The specific charged hadron yield in electron semi-inclusive deep inelastic scattering off proton and deuteron

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Outline

- Introduction
- Our work
- Results
- Summary

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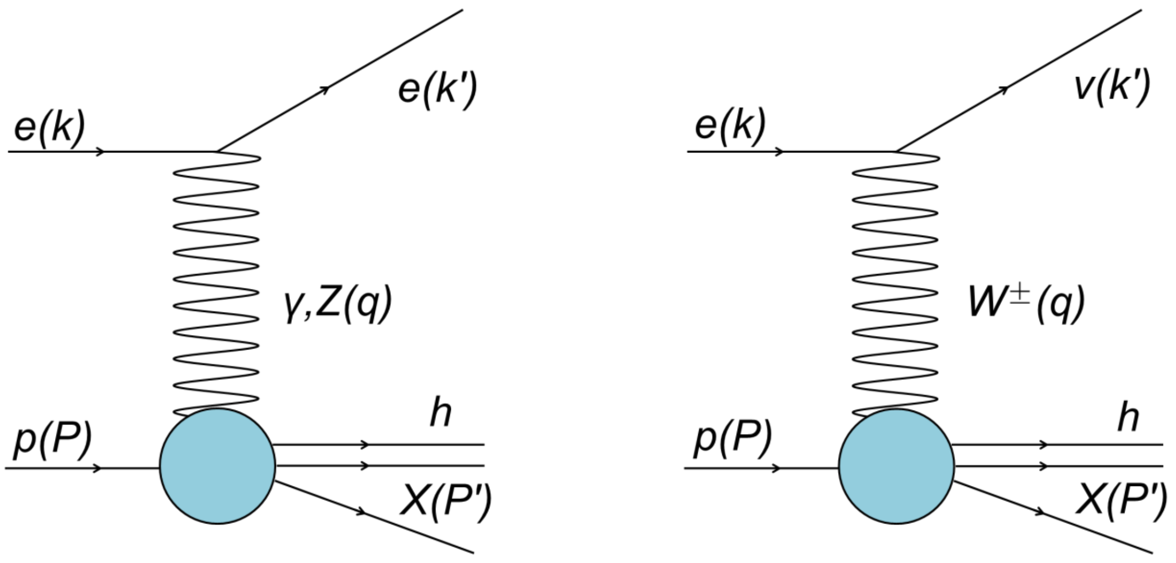
Semi-inclusive deep inelastic scattering (SIDIS)

SIDIS: the scattered lepton and one specific hadron are measured.

We simulate SIDIS with PACIAE 2.2, which has been extended for l+p , l+n and l+A . (l: lepton , p: proton , n: neutron , A: nucleus)



NC (neutral current)

CC (charged current)

HERMES e^-+p & e^-+D SIDIS experiments

e^- energy: 27.6 GeV.   pure gas target: p, D.

At this low energy scale, HERMES provides the most precise results for multiplicities currently available.

Multiplicity: the normalized yield of specific hadron in the final state in SIDIS. A means of extracting FFs(fragmentation functions).

$$\frac{1}{N_{DIS}}\frac{dN^h}{dz} = \frac{1}{N_{DIS}}\int d^5N^h(x_B, Q^2, z, P_{h\perp}, \phi_h)dx_B dQ^2 dP_{h\perp} d\phi_h$$

N_{DIS} : DIS yield (yield of scattered e^-), N^h : yield of specific hadron ($\pi^\pm$,$K^\pm$…)

(z : Fractional energy of hadron h)

Our recent work

- Extended PACIAE model for l+p , l+n and l+A
- Calculated σ_{DIS} of l+A.
- Simulated e^-+p and e^-+D with PACIAE model

  and calculated the multiplicities of $\pi^{\pm}$,$K^{\pm}$
- Compared the results with HERMES

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PACIAE model

- PACIAE is a parton and hadron cascade model based on PYTHIA.

  Applications: $e^+ + e^-$, l+p, l+n, p+p, ..., l+A, p+A, A+A
- PYTHIA is a famous model for relativistic hadron-hadron collisions.

  Applications: $e^+ + e^-$, l+p, l+n, p+p, …
- The PACIAE model is composed of

  (1) Parton initialization

  (2) Parton rescattering

  (3) Hadronization

  (4) Hadron rescattering

PACIAE model

(1) Parton Initialization (e.g. A+A)

a) Initialization of nucleons in spatial phase space and momentum phase space.

b) Nucleus-nucleus collision is decomposed into nucleon-nucleon (NN) collisions.

c) NN collision is described by the PYTHIA model, and the string fragmentation is switched-off.

d) The diquarks (anti-diquarks) are broken into quarks (anti-quarks)

so the consequence is a partonic final state (quarks, anti-quarks, and gluons, beside a few remnants).

PACIAE model

(2) Parton Rescattering

Only 2→2 process are considered, 2 → 2 Leading-Order (LO-) pQCD differential cross sections.

(3) Hadronization

Two options: String Fragmentation (SF) model from PYTHIA;
Coalescence model by us.

The SF model is used here.

(4) Hadron Rescattering

Only $p, n, \pi, k, \Lambda, \Sigma, \Delta, \rho(\omega), J/\Psi$ and their antiparticles are considered, and the usual two-body collision model is used.

PACIAE model

We have updated PACIAE 2.0 to PACIAE 2.2 with extension for l+p , l+n and l+A .

l+p and l+n are based on PYTHIA 6.4 directly.

As for l+A , we decomposed it into l+nucleon. So we need σ_{DIS} of l+A to decide whether l+nucleon will occur more than once.（We set that DIS occurs in each event）.

DIS cross section (my work)

In leading order l+A differential DIS cross section: (m_l is ignored)

$$\frac{d^2\sigma_{NC}}{dxdy} = \frac{4\pi\alpha^2 ME_i}{Q^4}\left[\left(2-2y+y^2\right)F_2^{NC} - \lambda y\left(2-y\right)xF_3^{NC}\right]$$

$$\frac{d^2\sigma_{CC}}{dxdy} = \frac{G_F^2 ME_i}{8\pi}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2 (1+e\lambda)^2\left[\left(2-2y+y^2\right)W_2 - \lambda y\left(2-y\right)xW_3\right]$$

Structure functions (F_2^{NC}, xF_3^{NC}, W_2, xW_3) can be calculated by PDFs of the nucleus.

Then we can get σ_{DIS} :

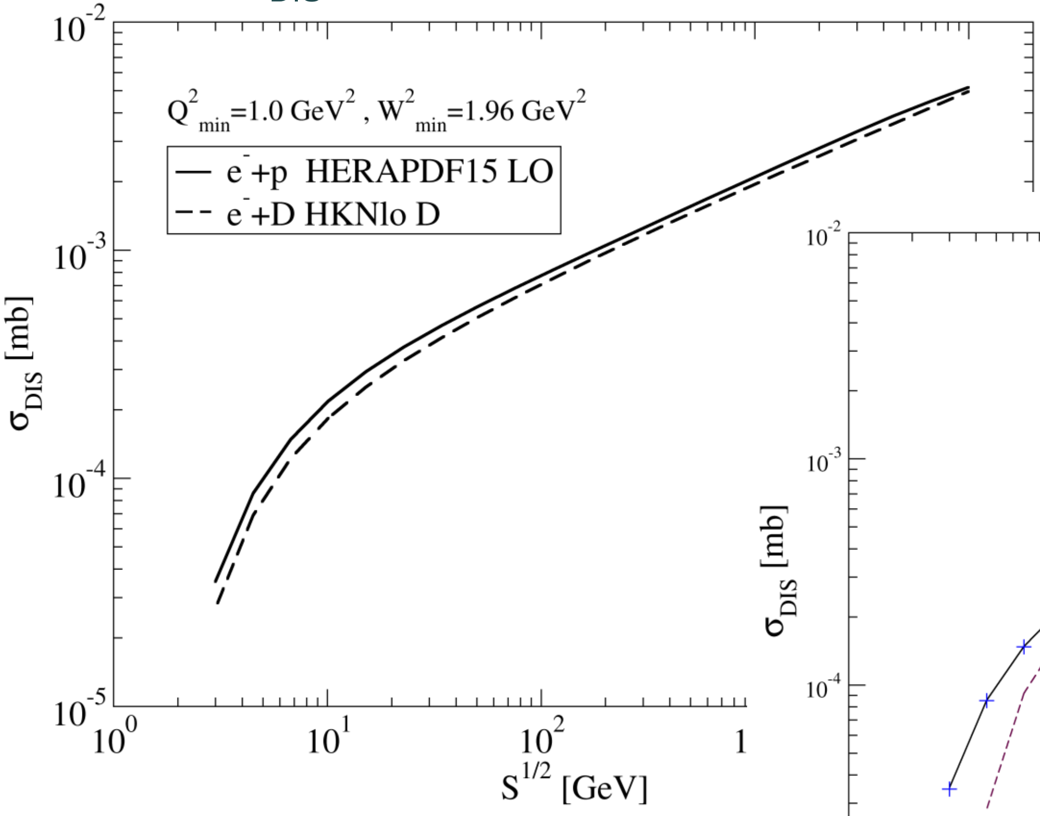
$$\sigma_{NC(CC)} = \iint \frac{d^2\sigma_{NC(CC)}}{dxdy}\, dxdy \quad , \qquad \sigma_{DIS} = \sigma_{NC} + \sigma_{CC}$$

The scope of x,y is determined by $cos^2\theta \leq 1$ and $Q^2_{\min}, W^2_{\min}$

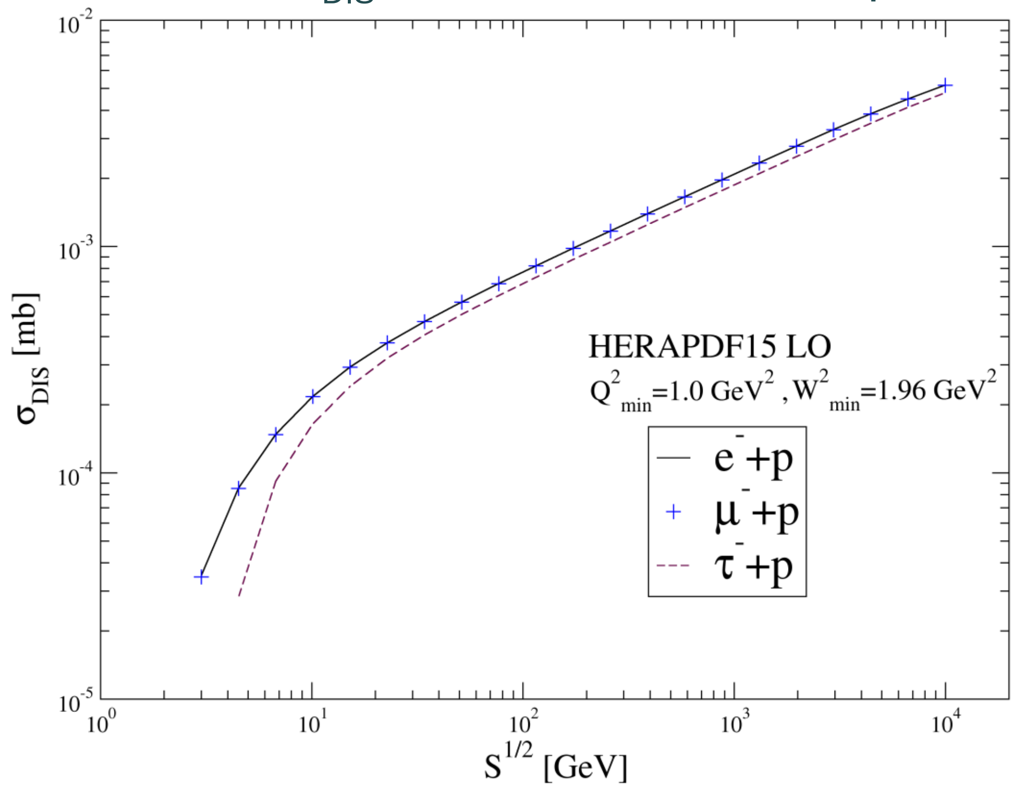
(x: Bjorken scaling variable. y: Fractional energy of the exchanged boson
PDFs: pardon distribution functions . θ: scattering angle of the lepton)

DIS cross section

σ_{DIS} of e^-+p and e^-+D



σ_{DIS} for different incident leptons



($s^{1/2}$: center-of-mass energy)

Simulation of e^-+p and e^-+D

- Approximation that σ_{DIS} of l+A is equal to that of e^-+p was adopted according to the DIS cross section results.

- 500 000 events were simulated. We set that DIS occurs in each event, so the DIS yield (N_{DIS}) was also 500 000.

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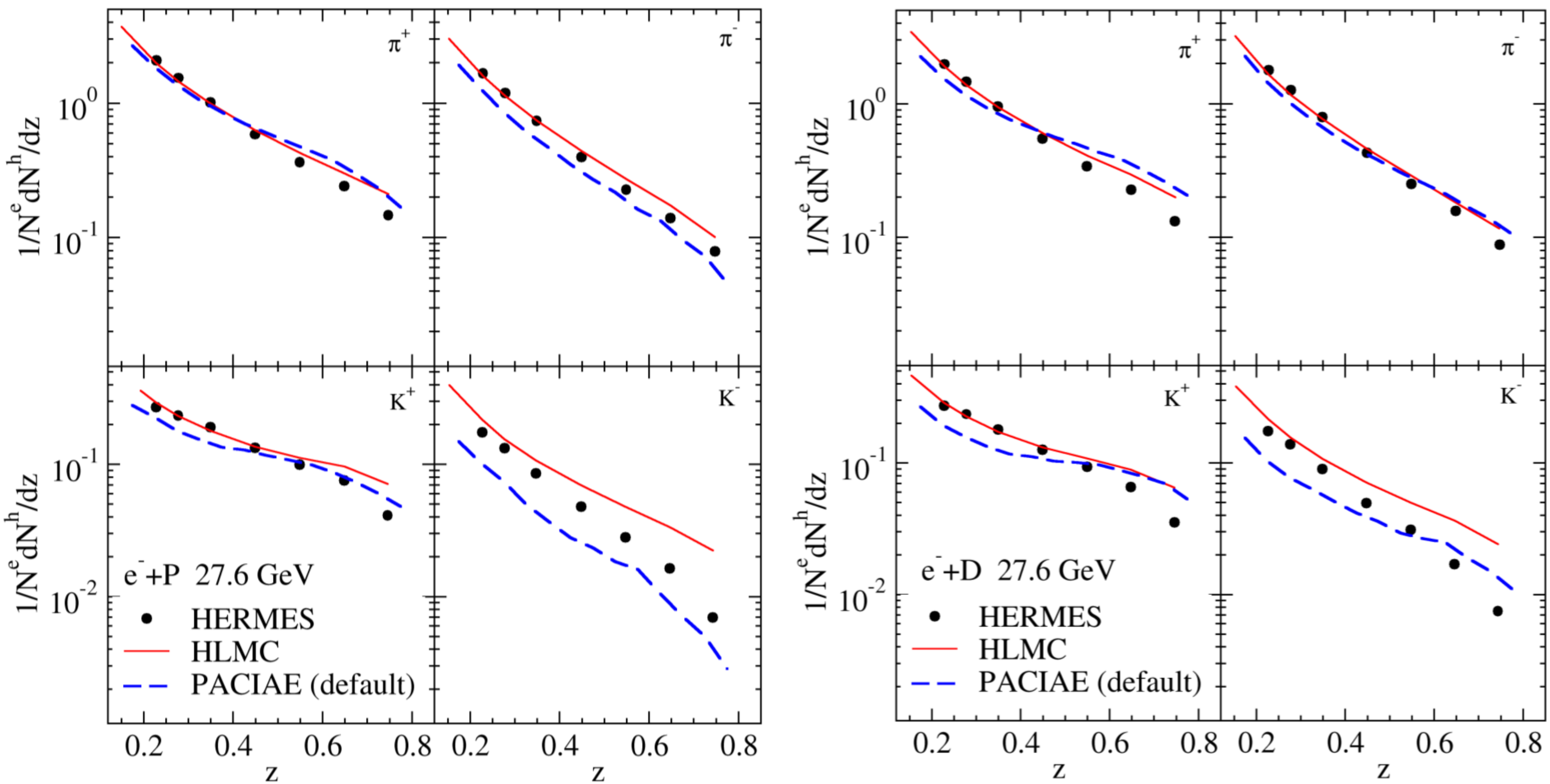
Comparison with data and other theories

The PACIAE reproduced HERMES data nearly as well as HLMC (HERMES Lund Monte Carlo).



The differences between HLMC and PACIAE

	HLMC	PACIAE (default)
base	JETSET 7.4 & PYTHIA 5.7	PYTHIA 6.4
parton rescattering	no	yes
hadron rescattering	no	yes
detector simulation & reconstruction process	yes	no
fragmentation parameters	tuned for HERMES kinematic conditions	default

(HLMC: HERMES Lund Monte Carlo)

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Summary

- PACIAE model has been extended for l+p , l+n and l+A.

- Approximation that σ_{DIS} of l+A is equal to that of e^-+p was adopted.

- Default PACIAE model reproduced HERMES data of multiplicities nearly as well as HLMC.

Thanks for your attention!

TABLE I: Kinematic variables in the semi-inclusive deep-inelastic scattering

$k = \left(E, \vec{k}\right), k' = \left(E', \vec{k}'\right)$	4-momenta of incident and scattered lepton l'
$P \overset{\text{lab}}{=} \left(M, \vec{0}\right)$	4-momentum of the target nucleon
$q = k - k'$	4-momentum of the virtual photon γ^*
$\nu = \frac{P \cdot q}{M} \overset{\text{lab}}{=} E - E'$	Energy transfer to the target
$Q^2 = -q^2 \overset{\text{lab}}{\approx} 4EE' \sin^2\left(\frac{\theta}{2}\right)$	Negative squared 4-momentum transfer
$W^2 = (P+q)^2$	Squared invariant mass of the photon-nucleon system
$x_{\mathrm{B}} = \frac{Q^2}{2P \cdot q} \overset{\text{lab}}{=} \frac{Q^2}{2M \cdot \nu}$	Bjorken scaling variable
$y = \frac{P \cdot q}{P \cdot k} \overset{\text{lab}}{=} \frac{v}{E}$	Fractional energy of the virtual photon
ϕ_h	Azimuthal angle between the lepton scattering plane and the hadron production plane
$z = \frac{P \cdot P_h}{P \cdot q} \overset{\text{lab}}{=} \frac{E_h}{\nu}$	Fractional energy of hadron h
$P_{h\perp} \overset{\text{lab}}{=} \frac{\left\lvert \vec{q} \times \vec{P_h} \right\rvert}{\lvert \vec{q} \rvert}$	Component of the hadron momentum, P_h ,transverse to q

$$[F_2^\gamma, F_2^{\gamma Z}, F_2^Z] = x\sum_q [e_q^2, 2e_q g_V^q, g_V^{q\,2} + g_A^{q\,2}](q+\bar{q}),$$

$$[xF_3^\gamma, xF_3^{\gamma Z}, xF_3^Z] = x\sum_q [0, 2e_q g_A^q, 2g_V^q g_A^q](q-\bar{q})$$

量耦合。对于CC过程，入射轻子为e^-, μ^-, τ^- 或$\bar{\nu}_e, \bar{\nu}_\mu, \bar{\nu}_\tau$ 时：

$$F_2^W = 2x\left(u+\bar{d}+c+\bar{s}+t+\bar{b}\right),$$

$$xF_3^W = 2x\left(u-\bar{d}+c-\bar{s}+t-\bar{b}\right)$$

入射轻子为e^+, μ^+, τ^+或ν_e, ν_μ, ν_τ时：

$$F_2^W = 2x\left(\bar{u}+d+\bar{c}+s+\bar{t}+b\right),$$

$$xF_3^W = 2x\left(-\bar{u}+d-\bar{c}+s-\bar{t}+b\right)$$

$$\frac{\mathrm{d}^2\sigma_I}{\mathrm{d}x\mathrm{d}y} = \frac{8\pi\alpha^2 M E_i}{Q^4}\left(c_1 F_1^I + c_2 F_2^I + c_3 x F_3^I\right)$$

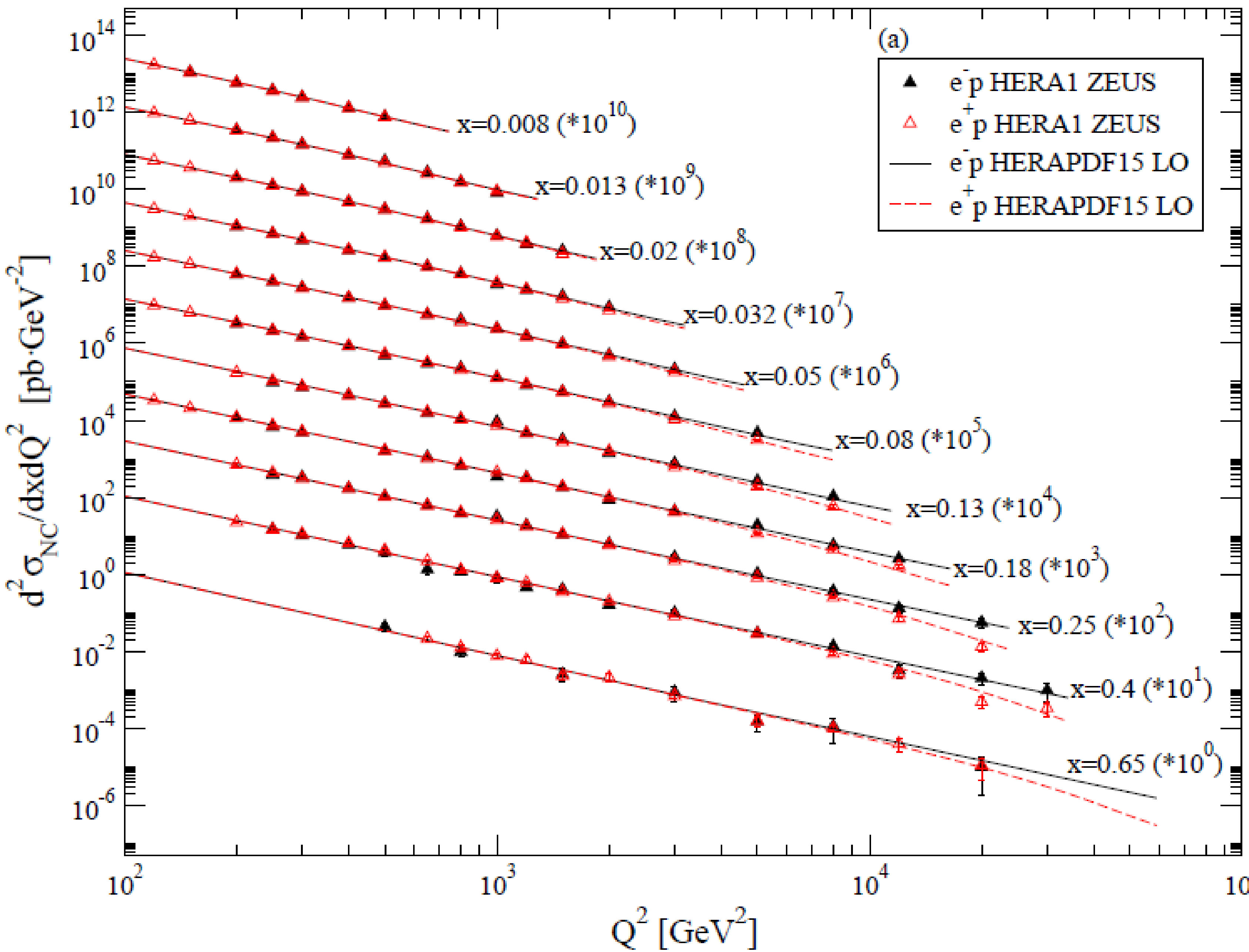
$$c_1 = xy^2 - \frac{\left(m_i^2 - m_o^2\right)^2}{8xM^2E_i} - \frac{y\left(5m_i^2 - m_o^2\right)}{4ME_i}$$

$$c_2 = 1 - y + \frac{\left(m_i^2 - m_o^2\right)\left(4x^2M^2 + m_i^2 - m_o^2\right)}{16x^2M^2E_i^2} - \frac{\left(m_i^2 - m_o^2\right)(y-4) + 4M^2x^2y}{8xME_i}$$

$$c_3 = \frac{\lambda y(y-2)}{2} - \frac{\lambda y\left(m_i^2 - m_o^2\right)}{4xME_i}$$

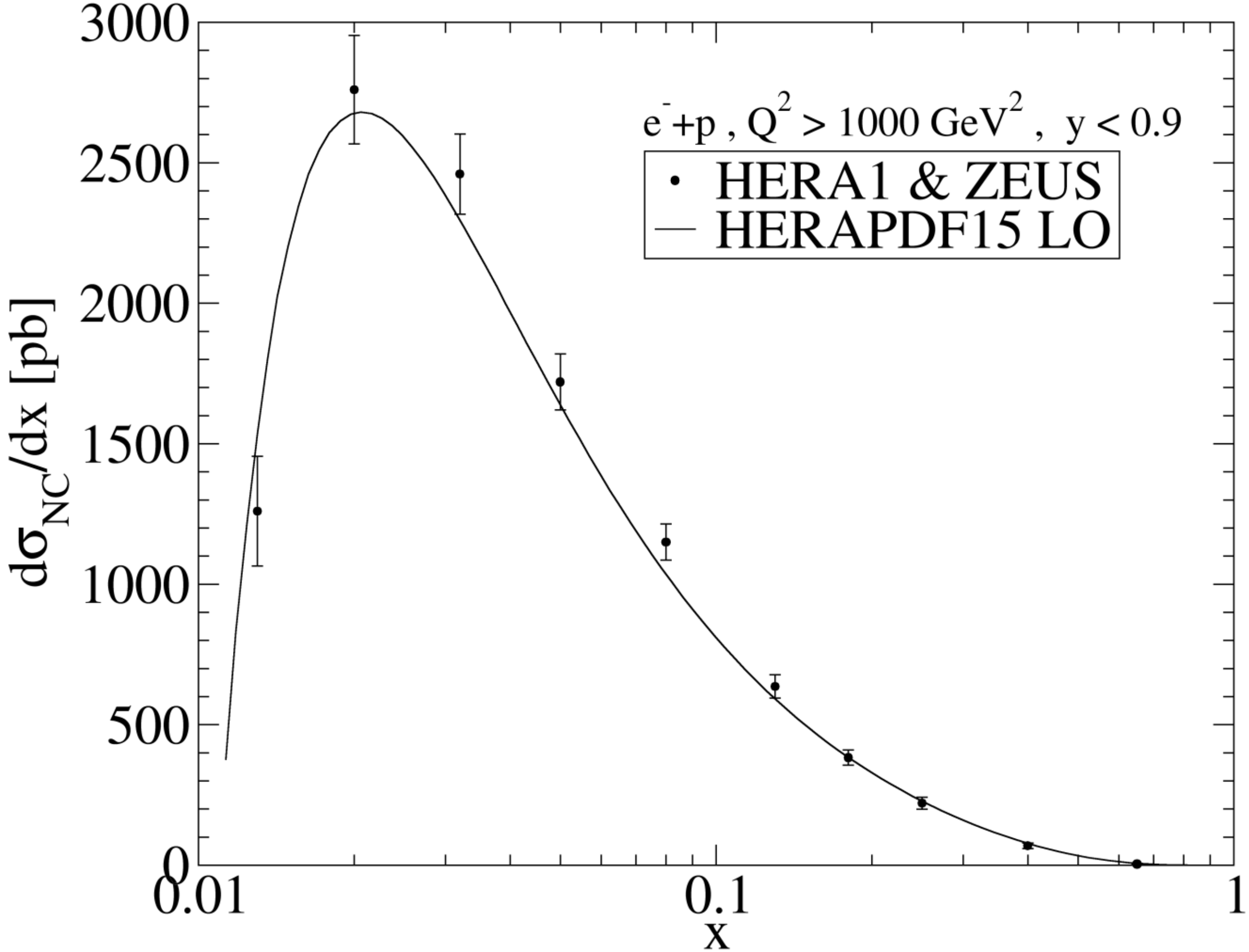
$$I = clNC, nuNC, clCC, nuCC$$

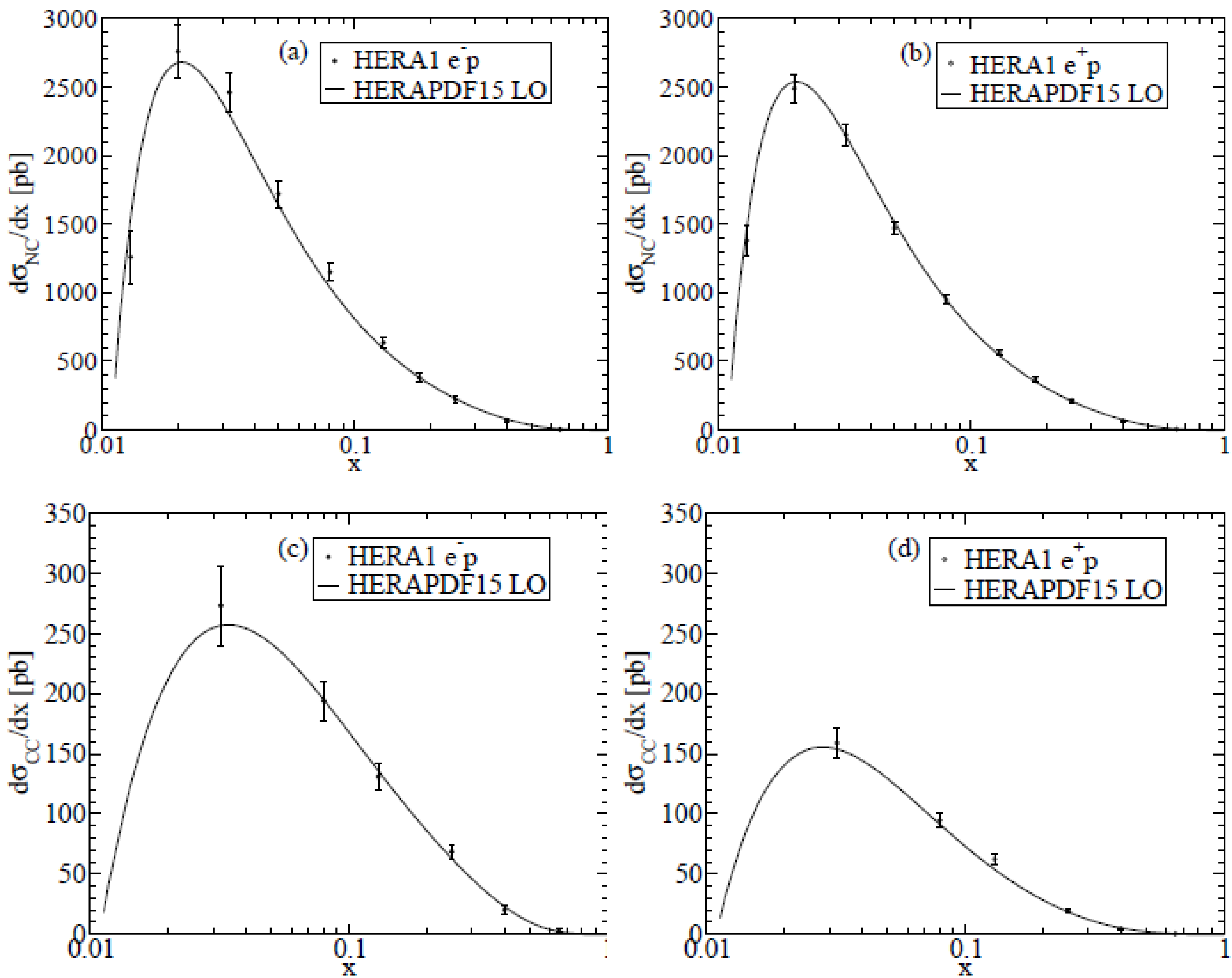
$$\boxed{\begin{aligned}
F_2^{clNC} &= F_2^\gamma - \left(g_V^{cl} + e\lambda g_A^{cl}\right)\eta_{\gamma Z} F_2^{\gamma Z} + \left(g_V^{cl} + e\lambda g_A^{cl}\right)^2 \eta_Z F_2^Z,\\
xF_3^{clNC} &= -\left(g_V^{cl} + e\lambda g_A^{cl}\right)\eta_{\gamma Z} xF_3^{\gamma Z} + \left(g_V^{cl} + e\lambda g_A^{cl}\right)^2 \eta_Z xF_3^Z\\
F_2^{clCC} &= (1 + e\lambda)^2 \eta_W F_2^W,\\
xF_3^{clCC} &= (1 + e\lambda)^2 \eta_W xF_3^W\\
F_2^{nuNC} &= (g_V^{nu} + g_A^{nu})^2 \eta_Z F_2^Z,\\
xF_3^{nuNC} &= (g_V^{nu} + g_A^{nu})^2 \eta_Z xF_3^Z\\
F_2^{nuCC} &= 4\eta_W F_2^W,\\
xF_3^{nuCC} &= 4\eta_W xF_3^W
\end{aligned}}$$


(a)
e-p HERA1 ZEUS
e+p HERA1 ZEUS
e-p HERAPDF15 LO
e+p HERAPDF15 LO
x=0.008 (*10^10)
x=0.013 (*10^9)
x=0.02 (*10^8)
x=0.032 (*10^7)
x=0.05 (*10^6)
x=0.08 (*10^5)
x=0.13 (*10^4)
x=0.18 (*10^3)
x=0.25 (*10^2)
x=0.4 (*10^1)
x=0.65 (*10^0)
d²σ_NC/dxdQ² [pb·GeV^-2]
Q² [GeV²]

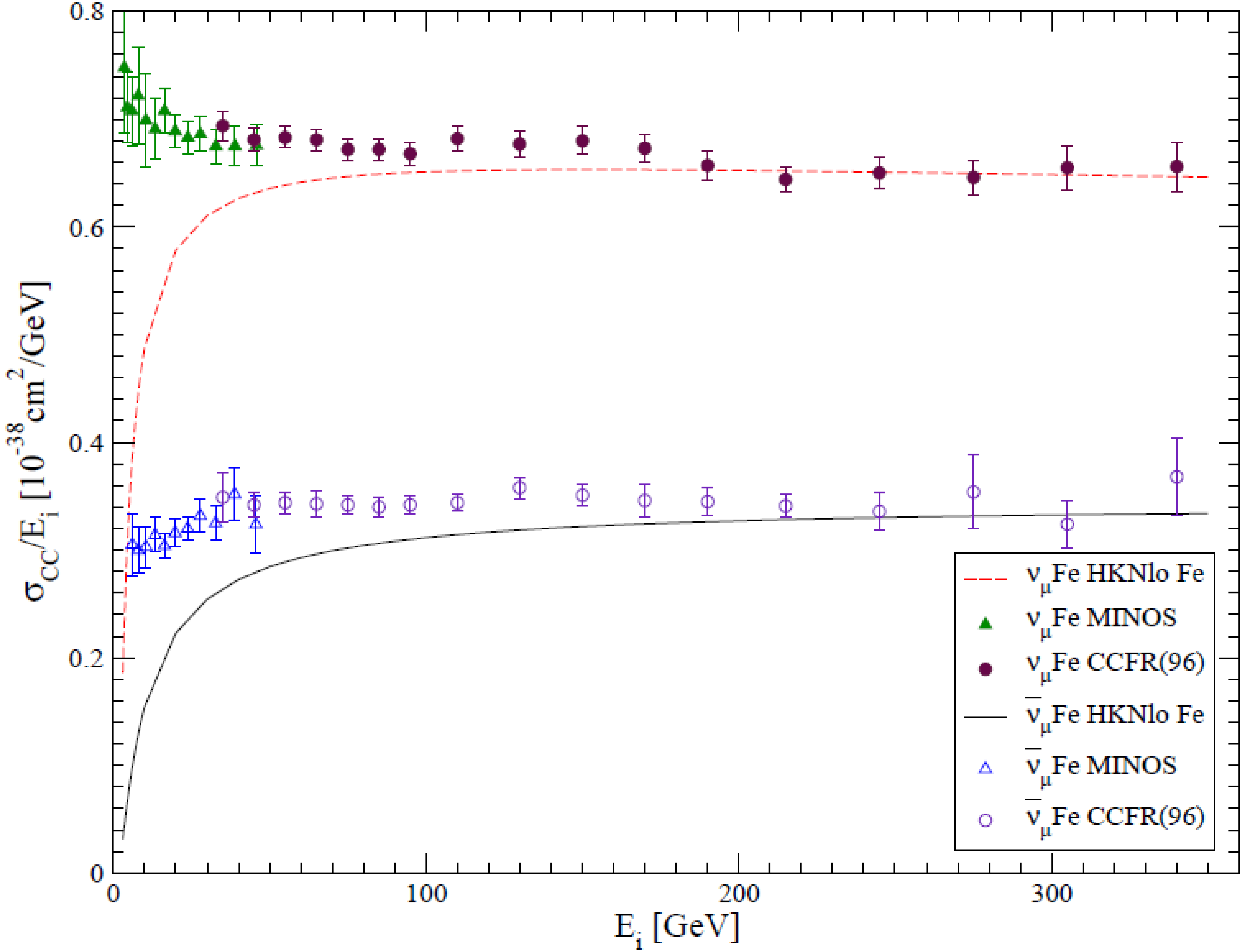
DIS cross section

For $d\sigma_{NC}/dx$, the calculated results agree with the experimental data.





(a)
HERA1 e⁻p
HERAPDF15 LO
(b)
HERA1 e⁺p
HERAPDF15 LO
(c)
HERA1 e⁻p
HERAPDF15 LO
(d)
HERA1 e⁺p
HERAPDF15 LO
dσ_NC/dx [pb]
dσ_CC/dx [pb]
x
0.01
0.1
1

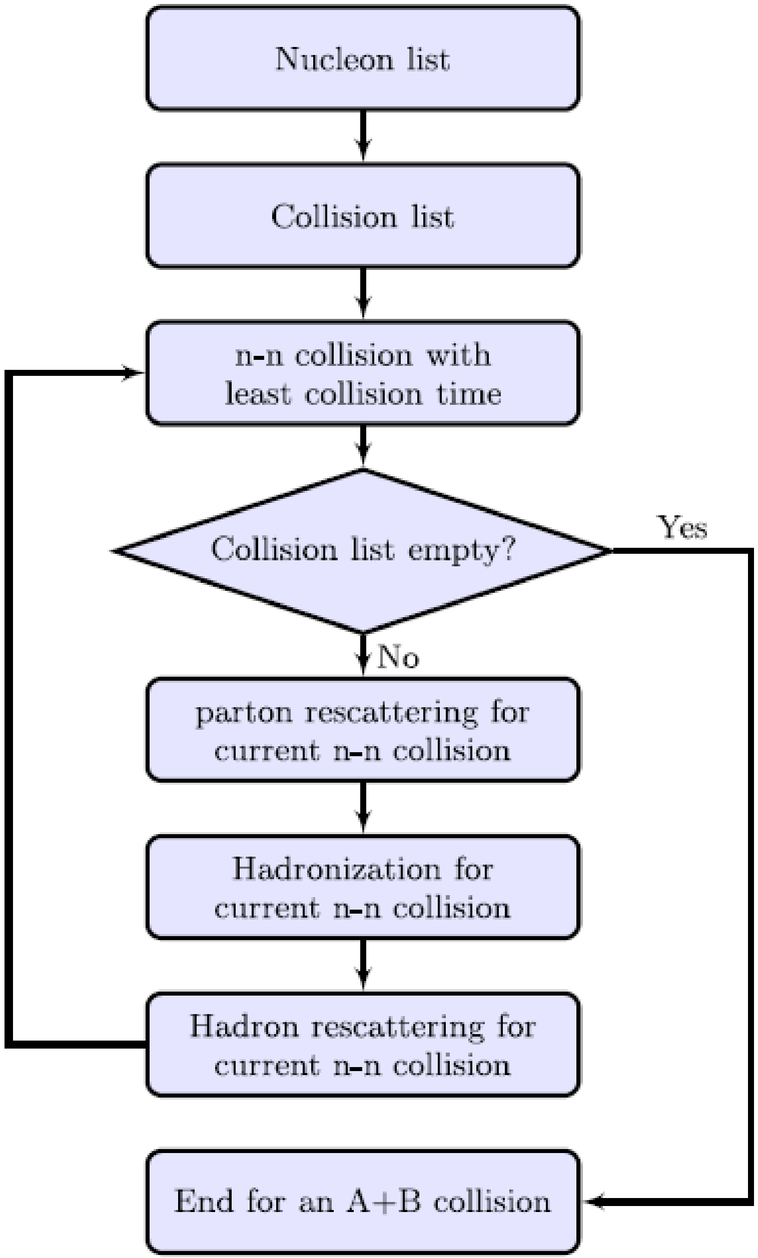


0.8
0.6
0.4
0.2
0
0
100
200
300
E_i [GeV]
σ_{CC}/E_i [10^{-38}cm^2/GeV]
ν_μFe HKNlo Fe
ν_μFe MINOS
ν_μFe CCFR(96)
$\overline{\nu}_\mu$Fe HKNlo Fe
$\overline{\nu}_\mu$Fe MINOS
$\overline{\nu}_\mu$Fe CCFR(96)

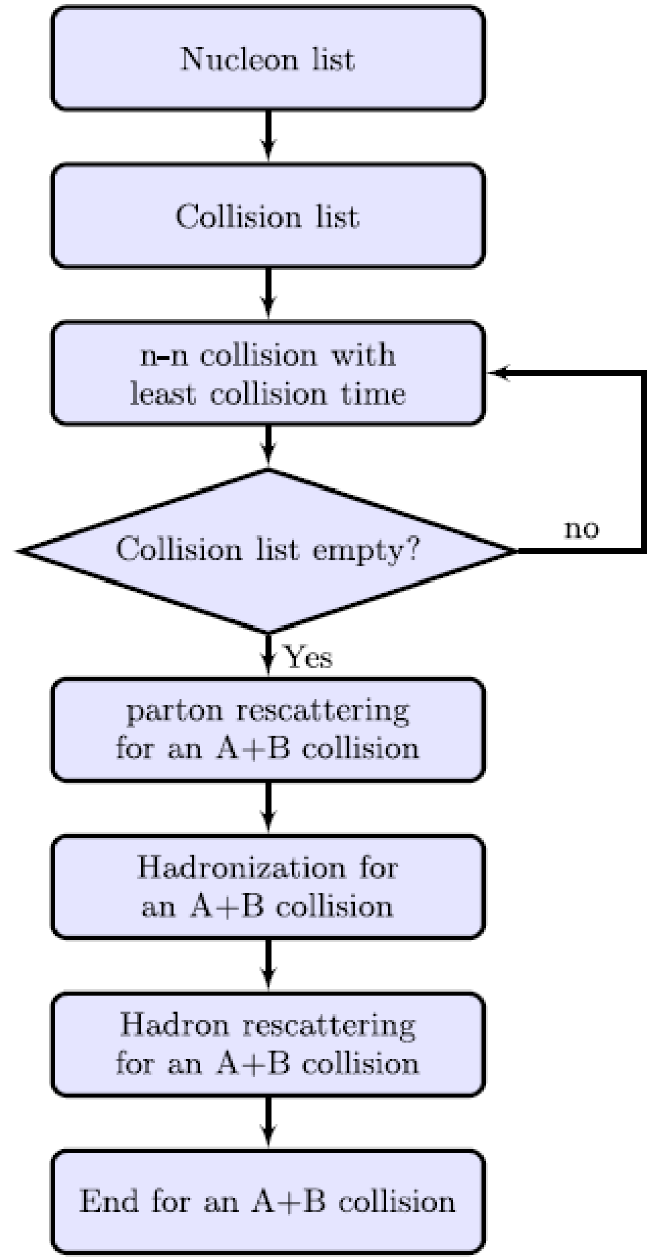
$$E_e = 27.6\,\mathrm{GeV} \;\rightarrow\; S^{1/2} = 7.3\,\mathrm{GeV}$$

$$\text{then} \quad \sigma_{DIS} = \begin{cases} 1.6\times10^{-4}\,\mathrm{mb} & \mathrm{e^- + p} \\ 1.3\times10^{-4}\,\mathrm{mb} & \mathrm{e^- + D} \end{cases}$$

PACIAE20b



PACIAE20c



Lund string fragmentation function

$$f(\hat{z}) \propto \frac{1}{\hat{z}}(1-\hat{z})^{\alpha} \exp(-\frac{\beta m_T^2}{\hat{z}})$$

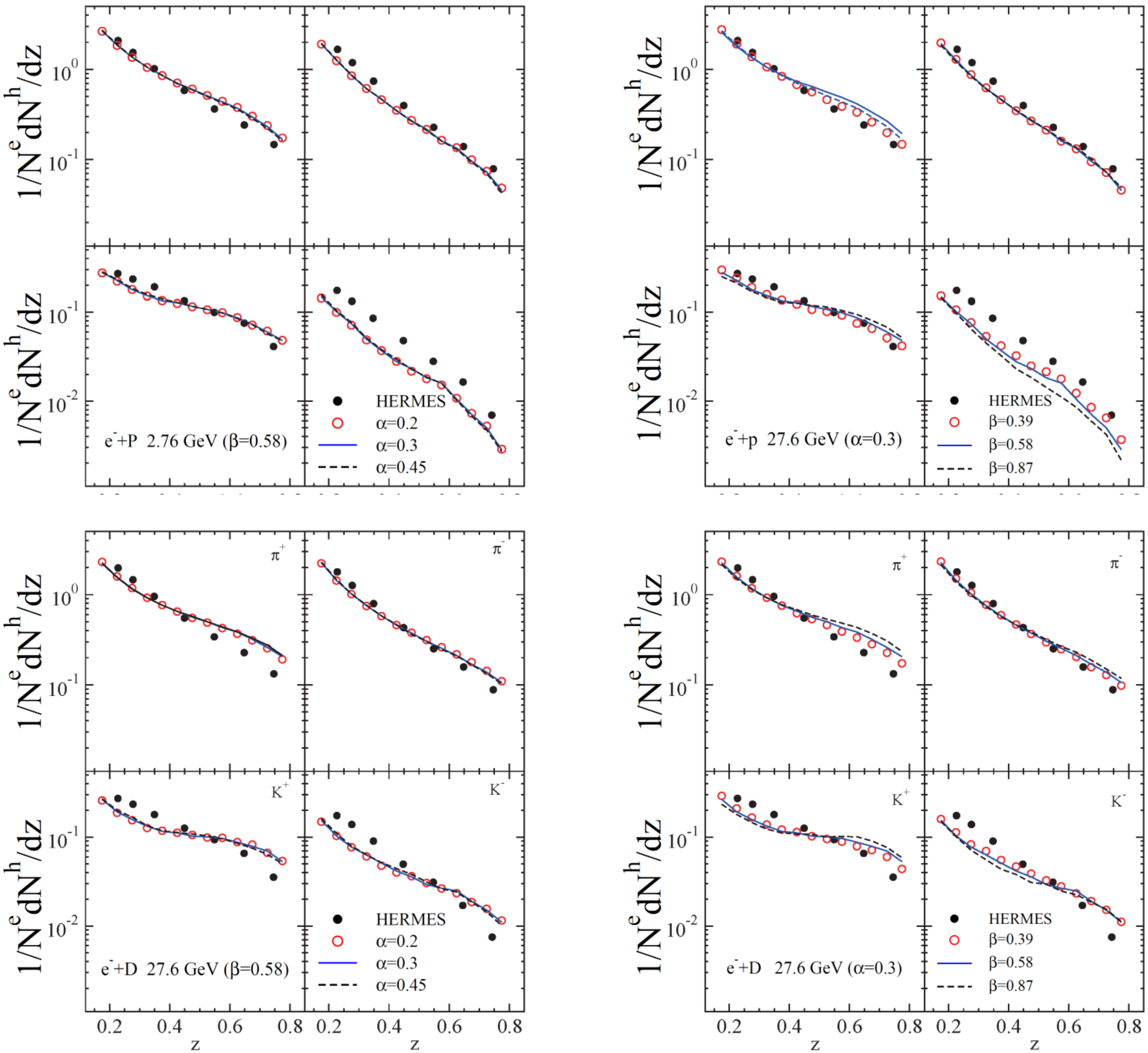


FIG. 4: (color online) The effect of parameter α (left panels) and β (right panels) in the Lund string fragmentation function on $\frac{1}{N_{DIS}}\frac{dN^h}{dz}$ in e^-+p (upper panels) and e^-+D (lower panels) DIS at 2.76 beam energy.

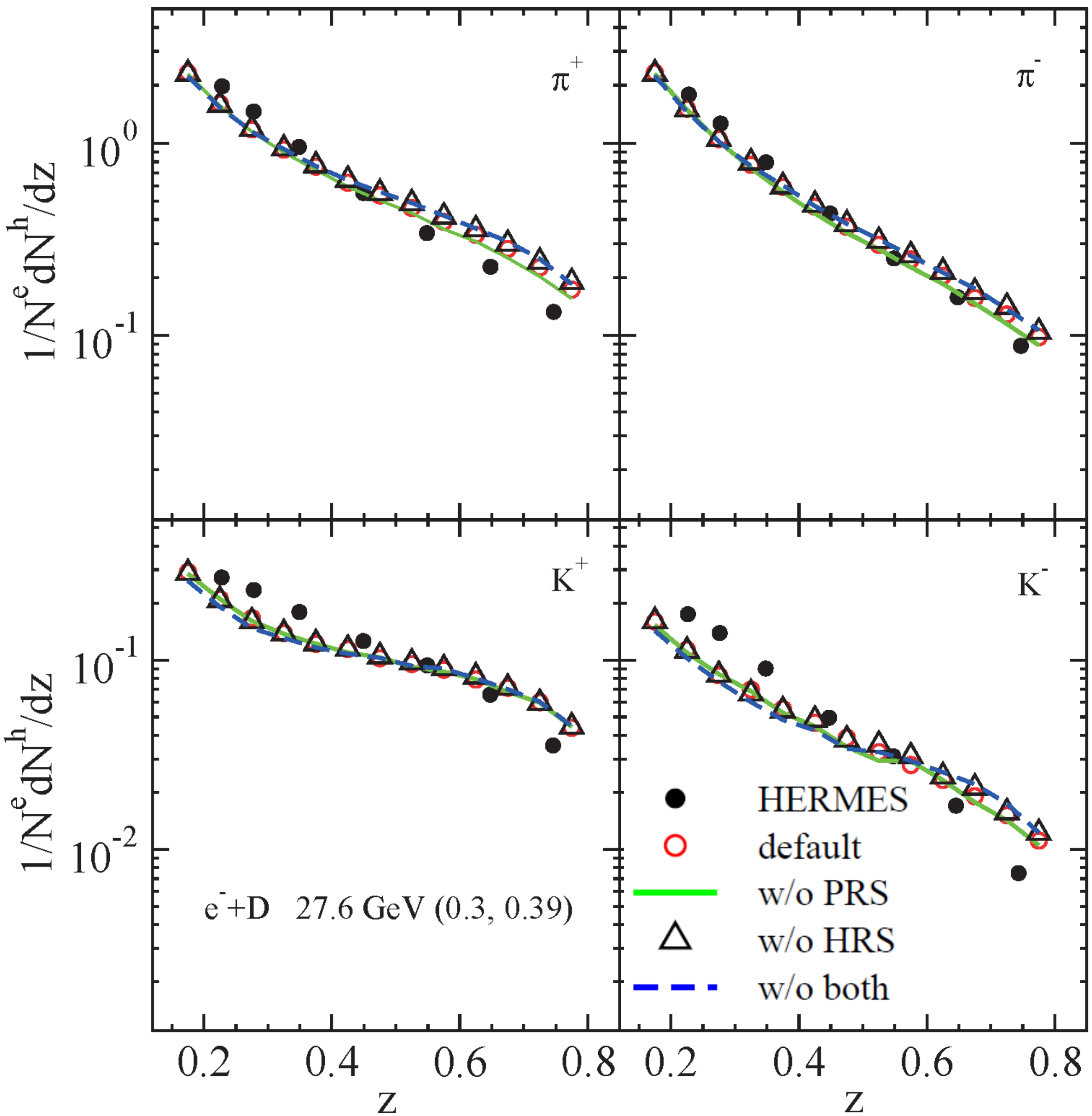


FIG. 5: (color online) The effect of PRS and HRS on $\frac{1}{N_{DIS}}\frac{dN^h}{dz}$ in the e^-+D DIS.

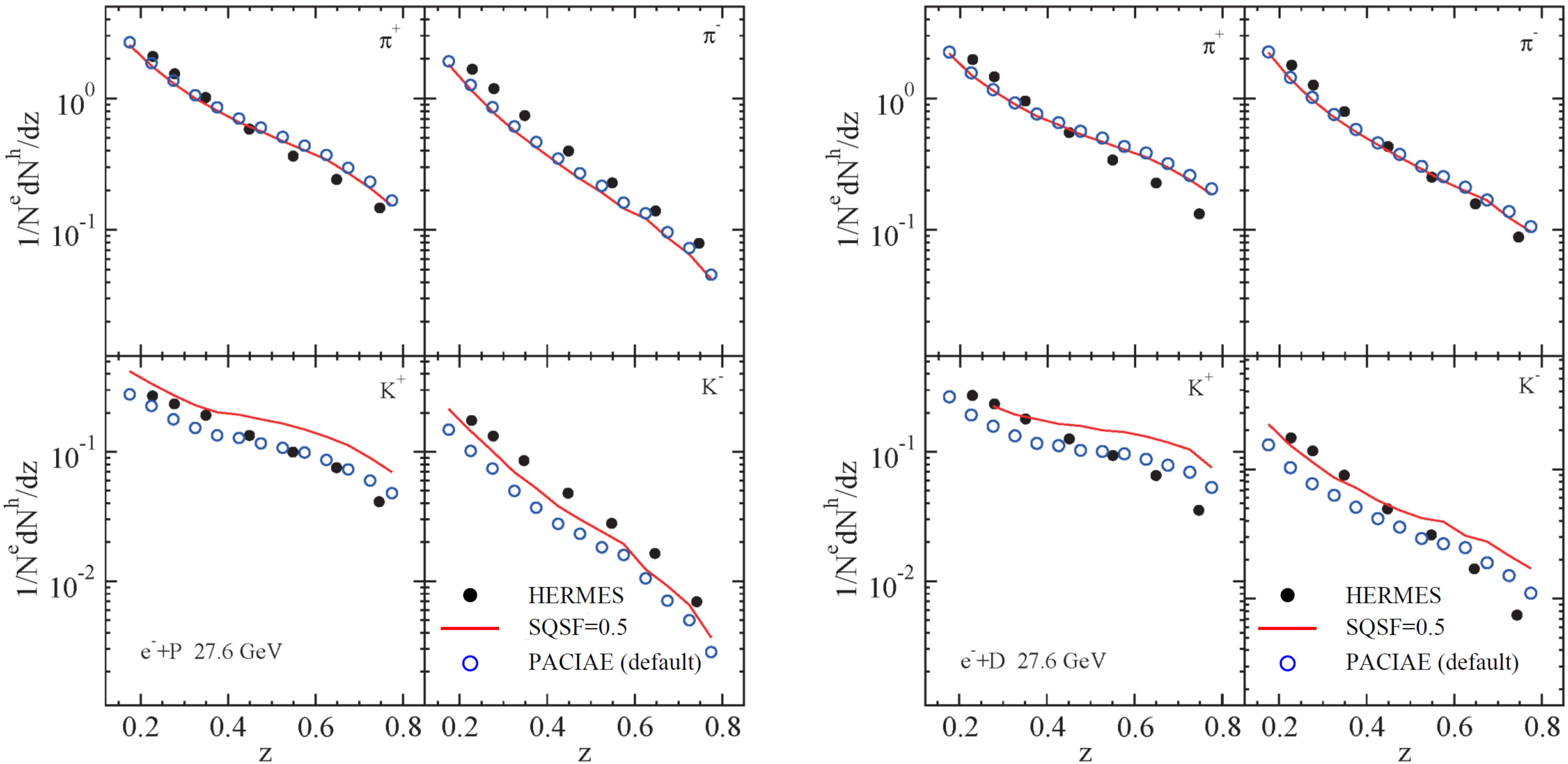


FIG. 6: (color online) The effect of strange suppression factor on the $\frac{1}{N_{DIS}}\frac{dN^h}{dz}$ in e^-+p (left panel) and e^-+D (right panel) DIS at 27.6 GeV/c beam momentum.