SUSY ANALYSIS WITH 2 LEPTONS

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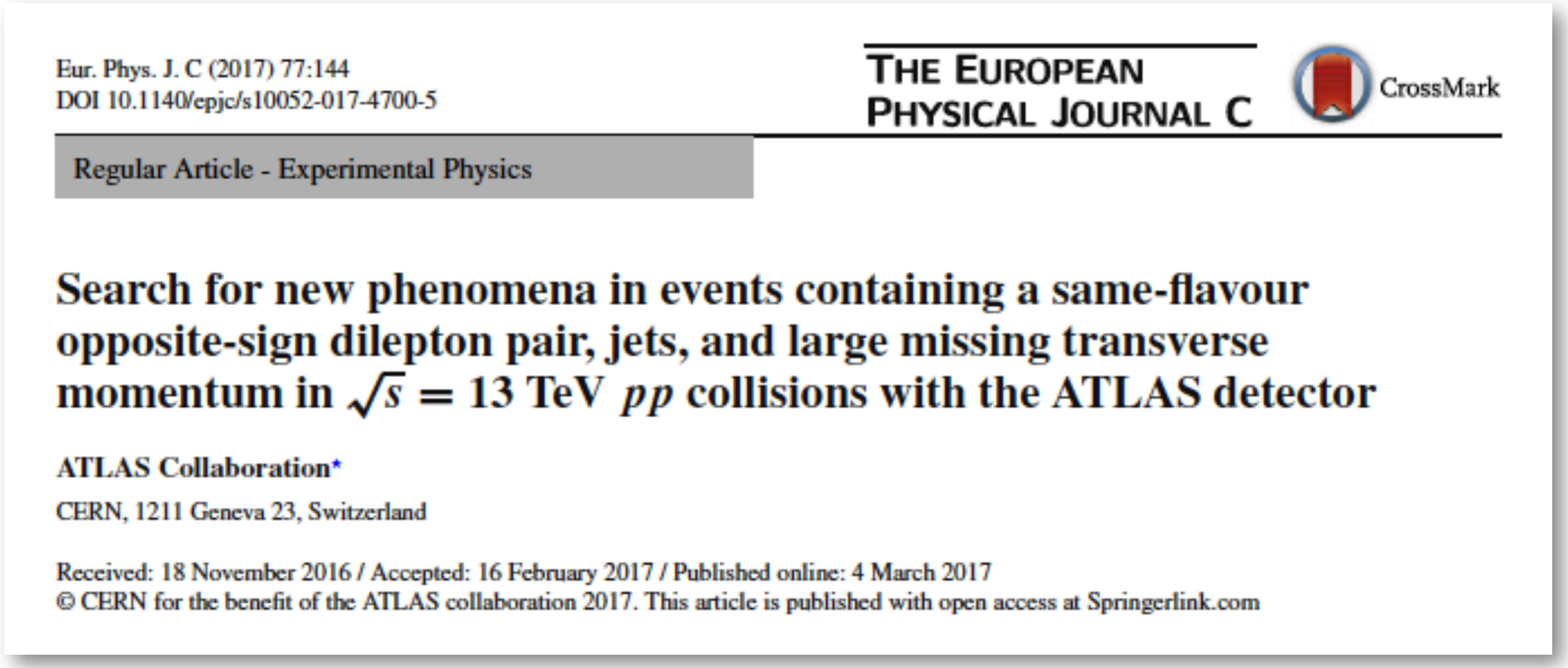

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THE EUROPEAN PHYSICAL JOURNAL C

CrossMark

Regular Article - Experimental Physics

Search for new phenomena in events containing a same-flavour opposite-sign dilepton pair, jets, and large missing transverse momentum in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector

ATLAS Collaboration*

CERN, 1211 Geneva 23, Switzerland

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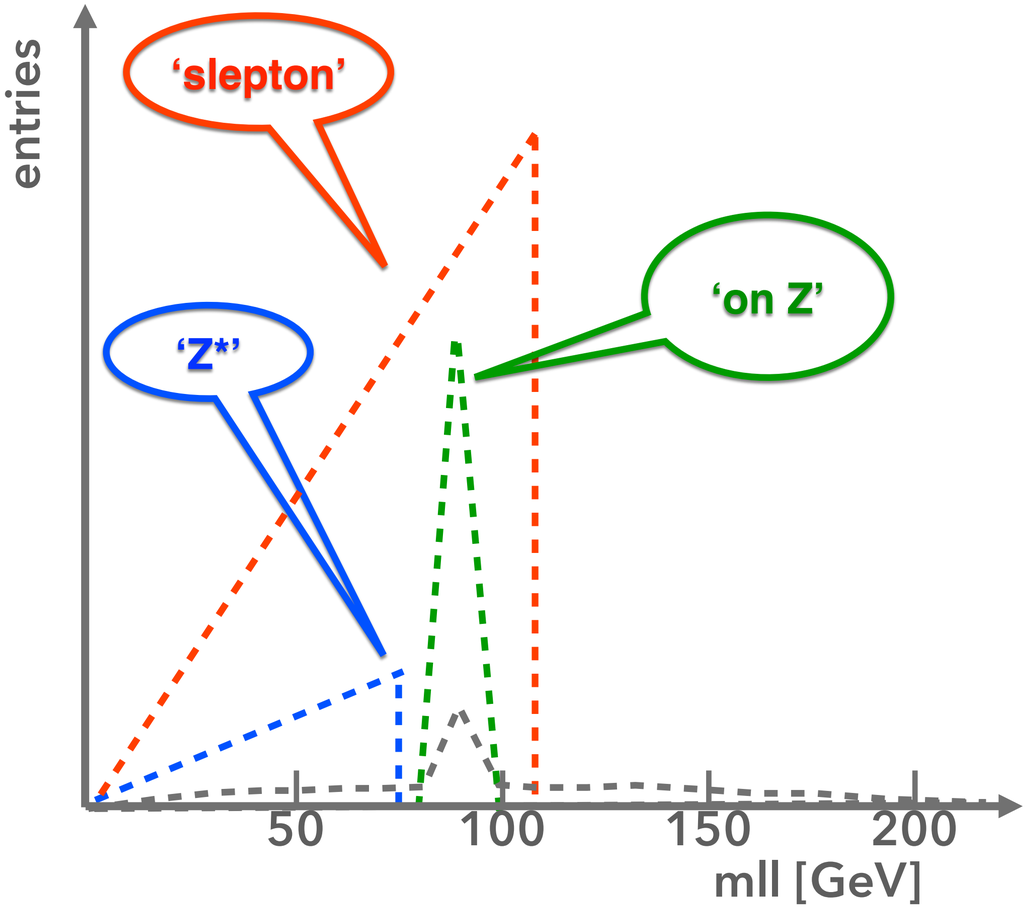
EPJC 77 (2017) 144 [arXiv:1611.05791]

ANALYSIS OVERVIEW

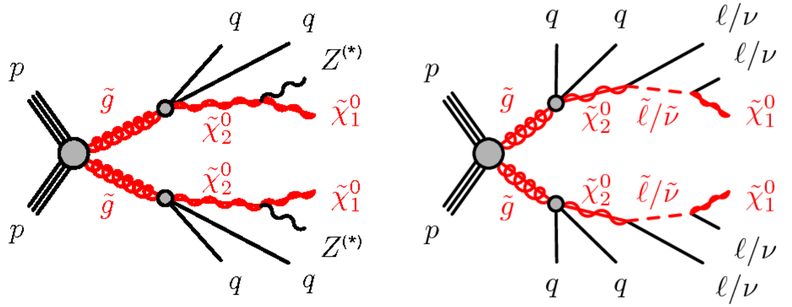
Targeting strong production with:

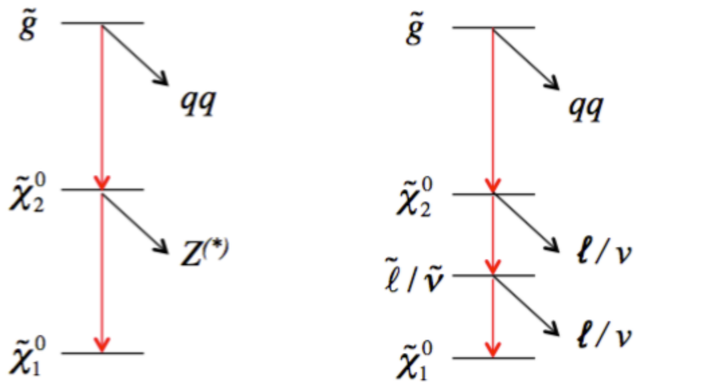
- 2 opposite sign, same flavour leptons
- Jets
- EtMiss



Analysis consists of:

- On-Z
- Edge



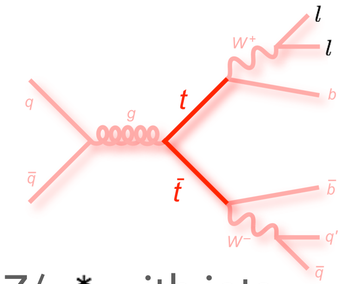


$$m_{\ell\ell}^{\max} = \sqrt{\frac{(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\ell}}^2)(m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0}^2)}{m_{\tilde{\ell}}^2}} \approx m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$$

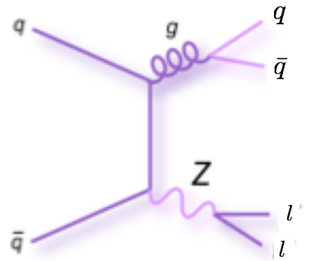
Dominant backgrounds

- Flavour-symmetric

$t\bar{t}, WW, Wt, Z \to \tau\tau$

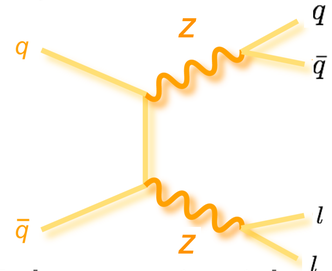


- Z/γ^* with jets



- Diboson and rare t

$WZ/ZZ \quad t\bar{t}W, t\bar{t}Z, t\bar{t}WZ$



- Fake or miss-identified leptons

FLAVOUR SYMMETRIC Z+JETS FAKES

Take different flavour (DF) control regions (CR) to estimate SF background, with corrections obtained from data for:

- Trigger efficiency of SF and DF events, from MC, $m_{\ell\ell}$ dependent.
- Kinematics for electrons and muons, from MC, p_T dependent.

Fraction of FS in CR (MC)

Fraction of FS in SR (MC)

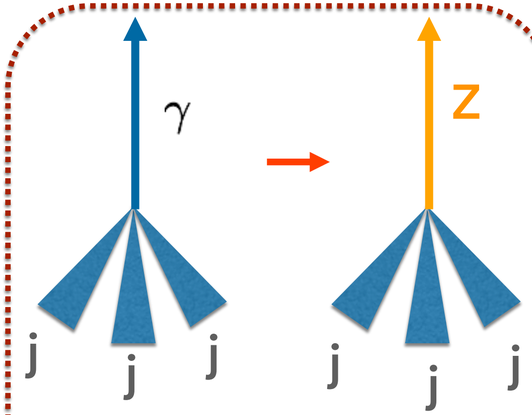
1 for Edge

Correction for e and μ kinematics

Correction for SF/DF trigger efficiency

$$N_{ee}^{\text{est}} = \frac{1}{2} \cdot f_{\text{FS}} \cdot f_{\text{Z-mass}} \cdot \sum_{i}^{N_{e\mu}^{\text{data}}} k_e(p_{\text{T}}^{i,\mu}, \eta^{i,\mu}) \cdot \alpha(p_{\text{T}}^{i,\mu}, \eta^{i,\mu})$$

$$N_{\mu\mu}^{\text{est}} = \frac{1}{2} \cdot f_{\text{FS}} \cdot f_{\text{Z-mass}} \cdot \sum_{i}^{N_{e\mu}^{\text{data}}} k_\mu(p_{\text{T}}^{i,e}, \eta^{i,e}) \cdot \alpha(p_{\text{T}}^{i,e}, \eta^{i,e})$$



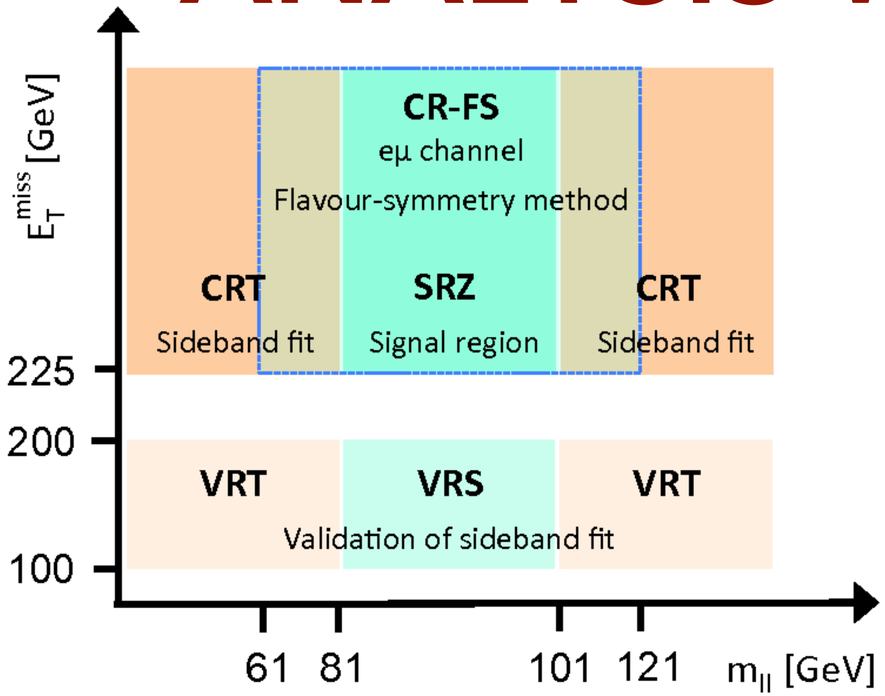
- Z+jets considered similar to γ+jets in right regime.
- Use γ+jets as EtMiss template for Z+jets to get $m_{\ell\ell}$ shape.
- Account for lepton miss-measurement.
- Reweight γ pT to match Z pT spectrum.

$$N_{\text{pass}}^{\text{fake}} = \frac{N_{\text{fail}} - (1/\epsilon^{\text{real}} - 1) \times N_{\text{pass}}}{1/\epsilon^{\text{fake}} - 1/\epsilon^{\text{real}}}$$

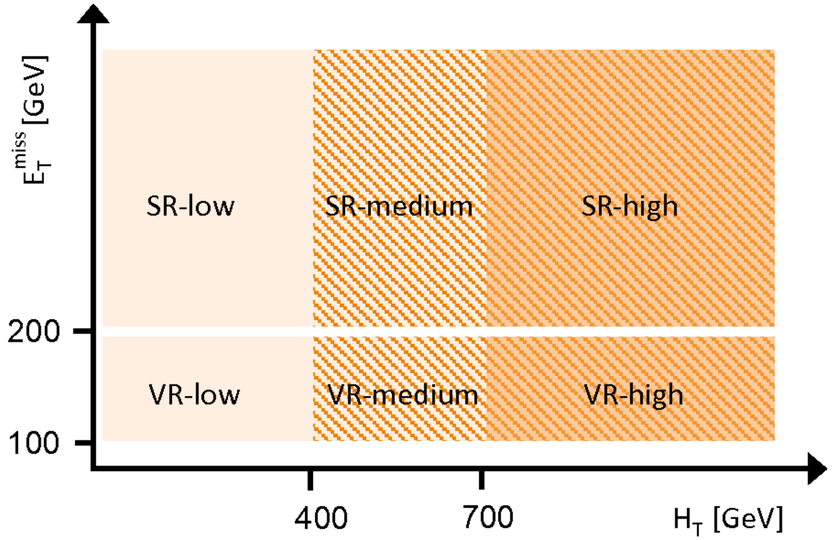
- Events from tt, W→ℓν, single t (s and t channel) can enter SR via fake leptons.
- Fake leptons from mis-identified hadrons, converted photons, or non-prompt leptons from b-decays.
- Matrix method to estimate fake leptons in SR.

ANALYSIS WITH 2 LEPTONS

On Z



Edge



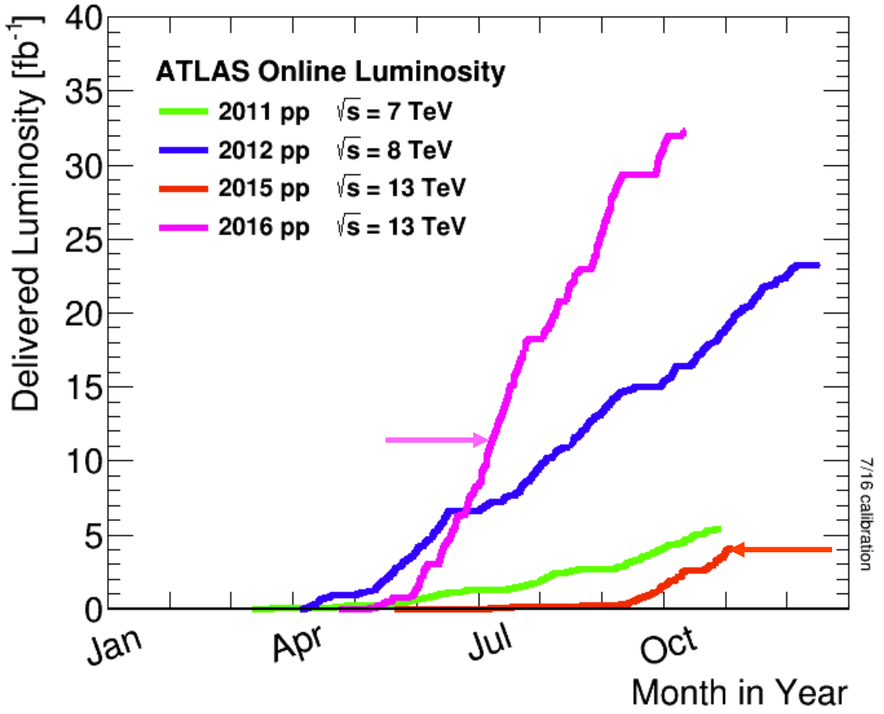
Defined exclusive regions in the selection:

- **Signal regions** (dominated by signal, optimised for highest sensitivity for a considered SUSY model).
- **Control regions** (background dominated, used to determine the background in the signal region).
- **Validation regions** (defined close to the signal regions, used to validate the background prediction in the signal region).

Statistical interpretation:

- **Model-independent** (p0, Z)
- **Model-dependent** (CLs)

TRIGGER AND EVENT SELECTION



- Analysis uses 14.7 fb^{-1} of 13 TeV data collected in 2015+2016.
- Trigger:
  - One lepton and two lepton trigger

On Z analysis: same event selection as for 8 TeV

On-shell Z regions	E_T^{miss} [GeV]	H_T^{incl} [GeV]	n_{jets}	$m_{\ell\ell}$ [GeV]	SF/DF	$\Delta\phi(jet_{12}, p_T^{miss})$	$m_T(\ell_3, E_T^{miss})$ [GeV]	$n_{b\text{-jets}}$
Signal region								
SRZ	> 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	–	–

Kinematic edge $m_{\ell\ell}$ windows span 12~1000 GeV

Edge regions	E_T^{miss} [GeV]	H_T [GeV]	n_{jets}	$m_{\ell\ell}$ [GeV]	SF/DF	OS/SS	$\Delta\phi(jet_{12}, p_T^{miss})$	$m_{\ell\ell}$ ranges
Signal regions								
SR-low	> 200	–	≥ 2	> 12	SF	OS	> 0.4	9
SR-medium	> 200	> 400	≥ 2	> 12	SF	OS	> 0.4	8
SR-high	> 200	> 700	≥ 2	> 12	SF	OS	> 0.4	7

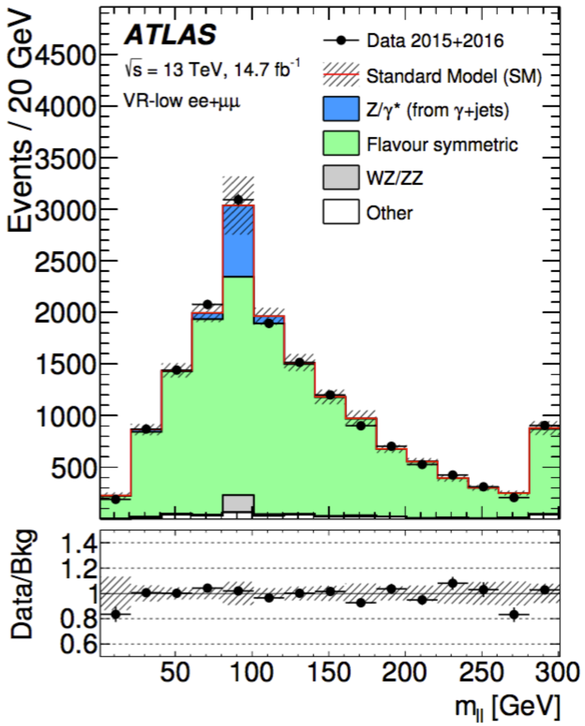
Event selection:

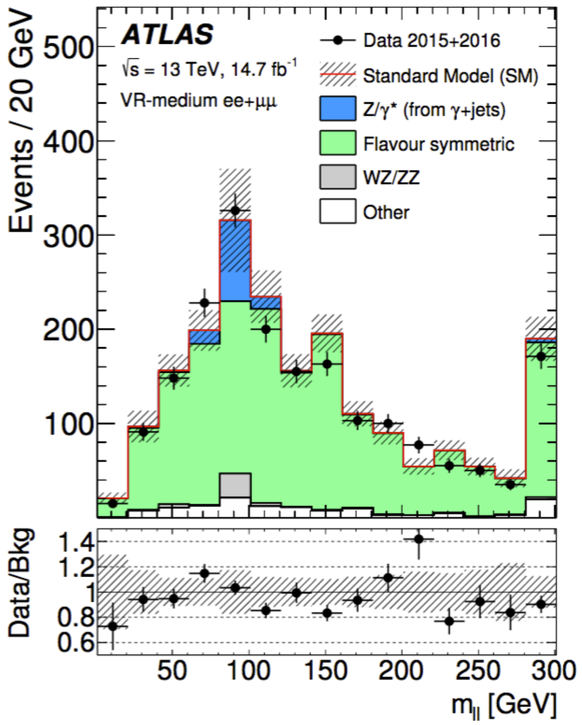
- **At least 2 jets**
- **2 same-flavour opposite-sign leptons**
  - 'On Z': $p_T(l_1) > 50$ GeV, $p_T(l_2) > 25$ GeV
  - 'Edge': $p_T(l_1) > 25$ GeV, $p_T(l_2) > 25$ GeV
- **Signal regions differ in EtMiss, Ht and mll**

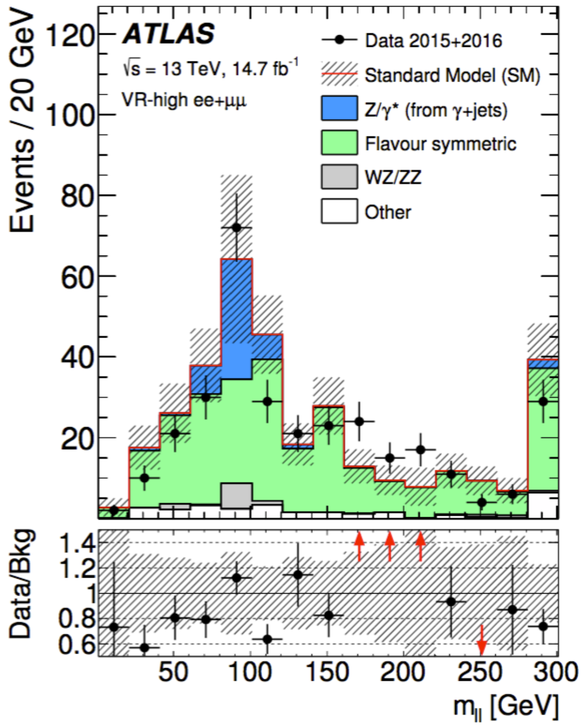
VALIDATION REGIONS

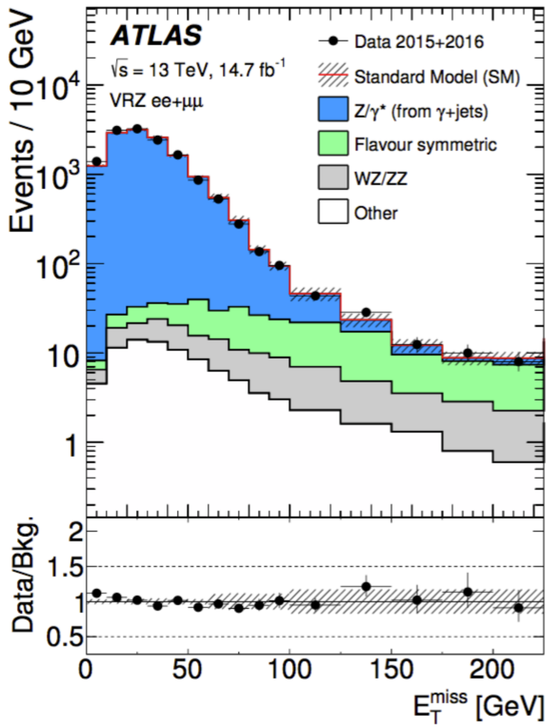
Edge

On Z









- Flavour symmetry has good closure.
- Z+jets have good closure.

Backgrounds determined in data-driven way have good agreement in VRs.

RESULTS

Dominant background contributions:

- On Z: Flavour symmetry and diboson bkg.
- Edge: Flavour symmetry, and smaller contributions from Z+jets, fake leptons and diboson bkg.

On Z

	SRZ
Observed events	60
Total expected background events	53.5 ± 9.3
Flavour-symmetric ($t\bar{t}$, Wt, WW and $Z \to \tau\tau$) events	33.2 ± 3.9
Z/γ^* + jets events	3.1 ± 2.8
WZ/ZZ events	14.2 ± 7.7
Rare top events	2.9 ± 0.8
Fake lepton events	$0.1^{+0.8}_{-0.1}$

Edge

	SR-low	SR-medium	SR-high
Observed events	1394	689	212
Total expected background events	1500 ± 100	700 ± 60	171 ± 18
Flavour-symmetric ($t\bar{t}$, Wt, WW and $Z \to \tau\tau$) events	1270 ± 70	584 ± 32	148 ± 14
Z/γ^* + jets events	90 ± 50	50 ± 40	3^{+7}_{-3}
WZ/ZZ events	68 ± 31	26 ± 11	7 ± 4
Rare top events	19 ± 5	11.3 ± 3.2	4.2 ± 1.4
Fake lepton events	59 ± 34	32 ± 19	10 ± 8

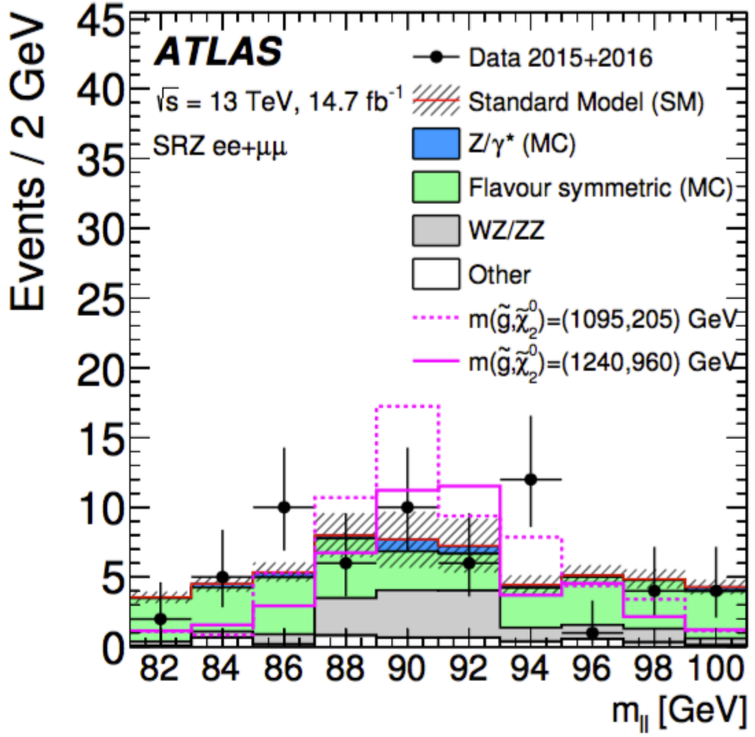
Source	Relative systematic uncertainty [%]			
	SRZ	SR-low	SR-medium	SR-high
Total systematic uncertainty	17	8–30	6–34	10–45
WZ/ZZ generator uncertainty	13	0–7	0–6	0–10
Flavour symmetry (statistical)	7	3–16	5–16	7–28
WZ/ZZ scale uncertainty	6	0–1	0–1	0–2
Z/γ^* + jets (systematic)	4	0–15	0–25	0–15
Flavour symmetry (systematic)	3	2–23	2–15	4–25
Z/γ^* + jets (statistical)	2	0–3	0–5	0–1
Fake-leptons	1	0–17	2–18	2–20

Dominant sources of systematic uncertainty:

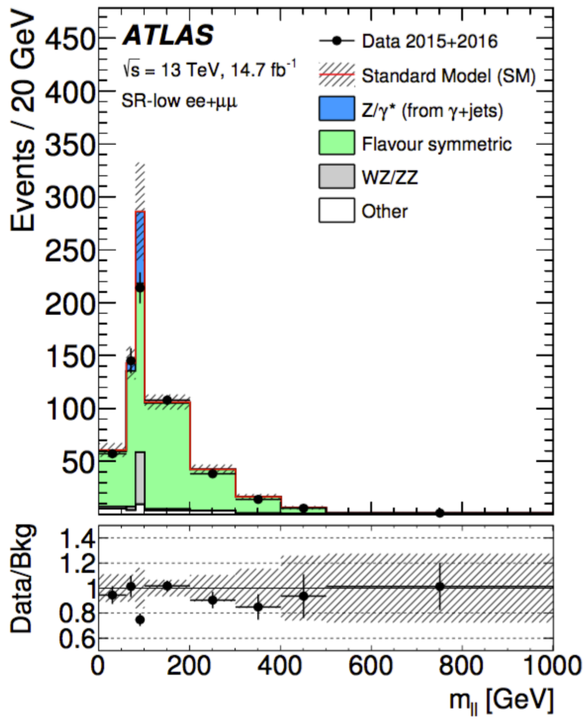
- Statistical and systematic uncertainty of flavour symmetry background
- Diboson generator uncertainty
- Fake leptons (for Edge)

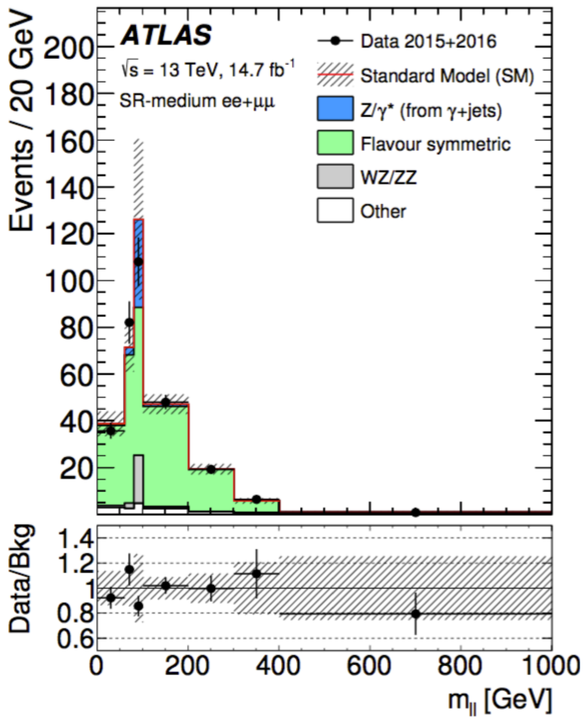
RESULTS

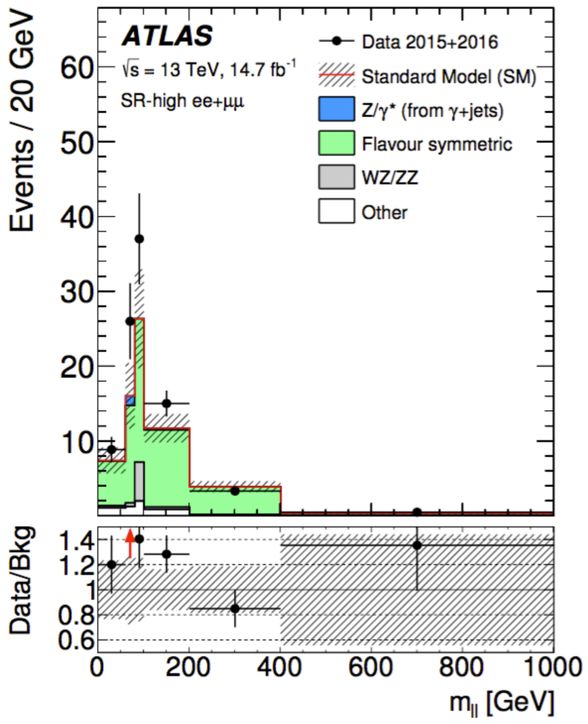
on-Z



Edge



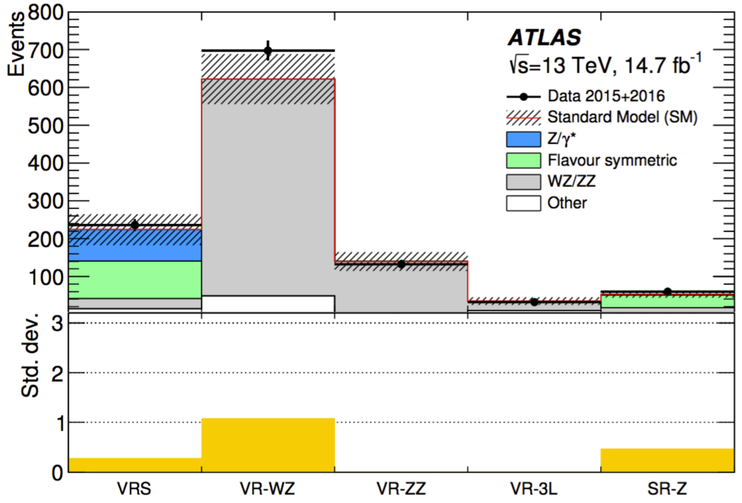




No significant excess observed in data for the ‘On Z’ nor ‘Edge’ selections.

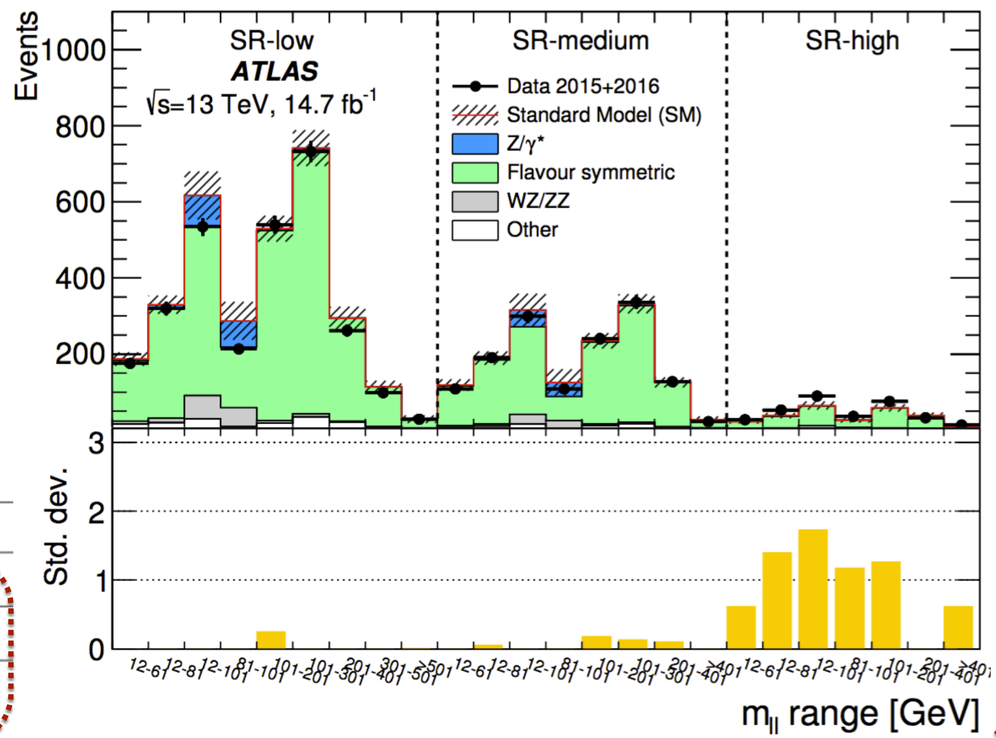
OVERALL RESULTS

on Z



	SRZ
Observed events	60
Total expected background events	53.5 ± 9.3
$p(s = 0)$	0.32
Significance (σ)	0.47

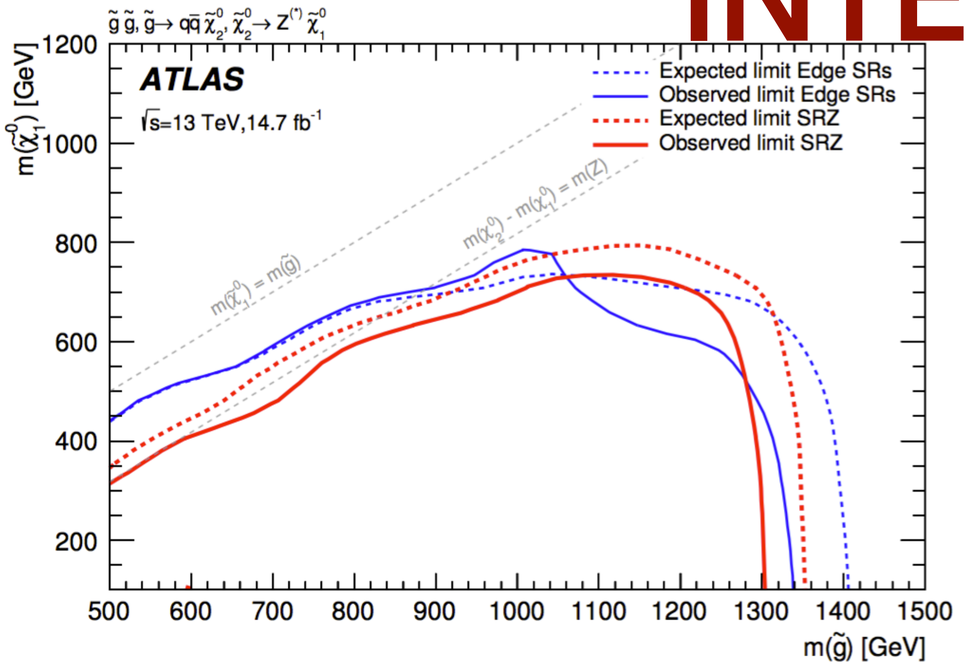
Edge

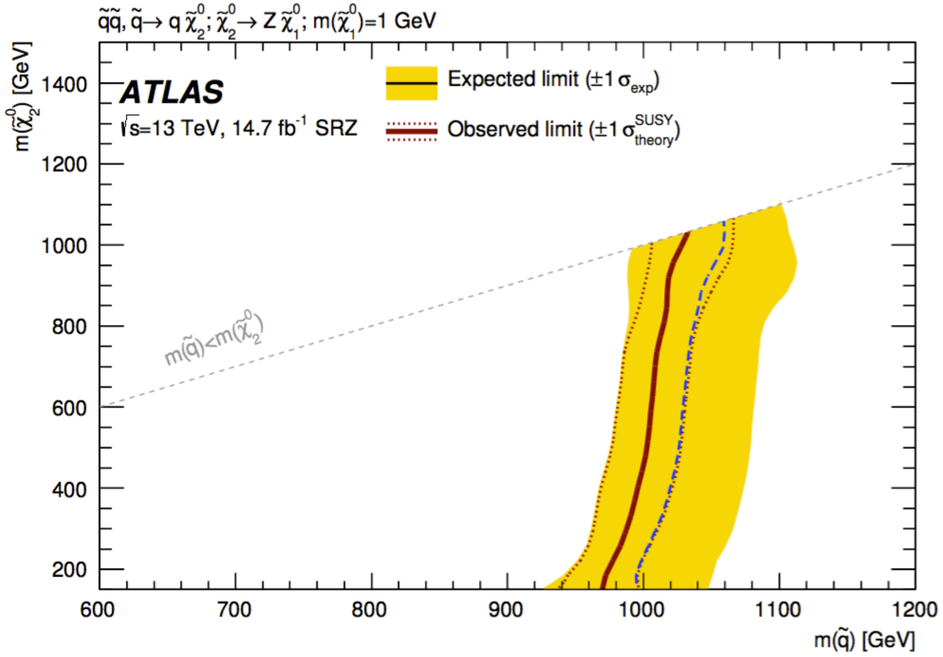


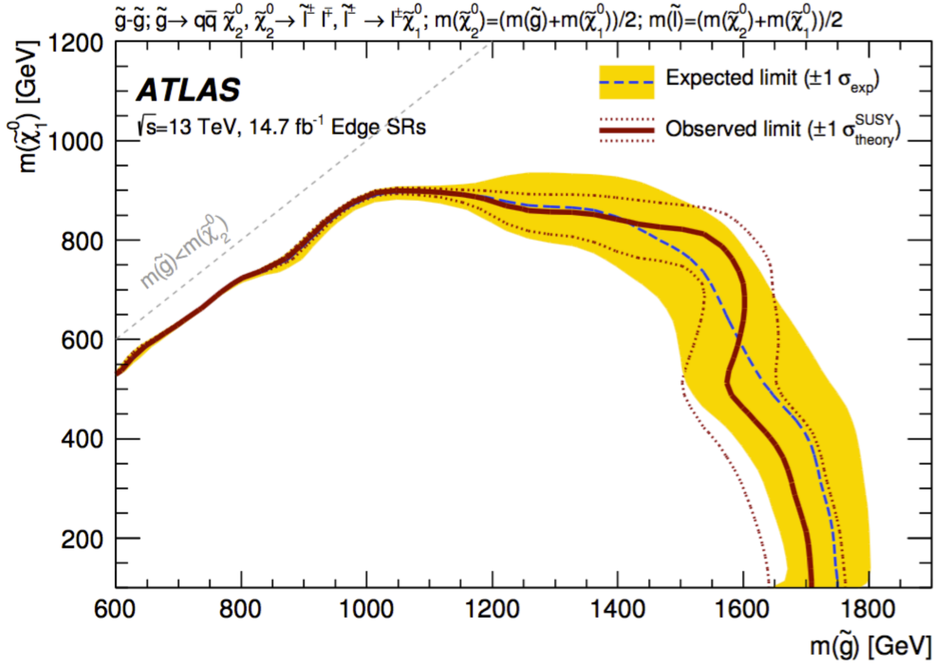
Signal Region	Total Bkg.	Data	$p(s = 0)$	$Z(s = 0)$
SR-low				
12–61	187 ± 18	175	0.50	0.00
12–81	330 ± 24	320	0.50	0.00
12–101	617 ± 63	534	0.50	0.00
81–101	287 ± 50	214	0.50	0.00
101–201	529 ± 34	540	0.40	0.26
101–301	741 ± 48	732	0.50	0.00
201–401	295 ± 30	262	0.50	0.00
301–501	113 ± 17	99	0.50	0.00
> 501	29 ± 10	29	0.50	0.01
SR-medium				
12–61	119 ± 15	109	0.50	0.00
12–81	190 ± 18	191	0.48	0.06
12–101	315 ± 43	299	0.50	0.00
81–101	125 ± 35	108	0.50	0.00
101–201	235 ± 20	240	0.42	0.19
101–301	332 ± 25	336	0.45	0.14
201–401	126 ± 13	128	0.46	0.11
> 401	28 ± 8	22	0.50	0.00
SR-high				
12–61	23 ± 5	27	0.27	0.62
12–81	39 ± 7	53	0.08	1.40
12–101	65 ± 10	90	0.04	1.73
81–101	26 ± 6	37	0.12	1.18
101–201	59 ± 9	75	0.10	1.27
201–401	39 ± 7	33	0.50	0.00
> 401	10 ± 5	14	0.27	0.62

Highest significance for ‘On Z’ 0.47 sigma and for the ‘Edge’ 1.73 sigma (local)

INTERPRETATION







Limits on slepton, Z* and other models have been set:

- Slepton: excludes gluino masses up to 1700 GeV and neutralino up to 900 GeV.
- Z*: Edge and on Z analyses compatible, Edge has better exclusion in the compressed and high gluino regions, on Z better in bulk region.
- Squark production: on Z analysis excludes squarks of ~980 GeV.

CONCLUSION

- Results of the SUSY strong production 2 lepton analysis presented [EPJC 77 (2017) 144] .
- Analysis targets signatures with 2 leptons of same flavour and opposite sign, consists of '**on Z**' and '**Edge**' analyses.
- Uses data-driven background determination. Good closure tests and performance in the validations regions.
- No significant excess observed in data:
- Interpretation performed in a number of simplified SUSY models. **Gluino** masses excluded up to ~**1700 GeV**, and **squark** masses of ~**980 GeV**.

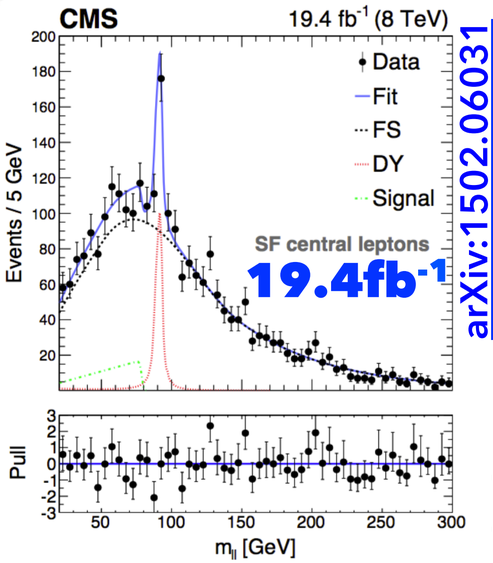
BACKUP

HISTORY

RUN I, 8 TeV

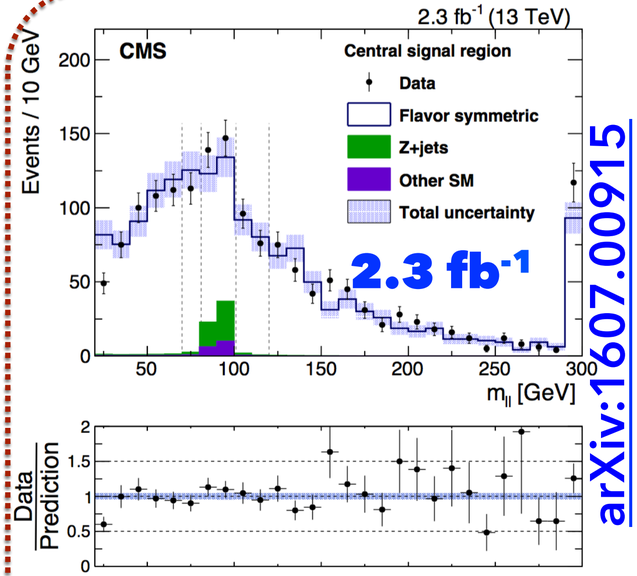
RUN II, 13 TeV

CMS



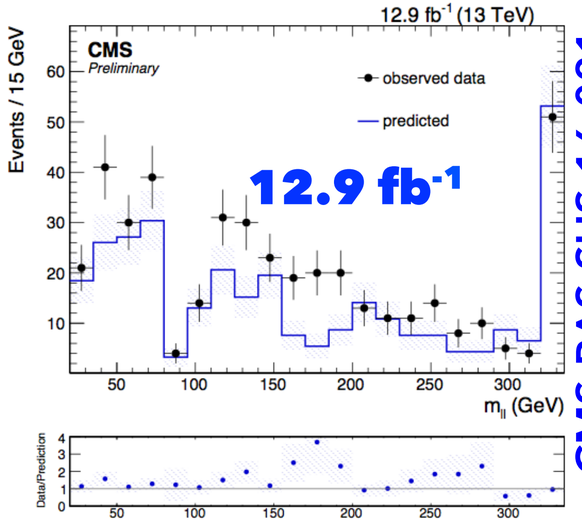
arXiv:1502.06031

2.6 σ below Z, no excess for on Z



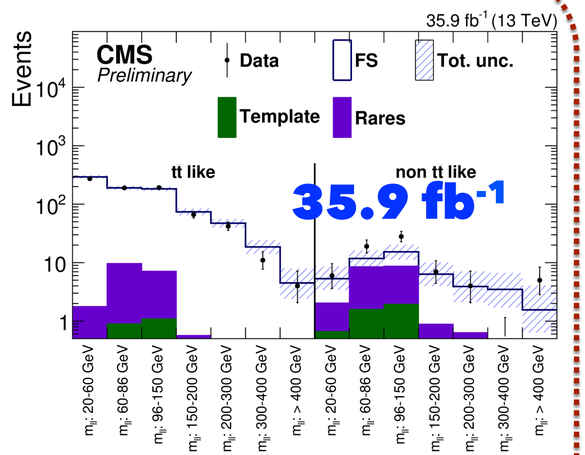
arXiv:1607.00915

No excess for on Z and Edge using 2.3 fb-1



CMS-PAS-SUS-16-021

3 σ excess in the high mass region, no excess on Z

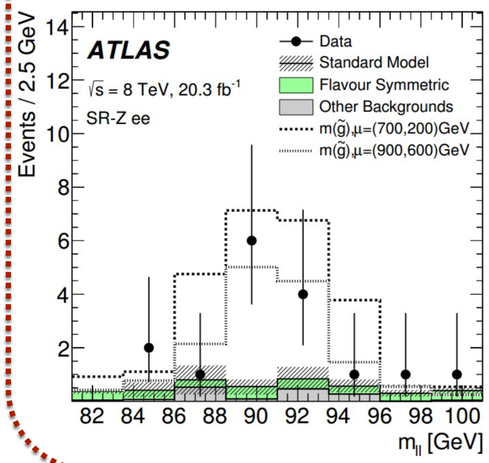


CMS-PAS-SUS-16-034

No significant excess found.

ATLAS

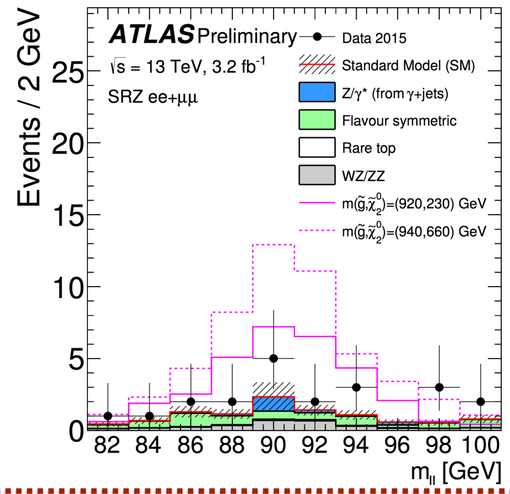
20.3 fb-1



arXiv:1503.03290

3 σ on Z, no excess in Edge

3.2 fb-1



ATLAS-CONF-2015-082

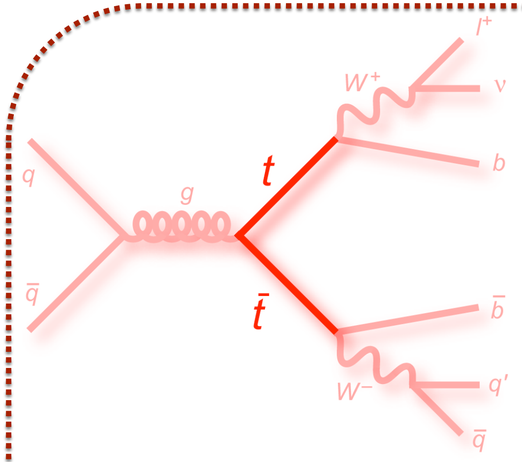
2.2 σ on Z

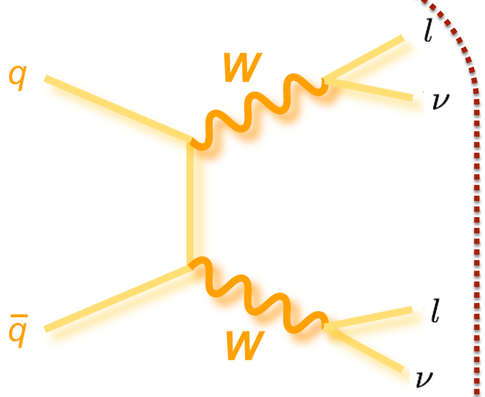
14.7 fb-1

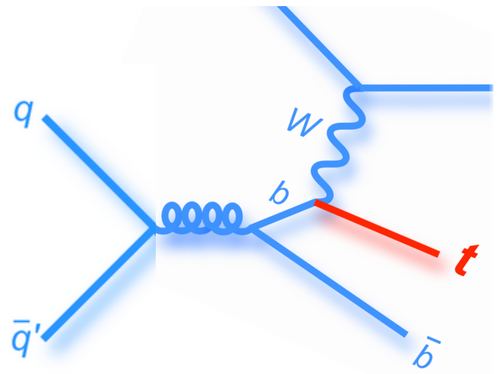
Analysis in the search for strong production with 2 leptons well motivated in SUSY models with possible on Z and kinematic edge excess, and interesting due to observed mild excesses in previous analyses.

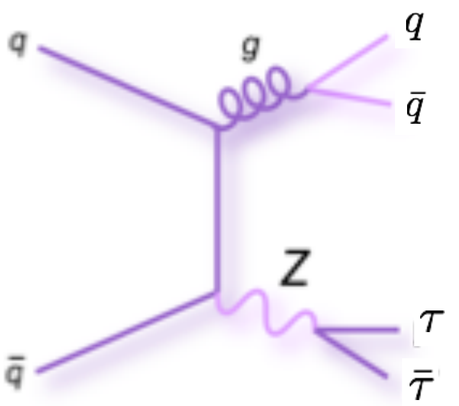
NOW!

DOMINANT BACKGROUNDS







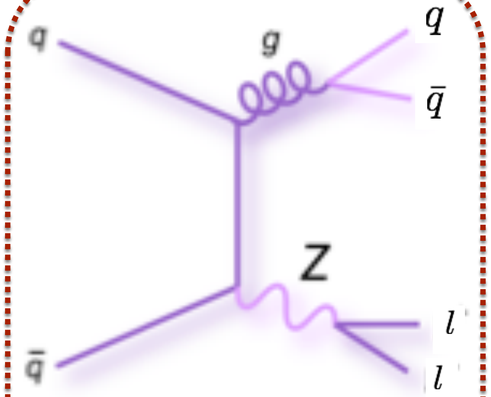


Flavour Symmetric

- Two SF leptons originate from independent $W \to l\nu$ processes

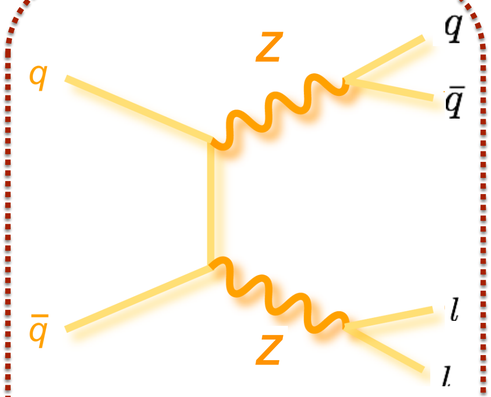
$ee : \mu\mu : e\mu = 1 : 1 : 2$

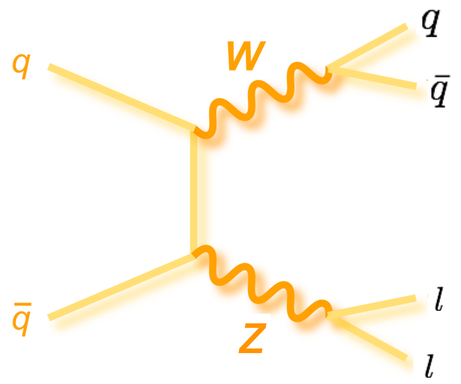
- Dominant background 60-90% in the SR (50-70% $t\bar{t}, WW, Wt, Z \to \tau\tau$).



Z/γ^*+ jets

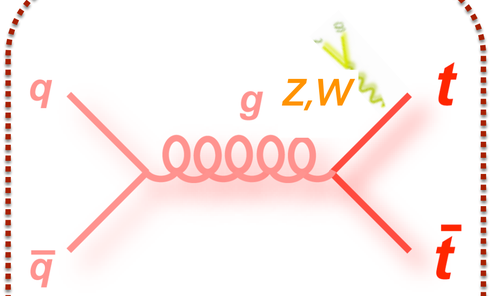
- Large EtMiss from ν in hadronic decay jets miss reconstruction, and leptons miss measurement.
- Not large,difficult to determine.





Diboson

- WZ/ZZ makes 20 -30% of the background.
- Estimated from MC.



Rare t

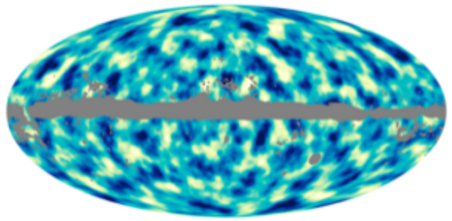
- ttW, ttZ, ttWZ
- Small, ~5% of all backgrounds, determined from MC.

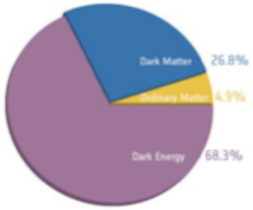
Fakes

- Fake or miss-identified leptons
- 5%, at most 15%

SUSY MOTIVATION

Dark Matter candidate





- Supersymmetry offers a Weakly Interacting Massive Particle (WIMP) candidate.

Hierarchy problem and Naturalness

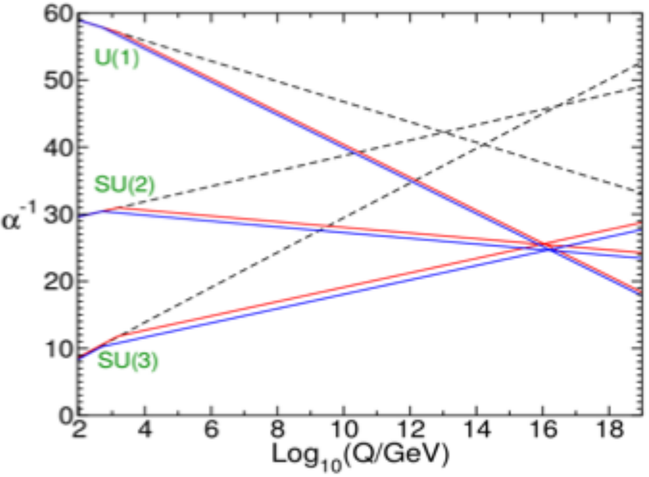
$$\lambda_s = 2y_f^2$$

- **Divergent radiative corrections to Higgs mass cancel out** if for each fermionic loop there is a scalar loop.

$$Q|Boson\rangle = |Fermion\rangle$$
$$Q|Fermion\rangle = |Boson\rangle$$

- **Supersymmetry operator of transformation** turns a bosonic state into a fermionic state, and vice versa.
- Supermultiplet consists of:
  - **Chiral** supermultiplet: SM (**quarks, leptons**) and SUSY partners ('**squarks**', '**sleptons**').
  - **Gauge** supermultiplet: SM gauge **bosons and** SUSY partners '**gauginos**'.
- **Soft SUSY breaking**, large sparticle masses.

Gauge couplings unification



- New physics can be introduced between electroweak and Grand Unified Theory (GUT) scale, which modifies the running of gauge couplings.

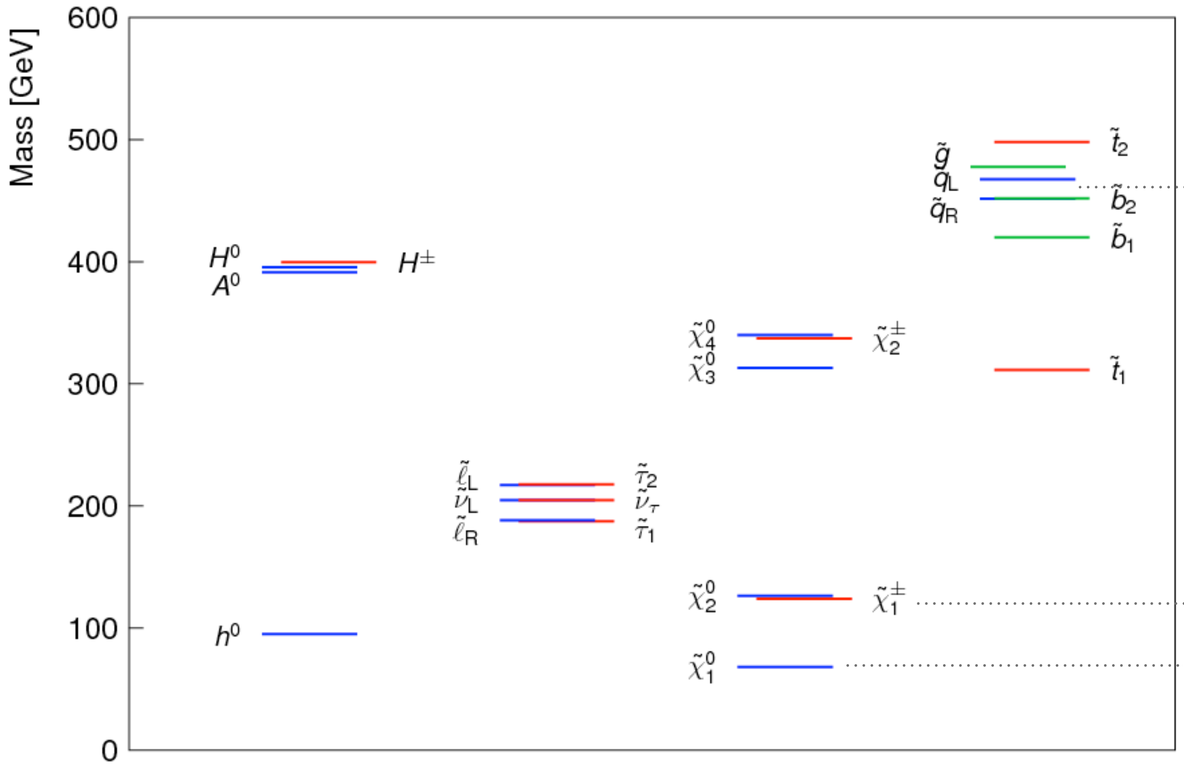
MSSM (Assume minimal number of couplings and fields):

- $\tilde{q}$ and $\tilde{l}$.
- 2 Higgs doublets, 5 Higgs particles (**h,H,A,H±).**
- $\tilde{B}$ and $\tilde{W}$ mix with H, form $\tilde{\chi}^0_{1,2,3,4}$ and $\tilde{\chi}^\pm_{1,2}$.

- **R-parity**, new quantum number introduced:
  - $R = (-1)^{3(B-L)+2S}$
  - SUSY particles produced **in pairs**.
  - **Lightest SUSY particle (LSP) stable**, is a WIMP.
  - **Long decay chains.**

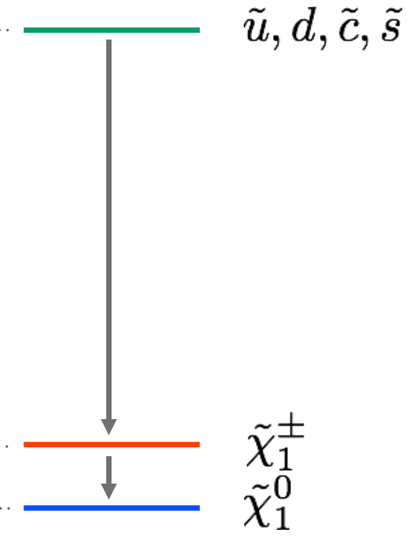
SIMPLIFIED MODELS

- Types of models for analysis:
  - **Realistic** (SUSY breaking model, multiple production channels).
  - **Simplified** (selected sparticles production, decay products).
  - **Phenomenological** (pMSSM).



mSUGRA/CMSSM

- Single process
- Selected sparticles
- Assumed BR (100%)



Simplified squark production

SUSY SEARCH STRATEGIES

- SUSY Analyses:
  - Grouped around production channels.
  - Target broad range of final states.
  - Each analysis defines a set of selections with high sensitivity for considered models.

- Production cross-section:
  - **Strong production**
  - Third generation
  - Electroweak