Measurement of the photon structure function F_2^γ with single tag events for the Q^2 range 6-43 GeV^2 in two-photon collisions at LEP2

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Topics of Discussion

- Introduction, LEP, L3, $\gamma\gamma$ physics
- Theoretical considerations
- Measurement of F_2^γ
- Data analysis
- Conclusion

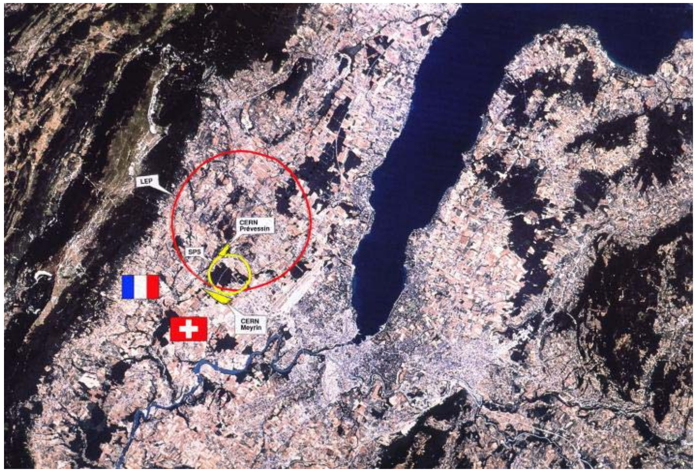
Introduction

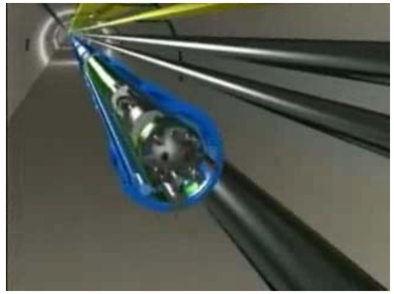
PURPOSE:

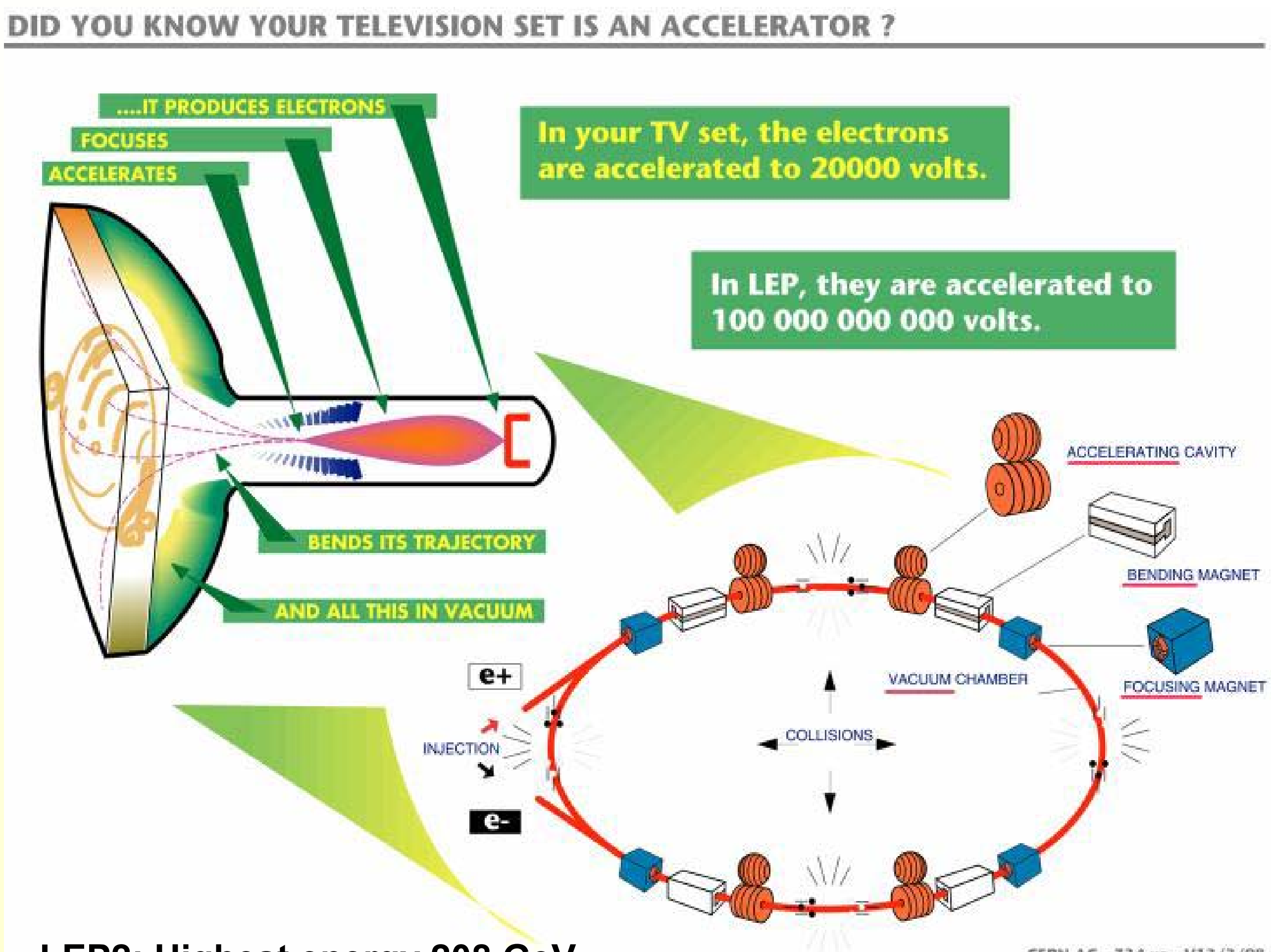
- measure the <u>photon structure function</u> $\Rightarrow$ understand complex behavior of interacting photons and structure of the photon

MEASUREMENTS:

- L3 detector at LEP, CERN, Geneva, Switzerland





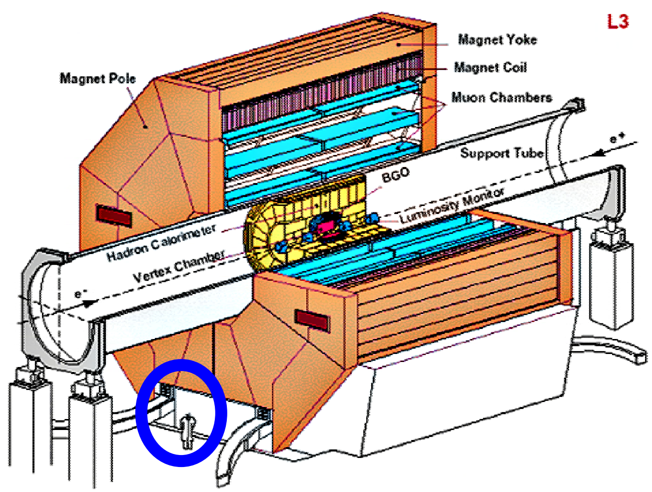


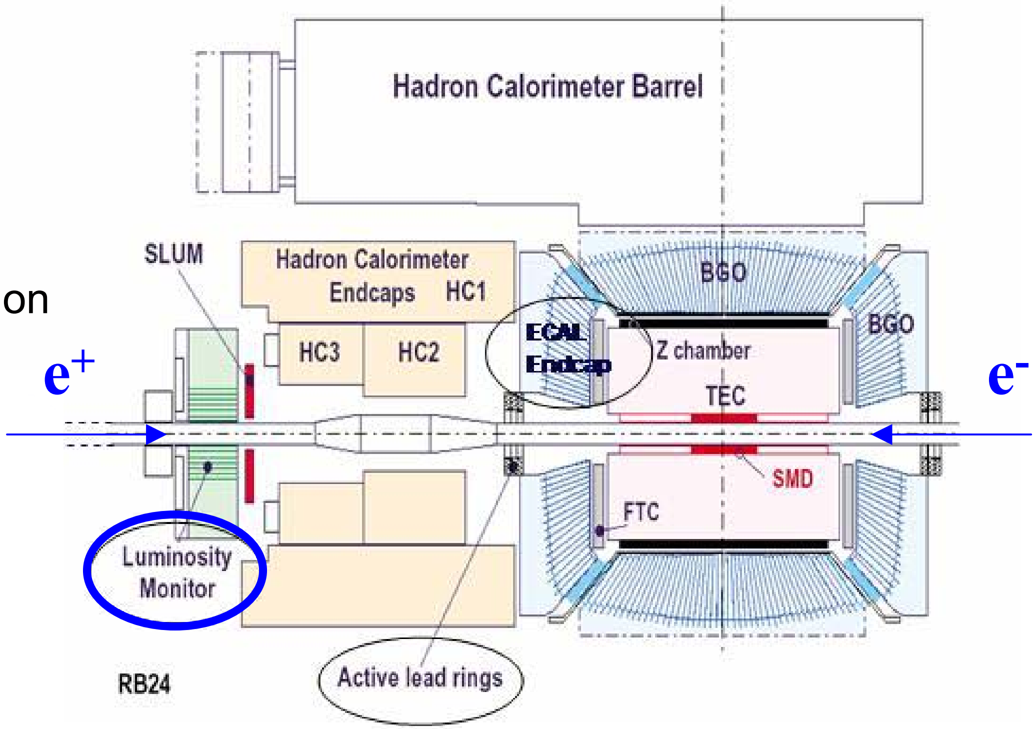
When an electron and a positron collide, they disappear in a burst of energy which, almost immediately, changes back into particles. LEP was designed so that the collisions took place inside four detectors - ALEPH (Apparatus for LEP Physics at CERN), L3, OPAL (the Omni-purpose Apparatus at LEP) and DELPHI (Detector with Lepton, Photon and Hadronic identification at LEP - where the particles produced could be studied in detail.

LEP2: Highest energy 208 GeV

The L3 experiment

MAIN SUBSYSTEMS: central tracker (SMD, TEC) electromagnetic (ECAL), hadronic (HCAL) calorimeters, and muon chambers.

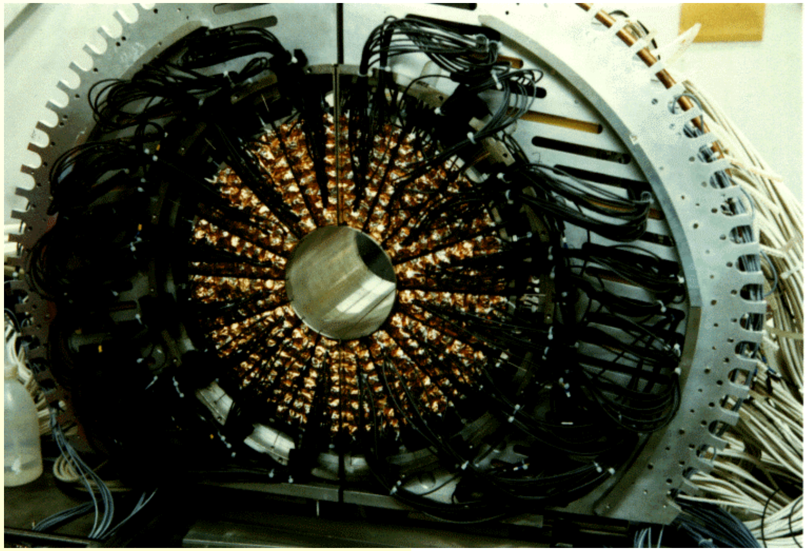


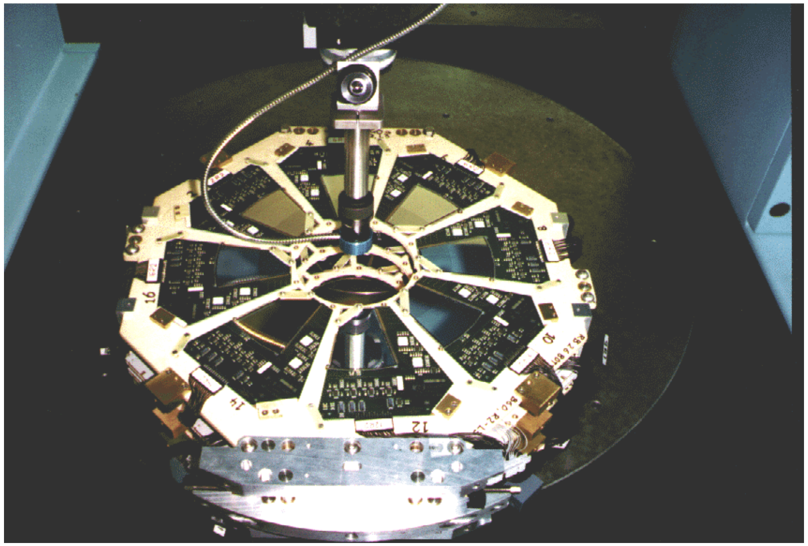


Tagging: Very Small Angle Tagger (VSAT), Luminosity Monitor (LUMI), Active Lead Rings (ALR), Electromagnetic Calorimeter endcaps

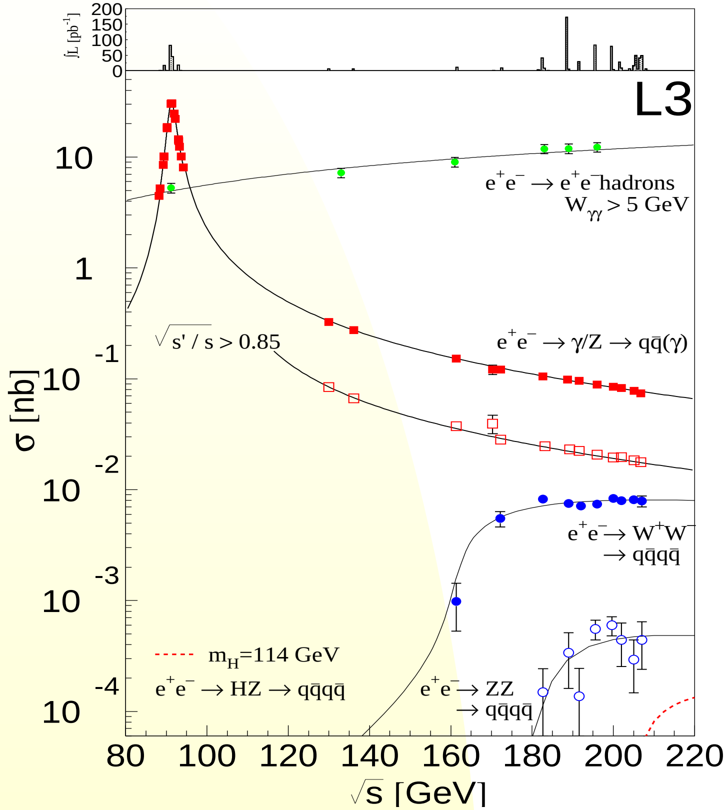
Subdetectors of LUMI

1. A calorimeter made of 304 Bismuth Germanium Oxide (BGO) crystals, arranged in 16 sectors of 19 crystals (of varying size) each.
2. A silicon detector placed in front of each monitor measures the polar angle θ and the azimuthal angle ϕ with very good accuracy.

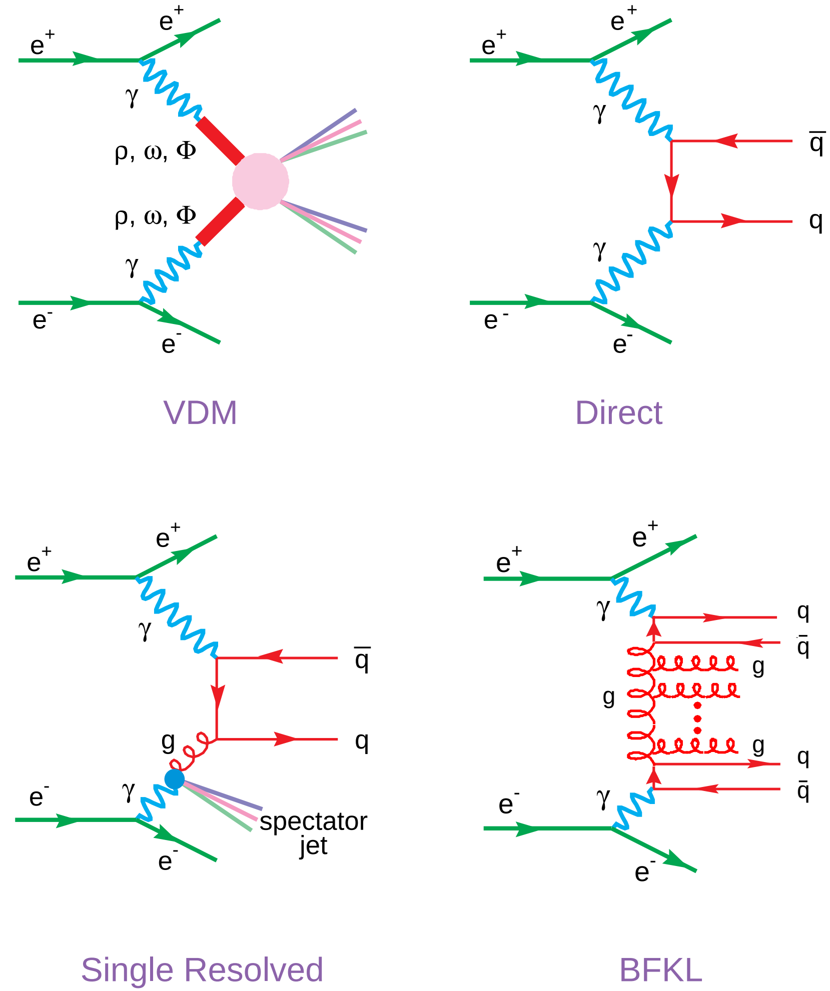




When electrons and positrons interact in LEP they radiate photons at small angles relative to the beam axis. This is the source of two-photon collisions, producing a hadronic state X according to $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^- + X$.



Two-photon reactions with hadronic final states are the dominant process at LEP2 energies.



The main Feynman diagrams, contributing to two-photon reactions

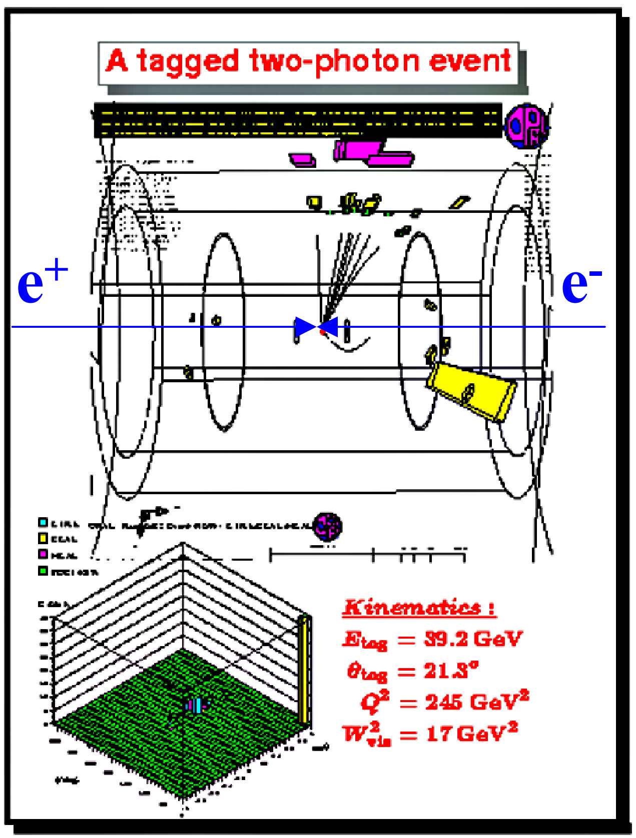
Classification of two-photon physics studies by measurements

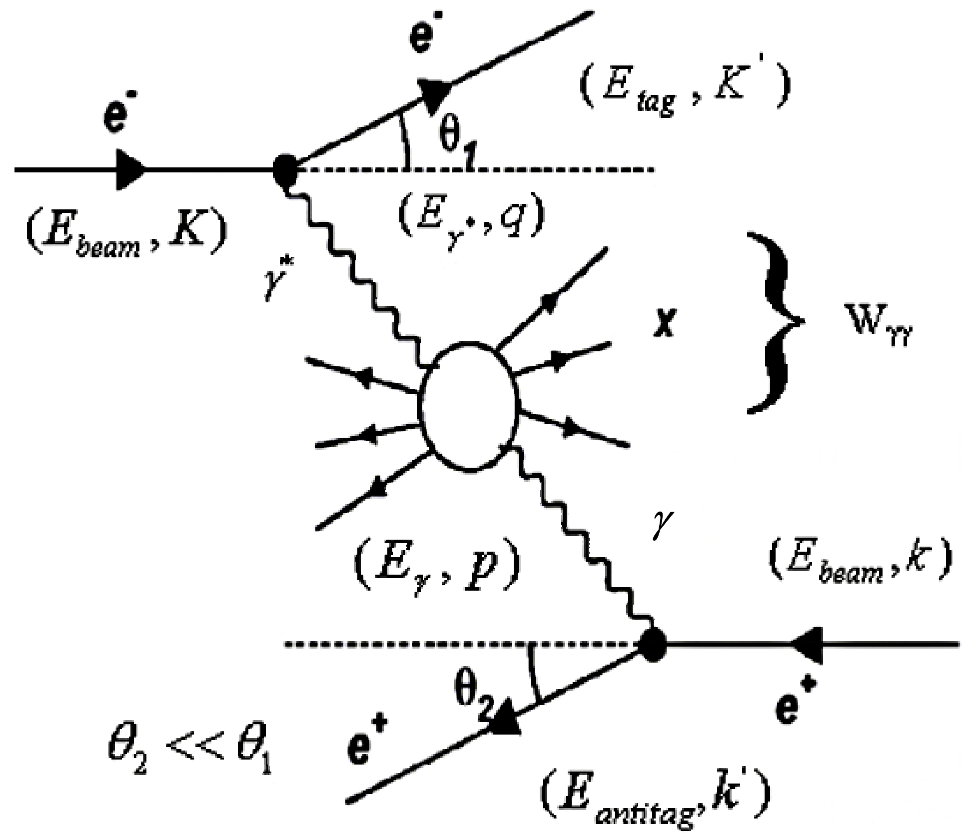
PRODUCTION	MEASUREMENT
No tag hadron production	Total hadronic cross section
Single-tagged hadron prod.	study photon structure, $F_2^\gamma(x, Q^2)$
Double-tagged hadron prod.	study virtual photon structure, $F_2^\gamma(x, Q^2, P^2)$
Charm and beauty prod.	Study heavy flavor content of the photon
Jet and single (inclusive) particle production	Study QCD processes over large p_t range
Exclusive resonance prod.	Study quark content of mesons by measuring the two photon coupling

What is a “TAG” and a SINGLE TAG event?

If the scattering angle is large enough, an electron is observed inside the detector, which is called a “tag”.

If only one of the scattered electrons is measured in the forward detectors the event is said to be a single-tag event.





$(\theta_2 = \theta_{antitag} << \theta_1 = \theta_{tag})$

Photon Structure Function

F(x,Q²) ~ probability that the probe photon with virtuality Q^2 sees a quark with momentum fraction *x* inside the target quasi-real photon.

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

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

for single - tagged hadron production :

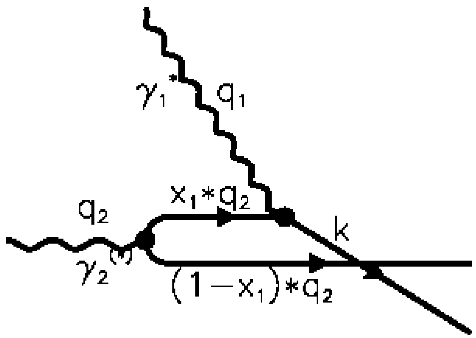
$$-q_1^2 = Q_1^2 \equiv Q^2 > 0$$

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

mass squared of the outgoing interacting fermion :

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

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



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.

THEORY

Single tagged $\gamma^*\gamma$ process

Goal: **measure the cross section for the single-tagged $\gamma^*\gamma$ process, extraction of the photon structure function $F_2^\gamma\,(x, Q^2)$**

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

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

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

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

For single tagged events: P $\cong$0

$$x = Q^2 \big/ \left(Q^2 + W^2\right)$$

Determination of cross section

$$\frac{d\sigma_{e(K)\gamma(p)\to e(K')X}(x,Q^2)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[(1+(1-y)^2)F_2^\gamma(x,Q^2) - y^2 F_L^\gamma(x,Q^2)]$$

$$y = (p\cdot q)/(p\cdot K) \approx 1-\left(E_{tag}/E_{beam}\right)\cdot\cos^2(\theta_{tag})$$ *, $y \approx 0 \rightarrow F_2^\gamma(x, Q^2)$*

effective gamma-gamma cross-section:

$$\sigma_{\gamma^*\gamma}(x,Q^2) = \frac{4\pi^2\alpha}{Q^2}F_2^\gamma(x,Q^2)$$

F_2^γ (x, Q^2) receives contributions from direct quark-antiquark production, VDM and resolved photon processes.

Extract F_2^γ

- In $e^+e^- \rightarrow e^+e^- \gamma^* \gamma \rightarrow e^+e^-$ + hadrons deep-inelastic scattering process the energy of the quasi-real target photon γ is not known $\Rightarrow$ kinematics must be determined from final state hadrons, measure $W_{vis} = W_{\gamma\gamma}$

- W_{vis} poorly measured, Q^2 well measured $\Rightarrow$ We need the true value of x.

- Monte Carlo and "unfolding" procedure (BAYES theorem) is used to get the x_{tru} distribution from the x_{vis} distribution:

$$x_{vis} = Q^2 / \left(Q^2 + W_{vis}^2\right), x_{true}(i) = \sum_{j=1}^{n} A_{ij} x_{vis}(j), A_{ij} \text{ unfolding matrix}$$

- Calculate the double differential cross section $\dfrac{d\sigma(x,Q^2)}{dxdQ^2}$

- Extract F_2^γ / α **unfolded** photon structure function

Data analysis

Data collected in 1998, 1999, 2000

$\sqrt{s} = 189 - 208\ \ GeV$

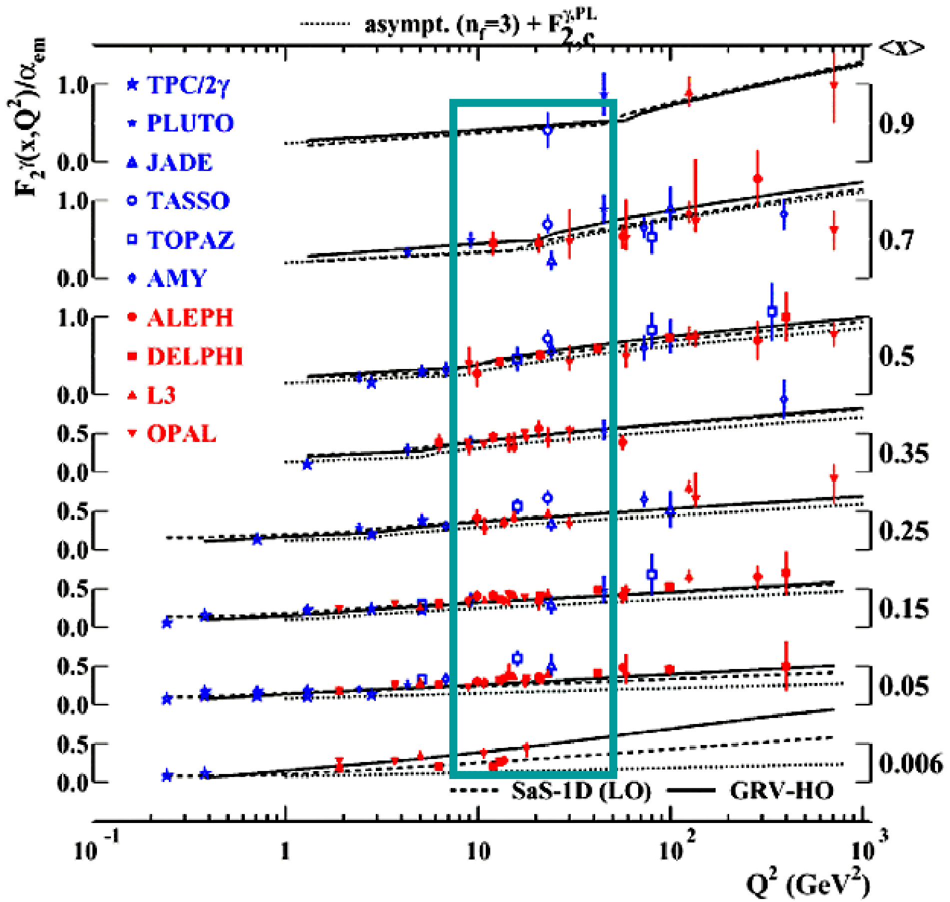
L_{tot} ~ 700 pb^{-1}.

Compared to other experiments

- LEP (ALEPH, DELPHI, L3, OPAL)
- TPC detector at PEP/SLAC, Stanford;
- PLUTO, JADE, and TASSO detectors at DESY, Hamburg, Germany;
- TOPAZ, AMY detectors at KEK-TRISTAN, Japan.

L3, LEP2

- higher energies
- higher statistics
- is using much better detector performance



slightly increasing tendency of the photon structure function!

$\Rightarrow$ Expect more data points, higher precision !

Status of work:

- Selections
- Calculate x, binning (x,Q^2)
- Unfolding
- Calculate $\frac{d\sigma(x,Q^2)}{dxdQ^2}$
- Extract unfolded F_2^{γ}/α