Search for Direct Production of Charginos and Neutralinos in Events with Three Leptons and Missing Transverse Momentum with the ATLAS Detector

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- Electroweak SUSY introduction
  - Motivation and features
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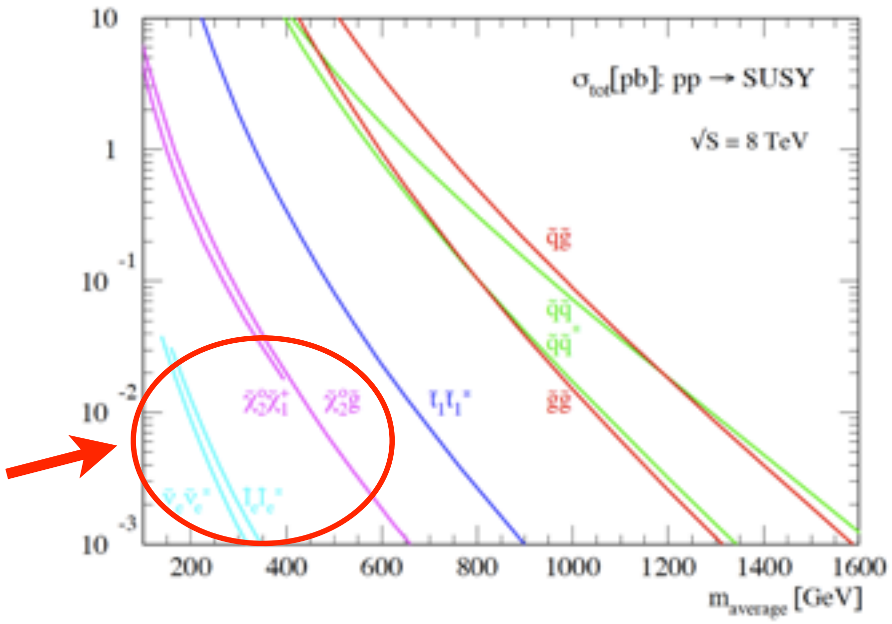
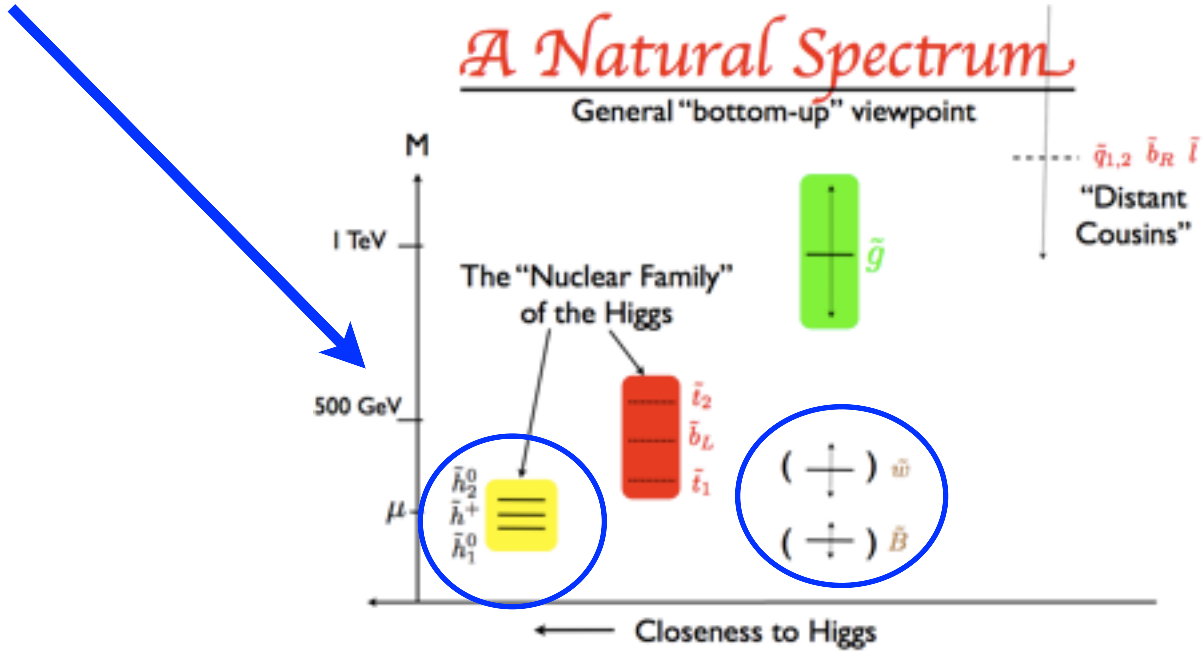
Results in this talk can be found at
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2013-035/

Electroweak SUSY

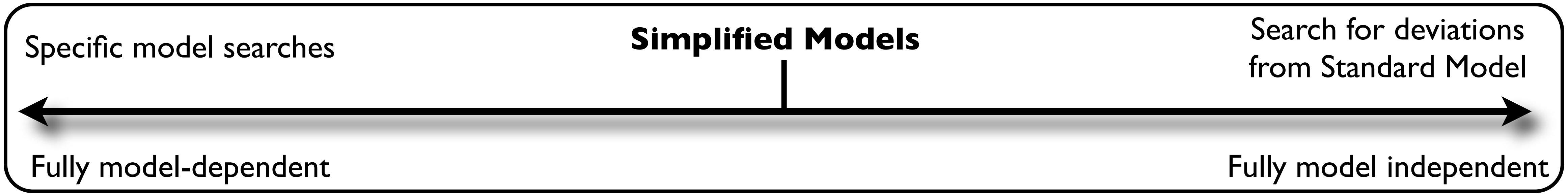
- EWK SUSY includes direct production of the partners of the gauge bosons, Higgs boson(s), and leptons
- Squark and gluino mass limits are already at the TeV scale
  - EWK production might be the dominant SUSY process at the LHC
- Natural SUSY prefers light gauginos and higgsinos
  - EWK searches complementary to 3rd gen squark searches
- EWK production can give multi-lepton signatures with low hadronic activity
  - Low Standard Model background





Analysis strategy

- General strategy
  - Search for production of gauginos and higgsinos in as many production/decay modes as possible
  - Aim for discovery of new particles, but if results are consistent with Standard Model then set limits on production cross sections
  - Formulate results in terms of simplified models which can represent many SUSY models


Specific model searches

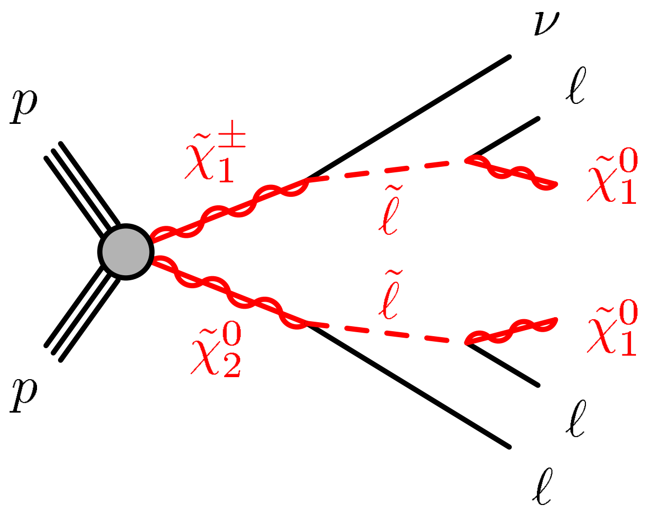
Simplified Models

Search for deviations from Standard Model

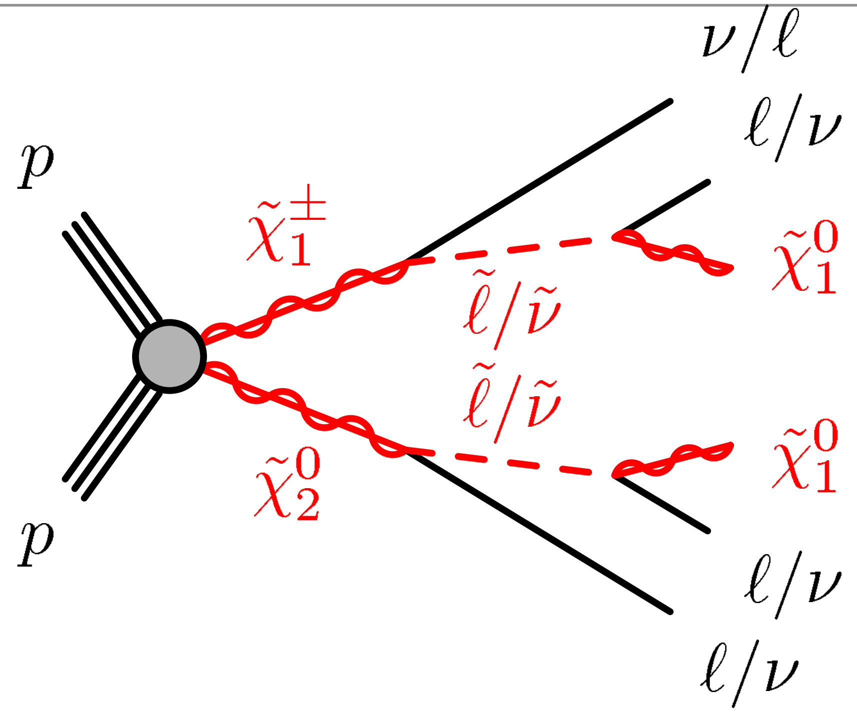
Fully model-dependent

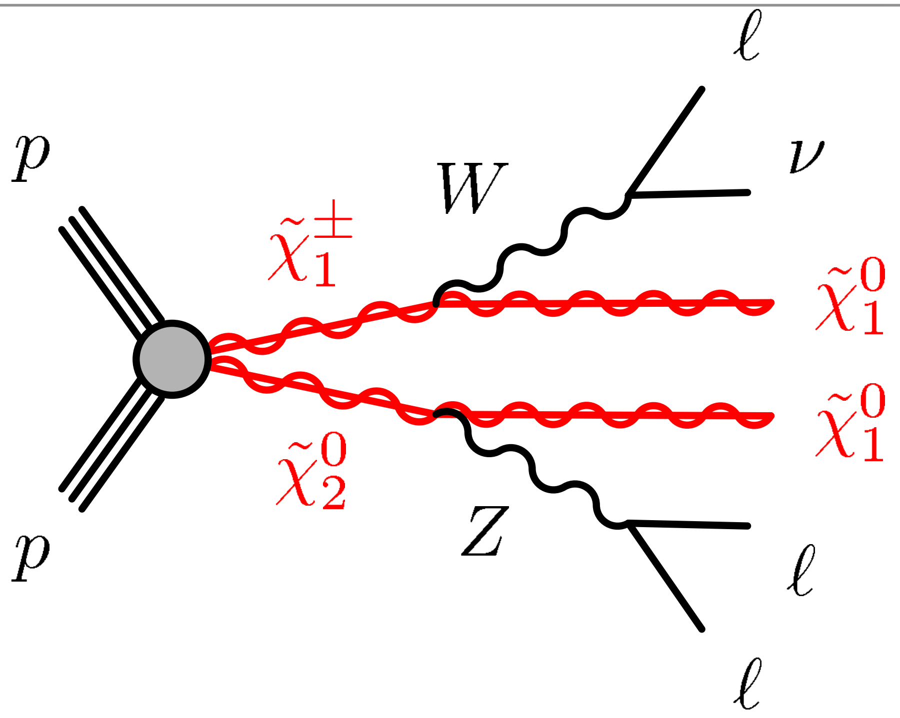
Fully model independent

- This analysis
  - Search for chargino1-neutralino2 production and decay into three-lepton final states with missing transverse momentum
  - Search for decay modes with intermediate sleptons and W/Z bosons



Signals: simplified models



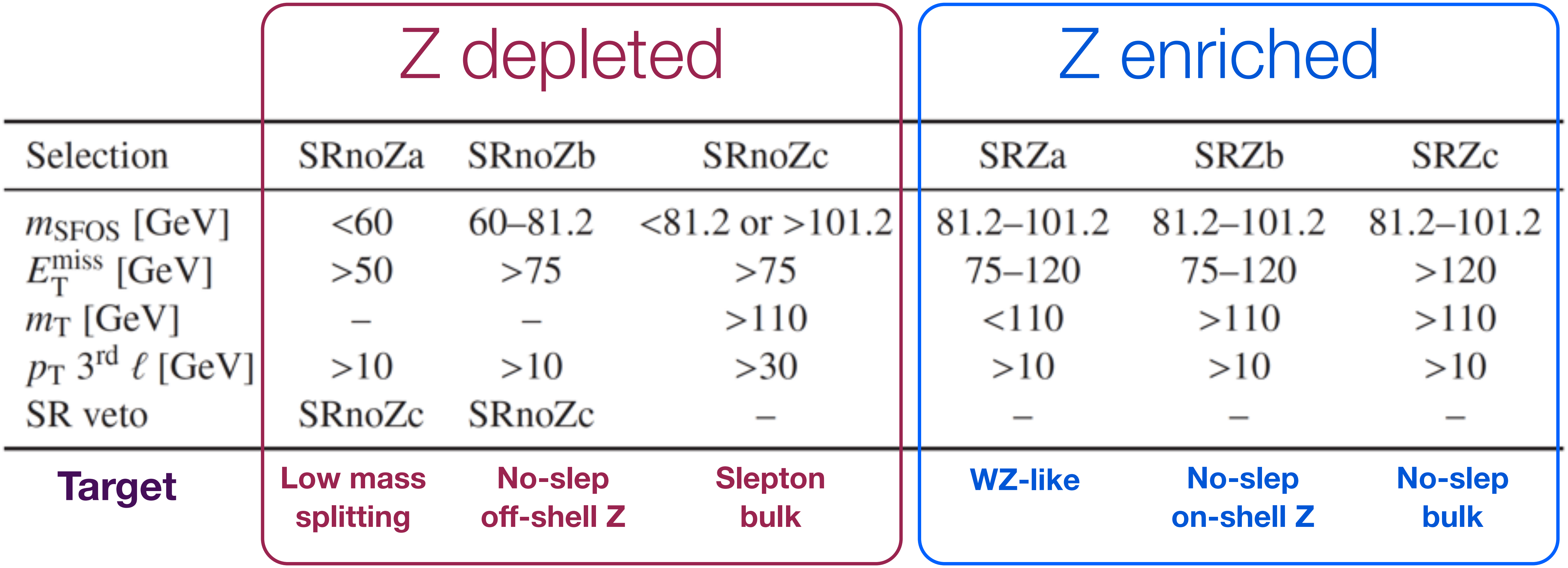


- Direct production of chargino1-neutralino2 (C1N2) with two decay modes
  - Intermediate sleptons/sneutrinos (flavor democratic)
  - Intermediate W and Z bosons (on-shell and off-shell)
- Results are generic and can be applied to any SUSY-like model
- Technical details
  - C1 and N2 are wino-like and mass degenerate
  - N1 is bino-like
  - Slepton, sneutrino mass degenerate
    - Set halfway between C1/N2 and N1

Object selection

- Electrons
  - Combines ID track and calorimeter shower
  - $p_T > 10$ GeV
  - ID track and calorimeter isolation cuts
  - Impact parameter cuts
- Muons
  - Statistical combination of an ID track with a muon spectrometer track
  - $p_T > 10$ GeV
  - ID track isolation cuts
  - Impact parameter cuts
- Jets
  - Hadronic calorimeter shower clusters and ID tracks
  - $p_T > 20$ GeV
  - b-jets tagged by looking for a displaced vertex (85% efficient)
- Missing transverse energy (MET)
  - Calculated by summing all energy deposits in the calorimeters
  - Corrected for reconstructed electrons, muons, and photons

Event selection



	Z depleted			Z enriched		
Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
m_{SFOS} [GeV]	<60	60–81.2	<81.2 or >101.2	81.2–101.2	81.2–101.2	81.2–101.2
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	>50	>75	>75	75–120	75–120	>120
m_{T} [GeV]	–	–	>110	<110	>110	>110
p_{T} 3^{rd} ℓ [GeV]	>10	>10	>30	>10	>10	>10
SR veto	SRnoZc	SRnoZc	–	–	–	–
Target	**Low mass splitting**	**No-slep off-shell Z**	**Slepton bulk**	**WZ-like**	**No-slep on-shell Z**	**No-slep bulk**

- Signal regions are split into Z selection and Z veto regions with varying tightness designed to target different areas of our signal grids
- Orthogonality between SRs is imposed
  - Regions are statistically combined for the limits

Background model overview

- **Irreducible background: processes with 3 real, isolated leptons**
  - Diboson WZ and ZZ
  - Triboson
  - ttbar + W/Z

Modeled with Monte Carlo

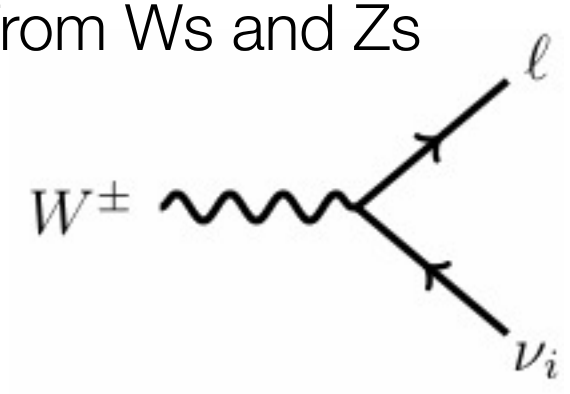
- **Reducible background: process with 1 or 2 fake leptons**
  - W+jets, Z+jets
  - ttbar, single top
  - WW

Modeled with Matrix Method

- Reducible background with 3 fake leptons is *negligible*

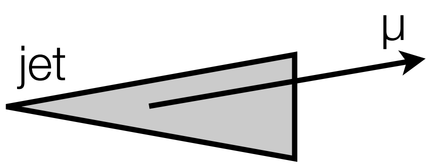
Real leptons

prompt leptons coming from Ws and Zs

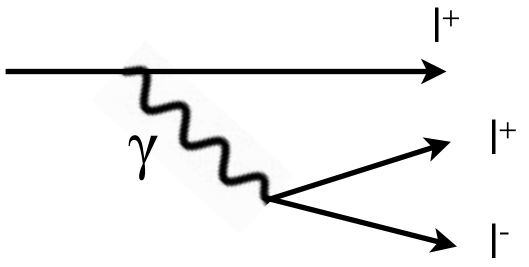


Fake leptons

HF/LF fakes from jets



Conversion leptons from photon radiation



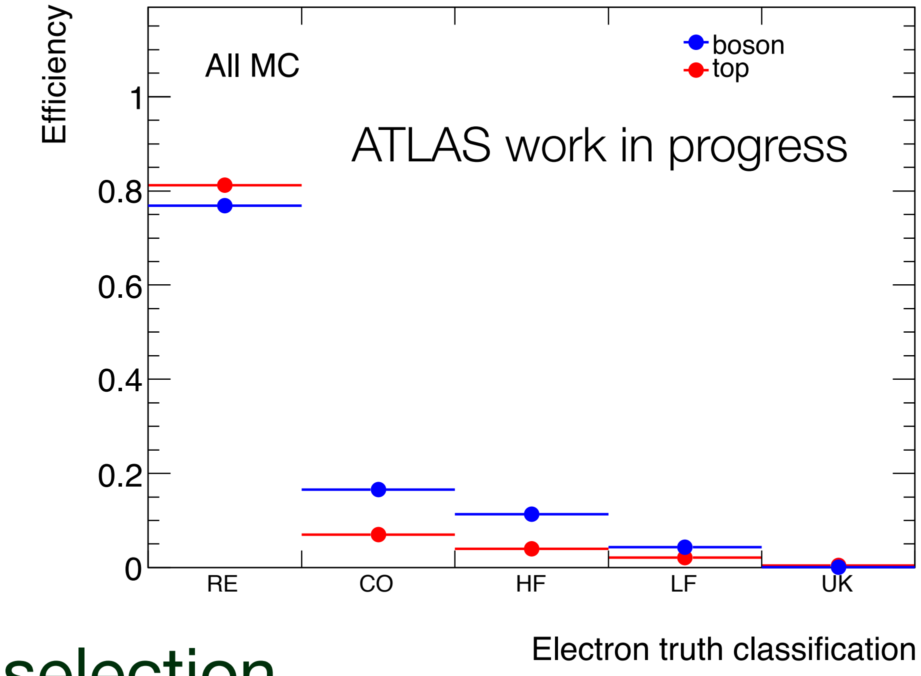
Matrix method fake lepton estimate

$$\underbrace{\begin{pmatrix} N_{TT} \\ N_{TL'} \\ N_{L'T} \\ N_{L'L'} \end{pmatrix}}_{\text{Measured in data}} = \underbrace{\begin{pmatrix} \epsilon_1\epsilon_2 & \epsilon_1 f_2 & f_1\epsilon_2 & f_1 f_2 \\ \epsilon_1(1-\epsilon_2) & \epsilon_1(1-f_2) & f_1(1-\epsilon_2) & f_1(1-f_2) \\ (1-\epsilon_1)\epsilon_2 & (1-\epsilon_1)f_2 & (1-f_1)\epsilon_2 & (1-f_1)f_2 \\ (1-\epsilon_1)(1-\epsilon_2) & (1-\epsilon_1)(1-f_2) & (1-f_1)(1-\epsilon_2) & (1-f_1)(1-f_2) \end{pmatrix}}_{\text{Measured in MC and data}} \cdot \underbrace{\begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}}_{\text{Desired solution}}$$

- Relates tight (T) and loose (L) lepton properties to real (R) and fake (F) objects in terms of real lepton efficiency (ϵ_i) and fake rate (f_i)
  - For **electrons**, we use isolation, impact parameters, and ID cuts
  - For **muons**, we use isolation and impact parameters
- Leading light lepton is not used in the matrix equation *(hence 4x4 matrix)*
  - Background dominated by leading real lepton + softer fakes
- Inversion of equation gives the estimate of events with 1 or 2 fake leptons:

$$N_{Fake\to TT} = \epsilon_1 f_2 \times N_{RF} + f_1\epsilon_2 \times N_{FR} + f_1 f_2 \times N_{FF}$$

Matrix method efficiencies



- Real and fake efficiencies can depend on type, physics process, and object/event kinematics
- Use both data and MC to derive weighted average efficiencies for each signal and validation region
  - Data/MC scale factors correct MC efficiencies
  - Baseline efficiencies measured in MC with loose selection
  - Process fractions measured in MC for each signal and validation region
- Weighted average fake efficiency for generic region XR:

$$f_{XR} = \sum_{i,j} (SF^i \times R^{ij}_{XR} \times f^{ij})$$

  - SF^i = scale factor for lepton fake type i (heavy flavor, conversion, etc.)
  - R^{ij} = fraction of type i and process j (tt, VV, etc.) in region
  - f^{ij} = fake efficiency for type i from process j

Background model validation

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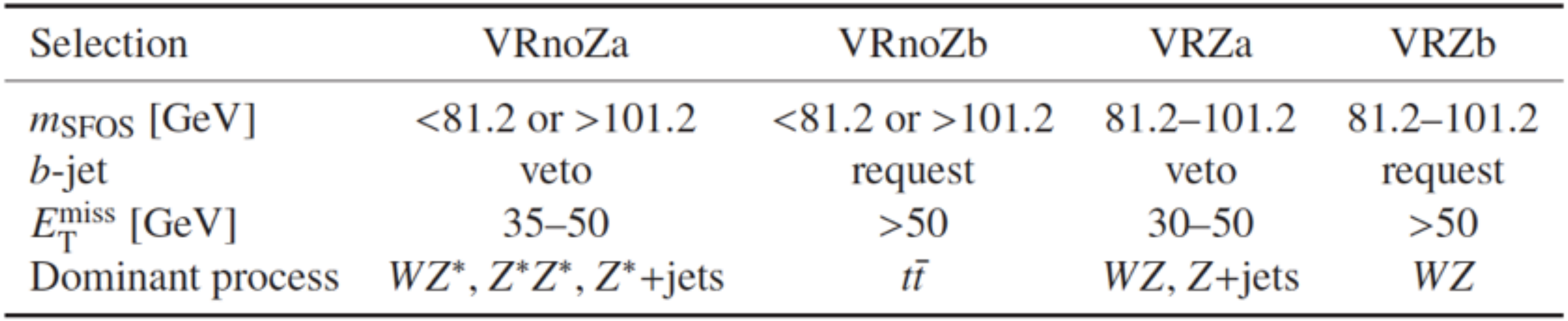
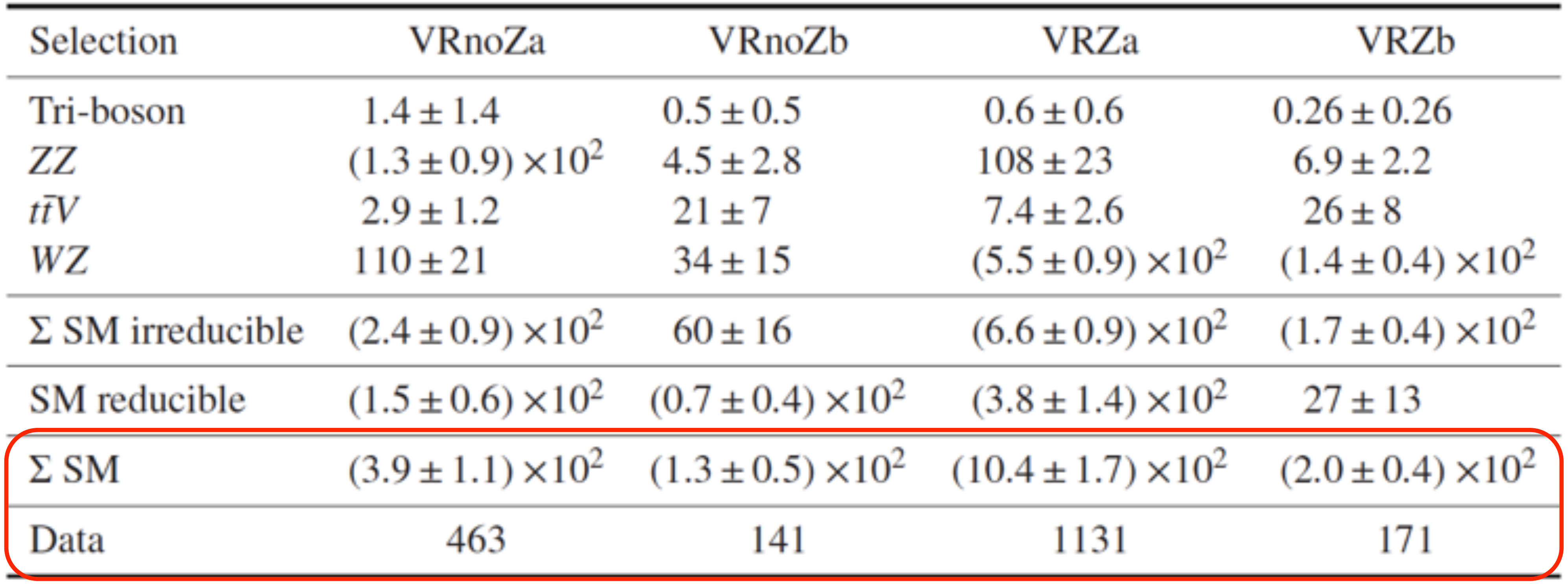
- We define validation regions which target various background sources



Selection	VRnoZa	VRnoZb	VRZa	VRZb
m_{SFOS} [GeV]	<81.2 or >101.2	<81.2 or >101.2	81.2–101.2	81.2–101.2
b-jet	veto	request	veto	request
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	35–50	>50	30–50	>50
Dominant process	WZ^*, Z^*Z^*, Z^*+jets	$t\bar{t}$	WZ, Z+jets	WZ

- We then compare the SM prediction with data



Selection	VRnoZa	VRnoZb	VRZa	VRZb
Tri-boson	1.4 ± 1.4	0.5 ± 0.5	0.6 ± 0.6	0.26 ± 0.26
ZZ	$(1.3 \pm 0.9) \times 10^2$	4.5 ± 2.8	108 ± 23	6.9 ± 2.2
$t\bar{t}V$	2.9 ± 1.2	21 ± 7	7.4 ± 2.6	26 ± 8
WZ	110 ± 21	34 ± 15	$(5.5 \pm 0.9) \times 10^2$	$(1.4 \pm 0.4) \times 10^2$
Σ SM irreducible	$(2.4 \pm 0.9) \times 10^2$	60 ± 16	$(6.6 \pm 0.9) \times 10^2$	$(1.7 \pm 0.4) \times 10^2$
SM reducible	$(1.5 \pm 0.6) \times 10^2$	$(0.7 \pm 0.4) \times 10^2$	$(3.8 \pm 1.4) \times 10^2$	27 ± 13
Σ SM	$(3.9 \pm 1.1) \times 10^2$	$(1.3 \pm 0.5) \times 10^2$	$(10.4 \pm 1.7) \times 10^2$	$(2.0 \pm 0.4) \times 10^2$
Data	463	141	1131	171

- **Good agreement is observed in each region**

Background model validation

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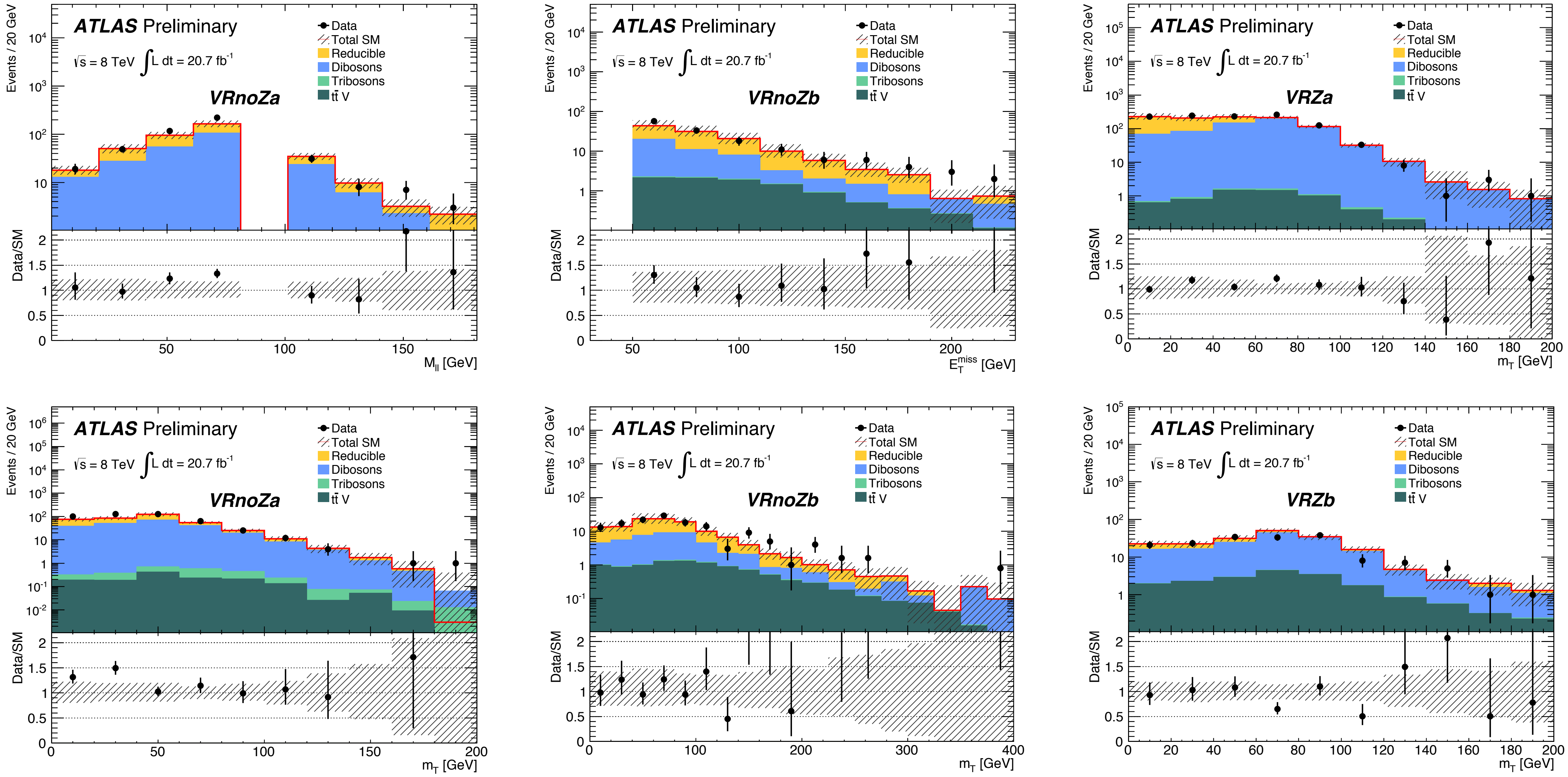

- Kinematic distributions in the validation regions show good agreement
- Background modeling looks ok -> open the signal region box!

Observed data in the signal regions

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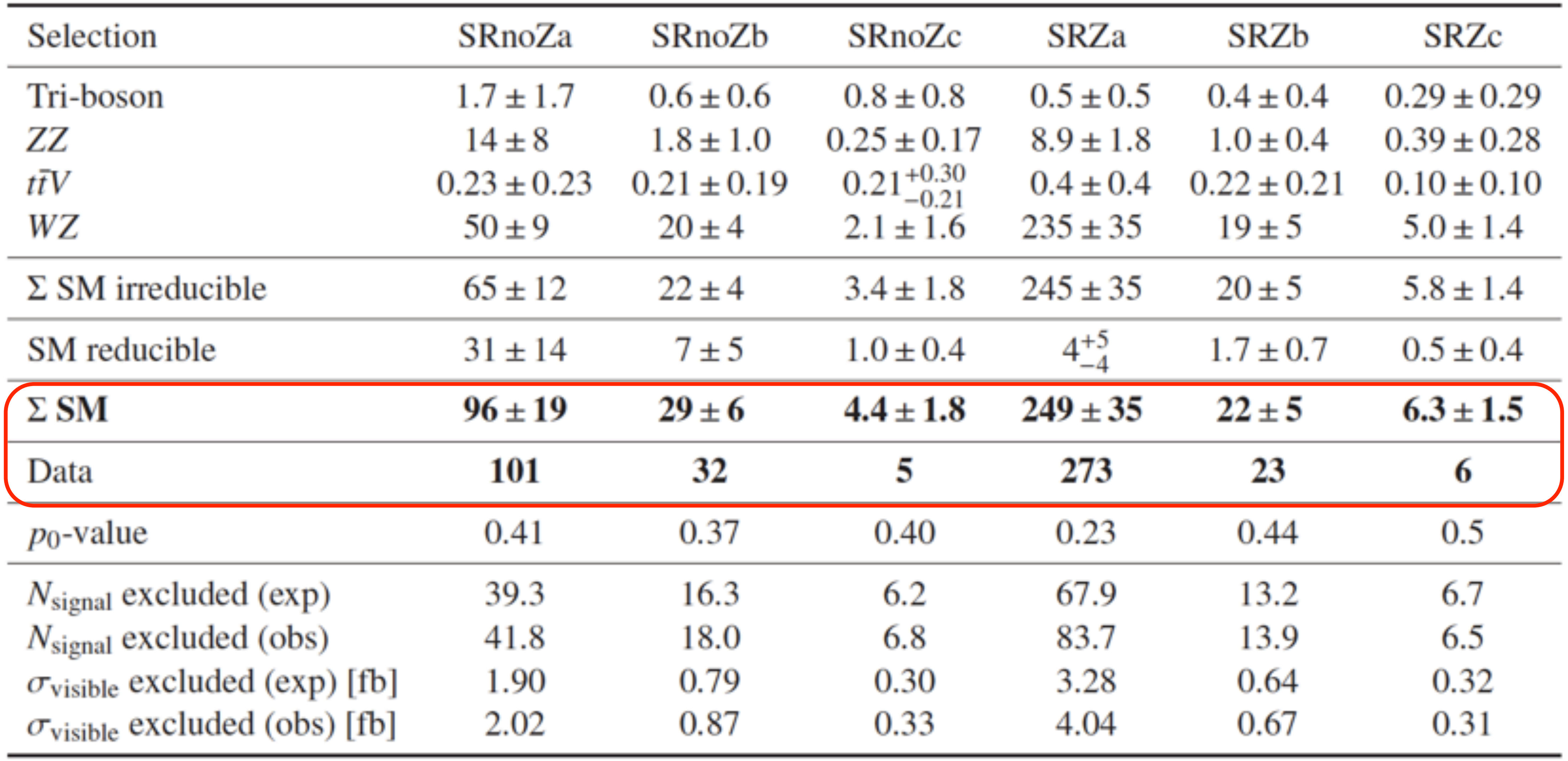

Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
Tri-boson	1.7 ± 1.7	0.6 ± 0.6	0.8 ± 0.8	0.5 ± 0.5	0.4 ± 0.4	0.29 ± 0.29
ZZ	14 ± 8	1.8 ± 1.0	0.25 ± 0.17	8.9 ± 1.8	1.0 ± 0.4	0.39 ± 0.28
$t\bar{t}V$	0.23 ± 0.23	0.21 ± 0.19	$0.21^{+0.30}_{-0.21}$	0.4 ± 0.4	0.22 ± 0.21	0.10 ± 0.10
WZ	50 ± 9	20 ± 4	2.1 ± 1.6	235 ± 35	19 ± 5	5.0 ± 1.4
Σ SM irreducible	65 ± 12	22 ± 4	3.4 ± 1.8	245 ± 35	20 ± 5	5.8 ± 1.4
SM reducible	31 ± 14	7 ± 5	1.0 ± 0.4	4^{+5}_{-4}	1.7 ± 0.7	0.5 ± 0.4
Σ SM	$\mathbf{96 \pm 19}$	$\mathbf{29 \pm 6}$	$\mathbf{4.4 \pm 1.8}$	$\mathbf{249 \pm 35}$	$\mathbf{22 \pm 5}$	$\mathbf{6.3 \pm 1.5}$
Data	**101**	**32**	**5**	**273**	**23**	**6**
p_0-value	0.41	0.37	0.40	0.23	0.44	0.5
N_{signal} excluded (exp)	39.3	16.3	6.2	67.9	13.2	6.7
N_{signal} excluded (obs)	41.8	18.0	6.8	83.7	13.9	6.5
σ_{visible} excluded (exp) [fb]	1.90	0.79	0.30	3.28	0.64	0.32
σ_{visible} excluded (obs) [fb]	2.02	0.87	0.33	4.04	0.67	0.31

- No excess observed. The data is consistent with the background predictions.
- We set limits on the visible cross section for new physics (production cross section times acceptance times efficiency) at 95% CL using a modified CL_S prescription
- Uncertainties modeled as nuisance parameters in the likelihood with correlations taken into account

Observed data in the signal regions

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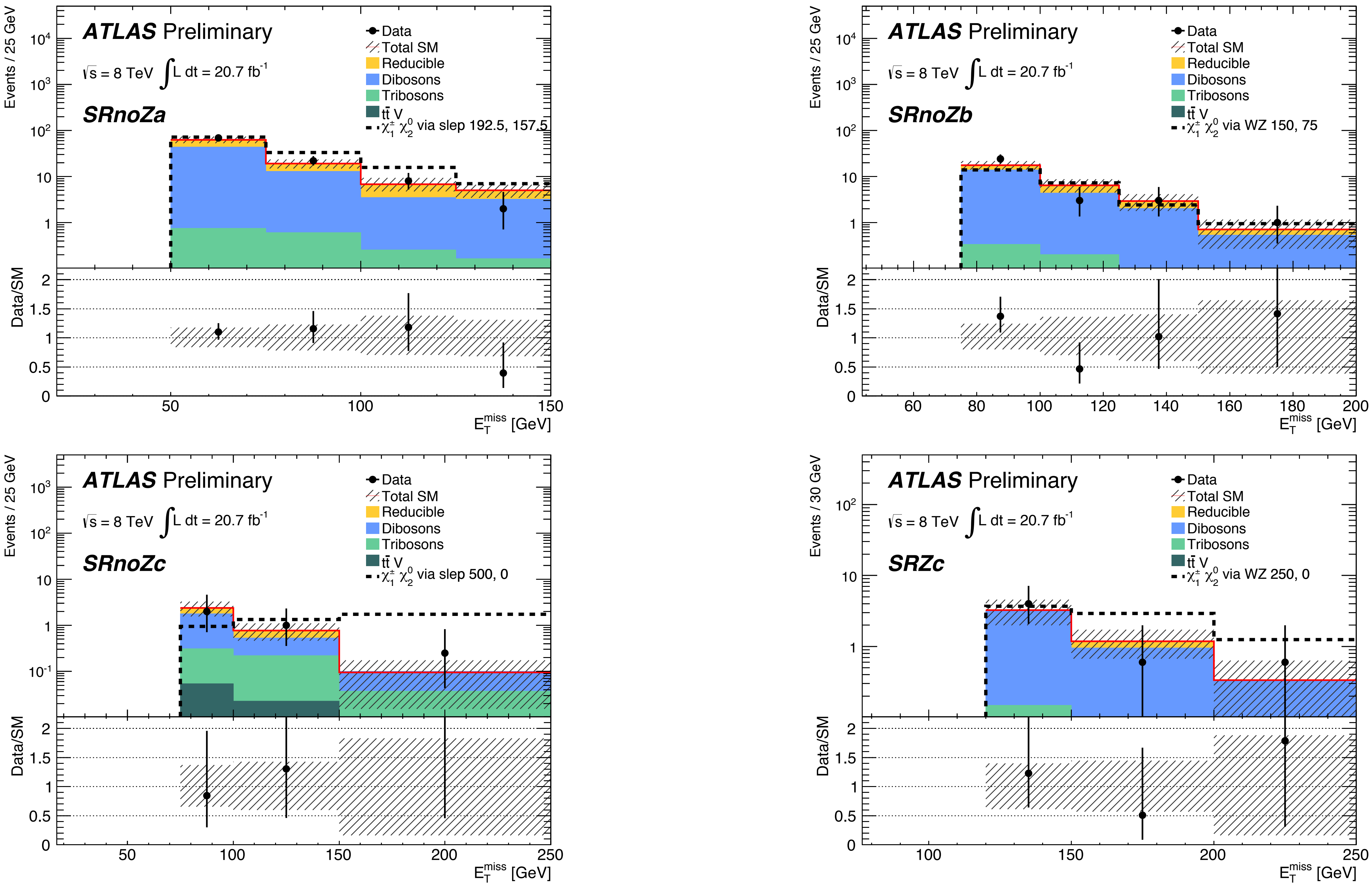

- Missing E_T distributions in the signal regions

Observed data in the signal regions

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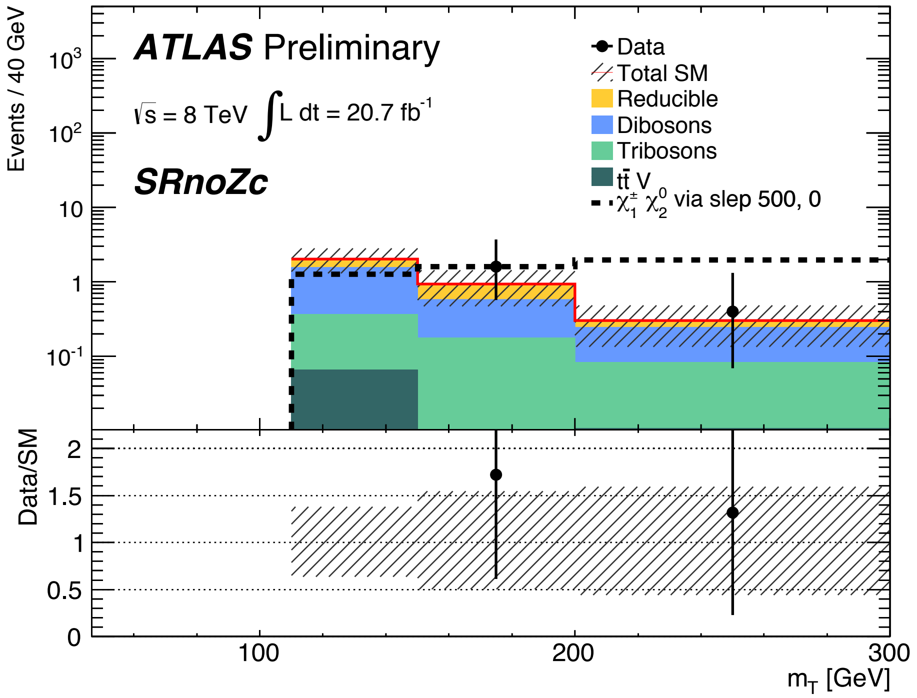

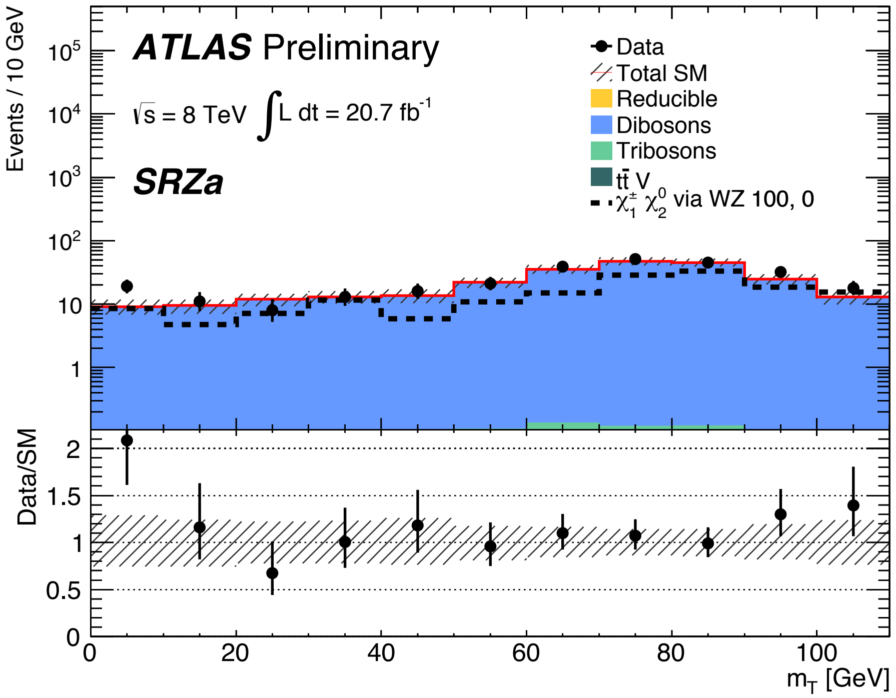

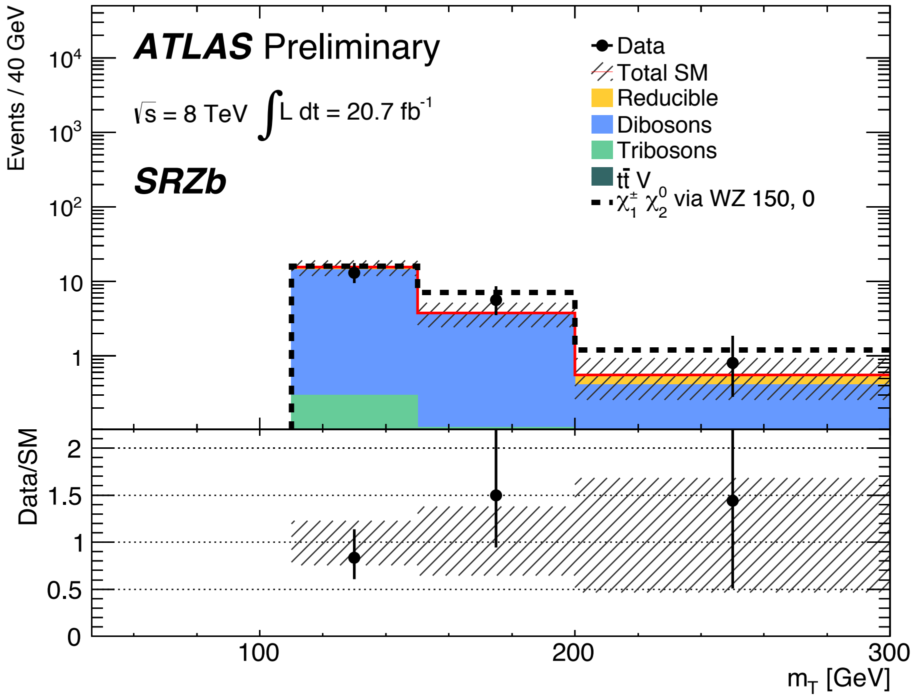

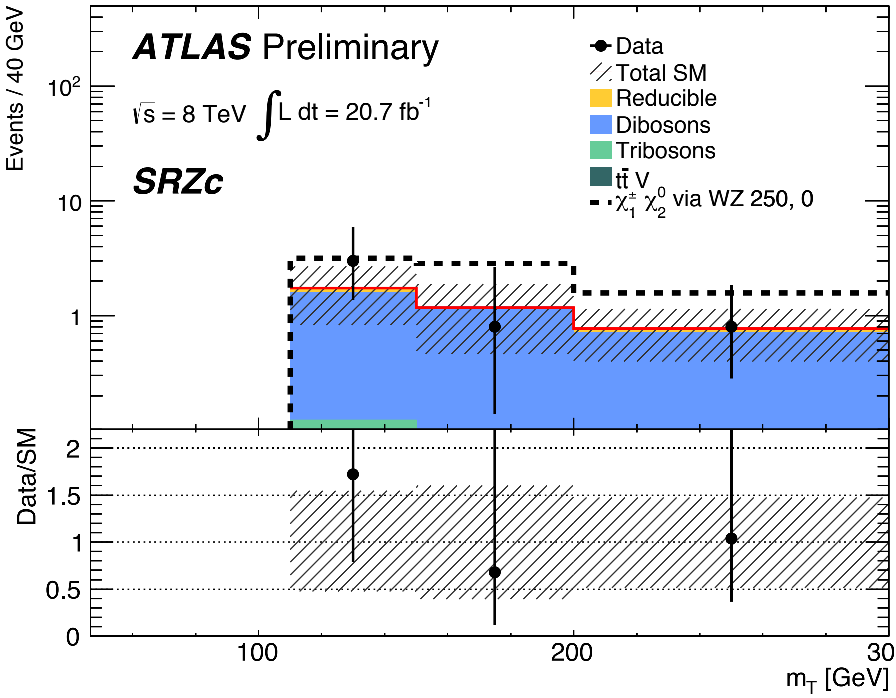

- Transverse mass distributions in the signal regions
    - Computed using non-SFOS pair lepton with the missing E_T

Limits in the simplified models

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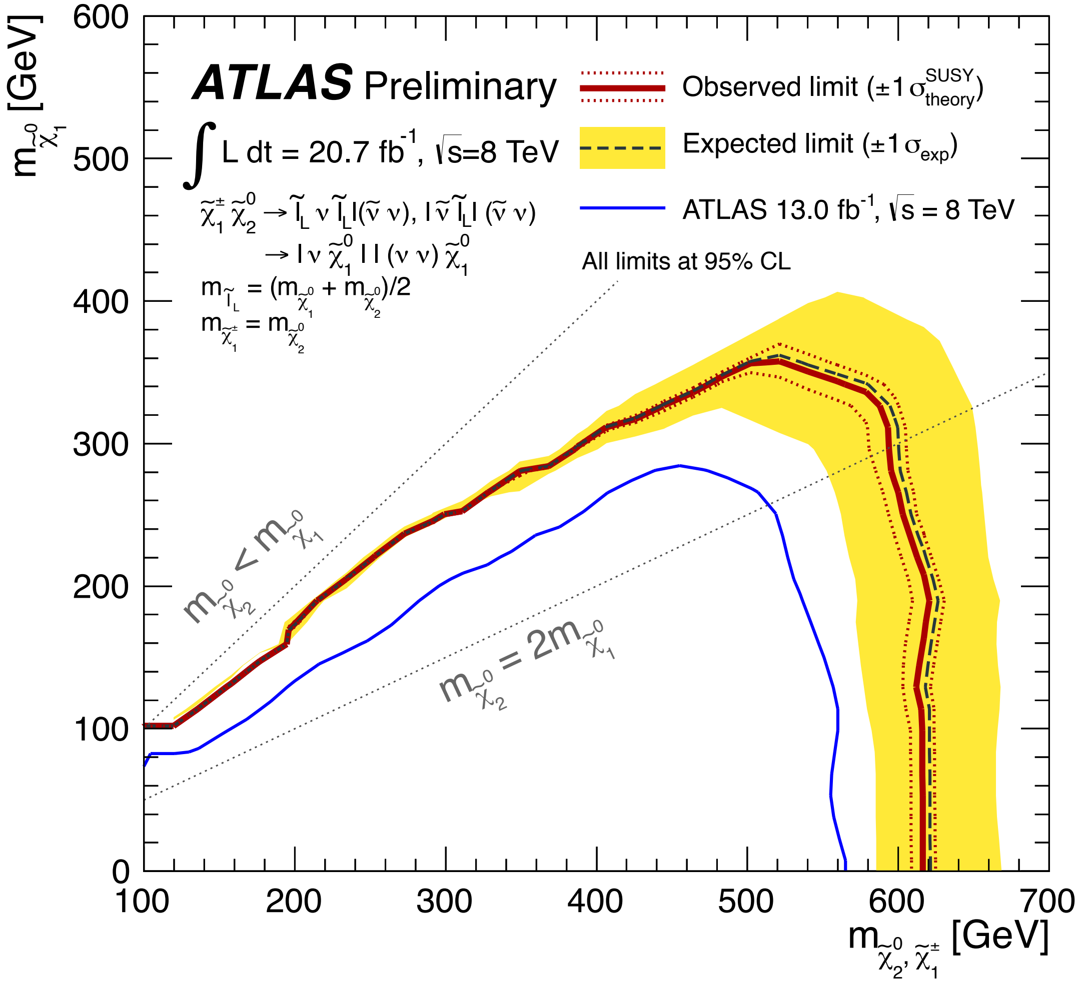
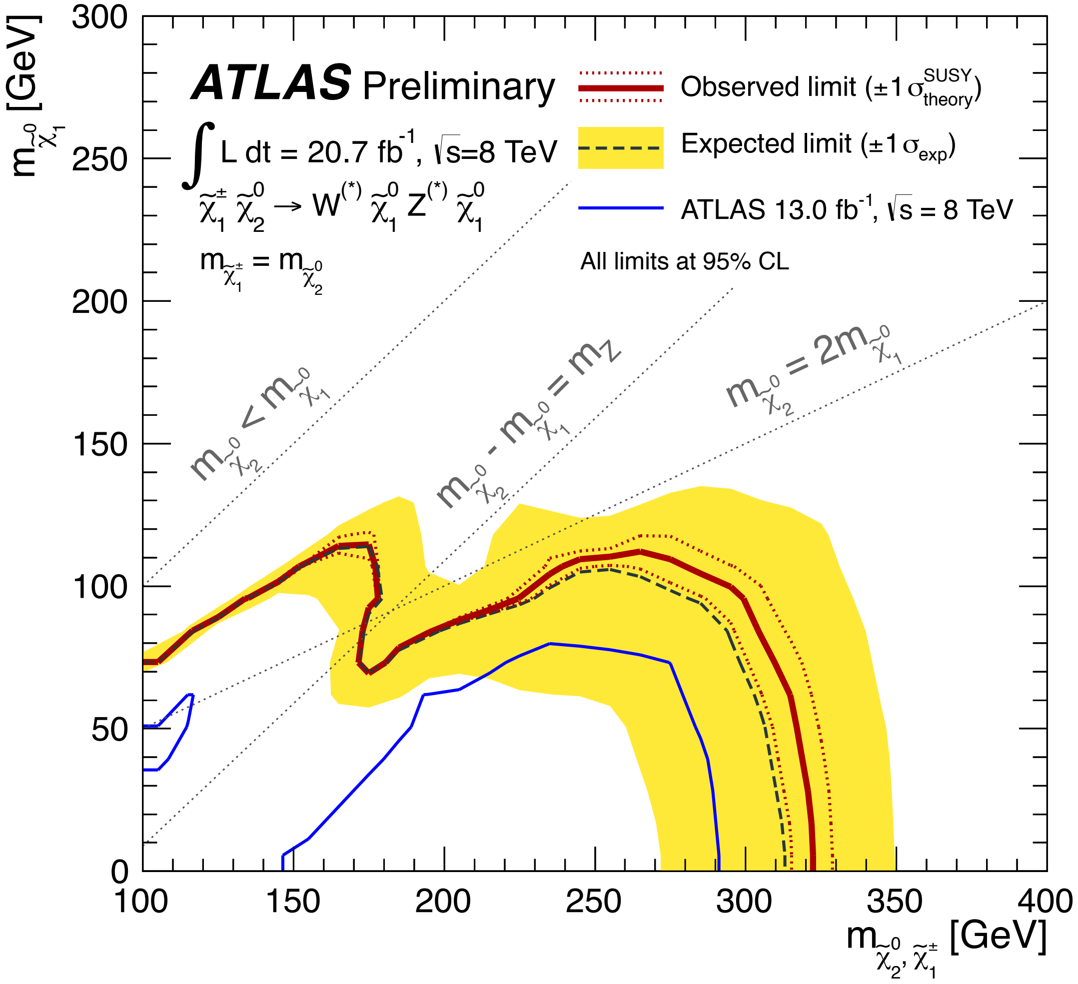
With light sleptons



Without light sleptons (SM bosons)

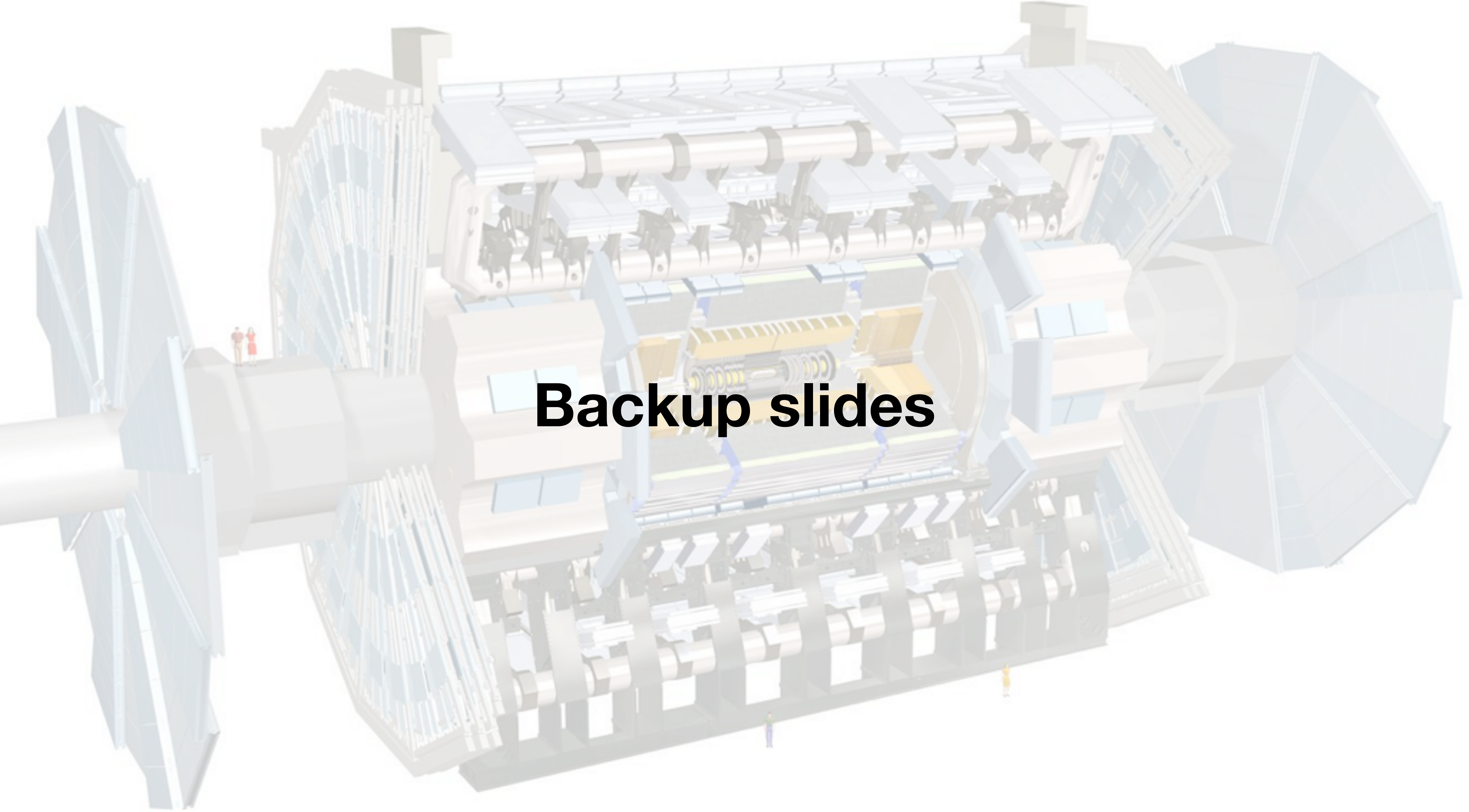


- 95% C.L. limits computed via a *modified frequentist CLs* with uncertainties modeled as nuisance parameters and correlations taken into account
- All six signal regions are statistically combined to give the best limits
- Previous result with 13 fb^{-1} of data is in blue
- Large improvement in challenging WZ*-like region (the gap in the right plot)

Conclusions

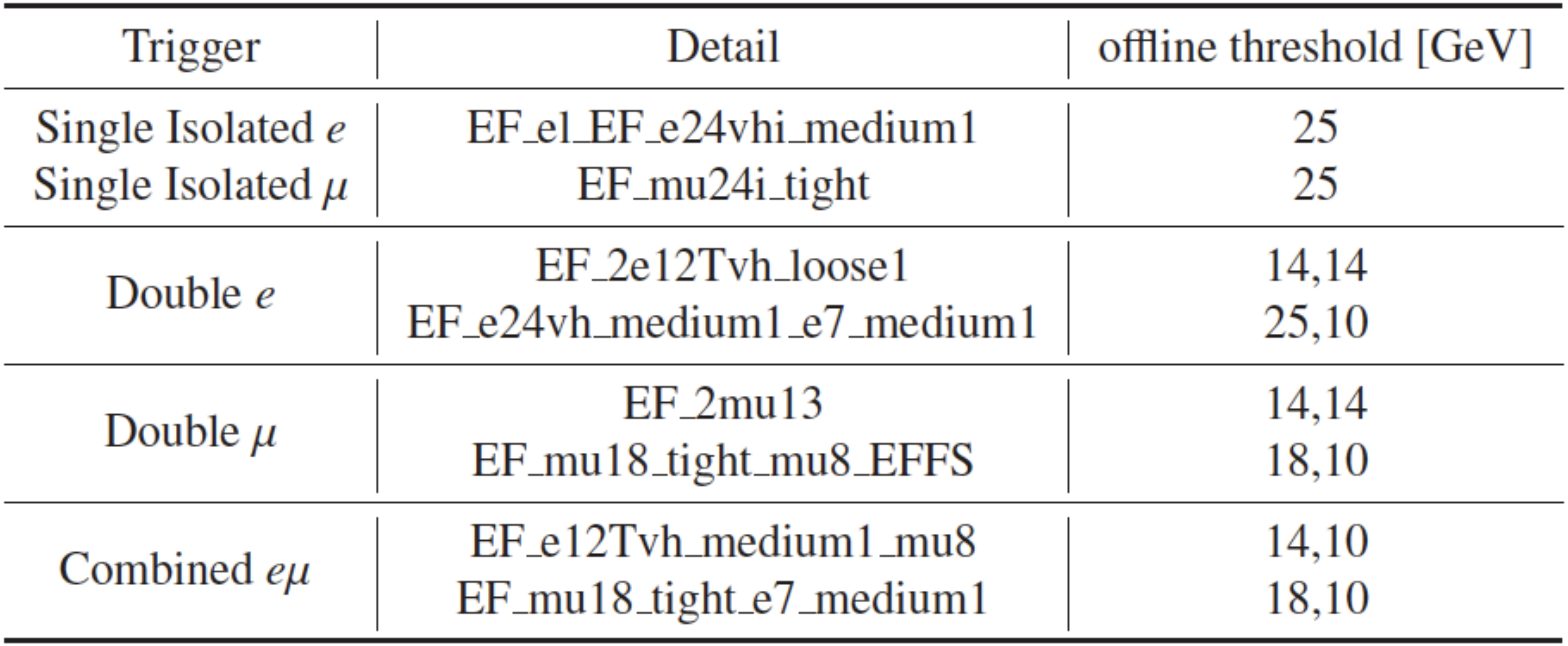
- I’ve presented an ATLAS search for electroweak SUSY in the three lepton channel with 21 fb^{-1} of 8 TeV data
- Results are consistent with the Standard Model prediction; no excess observed
- Limits have been placed on C1N2 production with intermediate sleptons and SM gauge bosons
    - Limits show good improvement over previous results
- Efforts are underway to finalize the 2012 data results in a journal publication

Results in this talk can be found at
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2013-035/



Backup slides

Trigger chains and thresholds



Trigger	Detail	offline threshold [GeV]
Single Isolated e	EF_el_EF_e24vhi_medium1	25
Single Isolated μ	EF_mu24i_tight	25
Double e	EF_2e12Tvh_loose1	14,14
	EF_e24vh_medium1_e7_medium1	25,10
Double μ	EF_2mu13	14,14
	EF_mu18_tight_mu8_EFFS	18,10
Combined $e\mu$	EF_e12Tvh_medium1_mu8	14,10
	EF_mu18_tight_e7_medium1	18,10

- Trigger requirement is a logical OR of all of the trigger chains above
- Leptons are required to be above the listed thresholds and matched to trigger features with dR < 0.15
- Only the leading lepton is considered for the single isolated triggers
    - Avoids issues with the matrix method which exploits the isolation of the subleading leptons

Systematic uncertainties

- Irreducible
  - Total uncertainty 14-71%
  - Generator uncertainty 12-66%
  - Cross section 10-12%
  - MC statistics 2-14%
- Reducible
  - Total uncertainty 37-80%
  - Data statistics 12-71%
  - Process fractions 5-29%
  - MET dependence of efficiencies 5-64%
  - Scale factors <1-13%