Distinguishing Z' models in ATLAS

- Motivations
- Current limits and discovery perspectives
- Discriminating variables at LHC:
  - Natural width and cross section
  - Forward – backward asymmetry

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Motivations for a Z'

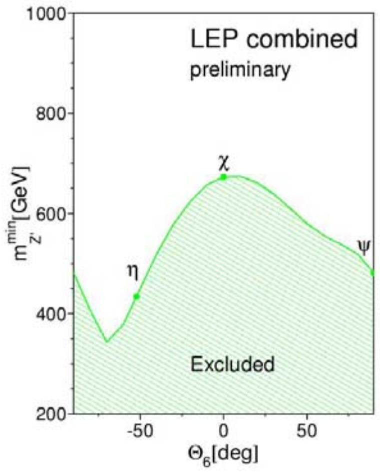
- Additional gauge bosons emerge in many extended gauge models :
  - E6 breaking models. Type of breaking described by a phase term θ_{E6}. Three particular cases usually considered : Z'_ψ, Z'_η, Z'_χ
  - LR model : $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ .Relative coupling strengths given by a parameter $\kappa = g_R/g_L$.
  - Little Higgs models.

- But also in extra dimensions models :
  - Kaluza Klein excitations.

- Also often considered :
  - Sequential standard models (SSM) : SM + 1 additional massive boson with the same couplings constants.

Typical current limits

- Indirect limits from the precision measurement at LEP (assuming no Z-Z' mixing):
  - E6 : ~ 400-600 GeV (depends on θ_{E6}).
  - LR : ~ 800GeV



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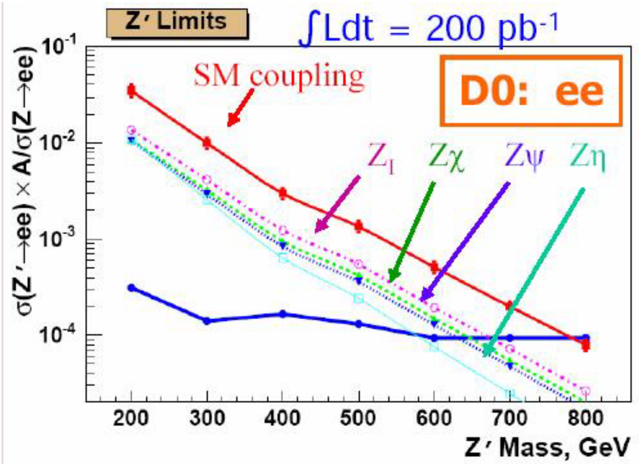
- Direct limits from the search at Tevatron :
  - E6 : ~ 600-700 GeV (depends on θ_{E6}). Best limits comes from run II !
  - LR : ~ 600 GeV.



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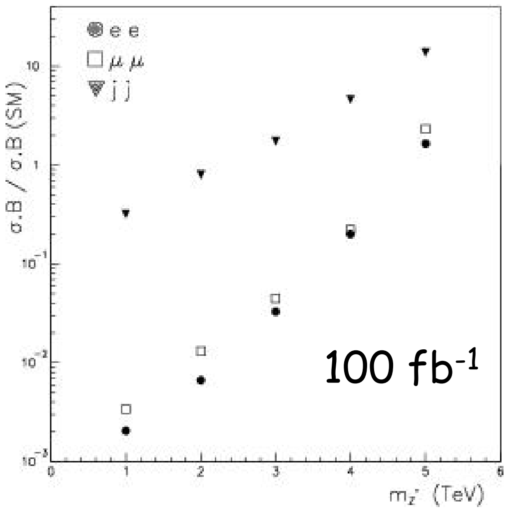
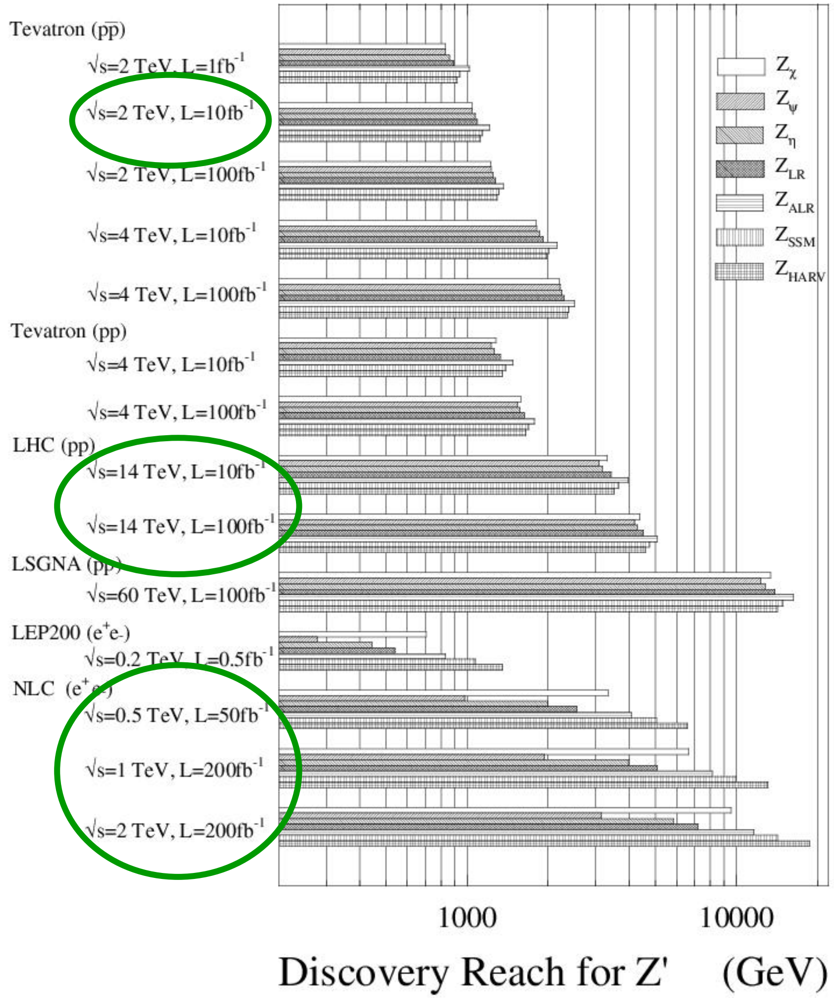
Discovery potential at colliders

- Very promising potential at Tevatron, LHC and NLC:
  - Already true with a reduced LHC luminosity.
- If a Z' is discovered, the next step will consist in determining the nature of the Z' !



Atlas - Physics Perf. TDR



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Disentangling Z' models

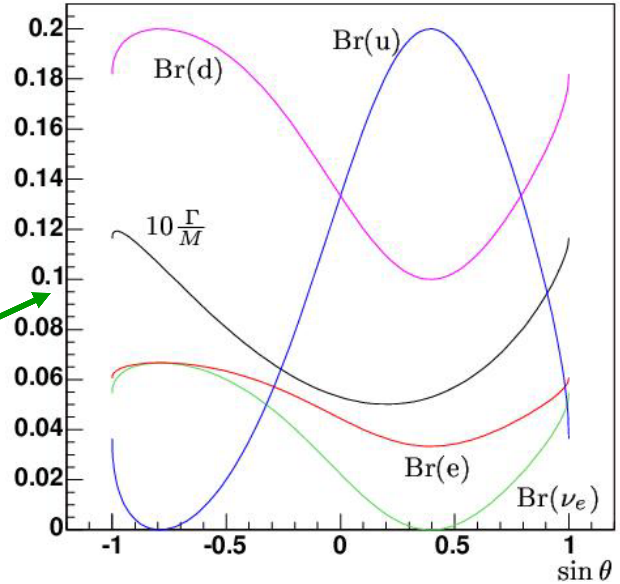
- Only $Z' \rightarrow ee$ channel (clean signal).
- Studied variables :
  - Natural width x cross section
  - Forward backward asymmetry
- Considered models :
  - 3 classical E6 models : Z'_ψ, Z'_η, Z'_χ – $M_{Z'}$ = 1.5 TeV
  - LR model with $\kappa = 1$ – $M_{Z'}$ = 1.5 TeV
  - Sequential Standard Model – $M_{Z'}$ = 1.5 /4 TeV
  - Kaluza Klein excitations : one small extra dimension compactified on S^1/Z_2. One considers only 1st resonance at 4 TeV (Azuelos / Polesello : Eur. Phys. Journal C39 (2005) 1-11)
- Available data samples :
  - Atlas full simulation (Geant 3) + official reconstruction
  - Data Challenge 01 Monte Carlo samples.

The width & leptonic cross sections

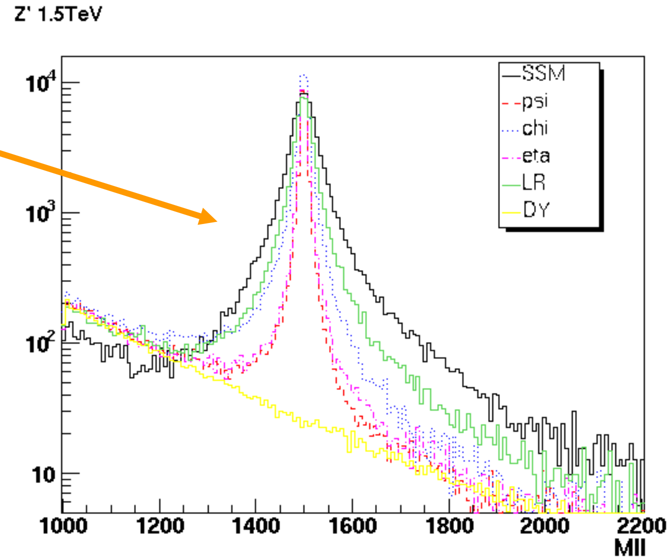
- Partial decay widths(light fermions):

$$\Gamma\left(Z'\to f\bar{f}\right)=N_c\,\frac{g^2}{\cos^2\theta_\omega}\,\frac{1}{48\pi}\left(g_V^2+g_A^2\right)M$$

- Width / branching ratios variations in E6 models (assuming no exotic decays)



- Resonance shape for several models (arbitrary normalization)



- Problem : total width altered if Z' decays in invisible particles (gauginos by e.g.)

$\rightarrow$ Consider instead the product :

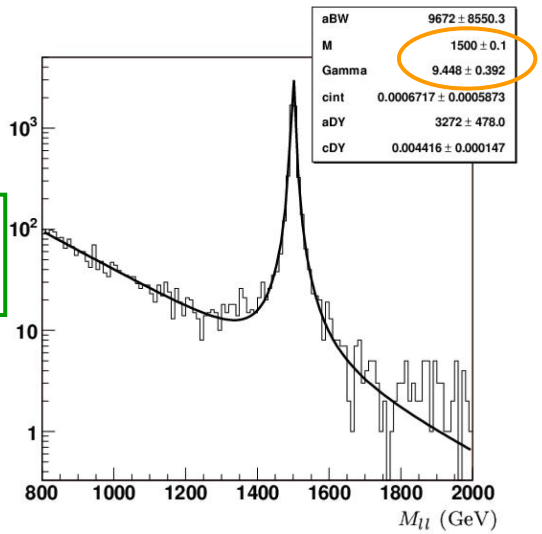
$$\sigma_{ll}\times\Gamma$$

The width extraction in Atlas

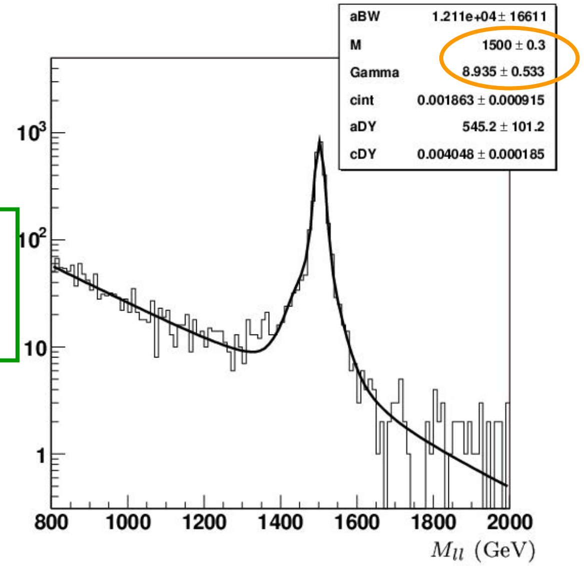
- Analytical fit of di-electron mass: $f(M_{ll}) = \frac{a_{BW} M^2 \Gamma^2}{(M_{ll}^2 - M^2)^2 + M^2\Gamma^2} \times e^{-c_{int} M_{ll}} + a_{DY} e^{-c_{DY} M_{ll}}$

- Example : η model ($M_{Z'}$ = 1.5TeV $\Gamma_{Z'}$ = 9.5GeV)

Generation level



Reconstructed level (convoluted with resolution function)



- Given the E/position resolution, the width can be accurately measured.

		M_{rec} (GeV)	Γ_{rec}(GeV)	Γ_{gen}(GeV)	$\Gamma_{theo.}$(GeV)
$M = 1.5\,\text{TeV}$	SSM	1501.0±0.7	45.2±1.4	44.1± 0.9	44.7
	ψ	1500.1±0.3	7.5±0.6	6.9± 0.5	8.0
	η	1500.5±0.3	8.7±0.6	9.4± 0.4	9.5
	χ	1500.7±0.4	16.5±0.9	18.2± 0.5	17.6
	LR	1499.3±0.6	29.3±1.2	31.8± 0.7	30.6
$M = 4\,\text{TeV}$	SSM	3996.5±2.5	112.9±4.6	121.1± 2.7	119.2
	KK	3987.2±6.8	151.4±13.8	159.8±8.0	

The product $\sigma_{ll} \times \Gamma$

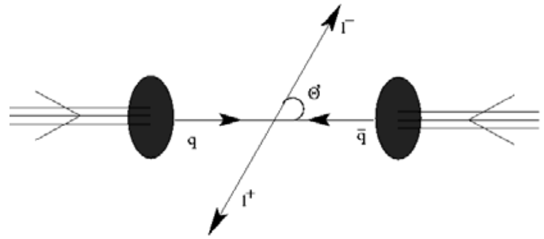
		σ_{ll}^{gen}(fb)	σ_{ll}^{rec}(fb)	$\sigma_{ll}^{rec} \times \Gamma_{rec}$(fb.GeV)
$M = 1.5$ TeV	SSM	78.4±0.8	78.5±1.8	3550±137
	ψ	22.6±0.3	22.7±0.6	166±15
	χ	47.5±0.6	48.4±1.3	800±47
	η	26.2±0.3	24.6±0.6	212±16
	LR	50.8±0.6	51.1±1.3	1495±72
$M = 4$ TeV	SSM	0.16±0.002	0.16±0.004	19±1
	KK	2.2±0.07	2.2±0.12	331±35

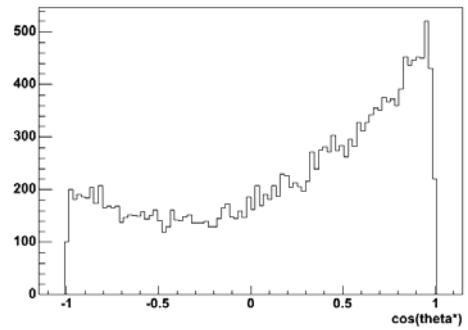
- Promising discriminating potential (independent on potential invisible decays).

The forward backward asymmetry : the potential

- Typical spin 1 particle behaviour (Z' may also have spin 2 in different models : warped extra dimensions by e.g. Not considered here) :

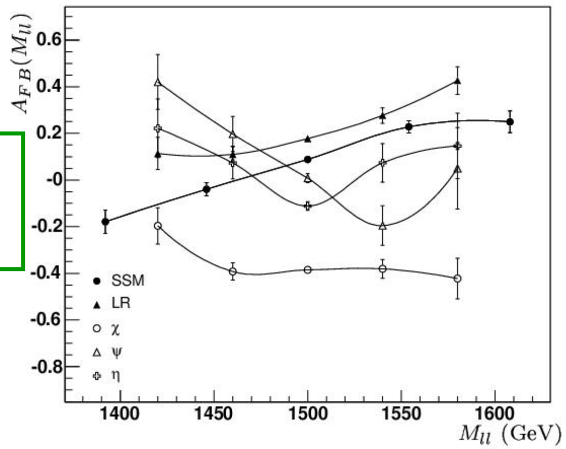
$$\frac{d\sigma}{d\cos\theta^*} \propto \frac{3}{8}\left(1+\cos^2\theta^*\right)+A_{FB}\cos\theta^*$$



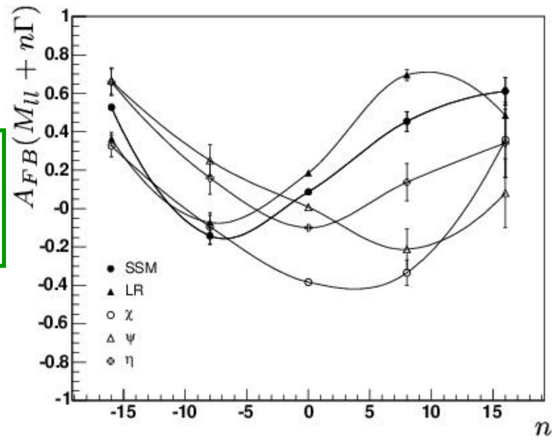


- Asymmetry at generation level for several models with $M_{Z'}$ = 1.5 TeV

Narrow Mass bins



Wide Mass bins

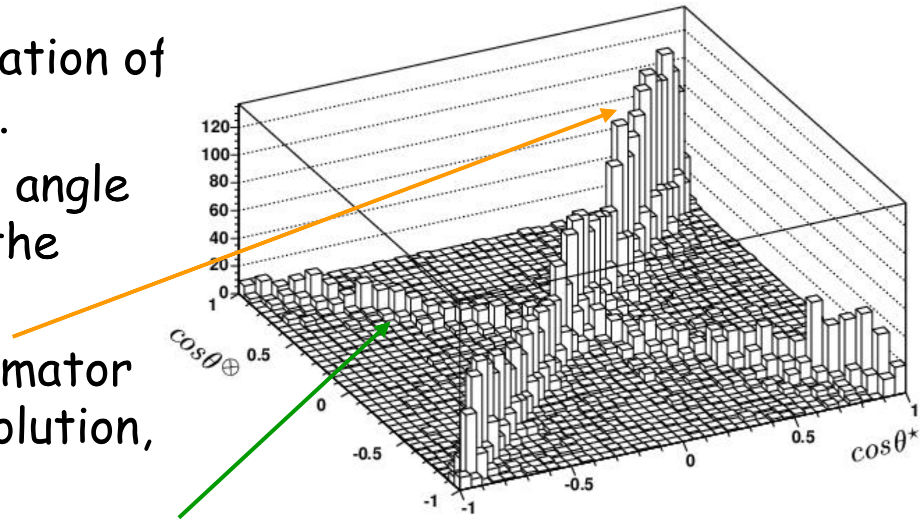


Angles definition

- Main problem at LHC (pp collider):
  - Determination of the quark direction.
  - More problematic than at the Tevatron.

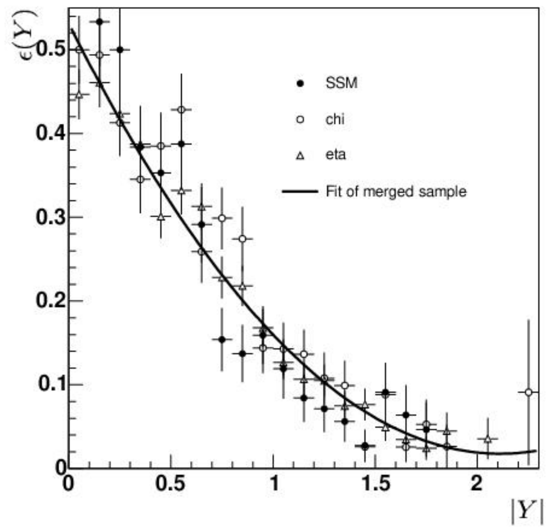
- Z' mainly originates from the annihilation of a valence quark with a sea antiquark.

→ cos Θ^* approximated by cos $\theta^{\otimes}$, the angle between the outgoing electron and the reconstructed Z'.
  - If $P_{quark} > P_{antiquark}$: unbiased estimator only degraded by E/position resolution, ISR.
  - Otherwise : maximally biased estimator (cos $\theta^{\otimes}$ = - cos θ^*).



Angles definition (2)

- Study at Monte Carlo level to extract the probability to be in the "maximal bias" configuration : $\varepsilon(Y)$.
  - Differences between models explained by the different u/d couplings in the initial state (source of systematic error).



- The impact of the imperfect knowledge of the quark direction:
  - $A_{FB}^{observed}$: roughly computed with $\cos\theta^{\otimes}$.
  - $A_{FB}^{observed} = (1 - 2 \times \langle\varepsilon\rangle) \times A_{FB}^{generation}$
  - Artificial reduction of the observed asymmetry. Known as the dilution effect.

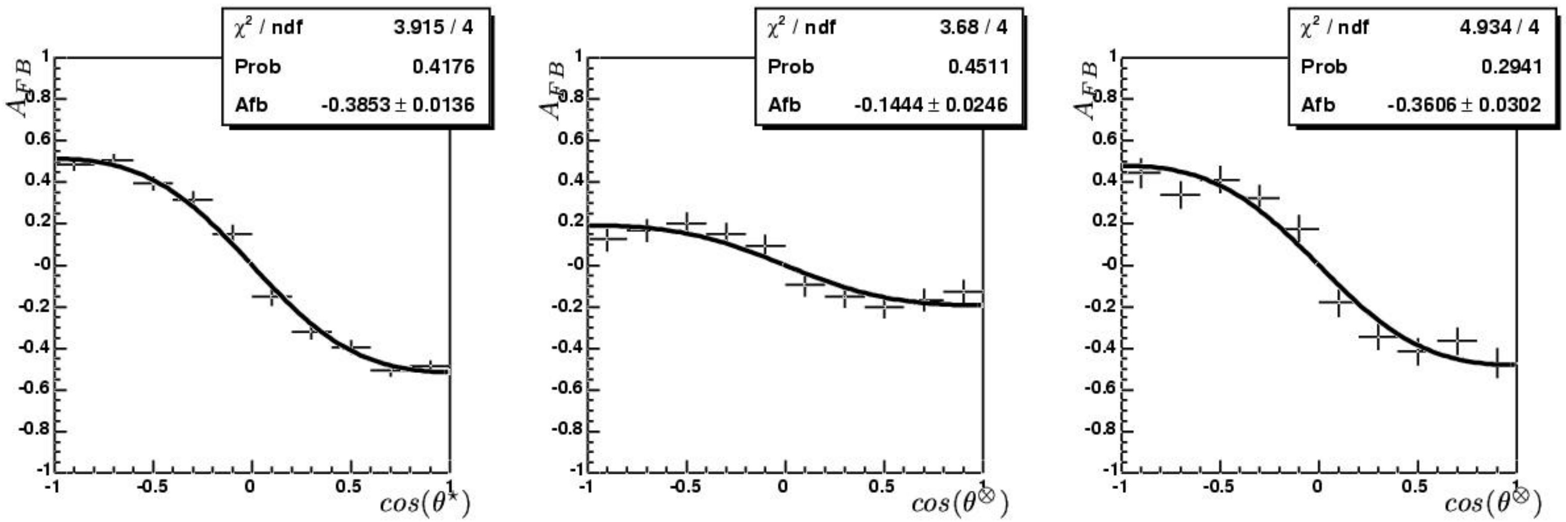
- A new corrected asymmetry is defined

$$A_{FB}^{corrected} = \frac{1}{(1 - 2 \times \langle\varepsilon\rangle)} A_{FB}^{observed}$$

The A_{FB} extraction in Atlas

- A_{fb} is deduced with the "ratio" method :
  - Compute $A_{FB}(\cos\theta)$ by the basic counting method ($N^{+}- N^{-}/N^{+}+N^{-}$) in several bins of $\cos\theta$
  - Extract A_{FB} by fitting $A_{FB}(\cos\theta) = \frac{8}{3} A_{FB} \times \frac{\cos\theta}{1+\cos^2\theta}$

- Example : χ model at $M_{Z'}$ = 1.5TeV (1.48TeV<M_{ll}<1.52TeV)



(a) *At generation level* (b) *Observed* (c) *Corrected*

The A_{FB} extraction in Atlas (2)

- The results for all models in the central mass bins

Model	$\int \mathcal{L}(fb^{-1})$	Generation	Observed	Corrected
1.5 TeV				
SSM	100	$+0.088 \pm 0.013$	$+0.060 \pm 0.022$	$+0.108 \pm 0.027$
χ	100	-0.386 ± 0.013	-0.144 ± 0.025	-0.361 ± 0.030
η	100	-0.112 ± 0.019	-0.067 ± 0.032	-0.204 ± 0.039
η	300	-0.090 ± 0.011	-0.050 ± 0.018	-0.120 ± 0.022
ψ	100	$+0.008 \pm 0.020$	-0.056 ± 0.033	-0.079 ± 0.042
ψ	300	$+0.010 \pm 0.011$	-0.019 ± 0.019	-0.011 ± 0.024
LR	100	$+0.177 \pm 0.016$	$+0.100 \pm 0.026$	$+0.186 \pm 0.032$
4 TeV				
SSM	10000	$+0.057 \pm 0.023$	-0.001 ± 0.040	$+0.078 \pm 0.051$
KK	500	$+0.491 \pm 0.028$	$+0.189 \pm 0.057$	$+0.457 \pm 0.073$

- Systematic error associated to ε lower then 10%.
- Possible to precisely measure the forward backward asymmetry in Atlas:
  - ε correction works well.
  - method remains efficient even far away from the resonance with a reduced statistic (not shown here).
  - very promising discriminating potential (especially when including analysis of all mass bins – cf slide 9).

Conclusion and prospects for the future

- If a Z' is discovered, one will have to discriminate between models:
  - Studies have shown that Atlas have a good potential to do this.

- Prospects for the future:
  - Study impact of PDF on accuracy (top priority).
  - Apply the method to more models and to other decay channels (taus, muons).
  - Study rapidity distribution to probe initial state (coupling to the initial quark). Higher luminosity required.
  - Extract a single set of parameters to disentangle Z' models (4 normalized couplings: γ^q_L, γ^l_L,U,D)

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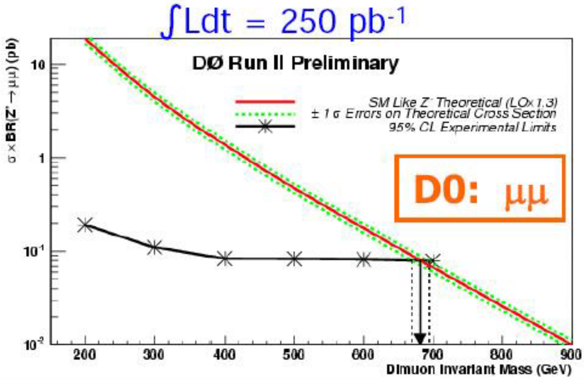
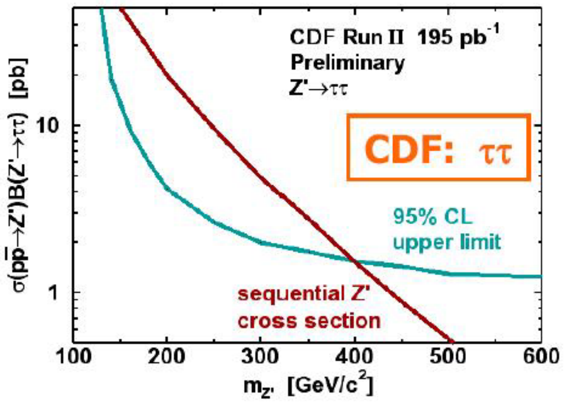
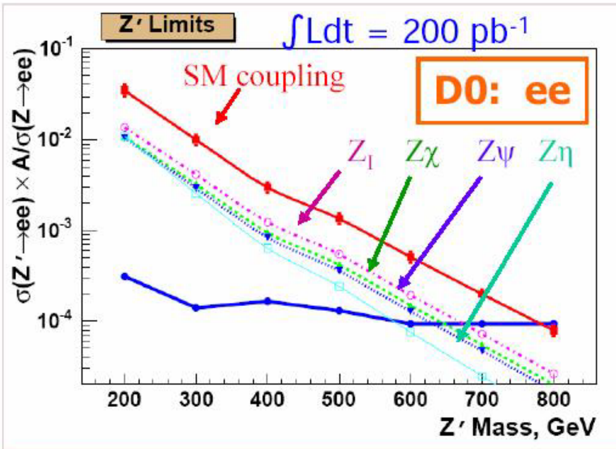
Spin-1, Z' limits







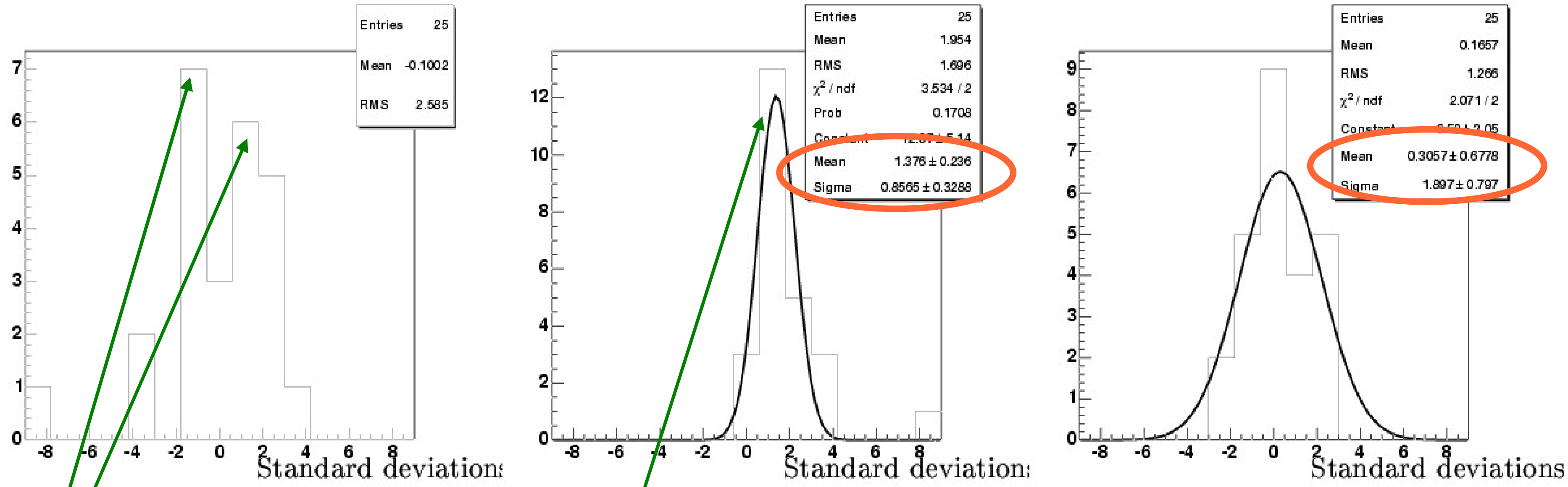
z' mass limits (in GeV/c^2)

SM Couplings	ee	μμ	ee+μμ	ττ
CDF :	750	735	815	394
DØ:	780	680		

E_6	Z_I	Z_χ	Z_ψ	Z_η	
CDF:	610	670	690	715	(ee+μμ)
DØ:	575	640	650	680	(ee)

The on peak analysis

- The summary of the whole analysis of 5 models in the 5 mass bins (therefore 25 independent analyses).



(a) $\frac{A_{FB}^{gen} - A_{FB}^{obs}}{\sqrt{\sigma^2_{stat;gen} + \sigma^2_{stat;obs}}}$

(b) $\frac{|A_{FB}^{gen} - A_{FB}^{obs}|}{\sqrt{\sigma^2_{stat;gen} + \sigma^2_{stat;obs}}}$

(c) $\frac{A_{FB}^{gen} - A_{FB}^{cor}}{\sqrt{\sigma^2_{stat;gen} + \sigma^2_{stat;cor}}}$

Double peak structure (cf $|A_{FB}^{gen}| > |A_{FB}^{obs}|$)

Dilution effect amplitude : 1.4 σ on average

The correction is an efficient and unbiased way to correct from the dilution

The off peak analysis

- Preliminary feasibility study :
  - Only at $M_{Z'}$ = 1.5TeV. A single mass bin :800Gev-1400GeV.

Model	$\int \mathcal{L}(fb^{-1})$	Generation	Observed	Corrected
1.5 TeV				
SSM	100	$+0.077 \pm 0.025$	$+0.086 \pm 0.038$	$+0.171 \pm 0.045$
χ	100	$+0.440 \pm 0.019$	$+0.180 \pm 0.032$	$+0.354 \pm 0.039$
η	100	$+0.593 \pm 0.016$	$+0.257 \pm 0.033$	$+0.561 \pm 0.039$
ψ	100	$+0.673 \pm 0.012$	$+0.294 \pm 0.033$	$+0.568 \pm 0.039$
LR	100	$+0.303 \pm 0.022$	$+0.189 \pm 0.033$	$+0.327 \pm 0.040$

- Correction procedure still efficient but less powerful than for the on peak analysis:
  - Due to the incorrect ε estimate (large mass bin and too few statistic)
  - Will be improved by an increased number of MC events to extract ε.