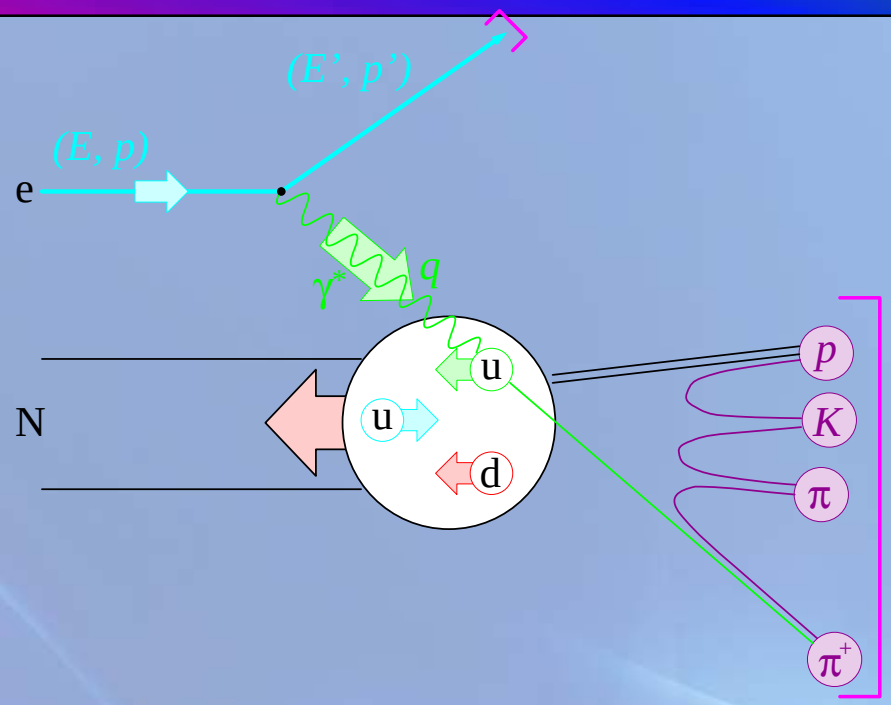
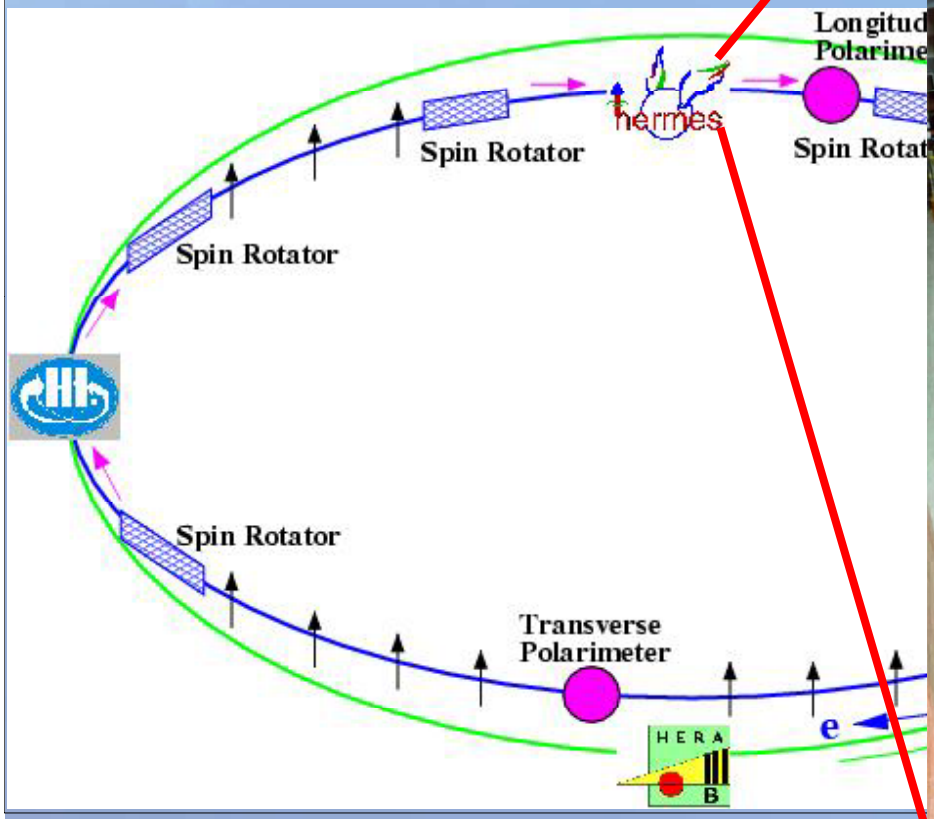
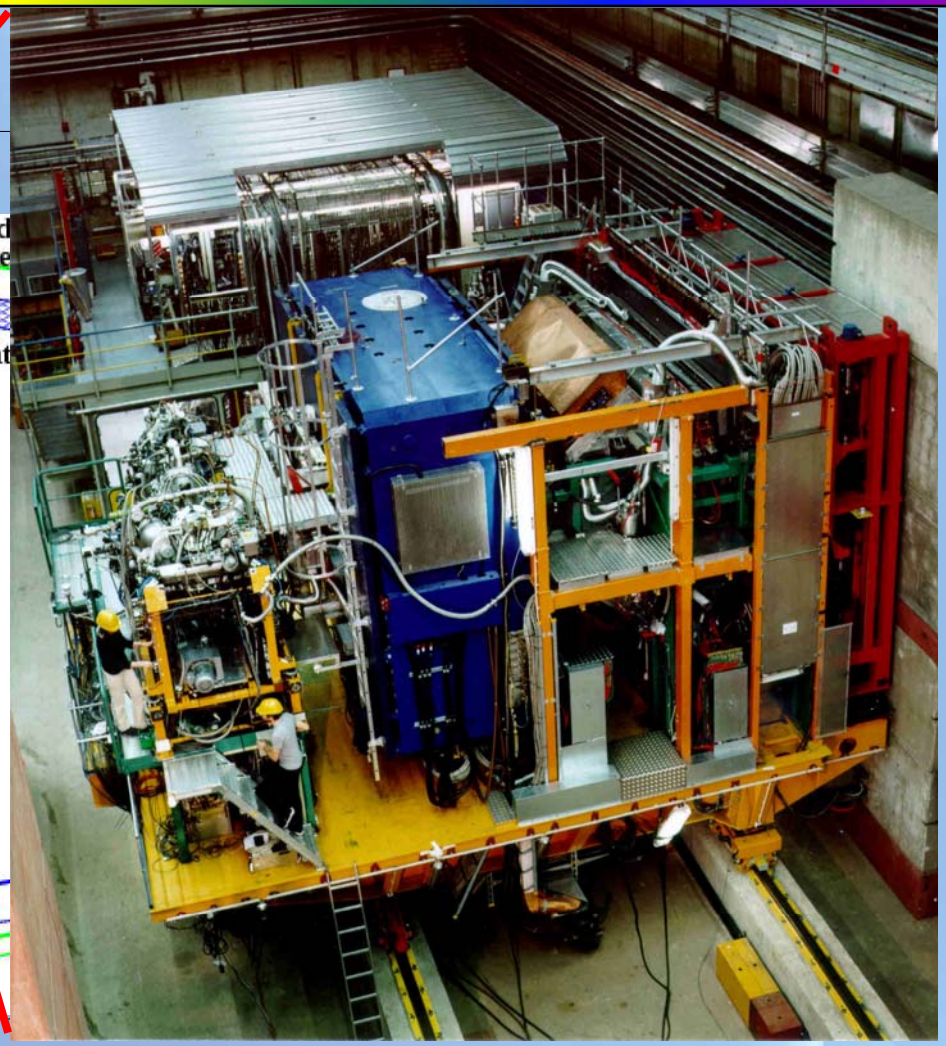
HERMES
News on fragmentation from nucleons to nuclei



HERMES@ HERA

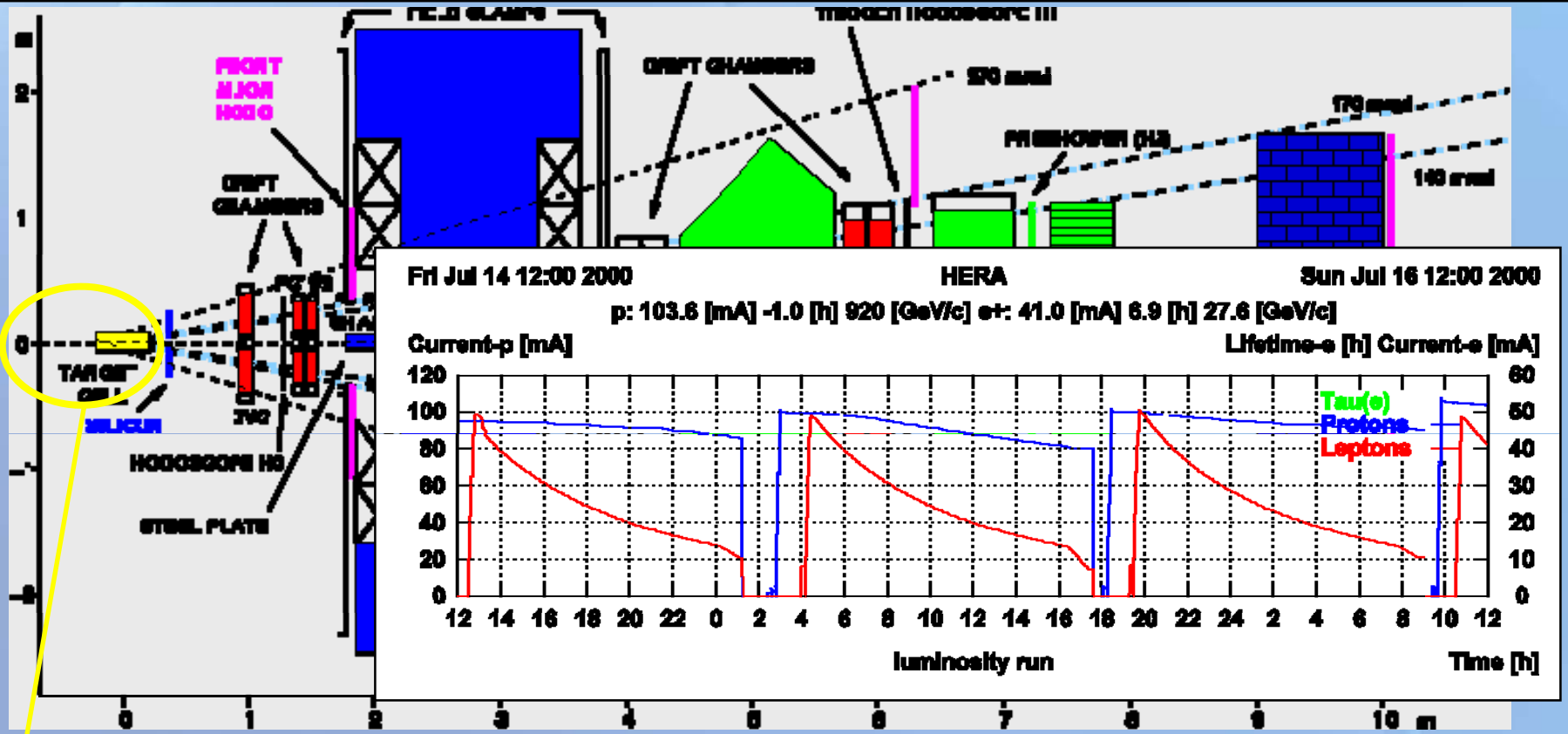




HERA: e^+/e^- (27GeV) - proton (920 GeV) collider

HERA-e self-polarizing due to Sokolov-Ternov effect

The HERMES Spectrometer



Internal Gas Target: $\overrightarrow{He}$, $\overrightarrow{H}$, $\overrightarrow{D}$, $H\uparrow$ unpol: $H_2, D_2, He, N_2, Ne, Kr, Xe$

Kinematic Range: $0.02 < x < 0.8$ at $Q^2 > 1\ GeV^2$ and $W > 2\ GeV$

Internal Gas Target: $\overrightarrow{He}$, $\overrightarrow{H}$, $\overrightarrow{D}$, $H\uparrow$ unpol: $H_2, D_2, He, N_2, Ne, Kr, Xe$

Reconstruction: $\Delta p/p < 2\%$, $\Delta\theta < 1$ mrad

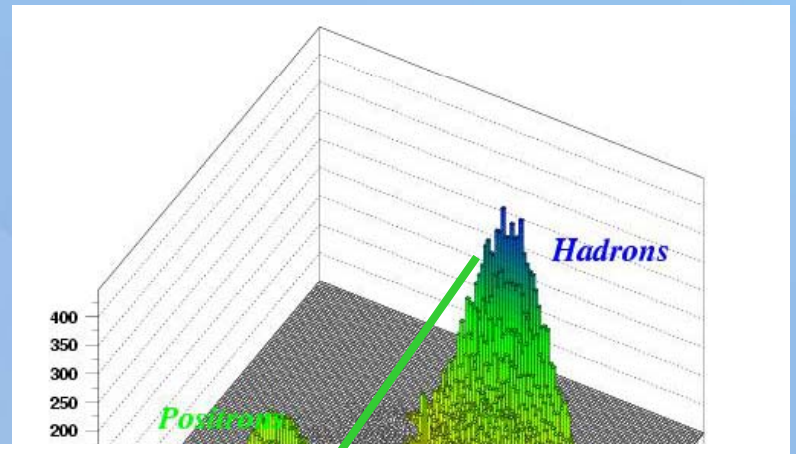
Particle ID: TRD, Preshower, Calorimeter

α 1997: Cherenkov, 1998 α: RICH + Muon-ID

Which Hadron (π,K,p) is Which

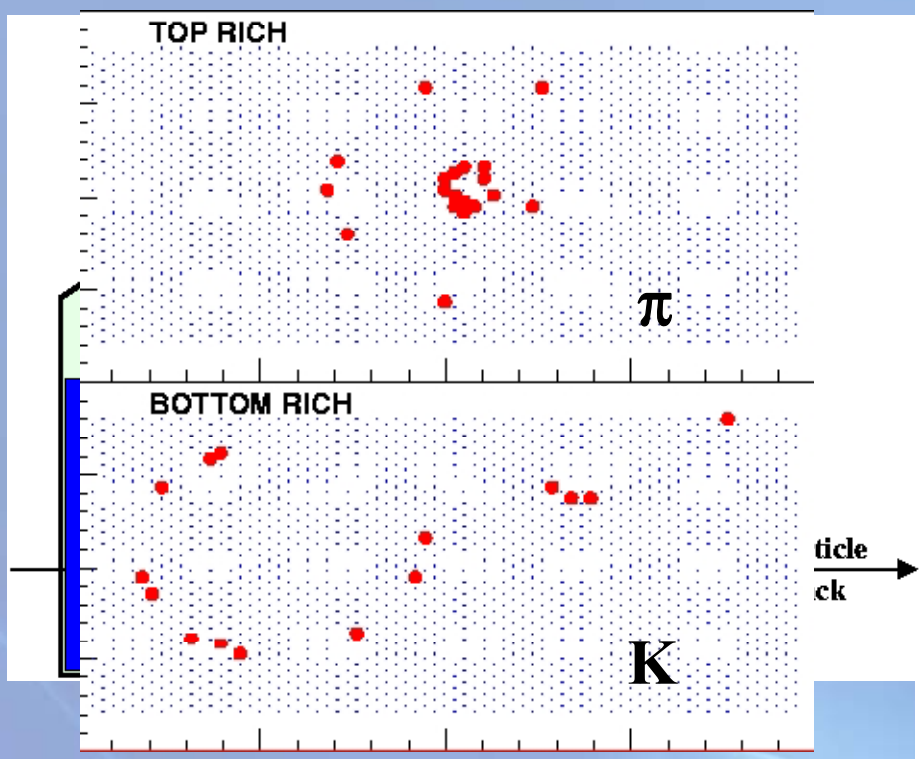
hadron/positron separation

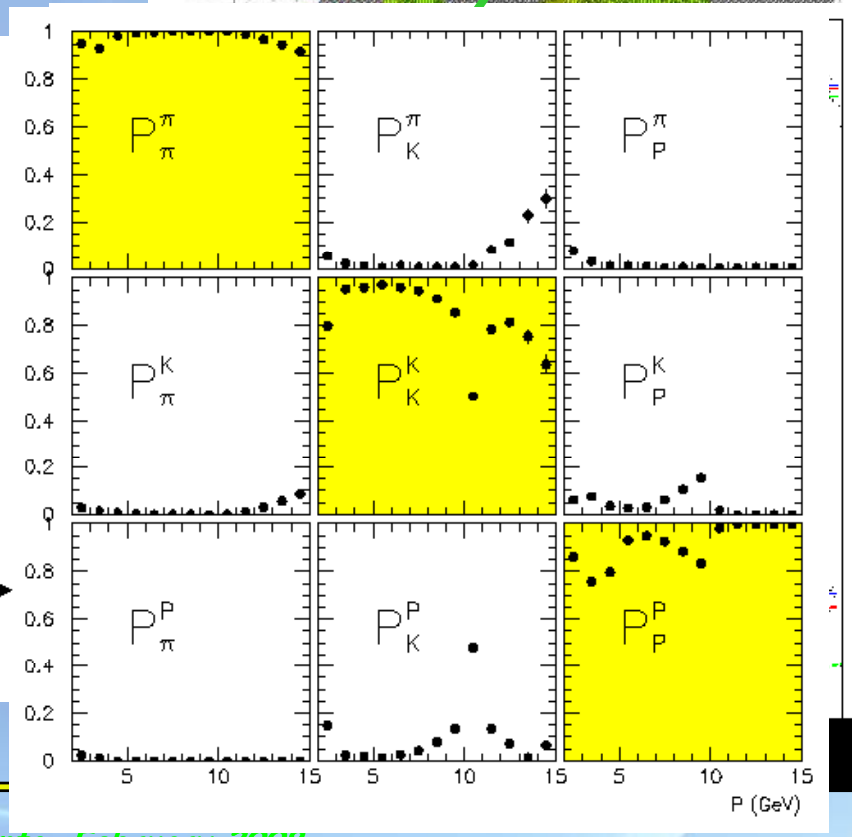
combining signals from:
TRD, calorimeter, preshower



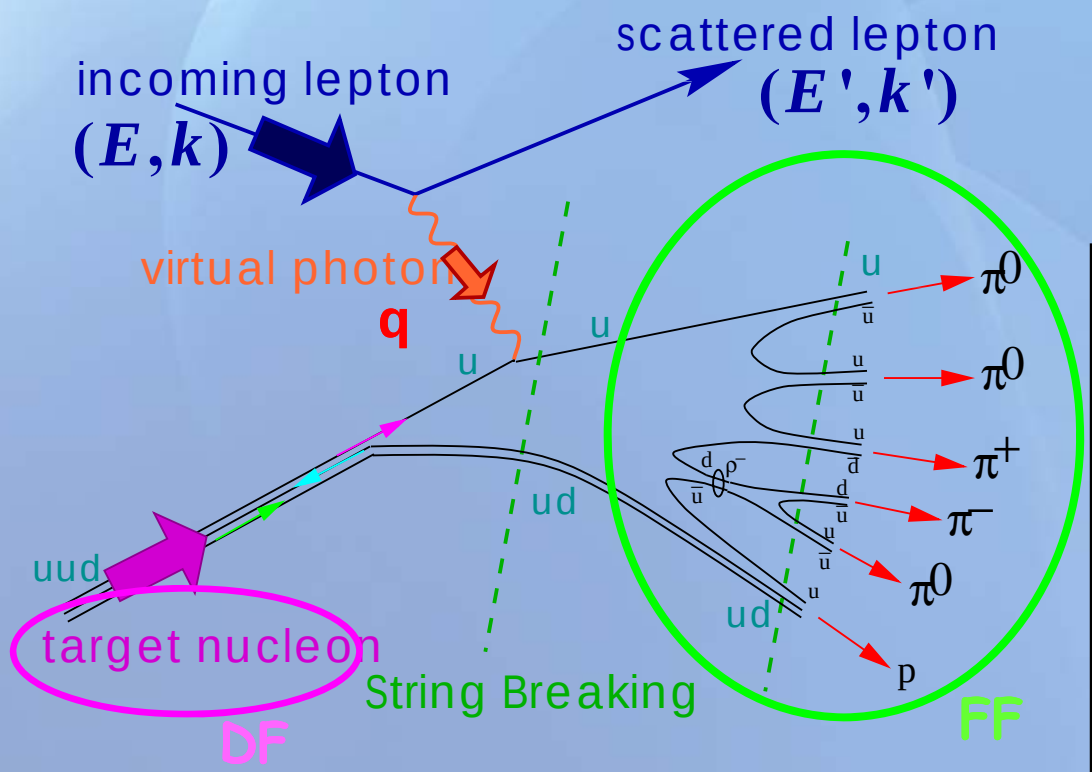
hadron separation

Dual radiator RICH for π, K, p





Deep Inelastic Scattering



Important kinematic variables:

Photon:

$$Q^2 = -q^2 = -(k-k')^2$$

$$\nu = E - E'$$

Quark: $x = \dfrac{Q^2}{2M\nu}$

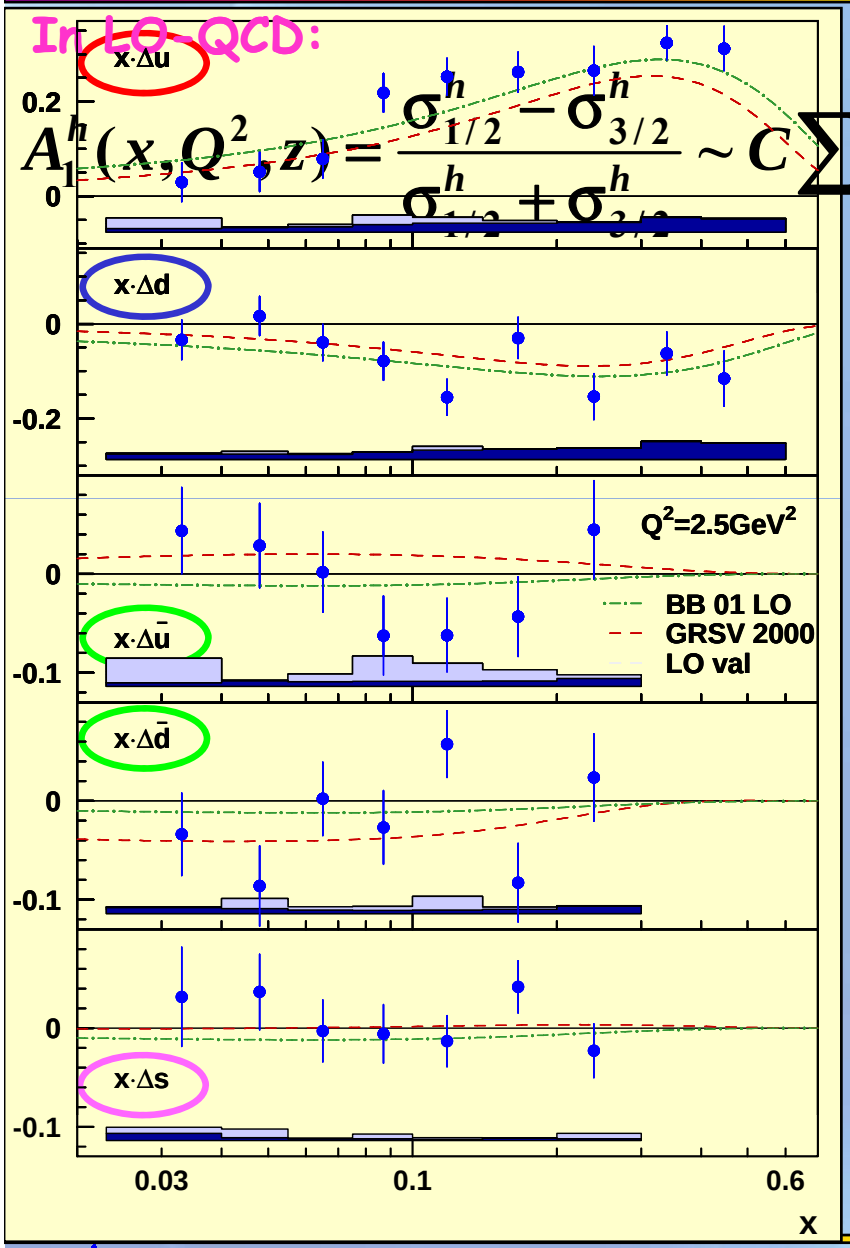
Hadron:

$$z = \frac{E_h}{\nu} \qquad p_t^2$$

cross section:

$$d\sigma^h(z) \sim \sum_f q_f(x) \otimes d\sigma_f \otimes D_f^h(z)$$

Polarized Quark Densities



- First complete separation of pol. PDFs without assumption on sea polarization
- $\Delta u(x) > 0$ $\Delta d(x) < 0$

  good agreement with NLO-QCD
- $\Delta\bar{u}(x), \Delta\bar{d}(x) \sim 0$
- No indication for $\Delta s(x) < 0$
- In measured range (0.023 – 0.6)

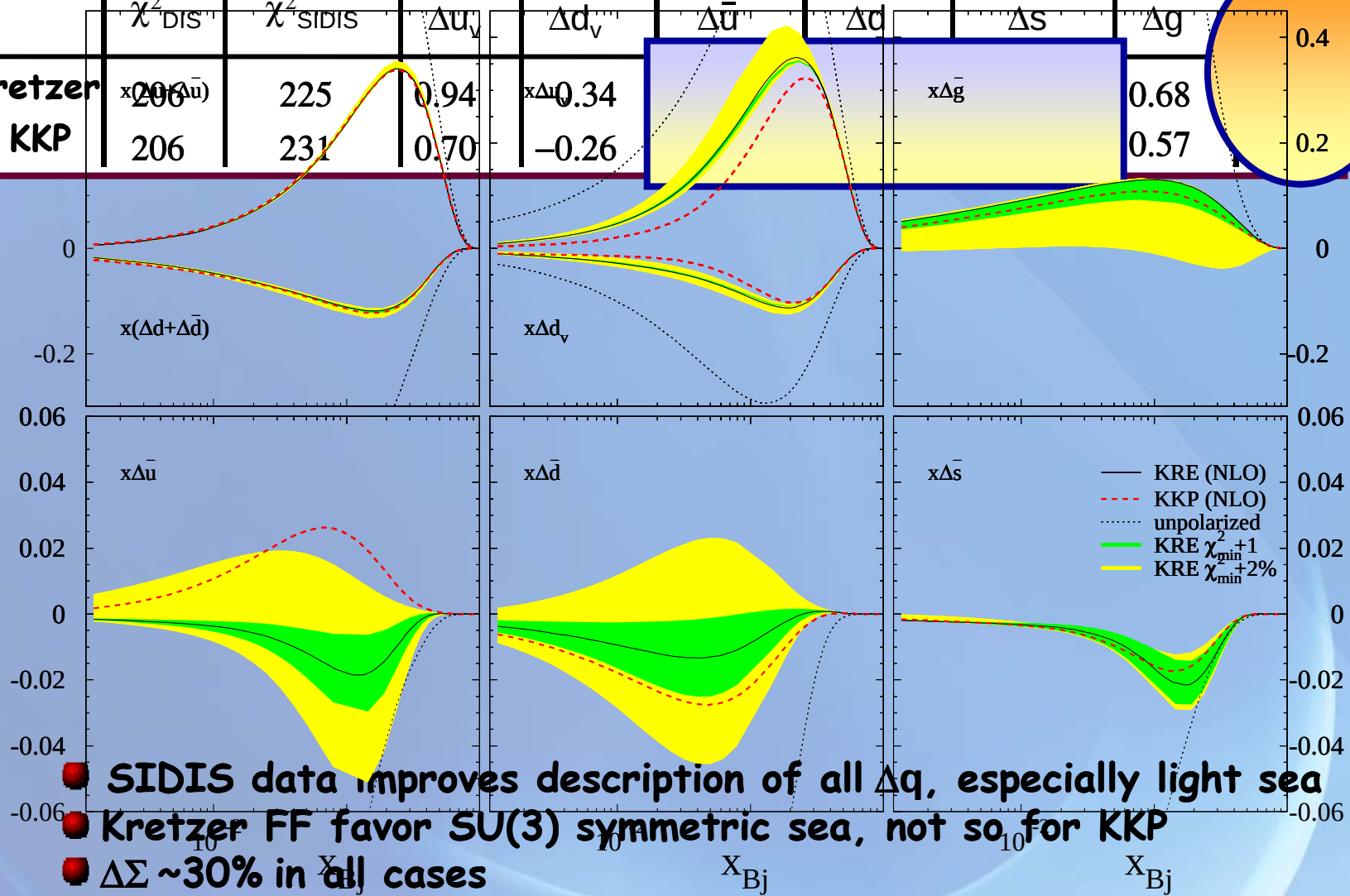
$$\int \Delta\bar{u} = -0.002 \pm 0.043$$
$$\int \Delta\bar{d} = -0.054 \pm 0.035$$
$$\int \Delta s = +0.028 \pm 0.034$$

NLO FIT to DIS & SIDIS Data

D. De Florian et al. hep-ph/0504155

NLO @ Q^2=10 GeV^2

	χ^2_{DIS}	χ^2_{SIDIS}	Δu_v	Δd_v	$\Delta\bar{u}$	$\Delta\bar{d}$	Δs	Δg
Kretzer	206	225	0.94	0.34				0.68
KKP	206	231	0.70	–0.26				0.57



- SIDIS data improves description of all Δq, especially light sea
- Kretzer FF favor SU(3) symmetric sea, not so for KKP
- $\Delta\Sigma$ ~30% in all cases

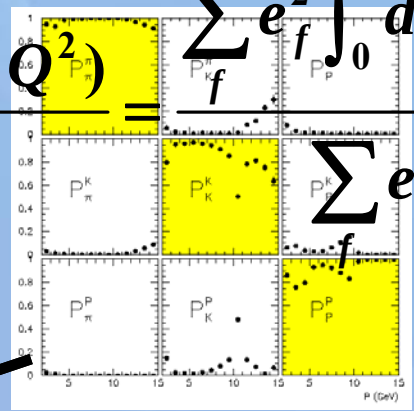
Multiplicity Extraction

unpolarised H & D data

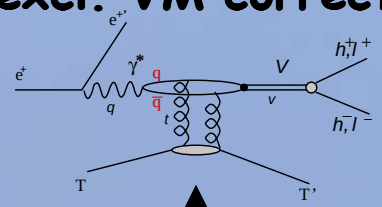
c.s. background correction

RICH – PID

$$\frac{1}{N_{DIS}}\frac{dN_h(z,Q^2)}{dz} = \frac{\sum_f e_f^2 \int_0^1 dx q_f(x,Q^2) D_f^h(z,Q^2)}{\sum_f e_f^2 \int_0^1 dx q_f(x,Q^2)}$$

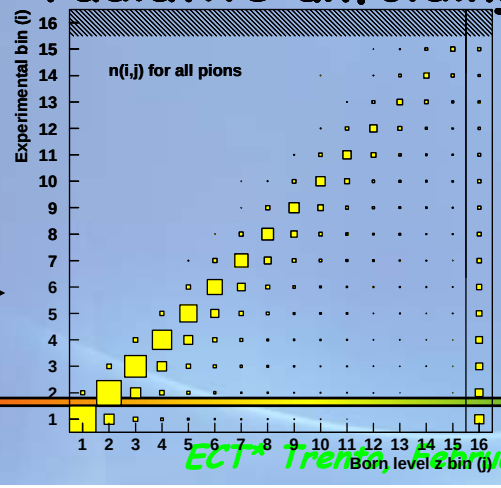


excl. VM correction



experimental multiplicities in acceptance

acceptance correction
radiative unfolding

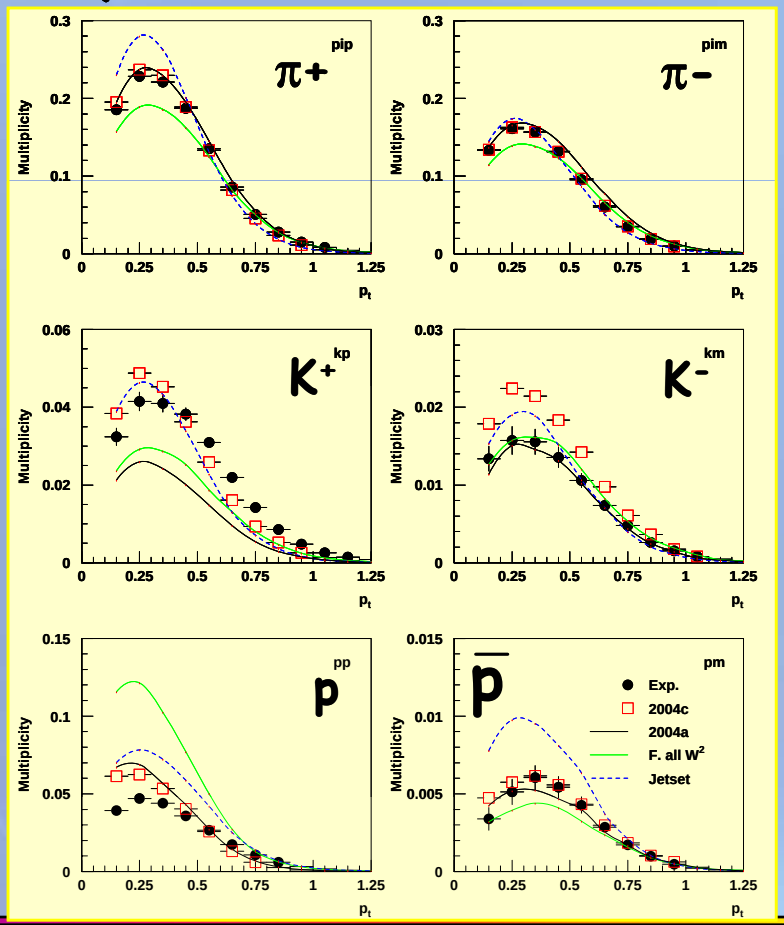


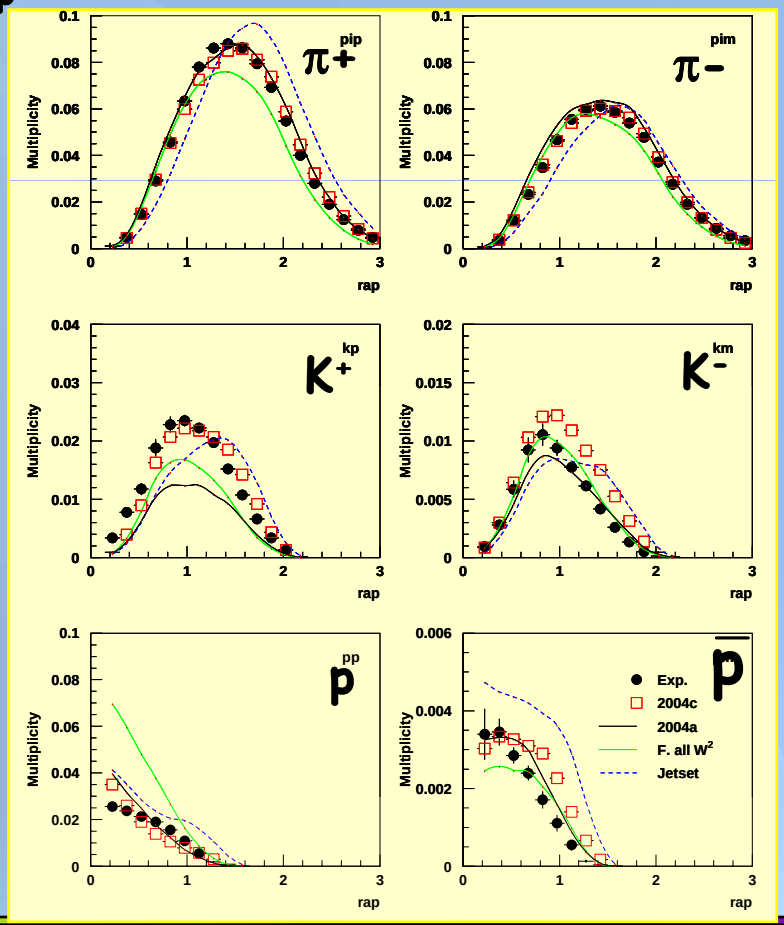
MC

Born-level multiplicities

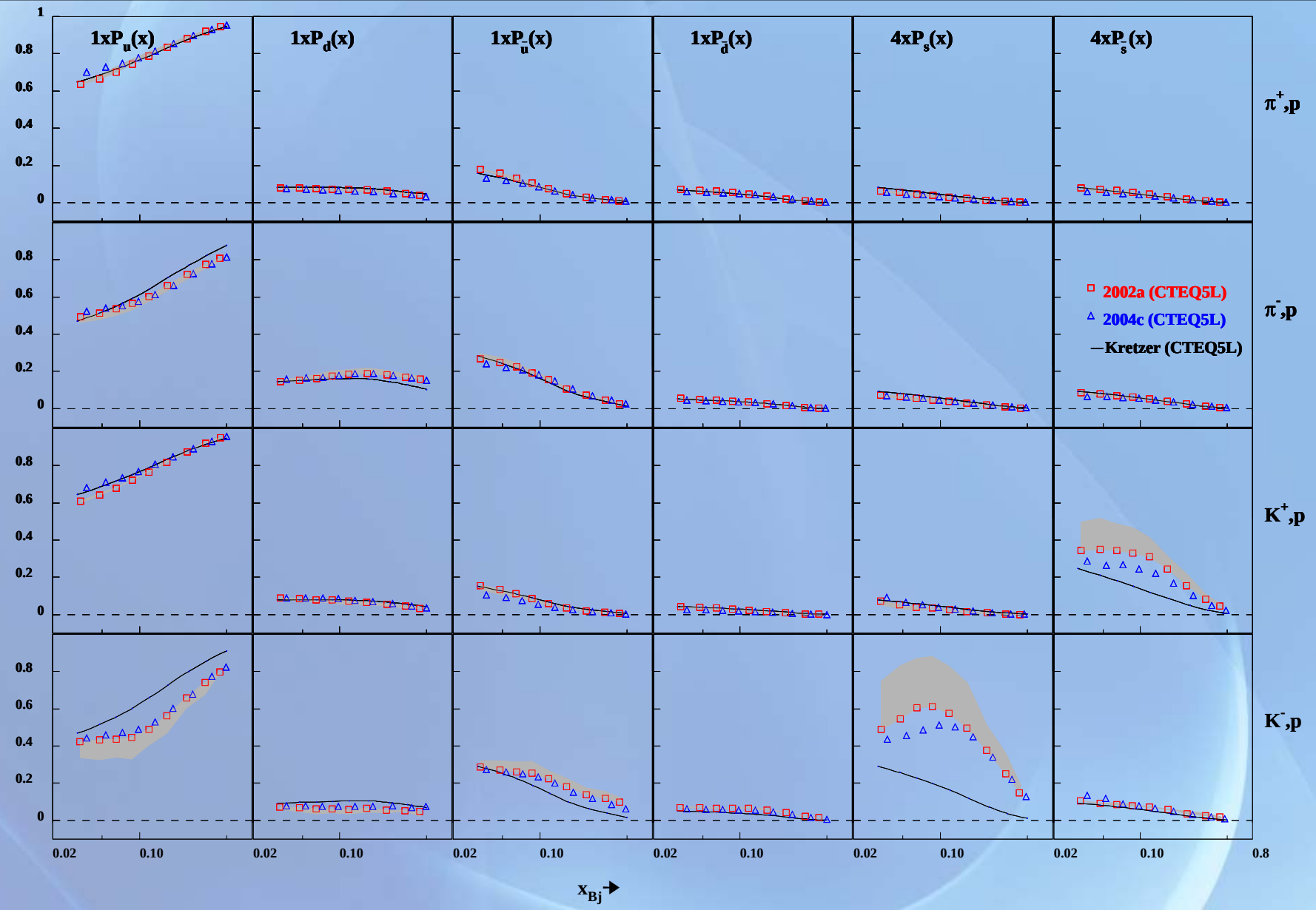
Data-MC Comparison

- **MC:**
  Lepto/Pythia-6 in combination with Jetset and complete Geant-3 detector model; PDF: Cteq-6L
- **Data:**
  $Q^2>1GeV^2$, $W^2>10GeV$, $2GeV<p_{\pi,K,p}<15GeV$



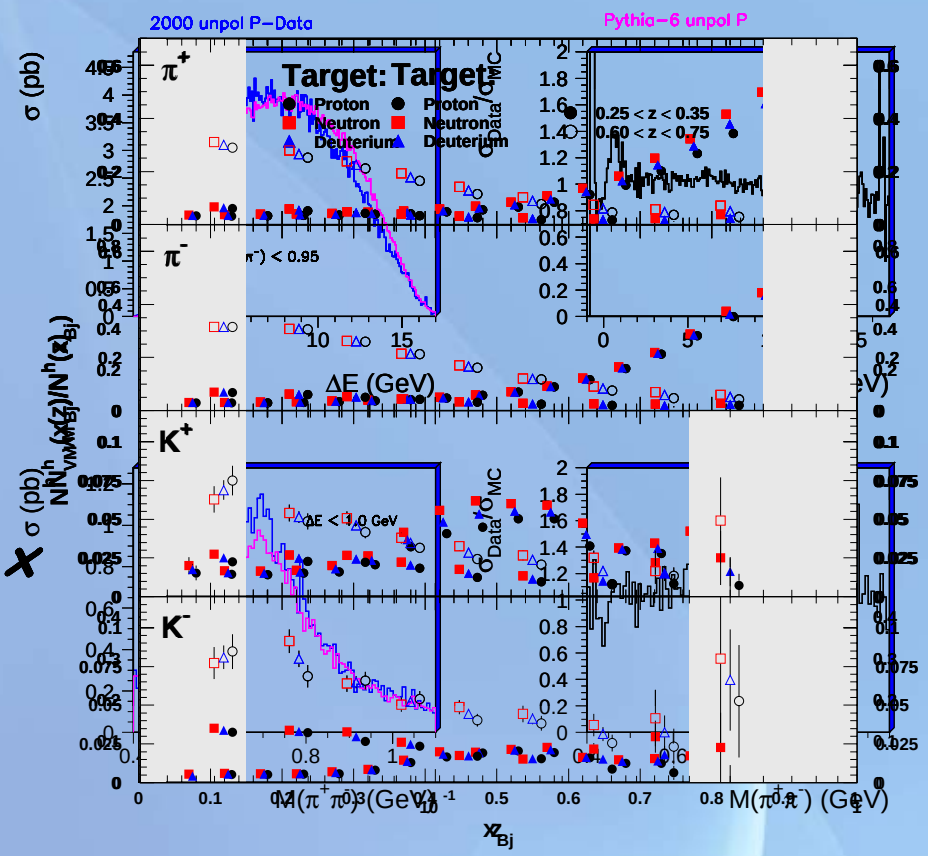


Purity Comparison

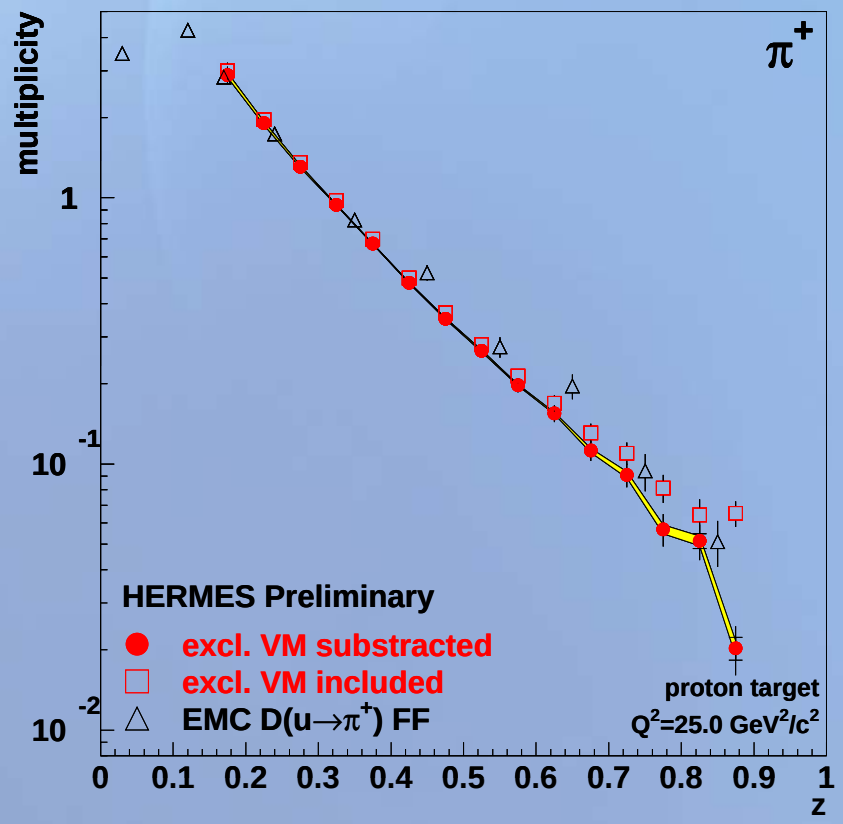


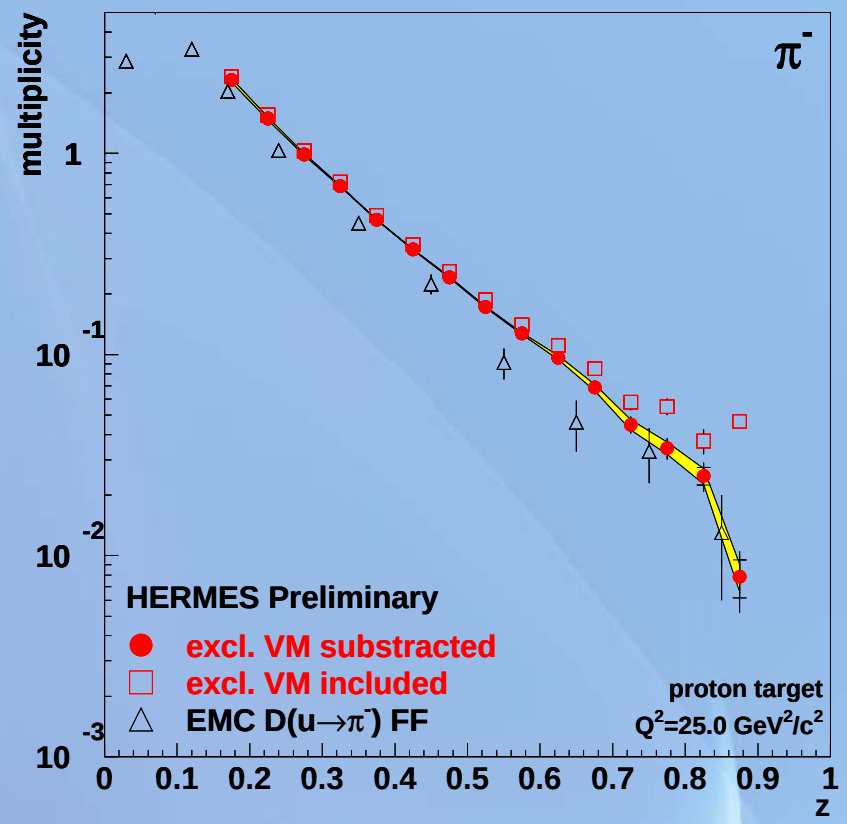
Exclusive VM Contribution

- exclusive VM production: different process than SIDIS
- estimate contribution from PYTHIA-6
- ratio: $N^{h}_{excl.VM}(z) / N^{h}_{SIDIS}(z)$
  - large contribution for π at high z
  - moderate contribution for K
- contribution increasing for decreasing x



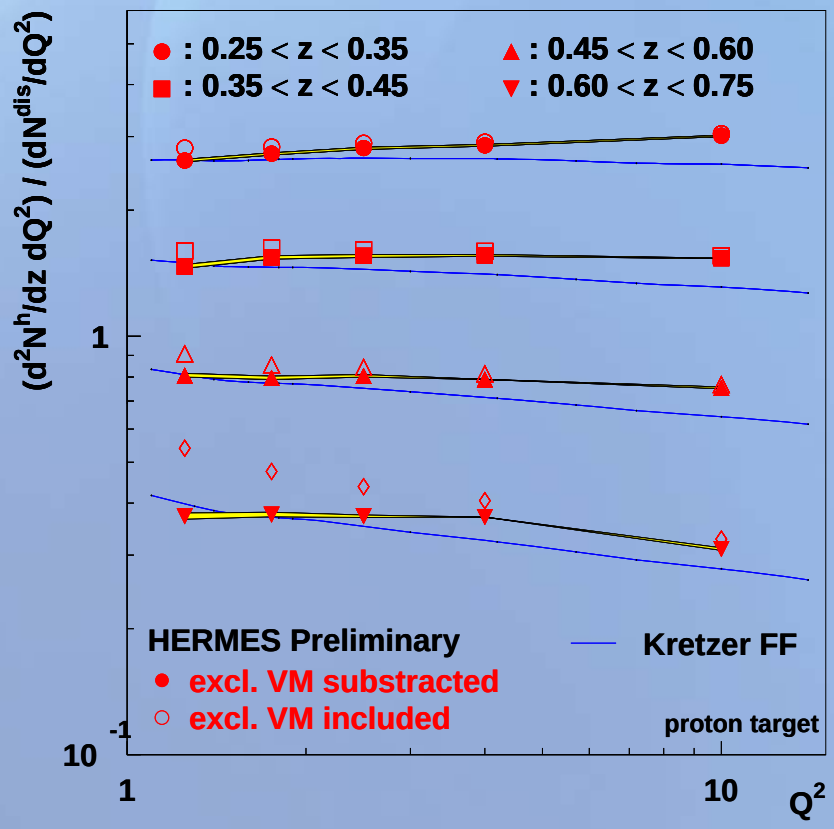
$\pi^{+/-}$ Multiplicities vs. z

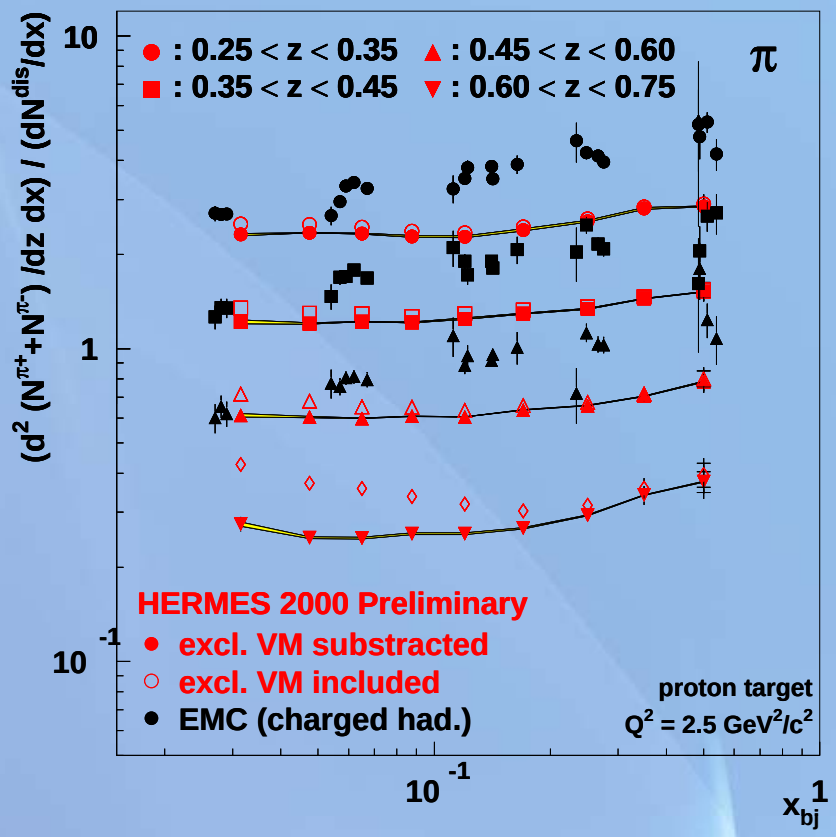




- EMC: Fragmentation Fct. $D_u^{\pi+/-}$ (Nucl. Phys. B321 (1989) 541)
- syst. error dominated by PID unfolding

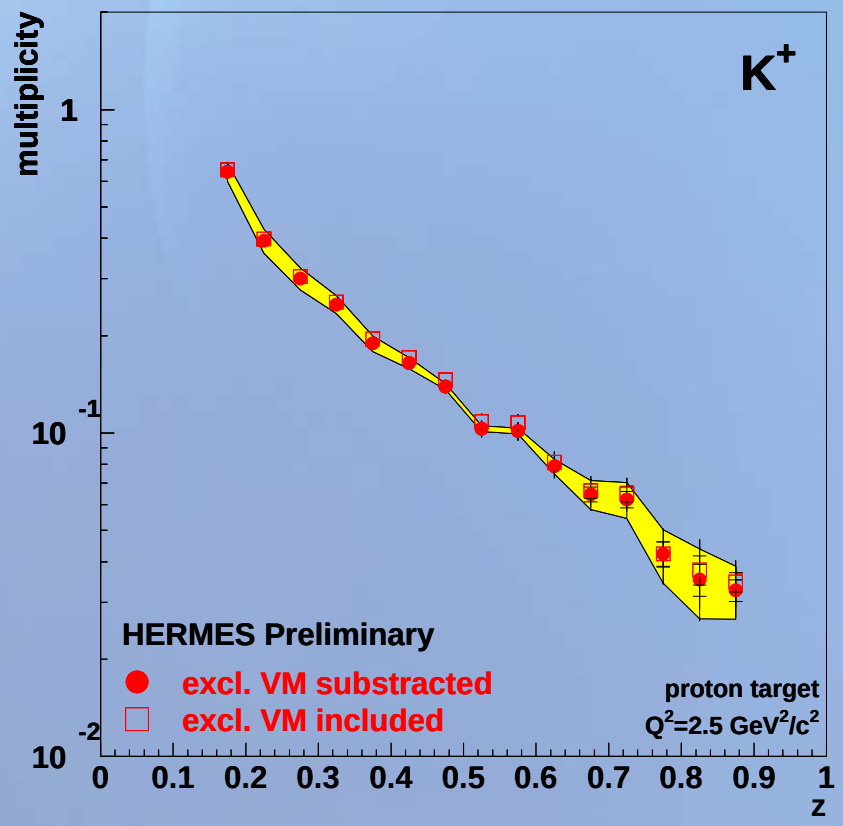
$\pi^{+/-}$ Multiplicities vs. x & Q^2

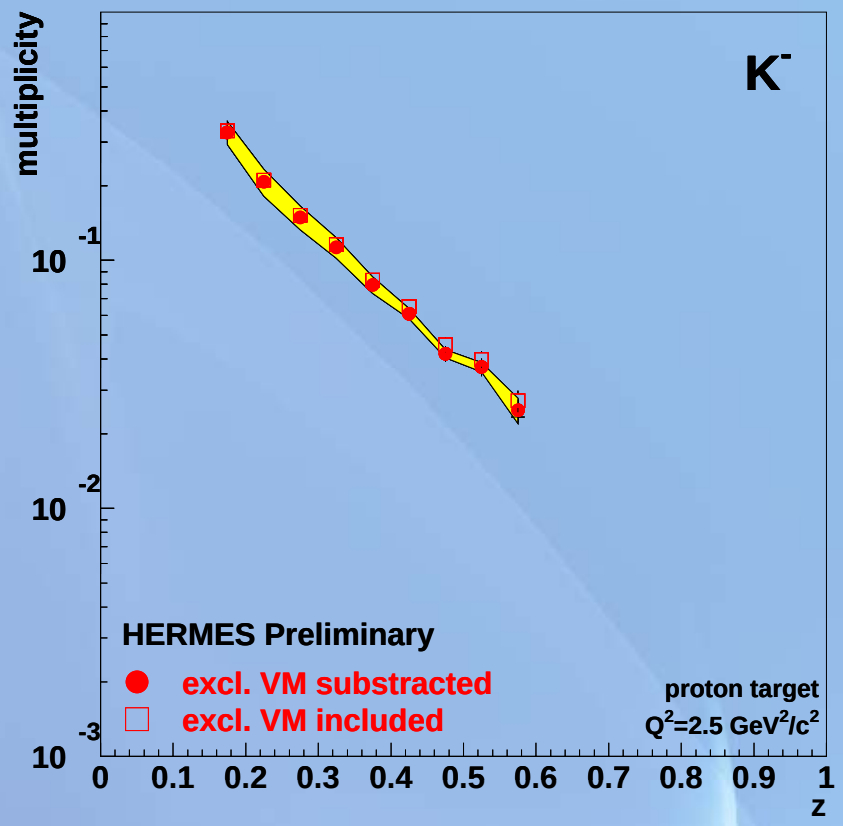




- reasonable agreement using Kretzer FF
- weak x dependence

$K^{+/-}$ Multiplicities vs. z





- factor 2/(10) more statistics on tape already analyzed
- syst. error dominated by PID unfolding

More on Kaon FF

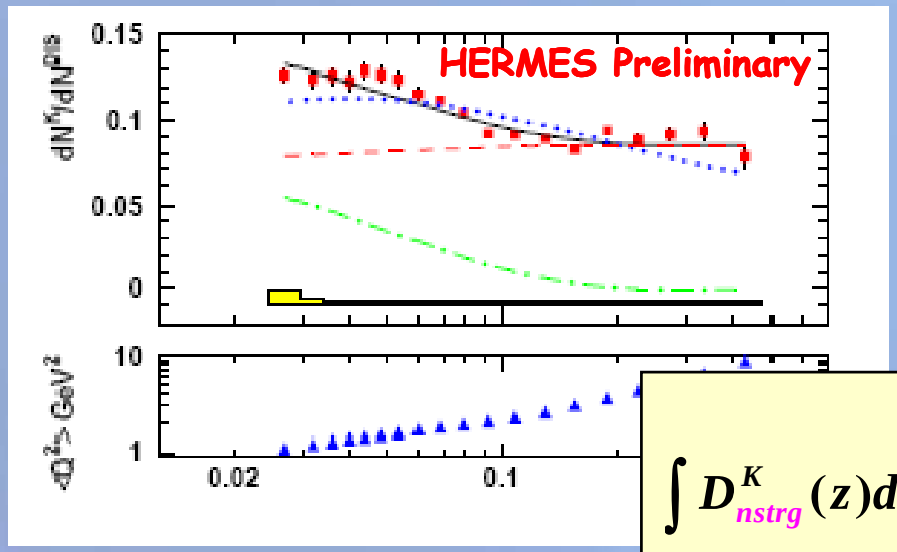
- Kaon multiplicities from Deuterium target
  - strange quark sea in proton and neutron identical
  - fragmentation simplifies
- Only assumptions used:
  - isospin symmetry between proton and neutron
  - charge-conjugation invariance in fragmentation

$$\int D^K_{n-str.}(z)dz = 4\int D(z)^{K^++K^-}_u dz + \int D(z)^{K^++K^-}_d dz$$

$$\int D^K_{strange}(z)dz = 2\int D(z)^{K^++K^-}_s dz$$

Fit x-depehdence of multiplicities using PDFs from CTEQ-6

$$\frac{dN^K(x)/dx}{dN^{Dis}(x)/dx} = \frac{Q(x)\int D^K_{n-str.}(z)dz + S(x)\int D^K_{strange}(z)dz}{5Q(x)+2S(x)}$$



dotted: CTEQ-6L & fit $\int D^K_S(z)dz$

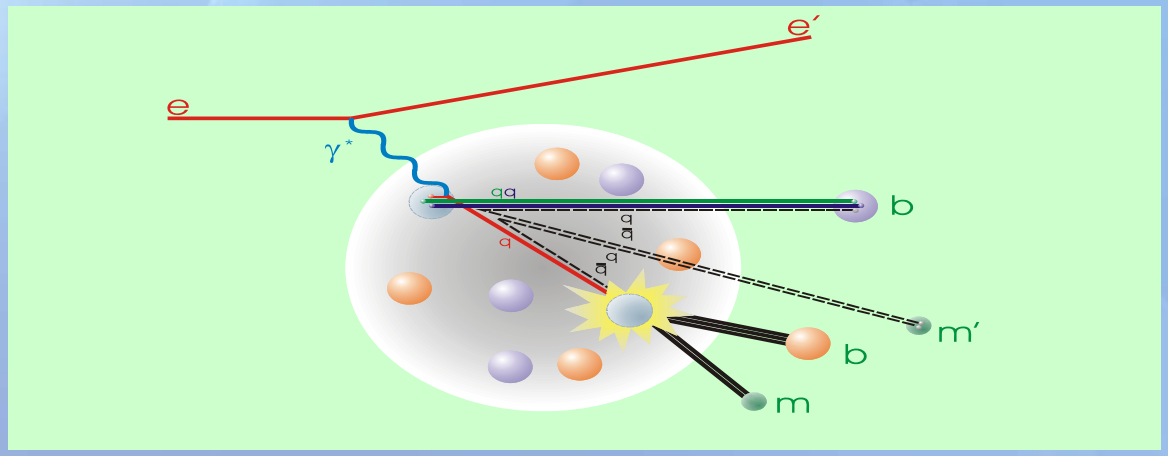
dashed: $\int D^K_Q(z)dz$

dashed-dotted: $\int D^K_S(z)dz$

solid:

	This Work	Kretzer	KKP	BSS
$\int D^K_{nstrg}(z)dz$	0.43 ± 0.01	1.103	1.111	0.44 ± 0.04
$\int D^K_{strg}(z)dz$	1.28 ± 0.29	0.783	0.296	1.27 ± 0.13

Fragmentation in Nuclear Medium



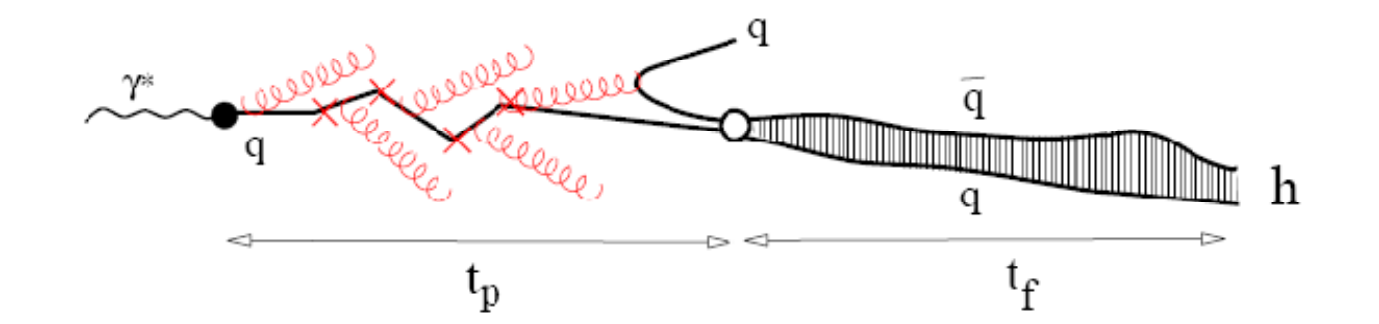
$$R_A^h(z,\nu,p_t,Q^2) = \frac{\left.\dfrac{N_h(z,\nu,p_t,Q^2)}{N_{DIS}}\right|_A}{\left.\dfrac{N_h(z,\nu,p_t,Q^2)}{N_{DIS}}\right|_D} = \frac{\left.\dfrac{1}{\sigma_{DIS}}\dfrac{d^2\sigma_h}{dz\,d\nu\,dp_t\,dQ^2}\right|_A}{\left.\dfrac{1}{\sigma_{DIS}}\dfrac{d^2\sigma_h}{dz\,d\nu\,dp_t\,dQ^2}\right|_D} = \frac{\left.\dfrac{\sum e_f^2 q_f(x,Q^2)\,D_f^h(z,p_t,Q^2)}{\sum e_f^2 q_f(x,Q^2)}\right|_A}{\left.\dfrac{\sum e_f^2 q_f(x,Q^2)\,D_f^h(z,p_t,Q^2)}{\sum e_f^2 q_f(x,Q^3)}\right|_D}$$

- Leptonic variables: ν (or x) and Q^2
- Hadronic variables: z and p_t^2
- Different nuclei: size and density
- Different hadrons: flavors and mixing of FFs

Double-ratio: approx. evaluation of FF medium modification

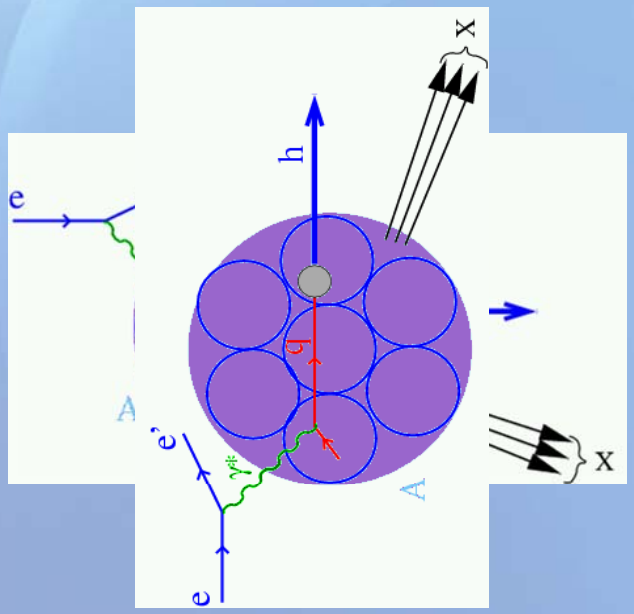
Systematic uncertainties are minimized in the double-ratio

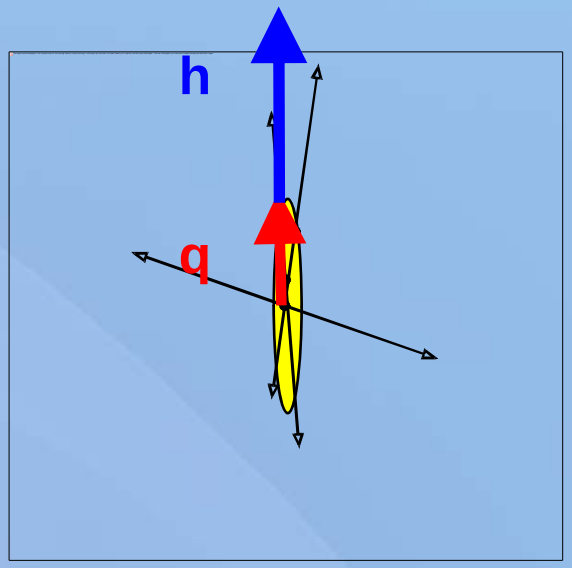
Space Time Evolution of Hadronization



- Parton propagation ($t<t_p$):
  - Gluon radiation (mainly energy loss)
  - Partonic scattering (mainly p_t broadening)
- Pre-hadron propagation ($t_p<t<t_f$):
  - Off shell and virtual hadrons
  - Colorless qqbar
  - Increasing transverse dimension & interaction probability
- Hadronic FSI ($t>t_f$):
  - Full hadronic cross section (10-30 mbarn)
  - Mainly formed after several tens of fm i.e. out of the nucleus

DIS vs. HIC





$E_q = \blacksquare = E_e - E_{e'}$ ⏲ 13 GeV

$E_h = z \blacksquare$ ⏲ 2 - 15 GeV

$E_q = p_T / z$

$E_h = p_T$ ⏲ 2 - 20 GeV

Hermes kinematics is relevant to Ion Ion mid-rapidity

...but beware the virtuality...

$Q^2 = \square q^2$ is measured

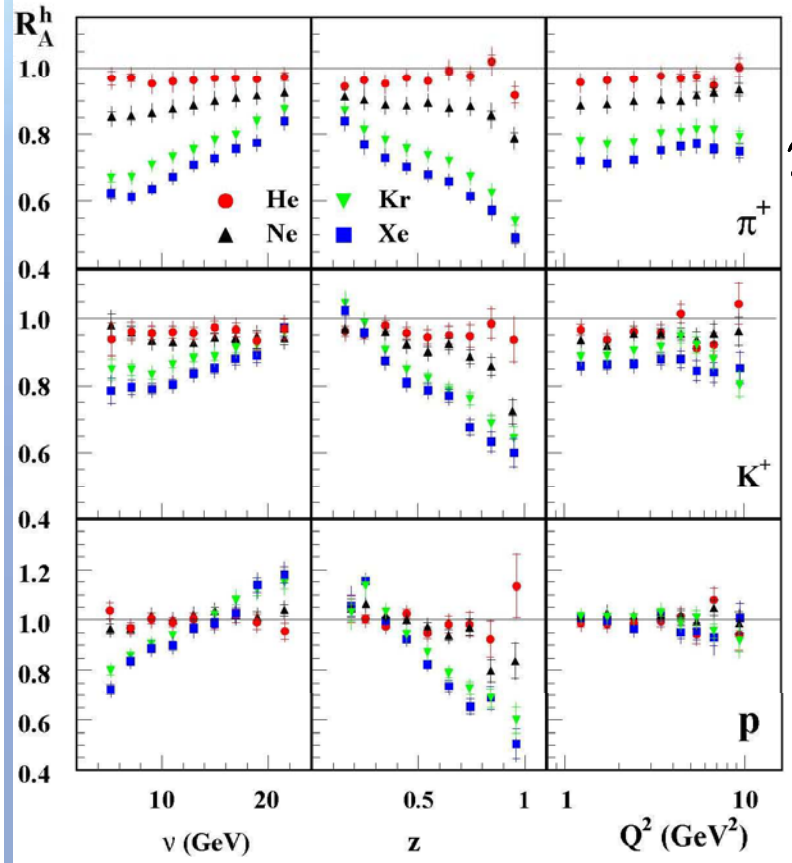
Q^2 ⏲ E_q^2 ✪ $(p_T/z)^2$

...and the rapidity...

always forward rapidity

rapidity can change

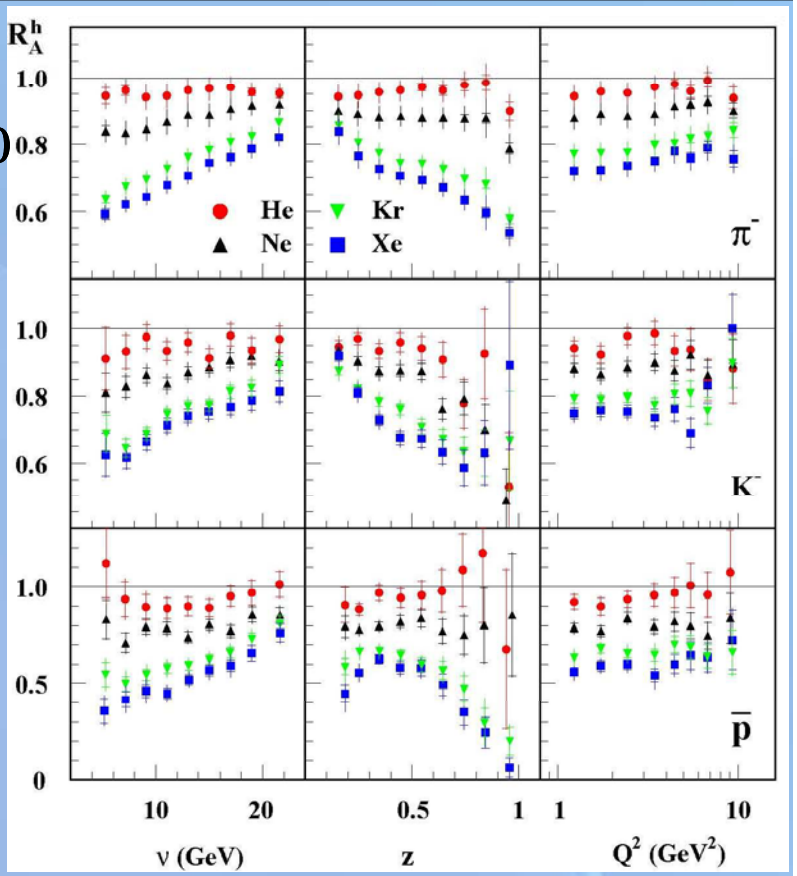
Multiplicity Ratio : Different Hadrons

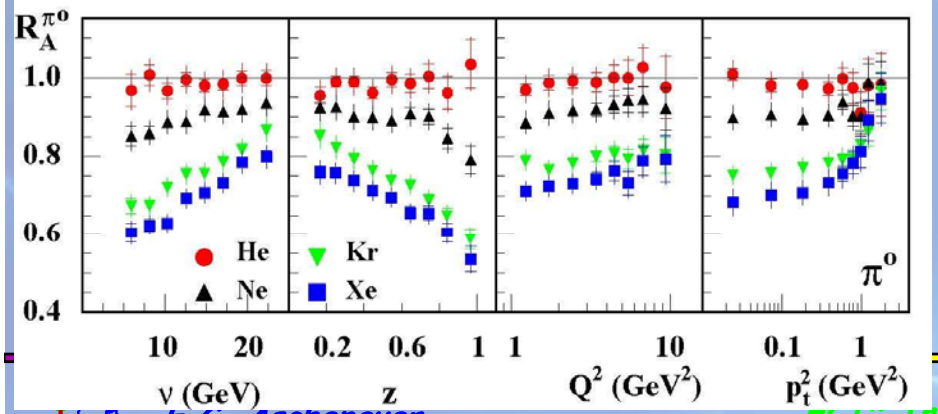


$\pi^+ = \pi^- = \pi^0$

$K^+ \neq K^-$

$p \neq \bar{p}$



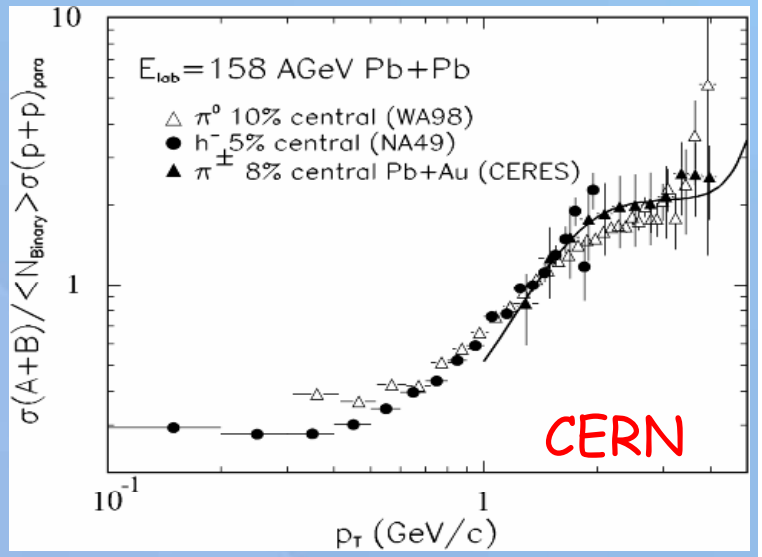


- Clear A-dependence
- clear z and ν dependence
- very small Q^2 dependence

Multiplicity Ratio vs. p_t^2

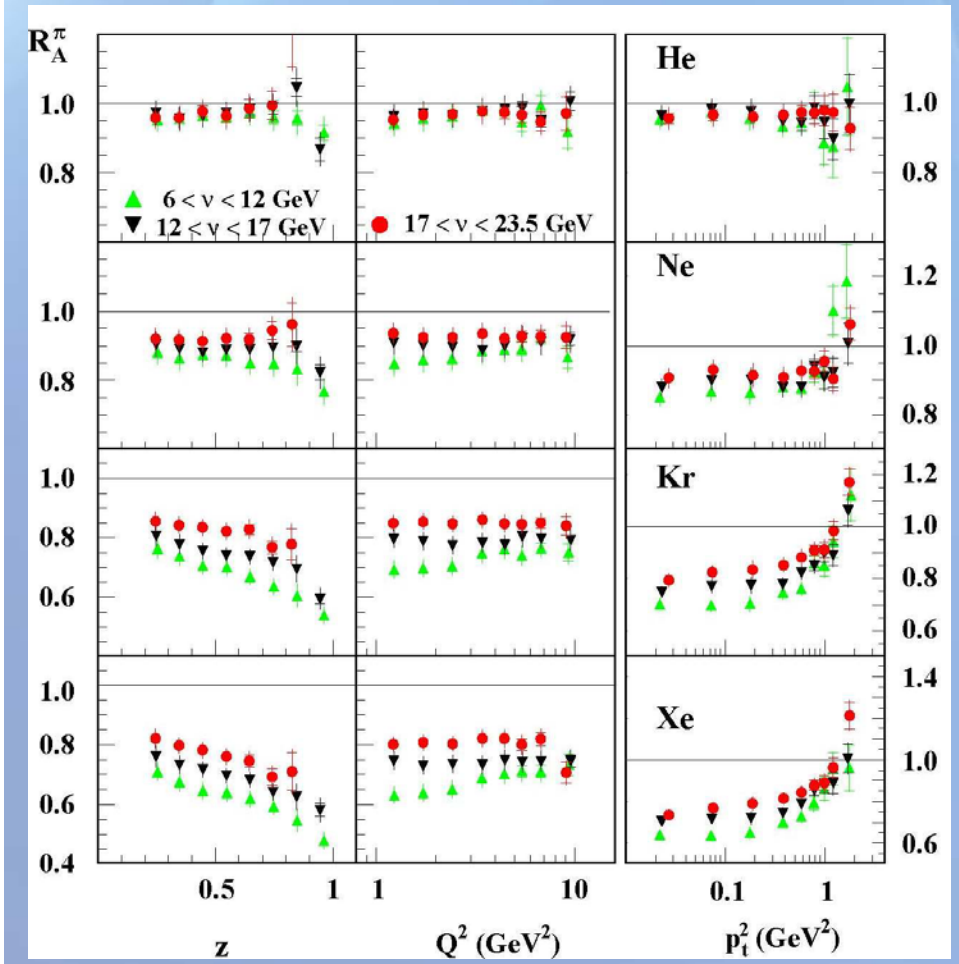
In pA and AA collisions hadrons gain extra transverse momentum due to the multiple scattering of partons

➡ Cronin effect



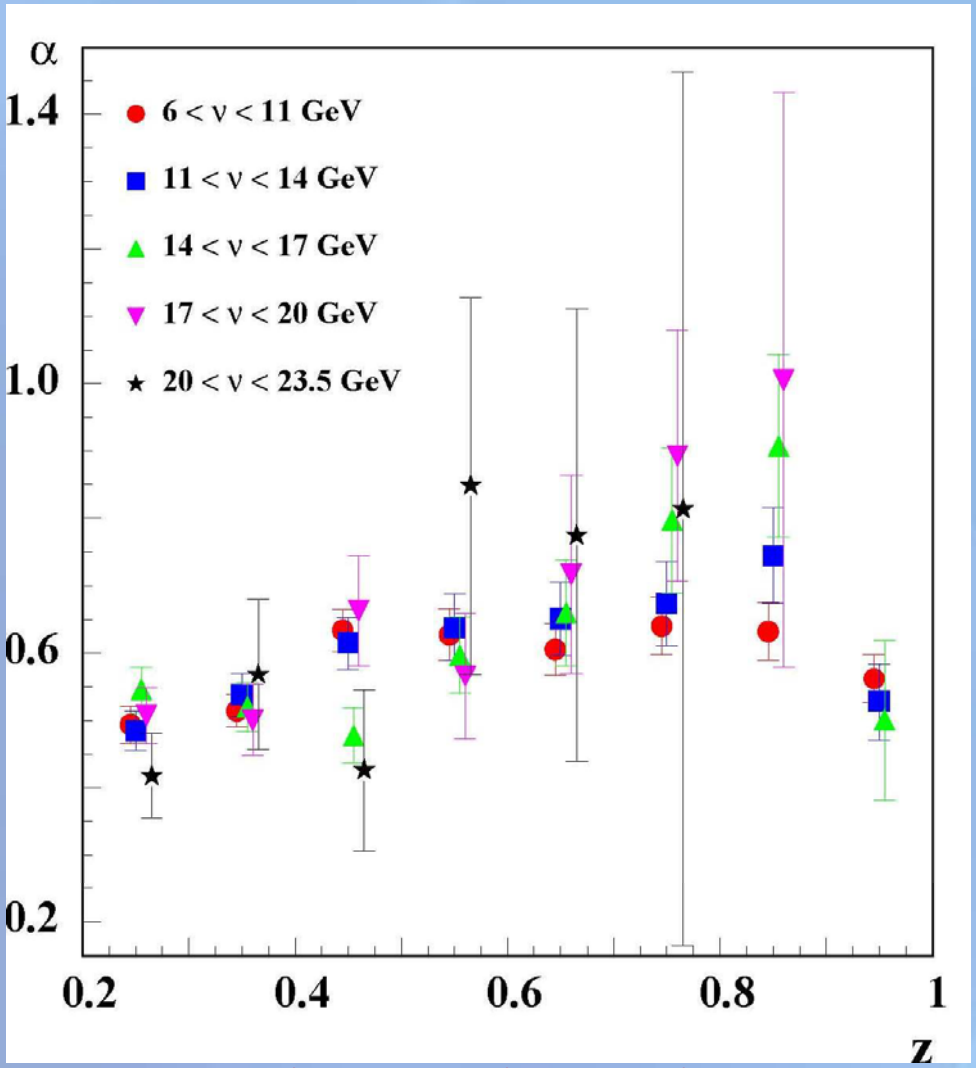
- DIS shows a p_t enhancement similar to that observed in HIC (SPS, RHIC non-central)
- Cronin effect without ISI
- Larger p_t enhancement for proton vs. pion

$\pi^{+/-}$ Multiplicity Ratio 2D



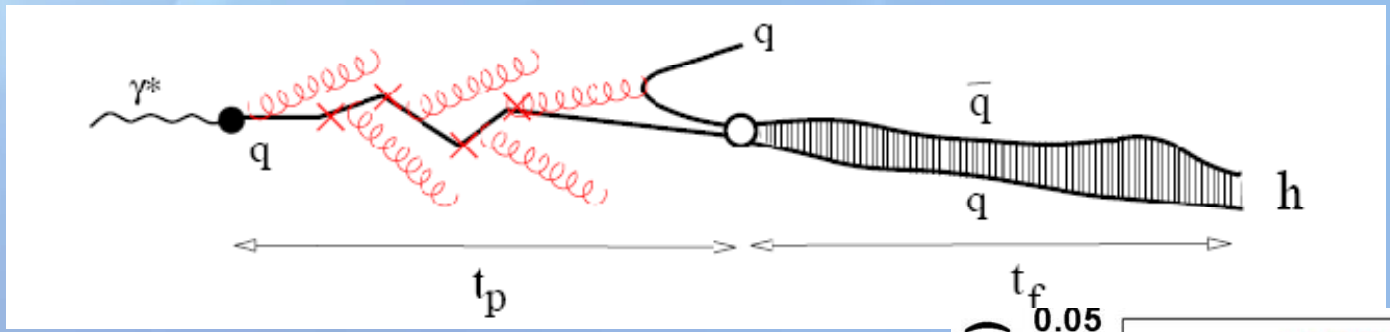
- Cronin effect reduced at high z

A dependence of attenuation



Data support a quadratic dependence on nuclear size A^{α} with α ~2/3

P_t-Broadening vs $A^{1/3}$

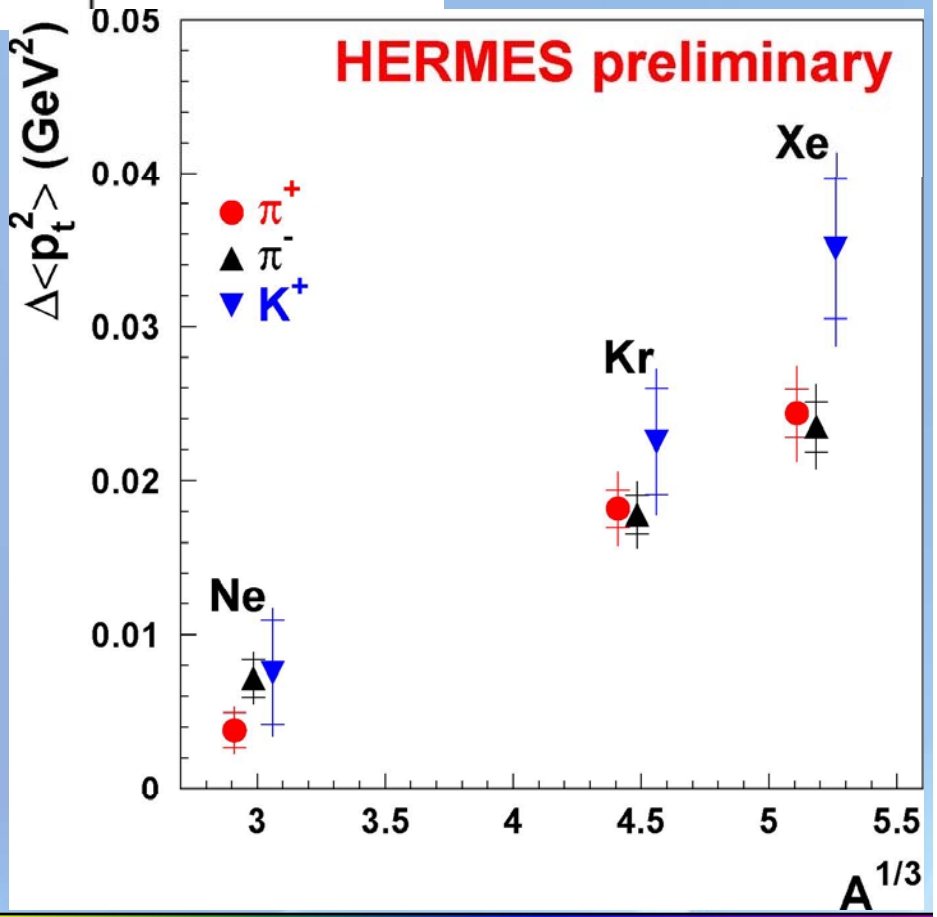


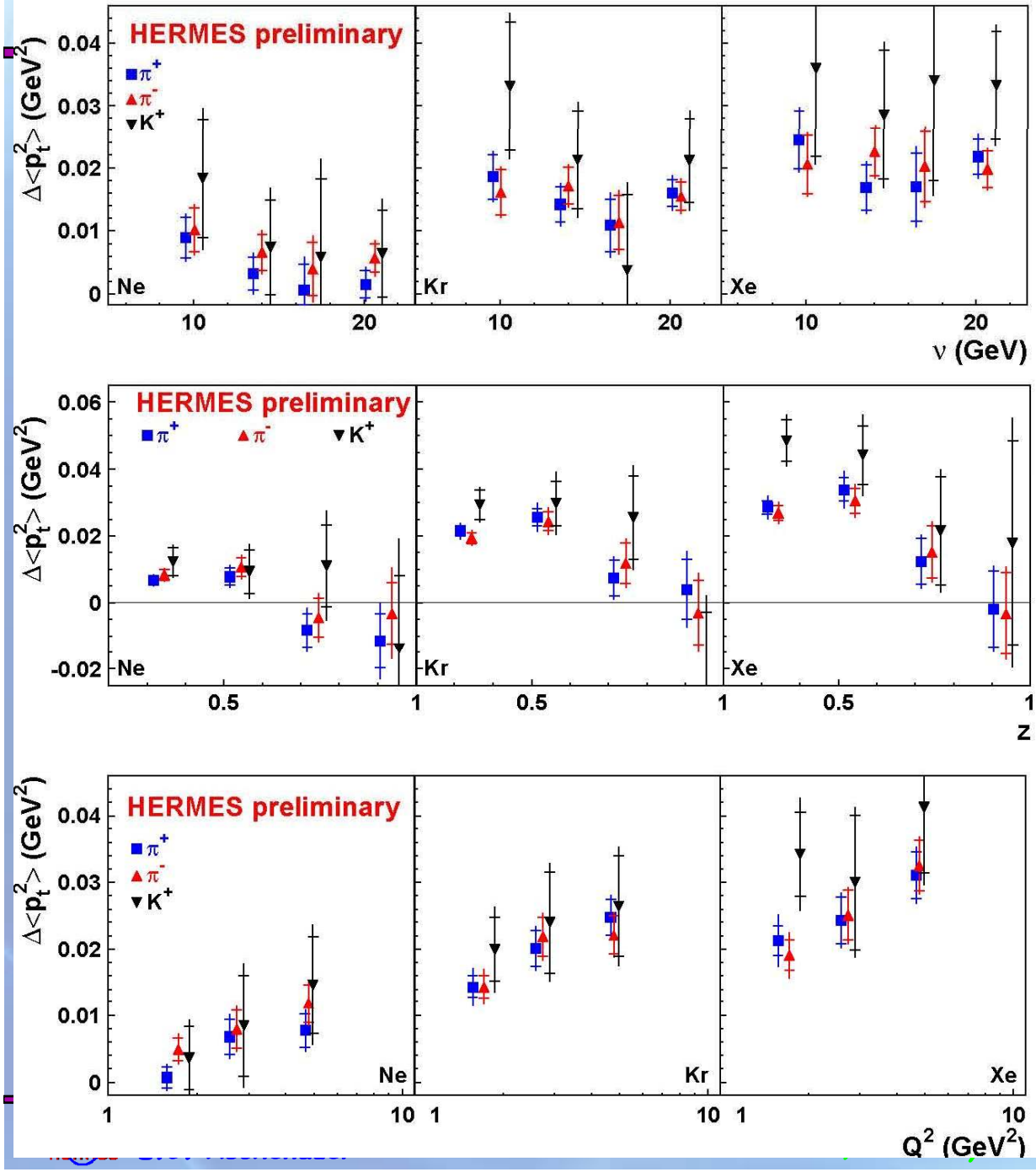
$$\Delta\langle p_t^2\rangle = \langle p_t^2\rangle_A - \langle p_t^2\rangle_D$$

$$\Delta\langle p_t^2\rangle \sim t_p$$

Mainly partonic scattering :
Incoherent → linear in nuclear size

In later stages no broadening:
elastic scattering very small





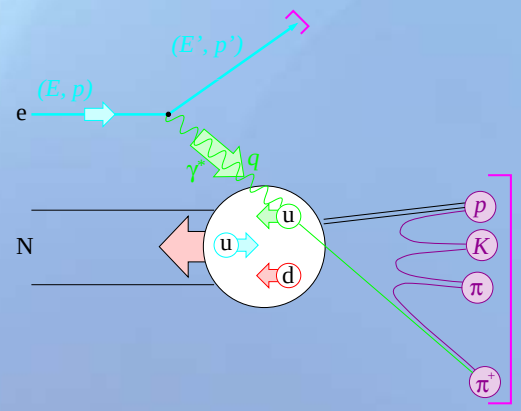
$\Delta\langle p_t^2\rangle$ up to 0.25 GeV^2

- No ν dependence : prehadron formed outside in favor of partonic effects
- No effect at z=1 (t_p=0)
- Increase with Q2: gluon radiation

Clear evidence for partonic effects

Constraints on pre-hadronic effects

Outlook and Summary



- factor 2/(10) more proton data on tape and analyzed
  - $\pi^{+/-}$, π^0, $K^{+/-}$, p, pbar, ...
  - as 1dim-fct of x, z, p_t, Q^2
  - 2 dim-dependences
- 800pb^{-1} deuteron data
- extraction of PDFs
  - S(x)
  - u_v/d_v
  - ubar – dbar
- finally publish
- not shown BE data

- data give access to different stages of fragmentation
- all nuclear data analyzed
- a bit more to come
  - updates on 2-hadron attenuation
  - attenuation of excl. ρ's
  - more 2 dim-dependences
- finalize last papers

BACKUP-SLIDES