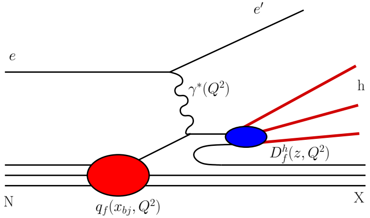
The fragmentation process at HERMES

DIS 2005 - XIII International Workshop on Deep Inelastic Scattering

Bino Maiheu
on behalf of the HERMES Collaboration

University of Gent, Belgium
Subatomic and Radiation Physics
bino@inwfsun1.ugent.be

Mission statement

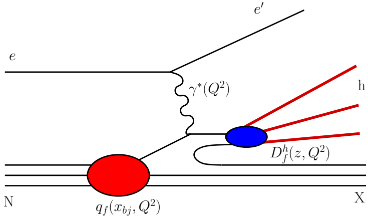


- SIDIS : $e + N \to e' + h + X$
- how do partons inside the nucleon break free to form hadrons ?
- described by $D_f^h(z,Q^2)$
- scale Q^2, momentum fraction x_{bj}
- $z = E_h/\nu$, where $\nu = E - E'$

flavor/charge separated hadron multiplicities

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

Mission statement

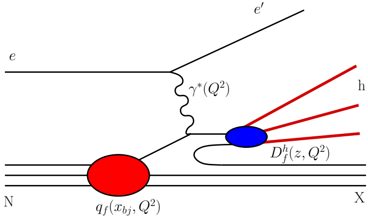


- SIDIS : $e + N \rightarrow e' + h + X$
- how do partons inside the nucleon break free to form hadrons ?
- described by $D_f^h(z, Q^2)$
- scale Q^2, momentum fraction x_{bj}
- $z = E_h/\nu$, where $\nu = E - E'$

flavor/charge separated hadron multiplicities

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

Mission statement



- SIDIS : $e + N \to e' + h + X$
- how do partons inside the nucleon break free to form hadrons ?
- described by $D_f^h(z,Q^2)$
- scale Q^2, momentum fraction x_{bj}
- $z = E_h/\nu$, where $\nu = E - E'$

flavor/charge separated hadron multiplicities

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

Motivation

- flavor separation of multiplicities : HERMES allows us to do this (RICH)
- Importance of this study at HERMES ?
  - test factorization at HERMES energies $\sqrt{s} \approx 7$ GeV
  - study fragmentation functions that were developed for e^+e^- at high energies
    $\rightsquigarrow$ still valid at $\langle Q^2 \rangle$ of 2.5 GeV^2 ?
- note : exclusive VM production $\rightsquigarrow$ contribution of hadrons in SIDIS sample. Totally different process ! $\longleftarrow$ correct for this.
- aim is to extract absolute numbers : difficult with HERMES acceptance !

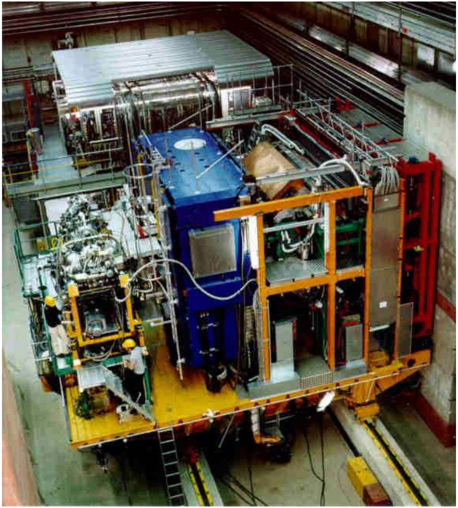
Motivation

- flavor separation of multiplicities : HERMES allows us to do this (RICH)
- Importance of this study at HERMES ?
  - test factorization at HERMES energies $\sqrt{s} \approx 7$ GeV
  - study fragmentation functions that were developed for e^+e^- at high energies
    $\rightsquigarrow$ still valid at $\langle Q^2 \rangle$ of 2.5 GeV^2 ?
- note : exclusive VM production $\rightsquigarrow$ contribution of hadrons in SIDIS sample. Totally different process ! $\longleftarrow$ correct for this.
- aim is to extract absolute numbers : difficult with HERMES acceptance !

Motivation

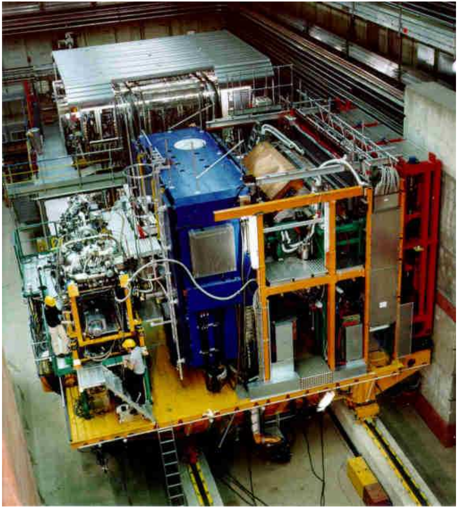
- flavor separation of multiplicities : HERMES allows us to do this (RICH)
- Importance of this study at HERMES ?
    - test factorization at HERMES energies $\sqrt{s} \approx 7$ GeV
    - study fragmentation functions that were developed for e^+e^- at high energies
      $\rightsquigarrow$ still valid at $\langle Q^2 \rangle$ of 2.5 GeV^2 ?
- note : exclusive VM production $\rightsquigarrow$ contribution of hadrons in SIDIS sample. Totally different process ! $\longleftarrow$ correct for this.
- aim is to extract absolute numbers : difficult with HERMES acceptance !

The HERMES experiment



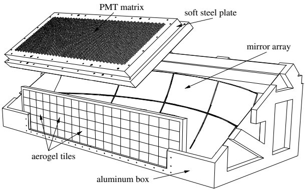
- 27.6 GeV e^+ beam at HERA (DESY)
- fixed gaseous internal H,D,... target (pol/unpol)
- lepton/hadron efficiency $> 98\%$
- Ring Imaging Čerenkov (RICH)
- excellent efficiency : $2 < p < 15$ GeV/c,
- hadron identification
  π : 98%, K : 88 %, p : 85 %

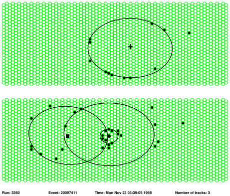
The HERMES experiment

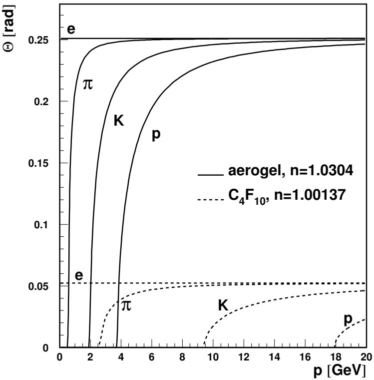


- 27.6 GeV e^+ beam at HERA (DESY)
- fixed gaseous internal H,D,... target (pol/unpol)
- lepton/hadron efficiency $> 98\%$
- Ring Imaging Čerenkov (RICH)
- excellent efficiency : $2 < p < 15$ GeV/c,
- hadron identification
  π : 98%, K : 88 %, p : 85 %

RICH particle identification





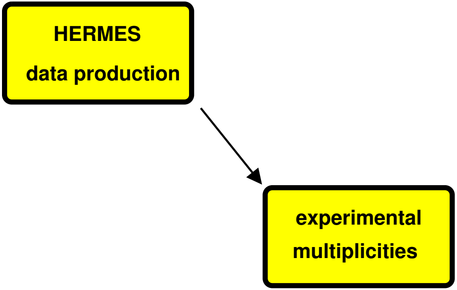


- $\cos\theta_c = \frac{c}{nv} = \frac{1}{\beta n}$
- two radiators: aerogel and C_4F_{10}
- cone projections and reconstruct Čerenkov angles (Ray Tracing)
- first dual radiator RICH

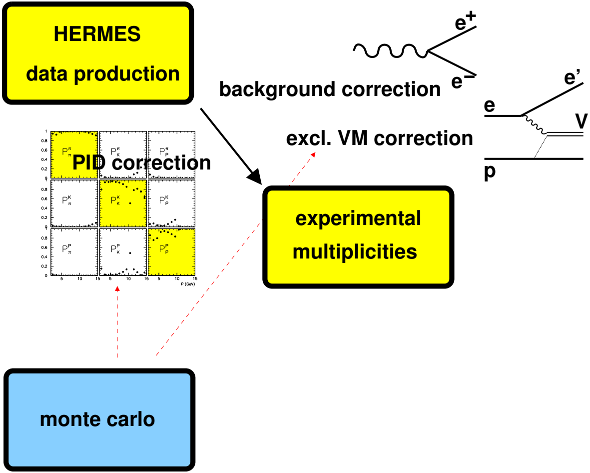
Analysis Overview

HERMES
data production

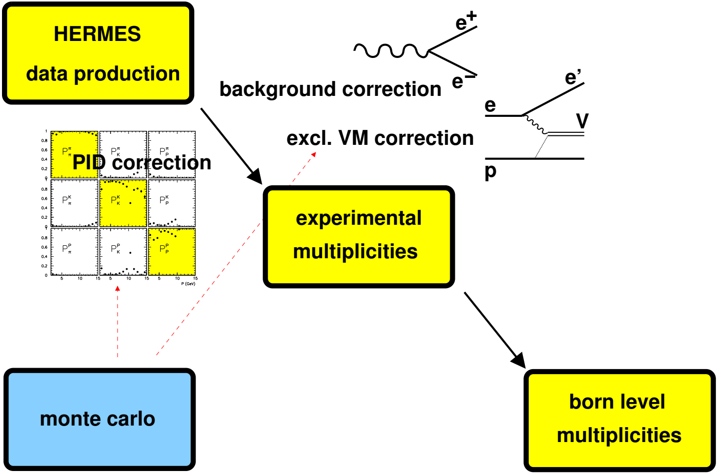
Analysis Overview



Analysis Overview



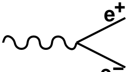
Analysis Overview

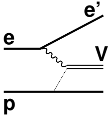


Analysis Overview

HERMES data production

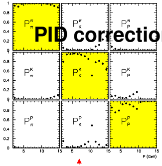
background correction





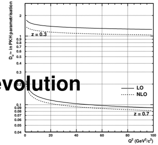
excl. VM correction

PID correction

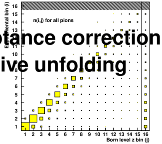


experimental multiplicities

Q^2 evolution



acceptance correction
radiative unfolding



monte carlo

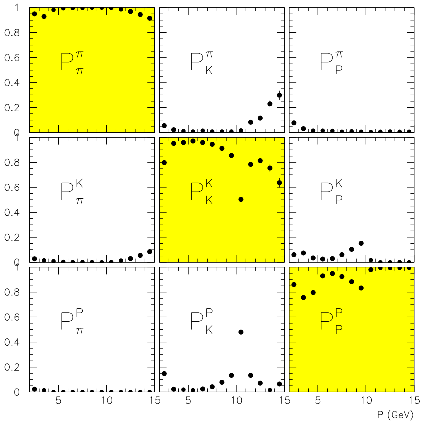
born level multiplicities

Hadron PID correction

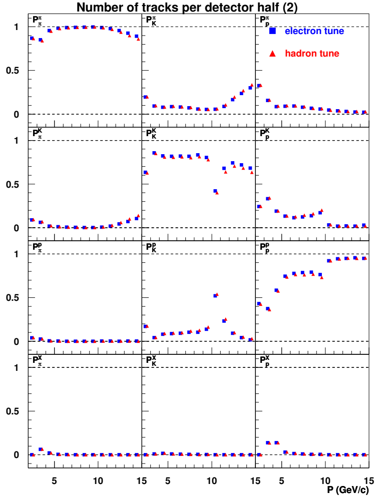
- important : extracting absolute numbers
- correct for misidentification
- *$\mathcal{P}_t^i$: probability that a particle of type t was identified as type i.*

$$\begin{pmatrix} I_\pi \\ I_K \\ I_P \end{pmatrix} = \begin{pmatrix} \mathcal{P}_\pi^\pi & \mathcal{P}_K^\pi & \mathcal{P}_P^\pi \\ \mathcal{P}_\pi^K & \mathcal{P}_K^K & \mathcal{P}_P^K \\ \mathcal{P}_\pi^P & \mathcal{P}_K^P & \mathcal{P}_P^P \end{pmatrix} \cdot \begin{pmatrix} N_\pi \\ N_K \\ N_P \end{pmatrix}$$

- $\mathcal{P}$ obtained from GEANT3 description of RICH
- $\vec{N} = \mathcal{P}_{trunc}^{-1} \cdot \vec{I}$
- $\rightsquigarrow$ weight for hadron tracks



Performance modeling of the RICH



non-perfect knowledge of the response of the RICH ⇝ systematic uncertainty

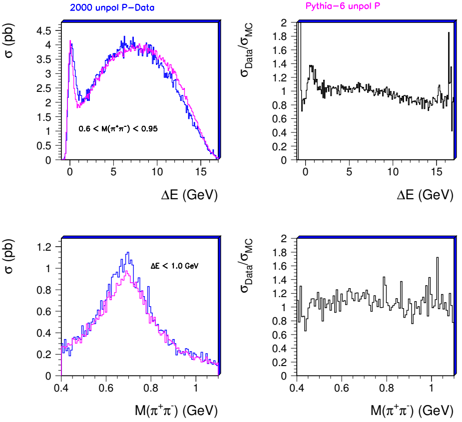
only one RICH :-) ⇝ no independent check for hadron efficiency over full momentum range and for different event topologies

2 tunes in RICH MC description :

- $\beta = 1$ particles : tune Čerenkov angle and photon yield distributions with electrons
- hadrons : tune using decaying particles (ϕ, K_S, Λ) from PYTHIA and data

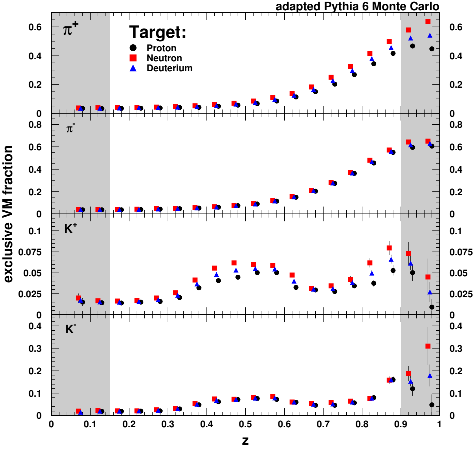
⇒ systematic uncertainty on the $\mathcal{P}$ matrix

Contamination from exclusive VM processes



- exclusive VM production : totally different process than SIDIS.
- estimate contribution from MC (VMD+SIDIS): PYTHIA 6 (adapted e.g. RADGEN)
- ratio : $N^h_{diffr}(z)/N^h_{SIDIS}(z)$
- large contribution at high z ($\sim$ 40 - 50 %) for π
- kaons only contribution of about 10 %

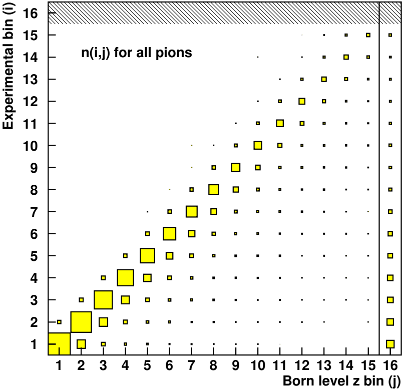
Contamination from exclusive VM processes



- exclusive VM production : totally different process than SIDIS.
- estimate contribution from MC (VMD+SIDIS): PYTHIA 6 (adapted e.g. RADGEN)
- ratio : $N^h_{diffr}(z)/N^h_{SIDIS}(z)$
- large contribution at high z ($\sim$ 40 - 50 %) for π
- kaons only contribution of about 10 %

Smearing/Acceptance correction

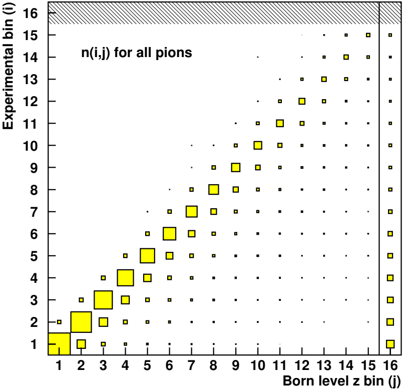
Smearing moves events from one kinematic bin into another. The flow is represented by $S(i,j)$ $\rightarrow$ aim is to move the events back !



- smearing involves both detector effects (track reconstruction) as well as QED radiative corrections
- treat all of the smearing with acceptance correction in one go
- reduce model dependency $S(i,j) = n(i,j)/n^B(j)$
- clear treatment of the uncertainties involved

Smearing/Acceptance correction

Smearing moves events from one kinematic bin into another. The flow is represented by $S(i,j)$ $\rightarrow$ aim is to move the events back !

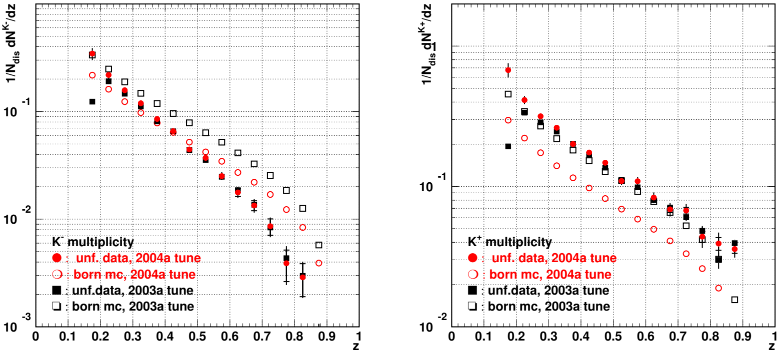


- smearing involves both detector effects (track reconstruction) as well as QED radiative corrections
- treat all of the smearing with acceptance correction in one go
- reduce model dependency $S(i,j) = n(i,j)/n^B(j)$
- clear treatment of the uncertainties involved

The HERMES acceptance

Acceptance very small at small z, up to about 35 % at high z

However the acceptance samples the phase space enough to fix the dynamics

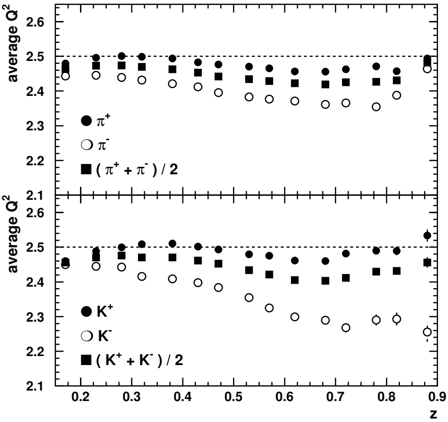


figures from systematic study, not to be seen as HERMES result

Another small word about the MC sample

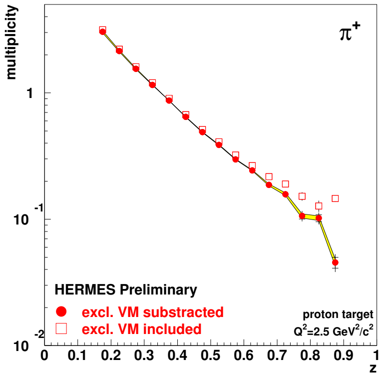
- Use LEPTO generator together with the JETSET model
- JETSET tune :
- parton distribution parametrization in MC : CTEQ6
- QED radiative corrections : RADGEN
- Detector was described by either
    - Full GEANT3 description + tracking code
    - Smearing generator (track lookup + kinematical smearing p, θ_x, θ_y, ...)

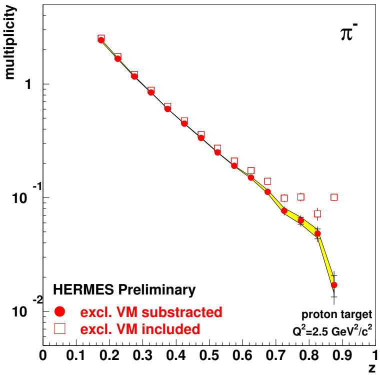
Q^2 evolution



- $$\frac{\sum_f e_f^2 \int_0^1 dx\, q_f(x, Q^2) D_f^h(z, Q^2)}{\int_0^1 \frac{dx}{x} F_2(x, Q^2)}$$
- Q^2 variation small in z, but... e.g. vs. x_{bj}
- want to compare to EMC ($Q^2 \approx 25$)
- use PKH (Kretzer) parametrization + CTEQ6 $\overline{\text{MS}}$
- systematic error on the correction factor (ALLM, integration, PDF set, NLO FF)
- vs z : $\sim 1 - 2\%$ ($Q_0^2 \sim 2.5$), up to 50 % ($Q_0^2 \sim 25$)
- vs x_{bj} : up to 50 %

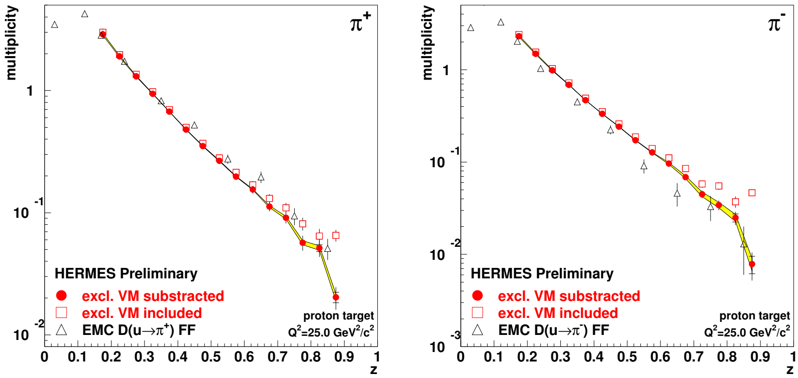
Results for pions :: multiplicity versus z





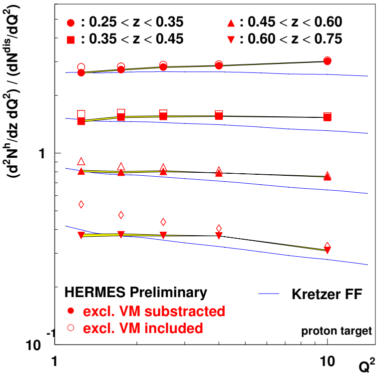
- Systematic uncertainty mainly from hadron PID correction
- $Q^2 > 1$ GeV^2, $W^2 > 10$ GeV^2

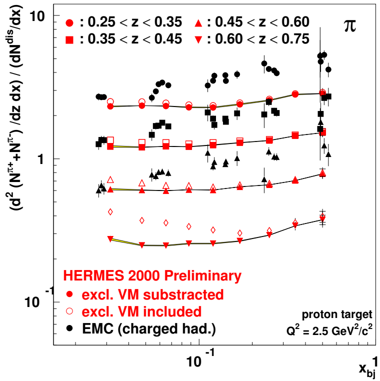
Results for pions :: multiplicity versus z ($Q_0^2 = 25\ \text{GeV}^2$)



- Comparison with EMC, Nucl. Phys. **B321** (1989) 541-560
- EMC: $D_u^{\pi^\pm}$

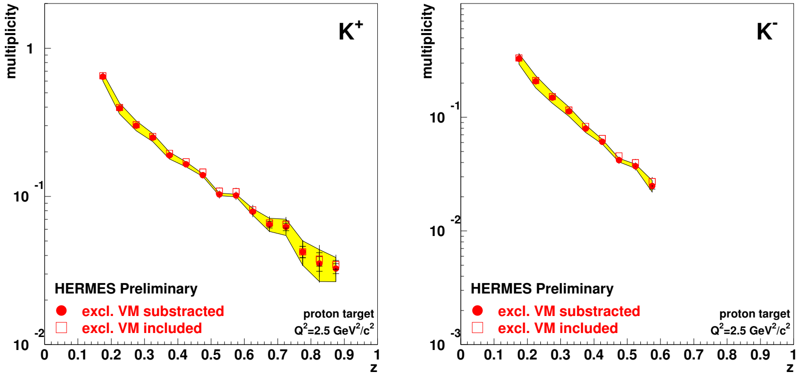
Results for pions :: multiplicity versus Q^2 and x_{bj}





- Comparison with a curve from S. Kretzer
- improved analysis compared to old HERMES data
- weak x_{bj} dependence

Results for kaons :: multiplicity versus z



- charge separated kaon multiplicities
- systematic uncertainty (RICH)
- low K^- statistics, and note different scale !

Summary

- extraction of charge and flavor separated hadron multiplicity distributions
- much attention went to obtain model independent results and clear treatment of uncertainties
- compared Q^2 dependence with e^+e^- FF developed at much higher Q^2
- first extraction of kaon multiplicities
- no signs for strong factorization breaking