COMPASS Hadron Multiplicity Measurements and Fragmentation Functions

M. Stolarski
LIP

On behalf of the COMPASS Collaboration

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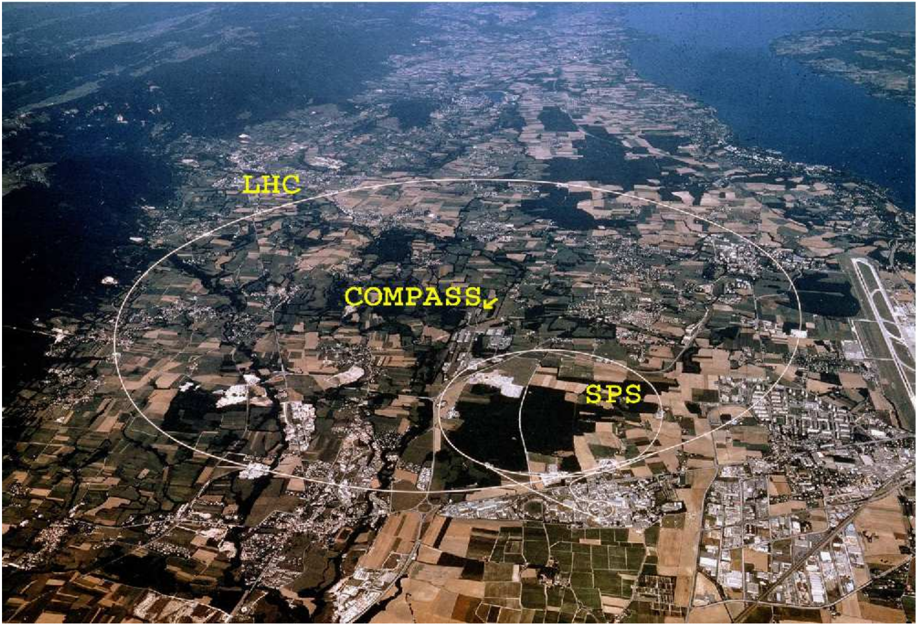
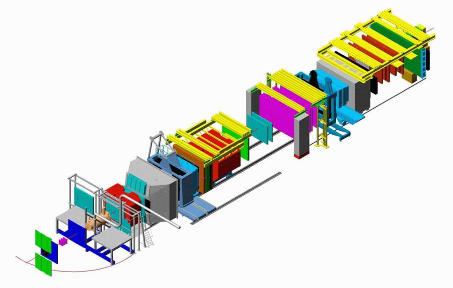
Outline

1. COMPASS @ CERN
2. Motivation
3. Multiplicity Extraction
3. Results

COMPASS at CERN



COMPASS Spectrometer 2002-2012



- COLLABORATION
  - about 210 physicists
  - 27 institutes
- DETECTOR
  - two stage spectrometer
  - 60 m length
  - about 350 detector planes

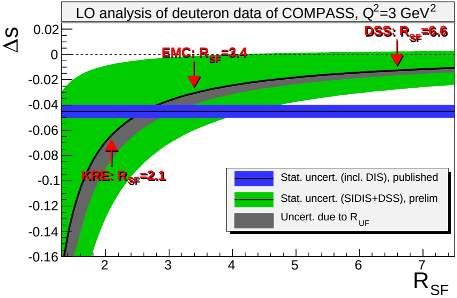
- POLARIZED TARGET
  - ^{6}LiD target (NH_3)
  - 2-3 cells (120 cm total length)
  - $\pm$ 50% (85%) polarization
  - pol. reversal every 8h-24h
- POLARIZED BEAM
  - μ^+ at 160 GeV/c
  - polarization –80 %
- FEATURES
  - angular acceptance: $\pm$70 mrad ($\pm$180 mrad from 2006)
  - track reconstruction: $p > 0.5$ GeV/c
  - identification h, e, μ: calorimeters and muon filters
  - identification: π, K, p (RICH) $p > 2, 9, 18$ GeV/c respectively

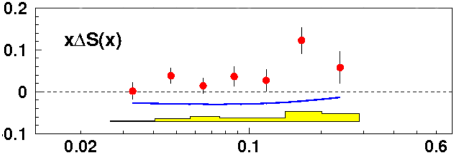
Motivation

- Fragmentation functions (FF, D_q^h) describe parton fragmentation into hadron
- They are needed for many types of the analyses which deals with a hadron(s) in the final state
- The cleanest way to access them is in e^+e^- annihilation. However,
    - only sensitive to $q + \bar{q}$ FF.
    - flavour separation possibilities are limited
- In the SIDIS data, FF are convoluted with PDFs, However,
    - possibility to separate fragmentation from q and $\bar{q}$
    - full flavour separation possible
- Studying pp collisions with a high p_T hadrons one have access to gluon fragmentation functions
- SIDIS data are crucial to understand quark fragmentation process

Motivation cont., ΔS Puzzle

- ΔS from fits of g_1 and SIDIS π is negative in the whole x region (assuming SU3 symmetry)
- However, SIDIS K data prefer zero or positive value at moderate x values
- Impact of Kaon data strongly dependent upon the choice of strange FF - D_S^K
- LSS group reported that problem disappears if HKNS FF set is used instead of DSS.





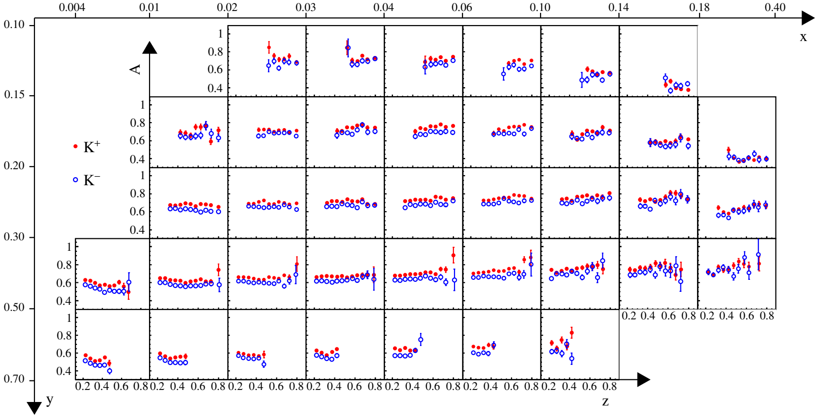
HERMES, PLB 666, 466
Blue line: LSS fit

Multiplicity Measurement

- Hadron multiplicities are defined as number of observed hadrons in a number of DIS events
- $Mult = \sigma_h/\sigma_{DIS} = d^3N_h(x,y,z)/d^2N_{DIS}(x,y)$
- In LO $Mult = \frac{\sum e_i^2 q_i(x,Q^2) D_i^h(z,Q^2)}{\sum e_i^2 q_i(x,Q^2)}$
- Experimentally measured hadron multiplicities needs to be corrected for various effects e.g.
  - spectrometer acceptance &reconstruction program efficiency
  - RICH efficiency & purity (for π and K)
  - radiative corrections
  - diffractive vector meson production
  - ...

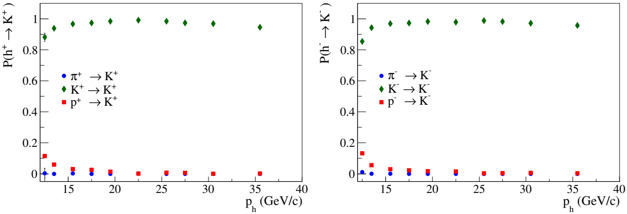
Acceptance

- To avoid model dependencies, acceptance should be calculated multidimensionally
- In fixed target experiments there is a large correlation between x and Q^2
  It is much better to make a binning in x and y
- COMPASS acceptance is high and rather flat



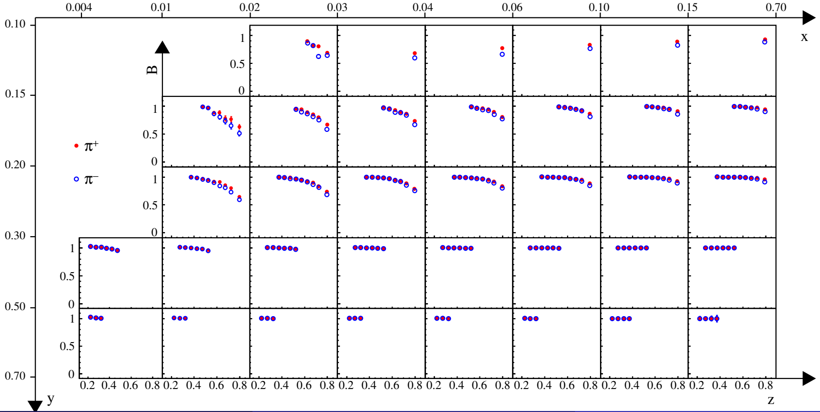
RICH Efficiency/Purity

- COMPASS RICH detectors is able to detect π, K, p starting from 3, 9, and 18 GeV/c respectively, and up to about 50 GeV/c
- A 3x3 efficiency-purity matrix is obtained from data based on decays of K^0, Φ and Λ
- The analysis region was limited to a momentum range where K identification is stable, namely 13-40 GeV/c
- In the selected range, efficiency of K id if very high at the same time, miss-identification of π as K is very low.
- In order to minimize possible systematic effects π and h multiplicities were extracted in the same momentum range as K



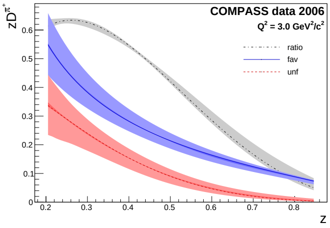
Diffractive Mesons Production and Decays

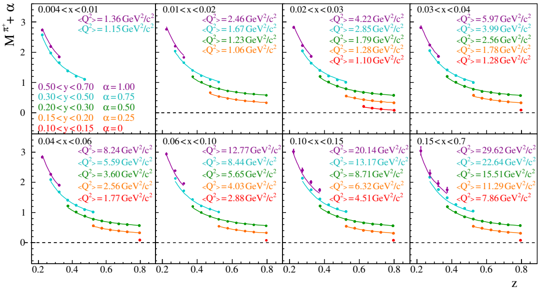
- FF are expected to be universal
- To keep their universality in the SIDIS case, one should correct obtained multiplicities by yield of hadrons resulted from decays of mesons produced in diffractive processes
- These contributions were estimated using dedicated MC generator HEPGEN
- The effect is sizable from $\rho^0 \rightarrow \pi\pi$, it contribute up to 40% in the high z region

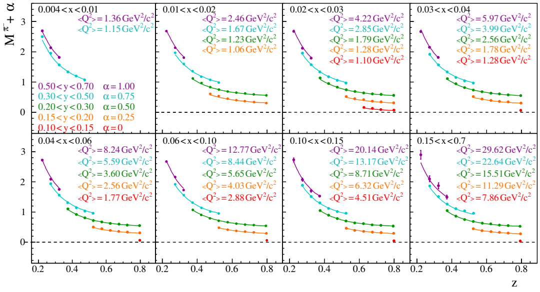


Multiplicities of π

- COMPASS extracted $\pi^{\pm}$ multiplicities
- Publication expected soon
- Some preliminary data were used in DSS+ fit.
- COMPASS performed LO FF fit
- Results agrees with world FFs. As expected $D_{fav} > D_{unf}$

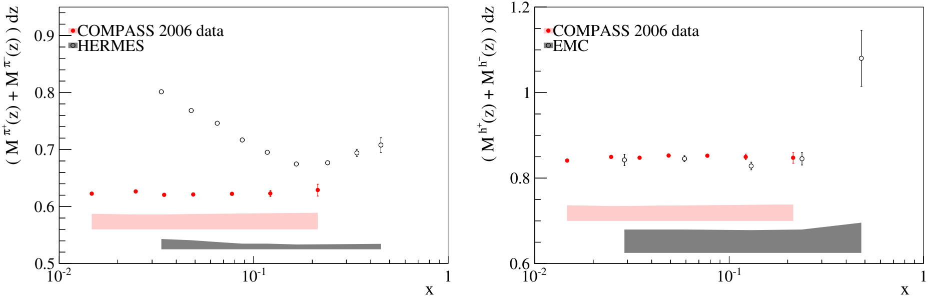






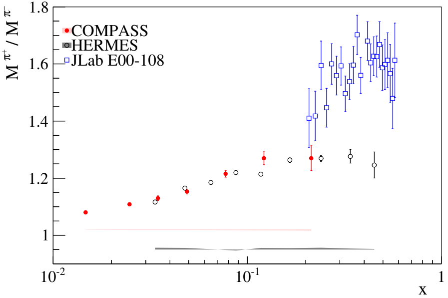
The π Multiplicity Sum

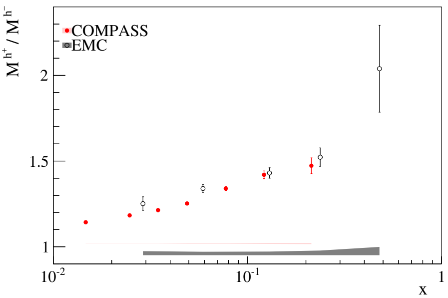
- Interesting observations can be made when studying π multiplicity sum
- For iso-scalar target:
  - $M^{\pi^+ + \pi^-} = D_{fav} + D_{unf} + \frac{2S}{5Q+2S}(D_{unf} - D_{fav}) \approx D_{fav} + D_{unf}$
  - $D(Q^2, z) \rightarrow$ obtained multiplicity sum is effectively independent of x
  - In fixed target experiment x and Q^2 are correlated, but Q^2 dependence of z integrated FF is weak
- $\int_{0.2}^{0.85} M^{\pi^+ + \pi^-} dz$ *vs.* x should be almost flat



The π^+/π^- Multiplicity Ratio

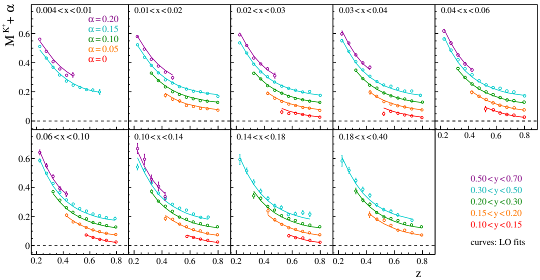
- The ratio of π^+/π^- or (h^+/h^-) is interesting to study due to significant cancellation of experimental systematic errors
- Here, a good agreement between HERMES and COMPASS is seen
- However, there is a tension between JLAB and HERMES at high x
- As previously there is a good agreement between COMPASS and EMC data for unidentified hadrons

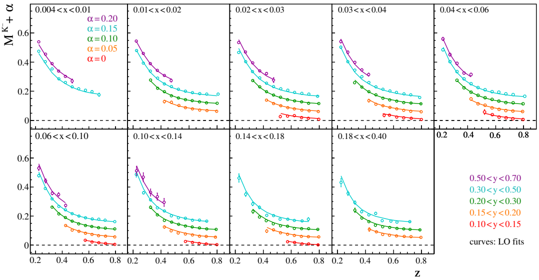




Kaon Multiplicities

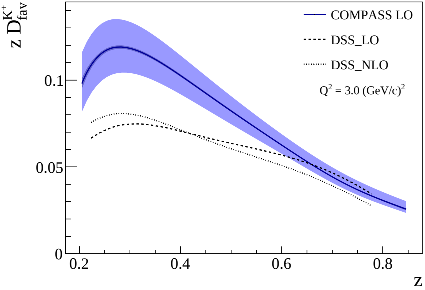
- Kaon multiplicities were extracted from COMPASS data
- Thanks to less model dependent way of extracting acceptance, more (x, y, z) points are available than in the presented π data
- The π data will be re-evaluated for the publication

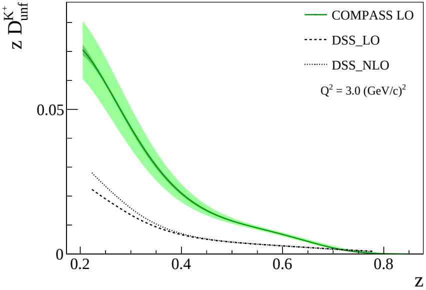




Kaon Fragmentation Functions @ LO

- COMPASS performed LO fit to kaon Multiplicities
- D_{fav} and D_{unf} are presented below
- D_{str} are not shown, while results of D_{fav} and D_{unf} are very stable, it is not the case with D_{str}
- Extracted D_{fav} and D_{unf} are significantly larger than in the DSS parametrisation
- Even keeping old D_{str} value, the ratio D_{str}/D_{fav} in COMPASS is smaller than expected from DSS fit

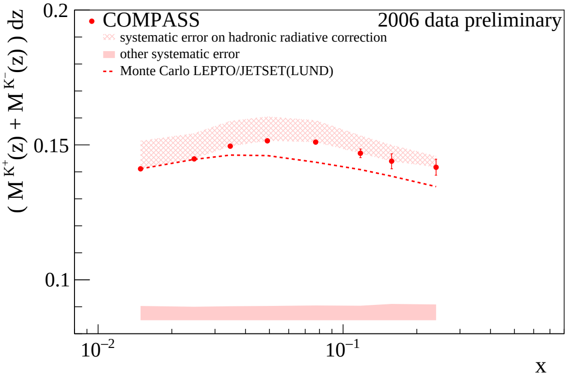




Kaon Multiplicity Sum

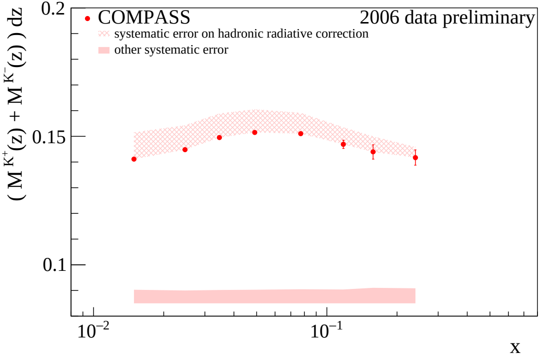
- Kaon multiplicity sum gives an "easy" access to $S \int D_S^K(z)dz$
- For the iso-scalar target:
- $5M^{K^+ + K^-} \approx \int D_Q^K + S/Q \int D_S^K$
  - here, $D_Q^K = 4D_{fav}^K + 6D_{unf}^K$; $Q = u + \bar{u} + d + \bar{d}$; $S = s + \bar{s}$
- High $x \to S \approx 0 \to$ access to D_Q^K; Low $x \to S \int D_S^K$ may be significant

- With DSS D_{str}/D_{fav}, a grow by 50% towards low x of $M^{K^+ + K^-}$ is expected
- Strong increase of $M^{K^+ + K^-}$ towards low x is not seen
- The results suggest lower D_{str}/D_{fav} than DSS
- MC with LUND fragmentation model describe data well



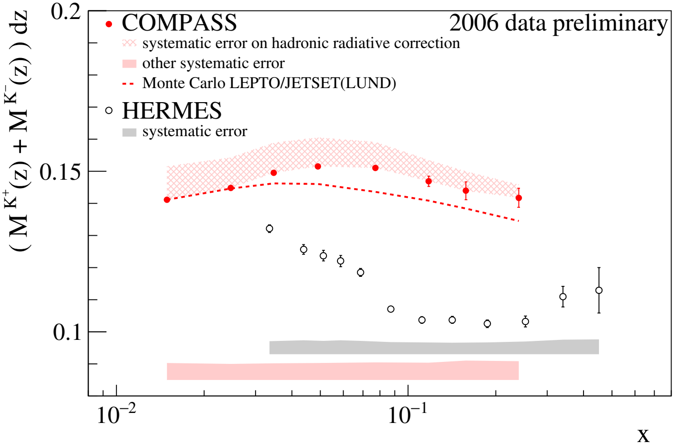
Kaon Multiplicity Sum cont.

- $5M^{K^{+}+K^{-}} \approx \int D_Q^K + S/Q \int D_S^K$
- In the LO FF fit it was shown that both D_{fav} and D_{unf} are larger than DSS FF
- using results at high x one can easily estimate that:
- $\int D_Q \approx 5M^{K^{+}+K^{-}} = 0.70$; $\quad D_Q = 4D_{fav} + 6D_{unf}$
- $\int D_Q \approx 0.43$ in DSS analysis
- COMPASS still investigate semi-inclusive radiative corrections using RADGEN
- Outcome of these studies cannot change qualitative conclusions presented here



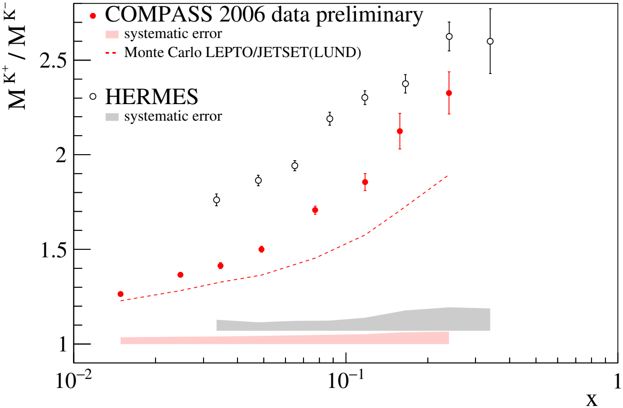
Kaon Multiplicity Sum cont.

- Kaon Multiplicity Sum from COMPASS and HERMES are compared
- There are large discrepancies observed:
    - Shape of the distribution a low x
    - The value of $M^{K^{+}+K^{-}}$ at high $x \rightarrow \int D_Q$!



K^+/K^- Multiplicity Ratio

- For the π case there is a good agreement between COMPASS and HERMES for the π^+/π^- multiplicity ratio
- There is an agreement, despite the fact that the shape of π multiplicity sum was quite different
- For the Kaon case, clear discrepancy between COMPASS and HERMES is observed even for the K^+/K^- Multiplicity Ratio



K^0 Multiplicities

- COMPASS collected considerable amount of K^0
- K^0 multiplicity is more sensitive to D_{unf} rather than D_{fav}
- The work on K^0 Multiplicities have started
- Since, there is no need for Kaon ID, K^0 Multiplicities can be extracted in much larger phase-space region than $K^{\pm}$
- Thus, there will be a region at low y where COMPASS kinematic will be much closer to the HERMES one
- In the case some energy dependence of multiplicities is a reason for discrepancy between COMPASS and HERMES multiplicity sum at high x, with K^0 multiplicities COMPASS has an access to a transition region
- Disclaimer: acceptance for K^0 at low y is not that flat, careful studies will be needed

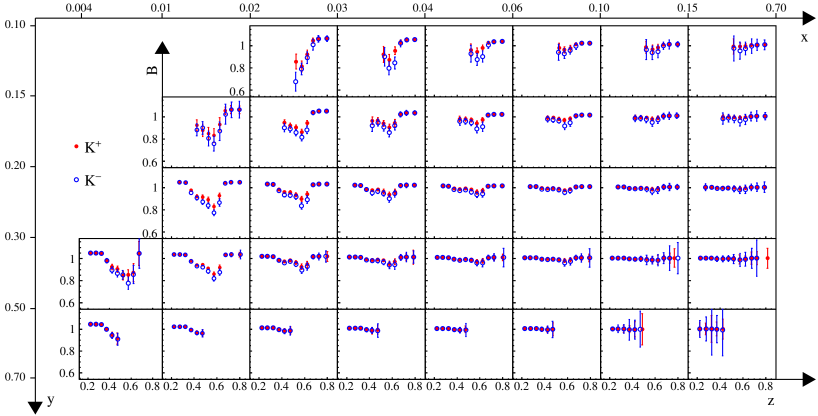
Summary

- COMPASS measured $h^{\pm}$,$\pi^{\pm}$,$K^{\pm}$ multiplicities in the wide kinematic range
- Publication of $h^{\pm}$,$\pi^{\pm}$ is expected soon
- There are tensions visible between COMPASS and HERMES results
- With K^0s COMPASS have access to more extended kinematic region, including the one closer to the HERMES kinematic
- EIC would be an ideal place to further study these subjects

Backups

Diffractive Mesons Production and Decays cont.

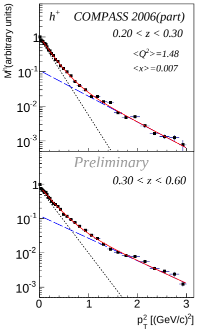
- For kaons decay of $\Phi \rightarrow K^+K^-$ contributes
- The maximum contribution is seen for $z \approx 0.5$, due to $K^\pm$ from Φ decay have low transverse momentum.

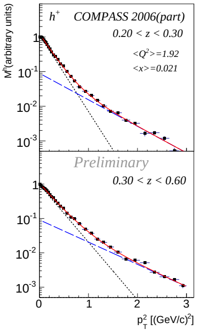


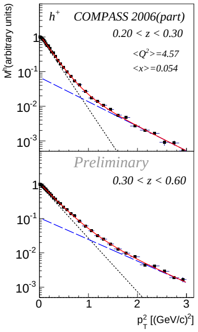
Transverse Momentum Dependent Multiplicities

Transverse Momentum Dependent Multiplicities

- Both intrinsic k_T of quarks in the nucleon as well as $p_\perp$ of the fragmentation needs to be better understood
- Hadron multiplicities were extracted in 4D $(x, Q^2, z, p_\mathrm{T}^2)$ binning
- Main features:
  - the 2-exp fits give reasonable fits to the data,
  - 2nd exp become dominant even as low as $p_\mathrm{T}^2 \approx 0.6$ GeV^2







Transverse Momentum Dependent Multiplicities cont.

- New results without the arbitrary normalization: