TWO-PHOTON COLLISIONS AT L3 AT LEP

Bertrand Echenard
University of Geneva

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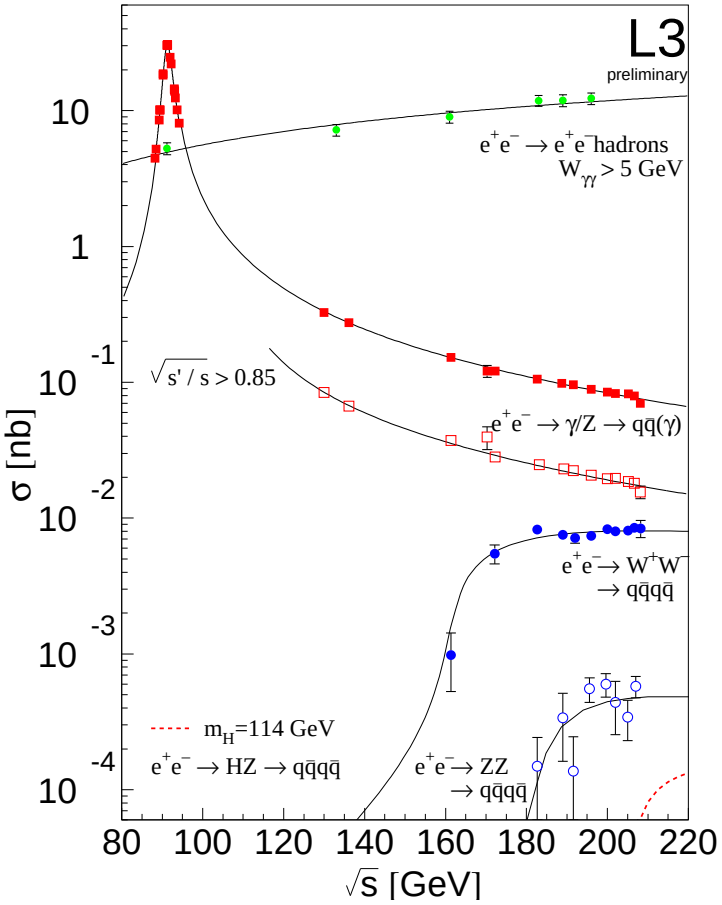
Outline

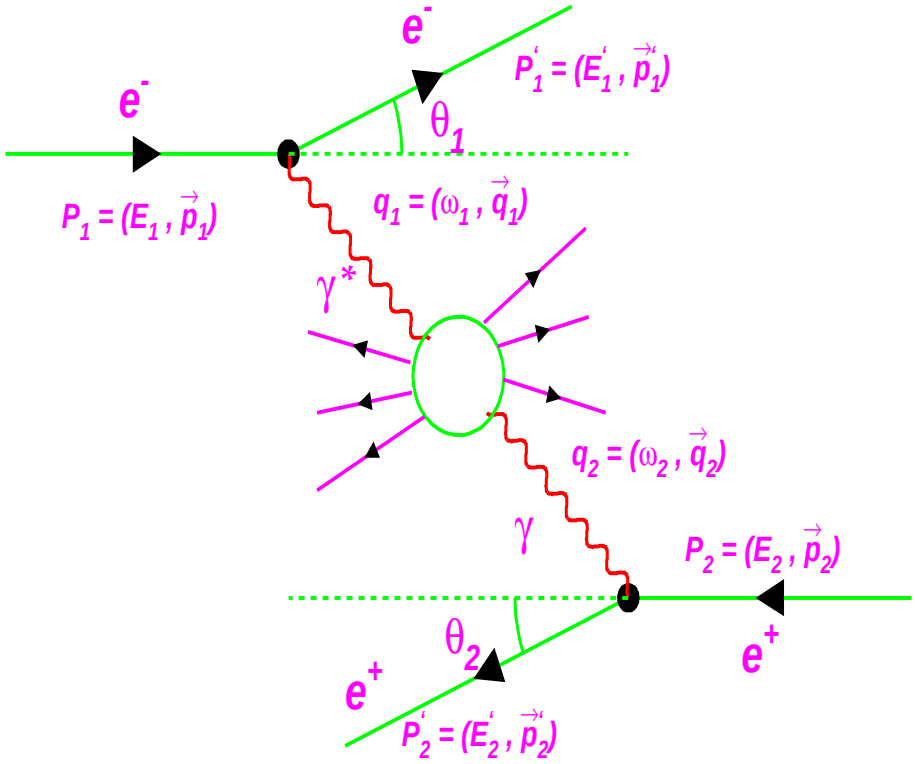
- Introduction to two-photon physics
- Inclusive charged hadron production
- Inclusive charm and bottom production
- Exclusive baryon pair production
- Summary



Two-photon collisions are the dominant source of hadrons production at LEP 2 energies.

⇒ Many tests of perturbative QCD.

The $\gamma\gamma$ kinematic



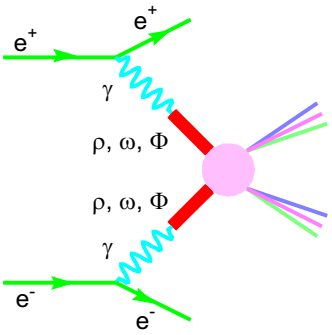
$$W^2_{\gamma\gamma} = (\sum_i E_i)^2 - (\sum_i \vec{p}_i)^2 = (q_1 + q_2)^2$$

For each virtual photon:

$$Q^2 = -q^2 = 2EE'(1 - \cos\theta)$$

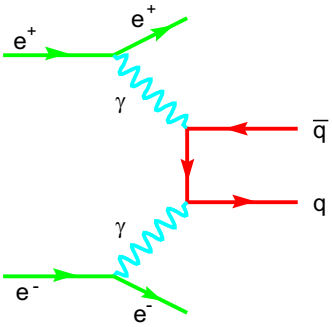
$\gamma\gamma \rightarrow$ *hadron processes*

SOFT:

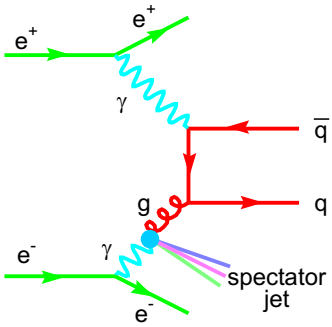


VDM

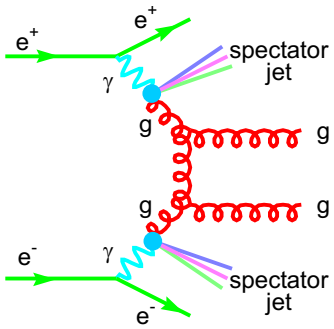
HARD:



Direct



Single Resolved



Double Resolved

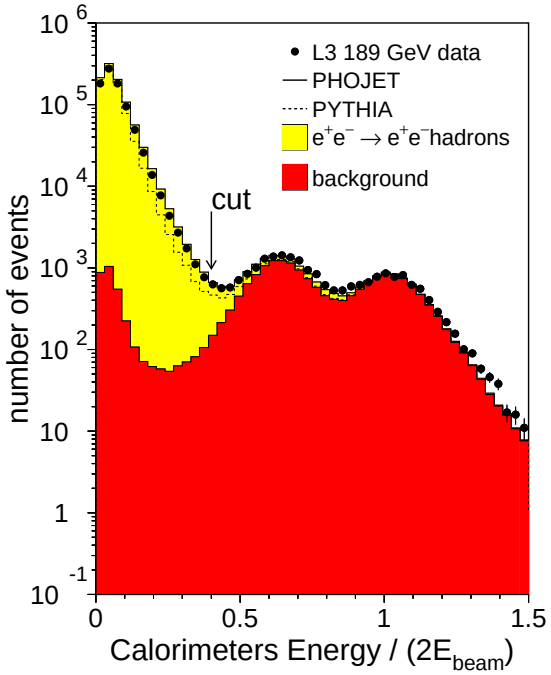
Direct process: photons couple to a $\mathrm{q\bar{q}}$ pair.

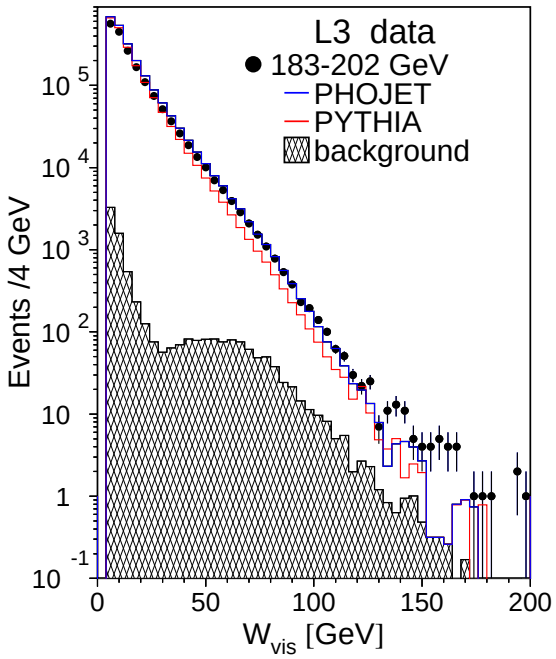
VDM process: photon fluctuates into vector meson (ρ, ω, ϕ)

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

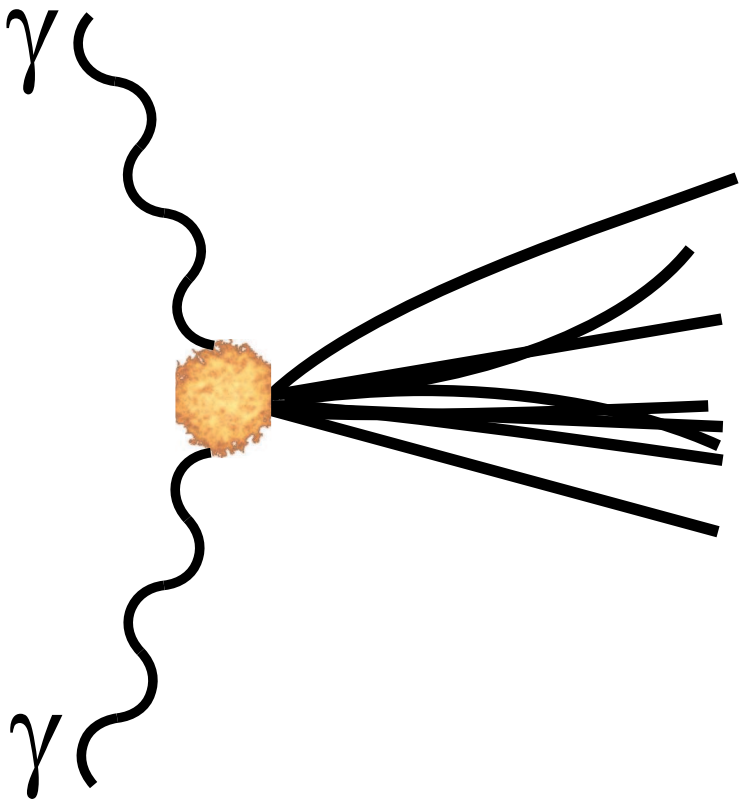




- Energy: $E_{tot} < 0.4\sqrt{s}$ to suppress annihilation events.
- Multiplicity: at least 6 particles to reject $e^+e^- \to e^+e^-\tau^+\tau^-$ background.
- Anti-tag: no cluster with $E > 70$ GeV in the detector $\to$ quasi-real photons.

INCLUSIVE SINGLE HADRON PRODUCTION

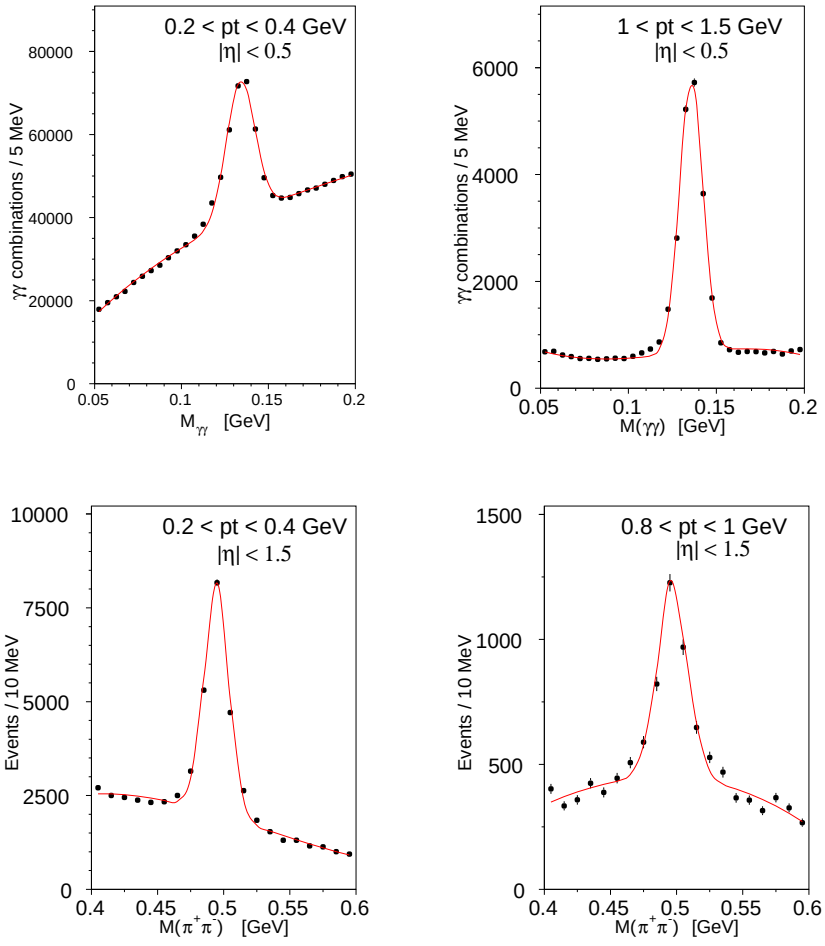
$\pi^0 X$, $\pi^{\pm} X$, $K^0_s X$, $K^{\pm}_s X$



Data set $\sqrt{s} = 189$ - 202 GeV , $\mathcal{L} = 414$ pb^{-1}
π^0 and K^0_S published in PLB524 (2001)
$\pi^{\pm}$ and $K^{\pm}$ preliminary

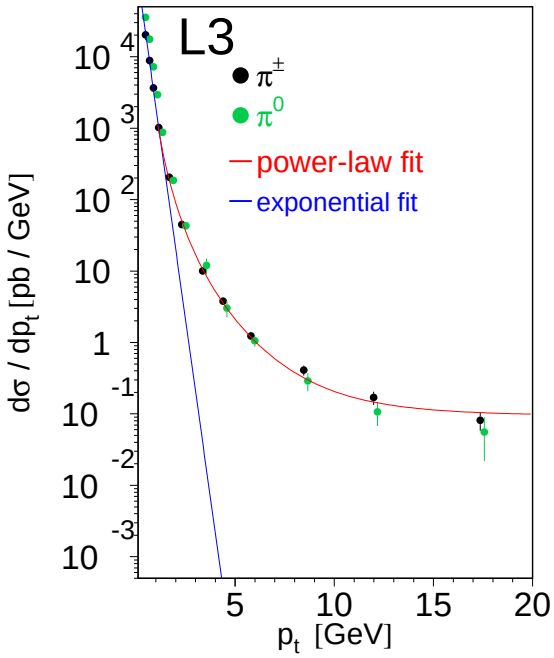
Monte Carlo Phojet v.1.05c and Pythia v.5.722

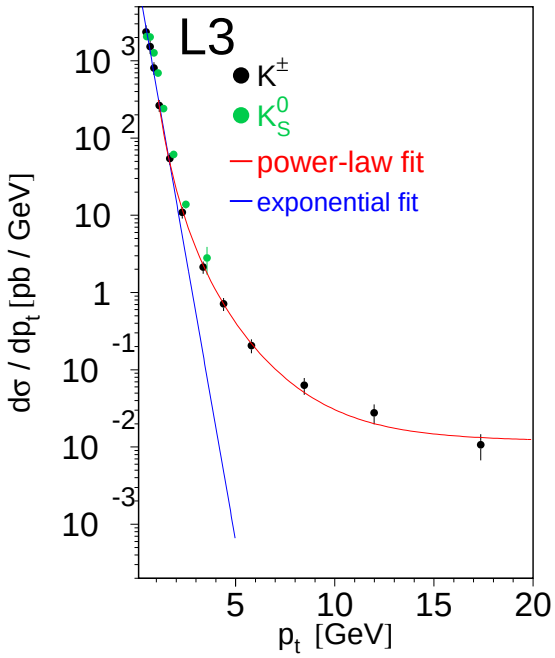
π^0 and K^0_S reconstruction



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

$\frac{d\sigma}{dp_t}$ *fits to the data*





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

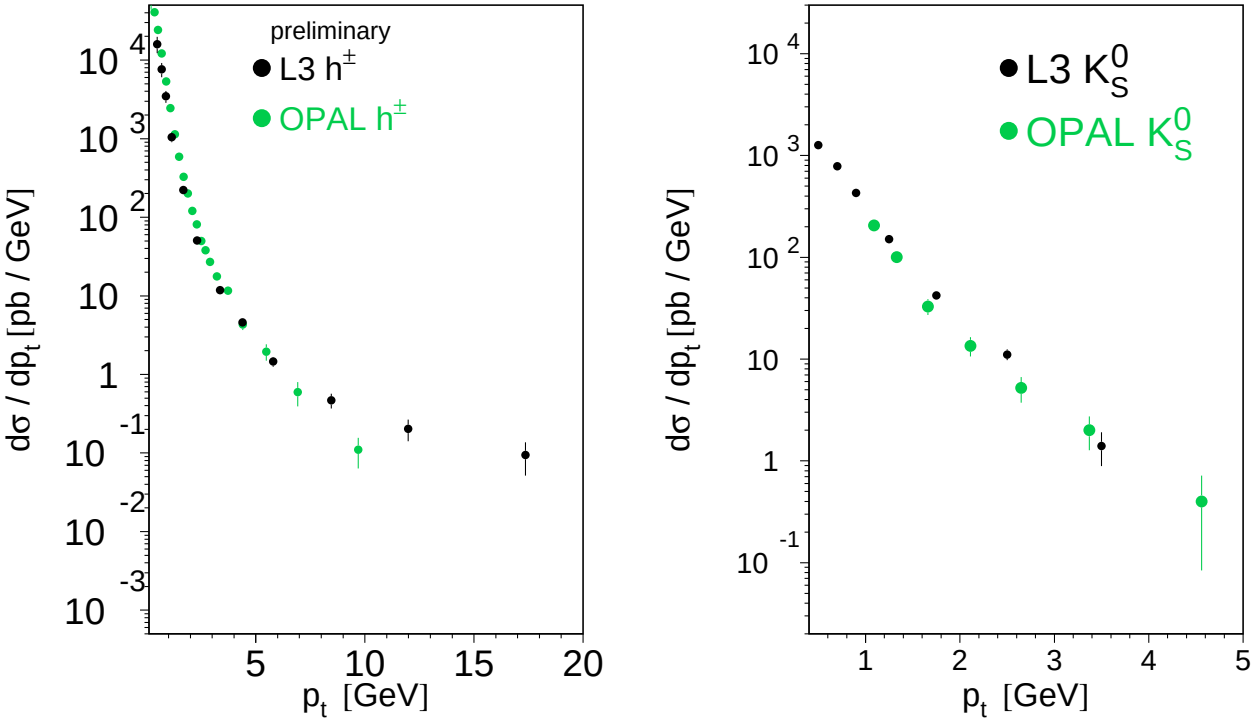
230 ± 11 MeV for π^0
218 ± 8 MeV for $\pi^\pm$
329 ± 4 MeV for K^0_S
296 ± 8 MeV for $K^\pm$

Power law Ap_t^{-B} B $=$

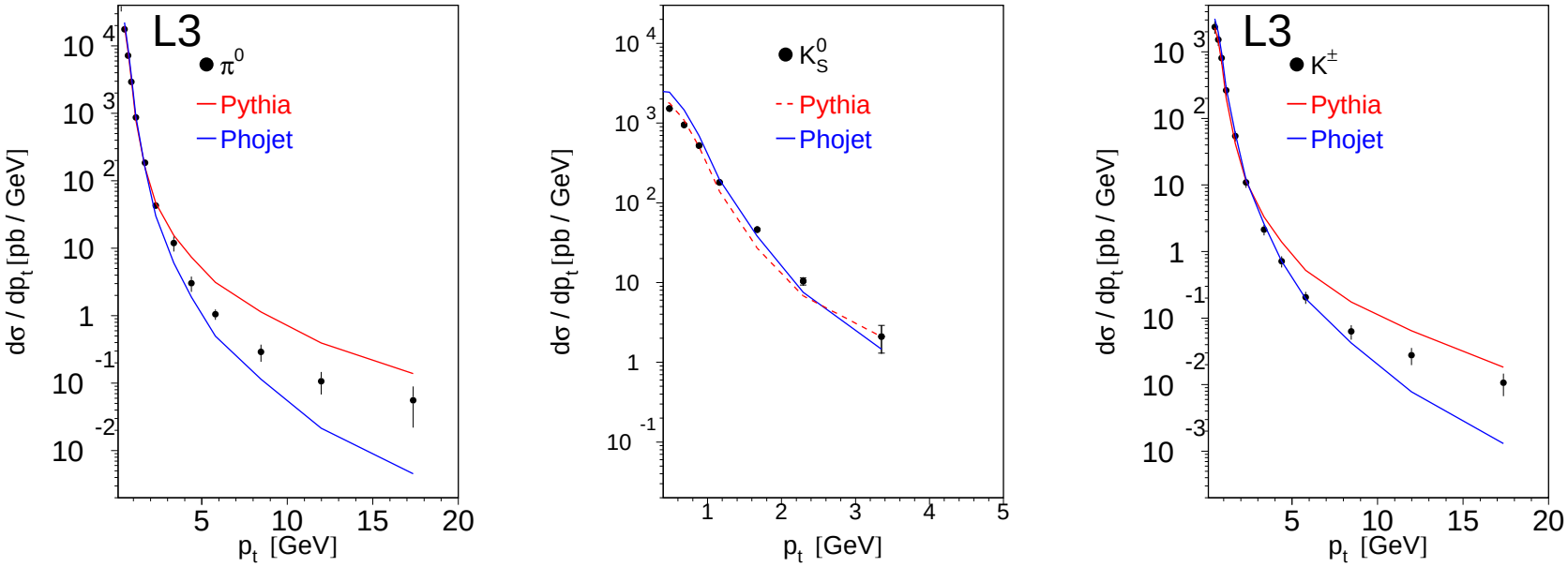
4.1 ± 0.2 MeV for π^0
4.1 ± 0.1 MeV for $\pi^\pm$
4.5 ± 1.2 MeV for K^0_S
4.4 ± 0.2 MeV for $K^\pm$

- For $p_t < 1.5$ GeV, exponential behaviour
  $\Rightarrow$ characteristic of soft interaction.
- For $p_t > 1.5$ GeV, power law behaviour
  $\Rightarrow$ direct and resolved processes.

Comparison with OPAL experiment



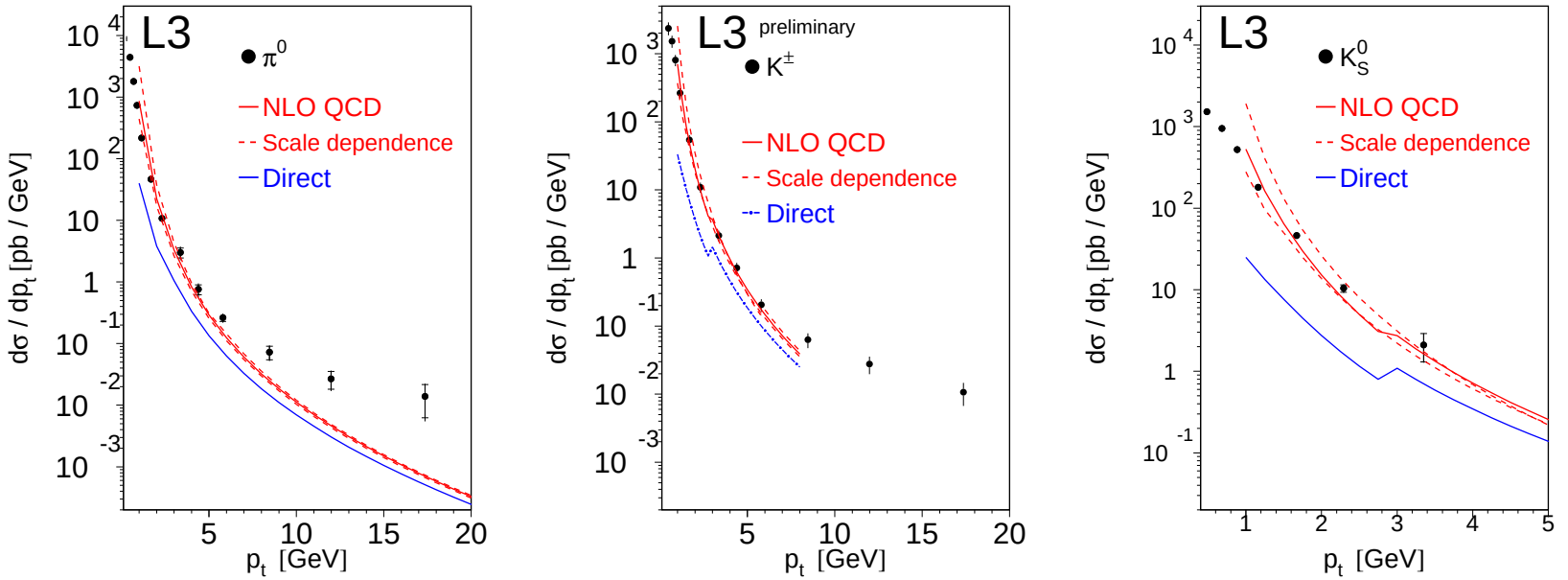
$\Rightarrow$ good agreement between experiments.



Low p_t : Agreement for $p_t \leq 3$ GeV.

High p_t : ▲ Pythia too high ▼ Phojet too low

$\frac{d\sigma}{dp_t}$ comparison with NLO QCD *

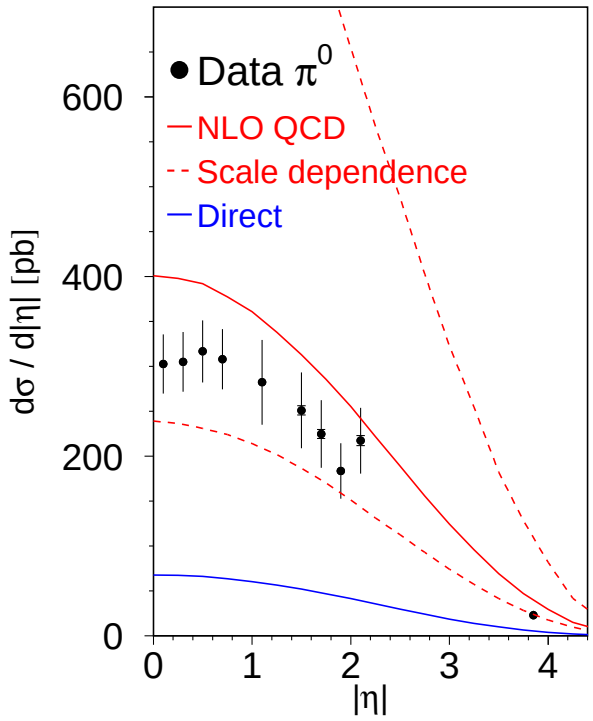


Clear excess in π^0 and $\pi^{\pm}$ data for $p_t > 5$ GeV !

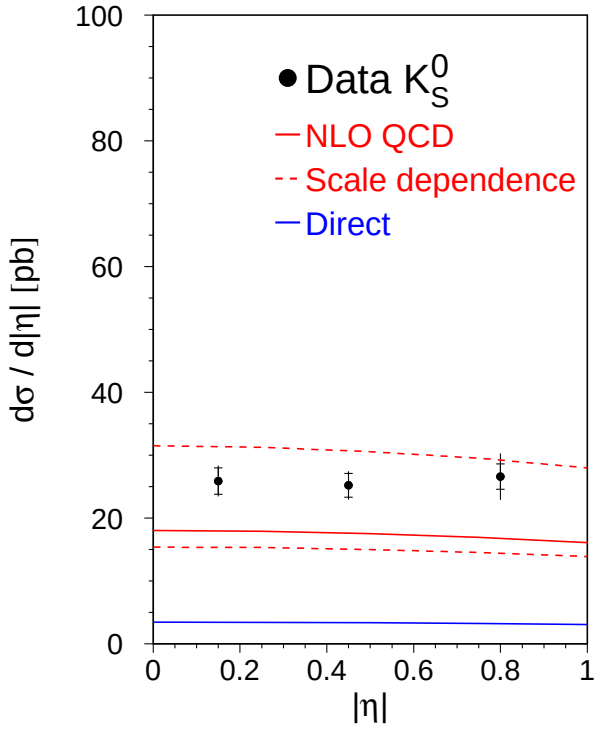
* J. Binnewies, **B.A. Kniehl** and G. Kramer, Phys. Rev. D53 (1996) 6110

$\frac{d\sigma}{d|\eta|}$ comparison with NLO QCD

$p_t > 1$ GeV



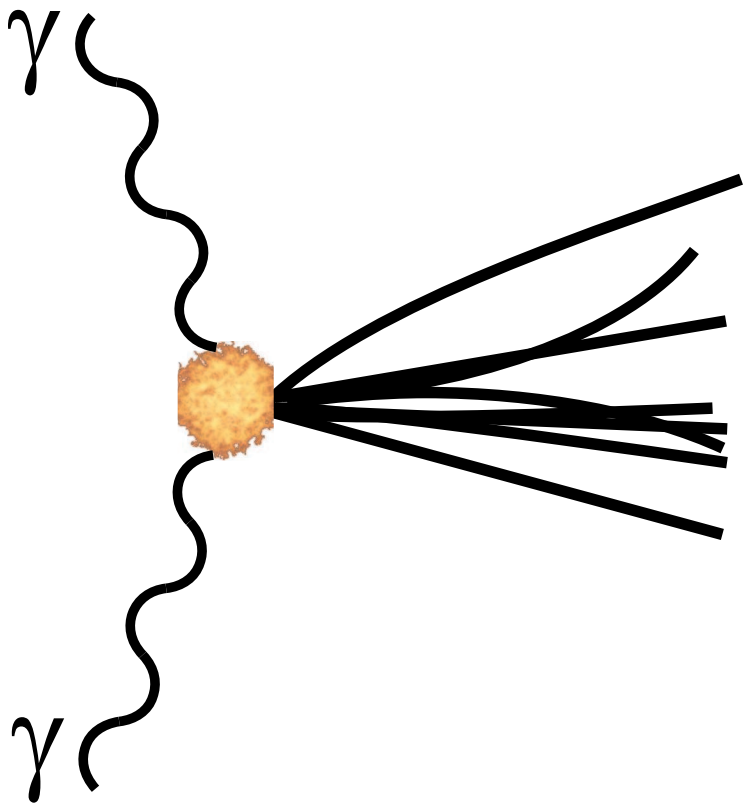
$p_t > 1.5$ GeV

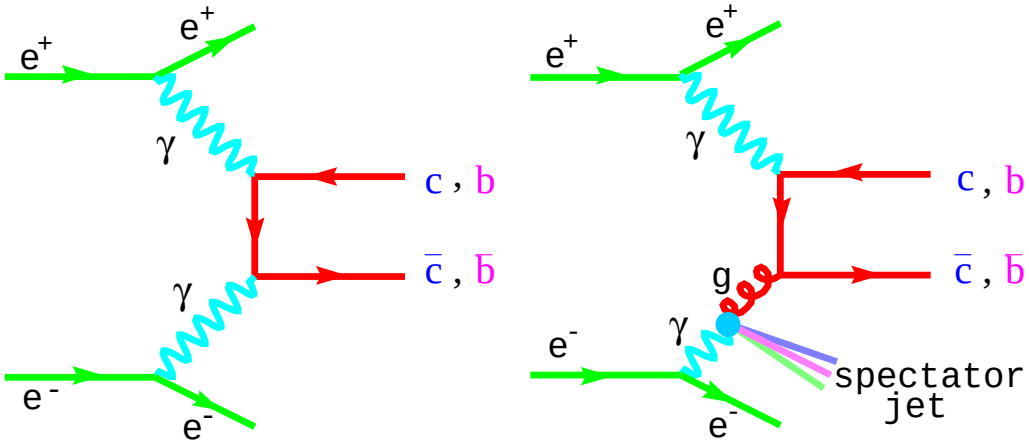


The pseudo-rapidity shape is well reproduced.

INCLUSIVE CHARM & BOTTOM PRODUCTION

$c\bar{c}\,X,\ b\bar{b}X$





Data set $\sqrt{s}$ = 183 - 209 GeV , $\mathcal{L} = 683$ pb^{-1}

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

Monte Carlo Pythia v.5.722

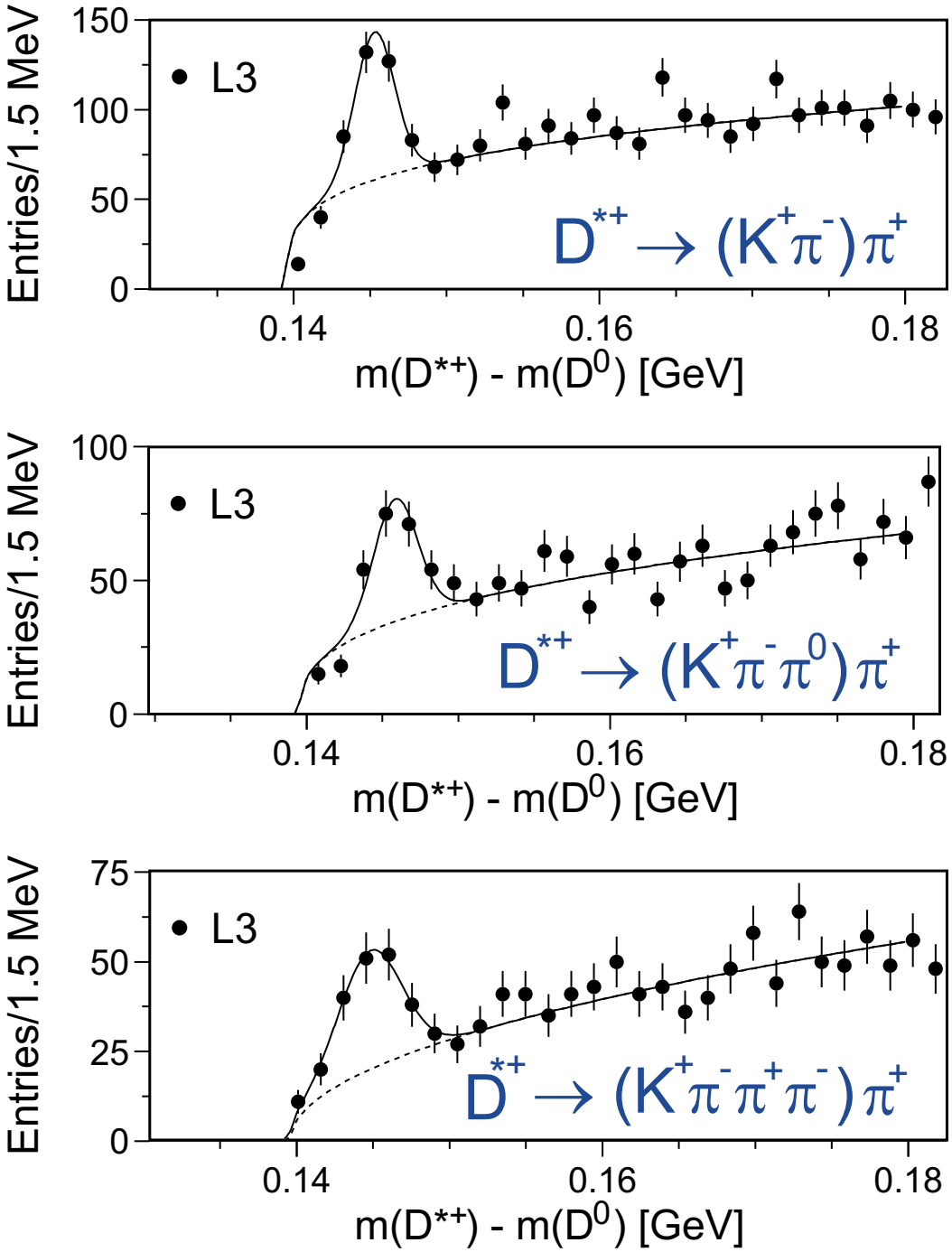
Charm identification

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

Bottom identification

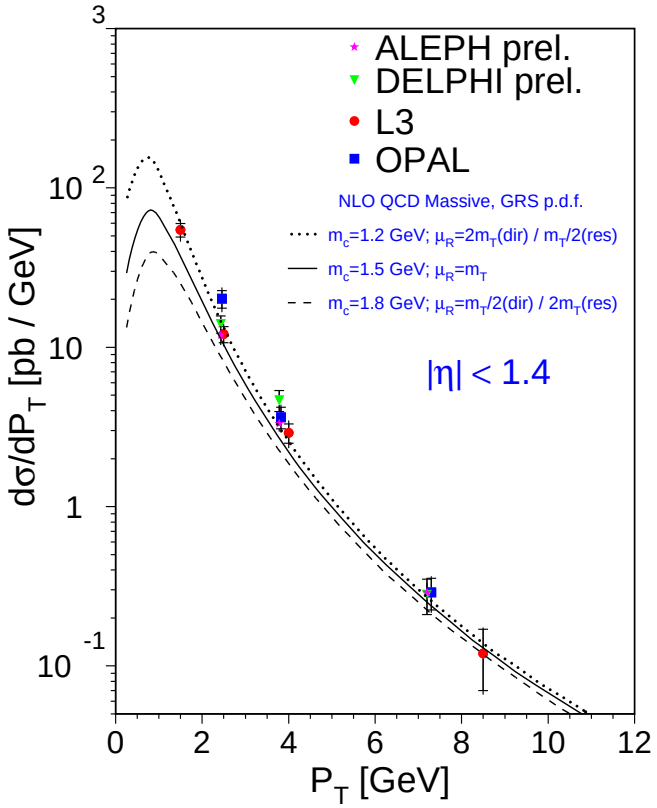
- lepton tagging $(b \rightarrow l^{\pm}X, l^{\pm} = e^{\pm}, \mu^{\pm})$

Inclusive D^{*+} production

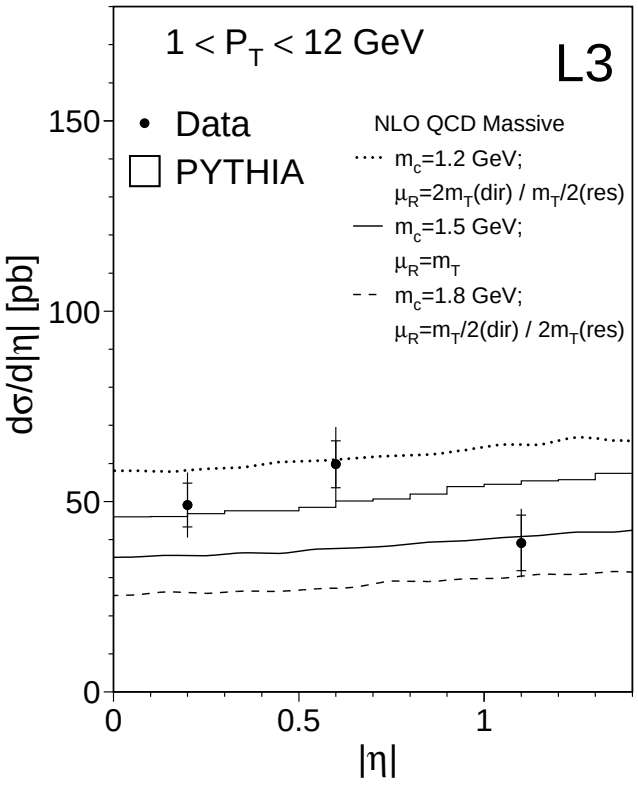


$$\sigma(e^+e^- \to e^+e^- c\bar{c}X) = 1120 \pm 90 \pm 160^{+540}_{-250} \text{ pb}$$

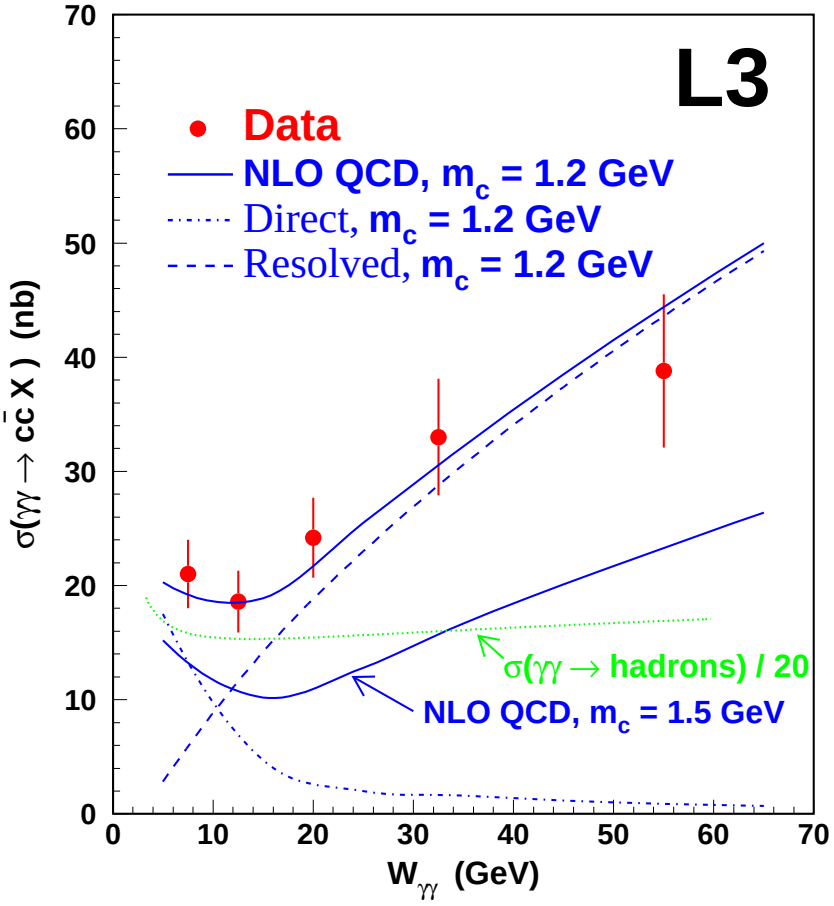
$\frac{d\sigma}{dp_t}$ cross section



$\frac{d\sigma}{d|\eta|}$ cross section



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

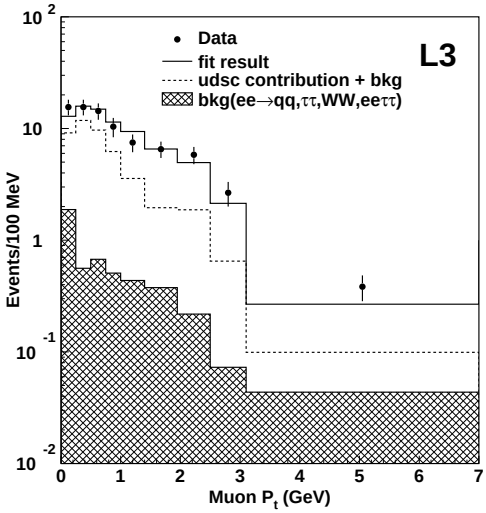


- Good agreement with NLO QCD predictions with $m_c = 1.2$ GeV.
- Direct process not sufficient, need resolved component.
- Steeper rise with energy than $\sigma(\gamma\gamma \to hadrons)$

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

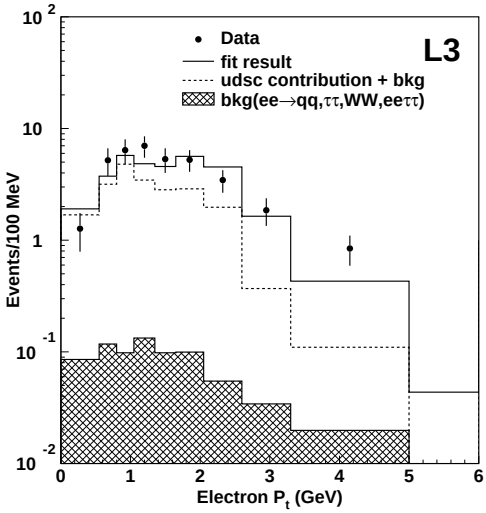
Fit the P_t distribution of the lepton with respect to the nearest jet to extract the $\mathrm{b\bar{b}X}$ signal. Leptons from bottom decays have a higher P_t.

Muon



$\mathrm{N}^{\mu}_{\mathrm{bb}} = 435$
$\epsilon^{\mu}_{bb} = 2.2\%$
$\Pi^{\mu}_{bb} = 41.2\% \pm 3.8\%$

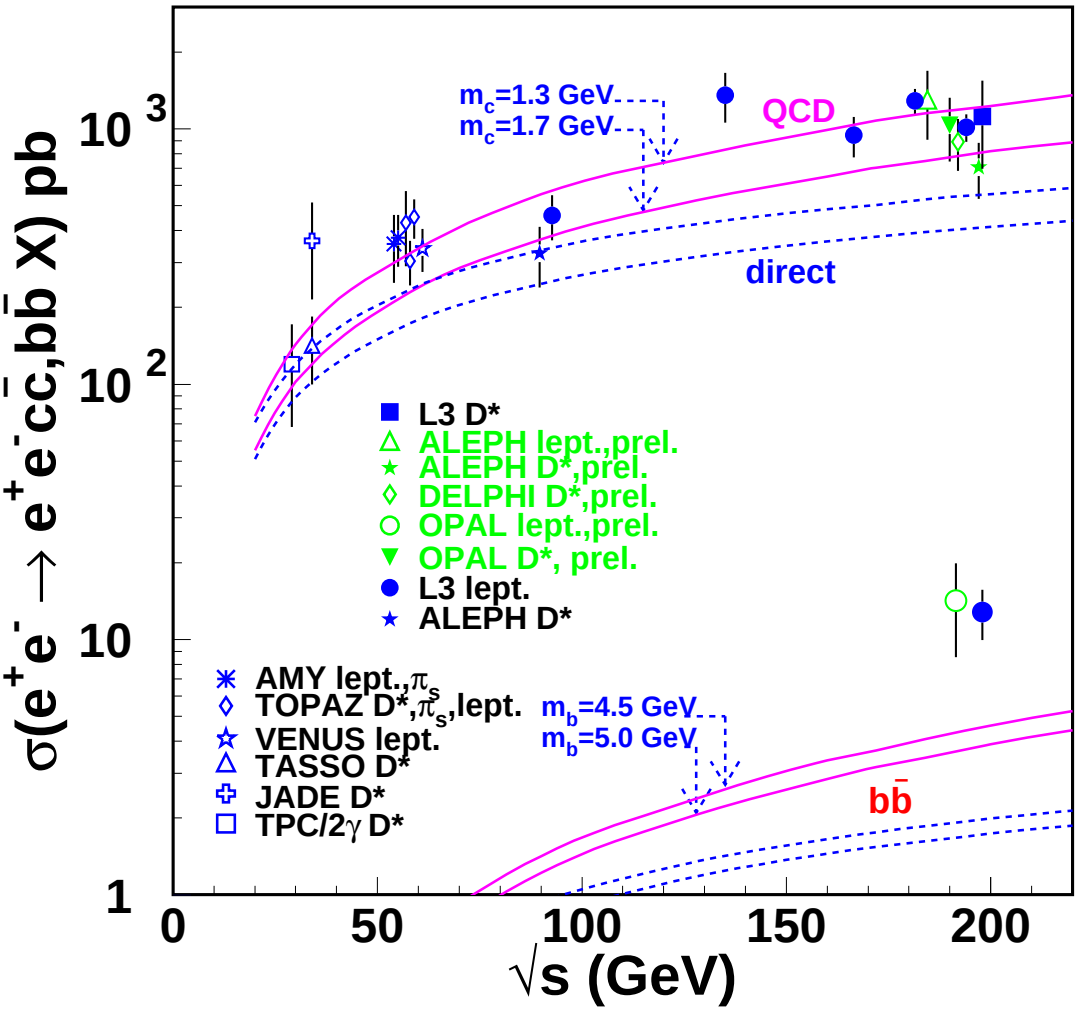
Electrons



$\mathrm{N}^{\mathrm{e}}_{\mathrm{bb}} = 219$
$\epsilon^{e}_{bb} = 1.25\%$
$\Pi^{e}_{bb} = 46.2\% \pm 5.1\%$

Muon: $\sigma_{\mathrm{b\bar{b}}} = 13.0 \pm 2.4 \pm 2.3$ pb
Electron: $\sigma_{\mathrm{b\bar{b}}} = 12.6 \pm 2.4 \pm 2.3$ pb
Combined: $\sigma_{\mathrm{b\bar{b}}} = 12.8 \pm 1.7 \pm 2.3$ pb

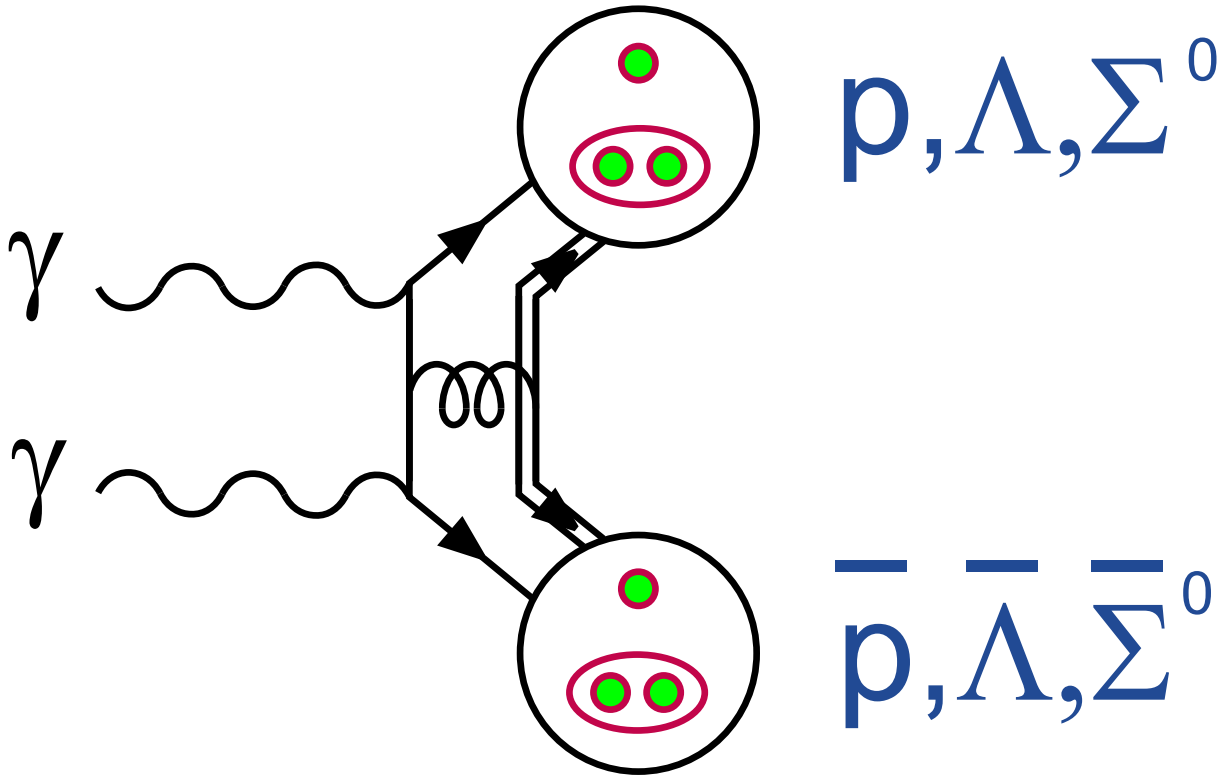
Inclusive charm and bottom cross section



- $c\bar{c}$ good agreement with theory *.
- $b\bar{b}$ in excess of the QCD predictions* by a factor of three !

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

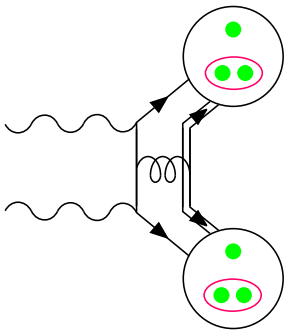
EXCLUSIVE BARYON PAIR PRODUCTION



Exclusive baryon pair production

Measure $\gamma\gamma \to p\overline{p}, \Lambda\overline{\Lambda}, \Sigma^0\overline{\Sigma}^0$ cross section to test:

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



$\gamma\gamma \to p\overline{p}$ reaction

Data set $\sqrt{s}$ = 183 - 209 GeV , $\mathcal{L} = 686$ pb^{-1}
preliminary results

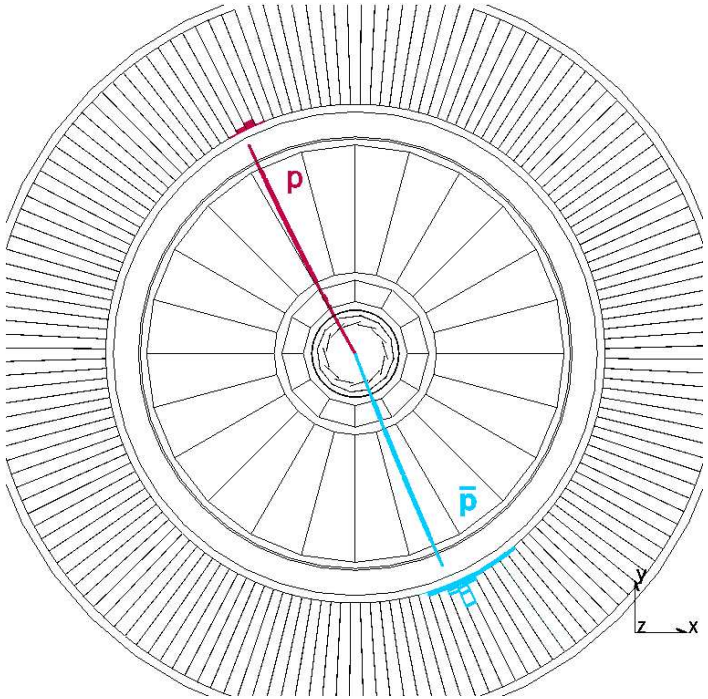
Monte Carlo EGPC v.2.07

$\gamma\gamma \to \Lambda\overline{\Lambda}$ and $\gamma\gamma \to \Sigma^0\overline{\Sigma}^0$ reactions

Data set $\sqrt{s}$ = 91 - 209 GeV , $\mathcal{L} = 844$ pb^{-1}
published in PLB536 (2002)

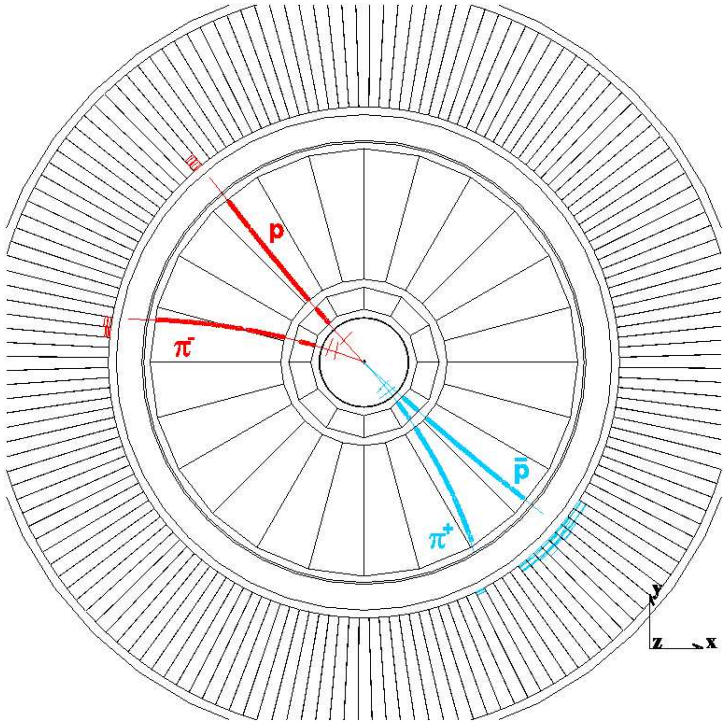
Monte Carlo EGPC v.2.07

$\gamma\gamma \to p\overline{p}$ event



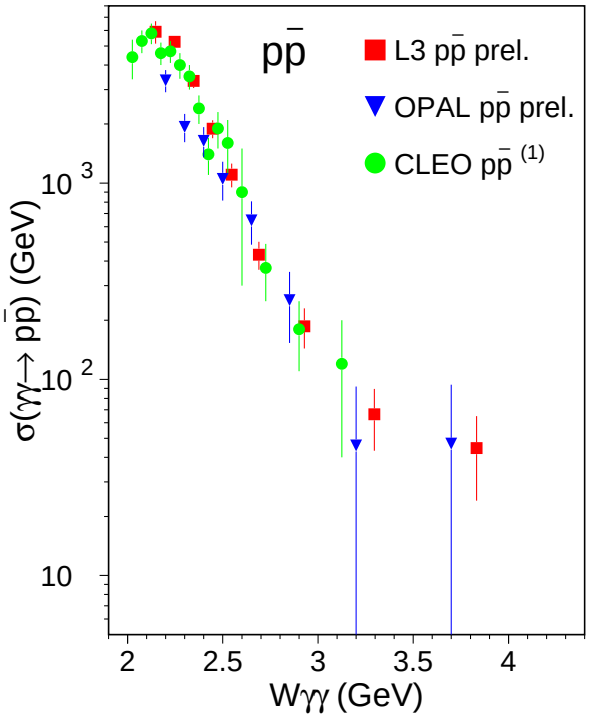
- Antiproton tag with dE/dx and electromagnetic calorimeter.

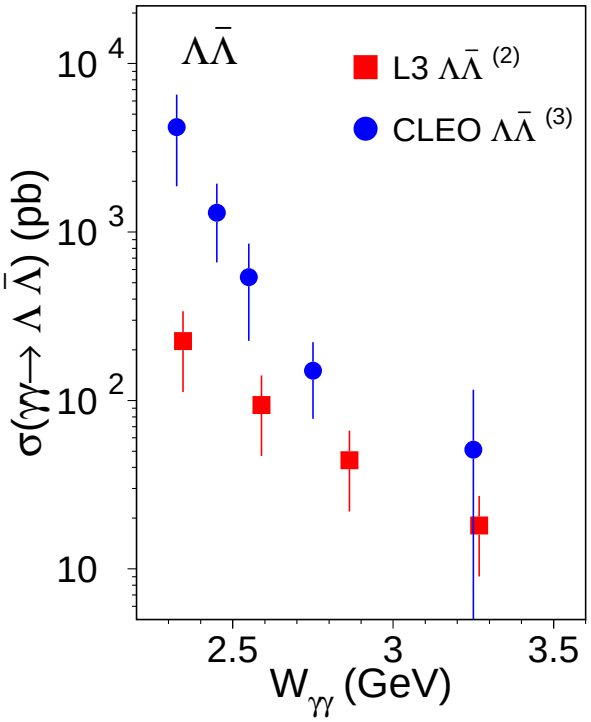
$\gamma\gamma \to \Lambda\overline{\Lambda}$ event



- Reconstruct secondary vertex.
- Antiproton tag to reject background.

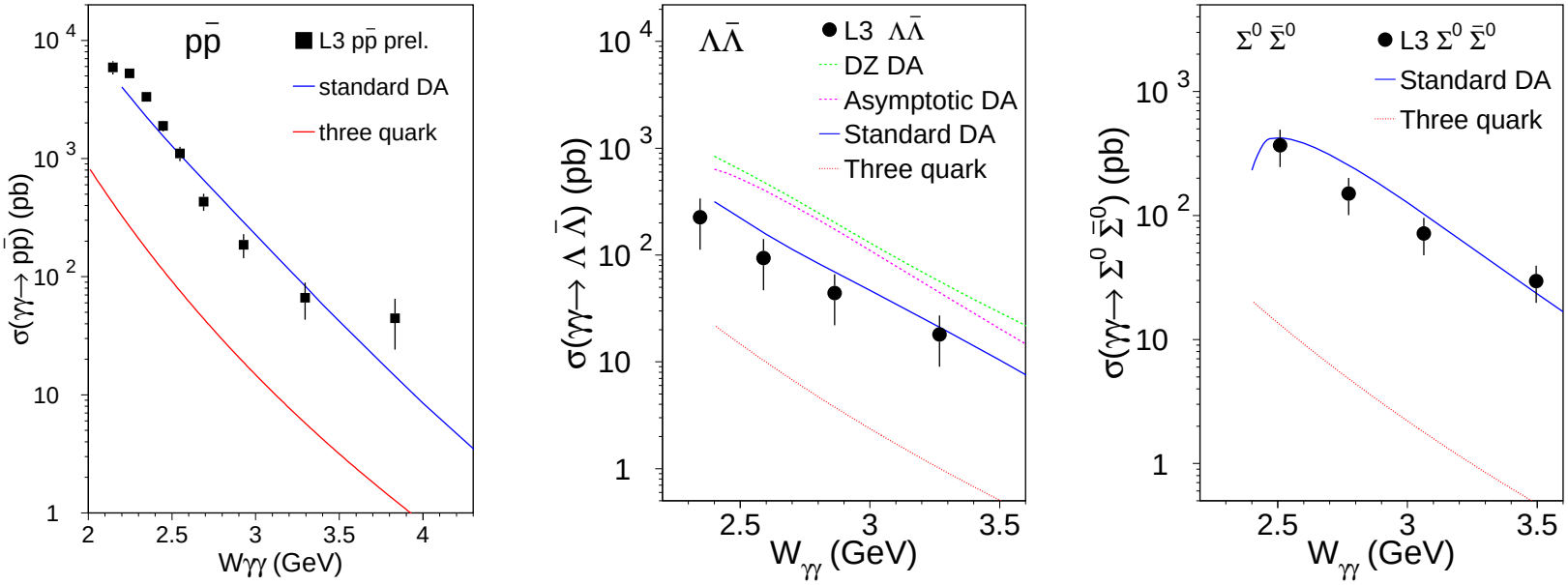
Comparison with other experiment





(1) CLEO collaboration, M. Artuso *et al.*, Phys. Rev. **D 50** (1994) 5484.
(2) L3 collaboration, P. Achard *et al.*, Phys. Lett. **B 536** (2002) 24.
(3) CLEO collaboration, S. Anderson *et al.*, Phys. Rev. **D 56** (1997) 2485.

Comparison with theory



➪ Good agreement with the diquark model, standard DA.

➪ Three quark model (G. Farrar *et al.**) excluded.

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

Summary

- Two-photon physics is a nice tool to study QCD.
- Inclusive single hadron production: $\pi^{\pm}$, π^0, $K^{\pm}$and K^0

  soft : $p_t < 1.5$ GeV

  - ➪ Exponential decrease of $d\sigma/dp_t$ seen, as expected.

  hard : $p_t > 5$ GeV

  - ➪ LO Monte Carlo predictions disagree with data.
  - ➪ $d\sigma/dp_t$ NLO QCD predictions disagree with data.

- Inclusive charm and bottom production

  - ➪ Charm production is in agreement with QCD predictions $\Rightarrow$ clear evidence of gluon content of the photon : $\gamma g \rightarrow c\bar{c}$ is needed.
  - ➪ Bottom production is in disagreement with NLO QCD predictions: $\sim$5 standard deviations higher than expected.

- Exclusive baryon pair production

  - ➪ Data are in agreement with the diquark model.
  - ➪ Three quark model is strongly disfavoured.