Recent and future measurements of transverse momentum distributions in SIDIS

Nour Makke
INFN/University of Trieste

On behalf of the COMPASS Collaboration

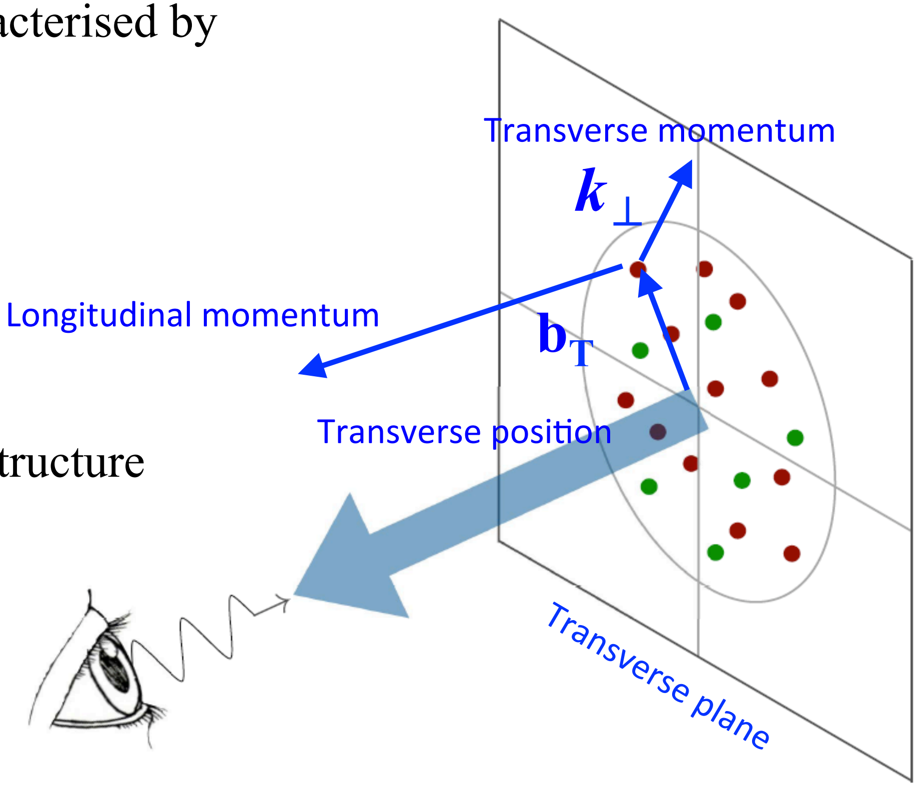
SPIN 2016

22nd International Spin Symposium, 25-30 September 2016, UIUC, USA

Transverse structure of the nucleon

Relative position and motion of a parton characterised by

- ✧ x Longitudinal momentum fraction
- ✧ $\boldsymbol{k}_\perp$ Intrinsic transverse momentum
- ✧ $\boldsymbol{b}_T$ Transverse position



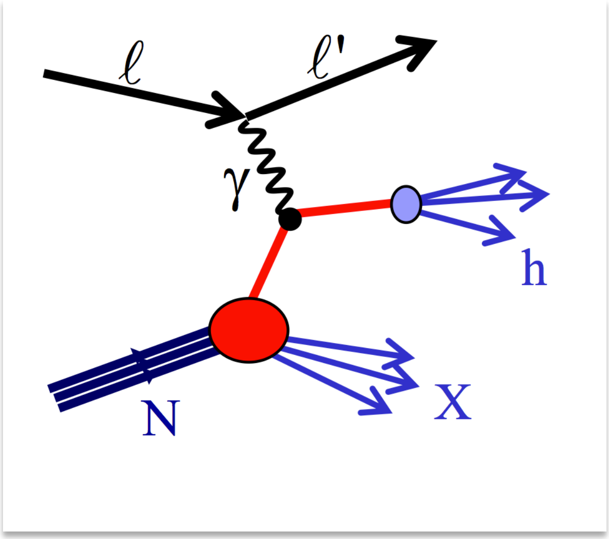
For a complete understanding of the nucleon structure

- ✧ Parton in longitudinal momentum space
  - Parton distribution functions (PDFs)
- ✧ Partons in transverse coordinate space
  - Generalized parton distributions (GPDs)
- ✧ Partons in transverse momentum space
  - Transverse momentum distributions (TMDs)

→ Could be assessed in Semi-inclusive DIS

Semi-Inclusive deep inelastic scattering

SIDIS: a powerful tool to study quark transverse momenta in the nucleon ($k_\perp$) and in the fragmentation ($p_\perp$)



- Assess PDFs/FFs
- Flavor/charge separation
- wide scale coverage
- Nuclear target provide laboratory for fragmentation in nuclear medium
- Relevant for spin physics kinematic

$$\mathrm{d}\sigma^{\ell p \to \ell h X} \sim \sum_q e_q^2 f_q(x, Q^2, \boldsymbol{k}_\perp) \otimes \mathrm{d}\sigma^{\ell q \to \ell q} \otimes D_q^h(z, Q^2, \boldsymbol{p}_\perp)$$

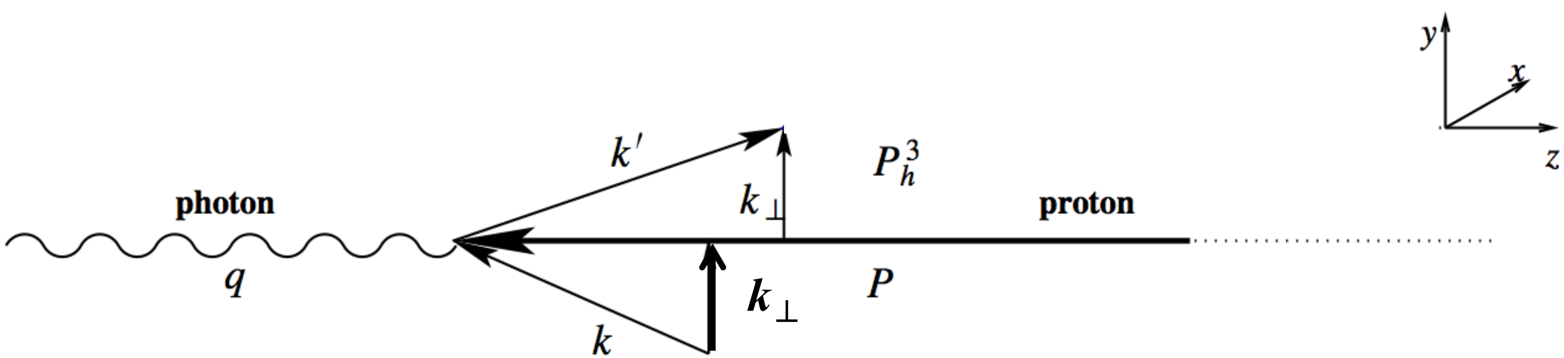
Transverse Momentum Dependent Parton distribution functions

elementary scattering

Transverse Momentum Dependent Fragmentation Functions

Transverse momentum dependence

- Transverse momenta of final-state hadron generated by
  - $\Rightarrow$ quark intrinsic transverse momentum $k_\perp$



TMD-PDFs

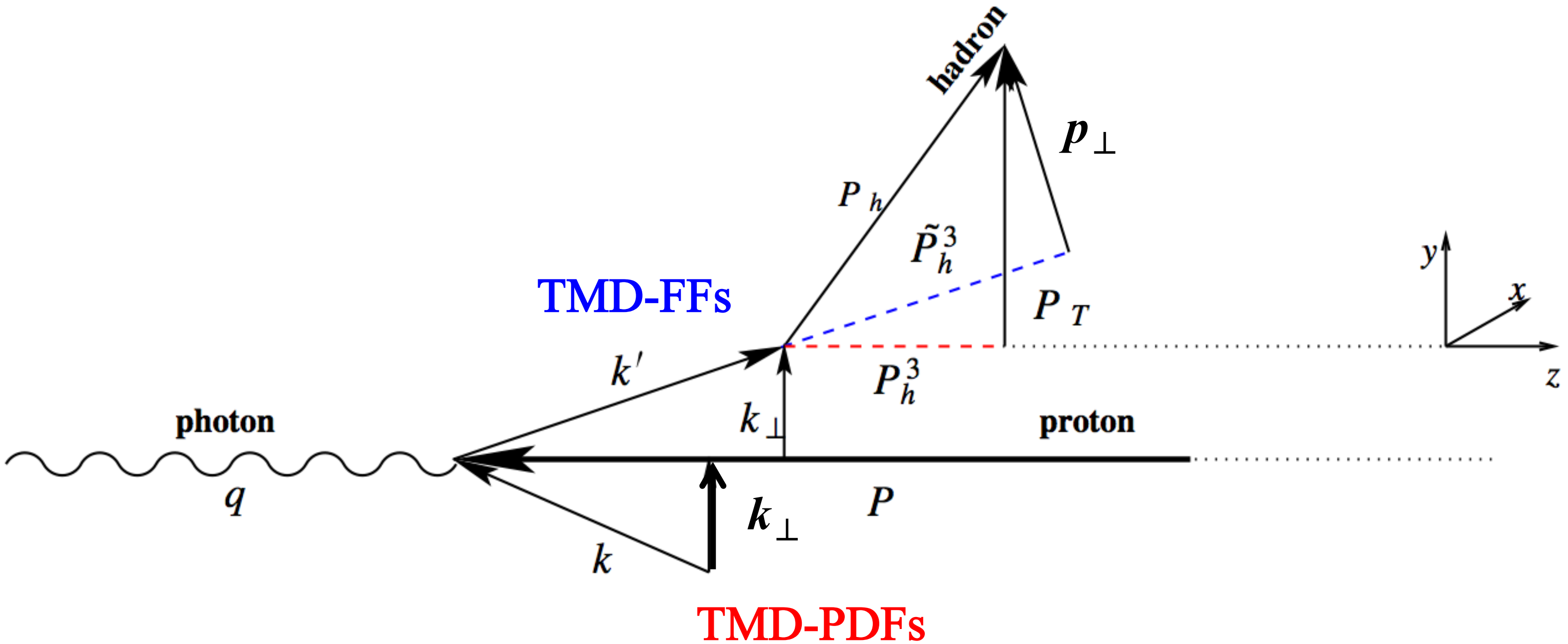
PRD 71, 074006, (2005)

Transverse momentum dependence

✧ Transverse momenta of final-state hadron generated by

⇒ quark intrinsic transverse momentum $k_\perp$

⇒ $p_\perp$ acquired in the quark fragmentation



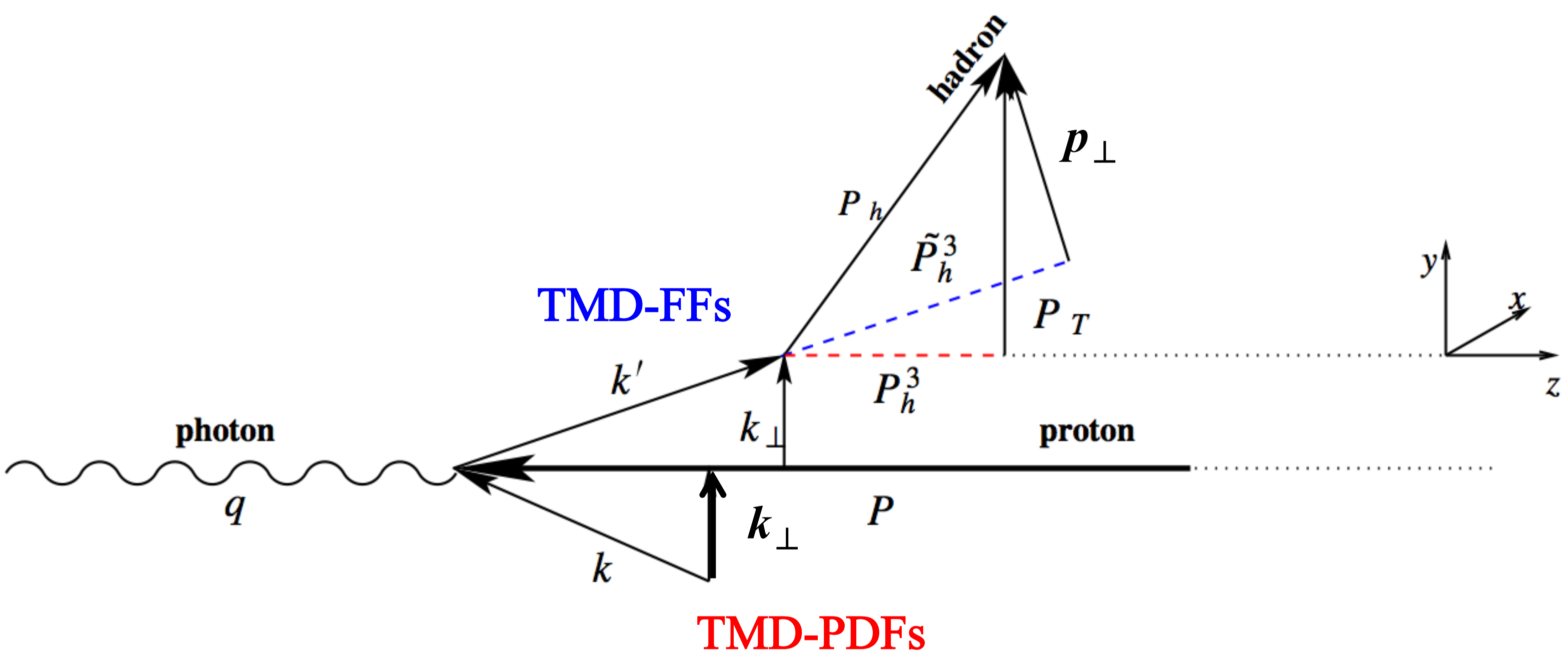
PRD 71, 074006, (2005)

Transverse momentum dependence

- Transverse momenta of final-state hadron generated by
  - ⇒ quark intrinsic transverse momentum $k_\perp$
  - ⇒ $p_\perp$ acquired in the quark fragmentation

- A Gaussian ansatz *for* $k_\perp$ *and* $p_\perp$ leads to

$$\langle p_T^2 \rangle = \langle p_\perp^2 \rangle + z^2 \langle k_\perp^2 \rangle$$



PRD 71, 074006, (2005)

Transverse momentum dependence

- Transverse momenta of final-state hadron generated by
  - ⇒ quark intrinsic transverse momentum $k_\perp$
  - ⇒ $p_\perp$ acquired in the quark fragmentation

- A Gaussian ansatz *for* $k_\perp$ *and* $p_\perp$ leads to

$$<p_T^2> = <p_\perp^2> + z^2 <k_\perp^2>$$

$$\mathrm{d}\sigma^{\ell p\to\ell hX} \sim \sum_q e_q^2 f_q(x, Q^2, \boldsymbol{k}_\perp) \otimes \mathrm{d}\sigma^{\ell q\to\ell q} \otimes D_q^h(z, Q^2, \boldsymbol{p}_\perp)$$

p_T distribution of final-state hadrons

The azimuthal modulations in the unpolarised cross-section result from

- intrinsic $k_\perp$ of the quarks -> **hadron multiplicities**, azimuthal asymmetries
- The Boer-Mulders PDF -> azimuthal asymmetries

Combined analysis allows to disentangle the different effects

Hadron Multiplicity

Hadron Multiplicities are defined as observed number of hadrons in a number of DIS events

$$\frac{\mathrm{d}^2 M^h(x,Q^2,z,p_T^2)}{\mathrm{d}z\,\mathrm{d}p_T^2} = \frac{\mathrm{d}^4\sigma^h(x,Q^2,z,p_T^2)/\,\mathrm{d}x\,\mathrm{d}Q^2\,\mathrm{d}z\,\mathrm{d}p_T^2}{\mathrm{d}^2\sigma(x,Q^2)/\,\mathrm{d}x\,\mathrm{d}Q^2}$$

quark FFs

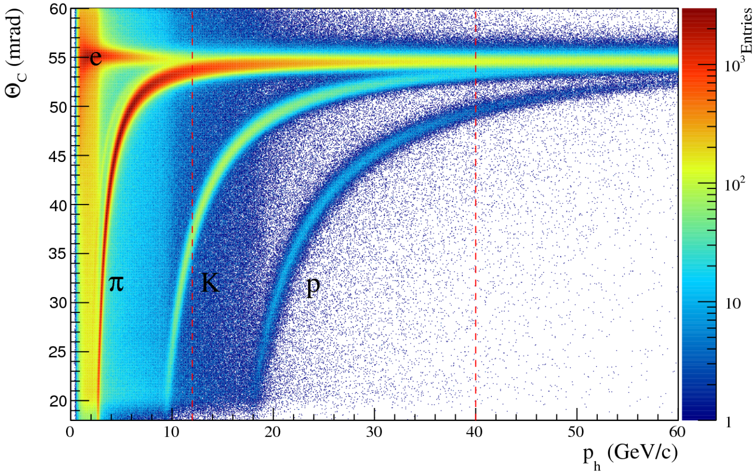
$$= \frac{\sum_q e_q^2 f_q(x,Q^2,k_\perp) D_q^h(z,Q^2,p_\perp)}{\sum_q e_q^2 f_q(x,Q^2,k_\perp)}$$

quark PDFs

Experimentally measured multiplicity must be corrected for many effects as

- ✧ Spectrometer acceptance + detector inefficiencies, bin migration
- ✧ Radiative effects
- ✧ Diffractive vector meson (ρ,Φ) production

COMPASS Spectrometer

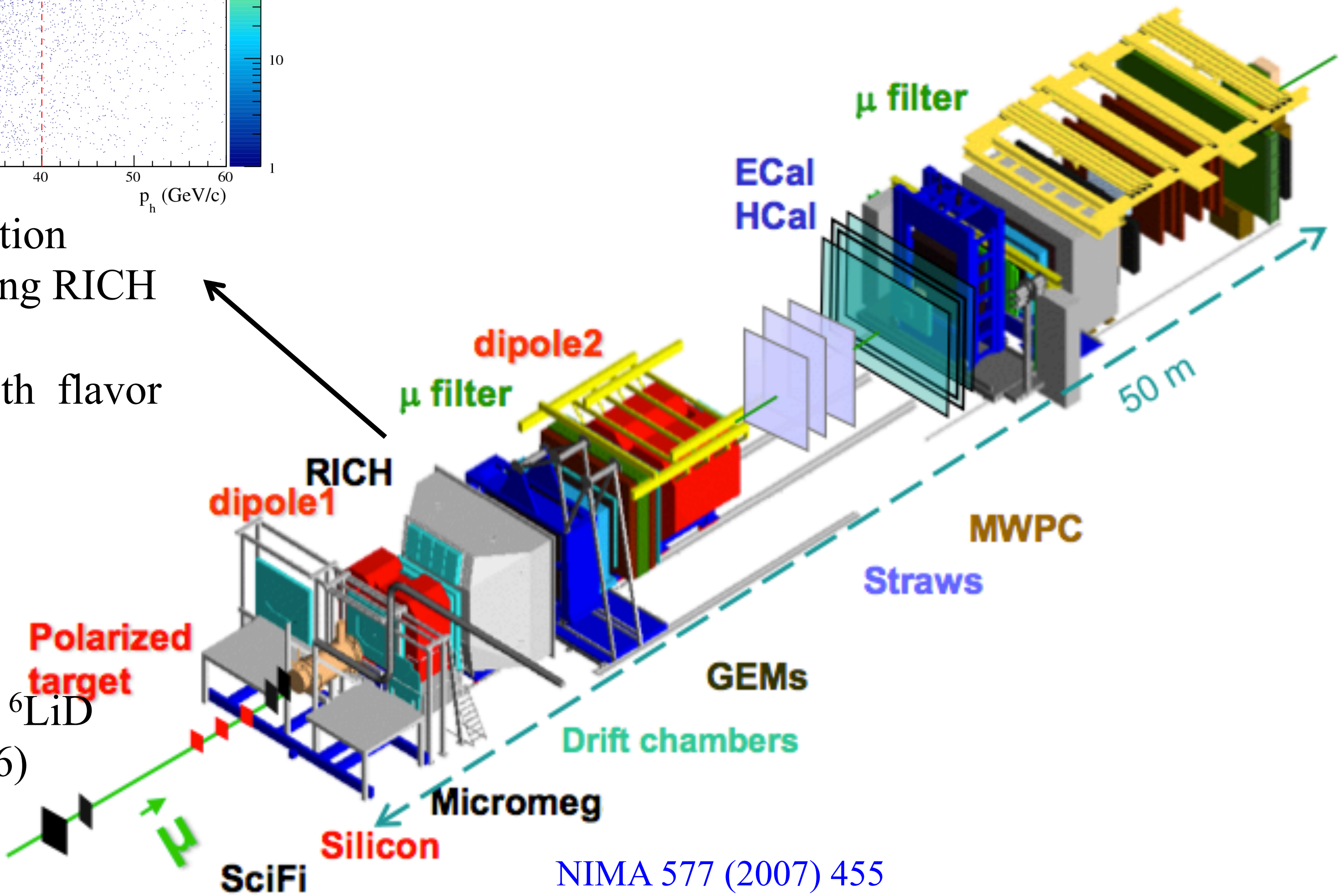


Excellent discrimination between π, K, p using RICH

For future studies with flavor separation

This analysis:
160 GeV μ^+ beam
1.2 m long polarised ^{6}LiD isoscalar target (2006)

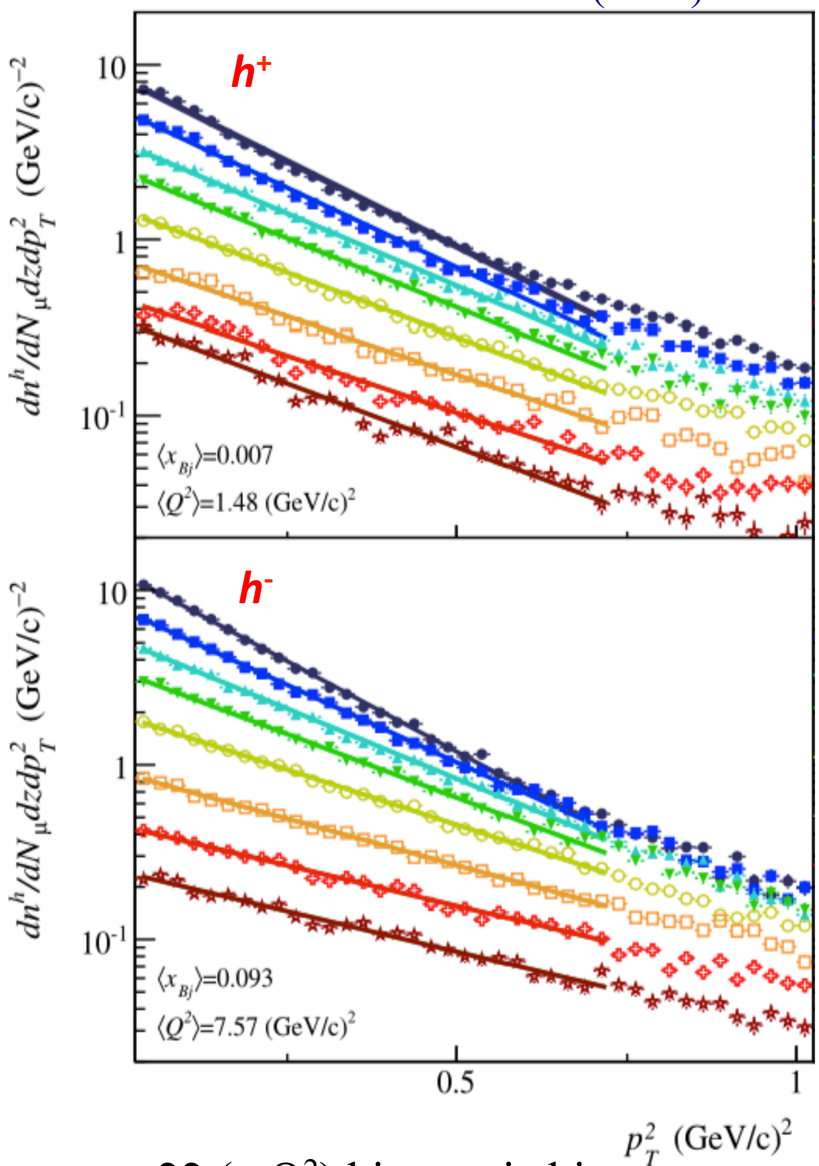
- Fixed-target
- Polarised muon beam & polarised targets p&d



NIMA 577 (2007) 455

p_T distributions of charged hadrons

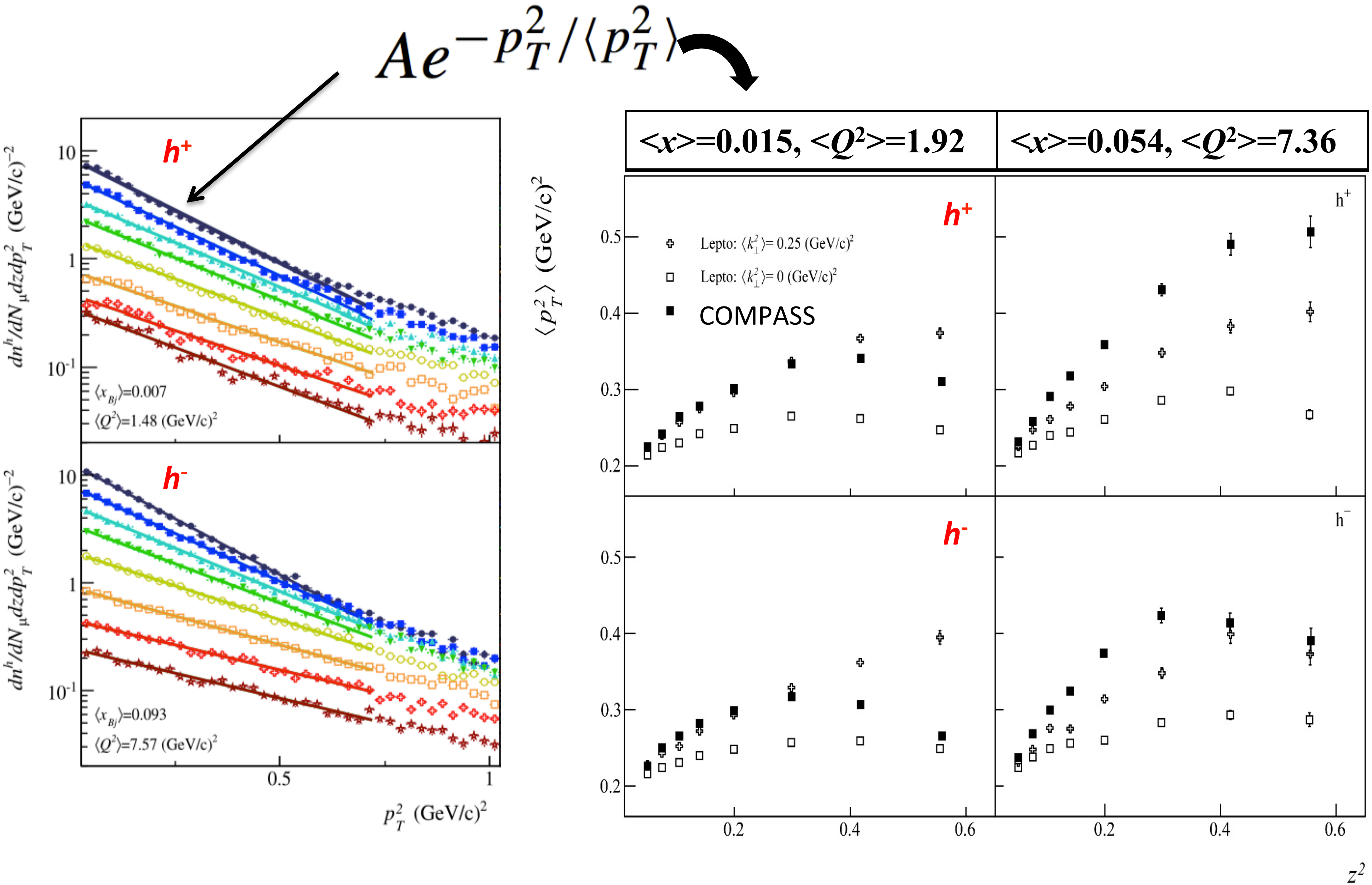
EPJC 73 (2013) 2531



+ 22 (x,Q^2) kinematic bins

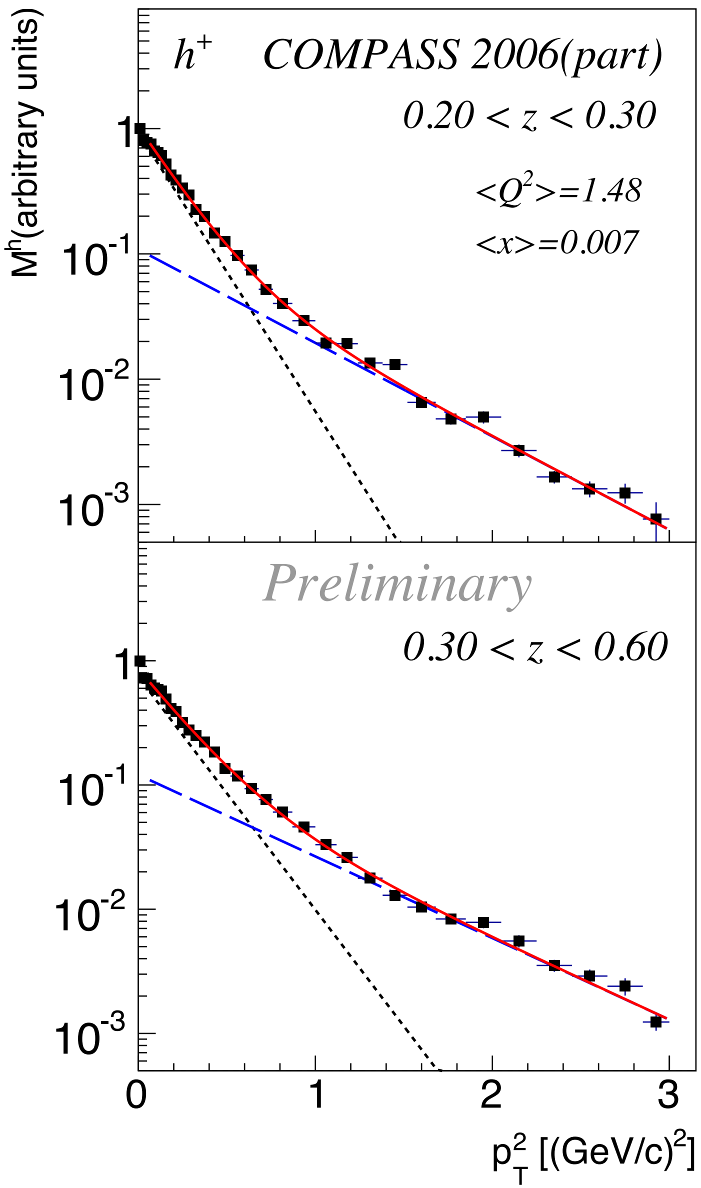
- First analysis to extract $h^{\pm}$ distributions vs. p_T^2 used:
  - data collected in 2004
  - in the kinematic domain:
    - $1 < Q^2$ (GeV/c)$^2 < 10$
    - $W > 5$ GeV/c^2
    - $0.1 < y < 0.9$
    - $0.004 < x < 0.12$
    - $0.2 < z < 0.8$
    - $0.01 < p_T^2 < 1.2$
  - 4-D binning in x, Q^2, z, p_T^2
- aimed to study the x, Q^2 and z kinematic dependences of $\langle p_T^2 \rangle$ assuming Gaussian distribution of quark transverse momentum $k_\perp$ and of the hadron transverse momentum wrt quark direction ($p_\perp$

p_T^2 averaged values



EPJC 73 (2013) 2531

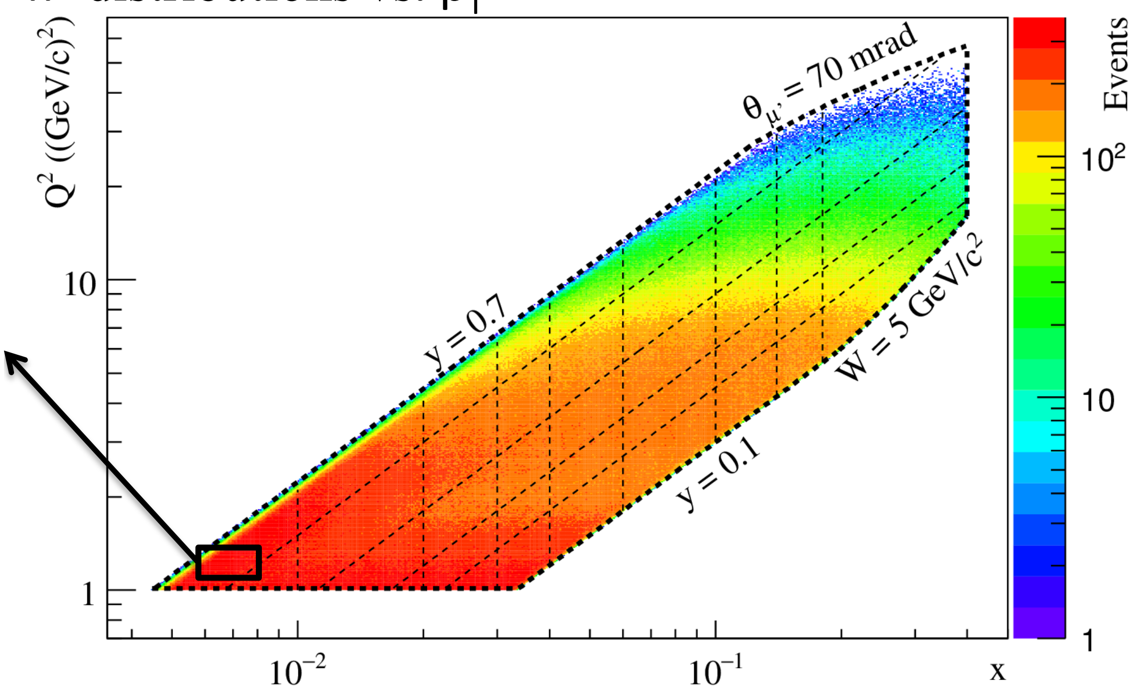
p_T distributions of charged hadrons



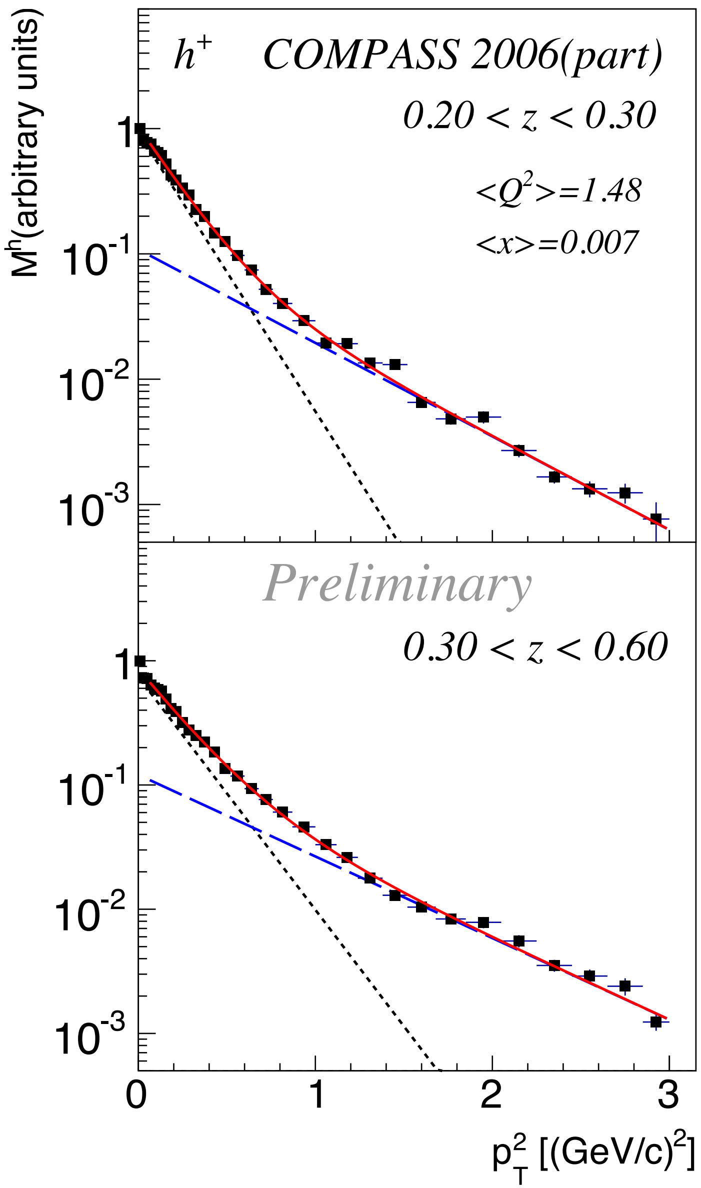
Data collected in 2006

- Larger angular acceptance, higher statistics, wider kinematic range
- First look in a restricted kinematic range: only 3 (x,Q^2) bins, 2 z bins, extending the p_T^2 range

$h^{\pm}$ distributions vs. p_T^2



p_T distributions of charged hadrons



Data collected in 2006

- ✧ Larger angular acceptance, higher statistics, wider kinematic range
- ✧ First look in a restricted kinematic range: only 3 (x,Q^2) bins, 2 z bins, extending the p_T^2 range

h± distributions fitted using

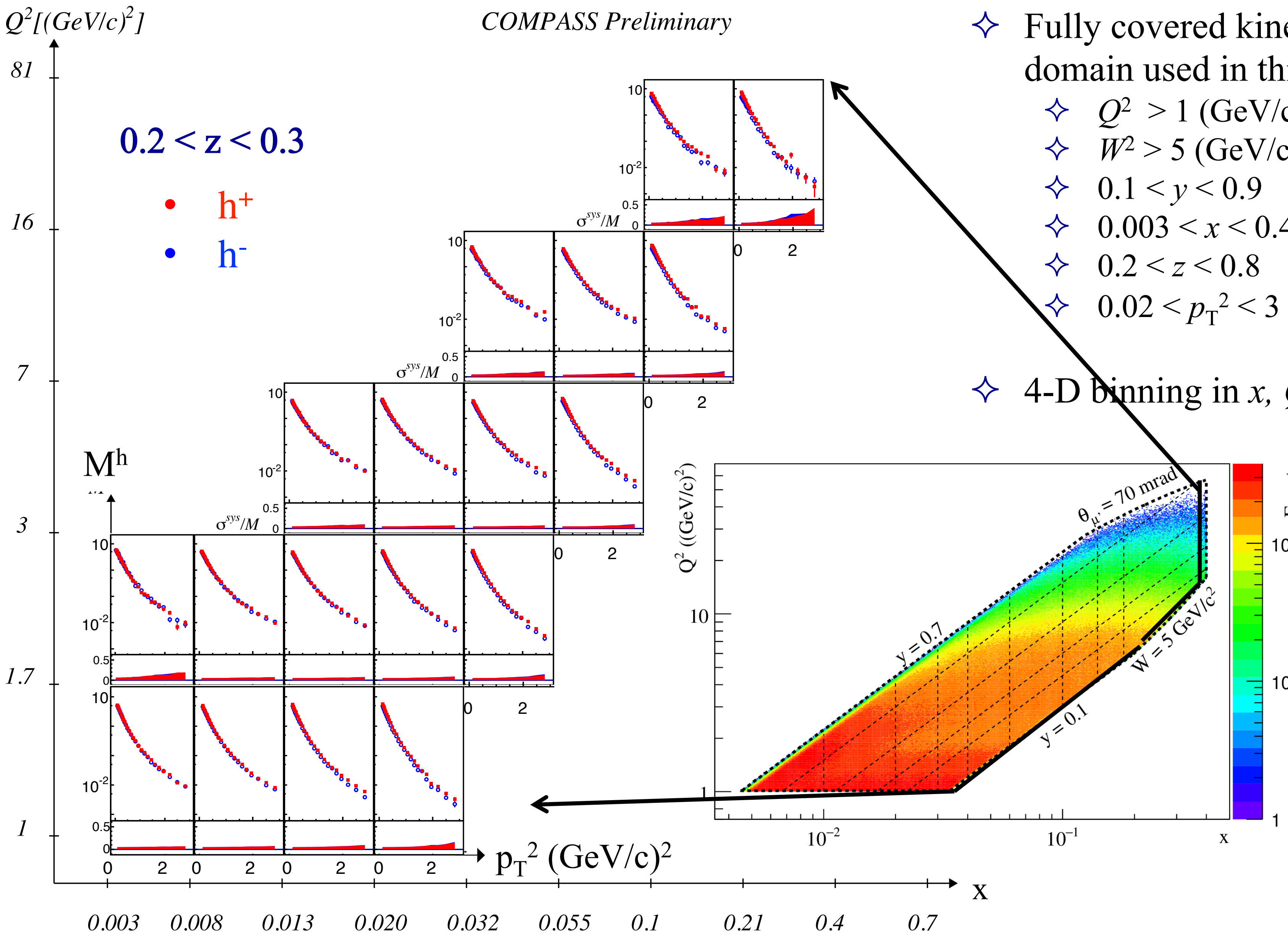
······ $N_1 \exp(-p_T^2/a_1)$ for $p_T^2 < 0.68$ (GeV/c)^2

— — $N_1 \exp(-p_T^2/a_1) + N_2 \exp(-p_T^2/a_2)$ for $p_T^2 < 3$ (GeV/c)^2

- ✧ Need two exponentials to describe the p_T^2 shape of the COMPASS data
- ✧ 2nd exp becomes dominant for $p_T^2 > 0.6$ (GeV)^2

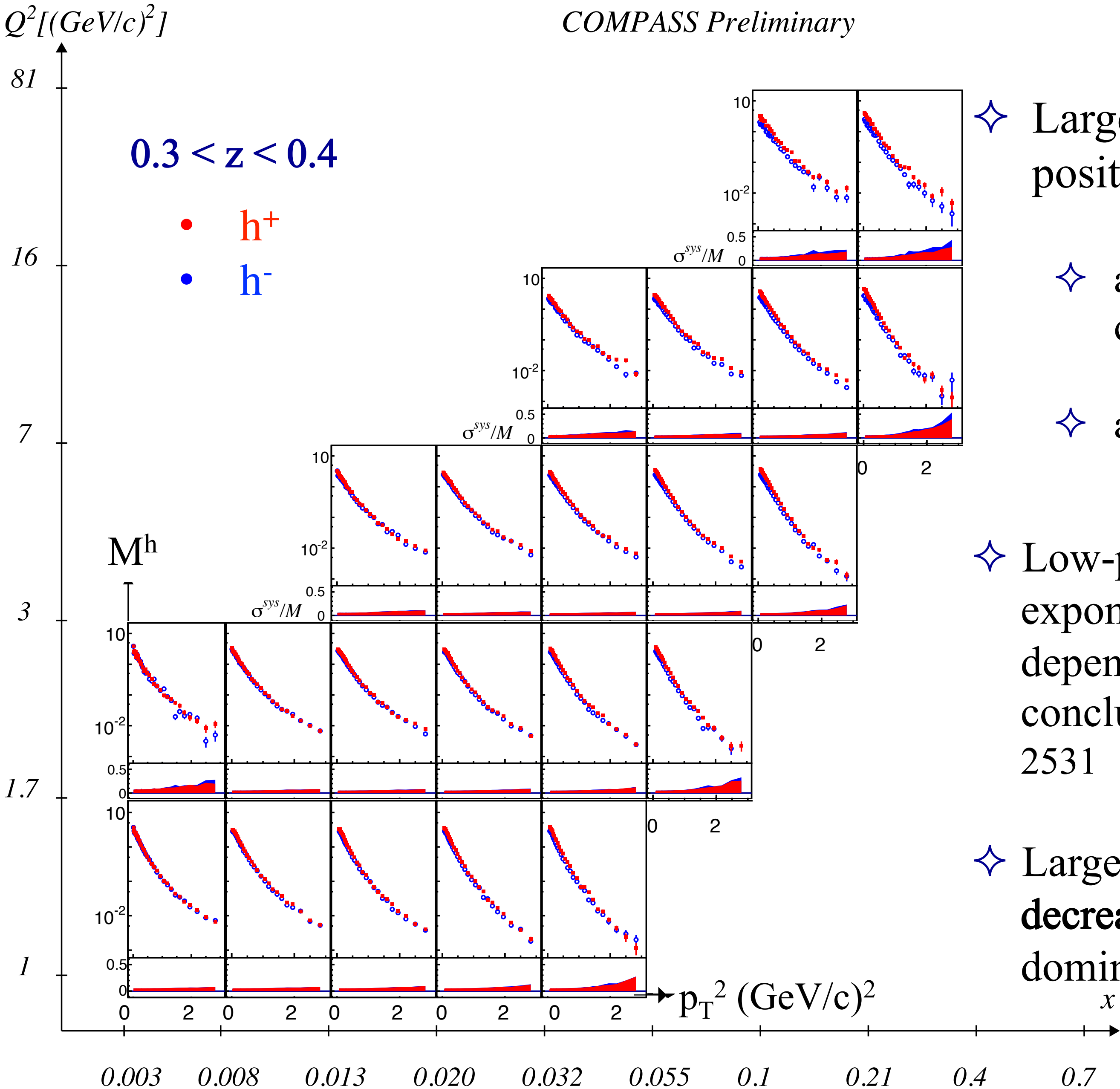
A more complexe curve than one Gaussian is needed to describe the p_T shape of experimental data

Multiplicities of charged hadron vs. p_T^2



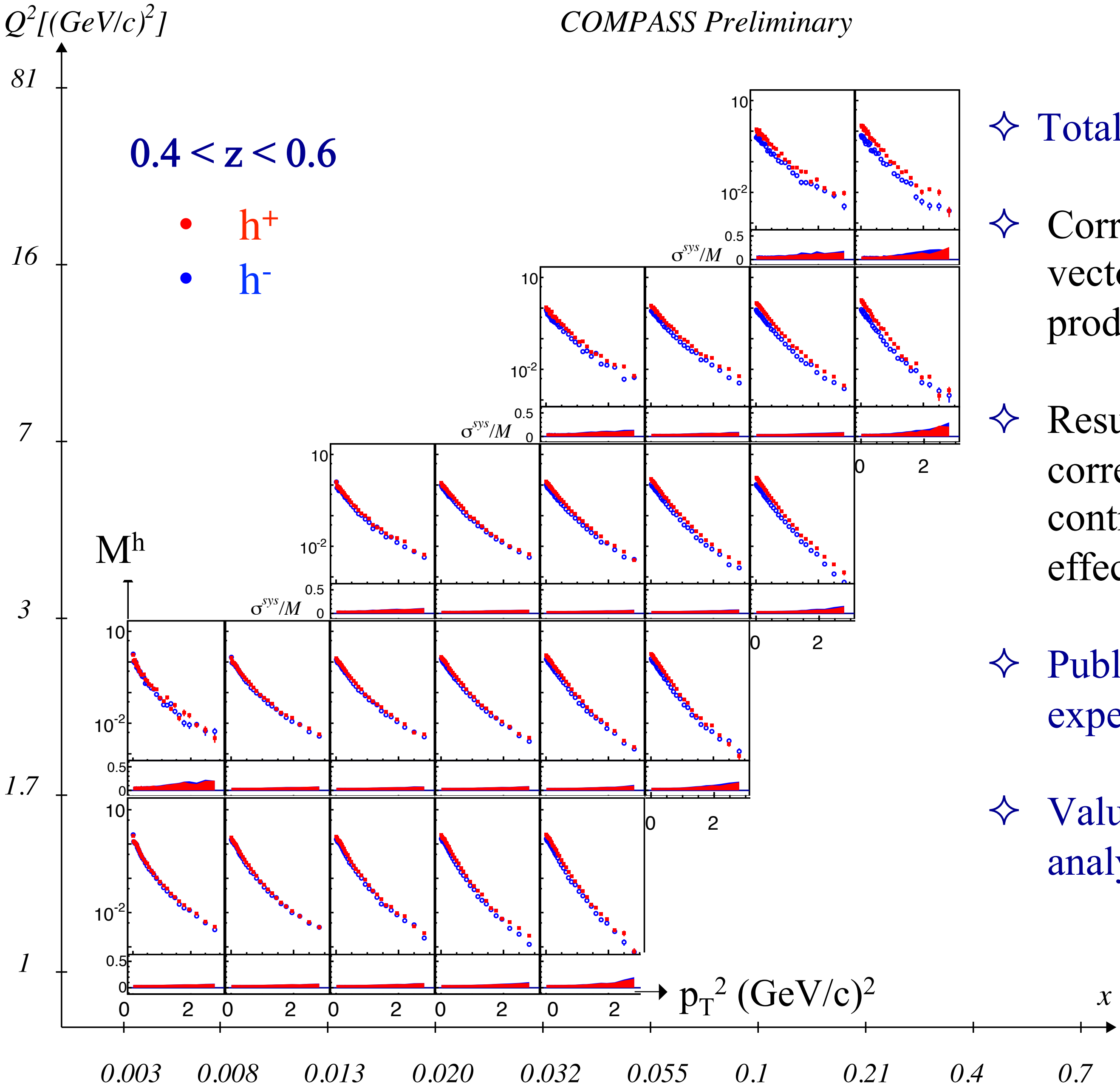
- Fully covered kinematic domain used in this analysis
  - $Q^2 > 1$ (GeV/c)^2
  - $W^2 > 5$ (GeV/c)^2
  - $0.1 < y < 0.9$
  - $0.003 < x < 0.4$
  - $0.2 < z < 0.8$
  - $0.02 < p_T^2 < 3$
- 4-D binning in x, Q^2, z, p_T^2

Multiplicities of charged hadron vs. p_T^2, cont.



- Larger multiplicities for positive hadrons
  - at **high x** due to valence u-quark dominance
  - at **large z**, where $D_u^{\pi+} > D_u^{\pi-}$
- Low-p_T range fitted using one exponential: non-linear z^2-dependence of $\langle p_T^2 \rangle$, confirms conclusions of EPJC 73 (2013) 2531
- Large-p_T shape flattens as **x decreases** and **Q^2 increases**, dominated by PGF,…

Multiplicities of charged hadron vs. p_T^2, cont.



- ✧ Total: 4918 kinematic bins
- ✧ Correction for diffractive vector meson (DVM) production evaluated
- ✧ Results available with/without correction for vector meson contribution and radiative effects
- ✧ Publication being prepared, expected soon
- ✧ Valuable input for TMD analyses and evolution studies

Summary

- Transverse momentum dependent multiplicities of charged hadron were measured using 2006 data collected with a deuteron target and 160 GeV μ^+
  - in a wide kinematic domain
  - in 4-D kinematic binning in x, Q^2, z and p_T^2
- Observations for the low-p_T^2 shape confirms 2004 results
- Flattening distributions at large-p_T^2, at low x (fixed Q^2) and at high Q^2 (fixed x)
- Paper expected soon
- COMPASS results on hadron multiplicities represent valuable inputs to global QCD analyses of FFs and TMD analyses
- Future measurements of hadron multiplicities on proton (LH_2) target from 2016-2017 data

Backup

TMD charged hadron multiplicities