Hadron production at COMPASS
SPIN-Praha-2010

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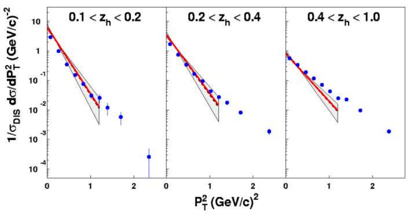
Outline

What can we learn about hadron distributions

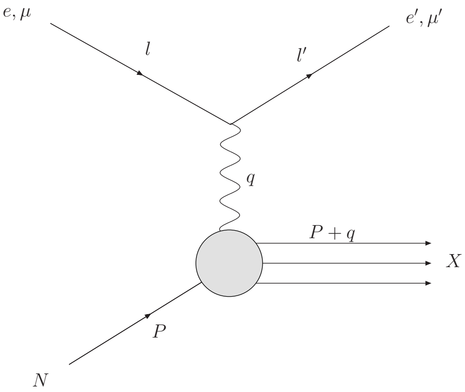
Reference for theory



Physics

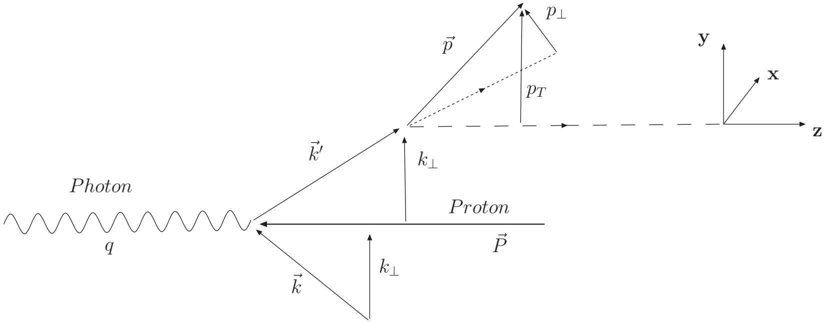
- Unintegrated parton distributions
- Fragmentation functions
- Gluon radiation

Event variables



- Q^2: $-q^2$
- x_{Bj}: $Q^2/2P \cdot q$
- W^2: $(p+Q)^2$
- y: $P \cdot q / P \cdot k$

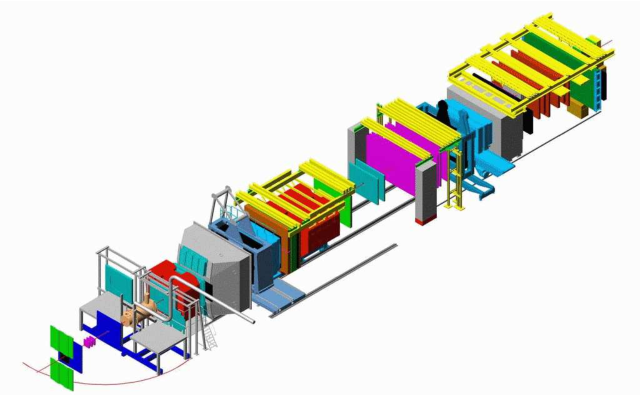
Hadron variables



- $k_\perp$: Intrinsic transverse momentum of the interacting parton w.r.t. nucleon direction ($\vec{P}$)
- p_T: Hadron transverse momentum w.r.t. γ^*
- $p_\perp$: Hadron transverse momentum w.r.t. scattered parton direction ($\vec{k}'$)
- z: $P \cdot p / P \cdot q$, Photon energy fraction carried by the hadron.

Properties of COMPASS muon programs (2004 setup)

- Beam: μ^+ 160 GeV
- Fixed target: ^{6}LiD
- $2 \cdot 10^8 \mu/cycle$
- Spill cycle every 16.8 seconds (flat top extraction 4.8 sec.)
- cms energy: $\approx$16 GeV
- Two cells target to measure asymmetries

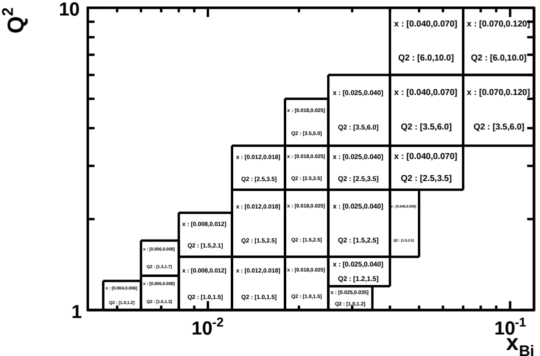


Outline

Data sample

Event selection

- Part of 2004 data
- $Q^2 > 1\ (\mathrm{GeV}/c)^2$, $0.1 < y < 0.9$
- 57.4M events

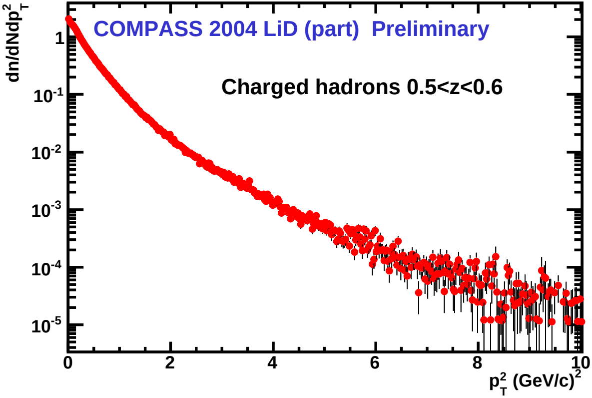


Hadron selection

- Charged hadrons
- z: [0.2, 0.25, 0.3, 0.35, 0.4, 0.5, 0.6, 0.7, 0.8]
- 115M hadrons $(0 < z < 1)$

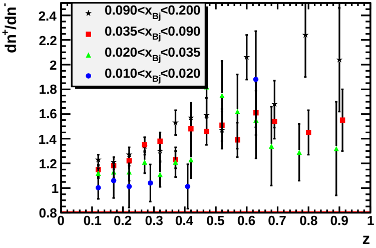
Outline

Example distribution



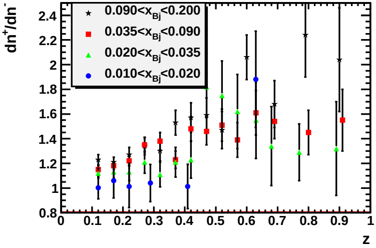
This distribution can be separated into 23 (Q^2, x_{Bj}) intervals. There are 8 such intervals in z which can also be separated in charge. Total of 368 distributions, how to present them in a digestible way?

Charge ratio

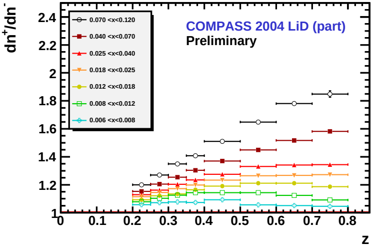


(a) EMC

Charge ratio



(c) EMC



(d) COMPASS

$\langle p_T^2 \rangle$ vs c.m. energy s

Phys.Rev.D81:094019,2010

Assuming a Gaussian distribution of $k_\perp$ and $p_\perp$ (more on this later)

$$\langle k_\perp^2(s) \rangle \approx \langle k_\perp^2(0) \rangle + C \cdot s,$$

where

- $\langle k_\perp^2(0) \rangle = 0.3\ (\mathrm{GeV/c})^2$
- $C = 0.7 \cdot 10^{-3}$.

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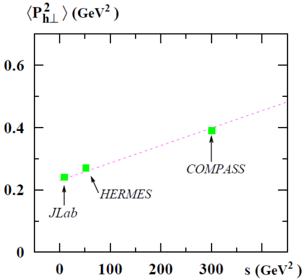
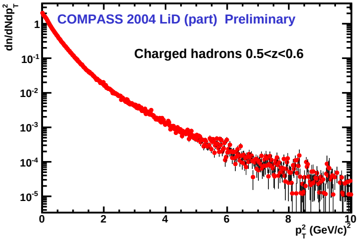
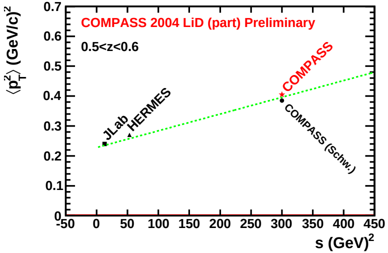


These values are for $0.5 < z < 0.6$. The COMPASS point comes from an average value not corrected for acceptance given in an asymmetry publication.

Providing an acceptance corrected average p_T^2

Using the p_T^2 distributions, the average p_T^2 is easily calculated:

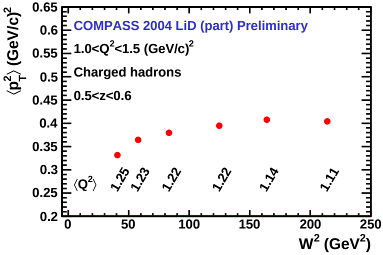


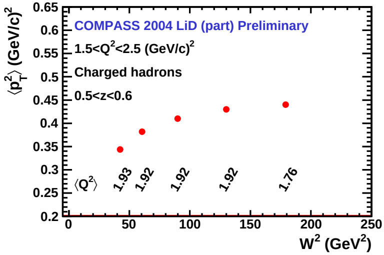


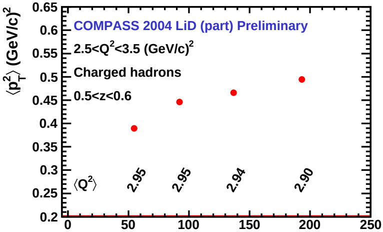
The average p_T^2 is 0.405 $(\mathrm{GeV/c})^2$.

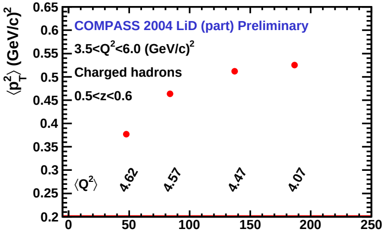
Dependence on W^2

More appropriate to make a dependence of the average p_T^2 on W^2 instead of s:









Outline

Framework

At $\mathcal{O}\left(\frac{k_\perp}{Q}\right)$, the SIDIS cross section looks like :

$$\frac{d^5\sigma^{\mu P\to\mu'+h+X}}{dx_{Bj}\,dQ^2\,dz\,d^2\vec{p}_T} \approx \sum_q e_q^2 \int d^2\vec{k}_\perp f_q(x_{Bj},k_\perp)\frac{d\hat{\sigma}^{\mu q\to\mu q}}{dQ^2} D_q^h(z,\vec{p}_\perp)$$

where $\frac{d\hat{\sigma}^{\mu q\to\mu q}}{dQ^2}$ is the QED point-like interaction μ + quark.

Assumptions

- QCD Parton model 1st order
- $k_\perp$ fully taken into account in parton distribution functions.

The Gaussian ansatz for the unintegrated PDFs

The $p_\perp$ and $k_\perp$ dependence are assumed to be Gaussian:

$$f_q(x, k_\perp) = f_q(x) \frac{1}{\pi \langle k_\perp^2 \rangle} e^{-k_\perp^2 / \langle k_\perp^2 \rangle}$$

$$D_q^h(z, \vec{p}_\perp) = D_q^h(z) \frac{1}{\pi \langle p_\perp^2 \rangle} e^{-p_\perp^2 / \langle p_\perp^2 \rangle}$$

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The cross section then becomes proportional to:

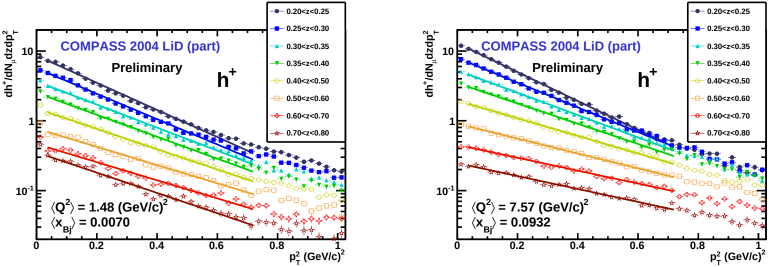
$$\frac{d^4 \sigma^{\mu P \to \mu + h + X}}{dx_{Bj} dQ^2 dz dp_T^2} \propto \sum_q e_q^2 f_q(x_{Bj}) D_q^h(z) \frac{e^{-p_T^2 / \langle p_T^2 \rangle}}{\pi \langle p_T^2 \rangle}$$

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

- Flavor independent
- Describes (integrated) data well up to $p_T \approx 1$ GeV/c

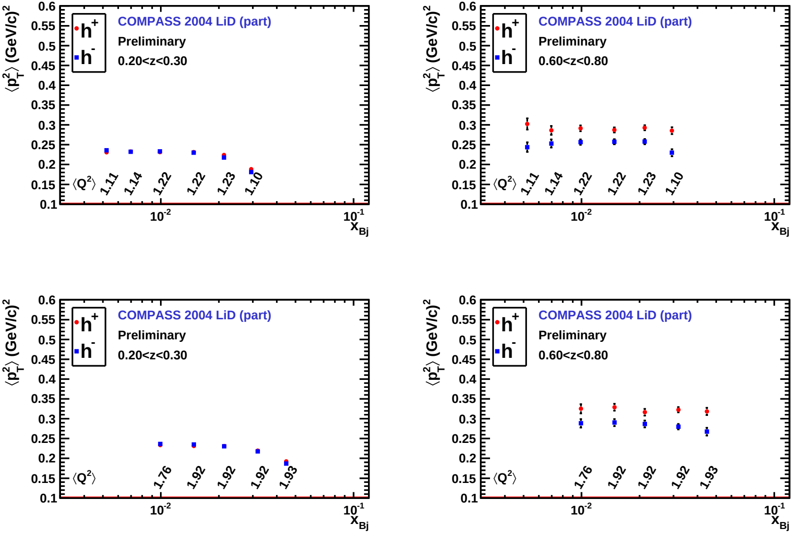
Fitting the p_T^2 distributions for various kinematical intervals

Using the $e^{-p_T^2/\langle p_T^2 \rangle}$ dependence of the cross section and the relation we fit the p_T^2 distributions with a Gaussian to get $\langle p_T^2 \rangle$.



The fits are limited to small p_T^2 in order to stay away from pQCD where the model is known to fail.

Fitted $\langle p_T^2 \rangle$ dependence on x_{Bj} and z



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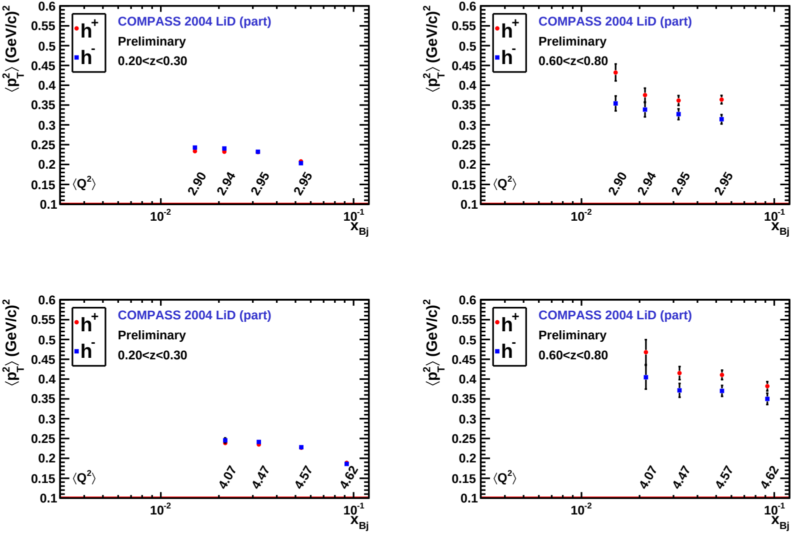
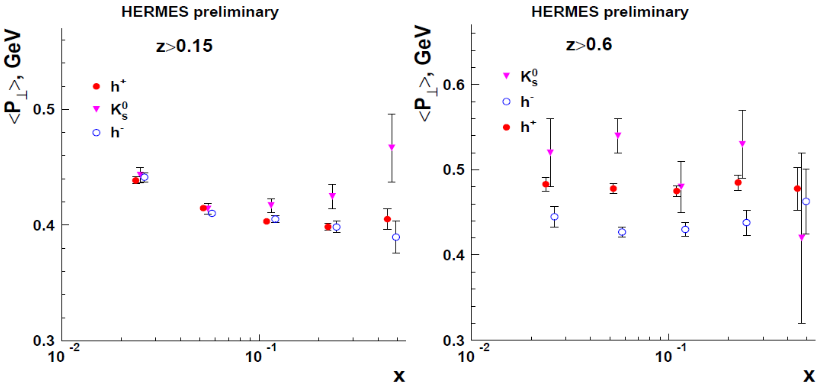
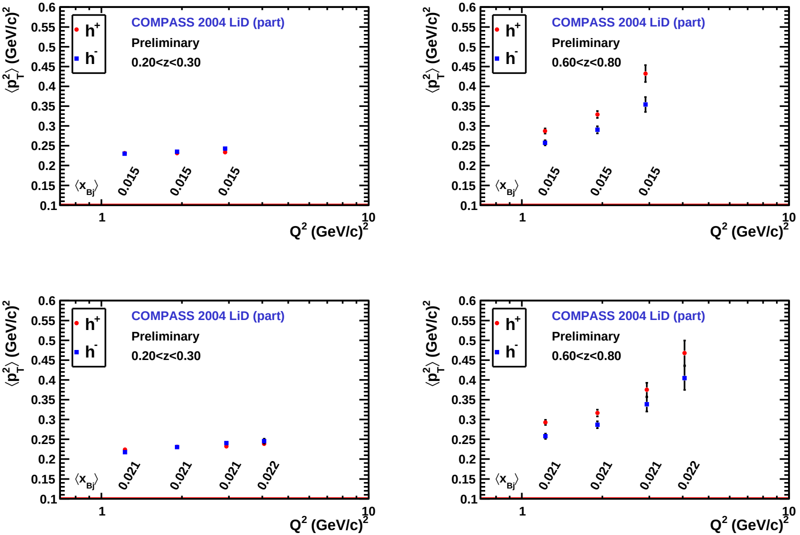


x_{Bj} dependence also seen by HERMES



Fitted $\langle p_T^2 \rangle$ dependence on Q^2 and z



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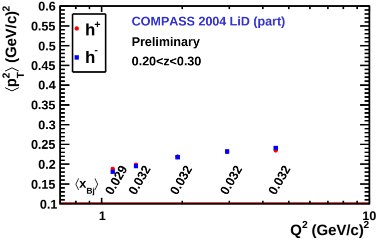
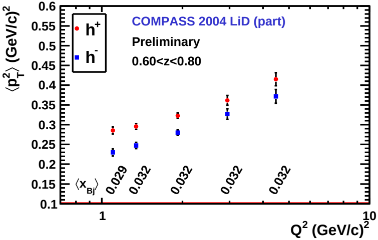
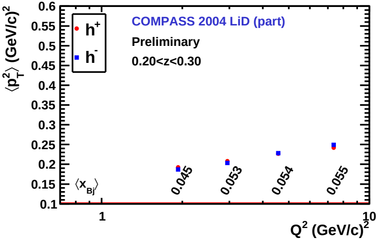
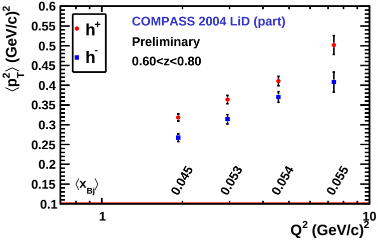
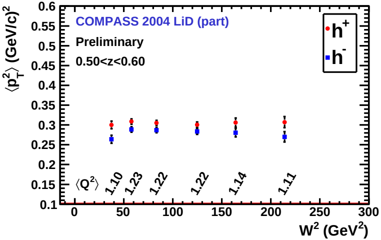


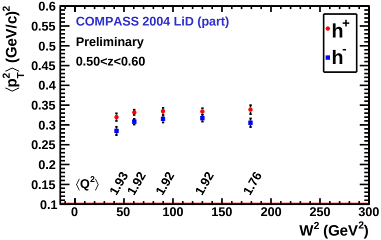


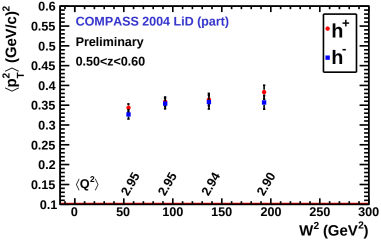


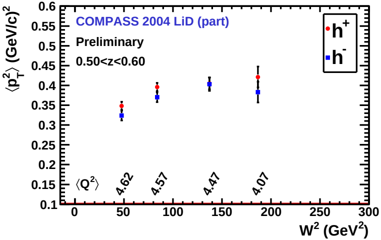


Fitted $\langle p_T^2 \rangle$ dependence on W^2 $(0.5 < z < 0.6)$





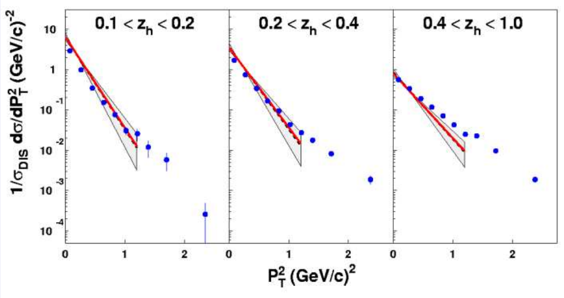




Global fit of the distribution

The Gaussian ansatz was used to determined $\langle k_\perp^2 \rangle$ and $\langle p_\perp^2 \rangle$ by fitting hadron distributions from various experiments.

Phys.Rev.D71:074006,2005



Fit results

$\langle p_\perp^2 \rangle$ = 0.20 (GeV/c)^2 (0.25 with Higher order pQCD)

$\langle k_\perp^2 \rangle$ = 0.25 (GeV/c)^2 (0.28 with Higher order pQCD)

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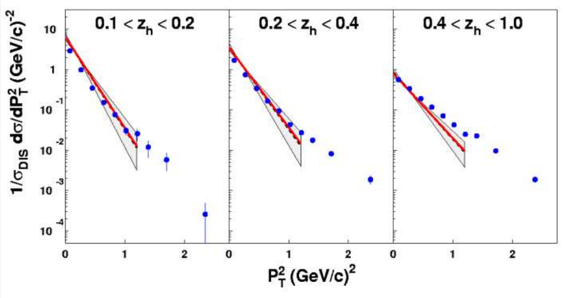

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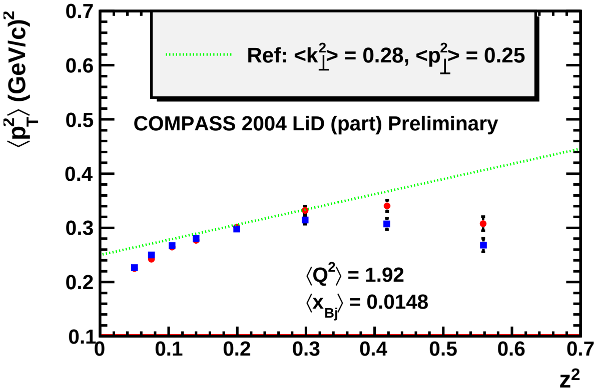
$\langle k_\perp^2 \rangle = 0.25\ (\mathrm{GeV/c})^2$ (0.28 with Higher order pQCD)

We can now check how these fitted values and the relation $\langle p_T^2 \rangle = \langle p_\perp^2 \rangle + z^2 \langle k_\perp^2 \rangle$ compares with COMPASS data.

p_T^2 vs z^2 compared to linear fit



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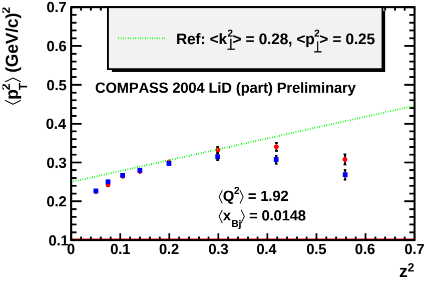
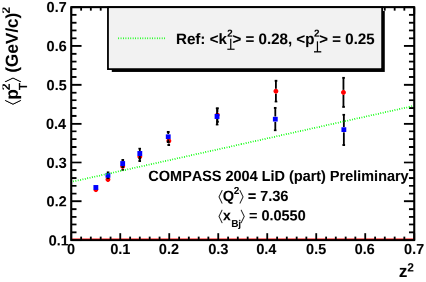


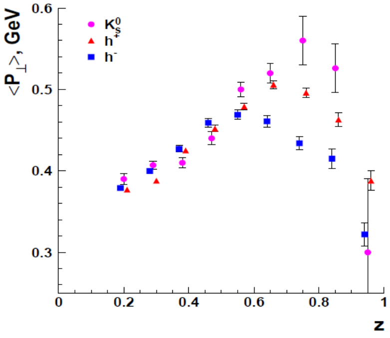
$$1.5 < Q^2 < 2.5 \;\; (\text{GeV}/c)^2$$
$$0.012 < x_{Bj} < 0.018$$



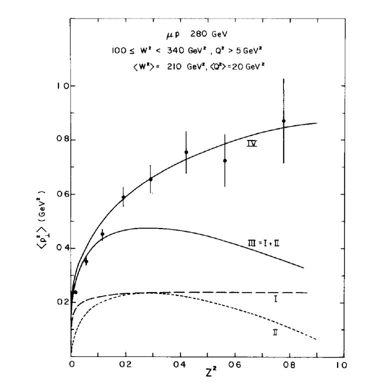
$$6 < Q^2 < 10 \;\; (\text{GeV}/c)^2$$
$$0.04 < x_{Bj} < 0.07$$

Non linearity p_T^2 vs z^2 already seen for average p_T^2

HERMES (hep-ex/0107003v1, 2001)



EMC (Phys.Lett95B, 1980)

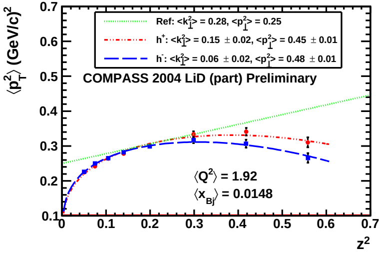


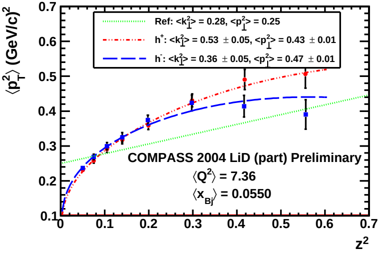
p_T^2 vs z^2 improved

The relation between $\langle p_T^2 \rangle$ and z^2 is not linear, but if we include a z dependence to $\langle p_\perp^2 \rangle$:

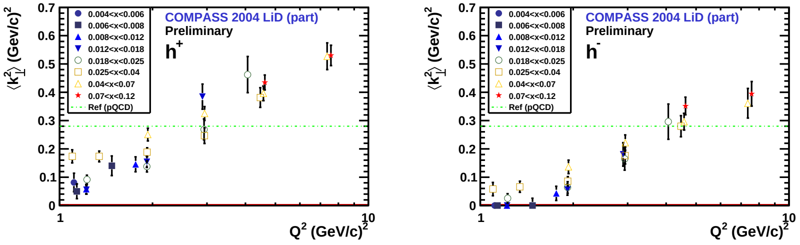
$$\langle p_T^2 \rangle = z^\alpha (1-z)^\beta \langle p_\perp^2 \rangle + z^2 \langle k_\perp^2 \rangle.$$

where $\alpha = 0.5$ and $\beta = 1.5$,





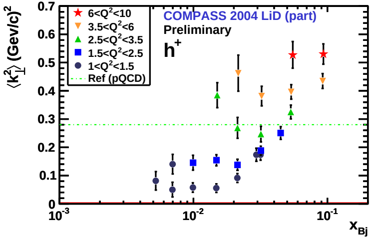
$\langle k_\perp^2 \rangle$ vs Q^2



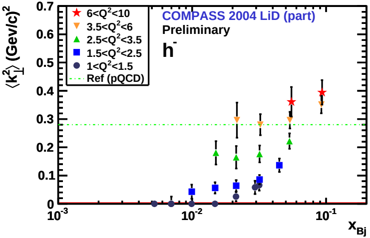
(a) h^+ (b) h^-

Note: The fit results for $\langle p_\perp^2 \rangle$ are not shown because the fit always gives the same value.

$\langle k_\perp^2 \rangle$ vs x_{Bj}

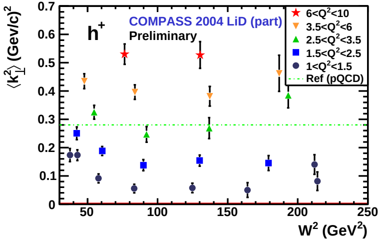


(a) h^+



(b) h^-

$\langle k_\perp^2 \rangle$ vs W^2



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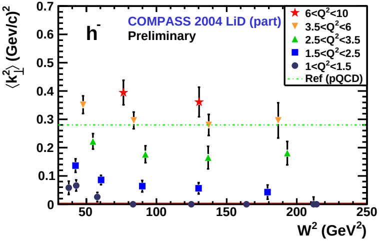
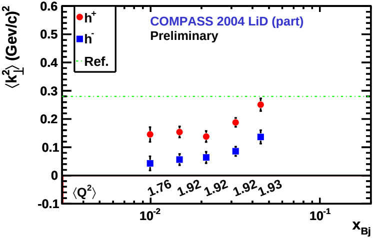
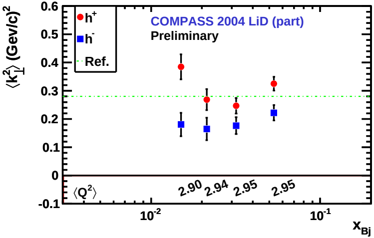
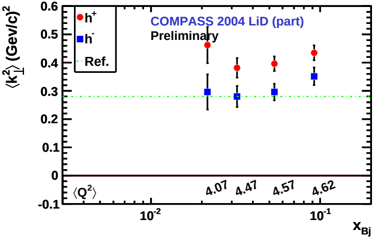


(b) h^-

$\langle k_\perp^2 \rangle$ vs x_{Bj}, charge comparison







Conclusion and outlook

- COMPASS hadron differential distributions corrected for acceptance are now available and can be used to verify theoretical models.
- The behavior agrees qualitatively with previous experiments.
- The low p_T distributions agree with a Gaussian behavior and can be fitted to have a $\langle p_T^2 \rangle$ independent of gluon radiation.
- The relation between $\langle p_T^2 \rangle$ and z^2 is not linear and can be reproduced by assuming a z dependence of $\langle p_\perp^2 \rangle$
- The extracted $\langle k_\perp^2 \rangle$ shows a clear dependence on Q^2 (no clear dependence on x_{Bj} and W^2).
- $\langle k_\perp^2 \rangle$ from h^+ are always higher ($\sim$0.1 (GeV/c)^2) than from h^-.

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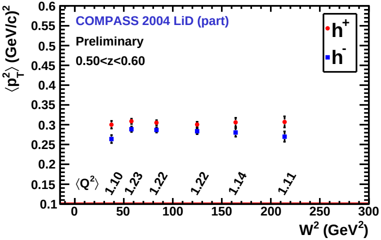
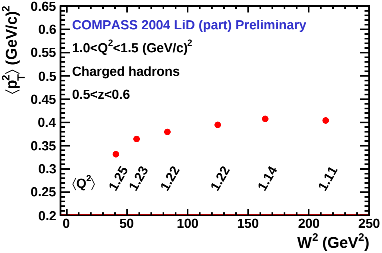
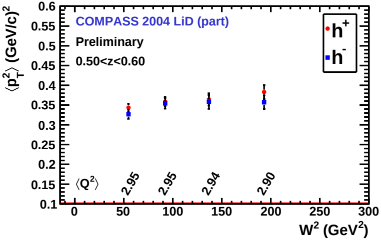
- $\langle k_\perp^2 \rangle$ from h^+ are always higher ($\sim$0.1 (GeV/c)^2) than from h^-.
- Further studies:
  - Particle identification
  - Azimuthal distributions ($\langle p_T^2 \rangle \propto z$)
  - Absolute cross sections

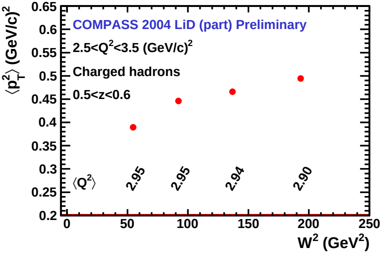
Extra slides

Average p_T^2 and fitted $\langle p_T^2 \rangle$ dependence on W^2 comparison









Average p_T^2 and fitted $\langle p_T^2 \rangle$ dependence on W^2 comparison