Measurement of Pion Multiplicities and Hadron $P_\perp$ in DIS at hermes

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on behalf of the HERMES Collaboration

INFN Frascati

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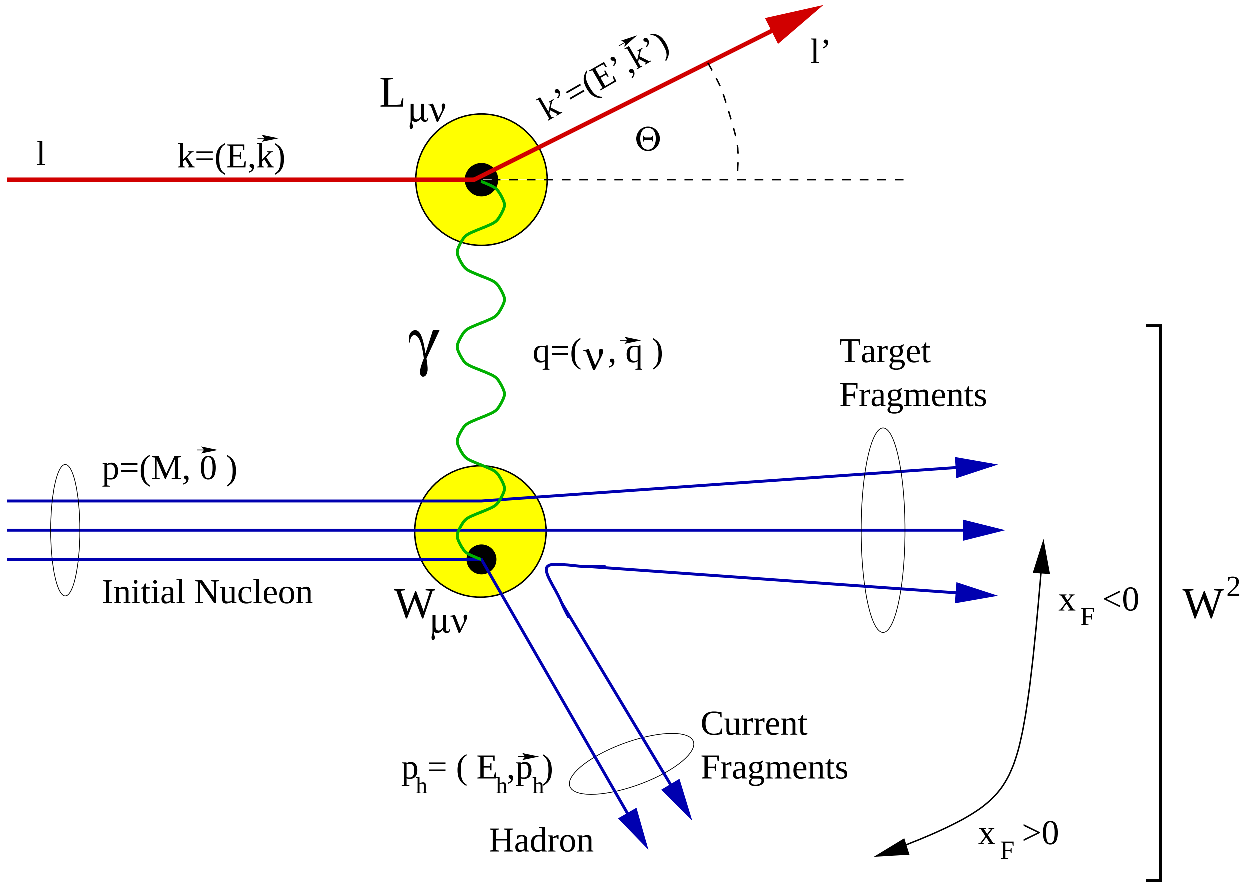
- QPM: factorization and scaling
- Charged and neutral pion multiplicities: $D^{\pi^{0/+/-}}$
- Isospin invariance measurement
- Scaling violation of FFs: Q^2 evolution
- $P_\perp$ distribution of $h^\pm$, $\pi^\pm$ and K_s^0

Semi-inclusive process



QPM including *factorization* and *scaling* hypothesis:

$$d\sigma^h(z) \propto \sum_f q_f(x) \cdot d\sigma_f \cdot D_f^h(z)$$

$$\frac{1}{N_{DIS}} \frac{dN^h(x,z)}{dz} = \frac{\sum_q e_q^2 q(x) D_q^h(z)}{\sum_q e_q^2 q(x)}$$

$z = E_h/\nu$

Quark distribution: $q(x)$

Fragmentation Function: $D_q^h(z) \longrightarrow D_q^h(z, Q^2)$

Multiplicity & FF

$$\frac{1}{N_{DIS}}\frac{N^{\pi^0}}{dz} =$$

$$= \frac{1}{\sum_f e_f^2 q_f}\left[\left(\frac{4}{9}u + \frac{1}{9}\bar{d} + \frac{4}{9}\bar{u} + \frac{1}{9}d\right) D_u^{\pi^0} + \frac{1}{9}(s+\bar{s}) D_s^{\pi^0}\right]$$

Neglecting s and $\bar{s}$ contributions:

$$\frac{1}{N_{DIS}}\frac{N^{\pi^0}}{dz} \simeq D_u^{\pi^0}(z)$$

For isospin invariance:

$$\sigma^{\pi^0} = \frac{\sigma^{\pi^+} + \sigma^{\pi^-}}{2}$$

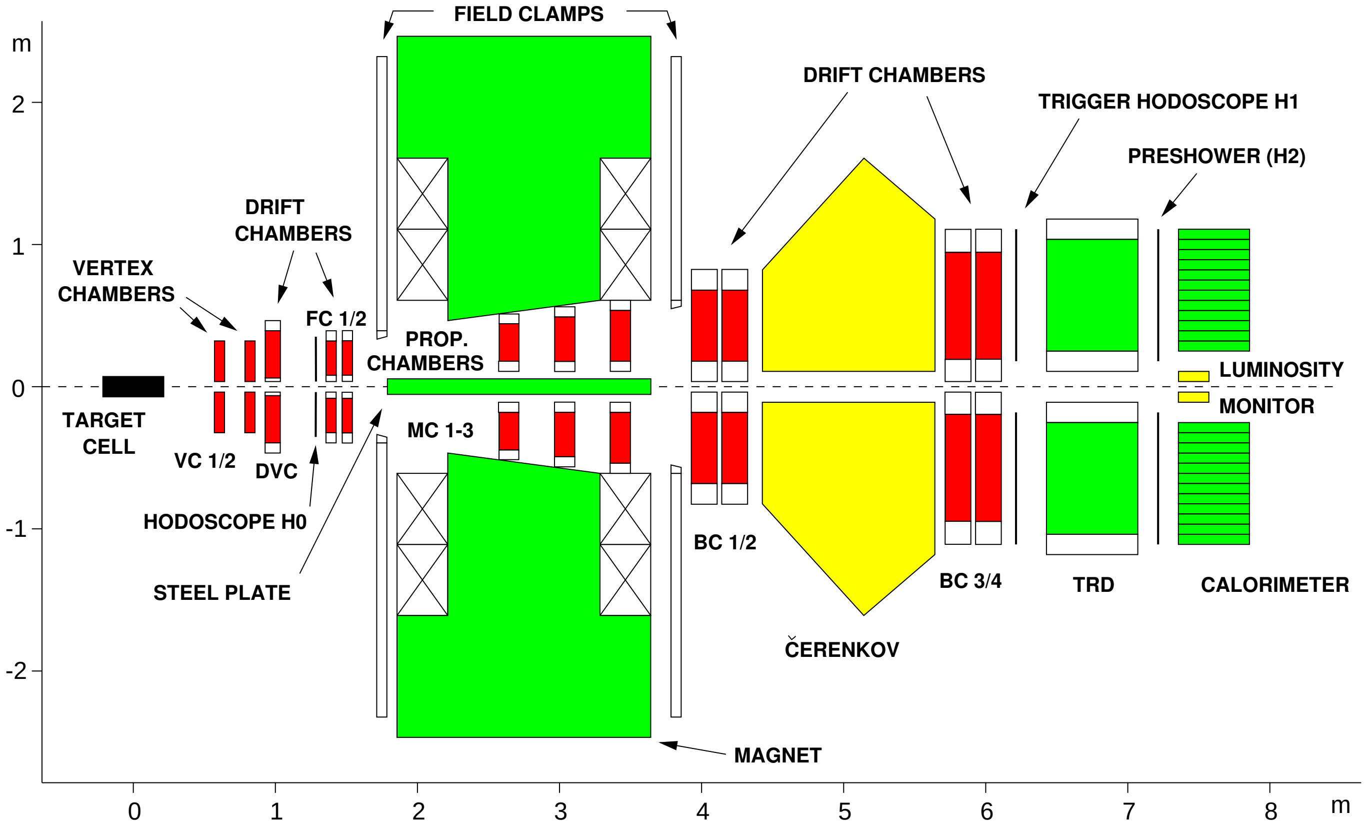
we can compare:

$$\sigma^{\pi^0} \leftrightarrow D^{\pi^0}; \quad \sigma^{\frac{\pi^+ + \pi^-}{2}} \leftrightarrow \sigma^{\pi^0}; \quad \sigma^{\pi^0} \leftrightarrow \frac{D_\pi^+ + D_\pi^-}{2}$$

The π^0 or $\frac{\pi^+ + \pi^-}{2}$ multiplicity provides the u-quark fragmentation for π^0 (i.e. $D_u^{\pi^0}$).

SPECTROMETER

(HERMES coll. NIM A417 (1998) 230)

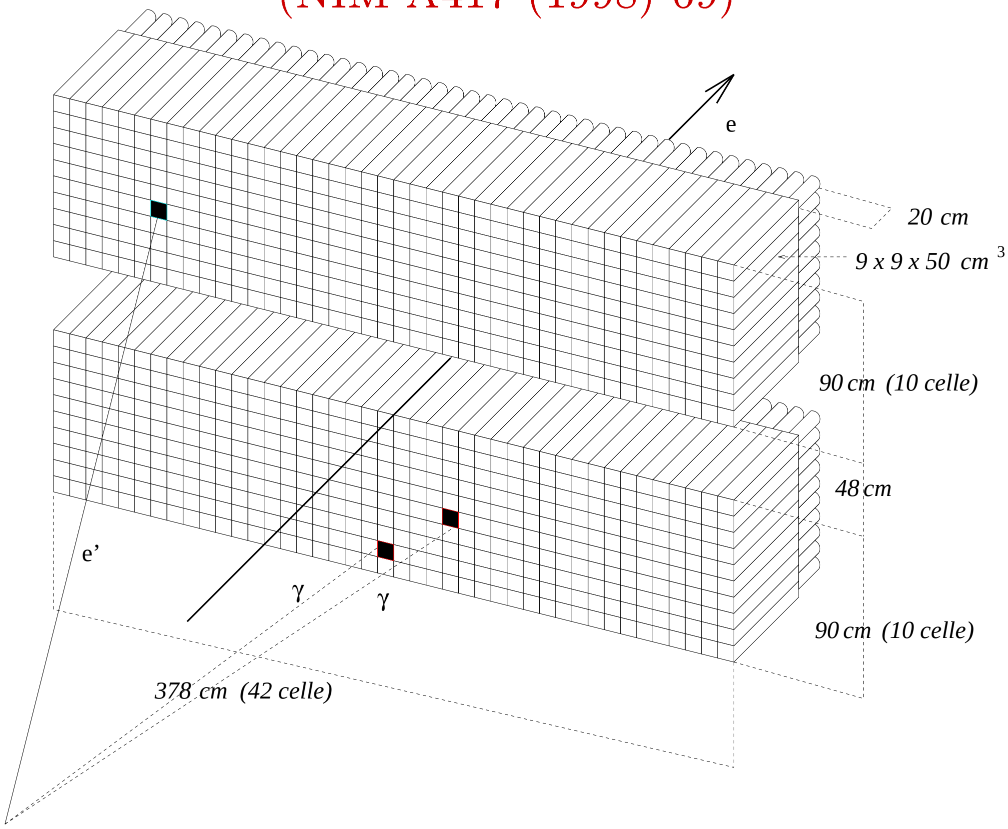


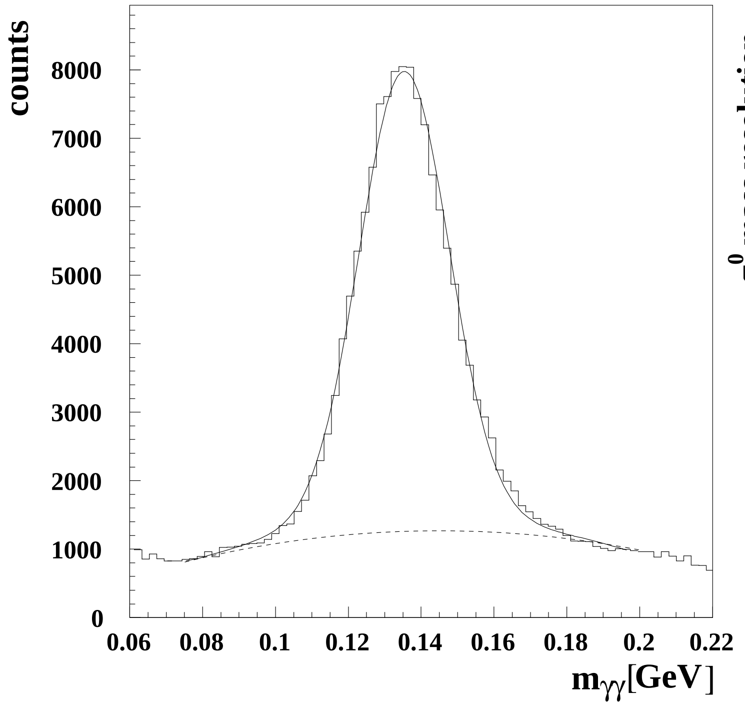
- **kinematic:** $0.004 < x < 0.8$ for $Q^2 > 0.2$ GeV^2 and $W^2 > 4$ GeV^2
- **Tracking**: 57 tracking planes, $\delta P/P = (0.7 - 1.3)\%$, $\delta\theta < 0.6$ mrad
- **Particle identification**: Cerenkov, TRD, Preshower, e.m. Calorimeter

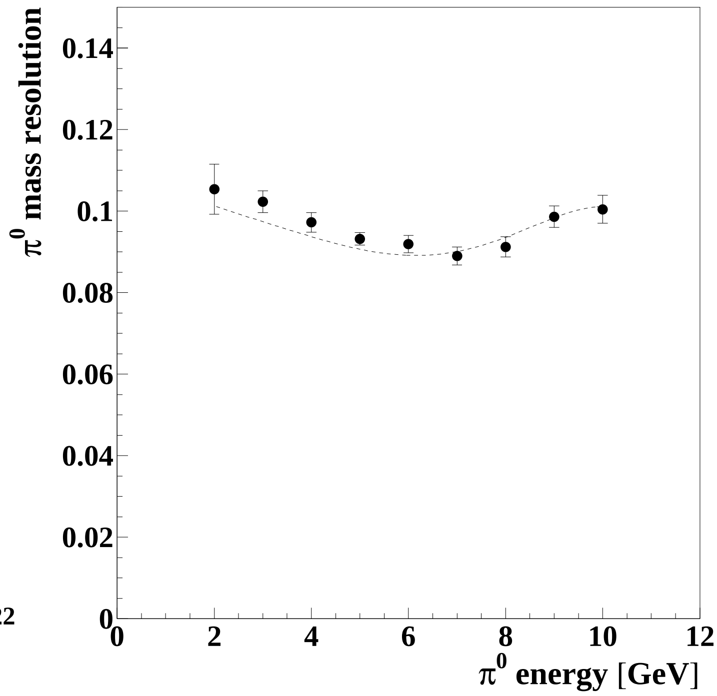
e^+ identification: 99% efficiency and $<1\%$ of contamination.

e.m. calorimeter

(NIM A417 (1998) 69)







$E_\gamma > 1.4$ GeV, $z = \frac{E_{\pi^0}}{\nu} > 0.1$

$$\boxed{M_{\pi^0} = 0.135 \pm 0.012 \text{ GeV}}$$

Monte Carlo + Radiative Corrections

Geometrical and kinematical acceptances have been corrected by the HERMES Monte Carlo (HMC):

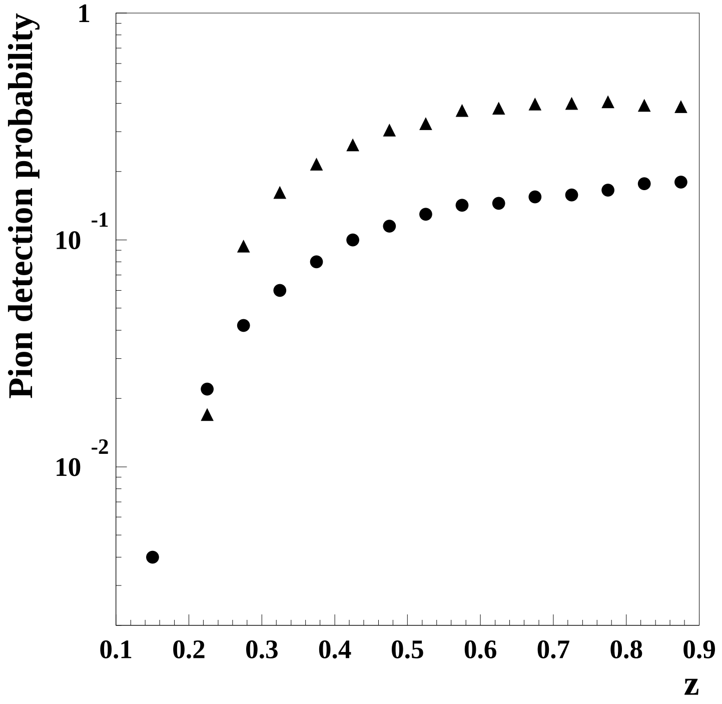
LEPTO + JETSET (Lund) + GEANT3

$$\frac{\sigma^{\pi}}{\sigma^{DIS}} =$$

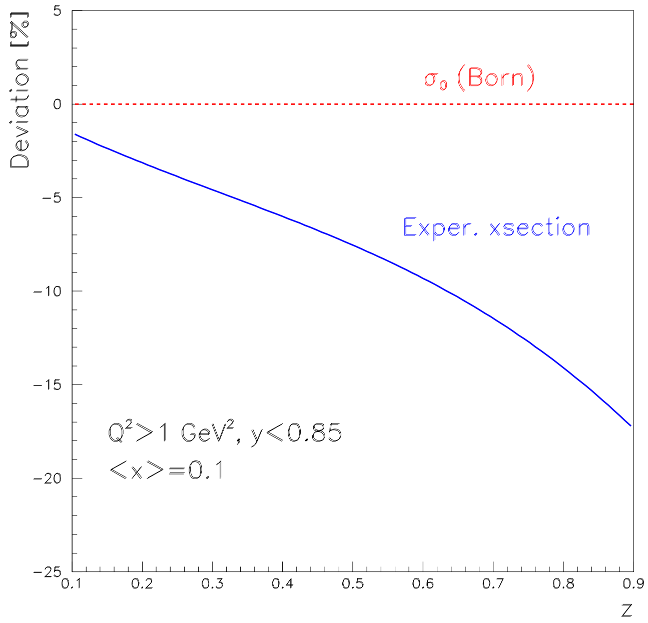
$$= \frac{N^{\pi}}{\epsilon(\pi \cap e^{+}) \cdot L} \cdot \frac{\epsilon(e^{+}) \cdot L}{N^{DIS}}$$

$$= \frac{N^{\pi}}{\epsilon(e^{+}) \cdot \epsilon(\pi | e^{+}) \cdot L} \cdot \frac{\epsilon(e^{+}) \cdot L}{N^{DIS}}$$

$$= \frac{N^{\pi}}{N^{DIS} \epsilon(\pi | e^{+})}$$



RC by the SIRAD code (EPJ C10 (1999) 681):



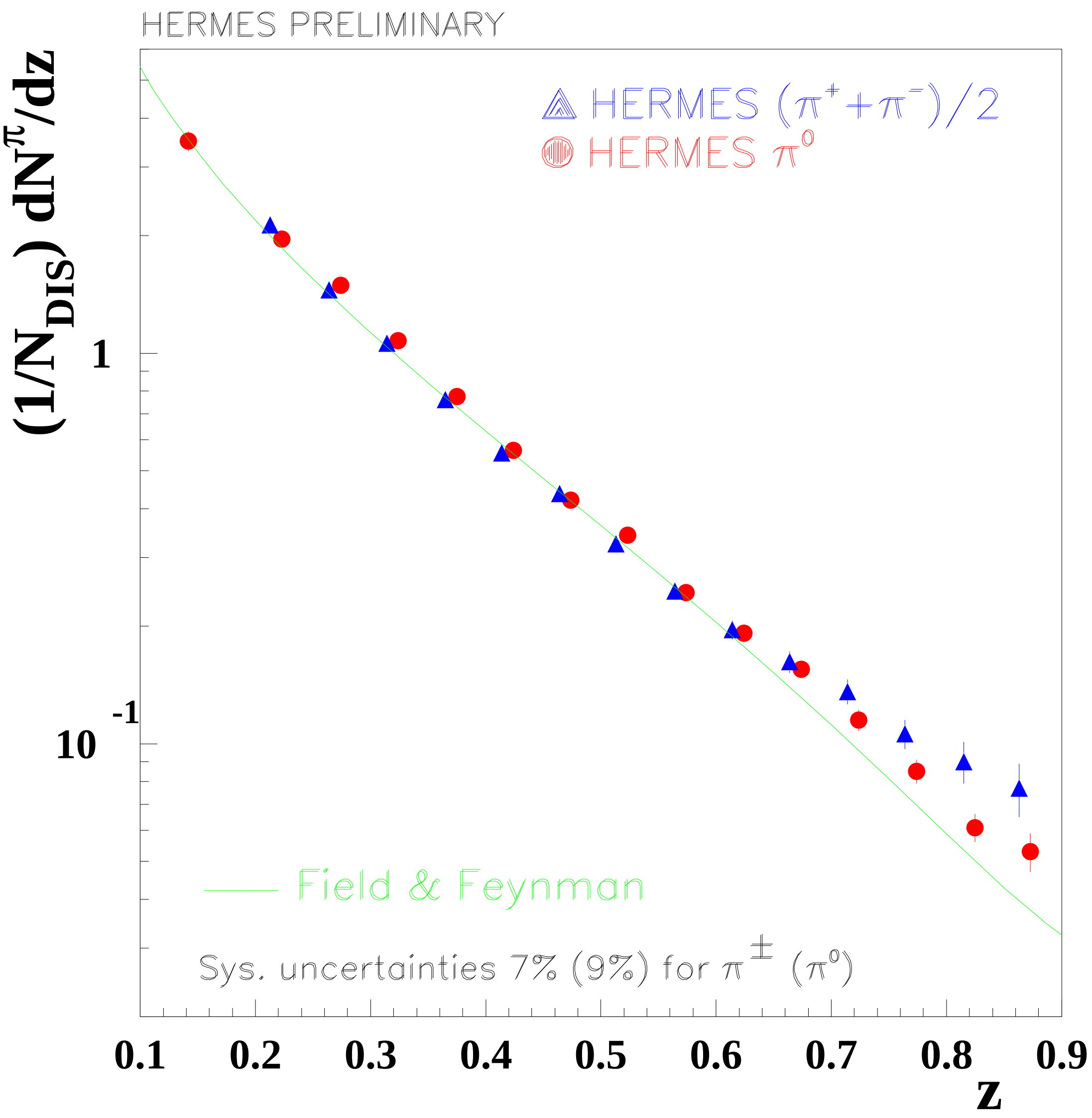
$\pi^{\pm}$, π^0 multiplicities

DIS selection: 96+97 data using unpolarised H target

$$Q^2 > 1\ GeV^2,\ W^2 > 10\ GeV^2,\ y < 0.85$$

π^0: $E > 2.8\ GeV$, $0.1 < z < 0.9$

$\pi^{\pm}$: $4.5 < E < 13\ GeV$, $0.2 < z < 0.9$



F&F (parameterization at fixed scale):

$$D^{\pi 0}(z) = \frac{(1-z)^2}{2z} \sum_{k=0}^{7} a_k C_k(z) + d$$

where $C_k(z) = cos[kcos^{-1}(2z-1)]$

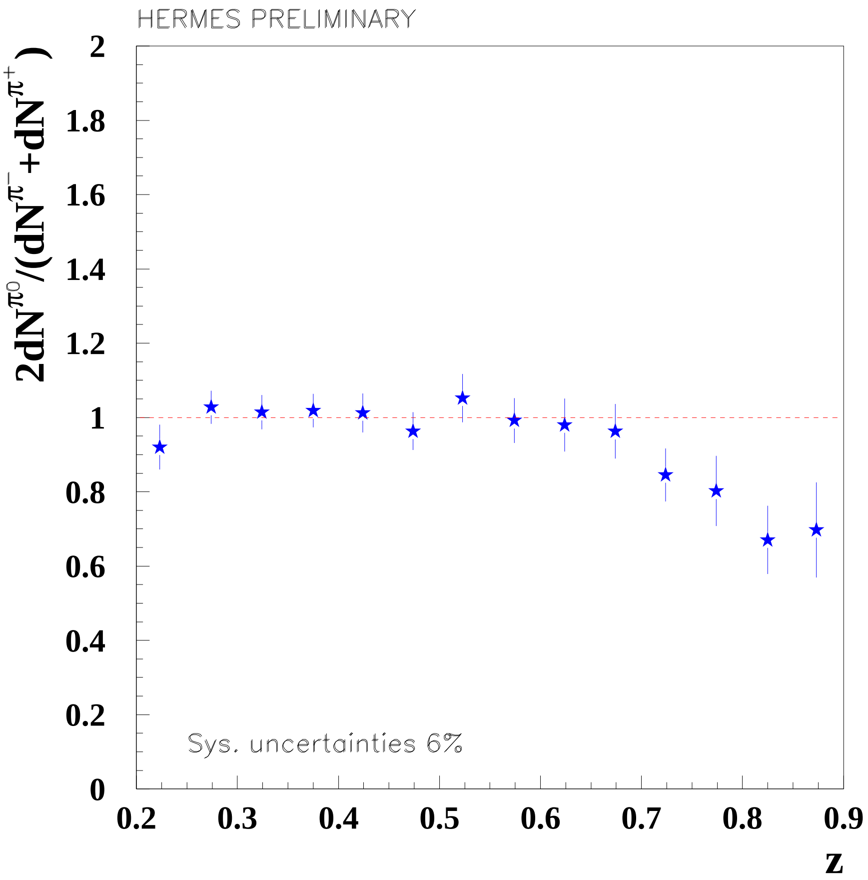
Only the statistical error is shown.

Isospin check

Basic assumption of fragmentation in QPM is the isospin invariance:

$$u \leftrightarrow d; \qquad D_u^{\pi+} = D_d^{\pi-}; \qquad \left.\begin{array}{ll} \pi^+ & I_3 = +1 \\ \pi^0 & I_3 = 0 \\ \pi^- & I_3 = -1 \end{array}\right\} I = 1$$

$$\frac{1}{N_{DIS}}\left(\frac{N^{\pi^0}}{dz} - \frac{1}{2}\left(\frac{N^{\pi^+}}{dz} + \frac{N^{\pi^-}}{dz}\right)\right) = 0$$



- Isospin invariance is satisfied, up to $z = 0.70$, by two data sets with completely different reconstruction procedure and efficiency.

- At high z there are possible contributions from exclusive processes (e.g. $\gamma^* + p \to \pi^+ + \Delta^0$) and higher-twist effects.

Fraction of the total energy transfered to pions

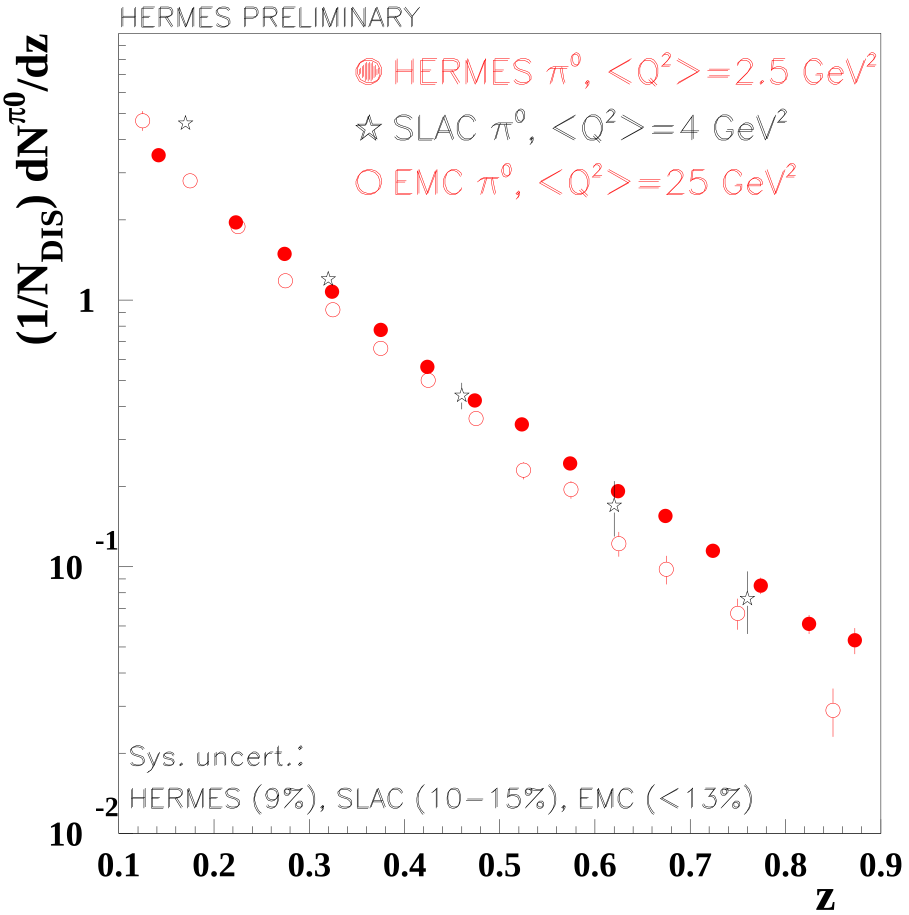
$$\int_0^1 z \frac{1}{N_{DIS}} \frac{dN^\pi}{dz} dz =$$

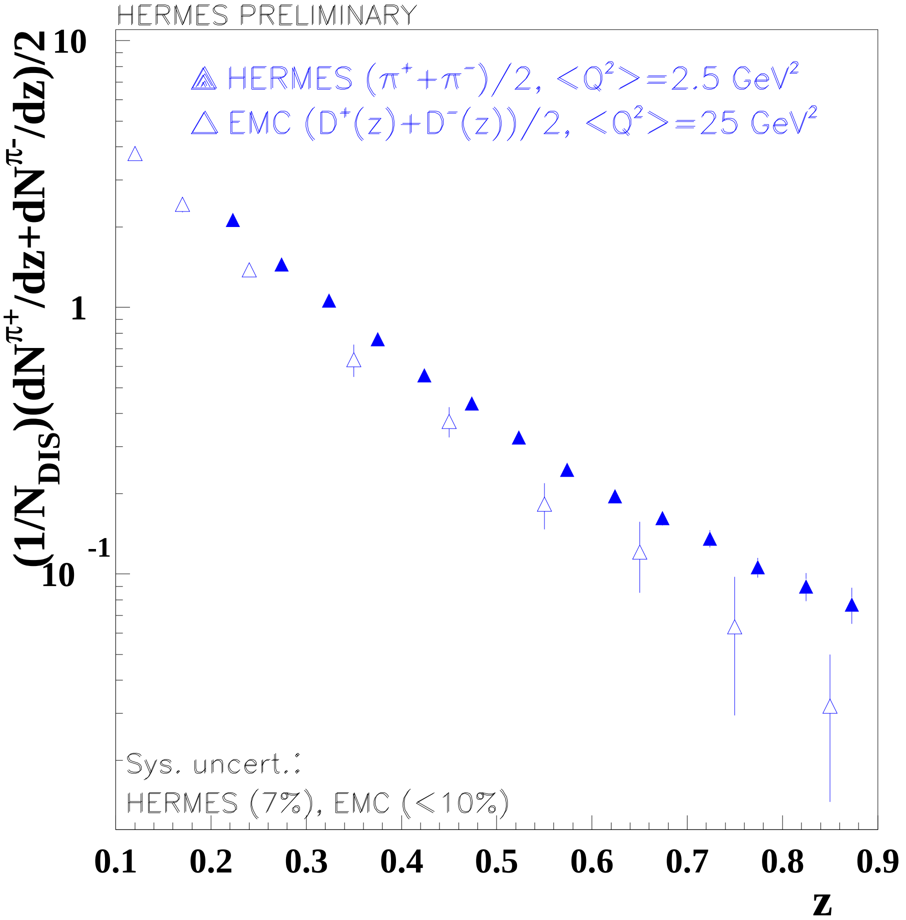
$$\int_0^{.1(.2)} F\&F + \int_{.1(.2)}^{.9} measured + \int_{.9}^{1} F\&F$$

$$\pi^0 : (0.19)_{meas} + (0.07)_{unmeas} = 0.26 \pm 0.01 \pm 0.04$$
$$\pi^\pm : (0.28)_{meas} + (0.23)_{unmeas} = 0.51 \pm 0.01 \pm 0.08$$

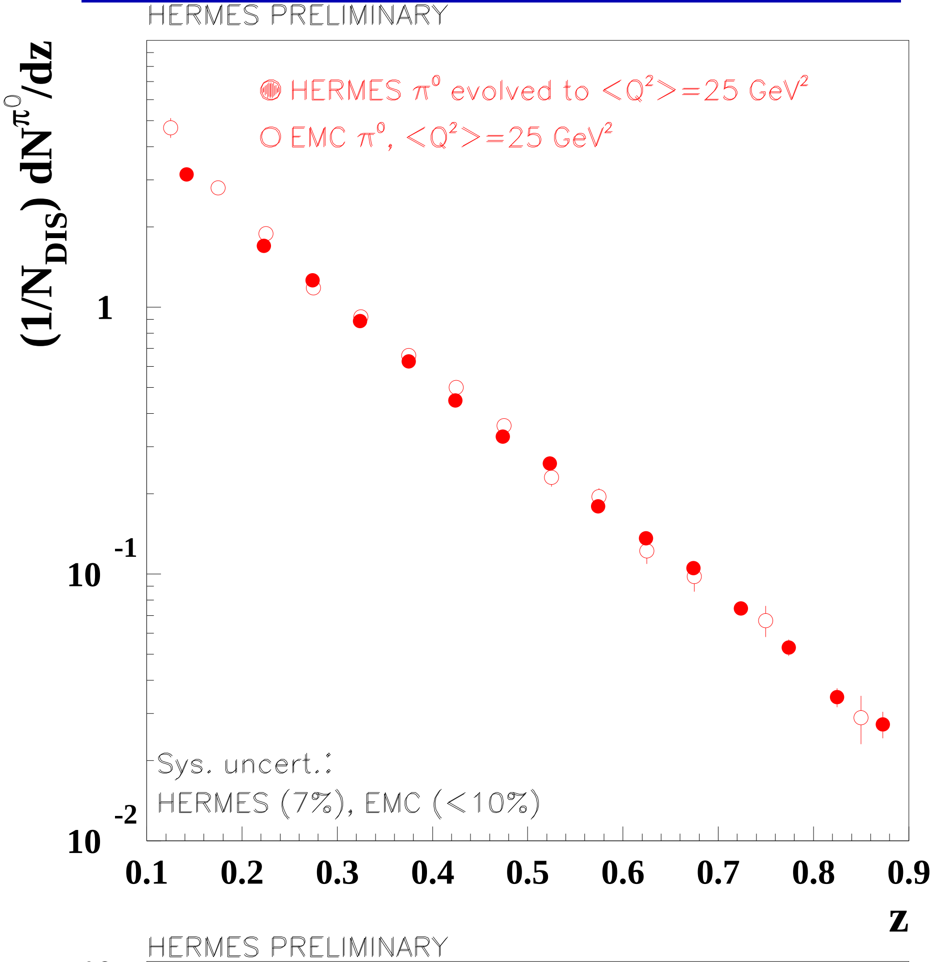
Therefore, hadrons heavier than pions, mainly $K^\pm$, p, and $\bar{p}$, carry only $\sim 23\%$ of the total energy.

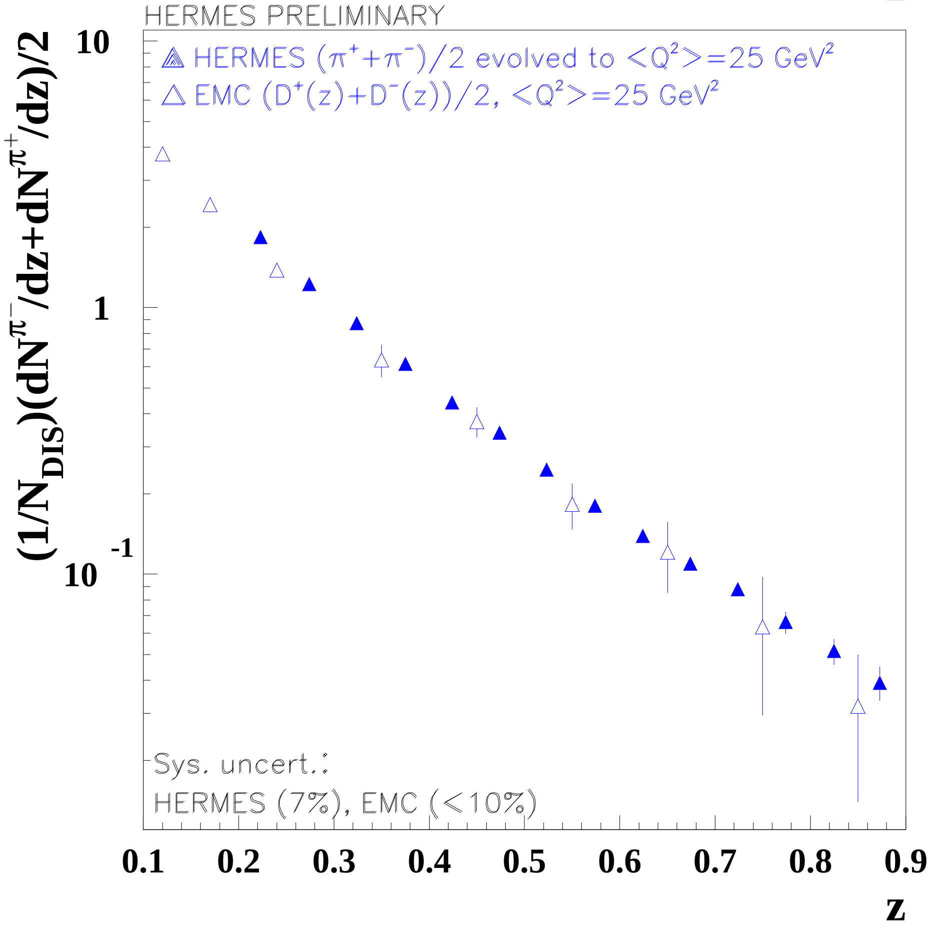
HERMES, EMC and SLAC





HERMES data evolved to Q^2=25 GeV^2



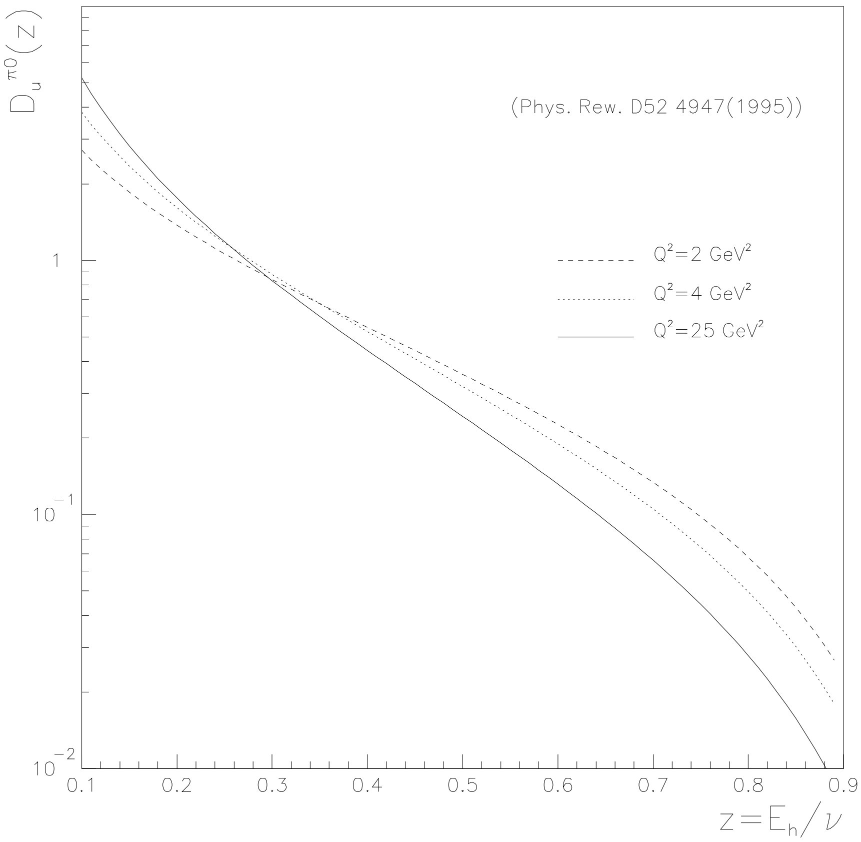


NLO-KKP Model

(Nucl.Phys. B582 (2000) 514)

$$D(z,Q^2) = N(\bar{s}) z^{\alpha(\bar{s})} (1-z)^{\beta(\bar{s})}$$

$$\bar{s} = \bar{s}(Q^2, Q_0^2) = ln \frac{ln(Q^2/\Lambda^2_{QCD})}{ln(Q_0^2/\Lambda^2_{QCD})}$$

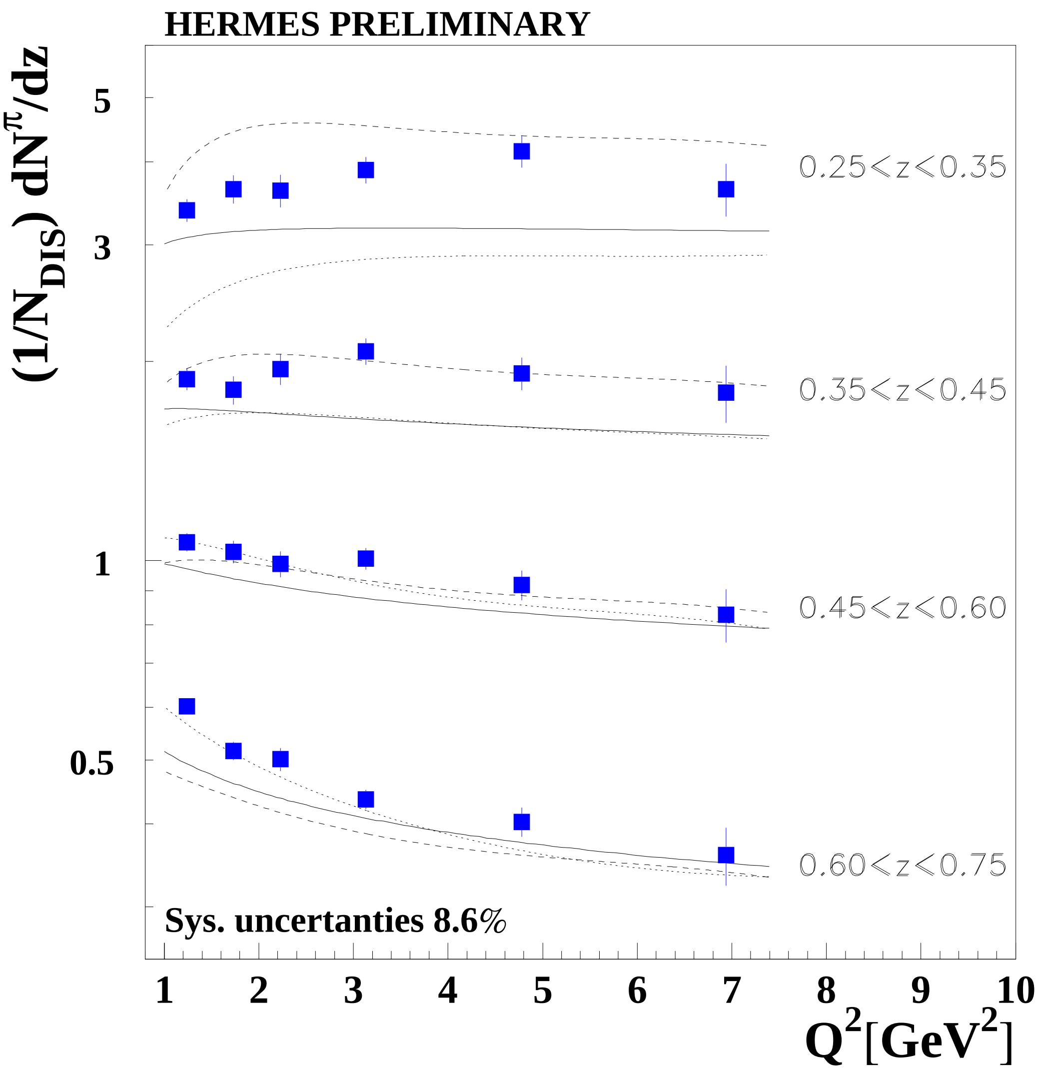


$$E_h \frac{d^3\sigma(\gamma p \to h+X)}{d^3 p_h} =$$

$$= \sum_{a,b,c} \int dx_\gamma dx_p \frac{dx_h}{x_h^2} G_a^\gamma(x_\gamma, M_\gamma^2) F_b^p(x_p, M_p^2) D_c^h(x_h, M_h^2) \times$$

$$\frac{1}{\pi \hat{s}} \left[\frac{1}{v} \frac{d\sigma^0_{ab\to c}}{dv}(\hat{s}, v; \mu^2)\delta(1-w) + \frac{\alpha_s(\mu^2)}{2\pi} K_{ab\to c}(\hat{s}, v, w; \mu^2, M_\gamma^2, M_p^2, M_h^2) \right]$$

Q^2 behavior for $\frac{dN^{\pi 0}+dN^{\pi +}+dN^{\pi -}}{dN^{DIS}}$



(solid) NLO-KKP $\sqrt{s}$=29-91 GeV, Λ=0.213 GeV

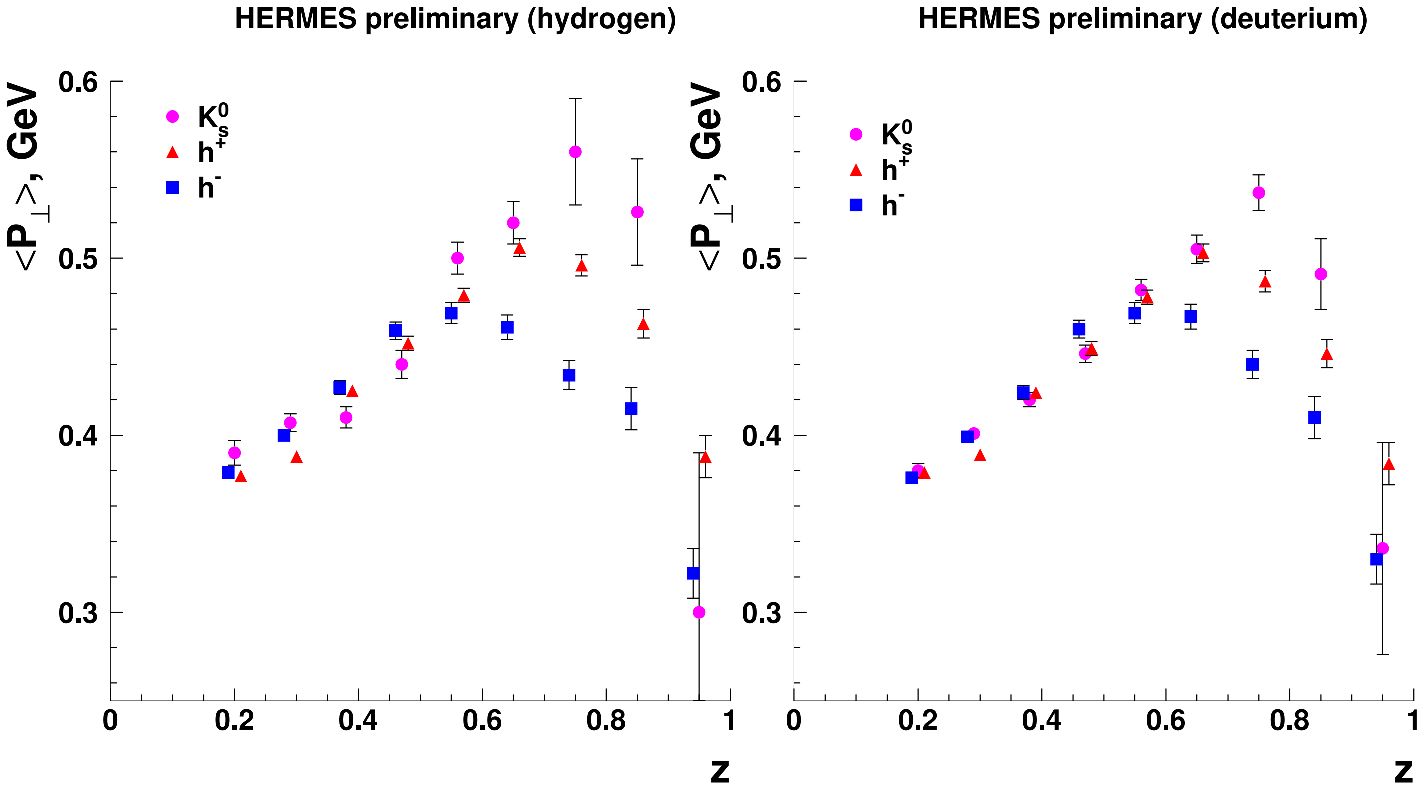
(dashed) NLO-BKK $\sqrt{s}$=29 GeV, Λ=0.190 GeV

(dotted) NLO-BKK $\sqrt{s}$=29-91 GeV, Λ=0.227 GeV

- Scaling violation of the fragmentation process.
- Variation in agreement with the Q^2-evolution predicted by NLO-QCD models (the systematic uncertainties for the models are $\sim 15\%$).

z dependence of $< P_\perp >$

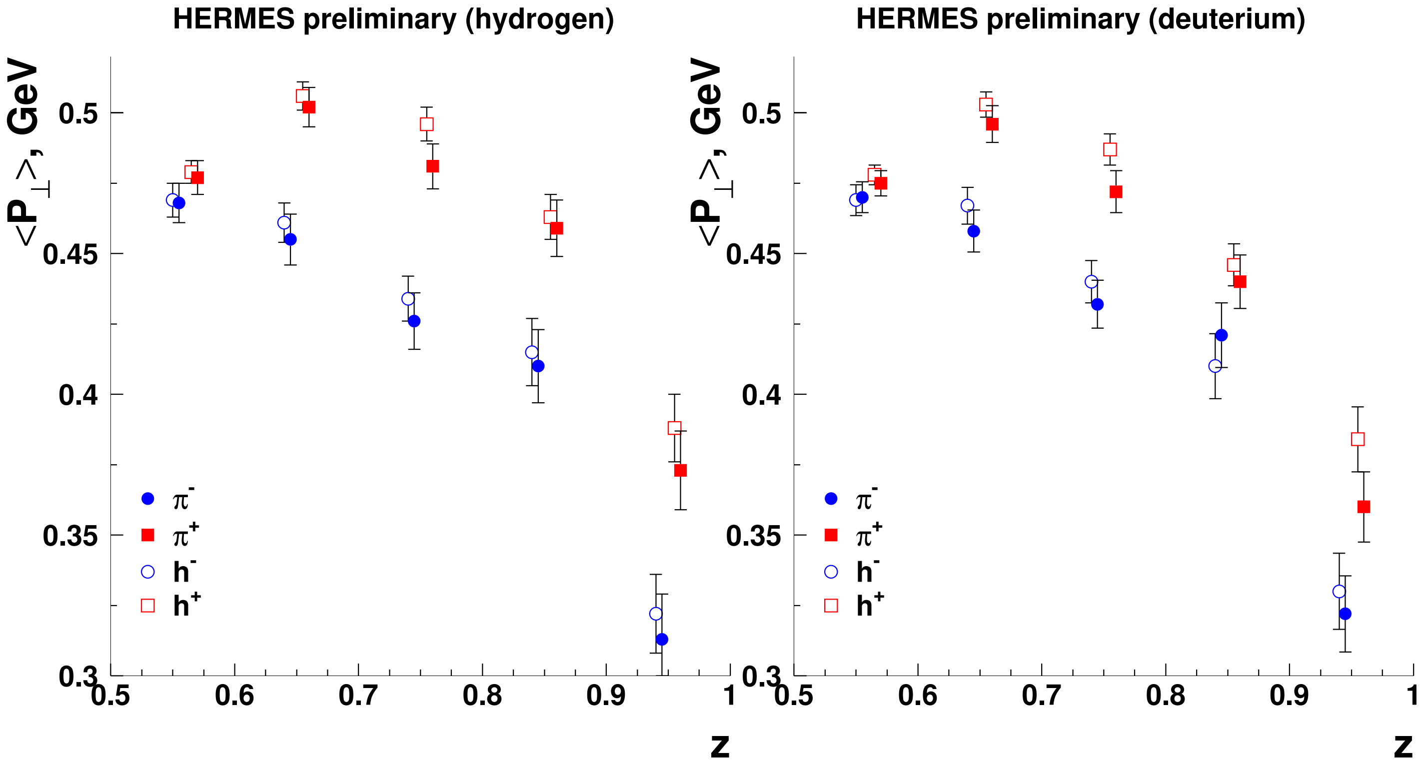
$$< P_\perp^2 > = < P_\perp^2 >^{QCD} + < k_\perp^2 > + z^2 < q_\perp^2 >$$



Both in H and D target:

- $< P_\perp >$ dependence on z is *universal* in the range $0.2 < z < 0.6$
- Clear discrepancy for $z > 0.6$ among the K_s^0, h^+ and h^- samples.

z dependence of $< P_\perp >$



- The fragmentation cannot explain the different $< P_\perp >$:
  $\pi^+(p) : u_v \bar{d}_s \longrightarrow 1$ step
  $\pi^-(p) : g \longrightarrow d\bar{d} \longrightarrow d_s \bar{u}_s \longrightarrow 3$ steps
  The data are in sharp contradiction with the above naive picture.
- The $< P_\perp >$ of u-quark dominates also in the isospin target case.

We must admit the hypothesis that the difference between $< P_\perp >$ for π^+ and π^- (and K_s^0) is related to the difference of the internal transverse momenta of u-quark and d-quark.

Conclusions

(Submitted to EPJ - hep-ex:0104004)

- Charged and neutral pion multiplicities have been measured with improved statistic and systematic accuracy.

- Isospin check by two completely different measurement procedure: possible contributions from Higher-Twist terms and exclusive channels.

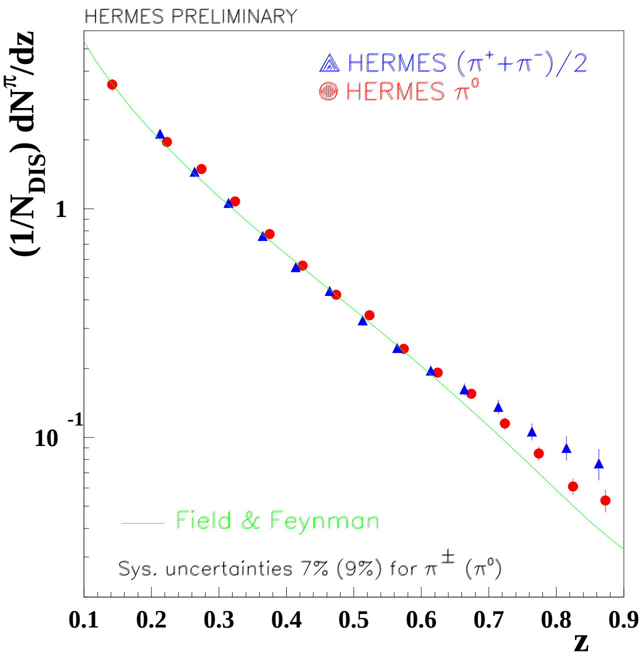
- Scaling violation of the Fragmentation Functions has been clearly measured.

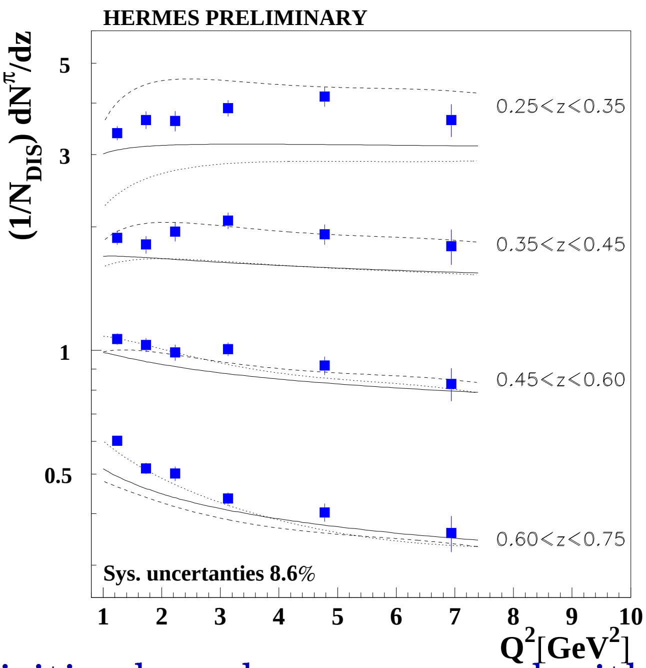
- Good agreement with NLO-KKP and NLO-BKK models even at low Q^2.

- The difference of $< P_\perp >$ for the production of π^+ and π^- suggests the hypothesis that the internal transverse momenta is flavour dependent.

Pion multiplicities and $< P_\perp >$

Pasquale Di Nezza for the HERMES collaboration

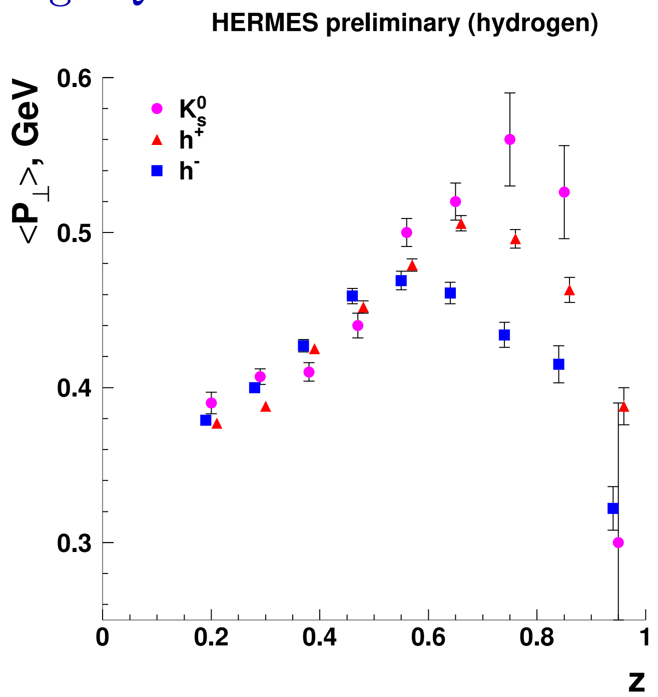




Charged and neutral pion multiplicities have been measured with high statistical and systematical accuracy:

- isospin violation at high z due to a possible contribution of Higher-Twist terms and exclusive channels;

- clear scaling violation of the Fragmentation Functions, good agreement with theoretical models (BKK, KKP) tuned at very high Q^2.



The difference of $< P_\perp >$ in the fragmentation process suggests the hypothesis that the internal transverse momenta is flavour dependent.