PHOTON STRUCTURE

- Introduction
- QED structure of the photon
- Hadronic structure of the photon
- Conclusions

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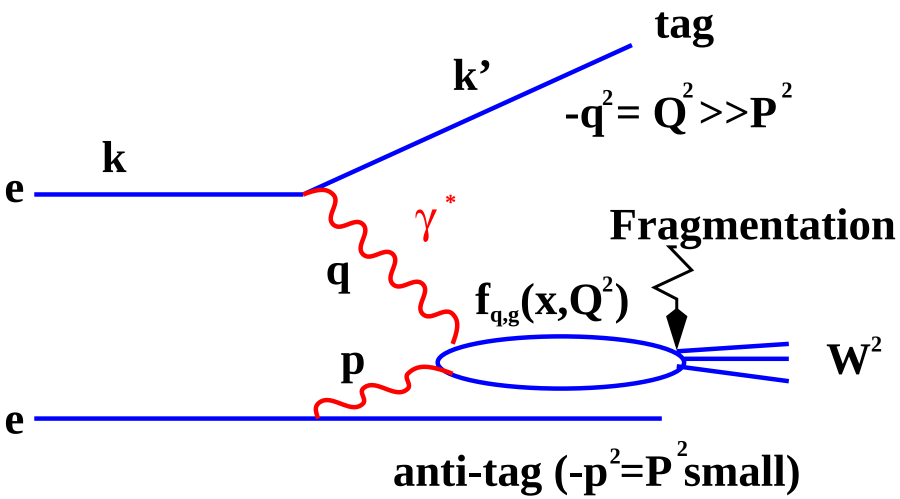
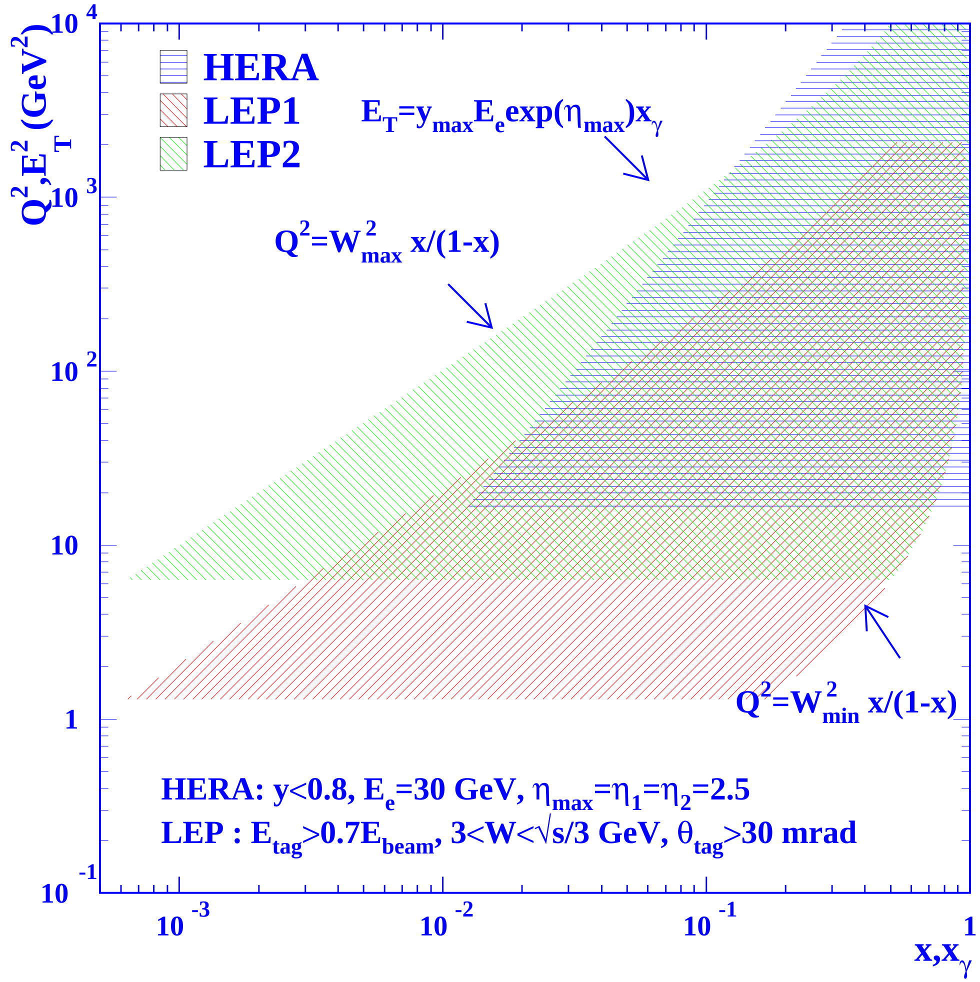
based on abstracts 644 (DELPHI), 112, 254 (OPAL) and 590 (L3)

Single-tag events:



- inv. mass of final state W
- virtuality of probe photon Q^2
- virtuality of target photon P^2
- $x = Q^2/(Q^2+W^2+P^2)$
- Inelasticity y

photon structure

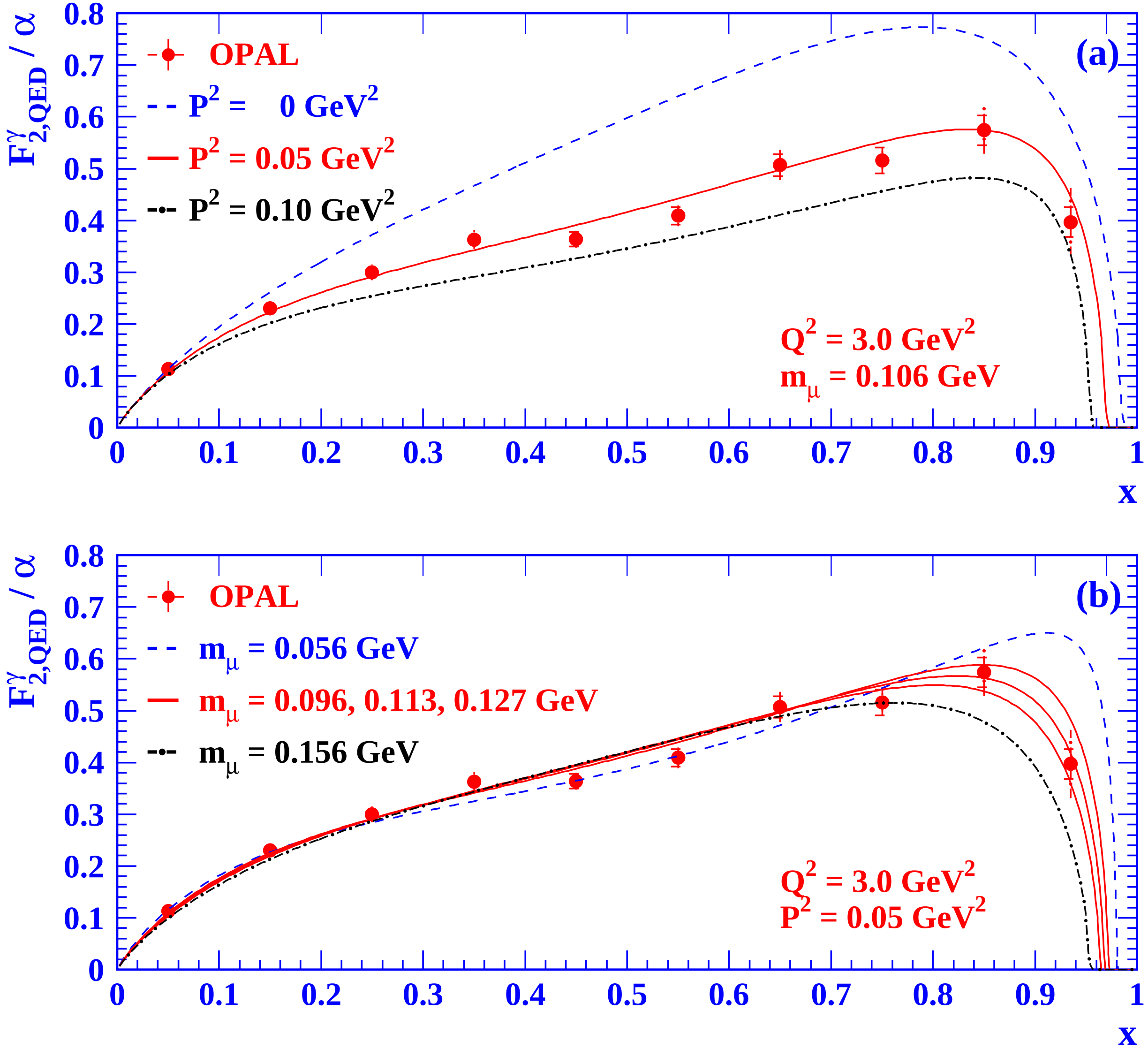


HERA jets: J.Butterworth
LEP jets: T. Wengler

=>gluons

A ‘simple’ model: QED

$e^+e^- \to e^+e^- \mu^+\mu^-$



structure function depends on virtuality of probed photon

=>

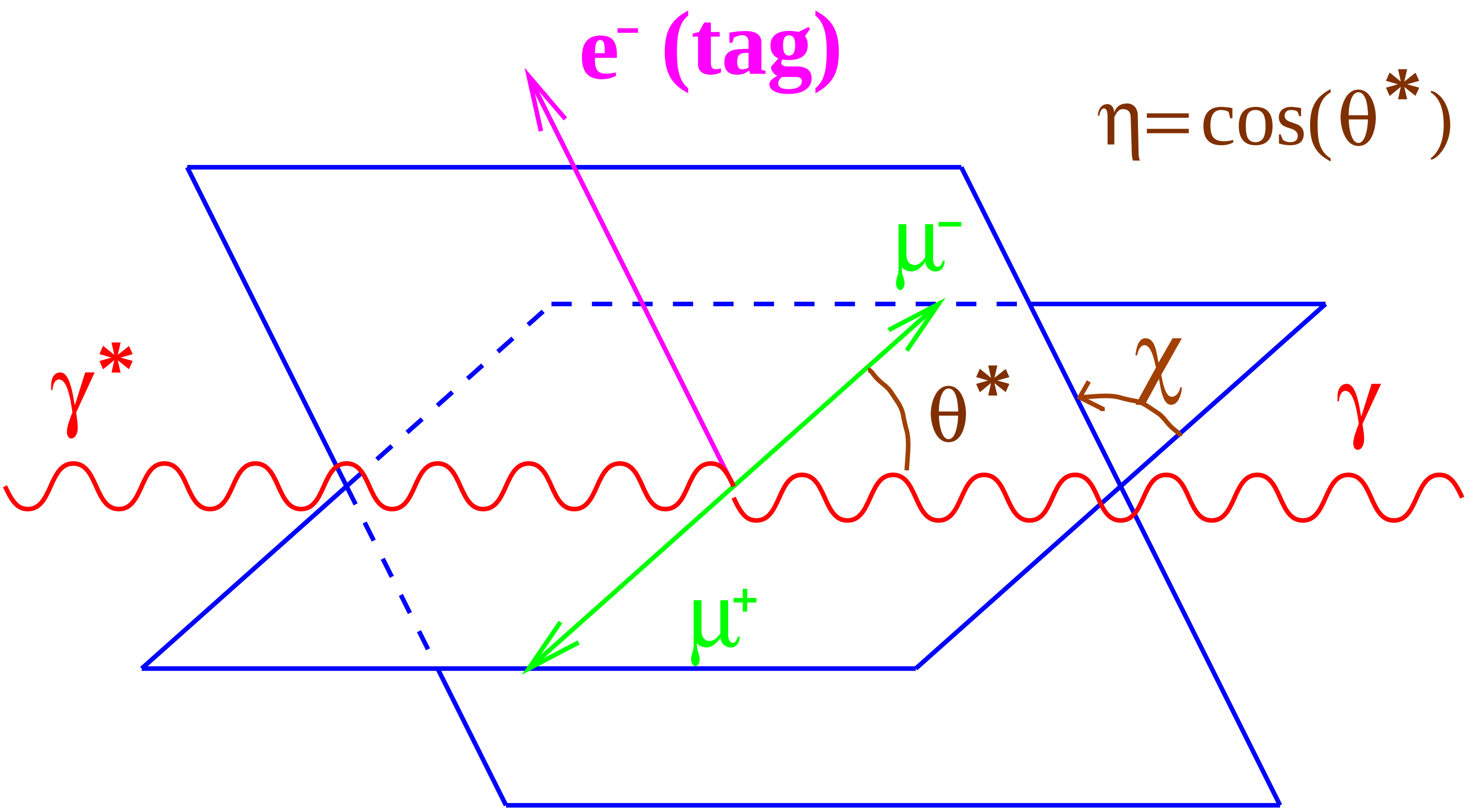
virtual photon structure

structure function depends on the muon mass

=>

hadronic SF: Λ_{QCD}

Azimuthal correlations



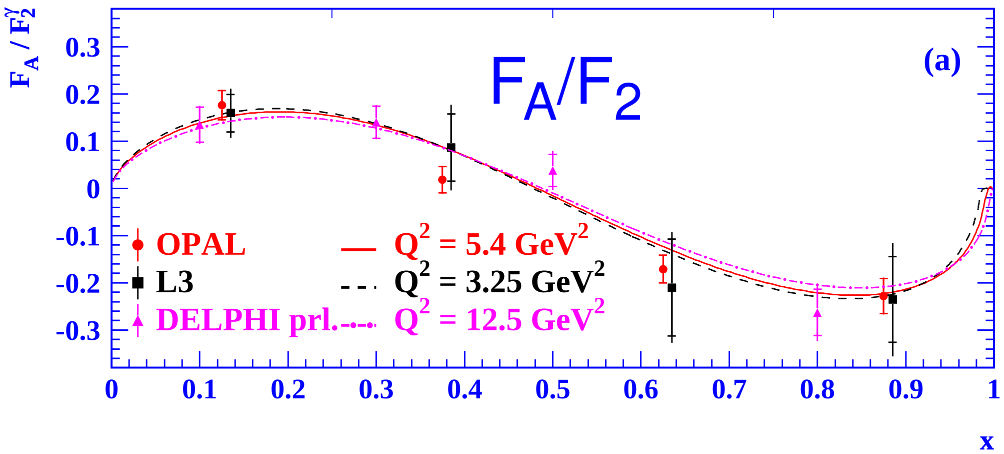
$$\frac{\mathrm{d}\sigma(e\gamma \to e\mu^+\mu^-)}{\mathrm{d}x\mathrm{d}y\mathrm{d}\eta\mathrm{d}\chi/2\pi} = \frac{2\pi\alpha^2}{Q^2}\left(\frac{1+(1-y)^2}{xy}\right)\times$$
$$\left[2x\tilde{F}_T^\gamma + \epsilon(y)\tilde{F}_L^\gamma - \rho(y)\tilde{F}_A^\gamma\cos\chi + \frac{\epsilon(y)}{2}\tilde{F}_B^\gamma\cos 2\chi\right]$$

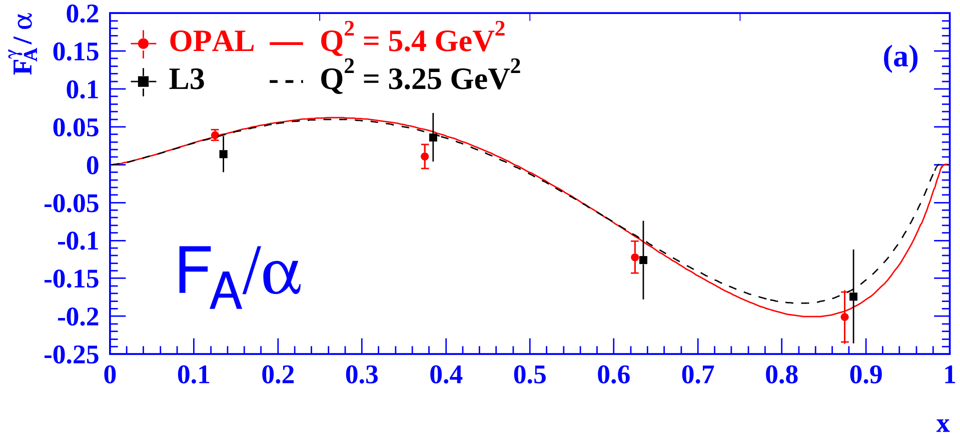
$$F_2^\gamma = 2xF_T^\gamma + F_L^\gamma \quad ; \quad F_{T,L,A,B}^\gamma = \int_{-1}^{1}\int_0^{2\pi}\frac{\mathrm{d}\chi\mathrm{d}\eta}{2\pi}\tilde{F}_{T,L,A,B}^\gamma$$

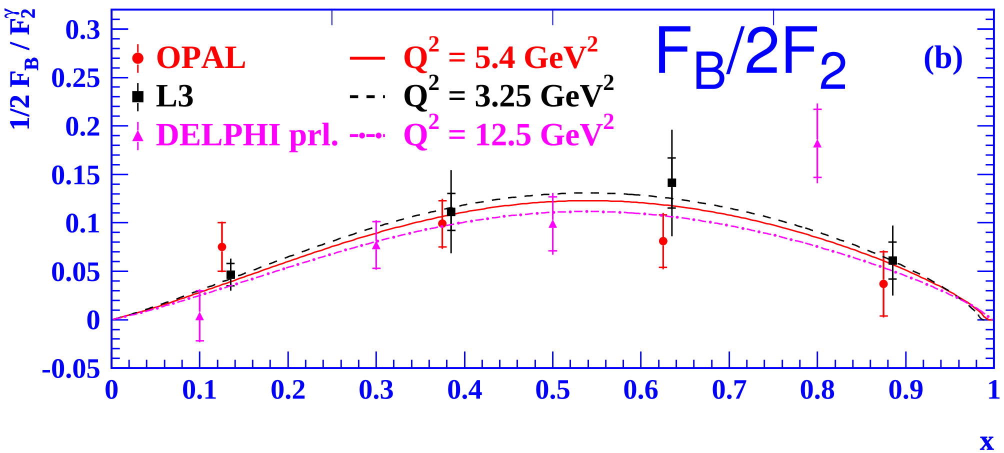
very difficult for hadrons, but interesting

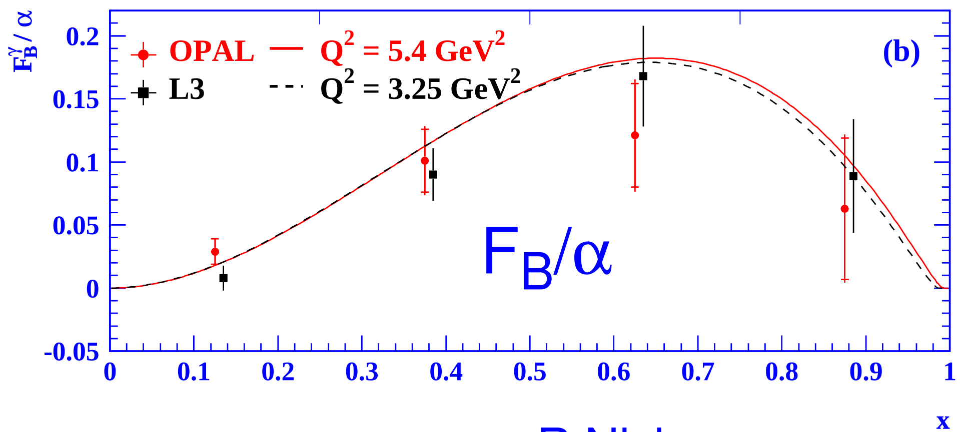
$P^2 = 0$ (transverse target photon) $\quad F_2 = 2xF_T + F_L \propto \sigma_{TT} + \sigma_{LT}$

F_A: related to transverse-longitudinal interference









R.Nisius

F_B: related to transverse-transverse interference

The hadronic structure function

$$\frac{d^2\sigma_{e\gamma\to eX}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^2}[(1+(1-y)^2)\ F_2^\gamma(x,Q^2) - y^2\ F_L^\gamma(x,Q^2)\ ]$$

Small contribution

$$y = 1 - \frac{E_{tag}}{E_b}\cos^2\theta_e$$

Small for $E_{tag} \geq 0.7\ E_b$ and small θ_e considered

Need distribution of events in Q^2 and x

$$x_{(\gamma)} = \frac{Q^2}{Q^2 + W^2 + P^2}$$

scattered electron

=

good resolution

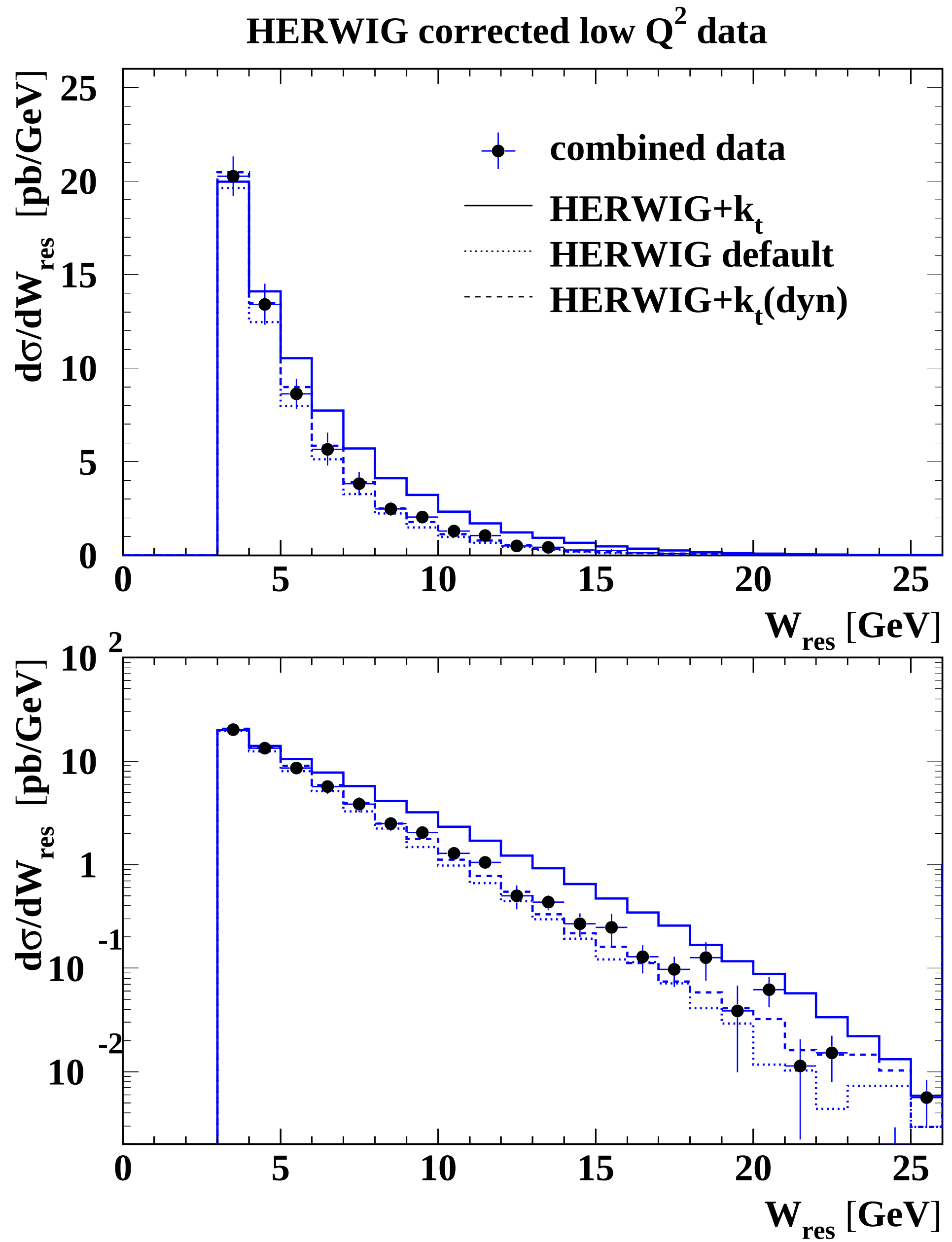
hadrons

=

bad resolution

=> unfolding

- **ALEPH, L3 and OPAL have made considerable progress in reducing the systematic errors due to unfolding and hadronisation uncertainties**
- **Combined LEP data is compared to generators (PHOJET, HERWIG)**
- **Example: Unbiased tune (from HERA) of HERWIG gives significant improvement**
- **CERN-preprint**



Improved unfolding

- Different methods for regularised unfolding like:

  maximum entropy method

  singular value decomposition

- Two-dimensional unfolding in x and a second variable

  ALEPH: E_{17}

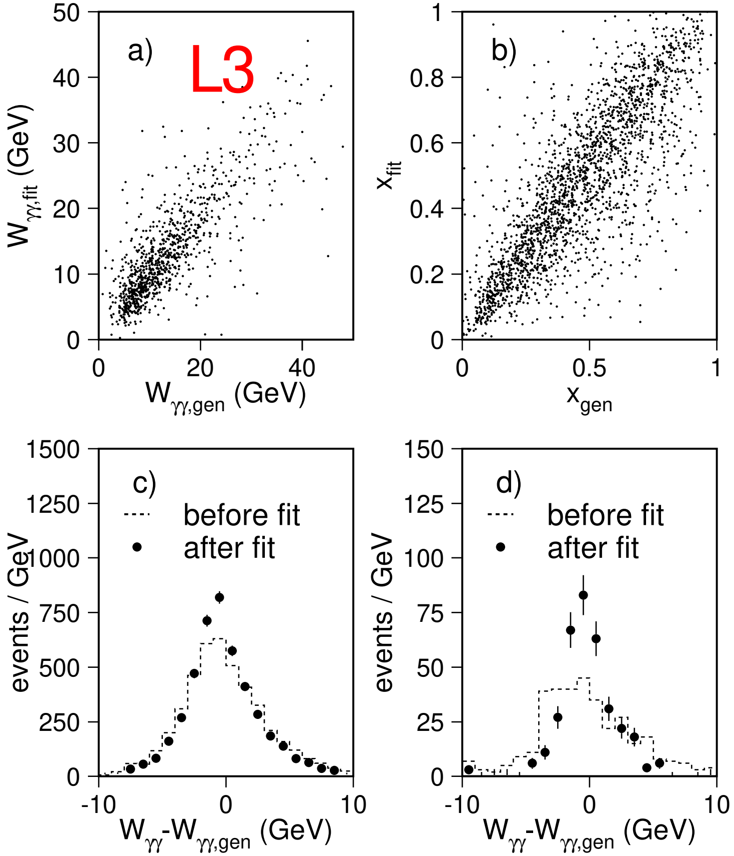
  OPAL: E_T^{out}/E_{tot}

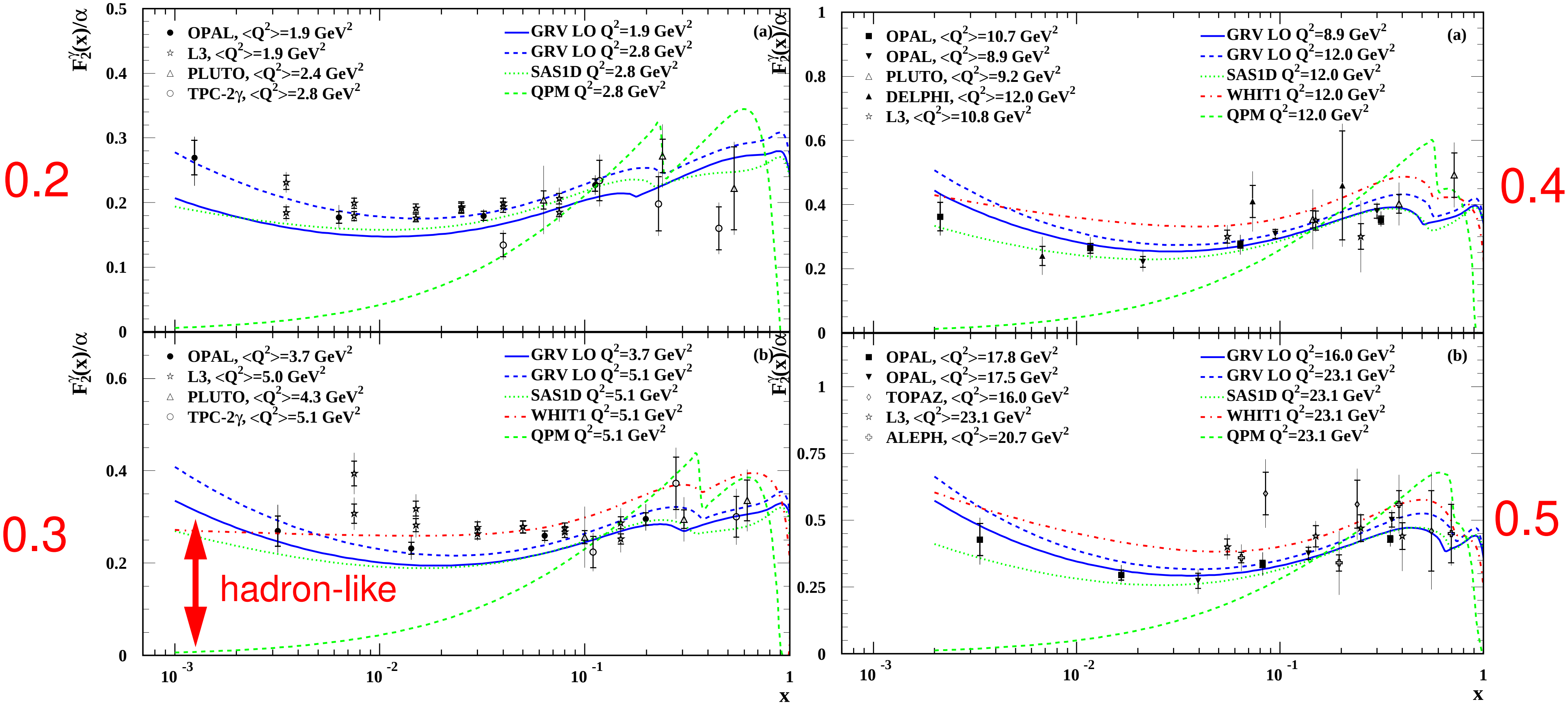
- Improved treatment of forward hadronic energy

Kinematic constraints for W

- energy/momentum conservation

- kinematic information from hadrons and electrons

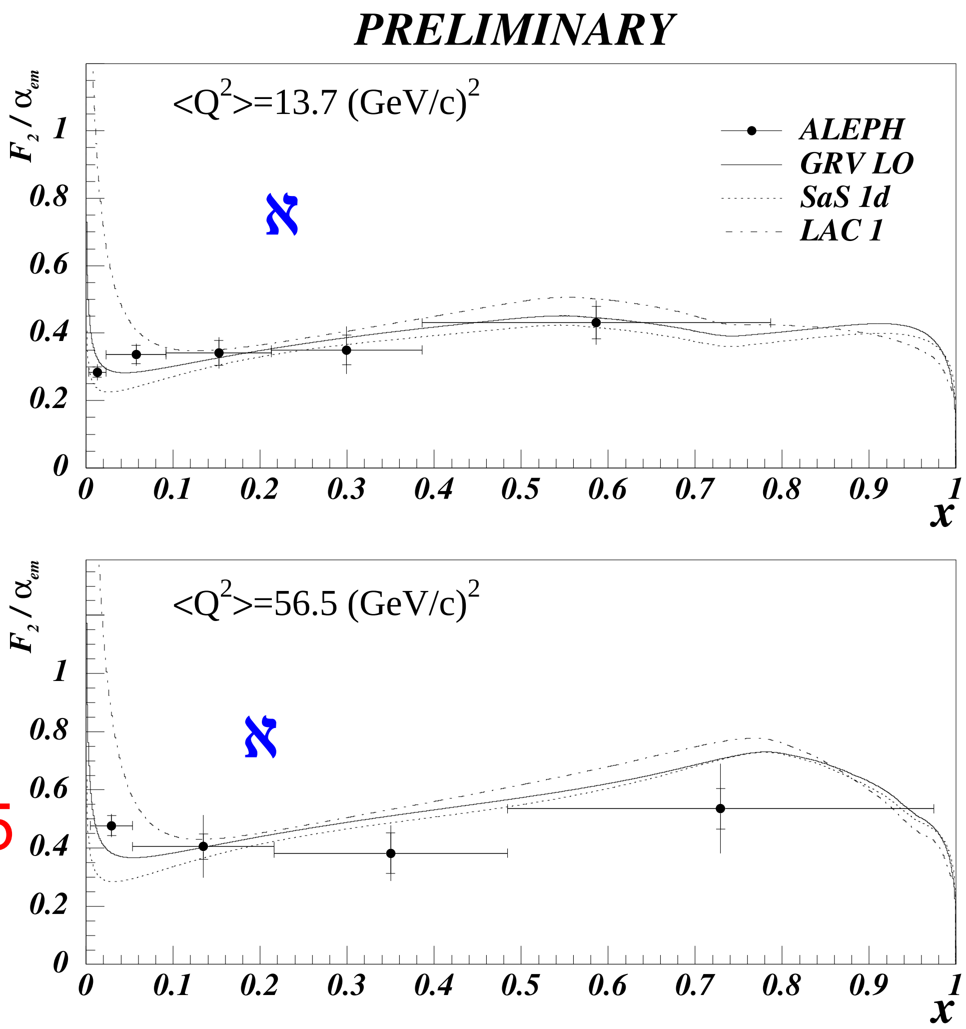


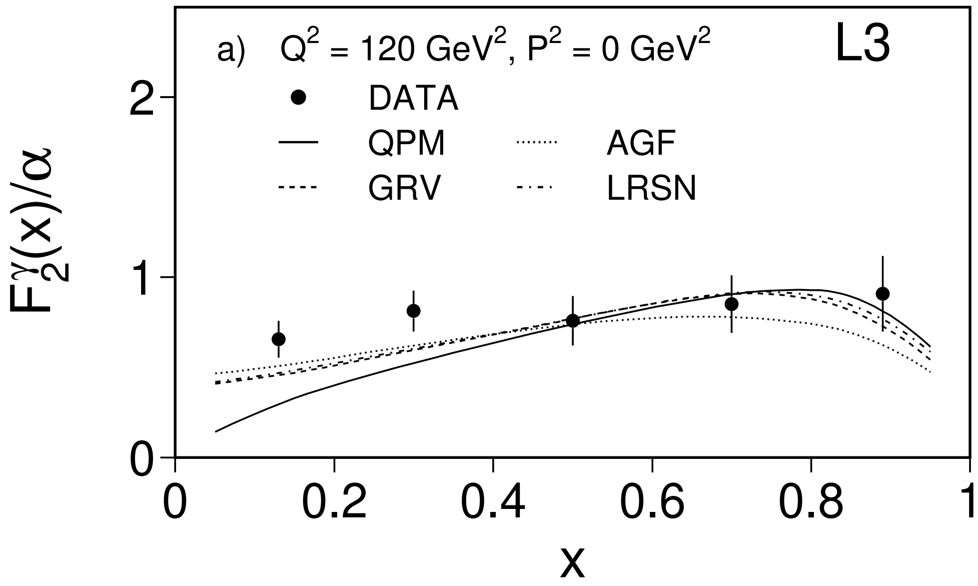


lowest x that can be measured at LEP1

0.4

0.5



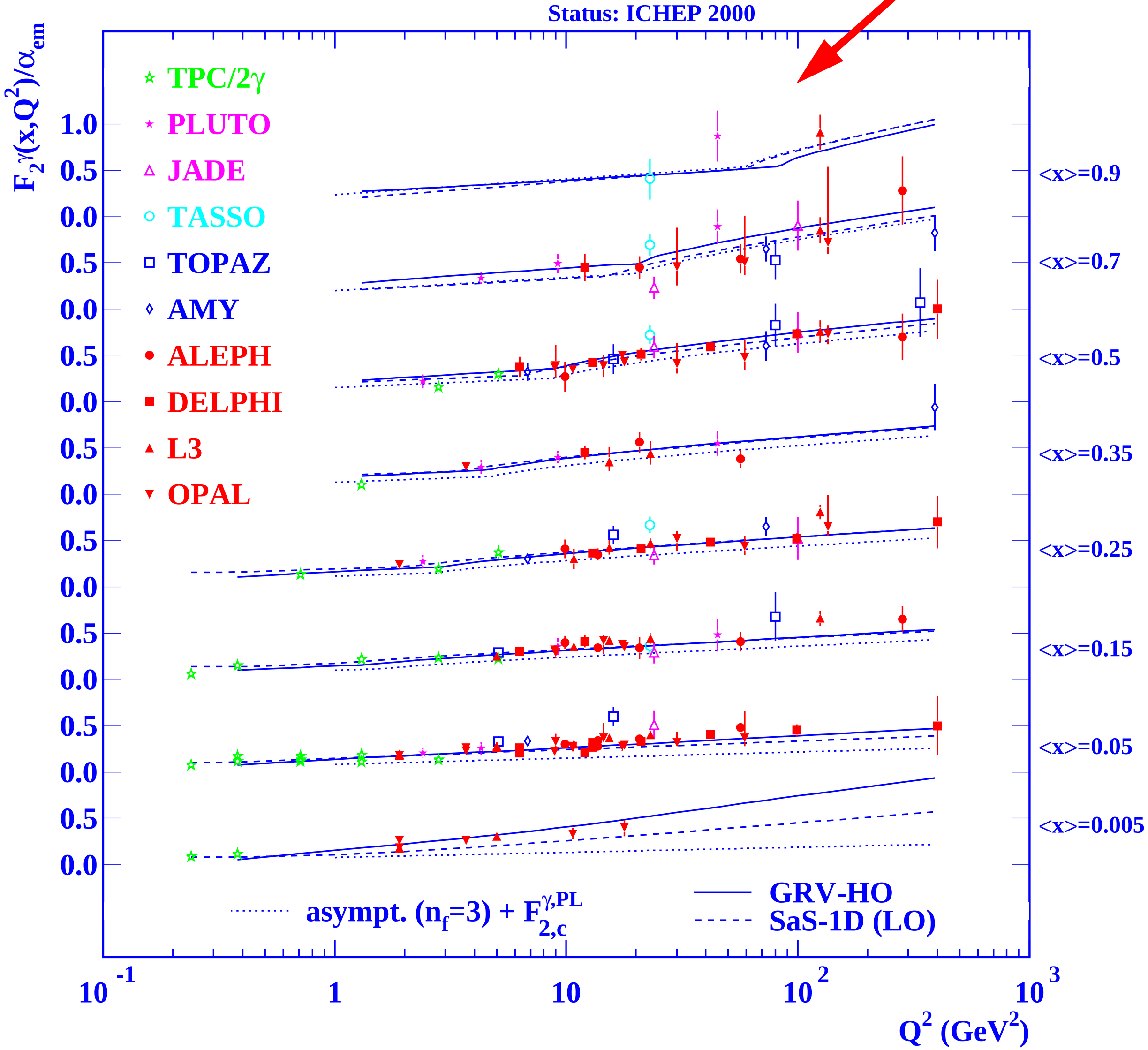


0.8

LO:
DG,GAL,LAC,SaS,WHIT

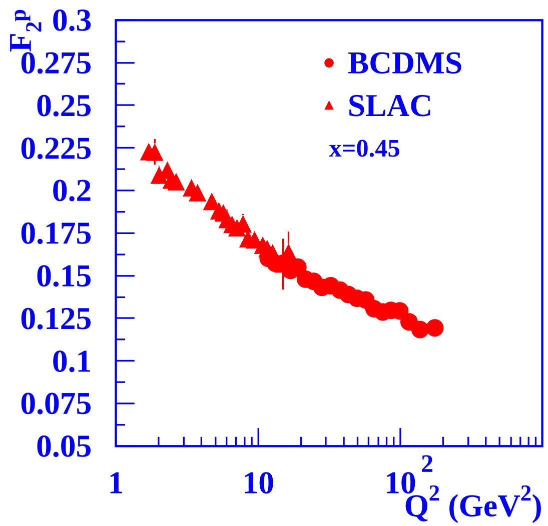
NLO:
AFG,GRS,GRV,GS

charm



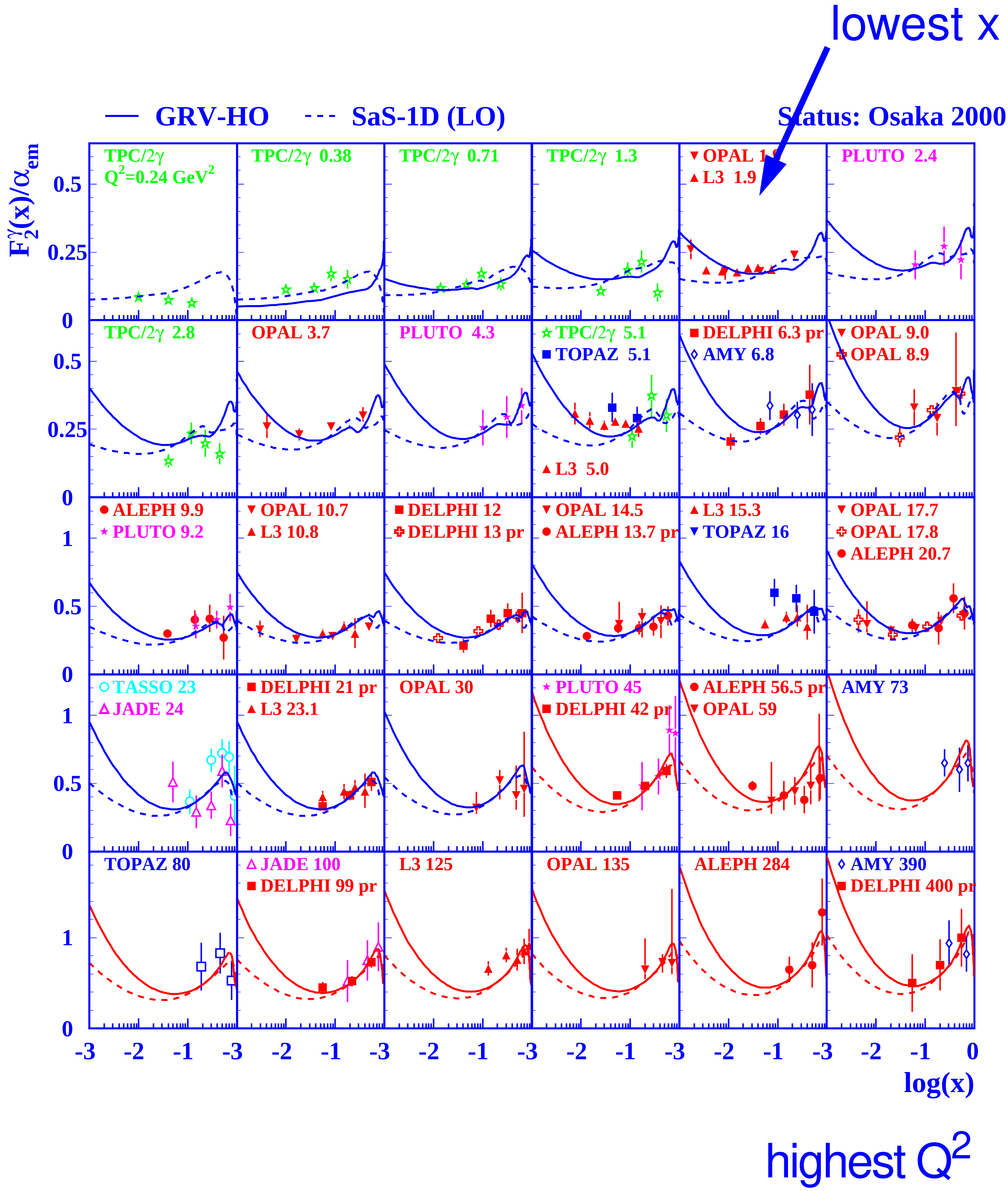
Linear rise with ln Q^2

Prediction of QCD !



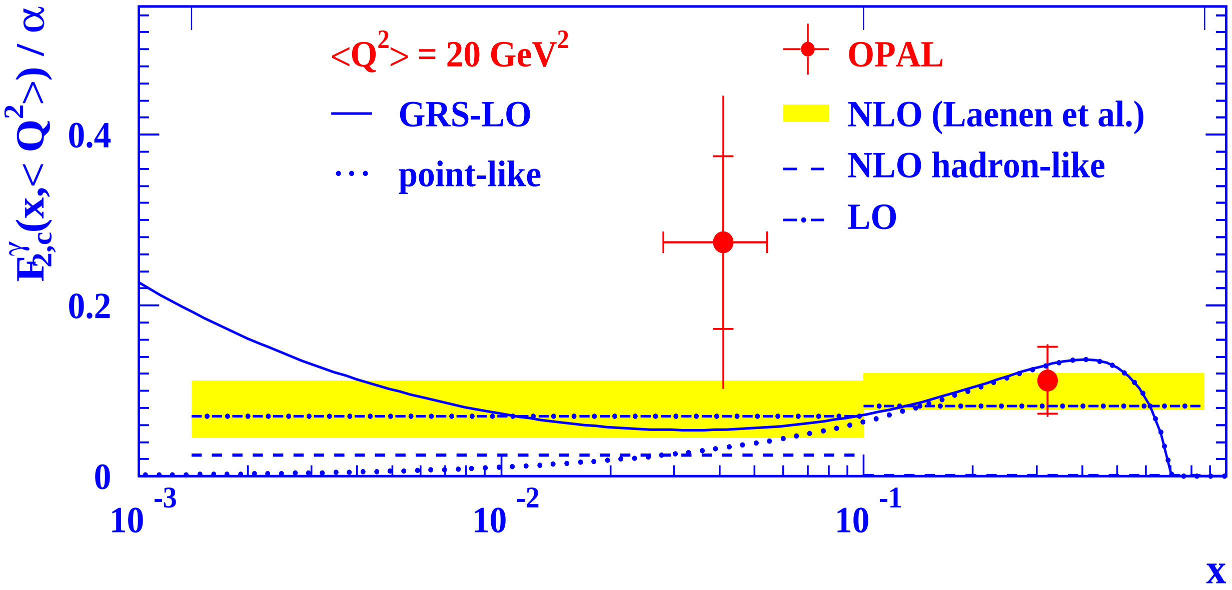
Positive scaling violations at all values of x due to inhomogenous DGLAP term from γ->qq splitting

The photon structure function



The first measurement of

$$\frac{d^2\sigma_{e\gamma\to ecc}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^2}[(1+(1-y)^2)\ F^{\gamma}_{2,c}(x,Q^2)]$$



- determined from about 30 single-tagged D*events
- see talk by A.Boehrer

$x < 0.1$:

hadron-like component

$x > 0.1$:

purely perturbative (N)LO QCD

About half of the photon is charm !

Virtual photon structure :

First measurement by PLUTO

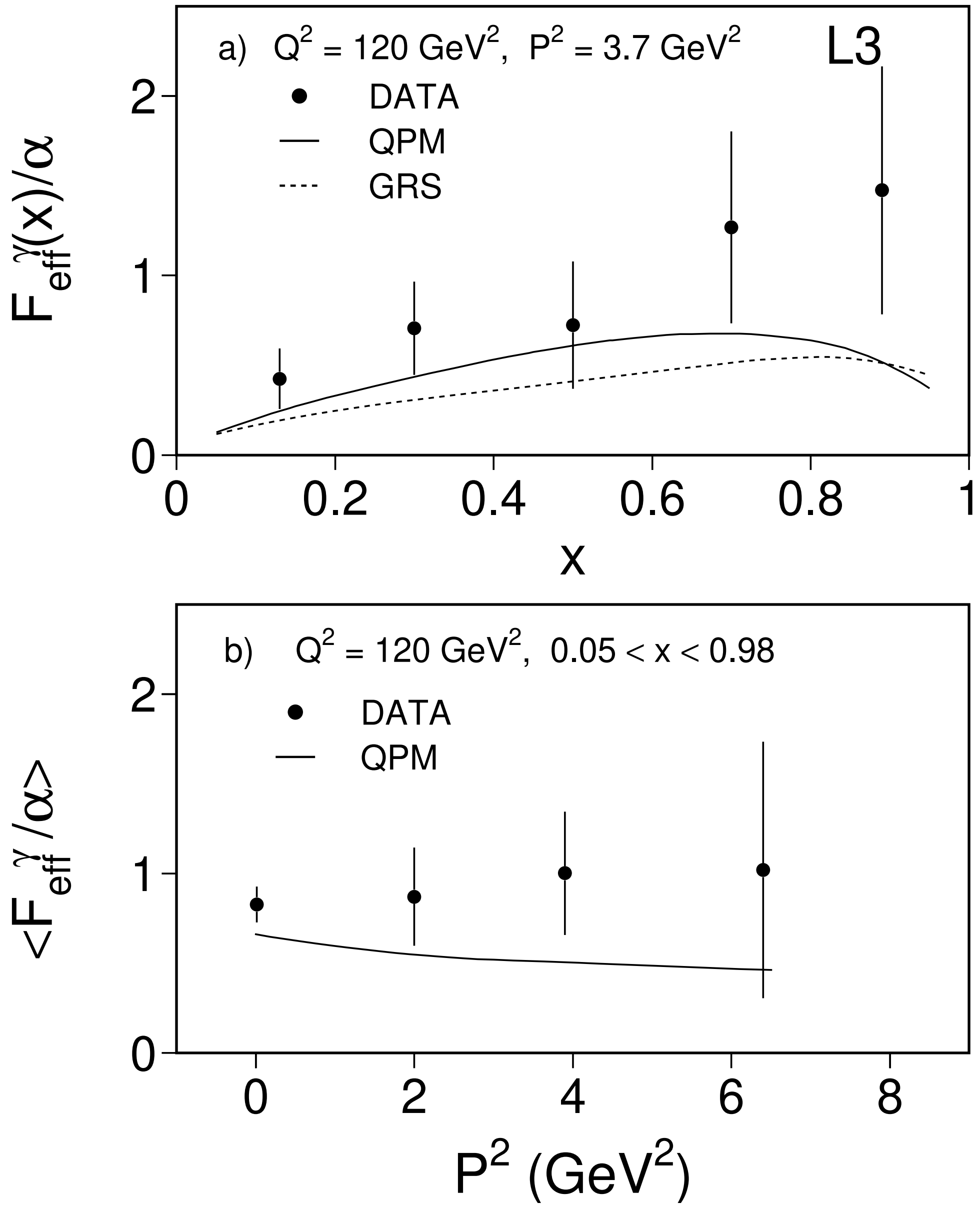
σ_{TL} cannot be neglected

=>

effective structure function

$Q^2 >> P^2 >> \Lambda^2_{QCD}$:

$$F_{\mathrm{eff}}^{\gamma} \sim \frac{Q^2}{4 \cdot \pi^2 \cdot \alpha} \cdot (\sigma_{TT} + \sigma_{LT} + \sigma_{TL} + \sigma_{LL})$$



Conclusions:

- QED structure functions studied in detail using muons
- effects of photon virtuality and interference terms have been demonstrated
- LEP measures QCD structure of photon in wide range of x and Q^2
- New experimental methods have improved data quality significantly, data suggest low x rise
- L3 has measured the effective structure function of the virtual photon for the first time at LEP, much more data in the pipeline of the LEP experiments
- A new combined fit of parton densities to LEP and HERA data is necessary
- thanks to ALEPH, DELPHI, L3 and OPAL for providing the results