# Semiinclusive DIS - learning about pdf's & open questions

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*Popular saying: New is well-forgotten old*

# Outline

## Basic tool

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**THE VALENCE AND STRANGE-SEA QUARK SPIN DISTRIBUTIONS IN THE NUCLEON FROM SEMI-INCLUSIVE DEEP INELASTIC LEPTON SCATTERING**

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Close & Milner, Phys.Rev. 1992

## How good it is

Strangeness, $p_t$ dependence

$N^h_{\uparrow\uparrow(\uparrow\downarrow)}$ is the number of hadrons produced in a given $x(x_{Bj}), z\left(z = \frac{P^h_+}{P^{\gamma*}_+}\right)$ bin

for parallel (antiparallel) helicities of colliding lepton and the target:

$$N^h_{\downarrow\uparrow(\uparrow\uparrow)} \propto \frac{4}{9}u_\pm(x)D^h_u(z) + \frac{1}{9}d_\pm(x)D^h_d(z) + \frac{4}{9}\overline{u}_\pm(x)D^h_{\overline{u}}(z) + \frac{1}{9}\overline{d}_\pm(x)D^h_{\overline{d}}(z) + \frac{1}{9}s_\pm(x)D^h_s(z) + \frac{1}{9}\overline{s}_\pm(x)D^h_{\overline{s}}(z)$$

D's are hadron fragmentation functions integrated over $p_t$, which do not depend on the quark helicity due to parity conservation

For h= $\pi^+$, $\pi^-$, there are three fragmentation functions only which also depend on $Q^2$

$$D_1(z) \equiv D^{\pi^+}_u(z) = D^{\pi^-}_d(z) = D^{\pi^+}_{\overline{d}}(z) = D^{\pi^-}_{\overline{u}}(z)$$

$$D_2(z) \equiv D^{\pi^+}_{\overline{u}}(z) = D^{\pi^-}_u(z) = D^{\pi^-} = D^{\pi^+}_d(z)_{\overline{d}}(z)$$

$$D_3(z) \equiv D^{\pi^+}_s(z) = D^{\pi^-}_s(z) = D^{\pi^+}_s(z) = D^{\pi^+}_{\overline{s}}(z) = D^{\pi^-}_{\overline{s}}(z).$$

For $N_{\uparrow\downarrow}^{\pi^+-\pi^-} \equiv N_{\uparrow\downarrow}^{\pi^+} - N_{\uparrow\downarrow}^{\pi^-}, N_{\uparrow\uparrow}^{\pi^+-\pi^-} \equiv N_{\uparrow\uparrow}^{\pi^+} - N_{\uparrow\uparrow}^{\pi^-}$ sea contribution cancels out

$$N_{\uparrow\downarrow}^{\pi^+-\pi^-} \sim \left[\frac{4}{9}u_+^v(x) - \frac{1}{9}d_+^v(x)\right][D_1(z) - D_2(z)]$$

$$N_{\uparrow\uparrow}^{\pi^+-\pi^-} \sim \left[\frac{4}{9}u_-^v(x) - \frac{1}{9}d_-^v(x)\right][D_1(z) - D_2(z)]$$

$$N_{\uparrow\downarrow}^{\pi^+-\pi^-} + N_{\uparrow\uparrow}^{\pi^+-\pi^-} \sim \left[\frac{4}{9}u^v(x) - \frac{1}{9}d^v(x)\right][D_1(z) - D_2(z)]$$

not sensitive to quark long. polarization

$$N_{\uparrow\downarrow}^{\pi^+-\pi^-} - N_{\uparrow\uparrow}^{\pi^+-\pi^-} \propto \left[\frac{4}{9}\Delta u^v(x) - \frac{1}{9}\Delta^v(x)\right][D_1(z) - D_2(z)]$$

contains information about polarized valence quark distributions

Asymmetry
$$A^p(x,z) = \frac{N_{\uparrow\downarrow}^{\pi^+-\pi^-} - N_{\uparrow\uparrow}^{\pi^+-\pi^-}}{N_{\uparrow\downarrow}^{\pi^+-\pi^-} + N_{\uparrow\uparrow}^{\pi^+-\pi^-}}$$

$$A^p(x,z) = \frac{4\Delta u^v(x) - \Delta d^v(x)}{4u^v(x) - d^v(x)}.$$

should be z -independent ➜ provides self consistency test = accuracy of the leading twist for fragmentation.

$$A^{deuteron}(x,z) = (1 - \frac{3}{2}P_D)\frac{\Delta u^v(x) + \Delta d^v(x)}{u^v(x) + d^v(x)}$$

depolarization ~ 10% due to D-wave

Most of experimental studies used multiplicities rather than inclusive cross sections - more difficult to perform self consistency check

# Other final states probing valence quark polarization

Consider two fastest charged pions with $z_1, z_2 > 0.2$.
My guess is that

$$D_d^{\pi^-+\pi^-}(z)/D_u^{\pi^-+\pi^-}(z) \gg D_d^{\pi^-}(z)/D_u^{\pi^-}(z) \quad where\ z = z_1 + z_2$$

worth exploring other two particle channels - data exist but to my knowledge were never analyzed

# Sea polarization

Challenging as effect is likely to be small

Combining inclusive and semi inclusive possible but errors are likely to be very large

## Close & Milner 1992

Asymmetry of the $K^-$ production multiplicity, $A^{p\to K^-}(z)$
for large z where fragmentation of bar u, and s to $K^-$ should dominate

$$D_s^{K^-}(z)/D_{\overline{u}}^{K^-}(z) = 1/R \simeq 1/0.3\,|_{z\to 1}$$

?

Since $\overline{s}/\overline{u} \le \frac{1}{2}(for\,Q^2 \sim\, few\,GeV^2)$ ⟶ $A^{p/K^-}(x,z)\,measures\,\overline{u} + \lambda\overline{s}(\lambda \le 0.3)$

However fragmentation functions to kaons are poorly known

large uncertainties in multivariable analyses (HERMES) - previous talks

Additional serious problem - possible evidence for late onset of the scaling behavior for fragmentation to leading kaons

# Another idea (FMRSSS89) for strange sea measurement - use fragmentation to $h=\pi^+ + \pi^-$ ($\pi^0$ or $\varphi$)

in all these cases only two fragmentation functions -

$$D_u^{(\pi^+ + \pi^-)}(z) = D_{\bar{u}}^{(\pi^+ + \pi^-)}(z) = D_d^{(\pi^+ + \pi^-)}(z) = D_{\bar{d}}^{(\pi^+ + \pi^-)}(z) \equiv D(z),$$

$$D_s^{(\pi^+ + \pi^-)}(z) = D_{\bar{s}}^{(\pi^+ + \pi^-)}(z) \equiv D_s(z).$$

$$n^{\uparrow\downarrow}(x,z) \equiv \frac{1}{\sigma^T_{\uparrow\downarrow}} \frac{d\sigma^{(\pi^+ + \pi^-)}_{\uparrow\downarrow}}{dz} = \frac{[\frac{4}{9}u_+(x) + \frac{1}{9}d_+(x)]D(z) + \frac{1}{9}s_+(x)D_s(z)}{[\frac{4}{9}u_+(x) + \frac{1}{9}d_+(x) + \frac{1}{9}s_+(x)]}$$

$$n^{\uparrow\uparrow}(x,z) \equiv \frac{1}{\sigma^T_{\uparrow\uparrow}} \frac{d\sigma^{(\pi^+ + \pi^-)}}{dz} = \frac{[\frac{4}{9}u_-(x) + \frac{1}{9}d_-(x)]D(z) + \frac{1}{9}s_-(x)D_s(z)}{[\frac{4}{9}u_-(x) + \frac{1}{9}d_-(x) + \frac{1}{9}s_-(x)]}$$

here q(u,d,s) is short hand for $q + \overline{q}$

$$q(x) \equiv q_+(x) + q_-(x), \quad \Delta q(x) \equiv q_+(x) - q_-(x)$$

$$n^{(\uparrow\downarrow),(\uparrow\uparrow)}(x,z) = D(z) + \frac{[D_s(z) - D(z)][s(x) \pm \Delta s(x)]}{18 F_1^p(x)[1 \pm A_1^p(x)]}$$

$A_1^p(x)$ inclusive asymmetry

$F_1^p(x)$ spin independent structure function of the proton

$$n^{\uparrow\downarrow}(x,z) - n^{\uparrow\uparrow}(x,z) = \frac{[D_s(z) - D(z)]}{18F_1^p(x)}\left(\frac{s(x) - \Delta s(x)}{1 + A_1^p(x)} - \frac{s(x) + \Delta s(x)}{1 - A_1^p(x)}\right)$$

$$= \frac{[D_s(z) - D(z)]}{9F_1^p(x)}\left(\frac{\Delta s(x) - A_1^p(x)s(x)}{1 - [A_1^p(x)]^2}\right)$$

For large z

$$D_s^{\pi^+ + \pi^-}(z) \ll D^{\pi^+ + \pi^-}(z)$$

$$D_s^{\pi^0}(z) \ll D^{\pi^0}(z)$$

$$D_s^{\phi}(z) \gg D^{\phi}(z)$$

- certain advantages for $\pi^0$ ($\pi^0 + \eta$) channel as compared to charged pions
- opposite sign of the effect for pions and φ-mesons

Using spin averaged multiplicities we can also write

$$n^{\uparrow\downarrow}(x,) - n^{\uparrow\uparrow}(x,z) = [n^{\uparrow\downarrow}(x,z) + n^{\uparrow\uparrow}(x,z) - 2D(z)] \left( \frac{\Delta s(x) - A_1^p(x)s(x)}{s(x) - A_1^p(x)\Delta s(x)} \right)$$

*Studies of Δs are difficult but not hopeless. In some sense easier than studies of s.*

# Open questions

*Precocious scaling for fragmentation if no (practically) antibaryons is produced for W < 4 (6) GeV. Baryons migrate from target fragmentation to current fragmentation.*

EMC data including extrapolation

$$\Delta^{\pi} = \int_0^1 \left[ D_u^{\pi^+}(z) - D_u^{\pi^-}(z) \right] dz = 0.382 \pm 0.031 ,$$

$$\Delta^{p} = \int_0^1 \left[ D_u^{p}(z) - D_u^{\bar{p}}(z) \right] dz = 0.047 \pm 0.011 ,$$

$$\Delta^{K} = \int_0^1 \left[ D_u^{K^+}(z) - D_u^{K^-}(z) \right] dz = 0.122 \pm 0.023 .$$

Charge sum rule for u-quark roughly OK

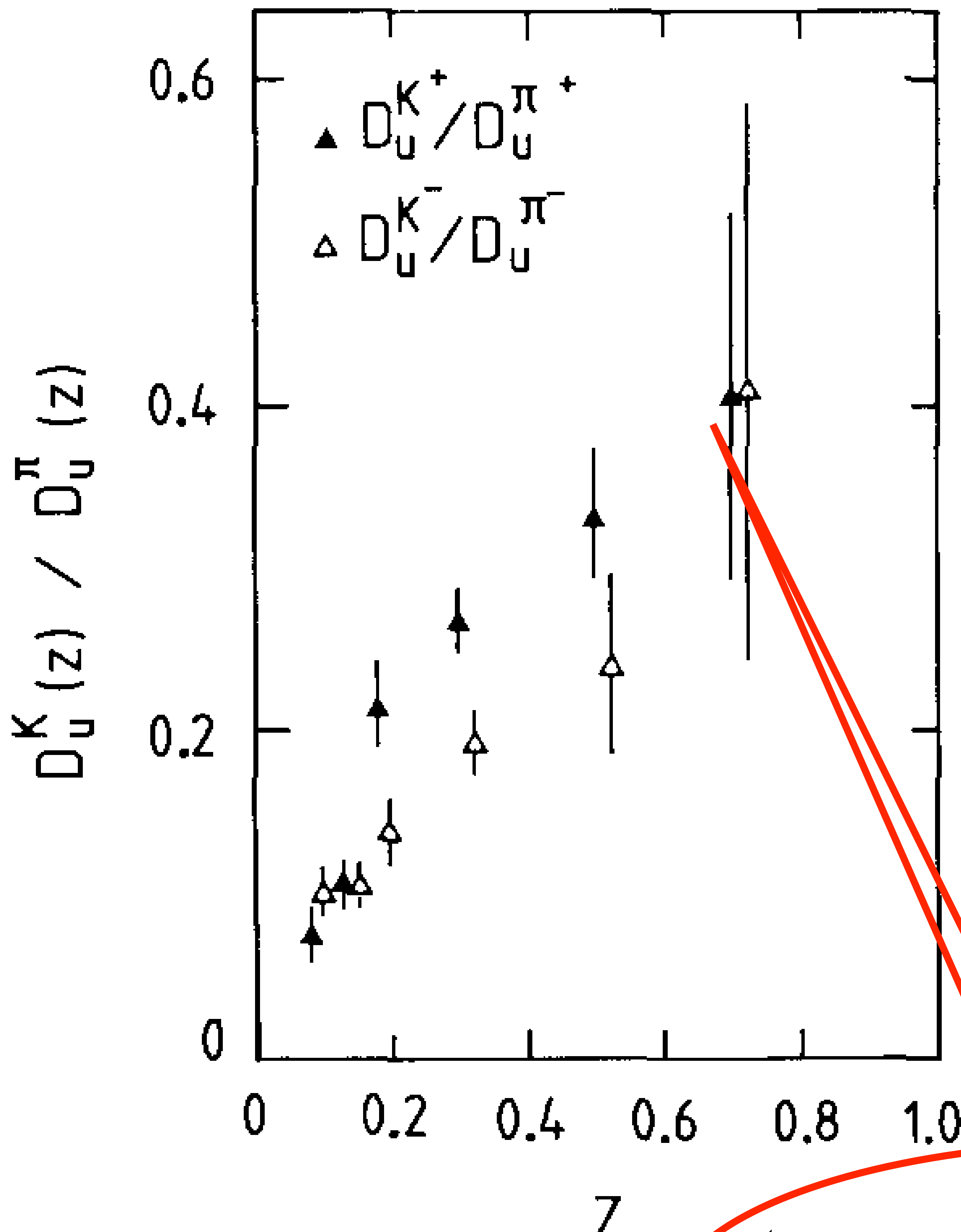
$$\Delta^{\pi} + \Delta^{p} + \Delta^{K} = 0.551 \pm 0.04$$

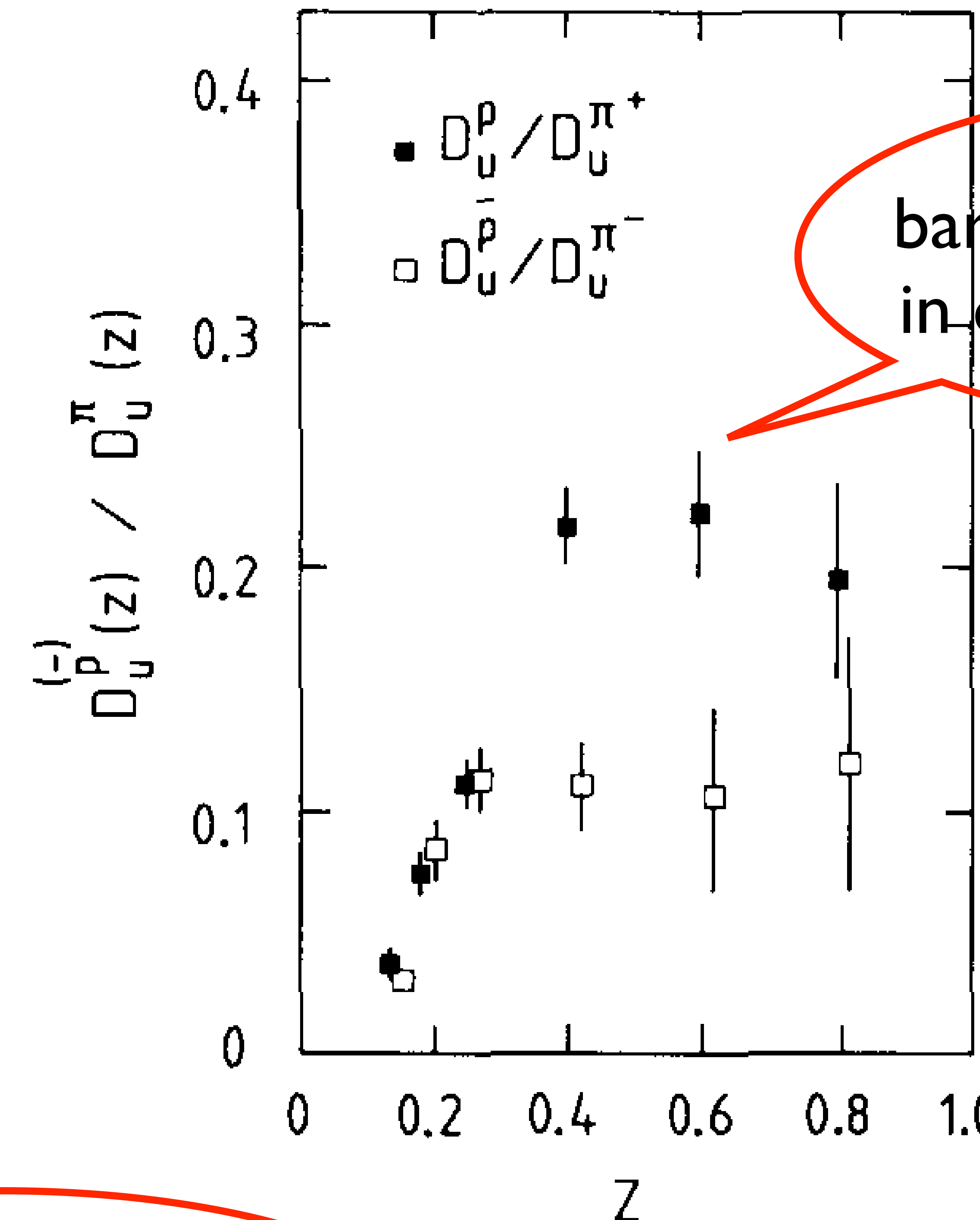
Baryon Charge sum rule bad

$$\Delta^{B} < \Delta^{p} \times 2 \times (1 + \lambda_s)^2 < 0.2$$

neutrons

Ratios of the u quark fragmentation functions into kaons (protons antiprotons) and pions vs. the energy fraction. The errors shown are the statistical errors.




baryons are important in quark fragmentation

strangeness suppression, $\lambda_s$ is rather mild

$\lambda_s(\text{EMC}) \sim 0.4 \gg \lambda_s(\text{HERMES}) \sim 0.16$

from fit using PYTHIA ??

Does $\lambda_s$ appears to increases with hardness of the process?
(perhaps also W- see next slides)

Corrections to factorize form for semi inclusive DIS are probably large/significant in a wide energy range. Perhaps "optimal" choices of variables / lack of dynamics range mask them.

$$z = \frac{P_+^h}{P_+^{\gamma *}} \quad \text{vs} \quad z = \frac{E^h}{\nu}$$

Example: Taking spectrum ~ $(1-z)^2$, for $x=1/3$, $Q^2= 2\text{GeV}^2$ difference is 20%

# Fragmentation and $p_t$ broadening. Open questions - of relevance for transverse spin asymmetries.

*Will illustrate using EMC data:*

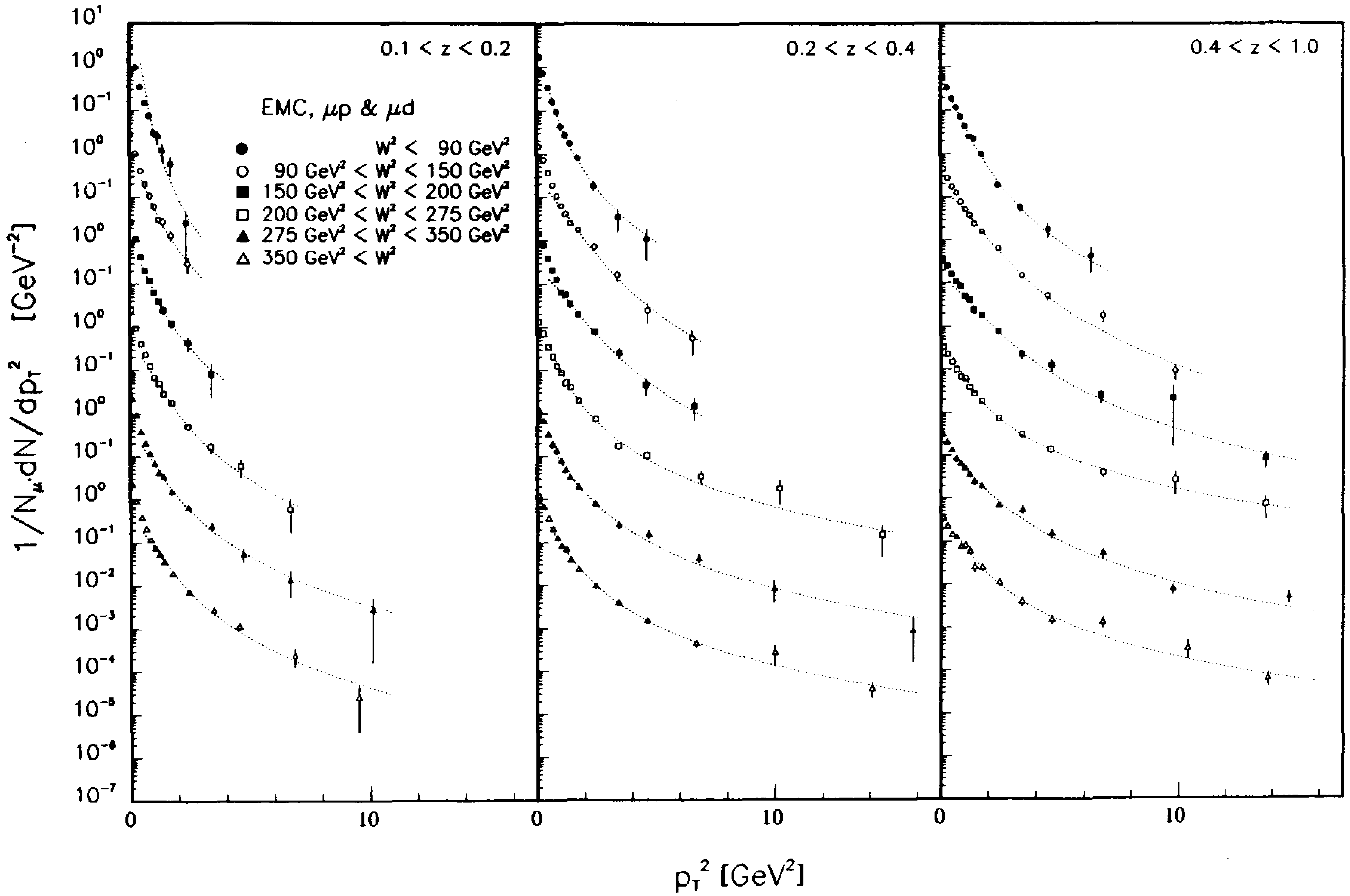



**Fig. 3.** Normalised differential $p_t^2$ distributions for charged hadrons of the merged $\mu p$- and $\mu d$-data in different $W^2$ and $z$ bins. The dotted lines represent fits using the ansatz $\frac{1}{N_\mu} \cdot \frac{dN_h}{dp_t^2} \propto 1/(m^2 + p_t^2)^\alpha$ inspired by a propagator form. The errors shown are statistical only

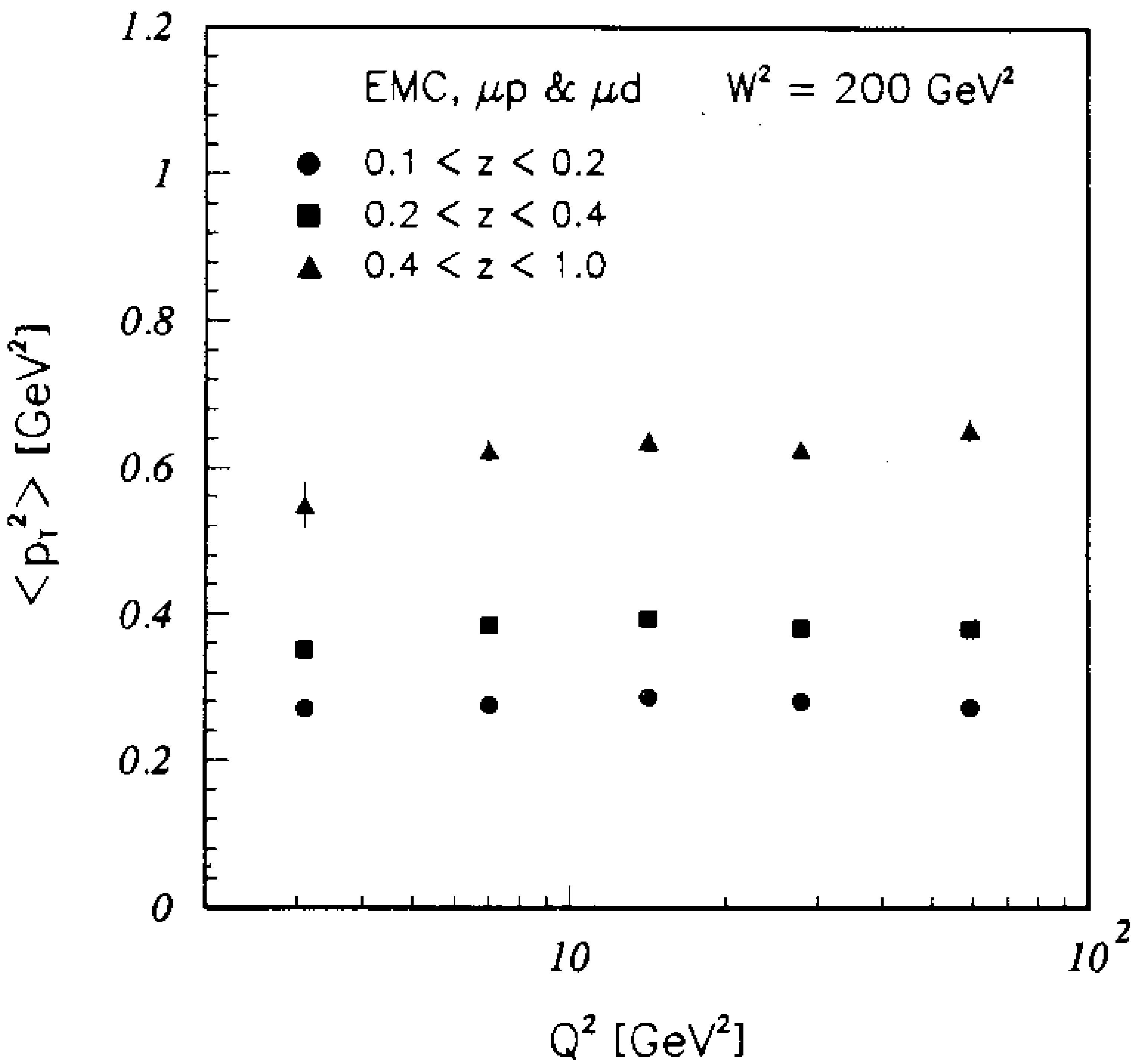



**Fig. 5.** $\langle p_t^2 \rangle$ of charged hadrons for fixed $W^2$ as a function of $Q^2$ in different $z$ bins. The errors shown are statistical only

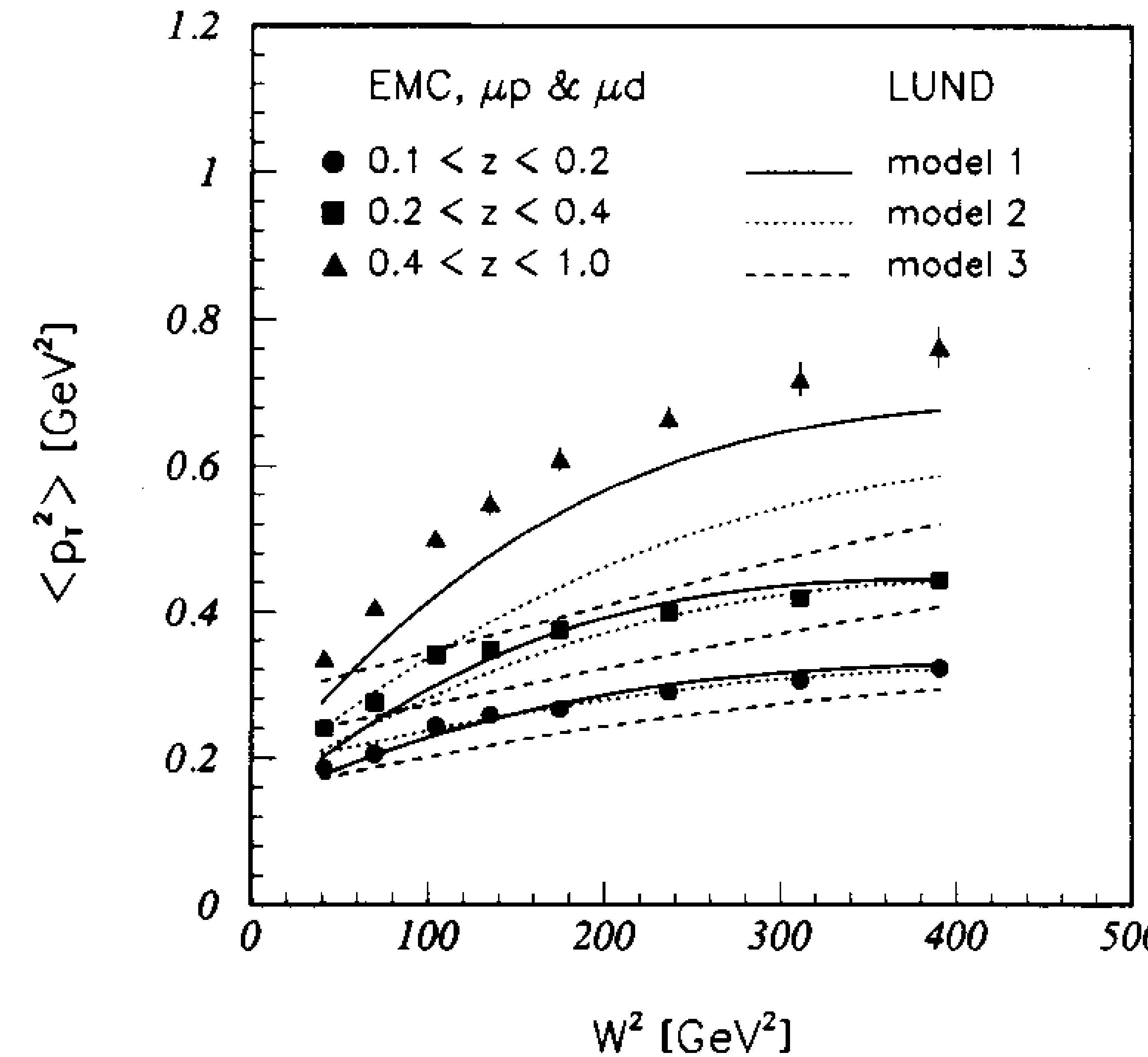



**Fig. 8.** Comparison of the $W^2$ and $z$ dependence of $\langle p_t^2 \rangle$ of charge hadrons with different versions of the Lund fragmentation mod [18, 20]. The errors shown are statistical only

Weak increase with $Q^2$ - pQCD?

Strong increase with $W^2$ - pQCD????

Effect of larger phase volume ?

The rise was seen before EMC:

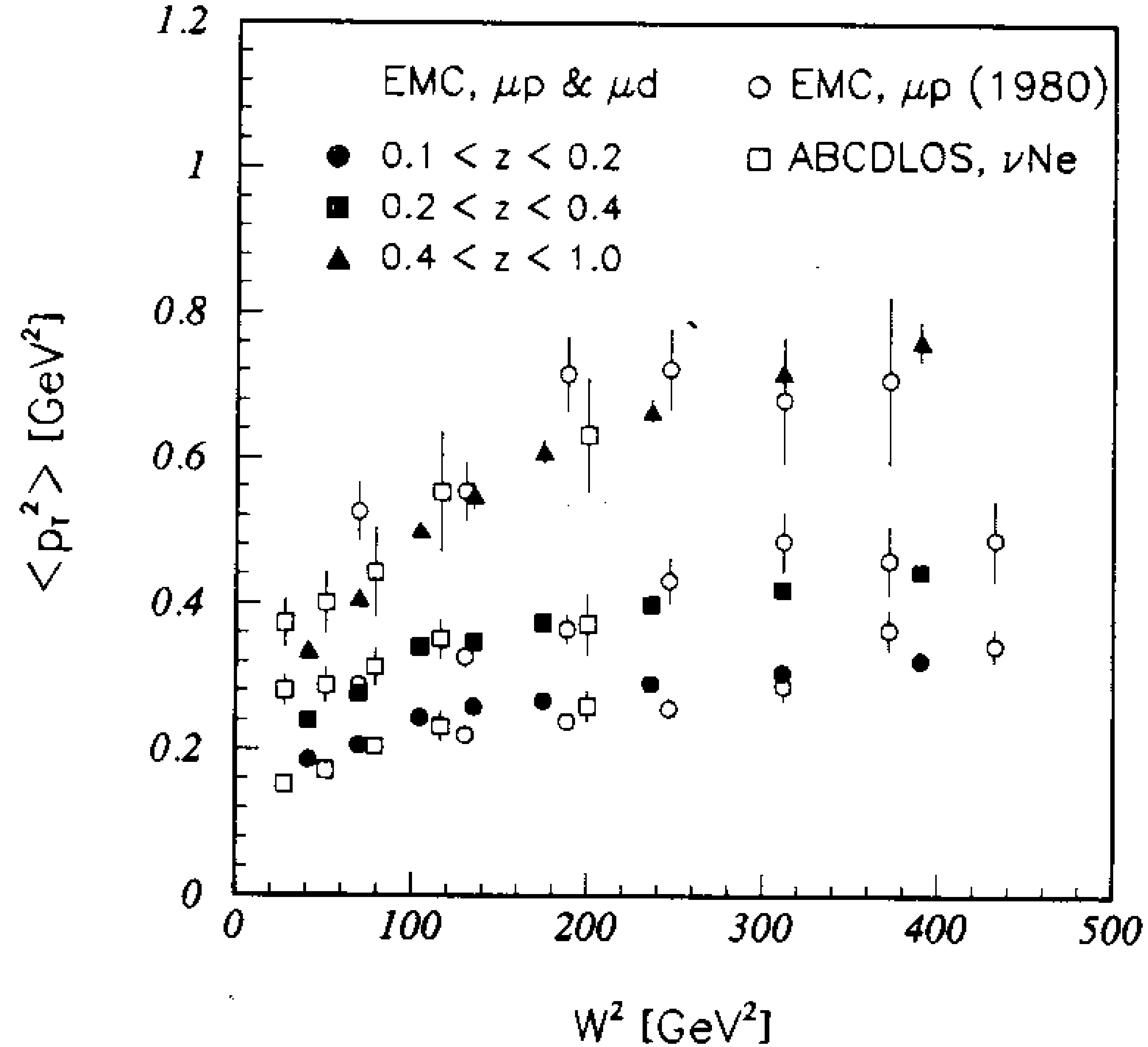



**Fig. 6.** Comparison of $\langle p_t^2 \rangle$ of charged hadrons as a function of $W^2$ with BEBC data of the collaboration ABCDLOS [29] and a previous EMC analysis [27]. The three $z$ ranges for the data shown are the same for the three analyses. The errors shown are statistical only

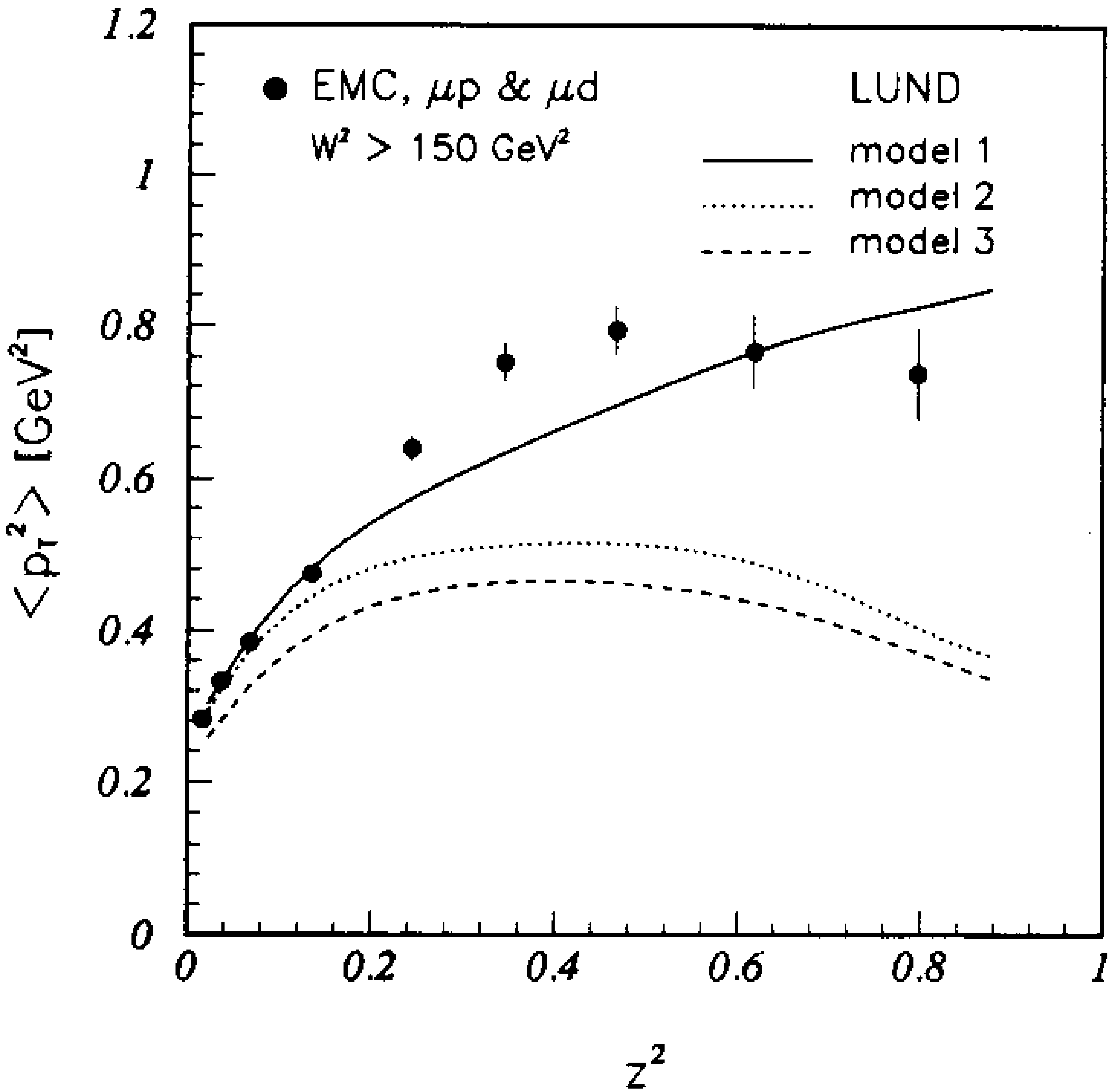



**Fig. 9.** Comparison of the $z^2$ dependence of $\langle p_t^2 \rangle$ of charged hadrons with different versions of the Lund fragmentation model [18, 20]. The errors shown are statistical only

# Parton model:

$$< p_t^2 >=< p_t^2(q \to h) > + < k_t(primordial)^2 > z^2$$

pQCD including
soft interactions
of knocked out parton:

$$< p_t^2 >=< p_t^2(q \to h) > +$$

$$(< k_t(primordial)^2 > + < k_t(soft)^2 >)z^2$$

$$< p_t^2(q \to h)(z) >$$

drops at large z due to suppression of the gluon radiation

Is broadening seems too large for primordial $k_t$ effect grows with W (decrease of x). Sea quarks have larger <$k_t$ >. EMC : correlations in rapidity between leading hadron and hadrons in the target fragmentation would be different- probably wrong argument as the second parton is also at smallish x. Good check would be to compare pt distributions for channels dominated by valence quarks and by sea quarks.

Coulomb exchange effect? Elastic rescattering. Could increase with W.

Could increase with decrease of x - larger longitudinal distances

need effect >> than $p_t$ broadening in pA scattering where

$$\Delta p_t^2(A \sim 200) \sim 0.1 GeV^2$$

while the gluon thickness 3 times larger

need to check what hadrons and at what rapidities balance $p_t$ of leading hadron. ( sum rule $\Sigma$ $p_t$= -$p_t$ forward)

# Conclusions

More attention is necessary to accuracy LT for fragmentation.

Probably the biggest challenge is transverse momentum dependence on W.

For strange sea - channels with smallest systematics are should be investigated - $\pi^0$ , $\varphi$.

Comment on experiments with polarized nuclear targets.
If one wants to use $^3He$, one needs in parallel experiments with $^7Li$,...