Discovery and identification of a new neutral gauge boson in the e^+e^- channel with the ATLAS detector

Julien MOREL

Fabienne LEDROIT
Benjamin TROCME

ATLAS Exotic group
LPSC - Grenoble

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Plan

- Introduction and motivations
- The different theoretical Z' models
- The LHC and the ATLAS experiment
- The ATLAS Z' discovery potential
- How can we infer the underlying theory ?
- Conclusions and outlook

The Standard model

☺

- It is very well verified
- It makes very good prediction

☹

- Hypothetical particle : Higgs boson
- Lot of parameters
- Divergences
- Number of fermion familly
- The forces are not describe by the same gauge theory

We need to search beyond the standard model

Z' is a signature of new physics

Many theories beyond the standard model predict new neutral gauge bosons (Z') :

- Grand Unified Theory (GUT)
  Z'_ψ, Z'_χ, Z'_η from E(6) and Z'_{LR} from SO(10), CDDT parameterization
- Little Higgs theory
  New gauge bosons come from new gauge groups.
- Almost all theories with extra-dimensions
  New gauge bosons are standard Z/γ Kaluza-Klein excitations.
- …

Z’ at hadrons collider

Backgrounds

•Hadronic channel

Signal over background ratio very small

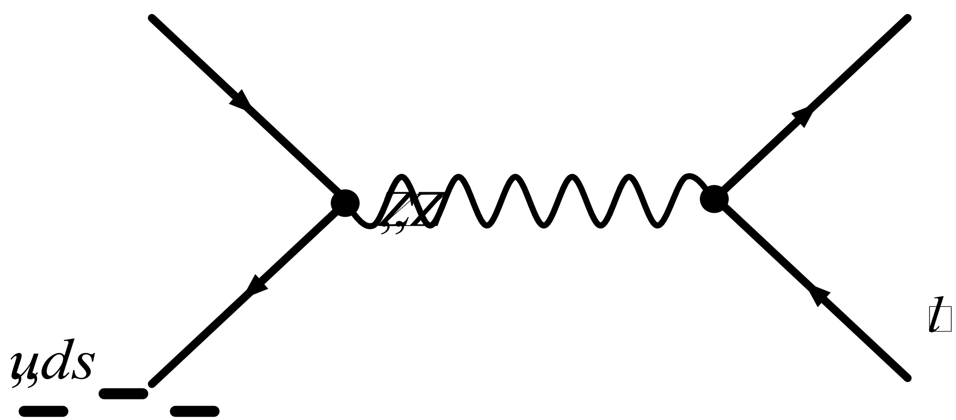
•Leptonic channel

Small physic background (mainly Z/γ process or rare processes)

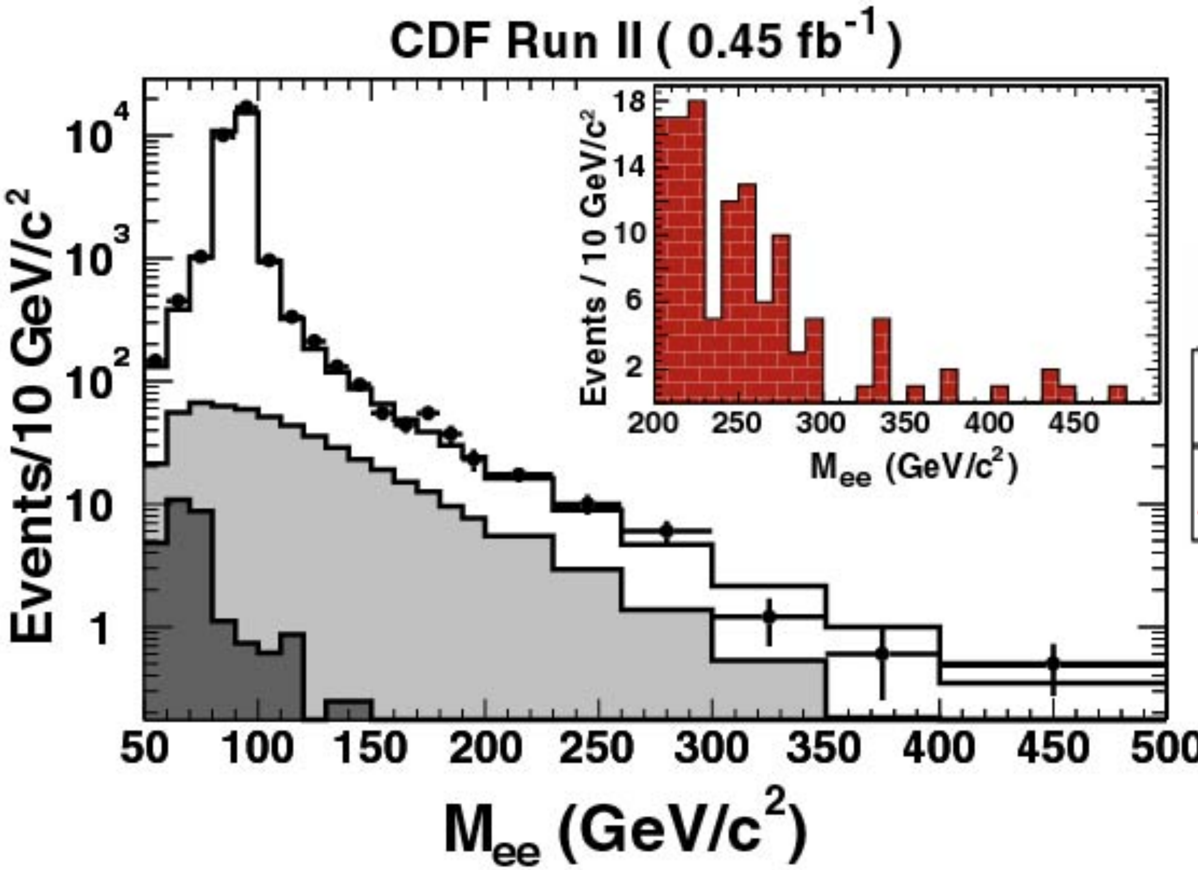
For our studies

•We focus on the ppZee channel

•To study the discovery potential and the underling Z’ theory



Experimental limits on the Z' mass



	Mass Limit	Experiment
Z'_{GUT}	≈ 680 GeV	Tevatron
$Z'_{X\text{-}Dim}$	≈ 4 TeV	LEP

Mass limit with 200 pb^{-1}

Tevatron ultimate limit

With 2 fb^{-1}, Tevatron Run II can probe up to $M_{Z'} \approx 1$ TeV

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Different theoretical Z' models

Grand unified theories

- Based on the existence of a large gauge group including the SU(3)×SU(2) ×U(1) SM gauge group
- Provide a framework for the unification of the SM forces

Extra-dimension theories

Original ADD : [N.Arkani-Hamed, S.Dimopoulos ,G.Dvali : Phys. Rev D59 086004 (1999)]

- 4D brane + n compactified X-dim in which only the graviton can propagate
- Provide an explanation of the weakness of gravity

Original RS : [L.Randall, R.Sundrum, Phys. Rev. Lett. 83 3370 (1999)]

- 5D bulk with a warped geometry bounded with two 4D brane (Plank and TeV)
- Provide a reduction of the Plank scale on the TeV Brane

Grand Unified Theories

Up to now, we study GUT **Z' from specific models**
(E$_6$ models : Z'$_\psi$, Z'$_\eta$, Z'$_\chi$
SO(10) model : Z'$_{LR}$)

Carena, Daleo, Dobrescu, Tait (CDDT) propose a **model independent** parameterisation
[Phys. Rev. D70, 093009 (2004)]

It's based on the existence of a additional U(1) gauge group :

(3)(2)(1)

Theoretical assumptions and experimental constraints :

- Z-Z' mixing small (LEP)
- Flavour changing neutral currents constraints
- No Z' decay into new particles
- Anomaly cancellations

Grand Unified Theories - CDDT parameterization

4 classes of solutions are found :

BxL qxu

$10+x5$ $-$ dxu

Each model fully described by 3 free parameters :

- Z' mass
- Coupling strength normalisation $g_{Z'}$
- An x parameter (fermions coupling relate

These new 4 classes contain :

- The E_6 models:
  - χ, $10+x5$ with $x=-3$ and $g=0.2144$
  - $-$
  - $-$
- Some little higgs models
- ...

X-dim theory - ADD model

•Fermions confined on the 4-brane

•Graviton propagates in 4-brane + 1 large extra dimension

R >>1 TeV^{-1}

•Gauge fields propagate in 1 small extra dimension

compactified on S^1/Z_2
R ~1 TeV^{-1}

[T.G.Rizzo : Phys. Rev D61 055005 (2001)]

•Masses of the KK modes $M_n^2 = M_0^2 + (nM_c)^2$

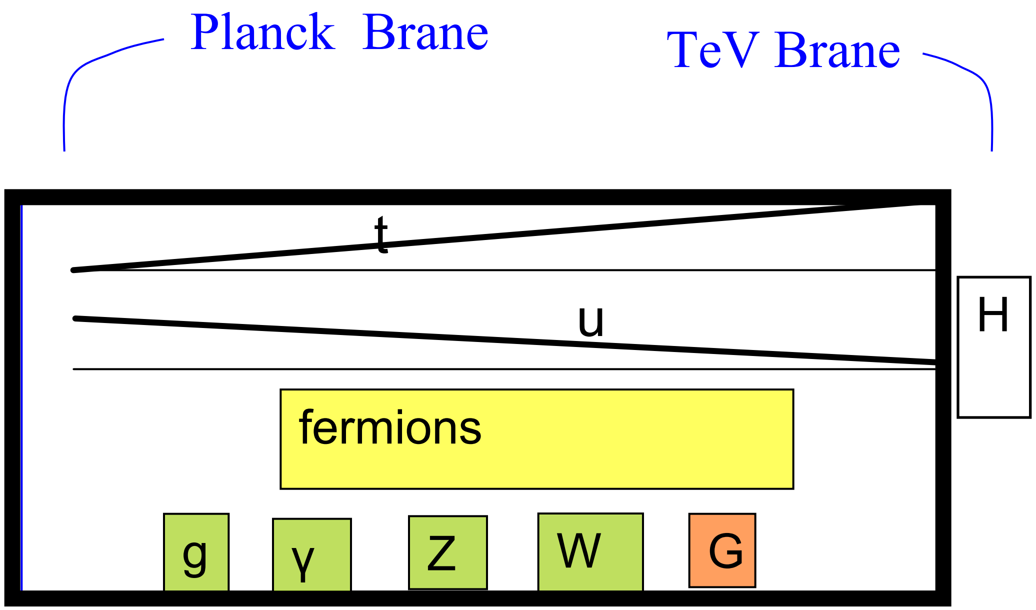
Mc is the only parameter

•$Z'_{ADD} = Z / \gamma$ first KK mode (mass degenered)

Couplings $\sqrt{2}$ SM Couplings

X-dim theory - Randall-Sundrum with bulk matter

RS with bulk matter : [G.Moreau, J. I. Silva-Marcos, Hep-ph/0602155]



•Gauge fields are in the bulk.

•Higgs field remains on the TeV brane.

•Fermions are in the bulk with different localizations along the extra-dimension.

•Z' gauge coupling non universal

3 important features :

•New interpretation of the fermion mass hierarchy.

•Compatible with a Grand Unified Theory [hep-th/0108115] .

•KK excitation provides WIMP candidate.

Fermion mass in the RS model

RS model : 1 spatial X-dim compactified over with radius R_c

Fermion 5D masses :

Effective 4D masses matrix:

c_i = new dimensionless parameters

k_{ij} = new parameters related to the yukawa coupling

Selected points for our studies

Experimental constraints :

- SM charged Fermions masses and mixing angles (5% uncertainty)
- SM neutrino masses and mixing angles (4σ)
- Flavor Changing Neutral Current
- S and T parameters

We study two sets of parameters (labeled A and B) :

Point A = Realistic model

Point B = Strong coupling

Z' Generators

Grand Unified Theories

•Standard Pythia : process n° → 141

Extra-dimension theories

•Pythia with an user-defined process developed by T.Rizzo and interface with pythia by G.Azuelos and G.Polesello for the ADD model.

• Pythia with an user-defined process developed by G. Moreau based on G.Azuelos and G.Polesello code for the RS model

These generators provide Z'_{RS} calculation with full interference $Z/Z^{(1)}/Z^{(2)}/\gamma/\gamma^{(1)}/\gamma^{(2)}$

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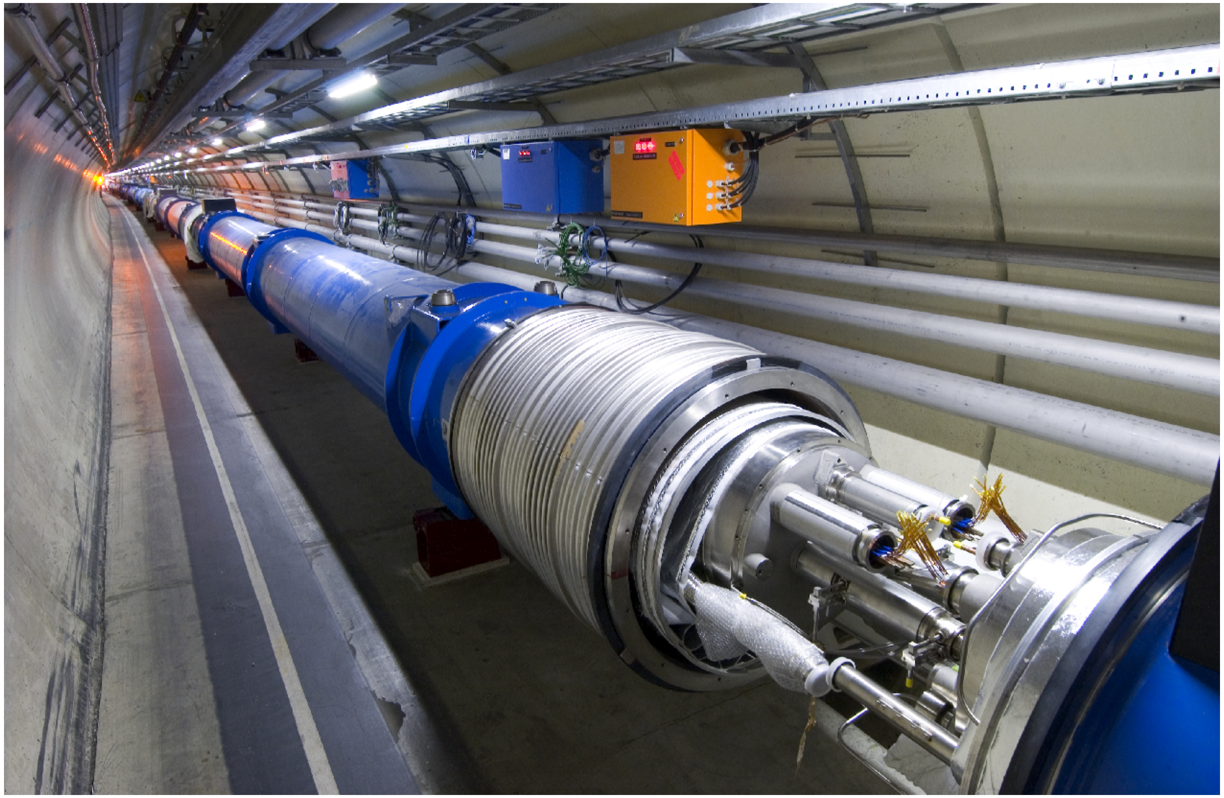
The Large Hadron Collider



The installation of the LHC's magnets is progressing rapidly

The beam pipe closure date will be August 2007

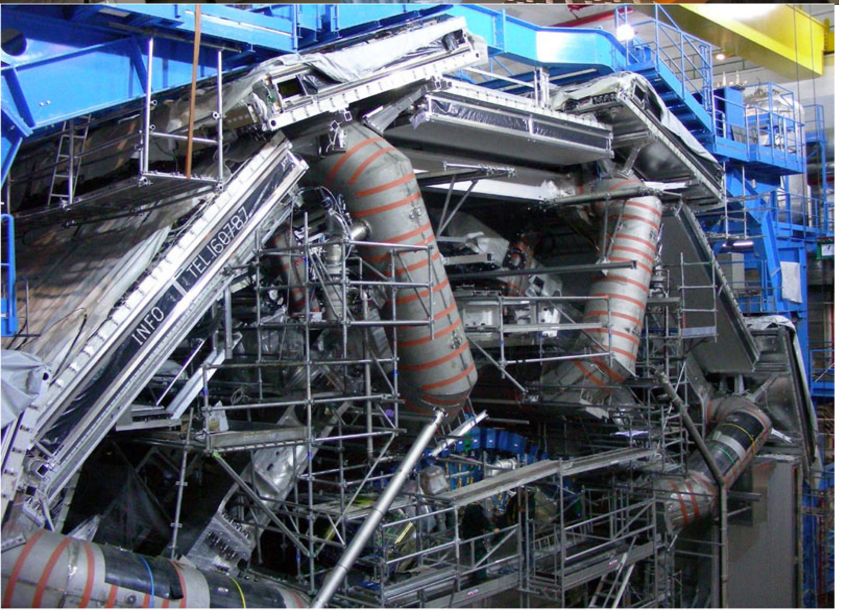
LHC will start in 2007 with 450 GeV per beam

2008 :
- 7 TeV per beam
- Instantaneous luminosity = 10^{33} cm^{-2} s^{-1} (low lumi)

  = 10^{34} cm^{-2} s^{-1} (high lumi)

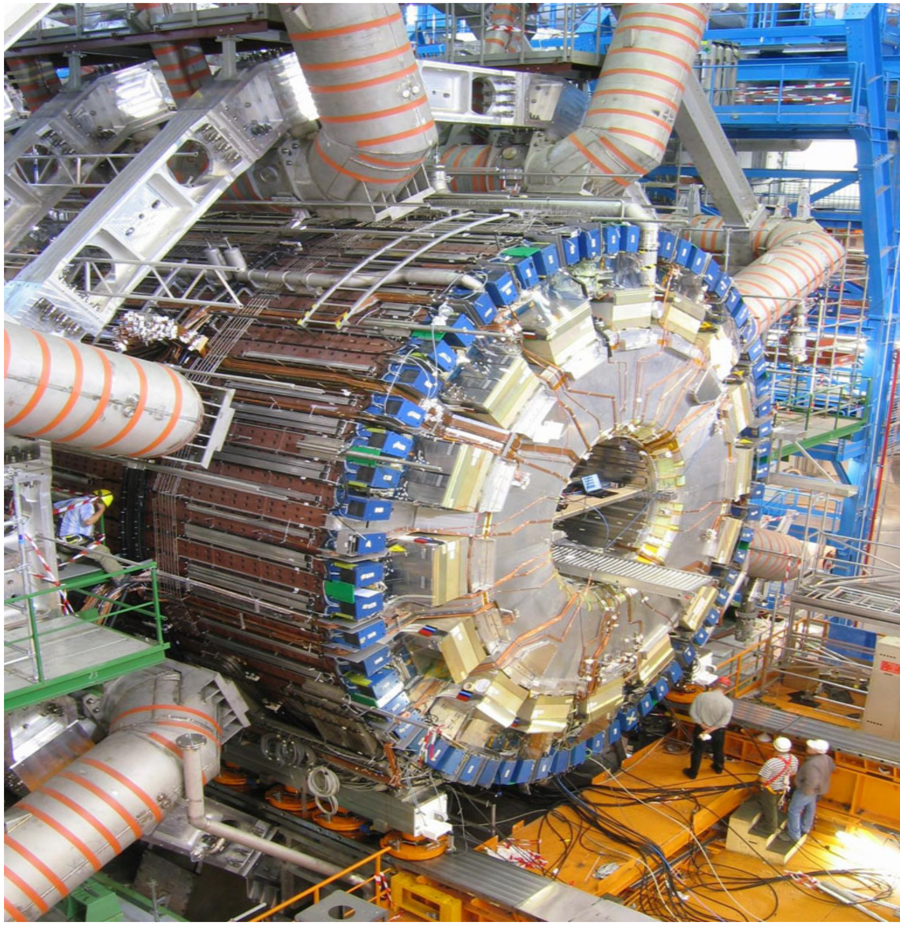
The ATLAS experiment

Inner detector is about to be installed (mid 2007)



288 muon Stations have been installed (47%)

Calorimeters are already installed



ATLAS simulations

Fast simulation :

Simulation using a parameterization of the detector resolutions

Full simulation :

Real simulation of the whole detector using Geant4

	$M_{Z'}$ =1500 GeV	$M_{Z'}$ =4000 GeV	
	Z'_{GUT}	Z'_{ADD}	Z'_{RS}
Generated	6M	6M	6M
Fully simulated	120k	3k	-

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ATLAS Discovery potential for a Z'

To compute the Z' ATLAS Discovery potential we need :

- The detector efficiency (ε)
- The cross section ($\sigma_{Z'}$)
- The DY cross section (σ_{DY})
- A significance convention (S_{12})

= **Effective cross section**

According to hep-ph/0204326 we use the significance S_{12} (realistic) :

We ask $|S_{12}| > 5$ for a discovery

The detector efficiency

•We use the channel with the ATLAS detector efficiency

(see next slides)

•We also use the channel for the Z'_{RS} with a CMS like detector efficiency inspired from CMS-NOTE-2005-002

CMS efficiency (acceptance, trigger, reconstruction) lies in the range 70-75 %

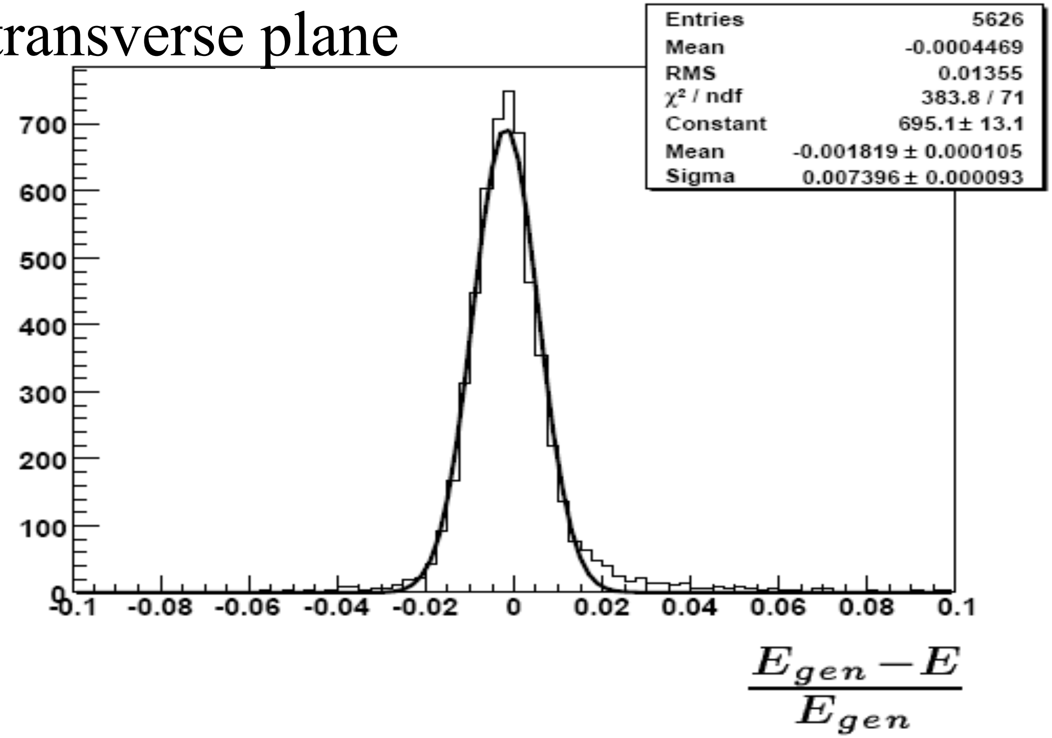
The ATLAS detector efficiency …

Selection criteria :

- 2 identified e±
- 2 $e^{\pm}$ with $|\eta|<2.5$
- Opposite charges
- ≈back to back in the transverse plane

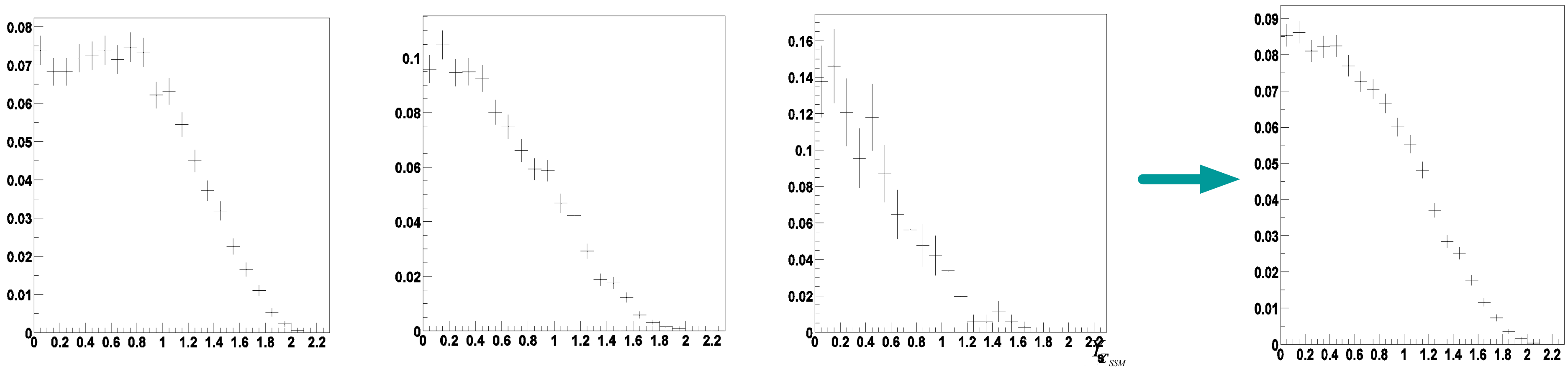
The efficiency of the event selection depends on :

- The di-lepton mass
- The angle between the electron and the beam in the lab frame



The ATLAS detector efficiency …

This angular dependence is related to the Z' boost :



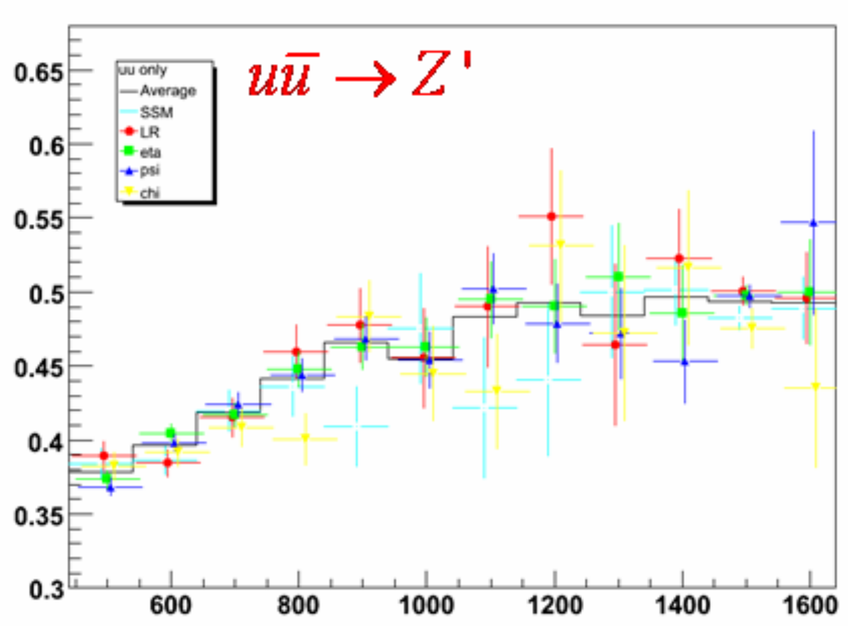
Z' rapidity: model-independent shapes → 1 model-dependent combination (different couplings)

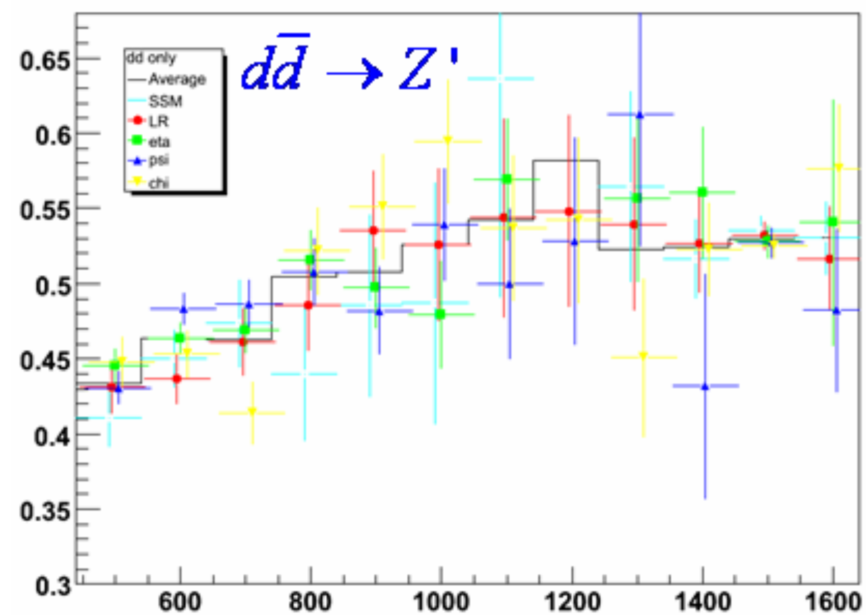
The efficiency depend on the model due to the Z' boost :

dileptons coming from are more boosted than
di-leptons coming from because of different pdfs.

The ATLAS detector efficiency …

Selection efficiency vs di-electron mass
For and events *separately* (low masses):



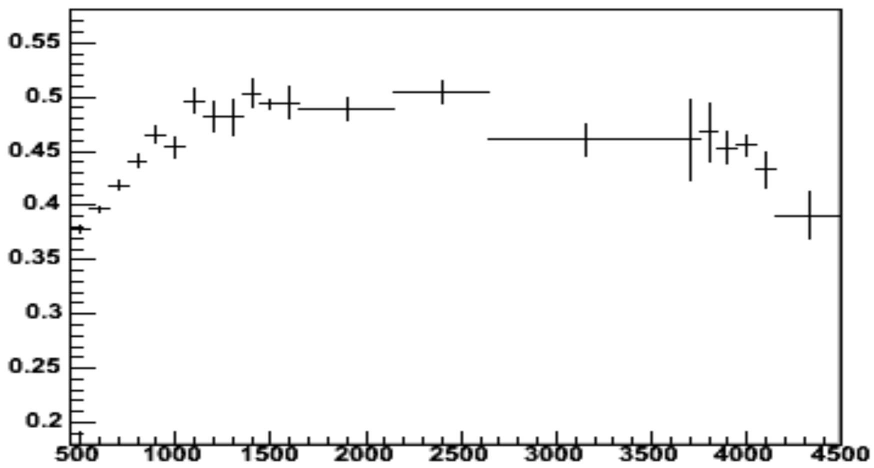


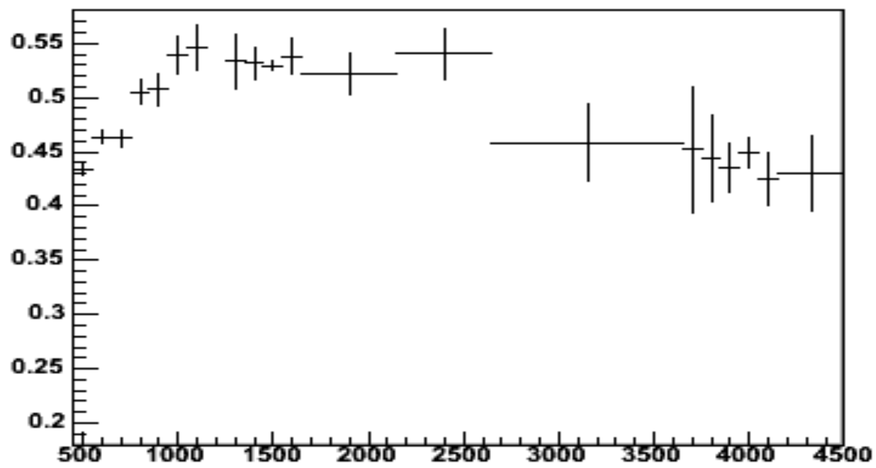
- All models compatible for a given parton flavour
- Efficiency only depends on initial parton flavour (for a given mass)
- Efficiency for events *lower* than efficiency for

A model-independent method to take into account the efficiency ...

Selection efficiency vs di-electron mass

For , , events *separately* (all masses and all models)





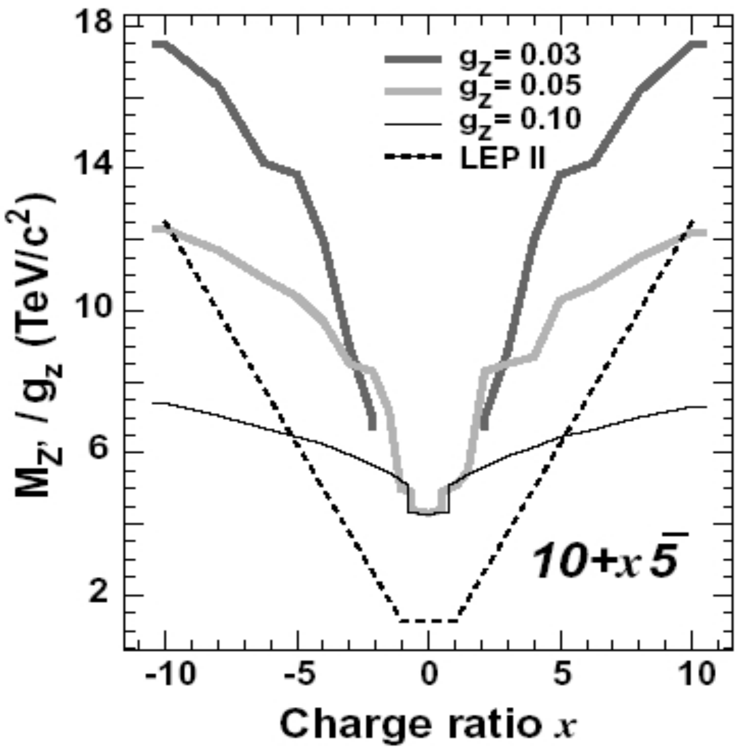
In the effective cross section calculation

We assign the right efficiency depending on the initial parton flavour and the invariant mass, event by event.

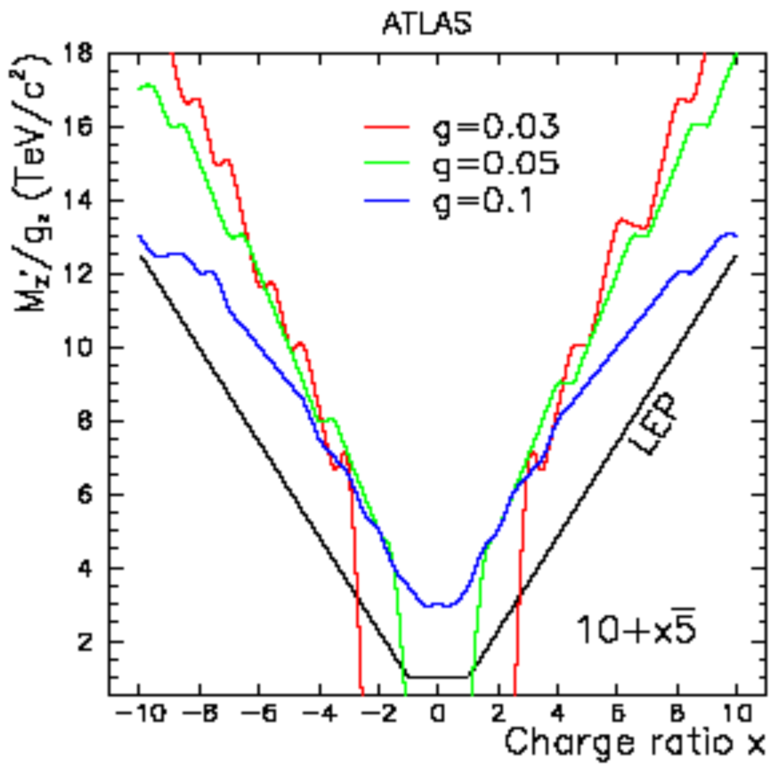
Z'_{GUT} discovery potential - CDDT parameterization

3 free parameters in the CDDT parametrization : x , $m_{Z'}$ and $g_{Z'}$

$M_{Z'}/g_{Z'}$ as a function of x for different values of $g_{Z'}$



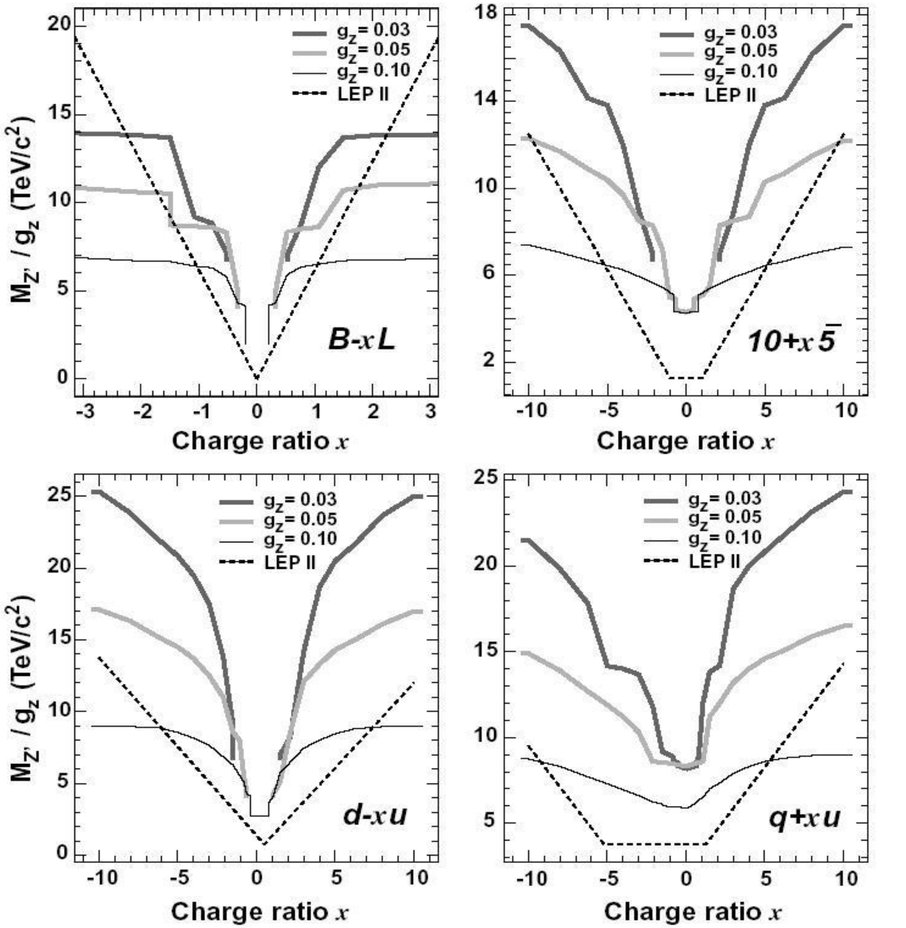
CDF exclusion plots



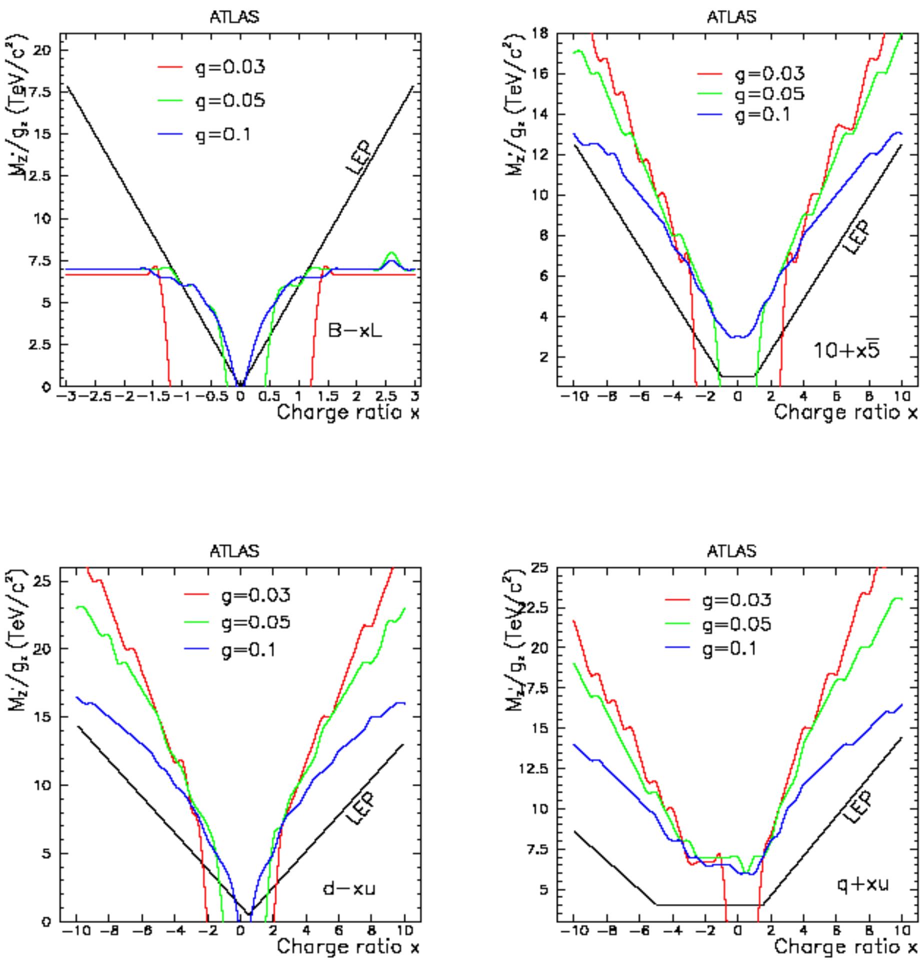
ATLAS discovery plots

Z'$_{GUT}$ discovery potential - CDDT parameterization

[hep-ex/0602045]



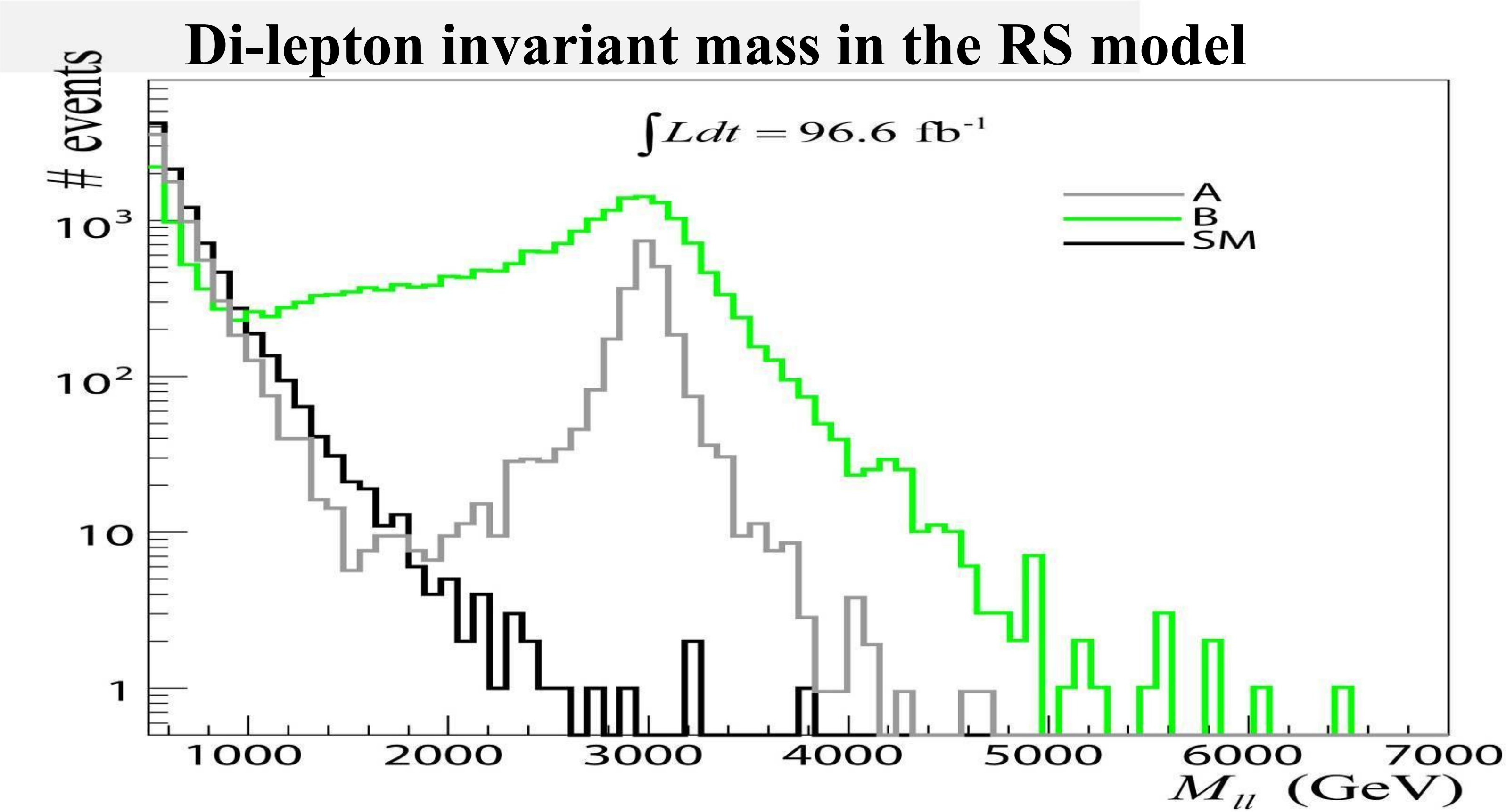
Exclusion plots



Discovery plots

Good hope to discover model not yet excluded by cdf in 2008 with atlas

$Z'_{X\text{-}Dim}$ discovery potential - RS model



According to the G.Azuelos and G.Polesello idea,

to discover a Z' we are looking for :

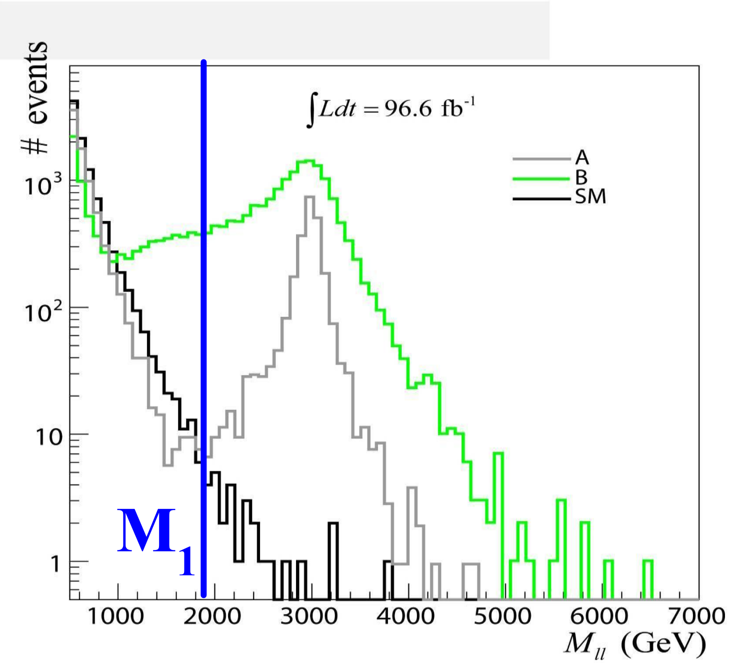
- **An excess of cross section due to a resonance**
- **A lower cross section due to a destructive interference**

Z'_{RS} discovery potential - RS model

The parameter M_1 represent the integration bounds

We chose it model-independent such as :

M_1 depend on the luminosity and represents the end of the DY process. We keep 15 events above M_1 to allow a S_{12} calculation with a non-zero background value



We calculate the significance S_{12} in two regions of the mass spectra :

- In the resonance region

  Above M_1 → **Excess of events** →

- In the interference region

  Between 500 Gev and M_1 → **Lack of events** →