K^-/K^+ multiplicity ratio for kaons produced in DIS with a large fraction of the virtual photon energy

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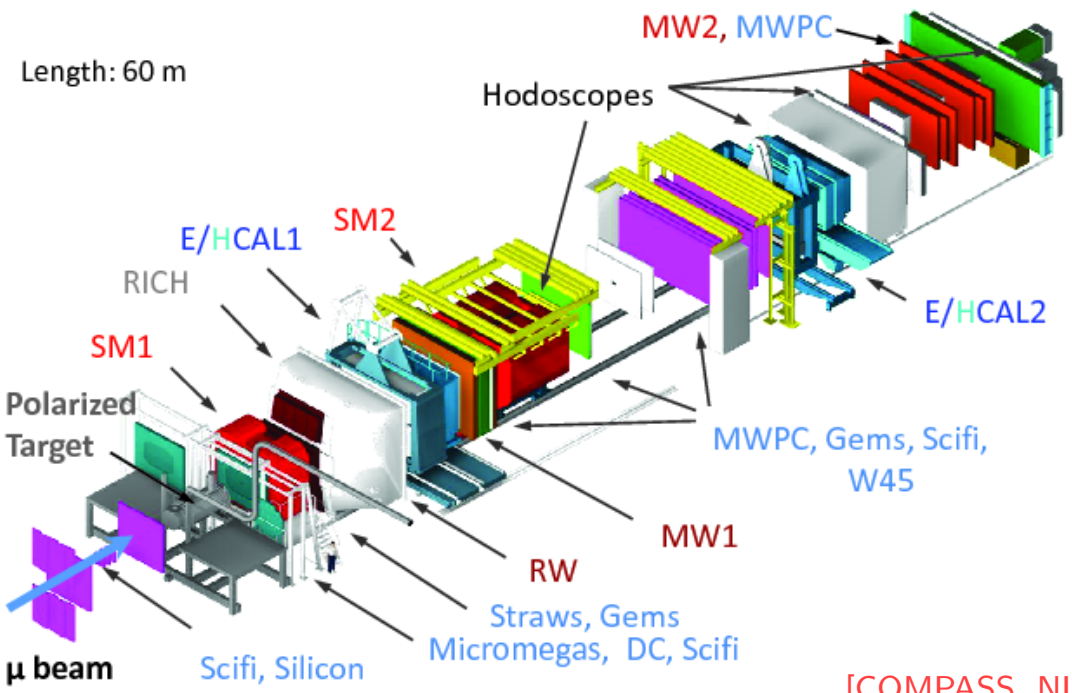
Outline

COMPASS @ CERN

[**CO**mmon **M**uon **P**roton **A**pparatus for **S**tructure and **S**pectroscopy]

- Ground level **fixed target experiment** at the SPS using a tertiary **muon beam** ($\mu^{\pm}$) or a secondary **hadron beam** ($\pi^{\pm}$, $K^{\pm}$, p)
- Collaboration of around 220 members from 13 countries and 24 institutions
- Data-taking started in 2002 $\Rightarrow$ See also Bakur Parsamyan and Michela Chiosso's talks
- Future plans $\Rightarrow$ See Barbara Badełek's talk

COMPASS spectrometer (2006)



[COMPASS, NIMA 577 (2007) 455]

- **160 GeV μ^+ naturally polarised beam**
- **^{6}LiD**, 1.2 m long, 3 cells, longitudinally **polarised target**

- Large acceptance, two staged spectrometer
- Tracking detectors in the 2 stages
- Particle identification: muon walls, **RICH**, calorimetry
- Hodoscope-based trigger (on scattered muon)

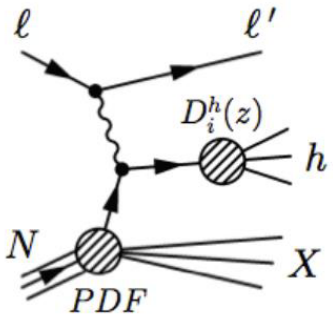
Hadron multiplicities in muon-nucleon scattering

Motivation

- **Quark fragmentation functions (FFs)** measure the probability of a given quark giving rise to a given hadron
- **Quark fragmentation functions**: fundamental non-perturbative, universal
- FFs are ingredients of global pQCD fits
- COMPASS data can give access to FFs $D_q^h(z, Q^2)$ via **hadron multiplicities M^h in SIDIS**:

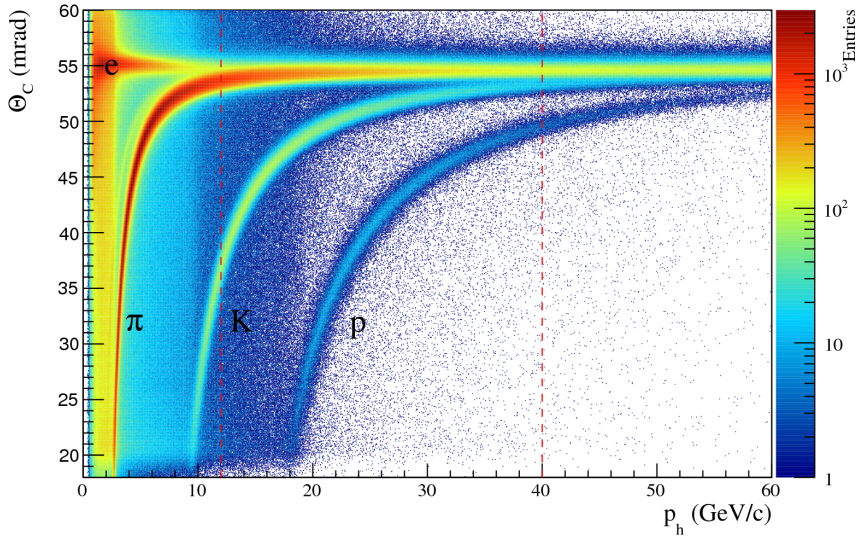
$$\frac{dM^h(x, Q^2, z)}{dz} \equiv \frac{d^3\sigma^h_{\text{DIS}}(x, Q^2, z)/dx\, dQ^2\, dz}{d^2\sigma^{\text{DIS}}(x, Q^2)/dx\, dQ^2}$$

$$\frac{dM^h(x, z, Q^2)}{dz} \underset{\text{LO}}{=} \frac{\sum_q e_q^2 f_q(x, Q^2) D_q^h(z, Q^2)}{\sum_q e_q^2 f_q(x, Q^2)}$$



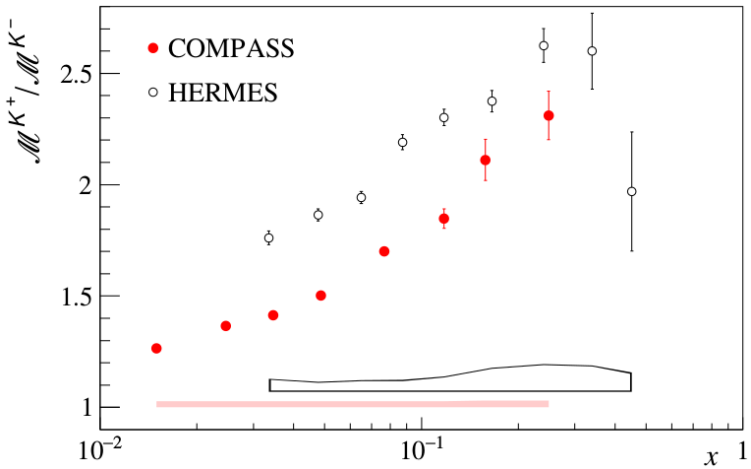
$k_\mu = (E_\mu, \mathbf{k}_\mu)$
$k'_\mu = (E'_\mu, \mathbf{k}'_\mu)$
$P = (M, 0)$
$q = k_\mu - k'_\mu = (\nu, \mathbf{q})$
$Q^2 = -q^2$
$\nu = P \cdot q/M = E_\mu - E'_\mu$
$W^2 = M^2 + 2M\nu - Q^2$
$x = Q^2/(2M\nu)$
$y = \nu/E_\mu$
$z = E_h/(E_\mu - E_{\mu'})$

COMPASS RICH: Θ_C vs momentum



COMPASS previous results on multiplicities

- "Multiplicities of **charged pions** and **unidentified charged hadrons** from deep-inelastic scattering of muons off an isoscalar target" [COMPASS, PLB 764 (2017) 001]
  - Well described by (N)LO pQCD
- "Multiplicities of **charged kaons** from deep-inelastic muon scattering off an isoscalar target" [COMPASS, PLB 767 (2017) 133]
  - Not well described by (N)LO pQCD, particularly at high z
  - Discrepancy between COMPASS and HERMES:



- "**Transverse-momentum-dependent** multiplicities of **charged hadrons** in muon-deuteron deep inelastic scattering" [COMPASS, PRD 97 (2018) 032006]

Expected values for $R_K = M^{K^-}/M^{K^+}$

- In LO:

$$\frac{\mathrm{d}M^{\mathrm{h}}(x,Q^2,z)}{\mathrm{d}z} = \frac{\sum_q e_q^2 f_q(x,Q^2) D_q^{\mathrm{h}}(z,Q^2)}{\sum_q e_q^2 f_q(x,Q^2)}$$

  PDFs f_q: u, $\bar{\mathrm{u}}$, d, $\bar{\mathrm{d}}$, s, $\bar{\mathrm{s}}$

- Assuming isospin and charge symmetry, equality of all unfavoured FFs and equality of favoured s and $\bar{s}$ FFs:

  - $D_{\mathrm{fav}} = D_{\mathrm{u}}^{\mathrm{K}^+} = D_{\bar{\mathrm{u}}}^{\mathrm{K}^-}$
  - $D_{\mathrm{unf}} = D_{\bar{\mathrm{u}}}^{\mathrm{K}^+} = D_{\mathrm{d}}^{\mathrm{K}^+} = D_{\bar{\mathrm{d}}}^{\mathrm{K}^+} = D_{\mathrm{s}}^{\mathrm{K}^+}$ and their charge conjugates
  - $D_{\mathrm{str}} = D_{\bar{\mathrm{s}}}^{\mathrm{K}^+} = D_{\mathrm{s}}^{\mathrm{K}^-}$

- For an isoscalar target, in LO:

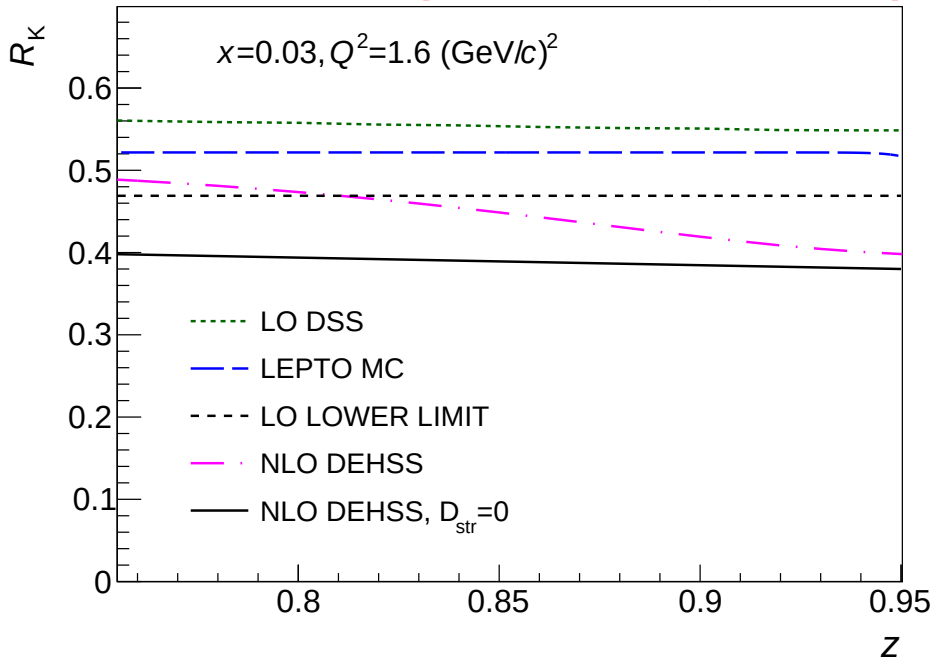
$$R_{\mathrm{K}}(x,Q^2,z) = \frac{\mathrm{d}M^{\mathrm{K}^-}(x,Q^2,z)/\mathrm{d}z}{\mathrm{d}M^{\mathrm{K}^+}(x,Q^2,z)/\mathrm{d}z} > \frac{\bar{\mathrm{u}}+\bar{\mathrm{d}}}{\mathrm{u}+\mathrm{d}}$$

  (Neglecting D_{unf} and the terms with s and $\bar{s}$; and noting that $D_{\mathrm{str}} > D_{\mathrm{fav}} > 0$ and $\bar{u}/u < 1$, $\bar{d}/d < 1$.)

Expected values for $R_K = M^{K^-}/M^{K^+}$ (ctnd.)

(assuming usual assumptions of QCD)

[COMPASS, hep-ex/1802.00584]



- Curves: expected LO lower limit for R_K using LO MSTW08 PDFs, result from LEPTO and using Refs. 1-3 for $x = 0.03$ and $Q^2 = 1.6$ (GeV/c)^2

(1) [D. de Florian, M. Stratmann and W. Vogelsang, Phys. Rev. D 57 (1998) 5811]
(2) [D. de Florian, R. Sassot and M. Stratmann, Phys. Rev. D 75 (2007) 114010]
(3) [G. Ingelman, A. Edin and J. Rathsman, Comput. Phys. Commun. 101 (1997) 108]

Multiplicity extraction

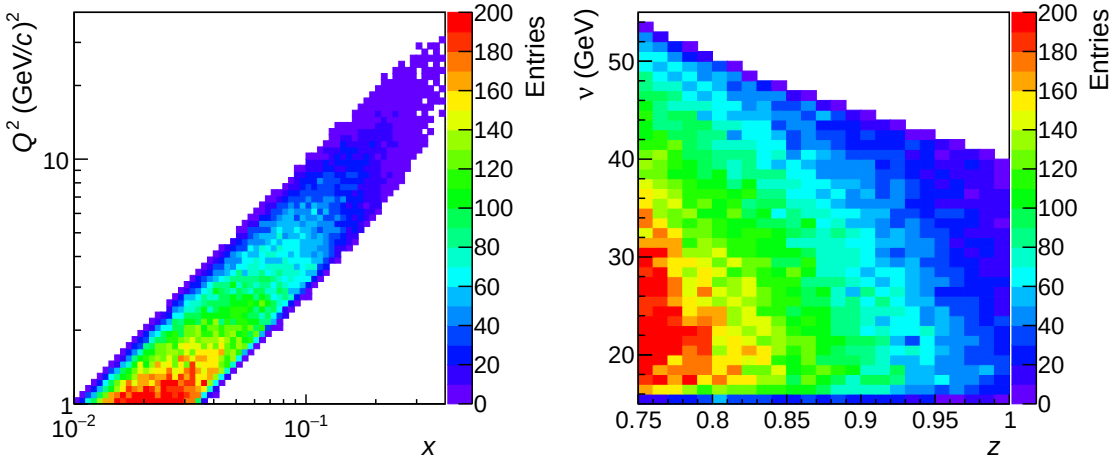
- The multiplicity extraction requires:

1. **Data selection**
2. Spectrometer **acceptance** and reconstruction **efficiency** correction
3. **RICH efficiency and purity correction**
4. Correction for decays of diffractively produced vector mesons
5. Correction for decays of charm quark
6. Correction for radiative effects

Data selection

- Data taken in 2006 with 160 GeV μ^+ beam and ^{6}LiD isoscalar target
- Reconstructed μ and μ', $Q^2 > 1$ (GeV/c)^2, $W > 5$ GeV/c^2, $y > 0.1$
- $z_{\text{rec}} > 0.75$
- $12 < p_h/(\text{GeV}/c) < 40$ (RICH PID range)
- Particle identified as a kaon (conservatively, to end up with a very pure sample)
- Kinematic coverage of the final sample with kaon events:

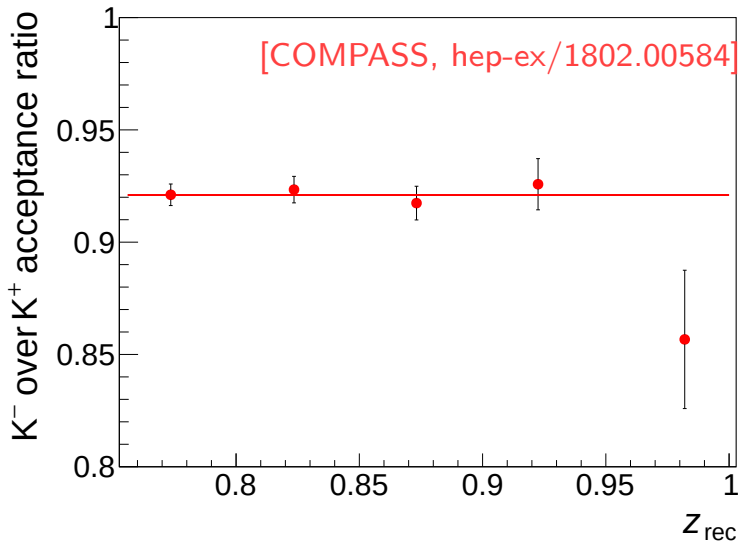
[COMPASS, hep-ex/1802.00584]



- $N_{\text{kaons}} \sim 64000$
- Two x bins: $x < 0.05$, $x > 0.05$ (with $\langle Q^2 \rangle = 1.6$ (GeV/c)^2 and $\langle Q^2 \rangle = 4.8$ (GeV/c)^2, respectively)
- z bin limits: 0.75, 0.80, 0.85, 0.90, 0.95, 1.05

Acceptance and other corrections

- Ratio of acceptances of K^- and K^+ is constant over z

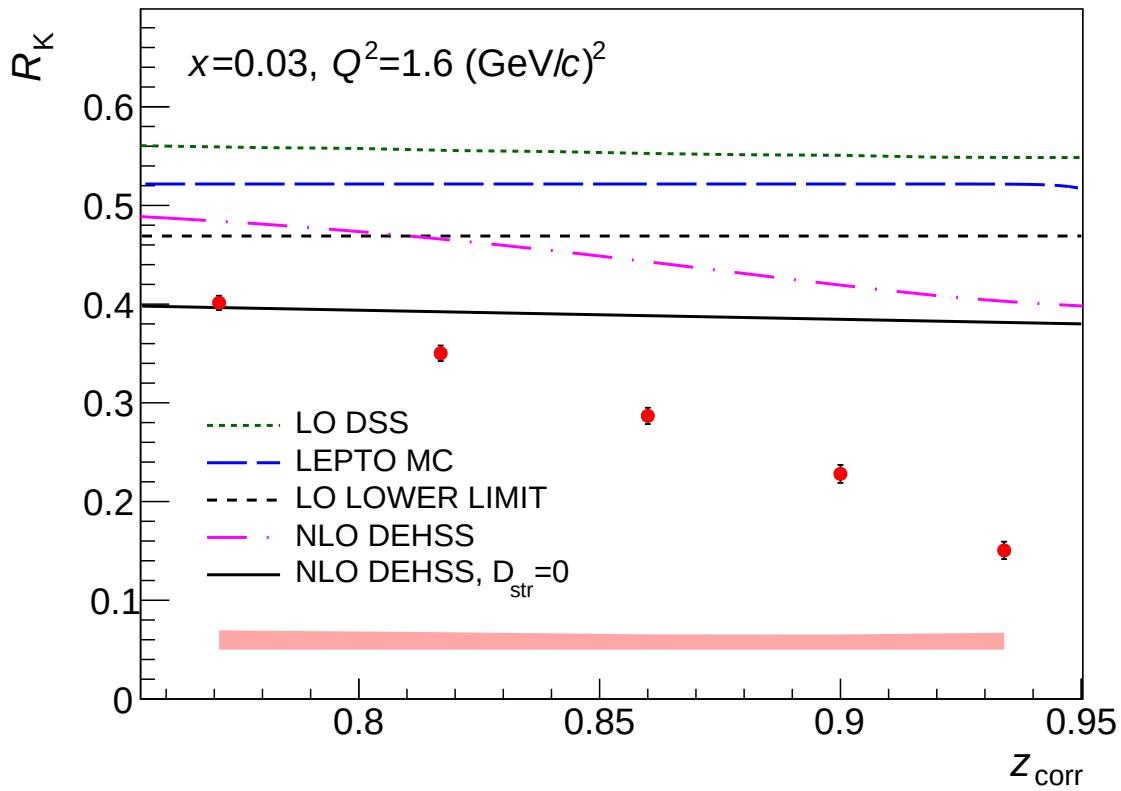


- Great purity of the sample $\Rightarrow$ simplified unfolding
- Vector mesons correction: simulated with HEPGEN; ϕ decay is not important in high-z region
- Charm quark decay correction is very small
- Correction for radiative effects done with TERAD, and cancel

Results vs expectation for $R_K = M^{K^-}/M^{K^+}$

(assuming usual assumptions of QCD)

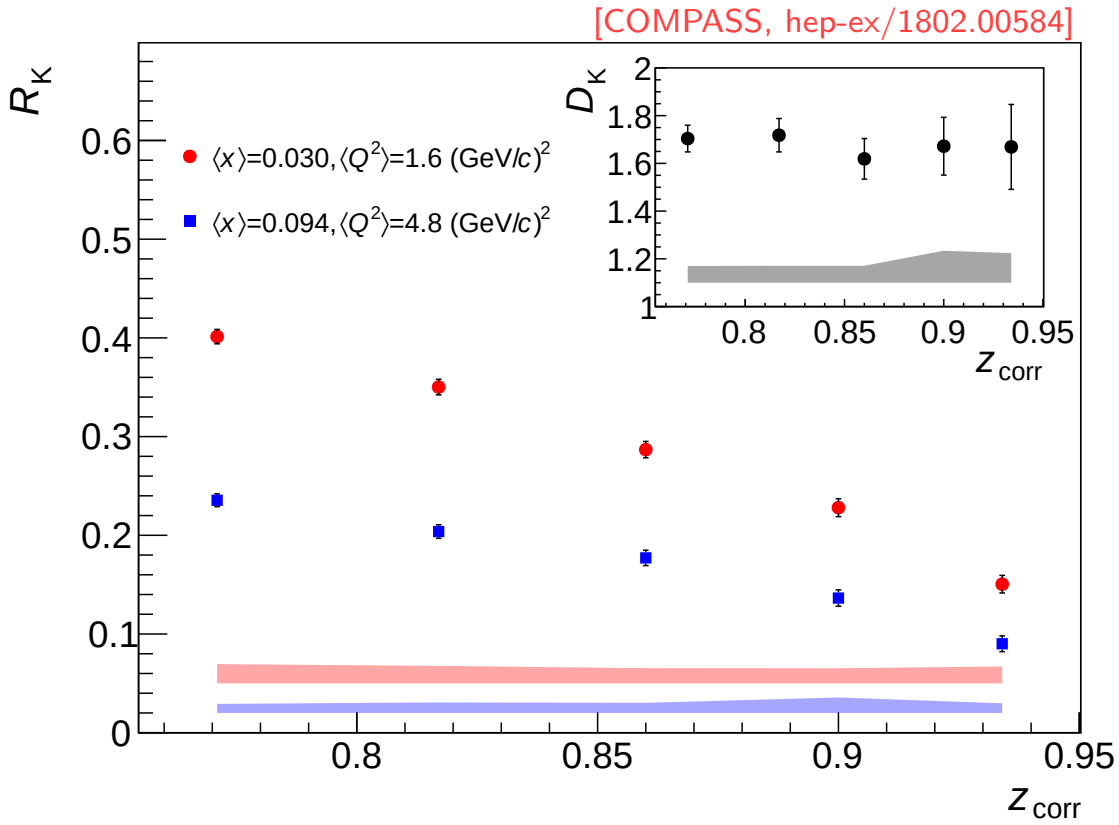
[COMPASS, hep-ex/1802.00584]



- $z_{corr} = z_{rec}^{data} - (z_{rec}^{MC} - z_{gen}^{MC})$
- Data of bin $x < 0.05$
- $R_K = M^{K^-}/M^{K^+}$ is **below its predicted values**
- Further corrections of vector meson production or of pion misidentification as kaon further decrease R_K and increase the tension

Results for $R_K = M^{K^-}/M^{K^+}$ in two x bins

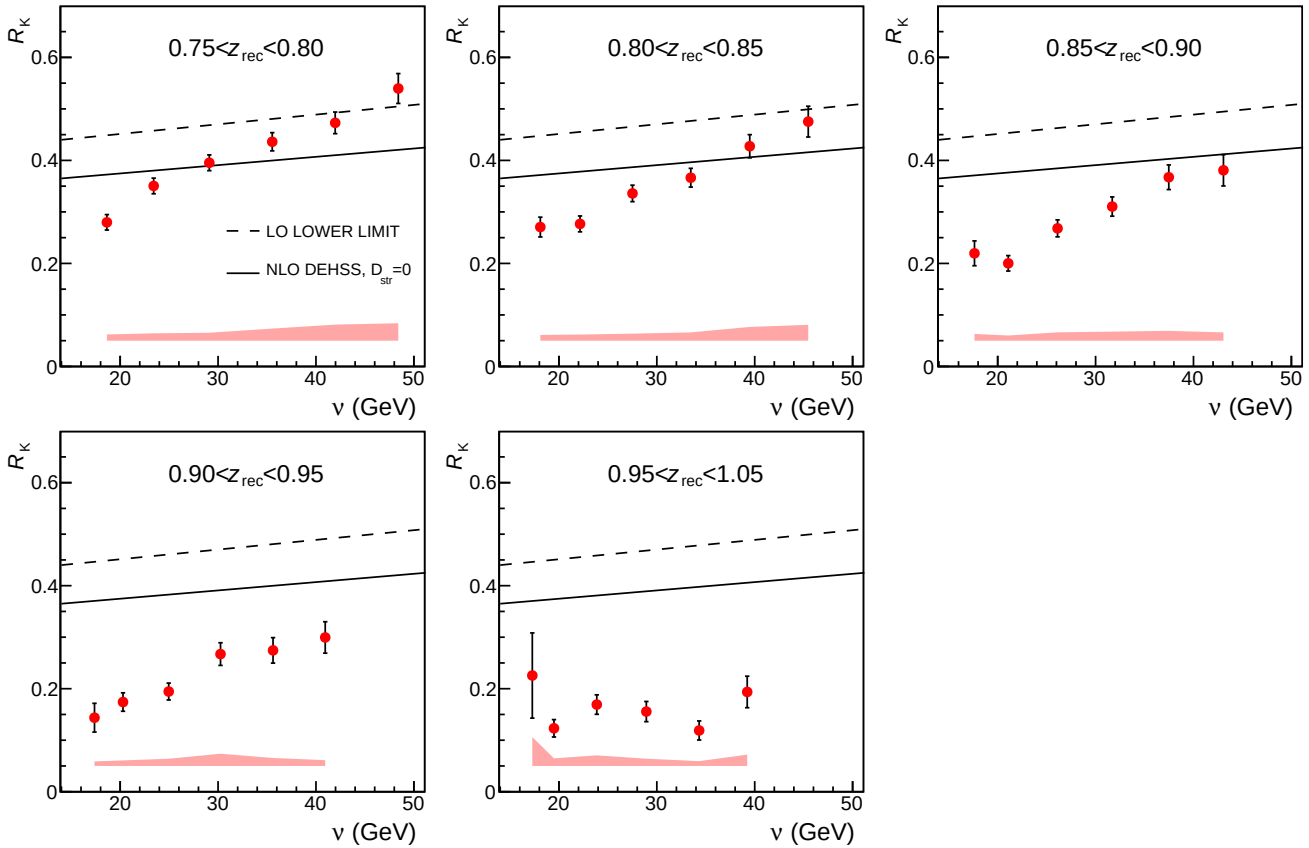
[COMPASS, hep-ex/1802.00584]



- The results of both x bin can be well described by the same functional form, *e.g.* $\propto (1-z)^{\beta}$
- The **ratio of the results in the two x bins is constant over z**

$R_K(\nu)$ in 5 bins of z

[COMPASS, hep-ex/1802.00584]

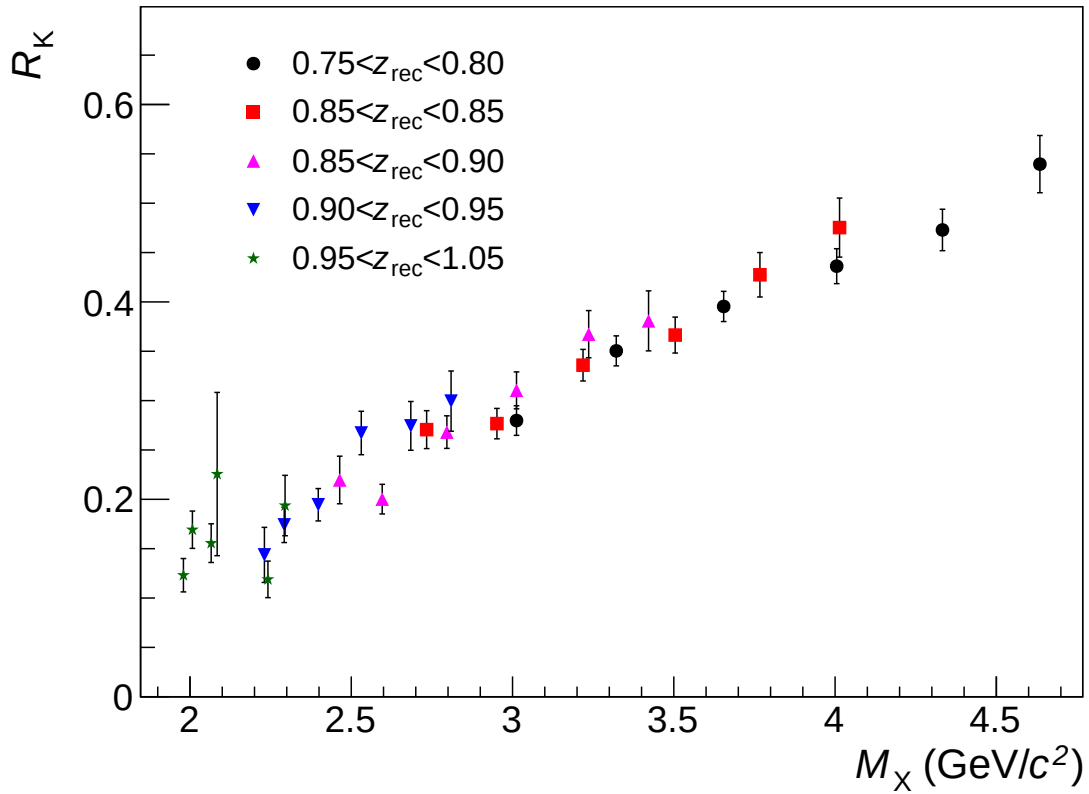


- $R_K = M^{K^-}/M^{K^+}$ is **below predictions for low ν**
- Agreement with LSS group observation ("the largest discrepancy between pQCD expectations and experimental results is observed in the region of **large z and small y,** *i.e.* **small ν")**

Ratio R_K as a function of the missing mass

- High z kaon $\Rightarrow$ reduced phase space for other particles
- Missing mass, $M_X \approx \sqrt{M_p^2 + 2M_p\nu(1-z) - Q^2(1-z^2)}$: natural variable to describe effect

[COMPASS, hep-ex/1802.00584]



- Smooth trend of R_K vs M_X
- **Correction within the pQCD formalism may be required** to take into account the phase space available for the hadronisation of the target remnants

Summary

- Data obtained with a 160 GeV muon beam and isoscalar ^{6}LiD target
- **K^-/K^+ multiplicity ratio** measured in **DIS** for the first time for **high z**
- Results contradict expectations **for $z > 0.8$ using the formalism of (N)LO pQCD**
- The contradiction is larger at large z and small ν
- Possible implications: **cross-section factorisation or/and universality of (kaon) fragmentation functions do not hold**
- Within this formalism, an **additional correction** may be required to describe the data, taking into account the phase space available for hadronisation

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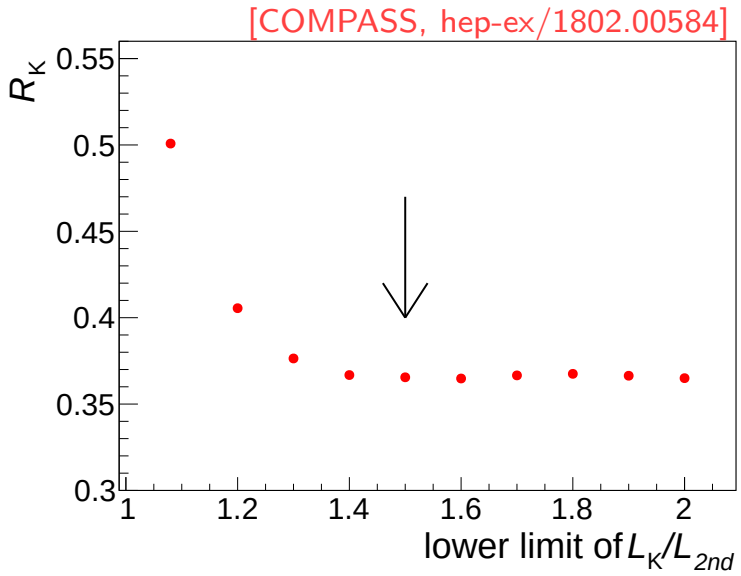
Thank you!

BACKUP

Kaon selection



- $R_K = M^{K^-}/M^{K^+}$ becomes stable at about $L_K/L_{2\text{nd}} = 1.4 \Rightarrow$ imposed cut is $L_K/L_{2\text{nd}} > 1.5$

Systematic uncertainties

- Results **agree with previously published results** in the overlap region ($0.75 < z < 0.85$)
- Results obtained from data originated by **different triggers** are consistent within 2%
- R_K **constant with respect to** $\mathbf{z_{vtx}}$ after acceptance correction applied
- **Acceptance systematic uncertainty**: 2%, dominated by trigger-by-trigger variations
- Uncertainty due to **variations in** ϕ **(in the spectrometer coordinate system)**: 3%-11% (correlated for different z bins)
- Uncertainty in the **RICH unfolding**: 3%
- Beam **spin dependent contributions** $\propto \sin\phi_h \Rightarrow$ can be neglected in ϕ-integrated multiplicities
- **Total relative uncertainty:** 5%-12% depending upon z-bin (highly correlated in different z bins)