MC generator HARDPING: high-energy scattering leptons and hadrons off nuclei

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QUARKS-2014

Outline

- Introduction: Monte Carlo event generator HARDPING
  (HARD Probe INteraction Generator)

- HARDPING: soft interactions of hadrons produced in hard lepton-nucleus scattering and formation length of this hadrons

- HARDPING: soft interactions of hadrons before hard interaction in hard proton-nucleus scattering (Drell-Yan reaction), energy losses and soft re-scatterings

- HARDPING: predictions for NuSea experiment (Fermilab)

- Conclusion

Monte Carlo event generator HARDPING

HARDPING 1.0: lepton pair production in the hard proton-nucleus interactions (Drell-Yan reaction).

- multiple re-scatterings and energy losses are implemented for projectile hadrons

- parameters: the mean value of transverse momentum of nucleon inside the nucleus, the mean value of transverse momentum of quark inside intranuclear nucleon, the value of quark nucleon cross section were fitted from DY pA data at 800 GeV (Fermilab)

HARDPING 2.0: hadron production in the hard lepton-nucleus interactions

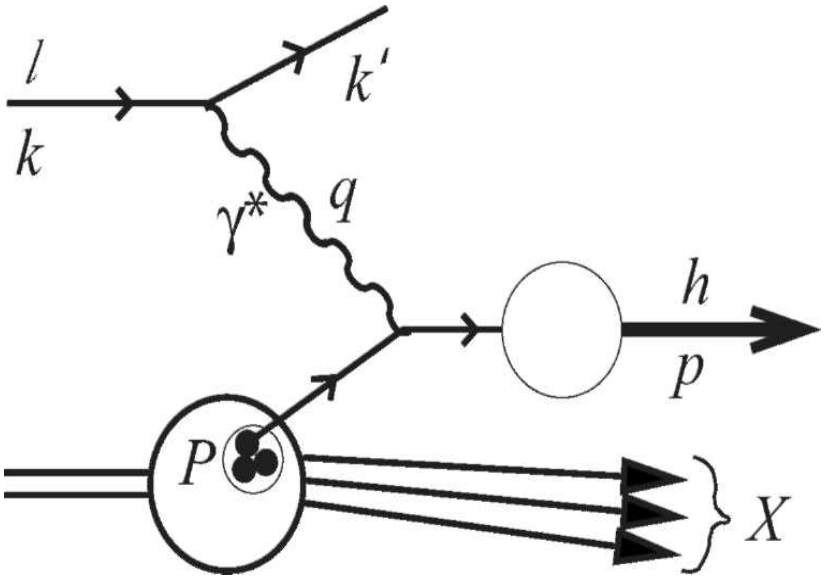
- multiple re-scatterings and energy losses are implemented for produced hadrons

- formation length of produced hadrons

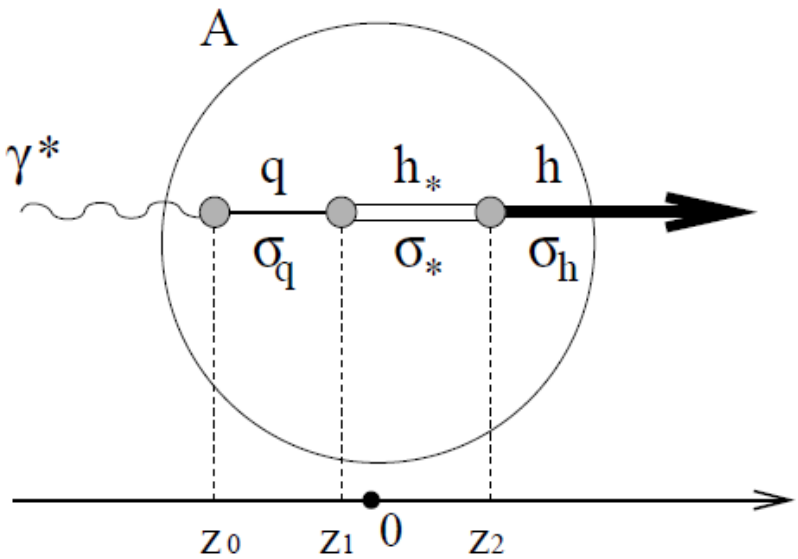
- the mean value of transverse momentum of nucleon inside the nucleus, the mean value of transverse momentum of quark inside intranuclear nucleon, the value of quark nucleon cross section were fitted from HERMES data (DESY).

HARDPING 3.0: hadron production in hard proton-nucleus interactions (Cronin effect). The all parameters had been fixed in the previous versions.

Interaction of produced hadrons after hard scattering: lepton-nucleus scattering



$\sigma_q = 0$ $\sigma_* < \sigma_h$

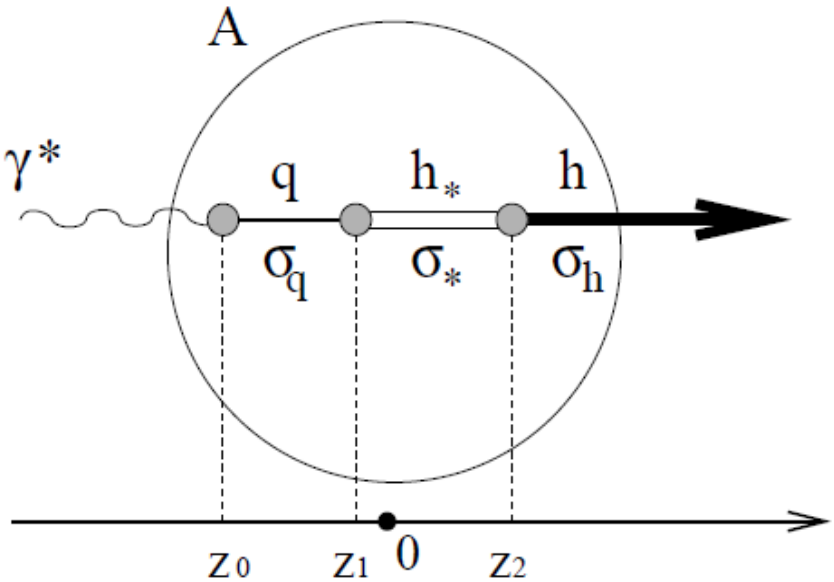


Two step hadron formation process:

- Formation of colorless pre-hadron state

- Formation of final hadron from pre-hadron state

Interaction of produced hadrons after hard scattering: lepton-nucleus scattering



on the path z_0->z_1 quark loses energy due to perturbative emission of gluons

on the path z_1->z_2 quark loses energy due to string tension

$$\Delta E = -k_s L$$

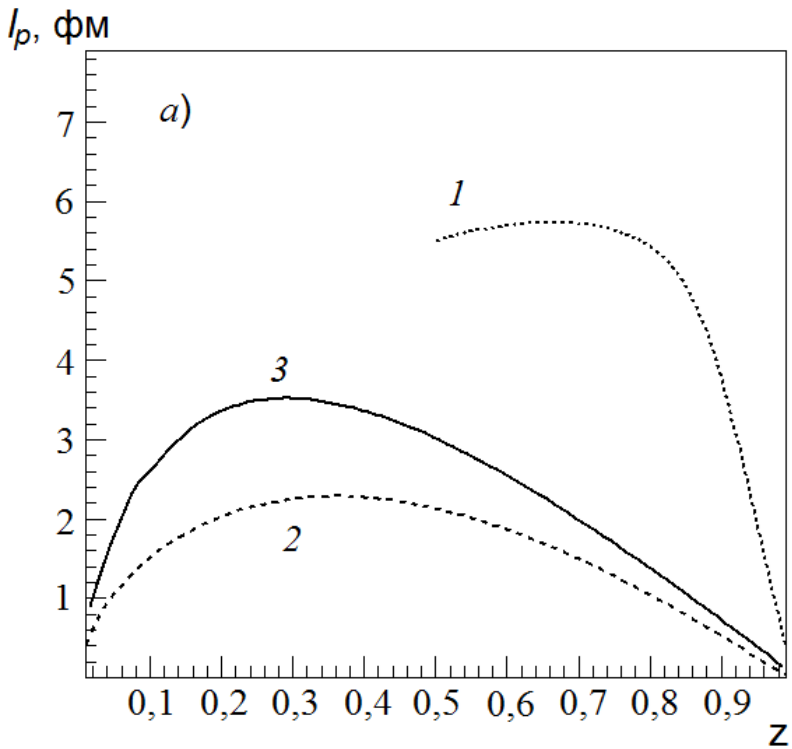
Formation length

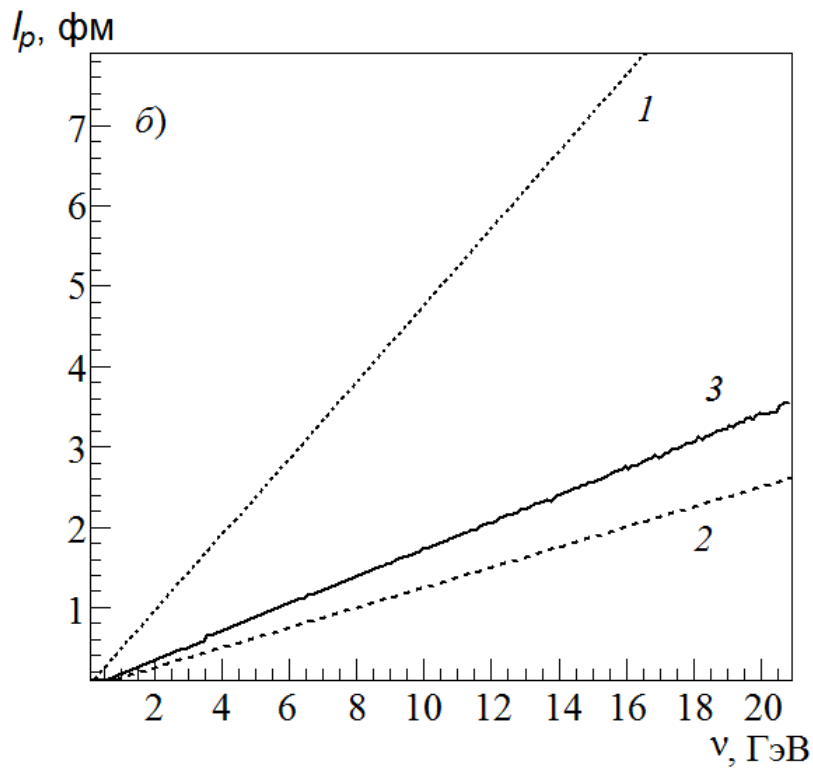
Formation length as a function of z and quark initial energy

$$z=\frac{pP}{qP}=\frac{E_h}{\nu}=\frac{E_h}{E_q}$$

1. Perturbative approach (Kopeliovich B.Z. etc.)
2. Nonperturbative approach (Pirner G.J. etc.)
3. HARDPING (Berdnikov Ya.A. etc.)

$$E_q=\nu=\frac{qP}{\sqrt{P^2}}=E'-E$$





Y. A. Berdnikov, A. E. Ivanov, V. T. Kim and V. A. Murzin, JETP Lett. 96, 85 (2012) [arXiv:1204.4595 [hep-ph]]

HARDPING vs HERMES data: hadrons yields ratios for nuclei N^{14} and D^2

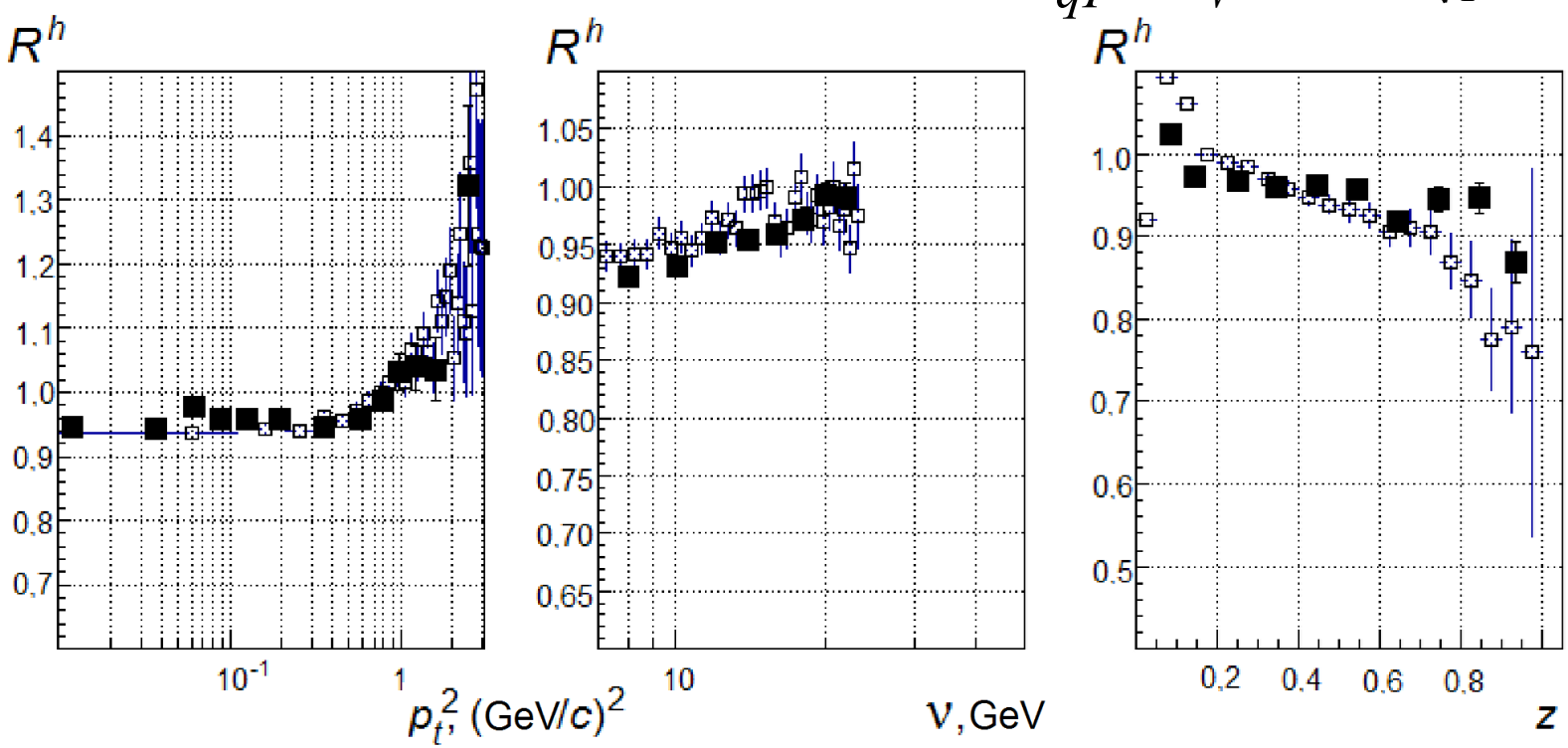
$$R^h\left(z,\nu,p_t^2,Q^2\right) = \left.\frac{\dfrac{N_h\left(z,\nu,p_t^2,Q^2\right)}{N_e\left(\nu,Q^2\right)}}{\dfrac{N_h\left(z,\nu,p_t^2,Q^2\right)}{N_e\left(\nu,Q^2\right)}}\right|_A \Bigg|_D$$

e^+(27.6 GeV) + A -->$e^{+\prime}$ + hh + X

■ HERMES
□ HARDPING

σ^{qN}= 7 mb $\quad k_s = 1.7$ GeV/Fm

$$z = \frac{pP}{qP} = \frac{E_h}{\nu} \qquad \nu = \frac{qP}{\sqrt{P^2}} = E' - E$$



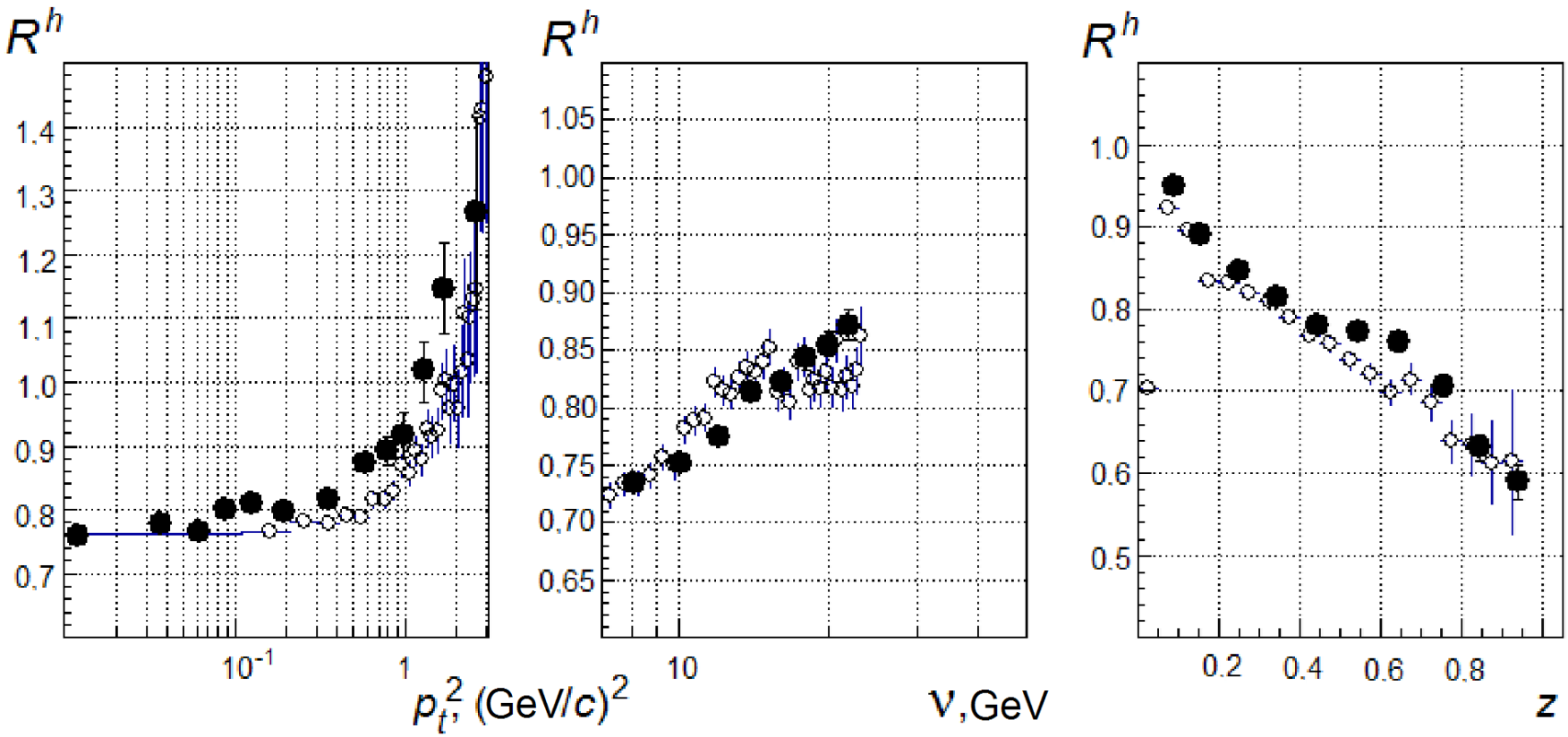
Y. A. Berdnikov, A. E. Ivanov, V. T. Kim and V. A. Murzin, Nucl. Phys. Proc. Suppl. 219-220, 308 (2011).

HARDPING vs HERMES data (2003): hadrons yields ratios for nuclei Kr^{14} and D^2

● HERMES
○ HARDPING

$\sigma^{qN} = 7$ mb

$k_s = 1.7$ GeV/Fm



Y. A. Berdnikov, A. E. Ivanov, V. T. Kim and V. A. Murzin, Nucl. Phys. Proc. Suppl. 219-220, 308 (2011).

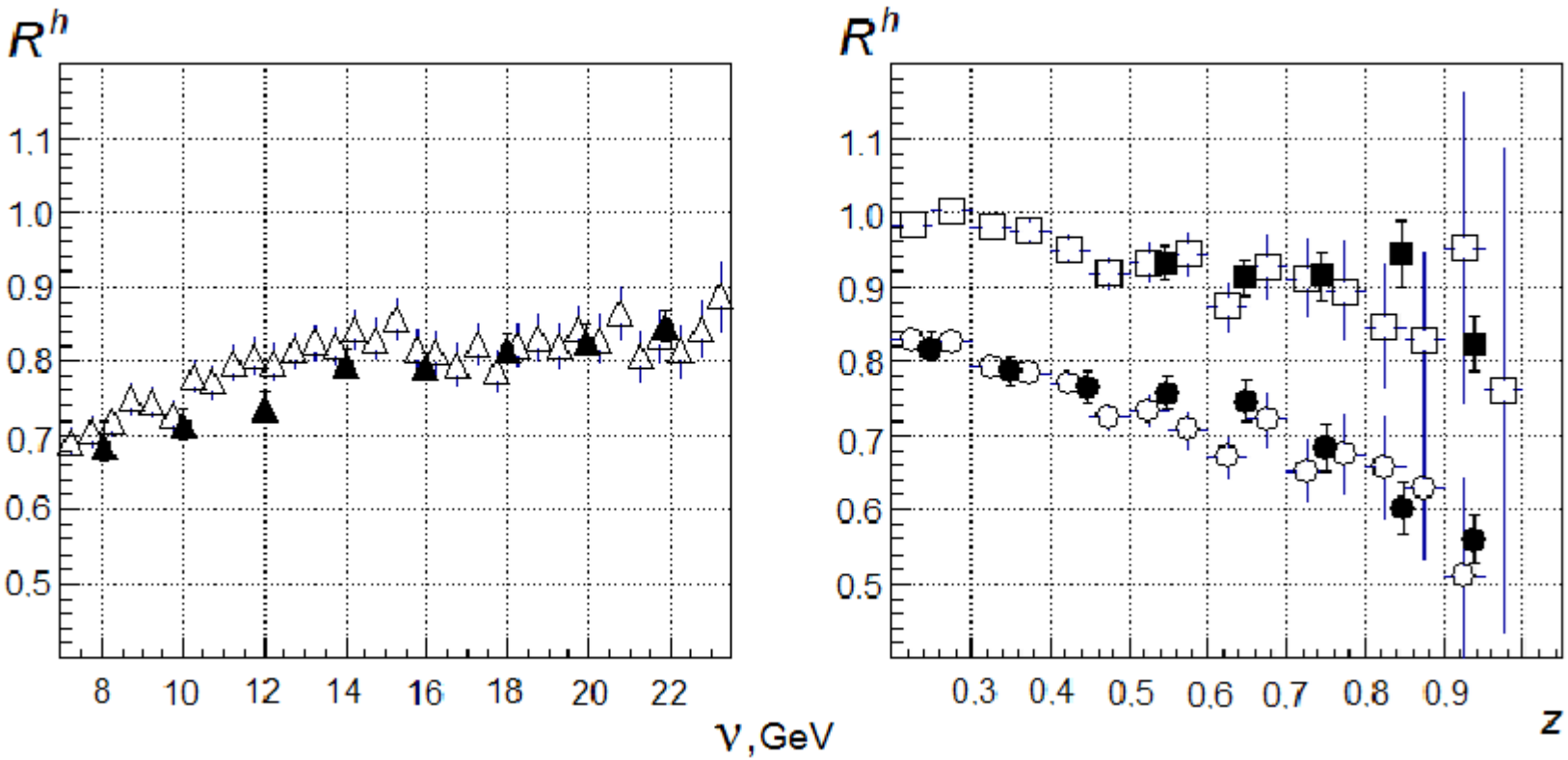
HARDPING vs HERMES data: π^+ mesons yields ratios for Kr, N and D nuclei

$\sigma^{qN} = 7$ mb

$k_s = 1.7$ GeV/Fm

▲ HERMES Kr
△ HARDPING Kr

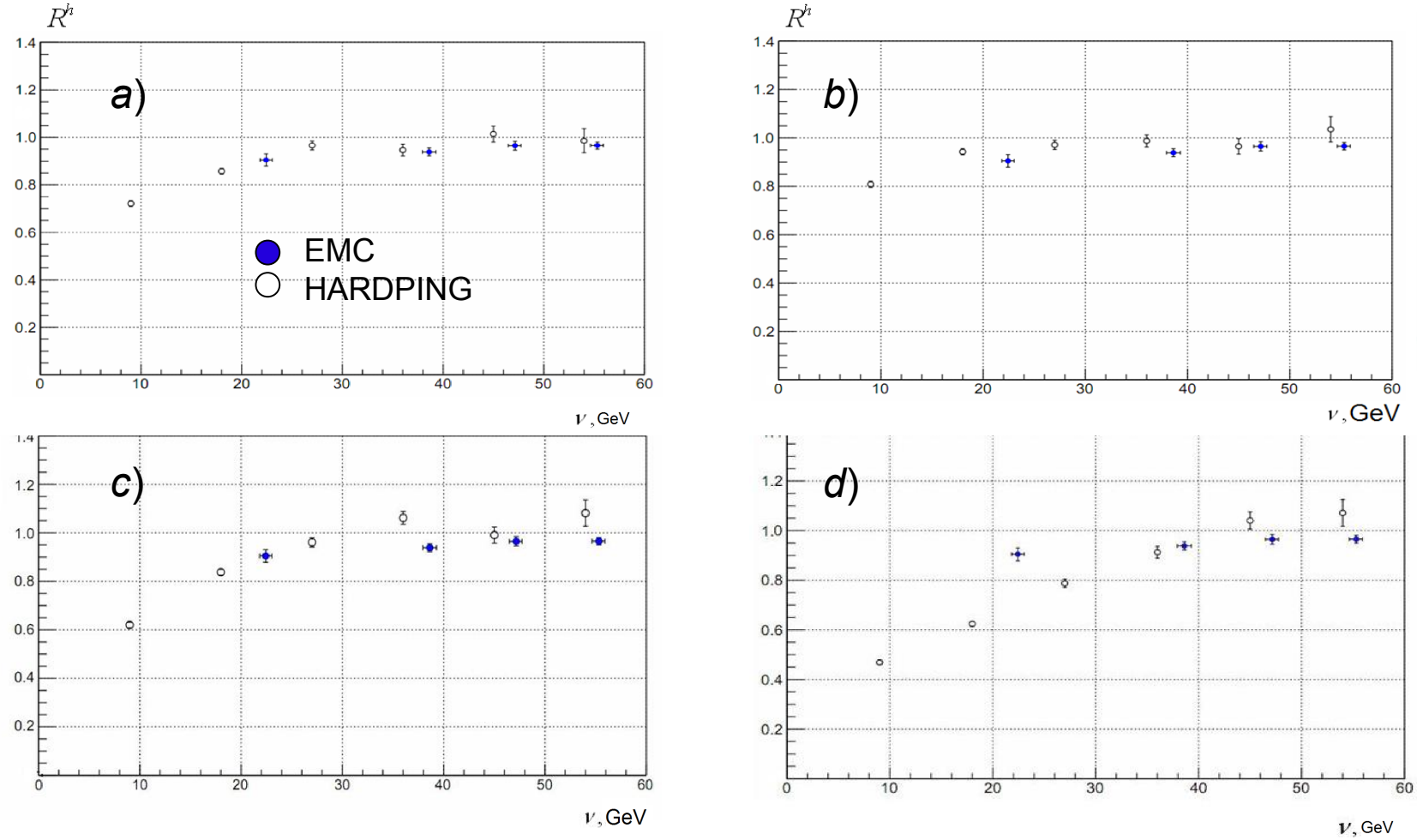
● HERMES Kr
○ HARDPING Kr
■ HERMES N
□ HARDPING N



Y. A. Berdnikov, A. E. Ivanov, V. T. Kim and V. A. Murzin, Nucl. Phys. Proc. Suppl. 219-220, 308 (2011).

HARDPING vs EMC Coll. data (1991)

ratios of cross sections of hadron production for nuclei Cu & D as a function of virtual photon energy

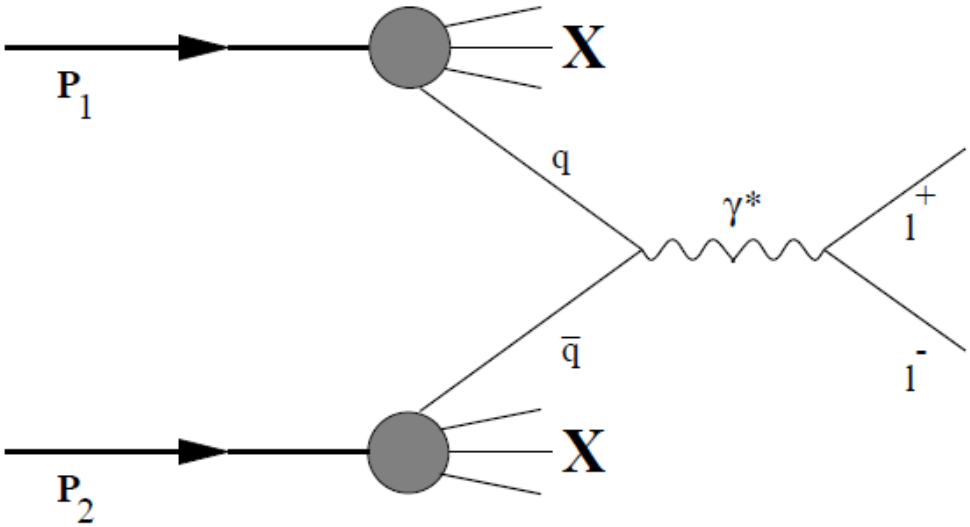


μ^-(280 GeV) + A -->μ^-' + hh

a - 5 mb и 1.5 GeV/Fm, b - 5 mb и 3.0 GeV/Fm,
c - 20 mb и 1.5 GeV/Fm, d - 20 mb и 3.0 GeV/Fm

HARDPING: soft hadron-nucleus interaction before hard scattering in proton-nucleus scatterings (Drell-Yan reaction)

- Multiple soft re-scatterings of quark of projectile hadron give the main contribution to the observable A-dependency of produced lepton pairs
- Such effects as soft re-scatterings, energy losses and screening if structure function of intranuclear nucleons are implemented into HARDPING



$p_1 = E_{beam}(x_1; 0, 0, x_1)$

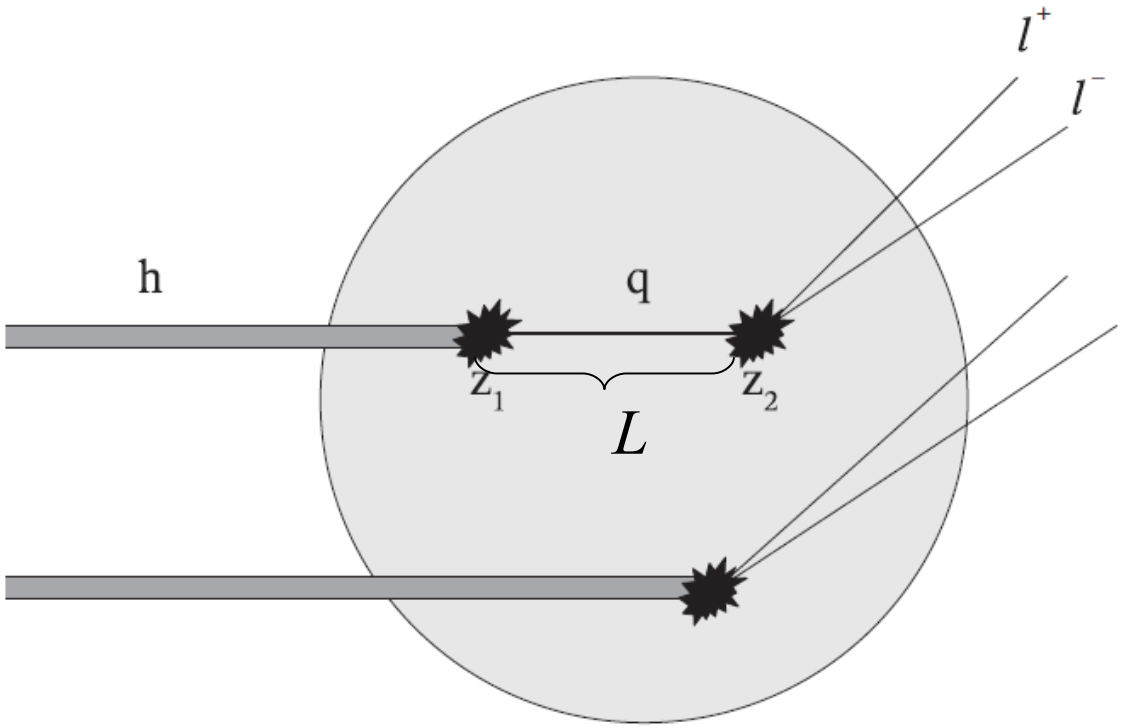
$p_2 = E_{beam}(x_2; 0, 0, -x_2)$

$\tau = x_1 x_2 = M_{ll}^2/S$

$x_F = x_1 - x_2$

HARDPING: energy losses of initial quark

$$\Delta E = -k_s L$$



k_s **[GeV/Fm] — the mean of string tension inside the nuclear medium**

L **— path length of quark inside the nucleus**

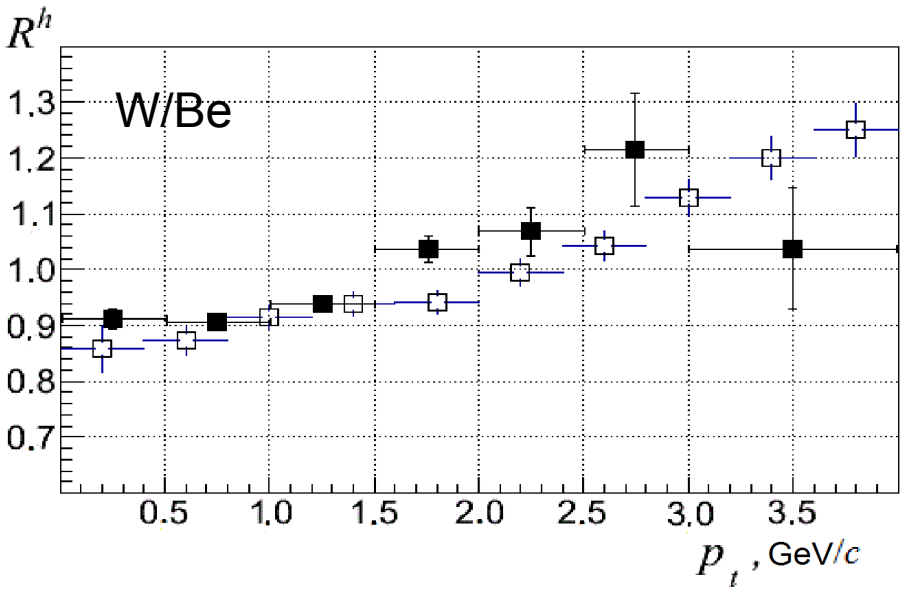
Y.A. Berdnikov, V.T. Kim, V. F. Kosmach et al., Eur. Phys. J. A 26, 179 (2005) [hep-ph/0510260]

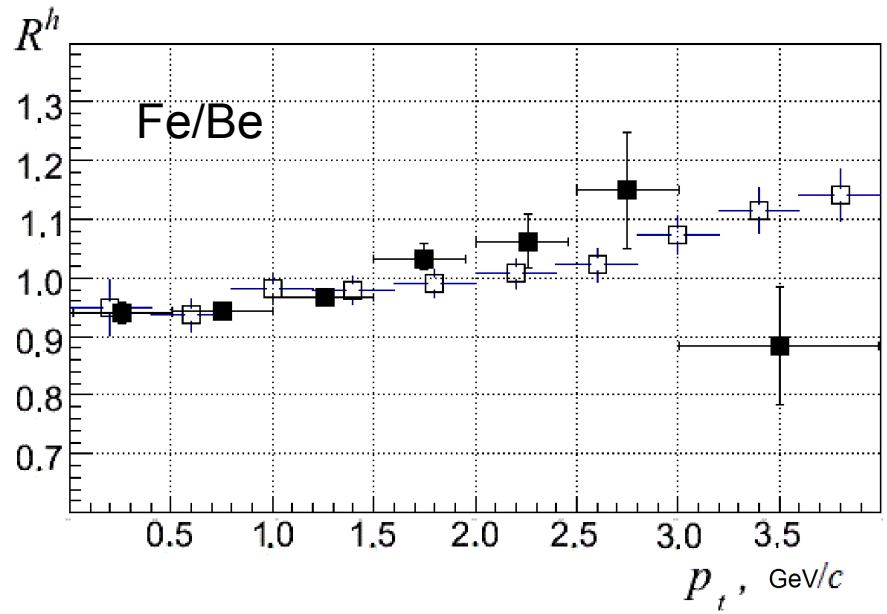
HARDPING vs E866 data: pA → l^+l^- X 800 GeV

Ratios of production cross sections of muon pairs on the heavy nuclei to the light nuclei as a function of pair's transverse momentum

■ E866
□ HARDPING

4 GeV/c² < M_{ll} < 8.4 GeV/c²





σ^{qN}= 7 mb k_s = 1.7 GeV/Fm

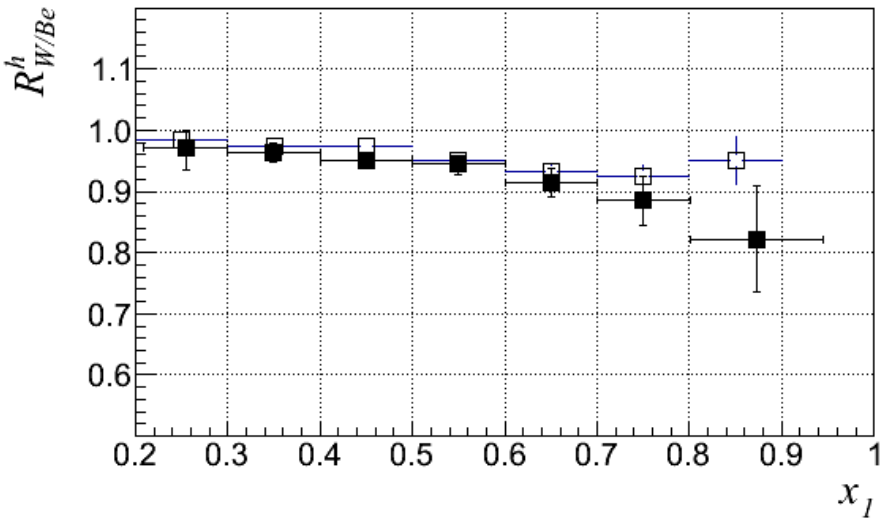
Comparison of HARDPING data with data obtained in E866 experiment: pA → l^+l^- X 800 GeV

Ratios of production cross sections of muon pairs on the heavy nuclei to the light nuclei as a function of pair's x_1

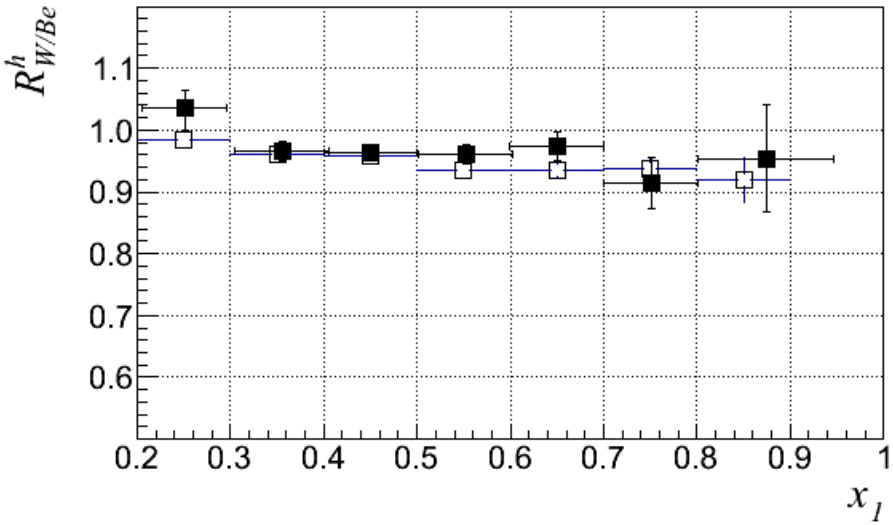
■ E866
□ HARDPING

4 GeV/c² < M_{ll} < 8.4 GeV/c²

W/Be



Fe/Be



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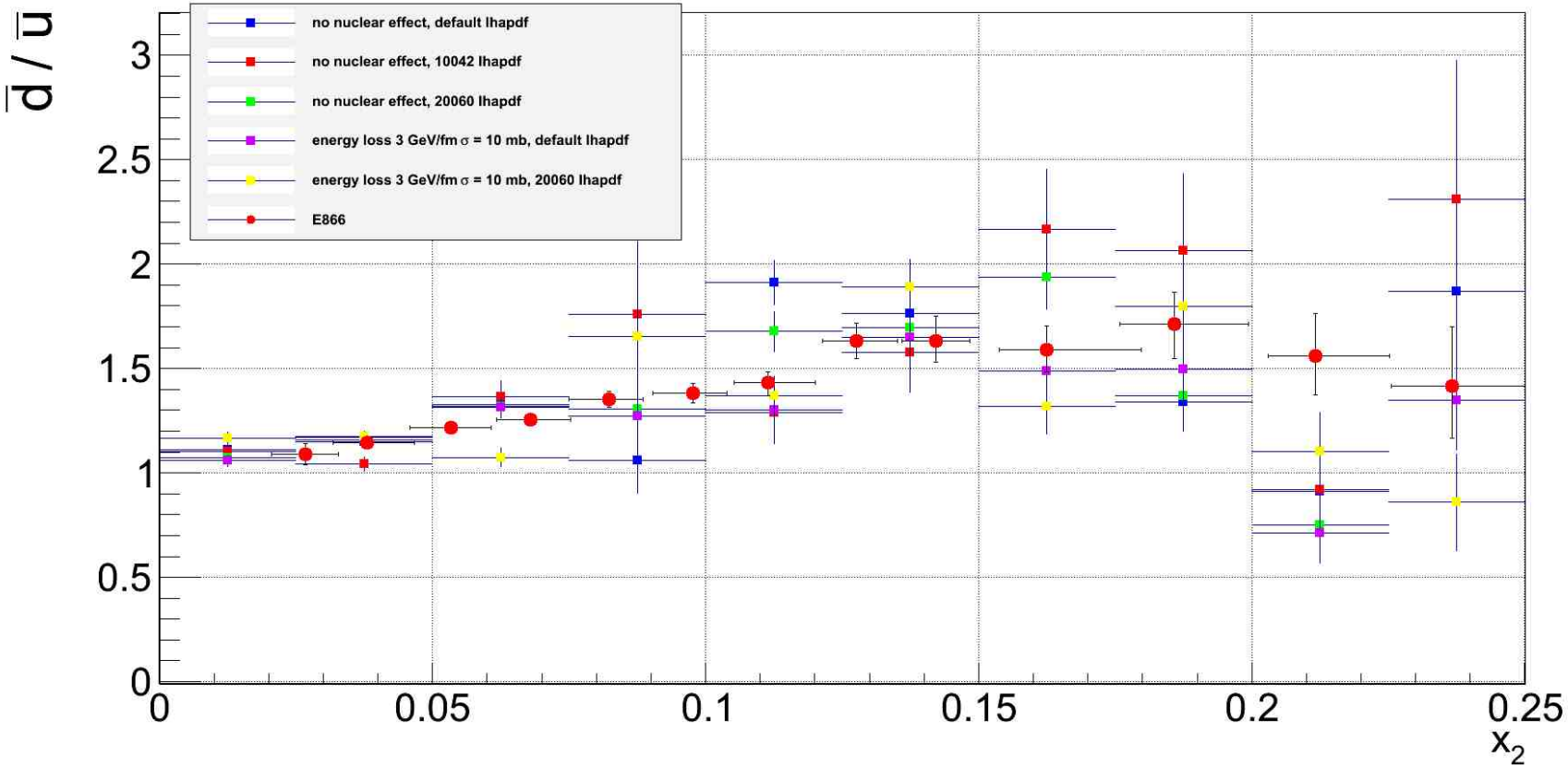
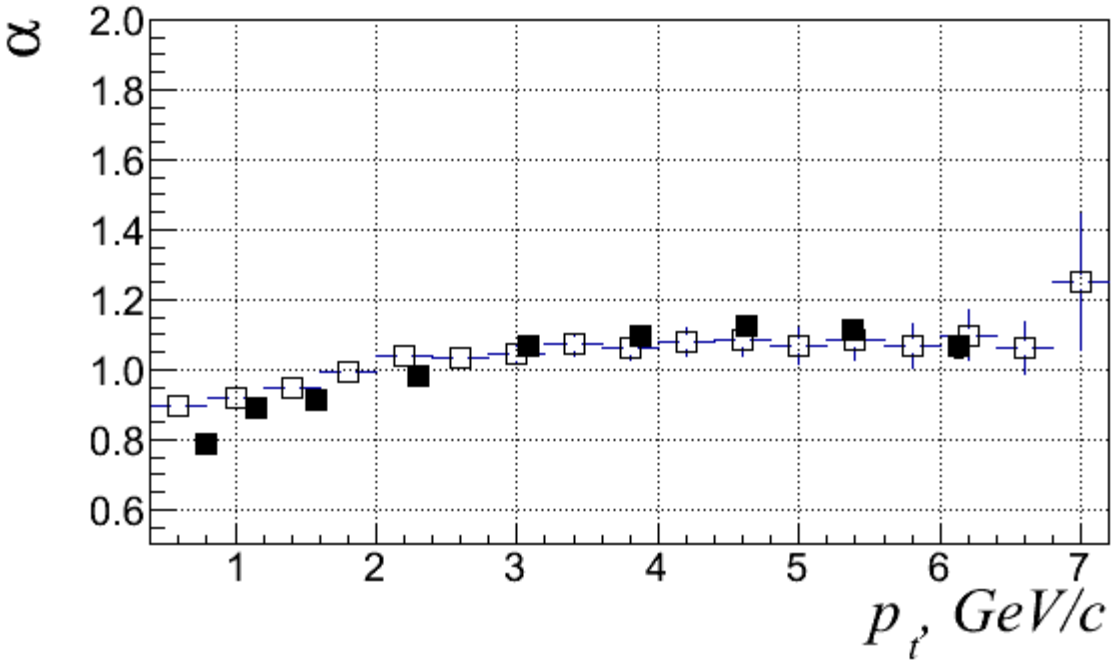
Comparison of HARDPING data with data obtained in E866 experiment: pA → l^+l^- X 800 GeV



HARDPING 3.0: hadron production in proton-nucleus interactions pA → π+ X 400 GeV

$$I_i(p_T^a, A) = I_i(p_T^a, 1) \cdot A^{\alpha_i(p_T^a)}$$

The measurements were made at a laboratory angle of 77 mrad.
power α_i as a function of transverse momentum of produced π^+-mesons



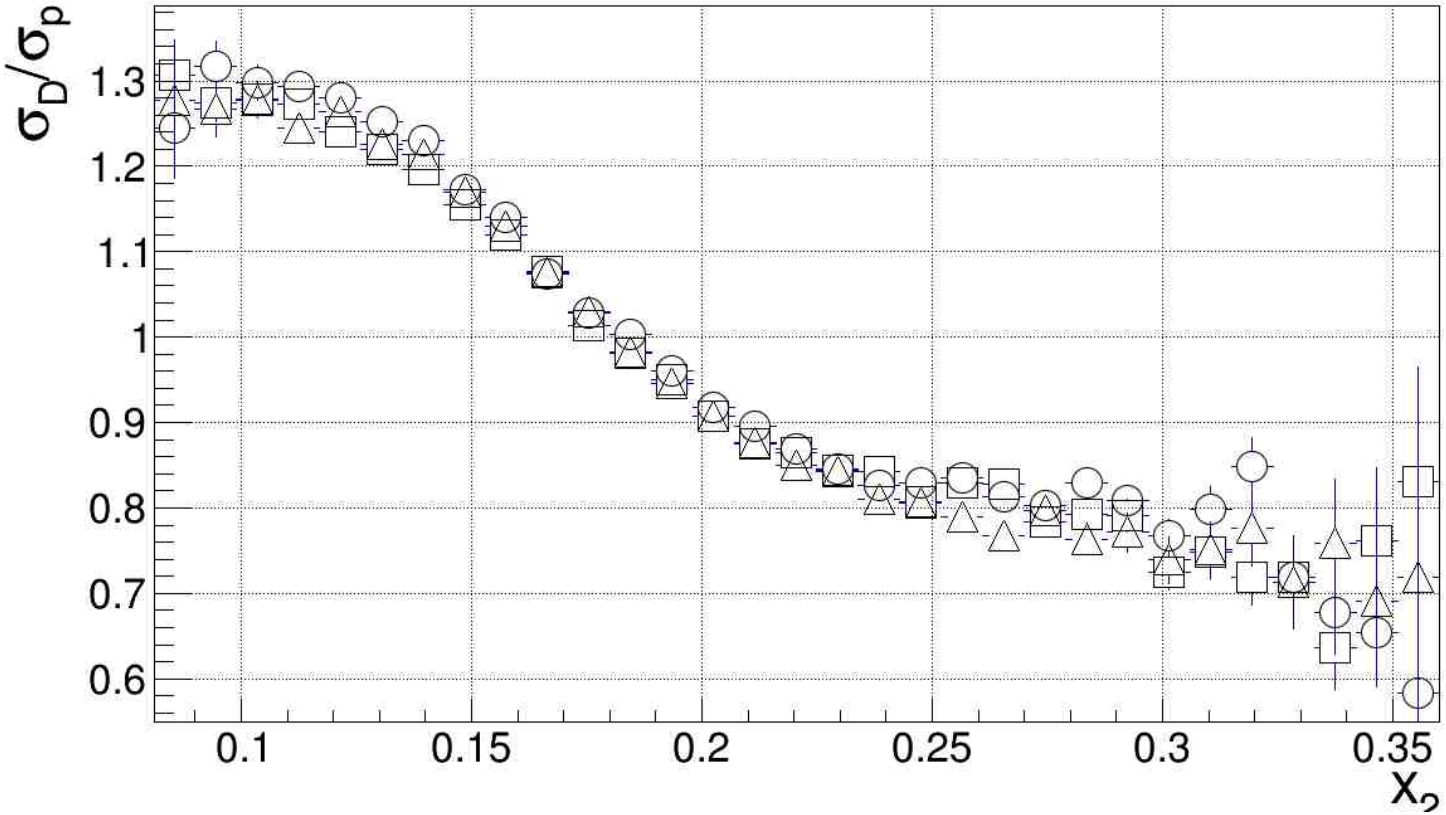
■ Cronin J. et al (79)
□ HARDPING

$\sigma^{qN} = 7$ mb

$k_s = 1.7$ GeV/Fm

HARDPING predictions for NuSea experiment (Fermilab)
$pA \rightarrow l^+l^- X$ 120 GeV (targets: D and p)

Lepton pair cross sections ratio as a function of x_2



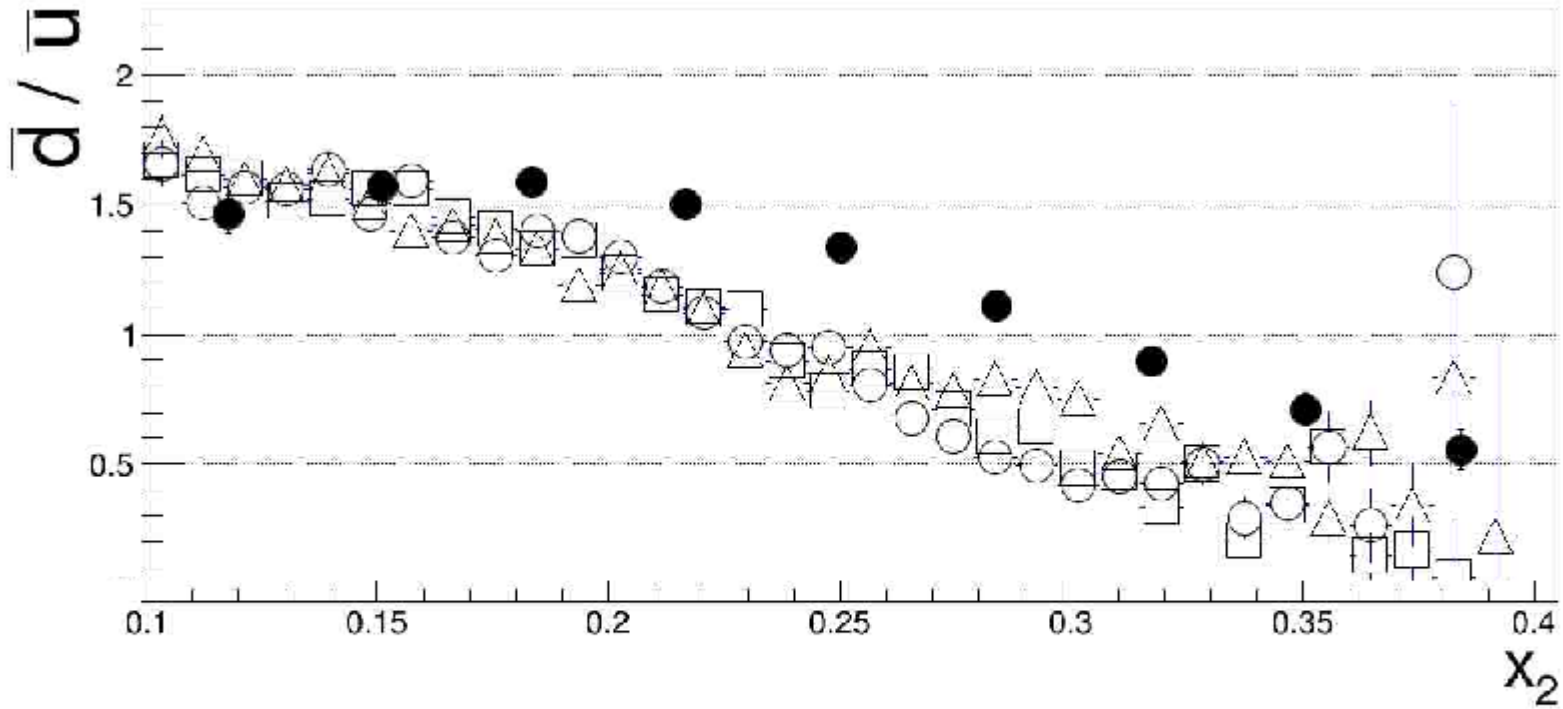
HARDPING CTEQ6L no nuclear effects

HARDPING CTEQ5L

HARDPING CTEQ6L

HARDPING predictions for NuSea experiment (Fermilab)
pA → l^+l^- X 120 GeV (targets: D and p)

$$\left.\frac{\sigma_{pd}}{2\sigma_{pp}}\right|_{x_1 \gg x_2} = \frac{1}{2}\left[1 + \frac{\bar{d}(x_2)}{\bar{u}(x_2)}\right]$$



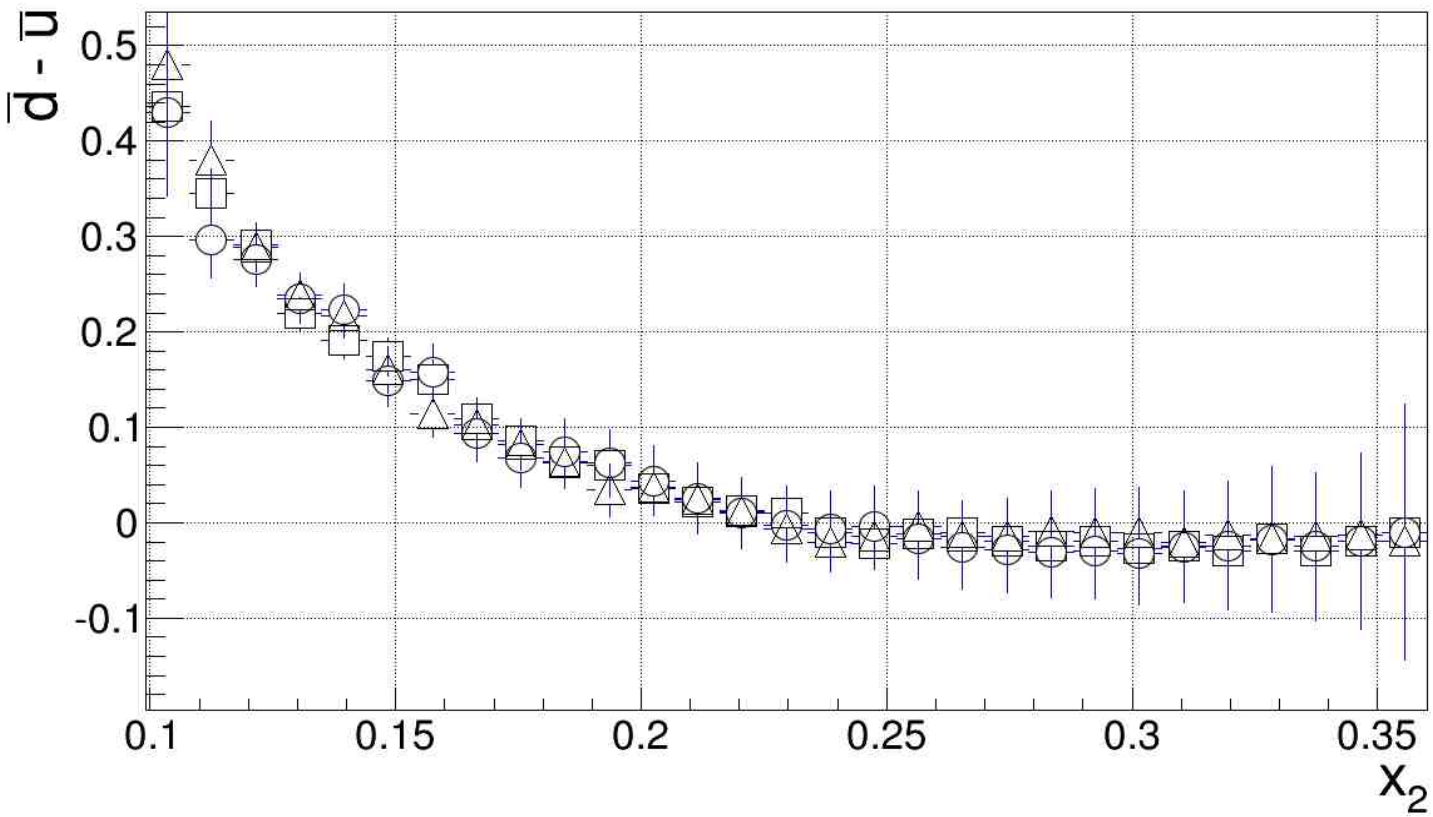
● E906 simulation with CTEQ6M

□ HARDPING CTEQ6L no nuclear effects

△ HARDPING CTEQ5L

○ HARDPING CTEQ6L

HARDPING predictions for NuSea experiment (Fermilab)
$pA \rightarrow l^+l^- X$ 120 GeV (targets: D and p)

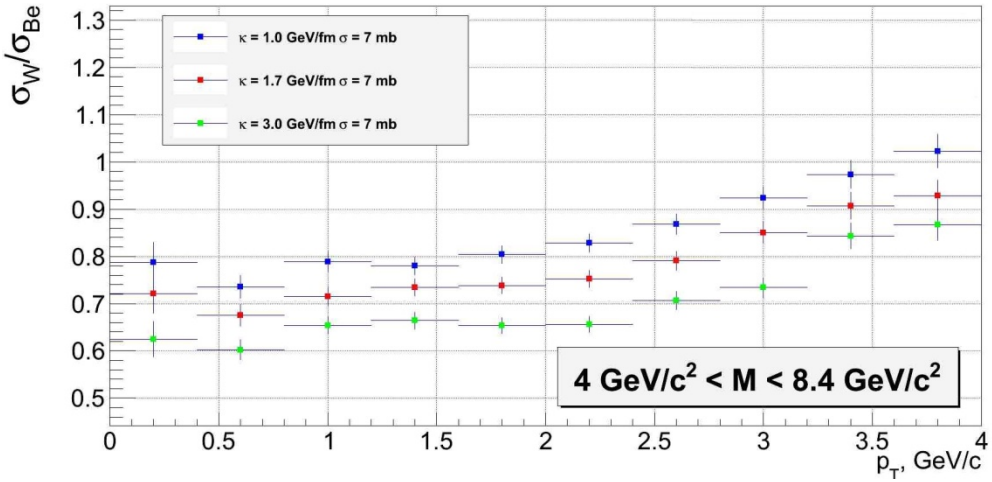


□ HARDPING CTEQ6L no nuclear effects

△ HARDPING CTEQ5L

○ HARDPING CTEQ6L

HARDPING predictions for NuSea (E906, Fermilab) pA → l^+l^- X at 120 GeV



$$M = \sqrt{x_1 x_2 S}$$

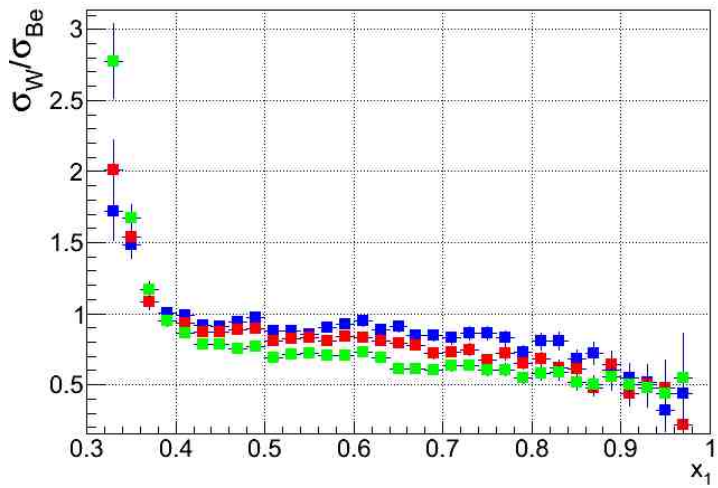
$$x_F = p_L^{¿} / p_L^{¿,\,max} = x_1 - x_2$$

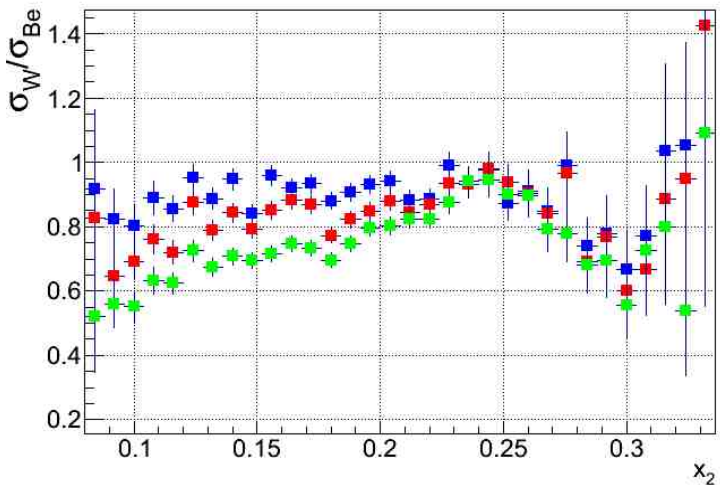
string tension parameter:

blue : k = 1.0 GeV/fm

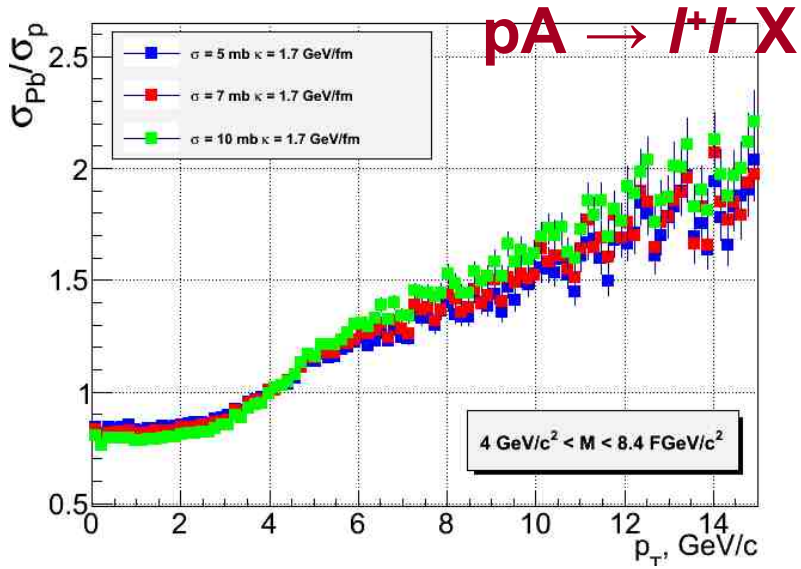
red : k = 1.7 GeV/fm (HARDPING)

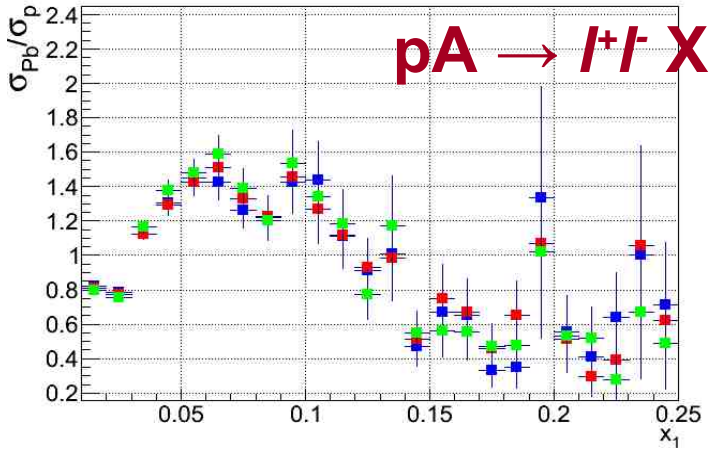
green : k = 3.0 GeV/fm

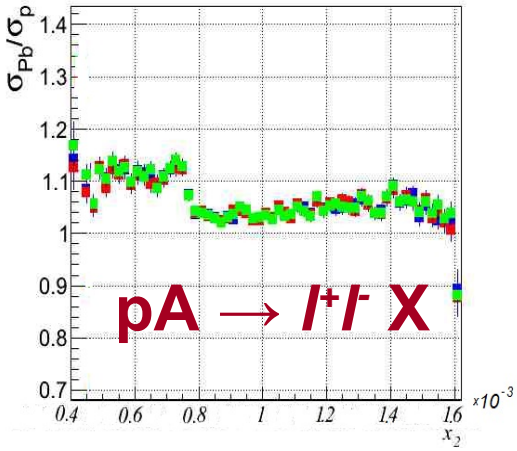




HARDPING predictions for LHC
pA → l^+l^- X and pA → *h* X √S = 5.02 TeV







Conclusions

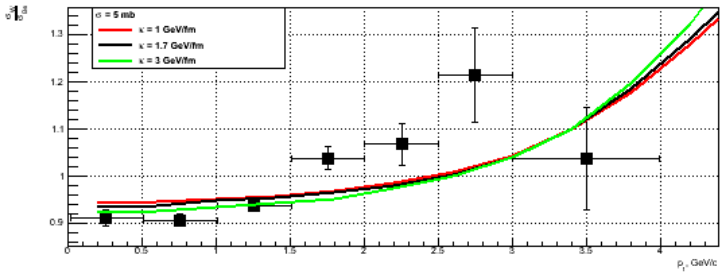
- **MC generator HARDPING 3.0 has been developed. It provides simulation of hadron production in lepton-nucleus and hadron-nucleus interactions. It takes into account produced hadron's formation length, soft multiple re-scatterings and energy losses in the nuclear medium.**

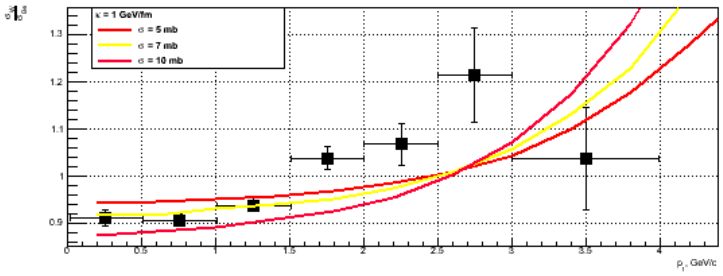
- **HARDPING 3.0, with parameters of soft interaction of hadrons with nuclear medium for projectile and produced hadrons, which were fixed in lepton-nucleus interactions and Drell-Yan reactions, provides a reasonably good description of hadron production in proton-nucleus collisions at 400 GeV (Cronin effect)**

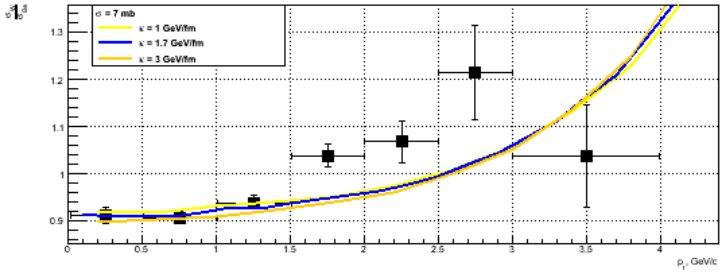
HARDPING plans:

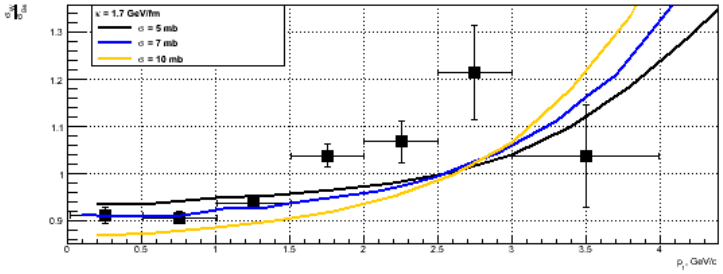
- **more detail comparison with pA collisions data: Protvino, Tevatron, LHC and predictions for various observables**
- **including nuclear density fluctuation (multiquark fluctons)**
- **hard nucleus-nucleus collisions**

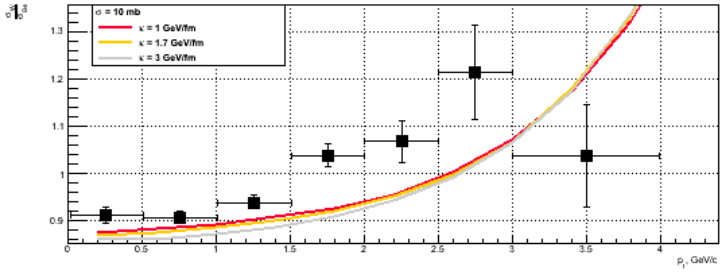
Back Up

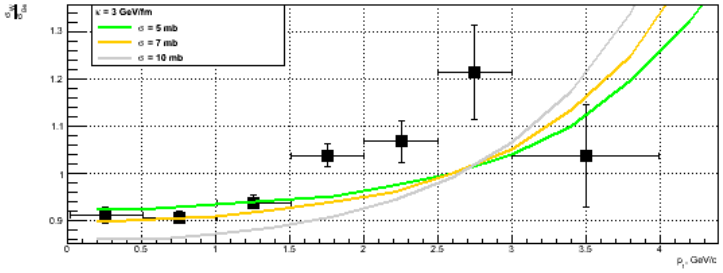

σ = 5 mb
κ = 1 GeV/fm
κ = 1.7 GeV/fm
κ = 3 GeV/fm
p_T, GeV/c

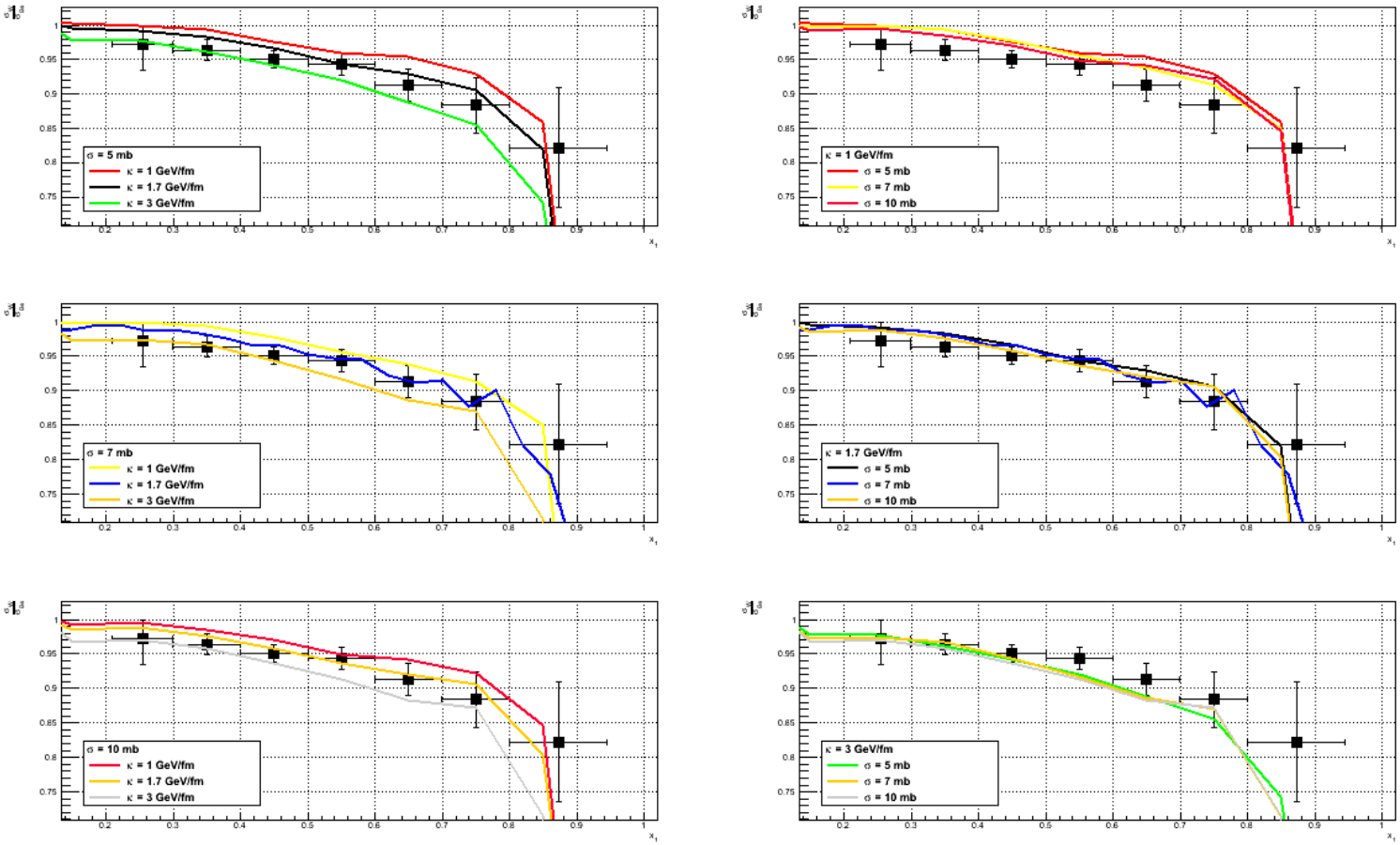

κ = 1 GeV/fm
σ = 5 mb
σ = 7 mb
σ = 10 mb
p_T, GeV/c


σ = 7 mb
κ = 1 GeV/fm
κ = 1.7 GeV/fm
κ = 3 GeV/fm
p_T, GeV/c


κ = 1.7 GeV/fm
σ = 5 mb
σ = 7 mb
σ = 10 mb
p_T, GeV/c


σ = 10 mb
κ = 1 GeV/fm
κ = 1.7 GeV/fm
κ = 3 GeV/fm
p_T, GeV/c


κ = 3 GeV/fm
σ = 5 mb
σ = 7 mb
σ = 10 mb
p_T, GeV/c


σ = 5 mb
κ = 1 GeV/fm
κ = 1.7 GeV/fm
κ = 3 GeV/fm
κ = 1 GeV/fm
σ = 5 mb
σ = 7 mb
σ = 10 mb
σ = 7 mb
κ = 1 GeV/fm
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κ = 3 GeV/fm
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κ = 3 GeV/fm
σ = 5 mb
σ = 7 mb
σ = 10 mb