Hadron multiplicity measurements from HERMES

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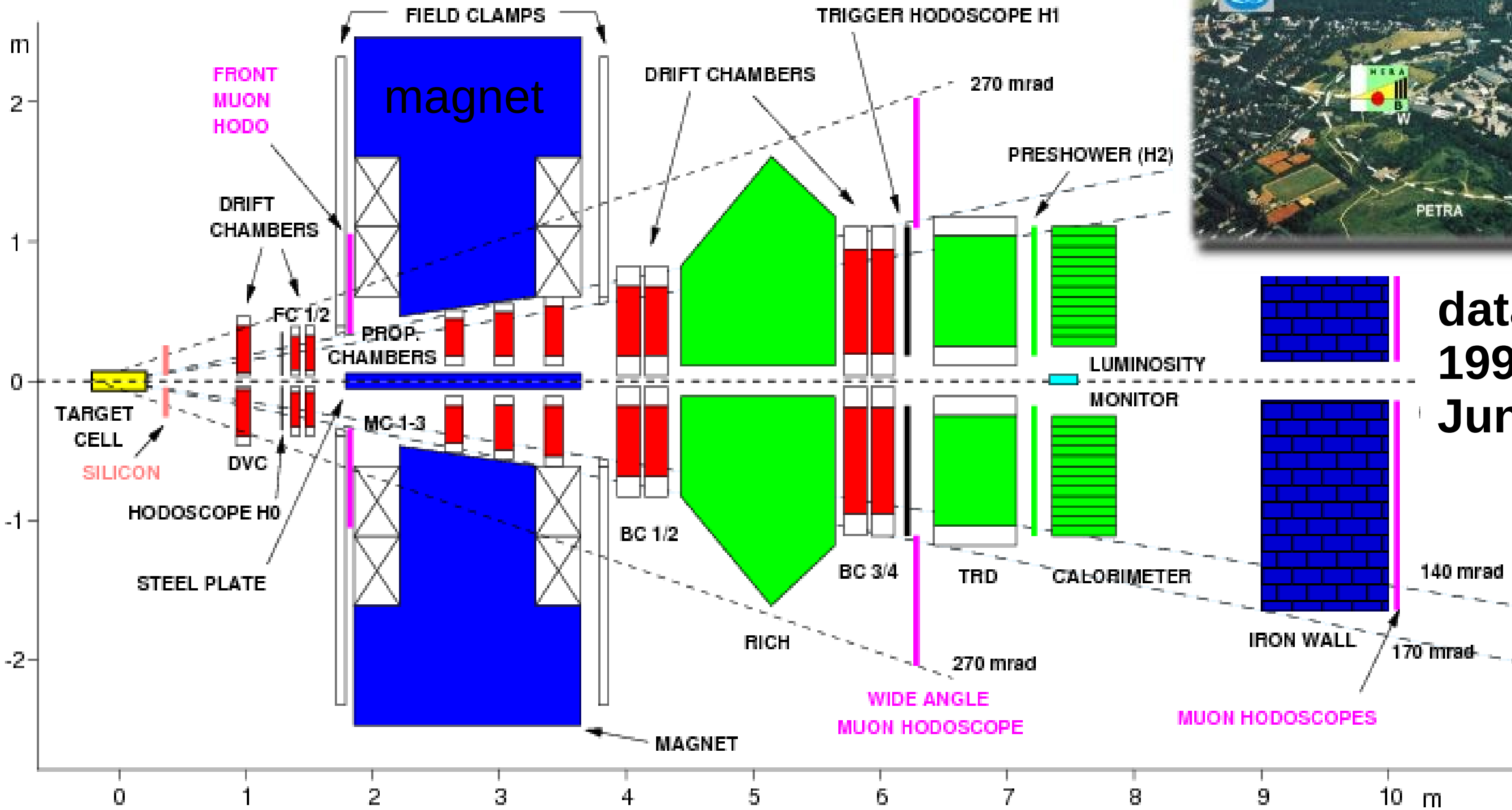
hermes

Fragmentation 2012
November 9, 2012 – RIKEN

Outline

- HERMES experiment
- semi-inclusive deep-inelastic scattering
- pion and kaon multiplicites on hydrogen and deuterium
- hadronization in nuclei

HERMES: HERA MEasurement of Spin



data taking from 1995 until June, 30 2007

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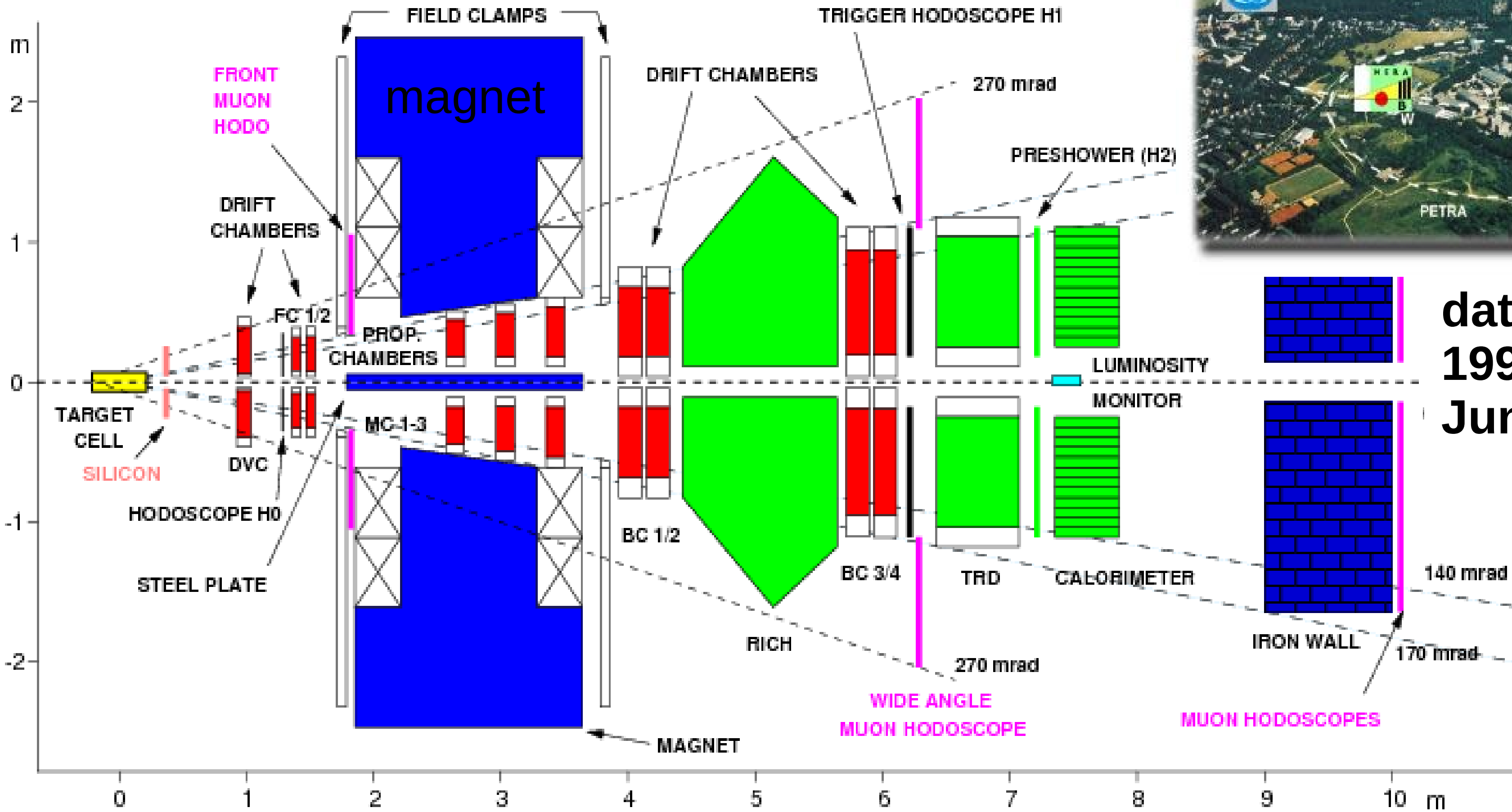

data taking from 1995 until June, 30 2007

<u>Beam</u>
e^+ & e^-
E= 27.6 GeV
longitudinally pol.

<u>Gaseous internal target</u>
transversely pol. H (~75%)
unpol. H,D,He,Ne,Kr,Xe
longitudinally pol. H,D,He (~85%)

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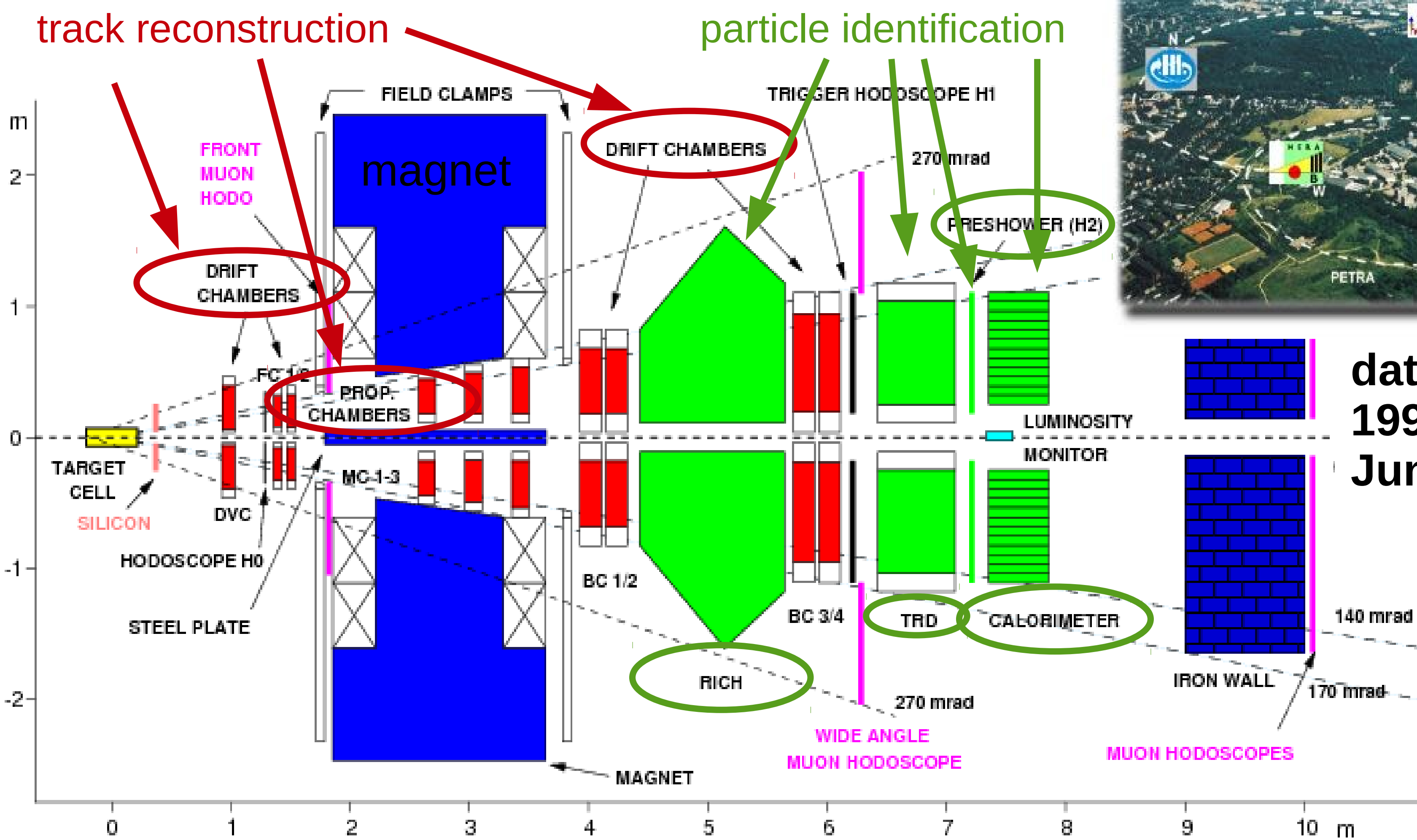


data taking from 1995 until June, 30 2007

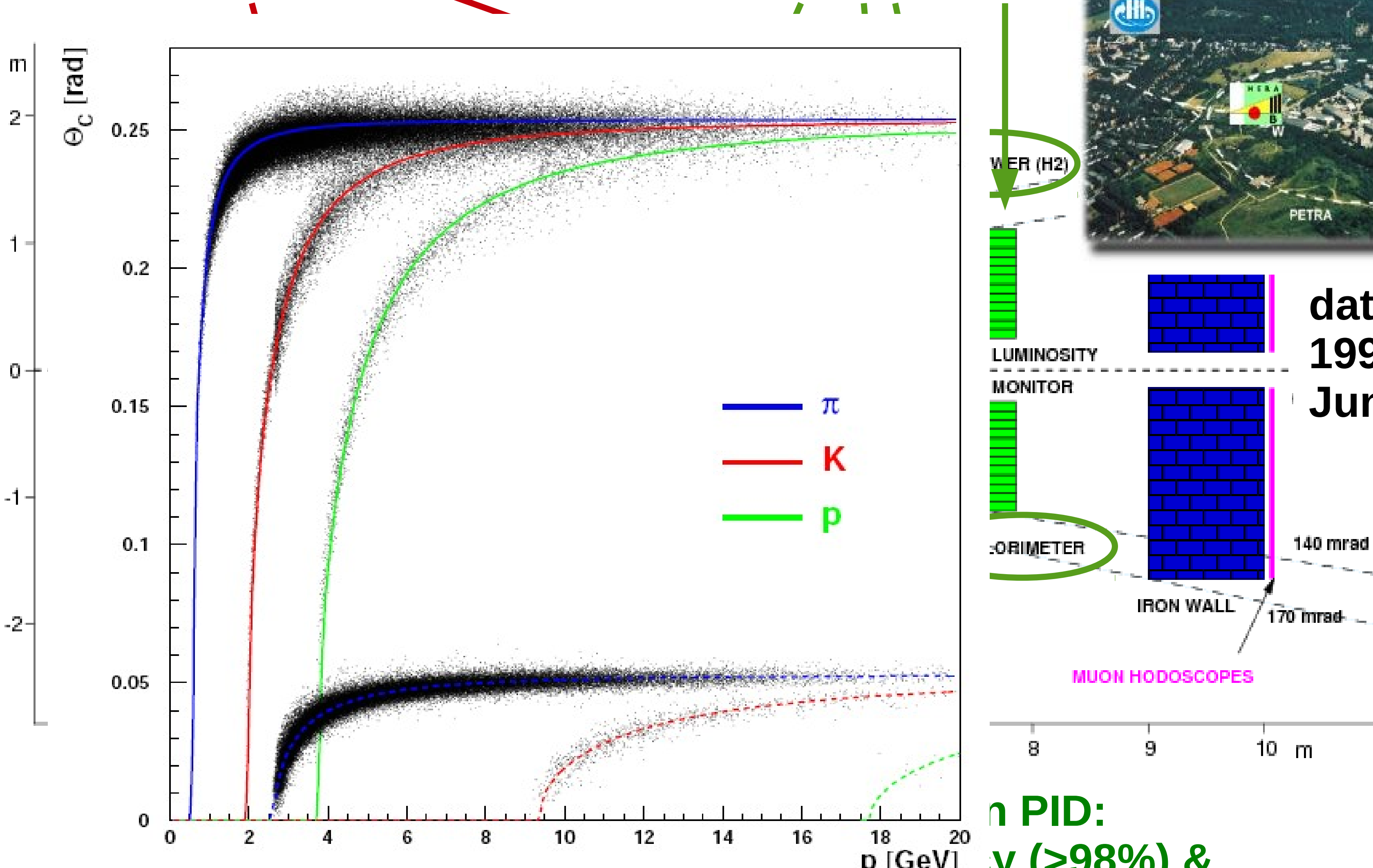
- $\delta\theta \leq 1.8$ mrad
- $\delta p/p \leq 2.6\%$

- **lepton-hadron PID: high efficiency (>98%) & low contamination (<1%)**
- **hadron PID: RICH 2-15 GeV**

HERMES: HERA MEasurement of Spin

track reconstruction

particle identification

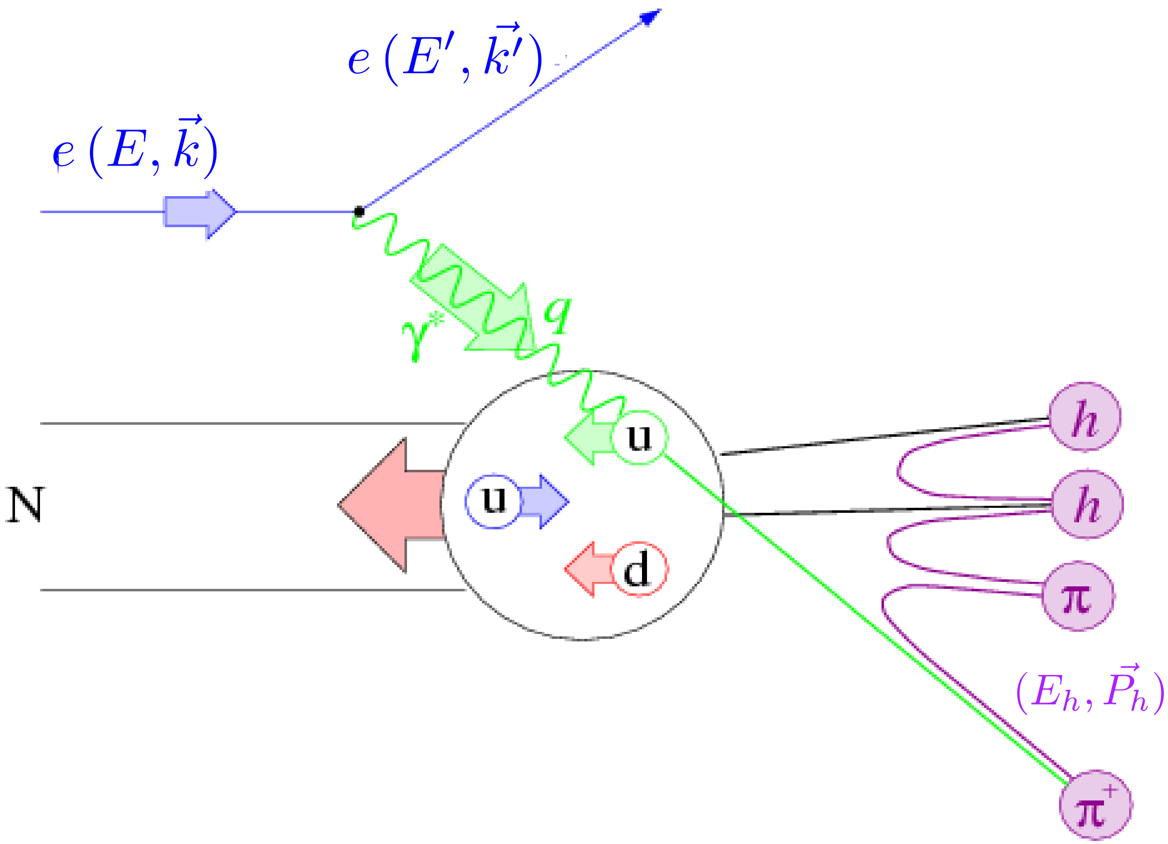


data taking from 1995 until June, 30 2007

n PID:
y (>98%) &
low contamination (<1%)

- hadron PID: RICH 2-15 GeV

Semi-inclusive deep-inelastic scattering



$$Q^2 \equiv -q^2$$

$$\nu \equiv \frac{Pq}{M} \stackrel{lab}{=} E - E'$$

$$y \equiv \frac{Pq}{Pk} \stackrel{lab}{=} \frac{\nu}{E}$$

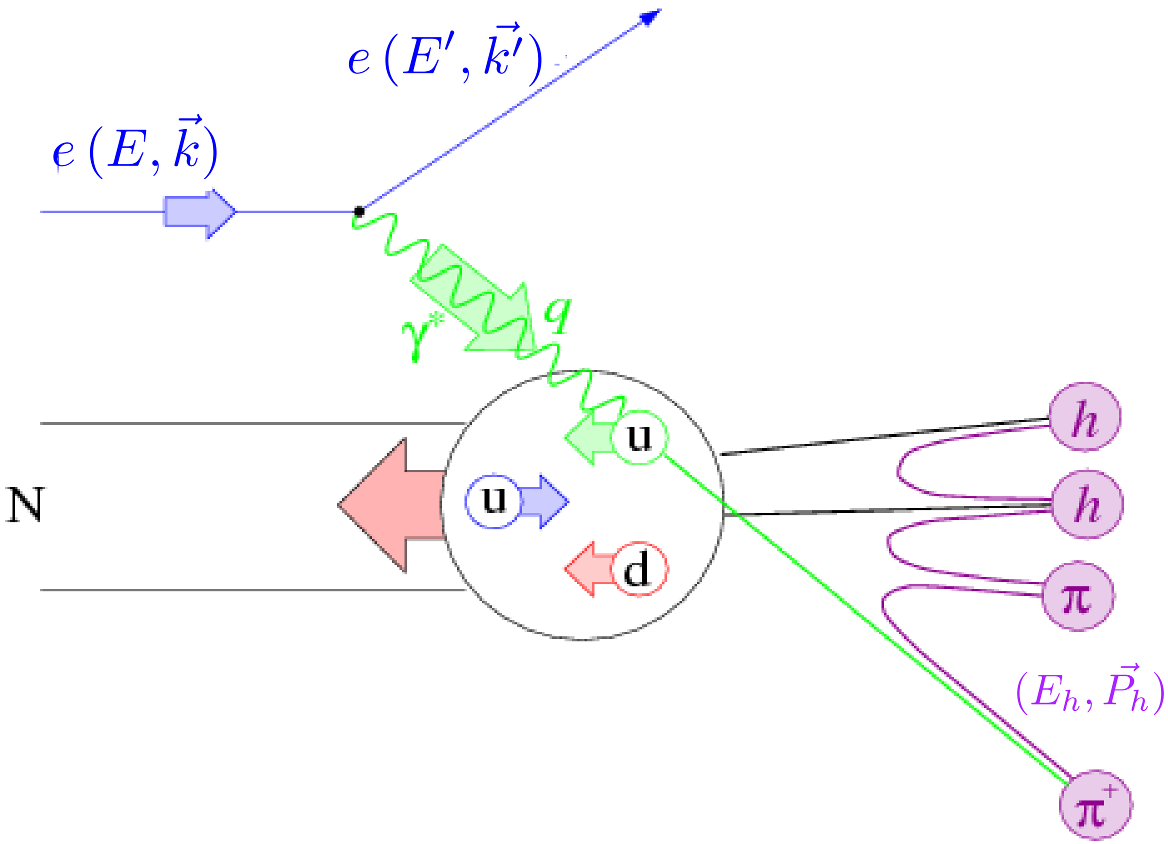
$$x_B \equiv \frac{Q^2}{2Pq}$$

$$W^2 \equiv M^2 + Q^2(x_B - 1)$$

$$z \equiv \frac{PP_h}{Pq} \stackrel{lab}{=} \frac{E_h}{\nu}$$

$$P_{hT} = \frac{|\vec{q} \times \vec{P}_h|}{|\vec{q}|}$$

Semi-inclusive deep-inelastic scattering



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$$P_{hT} = \frac{|\vec{q} \times \vec{P}_h|}{|\vec{q}|}$$

$$\sigma^{ep\to ehX} = \sum_q DF^{p\to q}(x_B, k_\perp^2, Q^2) \otimes \sigma^{eq\to eq} \otimes FF^{q\to h}(z, p_\perp^2, Q^2)$$

distribution function (DF):
distribution of quarks in nucleon
$k_\perp$: transverse momentum of struck quark

fragmentation function (FF): fragmentation of struck quark into final-state hadron
$p_\perp$: transverse momentum of fragmenting quark

Hadron multiplicities and fragmentation functions

$$\mathrm{M}^h(x_B, Q^2, z, P_{hT}) = \frac{1}{d^2 N^{DIS}(x_B, Q^2)} \frac{d^4 N^h(x_B, Q^2, z, P_{hT})}{dz dP_{hT}} \qquad (*)$$

$$\propto \frac{\sum_q e_q^2 \mathcal{I}[f_1^q(x_B, k_\perp^2, Q^2) \otimes \mathcal{W}\, D_1^q(z, p_\perp^2, Q^2)]}{\sum_q e_q^2 f_1^q(x_B, Q^2)}$$

collinear

$$\propto \frac{\sum_q e_q^2 f_1^q(x_B, Q^2)\, D_1^q(z, Q^2)}{\sum_q e_q^2 f_1^q(x_B, Q^2)}$$

access to fragmentation function $\mathrm{D}_1^q(z, (p_\perp^2), Q^2)$:

- probe fragmentation function complementary to e^+e^- and $p\overset{(-)}{p}$
- charge-separated fragmentation functions
- flavor-separated fragmentation functions

(*) integrated of hadron azimuthal angle

Extraction of multiplicities

- charge-separated pion and kaon multiplicities
- hydrogen and deuterium targets
- kinematic requirements:

$$Q^2 > 1\ \mathrm{GeV}^2 \qquad 2\ \mathrm{GeV} < P_h < 15\ \mathrm{GeV}$$

$$W^2 > 10\ \mathrm{GeV}^2 \qquad 0.2 < z < 0.8$$

$$0.1 < y < 0.85$$

- 3D binning: (x_B, z, P_{hT}) and (Q^2, z, P_{hT}) (x_B and Q^2 strongly correlated)

Extraction of multiplicities

- correction for charge-symmetric background
- correction for RICH misidentification
- correction for trigger inefficiencies
- subtraction of dominant exclusive VM contributions: not done for the results that follow
- correction for particle decay and loss through detector acceptance and/or smearing via unfolding

Extraction of Born multiplicities

$$M^h_{Born}(j) = \frac{1}{n^{DIS}_{Born}(j)} \sum_i \left[S_h^{-1}\right](j,i) \left[M^h_{meas}(i)\,\frac{N^{DIS}_{meas}}{N^{DIS}_{tracked\,MC}} - n^h(i,0)\right]$$

smearing matrix from LEPTO+JETSET Monte-Carlo simulation

$$S_h(i,j) = \frac{n^h(i,j)}{n^h_{Born}(j)}$$

reconstructed

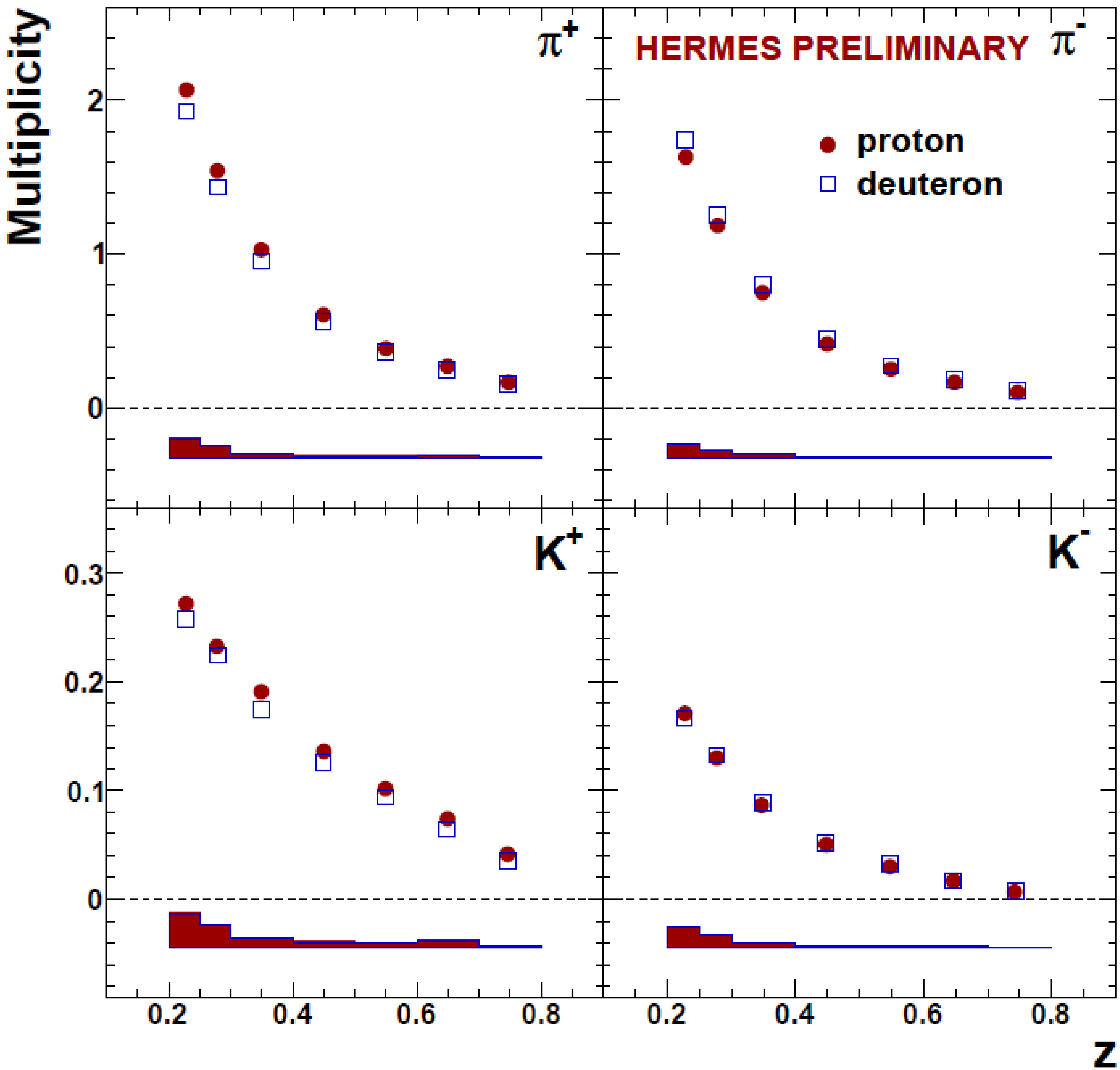
generated (Born)

$n^h(i,0)$ migration of events outside acceptance into acceptance

accounts for

- QED radiative effects (RADGEN)
- limited geometric and kinematic acceptance of spectrometer
- detector resolution and particle decay

Results $M^{h}_{p/d}$ projected in z



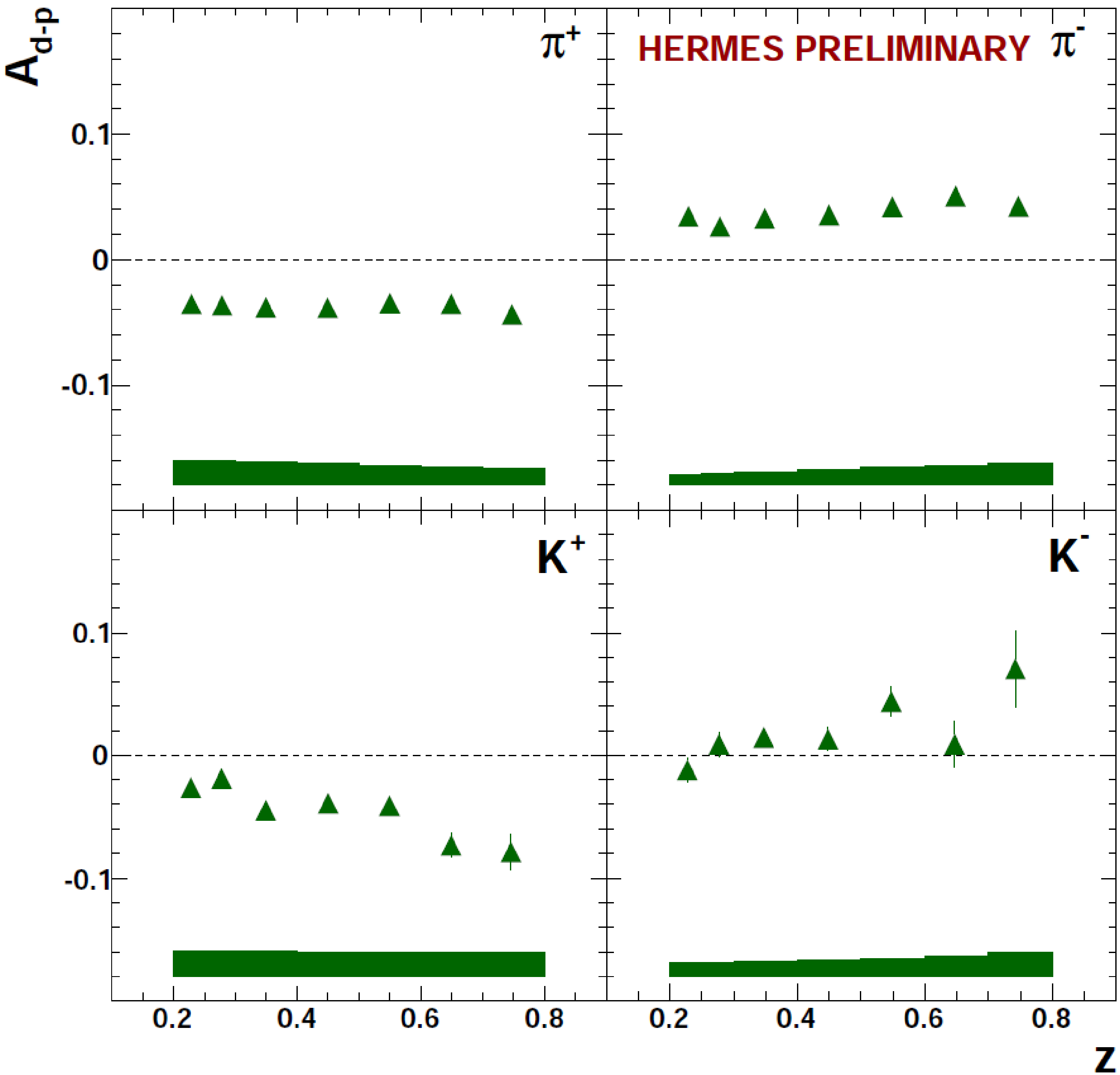
$$\frac{M^{\pi^+}_{p(d)}}{M^{\pi^-}_{p(d)}} = 1.2 - 2.6\,(1.1 - 1.8)$$

$$\frac{M^{K^+}_{p(d)}}{M^{K^-}_{p(d)}} = 1.5 - 5.7\,(1.3 - 4.6)$$

multiplicities reflect

- nucleon valence-quark content (u-dominance)
- favored $\leftrightarrow$ unfavored fragmentation

Results $A^h_{p\text{-}d}$ projected in z



$$A^h_{d-p} = \frac{M^h_d - M^h_p}{M^h_d + M^h_p}$$

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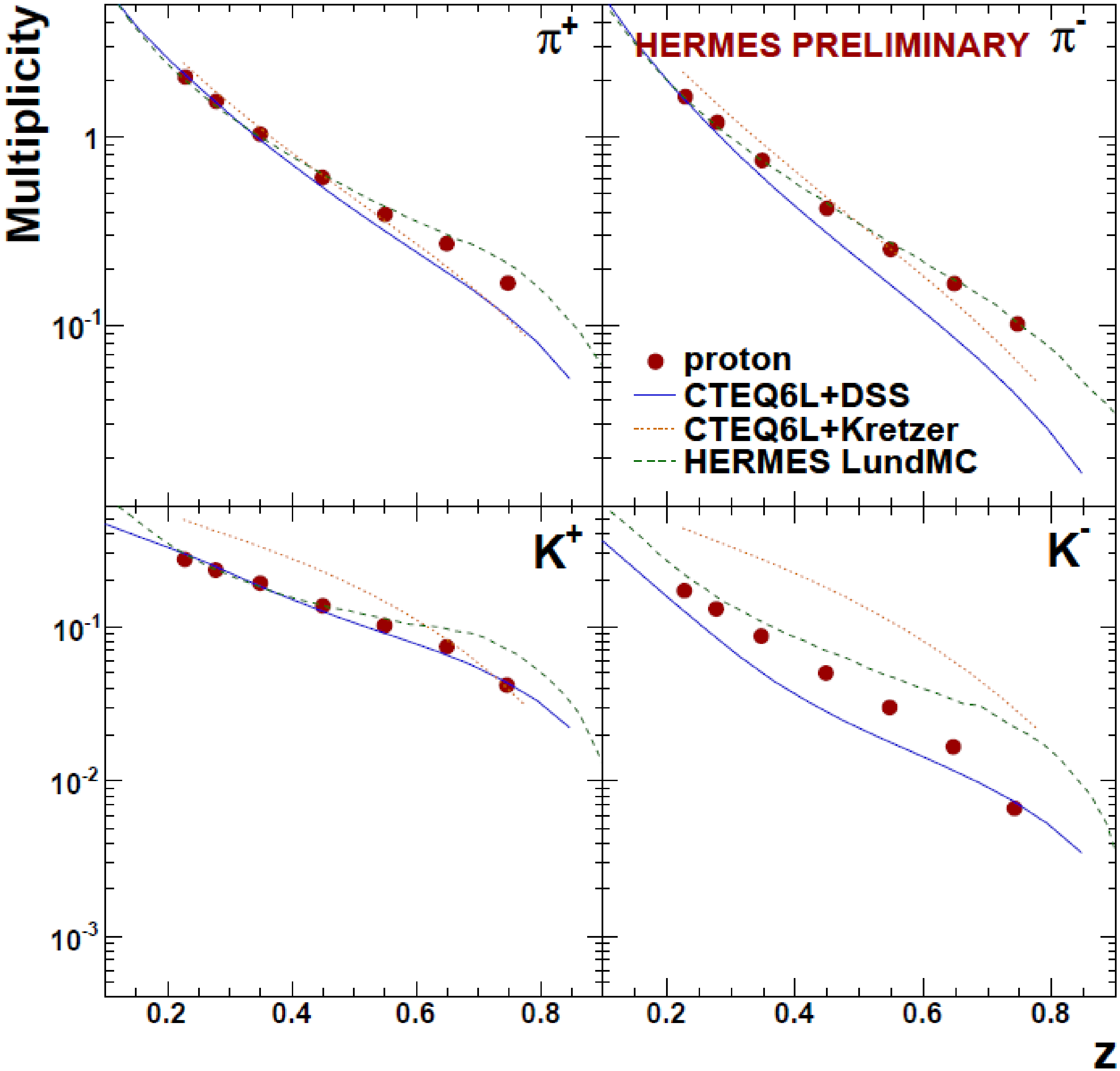
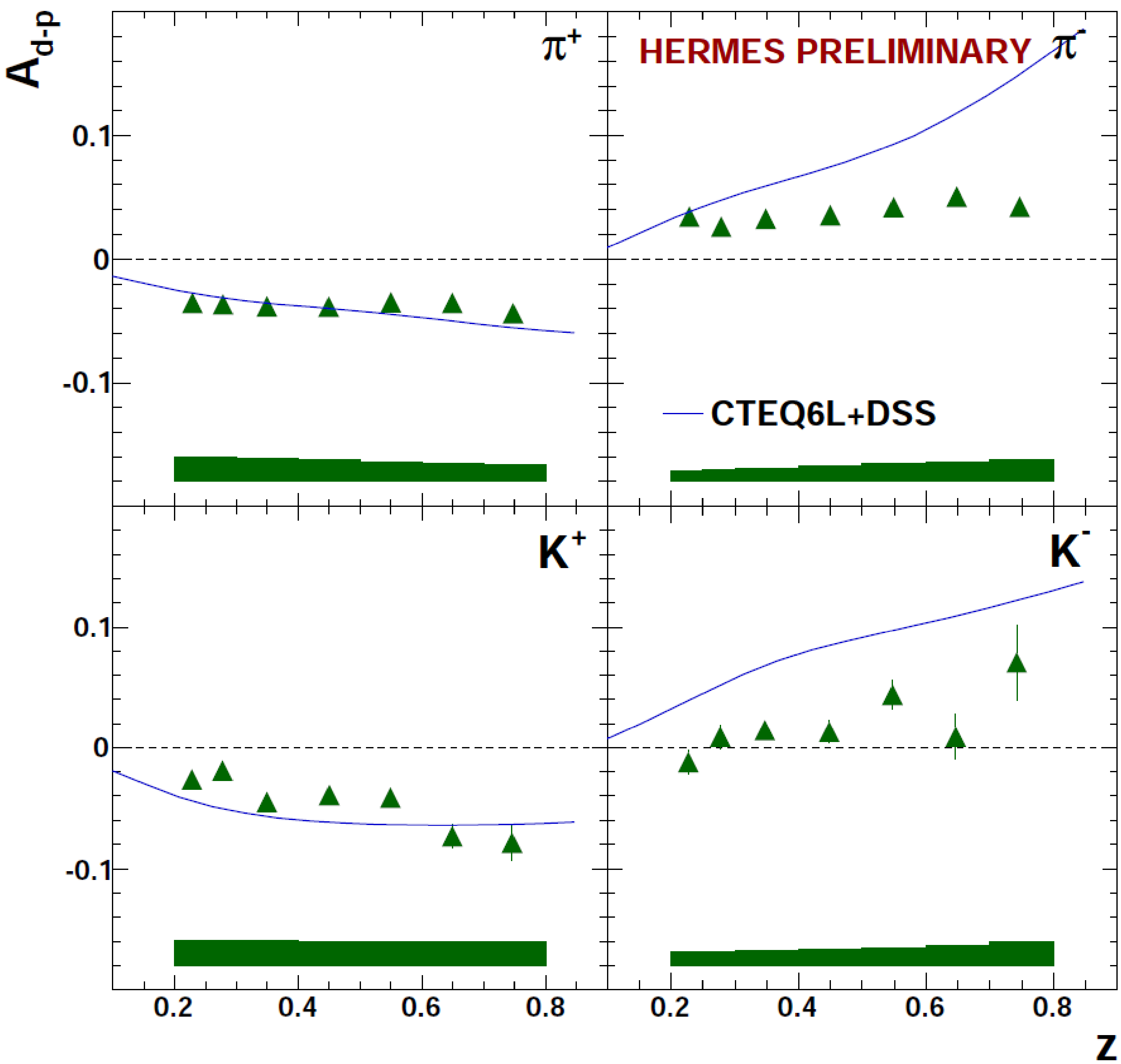
Comparison with models



- LO in α_S
- CTEQ6L PDFs
  JHEP **0602** (2006) 032
- DSS FFs
  Phys. Rev. D**75** (2007) 114010
- Kretzer FFs
  Phys. Rev. D**62** (2000) 054001

Comparison with models



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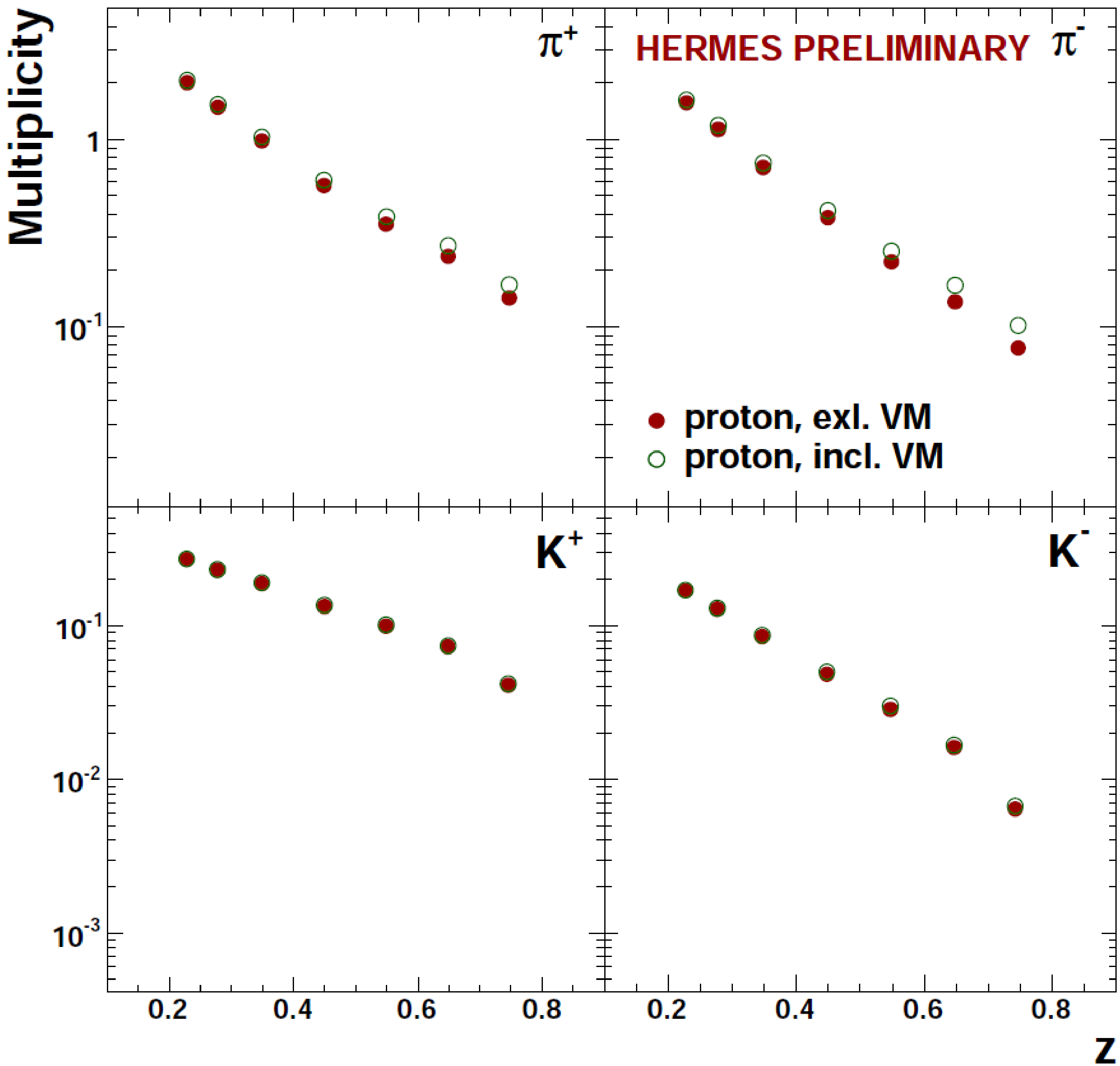
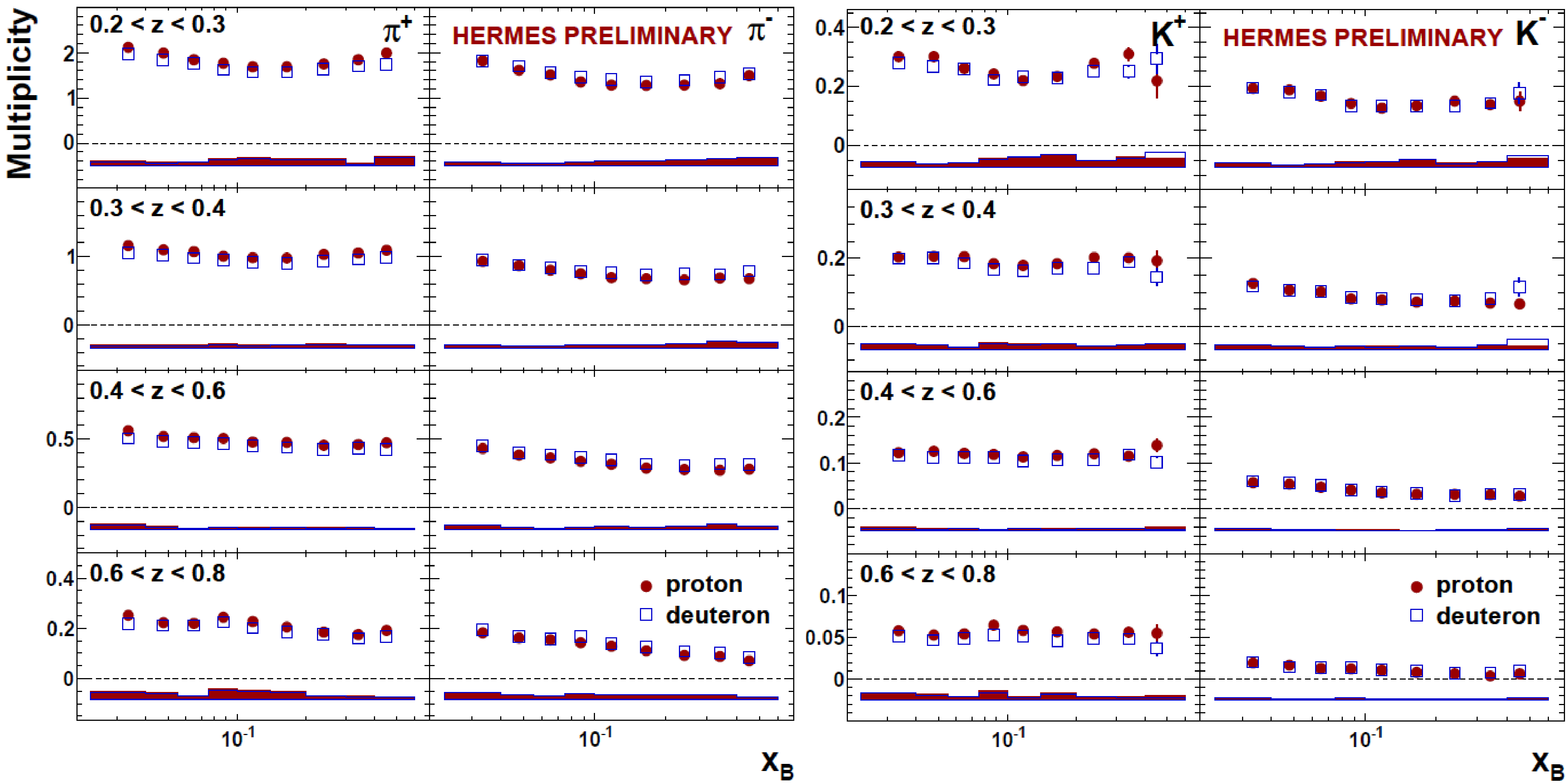
Exclusive vector-meson contribution



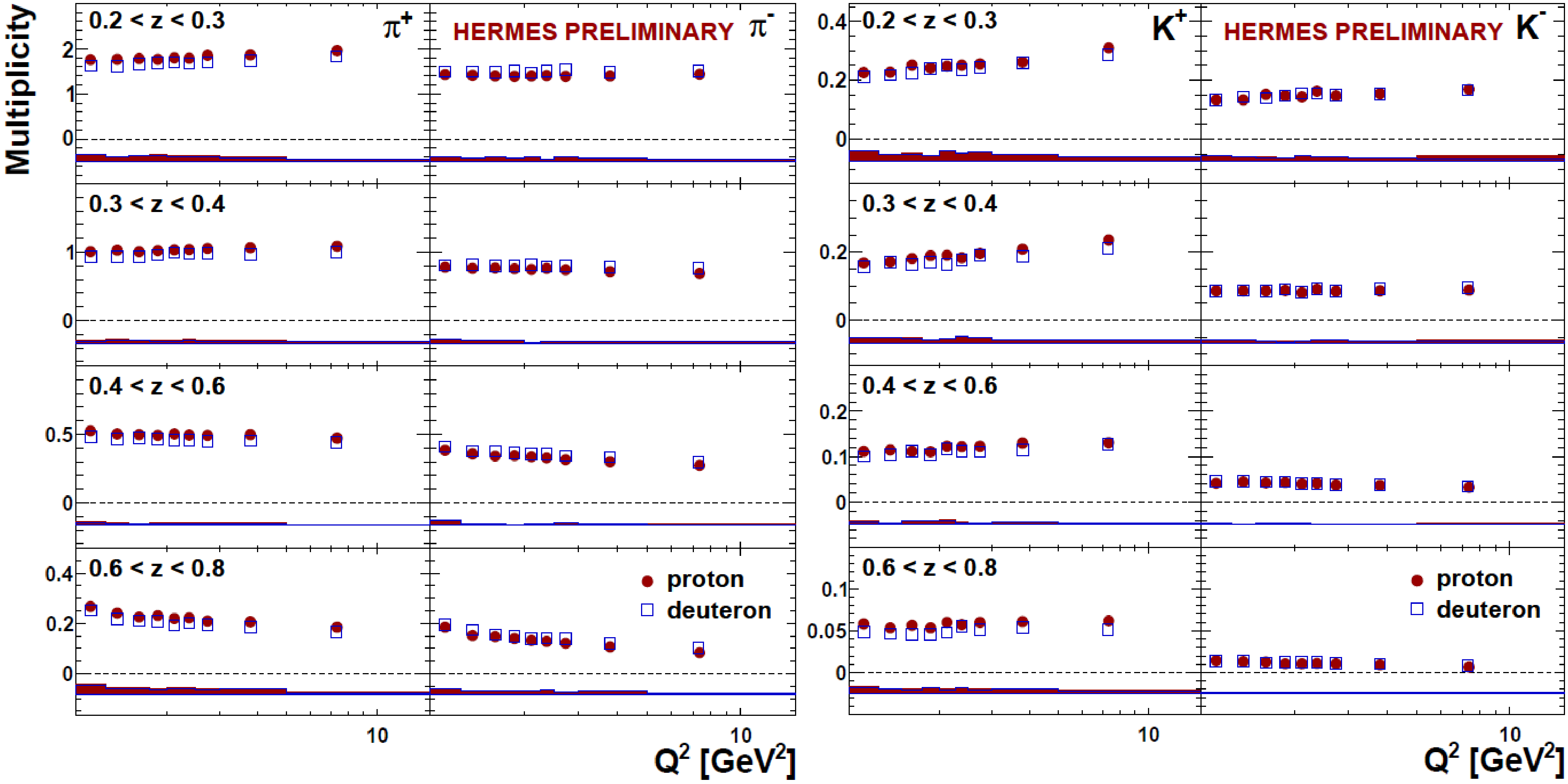
- modeled using PYTHIA
- pions (exclusive ρ^0)
  - large z: up to 50%
  - low z: negligible
- kaons (exclusive ϕ)
  less than 10%

Results $M^h_{p/d}$ projected in z and x_B



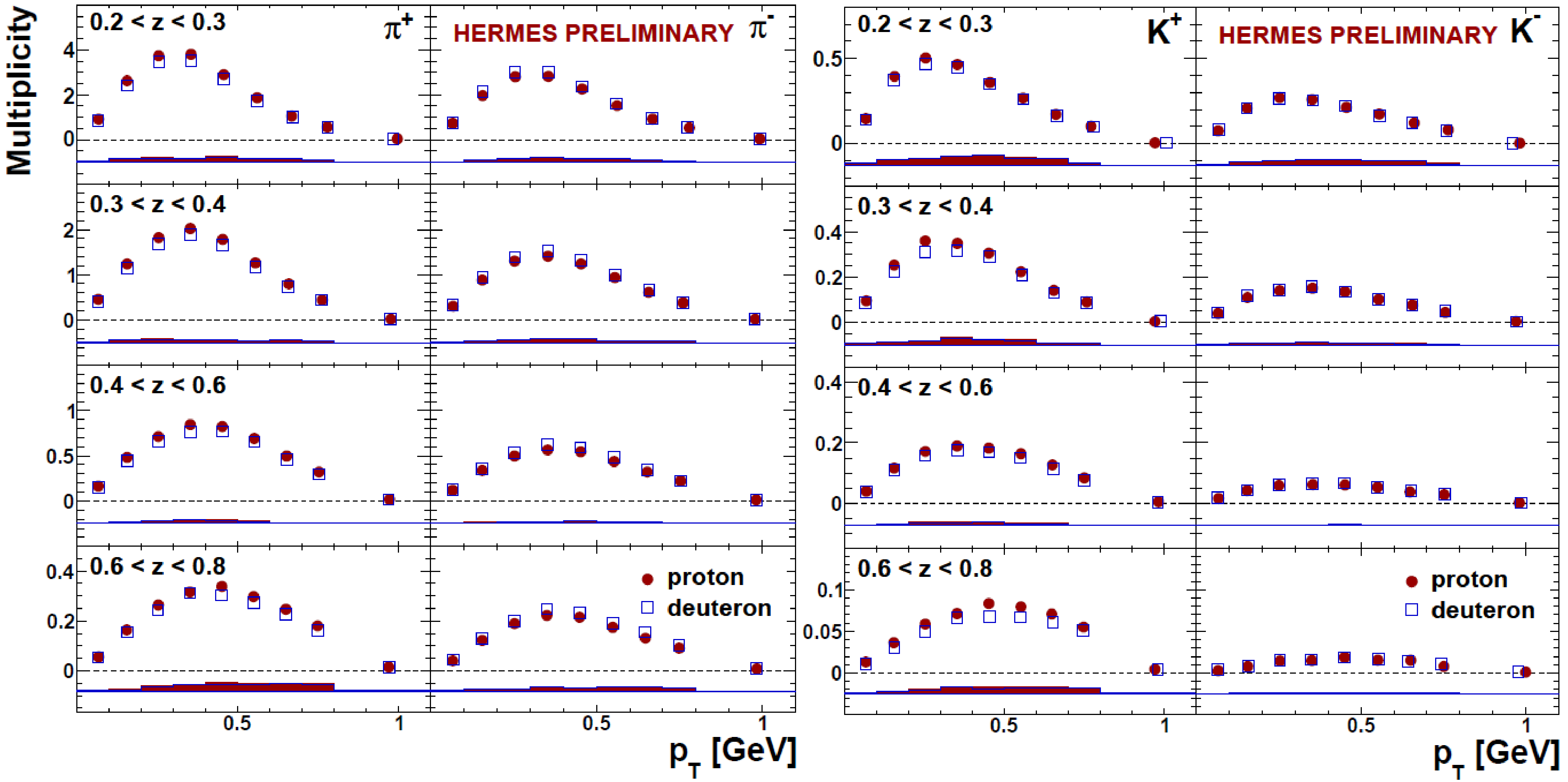
- no strong dependence on x_B

Results $M^{h}_{p/d}$ projected in z and Q^2



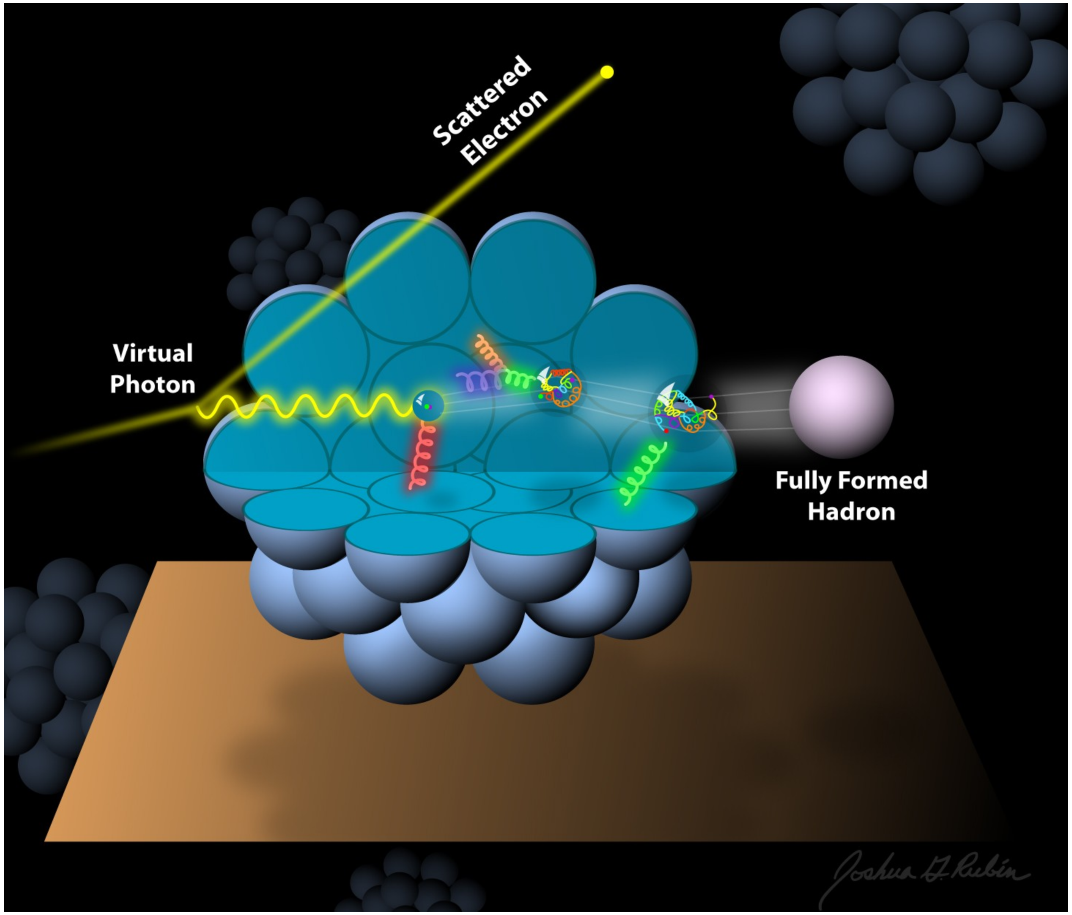
- hint for increase at low z and decrease at high z with in increasing Q^2 cf. Q^2 evolution
- strong correlation x_B and Q^2

Results $M^h_{p/d}$ projected in z and P_{hT}



- P_{hT} (=p_T on figures): - transverse intrinsic struck-quark momentum
  - transverse momentum from fragmentation process
  - soft gluon radiation (NLO)
- K^-: broader distribution

Multiplicity ratios and hadronization in nuclei



$$\mathrm{R}_A^h(\nu, Q^2, z, P_{hT}^2) = \frac{M_A^h(\nu, Q^2, z, P_{hT}^2)}{M_D^h(\nu, Q^2, z, P_{hT}^2)}$$

- insight into space-time evolution of hadronization
- input for extraction of nuclear PDFs
- insight into jet quenching and parton energy losses in heavy-ion collisions

Extraction of multiplicity ratios

- charge-separated pions and kaons, protons and anti-protons
- Ne, Kr, and Xe targets
- kinematic requirements:

$$Q^2 > 1\ \mathrm{GeV}^2 \qquad 2\ \mathrm{GeV} < P_h < 15\ \mathrm{GeV}$$

$$W^2 > 4\ \mathrm{GeV}^2 \qquad 0.2 < z$$

$$0.1 < y < 0.85 \qquad x_F = P_{h||}^{\gamma^* - N\ cm} / |\vec{q}| > 0$$

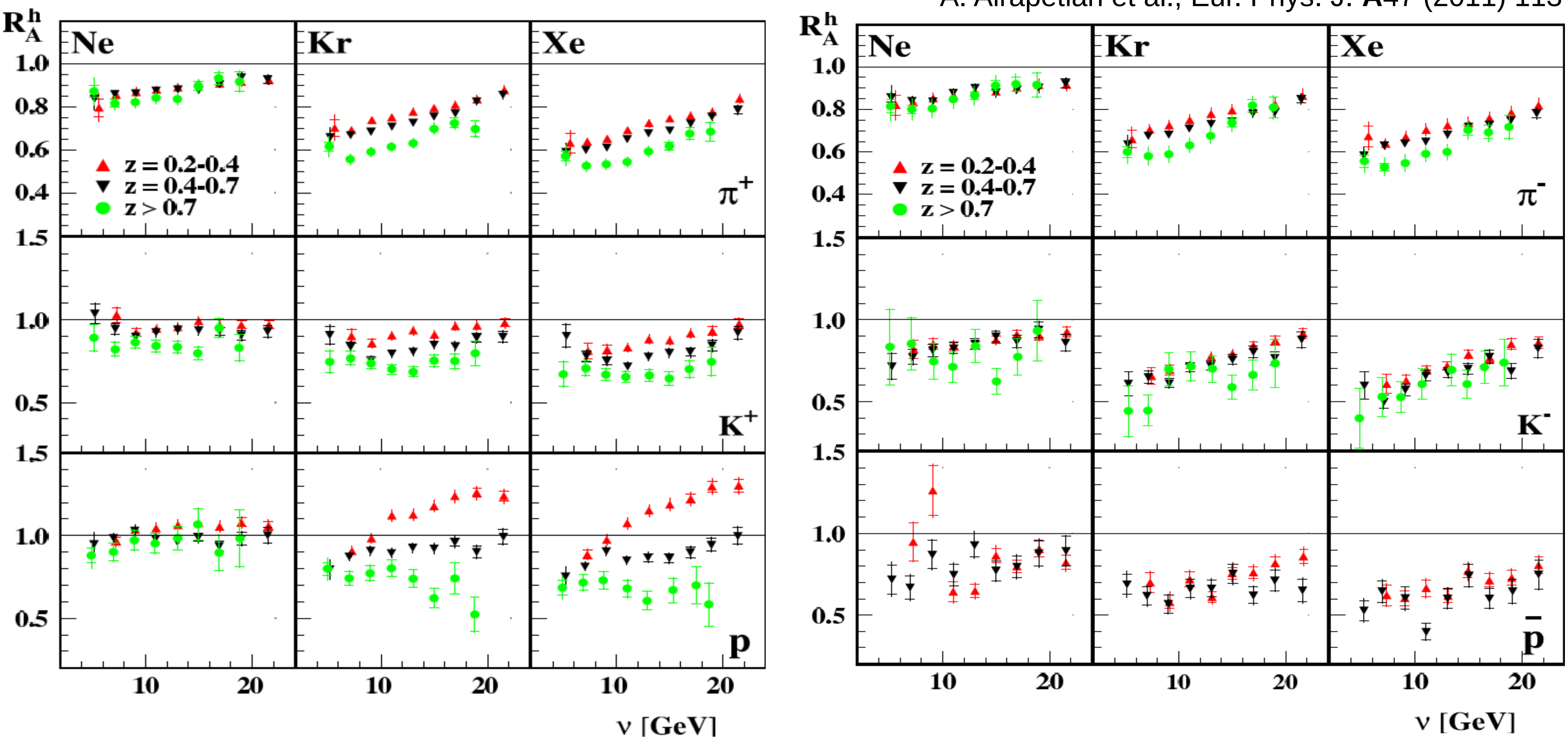
- 2D binning:

  - ν for slices of z
  - z for slices of ν
  - P_{hT}^2 for slices of z
  - z for slices of P_{hT}^2

- radiative corrections applied
- other effects (detector acceptance, PID, VM contribution,...)
  ≈ cancel: included in systematic uncertainties

Results in ν for slices of z

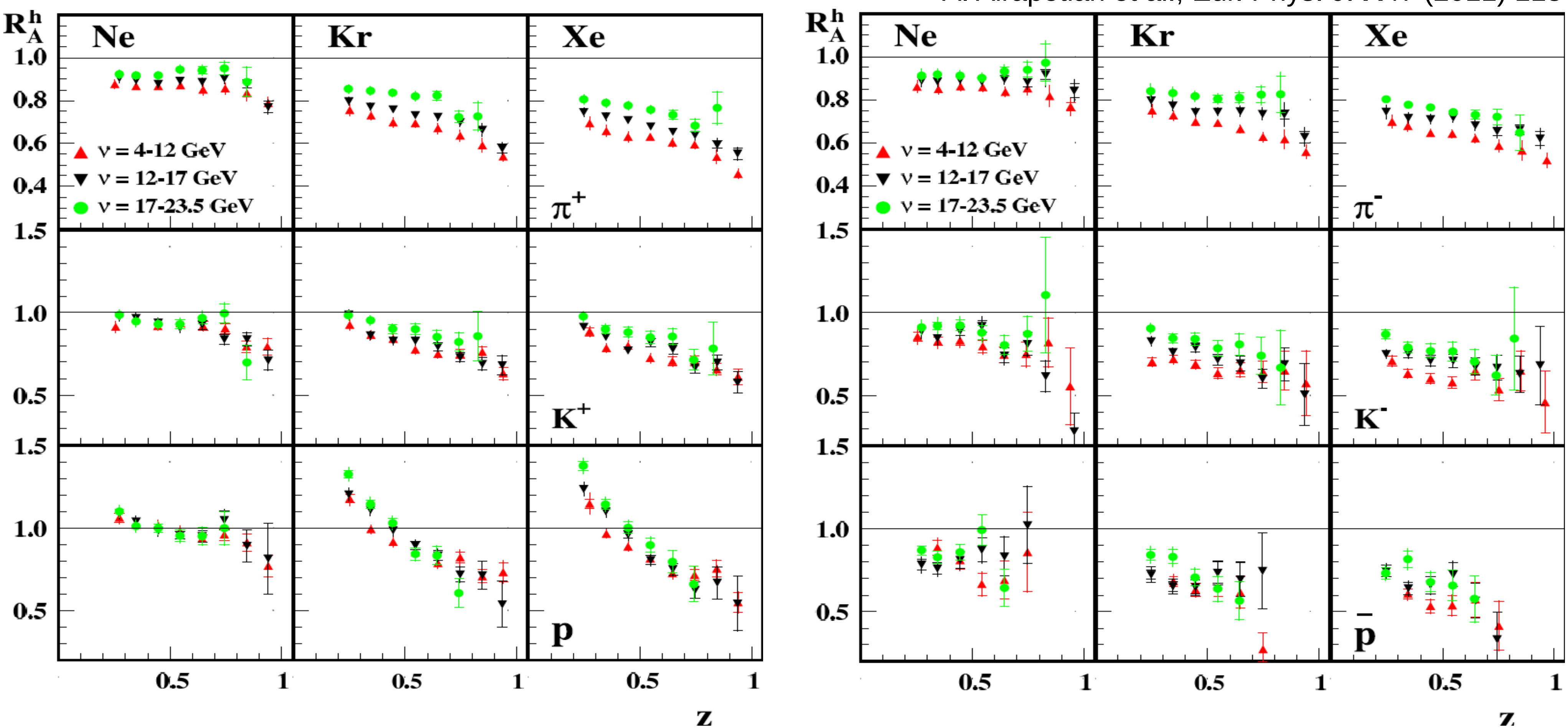
A. Airapetian et al., Eur. Phys. J. **A**47 (2011) 113



- R_A^h decreases with increasing A (except for protons)
- $\pi^\pm$ & K^-: R_A^h increases with increasing ν
- K^+: R_A^h increases with increasing ν, but different behavior
- p: $R_A^h > 1$ at low z

Results in z for slices of ν

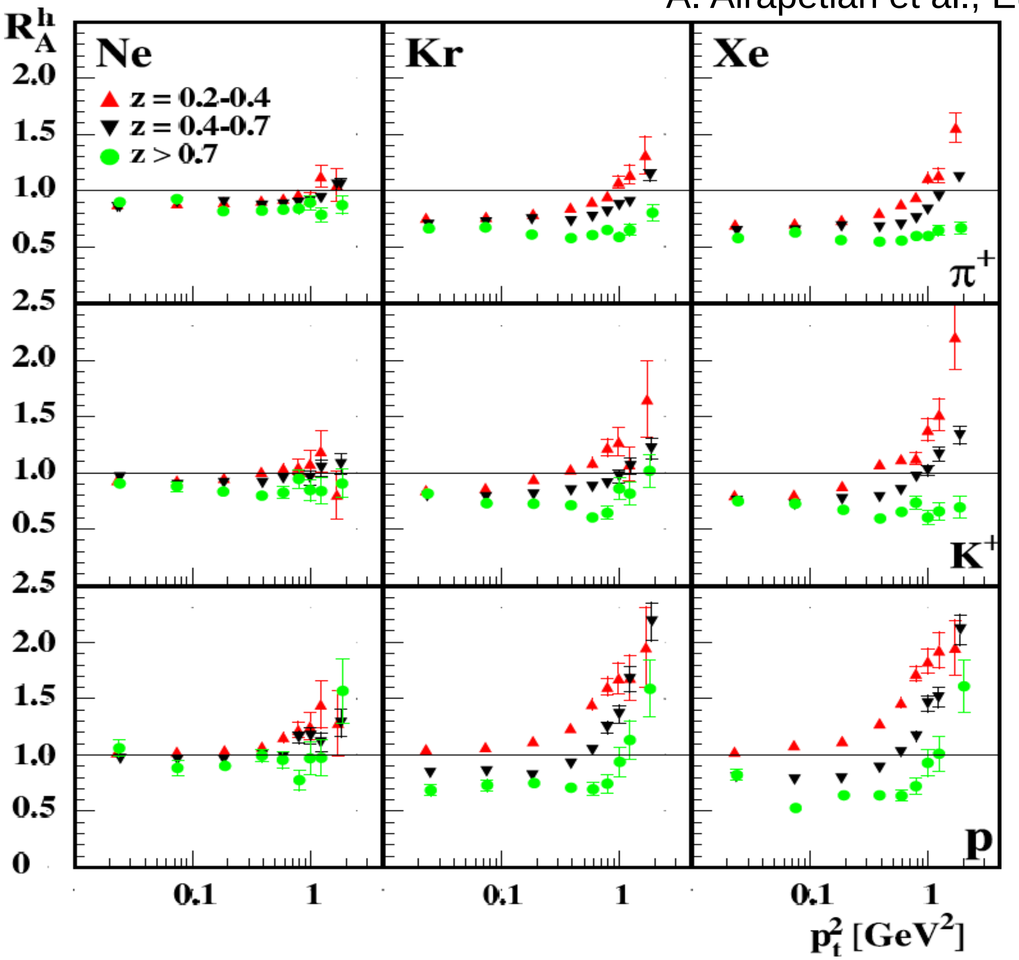
A. Airapetian et al., Eur. Phys. J. **A**47 (2011) 113



- R_A^h decreases with increasing z
- effect increases with increasing A
- p: $R_A^h > 1$ at low z
- K^+: $R_A^h \simeq 1$ at low z

Results in P_{hT}^2 for slices of z

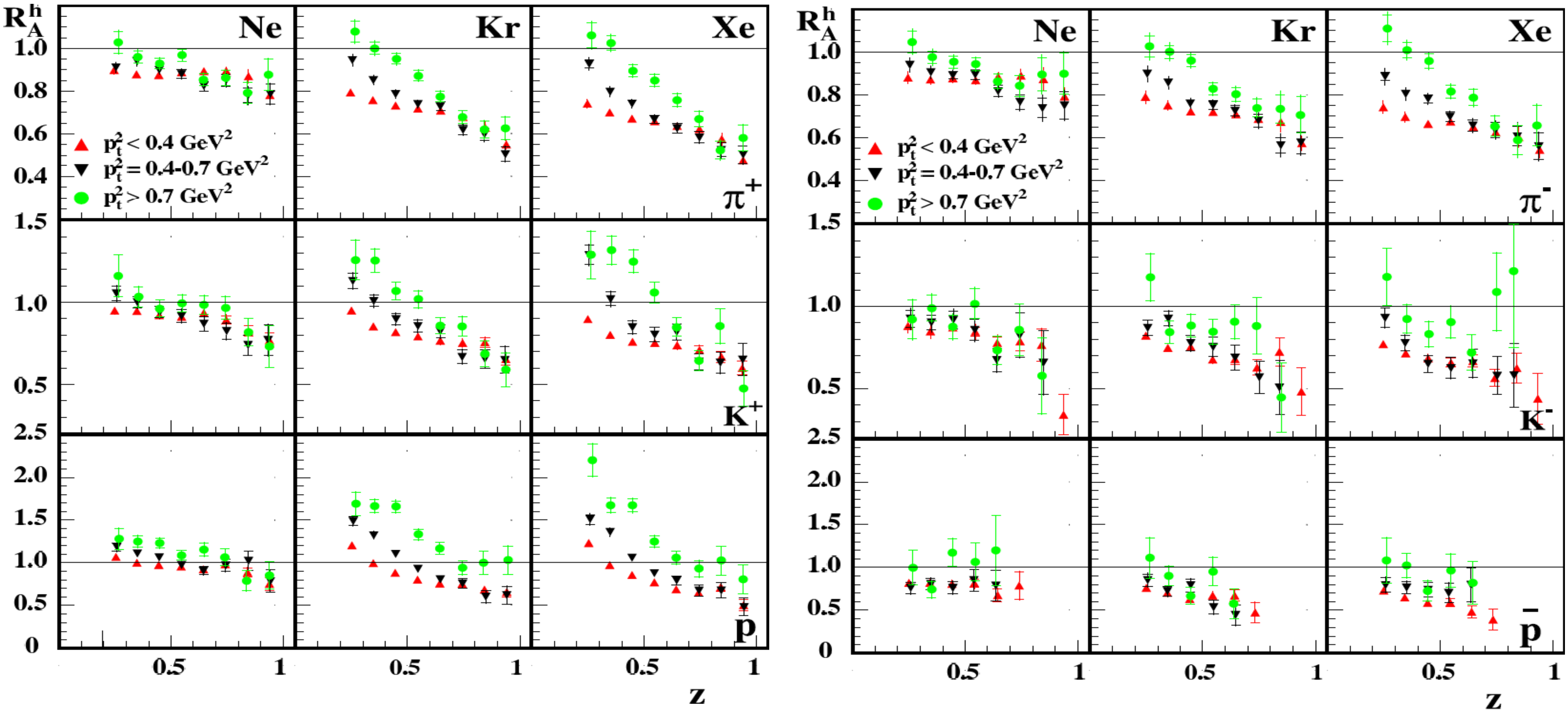
A. Airapetian et al., Eur. Phys. J. **A**47 (2011) 113



- R_A^h increases strongly with increasing P_{hT}^2 (Cronin effect)
- except at large z for π^+ and K^+

Results in z for slices of P^2_{hT}

A. Airapetian et al., Eur. Phys. J. **A**47 (2011) 113



- decrease of R^h_A with increasing z stronger at large P^2_{hT} and A
- no Cronin effect at large z
- p: R^h_A at low z larger for large P^2_{hT}

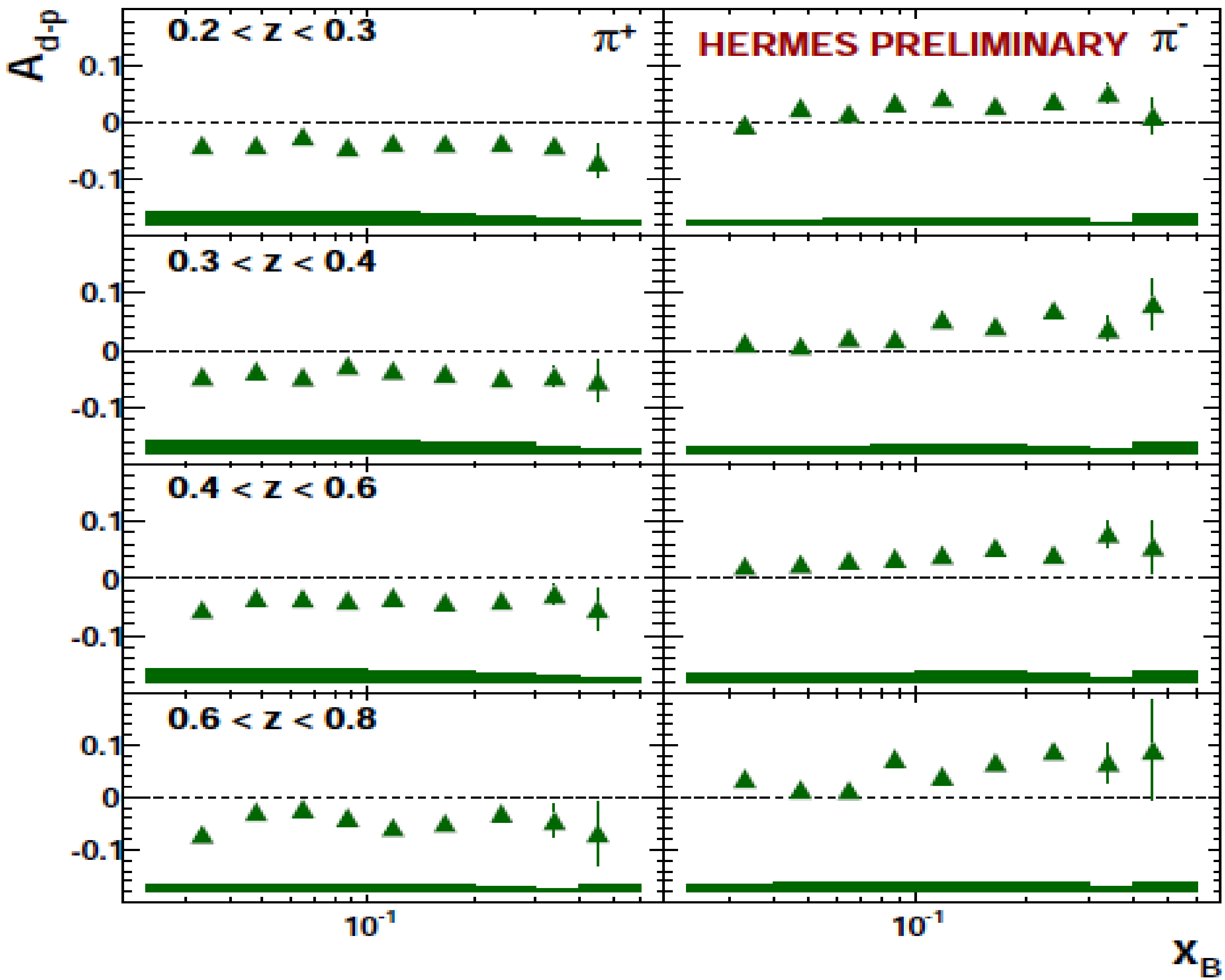
Summary

- $\pi^{\pm}$ and $K^{\pm}$ multiplicities on hydrogen and deuterium:
  - 3-dimensional extraction
  - support notion of favored fragmentation

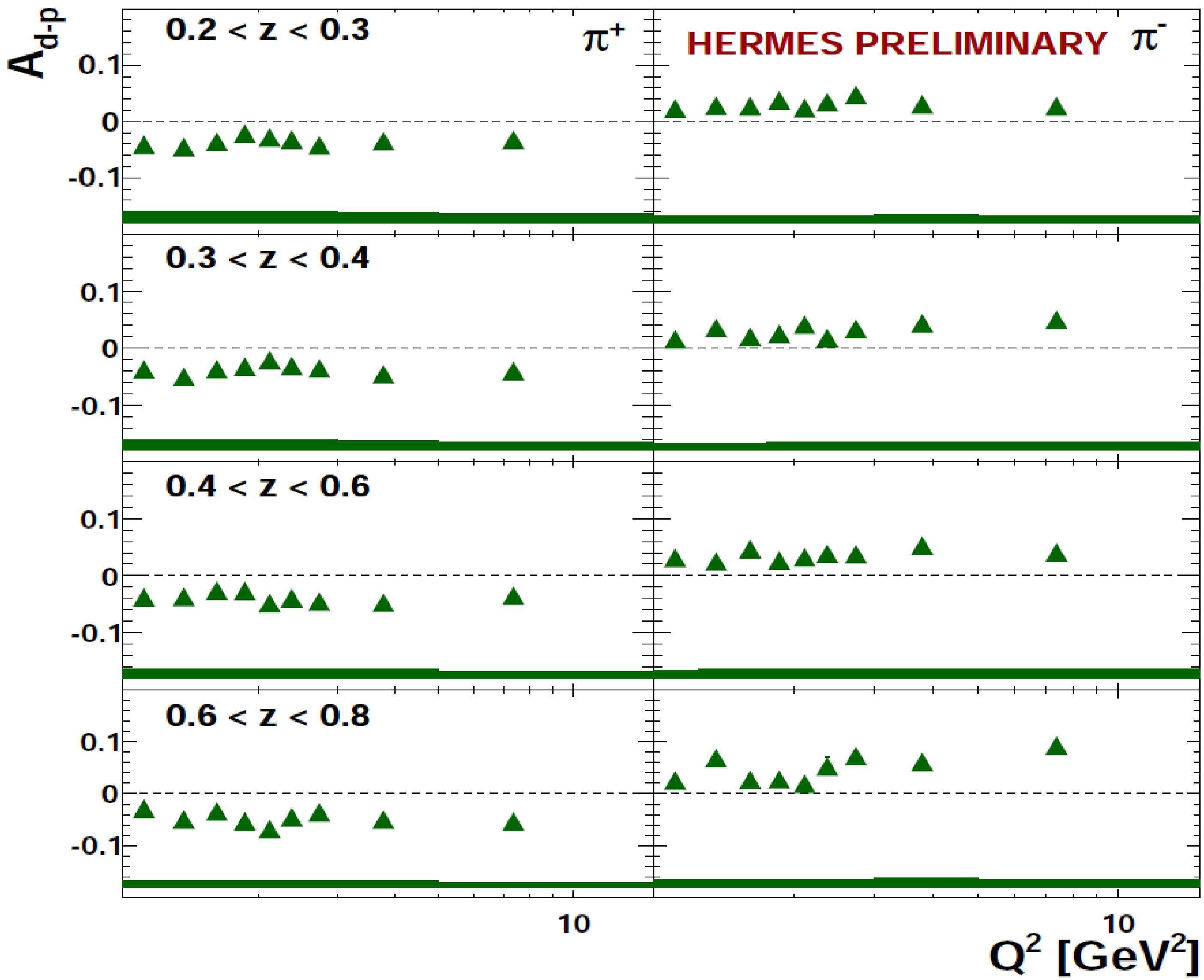
- hadronization in nuclei:
  - 2-dimensional extraction
  - contribute to increased understanding of fragmentation process

Back up

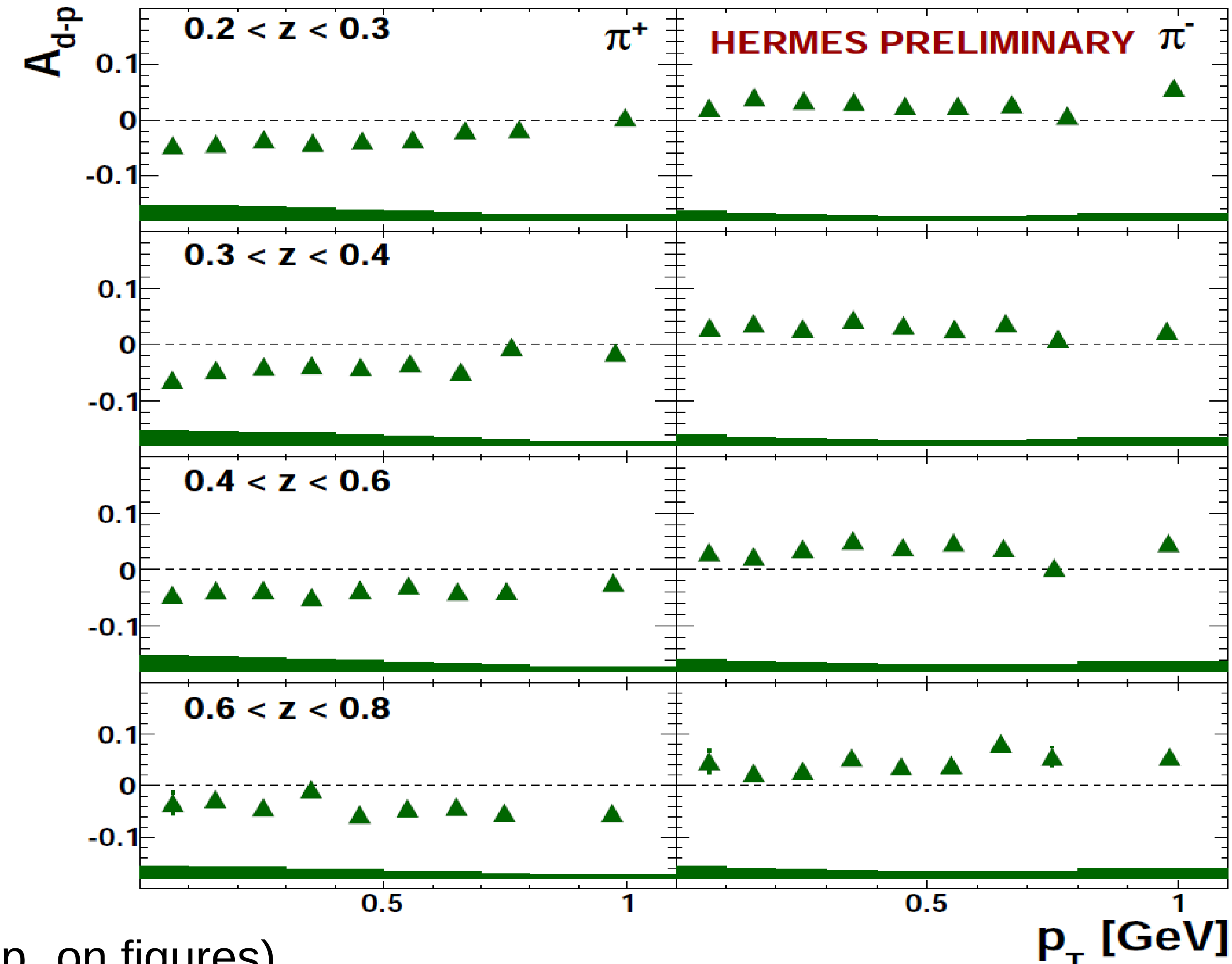
Results $A^{h}_{p\text{-}d}$ projected in z and x_B



Results $A^{h}_{p\text{-}d}$ projected in z and Q^2



Results $A^{h}_{p\text{-}d}$ projected in z and $P_{h\perp}$



P_{hT} (=p_T on figures)