Measurement of the photon structure function $F_2^{\gamma}(x,Q^2)$ with the LUMI detector at L3

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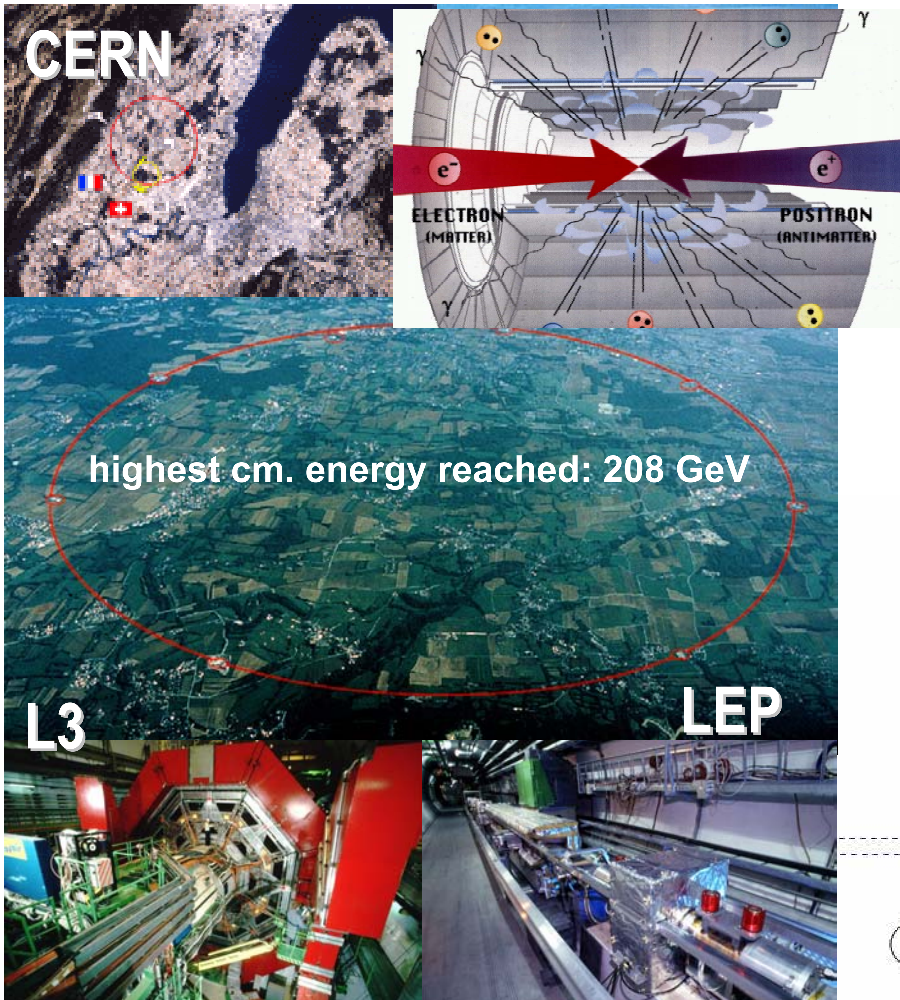
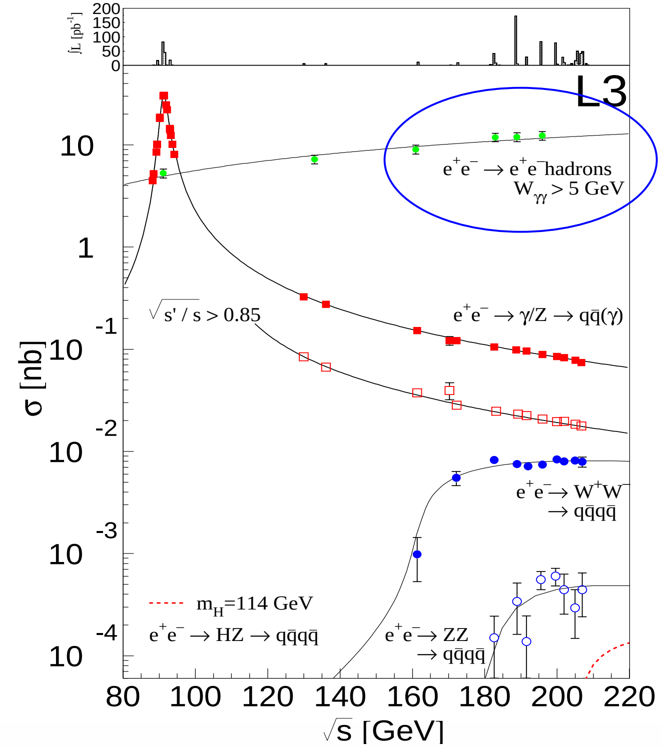
Topics of Discussion

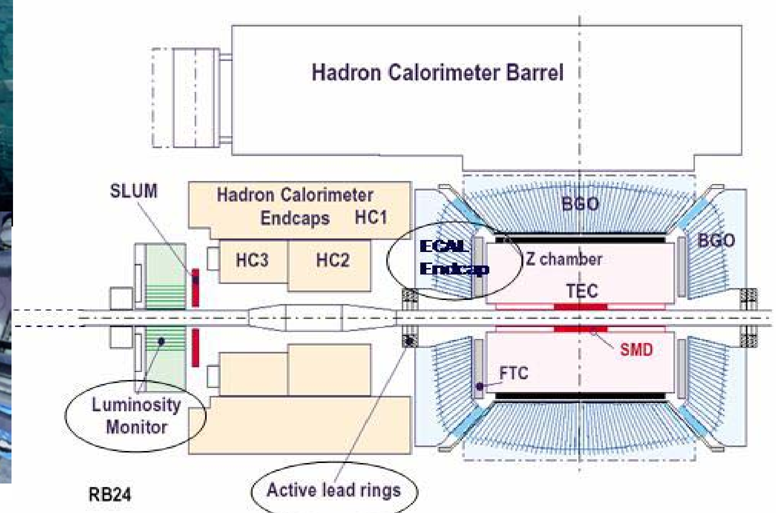
- Introduction:CERN, L3, LUMI
- Theoretical considerations
- Data analysis and results
- Summary

Introduction

L3 (LEP, CERN), LUMI (tagger)







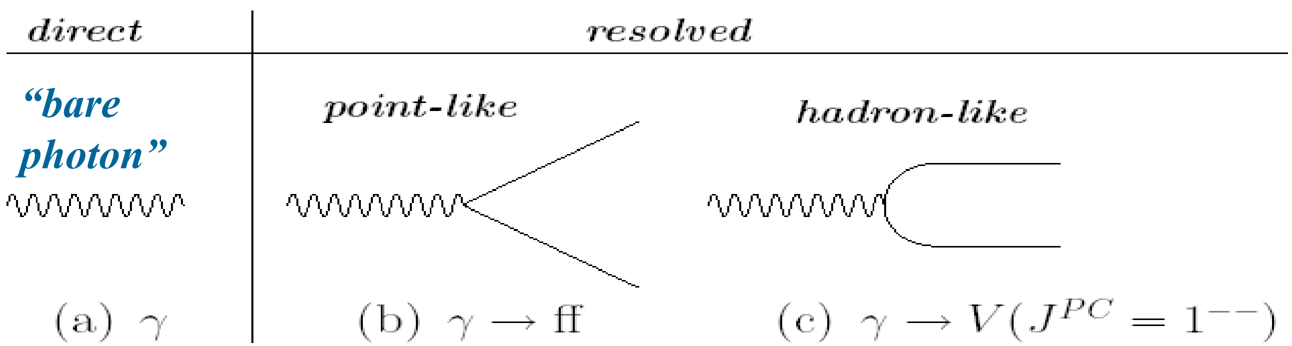
Different appearances of the photon

- **QED**: photon mediator, **structureless: direct/bare photon**
- Photon violates conservation of energy: $\Delta E \cdot \Delta t > 1$

  If fermion or antifermion interacts => parton content resolved

  Photon extended object=> charged fermions+gluons
- Dual nature of photon: direct or resolved $\gamma \to f\bar{f}$
- One possible description: **Photon Structure Function**

Photon interactions receive several contributions:



Photon couples to fermions (quarks & leptons)

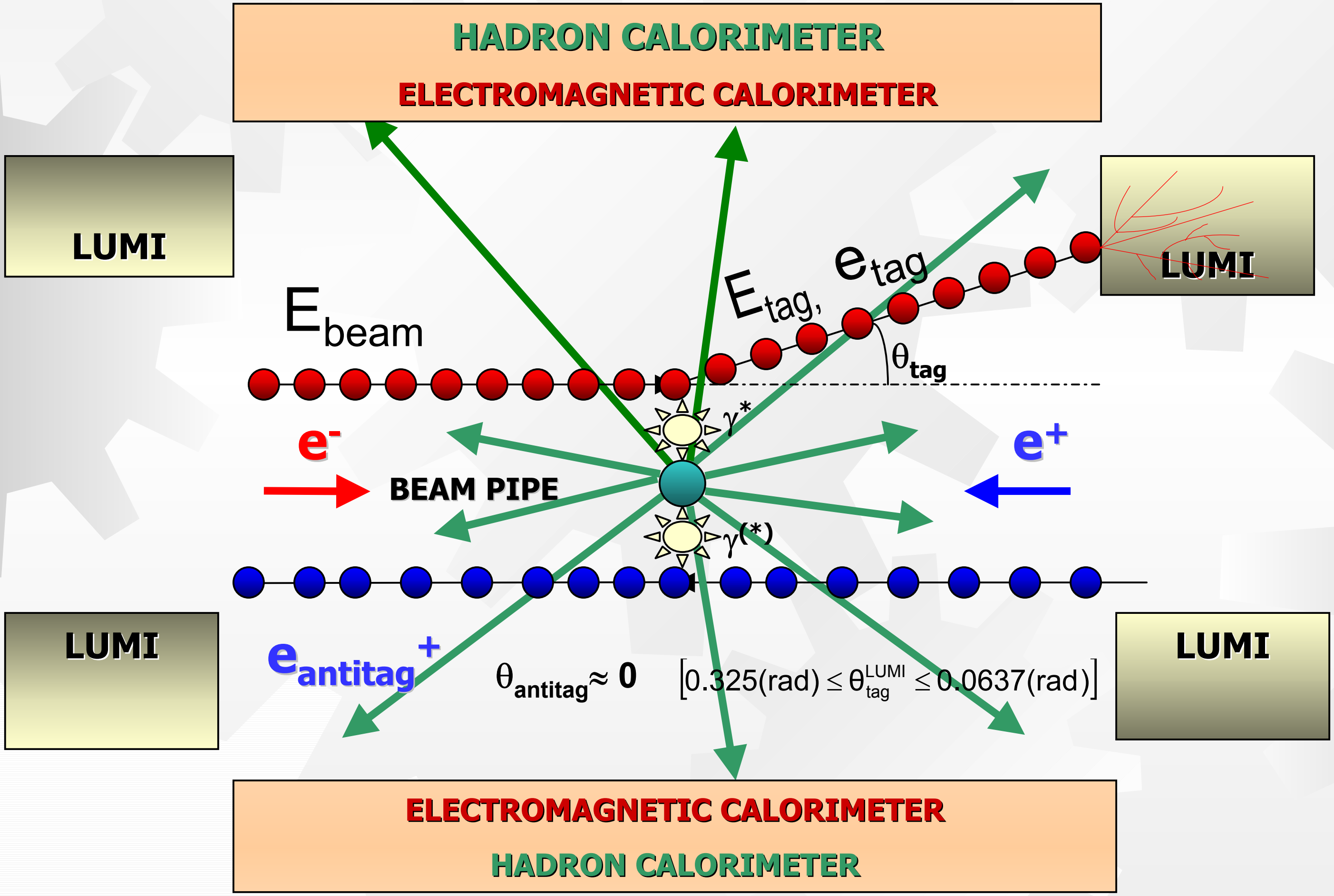
- **Lepton pair production** => process can be **calculated in QED**

  The QED structure functions can only be used for the analysis of leptonic final states.
- **Quark pair production** => **QCD corrections**

  For hadronic final states the leading order QED diagrams are not sufficient and QCD corrections are important.

$e^+e^- \rightarrow e^+e^- \gamma^* \gamma^* \rightarrow e^+e^-$ + hadrons deep-inelastic scattering reaction

$\theta_{tag} >> 0 \rightarrow$ electron observed inside the detector
$\theta_{antitag} \approx 0 \rightarrow$ other electron undetected $\rightarrow$"single-tag"



Photon Structure Function

$F_2^\gamma(x,Q^2)$ ~ probability that the probe photon with virtuality Q^2 sees a parton (quark or gluon) with momentum fraction *x* inside the target quasi-real photon.

$$\frac{d\sigma_{e(k)\gamma^*(q)\to e_{tag}(k')X}(x,Q^2)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[(1+(1-y)^2)F_2^\gamma(x,Q^2) - y^2F_L^\gamma(x,Q^2)\right]$$

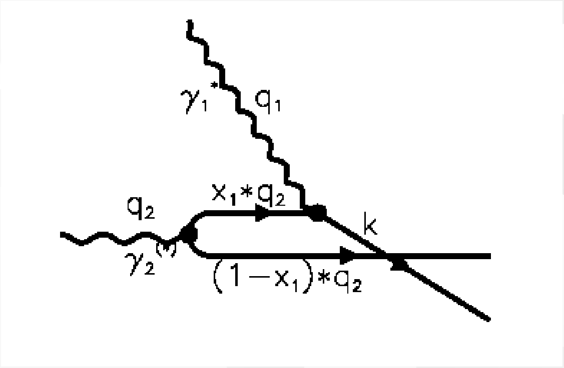
$$y = (p\cdot q)/(p\cdot K) \approx 1-\left(E_{tag}/E_{beam}\right)\cdot\cos^2(\theta_{tag}),\ y\approx 0$$

$$q_i = (E_{\gamma_i^*}, \vec{p}_{\gamma_i^*}),\ \ (i=1,2)$$

$$q_i^{\ 2} = E_{\gamma_i^*}^{\ 2} - \vec{p}_{\gamma_i^*}^{\ 2}$$

$$-q_1^2 = Q_1^2 \equiv Q^2 > 0$$

$$-q_2^2 = Q_2^2 \cong 0$$



mass squared of the outgoing interacting fermion:

$$k^2 = (xq_2+q_1)^2 = q_1^2 + 2xq_1\cdot q_2 \cong 0$$

$$\Rightarrow\ x = -\frac{q_1^2}{2q_1\cdot q_2} = \frac{Q^2}{2q_1\cdot q_2}$$

Single-tag variables:

$$Q^2 = -q^2 \approx 2E_{tag}E_{beam}(1-\cos\theta_{tag})$$

$$x = Q^2/\left(Q^2+W^2+P^2\right) = Q^2/2(p\cdot q)$$

$$W^2 = (q_1+q_2)^2 = (E_{\gamma^*}+E_\gamma)^2 - (\vec{q}+\vec{p})^2$$

$$q_1 = (E_{\gamma^*}, q),\ q_2 = (E_\gamma, p)$$

For single tagged events: P

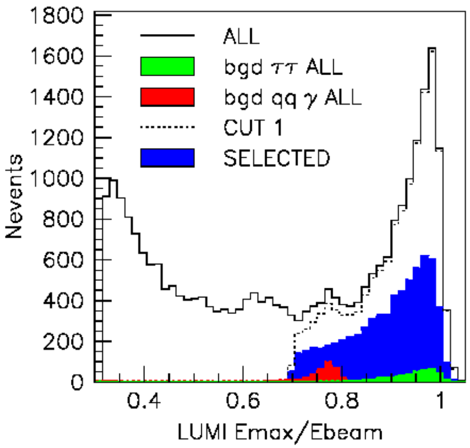
$$x = \frac{Q^2}{Q^2+W^2}$$

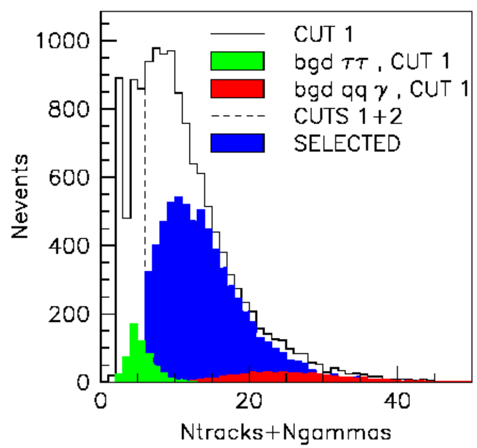
The Bjorken variable *x* tells us what fraction of the photon four momentum was carried by the particle which participated to the interaction: the target photon itself or a parton (quark or gluon) inside the photon.

Analysis Method

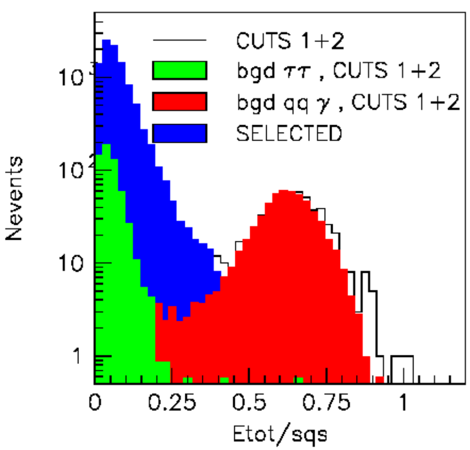
1) Selection
2) Split x and Q^2 in several bins
3) Unfolding (Bayes)
   energy of the target photon is not known
   ⇒ Correction with MC
   (Pythia, Phojet, Twogam)
4) Calculate measured cross section
5) $F_2^{\gamma}(x,Q^2)$ obtained using analytically calculated differential cross section (program Galuga)

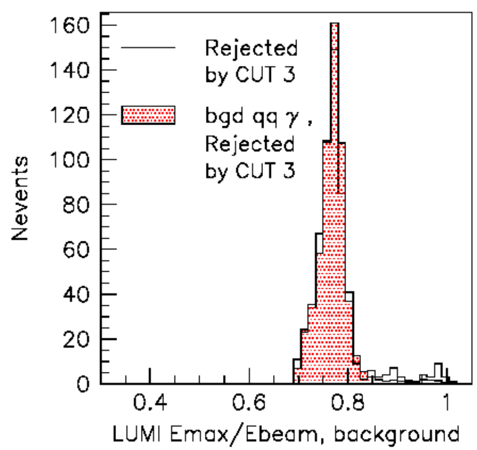
Selection

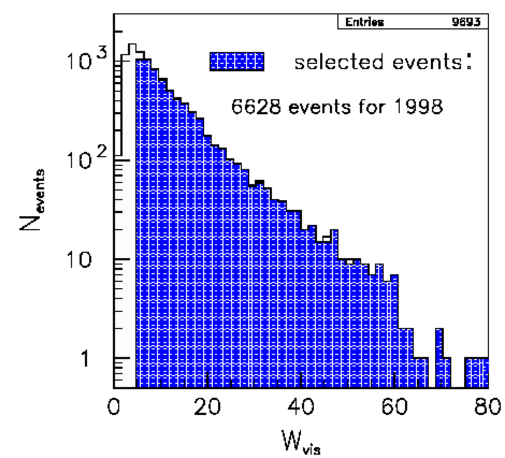




$\sqrt{s}$ = 189 – 209 GeV
L= 608.1 pb^{-1}.
22771 events selected
Q^2 11 -34 GeV^2.

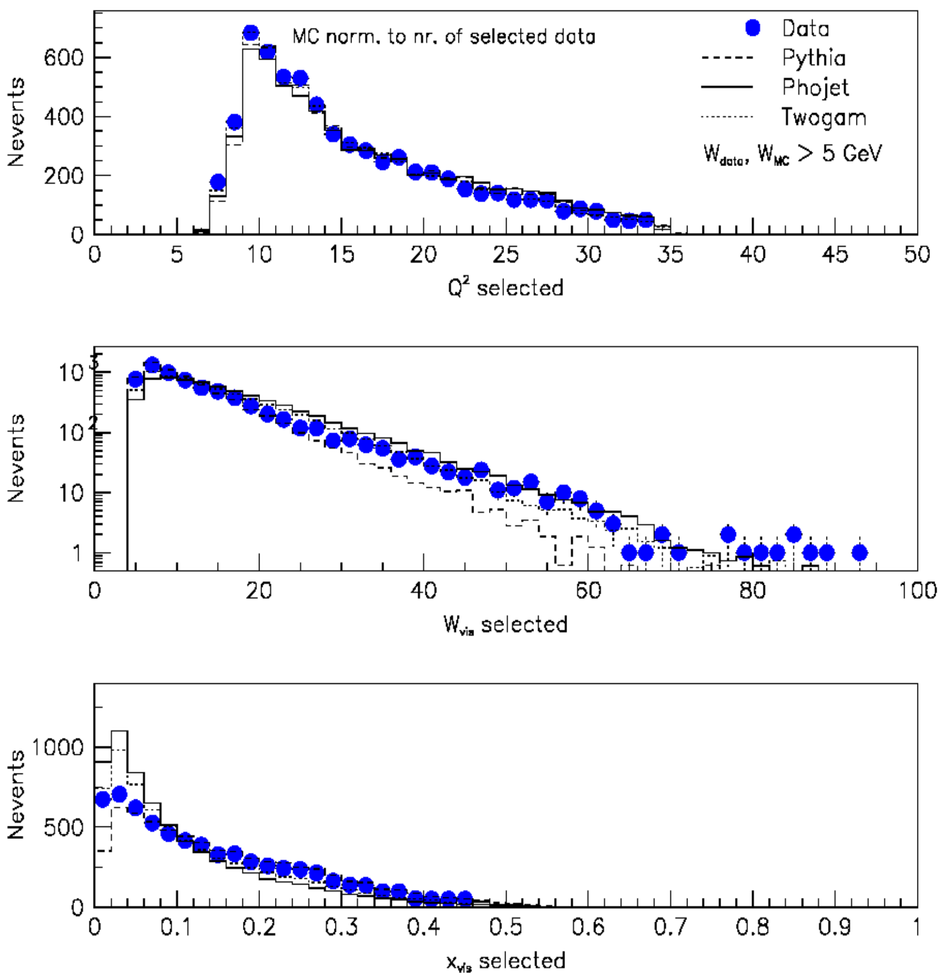


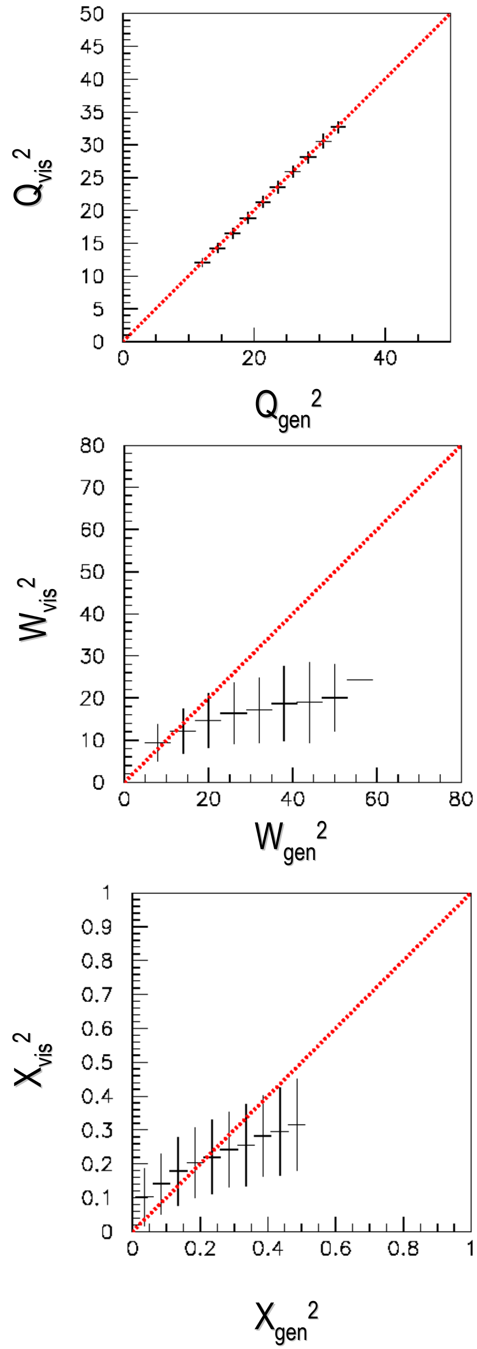




Selection

Superposed distributions of selected data (1998) and MC for Q^2, W_{vis}, X_{vis}





well correlated

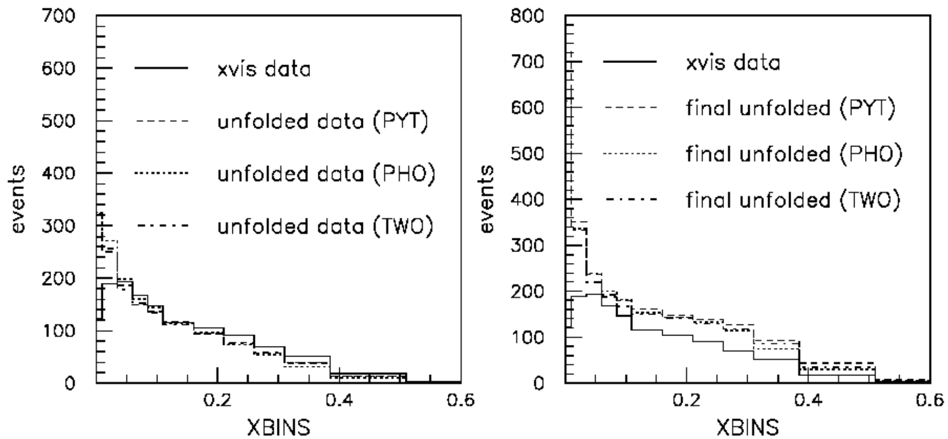
needs unfolding

needs unfolding

Data			
year	E_{beam}(GeV)	L(pb^{-1})	$N_{selected}$
1998	94.3	171.8	6628
1999a	97.3	111.4	4220
1999b	100.0	90.1	3095
2000	103.1	210.5	7990
Monte Carlo			
PHOJET	94.5 97.8 99.8 102.0	2807.4 1817.4 1818.1 1754.3	54073 33603 33341 33380
PYTHIA	94.5 98.7 103	318.2 456.4 453.3	21223 26169 28570
TWOGAM (QCD+QPM+VDM)	94.5 97.8 99.8 102.0	5489.1 4264.4 4390.4 5298.5	81127 61265 62067 73949
Background MC			
$\gamma^*\gamma^* \rightarrow \tau\bar{\tau}$	94.5 98.0 102	1022.7 224.7 1100.0	1057 211 1148
$Z\gamma \rightarrow q\bar{q}\gamma$	94.3 97.8 99.8 103.3	1960.7 1123.5 1141.5 11318.4	381 200 210 396

Unfolding

Florida Institute of Technology



Extraction of F_2^γ

To obtain F_2^γ/α: $F_2^\gamma / \alpha = \dfrac{\Delta\sigma_{meas}(e^+e^- \to e^+e^- X)}{\Delta\sigma_{Galuga}(e^+e^- \to e^+e^- X)}$. $\Delta\sigma_{meas} = \dfrac{N_{unfolded} - N_{background}}{L \cdot \text{acceptance} \cdot \text{trigger efficiency}}$

GALUGA calculates the **integrated cross section** $\Delta\sigma_{e^+e^-}$, using a parametrization similar to equation:

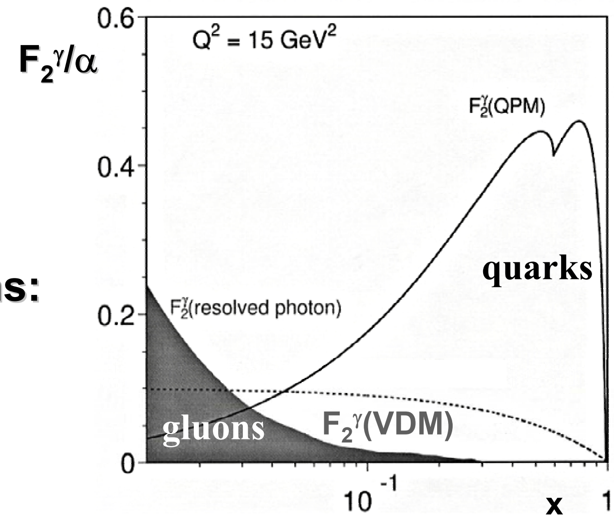
$$\Delta\sigma_{e^+e^-}^{GALU} = \int [L_{TT} F_T(Q_1^2) F_T(Q_2^2) \sigma_{TT} + L_{LT} F_L(Q_1^2) F_T(Q_2^2) \sigma_{LT} + L_{TL} F_T(Q_1^2) F_L(Q_2^2) \sigma_{TL} +$$

$$L_{LL} F_L(Q_1^2) F_L(Q_2^2) \sigma_{LL}] \, dQ_1^2 \, dQ_2^2 \, dW$$

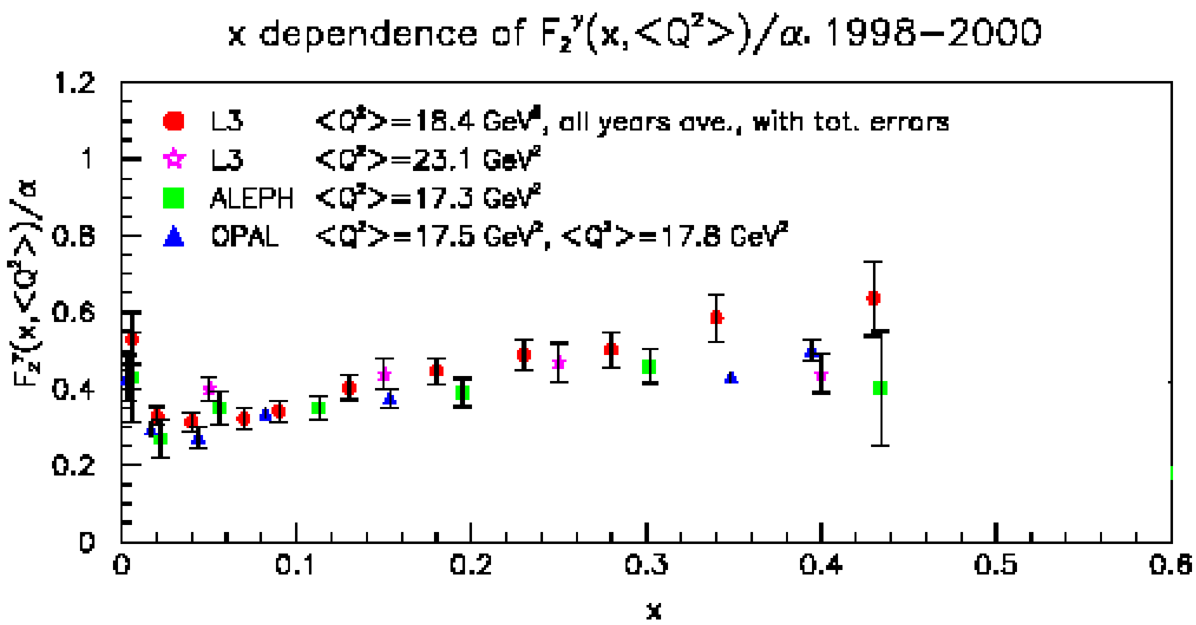
Evolution of F_2^γ with x

$F_2^\gamma(x,Q^2)$ vs x with the different contributions:

VDM, QCD, QPM



Preliminary results:

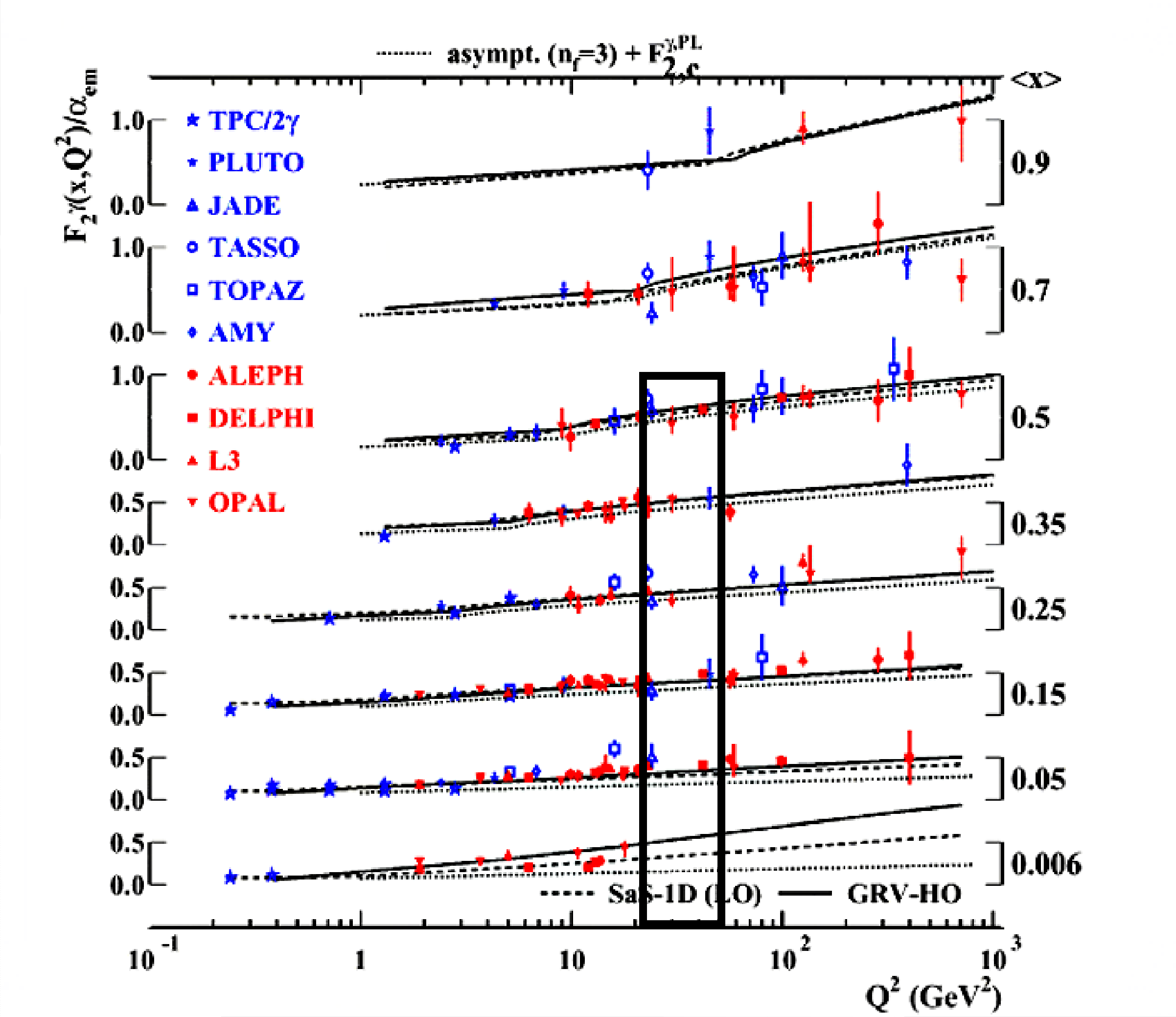


Q^2 evolution of F_2^γ

Expected LUMI-L3 results

add data points to the low x region!

High statistics! Test of QCD and QED.



Summary and outlook

- Photon structure function analyzed for
  $e^+e^- \rightarrow e^+e^- \gamma^* \gamma^* \rightarrow e^+e^-$ + hadrons
- Single tag events selection done for 189-209 GeV, high enough statistics, low background.
- Compared MC's (Pythia, Phojet, Twogam) with data=>Pythia best.
- Used binning similar to other measurements by L3, OPAL, ALEPH experiments
- Used unfolding (Bayes method) to correct for detector effects and acceptance. Data unfolded with Pythia, Phojet, Twogam.
- Calculated measured cross-section and analized x dependence using 3 MC average.
- Obtain F_2^γ using GALUGA.
- Evolution of F_2^γ with x analyzed and compared to ALEPH,L3,OPAL. Comparison based on the average of the 3 MC's.
- Comparison with theoretical predictions and Q^2 dependence under investigation.

Thank you! ☺