Heavy flavour production in two-photon processes

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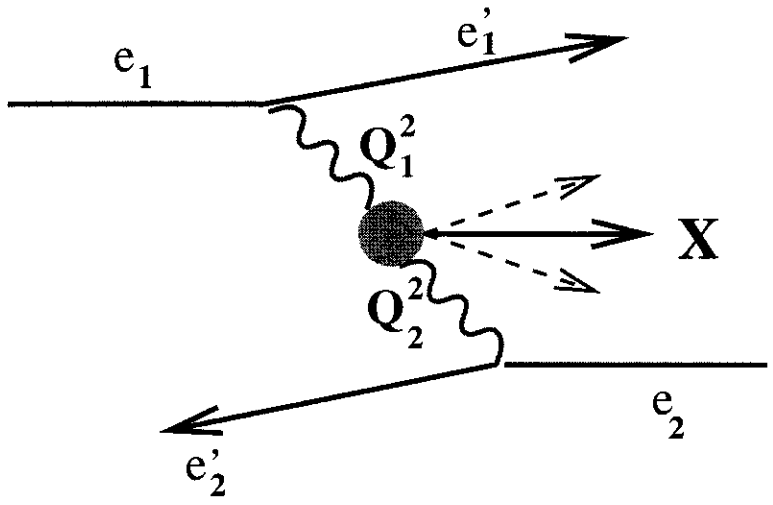
- Inclusive open charm
- Inclusive open bottom
- Charmonium and bottomium
- $F_{2,c}^{\gamma}$ in $e\gamma$ scattering
- Future experiments

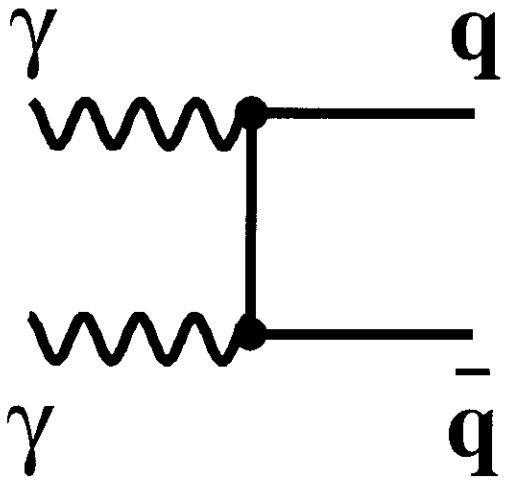
Two-photon interactions



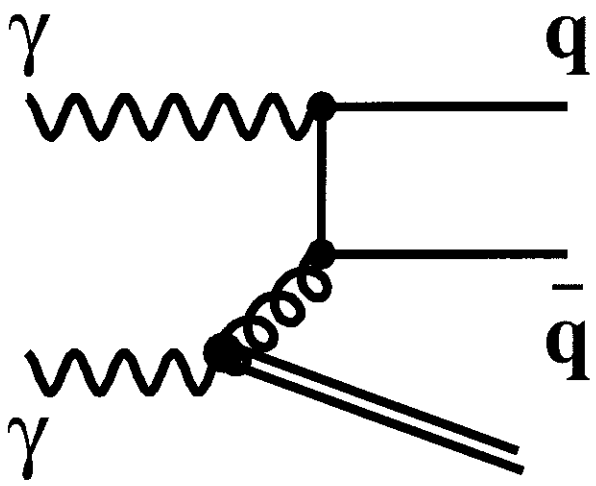
Multiperipheral e^+e^- collisions can be regarded as $\gamma\gamma$ collisions

- photons are emitted at low angles with low energy
- electrons usuallally not detected (anti-tag),
  this means low photon virtuality, $\langle Q^2 \rangle \approx 0$
- low photon-photon invariant mass, $W_{\gamma\gamma} << \sqrt{s_{ee}}$
- significant longitudinal boost

Contributing processes



direct



(single-)resolved

- photons participate directly
- QED at leading order
- only free parameter is m_{q}

- one photon interacts through its parton content (npQCD)
- sensitive to the gluon content

double-resolved is usually negligible

NLO QCD calculations are available

Massive and massless calculations

Two basic theoretical approaches to HF production in $\gamma\gamma$:

- **massive** approach with fixed flavour number

  no HF in PDF, HF produced in hard interaction

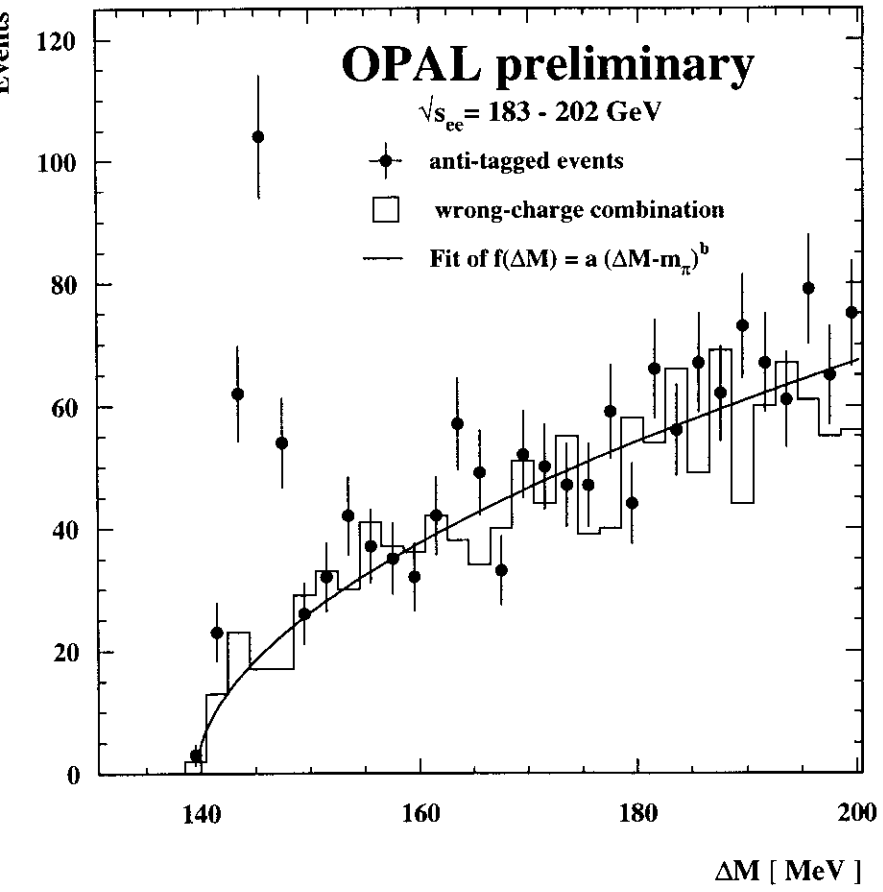
  valid if hard scale is small ($\mu \leq m_{\mathrm{Q}}$)

- **massless** approach with variable flavour number

  HF may come from photon above threshold

  valid hard scale is high ($\mu \gg m_{\mathrm{Q}}$)

Charm measurement from inclusive D^* production



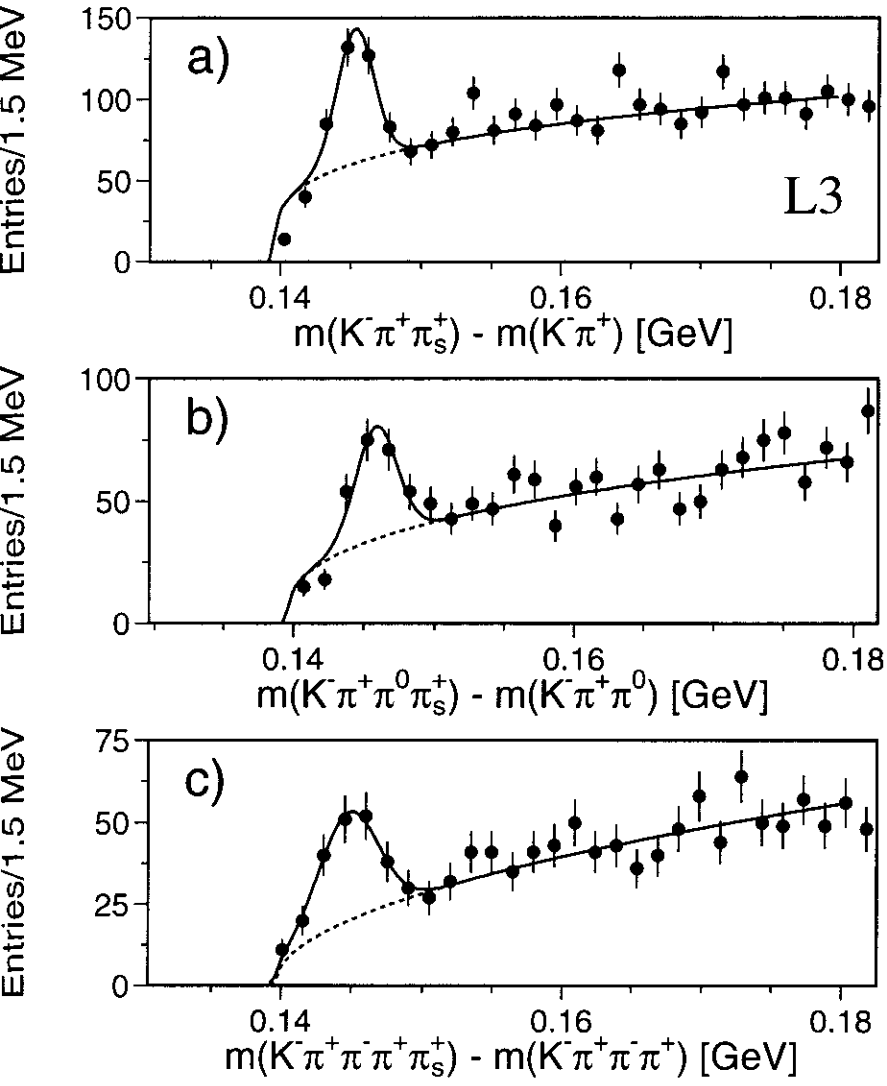
fully reconstructed $D^{\star+} \longrightarrow D^0\pi_s^+$

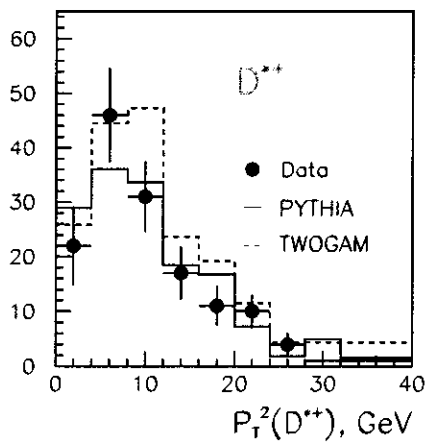
- the D^*-D^0 mass difference is small

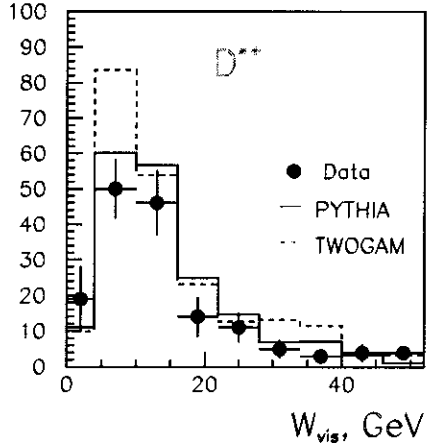
$\Rightarrow$ small phase-space for background

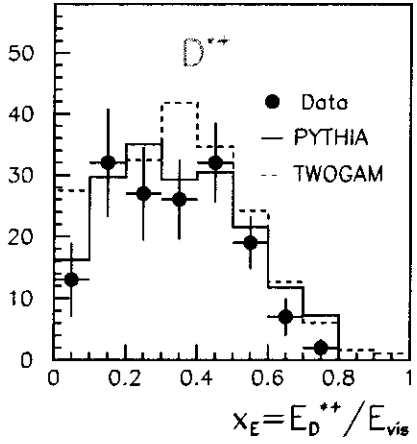
- the difference is less sensitive to D^0 reconstruction $\Rightarrow$ better resolution
- possibility for differential measurements

Inclusive D* production









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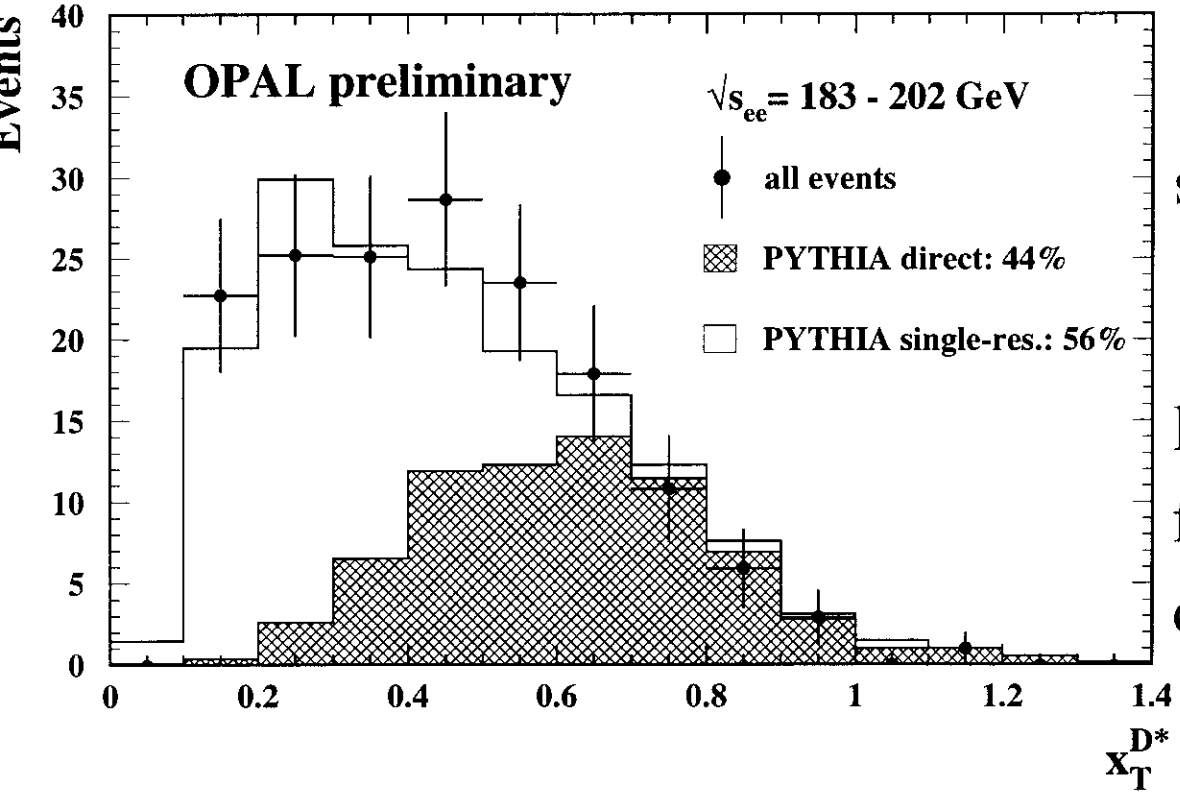
hadronic final state well described

Ratio of direct / resolved processes

needed because detection efficiency is different



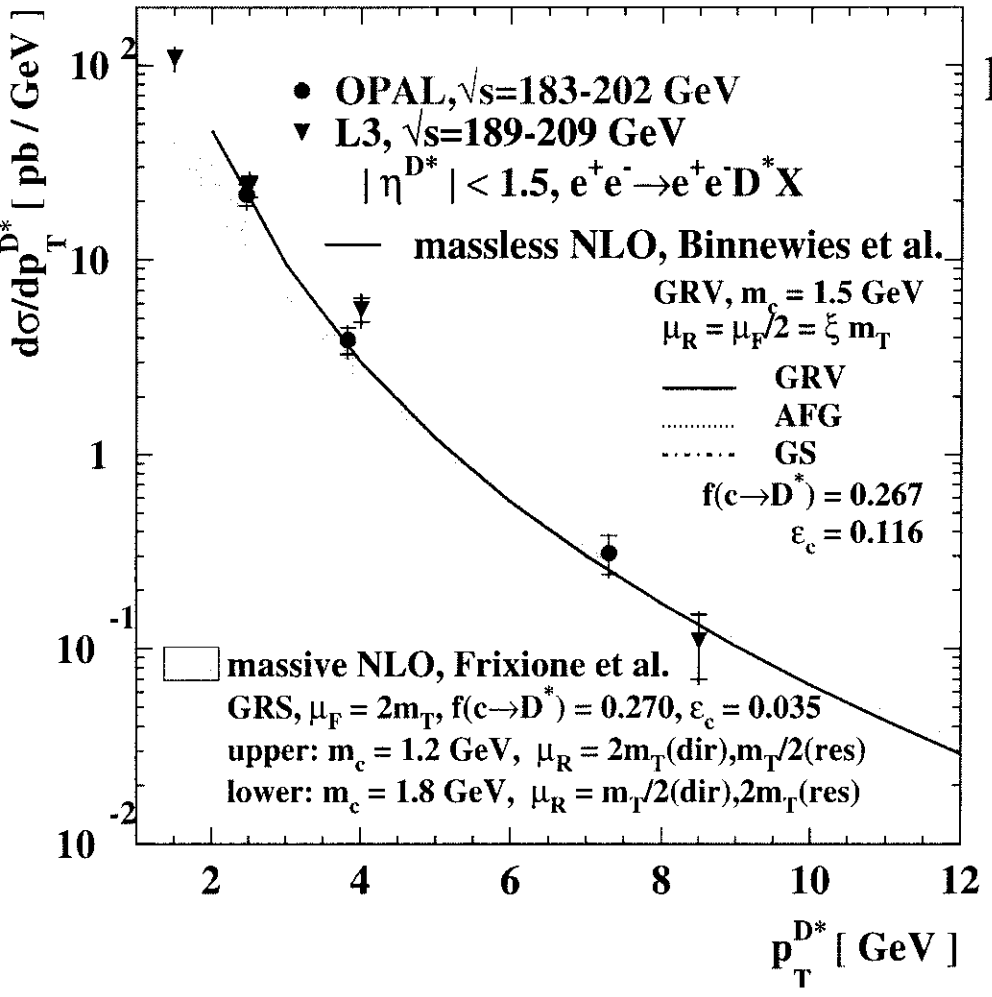
scaled transverse momentum

$$x_{\mathrm{T}}^{\mathrm{D}^*} = \frac{2p_{\mathrm{T}}^{\mathrm{D}^*}}{W_{\mathrm{vis}}}$$

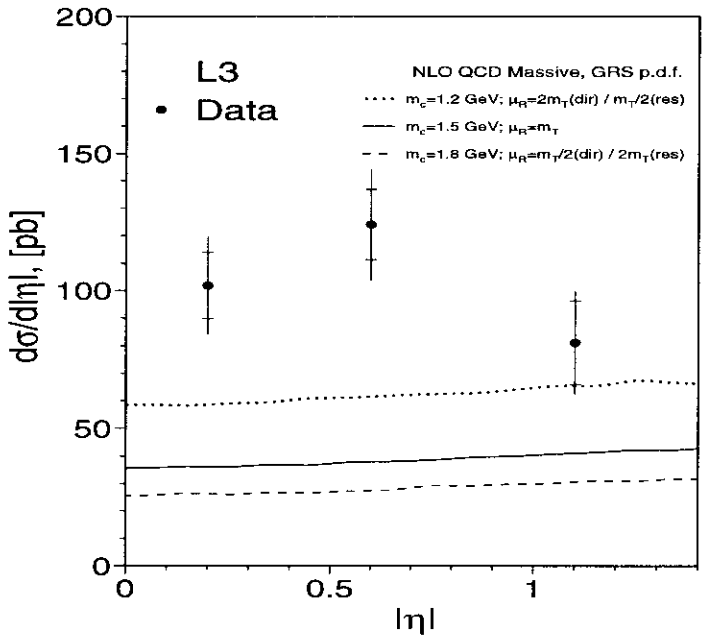
larger for direct process than for resolved ⇒ ratio can be obtained from a fit

data consistent with equal contributions

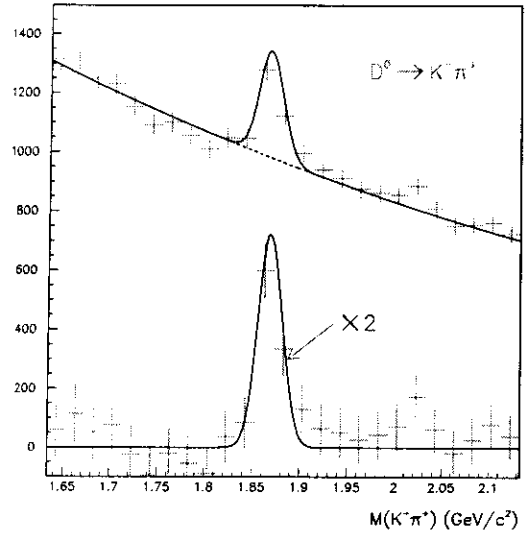
Differential D* cross-sections

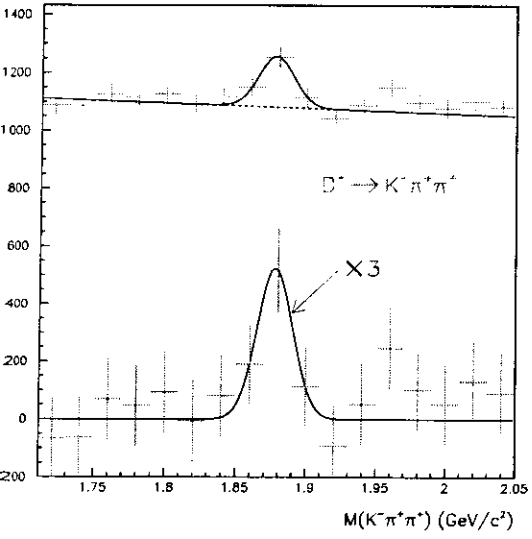


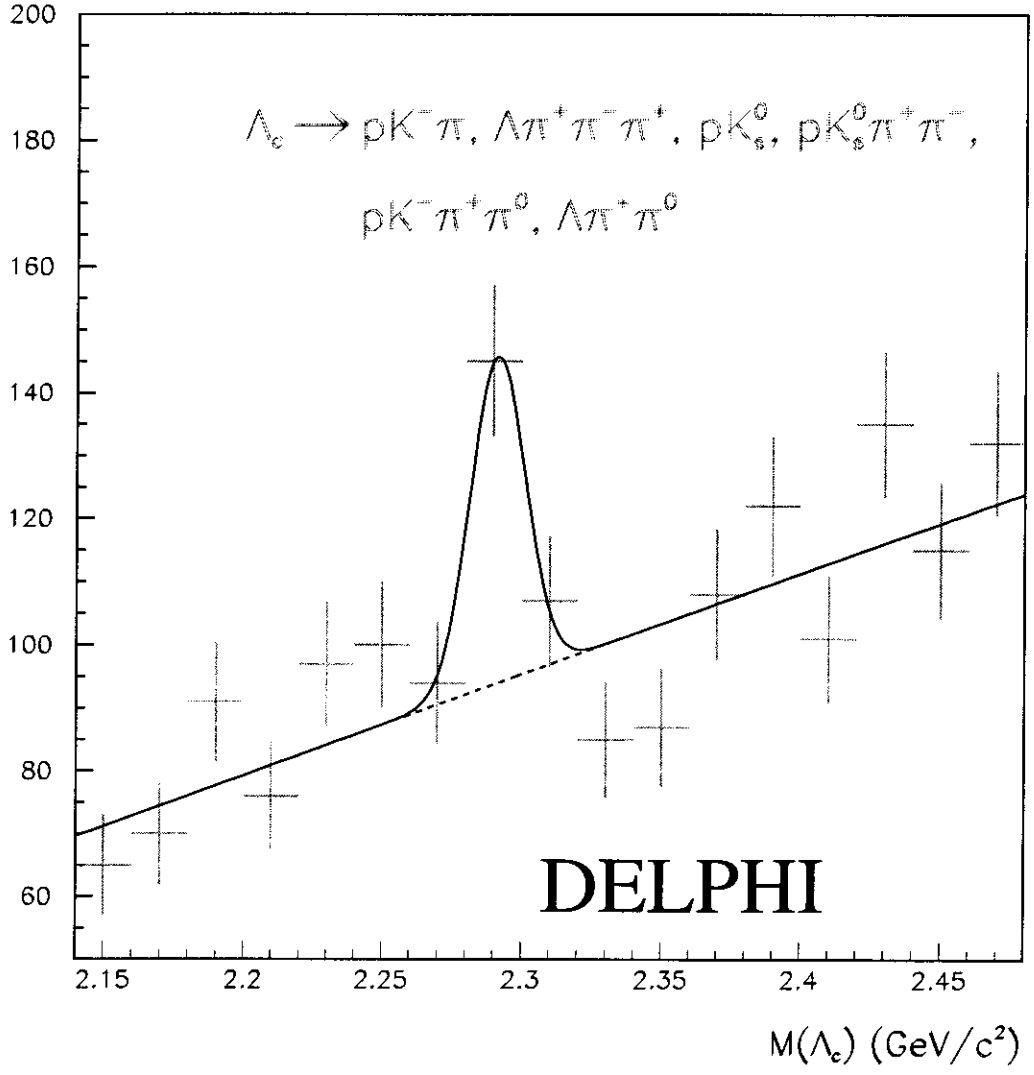
predictions are below the data
at low transverse momenta
rapidity is flat in this region



Other charm hadrons: D^0, D^+ and Λ_c



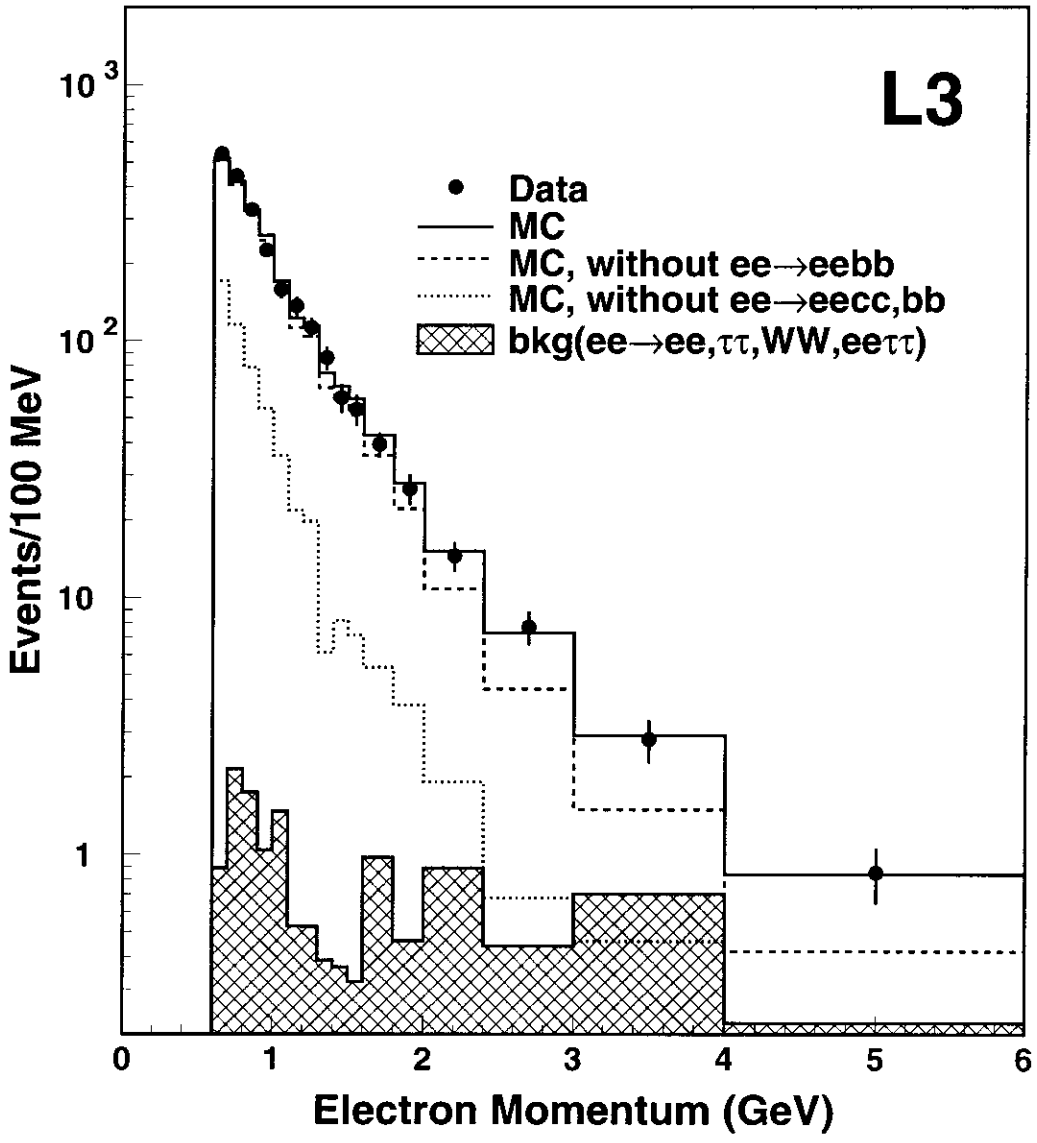




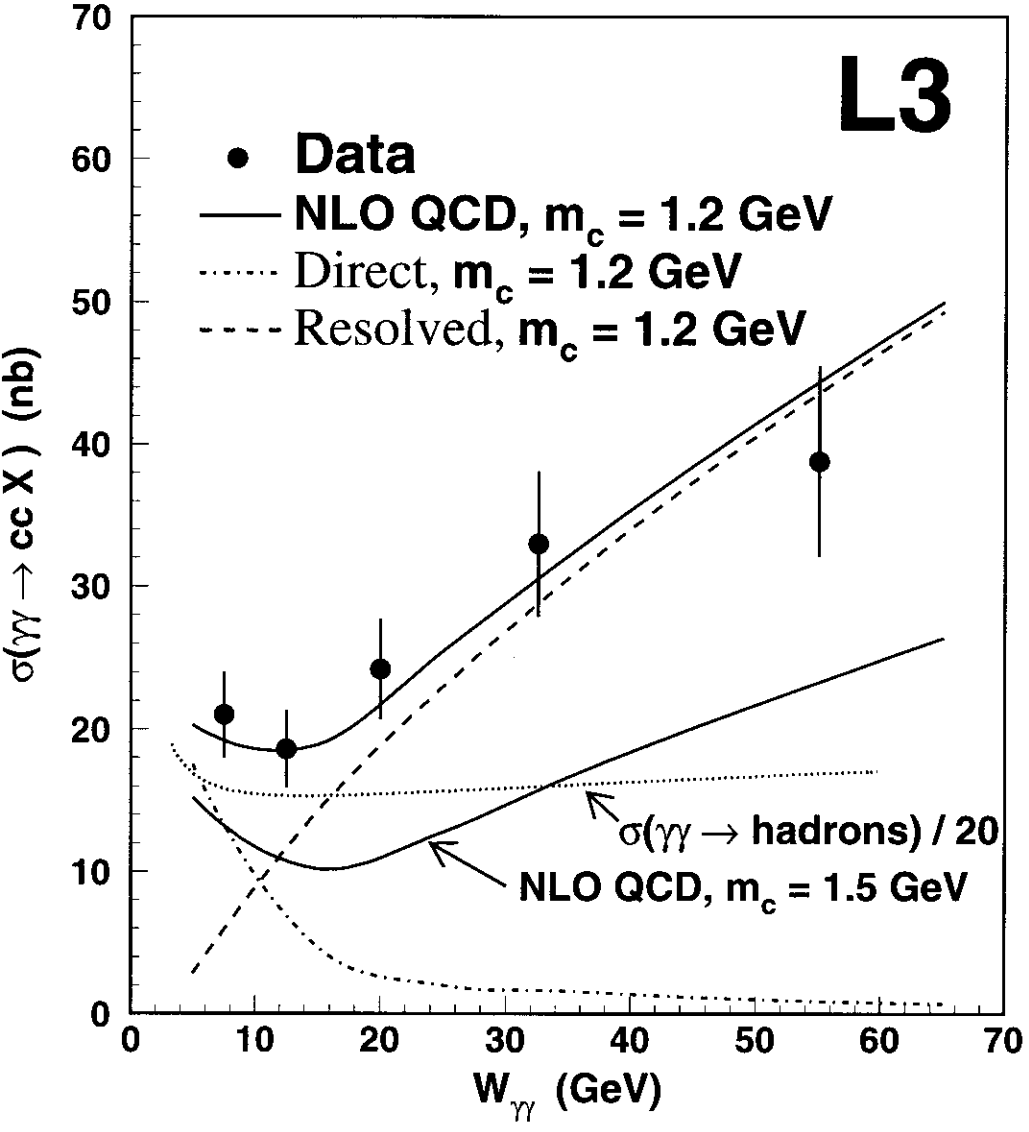
$\sigma_{c\bar{c}}$ with lepton tag

Other method for identifying charm: most of the leptons in the hadronic final state come from charm decay

more statistics, but less purity



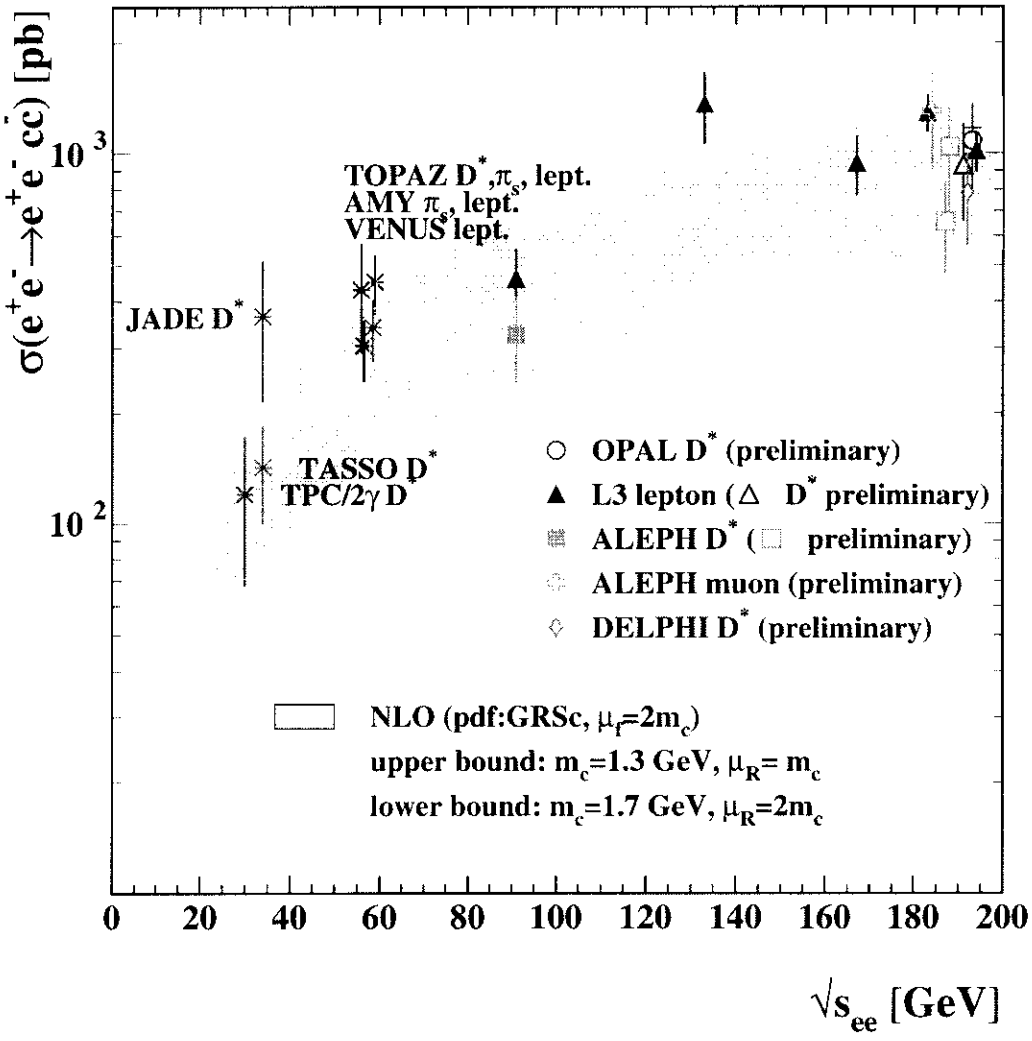
$\sigma_{c\bar{c}}(W_{\gamma\gamma})$ with lepton tag



$W_{\mathrm{vis}} \rightarrow$ unfolding $\rightarrow W_{\gamma\gamma}$ and $\sigma_{\mathrm{ee}} \rightarrow \sigma_{\gamma\gamma}$ like in total cross-section measurement rise with energy much faster than for light quarks, similar to J/Ψ photoproduction at HERA

Charm total cross section

- measured cross-section is extrapolated to total cross-section
- extrapolation error dominates
- theory also uncertain in extreme kinematic region
- restricted kinematic range preferred
- NLO calculation agrees with measurements

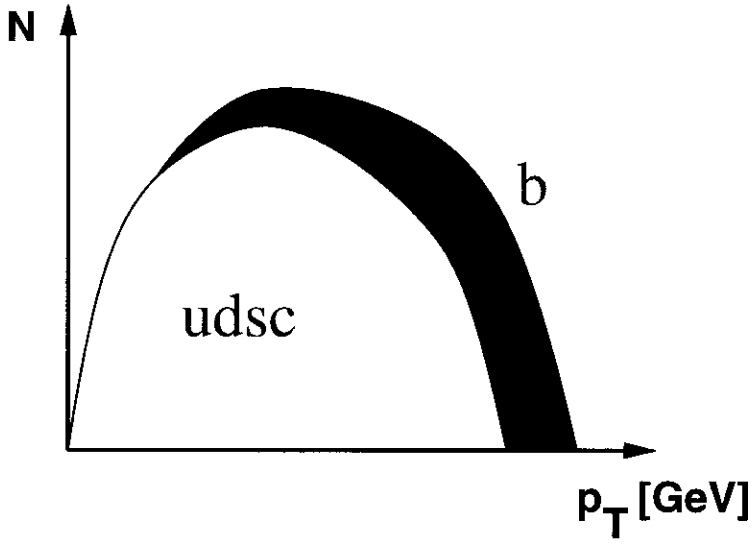


Bottom production

b decays also produce leptons

p_{T} larger than for charm and uds

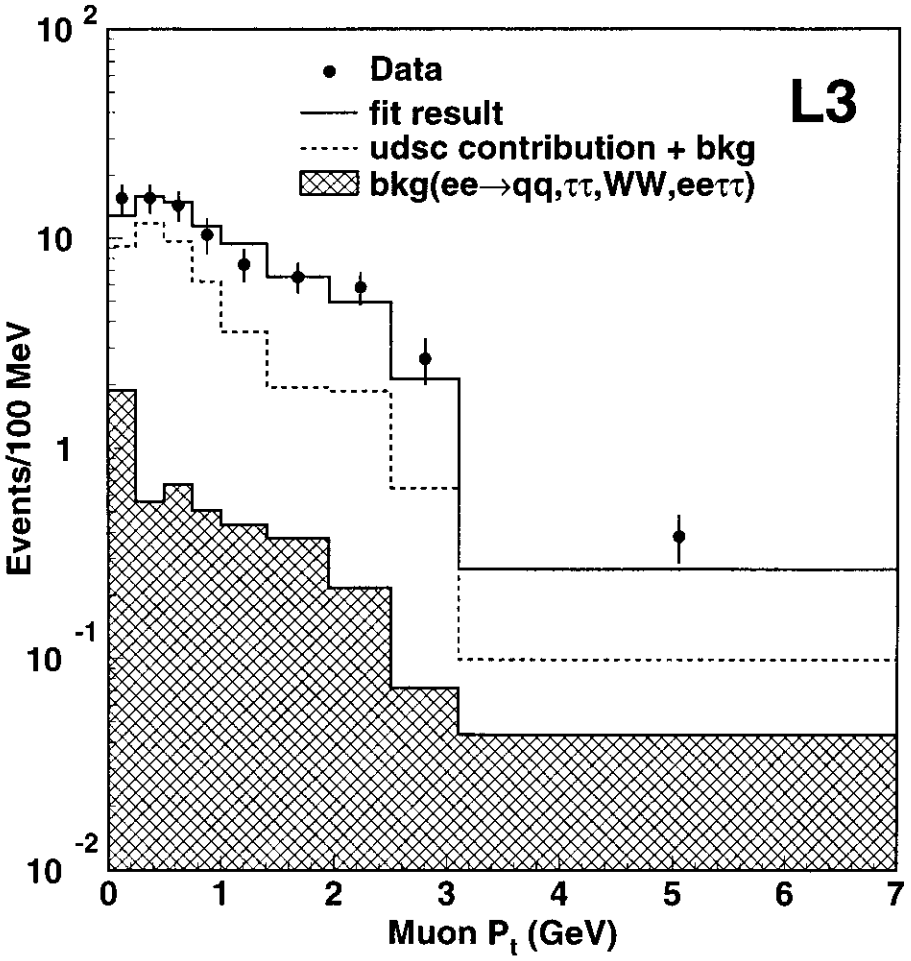
plot P_{T} relative to closest jet

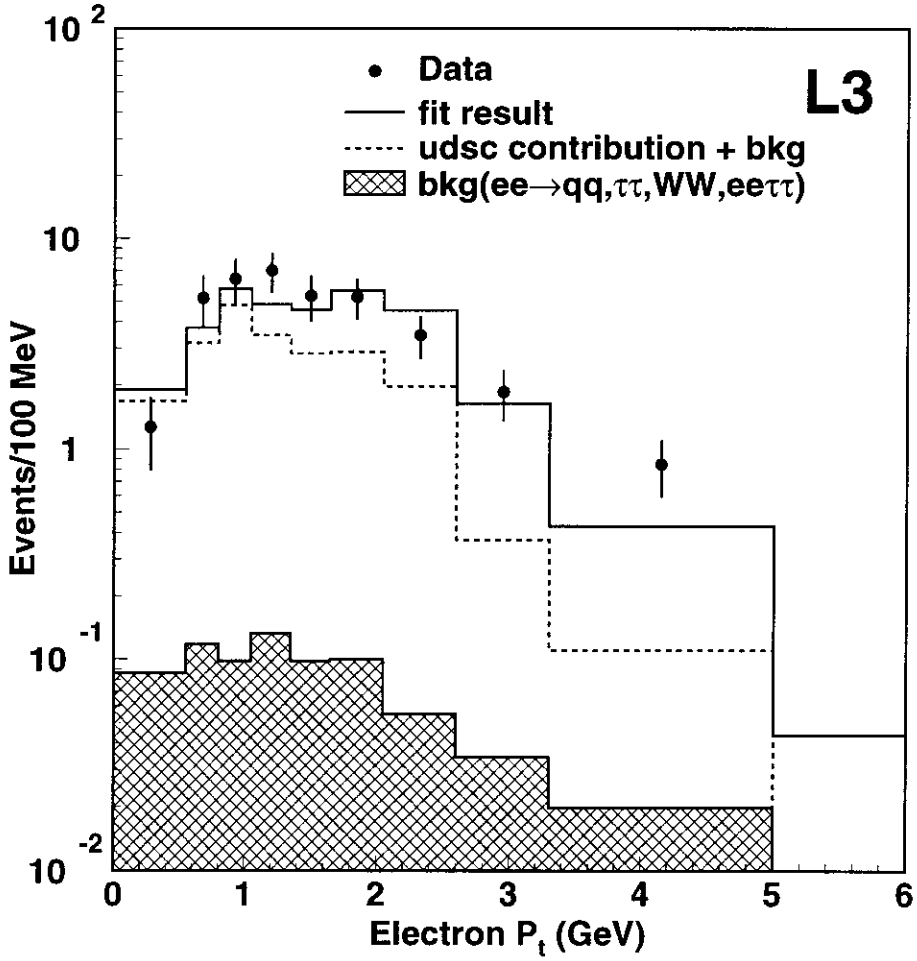


Two main possibilities:

either fit uds + charm + bottom using MC distributions

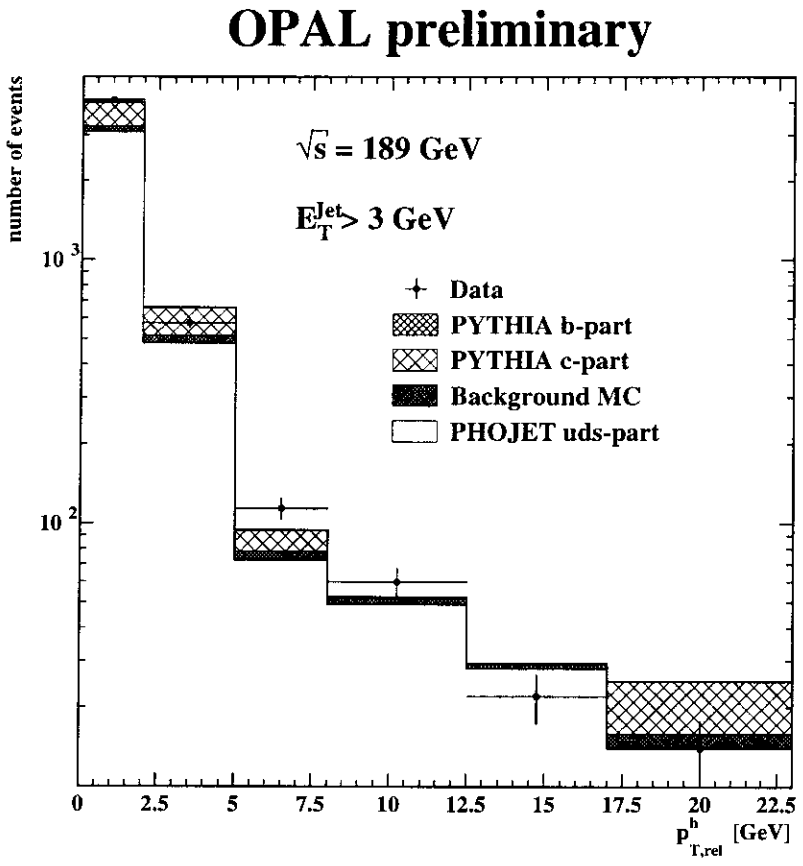
or fix uds and charm from other measurements



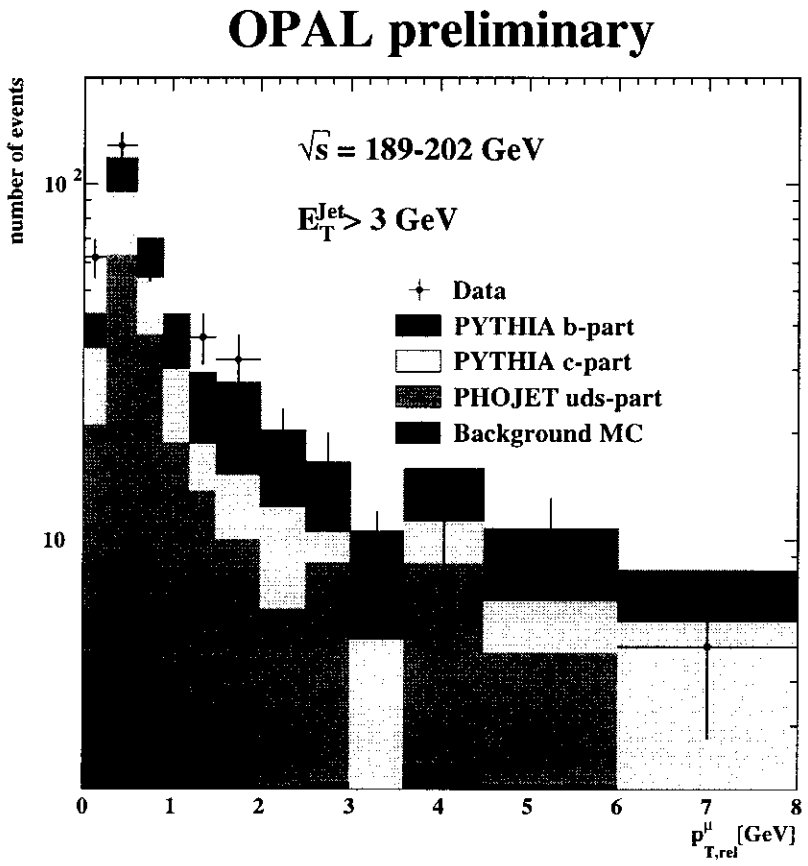


P_{T} with respect to closest jet

fit uds, charm and bottom contributions simultaneously



B-depleted sample



B-enriched sample

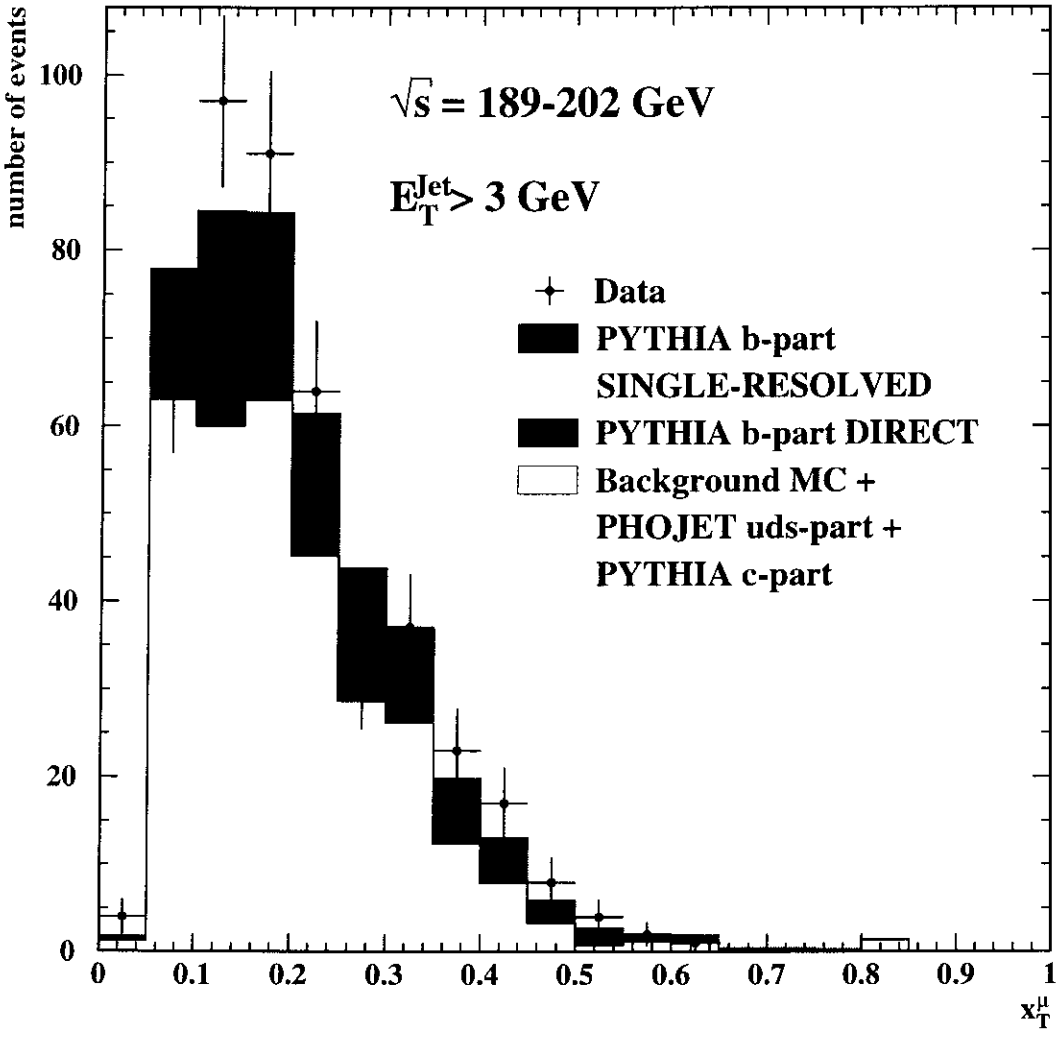
Ietermine uds background from b-depleted sample

ake charm from published measurement

et bottom from one-parameter fit

Direct and resolved contributions

OPAL preliminary

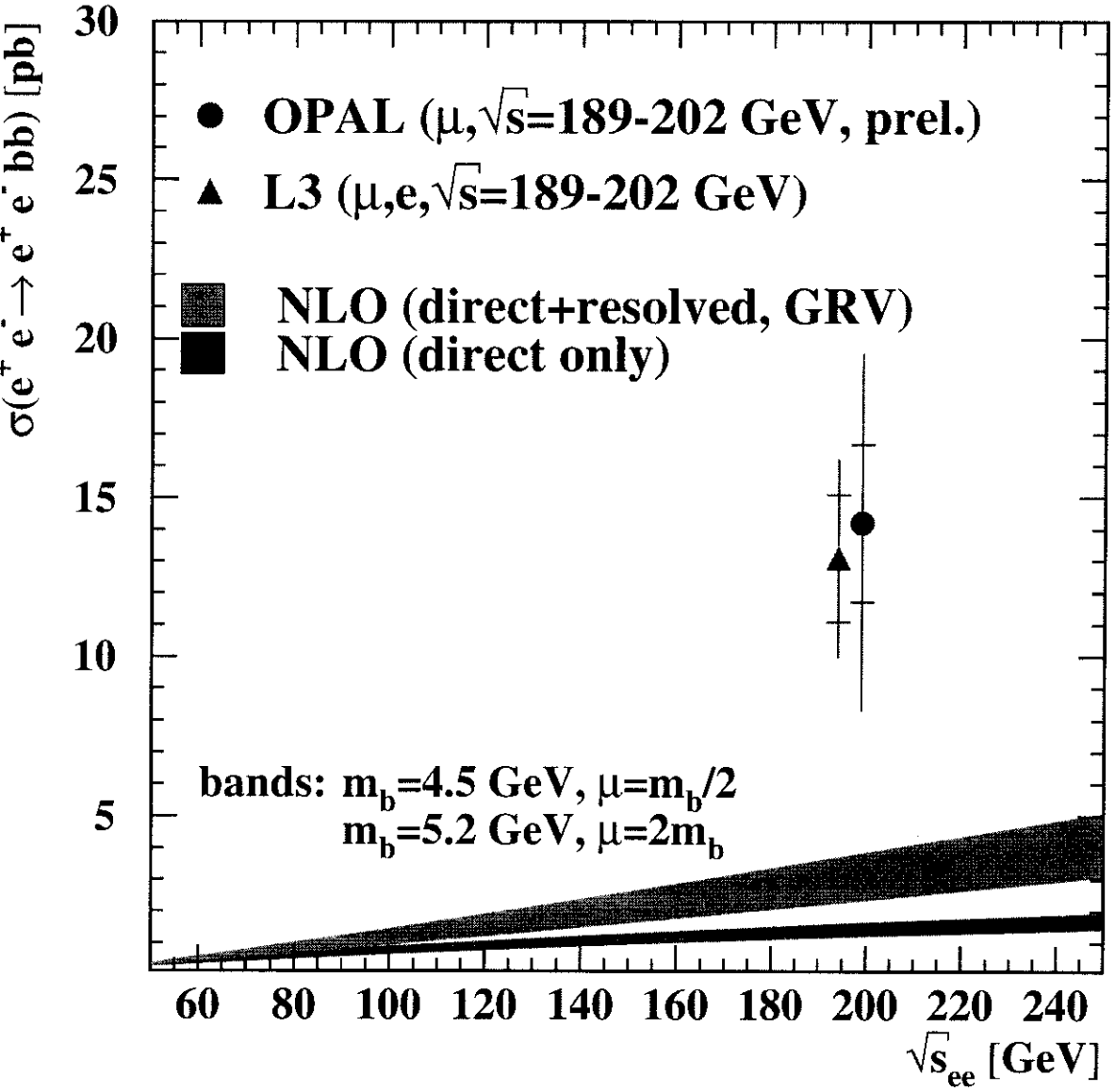


$$x_{\mathrm{T}}^{\mu} = \frac{2p_{\mathrm{T}}^{\mu}}{W_{\mathrm{vis}}}$$

larger for direct than for resolved

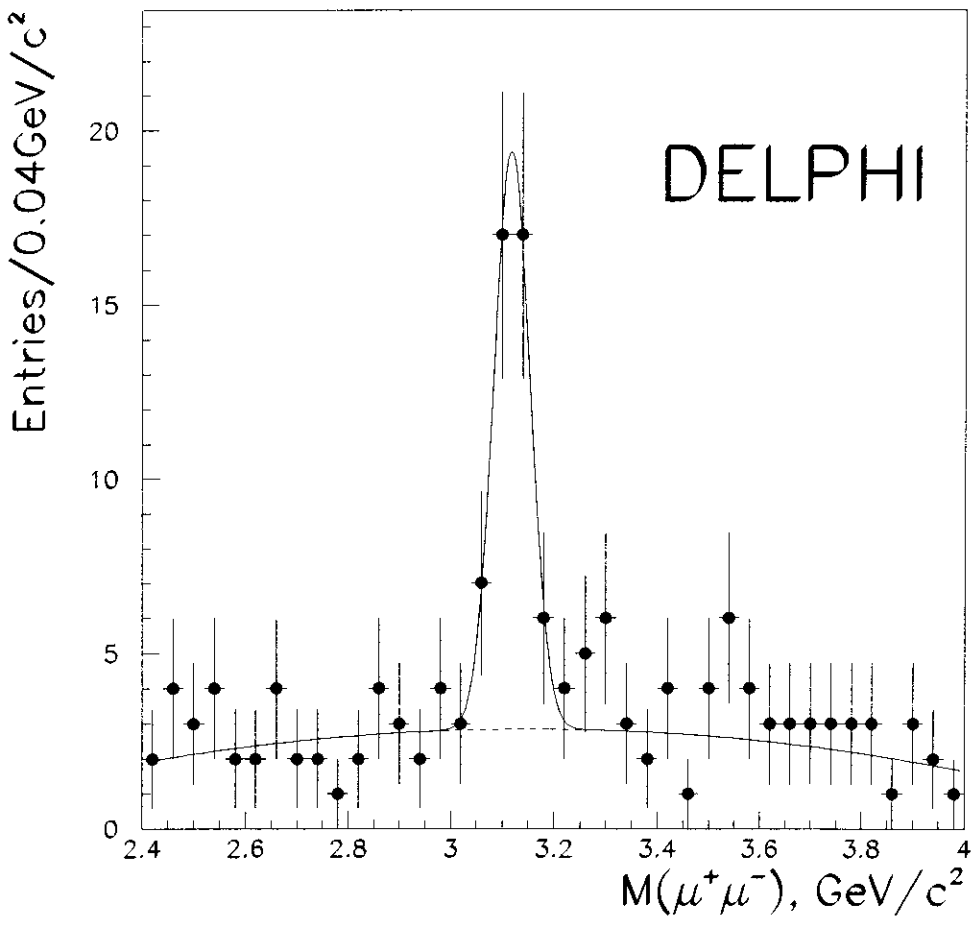
direct and resolved components from MC, good agreement with data assuming equal contribution

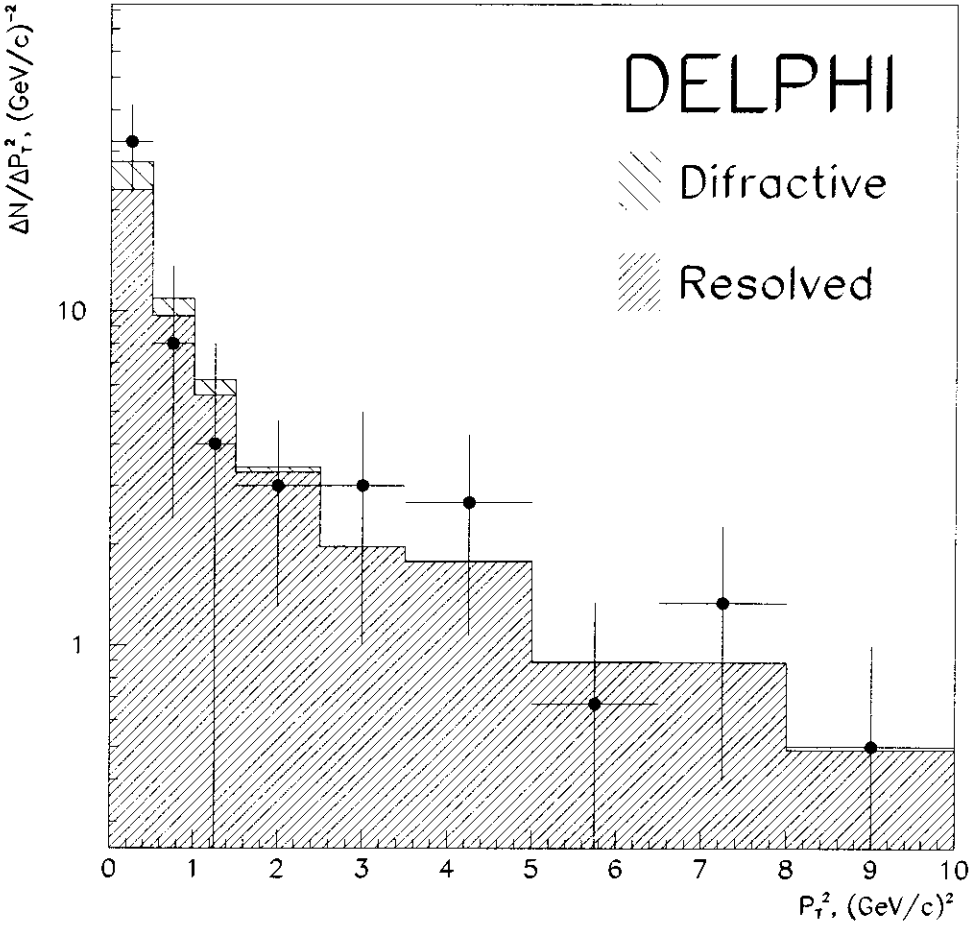
Bottom production cross-section



Excess of about 3 σ above the NLO QCD calculation

Inclusive J/ψ production





Mostly produced in the single-resolved process

Exclusive η_c production

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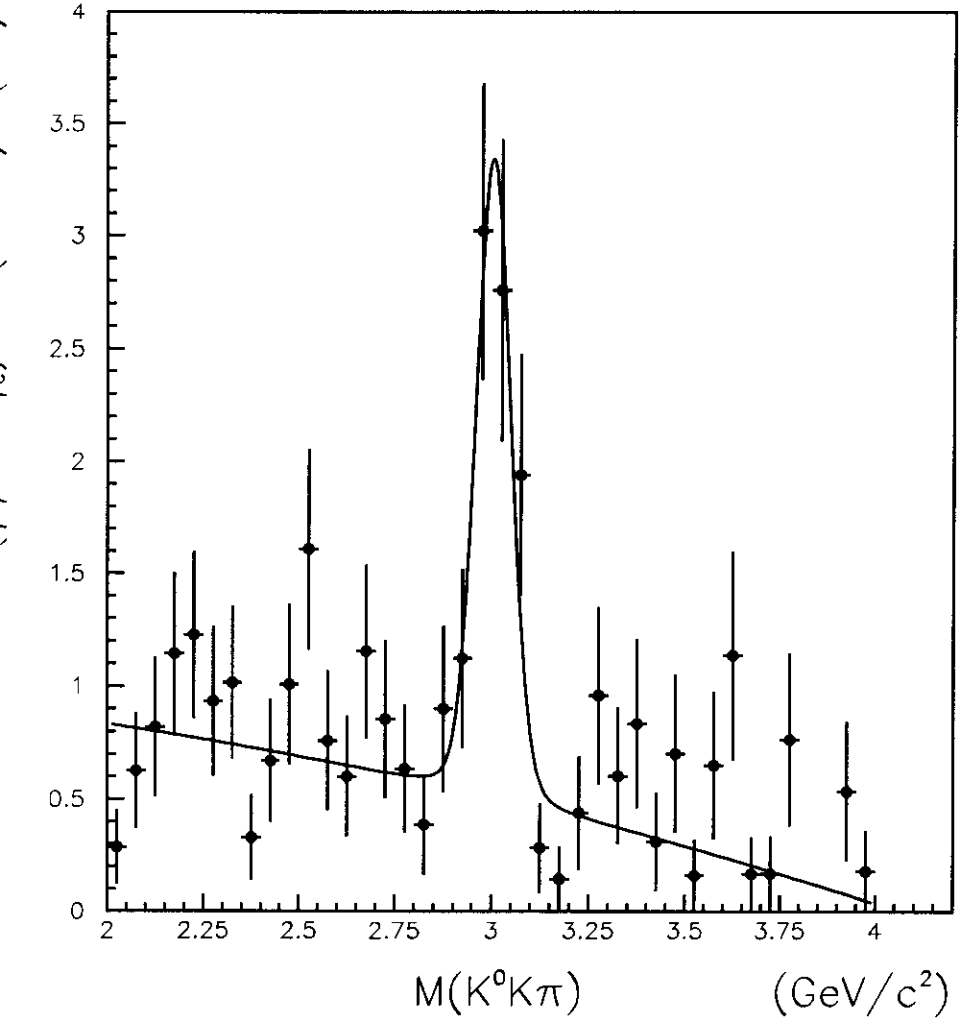
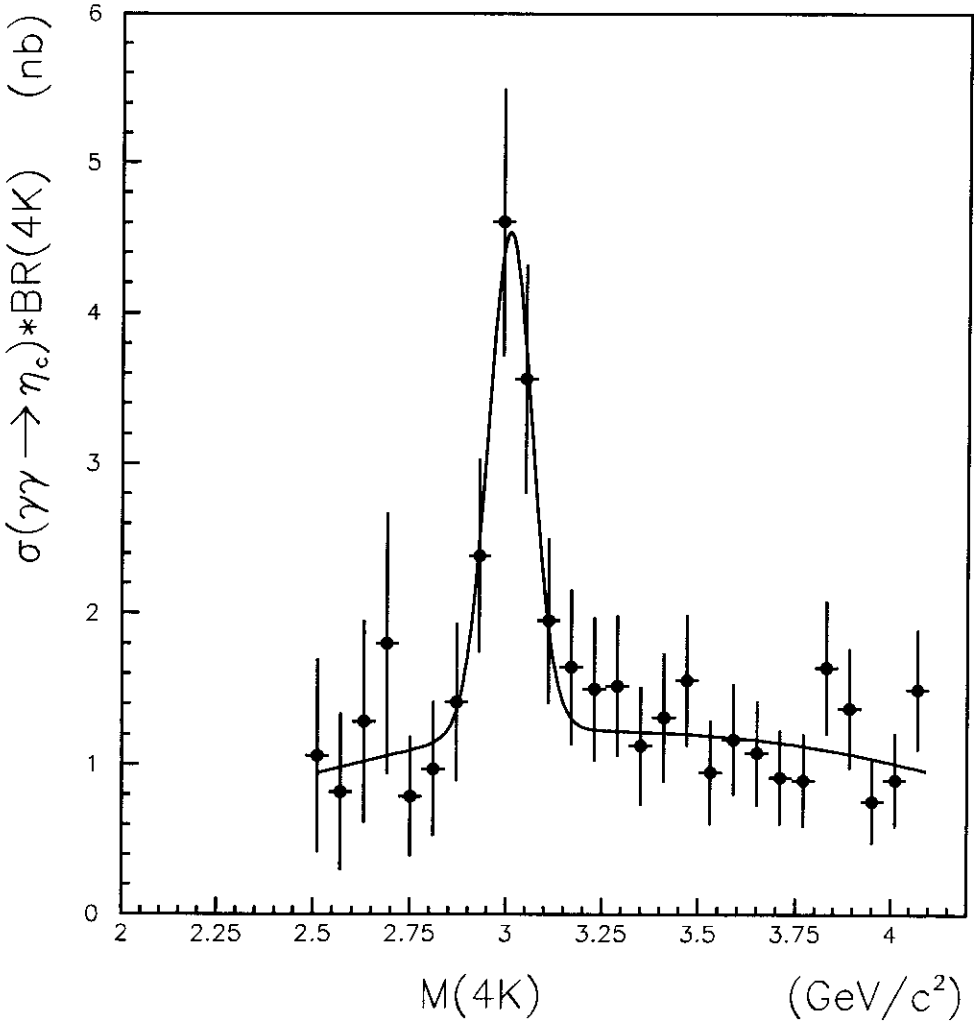
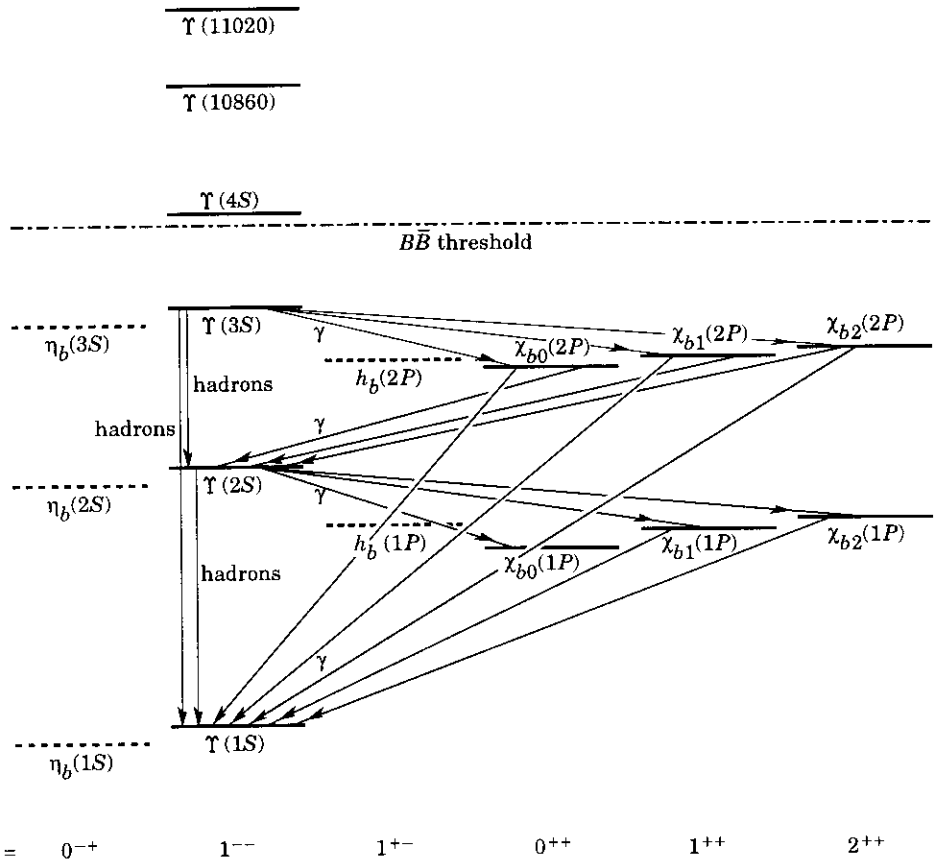
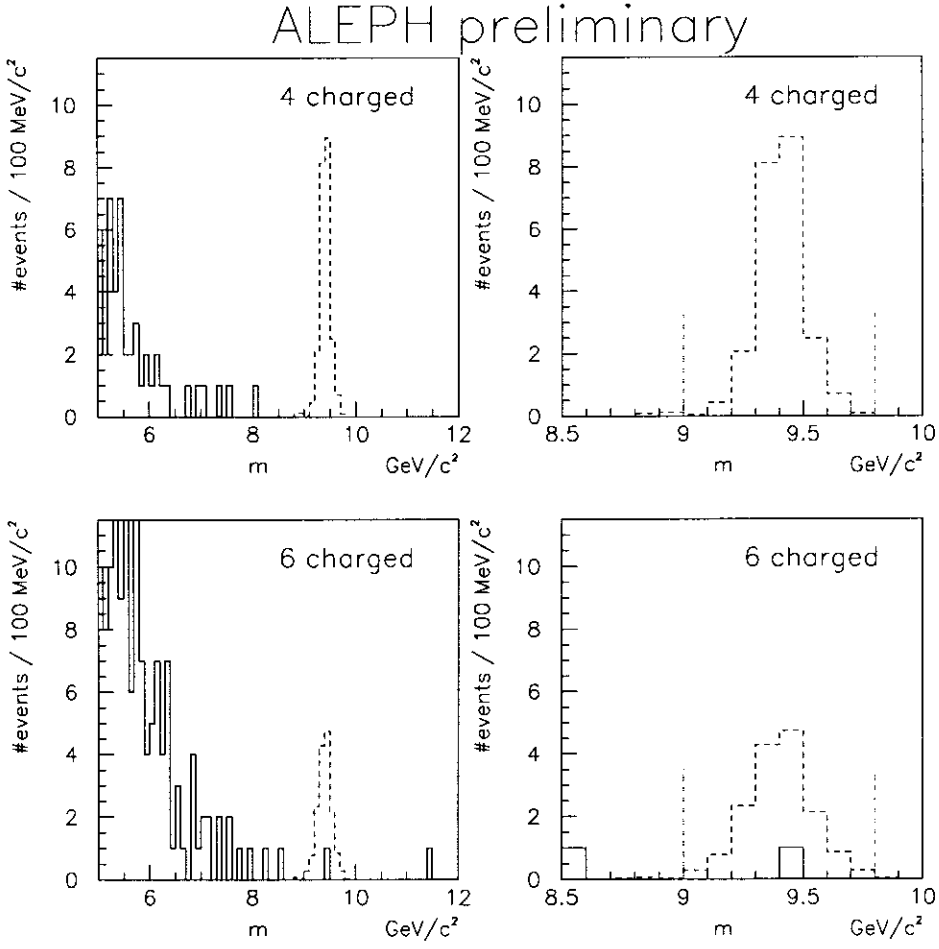




Bottomium: search for η_b

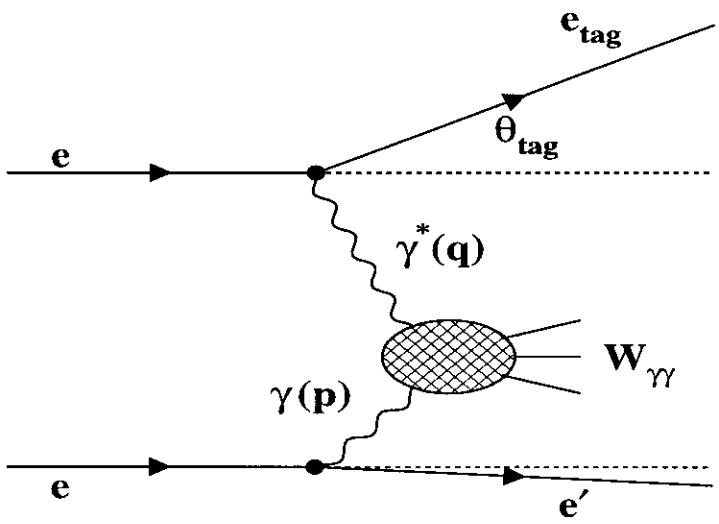


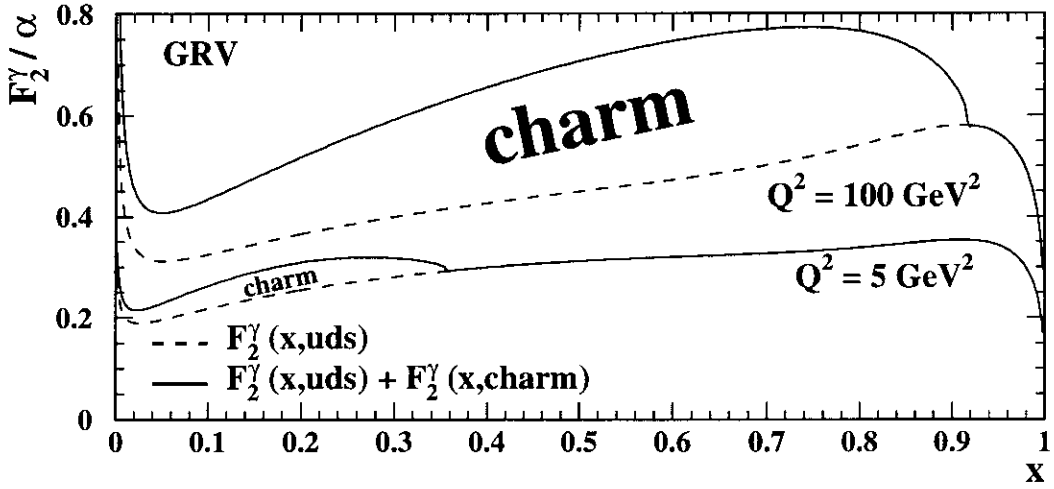


η_b has never been observed

Expected: 1.2 signal and 1.2 ± 0.5 background events, observed 1 event

Charm in deep inelastic eγ scattering





$$\frac{\mathrm{d}^2\sigma_{e\gamma\to eX}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^4}\left[\left(1+(1-y)^2\right)F_2^\gamma(x,Q^2) - y^2 F_L^\gamma(x,Q^2)\right]$$

$$Q^2 = -q^2 = 2EE_{\mathrm{tag}}(1-\cos\theta_{\mathrm{tag}})$$

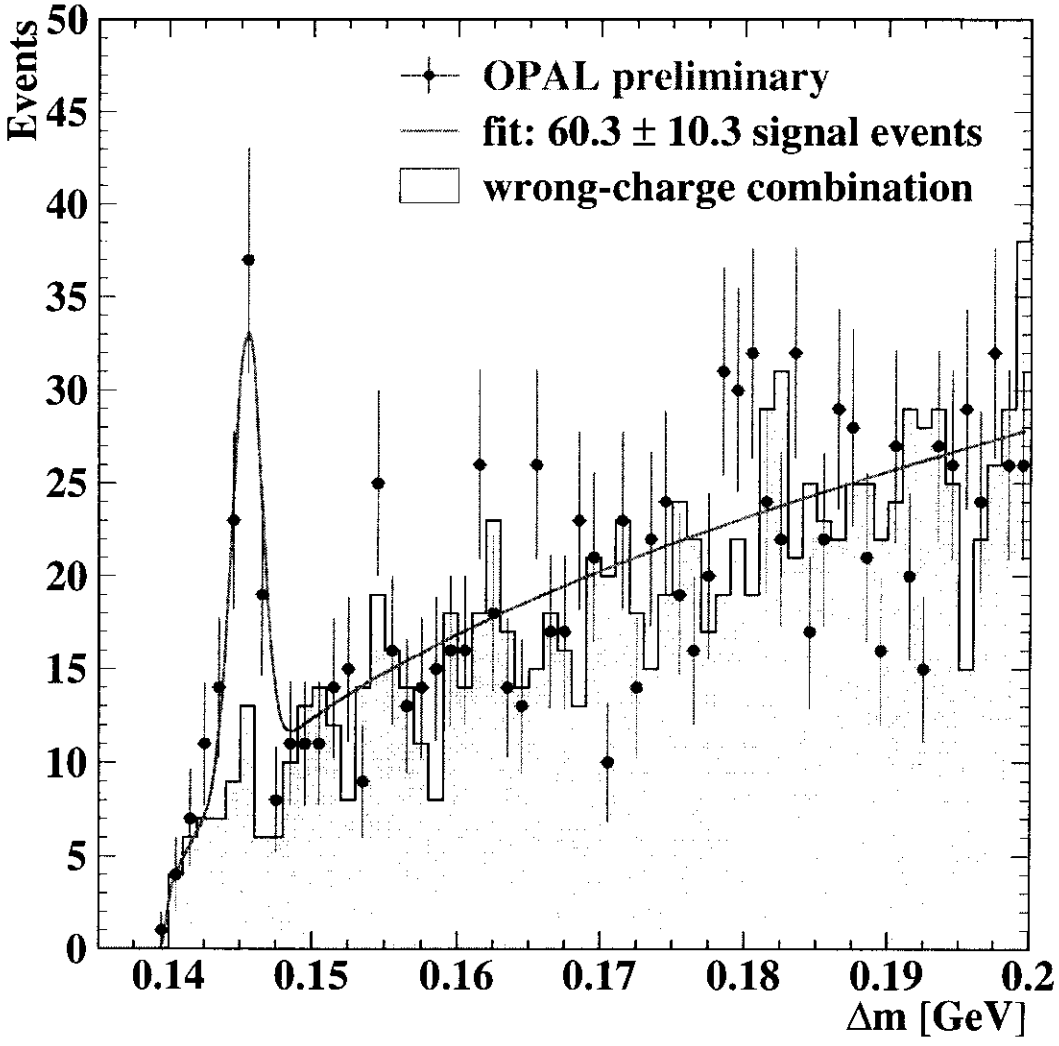
$$P^2 = -p^2 \approx 0$$

$$x = \frac{Q^2}{Q^2+W^2+P^2}$$

$$y = 1 - \frac{E_{\mathrm{tag}}}{E}\cos^2\theta_{\mathrm{tag}} \ll 1$$

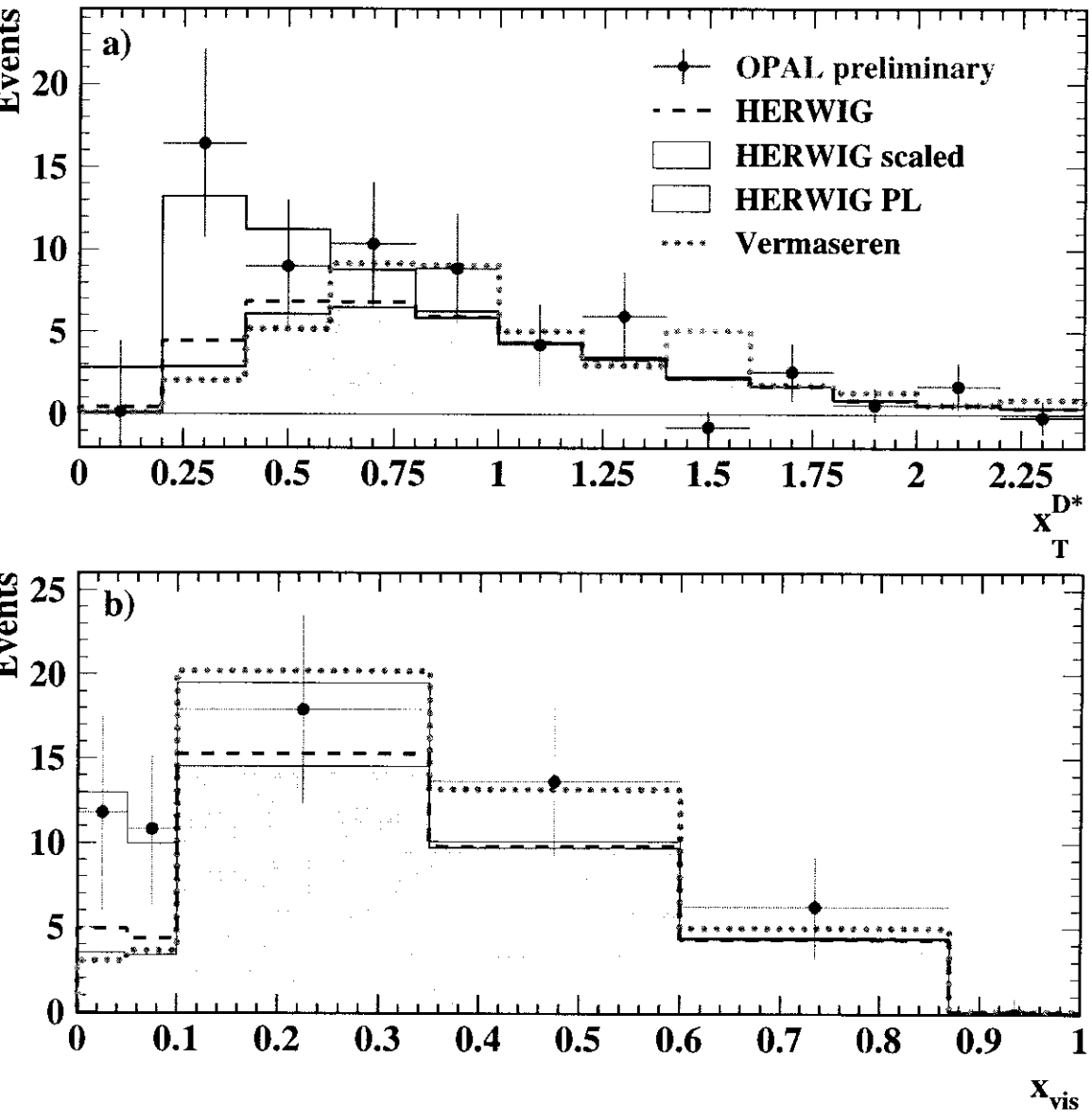
charm contribution more important at large Q^2

Charm in tagged two-photon events



Measure $D^{\star}$ production in single-tag two-photon events ($e\gamma$ DIS)

Pointlike and hadronlike contributions



Excess at low $x_T^{D^*} = \frac{2p_T^{D^*}}{W_{vis}}$

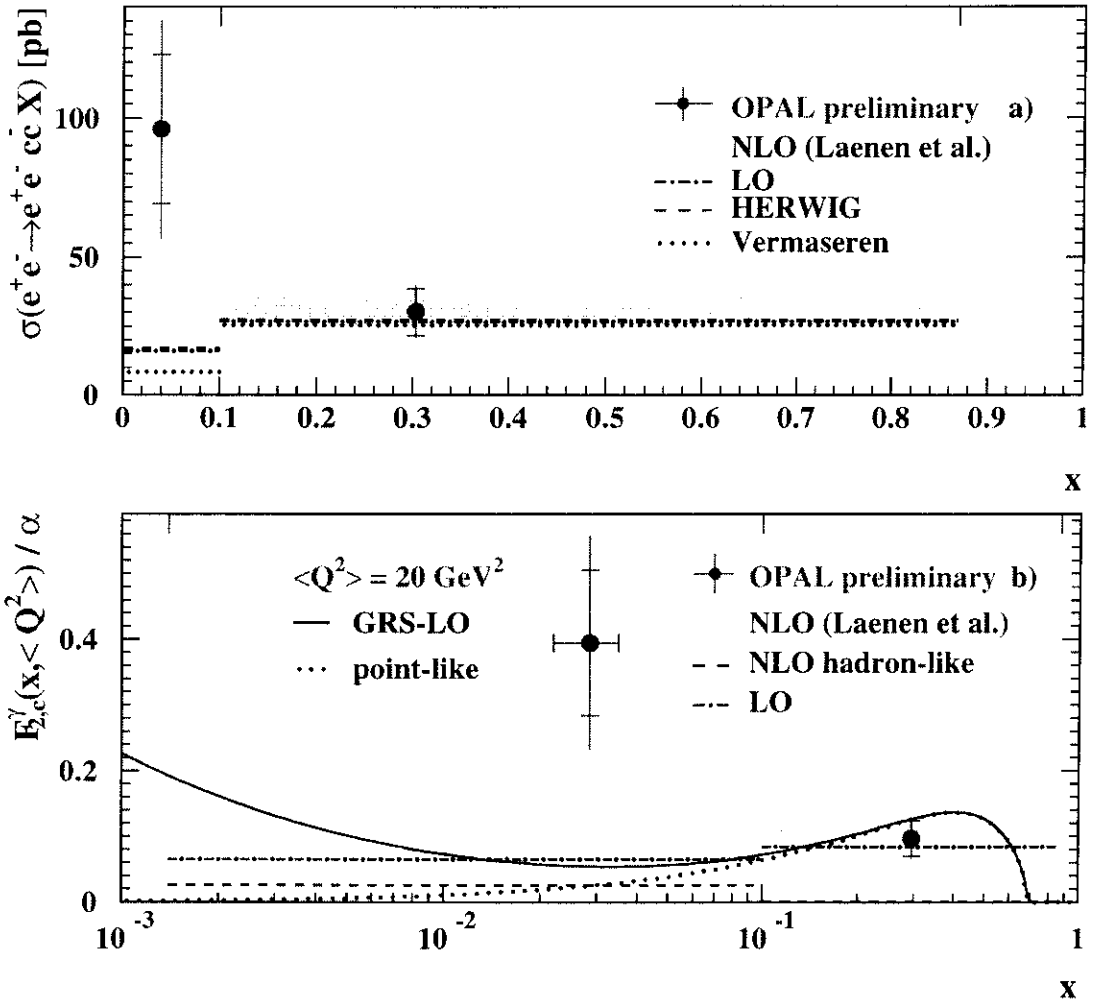
fix pointlike ($\sim$ direct) component and scale hadronlike ($\sim$ resolved) to fit data ($\times 6.6 \pm 2.7$)

use scaled MC for efficiency

excess might be:

- gluon content
- overall scale
- $p_T^{D^*}$, η^{D^*} modelling

Charm structure function of the photon $F_{2,c}^{\gamma}$



$x < 0.1$ —

- hadronlike process
- higher than expected

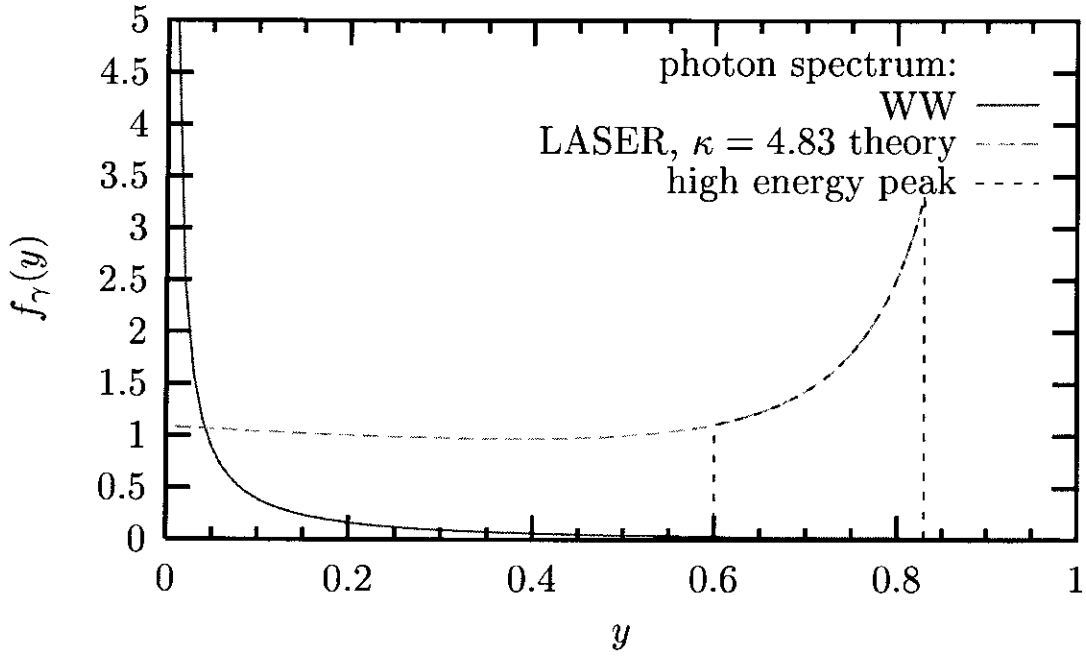
$x > 0.1$ —

- pointlike process
- very good agreement

Two-photon physics at a Linear Collider

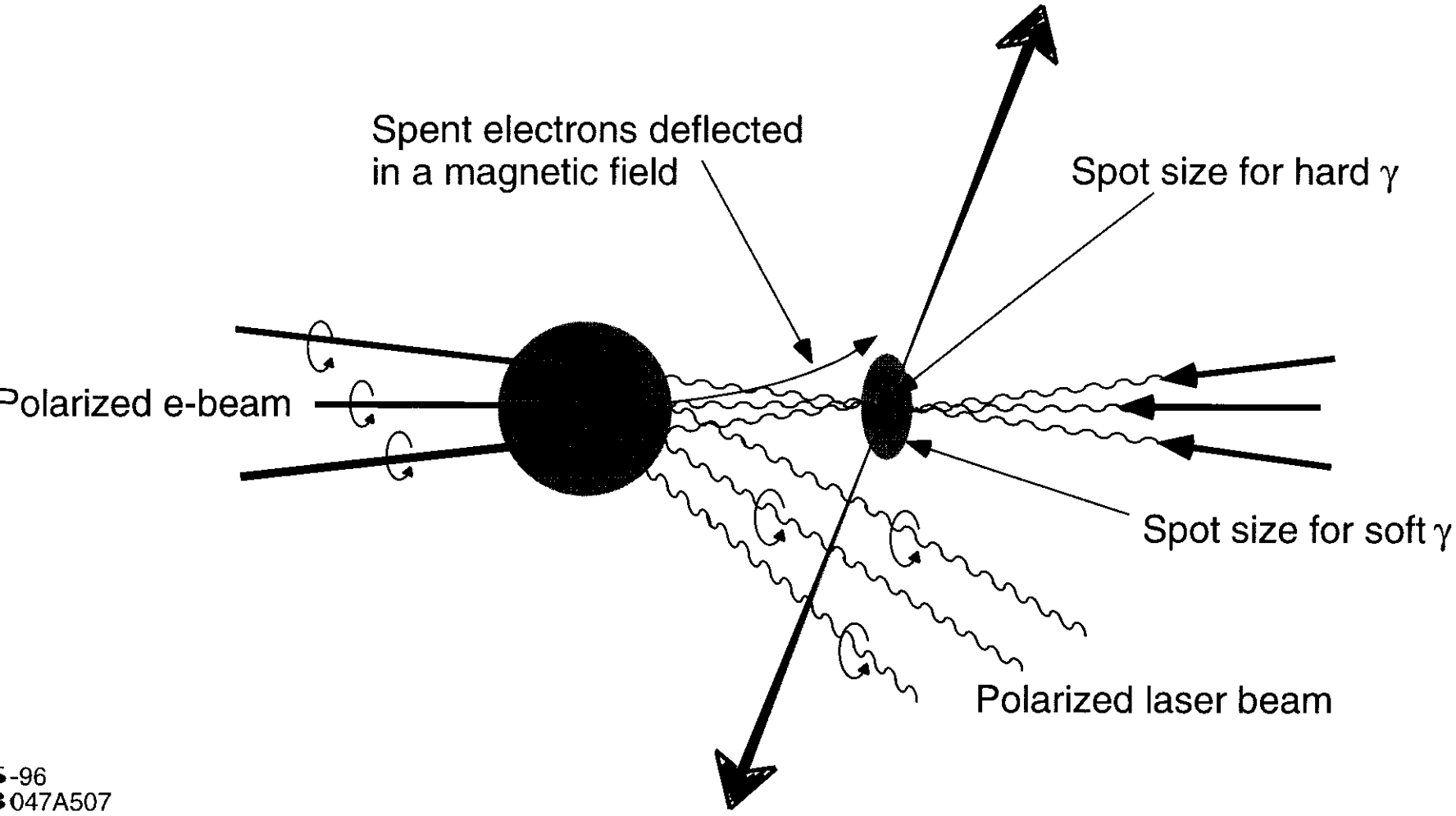
A linear e^+e^- collider can produce photon-photon collisions in two modes:

- photons radiated by the lepton beams (WW)
- laser photons back-scattered on the electron beam (PC)



$$y = E_\gamma / E_e$$

Compton photon collider



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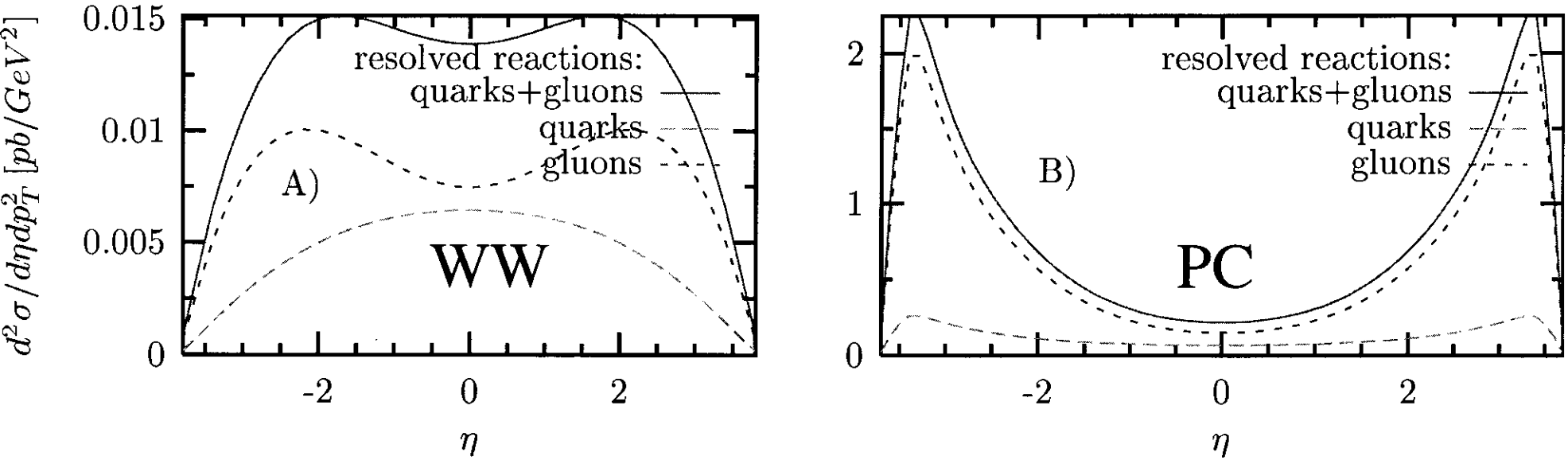
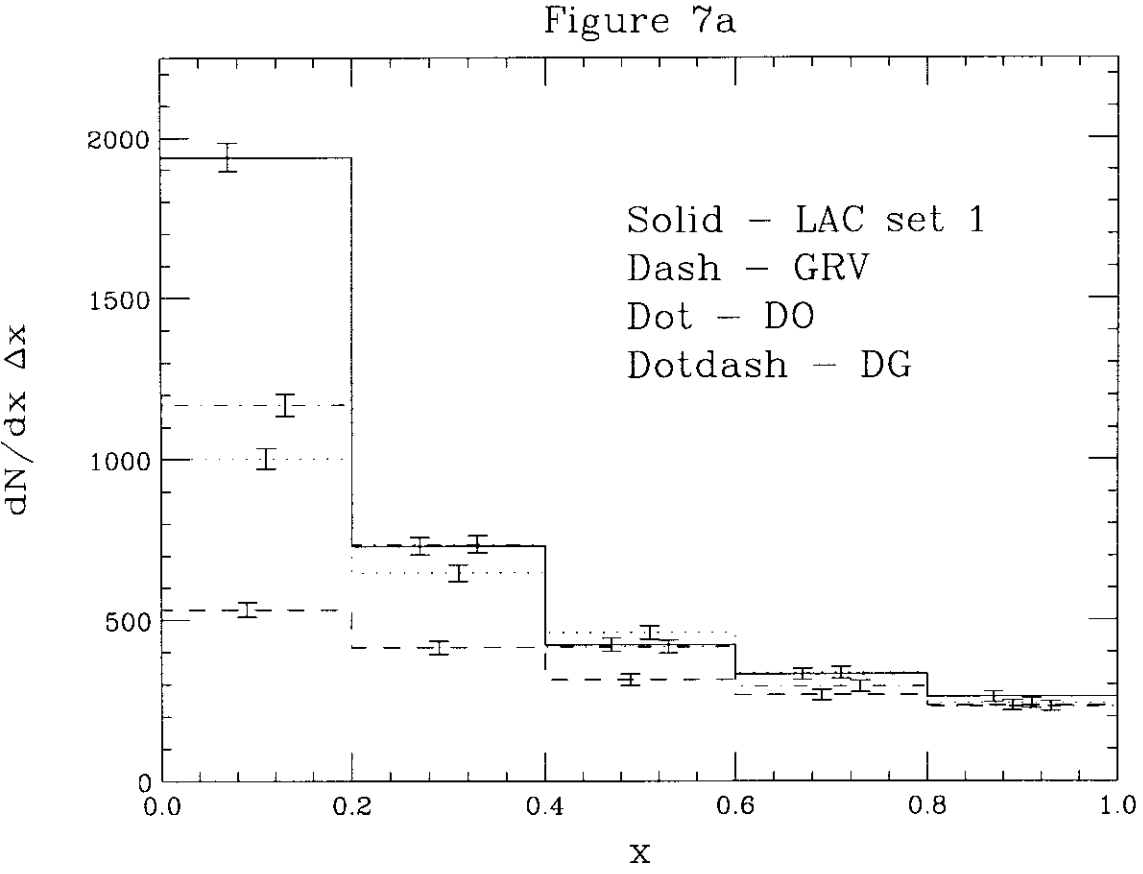
Charm production at the LC

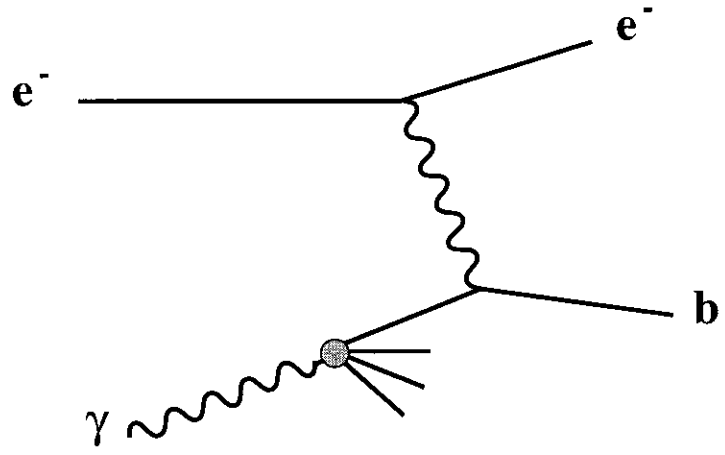
gluon-induced processes dominate charm production at PC

$\Rightarrow$ it can be used to constrain the gluon content of the photon



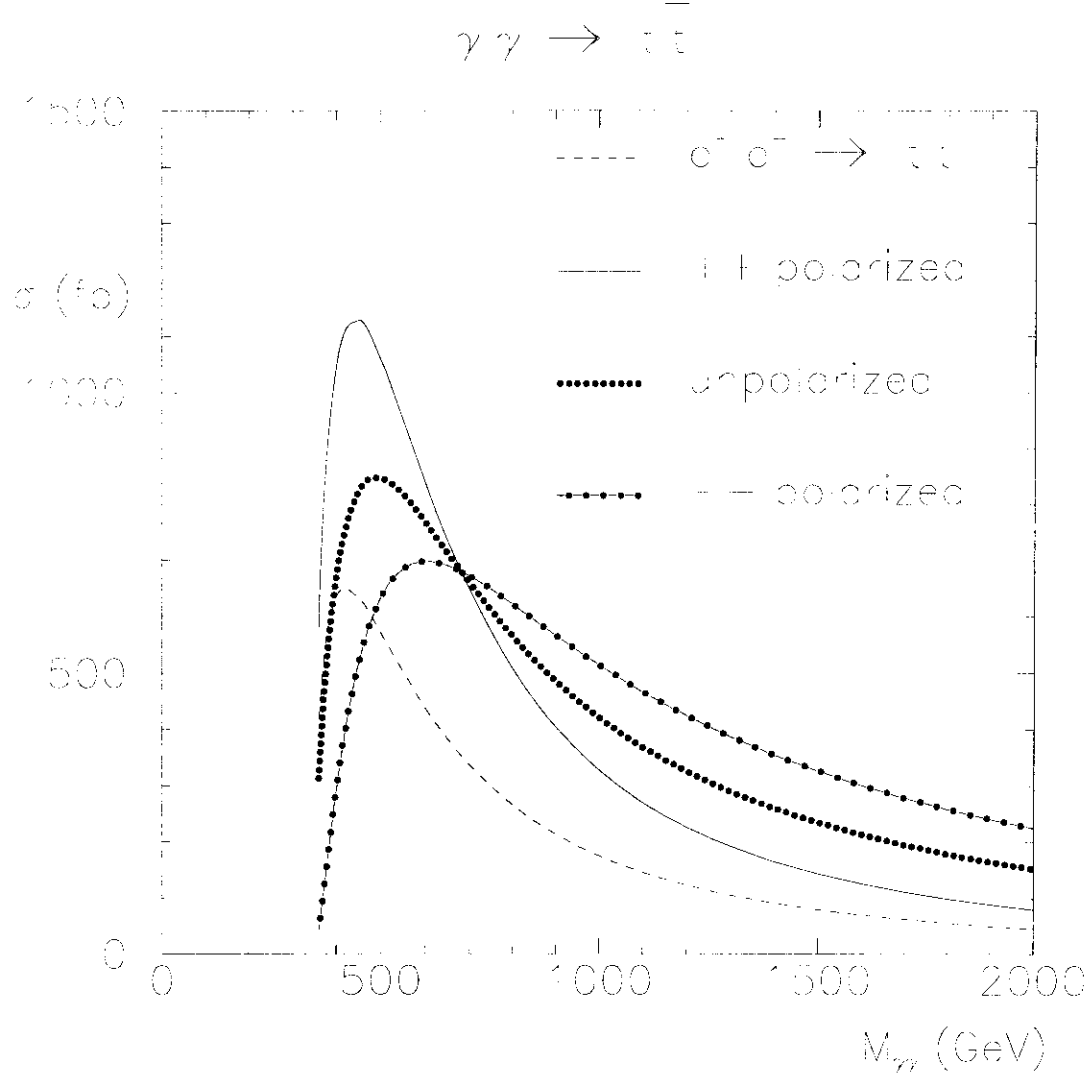
Bottom content of the photon at LC





number of events expected in single-tag $e\gamma$ DIS at a photon-electron collider

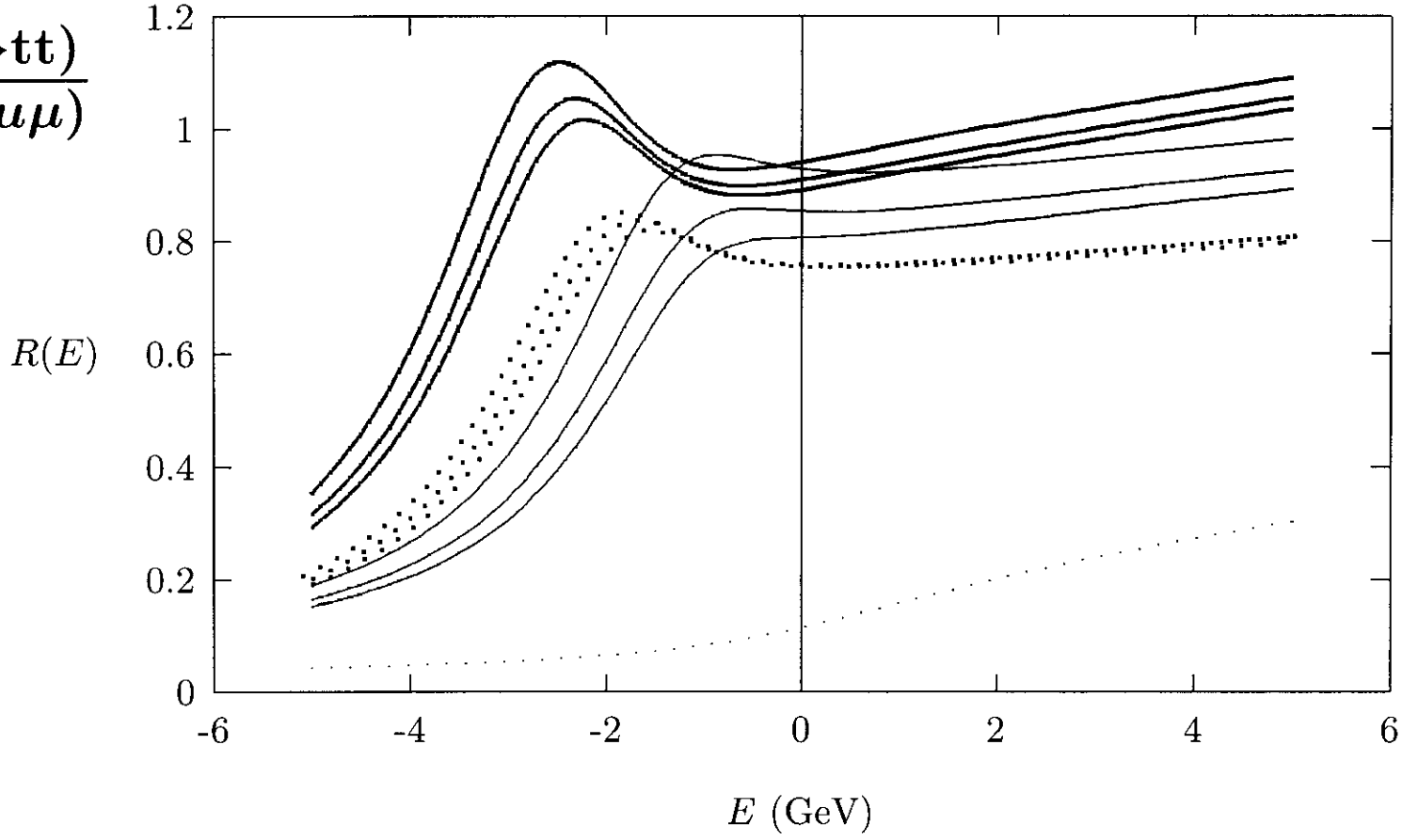
Top pair production in $\gamma\gamma$ at LC



leading order cross-section

Top pair production in $\gamma\gamma$ at LC

$$\frac{\sigma(\gamma\gamma\to tt)}{\sigma(ee\to\mu\mu)}$$



normalised cross-section vs. $\gamma\gamma$ energy from threshold

(LO, NLO and NNLO, with Coulomb corrections)

Conclusions

Heavy quark production measured in two-photon processes

- charm in general well described by NLO QCD
  except for a few specific cases
- bottom considerably underestimated by NLO QCD
- much more LEP data to analyse
- exciting new possibilities at Linear Collider