Intrinsic Transverse Momenta from SIDIS data

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In collaboration with

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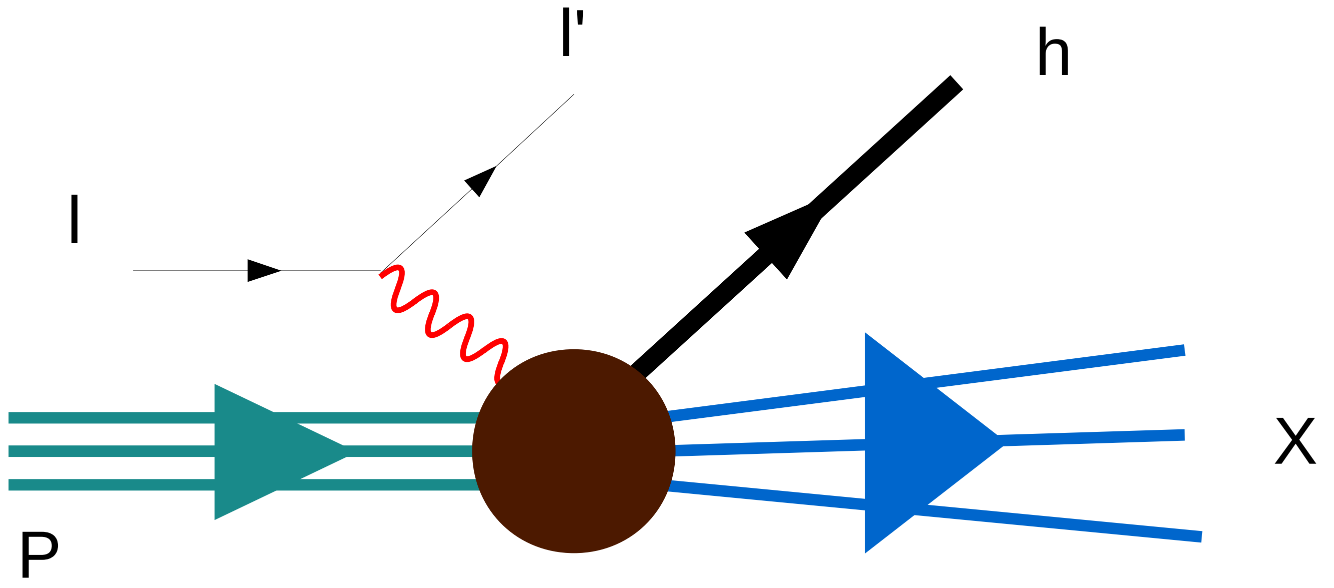
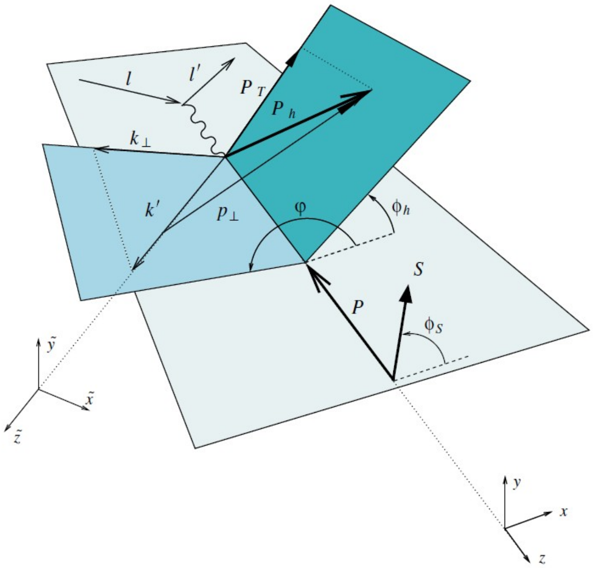
OUTLINE

- Accessing Intrinsic transverse momenta.
- Previous unpolarized TMD extraction (Torino 2005) and new data.
- Unpolarized TMD extraction from HERMES data.
- Unpolarized TMD extraction from COMPASS data.
- Additional comments.
- Final Remarks.



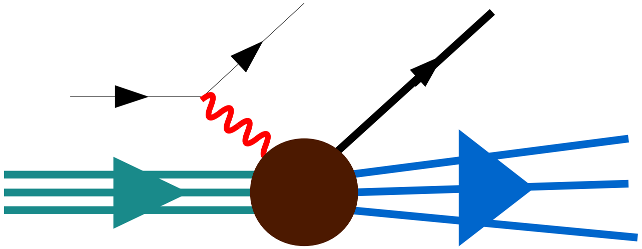
Access to Intrinsic Transverse Momentum
(Unpolarized SIDIS)

Kinematics...



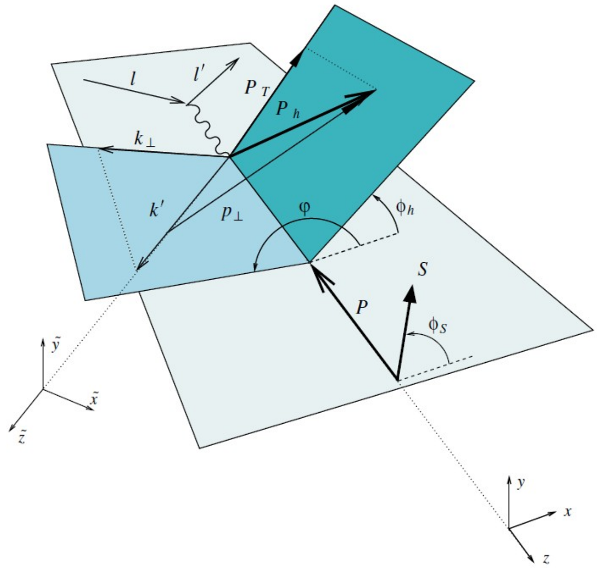
$$\boldsymbol{P}_T = z\,\boldsymbol{k}_\perp + \boldsymbol{p}_\perp$$

Dynamics...

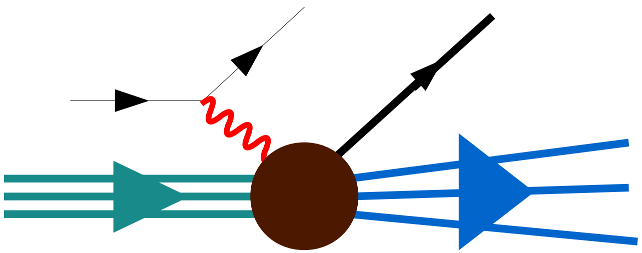


$$\sum_q e_q^2 \int d^2\boldsymbol{k}_\perp f_q(x_B, k_\perp) \frac{2\pi\alpha^2}{x_B^2 s^2}$$
$$\times \frac{\hat{s}^2 + \hat{u}^2}{Q^4} D_q^h(z_h, p_\perp),$$

Kinematics...



Dynamics...

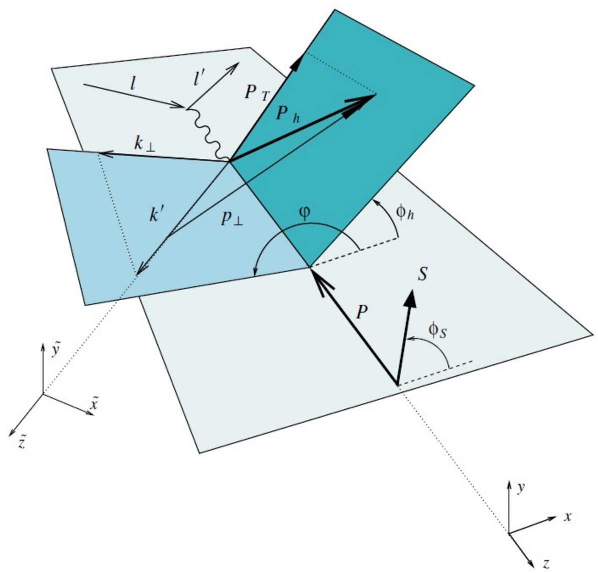


Gaussian model:

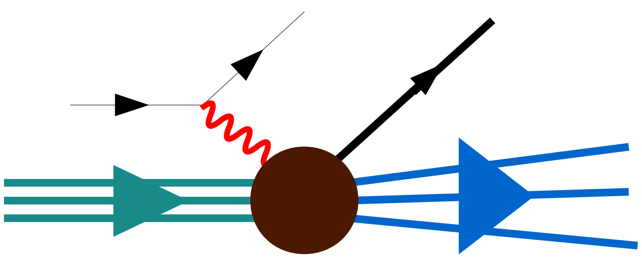
$$f_q(x, k_\perp) = f_q(x) \frac{1}{\pi \langle k_\perp^2 \rangle} e^{-k_\perp^2 / \langle k_\perp^2 \rangle}$$

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

Kinematics...



Dynamics...



Gaussian model:

$$\langle P_T^2 \rangle = \langle p_\perp^2 \rangle + z_h^2 \langle k_\perp^2 \rangle.$$

$$\sigma \propto \frac{1}{\pi \langle P_T^2 \rangle} e^{-P_T^2 / \langle P_T^2 \rangle}$$

In the simplest form of this model:

Flavor-independent average transverse momenta.

No x-dependence.

No z-dependence.

Two parameters in total.

Gaussian model:

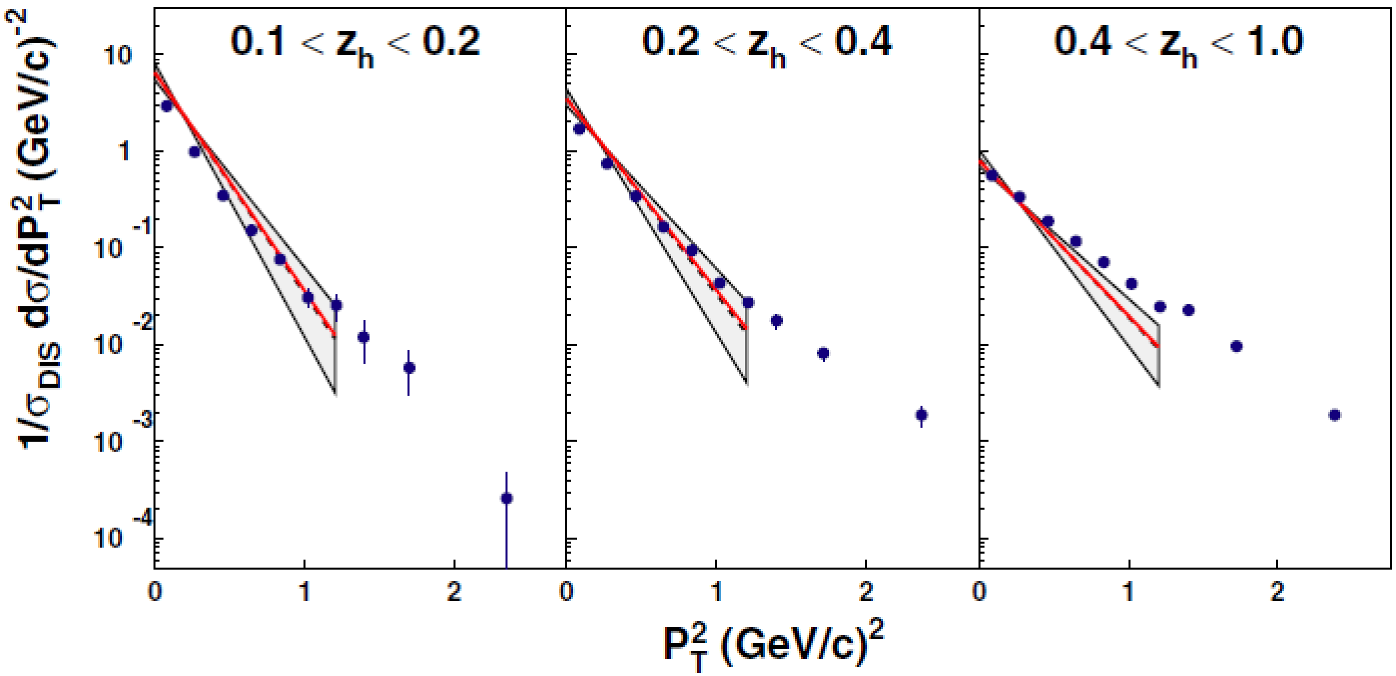
$$\langle P_T^2 \rangle = \langle p_\perp^2 \rangle + z_h^2 \langle k_\perp^2 \rangle.$$

$$\sigma \propto \frac{1}{\pi \langle P_T^2 \rangle} e^{-P_T^2/\langle P_T^2 \rangle}$$

Previous Extraction (2005).

From EMC data:
Ashman, J. et al. Z.Phys. C52 (1991) 361-388 CERN-PPE-91-53

$$\langle k_\perp^2 \rangle = 0.25\ \text{GeV}^2 \qquad \langle p_\perp^2 \rangle = 0.20\ \text{GeV}^2$$



Anselmino, M. et al. Phys.Rev. D71 (2005) 074006 hep-ph/0501196

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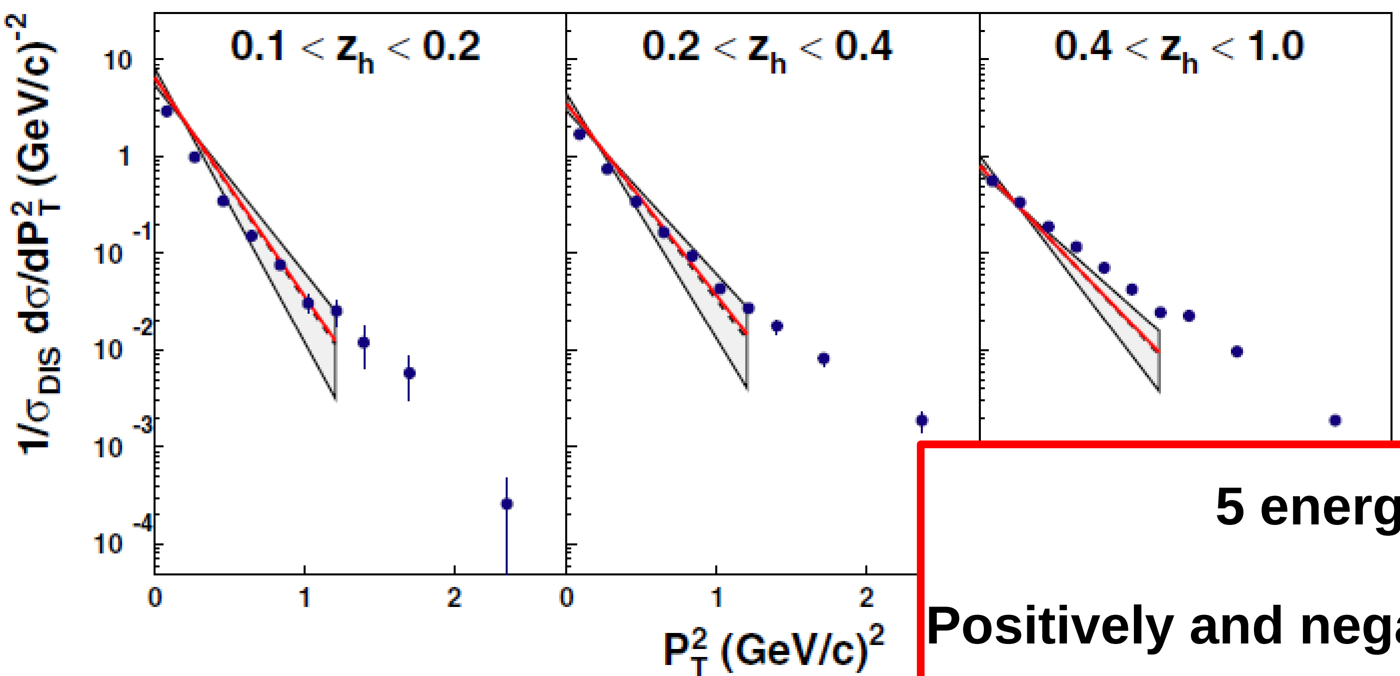

Anselmino, M. et al. Phys.Rev. D71 (2005)

5 energies,

Positively and negatively charged particles . . .

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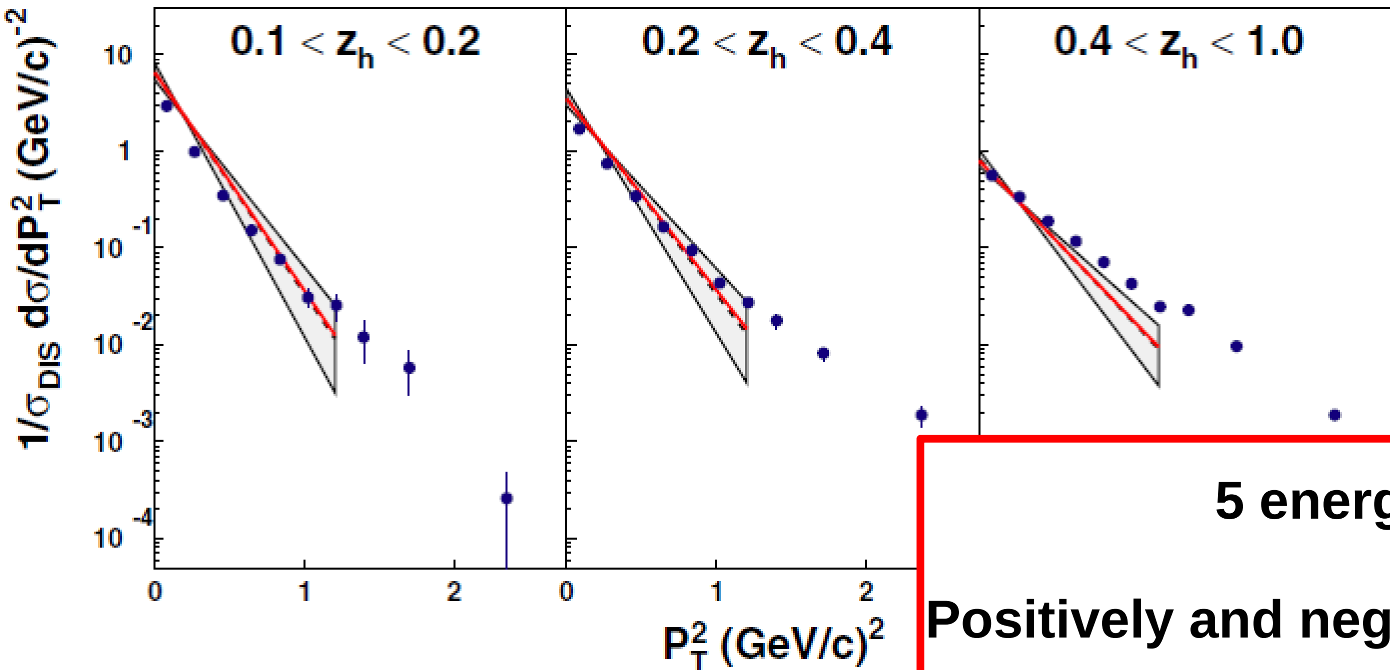

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5 energies,

Positively and negatively charged particles . . .

. . . 1 data set.

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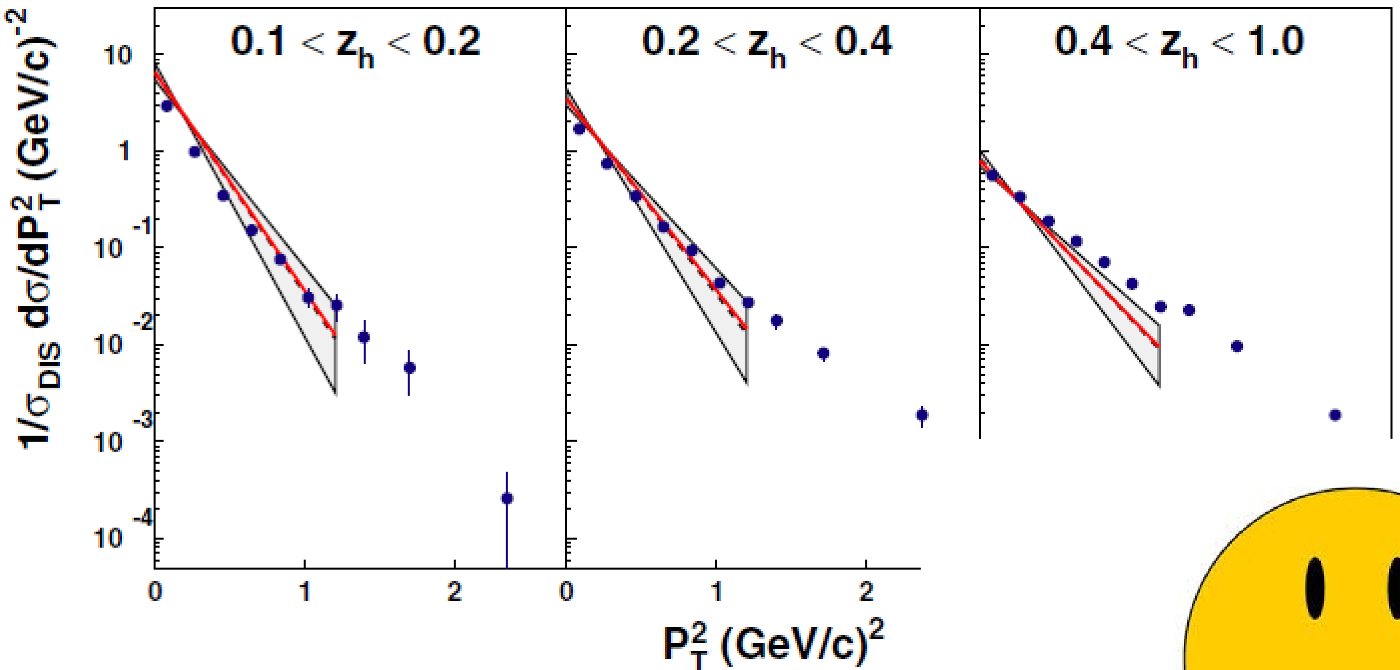

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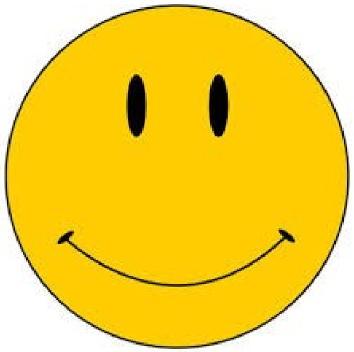


New data releases...

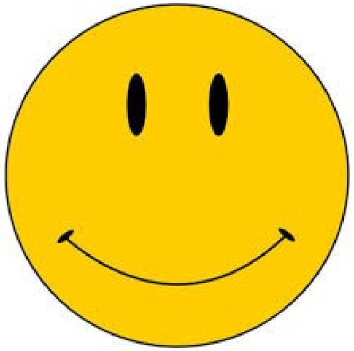
HERMES

Airapetian, A. et al. Phys.Rev. D87 (2013) 074029

COMPASS

Adolph, C. et al. Eur.Phys.J. C73 (2013) 2531

New data $\rightarrow$ Update



New data releases...

HERMES
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Multidimensional data → An opportunity
to explore new things.

Extraction from HERMES data.

Extraction from HERMES data.

About the data:

- Normalized SIDIS data (Multiplicities).
- From Proton and Deuteron.
- Charge separated.
- Hadron separated (Pions and Kaons).
- 3D-binning: Q^2 (x_B) , z , P_T
- Total number of points: 1341

Extraction from HERMES data.

About the data:

- **Normalized SIDIS data (Multiplicities)** → • **Overall normalization.**
- From Proton and Deuteron.
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Signori, Bacchetta, Radici, Schnell
arXiv:1309.3507 [hep-ph] NIKHEF-2013-030

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→

- **The meaning of large Q^2.**
- **Correlations between transverse momenta and other variables.**

Extraction from HERMES data.

Model

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

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

Extraction from HERMES data.

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Kinematical Cuts

$$Q^2 > 1.69 \text{ GeV}^2$$

$$0.2 < P_T < 0.9 \text{ GeV}$$

$$z < 0.6$$

Extraction from HERMES data.

Model

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Kinematical Cuts

$$Q^2 > 1.69 \text{ GeV}^2$$
$$0.2 < P_T < 0.9 \text{ GeV}$$
$$z < 0.6$$

Processes included

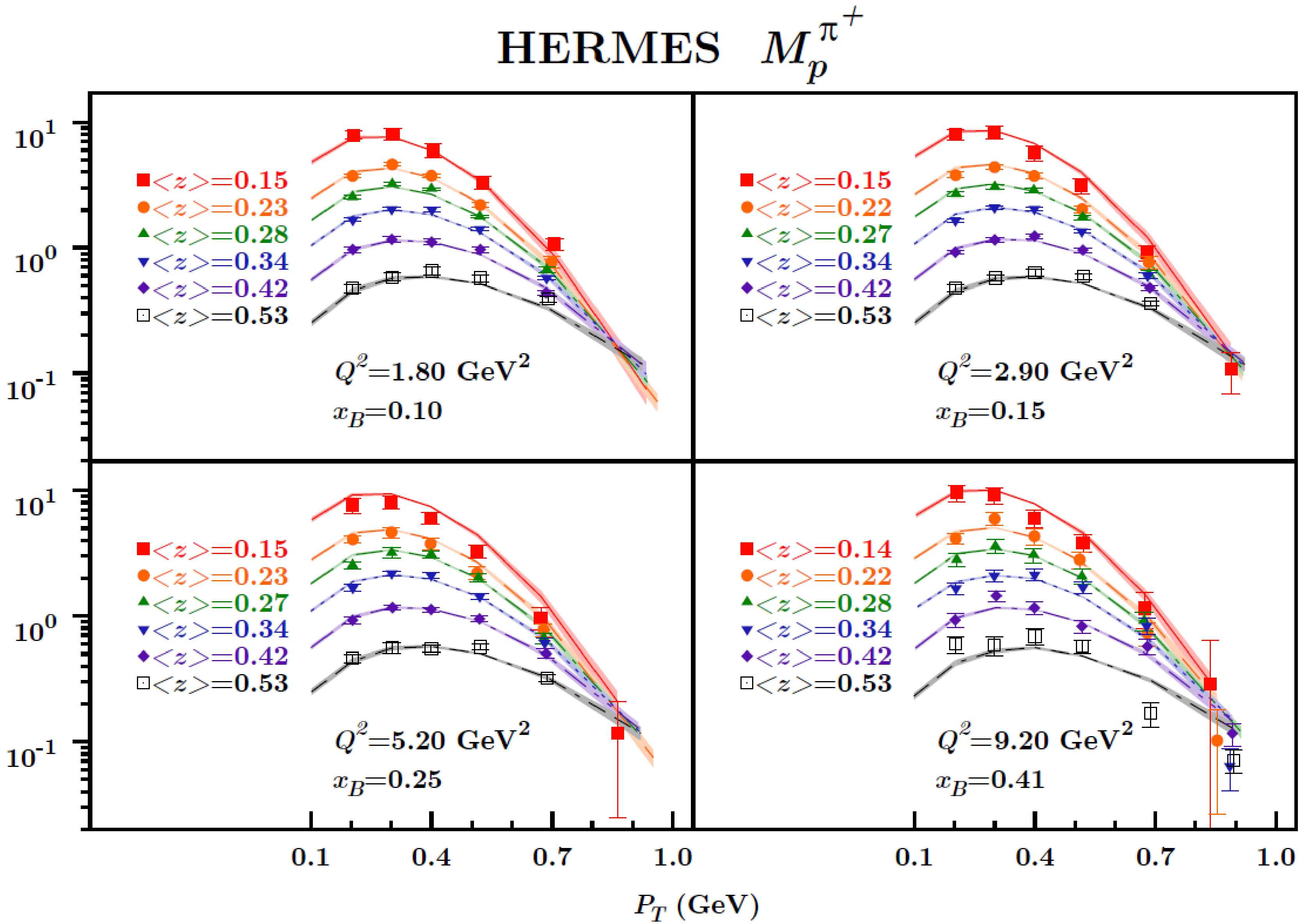
π^+ and π^- production from both

P and D targets

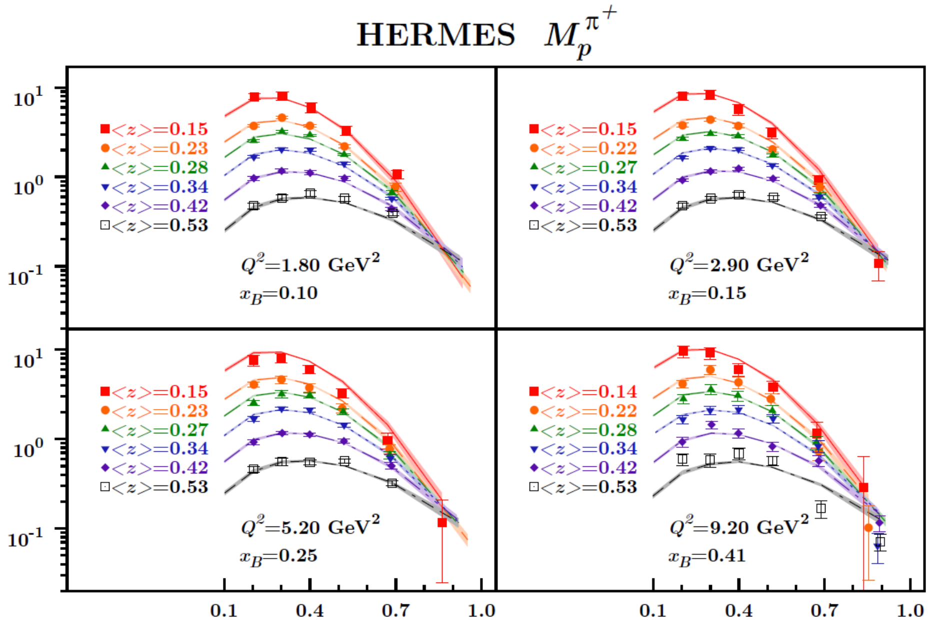
Extraction from HERMES data.

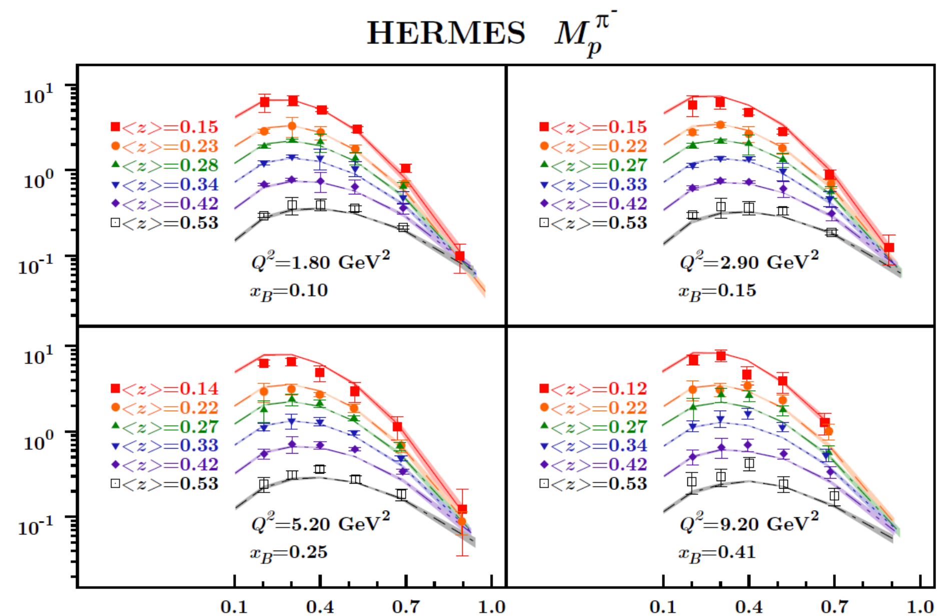
HERMES					
Cuts	χ^2_{pts}	n. points	$[\chi^2_{pts}]^{\pi^+}$	$[\chi^2_{pts}]^{\pi^-}$	Parameters
$Q^2 > 1.69$ GeV^2 $0.2 < P_T < 0.9$ GeV $z < 0.6$	1.69	497	1.93	1.45	$\langle k_\perp^2 \rangle = 0.57 \pm 0.08$ GeV^2 $\langle p_\perp^2 \rangle = 0.12 \pm 0.01$ GeV^2

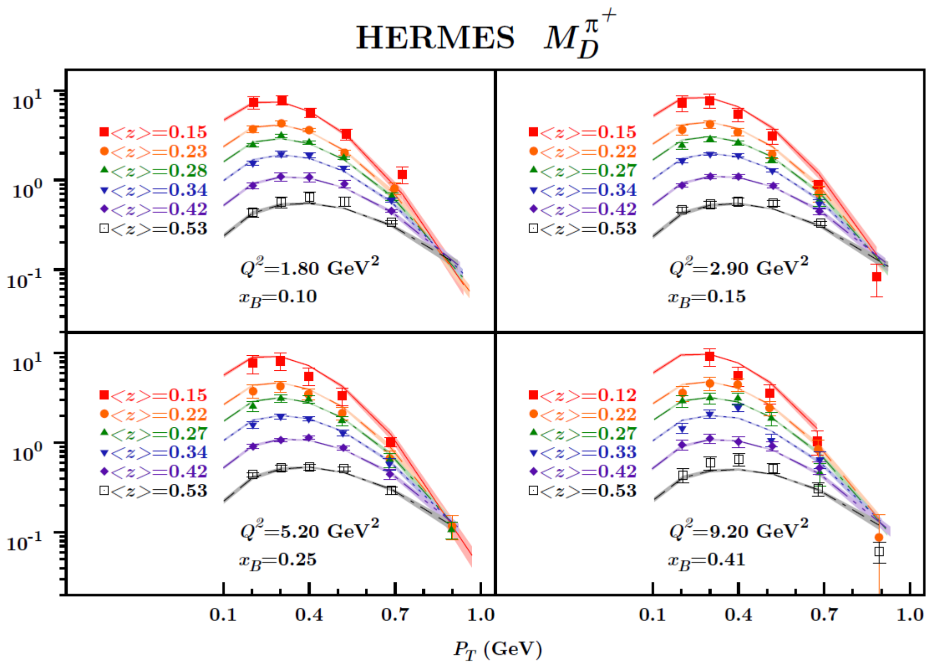
Extraction from HERMES data.

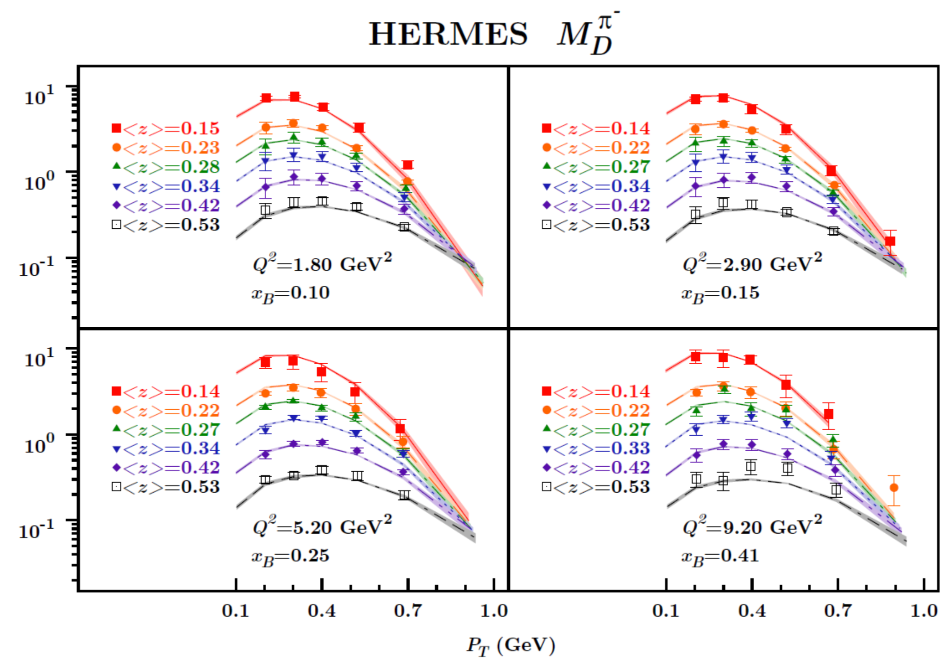


Extraction from HERMES data.





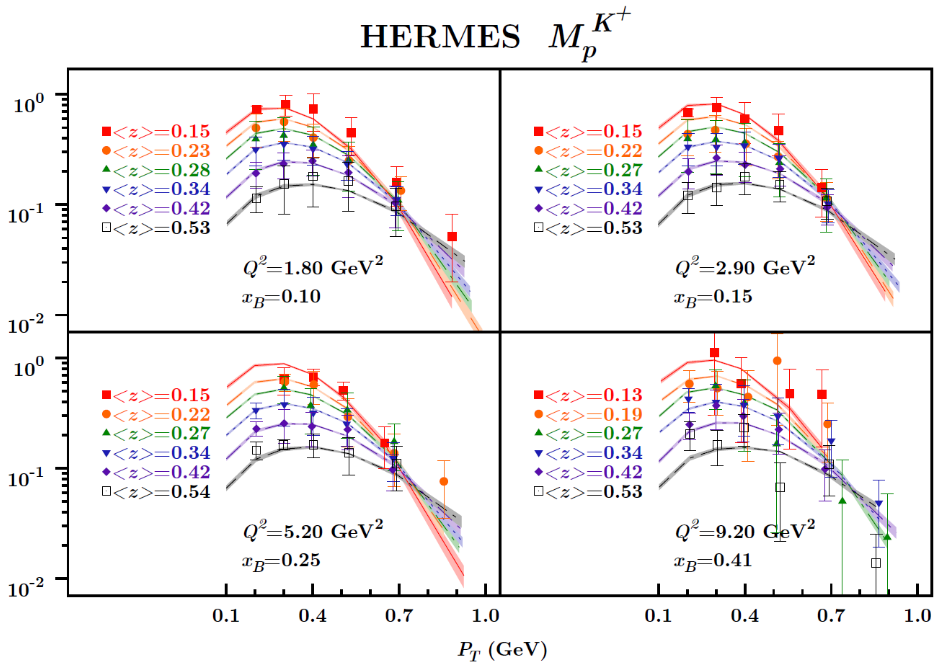


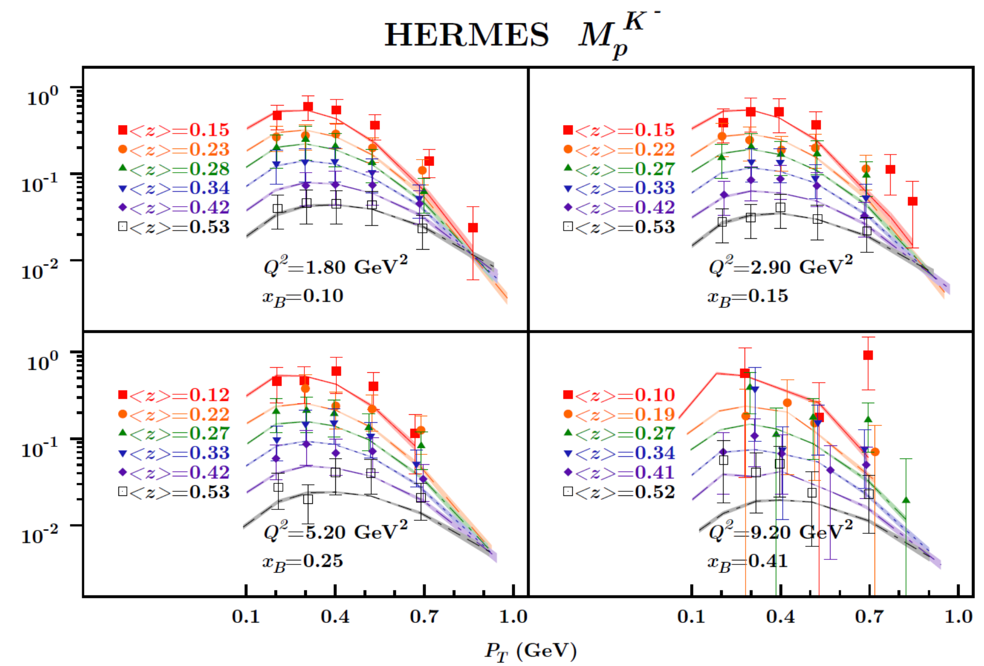


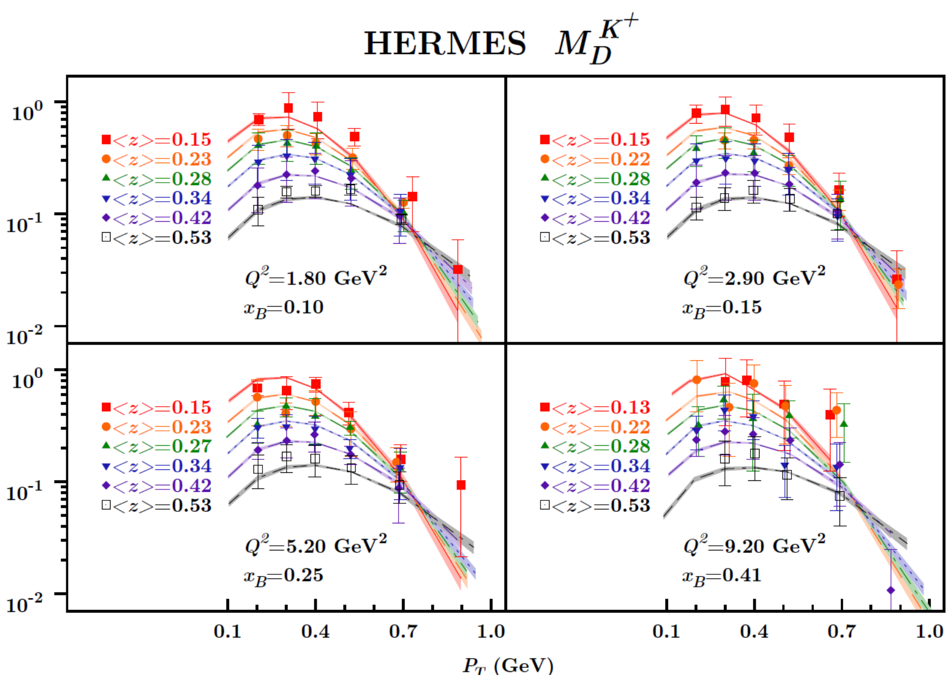
Extraction from HERMES data.

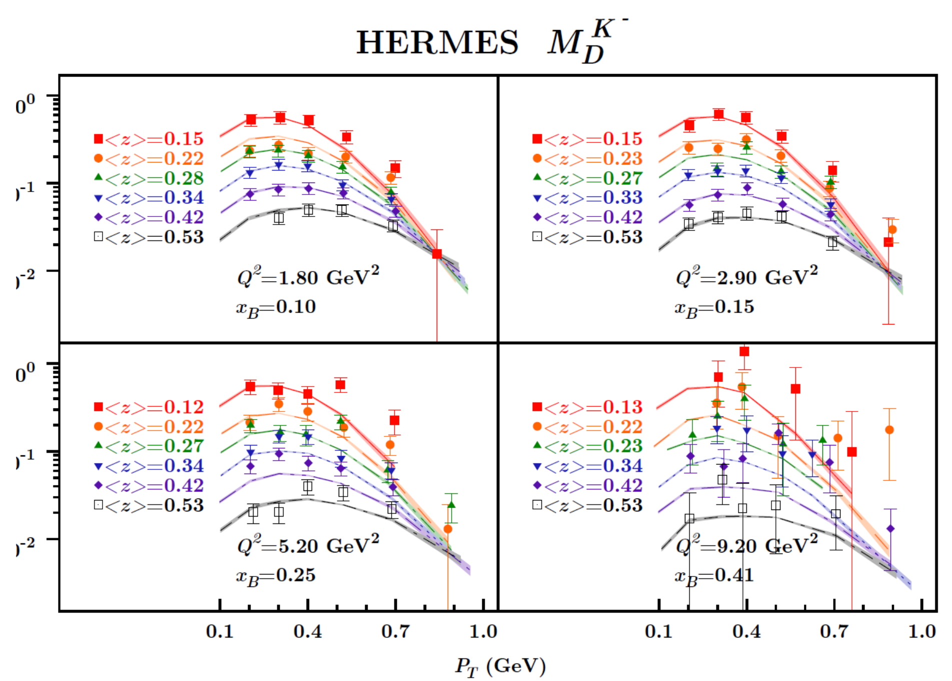
What about Kaons?

K^+ and K^+ production (HERMES)









Kaons in the fit. HERMES data.

π only

$\chi^2_{pt} = 1.69$

$\langle k_\perp^2 \rangle = 0.57 \pm 0.08$ GeV^2

$\langle p_\perp^2 \rangle = 0.12 \pm 0.01$ GeV^2

Kaons in the fit. HERMES data.

π only

$\chi^2_{pt} = 1.69$

$\langle k_\perp^2 \rangle = 0.57 \pm 0.08$ GeV^2

$\langle p_\perp^2 \rangle = 0.12 \pm 0.01$ GeV^2

π and K

$\chi^2_{pt} = 1.25$

$\langle k_\perp^2 \rangle = 0.55 \pm 0.10$ GeV^2

$\langle p_\perp^2 \rangle = 0.13 \pm 0.01$ GeV^2

Kaons in the fit. HERMES data.

π only

$\chi^2_{pt} = 1.69$

$\langle k_\perp^2 \rangle = 0.57 \pm 0.08$ GeV^2

$\langle p_\perp^2 \rangle = 0.12 \pm 0.01$ GeV^2

K only

$\chi^2_{pt} = 0.64$

$\langle k_\perp^2 \rangle = 0.40 \pm 0.17$ GeV^2

$\langle p_\perp^2 \rangle = 0.16 \pm 0.02$ GeV^2

π and K

$\chi^2_{pt} = 1.25$

$\langle k_\perp^2 \rangle = 0.55 \pm 0.10$ GeV^2

$\langle p_\perp^2 \rangle = 0.13 \pm 0.01$ GeV^2

Extraction from COMPASS data.

Extraction from COMPASS data.

HERMES data

- Normalized SIDIS data (Multiplicities).
- From Proton and Deuteron.
- Charge separated.
- Hadron separated (Pions and Kaons).
- 3D-binning: Q^2 (x_B) , z , P_T
- Total number of points: **1341**

COMPASS data

- From Deuteron only.
- No hadron separation.
- 4D-binning: Q^2, x_B , z , P_T
- Total number of points: **18624**

Extraction from COMPASS data.

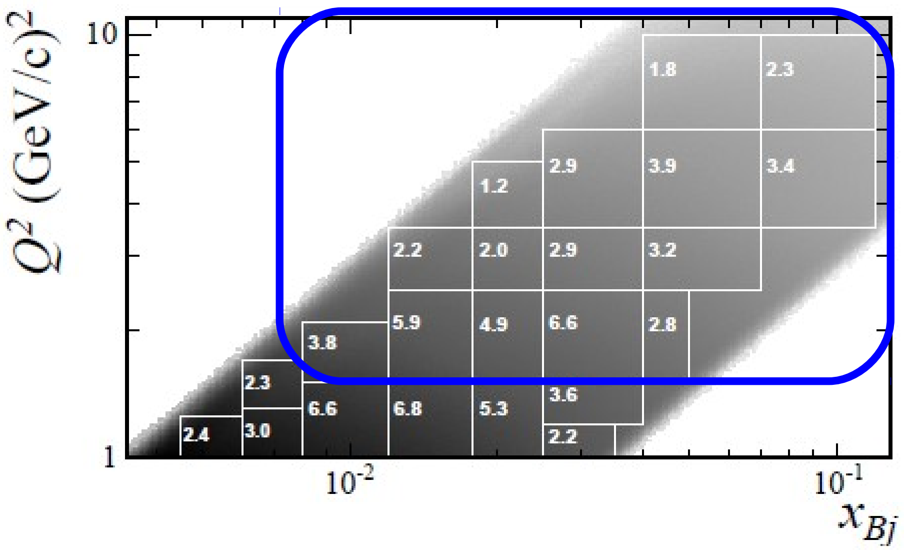


Figure from: Adolph, C. et al. Eur.Phys.J. C73 (2013) 2531

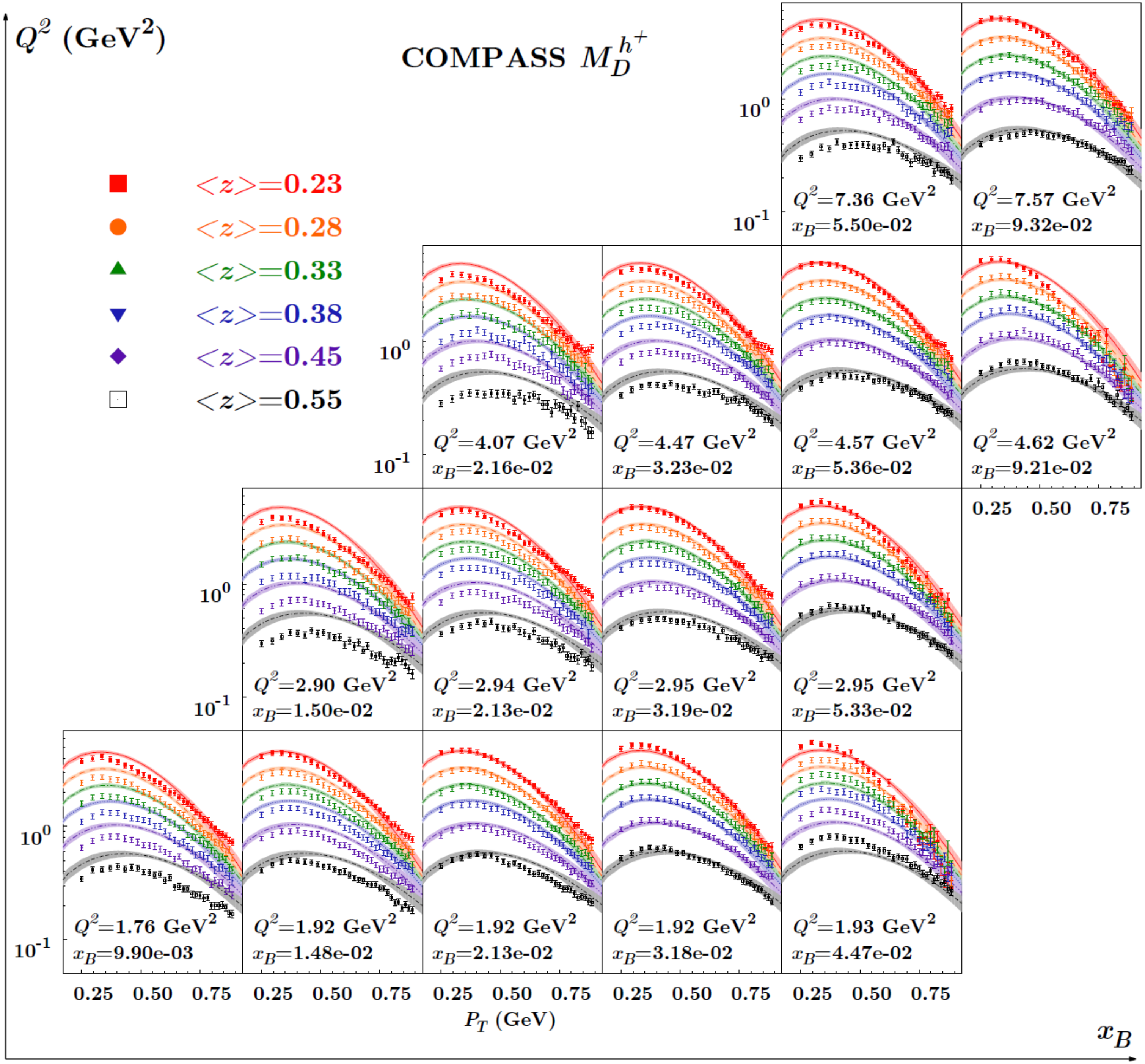
COMPASS data

- From Deuteron only
- No hadron separation
- 4D-binning: Q^2, x_B , z , P_T
- Total number of points: **18624**

Extraction from COMPASS data.

			COMPASS		
Cuts	$\chi^2_{\rm dof}$	n. points	$[\chi^2_{\rm dof}]^{h^+}$	$[\chi^2_{\rm dof}]^{h^-}$	Parameters
$Q^2 > 1.69$ GeV^2 $0.2 < P_T < 0.9$ GeV $z < 0.6$	8.54	5385	8.94	8.15	$\langle k_\perp^2 \rangle = 0.61 \pm 0.20$ GeV^2 $\langle p_\perp^2 \rangle = 0.19 \pm 0.02$ GeV^2

Extraction from COMPASS data.



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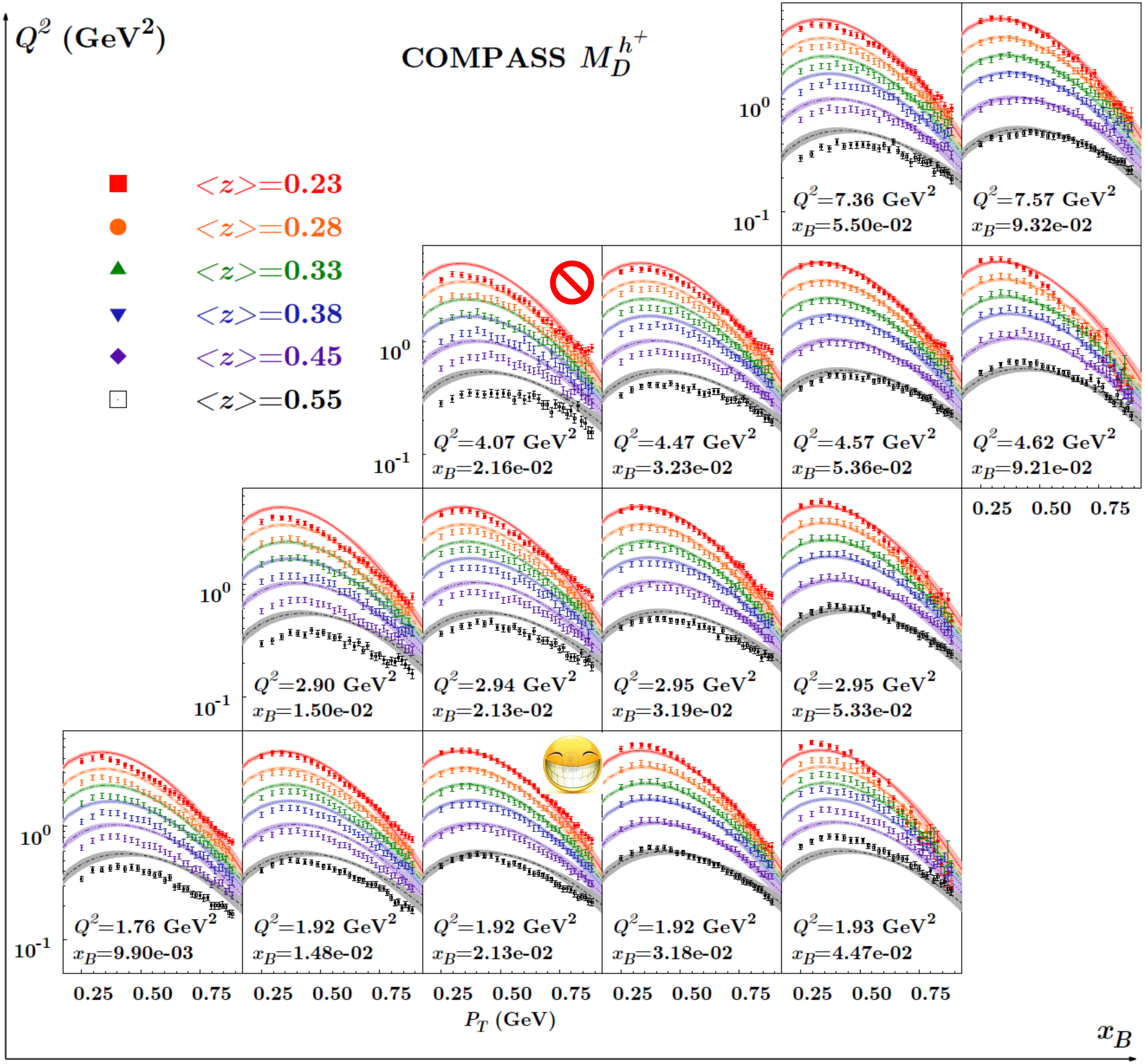

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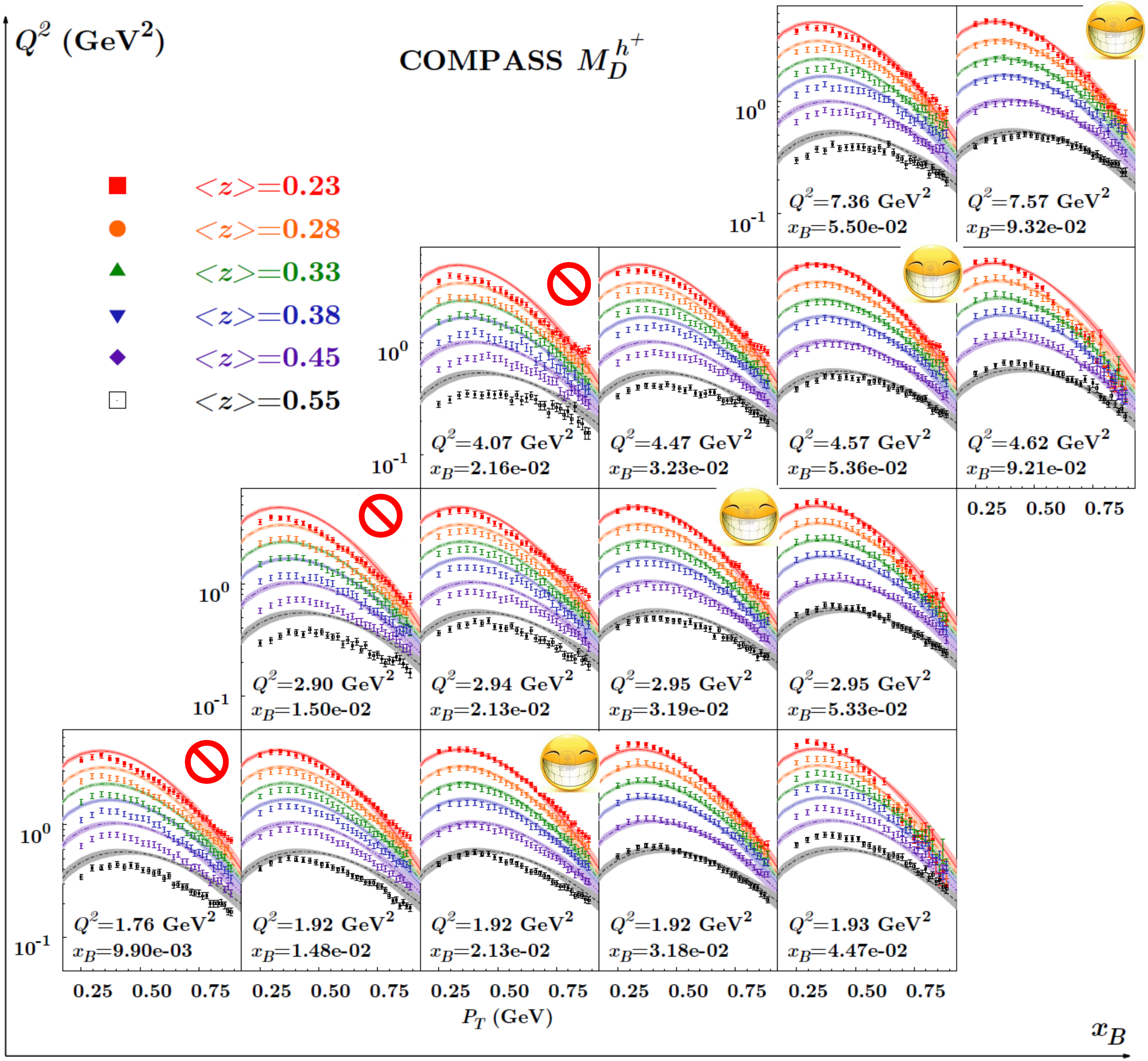

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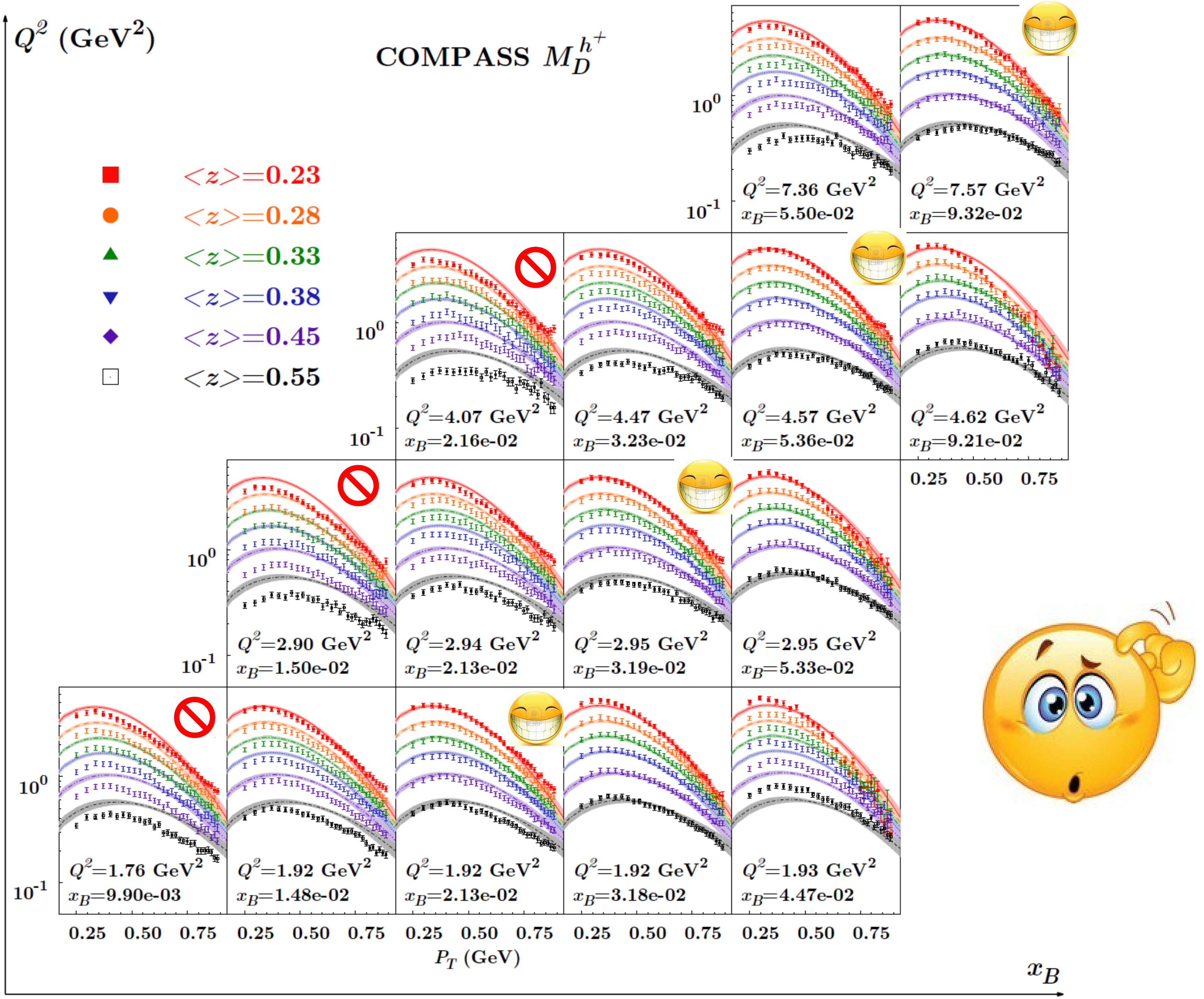
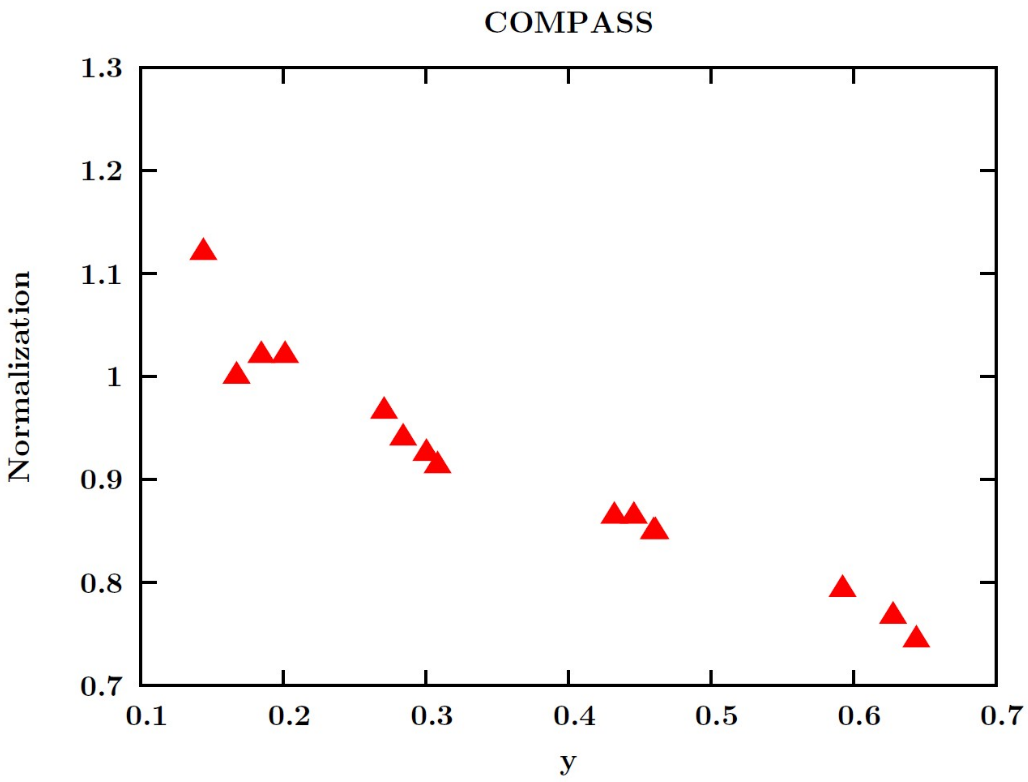


Extraction from COMPASS data.

Fit model one bin in Q^2-x_B at the time, with a free normalization.



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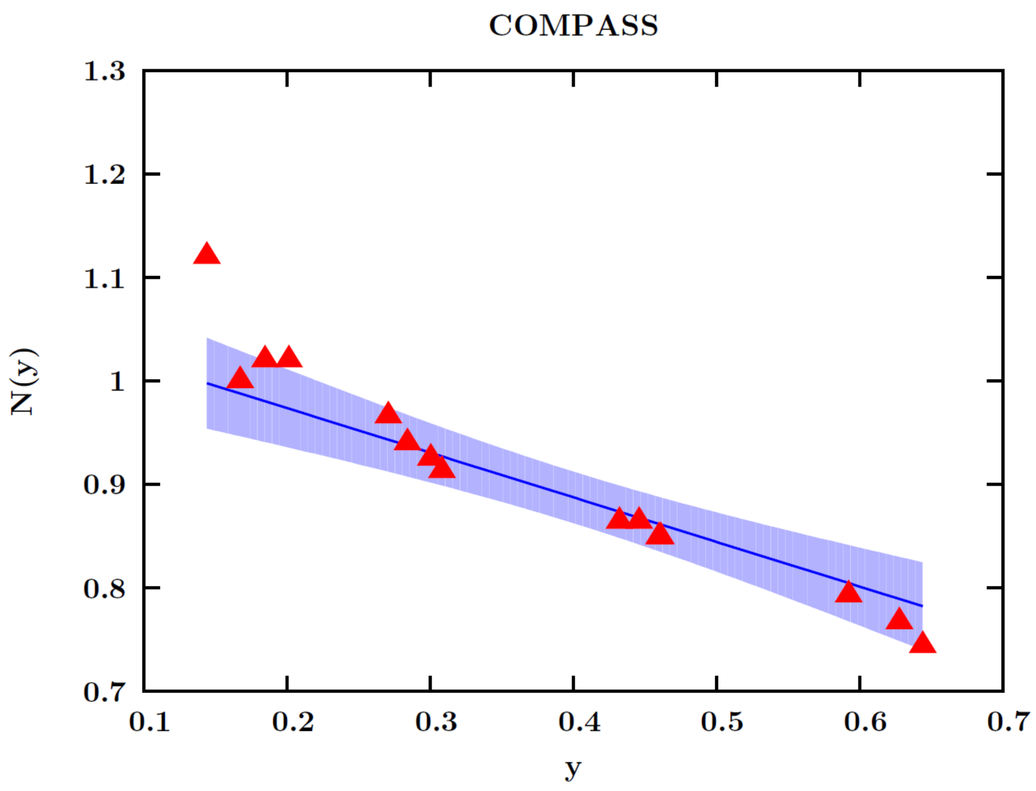
Try a normalization factor

$$N_y = A + B\, y$$

Extraction from COMPASS data.

$$N_y \sim 1 - y/2$$



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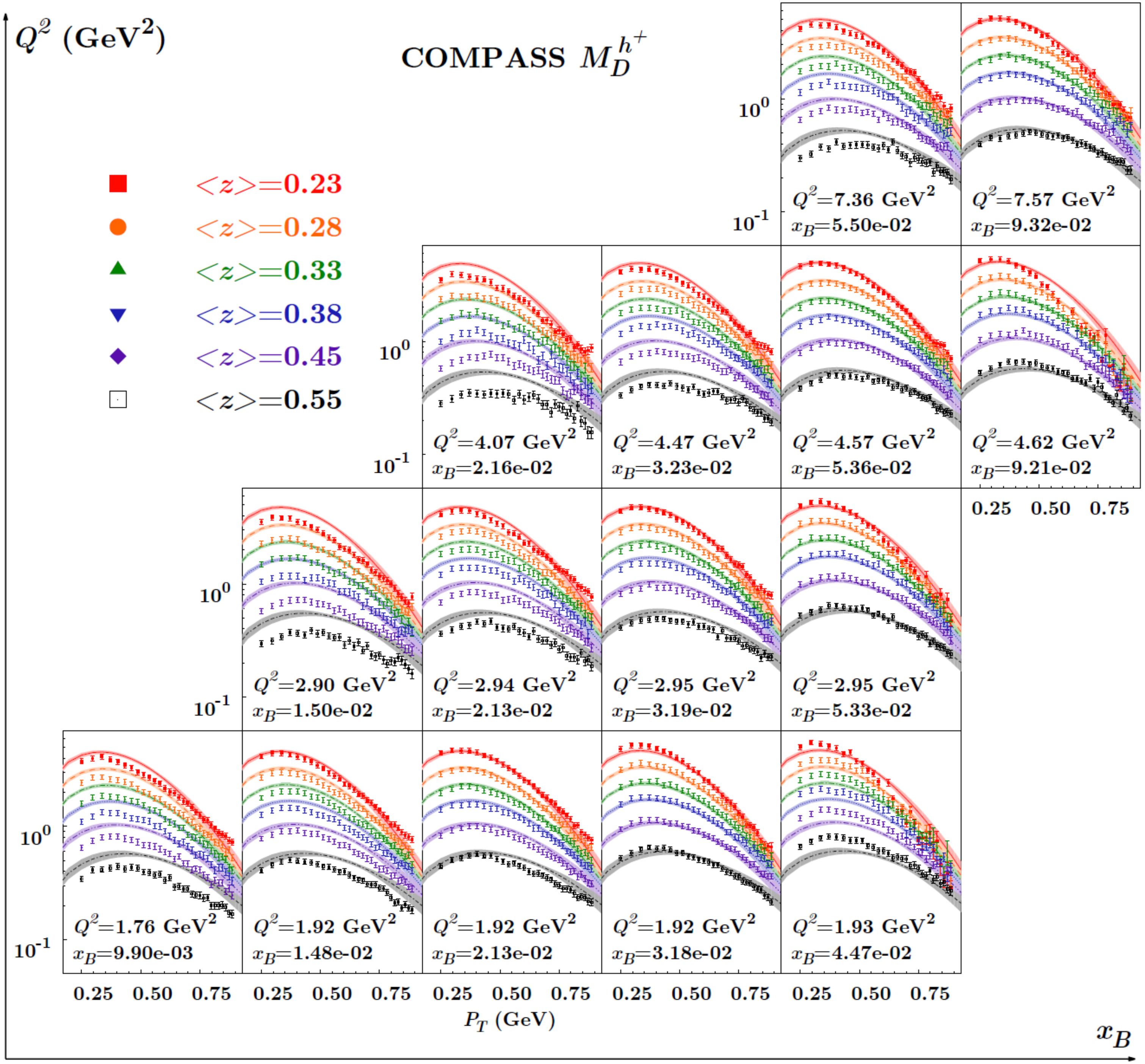
$Q^2 > 1.69$ GeV^2 $0.2 < P_T < 0.9$ GeV $z < 0.6$ $N_y = A + B\,y$	3.42	5385	3.25	3.60	$\langle k_\perp^2 \rangle = 0.60 \pm 0.14$ GeV^2 $\langle p_\perp^2 \rangle = 0.20 \pm 0.02$ GeV^2 $A = 1.06 \pm 0.06$ $B = -0.43 \pm 0.14$

Extraction from COMPASS data.



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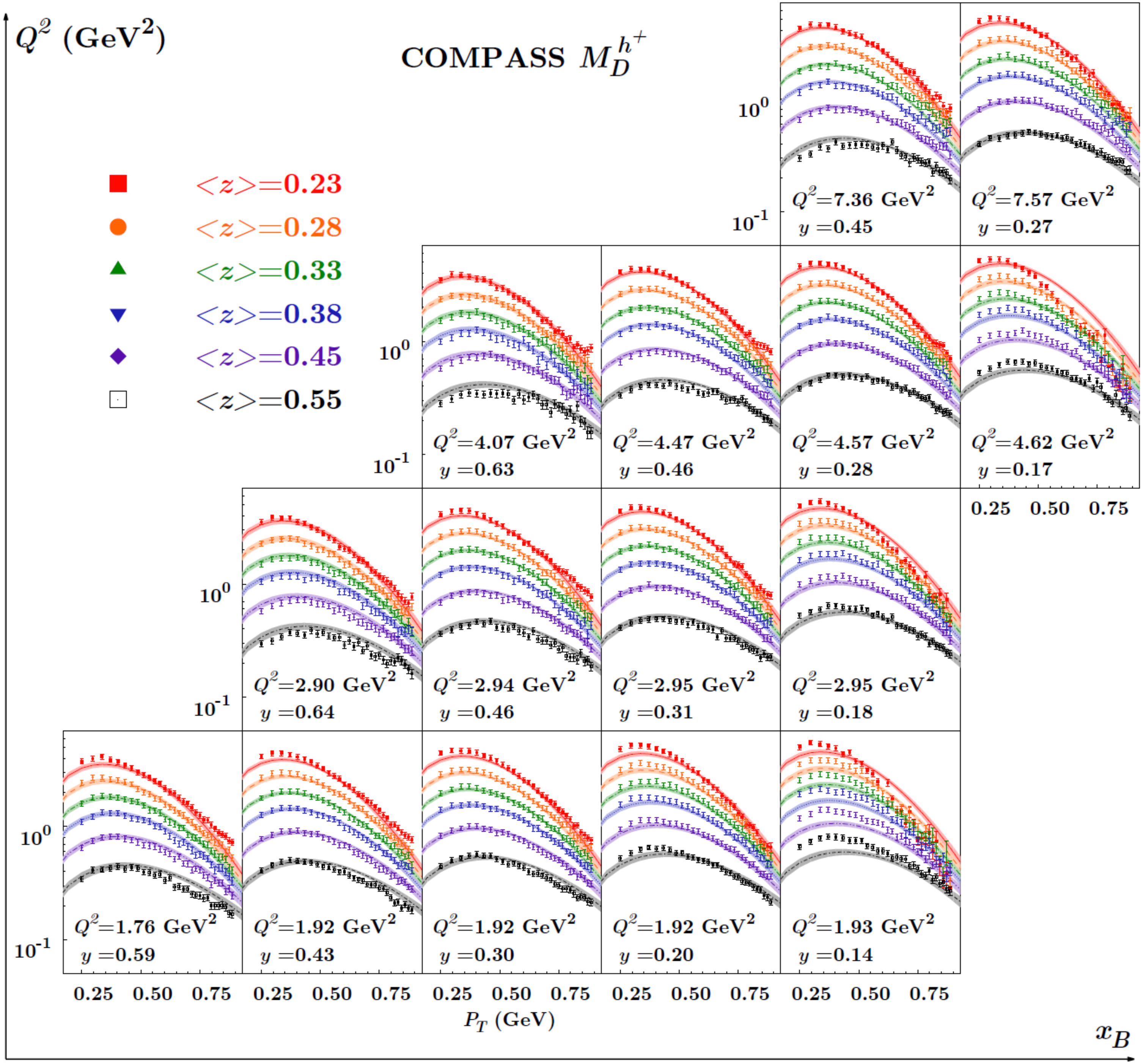

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Additional comments.

Comparing extractions

Extraction from EMC data (2005)

$$\langle k_\perp^2 \rangle = 0.25 \ \mathrm{GeV}^2 \qquad \langle p_\perp^2 \rangle = 0.20 \ \mathrm{GeV}^2$$

Extraction from HERMES data (2013)

$$\langle k_\perp^2 \rangle = 0.57 \pm 0.08 \ \mathrm{GeV}^2 \ , \qquad \langle p_\perp^2 \rangle = 0.124 \pm 0.008 \ \mathrm{GeV}^2$$

Extraction from COMPASS data (2013)

$$\langle k_\perp^2 \rangle = 0.61 \pm 0.20 \ \mathrm{GeV}^2 \qquad \langle p_\perp^2 \rangle = 0.19 \pm 0.02 \ \mathrm{GeV}^2$$

Comparing extractions

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Extraction from COMPASS data (2013)

$$\langle k_\perp^2 \rangle = 0.61 \pm 0.20\ \mathrm{GeV}^2 \qquad \langle p_\perp^2 \rangle = 0.19 \pm 0.02\ \mathrm{GeV}^2$$

In order to compare, one needs to take into account correlations between parameters.

$$\sigma \propto \frac{1}{\pi \langle P_T^2 \rangle} e^{-P_T^2/\langle P_T^2 \rangle}$$

$$\langle P_T^2 \rangle = \langle p_\perp^2 \rangle + z_h^2 \langle k_\perp^2 \rangle .$$

Going back to HERMES data...

z dependence in the Gaussian Model

Other kinematical dependences.

π only, simplest model

$\langle k_\perp^2 \rangle = 0.57 \pm 0.08$ GeV^2

$\langle p_\perp^2 \rangle = 0.12 \pm 0.01$ GeV^2

$\chi^2_{pt} = 1.69$

z dependence?

Other kinematical dependences.

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$\langle k_\perp^2 \rangle = 0.57 \pm 0.08$ GeV^2

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π only, z dependence

$$\langle p_\perp^2 \rangle \rightarrow A\,(1-z)^B\, z^C$$

z dependence?

Other kinematical dependences.

π only, simplest model

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π only, z dependence

$$\langle p_\perp^2 \rangle \to A\,(1-z)^B\, z^C$$

$\langle k_\perp^2 \rangle = 0.48 \pm 0.54$ GeV^2

$A = 0.21 \pm 0.60$ GeV^2

$B = 0.34 \pm 6.42$

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- TMD evolution ?
    - We found no conclusive evidence for evolution in COMPASS data.
    - We found no sign of evolution in HERMES data.

Grazie Mille.

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Flavor Dependence. HERMES.

#pts = 497 chi2pt = 1.60 chi2 = 794.89

#optimal parameters: YES

#TMDPDF version 0 : k2avg = a

#TMDFF version 0 : pt2avg = A

#name	free	val	err	lim	min	max
a	1	5.91e-01	3.79e-02	1	0.00e+00	1.00e+00
b	0	0.00e+00	0.00e+00	0	0.00e+00	1.00e+00
c	1	1.16e-01	4.92e-03	1	0.00e+00	1.00e+00
A	1	1.36e-01	6.35e-03	1	0.00e+00	1.00e+00

Flavor Dependence. COMPASS.

#pts = 5385 chi2pt = 3.42 chi2 = 18436.98

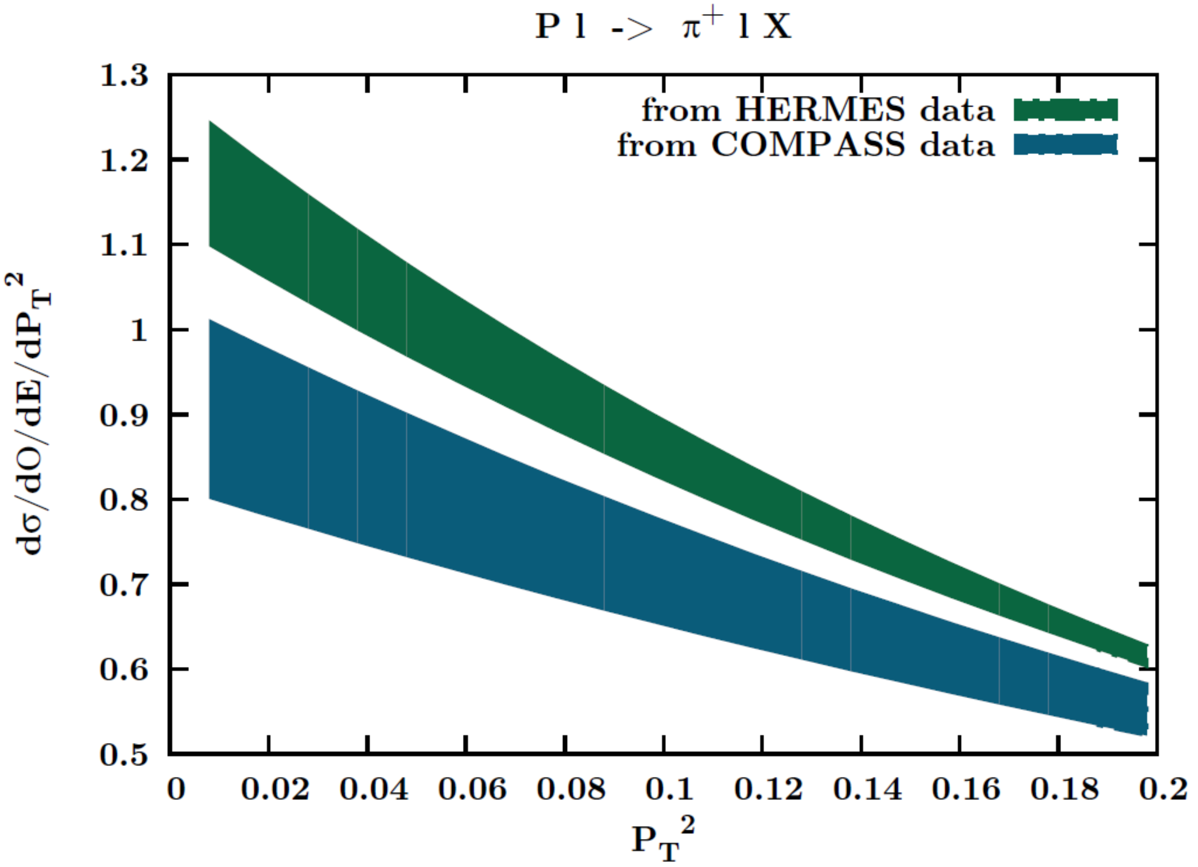
#optimal parameters: YES

#TMDPDF version 0 : k2avg = a

#TMDFF version 0 : pt2avg = A

#name	free	val	err	lim	min	max
a	1	6.04e-01	1.68e-02	1	0.00e+00	1.00e+00
b	0	0.00e+00	0.00e+00	0	0.00e+00	1.00e+02
c	1	1.98e-01	4.31e-03	1	0.00e+00	1.00e+00
A	1	2.02e-01	5.40e-03	1	0.00e+00	1.00e+00

Jlab Kinematics. 2013 extractions.



Jlab SIDIS data (2012).