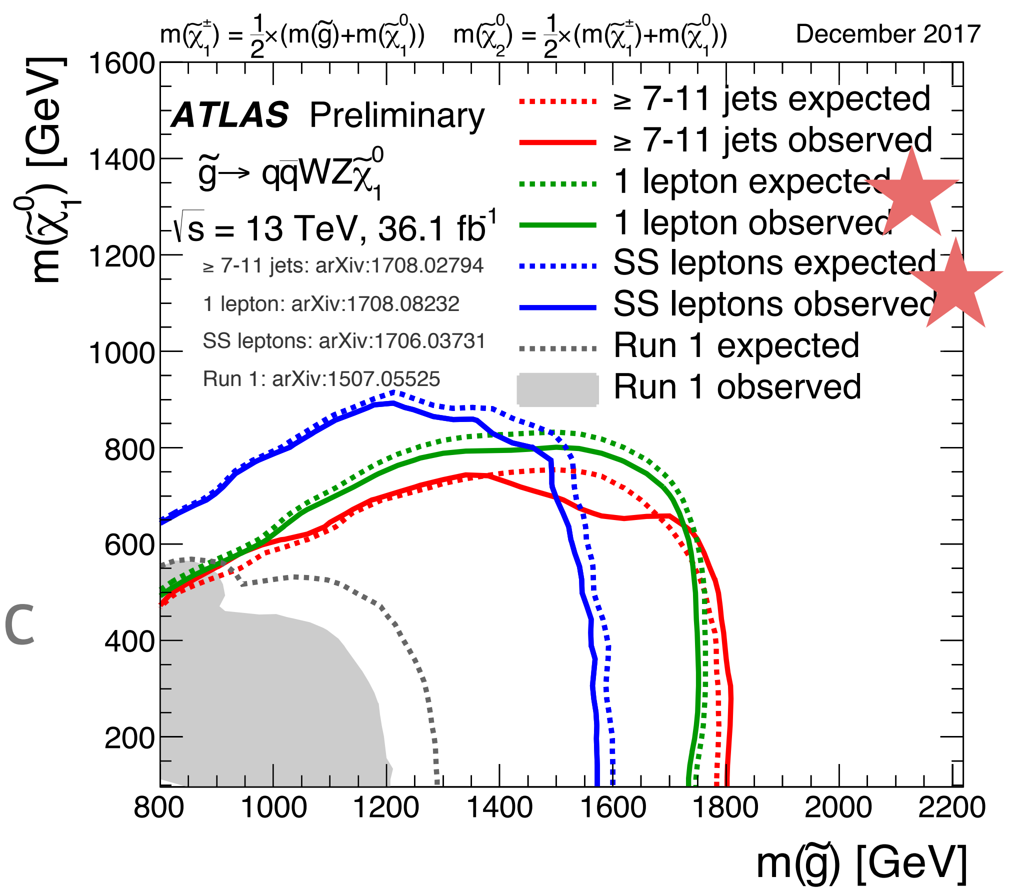


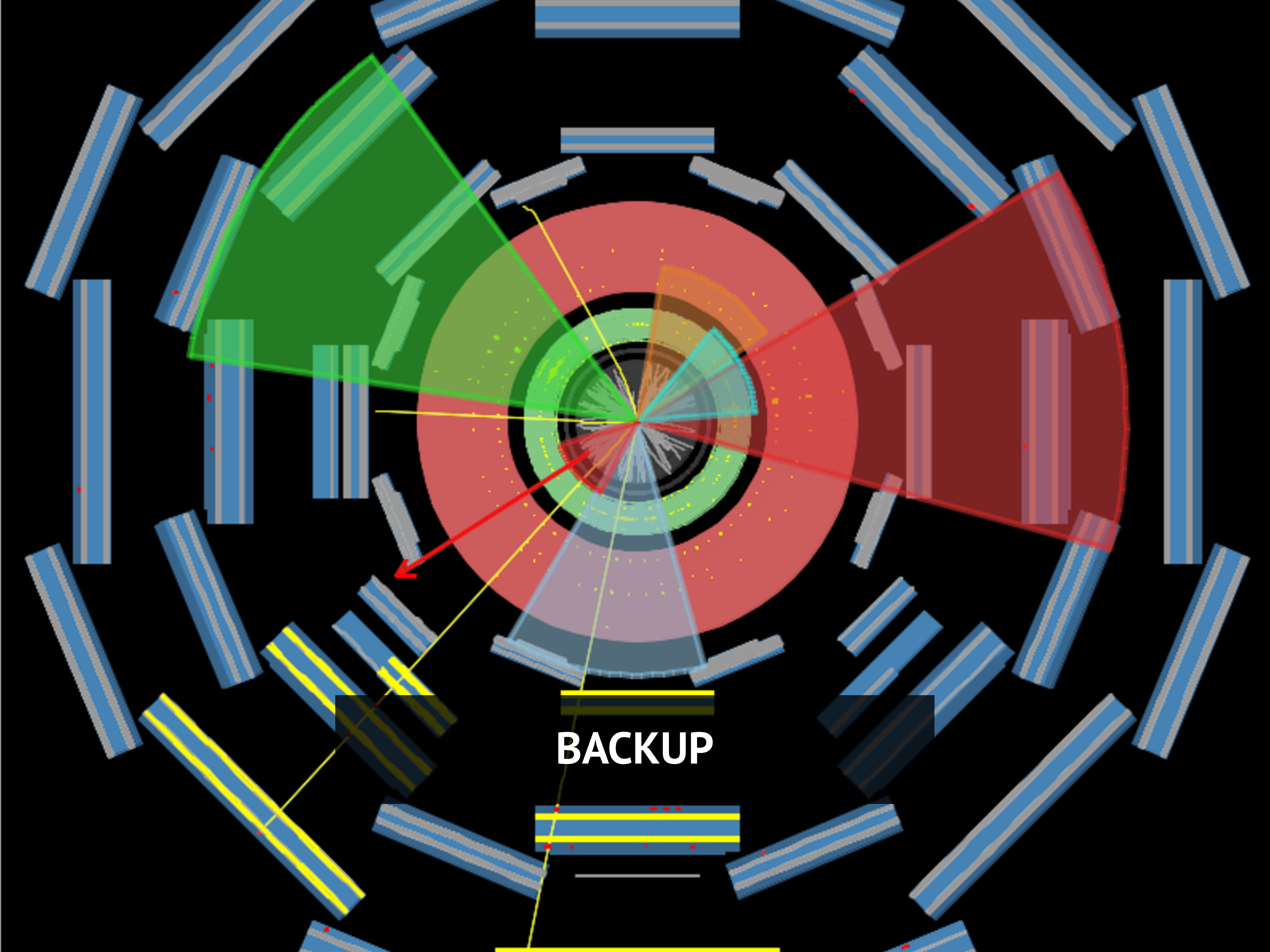


Conclusions



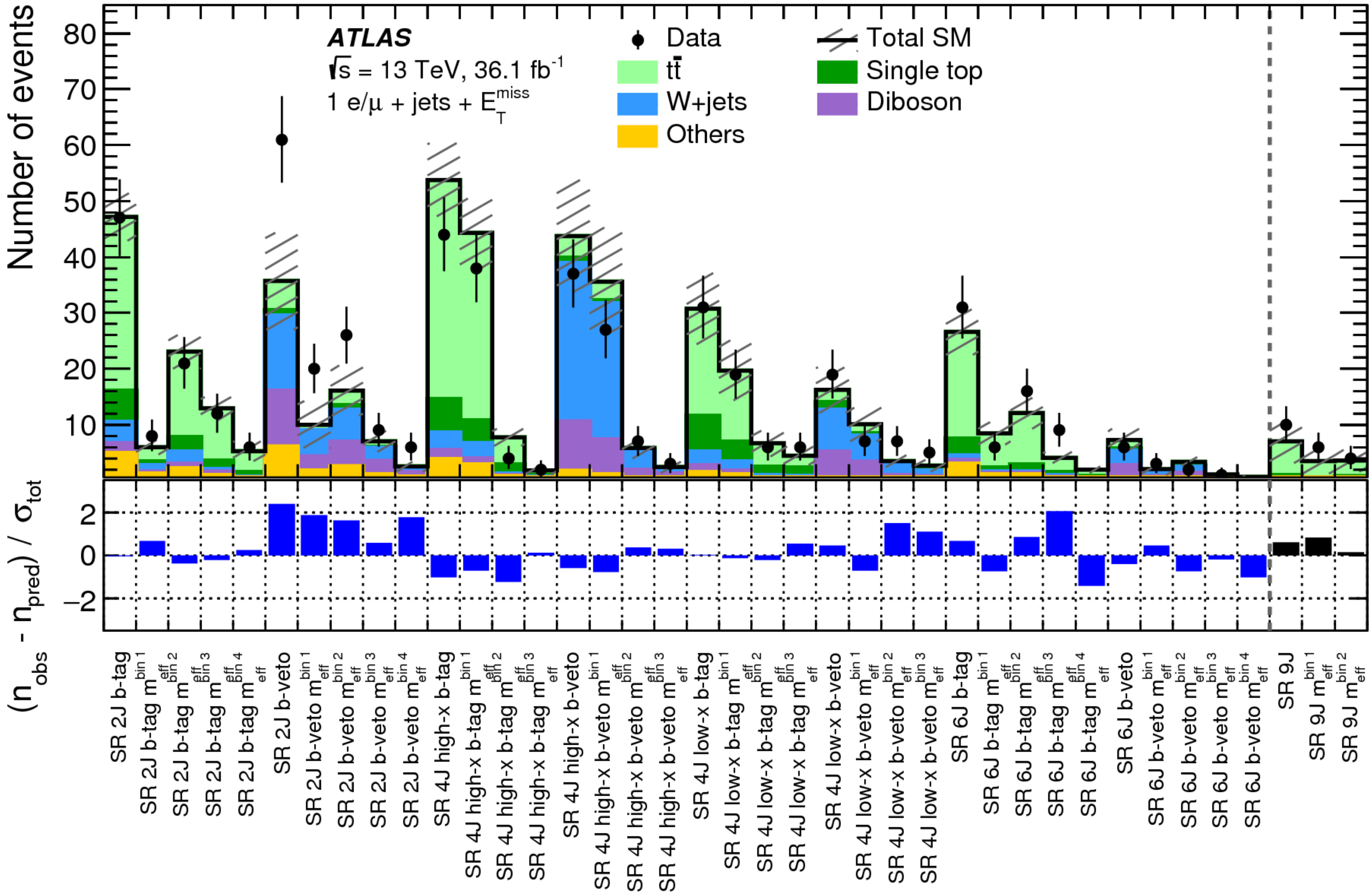
- Strong SUSY searches exclude gluinos past 2 TeV and squarks nearly as massive
- Leptonic searches have helped extend these limits, covering many different possible mass hierarchies and possible decays
  - Many more new limits — check out the public results for more:
    - 1 lepton, 2 lepton, 2 same-sign / 3 leptons



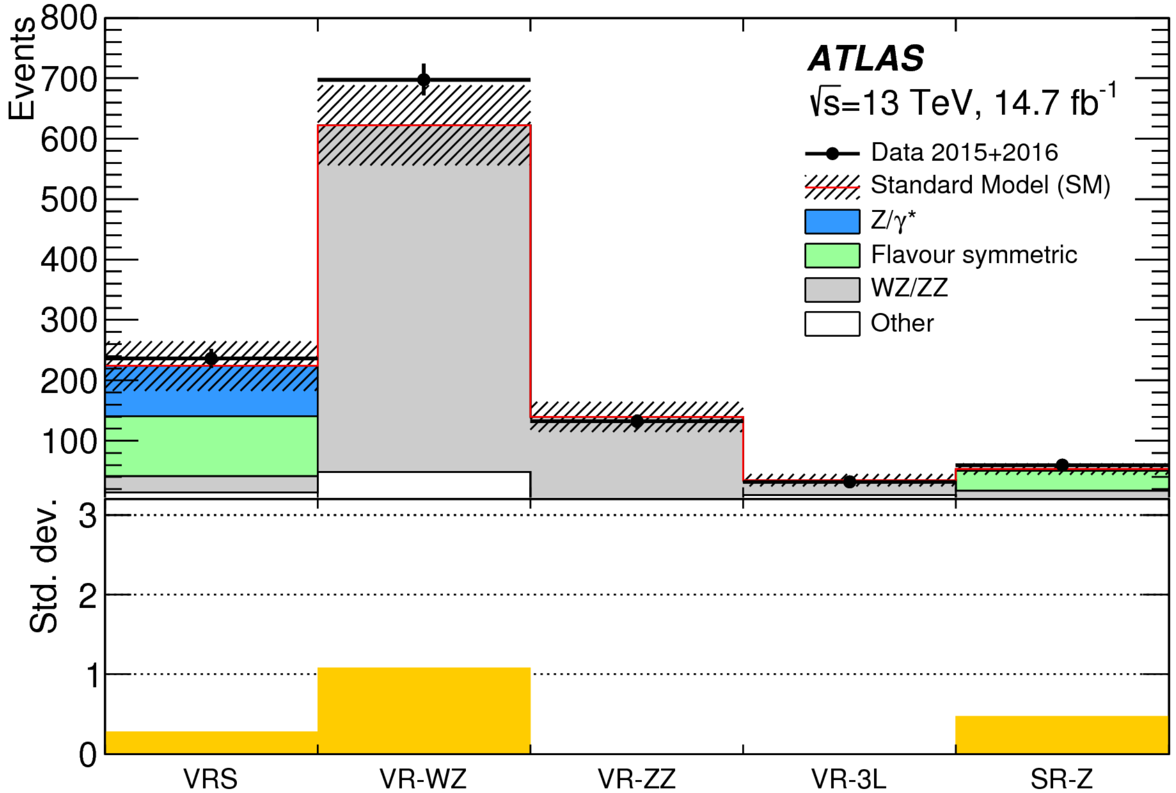


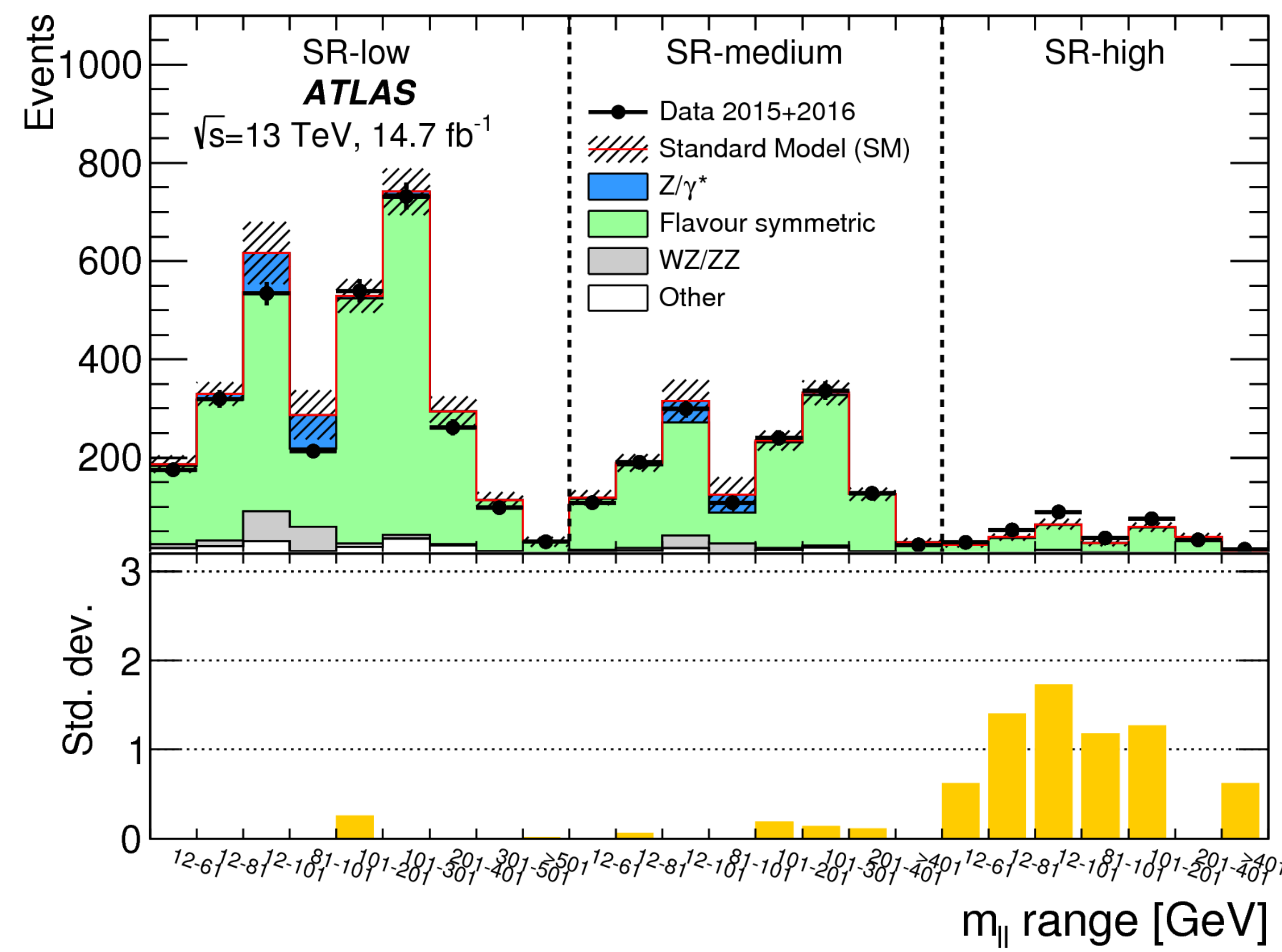
BACKUP

1-Lepton Results

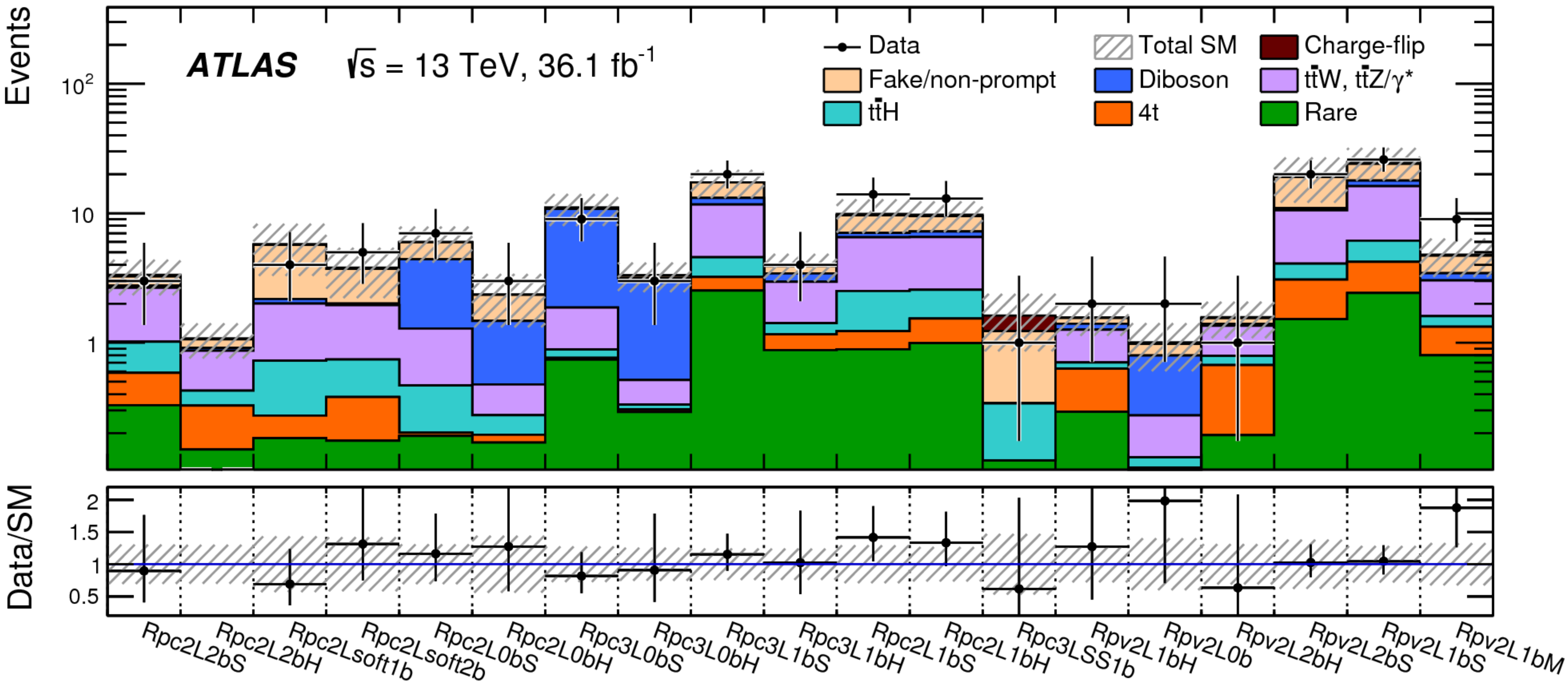


2-Lepton Results





3-Lepton Results



1-Lepton SRs

SR	**2J**	**4J high-x**	**4J low-x**	**6J**
N_ℓ	$=1$	$=1$	$=1$	$=1$
p_{T}^{ℓ} [GeV]	$>7(6)$ for $e(\mu)$ and $<\min(5\cdot N_{\mathrm{jet}}, 35)$	>35	>35	>35
N_{jet}	≥ 2	4–5	4–5	≥ 6
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	>430	>300	>250	>350
m_{T} [GeV]	>100	>450	150–450	>175
Aplanarity	–	>0.01	>0.05	>0.06
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}$	>0.25	>0.25	–	–
$N_{b-\mathrm{jet}}$ (excl)	$=0$ for b-veto, ≥ 1 for b-tag			
m_{eff} [GeV] (excl)	3 bins $\in$ [700,1900] + [$>$ 1900]	2 bins $\in$ [1000,2000] + [$>$ 2000]	2 bins $\in$ [1300,2000] + [$>$ 2000]	3 bins $\in$ [700,2300] + [$>$ 2300]
m_{eff} [GeV] (disc)	>1100	>1500	$>1650(1300)$ for gluino (squark)	$>2300(1233)$ for gluino (squark)

SR	**9J**
N_ℓ	$=1$
p_{T}^{ℓ} [GeV]	≥ 35
N_{jet}	≥ 9
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	>200
m_{T} [GeV]	>175
Aplanarity	>0.07
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ [GeV$^{1/2}$]	≥ 8
m_{eff} [GeV] (excl)	[1000, 1500], [$>$1500]
m_{eff} [GeV] (disc)	>1500

2-Lepton SRs (on-Z)

On-shell Z regions	$E_{\mathrm{T}}^{\mathrm{miss}}$ **[GeV]**	$H_{\mathrm{T}}^{\mathrm{incl}}$ **[GeV]**	$n_{\mathbf{jets}}$	$m_{\ell\ell}$ **[GeV]**	**SF/DF**	$\Delta\phi(\mathbf{jet}_{12}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})$	$m_{\mathrm{T}}(\ell_3, E_{\mathrm{T}}^{\mathrm{miss}})$ [GeV]	$n_{b\text{-jets}}$
Signal region								
SRZ	> 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	–	–
Control regions								
CRZ	$\boldsymbol{< 60}$	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	–	–
CR-FS	> 225	> 600	≥ 2	$\boldsymbol{61 < m_{\ell\ell} < 121}$	**DF**	> 0.4	–	–
CRT	> 225	> 600	≥ 2	$\boldsymbol{> 40, m_{\ell\ell} \notin [81, 101]}$	SF	> 0.4	–	–
CRγ	–	> 600	≥ 2	–	0ℓ, 1γ	–	–	–
Validation regions								
VRZ	$\boldsymbol{< 225}$	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	–	–
VRT	**100–200**	> 600	≥ 2	$\boldsymbol{> 40, m_{\ell\ell} \notin [81, 101]}$	SF	> 0.4	–	–
VR-S	**100–200**	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	–	–
VR-FS	**100–200**	> 600	≥ 2	$\boldsymbol{61 < m_{\ell\ell} < 121}$	**DF**	> 0.4	–	–
VR-WZ	**100–200**	–	–	–	$\boldsymbol{3\ell}$	–	< 100	0
VR-ZZ	< 100	–	–	–	$\boldsymbol{4\ell}$	–	–	0
VR-3L	**60–100**	$\boldsymbol{> 200}$	≥ 2	$81 < m_{\ell\ell} < 101$	$\boldsymbol{3\ell}$	> 0.4	–	–

2-Lepton SRs (off-Z)

Edge regions	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	H_{T} [GeV]	n_{jets}	$m_{\ell\ell}$ [GeV]	**SF/DF**	**OS/SS**	$\Delta\phi(\mathbf{jet}_{12}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})$	$m_{\ell\ell}$ **ranges**
Signal regions								
SR-low	> 200	–	≥ 2	> 12	SF	OS	> 0.4	9
SR-medium	> 200	> 400	≥ 2	> 12	SF	OS	> 0.4	8
SR-high	> 200	> 700	≥ 2	> 12	SF	OS	> 0.4	7
Control regions								
CRZ-low	$\mathbf{< 60}$	–	≥ 2	> 12	SF	OS	> 0.4	–
CRZ-medium	$\mathbf{< 60}$	> 400	≥ 2	> 12	SF	OS	> 0.4	–
CRZ-high	$\mathbf{< 60}$	> 700	≥ 2	> 12	SF	OS	> 0.4	–
CR-FS-low	> 200	–	≥ 2	> 12	**DF**	OS	> 0.4	–
CR-FS-medium	> 200	> 400	≥ 2	> 12	**DF**	OS	> 0.4	–
CR-FS-high	> 200	> 700	≥ 2	> 12	**DF**	OS	> 0.4	–
CRγ-low	–	–	≥ 2	–	0ℓ, 1γ	–	–	–
CRγ-medium	–	> 400	≥ 2	–	0ℓ, 1γ	–	–	–
CRγ-high	–	> 700	≥ 2	–	0ℓ, 1γ	–	–	–
CR-real	–	$\mathbf{> 200}$	≥ 2	**81–101**	2ℓ SF	OS	–	–
CR-fake	$\mathbf{< 125}$	–	–	$\in [12, \infty)$, $\notin [81, 101]$**(SF)**	2ℓ **SF/DF**	**SS**	–	–
Validation regions								
VR-low	**100–200**	–	≥ 2	> 12	SF	OS	> 0.4	–
VR-medium	**100–200**	> 400	≥ 2	> 12	SF	OS	> 0.4	–
VR-high	**100–200**	> 700	≥ 2	> 12	SF	OS	> 0.4	–
VR-fake	$\mathbf{> 50}$	–	≥ 2	$\in [12, \infty)$, $\notin [81, 101]$**(SF)**	**SF/DF**	**SS**	–	–

3-Lepton SRs

Signal region	$N_{\text{leptons}}^{\text{signal}}$	$N_{b\text{-jets}}$	N_{jets}	p_T^{jet} [GeV]	E_T^{miss} [GeV]	m_{eff} [GeV]	$E_T^{\text{miss}}/m_{\text{eff}}$	Other	Targeted Signal
Rpc2L2bS	$\geq$ 2SS	≥ 2	≥ 6	> 25	> 200	> 600	> 0.25	–	Fig. 1(a)
Rpc2L2bH	$\geq$ 2SS	≥ 2	≥ 6	> 25	–	> 1800	> 0.15	–	Fig. 1(a), NUHM2
Rpc2Lsoft1b	$\geq$ 2SS	≥ 1	≥ 6	> 25	> 100	–	> 0.3	$20{,}10 < p_T^{\ell_1}, p_T^{\ell_2} < 100$ GeV	Fig. 1(b)
Rpc2Lsoft2b	$\geq$ 2SS	≥ 2	≥ 6	> 25	> 200	> 600	> 0.25	$20{,}10 < p_T^{\ell_1}, p_T^{\ell_2} < 100$ GeV	Fig. 1(b)
Rpc2L0bS	$\geq$ 2SS	$= 0$	≥ 6	> 25	> 150	–	> 0.25	–	Fig. 1(c)
Rpc2L0bH	$\geq$ 2SS	$= 0$	≥ 6	> 40	> 250	> 900	–	–	Fig. 1(c)
Rpc3L0bS	≥ 3	$= 0$	≥ 4	> 40	> 200	> 600	–	–	Fig. 1(d)
Rpc3L0bH	≥ 3	$= 0$	≥ 4	> 40	> 200	> 1600	–	–	Fig. 1(d)
Rpc3L1bS	≥ 3	≥ 1	≥ 4	> 40	> 200	> 600	–	–	Other
Rpc3L1bH	≥ 3	≥ 1	≥ 4	> 40	> 200	> 1600	–	–	Other
Rpc2L1bS	$\geq$ 2SS	≥ 1	≥ 6	> 25	> 150	> 600	> 0.25	–	Fig. 1(e)
Rpc2L1bH	$\geq$ 2SS	≥ 1	≥ 6	> 25	> 250	–	> 0.2	–	Fig. 1(e)
Rpc3LSS1b	$\geq \ell^\pm\ell^\pm\ell^\pm$	≥ 1	–	–	–	–	–	veto $81 < m_{e^\pm e^\pm} < 101$ GeV	Fig. 1(f)
Rpv2L1bH	$\geq$ 2SS	≥ 1	≥ 6	> 50	–	> 2200	–	–	Figs. 1(g), 1(h)
Rpv2L0b	$=$ 2SS	$= 0$	≥ 6	> 40	–	> 1800	–	veto $81 < m_{e^\pm e^\pm} < 101$ GeV	Fig. 1(i)
Rpv2L2bH	$\geq$ 2SS	≥ 2	≥ 6	> 40	–	> 2000	–	veto $81 < m_{e^\pm e^\pm} < 101$ GeV	Fig. 1(j)
Rpv2L2bS	$\geq \ell^-\ell^-$	≥ 2	≥ 3	> 50	–	> 1200	–	–	Fig. 1(k)
Rpv2L1bS	$\geq \ell^-\ell^-$	≥ 1	≥ 4	> 50	–	> 1200	–	–	Fig. 1(l)
Rpv2L1bM	$\geq \ell^-\ell^-$	≥ 1	≥ 4	> 50	–	> 1800	–	–	Fig. 1(l)