Heavy Flavour Production in $\gamma\gamma$ Collisions

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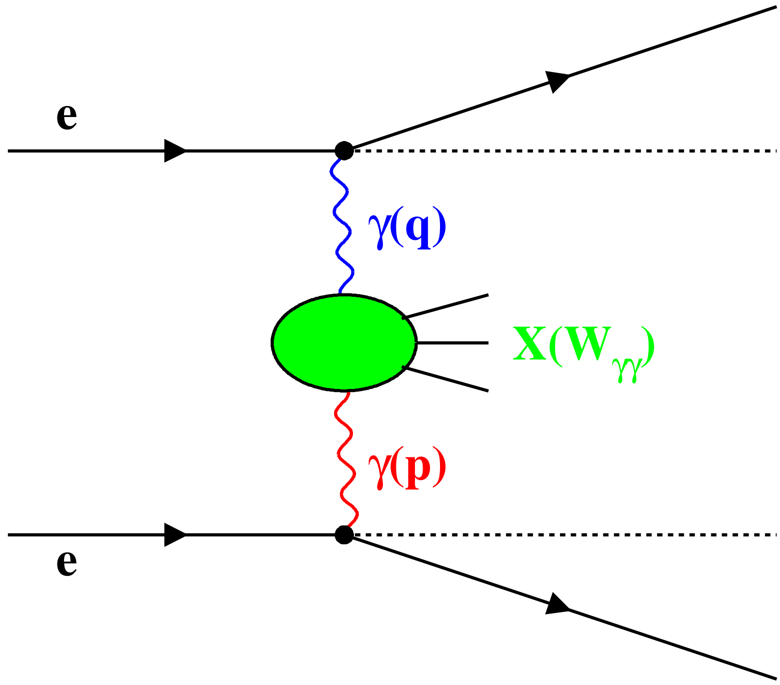
International Europhysics Conference on High Energy Physics
July 12-18, 2001, Budapest, Hungary

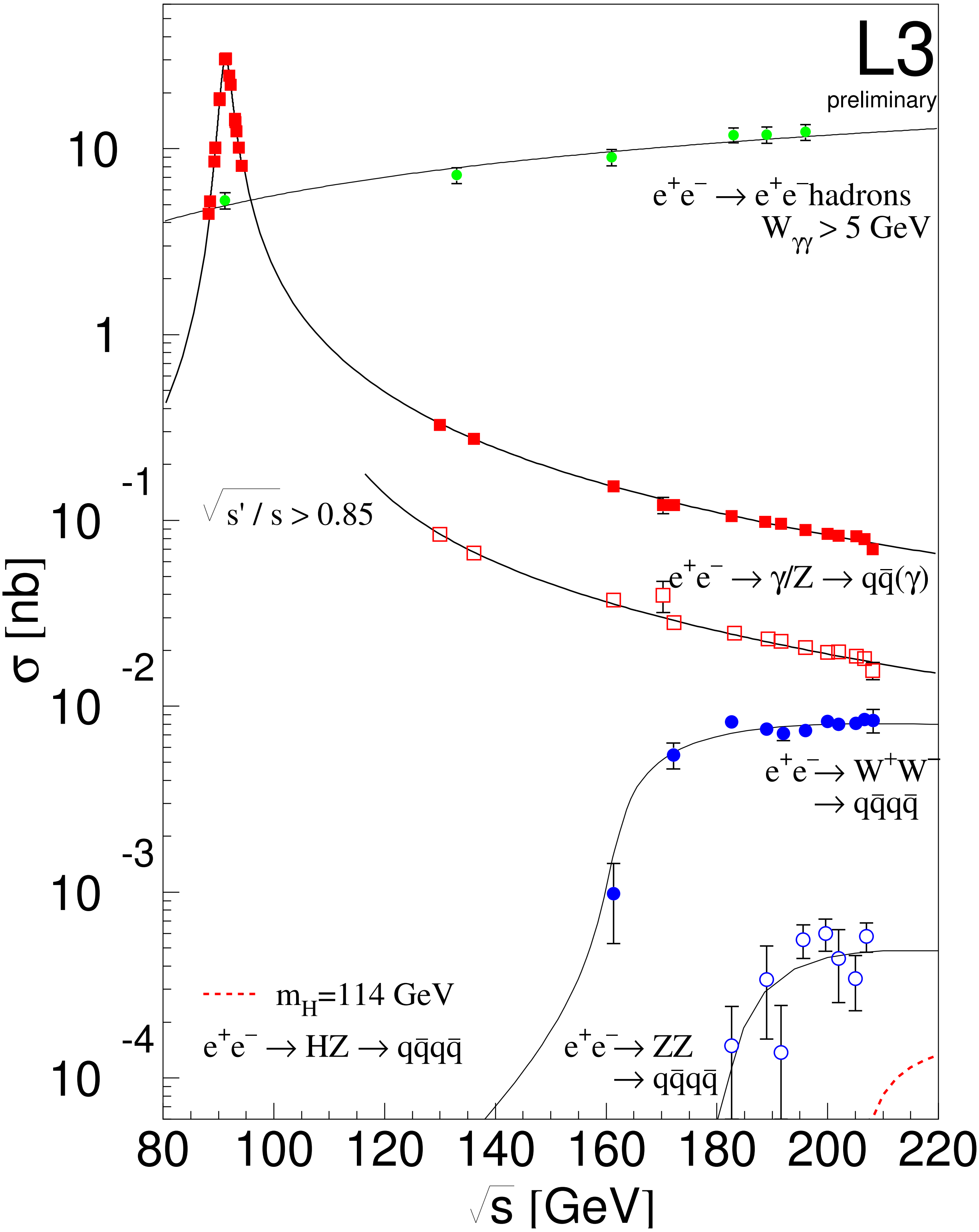
Outline:

- Charm Production
- Beauty Production
- Jet Production



- **Test of the perturbative QCD**

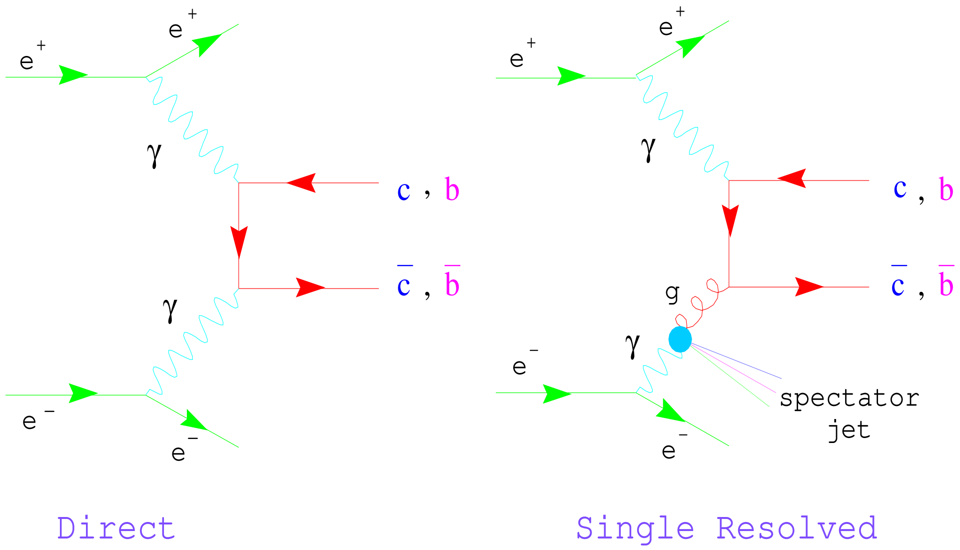
Hadron production at LEP



Two-photon collisions are the dominant source of hadrons at LEP2 energies

Inclusive Charm and Beauty Production

Motivation :



- 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
- ➢ $c\bar{c}$ vs $b\bar{b}$

Inclusive Heavy Flavour Production

Data :

L3 : 91 - 202 GeV, $\mathcal{L} = 792\ \text{pb}^{-1}$
PLB453 (1999) 83; PLB467 (1999) 137; PLB503 (2001) 10;
CERN-EP/2000-155; + Preliminary.

OPAL : 183 - 202 GeV, $\mathcal{L} = 428\ \text{pb}^{-1}$
Eur. Phys. J C16 (2000) 579; + Preliminary.

ALEPH : 91 - 183 GeV, $\mathcal{L} = 126\ \text{pb}^{-1}$
PLB355 (1995) 595; + Preliminary.

DELPHI : 161 - 204 GeV, $\mathcal{L} = 458\ \text{pb}^{-1}$
Preliminary.

Charm identification :

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

OPAL: D^{*+}, lepton ($c \to l^{\pm}$X , $l^{\pm} \equiv \mu^{\pm}$)

ALEPH: lepton ($c \to l^{\pm}$X , $l^{\pm} \equiv \mu^{\pm}$), D^{*+}

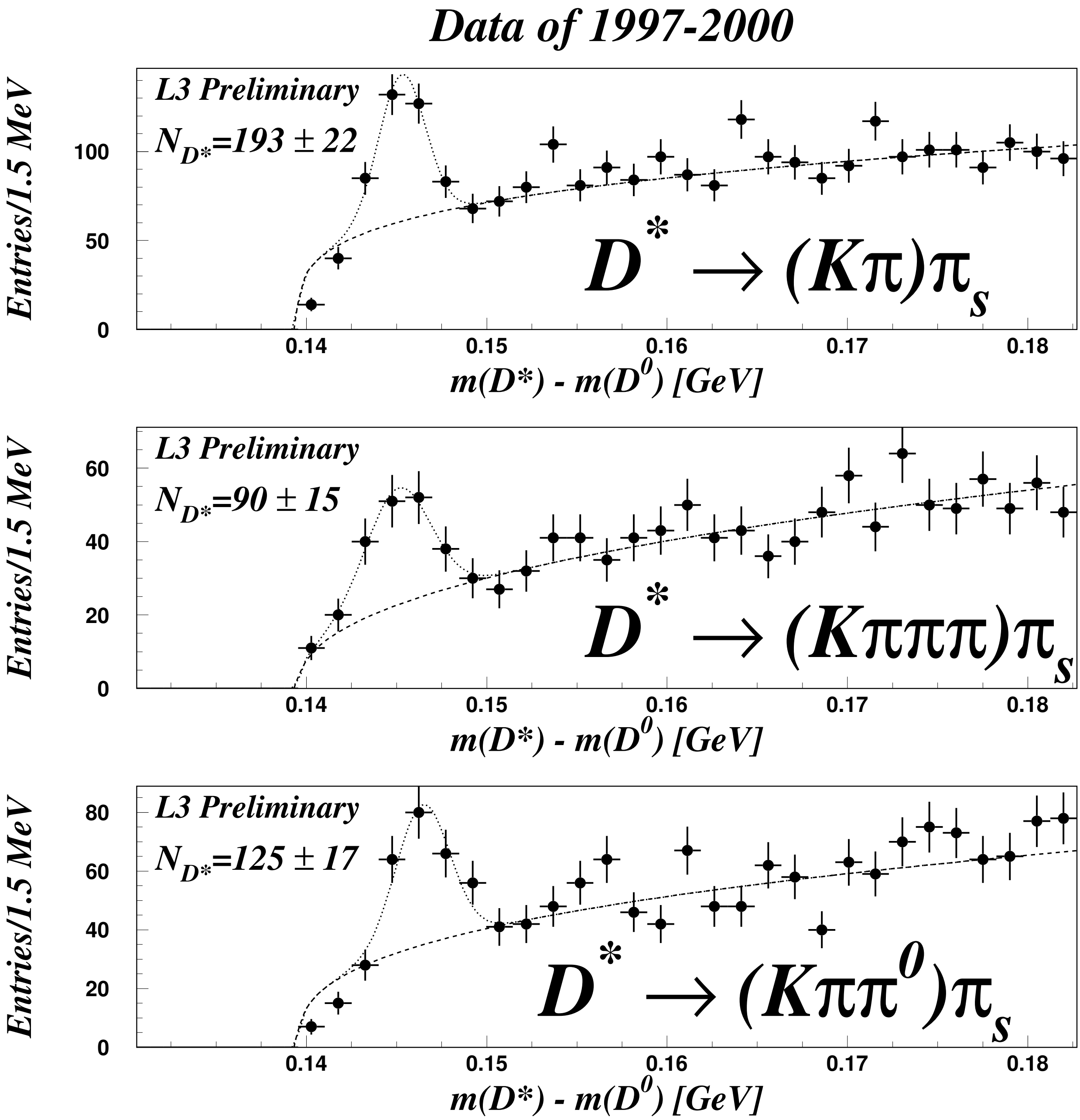
DELPHI: D^{*+}

Bottom identification :

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

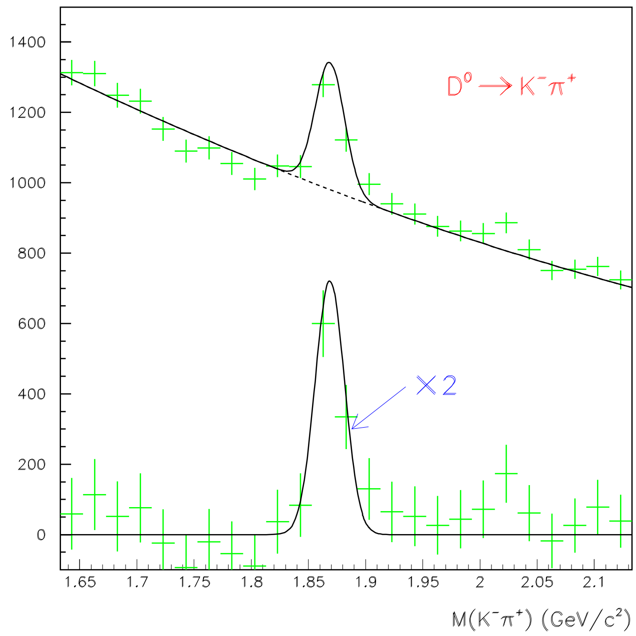
OPAL : lepton ($c \to l^{\pm}$X , $l^{\pm} \equiv \mu^{\pm}$)

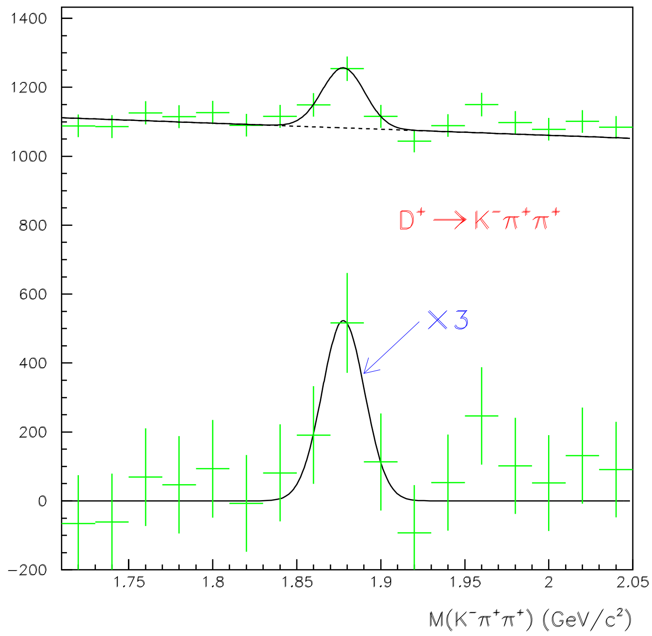
D* Production :

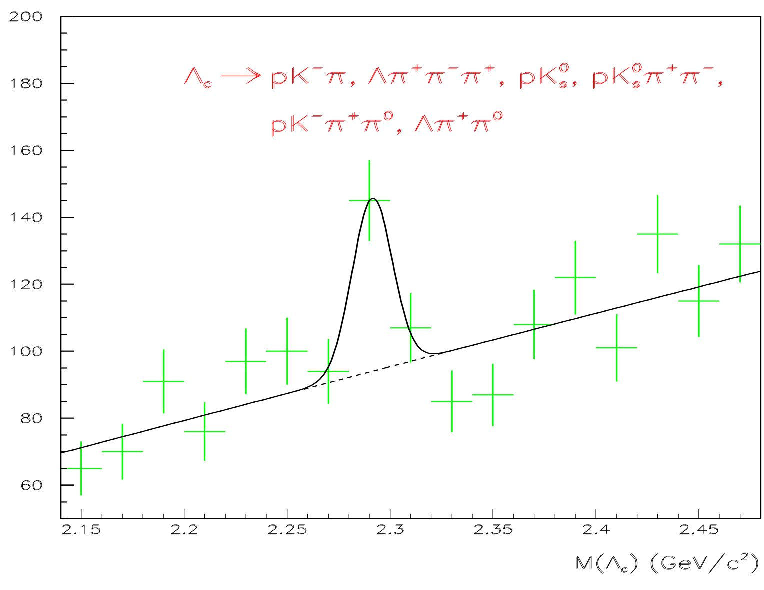


- well identified signal
- $\sigma(e^+e^- \to e^+e^- c\bar{c}X) = 929 \pm 71 \pm 261$ pb

D^0, D^+, Λ_c Production: DELPHI preliminary







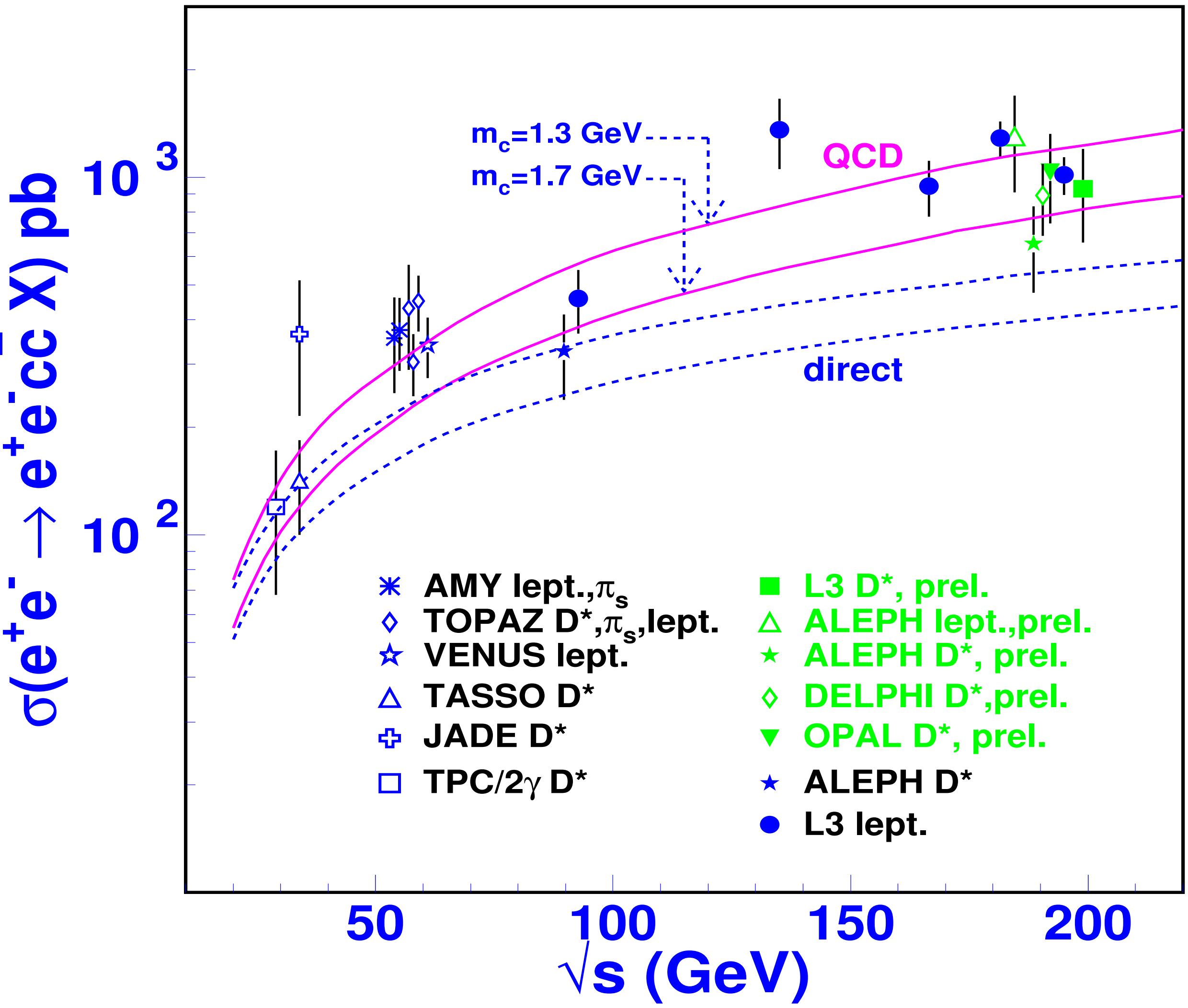
$$N_{D^0} = 498 \pm 74$$
$$N_{D^+} = 277 \pm 66$$
$$N_{\Lambda_c} = 62 \pm 26$$

$$\sigma(e^+e^- \to e^+e^- D^0 X) = 918 \pm 149(\mathrm{st.}) \pm 157(\mathrm{sys.})\ \mathrm{pb}$$
$$\sigma(e^+e^- \to e^+e^- D^+ X) = 362 \pm 97(\mathrm{st.}) \pm 62(\mathrm{sys.})\ \mathrm{pb}$$
$$\sigma(e^+e^- \to e^+e^- \Lambda_c X) = 85 \pm 42(\mathrm{st.}) \pm 14(\mathrm{sys.})\ \mathrm{pb}$$

from D^* :

$$\sigma(e^+e^- \to e^+e^- c\bar{c} X) = 889 \pm 128(\mathrm{st.}) \pm 157(\mathrm{sys.})\ \mathrm{pb}$$

Charm production in $\gamma\gamma$ collisions

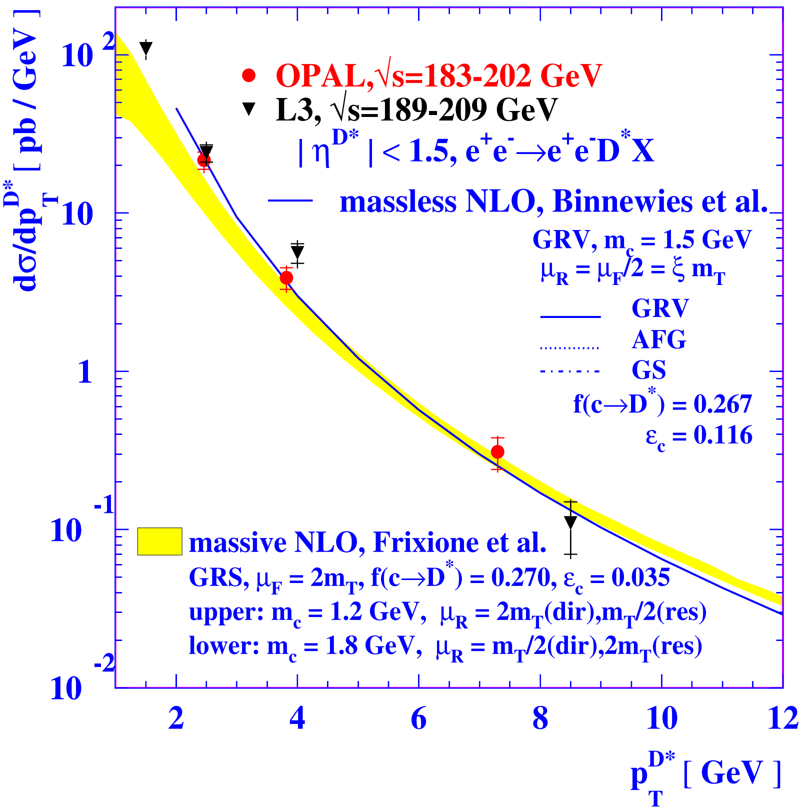


- clear evidence of gluon content of photon

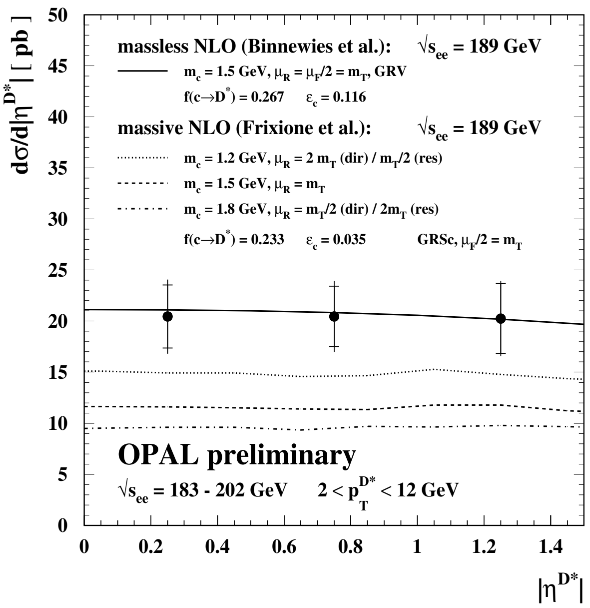
theory prediction from
M.Drees,M.Krämer,J.Zunft and P.M.Zerwas,Phys. Lett. B306 (1993) 371), $M_R = M_F = m_c$; GRV p.d.f.

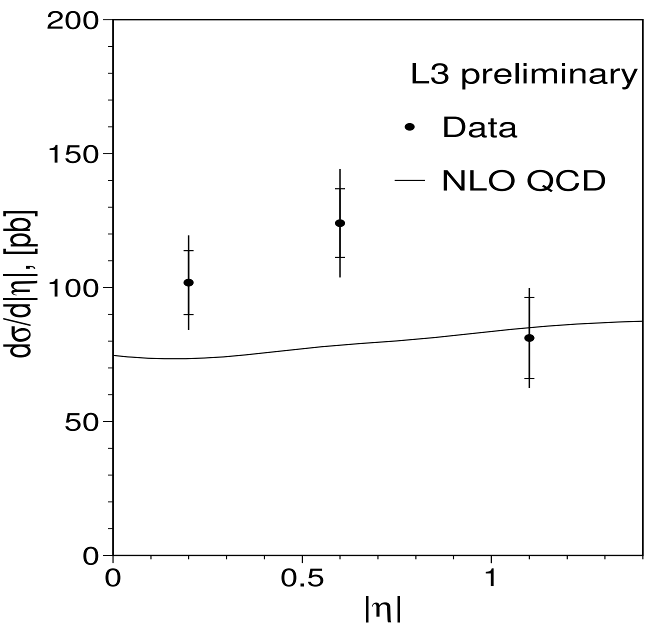
D* Production : differential cross-sections

❐ $\frac{d\sigma}{dp_t}$:



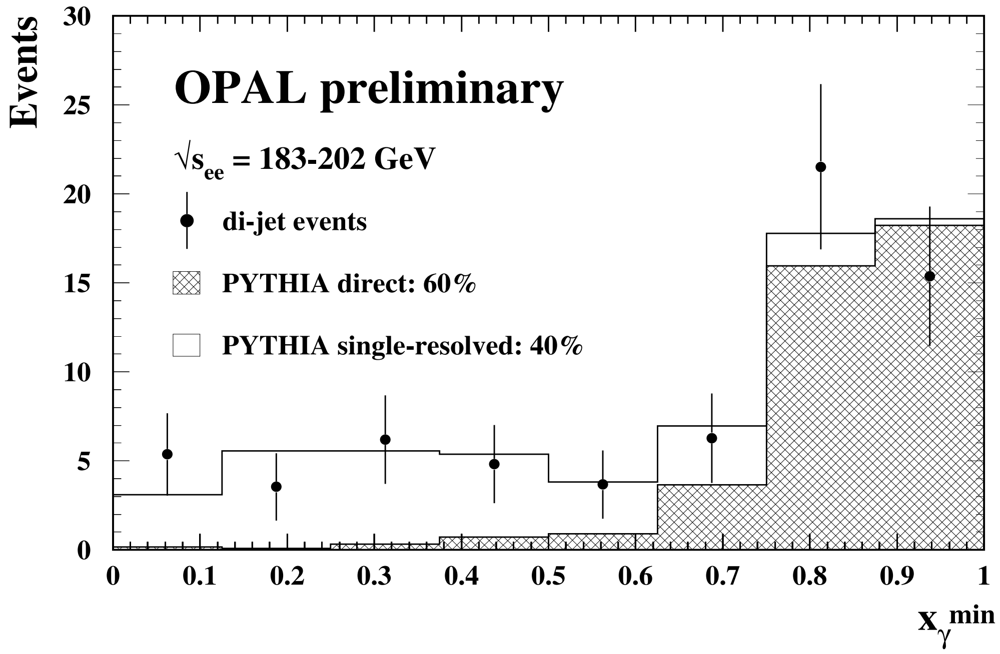
❐ $\frac{d\sigma}{d|\eta|}$:

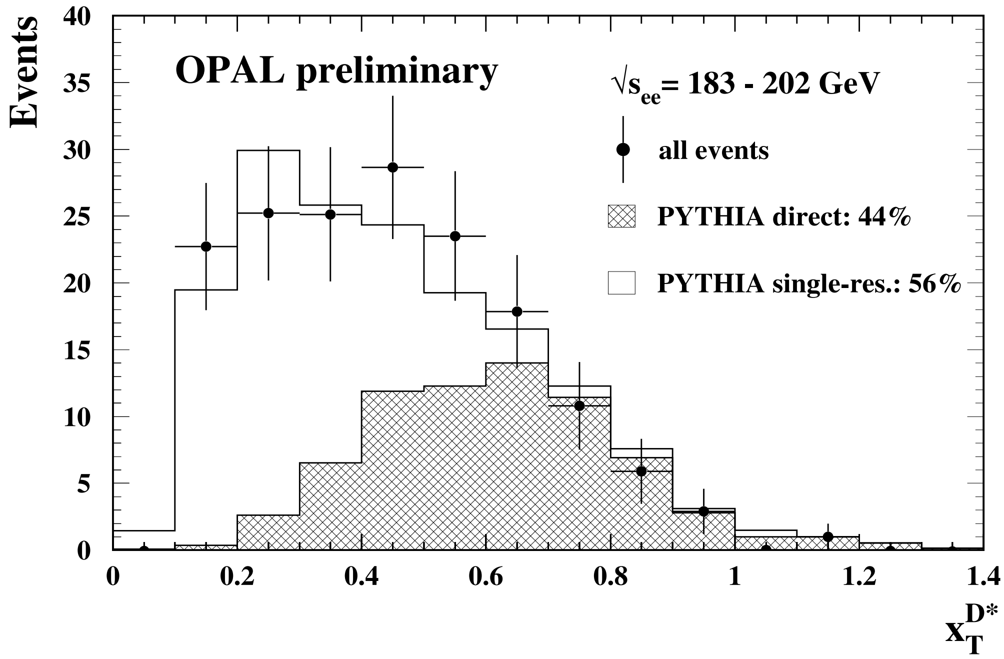




D* Production

❒Separation of Direct and Resolved processes

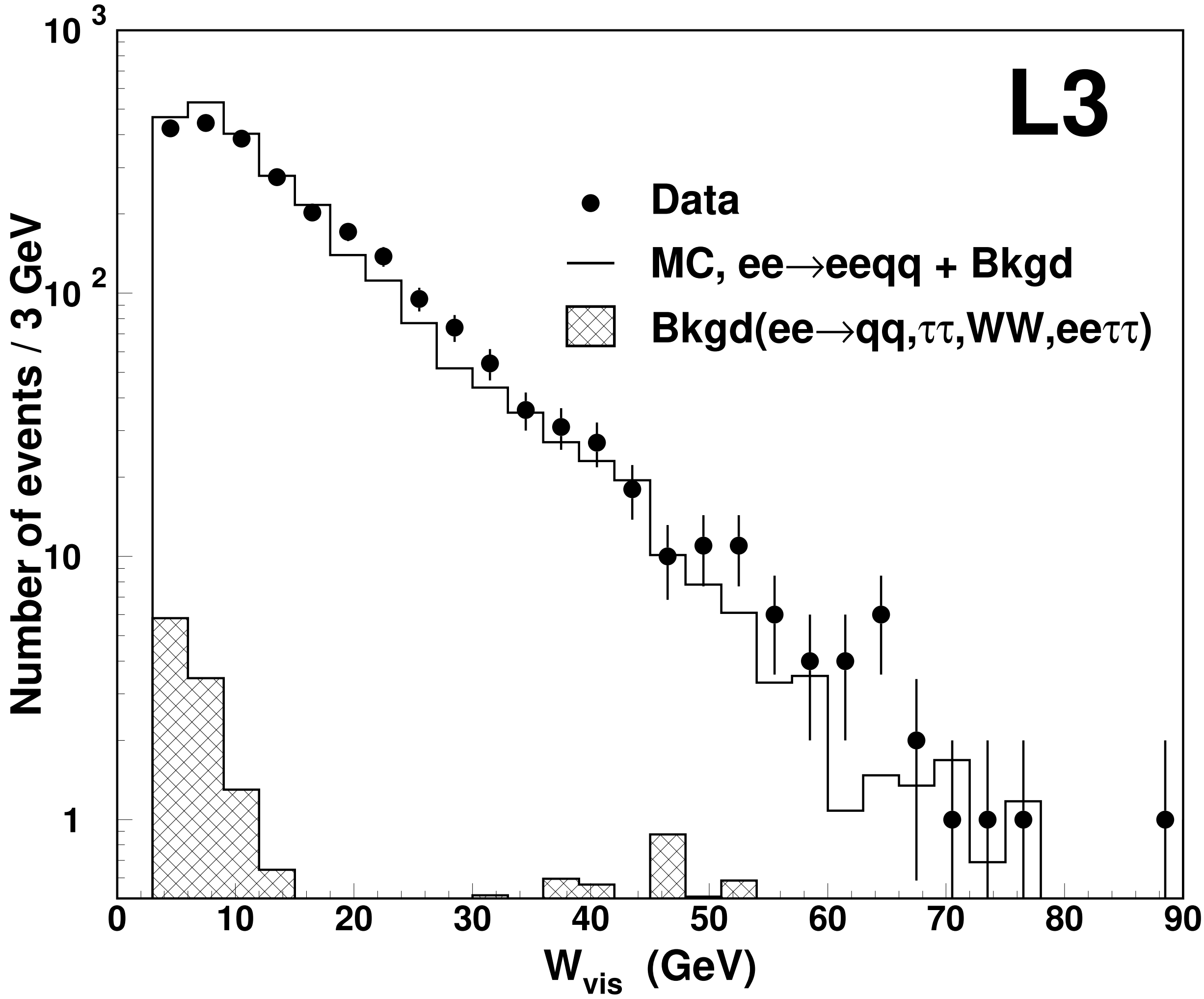




$e^+e^- \rightarrow e^+e^-c\bar{c}$ (using LO Monte Carlo !) :

$\sigma_{\rm dir} = 362 \pm\ 99$ pb $\sigma_{res} = 671 \pm\ 223$ pb

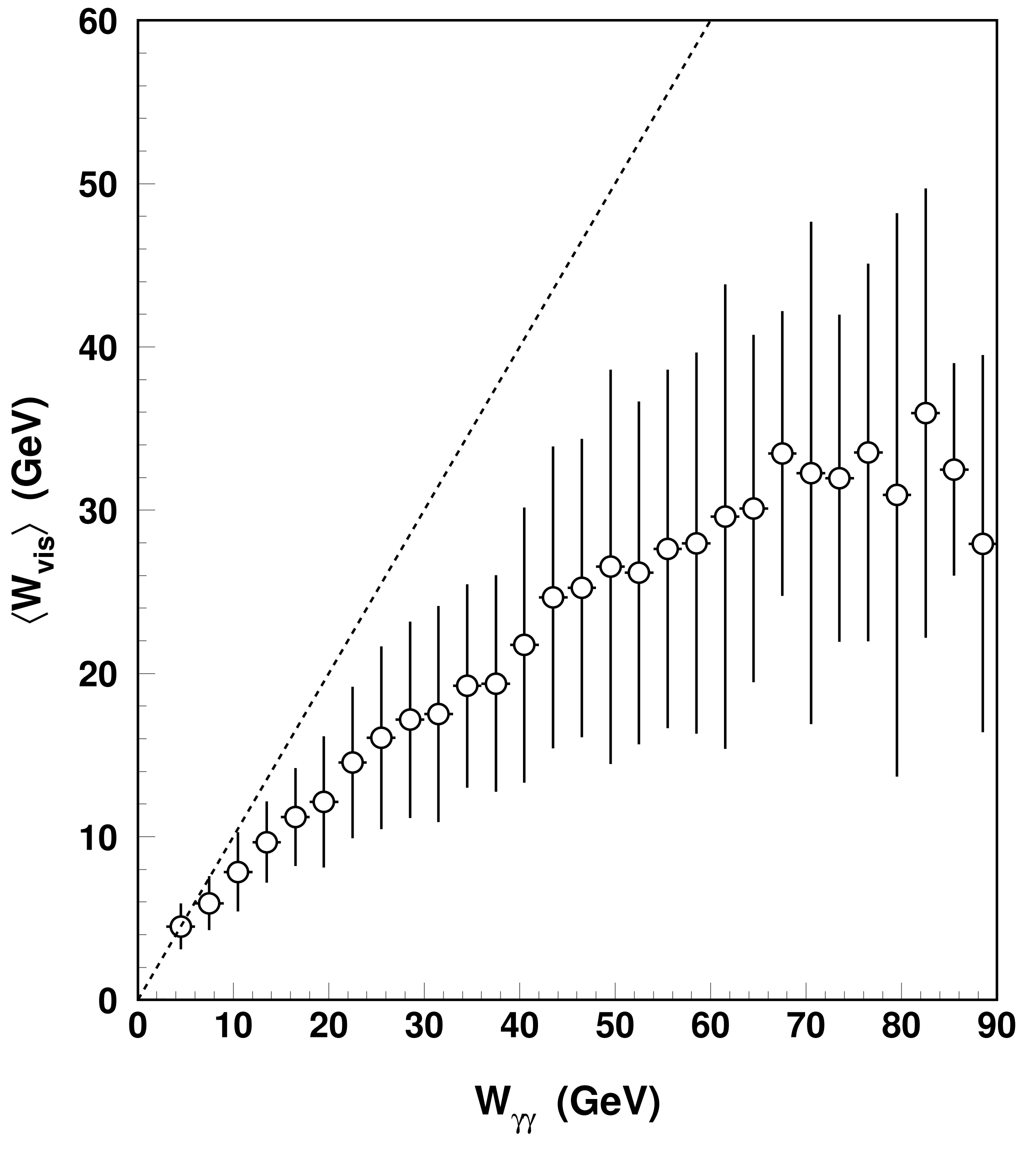
$\sigma(\gamma\gamma \to c\bar{c})$ vs $W_{\gamma\gamma}$



- Data are in excess of MC for high visible mass

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

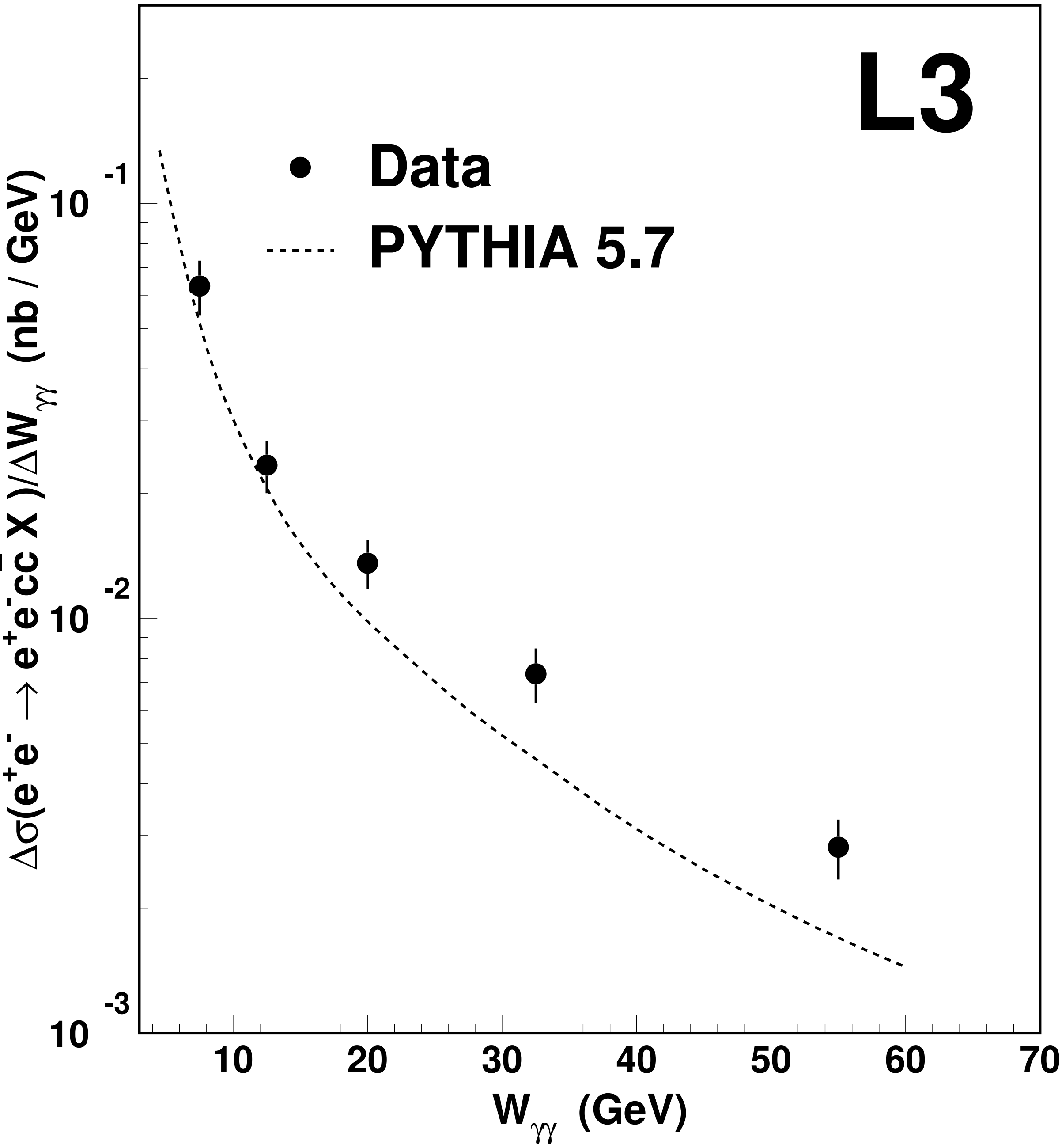
- Unfolding corrects for acceptance (missing energy) and detector resolution



❑ unfolding with Bayes (G. D'Agostini, NIM A362(1995) 487)

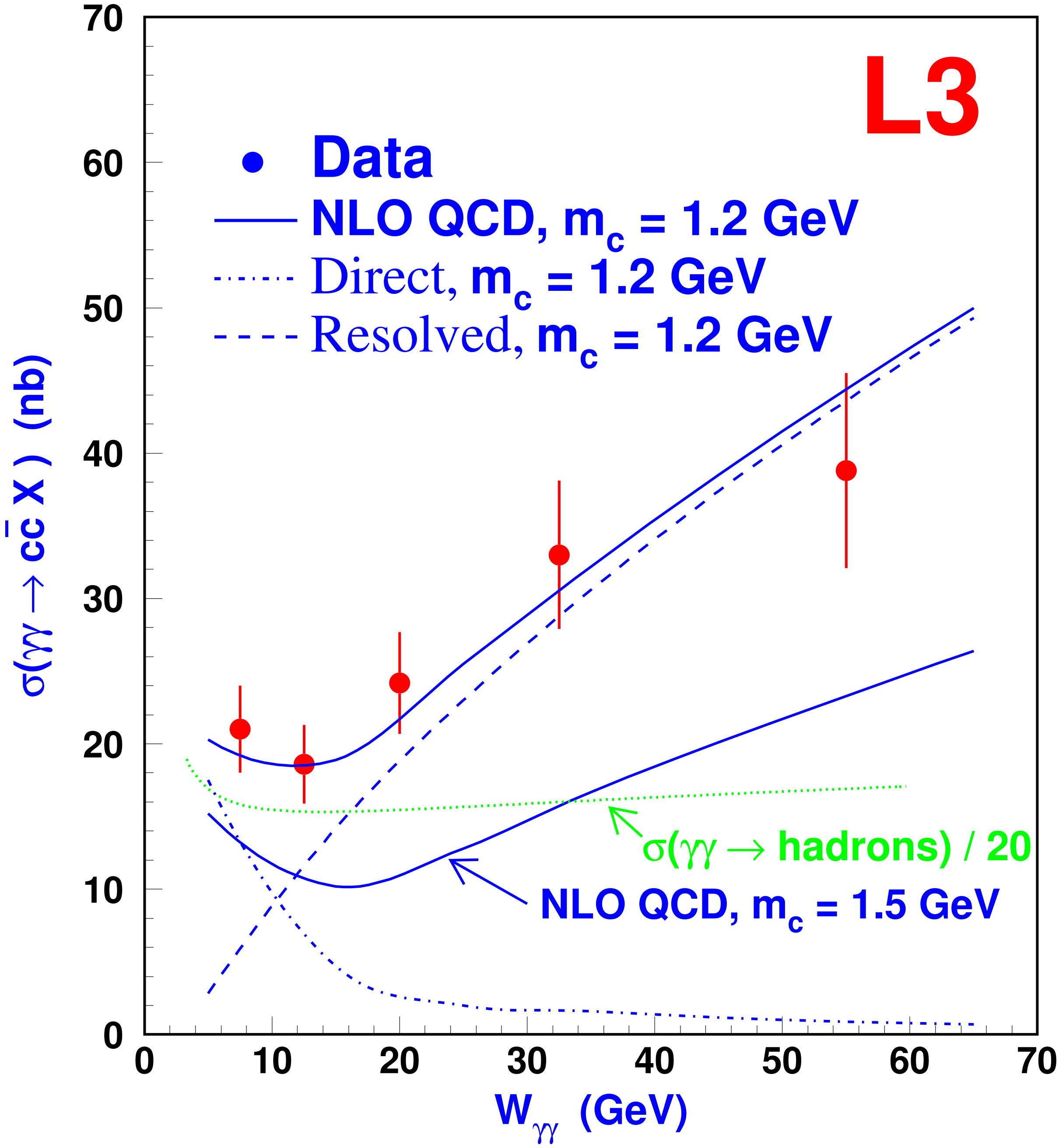
❑ $\sigma_{ee} = \mathcal{L}_{\gamma\gamma} \otimes \sigma_{\gamma\gamma}$

$\sigma(ee \to eec\bar{c}X)$ vs $W_{\gamma\gamma}$:



- data harder than LO MC prediction

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



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

$\sigma(\gamma\gamma \to c\bar{c})$: DL fit

- Fit with Donnachie and Landshoff parametrisation (Phys. Lett., B296 (1992) 227):

$$\sigma_{\gamma\gamma} = As^{\varepsilon} + Bs^{-\eta} \ , \ \ s = W_{\gamma\gamma}^2$$

- Universal fit (PDG 2000):

$$\varepsilon = 0.093 \pm 0.002, \ \ \eta = 0.358 \pm 0.015$$

- L3 fit for $\sigma(\gamma\gamma \to c\bar{c})$, $\eta = 0.358$ fixed; A,B, ϵ free

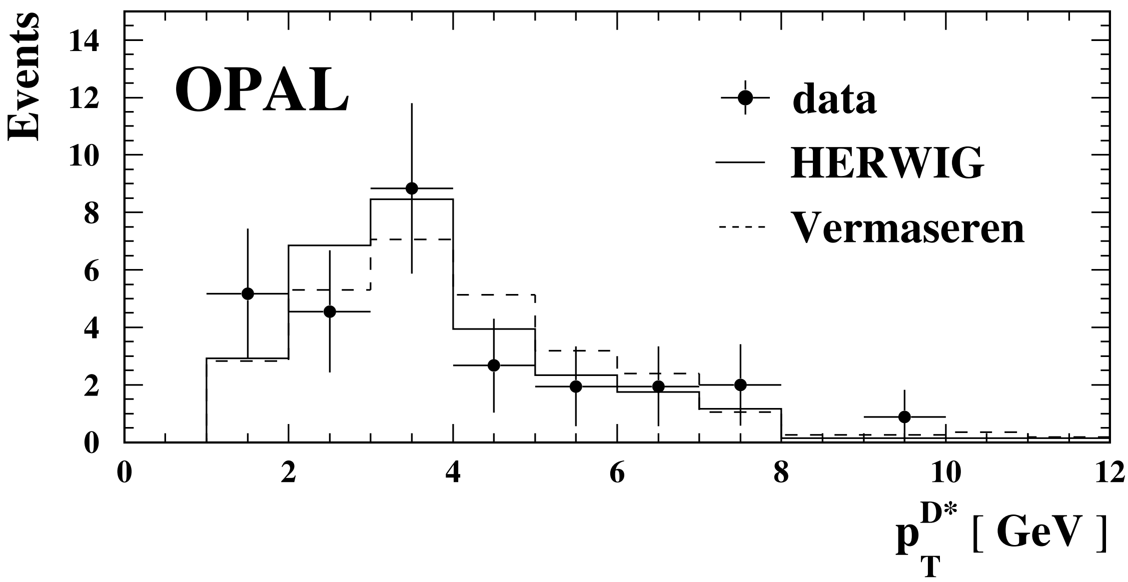
$$\varepsilon = 0.40 \pm 0.08 \qquad 5 < \mathrm{W}_{\gamma\gamma} < 70\mathrm{GeV}$$

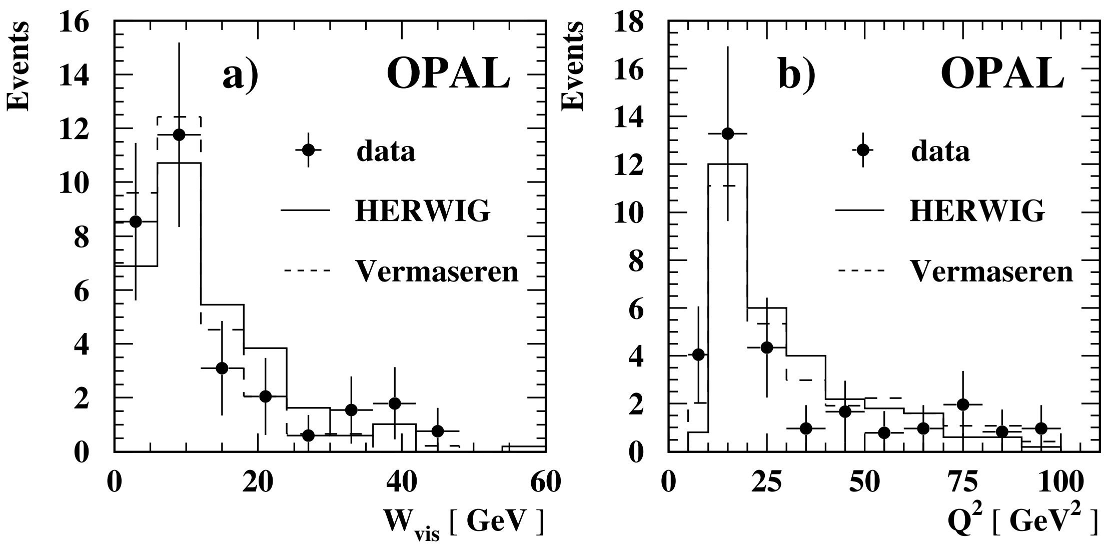
- L3 fit for $\sigma(\gamma\gamma \to c\bar{c})$ by $\sigma_{\gamma\gamma} = As^{\varepsilon}$; A,$\epsilon$ free

$$\varepsilon = 0.26 \pm 0.04 \qquad 10 < \mathrm{W}_{\gamma\gamma} < 70\mathrm{GeV}$$

Charm structure function

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

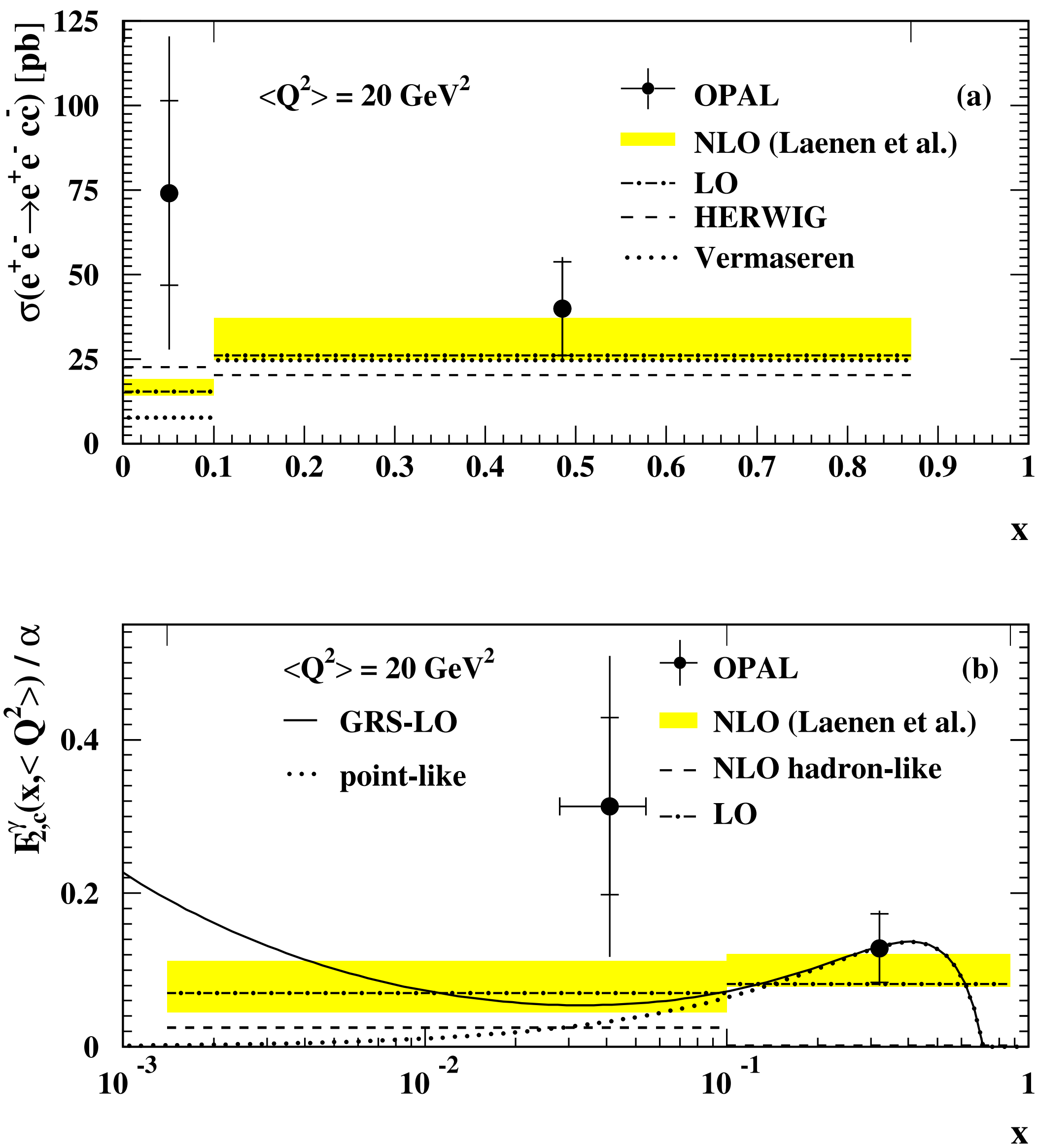




- Both HERWIG and Vermaseren MC describe the shape of the data

Charm structure function:

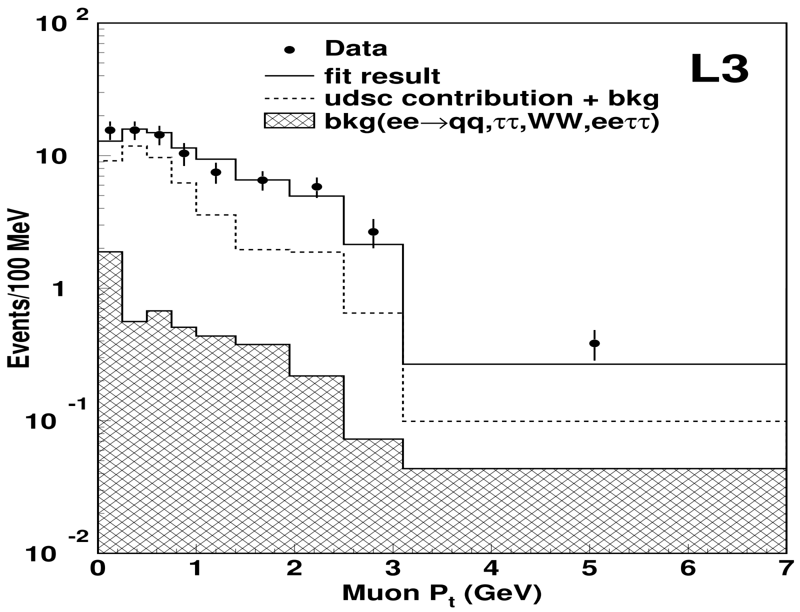
- ❒ $0.0014 < x < 0.1$, $0.1 < x < 0.87$
- ❒ $\langle Q^2 \rangle = 20$ GeV^2



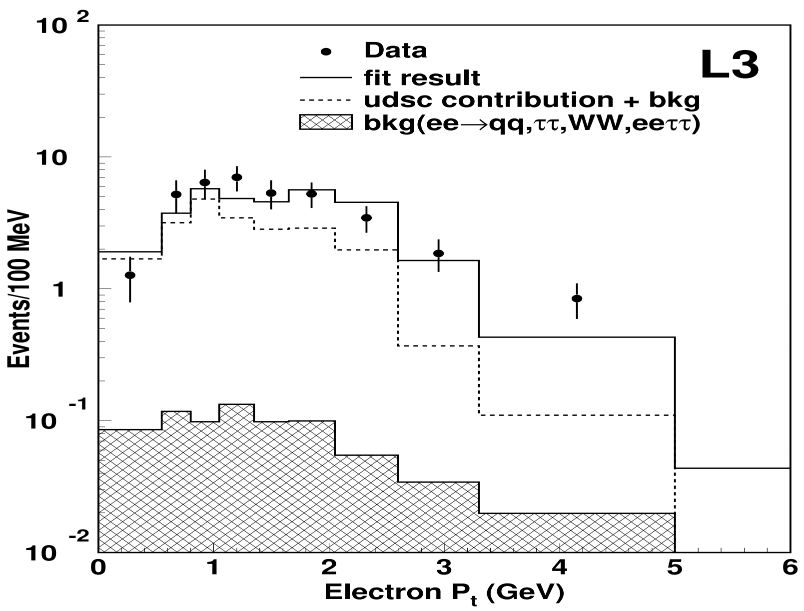
• Hadron-like component of $F_{2,c}^{\gamma}$ is needed

Search for Beauty:
L3, PLB503 (2001) 10.

Fit P_t with respect to the nearest jet spectrum



$P_\mu > 2.0$ GeV
$N_{ev} = 269$
$\varepsilon_b = 2.2\%$
$f_b = 51.6 \pm 9.8\%$



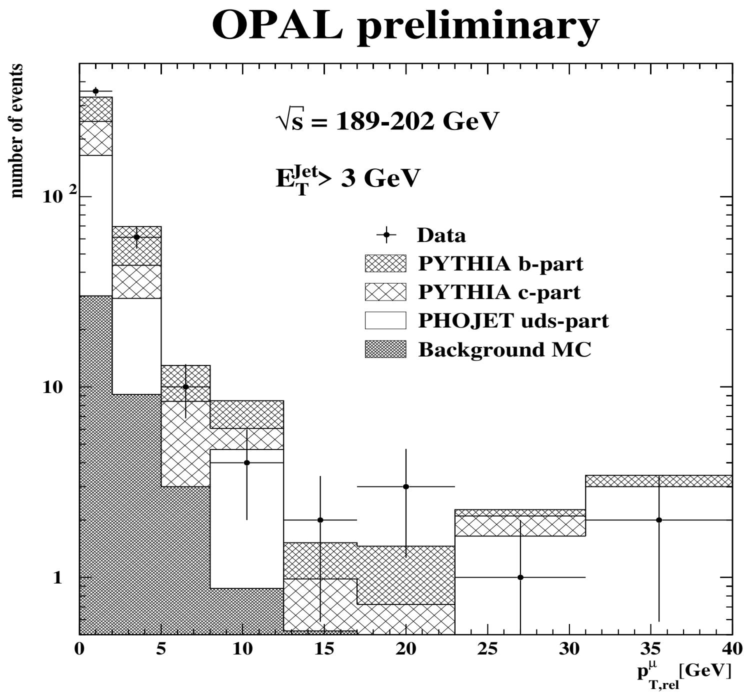
$P_e > 2.0$ GeV
$N_{ev} = 137$
$\varepsilon_b = 1.25\%$
$f_b = 42.3 \pm 11.4\%$

Leptons from bottom decays have higher P_t

$\mu^\pm$: $\sigma_{b\bar{b}} = 14.9 \pm 2.8(\text{st.}) \pm 2.6(\text{sys.})$ pb
$e^\pm$: $\sigma_{b\bar{b}} = 10.9 \pm 2.9(\text{st.}) \pm 2.0(\text{sys.})$ pb
Combined (L3): $\sigma_{b\bar{b}} = 13.1 \pm 2.0(\text{st.}) \pm 2.4(\text{sys.})$ pb

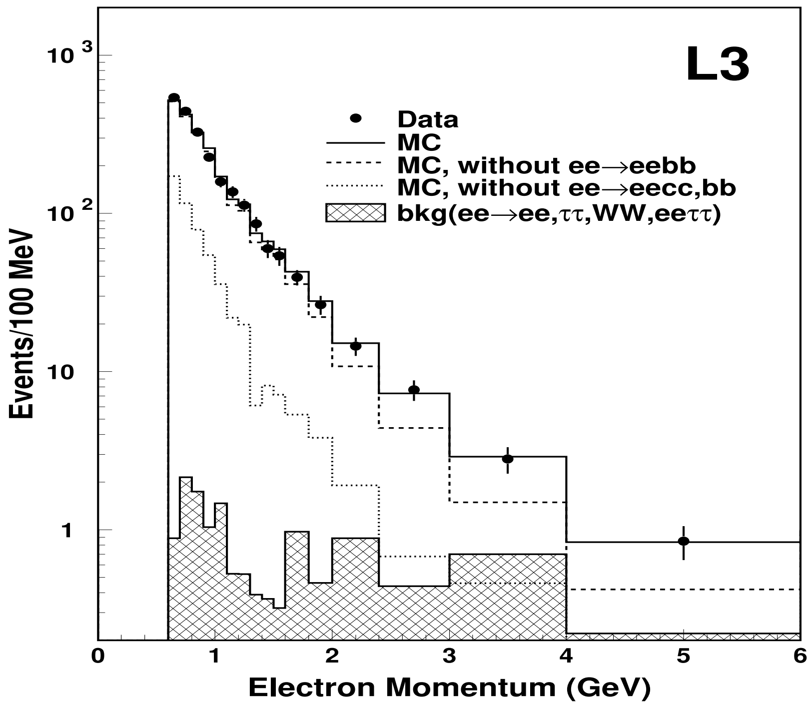
Search for Beauty:

OPAL, p_t^μ w.r.t. the nearest jet, counting method



$P_\mu > 2.0$ GeV
$N_{ev} = 444$
$\varepsilon_b = 1.0\%$
$f_b = 27.2 \pm 4.8\%$

L3, Electron momentum

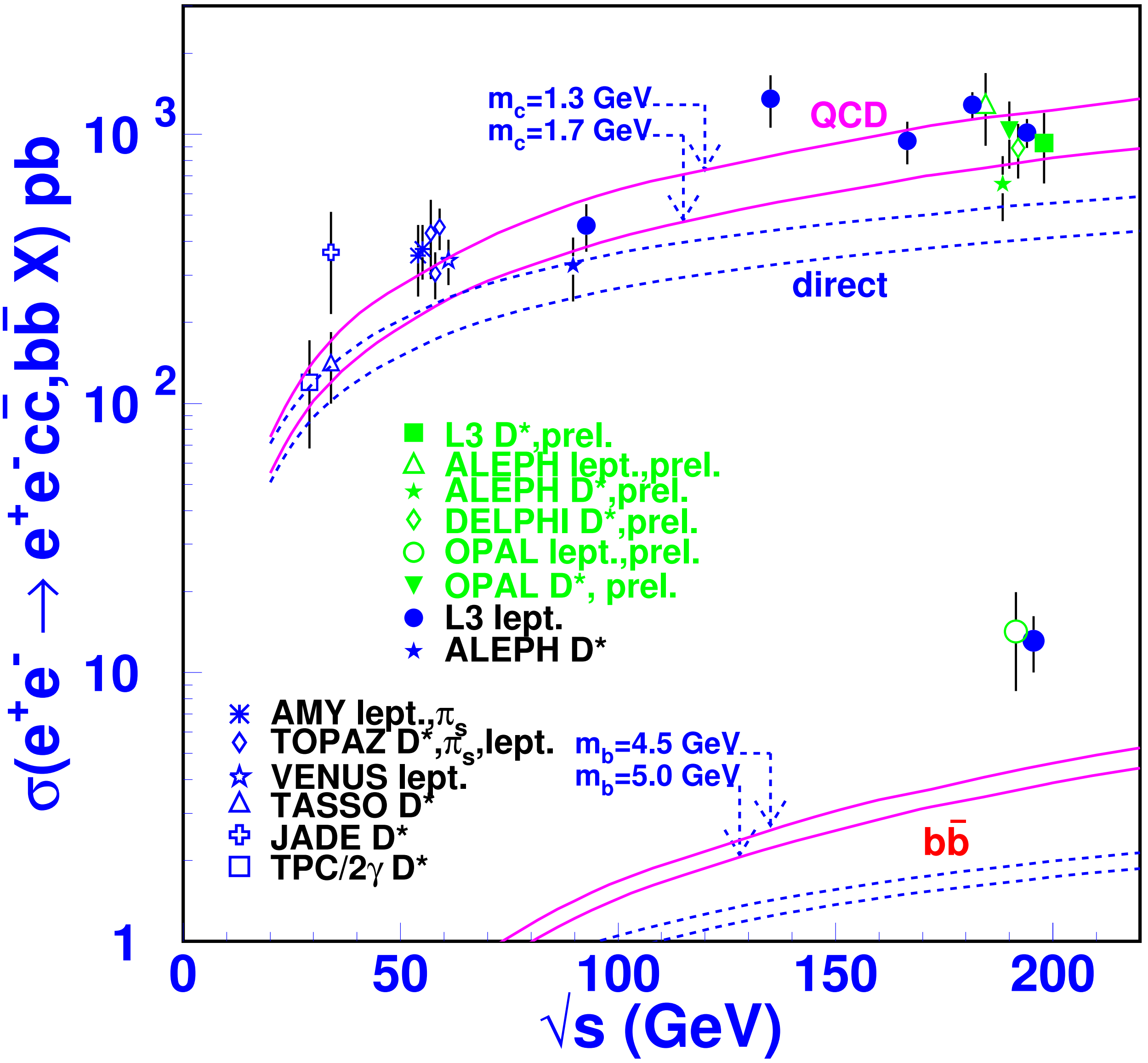


$P_e > 0.6$ GeV
$N_{ev} = 2434$

L3: $\sigma_{b\bar{b}} = 13.1 \pm 2.0(\text{st.}) \pm 2.4(\text{sys.})$ pb

OPAL prel.: $\sigma_{b\bar{b}} = 14.2 \pm 2.5(\text{st.})\ ^{+5.3}_{-4.8}\ (\text{sys.})$ pb

Charm and beauty in $\gamma\gamma$ collisions



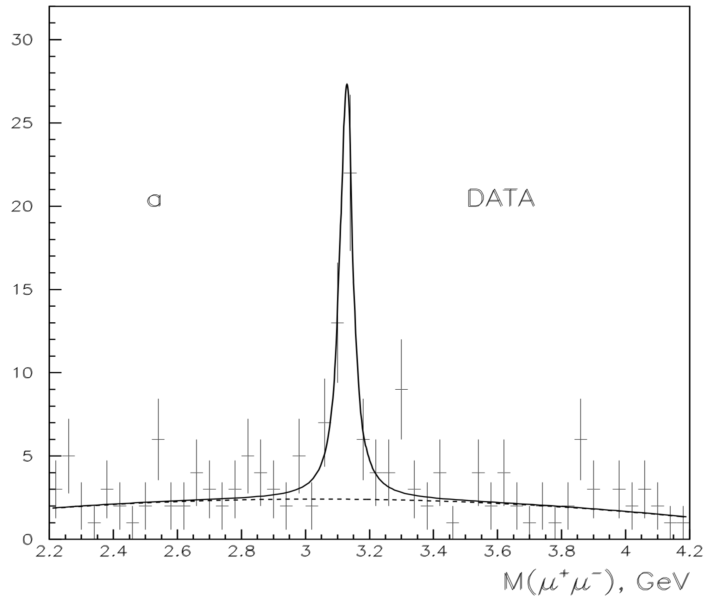
$b\bar{b}$ in excess of the QCD prediction

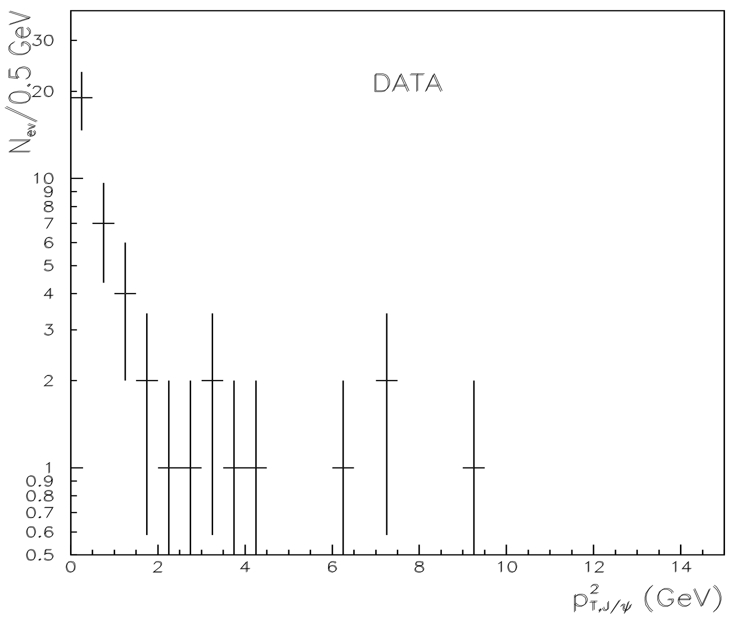
by 4 standard deviations !

Inclusive J/ψ production:

DELPHI (DIS2001): **161 - 204 GeV, $\mathcal{L} = 673$ pb^{-1}**

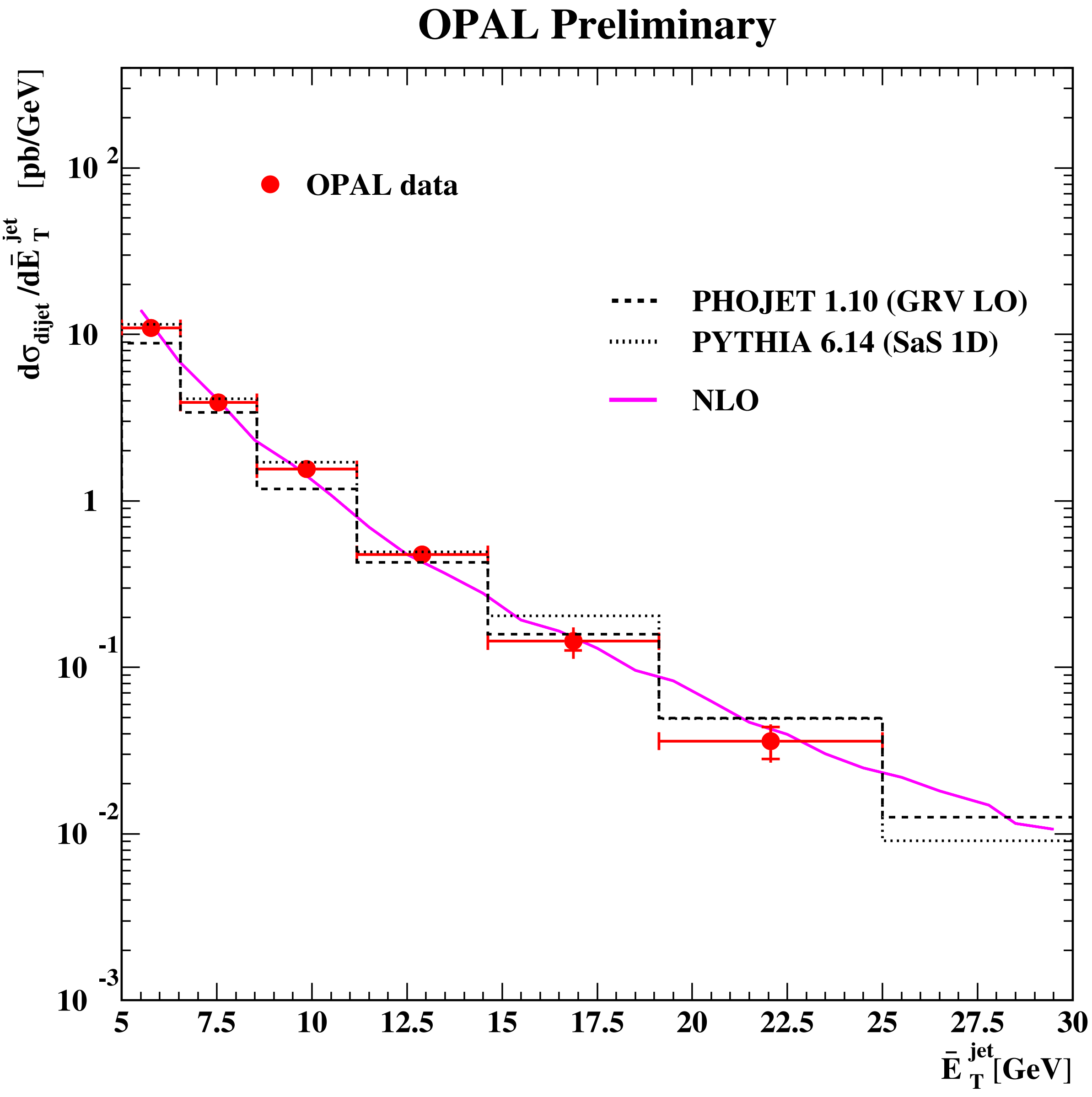
Very Preliminary





- $N(J/\psi \to \mu^+\mu^-) = 47 \pm 6.8$

DiJet Production: OPAL



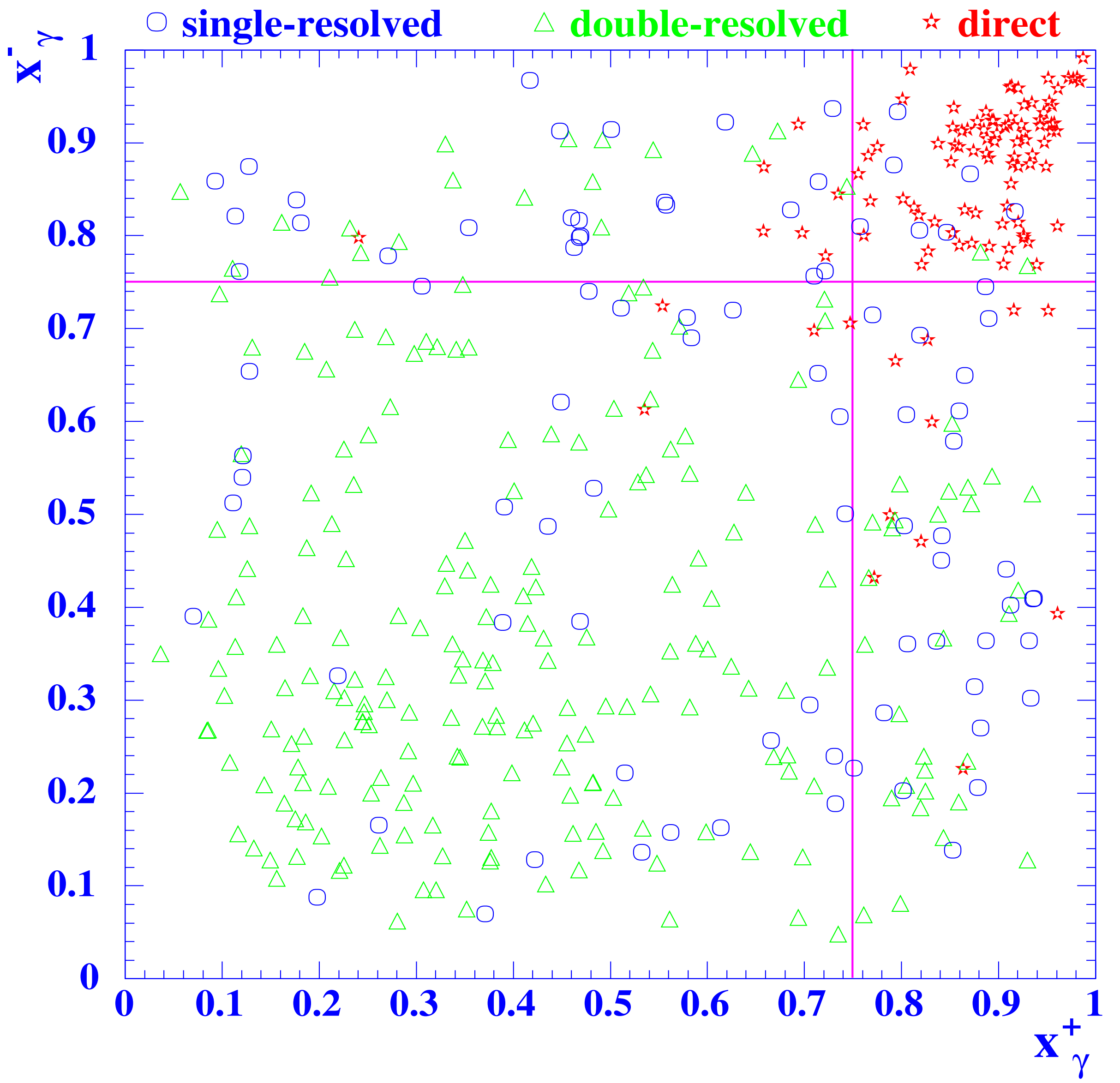
❐ NLO QCD calculation by M. Klasen, T. Kleinwort, G. Kramer; Eur. Phys. J. C1 (1998) 1.

DiJet Production :

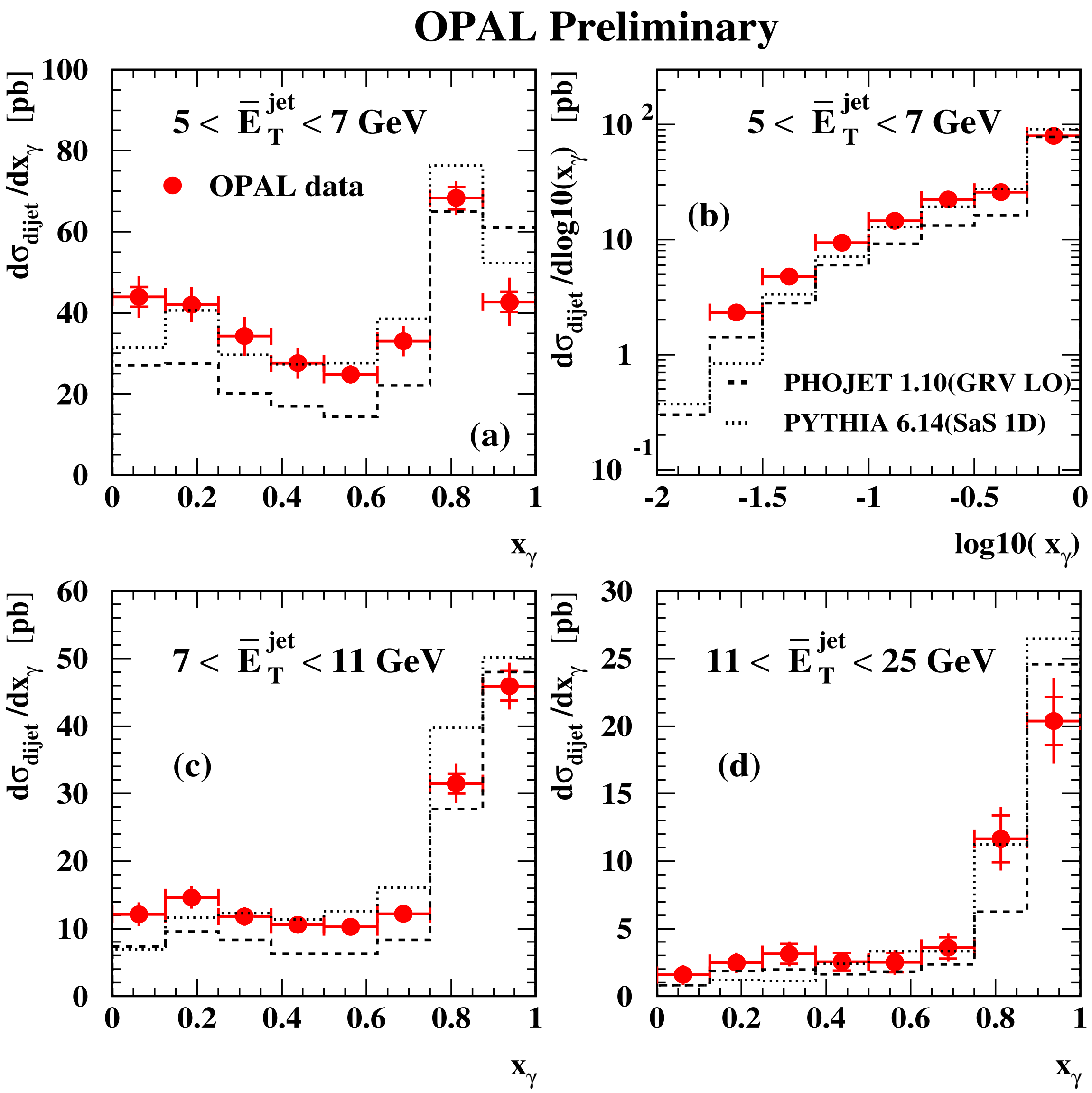
❒Separation of Direct and Resolved processes

$$x_\gamma^\pm = \frac{\sum_{\mathrm{jets}=1,2}(E \pm p_z)}{\sum_{\mathrm{hadrons}}(E \pm p_z)}$$

$x_\gamma^\pm$: Fraction of photon momentum in hard process

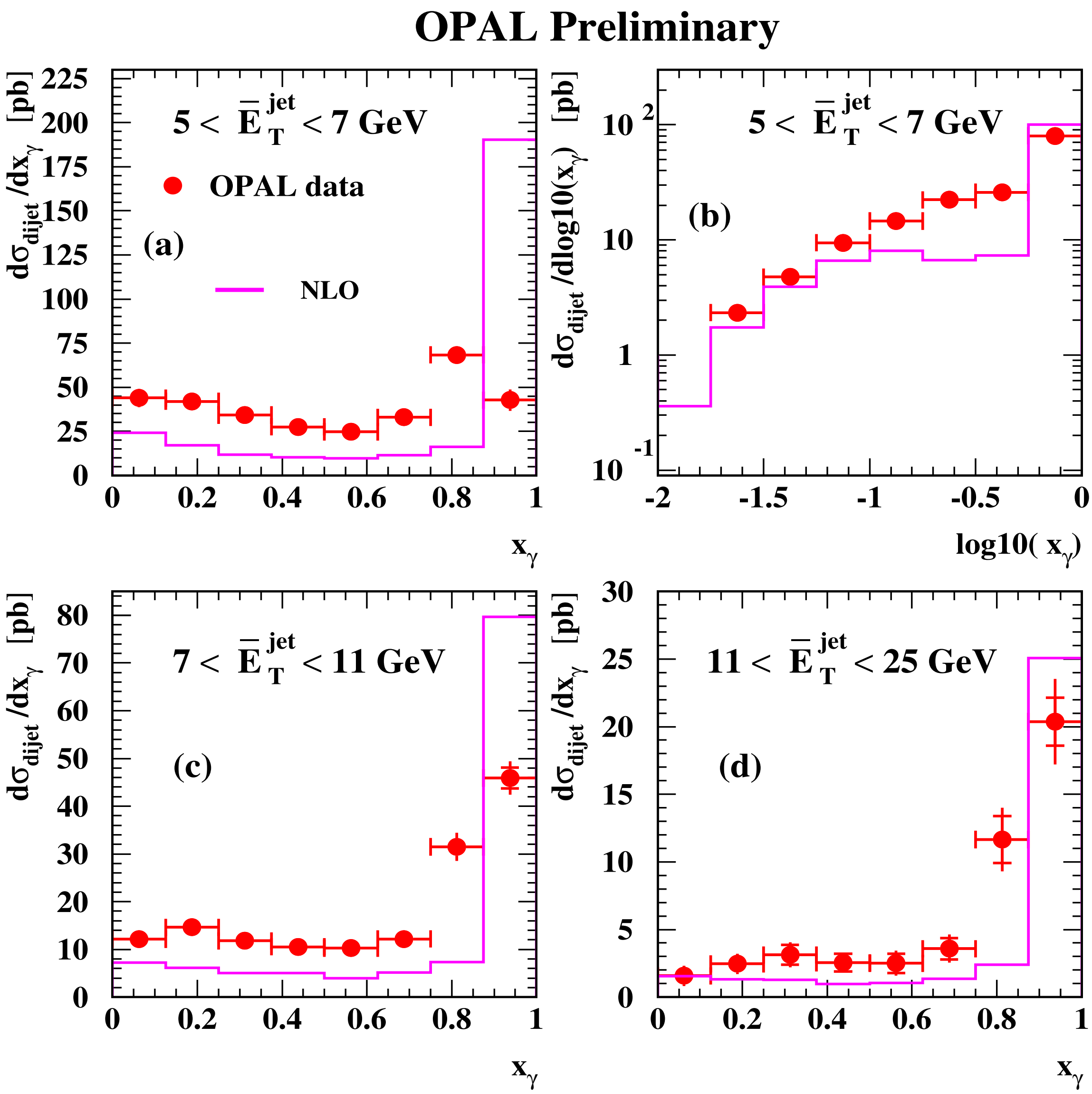


DiJet Production: x_γ vs MC



❒ PYTHIA and PHOJET are in a reasonable agreement with the data

DiJet Production: x_γ vs NLO QCD



❒ NLO QCD calculation by M. Klasen, T. Kleinwort, G. Kramer; Eur. Phys. J. C1 (1998) 1.

Summary

❏ Heavy Flavour Producion in $\gamma\gamma$ collisions

➢ Charm production is in agreement with QCD prediction, ➪ $\gamma g \to c\bar{c}$ is important

➢ Pomeron slope value for charm production $\epsilon = 0.40 \pm 0.08$ is larger than PDG value
➜ as expected by NLO QCD calculation

➢ Beauty production is in disagreement with NLO QCD prediction, about 4 standard deviations higher than expected !

❏ Jet Production in $\gamma\gamma$ collisions

➢ Jet production is in agreement with PYTHIA and PHOJET LO MC models prediction

➢ Jet production is in agreement with NLO QCD calculation for energy spectrum, but shows the discrepancy for x_γ