Plans for Studies in Fermion-pair Production: Electroweak Precision Measurements, Extra Dimensions, Compositeness, Z′

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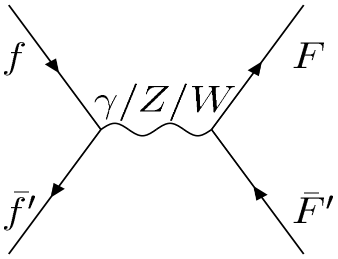
CERN, LHC / LC Study Group Meeting

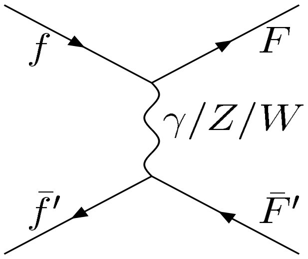
- **Fermion-pair production at colliders**
- **Measurements of cross sections and asymmetries at LHC**
- **Electroweak mixing angle and P.D.F.**
- **Searches for new phenomena - LHC/LC**
  Extra Dimensions
  Contact interactions & Compositeness
  Z′, sneutrino exchange

S. Haywood *et al.*, “Electroweak physics,” arXiv:hep-ph/0003275, LHC SM Workshop

D.Bourilkov, CMS IN 2000/035, CERN, 2000

http://cern.ch/bourilkov/lhc-lc-ff.ps.gz





parton cross section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = |\gamma_{\mathrm{s}} + \mathrm{Z_s} + \text{New Physics ?!}|^2$$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{\alpha^2}{4\mathrm{s}}[\mathrm{A_0}(1+\cos^2\theta) + \mathrm{A_1}\cos\theta]$$

parton distribution functions (P.D.F.): $\mathrm{pp} \longrightarrow \mathrm{l_1 l_2}$

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}M_{ll}\mathrm{d}y}[pp \to l_1 l_2] = \sum_{ij} \frac{1}{1+\delta_{ij}} \left(f_{i/p}(x_1) f_{j/p}(x_2) + (i \leftrightarrow j)\right) \hat{\sigma}$$

$\hat{\sigma}$ - the cross section for the partonic subprocess $ij \to l_1 l_2$

$x_1 = \sqrt{\tau}e^{y}$, $x_2 = \sqrt{\tau}e^{-y}$, $M_{ll} = \sqrt{\tau s} = \sqrt{\hat{s}}$ - mass

y - rapidity of the l^+l^- pair

$$\sigma_{F\pm B}(y, M) = [\textstyle\int_0^1 \pm \int_{-1}^0]\sigma_{ll} d(\cos\theta^*)$$

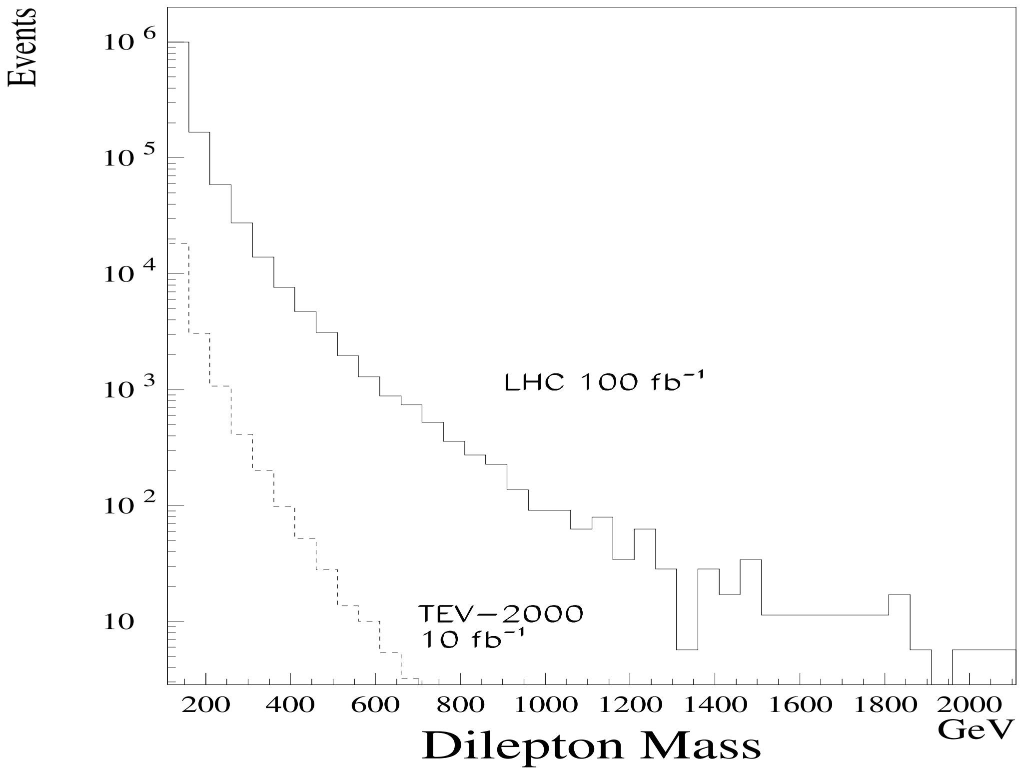
$$\mathrm{A_{FB}}\ (\mathrm{y, M}) = \frac{\sigma_{\mathrm{F-B}}(\mathrm{y, M})}{\sigma_{\mathrm{F+B}}(\mathrm{y, M})}$$

include uncertainties of modern P.D.F. in the study

y	0	2	4
M = 91.2 GeV			
x_1	0.0065	0.0481	0.3557
x_2	0.0065	0.0009	0.0001
M = 200 GeV			
x_1	0.0143	0.1056	0.7800
x_2	0.0143	0.0019	0.0003
M = 1000 GeV			
x_1	0.0714	0.5278	-
x_2	0.0714	0.0097	-

LHC: for both leptons $|\eta| < 2.5$, $p_T > 20$ GeV

TEV-2000: one lepton $|\eta| < 1$, second $|\eta| < 2.5$



Events in one channel/experiment (e.g. pp$\longrightarrow$ e^+e^-)

- Z - huge sample:
  interplay between $\sin^2\theta_{\rm eff}^{\rm lept}(\rm M_Z^2)$ and P.D.F.
- high mass 110-400 GeV - very large sample:
  LEP2 up to 208 GeV
  TEV-2000 up to 400-600+ GeV
  LHC - precision studies
- very high mass 400-3000 GeV - sizeable sample:
  test of SM at highest $\rm Q^2$
  searches for new phenomena

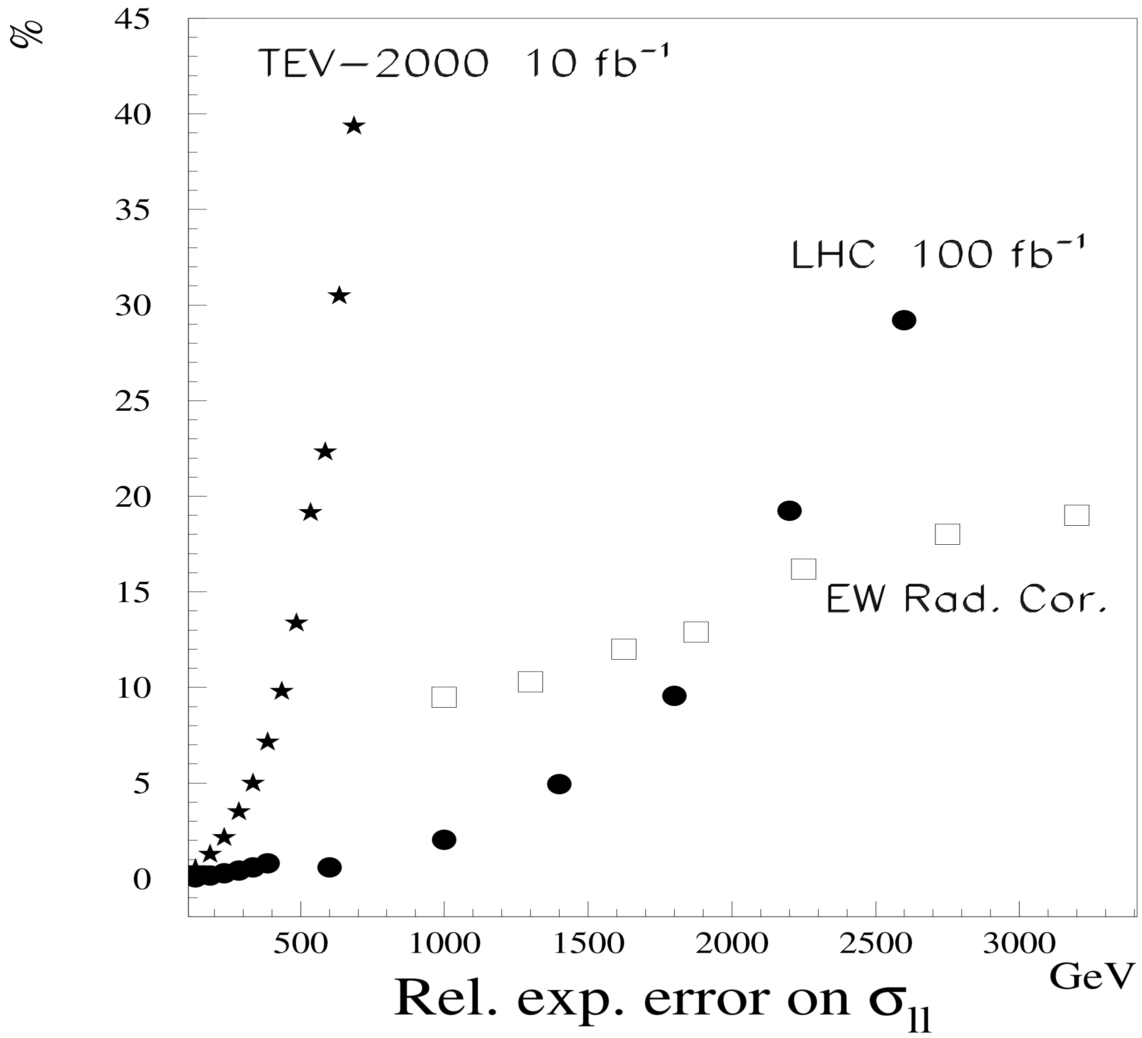
Mass $\rm e^+e^-$ $\mu^+\mu^-$	LEP2 ($\rm q\bar{q}$) 700 $\rm pb^{-1}$ SM / Data	CDF 110 $\rm pb^{-1}$ Data	TEV-2000 10 $\rm fb^{-1}$ PYTHIA	LHC 100 $\rm fb^{-1}$ PYTHIA
Z pole	-	-	$\sim$1.5 x 10^6	$\sim$134 x 10^6
$>$ 110 GeV	14500	148 ($>$ 150)	46000	2.6 x 10^6
$>$ 400 GeV	-	1	250	33 000

rough estimate: seen/expected number of events in one experiment for $\rm e^+e^-$ and $\mu^+\mu^-$

Precise measurement of σ and A_{FB} at large $\hat{s} \Rightarrow$

Electroweak radiative corrections to DY
vertex, propagator, EW boxes

complete 1-loop parton cross section

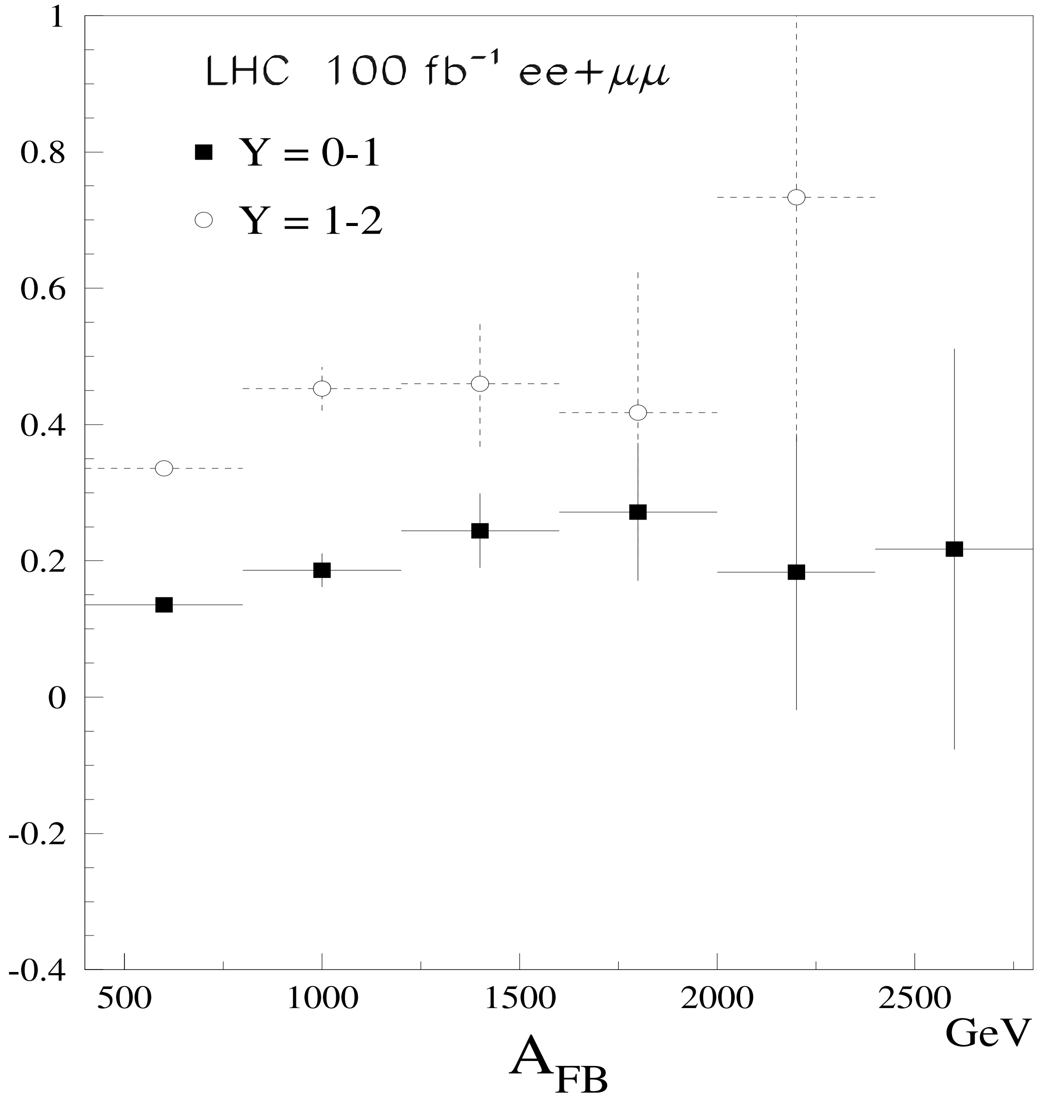


CMS study - cross section for e^+e^- and $\mu^+\mu^-$

Rad. corrections from O.Brein, W.Hollik, Ch.Schappacher

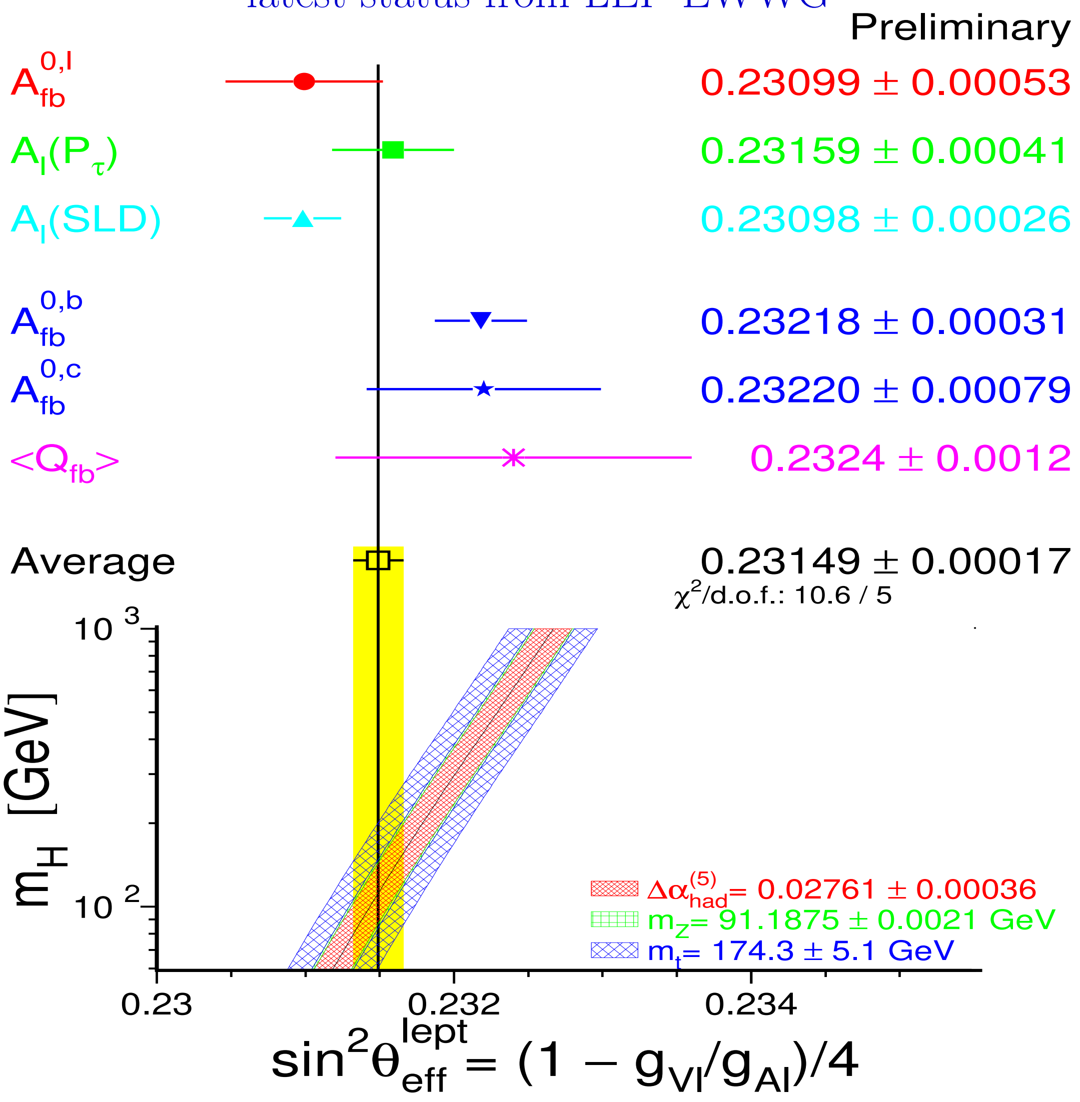
TEVATRON: $p\bar{p}$ - natural label for valence (anti)quark

LHC: pp - initial state is symmetric
but $q\bar{q} \longrightarrow l^+l^-$ - q can be valence (harder) $\Rightarrow$
expect A_{FB} in the boost direction of the ll system



CMS study

latest status from LEP EWWG



a central detector $|\eta| < 2.5$ has a much reduced sensitivity compared to the TEVATRON

a conservative estimate for 100 fb^{-1} at LHC gives

$$\Delta\sin^2\theta_{\rm eff}^{\rm lept}(M_Z^2) = 0.0005 \text{ per channel}$$

$$\Delta\sin^2\theta_{\rm eff}^{\rm lept}(M_Z^2) = 0.00025 \text{ for 2 x 2 channels/exp.}$$

control of charge confusion (knowledge of P.D.F.) *tricky*

Best limits at LEP2 come from combined analysis of Bhabha scattering and $\gamma\gamma$ events

$\mathrm{M_s} > 1.13$ TeV for $\lambda = +1$ and
$\mathrm{M_s} > 1.39$ TeV for $\lambda = -1$ at 95 % CL

(D.Bourilkov, arXiv:hep-ex/0103039)

Drell-Yan:unique contribution from s-channel exchange (J.Hewett, arXiv:hep-ph/9811356)

$$\mathrm{gg} \longrightarrow \mathrm{l^+l^-}$$

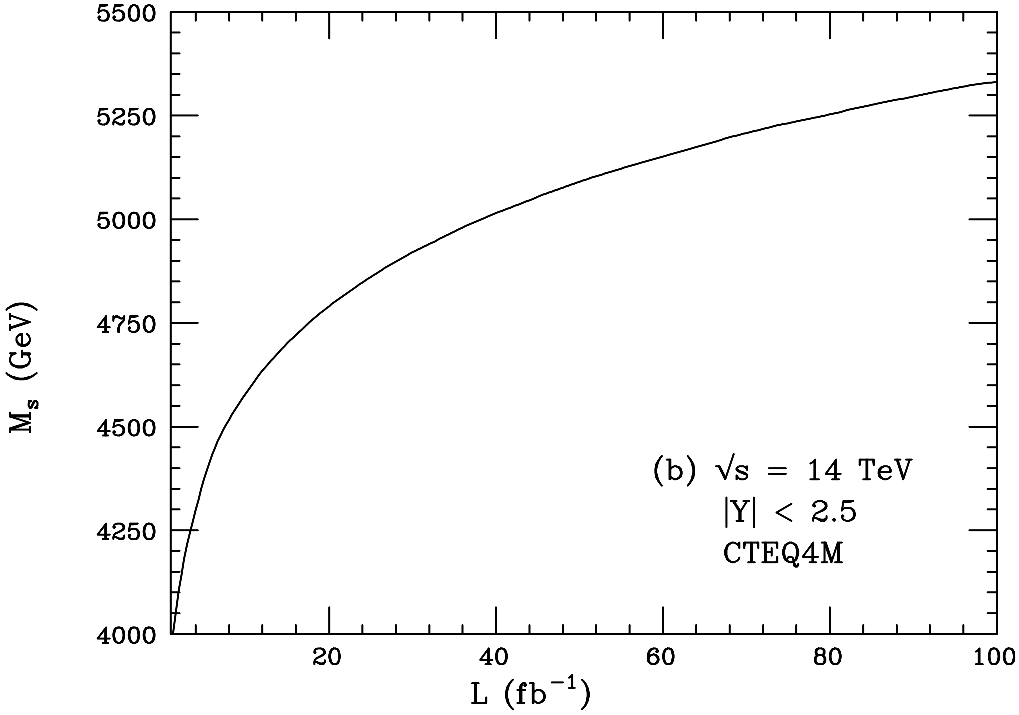
$$\frac{\mathrm{d}\,\sigma}{\mathrm{d}\,\cos\theta} = \frac{\lambda^2 \hat{\mathrm{s}}^3}{64\pi \mathrm{M_s^8}}(1 - \cos^4\theta)$$

the large parton luminosity for gluons at LHC may also compensate the M_s^{-8} suppression

LC: $\mu^+\mu^-$, $\mathrm{c\bar{c}}$, $\mathrm{b\bar{b}}$ - 4.9 TeV at 0.5 TeV ($\mathrm{P_{e^+}} = 0$)
(S.Riemann, LC-TH-2001-007)

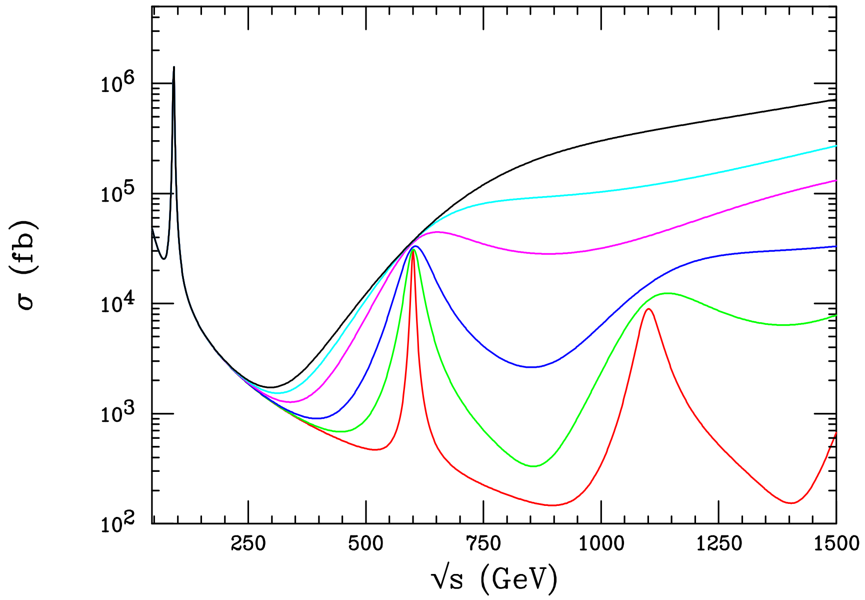
TO DO: add Bhabha scattering

J.Hewett (virtual graviton exchange)



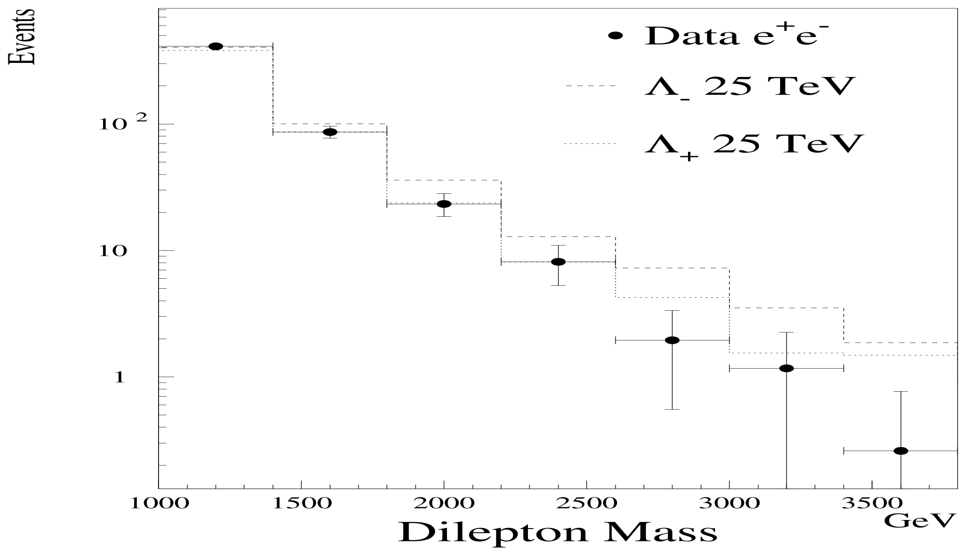
H.Davoudiasl, J.Hewett, T.Rizzo, arXiv:hep-ph/9909255.

$e^+e^- \longrightarrow \mu^+\mu^-$ RS model



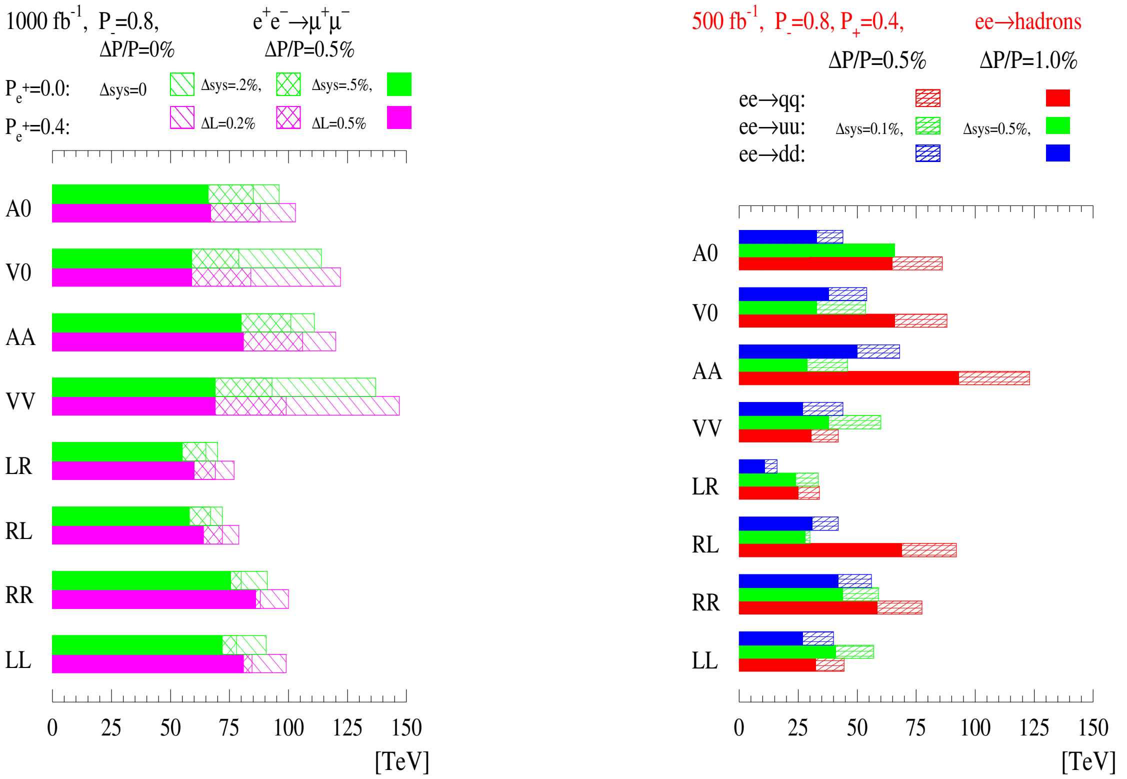
general framework for a new interaction with coupling g and typical energy scale $\Lambda \gg \sqrt{s}$

LHC:scales 25-30 TeV are reachable



CMS study

LC: S.Riemann, LC-TH-2001-007

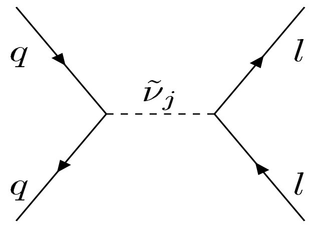


R-parity Violation $\not{R}_p \Rightarrow$

($9\ \lambda + 27\ \lambda' + \ldots$) independent Yukawa couplings; $\lambda_{ijk} \neq 0$ only for $i \neq j$

Resonance formation of single $\tilde{\nu}$ in $\not{R}_p$ theories

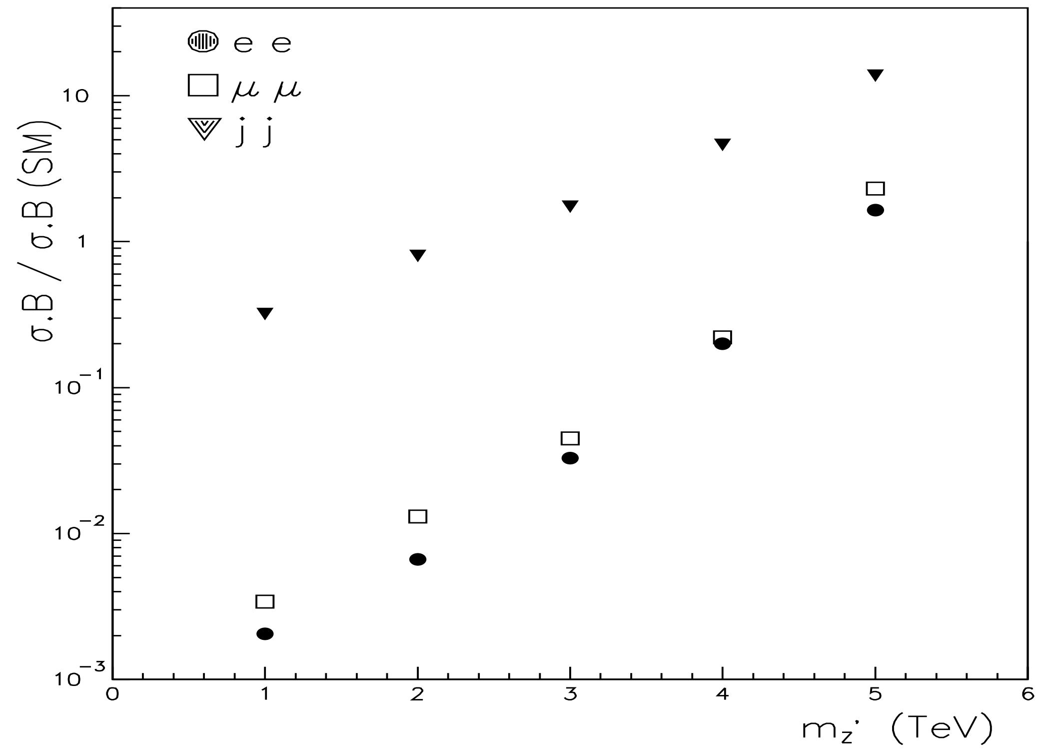
s-channel



Kalinowski et al. (hep-ph/9708272) - study for CDF

masses up to $\sim$ 4 TeV can be probed at LHC

- Z': mass $m_{Z'}$, Z' couplings, $Z - Z'$ mixing θ_M



ATLAS study

Outlook

- systematic error on $\frac{\sigma_{\rm DY}^{\rm high\ Q^2}}{\sigma_{\rm Z}} < 1$ % is possible
- $\rm A_{FB}$ can be measured up to 2 TeV with $> 3\ \sigma$
- LHC can probe EW radiative corrections up to 1.5 TeV at 2 σ level as a function of $\rm Q^2$

TO DO:

- effects of P.D.F. uncertainty on SM predictions / searches
- $\sin^2\theta_{\rm eff}^{\rm lept}(\rm M_Z^2)$ - is a competitive “hadron” measurement possible? (TEVATRON ?) (central acceptance, P.D.F. control) $\Rightarrow$ can improve P.D.F.
- the high energy/luminosity of LHC offers a rich search field in the DY channel (extra dimensions, contact interactions, sneutrinos, Z’ ...) $\Rightarrow$ revisit the search reach and compare with LC
- LC: include the Bhabha channel and revisit extra dimensions, compositeness ...