Search for SUSY Electroweak production at LHC Run 2 and study of CMOS sensor performance for ITK replacement in second-half of HL-LHC

Centre de Physique des Particules de Marseille – CPPM
Aix-Marseille University – AMU
CPPM seminar

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December 07th,
2020

Outline

➊ PhD project

➋ ATLAS detector

➌ Analysis
- Supersymmetry (SUSY) model, signal model, reconstructed objects, simulated samples and data
- General analysis strategy, Signal region (SR) optimization, background estimation
- Preliminary results

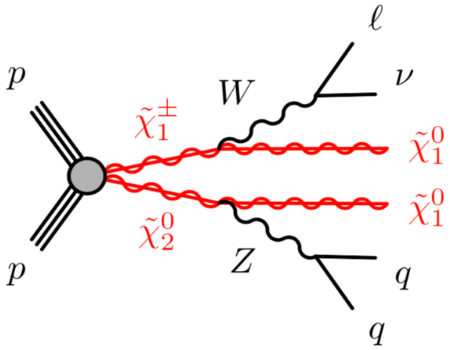
➍ Instrumentation
- High luminosity LHC (HL-LHC), ITK tracker
- CMOS sensors
- Simulation

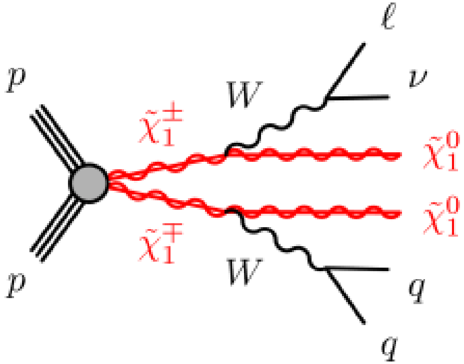
➎ Summary

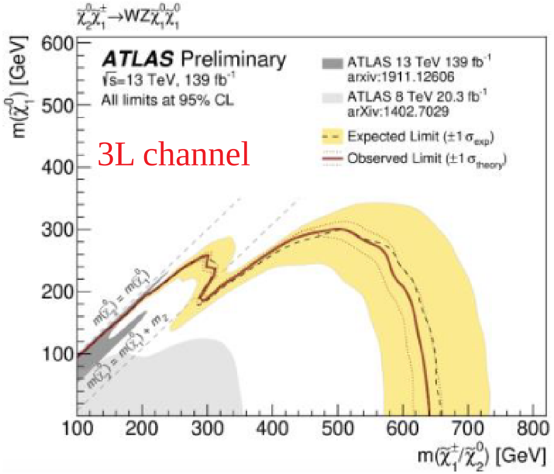
PhD project

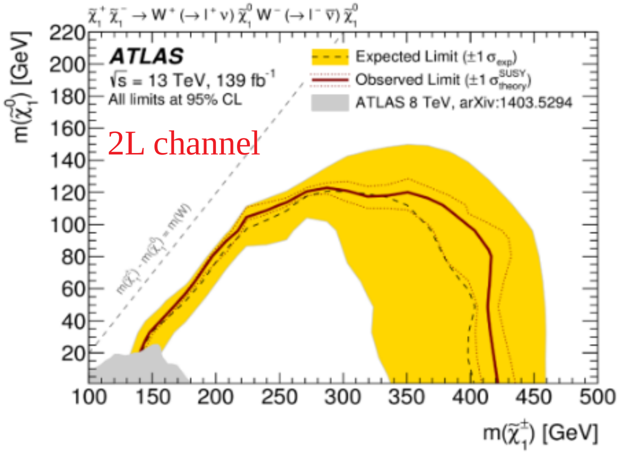
- 11/2018 – 10/2021, granted by AMU ED 352, contains **2 main parts**:

Analysis (Steve MUANZA)



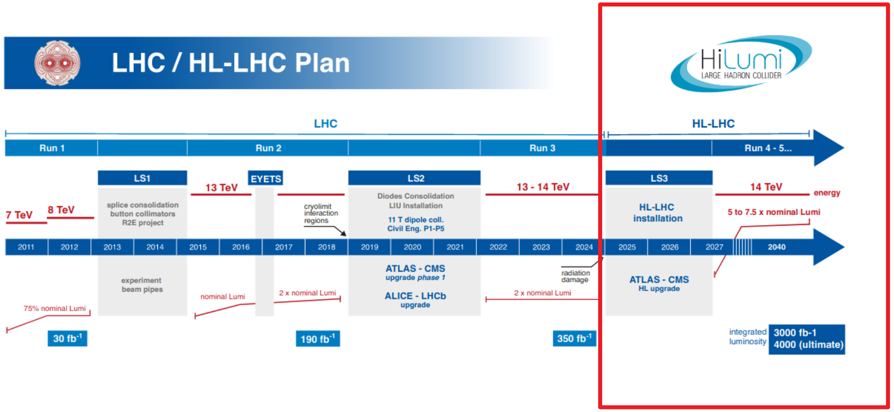




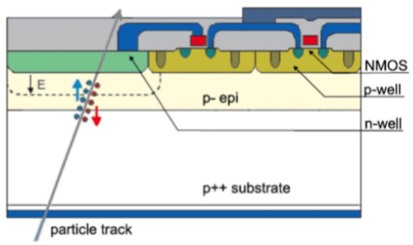


- Conduct searches for SUSY EWK production, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ in events with **isolated lepton**, **jets** and **missing transverse momentum** at $\sqrt{s} = 13$ TeV with ATLAS detector.
- First time at LHC via 1 lepton channel, target integrated luminosity of 139 fb^{-1}, corresponding to full Run 2 collected data (2015 – 2018).

Instrumentation (Farès DJAMA)

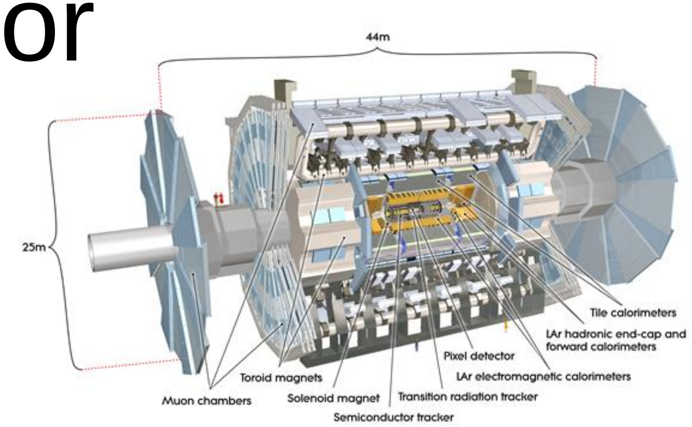


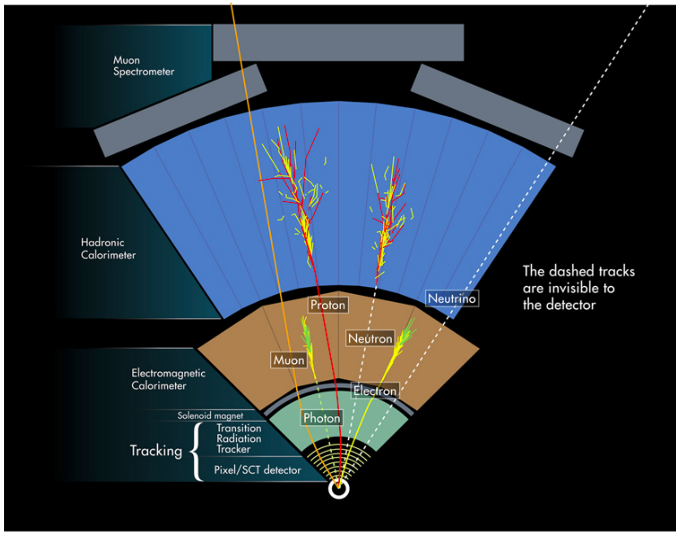
Monolithic CMOS sensor



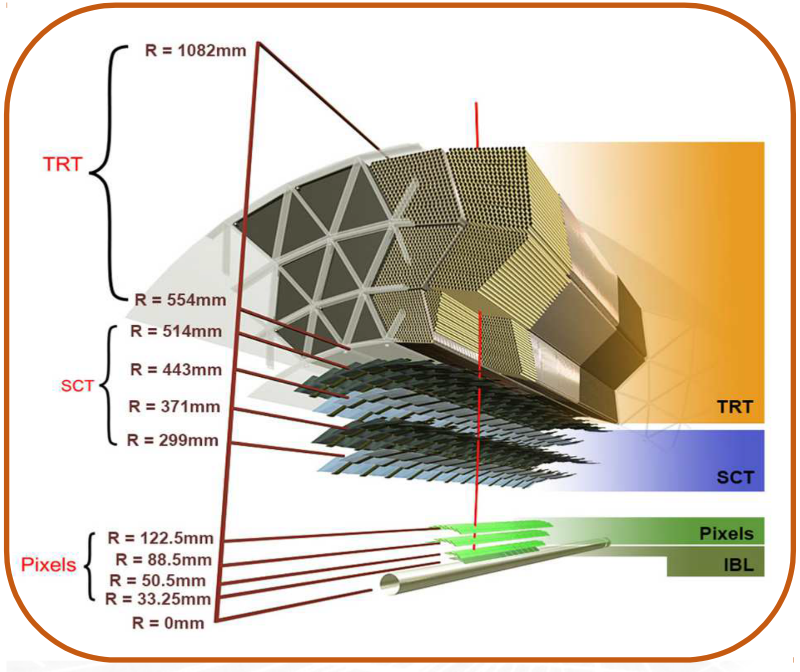
- Study physics performance of **CMOS sensor** for **ITK replacement** of ALTAS Pixel detector in **2nd-half of HL-LHC**.

ATLAS detector





- **A Toroidal LHC ApparatuS (ATLAS):**
  - **Multipurpose particle detector** with nearly 4π coverage in solid angle. Consists of 4 sub-components.
  - **Inner tracking detector**: measures direction, momentum of charged particles.
  - **Electromagnetic and hadron calorimeters**: stop most of particles and measure their energy and direction.
  - **Muon spectrometer**: measures momenta of muons.
- **ATLAS pixel detector**:
  - innermost element of inner detector. Composed of 4 barrel and 6 end-cap disk layers. ~ 92 million pixels.
  - provides excellent spatial resolution for 1st vertices
  - **Most important for identification and reconstruction of secondary vertices (b-tagging).**
  - **Insertable B-layer (IBL)** added before start of Run 2 (2015) improving b-jet identification.



Analysis

Supersymmetry (SUSY)

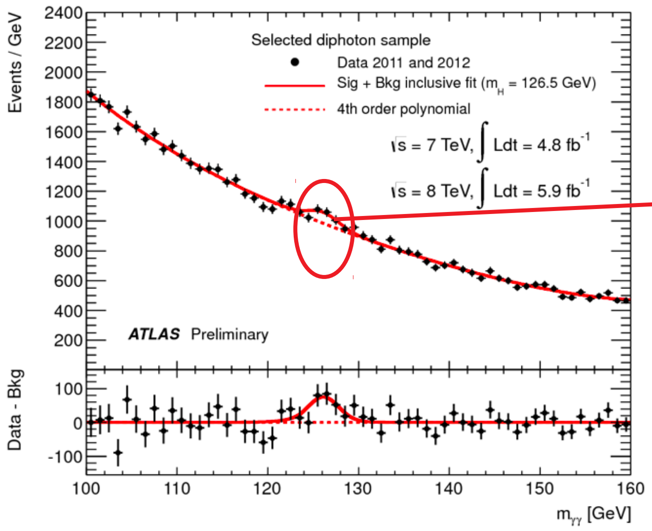
- **Standard Model** (SM) **very successful**; however, leaves **many open questions** (neutrino mass, hierarchy problem, Dark Matter, Dark Energy, etc.).

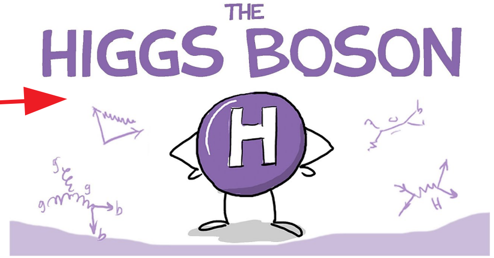
- **Supersymmetry** (SUSY) postulates **existence of SUSY particles. each associated to SM one and differ ½ in spin**.

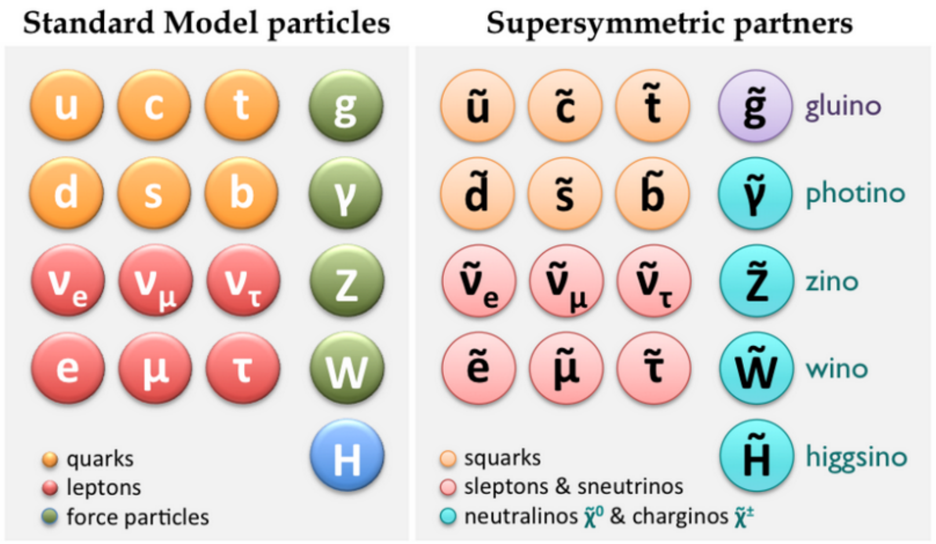
- no sparticles observed → **broken symmetry** → sparticle mass ≠ SM partner ones.

- **Charginos** $\tilde{\chi}^{\pm}_{1,2}$, **neutralinos** $\tilde{\chi}^{0}_{1,2,3,4}$: **linear superpositions of SUSY partners of Higgs and of electroweak gauge bosons**.

- If **R-parity:** $P_R = (-1)^{3B+L+2s}$ **conserved** (RPC):
  - SUSY particles **produced in pairs**.
  - **Lightest supersymmetric particles** (LSP) **stable, weakly interacting**, thereby **invisible to detector** → **Dark Matter candidate**.



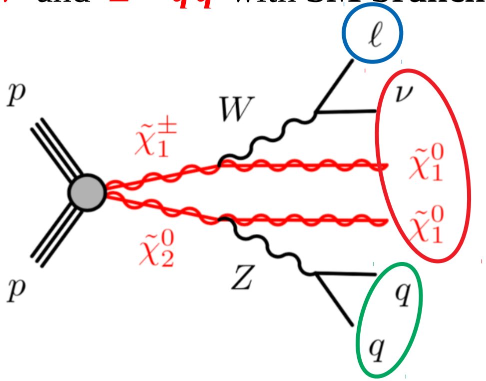




Signal simplified models

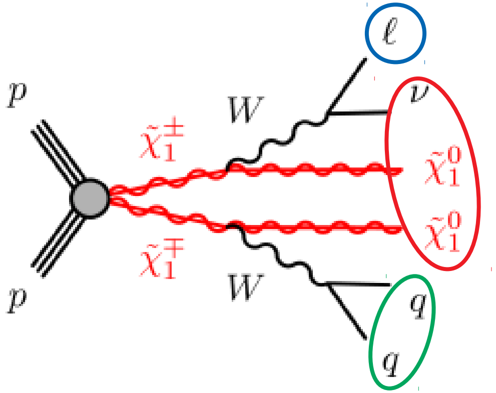
WZ model

- $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ directly pair-produced, $m_{\tilde{\chi}_1^{\pm}} = m_{\tilde{\chi}_2^0}$.
- $\tilde{\chi}_1^{\pm} \rightarrow W \tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \rightarrow Z \tilde{\chi}_1^0$ with **branching ratios set to 100%.**
- $W \rightarrow l\nu$ and $Z \rightarrow q\bar{q}$ with **SM branching ratios**.



WW model

- $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ directly pair-produced.
- Each $\tilde{\chi}_1^{\pm} \rightarrow W \tilde{\chi}_1^0$ with **branching ratios set to 100%.**
- $W \rightarrow l\nu$ and $W \rightarrow q\bar{q}'$ with **SM branching ratios**.



Final state: **1 lepton** + **jets** + E_T^{miss}

Reconstructed objects

leptons
p_T > 7 (6) GeV for e (μ) |η|(*) < 2.47 (2.5) for e (μ) Isolation conditions

jets
PFlow algorithm p_T > 25 GeV |η| < 2.8 Central jets: p_T > 30 GeV b-jets: DL1r tagger

Missing transverse momentum
negative vectorial sum of momenta of leptons and jets and soft terms.

(*) pseudorapidity $\eta = -\ln[\tan(\frac{\theta}{2})]$

Data and simulated samples

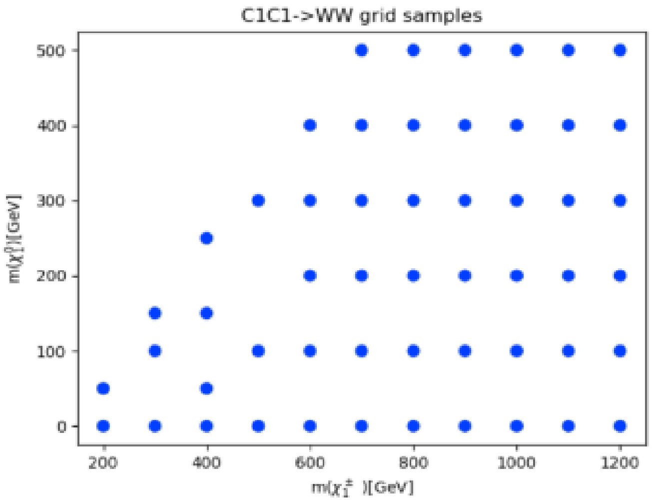
- **Data**: **ATLAS full Run 2 data** (2015 – 2018, L = 139 fb^{-1}, $\sqrt{s}$ = 13 TeV).

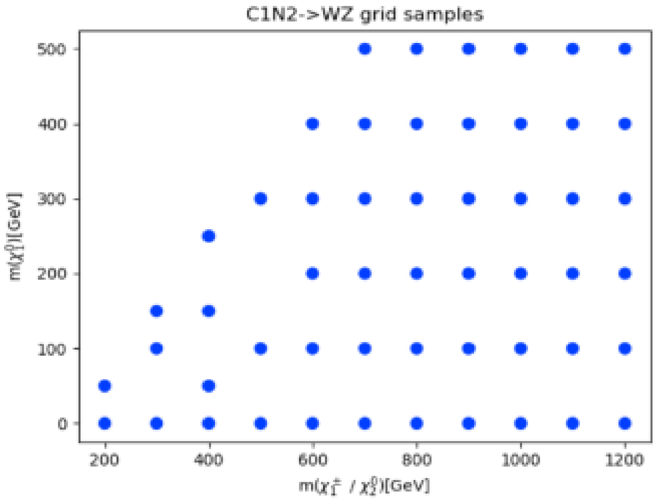
- **Monte Carlo (MC) simulated samples** used to model SM backgrounds and signals. Produced using **full/fast ATLAS simulation**[1] and **GEANT 4**[2].

- **WZ and WW signal samples**:
  - generated for each mass point $\left(m_{\tilde{\chi}_2^0}, m_{\tilde{\chi}_1^0}\right)$, at **leading order**, using **MadGraph, Pythia 8, EvtGen (MGPy8EG)**.
  - **Cross-sections** computed at **NLO + NLL accuracy**.

- **Background samples**:

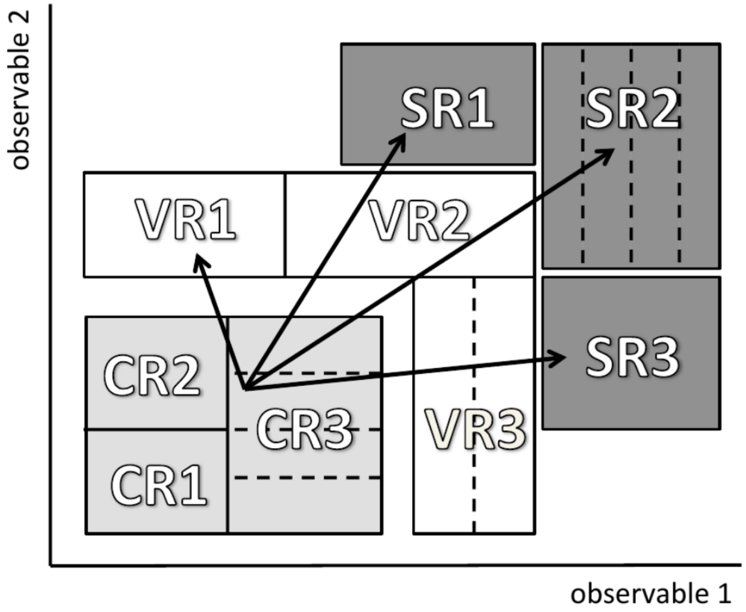
W/Z+jets (Sherpa 2.2.1)
Diboson, Triboson (Sherpa 2.2.1)
Ttbar, Single Top (PowhegPy8)
VH (PowhegPy8)
ttH (PowhegPy8)
ttV (PowhegPy8)





[1] arXiv:1005.4568
[2] GEANT4 - a simulation toolkit

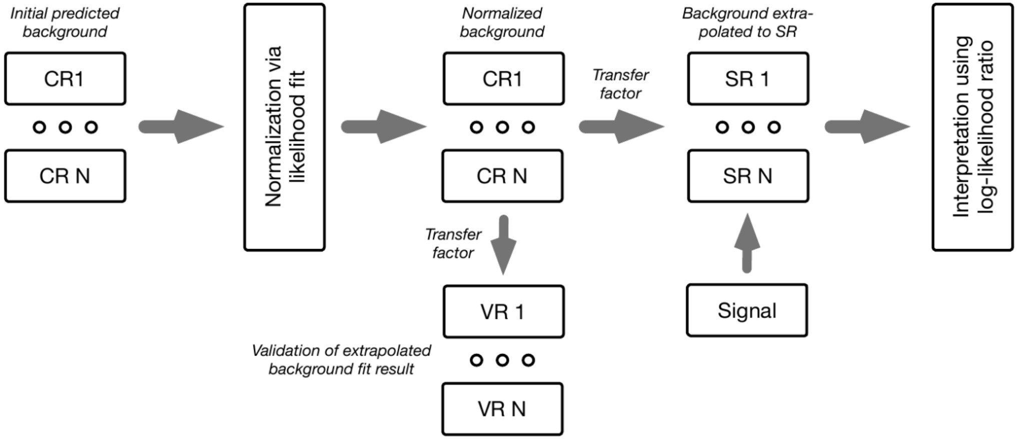
General analysis strategy



- Define several **regions in phase-space**, categorized to **3 types**:
  - **Signal region (SR)**: signal-rich region.
  - **Control region (CR)**: background-rich region, fit simulated backgrounds to data.
  - **Validation region (VR)**: between SR and CR, validation of extrapolation.

- CR/VR/SR **statistically independent**, **modeled by separate P.D.Fs**, combined in a simultaneous fit.

- **Analysis flow**:
  - Normalize backgrounds to data in fit of CRs.
  - Extrapolate to VRs/SRs using transfer factors (ratio of event counts between CR and SR/VR).
  - If good data/background agreement in VRs, unblind SRs.
  - If no excess, add signal prediction and interpret/set limits.`



Initial predicted background

CR1

CR N

Normalization via likelihood fit

Normalized background

CR1

CR N

Transfer factor

Background extra-polated to SR

SR 1

SR N

Signal

Interpretation using log-likelihood ratio

Transfer factor

VR 1

VR N

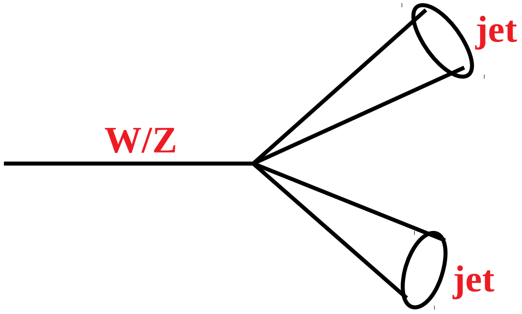
Validation of extrapolated background fit result

- **3 different likelihood fit strategies**:
  - **Background-only fit**: estimates backgrounds in VRs/SRs, only include CRs in fit to data, no signal contribution.
  - **Model-dependent fit**: simultaneous fit to data in all SRs and CRs, including signal contribution, hypothesis test for exclusion limit.
  - **Model-independent fit**: inject signal contribution to SR only. Compute signal contribution upper limit in SR and p-value for background-only hypothesis.

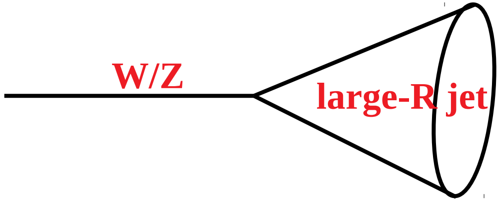
- handled effectively with **HistFitter** (arXiv:1410.1280)

Signal regions

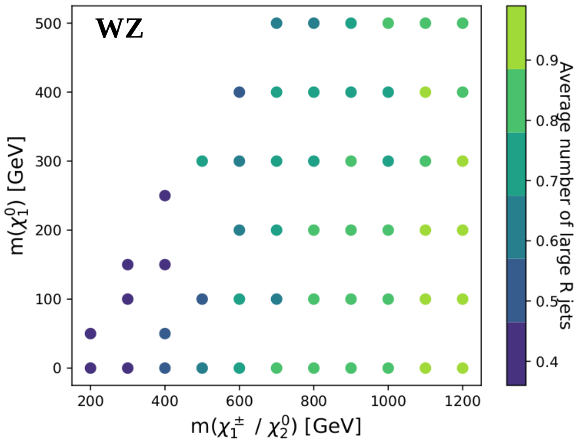
- low $\boldsymbol{\delta m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^{0}, \tilde{\chi}_1^{0})}$

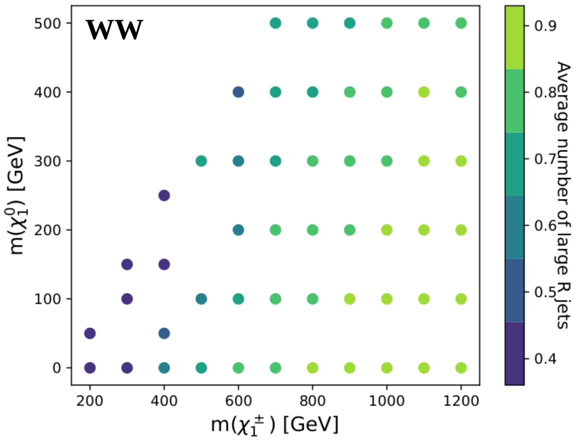


- high $\boldsymbol{\delta m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^{0}, \tilde{\chi}_1^{0})}$



- higher average number of large-R jet in region with high $\boldsymbol{\delta m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^{0}, \tilde{\chi}_1^{0})}$





- Define **2 kinds of SR** to optimize the sensitivities for low and high mass regions of the grid.
  - **boosted SR**: number of large-R jets >= 1.
  - **resolved SR**: number of large-R jets = 0.

- Discriminating kinematic variables used to define SRs:
  - **Transverse mass**:

$$m_T = \sqrt{2\, p_T(l)\, E_T^{miss}\left(1-\cos[\Delta\phi(l, E_T^{miss})]\right)}$$

  - **Invariant mass of 2 leading jet**

$$m_{jj} = \sqrt{2\, p_T(j_1)\, p_T(j_2)\left(\cosh(\eta_1-\eta_2)-\cos(\phi_1-\phi_2)\right)}$$

  - **Missing transverse momentum significance**

$$S^2 = 2\ln\left[\frac{\max_{\boldsymbol{p}_{\mathrm{T}}^{\mathrm{inv}} \neq 0} \mathcal{L}\left(E_{\mathrm{T}}^{\mathrm{miss}} | \boldsymbol{p}_{\mathrm{T}}^{\mathrm{inv}}\right)}{\max_{\boldsymbol{p}_{\mathrm{T}}^{\mathrm{inv}} = 0} \mathcal{L}\left(E_{\mathrm{T}}^{\mathrm{miss}} | \boldsymbol{p}_{\mathrm{T}}^{\mathrm{inv}}\right)}\right]$$

  - **Boosted W/Z tagger**.

Signal regions

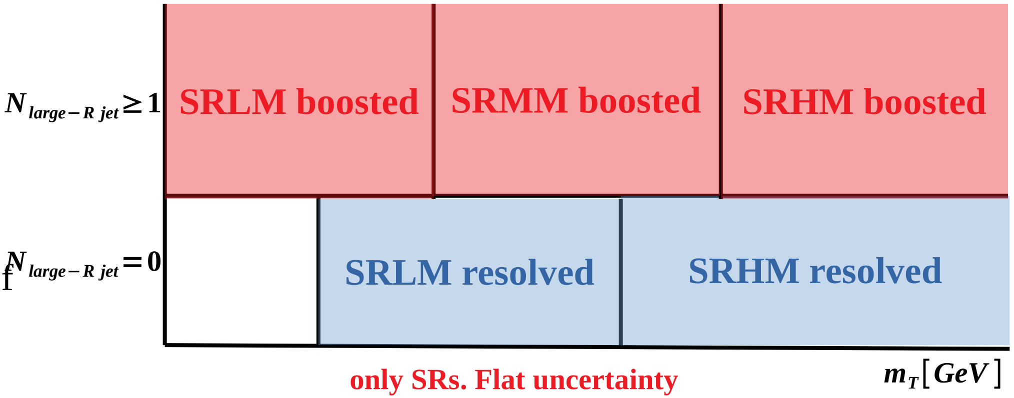
- **Boosted regions**: **main contribution** to the sensitivity. **Designed separately** for each model, used **large-R jet momentum**.
- **Resolved regions**: **complementary regions** to increase sensitivity of boosted ones. **Designed commonly** for both models, use invariant mass of 2 leading jet m_{jj}

WZ model

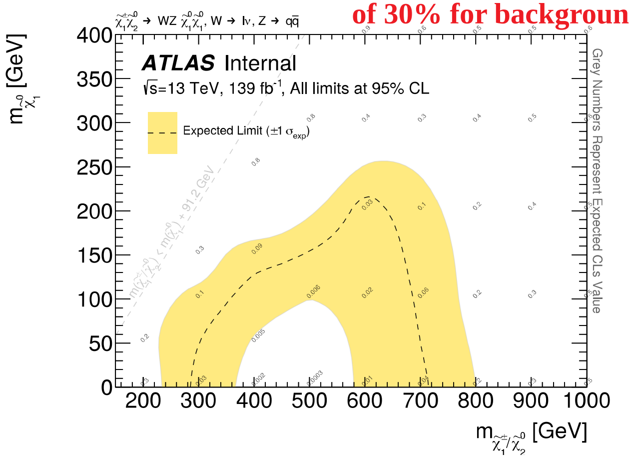
Variable	Cuts				
	SRLM resolved	SRHM resolved	SRLM boosted	SRMM boosted	SRHM boosted
N_{lep}	1		1		
p_{T}^{ℓ}[GeV]	> 25		> 25		
N_{jet} ($p_{\text{T}}^{\text{jets}}$> 30 GeV)	2 - 3		≤ 3		
$N_{\text{b-jet}}$ ($p_{\text{T}}^{\text{jets}}$> 30 GeV)	0		≤ 2		
$E_{\text{T}}^{\text{miss}}$ [GeV]	> 200		> 200		
$\Delta\phi(\ell, E_{\text{T}}^{\text{miss}})$	< 2.8		< 2.6		
m_{jj}[GeV]	70 - 105		-		
$N_{\text{large-Rjets}}$	0		≥ 1		
Z-tagged large-R jet	-		yes		
$p_{\text{T}}^{large-Rjet}$[GeV]	-		> 250		
$E_{\text{T}}^{\text{miss}}$ significance	-		> 15		
m_{T}[GeV]	200 - 380	> 380	120 - 240	240 - 420	> 420

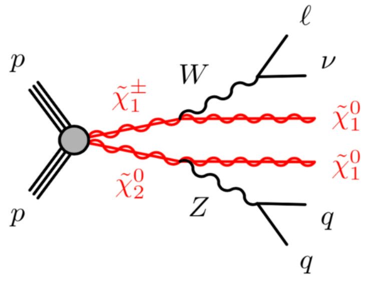
WW model

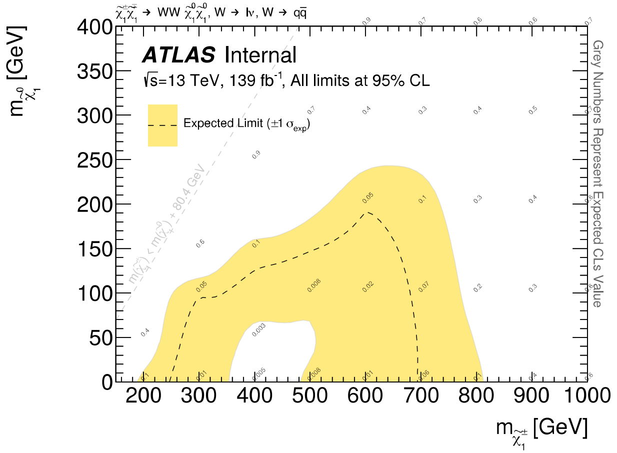
Variable	Cuts				
	SRLM resolved	SRHM resolved	SRLM boosted	SRMM boosted	SRHM boosted
N_{lep}	1		1		
p_{T}^{ℓ}[GeV]	> 25		> 25		
N_{jet} ($p_{\text{T}}^{\text{jets}}$> 30 GeV)	2 - 3		≤ 3		
$N_{\text{b-jet}}$ ($p_{\text{T}}^{\text{jets}}$> 30 GeV)	0		0		
$E_{\text{T}}^{\text{miss}}$ [GeV]	> 200		> 200		
$\Delta\phi(\ell, E_{\text{T}}^{\text{miss}})$	< 2.8		< 2.9		
m_{jj}[GeV]	70 - 105		-		
$N_{\text{large-Rjets}}$	0		≥ 1		
W-tagged large-R jet	-		yes		
$p_{\text{T}}^{large-Rjet}$[GeV]	-		> 300		
$E_{\text{T}}^{\text{miss}}$ significance	-		> 14		
m_{T}[GeV]	200 - 380	> 380	120 - 240	240 - 360	> 360

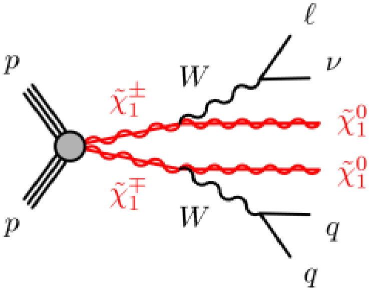


only SRs. Flat uncertainty of 30% for backgrounds









Background estimation

- Because of **similarity in SR definition**, **CRs** and **VRs designed commonly** for both WZ and WW models.

- Build dedicated CRs and VRs for each **dominant background in SRs**: **Diboson 2L**, **Diboson 1L**, **W+jets** and **ttbar**.

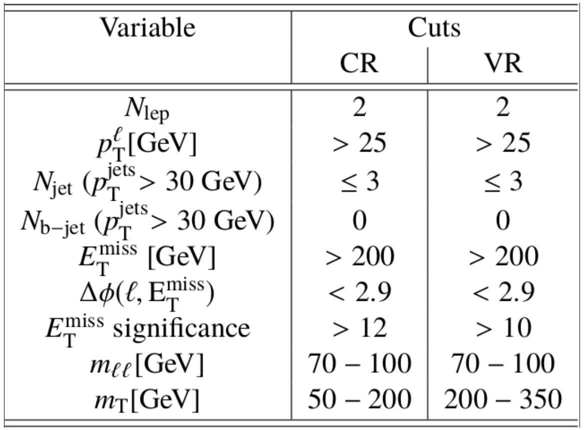
- CRs and VRs should:
  - show **good agreement between data and MC**;
  - have **large enough statistics**;
  - have **high purity of considered backgrounds** and **low signal contamination**.

CRs/VRs: Diboson 2L (DB2L)

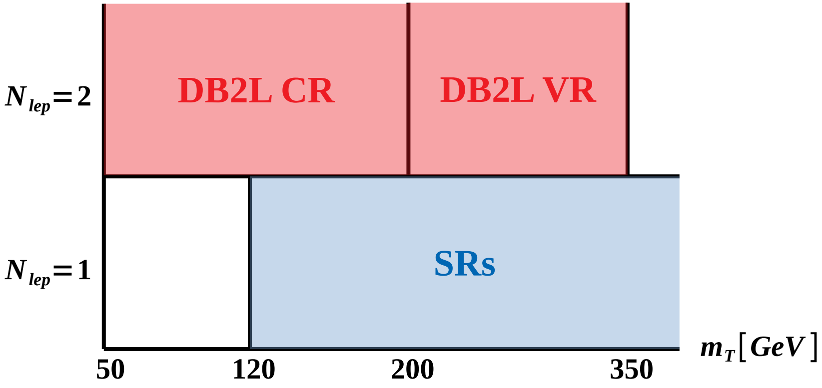
- target diboson contribution coming from diboson processes with ≥ **2 leptons in final state**.

- Require **exactly 2 leptons**, and add **invariant mass of 2 leptons** to define CR and VR.

$$m_{ll} = \sqrt{2\, p_T(l_1)\, p_T(l_2)\left(\cosh(\eta_{l_1} - \eta_{l_2}) - \cos(\phi_{l_1} - \phi_{l_2})\right)}$$



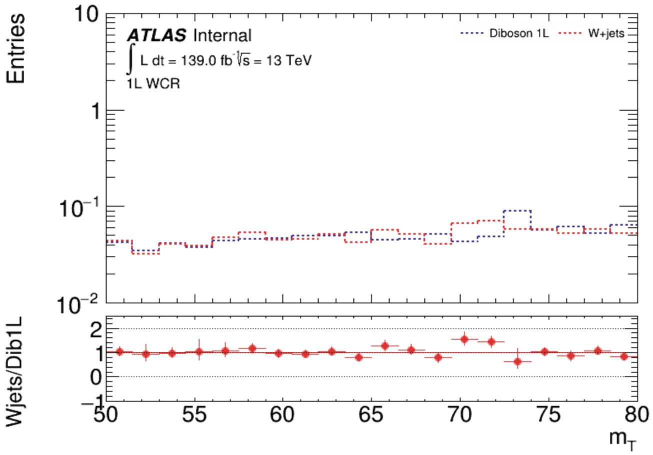
Variable	Cuts CR	Cuts VR
N_{lep}	2	2
p_{T}^{ℓ}[GeV]	> 25	> 25
N_{jet} ($p_{\mathrm{T}}^{\mathrm{jets}} > 30$ GeV)	≤ 3	≤ 3
$N_{\mathrm{b-jet}}$ ($p_{\mathrm{T}}^{\mathrm{jets}} > 30$ GeV)	0	0
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 200	> 200
$\Delta\phi(\ell, \mathrm{E}_{\mathrm{T}}^{\mathrm{miss}})$	< 2.9	< 2.9
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	> 12	> 10
$m_{\ell\ell}$[GeV]	$70 - 100$	$70 - 100$
m_{T}[GeV]	$50 - 200$	$200 - 350$



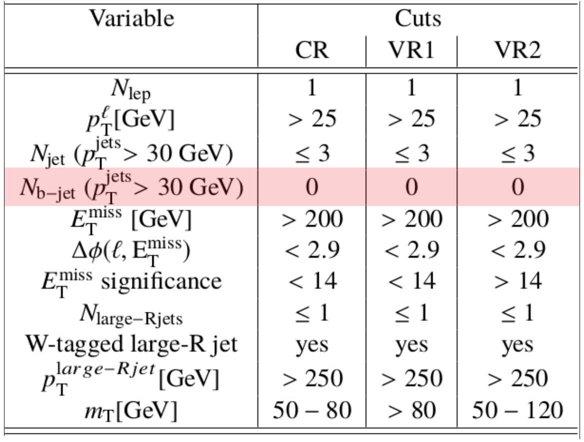
Background estimation

CRs/VRs: W+jets and Diboson 1L (WDB1L)

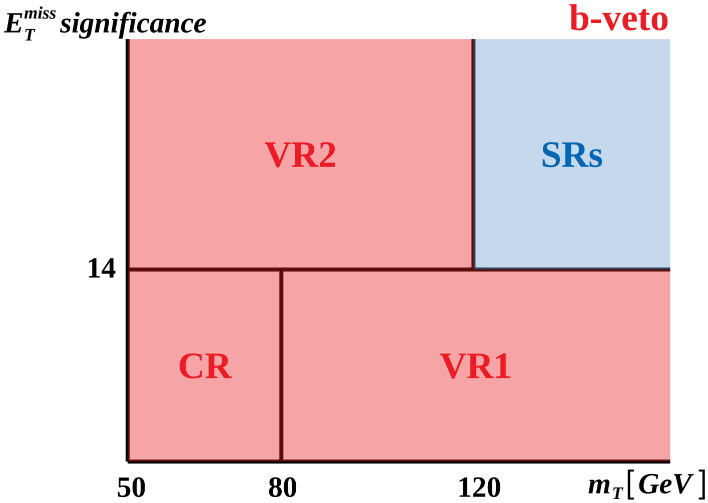
- **Diboson 1L very similar to W+jets in kinematics** → difficult to design proper regions. Instead, **use common CRs and VRs**.
- Define **separate regions for boosted and resolved cases**.
- Harmonize ***E_T^{miss} significance , m_T***



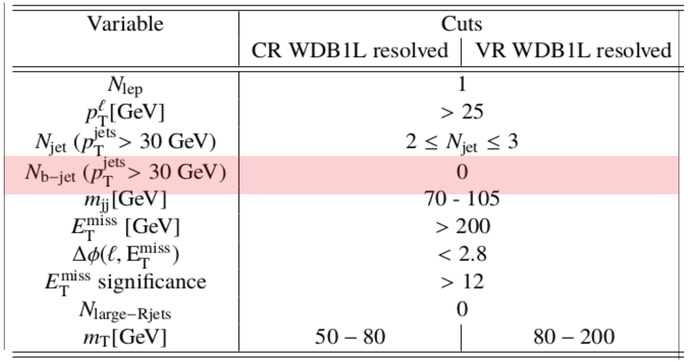
Boosted WDB1L CRs/VRs



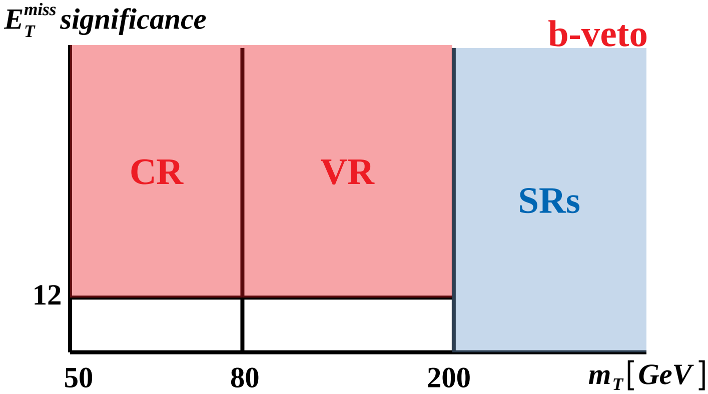
Variable	Cuts		
	CR	VR1	VR2
N_{lep}	1	1	1
p_T^{ℓ}[GeV]	> 25	> 25	> 25
N_{jet} (p_T^{jets}> 30 GeV)	≤ 3	≤ 3	≤ 3
$N_{\mathrm{b-jet}}$ (p_T^{jets}> 30 GeV)	0	0	0
E_T^{miss} [GeV]	> 200	> 200	> 200
$\Delta\phi(\ell, E_T^{\mathrm{miss}})$	< 2.9	< 2.9	< 2.9
E_T^{miss} significance	< 14	< 14	> 14
$N_{\mathrm{large-Rjets}}$	≤ 1	≤ 1	≤ 1
W-tagged large-R jet	yes	yes	yes
$p_T^{large-Rjet}$[GeV]	> 250	> 250	> 250
m_T[GeV]	50 – 80	> 80	50 – 120



Resolved WDB1L CR/VR



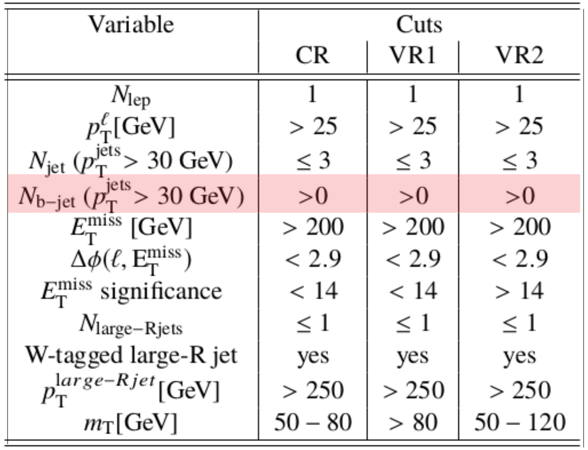
Variable	Cuts	
	CR WDB1L resolved	VR WDB1L resolved
N_{lep}	1	
p_T^{ℓ}[GeV]	> 25	
N_{jet} (p_T^{jets}> 30 GeV)	$2 \leq N_{\mathrm{jet}} \leq 3$	
$N_{\mathrm{b-jet}}$ (p_T^{jets}> 30 GeV)	0	
m_{jj}[GeV]	70 - 105	
E_T^{miss} [GeV]	> 200	
$\Delta\phi(\ell, E_T^{\mathrm{miss}})$	< 2.8	
E_T^{miss} significance	> 12	
$N_{\mathrm{large-Rjets}}$	0	
m_T[GeV]	50 – 80	80 – 200



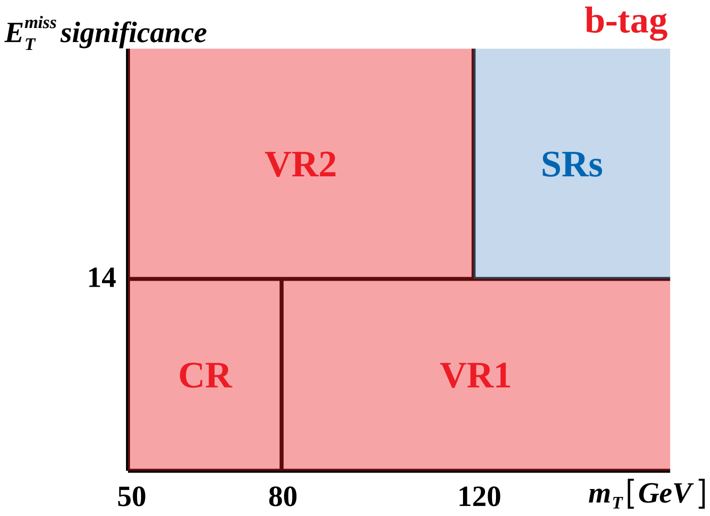
Background estimation

CRs/VRs: ttbar (Top)

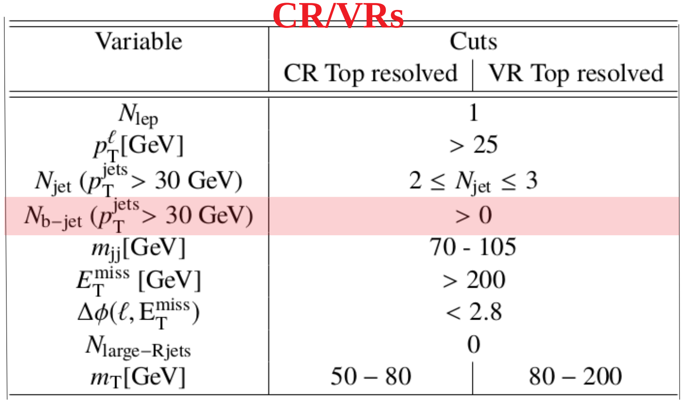
Boosted Top CR/VRs



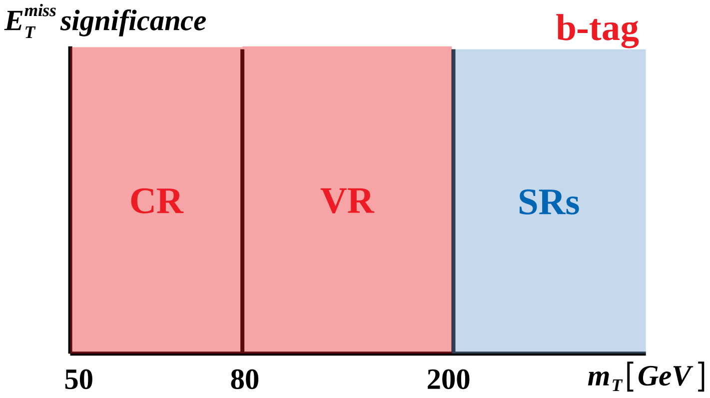
Variable	Cuts		
	CR	VR1	VR2
N_{lep}	1	1	1
p_T^{ℓ}[GeV]	> 25	> 25	> 25
N_{jet} ($p_T^{\text{jets}} > 30$ GeV)	≤ 3	≤ 3	≤ 3
$N_{\text{b-jet}}$ ($p_T^{\text{jets}} > 30$ GeV)	>0	>0	>0
E_T^{miss} [GeV]	> 200	> 200	> 200
$\Delta\phi(\ell, E_T^{\text{miss}})$	< 2.9	< 2.9	< 2.9
E_T^{miss} significance	< 14	< 14	> 14
$N_{\text{large-Rjets}}$	≤ 1	≤ 1	≤ 1
W-tagged large-R jet	yes	yes	yes
$p_T^{large-Rjet}$[GeV]	> 250	> 250	> 250
m_T[GeV]	50 – 80	> 80	50 – 120



Resolved Top CR/VRs



Variable	Cuts	
	CR Top resolved	VR Top resolved
N_{lep}	1	
p_T^{ℓ}[GeV]	> 25	
N_{jet} ($p_T^{\text{jets}} > 30$ GeV)	$2 \leq N_{\text{jet}} \leq 3$	
$N_{\text{b-jet}}$ ($p_T^{\text{jets}} > 30$ GeV)	> 0	
m_{jj}[GeV]	70 - 105	
E_T^{miss} [GeV]	> 200	
$\Delta\phi(\ell, E_T^{\text{miss}})$	< 2.8	
$N_{\text{large-Rjets}}$	0	
m_T[GeV]	50 – 80	80 – 200

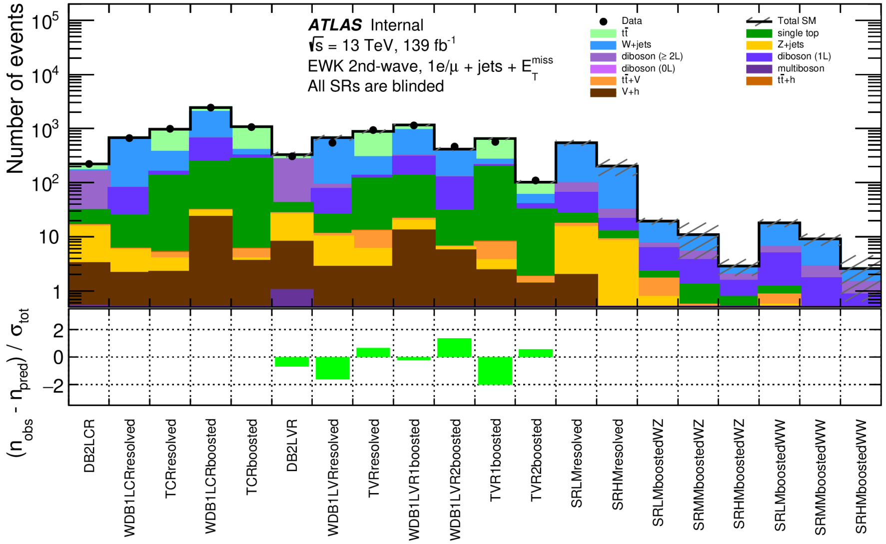


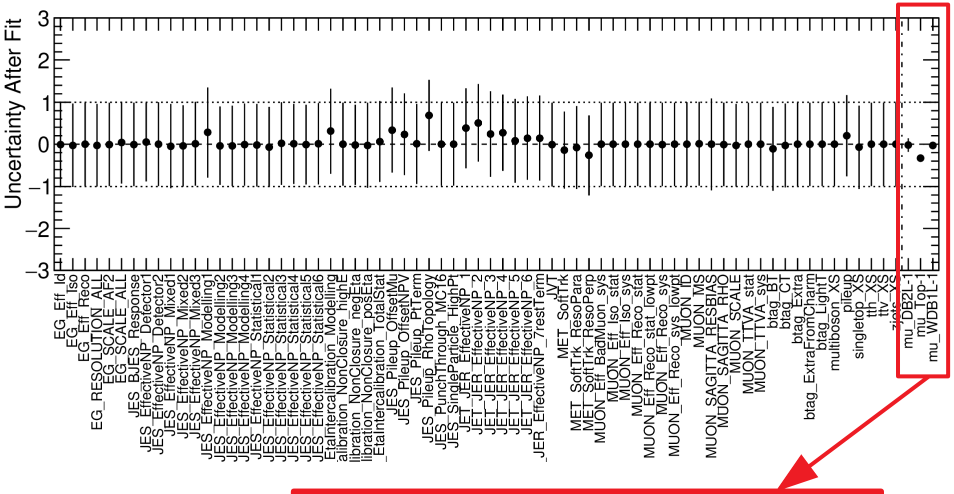
Preliminary results

- Run **background-only fit** and **model-dependent fit** using HistFitter package, including **all SRs, CRs and VRs**.
- For the moment, **only add experimental systematic uncertainties** into fits, no theory systematic uncertainties included yet.

Background-only fit

- only **unblind data in CRs and VRs**, while keeping **SRs blinded**.
- After fit, **background yields** normalized in CRs and extrapolated into VRs show **good agreement with data**.





mu_Top = 6.6786e-01 +/- 3.73e-02

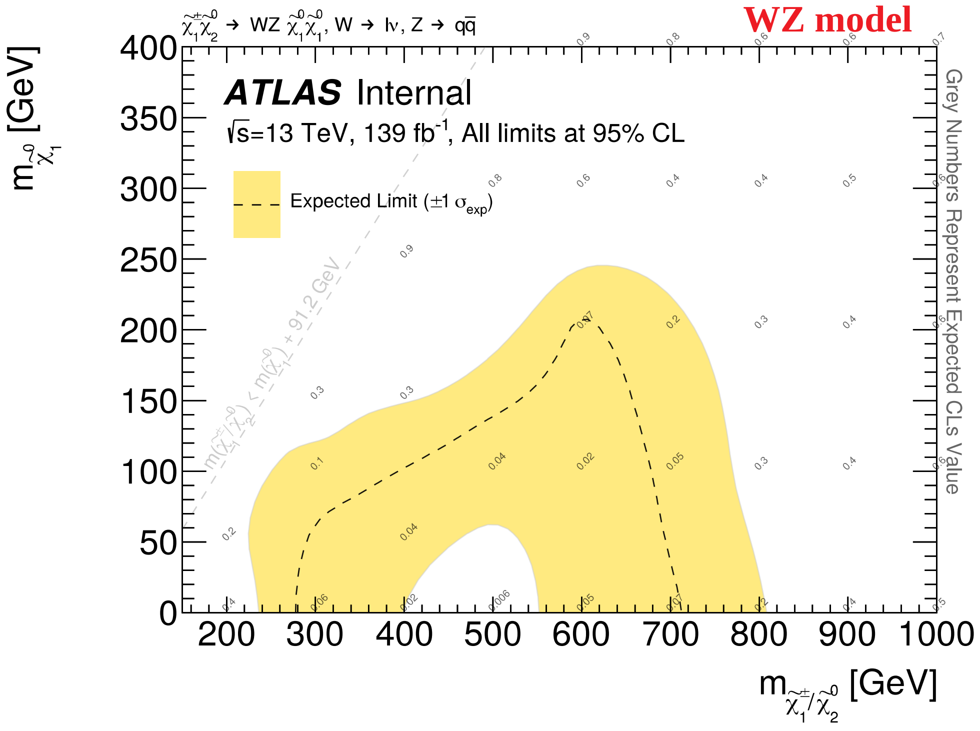
mu_DB2L = 9.8448e-01 +/- 1.63e-01

mu_WDB1L = 9.7142e-01 +/- 3.55e-02

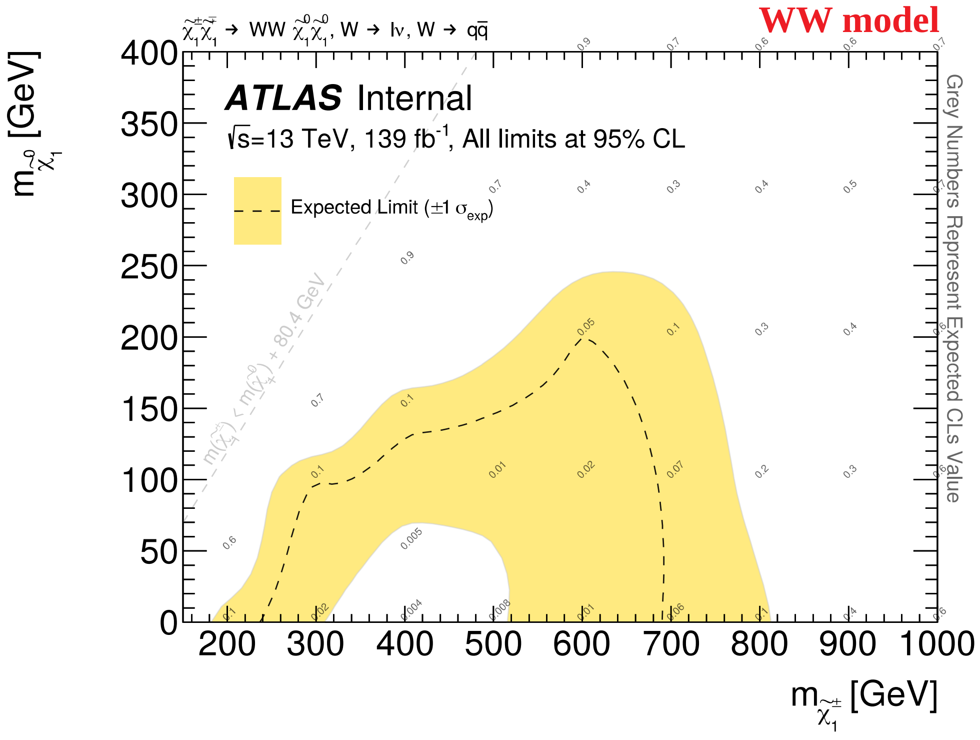
Preliminary results

Model-dependent fit

- Run hypothesis test and obtain **exclusion contour limit at 95% CL** for WZ and WW models



WZ model



WW model

- **$m_{\tilde{\chi}_1^\pm/\tilde{\chi}_2^0}$ up to ~ 700 GeV expected to be excluded at 95% CL for massless $\tilde{\chi}_1^0$**

Instrumentation

High luminosity LHC (HL-LHC)

- **HL-LHC**: **upgrade of LHC**, plan to be **installed during Long Shutdown 3** (LS3, **2025 – 2026**) and **start in 2027**.
- aims to **increase luminosity by factor of 10**.

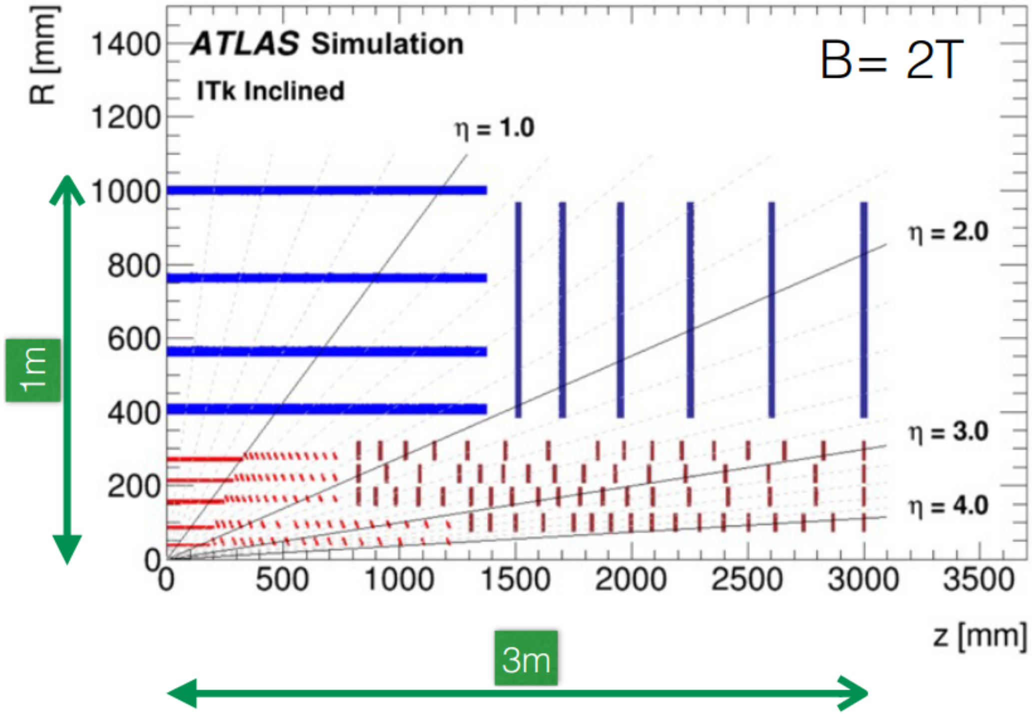
➡ **allow better studies of mechanisms and boost potential for new physics discoveries.**

ATLAS Inner Tracker (ITk)

- Current ATLAS Inner Dectector (ID) works excellently, however,
  - **B-Layer**: designed for **fluence up to 10^{15} n(1 MeV)/cm^2**.
  - **IBL**: **2×10^{15} n(1 MeV)/cm^2**

➡ **suffer during Run 3 and cannot withstand HL-LHC radiation levels**.

- Current ID tracker replaced by **ITk** in LS3 (2025 – 2026):
  - All silicon design;
  - η coverage up to 4 (ID ~2.5).
  - **Pixel**: 5 barrel layers (short barrel + inclined modules) + ring disks (**ATLAS-CPPM involved**).
  - **Strip**: 4 barrel layers + 6 end-cap rings.
- ITk should have the **same or better performance** as the current detector but **in the harsher environment of the HL-LHC**.



- **Innermost layer of ITk** designed for up to **10^{16}** n(1 MeV)/cm^2, while **total dose of HL-LHC** foreseen up to **2×10^{16}** n(1 MeV)/cm^2.

➡ **should be replaced by half-life of HL-LHC**.

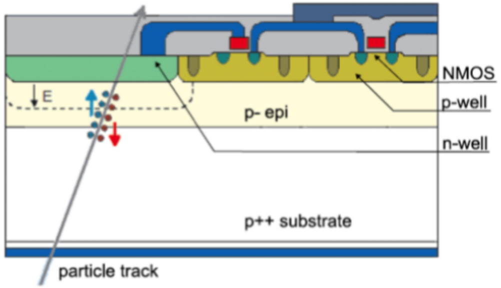
CMOS sensors

- CMOS technology **widely used** in electronics industry (e.g digital cameras) for ~20 years, shown up **many advantages.**

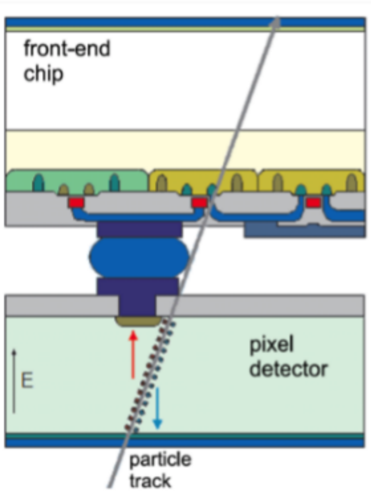
- CMOS possible to have **monolithic design**: **sensor substrate and electronics layers embedded in same silicon die**.

- The monolithic design would be more interesting:
  - **thinner and smaller pixels, less material, reduction of detector cost.**
  - **reduce multiple scatterings, better spatial resolution, faster production time.**

Monolithic



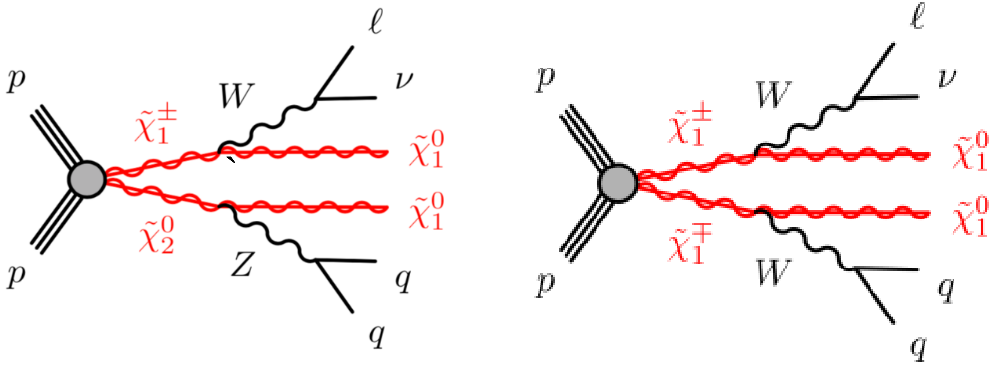
Hybrid



- However, CMOS **has not been designed** to withstand radiation levels of HL-LHC. **Is it woth?** Depend on Pt scale of new physics processes.

- Let’s see by simulation
  - So far, already known CMOS geometry (pixel size, sensor thickness) and parameters in digitization (noise, threshold).
  - Next, run with generated samples for high-Pt processes at HL-LHC to study tracking performance, b-tagging performance and later study with low/medium-Pt processes.

Summary



Analysis

- Search for SUSY EWK production, $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$ with ATLAS Run 2 collected data (2015 – 2018, L=139 fb^{-1}, 13 TeV).
- Defined SRs/CRs/VRs for boosted and resolved scenarios using large-R jet information.
- Obtained preliminary results with only experimental uncertainties included
  - **Background-only fit**: good agreement between data and MC in CRs and VRs, good normalization factors after fit.
  - **Model-dependent fit**: expected limit up to **$m_{\tilde{\chi}_1^\pm/\tilde{\chi}_2^0}$ of 700 GeV for massless $\tilde{\chi}_1^0$**
- Next step: add theory uncertainties, run model-independent fit, unblind SRs.

Instrumentation

- Study performance of CMOS sensors for replacement of ITk innermost layers in 2nd-half HL-LHC.
- So far, already have CMOS geometry and parameters for simulation.
- Next: use simulated samples to evaluate CMOS performance in traking and in b-tagging.

Other activities

- Contributed to search for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production through Wh1lbb channel, was published in EPJC. [arXiv:1909.09226]
- Study pixel-level leakage current for IBL and Pixel modules (Qualification task). [link]
- Estimation of pixel-hit loss rate using real data. [link]

Cảm ơn

Back up

Backup: Statistical analysis in SUSY searches

For most SUSY searches construct likelihood for hypothesis testing based on data and predicted SM background in all SRs/CRs:

Signal strength parameter, and normalisation parameters for dominant backgrounds

Systematic uncertainties modelled by (unit) gaussian

$$\mathcal{L}(\boldsymbol{n}, \boldsymbol{\theta}^{\boldsymbol{0}} | \mu_s, \boldsymbol{\mu_b}, \boldsymbol{\theta}) = \prod_{i \in CR} P(n_i | \lambda_i(\mu_s, \boldsymbol{\mu_b}, \boldsymbol{\theta})) \times \prod_{j \in SR} P(n_j | \lambda_j(\mu_s, \boldsymbol{\mu_b}, \boldsymbol{\theta})) \times P_{syst}(\boldsymbol{\theta}^{\boldsymbol{0}}, \boldsymbol{\theta})$$

Data yields in SRs/CRs

Poisson probabilities for the CRs and SRs. For binned SRs/CRs include each bin as a separate region.

Dimensions

- We chose the use the dimension of present sensors of innermost layer of ITK pixels:

$$2 \times 4\ cm^2$$

  - This will minimize efforts needed to modify geometry.
  - And seems realistic.
- Sensor thickness:

$$50\ \mu m$$

  - A most probable value of charge released by a MIP will be about 4 000 electrons.
- Pixel size:

$$25\ \mu m \times 25\ \mu m$$

  - Is already feasible.
  - Going smaller with the present services scheme will be difficult.
  - But we should stay open for possible future developments.

Digitization Parameters

- Threshold:

600 electrons

  - Still efficient if charge is divided by 2 because of radiation effects.
  - What can be the threshold spread after tuning ? 200 electrons ?
- Noise:

50 electrons

  - This is half of present noise.
  - Keeps S/N at high values (about 80) before radiation effects.
- ToT coded on:

4 Bits

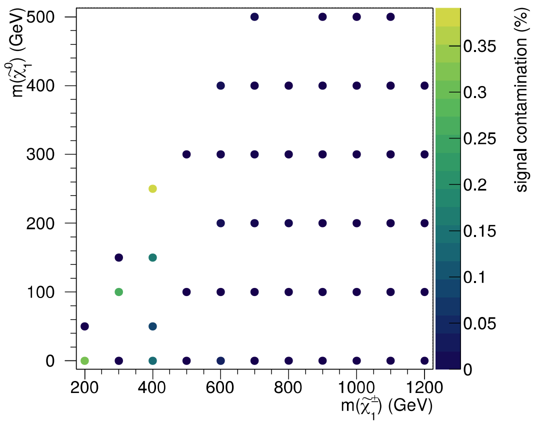
  - Like IBL and present ITK

Signal contamination in DB2L CR/VR

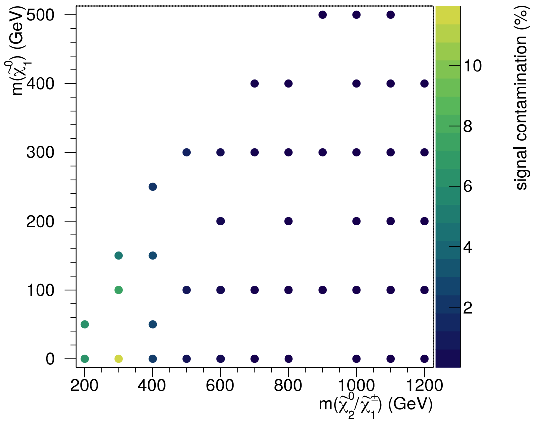
Silvia

- WZ and WW signal contamination in DB2L CR/VR

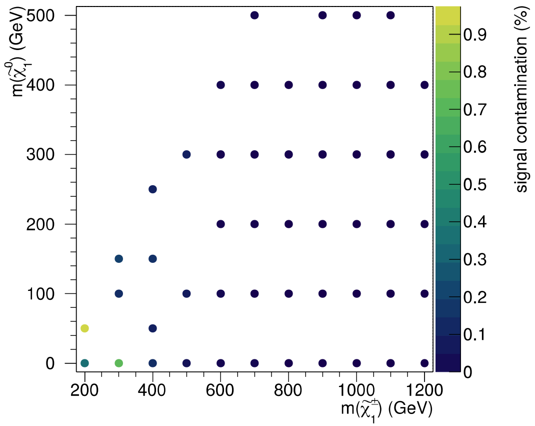
CR WW signal contamination



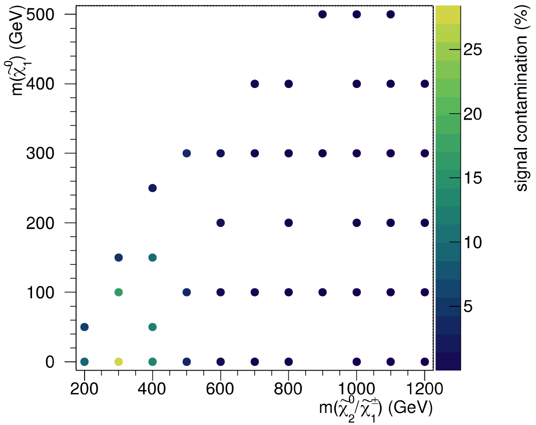
CR WZ signal contamination



VR WW signal contamination



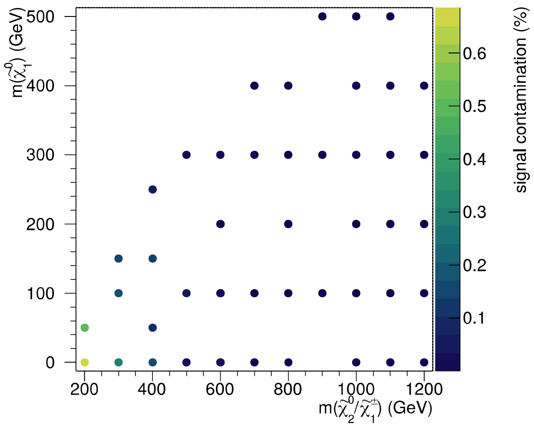
VR WZ signal contamination



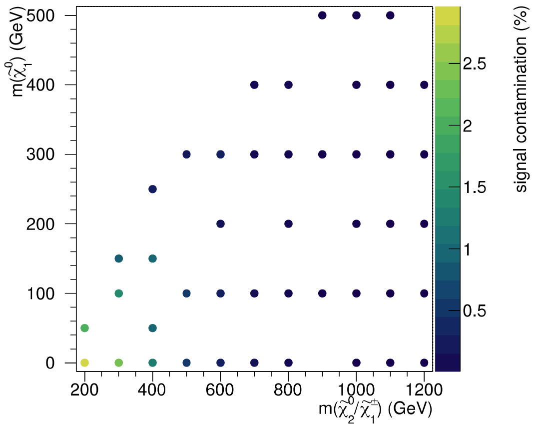
Silvia

signal contamination in boosted WDB1L CR/VRs

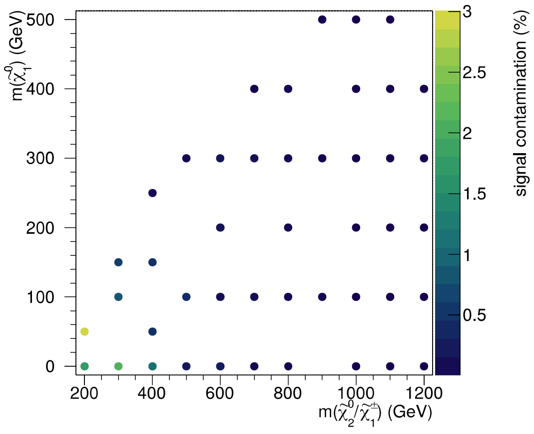
CR Wjets boost WZ signal contamination



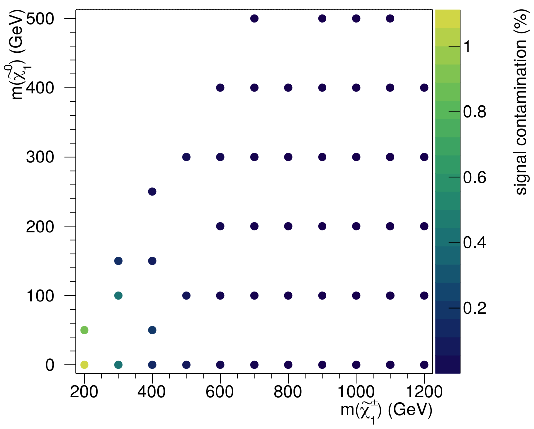
VR1 Wjets boost WZ signal contamination



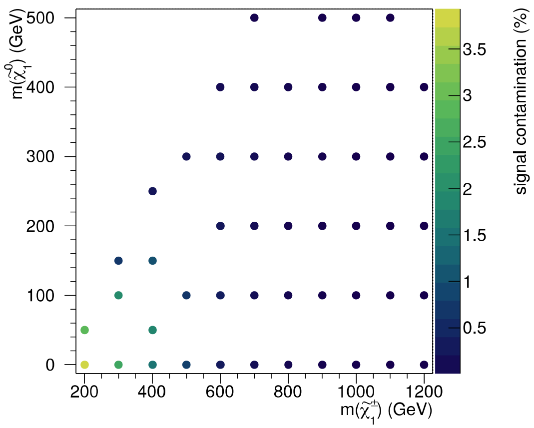
VR2 Wjets boost WZ signal contamination



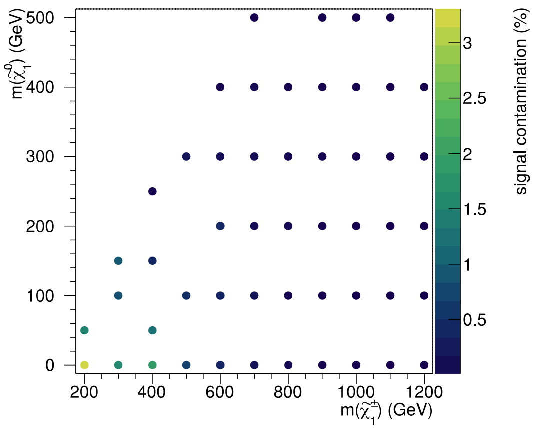
CR Wjets boost WW signal contamination



VR1 Wjets boost WW signal contamination

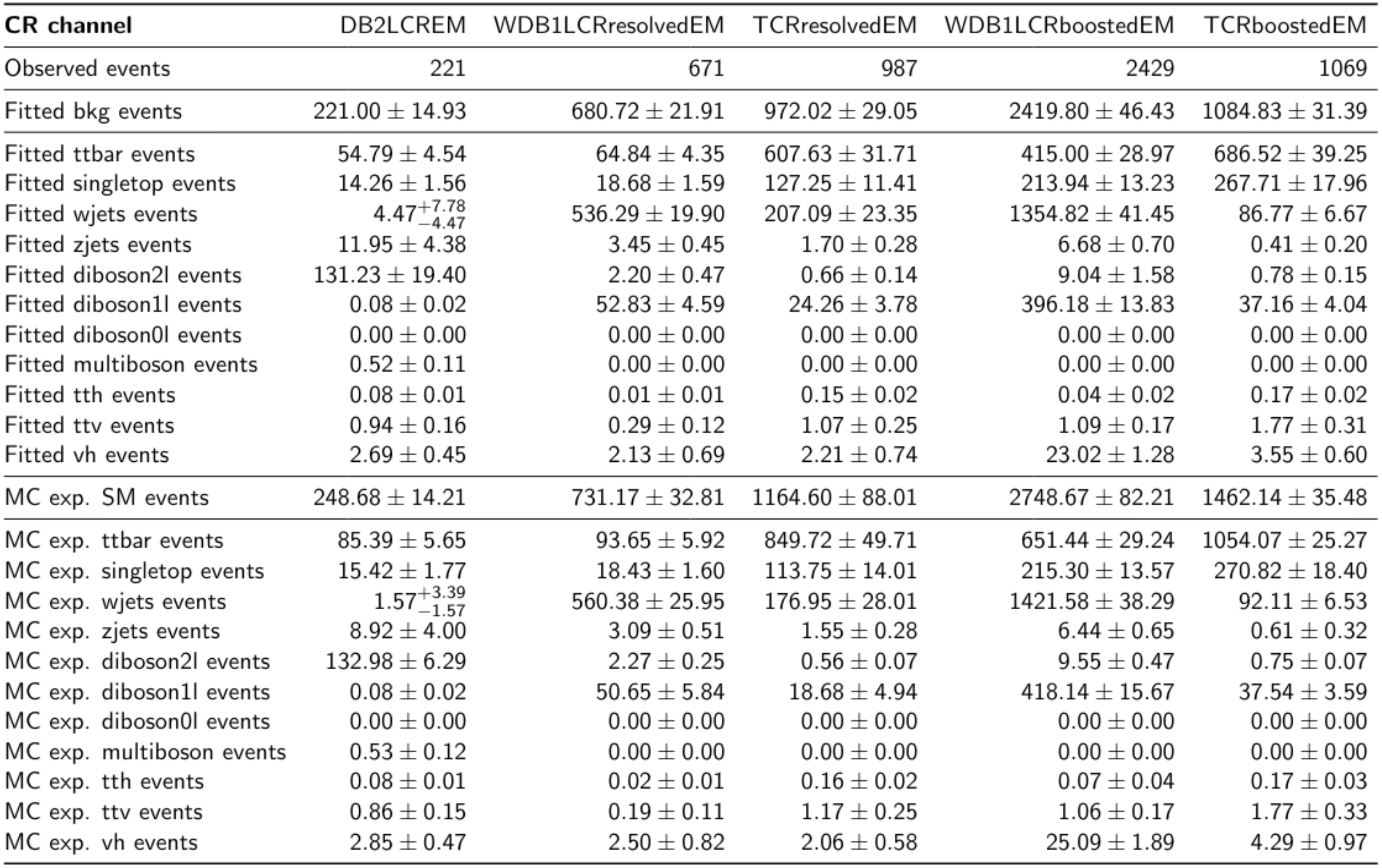


VR2 Wjets boost WW signal contamination



bgk-only fit results

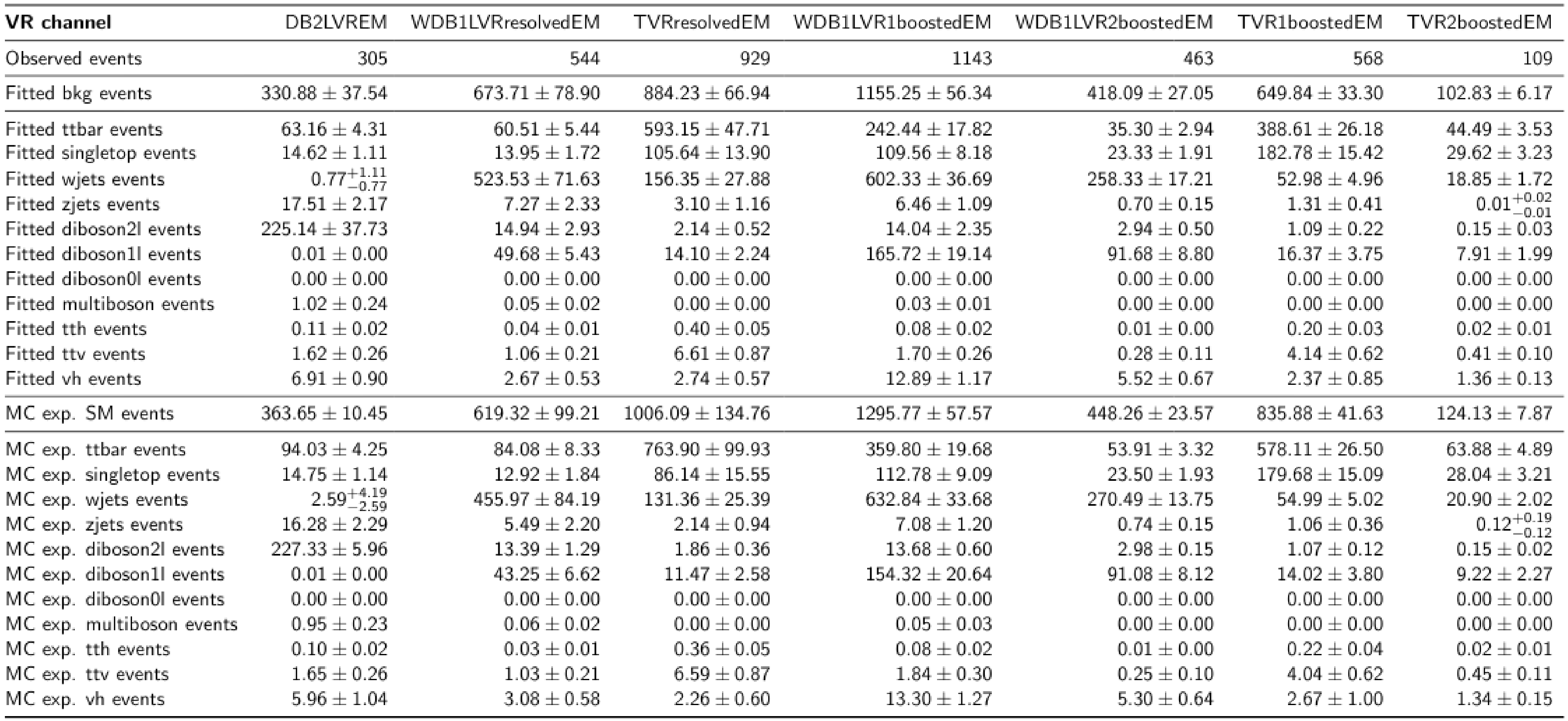
Yieldstable in CRs



CR channel	DB2LCREM	WDB1LCRresolvedEM	TCRresolvedEM	WDB1LCRboostedEM	TCRboostedEM
Observed events	221	671	987	2429	1069
Fitted bkg events	221.00 ± 14.93	680.72 ± 21.91	972.02 ± 29.05	2419.80 ± 46.43	1084.83 ± 31.39
Fitted ttbar events	54.79 ± 4.54	64.84 ± 4.35	607.63 ± 31.71	415.00 ± 28.97	686.52 ± 39.25
Fitted singletop events	14.26 ± 1.56	18.68 ± 1.59	127.25 ± 11.41	213.94 ± 13.23	267.71 ± 17.96
Fitted wjets events	$4.47^{+7.78}_{-4.47}$	536.29 ± 19.90	207.09 ± 23.35	1354.82 ± 41.45	86.77 ± 6.67
Fitted zjets events	11.95 ± 4.38	3.45 ± 0.45	1.70 ± 0.28	6.68 ± 0.70	0.41 ± 0.20
Fitted diboson2l events	131.23 ± 19.40	2.20 ± 0.47	0.66 ± 0.14	9.04 ± 1.58	0.78 ± 0.15
Fitted diboson1l events	0.08 ± 0.02	52.83 ± 4.59	24.26 ± 3.78	396.18 ± 13.83	37.16 ± 4.04
Fitted diboson0l events	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Fitted multiboson events	0.52 ± 0.11	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Fitted tth events	0.08 ± 0.01	0.01 ± 0.01	0.15 ± 0.02	0.04 ± 0.02	0.17 ± 0.02
Fitted ttv events	0.94 ± 0.16	0.29 ± 0.12	1.07 ± 0.25	1.09 ± 0.17	1.77 ± 0.31
Fitted vh events	2.69 ± 0.45	2.13 ± 0.69	2.21 ± 0.74	23.02 ± 1.28	3.55 ± 0.60
MC exp. SM events	248.68 ± 14.21	731.17 ± 32.81	1164.60 ± 88.01	2748.67 ± 82.21	1462.14 ± 35.48
MC exp. ttbar events	85.39 ± 5.65	93.65 ± 5.92	849.72 ± 49.71	651.44 ± 29.24	1054.07 ± 25.27
MC exp. singletop events	15.42 ± 1.77	18.43 ± 1.60	113.75 ± 14.01	215.30 ± 13.57	270.82 ± 18.40
MC exp. wjets events	$1.57^{+3.39}_{-1.57}$	560.38 ± 25.95	176.95 ± 28.01	1421.58 ± 38.29	92.11 ± 6.53
MC exp. zjets events	8.92 ± 4.00	3.09 ± 0.51	1.55 ± 0.28	6.44 ± 0.65	0.61 ± 0.32
MC exp. diboson2l events	132.98 ± 6.29	2.27 ± 0.25	0.56 ± 0.07	9.55 ± 0.47	0.75 ± 0.07
MC exp. diboson1l events	0.08 ± 0.02	50.65 ± 5.84	18.68 ± 4.94	418.14 ± 15.67	37.54 ± 3.59
MC exp. diboson0l events	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
MC exp. multiboson events	0.53 ± 0.12	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
MC exp. tth events	0.08 ± 0.01	0.02 ± 0.01	0.16 ± 0.02	0.07 ± 0.04	0.17 ± 0.03
MC exp. ttv events	0.86 ± 0.15	0.19 ± 0.11	1.17 ± 0.25	1.06 ± 0.17	1.77 ± 0.33
MC exp. vh events	2.85 ± 0.47	2.50 ± 0.82	2.06 ± 0.58	25.09 ± 1.89	4.29 ± 0.97

bgk-only fit results

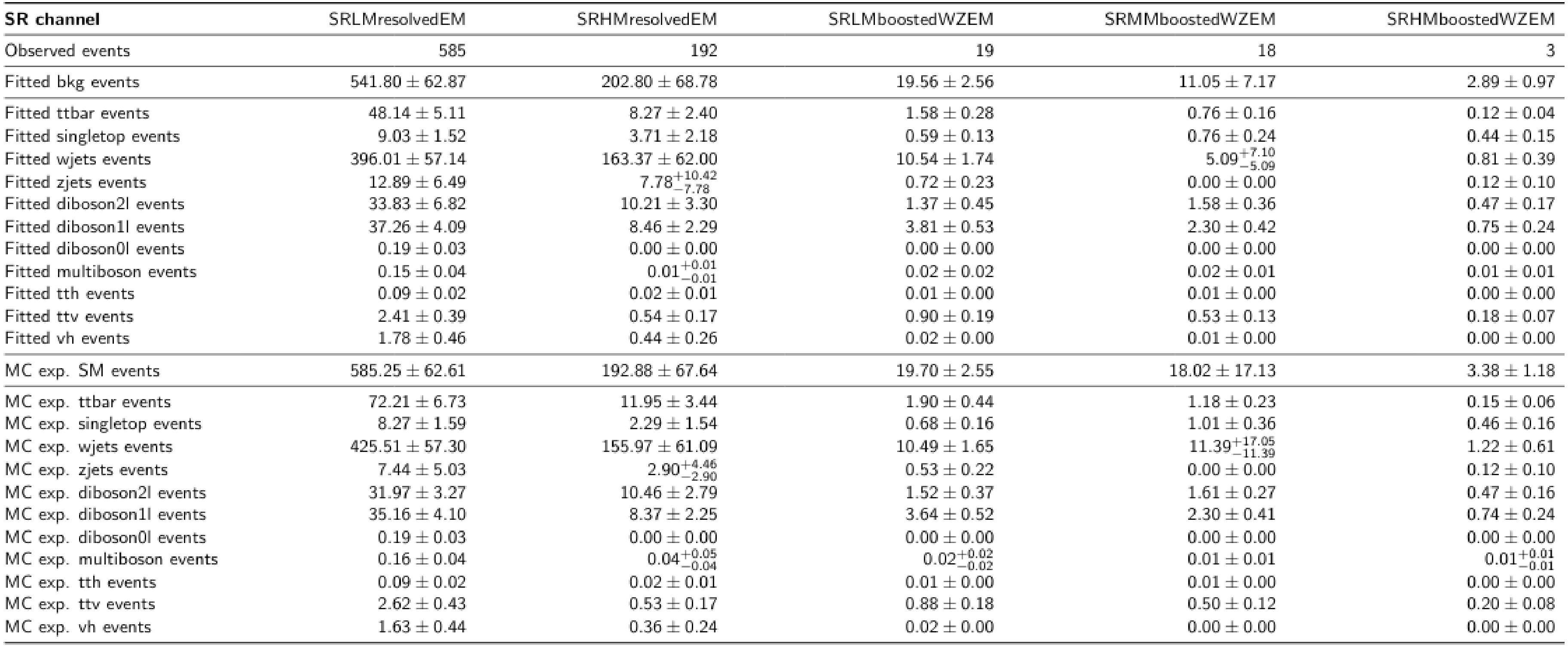
Yieldstable in VRs



VR channel	DB2LVREM	WDB1LVRresolvedEM	TVRresolvedEM	WDB1LVR1boostedEM	WDB1LVR2boostedEM	TVR1boostedEM	TVR2boostedEM
Observed events	305	544	929	1143	463	568	109
Fitted bkg events	330.88 ± 37.54	673.71 ± 78.90	884.23 ± 66.94	1155.25 ± 56.34	418.09 ± 27.05	649.84 ± 33.30	102.83 ± 6.17
Fitted ttbar events	63.16 ± 4.31	60.51 ± 5.44	593.15 ± 47.71	242.44 ± 17.82	35.30 ± 2.94	388.61 ± 26.18	44.49 ± 3.53
Fitted singletop events	14.62 ± 1.11	13.95 ± 1.72	105.64 ± 13.90	109.56 ± 8.18	23.33 ± 1.91	182.78 ± 15.42	29.62 ± 3.23
Fitted wjets events	$0.77^{+1.11}_{-0.77}$	523.53 ± 71.63	156.35 ± 27.88	602.33 ± 36.69	258.33 ± 17.21	52.98 ± 4.96	18.85 ± 1.72
Fitted zjets events	17.51 ± 2.17	7.27 ± 2.33	3.10 ± 1.16	6.46 ± 1.09	0.70 ± 0.15	1.31 ± 0.41	$0.01^{+0.02}_{-0.01}$
Fitted diboson2l events	225.14 ± 37.73	14.94 ± 2.93	2.14 ± 0.52	14.04 ± 2.35	2.94 ± 0.50	1.09 ± 0.22	0.15 ± 0.03
Fitted diboson1l events	0.01 ± 0.00	49.68 ± 5.43	14.10 ± 2.24	165.72 ± 19.14	91.68 ± 8.80	16.37 ± 3.75	7.91 ± 1.99
Fitted diboson0l events	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Fitted multiboson events	1.02 ± 0.24	0.05 ± 0.02	0.00 ± 0.00	0.03 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Fitted tth events	0.11 ± 0.02	0.04 ± 0.01	0.40 ± 0.05	0.08 ± 0.02	0.01 ± 0.00	0.20 ± 0.03	0.02 ± 0.01
Fitted ttv events	1.62 ± 0.26	1.06 ± 0.21	6.61 ± 0.87	1.70 ± 0.26	0.28 ± 0.11	4.14 ± 0.62	0.41 ± 0.10
Fitted vh events	6.91 ± 0.90	2.67 ± 0.53	2.74 ± 0.57	12.89 ± 1.17	5.52 ± 0.67	2.37 ± 0.85	1.36 ± 0.13
MC exp. SM events	363.65 ± 10.45	619.32 ± 99.21	1006.09 ± 134.76	1295.77 ± 57.57	448.26 ± 23.57	835.88 ± 41.63	124.13 ± 7.87
MC exp. ttbar events	94.03 ± 4.25	84.08 ± 8.33	763.90 ± 99.93	359.80 ± 19.68	53.91 ± 3.32	578.11 ± 26.50	63.88 ± 4.89
MC exp. singletop events	14.75 ± 1.14	12.92 ± 1.84	86.14 ± 15.55	112.78 ± 9.09	23.50 ± 1.93	179.68 ± 15.09	28.04 ± 3.21
MC exp. wjets events	$2.59^{+4.19}_{-2.59}$	455.97 ± 84.19	131.36 ± 25.39	632.84 ± 33.68	270.49 ± 13.75	54.99 ± 5.02	20.90 ± 2.02
MC exp. zjets events	16.28 ± 2.29	5.49 ± 2.20	2.14 ± 0.94	7.08 ± 1.20	0.74 ± 0.15	1.06 ± 0.36	$0.12^{+0.19}_{-0.12}$
MC exp. diboson2l events	227.33 ± 5.96	13.39 ± 1.29	1.86 ± 0.36	13.68 ± 0.60	2.98 ± 0.15	1.07 ± 0.12	0.15 ± 0.02
MC exp. diboson1l events	0.01 ± 0.00	43.25 ± 6.62	11.47 ± 2.58	154.32 ± 20.64	91.08 ± 8.12	14.02 ± 3.80	9.22 ± 2.27
MC exp. diboson0l events	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
MC exp. multiboson events	0.95 ± 0.23	0.06 ± 0.02	0.00 ± 0.00	0.05 ± 0.03	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
MC exp. tth events	0.10 ± 0.02	0.03 ± 0.01	0.36 ± 0.05	0.08 ± 0.02	0.01 ± 0.00	0.22 ± 0.04	0.02 ± 0.01
MC exp. ttv events	1.65 ± 0.26	1.03 ± 0.21	6.59 ± 0.87	1.84 ± 0.30	0.25 ± 0.10	4.04 ± 0.62	0.45 ± 0.11
MC exp. vh events	5.96 ± 1.04	3.08 ± 0.58	2.26 ± 0.60	13.30 ± 1.27	5.30 ± 0.64	2.67 ± 1.00	1.34 ± 0.15

bgk-only fit results

Yieldstable in SRs



SR channel	SRLMresolvedEM	SRHMresolvedEM	SRLMboostedWZEM	SRMMboostedWZEM	SRHMboostedWZEM
Observed events	585	192	19	18	3
Fitted bkg events	541.80 ± 62.87	202.80 ± 68.78	19.56 ± 2.56	11.05 ± 7.17	2.89 ± 0.97
Fitted ttbar events	48.14 ± 5.11	8.27 ± 2.40	1.58 ± 0.28	0.76 ± 0.16	0.12 ± 0.04
Fitted singletop events	9.03 ± 1.52	3.71 ± 2.18	0.59 ± 0.13	0.76 ± 0.24	0.44 ± 0.15
Fitted wjets events	396.01 ± 57.14	163.37 ± 62.00	10.54 ± 1.74	$5.09^{+7.10}_{-5.09}$	0.81 ± 0.39
Fitted zjets events	12.89 ± 6.49	$7.78^{+10.42}_{-7.78}$	0.72 ± 0.23	0.00 ± 0.00	0.12 ± 0.10
Fitted diboson2l events	33.83 ± 6.82	10.21 ± 3.30	1.37 ± 0.45	1.58 ± 0.36	0.47 ± 0.17
Fitted diboson1l events	37.26 ± 4.09	8.46 ± 2.29	3.81 ± 0.53	2.30 ± 0.42	0.75 ± 0.24
Fitted diboson0l events	0.19 ± 0.03	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Fitted multiboson events	0.15 ± 0.04	$0.01^{+0.01}_{-0.01}$	0.02 ± 0.02	0.02 ± 0.01	0.01 ± 0.01
Fitted tth events	0.09 ± 0.02	0.02 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.00 ± 0.00
Fitted ttv events	2.41 ± 0.39	0.54 ± 0.17	0.90 ± 0.19	0.53 ± 0.13	0.18 ± 0.07
Fitted vh events	1.78 ± 0.46	0.44 ± 0.26	0.02 ± 0.00	0.01 ± 0.00	0.00 ± 0.00
MC exp. SM events	585.25 ± 62.61	192.88 ± 67.64	19.70 ± 2.55	18.02 ± 17.13	3.38 ± 1.18
MC exp. ttbar events	72.21 ± 6.73	11.95 ± 3.44	1.90 ± 0.44	1.18 ± 0.23	0.15 ± 0.06
MC exp. singletop events	8.27 ± 1.59	2.29 ± 1.54	0.68 ± 0.16	1.01 ± 0.36	0.46 ± 0.16
MC exp. wjets events	425.51 ± 57.30	155.97 ± 61.09	10.49 ± 1.65	$11.39^{+17.05}_{-11.39}$	1.22 ± 0.61
MC exp. zjets events	7.44 ± 5.03	$2.90^{+4.46}_{-2.90}$	0.53 ± 0.22	0.00 ± 0.00	0.12 ± 0.10
MC exp. diboson2l events	31.97 ± 3.27	10.46 ± 2.79	1.52 ± 0.37	1.61 ± 0.27	0.47 ± 0.16
MC exp. diboson1l events	35.16 ± 4.10	8.37 ± 2.25	3.64 ± 0.52	2.30 ± 0.41	0.74 ± 0.24
MC exp. diboson0l events	0.19 ± 0.03	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
MC exp. multiboson events	0.16 ± 0.04	$0.04^{+0.05}_{-0.04}$	$0.02^{+0.02}_{-0.02}$	0.01 ± 0.01	$0.01^{+0.01}_{-0.01}$
MC exp. tth events	0.09 ± 0.02	0.02 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.00 ± 0.00
MC exp. ttv events	2.62 ± 0.43	0.53 ± 0.17	0.88 ± 0.18	0.50 ± 0.12	0.20 ± 0.08
MC exp. vh events	1.63 ± 0.44	0.36 ± 0.24	0.02 ± 0.00	0.00 ± 0.00	0.00 ± 0.00