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Searching for Z' and model discrimination in Atlas

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If a heavy Z' boson exists, it could be one of the first particles to be discovered at the LHC, since its decay into two leptons will provide a clean signature. Interpreting the resonance may be more complicated. Here, we summarize a full detector simulation study on the possibility of distinguishing between models of Z' like narrow resonances, using as observables the width, cross section and forward-backward asymmetry.

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The presence of additional neutral spin 1 bosons (denoted as Z' in this note) is predicted in many extensions of the Standard Model: models derived from the breakings of the E_6 gauge group, left-right symmetric models, extra dimensions models...The current most stringent limits are derived from the recent searches at the Tevatron[1][2] and range between 600 GeV and 800 GeV, depending on the assumed model. The Large Hadron Collider at Cern whose first collisions are expected in fall 2007, should open a new frontier in this field : bosons of mass up to 4 TeV could in fact be discovered in one year of data taking at the design luminosity (see [3] for instance).
If a Z' is discovered, the next challenge will consist in determining the underlying theory at the origin of this new gauge boson; this can be done by precisely measuring specific observables such as : natural decay width, rapidity, forward backward asymmetry... The measurement of the latter, not trivial at a hadronic collider, is detailed in this note, in the case of a Z' decay to electron-positron.

1. Angular considerations

Due to the spin 1 nature of the Z', its production cross section strongly depends on $cos\theta^\star$, the angle between the final lepton and the initial quark in the rest frame, with the behaviour:

$$\frac{d\sigma}{d\cos\theta^\star} \propto \frac{3}{8}(1+\cos^2\theta^\star) + A_{FB}\cos\theta^\star \tag{1.1}$$

Checking this dependence can be a way to probe the spin value of the new gauge boson but also to disentangle between spin 1 models by precisely measuring the A_{FB} parameter. This measurement is challenging at the LHC, where the direction of the initial quark remains inaccessible.
In all the following, two angular quantities are considered:

- $\cos\theta^\star$ is the angle between the outgoing electron and the quark, in the Z' rest frame, deduced from the generator history.

- $\cos\theta^\otimes$ is the angle between the outgoing electron candidate, in the reconstructed Z' rest frame, and the direction of the reconstructed Z'.

The first quantity will be used to extract the reference asymmetry, whereas the second one will be used as an estimator; the correlation between the two quantities is represented on Fig. 1, two main populations of events being exhibited:

- when the quark is in the same direction as the Z', the $\cos\theta^\otimes$ quantity is an unbiased estimator of the $\cos\theta^\star$ angle, degraded only by initial state radiation, energy and angular resolution. As the Z' is produced by the annihilation of a quark and a sea antiquark, this configuration is the most frequent.

- if not, the estimator is strongly biased, with $\cos\theta^\otimes \approx -\cos\theta^\star$

The relative proportion ε of the second population of events can be estimated as a function of the rapidity and is represented on figure 1.

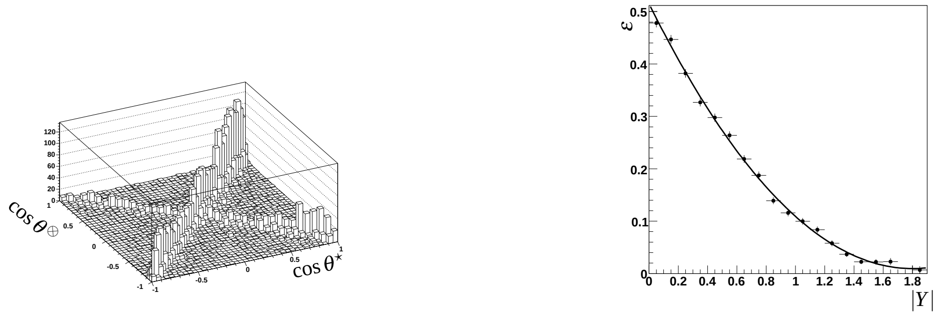

Figure 1: Left: $\cos\theta^\star$ vs $\cos\theta^\otimes$; Right: $\varepsilon(|Y|)$ at $M = 1.5\,TeV$ (with a parabolic parametrisation superimposed)

2. The A_{FB} extraction

Given relation 1.1, the A_{FB} parameter can be classicly extracted at the generation level by a counting method:

$$A_{FB}^{gen} = \frac{N_+ - N_-}{N_+ + N_-} \tag{2.1}$$

where N_+ (N_-) denotes the number of events with $\cos\theta^\star > 0$ (< 0).
Applying the same formula to measure the observed asymmetry by taking $\cos\theta^\otimes$ as an estimator of $\cos\theta^\star$ leads to a bias due to the imperfect knowledge of the quark direction. Ignoring the detector effects and the Z' transverse momentum, this bias can be quantified with the knowledge of the ε proportion defined in section 1 :

$$A_{FB}^{obs} = (1 - 2 < \varepsilon >) A_{FB}^{gen} \tag{2.2}$$

A corrected asymmetry is then defined by:

$$A_{FB}^{cor} = \frac{1}{1 - 2 < \varepsilon >} A_{FB}^{obs} \tag{2.3}$$

This method is very easy to implement and efficient but the whole angular information is unfortunately lost, when integrating over an hemisphere; the spin 1 behaviour of the new particle is consequently not tested at all. To allow such a test, a differential analysis is performed : a differential asymmetry is deduced by a counting method, the quantity $N_\pm$ being extracted on a limited $\cos\theta^\star$ (or $\cos\theta^\otimes$) range. The running of this quantity can be easily deduced from expressions (1.1) and (2.1):

$$A_{FB}(\cos\theta) = \frac{8}{3} A_{FB} \times \frac{\cos\theta}{1 + cos^2\theta} \tag{2.4}$$

Performing an analytical χ^2 fit to these differential asymmetry distributions in the $[0,1]$ interval then allows to extract the A_{FB}^{gen}, A_{FB}^{obs}, and A_{FB}^{cor} quantities.

3. Application to the ATLAS case

In order to validate the above method, Monte Carlo event samples have been considered; they have been produced by the PYTHIA generator[4], the ATLAS detector response being simulated

in the Geant3 framework. Several models involving a new gauge boson of mass 1.5 TeV have been considered : χ, ψ, η (all derived from a E_6 theory) and a left right symmetric model. Given the ATLAS detector performances, the signal signature should be very clean (two highly energetic leptons) and the background should remain limited; no background was therefore included in this study.
The three asymmetries detailed in the section 2 are represented on figure 3 for the χ model in 5 different dileptons mass bins, and for a luminosity of $100\,fb^{-1}$. The 5 - independent- measurements exhibit the same behaviour : due to the imperfect knowledge of the incoming quark direction, the observed asymmetry is much lower in absolute value than the one computed at the generation level. Applying the adequate ε correction factor however allows to recover from this effect. Due to the different coupling constants to quarks, a systematic error must be associated to the estimate of the ε quantity; the impact on the A_{FB} measurement was found to be limited, below 10%.
Finally, applying this method on all available samples leads to identical conclusions; on figure 3, are represented all the corrected asymmetries; the variety of behaviours is a clear proof of the discrimination potential of this observable.

Figure 2: Left: Asymmetries measurement - χ model ($M'_Z = 1.5\,\text{TeV}$) - $\int \mathscr{L} = 100\,fb^{-1}$; Right: Corrected asymmetry - $\int \mathscr{L} = 100\,fb^{-1}$

4. Conclusion

A method to measure the leptonic forward-backward asymmetry at the LHC was presented. The accuracy reached with a realistic luminosity was found to be promising; this measurement, associated with the one of other observables (natural width, rapidity) should provide large constraints on the model at the origin of any -potential- new massive gauge boson.

References

[1] The CDF collaboration, *Search for new particles decaying to high mass dielectrons or dimuons at CDF II*, CDF note 7286

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[4] T.Sjöstrand et al., *PYTHIA 6.2 Physics and Manual, Comp. Phys. Comm.* **135** (2001) 238 [hep-ph/0108264]