Electroweak and strong production SUSY search in SS/3L final states

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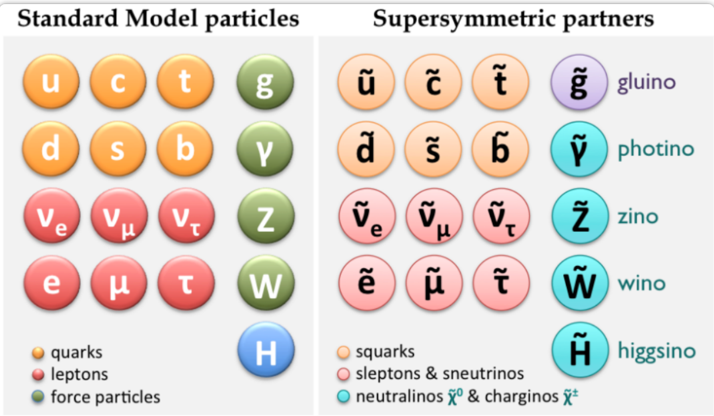
Introduction(SUSY)



Minimal Supersymmetric Model

with exact R-parity conservation

Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	−1	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$	(same)
			$\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$	(same)
			$\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$	$\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$
sleptons	0	−1	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$	(same)
			$\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$	(same)
			$\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$	$\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$
neutralinos	1/2	−1	$\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$	$\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$
charginos	1/2	−1	$\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$	$\tilde{C}_1^\pm\ \tilde{C}_2^\pm$
gluino	1/2	−1	$\tilde{g}$	(same)
goldstino (gravitino)	1/2 (3/2)	−1	$\tilde{G}$	(same)

- **R-parity:** $P_R = (-1)^{3(B-L)+2S}$: Sparticles →odd R-parity; SM-particles →even R-parity

- R-parity conserved:
  Sparticles produced in pairs, Lightest Sparticle(LSP) stable as a dark matter candidate

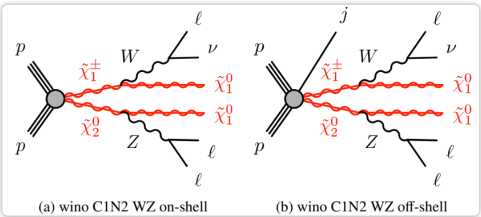
- R-parity violated:
  New terms added in superpotential: λ_{ijk}, λ'_{ijk} , λ''_{ijk} (lepton/quark superfield coupling)
  R-parity violation implies lepton/baryon number violation

Searches with SS/3L final states

- Search for **electroweak** and **strong** production
- Considering both **R-parity conserving** and **R-parity violating** models
- Using full of Run2 data in **ATLAS experiment** $\sqrt{s}$ **= 13 TeV**, integrated luminosity of **139 fb^{-1}**

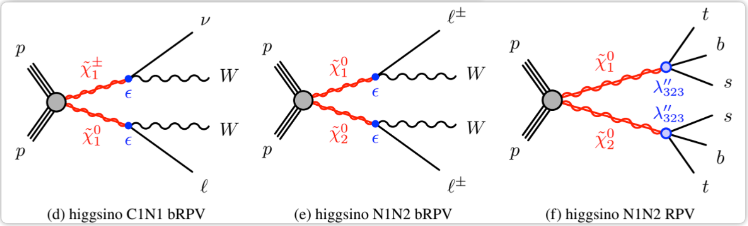
SS/3L—EWK (After the 2nd EB)

RPC



(a) wino C1N2 WZ on-shell (b) wino C1N2 WZ off-shell

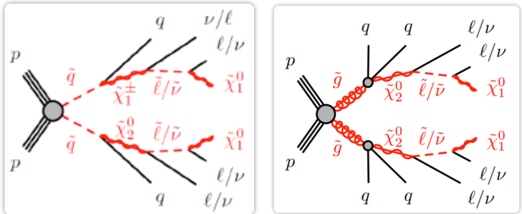
RPV



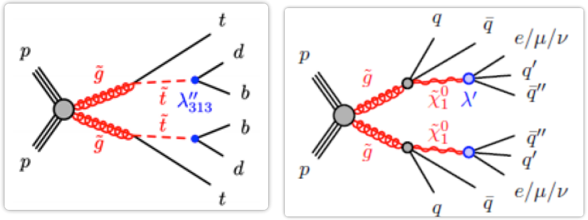
(d) higgsino C1N1 bRPV (e) higgsino N1N2 bRPV (f) higgsino N1N2 RPV

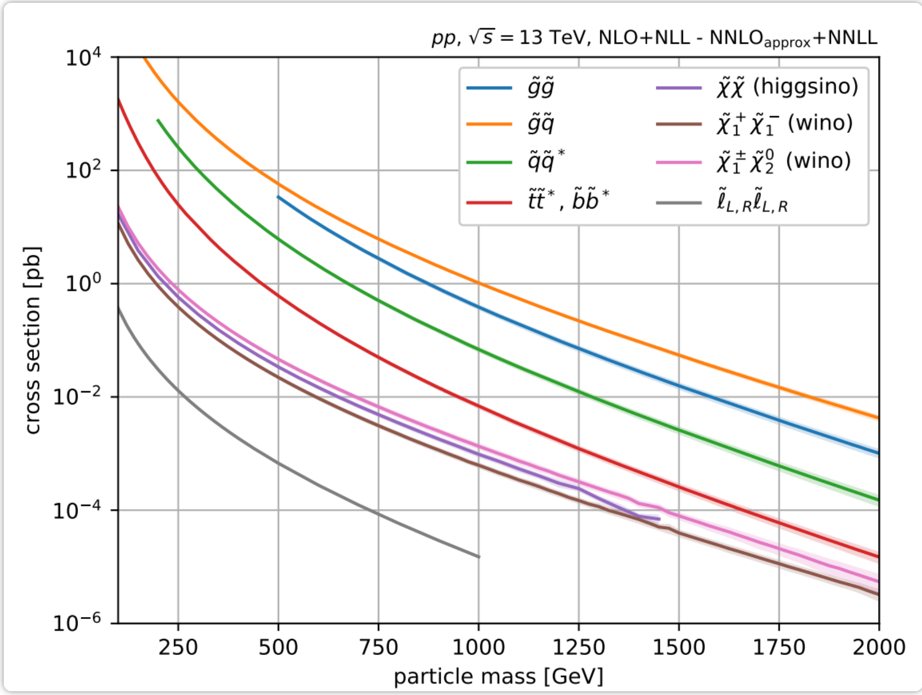
SS/3L—strong (during Signal region optimization)

RPC



RPV





Preselection

Bad event cleaning:

- Jet cleaning, Bad muon veto
- Primary vertex requirement

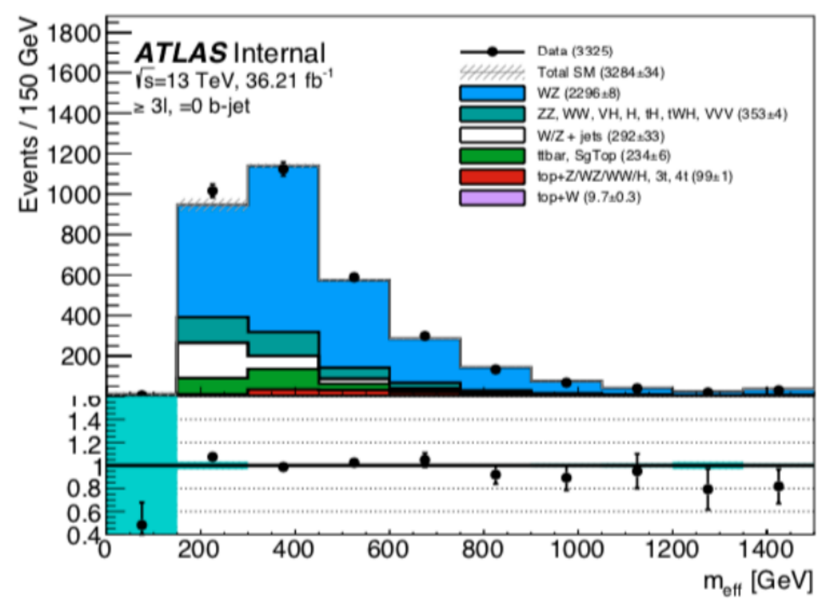
Trigger strategy:

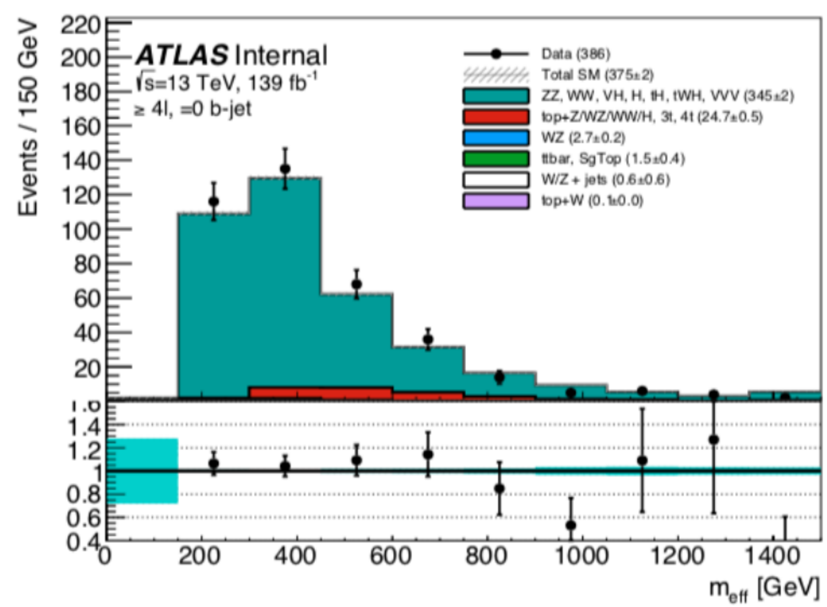
- Di-lepton triggers and MET triggers (only for MET>250 GeV)

Pre-selection:

- At least two signal leptons
- Trigger and trigger match for online and offline leptons

Good data/MC agreement for dominant backgrounds (top, WZ, ZZ)





Background Source

Irreducible background:

(SM processes leading to prompt SS or 3 leptons)

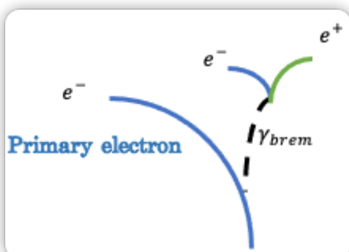
- $t\bar{t}W$, $t\bar{t}Z$
- ZZ, $W^{\pm}W^{\pm}$, WZ
- t(W)Z, $t\bar{t}VV$, 3t, 4t, $t\bar{t}H$, VH, VVV

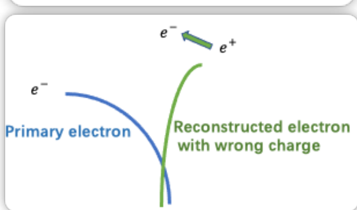
Reducible (or detector) background:

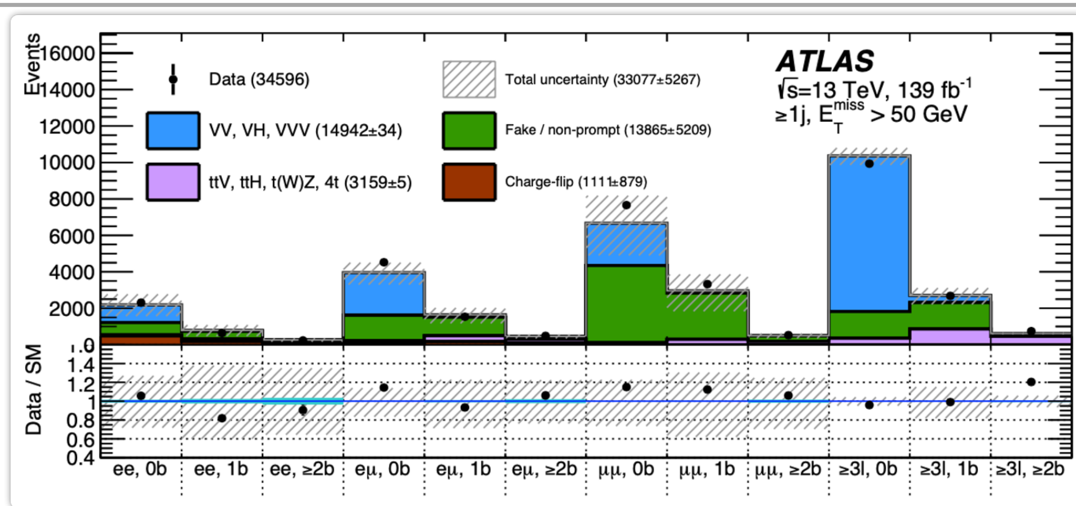
- **Charge-flip** → data-based approach estimation
- **Fake/Non-Prompt:** electrons and muons from semi-leptonic decay of heavy-flavour hadrons and light-flavour jets being mis-identified as electrons

→ **Matrix-Method** (MxM): **purely data-driven approach** used to estimate the number of fake leptons in regions of interest.

→ **MCTemplat**e method: **Monte Carlo simulations-based** method is available to estimate the electron charge flip and fake lepton backgrounds in the regions of interest.





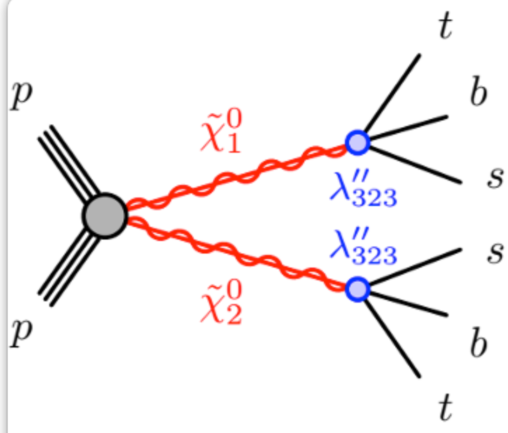


SS/3L-EWK

Signal regions: Higgsino RPV UDD

$$W_R = \lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}_k^C + \lambda'_{ijk}\hat{L}_i\hat{L}_j\hat{E}_k^C + \lambda''_{ijk}\,\hat{U}_i^C\hat{D}_j^C\hat{D}_k^C + \epsilon_i\hat{L}_i\hat{L}_j$$

- RPV UDD: λ'_{323} dominant under **minimal flavour violation hypothesis,** and sufficiently strong to have prompt decays.



(f) higgsino N1N2 RPV

- SRs are **categorized by N_{b-jets}**, in which more refined SRs are defined for different target mass points.
- SRs have been well-tuned and finalized.

1 b-jets SRs

$N_{\rm lept}^{\rm signal}$ ($N_{\rm lept}^{\rm base}$), $p_T > 25$ GeV	$N_{b-\rm jets}$ [20 GeV]	$N_{\rm jets}$ [25 GeV]	$m_{\rm eff}$ [GeV]	$E_T^{\rm miss}$ [GeV]
= 2 (= 2)	= 1	≥ 1 and ≤ 6	> 300	> 50

SR name	$N_{\rm jets}$ [25 GeV]	$\sum p_T^{b-\rm jet}/\sum p_T^{\rm jet}$	$\sum p_T$ (jet) [GeV]	$\sum p_T$ (lept) [GeV]	$\Delta R(\ell_1,\ell_2)$	$\Delta R(\ell_1,\rm jet)$	$E_T^{\rm miss}$ [GeV]
Rpv2L1bL	≤ 2	> 0.70	> 120	> 100	> 2.0	< 1.2	> 100
Rpv2L1bM	= 2 or = 3	> 0.45	> 400	> 100	> 2.5	< 1.0	–

2 b-jets SRs

$N_{\rm lept}^{\rm signal}$ ($N_{\rm lept}^{\rm base}$), $p_T > 25$ GeV	$N_{b-\rm jets}$ [20 GeV]	$N_{\rm jets}$ [25 GeV]	$E_T^{\rm miss}$ [GeV]
= 2 (= 2)	= 2	≥ 1 and ≤ 6	> 80

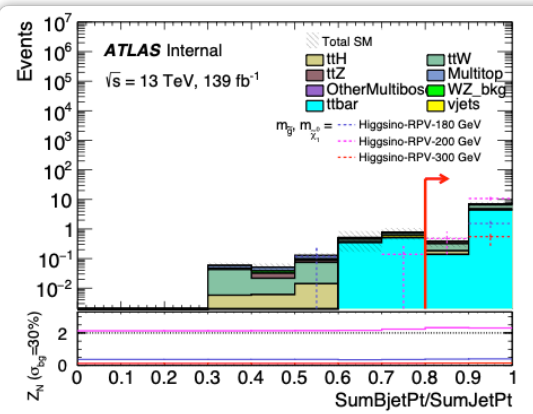
SR name	$N_{\rm jets}$ [25 GeV]	$\sum p_T^{b-\rm jet}/\sum p_T^{\rm jet}$	$\sum p_T$ (jet) [GeV]	$\Delta R(\ell_1,\ell_2)$	$\Delta R(\ell_1,\rm jet)$
Rpv2L2bL	≤ 3	> 0.90	> 300	> 2.5	< 1.0
Rpv2L2bM	= 3 or = 4	> 0.75	> 420	> 2.5	< 1.0
Rpv2L2bH	≥ 5	–	> 420	> 2.0	< 1.0

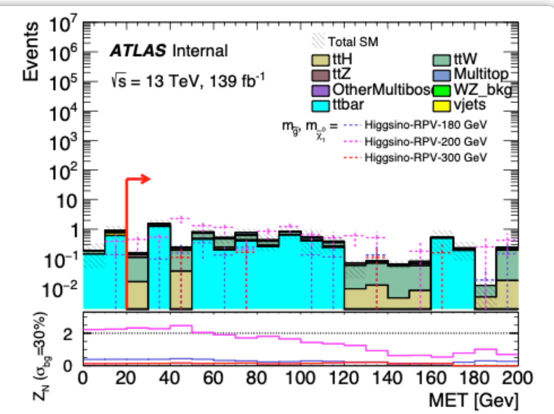
3 b-jets SRs

$N_{\rm lept}^{\rm signal}$ ($N_{\rm lept}^{\rm base}$), $p_T > 25$ GeV	$N_{b-\rm jets}$ [20 GeV]	$N_{\rm jets}$ [25 GeV]	$E_T^{\rm miss}$ [GeV]
= 2 (= 2)	≥ 3	≥ 1 and ≤ 6	> 20

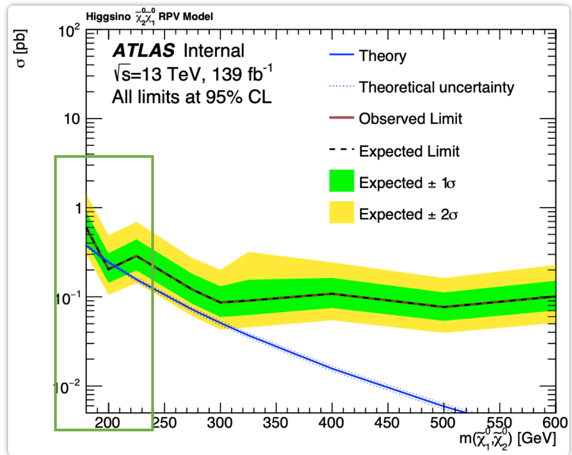
SR name	$N_{\rm jets}$ [25 GeV]	$\sum p_T^{b-\rm jet}/\sum p_T^{\rm jet}$	$\sum p_T$ (jet) [GeV]	$\Delta R(\ell_1,\ell_2)$	$\Delta R(\ell_1,\rm jet)$
Rpv2L3bL	≤ 3	> 0.8	–	> 2.0	< 1.5
Rpv2L3bM	≤ 3	> 0.8	–	–	–
Rpv2L3bH	≤ 6	> 0.5	> 350	> 2.0	< 1.0

Rpv2L3bM (N_1 Plots)





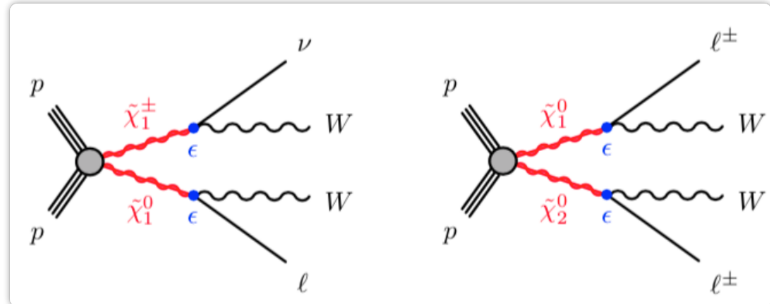
Expected 95% CL upper limits (black dashed line)



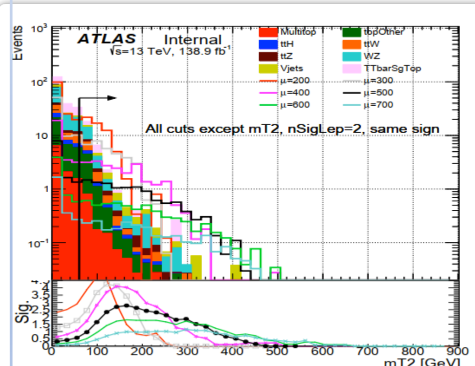
Signal regions: Higgsino bRPV

$$W_R = \lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}^C_k + \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}^C_k + \lambda''_{ijk}\hat{U}^C_i\hat{D}^C_j\hat{D}^C_k + \epsilon_i\hat{L}_i\hat{L}_j$$

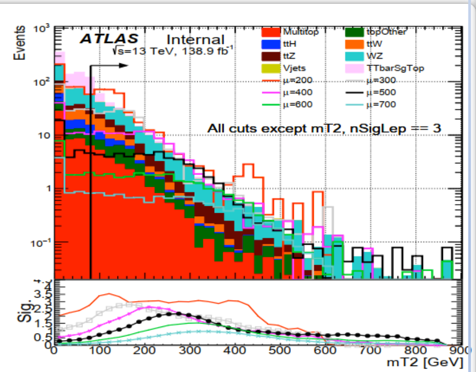
- **Motivation**: Bilinear terms related to **neutrino oscillation**
- **First analysis of the model using higgsino production.**



Variables	Two leptons final state	Three leptons final state
$N_{\mathrm{Sig}}(\ell)$	= 2	= 3
isSameSign	Yes	-
leading lepton p_{T}	20 GeV	20 GeV
subleading lepton p_{T}	20 GeV	20 GeV
third lepton p_{T}	-	10 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	$\geq$ 100 GeV	$\geq$ 120 GeV
m_{eff}	-	$\geq$ 350 GeV
m_{T2}	$\geq$ 60 GeV	$\geq$ 80 GeV
$N_{b\text{-jets}}(p_{\mathrm{T}} > 20$ GeV $)$	= 0	-
$N_{\mathrm{jets}}(p_{\mathrm{T}} > 25$ GeV$)$	$\geq$ 1	$\geq$ 1
$N_{\mathrm{jets}}(p_{\mathrm{T}} > 40$ GeV$)$	$\geq$ 4	-
$M_{ee}/M_{\mu\mu}$ SFOS pairs	-	< 81 or > 101 GeV

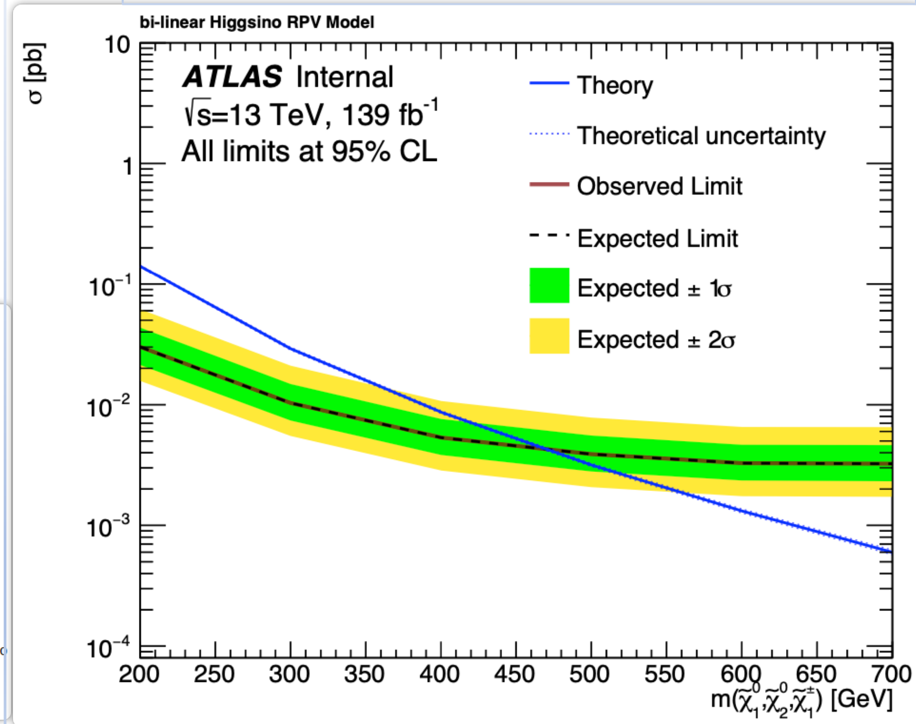


(c)



(d)

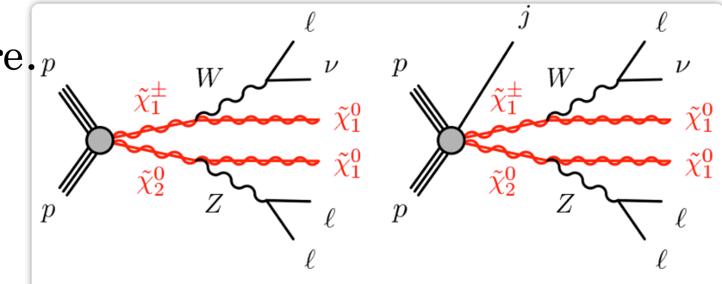
Expected 95% CL upper limits



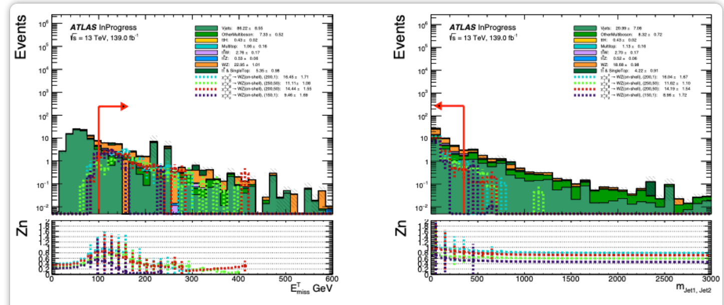
Signal regions: Wino WZ(RPC)

First search of Wino WZ with 2 same-sign leptons signature.

- The orthogonality towards other analyses is ensured by requiring $N_{Coml}(l) == 2$.
- **Multi-bin fit** in most SRs is found to be helpful to improve sensitivity.
- **No sensitivity found in WZ-offshell part** will abandon it

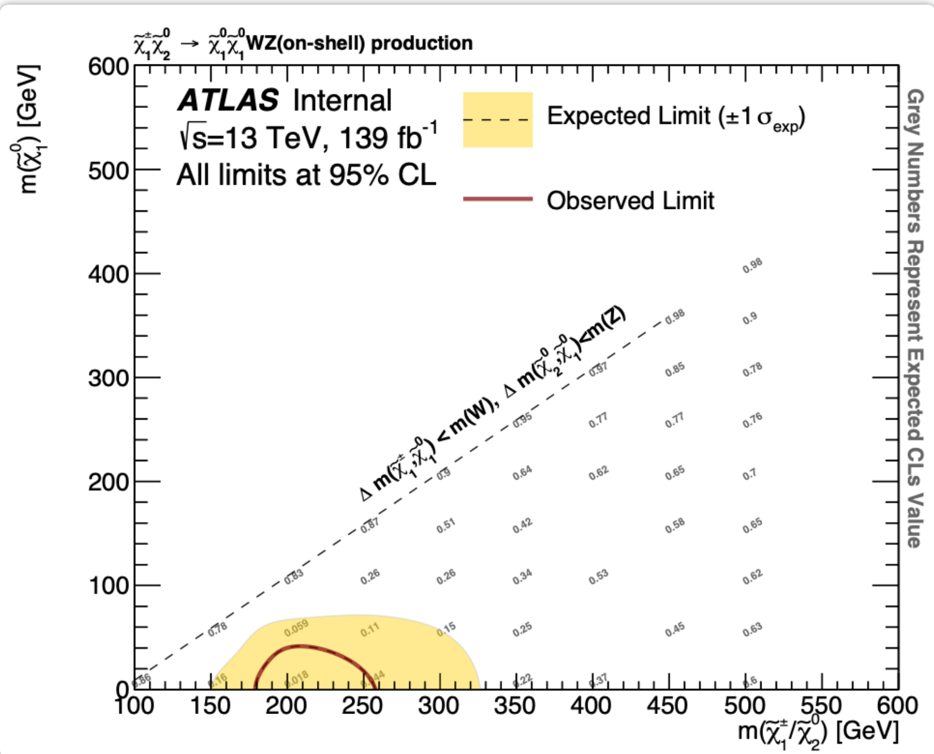


(a) wino C1N2 WZ on-shell (b) wino C1N2 WZ off-shell



(a) (b)

Expected 95% CL upper limits



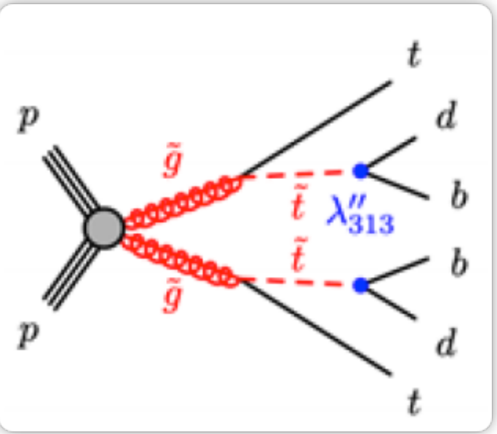
	SR-WZonshell1	SR-WZonshell2
$N_{Comb}(l)$	=2	
$N_{BL}(l)$	=2	
$N_{Sig}(l)$	=2	
Charge(l)	Same-Sign	
$p_T(l)$	≥25 GeV	
$N_{jets}(p_T > 25$ GeV)	≥1	
N_{b-jets}	=0	
m_{jj}	≤350 GeV	
m_T2	≥100 GeV	≤100 GeV
m_T^{min}	≥100 GeV	≥130 GeV
E_T^{miss}	≥100 GeV	≥140 GeV
m_{eff}	-	≤600 GeV
$\Delta R(\ell^{\pm},\ell^{\pm})$	-	≤3
Bins	Sig(E_T^{miss}): [0-10], Spread(Φ) ≥2.2 Sig(E_T^{miss}): [10-13] Sig(E_T^{miss}): [13-∞], $\Delta R(\ell^{\pm},\ell^{\pm})$ ≥1	-

SS/3L-strong

Signal regions: RPV lampp331

- **SR:** Scanning important variables to get large significance
- Features: the requirements of jet-pt and numbers of jets.
- **RPVSR3new** seems to be best candidate as final signal region.

- **SR optimization ongoing**

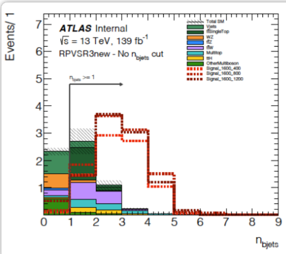


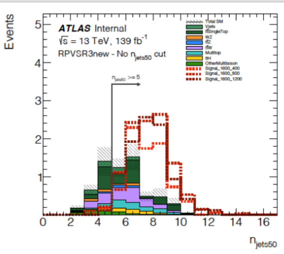
RPVSR1new	$N_{Lep} ==$	$N_{BJets} \geq$	$N_{Jets25} \geq$	$m_{eff} \geq$	$met \geq$	$Pt\_l \geq$	$SumJetPt \geq$	Zveto
	2	1	5	2300 GeV	-	30 GeV	1900 GeV	-
RPVSR2new	$N_{Lep} ==$	$N_{BJets} \geq$	$N_{Jets40} \geq$	$m_{eff} \geq$	$met \geq$	$Pt\_l \geq$	$SumJetPt \geq$	Zveto
	2	-	6	2100 GeV	-	20 GeV	1900 GeV	-
RPVSR3new	$N_{Lep} ==$	$N_{BJets} \geq$	$N_{Jets50} \geq$	$m_{eff} \geq$	$met \geq$	$Pt\_l \geq$	$SumJetPt \geq$	Zveto
	2	1	5	2200 GeV	-	30 GeV	1800 GeV	-

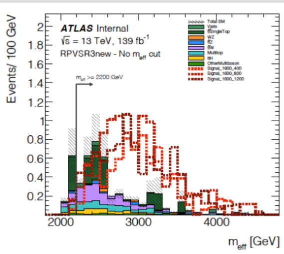
Best SRs for (1600,1200) GeV

RPVSR2v3	$N_{Lep} ==$	$N_{BJets} \geq$	$N_{Jets40} \geq$	$m_{eff} \geq$	$met \geq$	$Pt\_l \geq$	$SumJetPt \geq$	Zveto
	2	1	5	-	-	20 GeV	1900 GeV	-
RPVSR3v3	$N_{Lep} ==$	$N_{BJets} \geq$	$N_{Jets50} \geq$	$m_{eff} \geq$	$met \geq$	$Pt\_l \geq$	$SumJetPt \geq$	Zveto
	2	-	5	2200 GeV	-	20 GeV	2000 GeV	-

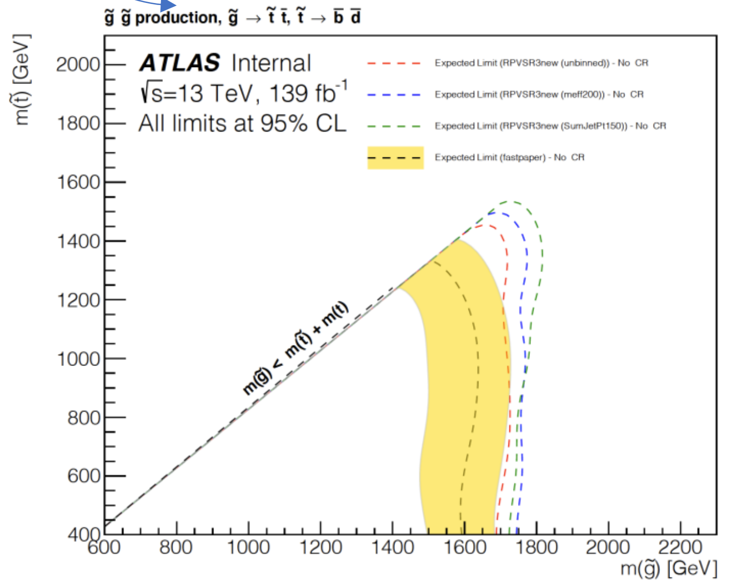
Best SRs for (1600,1400) GeV







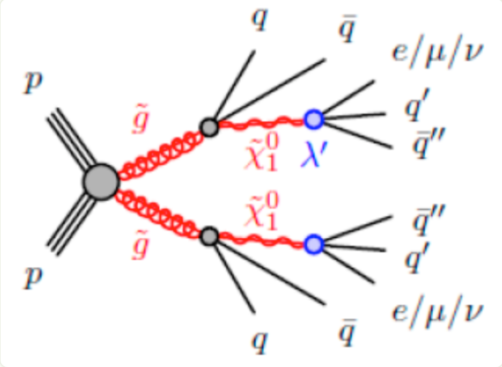
Binned fit performances better



Comparison between unbinned and binned fit

Signal regions:RPV_LQD

- Three nJets configurations are used respectively
- SRs are optimized with the best signal significance Z (30% flat sys)
- Reference Points: $(\tilde{g}, \tilde{\chi}_1^0) = (1800, 450)$, $(2000, 200)$
- Compared different variables-cut configurations



Variables		Scan Range	Step
nJets	$nJets25 \geq$	$4 \to 11$	1
	$nJets40 \geq$	$3 \to 10$	1
	$nJets50 \geq$	$3 \to 10$	1
SumJetsPt	$SumJetPt \geq$	$800 \to 2200$ GeV	100 GeV
Effective Mass	$meff \geq$	$1200 \to 3000$ GeV	100 GeV
SumLepPt	$sumPtLep \geq$	$20 \to 200$ GeV	10 GeV
1st-Lep Pt	Pt_l $\geq$	$10 \to 60$ GeV	5 GeV

MP1800_450

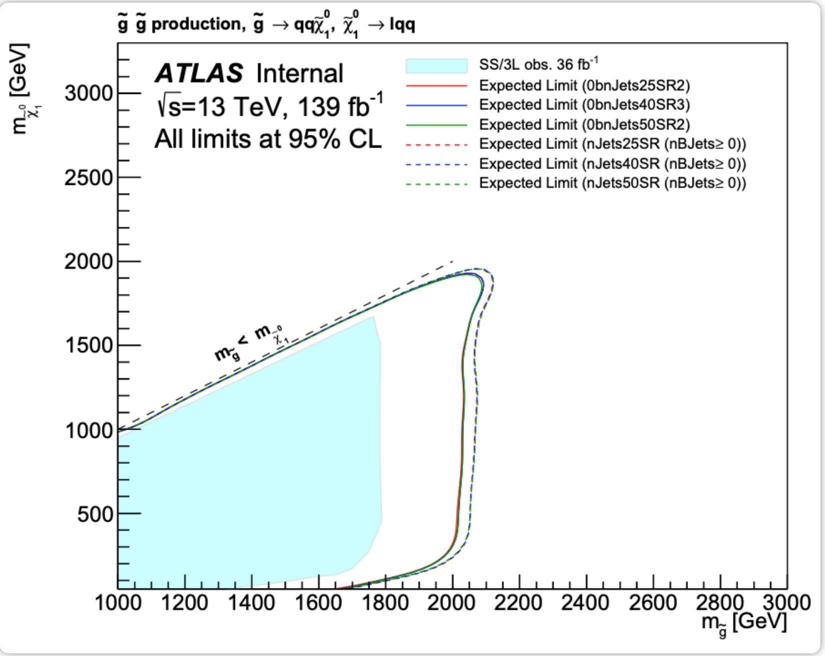
Config.	$nJets(25, 40, 50) \geq$	$SumJetPt \geq$	$meff \geq$	$met/meff <$	Z_{root}	$Z_{general}$
0bnJets25SR1	6	1500 GeV	2100 GeV	0.15	4.698	4.072
0bnJets40SR1	5	1700 GeV	2000 GeV	0.25	4.705	4.069
0bnJets50SR1	5	1100 GeV	2000 GeV	0.10	4.708	4.073

MP1800_1320

Config.	$nJets(25, 40, 50) \geq$	$SumJetPt \geq$	$meff \geq$	$met/meff <$	Z_{root}	$Z_{general}$
0bnJets25SR1	6	1500 GeV	2100 GeV	0.15	5.355	4.787
0bnJets40SR2	5	1300 GeV	2100 GeV	0.10	5.382	4.806
0bnJets50SR1	5	1100 GeV	2000 GeV	0.10	5.411	4.837

MP2000_200

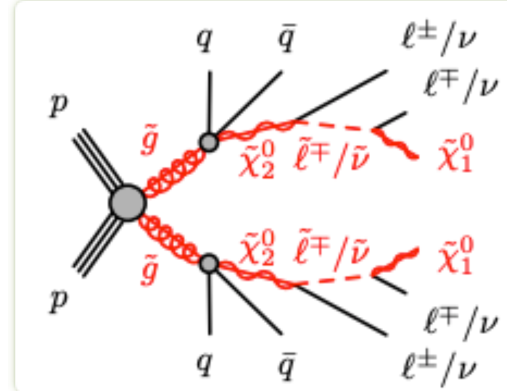
Config.	$nJets(25, 40, 50) \geq$	$SumJetPt \geq$	$meff \geq$	$met/meff <$	Z_{root}	$Z_{general}$
0bnJets25SR2	5	1200 GeV	2500 GeV	0.15	2.300	1.342
0bnJets40SR3	5	1200 GeV	2300 GeV	0.20	2.317	1.363
0bnJets50SR2	5	1100 GeV	2200 GeV	0.20	2.282	1.346



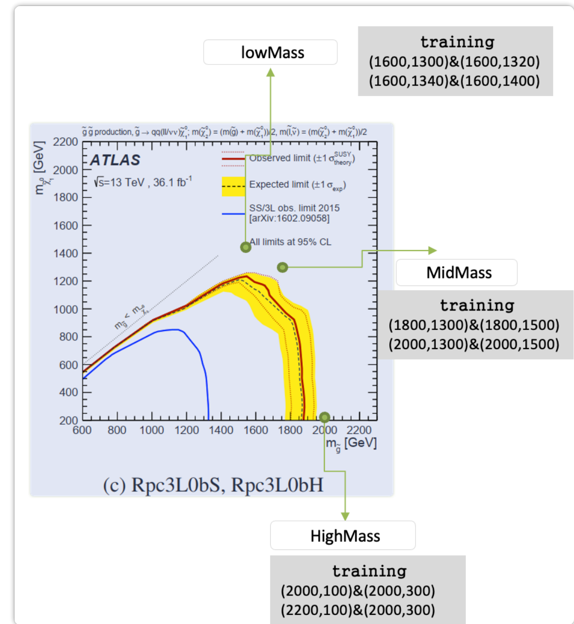
- Similar performance among all nJets-region
- Large improvement compared with Run1 result
- SR optimization ongoing

Signal regions: GG-N2-SLN1

- Model parameter assumption:
  $M(\tilde{X}_2^0) = \frac{1}{2}\{M(\tilde{g}) + M(\tilde{X}_1^0)\}$; $M(\tilde{l}^{\mp}/\tilde{\nu}) = \frac{1}{2}\{M(\tilde{X}_2^0) + M(\tilde{X}_1^0)\}$
- Tried cut-count and BDT method.
- Exclusion of $M_{\tilde{g}}$ reaches ~2.2TeV

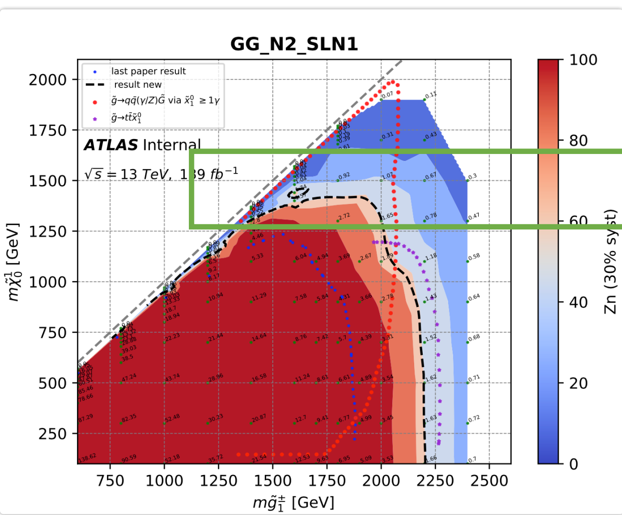


- Comparison:
  → BDT performs better in High LSP and compressed region, getting more yields in BDT SRs
  → Based on BDT, we are trying to do bkg estimation.

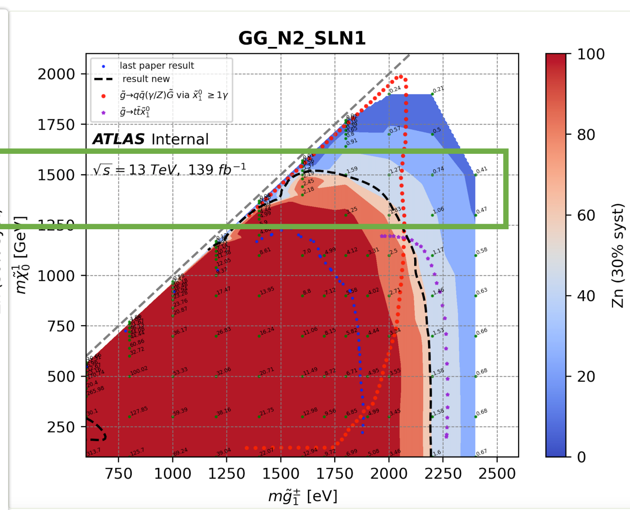


(c) Rpc3L0bS, Rpc3L0bH

Cut_count



BDT

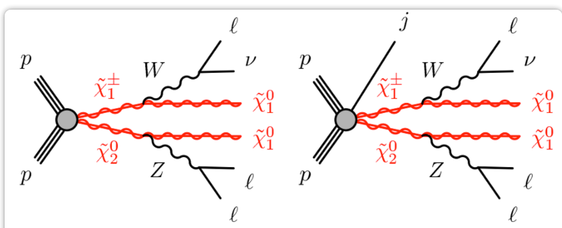


SR-BDT-SRs			
BDT-lowmass	BDT-midmass1	BDT-midmass2	BDT-highmass
N_leptons ≥ 3			
N_Bjet $= 0$			
N_Jet25 ≥ 4			
Pt_Jet(1-2) ≥ 40			
BDT_low ≥ 0.98	BDT_mid ≥ 0.96	BDT_mid ≥ 0.90	BDT_high ≥ 0.76
-	$\Delta\phi(ss, met) \geq 1.0$	$\Delta\phi(ss, met) \geq 1.0$	-
-	-	meff ≥ 1500	met ≥ 200
-	-	-	Z-veto

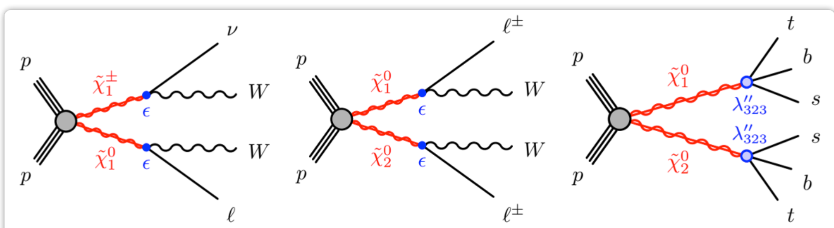
Summary(SS/3L−EWK/strong)

- Studied RPC and RPV models with EWK/strong productions
- Compared with published result, the results now have large improvement. For some sparticles, we pushed the exclusion lines ~300Gev further

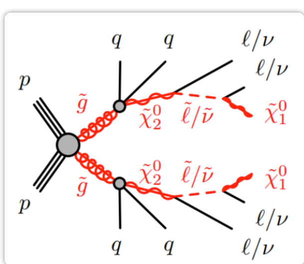
- Many studies ongoing, will publish 2 papers separately for EWK and strong production next year.

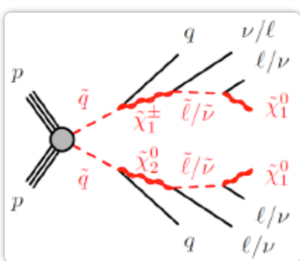


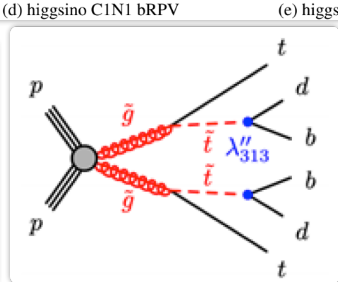
(a) wino C1N2 WZ on-shell (b) wino C1N2 WZ off-shell

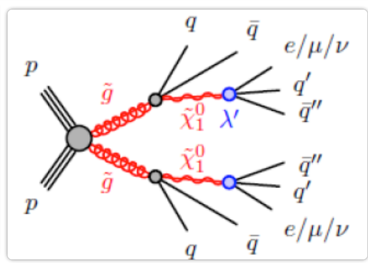


(d) higgsino C1N1 bRPV (e) higgsino N1N2 bRPV (f) higgsino N1N2 RPV









Backup

Object definitions

~ Using EWK combinations preselection (TWiki) to obtain orthogonality,
~ adding analysis preselection for better sensitivity, overlap removal and signal selection

Object selection:

EWK Combinations pre-selection

↓

Pre-selection

↓

Overlap removal

↓

Signal selection

Table 5: Summary of the electron and muon selection criteria. The signal selection requirements are applied on top of the preselection.

	Pre-selected Electron	Pre-selected Muon
Acceptance	$p_T > 10\,\text{GeV}, \lvert\eta^{\text{clust}}\rvert < 2.47$ except $1.37 < \lvert\eta^{\text{clust}}\rvert < 1.52$	$p_T > 10\,\text{GeV}, \lvert\eta\rvert < 2.5$
Quality	`LooseAndBLayerLLH`	`xAOD::Muon::Medium`
Impact parameter	$\lvert d_0/\sigma(d_0)\rvert < 5.0$ $\lvert z_0 \cdot \sin(\theta)\rvert < 0.5\,\text{mm}$	$\lvert z_0 \cdot \sin(\theta)\rvert < 0.5\,\text{mm}$
	Signal Electron	**Signal Muon**
Quality	`MediumLH` $\lvert\eta\rvert < 2.0$ [a] `ElectronChargeIDSelector` tool, 97% Loose WP [b]	- - -
ℓ-jet Isolation	see Section 4.5	
Isolation	"FCTight "	"FCTightTrackOnly"
Impact parameter		$\lvert d_0/\sigma(d_0)\rvert < 3.0$

[a,b] Cuts applied on all electrons, even in events with three leptons.

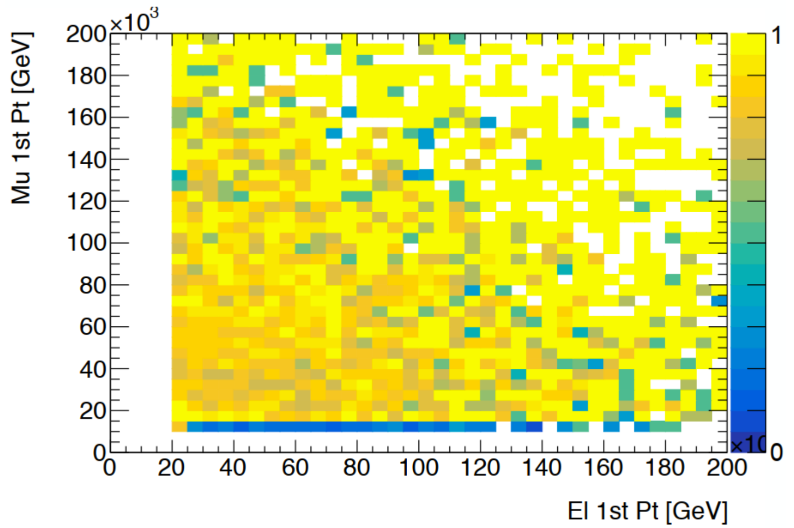
Table 4: Summary of the jet selection criteria.

Preselected jet	
Collection	`AntiKt4PFlow`
Signal jets	
Acceptance	$p_T > 20\,\text{GeV}, \lvert\eta\rvert < 2.8$
Jet vertex tagger	JVT Tight working point
Overlap	see Section 4.5
Signal b-jets	
Acceptance	$p_T > 20\,\text{GeV}, \lvert\eta\rvert < 2.8$
b-tagging Algorithm	DL1r, 70% WP efficiency

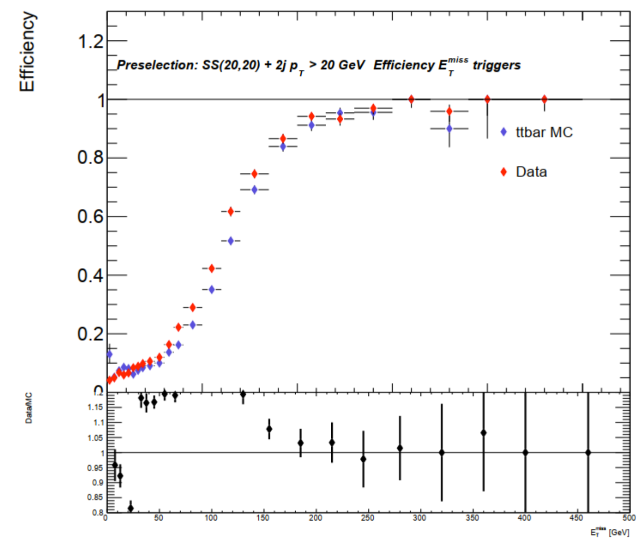
→ Using latest CP group recommendations: PFlow jets and DL1r b-jets tagger

Trigger strategy

Year	$E_T^{miss} < 250$ GeV		$E_T^{miss} > 250$ GeV
2015	HLT_2e12_lhloose_L12EM10VH HLT_e17_lhloose_mu14 HLT_mu18_mu8noL1	$p_T(e) > 20$ GeV $p_T(e) > 20$ GeV, $p_T(\mu) > 20$ GeV $p_T(\mu) > 10$ GeV $p_T(\text{Leading}\mu) > 20$ GeV	HLT_xe70
2016	HLT_2e17_lhvloose_nod0 HLT_e17_lhloose_nod0_mu14 HLT_mu22_mu8noL1	$p_T(e) > 20$ GeV $p_T(e) > 20$ GeV, $p_T(\mu) > 20$ GeV $p_T(\mu) > 10$ GeV $p_T(\text{Leading}\mu) > 23$ GeV	HLT_xe90_mht_L1XE50 (period AD3) HLT_xe100_mht_L1XE50 (period D4-F1) HLT_xe110_mht_L1XE50 (period F2-open)
2017	HLT_2e24_lhvloose_nod0 HLT_e17_lhloose_nod0_mu14 HLT_mu22_mu8noL1	$p_T(e) > 25$ GeV $p_T(e) > 20$ GeV, $p_T(\mu) > 20$ GeV $p_T(\mu) > 10$ GeV $p_T(\text{Leading}\mu) > 23$ GeV	HLT_xe110_pufit_L1XE55
2018	HLT_2e24_lhvloose_nod0 HLT_e17_lhloose_nod0_mu14 HLT_mu22_mu8noL1	$p_T(e) > 20$ GeV $p_T(e) > 20$ GeV, $p_T(\mu) > 20$ GeV $p_T(\mu) > 10$ GeV $p_T(\text{Leading}\mu) > 23$ GeV	HLT_xe110_pufit_xe70_L1XE50



(c) Electron-muon triggers



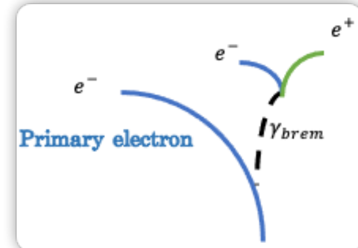
(d) E_T^{miss} triggers

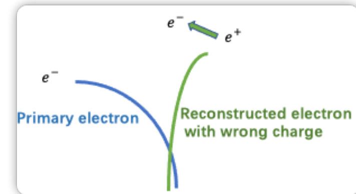
Charge flip estimation

Charge flip(wrong charge measurement):

@ due to bremsstrahlung or low track curvature (links: 1 and 2)

→ Opposite-sign events are misidentified as same-sign events
→ Highly reduced with the ECIDS tool (link)
→ Negligible for muons
→ Mainly from dileptonic background in current SRs





Estimation Strategy:

* Re-weight the opposite-sign DATA events after applying the same selection as for the SS pairs

$$\omega_{os\rightarrow ss} = \zeta_1(1-\zeta_2) + \zeta_2(1-\zeta_1)$$

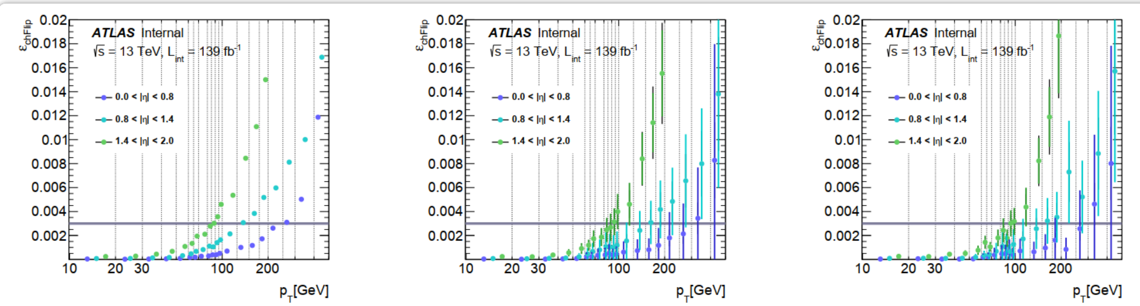
where ζ_i is the charge mis-identification rate, as a function of electron η and p_t

$$\begin{pmatrix} n_{\text{pass}} \\ n_{\text{fail}} \end{pmatrix} = \begin{pmatrix} \varepsilon & \zeta \\ 1-\varepsilon & 1-\zeta \end{pmatrix} \begin{pmatrix} n_{\text{real}} \\ n_{\text{FNP}} \end{pmatrix};$$

* the charge flip rates in date are obtained by

$$\zeta_{Data} = \zeta_{MC} \times SF$$

where ζ_{MC} are the truth rates obtained from $t\bar{t}$ events, SF are the scale factors provided by Egamma group



(a) True Rates, $t\bar{t}$ (b) True Rates × SFs, $t\bar{t}$ (c) True Rates × SFs, Zjets

Matrix Method

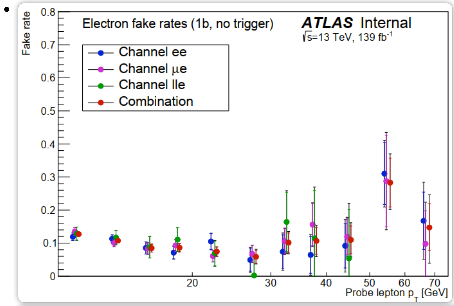
→ Fakes contribution is estimated directly on the region of interest, no extrapolation from CR is required.
→ There is no separation on the different sources of fake leptons.
→ Contribution from charge flipped electrons is subtracted.

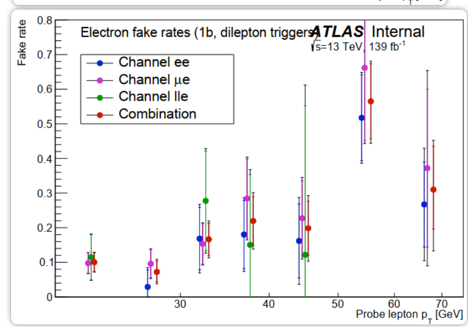
➔ Fake lepton rates: measured independently in six orthogonal channels:

Channel	$e^\pm e^\pm$	$\mu^\pm e^\pm$	$e^\pm \mu^\pm$	$\mu^\pm \mu^\pm$	$\ell^\pm \ell'^\mp e^\mp$	$\ell^\pm \ell'^\mp \mu^\mp$
Event selection	≥ 1 b-jet, ≥ 2 jets ($p_\mathrm{T} > 25$ GeV), $E_\mathrm{T}^\mathrm{miss} > 30$ GeV $E_\mathrm{T}^\mathrm{miss} < 150$ GeV, $m_\mathrm{eff} < 1.5$ TeV no extra baseline lepton					
Extras	≥ 3 jets				no OSSF pair with $m \in [81, 101]$ GeV	
Tag lepton	Lead. e	μ	e	Lead. μ	ℓ'	ℓ'
Probe lepton	Sublead. e	e	μ	Sublead. μ	e	μ
Tag cuts	$p_\mathrm{T} > p_\mathrm{T}^\mathrm{probe} + 20$ GeV, signal lepton selection, $\max\{\mathrm{ptvarcone40}, \mathrm{topoetcone40}\} < 0.02 \times p_\mathrm{T}$ + tag electrons must also satisfy tightLH PID					
Trigger (*)	di-e || single-e	e-μ || single-μ	e-μ || single-e	di-μ || single-μ	same as $\ell' e$	same as $\ell' \mu$
	+ the tag lepton must be trigger-matched when the event was acquired with the single-ℓ trigger					

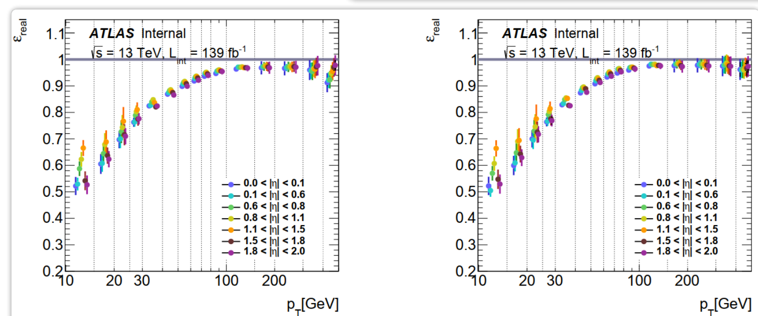
(*) the trigger chains used for 2015 data are respectively e24_lhmedium_iloose_L1EM20VH (single-e), mu20_iloose_L1MU15 (single-μ), e17_lhloose_mu14 (e-μ), mu18_mu8noL1 (di-μ) and 2e12_lhloose_L12EM10VH – and similar unprescaled chains for 2016–2018 data (in particular 2e24_lhvloose_nod0 for 2017–2018).

Table 27: Dedicated event selection used to measure fake rates for electron (ee, μe and $\ell\ell e$ channels) and muon ($e\mu$, $\mu\mu$ and $\ell\ell\mu$ channels). The measurements are performed independently in the six orthogonal channels and subsequently combined.





➔Real lepton rates:
→ Measured in $t\bar{t}$ events as a function of lepton η and pT
→ Leptons are selected as recommended by Egamma and Isolation and Fake Forum groups.



(a) True e Rates × SFs, $t\bar{t}$ (b) True e Rates × SFs, Zjets

MCTemplate fit method

- MC template method (references: PhD thesis, first-wave SS/3L INT note, talk) to cross-check the MxM estimation in the SRs

Method presentation:

→ A **semi-data driven** method using CRs enriched in fake/non-prompt and charge flip backgrounds

→ **Relies on kinematic distributions from MC simulations** to extrapolate the background predictions from some ($\leq$ 1 b-jets, == 2 b-jets) CRs to the SRs

→ **Main assumption:** MC simulations describe the kinematic distributions correctly and predict accurately the rate of fake/non-leptons up to **a global factor** (for each type of fake/non-prompt lepton) independent of the event kinematics and the process type

→ **Second assumption:** the fake rates are uncorrelated in events with multiple fake leptons (expected to be negligible)

Main motivation to use this method:

→ MxM assumes that the lepton fake rates are the same in control and signal regions regardless of the selection requirements.

→ Not the case for the MC template method, making it a suitable cross-check

WZ normalization factor

- The study of WZ normalisation factor has been carried out on unbinned and binned at N_{jets} distribution. $\rightarrow$ Inconsistency found in binned case. (slides 1, 2)

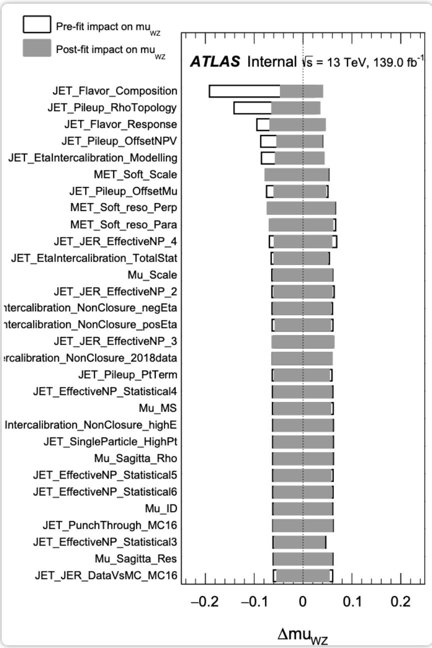
- The control region defined for WZ background:

	N^{signal}_{lept} (N^{base}_{lept}, N^{combi}_{lept})	N_{b-jets}	N_{jets} ($p_T \geq 25$ GeV)	Other cuts
CRWZ2j	==3 (==3,==3)	==0	≥ 2	$50 < E_T^{miss} <$150 GeV, $m_{eff} < 1$ TeV, $81 < m_{SFOS} < 101$ GeV $p_T > 20$ GeV for leading and sub-leading leptons

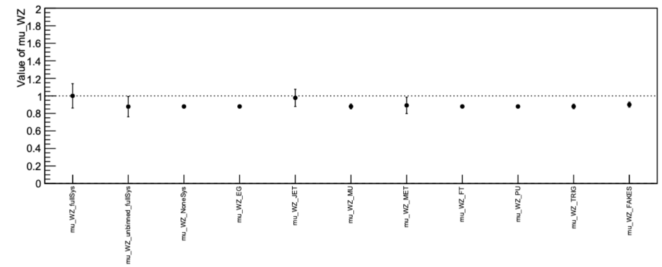
- The estimation strategy: normalise the WZ background and then extrapolate the SF to SRs to achieve better background modelling
  - A bkg-only fit has been performed to normalise the WZ background in CRWZ2j.
  - Include only background samples and neglect any contamination from signal
  - Unblind CR and backgrounds are normalised to all observed events in CRWZ2j
  - μ_{WZ} is set as the normalisation parameter for WZ background

- μ_{WZ} obtained with different distributions.
(Uncertainty is calculated by HESSE)

Distribution	μ_{WZ}
N_{jets}	1.0004 ± 0.139
unbinned	0.8776 ± 0.116
N_{jets}-inclusive5j	0.95994 ± 0.129
N_{jets}-inclusive6j	0.99934 ± 0.141

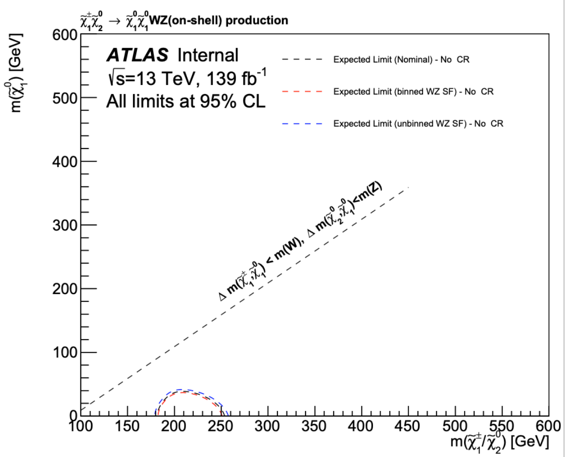


- Goal: Add systematics from certain category to see the impact on μ_{WZ}



	μ_{WZ}	Description
mu_WZ_fullSys	1.0004 ± 0.139	binned fit on N_{jets} with full sys
mu_WZ_unbinned_fullSys	0.8776 ± 0.116	unbinned fit with full sys
mu_WZ_NoneSys	0.87899 ± 0.0210	binned fit on N_{jets} without sys
mu_WZ_EG	0.87943 ± 0.0240	binned fit on N_{jets} with sys only from EG category
mu_WZ_JET	0.97741 ± 0.0981	binned fit on N_{jets} with sys only from JET category
mu_WZ_MU	0.87933 ± 0.0271	binned fit on N_{jets} with sys only from MU category
mu_WZ_MET	0.89162 ± 0.0937	binned fit on N_{jets} with sys only from MET category
mu_WZ_FT	0.87939 ± 0.0218	binned fit on N_{jets} with sys only from FT category
mu_WZ_PU	0.87917 ± 0.0214	binned fit on N_{jets} with sys only from PU category
mu_WZ_TRIG	0.87947 ± 0.0256	binned fit on N_{jets} with sys only from TRIG category
mu_WZ_FAKES	0.90007 ± 0.0291	binned fit on N_{jets} with sys only from FAKES category

- Expected limits of WZonshell model



Small impact of the WZ SF on the exclusion limits

Summary of WZ normalisation factor

1. Better agreement between MC and data after normalisation.
2. The impact of WZ SF on expected limits is small.
   - JET systematics have higher impact on μ_{WZ}
   - There are significant correlations between JET systematics and μ_{WZ}
3. The binning of N_{jets} also has impact on μ_{WZ}
4. **Discussion**: which WZ SF to be implemented in non-Wh analysis?

Distribution	μ_{WZ}
N_{jets}	1.0004 ± 0.139
unbinned	0.8776 ± 0.116
N_{jets}-inclusive5j	0.95994 ± 0.129
N_{jets}-inclusive6j	0.99934 ± 0.141

FAR checklist

- FAR checklist completed for Wh (see relevant sections in the INT note):
  - Standard occupancy maps and plots
  - No significant dependencies w.r.t. RunNumber, pile-up or data period
  - No missing data or duplicated events
  - No event from debug stream data sets passing any of the region selections
  - To-do: Cutflow for the background and for representative signal points.
- For non-Wh, most are doen and require checks listed:
  - To-do: Run number and data period dependencies
  - To-do: Check for missing data

J cutflow

This appendix presents some unweighted Cutflow tables added for non-Wh analysis:
Signal:
wino C1N2 WZ_onshell MC16e, signal higgsino C1N2/N1N2 Bilinear RPV model, signal higgsino N1N2 RPV, signal higgsino GGM
Data:
Data2018 period Q background:
background WZ
Following is a signal cutflow of WZ_onshell at point (150,1) in 2018.
The sample used here is:

Table 84: WZ-onshell-(150,0)

Events Total	34245
MC Truth veto	34245
GoodRunList	34245
Primary vertex	34245
Global flags	34245
Trigger	29135
Bad muons veto	29135
1 jet pass OR	24563
Bad jet veto	24563
1 signal jet	20355
Cosmics veto	20355
>=2 baseline lep.	17969
>=2 signal lep.	14612
>=2 EW combi lep.	14612
SS leptons	6414
Trigger match	6123
——Channel mu-mu——	
mumu channel	2397
mumu NBjets>0	40
mumu NJets>3	0
mumu MET>125	0
——Channel e-e——	
ee channel	967
ee NBjets>0	21
ee NJets>3	2
ee MET>125	1
——Channel e-mu——	
emu channel	2759
emu NBjets>0	48
emu NJets>3	0
emu MET>125	0

K Event duplication checks

Following the Checklist twiki, we show here the results of event duplication check in each signal region, control region and validation region.

K.1 Event duplication checks for non-Wh models

In the course of this checking, we still kept signal region blind, only checking data in the control and validation regions. (event number, random number, channel number) should the unique tag for each events. If there are more than one events sharing the same tag, we will check further if these events have close P_T, η and ϕ. If they are also very close, We can confirm that there are duplicated events in a region.

The Signal regions are listed below whose definitions can be found in the chapters ahead.

C1N2_WZ_on => (SRWZonshell1, SRWZonshell2)
C1N2_WZ_off => (SRWZoffshellBoost1, SRWZoffshellBoost2, SRWZoffshellDiagonal1, SRWZoffshellDiagonal2)
bRPV =>(SRbRPV2LSS, SRbRPV3L)
GGM =>(Rpc2LS0BR, Rpc2LH0BR, Rpc2LS25BR, Rpc2LH25BR, Rpc2LS50BR, Rpc2LH50BR, Rpc3LS0BR, Rpc3LH0BR, Rpc3LS25BR, Rpc3LH25BR, Rpc3LS50BR, Rpc3LH50BR, Rpc3LH75BR, Rpc3LH100BR, Rpc4LS0BR, Rpc4LS25BR, Rpc4LH25BR, Rpc4LS50BR, Rpc4LH50BR, Rpc4LS75BR, Rpc4LM75BR, Rpc4LHF75BR, Rpc4LHS75BR, Rpc4LS100BR, Rpc4LM100BR, Rpc4LHF100BR, Rpc4LHS100BR)
RPVudd =>(RPV2L1bL, RPV2L1bM, RPV2L2bL, RPV2L2bM, RPV2L2bH, RPV2L3bL, RPV2L3bM, RPV2L3bH)

The control and validation regions are listed below whose definitions can be found in the chapters ahead.

CR =>(SRWZoffshellSRVeto, CRWZ2j, VRWZ4j, VRWZ5j, VRTTV)

Conclusion:
There are no events sharing the same number tag(event number, random number, channel number). The signal region and control regions have no duplicated events.

K.2 Event duplication checks for Wh-SS model

Analogous checks have been performed for all SRs, CRs and VRs defined for the Wh-SS model. No duplicated event has been found in either data or MC samples.

L Debug stream checks for FAR

Following the Checklist twiki, checks have been performed to assess whether events belonging to the debug stream would pass the selection of the SRs and CRs of this analysis.

The debug stream samples used for these checks have been produced using the following settings: SUSY2 derivations with p3993. The full list of samples is retrievable by matching it to the following pattern:

Data1*_13TeV.*.debugrec_hlt.deriv.DAOD_SUSY2.*_p3993

L.1 Checks for Wh-SS search

It has been found that no event from the debug stream data samples passes the selections for the CRs and VRs (...) of the Wh-SS search. Moreover, given the fact that no event passes even the pre-selection requirements (...), which is applied online when the ntuples are produced and it represents a common baseline selection shared between the Fake/charge-flip VRs and the Wh-SS SRs, it can be assessed with certainty that no such event would fall into the SRs either once they are unblinded.

L.2 Checks for other scenarios

It has been found no event from debug stream data samples passes the preselection. The following cutflow shows more details:

CR/VR for W Z and ttV

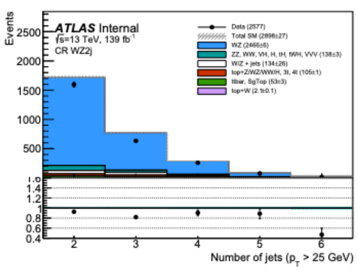
CR/VR defined for WZ

	$N_{\rm lept}^{\rm signal}$ ($N_{\rm lept}^{\rm base}$, $N_{\rm lept}^{\rm combi}$)	$N_{b-\rm jets}$	$N_{\rm jets}$	jet $p_{\rm T}$ [GeV]	Other cuts
CRWZ2j	==3 (==3 ,==3)	==0	≥ 2	25 GeV	$150 > E_{\rm T}^{\rm miss} > 50$ GeV, $m_{\rm eff} < 1$ TeV, $81 < m_{\rm SFOS} < 101$ GeV $p_{\rm T} > 20$ GeV for $\ell_{1,2}$
WZ4j-VR	==3 (==3, ==3)	==0	$\geq$4	> 25	$81 < m_{\rm SFOS} < 101$ GeV, $E_{\rm T}^{\rm miss} > 50$ GeV, $m_{\rm eff} > 600$
WZ5j-VR	==3 (==3, ==3)	==0	$\geq$5	> 25	$81 < m_{\rm SFOS} < 101$ GeV, $E_{\rm T}^{\rm miss} > 50$ GeV, $m_{\rm eff} > 400$

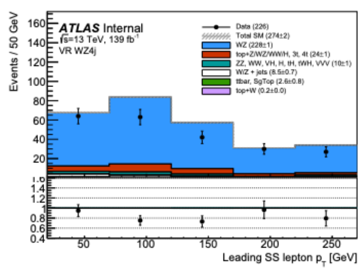
VR defined for $t\bar{t}V$

	$N_{\rm lept}^{\rm signal}$ ($N_{\rm lept}^{\rm base}$, $N_{\rm lept}^{\rm combi}$)	$N_{b-\rm jets}$	$N_{\rm jets}$	jet $p_{\rm T}$ [GeV]	$m_{\rm eff}$ [GeV]	Other cuts
$t\bar{t}V$-VR	$\geq$2 ($\geq$2, –) $\geq$1 SS pair	$\geq$1	$\geq$3	> 40	> 600	$p_{\rm T} > 30$ GeV for leptons of the SS pair, $\Delta R(\ell_1, {\rm jet}) > 1.1$, $\sum p_T^{b-j} / \sum p_T^j > 0.4$, $E_{\rm T}^{\rm miss} / m_{\rm eff} > 0.1$

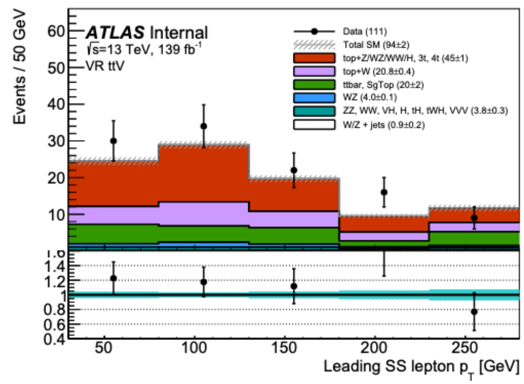
$N_{\rm jets}$ in CRWZ2j



Leading lepton $p_{\rm T}$ in VRWZ4j



Leading lepton $p_{\rm T}$ in VRTTV



1. CR/VR for WZ normalisation, to extract the WZ normalisation factor (to be discussed in next slides)
2. VRTTV designed to validate $t\bar{t}V$ background
3. Very small signal contamination ($< 10\%$)

* All CR/VRs: $m_{\rm eff} < 1.5$ TeV, $E_{\rm T}^{\rm miss} < 250$ GeV; veto SRs defined for WZon/offshell and Higgsino bRPV); the blinding veto is applied.

Validation of background modelling

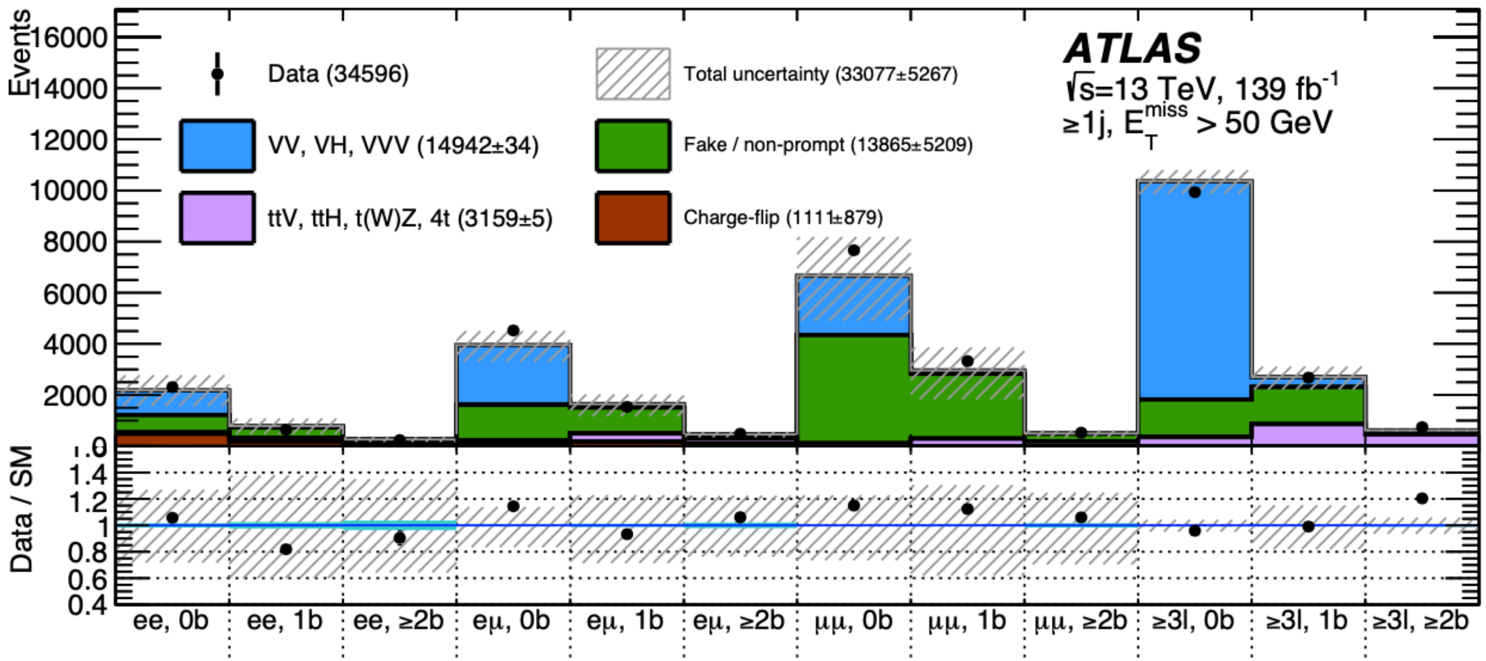


Figure 55: Number of events classified as function of the flavour of the leptons and the number of b-tagged jets, for observed data and expected SM contributions, in a selection with at least three leptons, at least one jet ($p_{\mathrm{T}} > 25$ GeV) and $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV. The error bars only include statistical uncertainties, as well as the full uncertainties for data-driven background estimates.

5.3.1 The $M_{\ell W}^{\text{shifted}}$ variable

Another useful variable the shape of which can be used to distinguish between signal and background is the shifted W boson mass, $M_{\ell W}^{\text{shifted}}$. The $m_{\mu W}$, i.e. $m_{\mu jj}$ invariant mass reconstructing an hadronically decaying W and a muon targeting the $\tilde{\chi}_1^0$ mass was used in an earlier study of bRPV in ATLAS [28]. The "shift" to correct for the known W mass was introduced in the (similar) $M_{\ell Z}^{\text{shifted}}$ variable used in the reconstruction of a three-lepton resonance in the $B-L$ RPV ATLAS analysis [132, 133]. The idea is to reconstruct the $\tilde{\chi}_1^0$ mass when $\tilde{\chi}_1^0 \to \ell W$ and W decays hadronically. Here we reconstruct the mass of the lepton and a hadronically decaying W boson, after correcting this variable with the true W boson mass. Therefore the variable is defined as:

$$M_{\ell W}^{\text{shifted}} = m_{\ell jj} - m_{jj} + 80.4 \text{ GeV} \tag{3}$$

where $m_{\ell jj}$ is the lepton and jet pair invariant mass and m_{jj} is the jet pair invariant mass. Only those jet pairs are considered which has invariant mass within the window of 10 GeVof mass of W boson (m_W), hence $|m_{jj} - m_W| < 10$ GeV. If there are multiple jet pairs satisfying this criteria, then that jet pair is selected for which the ΔR cone is the smallest. The closest lepton to the selected jet pair is taken for this calculation.

The $M_{\ell W}^{\text{shifted}}$ distributions for the two signal regions are shown in Figure 40. There one can see the peak of $M_{\ell W}^{\text{shifted}}$ variable at the $\tilde{\chi}_1^0$mass. This shape is markedly different between the signal samples and the background samples, with the signal peaking at the $\tilde{\chi}_1^0$ mass.

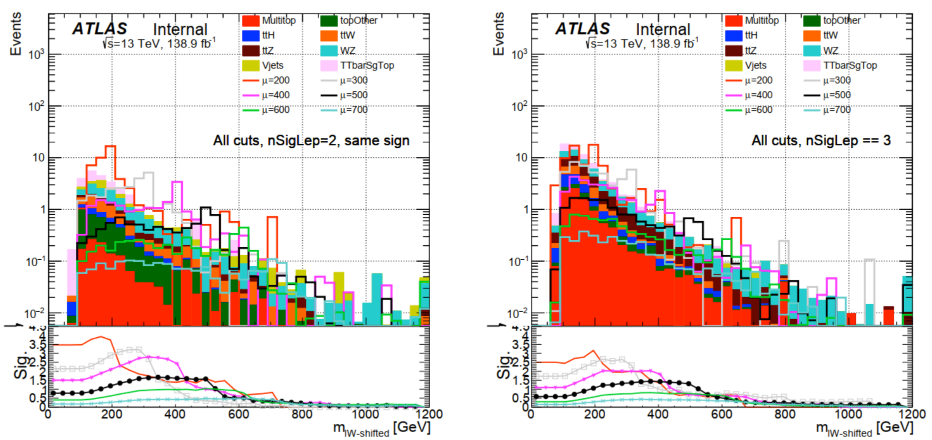
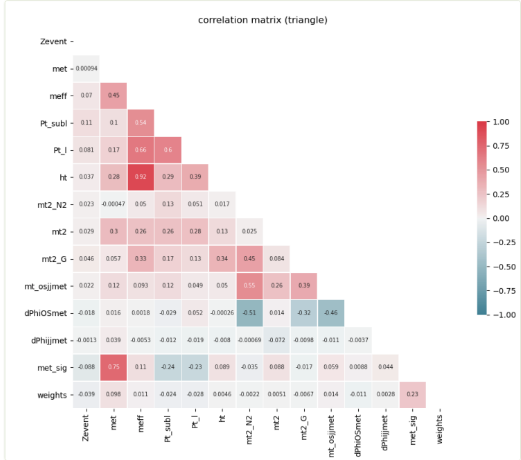
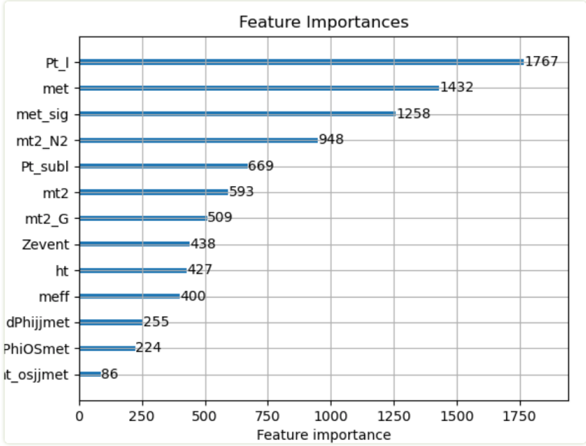


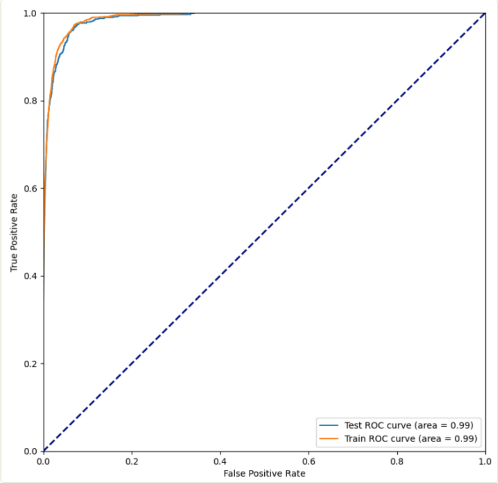
Figure 40: The $M_{\ell W}^{\text{shifted}}$ variable for the two leptons selection on the left and the three leptons selection on the right. One can see the presence of the peak in the signal samples at the relevant mass scale of the signal whereas the shape of background does not have any such shape.

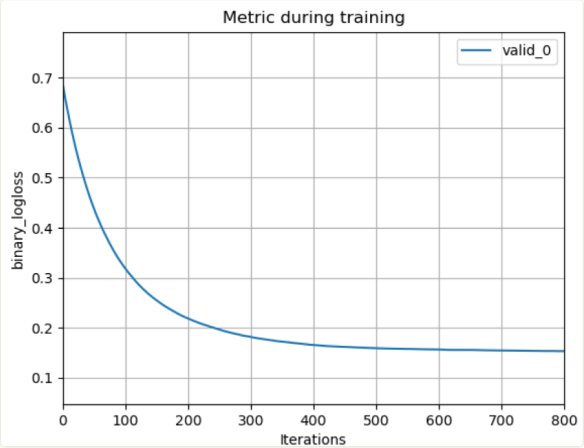
GG_N2_SLN1: BDT lowmass region

```
lightgbm:{
    objective: binary,
    metric: binary_logloss,
    boost_from_average: false,
    num_threads: -1,
    learning_rate: 0.01,
    num_iterations: 800,
    num_leaves:30,
    early_stopping_rounds: 20,
    max_depth:6,
    lambda_l1: 0.001,
    feature_fraction: 0.8,
    bagging_freq: 5,
    bagging_fraction: 0.8,
    min_data_inuleaf: 30,
    min_sum_hessian_in_leaf: 10.0,
    verbosity: 1,
    seed: 369
},
```





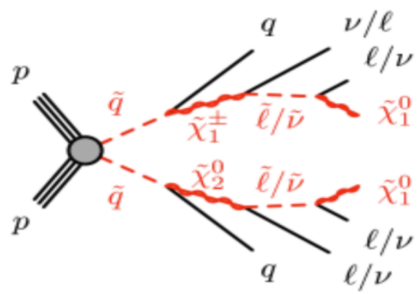




SRO RPC SS N2 SLN1

Signal region optimisation: Plan to have $==2SS$, $==3$ and $==4$ signal leptons SRs.

Today: $==3$ signal leptons SRs



- Three SRs will be defined with the following preselection:

  BM if BM phase space (BM = boosted and middle)
  $m_{eff} > 1000$ GeV, $\Delta R(\ell_1, \ell_2) > 1$

  C if C phase space (C = compressed)
  $H_{T,jets} > 200$ GeV, $p_T\ell_1 < 60$ GeV, $p_T\ell_{2,3} < 40$ GeV

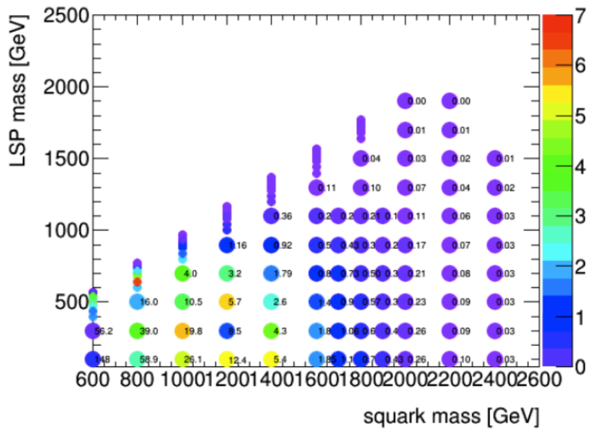
  AC if AC phase space (AC = almost compressed)
  $m_{eff} > 700$ GeV, $p_T\ell_1 < 120$ GeV

- Optimisation will be done by looking at the best SR and the significance at each grid point by scanning the following variables:
  E_T^{miss}, $HTlep$ (or HTjets), m_{eff}, E_T^{miss}/m_{eff}, $\phi_{\ell_1\ell_2} - \phi_{E_T^{miss}}$, nJets and jet p_T threshold.

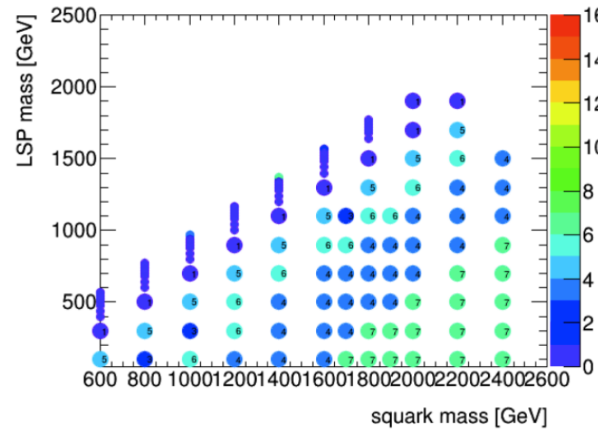
- The best SR will be selected for each category.

SRO RPC SS N2 SLN1

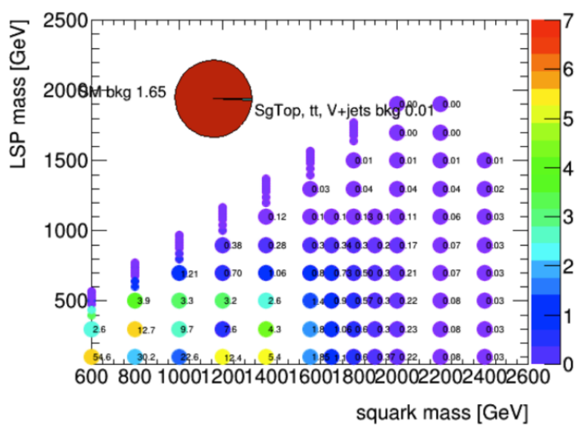
Currently, results available just for BM



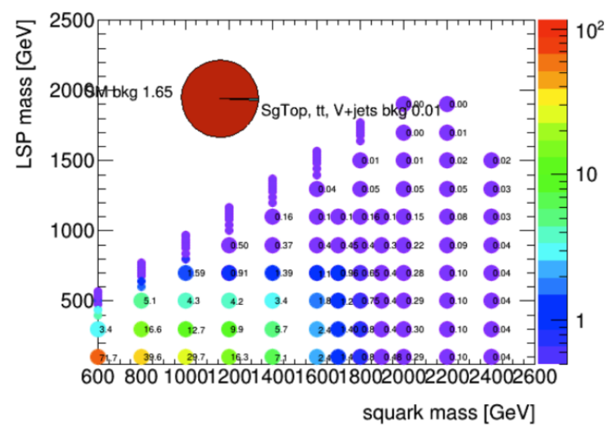
(p) best signif



(q) best SR



(r) SR4, signif



(s) SR4, signal yields

https://indico.cern.ch/event/389531/contributions/929493/attachments/1147997/1646586/RPV-status.pdf

RPV SUSY in short

$$W_{\mathrm{RPV}} = \frac{1}{2}\lambda_{ijk}\, L_i L_j E_k^c + \lambda'_{ijk}\, L_i Q_j D_k^c + \frac{1}{2}\lambda''_{ijk}\, U_i^c D_j^c D_k^c$$

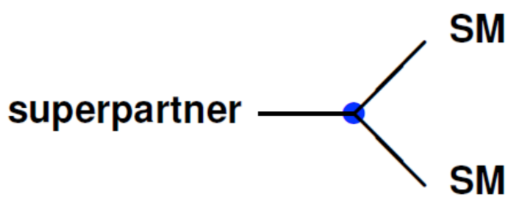
L = left-handed lepton/neutrino E = right-handed lepton

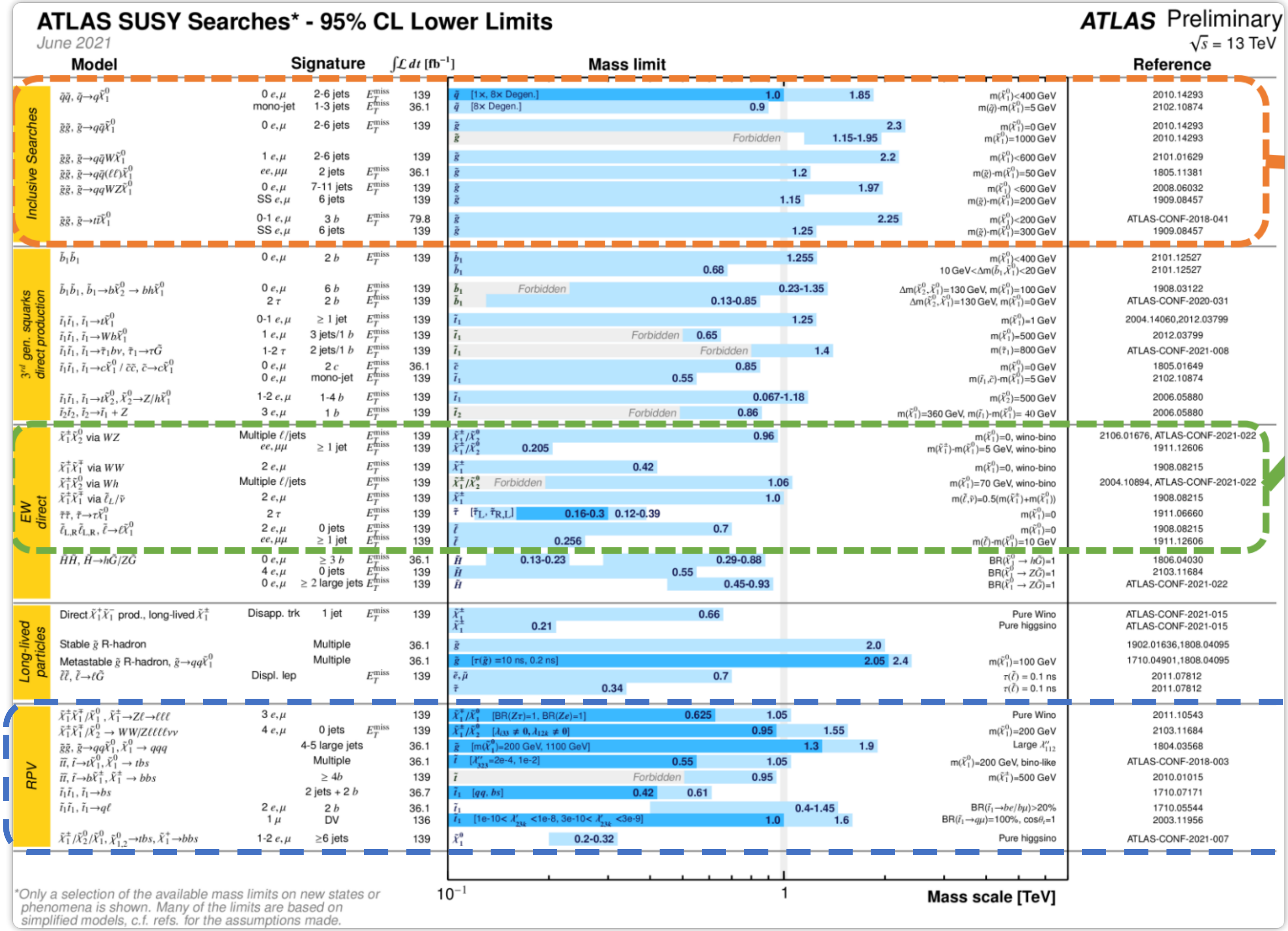
Q = left-handed quark U, D = right-handed quark

i, j, k = generation indices

*Bilinear terms, soft SUSY breaking terms, and other RPV possibilities are omitted only for simplicity.

R-parity violating superpotential terms as above allow the LSP to decay to SM particles.




ATLAS SUSY Searches* - 95% CL Lower Limits
June 2021
ATLAS Preliminary
$\sqrt{s}$ = 13 TeV
Model
Signature
$\int \mathcal{L}\,dt$ [fb^{-1}]
Mass limit
Reference
Inclusive Searches
3rd gen. squarks direct production
EW direct
Long-lived particles
RPV
Forbidden
10^{-1}
1
Mass scale [TeV]
*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.

Variables

- The inclusive effective mass m_{eff} defined as the scalar sum of all the signal leptons p_{T} (see Table 5), all signal jets p_{T} (see Table 4) and $E_{\text{T}}^{\text{miss}}$;
- Ratio between the p_{T} scalar sum of all b-jets and all jets in the event, $\sum p_T^{b-j} / \sum p_T^j$.
- The transverse momentum scalar sum of all leptons in the event (Ht_{lep});
- The invariant mass of a pair of same-sign leptons, m_{SS}.
- The transverse mass of the leptons (leading leptons unless specific noted in other places) and $E_{\text{T}}^{\text{miss}}$, m_{T}, and the minimum transverse mass, m_{T}^{min}.
- The angular distance between the pair of he same-sign leptons, $\Delta R(\ell^{\pm}, \ell^{\pm})$.
- The angular distance in ϕ direction between $E_{\text{T}}^{\text{miss}}$ and the pair of same-sign leptons, $\Delta\phi(SS, E_{\text{T}}^{\text{miss}})$.
- The angular distance in ϕ direction between $E_{\text{T}}^{\text{miss}}$ and the leading two leptons in the event, $\Delta\phi(\ell\ell, E_{\text{T}}^{\text{miss}})$ (used to define the GGM SRs).
- The spread of the Φ angels of the leptons, $E_{\text{T}}^{\text{miss}}$, and jets is used to describe the event topology in the transverse plane. The definition is as follows:

$$Spread(\Phi) = \frac{\mathcal{R}(\phi_{\ell 1},\ \phi_{\ell 2},\ \phi_{E_{\text{T}}^{\text{miss}}}) \cdot \mathcal{R}(\phi_{j1},\ \phi_{j2}, \ldots)}{\mathcal{R}(\phi_{\ell 1},\ \phi_{\ell 2},\ \phi_{E_{\text{T}}^{\text{miss}}},\ \phi_{j1},\ \phi_{j2}, \ldots)}$$

- The significance of $E_{\text{T}}^{\text{miss}}$, $\text{Sig}(E_{\text{T}}^{\text{miss}})$ which is very useful variable to this analysis to separate signals and backgrounds. In this analysis, object based significance of $E_{\text{T}}^{\text{miss}}$ is used, which was obtained directly from `SUSYTool`.
- The invariant mass of two jets, m_{jj}. Those jets should pass the signal jets requirements.
- The invariant mass of a pair of same-flavor-opposite-sign (SFOS) leptons, m_{SFOF}. Those leptons usually are signal leptons unless there is a specific statement. This variable is very sensitive to select events with Z bosons which can be used to define CRs with Z bosons.
- The "Stransverse Mass", m_{T2}, which is newly introduced in the analysis. This is an event variable used to bound the masses of an unseen pair of particles which are presumed to have decayed semi-invisibly into particles which were seen. $m_{\text{T}}2$ is therefore a function of the momenta of two visible particles and the missing transverse momentum in an event, see more details here. Always, the leading two leptons kinematics are used in the computations.
- The variable $m_{\text{T}}2^{m_\chi}$ is a variable similar to $m_{\text{T}}2$ instead $m_{\text{T}}2^{m_\chi}$ set the mass of the invisible particles as the mass of the m_χ which can be very useful to characterize the topology of the signals. As shown in the Figure 5, $m_{\text{T}}2^{m_\chi}$ gives a sharp cut-off in its shape in case of signals and the value lies in the range $[m(\tilde{\chi}_1^0, \Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0))]$. With the increasing of the mass of $\tilde{\chi}_1^{\pm}/\tilde{\chi}_1^0$, the compressed trend of signals are more clearer. Considering the maximum exclusion power that his channel could achieve on those included models, $m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_1^0) = 120$ GeV is chosen to be used for further studies (on WZ model). And the variable with such setting is called as $m_{\text{T}}2^{120}$ in this note. Always, the leading two leptons kinematics are used in the computations.