S. Godfrey
DPF 2000
Columbus Ohio
August 12 2000

Discovery and Identification of W' Bosons at e^+e^- Colliders

S.Godfrey, P. Kalyniak, B. Kamal
Carleton University, Ottawa
A. Leike
LMU München
M. Doncheski
Pennsylvania State - Mont Alto

1. Introduction
2. $e^+e^- \to \nu\bar{\nu}\gamma$
3. $e\gamma \to \nu q + X$
4. Summary

- Discovery and ID of Extra Gauge Bosons in $e^+e^- \to \nu\bar{\nu}\gamma$ PR **D61**, 113009 [hep-ph/0002052]
- Extra Gauge Bosons: M. Cvetic & S. Godfrey [hep-ph/9504216]
- A. Leike, Phys. Rept. **317**, 143 (1999).

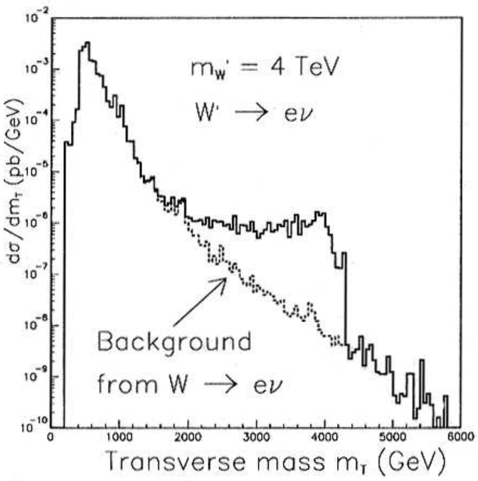
1 Introduction

- Many models approximate SM at present energies but have much richer particle spectrum above 100 GeV
- Many models include Extra Gauge Bosons
- Sequential Standard Model (SSM)
  - Includes Z' and/or W' of higher mass with SM couplings
- L-R Model ($SU(2)_L \times SU(2)_R \times U(1)$)
  - f_L transform as $SU(2)_L$ doublets and $SU(2)_R$ singlets with reverse for f_R
- "Un-Unified Model" ($SU(2)_q \times SU(2)_l \times U(1)_Y$)
  - Quarks and Leptons transform as doublets under separate $SU(2)$ groups
- KK excitations- Large Extra Dimensions
  - We consider W' and Z' corresponding to first KK excitation where the Fermion couplings are SM couplings enhanced by $\sqrt{2}$

1. Discovery
2. Identification

2 W' Search and Identification

- $pp \to W_R + X$



  - W' up to 6 TeV

Present Limits (PDB' 99):

- $M(W'_R) > 549$ GeV (ν_R is light)
- $M(W') > 720$ GeV (W' couples like W)

Future Limits from LHC:

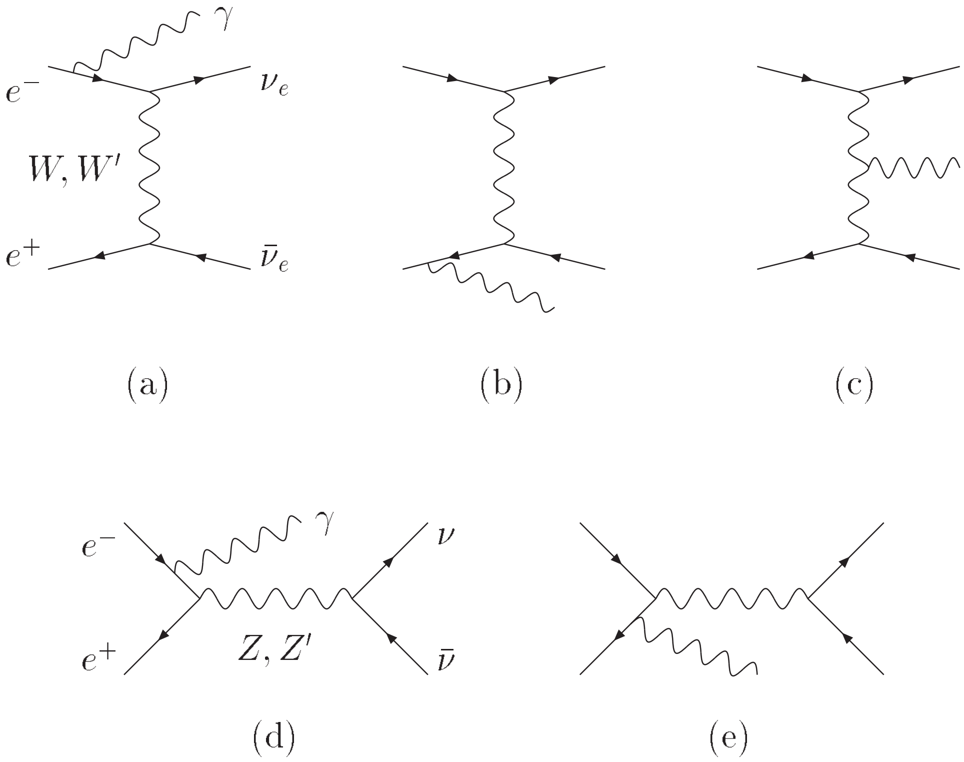
- $M(W) > 4$ to 5 TeV (GUTs)
- $M(W'_R) > 6.4$ TeV (J. Collet, A. Ferrari; ATLAS)

Future Limits NLC:

- $e^+e^- \to W_R^+ W_R^-$ Up to kinematic limit
- $e^\pm \gamma \to W_R^\pm N$ Large rate up to kinematic limit

3 The Process $e^+e^- \to \nu\bar{\nu}\gamma$

PR **D61**, 113009 [hep-ph/0002052]

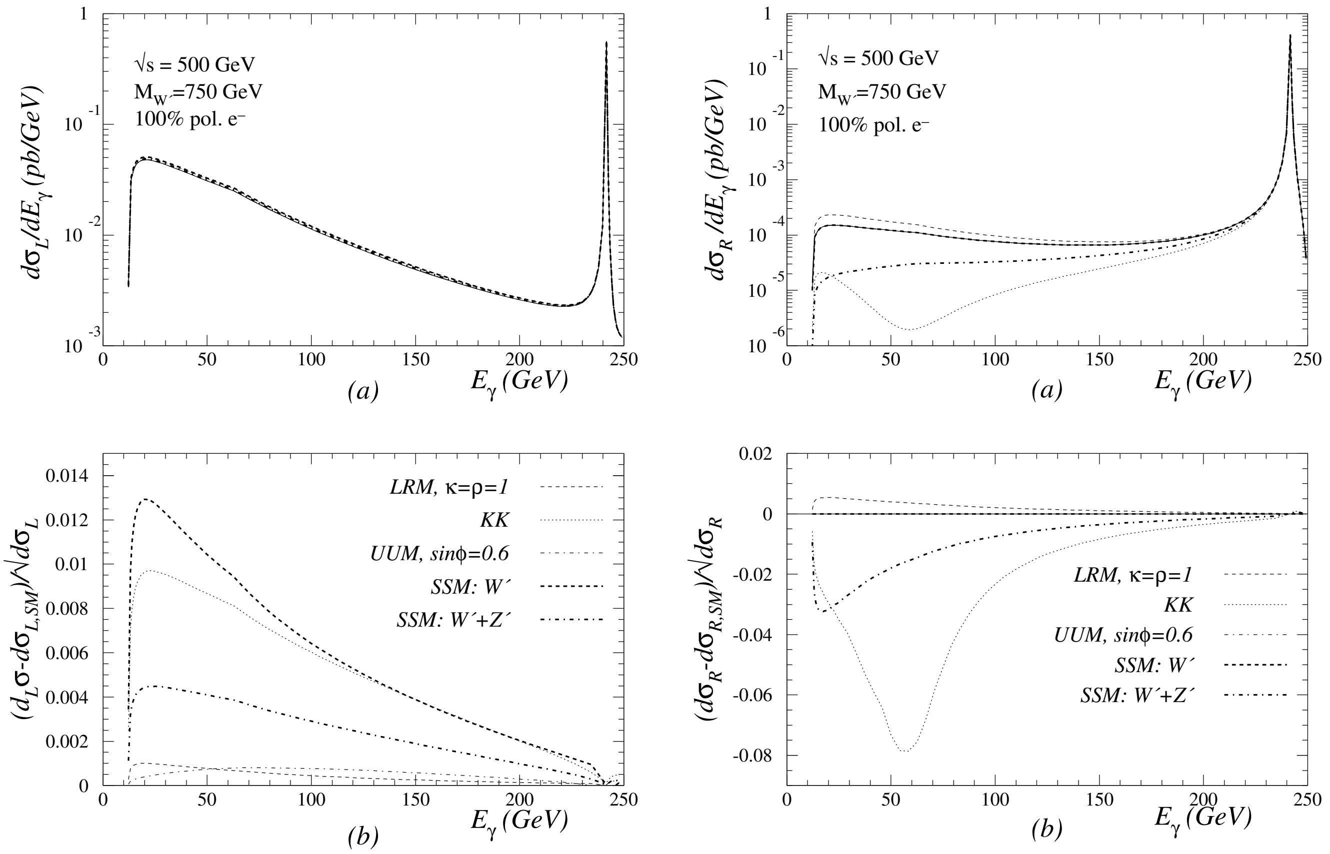


- Kinematic cuts to reflect finite detector acceptance:
  - $10^o \leq \theta_\gamma \leq 170^o$ and $E_\gamma > 10$ GeV
- Backgrounds:
  - Radiative Bhabba-scatter with e^+ and e^- lost down beam pipe

$$p_T^\gamma > \frac{\sqrt{s}\sin\theta_\gamma \sin\theta_v}{\sin\theta_\gamma + \sin\theta_v}$$

where $\theta_v = 25$ mrad is minimum angle for veto detector

  - $e^+e^- \to \nu\bar{\nu}\nu'\bar{\nu}'\gamma$ must be taken into account but can be calculated in SM



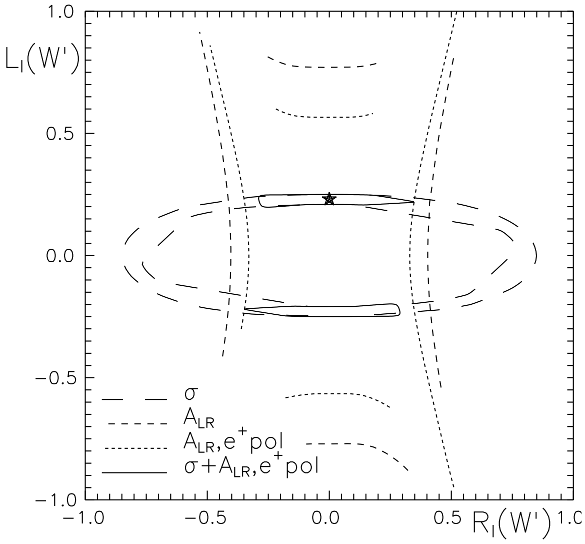
- Bulk of cross section from radiative return of Z^0
- For e_R^- large deviations but small cross section
- Pollution from e_L^- could overwhelm $\sigma(e_R^-)$
- Low E_γ region most sensitive to Z'
- Can increase statistical significance by binning
- Used 10 equal sized bins with:

$$E_\gamma^{min} < E_\gamma < E_\gamma^{max} \quad \text{where} \quad E_\gamma^{min} = \frac{\sqrt{s}\sin\theta_v}{1+\sin\theta_v}$$

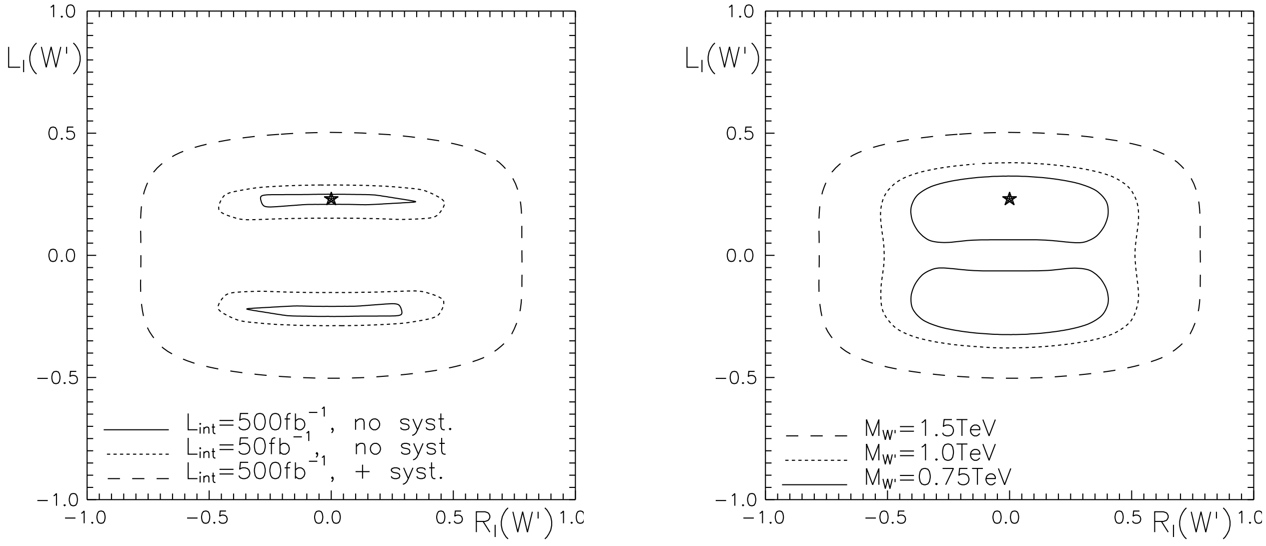
- Included 2% systematic error in quadrature with statistical error

Constraints on Couplings

- Define: $L_f(W) = \frac{g}{2\sqrt{2}} a_{W_i}$
- $\sqrt{s} = 0.5$ TeV, $L_{\rm int} = 500$ fb^{-1} 90% electron and, where indicated, 60% positron polarization are used.
- The assumed model [SSM (W')] is indicated by a star.



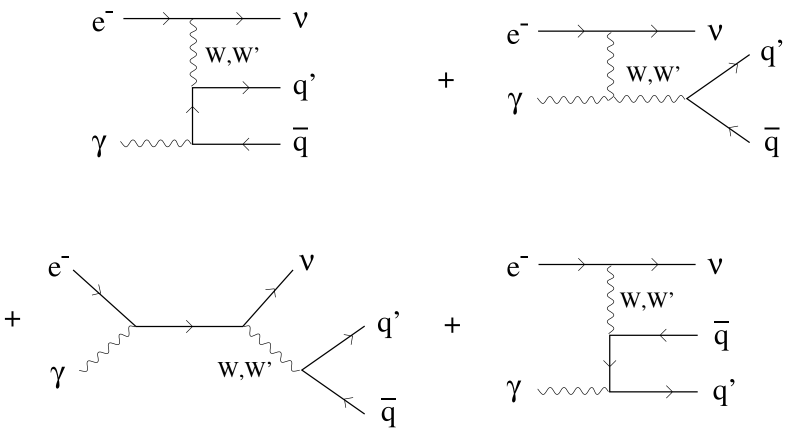
$M_{W'} = 1.5$ TeV. Only statistical errors included in this figure.



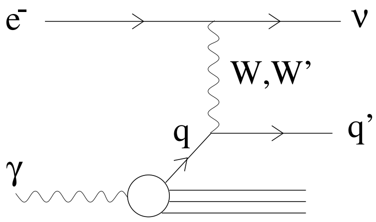
Using σ and A_{LR} combined.

1. $M_{W'} = 1.5$ TeV.
2. For different W' masses. 90% electron and 60% positron polarization. A systematic error of 2% (1%) is included for σ (A_{LR}).

4 The Process $e\gamma \to \nu q + X$



$e\gamma \to \nu q\bar{q}$.



$eq \to \nu q'$.

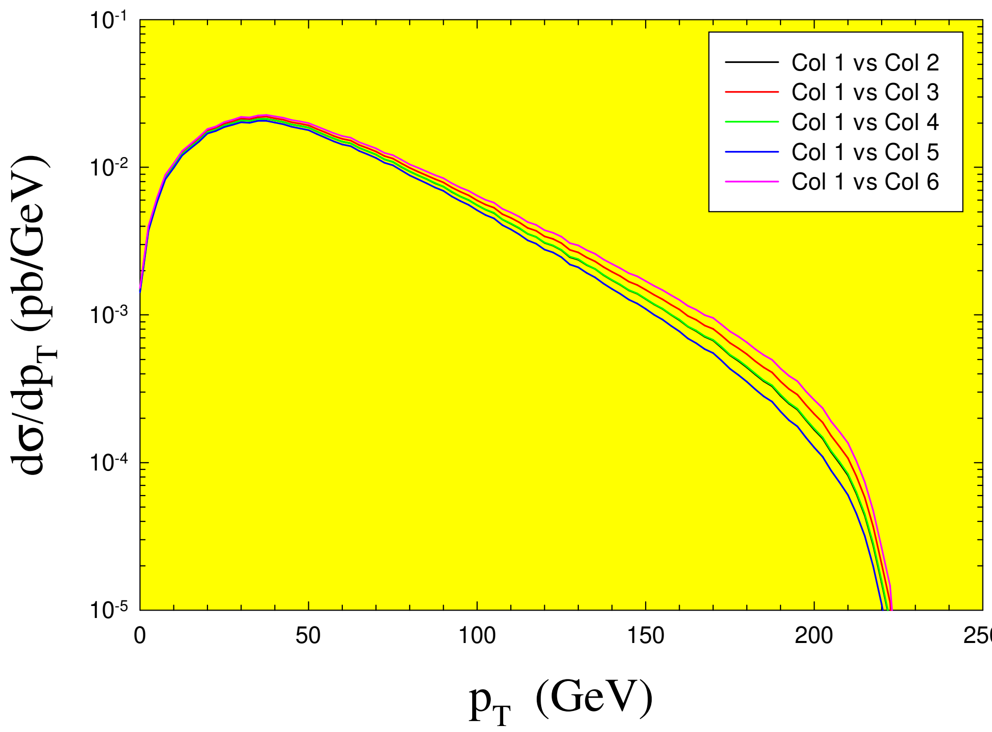
$$\sigma = \int dx \int dy f_{\gamma/e}(x, \sqrt{s}/2) f_{q/\gamma}(y, Q^2) \hat{\sigma}(eq \to \nu q') \qquad (1)$$

where

$$\begin{aligned}
\hat{\sigma}(e^- q \to \nu q') \quad = \quad & \frac{\pi\alpha^2}{4\sin^4\theta_w} \int d\hat{t} \frac{1}{(\hat{t} - M_W^2)^2} \left\{ 1 + 2C_L^q C_L^l \left(\frac{\hat{t} - M_W^2}{\hat{t} - M_{W'}^2} \right) \right. \\
& + \frac{1}{2} \left(\frac{\hat{t} - M_W^2}{\hat{t} - M_{W'}^2} \right)^2 \left[({C_L^q}^2 + {C_R^q}^2)({C_L^l}^2 + {C_R^l}^2)(1 + \hat{u}^2/\hat{s}^2) \right. \\
& \left. \left. + ({C_L^q}^2 - {C_R^q}^2)({C_L^l}^2 - {C_R^l}^2)(1 - \hat{u}^2/\hat{s}^2) \right] \right\}
\end{aligned}$$

- Include backscattered laser photon spectrum or WW spectrum
- Kinematic cuts to reflect finite detector acceptance:
  - $10^o \leq \theta_\gamma \leq 170^o$
  - Assume 2% systematic error

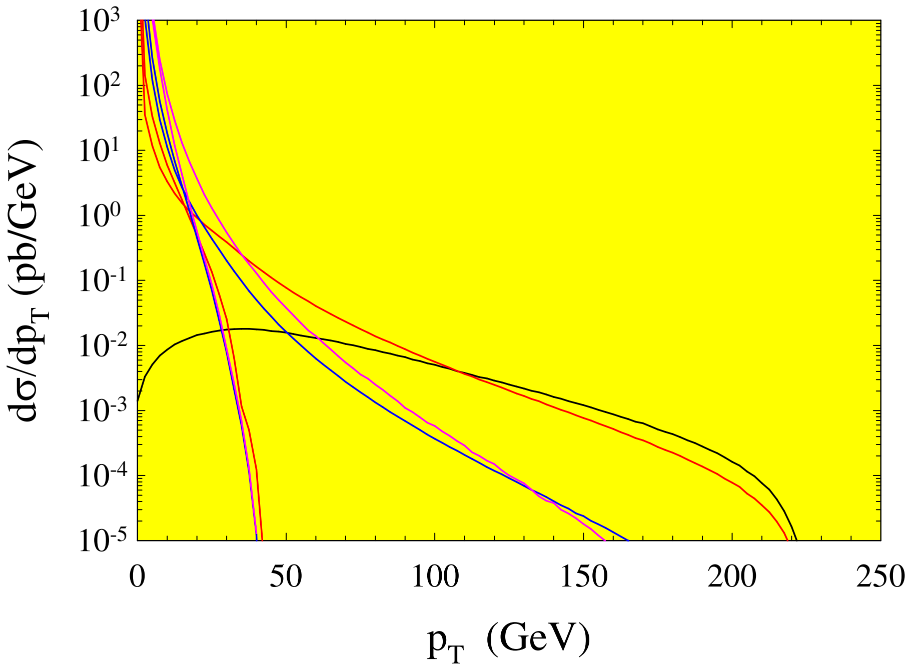
- Looked at many observables:
  - σ, σ_L, σ_R, A_{LR}, $d\sigma/dp_{T_q}$, $d\sigma/dE_q$, $d\sigma/d\cos\theta_q$
- $d\sigma/dp_{T_q}$ most sensitive to W'
- σ_R only sensitive to LR model but even small pollution of e_L swamps σ_R



$\sqrt{s} = 500$ GeV, $M_{W'} = 750$ GeV. For the SM, SSM, LRM, UUM and the KK model.

Backgrounds

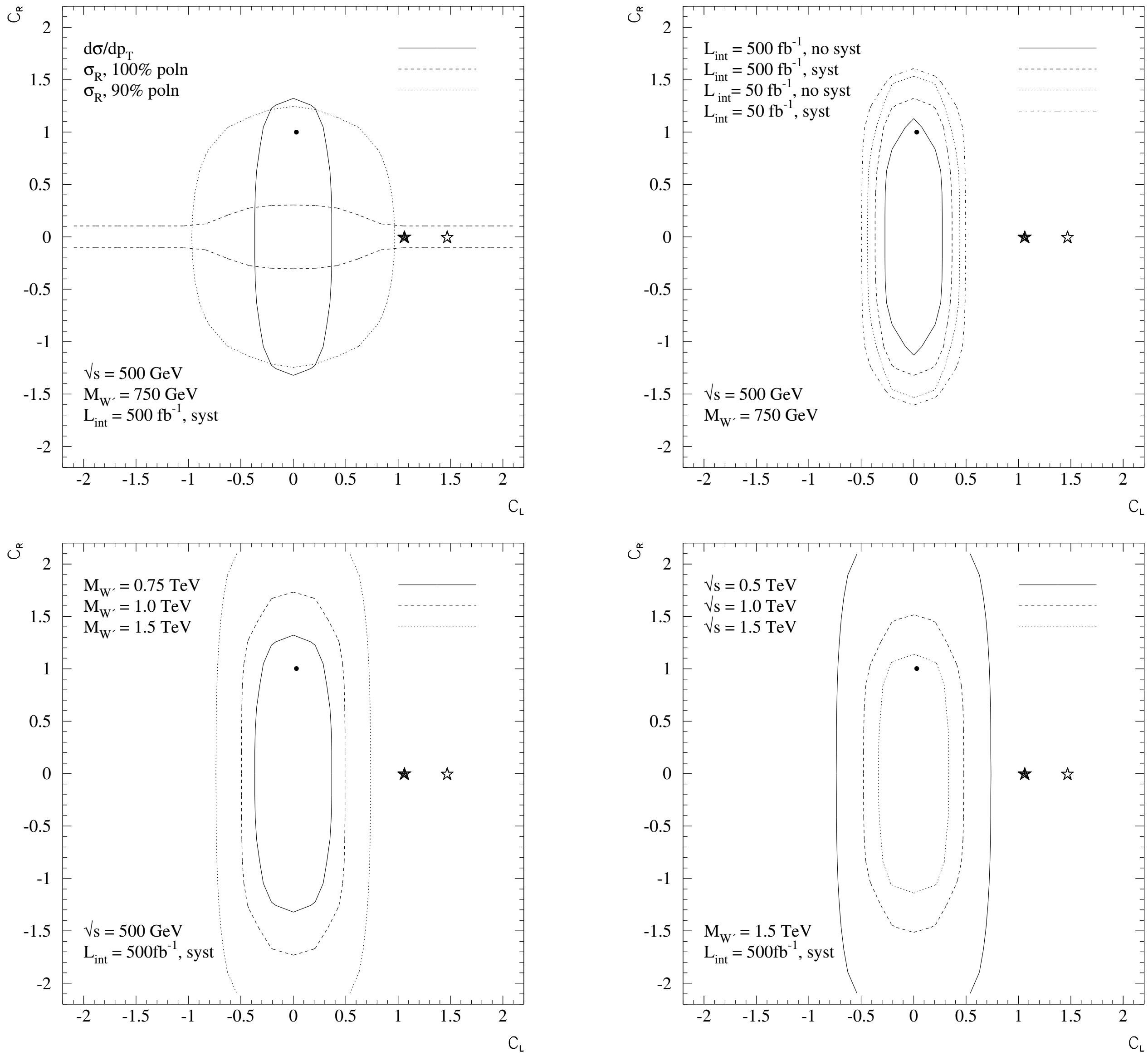
- Dominant backgrounds are two jet final states with one jet lost down the beam pipe
- The dominant two jet final states are:
  - $\gamma\gamma \to q\bar{q}$
  - Once resolved reactions: $\gamma g \to q\bar{q}$ and $\gamma q \to gq$
  - Twice resolved reactions: $gg \to q\bar{q}$, $q\bar{q} \to q\bar{q}$, $qg \to qg$, $gg \to gg$, $qq \to qq$ ....



- Introduce ${p_T}_q$ cuts to eliminate these backgrounds:
  - $\sqrt{s} = 500$ GeV ${p_T}_q > 40$ GeV
  - $\sqrt{s} = 1000$ GeV ${p_T}_q > 75$ GeV
  - $\sqrt{s} = 1500$ GeV ${p_T}_q > 100$ GeV

Constraints on Couplings

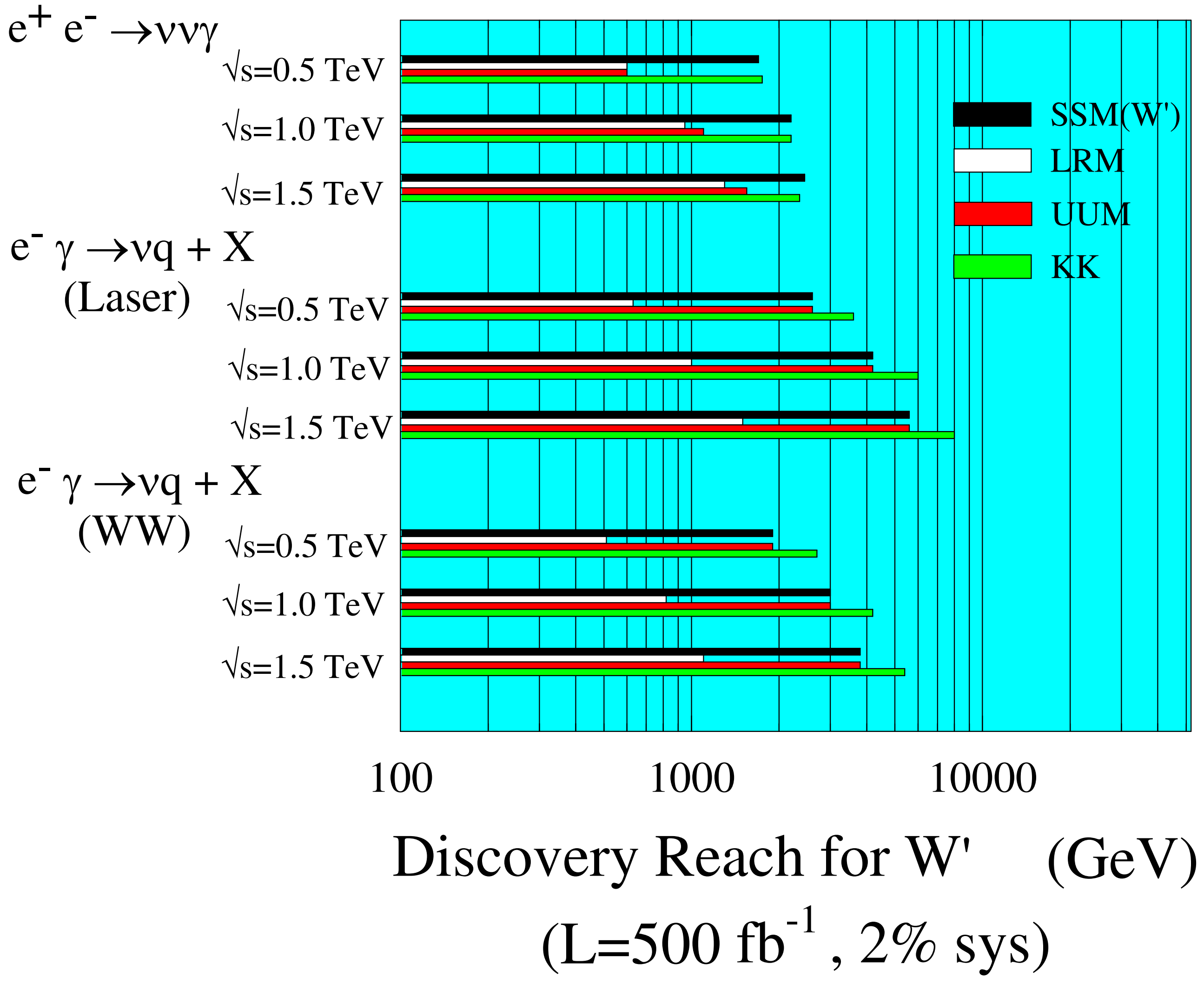
- $\star$-SSM $\bullet$-LRM $\diamond$-KK



1. Different observables
2. Different luminosities and with and without systematic errors
3. Different W' masses.
4. Different $\sqrt{s}$

Discovery Limits

- Divide p_{T_q} into 10 bins
- 500 fb^{-1} + 2% systematic error



5 Summary and Outlook

- Discovery Limits of W' in same ball park as LHC
- If LHC discovers W' NLC important tool for identification
- Process can measure $Z'\nu\bar{\nu}$ couplings
- Limits severely degraded by systematic errors
- Need high luminosity and must minimize systematic errors