

Some recent conferences' transparencies on $c\&b$ production
in $\gamma\gamma$ collisions

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Stolen from:

I PHOTON 2003 - Frascati 4/03 - Charm and beauty session:

1. J. Hess (Siegen Univ.): Charm production in $\gamma\gamma$ collisions
at LEP2 energy

2. W. Da Silva (LPMHE, Paris):

Charm and beauty production in $\gamma\gamma$ collisions
using semileptonic decays

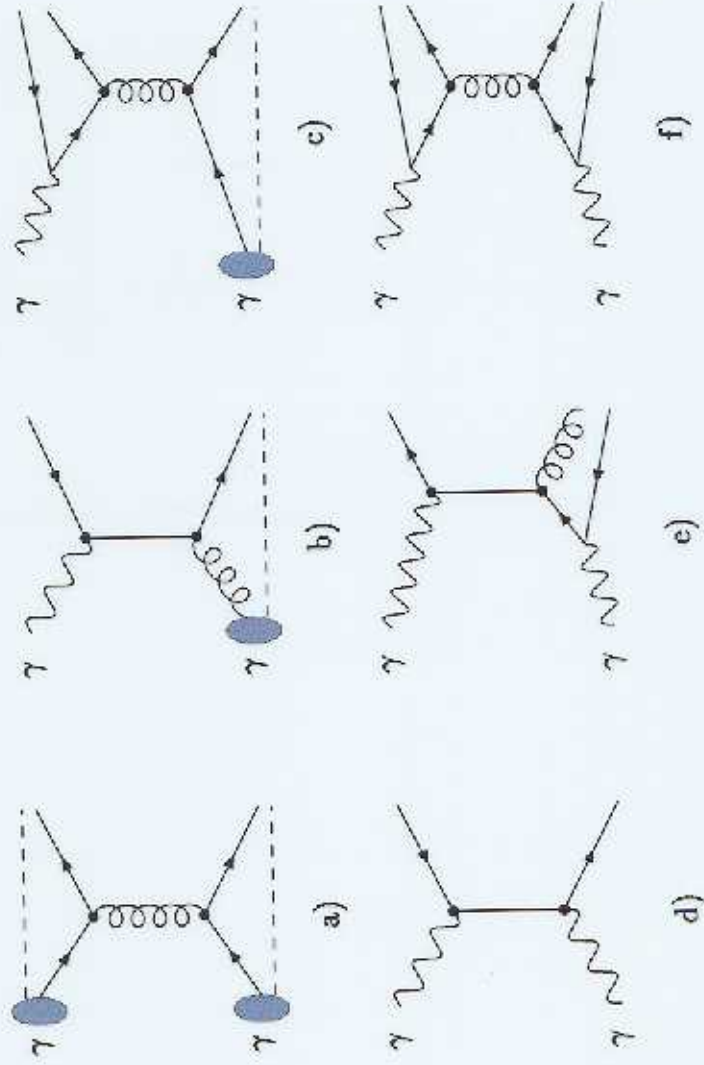
3. F. Kapusta (LPMHE, Paris): Too much beauty...

II EPS 2003 - Aachen 7/03 - Hard QCD session
heavy flavour production

W. Da Silva (LPMHE, Paris):

Bottom and charm production in 2γ collisions at LEP

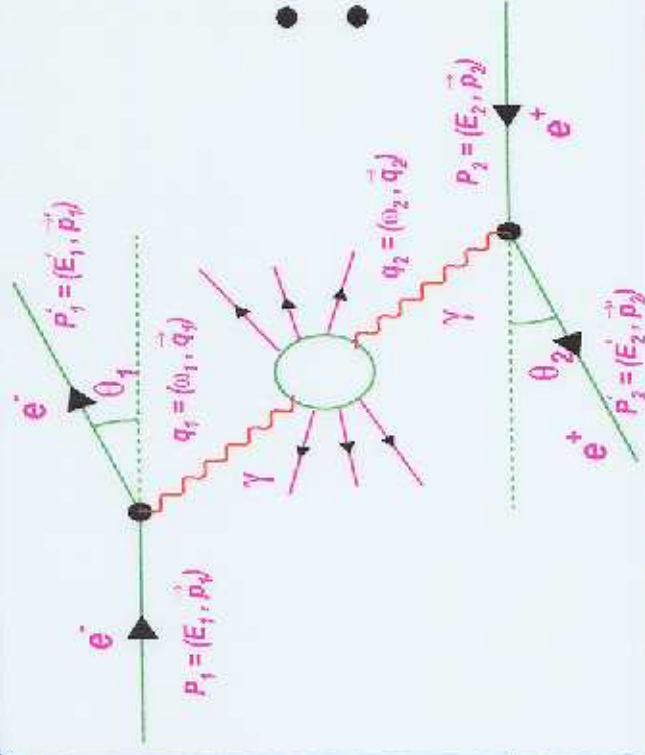
Introduction Photon-Photon Scattering



The more common classification of events at the parton level:

1. **Direct process** $\gamma\gamma \rightarrow q\bar{q}$ in which both photons interact as a bare particle.
2. **Single-resolved process** where one of the photons couples directly to the parton of the other resolved photon.
3. **Double-resolved process** wherein two resolved photons interact with each other.

Two-photon Physics at LEP

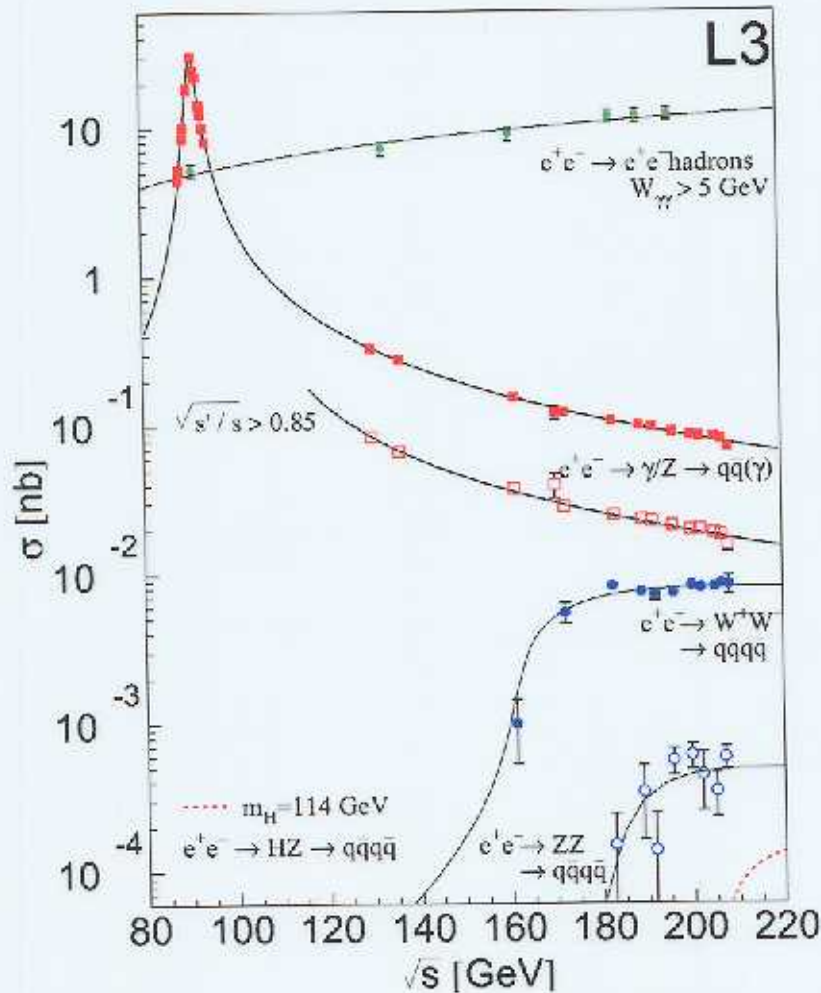


- $Q_i^2 \approx 2E_i E_i' (1 - \cos\theta_i)$
- $W_{\gamma\gamma}^2 = (q_1 + q_2)^2$

Event classification

- ★ **No-tag:** Neither scattered electrons is detected. $Q_i^2 \approx 0$.
- ★ **Single-tag:** Only one scattered electron is detected. $Q_1^2 \gg Q_2^2 \approx 0$.
- ★ **Double-tag:** Both scattered electrons are detected. $Q_1^2 \gg 0$.

Two-photon Physics at LEP Total cross section

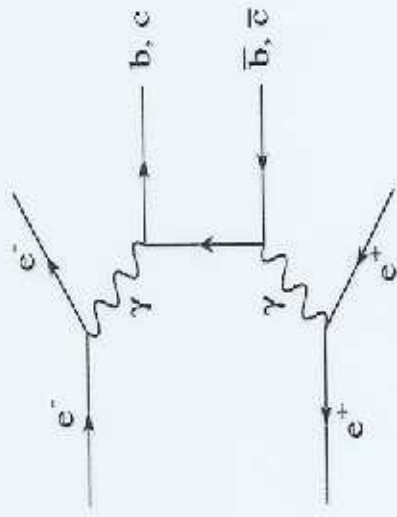


- ★ The **two-photon production** is by far the dominant process at LEP 2 energies.
- ★ The main processes of interest are deep-inelastic scattering, large p_T phenomena and **heavy flavour production**.

Measurement of $\sigma(e^+e^- \rightarrow e^+e^-c\bar{c}X)$ and $\sigma(e^+e^- \rightarrow e^+e^-b\bar{b}X)$

Open charm and beauty production measurement \Rightarrow provide a good test of PQCD

- Two LO main contributions
direct and single resolved terms



Large m_b and $m_c \Rightarrow$ more reliable calculations.

NLO total cross sections computations available

\Rightarrow Use the 10 years old Drees, Kraemer, Zunft, Zerwas

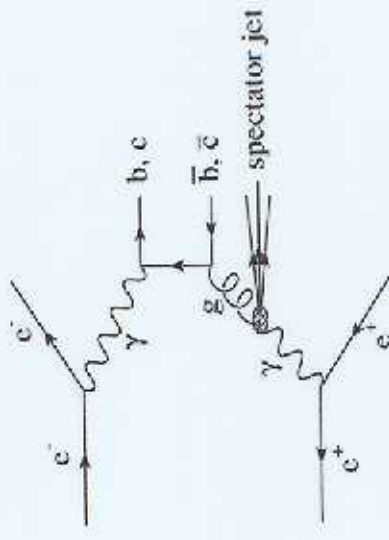
$$\kappa = \frac{\sigma_{\text{direct } b\bar{b}}^{\text{NLO}}}{\sigma_{\text{direct } b\bar{b}}^{\text{LO}}} \simeq 1.236$$

$$\kappa = \frac{\sigma_{\text{DG,GRV}}^{\text{res } b\bar{b}}}{\sigma_{\text{direct } b\bar{b}}^{\text{NLO}}} = 0.997, 1.039$$

at $\sqrt{s} = 180 \text{ GeV}$

Direct term

\Rightarrow At LEP2 energies direct and single resolved contributions are of the same order



\Rightarrow VDM and double resolved contribution are expected to be small

- Default MC used in all analyses : PYTHIA / γ pdf SaS1D

Single resolved term

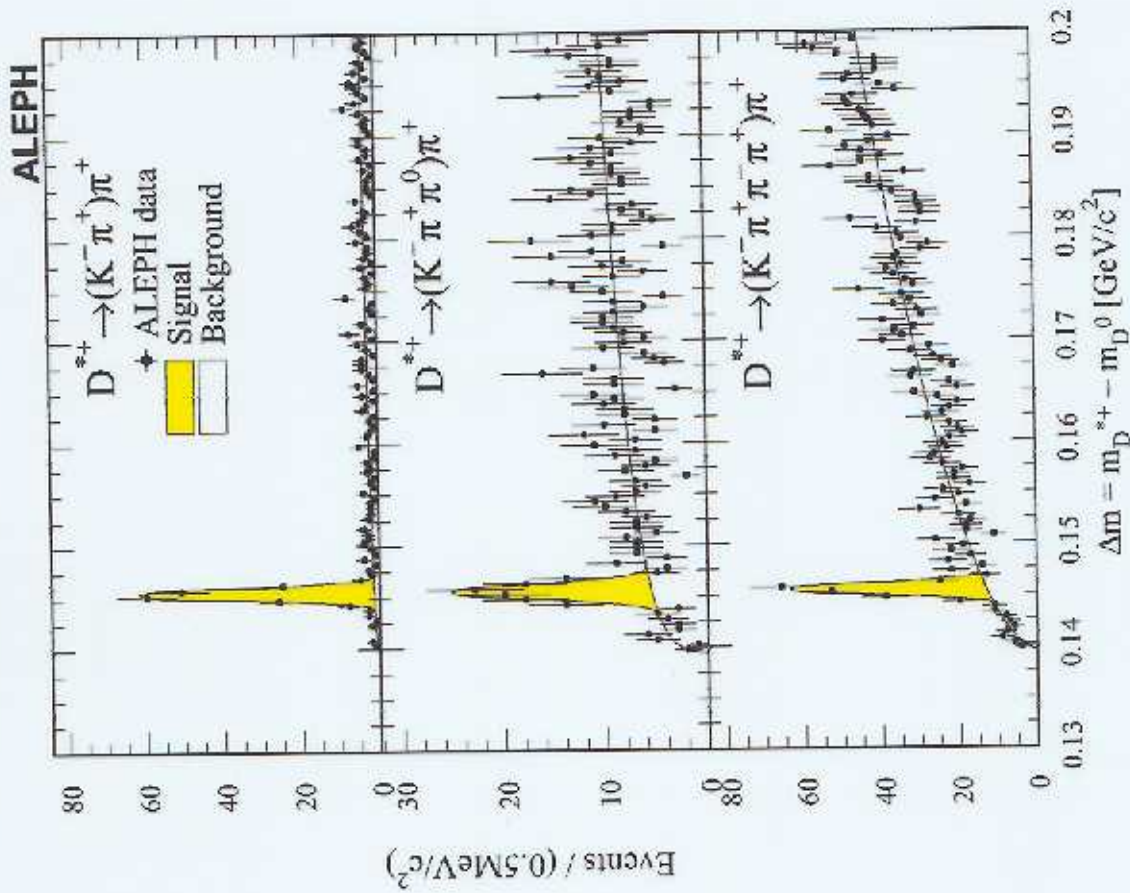
Charm Tagging via D^* Reconstruction



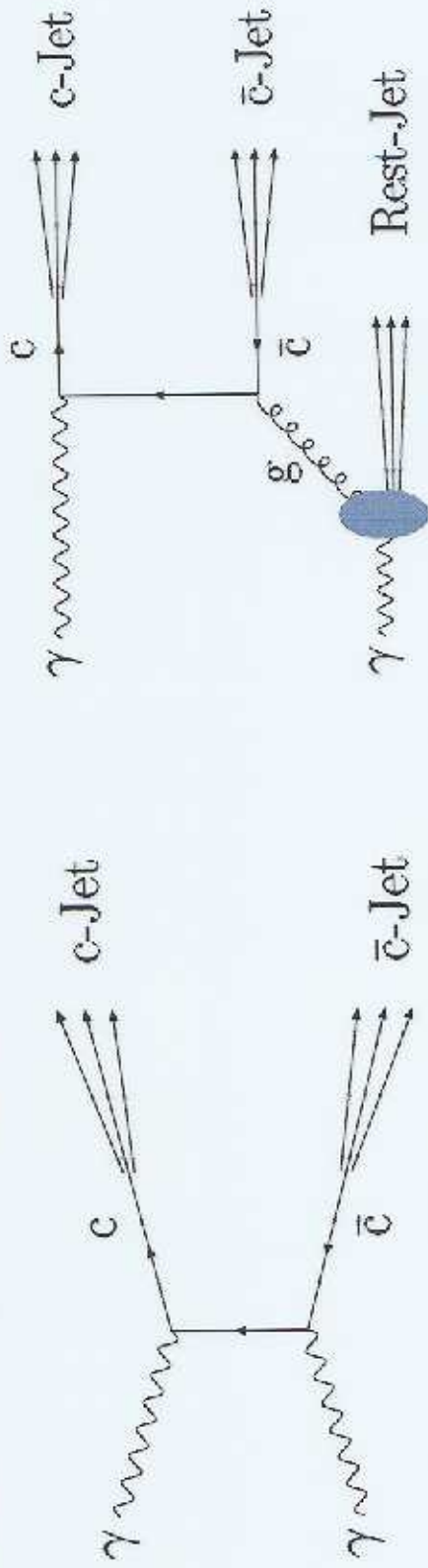
$$\begin{aligned}
 \Delta m &= m(D^{*+}) - m(D^0) \\
 &= 145 \text{ MeV}
 \end{aligned}$$

\Rightarrow 6 MeV kin. energy only

\Rightarrow clear signature



Separation of Contributing Processes



Sensitive Variables:

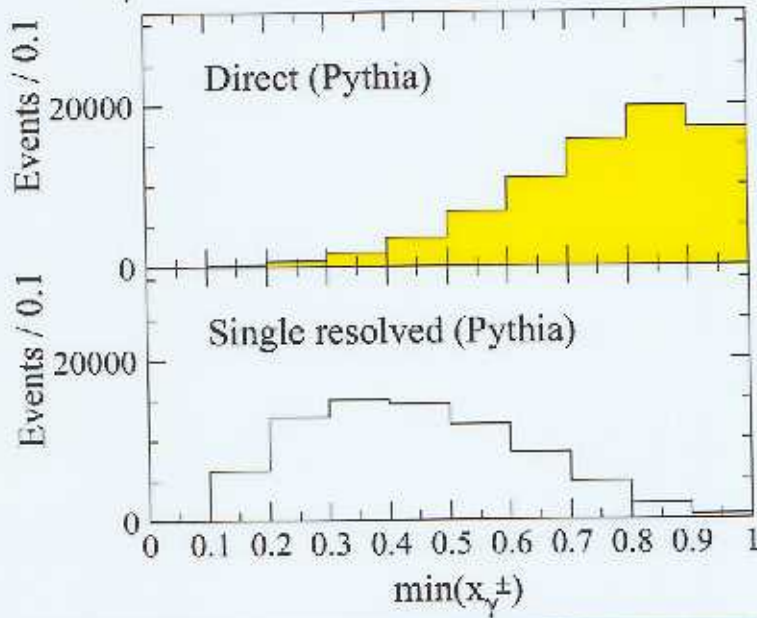
$$x_{\gamma}^{\pm} = \frac{\sum_{\text{jets}} (E \pm p_z)}{\sum E_{\text{flow}} (E \pm p_z)}$$

$$x_{\gamma}^{\text{min}} = \min(x_{\gamma}^{\pm})$$

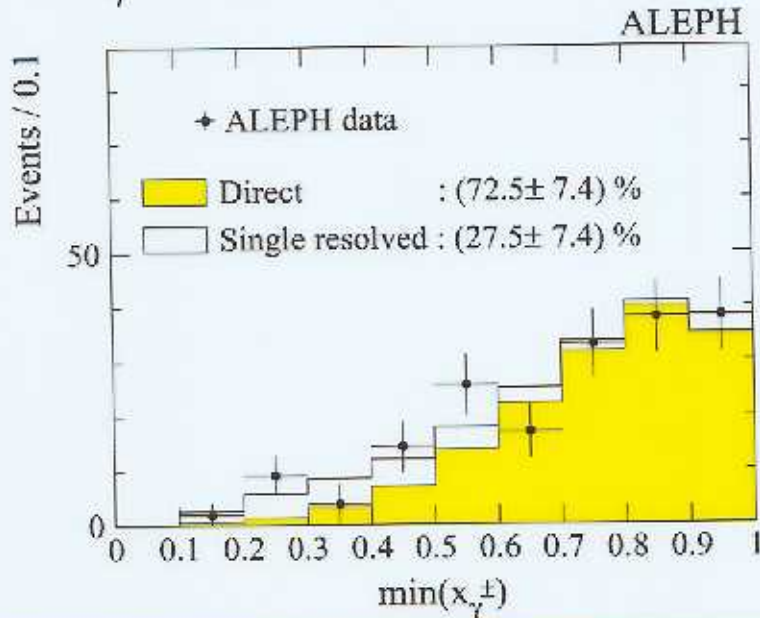
$$p_t^{D^*} / W_{\text{vis}}$$

Fractions of Direct and Single Resolved Processes

x_γ^{\min} distribution in MC

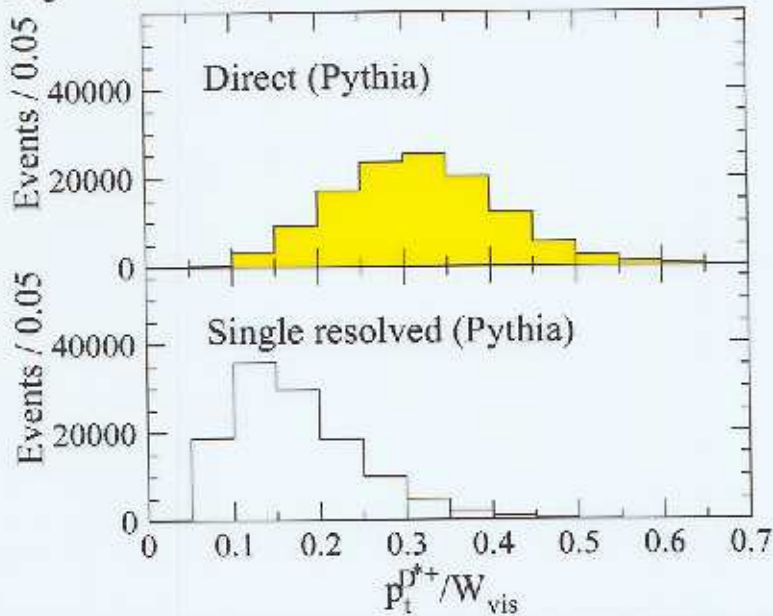


x_γ^{\min} distribution in data

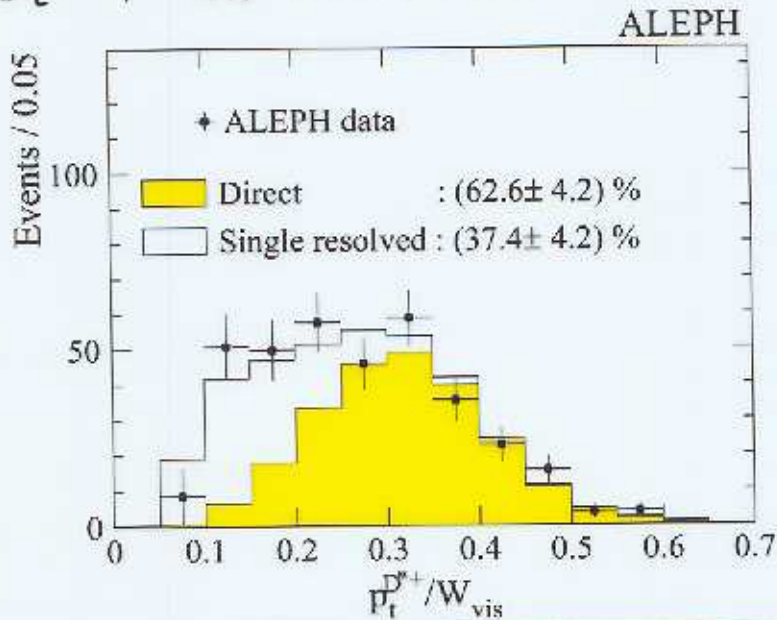


Fractions of Direct and Single Resolved Processes

$p_t^{D^{*+}} / W_{vis}$ distribution in MC



$p_t^{D^{*+}} / W_{vis}$ distribution in data



Measurement of $\sigma(e^+e^- \rightarrow e^+e^-c\bar{c}X)$ using $D^{*\pm}$

LEP II data $\sqrt{s} = 183 - 209 \text{ GeV}$ $L = 683 \text{ pb}^{-1}$

$\gamma\gamma$ selection and antitagged events



Charm tagged by $D^{*\pm}$:



Results :

$d\sigma/dp_T(D^{*\pm})$ with $|\eta| < 1.4$ and $1. \text{ GeV} < p_T < 12. \text{ GeV}$

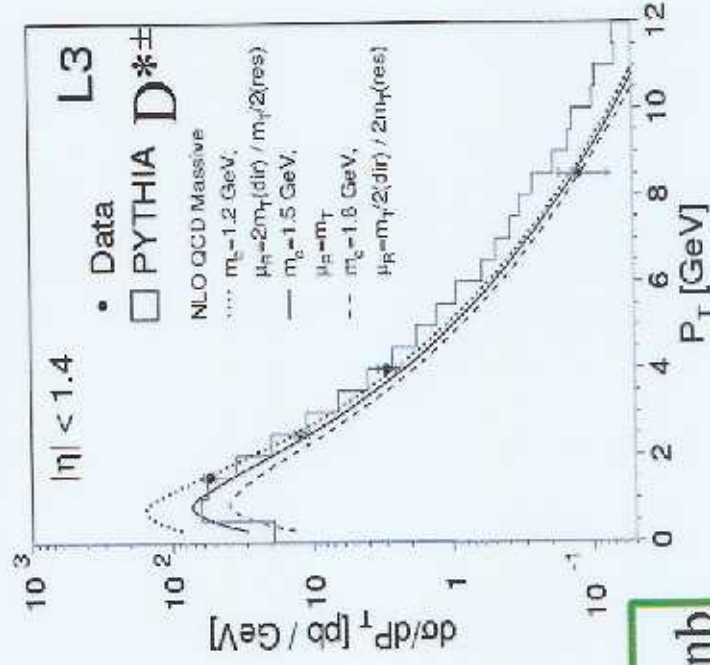
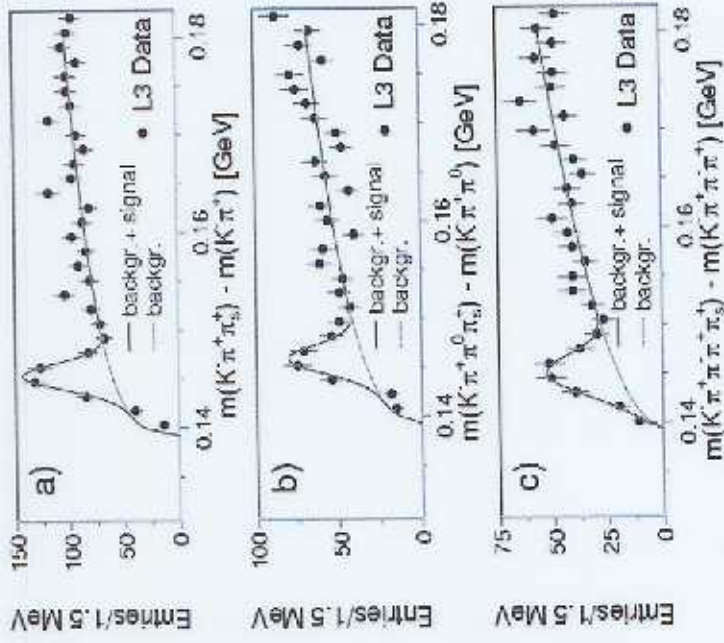
Visible region

Comparison with **PYTHIA LO**
Frixione NLO MC

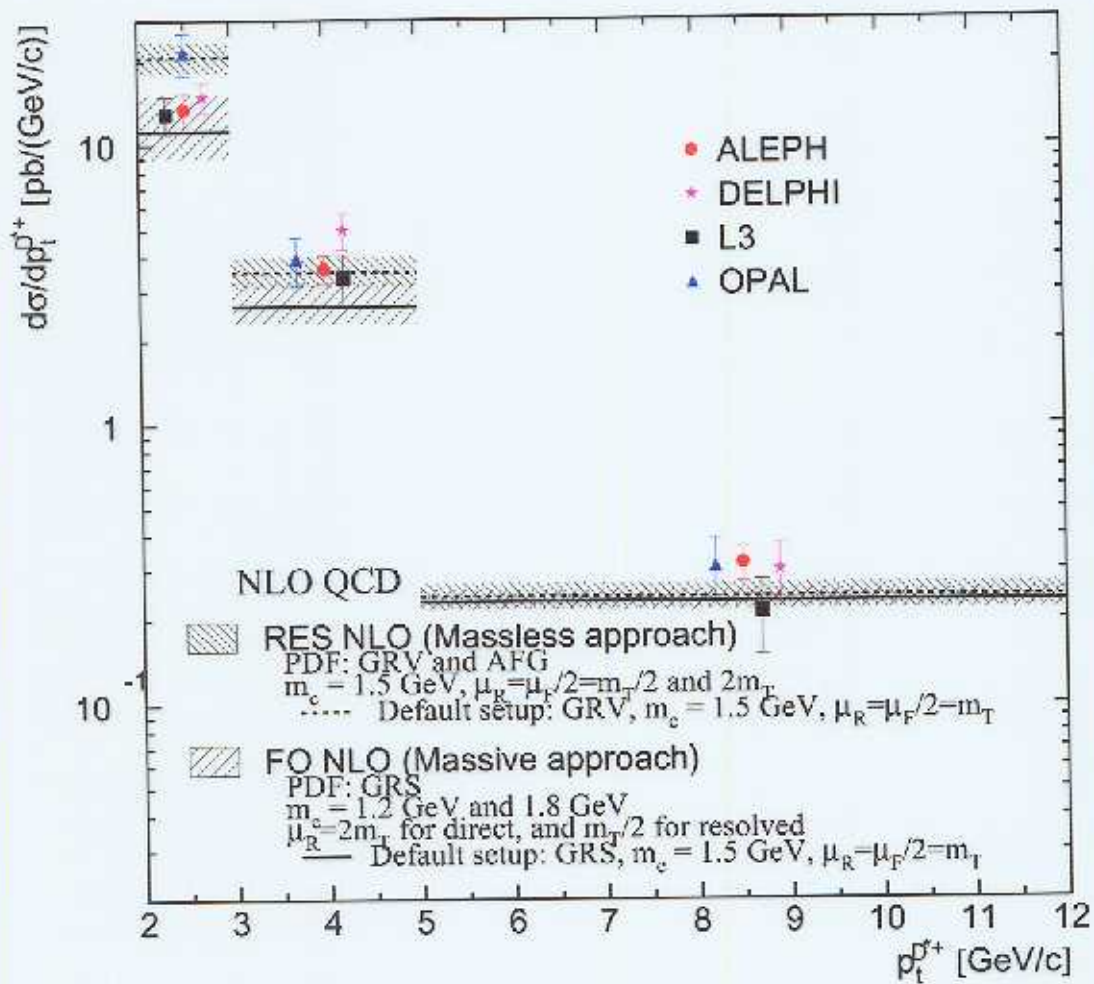
$\sigma(e^+e^- \rightarrow e^+e^-D^{*\pm}X)_{\text{vis}} = 71.2 \pm 5.3 \text{ (stat)} \pm 9.8 \text{ (syst)} \text{ pb}$

Extraction of the charm cross section

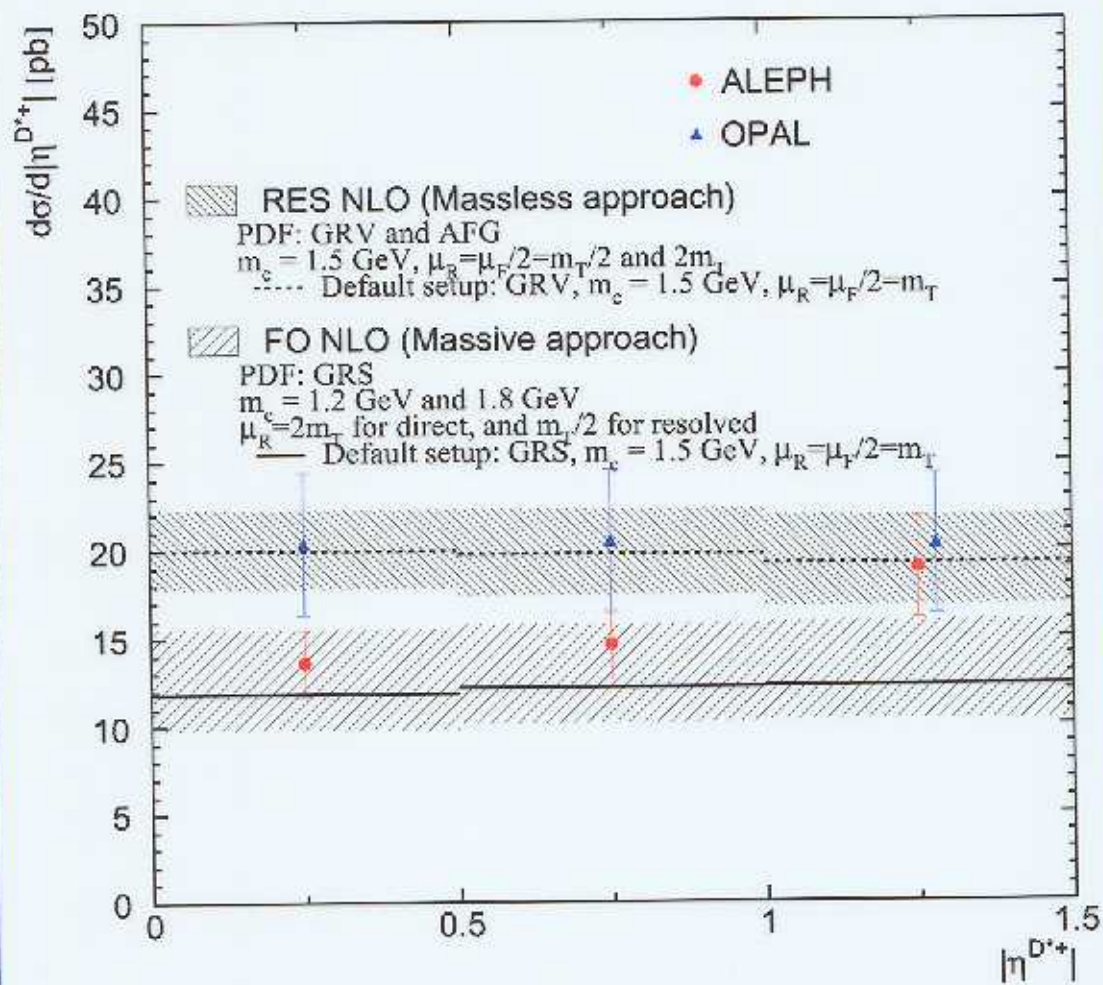
$$\sigma(e^+e^- \rightarrow e^+e^-c\bar{c}X) = (1.12 \pm 0.09 \text{ (stat)} \pm 0.16 \text{ (syst)}_{-0.25}^{+0.54}) \text{ nb}$$



$$d\sigma/dp_t^{D^{*+}} (e^+e^- \rightarrow e^+e^-D^{*+}X)$$



$$d\sigma/d|\eta^{D^{*+}}|(e^+e^- \rightarrow e^+e^-D^{*+}X)$$



Total Visible Cross Section

$$(2 < p_t^{D^{*+}} < 12) \text{ GeV}; |\eta^{D^{*+}}| < 1.5$$

ALEPH

$$\sigma_{\text{vis}}^{D^{*+}}(e^+e^- \rightarrow e^+e^-D^{*+}X) = 23.39 \pm 1.64_{\text{stat}} \pm 1.52_{\text{syst}} \text{ pb}$$

OPAL

$$\sigma_{\text{vis}}^{D^{*+}}(e^+e^- \rightarrow e^+e^-D^{*+}X) = 30.7 \pm 2.8_{\text{stat}} \pm 3.3_{\text{syst}} \text{ pb}$$

NLO QCD (Frixione et al.):

$$\sigma_{\text{vis}}^{D^{*+}}(e^+e^- \rightarrow e^+e^-D^{*+}X) = 17.3^{+5.1}_{-2.9} \text{ pb}$$

Total Cross Section ($e^+e^- \rightarrow e^+e^-c\bar{c}$) @ 183 – 209 GeV
extrapolated using

[NLO calculation from Frixione et.al](#)

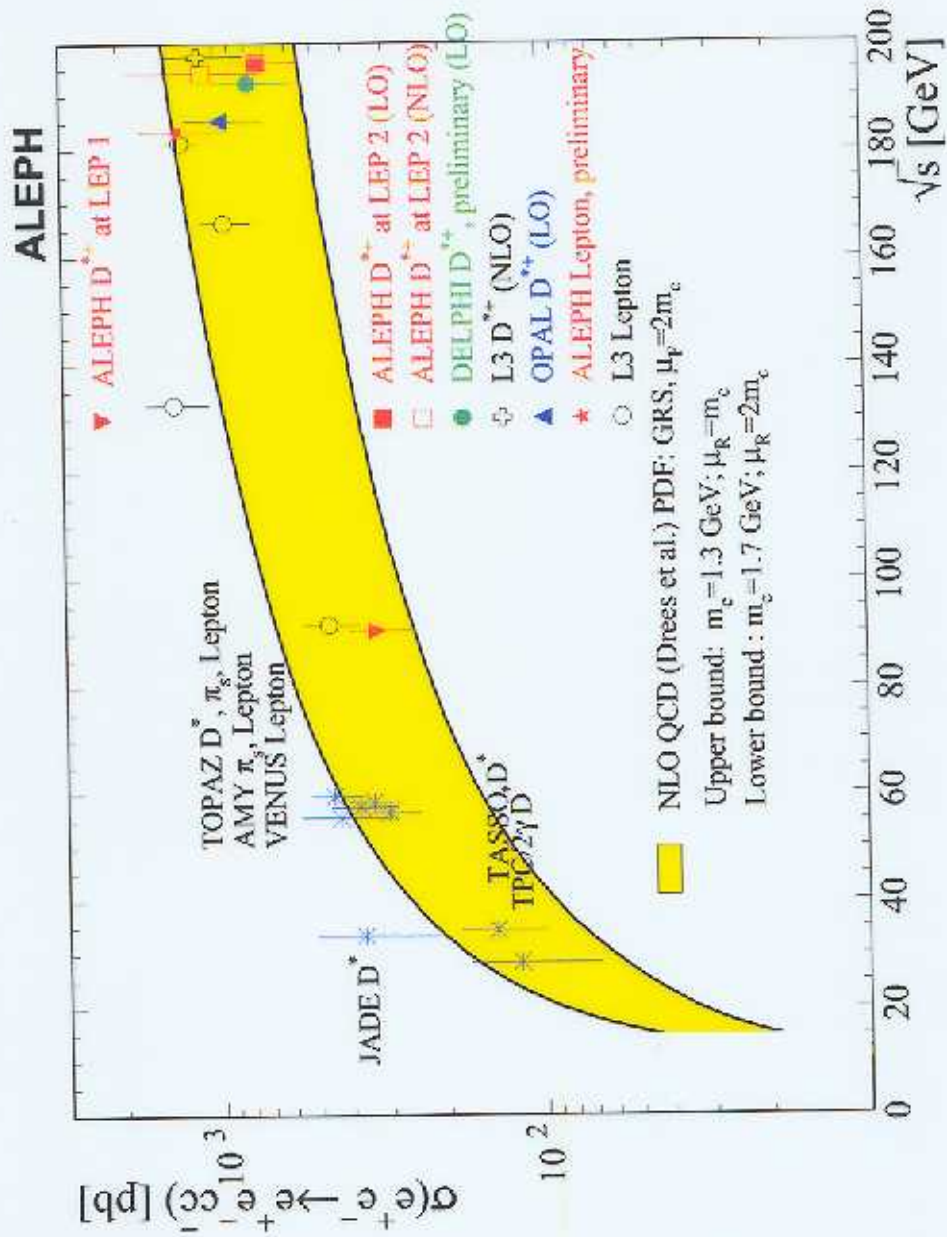
$$\sigma_{\text{tot}}^{c\bar{c}} = \frac{\sigma_{\text{vis}}^{D^{*+}}}{2 \cdot P_{c \rightarrow D^{*+}}} \cdot R_{\text{tot}}$$

Extrapolation factor R_{tot} :

$$R_{\text{tot}} = 22.2 \begin{matrix} +16.0 \\ -7.3 \end{matrix}$$

$$\sigma_{\text{tot}}^{c\bar{c}} = 1087 \pm 86 \text{ (stat.)} \pm 70 \text{ (sys.)} \begin{matrix} +783 \\ -357 \end{matrix} \text{ (extr.) pb.}$$

Total cross section $\sigma(e^+e^- \rightarrow e^+e^-c\bar{c})$



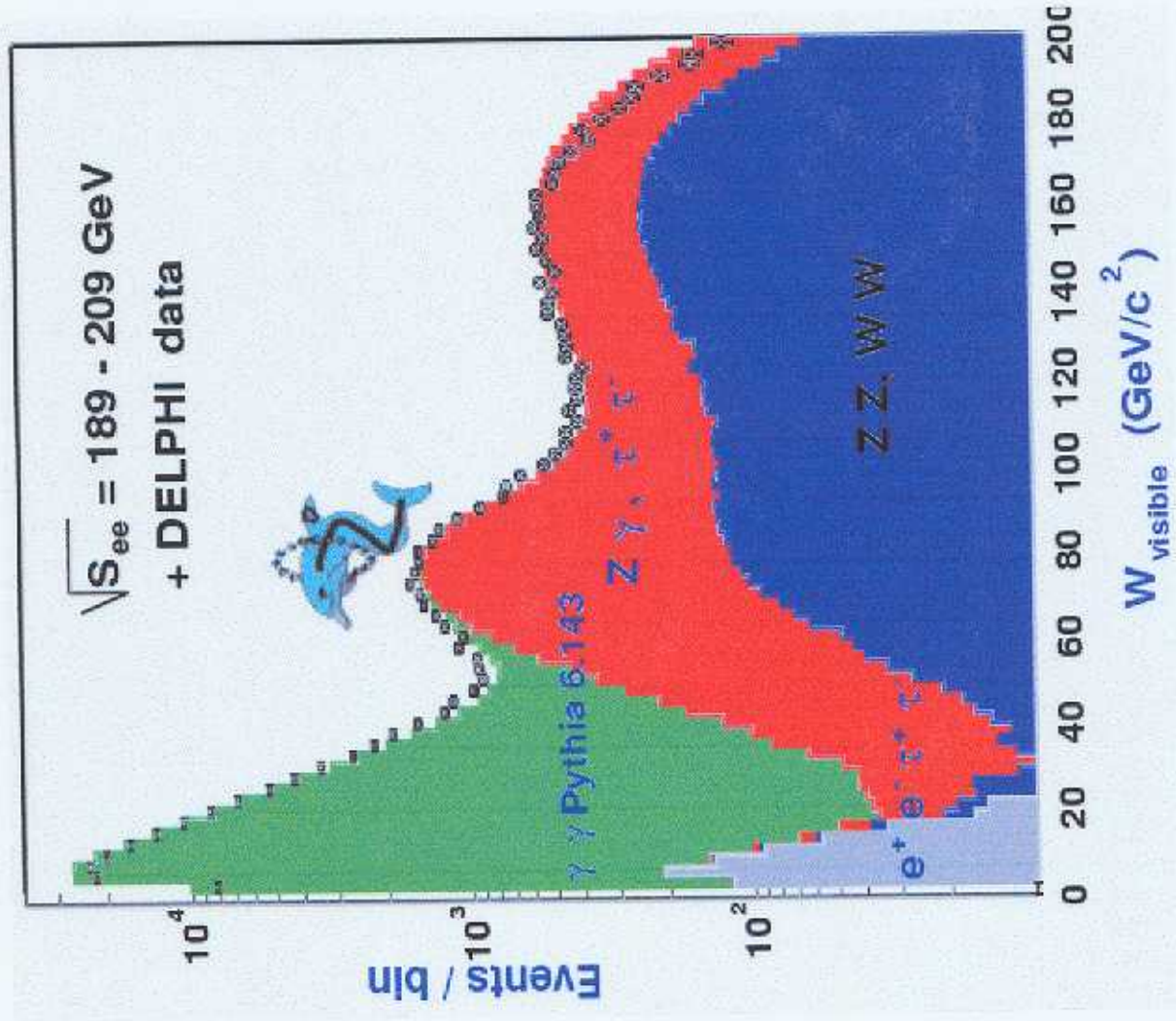
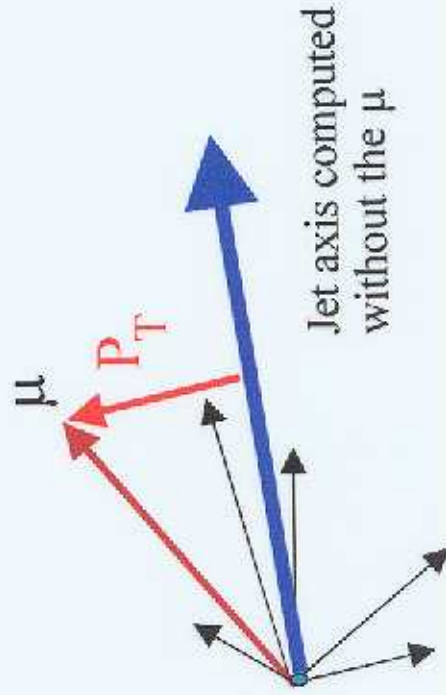
Measurement of $\sigma(e^+e^- \rightarrow e^+e^-c\bar{c}X)$ and $\sigma(e^+e^- \rightarrow e^+e^-b\bar{b}X)$

Event selection strategy
(for L3 and DELPHI)

Select anti-tagged $\gamma\gamma$ events

Identify a lepton as
a signature for semi-leptonic
charm and beauty decays

Reconstruct jets and compute the sensitive
variable (the lepton transverse momentum
with respect to the lepton jet axis)



Measurement of $\sigma(e^+e^- \rightarrow e^+e^-c\bar{c}X)$ and $\sigma(e^+e^- \rightarrow e^+e^-b\bar{b}X)$

⇒ Upgrade of their previous measurement

Data $\sqrt{s} = 189 - 209$ GeV $L = 627$ pb⁻¹



. Use **muons** and **electrons**

. χ^2 : 3 variable fit N_{bb} , N_{cc} , N_{uds}

Results

$$\sigma(e^+e^- \rightarrow e^+e^-b\bar{b}X)_{\text{muons}} = 13.0 \pm 2.3 \text{ (stat)} \pm 2.3 \text{ (syst)} \text{ pb}$$

$$\sigma(e^+e^- \rightarrow e^+e^-b\bar{b}X)_{\text{electrons}} = 12.6 \pm 2.4 \text{ (stat)} \pm 2.3 \text{ (syst)} \text{ pb}$$

⇒ μ and e tag results are consistent

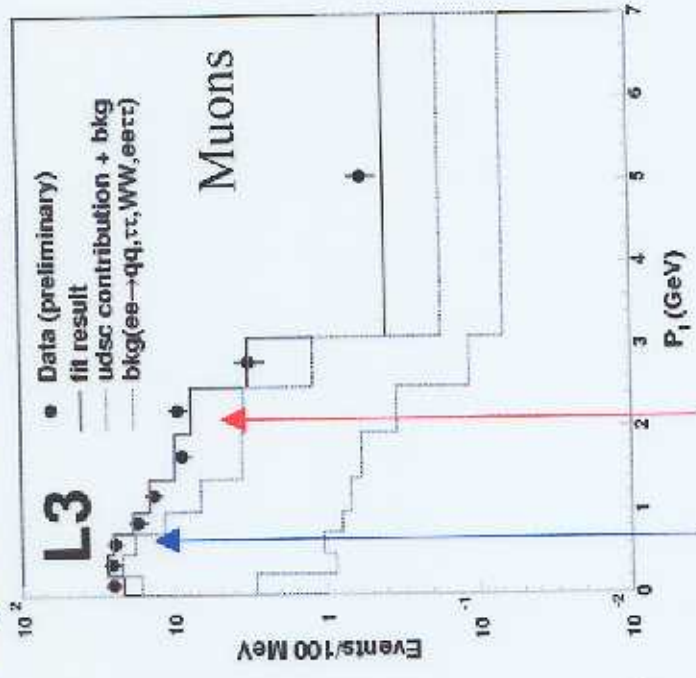
$$\sigma(e^+e^- \rightarrow e^+e^-b\bar{b}X)_{\text{combined}} = 12.8 \pm 1.7 \text{ (stat)} \pm 2.3 \text{ (syst)} \text{ pb}$$

↑ result in agreement with L3 previous measurement

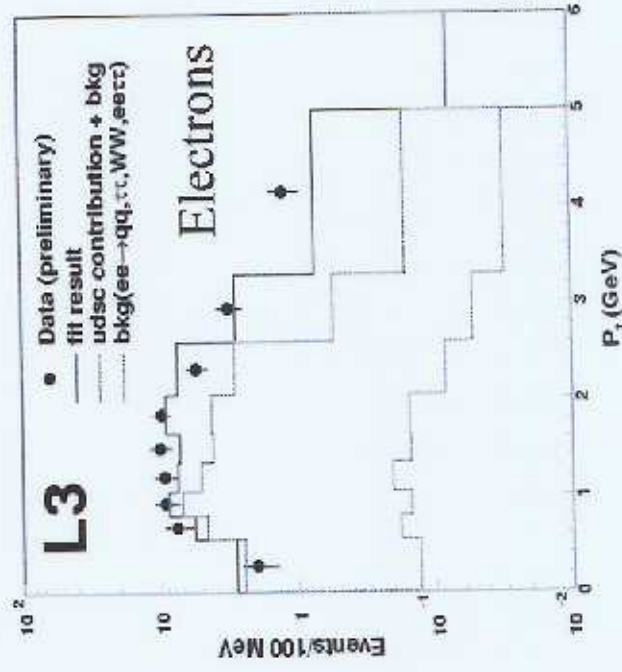
↑ as a subproduct of the control test of the charm sample

$$\sigma(e^+e^- \rightarrow e^+e^-c\bar{c}X)_{\text{combined}} = 998 \pm 117 \text{ (stat)} \text{ pb}$$

(in agreement with L3 previous measurement)



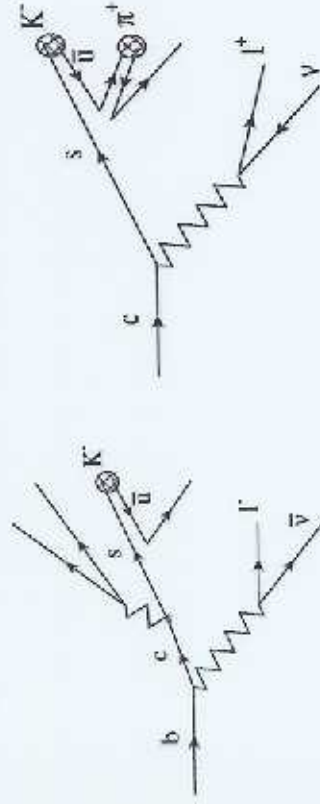
Charm Beauty



Measurement of $\sigma(e^+e^- \rightarrow e^+e^-c\bar{c}X)$ and $\sigma(e^+e^- \rightarrow e^+e^-b\bar{b}X)$



K-lepton charge correlations for beauty or charm enrichment



Identify a K in lepton jet with RICH and TPC

$c\bar{c}$: K^+l^- charge correlation

fix N_{bb} : value given by the previous measurement
fit N_{cc}

$$\sigma^{c\bar{c}} = 937 \pm 191 \text{ (stat)} \pm 206 \text{ (syst)} \text{ pb}$$

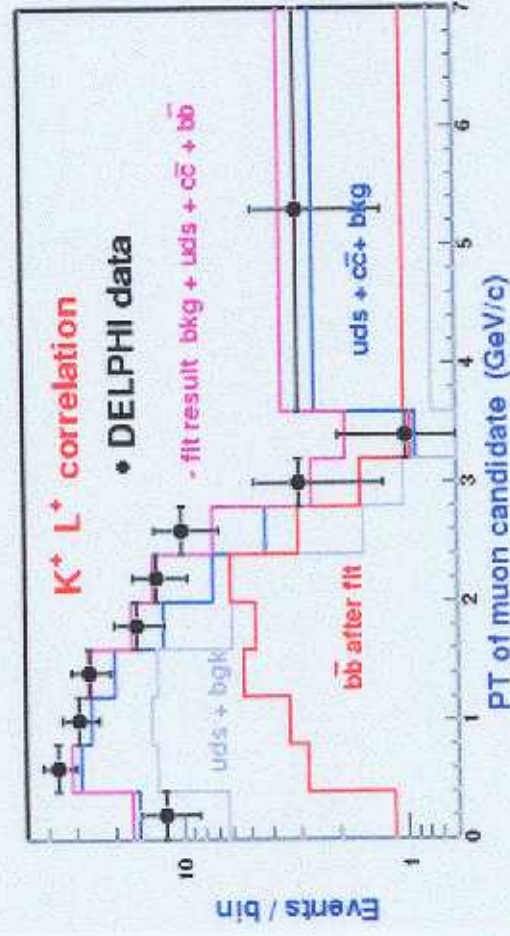
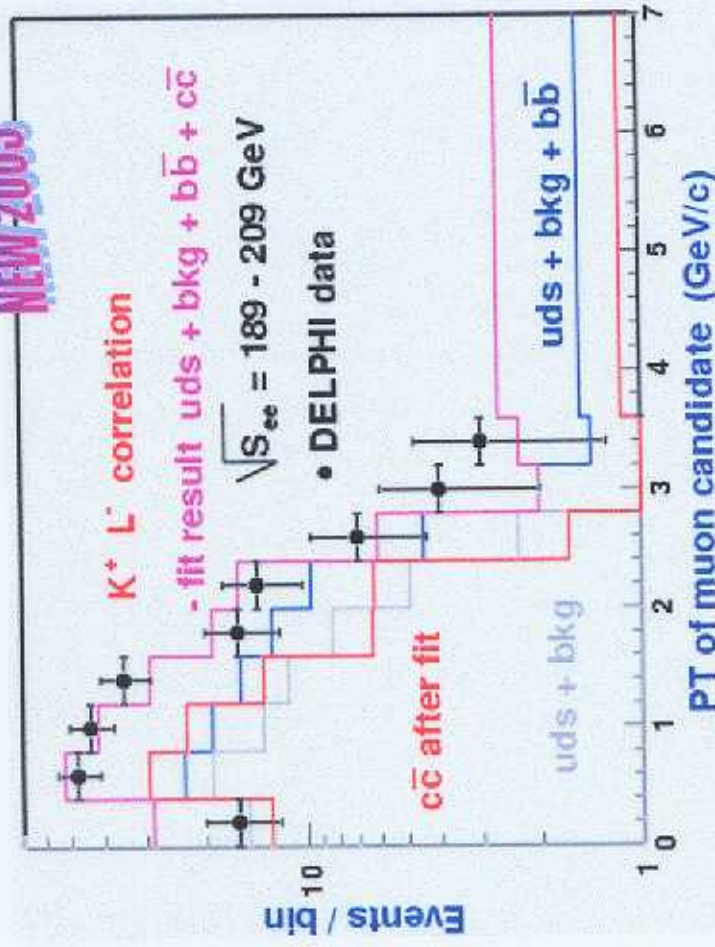
$b\bar{b}$: K^+l^+ charge correlation

fix N_{cc} : value given by LEP average
fit N_{bb}

$$\sigma^{b\bar{b}} = 11.4 \pm 4.5 \text{ pb}$$

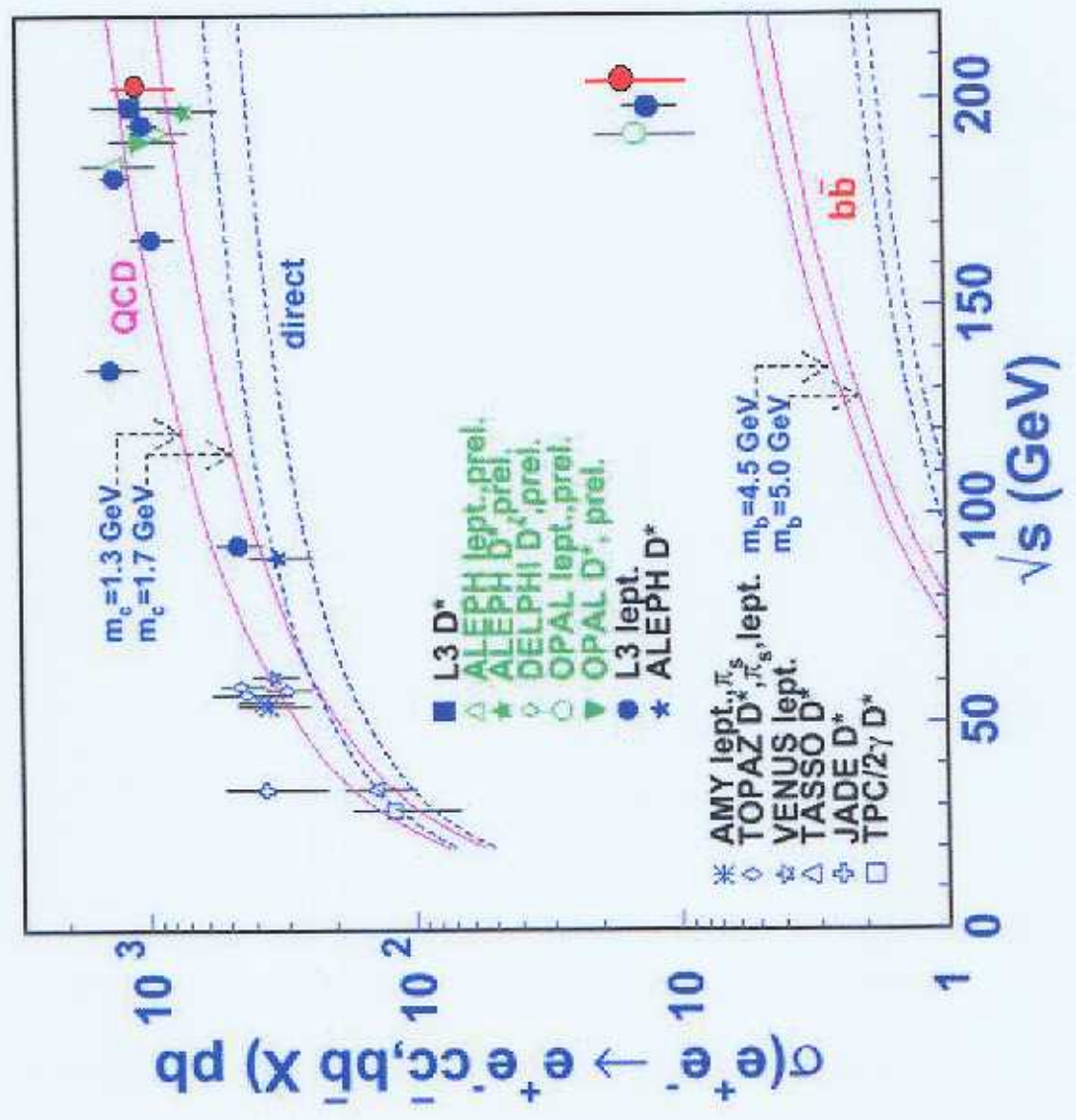
↑ in agreement with previous DELPHI measurement

NEW 2003



Comparison with L3 and OPAL

● DELPHI



Hints towards a solution ?

Play with fragmentation functions (you can also do that within PYTHIA)

Fit pdfs to LEP and HERA data

Improve QCD calculations with masses and different scales

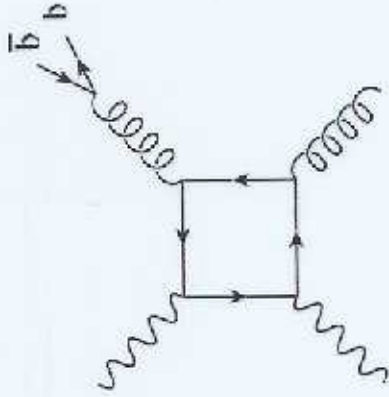
Recent theoretical computations are getting closer :

(... many good reviews at International Conferences)

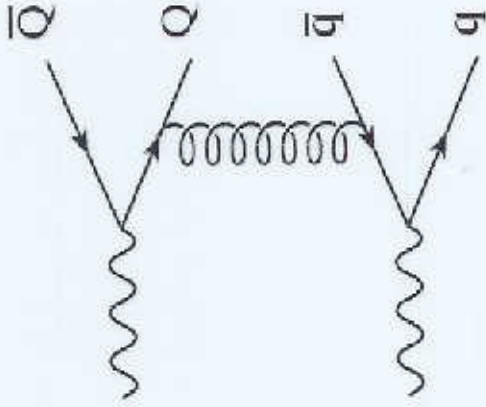
Missing components ?

$\gamma\gamma \rightarrow gg$ through the box diagram (cf B. De Tollis...)

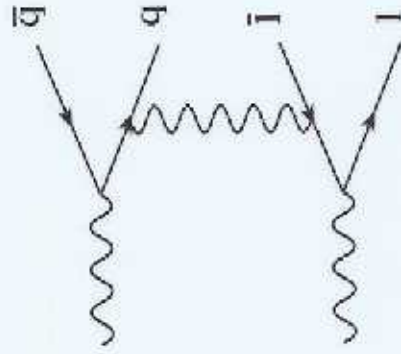
All the physics is in the box.



The $\gamma\gamma \rightarrow 4$ quarks connection (cf Jiri Chyla ...)



The $\gamma\gamma \rightarrow 2$ quarks 2 leptons background



In a more general way 2 lepton QED corrections.. to the total $\gamma\gamma$ cross section .

Conclusions

A new measurement of open beauty production with real photon collisions is needed ... maybe soon at SLAC with the LEPC.

And wait a bit for an open **top** cross section measurement at the PLC