PA-5d

Osaka - 28th July, 2000

MULTIPHOTON PRODUCTION and TESTS of QED at LEP-II

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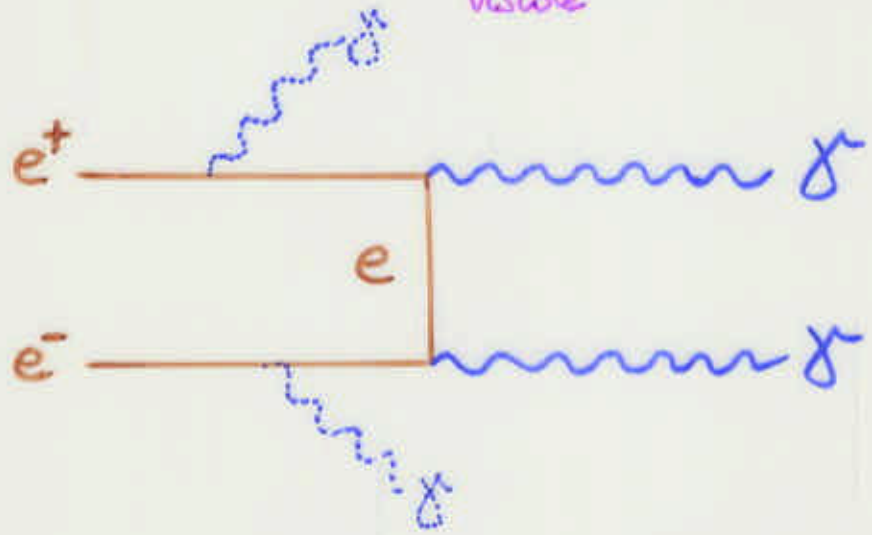
- Physics Motivations
- Event Selection
- Results :
  - test of QED
  - test of New Physics
- Conclusion - Summary

on behalf of the LEP collaborations

$e^+e^- \longrightarrow \gamma\gamma(\gamma,\gamma,..)$

Measurements of σ_{tot} ("visible") and $\frac{d\sigma}{d\cos\theta^*_\gamma}$ for



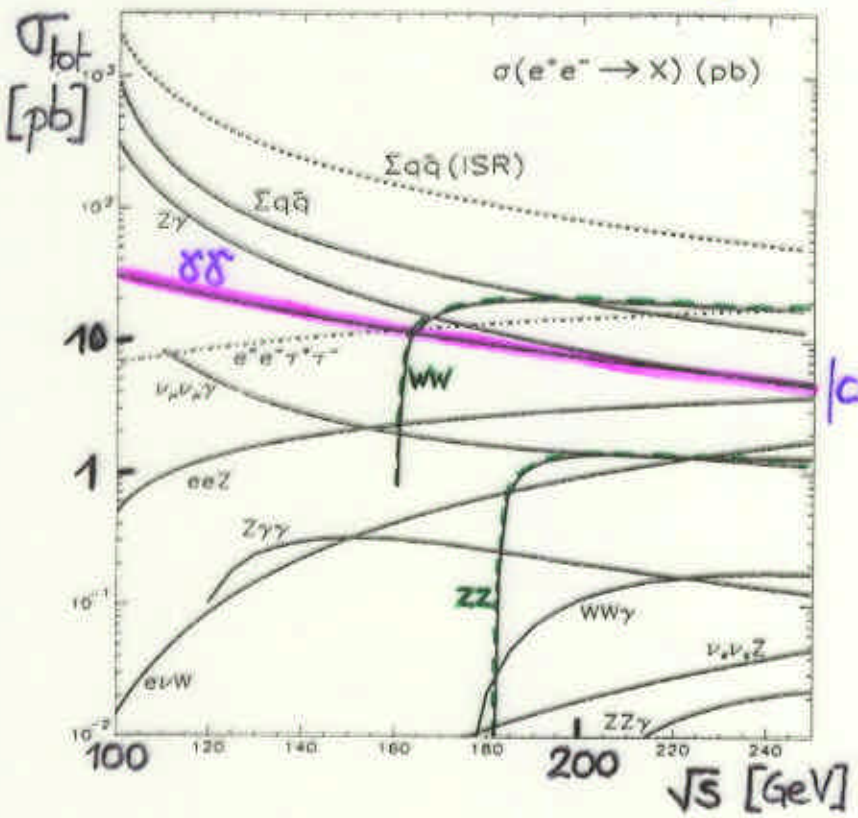
at collision energies ($\sqrt{s}$) of:

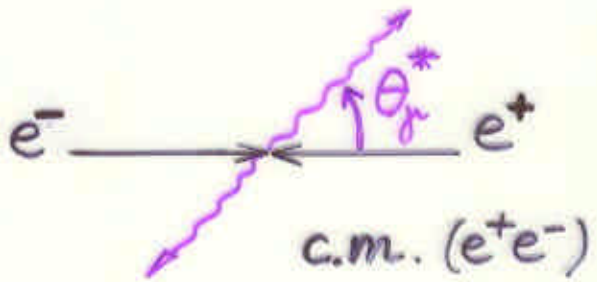
130 - 140 GeV	('95, '97)	published (nearly)
161 - 172 GeV	('96)	
183 GeV	('97)	
189 GeV	('98)	
192 - 202 GeV	('99)	~ pub. / preliminary
202 - 208 GeV	(2000)	very preliminary

1/ QED

3-6%

$$\frac{d\sigma^{QED}}{d\cos\theta^*_\gamma} = \frac{\alpha^2}{s}\cdot\frac{1+\cos^2\theta^*}{1-\cos^2\theta^*}\left(1+\delta^{(\cos\theta^*)}_{QED}\right)$$

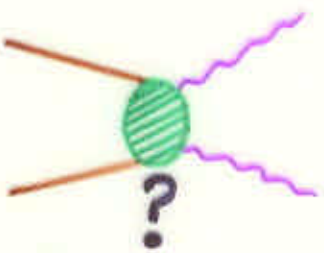




$|\cos\theta_{\gamma/e}| < 0.9$

$$\cos\theta^*_\gamma = \frac{\left|\sin\left(\frac{\theta_1-\theta_2}{2}\right)\right|}{\sin\left(\frac{\theta_1+\theta_2}{2}\right)}$$

2/ Beyond QED



Process sensitive to :

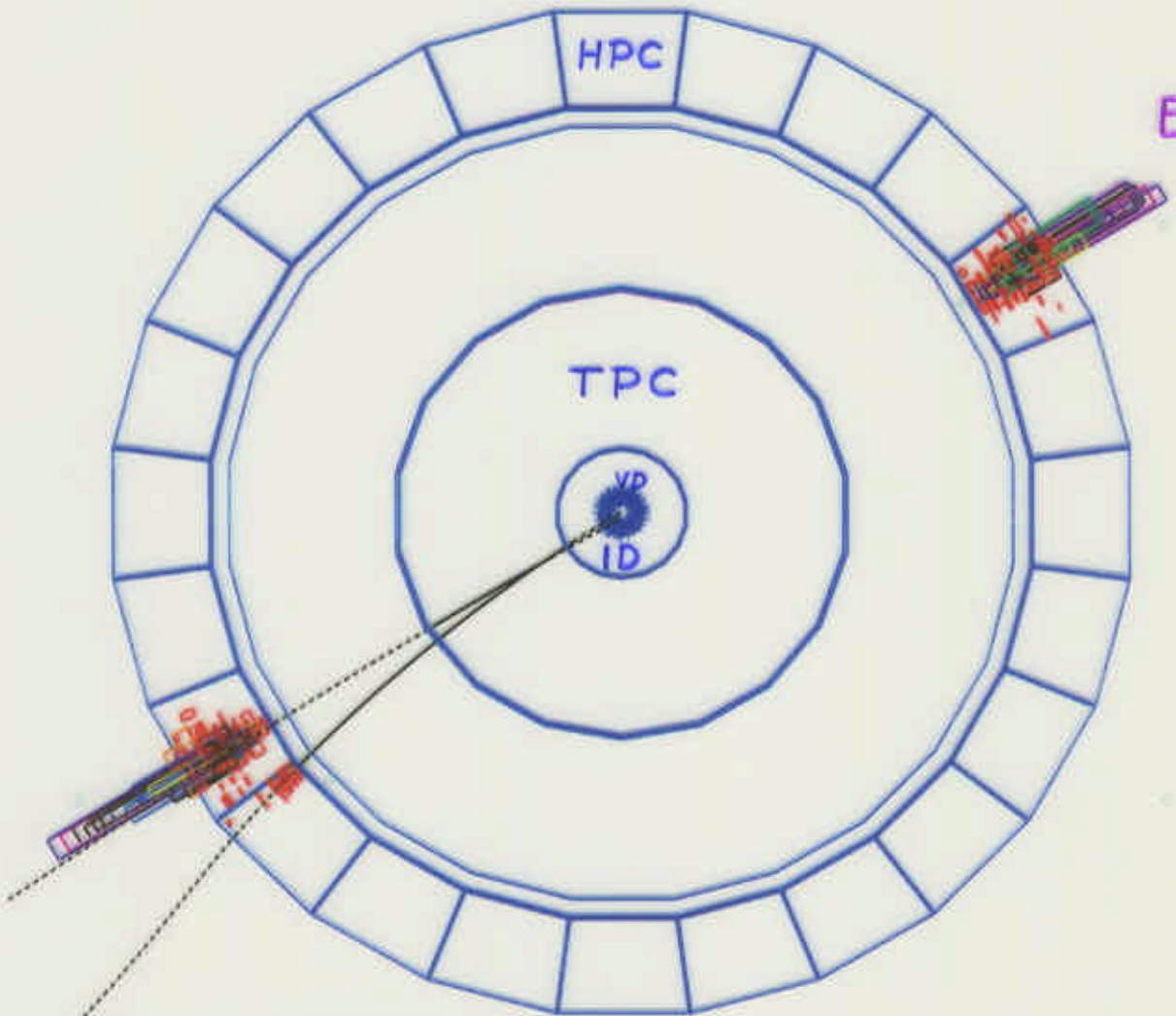
- substructure of matter fermions
- new forces
- composite/excited electrons
- low energy Quantum Gravity

⋮

$e^+e^- \longrightarrow \gamma\gamma_{conv}$, $\gamma_{conv} \rightarrow e^+e^-$

DELPHI Run: 111226 Evt: 2993
Beam: 102.6 GeV Proc:12-Jun-2000
DAS: 12-Jun-2000 Scan:14-Jul-2000
05:29:16 DST

	TO	TE	TM	TK	TV	ST	PA
Act.	0	18	0	2	0	0	0
	(28)	45)	0)	2)	0)	0)	0)
Deact.	0	0	0	0	0	0	0
	(0)	0)	0)	0)	0)	0)	0)



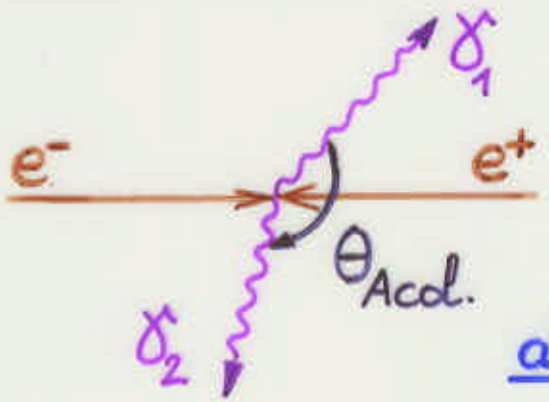
$E_\gamma = 95.5$ GeV
$\theta = 126°$
$\phi = 32°$

$E_{ee} = 109.5$ GeV
$\theta = -56°$
$\phi = +212°$

Event Selection

Fig →

1/ Basic Criteria



ex. of ALEPH:

$E_{1,2} > 0.50 \frac{\sqrt{s}}{2}$

$160° < \theta_{Acol} < 180°$

also: recuperate events with 1 γ_{conv}

→ add ~ 10% events

2/ Major Backgrounds

Bhabha scattering } reject events with
Compton scattering } more than 1 $\gamma_{conv.}$

→ residual background ~ 0.1 - 1%

Fig →

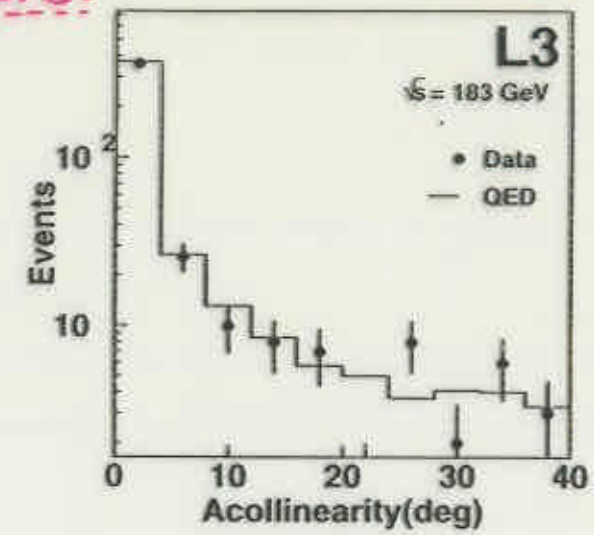
3/ Statistics Overview

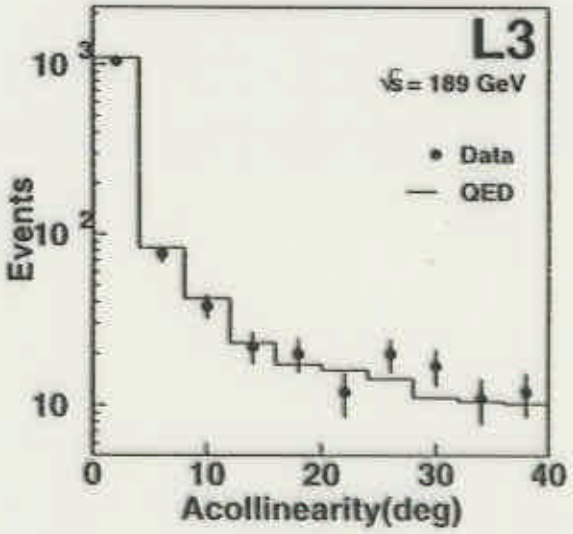
	Year	$\int L dt$ [pb^{-1}]	$N_{evts}^{obs.}$	$\sigma_{tot}^{189\,GeV}$ [pb]
A	95-99	496	~3800	$9.08 \pm 0.25 \pm 0.20$
D	95-99	454	~1800	$6.34 \pm 0.25 \pm 0.16$
L	95-98	256	~2200	$11.54 \pm 0.30 \pm 0.14$
O	95-99	479	~4100	$7.55 \pm 0.18 \pm 0.14$
D+O	2000	~200	~900	
		~1900	~13000	

Data versus Monte-Carlo → $\varepsilon_{sel.}$, $\langle bg \rangle$

- **Signal Generators:**
  - RADCOR : $O(\alpha^3)$ [N.P.B 186 (1981) 22]
  - FGAM : $O(\alpha^4)$ not for $\theta_\gamma \simeq 0$!

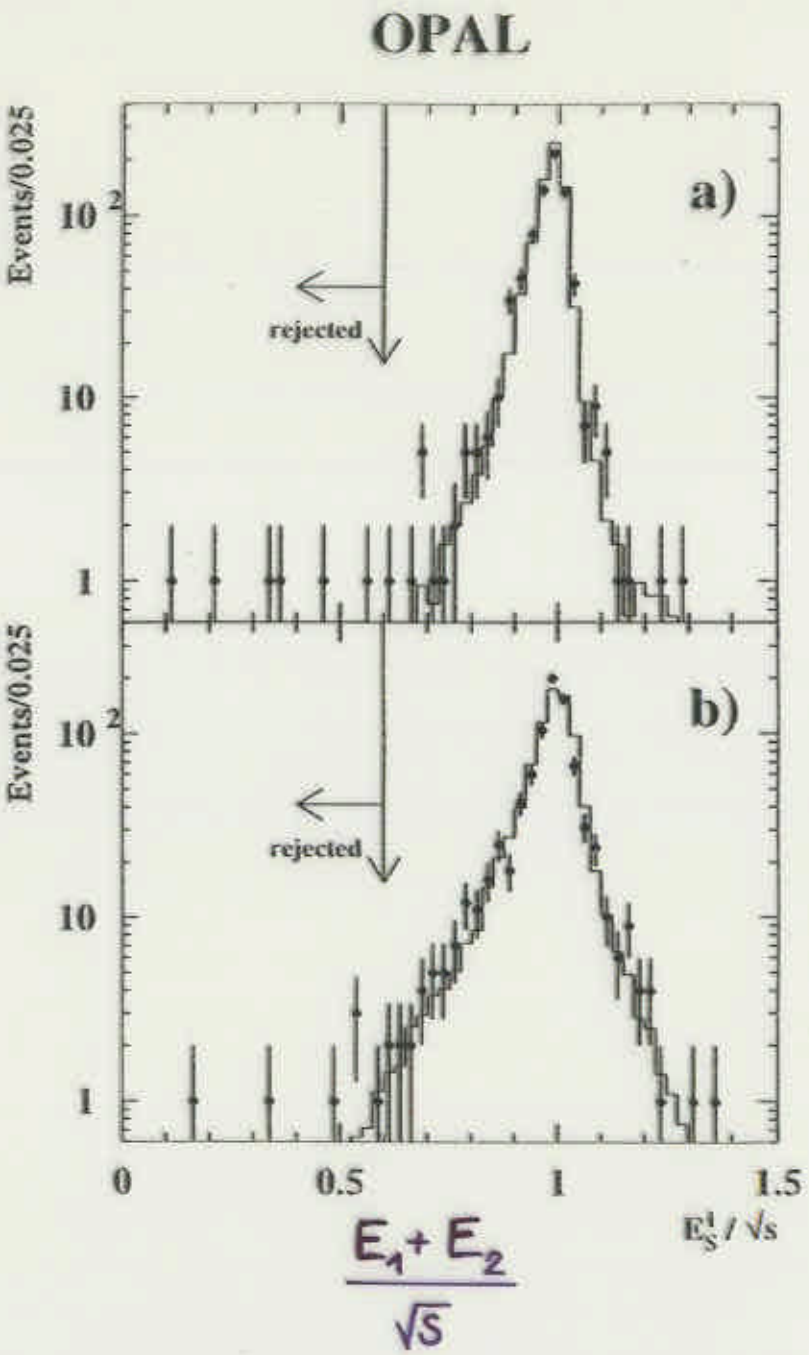
→ missing H.O.: $\Delta_{syst} \sim 0.5-1.0\%$





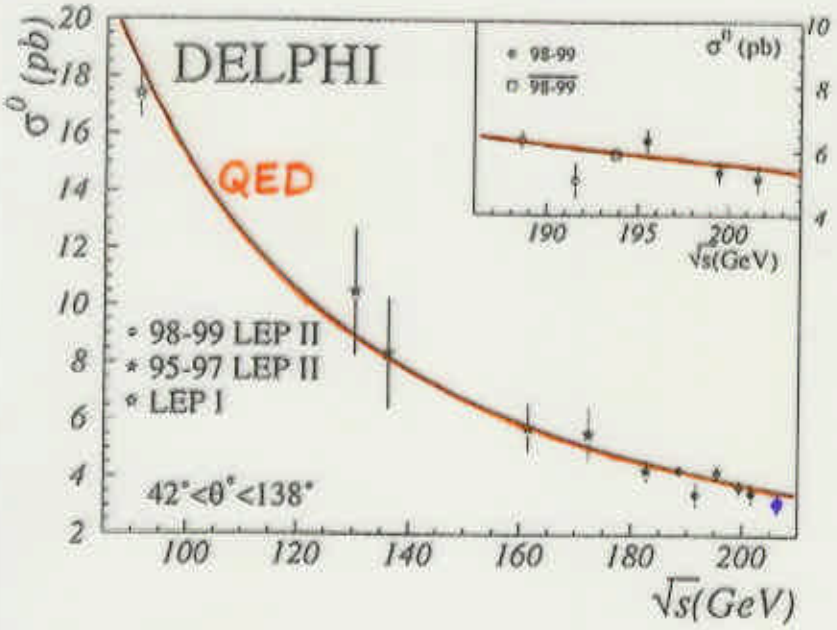
$\equiv 1 - \theta_{Acol.}$

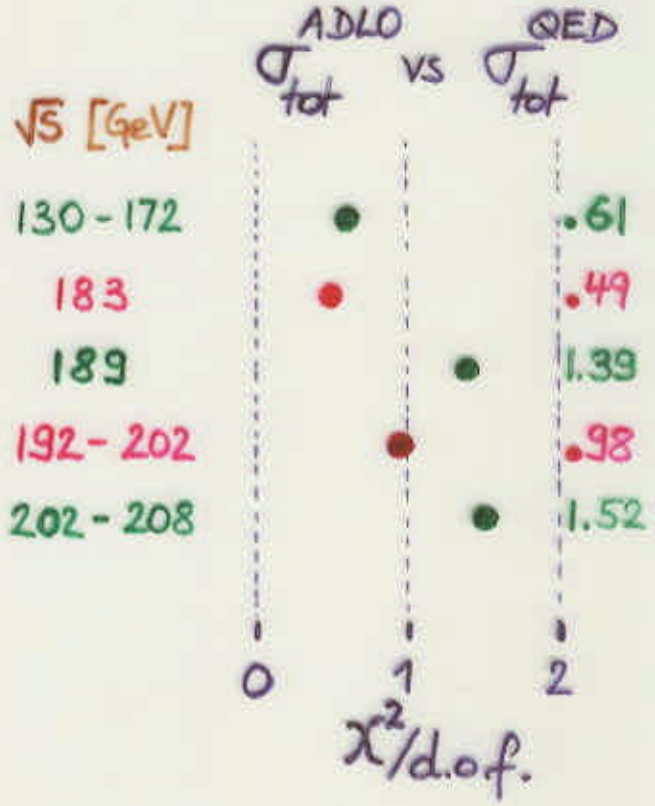
agreement satisfactory



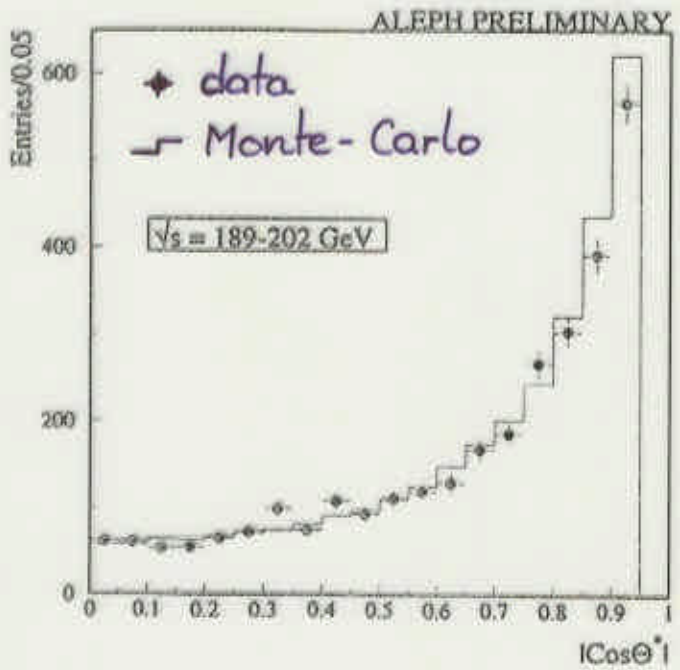
Measured cross-sections versus QED predictions

$$1/\underline{\sigma_{tot}^{Born}} = \frac{N_{sel} - \langle bg \rangle}{\varepsilon_{sel} L} \quad \text{for } |\cos\theta^*| < 0.90 - 0.97$$





$$2/\ \frac{d\sigma}{d\cos\theta^*}$$

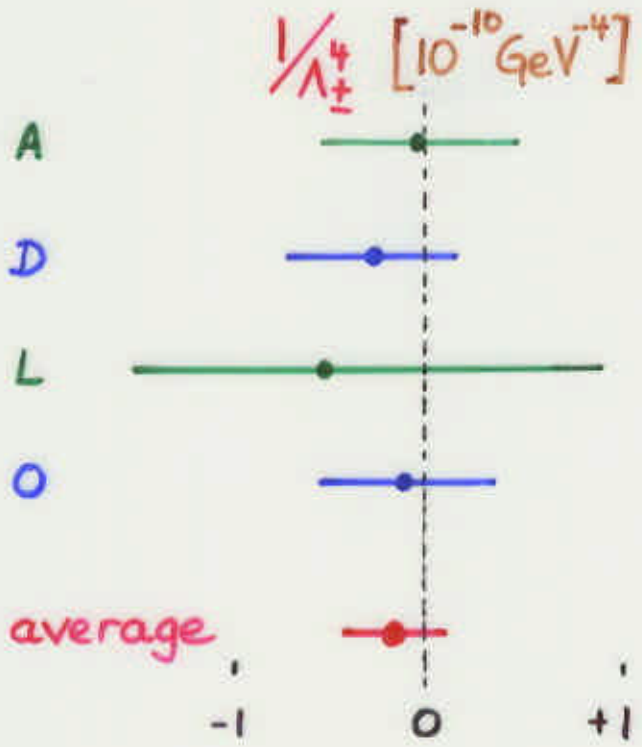


All measurements are compatible with QED at $O(\alpha^3)$

Beyond QED (1)

1/ Cut-off parameter

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma^{QED}}{d\Omega} \pm \frac{\alpha^2 s}{2} \cdot \left(\frac{1}{\Lambda_\pm}\right)^4 \cdot (1+\cos^2\theta^*)$$ [Low - PRL 14 (1965) 238]



ADLO (>95% C.L. limits:

$\Lambda_+ > 385$ GeV (444)

$\Lambda_- > 355$ GeV

Fig.

2/ Excited electron

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma^{QED}}{d\Omega} + \frac{\alpha^2 s}{2} \cdot \left(\frac{K}{M_{e^*}^2}\right)^2 \cdot (1+\cos^2\theta^*)\, F(\cos^2\theta^*, M_{e^*}^2)$$ [Blondel et al. CERN-EP/87-050]

	Lim. (M_{e^*}) [GeV]
A	337
D	323
L	283
O	337

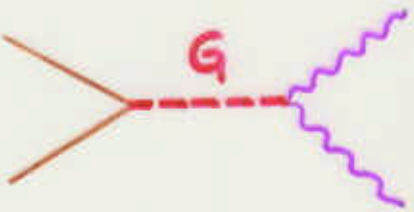
assuming $K=1$

$\Rightarrow$ more sensitive than $e^+e^- \to e^*e$ / e^*e^*

Fig.

Beyond QED (2)

3/ Low Scale Quantum Gravity:



$$\frac{d\sigma}{d\Omega} = \frac{d\sigma^{QED}}{d\Omega} + \frac{\alpha_S}{4\pi}\cdot\frac{\lambda}{M_S^4}\cdot(1+\cos^2\theta^*) + H.O.$$

[Giudice et al., NPB 544 (1999) 3]
[Agashe et al., PLB 456 (1999) 60]
[Hewett, PRL 82 (1999) 4765]

• various formulae → param.

$$\frac{\lambda}{M_S^4} = \pi\left(\frac{1}{\Lambda_T^{\pm}}\right)^4 = \left(\frac{1}{G_{\pm}}\right)^4 = 2\alpha\pi\left(\frac{1}{\Lambda_{\pm}^{QED}}\right)^4$$

• LEP average : $\frac{\lambda}{M_S^4} = (-0.78 \pm 1.19)\, 10^{-12}\ GeV^{-4}$

→ lim. (@ 95% C.L.): $M_S > 830$ GeV ($\lambda = +1$) (960 GeV)

$M_S > 770$ GeV ($\lambda = -1$)

4/ Contact Interactions:

case of negligible effect on anomalous mag. $m^{\pm}(\ell)$
[Eboli, PLB 271 (1991) 274]

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma^{QED}}{d\Omega} + \frac{s^2}{32\pi\Lambda_7^6}$$

$\mathcal{L}_{eff}$ (dim. 7) preserving $U(1)_{em}$

lim (Λ_7) [GeV]

A	705
L	703
O	737

(dim. 6) → $\left(\frac{1}{\Lambda_6}\right)^4 = \frac{\alpha}{2}\left(\frac{1}{\Lambda_{\pm}^{QED}}\right)^4$

(dim. 8) → $\left(\frac{1}{\Lambda_8}\right)^8 = \frac{1}{m_e^2}\left(\frac{1}{\Lambda_7}\right)^6$

Summary - Conclusion

- $\sim 1900\ pb^{-1}$ analyed at $\sqrt{s} = 130 \longrightarrow 208$ GeV
- σ_{tot}, $\frac{d\sigma}{d\Omega}(e^+e^- \to \gamma\gamma(\gamma))$ measured with an accuracy of few %
- QED reproduces the measurements well
- several models going beyond the S.M. have been constrained:
  - $\Lambda_+^{QED} \gtrsim 385$ GeV $\Lambda_-^{QED} \gtrsim 355$ GeV
  - $M_{e^*} \gtrsim 350$ GeV $(\lambda=1)$
  - $M_S \gtrsim 830$ GeV $(\lambda=+1)$ $M_S \gtrsim 770$ GeV $(\lambda=-1)$
  - $\Lambda_7 \gtrsim 0.8$ TeV

→ limits improved by factor ~ 3 w.r.t. LEP-1 results