



# Search for Non-Resonant exotic physics in the dilepton channels with the ATLAS detector at the LHC

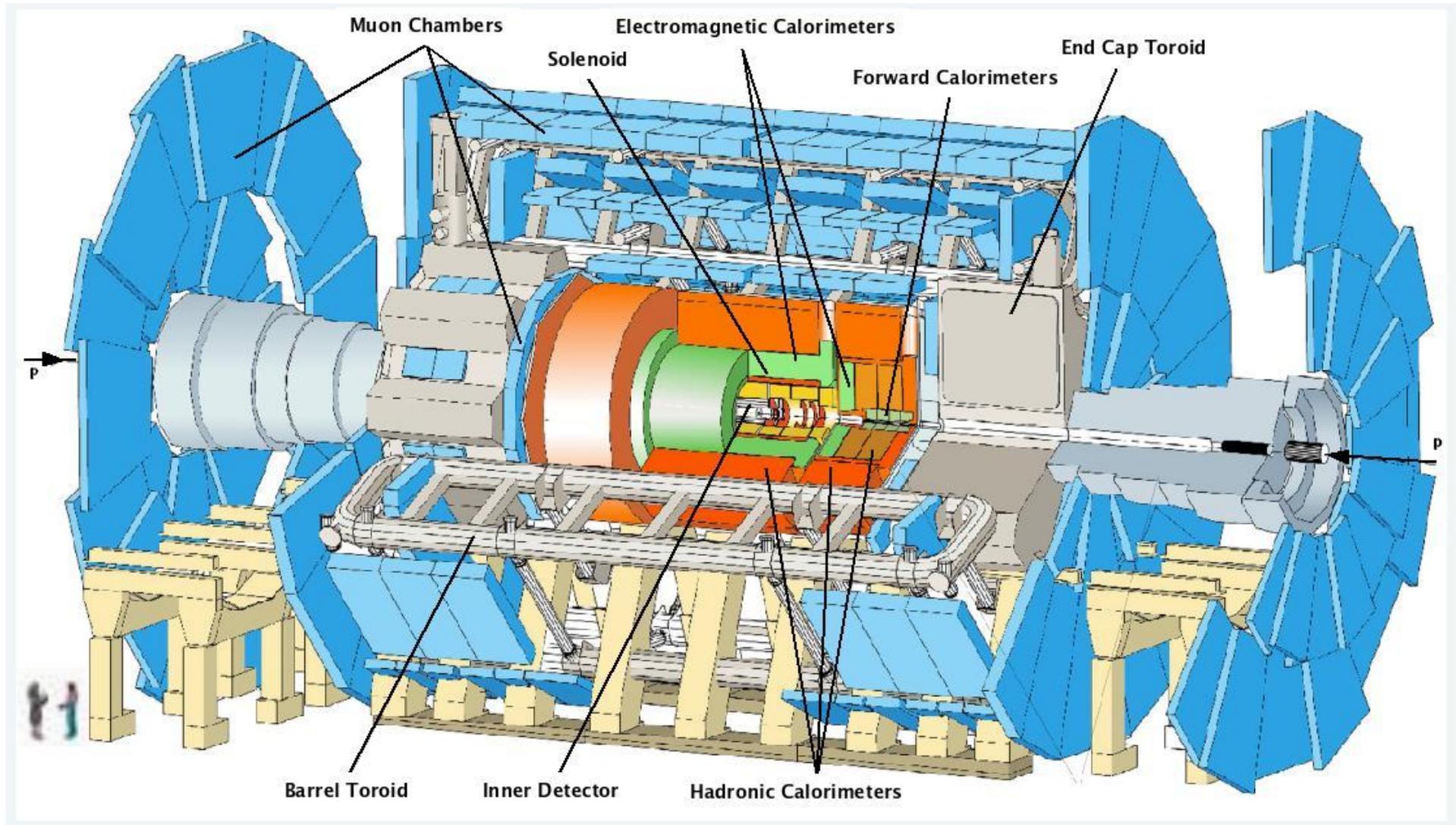
IOP HEPP & APP MEETING 2013

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# Overview

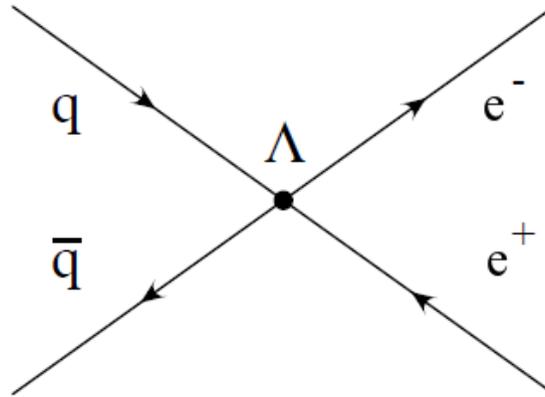
- ATLAS Detector
- Contact Interactions and ADD theory
- 2011 Non-resonance Analysis on  $4.9 \text{ fb}^{-1}$  of data
  - [arXiv:1211.1150](https://arxiv.org/abs/1211.1150)
    - Focus on electron analysis (Group at Royal Holloway University of London – T.Berry, D.Hayden, L.Duguid)
    - Muon analysis not shown here (Group at University of Massachusetts – S.Willocq, T.Varol)
    - Cut-flow
    - Results
    - Statistical analysis and limits
- 2012 data analysis prospects
  - Angular analysis

# ATLAS detector



# Contact Interactions Theory

- Beyond the standard model phenomena such as quark/lepton compositeness can be described as a 4-fermion contact interaction.



- For the purely Left-Left Isoscalar Model, we use as a benchmark, the Lagrangian is:

$$\mathcal{L} = \frac{g^2}{2\Lambda^2} [ \eta_{LL} (\bar{\psi}_L \gamma_\mu \psi_L) (\bar{\psi}_L \gamma^\mu \psi_L) ]$$

where  $\eta_{LL} = \pm 1$  and defines whether the new interaction interferes constructively ( $\eta = -1$ ) or destructively ( $\eta = +1$ ) with Drell-Yan.

- The differential cross section for the process is then:

$$\frac{d\sigma}{dm_{\ell\ell}} = \frac{d\sigma_{DY}}{dm_{\ell\ell}} - \eta \frac{F_I}{\Lambda^2} + \frac{F_C}{\Lambda^4}$$

Including both the DY-CI interference ( $F_I$ ) and pure Contact Interaction ( $F_C$ ) terms.

# ADD Theory

- Large Flat Extra Dimensions (ED) are introduced to dilute gravity.
- A Graviton propagates in the bulk causing Kaluza-Klein modes with small spacings leading to a non-resonant excess over the SM.
- UV cut-off is imposed against divergences.
- Model Parameters: Number of ED ( $n \geq 2$ ),  
 Fundamental Planck scale in the  $4+n$  dimensional space-time, ( $M_D$ ).

$$M_S = 2\sqrt{\pi} \left[ \Gamma\left(\frac{n}{2}\right) \right]^{1/(n+2)} M_D$$

- The string scale, ( $M_S$ ), is related to  $M_D$  so that the effect of the ED on gravity can be parametrised by using the formalism dependent parameter  $\eta_G$ :

$$\eta_G = \mathcal{F} / M_S^4$$

$$\mathcal{F} = \begin{cases} 1 & n = 2 \\ \frac{2}{n-2} & n > 2 \end{cases}, \text{ (HLZ)}$$

$$\mathcal{F} = 1, \text{ (GRW)}$$

$$\mathcal{F} = \pm \frac{2}{\pi}, \text{ (Hewett)}$$

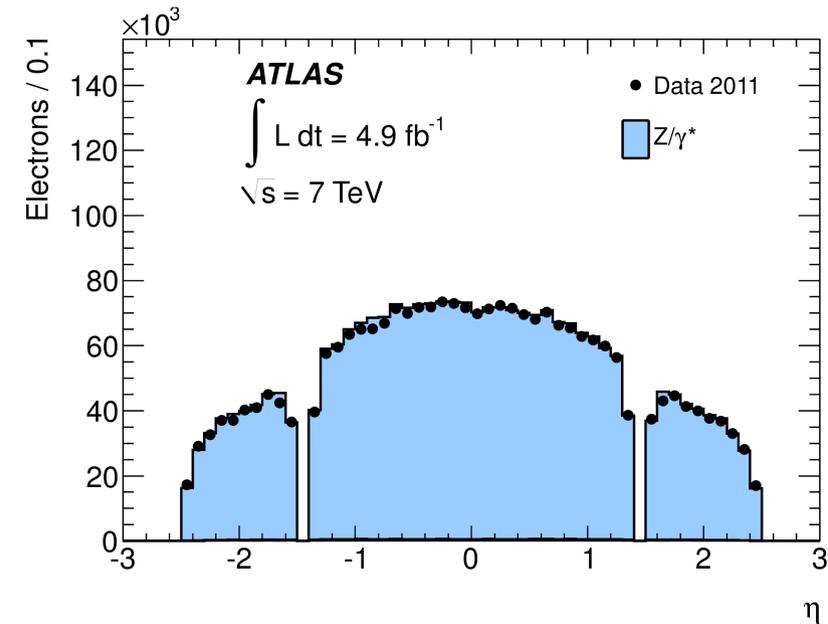
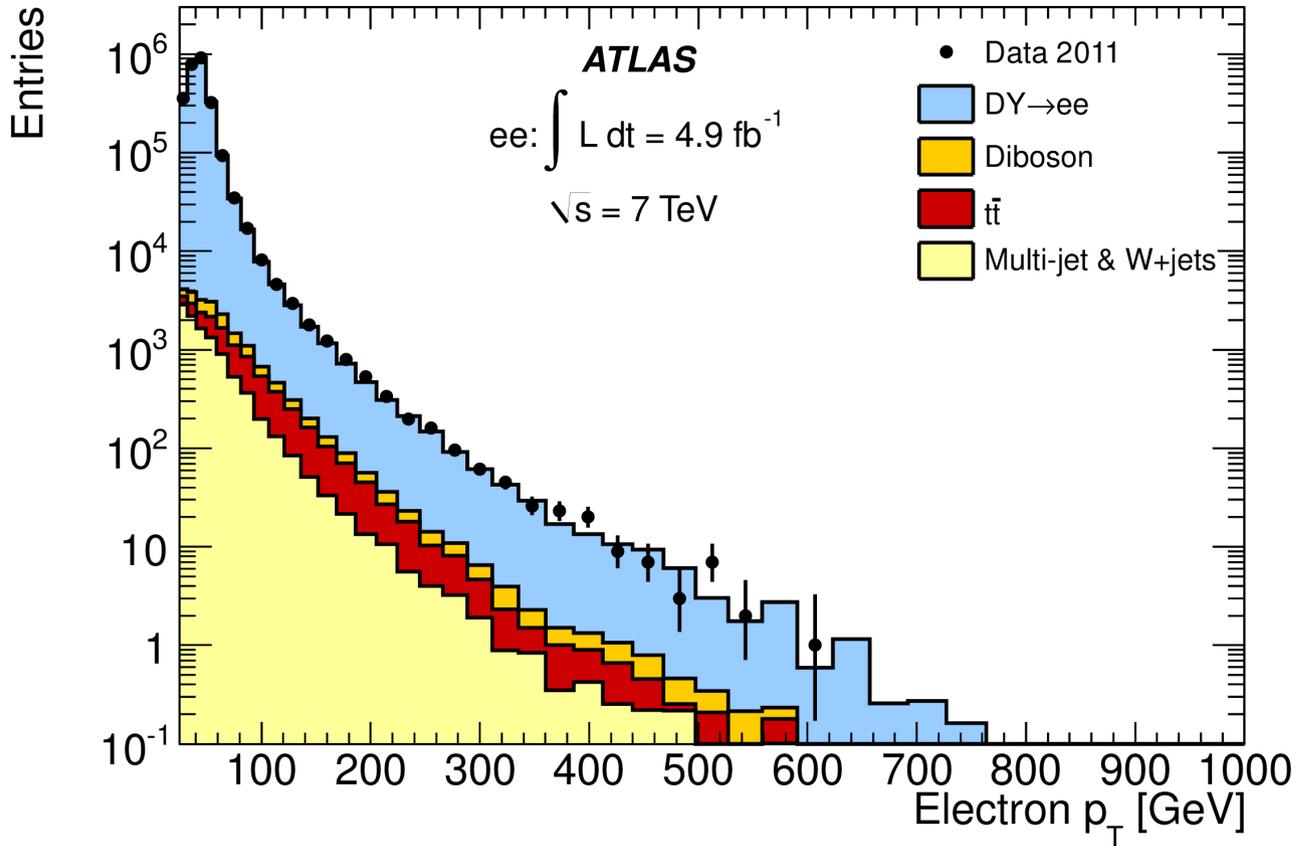
# Electron Analysis

- Event requirements:
  - More than 2 primary vertices
  - Pass trigger
- Electron requirements:
  - $E_T > 25 \text{ GeV}$ ;
  - $|\eta| < 2.5$  and exclude the crack region ( $1.37 < |\eta| < 1.52$ );
  - Good electron object requirement;
  - Hit in inner most track layer if expected;
  - Cone track isolation ( $\Delta R < 0.2$ )  $< 7 \text{ GeV}$  on highest  $p_T$  electron.
- Choose highest  $p_T$  electron pair and reject if invariant mass  $< 70 \text{ GeV}$ .

# MC background estimate

- Drell-Yan produces an irreducible background of our signal and is estimated with **PYTHIA 6**.
- Reducible background:
  - ttbar production (**MC@NLO**)
  - Diboson production (**HERWIG++**)
  - QCD & W+jets background estimated with fake factor method on data
- Signal estimation:
  - Contact Interactions (**PYTHIA 6**)
  - ADD gravitons (**SHERPA**)
- All MC are run through **GEANT4** to simulate the ATLAS detector.

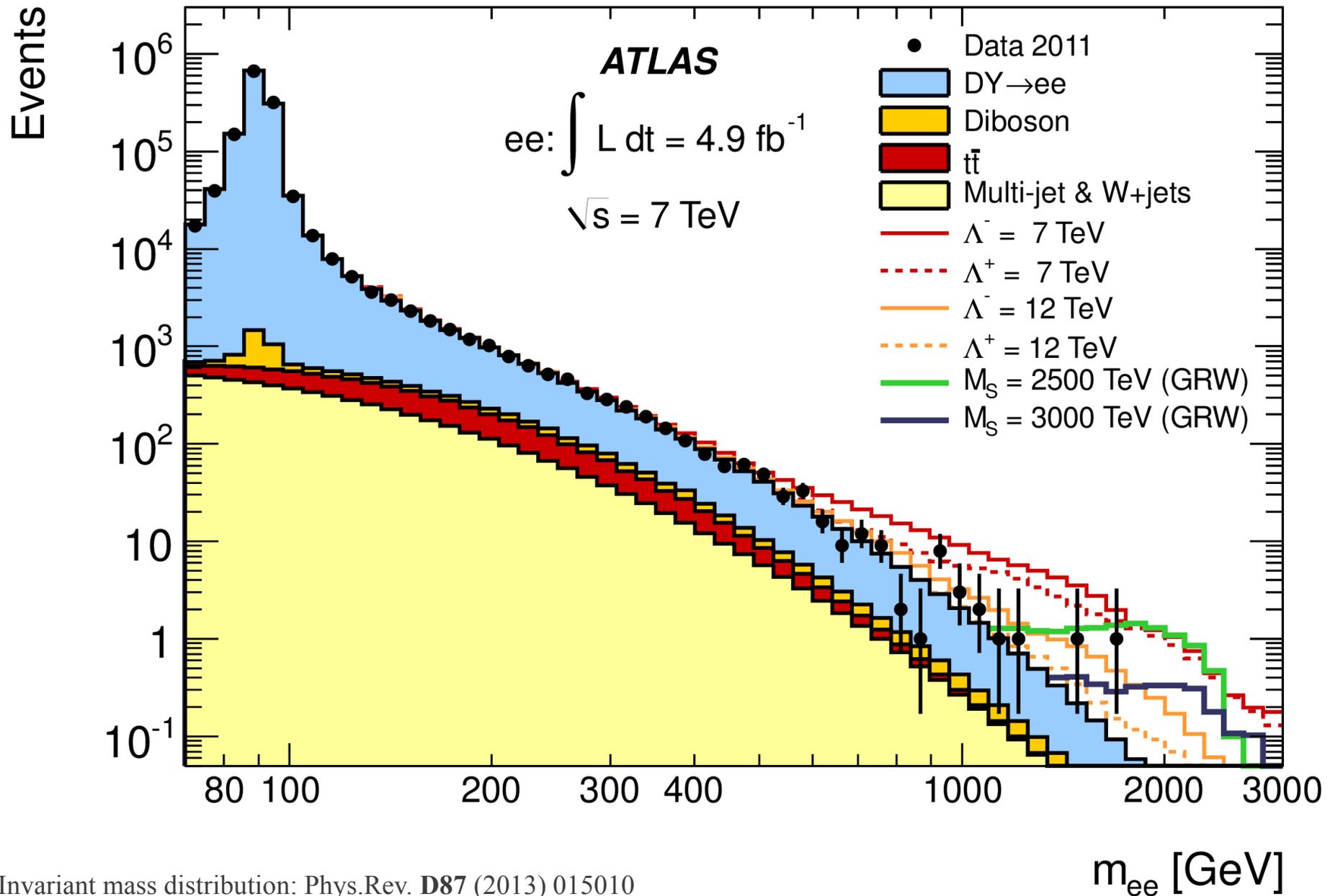
# Data MC comparison



$p_T$  distribution: Phys.Rev. **D87** (2013) 015010

$\eta$  distribution: Journal of High Energy Phys. **11** (2012)138

# Results



Invariant mass distribution: Phys.Rev. **D87** (2013) 015010

# Statistical Analysis

- We use the Bayesian Analysis Toolkit (BAT) to set limits on the scale of new physics (either  $\Lambda$  or  $M_s$ ).
- A prior probability is set to be flat in either  $1/\Lambda^2$  and  $1/\Lambda^4$  for CI or  $1/M_s^4$  and  $1/M_s^8$  for ADD.
- In the case of CI the first prior is more suitable for the Interference term while the second is more suitable for the pure contact interaction term, it depends on which physics is dominant. Similar in true of ADD.
- Expected limits are produced by generating 1000 SM-like pseudo-experiments and running these through the BAT limit setting.
- Limits are shown for the electron and muon channel, alone and combined.
- For the ADD model the photon channel is also shown and combined with the leptons.

# Combined Limits

## Contact Interactions

Channel	Prior	Expected limit (TeV)		Observed limit (TeV)	
		Constr.	Destr.	Constr.	Destr.
$ee$	$1/\Lambda^2$	13.8	10.4	12.1	9.5
	$1/\Lambda^4$	12.5	9.8	11.4	9.1
$\mu\mu$	$1/\Lambda^2$	12.7	9.9	12.9	9.6
	$1/\Lambda^4$	11.6	9.1	11.7	9.0
$ee + \mu\mu$	$1/\Lambda^2$	15.0	11.3	13.9	10.2
	$1/\Lambda^4$	13.8	10.5	12.9	9.8

ADD

Channel	Prior	Exp. limit (TeV)	Obs. limit (TeV)
$ee$	$1/M_S^4$	2.88	2.73
	$1/M_S^8$	2.72	2.62
$\mu\mu$	$1/M_S^4$	2.83	2.83
	$1/M_S^8$	2.61	2.61
$ee + \mu\mu$	$1/M_S^4$	3.16	3.00
	$1/M_S^8$	2.96	2.85
$ee + \mu\mu + \gamma\gamma$	$1/M_S^4$	3.43	3.22
	$1/M_S^8$	3.27	3.12

ATLAS Collaboration (G Aad et al.), Phys.Rev. **D87** (2013) 015010

# 2012 Analysis prospects (8 TeV)

- Derived new cone isolation cut on both highest  $p_T$  and second highest  $p_T$  electrons running in  $E_T$ .
- Updated to newer MC generators (PYTHIA 8)
- Statistical analysis change using Collins-Soper frame to set limits using both invariant mass and angular  $\text{Cos}\theta^*$  shape information.

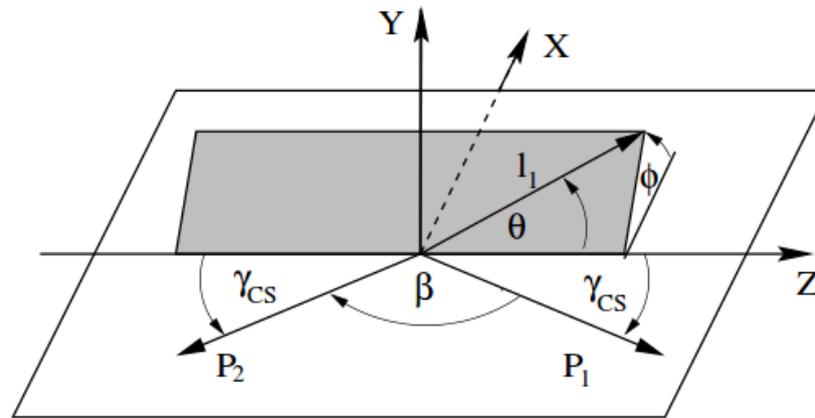


Fig. 1: The Collins-Soper frame: the  $z$ -axis cuts the angle between  $\mathbf{P}_1$  and  $-\mathbf{P}_2$  into halves (the half angle is called the Collins-Soper angle  $\gamma_{CS}$ ) while the  $x$ -axis is perpendicular to  $\mathbf{P}_1$  and  $\mathbf{P}_2$ . The direction of one lepton momentum  $\mathbf{l}_1$  can then be given by the angles  $\theta$  and  $\phi$

Thank-you  
Questions?

# Backup

# Fake factor method

$$\begin{pmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{pmatrix} = \begin{pmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1(1-r_2) & r_1(1-f_2) & f_1(1-r_2) & f_1(1-f_2) \\ (1-r_1)r_2 & (1-r_1)f_2 & (1-f_1)r_2 & (1-f_1)f_2 \\ (1-r_1)(1-r_2) & (1-r_1)(1-f_2) & (1-f_1)(1-r_2) & (1-f_1)(1-f_2) \end{pmatrix} \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

$$r = N_{tight}^{real} / N_{loose}^{real} \qquad f = N_{tight}^{fake} / N_{loose}^{fake}$$

Assumption:  $r = \frac{N_{tight}^{real}}{N_{loose}^{real}} = 1$

$$\begin{pmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{pmatrix} = \begin{pmatrix} 1 & f_2 & f_1 & f_1 f_2 \\ 0 & 1-f_2 & 0 & f_1(1-f_2) \\ 0 & 0 & 1-f_1 & (1-f_1)f_2 \\ 0 & 0 & 0 & (1-f_1)(1-f_2) \end{pmatrix} \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

$$N_{di-jet \& W+Jets} = N_{TT}^{fake} = F_2 N_{TL} + F_1 N_{LT} + F_1 F_2 N_{LL}$$

$$F_i \equiv \frac{f_i}{1-f_i} \text{ is called } \underline{\text{fake factor}}$$