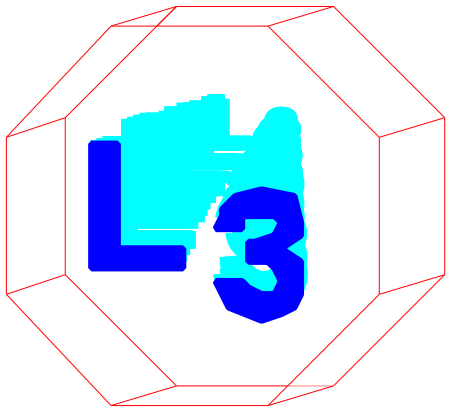
Two-Photon Physics at L3 at LEP



Daniel Haas
DPNC Genève

Diffraction 2002
Alushta, 31 Aug - 5 Sep

Overview

Introduction

- Two-Photon Collisions
- Kinematics
- Classification
- The L3 Detector

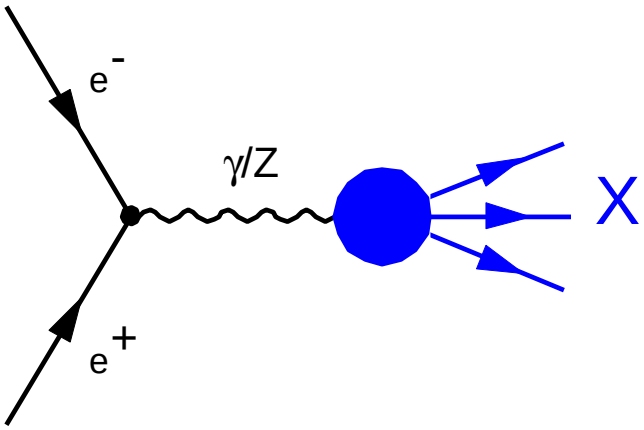
Selected Results from L3 at LEP

- $\sigma(\gamma\gamma \to hadrons)$
- Photon structure function $F^{\gamma}_{2,QCD}$
- $\gamma^*\gamma^*$
- Inclusive production
- Inclusive $\mathrm{c\bar{c}}$, $\mathrm{b\bar{b}}$
- Exclusive $\mathrm{p\bar{p}}, \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}$

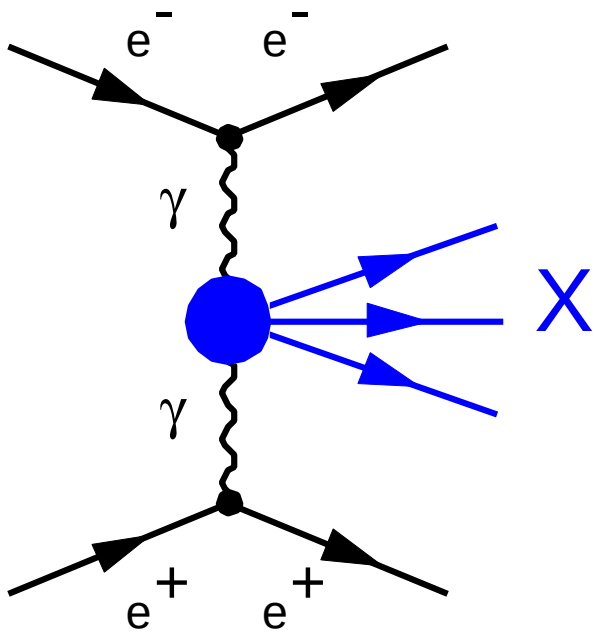
Conclusions

Introduction

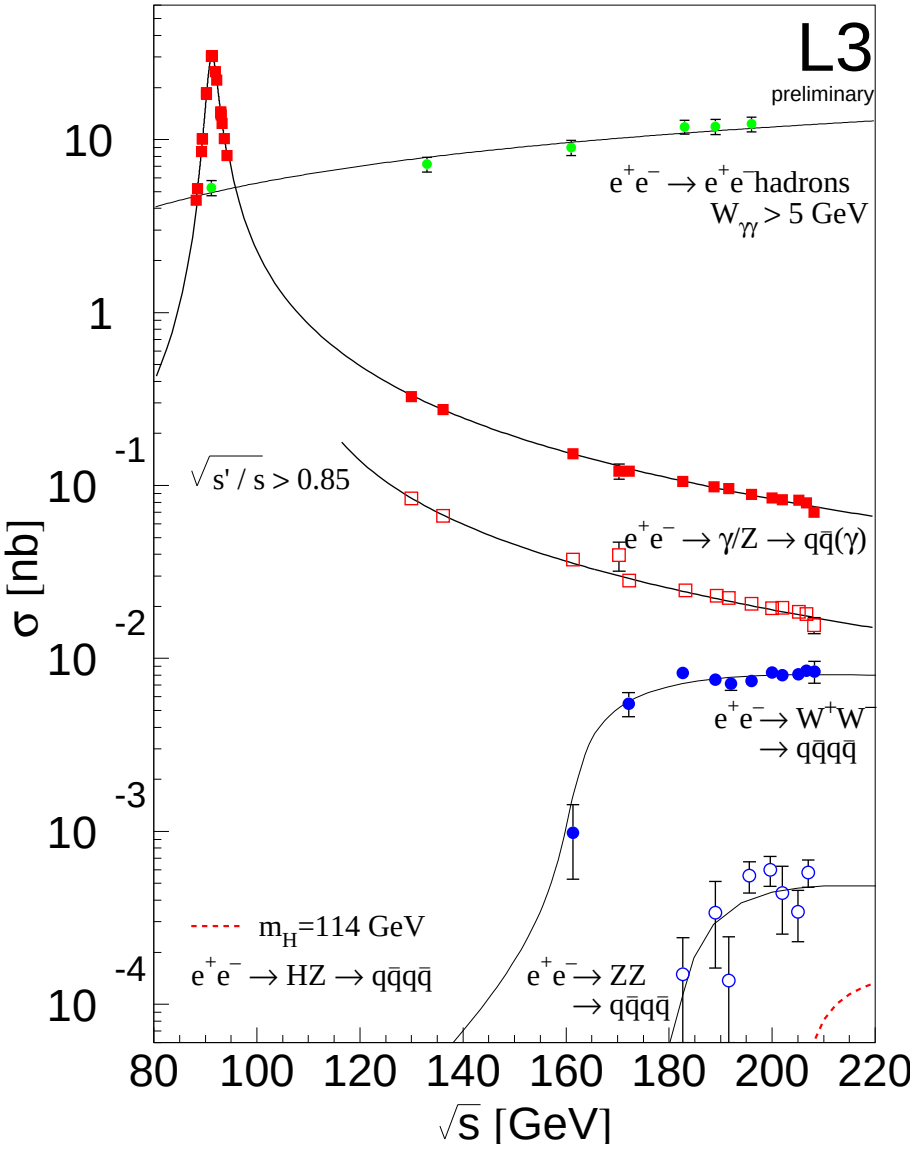
- "Standard" Process at LEP:
  $\mathrm{e^+e^-} \to \mathrm{Z}/\gamma \to X$



- Two-Photon Collision:
  $\mathrm{e^+e^-} \to \mathrm{e^+e^-}\gamma\gamma \to \mathrm{e^+e^-}X$

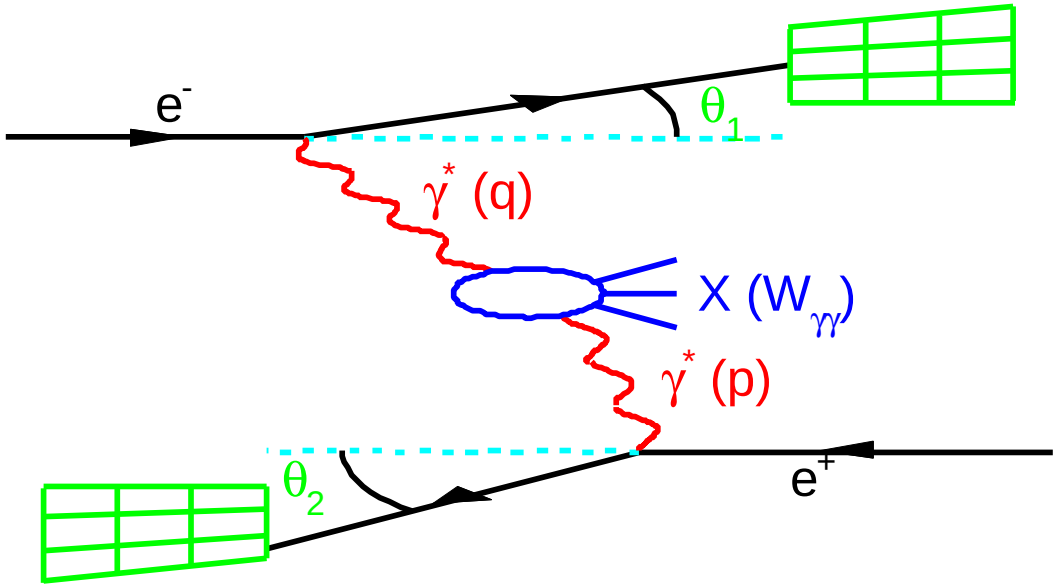


Introduction



- $\gamma\gamma$ processes are dominant at LEP!
- LEP2 is the best place to study $\gamma\gamma$ collisions

Kinematics

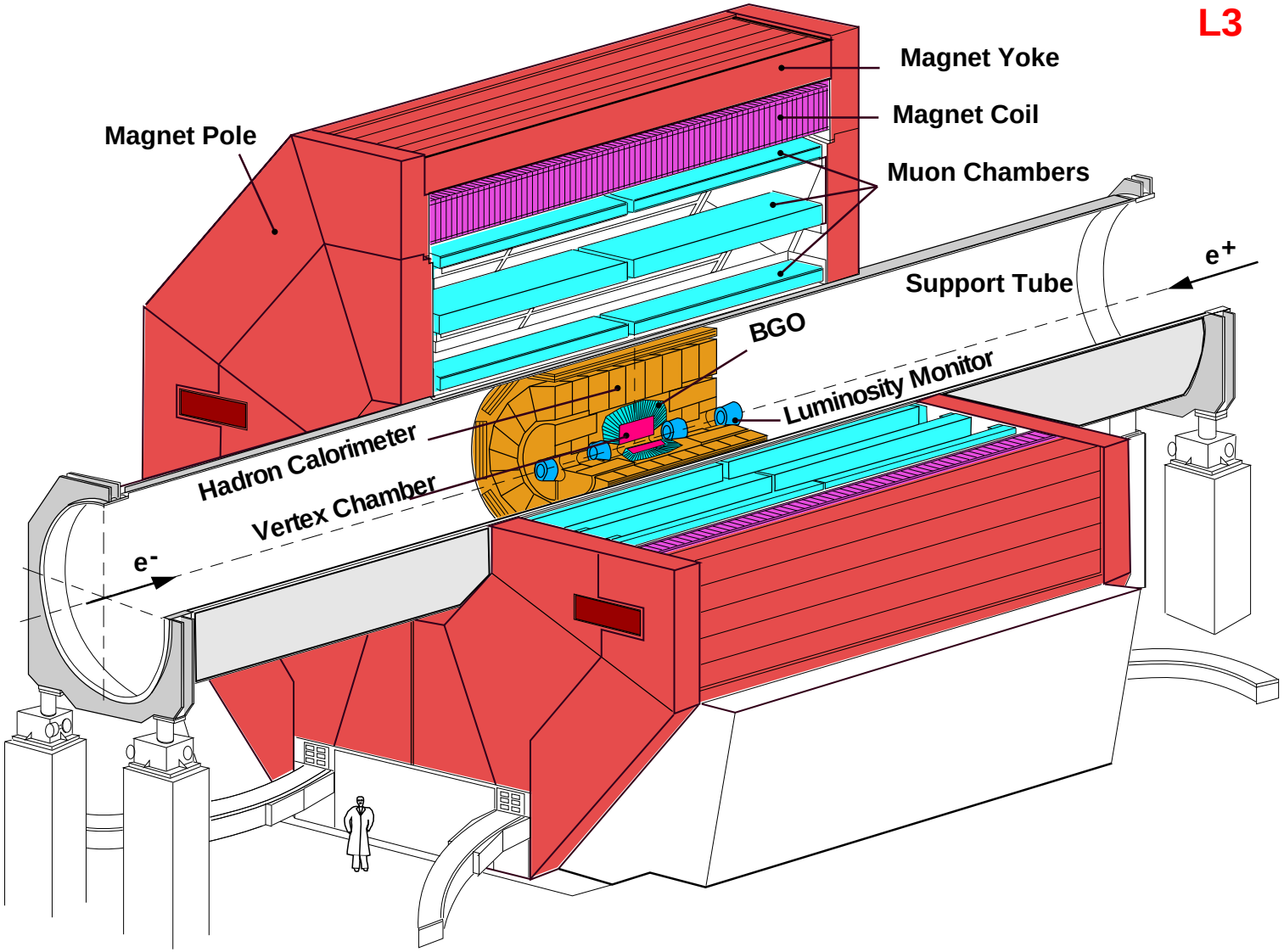


- Squared mass of the photons: $q^2 \approx -2E_{beam}E'_i(1-\cos\theta_i)$
- Virtuality of the photons: $Q^2 = -q^2 \qquad P^2 = -p^2$
- $\gamma\gamma$ center-of-mass energy: $W_{\gamma\gamma} = \sqrt{(q+p)^2}$

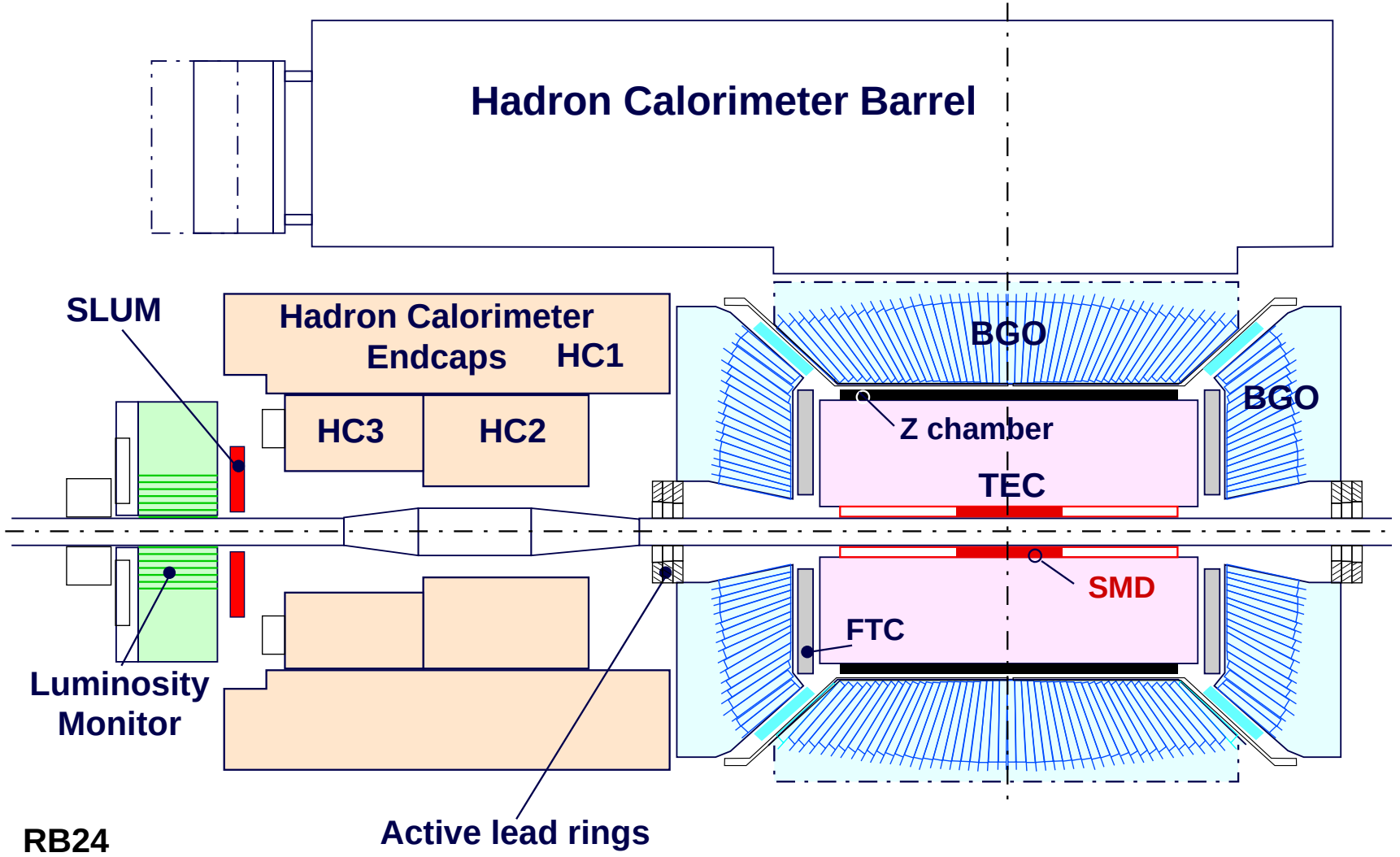
Classification

- Untagged events $(Q^2 \sim P^2 \sim 0)$
  - Scattered $\mathrm{e}^{\pm}$ are *undetected*
  - Photons are *quasi-real*
  - Topics: Total cross-section, inclusive charm production, resonances...
- Single-Tagged events $(Q^2 \gg P^2 \sim 0)$
  - One scattered electron is detected
  - One photon is *highly virtual*, one is *quasi-real*
  - Q^2 is well measured
  - Topics: Photon structure functions, photon-meson transition form factor
- Double-Tagged events
  - Both scattered electrons are detected
  - Q^2 and P^2 are well measured
  - $W_{\gamma\gamma}$ can be measured directly
  - Topics: Cross-section of $\gamma^*\gamma^*$ collisions, virtual photon structure function

L3 Detector

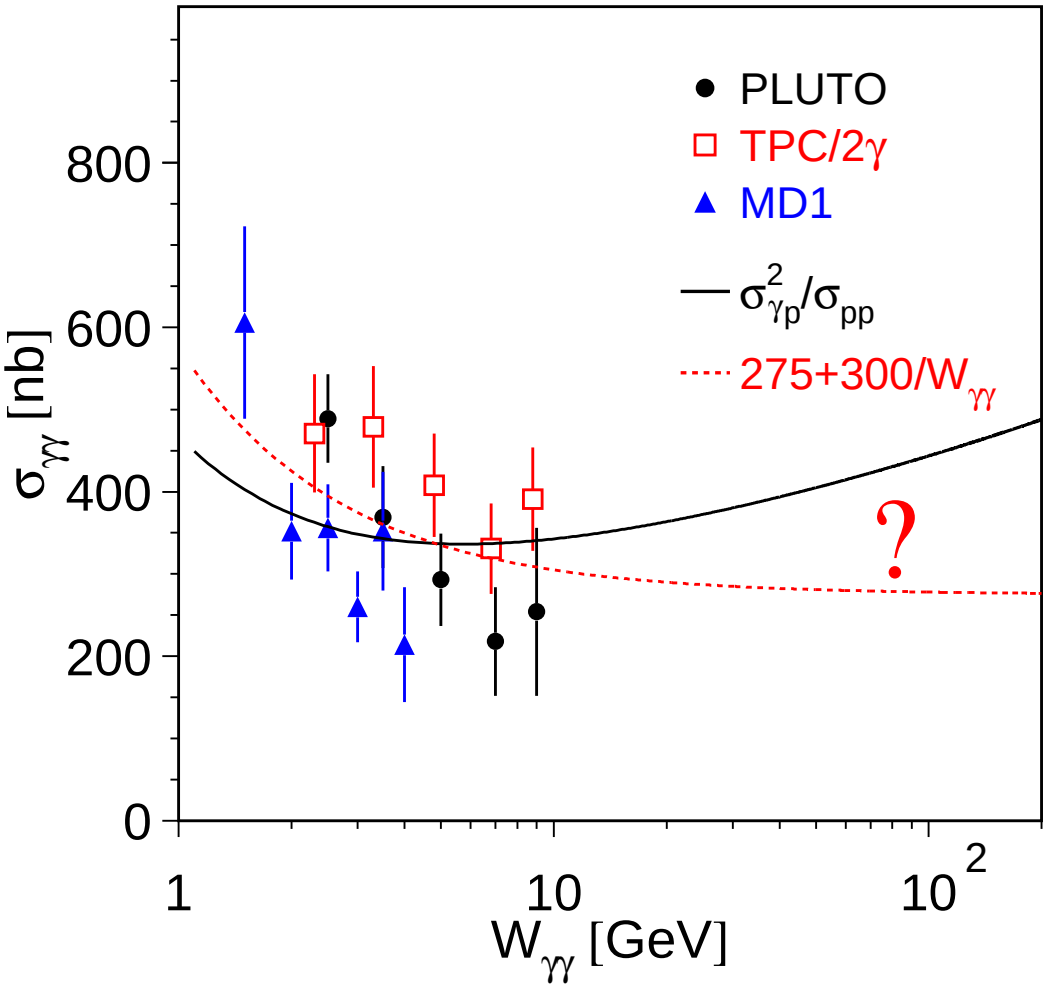

L3
Magnet Yoke
Magnet Coil
Muon Chambers
Magnet Pole
Support Tube
e+
BGO
Luminosity Monitor
Hadron Calorimeter
Vertex Chamber
e-

L3 Detector


Hadron Calorimeter Barrel
SLUM
Hadron Calorimeter
Endcaps
HC1
HC3
HC2
BGO
BGO
Z chamber
TEC
SMD
FTC
Luminosity
Monitor
RB24
Active lead rings

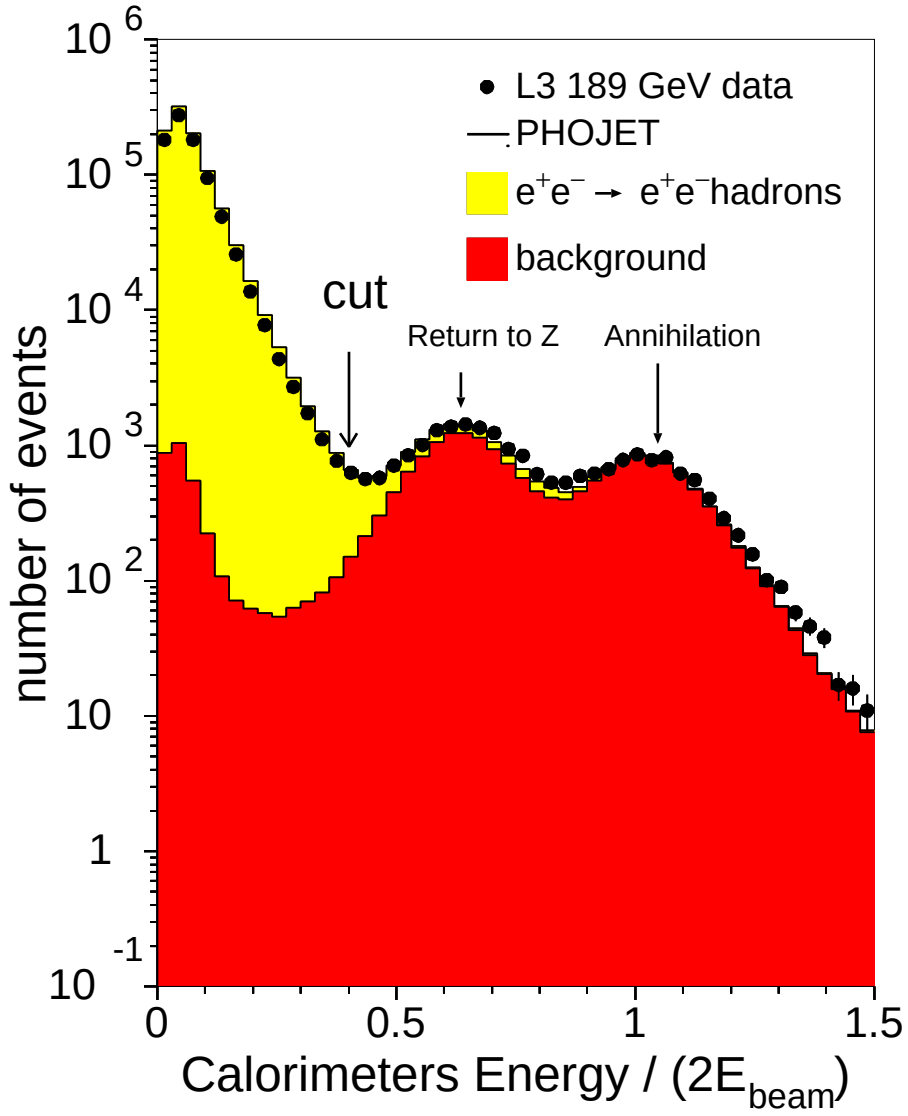
Total $\sigma_{\gamma\gamma}$ - Motivation

Measurements before LEP:



- Limited by beam energy $\rightarrow W_{\gamma\gamma} < 10$ GeV
- Very wide spread of the data
- Does $\sigma_{\gamma\gamma}$ increase at high energy?
- At LEP, $5 \text{ GeV} < W_{\gamma\gamma} < 185 \text{ GeV}$ has been measured

Total $\sigma_{\gamma\gamma}$ - Selection



- $e^+e^- \rightarrow e^+e^- hadrons$ peak at low energies $\rightarrow E_{tot} \leq 40\%\sqrt{s}$
- Background contributions are small
- L3 data $\sqrt{s} = 183 - 202$ GeV, $\mathcal{L} = 444$ pb^{-1}

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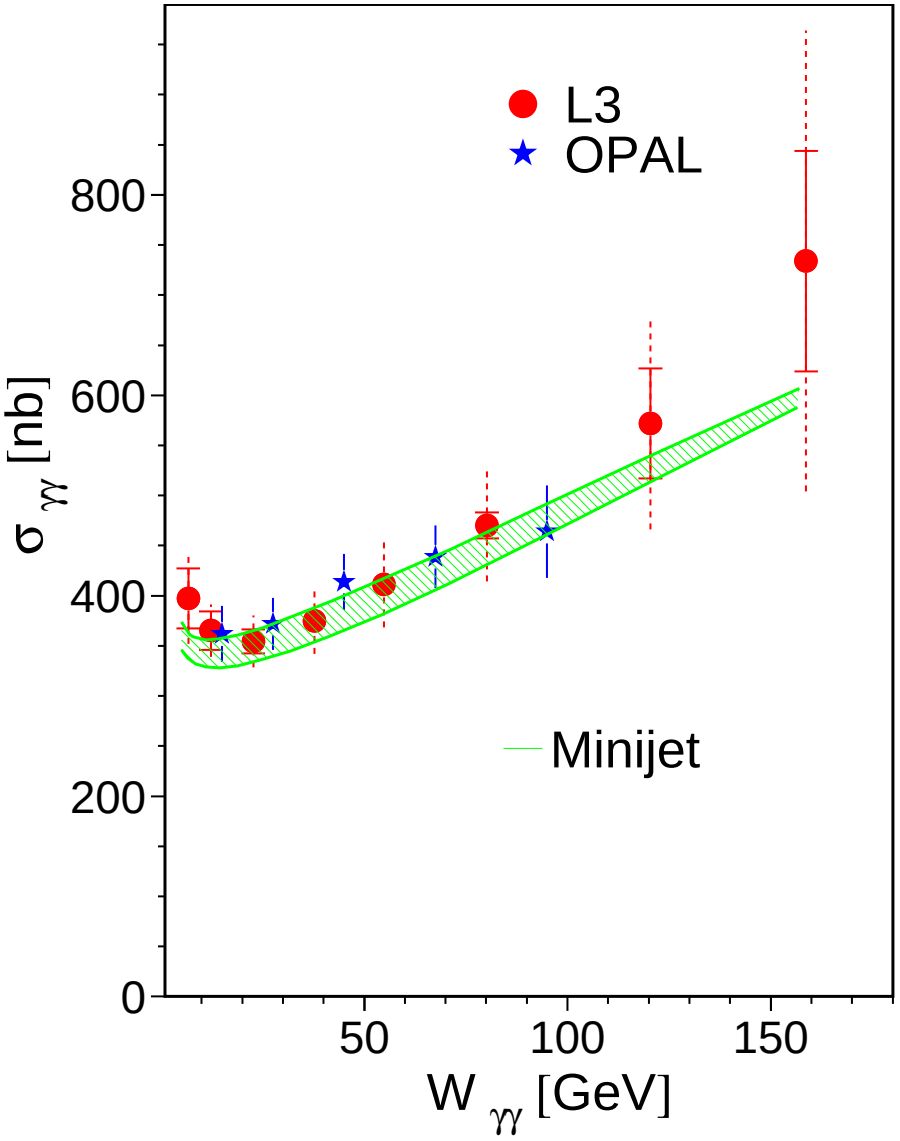
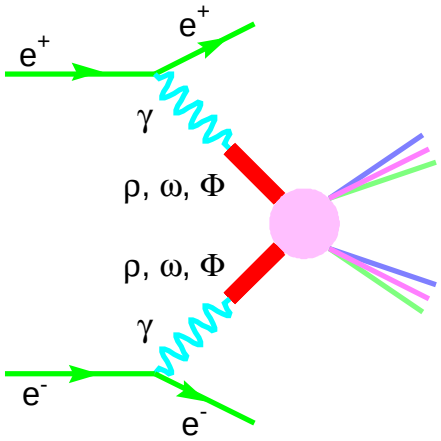
Total $\sigma_{\gamma\gamma}$ - Results

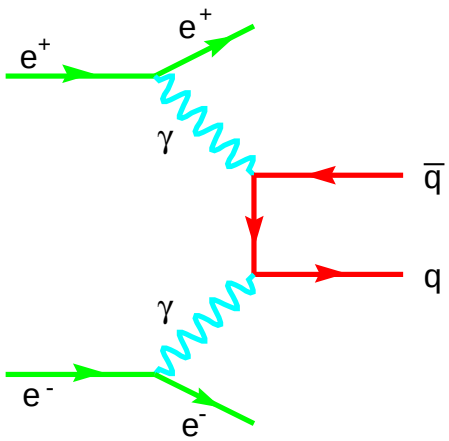


- Good agreement between experiments
- $\sigma_{\gamma\gamma}$ increases at high $W_{\gamma\gamma}$
- $\sigma_{\gamma\gamma}$ also increases versus low $W_{\gamma\gamma}$
- Universal Regge fit is excluded
- Newer QCD Models (Minijet) can describe the data

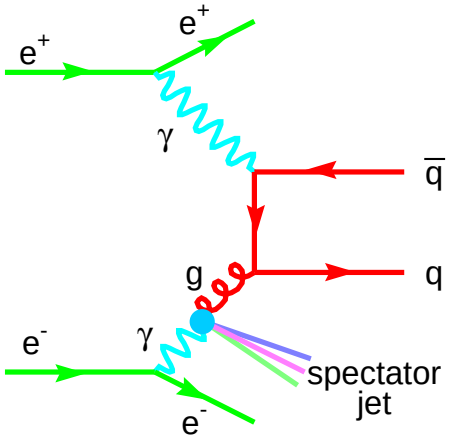
$\gamma\gamma \to hadrons$ **processes**



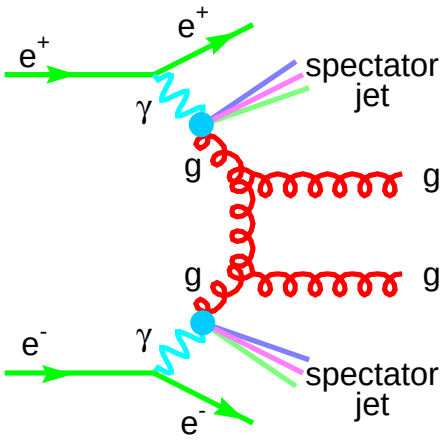
VDM



Direct



Single Resolved



Double Resolved

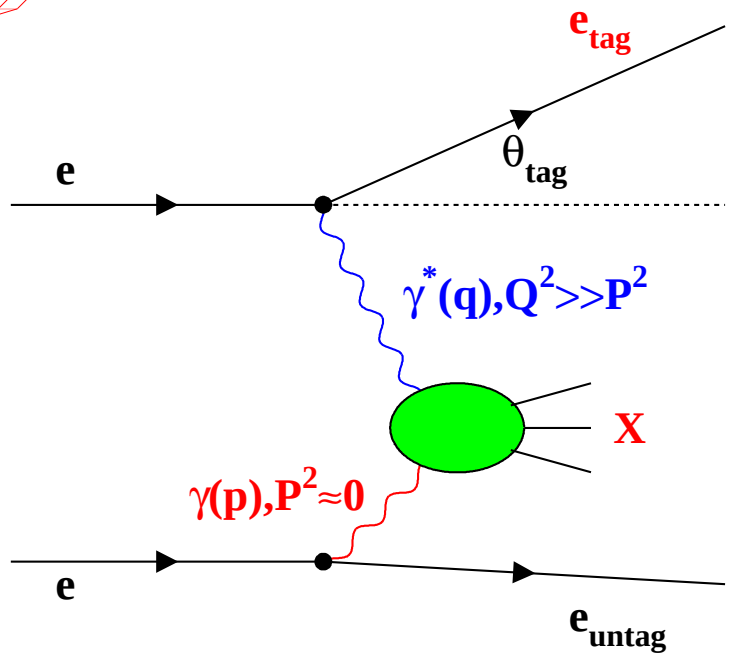
What is the contribution of the different processes?

What are the differences in event shapes?

$\Rightarrow$ Hard scale (F_2^γ, $c\bar{c}$, $b\bar{b}$)

$\Rightarrow$ Inclusive Hadron production

Photon Structure Function



Single Tag Events:

Tagged photon serves as probe, the other as target

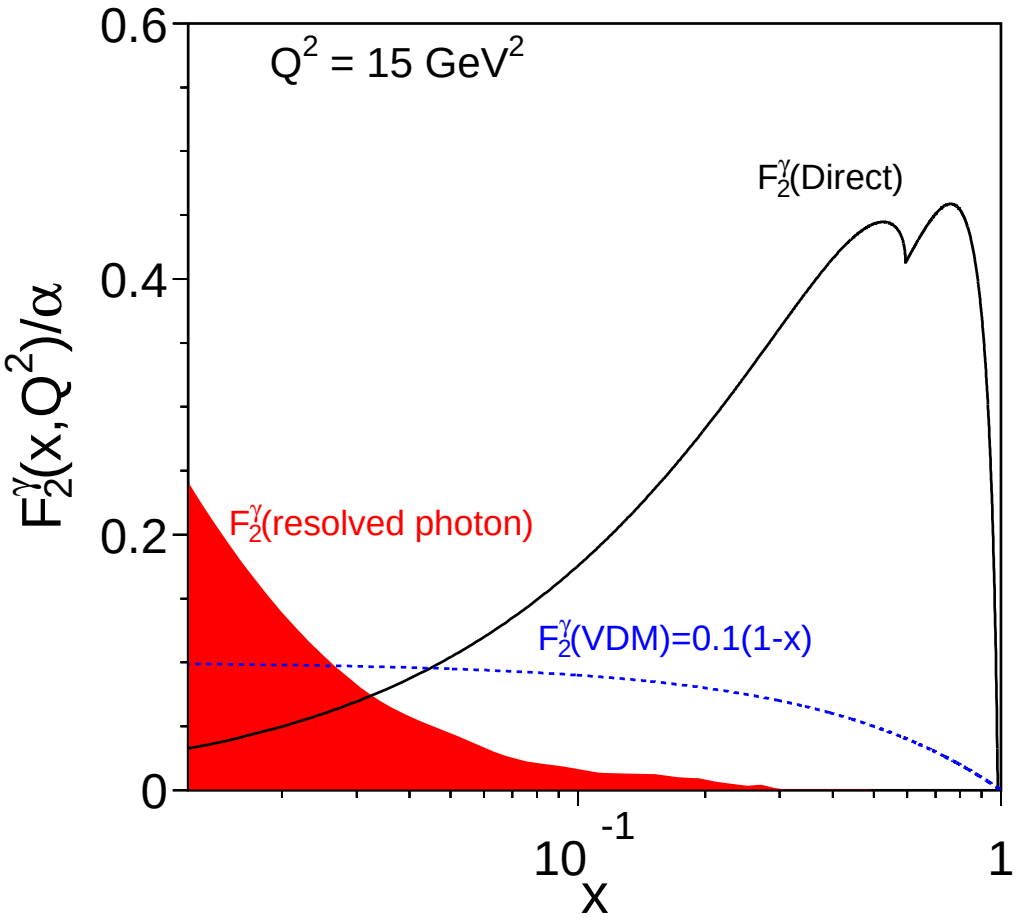
- Differential cross-section:

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

$x = \frac{Q^2}{Q^2+P^2+W_{\gamma\gamma}^2}$, $y = 1 - \frac{E_{tag}}{E_{beam}}\cos^2\frac{\theta}{2} \ll 1$ (Bjorken Scaling Variables)

- Only F_2^γ is measurable since y^2 is small

$F^{\gamma}_{2,QCD}$: Physics

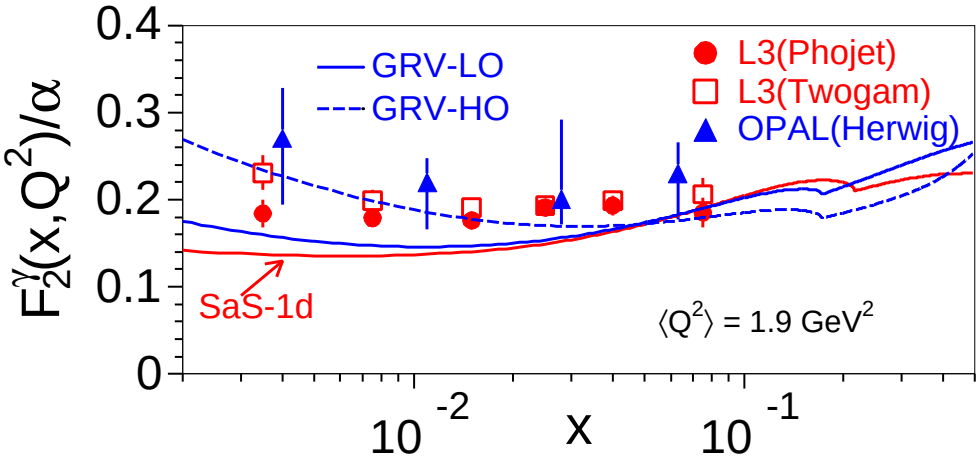


- At high x: Quark constituents are dominant
- At low x: Gluon constituents are dominant
- Low x region is sensitive to the gluon density

$F^{\gamma}_{2,QCD}$: Results

$F^{\gamma}_{2,QCD}$ at low Q^2

$\rightsquigarrow$ access to low x



F^{γ}_{2} measured at low x

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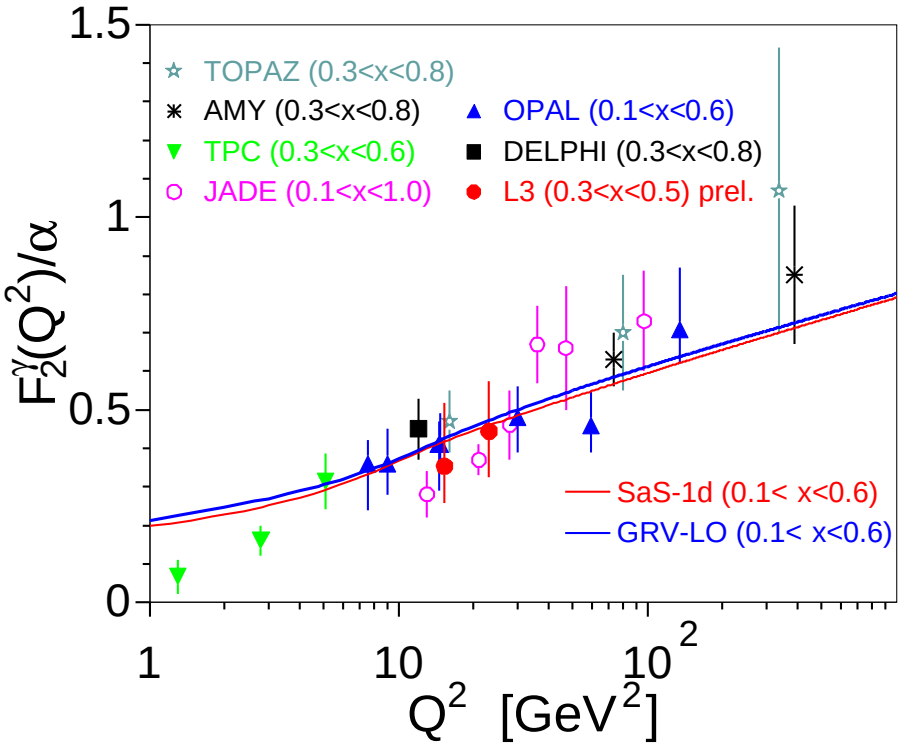
$F^{\gamma}_{2,QCD}$ as a function of $\ln Q^2$ at high x



$\ln Q^2$ evolution

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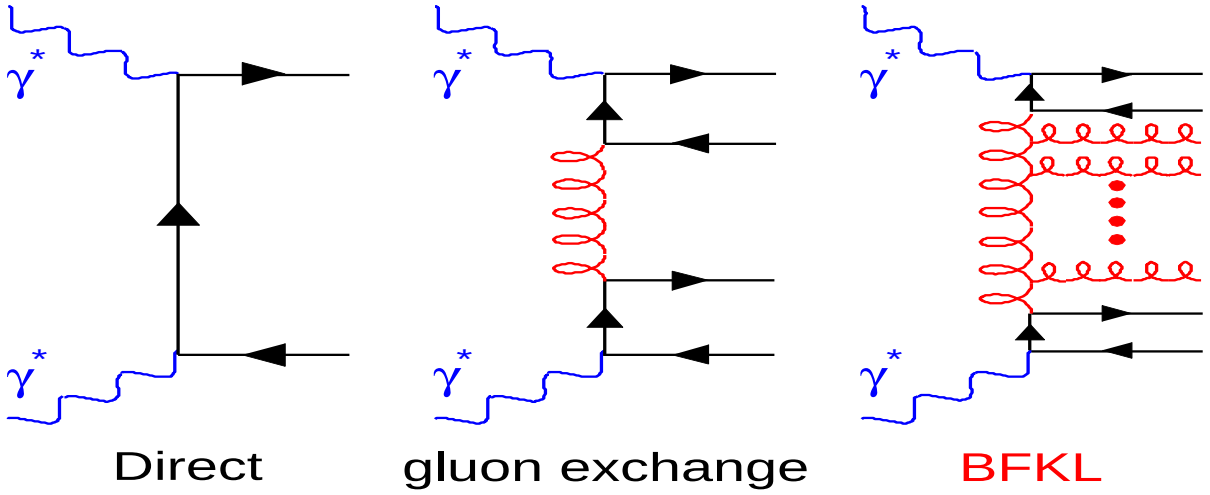
Double Tag: $\gamma^*\gamma^*$

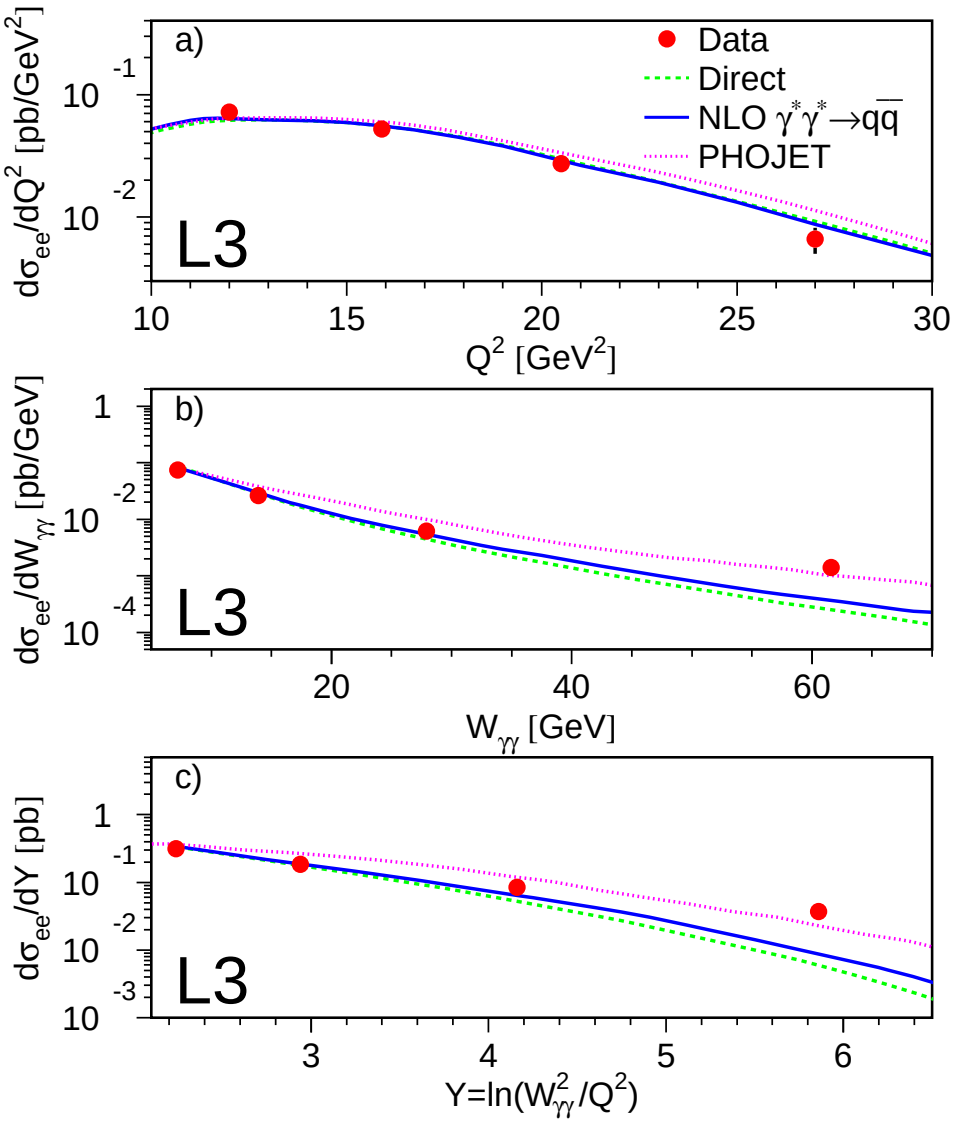


- Both electrons detected $\rightsquigarrow$ full access to kinematics
- BUT: Low statistics
- Non-Perturbative part (VDM) vanishes with large Q^2

- Direct (QED) process is well known
- pointlike coupling, no unknown parameters
- We can calculate the process

Good scenario to test new models like BFKL (for $Q^2 = P^2$)

Double Tag - Results

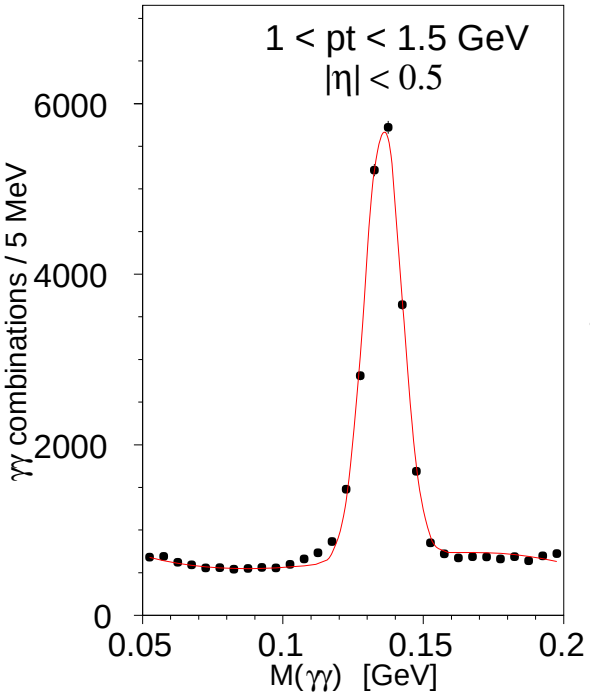


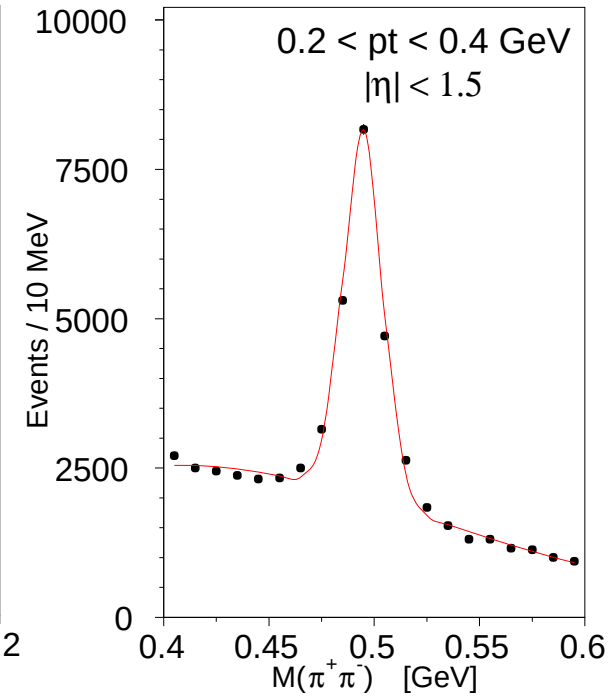
- $Y = \ln\left(\frac{W^2_{\gamma^*\gamma^*}}{\sqrt{Q_1^2 Q_2^2}}\right)$
- Direct process is insufficient
- Direct process with QCD corrections still too low
- Phojet can describe the data

PLB 436 (1998) 403, PLB 531 (2002) 39

Inclusive Hadron Production

π^0 $\qquad$ K^0_S





Data Set $\sqrt{s} = 189 - 202$ GeV, $\mathcal{L} = 414$ pb$^{-}1$

Monte Carlo Phojet 1.05c and Pythia 5.722

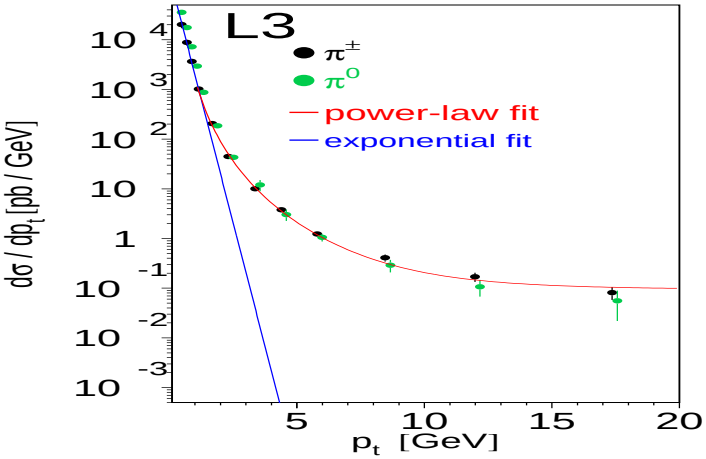
π^0 and K^0_S in PLB 524 (2001)

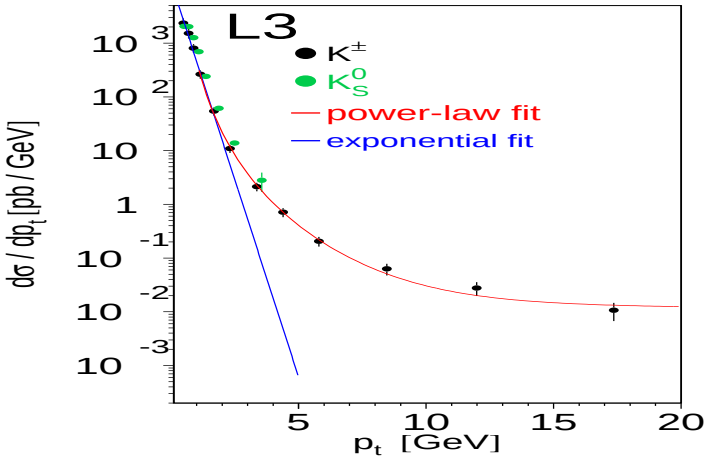
$\pi^{\pm}$ and $\mathrm{K}^{\pm}$ preliminary

π^0 and K^0_S reconstruction

$\Rightarrow$ well identified π^0 and K^0_S!

Inclusives - $\frac{d\sigma}{dp_t}$ fits





Exponential $Ae^{-p_t/<p_t>}$

$< p_t >$ = 230 ± 11 MeV for π^0

218 ± 8 MeV for $\pi^{\pm}$

329 ± 4 MeV for $\mathrm{K^0_S}$

296 ± 8 MeV for $\mathrm{K^{\pm}}$

Power law Ap_t^{-B}

B = 4.1 ± 0.2 MeV for π^0

4.1 ± 0.1 MeV for $\pi^{\pm}$

4.5 ± 1.2 MeV for $\mathrm{K^0_S}$

4.4 ± 0.2 MeV for $\mathrm{K^{\pm}}$

$p_t < 1.5$ GeV $\rightarrow$

exponential behaviour

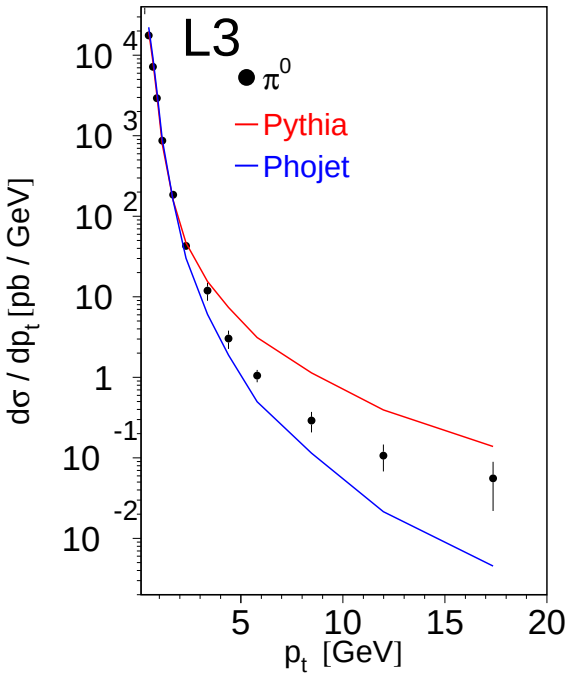
$\Rightarrow$ soft interaction

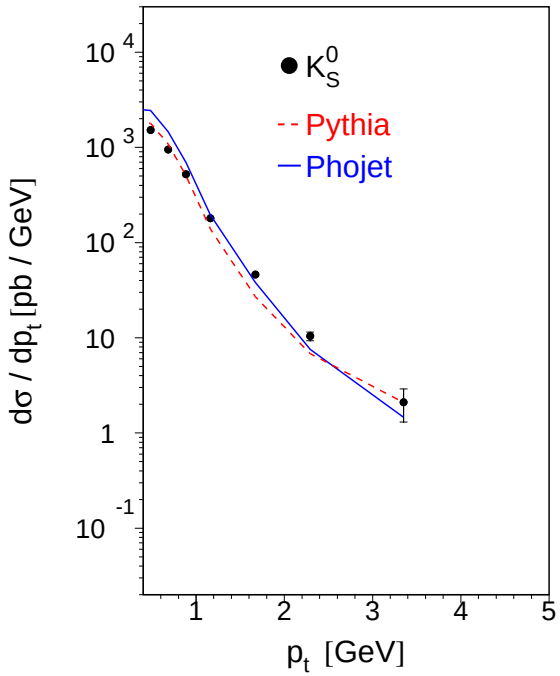
$p_t > 1.5$ GeV $\rightarrow$

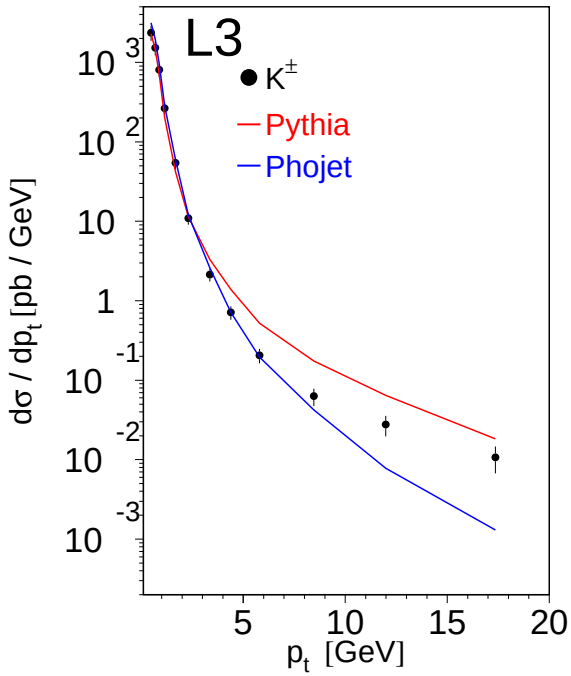
power law behaviour

$\Rightarrow$ direct and resolved processes

Inclusives
Comparison with MC



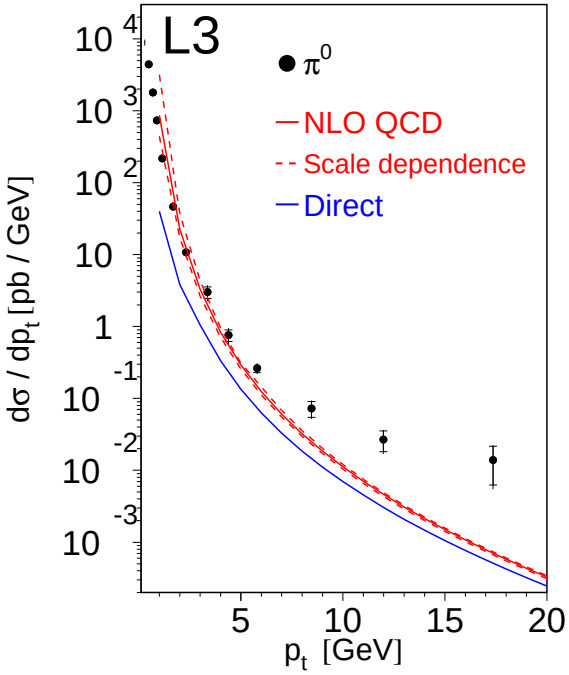


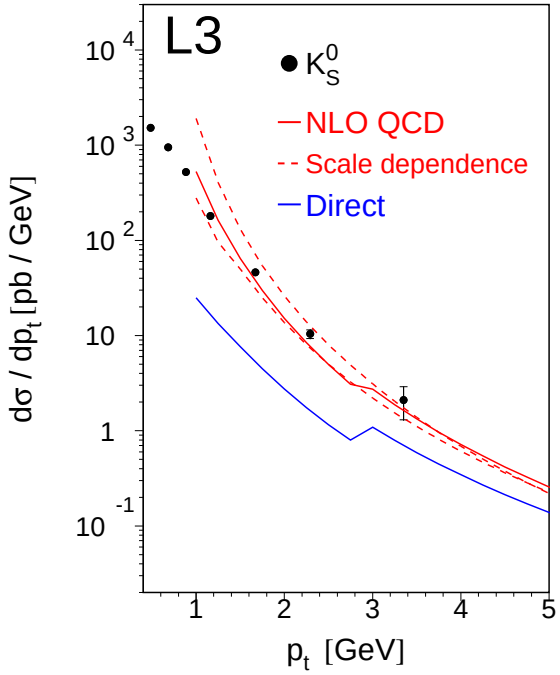


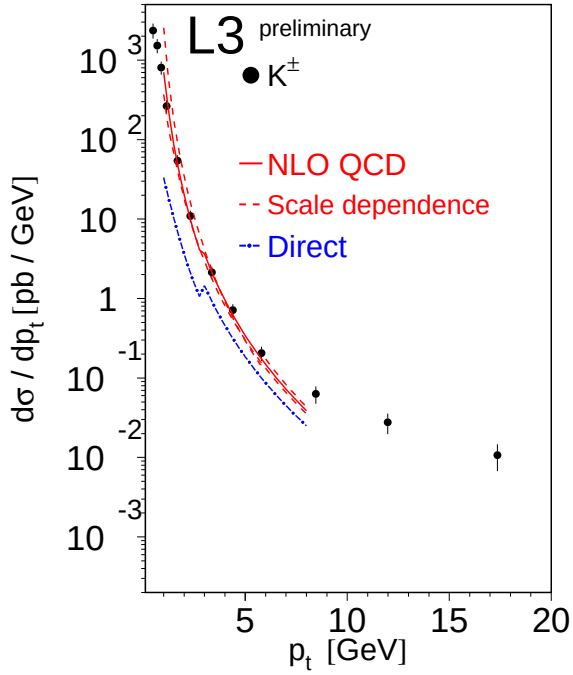
Low p_t : Agreement for $p_t < 3$ GeV

High p_t : Pythia too high and Phojet too low

Inclusives
Comparison with NLO QCD*







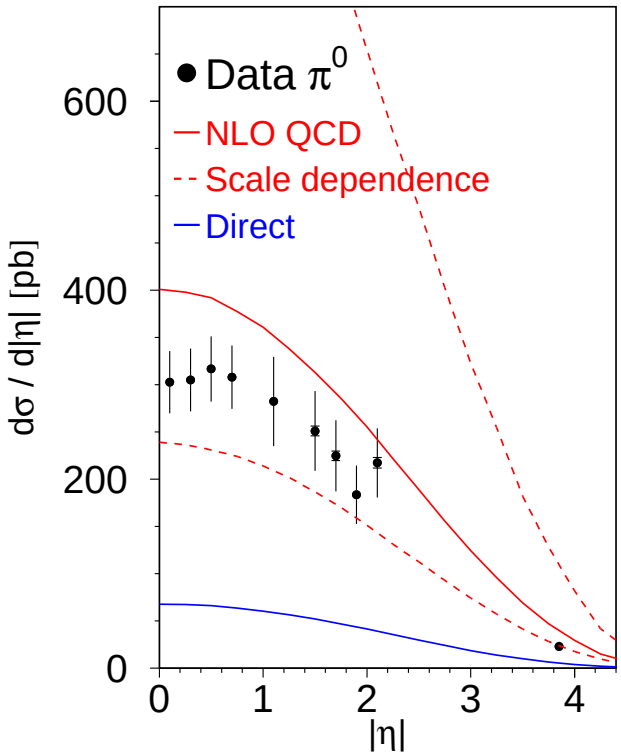
Clear excess for pion data for $p_t > 5$ GeV

K^0_S Data limited and Calculations for $K^{\pm}$ to be done

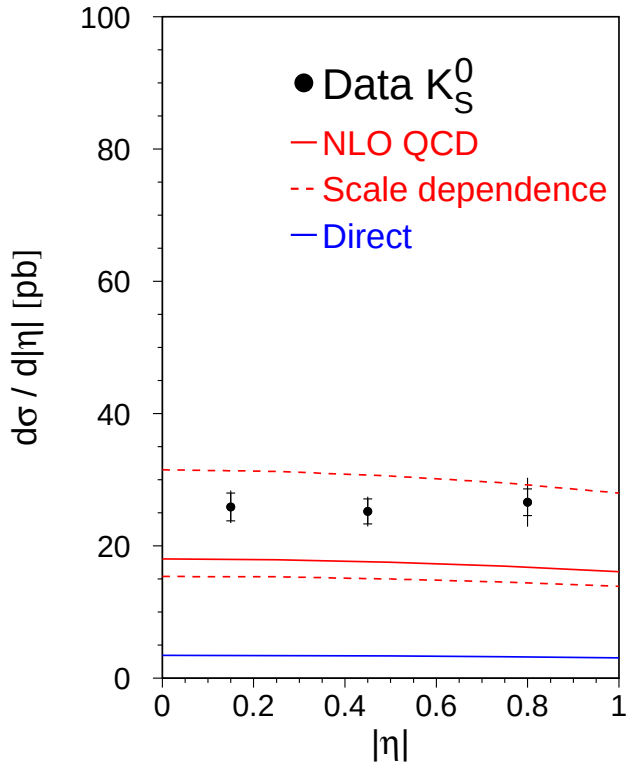
* J. Binnewies, **B.A. Kniehl** and G. Kramer, Phys. Rev. D53 (1996) 6110

Inclusives
Comparison with NLO QCD

$p_t > 1$ GeV



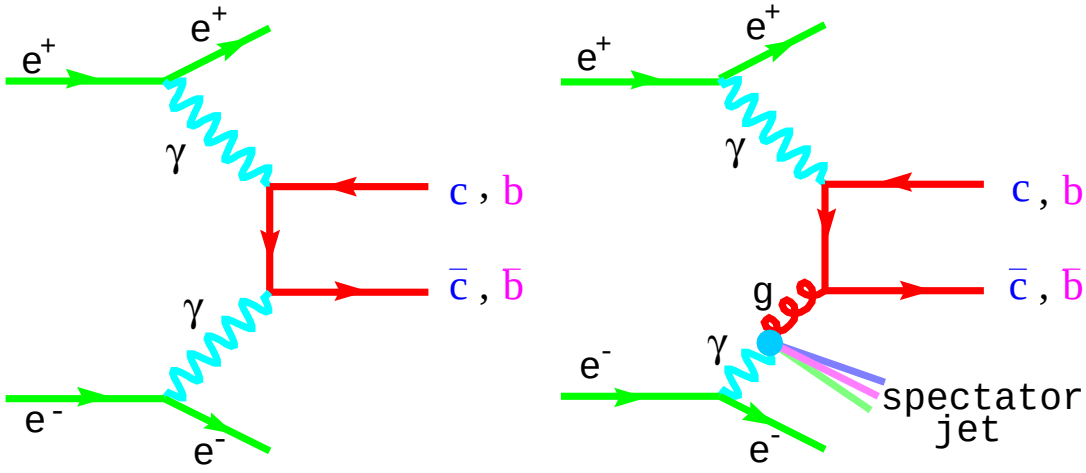
$p_t > 1.5$ GeV



The pseudo-rapidity shape is well reproduced

Direct process is not enough to describe the data

Inclusive $c\bar{c}$ and $b\bar{b}$

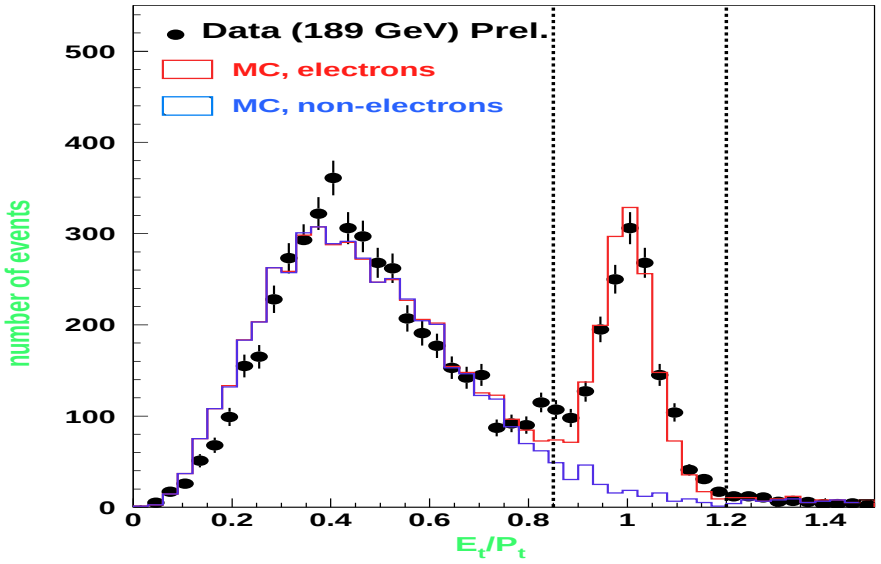


- Test of perturbative QCD
  - Direct Process depends on quark mass and α_s
  - Resolved process also depends on gluon content
- At LEP energies the resolved processes are of the same order as the direct ones!
- Data set $\sqrt{s} = 183 - 209$ GeV, $\mathcal{L} = 683$ pb$^{-}1$

published in PLB503 (2001), PLB514 (2001), PLB535 (2002)
preliminary L3 Note 2761

Charm Tag

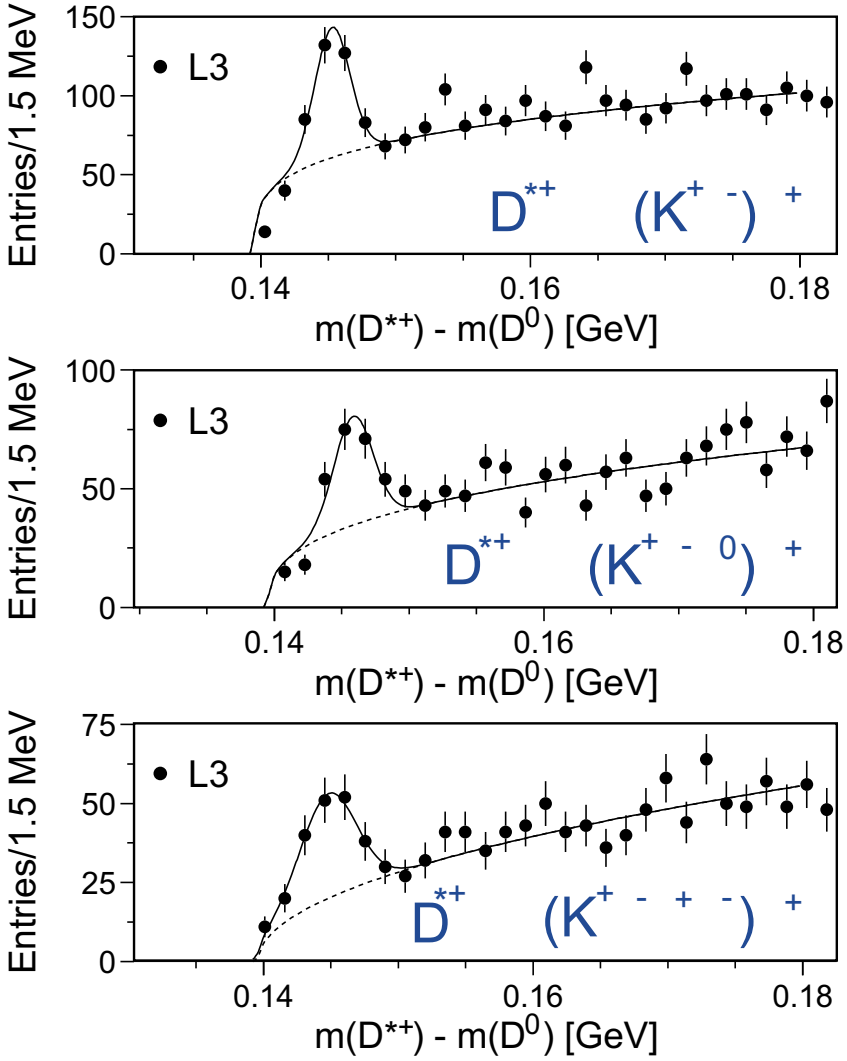
Electron-Tag:



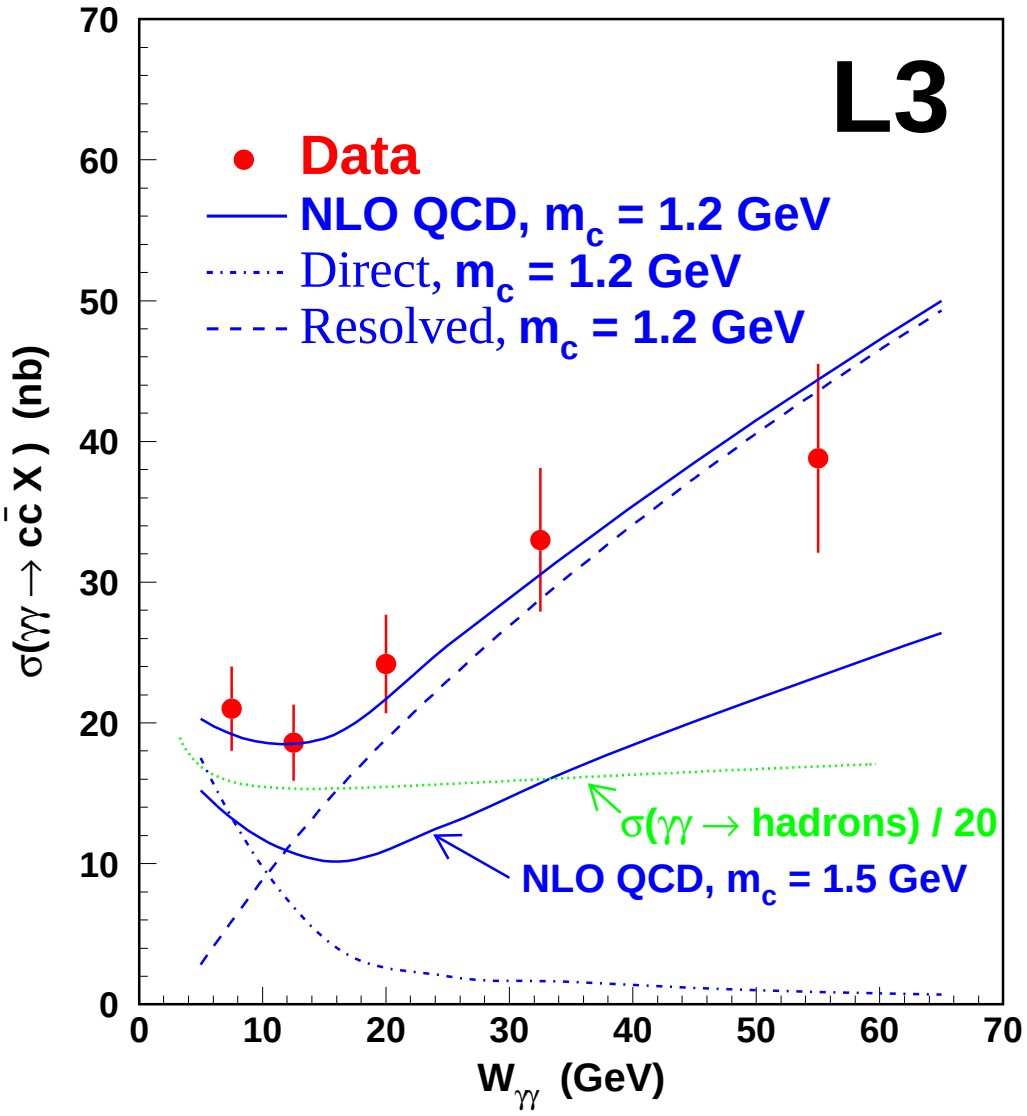
$$\sigma(e^+e^- \to e^+e^- c\bar{c}X) = 1120 \pm 90 \pm 160^{+540}_{-250}\ \text{pb}$$

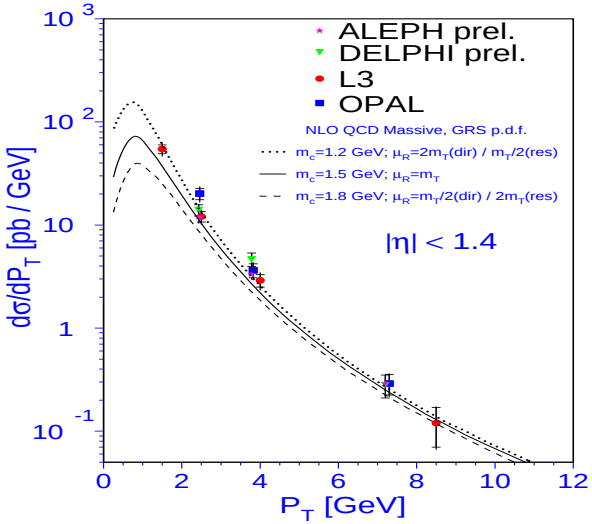
$\Leftarrow$

D^{*+}-tag:



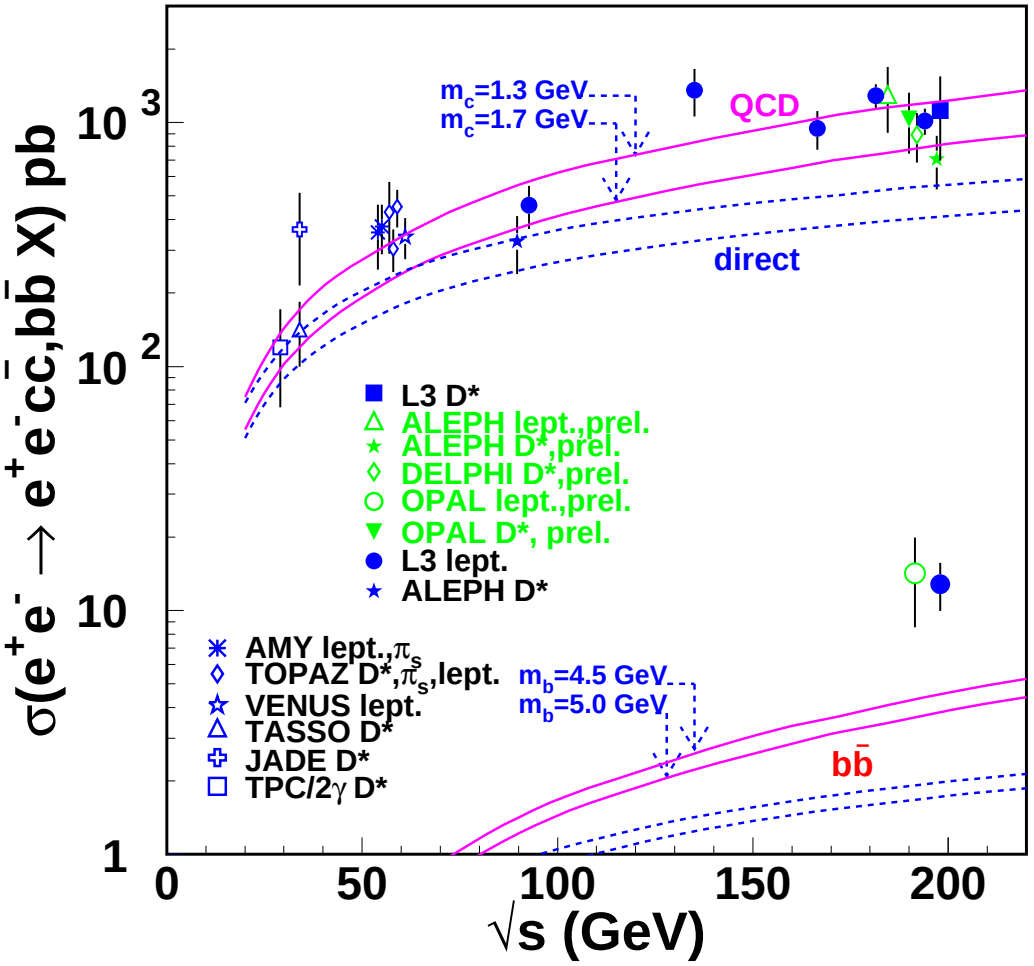
Inclusive charm production





- Good agreement with NLO QCD predictions with low $m_c = 1.2$ GeV
- Direct process not sufficient, need resolved components
- Steeper rise with energy than $\sigma(\gamma\gamma \to hadrons)$

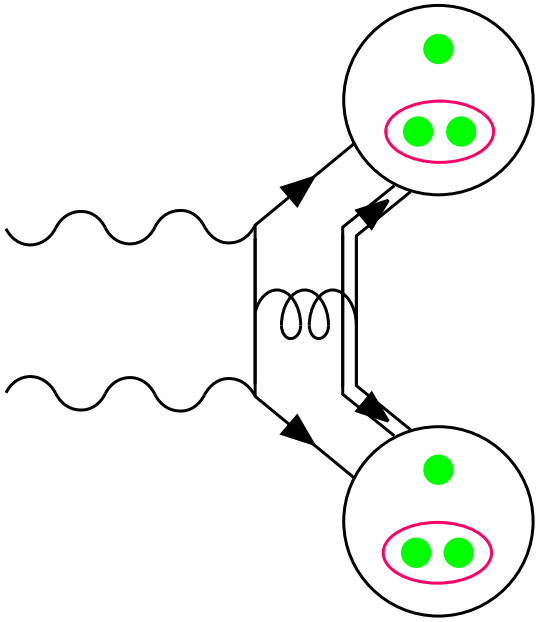
Inclusive $c\bar{c}$ and $b\bar{b}$



- Charm production in $\gamma\gamma$ collisions
  - $c\bar{c}$ in good agreement with theory*
  - direct process is not sufficient
  - clear evidence of gluon content of the photon
- Beauty production in $\gamma\gamma$ collisions
  - $b\bar{b}$ in excess of the QCD predictions* by a factor three

* M. Drees et al., Phys. Lett. B 301 (1993) 371

Exclusive $p\bar{p}, \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}$



$\gamma\gamma \to p\bar{p}, \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}$ tests for:

- Diquark model
  baryon = quark + diquark
- Three quark model

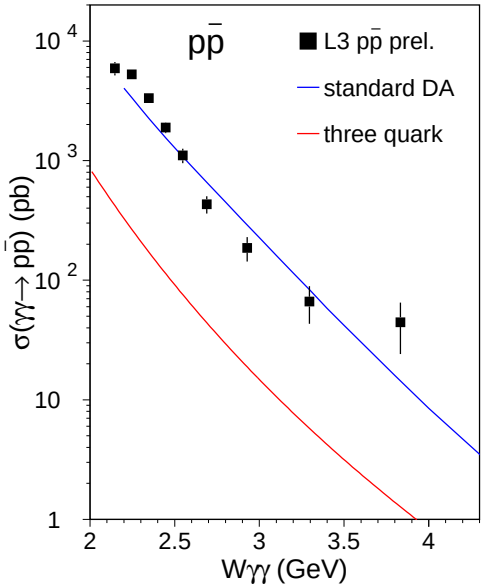
- $\gamma\gamma \to \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}$:
  Data set: $\sqrt{s} = 91 - 209$ GeV,
  $\mathcal{L} = 844$ pb^{-1}
  Monte Carlo EGPC v.207

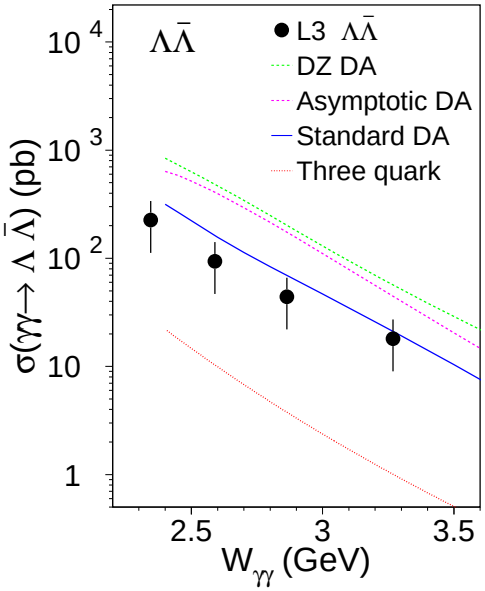
  PLB 536 (2002)

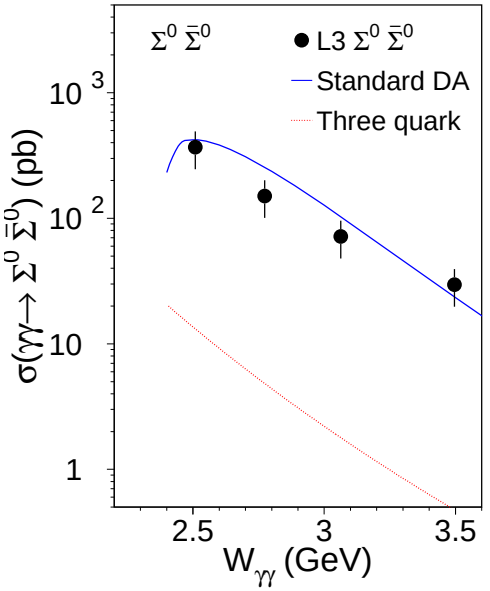
- $\gamma\gamma \to p\bar{p}$:
  Data set: $\sqrt{s} = 183 - 209$ GeV,
  $\mathcal{L} = 686$ pb^{-1}
  Monte Carlo EGPC v.207

  preliminary results

Exclusive $p\bar{p}, \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}$
Comparison with theory







Good agreement with the diquark model

Three quark model* disfavoured

*G. Farrar *et al.*, Nucl. Phys. B 259 (1985) 702

Conclusions

Two-photon physics offer rich field of QCD tests

- Hadronic processes:
  - $\sigma_{\gamma\gamma}$ increases at high energies
  - High-pt inclusive pion production: NLO QCD prediction is too low
  - Charm production agrees with NLO QCD
  - Gluon content of the photon is necessary
  - Beauty production is 4σ higher than expected
- Structure Function:
  - Large range of x and Q^2 studied
  - We need resolved processes at low x
- Double Tag:
  - Dominated by $\gamma\gamma \to q\bar{q}$
  - Resolved processes (or BFKL) necessary at high Y
- Exclusive Baryons:
  - Data agree with diquark model
  - Three quark model is disfavoured