Heavy flavour production in photon-photon collisions at LEP

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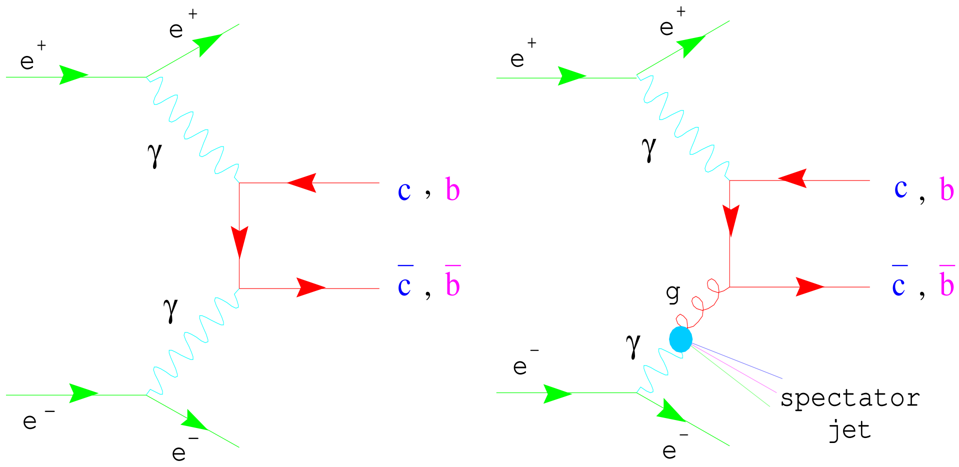
Outline

- Charm: $\sigma(e^+e^- \to e^+e^- c\bar{c}X)$
  (L3, OPAL, ALEPH)
- Charm: $\sigma(e^+e^- \to e^+e^- c\bar{c}X)_{\mathrm{dir,res}}$
  (OPAL)
- Charm: $d\sigma/dp_t^{D^*}, d\sigma/d\eta^{D^*}$
  (L3, OPAL)
- Charm: $\sigma(\gamma\gamma \to e^+e^- c\bar{c}X)$
  (L3)
- Charm: $F_{2,c}^{\gamma}$
  (OPAL)
- Beauty: $\sigma(e^+e^- \to e^+e^- b\bar{b}X)$
  (L3)

Inclusive Charm and Beauty Production

Motivation :



Direct Single Resolved

- **Test of the perturbative QCD**
  - ➩ **Direct Process depends on $m_c(m_b)$ and α_s**
  - ➩ **Resolved Process also depends on gluon content of the photon.**
    - ∗ **at high energies the resolved processes are of the same order as the direct ones**

Inclusive Heavy Flavour Production

Data :

L3 : 91 - 183 GeV, $\mathcal{L} = 165\ \mathrm{pb}^{-1}$

PLB453(1999)83.

L3* : 189 - 202GeV, $\mathcal{L} = 410\ \mathrm{pb}^{-1}$

OPAL : 183 - 189 GeV, $\mathcal{L} = 220\ \mathrm{pb}^{-1}$

CERN-EP/99-157.

ALEPH* : 183 GeV, $\mathcal{L} = 53\ \mathrm{pb}^{-1}$

⋆ Preliminary

Charm identification :

L3: lepton tag ($c \rightarrow l^{\pm}\mathrm{X}$, $l^{\pm} \equiv \mathrm{e}^{\pm}, \mu^{\pm}$),
D^{*+} tag

OPAL: D^{*+} tag

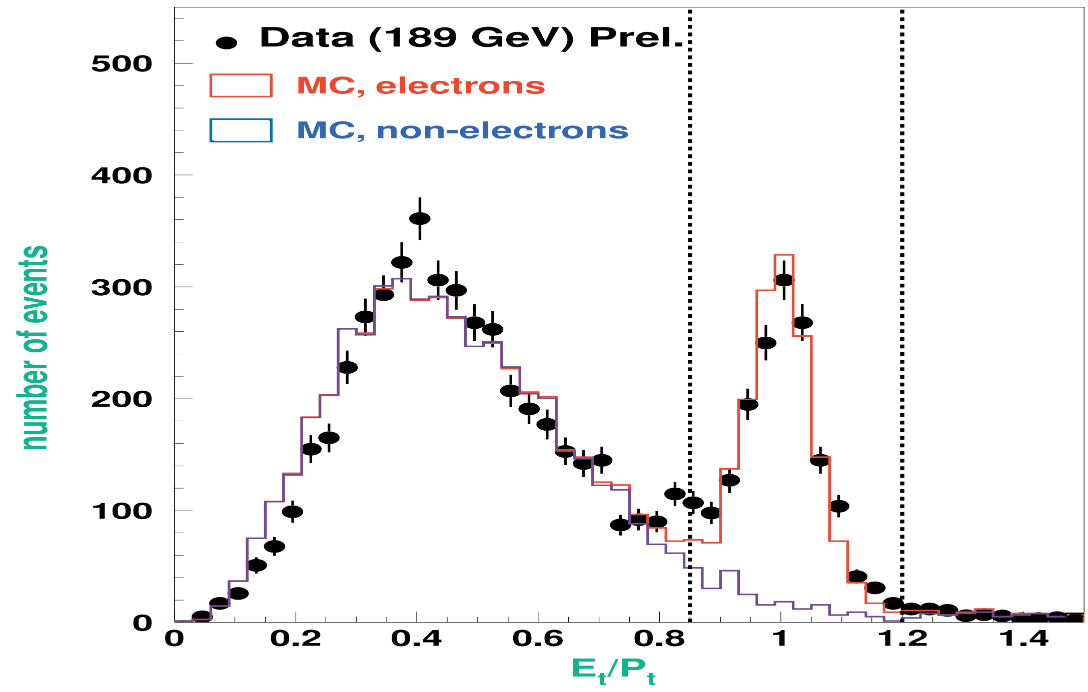
ALEPH: lepton tag ($c \rightarrow l^{\pm}\mathrm{X}$, $l^{\pm} \equiv \mu^{\pm}$)

Bottom identification :

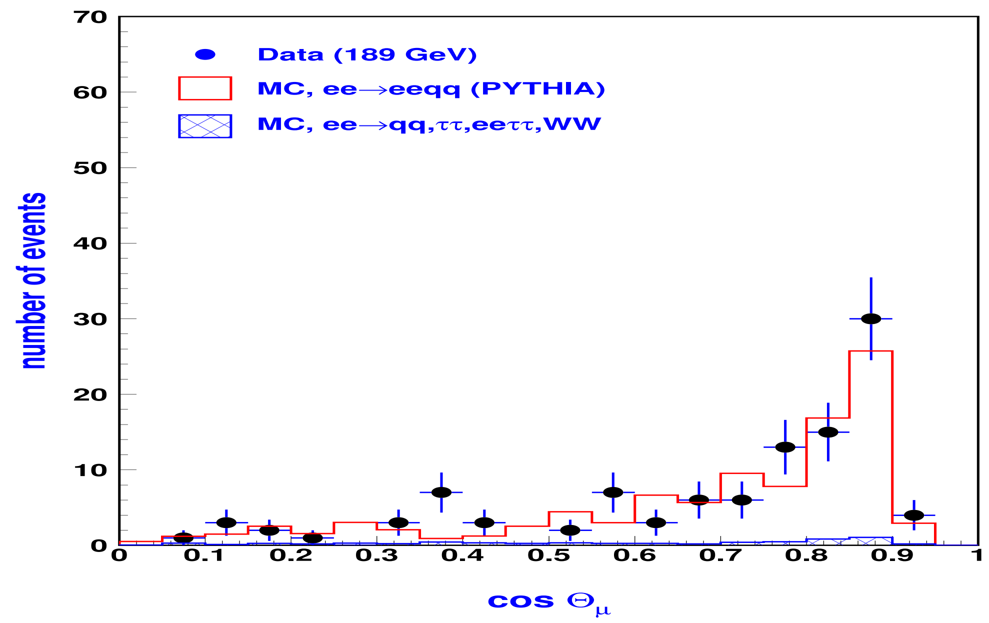
L3 : lepton tag ($c \rightarrow l^{\pm}\mathrm{X}$, $l^{\pm} \equiv \mathrm{e}^{\pm}, \mu^{\pm}$)

Heavy flavour tagged by semileptonic decays: L3

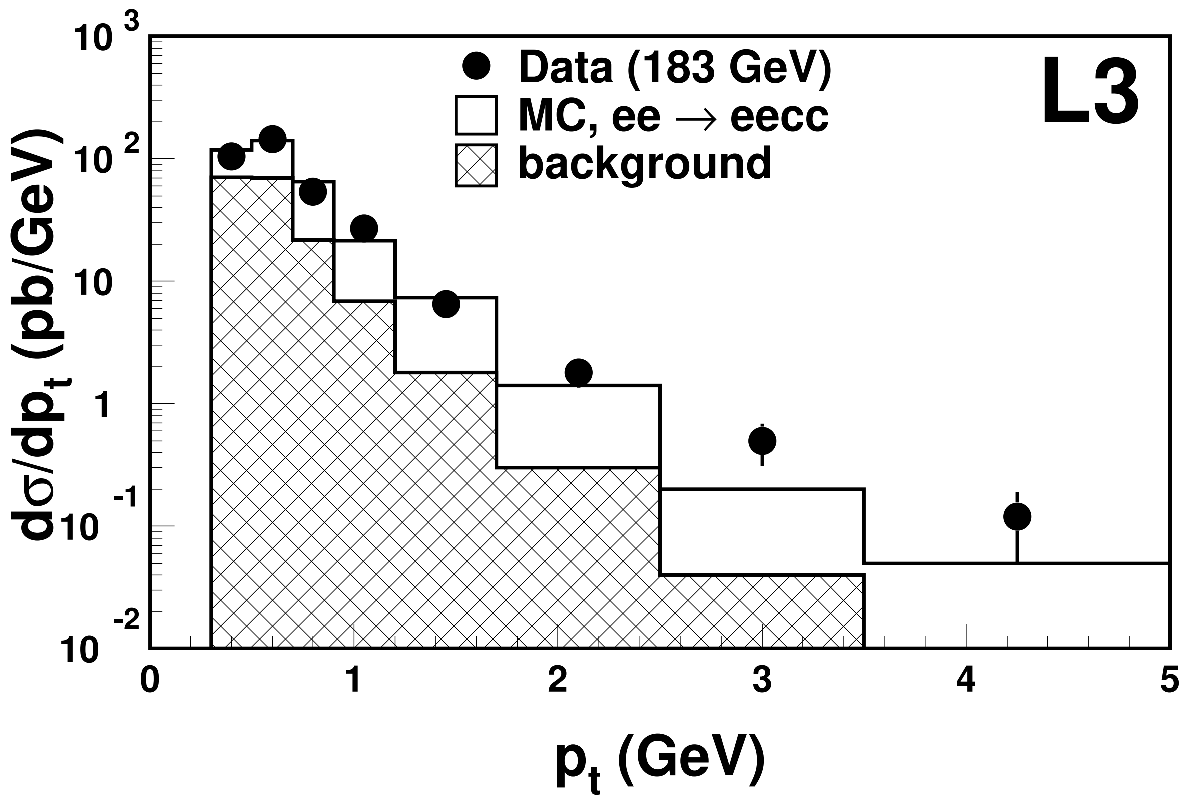
❒ Electron Identification: $P_e > 0.6$ GeV, 2455 ev.

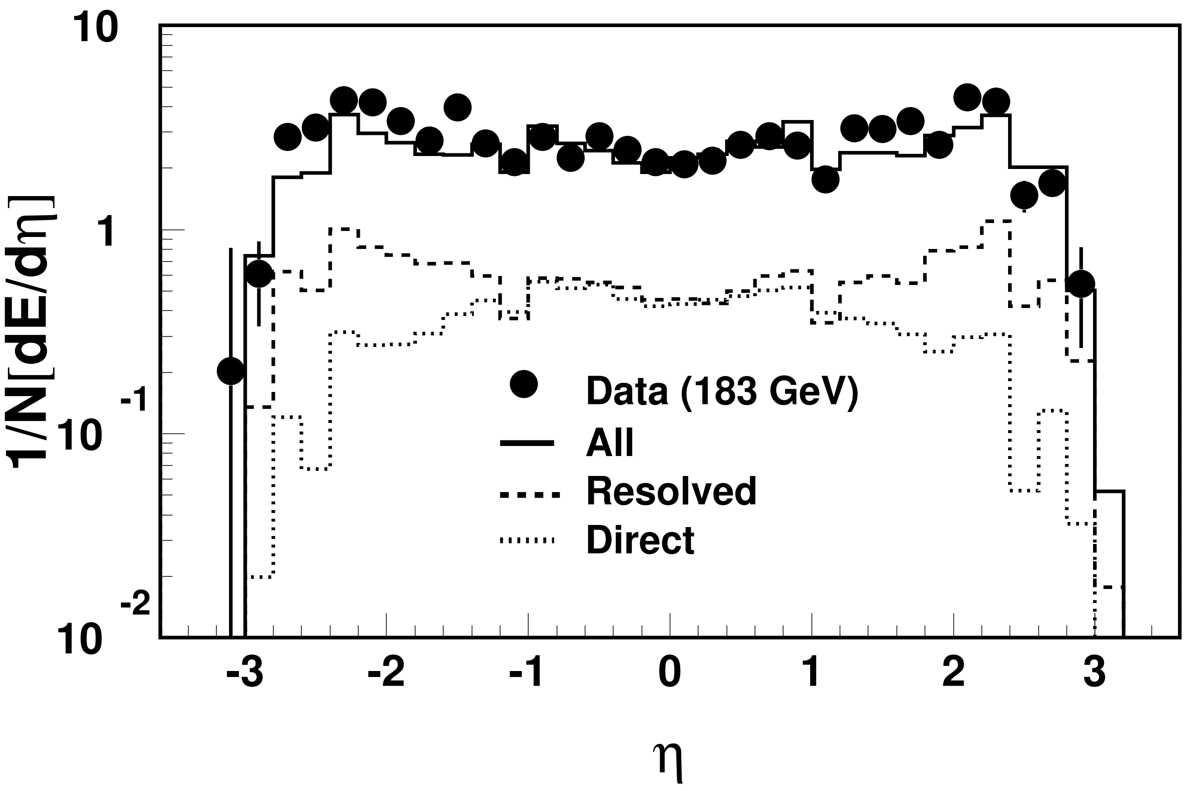


❒ Muon Identification (Muon Chambers): $P_\mu > 2.0$ GeV, 308 events, data $98 + 99$



Direct vs Resolved : L3

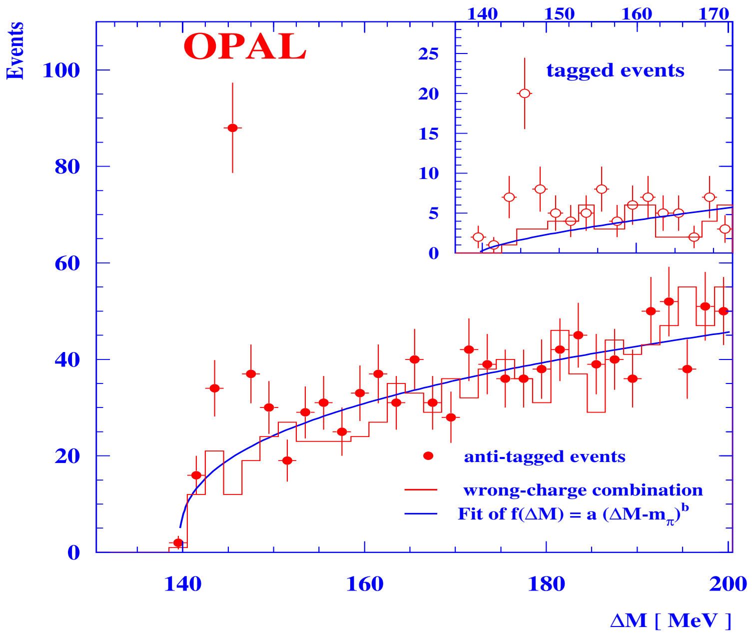




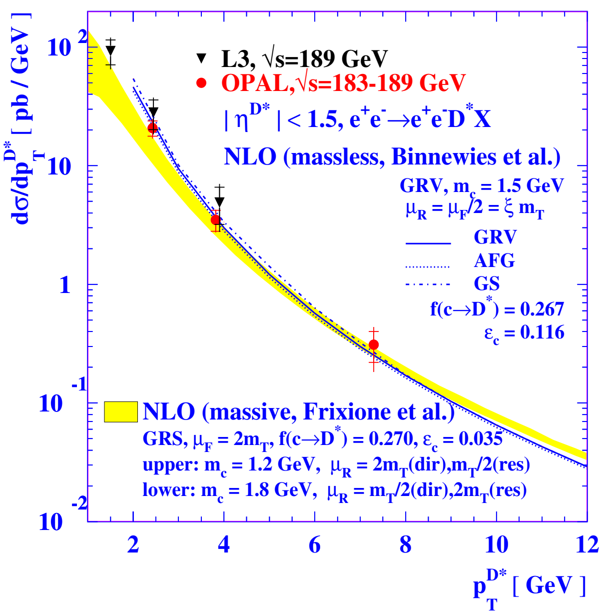
- resolved processes are needed to describe the data

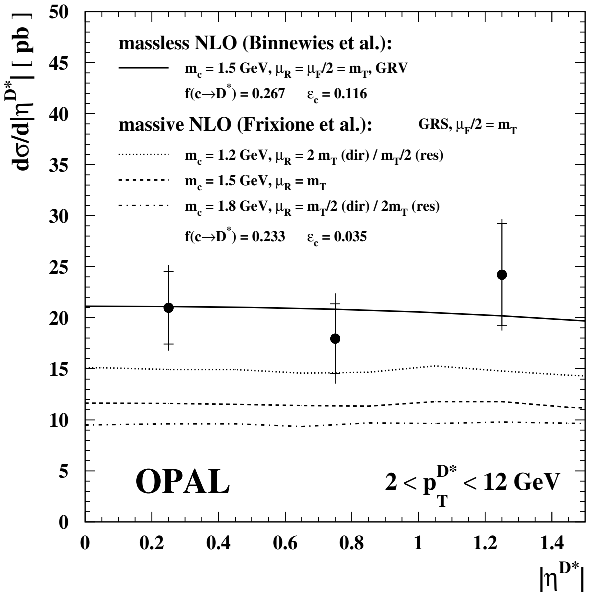
D* Production : OPAL

- Data: $\sqrt{s}$ = 183-189 GeV, $N_{ev}^{antitag} = 100 \pm 13$, $N_{ev}^{tag} = 30 \pm 6$
- $D^{*\pm} \rightarrow D^0 \pi_s^\pm$,
  $D^0 \rightarrow K^\pm \pi^\mp$, $D^0 \rightarrow K^\pm \pi^\mp \pi^+ \pi^-$



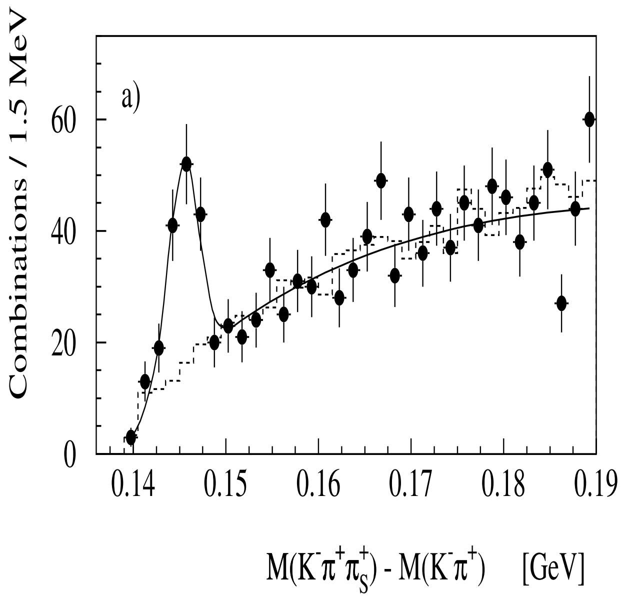
- Differential cross-sections:

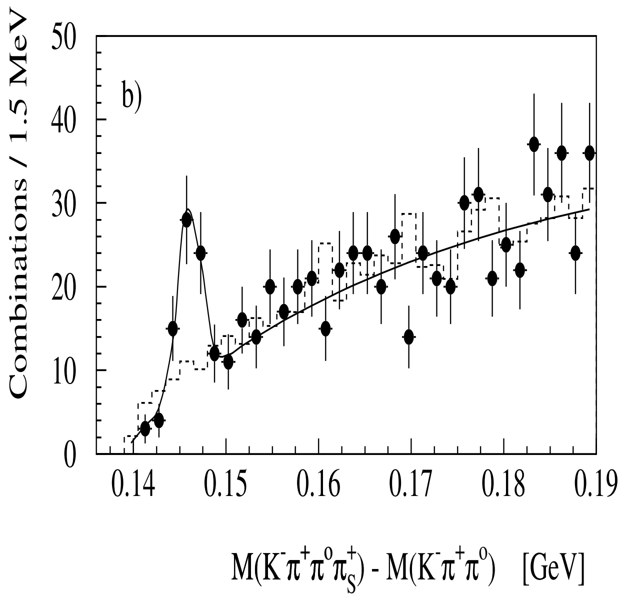




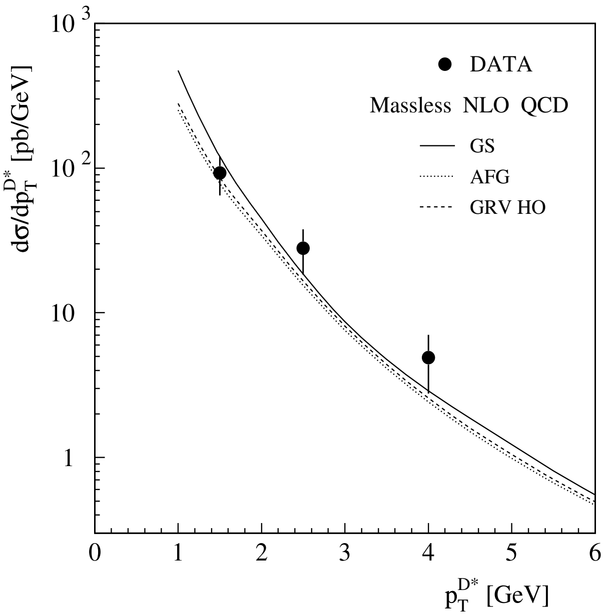
D* Production : L3

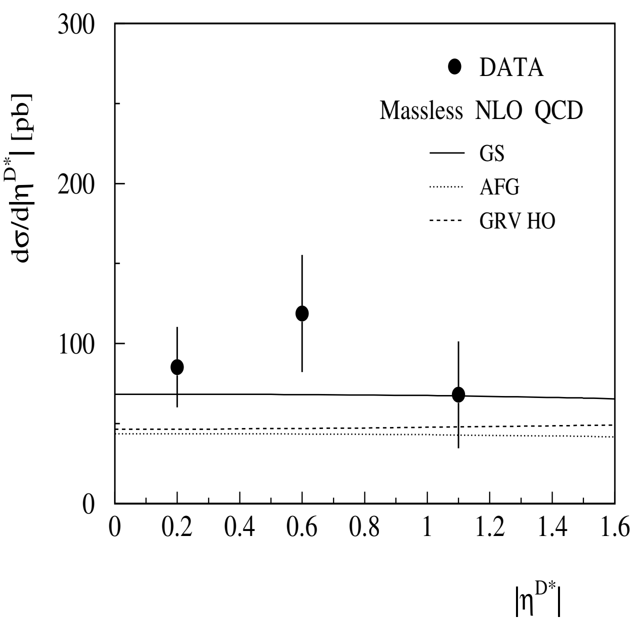
- Data: $\sqrt{s} = 189$ GeV
- $D^{*\pm} \to D^0 \pi_s^\pm$,
  $D^0 \to K^\pm \pi^\mp$, $D^0 \to K^\pm \pi^\mp \pi^0$
  Nevents $= 102 \pm 17$ Nevents $= 42 \pm 11$





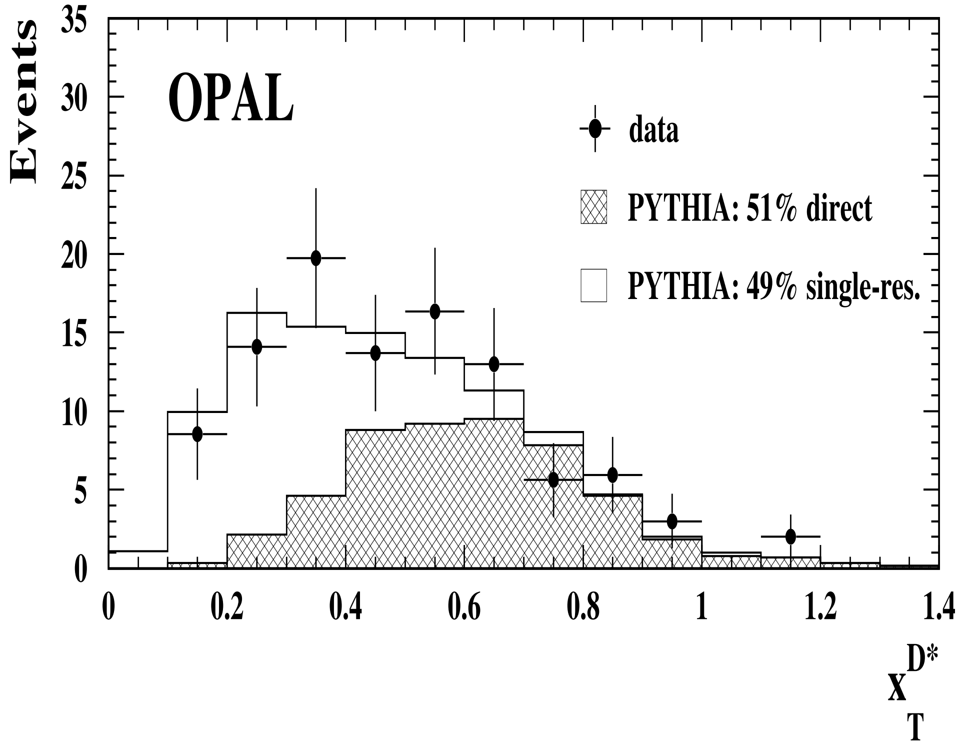
- Differential cross-sections:

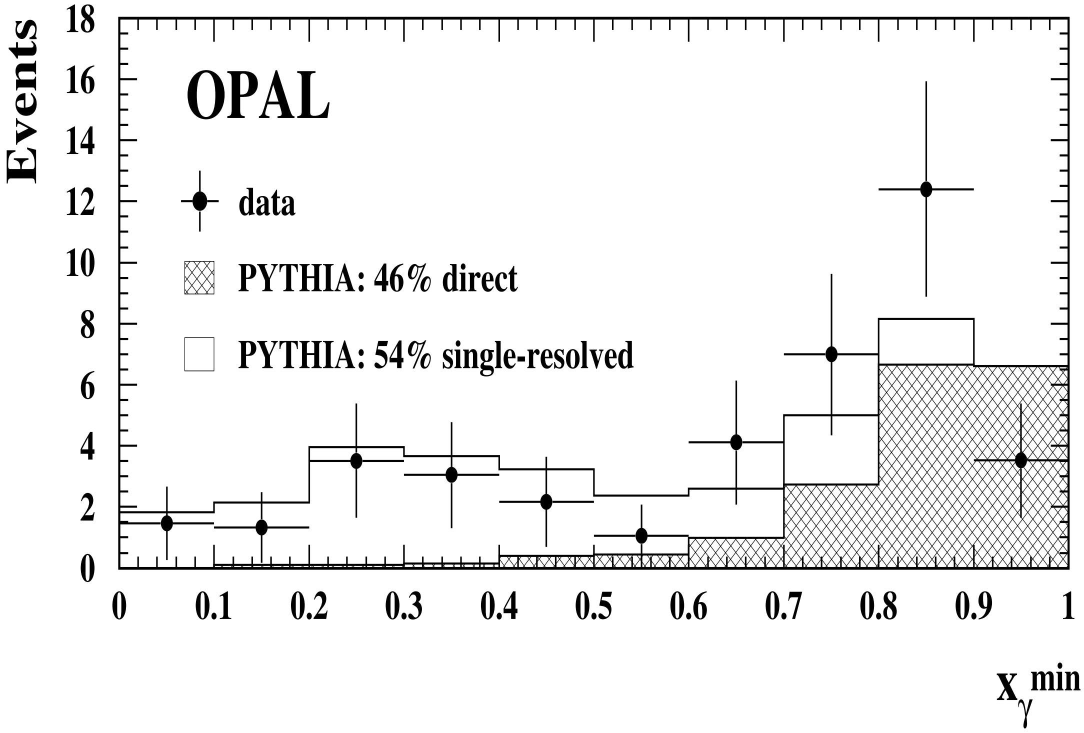




D* Production

❐Separation of Direct and Resolved processes

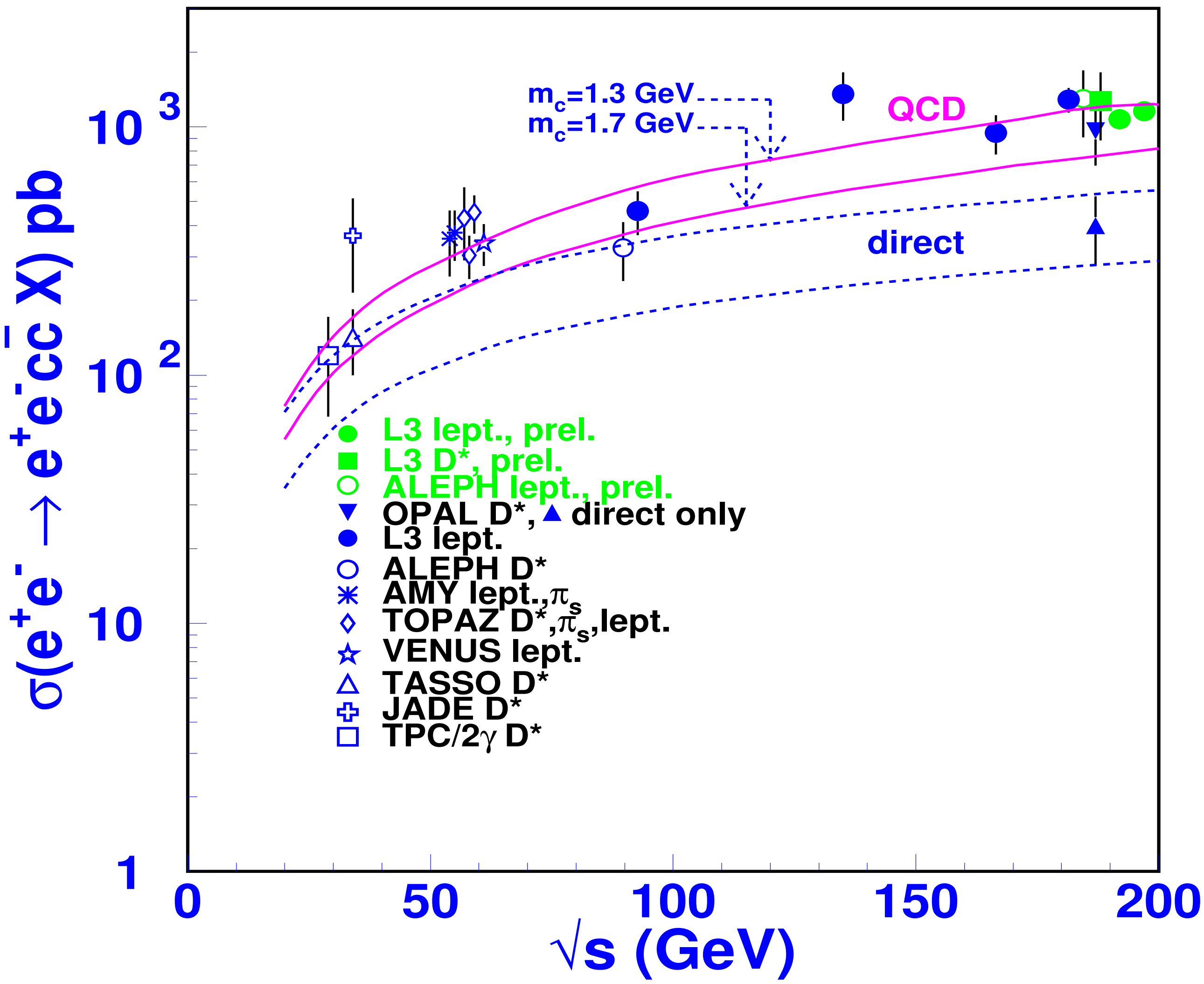




$$e^+e^- \to e^+e^-c\bar{c}:$$

$$\sigma_{dir} = 401\pm\ 124\ \text{pb} \qquad \sigma_{res} = 562\pm\ 202\ \text{pb}$$

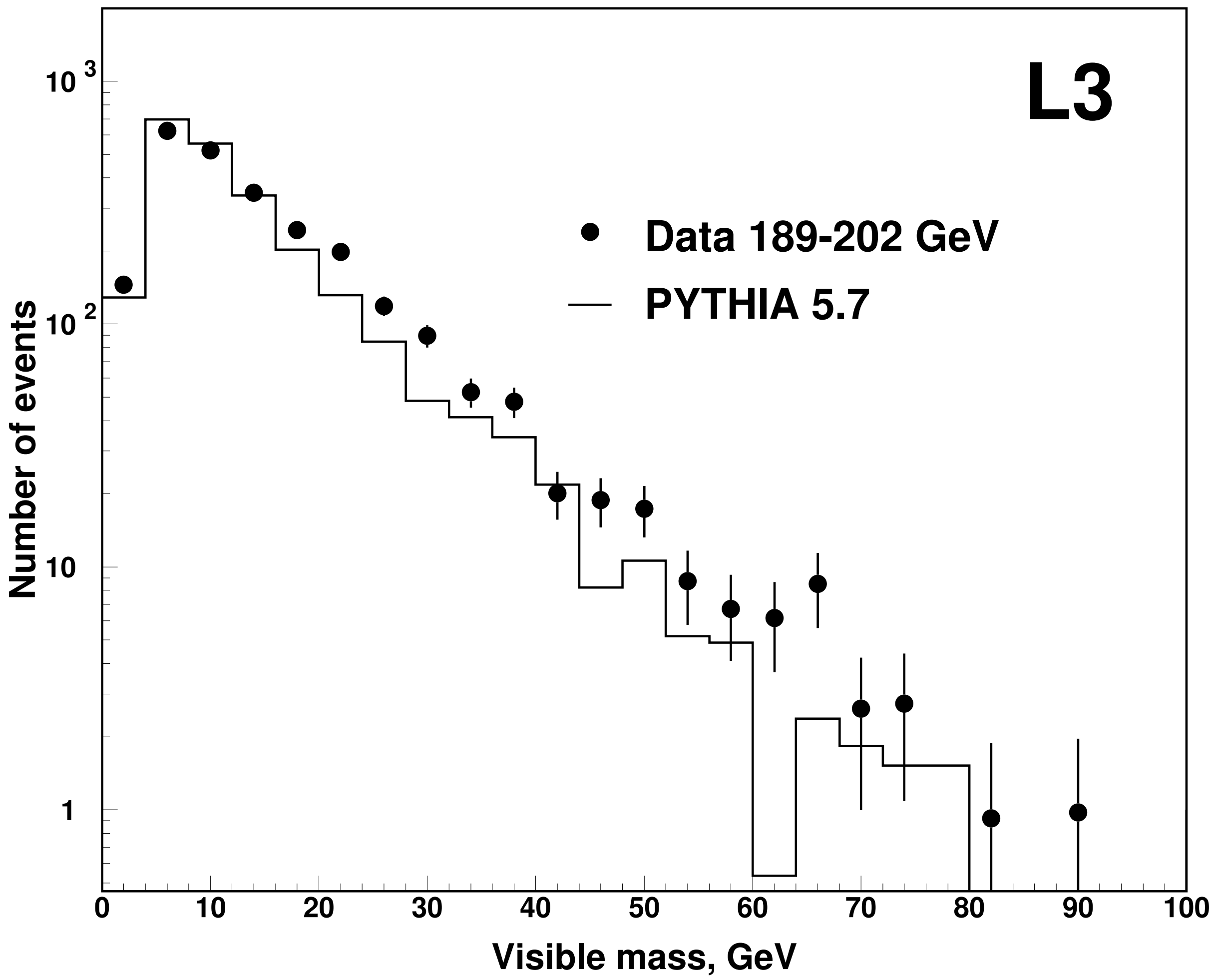
Charm production in $\gamma\gamma$ collisions



- clear evidence of gluon content of photon

theory prediction from
M.Drees,M.Krämer,J.Zunft and P.M.Zerwas,Phys. Lett. B306 (1993) 371), $M_R = M_F = m_c$; GRV p.d.f.

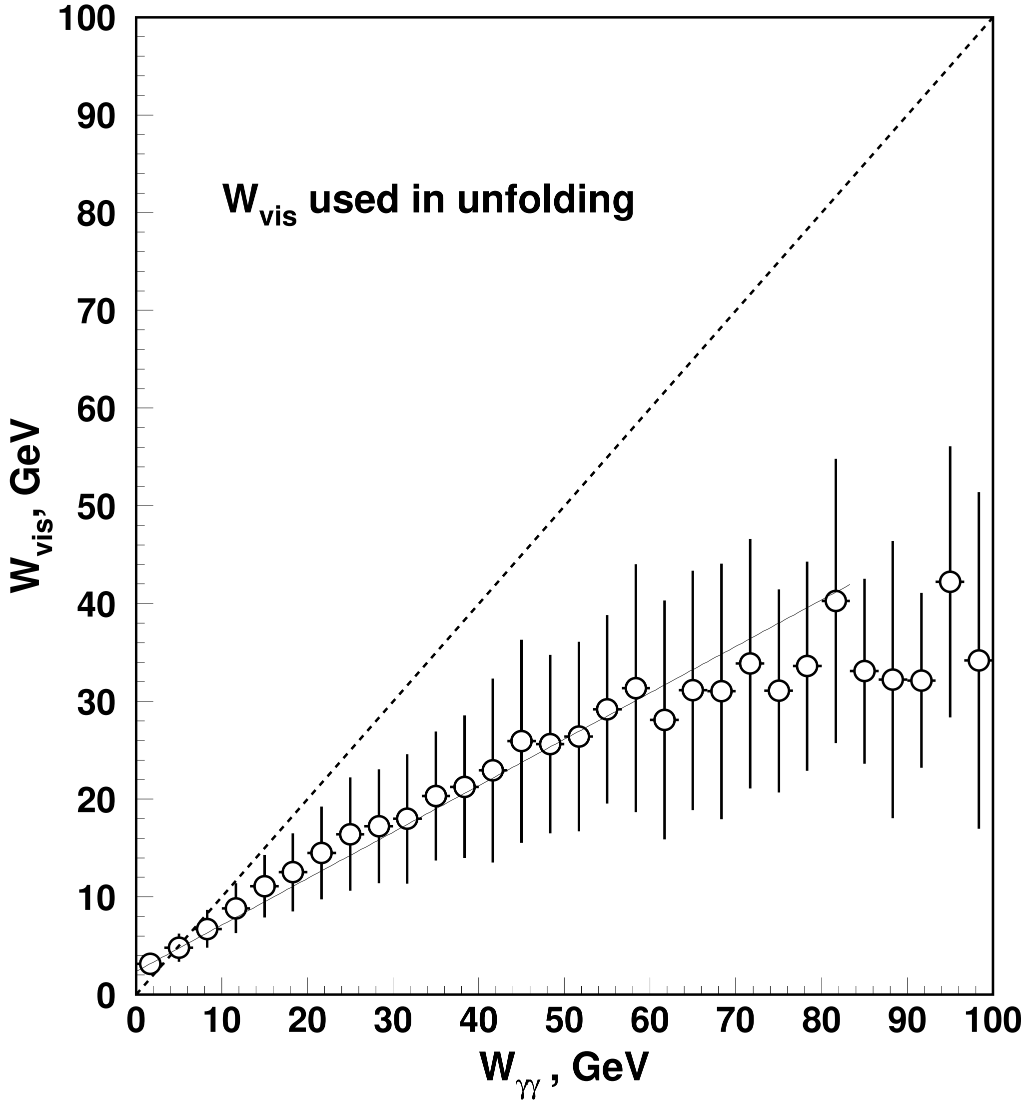
$\sigma(\gamma\gamma \to c\bar{c})$ vs $W_{\gamma\gamma}$



- Data are in excess of MC for high visible mass

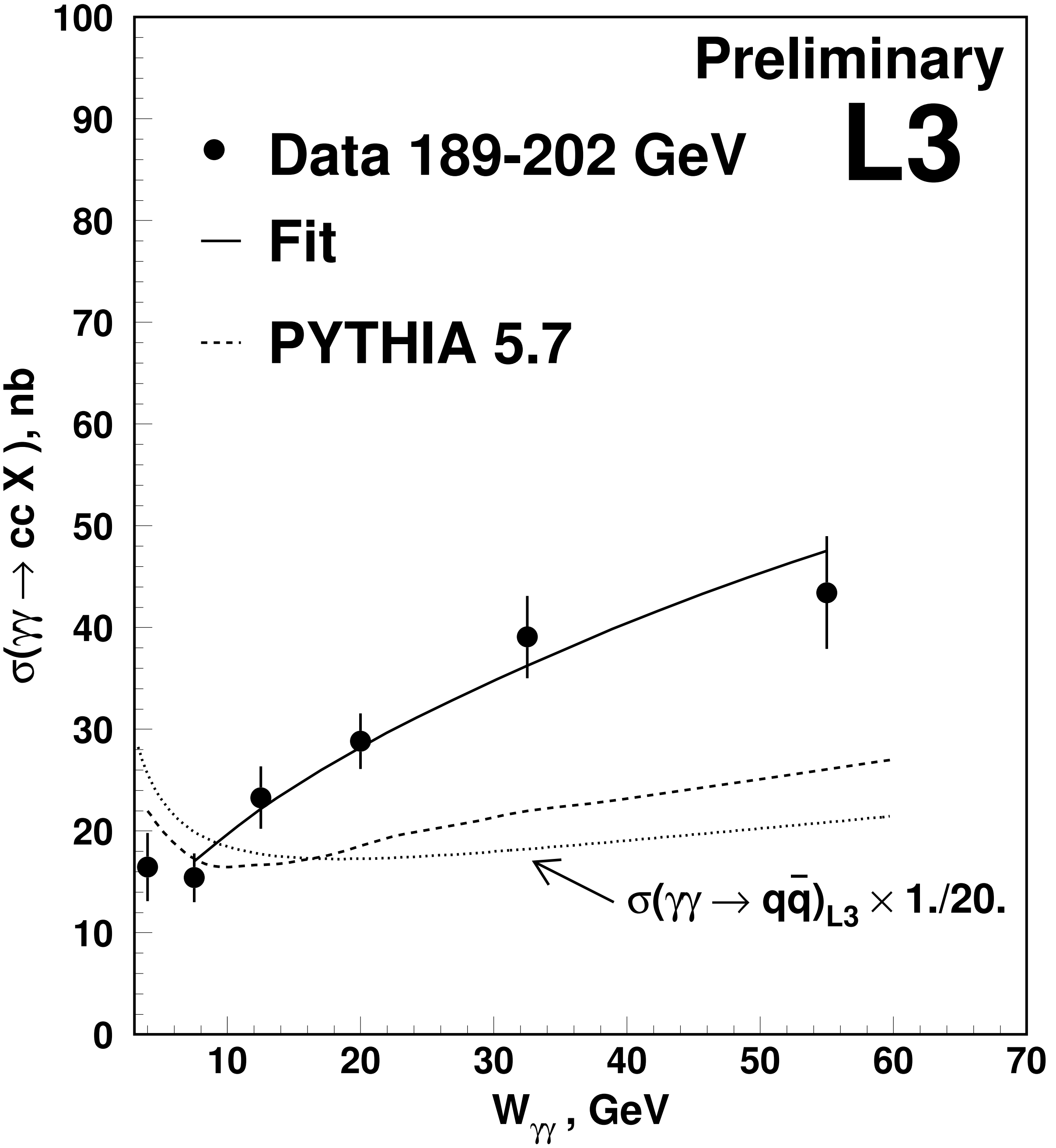
$\sigma(\gamma\gamma \to c\bar{c})$ vs $W_{\gamma\gamma}$, Unfolding

Unfolding corrects for acceptance (missing energy) and detector resolution



- unfolding with Bayes (G. D'Agostini, NIM A362(1995) 487)
- $\sigma_{ee} = \mathcal{L}_{\gamma\gamma} \otimes \sigma_{\gamma\gamma}$

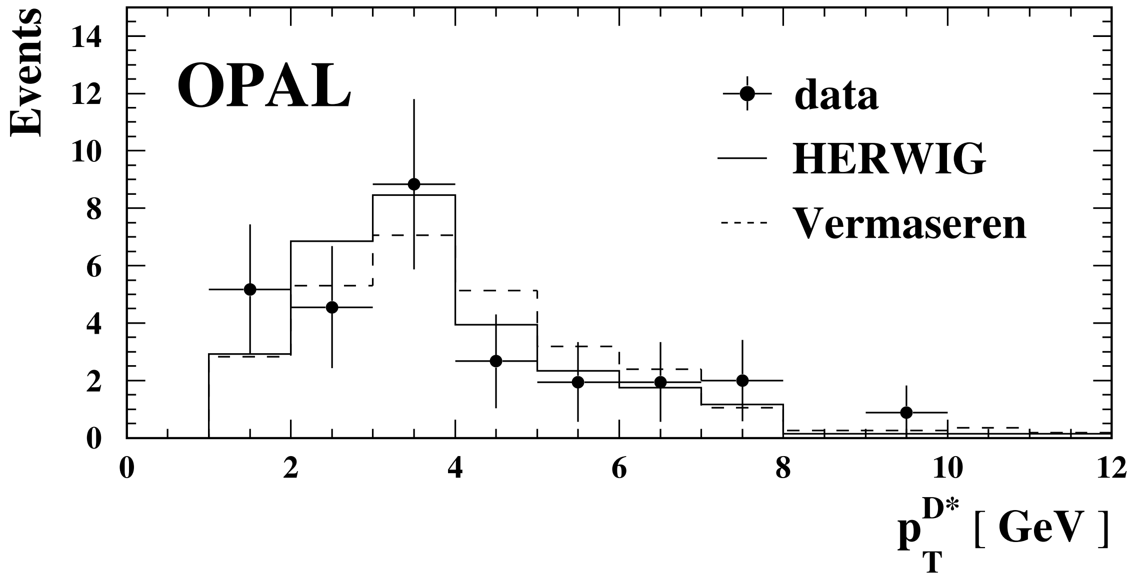
$\sigma(\gamma\gamma \to c\bar{c})$ vs $W_{\gamma\gamma}$: L3

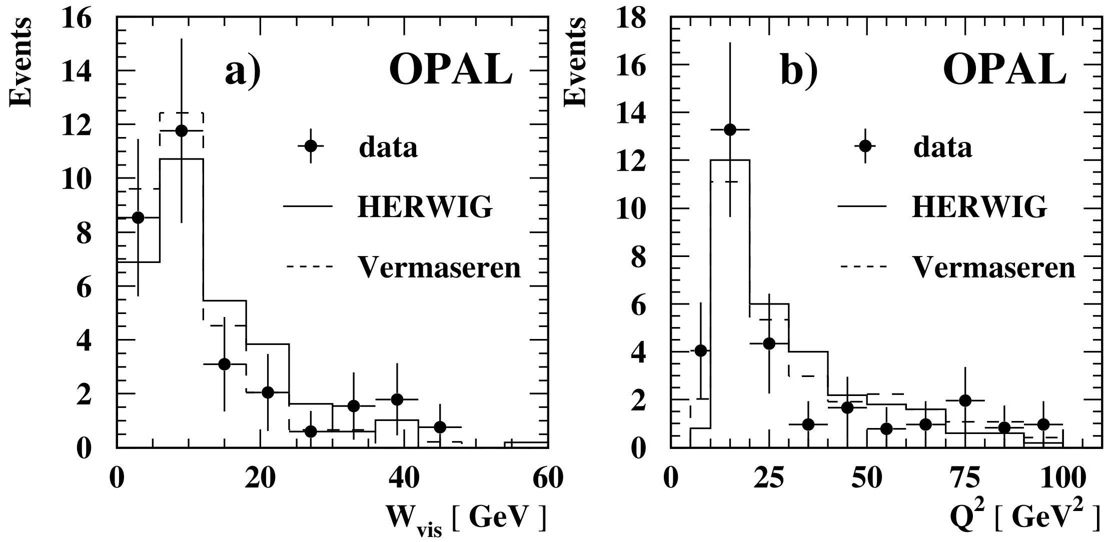


- A steeper rise with energy as compared to $\sigma(\gamma\gamma \to hadrons)$

Charm structure function

❐ 33 mrad $< \theta' <$ 55 mrad, $P_t^{D^*} > 1$ GeV
❐ 60 mrad $< \theta' <$ 120 mrad, $P_t^{D^*} > 3$ GeV

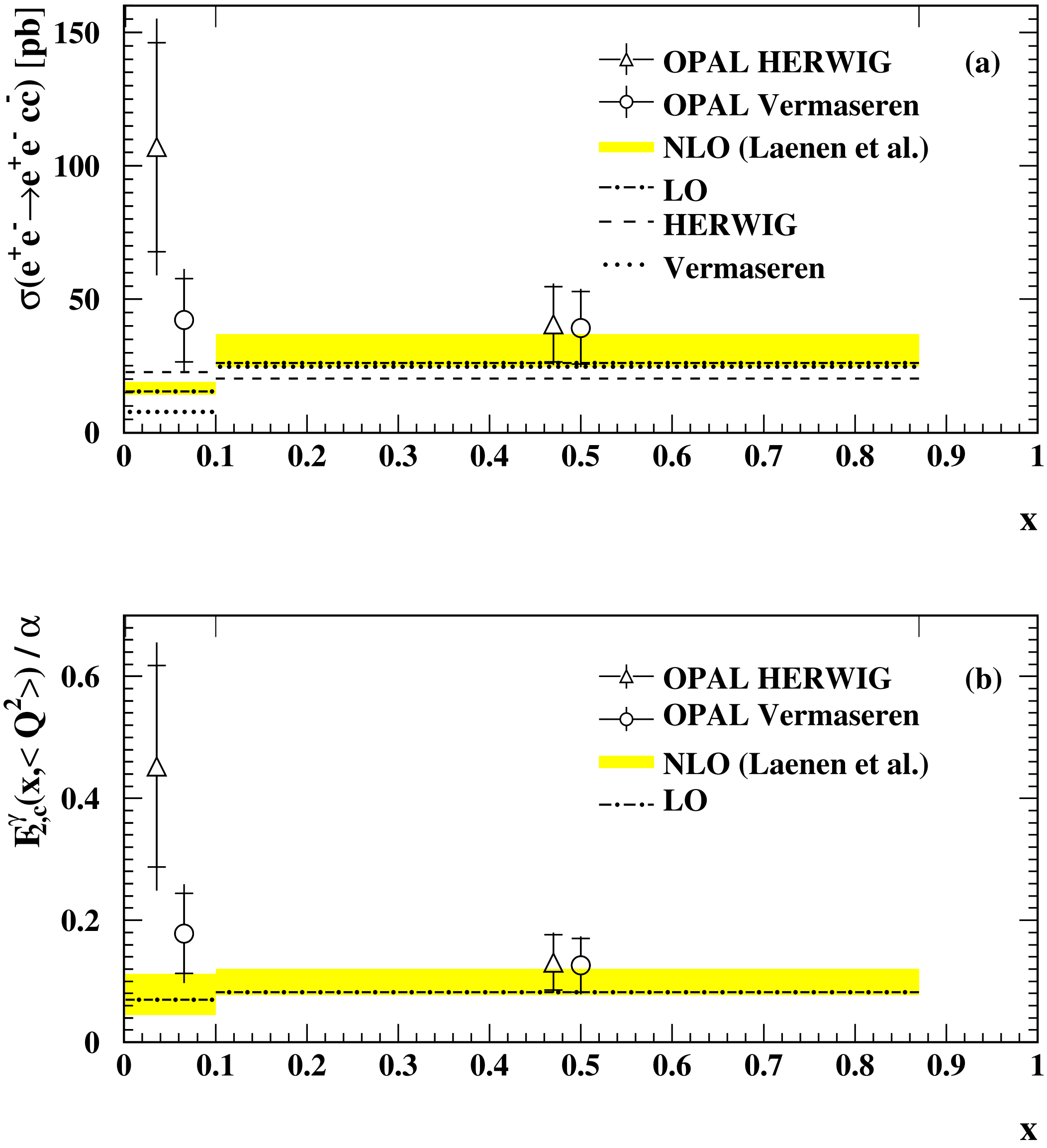




- Both HERWIG and Vermaseren MC describe the shape of the data

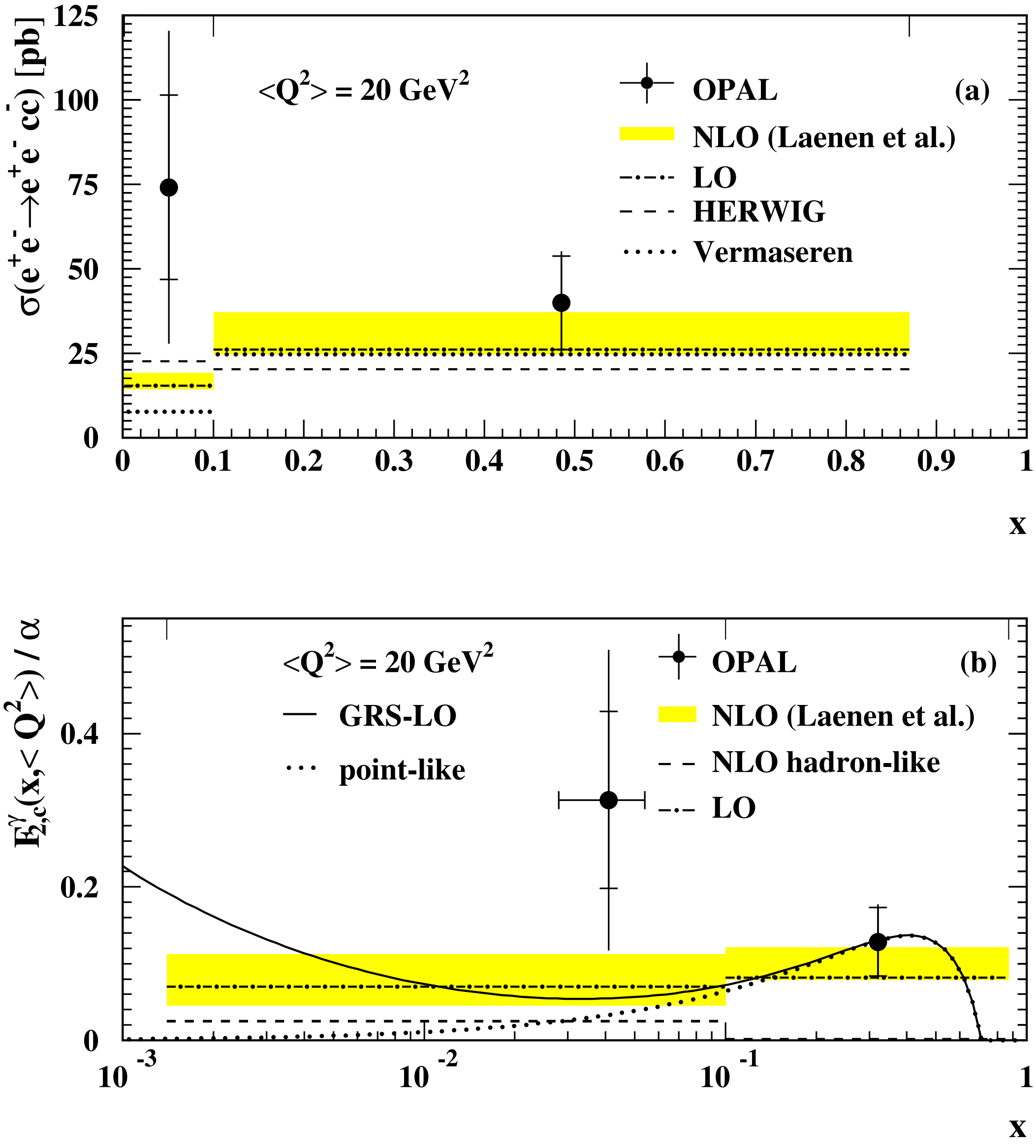
Charm structure function

❒ $0.0014 < x < 0.1$, $0.1 < x < 0.87$
❒ $\langle Q^2 \rangle = 20\ \mathrm{GeV}^2$



- $F_{2,c}^{\gamma}$ in $\gamma\gamma$ collisions measured for the first time !

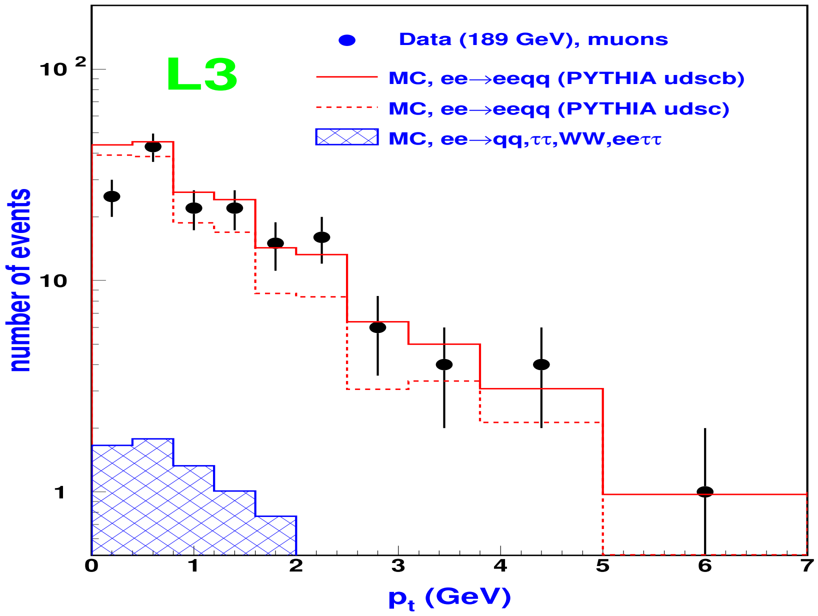
Charm structure function: OPAL



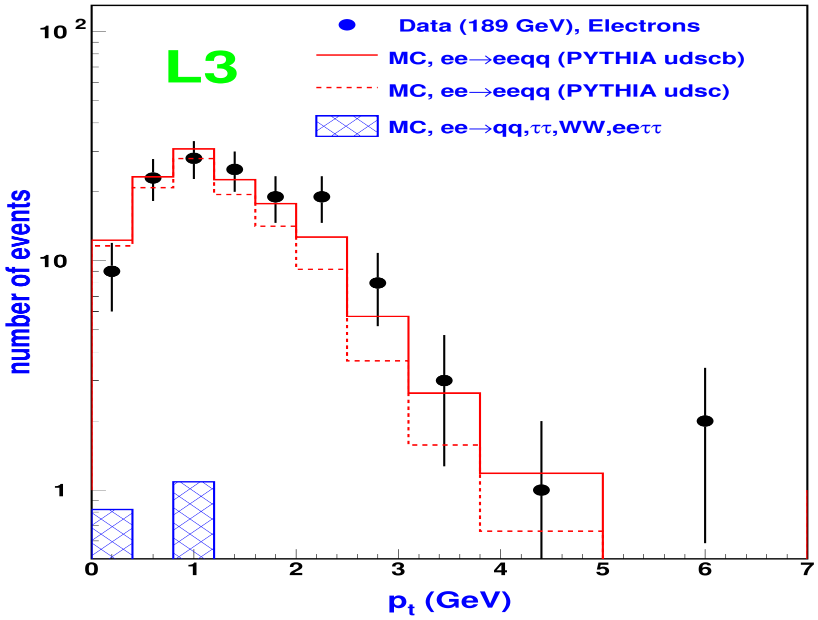
- Hadron-like component of $F_{2,c}^{\gamma}$ is needed

Search for Beauty: L3 Data

p_t with respect to the nearest jet



$\mathrm{P}^{\mu} > 2.5$ GeV
$\mathrm{P}^{\mu}_{\mathrm{t}} > 1.5$ GeV
$\mathrm{N}^{\mu}_{\mathrm{ev}} = 49$
$\varepsilon^{\mu}_{b} = 0.9\%$
$\Pi^{\mu}_{b} = 34\%$



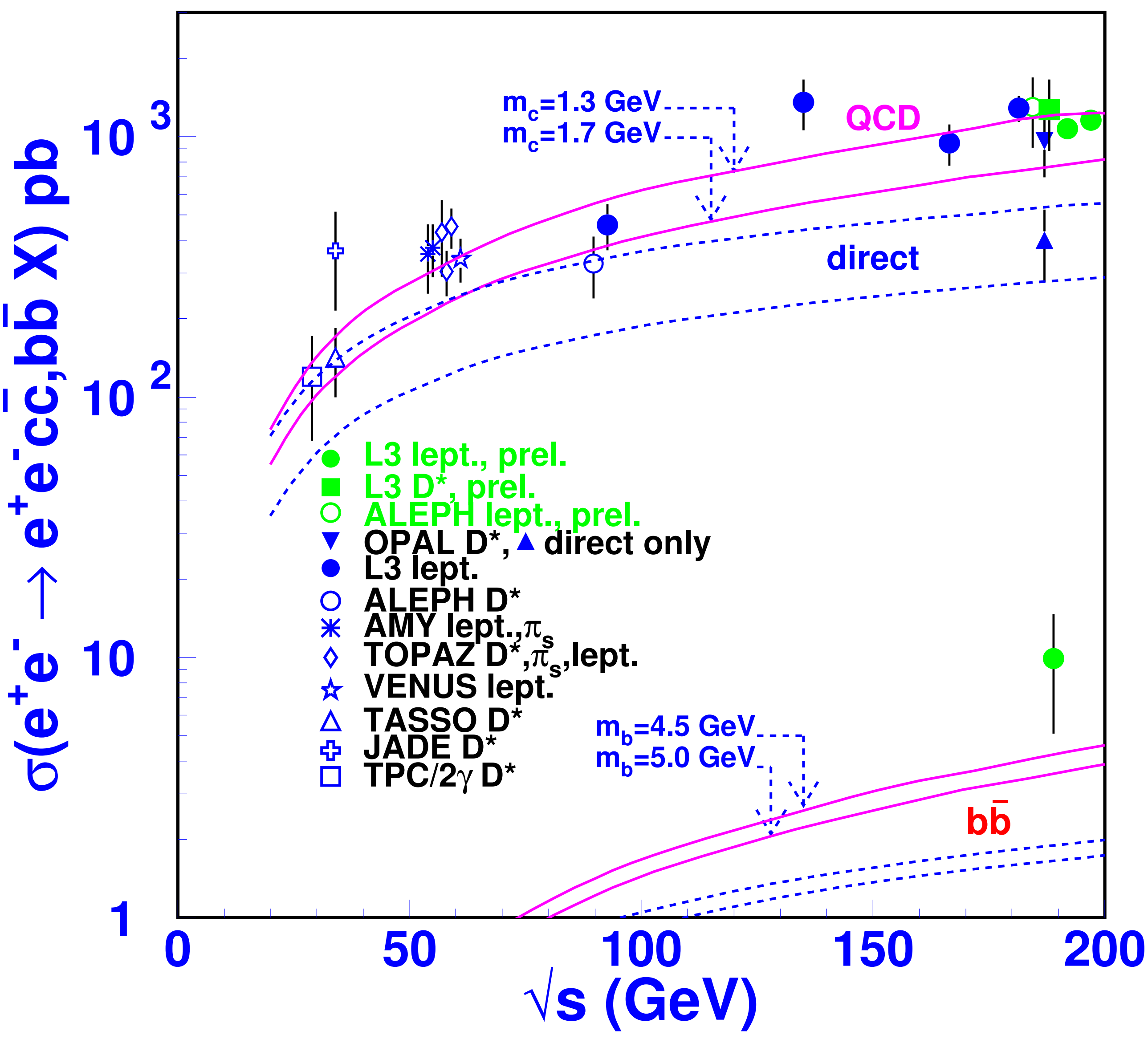
$\mathrm{P}^{\mathrm{e}} > 2.0$ GeV
$\mathrm{P}^{\mathrm{e}}_{\mathrm{t}} > 1.0$ GeV
$\mathrm{N}^{\mathrm{e}}_{\mathrm{ev}} = 96$
$\varepsilon^{e}_{b} = 1.6\%$
$\Pi^{e}_{b} = 28\%$

Leptons from bottom decays have higher p_t.

Preliminary:

Muons:	$\sigma_{\mathrm{b\bar{b}}} = 10.3 \pm 4.6(\mathrm{stat}) \pm 3.3(\mathrm{syst})$ pb
Electrons:	$\sigma_{\mathrm{b\bar{b}}} = 9.6 \pm 3.6(\mathrm{stat}) \pm 4.1(\mathrm{syst})$ pb
Combined:	$\sigma_{\mathrm{b\bar{b}}} = 9.9 \pm 2.9(\mathrm{stat}) \pm 3.8(\mathrm{syst})$ pb

Charm and beauty in $\gamma\gamma$ collisions



$b\bar{b}$ in $\gamma\gamma$ collisions measured for the first time !

Summary

- Heavy flavour production in agreement with QCD prediction, ➜ $\gamma g \rightarrow c\bar{c}, b\bar{b}$ is important

Clear evidence for gluon content of the photon

➩ Consistent measurements of charm production by L3, OPAL, and ALEPH, and by using lepton and D^* tags

- First measurement of $\gamma\gamma \rightarrow b\bar{b}$ by L3
- First measurement of $F_{2,c}^{\gamma}$ by OPAL
- First measurement of $\sigma(\gamma\gamma \rightarrow c\bar{c})$ energy dependence by L3.
  Steep rise of the cross section is observed.