Search for baryonic number violation at LHC

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Baryonic number violation (BNV)

- The **baryonic** number symmetry is not expected to be **conserved** in BSM physics
  - "**Accidental**" in the SM. Not associated to any fundamental force.
  - Even **violated** in the SM at quantum level (*sphaleron*)
  - Baryonic **asymmetry** in the **Universe.**
    We actually need baryonic violation according to *Sakharov* rules!

    $\longrightarrow$ Necessity to search for BNV at LHC

- However, low energy observations give **strong constraints** on BNV
  - Proton stability
  - $\bar{n}$-n oscillations

- But BNV is still possible at LHC scale [arXiv:1210.6598, C. Smith *et al*]
  - Violation of two units ($\Delta B = 2$) *ex:* $u_i d_j d_k \times u_{i'} d_{j'} d_{k'}$ (with i,j,k flavor indices)
  - Involving third generation

    $\longrightarrow$ Search for **tops** + extra quarks

- LHC is a powerful machine with a **non-zero initial baryonic number** !

R-parity violation (RPV) supersymmetry

- Supersymmetry includes **leptonic** and **baryonic** number violation vertex:

$$W = \mu HL + \frac{1}{2}\lambda_{ijk}L_iL_jE_k + \lambda'_{ijk}L_iQ_jD_k + \frac{1}{2}\lambda''_{ijk}U_iD_jD_k$$

- Originally suppressed by including a R-parity conservation: $R = (-1)^{3(B-L)+2s}$
  - Keep the proton stable
  - Stable and dark-matter-candidate LSP

    $\longrightarrow$ MSSM start to be constrained by the LHC 13TeV limits

- **Alternative**: R-parity violation SUSY
  - By considering a **hierarchy** order between the flavor couplings $\lambda_{ijk}/\lambda'_{ijk}/\lambda''_{ijk}$
  - Achieved in Minimal Flavor Violation (MFV) scenario [arXiv:0710.3129v2]
    - λ''_{3jk} will naturally be the highest term, involving **top** quarks.
  - Enable to respect low energy constraints

    $\longrightarrow$ Allow us to search for BNV processes at LHC scale !

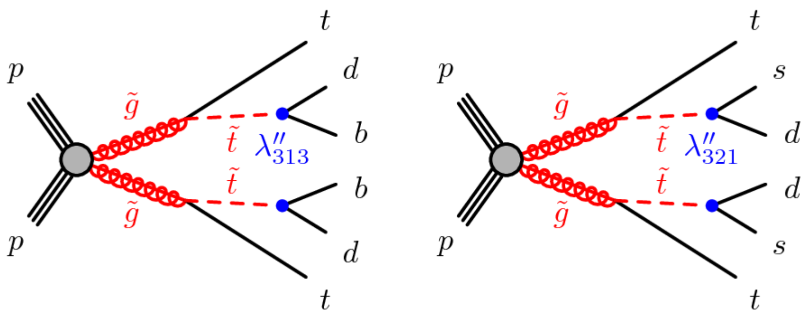
λ''_{IJK}		Full MFV			Holomorphic MFV		
		ds	sb	db	ds	sb	db
$\tan\beta = 5$	u	10^{-5}	10^{-5}	10^{-5}	10^{-13}	10^{-8}	10^{-10}
	c	10^{-4}	10^{-6}	10^{-5}	10^{-10}	10^{-6}	10^{-7}
	t	0.1	10^{-5}	10^{-4}	10^{-6}	10^{-5}	10^{-6}

From arXiv:1307.1355

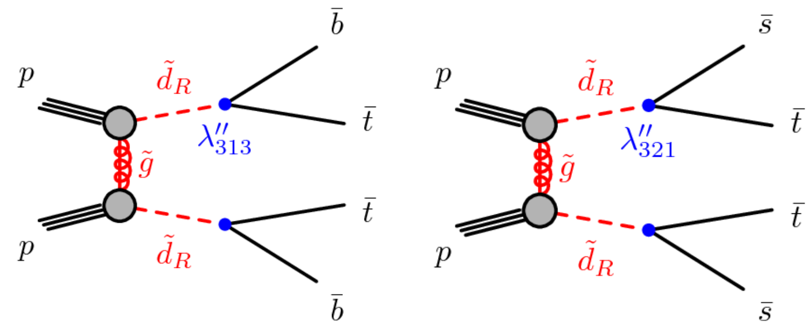
Search for RPV at LHC

- We search for **generic topology** from RPV models involving the 3[rd] generation:

gluino-pair production:



Same-sign d-squark production:



  - $\Delta B = 2$ processes !
  - Leading to **same-sign leptons** + b-jets + **extra jets** (and low MET)

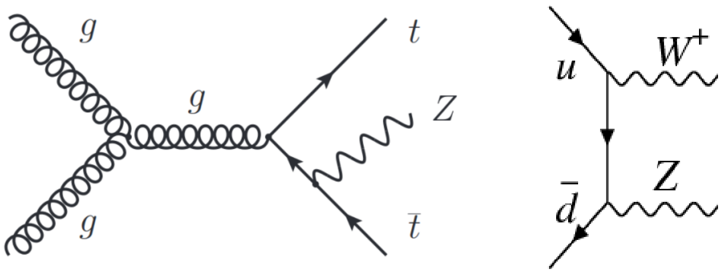
- RPV signal regions defined for 13.2 fb^{-1} of 13TeV data luminosity:
  - Based on **same-sign lepton** requirement
  - Giving the best discovery sensitivity

Signal region	$N_{\text{lept}}^{\text{signal}}$	$N_{b-\text{jets}}^{20}$	N_{jets}	$p_{\text{T,jets}}$ [GeV]	$E_{\text{T}}^{\text{miss}}$ [GeV]	m_{eff} [GeV]	Other
SR1b-DD	≥ 2	≥ 1	≥ 4	50	-	> 1200	≥ 2 negatively-charged leptons
SR3b-DD	≥ 2	≥ 3	≥ 4	50	-	> 1000	≥ 2 negatively-charged leptons
SR1b-GG	≥ 2	≥ 1	≥ 6	50	-	> 1800	-

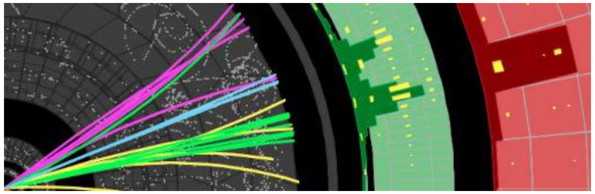
From ATLAS-CONF-2016-037

Background composition

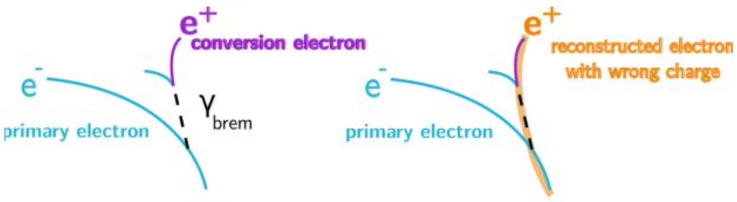
1) **True same-sign/three leptons**
   - From Standard Model
   - Dominant: $t\bar{t} + V$ and VV
   - Simulated by *Monte-Carlo* method



2) **Fake/non-prompt lepton**
   - Light jet reconstructed as lepton
   - Or lepton coming from heavy-flavor jet
   - Estimated by *data-driven* method

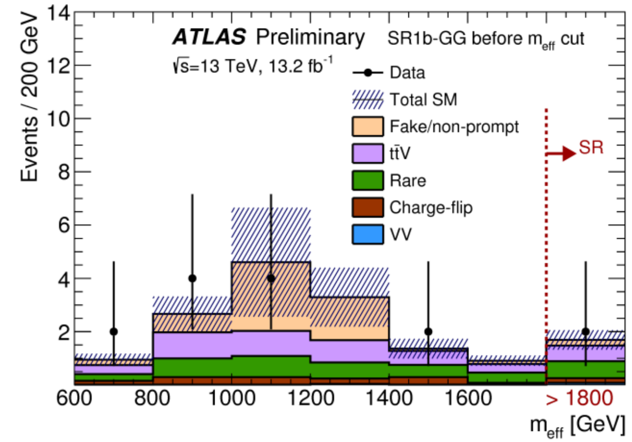


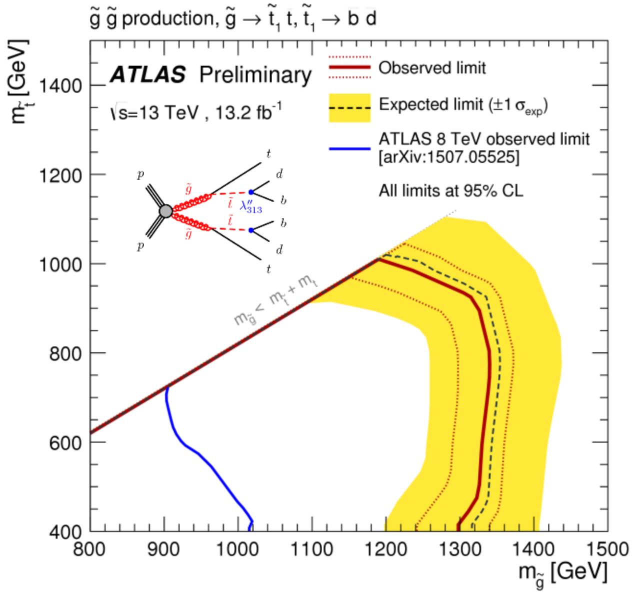
3) **Charge mis-identification**
   - Detector effect
   - Negligible for muon
   - Two sources:
     - **Tracker** charge reconstruction efficiency
     - Electron from **photon conversion**
   - Estimated by *data-driven* method

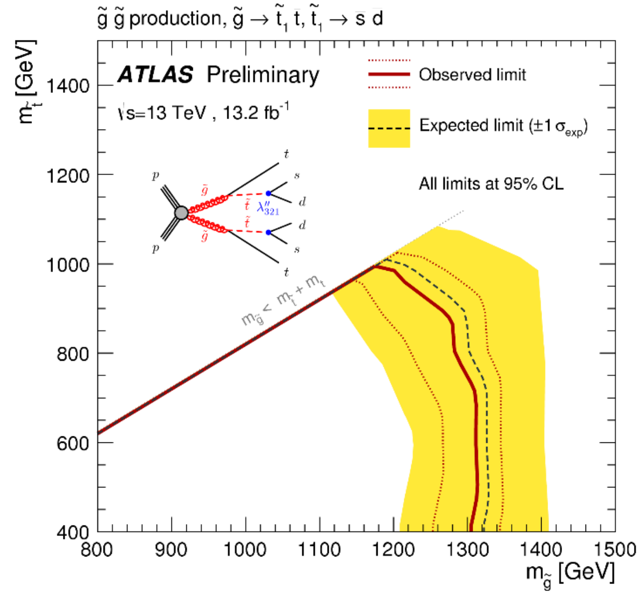


Results (1)

- Comparison data/expected background were performed with 13.2fb^{-1} of data
  - Unfortunately no significant excess was found
  - 95% CL limits are set on simple scenario of RPV models:
    - Assuming branching ratio = 1
    - In 2D mass plane ($m_{\tilde{g}}$,$m_{\tilde{q}}$)



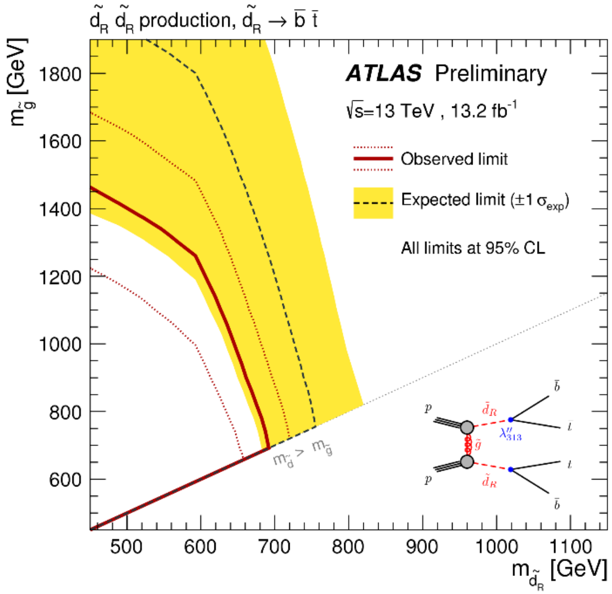


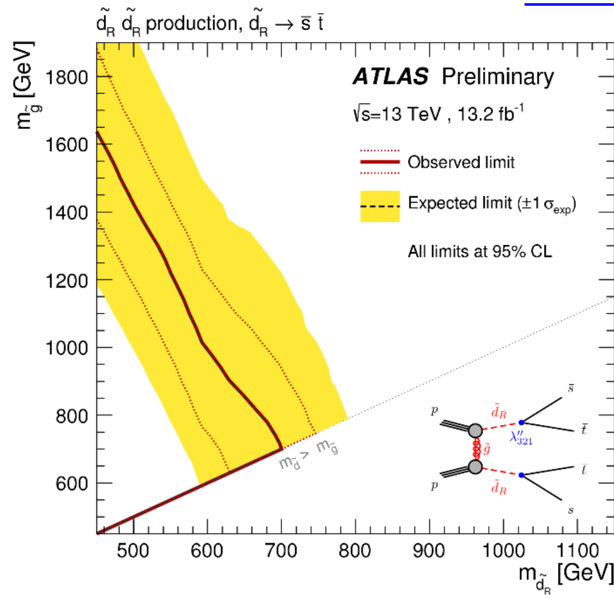


From ATLAS-CONF-2016-037

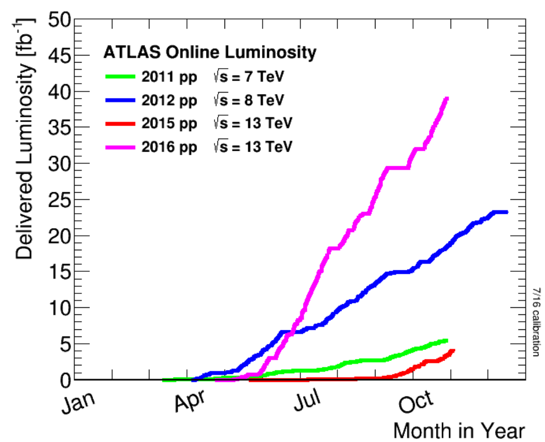
Results (2)

From ATLAS-CONF-2016-037



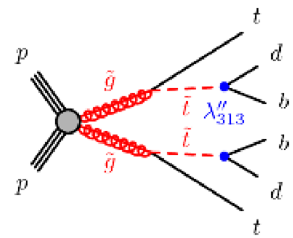


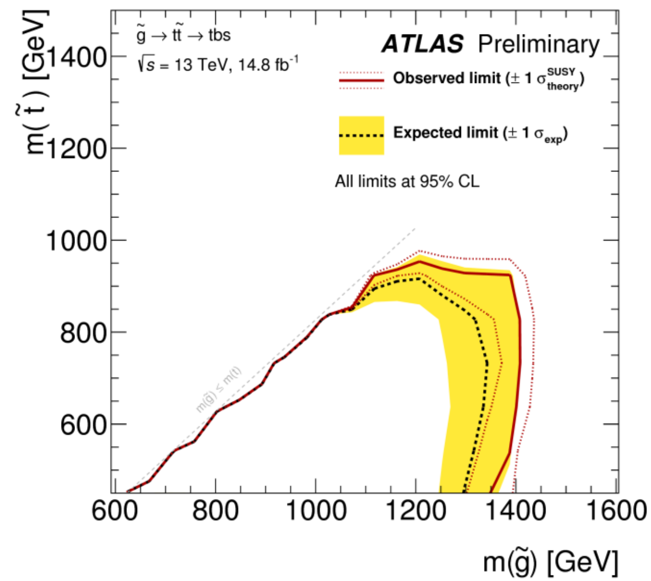
- The search is not over !
  - $36fb^{-1}$ of recorded luminosity this year !
  - We still have sensitivity for a large part of RPV with more luminosity
  - And we have new ideas to improve the search !

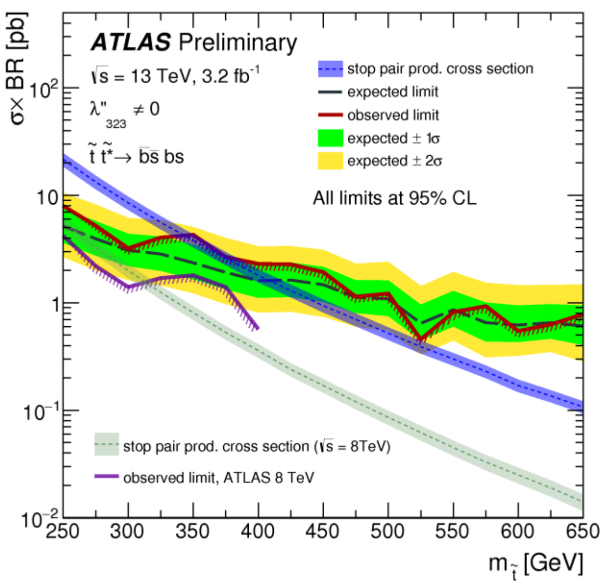


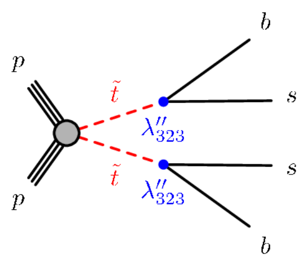
Other baryonic RPV searches in ATLAS

- 1 lepton + multijet search
  - [ATLAS-CONF-2016-094]
  - Targeting gluino pair-production
  - Similar 13TeV limits









- Four-jet final states:
  - [ATLAS-CONF-2016-022]
  - Targeting stop pair-production
  - Stop mass exclusion: ~400GeV

Conclusion

- The search for RPV models is theoretically motivated by the search of baryonic number violation
  - Large effort is performed in the ATLAS collaboration
- For the moment, no excess was found in the ATLAS experiment
- Limits are set on RPV simplified models
- The limits are also re-interpreted by RPV phenomenologists
  - arXiv:1601.03737v4, arXiv:1403.7197v1

Thank you for listening!
Question?

Backup

Low energy constraints on RPV

- Proton stability: $\tau_p > 10^{34}$years

$$|\lambda'_{i1k}\lambda''_{11k}| < 2 \times 10^{-27}(\frac{\tilde{m}}{100\ GeV})^2$$

- $\bar{n}$-n oscillations:

$$|\lambda''_{11k}| < 10^{-7}(\frac{\tilde{m}}{100\ GeV})^{\frac{5}{2}}$$

$$|\lambda''_{321,313}| < 10^{-2}(\frac{\tilde{m}}{200\ GeV})^{5/2}$$

- $\bar{K}$- K oscillations:

$$|\lambda''_{321}\lambda''_{313}| < 10^{-3}\left(\frac{m_{\widetilde{u_i}}}{100\ GeV}\right)$$

arXiv:1602.04821v2

arXiv:hep-ph/0406039v2

Promising processes

ΔB	ΔL	Fermionic cores	Examples	Promising LHC processes	$A_{e\mu}$
0	± 6	NNN NNN	$\nu_e\,\nu_\mu\,\nu_\tau \otimes \nu_e\,\nu_\mu\,\nu_\tau$	$u\,\bar{u} \to e^- \mu^- \nu_\tau \nu_e \nu_\mu \nu_\tau \quad W^+W^+$	0
± 1	± 3	UUU EEN	$t\,c\,u \otimes e^-\,\mu^-\,\nu_\tau$	$u\,c \to \bar{t} \quad e^+\,\mu^+\,\bar{\nu}_\tau$	+
				$u\,g \to \bar{t}\,\bar{c} \quad e^+\,\mu^+\,\bar{\nu}_\tau$	+
				$g\,g \to \bar{t}\,\bar{c}\,\bar{u} \quad e^+\,\mu^+\,\bar{\nu}_\tau$	0
				$u\,c \to \bar{t} \quad e^+\,\mu^+\,\tau^+ \quad W^-$	+
		UUD ENN	$t\,c\,d \otimes e^-\,\nu_\mu\,\nu_\tau$	$d\,c \to \bar{t} \quad e^+\,\mu^+\,\bar{\nu}_\tau \quad W^-$	+
		UDD NNN	$t\,s\,d \otimes \nu_e\,\nu_\mu\,\nu_\tau$	$d\,s \to \bar{t} \quad e^+\,\mu^+\,\bar{\nu}_\tau \quad W^-W^-$	+
± 1	∓ 3	UDD $\bar{\text{N}}\bar{\text{N}}\bar{\text{N}}$	$t\,s\,d \otimes \bar{\nu}_e\,\bar{\nu}_\mu\,\bar{\nu}_\tau$	$d\,s \to \bar{t} \quad e^-\,\mu^-\,\nu_\tau \quad W^+W^+$	−
		DDD $\bar{\text{E}}\bar{\text{N}}\bar{\text{N}}$	$b\,s\,d \otimes e^+\,\bar{\nu}_\mu\,\bar{\nu}_\tau$	$d\,s \to \bar{t} \quad e^-\,\mu^-\,\nu_\tau \quad W^+W^+$	−
± 2	0	UDD UDD	$t\,s\,d \otimes t\,s\,d$	$d\,d \to \bar{t}\,\bar{t} \quad \bar{s}\,\bar{s}$	−
				$d\,g \to \bar{t}\,\bar{t} \quad \bar{s}\,\bar{s} \quad \bar{d}$	−
				$g\,g \to \bar{t}\,\bar{t} \quad \bar{s}\,\bar{s} \quad \bar{d}\,\bar{d}$	0
			$t\,c\,d \otimes b\,s\,d$	$d\,u \to \bar{t}\,\bar{t} \quad \bar{s}\,\bar{s} \quad W^+$	−
				$d\,d \to \bar{t}\,\bar{t} \quad \bar{c}\,\bar{s} \quad W^+$	−

Table 1: *First two columns*: The selection rules for flavor-diagonal B and/or L violation and corresponding six-fermion cores. U, D, E, and N are flavor-generic up-, down-type quarks, charged lepton and neutrino, respectively. Charge-conjugate interactions are understood as well as antisymmetrization over the quark or lepton flavor indexes. *Third column*: Example of non-local fermionic channels corresponding to each fermionic core, with specific flavor assignments. *Fourth column*: Promising flavor-diagonal B and/or L violating transitions to look for at the LHC for each non-local fermionic channel. *Fifth column*: The expected dilepton charge asymmetry, as defined in Eq. (1), for an $e\mu$ final-state pair.

From arXiv:1210.6598

Four-jet search

- Pairing jets with the lower:

$$\Delta R_{min} = \sum_{i=1,2} |\Delta R_i - 1.0|$$

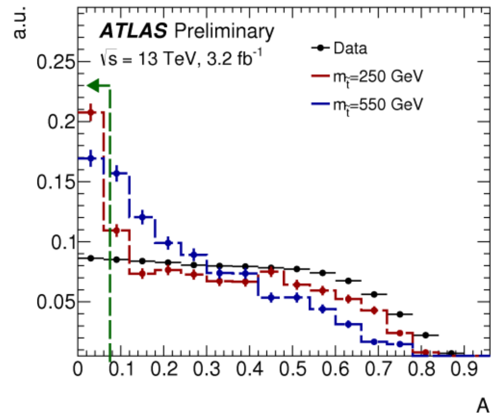
- Selection in A and cosθ*

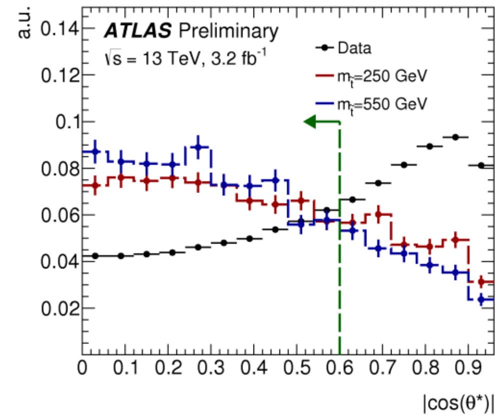
$$A = \frac{|m_1 - m_2|}{m_1 + m_2}$$

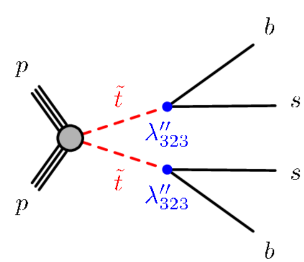
- Search for narrow peak in m_{avg} distribution:

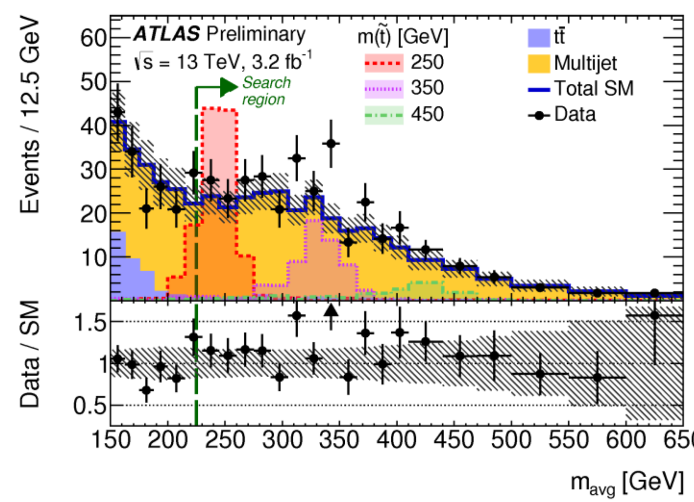
$$m_{avg} = \frac{m_1 + m_2}{2}$$

- Background estimated with ABCD method



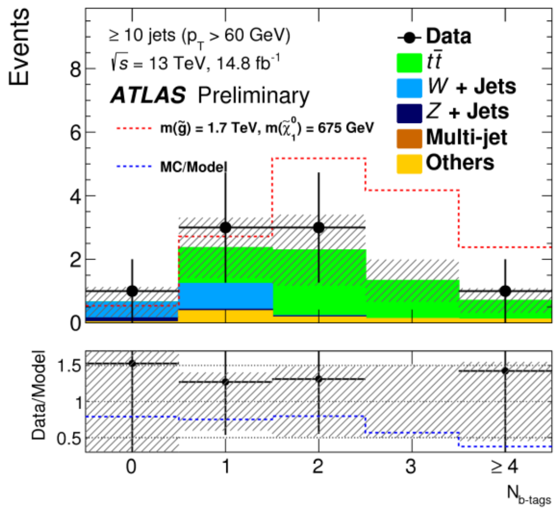


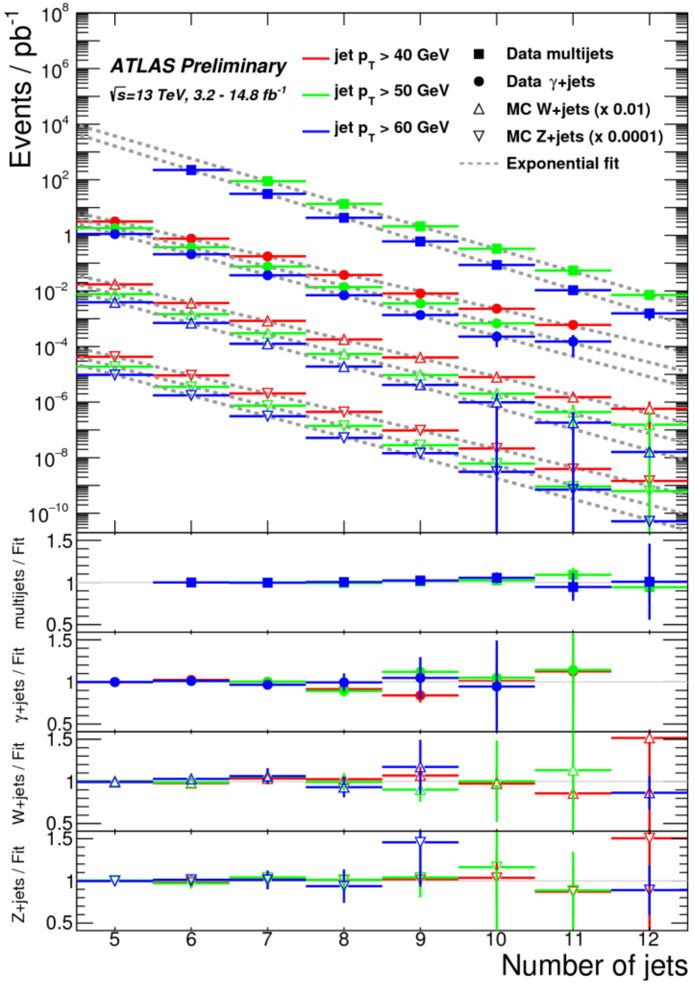




1 lepton + multi-jet

- Requirement: 1lepton and >=5jets
- Template global likelihood fits in jets and b-jets multiplicity





Charge mis-identification: Method

- Based on the **Charge flip rates ϵ**
  - Defined as the probability of one electron to have its charge mis-identified
  - **Parameterized** on Pt and $|\eta|$
- Then, assuming a **true** number of **opposite-sign** dielectron events, we have:

$$N_{SS}^{reco} = N_{OS}^{true}(\epsilon_1(1-\epsilon_2) + \epsilon_2(1-\epsilon_1))$$
$$N_{OS}^{reco} = N_{OS}^{true}((1-\epsilon_1)(1-\epsilon_2) + \epsilon_1\epsilon_2)$$

ϵ_1 charge flip rate of 1st electron
ϵ_2 charge flip rate of 2nd electron

- N_{SS}^{reco} can be estimated by weighting N_{OS}^{reco} by:

$$w = \frac{\epsilon_1(1-\epsilon_2) + \epsilon_2(1-\epsilon_1)}{(1-\epsilon_1)(1-\epsilon_2) + \epsilon_1\epsilon_2}$$

- Charge flip rate estimation on enriched pp→Z→ee data events:
  - $m_{ee} \in [m_z - X, m_z + X]$
    - ex: X=10GeV in **CMS T5/3**
  - Count the number of e^+e^- and same-sign $e^\pm e^\pm$
  - Charge flip rates estimated by Likelihood minimization

$$\mathcal{L}(\epsilon|N, N_{ss}) = Poisson(N_{ss}|N, \epsilon)$$

Fake/non-prompt lepton estimation method

- **Lepton definition:**
  - The fake estimation methods rely on the definition of lepton criteria: **loose** and **tight** criteria
    - **Tight = loose + isolation + identification criteria**
- **Matrix method:**

$$\begin{pmatrix} N_t \\ N_{\bar{t}} \end{pmatrix} = M \begin{pmatrix} N_{real} \\ N_{fake} \end{pmatrix} \quad M = \begin{pmatrix} \epsilon_r & \epsilon_f \\ (1-\epsilon_r) & (1-\epsilon_f) \end{pmatrix}$$

t=tight
$\bar{t}$=loose but not tight

  - N_{fake} is estimated by weighting N_t and $N_{\bar{t}}$ with the elements of M^{-1}
  - Generalized for 2 and 3 leptons
- **Efficiency estimation:**
  - ϵ_f estimated on enriched **fake** lepton region
    - *SS Dilepton* region: Tight muon + 1 loose lepton (V+jets and ttbar)
  - ϵ_r estimated on enriched **real** lepton region
    - *Dilepton* region: Z mass window (Z->ll)
  - **Parameterized** in **Pt** and **|η|** of the leptons

Real and fake efficiency measurement and systematic

- **Efficiency estimation:**
  - ϵ_f estimated on enriched **fake** lepton region
    - *Single lepton* region: Low MET and MT (multijet background)
    - *SS Dilepton* region: Tight muon + 1 loose lepton (V+jets and ttbar)
  - ϵ_r estimated on enriched **real** lepton region
    - *Single lepton* region: High MET and MT (W+jets)
    - *Dilepton* region: Z mass window (Z->ll)

- **Real** lepton contribution are **subtracted** from **fake** region
  - **Systematic** uncertainty associated to this subtraction

- **Kinematic dependence:**
  - Efficiency usually **parameterized** in **Pt** and **|η|** of the leptons
  - **Trigger** can also contain isolation/identification criteria
    The efficiencies can be split for different trigger
  - **Other** kinematic dependence can be also taken into account (ex: Pt_{jet}, ΔR(l,jet)…)
    or be taken as a **systematic** (ex: H_T)