Two Photon Physics at LEP

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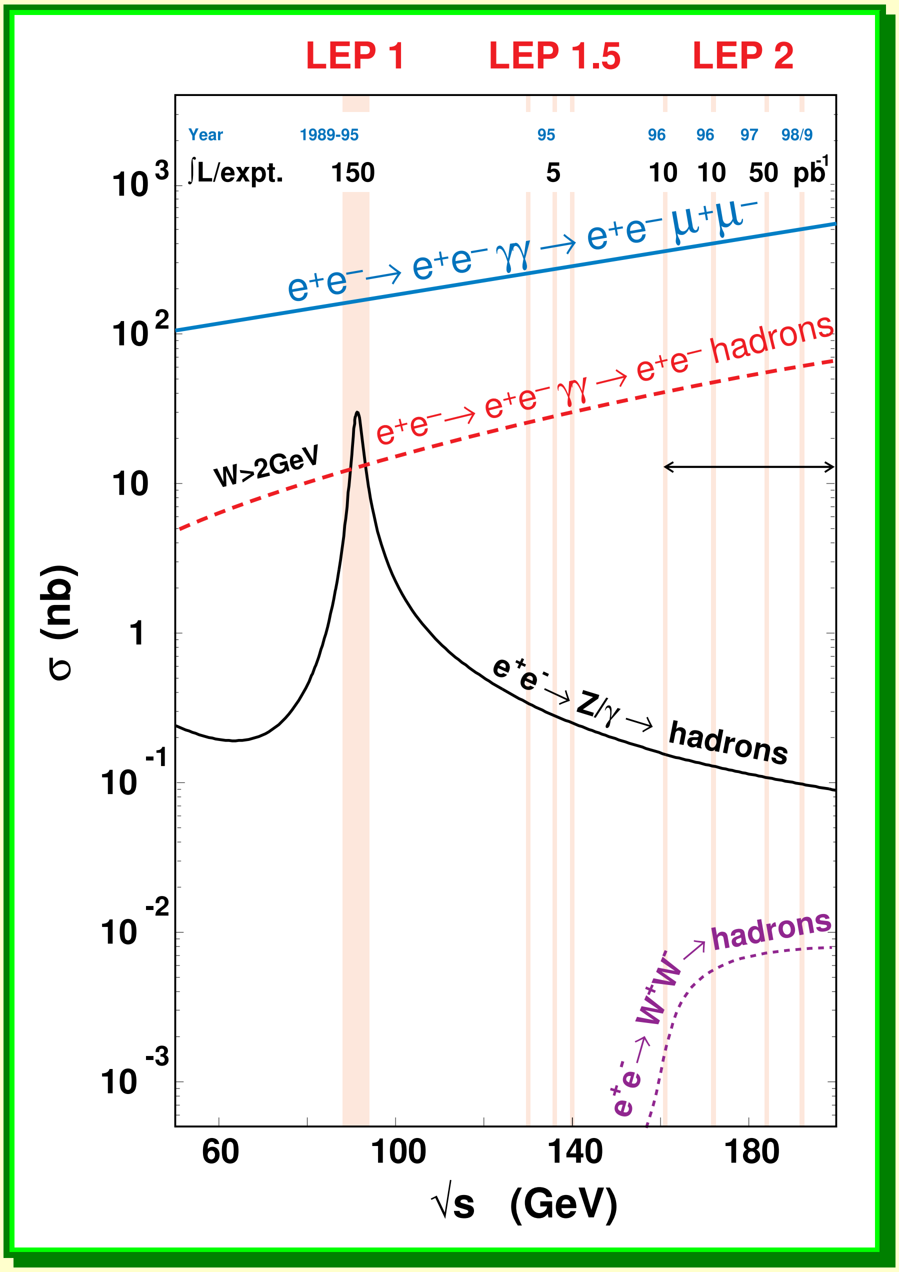
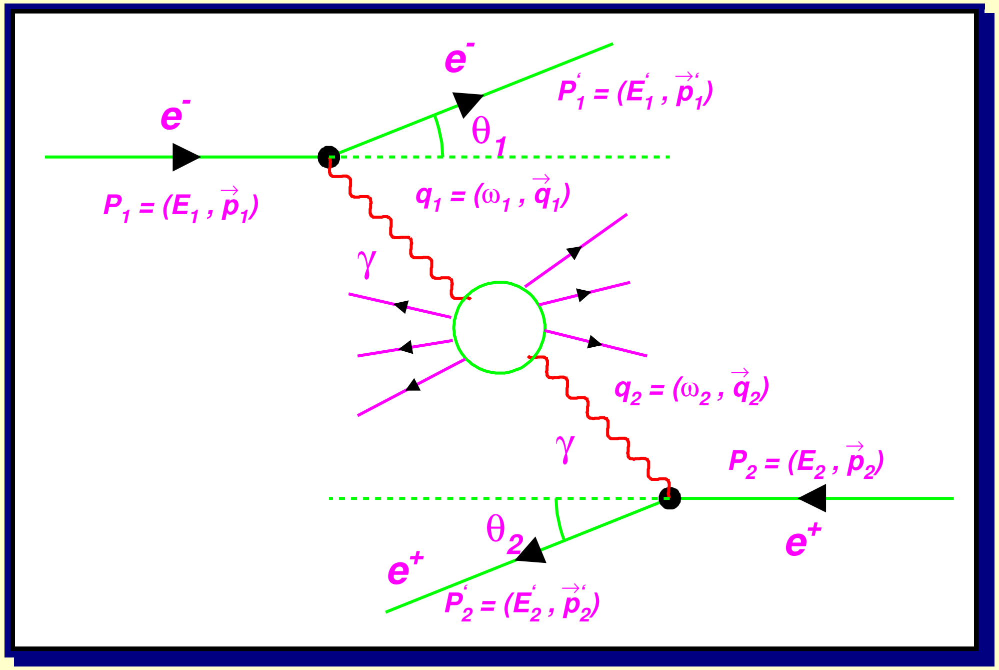
Introduction



❒ At LEP II $e^+e^- \to e^+e^-\gamma\gamma \to e^+e^-\mathrm{hadrons}$ is the highest cross section above the Z resonance.

❒ Good understanding is needed since this is most important and dangerous source of background for the new physics searches at LEP II.

Photon Photon Collision



$$Q_i^2 = -q_i^2 = 2E_iE_i'(1 - \cos\theta_i)$$

$$W_{\gamma\gamma}^2 = (\sum_h E_h)^2 - (\sum_h \vec{p})^2$$

- Photon Photon Scattering ($Q_1^2 \approx 0$ and $Q_2^2 \approx 0$) ➠ Untagged Events
  - ➠ Exclusive /Inclusive Hadronic States
- Electron Photon DIS ($Q_1^2 > 0$ and $Q_2^2 \approx 0$) ➠ Single Tag Events
  - ➠ The Structure function $F_2^\gamma(x, Q^2)$

Exclusive Hadronic States

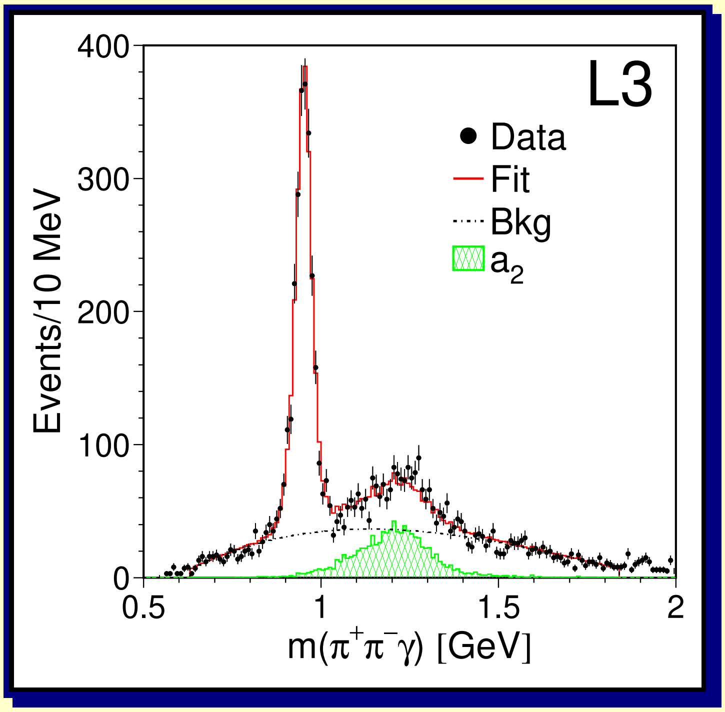
- Structure of hadron and its constituents
- Singlet-Octet mixing of $q\bar{q}$ mesons.
- $\Gamma_{\gamma\gamma}$ of heavy quark allows measurement of α_s
- QCD predicts the existence of Glueballs
- Possible Existence of Four Quark States

❒ L3 Experiment: Many Exclusive channels

Resonance	Final state	J^{PC}	$\Gamma_{\gamma\gamma}$(keV)	
$\eta^{'}$ (958)	$\pi^+\pi^-\gamma$	0^{-+}	$4.17 \pm 0.10 \pm 0.27$	✔
a_2 (1320)	$\pi^+\pi^-\pi^0$	2^{++}	$0.98 \pm 0.05 \pm 0.09$	
$a_2^{'}$ (1750)	$\pi^+\pi^-\pi^0$	2^{++}	$0.29 \pm 0.04 \pm 0.02$/(BR)	
$f_2^{'}$ (1525)	$K_s^0K_s^0$	2^{++}	$0.09 \pm 0.02 \pm 0.02$/(BR)	✔
η_c (2980)	12 Channels	0^{-+}	$8.0 \pm 2.3 \pm 2.4$	
χ_{c2}(3555)	$J/\psi\gamma$	2^{++}	$0.97 \pm 0.40 \pm 0.36$	✔

$\eta' \to \pi^+\pi^-\gamma$

- $\int \mathcal{L}\, dt = 129$ pb^{-1} @ LEP I



$N_{\eta'}$=2123 ± 53

$M_{\eta'}$=958 ± 1 MeV
σ =24 ± 1 MeV

$\Gamma_{\gamma\gamma} = (4.17 \pm 0.10 \pm 0.21)$ keV

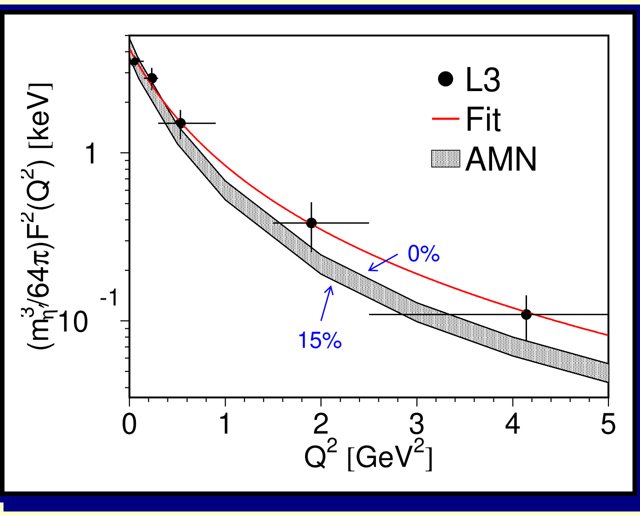
- <u>η' **Form Factor**</u>

➠ $\sum p_T^2 = Q^2$

$F^2(Q^2) = \left(\frac{1}{1+Q^2/\Lambda^2}\right)^2$

$\Lambda_{fit} = 900 \pm 51$ MeV

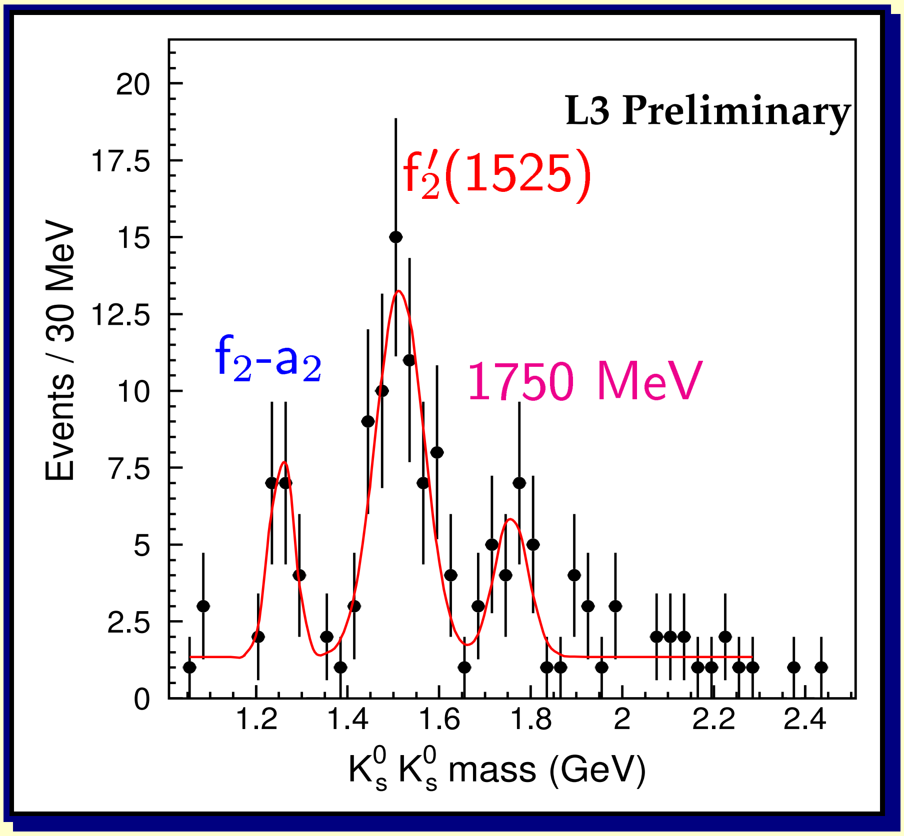
Consistent with VDM



➠ Anisovich *etal.* Phys. Rev. D55(1997) 2918.

$K^0_s K^0_s$

- ❐ $\gamma\gamma \rightarrow f_2' \rightarrow K^0_s K^0_s \;\; ; K^0_s \rightarrow \pi^+\pi^-$
- ❐ $\int \mathcal{L}\, dt = 160$ pb^{-1} @ LEP I + LEP II

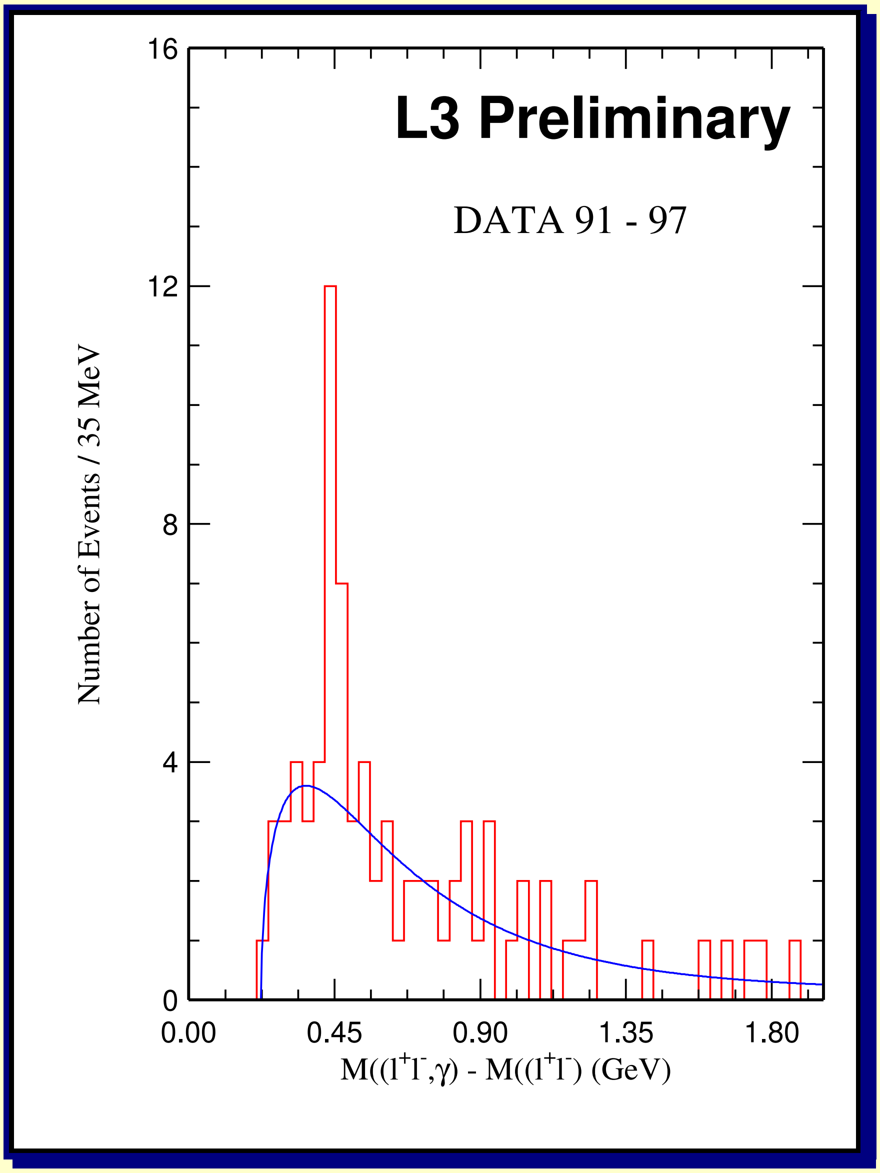


	Mass (MeV)	Width (MeV)	Events
f_2-a_2 Region	1270±11	24±5	14.6±4.5
$f_2'(1525)$	1515±10	112±19	57.4±9.2
1750 MeV Region	1760±14	119±26	17.4±5.6

- ➠ f_2-a_2 destructive interference
- ➠ Possible Enhancement around 1750 MeV (3 σ effect)
- ➠ OGE-SRM : (C.R.Münz, Nucl.Phys.A609:364,1996)
- ➠ f_2'', M=1740 Mev, $\Gamma_{\gamma\gamma}$= 1.040 KeV
- ➠ f_2''', M=1820 Mev, $\Gamma_{\gamma\gamma}$= 0.982 KeV

$\chi_{c2} \to l^+l^-\gamma$

- ❒ $\int \mathcal{L}\, dt = 140$ pb^{-1} at LEP I
- ❒ $\int \mathcal{L}\, dt = 52$ pb^{-1} at LEP II



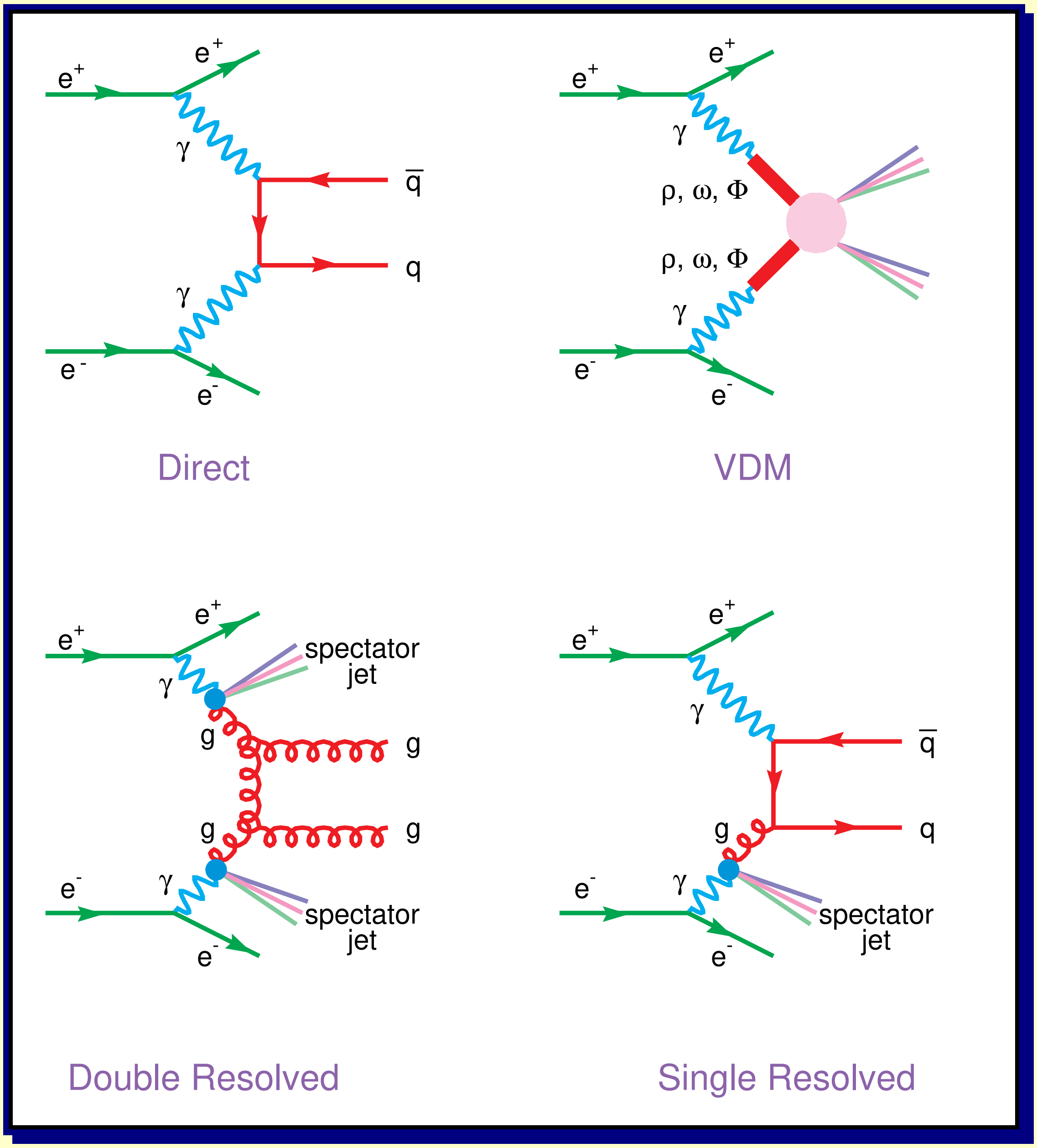
$N_{\chi_{c2}} = 13 \pm 5$

$\Delta M = 447 \pm 11$ MeV

$\sigma = 18 \pm 12$ MeV

$\Gamma_{\gamma\gamma} = (0.97 \pm 0.40 \pm 0.36)$ keV

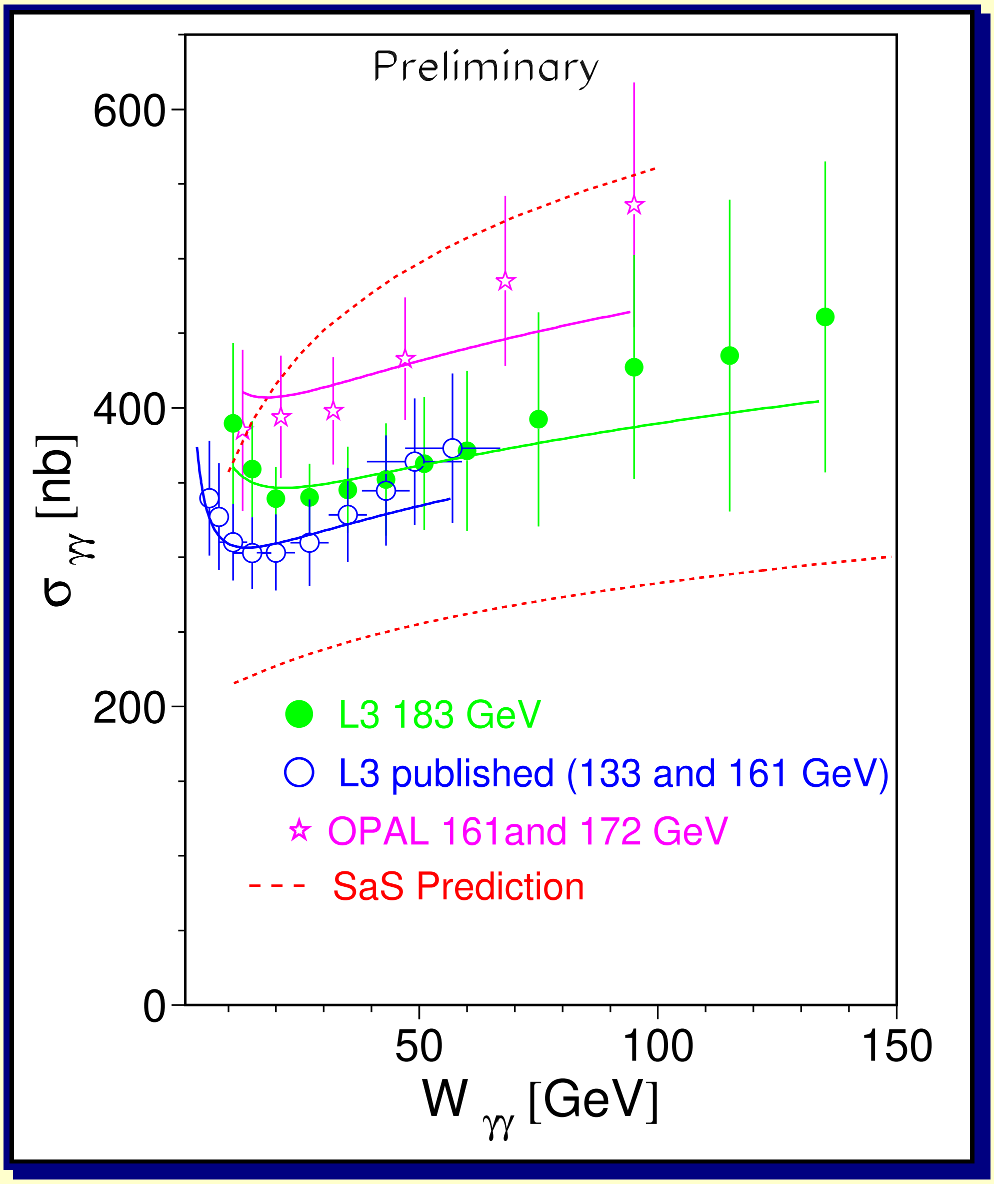
Inclusive Hadronic Production



VDM Diagram is dominant at low Q^2

$\gamma\gamma \to$ hadrons

❒ Data: LEP II



Cross Section dependence can be interpreted by
Regge model

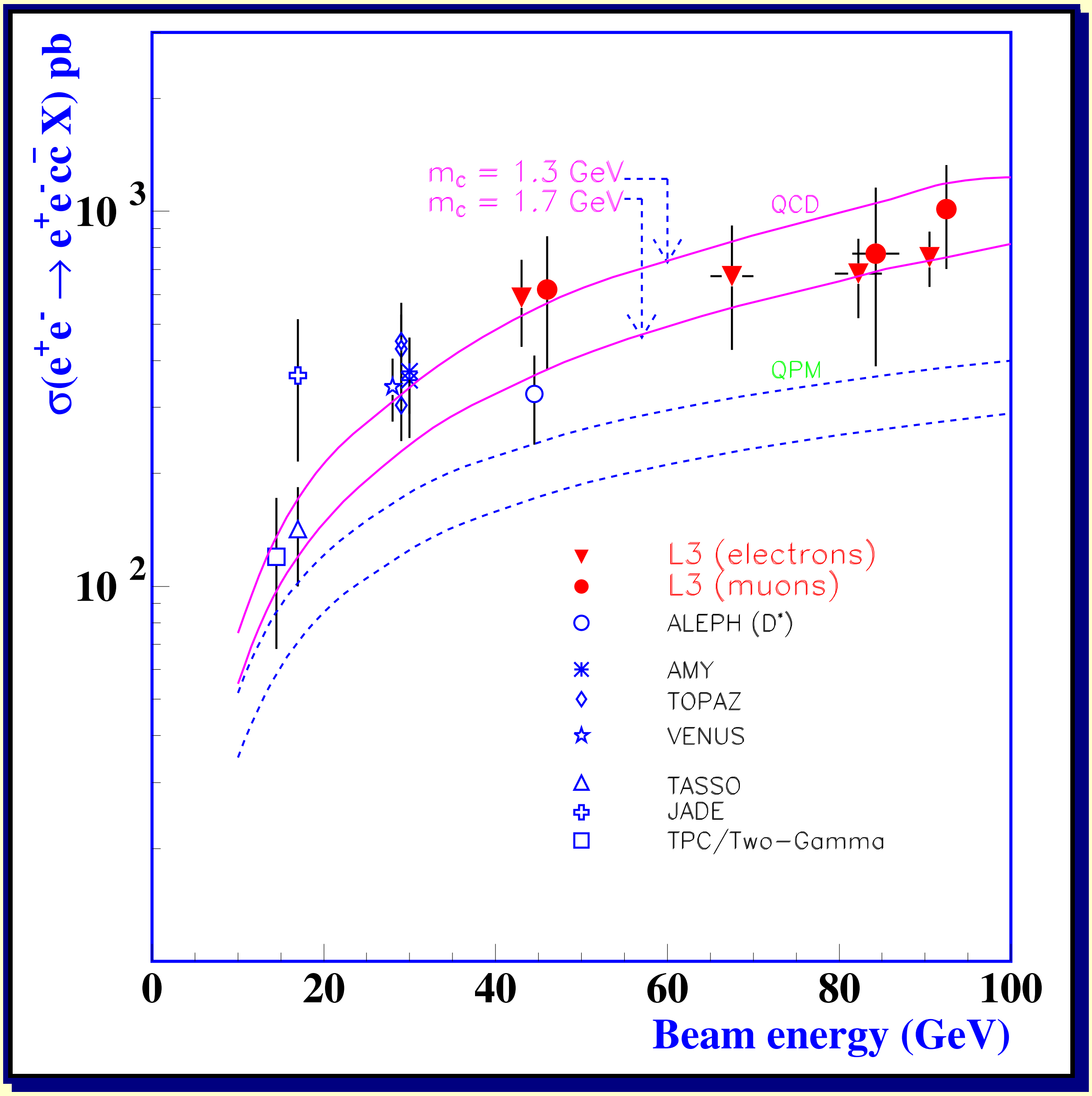
Using universal parameterization:

$$\sigma_{\gamma\gamma} = \mathrm{A.W}_{\gamma\gamma}^{0.079} + \mathrm{B.W}_{\gamma\gamma}^{-0.4678}$$

Cross Section $\mathrm{W}_{\gamma\gamma} > 10$ GeV is explored.

$c\bar{c}$ Production

❐ Data: LEP I + LEP II



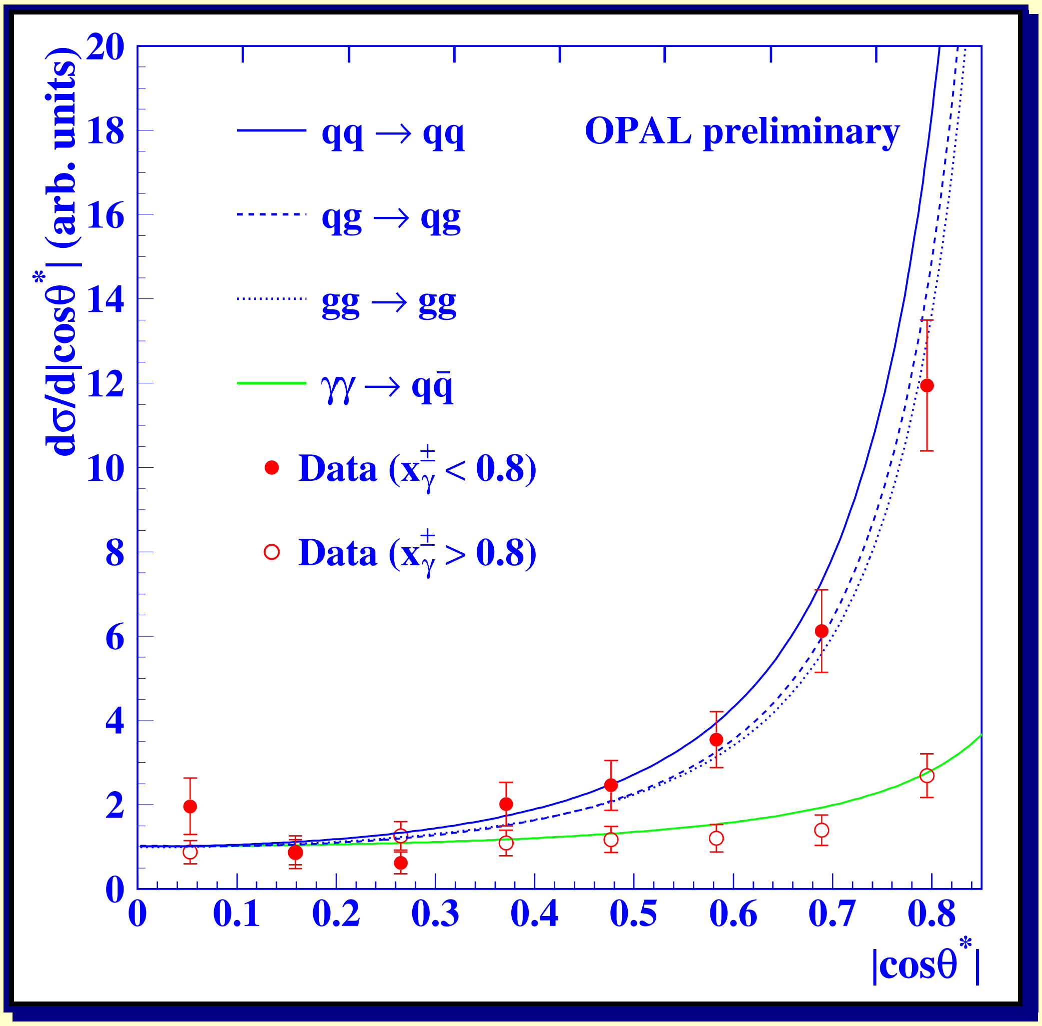
➠ For Details See A. Stone Talk

DiJet Production

- Data: $\sqrt{s} = 161$ and 172 GeV
- **Separation of Direct and Resolved processes**

$$x_\gamma^\pm = \frac{\sum_{\mathrm{jets}=1,2}(E \pm p_z)}{\sum_{\mathrm{hadrons}}(E \pm p_z)}$$

$x_\gamma^\pm$: Fraction of photon momentum in hard process

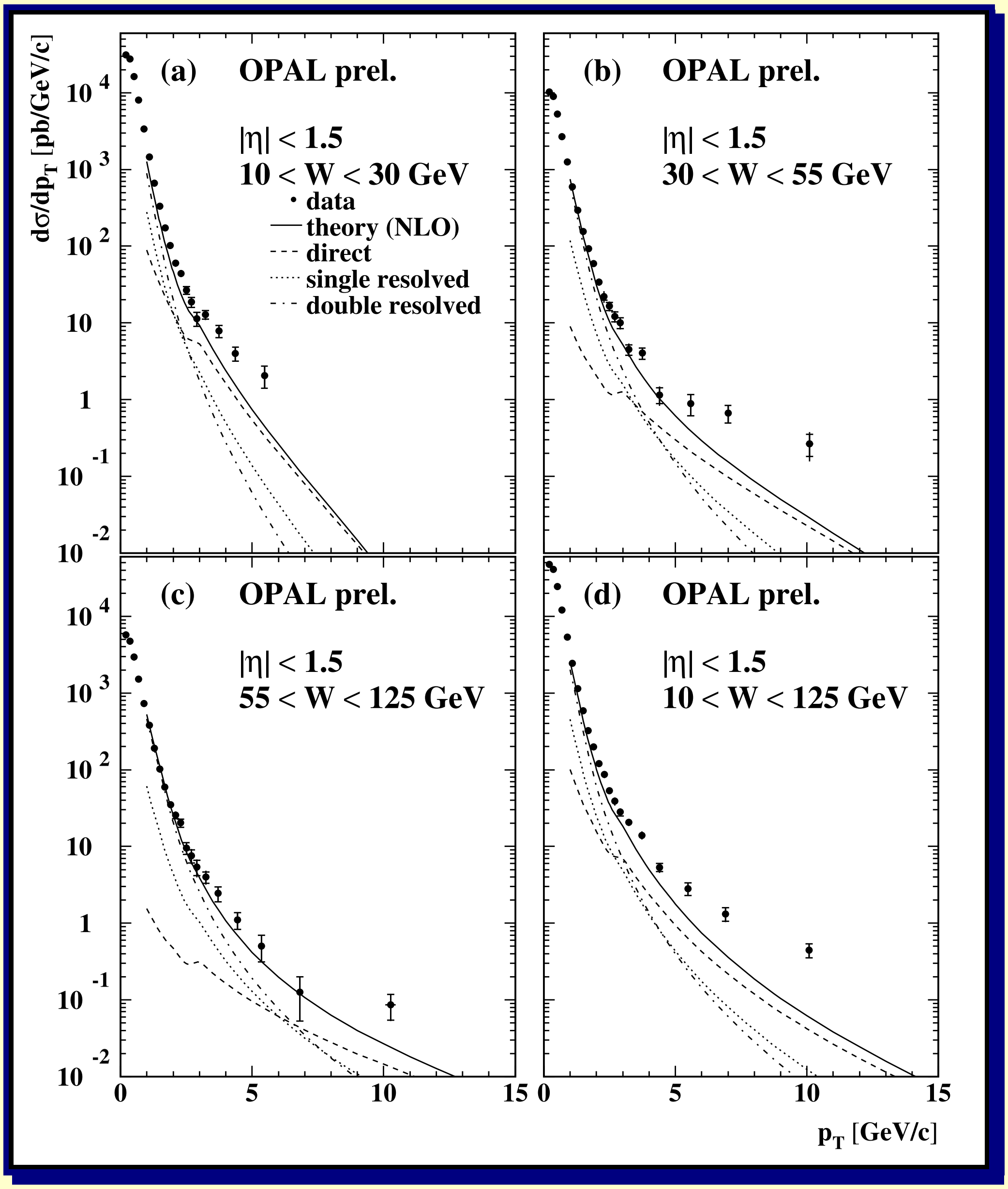


➠ $x_\gamma^\pm < 0.8$ Resolved Events (Gluon Exchange)

➠ $x_\gamma^\pm > 0.8$ Direct Events (Quark Exchange)

Production of Charged Hadrons

❒ Data: $\sqrt{s} = 161$ and 172 GeV

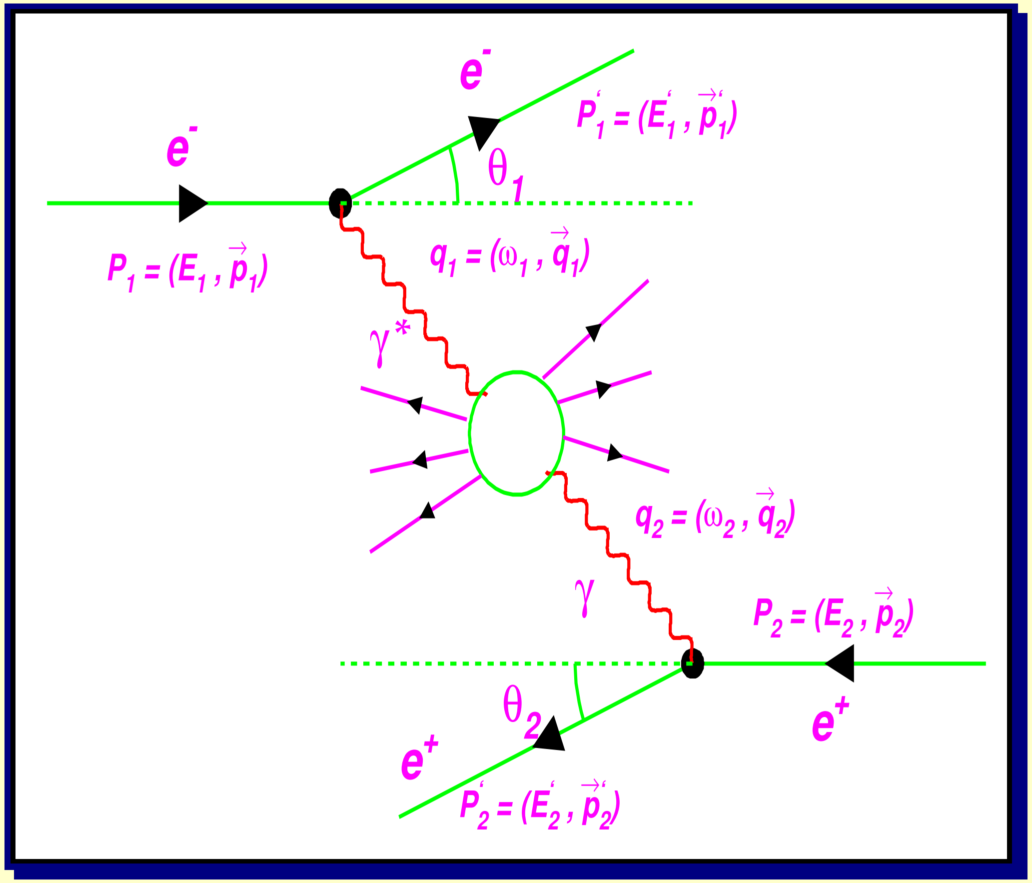


❒NLO calculations reproduces for $\mathrm{W} > 55$ GeV

❒More charged hadrons at large p_t for lower W

NLO ➠ Binnewies *et al* Phys Rev D52(1997) 4947

Electron Photon DIS



$$Q^2 = -q_1^2 = 2E_1E'_1(1 - \cos\theta_1)$$

$$P^2 = -q_2^2$$

$$W_{\gamma\gamma}^2 = (\sum_h E_h)^2 - (\sum_h \vec{p})^2$$

Bjorken scaling variable

$$x = \frac{Q^2}{Q^2+t^2+W_{\gamma\gamma}^2}$$

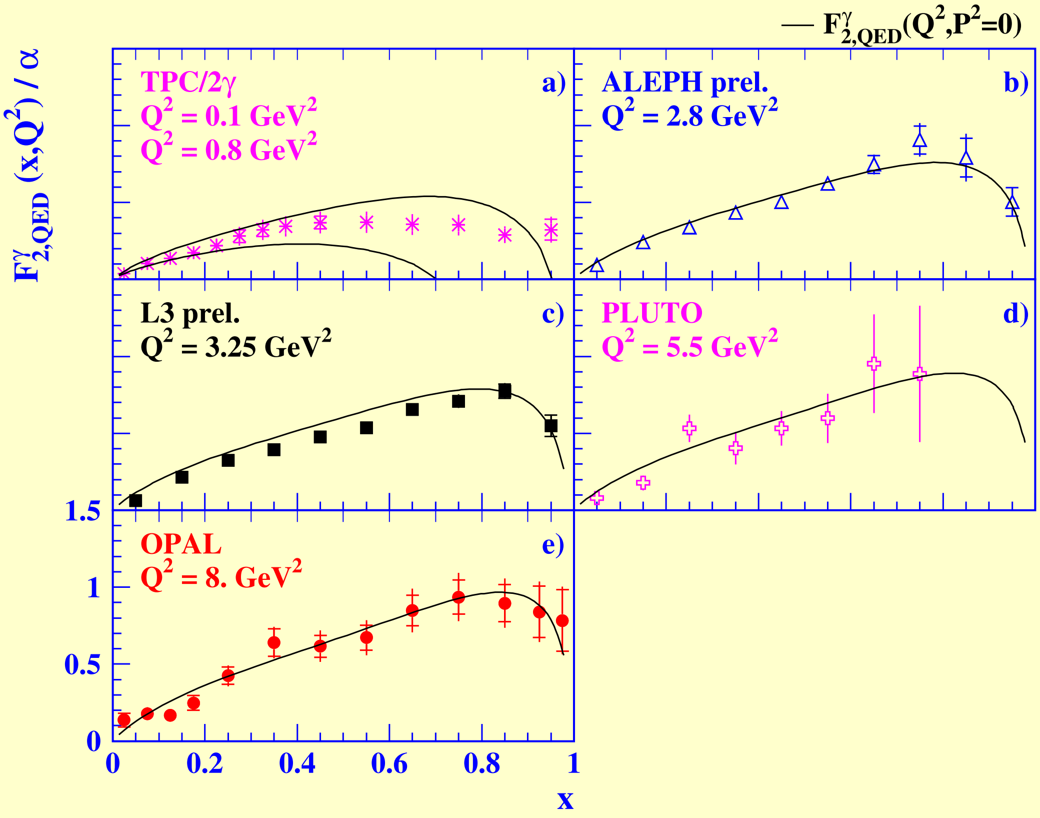
$$y \simeq 1 - \frac{E_1}{E_{beam}} \cos^2 \frac{\theta_1}{2}$$

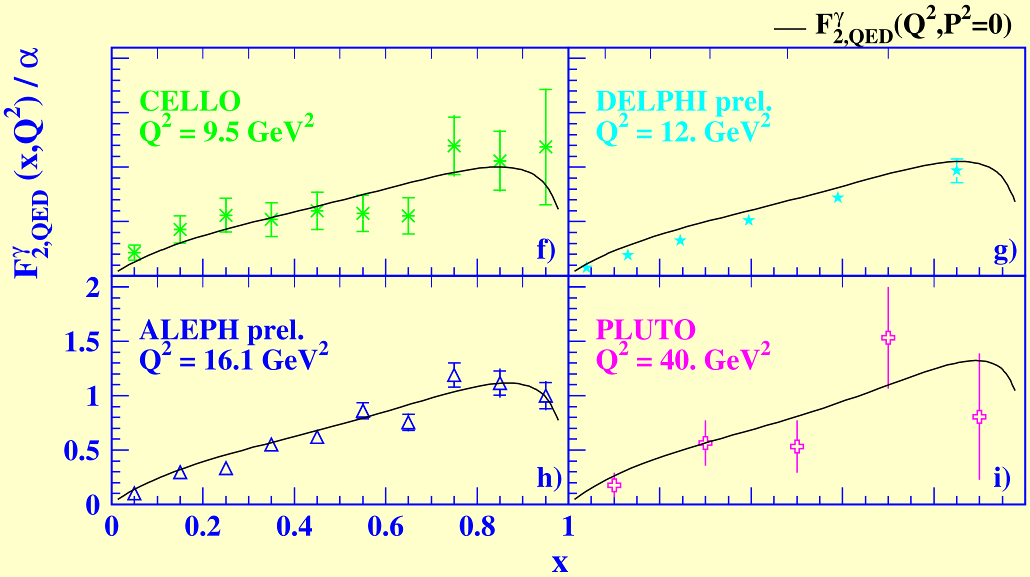
❒ Cross Section

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2}{Q^4}\frac{1}{x}\left\{1 + (1-y)^2 F_2^\gamma(x,Q^2) - \frac{y^2}{2} F_L^\gamma(x,Q^2)\right\}$$

➠ Leptonic and Hadronic $F_2^\gamma(x, Q^2)$

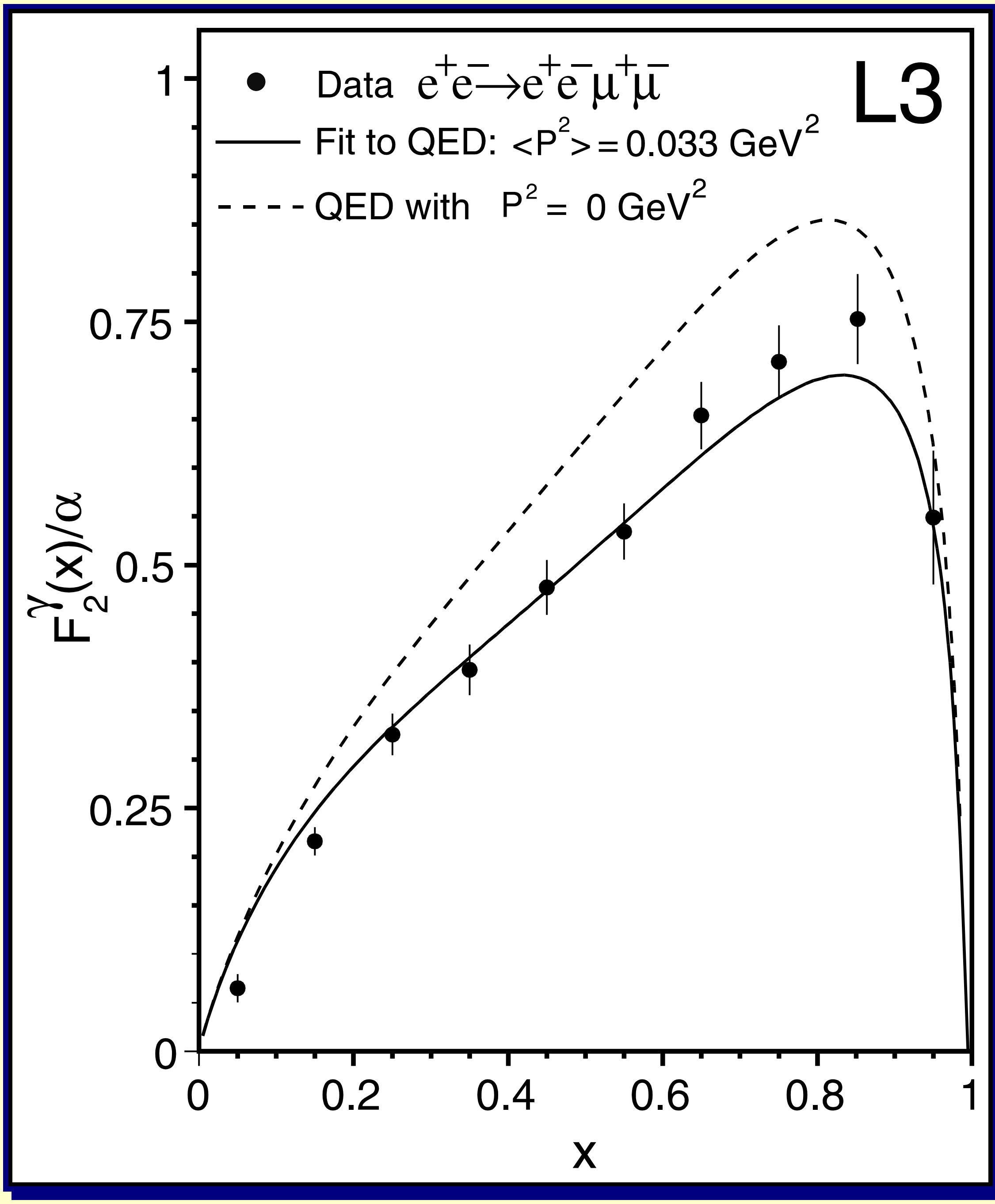
Measurements of $F^{\gamma}_{2,QED}$





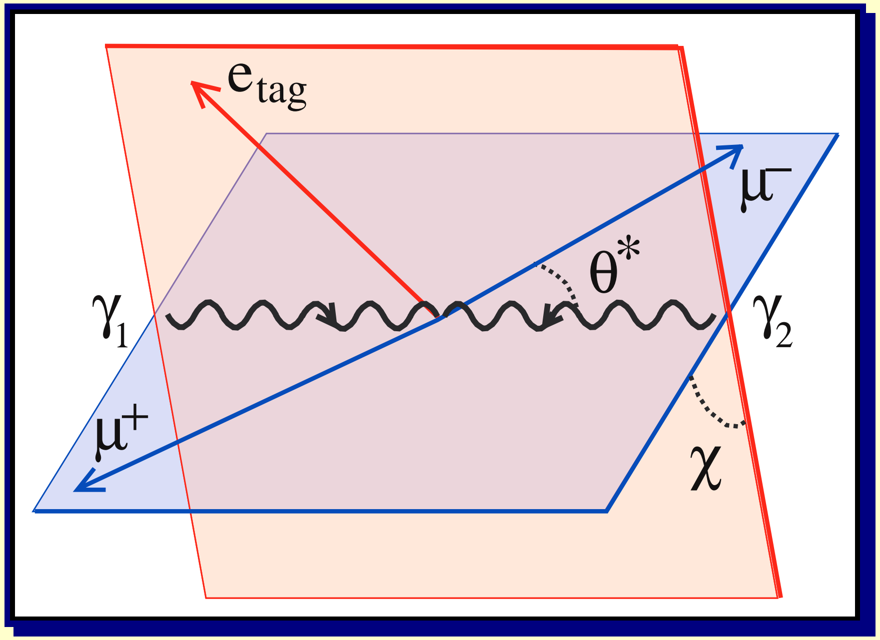
➠ Good agreement with QED

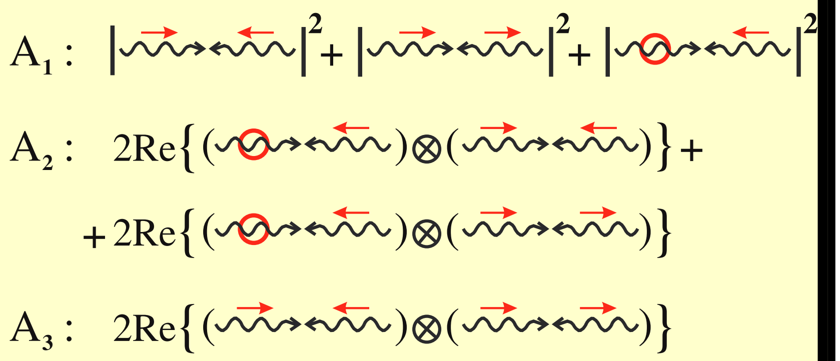
Photon Virtuality



- Effect of target photon Virtuality
- Consistent with QED including Radiative corrections

F_B and F_A





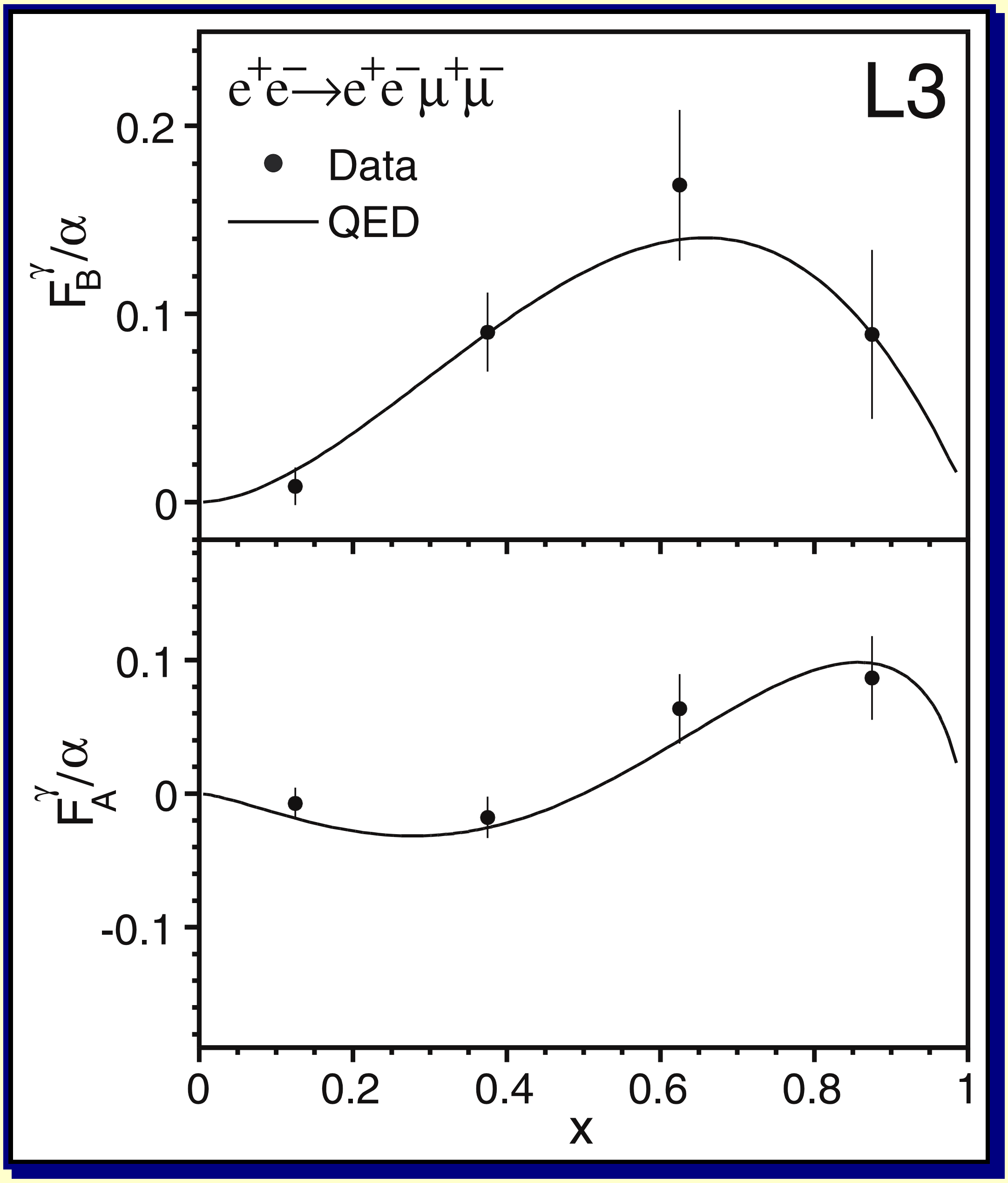
$$\frac{d^4\sigma}{dx\,dy\,dz\,d\chi} = \frac{2\pi\alpha^2}{Q^2}\frac{1+(1-y)^2}{xy}\left[A_1(x,z) + A_2(x,z)\cos\chi + A_3(x,z)\cos 2\chi\right]$$

A_1 ➠ Sum of all photon helicity

$A_2 \propto F_A$ ➠ Interference longitudinal-transverse photons

$A_3 \propto F_B$ ➠ Interference two transverse photons

F_B and F_A



➠ Non-zero longitudinal leptonic photon structure function

Hadronic $F^{\gamma}_{2,\mathrm{QCD}}$

Investigation of $F^{\gamma}_{2,\mathrm{QCD}}$

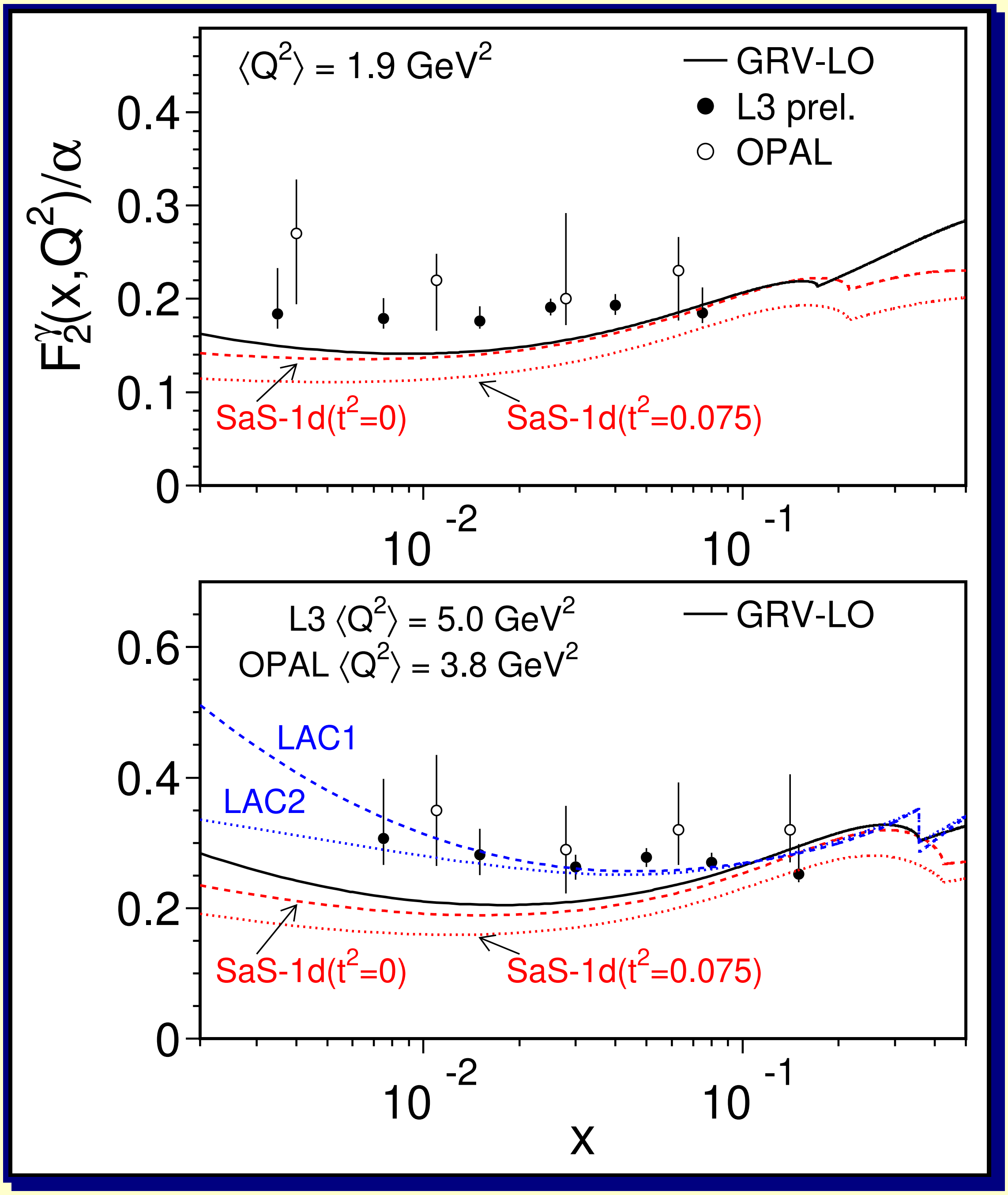
- ❒ Quantative test of perturbative QCD ➠ lnQ^2 dependence
- ❒ Probe the lower value of Scaling variable x

➠ $(x \approx 10^{-3})$ @ any given $Q^2 (Q^2 \approx 10^3\ GeV^2)$

- ❒ Uncertainty in the theoretical predictions

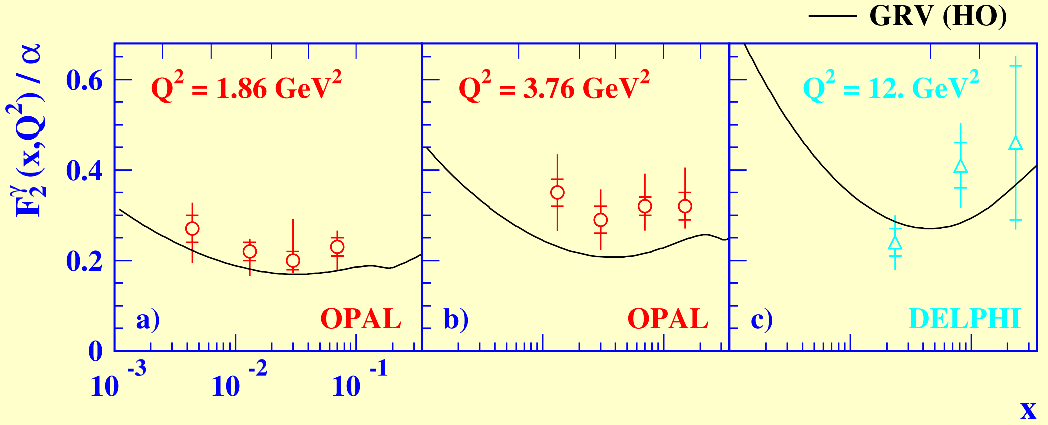
Measurements of $F^{\gamma}_{2,QCD}$

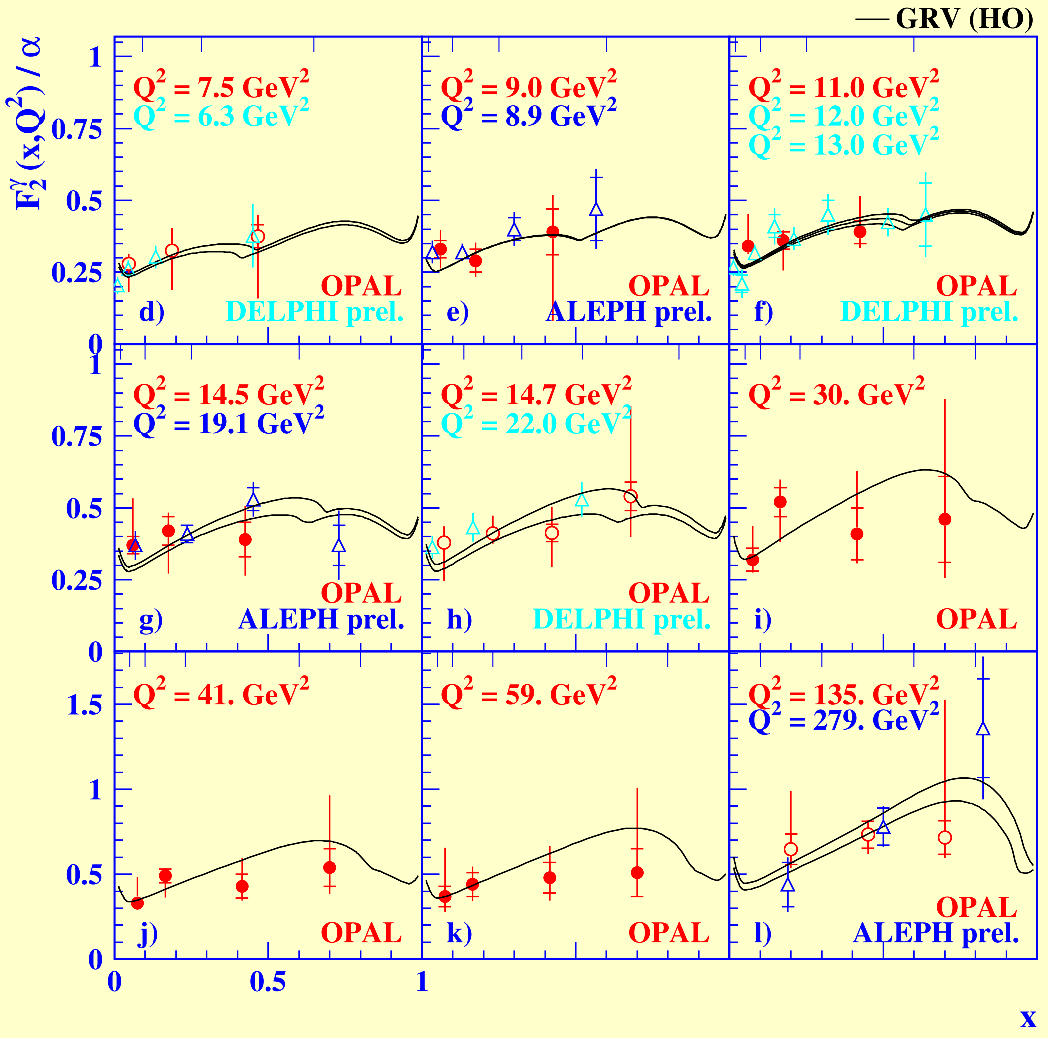
❒ Data: $\sqrt{s} = 91$ GeV



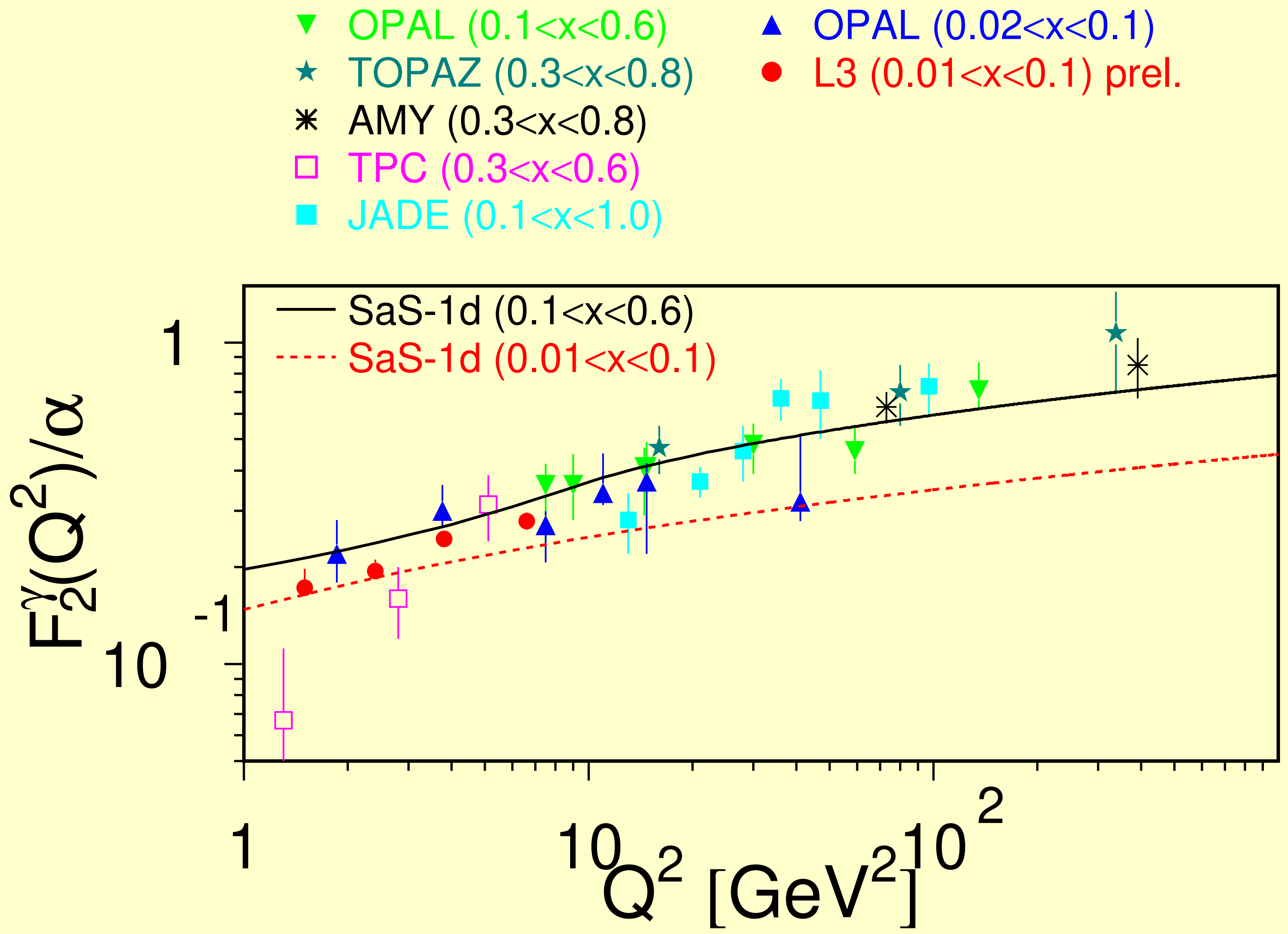
➠ No clear evidence of rise in $F^{\gamma}_{2,QCD}$ with decrease in x

Measurements of $F^{\gamma}_{2,QCD}$





$F^{\gamma}_{2,\mathrm{QCD}}$ vs Q^2



Conclusions

❐ Exclusive production

➠ Resonance formation

❐ Inclusive production

➠ Hadronic Cross section above $W_{\gamma\gamma} > 10$ GeV
➠ Separation of Direct and Resolved processes
➠ Differential cross section of Charged Hadrons as function of p_T

❐ Results on F_2^γ

➠ $F_{2,QED}^\gamma$ is in good agreement with QED predictions
➠ Target photon virtuality
➠ Interference terms of the scattering amplitudes
➠ No clear evidence of rise in $F_{2,QCD}^\gamma$ with decrease in x
➠ The lnQ^2 evolution of F_2^γ consistent with QCD.