Jet (and heavy flavour) production in hard photon-photon collisions

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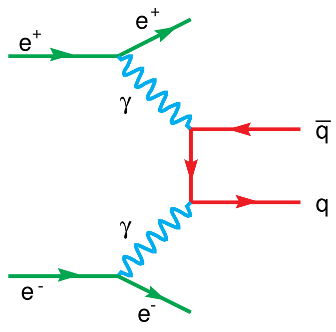
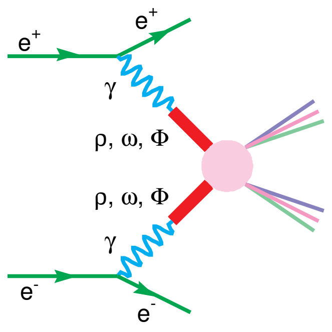
Outline

- ❑ Single particle and Jet production (OPAL)
- ❑ Heavy flavour production (L3, OPAL)

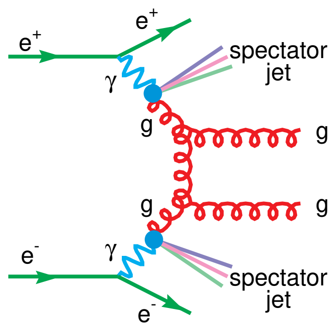
Motivation



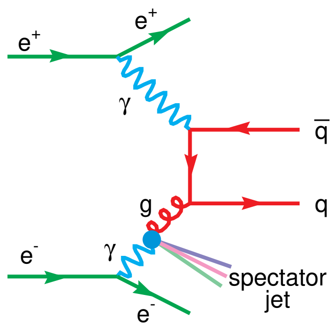
Direct



VDM



Double Resolved

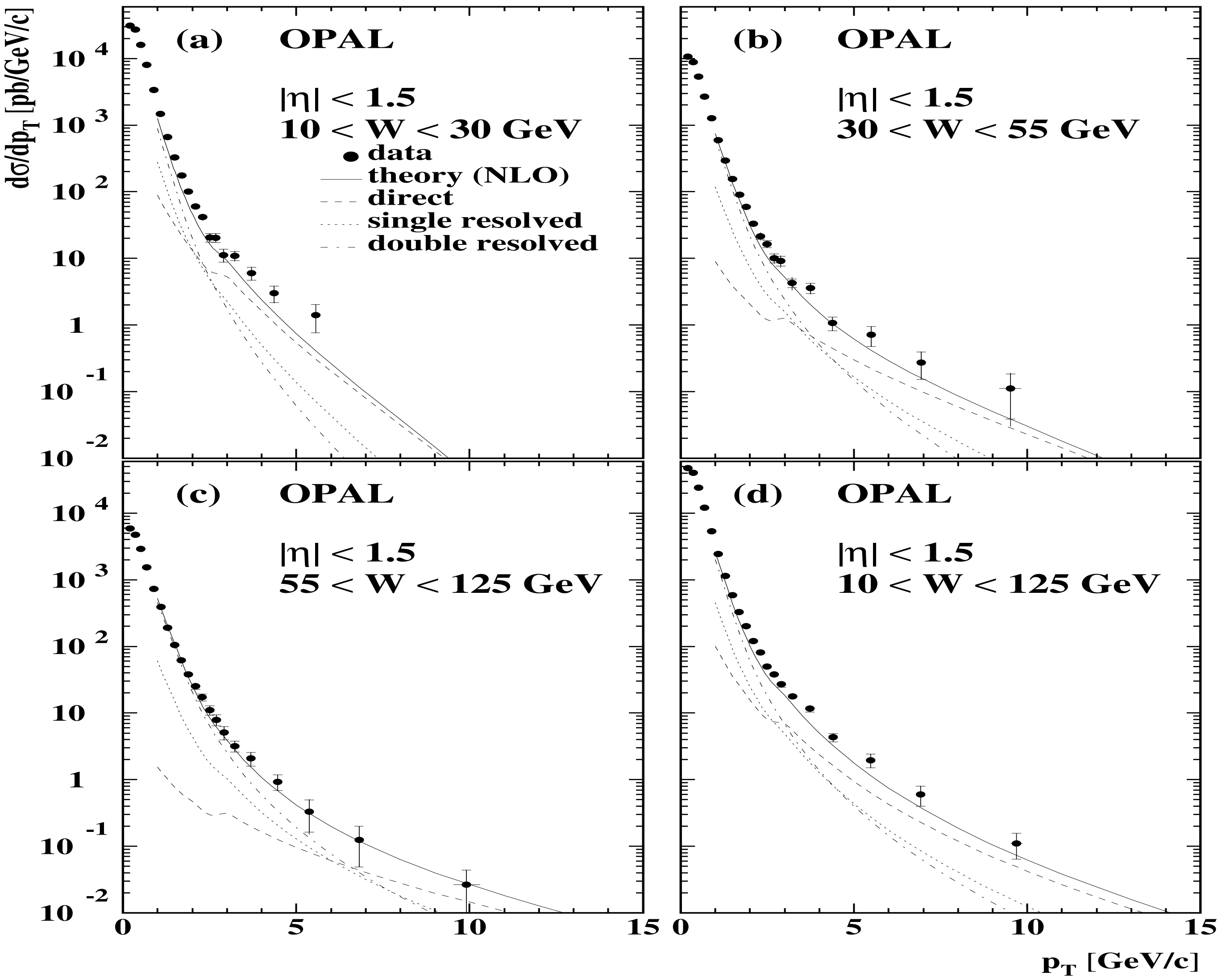


Single Resolved

- Test of the perturbative QCD

Inclusive particles $d\sigma/dp_T$

Inclusive charged hadron production[1] for $|\eta| < 1.5$

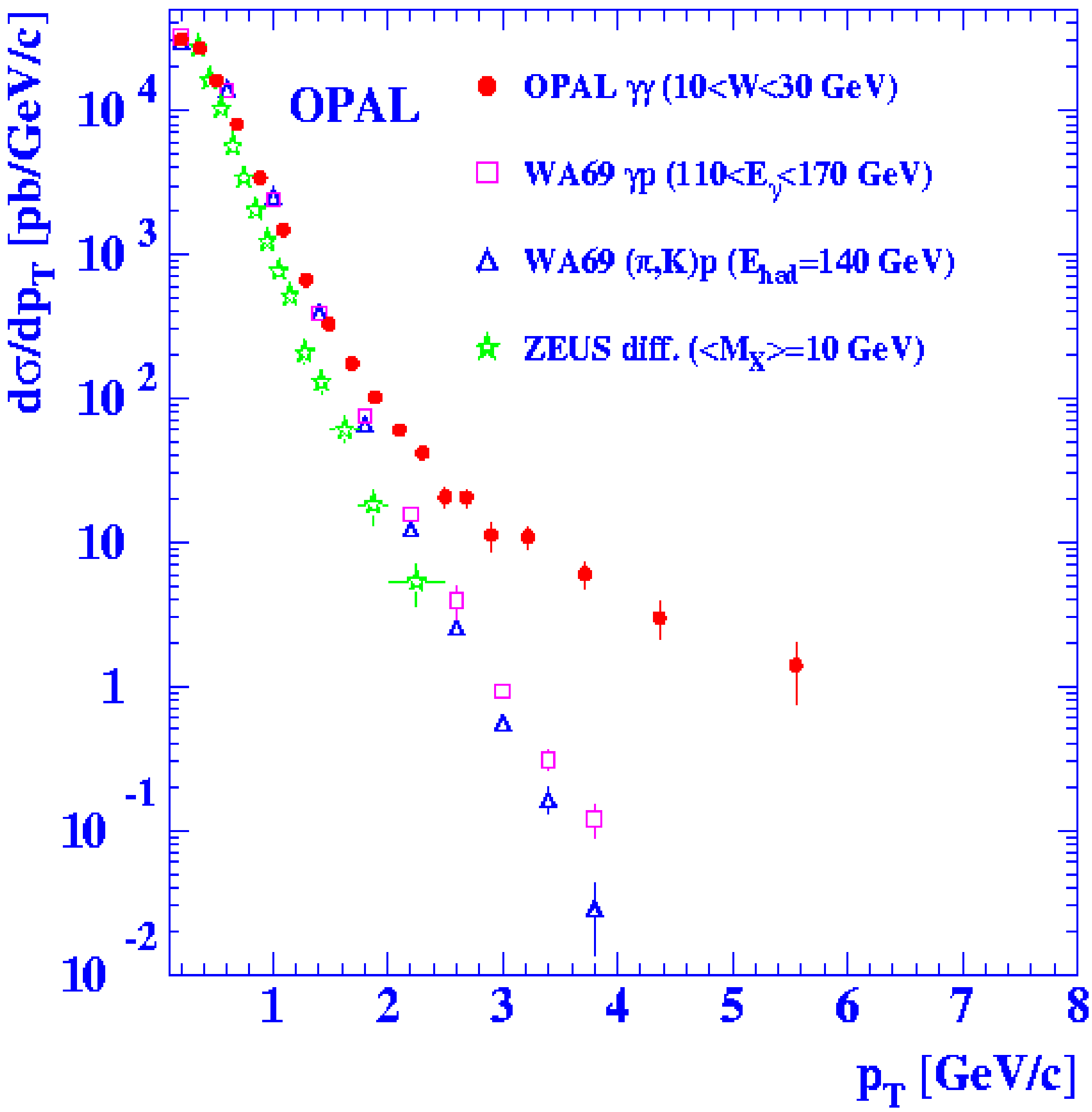


- ❒ NLO calculation by Binnewies, Kniehl and Kramer. (Phys. Rev. D53, 6110, 1996)
- ❒ The direct component is dominant at high p_T.
- ❒ For low $W_{\gamma\gamma}$, the NLO calculations lie below the data.

[1] OPAL Coll., Eur. Phys. J. C6 (1999) 253

Inclusive particles $d\sigma/dp_T$

- Compare to γp and (π, K)p interactions, normalised to $\gamma\gamma$ data at low p_T region.

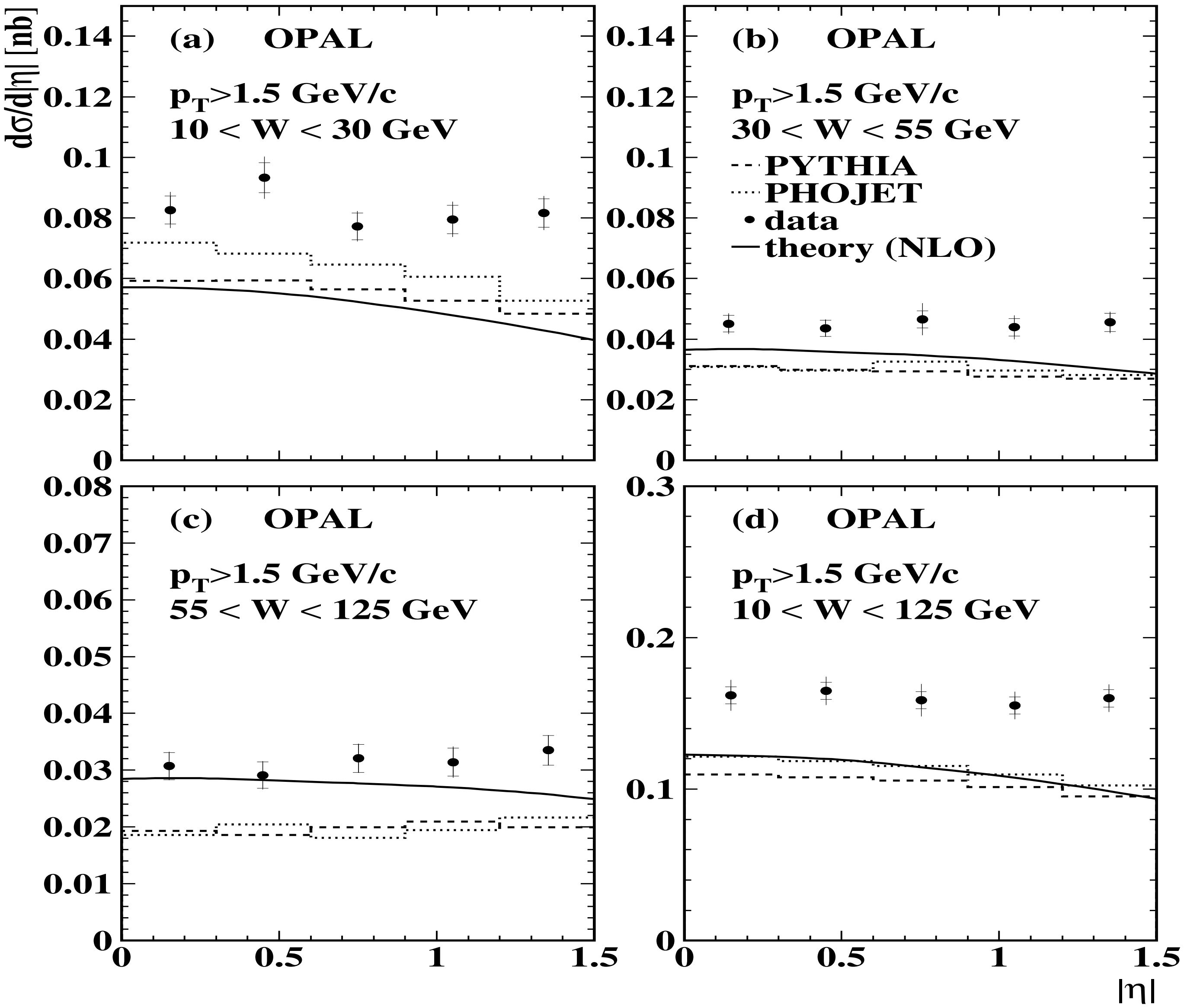


⇨ The $\gamma\gamma$ interaction is much harder because of the direct component.

WA69 : OMEGA Coll., Z. Phys. C43(1989) 63

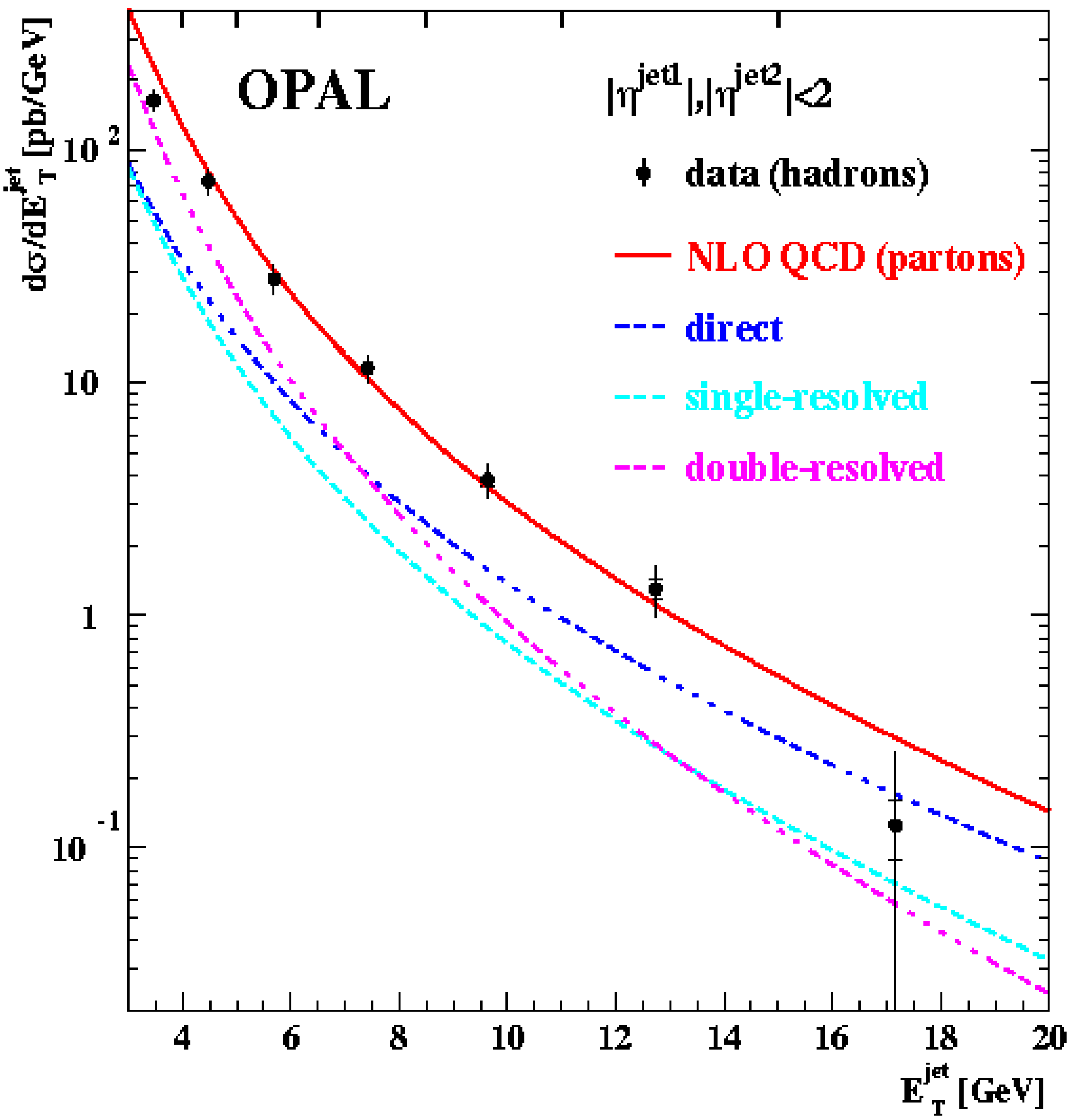
Inclusive particles $d\sigma/d\eta$

Inclusive charged particle production $d\sigma/d\eta$ for $|p_T| > 1.5$ GeV



- ➯ Monte Carlos and NLO calculation lie below the data for $W < 55$ GeV.
- ➯ NLO calculation agrees better for 55 GeV $< W < 125$ GeV.

DiJet Production



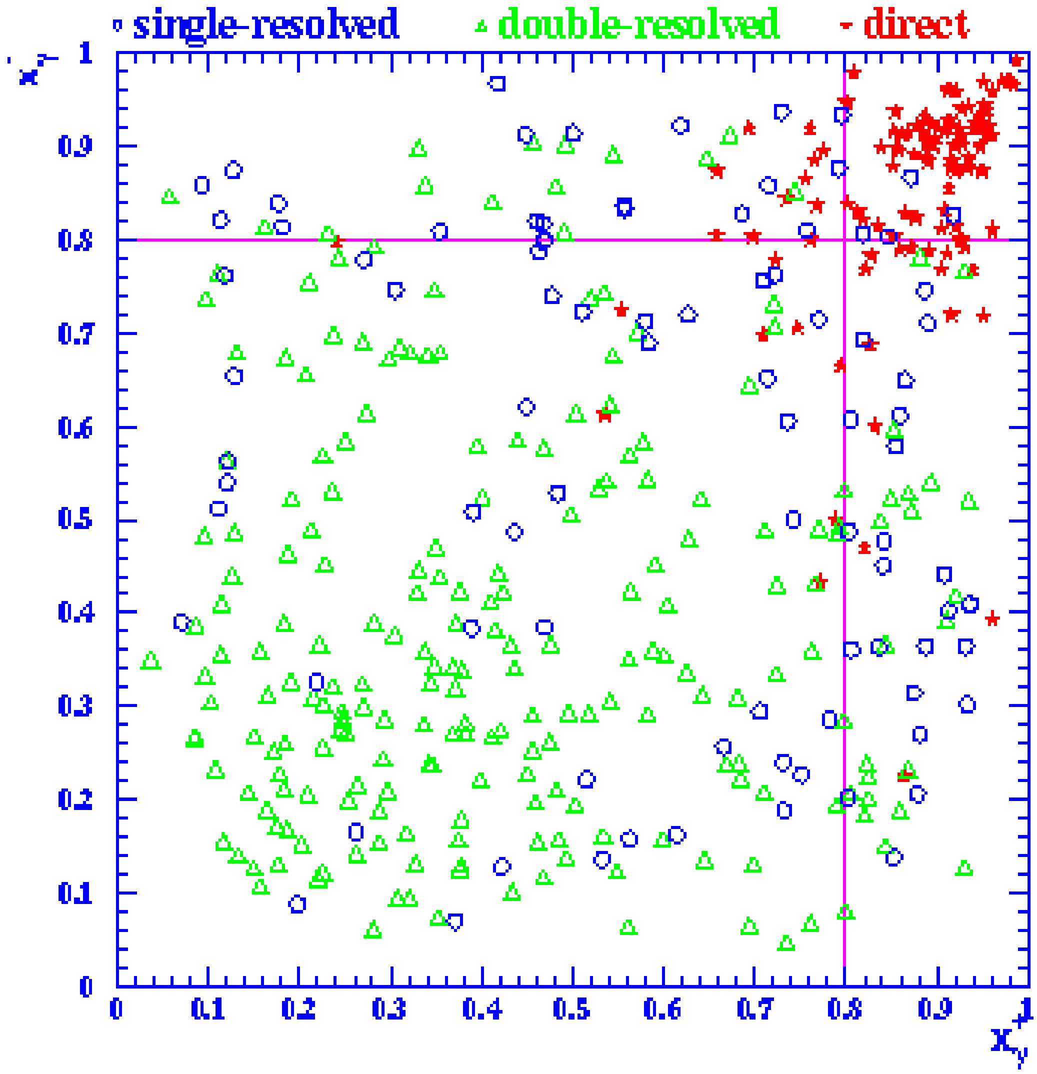
- ❐ NLO calculation by M. Klasen, T. Kleinwort, G. Kramer.
- ❐ The three processes are needed!

DiJet Production : OPAL

❐Separation of Direct and Resolved processes

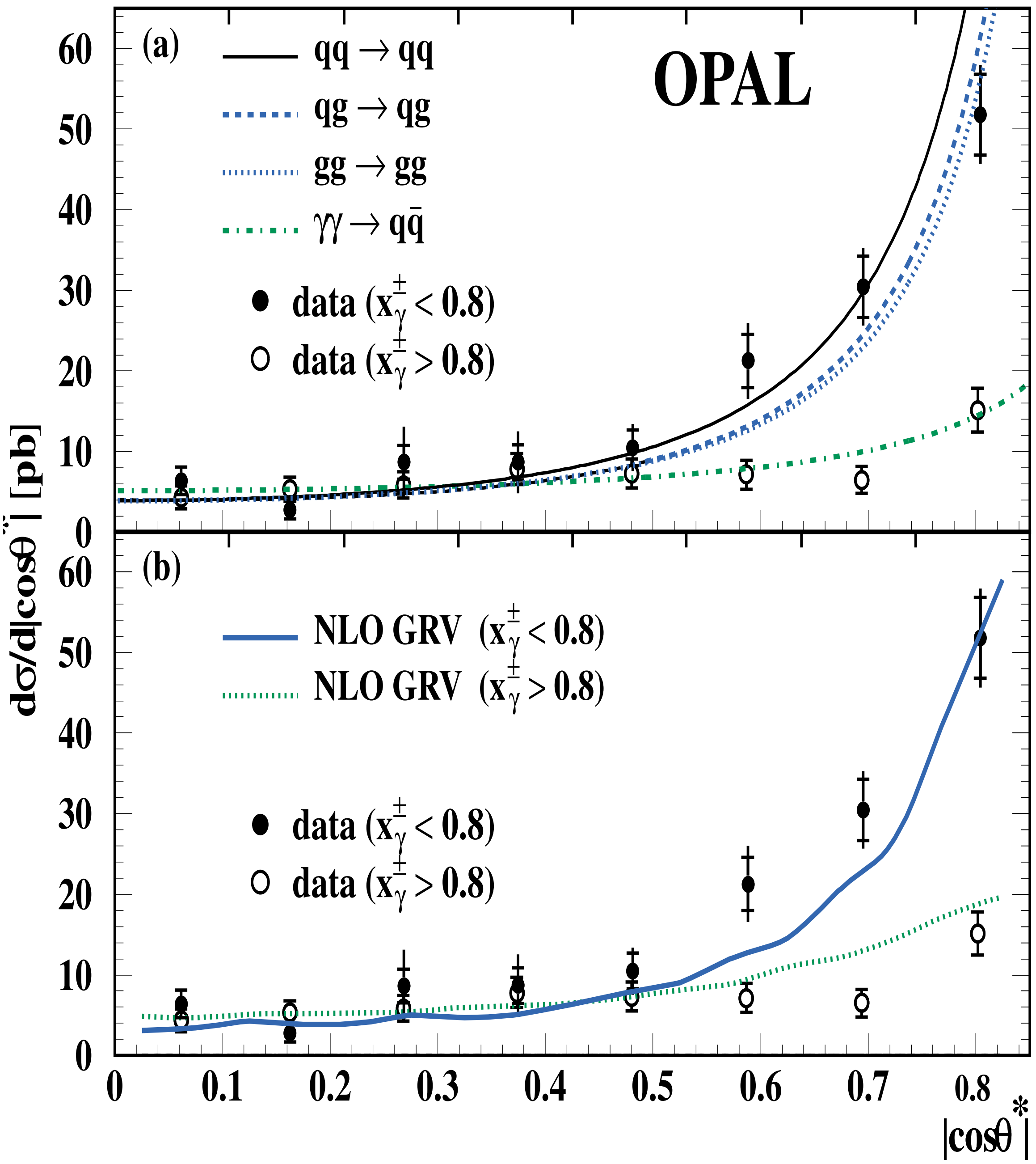
$$x_\gamma^\pm = \frac{\sum_{\text{jets}=1,2}(E \pm p_z)}{\sum_{\text{hadrons}}(E \pm p_z)}$$

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



DiJet Production

❐ Data: $\sqrt{s}$ = 161-172 GeV



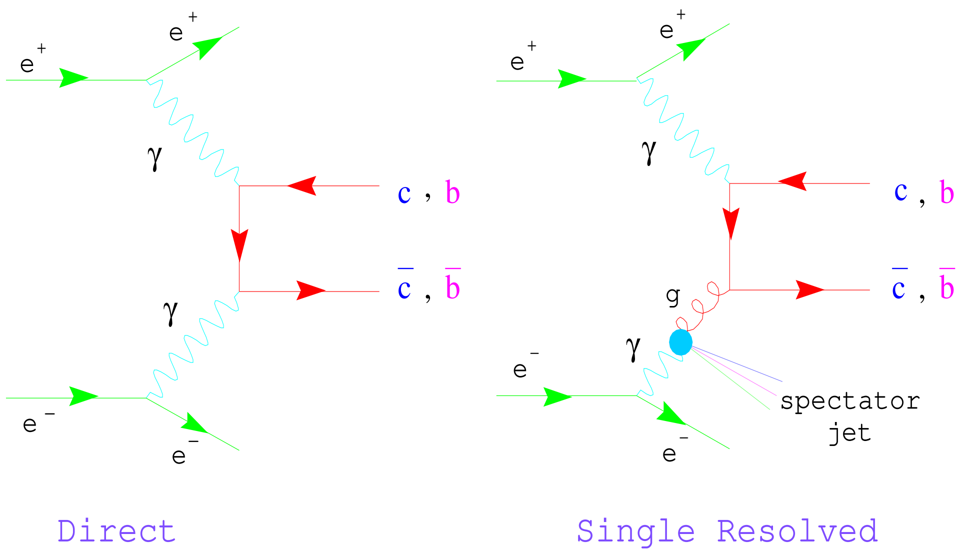
➠ $x_\gamma^\pm < 0.8$ Resolved (Gluon Exchange) $\propto (1 - |cos\theta^*|)^{-2}$

➠ $x_\gamma^\pm > 0.8$ Direct (Quark Exchange) $\propto (1 - cos^2\theta^*)^{-1}$

Sensitive to the spin of the Exchanged Particle

Inclusive Charm and Beauty Production

Motivation :



➩ Direct Process depends on $m_c(m_b)$ and α_s

➩ Resolved Process also depends on gluon content of the photon.

Data : (since EPS97)

L3 : 91 - 183 GeV, $\mathcal{L} = 165$ pb^{-1} PLB453(1999)83.
L3* : 189 GeV, $\mathcal{L} = 176$ pb^{-1}
OPAL* : 183 - 189 GeV, $\mathcal{L} = 220$ pb^{-1}

⋆ Preliminary

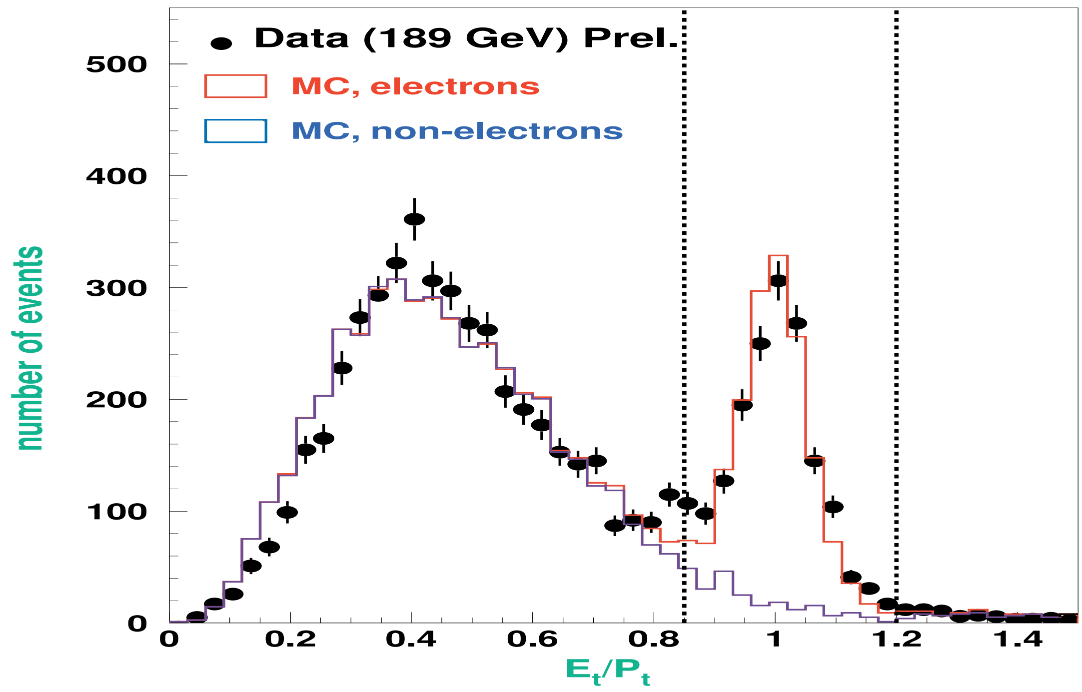
Charm identification :

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

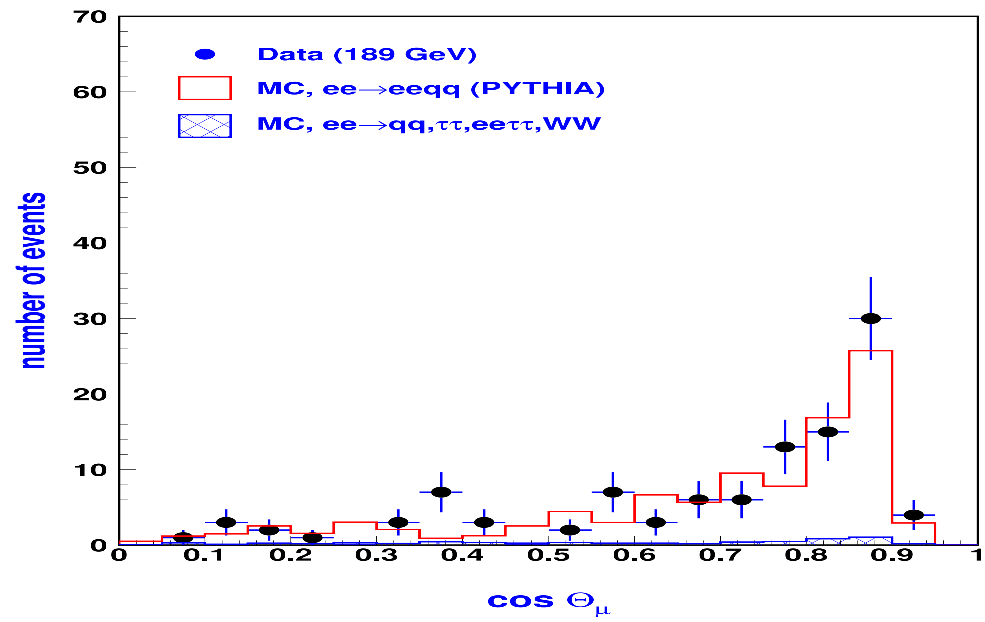
OPAL : D^{*+} tag

Heavy flavour tagged by semileptonic decays: L3

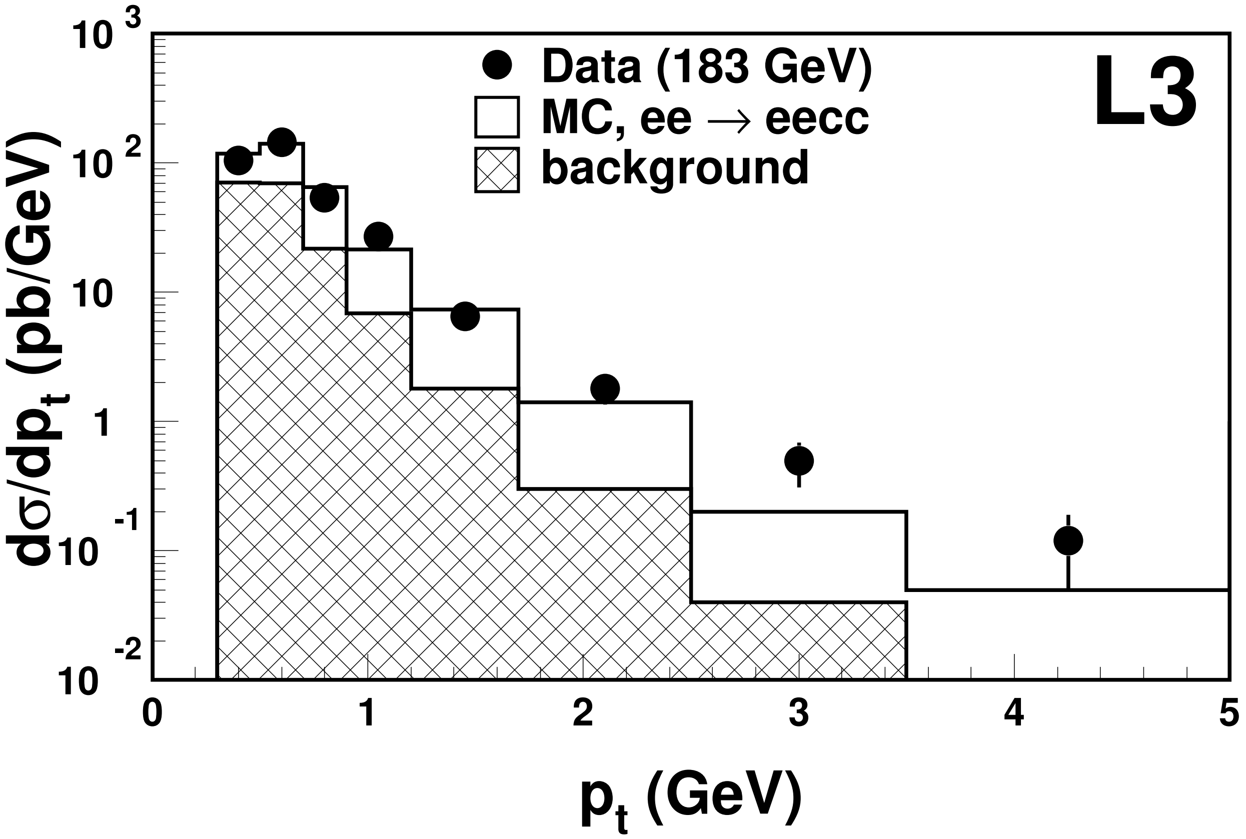
❒ Electron Identification: $P_e > 0.6$ GeV, 1710 ev.



❒ Muon Identification (Muon Chambers): $P_\mu > 2.0$ GeV, 208 events

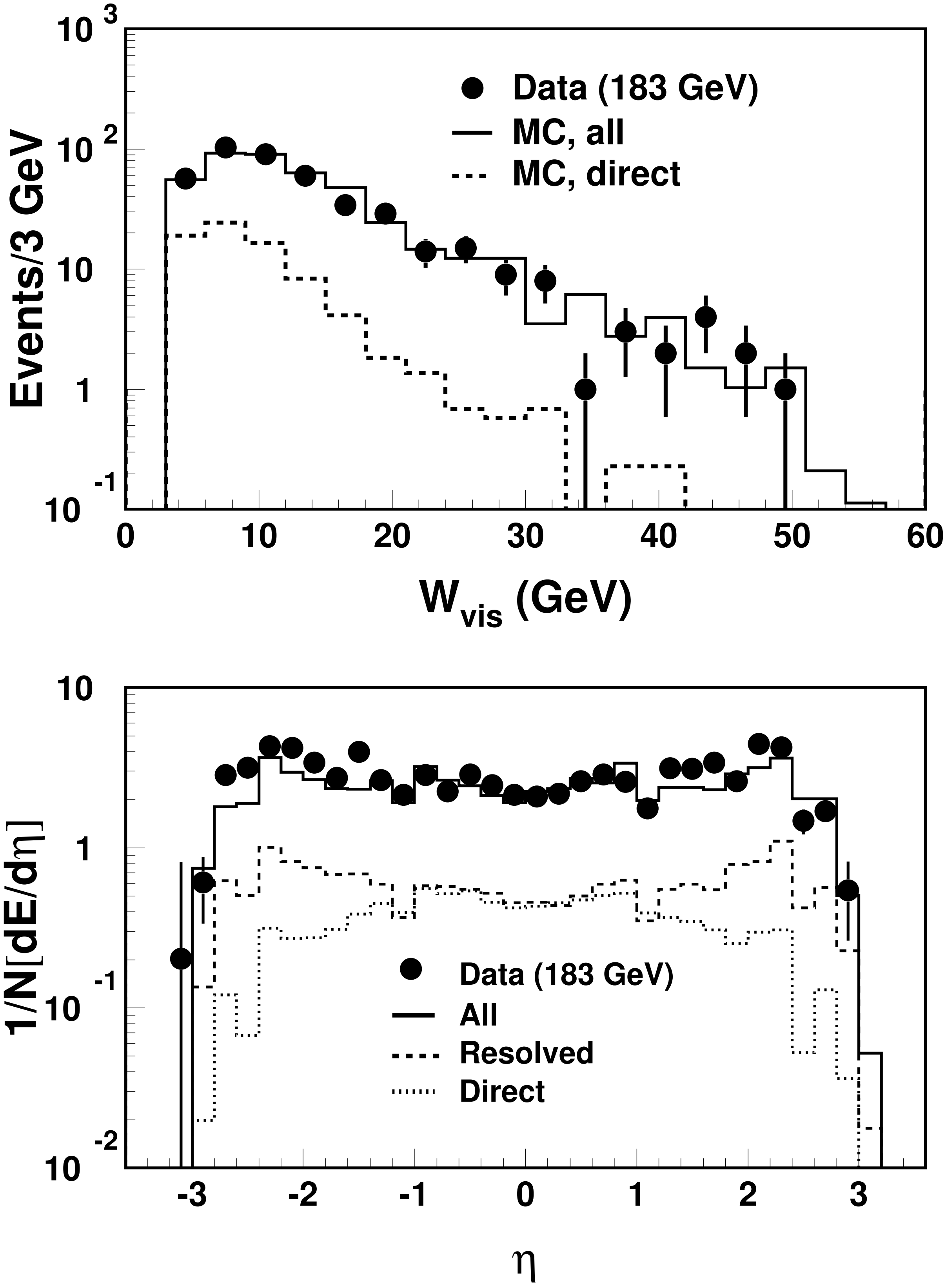


Inclusive lepton production



- p_t spectrum is well described by PYTHIA
- direct process produces more energetic leptons than resolved one
- fraction of charm events is increasing with p_t of lepton

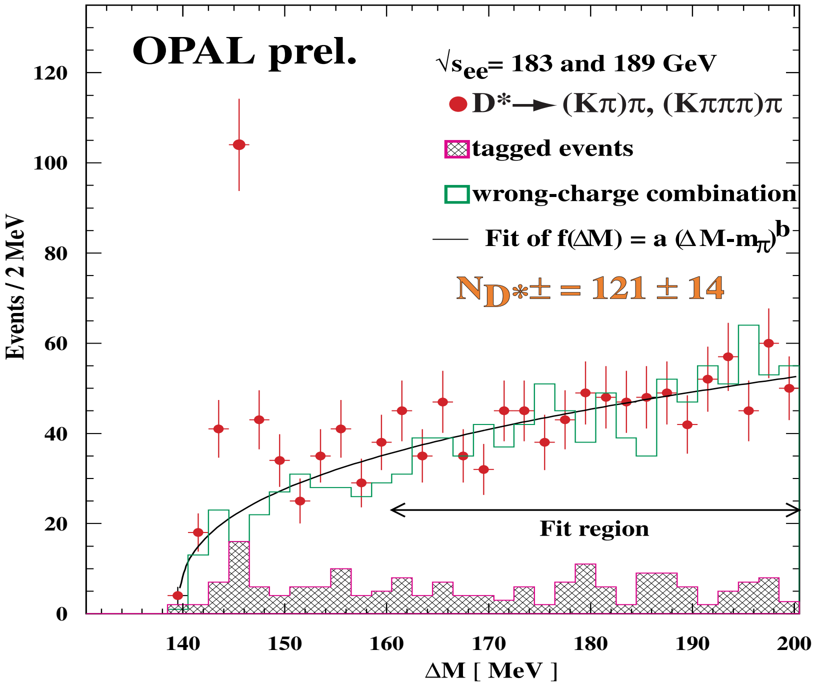
Direct vs Resolved : L3



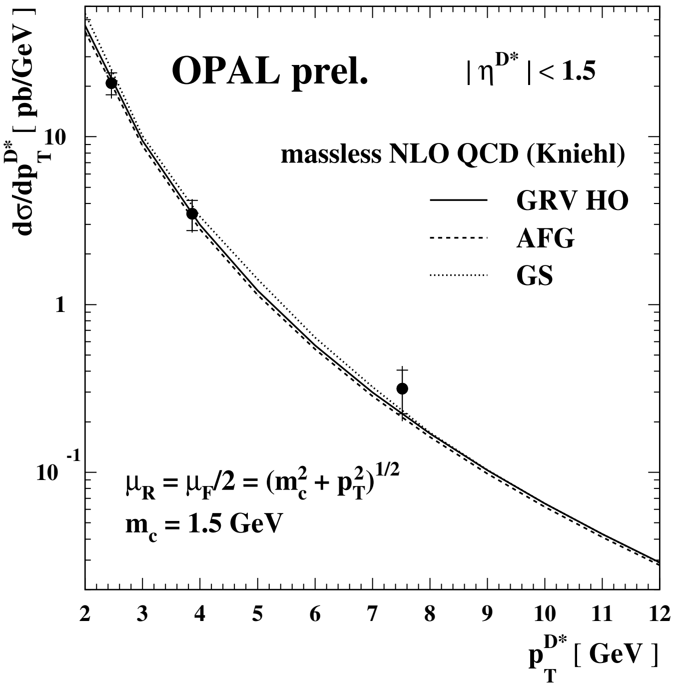
- resolved processes are needed to describe the data

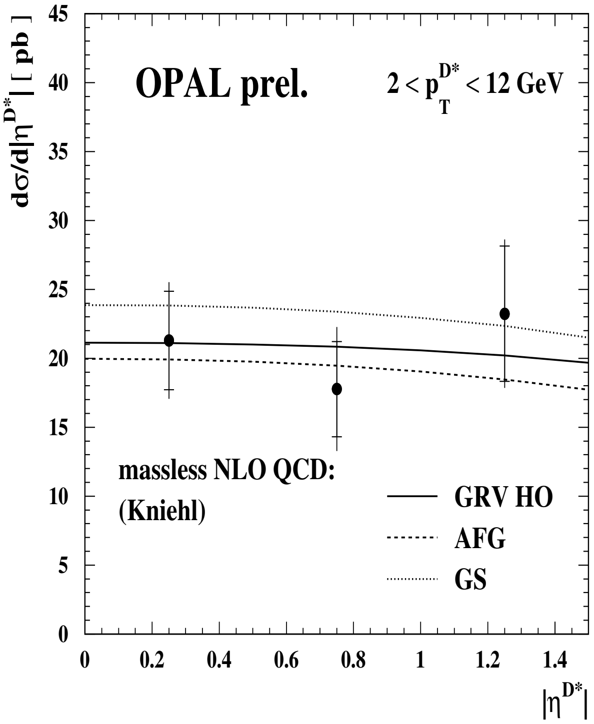
D* Production : OPAL

- Data: $\sqrt{s}$ = 183-189 GeV
- $D^{*\pm} \rightarrow D^0 \pi_s^\pm$,
  $D^0 \rightarrow K^\pm \pi^\mp$, $D^0 \rightarrow K^\pm \pi^\mp \pi^+ \pi^-$



- Differential cross-sections:



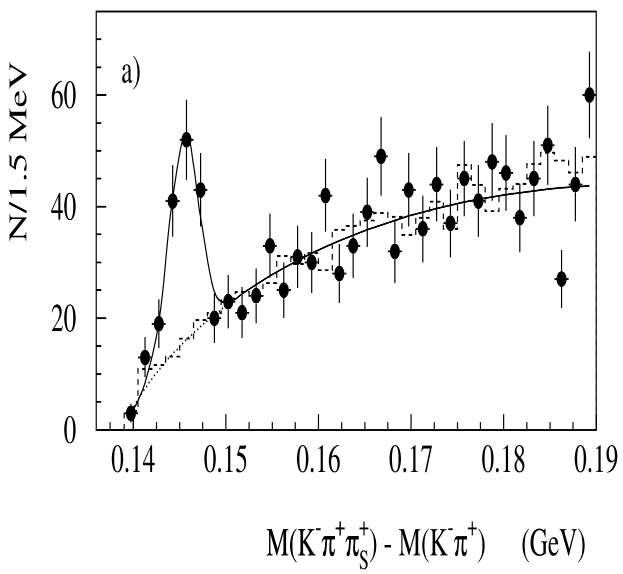


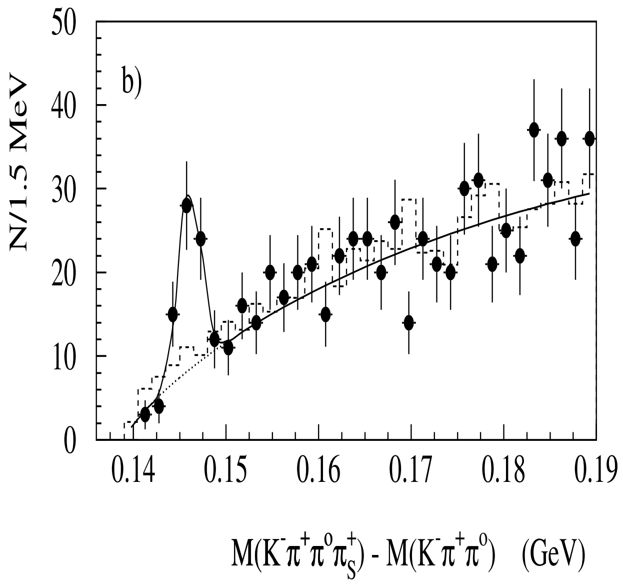
D* Production : L3

- Data: $\sqrt{s} = 189$ GeV
- $D^{*\pm} \to D^0 \pi_s^{\pm}$,

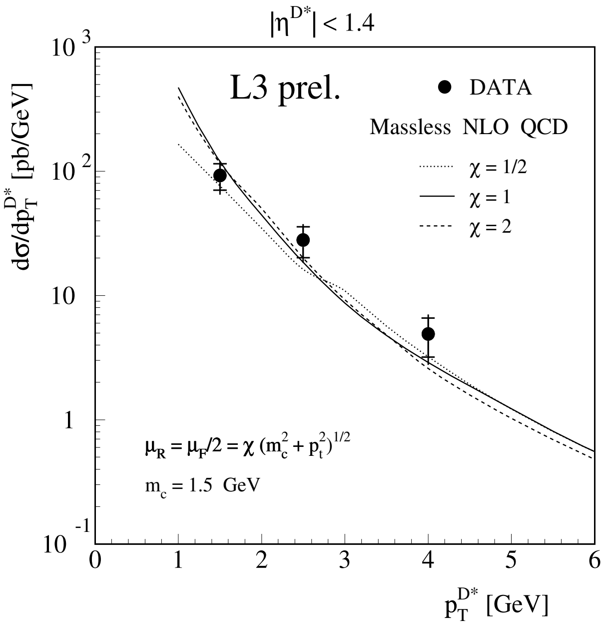
  $D^0 \to K^{\pm}\pi^{\mp}$, $D^0 \to K^{\pm}\pi^{\mp}\pi^0$

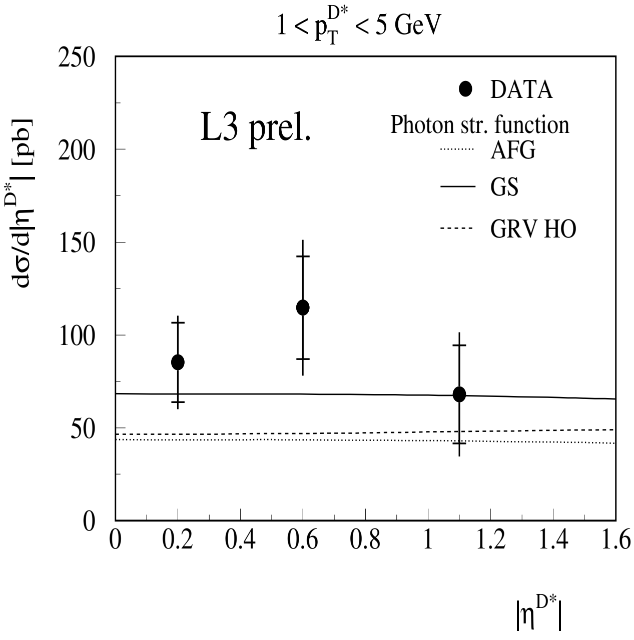
  Nevents $= 102 \pm 17$ Nevents $= 42 \pm 11$





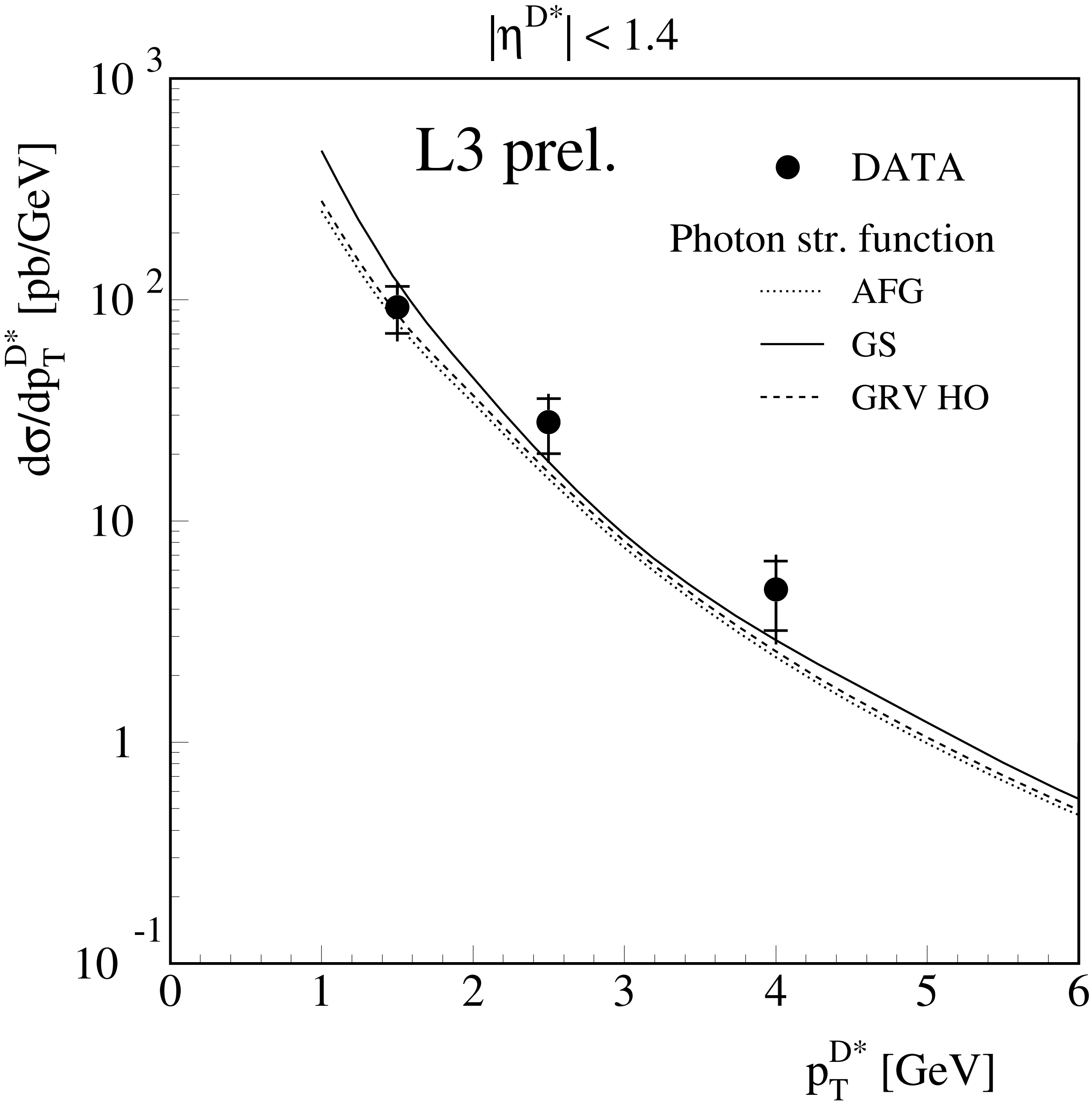
- Differential cross-sections:





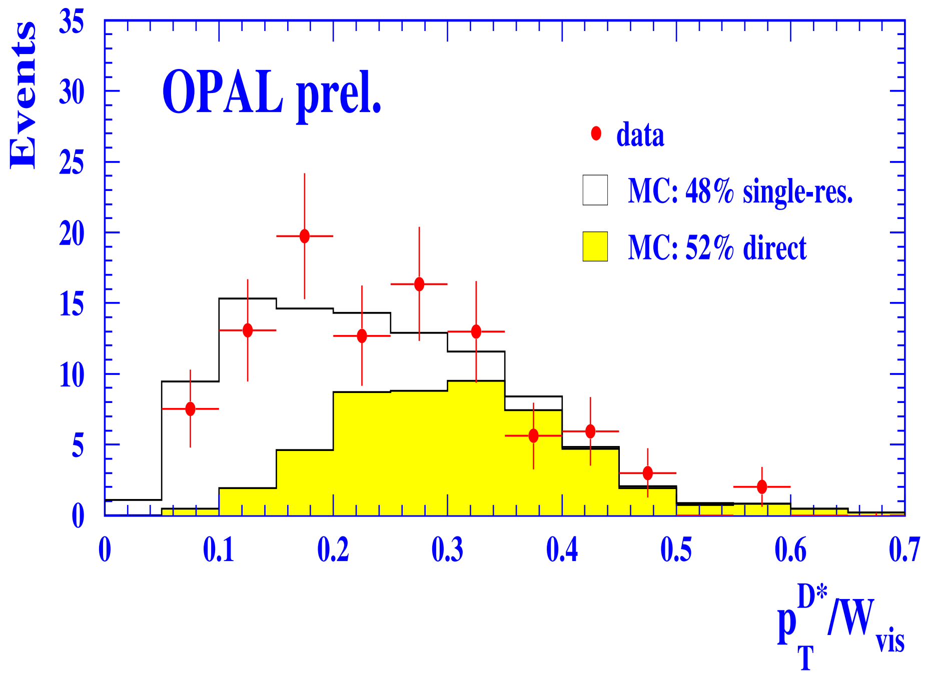
D* Production : L3

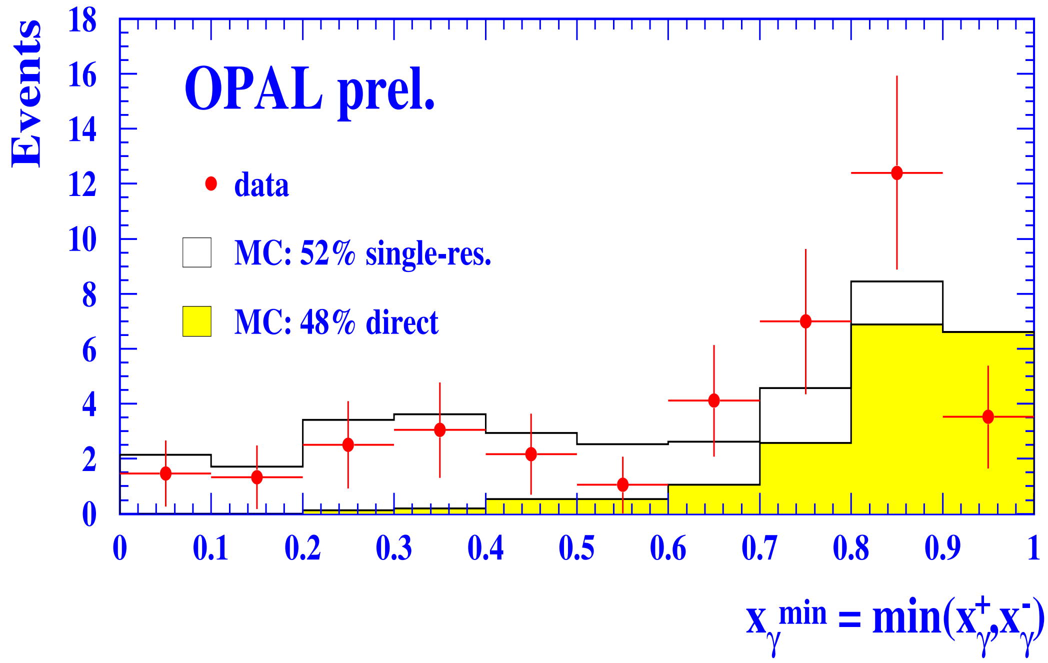
❐ Sensitivity to the photon structure function



D* Production

❐ Separation of Direct and Resolved processes

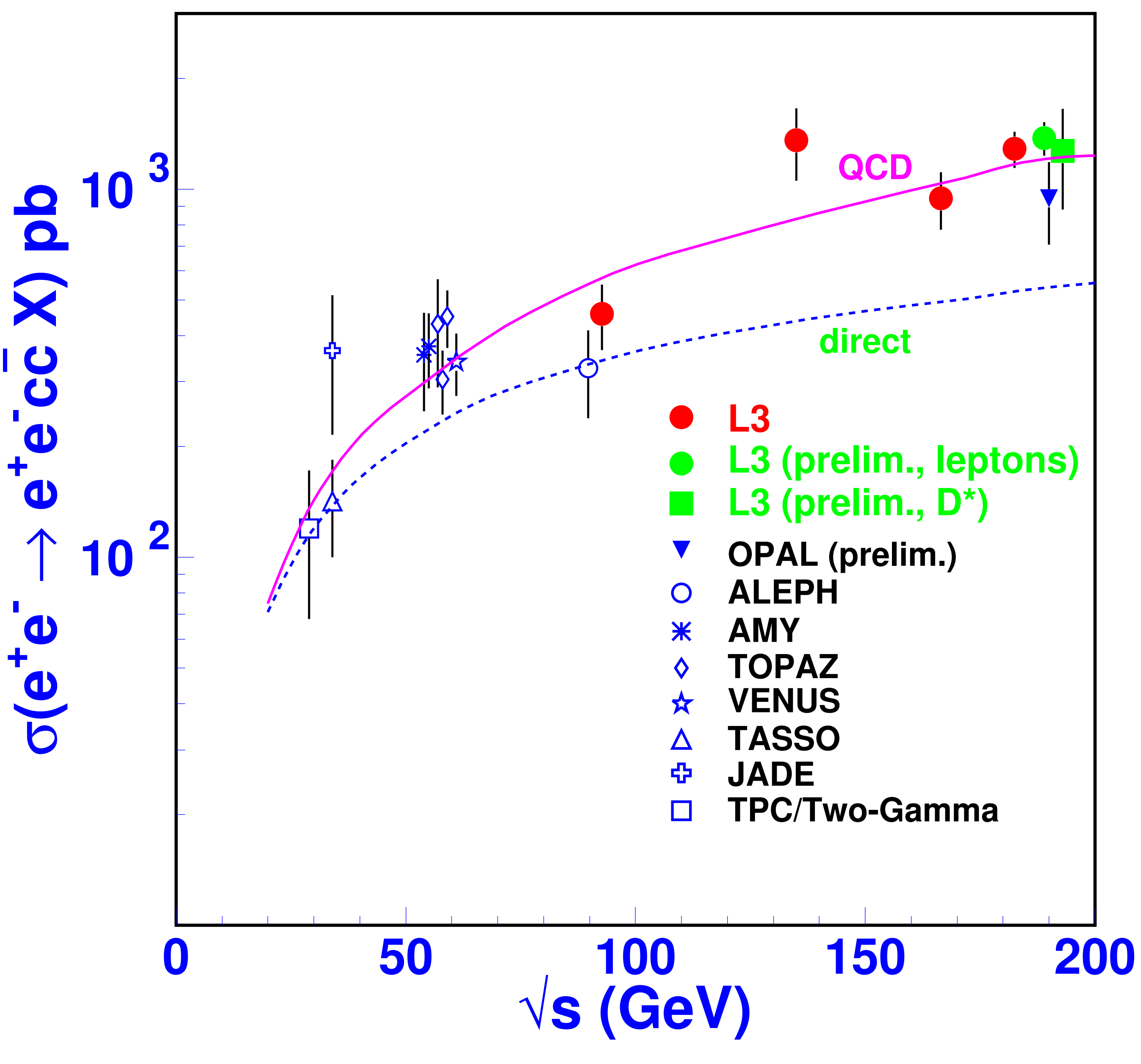




$e^+e^- \to e^+e^-c\bar{c}$:

$\sigma_{dir} = 392 \pm\ 117$ pb $\quad \sigma_{res} = 553 \pm\ 184$ pb

Charm production in $\gamma\gamma$ collisions

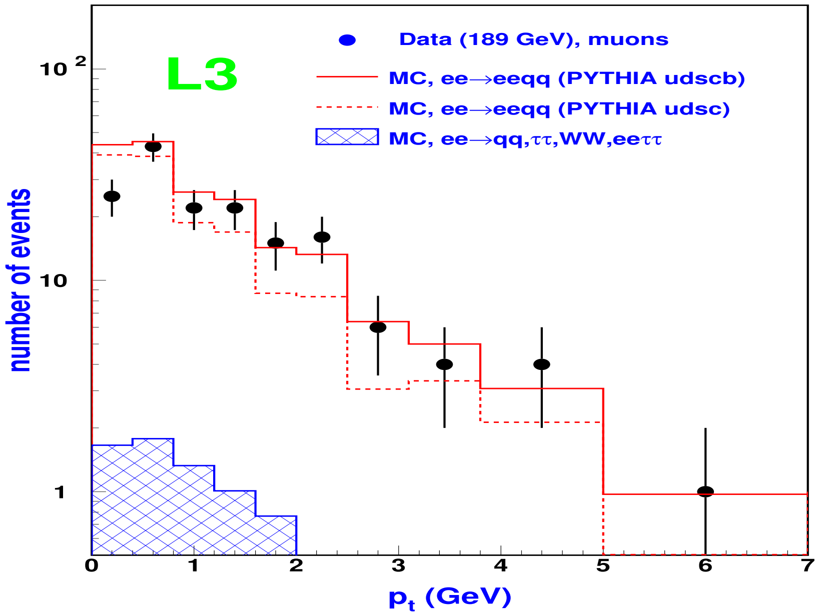


- clear evidence of gluon content of photon

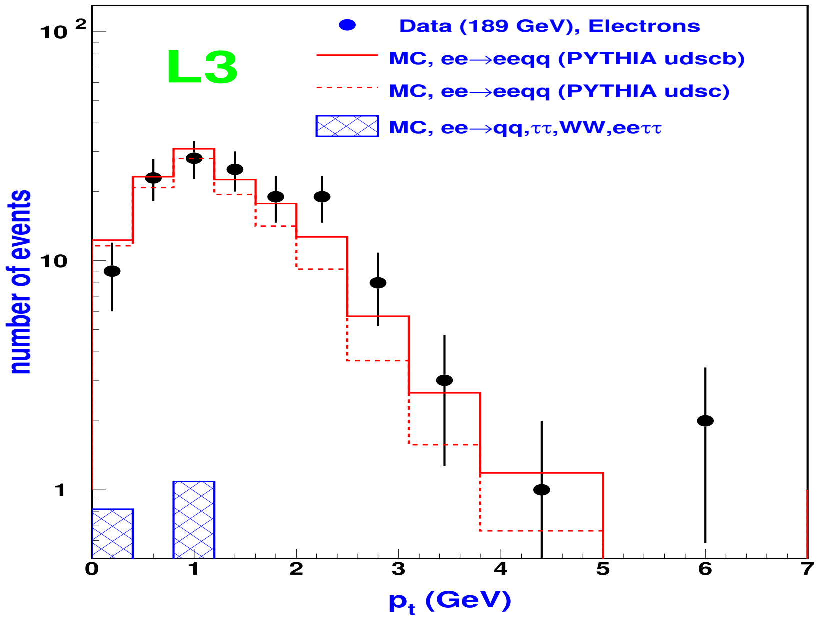
theory prediction from
M.Drees,M.Krämer,J.Zunft and P.M.Zerwas,Phys. Lett. B306 (1993) 371), $m_c = 1.3$ GeV

Search for Beauty: L3 Data

p_t with respect to the nearest jet



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



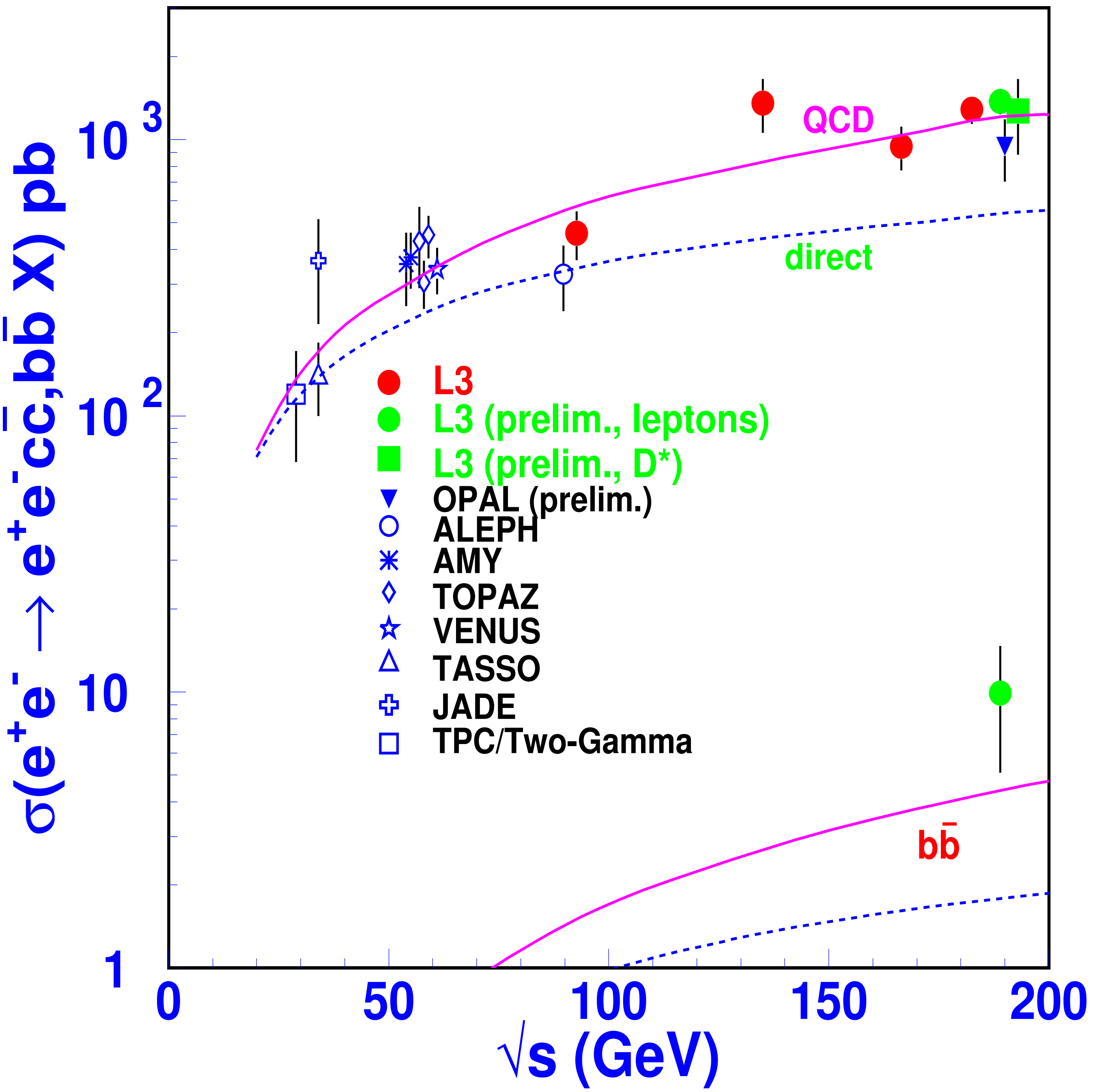
$P^{e} > 2.0$ GeV
$P^{e}_t > 1.0$ GeV
$N^{e}_{ev} = 96$
$\varepsilon^{e}_b = 1.6\%$
$\Pi^{e}_b = 28\%$

Leptons from bottom decays have higher p_t.

Preliminary:

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

Charm and beauty in $\gamma\gamma$ collisions



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

Summary

- Single particle and Jet production measurements at $\sqrt{s} = 161 - 172$ GeV by OPAL

- NLO pQCD calculations well describe the data

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

Evidence for gluon content of the photon

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

- First measurement of $\gamma\gamma \to b\bar{b}$ by L3

⇨ Need for theory covering low P_t and high P_t simultaneously