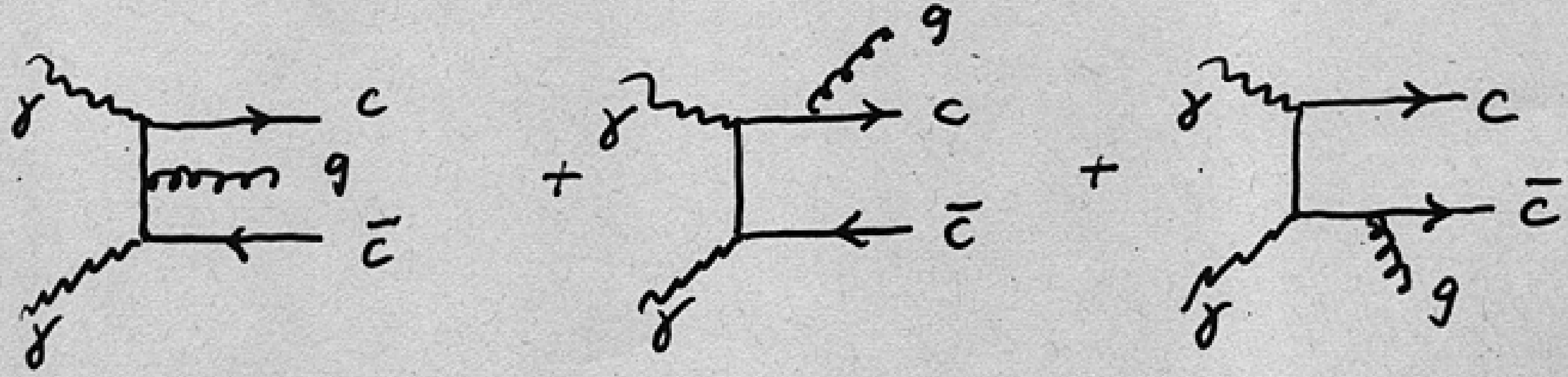
Inclusive D^* Production in Photon-Photon Collisions with Massive Quarks in NLO

Photon 2003, Frascati

Three approaches $\quad \gamma + \gamma \to D^{*\pm} + X$

NLO : $\quad \gamma + \gamma \to c + \bar{c} + g$

direct contribution



- (i) massless approach $\quad m_c = 0 \quad , \quad N_f = 4$

$$d\sigma(\gamma\gamma \to cX) = \frac{\alpha}{2\pi} P_{c\gamma}\, d\sigma(\gamma c \to cg) \ln \frac{S}{M^2}$$

M factorization scale $O(\sqrt{S})$

originates from collinear divergent piece

$$d\sigma(\gamma\gamma \to cX) = \frac{\alpha}{2\pi}\left(-\frac{1}{\varepsilon}\right)\left(\frac{4\pi\mu^2}{S}\right)^{\varepsilon} P_{c\gamma}\, d\sigma(\gamma c \to cg)$$

$$\to \left(\frac{4\pi\mu^2}{M^2}\right)^{\varepsilon}\left(\frac{M^2}{S}\right)^{\varepsilon}$$

$\left(\frac{M^2}{S}\right)^{\varepsilon} \to$ into NLO corr

$\left(\frac{4\pi\mu^2}{M^2}\right)^{\varepsilon} \to$ absorbed in f_c^{γ}

- (ii) massive approach $m_c \neq 0$, $N_f = 3$

$$d\sigma(\gamma\gamma \to cX) = \frac{\alpha}{2\pi} P_{c\gamma}\, d\sigma(\gamma c \to cg) \ln \frac{s}{m_c^2}$$

factorization scale $M = m_c$ large

charm only in final state : $f_c^\gamma = 0$

- (iii) massive approach $m_c \neq 0$, $N_f = 4$

$$\ln \frac{s}{m_c^2} = \ln \frac{s}{M^2} + \ln \frac{M^2}{m_c^2}$$

as in massless absorbed in f_c^γ

charm also in initial state :

single and double resolved with charm

same procedure for second and third diagram

factorization scale M_f

need fragmentation for $c \to D^*$: $D_c^{D^*}(x)$

- (i) $m_c = 0$ from start (ZM - VFN)

  m_c^2/p_T^2 terms neglected

  good only for large p_T^2

  $\ln \frac{M^2}{\mu^2}$ terms summed in evolved f_c^γ and $D_c^{D^*}$

- (ii) $m_c \neq 0$ (FFN) $n_f = 3$

  no c quarks in initial state

  $f_c^\gamma = 0$, $D_c^{D^*}$ not evolved, fragmentation pert.

  good for $p_T^2 \simeq m_c^2$, m_c^2/p_T^2 terms included

- (iii) $m_c \neq 0$ (Massive VFN) $n_f = 4$

  c quarks in initial state

  $f_c^\gamma \neq 0$, f_c^γ and $D_c^{D^*}$ evolved

  $\ln \frac{M^2}{m_c^2}$ terms summed

  m_c^2/p_T^2 terms included

  good for $p_T^2 \gtrsim m_c^2$, where $f_c^\gamma \neq 0$, $D_c^{D^*} \neq 0$

  $p_T^2 \lesssim m_c^2$ transition to FFN massless limit of (iii) neglects m_c^2/p_T^2 terms

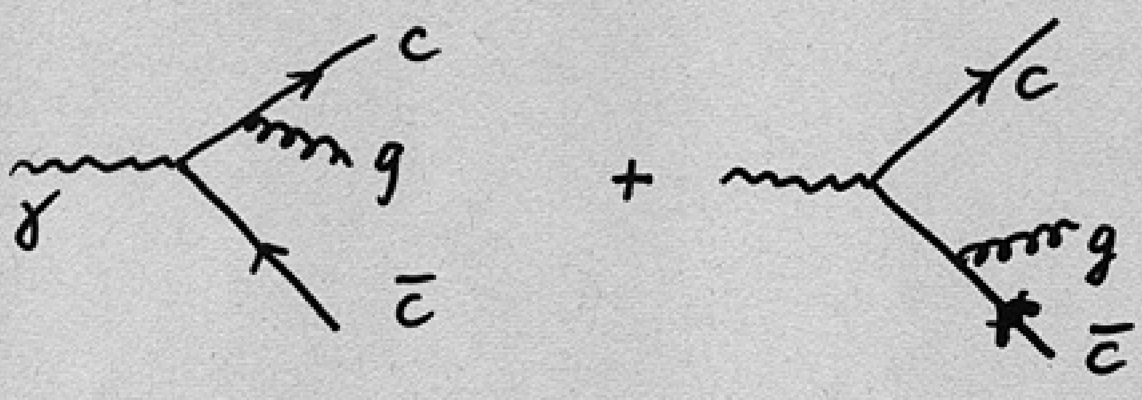
- (i) and $m_c \to 0$ limit of (iii) identical?

answer: no!

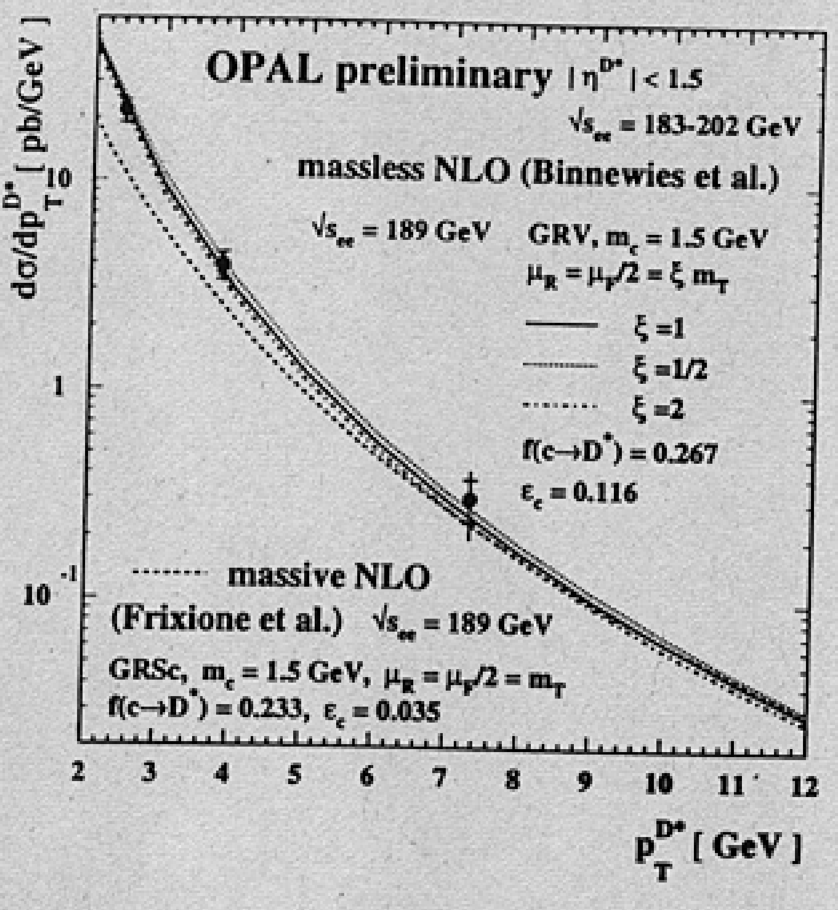
- (i) and (iii) differ by finite terms
  do not vanish for $m_c \to 0$

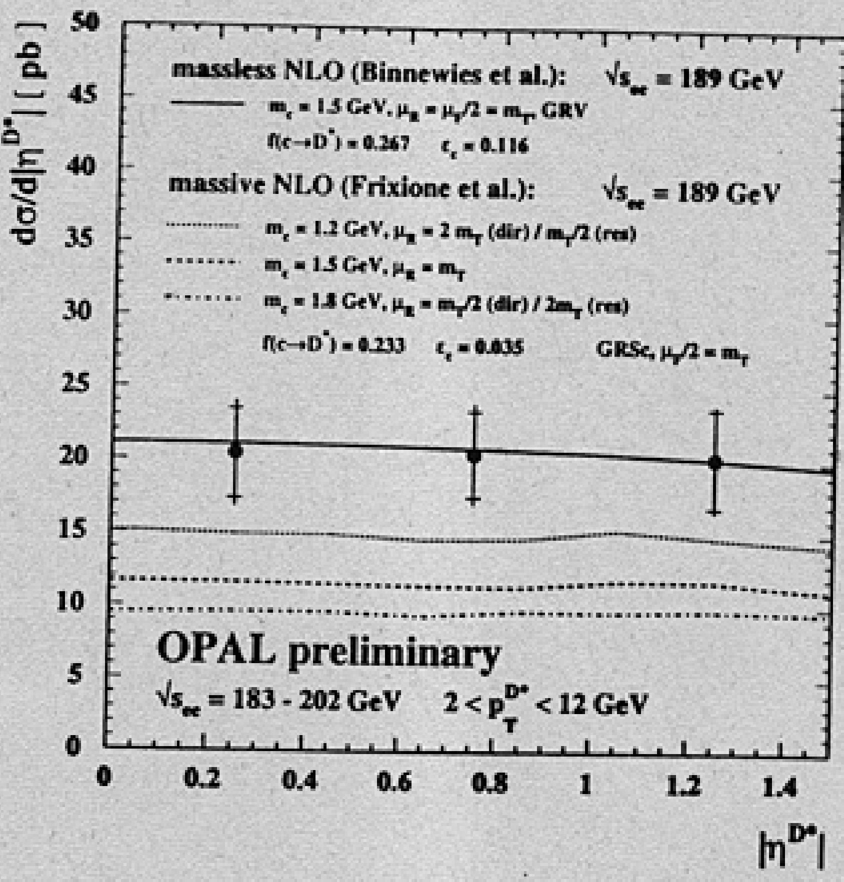
- finite terms subtracted to match (i)
  calculated for
  direct process — G.K. + H. Spiesberger, hep-ph/0109167, EPJC 22, 289 (2001)
  single-resolved process — hep-ph/0302081

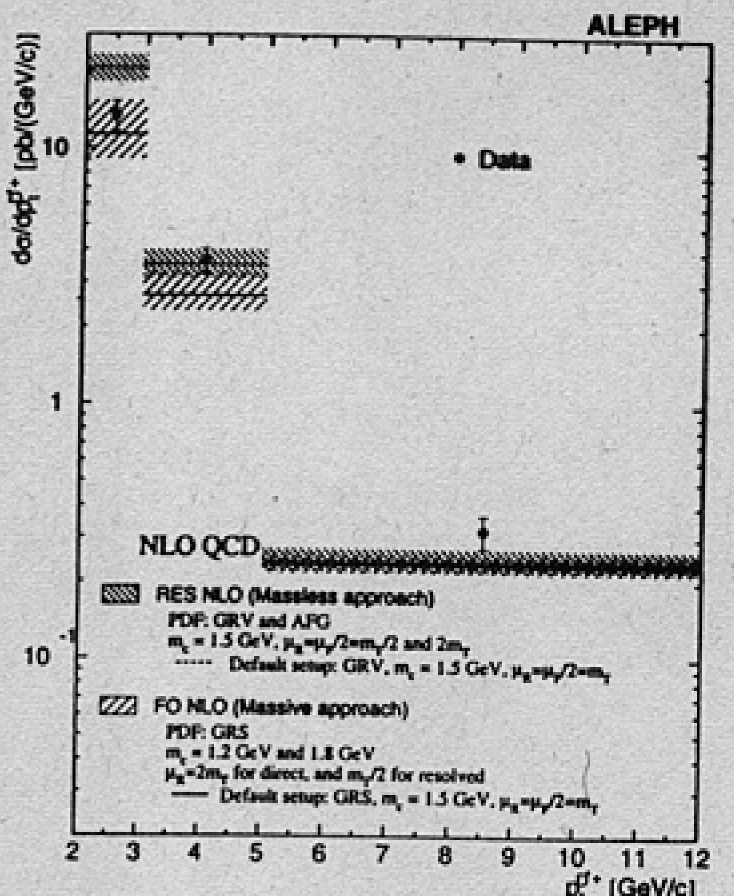
- direct process
  finite terms = LO pert. fragmentation functions
  B. Mele & P. Nason, Nucl. Phys. B 361, 173 (1991)

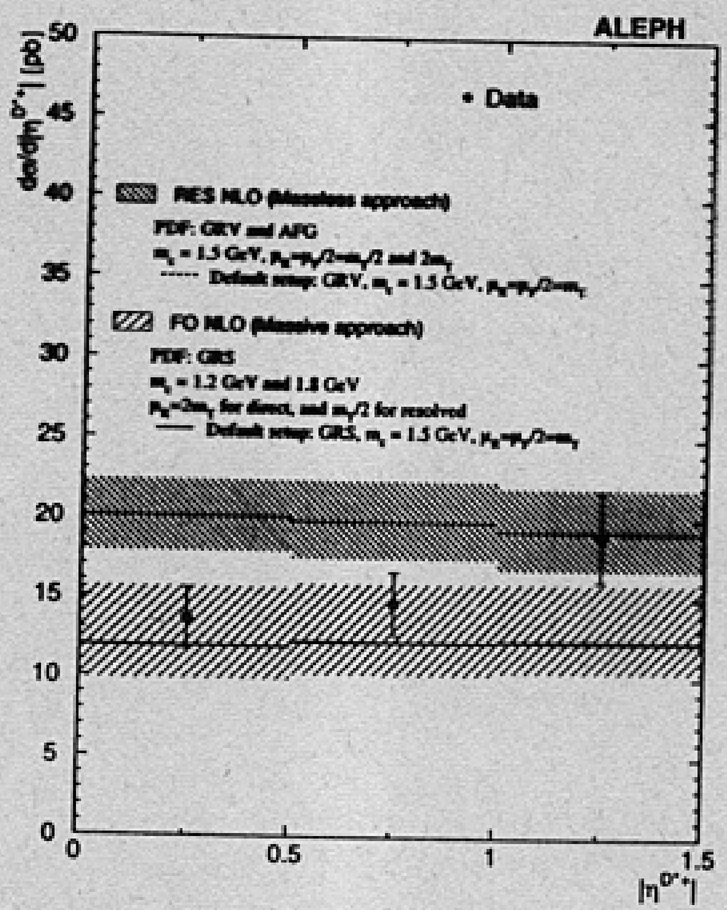


- finite terms in (iii) subtracted to match (i)
  (i) is for $\overline{MS}$ factorization scheme
  scheme for PDF and FF $c \to D^*$ is $\overline{MS}$


OPAL preliminary $|\eta^{D^*}| < 1.5$
$\sqrt{s_{ee}}$ = 183-202 GeV
massless NLO (Binnewies et al.)
$\sqrt{s_{ee}}$ = 189 GeV GRV, m_c = 1.5 GeV
$\mu_R = \mu_F/2 = \xi\, m_T$
ξ =1
ξ =1/2
ξ =2
$f(c \to D^*)$ = 0.267
ε_c = 0.116
massive NLO
(Frixione et al.) $\sqrt{s_{ee}}$ = 189 GeV
GRSc, m_c = 1.5 GeV, $\mu_R = \mu_F/2 = m_T$
$f(c \to D^*)$ = 0.233, ε_c = 0.035
$d\sigma/dp_T^{D^*}$ [pb/GeV]
$p_T^{D^*}$ [GeV]


massless NLO (Binnewies et al.): $\sqrt{s_{ee}}$ = 189 GeV
m_c = 1.5 GeV, $\mu_R = \mu_F/2 = m_T$, GRV
$f(c \to D^*)$ = 0.267 ε_c = 0.116
massive NLO (Frixione et al.): $\sqrt{s_{ee}}$ = 189 GeV
m_c = 1.2 GeV, μ_R = 2 m_T (dir) / $m_T/2$ (res)
m_c = 1.5 GeV, $\mu_R = m_T$
m_c = 1.8 GeV, $\mu_R = m_T/2$ (dir) / 2m_T (res)
$f(c \to D^*)$ = 0.233 ε_c = 0.035 GRSc, $\mu_F/2 = m_T$
OPAL preliminary
$\sqrt{s_{ee}}$ = 183 - 202 GeV $2 < p_T^{D^*} < 12$ GeV
$d\sigma/d|\eta^{D^*}|$ [pb]
$|\eta^{D^*}|$


ALEPH
Data
NLO QCD
RES NLO (Massless approach)
PDF: GRV and AFG
m_c = 1.5 GeV, $\mu_R = \mu_F/2 = m_T/2$ and 2m_T
Default setup: GRV, m_c = 1.5 GeV, $\mu_R = \mu_F/2 = m_T$
FO NLO (Massive approach)
PDF: GRS
m_c = 1.2 GeV and 1.8 GeV
μ_R=2m_T for direct, and $m_T/2$ for resolved
Default setup: GRS, m_c = 1.5 GeV, $\mu_R = \mu_F/2 = m_T$
$d\sigma/dp_t^{D^{*+}}$ [pb/(GeV/c)]
$p_t^{D^{*+}}$ [GeV/c]


ALEPH
Data
RES NLO (Massless approach)
PDF: GRV and AFG
m_c = 1.5 GeV, $\mu_R = \mu_F/2 = m_T/2$ and 2m_T
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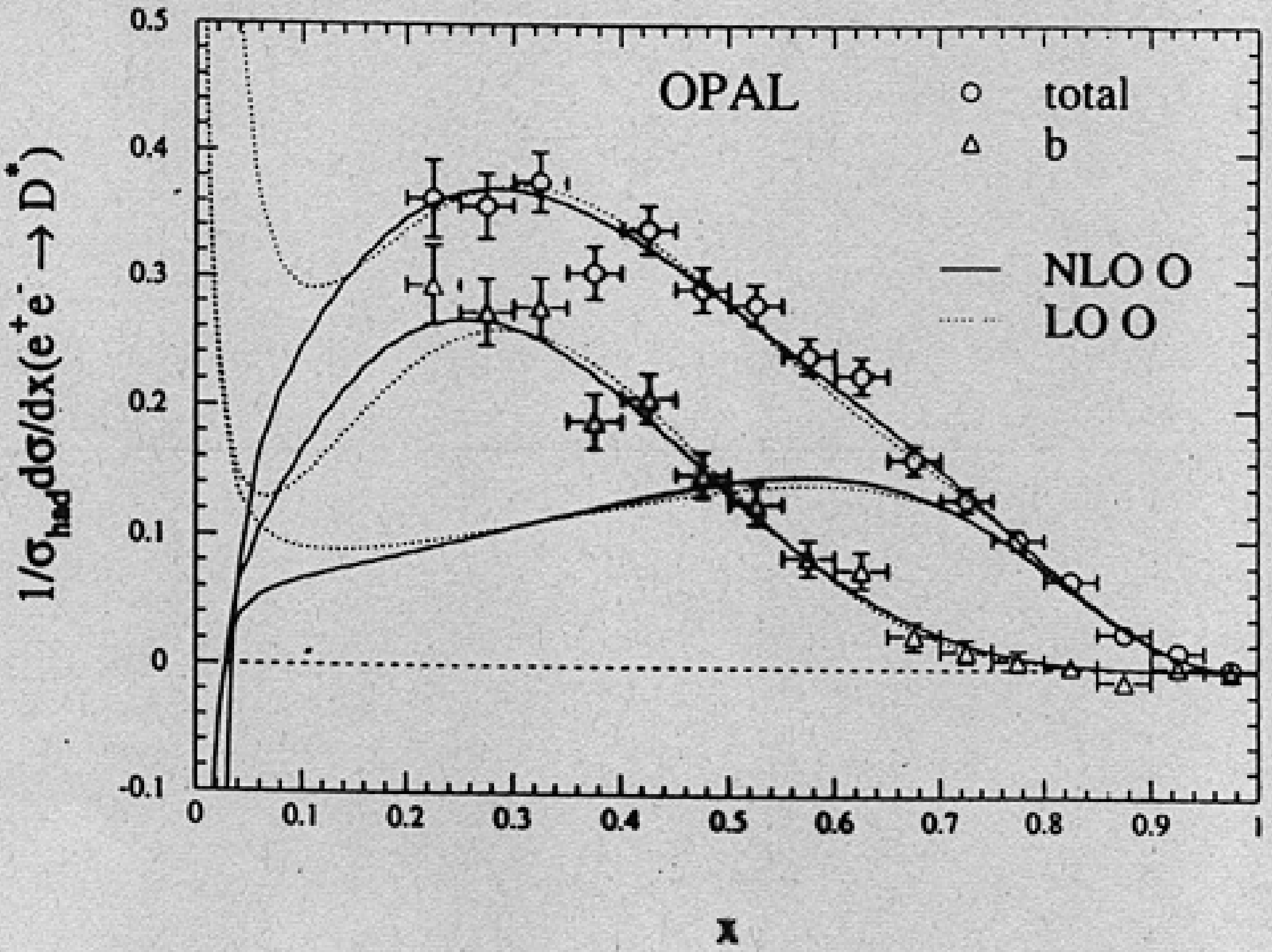
Default setup: GRS, m_c = 1.5 GeV, $\mu_R = \mu_F/2 = m_T$
$d\sigma/d|\eta^{D^{*+}}|$ [pb]
$|\eta^{D^{*+}}|$

$e^+ + e^- \to D^* + X$

two components : $e^+ + e^- \to c + X$
$\hookrightarrow D^*$

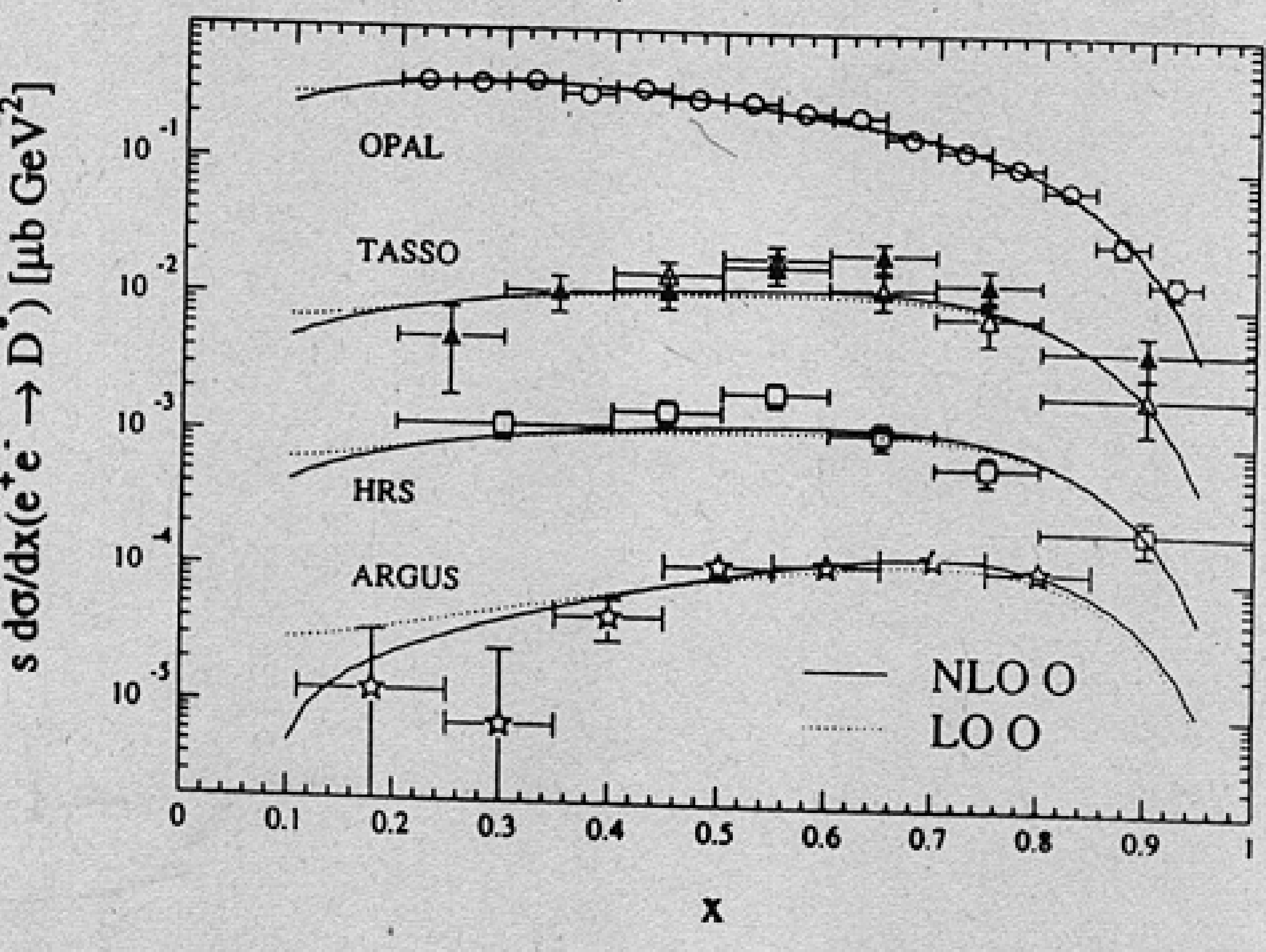
$e^+ + e^- \to b + X$
$\hookrightarrow D^*$

J. Binnewies, B.A. Kniehl & G.K., Phys. Rev. D 58, 014014 (1998)

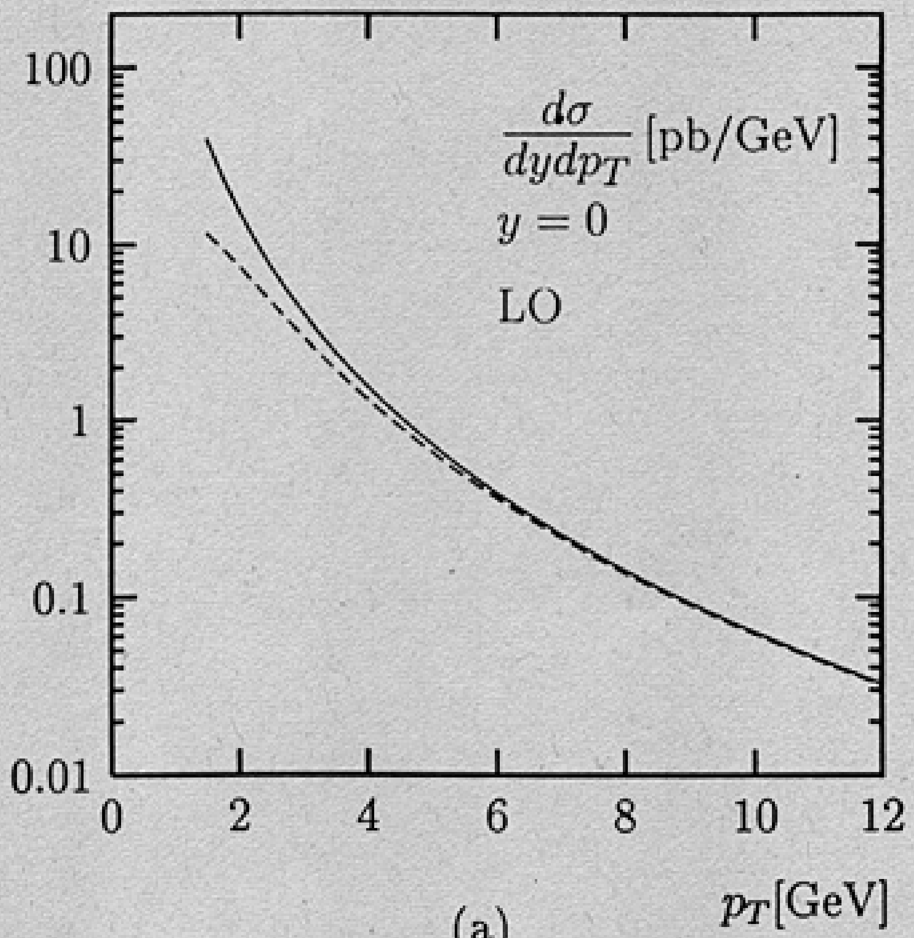


NLO

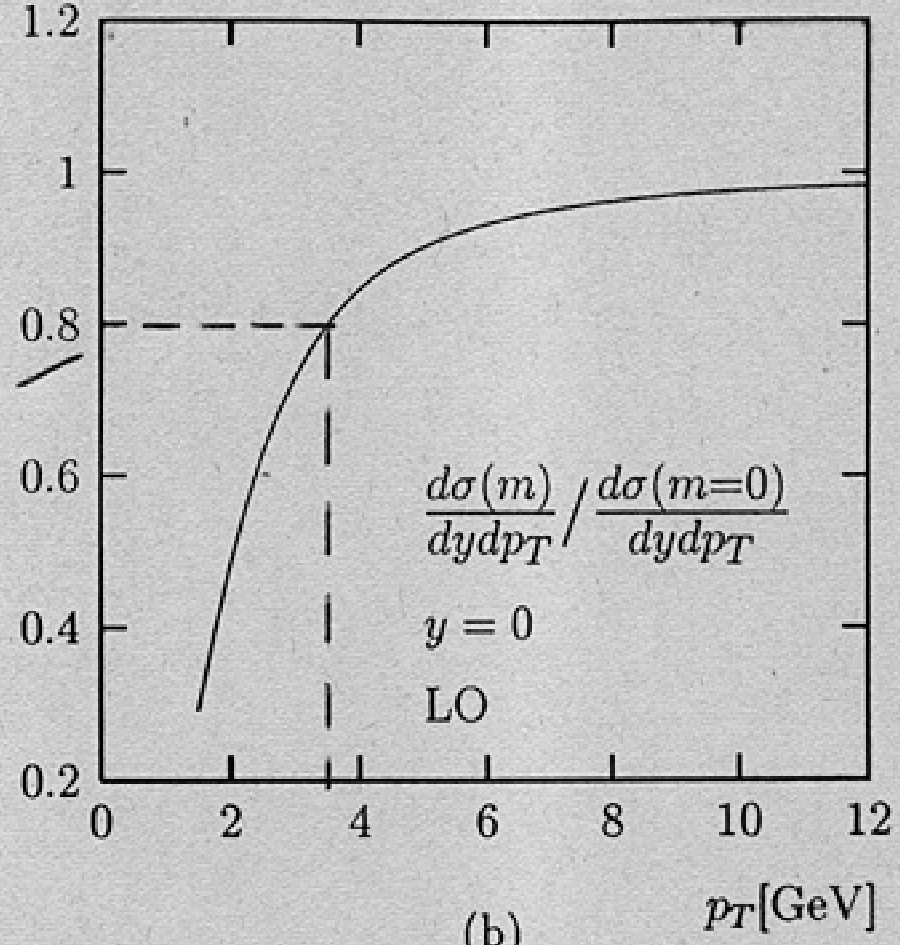
$\overline{MS}$ factorization



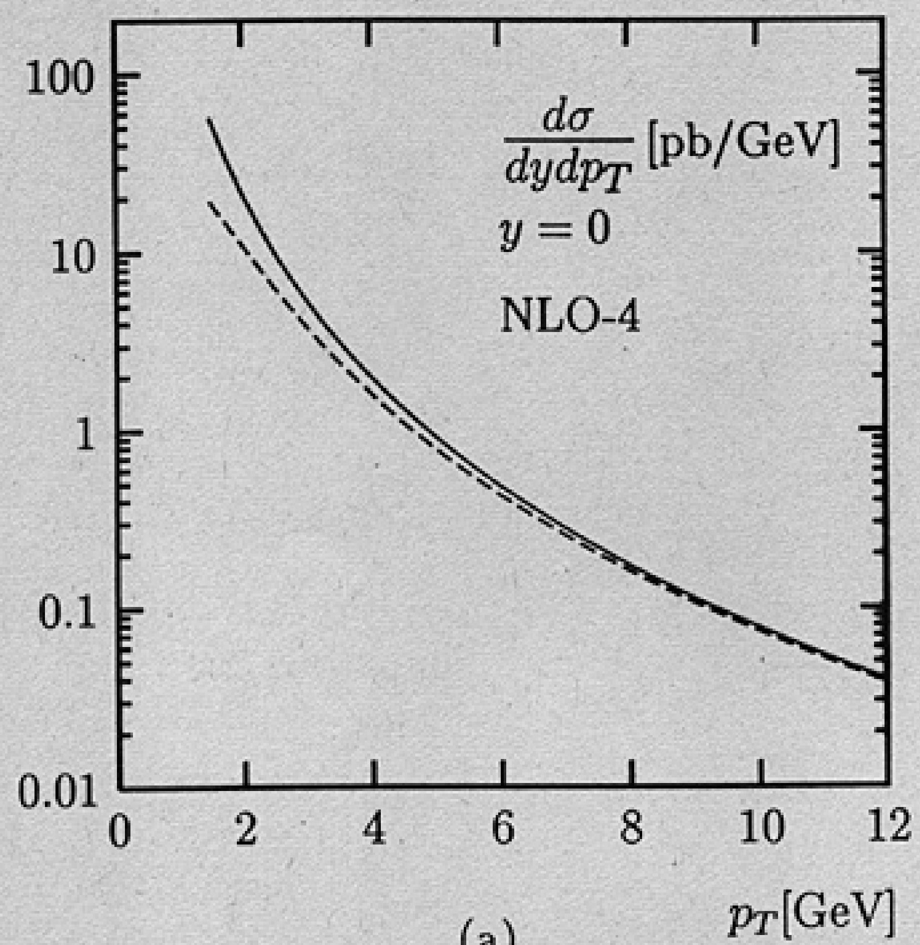
direct process



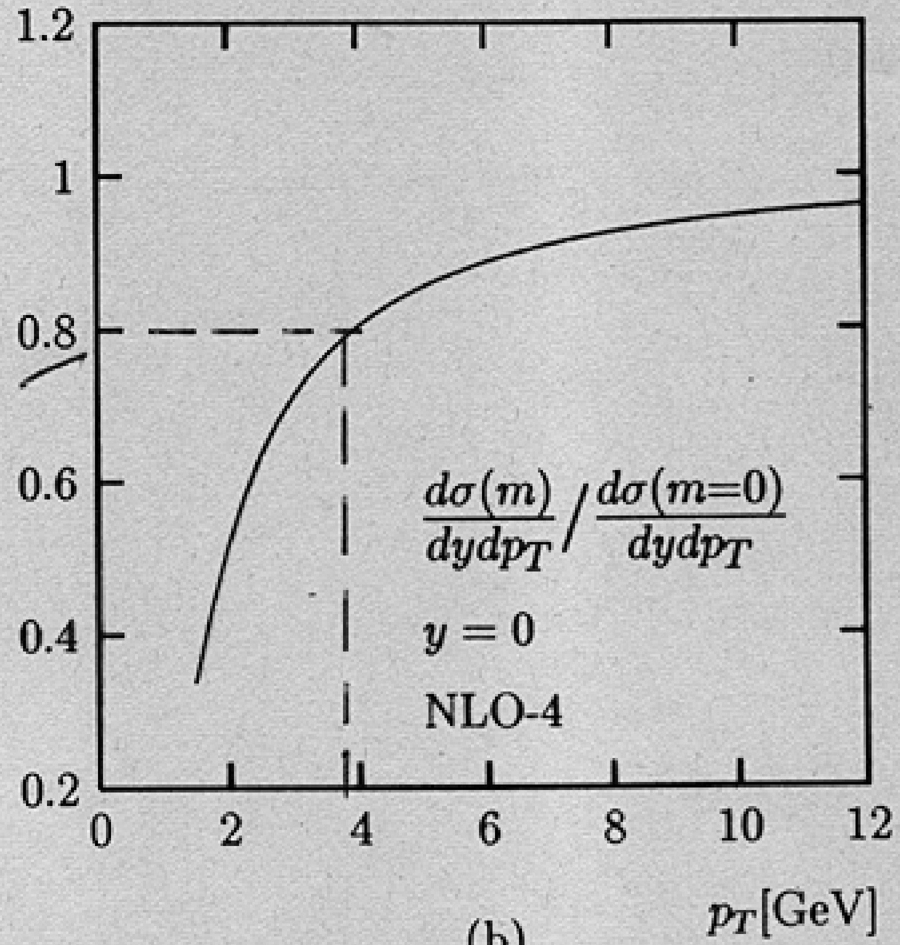
(a)



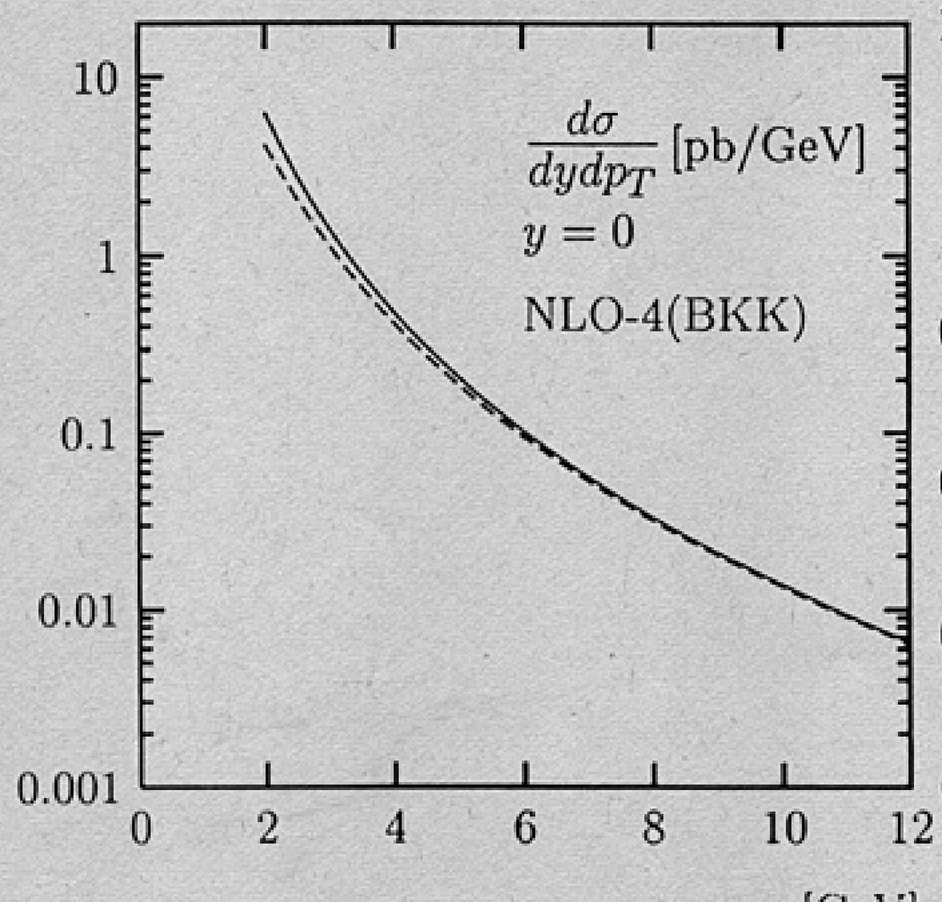
(b)

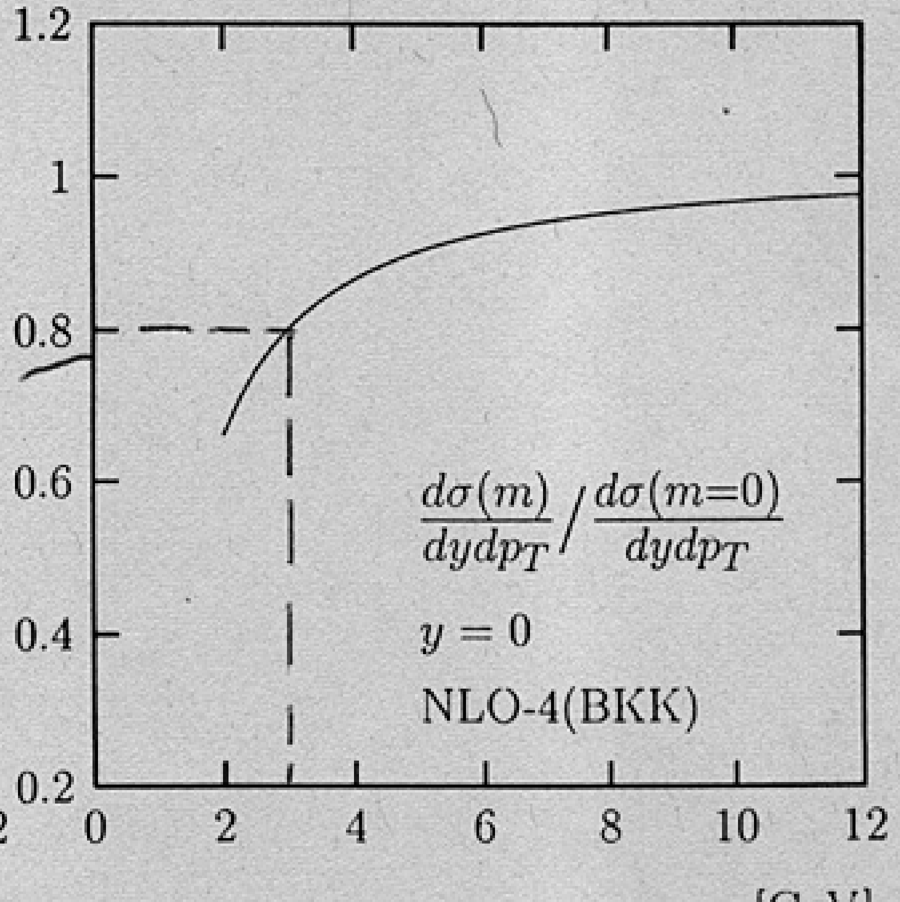


(a)

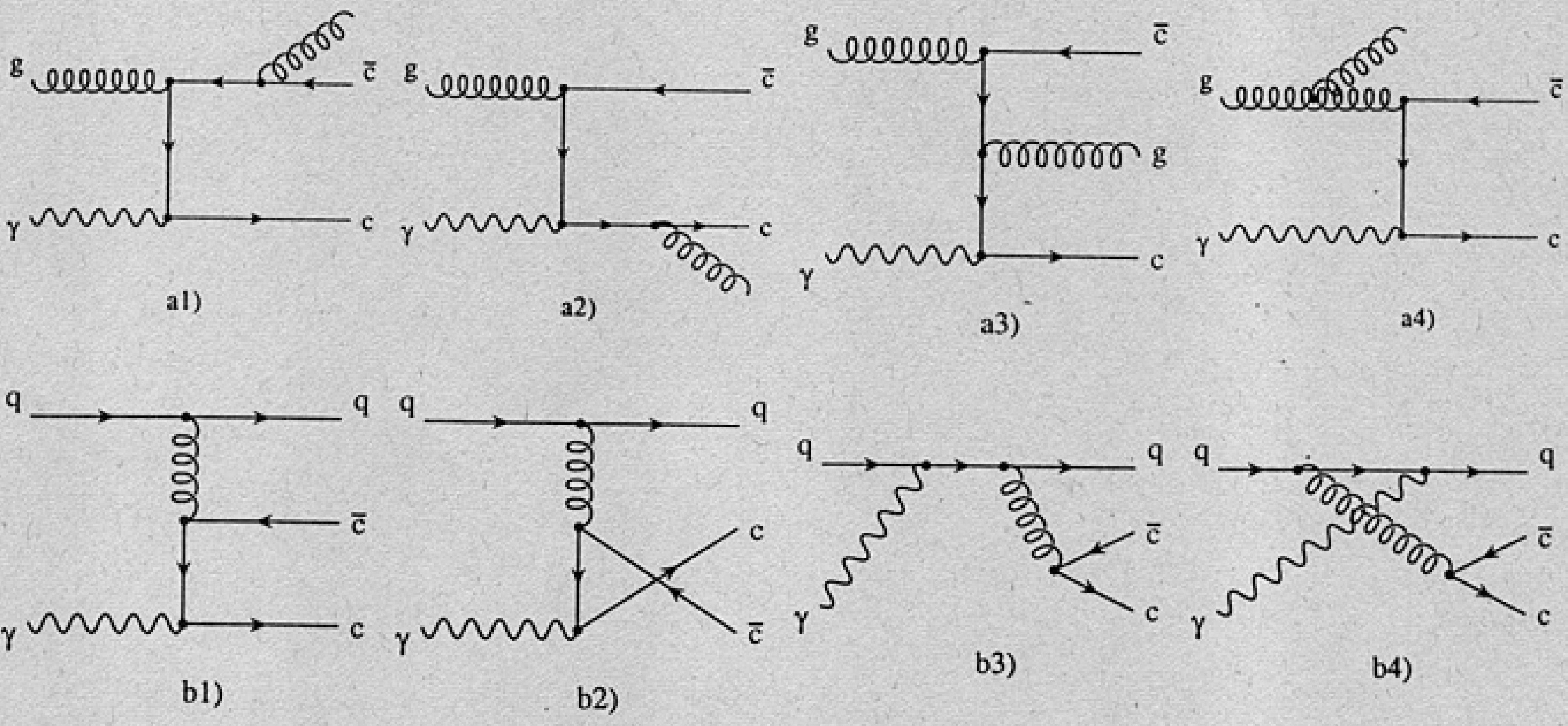


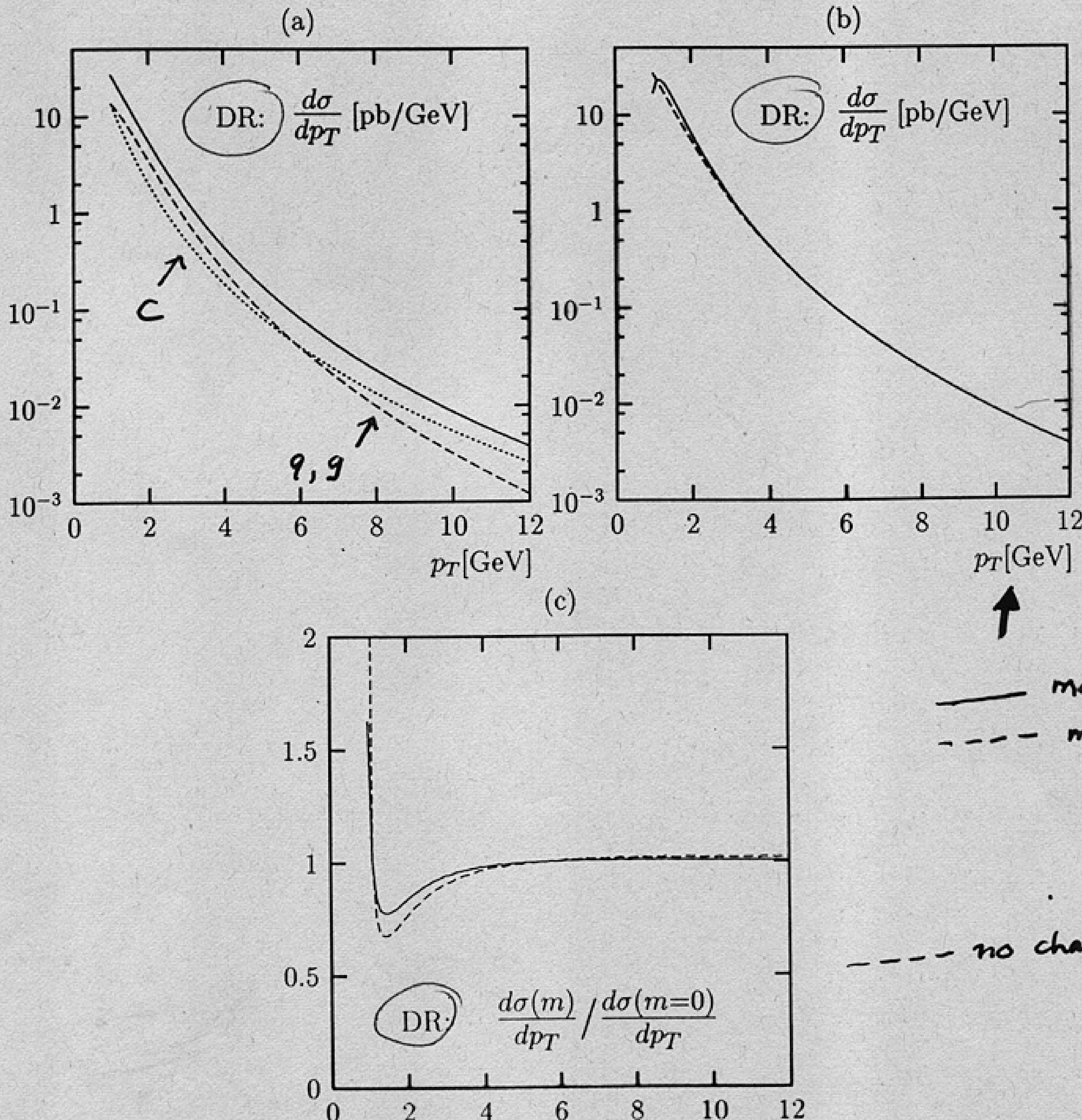
(b)





single - resolved process



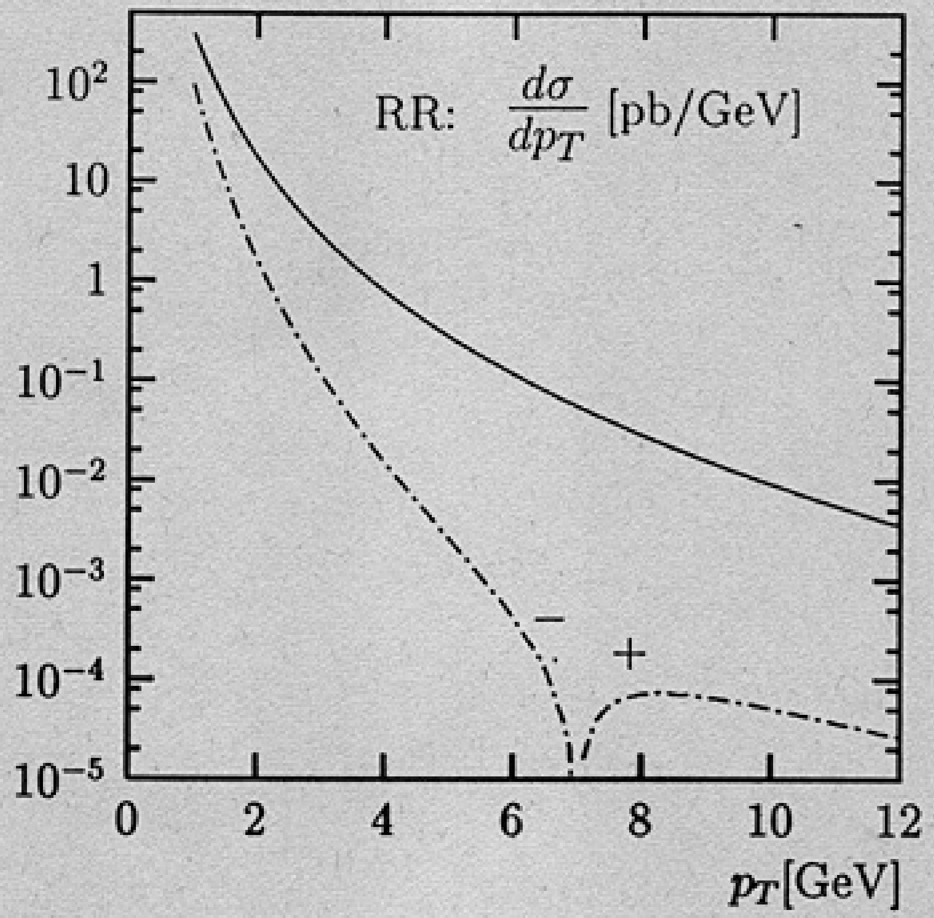


massless

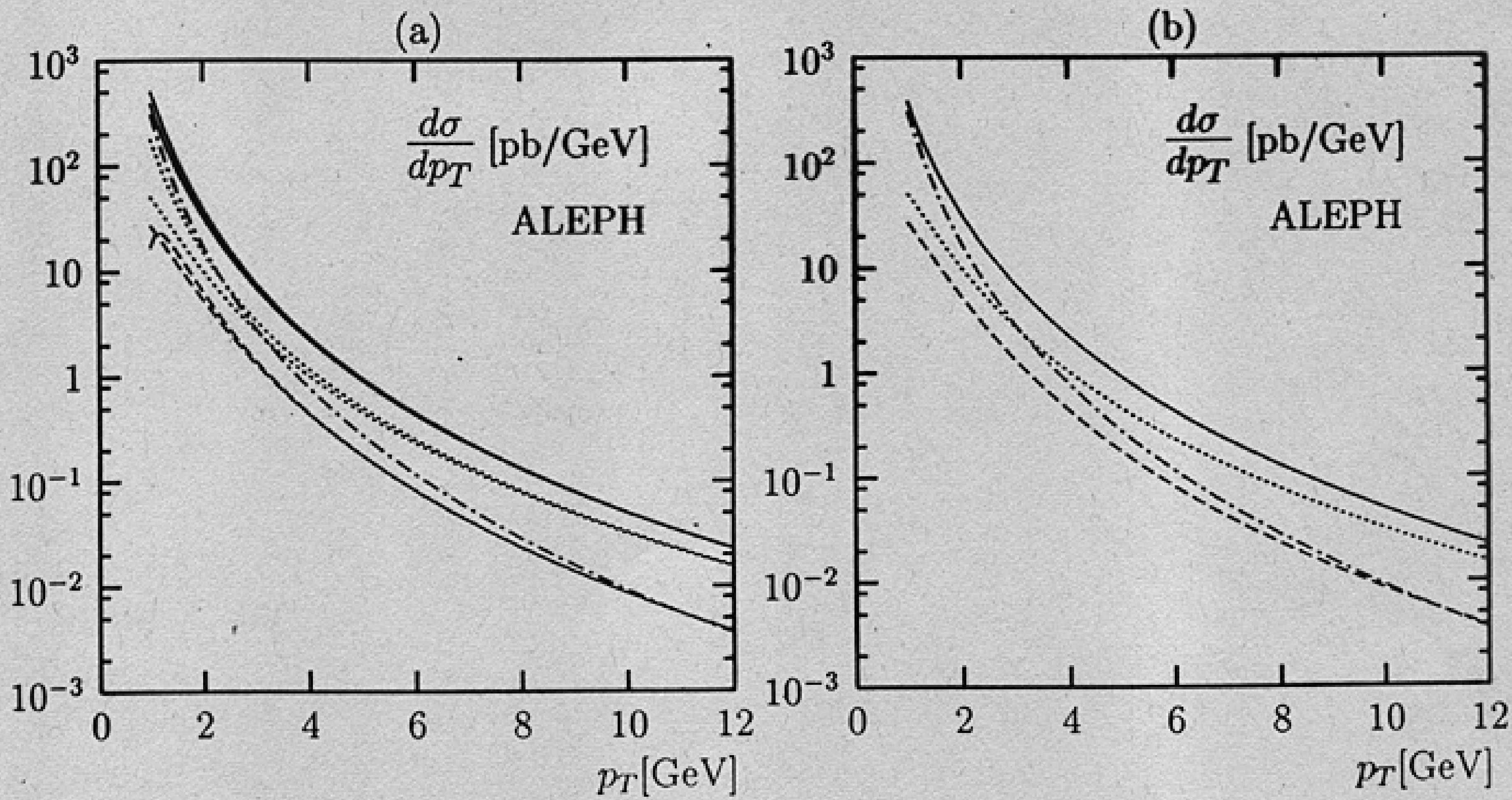
massive

no charm

double-resolved contribution



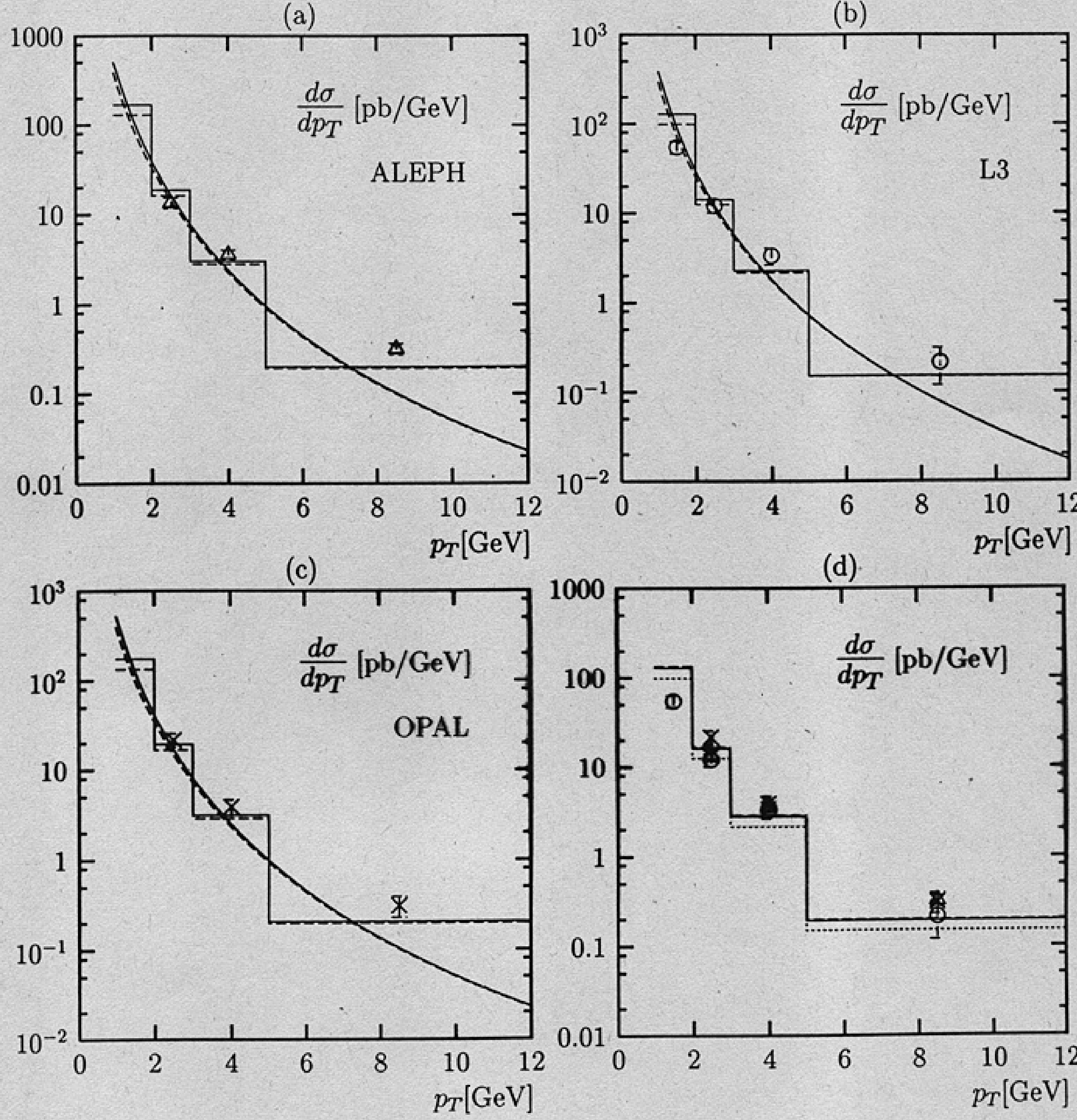
— · — · — · — no charm



—— direct + single resolved

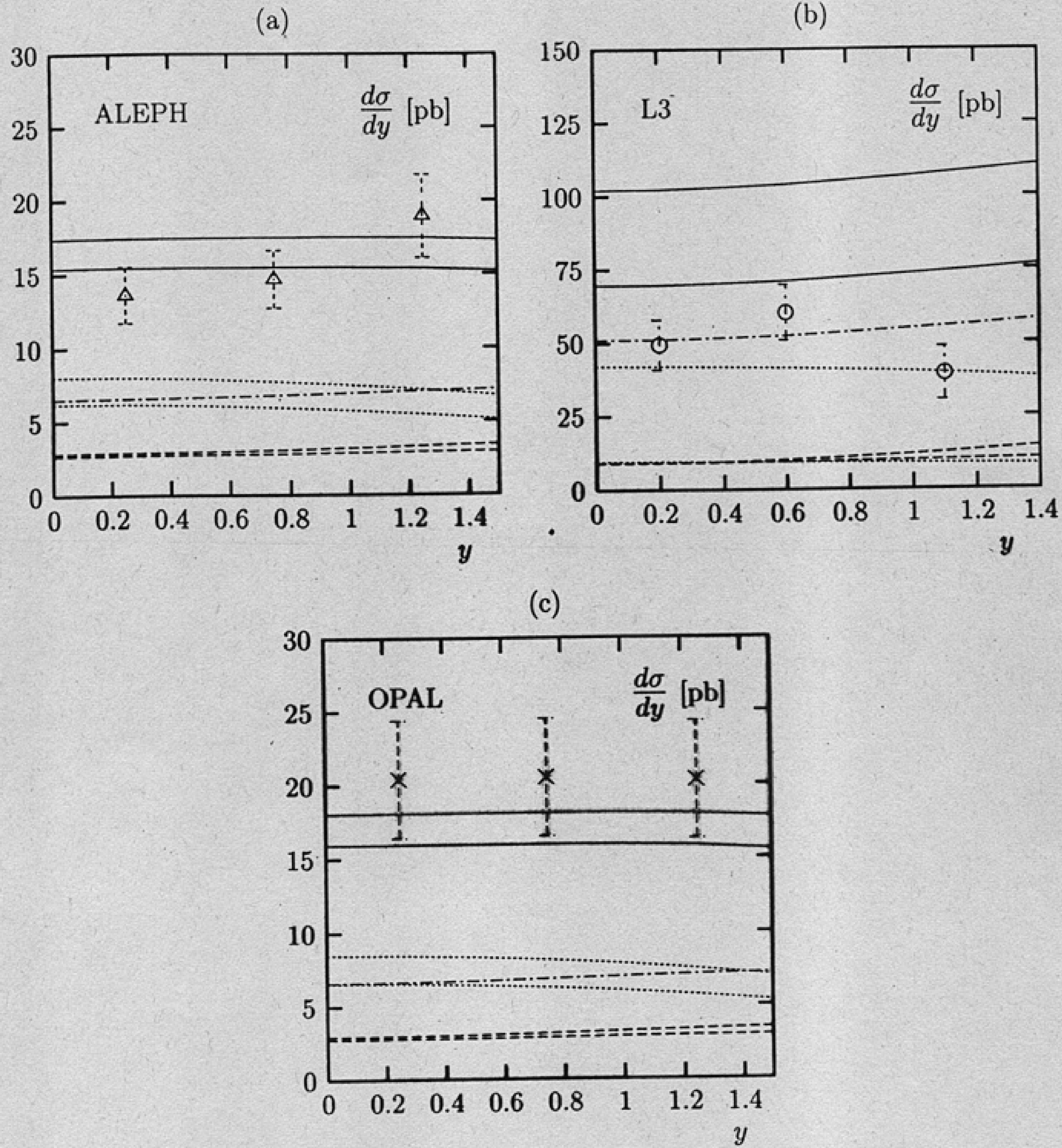
+ double resolved

effect of $m^2/$[illegible] terms small



ALEPH, L3, OPAL

different constraints on $\sqrt{s}_{av}$, tagging, η range


(a)
ALEPH
$\frac{d\sigma}{dy}$ [pb]
30
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
y
(b)
L3
$\frac{d\sigma}{dy}$ [pb]
150
125
100
75
50
25
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
y
(c)
OPAL
$\frac{d\sigma}{dy}$ [pb]
30
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
y

Conclusions

Resummed NLO calculation with $m_c \neq 0$ exists

Good agreement with ALEPH, L3 and OPA data

for $p_T > 2$ GeV

Matching to NLO FFN, $n_f = 3$

at small p_T needs further study