PHOTON STRUCTURE

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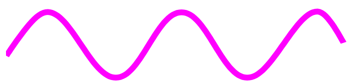
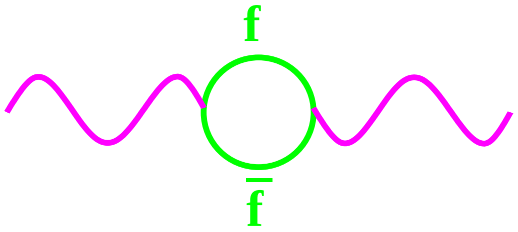
Outline:

- **What is Photon Structure**
- **Methods of extracting Structure Functions**
- **Leptonic Structure Functions**
- **Hadronic Structure Functions**

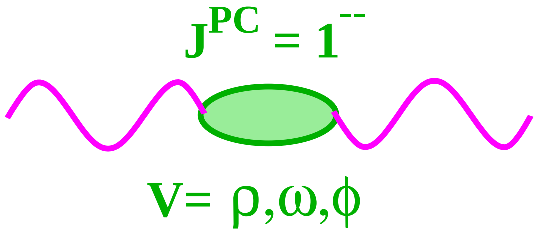
What is Photon Structure?



bare γ

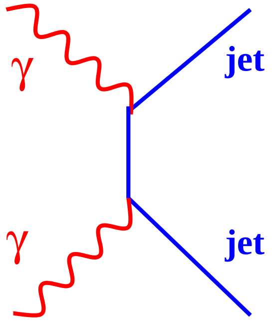


QPM

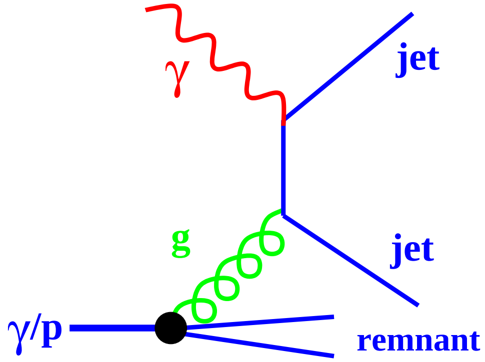


VDM

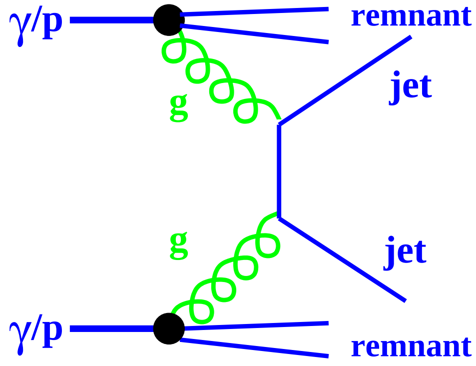
No photon self-interactions



Direct



Single-resolved



Double-resolved

Quantum Fluctuations $\Leftrightarrow$ Photon Structure

- **Test QED and QCD predictions**
- **How hadron-like is the photon?**
- **What is the parton content of the photon?**

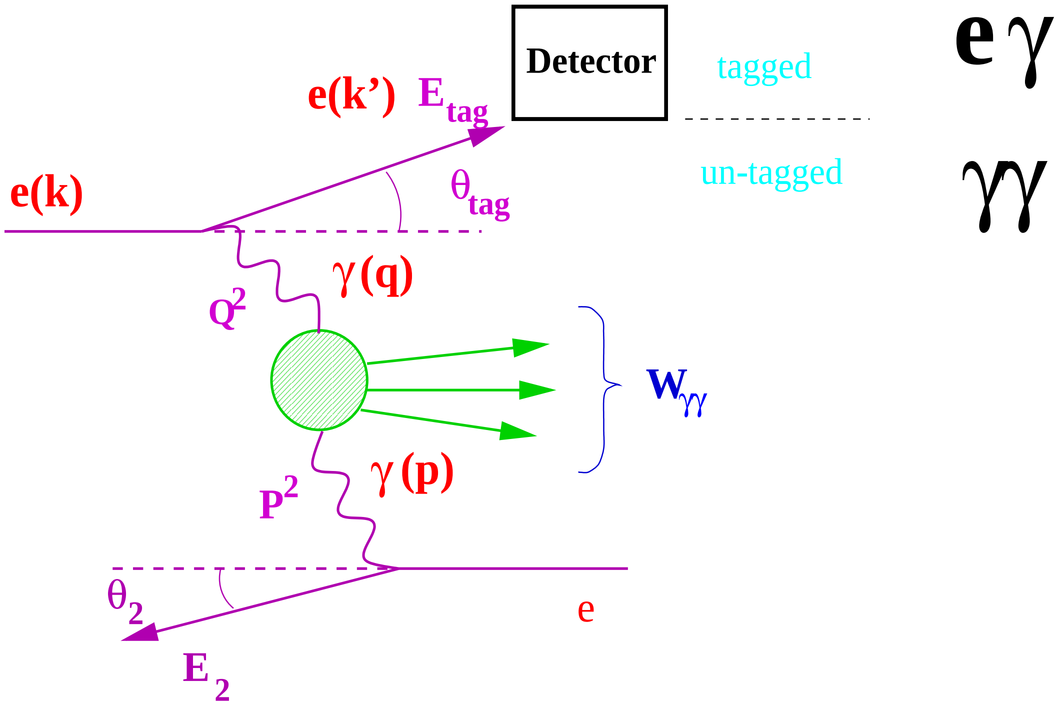
The Structure of the Photon is Currently Probed in:

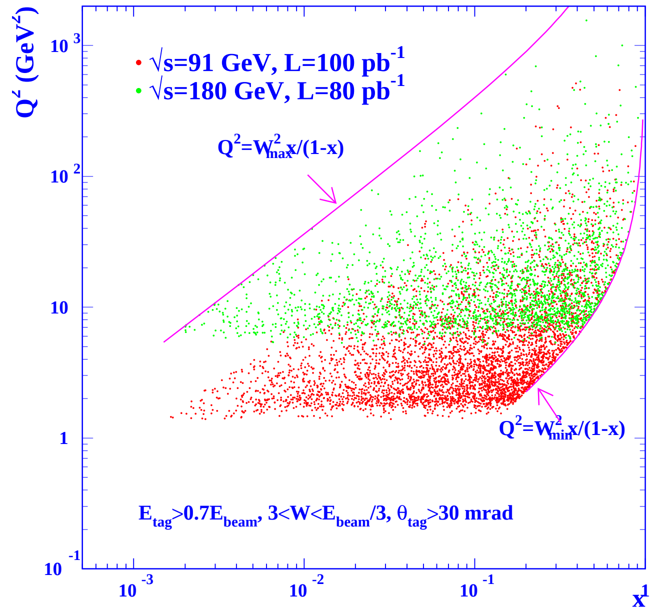
- F_2^γ **from** $e\gamma$ **scattering**
- **Total cross-section** $\gamma\gamma \rightarrow$ **hadrons**
- **Jet production in** $\gamma\gamma$, $e\gamma$ **and** γp **scattering**
- **resonance production in** $\gamma\gamma$ **scattering**

KINEMATICS

$$Q^2 = -q^2 = -(k-k')$$
$$= 2\cdot E_b E_{tag}(1-\cos\theta_{tag})$$

$$P^2 = -p^2, \text{ not measured}$$





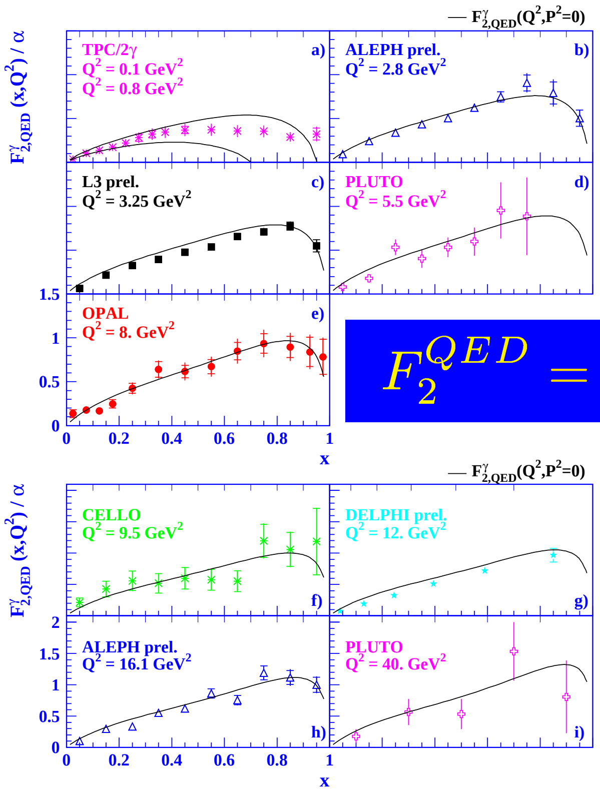
$$W^2 = (q+p)^2 = \left(\sum_h E_h\right)^2 - \left(\sum_h \vec{p}_h\right)^2$$

$$x = \frac{-q^2}{2p\cdot q} = \frac{Q^2}{Q^2+P^2+W^2} \simeq \frac{Q^2}{Q^2+W^2}$$

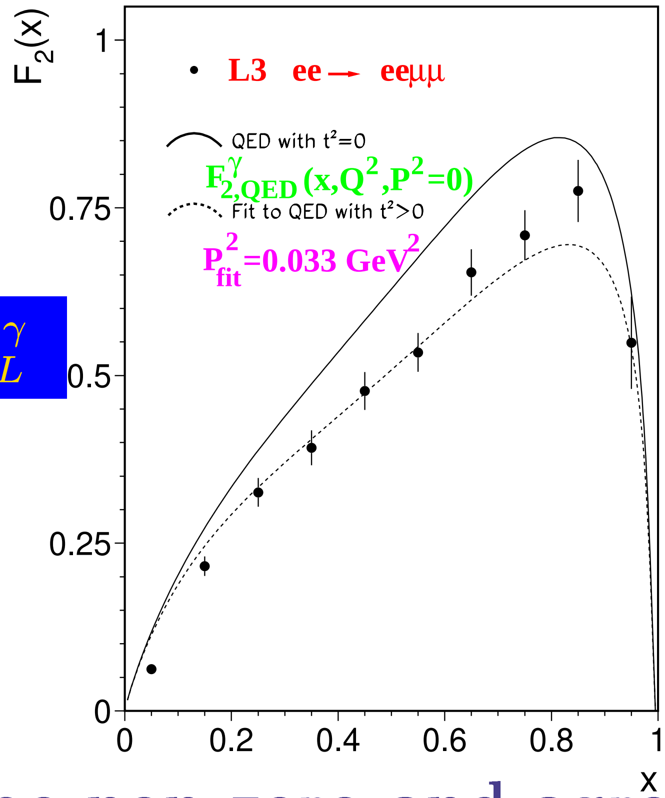
$$y = \frac{p\cdot q}{p\cdot k} \simeq 1 - \frac{E_{tag}}{E_b}\cos^2\left(\frac{\theta_{tag}}{2}\right) \ll 1$$

Leptonic Structure Functions

$$\frac{d^2\sigma_{e\gamma\to e\mu\mu}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} \times \left[\left(1+(1-y)^2\right) F_2^\gamma(x,Q^2) - y^2 F_L^\gamma(x,Q^2)\right]$$



$$F_2^{QED} = 2xF_T^\gamma + F_L^\gamma$$



The virtuality P^2 if found to be non-zero and agrees with the QED prediction.

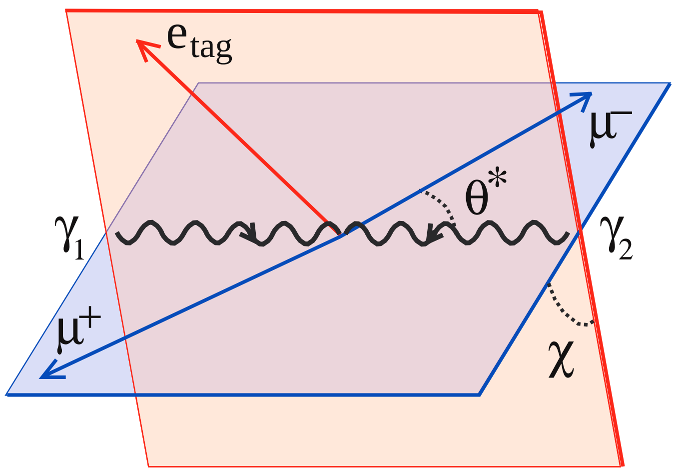
Azimuthal correlations

of leptons in the $\gamma\gamma$ c.m. system are sensitive to the photon helicity amplitudes and thus to $F_L^\gamma(x,Q^2)$:

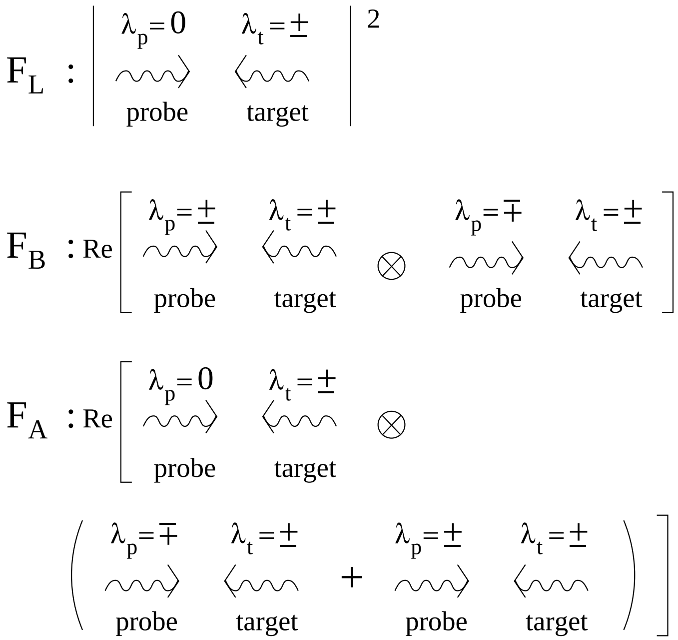
$$\frac{d^2\sigma_{e\gamma\to e\mu\mu}}{dx\,dy\,d\eta\,d\chi/4\pi} = \frac{2\pi\alpha^2}{Q^4}\,\frac{1+(1-y)^2}{xy}\times\left[(2x\tilde{F}_T+\epsilon\tilde{F}_L)-\rho\tilde{F}_A\cos\chi+\frac{1}{2}\epsilon\tilde{F}_B\cos 2\chi\right],$$

where

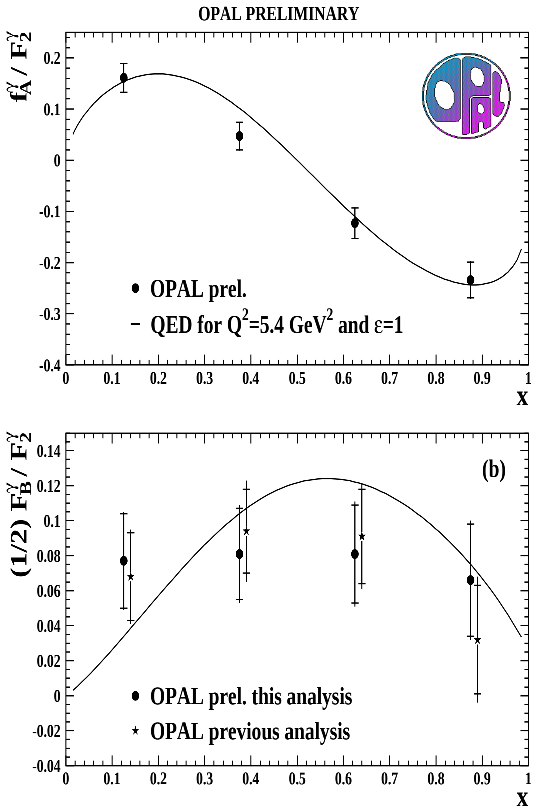
$$F_{T,L,A,B} = \int_0^\pi\int_0^{2\pi}\frac{d\eta\,d\chi}{4\pi}\,\tilde{F}_{T,L,A,B}$$

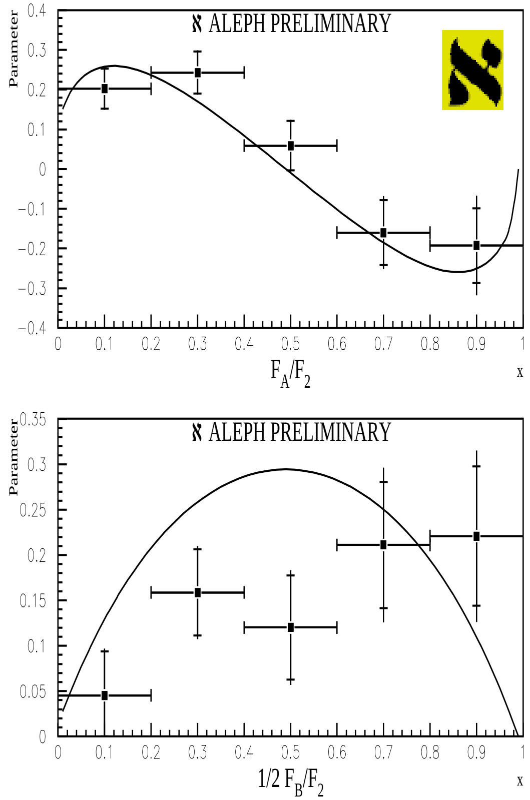


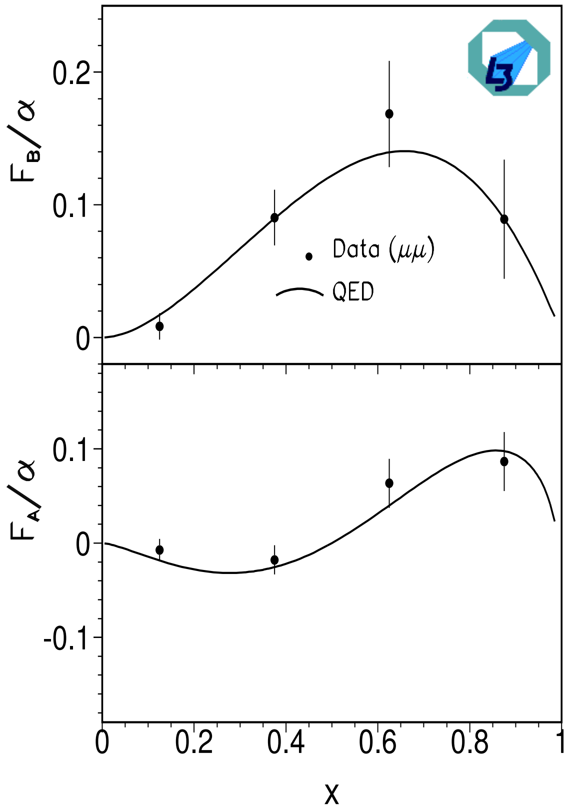
λ is the photon helicity



Azimuthal Correlations







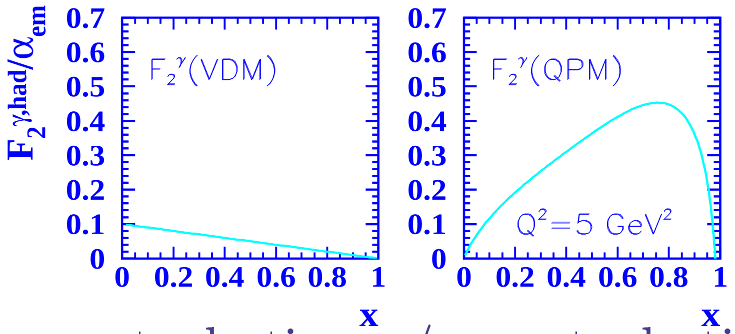
In leading order and for $m_\mu = 0$: $F_B^\gamma = F_L^\gamma = \frac{4\alpha}{\pi} x^2 (1-x)$

Both F_A^γ and F_B^γ are non-zero and in good agreement with QED (modulo a sign?)

$$\frac{d^2\sigma_{e\gamma\to eX}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} \times \left[\left(1+(1-y)^2\right) F_2^\gamma(x,Q^2) - y^2 F_L^\gamma(x,Q^2)\right]$$

.

Only F_2^γ directly measurable, since $y^2 F_L^\gamma$ small

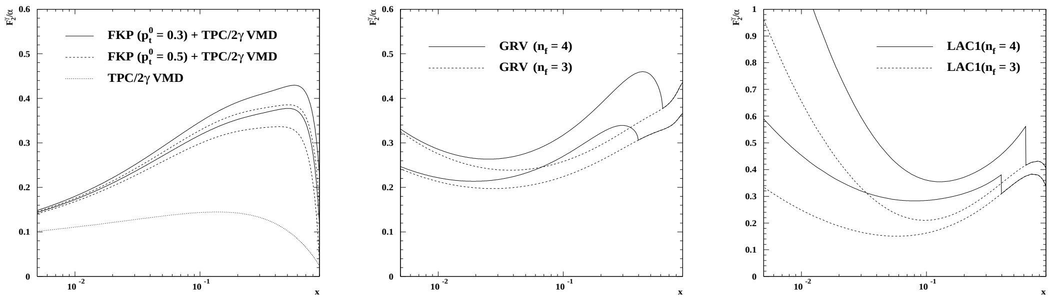


$$F_2^\gamma = 2x \sum_{uds(c)} e_q^2 q(x,Q^2)$$

Leading order parton distribution

non- perturbative / perturbative QCD

Many calculations and parameterisations exist using different evolutions and assumptions about the gluon content



The shape of the quark densities of the photon at low scales of Q_0^2 are assumed to be identical to the hadronic (VDM) shape

$\Rightarrow$ evolution using inhomogeneous DGLAP equations

Hadronic Final State

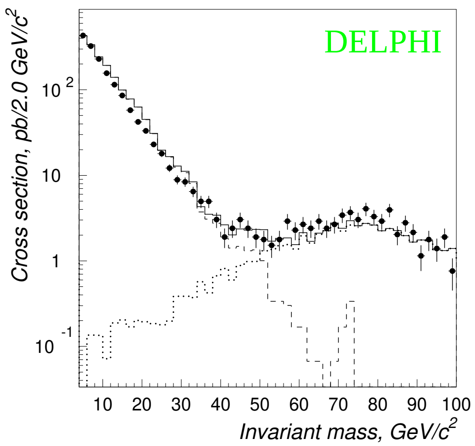
To measure F_2^γ

$\Uparrow$

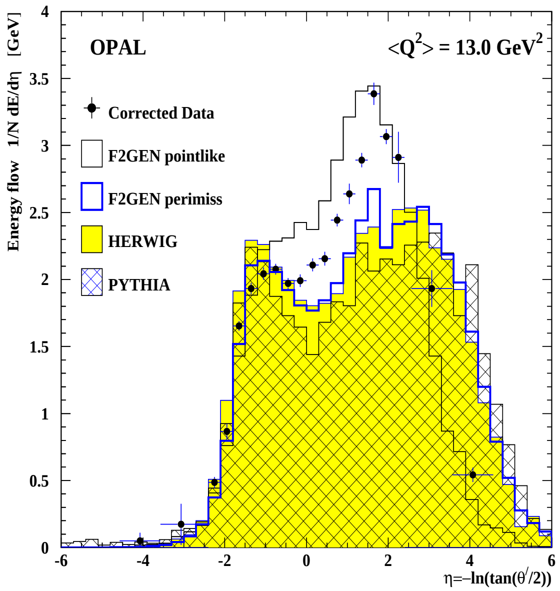
unfold x

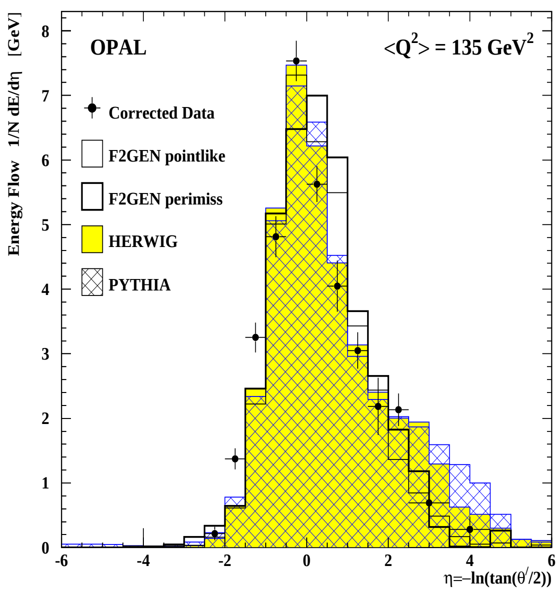
$\Uparrow$

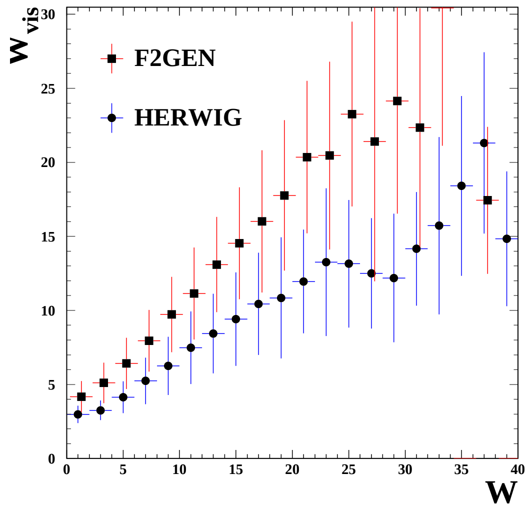
measure W



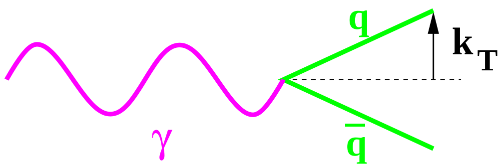
Since detectors are NON-uniform, especially in the forward regions, this measurement is sensitive to the modeling of the hadronic final state

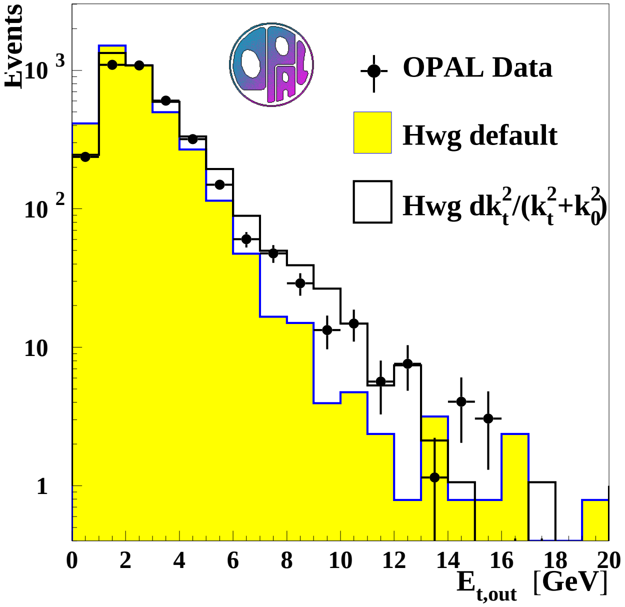


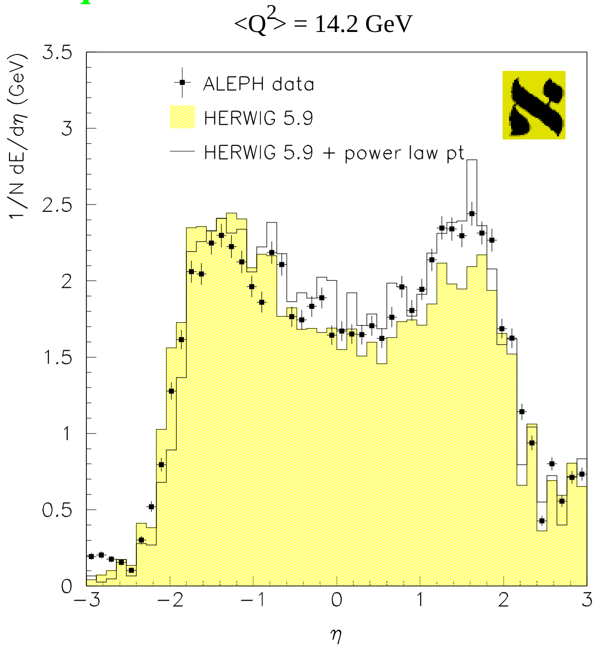




Tuning the Models







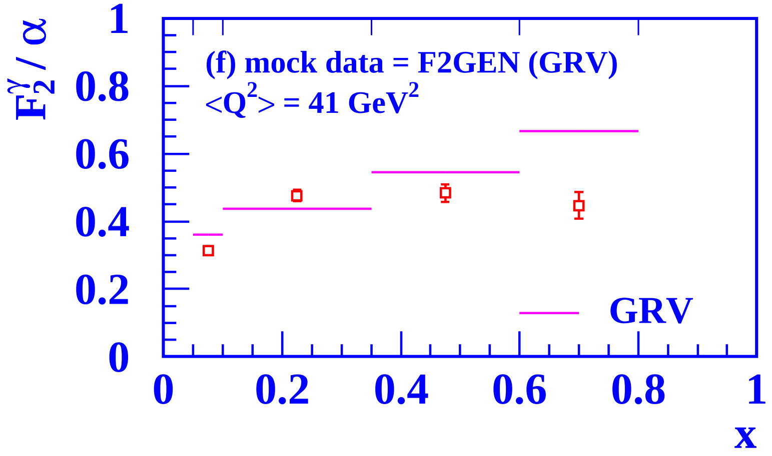
Tune the k_T distribution of the "target" quark in the photon from a Gaussian to a power-like shape:

$$dk_T^2/(k_T^2+k_0^2); \qquad k_0 = 0.66\ GeV$$

Regularized Unfolding

$$g^{\text{det}}(x_{vis}) = \int A(x_{vis}, x) f^{\text{part}}(x) dx + B(x_{vis})$$

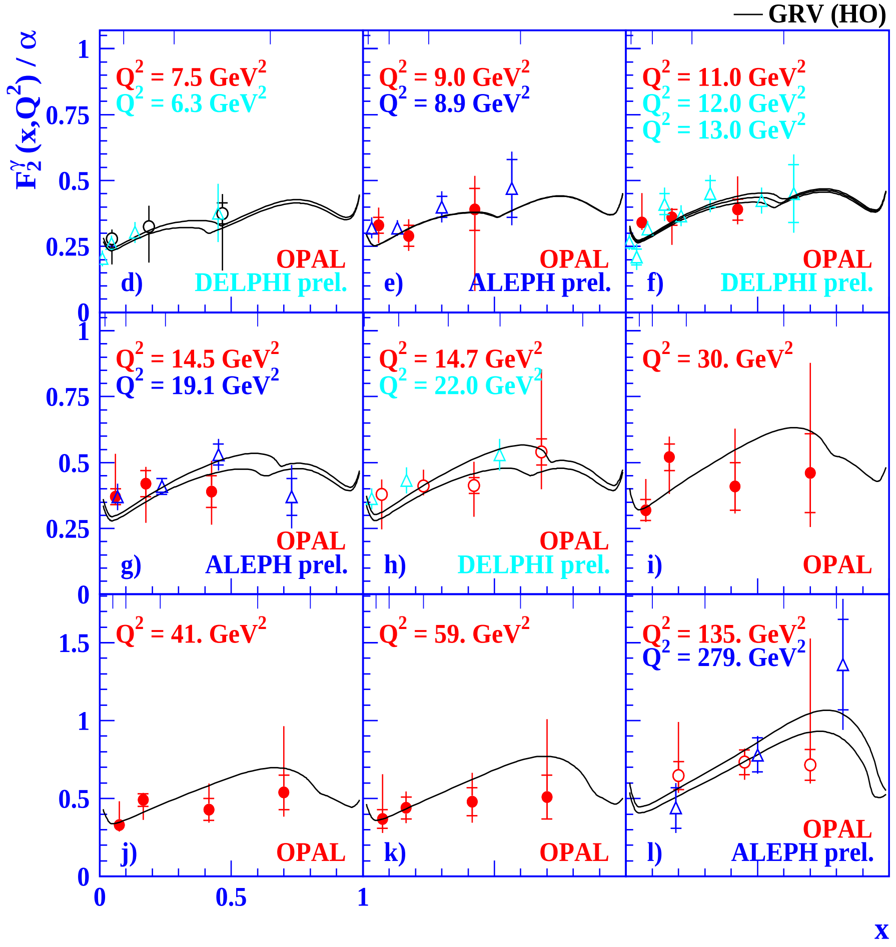
Use same structure function (here GRV) and unfold
F2GEN with HERWIG (different fragmentations)



Unfolding is only independent of the input F_2^γ,
if the $\gamma^\star\gamma$ fragmentation and F_2^γ "factorise"!
$\Rightarrow$ largest systematic error

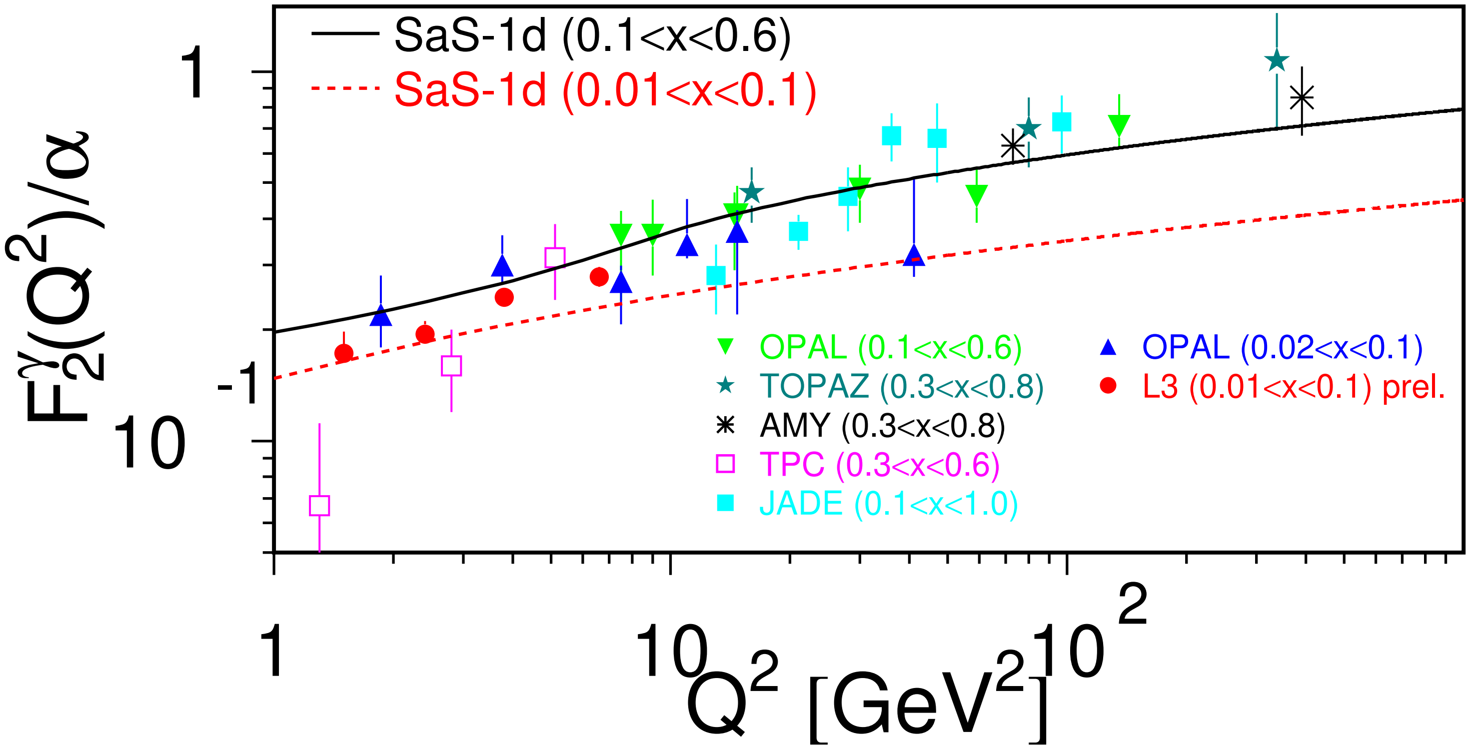
$\Rightarrow$ Try multi-dimensional unfoldings to reduce errors

HADRONIC STRUCTURE OF THE PHOTON



- F_2^γ **over a large** Q^2 **range**
- **Agreement with models**
- **Systematic errors large**
- **Improvements in progress**

SCALING VIOLATION I



Witten, Bardeen & Buras: $F_2^\gamma/\alpha = a(x)/\alpha_s(Q^2) + b(x)$

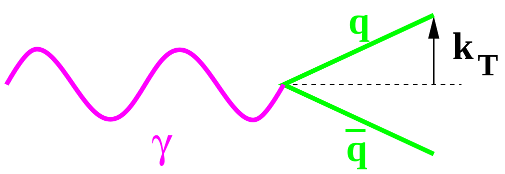
$a(x)$ **and** $b(x)$ **calculable, but divergent for** $x \to 0$

$F_2^\gamma = (0.16 \pm 0.05^{+0.17}_{-0.16}) + (0.10 \pm 0.02^{+0.05}_{-0.02}) \ln(Q^2/\mathrm{GeV}^2)$ **(OPAL)**

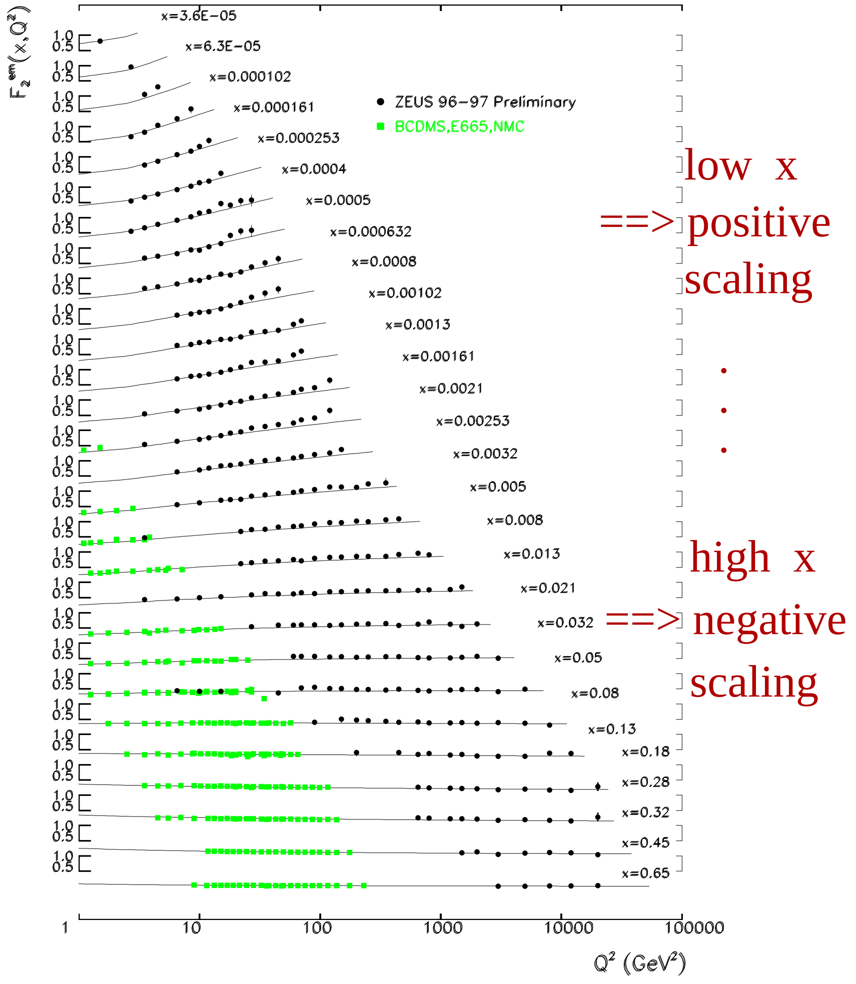
Errors to large to distinguish between models or measure $\alpha_s(Q^2)$

Scaling Violation II

- Positive Bjorken scaling at low x due to gluon emission
- Large x quark component shifted to low x $\Rightarrow$ negative scaling at high x
- Unlike the nucleons, the photon displays positive scaling at high x due to the point-like photon

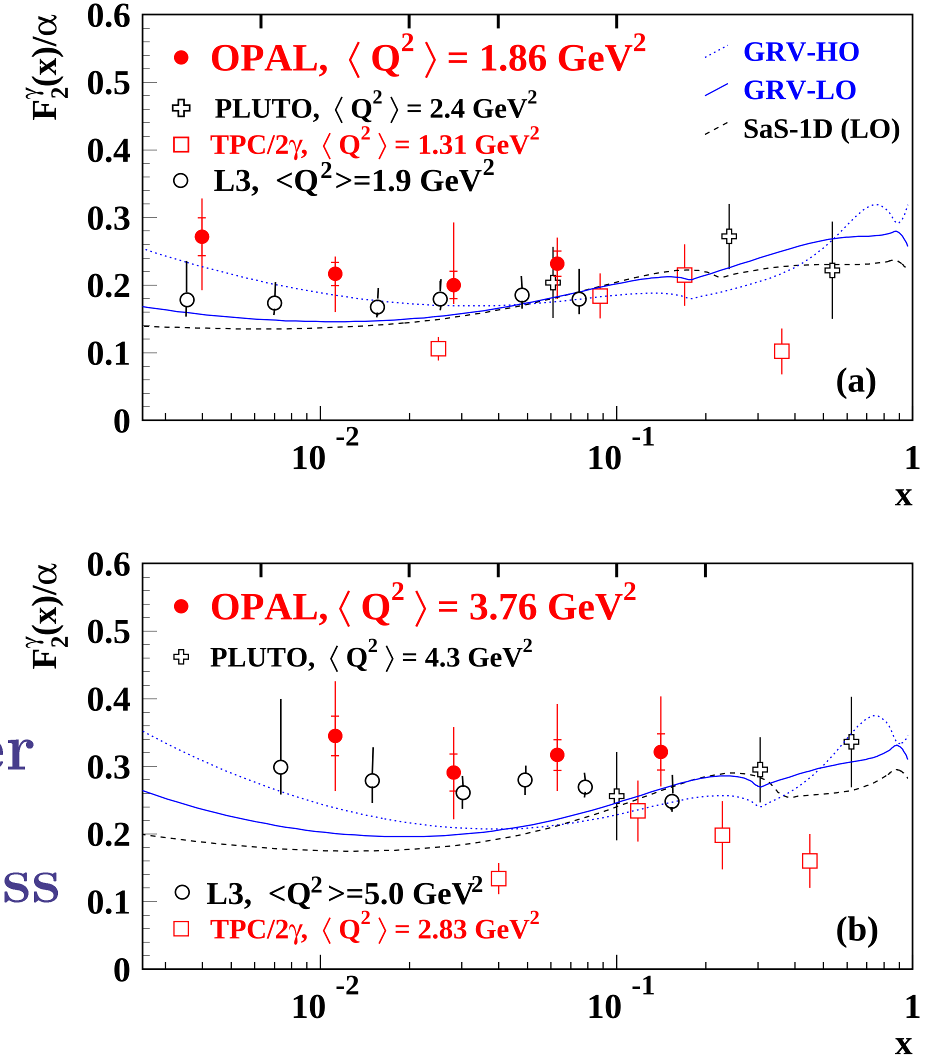


ZEUS : Proton Structure

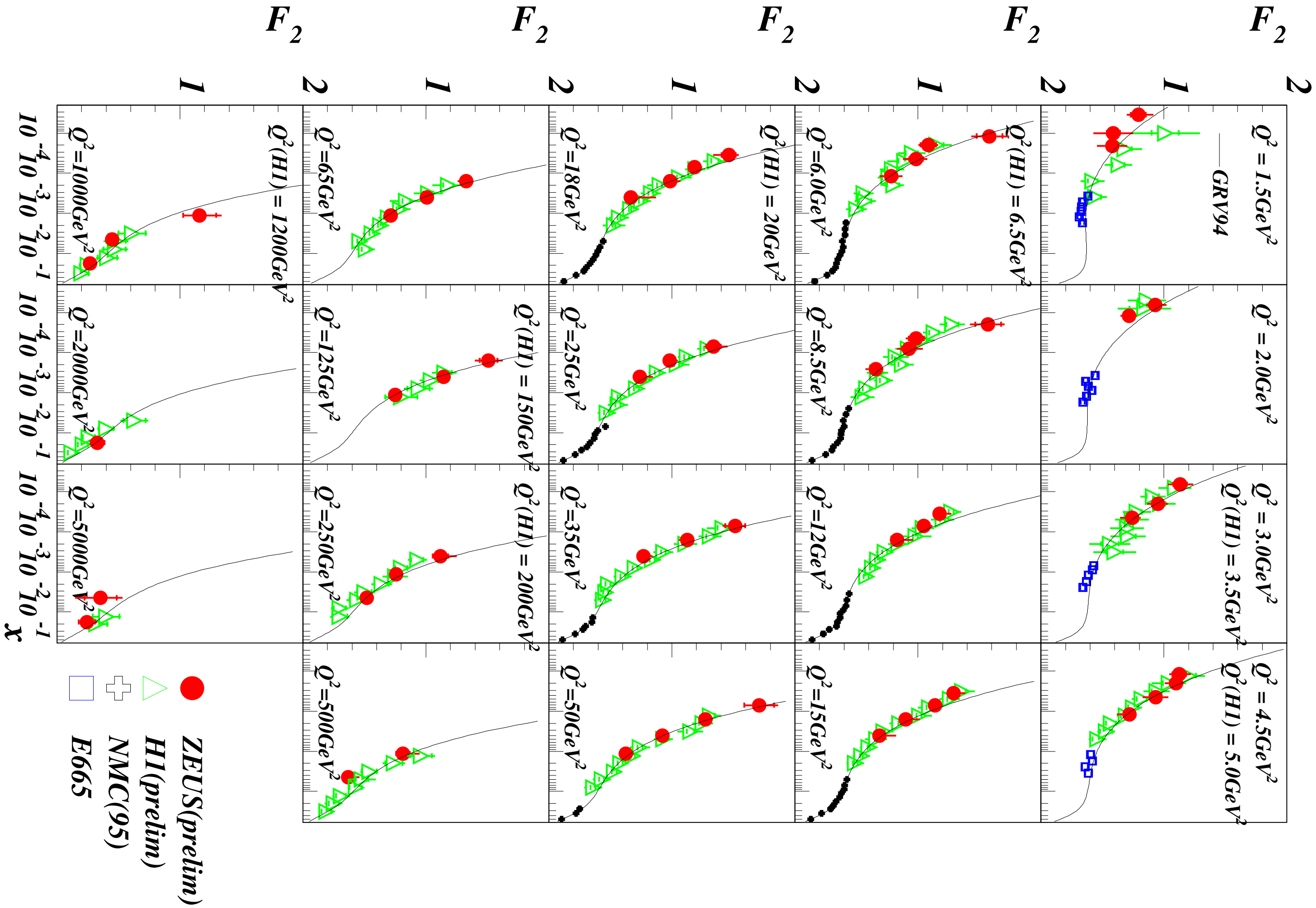


Low x

- **Lowest x at LEP I**
- **New measurements from OPAL and L3**
- **Continuous with low Energy data**
- **Low x rise?**
- **GRV-HO fits data better**
- **Improvements in progress**



The Proton Structure Function



low x parameterisations: *Abramowicz, Gurvich and Levy*

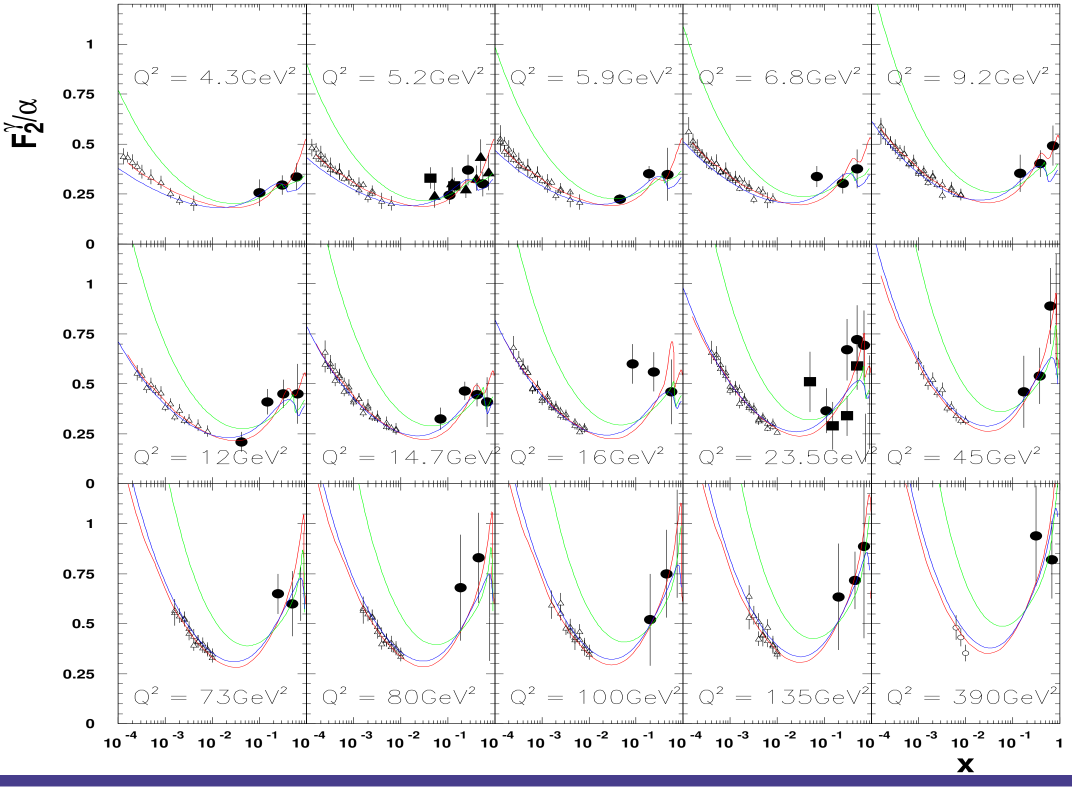
$\Rightarrow$ **use** F_2^p **measurements + Gribov factorization (universal Pomeron trajectory) as low x 'data':**

$$F_2^\gamma(x, Q^2) = F_2^p(x, Q^2) \cdot \frac{\sigma_{\gamma p}(W^2)}{\sigma_{pp}(W^2)}$$

AGL

SaS 1D

GRV-LO



SUMMARY

- **Quantum fluctuations** $\Leftrightarrow$ **Photon structure**
- **Leptonic Structure Functions agree well with QED**
- **Hadronic Structure Functions measured over a large range of** x **and** Q^2
- **Better modeling desirable**
- **Methods of extracting Structure Functions improved**
- **Active field** $\Rightarrow$ **much more to come**
- **Thanks to all LEP** $\gamma\gamma$ **working groups!**

http://www.hep.ucl.ac.uk/∼jal