Measurements of the selfcoupling of electroweak bosons at LEP II

Peter Molnár

Humboldt Universität zu Berlin
& L3 Collaboration

Workshop on Physics and Detectors for Future
$e^{+}e^{-}$ Linear Colliders
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Outline

The Triple-Gauge Boson Vertex

Coupling measurements in

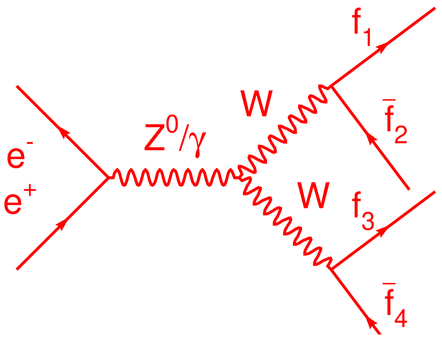
$e^+e^- \to \nu\nu\gamma$

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

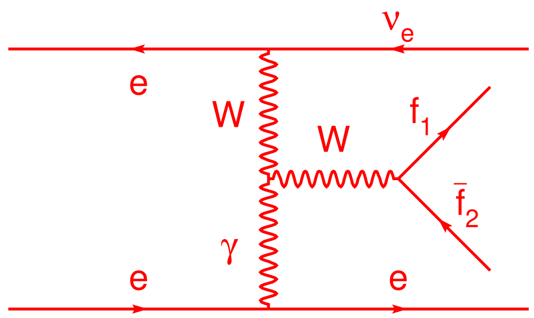
$e^+e^- \to W^+W^-$

Summary

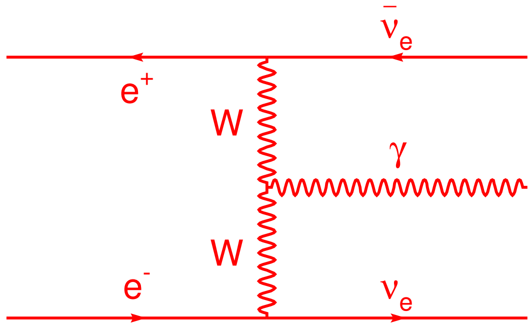
$e^+e^- \to W^+W^-$



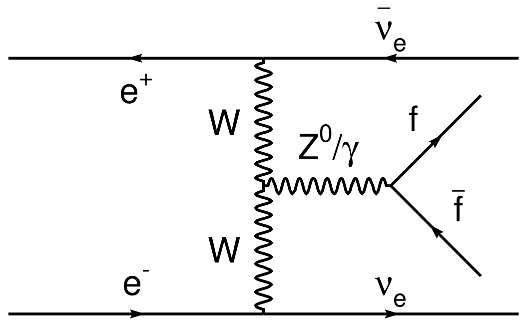
$e^+e^- \to We\nu_e$



$e^+e^- \to \nu\nu\gamma$



Not discussed :



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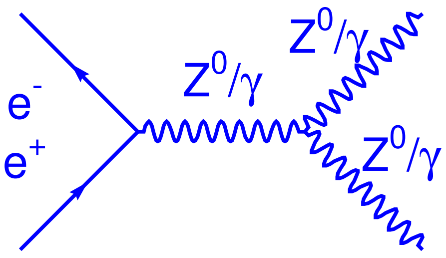
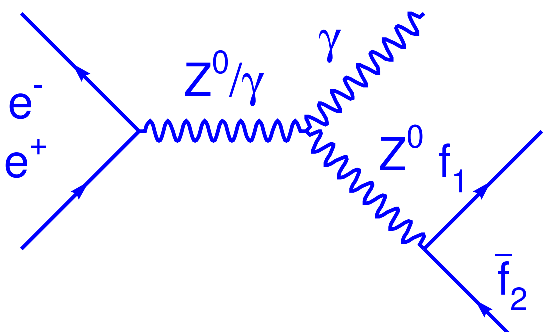
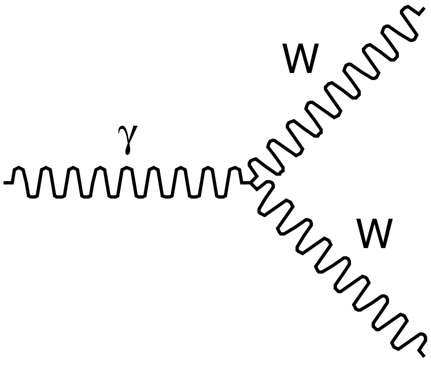




The Three Boson Vertex

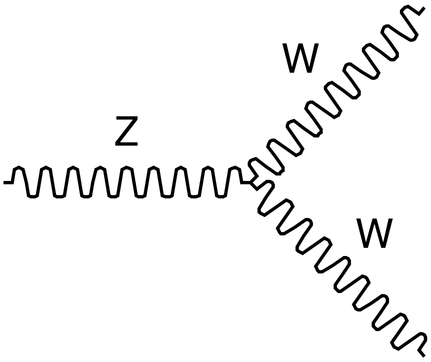


$$E1 = eg_1^\gamma$$

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

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

SM : $g_\gamma^1 = 1,\ \kappa_\gamma = 1,\ \lambda_\gamma = 0$



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

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

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

The Three Boson Vertex

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

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

$$+ \kappa_V W^+_\mu W^-_\nu V^{\mu\nu}$$

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

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

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

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

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

The Three Boson Vertex

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

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

The Three Boson Vertex

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 :

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

observable consequences :

- total cross section is coupling dependent $\boldsymbol{\sigma = \sigma(TGC)}$
- differential cross section is coupling dependent $\boldsymbol{\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}(TGC)}$
- dependence on TGC constants is quadratic

The coupling measurement

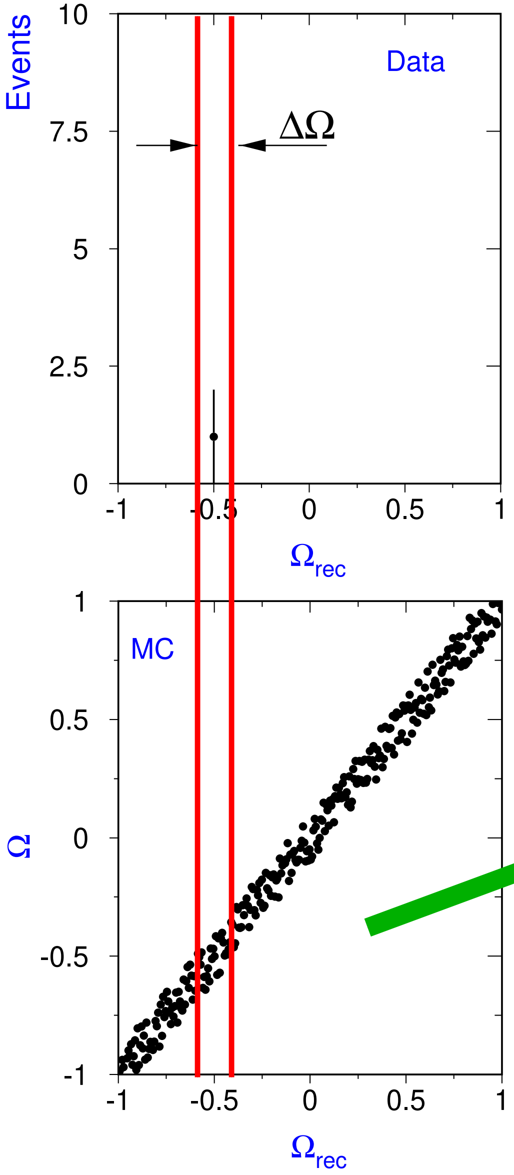
Fit of the total cross section

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

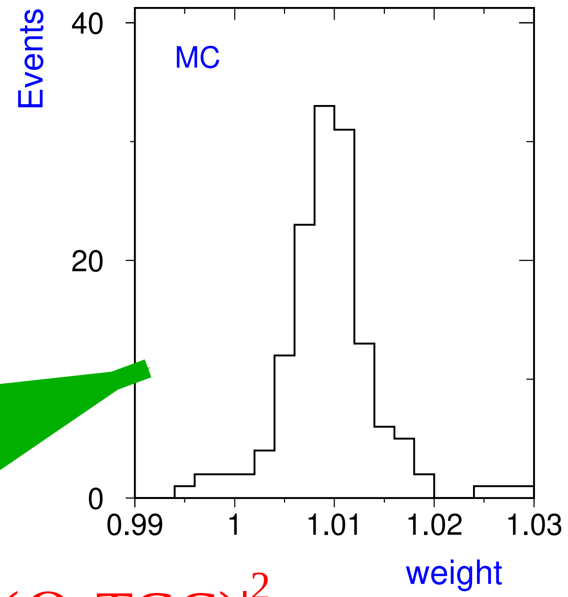
$$\mu_i(\kappa_\gamma) = L(\sigma(\kappa_\gamma)\epsilon(\kappa_\gamma) + \sigma_{\text{bckg}})$$

Fit of the differential cross section
(e.g. $e^+e^- \to \nu\nu\gamma$)

$$\ln \mathcal{L}_{\text{diff}} = \sum_{\text{events}} \ln \left\{ \frac{1}{\sigma(\kappa_\gamma)} \cdot \frac{d^2\sigma}{dE_\gamma d\cos\theta_\gamma}(\kappa_\gamma) \right\}$$

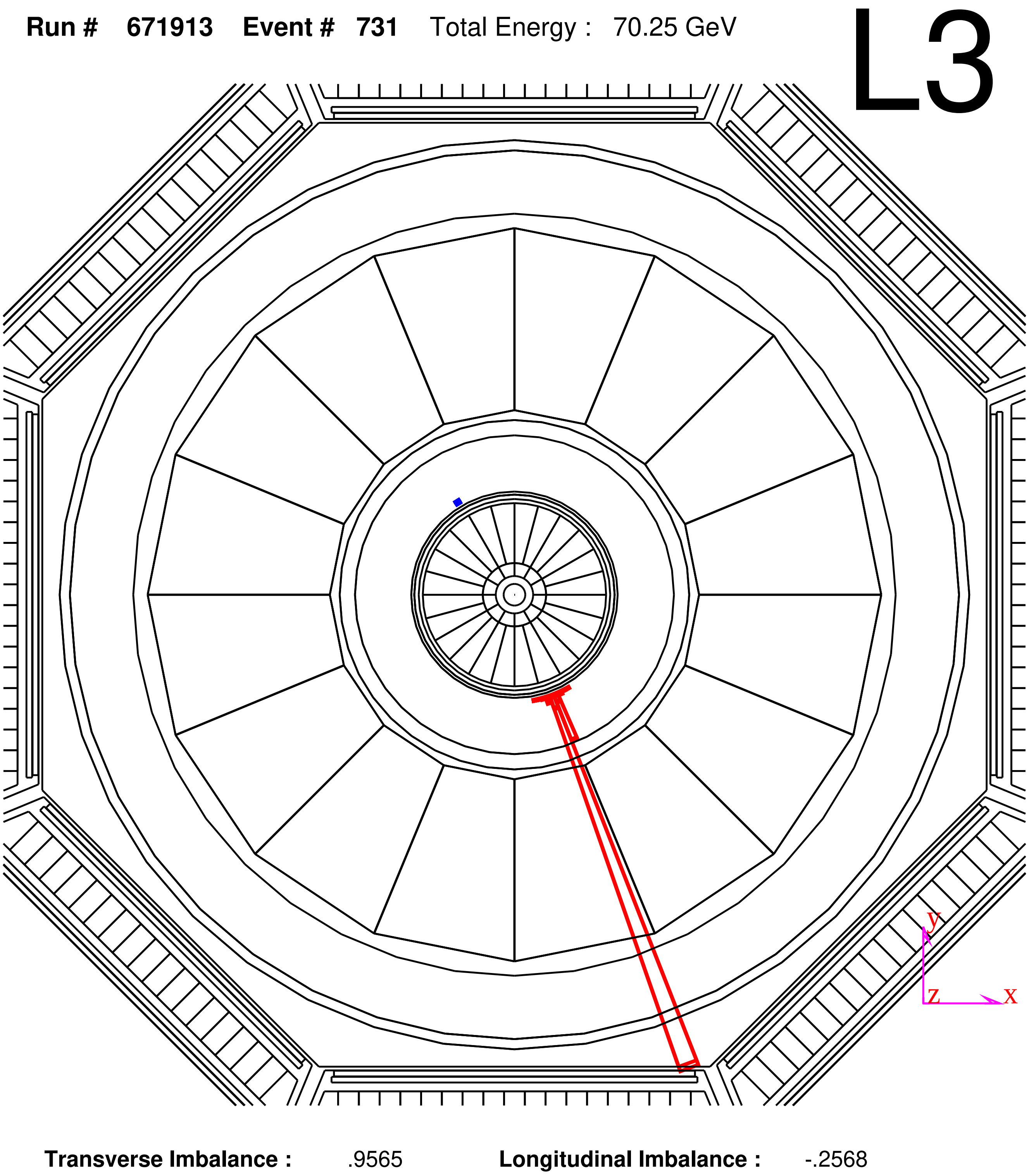


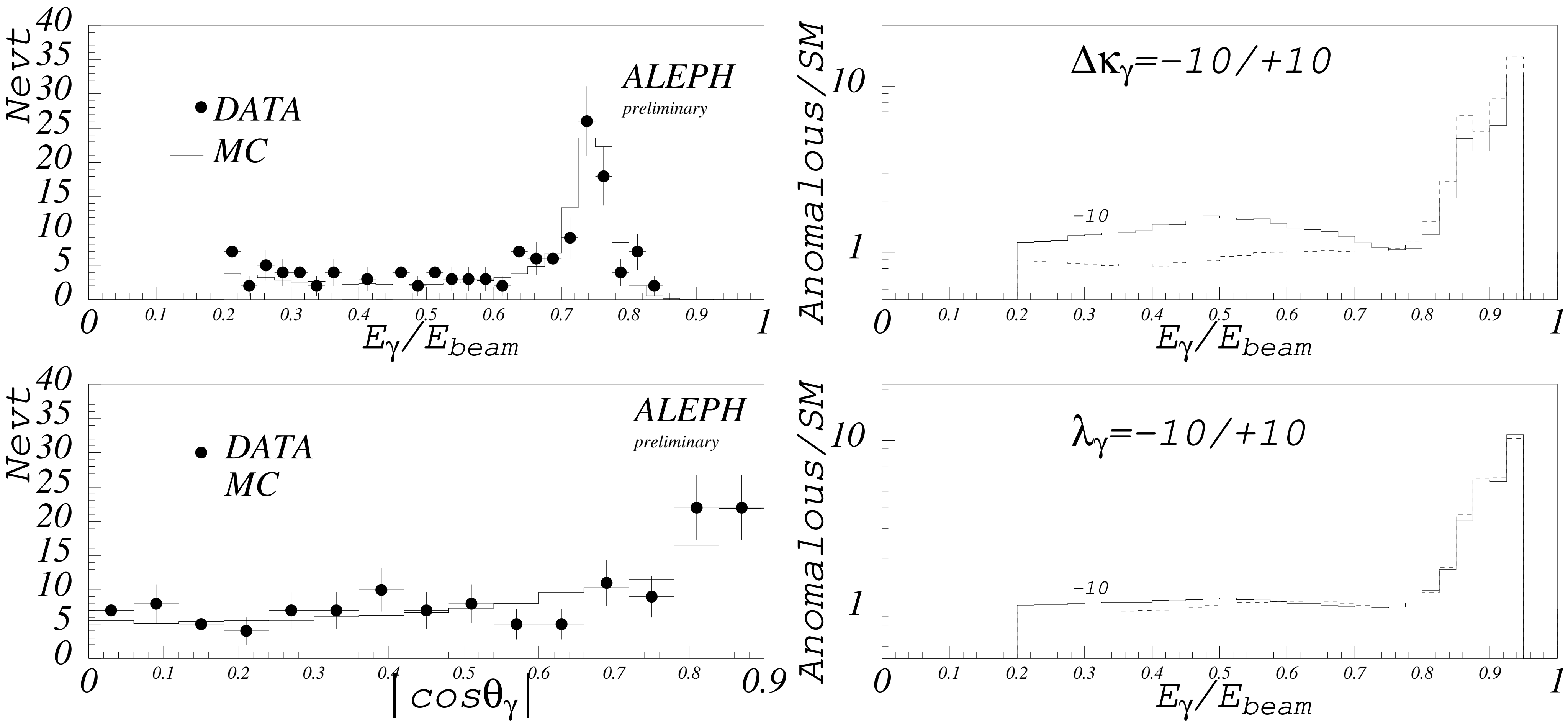
$$\frac{d\sigma}{d\Omega}(TGC)= \frac{\sigma^{MC}}{N_{MC}}\frac{1}{\Delta\Omega}\sum \mathrm{weight}_j(TGC)$$



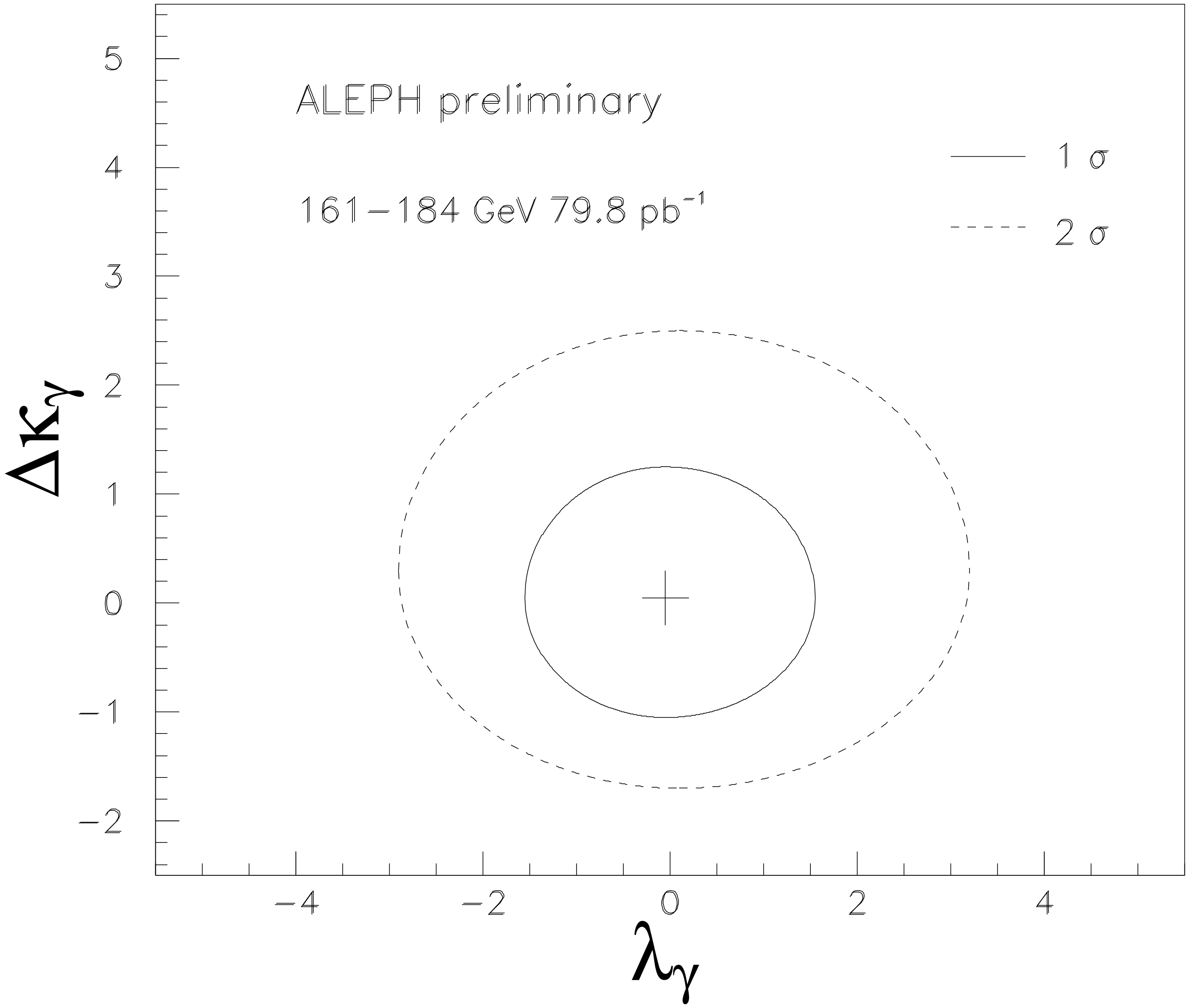
$$\mathrm{weight}_j(TGC)= \frac{|M(\Omega,TGC)|^2}{|M(\Omega,SM)|^2}$$

$e^+e^- \to \nu\nu\gamma$

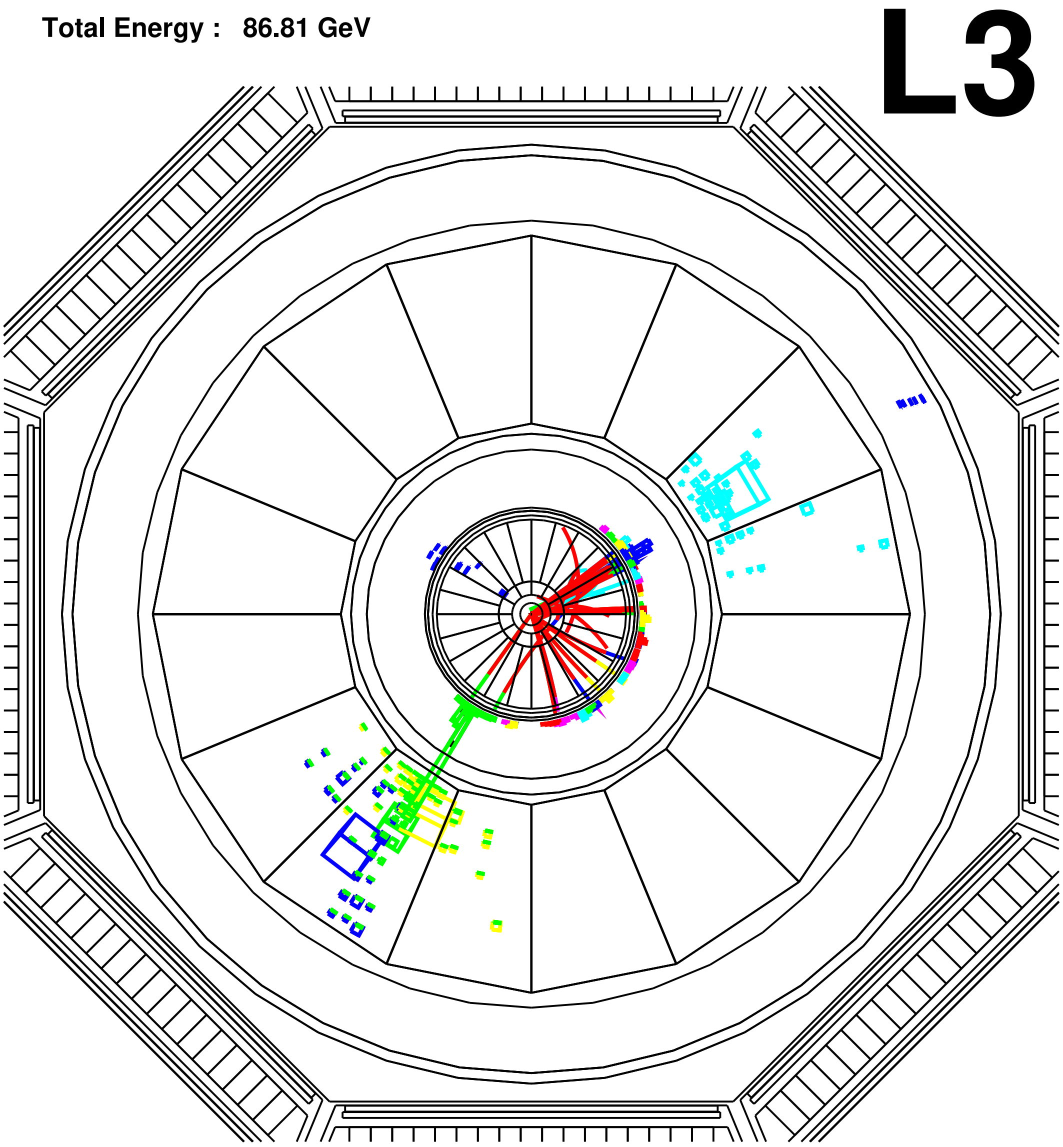



ALEPH
preliminary
DATA
MC
Nevt
E_γ/E_{beam}
$|cos\theta_\gamma|$
$\Delta\kappa_\gamma$=-10/+10
λ_γ=-10/+10
-10
Anomalous/SM

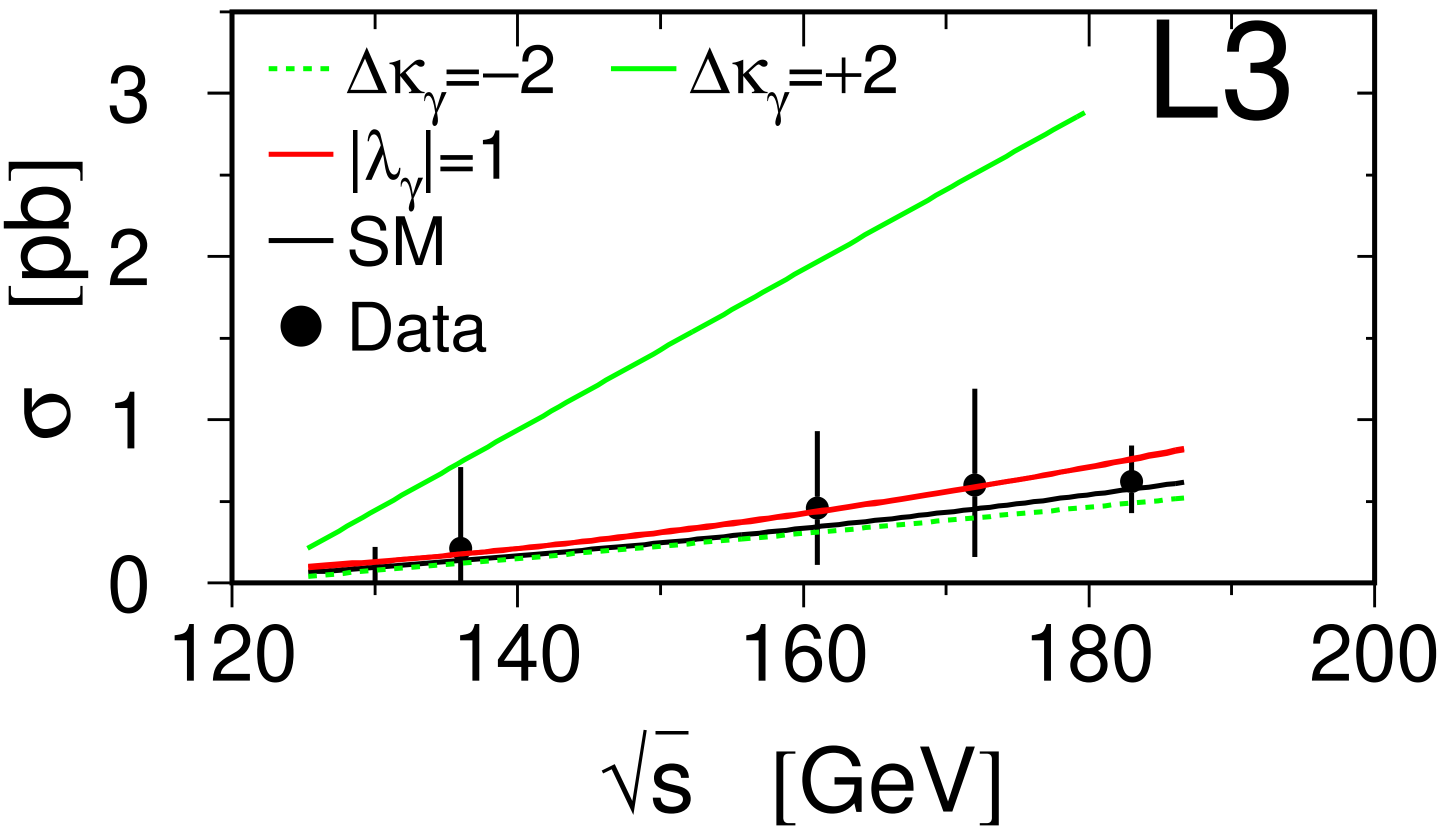
Fit of $\sigma(\nu\nu\gamma)$ and $\frac{1}{\sigma(\nu\nu\gamma)} \frac{d^2\sigma}{dE_\gamma d\cos\Theta_\gamma}$

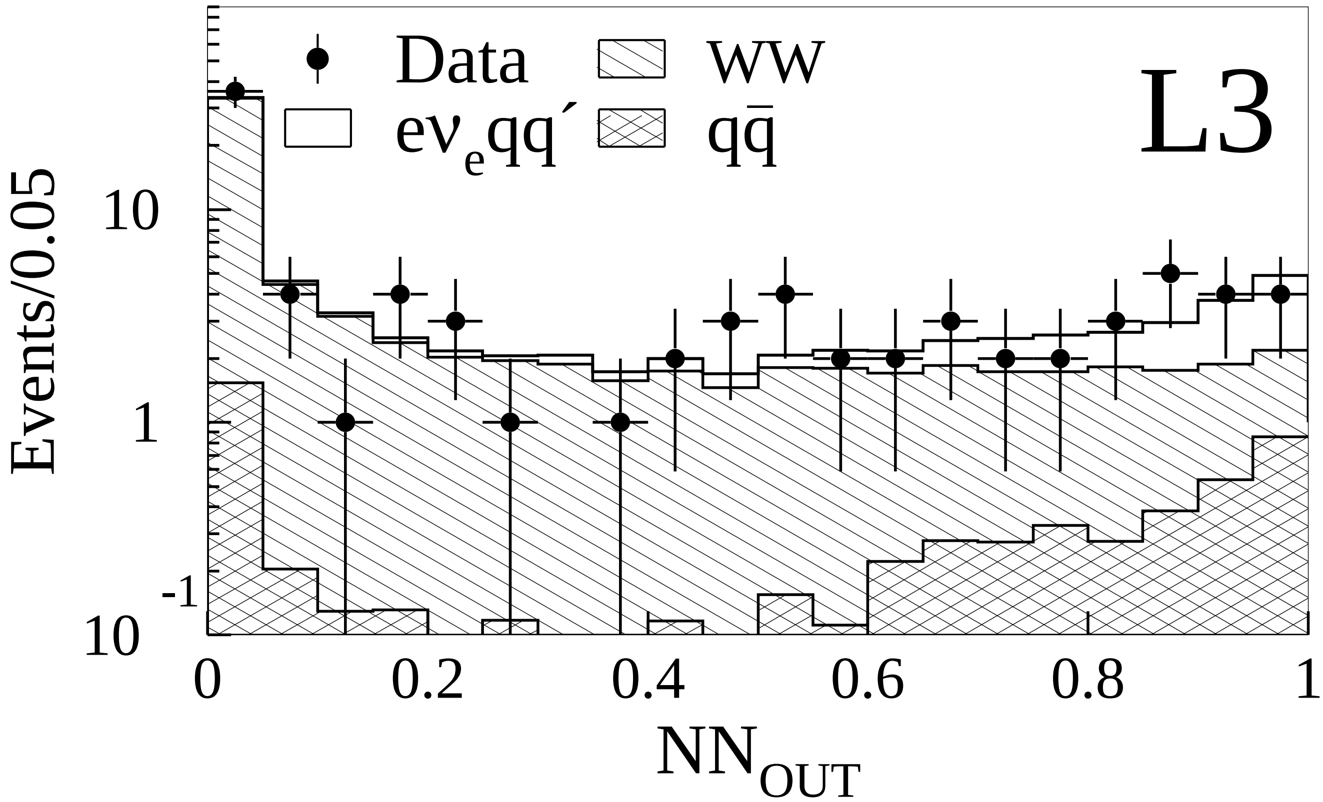


$e^+e^- \to W e\nu$



electron is lost in beam pipe $\rightarrow$
single W seen in the detector

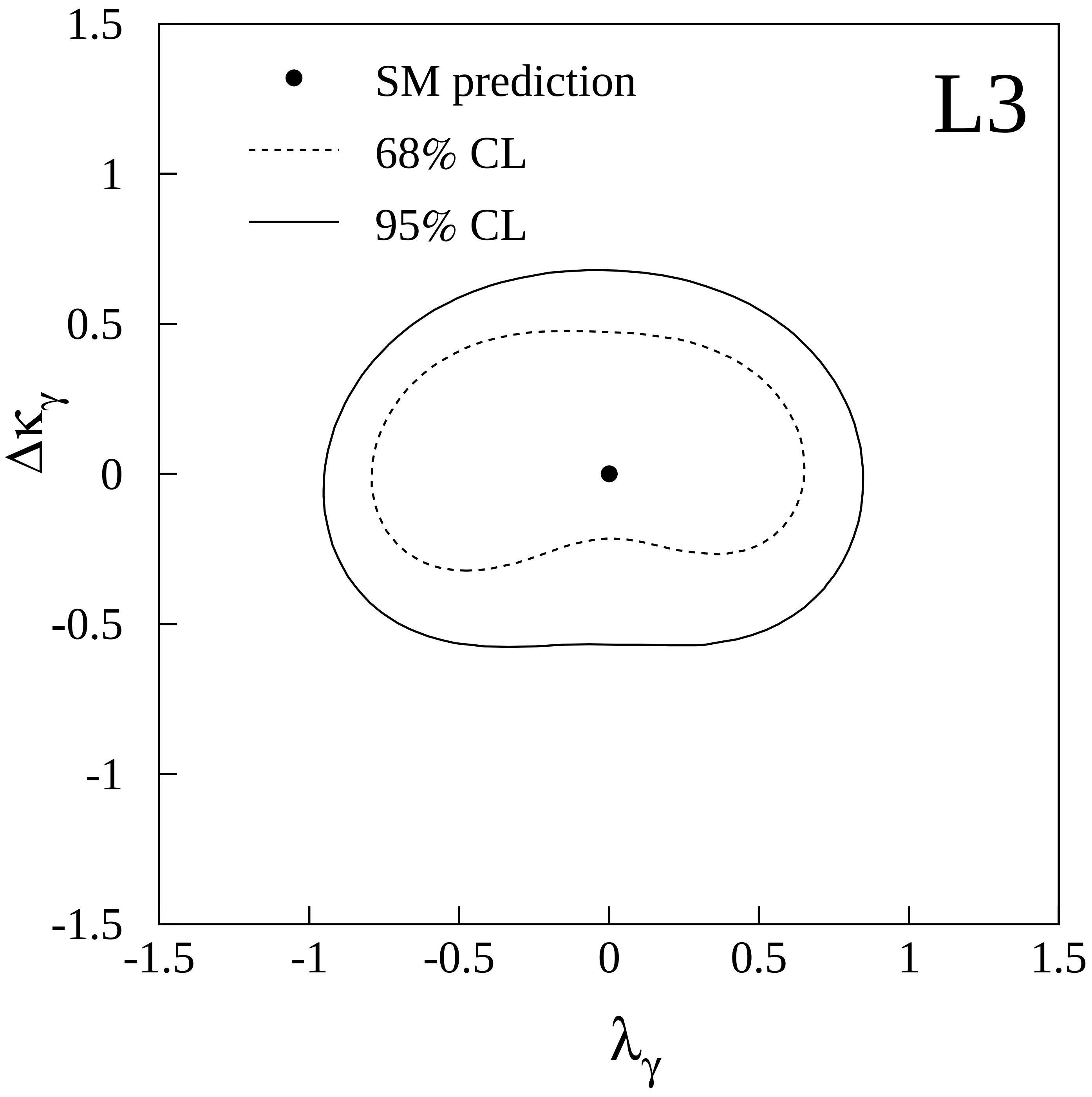

L3
Δκγ=−2
Δκγ=+2
|λγ|=1
SM
Data
σ [pb]
0
1
2
3
120
140
160
180
200
√s [GeV]


L3
Data
WW
eνeqq´
qq̄
Events/0.05
10
1
10-1
0
0.2
0.4
0.6
0.8
1
NNOUT

$e^+e^- \rightarrow We\nu$ at $\sqrt{s} = 130 - 183$ GeV

Fit of

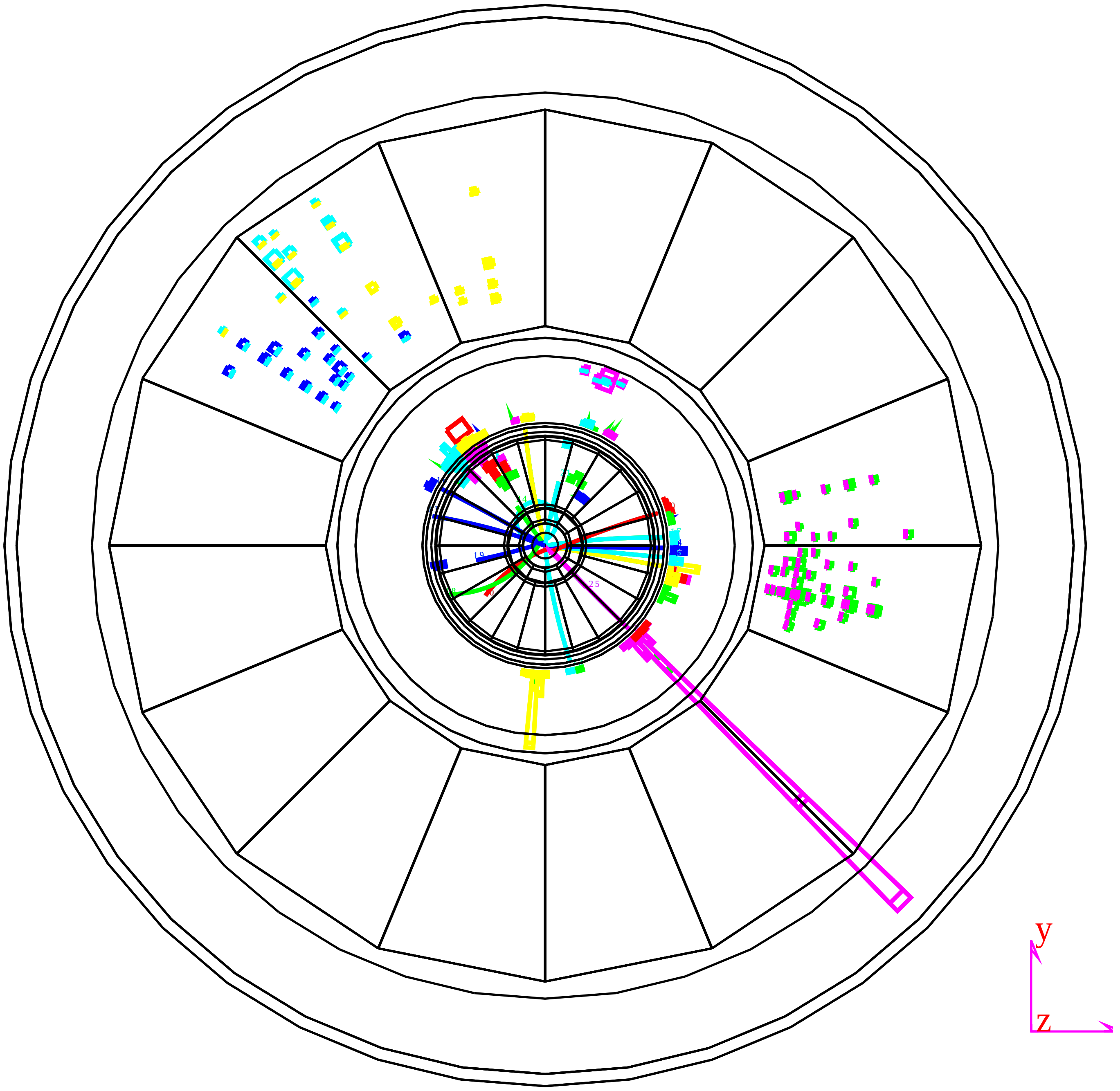
$\sigma(e\nu W \rightarrow l\nu, qq')$ and $\frac{1}{\sigma(e\nu W\rightarrow qq')}\frac{d\sigma(e\nu W\rightarrow qq')}{d(NN_{\text{out}})}$



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

un # 671603 Event # 3681 Total Energy : 132.88 GeV

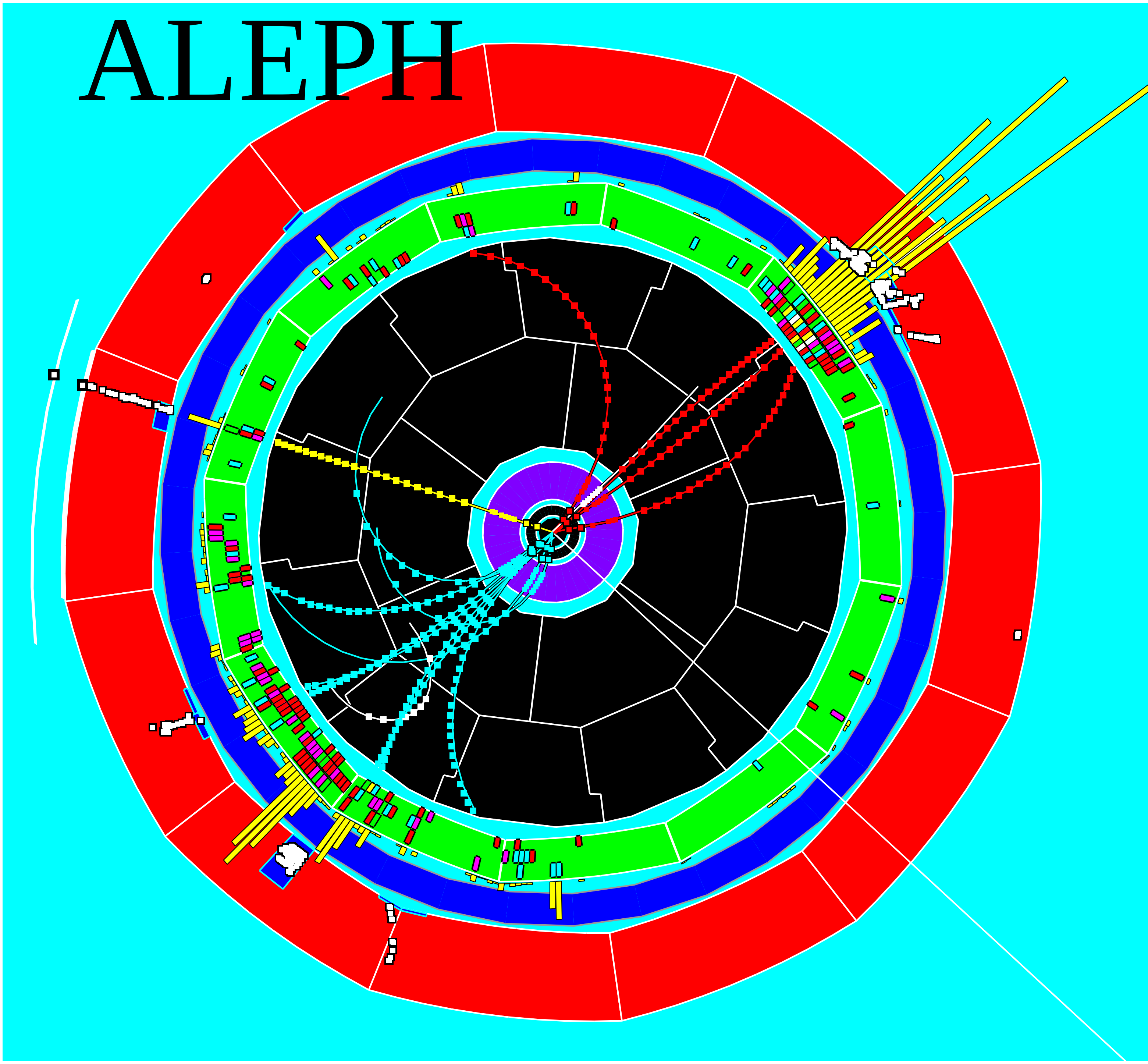
L3



Efficiency : 80% Purity : 90%

$N_{\text{events}}^{\text{LEP2}}(\mathbf{161-183}\ \text{GeV}) = \mathbf{550}$

$$e^+e^- \rightarrow W^+W^- \rightarrow qq\mu\nu_\mu$$



Efficiency : 80%   Purity : 90%

$N^{\text{LEP2}}_{\text{events}}(161 - 183\ \text{GeV}) = 550$