Single tagged 2γ events with BGO, ALR, and VSAT of L3

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The Concept of the "Structure of the Photon"

- Photon is ideal tool for probing structure of objects
- Structure of light-quanta → natural in QFT, since able to fluctuate into various states (leptons, quarks, $W^{\pm}$ bosons, …)
  - "through an interaction with a Coulomb field the photon could materialize as a pair of electrons, $\gamma \to e^{+}e^{-}$. Although not usually thought of in these terms, this phenomenon was the earliest manifestation of photon structure."

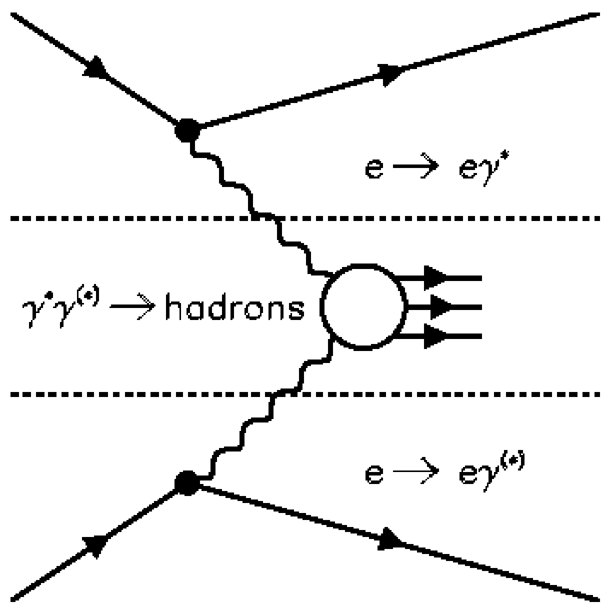
    T.H. Bauer et al. Rev. of Modern Phys. 50 (1978) 262
  - Similarly: $\gamma \to q\bar{q}$ leads to "hadronic (partonic) structure of the photon".

The Hadron-Like Properties of the Photon

- Transition $\gamma^* \gamma^* \rightarrow h$ studied with $e^{\pm}e^{-} \rightarrow e^{\pm}e^{-}\gamma^*\gamma^* \rightarrow e^{\pm}e^{-}X$, with X: hadrons

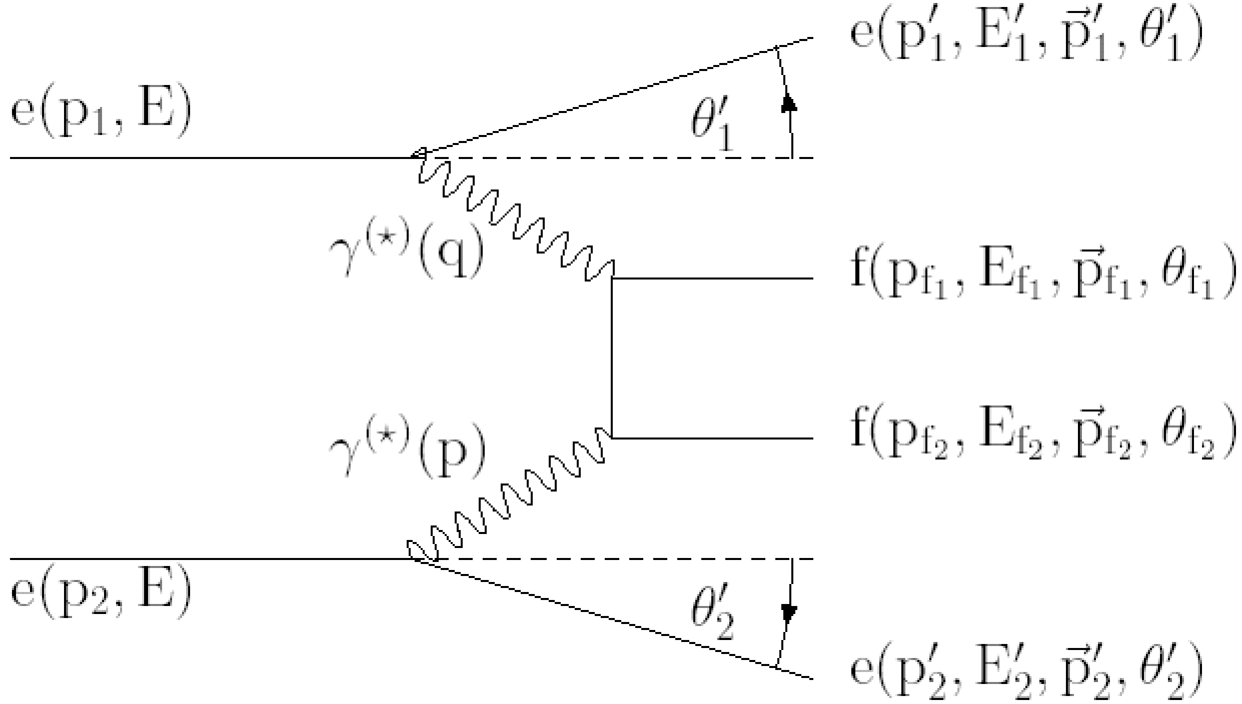
  Budnev et al., "The Two-Photon Particle Production Mechanism", Phys. Rep. 15 (1975) 181.

DIS



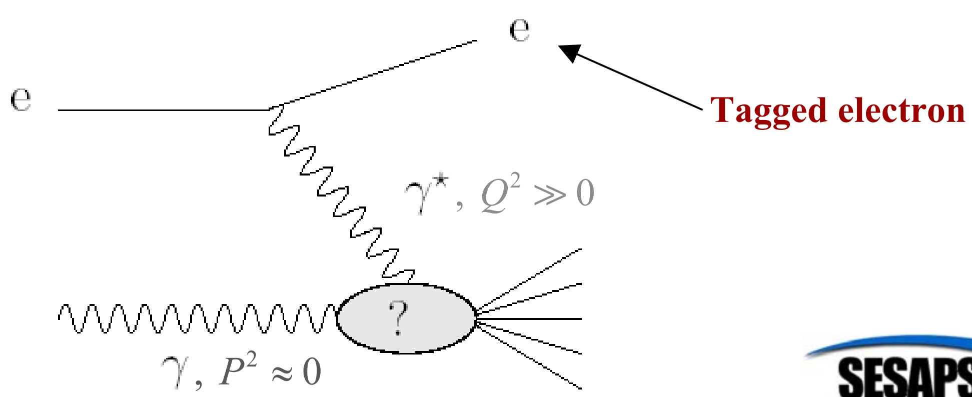
The Hadron-Like Properties of the Photon

- Classical way to investigate structure of the photon at e^+e^- colliders is to measure the *Photon Structure Function*.



Partonic Content of the Real Photon

- $\text{DIS}_{e\gamma} \rightarrow$ hadronic final state produced in single-tag events is main source of information of *partonic content* of real photon
  $\rightarrow \gamma^{*}\gamma$ collisions at $e^{+}e^{-}$ colliders.
- For unpolarized $e^{+}e^{-}$ case you can introduce hadronic structure functions $F_{1,2}^{\gamma}$, in analogous way as for protons in DIS_{ep} experiments.
- $\text{DIS}_{e\gamma}$ is characterized in the case where one photon is highly virtual, $Q^2 \gg 0$ and the other photon is quasi-real, $P^2 \approx 0$.



Partonic Content of the Real Photon

- Cross-section for single-tag condition :

$$\frac{d\sigma^{e\gamma\to eX}}{dx_{Bj}dQ^2} = \frac{4\pi\alpha^2}{x_{Bj}Q^4}\left[1+(1-y)^2 F_2^{\gamma}\right]$$

with

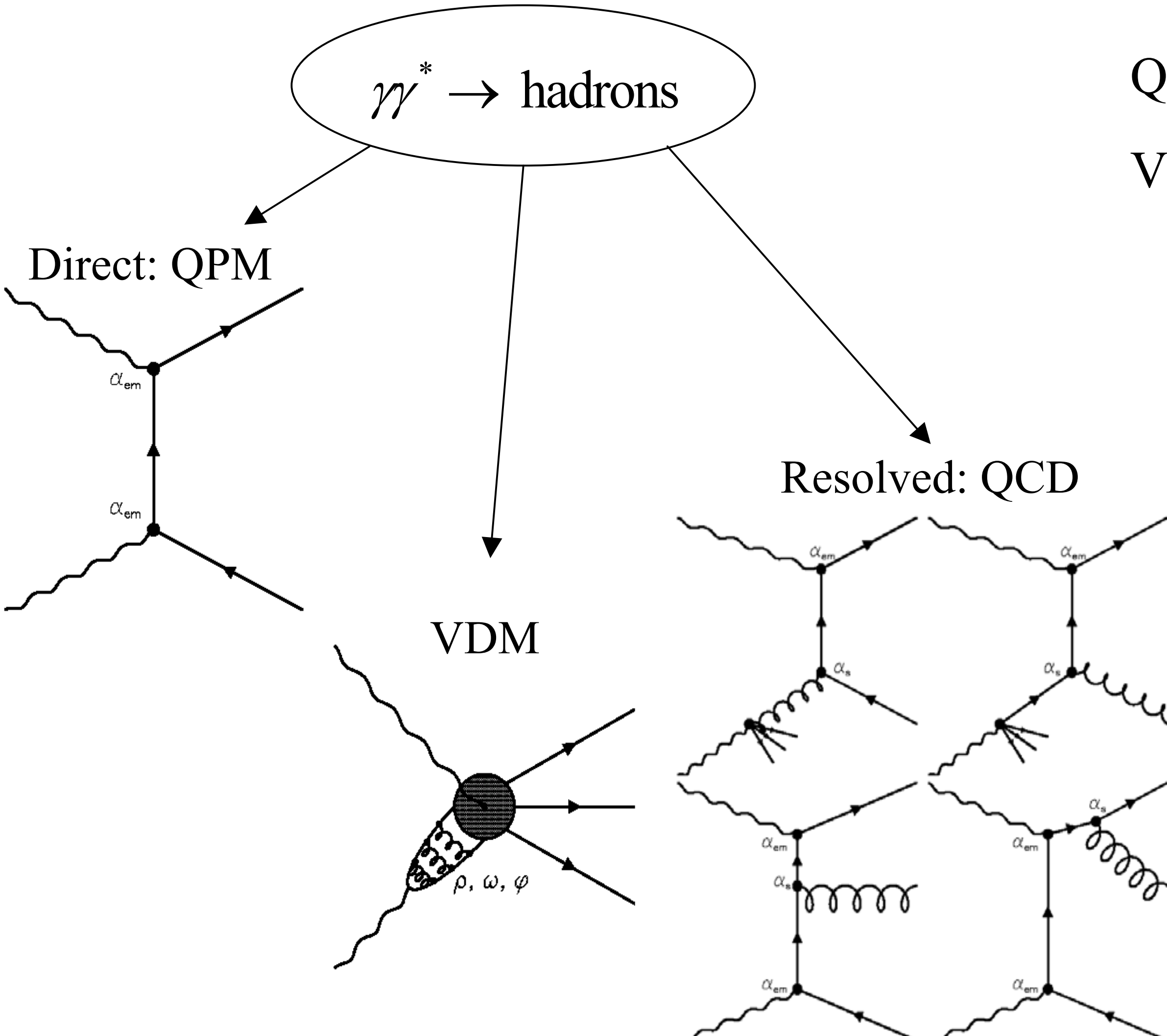
$$x_{Bj} = \frac{Q^2}{2p\cdot q},\ y = \frac{p\cdot q}{p_1\cdot p}$$

accessible from data:

$$d\sigma^{e\gamma\to eX} = \Gamma_T \sigma_{\gamma^*\gamma^{(*)}} dQ^2 dQ_2^2 dW$$

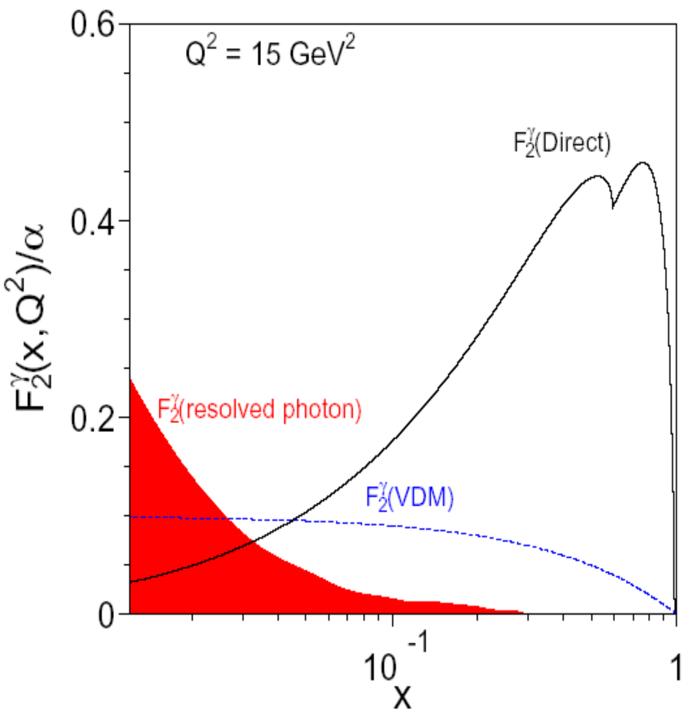
$$\sigma_{\gamma^*\gamma^{(*)}} = \frac{\Delta\sigma^{ee\to eeX}}{\int N_{\gamma^{(*)}}\Gamma_T dQ^2 dQ_2^2 dW} = \frac{\Delta\sigma^{ee\to eeX}}{\Delta L}$$

Contribution to the Partonic Content of the Real Photon



QPM: Quark Parton Model

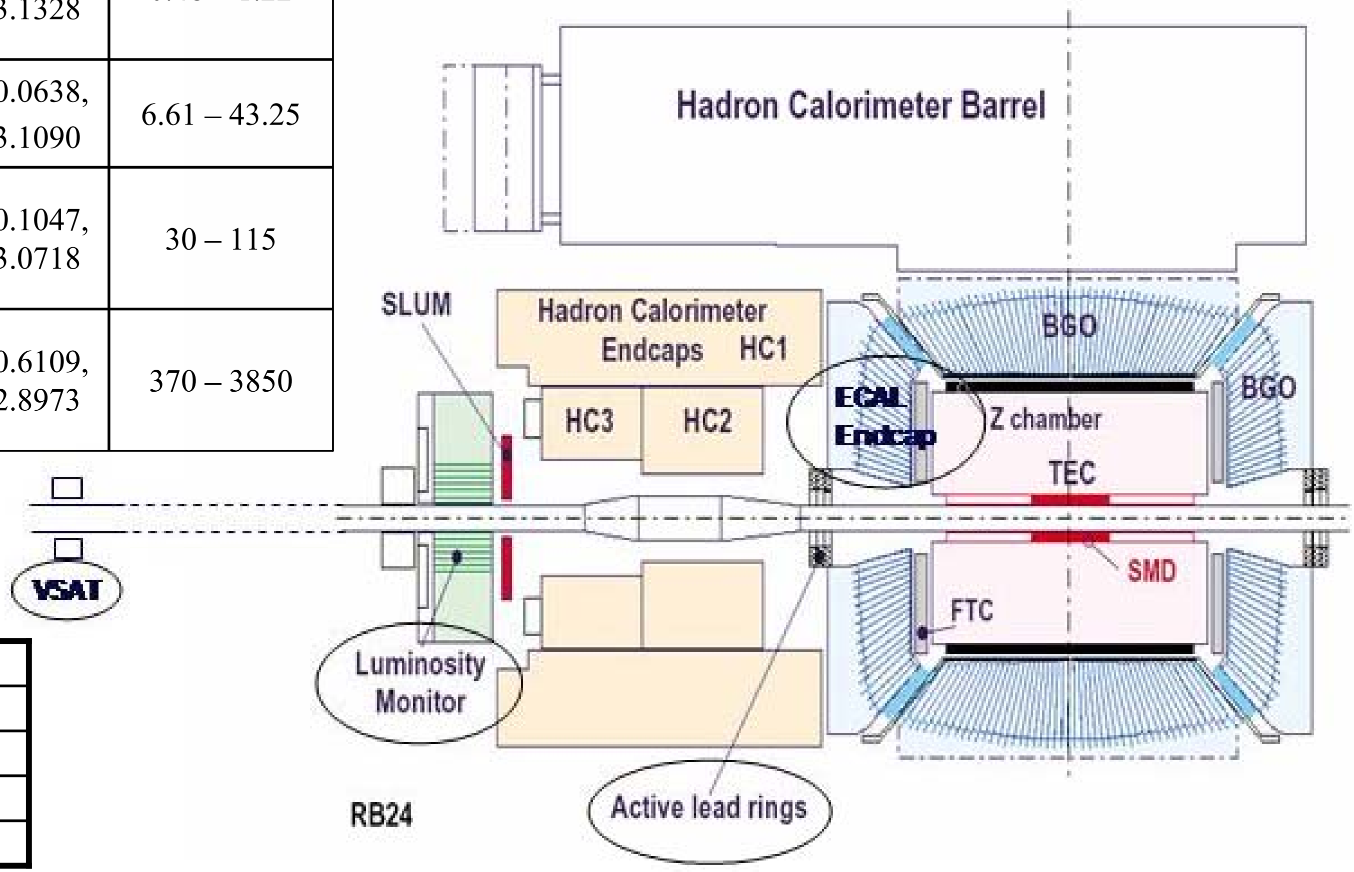
VDM: Vector Dominance Model



(D. Haas, *Diffraction 2002*)

The L3 Detector

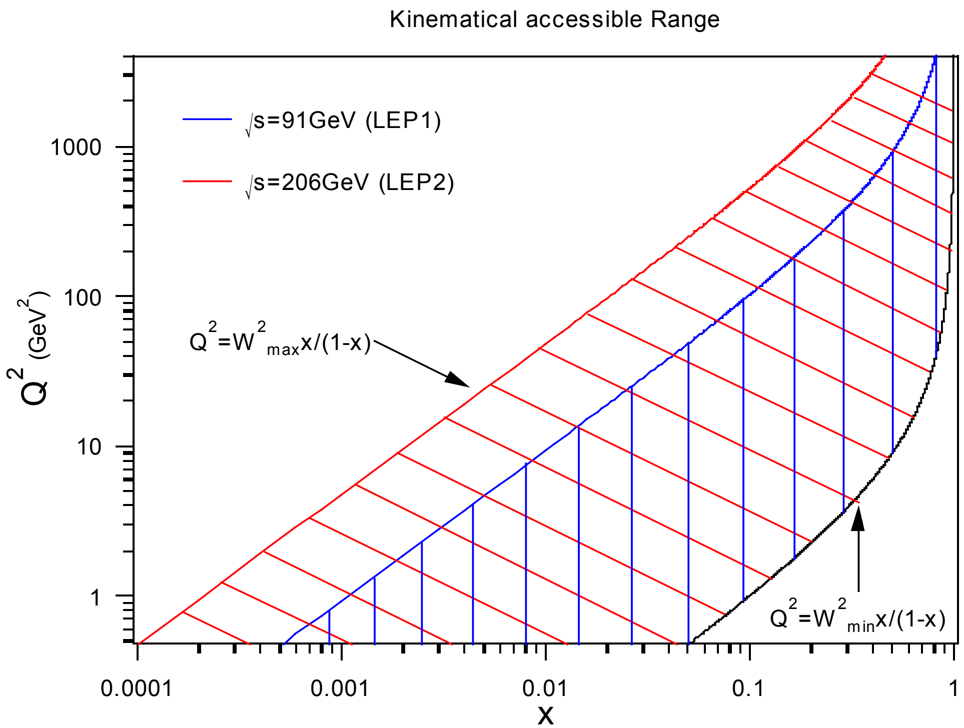
Sub-detector	Angular range (rad)	Q^2 range (GeV^2)
VSAT (Very Small Angle Tagger)	0.0088 – 0.0107, 3.1309 – 3.1328	0.48 – 1.22
LUMI	0.0326 – 0.0638, 3.0778 – 3.1090	6.61 – 43.25
ALR (Active Lead Ring)	0.0698 – 0.1047, 3.0370 – 3.0718	30 – 115
BGO (ECAL Endcaps)	0.2443 – 0.6109, 2.5307 – 2.8973	370 – 3850

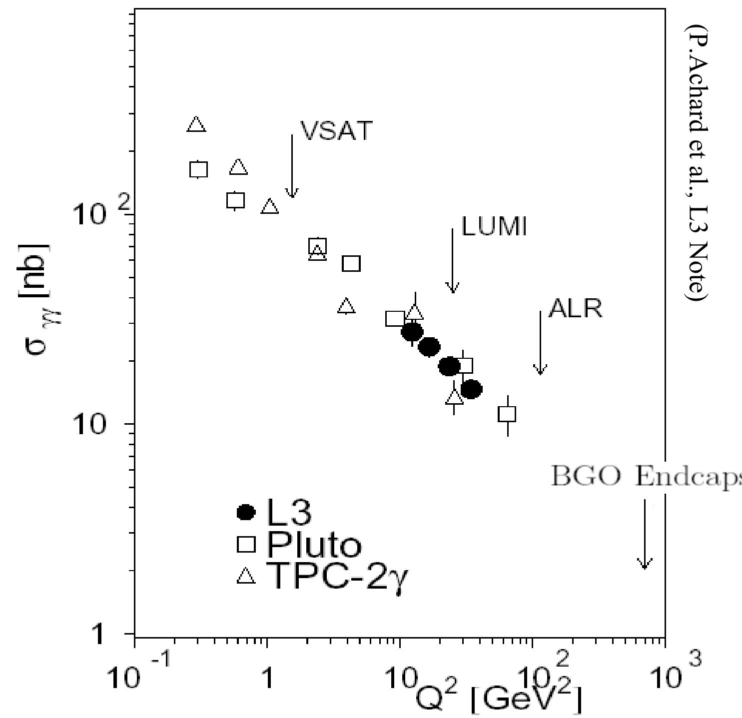


Year	$\overline{E}_{beam}/GeV$
1998	94.3
1999	97.3
1999	100.0
2000	103.1

Analysis Goal

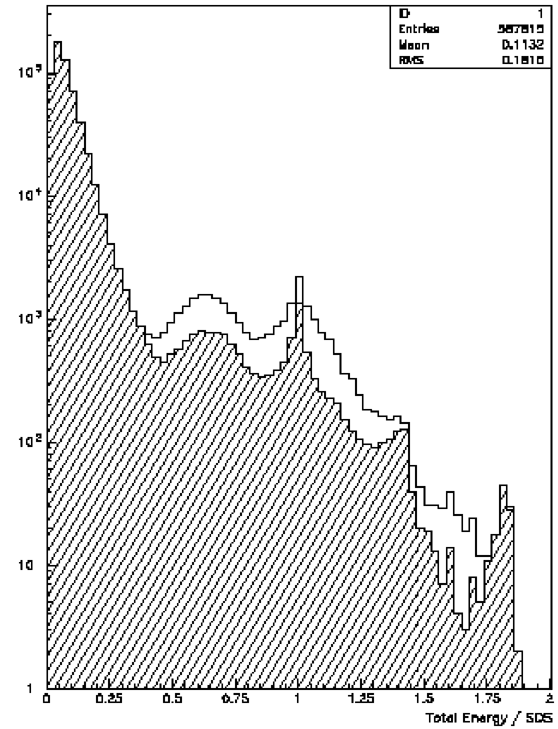
- Extract $F_2^{\gamma}(x,Q^2)$ out of differential cross-section.
- Use VSAT, ALR, and BGO → extend the kinematic reach both to lower x_{Bj} and higher Q^2.

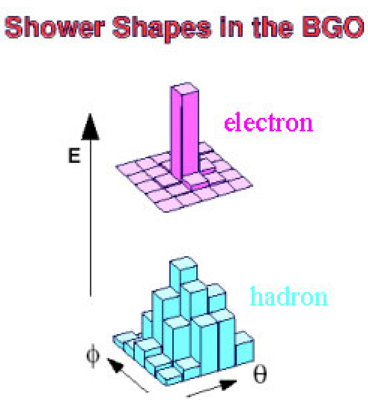




Event Selection

- Data samples from 1998, 1999, 2000
  $\rightarrow$ total integrated luminosity $\mathfrak{L}_{total} \approx 600\ pb^{-1}$.
- General event consideration:
  - Hadronic channel: $N_{tracks} + N_{\gamma} \geq 6 \rightarrow$ select hadrons
  - Background rejection: $E_{ECAL} + E_{HCAL} < 0.4\sqrt{s}$
    $\rightarrow$ reject $e^{+}e^{-} \rightarrow q\bar{q}\,\gamma$
  - Exclude low masses: $W_{vis} > 3 GeV$
  - Electron tag and antitag
  - Electron identification $\rightarrow$ high energy and corresponding shape to electromagnetic shower with $E_{raw} > 0.8 \cdot E_{clus}$





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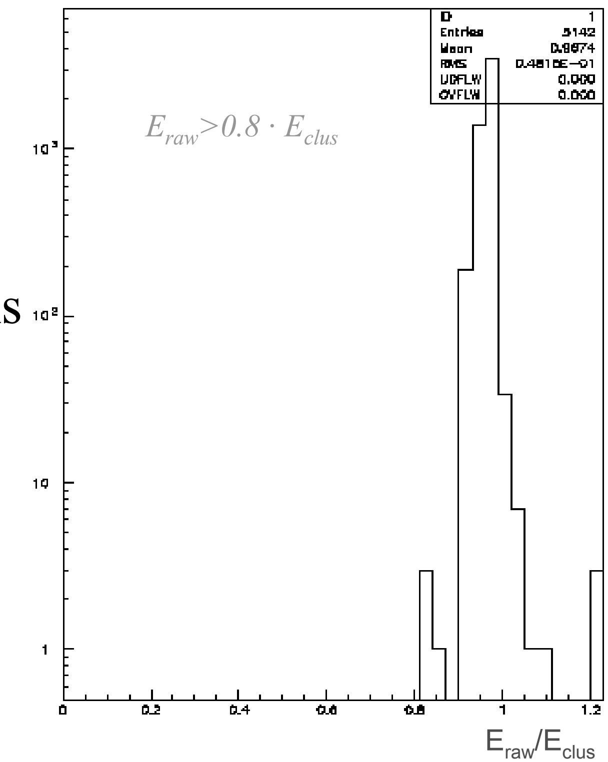
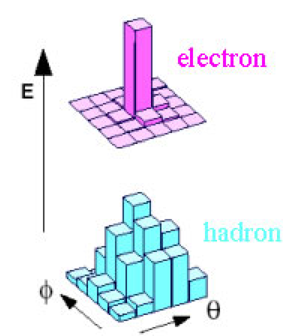
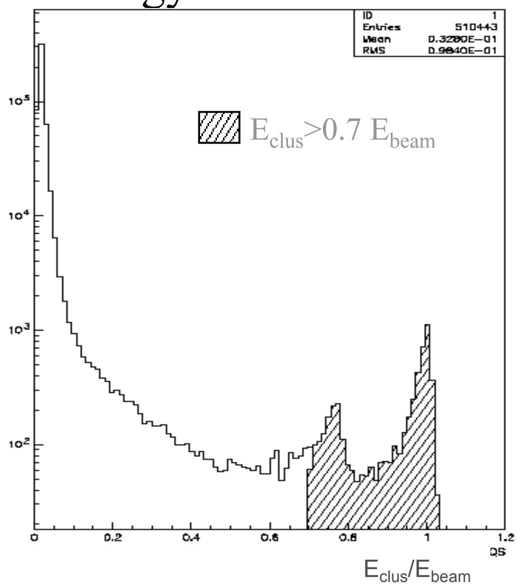




Event Selection

- Specific tagging detectors (will be guided by fully simulated event samples from *2γ* Monte Carlo generators *TWOGAM, PHOJET,PYTHIA*):
  - BGO Endcaps:
    - $\boldsymbol{E_{clus}}$ must be greater than a certain fraction of the beam energy
    - Transverse momentum cut
    - Missing momentum of unobserved electron
    - Event rapidity $\eta = \frac{1}{2}\frac{\sum_i (E_i + p_{z,i})}{\sum_i (E_i - p_{z,i})}$
    - Thrust T and thrust axis $T = \frac{Max \sum_i \left| \vec{p}_i^{\,h,*} \cdot \vec{n} \right|}{\sum_i \vec{p}_i^{\,h,*}}$



  - ALR and VSAT: similar
    - In addition, for VSAT due to overwhelming background from off-momentum electrons: two-track events → exclusive reaction is constrained

$$\sum p_t = -p_t^{VSAT}$$

Summary & Outlook

- $DIS_{e\gamma}$ allows to test the structure of the photon.
- LEP2 has rich sample of data to explore QCD.
- Usage of VSAT, ALR, and BGO of L3 as tagging devices extend kinematic reach.
- Event selection strategies $\rightarrow$ will be guided by fully simulated event samples from several $\gamma\gamma$ Monte Carlo generators.
- Unfolding procedure: detector acceptance and efficiency require to deconvolute visible data with simulated data $\rightarrow$ Bayesian Unfolding procedure.
- Expecting higher statistics and better precision compared to previous analysis.

Some Kinematics

$$s_{ee} \equiv (p_1 + p_2)^2 = 2p_1 \cdot p_2 = 4E^2,\ s_{e\gamma} \equiv (p_1 + p)^2,\ s_{\gamma\gamma} \equiv W^2 \equiv (q + p)^2 = Q^2 \frac{1-x}{x} - P^2,$$

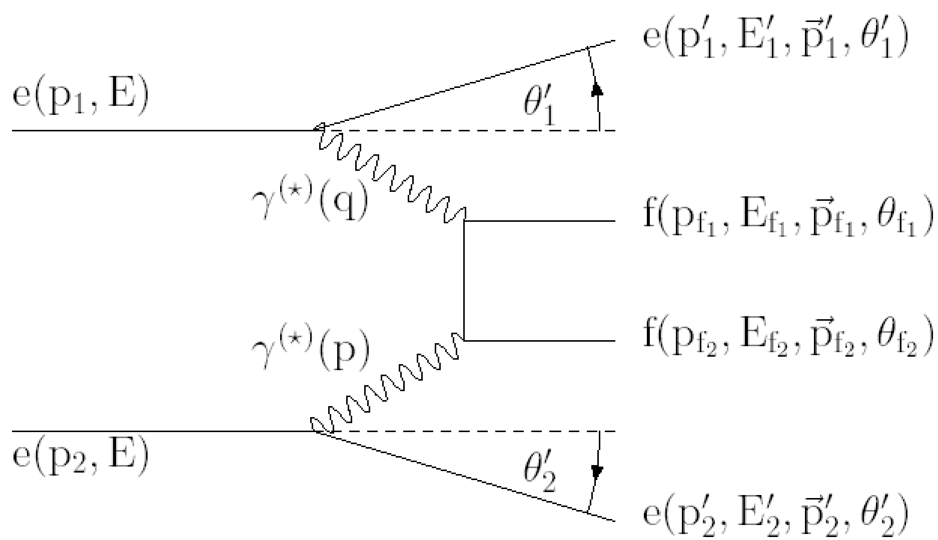
$$x = \frac{Q^2}{2p \cdot q} = \frac{Q^2}{W^2 + Q^2 + P^2},\ y \equiv \frac{p \cdot q}{p_1 \cdot q},\ r \equiv \frac{p \cdot q}{p_2 \cdot q},$$

$$Q^2 = xy(s_{e\gamma} + P^2) = 2EE_1'(1 - \cos\theta_1'),$$

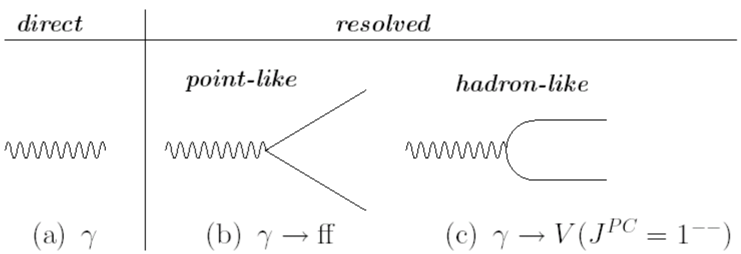
$$P^2 = 2EE_1'(1 - \cos\theta_2').$$

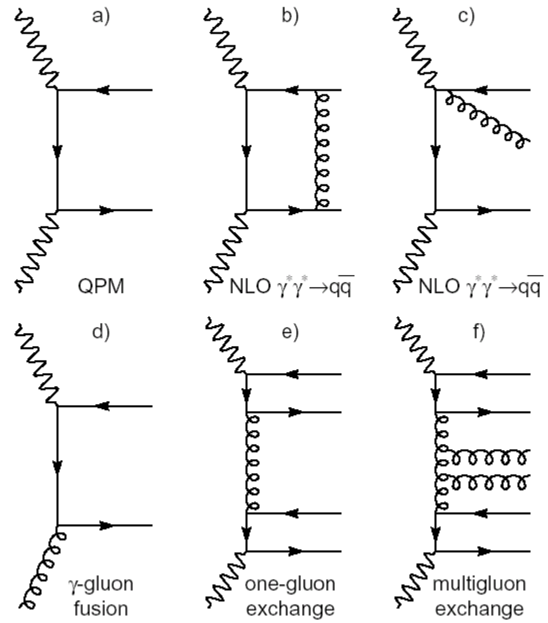
$$s_{e\gamma} = (p_1 + p)^2 = 2p_1 \cdot p = 4EE_\gamma,$$

$$y = 1 - \frac{E_1'}{2E}(1 - \cos\theta_1'),\ r = \frac{E_\gamma}{E} \equiv z.$$



Some Diagrams and Formulas





F_L^γ

$$F_T^\gamma \,(= F_1^\gamma)$$

$$F_2^\gamma = F_L^\gamma + 2x_{Bj} F_1^\gamma .$$

$$\sigma_{ee} = \sigma(e^+e^- \to e^+e^- \; hadrons),$$

$$d\sigma_{ee} = \sigma_{e\gamma^{(*)}} N_{\gamma^{(*)}}(z,\theta_2^{\max})dz, \; z = E_{\gamma^{(*)}} / E_{beam}$$

2γ Monte Carlo Generators

- The following MC generators will be used for this analysis:
  - TWOGAM
  - PHOJET
  - PYTHIA

  These MC generators contain LO QCD and VDM models, using different parameterizations.
- Background will be evaluated with PYTHIA $(e^+e^- \rightarrow Z\gamma)$ and Diag36 $(e^+e^- \rightarrow e^+e^-\tau\bar{\tau})$.