Discovery and Identification of New Gauge Bosons at the LHC and ILC

S. Godfrey, P. Kalyniak & A.Tomkins
Carleton University

ALCPG Workshop, Vancouver, July 20, 2006

Many Models of New Physics

American Linear Collider Physics Group

- Little Higgs: $W_H^{\pm}$ Z_H B_H

- Extra dimensions (ADD, RS, UED…): KK excitations
  - ADD: Graviton tower exchange effective operators: $i\frac{4\lambda}{M_H^4}T^{\mu\nu}T_{\mu\nu}$
  - Randall-Sundrum Gravitons: Discrete KK graviton spectrum
  - Ununified Extra Dimensions (UED)
  - High Curvature TeV scale Gravity

- Extended gauge sectors
  - Extra U(1) factors: $E_6 \to SU(5) \times U(1)_\chi \times U(1)_\psi$
  - Left-Right symmetric model: $SU(2)_L \times SU(2)_R \times U(1)$

- Topcolour

Many, many models

New Bosons

New s-channel structure at ~TeV scale appear in almost all these models

Spin 1 appear in many models:

- Z′ in string inspired models
- Z′, W′ in extended gauge sectors
- Z_R, W_R in left-right symmetric models
- Z_{KK}, γ_{KK}, W_{KK}, in theories with extra dimensions
- Z_H, W_H in Little Higgs Models

Also possible higher spin states:

- Gravitons in theories with extra dimensions
- String resonances

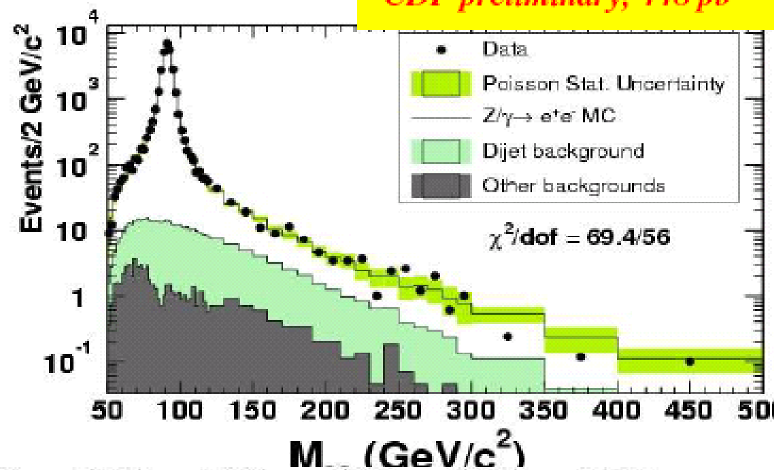
And scalar states:

- Radions
- Graviscalars

Di-lepton Resonance Search

- Select 2 opposite sign high p_T isolated leptons and examine invariant mass distributio
- If you find a peak:
    - quantify its significance
    - Measure its σ x BR
- If you don't:
    - Derive upper limit on σ x BR
    - Constrain models

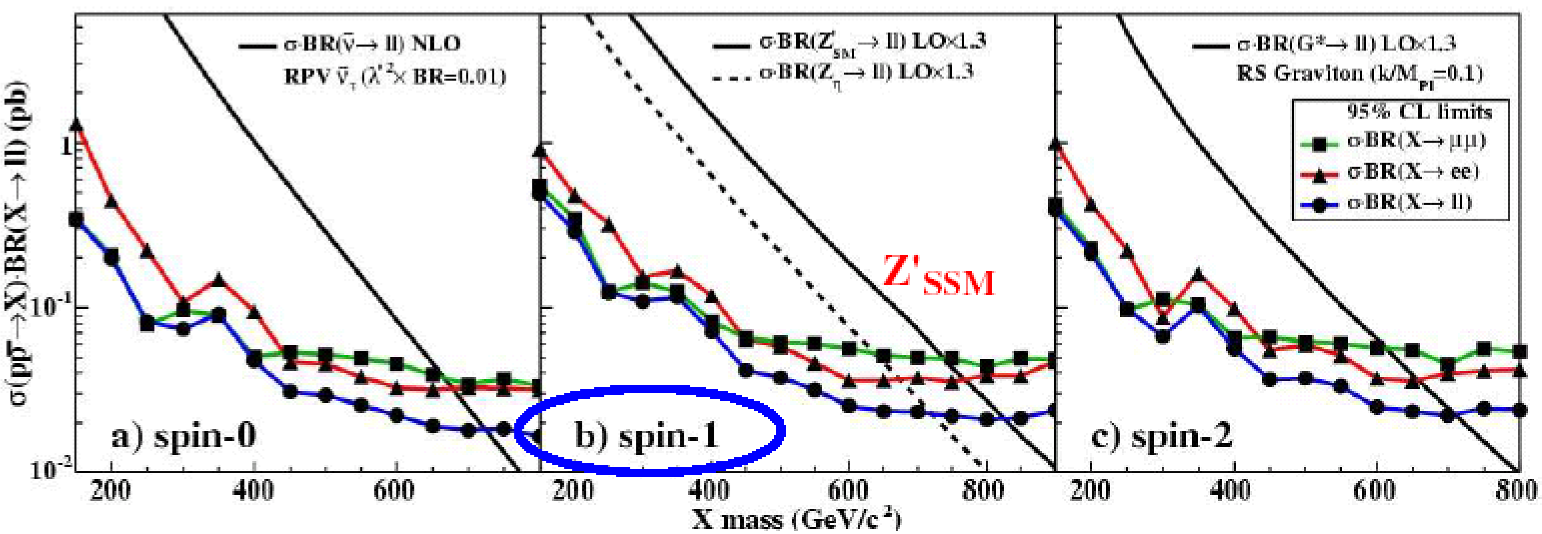
CDF preliminary, 448 pb^{-1}



Z′ Mass

CDF, di-electrons and di-muons combined, 200 pb-1

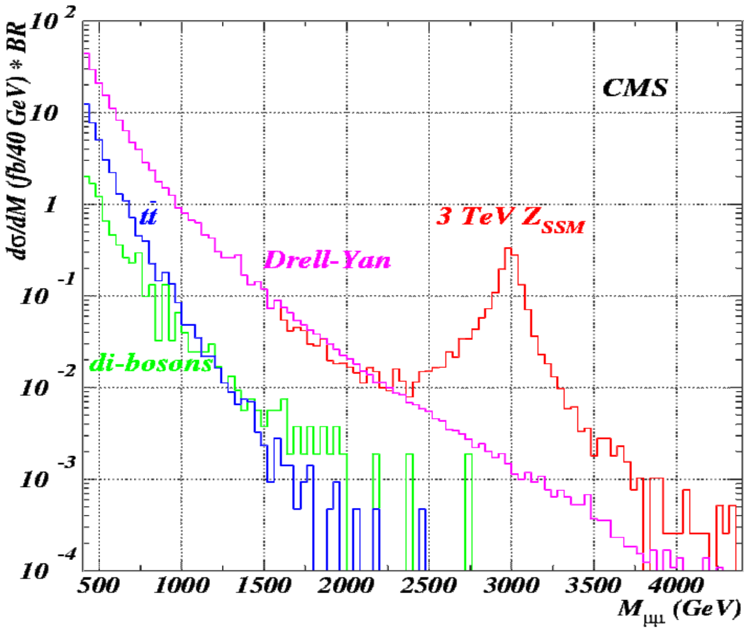
hep-ex/0507104



New Z' Gauge Bosons at the LHC

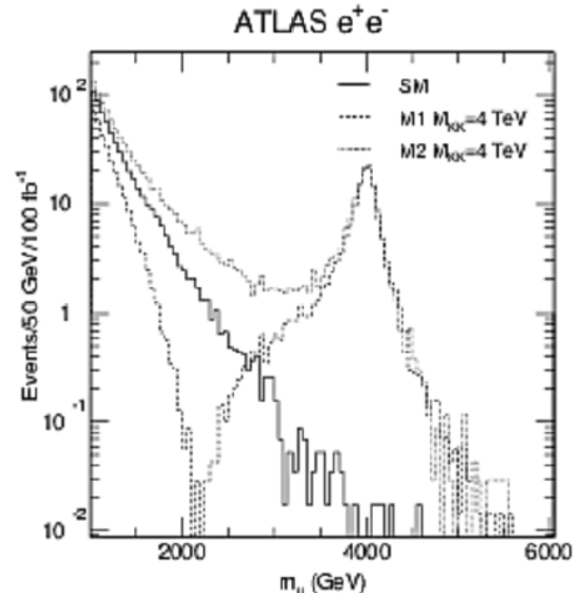
American Linear Collider Physics Group

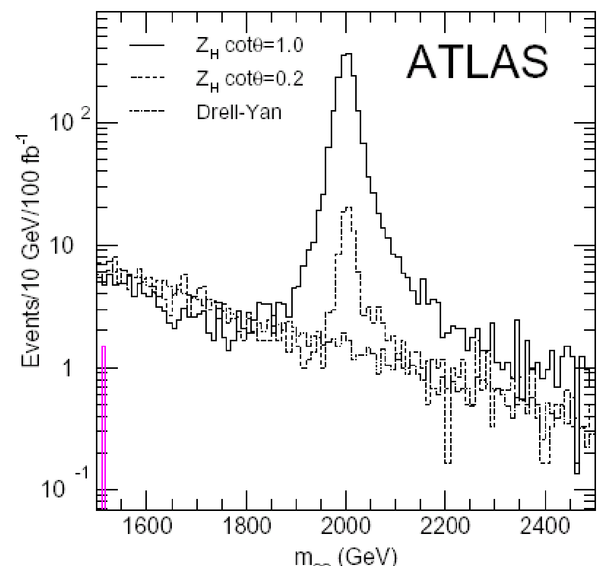
Z'→μμ production



Note: Theory knowledge on DY spectrum will be needed (tails!)

Azuelos & Polesello, Eur. Phys. J C39, s2, s1 (2004)



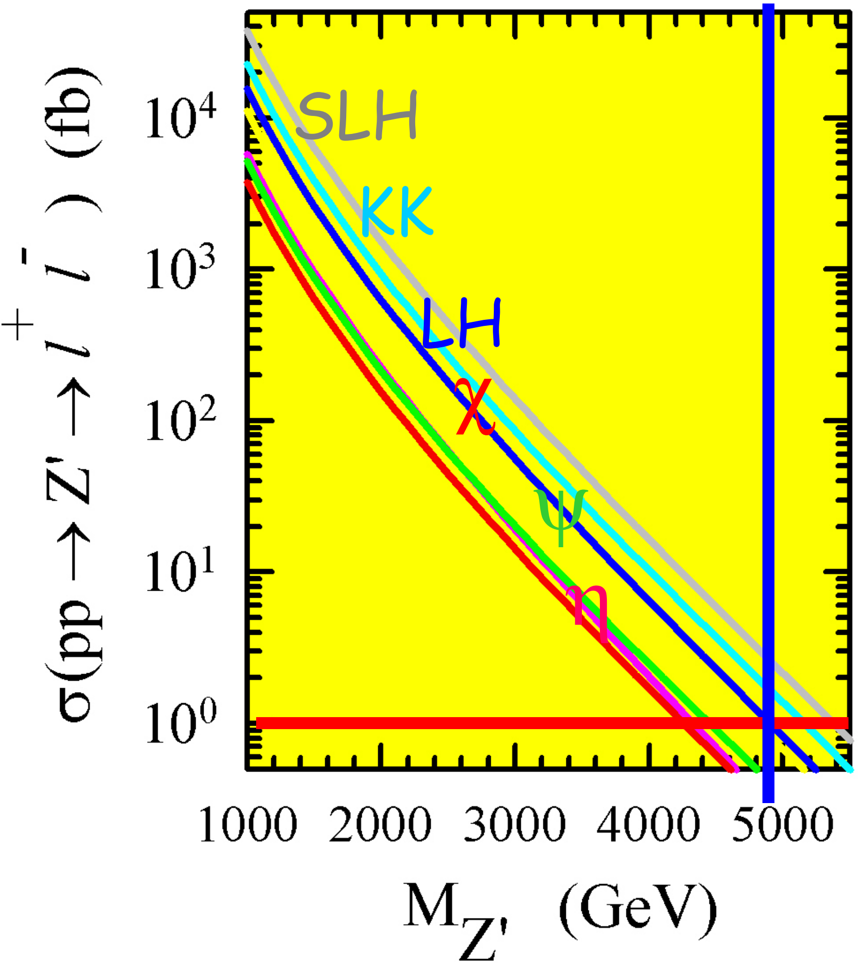


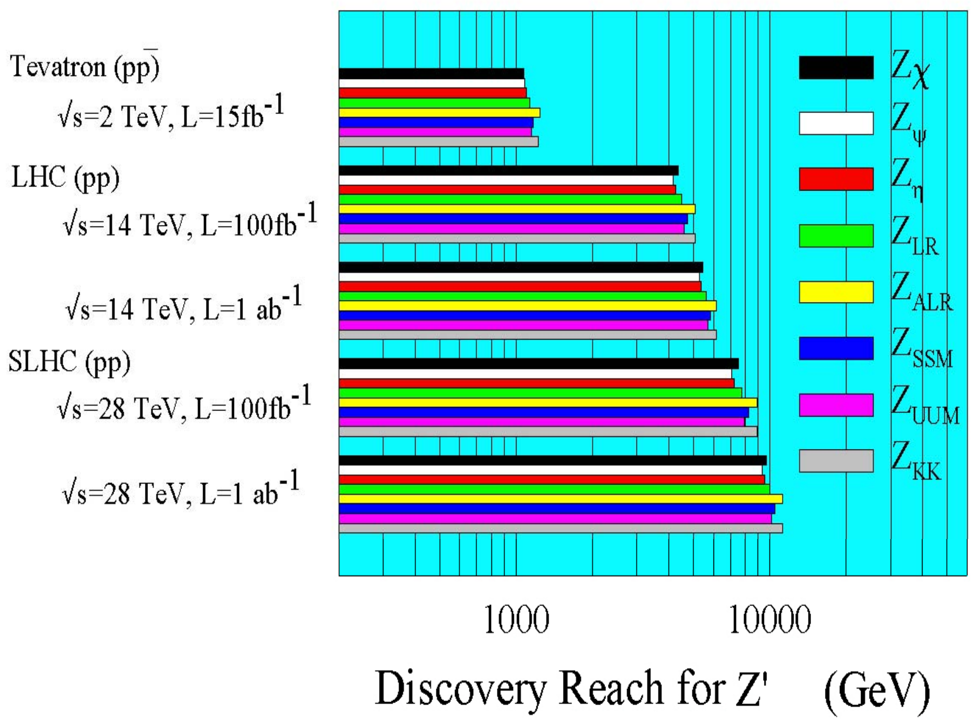
[Azuelos et al, hep-ph/0402037]

Discovery Limits for Z′ Gauge Bosons at the LHC

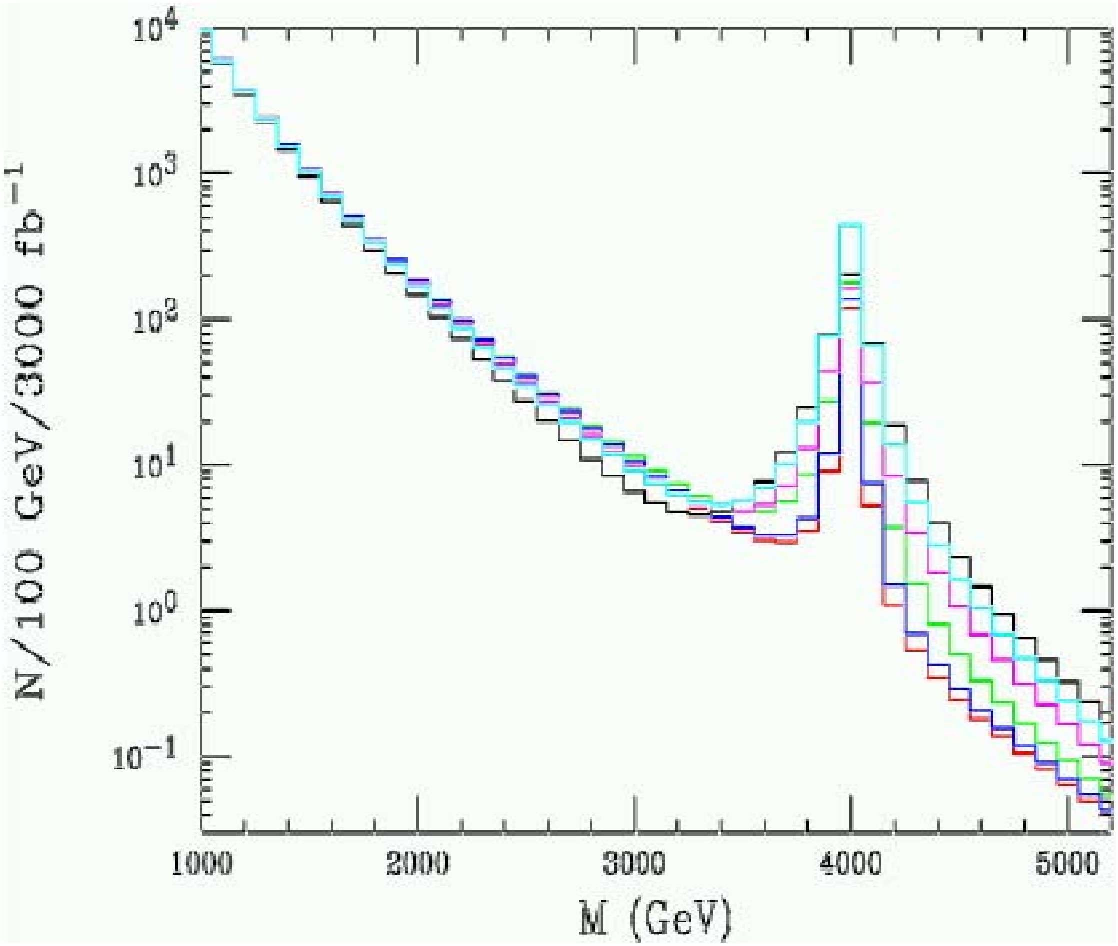
American Linear Collider Physics Group

Z′→μμ production





LHC Discovers S-channel Resonance !!

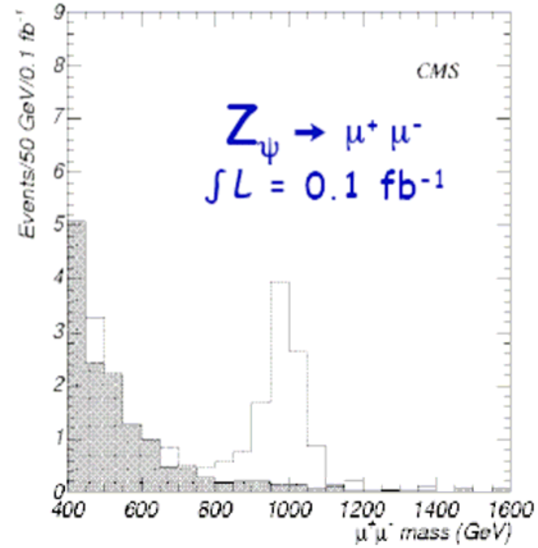


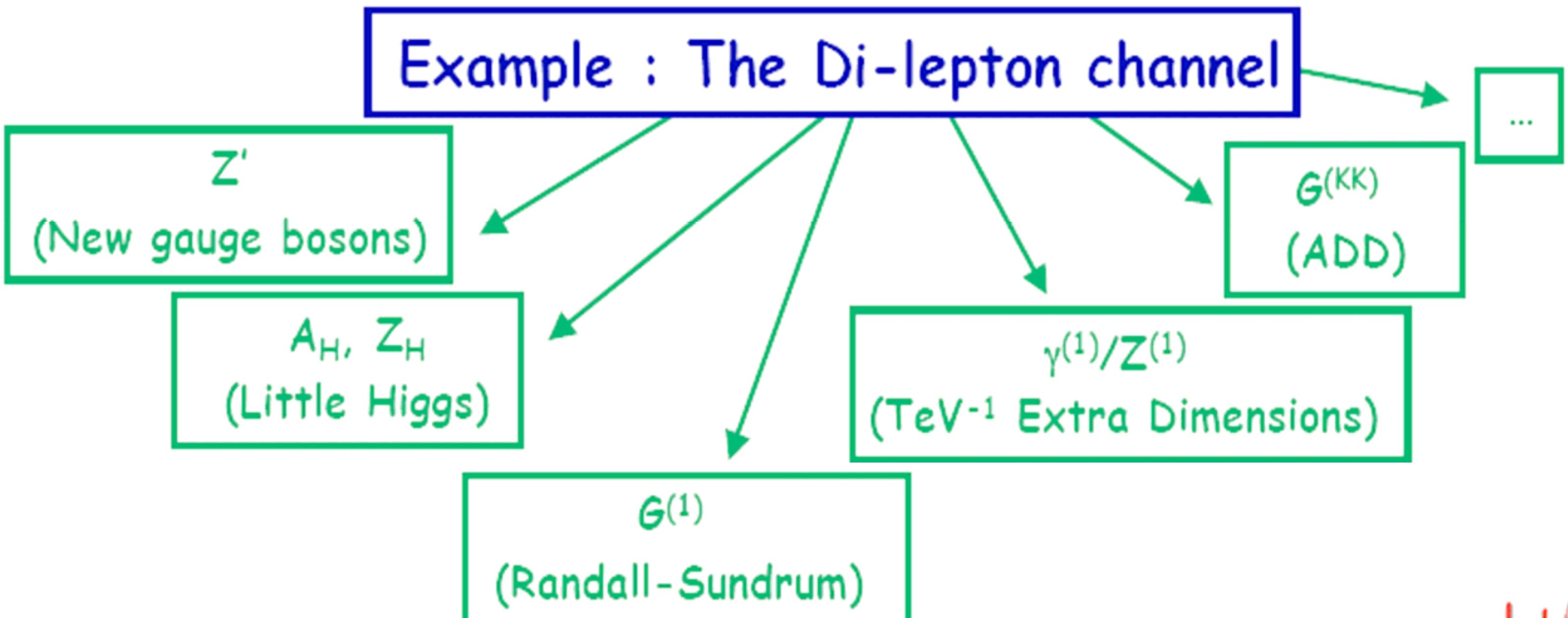
May be seen very early: first weeks

What is it?

Many possibilities for an s-channel resonances:

graviton, KK excitations, Z' …d





How do we distinguish them?

How do we distinguish the models?

1. Need to map out the low energy particle content
2. Measure their properties

Tools are:

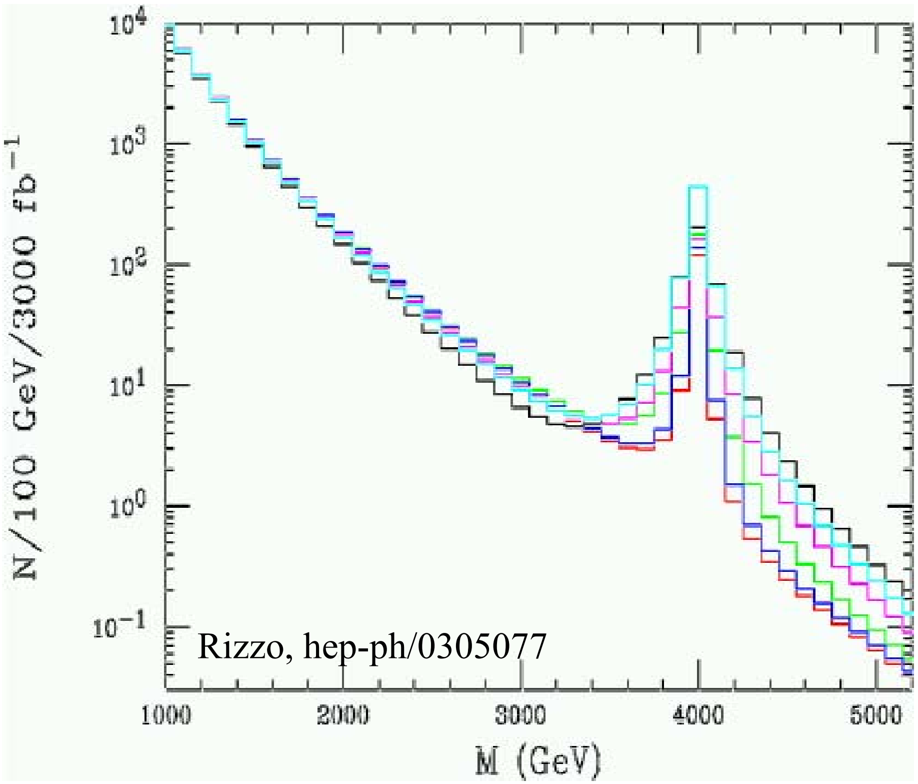
- Cross sections & Widths
- Angular Distributions, Asymmetries
- Couplings (decays, polarization…)

LHC can give some information:

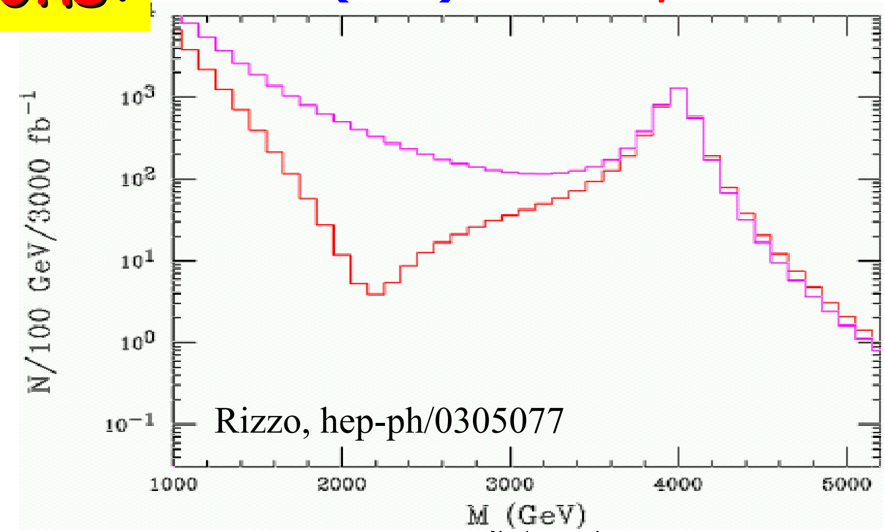
1. Invariant Mass Distributions:

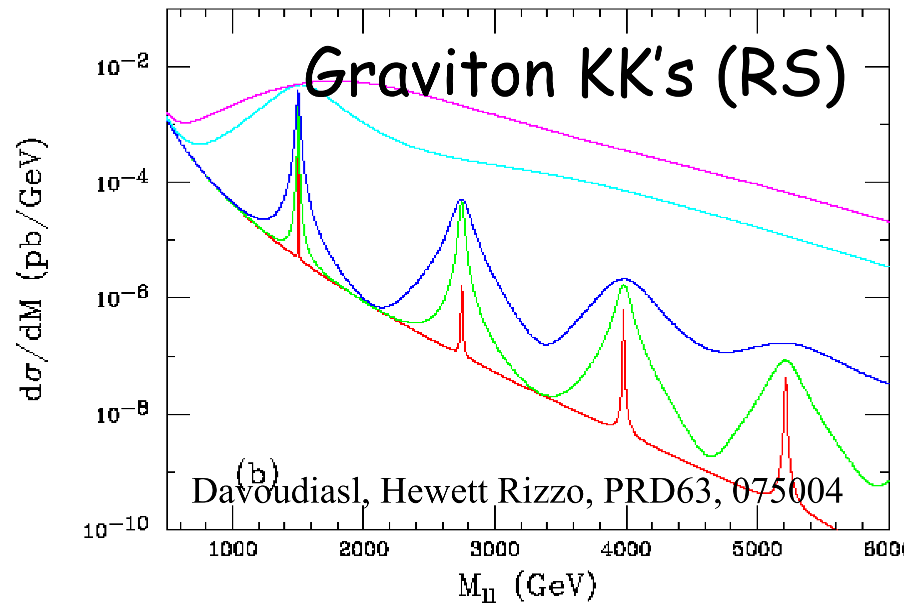
American Linear Collider Physics Group

Z': ψ, χ, η, LR, ALR, SSM



KK (RS): D=0, D=πR



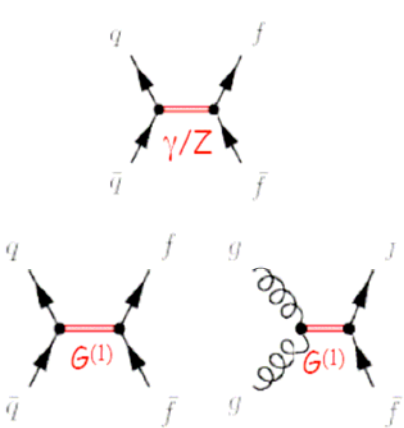


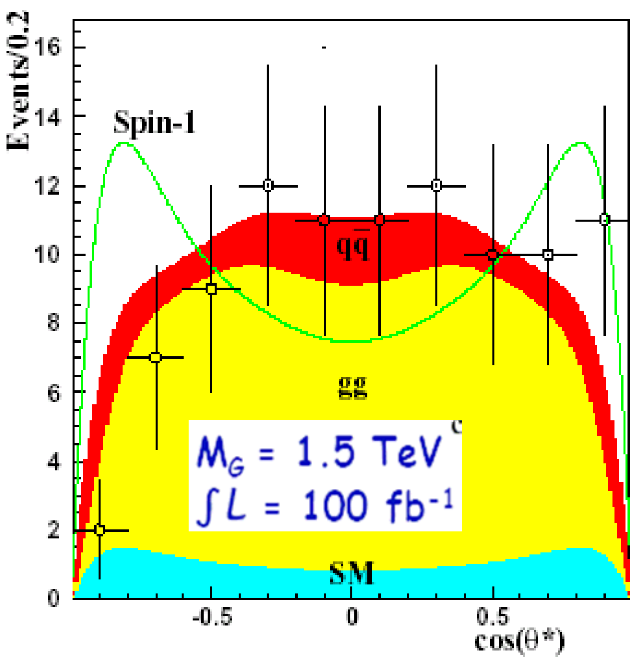
2. Angular Distributions

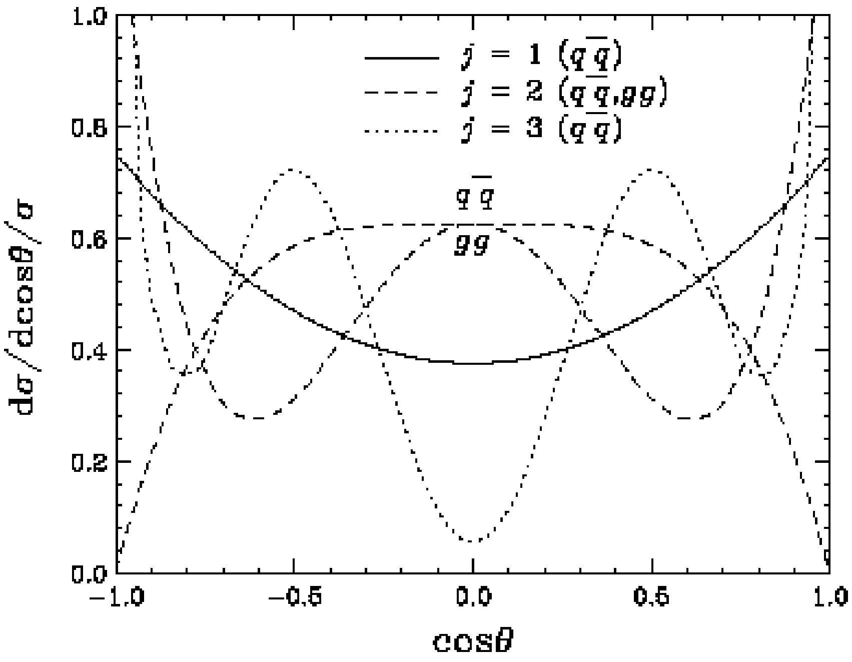
We observe a peak in di-lepton spectrum

- Is it a new gauge boson or a RS KK excitation?

⇒ Use angular distributions to study the spin of the object: spin 1 versus spin 2





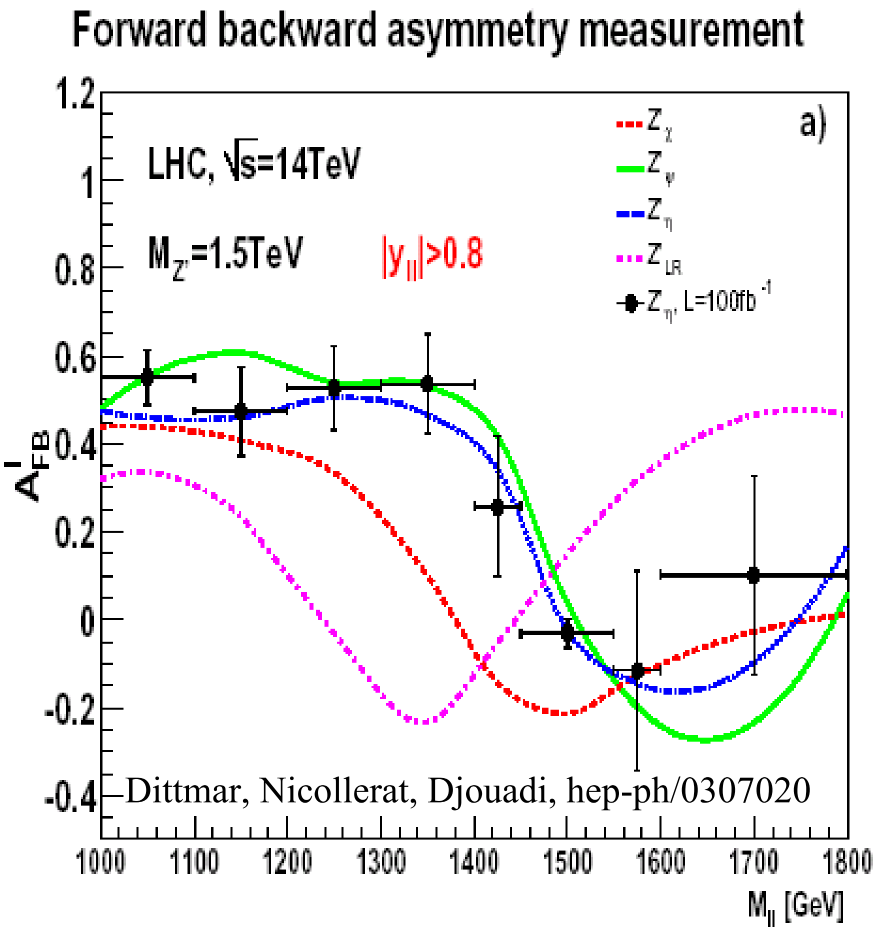


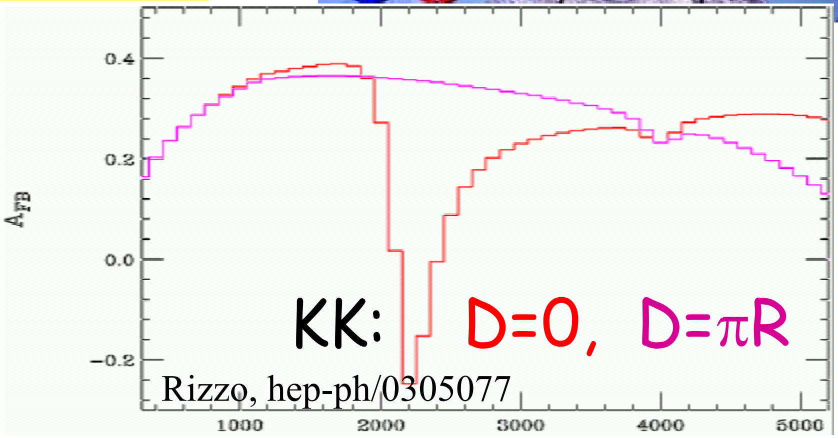
Straightforward angular measurements and fitting.

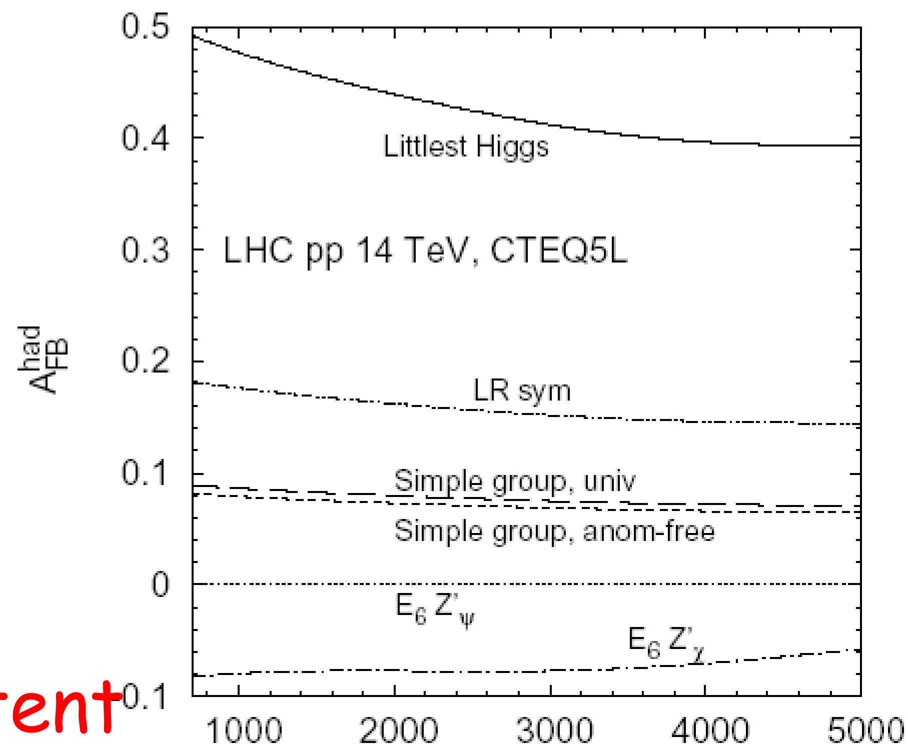
Allanach et al., hep-ph/0006114; Burikham et al., hep-ph/0411094.

3. Forward Backward Asymmetries

$$A_{FB}^{i,f} = \frac{3}{4} A_i A_f, \qquad A_i = \frac{g_L^2 - g_R^2}{g_L^2 + g_R^2}.$$







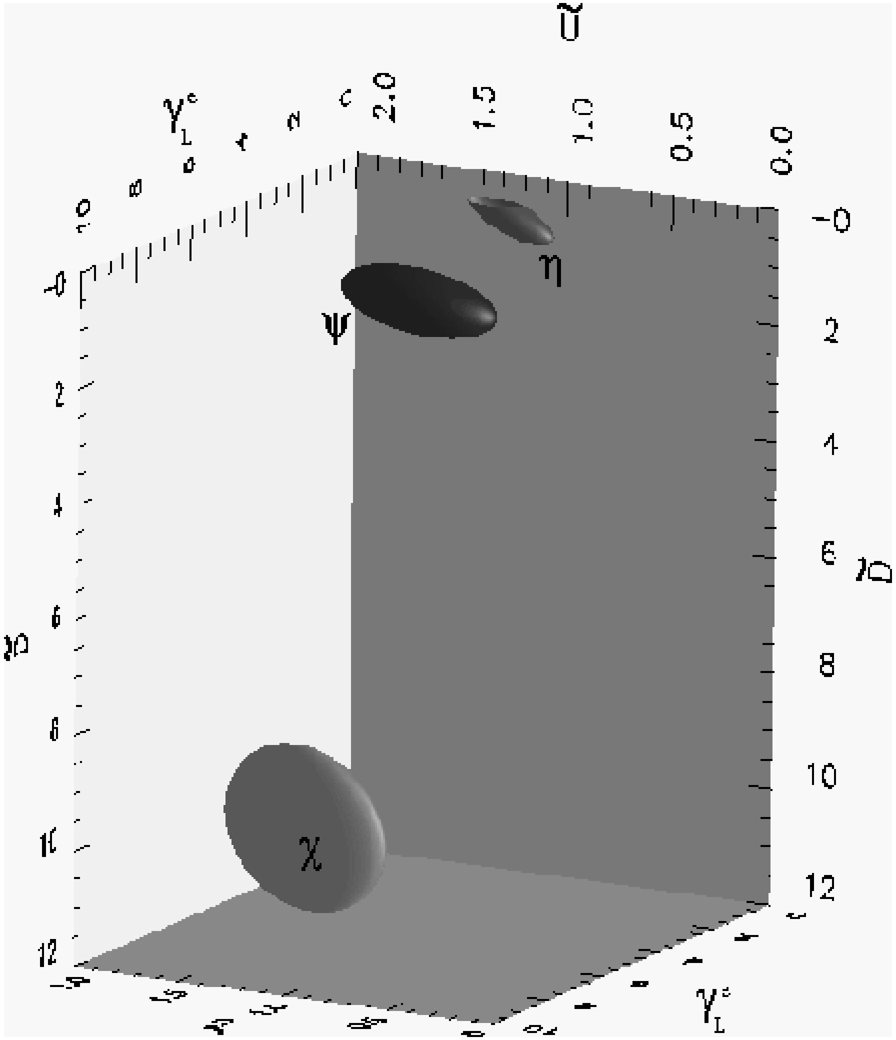
LHC can resolve to some extent

Langacker, Rosner, Robinett (1984); Carena, Daleo, Dobrescu, Tait, hep-ph/0408098; Hewett, Rizzo; Han, Logan, Wang, hep-ph/0506313.

$\sqrt{s} = 14$ TeV

$L = 100$ fb^{-1}

$M_{Z'} = 1$ TeV



A_{FB}

r_{y_1}

$A_{FB_{y1}}$

$r_{l\nu W}$

$R_{Z'Z}$

$R_{Z'W}$

$R_{Z'\gamma}$

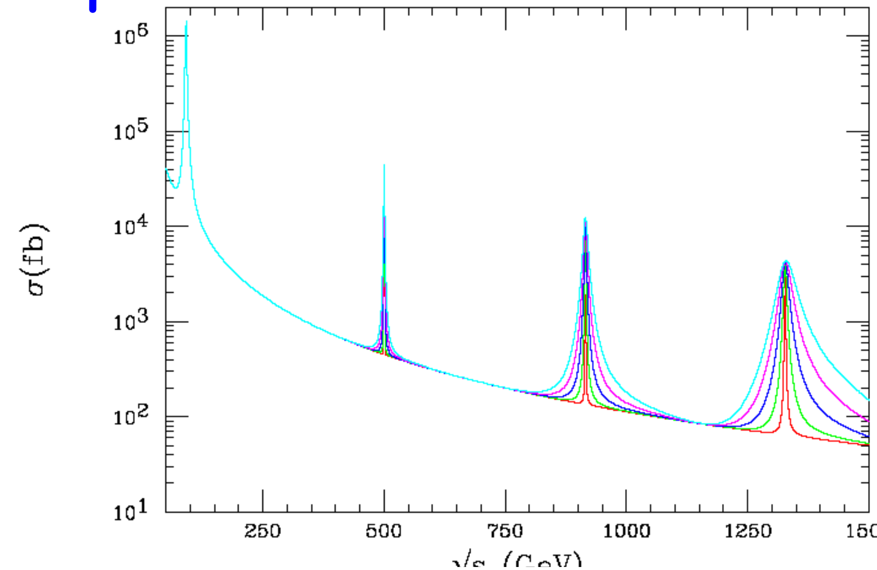
Follows del Aguila, Cvetic and Langacker, PR D48 R969 (1993)
Godfrey & Cvetic, [hep-ph/9504216]

What about the ILC?

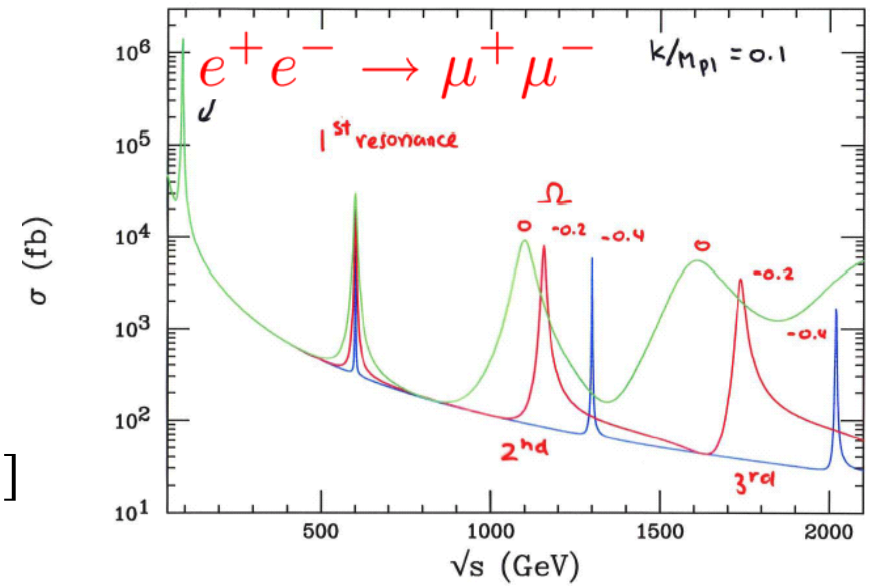
American Linear Collider Physics Group

Look at Cross section for multiple resonances

Eg. In Randall-Sundrum the spectrum of the graviton KK states is discrete and unevenly spaced



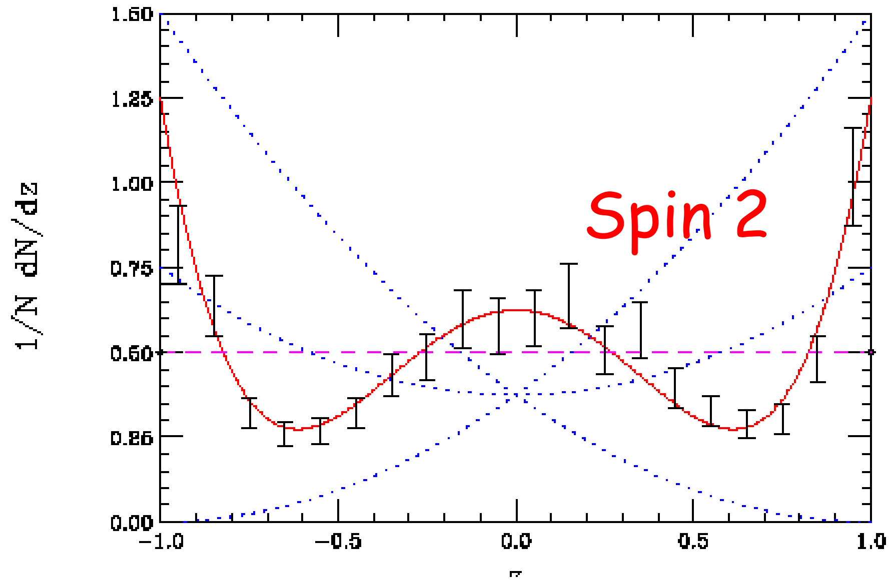
In Higher Curvature Gravity KK mass shifts



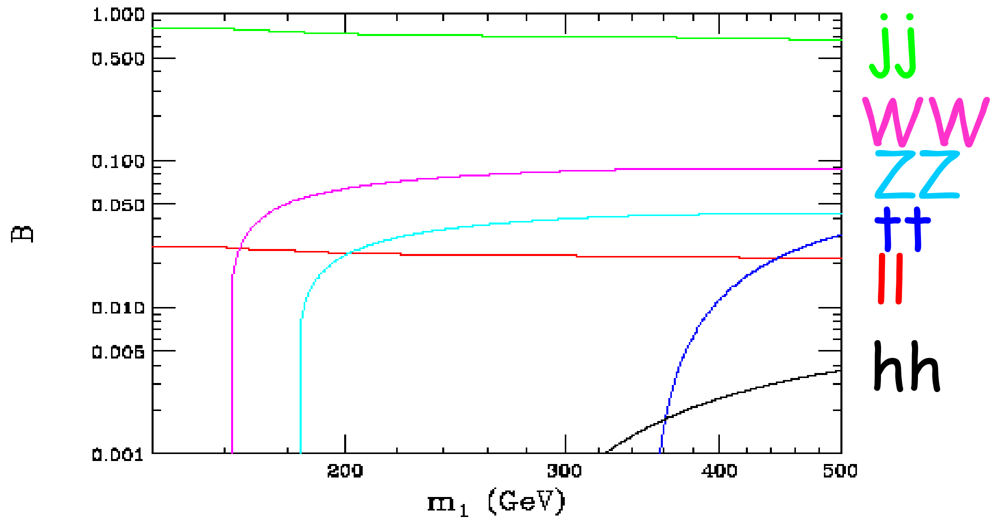
Rizzo [hep-ph/0504118]

Eg: On resonance production of (RS) Gravitons

Determine spin:



Measure BR's to test for Universal couplings



Davoudiasl, Hewett and Rizzo, Phys. Rev. D63, 075004 (2001) [hep-ph/0006041].

Numerous difermion observables

18 di-fermion observables:

σ^{μ}

A^{μ}_{FB}

A^{μ}_{LR}

$A^{\mu}_{FB}(pol)$

σ^{τ}

A^{τ}_{FB}

A^{τ}_{LR}

P_{τ}

R^{had}

A^{had}_{LR}

σ^{b}

A^{b}_{FB}

A^{b}_{LR}

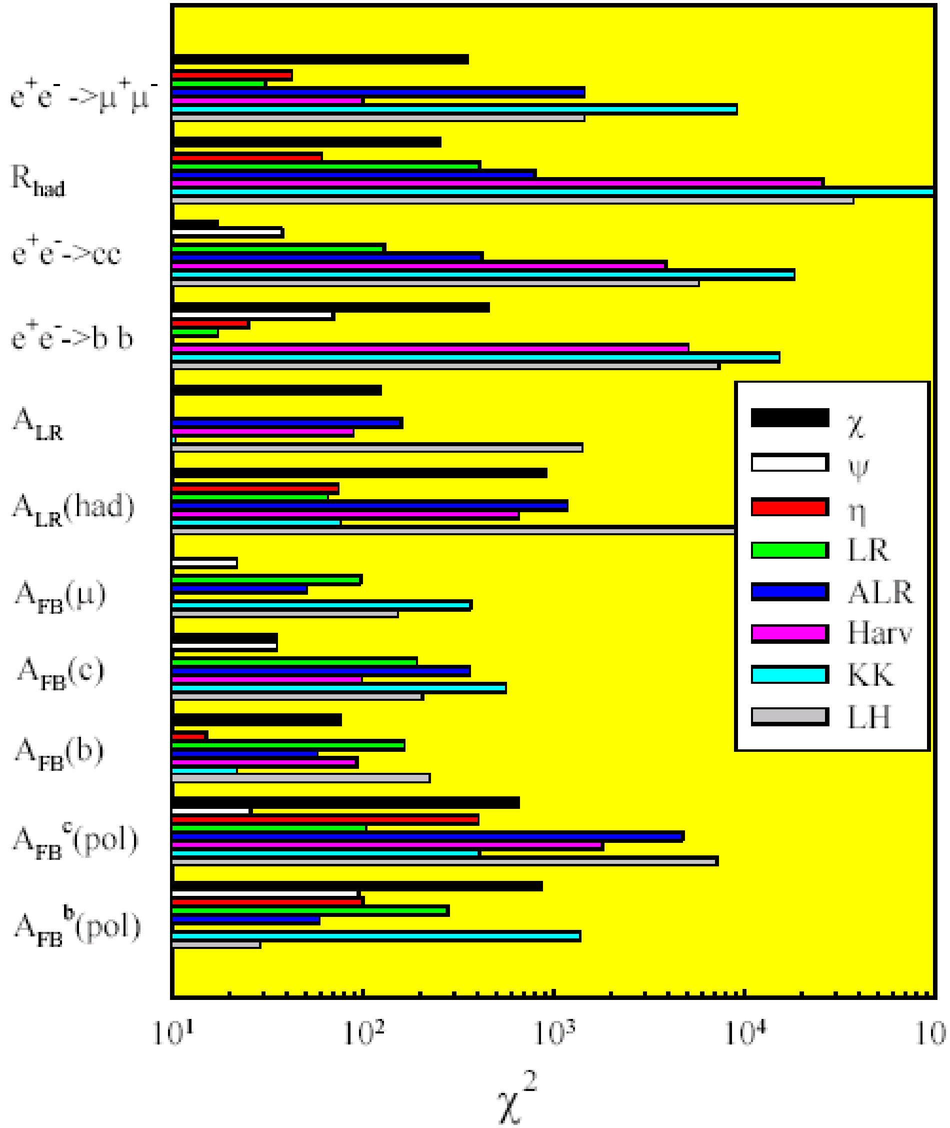
$A^{b}_{FB}(pol)$

σ^{c}

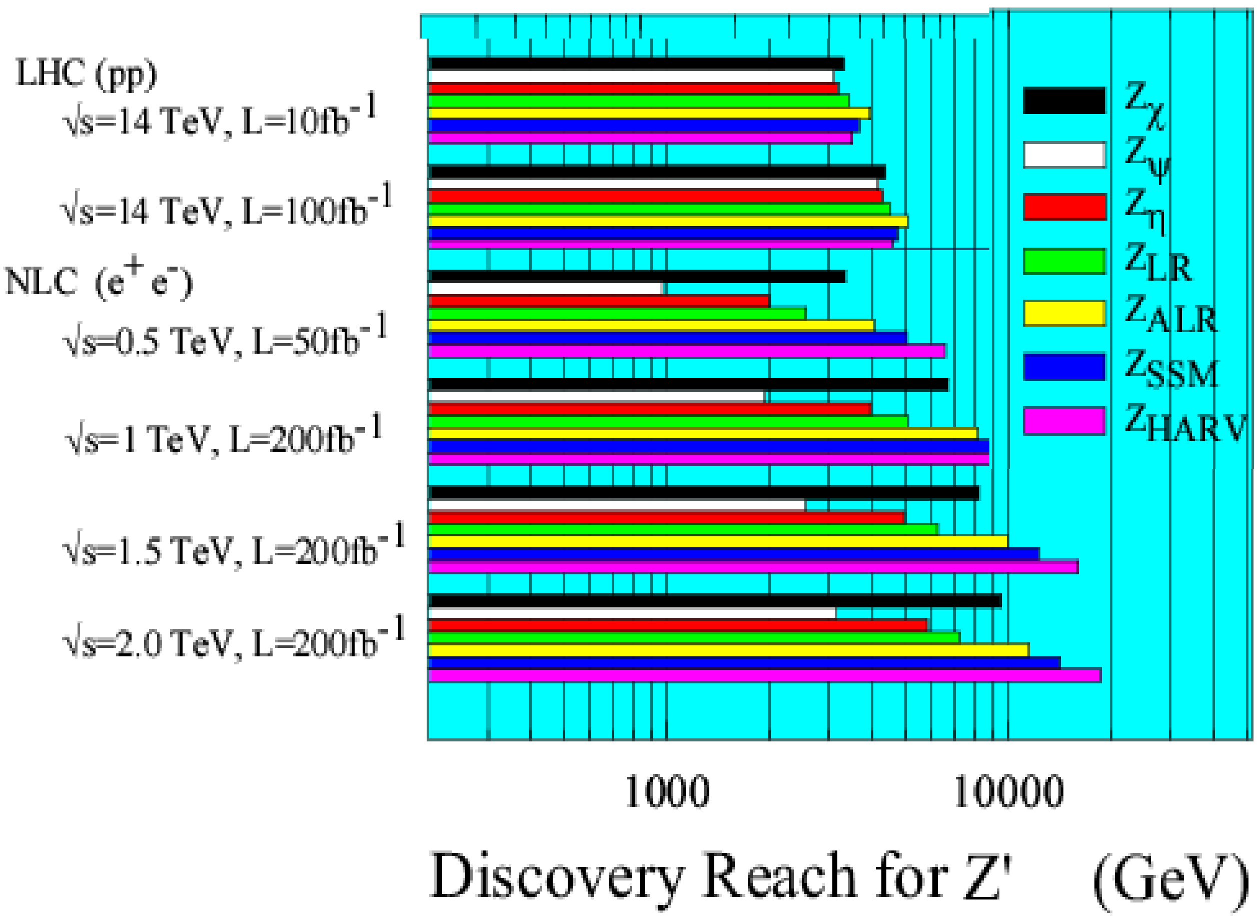
A^{c}_{FB}

A^{c}_{LR}

$A^{c}_{FB}(pol)$



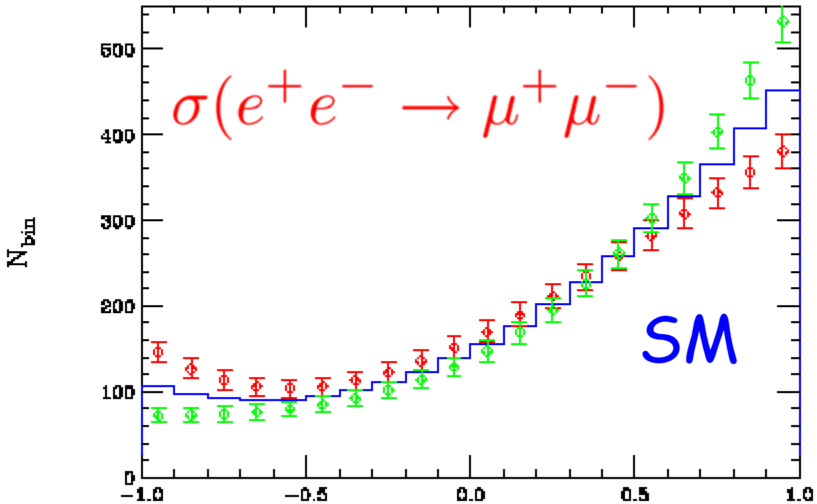
American Linear Collider Physics Group



Indirect Signatures for Gravitons

Off Resonance: Interference of exchange of virtual graviton KK states with SM amplitudes

Leads to deviations in $e^+e^- \to f\bar{f}$ dependent on both λ and s/M_H



Hewett, hep-ph/9811356

$\sqrt{s} = 5$ TeV

$L = 1$ ab^{-1}

$M_s = 15$ TeV

$\lambda = \pm 1$

Can use multipole moments to distinguish spin 2 from spin 1

Rizzo: hep-ph/0208027

Z' couplings

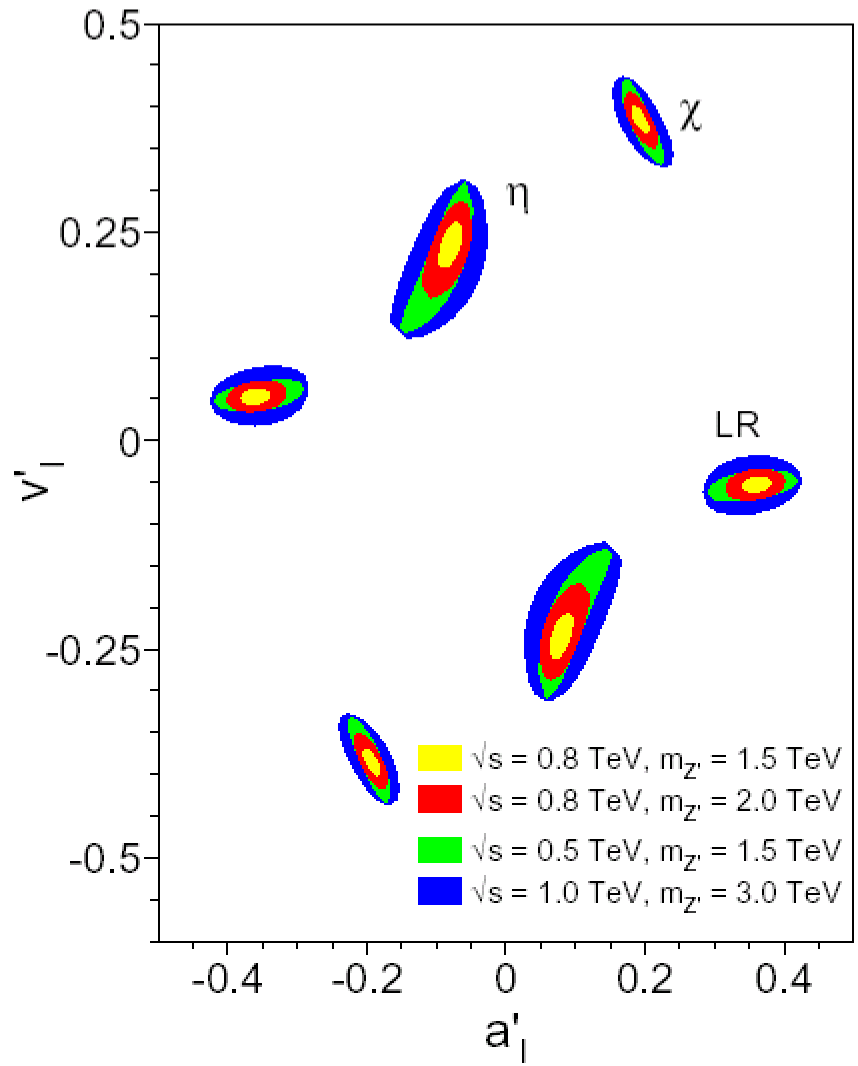
Extraction of Z' couplings
assuming $M_{Z'}$ is known from LHC

$\sigma^{\mu}_{P_e^- P_e^+}$ A^{μ}_{FB} A^{μ}_{LR}

95% C.L. bounds

L=1 ab^{-1} ΔL=0.2%, P_-=0.8, P_+=0.6, ΔP=0.5%

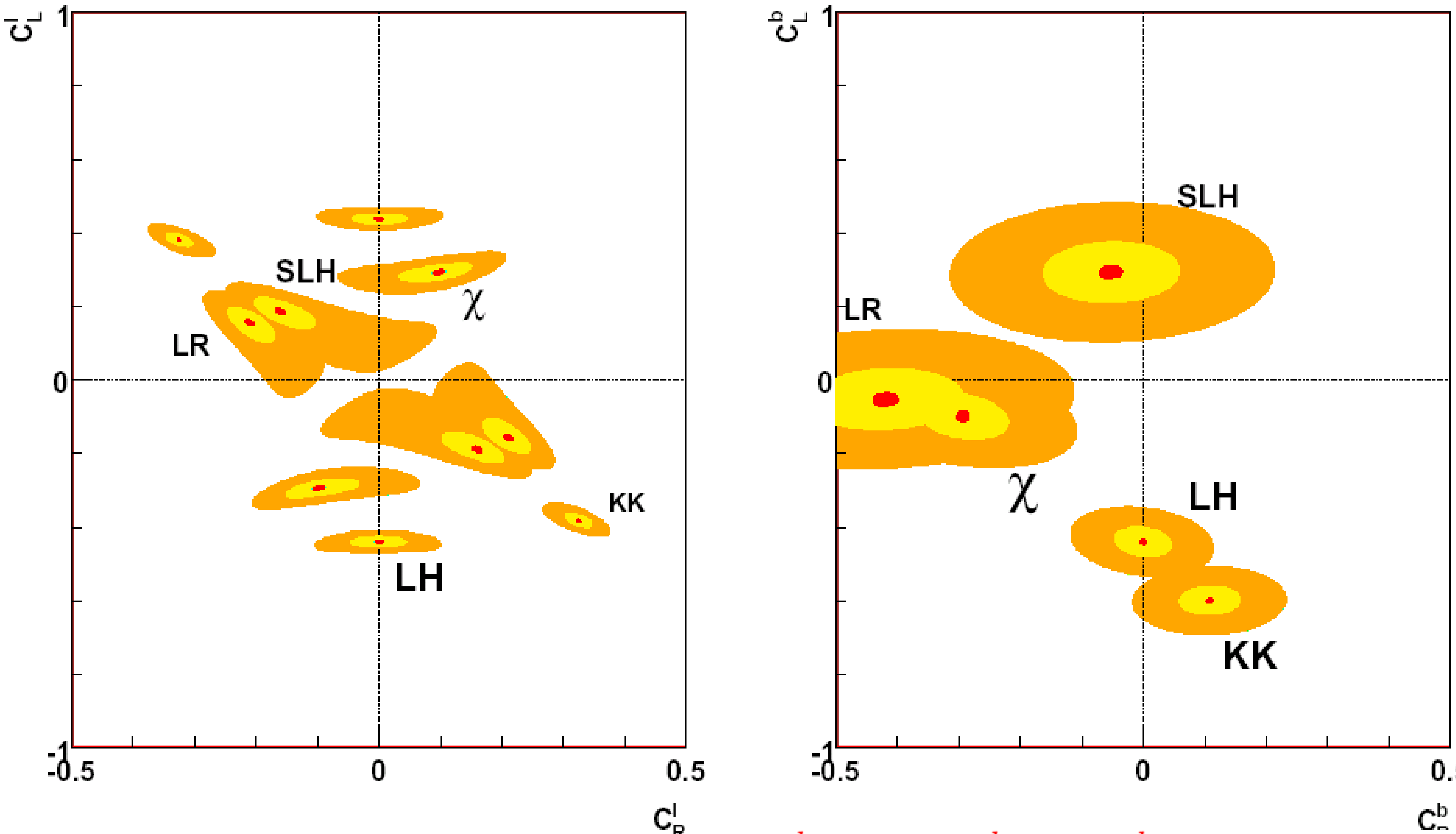
Note sign ambiguity



S. Riemann: TESLA TDR & LHC/LC Study

1. Can we resolve the sign ambiguity?

$\sqrt{s} = 500\ \mathrm{GeV}$ $\mathcal{L}_{int} = 1\ \mathrm{ab}^{-1}$ $M_{Z'} = 1,\ 2,\ 3\ \mathrm{TeV}$



$\sigma^{\mu}_{P_e^- P_e^+}$ A^{μ}_{FB} A^{μ}_{LR} $\sigma^{b}_{P_e^- P_e^+}$ A^{b}_{FB} $A^{b}_{FB}(pol)$ $(\epsilon_b = 70\%)$

2. The Importance of Polarization

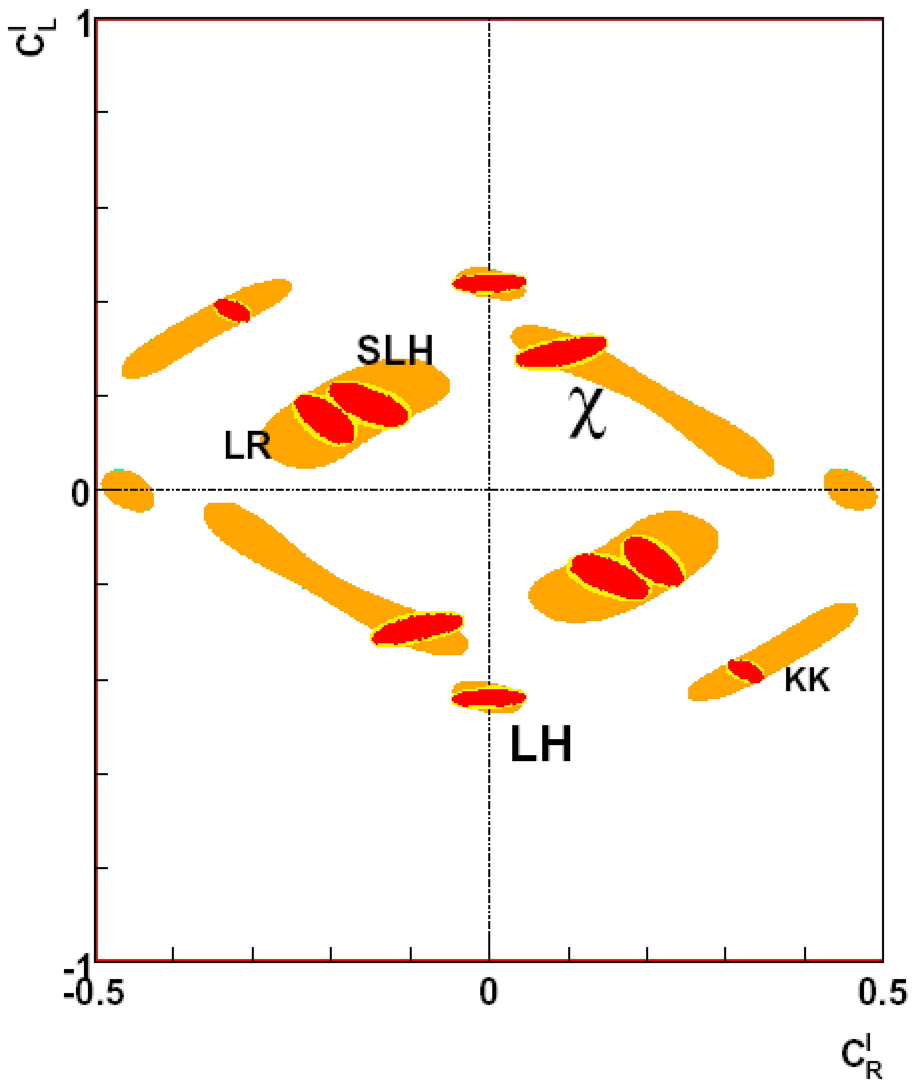
$\sqrt{s} = 500$ GeV

$\mathcal{L}_{int} = 1$ ab^{-1}

$M_{Z'} = 2$ TeV

$\sigma^{\mu}_{P_e^- P_e^+}$ A^{μ}_{FB} A^{μ}_{LR}

- No polarization
- Only electron
- electron & positron



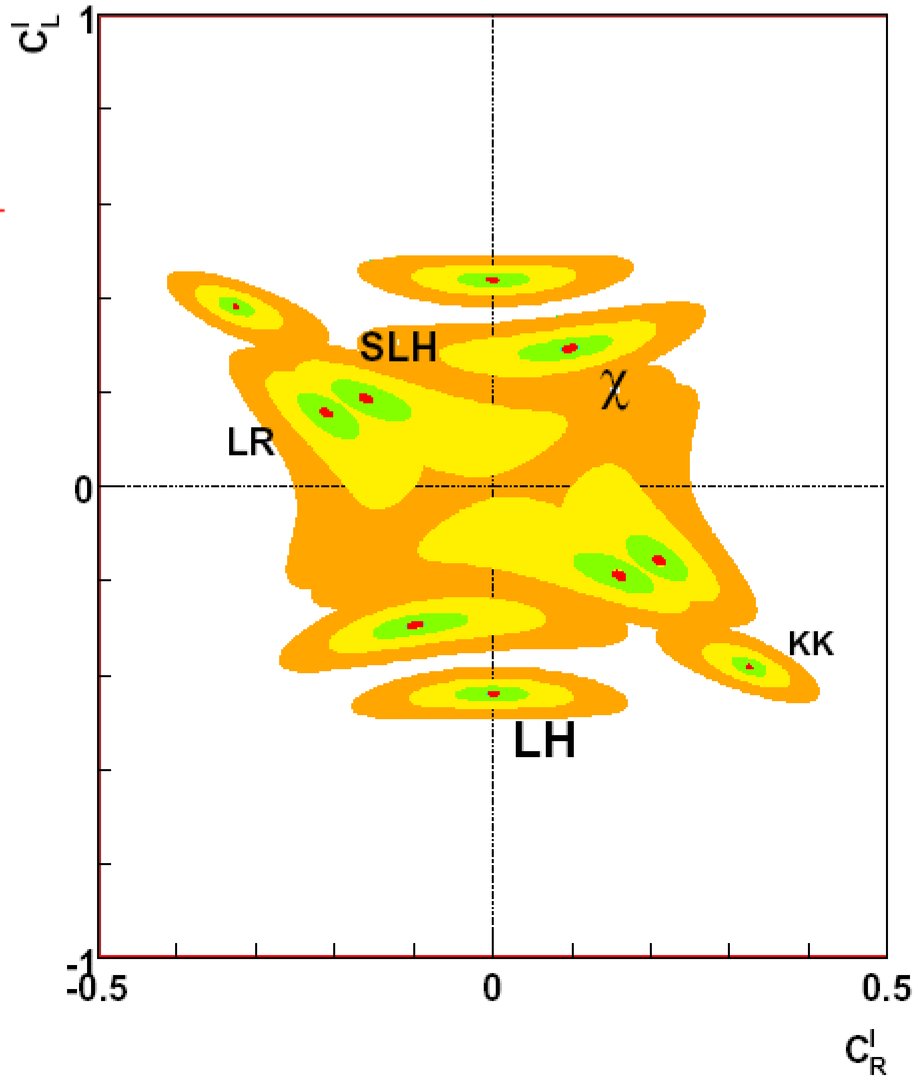
3. What happens for higher mass?

American Linear Collider Physics Group

$M_{Z'} = 1,\ 2,\ 3,\ 4$ TeV

$\sqrt{s} = 500$ GeV $\mathcal{L}_{int} = 1$ ab^{-}

$\sigma^{\mu}_{P_e^- P_e^+}$ A^{μ}_{FB} A^{μ}_{LR}

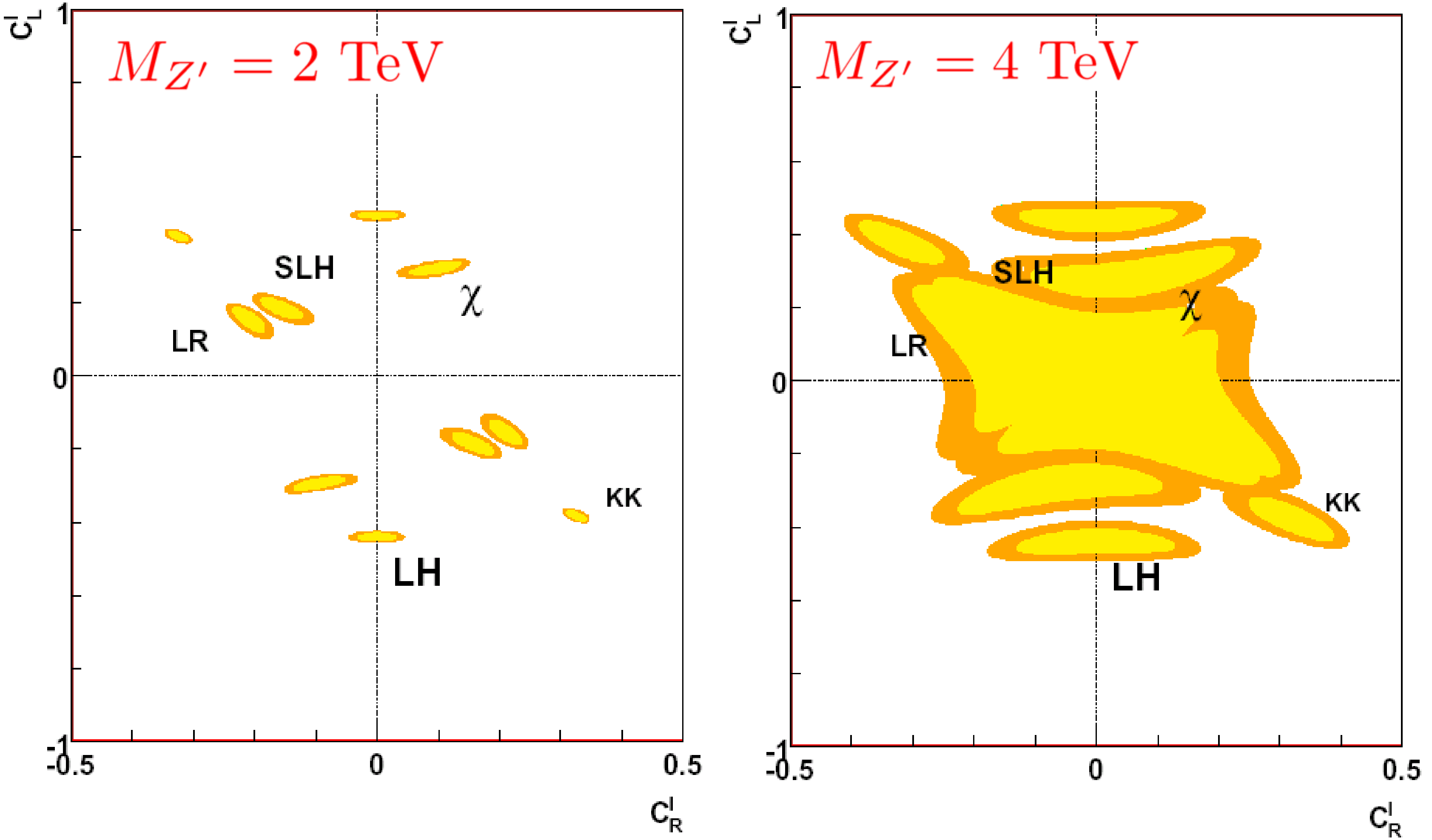


4. How does it change with more observables?

American Linear Collider Physics Group

$$\sqrt{s} = 500 \text{ GeV} \quad \mathcal{L}_{int} = 1 \text{ ab}^{-1}$$

$\sigma^\mu \; A^\mu_{FB} \; A^\mu_{LR}$ $\quad$ $\sigma^\mu \; A^\mu_{FB} \; A^\mu_{LR} \; A^\mu_{FB}(pol) \; \sigma^\tau \; A^\tau_{FB} \; A^\tau_{LR} \; P_\tau$

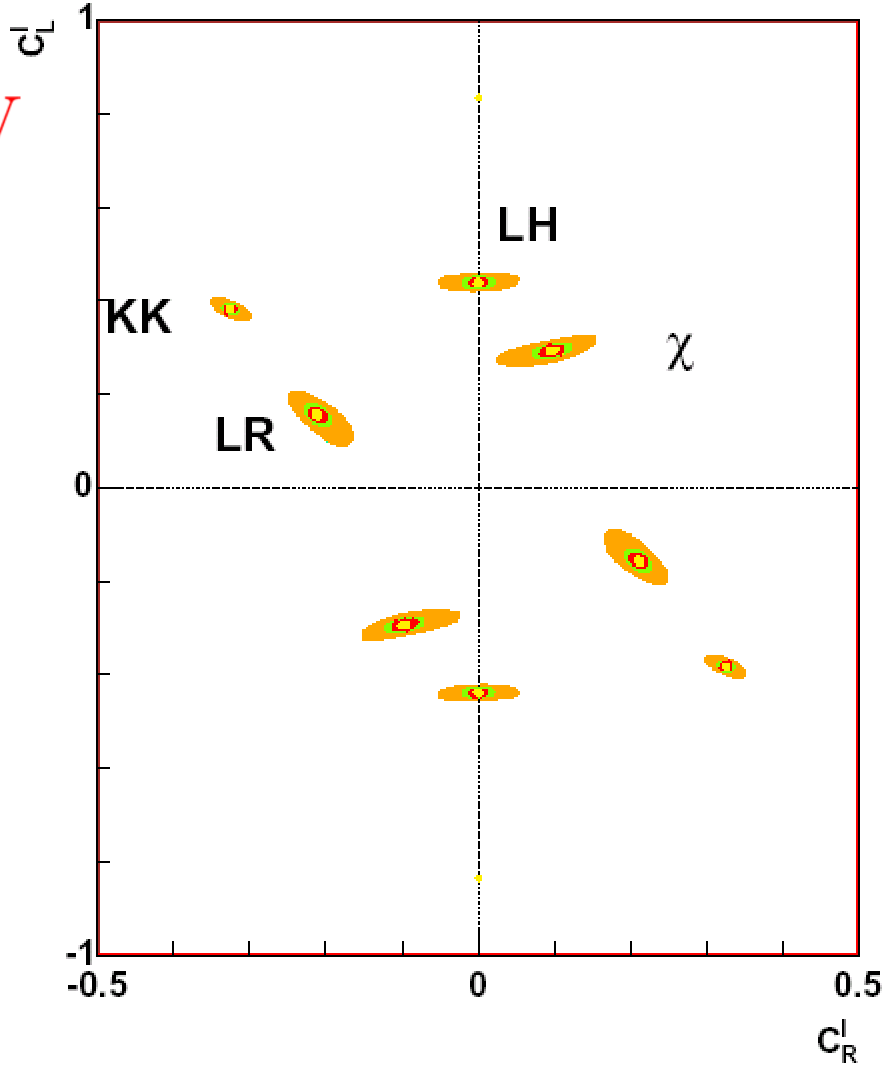


5. What happens with higher energy?

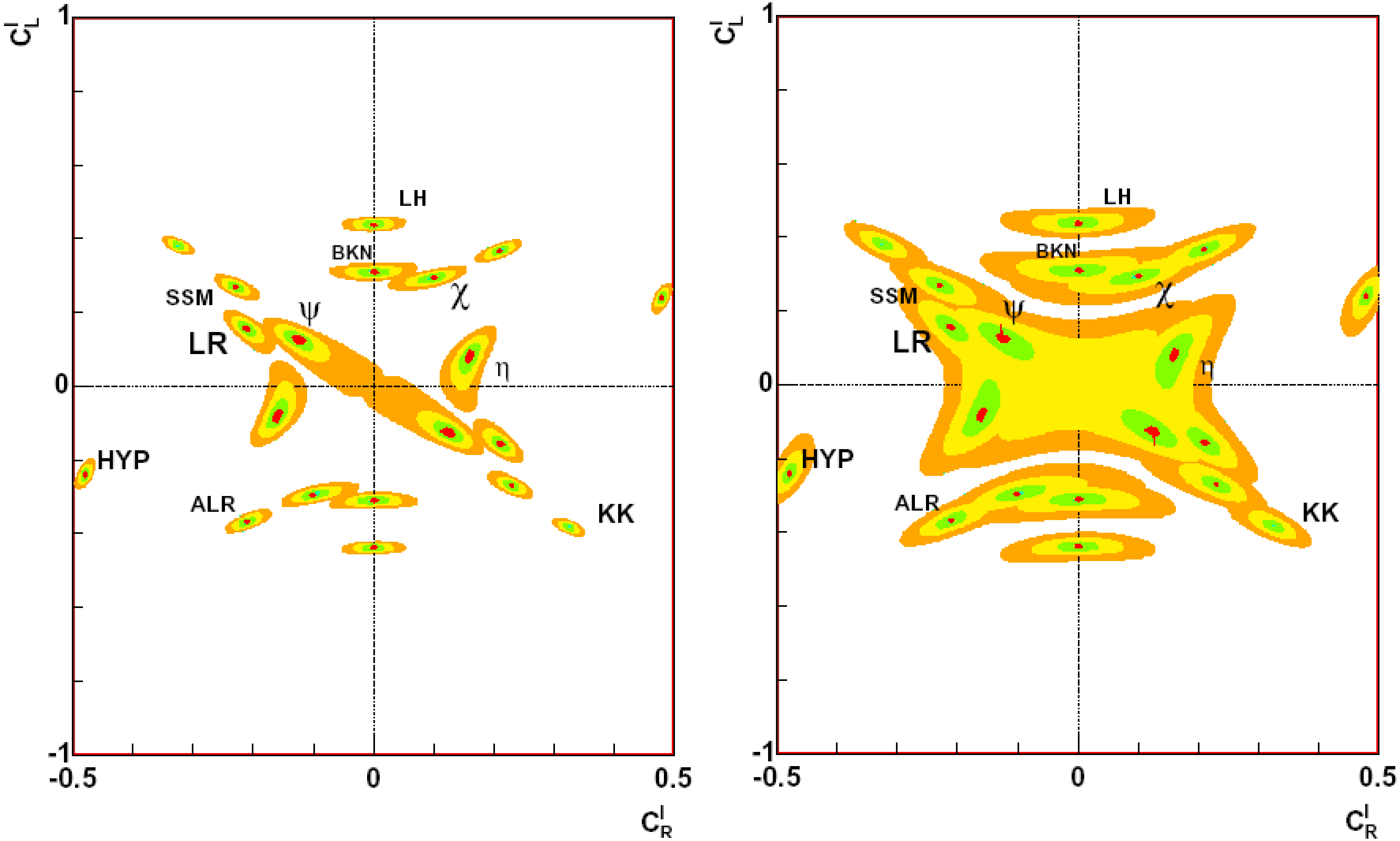
American Linear Collider Physics Group

$M_{Z'} = 2.5$ TeV

$\sqrt{s} = 500,\ 800,\ 1000,\ 1500$ GeV



$M_{Z'} = 1,\ 1.5,\ 2,\ 2.5$ TeV $\qquad$ $M_{Z'} = 1,\ 2,\ 3,\ 4$ TeV



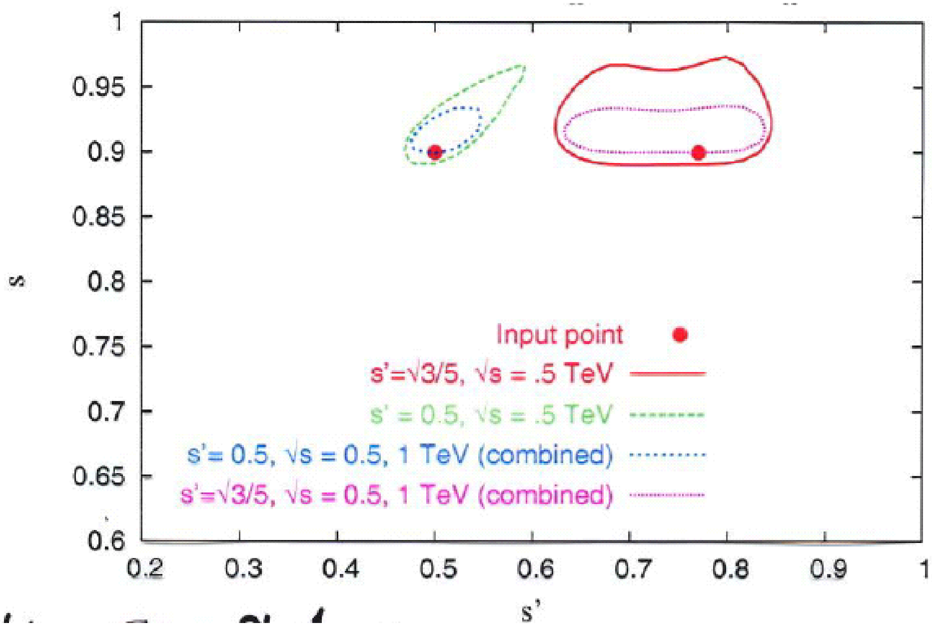
$\sqrt{s} = 500$ GeV $\mathcal{L}_{int} = 1$ ab^{-1}

Measuring Little Higgs Parameters

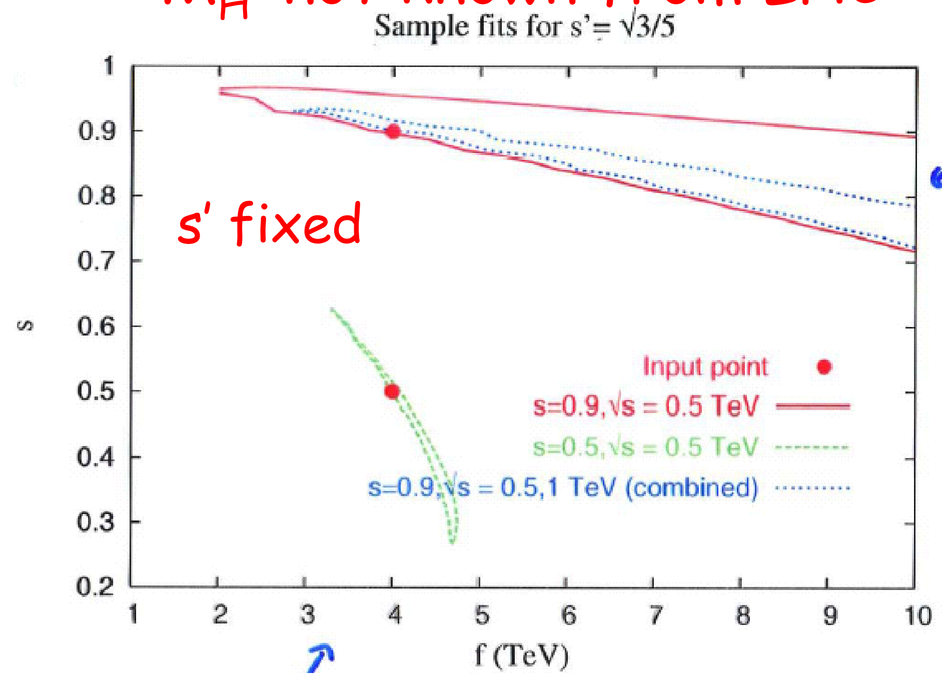
$$e^+e^- \rightarrow f\bar{f}$$

J. Conley, M.P. Le, J. Hewett

$M_H = 3.3$ TeV $\quad m_{A_H} \rightarrow \infty$



M_H not known from LHC



$$\mathcal{L} = 500 \text{ fb}^{-1}$$

Summary

- The ILC will be an extremely powerful tool for understanding a resonance discovered at the LHC

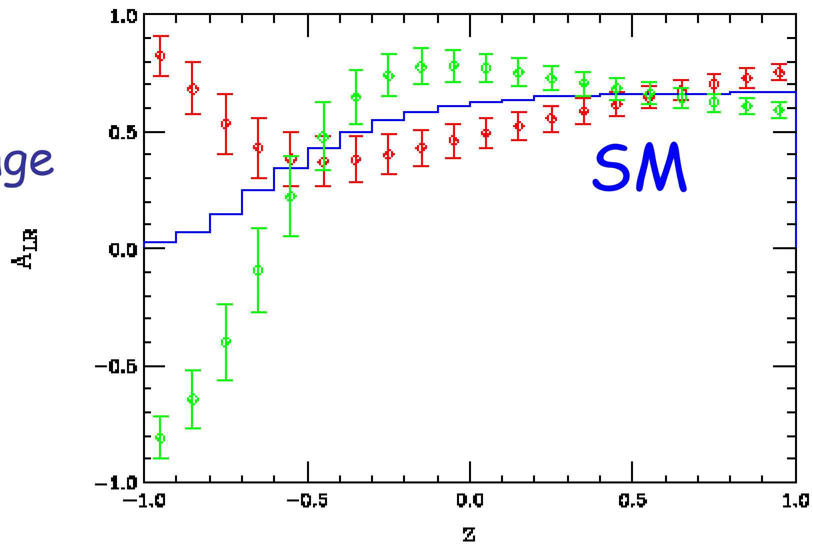
- But the LHC is coming soon
  - Important to study s-channel resonance identification at the LHC

$$A_{LR}(e^+e^- \to b\bar{b})$$

Eg. A_{LR}

Interference of exchange of virtual graviton KK States with SM amplitudes

Hewett, hep-ph/9811356



$\sqrt{s} = 5$ TeV

$L = 1\ \text{ab}^{-1}$

$M_s = 15$ TeV

$\lambda = \pm 1$