HERMES SIDIS multiplicities of charged pions and kaons on the proton and the deuteron

http://www-hermes.desy.de/multiplicities

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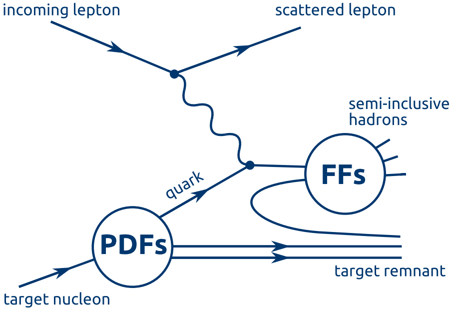
On behalf of the HERMES collaboration

GHP April 2013,
Denver, CO
5th Workshop of the APS Topical Group on Hadronic Physics

3D Multiplicities in Unpolarized SIDIS at HERMES



- Evaluation and improvement of **PDFs and FFs**
- Access to the **transverse momentum structure**
- **Precise tests** of a leading twist **approach** at intermediate energies

Multiplicity: SIDIS cross section normalized to DIS

$$M^h(Q^2, x, z, P_{h\perp}) \equiv \frac{dxdQ^2}{d^2\sigma^{\mathrm{DIS}}(Q^2, x)} \frac{d^4\sigma^h(Q^2, x, z, P_{h\perp})}{dxdQ^2dzdP_{h\perp}}$$

Measuring SIDIS multiplicities at HERMES

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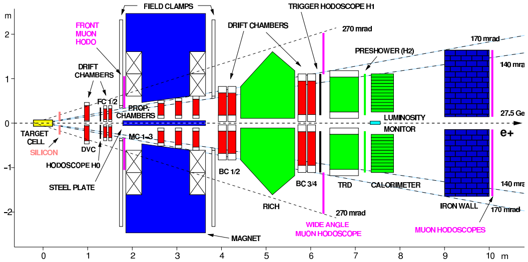
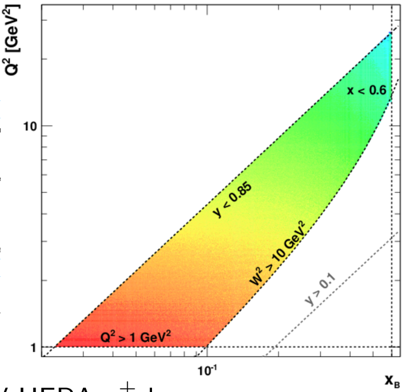
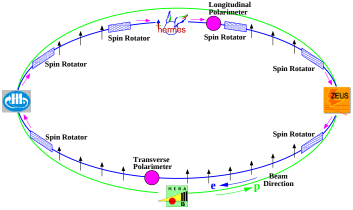




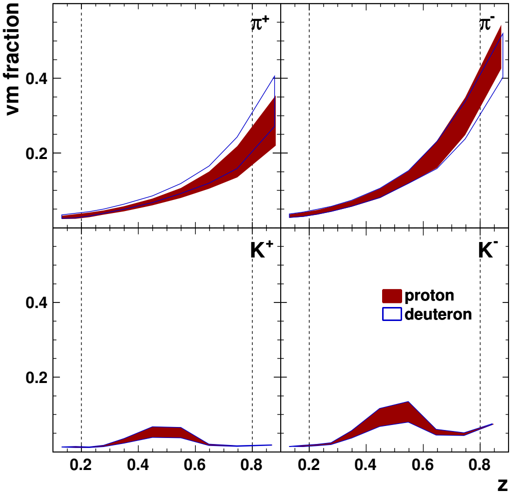


- 27.6 GeV HERA $e^{\pm}$ beam
- Forward spectrometer
  - Pure H and D atomic gas target
  - Clean lepton-hadron identification
  - Very good $\pi - K$ separation with RICH

SIDIS Multiplicities: New HERMES Results

- **High statistics**
- **3D analysis** (in $x, z, P_{h\perp}$ and $Q^2, z, P_{h\perp}$)
- For identified and charge-separated $\pi^{\pm}$ **and** $K^{\pm}$
- High statistics data require **sophisticated analysis**:
  - Corrections for trigger inefficiencies
  - Charge-symmetric background correction
  - **RICH unfolding**
  - Correction for the contamination by **exclusive vector mesons** (optional)
  - Multidimensional **smearing-unfolding** for radiative effects, limited acceptance and detector smearing
- Final results corrected to 4π Born, with well-understood systematics.

Exclusive vector meson contamination



- Diffractive ρ^0 and ϕ contaminate the SIDIS π and K sample
- Correction obtained from tuned PYTHIA
  - Applied at the fully differential level
  - Most of the correction canceled by the corresponding inclusive correction
  - **systematic** $< 1\%$
- **results** available both **with and without** this correction
- This presentation: **with** VM correction

Smearing-unfolding in SIDIS

- A raw measurement does not give experiment-independent information:
  - Usually not known if any **radiative effects** occured (eg. ISR and FSR)
  - Detector has less than full 4π **coverage**
  - Detector has a finite **resolution**

Relation between true and measured quantities

$$\nu_i = \mu_{\text{tot}} \sum_{j=1}^{M} \frac{\int_{\text{bin } i} dX \int_{\text{bin } j} dY \int d\bar{Y} f(Y) \rho(\bar{Y}|Y) A(\bar{Y}) M(\bar{Y}|X)}{\int_{\text{bin } j} dY f(Y)} \mu_j + \beta_i$$

-
  - **Physics distribution** f
  - **Background** from outside the acceptance β

Smearing-unfolding in SIDIS

Relation between true and measured quantities

$$\nu_i = \mu_{\text{tot}} \sum_{j=1}^{M} \frac{\int_{\text{bin }i} dX \int_{\text{bin }j} dY \int d\bar{Y} f(Y) \rho(\bar{Y}|Y) A(\bar{Y}) M(\bar{Y}|X)}{\int_{\text{bin }j} dY f(Y)} \mu_j + \beta_i$$

- Has the shape of a **matrix equation**

$$\nu_i = \sum_{j=1}^{M} S_{ij} \mu_j + \beta_i$$

Smearing-unfolding in SIDIS

Relation between true and measured quantities

$$\nu_i = \mu_{\text{tot}} \sum_{j=1}^{M} \frac{\int_{\text{bin } i} dX \int_{\text{bin } j} dY \int d\bar{Y} f(Y) \rho(\bar{Y}|Y) A(\bar{Y}) M(\bar{Y}|X)}{\int_{\text{bin } j} dY f(Y)} \mu_j + \beta_i$$

- Has the shape of a **matrix equation**
- **Smearing matrix** S is calculated using **two MC** simulations
- **Solve** for true data by simple **matrix inversion**

$$\mu_j = \sum_{i=1}^{M} S_{ji}^{-1} (\nu_i - \beta_i)$$

Smearing-unfolding in SIDIS

Relation between true and measured quantities

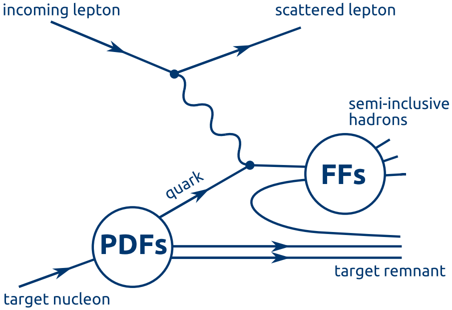
$$\nu_i = \mu_{\text{tot}} \sum_{j=1}^{M} \frac{\int_{\text{bin } i} dX \int_{\text{bin } j} dY \int d\bar{Y} f(Y) \rho(\bar{Y}|Y) A(\bar{Y}) M(\bar{Y}|X)}{\int_{\text{bin } j} dY f(Y)} \mu_j + \beta_i$$

- **Smearing matrix** S is calculated using **two MC** simulations
- Completely **model-independent if either**:
  - **Acceptance function** A is **flat** within each bin
  - **Distribution** f is **flat** within each bin
- If this is **not the case**, a **reasonable** (better than 10% level) **model for** f is required
- This analysis: systematic uncertainty from the 1σ contour in MC parameter space

Section 2

Fragmentation in collinear DIS

Factorizing the SIDIS cross section

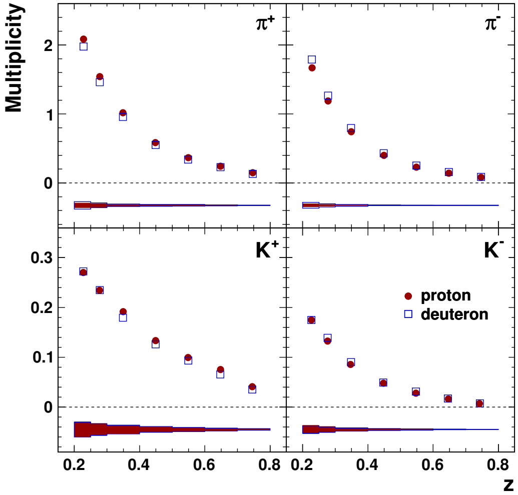


- Separate
  - The **proton structure**
  - The interaction with the **quasi free** quarks
  - The **hadronization process** enforced by confinement
- These results enable:
  - Deeper understanding of the **hadronization process**
  - Better constrain the **FFs**
  - Explore the **limits** of a *simple* factorized approach

LO SIDIS cross section

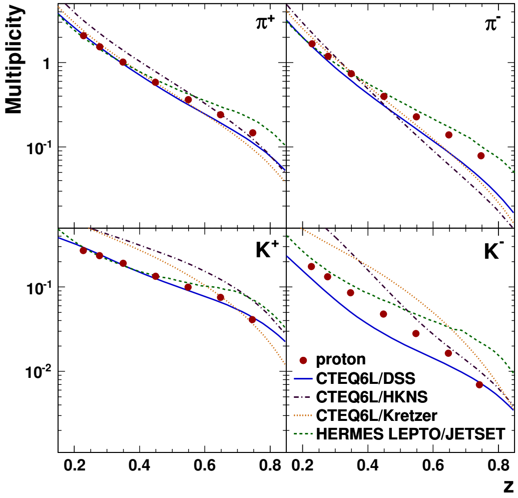
$$\frac{d^3\sigma_n^h(Q^2,x,z)}{dx dQ^2 dz} \propto \sum_q e_q^2 f_1^q(Q^2,x) D_q^h(Q^2,z)$$

Multiplicities: Projected vs z



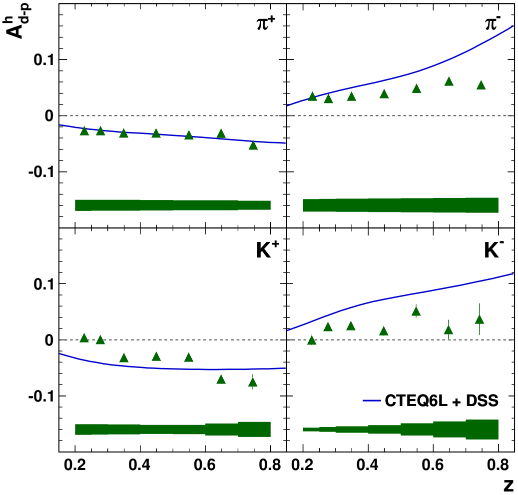
- ***u*-quark dominance**
- deuteron has less u-quarks
- K^- pure sea object
- **systematic uncertainties** between particles/targets **correlated**
- **Asymmetries** and difference ratios can **increase precision** even further

One dimensional comparison with LO predictions



- **Good agreement CTEQ6+DSS for π^+ and K^+** up to medium z
- CTEQ6+Kretzer performs well for pions
- Larger deviations for π^- and K^-
- Room for **improvement at high z, and in the disfavored sector**

Proton-deuteron multiplicity asymmetry

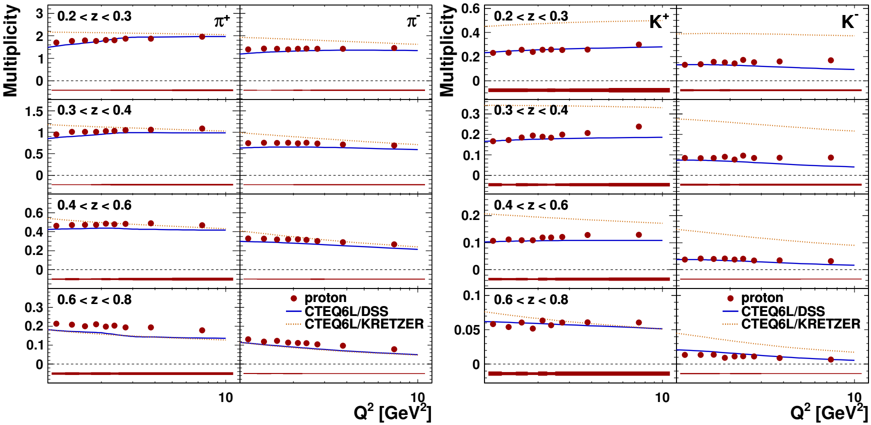


definition:

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

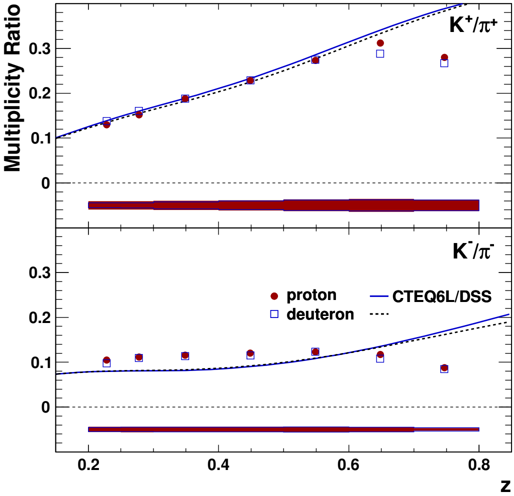
- Reflects different valence quark content
- **Improved precision by cancellations** in the systematic uncertainty

Input for the next generation of FFs



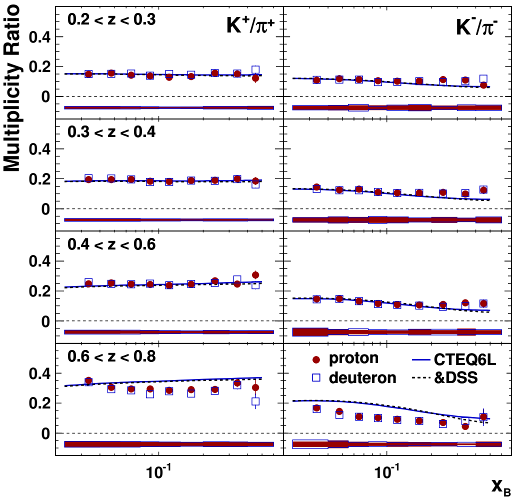
- CTEQ6L+DSS perform **very well up to medium** z
- **Larger discrepancies at high** z

K/π and strangeness suppression



- **Very good agreement** with the LO prediction
- u dominance: K^+/π^+ at high z shows the **extra cost of producing an $s\bar{s}$** compared to a $d\bar{d}$.
- **Strangeness suppresion larger** than current parametrizations suggest
- Also observed during the HERMES MC tuning

K/π in 2 dimensions



- **LO parametrizations** predict the π/K ratio **very well up to medium z**
- **At high z**, LO calculations **overshoot** the measurement for **the entire valence region**

Transverse momentum dependence of the multiplicities

Transverse momentum dependence

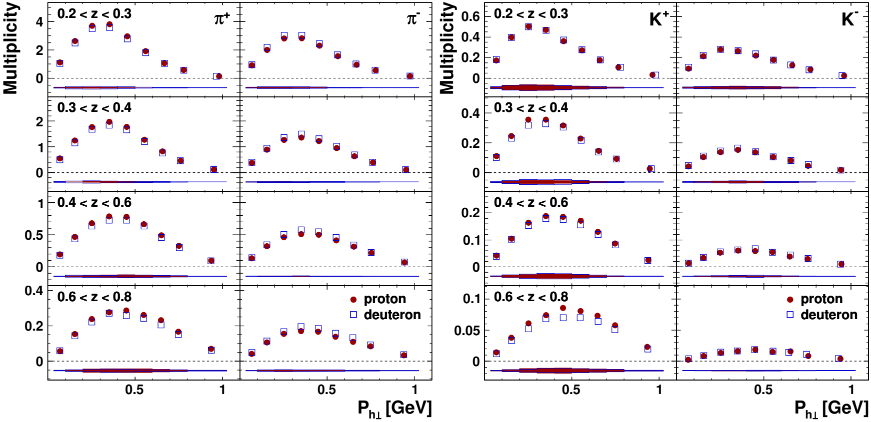
- The multidimensional results provide leverage in the **quest to unfold intrinsic quark p_T and fragmentation k_T from the transverse hadron momentum $P_{h\perp}$**
  - Leverage the simultaneous binning in $P_{h\perp}$, z and x (or Q^2)
  - Access the shape of the unpolarized TMD
  - Provide a handle on flavor separation
  - Constrain TMD models and calculations

$P_{h\perp}$ dependence in the LO TMD formalism

$$\frac{d^5\sigma^h}{dx\,dQ^2\,dz\,d^2\vec{P}_{h\perp}} \propto$$

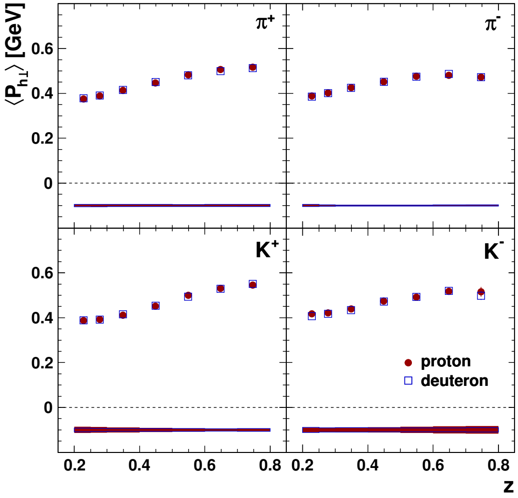
$$\sum_q e_q^2 \int d^2\vec{p}_T d^2\vec{k}_T \delta^2(\vec{P}_{h\perp} - \vec{k}_T - z\vec{p}_T) f_1^q(x, Q^2, p_T) D_q^h(z, Q^2, k_T)$$

The shape of $P_{h\perp}$ in z slices



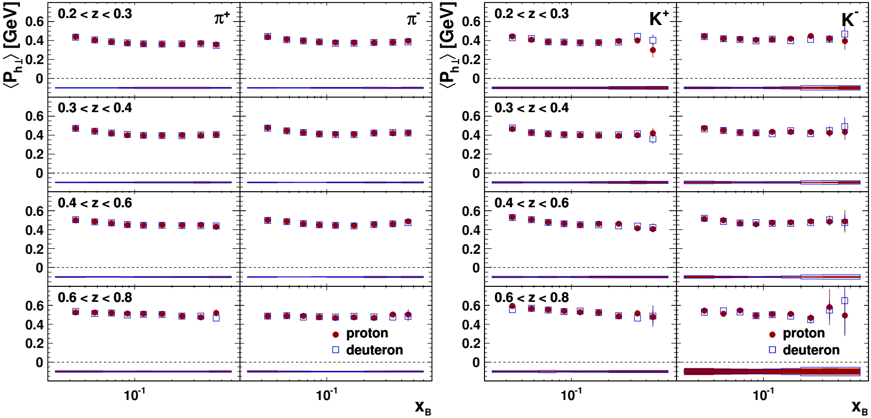
- Superficially consistent with the **Gaussian ansatz**
- **Average and width** function of kinematics and hadron type.

$\langle P_{h\perp} \rangle$ as a function of z



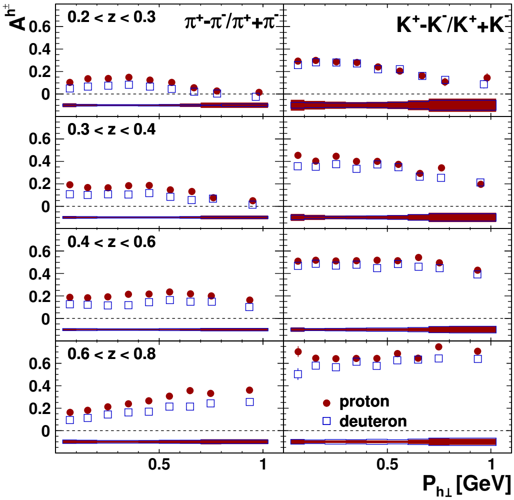
- Rising function of z
- $\langle P_{h\perp} \rangle$ for K **higher than** π at larger z
  - Point-to-point significance of 2σ
  - **Strangeness suppression**: at high z, K sample contains (relatively) more sea events than π
  - Could *hint* at **higher intrinsic** $\langle p_T \rangle$ for the sea?

$\langle P_{h\perp} \rangle$ in 2 dimensions



- Slightly falling function of x
  - Also hints at **higher intrinsic** $\langle p_T \rangle$ for the sea

Hadron charge asymmetry



- Numerator contains proportionally more valance than the denominator
- Especially at higher z
- Ratio encodes information about the **shape of the intrinsic p_T distribution**

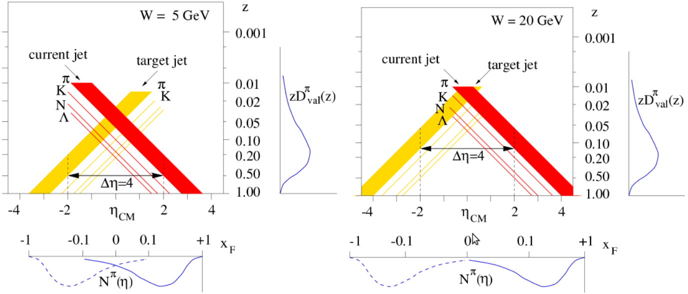
Section 4

Pushing the envelope

Applicability of simple LO, leading-twist factorization for high-precision data at intermediate energies

Limits of the Factorization Theorem

- Factorization in x and z not exact, both from theoretical and experimental point-of-view
  - **Theoretical**: Reinteraction of final state quarks with the target remnant (higher-twist effects); mass effects
  - **Experimental**: Contamination of the current jet with the target jet



Mulders, AIP Conf.Proc. 588 (2001) 75-88

★ Effect minimized by choosing a lower rapidity limit (described by the Berger Criterion) → lower z limit for SIDIS experiments (here: > 0.2)

- Need factorization for **universality**!

Probing the limits in a LO, leading twist framework

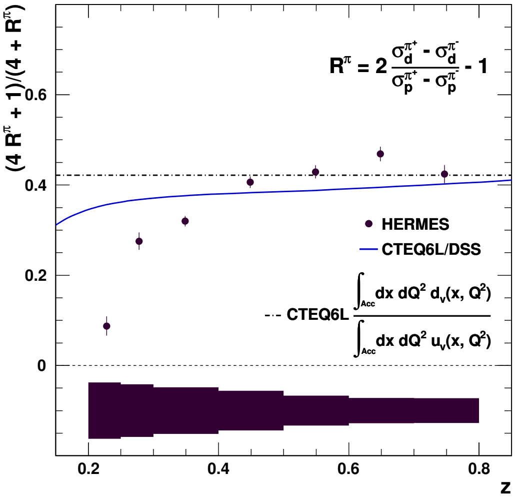
LO access (assuming isospin symmetry)

$$R^\pi(z) \equiv 2\frac{\int_{Acc.} dx dQ^2(\sigma_d^{\pi^+} - \sigma_d^{\pi^-})}{\int_{Acc.} dx dQ^2(\sigma_p^{\pi^+} - \sigma_p^{\pi^-})} - 1 \approx \frac{\int_{Acc.} dx dQ^2(u_v - 4d_v)}{\int_{Acc.} dx dQ^2(d_v - 4u_v)}$$

$$\rightarrow \frac{\int_{Acc.} dx dQ^2 d_v}{\int_{Acc.} dx dQ^2 u_v} \approx \frac{4R^\pi + 1}{4 + R^\pi}$$

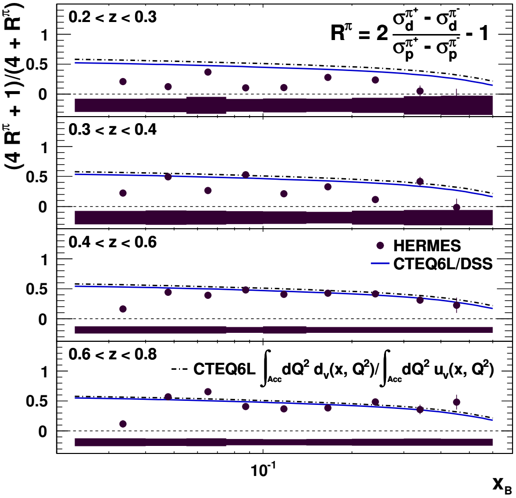
- Pushes the experimental precision to a limit
  - A proper treatment of the **correlated systematics** is crucial
- Very **sensitive to theoretical assumptions**
  - Applicability of the LO, leading twist framework
  - Additional assumptions (eg. isospin symmetry)
- Consequences of interest for future high-precision measurements

Pushing the envelope



- **Lowest point** $> 3\sigma$ from the prediction
  - Target remnant or theory?
  - Small isospin violation of the FF (as in DSS) strongly lessens the discrepancy
  - →Probably mix
- Very good **agreement for mid-to-high** z
- Results generally systematics dominated
- **CTEQ curve below 0.5 due to the integral over the HERMES acceptance (cfr page 4)**

Pushing the envelope



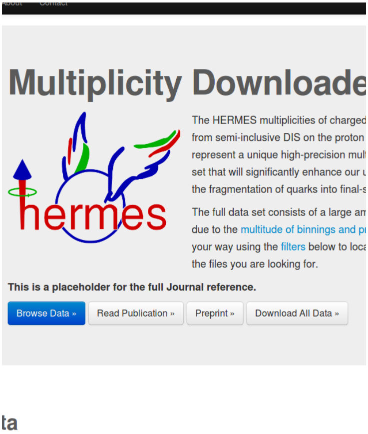
- Discrepancy is a function of z
- Lessons
  - More **precise knowledge of FF symmetries** required
  - Possible **target remnant** influence should be carefully **considered** when analyzing data near the **low-z** limit
  - The framework holds surprizingly well mid-to-high z at intermiate energies

Getting the data

A. Airapetian et al, Phys. Rev. D (2013) (in press)
arXiv:1212.5407v1 [hep-ex]

`http://www-hermes.desy.de/multiplicities`

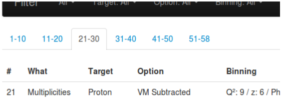
Getting the data: the multiplicity website



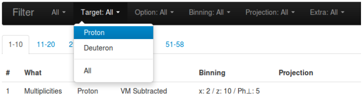
- `http://www-hermes.desy.de/multiplicities`
- Provides all **datafiles and available figures**.
  - **Multiplicities** (differential and in various projections)
  - Both **with and without** the correction for **exclusive vector mesons**
  - **Asymmetries and ratios** (Proper handling of the **correlated systematics**)

http://www-hermes.desy.de/multiplicities

- **Browse** the data files

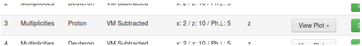


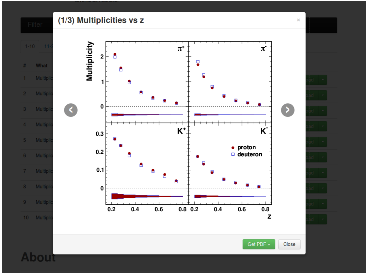
- Use **filters** for intuitive file selection



- **Download** the final results

- **View and download** available figures





http://www-hermes.desy.de/multiplicities

- **Understand** what version of the data you have.

File name structure

```
hermes.(TARGET.)BINNING.(PROJECTION.)OPTION.WHAT.list.gz
```

- `TARGET` : Either `proton` or `deuteron` . Blank in case of the target asymmetries.
- `BINNING` : Can be `z-3D` , `zpt-3D` , `zQ2-3D` `zx-3D` or `zxpt-3D` . The binning codes are defined below in
- `PROJECTION` : Blank in case of the 3D data without projection, or `VARIABLE-proj` for projected data. For exa projection versus z, or `zx-proj` for a 2D projection versus x in z slices.
- `OPTION` : Results with the vector meson contribution subtracted are labelled `vmsub` , results without this correc
- `WHAT` :
  - Multiplicity files are labelled `mults_PARTICLE` (for example: `mults_piplus`).
  - The covariance matrices for the multiplicities are labelled `covmat_mults` .
  - Target asymmetry files are labelled `asymm_PARTICLE` (for example: `asymm_piplus`).
  - The covariance matrices for the target asymmetries are labelled `covmat_asymm` .

- Get an **overview** of what is available.

Binning

The smearing-unfolding method to correct for QED radiative effects, limited geometric acc minimum granularity in all variables, allowing us to pursuit five different specialized binning be accomodated.

1. High resolution in z.
2. High resolution in $P_{h\perp}$ with z slices.
3. High resolution in x with z and $P_{h\perp}$ slices.
4. High resolution Q^2 with z and $P_{h\perp}$ slices

- Detailed **description** of the different binnings.

High resolution in z

- **Name:** `z-3D`
- **Profile:** x: 2 / z: 10 / $P_{h\perp}$: 5
- **Use for:** The projection versus z, and for analyses that benefit from the full binning
- **Edges:**

Variable	Edges
Q^2 [GeV^2]	> 1
x	0.023 - 0.085 - 0.6
z	0.1 - 0.15 - 0.2 - 0.25 - 0.3 - 0.4 - 0.5 - 0.6 - 0.7 - 0.8 - 1.1
$P_{h\perp}$ [GeV]	0.0 - 0.1 - 0.3 - 0.45 - 0.6 - 1.2

High resolution in $P_{h\perp}$ with z slices

- **Name:** `zpt-3D`
- **Profile:** x: 2 / z: 6 / $P_{h\perp}$: 9
- **Use for:** The projection versus $P_{h\perp}$, The projection versus z and $P_{h\perp}$, and for analys
- **Edges:**

Variable	Edges
Q^2 [GeV^2]	> 1
x	0.023 - 0.085 - 0.6
z	0.1 - 0.2 - 0.3 - 0.4 - 0.6 - 0.8 - 1.1
$P_{h\perp}$ [GeV]	0.0 - 0.1 - 0.2 - 0.3 - 0.4 - 0.5 - 0.6 - 0.7 - 0.8 - 1.2

High resolution in x with z slices

Summary

- Unique set of 3D high-precision SIDIS multiplicities for $\pi^{\pm}$ and $K^{\pm}$ on p and d are presented
- Enabling:
  - **Evaluation of the quality** of FF (and PDF) **parametrizations**
  - **Input** for the **next generation** of parametrizations
  - Access to the **transverse distributions**
  - **Tests of the applicability** of the usual LO, leading-twist model **assumptions**
- For proper interpretation at this level of precision:
  - Crucial to consider the **fully differential case**
  - If possible, study the possible correlations in the systematic uncertainties when calculating derived quantities
- Get the data at `http://www-hermes.desy.de/multiplicities`

arXiv:1212.5407v1 [hep-ex]

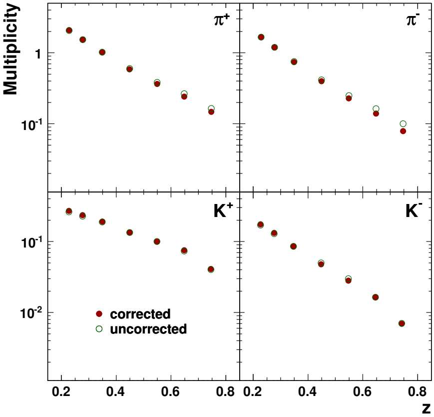
A. Airapetian et al, Phys. Rev. D (2013) (in press)

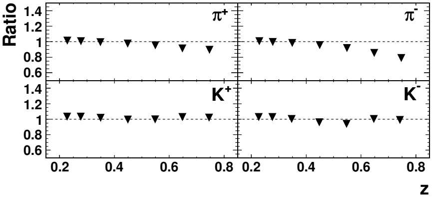
http://www-hermes.desy.de/multiplicities

https://www.npl.illinois.edu

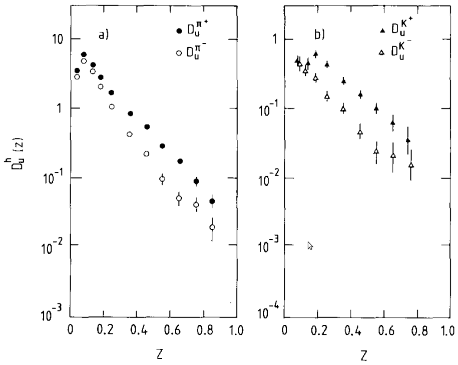
http://nsf.gov

BACKUP: Effect of the correction for exclusive VM

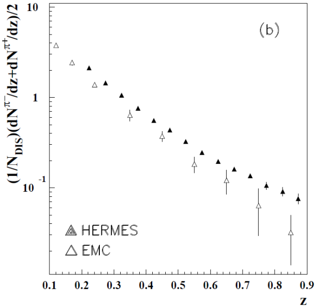




BACKUP: SIDIS Multiplicities: Historical



EMC FFs
Nucl.Phys. B321 (1989) 541



HERMES multiplicities
1996-97 data
Eur.Phys.J. C21 (2001) 599-606