# New Gauge Theories

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Outline:

- Short summary of the existing material
- Focus:
  - $Z'$
  - identification of new physics with LHC, LC

# Planned Contributions for the Document

## Scenarios with extra gauge bosons

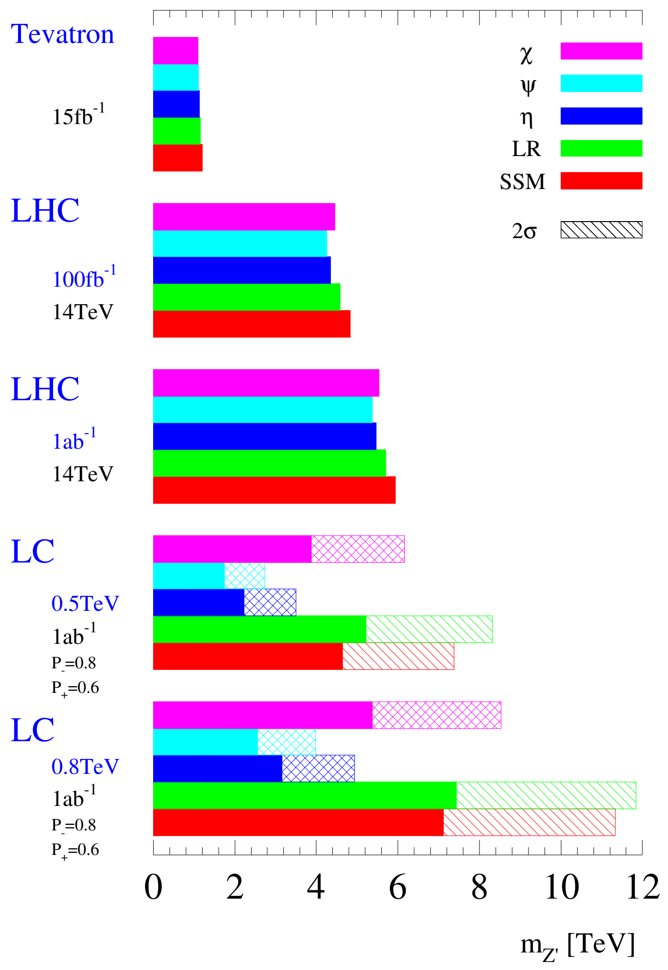
- Discovery of extra gauge bosons at LHC
- Large indirect reach of LC
- Mass measurements of $Z'$, $W'$ at the LHC as input for determining couplings at the LC
- Investigation of nature of extra gauge bosons
- Scanario of a leptophobic $Z'$
- Distinction between extended gauge group and KK excitation

## Scenarios with extra fermions

- Scenarios with $E_6$-type fermions, mirror fermions
- 'Little Higgs' scenarios: both new fermions ands bosons, complicated Higgs sector
- Precise measurement of properties of light new leoptons and quarks, heavier states from LHC.
- Decay modes in flavor-changing neutral currents: challenging for LHC
- LC information to trigger dedicated search at LHC

- Discovery of extra gauge bosons at LHC
  (Godfrey, Bourilkov?,...)
- Large indirect reach of LC
  (Godfrey, Rizzo, Riemann,...)
- Distinction between extended gauge group and KK excitation
  (Rizzo)
- Investigation of nature of extra gauge bosons: couplings...
  (Riemann)
- Little Higgs and new gauge bosons
  (Richard)
- $+$ summarizing and combining (old) existing papers (hopefully, with synergetic output)
  (Hewett, Cvetic, del Aguila, Langacker, Leike,...)

# Discovery of a Z′




## Limits are model dependent!

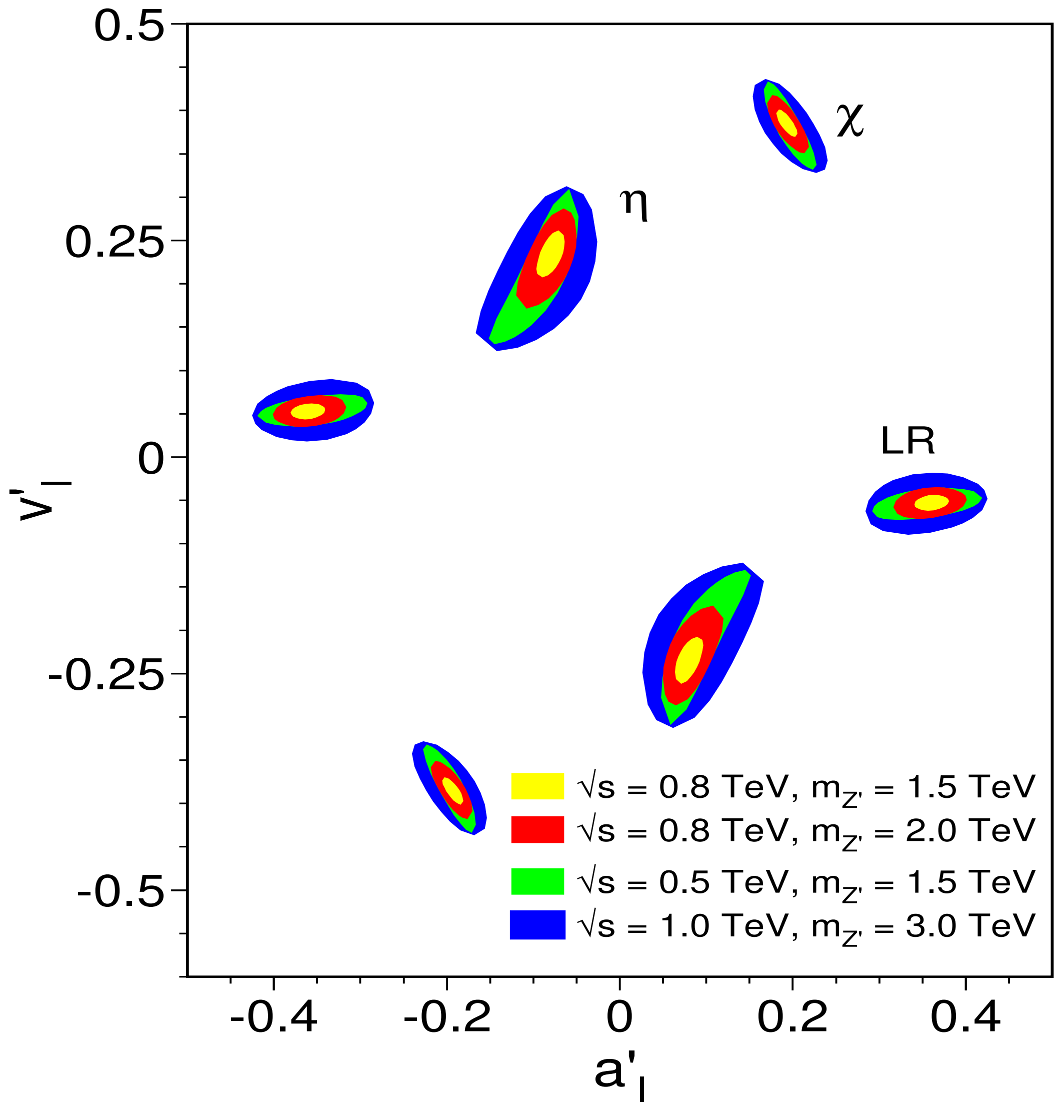
LC Results shown for 95% C.L. (hatched) and $5\sigma$

LHC: see Godfrey, hep-ph/0201093

LC: consider $ee \longrightarrow f\bar{f}$

- $\mathcal{L}_{int} = 1ab^{-1}, \quad \Delta\mathcal{L}_{int} = 0.2\%$
- $P_- = 0.8, \quad P_+ = 0.6, \quad \Delta P_- = \Delta P_+ = 0.5\%$
- $\Delta$sys(lept)=0.2%, $\Delta$sys(had)=0.1%

## Ideal case: LHC finds a Z′, $M_{Z'} < 4.5$ TeV



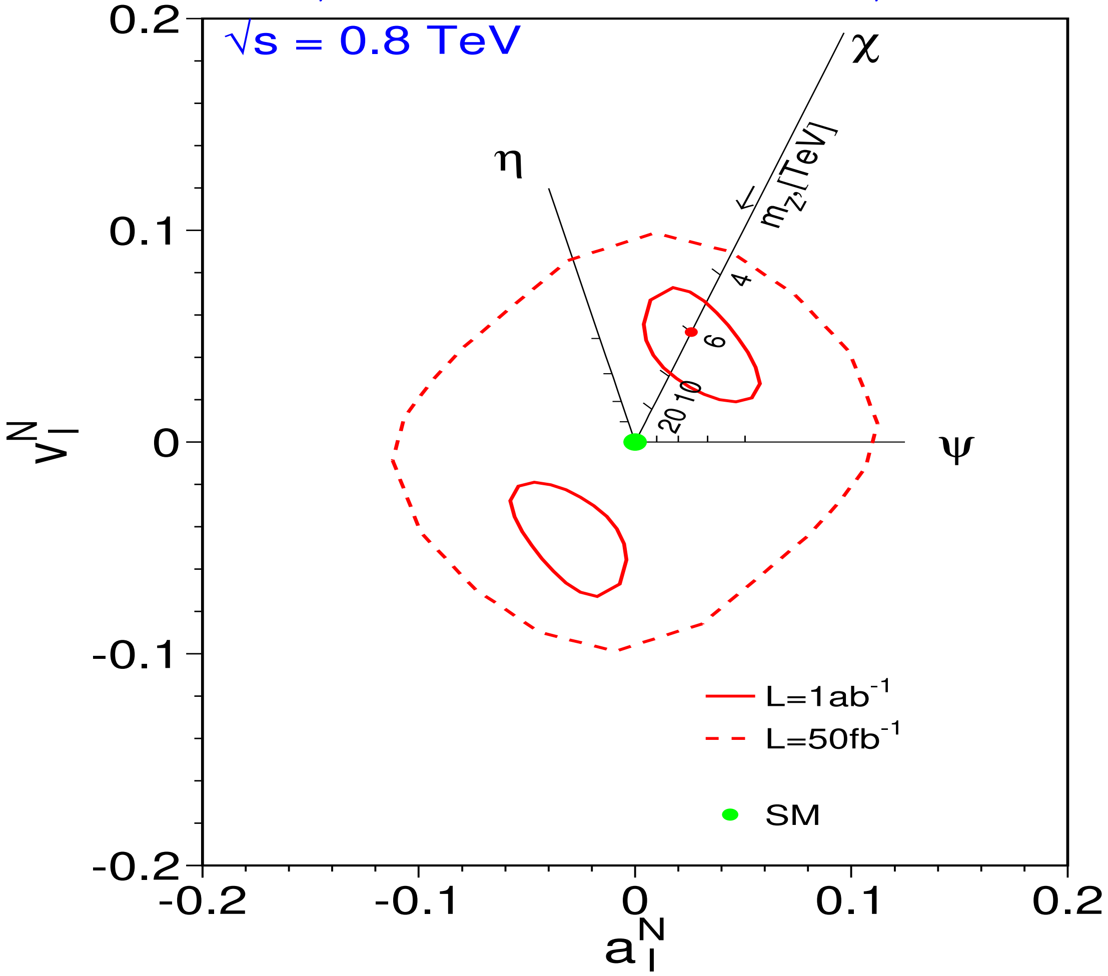

95% C.L. contours on leptonic Z′ couplings;
consider $ee \rightarrow l^+l^-$, $\mathcal{L}_{int} = 1$ ab$^{-1}$

Bounds on Z′$q\bar{q}$ couplings are weaker due to uncertainties of Z′$l^+l^-$ coupl. and measuring quark final states. (Updated examples are in production.)

No Z′ at LHC ⇒ situation is NOT hopeless!

$m_{Z'} > 5$ TeV

$$a_f^N = a'_f \sqrt{\frac{s}{m_{Z'}^2 - s}}; \qquad v_f^N = v'_f \sqrt{\frac{s}{m_{Z'}^2 - s}}.$$

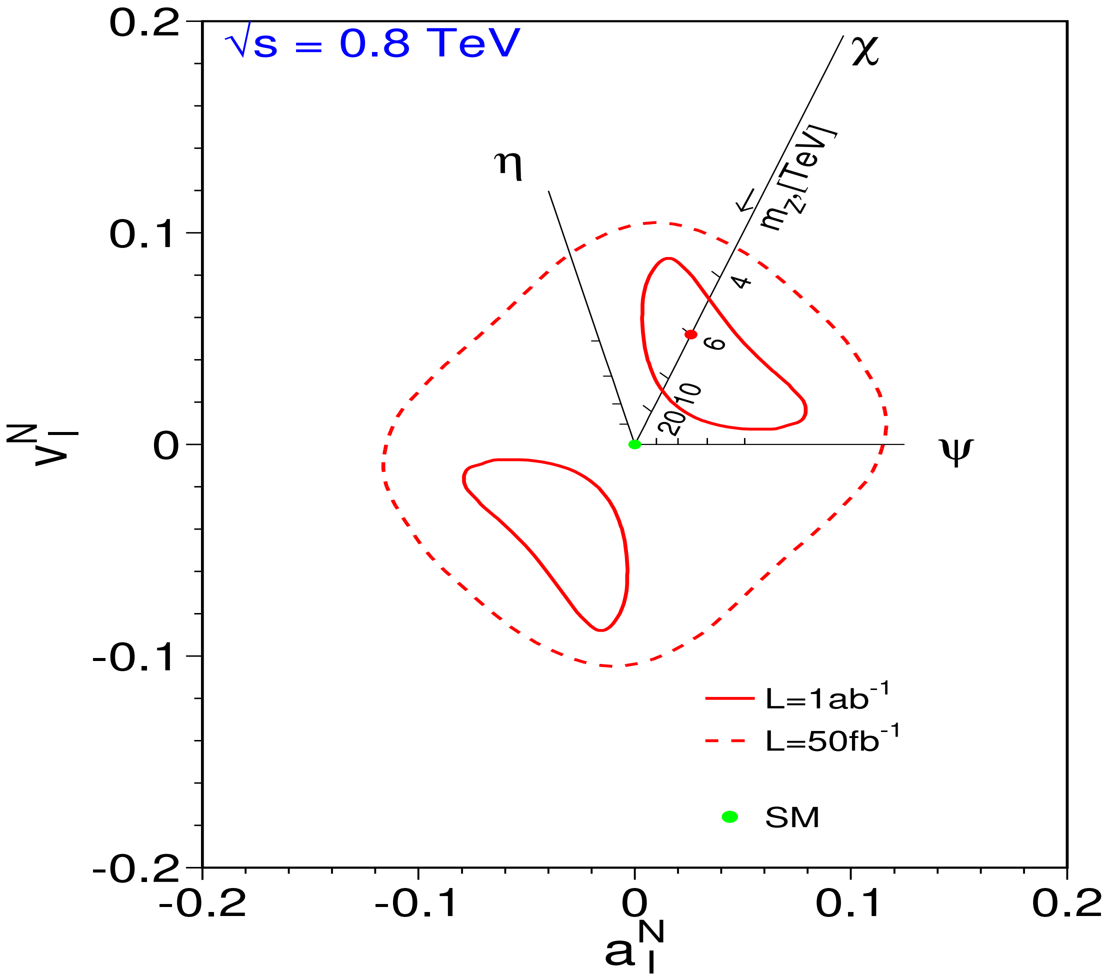



Reconstruction of a 6 TeV Z′($\chi$ model) (95% C.L.):

- $\mathcal{L}_{int} = 1ab^{-1}, \quad \Delta\mathcal{L}_{int} = 0.2\%$
- $P_- = 0.8, \quad P_+ = 0.6, \quad \Delta P_- = \Delta P_+ = 0.5\%$
- $\Delta$ sys(lept)=0.2%

Similar updated figures for $q\bar{q}$ final states will come soon.

Reconstrution of a Z′ with $m_{Z'} = 6$TeV, $\chi$ model:




Assumption:

- $\mathcal{L}_{int} = 1ab^{-1}, \quad \Delta\mathcal{L}_{int} = 0.5\%$
- $P_- = 0.8, \quad P_+ = 0.6, \quad \Delta P_- = \Delta P_+ = 0.5\%$
- $\Delta$ sys(lept)=0.5%

# Faking Scenarios ?

Distinguish Z′ from other new physics scenarios (SUSY, KK,...)

- new physics in s-channel: spin-0, spin-1, spin-2 $\longrightarrow$ study the angular distribution of ee$\longrightarrow f\bar{f}$ processes
- Spin-2: typical modification of helicity amplitudes:

$$A_{LL} = [A_{LL}^{SM} + F(2\cos\theta - 1)](1 + \cos\theta)$$

$$A_{RR} = [A_{RR}^{SM} + F(2\cos\theta - 1)](1 + \cos\theta)$$

$$A_{LR} = [A_{LR}^{SM} + F(2\cos\theta + 1)](1 - \cos\theta)$$

$$A_{RL} = [A_{RL}^{SM} + F(2\cos\theta + 1)](1 - \cos\theta)$$

- Exp. analyses: disentangle the angular distribution

  spin=0,1:

$$A_{ik} = [A_{ik}^{SM} + F_{ik}](1 \pm \cos\theta)$$

  $F_{ik}$ is constant

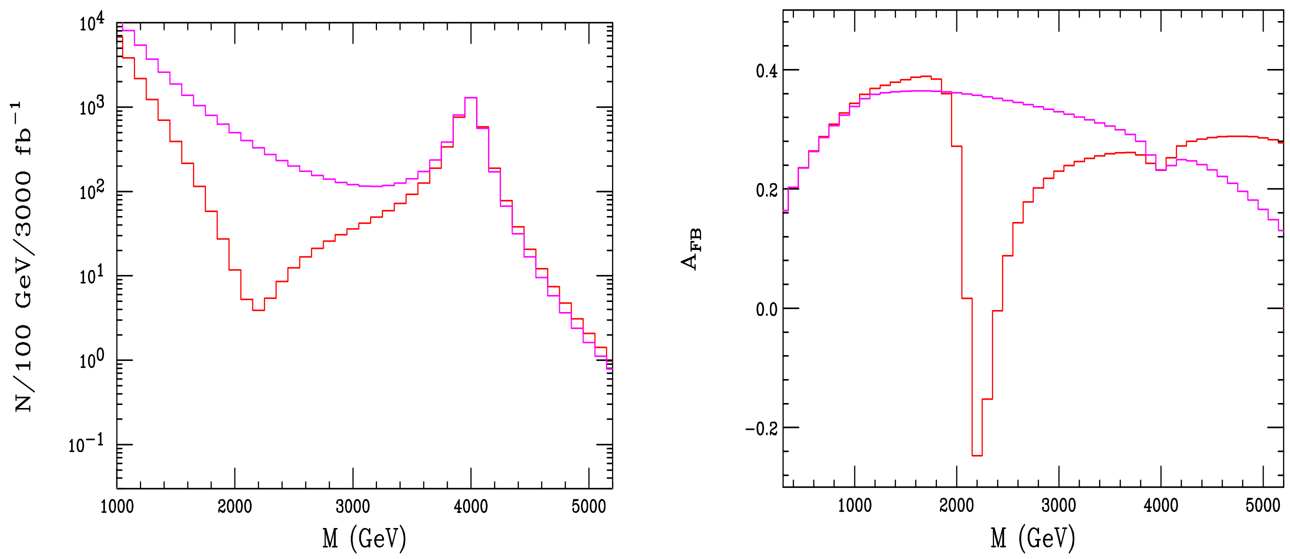
- see, e.g., also talks in Prag, Amsterdam... (and related papers) and D. Bourilkov's talk today

KK excitations of SM gauge bosons within TeV-scale extra dim. scenarios: variety of models!

Gauge KK and Z′: Spin-1

See T. Rizzo, SLAC-PUB-9731, May 2003:
Study 'simple' case:

- one flat extra dim, all fermions on one of the 2 orbifold fixed points: D=$0$, $\pi R$ (R = compact. radius)
- Look for bounds on compct. scale, $M_c$
- $M_c \leq 7$ TeV: directly accessible at LHC,
  indirect observation at LC

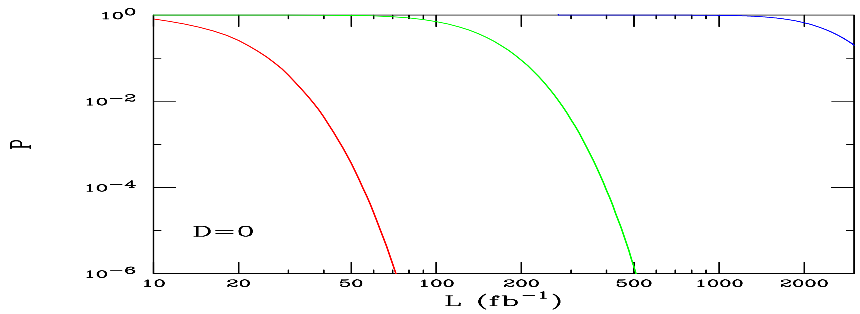


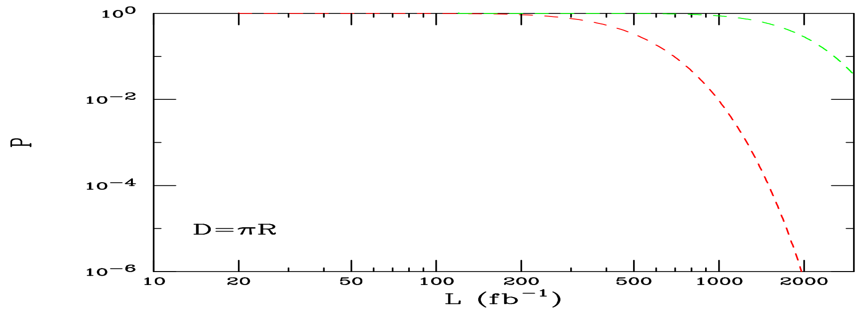

Lepton pair inv. mass spectrum and asymmetry for D=0 ($\pi R$)

# Probality of Z′ interpretation

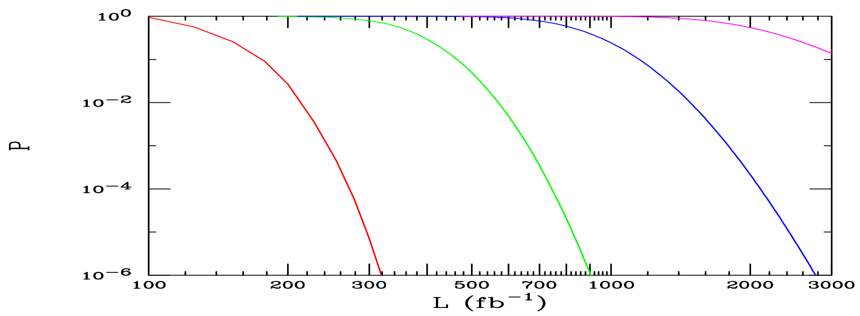
Probability P to interprete KK with $M_c = 4, 5, 6...$ TeV as Z′

*LHC*

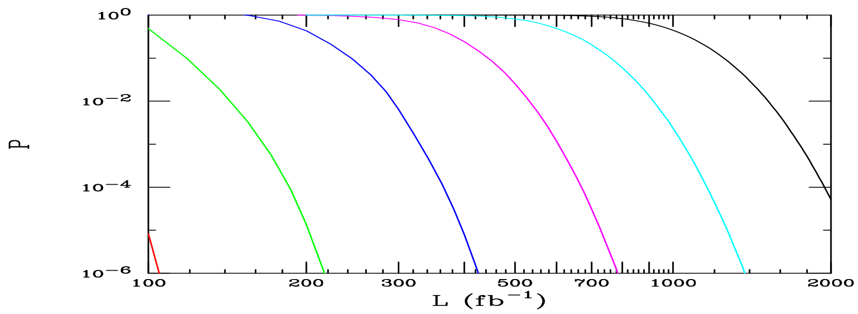



*LC*




$\sqrt{s}$ = .5TeV




$\sqrt{s}$ = 1TeV

LC: $M_c$ is known from LHC !!!

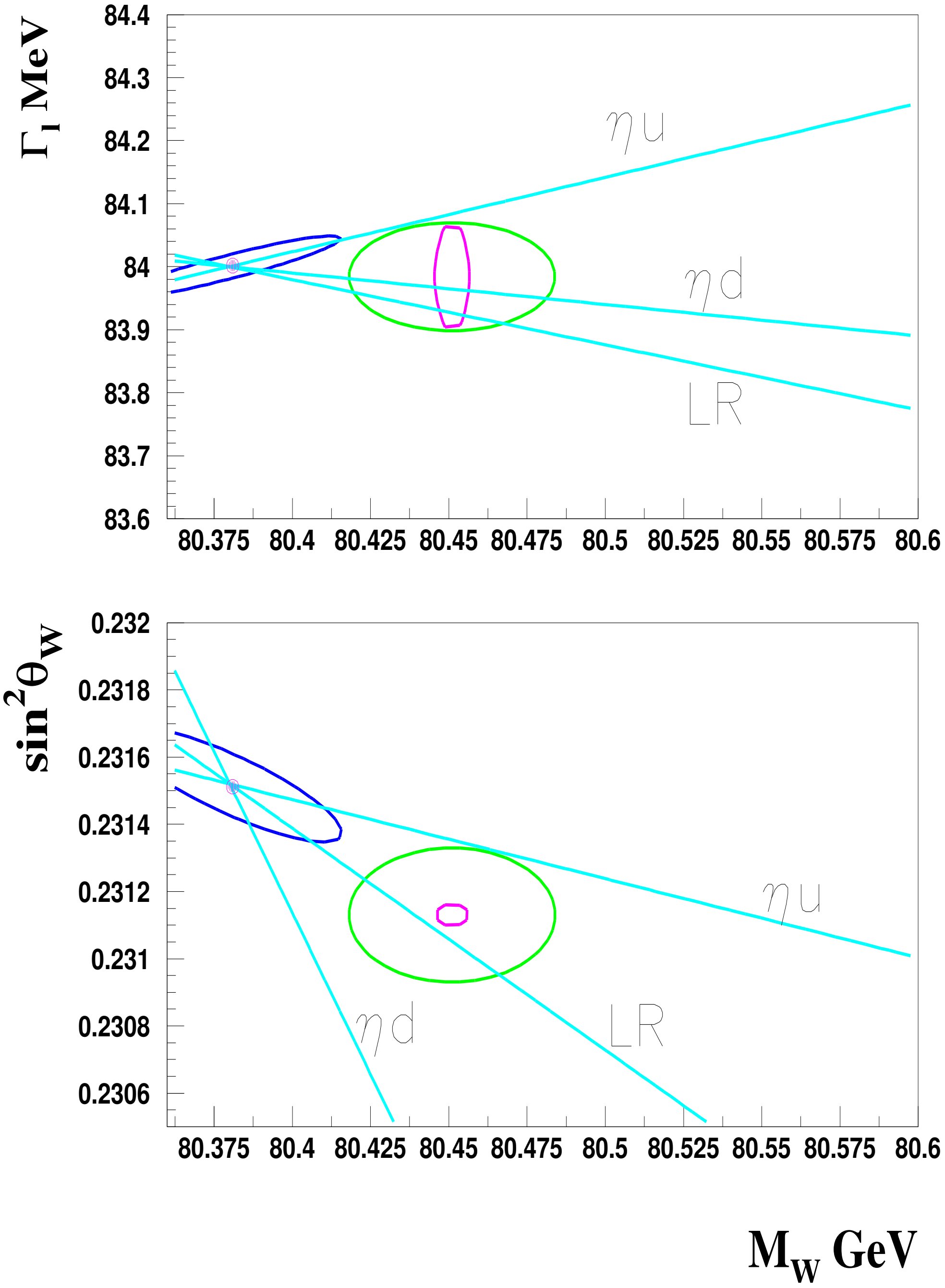
# Probality of Z′ interpretation

- LHC: for the case D=0 better resolution
- LC results base on knowledge of $M_c$ from LHC
- LC: for energies above 0.5 TeV (e.g. 1 TeV) better resolution than LHC

F. Richard, hep-ph/0303107

Detailed studies of the GigaZ impact to learn about a Z′:

- ZZ′ mixing $\longrightarrow$ modification of electroweak parameters
- quantities sensitive to Z′ and ZZ′ mixing: $M_W$, $\sin^2\theta^{lept}_{eff}$, Z total and partial widths
- New physics searches at GigaZ are the test of consistency between LEP, SLD, LHC and LC !!!
- Precise LC results can trigger dedicated searches at LC (Higgs, SUSY)
- Comment: For LR models with $\rho \neq 1$ at tree level see talk of J. Gluza in Amsterdam!
- Example for resolution power of GigaZ: $\Rightarrow$




SM prediction, LEP/SLD and GigaZ expected precision compared with Z′ models ($m_H$=115 GeV)

Do we need LHC $\Leftrightarrow$ LC to resolve new physics ?

YES !!!

- LC is only sensitive to the ratio coupling/mass.
  $\Rightarrow$ knowledge of mass from LHC is appriciated!
- Extended consistency checks are only possible with a variety of experimental results: LEP/SLD/LHC/LC/APV....
- Studies are going on....
- Contributions are welcome!!

PS: Thank you, Georg !!!