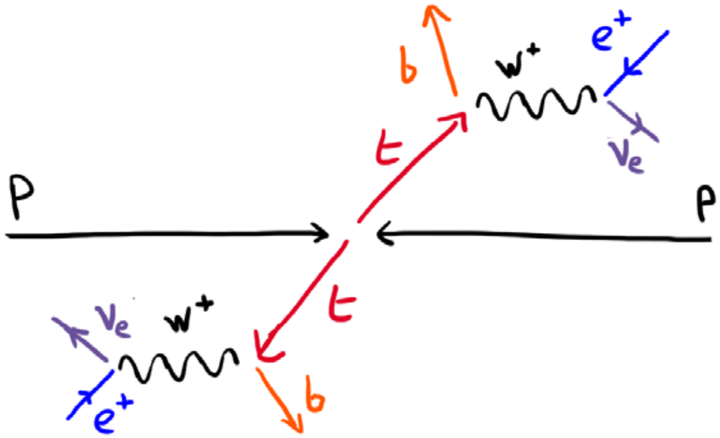
Search for new physics with same-sign top quarks with ATLAS detector

Simon Berlendis

Supervisor: Annick Lleres and Christopher Smith

Introduction

- LHC : **proton-proton** collision
  - Search for Standard Model deviation
  - “top factory”: produce mainly opposite-sign top quarks $t\bar{t}$
- Search for a more exotic signal: **same-sign top quarks**



  - Predicted by several Beyond Standard Models (BSM)
  - Signature: **same-sign leptons** + b-jets + Missing energy (from ν‘s)
- Several sources of **background** can have the same signature
  - Need to use **sophisticated techniques** to estimate them accurately

Contents

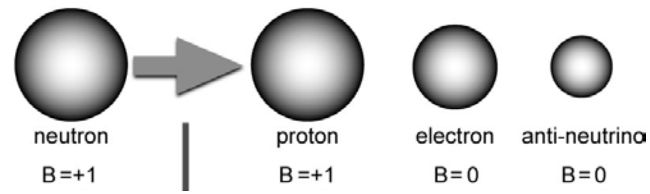
I. **Phenomenology:**
R-parity violation supersymmetry model for the search of baryonic number violation

II. **Data analysis:**
Background estimation by data-driven and Monte-Carlo simulation

Baryonic number symmetry paradox

- Baryonic number:
  - Baryon (ex: proton) **B=+1**
  - Anti-baryon (ex:anti-proton) **B=-1**
  - Everything else **B=0**

Symmetry (at tree level)
In the Standard Model



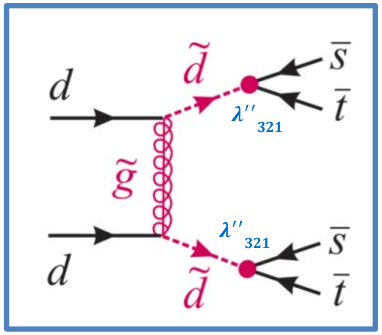
- On one hand:
  - This symmetry is **accidental** in the Standard Model
  - No theoretical reason to be respected in BSM models
  - **Baryonic asymmetry** in the Universe

- One the other hand:
  - Low energy observations put strong constraints on baryonic number violation
    - Proton stability
    - Neutron-antineutron oscillation
  - For example: MSSM adds a parity to remove baryonic violation: **R-Parity**

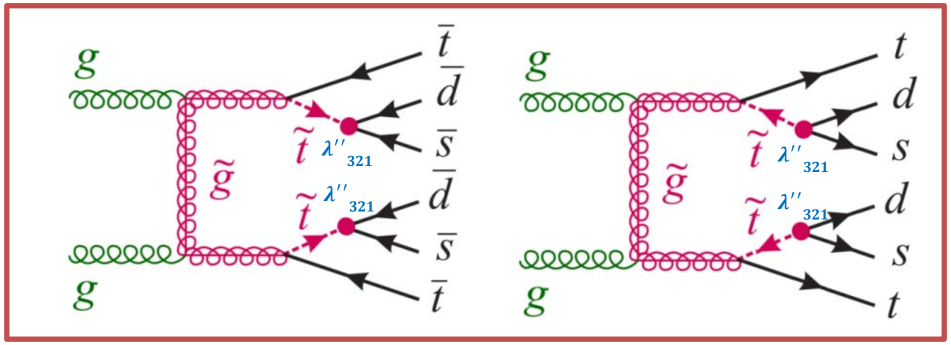
Same-sign top quarks

- Violation baryonic number is possible at LHC [arXiv:1210.6598, C. Smith *et al*]
  - Respecting low energy constraints only if involving top quarks
- Can be achieved with a model:
  - **R-Parity violation** supersymmetry model (**RPV**)
  - MSSM + extra vertex $W = \frac{1}{2}\lambda''_{ijk} U_i D_j D_k$
  - Leading to two signal topologies

d-quark scattering (DD)



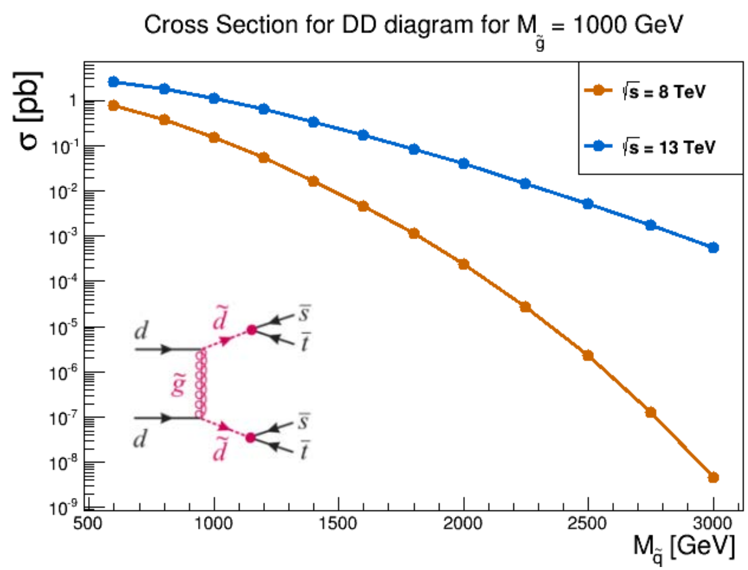
gluon fusion (GG)

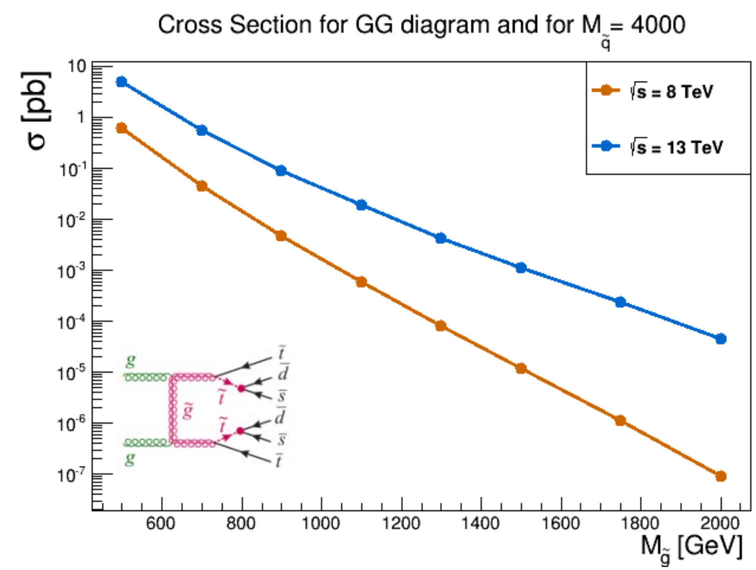


- I decided to use this model as a **generic model** for the search for baryonic number violation processes

Signal generation

- Need to predict the **signature** at LHC by **Monte-Carlo** simulation
- I've built a setup to generate signal samples with ATLAS software
  - Based on **MadGraph5** for short distance physics and **Pythia8** for long distance physics
- Cross-sections at 8 and 13TeV:



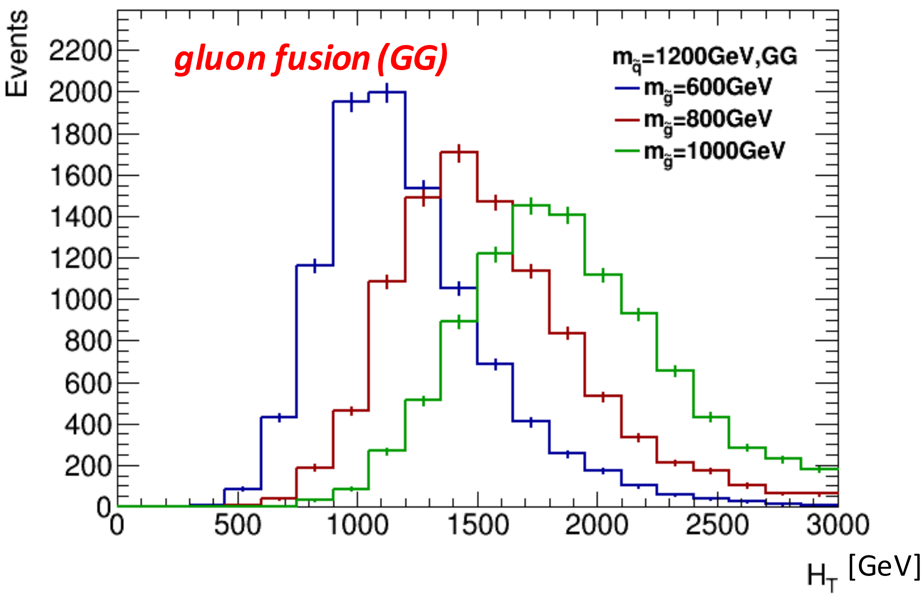


- Signal generation **approved** by ATLAS
  - Production step launched
  - Will be available for first 2016 data
  - Plan to use this model for ICHEP 2016

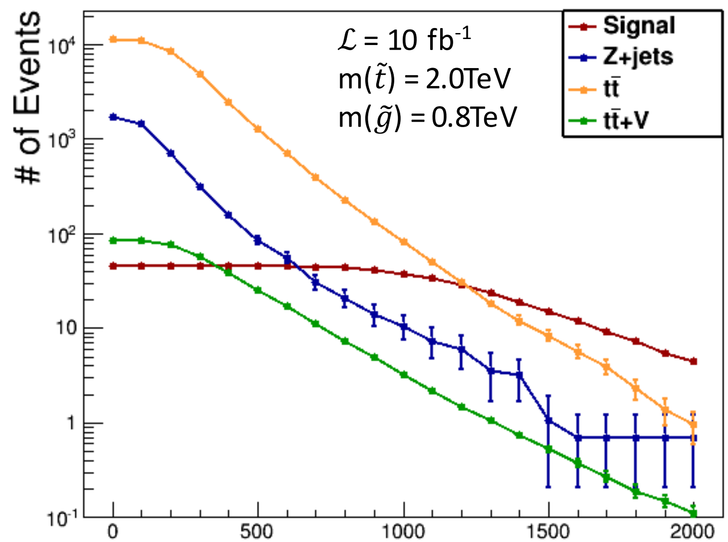
Signal region optimization

- Test of different selections:
  - **Aim**: find the best signal region
  - Preliminaty study: no detector simulation

Jet activities (∑Pt)



Number of Events



- Signal region proposal:
  - Same sign leptons, $N_{jet} \geq 3$ and $N_{bjet} \geq 1$
  - $HT = \sum Pt_{jet} \geq 1500$ GeV

Will be updated with detector simulation

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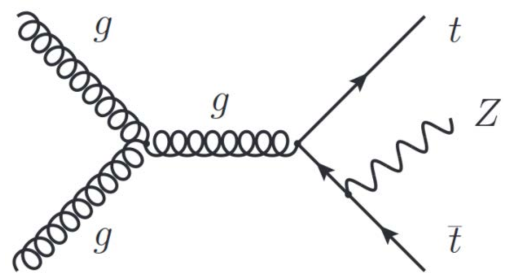
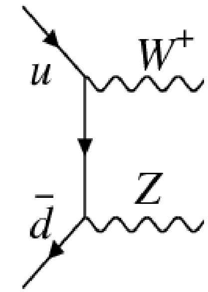
Background composition

1) Prompt same-sign leptons

- From Standard Model
- Dominant: $t\bar{t}+V$ (σ_{fid}≈20fb) and VV (σ_{fid}≈300fb)
- Simulated by *Monte-Carlo* method

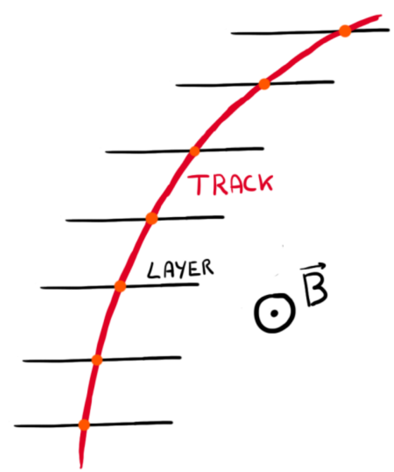




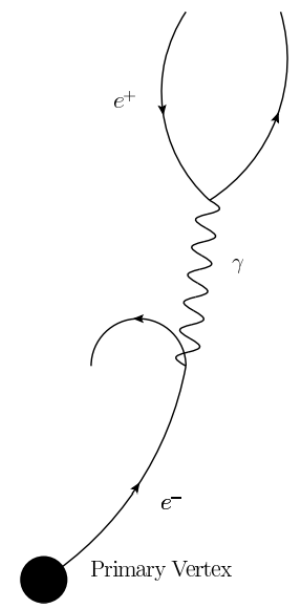
2) Charge mis-identification

- Detector effect
- Negligible for muon
- Two sources:
  - **Tracker** charge reconstruction
  - Electron from **photon conversion**
- Estimated by *data-driven* method

Inner tracker:



Photon conversion:



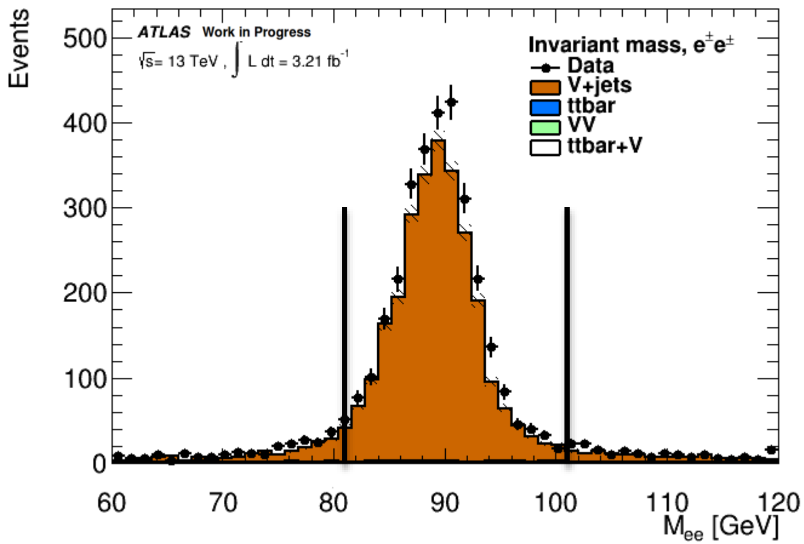
3) Fake/non-prompt lepton

- Jet reconstructed as lepton
- Lepton coming from jet
- Estimated by *data-driven* method

Charge mis-identification bkg estimation: Principle

- Let’s define the charge flip rate ϵ:
  - probability of one electron to have his charge mis-identified
  - Assumed to be dependent on pt/|η|

- Estimation of the charge flip rates on enriched pp→Z→ee data events:
  - Z invariant mass window
  - Count the number of e^+e^- and the number of same-sign $e^\pm e^\pm$
  - ϵ estimated by **likelihood minimization**

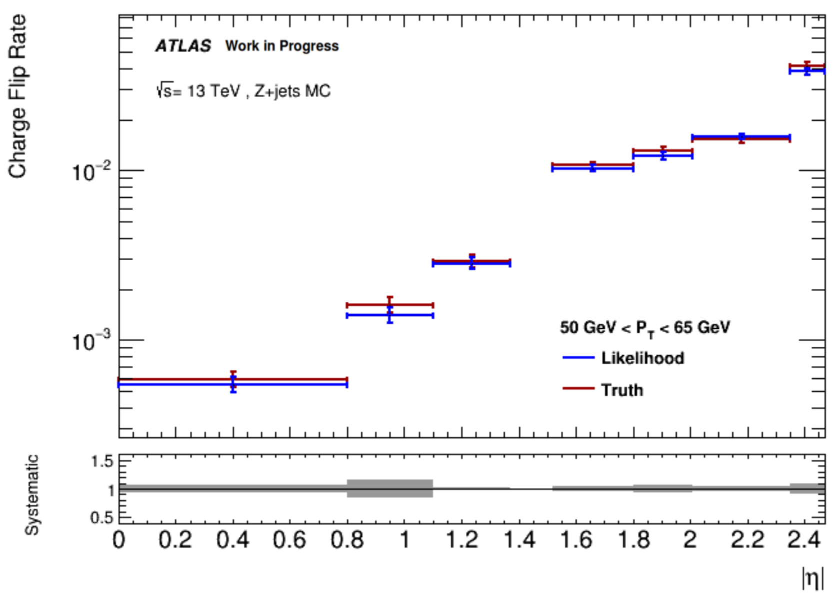


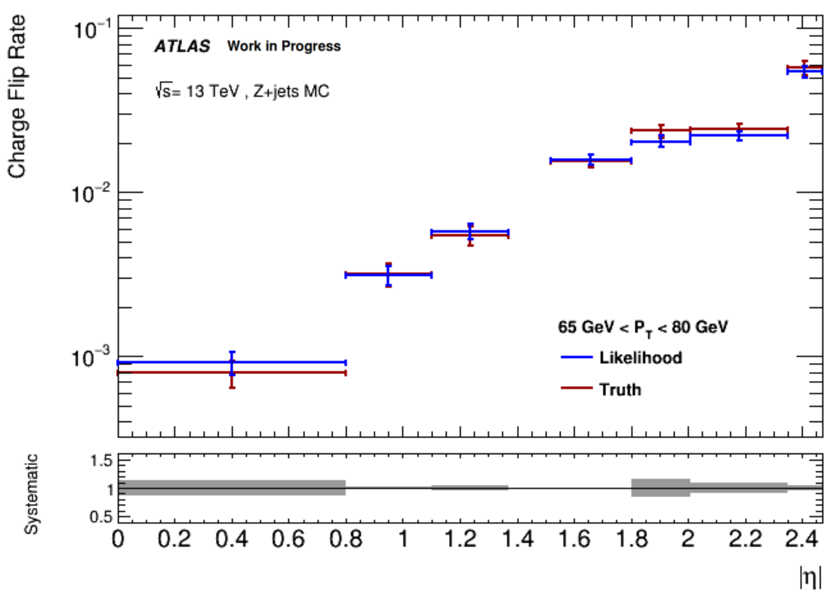
- One can then estimate the Charge MisID background by weighting the opposite-sign events by:

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

Technicalities and cross checks

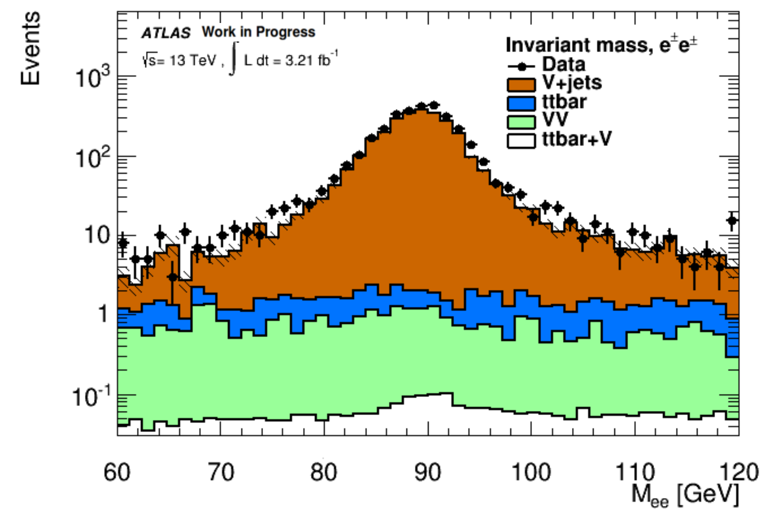
- I built a c++ code:
  - Extract N and Nss for a given pt/|η| binning
  - For a given Z-mass window
  - And minimize the likelihood
- Cross-checks:
  - compare the results with a truth matching method on a Monte-Carlo simulation



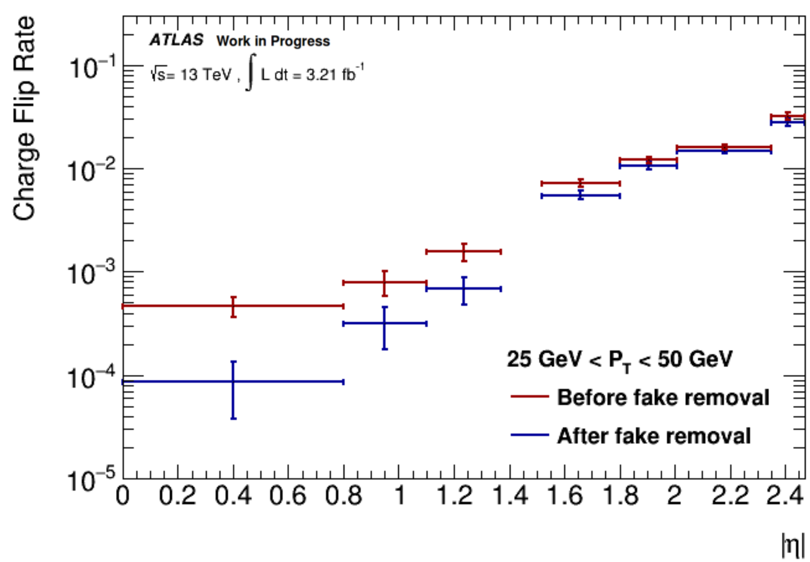


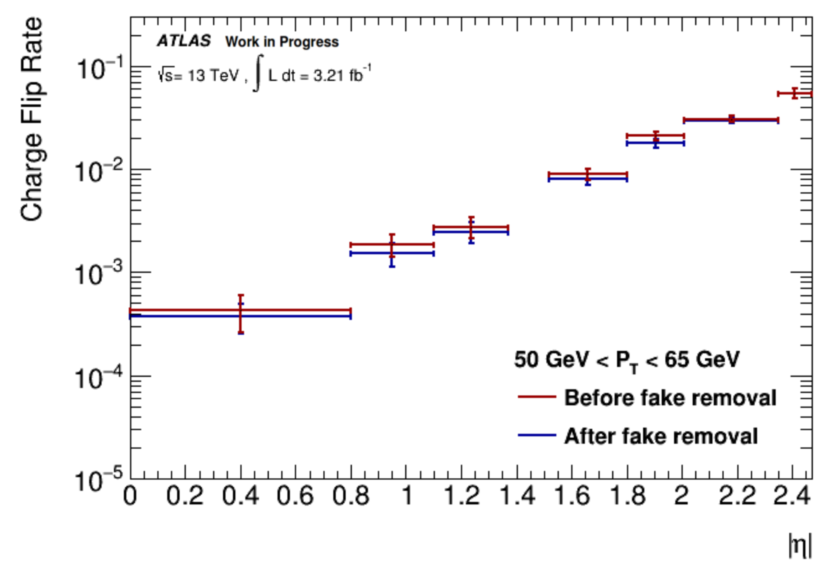
Background and fake subtraction

- Other dilepton processes can affect the region
  - Use outside region to estimate the amount of other background in the Z-mass window
  - We use a sideband subtraction of 10 GeV



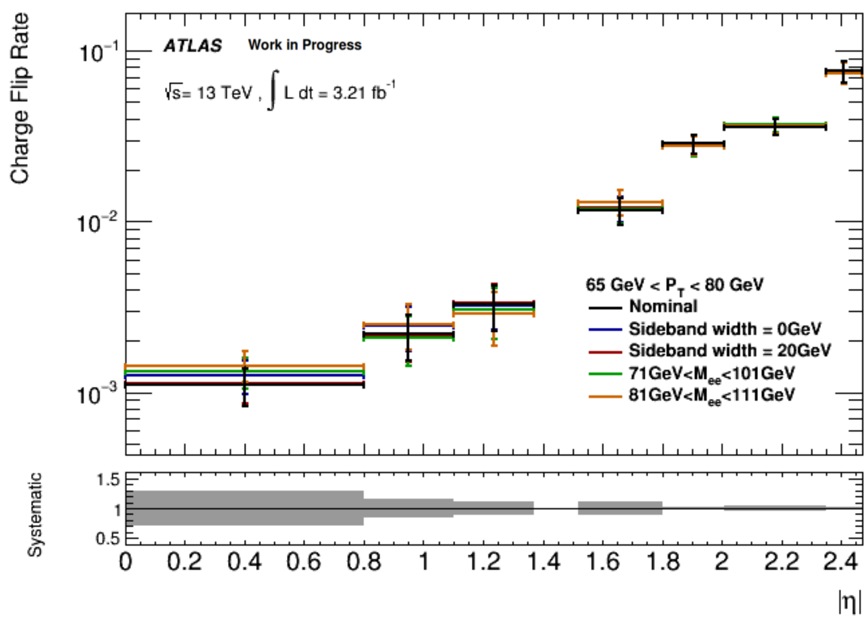
- Overlap between Fake and ChargeMisID need to be removed
  - Charge MisID events can be taken as fake
  - I remove the fake estimation in each N, Nss bins

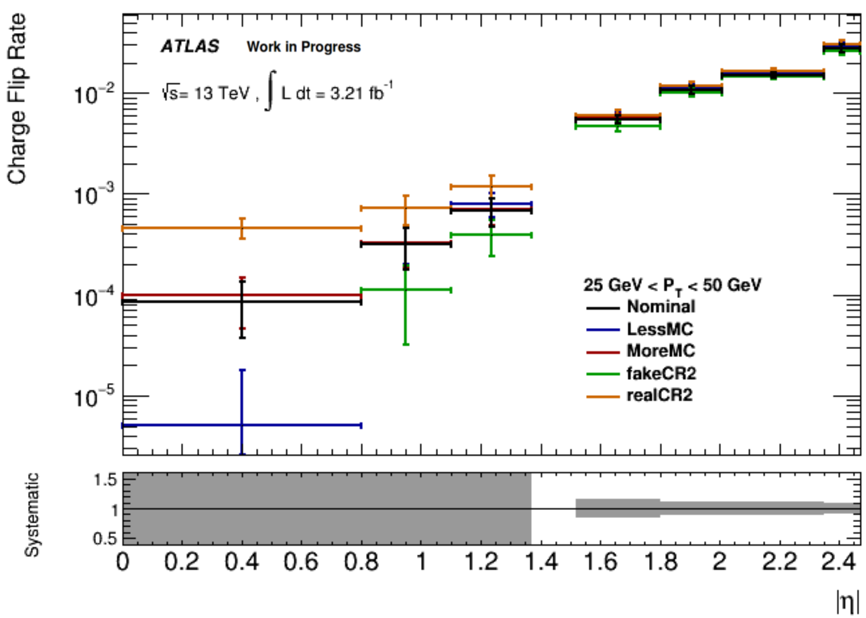




Systematics Uncertainty on charge flip rates

- Uncertainty sources:
  - Statistical uncertainty from likelihood minimization method
  - Difference between truth-matching and likelihood method on MC sample
  - **Z mass window and sideband definition variation**
  - **fakes/non-prompt estimation systematic**



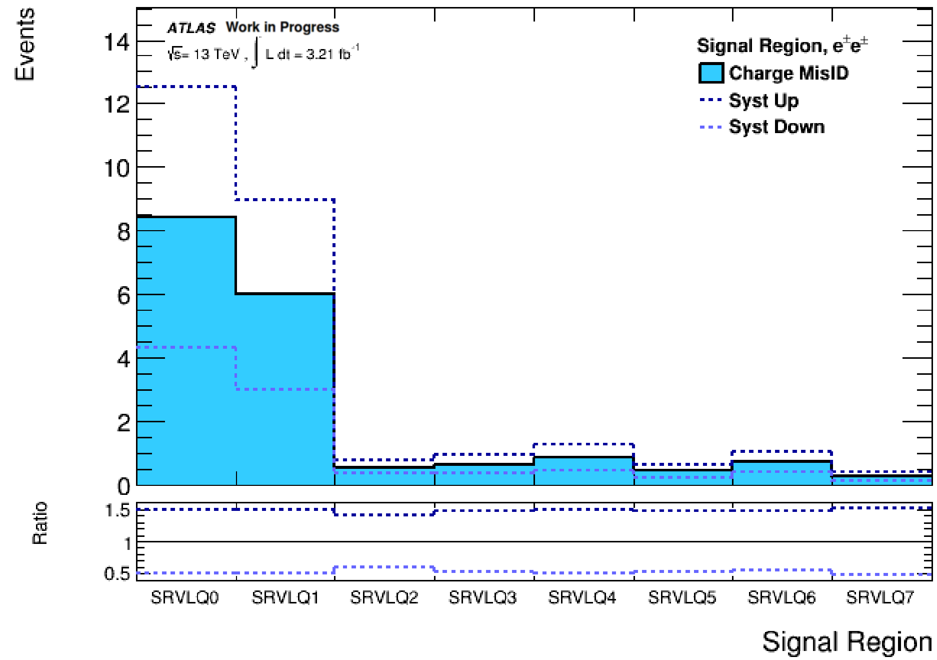


Signal regions

- Estimate of charge mis-identification background :

Signal regions optimized for different other BSM models:

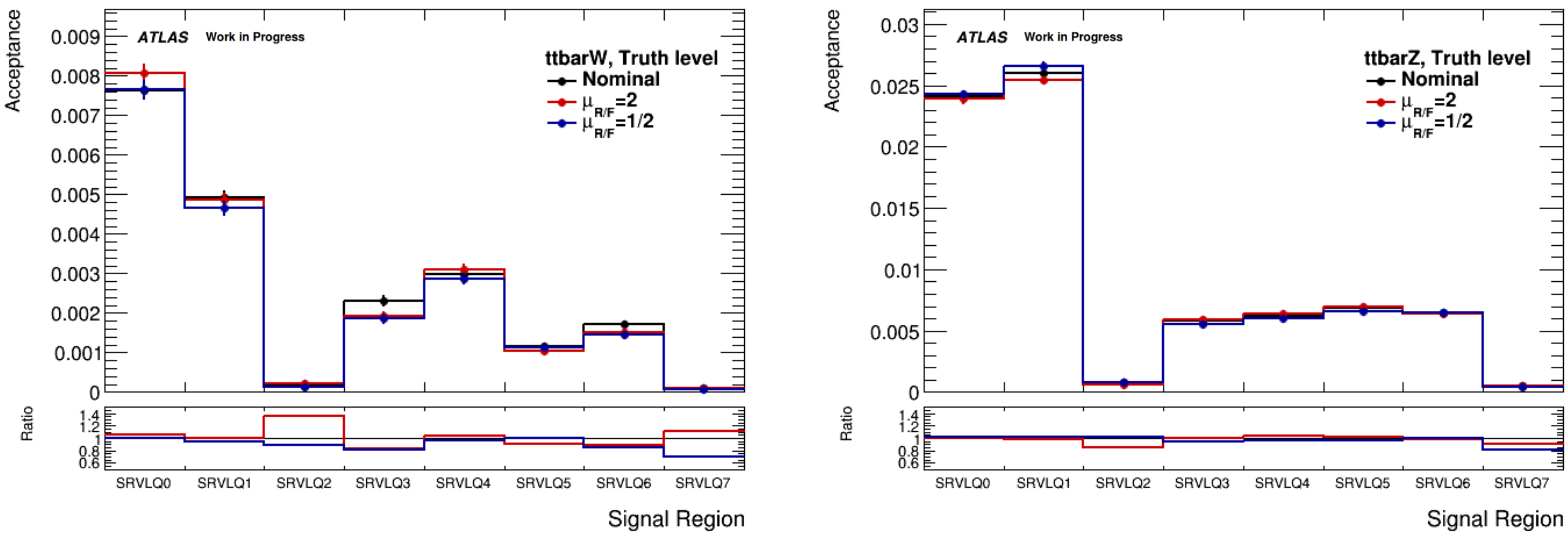
Definition			Name	
$400 < H_T < 700$ GeV	$N_b = 1$	$E_T^{miss} > 40$ GeV	SRVLQ0	
	$N_b = 2$		SRVLQ1	SR4t0
	$N_b \geq 3$		SRVLQ2	SR4t1
$H_T \geq 700$ GeV	$N_b = 1$	$40 < E_T^{miss} < 100$ GeV	SRVLQ3	
		$E_T^{miss} \geq 100$ GeV	SRVLQ4	
	$N_b = 2$	$40 < E_T^{miss} < 100$ GeV	SRVLQ5	SR4t2
		$E_T^{miss} \geq 100$ GeV	SRVLQ6	SR4t3
	$N_b \geq 3$	$E_T^{miss} > 40$ GeV	SRVLQ7	SR4t4



- Currently checking agreement between background/data on control regions
- Systematic will be optimized in the future

Monte-Carlo generation and systematic uncertainty

- Monte-Carlo generation of rare background processes:
  - $t\bar{t}t\bar{t}$ and $t\bar{t}+WW$
- Systematic uncertainty estimation
  - Ex: Variation of factorization and renormalization scale μ



- Technical involvement on the performances of new Monte-Carlo generators

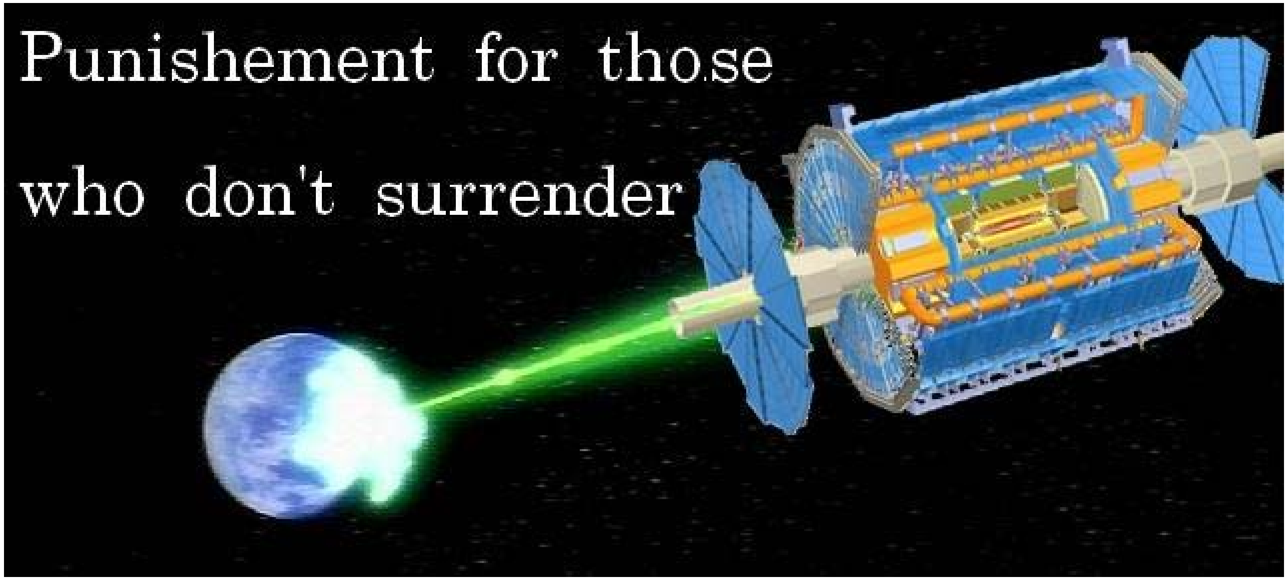
Conclusion

- ATLAS authorship since November 2015
  - 4 papers since then
  - 2 in preparation

- Performed a phenomenology-related work:
  - Implementation of a new **theoretical-motivated** model
  - **Approved** by ATLAS
  - To be used on **2016 data**

- Active and **central** role in data analysis:
  - Background **estimation** by data-driven method
  - Technical involvement on **Monte-Carlo simulations**

- Ready to go ahead with the future 2016 data !
  - And let's hope that new physics will come up significantly :)



Thank you for your attention

Questions ?

Backup

Papers

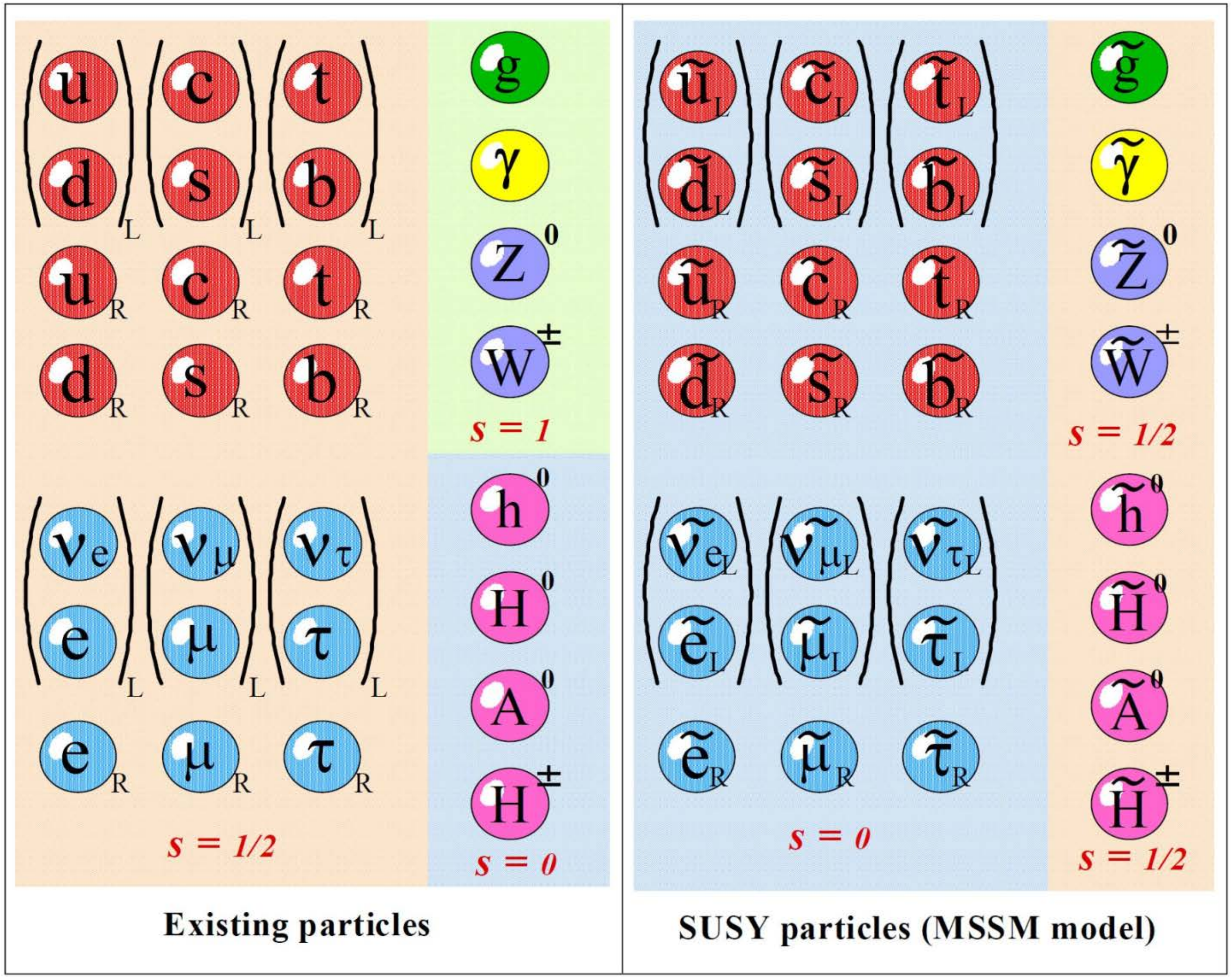
- *Current papers:*
  - Search for supersymmetry at sqrt{s}=13 TeV in final states with jets and two same-sign leptons or three leptons with the ATLAS detector, 2016, **arXiv:1602.09058**
  - Search for supersymmetry at sqrt(s)= 13 TeV in final states with jets and two same-sign leptons or three leptons with the ATLAS detector, 2015, **ATLAS-CONF-2015-078**
  - Studies on the MC generator modelling of ttX (X=W,Z,gamma,Higgs or heavy flavor jets) processes as used in Run2, 2015, **ATL-PHYS-PUB-2016-005**
  - Studies on the MC generator modelling of boson+jets processes as used in Run2, 2015, **ATL-PHYS-PUB-2016-003**

- *In preparation:*
  - Search for new physics in SS+b-jets final states at 13 TeV
  - A study of optimal parameter setting for MadGraph5+Pythia8 matched setup

- *In the future:*
  - RPV Susy contraints at sqrt(s)= 13 TeV [for ICHEP2016]

Supersymmetry

- For any SM particle, there is a supersymmetric partner:



MSSM = Minimal Supersymmetric Standard Model

R-Parity Violation

- Variant of Susy: **R-Parity Violation** SUSY (RPV)
- Adding extra violating leptonic number L and baryonic number B:

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

- Originally removed in MSSM by adding the R-Parity

$$R = (-1)^{3(B-L)+2s}$$

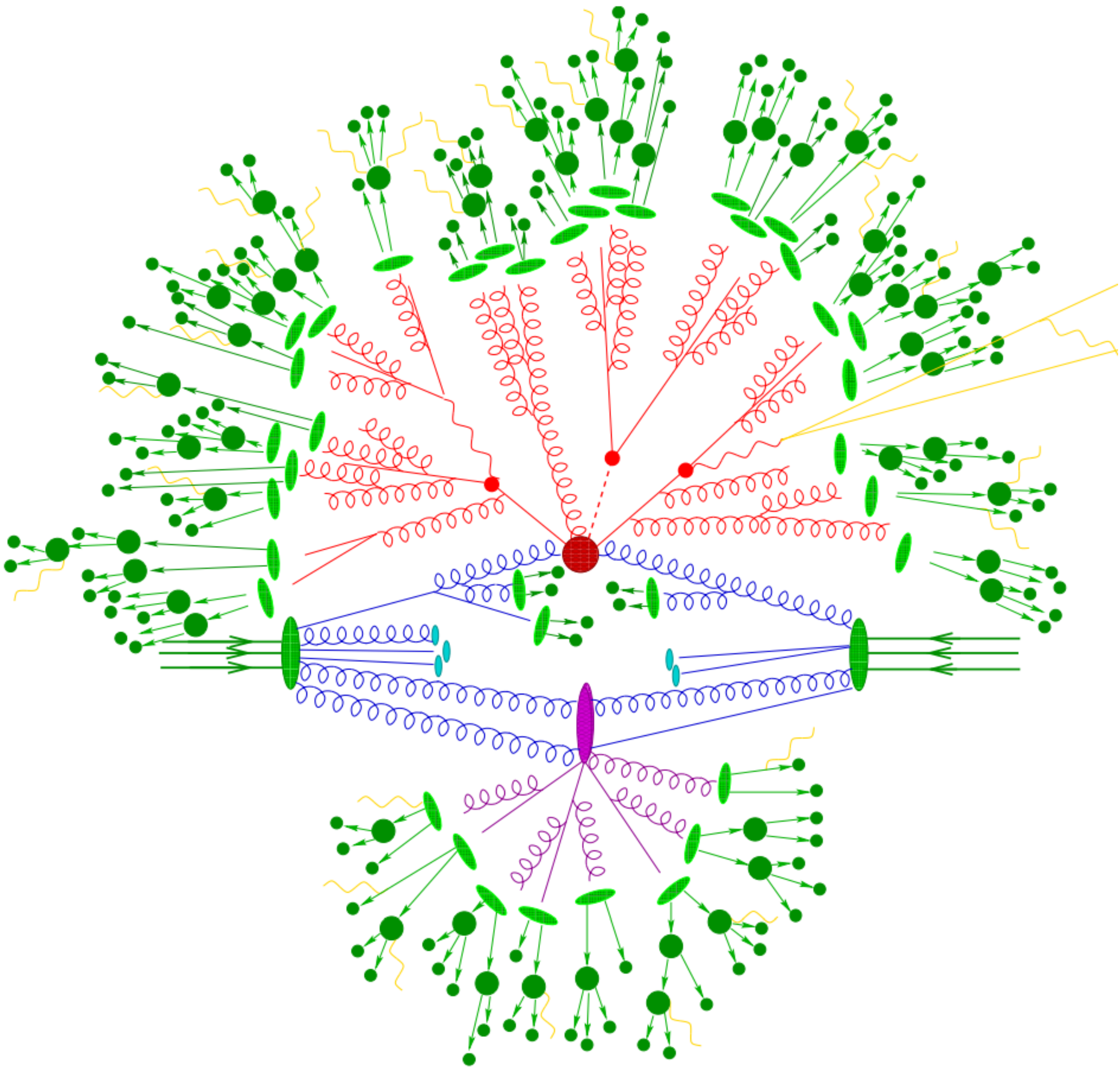
  - Enable to keep the **proton stable** and to have a **Dark Matter** candidate (LSP)
- In this RPV model, we consider only one $\boldsymbol{\lambda''_{ijk}}$ coupling and suppress the others :
  - Involving top quarks (ex: $\boldsymbol{\lambda''_{321}TSD}$)
  - Achieved by Minimal Flavor Violation models imagined by C.Smith *and all*
  - Can respect the low energy constraints on baryonic number B violation

Monte-Carlo Generations description

Monte-Carlo Desciption:

- Hard Interaction
  - Matrix element
- QCD bremsstrahlung
  - Parton showers
- Hadronization
  - non-perturbative QCD
- Hadron Decays
- Multiple Interactions

and etc



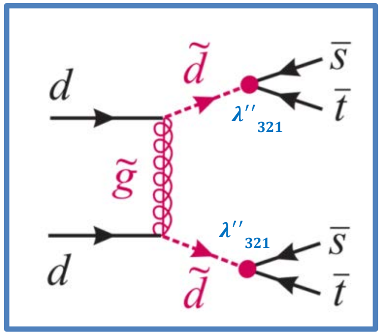
Generators:

- MadGraph5
- Pythia8
- Sherpa

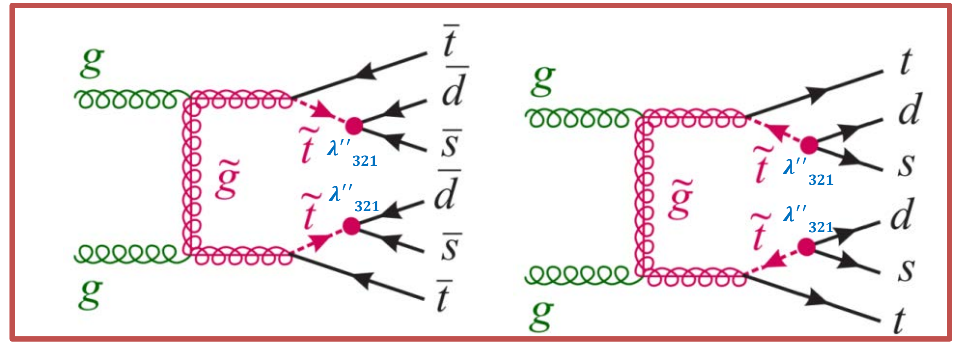
Same-sign top signal with RPV

- Two signal topologies are considered:

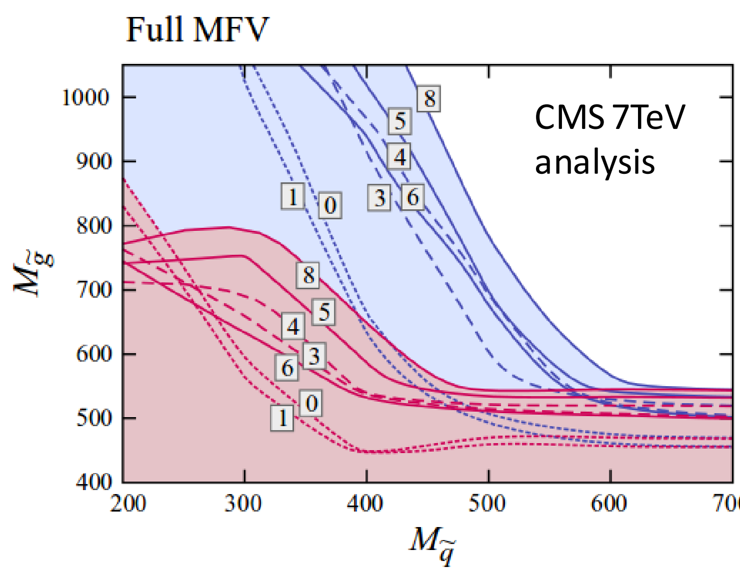
d-quarks scattering (DD)



gluons fusion (GG)

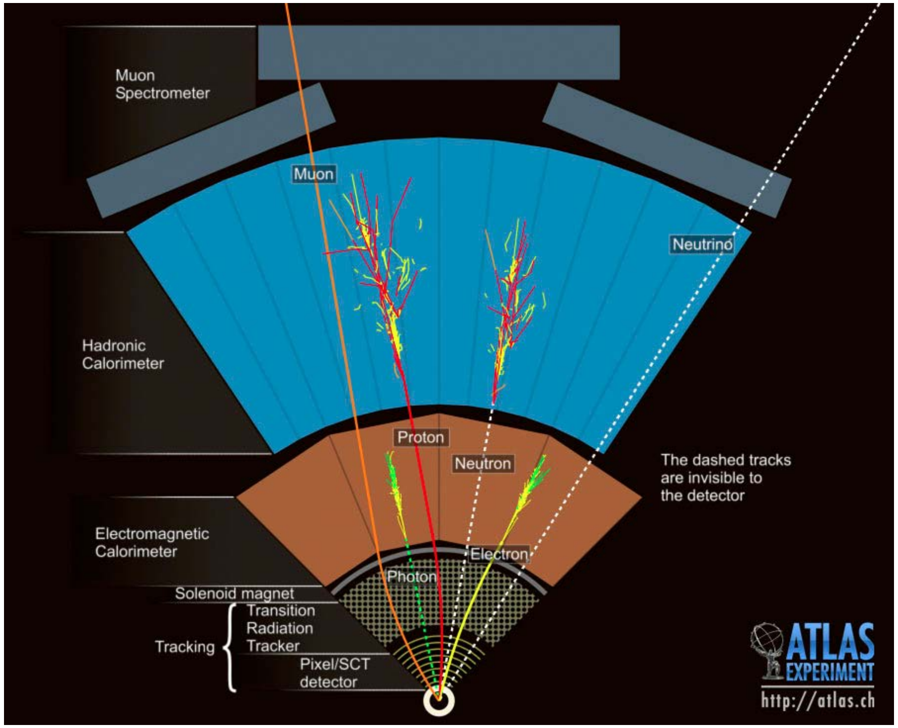


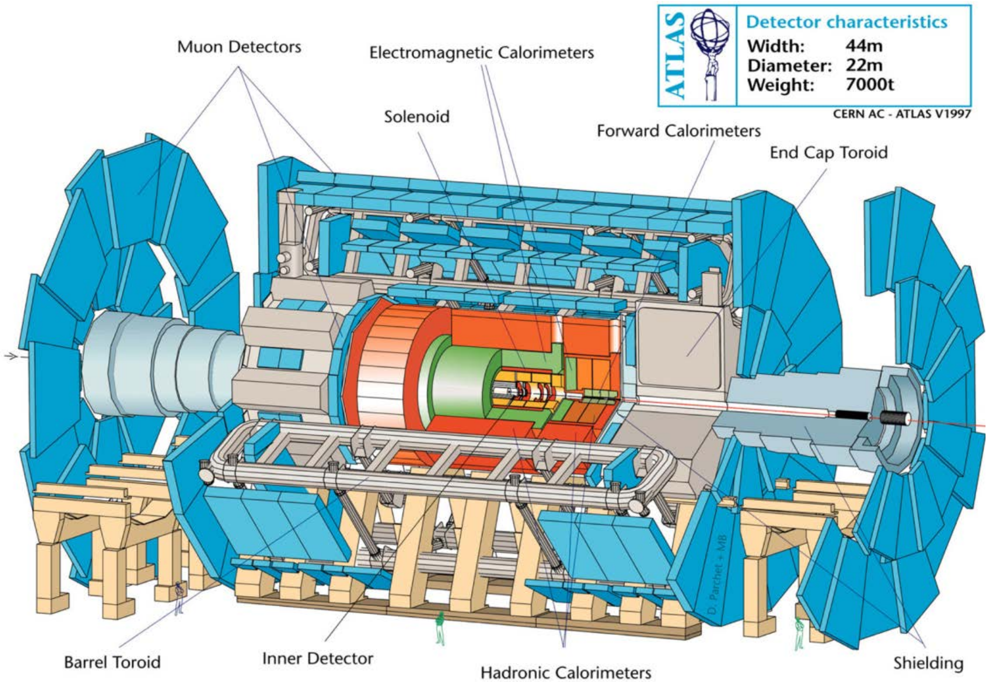
- Leading both to same-sign top quarks
- Several advantages:
  - Low constraints at 7 TeV
  - The baryonic number is violated by ΔB=2. It's a powerful generic model to test the baryonic violation at LHC !
  - Easy to select with the jet activities



G.Durieux and C.Smith

- The Large Hadron Collider
  - Proton collision with energy of center of mass at 13TeV
- ATLAS particle detector:

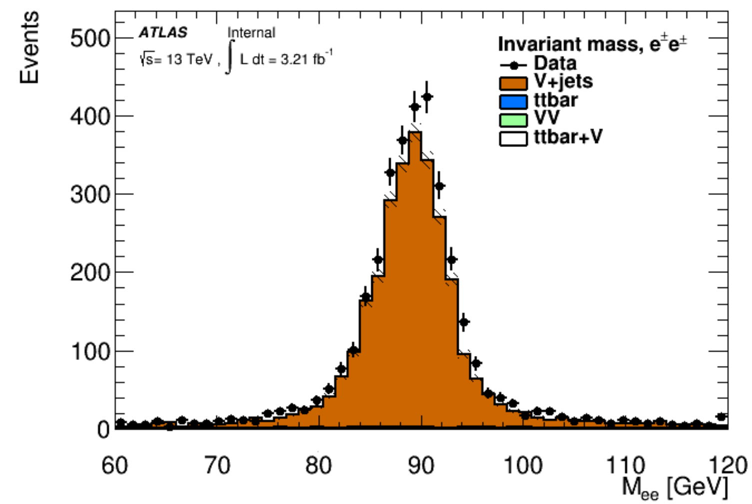




Charge mis-identification bkg estimation: Principle

- Let's define the charge flip rate ϵ:
  - probability of one electron to have his charge mis-identified
  - Assumed to be dependent of pt/|η|
- Then, we can expect :

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



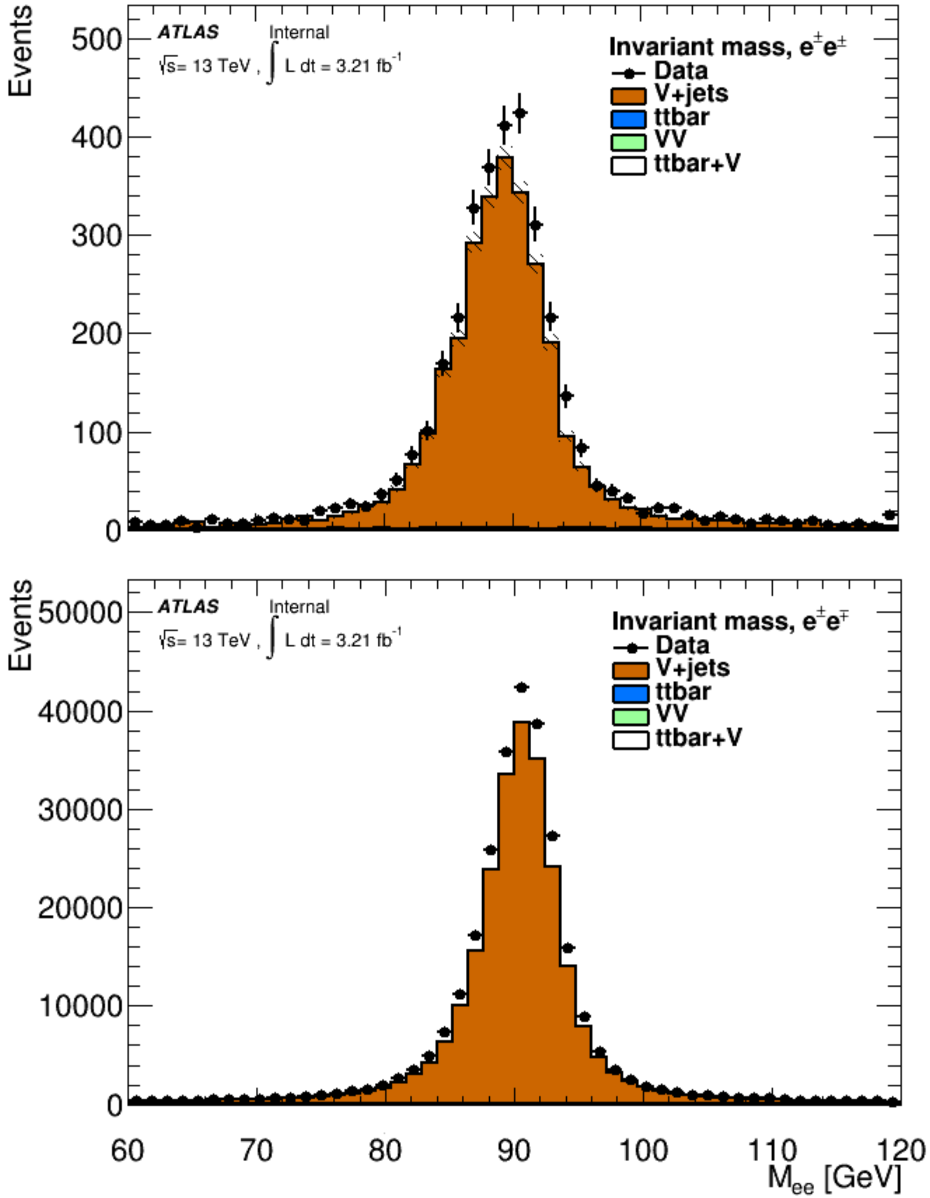
- Estimation of the charge flip rates on enriched pp→Z→ee data events:
  - On Z invariant mass window
  - Count the number of same-sign electrons N_{ss} and di-election N for each pt/|η| bins
  - Minimize the following likelihood:

$$-lnL(\epsilon|N_{SS}, N) = \sum_I ln[N(\epsilon_1(1-\epsilon_2) + \epsilon_2(1-\epsilon_1))]N_{SS} - N(\epsilon_1(1-\epsilon_2) + \epsilon_2(1-\epsilon_1))$$

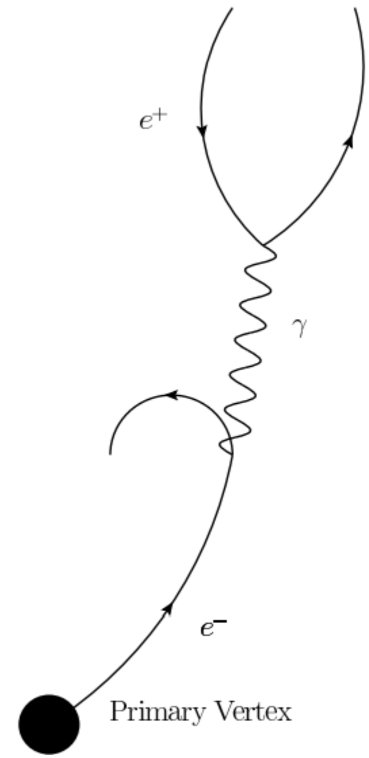
- One can then estimate the Charge MisID background by weighting the opposite-sign events by:

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

Invariant mass

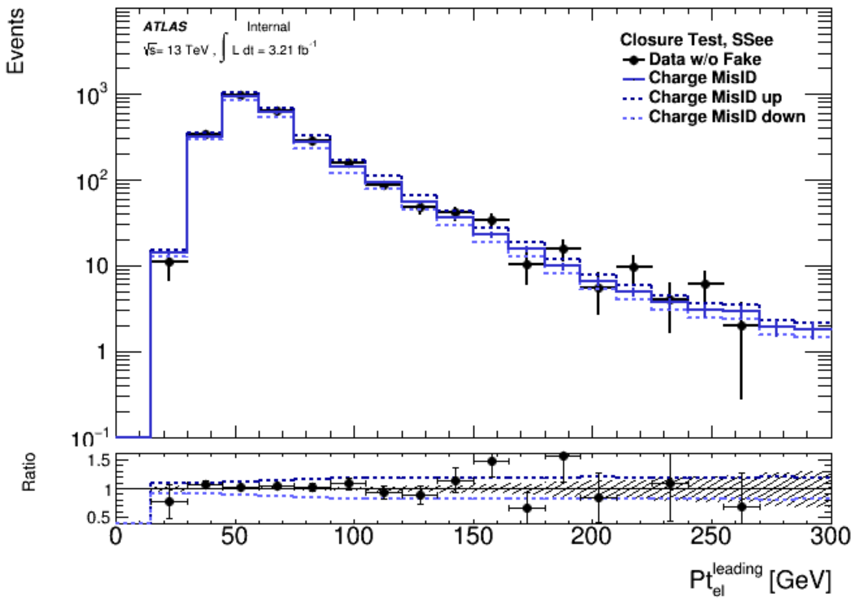


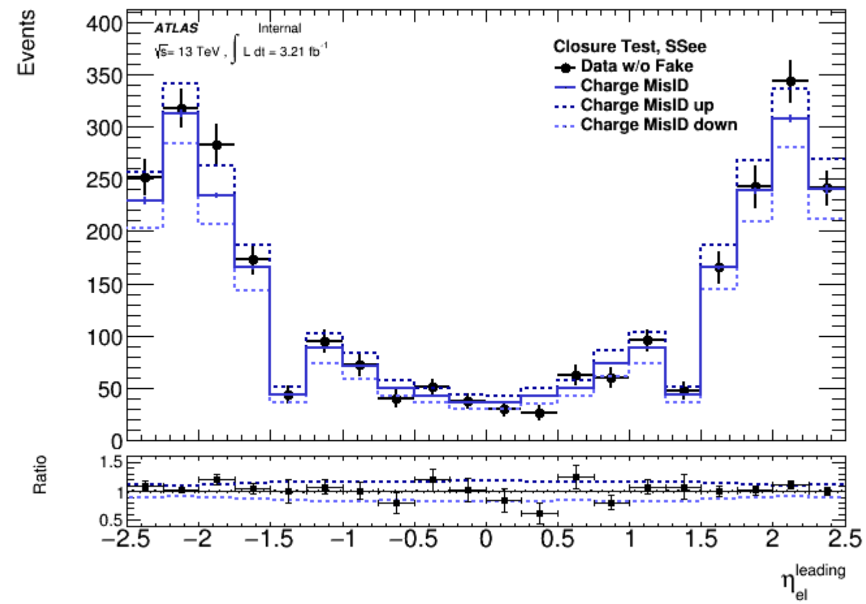
Photon conversion:



Closure tests and prospectives

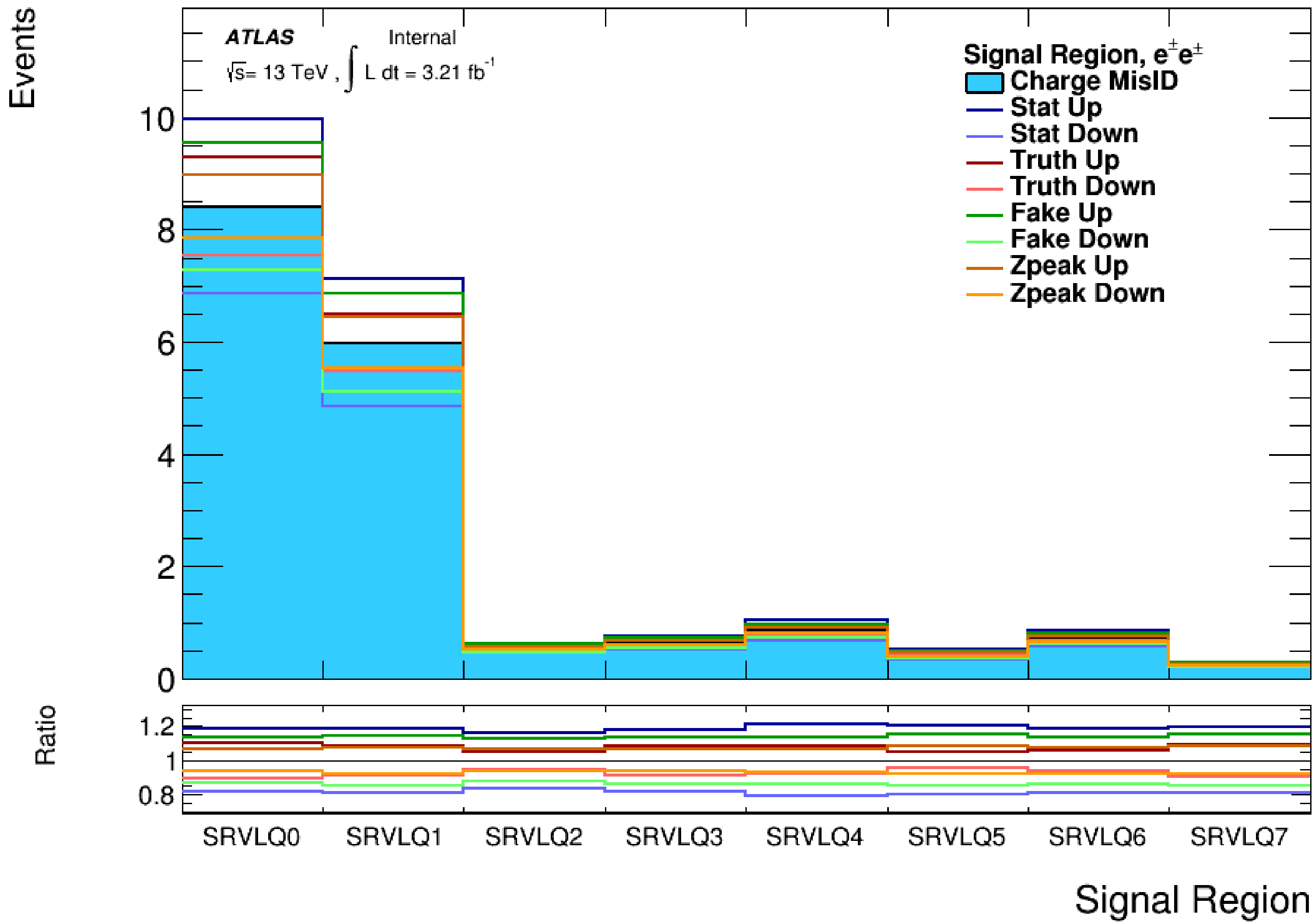
- Comparison of:
  - Opposite-sign di-electron events weighed
  - True same-sign di-electron events without fake contribution





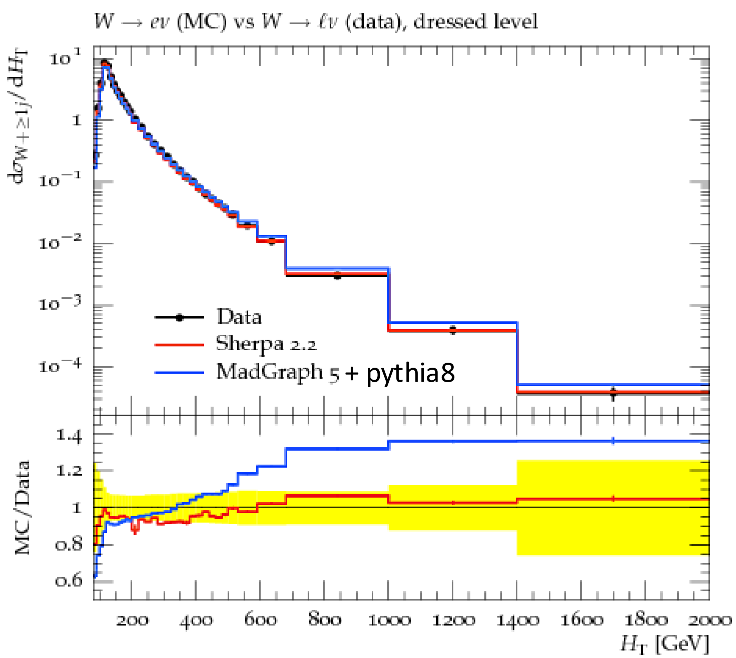
- Current checking the other analysis control regions
  - On going …

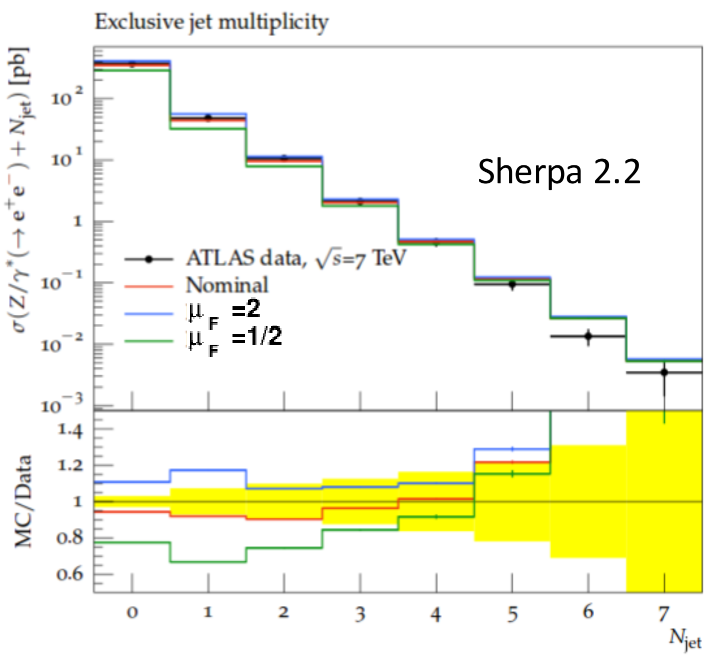
Systematics



Z/W+jets Monte-Carlo validation

- **Aim:** Validate the new generation of Monte-Carlo samples
  - Compared to unfolded data at 7 TeV using **Rivet** analysis
  - Estimate systematic uncertainties (μ_R , μ_F , truth matching …)





- I continue to contribute on the performance of the new Monte-Carlo generators