The properties of the charged weak boson $W^{\pm}$

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Outline

The W-mass in the electroweak theory

The Triple-Gauge Boson Vertex

W-mass measurement in W-pair production

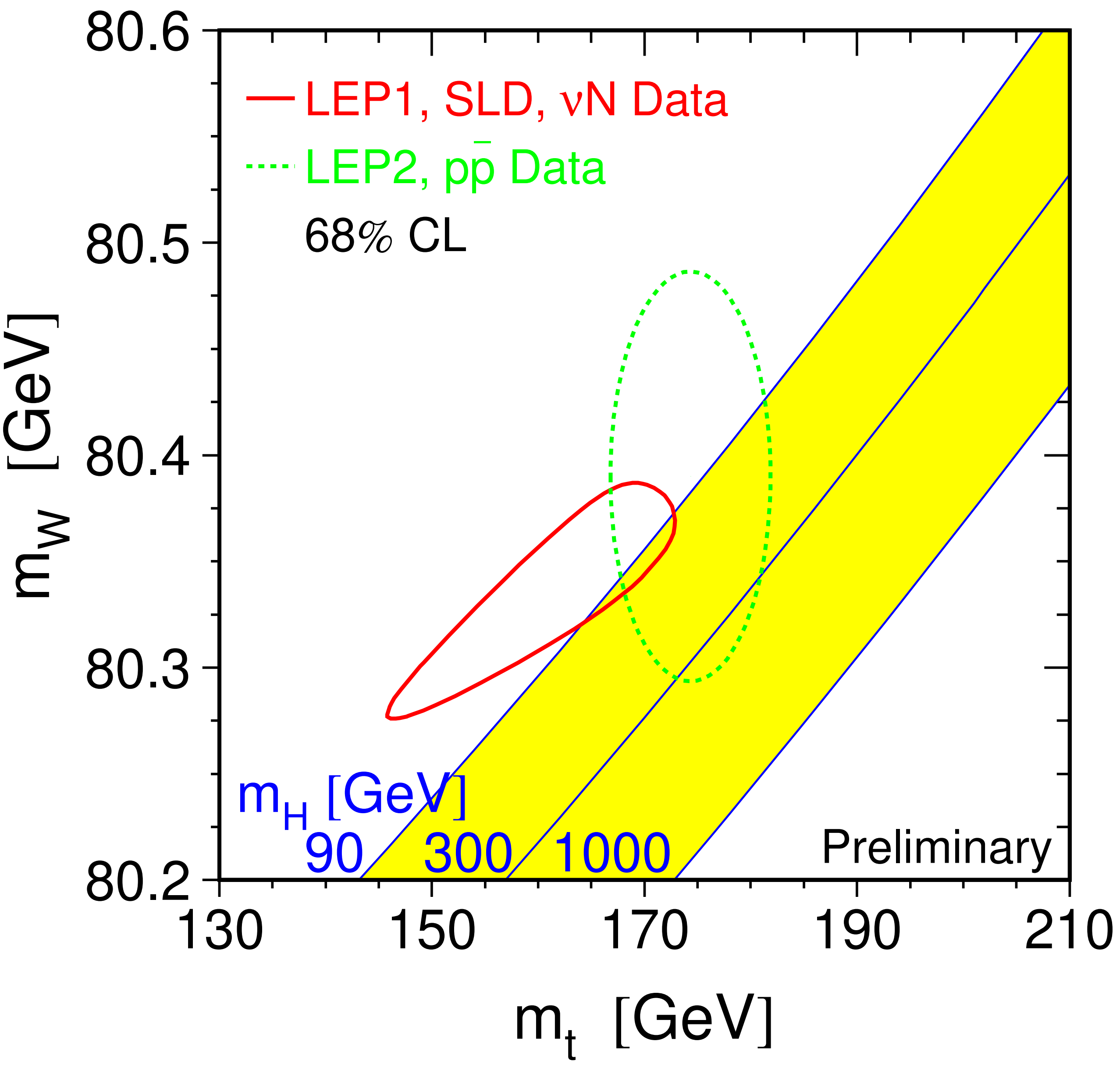
Coupling measurements in

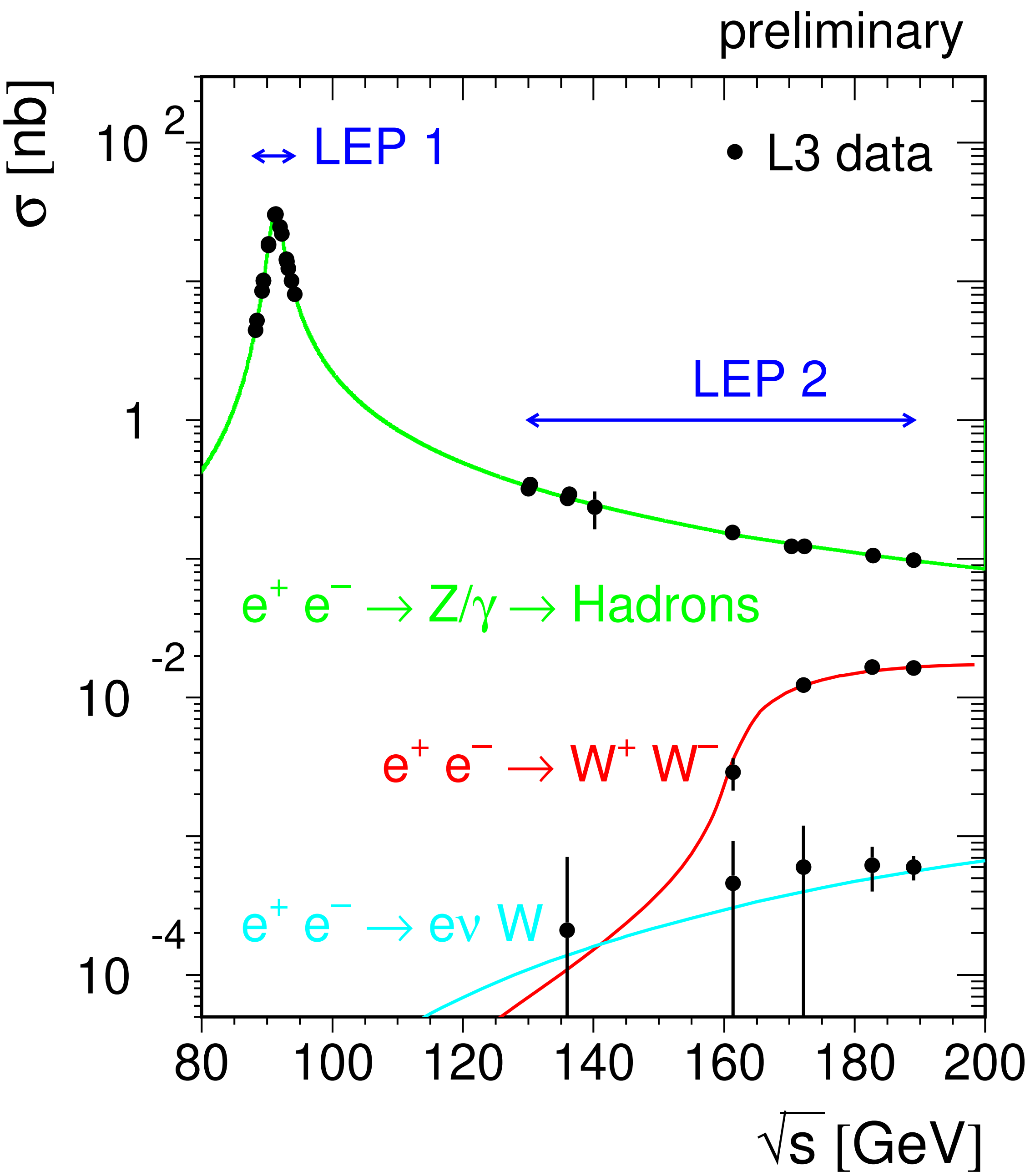
$$e^+e^- \to We\nu_e$$

$$e^+e^- \to W^+W^-$$

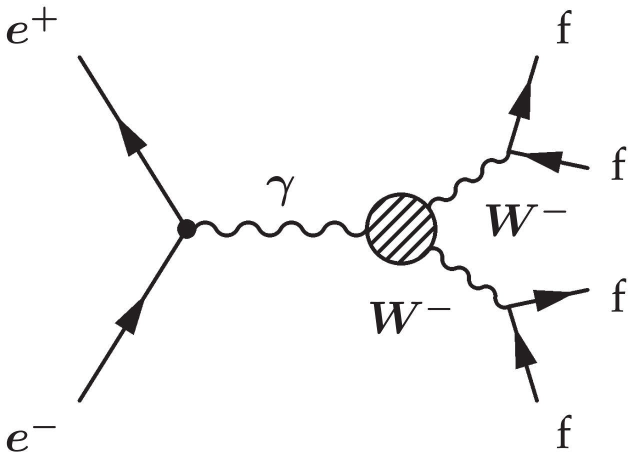
Summary

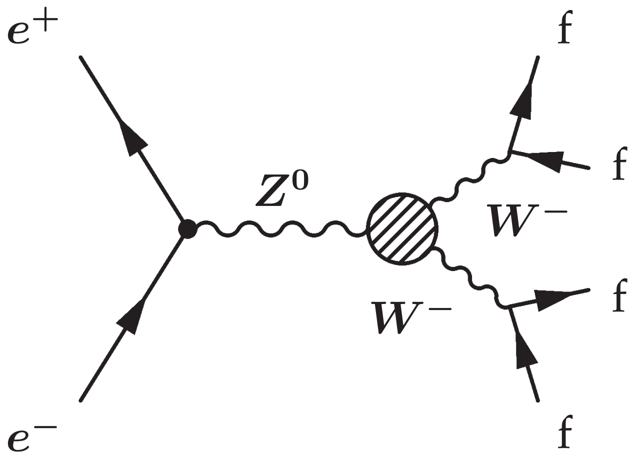
Standard Model Calculations with LEP 1, SLAC and TEVATRON data

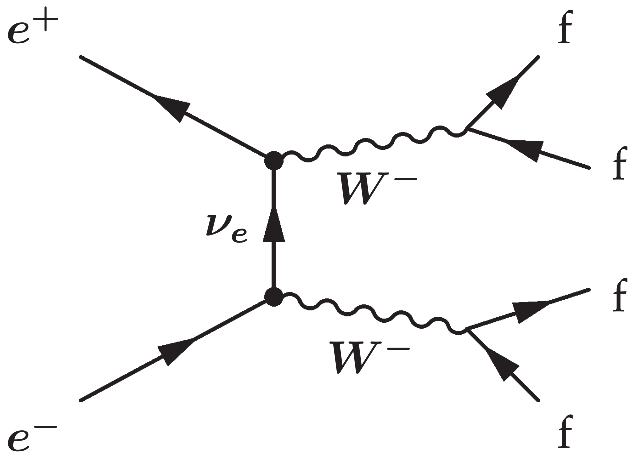


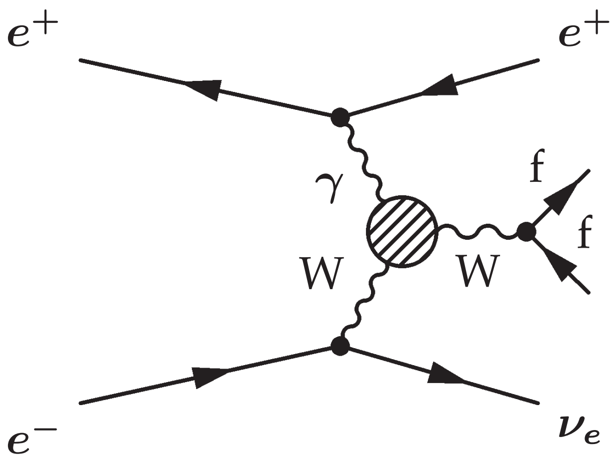


- LEP 2: luminosity of 250 pb^{-1}/experiment collected at 161-189 GeV
- 3500 WW, 100 $We\nu_e$ events

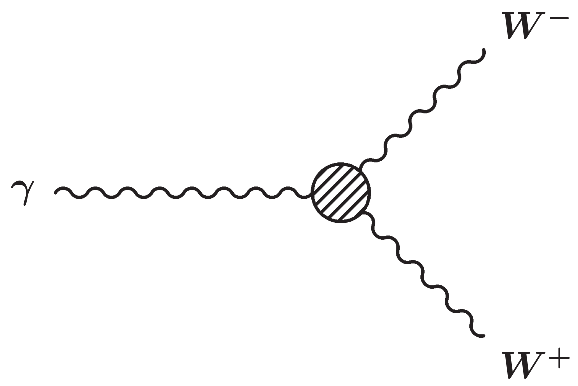

e^+
f
f
γ
W^-
W^-
f
e^-
f


e^+
f
f
Z^0
W^-
W^-
f
e^-
f


e^+
f
f
W^-
ν_e
f
W^-
e^-
f


e^+
e^+
f
γ
f
W
W
e^-
ν_e

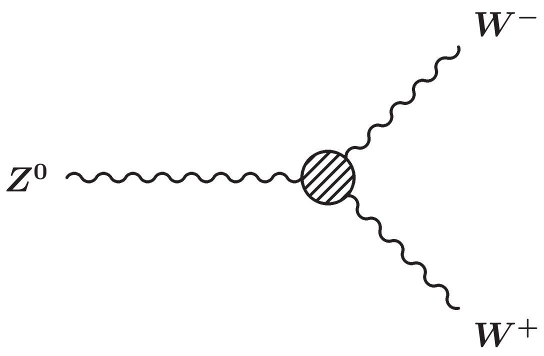
The Three Boson Vertex



$$E1 = e g_1^\gamma$$

$$M2 = \frac{e}{2M_W}\left(g_1^\gamma + \kappa_\gamma + \lambda_\gamma\right) \stackrel{SM}{=} \frac{e}{M_W}$$

$$E4 = -\frac{e}{M_W^2}\left(\kappa_\gamma - \lambda_\gamma\right) \stackrel{SM}{=} -\frac{e}{M_W^2}$$



$$g_1^Z \stackrel{SM}{=} 1$$

$$\kappa_Z \stackrel{SM}{=} 1$$

$$\lambda_Z \stackrel{SM}{=} 0$$

The Three Boson Vertex

Extending the Lagrangian to an effective Lagrangian (purely phenomenological) including C/P and CP violating terms gives 14 free parameter.

constraints :

no C,CP violation $\tilde{\lambda}_V = \tilde{\kappa}_V = g_4^V = g_5^V = 0$

electromagnetic gauge invariance $g_1^\gamma = 1$

gauge invariance

$$\lambda_\gamma = \lambda_Z$$

$$\Delta\kappa_Z = \Delta\kappa_\gamma \tan^2\theta_W + \Delta g_1^Z$$

remaining parameter set :

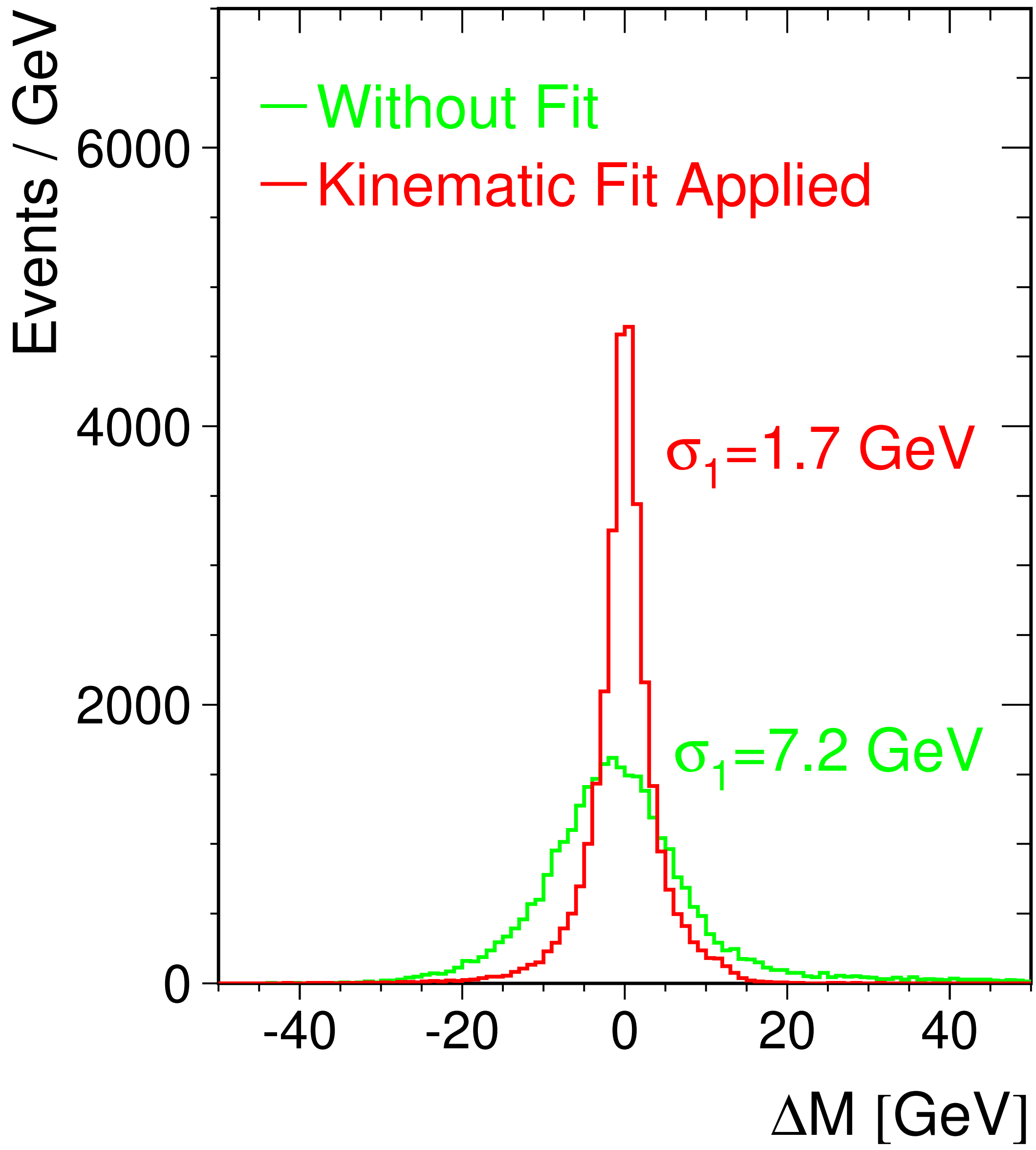
$$(\Delta g_1^Z, \Delta\kappa_\gamma, \lambda_\gamma)$$

The kinematic fit (qq$\mu\nu$)

Problem : Improvement of the mass resolution

Solution : Four-momentum conservation

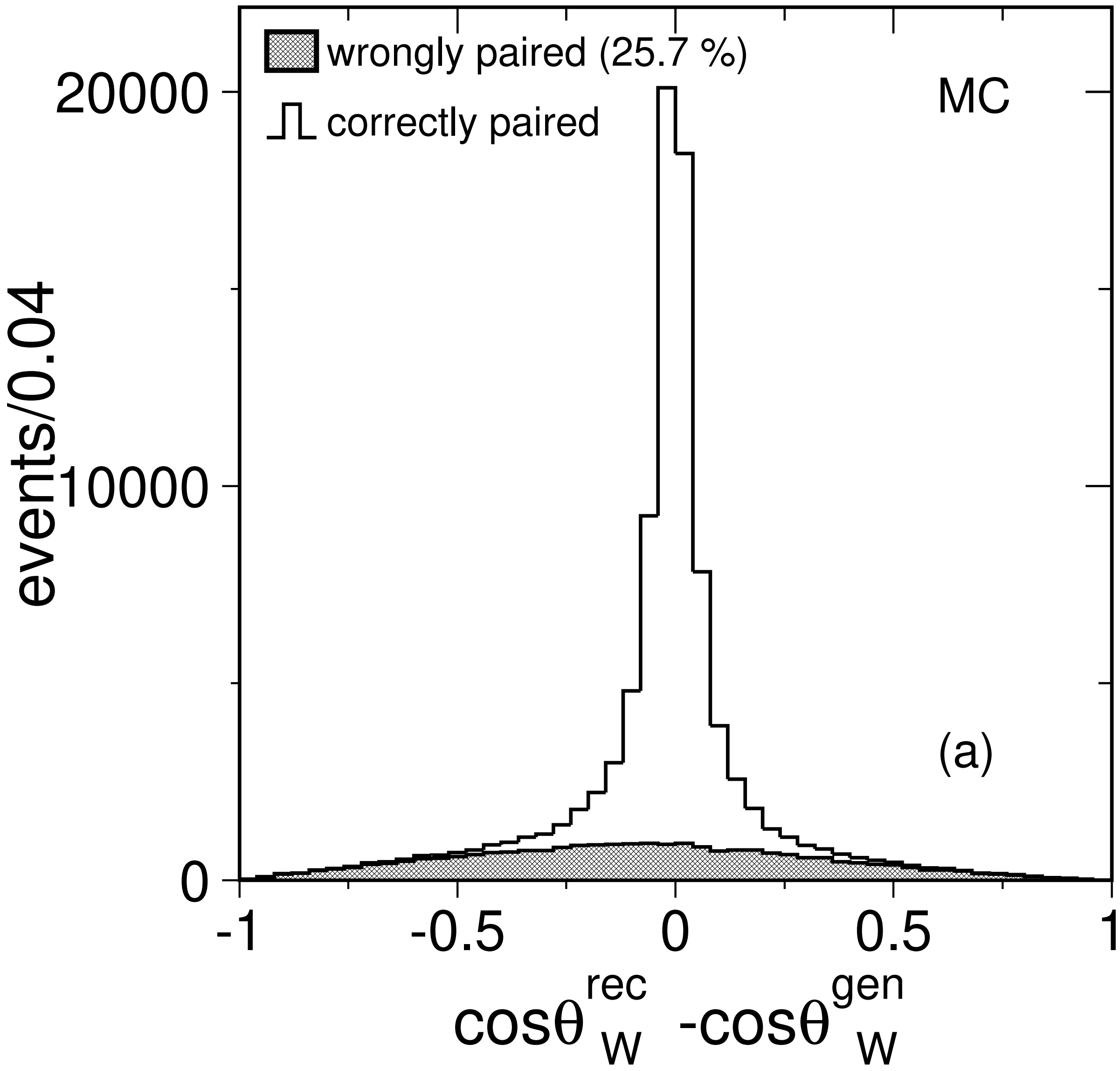
Equality of the two W masses

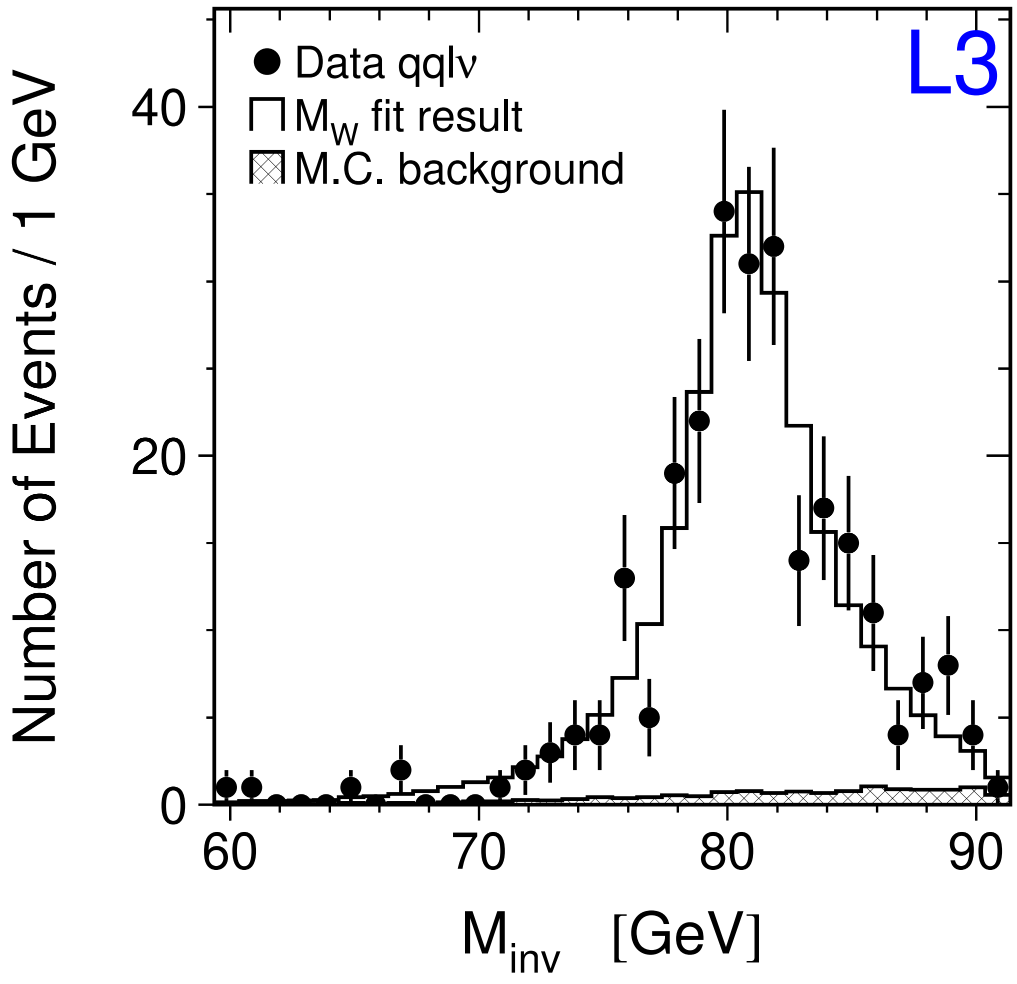


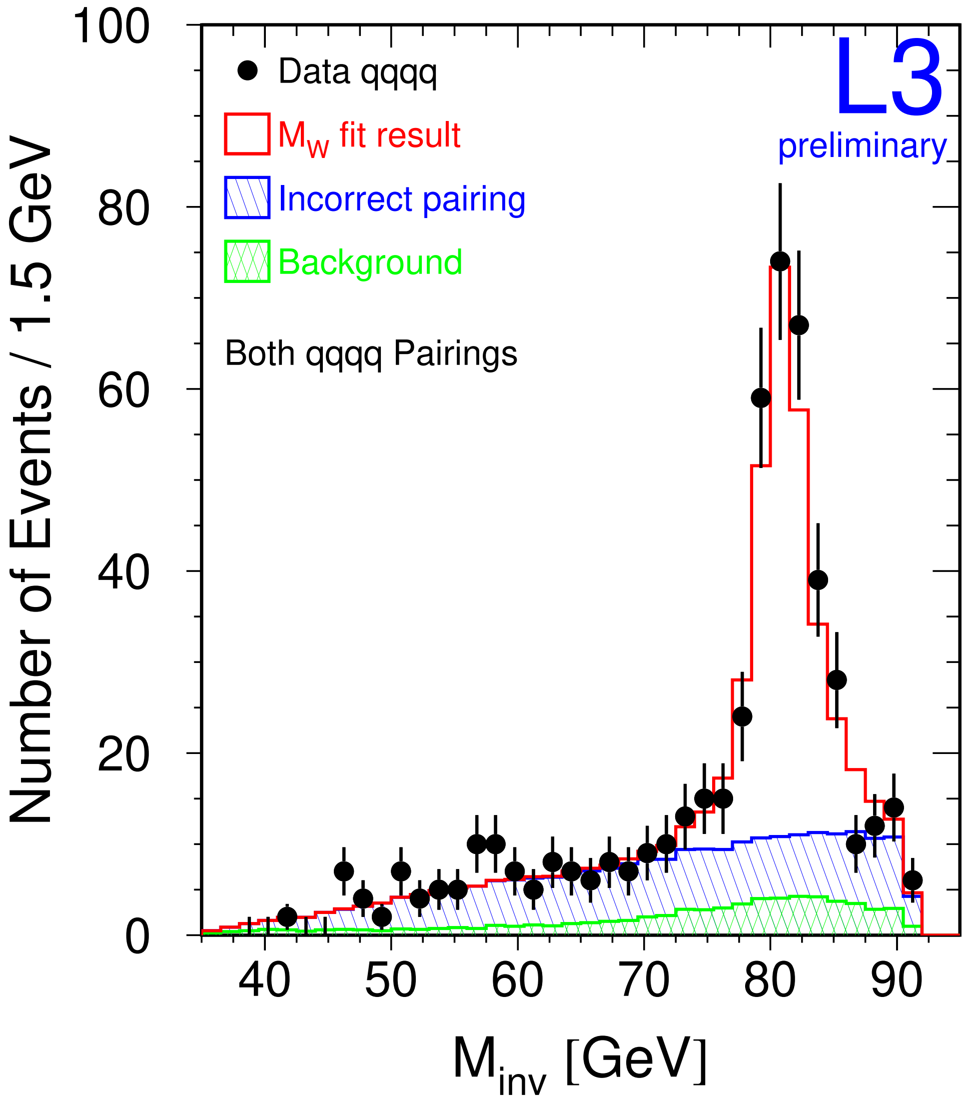
The pairing (qqqq)

Problem : Three possibilities to form two Ws out of four jets

Solution : Equality of the two W masses




Number of Events / 1 GeV
Data qqlν
M_W fit result
M.C. background
L3
M_{inv} [GeV]
0
20
40
60
70
80
90


Number of Events / 1.5 GeV
Data qqqq
M_W fit result
Incorrect pairing
Background
L3
preliminary
Both qqqq Pairings
M_{inv} [GeV]
0
20
40
60
80
100
40
50
60
70
80
90

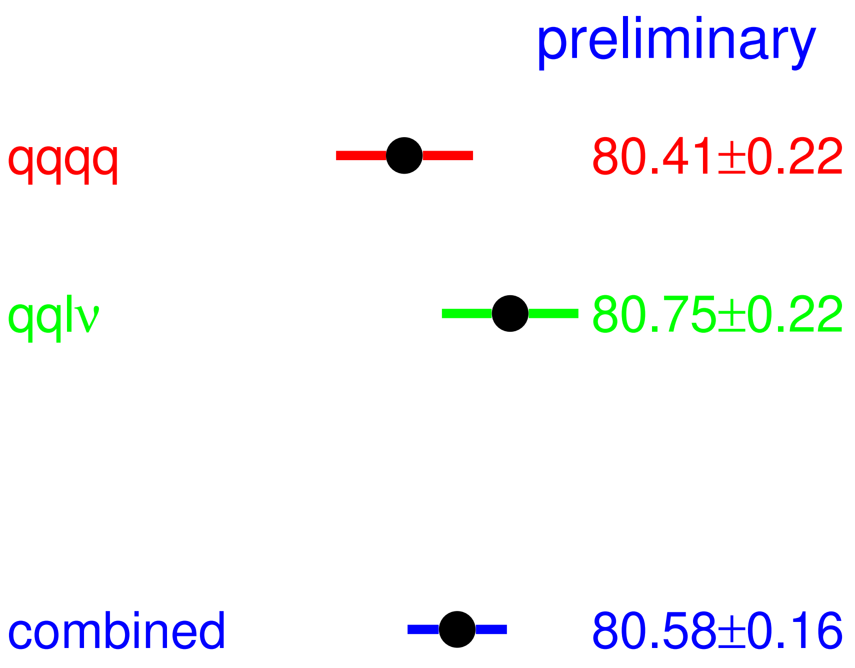
Fit method

- Maximum Likelihood fit to the M_{inv} distribution

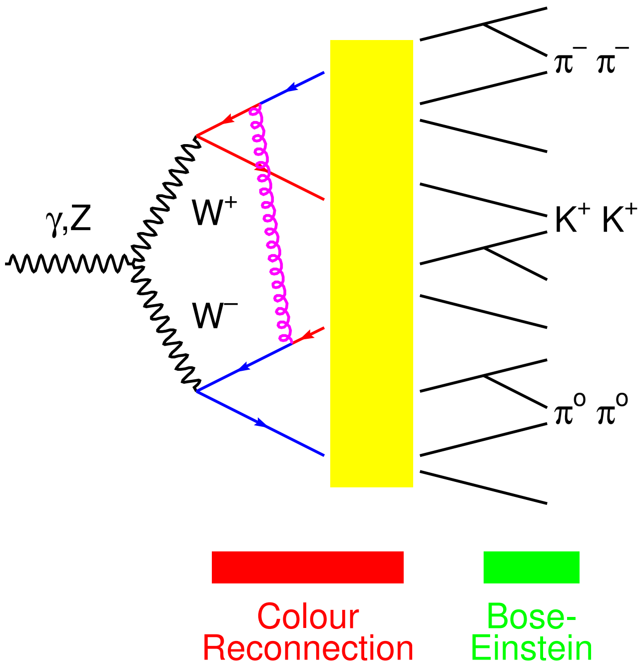
- Computation of $\frac{d\sigma}{dM_{\text{inv}}}(M_W)$ with reweighting of MC samples

$$w_i = \frac{\mathcal{M}^2(M_W)}{\mathcal{M}^2(M_W^{\text{MC}})}$$

The W-mass

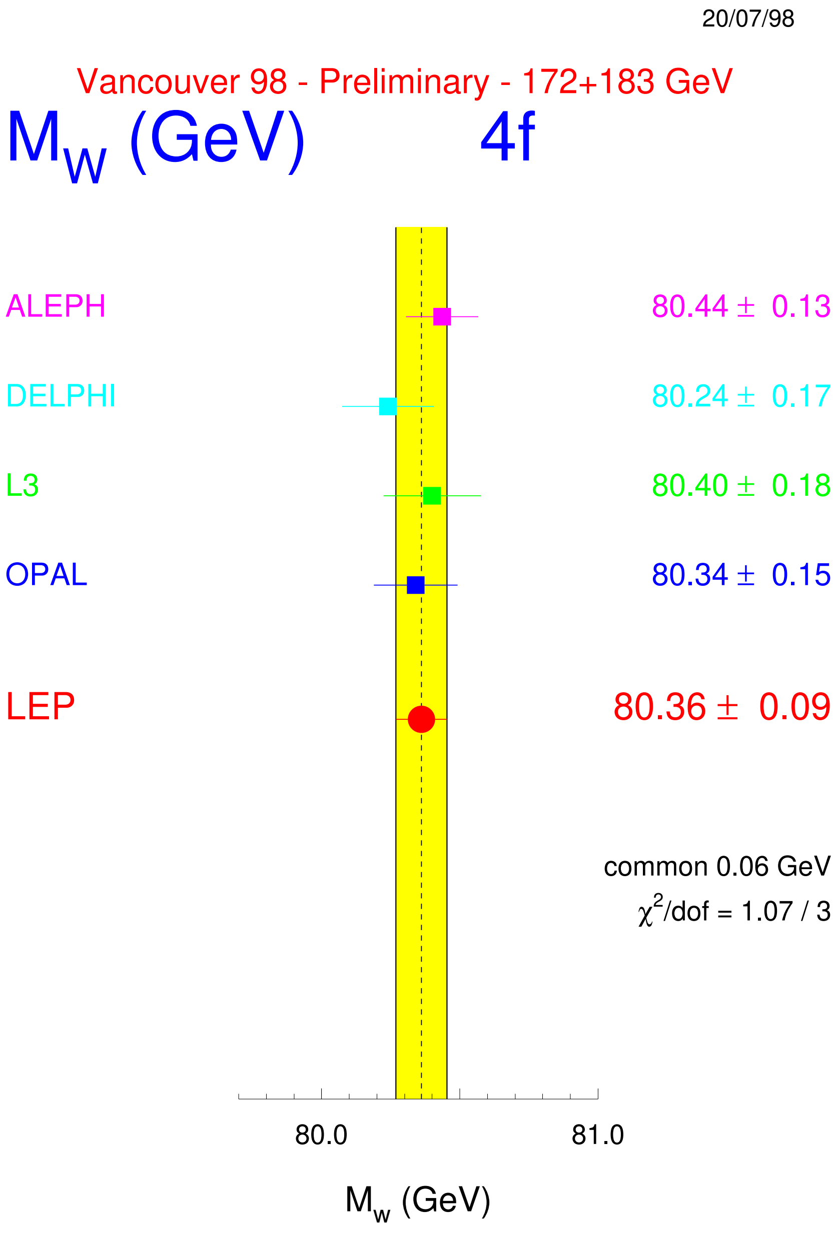


Color Reconnection and Bose Einstein effect mass measurement :



$$\langle N_{\text{ch}}^{qqqq} \rangle - 2\langle N_{\text{ch}}^{ql\nu} \rangle = -1.0 \pm 0.9$$

The W-mass at LEP



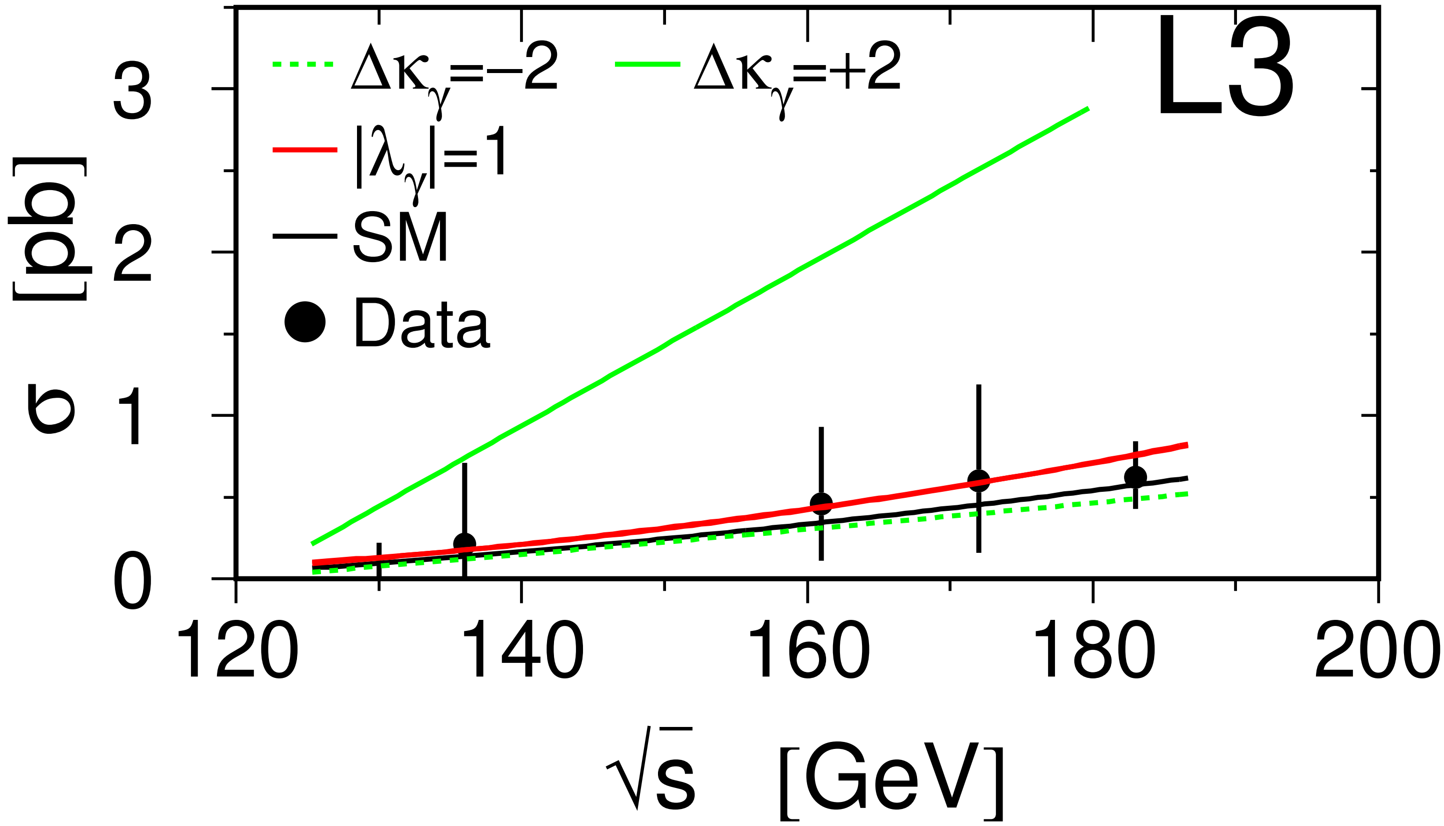
The coupling measurement

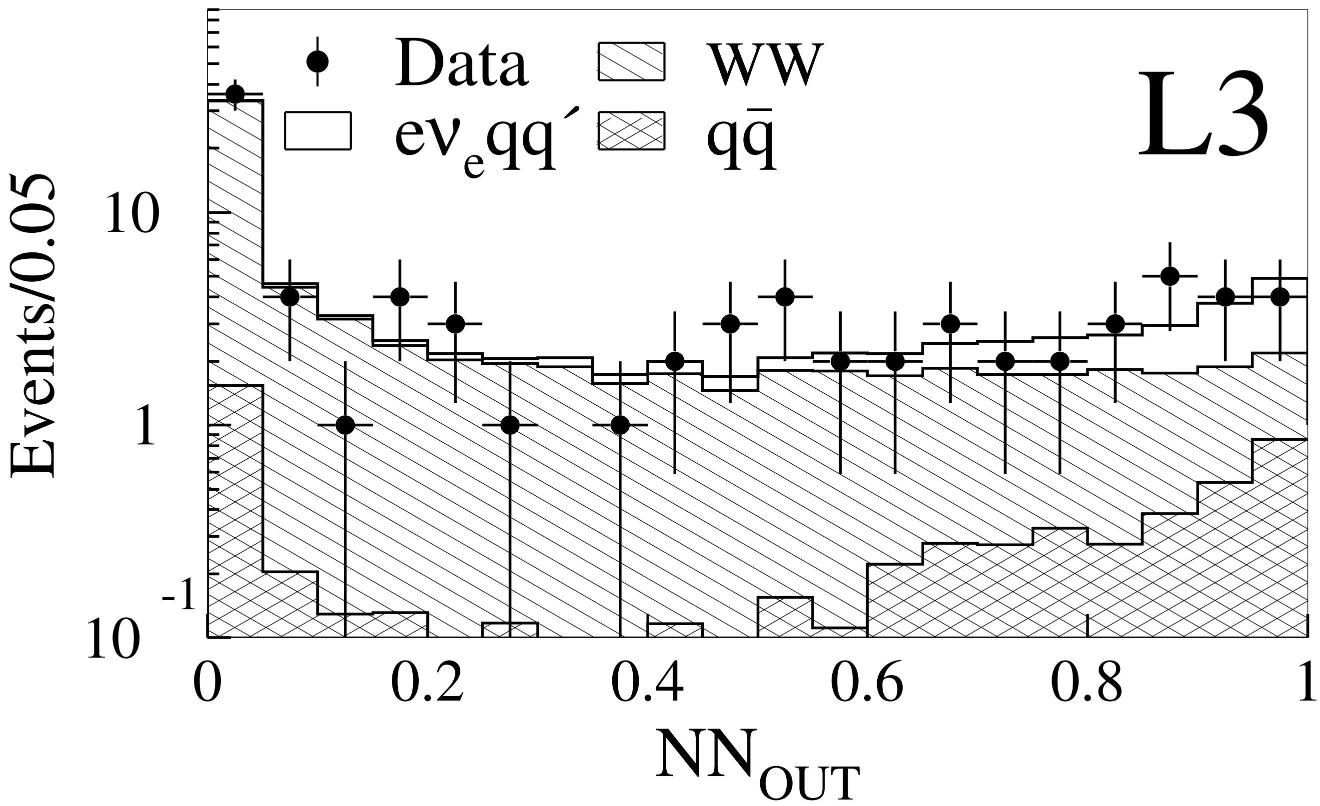
Fit of the total cross section

$$\ln \mathcal{L}_{\text{tot}} = \sum_{\text{channels}} \ln \left\{ \frac{\mu_i(\kappa_\gamma)^{N_i^{\text{data}}} e^{-\mu_i(\kappa_\gamma)}}{N_i^{\text{data}}!} \right\}$$

$$\mu_i(\kappa_\gamma) = L(\sigma(\kappa_\gamma)\epsilon(\kappa_\gamma) + \sigma_{\text{bckg}})$$

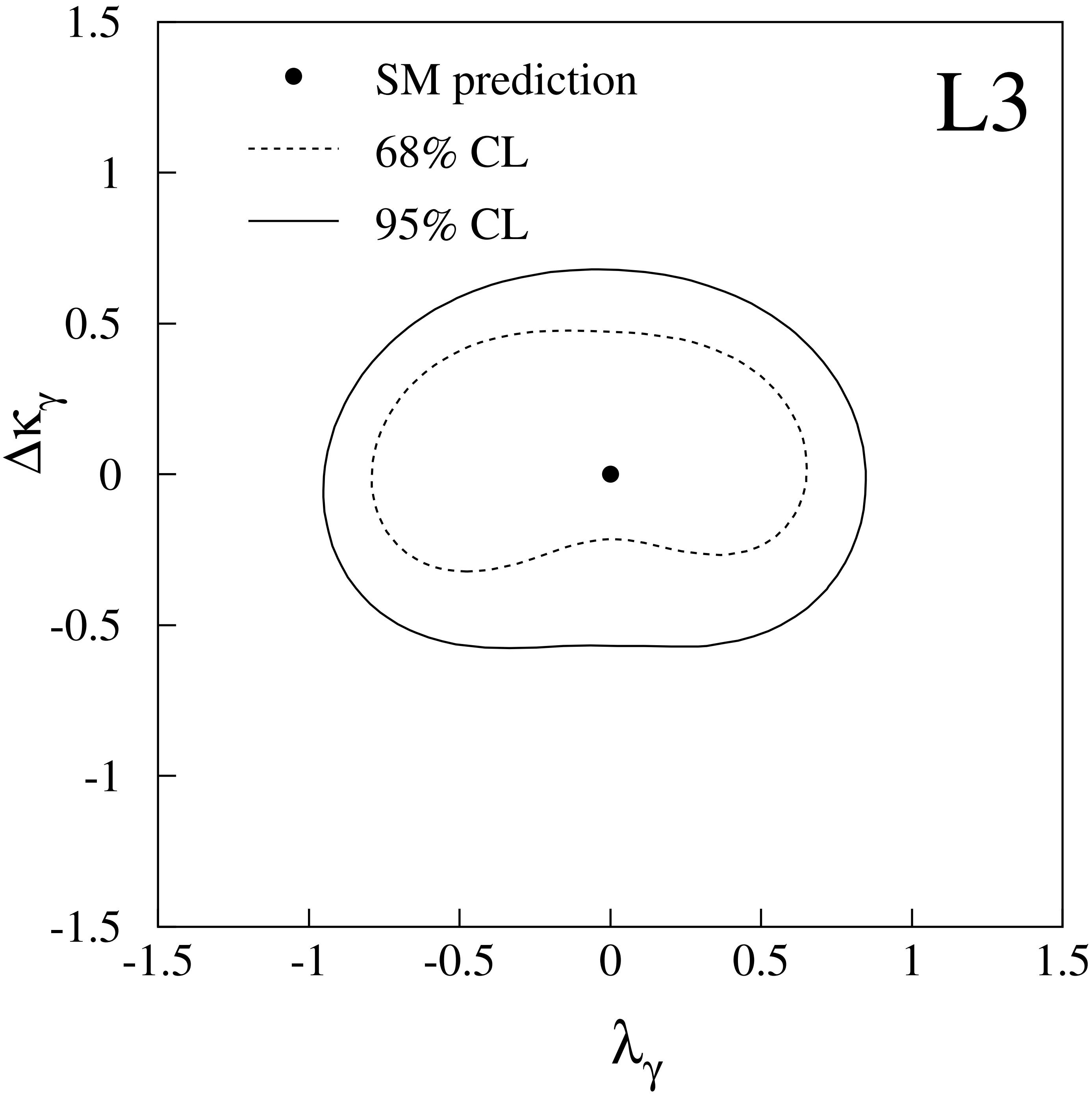
Fit of the differential cross section as for the mass


L3
Δκ_γ=−2
Δκ_γ=+2
|λ_γ|=1
SM
Data
σ [pb]
0
1
2
3
120
140
160
180
200
√s [GeV]

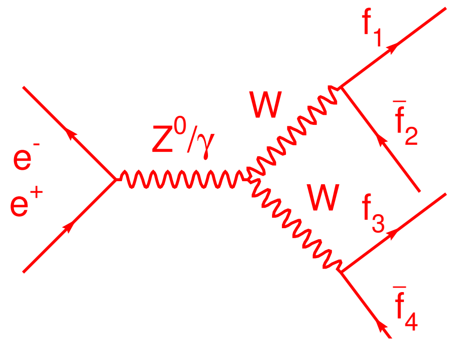

L3
Data
WW
eν_e qq´
q q̄
Events/0.05
10^-1
1
10
0
0.2
0.4
0.6
0.8
1
NN_OUT

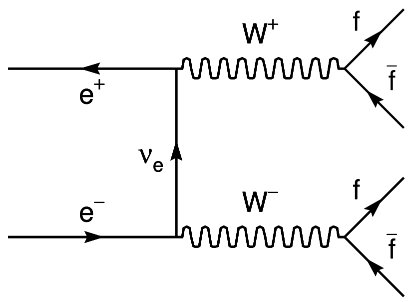
Fit of

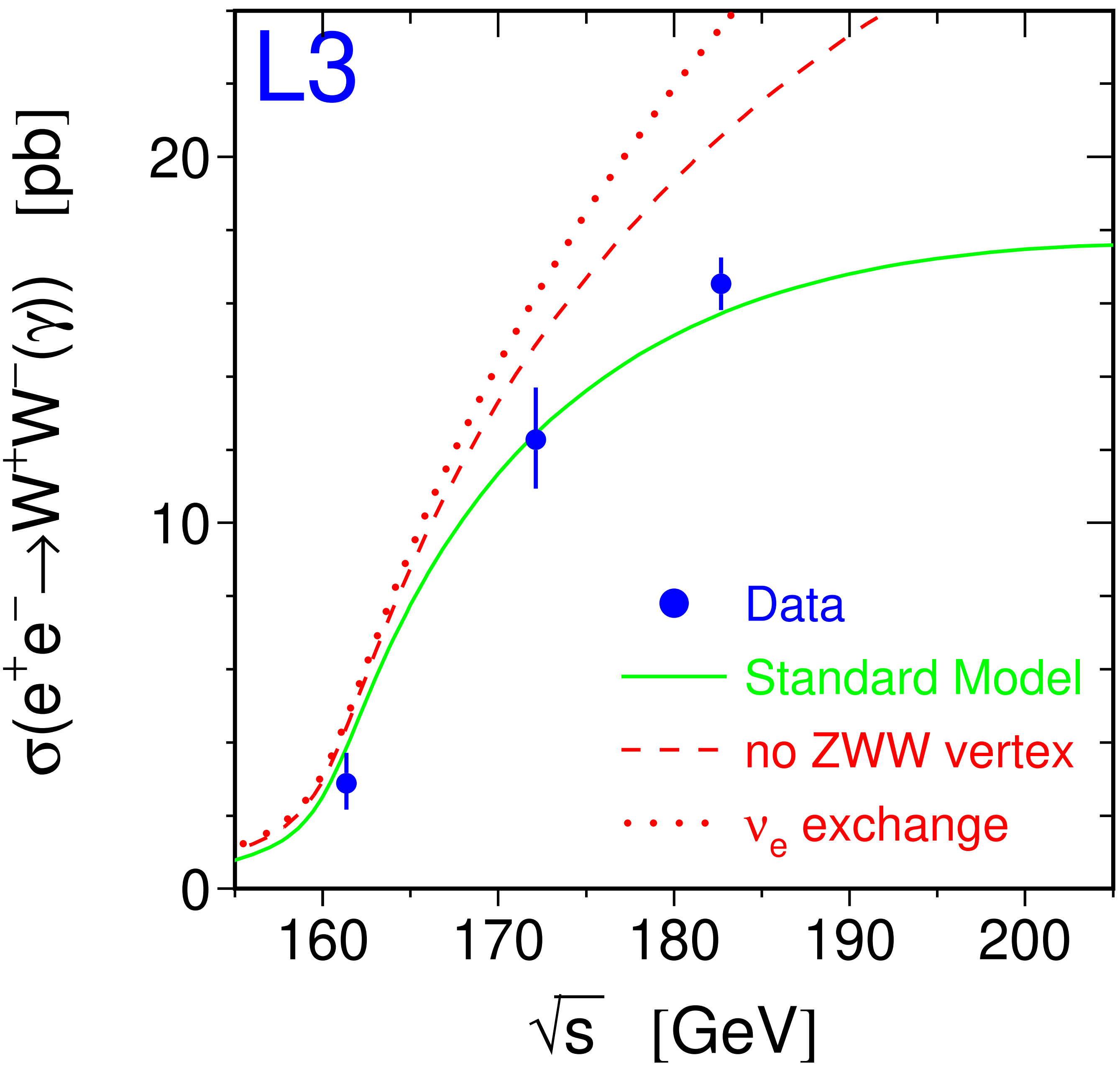
$\sigma(e\nu W \rightarrow l\nu, qq')$ and $\frac{1}{\sigma(e\nu W \rightarrow qq')} \frac{d\sigma(e\nu W \rightarrow qq')}{d(NN_{\text{out}})}$



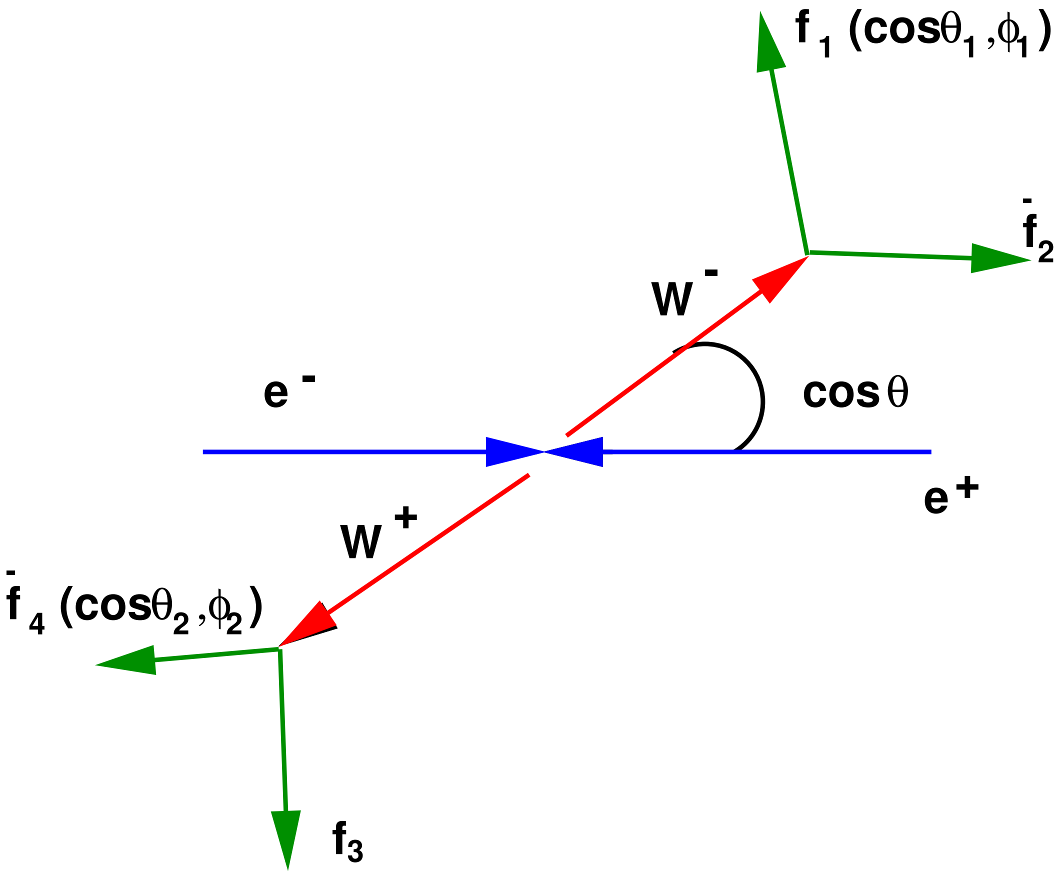
$e^+e^- \rightarrow W^+W^-$







Independent variables of WW-events



Number of independent variables :

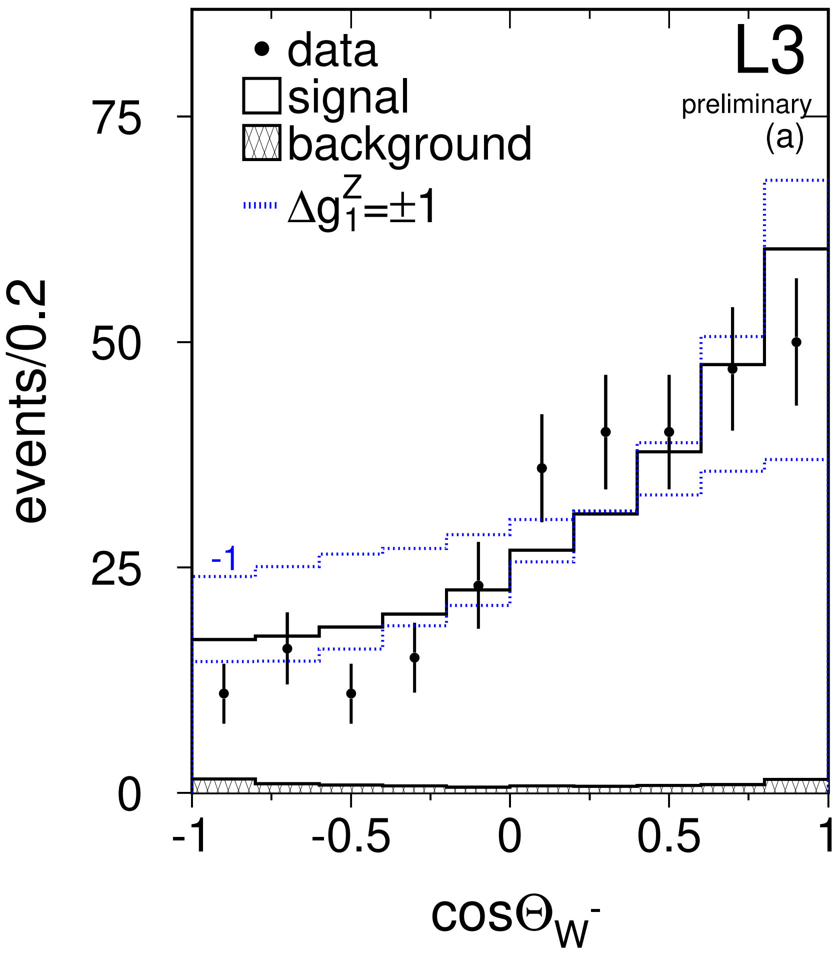
four four-momentum vectors	4×4
four momentum conservation	- 4
masses of final state particles	- 4
W-masses	- 2
assume azimuthal independence	- 1
number of independent parameters	= 5

Set of independent variables :

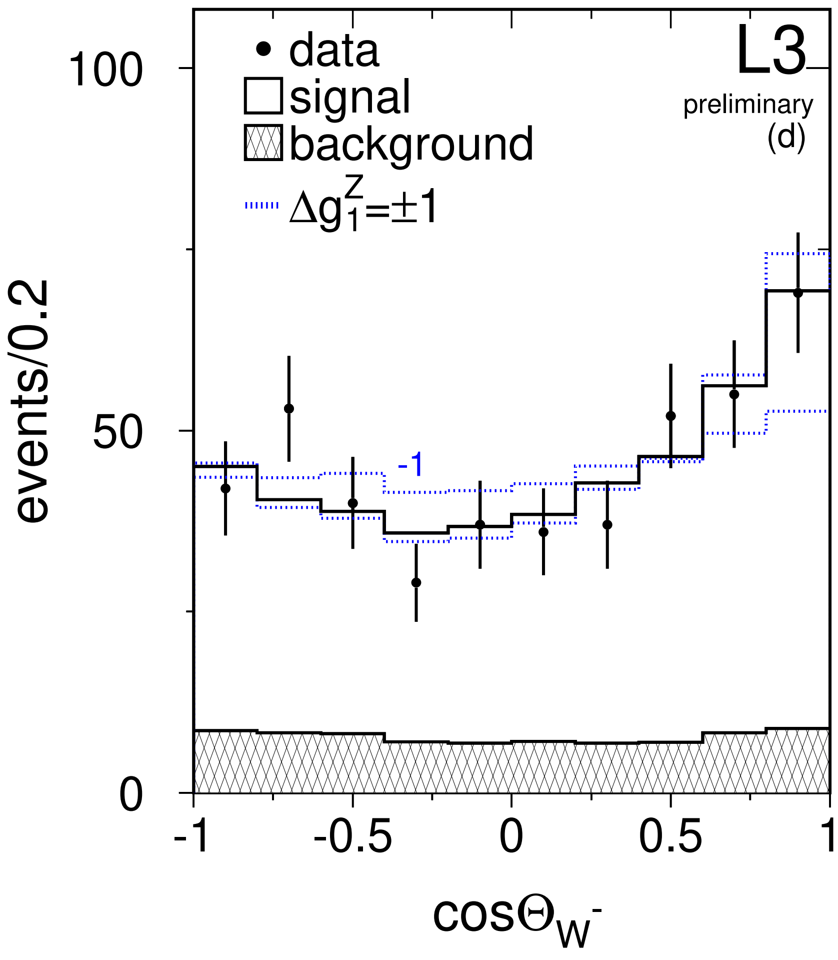
$$\Omega = \cos\theta_W, \cos\theta_1, \phi_1, \cos\theta_2, \phi_2$$

$qql\nu_l$

$qqqq$

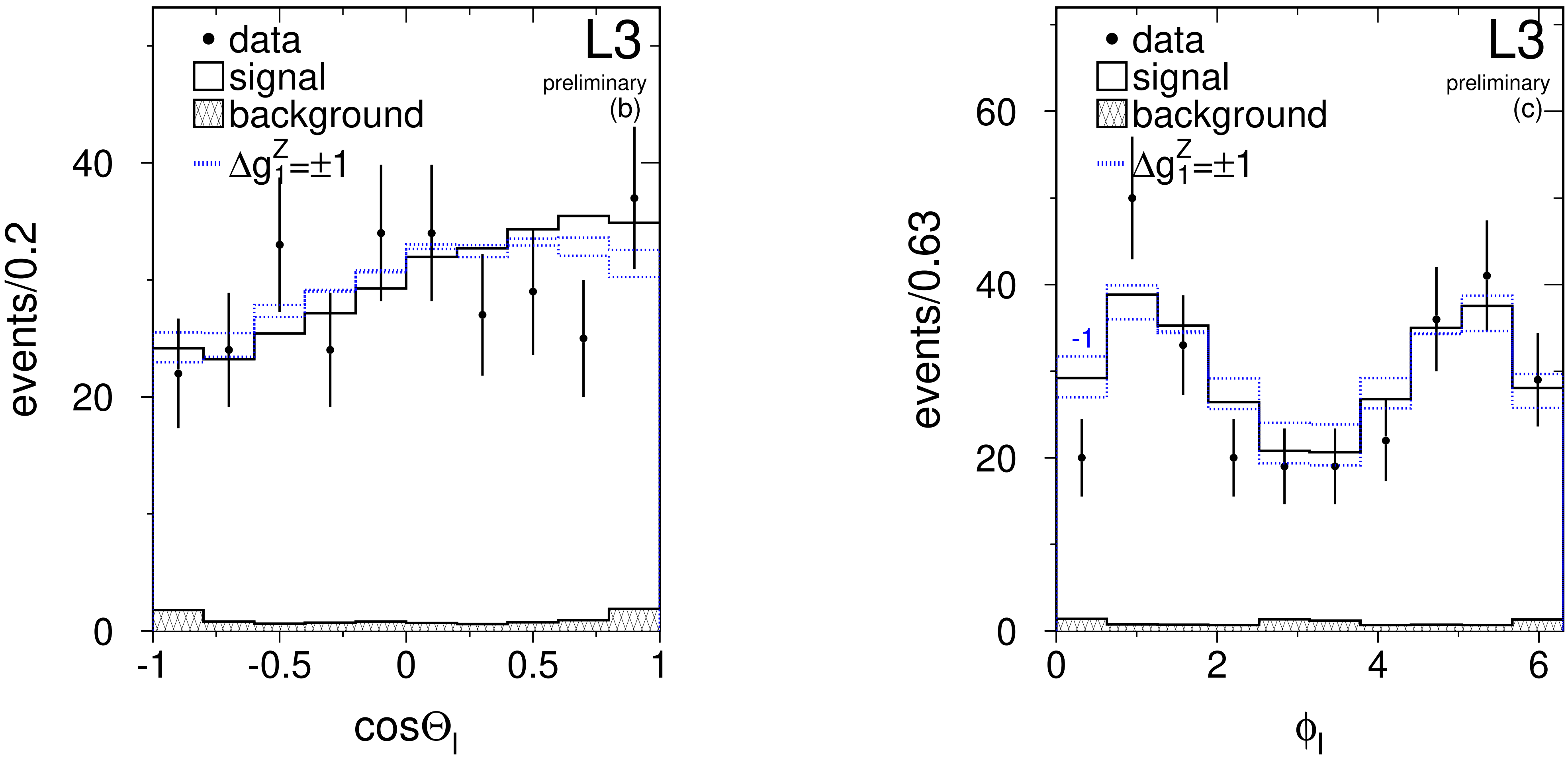


data
signal
background
Δg1Z=±1
L3
preliminary
(a)
-1
events/0.2
cosΘW-



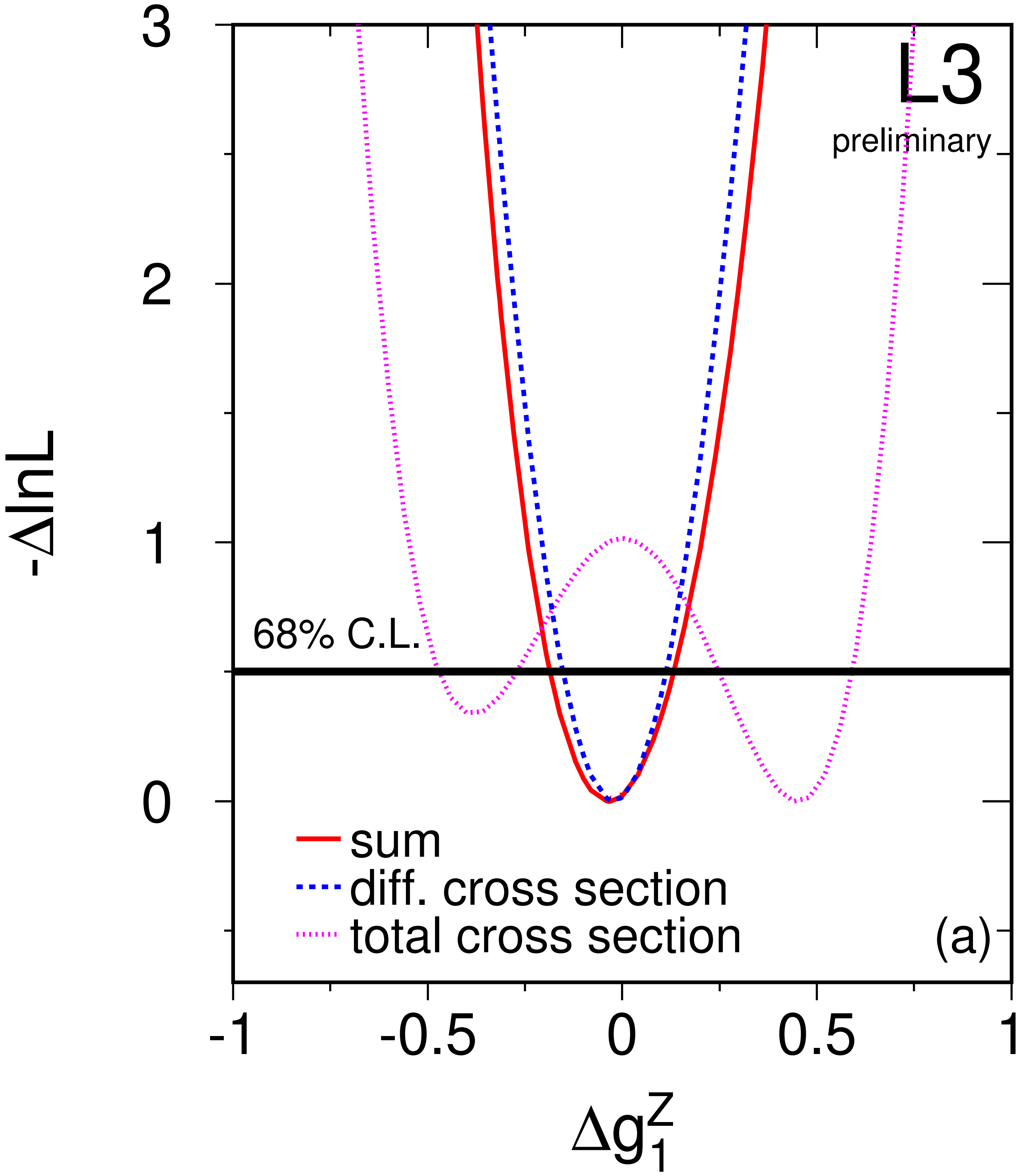
data
signal
background
Δg1Z=±1
L3
preliminary
(d)
-1
events/0.2
cosΘW-

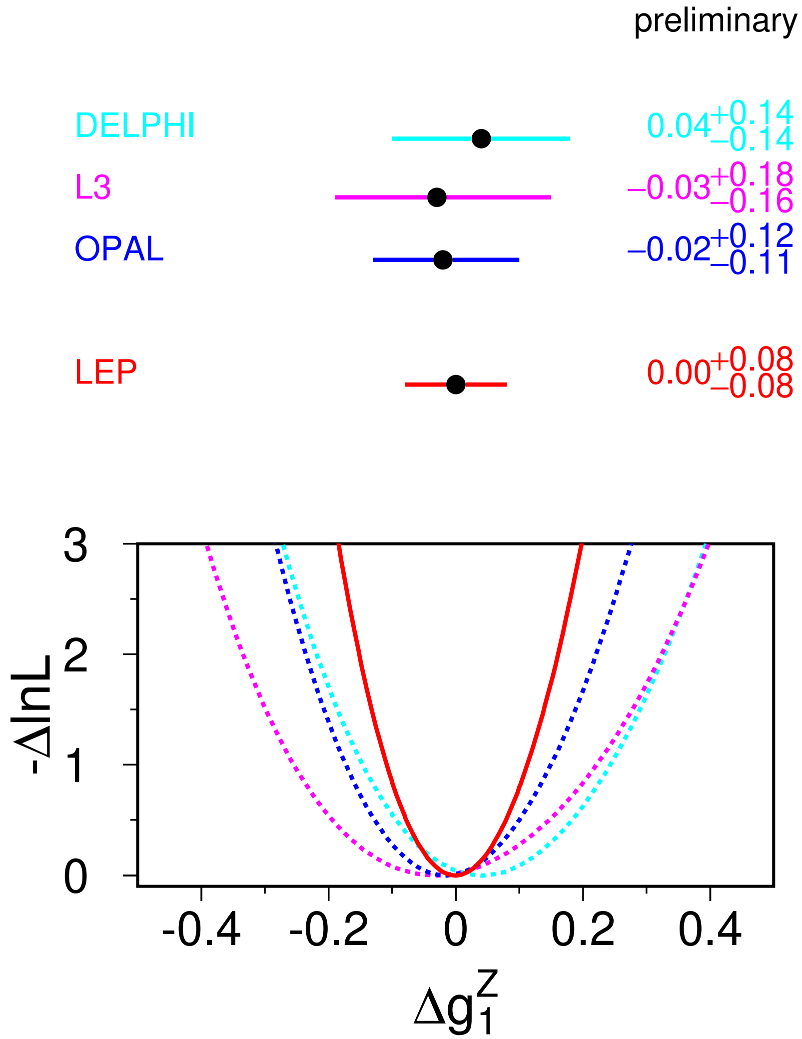
$qql\nu_l$

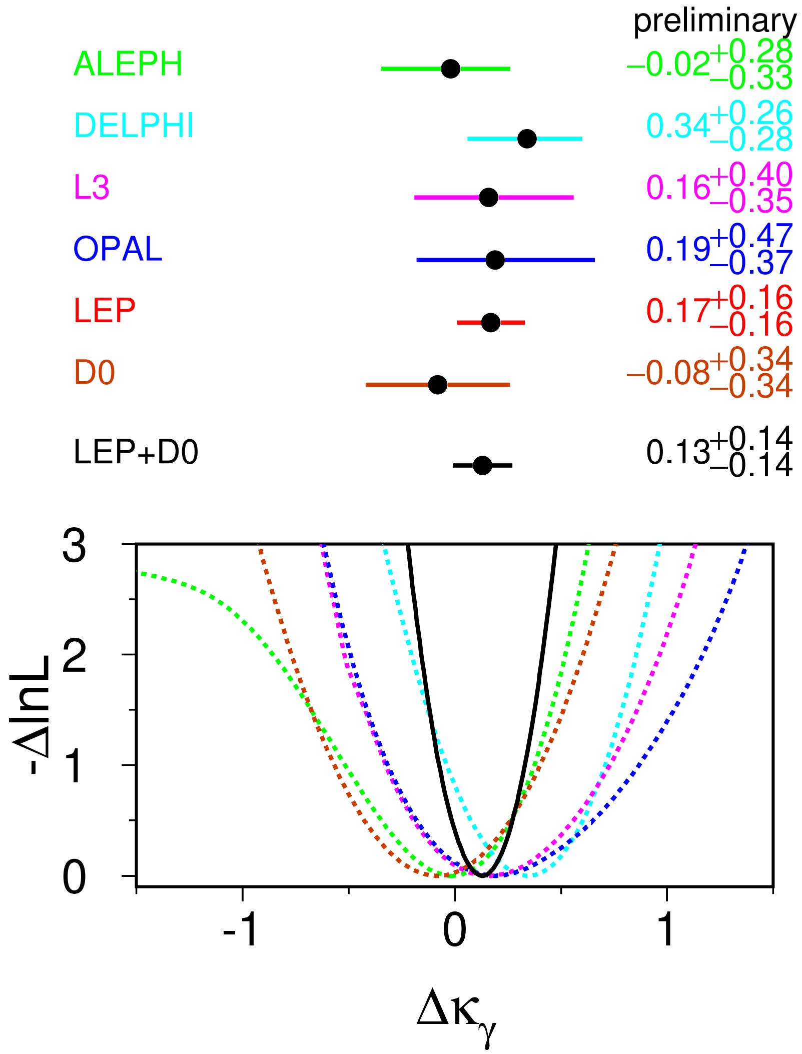


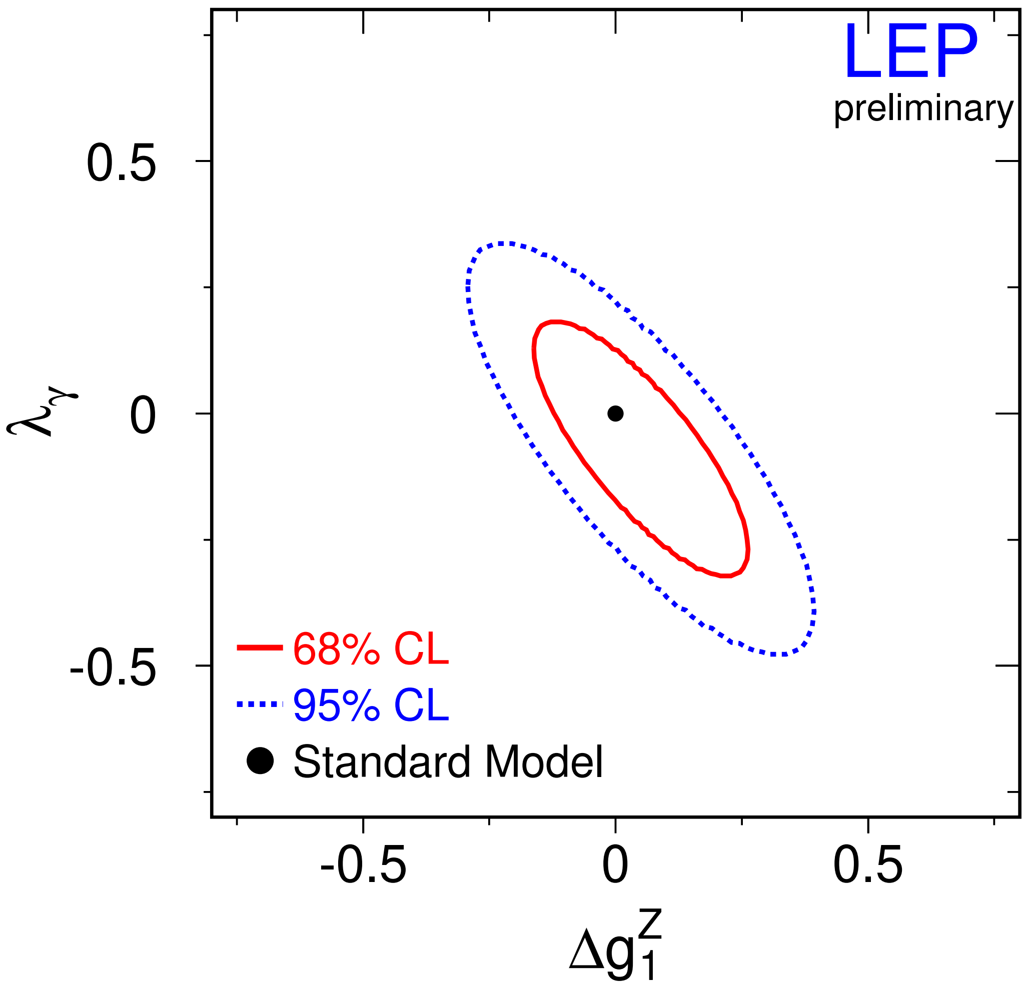
data
signal
background
$\Delta g_1^Z=\pm1$
L3
preliminary
(b)
events/0.2
40
20
0
-1
-0.5
0
0.5
1
$\cos\Theta_l$
data
signal
background
$\Delta g_1^Z=\pm1$
L3
preliminary
(c)
-1
events/0.63
60
40
20
0
2
4
6
ϕ_l

Coupling measurement

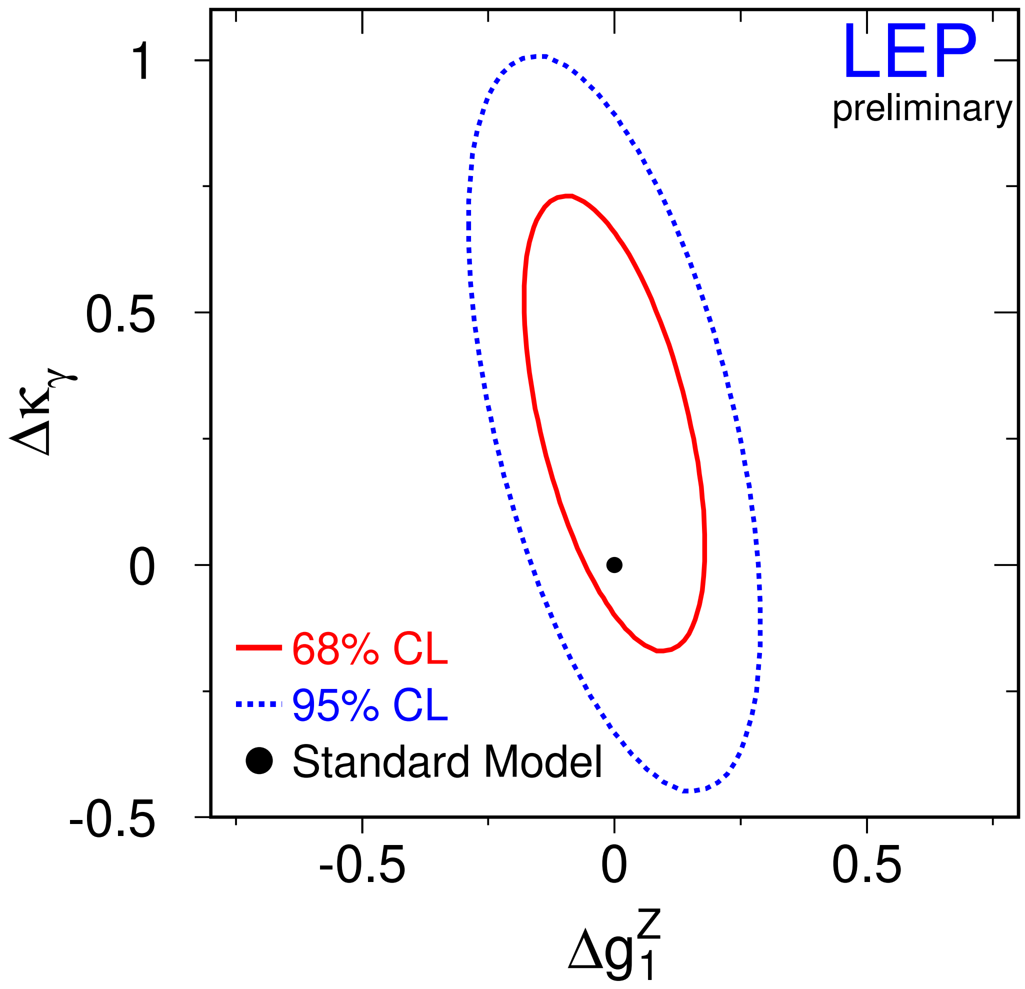



preliminary
DELPHI
$0.04^{+0.14}_{-0.14}$
L3
$-0.03^{+0.18}_{-0.16}$
OPAL
$-0.02^{+0.12}_{-0.11}$
LEP
$0.00^{+0.08}_{-0.08}$
-ΔlnL
Δg_1^Z


preliminary
ALEPH
$-0.02^{+0.28}_{-0.33}$
DELPHI
$0.34^{+0.26}_{-0.28}$
L3
$0.16^{+0.40}_{-0.35}$
OPAL
$0.19^{+0.47}_{-0.37}$
LEP
$0.17^{+0.16}_{-0.16}$
D0
$-0.08^{+0.34}_{-0.34}$
LEP+D0
$0.13^{+0.14}_{-0.14}$
-ΔlnL
$\Delta\kappa_\gamma$



LEP
preliminary
0.5
0
-0.5
λ_γ
-0.5
0
0.5
Δg_1^Z
68% CL
95% CL
Standard Model



LEP
preliminary
1
0.5
0
-0.5
$\Delta\kappa_\gamma$
-0.5
0
0.5
Δg_1^Z
68% CL
95% CL
Standard Model

Summary

Non abelian gauge theories require γ/Z-WW vertex

experimental proof of the existence of the ZWW and the γWW vertex

- $g_1^Z = 1.00 \pm 0.08$
- $\kappa_\gamma = 1.13 \pm 0.14$
- $\lambda_\gamma = -0.03 \pm 0.07$

LEP 1 and LEP 2 W-mass are compatible !

- $M_W = 80.36 \pm 0.09$ GeV

At the end of LEP II :

- error of Δg_1^Z, $\lambda_\gamma < 0.04$
- error on $M_W < 0.04$ GeV

- short term : TEVATRON Run II

  $> \mathbf{20}\times$ luminosity $\Rightarrow$

  $$|\boldsymbol{\Delta\kappa_\gamma}| < \mathbf{0.1},\ |\boldsymbol{\lambda_\gamma}| < \mathbf{0.03}$$

- long term :
  - LHC $|\boldsymbol{\Delta\kappa_\gamma}| < \mathbf{0.04},\ |\boldsymbol{\Delta\kappa_Z}| < \mathbf{0.07},$ $|\boldsymbol{\lambda_\gamma}| < \mathbf{0.0025},\ |\boldsymbol{\lambda_Z}| < \mathbf{0.005}$
  - LC ?

The Three Boson Vertex

Extending the Lagrangian to an effective Lagrangian (purely phenomenological) including C/P and CP violating terms

$$\imath \frac{\mathcal{L}_{eff}^{WWV}}{g_{WWV}} = g_1^V V^\mu \left(W_{\mu\nu}^- W^{+\nu} - W_{\mu\nu}^+ W^{-\nu} \right)$$

$$+ \kappa_V W_\mu^+ W_\nu^- V^{\mu\nu}$$

$$+ \frac{\lambda_V}{m_W^2} V^{\mu\nu} W_\nu^{+\rho} W_{\rho\mu}^-$$

$$+ \imath g_5^V \epsilon_{\mu\nu\rho\sigma} \left(\left(\partial^\rho W^{-\mu} \right) W^{+\nu} - W^{-\mu} \left(\partial^\rho W^{+\nu} \right) \right) V^\sigma$$

$$+ \imath g_4^V W_\mu^- W_\nu^+ \left(\partial^\mu V^\nu + \partial^\nu V^\mu \right)$$

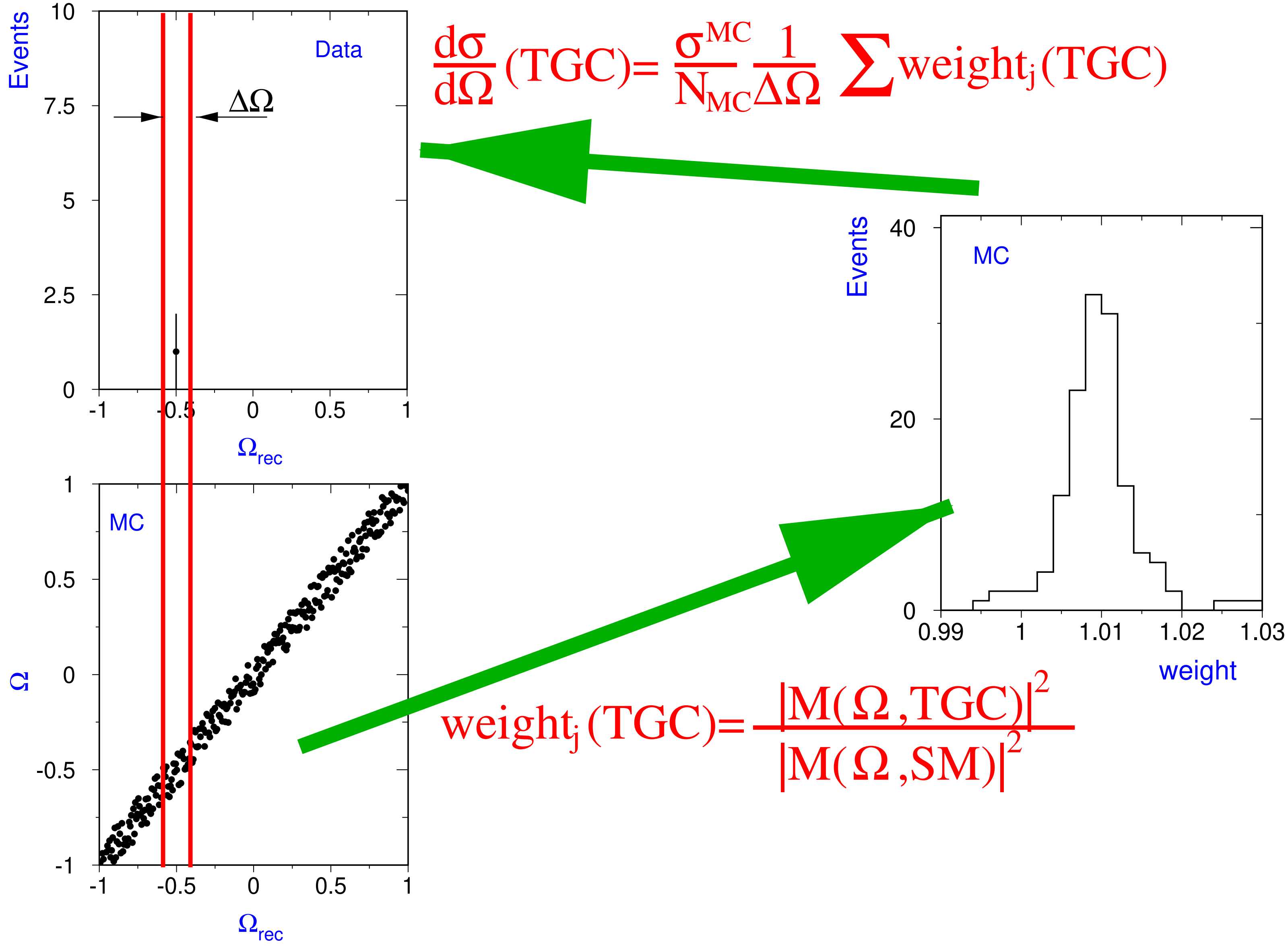
$$- \frac{\tilde{\kappa}_V}{2} W_\mu^- W_\nu^+ \epsilon^{\mu\nu\rho\sigma} V_{\rho\sigma}$$

$$- \frac{\tilde{\lambda}_V}{2m_W^2} W_{\rho\mu}^- W_\nu^{+\mu} \epsilon^{\nu\rho\alpha\beta} V_{\alpha\beta}$$

The Three Boson Vertex

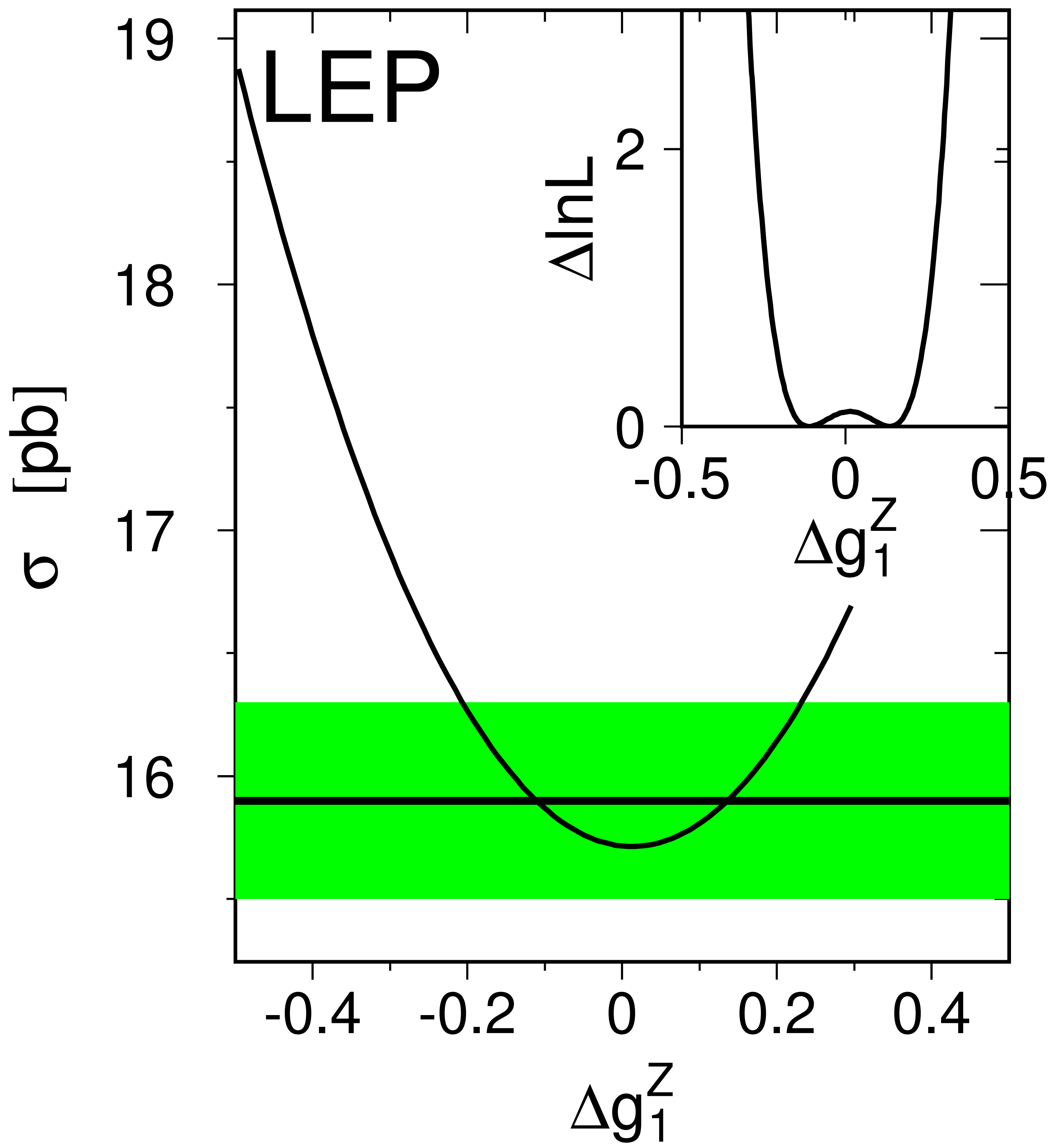
$$\mathcal{L}_{d=6}^{\mathrm{TGC}} = \imath g' \frac{\alpha_{B\phi}}{m_W^2} (D_\mu \Phi)^\dagger B^{\mu\nu} (D_\nu \Phi)$$
$$+ \imath g \frac{\alpha_{W\phi}}{m_W^2} (D_\mu \Phi)^\dagger \vec{\tau} \cdot \vec{\hat{W}}^{\mu\nu} (D_\nu \Phi)$$
$$+ g \frac{\alpha_W}{6 m_W^2} \vec{\hat{W}}^{\mu}{}_{\nu} \cdot (\vec{\hat{W}}^{\nu}{}_{\rho} \times \vec{\hat{W}}^{\rho}{}_{\mu})$$

$$\hat{W}_{\mu\nu} = W_{\mu\nu} - g W_\mu \times W_\nu$$

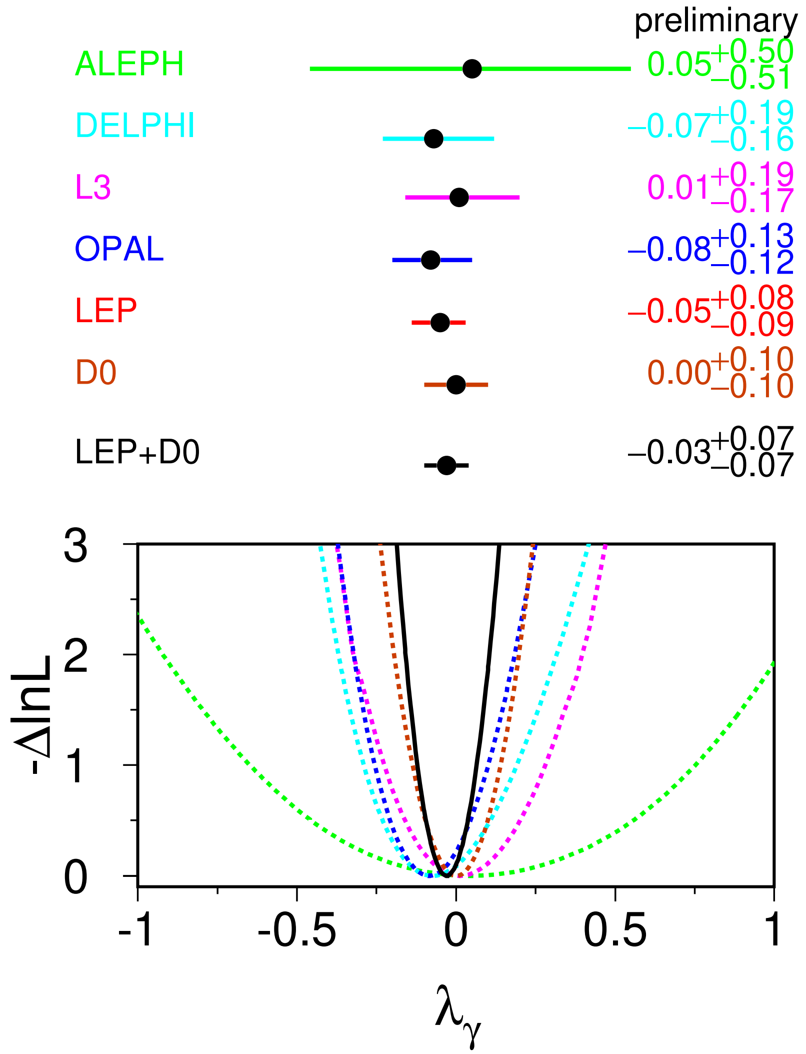


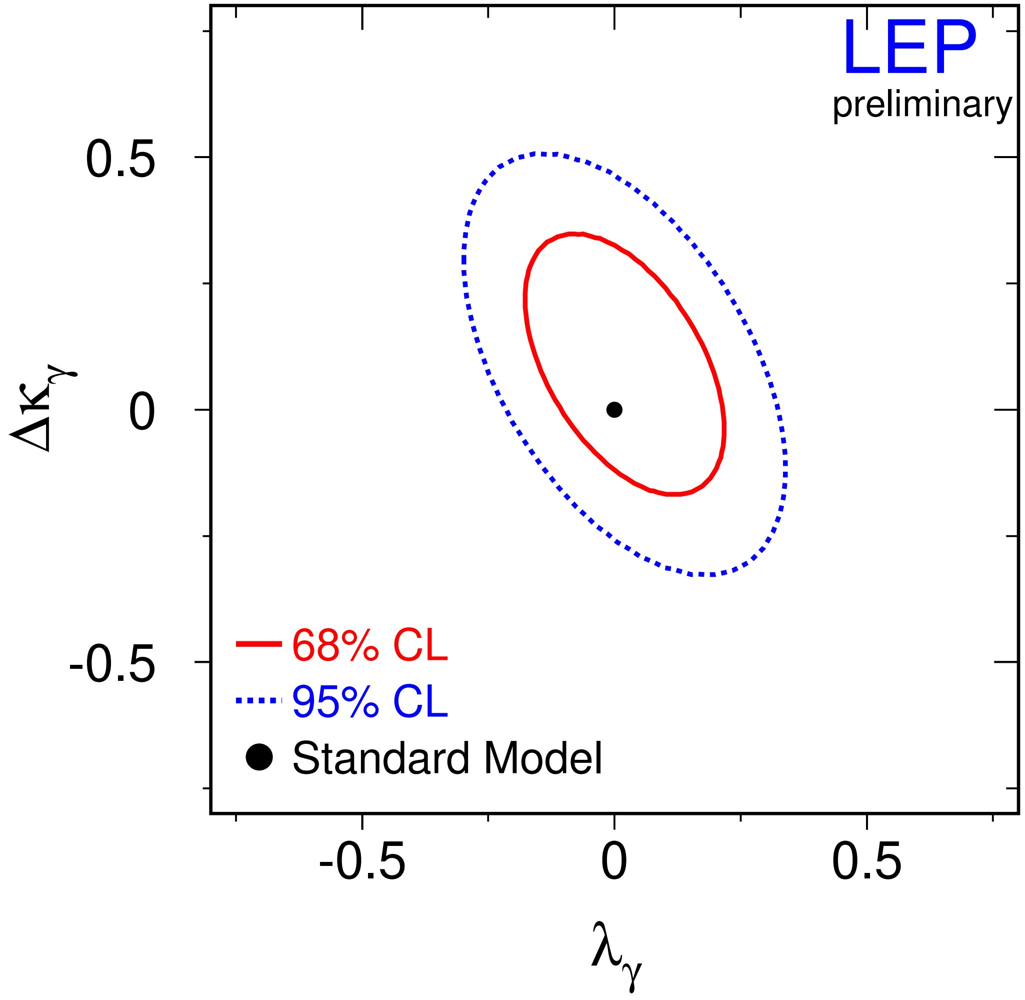
$$\frac{d\sigma}{d\Omega}(TGC) = \frac{\sigma^{MC}}{N_{MC}}\frac{1}{\Delta\Omega}\sum weight_j(TGC)$$

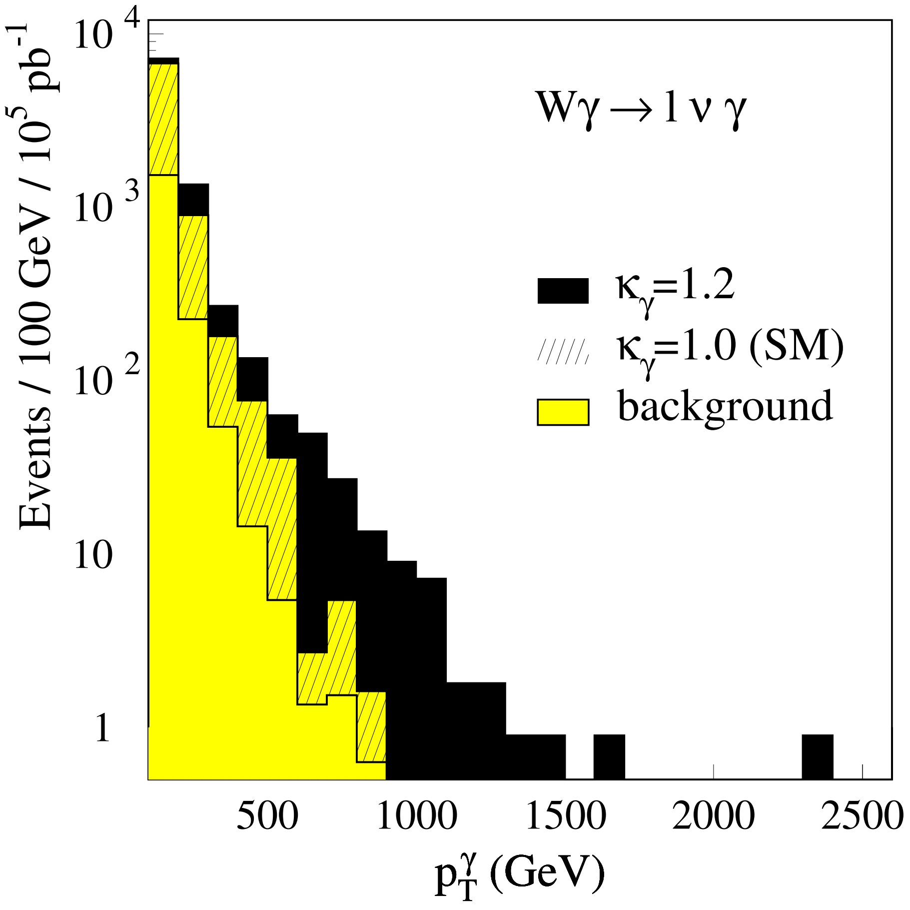
$$weight_j(TGC) = \frac{|M(\Omega, TGC)|^2}{|M(\Omega, SM)|^2}$$

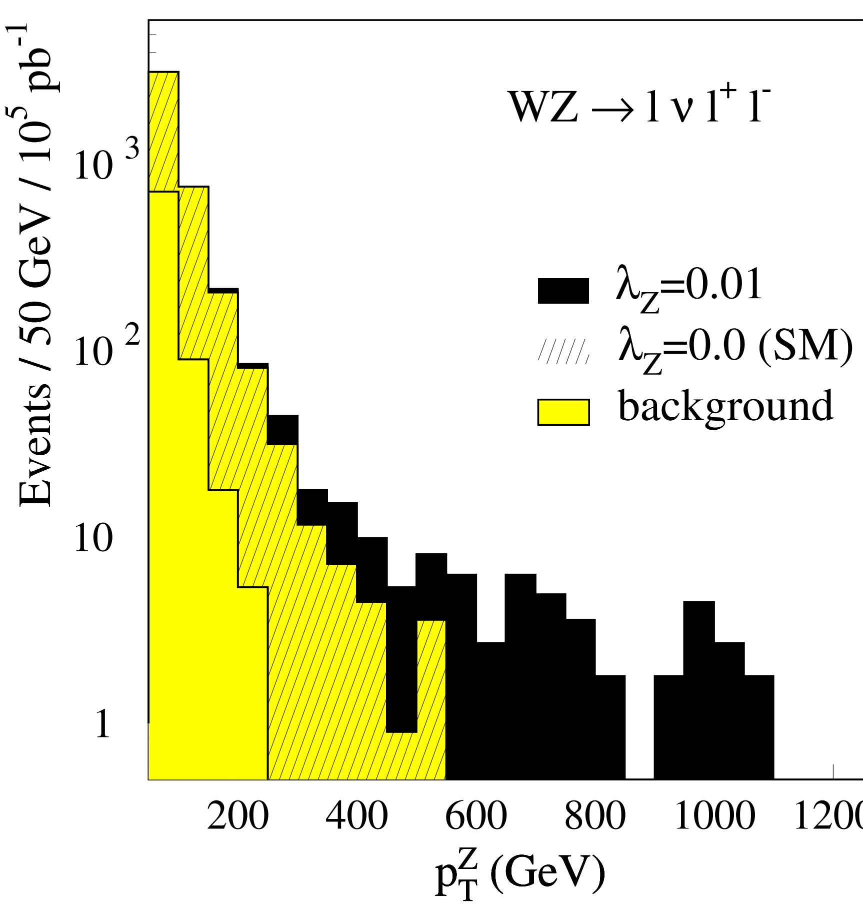


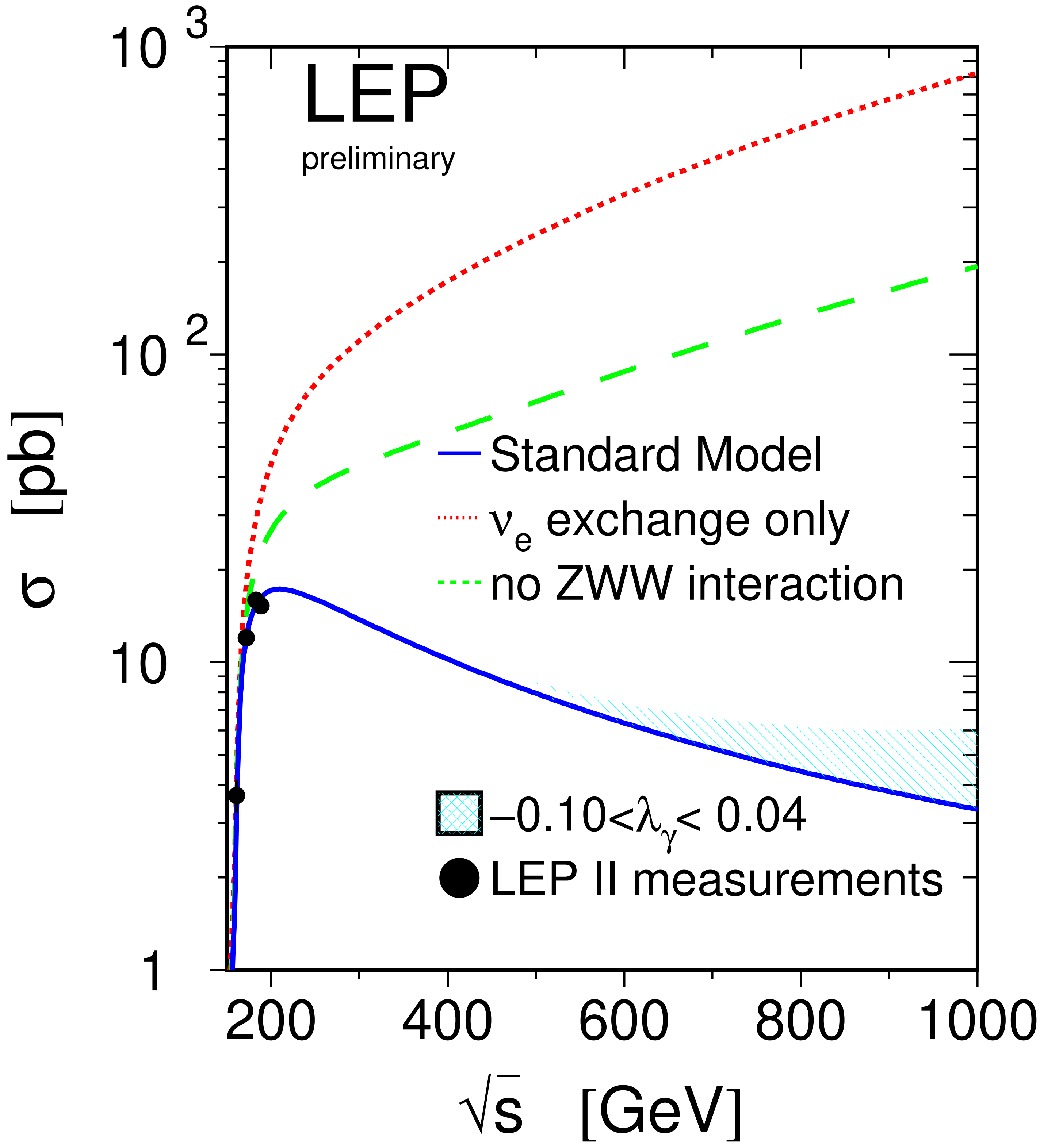
LEP
19
18
17
16
σ [pb]
-0.4
-0.2
0
0.2
0.4
Δg_1^Z
ΔlnL
2
0
-0.5
0
0.5
Δg_1^Z


preliminary
ALEPH
0.05 +0.50 −0.51
DELPHI
−0.07 +0.19 −0.16
L3
0.01 +0.19 −0.17
OPAL
−0.08 +0.13 −0.12
LEP
−0.05 +0.08 −0.09
D0
0.00 +0.10 −0.10
LEP+D0
−0.03 +0.07 −0.07
-ΔlnL
λγ


LEP
preliminary
Δκγ
λγ
68% CL
95% CL
Standard Model


$W\gamma \rightarrow l\,\nu\,\gamma$
κ_γ=1.2
κ_γ=1.0 (SM)
background
Events / 100 GeV / 10^5 pb^{-1}
p_T^γ (GeV)
1
10
10^2
10^3
10^4
500
1000
1500
2000
2500


$WZ \rightarrow l\,\nu\,l^+\,l^-$
λ_Z=0.01
λ_Z=0.0 (SM)
background
Events / 50 GeV / 10^5 pb^{-1}
p_T^Z (GeV)
1
10
10^2
10^3
200
400
600
800
1000
1200


LEP
preliminary
Standard Model
ν_e exchange only
no ZWW interaction
$-0.10<\lambda_\gamma<0.04$
LEP II measurements
10^3
10^2
10
1
200
400
600
800
1000
σ [pb]
$\sqrt{s}$ [GeV]