Z' studies at the LHC

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The Standard Model

SM gauge group:

$$SU(3)_c \times SU(2)_L \times U(1)_Y \xrightarrow{SSB} SU(3)_c \times U(1)_{em}$$

$\rightarrow$ 3 gauge couplings and

$8 + 3 + 1$ gauge bosons

$\sin^2 \theta_W$: free parameter

Why this structure ?
Is it possible to achieve a unification ?

(Glashow, Georgi; Pati, Salam; Fritsch, Minkowski)

$$G_{SM} \subset SU(5) \subset SO(10) \subset E_6 ???$$

Why a new gauge boson ?

$\rightarrow$ Extending the SM gauge group...

- Effective Rank-5 models:

  parameter: β $\qquad Z' = Z'_\chi \cos\beta + Z'_\psi \sin\beta$

$$E_6 \rightarrow SO(10)\times U(1)_\psi \rightarrow SU(5)\times U(1)_\chi \times U(1)_\psi \rightarrow SM \times U(1)_{\theta_{E_6}}$$

  Models studied: $Z'_\psi, Z'_\chi, Z'_\eta, Z'_d$

- Left-Right symmetric models:

  parameter: $\alpha_{LR} \equiv \sqrt{\frac{c_W^2}{s_W^2}\frac{g_R^2}{g_L^2} - 1}$

  $SO(10) \rightarrow SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

  Models studied: Z'_{LR}

- Sequential Standard Model:

  take the SM Z couplings $\rightarrow$ Z'_{SM}

  (Not gauge invariant but good for comparisons)

New gauge bosons:

Search and **Identification**

Favourite decay (this study): $Z' \to \ell\ell$

Z': already done, a few references...

- Z', theoretical point of view

  Robinett, Rosner, *Prospects for a second neutral vector boson at low mass in SO(10)*, Phys. Rev. D25 (1982) 3036

  Cvetič,Godfrey, *Discovery and identification of extra gauge bosons*, hep-ph/9504216

  Del Aguila, Langacker, Cvetič, *Determination of Z' couplings to quarks and leptons at future hadron colliders*, hep-ph/9303299

  Djouadi, Leike, Riemann, Schaile, Verzegnassi, *Signals of new gauge bosons at future e^+e^- colliders*, Z.Phys.C56:289-300,1992

- Forward-backward asymmetry

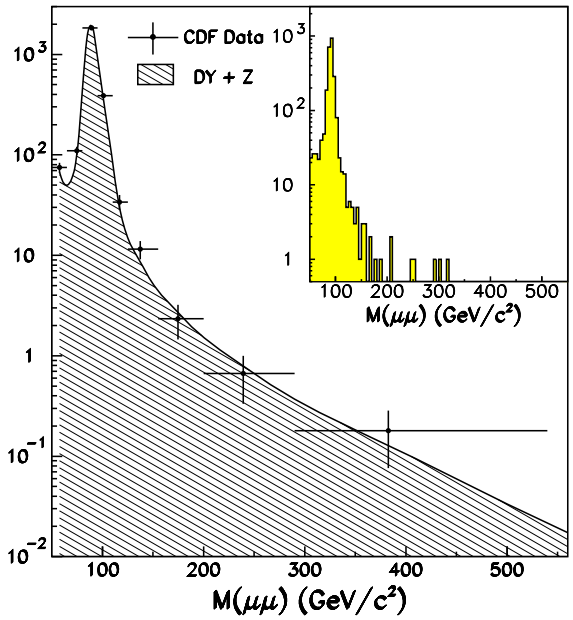
  Barger, Deshpande, Rosner, Whisnant,*Production, decay and forward-backward asymmetries of extra gauge bosons in E_6* Phys. Rev. D35 (1987)

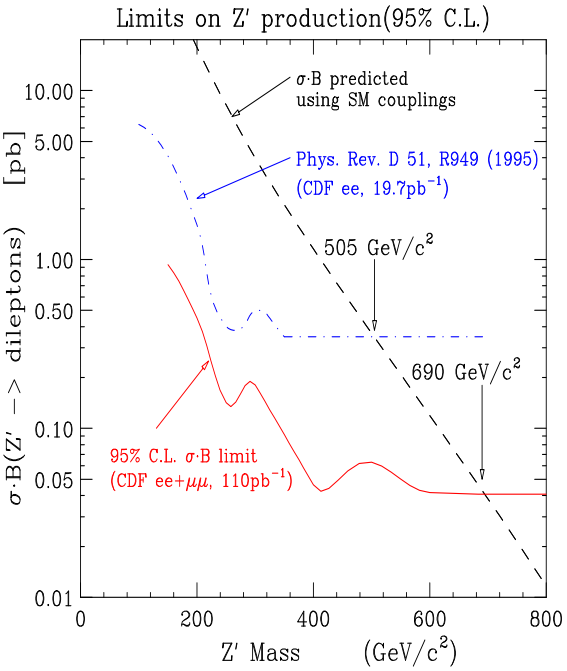
  Dittmar, *Neutral current interference in the TeV region; the experimental sensitivity at the LHC*, hep-ex/9606002

Z' experimental searches

Z' at CDF (direct search)

RUN I: $M_{Z'} > 690$ GeV



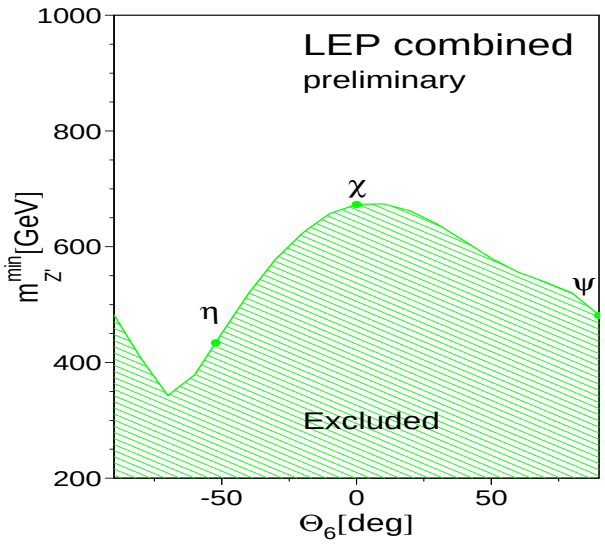


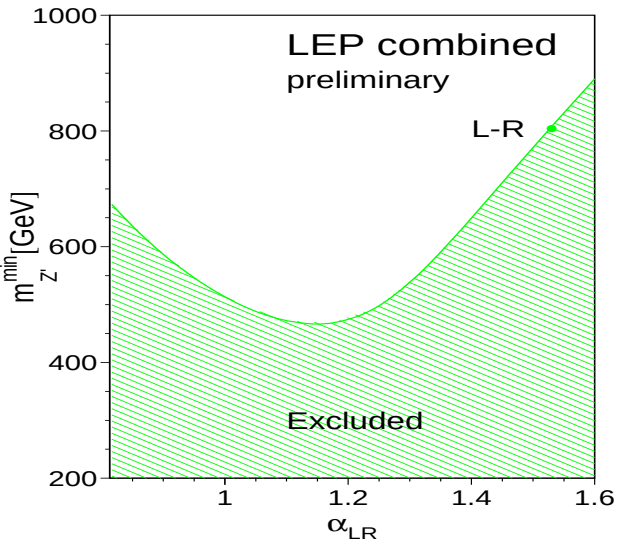
Prospects for RUN II:
with 2 fb^{-1}, $M_{Z'} > 1$ TeV 95% C.L.

LEP (indirect search: use A_{FB}^{ℓ} and $\sigma_{\ell\bar{\ell}}$,$\sigma_{q\bar{q}}$)

Upper limits:

Z' model	Z'_{χ}	Z'_{ψ}	Z'_{η}	Z'_{LR}	Z'_{SM}
$M_{Z'}$ [GeV]	673	481	434	804	1787





+ small mixing angle between Z and Z'

Forward backward asymmetry ?

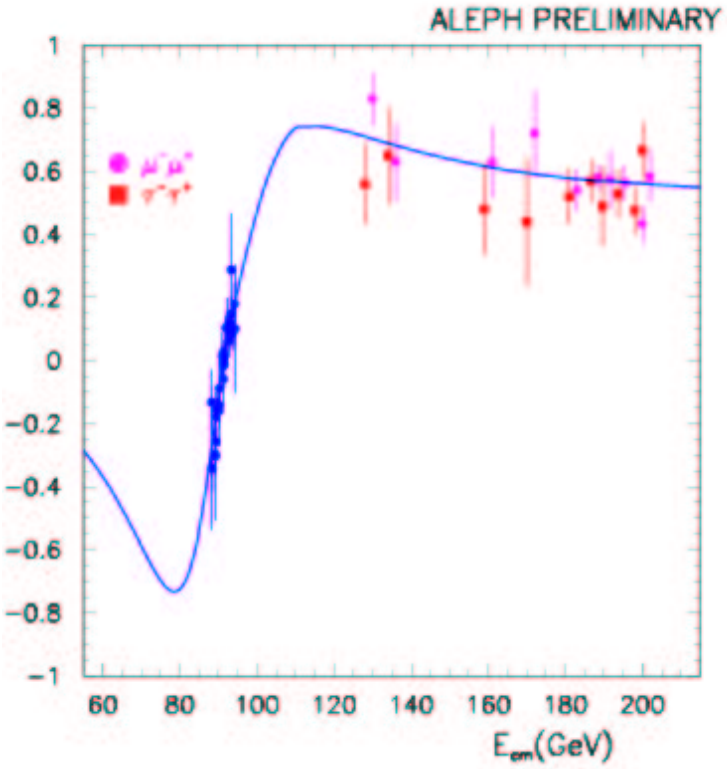
Z: Take $\cos\theta$ distribution in the Z rest frame:

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

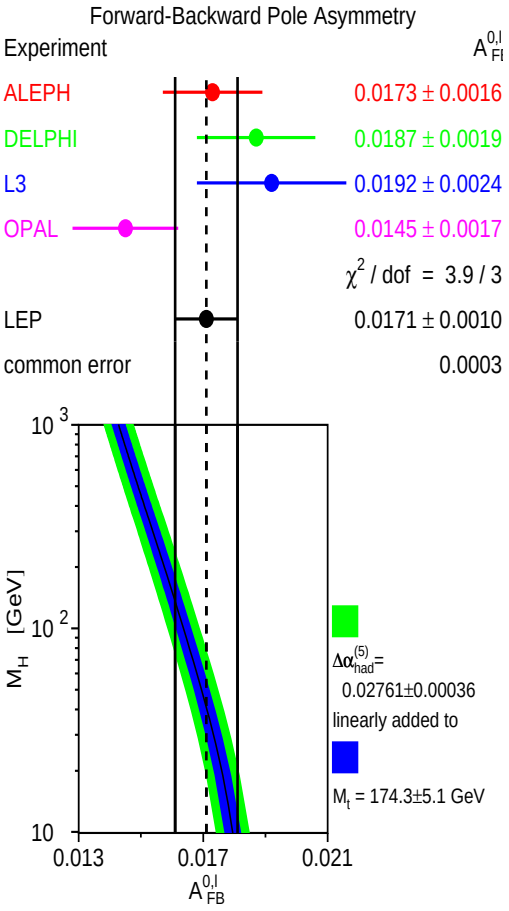
$$\mathbf{A_{FB}^{\ell}} : \gamma + \mathbf{Z} + \mathbf{interferences}$$

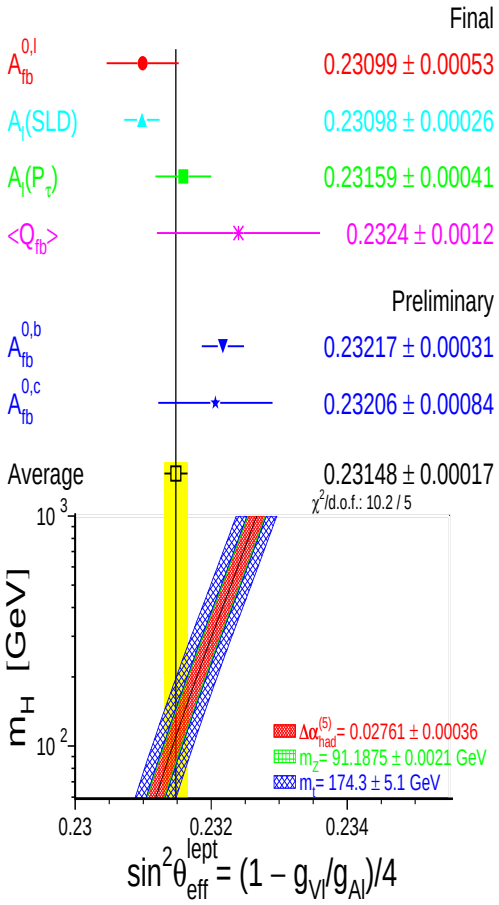
$$\mathbf{A_{FB}^{0\,\ell}} \propto \mathbf{a_\ell \cdot v_\ell \cdot a_f \cdot v_f}$$

LEP:



SM A_{FB}: electroweak fit



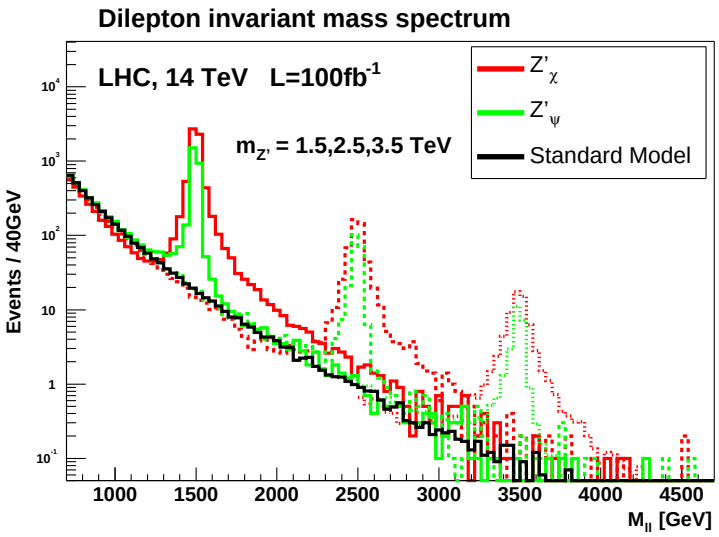


Test the SM, is there new physics ??

A_{FB} for a Z' : reveal its properties

Observables for a hadron collider

- Reconstruct a mass peak !



- Width: Non relativistic Breit-Wigner fit

- Cross section: Events within 3Γ

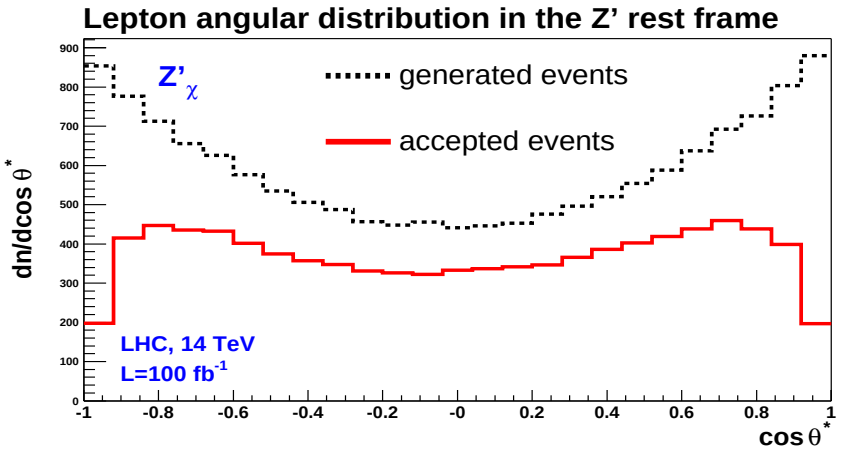
Use $\sigma_{\ell\ell} \cdot \Gamma$

(independant of Z' exotic decays)

- Lepton forward-backward asymmetry

  $\cos\theta$ distribution in the Z' rest frame:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta^*} \propto \frac{3}{8}(1+\cos^2\theta^*) + \mathrm{A}_{\mathrm{FB}}^{\ell}\cos\theta^*$$



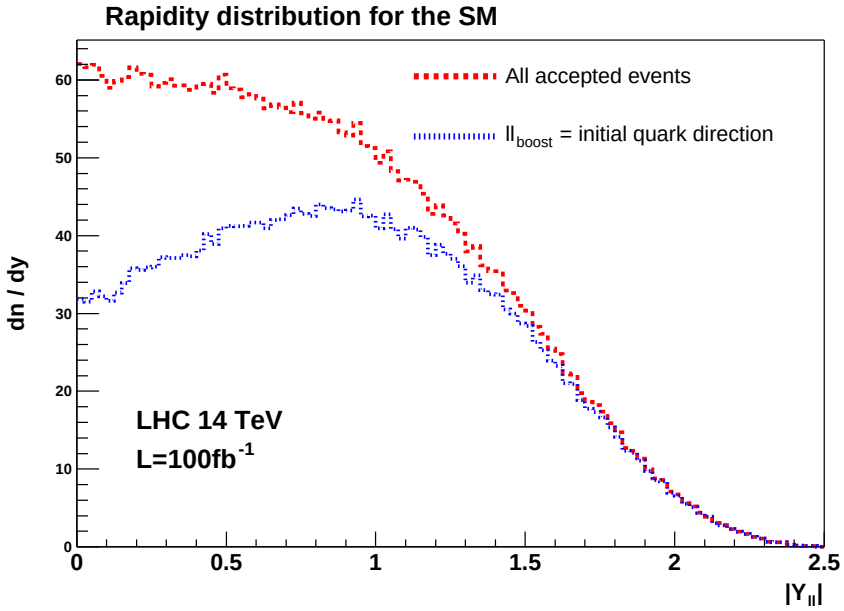
  $\Rightarrow$ Unbinned maximum likelihood fit

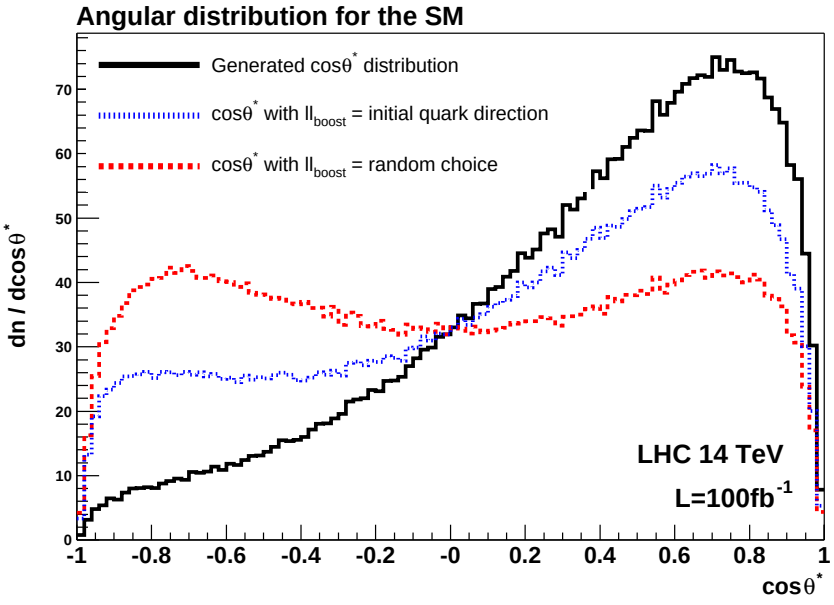
  LHC: pp collisions $\Rightarrow q\bar{q} \to Z' \to \ell^+\ell^-$

  Asymmetry in symmetric collisions ?

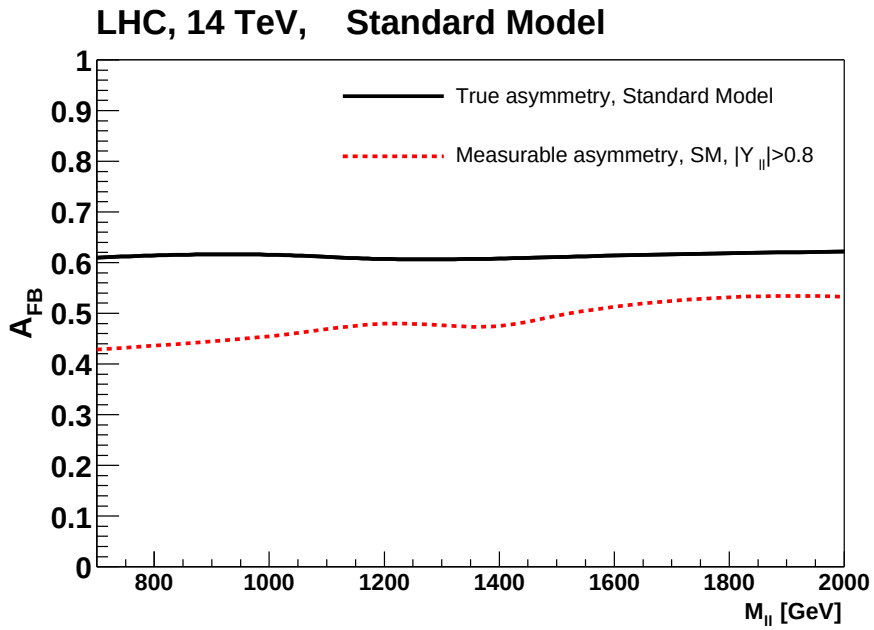
  $\Rightarrow$ Z' boost $\approx$ initial quark direction

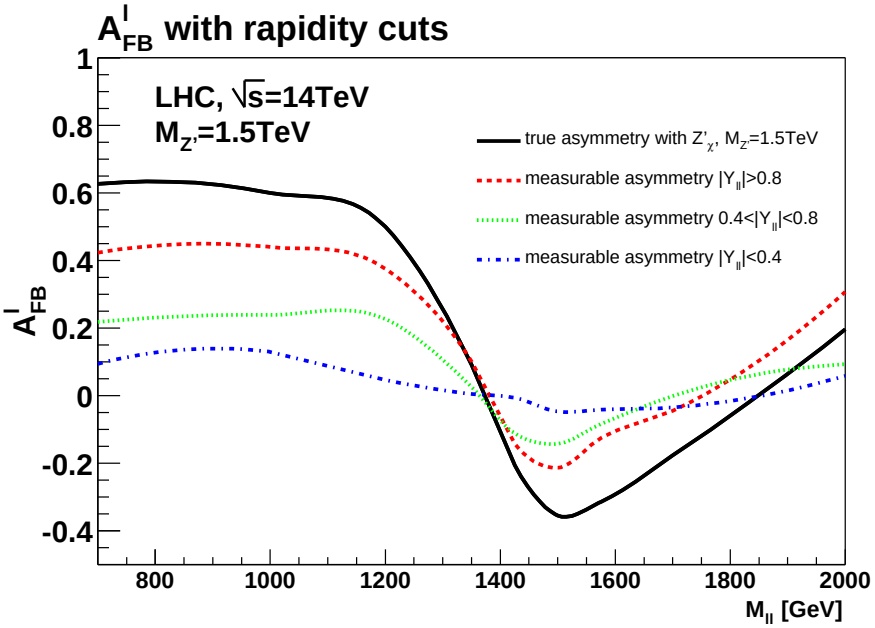
Asymmetry in symmetric collisions ?





Lepton forward-backward asymmetry

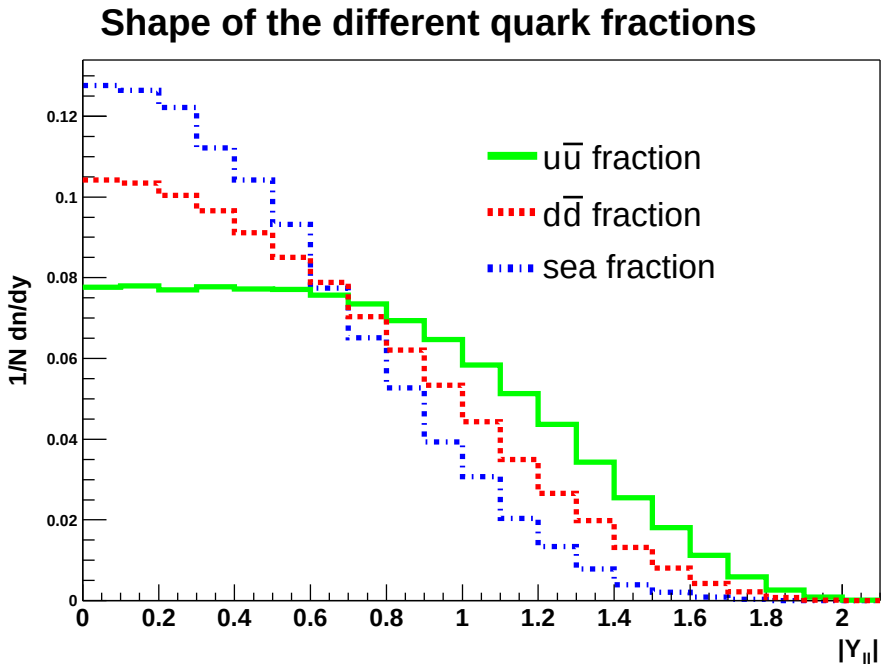




$\Rightarrow$ Require $|Y_{\ell\ell}| > 0.8$ ($\varepsilon_{cut} \approx 40\%$)

- Z' rapidity distribution:

  constrain Z' couplings to u and d



$Y_{Z'}$ depends on Z' couplings to u and d

$\Rightarrow$ Get $Y_{Z'_{u\bar{u}}}$, $Y_{Z'_{d\bar{d}}}$, $Y_{Z'_{sea}}$

$\Rightarrow$ Fit $Y_{\ell\ell}$ in a given Z' model

$\longrightarrow$ relative $u\bar{u}$, $d\bar{d}$ and sea fractions

Standard fast simulation

PYTHIA, $pp \rightarrow (Z, \gamma, Z') \rightarrow ee, \mu\mu$
$\sqrt{s}$: 14TeV, pp collisions

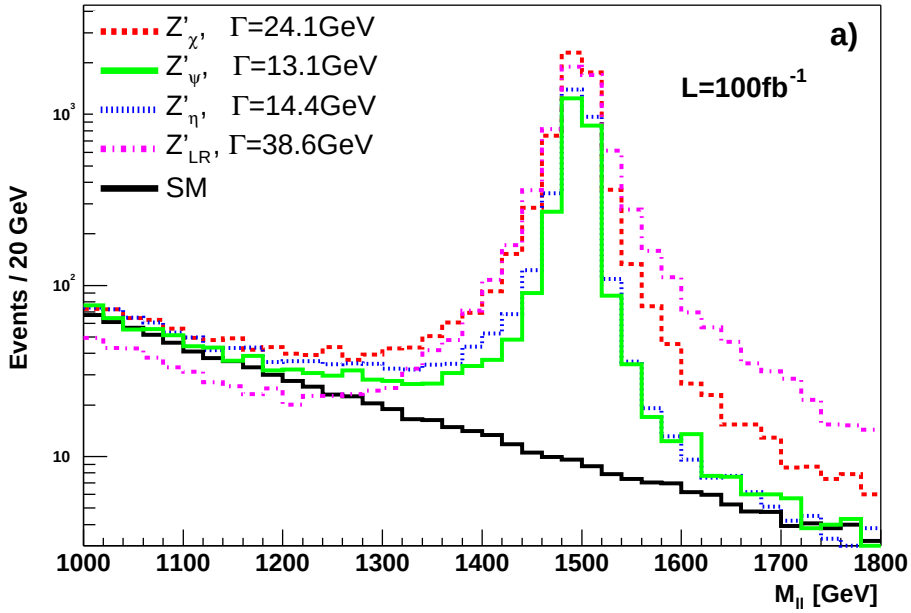
Reconstucting the events

$\rightarrow$ CMS/ATLAS $e^{\pm}$, $\mu^{\pm}$ acceptance

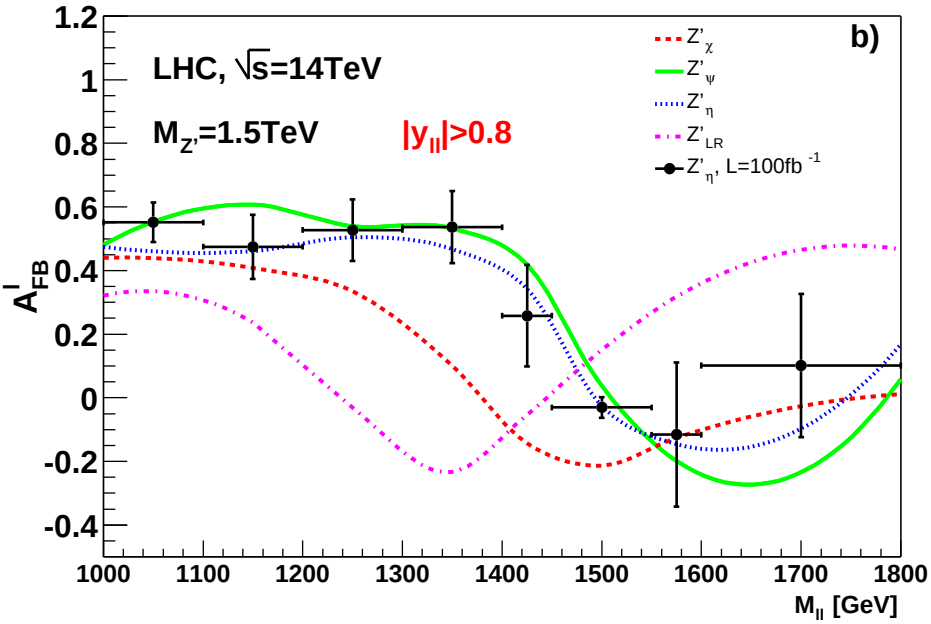
- Two isolated leptons with opposite charge
- $p_t^{min}(\ell) > 20$ GeV
- $|\eta|(\ell) < 2.5$
- Coplanar lepton pairs: $|\phi| > 160^{\circ} (\sum p_t \approx 0)$

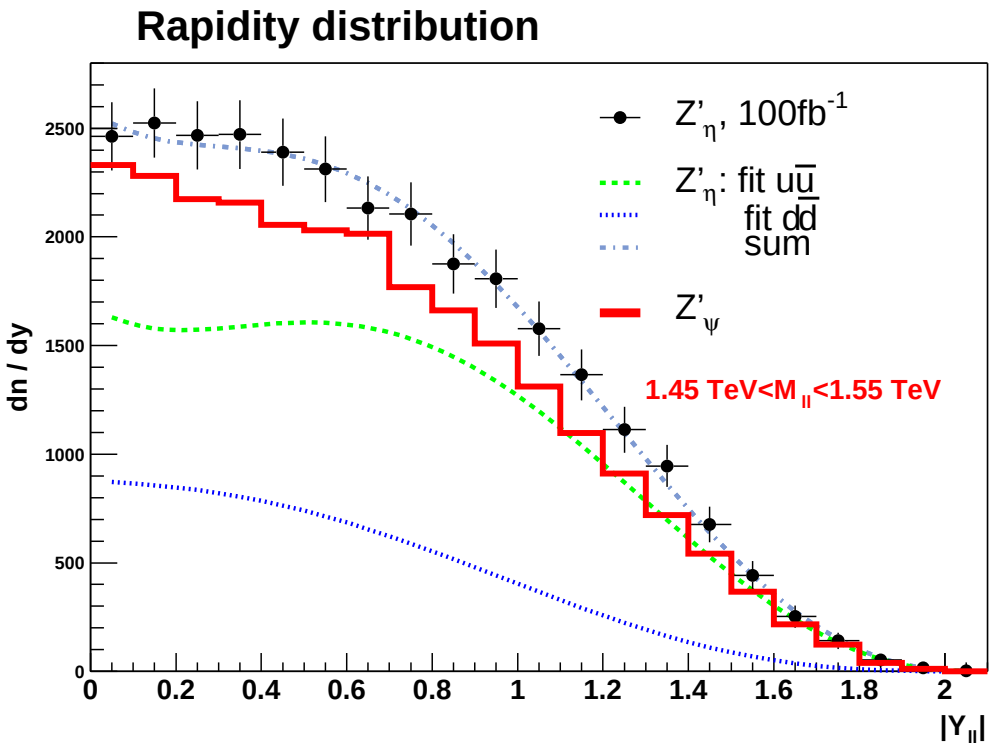
Discriminating the models

Dilepton invariant mass spectrum



Forward backward asymmetry measurement





$\Rightarrow$ Combine these observables !

Potential accuracies for 100 fb^{-1}

- $\boldsymbol{\Delta\sigma^{3\Gamma}_{\ell\ell}\cdot\Gamma/\sigma^{3\Gamma}_{\ell\ell}\cdot\Gamma}$

  $\sim 0.1-0.3\%\,(\text{stat.})\oplus 1\%\,??(\text{syst.})$ $(m_{Z'}=1.5$ TeV$)$

  $\sim 8-10\%\,(\text{stat.})\oplus 1\%\,??(\text{syst.})$ $(m_{Z'}=2.5$ TeV$)$

- $\boldsymbol{\Delta A_{FB}^{onpeak}}$

  $\sim 0.02-0.03\,(\text{stat.})$ $(m_{Z'}=1.5$ TeV$)$

  $\sim 0.07-0.1\,(\text{stat.})$ $(m_{Z'}=2.5$ TeV$)$

- $\boldsymbol{\Delta A_{FB}^{interference}}$

  $\sim 0.04-0.06\,(\text{stat.})$ $(m_{Z'}=1.5$ TeV$)$

  $\sim 0.1-0.2\,(\text{stat.})$ $(m_{Z'}=2.5$ TeV$)$

- $\boldsymbol{\Delta R_{u\bar{u}}}$

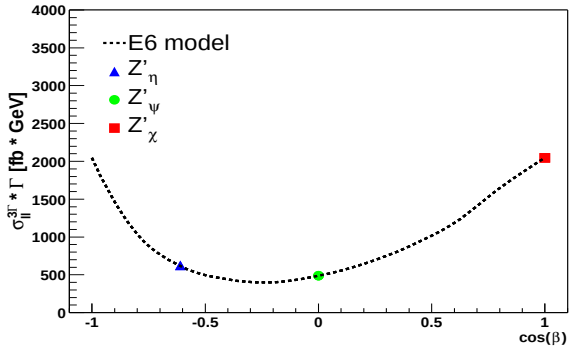
  $\sim 5-8\%\,(\text{stat.})$ $(m_{Z'}=1.5$ TeV$)$

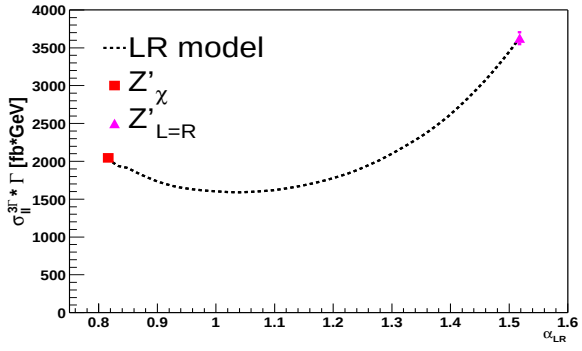
  $\sim 10-30\%\,(\text{stat.})$ $(m_{Z'}=2.5$ TeV$)$

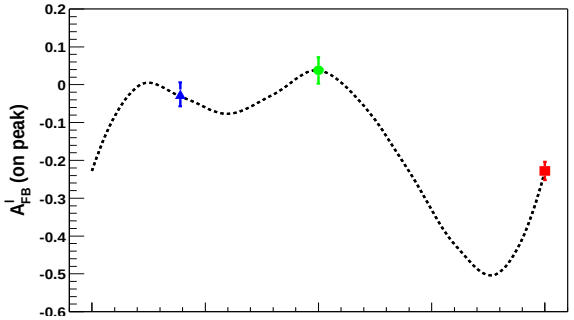
The 4 observables for a 1.5 TeV Z'

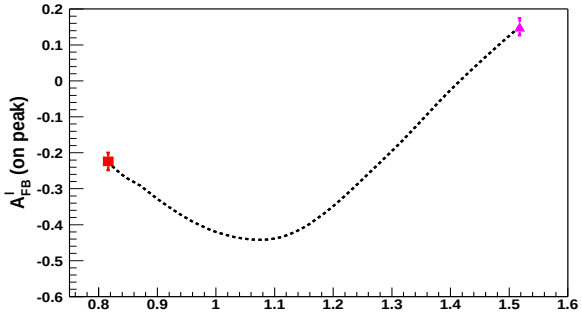
Model	$\sigma_{\ell\ell}^{3\Gamma} \times \Gamma$ [fb·GeV]	$A_{FB}^{\text{on-peak}}$	$A_{FB}^{\text{off-peak}}$	$R_{u\bar{u}}$
Z'_ψ	487 ± 5	0.04 ± 0.03	0.53 ± 0.04	0.60 ± 0.
Z'_η	630 ± 20	-0.03 ± 0.03	0.45 ± 0.04	0.71 ± 0.
Z'_d	1520 ± 40	-0.50 ± 0.02	0.26 ± 0.05	0.00 ± 0.
Z'_χ	2050 ± 40	-0.23 ± 0.02	0.26 ± 0.05	0.22 ± 0.
Z'_{LR}	3630 ± 80	0.15 ± 0.02	0.06 ± 0.06	0.45 ± 0.
Z'_{SM}	8000 ± 140	0.07 ± 0.02	0.18 ± 0.03	0.05 ± 0.

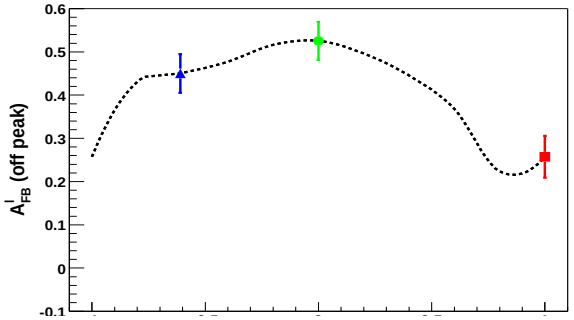
Observables vs. model parameters

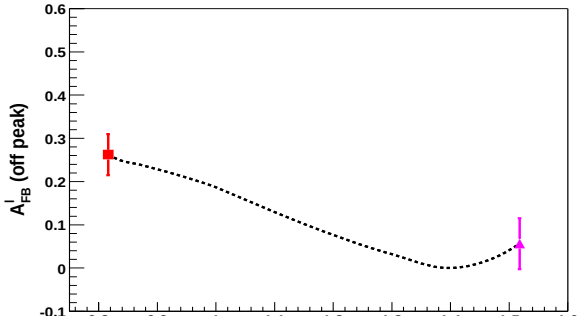


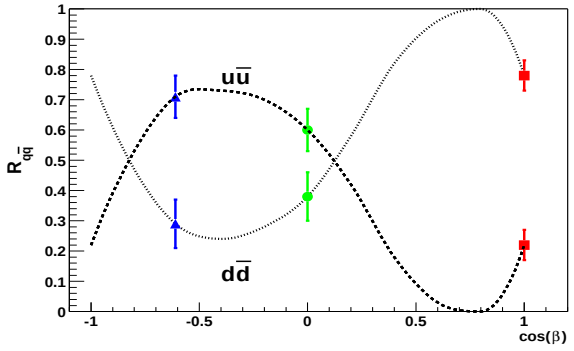


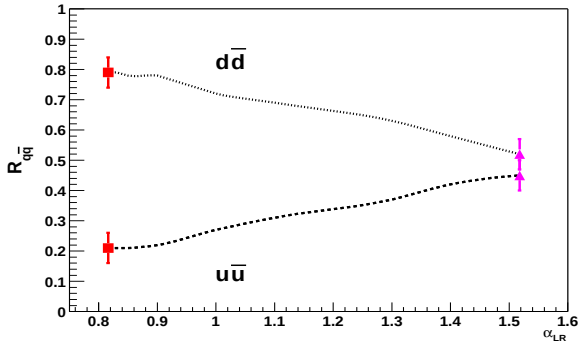












Outlook

LHC can already do a good job on identifying a Z':

Discovery: up to 5 TeV

Identification: up to 2-2.5TeV with 100fb^{-1}

Need to repeat this with a full detector simulation

Results of this study in hep-ph/0307020