Searches for squarks and gluinos in two lepton final states with the ATLAS detector

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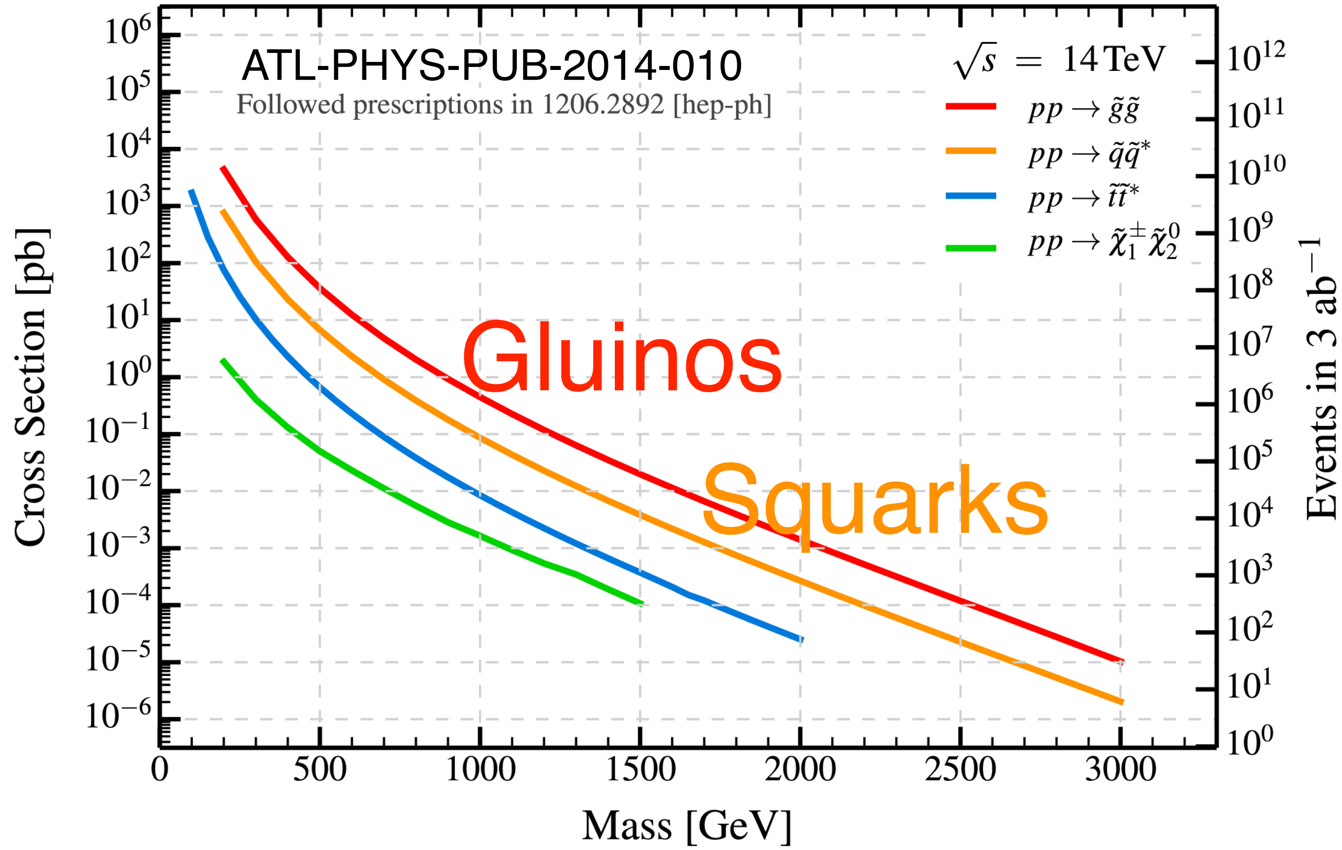
On behalf of the ATLAS Collaboration



- SUSY searches for squark/gluino final states are very attractive
  - High production cross section → good discovery potential with smaller amount of data
- ATLAS has a broad inclusive squark/gluino search strategy
  - 0L, 2-6 jets; 0L, ≥7 jets; 1L+jets; SS dilepton, ...
- **2L searches presented here**
  - **2L Razor analysis (http://arxiv.org/abs/1501.03555 - Jan 2015, JHEP)**
  - **Z+MET and dilepton edge analyses (http://arxiv.org/abs/1503.03290 - Mar 2015, Eur. Phys. J. C)**
- Probe simplified models with 2-step decays; gauge mediated supersymmetry-breaking models (GMSB), mUED models

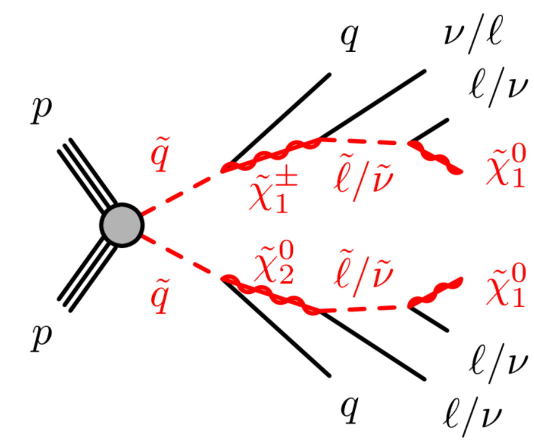
2L Razor Search

2L Razor - Models, Signal Region

1. Test simplified models
   - "Two-step" decays via intermediate sleptons/sneutrinos
   - Assume mass-degenerate sleptons/sneutrinos; mass-degenerate $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^0$
2. Test Minimal Universal Extra Dimensions (mUED) models
   - Combine 2L search with a search using 2 soft muons
   - Parameters: Compactification radius R_C, cutoff scale Λ, m_h=125 GeV

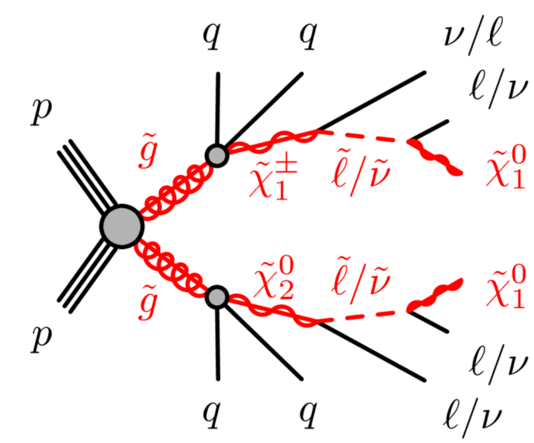
Signal Region Highlights

- Define 2 types of signal region:
  - **"Low-multiplicity" of jets - ≤2 jets**
  - **"High-multiplicity" of jets - ≥3 jets**
- ==2 or ≥2 leptons, depending on the model in question
- Veto events with b-tagged jets to suppress ttbar bkg
- Veto leptons with $81 < m_{ll} < 101$ GeV consistent with a Z-boson
- Define jets as having p_T>50 GeV
- Main discriminating variables: **Razor Variables** (next slide)



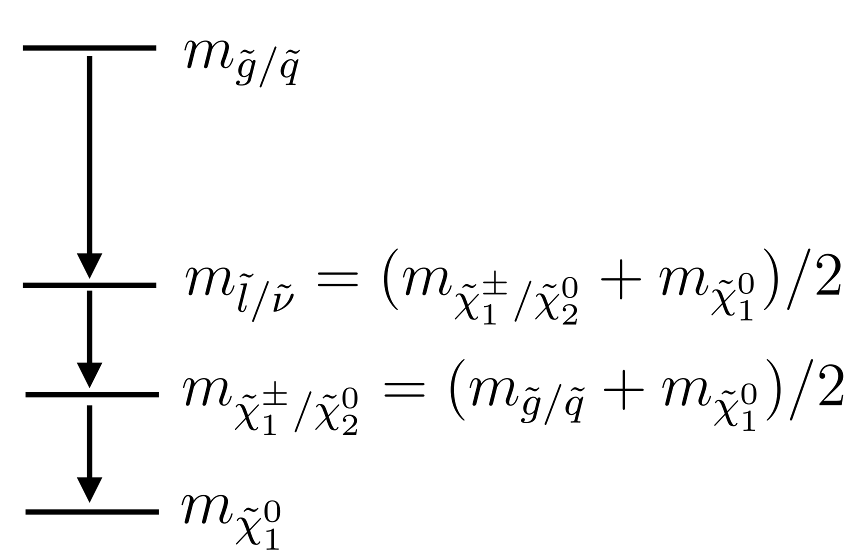
Squarks

low-multiplicity

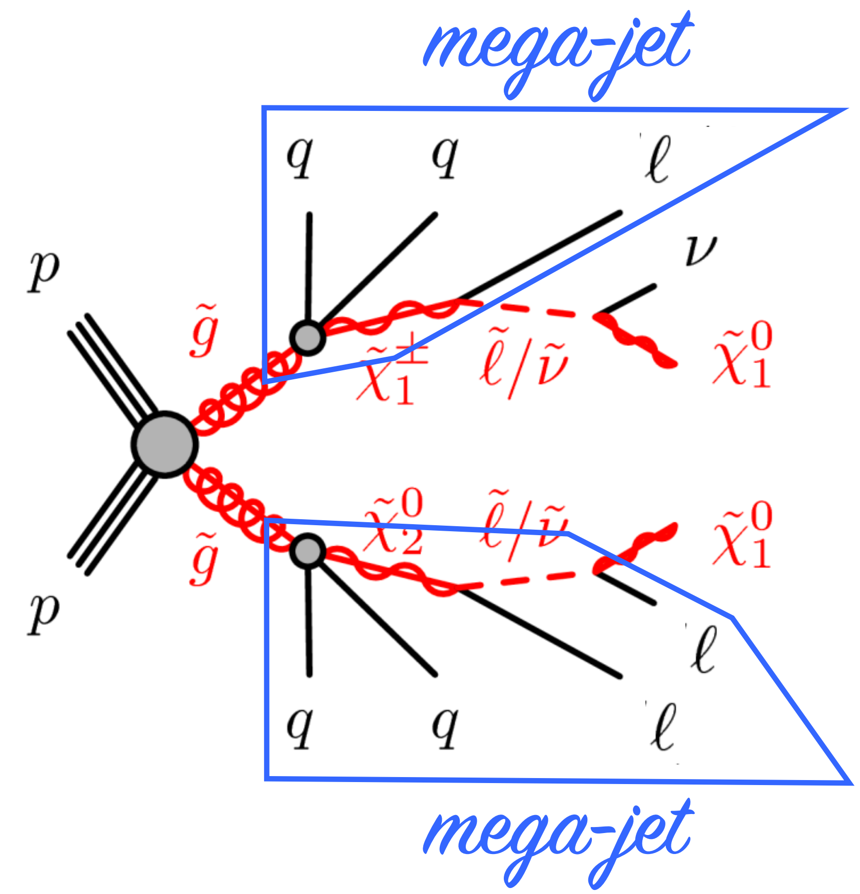


Gluinos

high-multiplicity



Main discriminating variables: Razor



- Method applies to pair-produced sparticles
- Construct 2 "mega-jets" using all visible decay products
    - Resolve ambiguities by minimizing sum of squared masses of the mega-jets
- M'_R: Energy of 2 mega-jets, boosted to the sparticle rest frame
    - E.g. ttbar should peak at ttbar mass
- M_{T}^R : Transverse mass (adds E_{TMiss} information from LSP/neutrinos)
    - Assign 1/2 the E_{TMiss} to each mega-jet
    - Mis-measured jets should have E_{TMiss} opposite to mega-jet, driving M_{T}^R toward 0
- $R = M_T^R / M'_R$ (> 0.5, low-multiplicity; > 0.35, high-multiplicity)
    - Sparticles should have a flat distribution, compared to falling distributions for SM backgrounds
- 2L analysis considers a binned signal region in M'_R as well as a single bin region

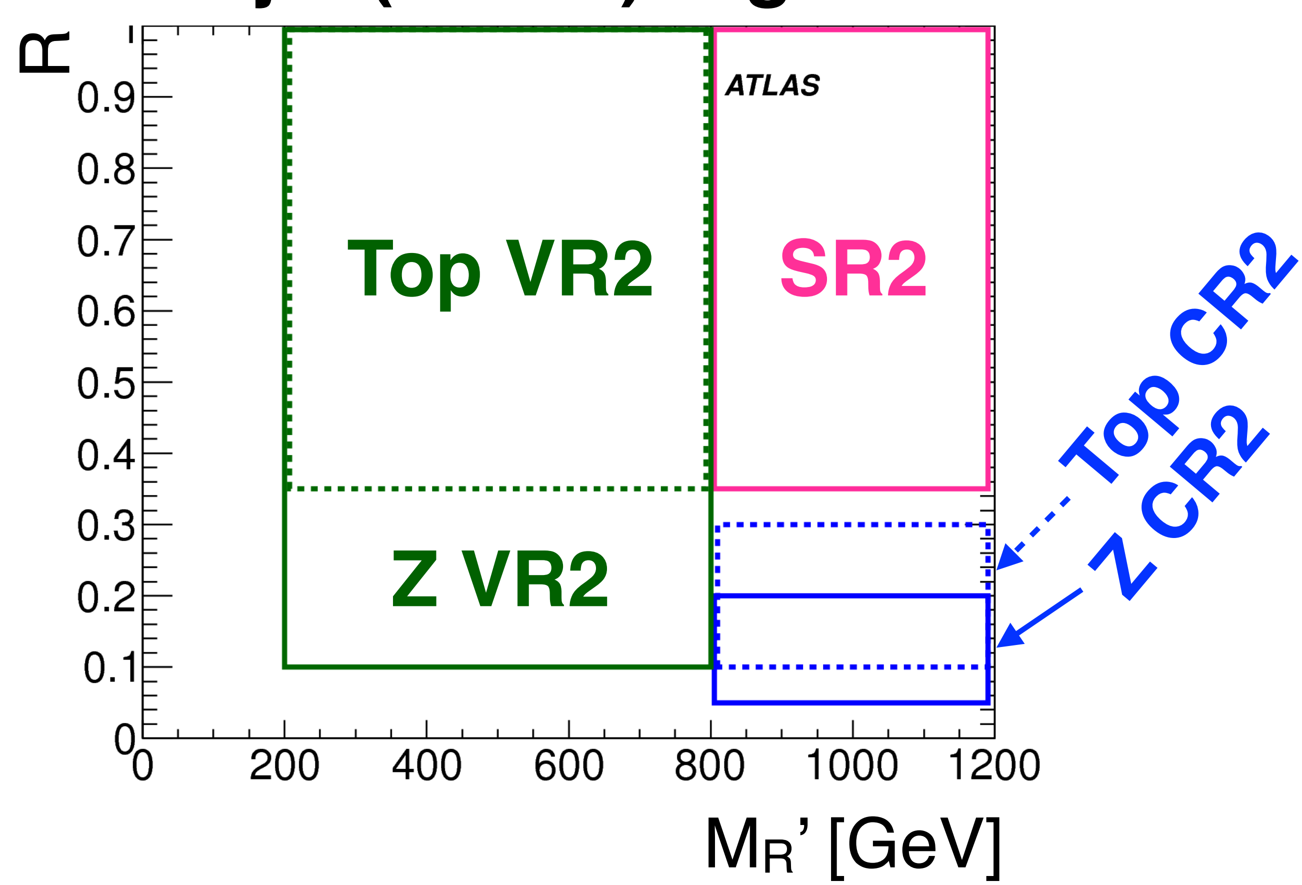
2L Razor Background Estimation

Bkg	<=2 jet SR Contribution	≥3 jet SR Contribution	Est. Method
ttbar	30-40%	50%	Control Region
Diboson	30-40%	10-15%	MC
W+jet/ttbar fakes	<10%	10-15%	Matrix Method
Z+jets	10-20%	10-15%	Control Region
t,tV,ttV,ttVV	<10%	10-15%	MC

*from single-binned ee/μμ post-fit results

- Backgrounds from Z+jets, ttbar constrained in **control regions**
  - Top CRs/VRs require a b-tag in right plot
  - Z CRs/VRs have b-veto in right plot
- Fake leptons from W+jet/ttbar evaluated using **Matrix Method**
- Diboson, other top backgrounds taken from MC simulation
- **Global fit** of CRs using profile likelihood method
- Background fits cross-checked in **validation regions**

≥3 jet ("SR2")Regions



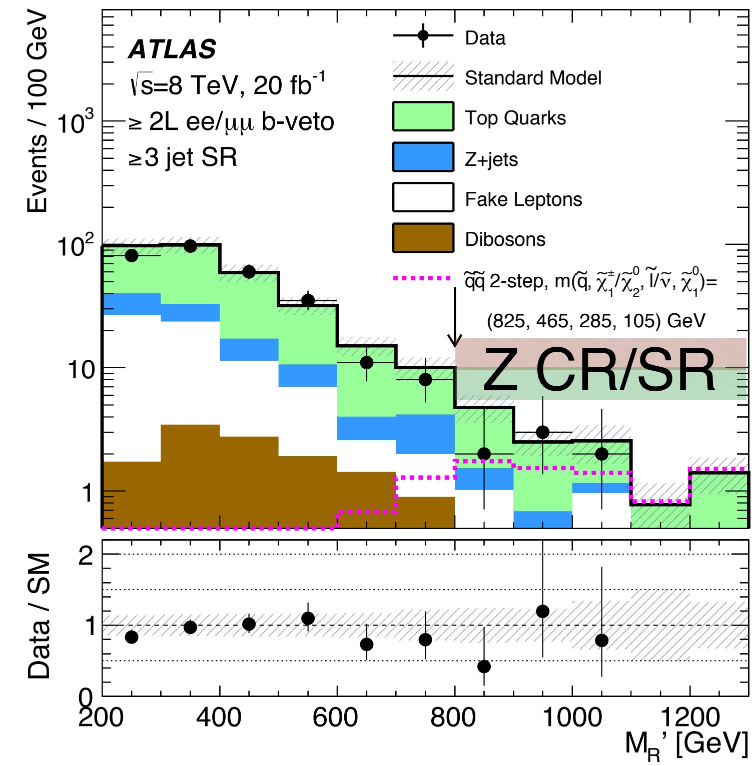
SR Plots, ee/μμ

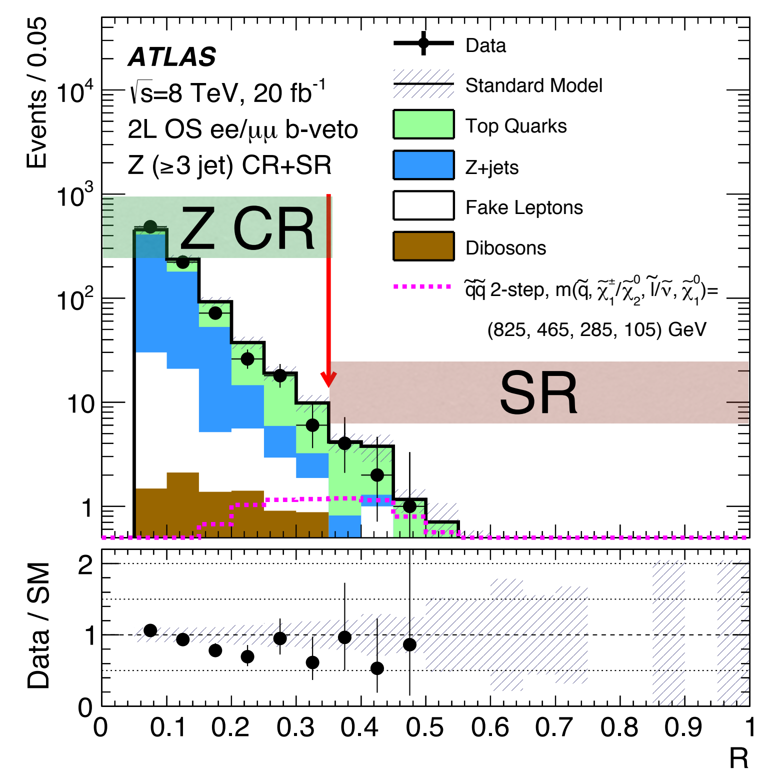
- Table shows single-bin SR yields before/ after background fit
- No excess *wrt* background expectation

Observed

Fitted Bkg

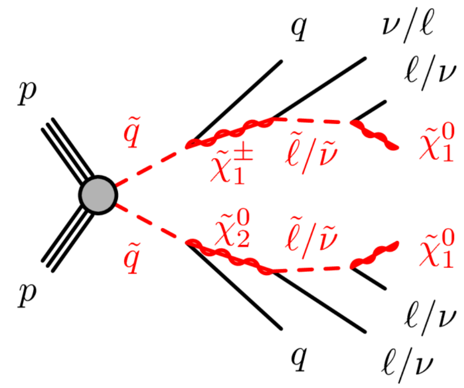
	Low-multiplicity $ee/\mu\mu$ Single-bin	Low-multiplicity $e\mu$ Single-bin	3-jet $ee/\mu\mu$	3-jet $e\mu$
Observed events	20	18	7	10
Fitted background events	20.0 ± 3.3	24 ± 4	11.8 ± 2.6	11.5 ± 2.0
$t\bar{t}$	6.7 ± 1.3	7.7 ± 1.5	5.9 ± 1.5	7.0 ± 1.6
Other top quarks	1.7 ± 0.7	2.1 ± 0.7	1.7 ± 0.3	1.4 ± 0.3
Diboson	7.4 ± 2.4	8.5 ± 2.6	1.3 ± 0.2	1.0 ± 0.3
Z+jets	2.6 ± 0.4	2.8 ± 1.4	1.3 ± 0.3	1.4 ± 0.4
Fake leptons	1.6 ± 1.4	3.2 ± 2.1	$1.5^{+2.0}_{-1.5}$	$0.6^{+0.9}_{-0.6}$
Expected background events before the fit	20.1	25	14.6	14.2
$t\bar{t}$	6.2	6.8	8.4	9.4
Other top quarks	1.5	2.1	1.8	1.4
Diboson	7.4	9.0	1.3	1.1
Z+jets	3.3	4.1	1.6	1.6
Fake leptons	1.6	3.2	1.5	0.6

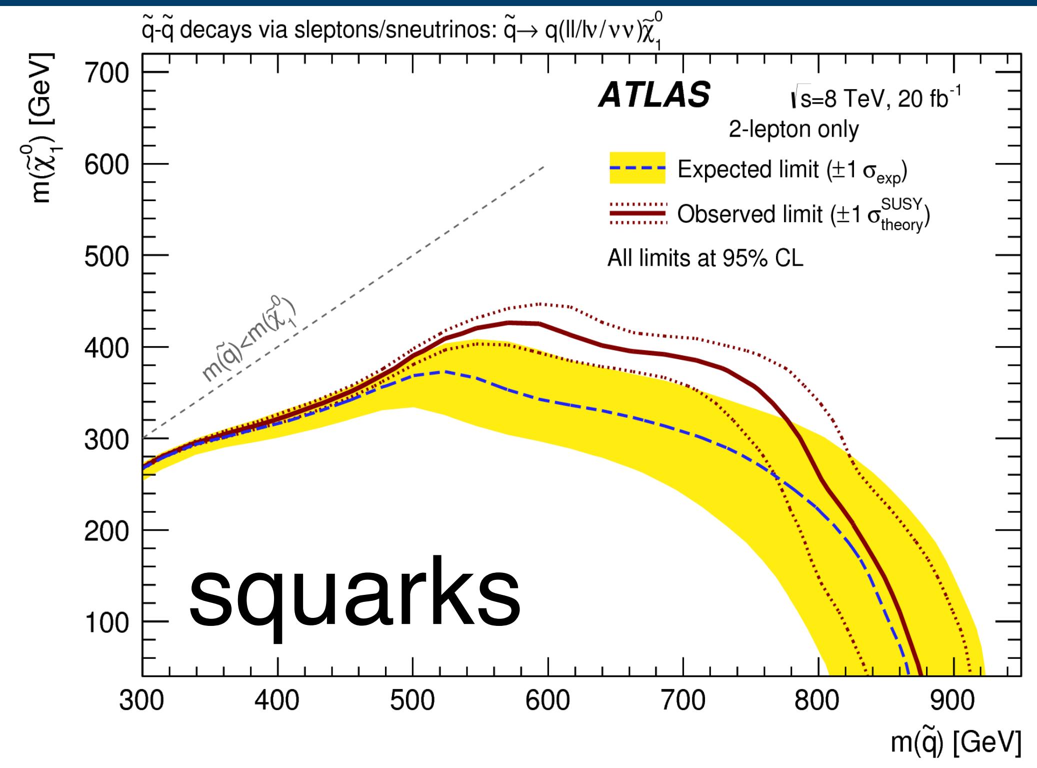


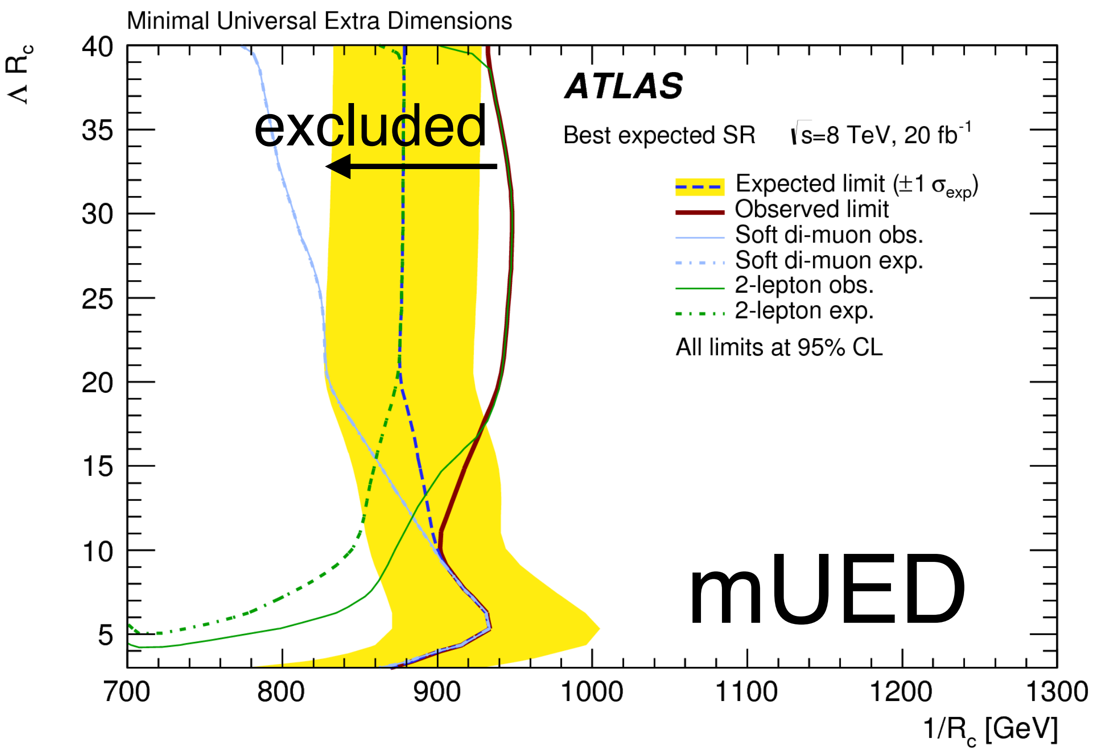


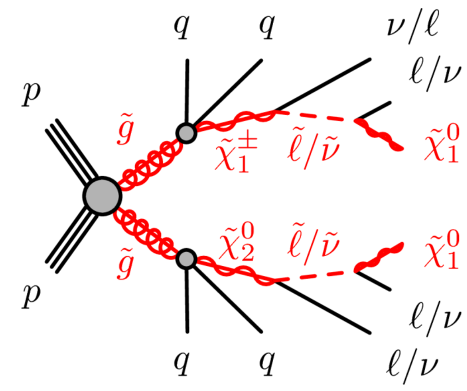
Interpretation and Limit Setting

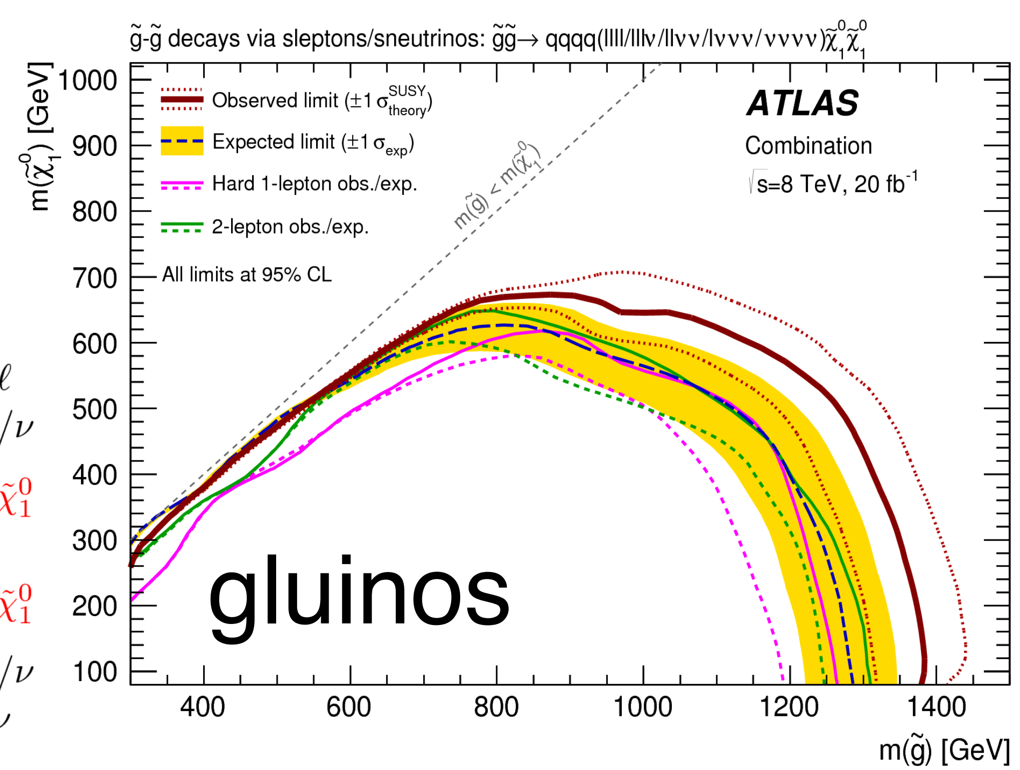
- Limits on two-step gluino/squark simplified model with sleptons
  - gluino(squark)-LSP plane
- Combining with statistically-independent 1-Lepton channel increases sensitivity (gluinos)
- Also set limits on mUED model
- Results from 2L Razor and a soft dimuon channel
  - Each point taken from better expected limit of the two analyses (overlapping signal regions)







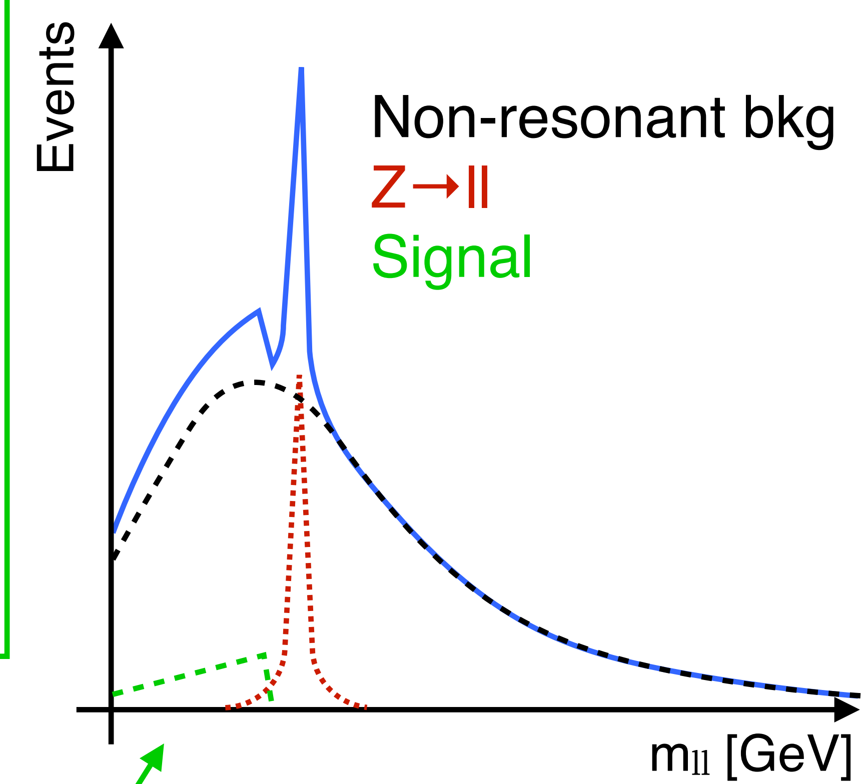




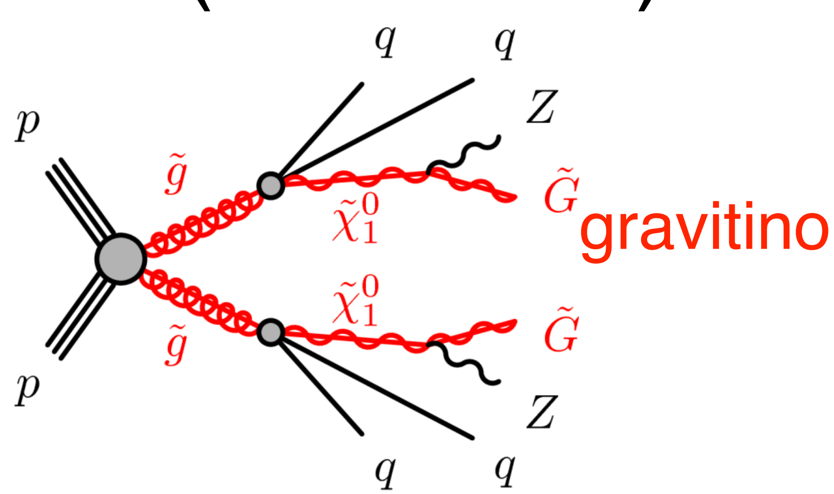
Z+MET, 2L Edge

2L Z+MET / Edge analysis Overview

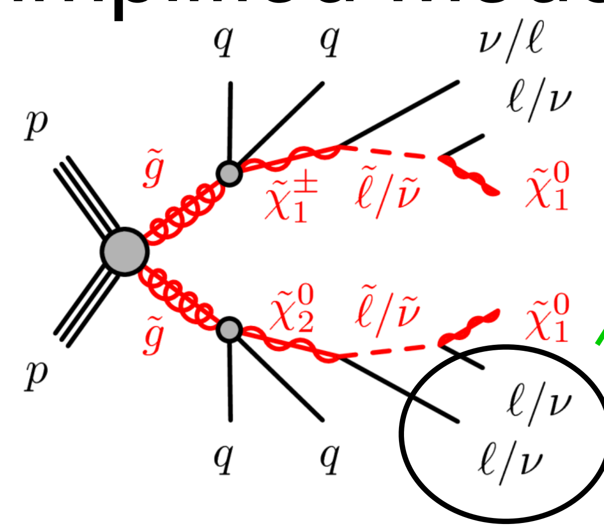
- **"On-Z" (Z+MET)** targets generalized gauge-mediated SUSY-breaking model (GGM)
  - gravitino (G) LSP
  - Two values of tanβ used to vary $\chi^0_1 \rightarrow ZG$ branching ratio (tanβ=1.5, 30)
- **"Off-Z" (Edge)** targets simplified model:
  - "Two-step" decays via intermediate sleptons/sneutrinos
  - Same mass hierarchy as in 2L Razor case
  - Leptons from $\tilde{\chi}^0_2$ have a characteristic kinematic edge in m_{ll}
  - Look for an edge above or below the Z-peak



GGM (on-shell Z)



Simplified Model



kinematic edge $m_{\max} \approx m(\tilde{\chi}^0_2) - m(\tilde{\chi}^0_1)$

Signal Regions

On-Z SR Highlights

- Require a $81<m_{ll}<101$ GeV SF dilepton pair
- Require large E_{TMiss} and H_T
  - $E_{TMiss} > 225$ GeV
  - $H_T > 600$ GeV
  - H_T includes p_T of all jets plus 2 leading leptons
- njets ≥ 2
- No b-jet requirement
- Additional requirement on $\Delta\phi(\text{jet}_{1,2}, E_{\text{T}}^{\text{miss}})$ to suppress fake MET from mismeasured jets
  - $\Delta\phi(\text{jet}_{1,2}, E_{\text{T}}^{\text{miss}}) > 0.4$

Off-Z SR Highlights

- Exclude $80<m_{ll}<110$ GeV SF dilepton pairs
- Require $E_{TMiss}>200$ GeV
- Split into jet multiplicity / btag regions:
  - **Bins of 2-jets, 4-jets**
  - **Bins of b-tag, b-veto**
  - **4 jet-binned regions total**
- Additional "Loose" regions:
  - **2 jets, $E_{TMiss}>150$ GeV**
  - **>2 jets, $E_{TMiss}>100$ GeV**
  - No b-tag requirements
  - Developed to match CMS search with excess (http://arxiv.org/abs/1502.06031)
- Raise lepton thresholds wrt On-Z analysis: $p_{T,leps}>20$ GeV
  - Also raise dilepton mass threshold to 20 GeV

2L Z+MET / Edge Backgrounds

Bkg	On-Z ee+μμ	Off-Z ee+μμ SR-4j-bveto*	Est. Method
flavor-symmetric (ttbar)	50-60%	>90%	eμ control regions
Z+jets	<1%	<5%	jet-smearing (On-Z), CR (off-Z)
Rare top	<5%	<2%	MC
Diboson	20-30%	<2%	MC
Fake leptons	10-20%	<2%	Matrix Method

*Similar fractions for other Off-Z SRs

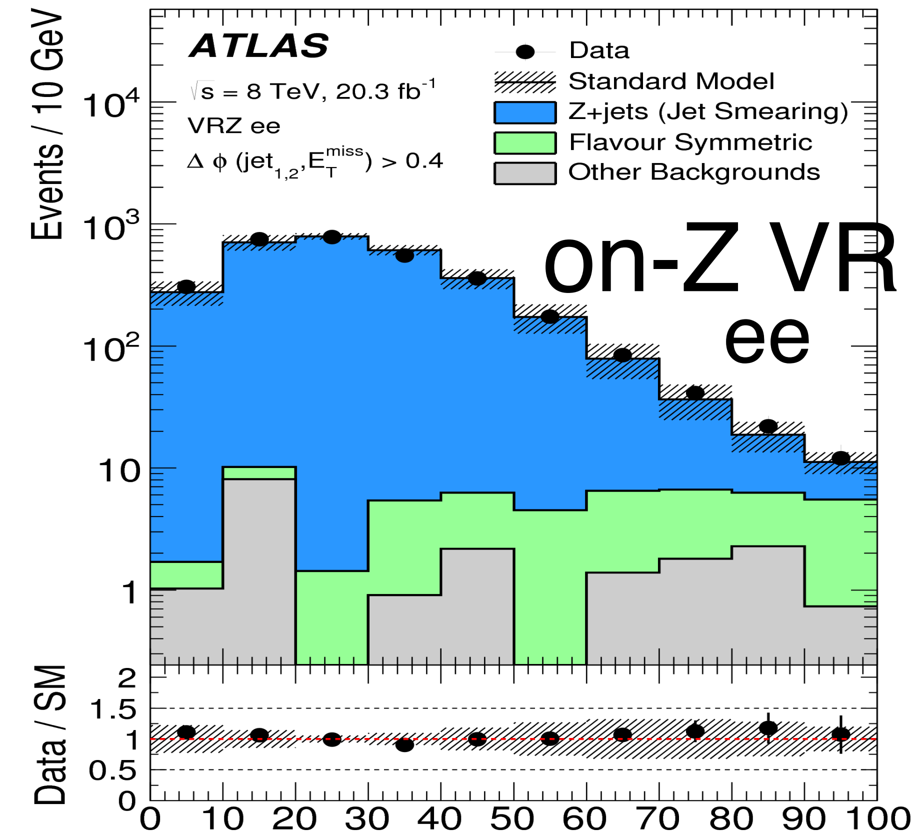
- Largest contribution from flavor-symmetric background
  - **eμ Control Region** estimates this background
- Also want to make sure **Z+jets** background is controlled

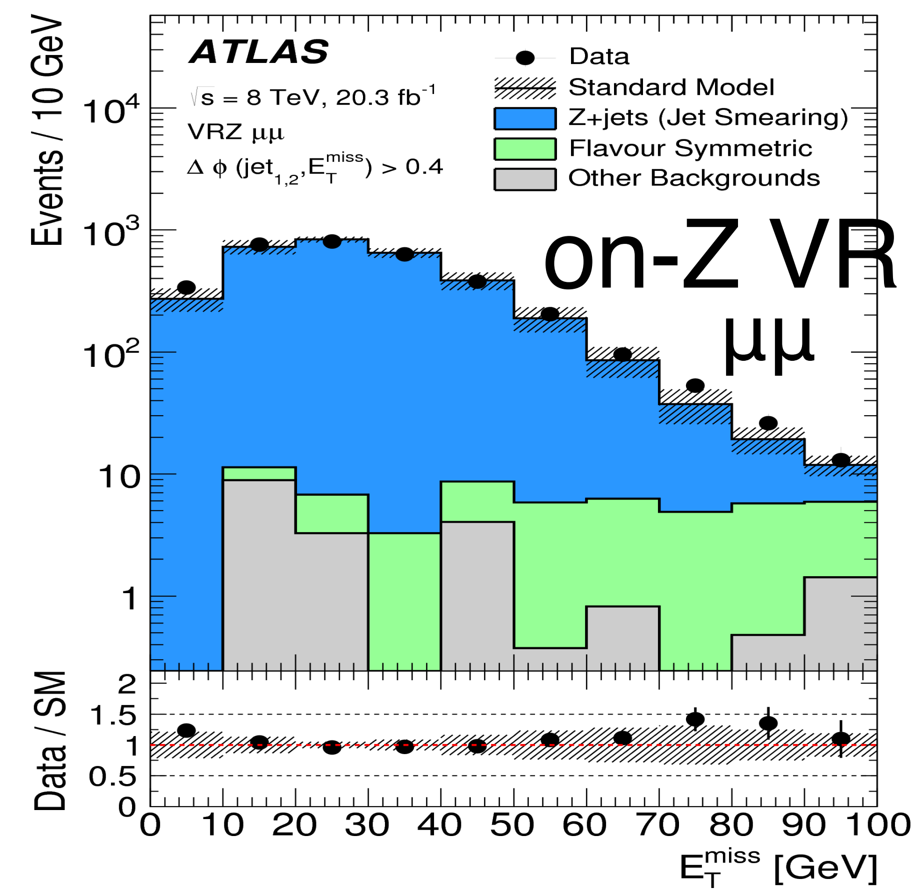
Z+fake MET background

- On-Z:
  - Largest concern is overestimated E_{TMiss} from mismeasured jets
  - Use jet smearing response functions (p_T and ϕ) that have been *tuned to data*
  - Using Z+jets from a “seed” region, apply jet response function and recalculate E_{TMiss}
  - Normalize this “pseudo-data” in low-E_{TMiss} part of VRZ Validation Regions

  - Result: SM Z+MET is negligible in SR:

Signal region	Jet-smearing	Z+jets MC
SR-Z ee	0.05 ± 0.04	0.05 ± 0.03
SR-Z $\mu\mu$	$0.02^{+0.03}_{-0.02}$	0.09 ± 0.05





- Off-Z:
  - Shape templates in region excluding Z-peak window taken from MC
  - Normalized using Z-peak CR, $80<m_{ll}<110$ GeV

Flavor-symmetric background (ttbar)

- **On-Z**: Estimated in eμ control region, extrapolated to ee/μμ signal regions with some correction factors:

$$N_{ee}^{\text{est}} = \frac{1}{2} N_{e\mu}^{\text{data,corr}} k_{ee} \alpha$$

$$k_{ee} = \sqrt{\frac{N_{ee}^{\text{data}}(\text{VRZ})}{N_{\mu\mu}^{\text{data}}(\text{VRZ})}}$$

e/μ selection efficiency correction

$$\alpha = \frac{\sqrt{\epsilon_{\text{trig}}^{ee} \epsilon_{\text{trig}}^{\mu\mu}}}{\epsilon_{\text{trig}}^{e\mu}}$$

trigger correction

- Method using m_{ll} sideband fit result yields compatible results
- **Off-Z**: Process repeated for *i* m_{ll} bins, with a shape correction derived in ttbar MC:

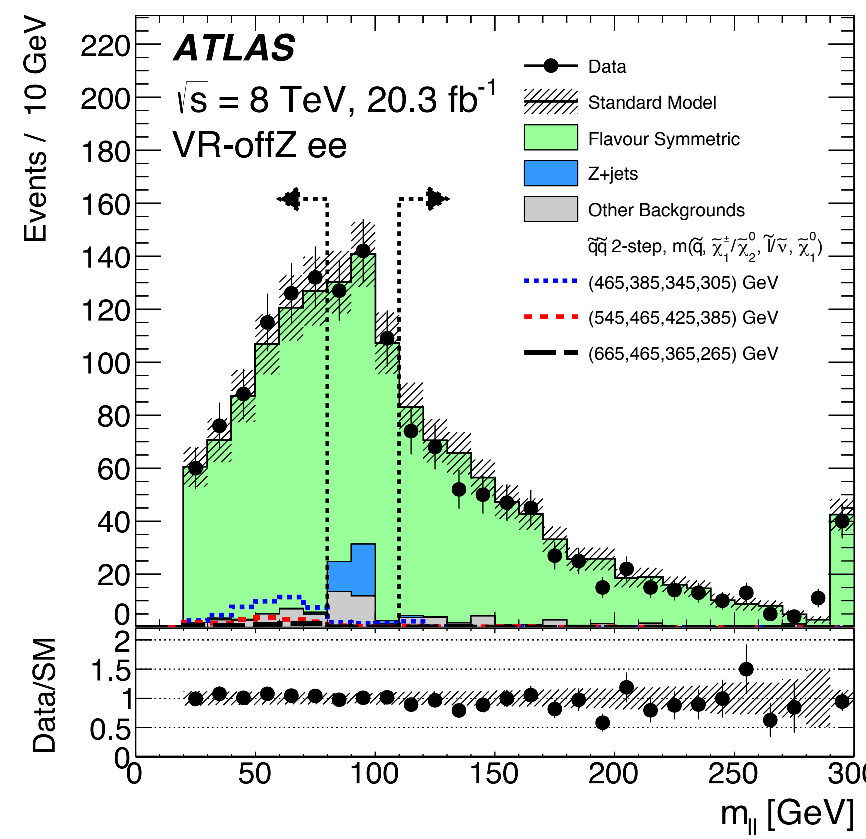
$$N_{ee}^{\text{est}}(i) = \frac{1}{2} N_{e\mu}^{\text{data,corr}}(i) k_{ee} \alpha \underline{S_{ee}(i)}$$

- Result checked in flavor-symmetric dominated validation region (right)

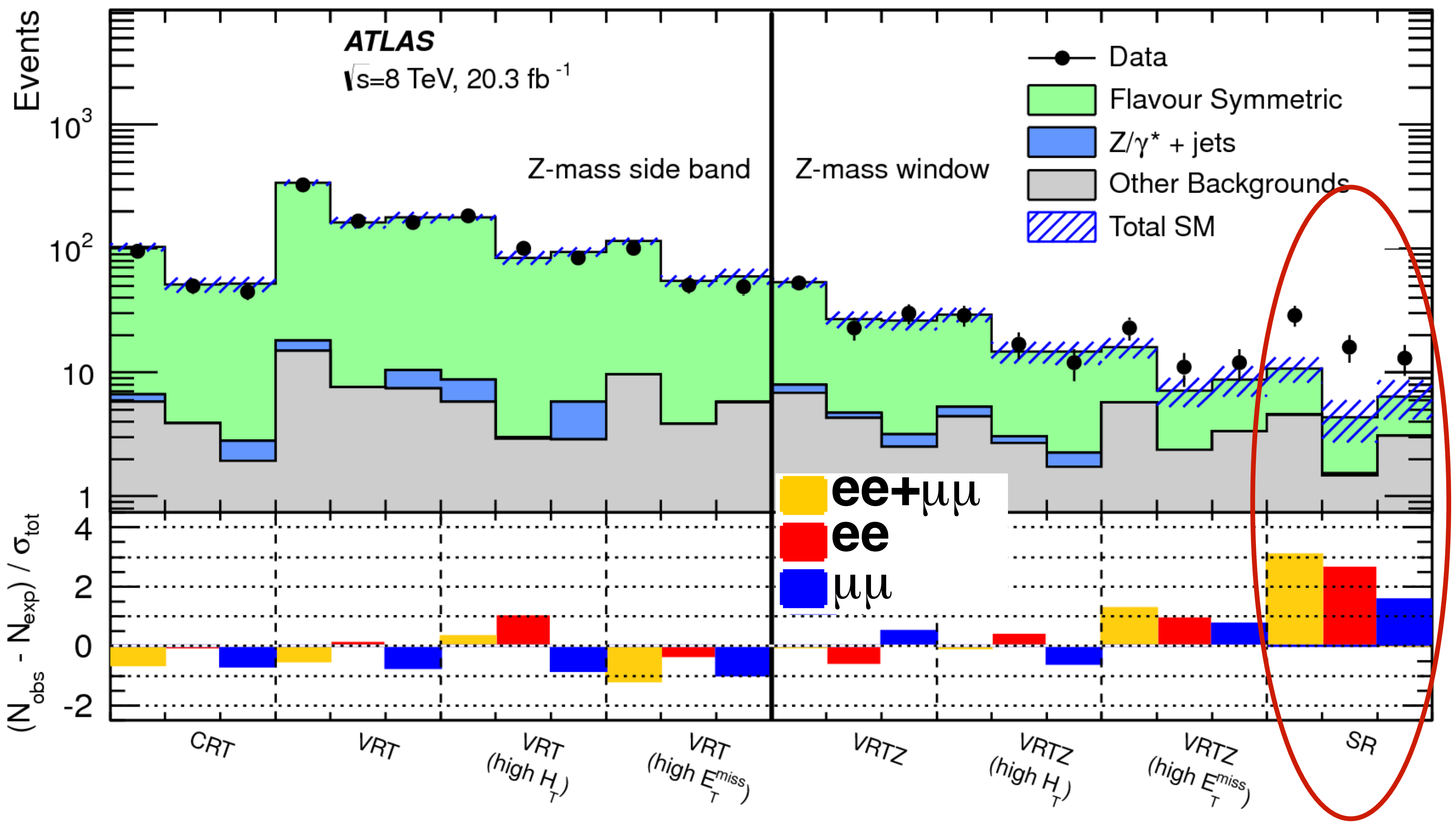
On-Z Cross-check

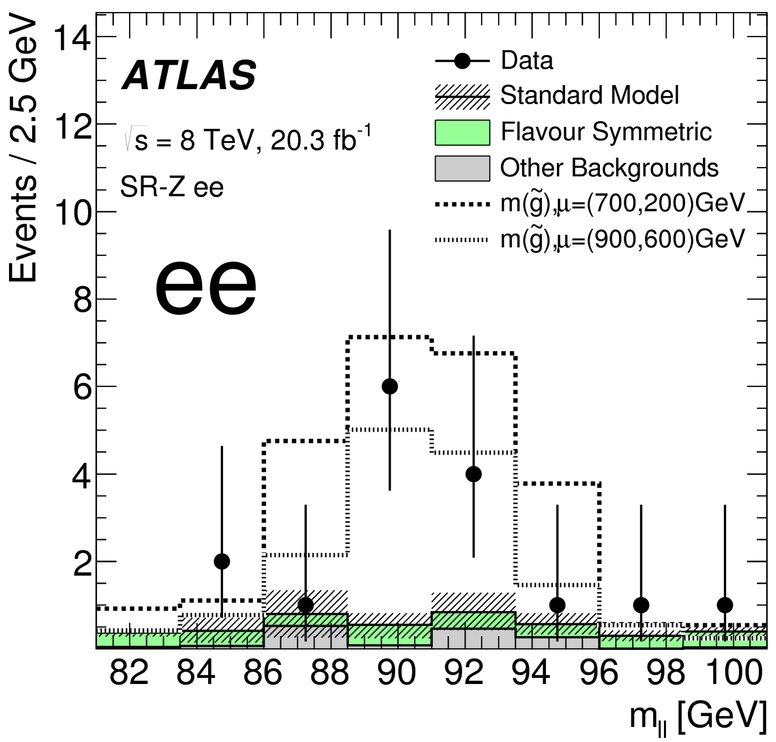
Signal region	Flavour-symmetry	Sideband fit
SR-Z ee	2.8 ± 1.4	4.9 ± 1.5
SR-Z $\mu\mu$	3.3 ± 1.6	5.3 ± 1.9

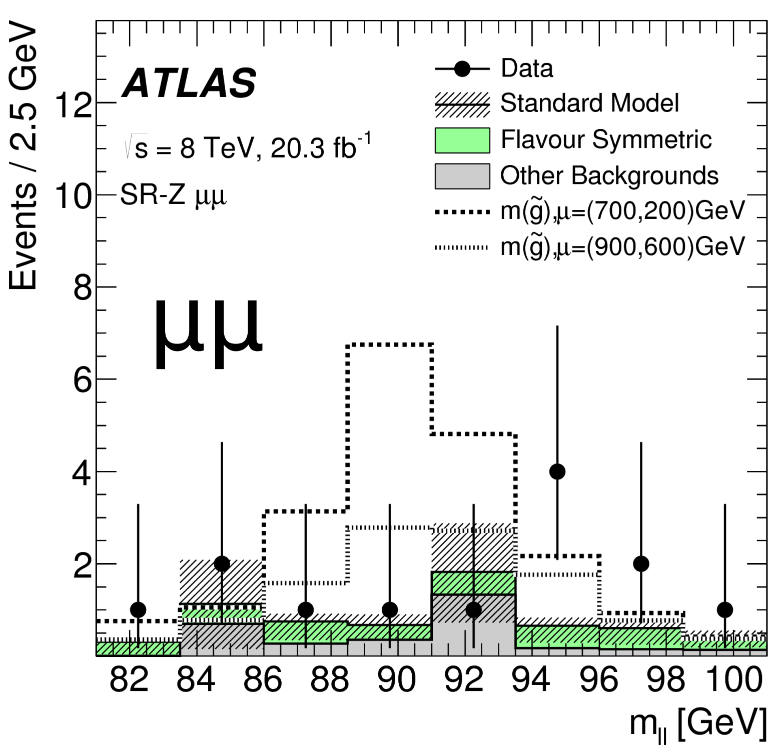
Off-Z VR (ee)



On-Z Analysis: Results



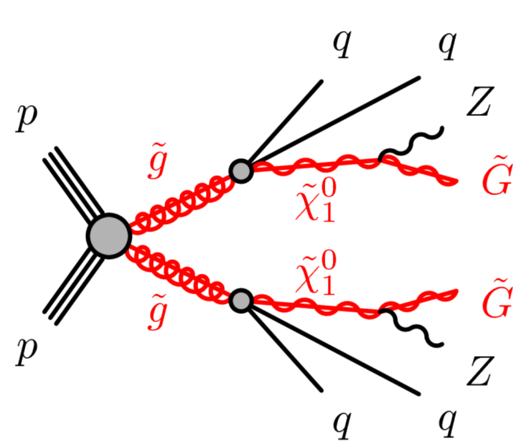


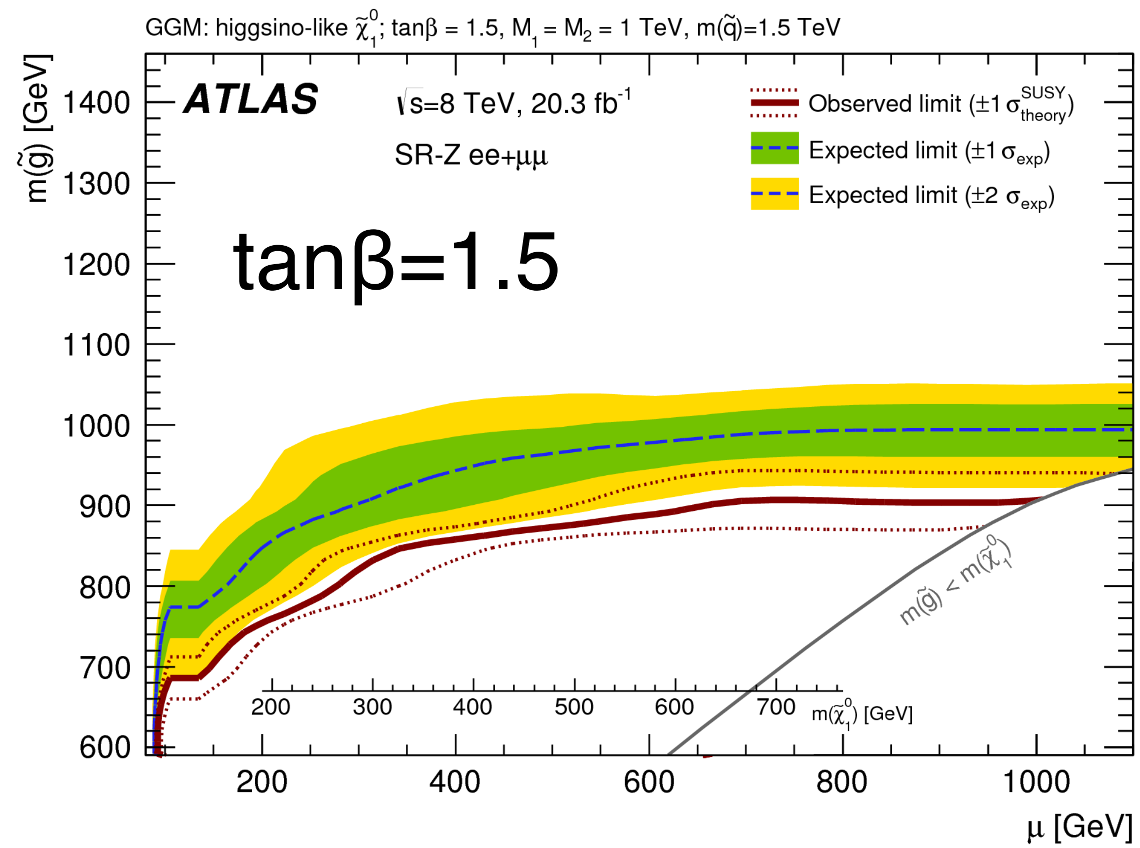


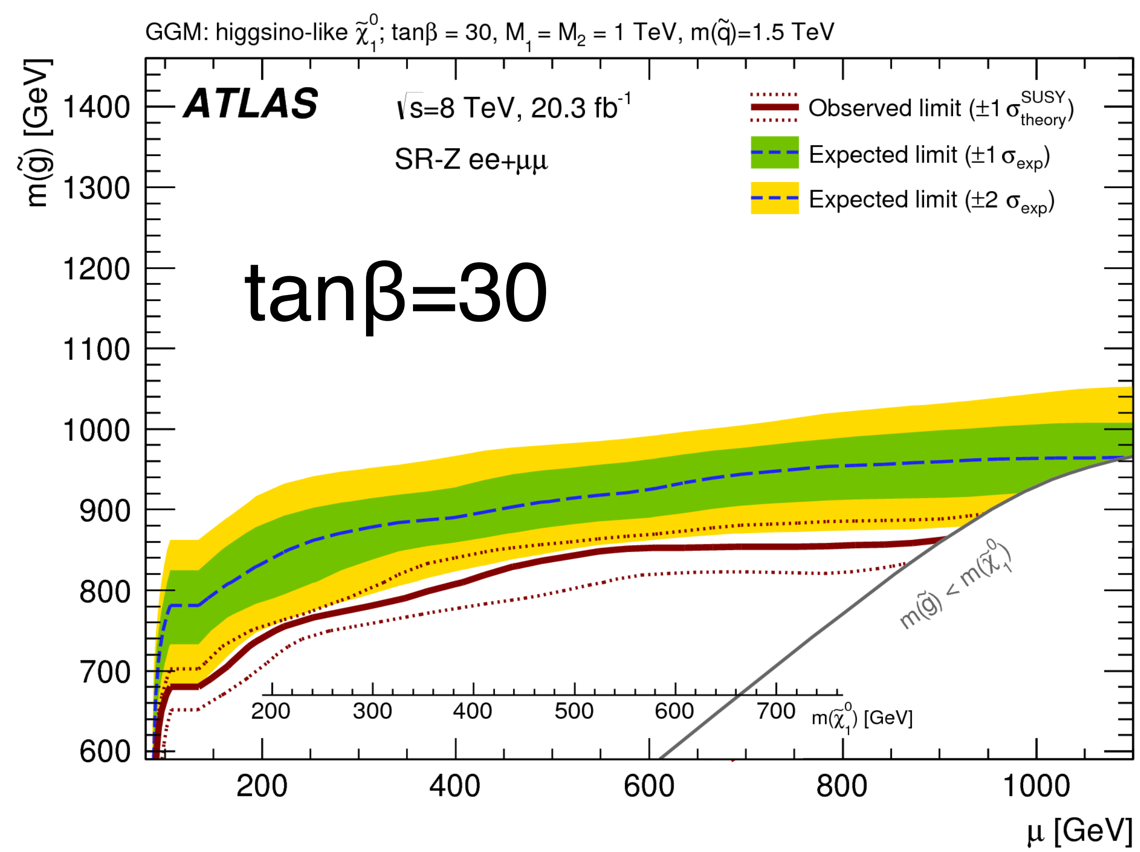
- Good agreement in validation regions
- Excesses in both ee and μμ signal regions
  - Corresponds 3.0σ (ee), 1.7σ (μμ) deviations

On-Z: Interpretation and Limit Setting

- Limits on gauge-mediated SB model
  - Dominant production mode is via gluino pair production
  - LSP is gravitino; $\tilde{\chi}_1^0$ is higgsino
  - Gravitino mass set sufficiently low such that NLSP decays are ~prompt (<2 mm, smaller for large values of μ parameter)
- Limits weak due to excess!

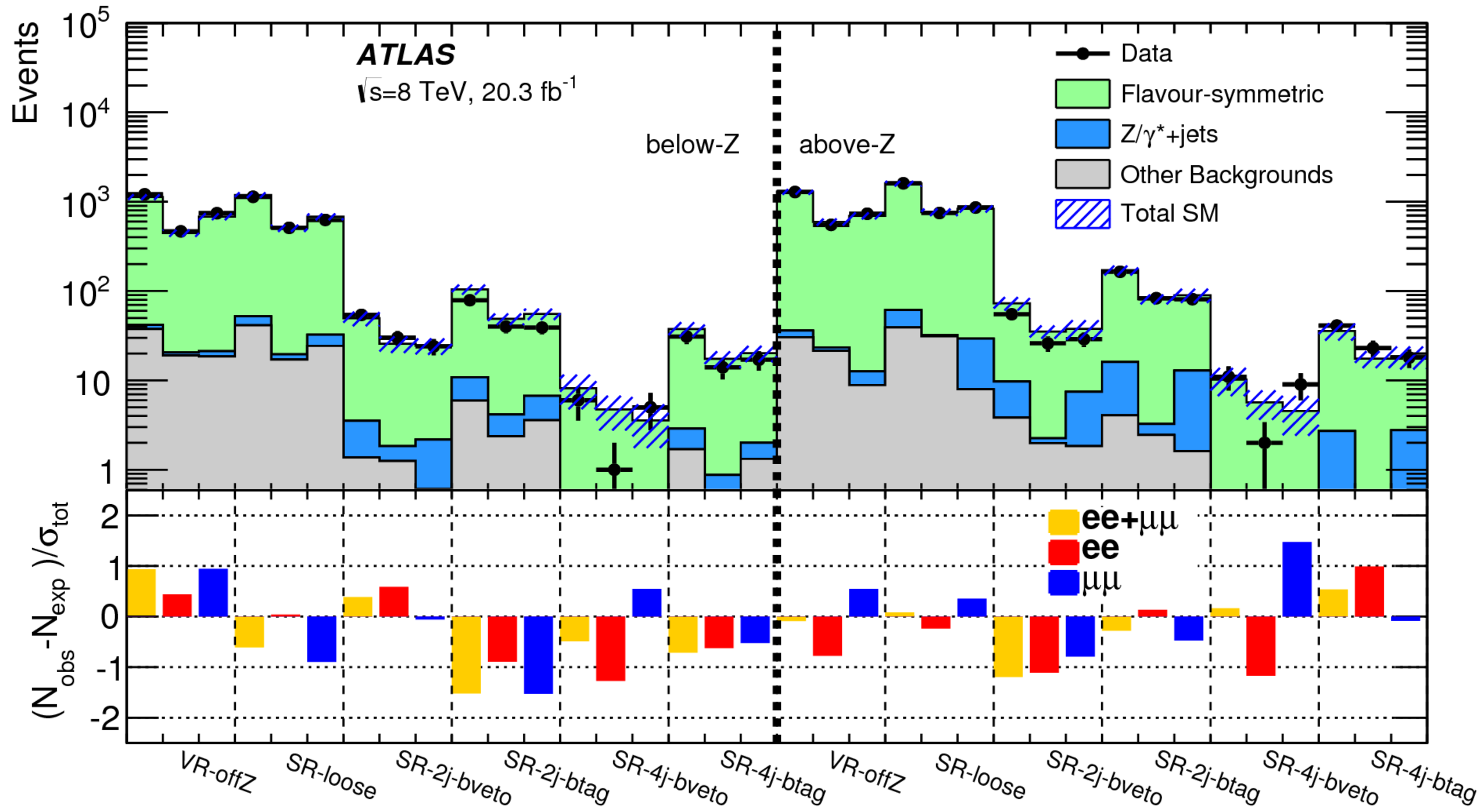




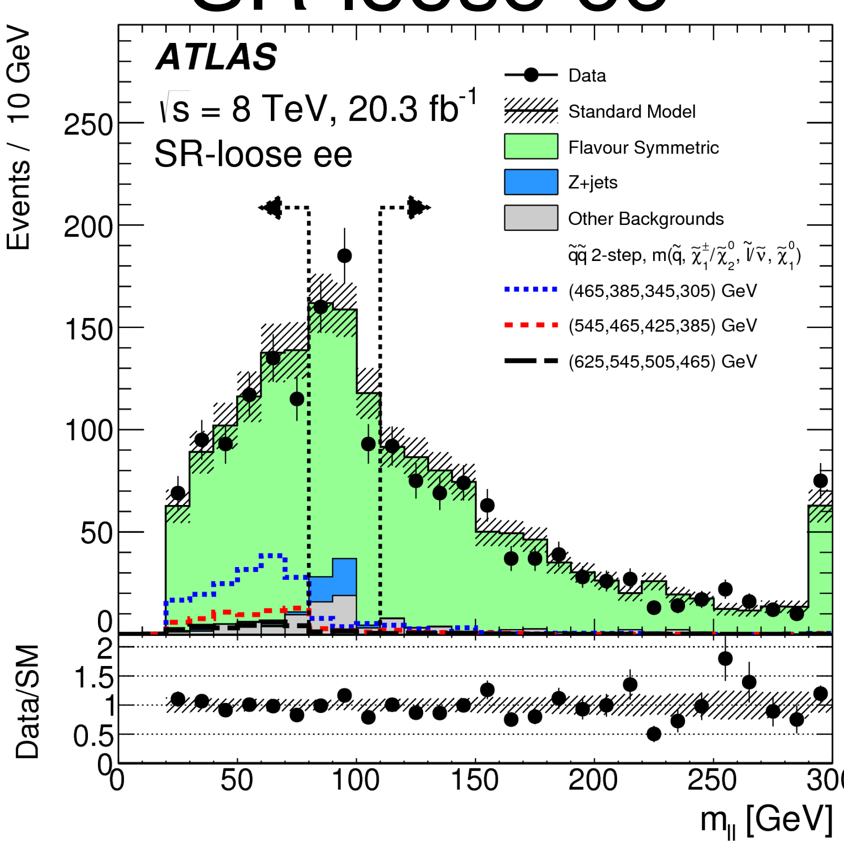


Results: off-Z

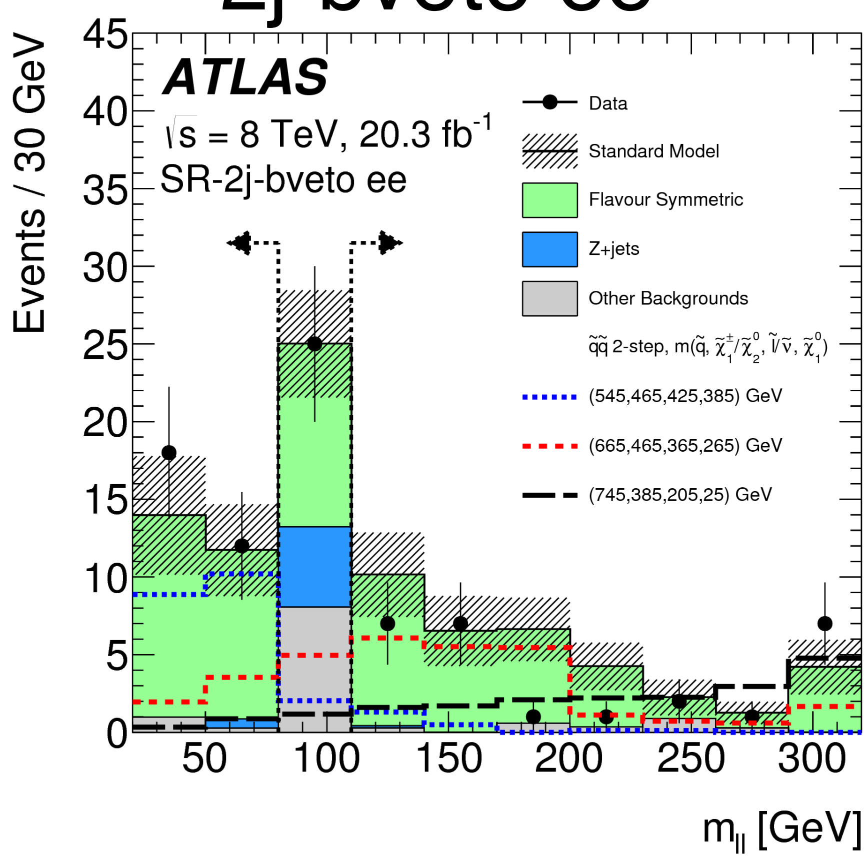
- No significant excesses in SRs
- Do not confirm SR-loose excess seen by CMS (2.6σ)



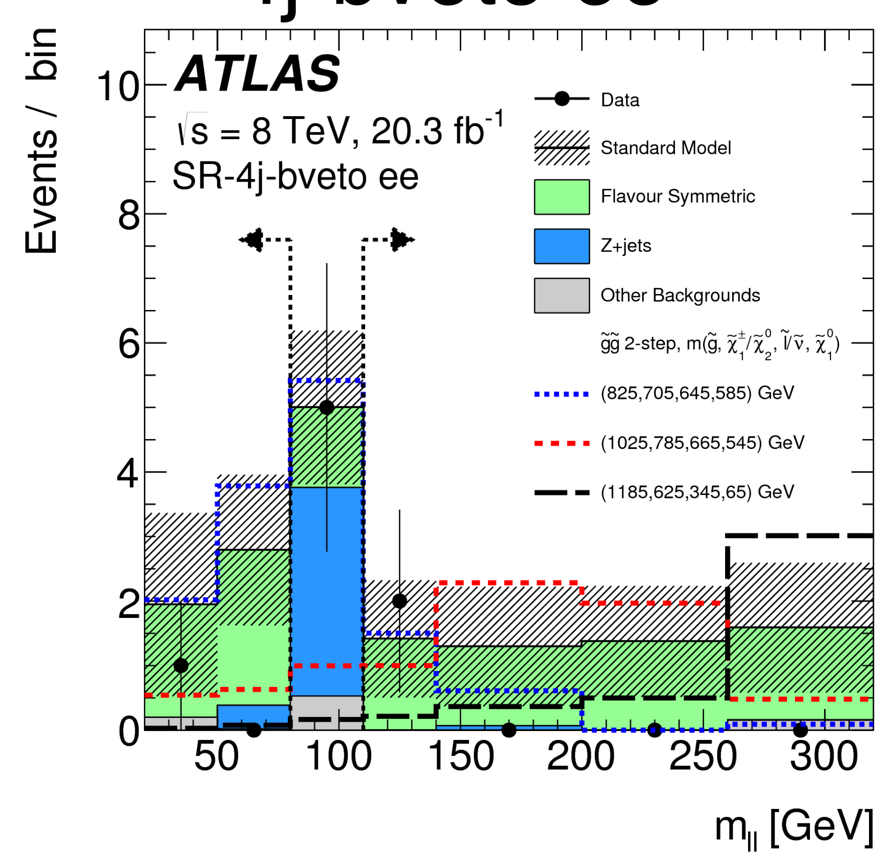
SR-loose ee



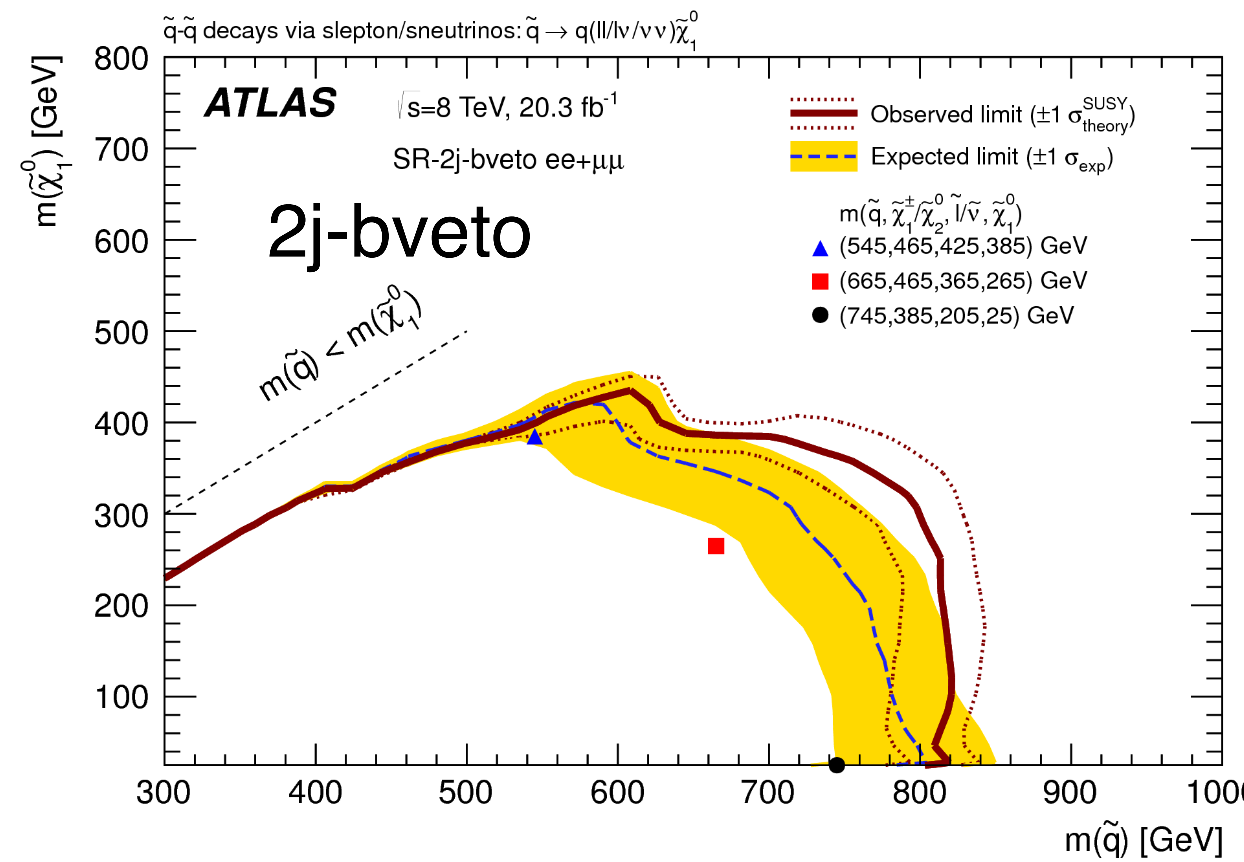
2j-bveto ee

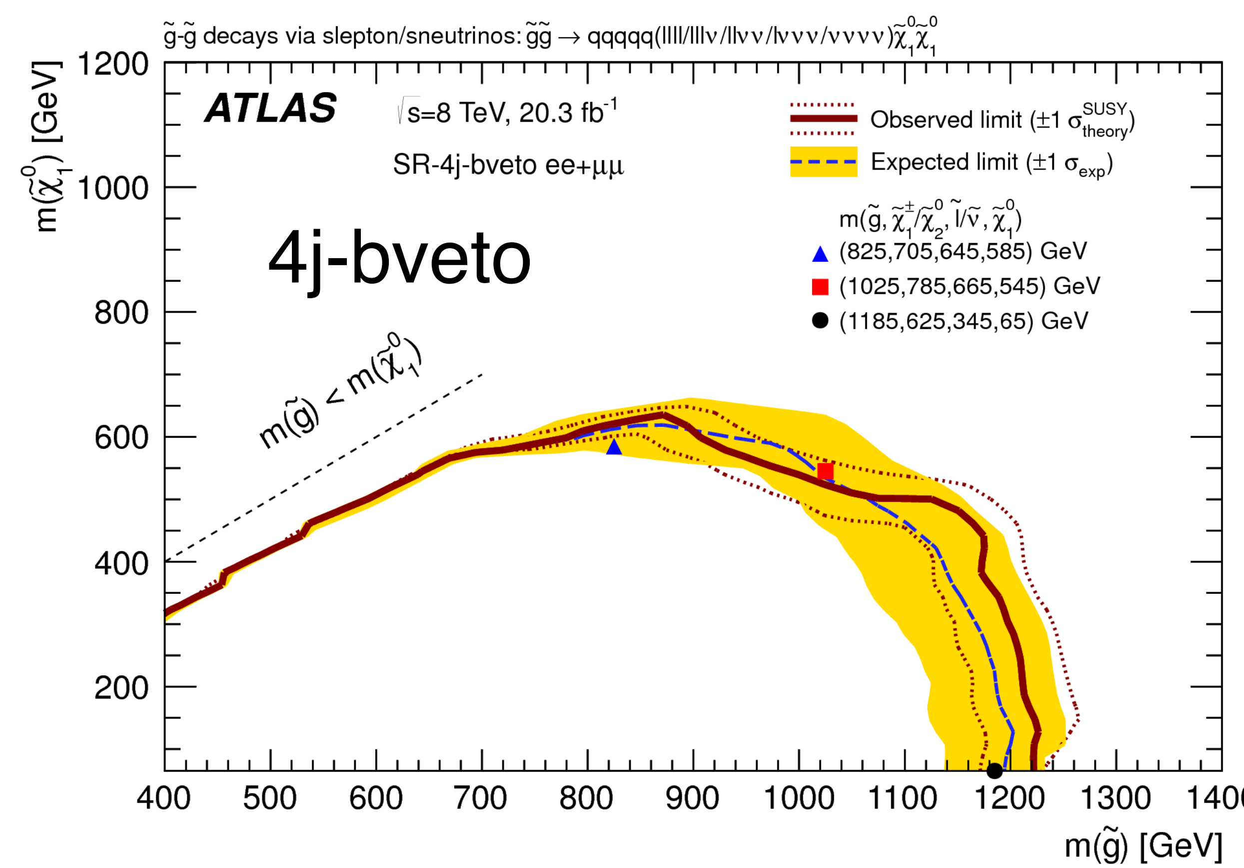


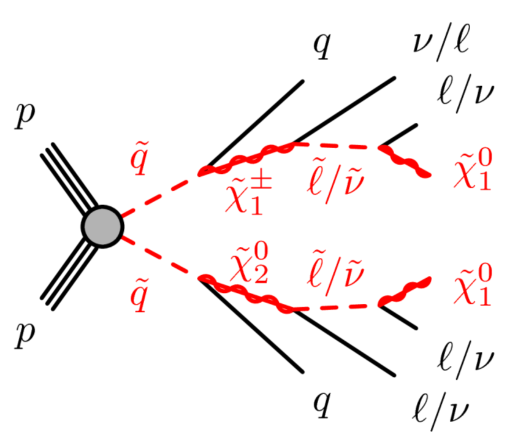
4j-bveto ee

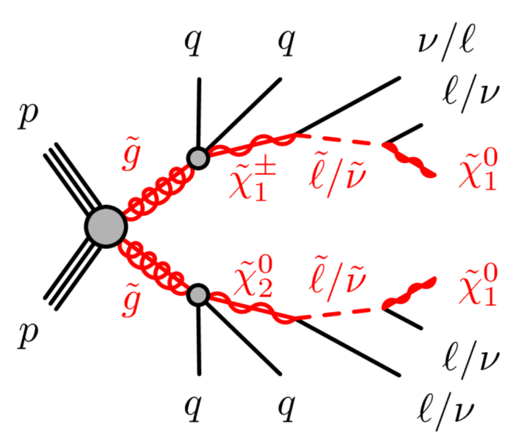


- Set limits on squark/gluino pair production models
  - Focus on b-veto signal regions for limit setting (better sensitivity / less ttbar bkg)
- 2j-bveto:
  - Must choose a m_{ll} window to set limit
  - Binning sets 45 possible windows
  - 10 windows with best expected sensitivity provide coverage of signal grid
  - Full exclusion limit obtained by taking best window at each signal grid point
- 4j-bveto:
  - 21 possible m_{ll} windows, of which 9 chosen





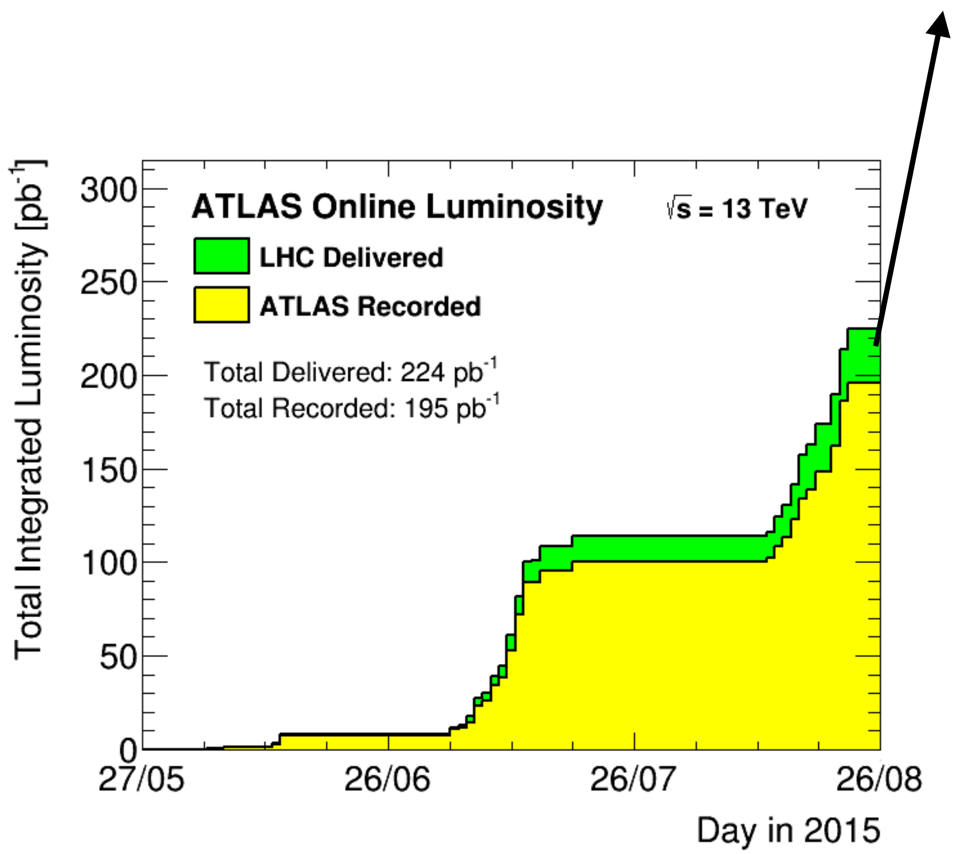




- **2L Razor**
  - Results consistent with SM expectations
  - Limits placed on squark/gluino production and decay via intermediate sleptons/sneutrinos
- **2L Z+MET**
  - Excess in ee and μμ channels (3.0σ)
  - Limits placed on GMSB models
- **2L Edge**
  - Non-resonant edge analysis sees no deviation from SM expectation
  - No confirmation of CMS excess

SUSY?

- **Run II Prospects**
  - Production cross sections increase drastically for regions of squark/gluino pair production phase space
    - 1350 GeV gluino: 26x higher cross section at $\sqrt{s}$=13 TeV vs 8 TeV
    - 1500 GeV gluino: 36x higher
- Work is progressing in earnest to prepare 13 TeV analyses
- Looking forward to revisiting intriguing excesses and extending our reach!



BACKUP

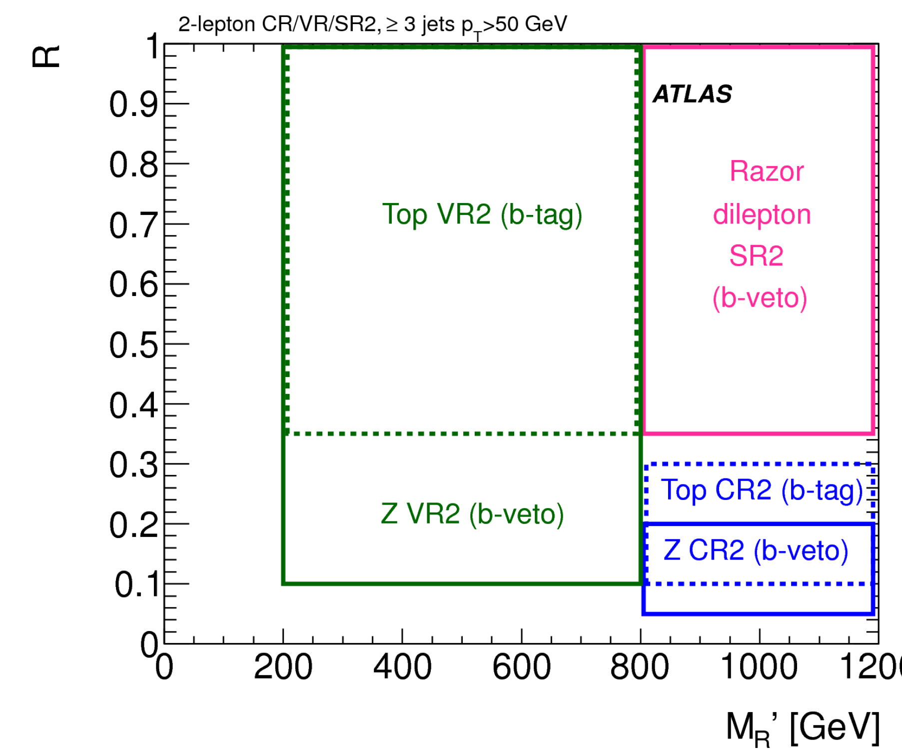
2L Razor

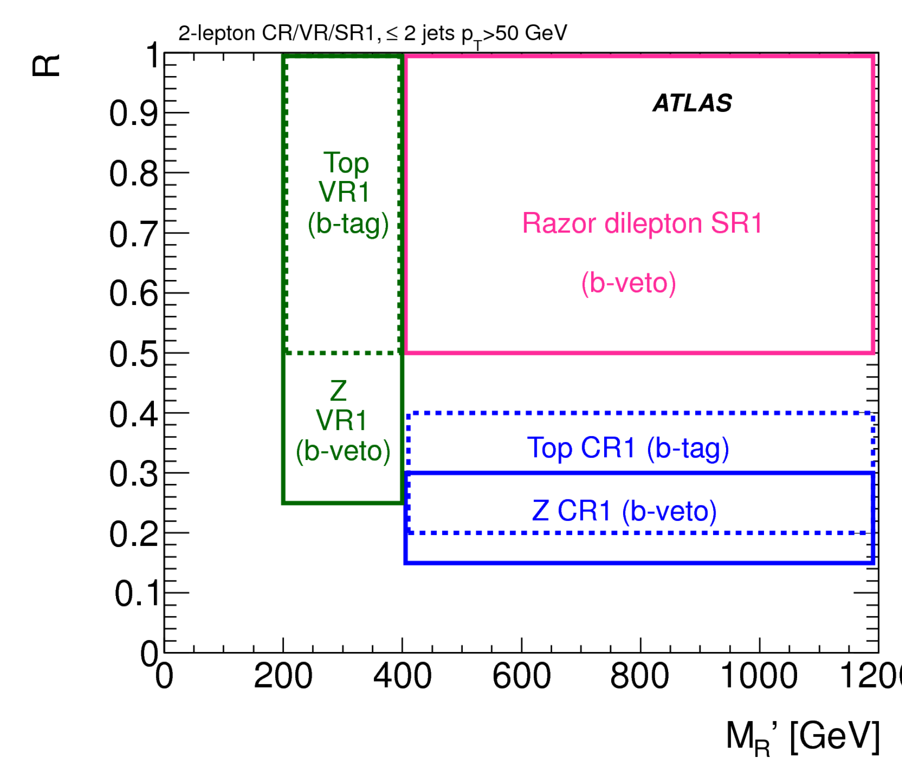
2L Razor

Relative systematic uncertainties (%)

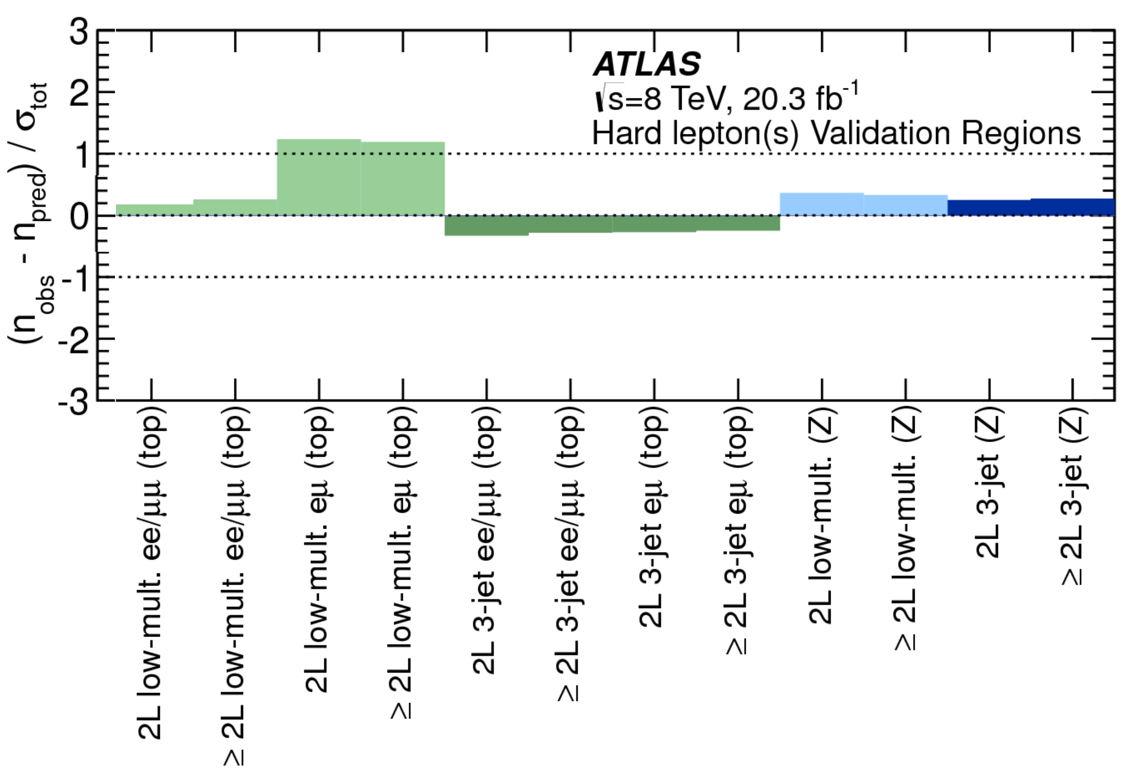
	Binned hard dilepton			
	Low-multiplicity ($\leq$ 2-jet)		3-jet	
	$ee/\mu\mu$	$e\mu$	$ee/\mu\mu$	$e\mu$
Total systematic uncertainty	11	11	23	18
b-tagging	7	6	11	11
JES (in-situ measurement)	–	–	–	5
Fake leptons	5	–	–	–
MC statistics	6	–	–	–

2L Control and Validation Regions



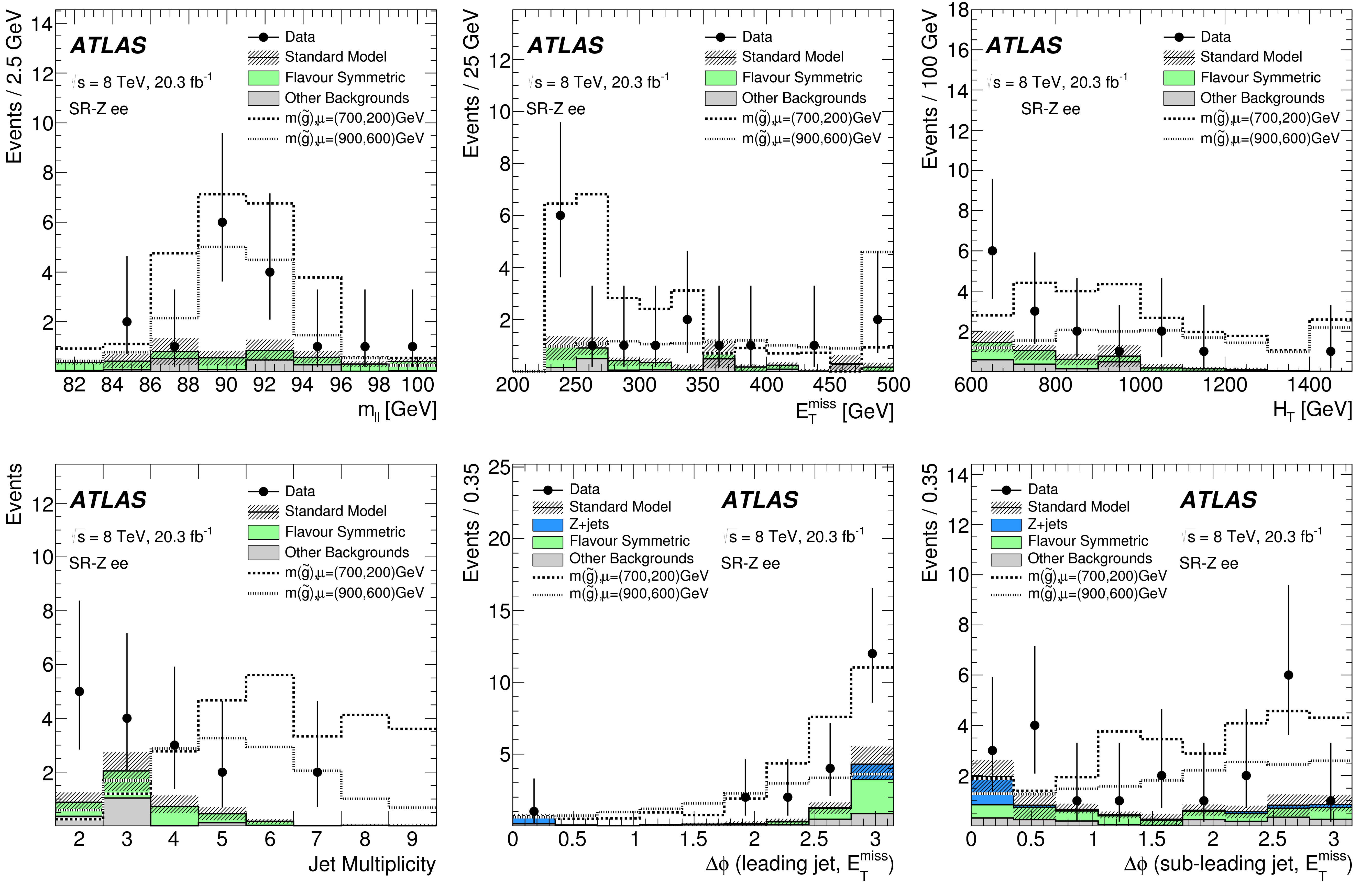


Agreement in validation regions, comparing to post-fit background estimates

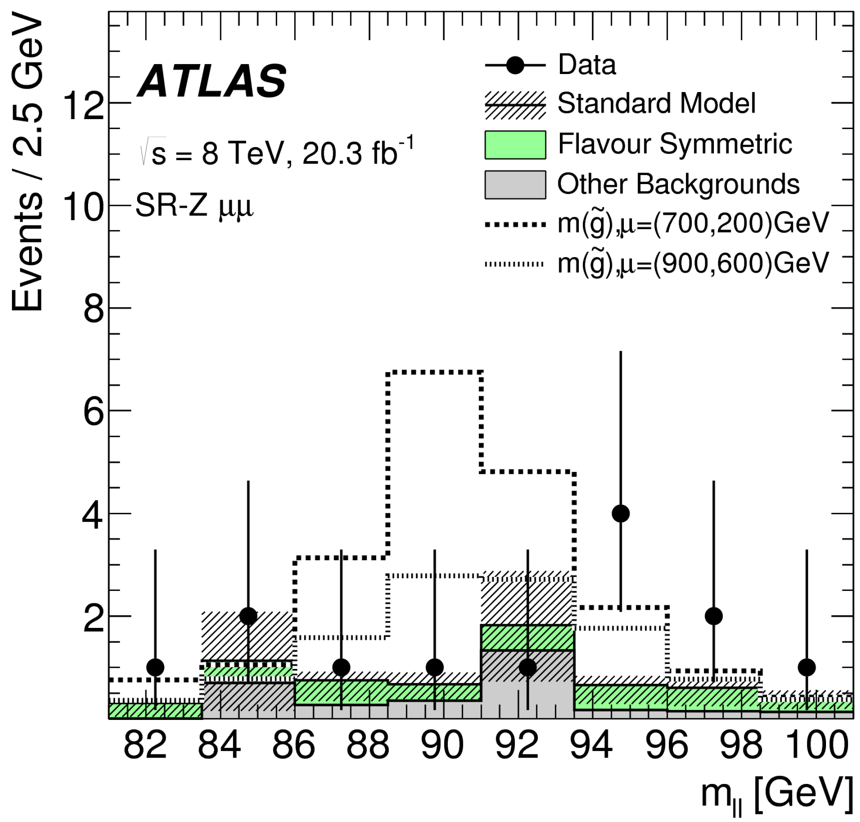


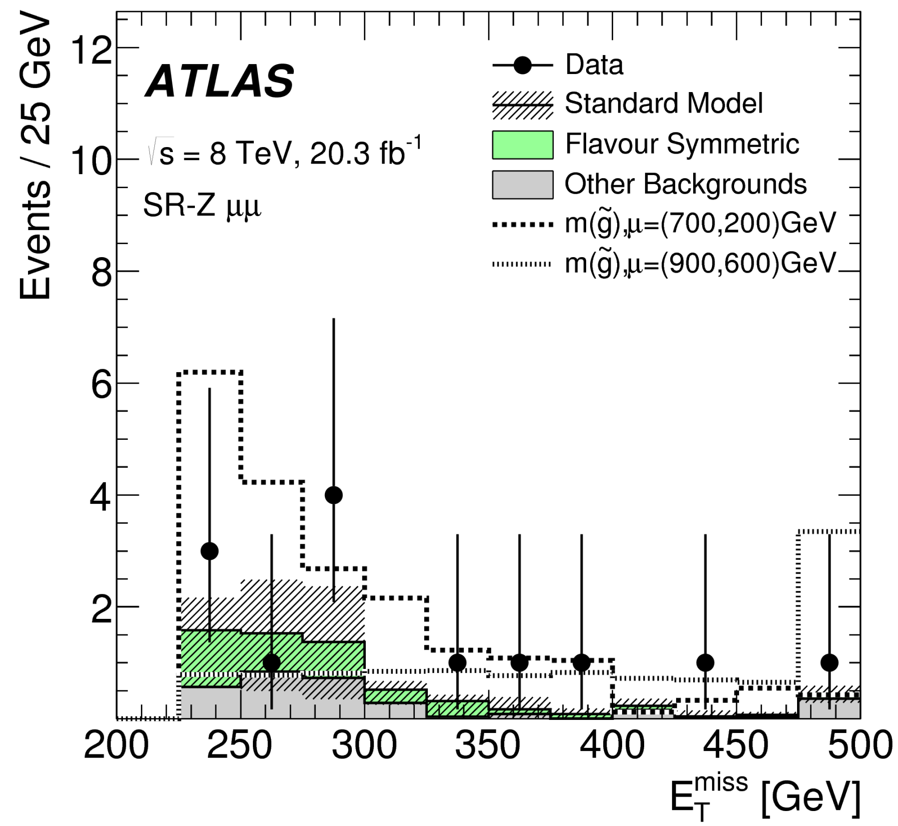
Z+MET, Edge

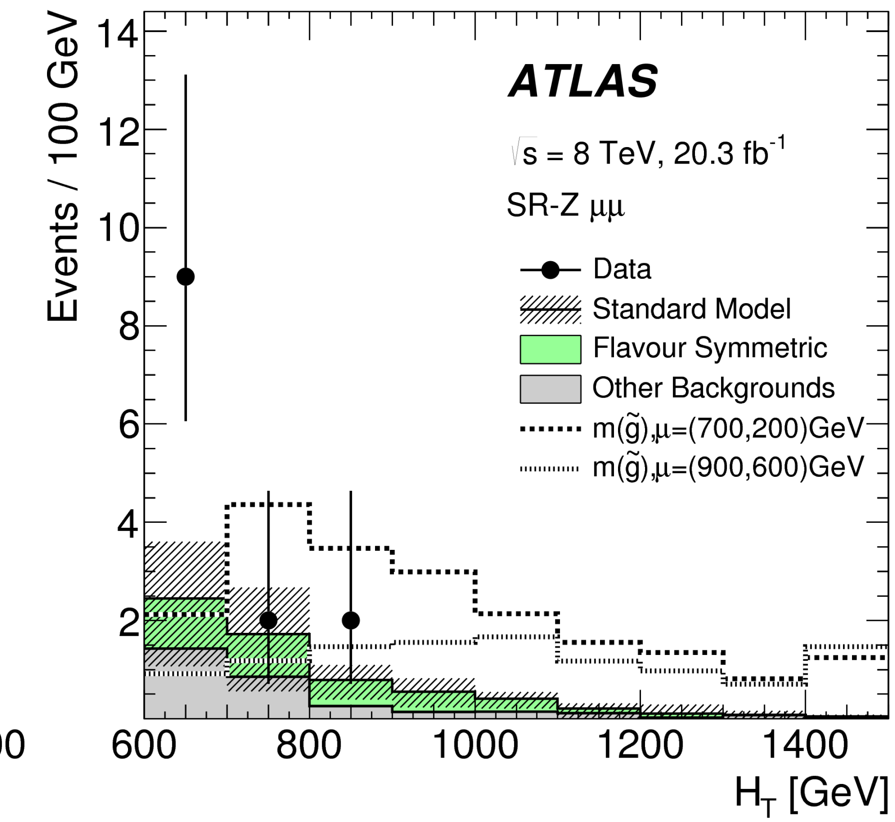
SR on-Z Distributions - *2e*

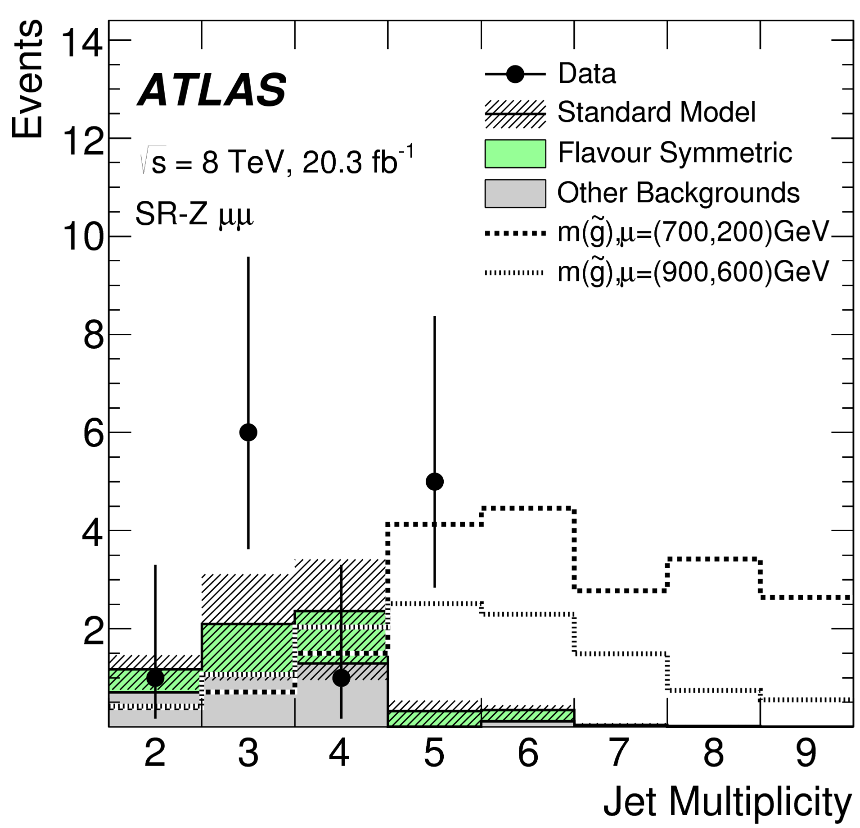


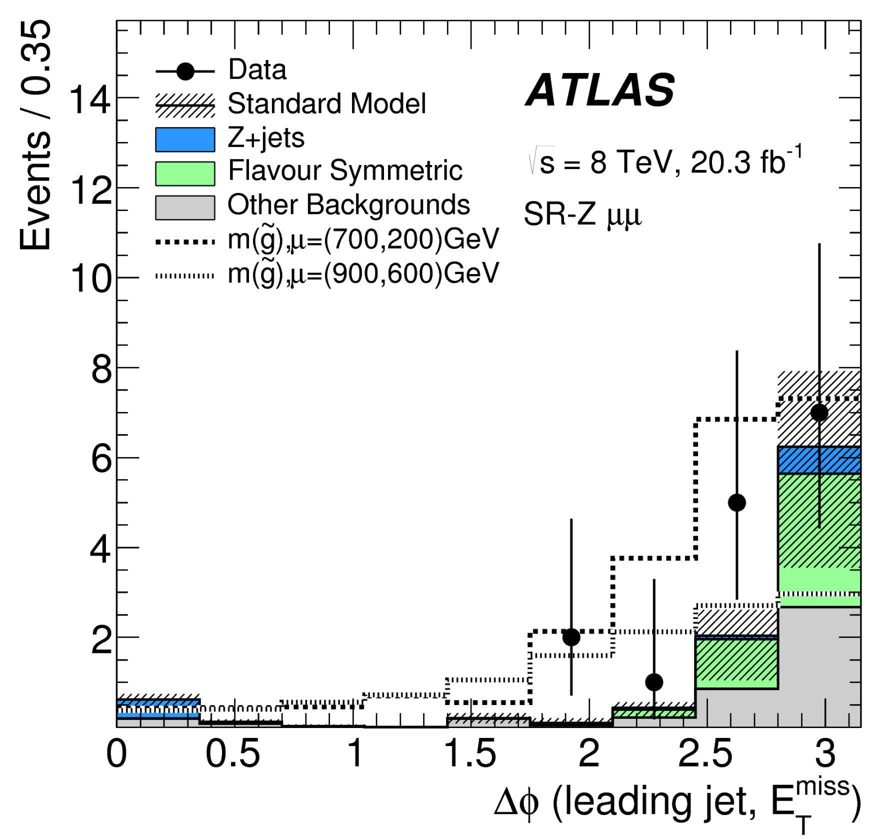
SR on-Z Distributions - *2μ*

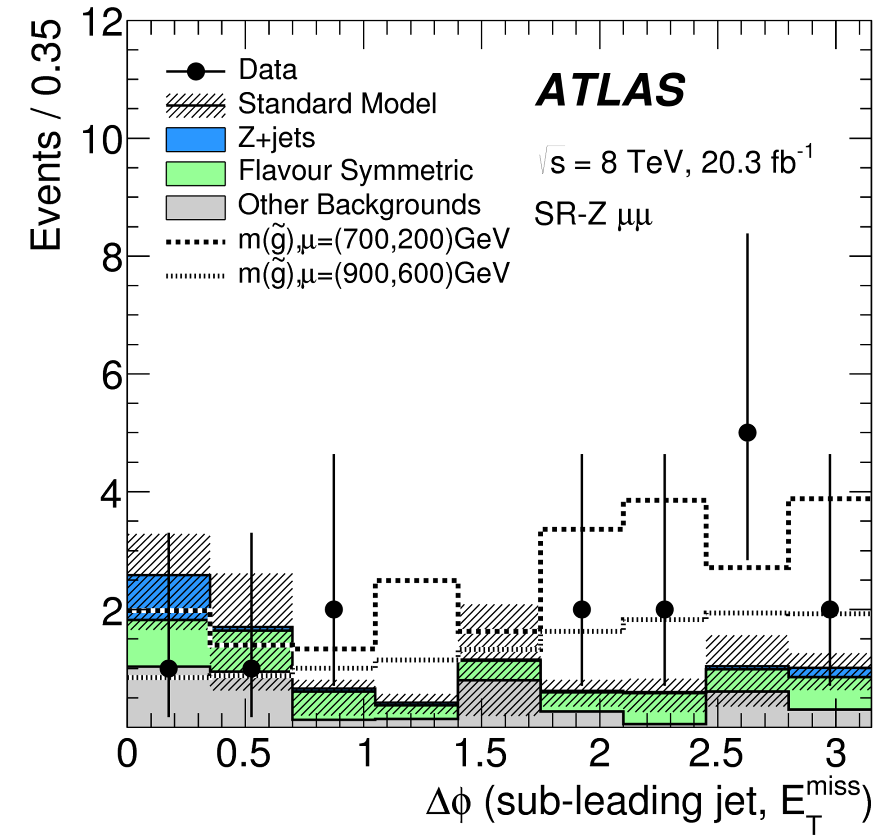




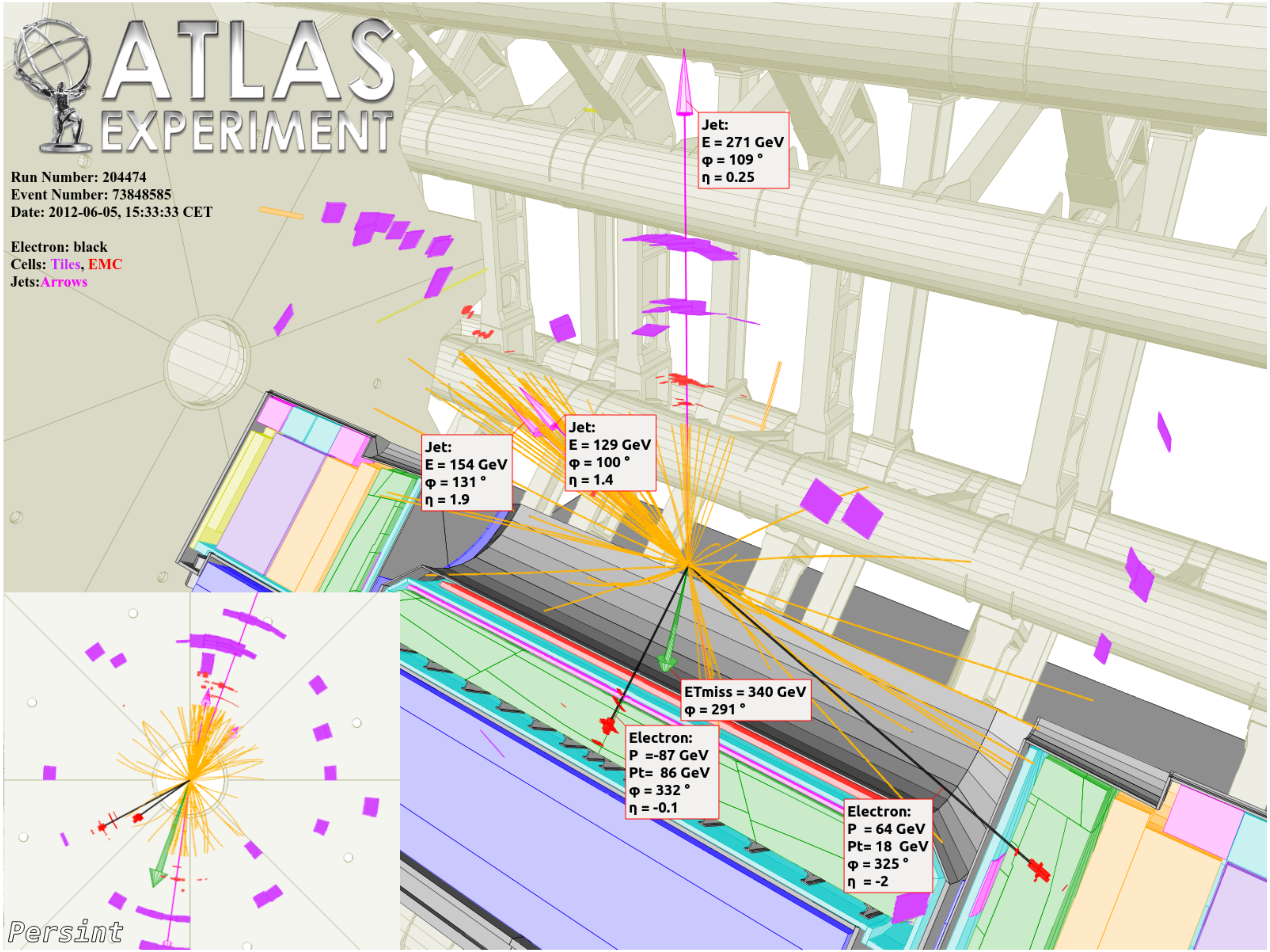






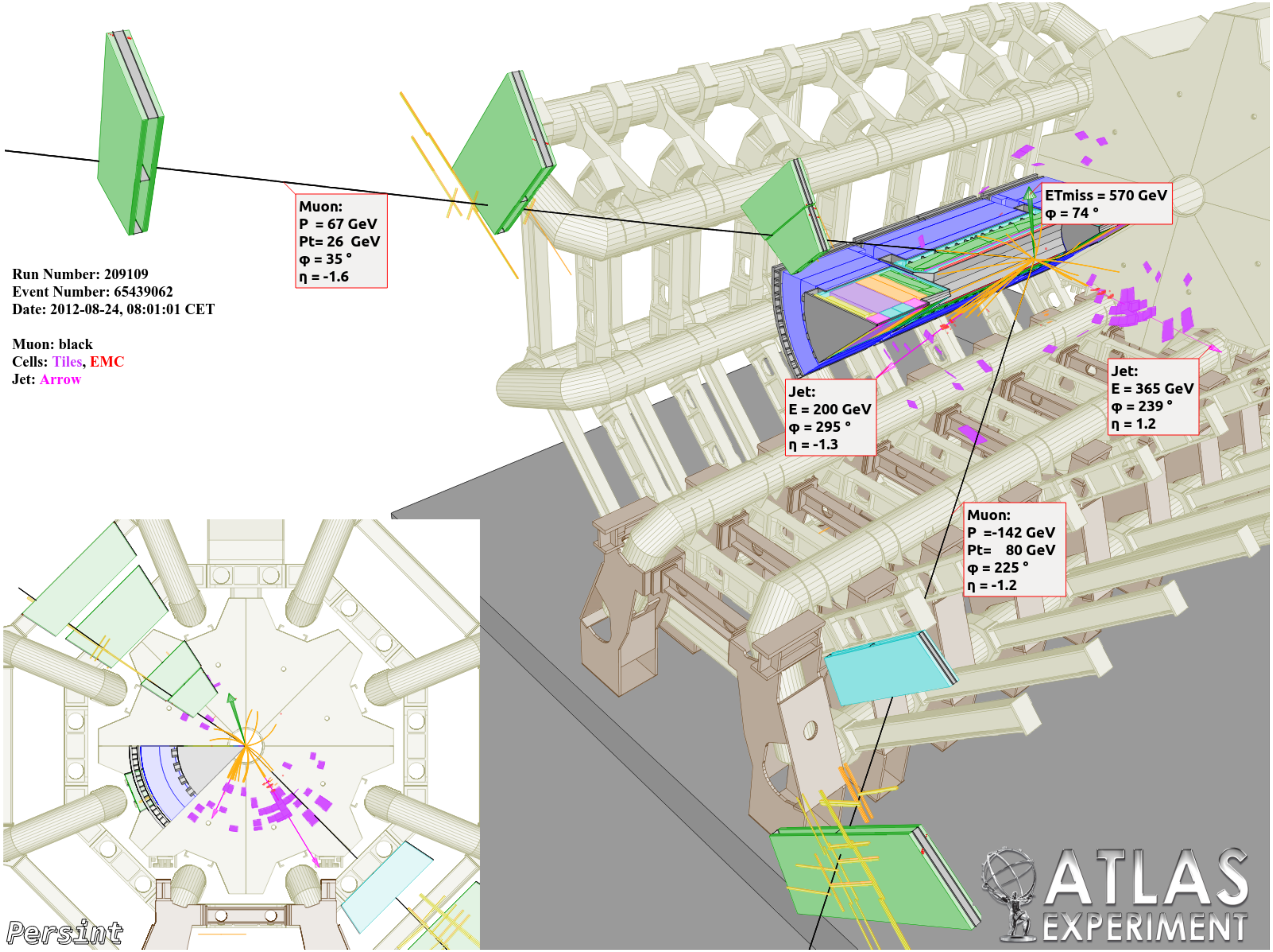


2L Z+MET Event Display



- Event display showing a *2e* pair consistent with a Z boson, large E_{TMiss} and large large H_T

2L Z+MET Event Display

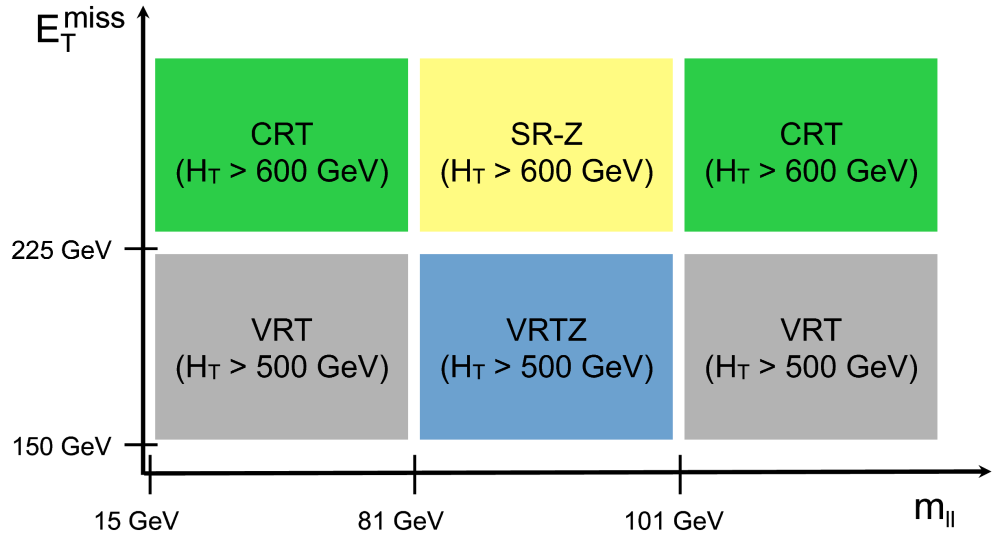


- Event display showing a *2μ* pair consistent with a Z boson, large E_{TMiss} and large H_T

Relative systematic uncertainties (% of total bkg expectation)

Source	Relative systematic uncertainty [%]					
	SR-Z	SR-loose	SR-2j-bveto	SR-2j-btag	SR-4j-bveto	SR-4j-btag
Total systematic uncertainty	29	7.1	13	9.3	30	15
Flavour-symmetry statistical	24	1.7	9.3	6.2	23	12
Flavour-symmetry systematic	4	5.7	6.7	5.9	11	6.6
Z/γ^* + jets	-	2.1	6.3	3.5	14	7.0
Fake lepton	14	3.2	1.4	1.2	1.8	2.2
WZ MC + parton shower	7	-	-	-	-	-

On-Z Cross-check (sideband) / VRs



Off-Z - SR-2j-btag