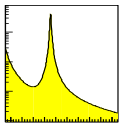

Update on Fermion-pair Production Processes

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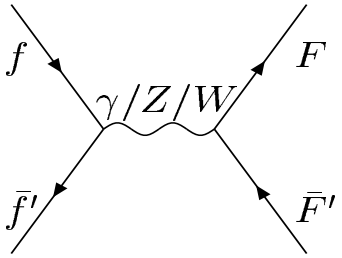
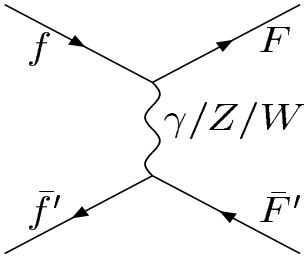
CERN, LHC / LC Study Group Meeting

- **Fermion-pair production at colliders**
- **P.D.F. uncertainties and the LHAPDF interface**
  Implementation in PYTHIA 6.2
- **Results for cross sections and asymmetries at LHC**
- **Electroweak mixing angle and P.D.F.**
- **Searches for new phenomena - LHC/LC**
  Contact interactions & Compositeness

http://cern.ch/bourilkov/lhc-lc-ff2.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

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

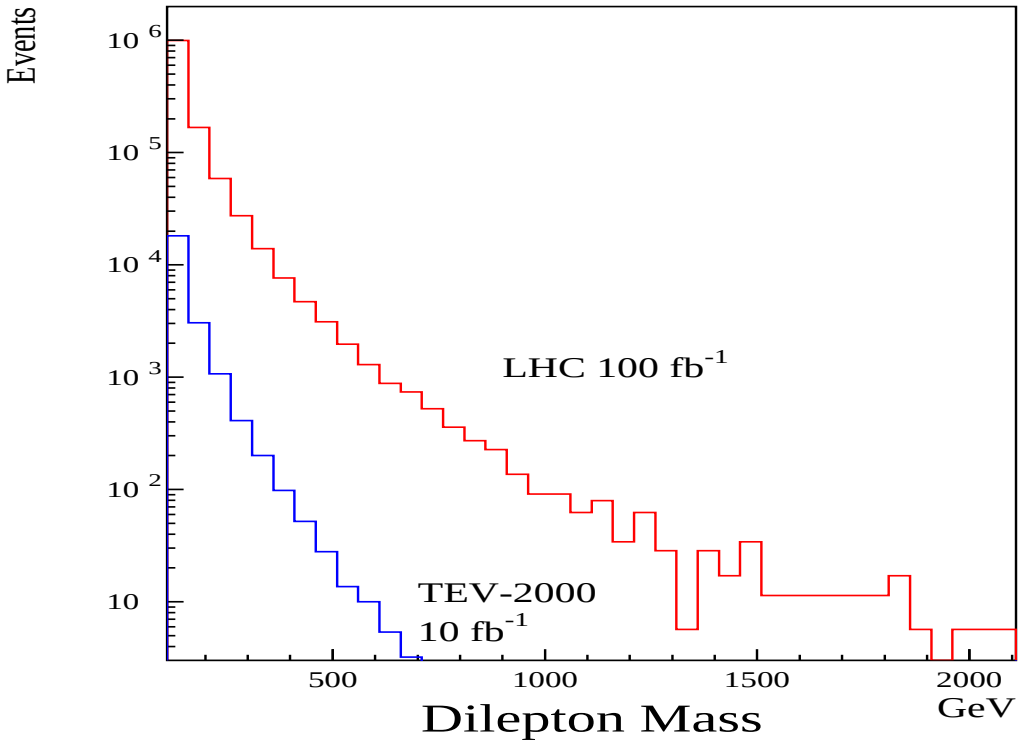
$$\mathrm{A_{FB}}\ (\mathrm{y}, \mathrm{M}) = \frac{\sigma_{\mathrm{F-B}}(\mathrm{y}, \mathrm{M})}{\sigma_{\mathrm{F+B}}(\mathrm{y}, \mathrm{M})}$$

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 $\sin^2\theta^{lept}_{eff}(M^2_Z)$ 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 Q^2
  searches for new phenomena

Mass e^+e^- $\mu^+\mu^-$	LEP2 ($q\bar{q}$) 700 pb^{-1} SM / Data	CDF 110 pb^{-1} Data	TEV-2000 10 fb^{-1} PYTHIA	LHC 100 fb^{-1} PYTHIA
Z pole	-	-	~1.5 x 10^6	~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 e^+e^- and $\mu^+\mu^-$

Les Houches Accord P.D.F. work with P.D.F. sets
Some available sets: CTEQ6 (40), MRST2001 (2),
Fermi2002 (100, 1000)

- a "fit" to the data is represented by a P.D.F. set with many members
- uncertainties on observables are estimated by calculating the observable for ALL members of the set (lots of CPU time!)
- CTEQ6 with 40 members: use eigenvectors for the P.D.F. parameters ($2 \cdot N_P$) and estimate uncertainty $\sim$ 90 % CL:

$$\Delta X = \frac{1}{2}\sqrt{\Sigma[X(S_+) - X(S_-)]^2}$$

- Fermi2002 with 100(1000) members: estimate the standard deviation from the set
- two Q^2 evolution codes: EVLCTEQ v1 and QCDNUM v 16.12

interfaced to PYTHIA 6.2

Cross section for Drell-Yan pairs (e^+e^-) with PYTHIA 6.206; samples of 100000 events

P.D.F. set	Comment	xsec
$81 < M < 101$ GeV		
CTEQ6	LHAPDF	1564 pb
MRST2001	LHAPDF	1591 pb
Fermi2002	LHAPDF	1299 pb
$M > 1000$ GeV		
CTEQ5L	PYTHIA internal	6.58 fb
CTEQ5L	PDFLIB	6.68 fb
CTEQ6	LHAPDF	6.76 fb
MRST2001	LHAPDF	7.09 fb
Fermi2002	LHAPDF	7.94 fb

good agreement between the CTEQ and MRST sets for a large Q^2 range (different evolution codes used)

Cross section for Drell-Yan pairs (e^+e^-) with PYTHIA 6.206; rapidity $<$ 2.5; samples of 1200000 events
probes the (anti)quark P.D.F

P.D.F. set	Comment	xsec [pb]	uncertainty %
$81 < M < 101$ GeV			
CTEQ6	LHAPDF	1065 ± 46	4.4
MRST2001	LHAPDF	1091 ±	
Fermi2002	LHAPDF	853 ± 18	2.2

good agreement between the CTEQ and MRST sets
the P.D.F. uncertainties are small ($\sim$ 2–3 %) and the two methods of estimation give close values

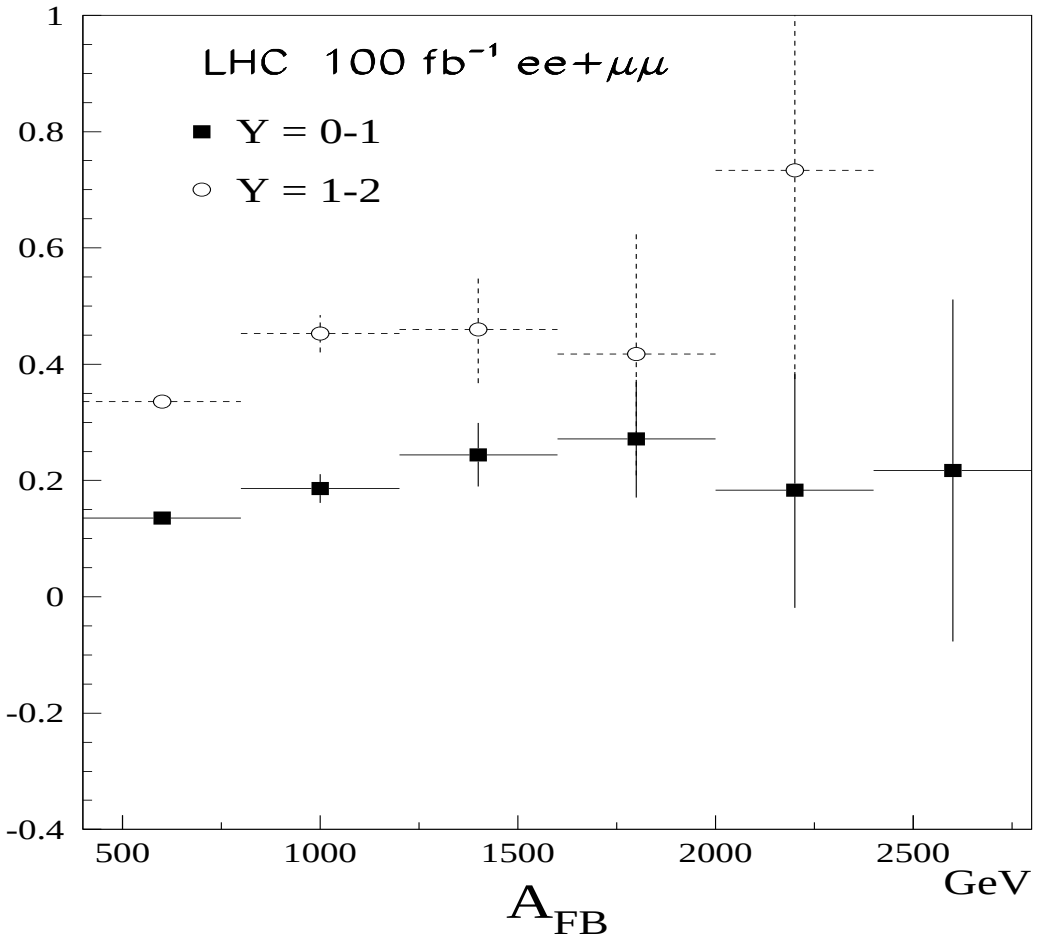
Cross section for $gg \rightarrow H$ probes the gluon P.D.F.
CTEQ6 used; samples of 100000 events

Higgs mass [GeV]	xsec [pb]	uncertainty %
120	16.26 ± 0.62	3.8
160	10.46 ± 0.32	3.1
200	7.41 ± 0.19	2.6

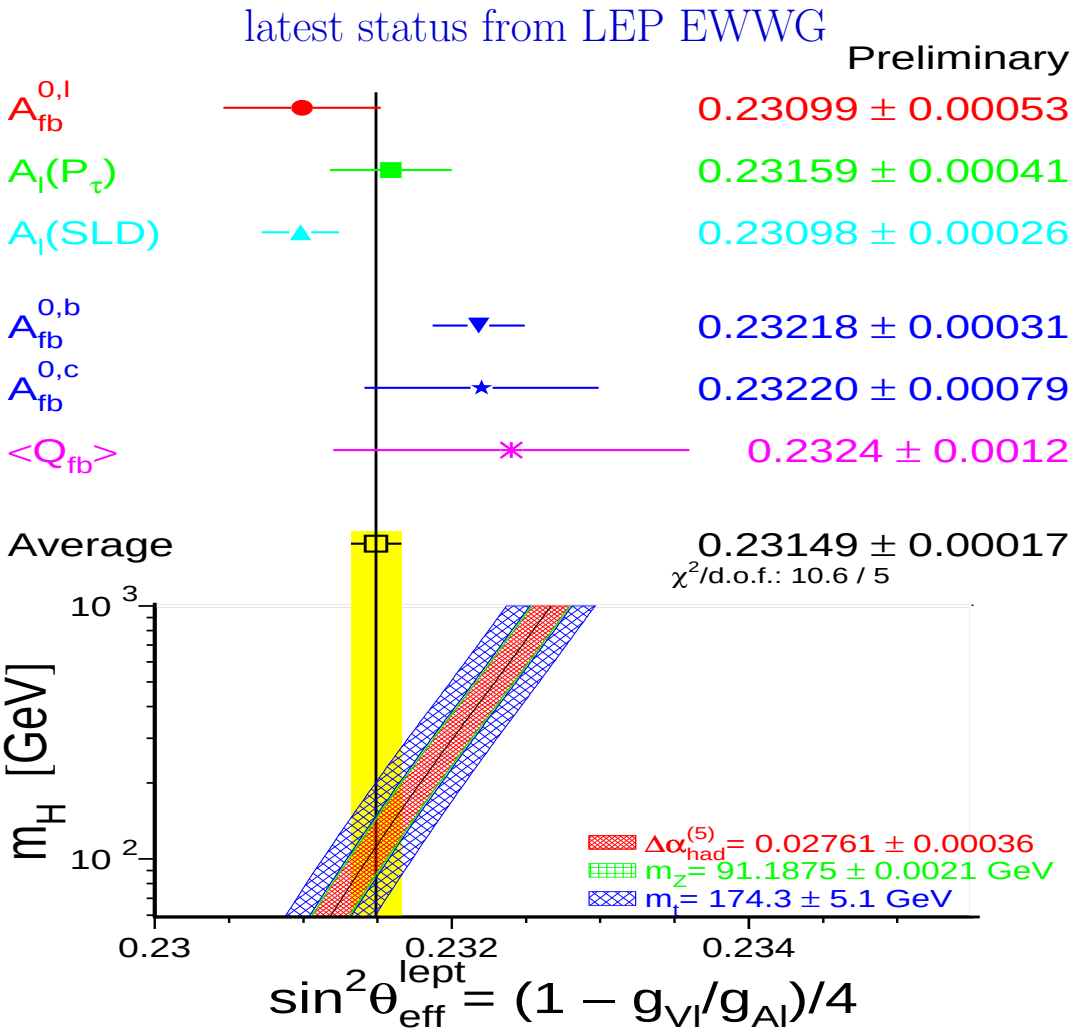
falling uncertainties for higher Higgs masses
the P.D.F. uncertainties are small ($\sim$ 2–4 %)
but extrapolations used for very low x

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



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

the interesting area for 100 fb^{-1} at LHC starts at

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

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

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

$$\frac{\Delta(A_{FB})}{\Delta(\sin^2\theta^{\rm lept}_{\rm eff}(M_Z^2))} = k$$

if we know the quark direction k $\sim$ 5

LHC and rapidity < 2.4 - much reduced sensitivity

$k < 1$

Samples of 50 000 000 events (after cuts) for different values of $\sin^2\theta^{\rm lept}_{\rm eff}(M_Z^2)$

Rapidity	0.0 - 0.8	0.8 - 1.6	1.6 - 2.4
k	~ 0.3	~ 0.7	~ 1.0

for $k \sim 0.7$ we need $\Delta(A_{FB}) = 0.00035$ or 8.2 x 10^6 events

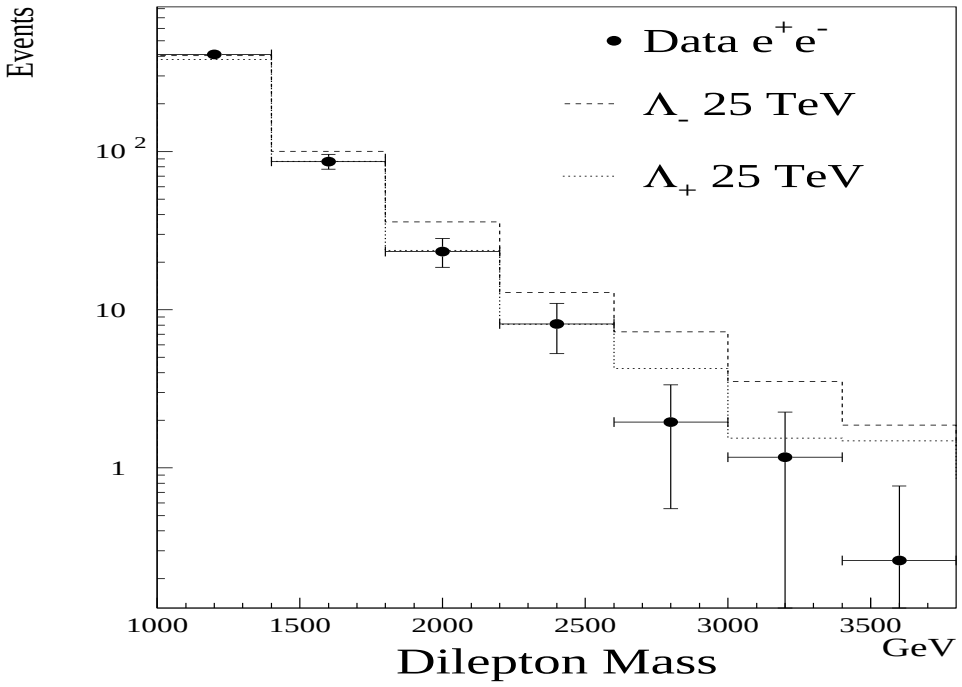
from runs with CTEQ and Fermi2002 - 40(100) x 1.2 x 10^6 events

$$Uncertainty(A_{FB}) < 0.001$$

with this statistics we can only set upper limit
it is well possible that the PDF uncertainty will not be the limiting factor, but runs with huge samples are needed

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

LHC:scales 25-30 TeV are reachable
study with P.D.F. uncertainties underway



CMS study

LC: add the Bhabha channel

- PYTHIA 6.2 interfaced to LHAPDF
- large scale calculations for Drell-Yan, Higgs production ... underway
- the effect of P.D.F. uncertainties on SM predictions for the investigated channels is below 5 %

IN THE PIPELINE:

- $\sin^2\theta^{\rm lept}_{\rm eff}(M_Z^2)$ - is a competitive "hadron" measurement possible? (TEVATRON ?)
  P.D.F. uncertainty is small - need larger data set to estimate it
- the high energy/luminosity of LHC offers a rich search field in the DY channel (extra dimensions, contact interactions, Z' ...) $\Rightarrow$ compare the search reach with LC
- LC: adding the Bhabha channel and updating the search reach for extra dimensions, compositeness ...