BSM Working Group III:
Lepton Resonances & Multi gauge Boson Signals

Tao Han   (Univ. of Wisconsin - Madison)
On behalf of kevin Black, Sabine Riemann, and Tom Rizzo

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The Charge to the WG

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The LHC Early Phase for the ILC, FNAL
(April 14, 2007)

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Activities in This Workshop

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Future Work

Recall: This Workshop –

"... to assess the prospects for LHC/ILC interplay based on early LHC data with an integrated luminosity of about 10 fb^{-1}.

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The more discoveries made at LHC, the stronger case made for ILC.

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Corollary:
The fewer discoveries made at LHC, the weaker arguments for ILC.

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"... to assess the prospects for LHC/ILC interplay based on early LHC data with an integrated luminosity of about 10 fb^{-1}.

"The Strong-Correlation Theorem":
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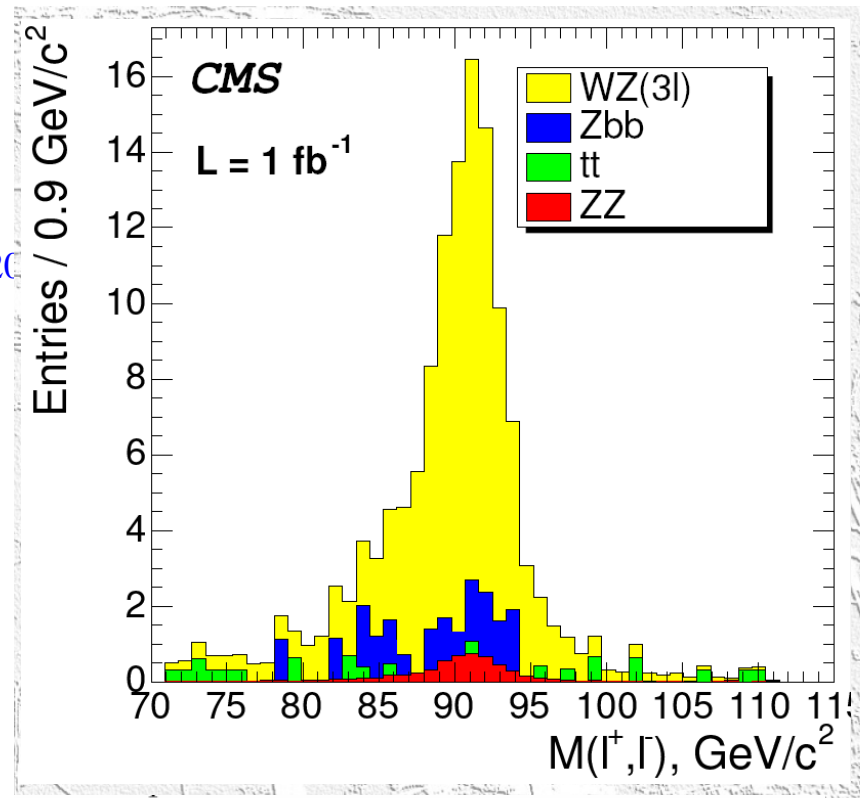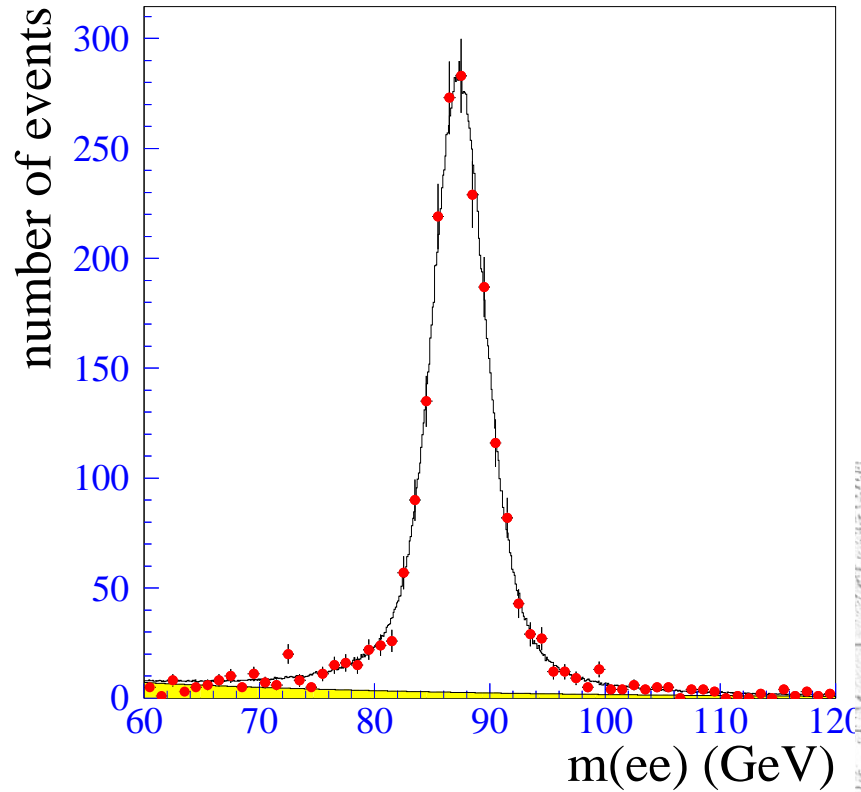
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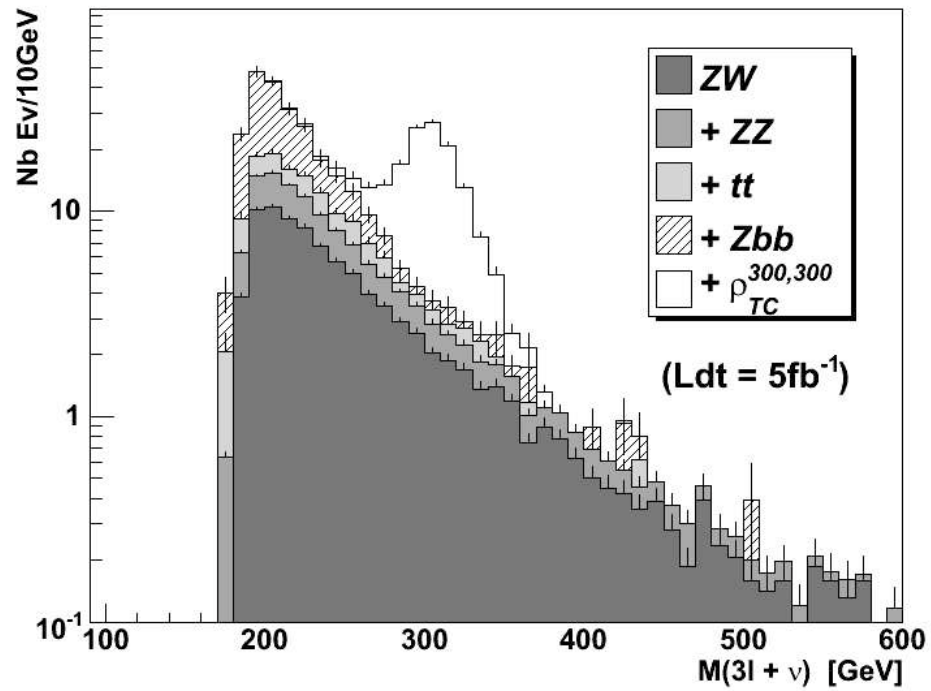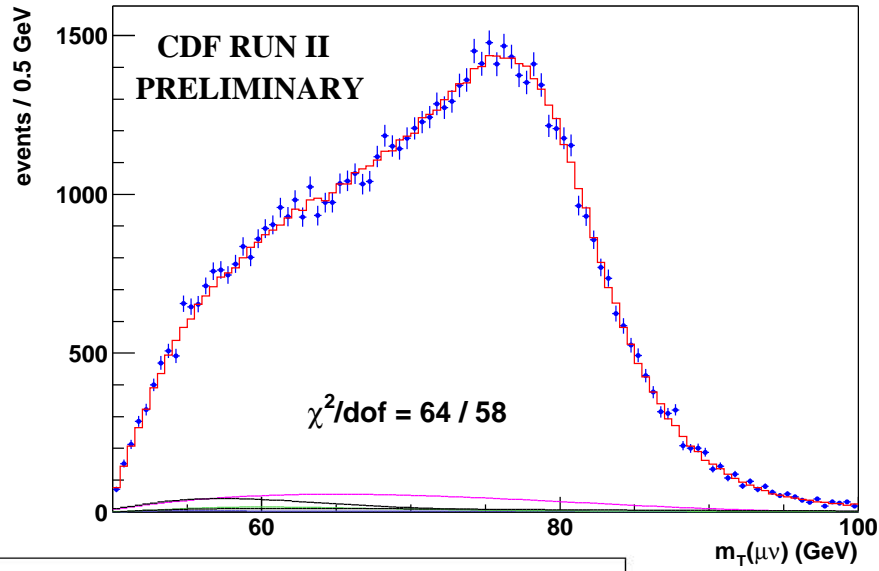
Charge to the Working Group:
Given a signal observation at the LHC, how would it impact on the ILC?
collider parameters adjustments, detector optimization ...

Signals of *leptonic resonances and multi gauge bosons.*

Transverse mass variables:

CDF RUN II
PRELIMINARY

$\chi^2/dof = 64 / 58$

events / 0.5 GeV

$m_T(\mu\nu)$ (GeV)

Nb Ev/10GeV

- ZW
- + ZZ
- + tt
- + Zbb
- + $\rho_{TC}^{300,300}$

$(Ldt = 5fb^{-1})$

M(3l + ν) [GeV]

CMS TDR

"All possible types of 2-body resonances are predicted by new models"

	e/μ	τ	ν	j	b	t	γ	W/Z	h
e/	Z', G*, ρTC,	LFV	W'	LQ, (2l-2j)	LQ, (2l-2j)	LQ, (2l-2j)	e*, μ*	e*, μ*, ν*, e',	
μ/τ	H++	Z', G*, ρTC, H++,	W'	LQ, (2l-2j)	LQ, (2l-2j)	LQ, (2l-2j)	τ*	μ*, τ', ν*	
ν		A/H		LQ, (2l-2j)	LQ, (2l-2j)	LQ, (2l-2j)	ν*(?)	ν*, ν'	
j				Z', G*, ρTC, H	πTC	πTC	q*	q*, q', D	D
b					Z', G*, ρTC, H,	W'	b*	b*, b', T	D
t					h	Z', G*, ρTC, H,	t*	T	T
γ						gKK	G*, ρTC, H	W'	
W/								Z', G*, ρTC, H,	W', Z', H
h								W'	H/A

''All possible types of 2-body resonances are predicted by new models''

	e/μ	τ	ν	j	b	t	γ	W/Z	h
e/μ	Z', G*, ρTC,	LFV	W'	LQ, (2l-2j)	LQ, (2l-2j)	LQ, (2l-2j)	e*, μ*	e*, μ*, ν*, e',	
τ	H++	Z', G*, ρTC, H++,	W'	LQ, (2l-2j)	LQ, (2l-2j)	LQ, (2l-2j)	τ*	τ*, τ', ν*	
ν		A/H		LQ, (2l-2j)	LQ, (2l-2j)	LQ, (2l-2j)	ν*(?)	ν*, ν'	
j				Z', G*, ρTC, H	πTC	πTC	q*	q*, q', D	D
b					Z', G*, ρTC, H,	W'	b*	b*, b', T	D
t					h	Z', G*, ρTC, H,	t*	T	T
γ						gKK	G*, ρTC, H	W'	
W/Z								Z', G*, ρTC, H, W'	W', Z', H
h									H/A

And bump searches we do the best:

Kinematics distinctive;
Statistics dominant; Systematics less a concern.

Activities in This Workshop:

Plenary talks:

Joachim Mnich: Multi gauge bosons

Georges Azuelos: Leptonic (and more) resonances at the LHC

Doreen Wackeroth: Lepton resonance & multi gauge bosons: Theory

Albert De Roeck: Beyond the Standard Model Signals at the LHC

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Session I

K.C. Kong: Resonances in Universal Extra Dimensions

Sabine Riemman: Discoveries through ILC precision measurements

Benjamin Lillie: Using top quarks to probe the Randall-Sundrum model

Session II

Greg Landsberg: Search for Extra Dimensions and Leptoquarks in Early LHC data

Gustaaf Brooijmans: New and old gauge boson discoveries in early LHC data

Tim Tait: New (and Not So New) Z' Gauge Bosons and the LHC/ILC Connection

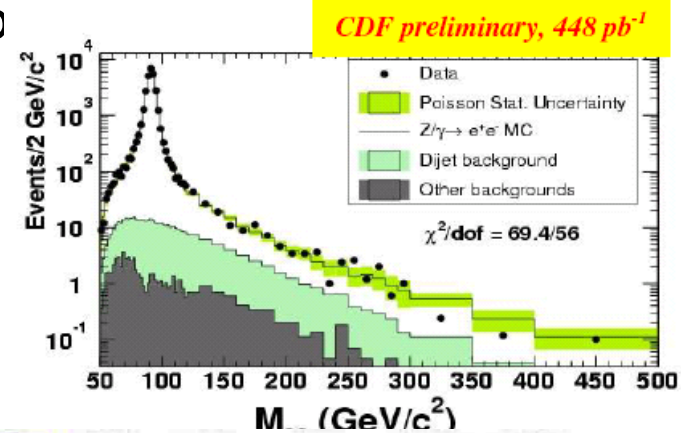Scott Thomas: Using object correlations to extract new physics from the LHC

Tom Rizzo: Discussions

(1). Search at the Tevatron: $M_{Z'} > 900$ GeV, $M_{W'} > 750$ GeV ...

Di-lepton Resonance Search

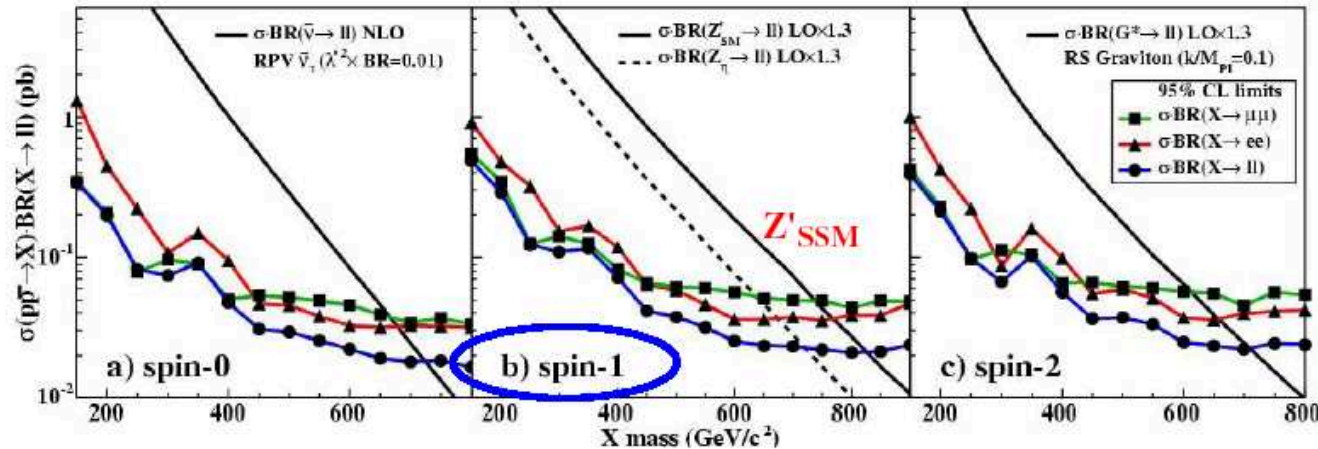American Linear Collider
Physics Group

- Select 2 opposite sign high p_T isolated leptons and examine invariant mass distribution
- 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}

- Data
- Poisson Stat. Uncertainty
- $Z/\gamma \to e^+e^-$ MC
- Dijet background
- Other backgrounds

$\chi^2/dof = 69.4/56$

Z' Mass

CDF, di-electrons and di-muons combined, 200 pb^{-1}

hep-ex/0507104

- $\sigma \cdot BR(\tilde{\nu} \to ll)$ NLO
  RPV $\tilde{\nu}_\tau$ ($\lambda'^2 \times$ BR=0.01)
- $\sigma \cdot BR(Z'_{SM} \to ll)$ LO×1.3
- $\sigma \cdot BR(Z_\eta \to ll)$ LO×1.3
- $\sigma \cdot BR(G^* \to ll)$ LO×1.3
  RS Graviton (k/M$_{Pl}$=0.1)

95% CL limits
- $\sigma \cdot BR(X \to \mu\mu)$
- $\sigma \cdot BR(X \to ee)$
- $\sigma \cdot BR(X \to ll)$

Z'$_{SSM}$

a) spin-0   b) spin-1   c) spin-2

X mass (GeV/c^2)

$\sigma(p\bar{p} \to X) \cdot BR(X \to ll)$ (pb)

(2). Signals at the LHC:

△ Z' or alike → $\mu^+\mu^-$, e^+e^-: (Gustaaf Brooijmans; K.C. Kong; Tim Tait)

- 5□discovery reach

- Systematics don't change these results much

- 2-3 TeV with 1 fb^{-1}

- 3-4 TeV with 10 fb^{-1}

- Early bad news for ILC?

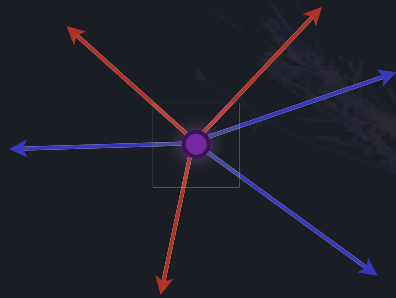 - Depends on what else is there....

- Dielectron reach similar
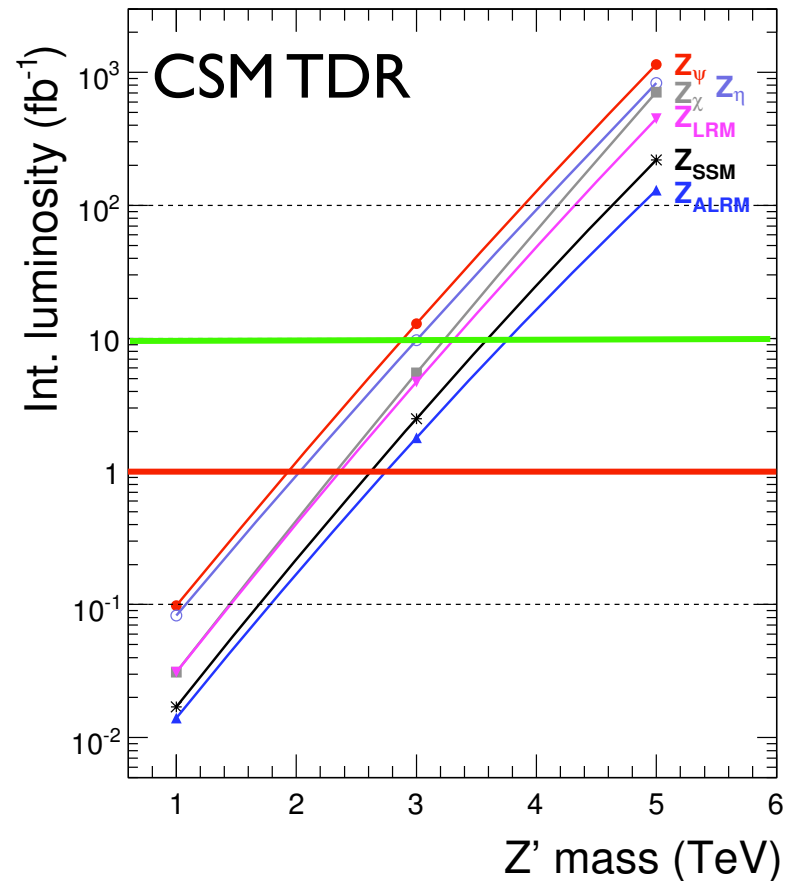
- Charge asymmetry may be constructed $A_{FB} \approx (g_{Li}^2 - g_{Ri}^2)(g_{Lf}2 - g_{Rf}^2)$.
- Greg Landsberg: Do not overlook $\tau^+\tau^-$.

△ Z', $G_{KK} \to t\bar{t}$: (Ben Lillie; Gustaaf Brooijmans; K.C. Kong)

Can be good resonant signal for $m_{tt} < 2$ TeV

Top collimation

Threshold production

High mass production

- Tops can be highly boosted

- Can they be resolved into separate objects for top ID and reconstruction?

△ Many good resonant signatures
(Georges Azuelos, Greg Landsberg, Gustaaf Brooijmans)

$$W'_R \rightarrow \ell\nu$$
$$\ell_q,\ \tilde{\ell} \rightarrow \ell q,\ \ell\bar{\ell'}$$
$$H^{++} \rightarrow \ell^+\ell^+$$
$$\ell^* \rightarrow \ell\gamma, \ell Z$$

...

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$$
\begin{aligned}
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H^{++} &\rightarrow \ell^+\ell^+ \\
\ell^* &\rightarrow \ell\gamma, \ell Z
\end{aligned}
$$

...

And,
$\triangle$ resonant signal in m_{jjj}? (Scott Thomas)

$$
pp \rightarrow Q\bar{Q} \rightarrow j_1 j_2 j_3,\ j_4 j_5 j_6
$$

$$
m_{j_1 j_2 j_3} \approx m_{j_4 j_5 j_6}.
$$

Typically large rate (QCD), but very challenging to dig out.

(3). At the ILC ...

A real challenge: $M > E_{CM}$, but it is the paradise of precision.

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A real challenge: $M \geq E_{CM}$, but it is the paradise of precision.
$\triangle\ e^{+}e^{-} \rightarrow Z'^{*} \rightarrow f\bar{f}$: (Steve Godfrey, Georg Weiglein et al. LHC/ILC study)

Z' couplings

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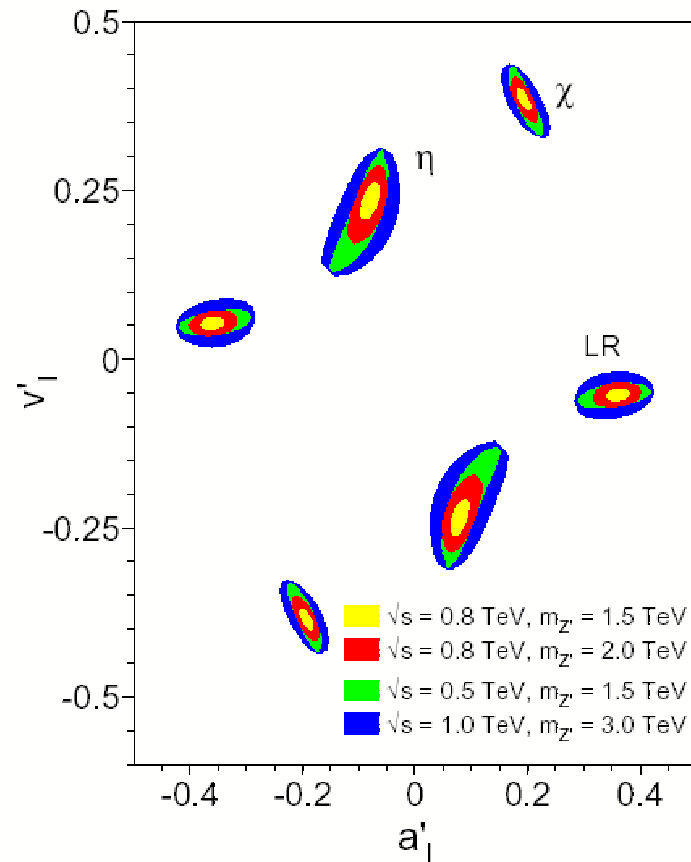assuming $M_{Z'}$ is known from LHC

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

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

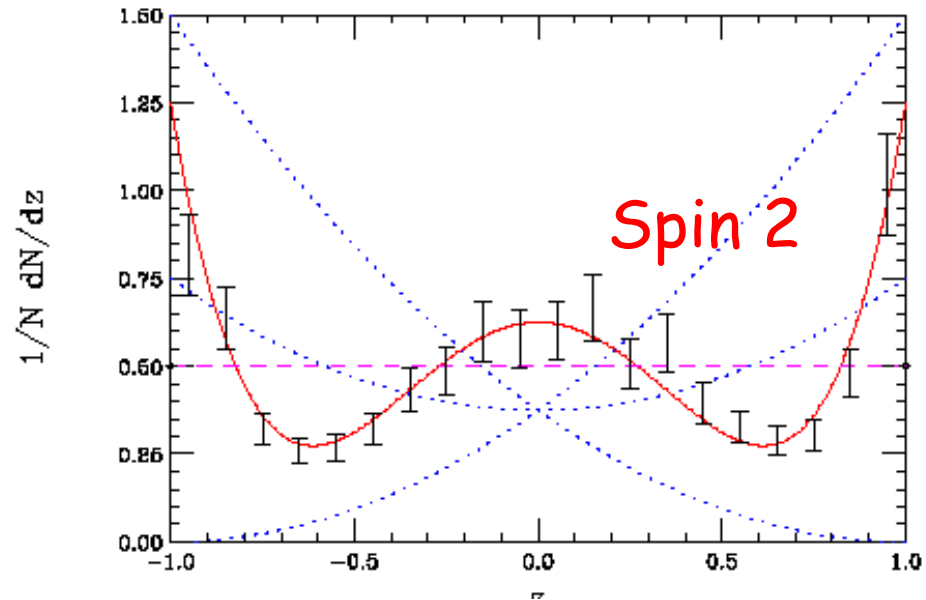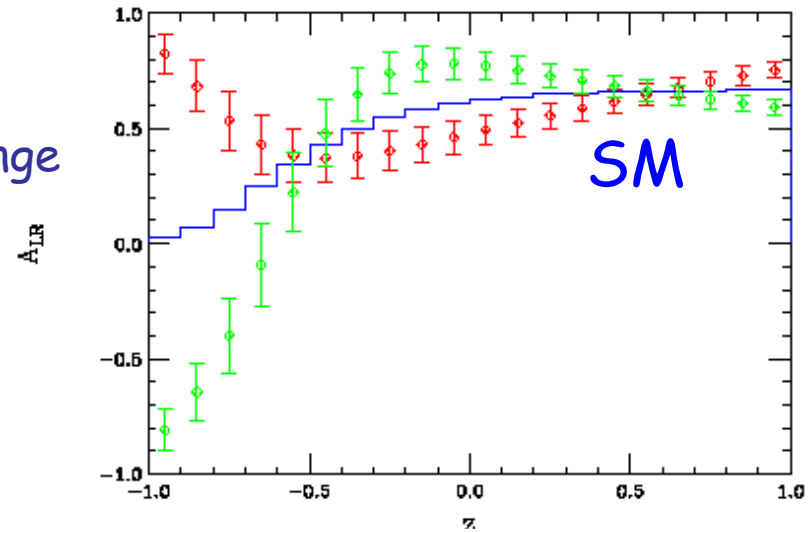△ Spin information (JoAnne Hewett, Steve Godfrey)

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

Eg. A_{LR}

Interference of exchange
of virtual graviton KK
States with SM
amplitudes

Hewett, hep-ph/9811356

SM

Spin 2

Interpretation of contact terms

The puzzle of model distinction

$$\frac{\eta_{ij}}{\Lambda^2} \Rightarrow \frac{g_i^X g_j^X}{s - m_X^2}$$

- Leptoquark, squark, sneutrino exchange

$$\frac{\eta_{LL}^{ef}}{\Lambda_{LL}^2} \cdot \frac{\eta_{RR}^{ef}}{\Lambda_{RR}^2} \neq \frac{\eta_{LR}^{ef}}{\Lambda_{LR}^2} \cdot \frac{\eta_{RL}^{ef}}{\Lambda_{RL}^2}$$

- New gauge bosons (Z')

$$\frac{\eta_{LL}^{ef}}{\Lambda_{LL}^2} \cdot \frac{\eta_{RR}^{ef}}{\Lambda_{RR}^2} = \frac{\eta_{LR}^{ef}}{\Lambda_{LR}^2} \cdot \frac{\eta_{RL}^{ef}}{\Lambda_{RL}^2} \quad = \quad \frac{g_L^e}{M_{Z'}} \cdot \frac{g_L^f}{M_{Z'}} \cdot \frac{g_R^e}{M_{Z'}} \cdot \frac{g_R^f}{M_{Z'}}$$

- KK excitation of gauge bosons

Parameterization

$$V \equiv 2 \sum_{\vec{n}} \left(\frac{g_{\vec{n}}^2}{g^2} \right) \frac{m_W^2}{\vec{n}^2 M_C^2}$$

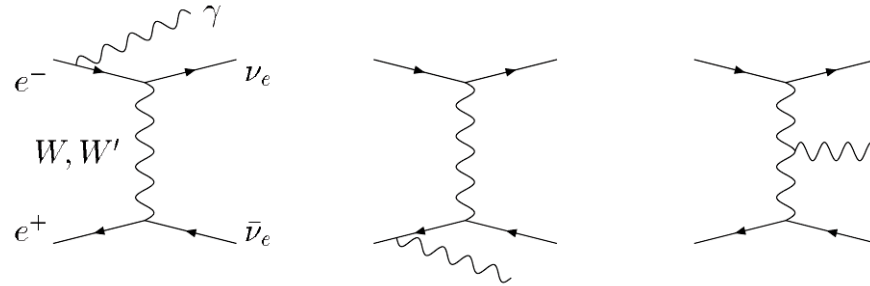$$\frac{\eta_{ij}}{\Lambda^2} \Rightarrow \left(Q_e Q_f + g_i^e g_j^f \right) \frac{\pi}{3 M_C^2}$$

△ Even the charged state W'_H (Sabine Riemann)

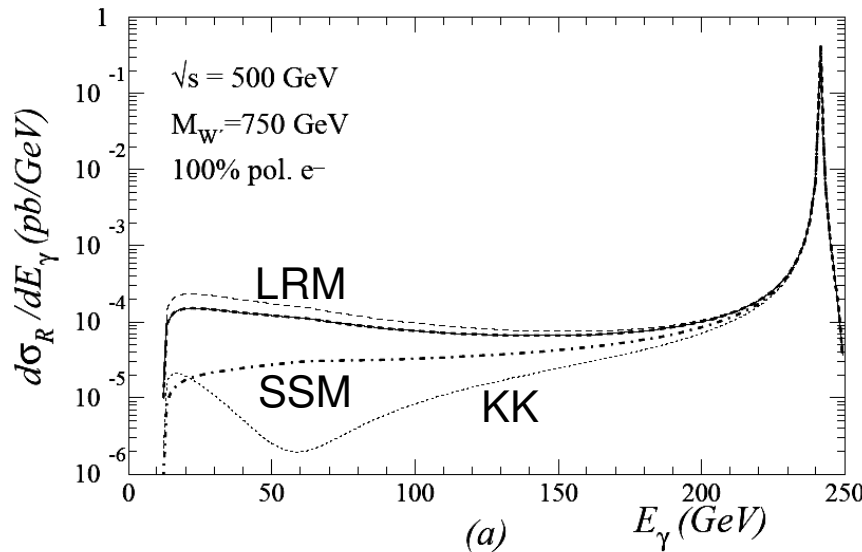# Search for W'

$$e^+e^- \rightarrow \nu \bar{\nu} \gamma$$

Godfrey, Kalyniak, Kamal, Leike

$d\sigma/dE\gamma$ depends on W' model → sensitivity to W':

(a)

ILC, 500GeV, 500/fb:

$M_{W'}$ <1.7TeV (SSM,KK)
       <0.6TeV (LRM)

Without systematic error
factor ~2.5 more sensitive

If W' discovered at LHC
➔ W' Couplings

Future Work:

(1). Systematic studies for other channels

△ $e^+e^- \to \tau^+\tau^-,\ t\bar{t}$: The largest mass of $\ell,\ q$.

△ $e^+e^- \to W^+W^-$: The largest rate.

△ $e^+e^- \to X...$?

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(2). More synergy between LHC (early phase) and ILC

$\triangle$ Very weakly coupled states: (Tom Rizzo)

Can be light ~ 100 GeV, Evading the observation at Tevatron.

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(need LHC simulation, and ILC study)

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(4). Next ...

Continue the discussions/work;

Prepare for the next meeting;

And aim at a comprehensive report.