European Organization for Nuclear Research

Quartic Gauge Boson Couplings Results at LEP

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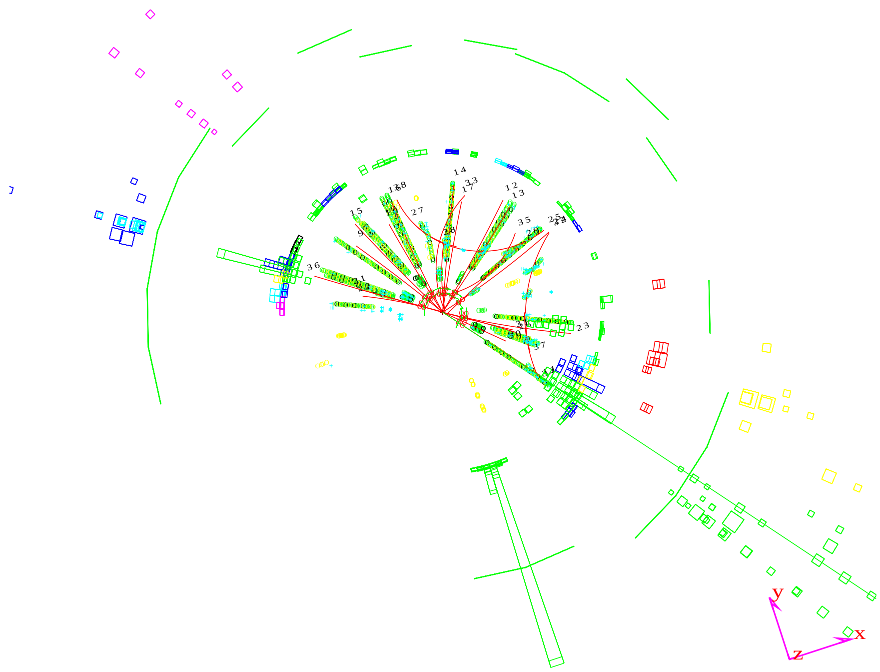
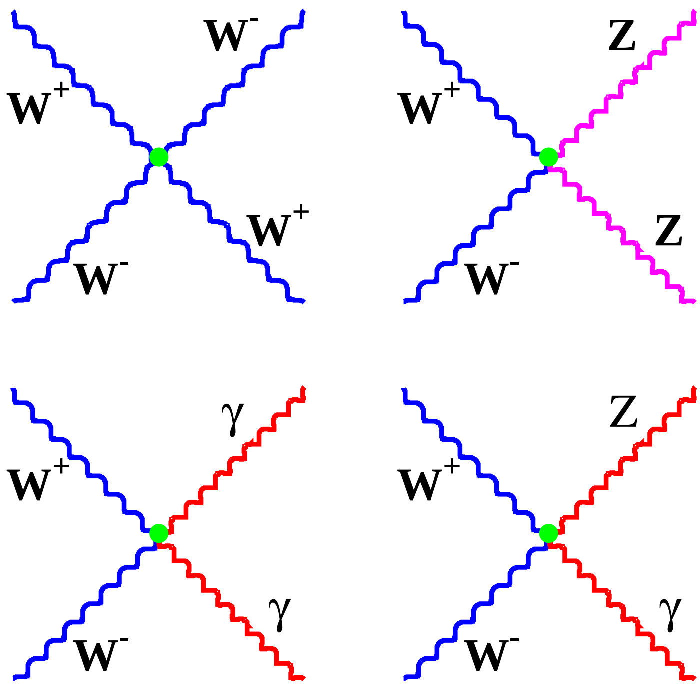


XXXVIth Rencontres de Moriond, March 2001

Charged boson self-interactions stem from the non-Abelian gauge structure of the SM



In the SM, the $SU_L(2)\otimes U_Y(1)$ gauge invariance tightly constrains the form and strength of all these couplings:

SM QGC $W^+W^-Z\gamma$ vertex: $ieg\cos\theta_W[g^{\alpha\delta}g^{\beta\gamma}+g^{\alpha\gamma}g^{\beta\delta}-2g^{\alpha\beta}g^{\gamma\delta}]$

- **As for TGCs, extensions of the SM Lagrangian include Anomalous QGC couplings which act as contact interactions**

• **Anomalous QGCs can be parametrised by additional terms in the SM Lagrangian,**

◇ **Dim–4 operators, so-called "non genuine", already constrained by TGC direct limits.**

◇ **Dim–6 operators:**

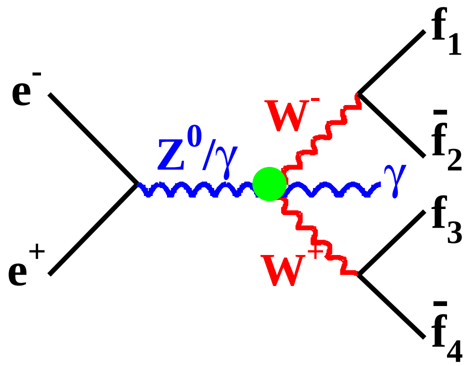
$$\mathcal{L}_0 = -\frac{e^2}{16}\frac{a_0}{\Lambda^2} F^{\mu\nu} F_{\mu\nu} \overrightarrow{W}^{\alpha} \cdot \overrightarrow{W}_{\alpha}$$
$$\mathcal{L}_c = -\frac{e^2}{16}\frac{a_c}{\Lambda^2} F^{\mu\alpha} F_{\mu\beta} \overrightarrow{W}^{\beta} \cdot \overrightarrow{W}_{\alpha}$$

$\Longrightarrow W^+W^-\gamma\gamma$, $ZZ\gamma\gamma$ [G.Bélanger et al., Nucl.Phys. B288, 1992]

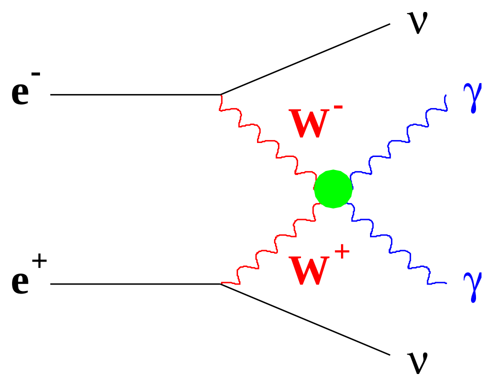
$$\mathcal{L}_n = -\frac{ie^2}{16}\frac{a_n}{\Lambda^2} \epsilon_{ijk} W^{(i)}_{\mu\alpha} W^{(j)}_{\nu} W^{(k)\alpha} F^{\mu\nu}$$

$\Longrightarrow W^+W^-Z\gamma$, ($\mathcal{CP}$–odd) [J.Stirling et al., Phys.Lett. B466, 1999]

where Λ is the New Physics energy scale.



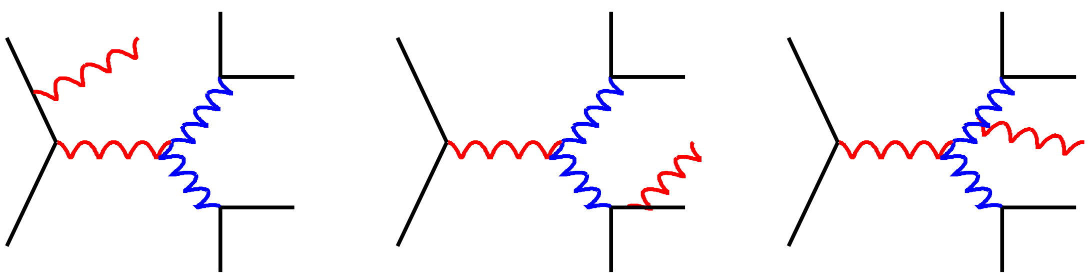
WWγ production



$\nu\bar{\nu}\gamma\gamma$ production

- **There are many diagrams for the ffffγ final state at $\mathcal{O}(\alpha)$ (142 only for $e^+e^- \rightarrow u\bar{d}e^-\bar{\nu}_e\gamma$)**

CC03



ISR **FSR** **WSR (small)**

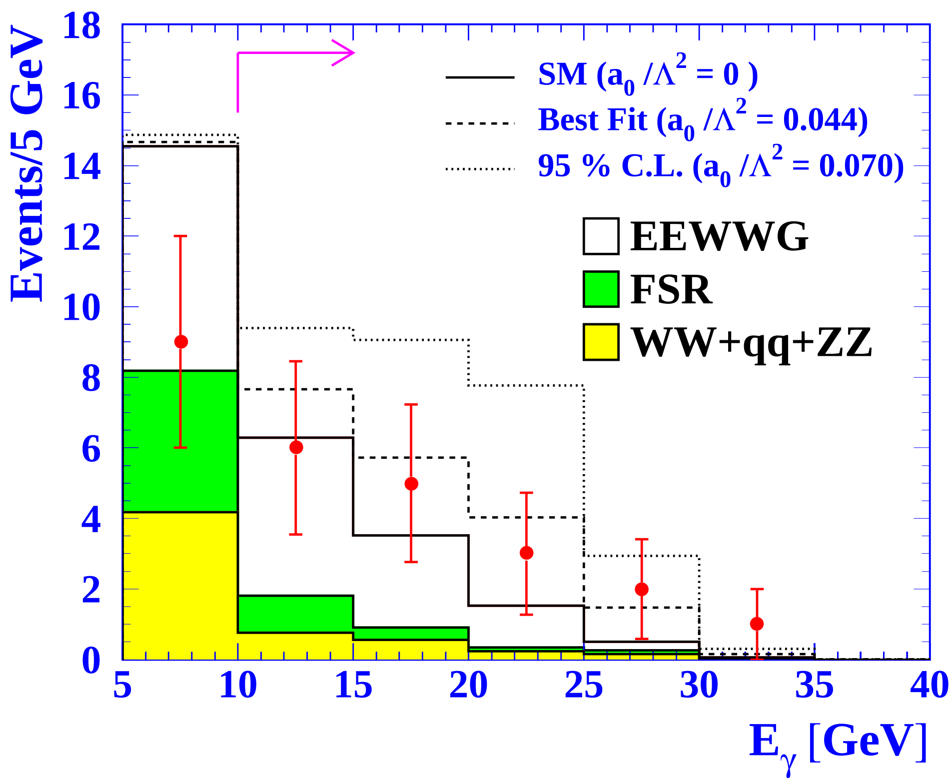
Effects of SM QGCs are very small:
at $\sqrt{s}$= 200 GeV, $\sigma_{\mathrm{WW}\gamma}$ = 304 fb (QGCs included)
$\sigma_{\mathrm{WW}\gamma}$ = 318 fb (QGCs excluded)

- **Available (CC03) MCs :**
  - **EEWWG includes ISR, WSR, QGC, and AQGC**
  - **KORALW includes ISR, FSR**

- **Signal definition :** $E_\gamma > 10$ GeV
  $|\cos\theta_\gamma| < 0.9$
  $\cos\theta_{f\gamma} < 0.9$
  $minM_{ff'} > 73$ GeV

$\Longrightarrow N_{data} = 17$ (13.2 expected)

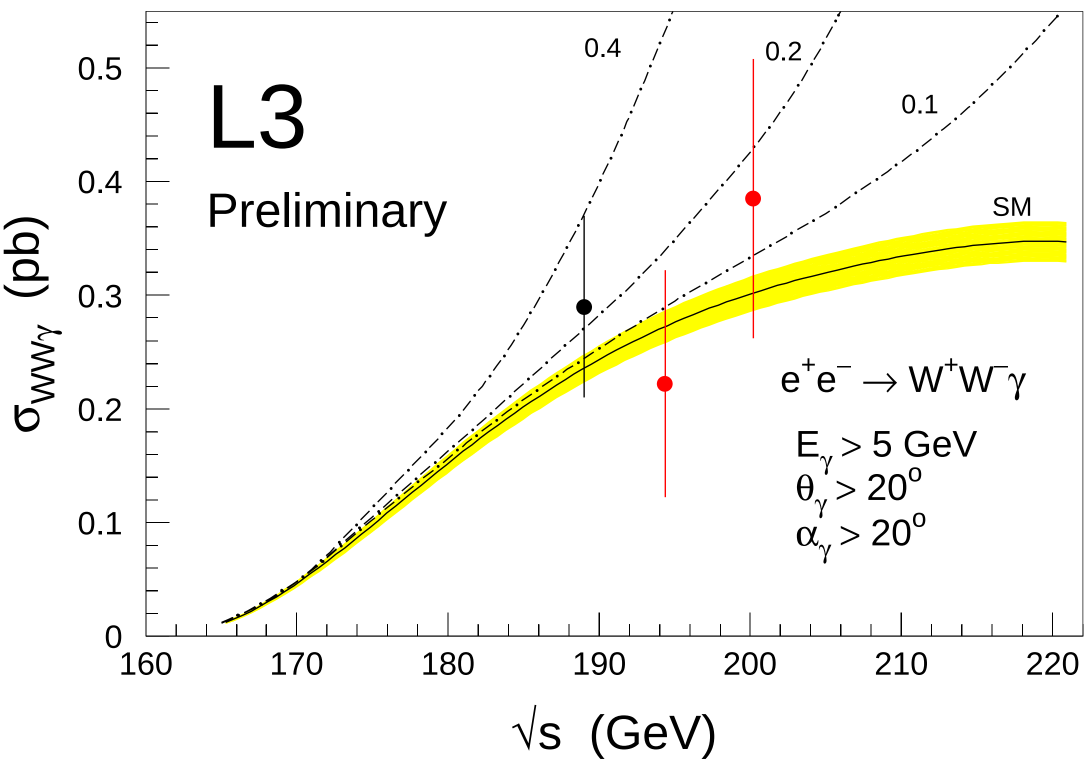
◇ **Opal** $\sigma_{WW\gamma} = 0.136 \pm 0.037 \pm 0.008$ pb
(SM: 0.085 – 0.102 pb)



AQGCs Limits at 189 GeV:

95% CL	Opal	L3
a_0/Λ^2	[-0.070, 0.070]	[-0.045, 0.045]
a_c/Λ^2	[-0.013, 0.019]	[-0.08 , 0.013]
a_n/Λ^2	[-0.61 , 0.57]	[-0.41 , 0.37]

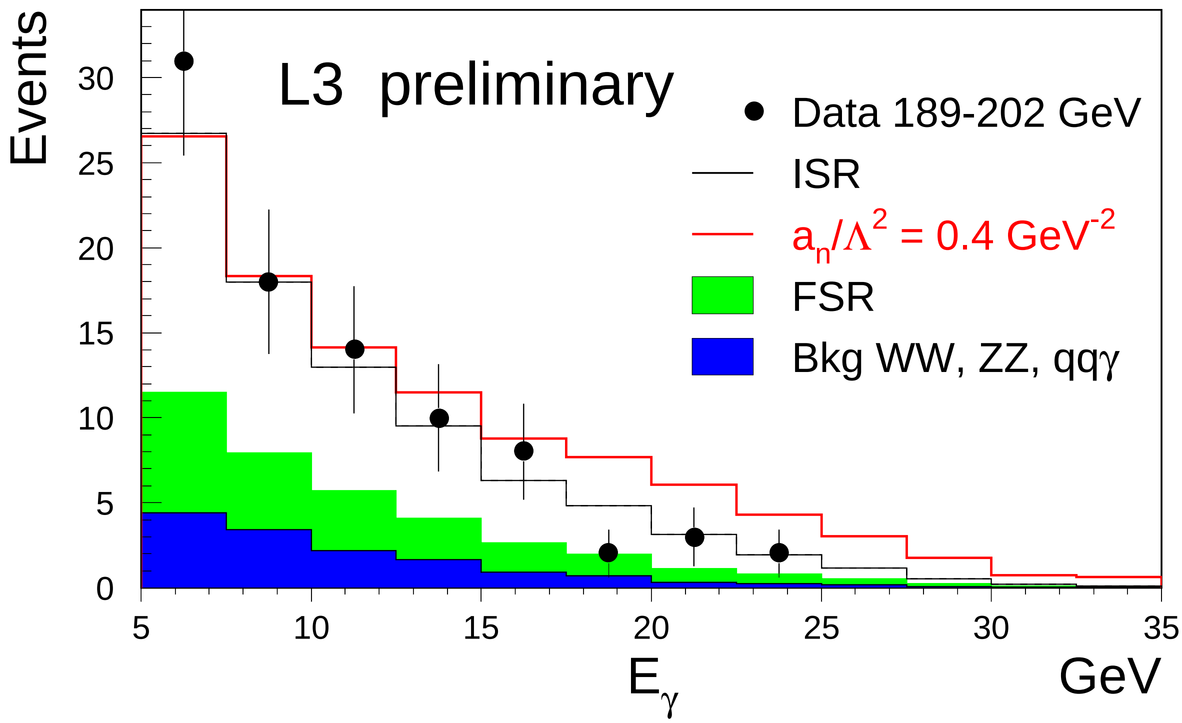
- Cross section measurement merging data
  between 192–196 GeV $(\int \mathcal{L} = 113.4\ \text{pb}^{-1})$
  and 196–202 GeV $(\int \mathcal{L} = 119.8\ \text{pb}^{-1})$



$$\sigma_{WW\gamma}(188.6\ \text{GeV}) = 0.29 \pm 0.08 \pm 0.02\ \text{pb}$$
$$\sigma_{WW\gamma}(194.4\ \text{GeV}) = 0.22 \pm 0.10 \pm 0.02\ \text{pb}$$
$$\sigma_{WW\gamma}(200.2\ \text{GeV}) = 0.39 \pm 0.12 \pm 0.02\ \text{pb}$$

All results are consistent with the SM expectations.

- **AQGCs measurement:**



1-parameter fit results:

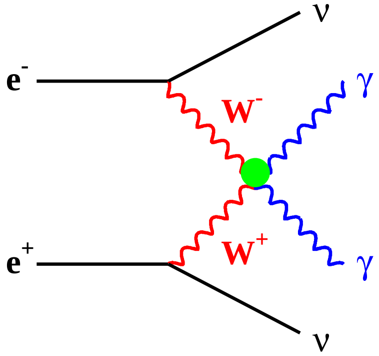
$$a_0/\Lambda^2 = 0.000 \pm 0.012 \text{ GeV}^{-2}$$
$$a_c/\Lambda^2 = 0.007 \pm 0.028 \text{ GeV}^{-2}$$
$$a_n/\Lambda^2 = 0.000 \pm 0.010 \text{ GeV}^{-2}$$

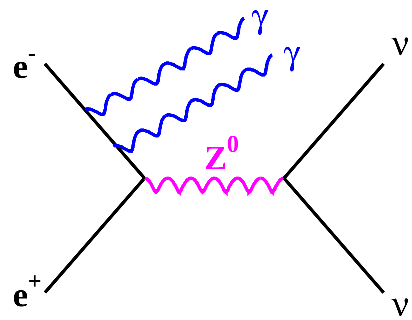
Derived limits at 95% CL are:

$$-0.023 \text{ GeV}^{-2} < a_0/\Lambda^2 < 0.023 \text{ GeV}^{-2}$$
$$-0.038 \text{ GeV}^{-2} < a_c/\Lambda^2 < 0.066 \text{ GeV}^{-2}$$
$$-0.20 \text{ GeV}^{-2} < a_n/\Lambda^2 < 0.18 \text{ GeV}^{-2}.$$

Factor $\simeq$ 2 of improvement w.r.t. 189 GeV data

$e^+e^- \to \nu\bar{\nu}\gamma\gamma$ **also probes** $WW\gamma\gamma$ **vertex:**





2 acoplanar γ**s,** a_0/Λ^2, a_c/Λ^2 **Bkg doubly rad. return to Z**

- **Theoretical predictions by**

⟶ EENUNUGANO [J.Stirling, et al., Phys.Lett B466 369]

For anomalous and SM QGCs.
Interference terms in the Z region are not included.

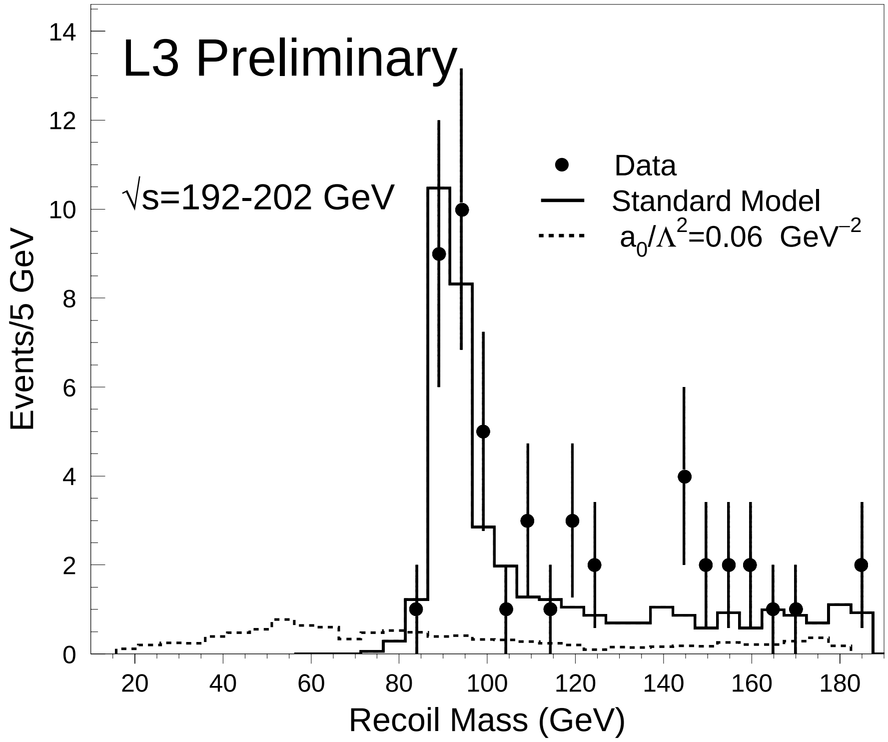
⟶ NUNUGPV [G.Montagna, et al., Nucl.Phys. B541 31]

SM exact $\mathcal{O}(\alpha^3)$ **for visible photons**

MCs are in good agreement only for $M_{\nu\bar{\nu}} < M_Z$

Suppress SM with recoiling mass against the $\gamma\gamma$ **system**

$e^+e^- \longrightarrow \nu\bar{\nu}\gamma\gamma$



$M_{\rm recoil} \leq 75 - 80$ GeV

No events are observed by Aleph, L3, Opal
(with a SM expectation of ≃0.2 events per experiment)

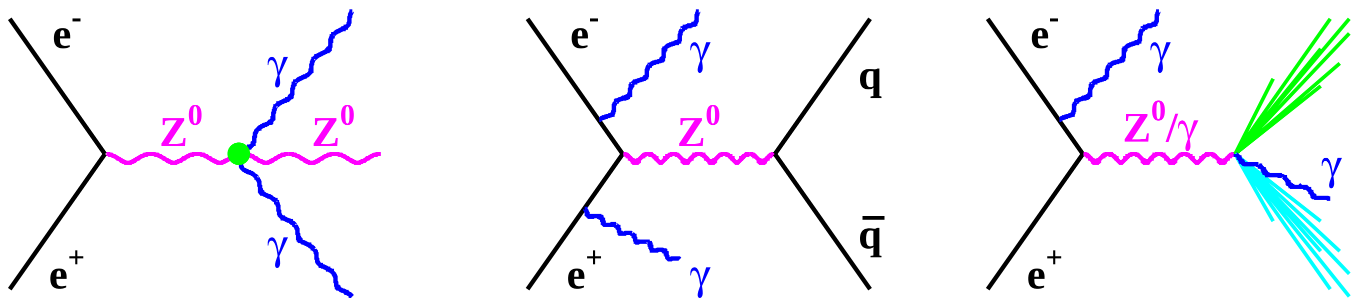
(Unofficial) Summary of LEP combined limits for
Charged AQGCs in $\nu\bar{\nu}\gamma\gamma \oplus WW\gamma$ processes at the energies

	Aleph	L3	Opal
$\nu\bar{\nu}\gamma\gamma$	189–202 GeV	183–202 GeV	189 GeV
$WW\gamma$	–	189–202 GeV	189 GeV

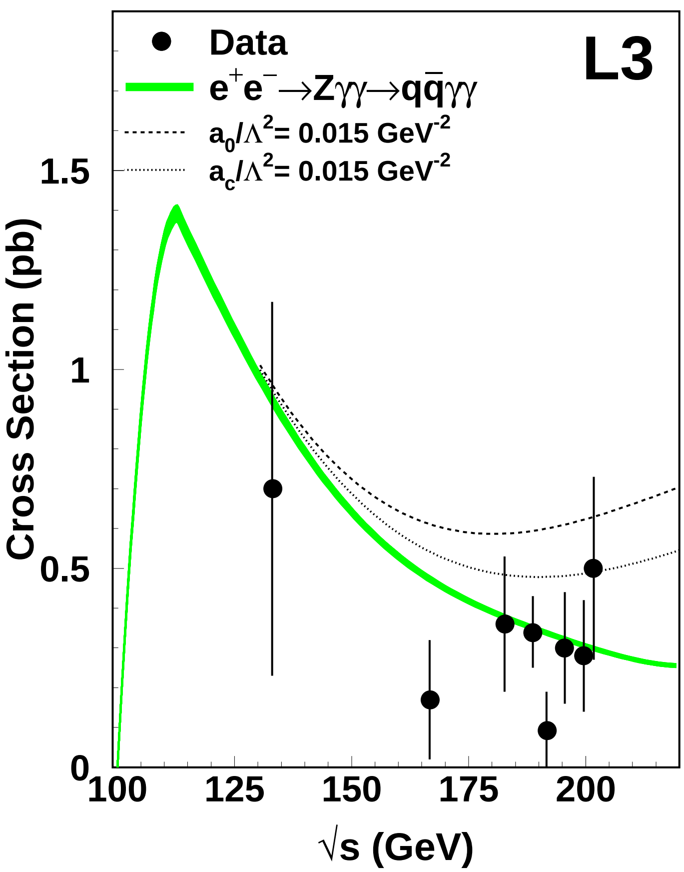
Results at 95% CL:

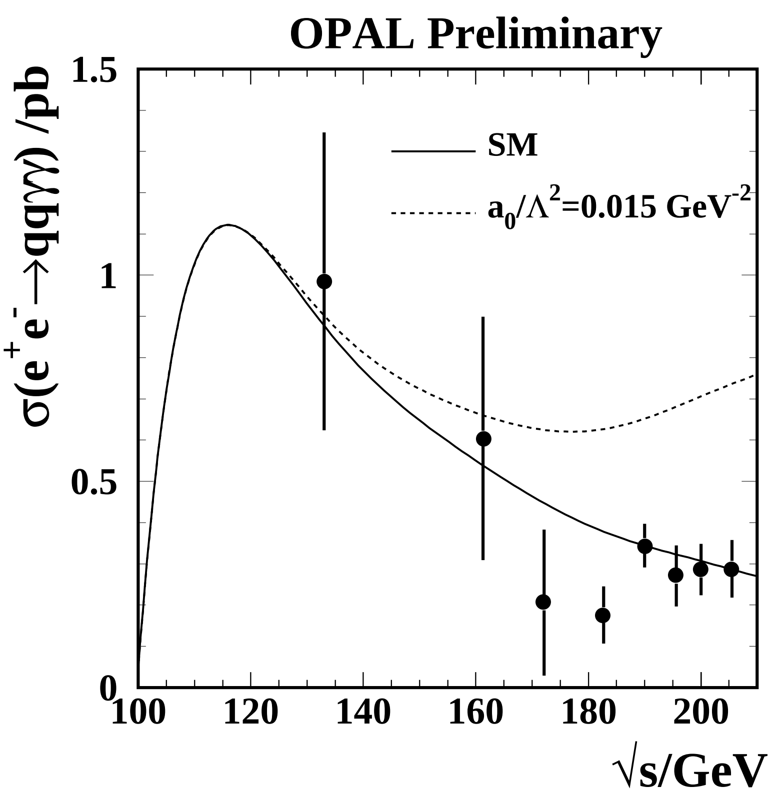
$$-0.022\ \mathrm{GeV}^{-2} < a_0/\Lambda^2 < 0.021\ \mathrm{GeV}^{-2}$$
$$-0.043\ \mathrm{GeV}^{-2} < a_c/\Lambda^2 < 0.058\ \mathrm{GeV}^{-2}$$
$$-0.022\ \mathrm{GeV}^{-2} < a_n/\Lambda^2 < 0.020\ \mathrm{GeV}^{-2}$$

Neutral AQGCs in $Z\gamma\gamma \longrightarrow q\bar{q}\gamma\gamma$ events



AQGCs, a_0/Λ^2, a_c/Λ^2 — **SM processes**



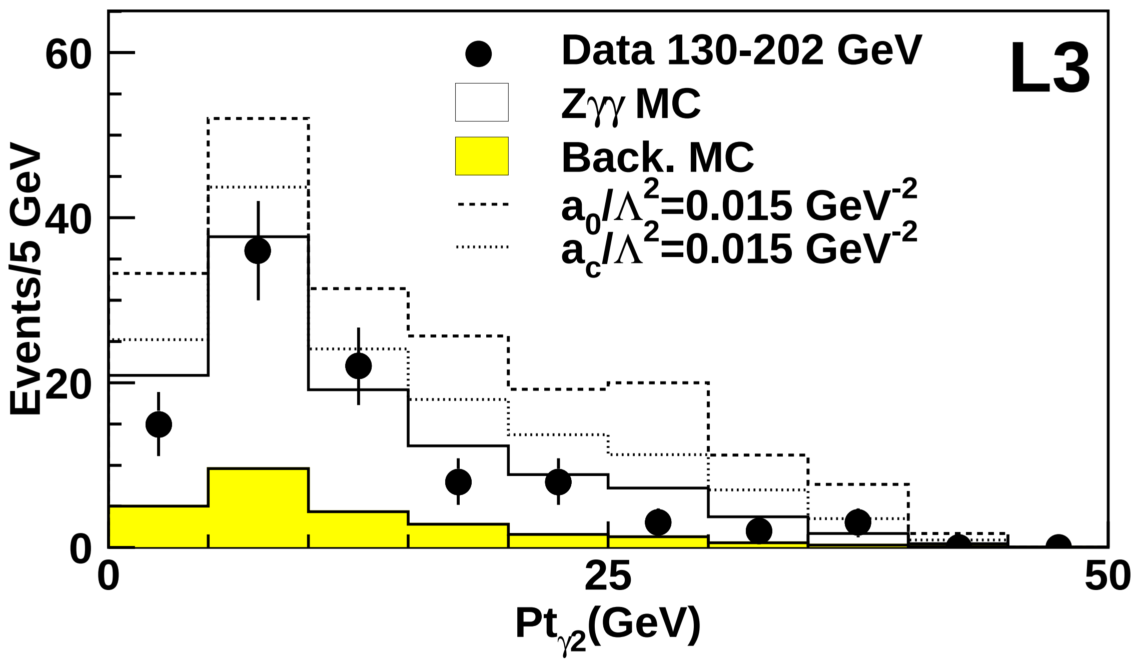


$E_\gamma > 5$ GeV
$|\cos\theta_\gamma| < 0.97$
–
$M_{q\bar{q}} = m_Z \pm 2\Gamma_Z$

$E_\gamma > 5$ GeV
$|\cos\theta_\gamma| < 0.95$
$|\cos\theta_{q\gamma}| < 0.9$
80 GeV$< M_{q\bar{q}} <$ 120 GeV

Limits are derived fitting differential distributions of

- **L3** $P_T(\gamma_2)$
- **Opal** $E(\gamma_2)$, $\max|\cos\theta_{\gamma_i}|$



95% CL	L3	Opal
a_0/Λ^2	[-0.008, 0.005]	[-0.006, 0.008]
a_c/Λ^2	[-0.007, 0.011]	[-0.008, 0.012]

$\Longrightarrow$ **Tightest limits on a_0/Λ^2 and a_c/Λ^2**

WARNING: Under more general theoretical assumptions, neutral QGCs may be different from charged QGCs

$\longrightarrow$ **no combination of $Z\gamma\gamma$ with $WW\gamma$, $\nu\bar{\nu}\gamma\gamma$ is performed**

Conclusion

- **Measurement of rare processes as $Z\gamma\gamma$, $WW\gamma$ and $\nu\bar{\nu}\gamma\gamma$ constitute an important test of SM**

- **New results were obtained for $WW\gamma$ up to 202 GeV for $\sigma_{WW\gamma}$ and charged AQGCs , with significant increase of precision.**

- **Still need for theoretical improvement in the acoplanar $\nu\bar{\nu}\gamma\gamma$ channel**

- **Potential of LEP data is not yet fully exploited for QGCs**

- **Results on $Z\gamma\gamma$ and $WW\gamma$ cross sections will be combined on a common definition for the phase space of the photon**

- **In the short term, Tevatron Run-II will have access to these couplings with similar level of accuracy of LEP (for a_0/Λ^2 and a_c/Λ^2)** [O.Éboli et al., hep-ph/0009262].