TWO-PHOTON PHYSICS AT LEP

Bertrand Echenard
University of Geneva

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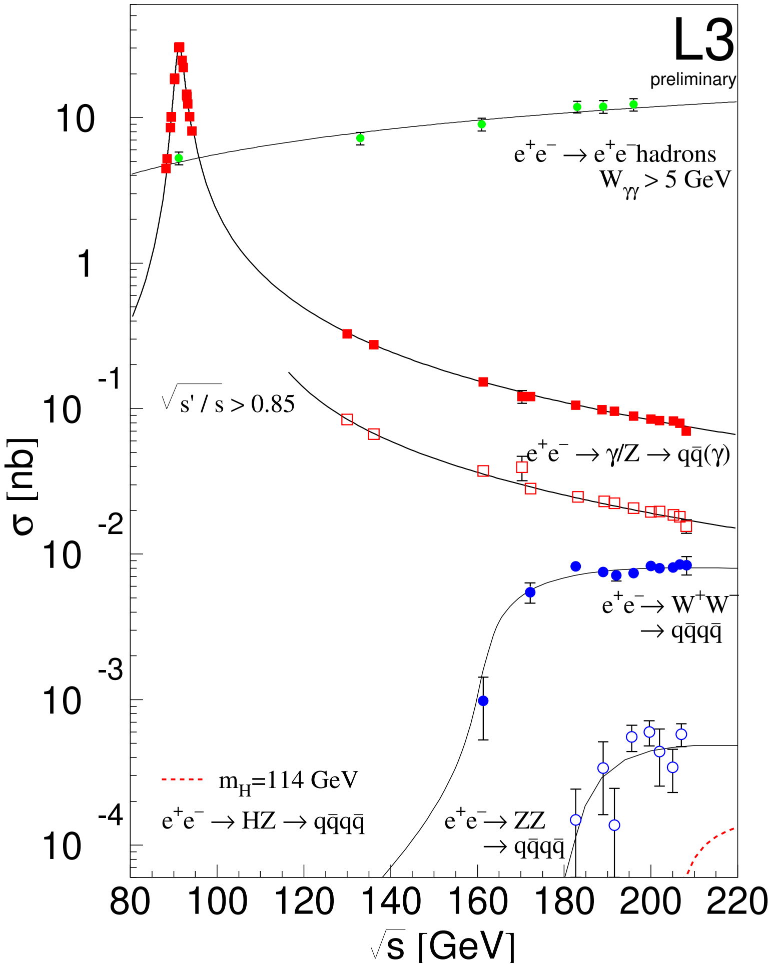
- Inclusive particle production
- Inclusive $c\bar{c}$ and $b\bar{b}$ production
- Exclusive pair production
- Search for pentaquark
- Conclusion

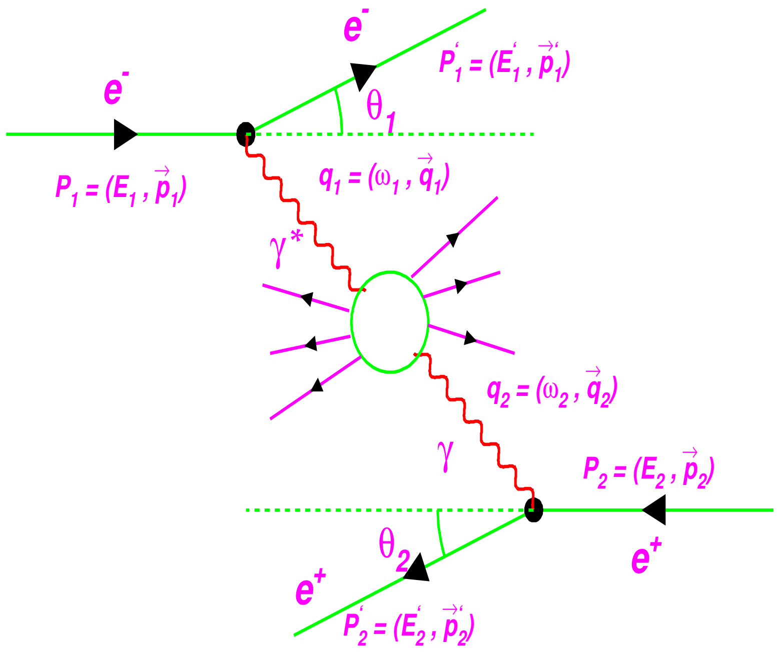
Hadron Production at LEP



Two-photon collisions are the dominant source of hadron production at LEP 2 energies, the cross-section increases as $ln^2(s)$.

➪ Many tests of QCD.

Two-Photon Kinematics



Energy in two-photon center-of-mass system

$$\mathrm{W}^2_{\gamma\gamma} = (\textstyle\sum_\mathrm{i} \mathrm{E_i})^2 - (\sum_\mathrm{i} \vec{\mathrm{p_i}})^2 = (\mathrm{q_1} + \mathrm{q_2})^2$$

Photon virtuality:

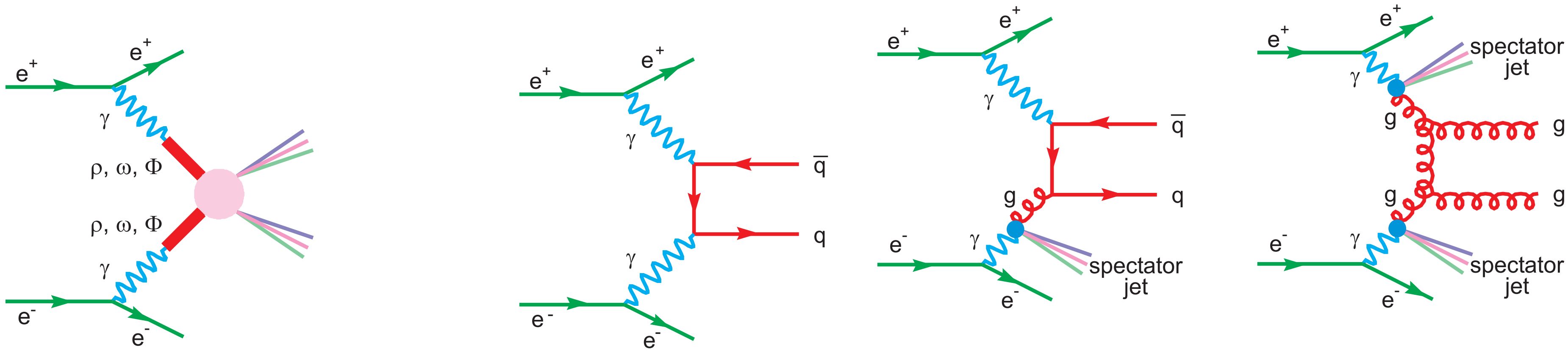
$$Q_i^2 = -q_i^2 = 2E_iE_i'(1 - \cos\theta_i)$$

Type of interaction:

Untagged	$Q_1^2 \simeq Q_2^2 \simeq 0$
Single-tag	$Q_1^2 > Q_2^2 \simeq 0$
Double-tag	$Q_1^2 \simeq Q_2^2 > 0$

$\gamma\gamma \rightarrow$ Hadron Processes

SOFT HARD



VDM Direct Single Resolved Double Resolved

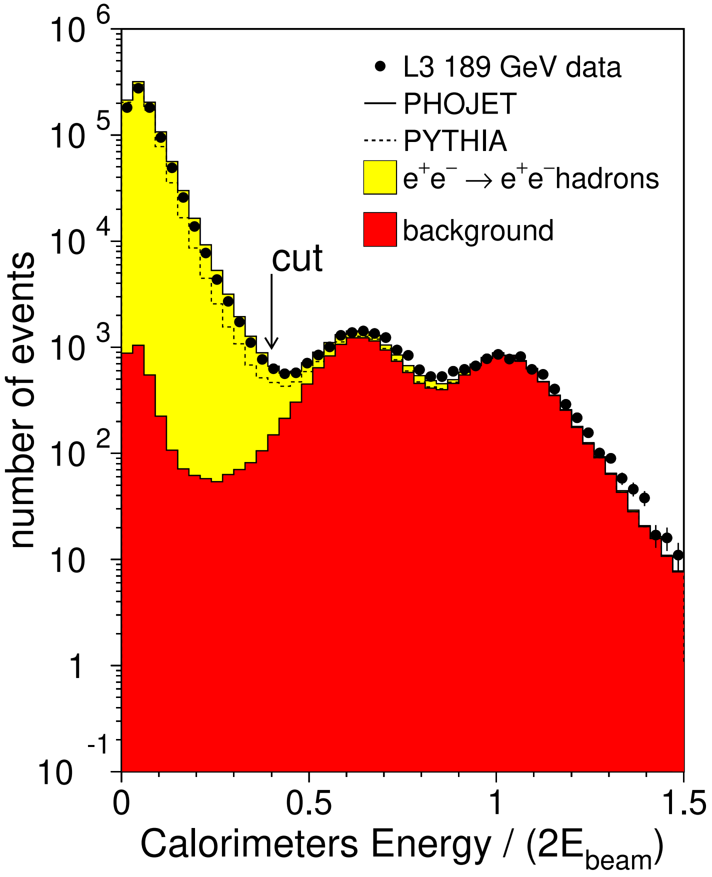
VDM process: photon fluctuates into vector meson (ρ, ω, ϕ), leading to hadronic interactions

Direct process: photons couple to a $q\overline{q}$ pair. (QED)

Single Resolved process: a parton from one photon interact with the other photon.

Double Resolved process: partons from both photons interact.

Two-photon Hadronic Selection



- **Selection**

  $E_{tot} \leq 0.4\sqrt{s}$

  at least 6 particles

- **Background $\leq$ 1%**

  $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$

  $e^+e^- \rightarrow$ hadrons

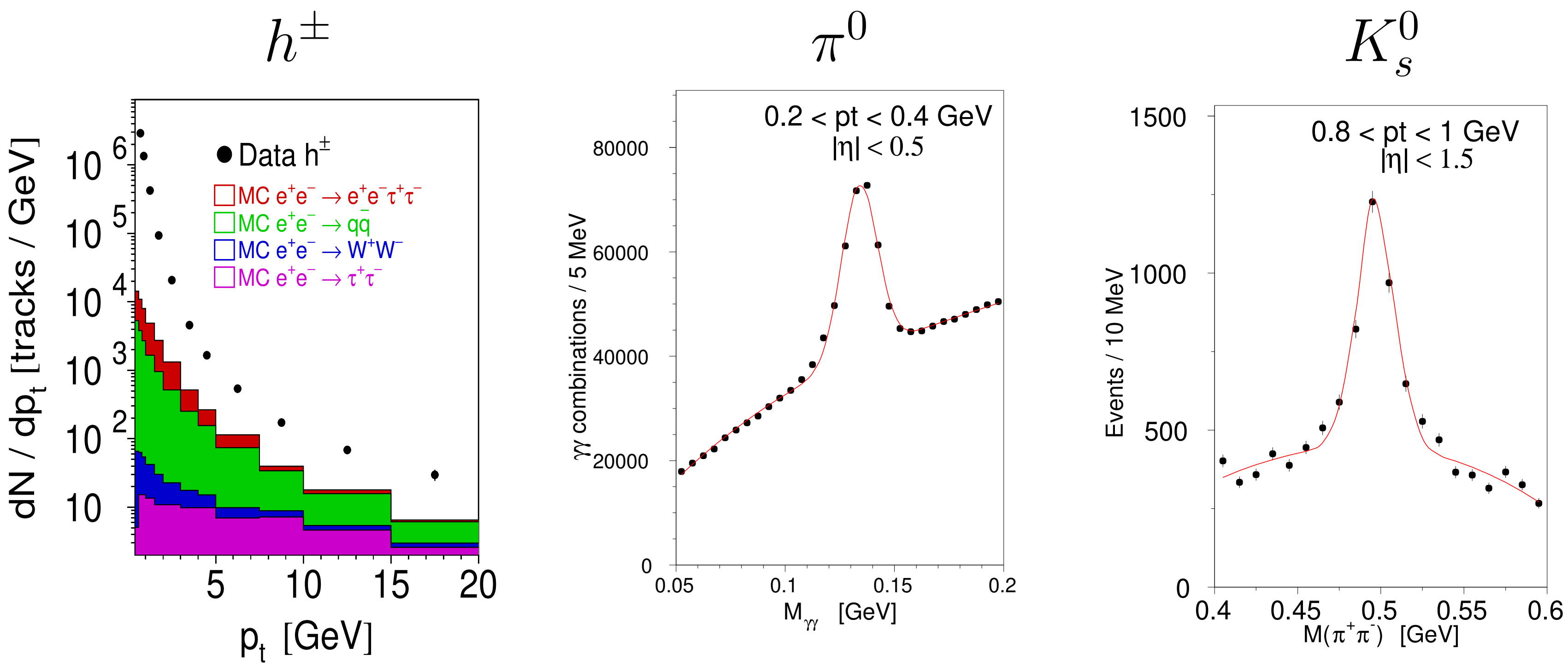
- **Monte Carlo**

  PYTHIA

  PHOJET

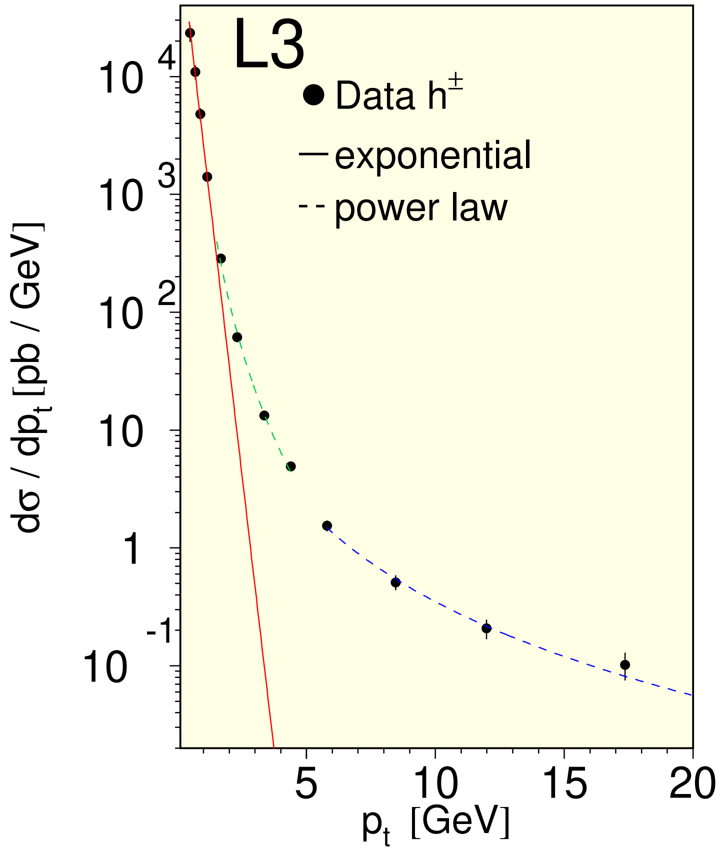
  TWOGAM

Inclusive Single Hadron Production



- Extract inclusive $\pi^{\pm}$ and $\mathrm{K}^{\pm}$ production from inclusive $\mathrm{h}^{\pm}$ production
- Well reconstructed π^0 and K^0_s

Fits to the Data



- For $p_t < 1.5$ GeV
  Exponential behaviour $Ae^{-p_t/<p_t>}$

  $< p_t > \simeq 230$ MeV for $\pi^{\pm}, \pi^0$
  $\simeq 300$ MeV for $K^{\pm}, K^0_S$

  ➪ characteristic of soft interaction.

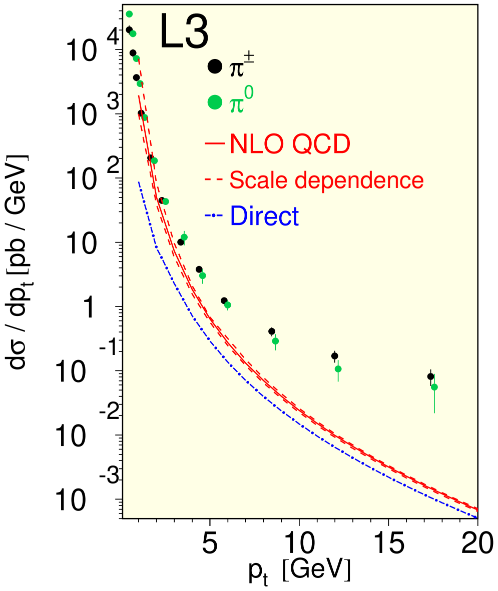
- For $p_t > 1.5$ GeV
  Power law behaviour Ap_t^{-B}

  $B \simeq 4$

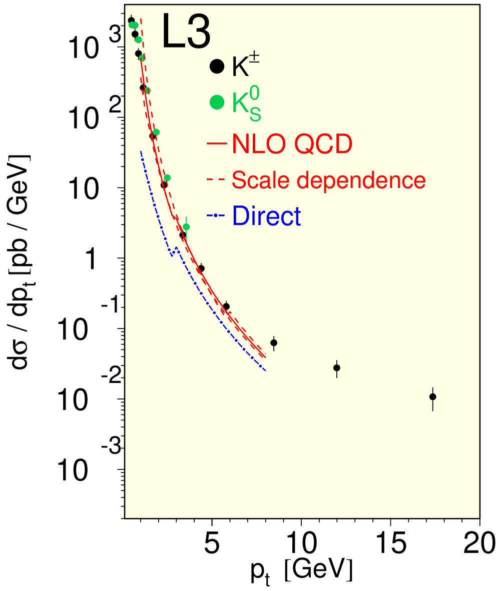
  ➪ direct and resolved processes.

Comparison with NLO QCD predictions

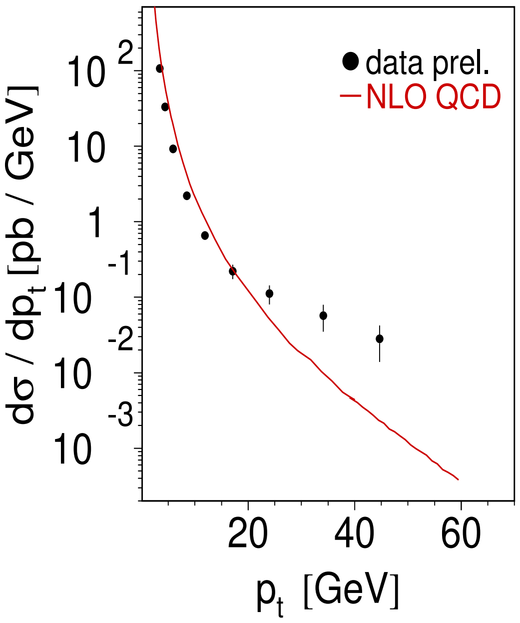
$\pi^{\pm}/\pi^{0}$



$K^{\pm}/K^{0}_{s}$



jets



➪ Overall consistency of the picture: $\pi^{\pm}/\pi^{0}$, $K^{\pm}/K^{0}_{s}$

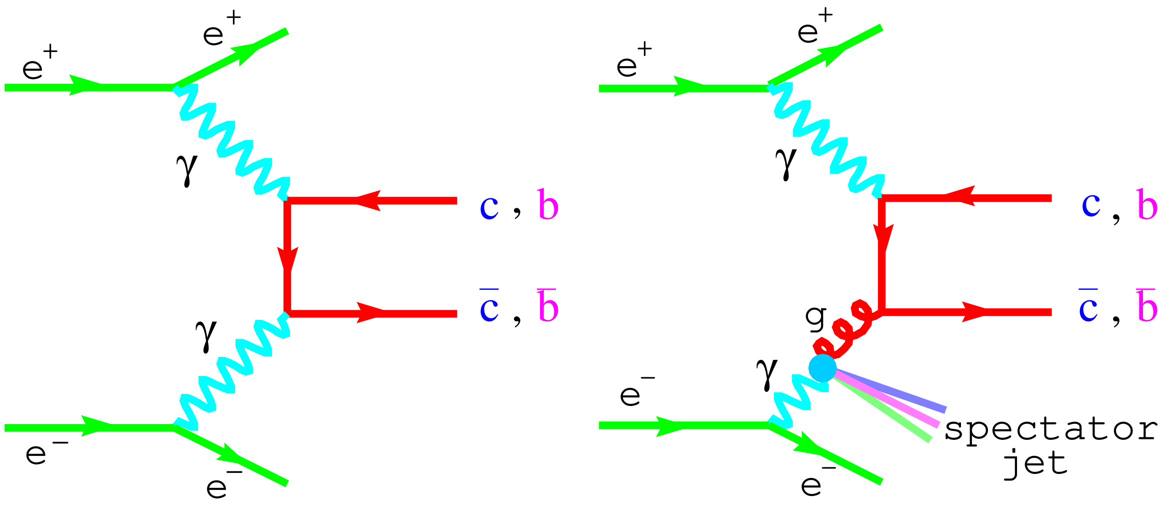
➪ Measurements exceed QCD predictions at high p_t[1]

[1] J.Binnewies, B.A.Kniehl and G. Kramer Phys.Rev. **D 53** (1996) 6110

Inclusive Charm and Bottom Production

Main processes:

- ❑ direct
- ❑ single resolved

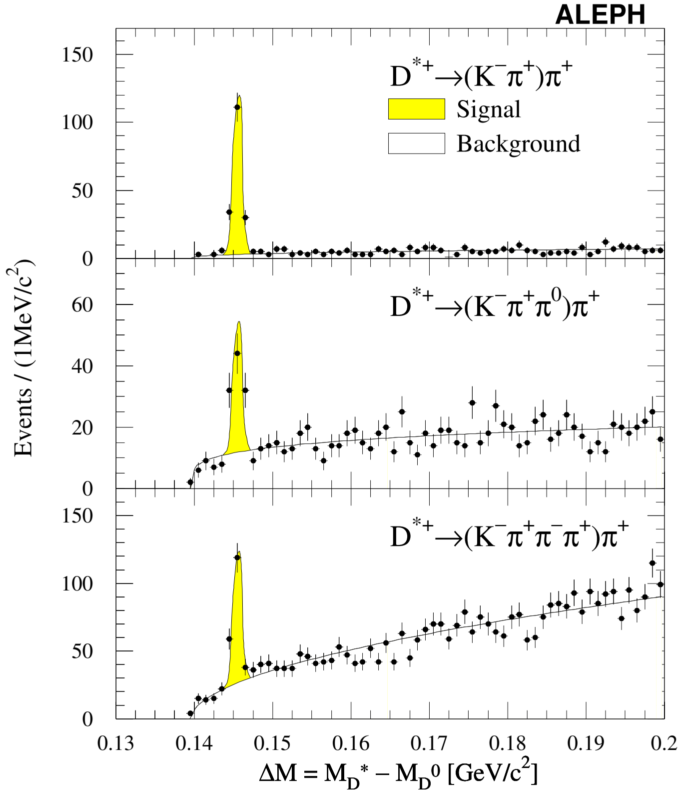


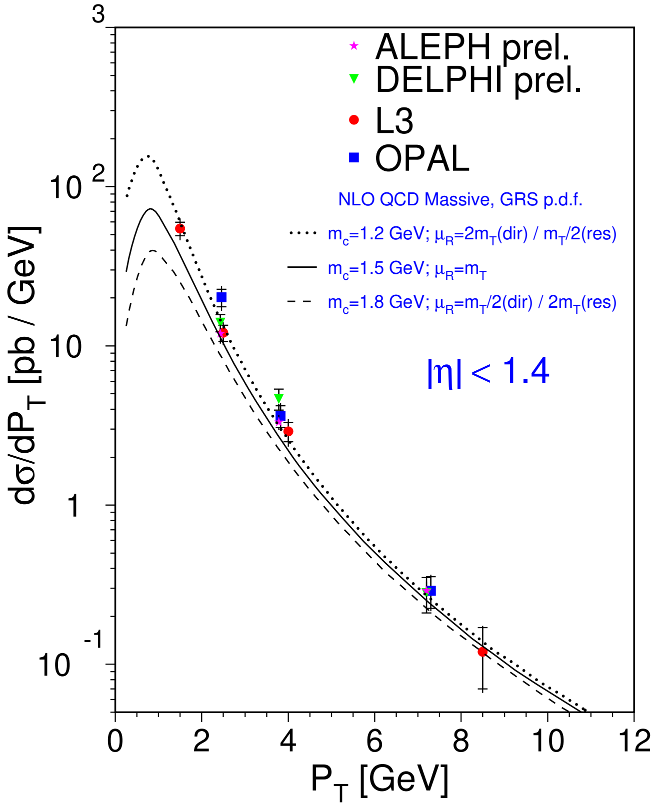
Direct Single Resolved

Charm identification: D^{*+} or lepton tagging $(c \rightarrow l^{\pm}X, l^{\pm} = e^{\pm}, \mu^{\pm})$

Bottom identification: lepton tagging $(b \rightarrow l^{\pm}X, l^{\pm} = e^{\pm}, \mu^{\pm})$

Inclusive D^{*+} Production





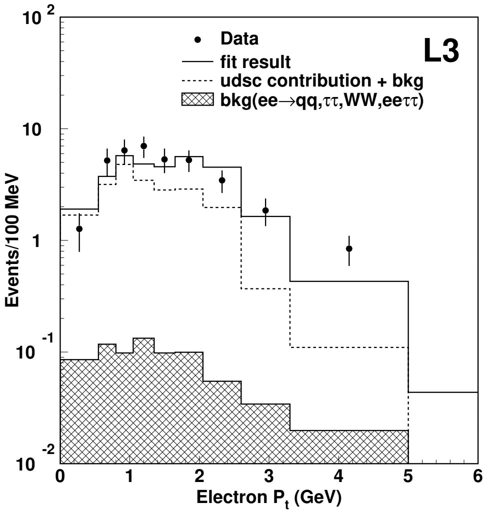
Good agreement with NLO QCD predictions with $\mathrm{m_c} = 1.2\ \mathrm{GeV}$

Inclusive Bottom Production

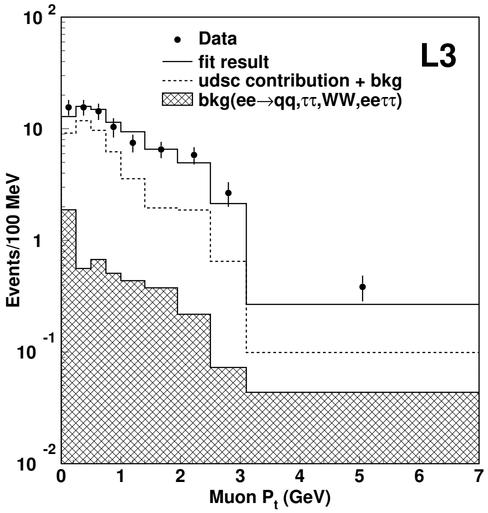
Lepton tagging: identify b quark by its semileptonic decays into an electron or muon.

Fit the P_t distribution of the lepton with respect to the nearest jet to extract the $\mathrm{b\bar{b}X}$ signal. Leptons from bottom decays have a higher P_t.

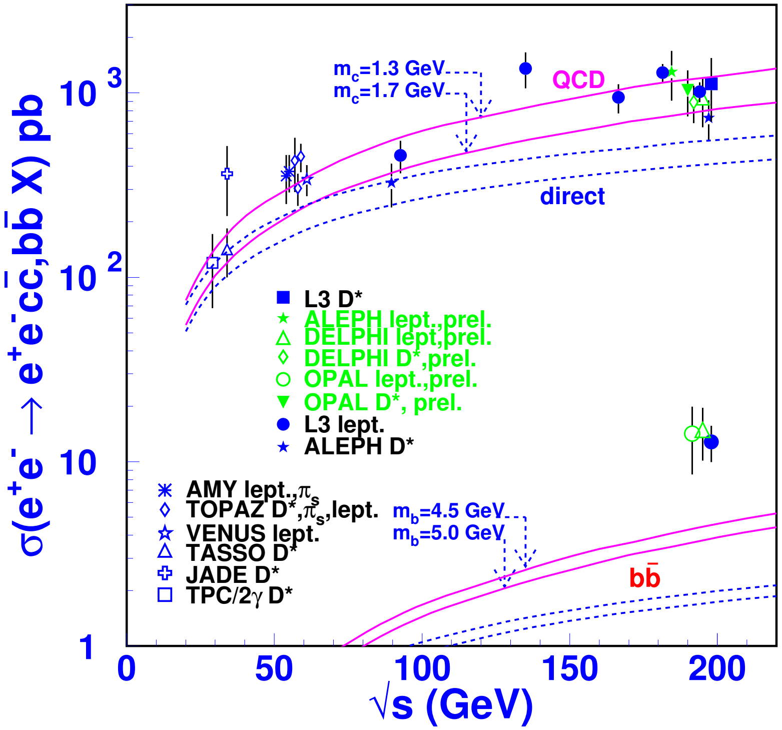
Electrons



Muons



Inclusive Charm and Bottom Cross Section



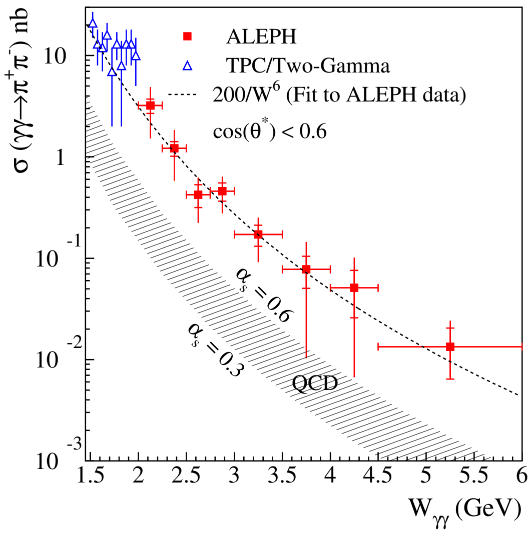
- $c\bar{c}$ cross-section:
  - ➪ Good agreement with theory
  - ➪ Direct ($\gamma\gamma \to c\bar{c}$) is not sufficient
  - ➪ Need $\gamma g \to c\bar{c}$
- $b\bar{b}$ cross-section:
  - ~ 4 st. dev. higher than predictions[1]

$b\bar{b}$ cross section: a challenge for the theory

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

Pions ans Kaons pair production

$\gamma\gamma \to \pi^+\pi^-$

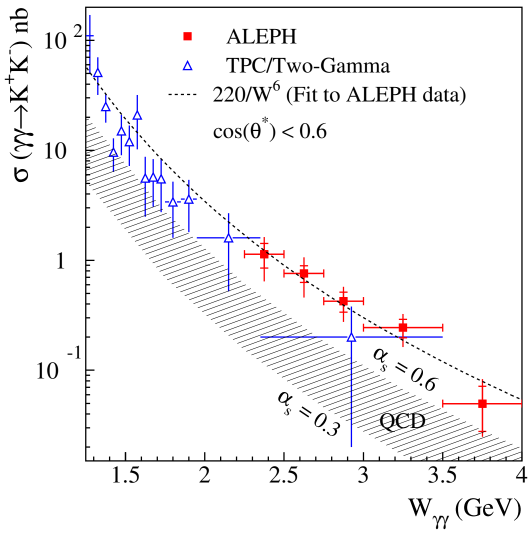


Fit AW^{-6}

$$\pi^+\pi^- \ : \ A = 200 \pm 40\text{nb} \cdot \text{GeV}^6$$
$$\text{K}^+\text{K}^- \ : \ A = 220 \pm 40\text{nb} \cdot \text{GeV}^6$$

$$\sigma(\gamma\gamma \to \text{K}^+\text{K}^-) \simeq \sigma(\gamma\gamma \to \pi^+\pi^-)$$

$\gamma\gamma \to \text{K}^+\text{K}^-$

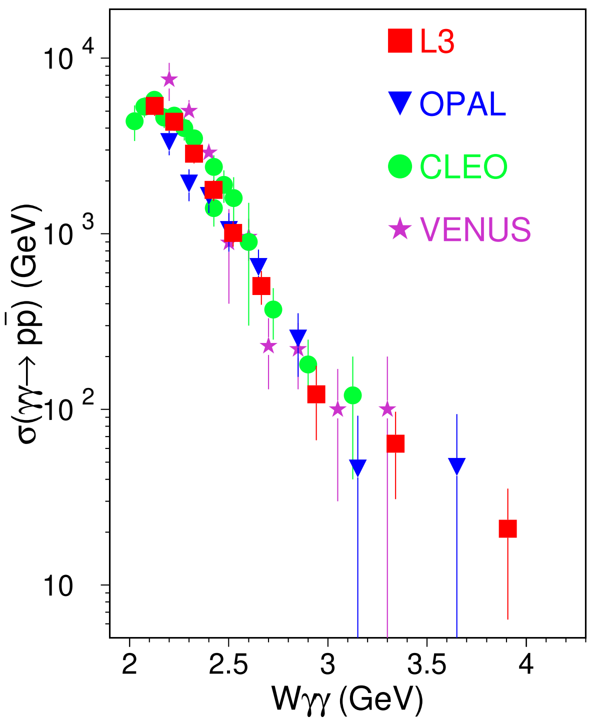


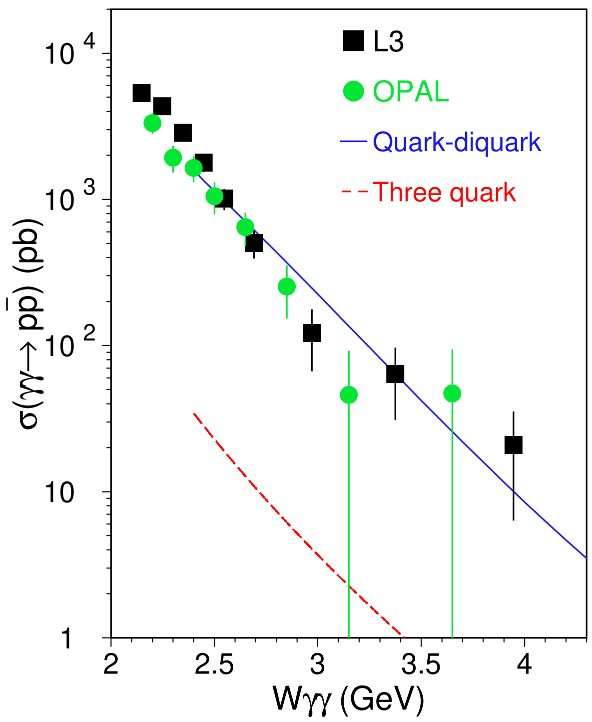
- Shapes are well described by the theory
- Disagreement in normalization and ratio K/π

$$\text{QCD}^{(1)}: \ \sigma(\gamma\gamma \to \text{K}^+\text{K}^-)/\sigma(\gamma\gamma \to \pi^+\pi^-) \simeq 2$$

(1) M. Diehl, P. Kroll and C. Vogt Phys.Lett. **B 532** (2002) 99.

Proton-Antiproton Pair Production





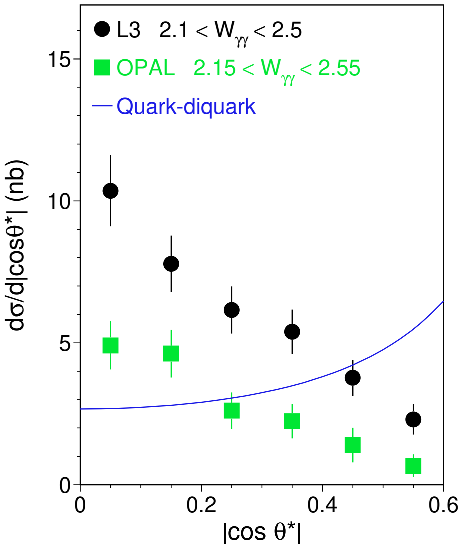
➪ Quite good agreement with the quark-diquark model [(1)]

➪ Three quark model excluded [(2)]

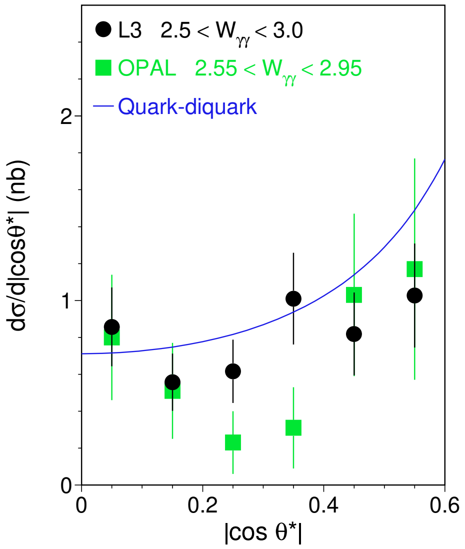
(1) C.F. Berger and W. Schweiger, Eur.Phys.J. **C 28** (2003) 249. (2) G.Farrar *et al.* Nucl.Phys. **B 259** (1985) 70.

Proton-Antiproton Pair Production (II)

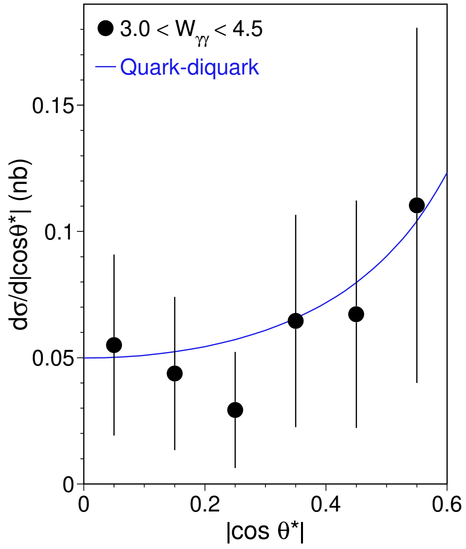
Low mass



Intermediate mass



High mass

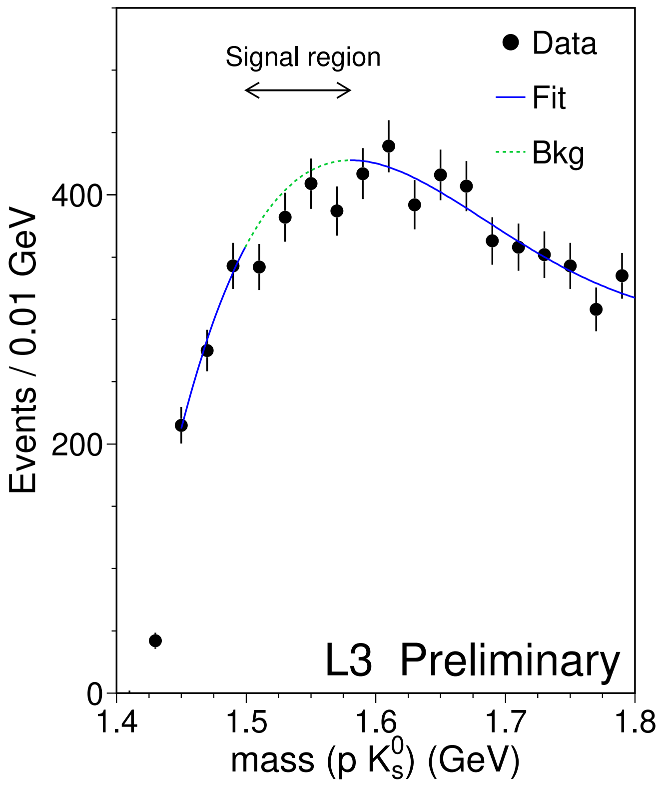


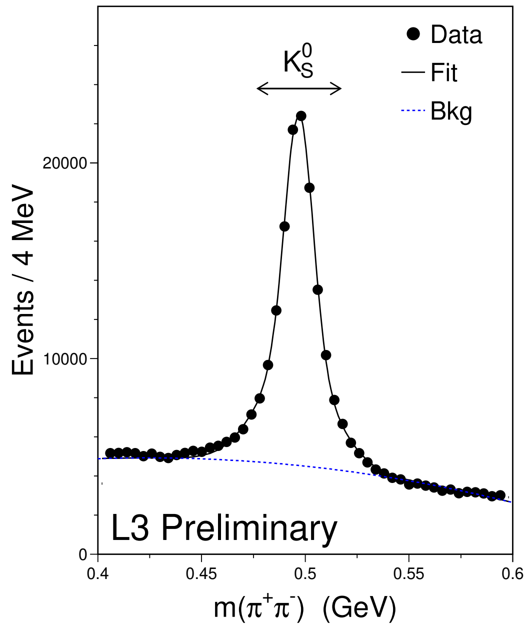
➪ At low masses : bound state not reproduced by the model

➪ At high masses : $\gamma\gamma \to q\bar{q}$ behaviour compatible with the model

Model : hard scattering $\otimes$ distribution amplitudes of the diquark

Search for pentaquarks $e^+e^- \to e^+e^-\Theta^+X$





Use the decay $\Theta^+ \to pK_s^0$

No signal is observed

Conclusions

➪ Diverse and accurate measurements of the photon interactions are performed at LEP (jets, inclusive and exclusive particle production, photon structure function, resonances) .

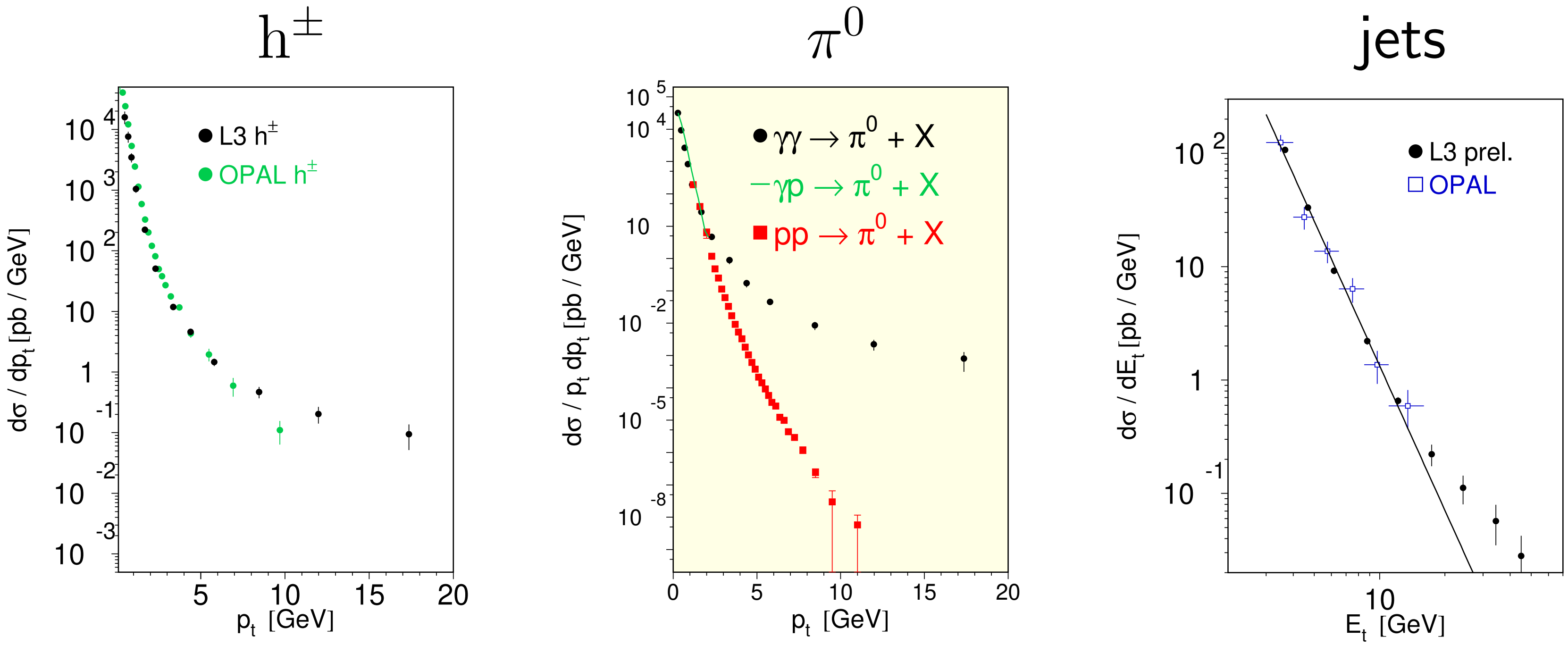
➪ They are the basis for understanding QCD not only in the perturbative sector, but also in the field of non-perturbative phenomena.

➪ Unexpected deviations from theoretical predictions are observed:

- ❑ $\mathrm{d}\sigma/\mathrm{dp_t}$ of π^0, $\pi^\pm$, and jets
- ❑ $\sigma(\gamma\gamma \to \mathrm{b\bar{b}X})$
- ❑ Exclusive $\pi^+\pi^-$, $\mathrm{K^+K^-}$ production
- ❑ Exclusive $\mathrm{p\bar{p}}$ production

A challenge for both theorists and expermientalists

Comparison with other experiments



➪ Good agreement between experiments