Search for sgluons in multitop final states at the LHC

Phenomenological search
Preliminary results in ATLAS

[Calvet, Fuks, Gris, Valéry JHEP '13]

[ATLAS-CONF-2013-051]

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Outline

1. Theoretical context - Sgluon phenomenology
2. Phenomenological search
3. Search within ATLAS
4. Conclusions - Outlooks

Progression

1. Theoretical context - Sgluon phenomenology
   - Theoretical context
   - Sgluon phenomenology
   - Summary
2. Phenomenological search
3. Search within ATLAS
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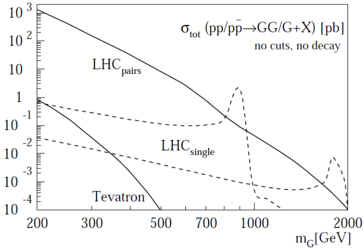
Theoretical context

- MSSM can be extended with a new symmetry (R-symmetry)
  $\rightarrow$ **new particles** are expected.
- Among them, a new **color-octet scalar** field, named **sgluon**, partner of the the gluon and gluino, denoted σ in the next slides.
- Such particles are also predicted in other BSM theories : UED theories for example.
- To describe generically these particles, we assumed an effective theory (inspired by MRSSM theories)

Productions and decays

Production modes

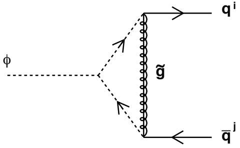
Pair-production cross section much higher than the single sgluon one.



[Plehn, Tait J.Phys. '09]

Decays

Decay to quarks mediated by squarks and gluinos in MRSSM.



Most favoured ones : **at least one top quark** (amplitude proportional to m_i and m_j).

Summary

Production

The sgluon pair production mode dominates.

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Mainly with at least one top quark. This leads to three different final states.

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Each sgluon decays into one top quark and a up-type light quark (*u* or *c*).

$tjt\bar{t}$ topology

One sgluon decays in $t\bar{t}$ and the other one in tj pair.

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4-top topology

Each sgluon decays into two top quarks.

Progression

1. Theoretical context - Sgluon phenomenology
2. Phenomenological search
   - Generation of samples
   - Cross sections
   - Dileptonic signatures
   - Selection criteria
   - Results
   - Summary
3. Search within ATLAS
4. Conclusions - Outlooks

In this study, we assume an integrated luminosity of 20 fb^{-1} at 8 TeV using pp collisions.

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Framework

- Parton level : MadGraph 5.1.2/5.1.3.
- Parton showering + hadronization : Pythia 6.
- Detector simulation : Delphes with ATLAS card.
  - Fast simulation of ATLAS and CMS detectors
  - Smearing and reconstruction of objects (electron, jets, ...)
  - Using a b-tagging efficiency of 60%.

Signal

- Model generated by FeynRules 1.6 for the 3 topologies.
- Five mass points : (200), 400, 600, 800 and 1000 GeV.
- Two scenarios :
  - Assuming universal couplings : $\sigma \to tq'$ with $q' = u, c, t$: **Scenario I**
  - Assuming a 100 % branching ratio of σ to $t\bar{t}$: **Scenario II**

Cross sections

Sample	Cross section [pb]
W+jets	35678
γ/Z+jets	3460
$t\bar{t}$	139.2
Single top	42.3
Dibosons	40.8
$t\bar{t}X$+jets	0.47
$t\bar{t}t\bar{t}$	7×10^{-4}
σ (m = 400 GeV)	2.77
σ (m = 600 GeV)	0.17
σ (m = 800 GeV)	0.02

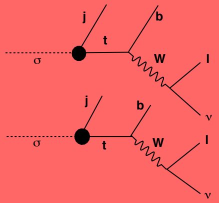
- All backgrounds are generated using Monte Carlo simulation.
- No simulation of the instrumental backgrounds (multijet for example).
- Most backgrounds rescaled to NLO or NNLO.
- Signal also rescaled to NLO.

[Goncalves-Netto et al., Phys.Rev. D '12]

Common signatures

- Several possible leptons in the final states
- Neutrino(s) in the final states : source of missing transverse energy.

tjtj topology



- 2 high p_T jets
- 2 b-jets

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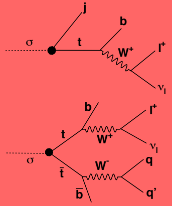
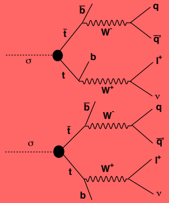


- 1 high p_T jets
- 3 b-jets

4-top topology



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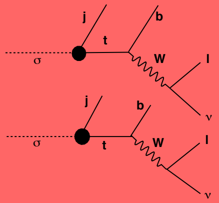

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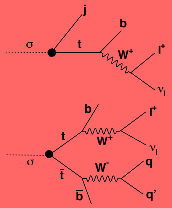

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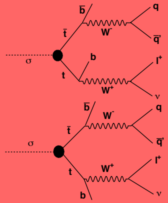


- 4 b-jets

IMPORTANT : the leptons can have the same electric charge.

Selection criteria

Preselection steps

- At least 2 same-sign leptons (ee, $\mu\mu$ and $e\mu$)
- $M(\ell, \ell) \geq 20$ GeV
- $\not{E}_T \geq 40$ GeV

tjtj topology

- ≥ 3 jets with $p_T \geq 25$ GeV
- ≥ 1 b-jet

Expected yields

- $m_\sigma = 400$ GeV : 281 ± 11 (eff : 0.8 %)
- Bkg : 4191 ± 35

tjt$\bar{\text{t}}$ topology

- ≥ 4 jets with $p_T \geq 25$ GeV
- ≥ 2 b-jets

Expected yields

- $m_\sigma = 400$ GeV : 36 ± 4 (eff : 1.5 %)
- Bkg : 286 ± 8

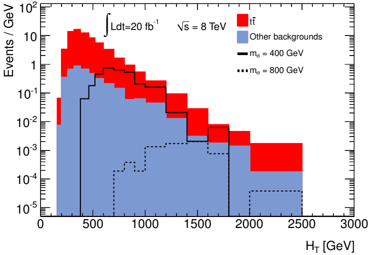
4-top topology

- ≥ 5 jets with $p_T \geq 25$ GeV
- ≥ 3 b-jets

Expected yields

- $m^{I}_\sigma = 400$ GeV : 0.69 ± 0.08 (eff : 0.70 %)
- $m^{II}_\sigma = 800$ GeV : 0.82 ± 0.07 (eff : 1.12 %)
- Bkg : 10.3 ± 1.5

Limit setting



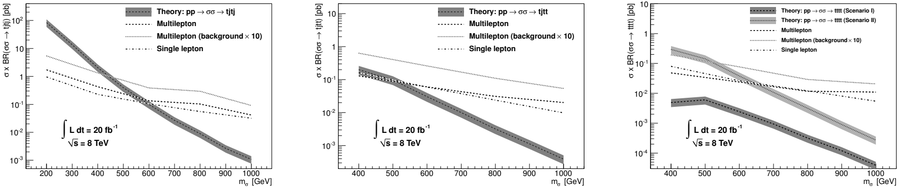
- After the selection, the remaining backgrounds are essentially SM $t\bar{t}$, single top and SM $t\bar{t}t\bar{t}$.
- $t\bar{t}$ and single top backgrounds : less objects than the signal. This difference can be described by H_T.

$$H_T = \sum p_T(\text{leptons}) + \sum p_T(\text{jets}) + \not{E}_T$$

- Limits estimated with McLimit software [CDF/DOC/STATISTICS/PUBLIC/8128] .
- Only statistical uncertainties are considered.

Expected limits

- A semi-leptonic study has also been performed (more details in the phenomenological paper).



	Single lepton analysis	Multilepton analysis	Multilepton analysis (background ×10)
tjtj	$590\ ^{+40}_{-30}$ GeV	$570\ ^{+30}_{-50}$ GeV	$440\ ^{+40}_{-15}$ GeV
tjtt	$480\ ^{+70}_{-80}$ GeV	$520\ ^{+35}_{-90}$ GeV	-
tttt (Sc. I)	-	-	-
tttt (Sc. II)	$640\ ^{+40}_{-30}$ GeV	$650\ ^{+30}_{-40}$ GeV	$520\ ^{+50}_{-110}$ GeV

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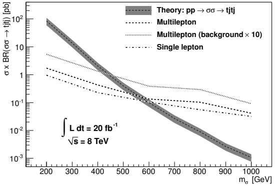

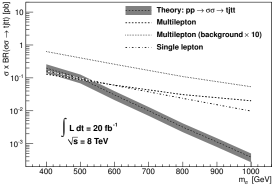

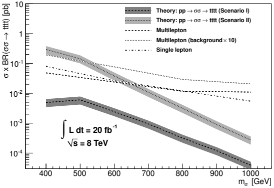

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- The most sensitive topology is the **4-top one** (assuming a 100 % BR to $t\bar{t}$).

Summary

- These signatures could **lead to a discovery**.
- More specifically, a general experiment (like ATLAS) could reach sgluons up to 650 GeV, focusing on the 4-top topology, and assuming 100 % BR.
- Much more details in the phenomenological paper published in JHEP, resulting of a collaboration between theorists and experimentalists :

Calvet, Fuks, Gris, Valéry JHEP '13

- **Limitations of the study**
  - All backgrounds are MC-simulated (no background from fake leptons)
  - The pile-up is not taken into account in this study

Progression

1 Theoretical context - Sgluon phenomenology

2 Phenomenological search

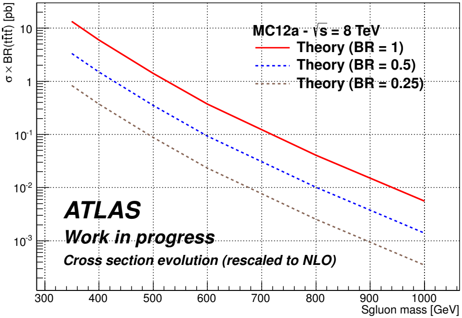
3 Search within ATLAS
- Introduction
- Backgrounds
- Events selection
- Results

4 Conclusions - Outlooks

Introduction

- Using the results of the phenomenological paper, the 4-top final state has been recently investigated in ATLAS in the context of the same-sign dilepton final states.
- Work done by S. Calvet and L. Valéry in a more general same-sign dilepton group.
- The generated signal assumes a 100 % BR of σ to $t\bar{t}$.
- Search using 14.3 fb^{-1} of data recorded by ATLAS at $\sqrt{s} = 8$ TeV.
- Results recently public :

[ATLAS-CONF-2013-051]



Background sources

- Two types of backgrounds to be considered :
  - Processes leading to **real** same-sign dilepton final state are simulated using Monte Carlo.
  - Processes leading to opposite sign or other non-same-sign-dilepton final state are estimated using data driven techniques.

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- **Monte-Carlo-generated samples**
  - Dibosons (WZ, ZZ, $W^{\pm}W^{\pm}$)
  - $t\bar{t} + X$ ($X = W, Z, WW$)

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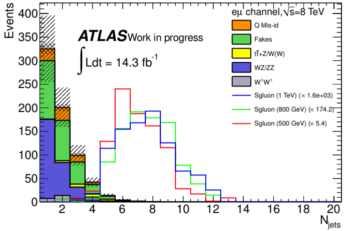
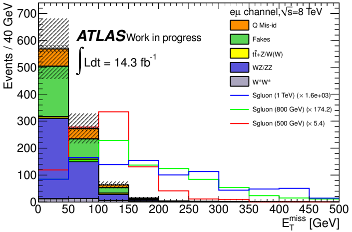
  - Dibosons (WZ, ZZ, $W^{\pm}W^{\pm}$)
  - $t\bar{t} + X$ ($X = W, Z, WW$)
- **Data-driven backgrounds**
  - Mis-identification of the electric charge of the leptons
  - Fake leptons

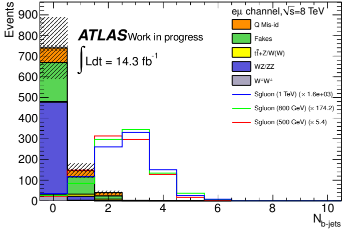
Preselection of events

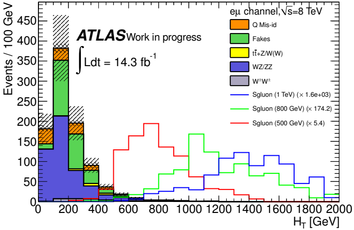
1. Quality criteria (trigger, bad jet rejection, ...)
2. $e - \mu$ overlap removal
3. Exactly two leptons in the event ($e\mu$, $\mu\mu$ or ee)
4. Same-sign dileptons
5. Trigger matching (at least one lepton matches the trigger)
6. Z / quarkonia veto : $M_{ll} > 15$ GeV and $|M_{ll} - 91 \text{ GeV}| > 10$ GeV

After the preselection - $e\mu$ channel









Final selection

- The last steps of the selection are optimized fro the 4-top final state.
- The optimization is performed in order to get the best expected limit (using both the statistic and systematic uncertainties).
- The total selection is then :
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  7. $\not{E}_T \geq 40$ GeV
  8. $N_j \geq 2$
  9. $N_b \geq 2$
  10. $H_T = \sum p_T(\text{jets}) + \sum p_T(\text{lepton}) \geq 650$ GeV

Yields

- After the whole selection, the expected numbers of signal and background events are :

Samples	Channel		
	ee	$e\mu$	$\mu\mu$
Charge mis-id	$0.16 \pm 0.04 \pm 0.05$	$0.41 \pm 0.07 \pm 0.12$	—
Fakes	$0.18 \pm 0.17 \pm 0.05$	$0.07 \pm 0.28 \pm 0.02$	< 1.14
Diboson			
• WZ/ZZ+jets	< 0.11	$0.01 \pm 0.09 \pm 0.01$	< 0.11
• $W^{\pm}W^{\pm}$+2 jets	< 0.03	$0.18 \pm 0.16 \pm 0.07$	< 0.03
$t\bar{t} + W/Z$			
• $t\bar{t}W$(+jet(s))	$0.31 \pm 0.04 \pm 0.12$	$0.93 \pm 0.06 \pm 0.35$	$0.65 \pm 0.06 \pm 0.25$
• $t\bar{t}Z$(+jet(s))	$0.09 \pm 0.02 \pm 0.04$	$0.34 \pm 0.04 \pm 0.14$	$0.14 \pm 0.02 \pm 0.06$
• $t\bar{t}W^{\pm}W^{\mp}$	$0.012 \pm 0.002 \pm 0.005$	$0.039 \pm 0.003 \pm 0.016$	$0.024 \pm 0.003 \pm 0.01$
Total	$\mathbf{0.75 \pm 0.21 \pm 0.14}$	$\mathbf{1.98 \pm 0.35 \pm 0.40}$	$\mathbf{0.82 \pm 1.15 \pm 0.26}$
Sgluon (350 GeV)	59 ± 22	167 ± 36	136 ± 31
Sgluon (400 GeV)	47 ± 11	141 ± 20	108 ± 18
Sgluon (500 GeV)	26.4 ± 4.3	93.1 ± 8.1	44.5 ± 5.3
Sgluon (600 GeV)	8.0 ± 1.2	32.9 ± 2.4	21.7 ± 2.0
Sgluon (800 GeV)	1.13 ± 0.15	4.3 ± 0.4	2.75 ± 0.25
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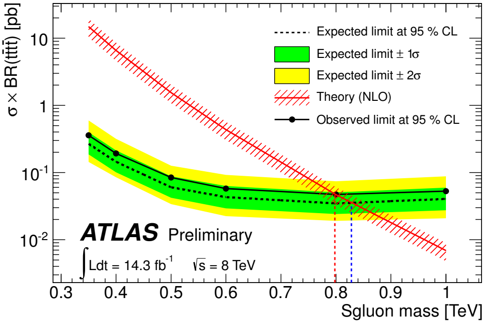
Sgluon (1000 GeV)	0.127 ± 0.019	0.448 ± 0.036	0.381 ± 0.033
Observed	1	6	1

- No significant excess seen in data compared to background expectations.

Limits

- The limits are computed using the McLimit software, including both statistical and systematic uncertainties.
- The vertical red dashed line represents the observed limit, while the blue one represents the expected limit.



- **Observed limit @ 0.8 TeV**.

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Conclusions - Outlooks

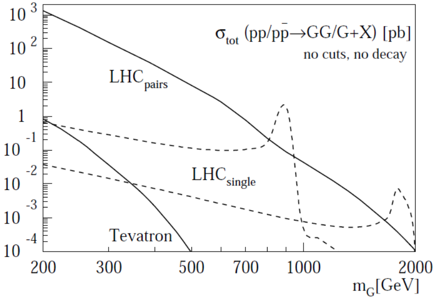
- The sgluon signatures have been investigated in a phenomenological paper, result of a collaboration between theorists and experimentalists.
- Such particles could be reached at the LHC until masses of about 0.65 TeV.

- Following the conclusions of this paper, the 4-top topology has been studied in ATLAS, using 14.3 fb^{-1} of pp collisions at $\sqrt{s} = 8$ TeV.
- The limitations of the pheno paper were corrected :
  - Pile up taken into account
  - Background more accurately described using both MC samples and data driven estimation.
- Consequently, a expected limit of 0.83 TeV is obtained, and the observed limit is of 0.80 TeV.

BACKUP

Sgluon production & decays

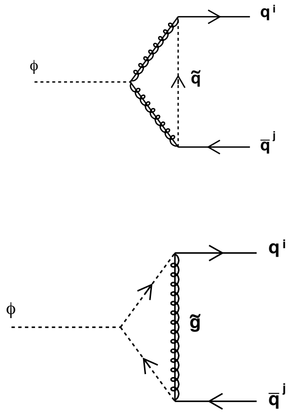
slguon production



Cross section of sgluon [pb] vs mass of sgluon [GeV].

- Sgluon sensitive to strong interaction : large coupling to quarks and gluons. Important production at the LHC.
- The pair production is always the main way to produce sgluons.
- The cross section is quite important for low masses, but decreases quickly.

sgluon decays



- The coupling between sgluon and quarks is mediated by squarks and gluinos.
- Assuming a maximal mixing between the up-type squarks.
- Final states with at least one top quark are equiprobable.

Effective model

Simplified model I

- In SUSY, the sgluon coupling to gluons or quarks is mediated by squarks and gluinos ... But they habe not (yet) been discovered $\Rightarrow$ coupling depends on the mass of these particles.
- Since *sgluon-like* particles are predicted in various kind of BSM theories, the couplings are expected to be different.
- **To describe generically sgluons, an effective model has been built.**
- To do so :
  - We minimally extend the Standard Model.
  - We only add one scalar field.
  - The allowed coupling are inspired of $N = 1/N = 2$-hybrid-like models.

Simplifed model II

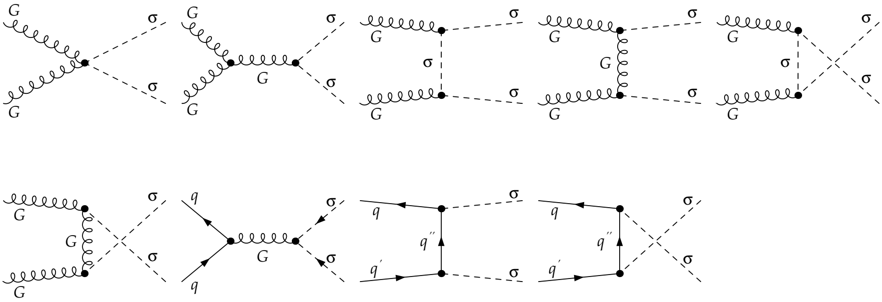
- **Kinematic term**
  - Covariante derivative of standard QCD.
  - G_μ^a : gluon

$$\mathcal{L}_{\text{kin}} = \frac{1}{2} D_\mu \sigma^a D^\mu \sigma_a - \frac{1}{2} m_\sigma^2 \sigma^a \sigma_a \quad \text{with} \quad D_\mu \sigma^a = \partial_\mu \sigma^a + g_s \, f_{bc}{}^a \, G_\mu^b \, \sigma^c$$

- **Interaction Lagangian**
  - An effective coupling between the sgluon and the matter fields is introduced.

$$\mathcal{L}_{\text{eff}} = \sigma^a \bar{d} T_a \left[a_d^L P_L + a_d^R P_R \right] d + \sigma^a \bar{u} T_a \left[a_u^L P_L + a_u^R P_R \right] u + a_g d_a{}^{bc} \sigma^a G_{\mu\nu b} G^{\mu\nu}{}_c + \text{h.c.}$$

Simplified model III

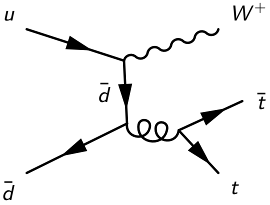


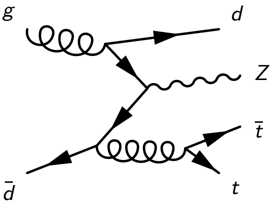
- Allowed coupling in the considered effective model.

Backgrounds

$t\bar{t} + W/Z$+jets

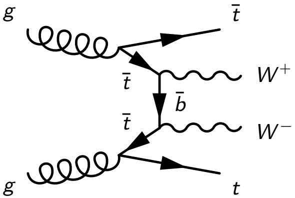
- MadGraph+Pythia (CTEQ6L1), fullsim
- Additional partons: $\in [0, 2]$





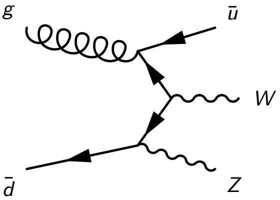
$t\bar{t} + WW$

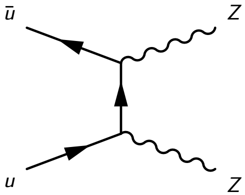
- MadGraph+Pythia (MSTW2008LO), AF2
- CTEQ6L1 sample used for comparison



Diboson+jets ($W^\pm Z/ZZ$)

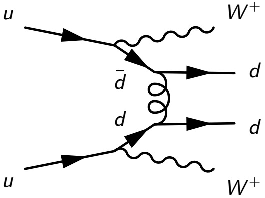
- Sherpa (CT10), fullsim
- Additional partons: $\in [0, 3]$
- `Alpgen+Jimmy` used for comparison





Same-sign diboson ($W^\pm W^\pm + jj$)

- `MadGraph+Pythia` (MSTW2008LO), AF2
- CTEQ6L1 sample used for comparison



A few words about data driven backgrounds

- **Mismeasured electric charge of the lepton**
  - **Origin** : trident electron (hard bremstrahlung), slightly curved track.
  - Negligible for muons (combination of different trackers)
  - Measurement performed using a $Z \to ee$ sample.
  - A correction to account for high p_T electrons is done using $t\bar{t}$ samples.
- **Fake leptons**
  - **Origin** : heavy flavour decays, photon conversion, ...
  - Uses the Matrix Method.
  - A *loose* selection of leptons is performed by relaxing the isolation cuts.
  - The yields of real or fake leptons in the *loose* sample are used to extrapolate the contamination in the signal region (more details in backup).

Matrix method

Matrix method I

- Loose lepton
  - If the lepton is a real one (region $E_T^{miss} > 150$ GeV for electrons and $m_T(W) > 100$ GeV for muons), the efficiency to pass the tight criteria is r.
  - If the lepton is a fake one (region defined by $E_T^{miss} < 20$ GeV and $E_T^{miss} + m_T(W) < 60$ GeV for the electrons and $|d_0/d_0^{sig}| > 5$ fro the muons) the efficiency to be selected as a real one is r.
- Matrix method

$$\begin{pmatrix} N^{\mathrm{tt}} \\ N^{\mathrm{tl}} \\ N^{\mathrm{lt}} \\ N^{\mathrm{ll}} \end{pmatrix} = \mathbf{M} \begin{pmatrix} N^{\mathrm{ll}}_{\mathrm{rr}} \\ N^{\mathrm{ll}}_{\mathrm{rf}} \\ N^{\mathrm{ll}}_{\mathrm{fr}} \\ N^{\mathrm{ll}}_{\mathrm{ff}} \end{pmatrix}$$

$$\mathbf{M} = \begin{pmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1(1-r_2) & r_1(1-f_2) & f_1(1-r_2) & f_1(1-f_2) \\ (1-r_1)r_2 & (1-r_1)f_2 & (1-f_1)r_2 & (1-f_1)f_2 \\ (1-r_1)(1-r_2) & (1-r_1)(1-f_2) & (1-f_1)(1-r_2) & (1-f_1)(1-f_2) \end{pmatrix}$$

Matrix method II

$$\begin{pmatrix} N^{\rm tt} \\ N^{\rm tl} \\ N^{\rm lt} \\ N^{\rm ll} \end{pmatrix} = \mathbf{M} \begin{pmatrix} N^{\rm ll}_{\rm rr} \\ N^{\rm ll}_{\rm rf} \\ N^{\rm ll}_{\rm fr} \\ N^{\rm ll}_{\rm ff} \end{pmatrix}$$

- **Known and unknown quantities**
  - In the first member of the equation
    - **Known** quantity (*e.g.* N^{tt} is the number of events in the loose selection for which the two leptons pass the tight criteria).
    -
  - In the second member of the equation
    - the matrix in **known** (r and f are parametrized as a function of η, p_T ...)
    - the column vector is **unknown** (number of lepton pairs that are rf, fr, rr or ff).

Matrix method III

- Inverting the matrix, the number of tight-tight events containing at least one fake lepton is :

$$\begin{aligned} N^{\mathrm{tt}}_{\mathrm{fake}} &= N^{tt}_{\mathrm{rf}} + N^{\mathrm{tt}}_{\mathrm{fr}} + N^{\mathrm{tt}}_{\mathrm{ff}} \\ &= r_1 f_2 N^{\mathrm{ll}}_{\mathrm{rf}} + f_1 r_2 N^{\mathrm{ll}}_{\mathrm{fr}} + f_1 f_2 N^{\mathrm{ll}}_{\mathrm{ff}} \\ &= \alpha r_1 f_2 \left[(f_1 - 1)(1 - r_2) N^{\mathrm{tt}} + (1 - f_1) r_2 N^{\mathrm{tl}} + f_1 (1 - r_2) N^{\mathrm{lt}} - f_1 r_2 N^{\mathrm{ll}} \right] \\ &\quad + \alpha f_1 r_2 \left[(r_1 - 1)(1 - f_2) N^{\mathrm{tt}} + (1 - r_1) f_2 N^{\mathrm{tl}} + r_1 (1 - f_2) N^{\mathrm{lt}} - r_1 f_2 N^{\mathrm{ll}} \right] \\ &\quad + \alpha f_1 f_1 \left[(1 - r_1)(1 - r_2) N^{\mathrm{tt}} + (r_1 - 1) r_2 N^{\mathrm{tl}} + r_1 (r_2 - 1) N^{\mathrm{lt}} + r_1 r_2 N^{\mathrm{ll}} \right] \end{aligned}$$

where

$$\alpha = \frac{1}{(r_1 - f_1)(r_2 - f_2)}.$$

Charge mis-ID

Charge mis-identification I

- Estimated using $Z \to ee$ events
  - In data, same-sign and opposite-sign events are selected.
  - In both kinds of samples, a Z peak can be seen.

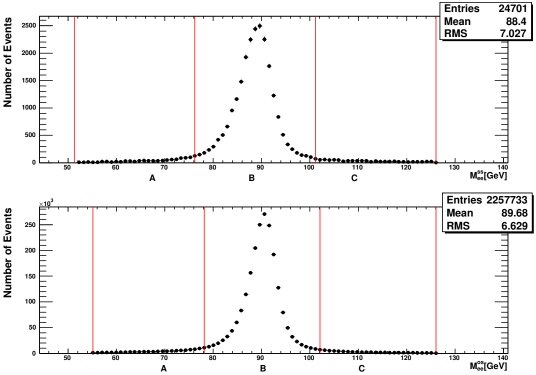


FIGURE: Up : Same-sign events. Bottom : Opposite sign events

Trigger

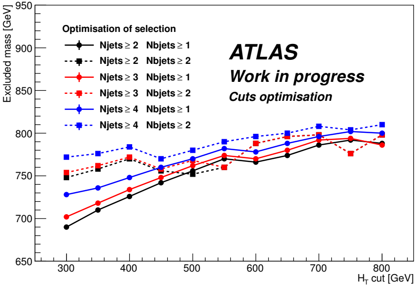
Trigger

- Electrons
  - EF_e24vhi_medium1
  - EF_e60_medium1
- Muons
  - EF_mu24i_tight
  - EF_mu36_tight

Optimisation of the selection

Optimization of the selection

- The optimization of the selection is performed in order to get the best expected limit (using both the statistic and systematic uncertainties).



- Selected set of cuts :

$N_{jets} \geq 2$ $N_b \geq 2$ $\sum p_T(\text{jets}) + \sum p_T(\text{lepton}) \geq 650$ GeV

Limits

- The limits are computed using the McLimit software, including both statistical and systematic uncertainties.
- The vertical red dashed line represents the observed limit, while the blue one represents the expected limit.