

HARDPING MC generator for proton and lepton collisions with nuclei.

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Plan of report

- 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, energy losses and soft re-scatterings
- 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.

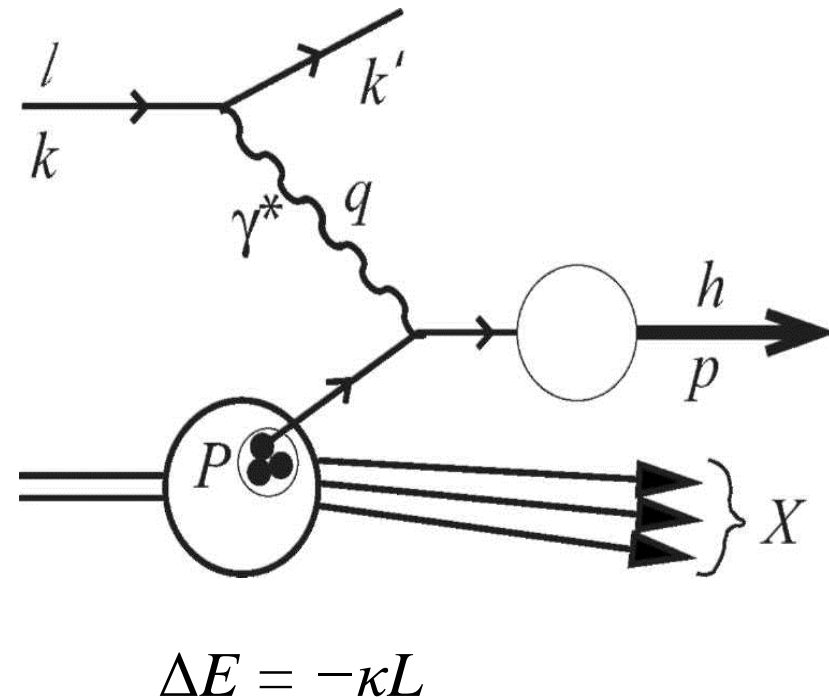
Interaction of produced hadrons after hard scattering: lepton-nucleus scattering

Two step hadron formation process:

- Formation of colorless pre-hadron state
- Formation of final hadron from pre-hadron state

$$f_f(\mathbf{k}_{fi}) = \frac{B_f}{\pi} e^{-B_f k_{fi}^2} \quad z = \frac{pP}{qP} = \frac{E_h}{\nu}$$

$$f_p(\mathbf{p}_{ti}) = \frac{B^2}{2\pi} e^{-Bp_{ti}} \quad \nu = \frac{qP}{\sqrt{P^2}} = E' - E$$



$$f_{pf}(\mathbf{k}_{ti}) = f_p \otimes f_f = \int f_p(\mathbf{p}_{ti}) f_f(\mathbf{k}_{fi}) \delta^2(\mathbf{k}_{ti} - \mathbf{p}_{ti} - \mathbf{k}_{fi}) d^2 p_{ti} d^2 k_{fi}$$

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

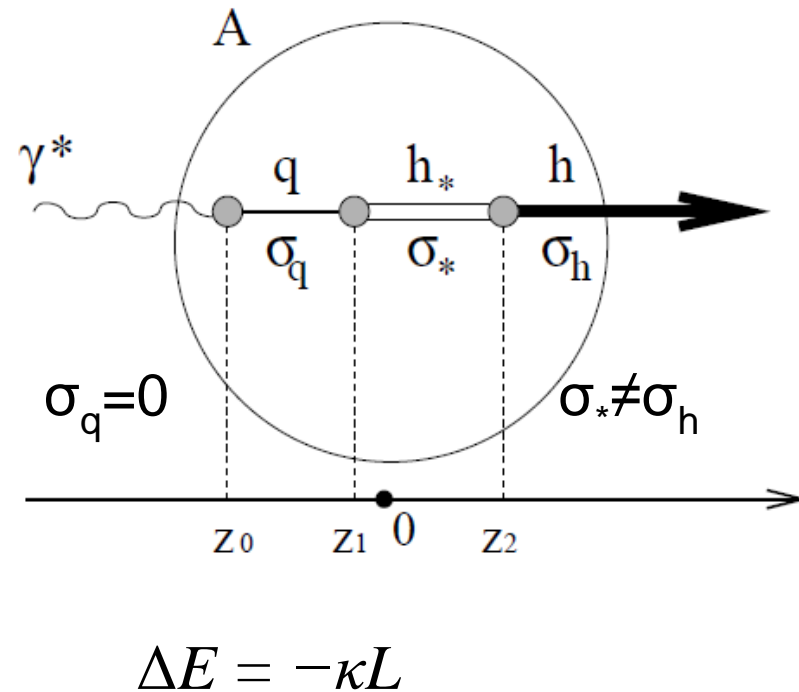
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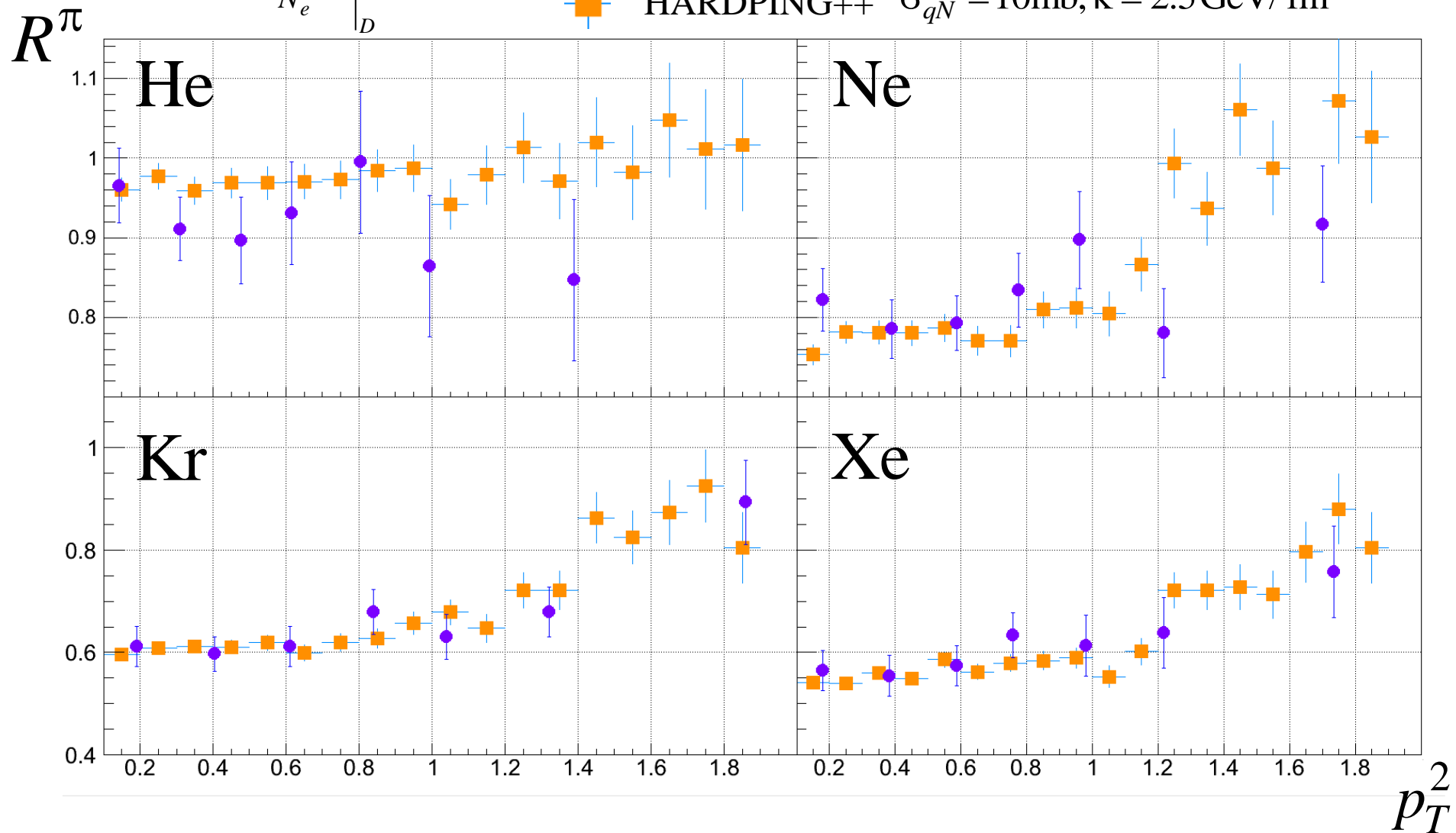
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HARDPING vs HERMES

$$R^\pi(p_T^2) = \frac{\left. \frac{N_\pi(p_T^2)}{N_e^A} \right|_A}{\left. \frac{N_\pi(p_T^2)}{N_e^D} \right|_D}$$

● HERMES $e^+(27.6\text{GeV}) + A \rightarrow e'^+ + \pi^+ + X$
■ HARDPING++ $\sigma_{qN} = 10\text{mb}, \kappa = 2.5\text{GeV/fm}$



HARDPING vs HERMES

$$R^\pi(\nu) = \frac{\left. \frac{N_\pi(\nu)}{N_e^A} \right|_A}{\left. \frac{N_\pi(\nu)}{N_e^D} \right|_D}$$

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

● HERMES

■ HARDPING++

$e^+(27.6\text{GeV}) + A \rightarrow e'^+ + \pi^+ + X$

$\sigma_{qN} = 10\text{mb}, \kappa = 2.5\text{GeV/fm}$

R^π

He

Ne

Kr

Xe

0.4

0.6

0.8

1

0.8

0.9

1

1.1

ν

6

8

10

12

14

16

18

20

22

24

6

8

10

12

14

16

18

20

22

24

HARDPING vs HERMES

$$R^\pi(z) = \frac{\left. \frac{N_\pi(z)}{N_e^A} \right|_A}{\left. \frac{N_\pi(z)}{N_e^D} \right|_D}$$

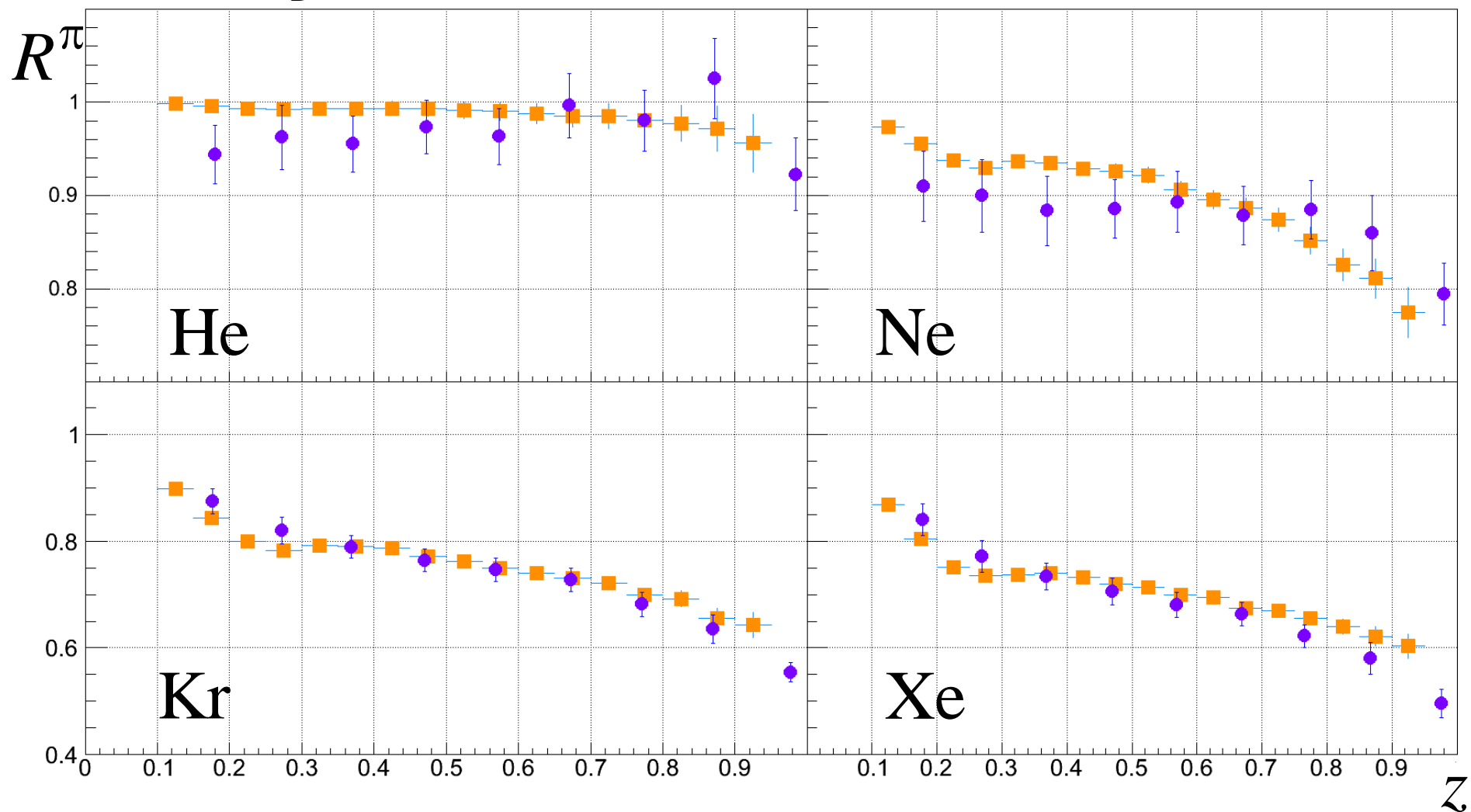
$$z = \frac{pP}{qP} = \frac{E_h}{\nu}$$

● HERMES

■ HARDPING++

$e^+(27.6\text{GeV}) + A \rightarrow e'^+ + \pi^+ + X$

$\sigma_{qN} = 10\text{mb}, \kappa = 2.5\text{GeV/fm}$



HARDPING++ vs WA/59

$$R^\pi(z) = \frac{\left. \frac{N_\pi(z)}{N_\mu^{\text{Ne}}} \right|_{\text{Ne}}}{\left. \frac{N_\pi(z)}{N_\mu^p} \right|_p}$$



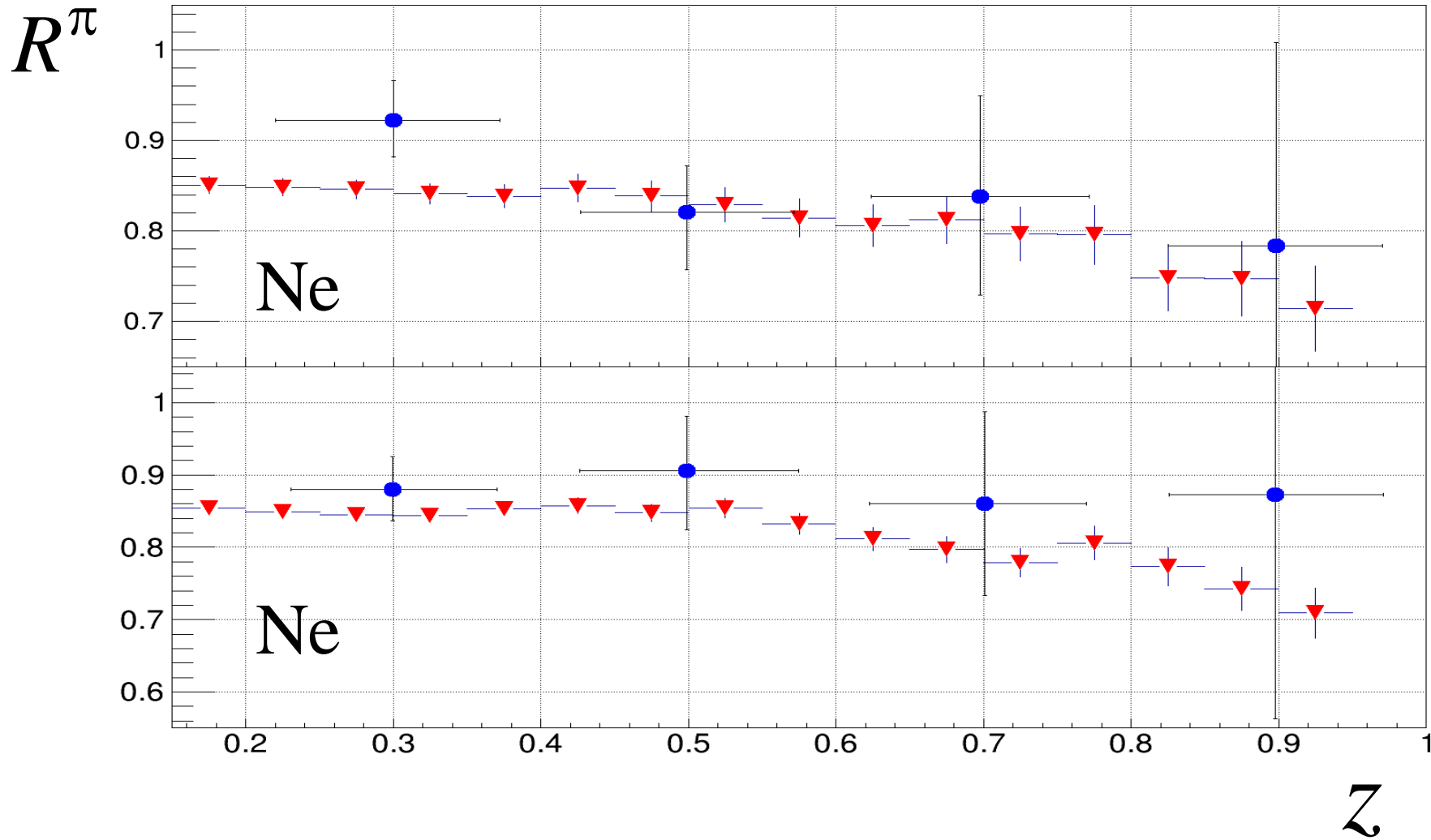
WA/59

$\nu_\mu (\langle \overline{E}_\nu \rangle \sim 56 \text{ GeV}) + \text{Ne} \rightarrow \mu + \pi + X$
 $\bar{\nu}_\mu (\langle \overline{E}_\nu \rangle \sim 44 \text{ GeV}) + \text{Ne} \rightarrow \mu + \pi + X$



HARDPING++

$\sigma_{qN} = 10 \text{ mb}, \kappa = 2.5 \text{ GeV/fm}$

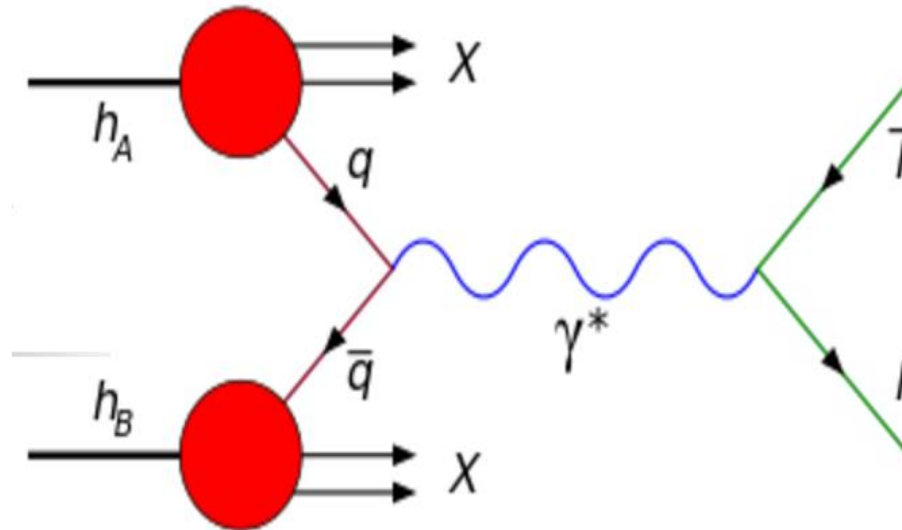


Hadron-nucleus interaction: Drell-Yan processes

- 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

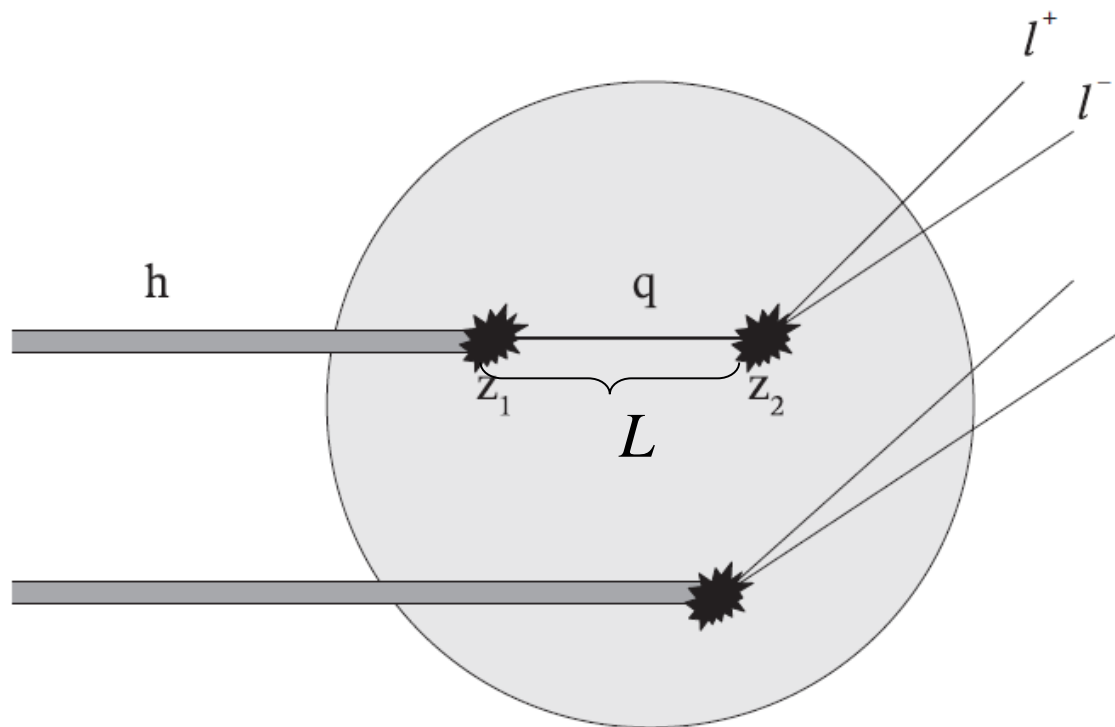
$$s = (p_A + p_B)^2$$

$$M_{l^+l^-}^2 = x_1 \cdot x_2 \cdot s$$



Energy losses of initial quark in Drell-Yan processes

$$\Delta E = -\kappa L$$



κ — [GeV/fm] — the mean of string tension inside the nuclear medium

L — path length of quark inside the nucleus

HARDPING ++ vs E866

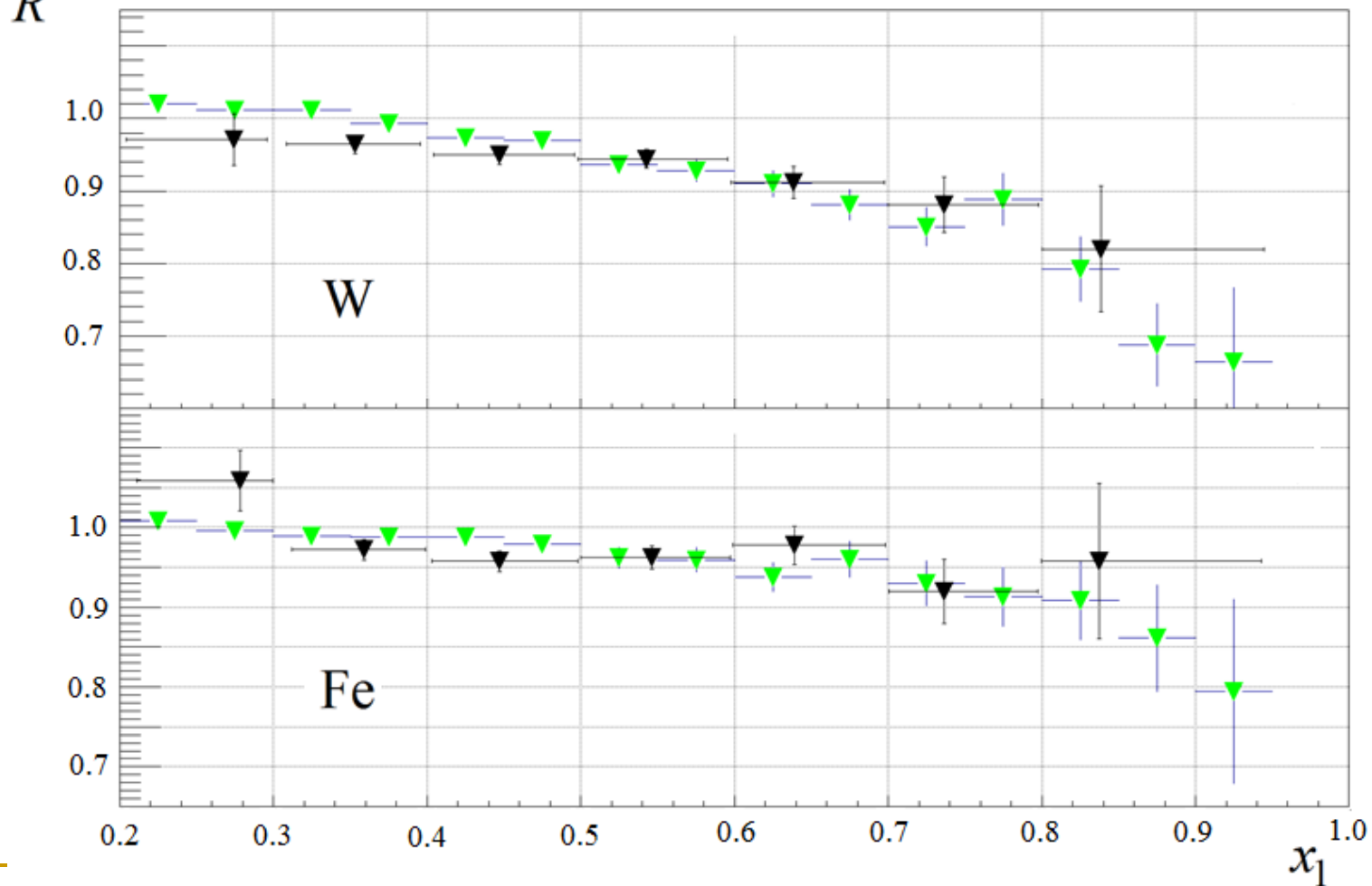
$$R^{l^+l^-}(x_1) = \frac{\frac{d\sigma^{p+A \rightarrow l^+l^-+X}}{Adx_1}}{\frac{d\sigma^{p+\text{Be} \rightarrow l^+l^-+X}}{A_{\text{Be}}dx_1}}$$

▼ E866

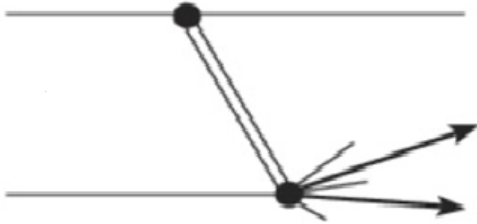
▼ HARDPING++

$p(800 \text{ GeV}) + A \rightarrow \mu^+\mu^- + X$

$\sigma_{qN} = 10 \text{ mb}, \kappa = 2.5 \text{ GeV/fm}$



Single diffraction processes



η

$$\sigma_{not_diff} : a + b \rightarrow X$$

$$\frac{dN}{d\Delta\eta} \sim e^{-\Delta\eta}$$

$$\sigma_{diff} : a + b \rightarrow a' + M_X$$

$$\frac{dN}{d\Delta\eta} \sim const$$

$$\xi = 1 - x_F = e^{-\Delta\eta}$$

$$x_F = \frac{|p'_z|}{p_z}$$

HARDPING ++ vs HELIOS

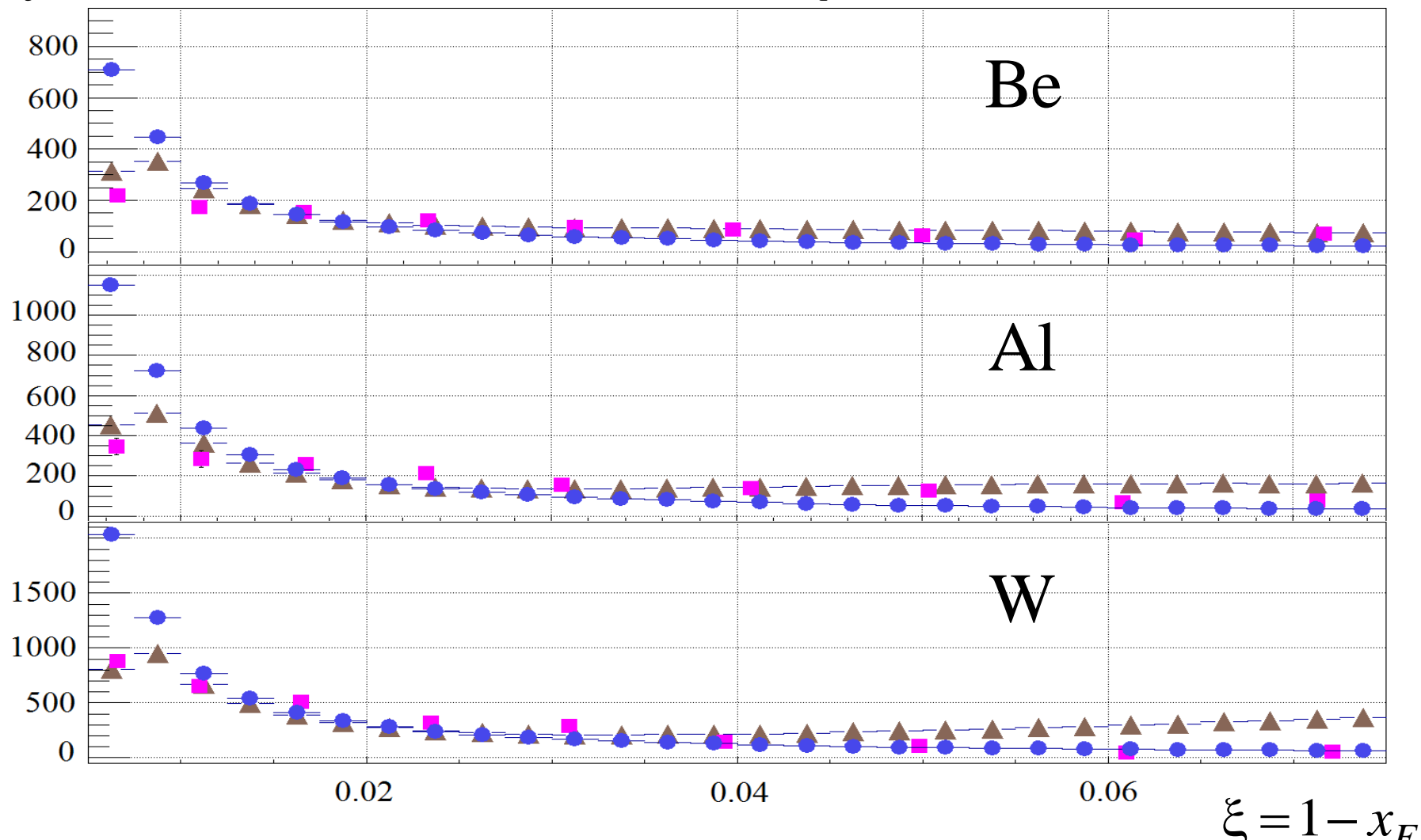
$$p(450 \text{ GeV}) + A \rightarrow p' + X$$

No nuclear effects

$$\sigma_{qN} = 10 \text{ mb}, \kappa = 2.5 \text{ GeV/fm}$$

$$\frac{d\sigma_{SD}}{d\xi} [\text{mb}]$$

- HELIOS
- HARDPING++
- ▲ HARDPING++



Conclusions

- MC generator HARDPING 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, with parameters, which were fixed in lepton-nucleus interactions and Drell-Yan reactions, provides a reasonably good description of diffraction of protons on nuclei at HELIOS collaboration energy

HARDPING plans:

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

Thank you for your attention

Backup slides

Formation length

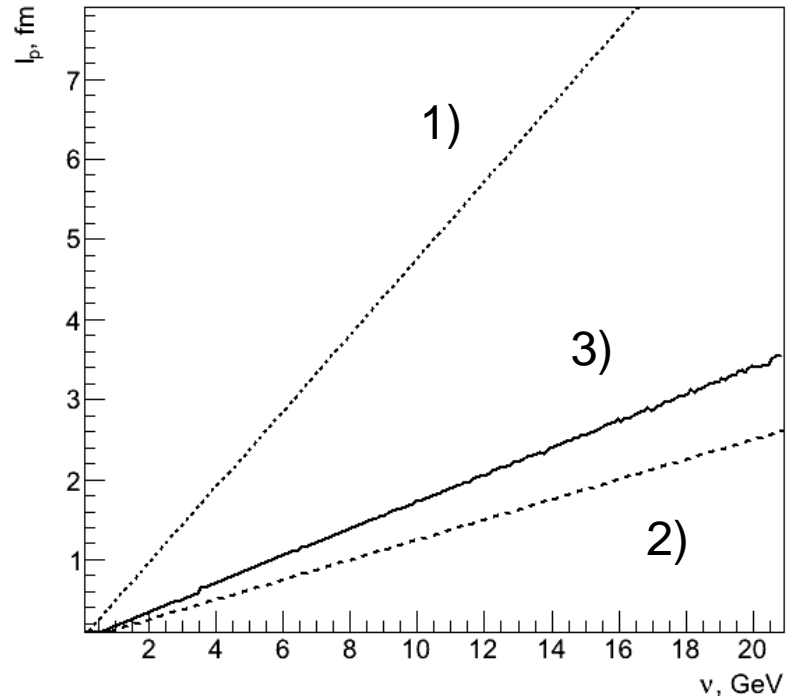
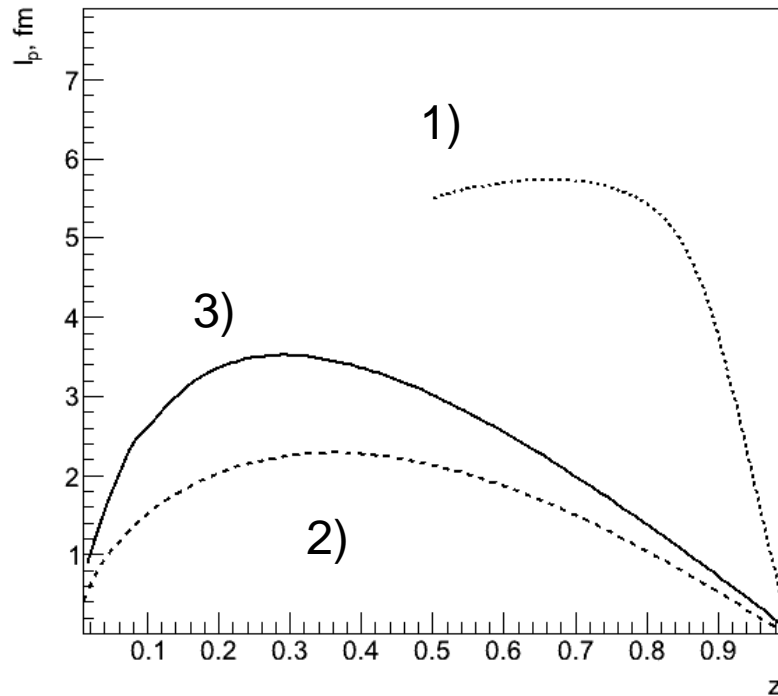
Dependencies of formation length on part of virtual photon energy and energy of virtual photon in hard IA scattering

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

1 Kopeliovich B.Z., ...

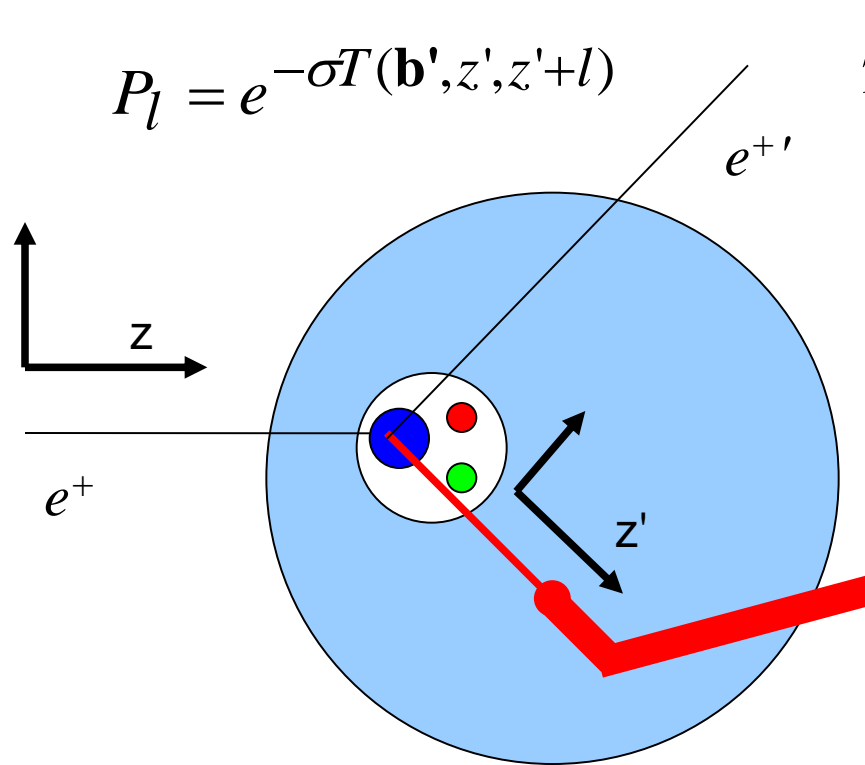
2 Pirner G.J., ...

3 HARDPING (Berdnikov Ya.A., ...) $\nu = \frac{qP}{\sqrt{P^2}} = E' - E$



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

HARDPING: multiple soft re-scatterings of hadrons produced in lepton-A interaction



$$T(\mathbf{b}', z', z'+l) = \int_{z'}^{z'+l} \rho(\mathbf{b}', z'') dz''$$

$$f_p(\mathbf{p}_{ti}) = \frac{B^2}{2\pi} e^{-B p_{ti}}$$

$$f_f(\mathbf{k}_{fi}) = \frac{B_f}{\pi} e^{-B_f k_{fi}^2}$$

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