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Extended Gauge Sectors at multi-TeV e^+e^- Colliders

1. Introduction
2. Extra Gauge Bosons
   (a) Models of Extended Gauge Theories
   (b) Z' Searches
   (c) W' Searches
3. Leptoquarks
4. Extra Fermions
5. Summary

1 Introduction

- Many models approximate SM at present energies but have much richer particle spectrum above 100 GeV
- Extensions of Standard Model Gauge Group
  - (SUSY) GUT
    - Extra U(1) Factors : $E_6 \to SU(5) \times U(1)_\chi \times U(1)_\psi$
    - Left-Right Symmetric Model
      $E_6/SO(10) \to SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)$
  - non-GUT
    - Sequential Standard Model
    - Un-unified model (Georgi et al)
      $SU(2)_q \times SU(2)_l \times U(1)_Y$
    - Horizontal gauge models (Bagneid et al, Li & Ma)
    - Axigluon (Frampton et al)
    - Topcolour (Hill and Parke)
    - and on and on and on . . .
- Many Many Models

- To extrapolate to Planck scale need complete low energy particle content
- Need to elucidate and complete the TeV particle spectrum
- Many types of new particles:
  - Extra Gauge Bosons: Z''s, W''s
  - New Fermions
    * 4th generations: $\begin{pmatrix} t' \\ b' \end{pmatrix}_L$, t'_R, b'_R
    * Mirror Fermions: t'_L, b'_L, $\begin{pmatrix} t' \\ b' \end{pmatrix}_R$
    * Vector fermions: $\begin{pmatrix} t' \\ b' \end{pmatrix}_L$, $\begin{pmatrix} t' \\ b' \end{pmatrix}_R$
    * Singlets (like massive neutrinos)
  - Leptoquarks: $B = \pm 1/3$ and $L = \pm 1$
  - Dileptons: $B = 0$ and $L = \pm 2$
  - Diquarks: $B = \pm 2/3$ and $L = 0$
  - Extended Higgs Sector

1. Discovery
   - Identify Signal
   - Distinguish it from background
2. Identification
   - Cross sections
   - Angular distributions
   - Decay signatures (Width, BR, etc)
   - Polarization

2 Extra Gauge Bosons

Models of Extra Gauge Bosons

- Many models include Extra Gauge Bosons

- Sequential Standard Model (SSM)
  - Includes Z' and/or W' of higher mass with SM couplings
  - Rather arbitrary but commonly used as benchmark
    * SSM(W') with only W'
    * SSM($W' + Z'$) with W' and Z' taking $M_{W'} = M_{Z'}$

- Effective Rank 5 E6 Model
  - $E_6 \to SO(10) \times U(1)_\psi \to SU(5) \times U(1)_\chi \times U(1)_\psi$
  - $Z' = Q_\chi \cos\theta_{E_6} + Q_\psi \sin\theta_{E_6}$

- L-R Model: $SU(2)_L \times SU(2)_R \times U(1)$
  - Left handed fermion fields transform as $SU(2)_L$ doublets and $SU(2)_R$ singlets
  - Right handed fermion fields - reverse is true
  - Right handed neutrinos included in fermion content
  - Model is parametrized by

$$\kappa = g_R/g_L \quad \text{where} \quad 0.55 \leq \kappa \leq 2.0$$

  - ρ depends on Higgs content of the model:
    * $\rho = 1$ for Higgs doublets and $\rho = 2$ for Higgs triplets

    where

$$\frac{M(Z')^2}{M(W')^2} = \frac{\rho\kappa^2}{\kappa^2 - \tan^2\theta_w}$$

  - The LRM Lagrangian is:

$$\begin{aligned} \mathcal{L}_{LR} \quad = \quad & \frac{e\kappa}{\sqrt{2}s_W} W'^{+}_{\mu} \bar{\nu}_R \gamma^\mu e_R \\ & + \frac{e}{s_W c_W^2 \sqrt{\kappa^2 - t_W^2}} Z'_\mu \left[\bar{l}\gamma^\mu P_L s_W^2 (T_{3L} - Q_{em}) l \right. \\ & \left. + \bar{l}\gamma^\mu P_R (\kappa^2 c_W^2 T_{3R} - s_W^2 Q_{em}) l \right] + h.c. \end{aligned}$$

  - The $Z - Z'$ and $W - W'$ mixing angles have been neglected

- "Un-Unified Model": $SU(2)_q \times SU(2)_l \times U(1)_Y$
  - Left handed Quarks and Leptons transform as doublets under separate $SU(2)$ groups
  - q_R and l_R are singlets under both $SU(2)_q$ and $SU(2)_l$
  - Parametrize by:
    * ϕ - the mixing angle of charged gauge bosons
    * $0.24 \leq \sin\phi \leq 0.99$
    * $M_{Z'} \simeq M_{W'}$
  - The UUM Lagrangian is:

$$\mathcal{L}_{UU} = -\frac{e}{2s_W}\frac{s_\phi}{c_\phi}\left[\sqrt{2}W'^{+}_{\mu}\bar{\nu}\gamma^\mu l_L + Z'_\mu(\bar{\nu}\gamma^\mu \nu_L - \bar{l}\gamma^\mu l_L)\right] + h.c.$$

  - The fermion couplings are all left-handed

- "3rd Family Model" (3FM): $SU(2)_h \times SU(2)_l \times U(1)_Y$
  - Quarks and Leptons of 3rd family transform as doublets under a separate $SU(2)$ group
  - Breaking scheme allows Z' and W' to be relatively light
  - Parametrize by mixing angle, ϕ, between the two $SU(2)$'s
  - The 3FM Lagrangian is:

$$\mathcal{L}_{3F} = -\frac{1}{\sqrt{2}}\left[g\frac{c_\phi}{s_\phi}\bar{u}\gamma^\mu d W'^{+}_{\mu} - g\frac{s_\phi}{c_\phi}\bar{t}\gamma^\mu b W'^{+}_{\mu}\right] + h.c.$$
$$+\text{neutral sector}$$

- KK excitations- Large Extra Dimensions
  - Extend SM to 5-dimensions
  - Size of extra dimension: $R \sim TeV^{-1}$ may imply an infinite tower of KK excitations of SM gauge bosons
  - Mass of excitation:

$$nM_c \quad (n = 1 \ldots \infty)$$

$$\text{where} \qquad M_c = 1/R$$

  - Electroweak observables are modified by KK towers
  - We include exchange of W' and Z' corresponding to first KK excitation
  - $M_{Z'} \simeq M_{W'} = M_c$
  - The Fermion couplings of 1st KK excitation are SM couplings enhanced by a factor of $\sqrt{2}$

Present and Future Limits

Present Limits (PDB' 00):

- $M(W'_R) > 715$ GeV (ν_R is light)
- $M(W') > 720$ GeV (W' couples like W)
- $M(Z'_\chi) > 595$ GeV
- $M(Z'_\psi) > 590$ GeV
- $M(Z'_{SSM}) > 690$ GeV (Z' couples like Z)

Future Limits from LHC:

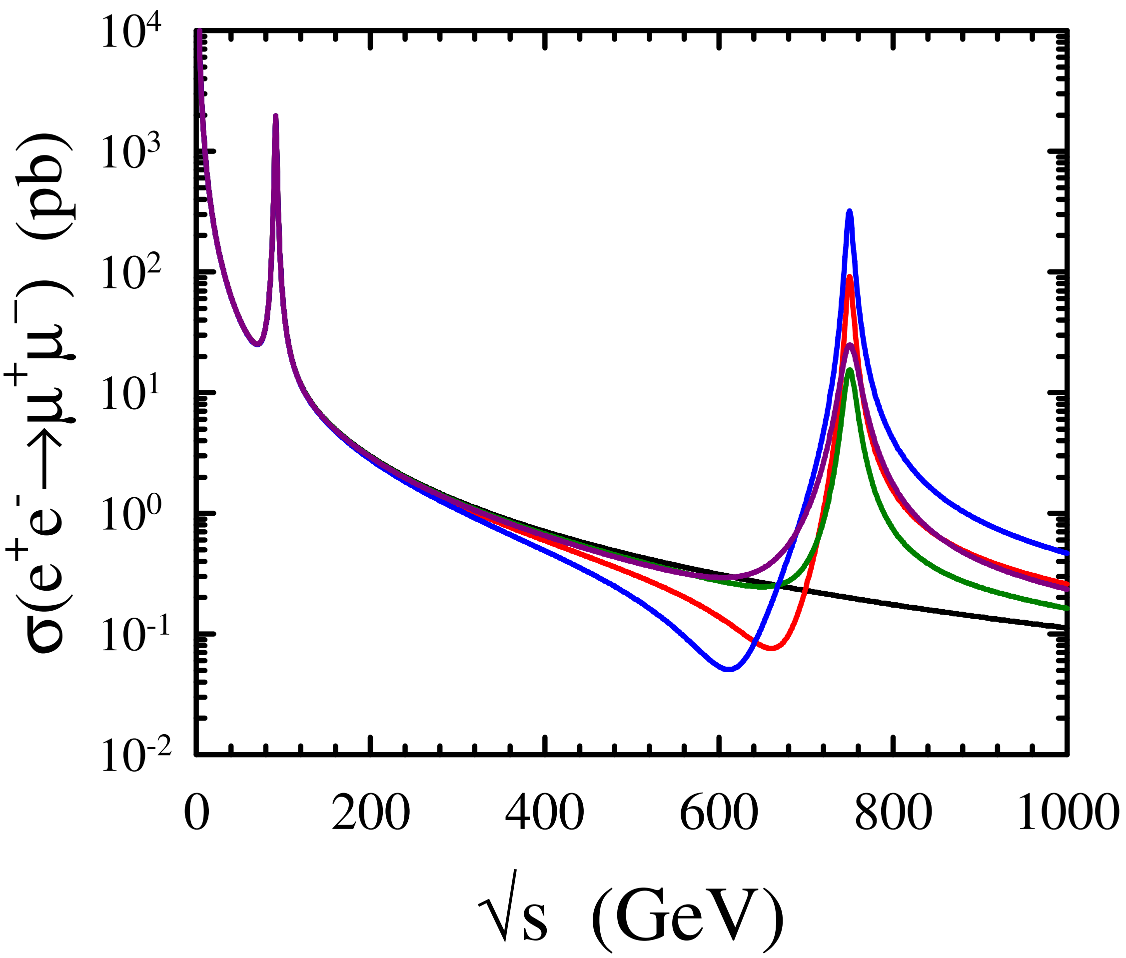
- $M(W) > 4$ to 5 TeV (GUTs)
- $M(W'_R) > 6.4$ TeV (J. Collet, A. Ferrari; ATLAS)
- $M(Z') > 4.5$ TeV (Z' in typical GUTs)

W' LHC limits depend on g_L/g_R and on the right-handed CKM Matrix and can degrade by a factor of 2 or more

Future Limits from NLC:

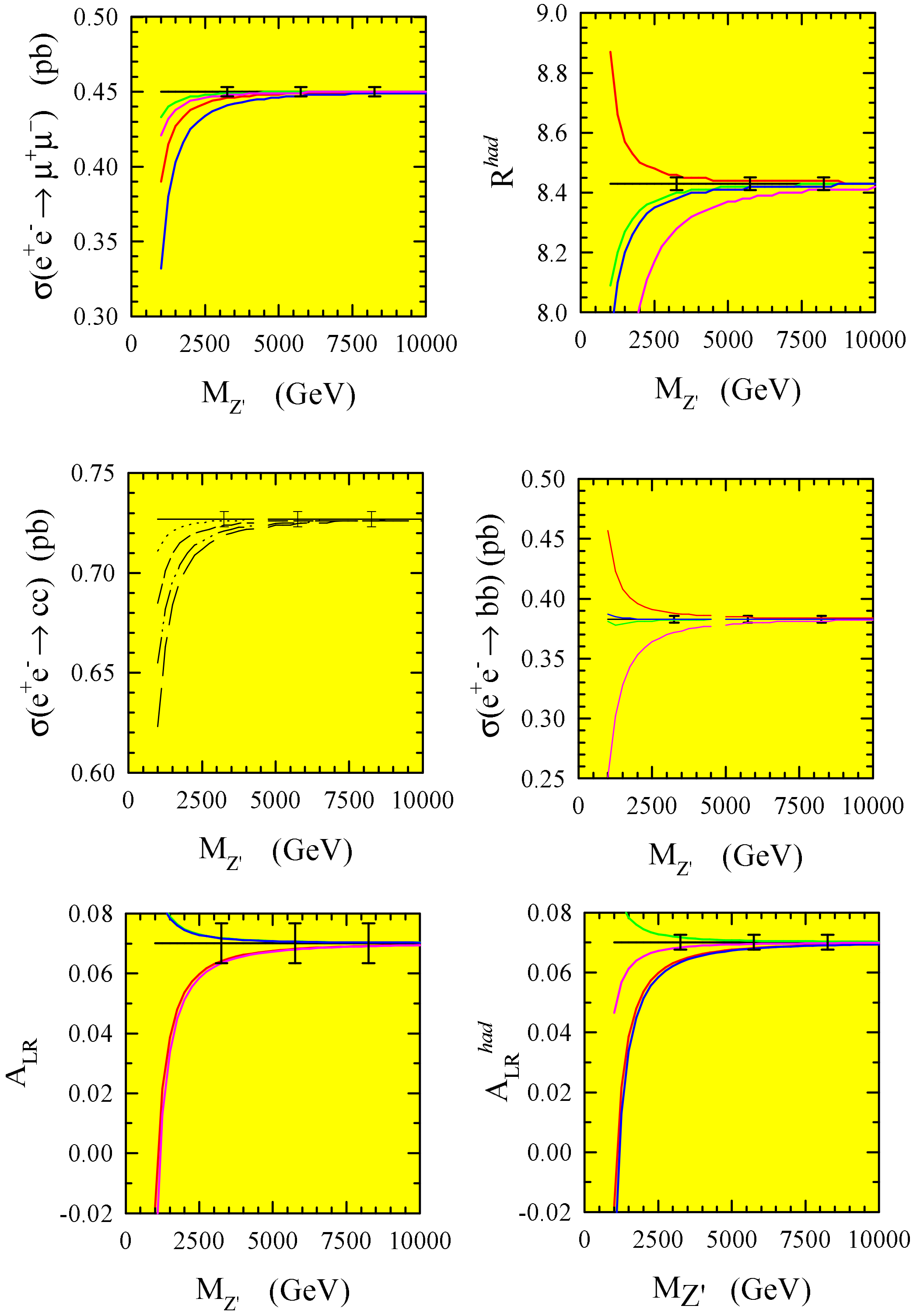
- $M(Z') > 1$ to 6 TeV ($\sqrt{s} = 0.5$ TeV, $L_{int} = 50$ fb^{-1})
- $M(Z') > 2$ to 12 TeV ($\sqrt{s} = 1.0$ TeV, $L_{int} = 200$ fb^{-1})

Z' Search and Identification



SM, $M_{Z'} = 750$ GeV: Z_χ, Z_{LR}, Z_{ALR}, Z_{SSM}

σ_f $\quad A^f_{FB}$ $\quad A^f_{LR}$ $\quad A^f_{FB}(pol)$

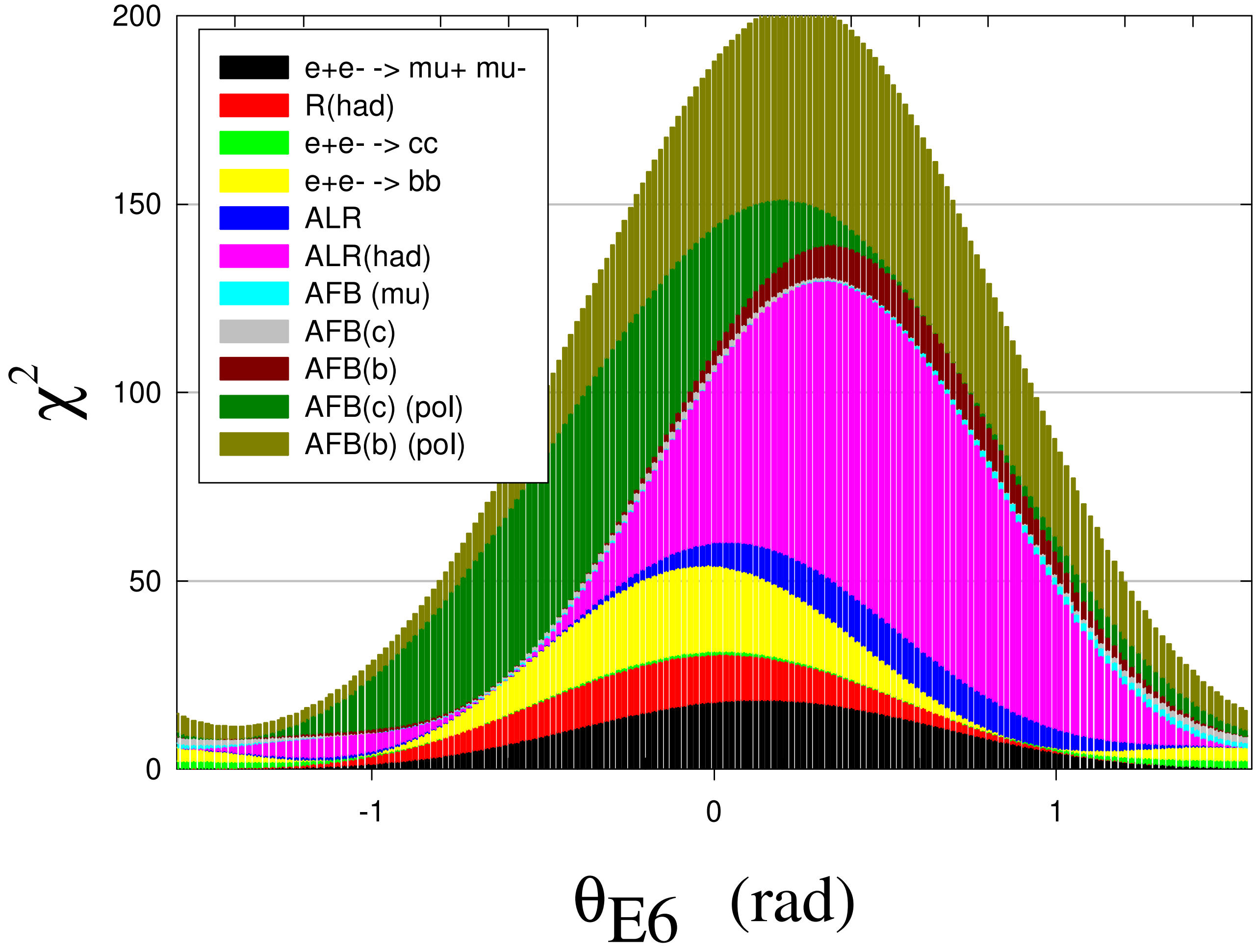


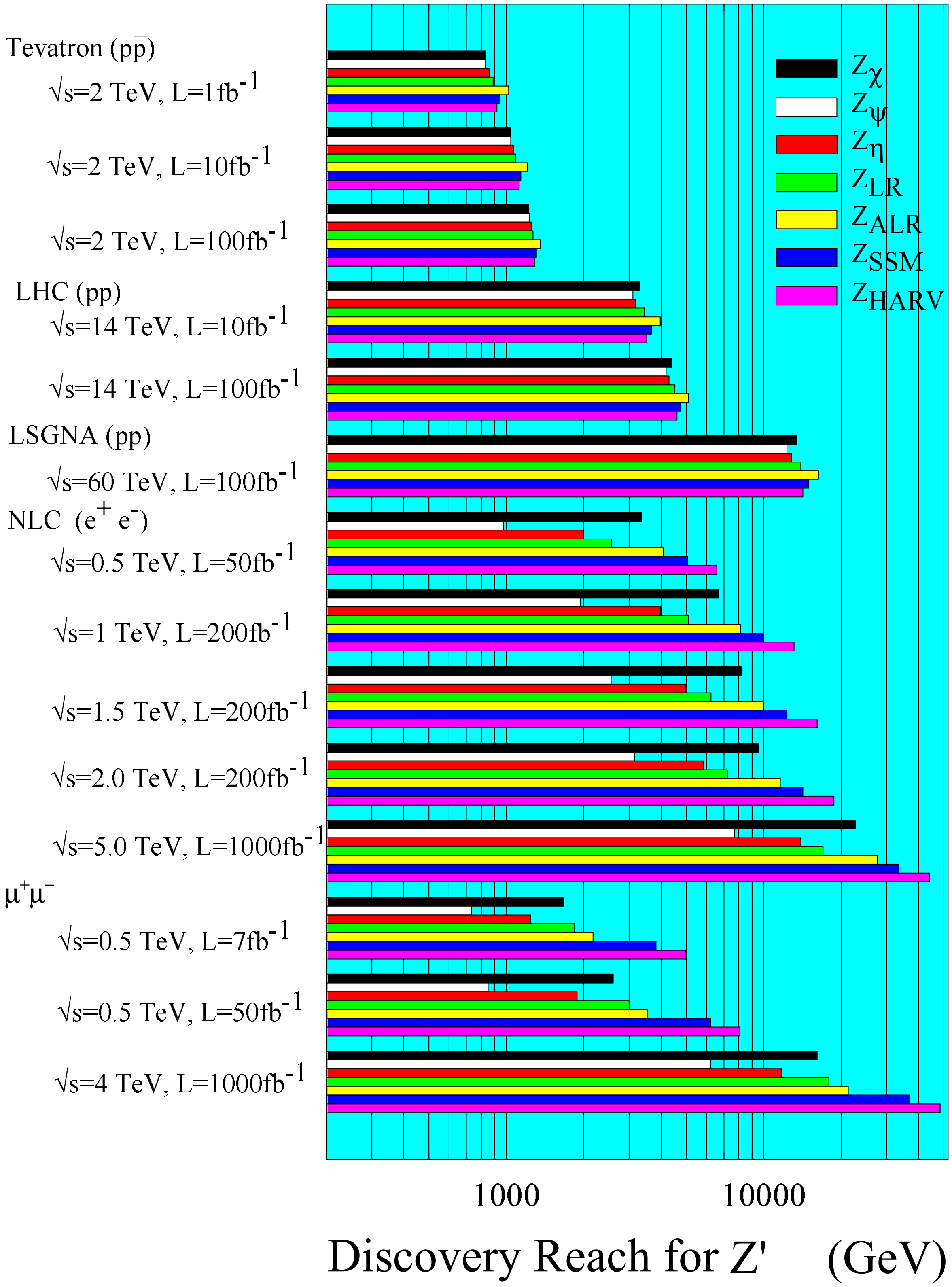
SM, Z_χ, Z_{LR}, Z_{ALR}, Z_{SSM}

In $E_6 \to SO(10) \times U(1)_\psi \to SU(5) \times U(1)_\chi \times U(1)_\psi$

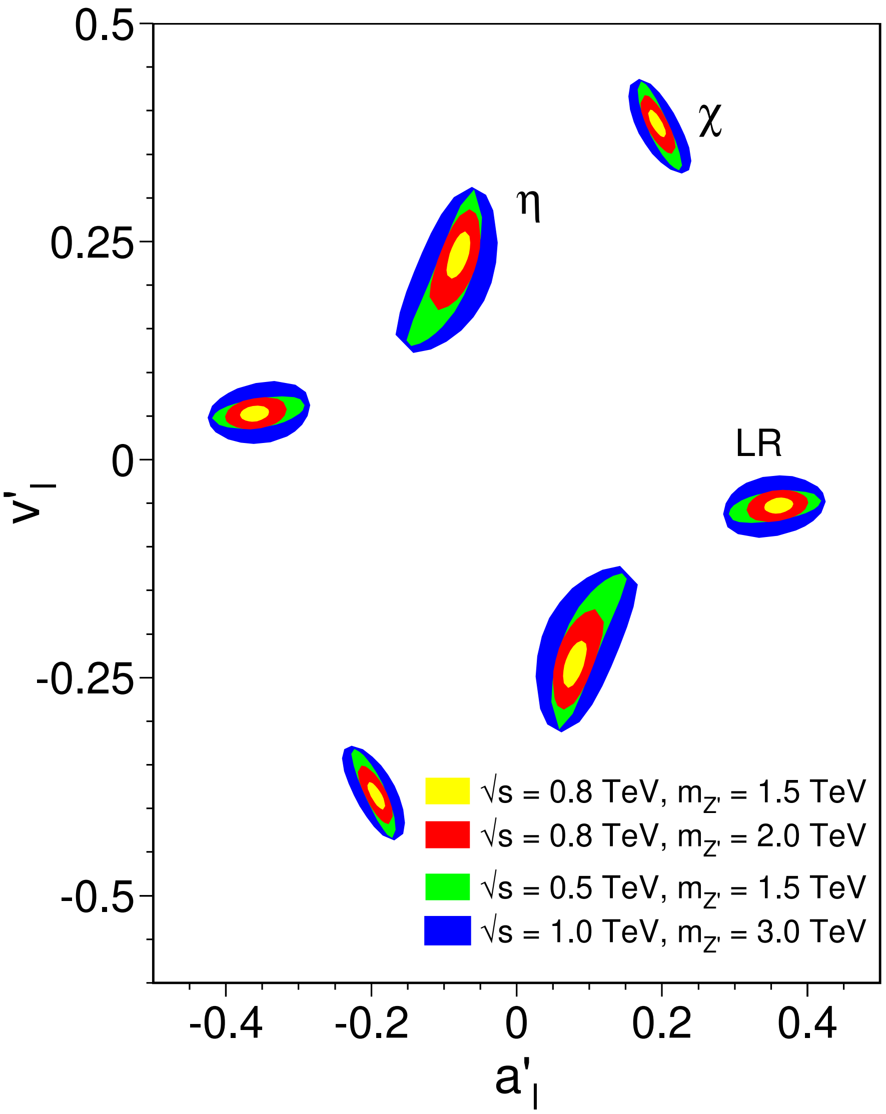
$$Z' = Z_\chi \cos\theta_{E_6} + Z_\psi \sin\theta_{E_6}$$

root s = 500 GeV, L=50 fb^{-1}, $M_{Z'}$=2 TeV

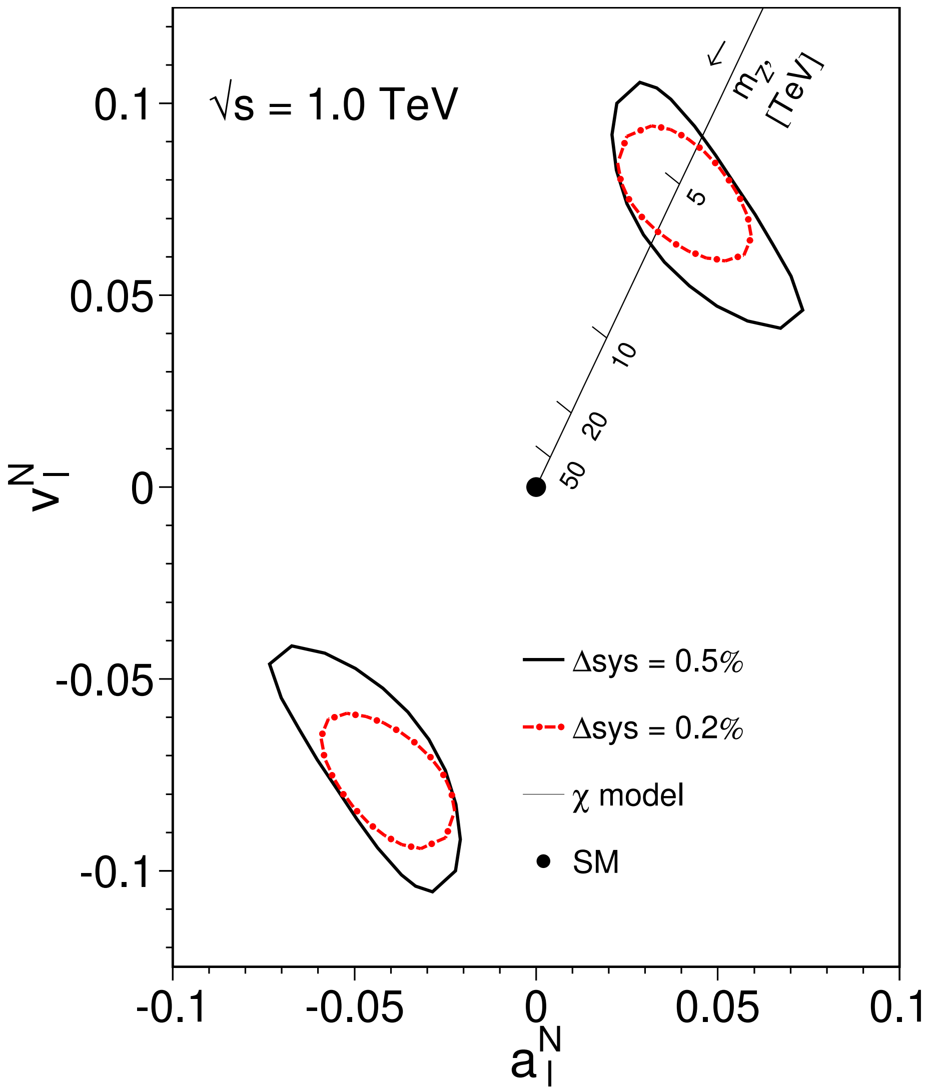



Tevatron (p$\bar{p}$)
√s=2 TeV, L=1fb^{-1}
√s=2 TeV, L=10fb^{-1}
√s=2 TeV, L=100fb^{-1}
LHC (pp)
√s=14 TeV, L=10fb^{-1}
√s=14 TeV, L=100fb^{-1}
LSGNA (pp)
√s=60 TeV, L=100fb^{-1}
NLC (e^+e^-)
√s=0.5 TeV, L=50fb^{-1}
√s=1 TeV, L=200fb^{-1}
√s=1.5 TeV, L=200fb^{-1}
√s=2.0 TeV, L=200fb^{-1}
√s=5.0 TeV, L=1000fb^{-1}
$\mu^+\mu^-$
√s=0.5 TeV, L=7fb^{-1}
√s=0.5 TeV, L=50fb^{-1}
√s=4 TeV, L=1000fb^{-1}
Z_χ
Z_ψ
Z_η
Z_{LR}
Z_{ALR}
Z_{SSM}
Z_{HARV}
1000
10000
Discovery Reach for Z' (GeV)

Z' Coupling Determination at e^+e^- Colliders



Resolution power (95% C.L.) for different $M_{Z'}$ based on measurements of leptonic observables at $\sqrt{s} = 500$ GeV, 800 GeV, 1 TeV with a luminosity of $L_{int} = 1\ ab^{-1}$. The leptonic couplings of the Z' correspond to the χ, η, or LR model.



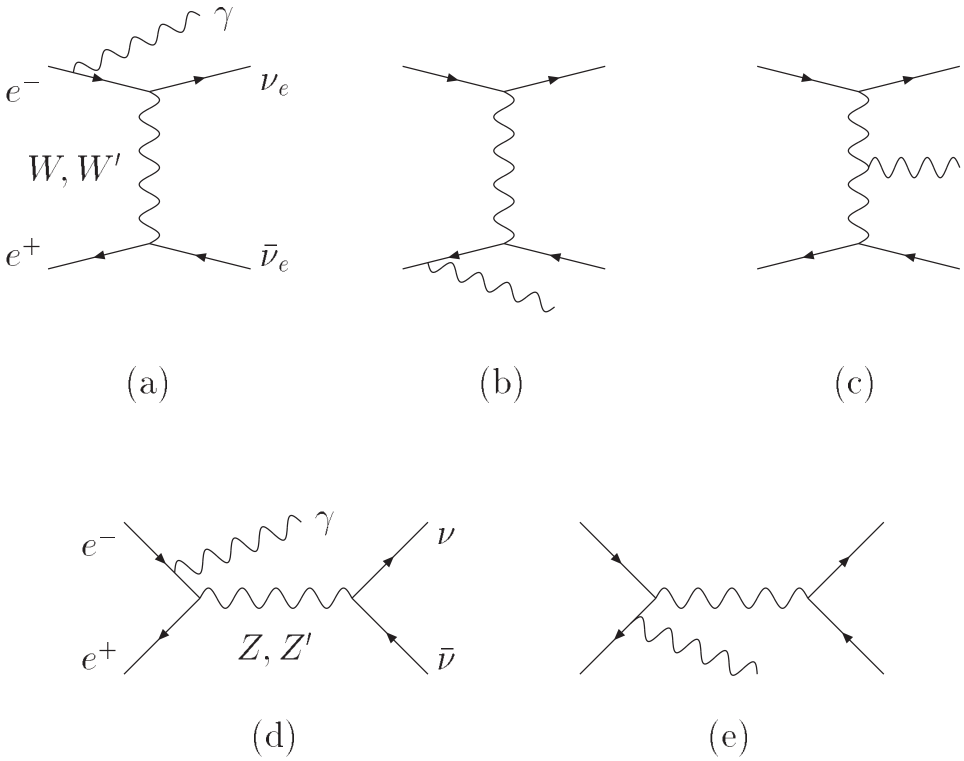
Resolution power (95% C.L.) for different $M_{Z'_\chi}$ based on measurements of leptonic observables at $\sqrt{s} = 1$ TeV with a luminosity of $L_{int} = 1\ ab^{-1}$.

W' Search and Identification

- $e^+e^- \to W_R^+ W_R^-$
  - Up to kinematic limit
  - Depends on κ, M_N, $M_{Z'}/M_{W_R}$
- $e^\pm\gamma \to W_R^\pm N$
  - Large rate up to kinematic limit

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

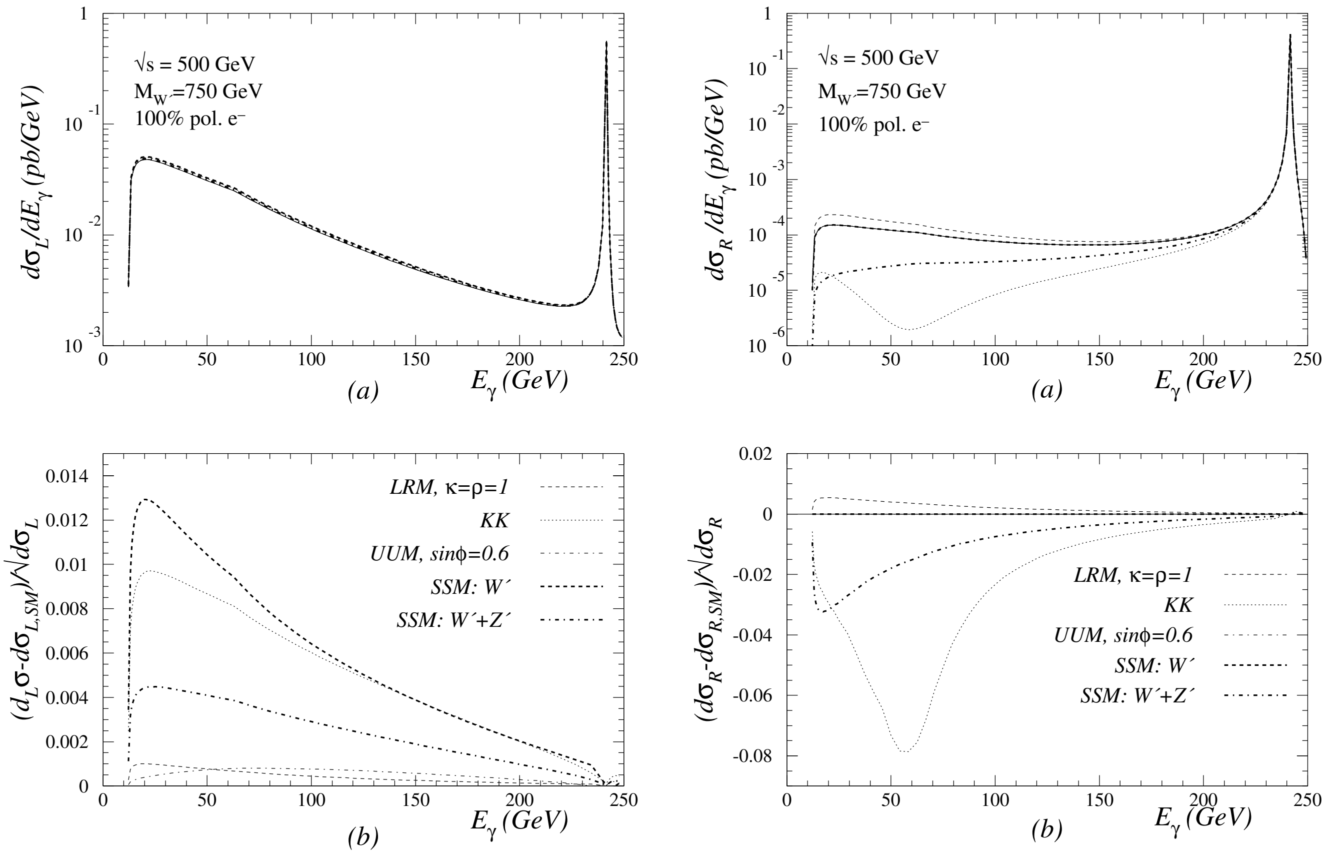
PR **D61**, 113009 [hep-ph/0002052]



- 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



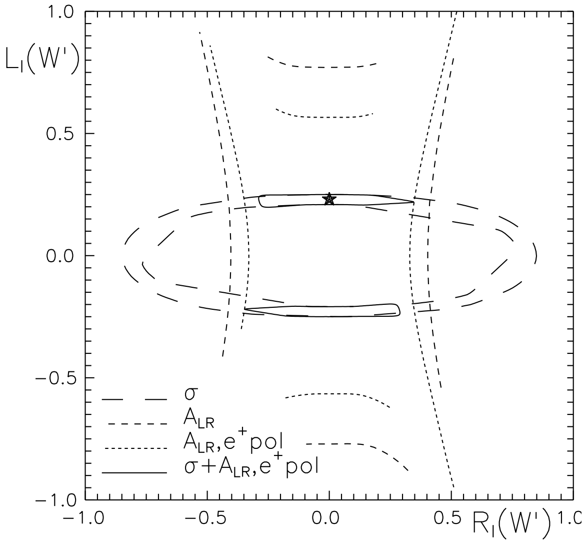
- Pollution from e_L^- could overwhelm $\sigma(e_R^-)$
- Low E_γ region most sensitive to Z'
- Best limits using $d\sigma/dE_\gamma$ combined with polarization
- Similar limits using σ with Z^0 radiative return removed
- Used 10 equal sized bins with:

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

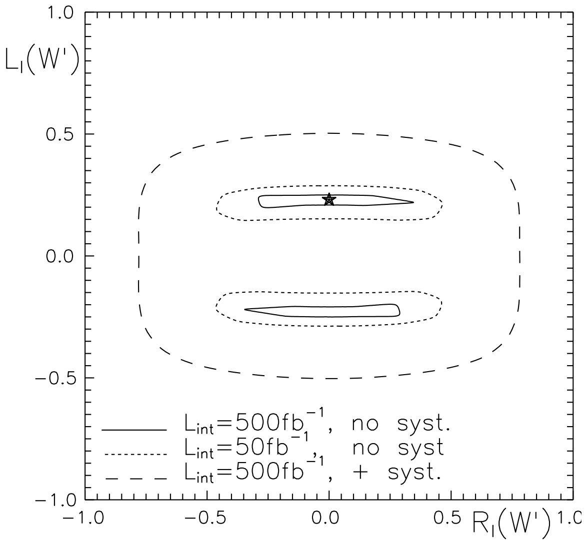
- Included 2% systematic error in quadrature with statistical error
- Used e_L^- except for LRM where used e_R^-

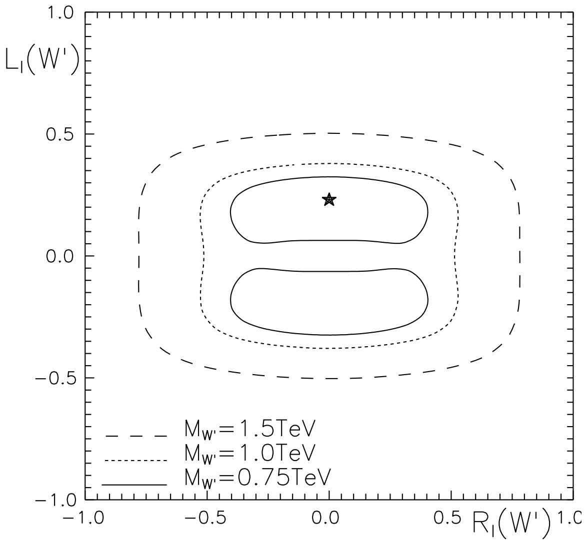
Constraints on Couplings

- 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.



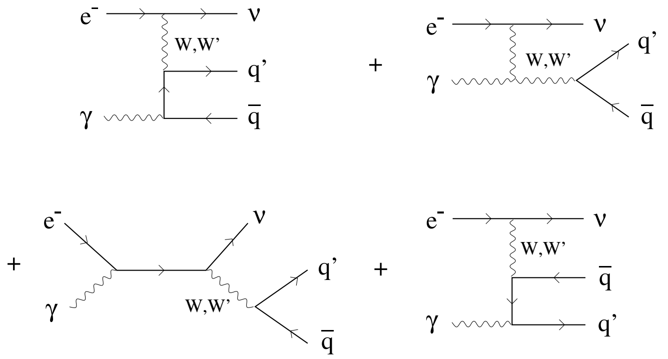


Using σ and A_{LR} combined.

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}).

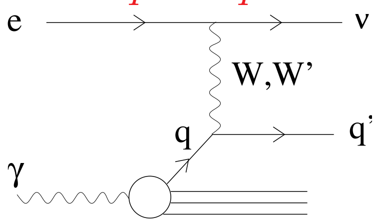
W' Searches via $e\gamma \to \nu q + X$

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



$\Rightarrow$

$eq \to \nu q'.$



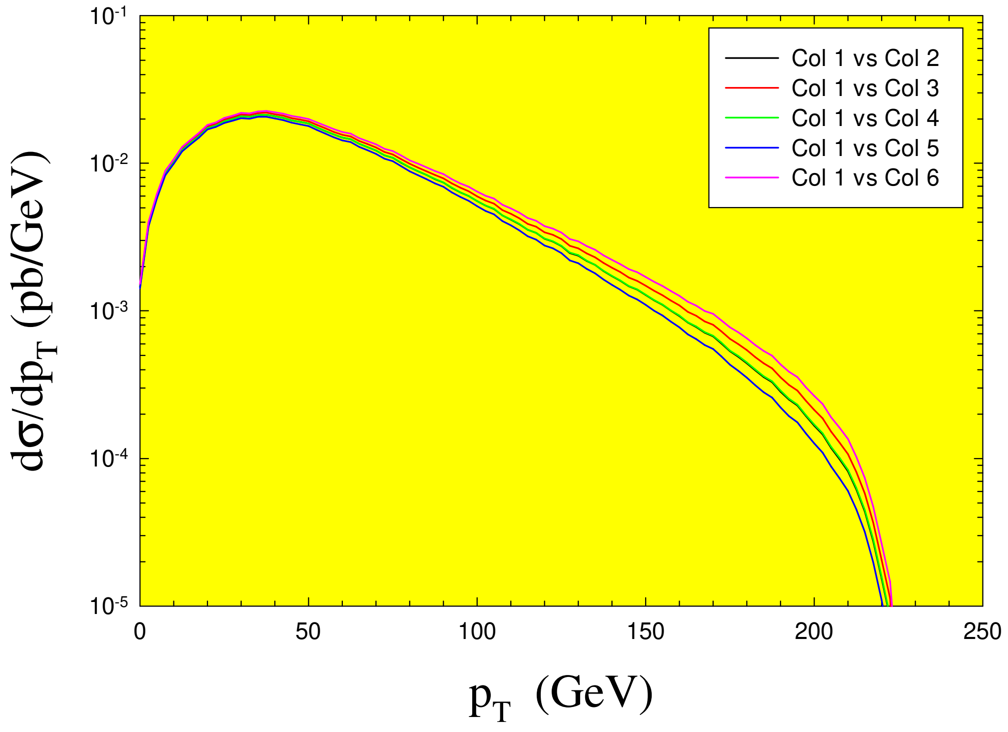
$$\sigma = \int dx \int dy f_{\gamma/e}(x, \sqrt{s}/2) f_{q/\gamma}(y, Q^2) \hat{\sigma}(eq \to \nu q')$$

included u, d, s, c using leading order GRV where

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

- 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

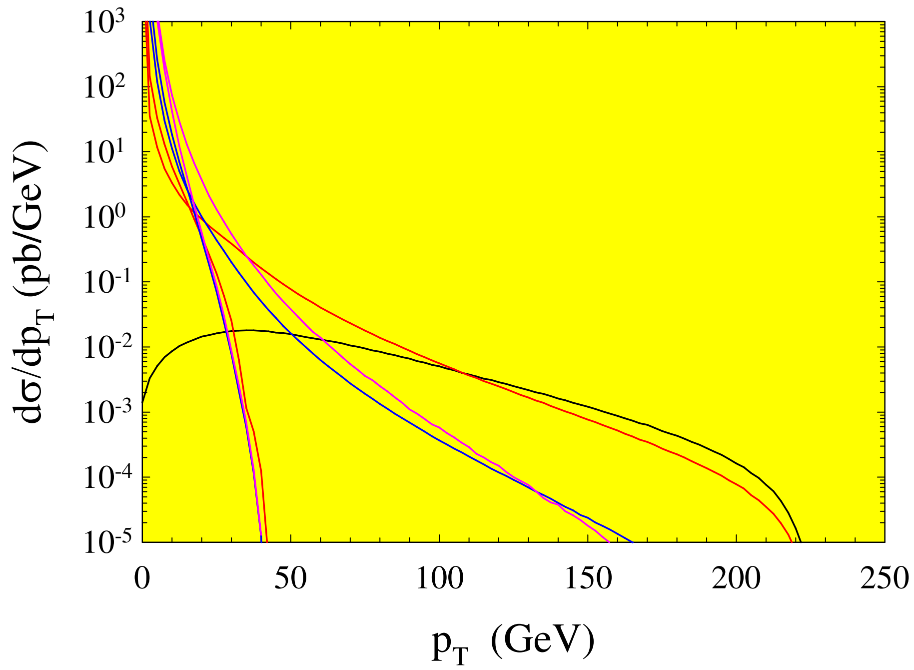


$\sqrt{s} = 500$ GeV, $M_{W'} = 750$ GeV.

For the SM, SSM, LRM, UUM and the KK model.

Backgrounds

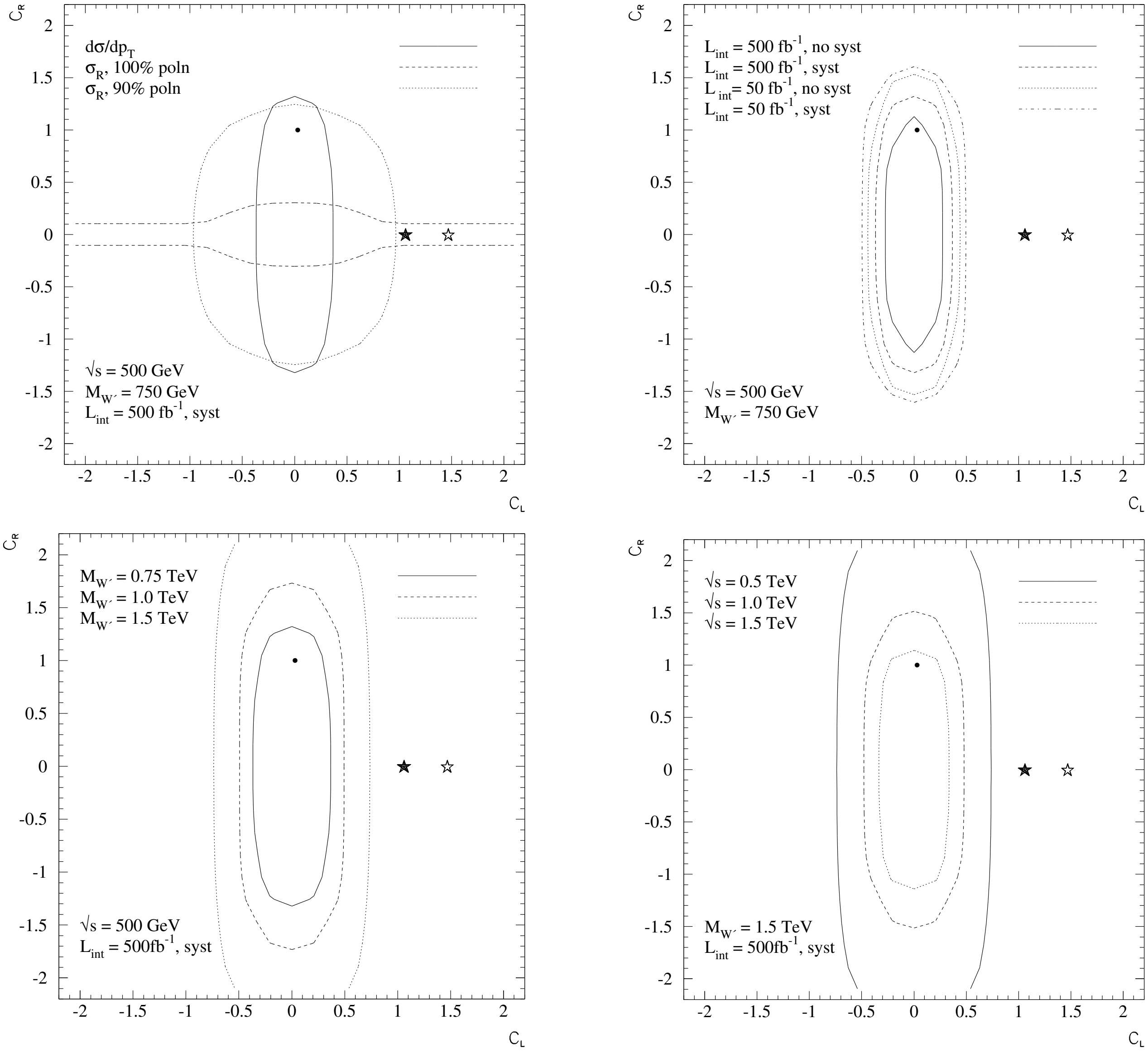
- Dominant backgrounds are two jet final states with one jet lost down the beam pipe
- The dominant two jet final states are:
  - $\gamma\gamma \to q\bar{q}$
  - Once resolved reactions: $\gamma g \to q\bar{q}$ and $\gamma q \to gq$
  - Twice resolved reactions: $gg \to q\bar{q}$, $q\bar{q} \to q\bar{q}$,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



- 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
- For exclusion limits divide p_{T_q} into 10 bins

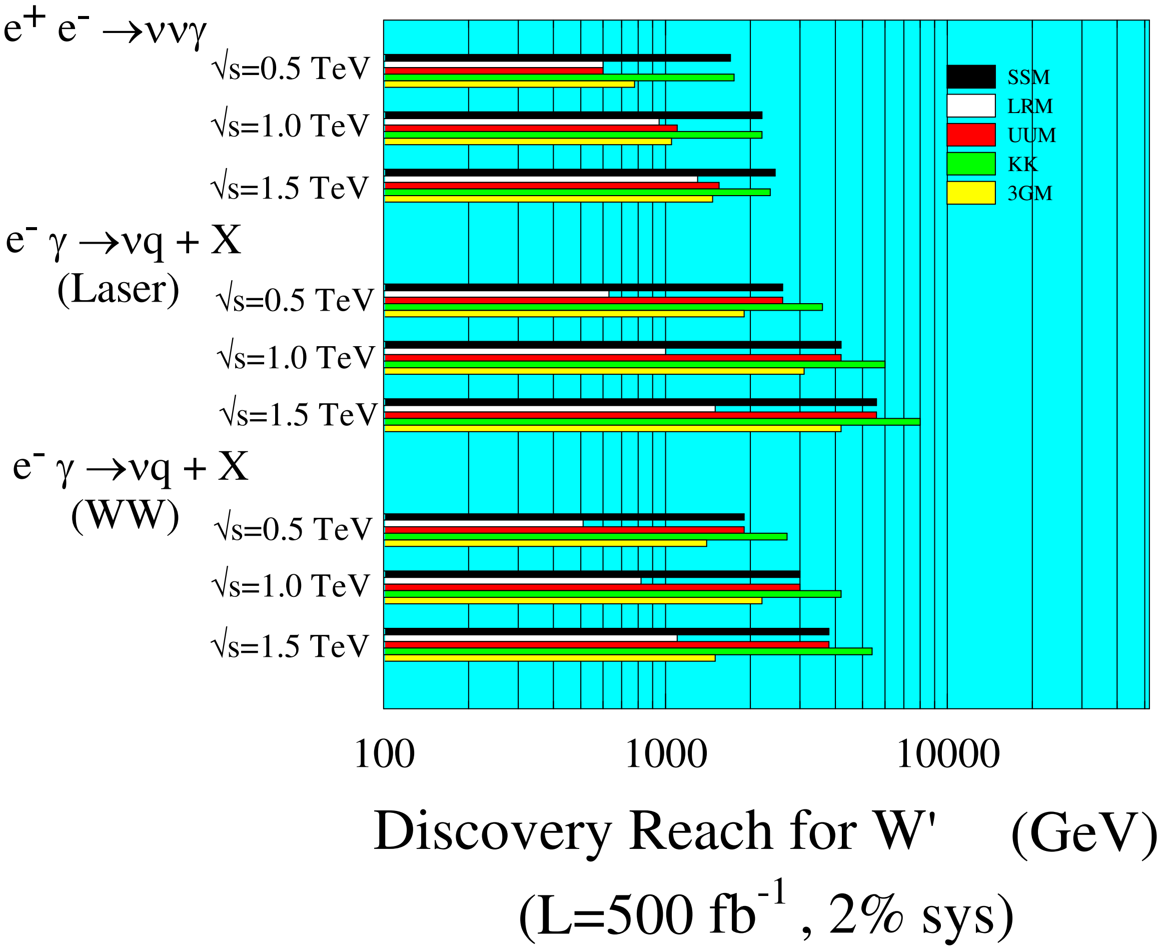
Constraints on Couplings

- $\star$-SSM $\bullet$-LRM $\diamond$-KK $(C_L^e = C_L^q,\ C_R^e = C_R^q)$



1. Various observables
2. Vary luminosity, and systematic errors
3. Vary W' masses.
4. Vary $\sqrt{s}$ for $M_{W'} = 1.5$ TeV

Exclusion Limits



Limits in TeV		SSM	LRM	UUM	KK
$\sqrt{s} = 0.5$ TeV	e^+e^-	1.9	0.5	1.9	2.7
	$e\gamma$	2.6	0.6	2.6	3.6
$\sqrt{s} = 1.0$ TeV	e^+e^-	3.0	0.8	3.0	4.2
	$e\gamma$	4.2	1.0	4.2	6.0
$\sqrt{s} = 1.5$ TeV	e^+e^-	3.8	1.1	3.9	5.4
	$e\gamma$	5.6	1.5	5.6	8.0

3 Leptoquark Production and Identification

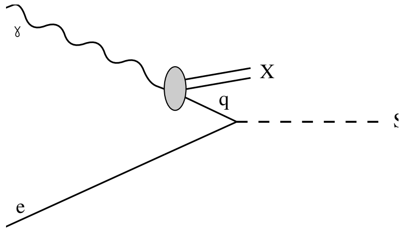
(M.A. Doncheski, S. Godfrey, Phys. Rev. **D49**, 6220 (1994) [hep-ph/9311288]; **D51**, 1040 (1995) [hep-ph/9407317]; Phys. Lett., **B393**, 355 (1997) [hep-ph/9608368]; Mod Phys Lett **A12**, 1719 (1997) [hep-ph/9704380].)

- Colour (anti-) triplets
- Spin 0 or 1
- Carry baryon and lepton quantum numbers
- Appear in Guts, technicolour, composite models
- Signal is high p_T lepton balanced by a jet
- 10 types according to B-R-W classification

At LHC, $L = 100\ fb^{-1}$ $(\kappa = 1)$ For scalar 1.4 TeV
for Vector 2.2 TeV

Leptoquark Production

- Produce via the quark content of the photon:



- The quark fuses with the electron:

$$\sigma(\hat{s}) = \frac{\pi^2 \kappa \alpha_{em}}{M_S} \delta(M_S - \sqrt{\hat{s}})$$

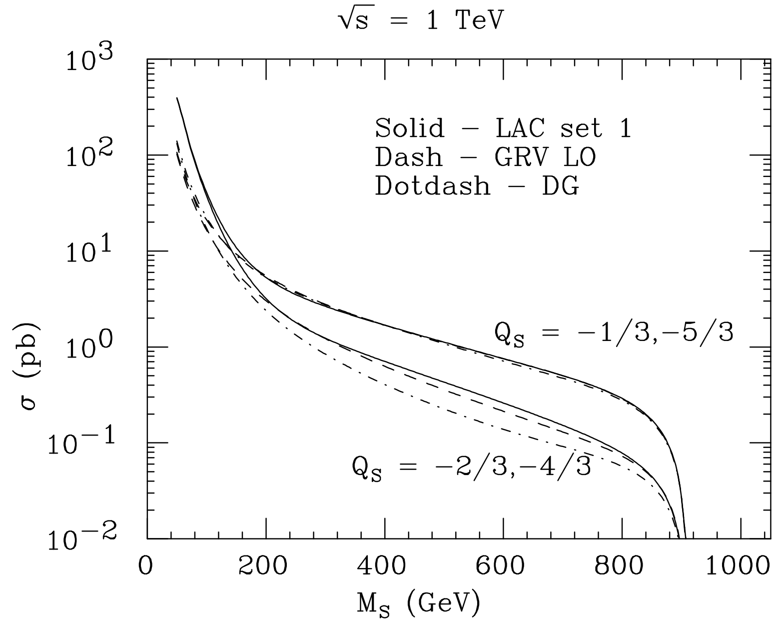
- Convolute with the quark distribution:

$$\sigma(s) = \int f_{q/\gamma}(z, M_s^2) \hat{\sigma}(\hat{s}) dz = f_{q/\gamma}(M_s^2/s, M_s^2) \frac{2\pi^2 \kappa \alpha_{em}}{s}$$

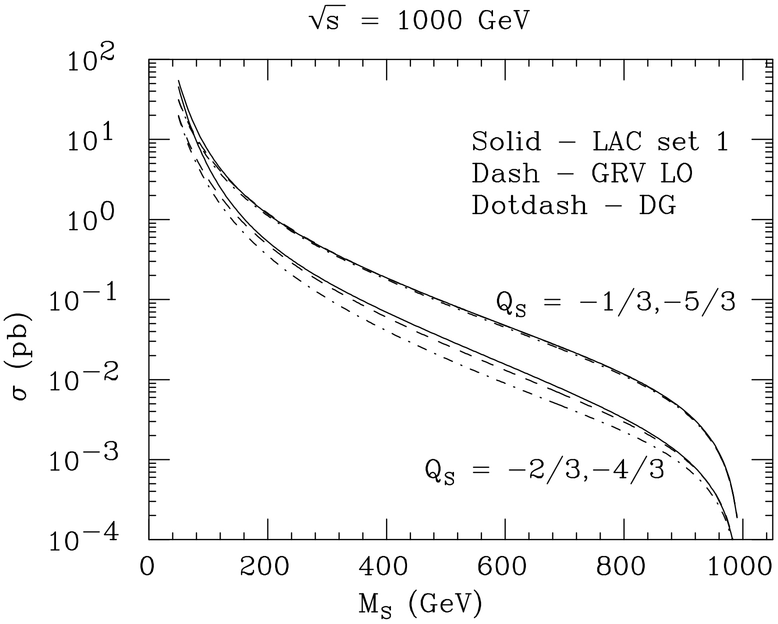
- And convolute with the photon distribution:

$$\begin{aligned} \sigma(e^+e^- &\to XS) \\ &= \frac{2\pi^2 \alpha_{em} \kappa}{s} \int_{M_s^2/s}^{1} \frac{dx}{x} f_{\gamma/e}(x, \sqrt{s}/2) f_{q/\gamma}(M_s^2/(xs), M_s^2) \end{aligned}$$

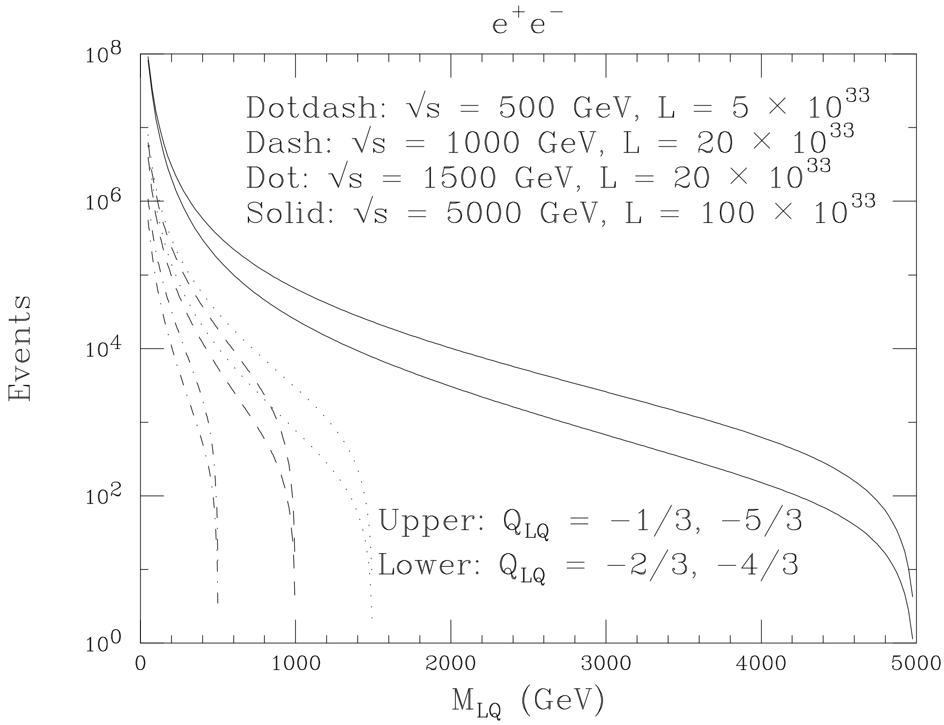
Backscattered Laser, $\sqrt{s} = 1$ TeV



e^+e^-, $\sqrt{s} = 1$ TeV



- Also have indirect limits via $e^+e^- \to q\bar{q}$
  (Hewett and Rizzo, PRD36, 3367 (1987))



Leptoquark discovery reach in GeV based on 100 events

e^+e^- Colliders					
$\sqrt{s}$ (TeV)	L fb^{-1}	Scalar		Vector	
		-1/3, -5/3	-4/3, -2/3	-1/3, -5/3	-4/3, -2/3
0.5	50	490	470	490	480
1.0	200	980	940	980	970
1.5	200	1440	1340	1470	1410
5.0	1000	4700	4200	4800	4500

$e\gamma$ Colliders					
$\sqrt{s}$ (TeV)	L fb^{-1}	Scalar		Vector	
		-1/3, -5/3	-4/3, -2/3	-1/3, -5/3	-4/3, -2/3
0.5	50	450	450	450	440
1.0	200	900	900	910	910
1.5	200	1360	1360	1360	1360
5.0	1000	4500	4400	4500	4500

Leptoquark Identification

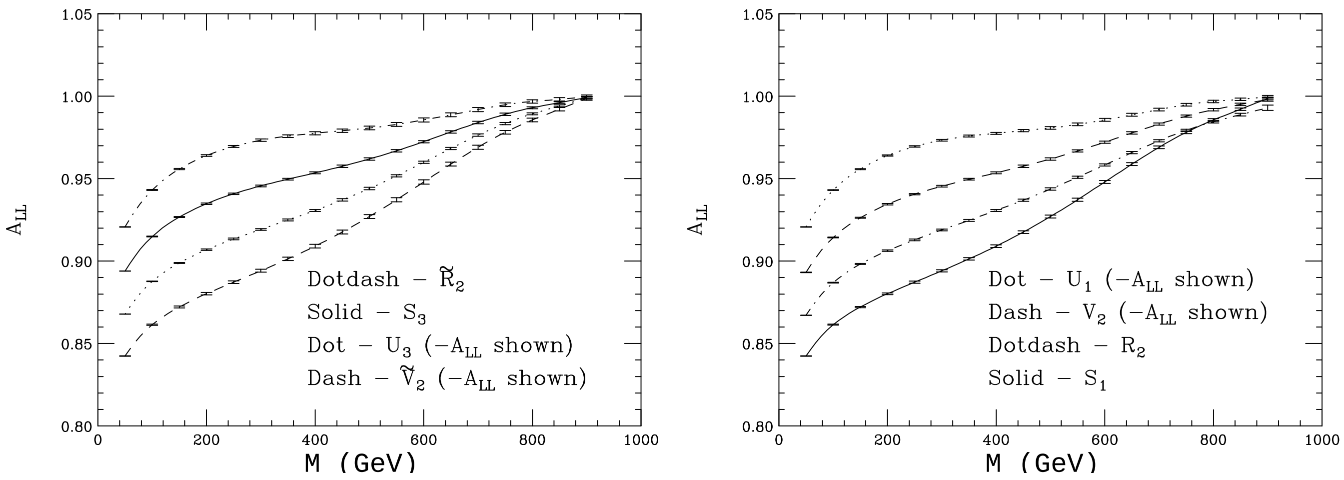
- Scalar or Vector by decay distributions
- Electron Polarization for coupling chirality; e_L e_R e_U

$$A^{+-} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{C_L^2 - C_R^2}{C_L^2 + C_R^2}$$

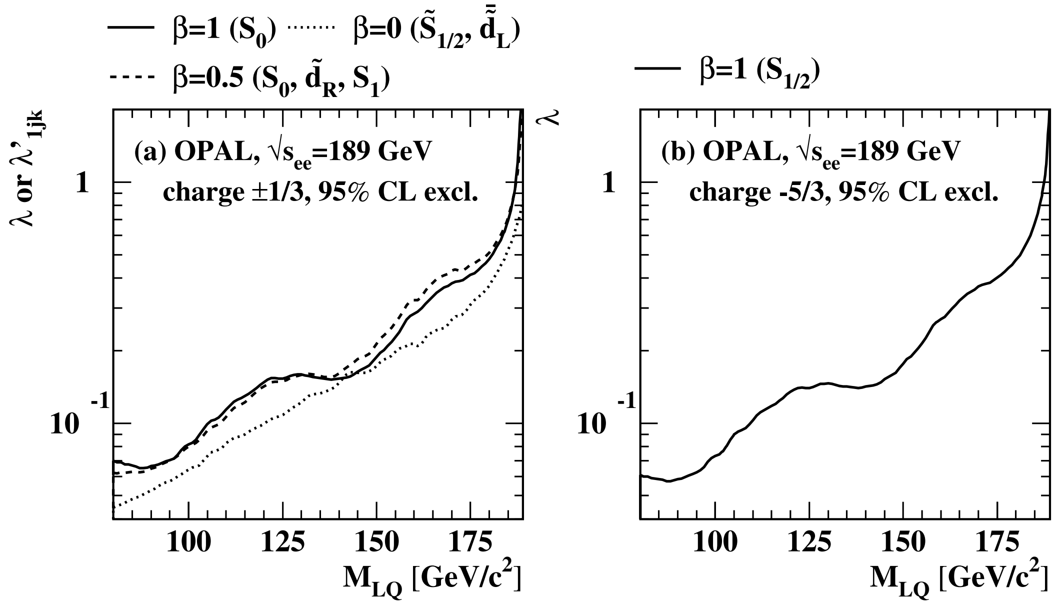
- Further divide using double asymmetry;
  - Scalars have σ^{++} σ^{--} and Vectors have σ^{+-} σ^{-+}

$$A_{LL} = \frac{(\sigma^{++} + \sigma^{--}) - (\sigma^{+-} + \sigma^{-+})}{(\sigma^{++} + \sigma^{--}) + (\sigma^{+-} + \sigma^{-+})}$$

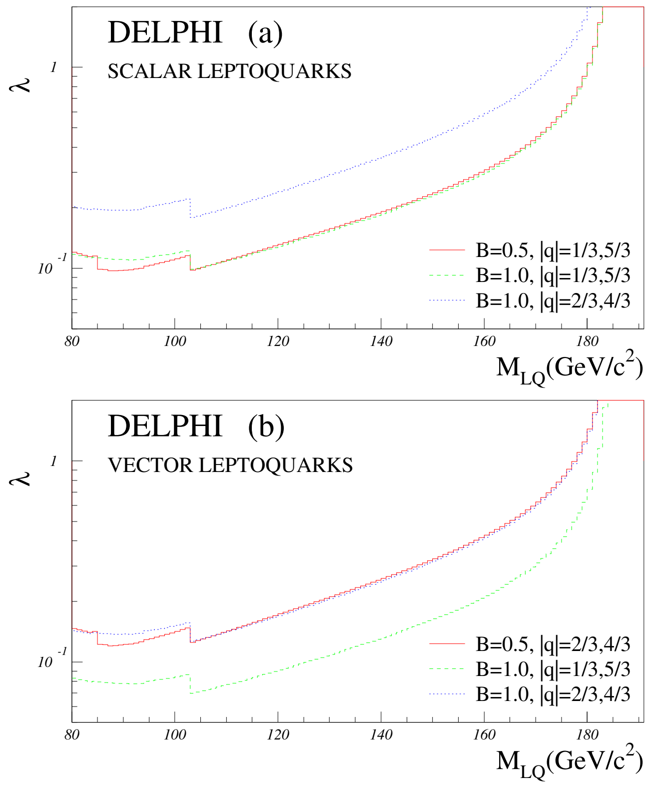
  - Scalars have +ve A_{LL}
  - Vectors have -ve A_{LL}
- Can uniquely determine leptoquark types
- Important to unravel underlying theory



Backscattered Laser, $\sqrt{s} = 1$ TeV



OPAL Collaboration (G. Abbiendi et al.) [hep-ex/0106031]

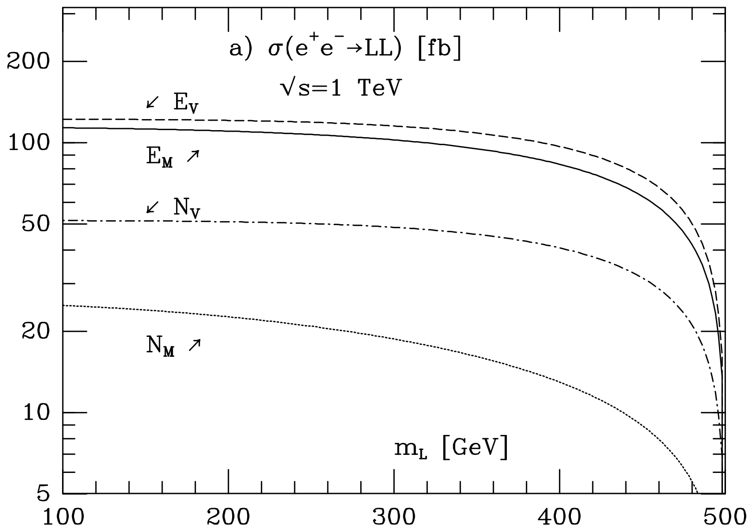


DELPHI Collaboration (P. Abreu et al.). Phys. Lett. **B446**, 62,1999.

4 New Elementary Fermions

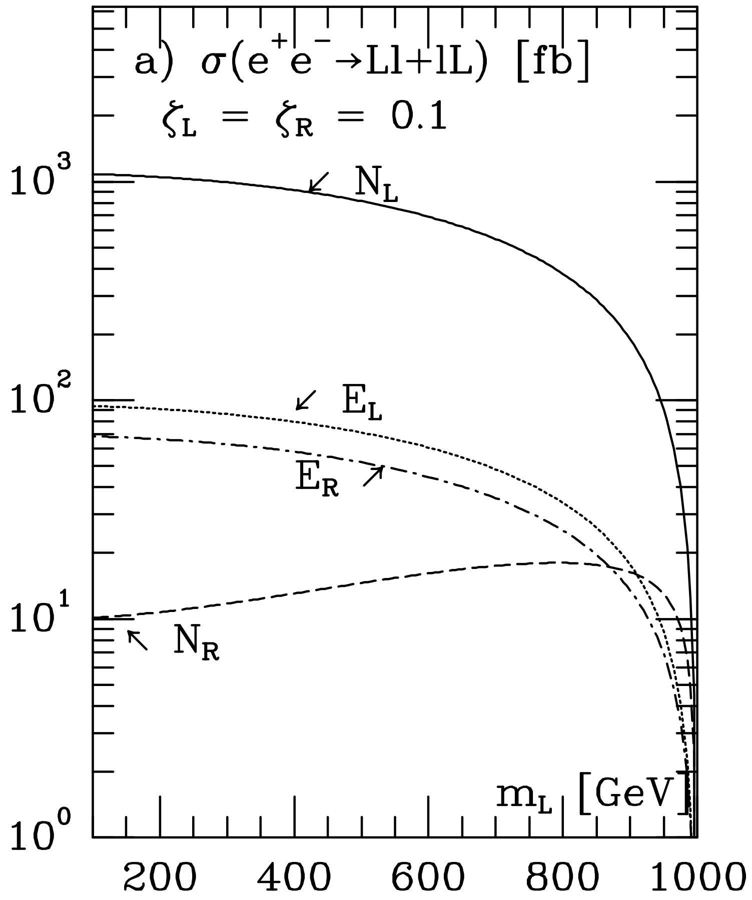
- 4th generation fermions
- vector-like fermions
- mirror fermions

Except for singlet neutrinos new fermions couple to the photon and/or weak bosons with full strength allowing for pair production with unambiguous cross section



- Produced via $e^+e^- \to F\bar{F}$ through s-channel so $\sigma \sim \sigma_0$
- Masses close to kinematic limit can be probed
- Detection straightforward in clean environment of e^+e^- collider

- For conventional QN's new fermions can mix with their SM partners
- Mixing constrained by non-observation of FCNC
- If mixing not too small can produce singly in association with light partners
- If possible the mass search is much higher for a given collider
- Dominant decay via charged current
  - for $\theta < 0.1$ $\Gamma < 10$ MeV for $M_F = 0.1$ TeV
  - for $\theta < 0.1$ $\Gamma < 10$ GeV for $M_F = 1$ TeV



Consider the group E_6

- The fundamental representation of E_6 is 27-dimensional
- In addition to conventional fermions there are 12 new exotic fields
  - charge -1/3 iso-singlet quark h and its antiquark h^c
  - the right handed neutrino N
  - a heavy lepton iso-doublet $(\nu_E,\ E^-)$
  - the conjugate iso-doublet $(N_E,\ E^c)$
  - a neutral lepton n
- Study the quantum numbers of the fermions of E_6 consider the maximal subgroup:

$$E_6 \to SU(3)_C \times SU(3)_L \times SU(3)_E$$

  - $SU(3)_C$ is the colour gauge group
  - $SU(3)_L$ contains $SU(2)_L$ of the standard model
  - the E of $SU(3)_E$ refers to "extra"
- Under this breakdown of E_6 the 27-plet is given by

$$27 = \underbrace{(3,3,1)}_{q} + \underbrace{(\overline{3},1,\overline{3})}_{\overline{q}} + \underbrace{(1,\overline{3},3)}_{l}$$

- There are 3 possibilities for deciding which colour-antitriplet corresponds to $\bar{u}$, $\bar{d}$ and $\bar{h}$
  - $Q_{em} = I_{3L} + I_{3R} + \frac{1}{2}(Y_L + Y_R)$

$$\begin{pmatrix} \overline{d} \\ \overline{u} \end{pmatrix} \quad \begin{pmatrix} \overline{\nu}_E \\ E^- \end{pmatrix} \quad \begin{pmatrix} E^+ \\ \nu_E \end{pmatrix} \quad \begin{pmatrix} e^+ \\ N \end{pmatrix}$$

$$\overline{h}, h, d, u, n, e^-, \nu_e$$

  - $Q_{em} = I_{3L} - I_{3E} + \frac{1}{2}(Y_L + Y_E)$

$$\begin{pmatrix} \overline{u} \\ \overline{h} \end{pmatrix} \quad \begin{pmatrix} n \\ e^+ \end{pmatrix} \quad \begin{pmatrix} \overline{\nu}_E \\ e^- \end{pmatrix} \quad \begin{pmatrix} \nu_e \\ E^+ \end{pmatrix}$$

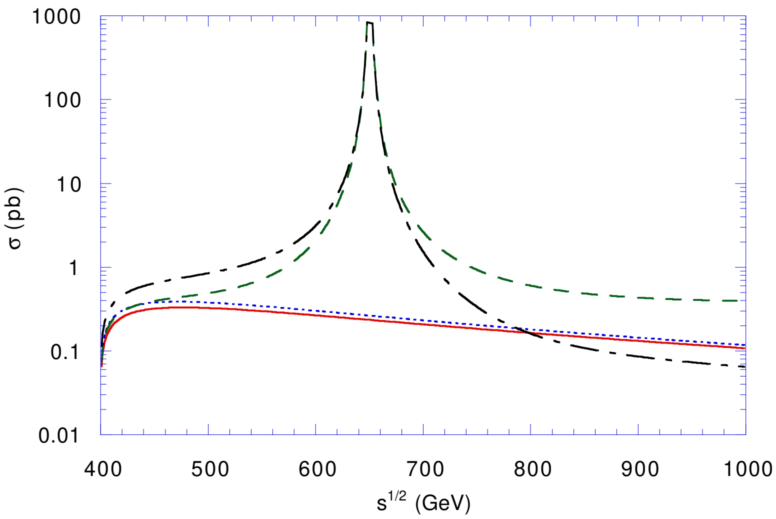
$$\overline{d}, h, d, u, E^-, \nu_E, N$$

  - $Q_{em} = I_{3L} + \frac{1}{2}Y_L - Y_E$

$$\begin{pmatrix} \overline{h} \\ \overline{d} \end{pmatrix} \quad \begin{pmatrix} N \\ n \end{pmatrix} \quad \begin{pmatrix} E^- \\ e^- \end{pmatrix} \quad \begin{pmatrix} \nu_E \\ \nu_e \end{pmatrix}$$

$$\overline{u}, h, u, d, \overline{\nu}_E, E^+, e^+$$

  - In this case $SU(2)_E$ does contribute to Q_{em} so the W's are neutral



5 Summary and Outlook

- Very rich phenomenology and only touched the surface
- Totally neglected
  - Bileptons
  - Diquarks
- For Z''s
  - Considerable body of work
  - Exclusion limits similar or exceed that of LHC
  - If discovered at LHC, LC important ID tool
- For W''s
  - Limits for W' in same ball park as LHC for some models
  - If LHC discovers W' LC important tool for identification
  - Room for new ideas
- Leptoquarks
  - Discovery reach almost up to $\sqrt{s}$
  - If discovered $e\gamma$ could contribute much to understanding
- Exotic Fermions
  - Direct searches straightforward
  - Perhaps room for analysis of extracting properties? origins

6 Some General References

DPF Study: Electroweak Symmetry Breaking & Beyond the Standard Model

- Extra Gauge Bosons: M. Cvetic & S. Godfrey (`hep-ph/9504216`)
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- Low-Energy Phenomenology of Superstring Inspired E6 Models, J. Hewett and T. Rizzo, Phys. Rept. **183**, 193 (1989).
- The Phenomenology of Extra Neutral Gauge Bosons, A. Leike, Phys. Rept. **317**, 143 (1999).