Charged Hadron Production at HERMES

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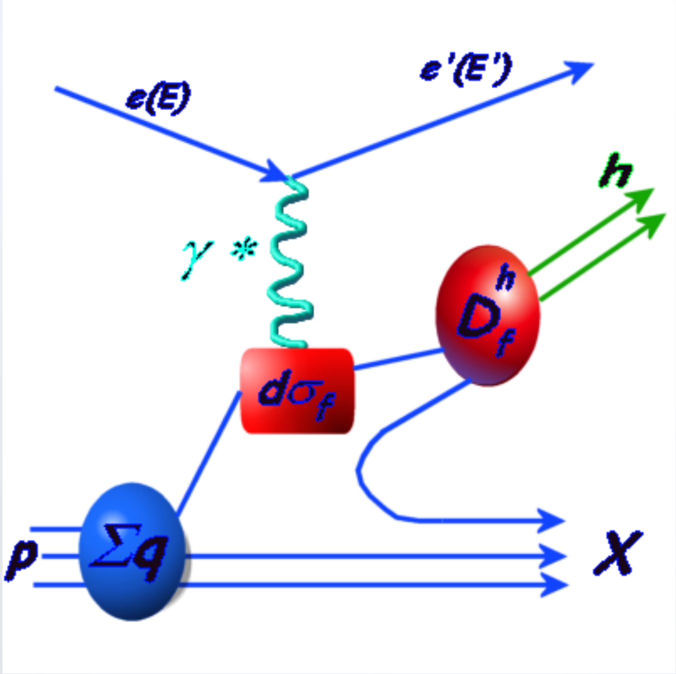
Baryons2013, Glasgow, 27/06/2013

Experimental Method

- **Semi-Inclusive Deep Inelastic Scattering (SIDIS)**
  - **Access parton fragmentation functions**



$$d\sigma^h = \sum q \otimes d\sigma_f \otimes D_f^h$$

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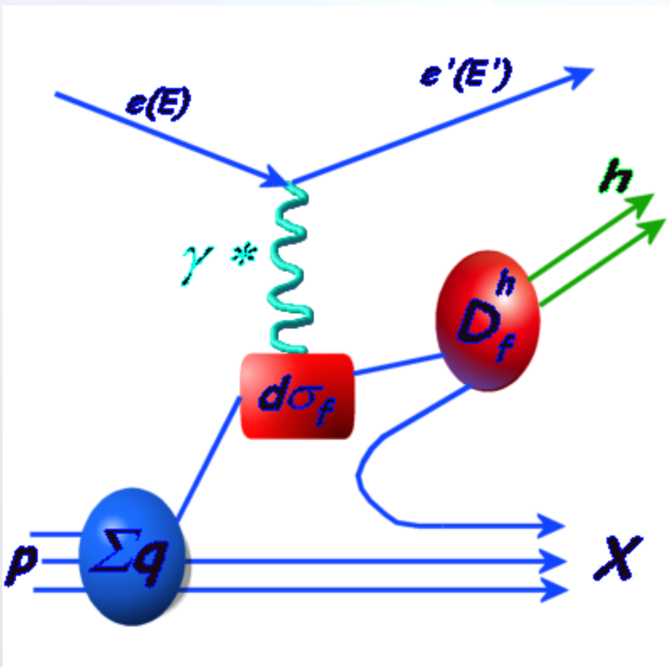
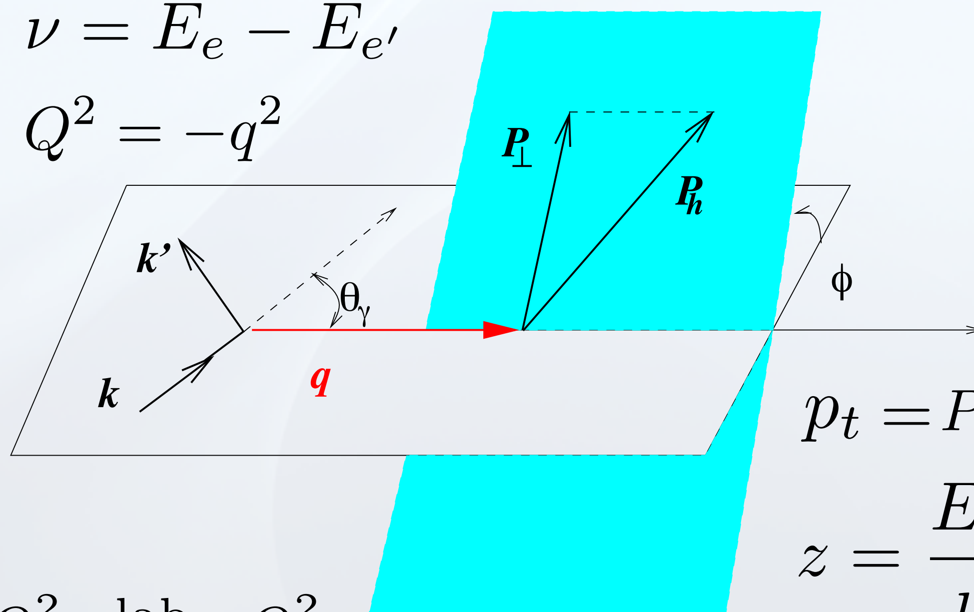


$$d\sigma^h = \sum q \otimes d\sigma_f \otimes D_f^h$$

$$\nu = E_e - E_{e'}$$

$$Q^2 = -q^2$$



$$p_t = P_{h\perp}$$

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

$$x_B = \frac{Q^2}{2P\cdot q} \overset{\text{lab}}{=} \frac{Q^2}{2M\cdot\nu}$$

Measurements on Nucleons

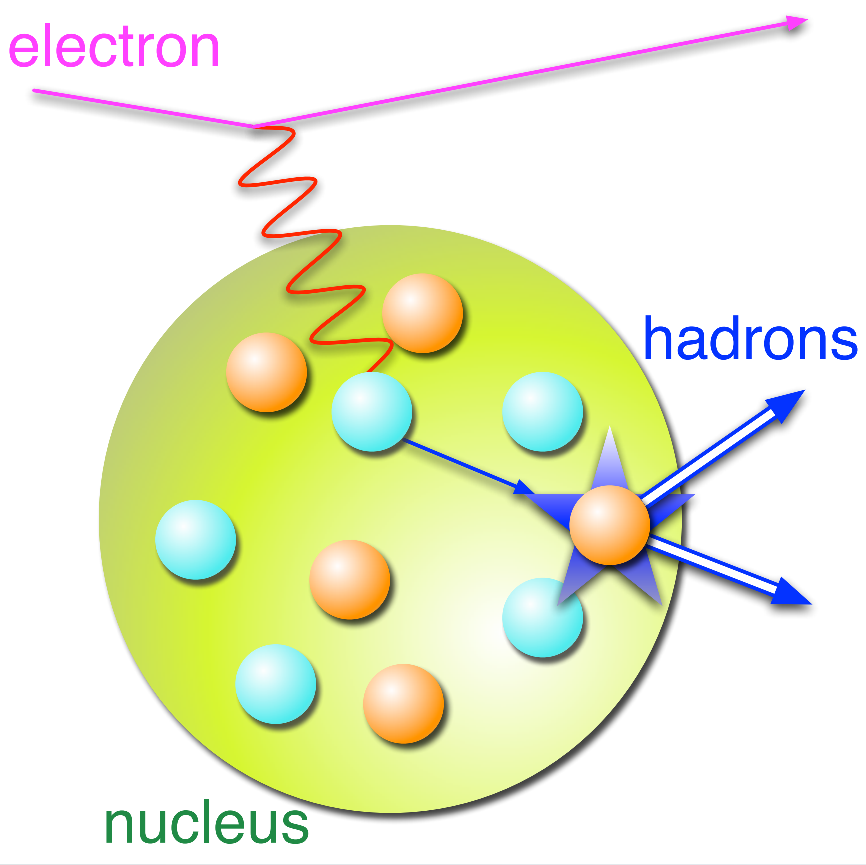
- Compare yields of positively and negatively charged pions and kaons on
  - the proton
  - the deuteron (accessing neutron contrib.)
- Probe flavour dependence of fragmentation
- Probe fragmentation functions at low energy scales
  - in contrast to lepton annihilation
- Differentiate between quark and antiquark contributions
- Improve QCD fits to extract fragmentation functions
- Observable: hadron multiplicity

$$M_n^h(x_{\rm B}, Q^2, z, P_{h\perp}) = \frac{1}{\frac{{\rm d}^2 N_{\rm DIS}(x_{\rm B},Q^2)}{{\rm d}x_{\rm B}\,{\rm d}Q^2}} \cdot \int_0^{2\pi} \frac{{\rm d}^5 N^h(x_{\rm B},Q^2,z,P_{h\perp},\phi_h)}{{\rm d}x_{\rm B}\,{\rm d}Q^2\,{\rm d}z\,{\rm d}P_{h\perp}\,{\rm d}\phi_h} {\rm d}\phi_h$$

$$= \frac{1}{\frac{{\rm d}^2 \sigma_{\rm DIS}(x_{\rm B},Q^2)}{{\rm d}x_{\rm B}\,{\rm d}Q^2}} \cdot \int_0^{2\pi} \frac{{\rm d}^5 \sigma^h(x_{\rm B},Q^2,z,P_{h\perp},\phi_h)}{{\rm d}x_{\rm B}\,{\rm d}Q^2\,{\rm d}z\,{\rm d}P_{h\perp}\,{\rm d}\phi_h} {\rm d}\phi_h .$$

Measurements on Nuclei

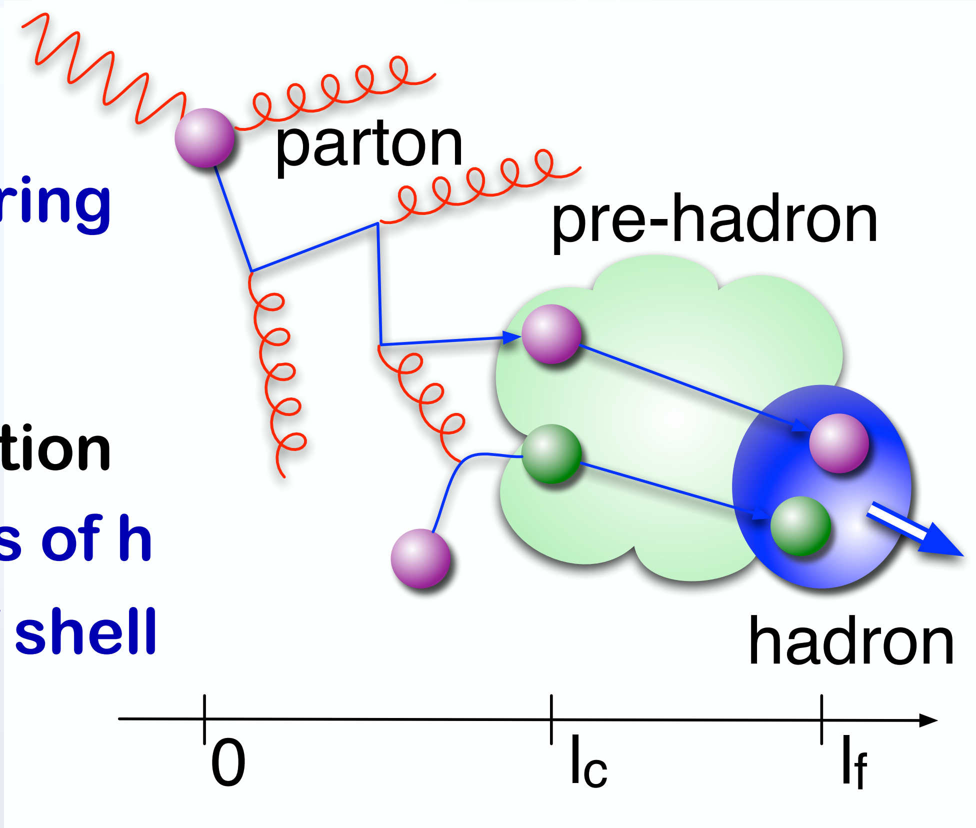
- **Initial reaction identical to nucleon SIDIS**
- **Final state influenced by nuclear matter**



- **Compare several nuclei**
- **Information on final state interaction**

Hadronisation in Matter

- Schematic evolution in space and time
- Parton propagation
  - Gluon radiation
  - Partonic rescattering
  - length < l_c
- Pre-hadron propagation
  - Quantum numbers of h
  - Colourless but off shell
- Hadron formation
  - Formation length l_f up to 10fm (outside N)

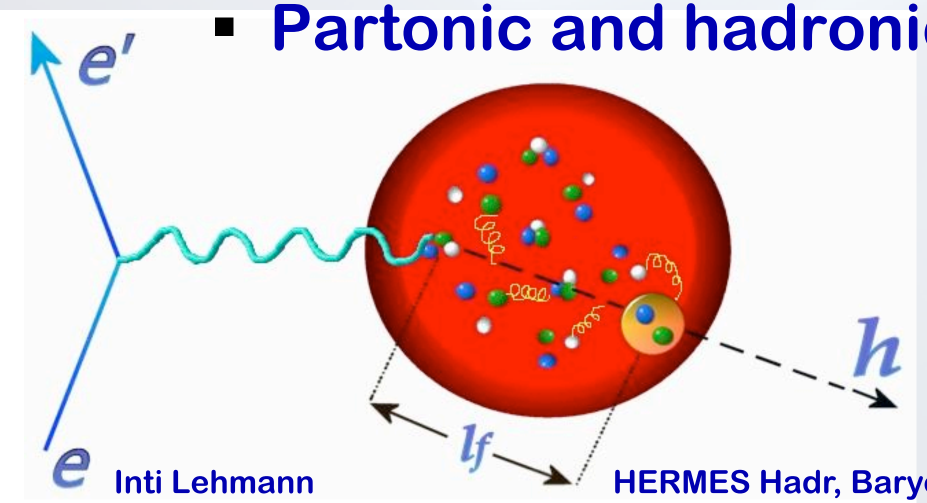


Experimental Observable

- **Hadron multiplicity ratio on nuclei**
  - **comparing nucleus A with deuterium D**

$$R_A^h(\nu, Q^2, z, p_t^2) = \frac{\left(\frac{N^h(\nu,Q^2,z,p_t^2)}{N^e(\nu,Q^2)}\right)_A}{\left(\frac{N^h(\nu,Q^2,z,p_t^2)}{N^e(\nu,Q^2)}\right)_D}$$

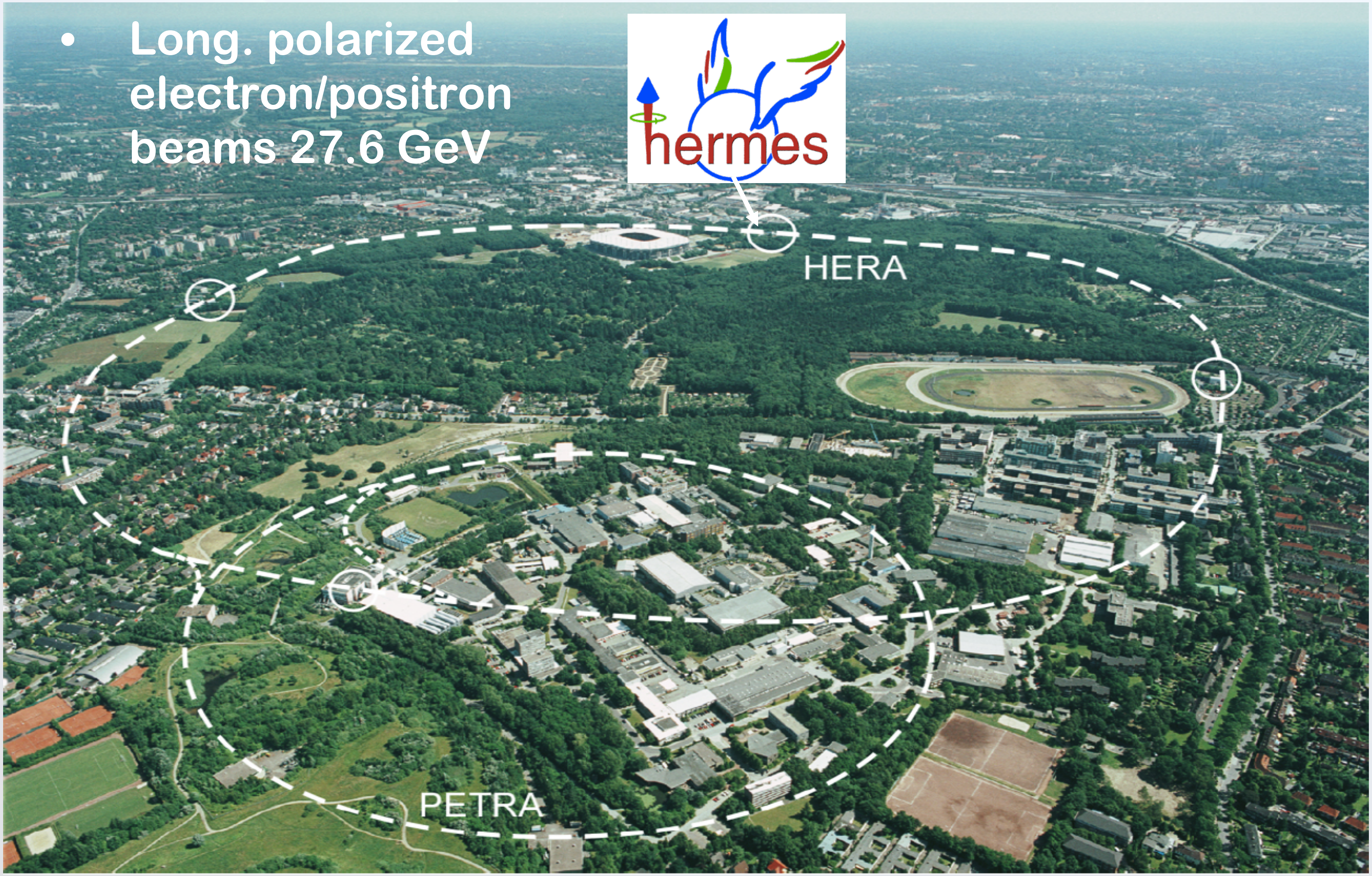
  - **Exp. systematics cancel largely**
  - **Partonic and hadronic effects contribute**



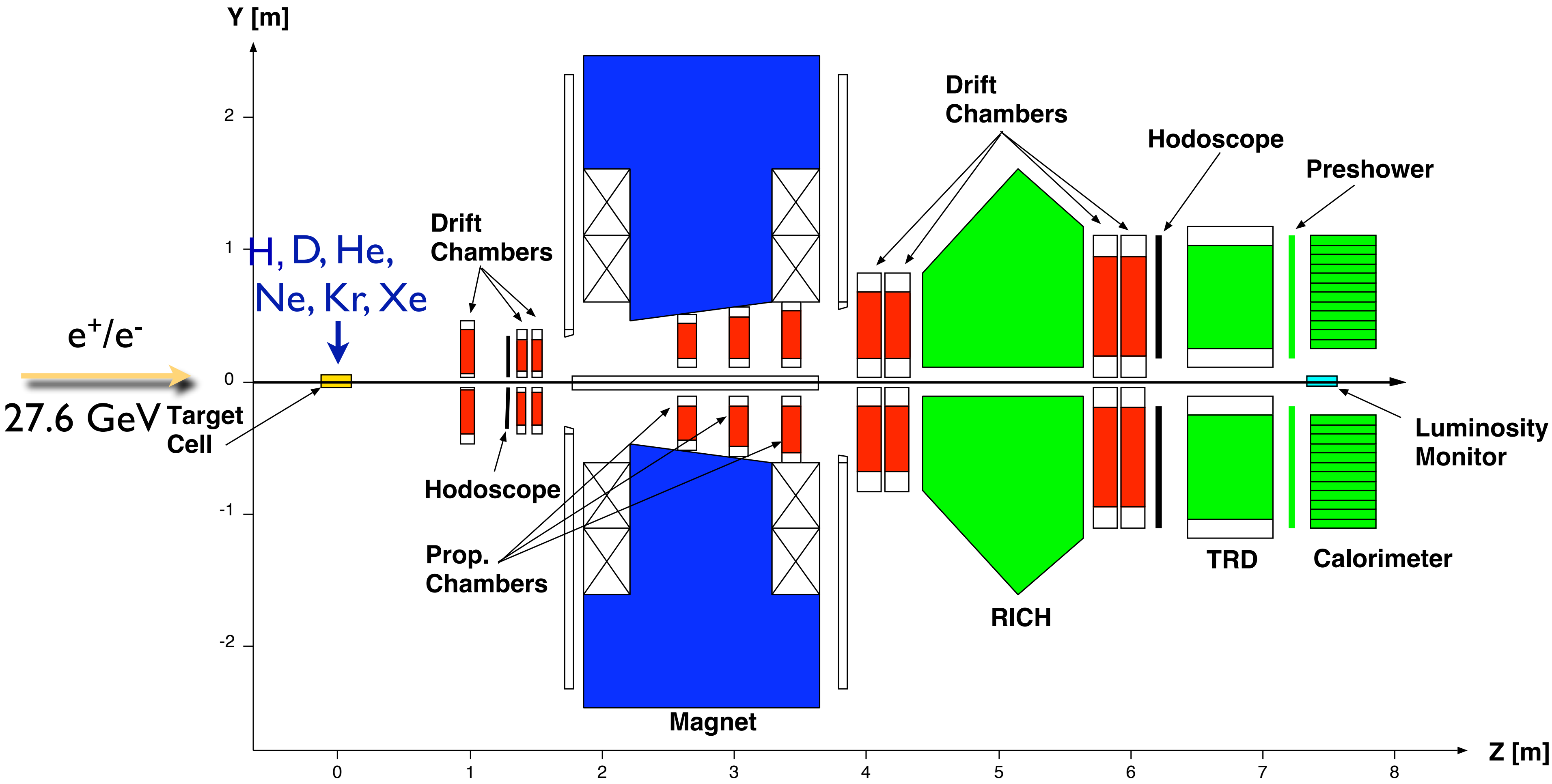
HERMES at HERA, DESY

- Long. polarized electron/positron beams 27.6 GeV

hermes



HERMES Spectrometer

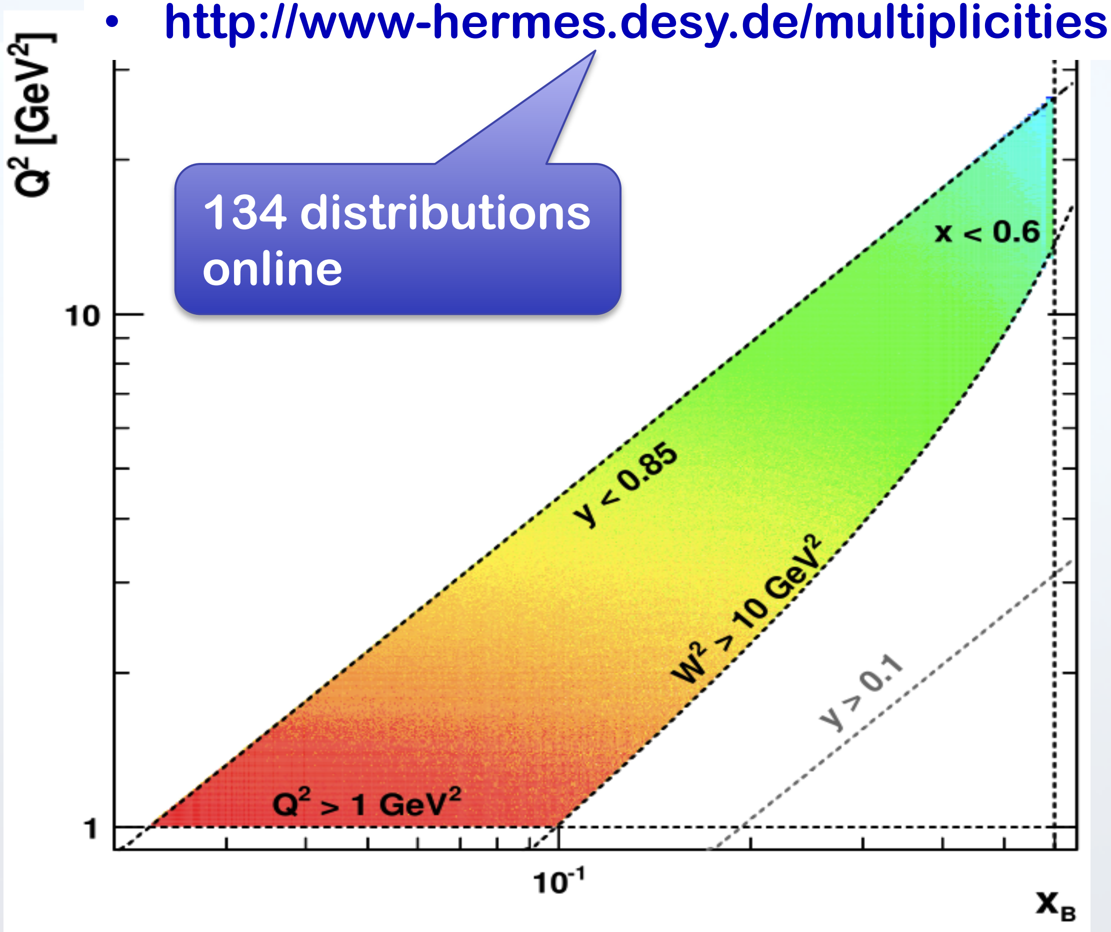


Magnetic spectrometer with transv. and long. polarized targets

Multiplicity on Nucleons

- **HERMES publication**
  - π^+, π^-
  - K^+, K^-
  - **On proton, deuteron**
  - **With, without vector meson contribution**
    - $\rho^0 \rightarrow \pi^+\pi^-$
    - $\phi \rightarrow K^+K^-$
  - **Function of**
    - $x_B, Q^2, z, P_{h\perp}$

- Phys. Rev. D87 (2013) 074029
- http://www-hermes.desy.de/multiplicities



Multiplicity on Nucleons

- In the following
  - vector-meson corrected
- Differences
  - proton, deuteron
  - explained by favoured or unfavoured fragmentation due to quark content

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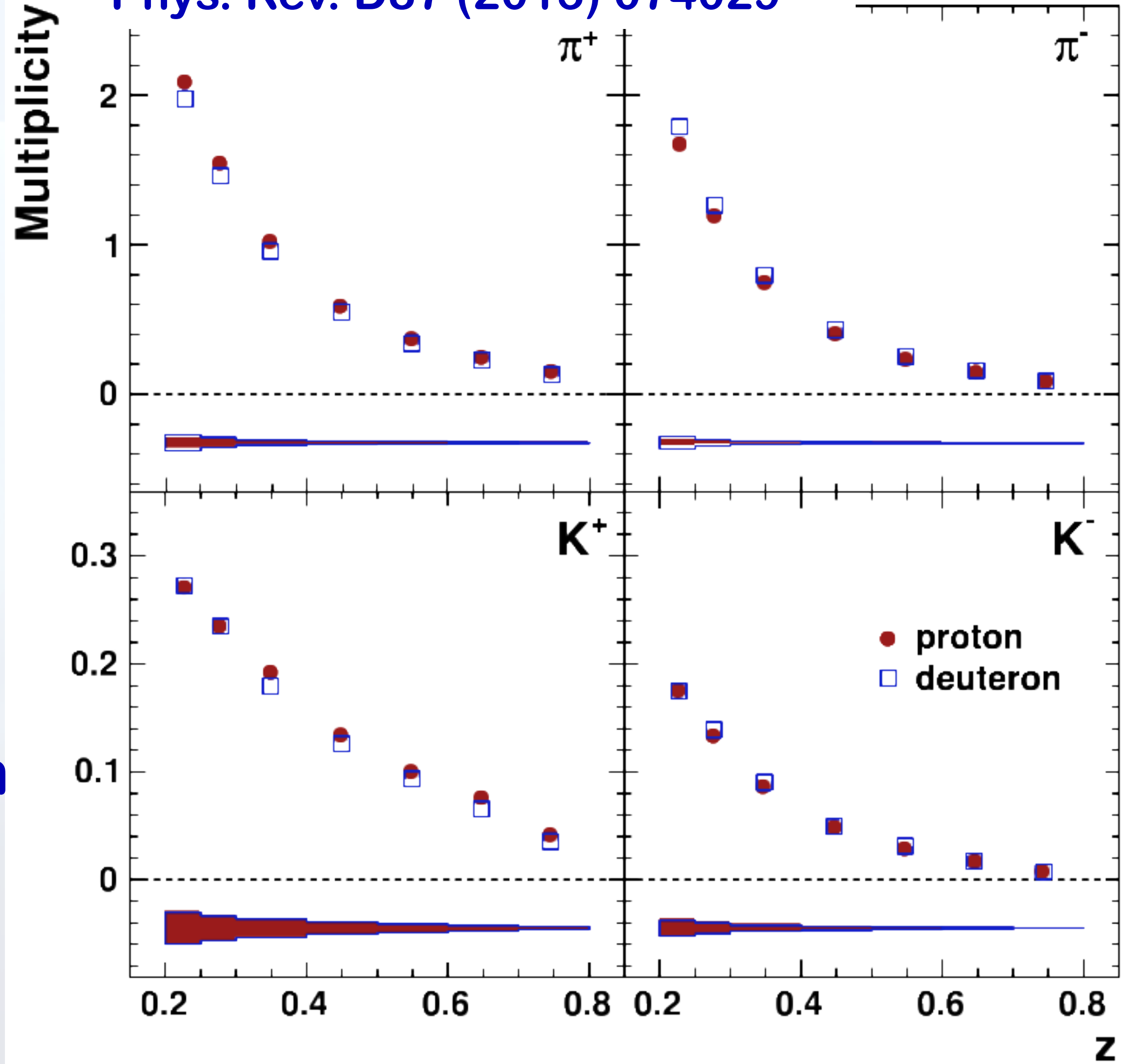
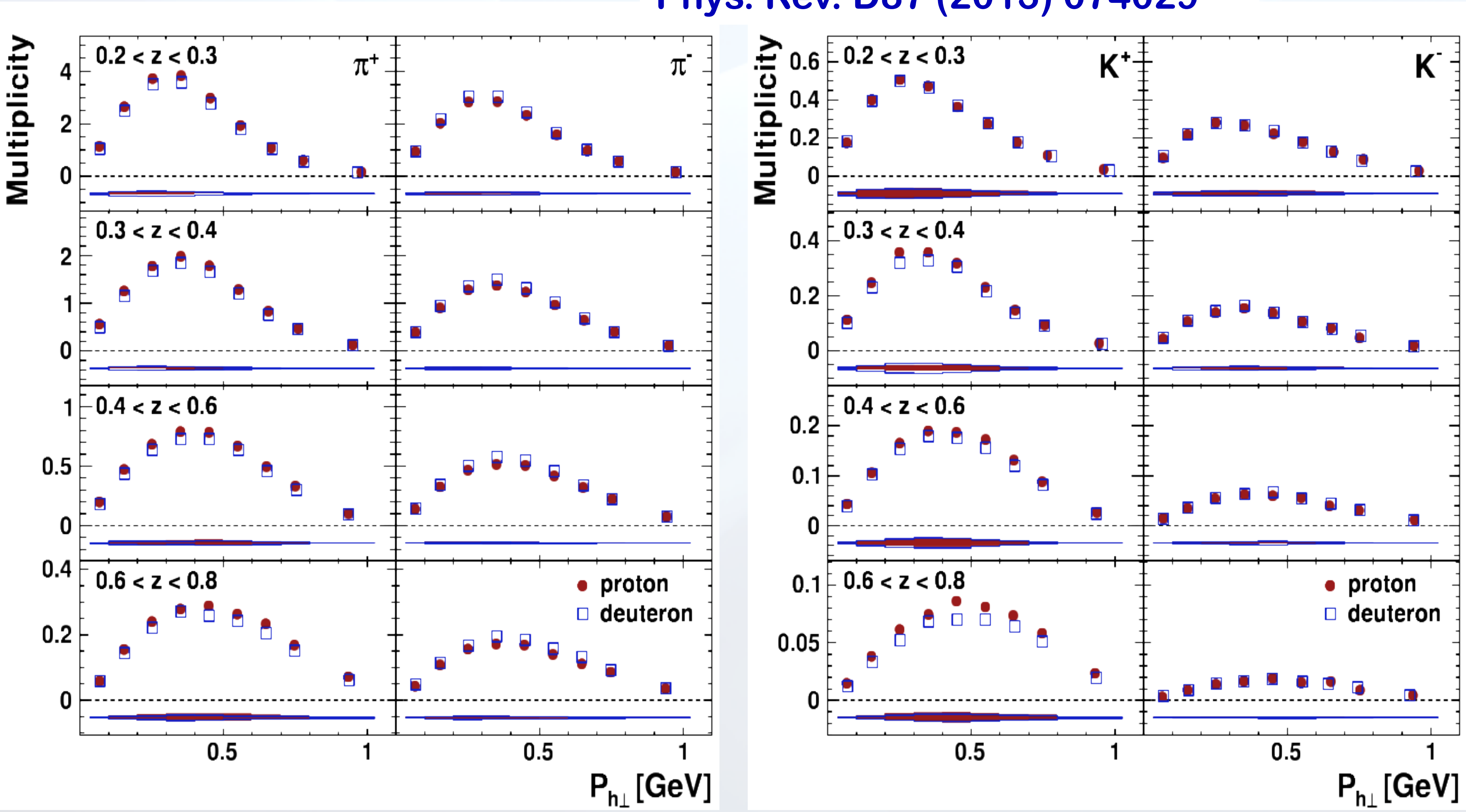


Multiplicity on Nucleons

Phys. Rev. D87 (2013) 074029

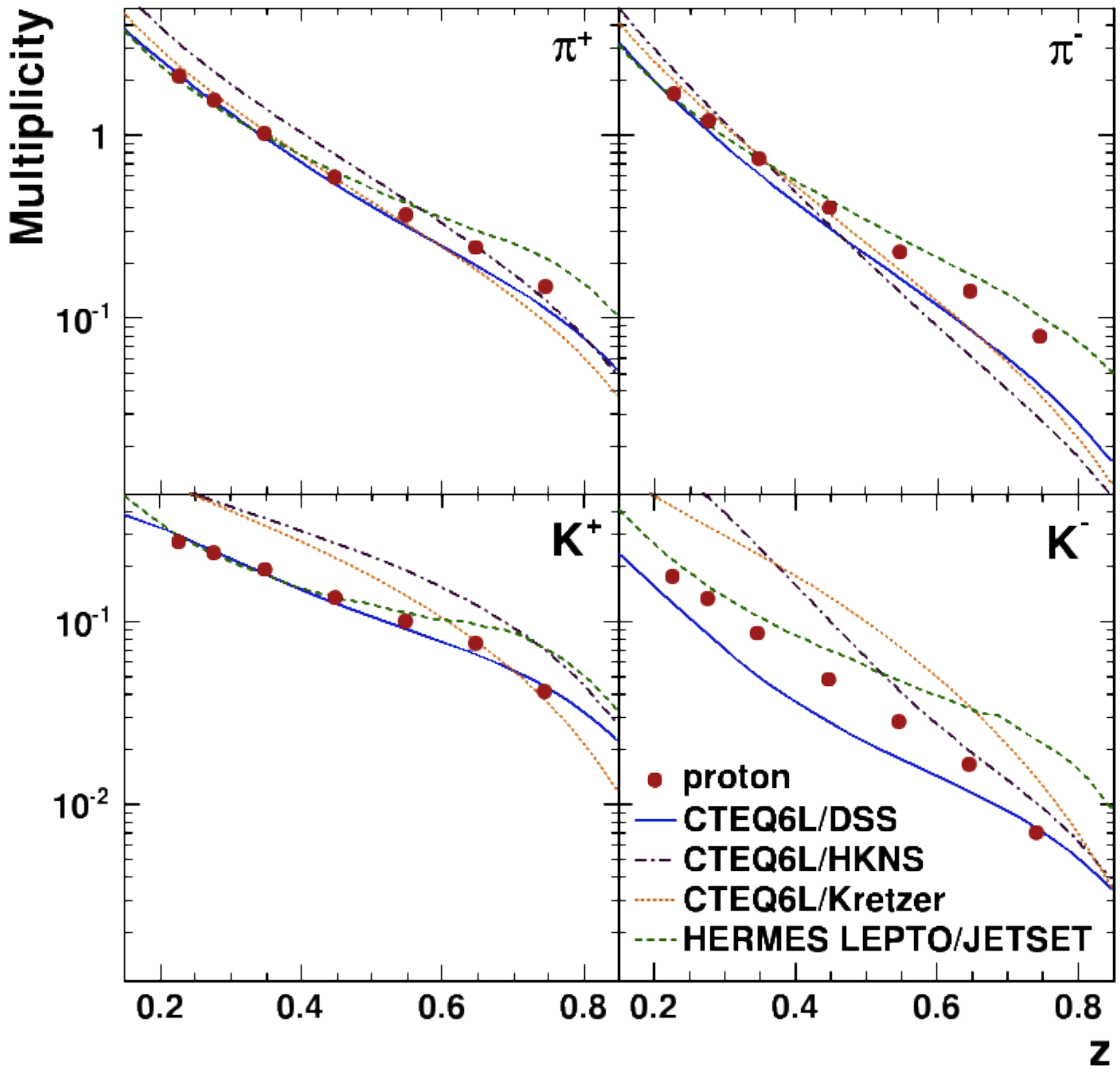


x_B and Q^2 dependencies more flat, as expected

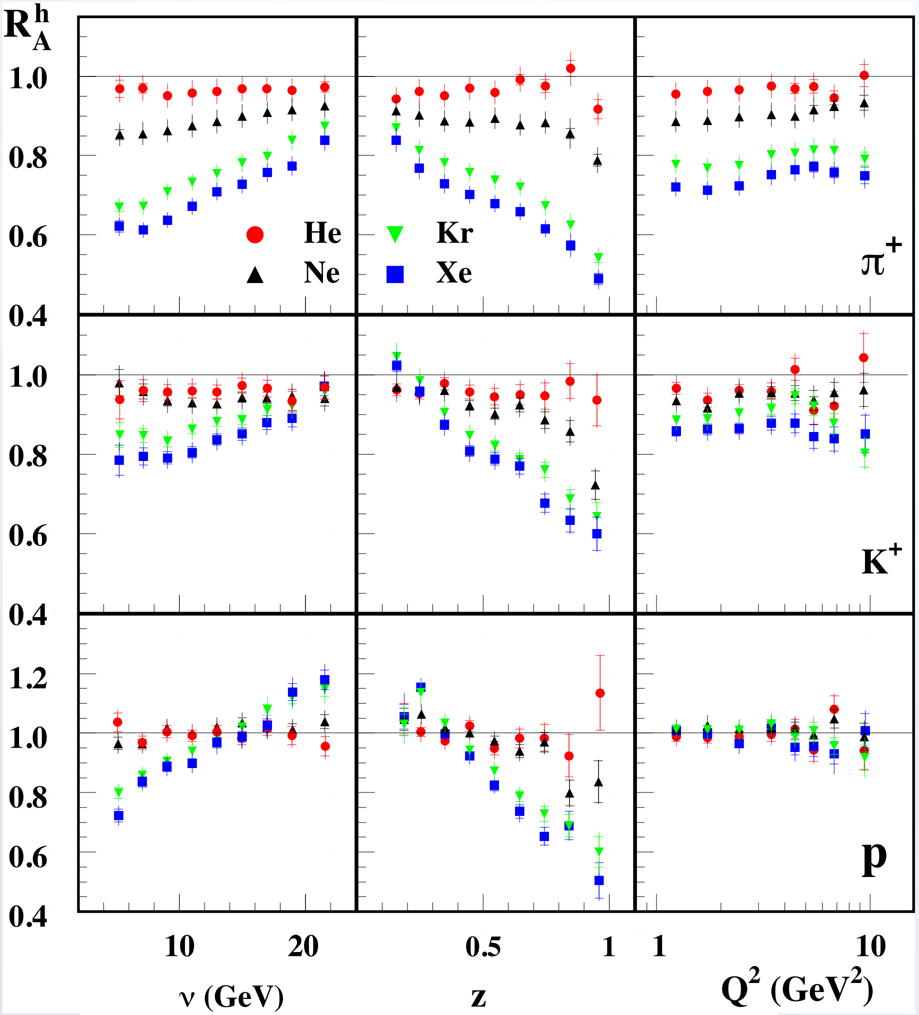
Multiplicity on Nucleons

- Comparison with LO calculations
  - collinear factorisation, ie integration over $P_{h\perp}$
  - discrepancies apparent

Phys. Rev. D87 (2013) 074029



First Ratios on Nuclei

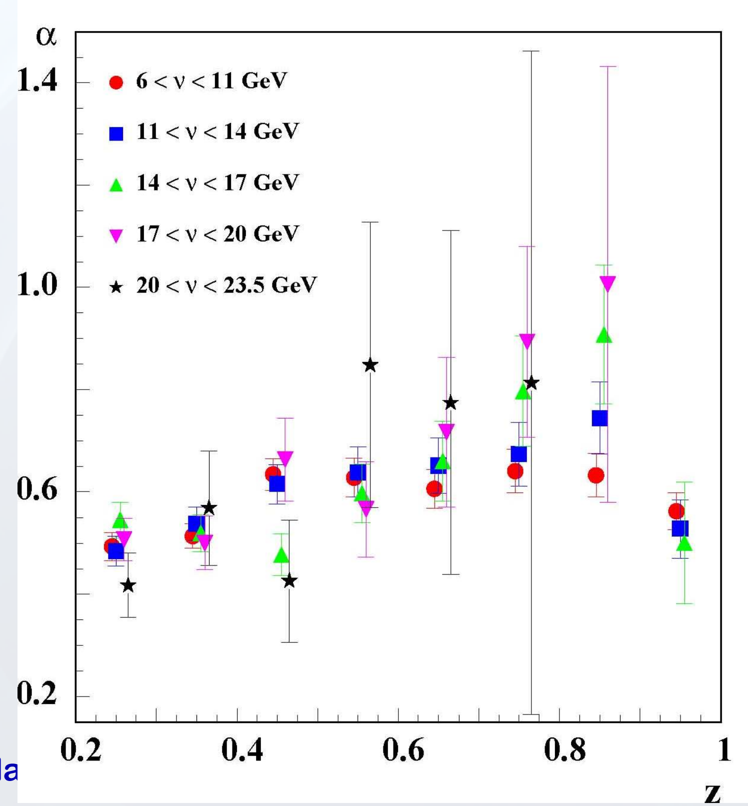


Nucl. Phys. B780 (2007)1-27

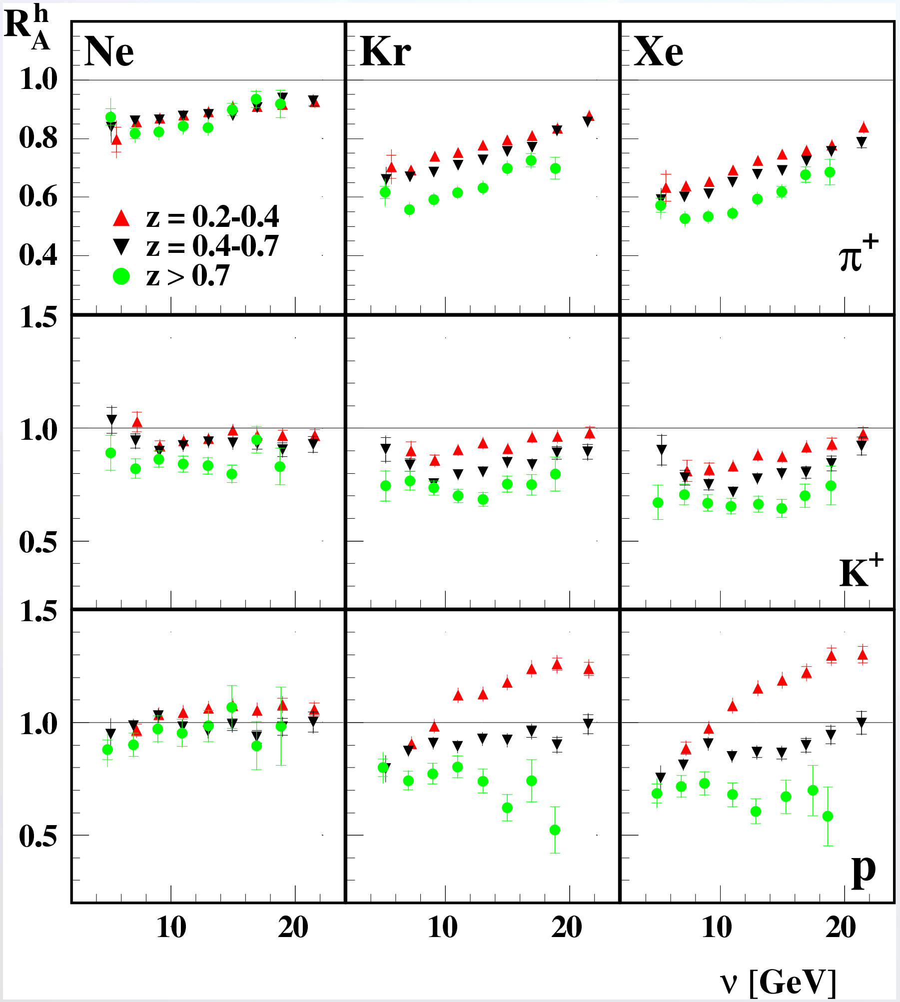
- **Multiplicity ratio**

$$R_A^h(\nu, Q^2, z, p_t^2)$$

  - 1 dim. dependence
- **A dependence**
  - compatible with $A^{2/3}$



2D Ratios on Nuclei



Eur. Phys. J. A 47 (2011) 113

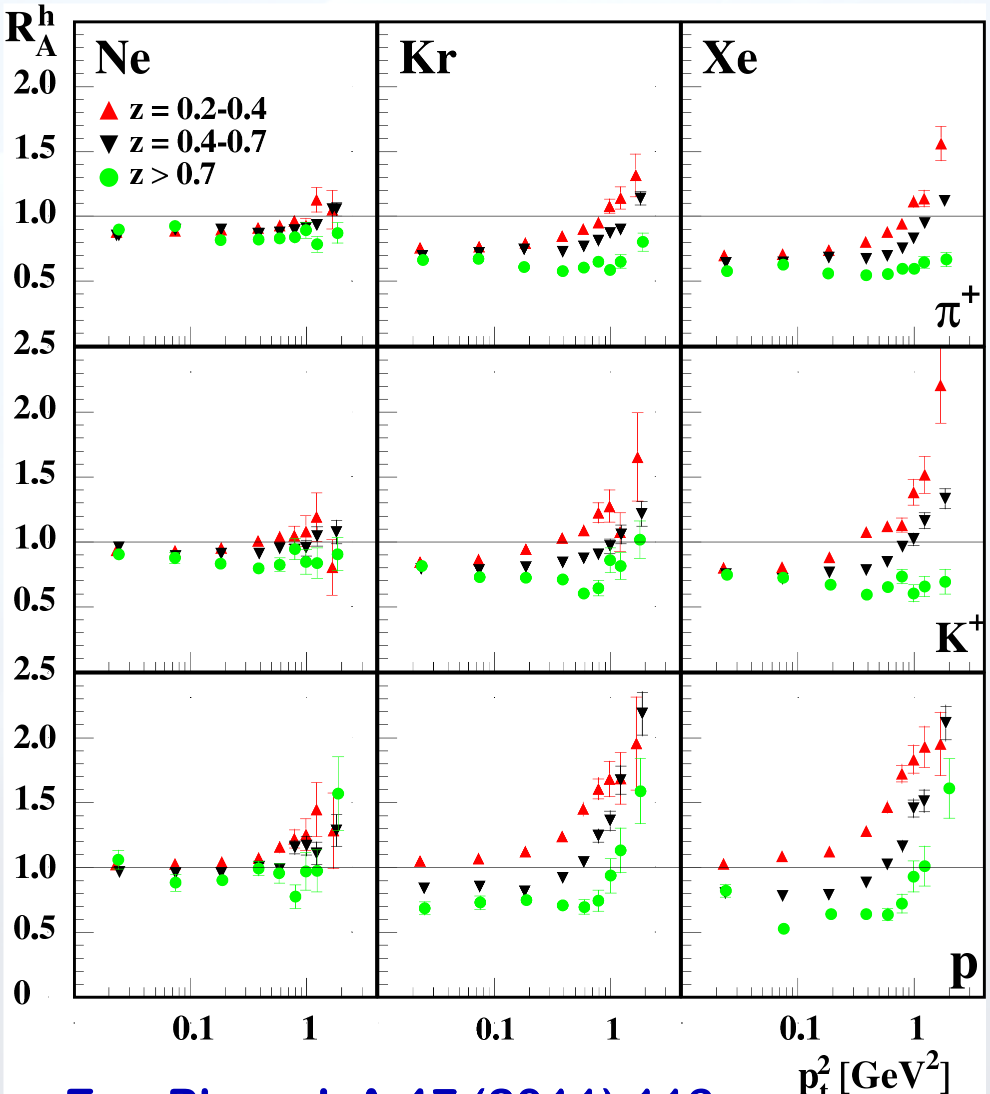
- Recent HERMES publication
- 2D dependences extracted
  - variables:
    $\nu \quad z \quad p_t \quad Q^2$

over 100 distributions online
Durham: http://durpdg.dur.ac.uk or
http://inspirehep.net/record/918944/files/

  - avoids integration
  - disentangles dependence
- ν dependence in z slices
  - substructures observed
  - π^+ and K^+ similar
  - protons pronounced differences for different z

2D Ratios on Nuclei

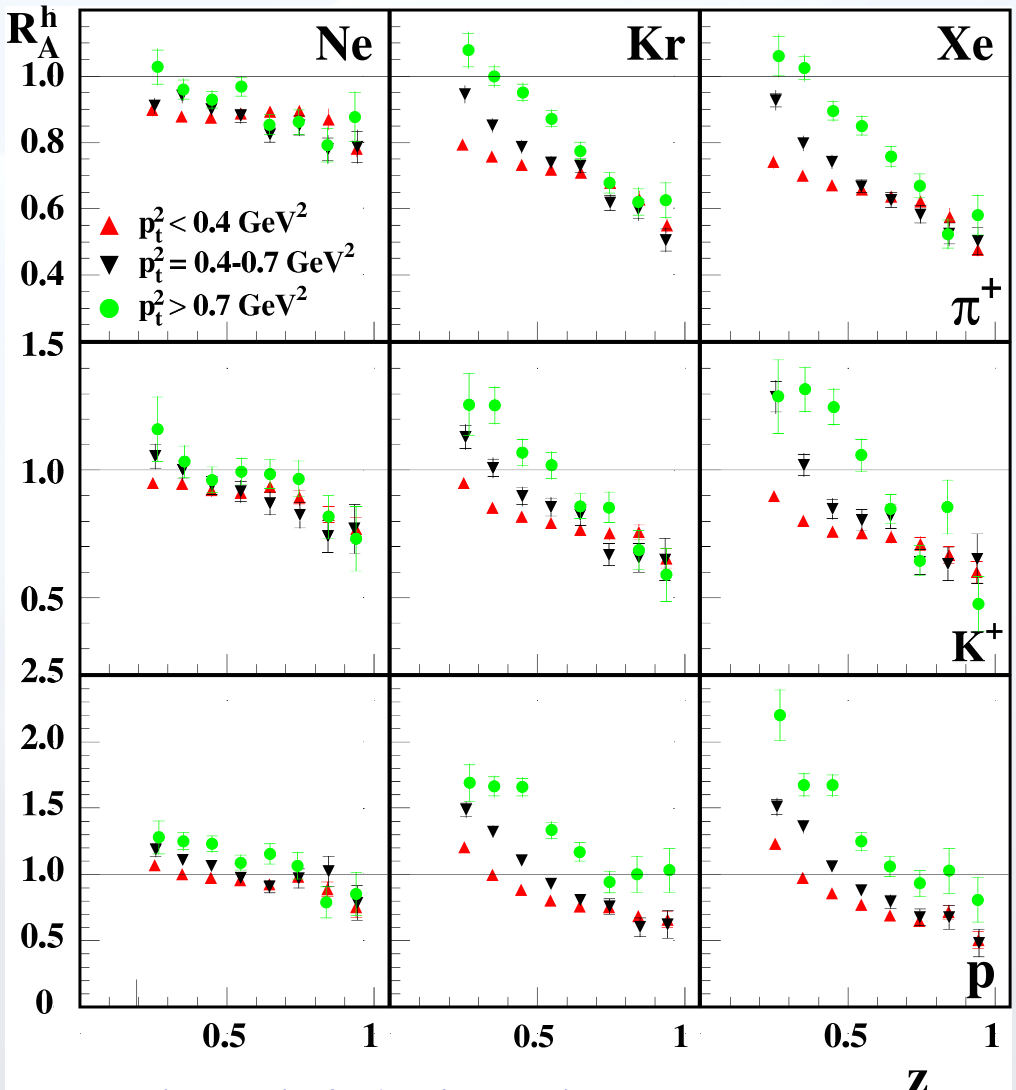
- p_t^2 dep. in z slices
  - Nuclear broadening – Cronin effect
    - Less than predicted in Nucl.Phys.A740 (2004)211
    - Disappears for high z
  - Compatible for negative hadrons



Eur. Phys. J. A 47 (2011) 113

2D Ratios on Nuclei

- z dep. in p_t^2 slices
  - z-dependence increases with p_t
  - p_t dependence disappears at high z



Eur. Phys. J. A 47 (2011) 113

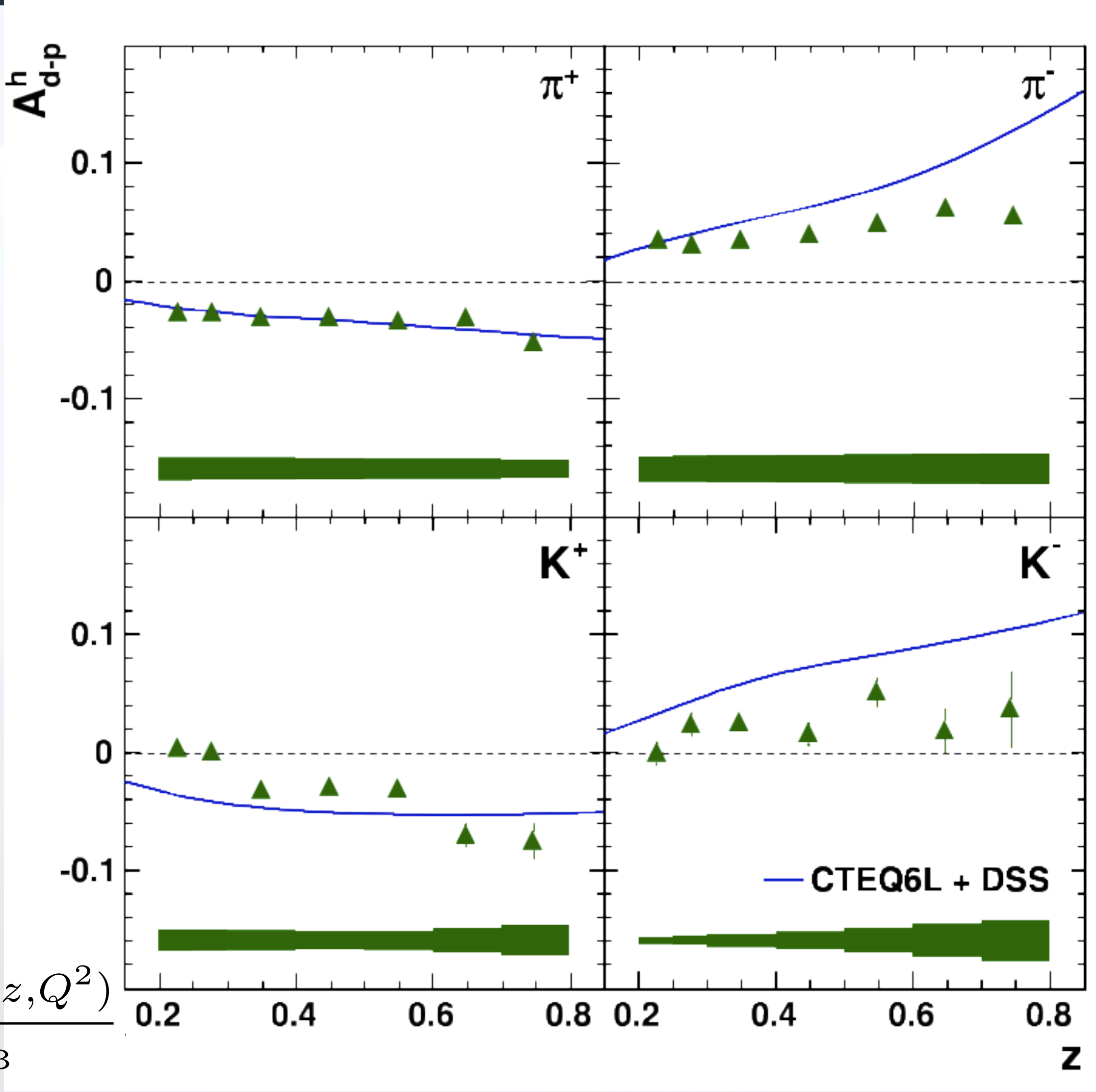
Summary

- Semi-Inclusive Deep Inelastic Scattering (SIDIS)
  - Nucleon: fragmentation functions
  - Nucleus: parton propagation + hadronisation
- HERMES Results
  - Fragmentation functions at low energies
  - Probe flavour dependence
  - Discriminate quark and antiquark contribution
  - Improve QCD fits
  - Strong nuclear effects on multiplicity ratio
  - Two-dim. correlations (some unexpected)
  - All dependencies published in databases

Backup

Multiplicity on Nucleons

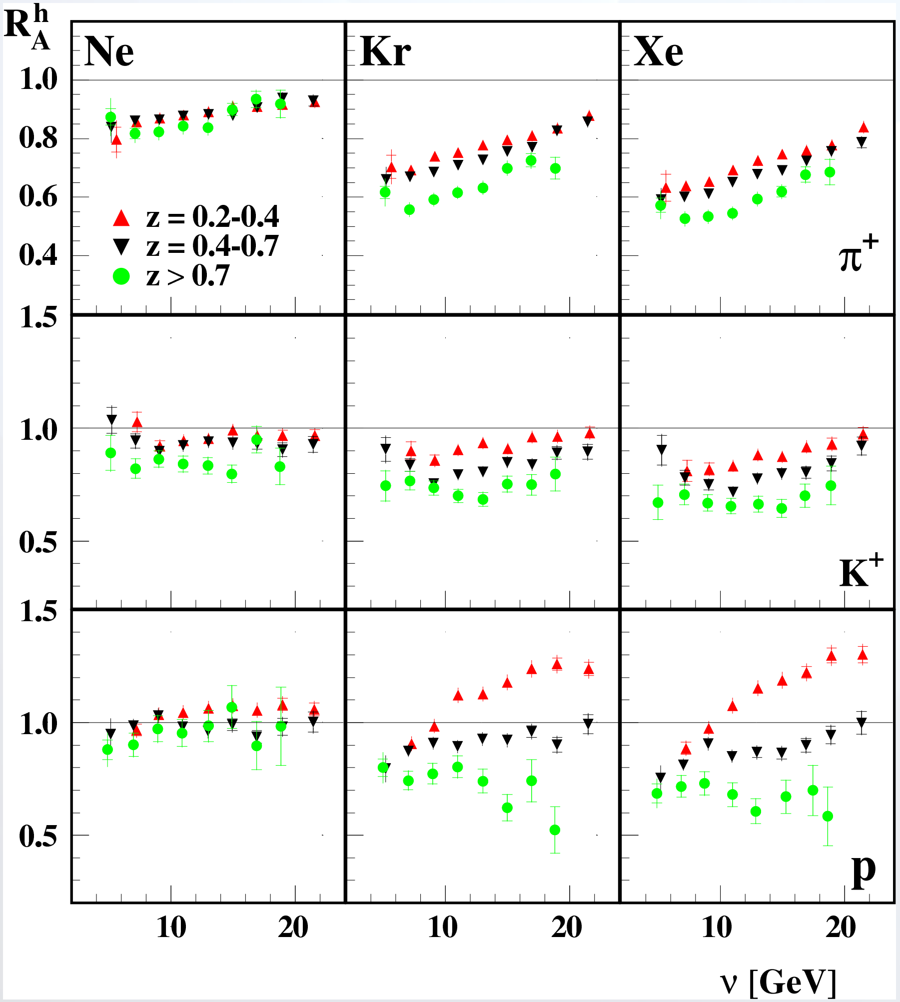
- s

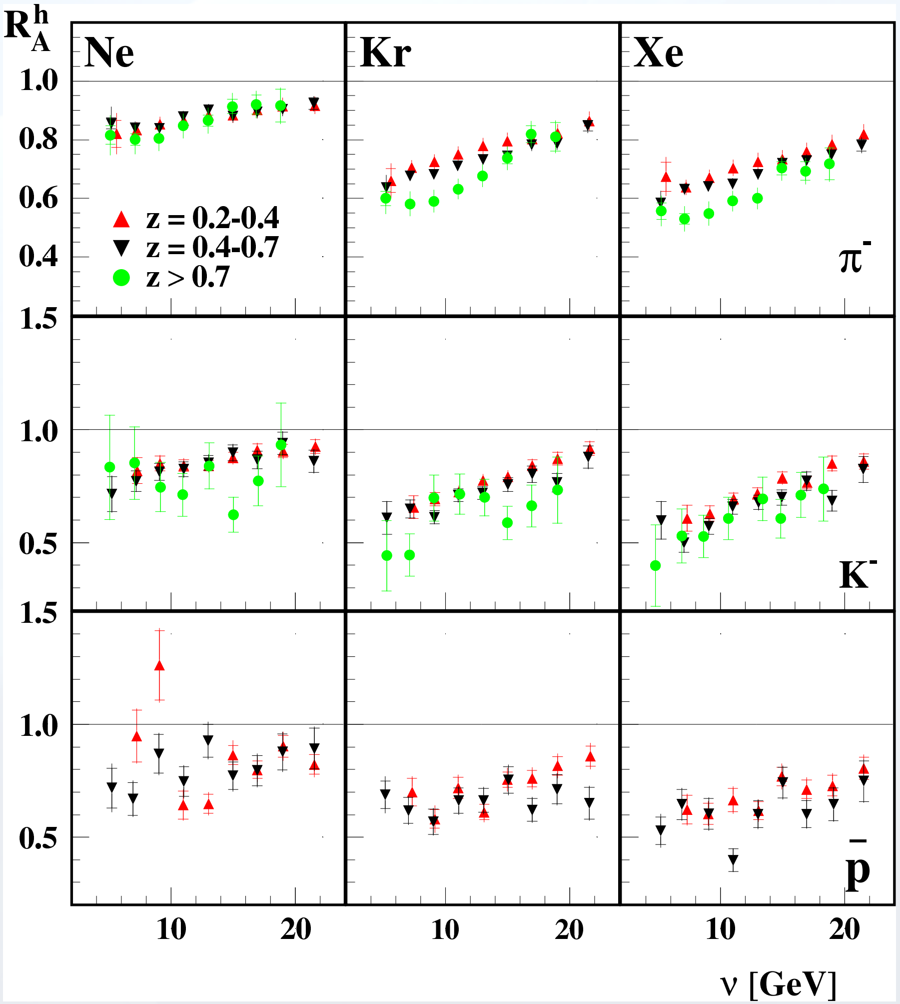


$$\frac{1}{N_{DIS}(Q^2)}\frac{\mathrm{d}N^h(z,Q^2)}{\mathrm{d}z}$$

$$= \frac{\sum_f e_f^2 \int_0^1 q_f(x_\mathrm{B},Q^2)\mathrm{d}x_\mathrm{B} D_f^\pi(z,Q^2)}{\sum_f e_f^2 \int_0^1 q_f(x_\mathrm{B},Q^2)\mathrm{d}x_\mathrm{B}}$$

2D Ratios on Nuclei





π^+ and π^- similar while K^- differ