Monte Carlo for TMD's

Mher Aghasyan

LNF INFN
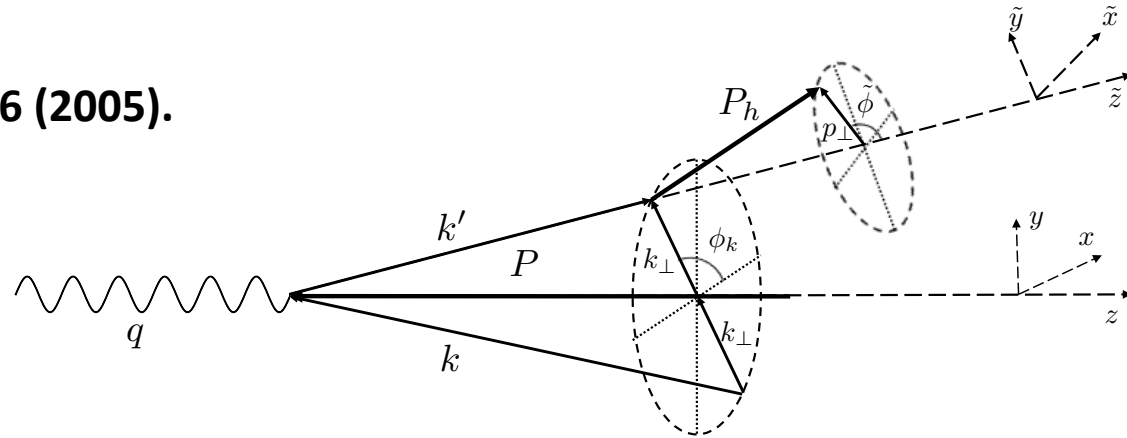
12 November 2013

Outline

- Fully differential MC
  - Old single hadron only
  - Multi-hadron production model
- Results
- Summary and outlook

Model for fully differential SIDIS dedicated MC

Anselmino: PRD 71, 074006 (2005).

Quark intrinsic motion with Torino model: $M_p \neq 0$ $x_{LC} = k^-/P^-$
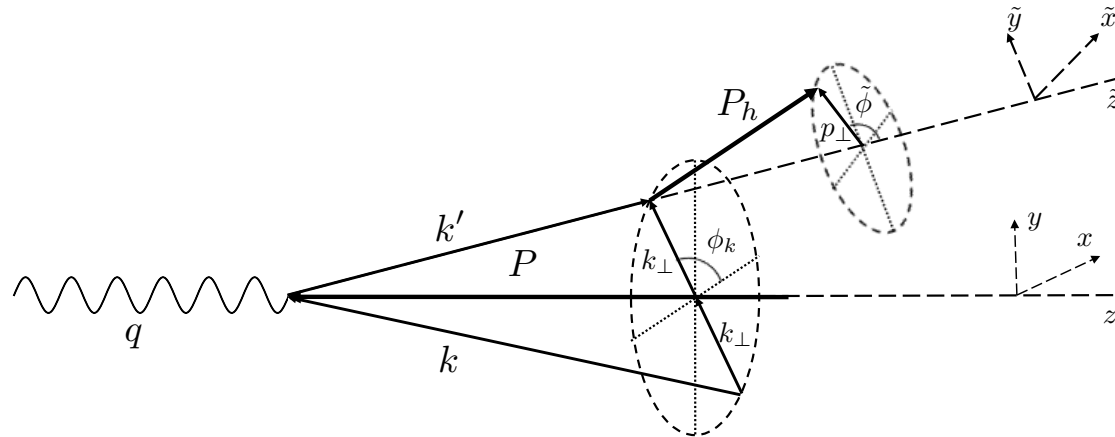
Quark inside the proton have the momentum:

$$k = \left(x_{LC}P' + \frac{k_\perp^2}{4x_{LC}P'}, \mathbf{k}_\perp, -x_{LC}P' + \frac{k_\perp^2}{4x_{LC}P'} \right)$$

$$x_{LC} = \frac{x}{x_N}\left(1 + \sqrt{1 + \frac{4k_\perp^2}{Q^2}} \right), \quad x_N = 1 + \sqrt{1 + \frac{4M_p^2 x^2}{Q^2}},$$

Where $P' = 0.5(E_p + |P_{pz}|)$ is the proton energy with non zero proton mass.

Thanks to: M. Anselmino, U. D'Alesio, S. Melis, A. Kotzinian

Fragmentation

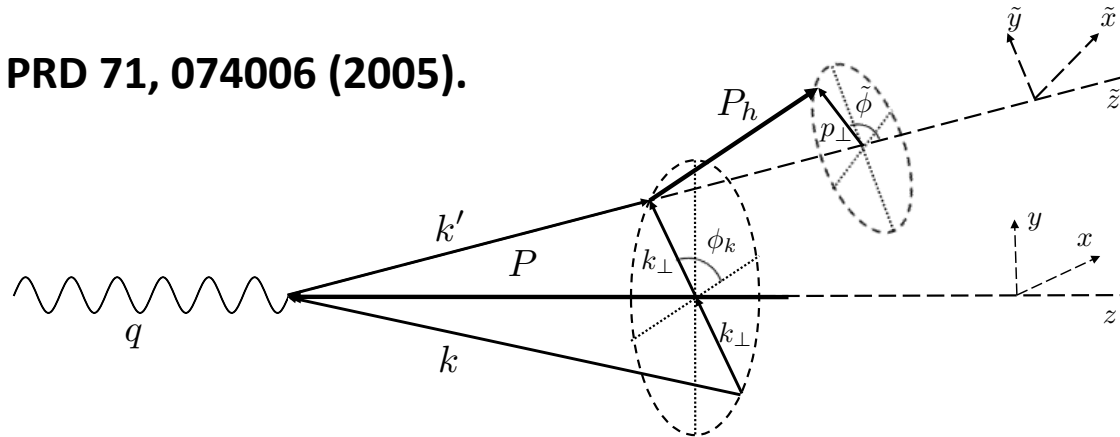Scattered quark 4 momentum calculated: $\qquad k' = k + q$

Final hadron generated with the momentum:

$$P_{\tilde{x},h} = p_\perp \cos(\tilde{\phi}) \qquad\qquad P_{\tilde{y},h} = p_\perp \sin(\tilde{\phi}) \qquad\qquad P_{\tilde{z},h} = z_{LC} E_{k'} - \frac{p_\perp^2 + M_h^2}{4 z_{LC} E_{k'}}$$

To account and understand all the assumptions, integrations, correlations and more, fully differential SIDIS cross-section should be studied.

Cahn effect in MC

Anselmino: PRD 71, 074006 (2005).

$$\frac{d\sigma}{dxdydzd^2\mathbf{p}_\perp d^2\mathbf{k}_\perp} = K(x,y)J(x,Q^2,k_\perp)\sum_q f_{1,q}(x,k_\perp)D_{1,q}(z,p_\perp)\frac{\hat{s}^2+\hat{u}^2}{Q^4}$$

$$\hat{s} = (l+k)^2$$

$$\hat{u} = (k-l')^2$$

Cahn effect implemented according to Anselmino: PRD 71, 074006 (2005).

Requirements for MC
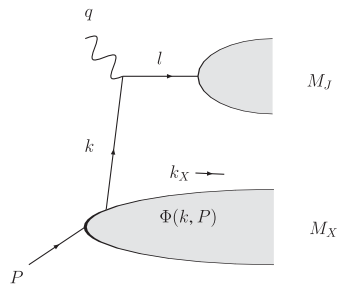
Collins,Rogers,Staśto:PRD77,085009,2009

FIG. 2. The amplitude for $\gamma^* p$ scattering into two jets with fixed masses.

- The kinematics of the initial and final states must be kept exact.
- The sums over physical final states must be kept explicit.
- To avoid making kinematical approximations in the initial and final states, the factors need to be function of all components of parton four-momentum.
- The hard-scattering matrix element should appear as <u>on-shell</u> parton matrix element in the final factorization formula.

Model for multi-hadron production

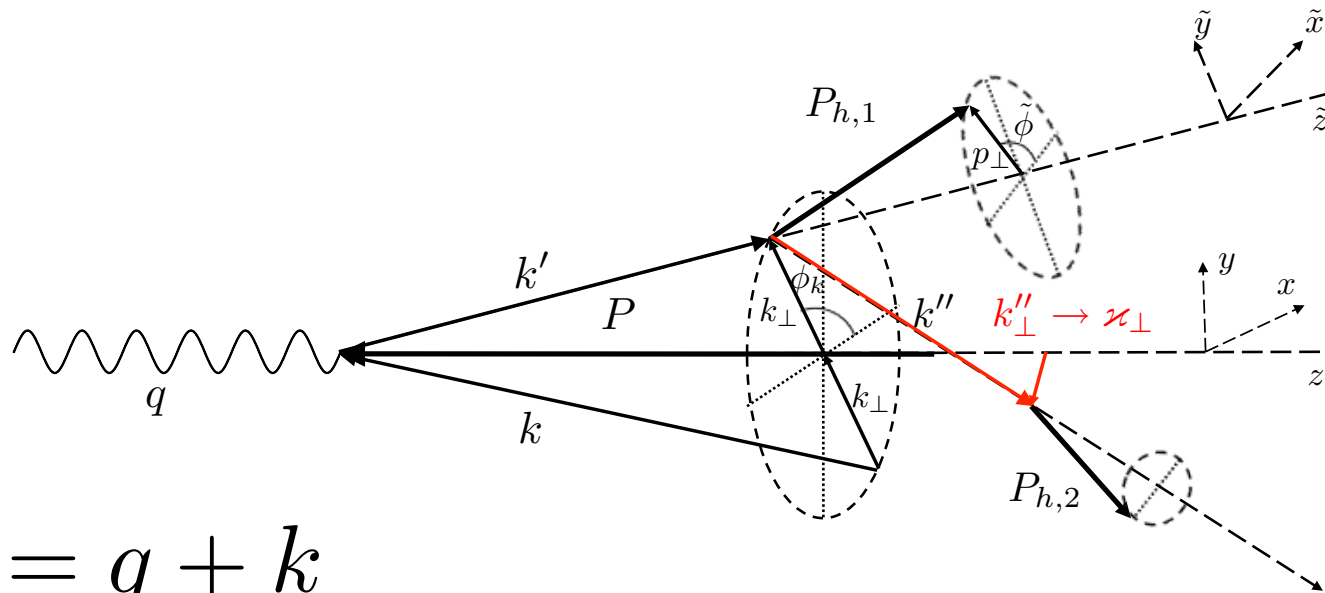**Collins,Rogers,Staśto:PRD77,085009,2009**
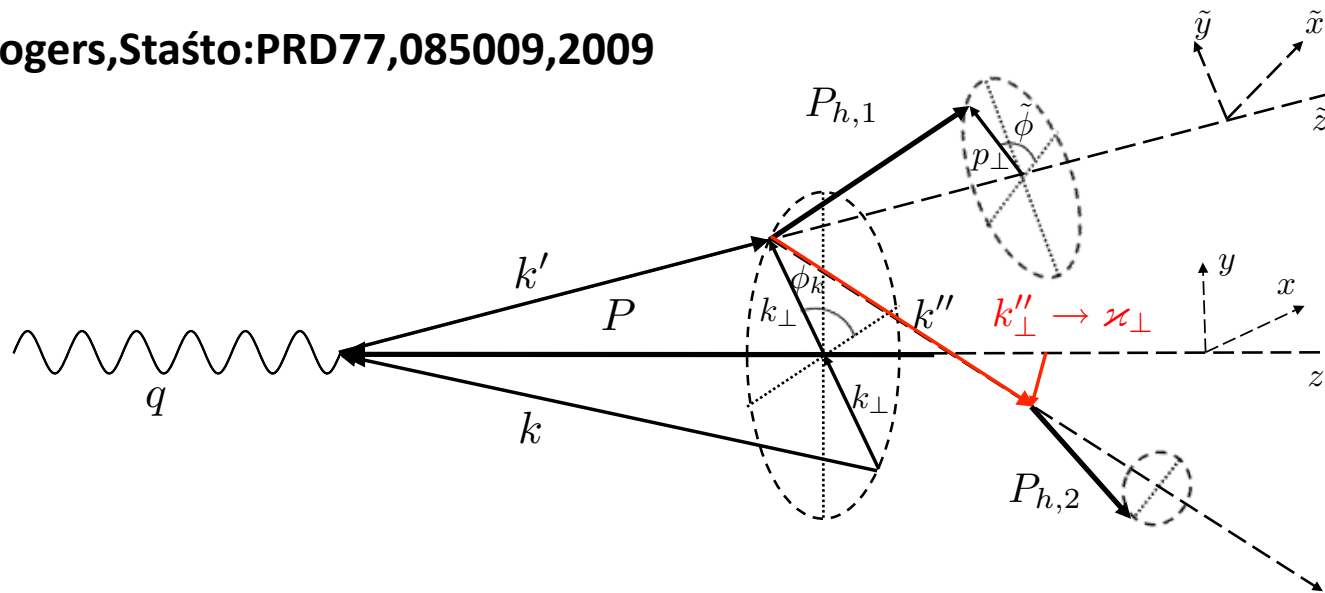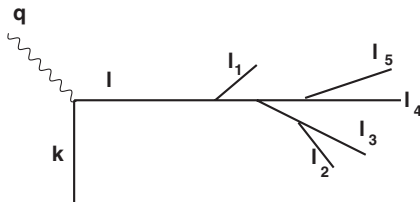
$$k' = q + k$$
$$k'' = k' - P_{h,1}$$

Four momenta conservation at each vertex.

Model for multi-hadron production

$$k' = q + k$$
$$k'' = k' - P_{h,1}$$
$$k''' = k'' - P_{h,2}$$

Change of notation for convenience $\quad k''_\perp \to \varkappa_\perp$
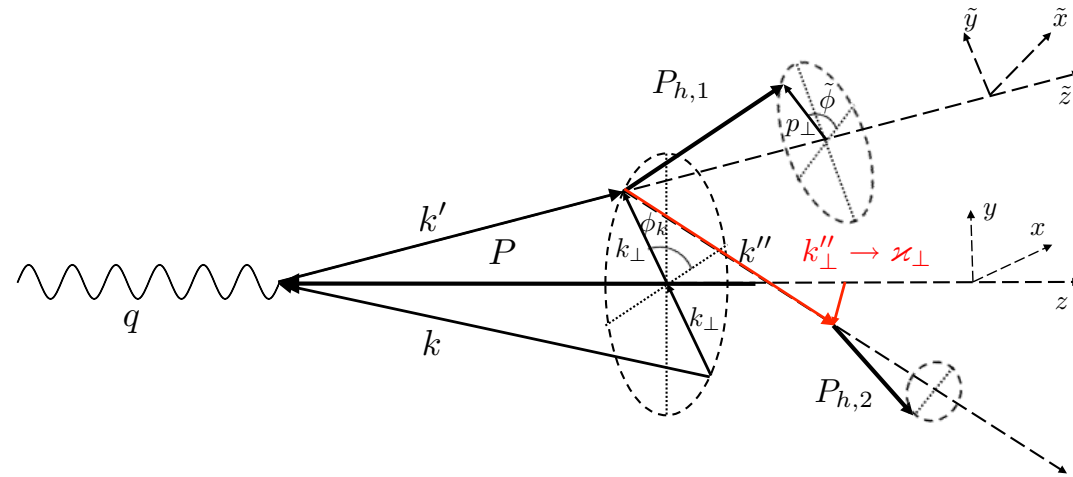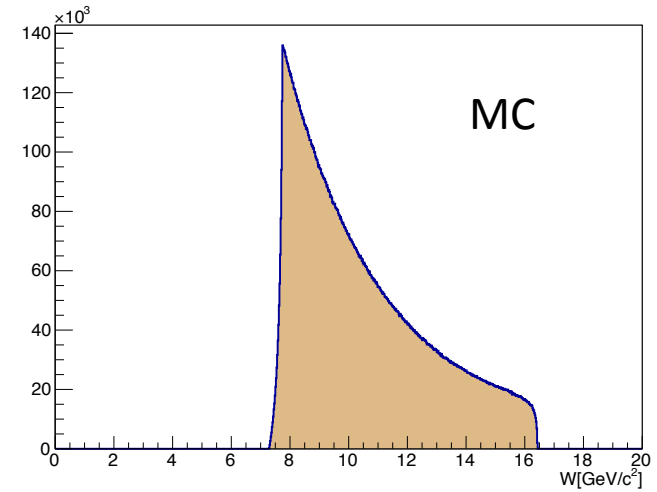
Inputs for MC

Collinear FFs: <u>DSS or HKNS</u>

Gaussian with:

$$\langle p_\perp^2 \rangle_q = C_q \times z \cdot (1-z)^{0.9}$$

Collinear PDFs: MSTW
Gaussian with:

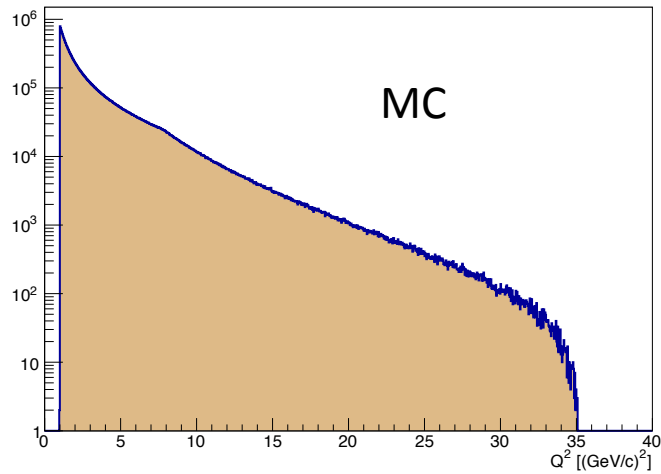$$\langle k_\perp^2 \rangle_q = D_q \times (0.01 + x)^{0.9} \cdot (1-x)^{6.}$$
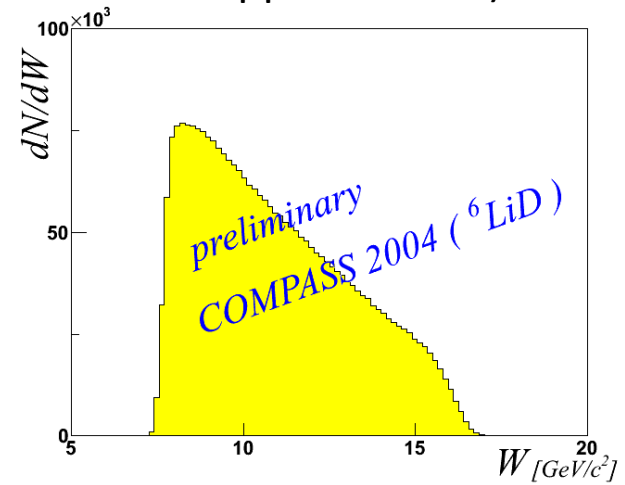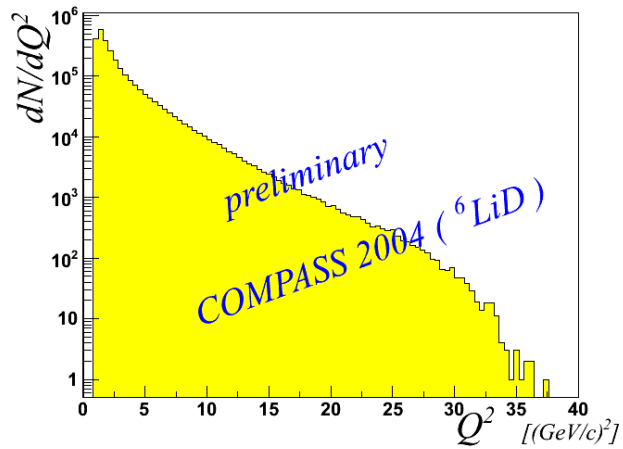
$$k' = q + k$$

$$k'' = k' - P_{h,1}$$

$$k''' = k'' - P_{h,2}$$

Unfavored FF and $k_\perp'' \to \varkappa_\perp$ is being calculated from four-momenta conservation.
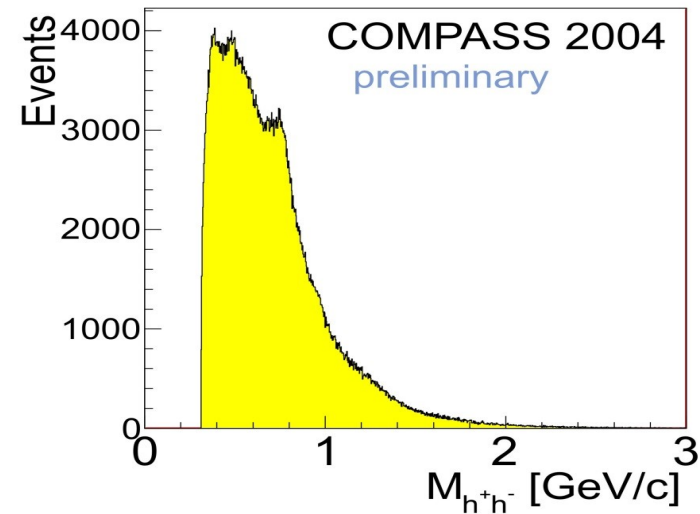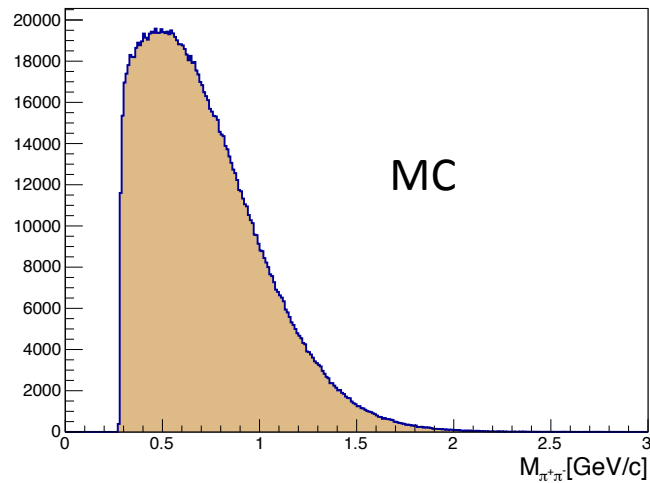
Outcome of MC at 160 GeV

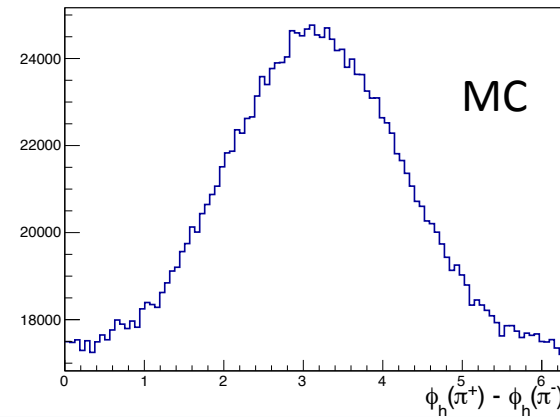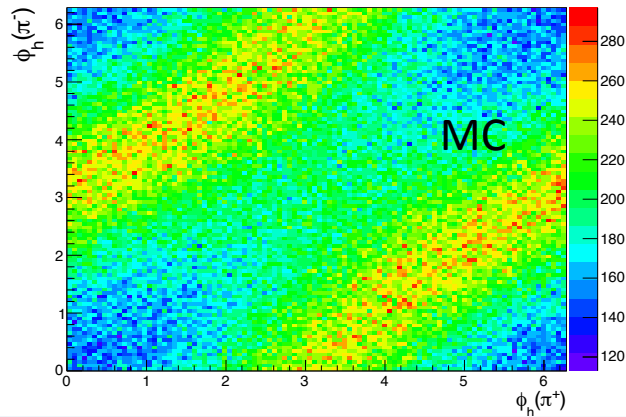Nice agreement (COMPASS acceptance is not applied to MC)

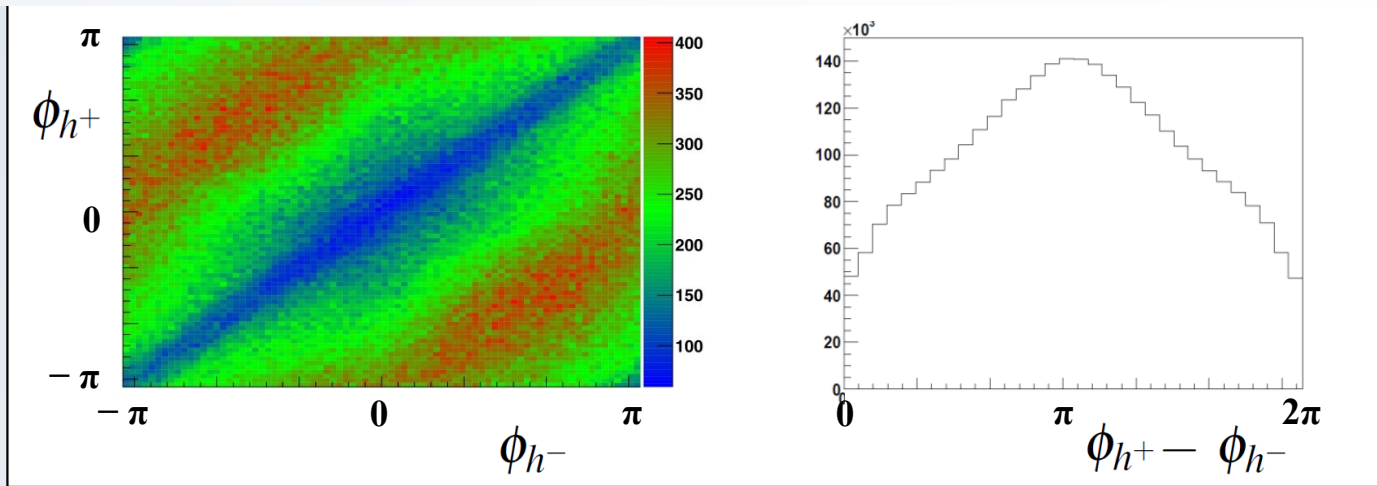# Outcome of MC at 160 GeV

From A.Martin presentation at Como.

Vector meson production in MC is not included yet!
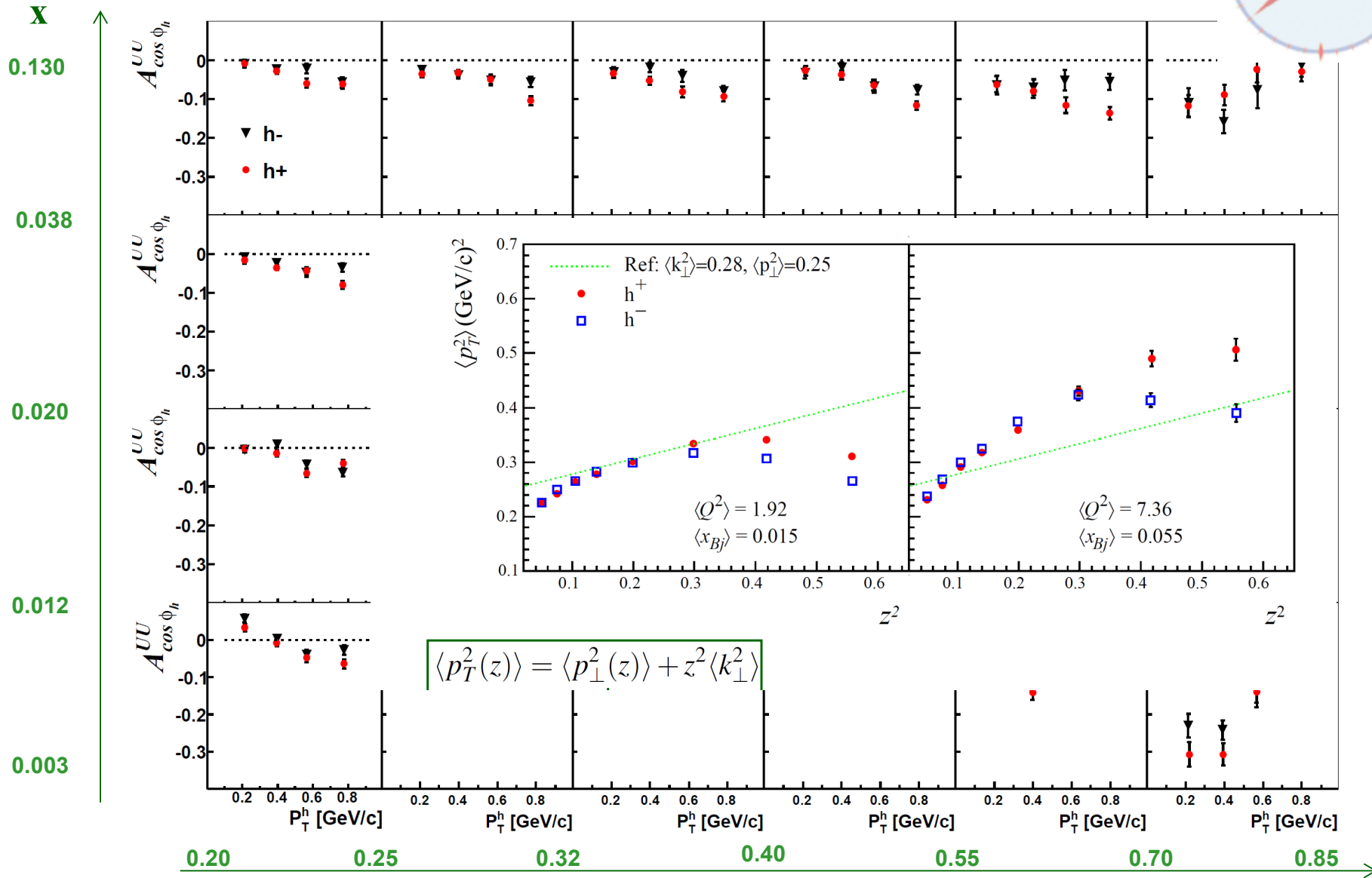
Outcome of MC at 160 GeV

MC

MC

Reasonable agreement even w/o COMPASS acceptance.

azimuthal asymmetries - cos ϕ

COMPASS ^{6}LiD (25% of 2004 data)   preliminary

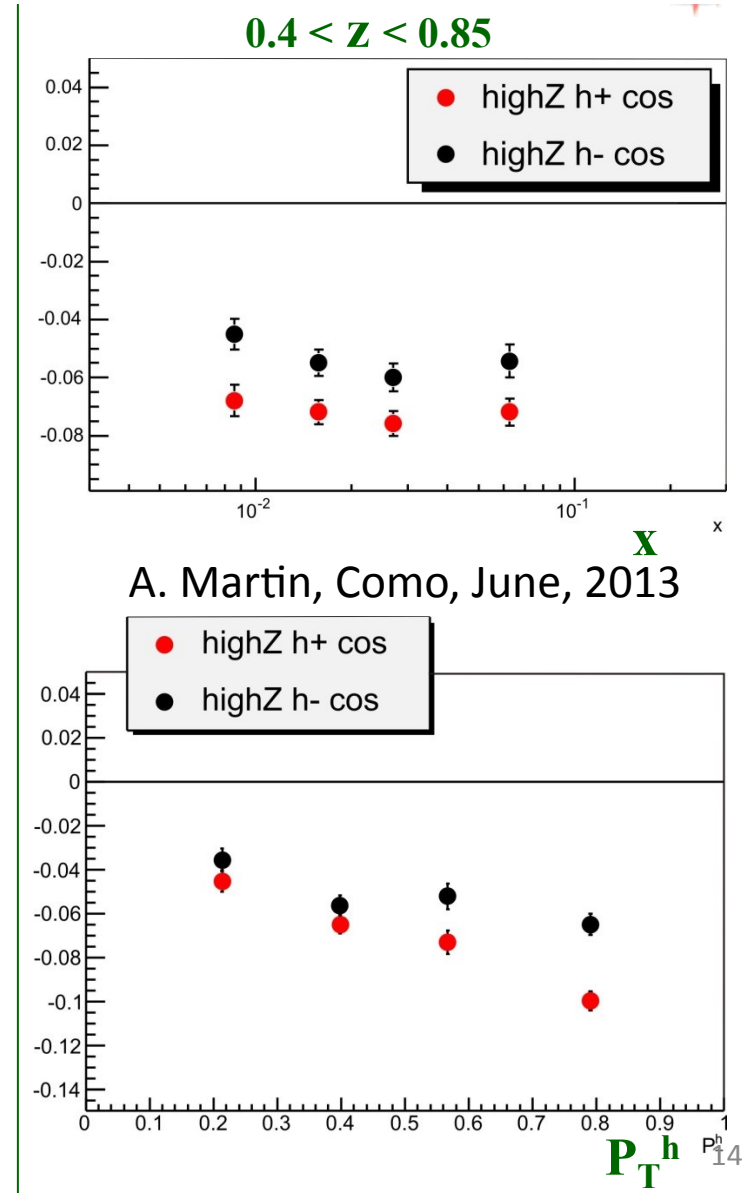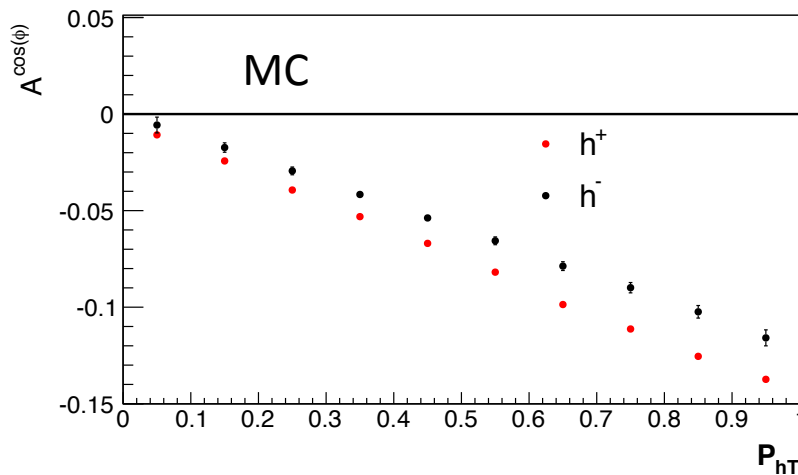$$\langle p_T^2(z) \rangle = \langle p_\perp^2(z) \rangle + z^2 \langle k_\perp^2 \rangle$$

Ref: $\langle k_\perp^2 \rangle = 0.28$, $\langle p_\perp^2 \rangle = 0.25$

$\langle Q^2 \rangle = 1.92$
$\langle x_{Bj} \rangle = 0.015$

$\langle Q^2 \rangle = 7.36$
$\langle x_{Bj} \rangle = 0.055$

Cahn effect from MC and $A^{\cos\phi}$ from Data

MC
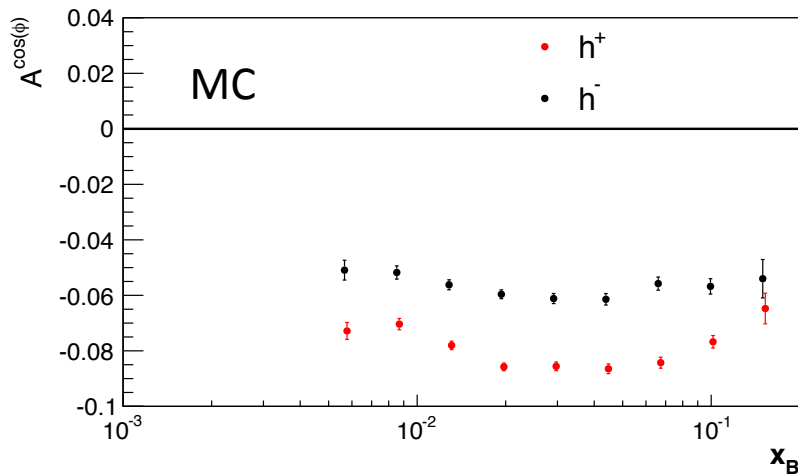
Reasonable agreement at high z

$0.4 < z < 0.85$

A. Martin, Como, June, 2013
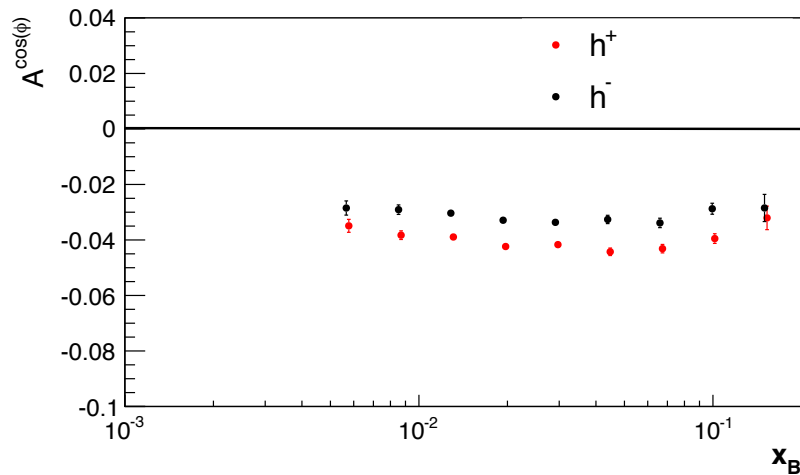
Cahn effect from MC and $A^{\cos\phi}$ from Data
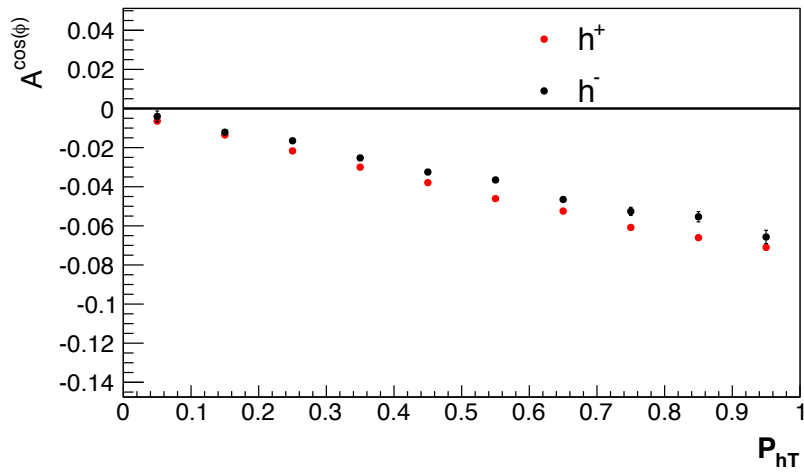
With current model I can not describe low z

A. Martin, Como, June, 2013
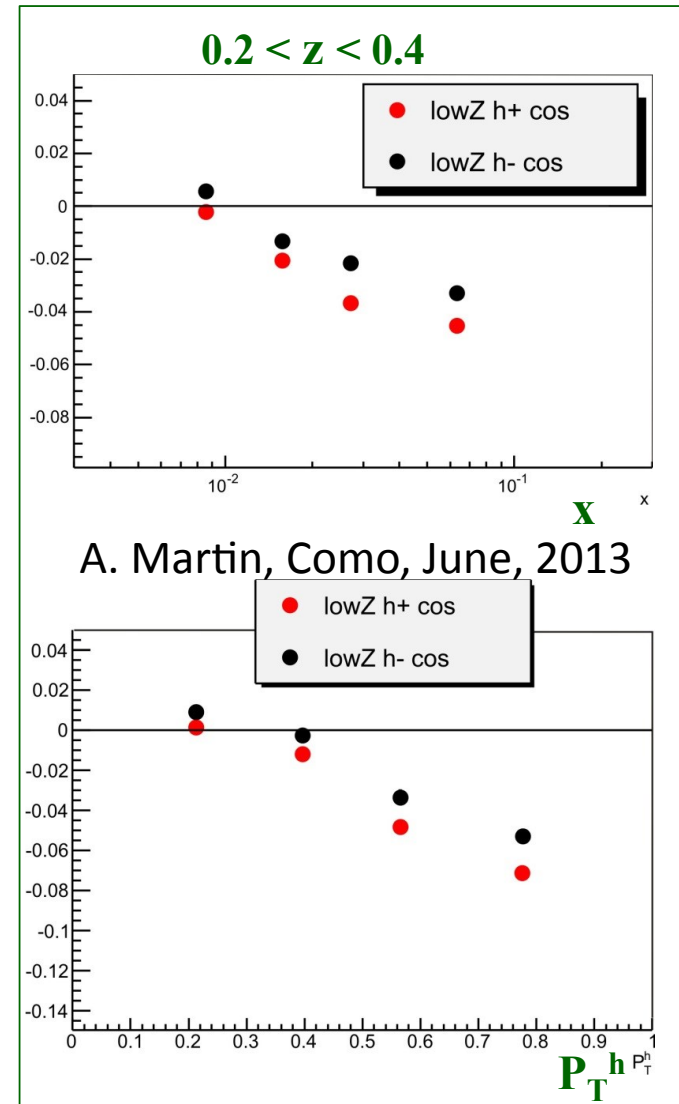
MC vs COMPASS average transverse widths

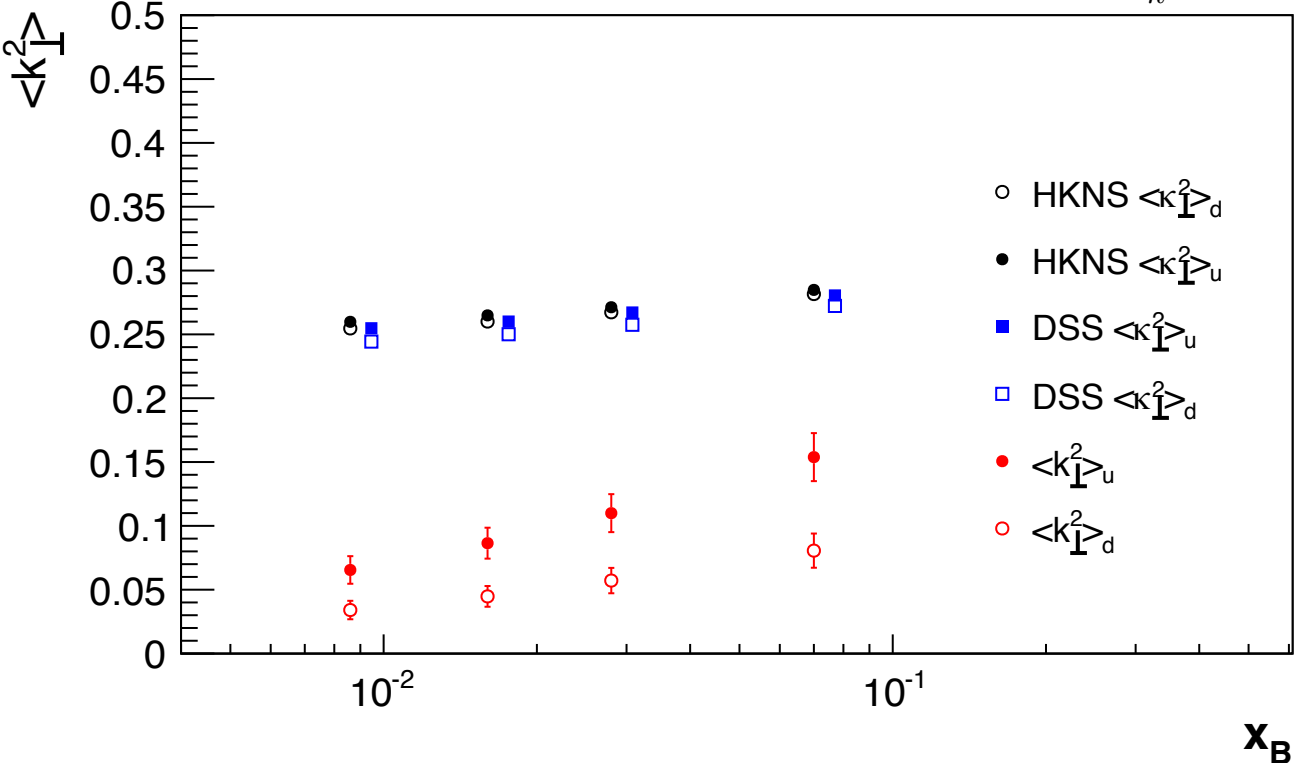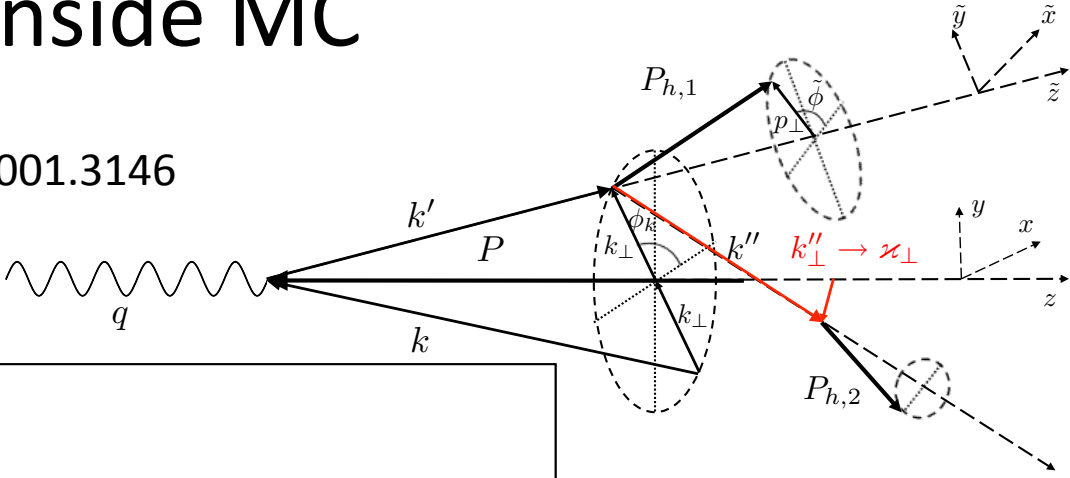$$\langle x_B \rangle = 0.0213, \langle Q^2 \rangle = 1.23 (GeV/c)^2$$
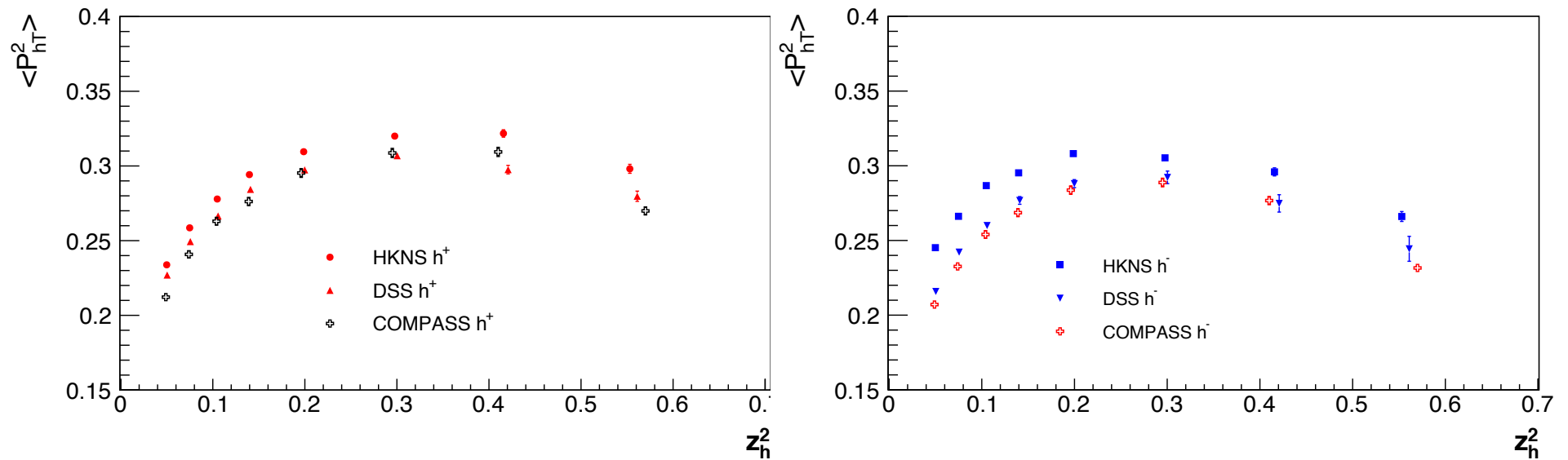
$$\langle p_\perp^2 \rangle_q = C_q \times z \cdot (1-z)^{0.9}$$

For fixed input transverse widths in FF and DF:
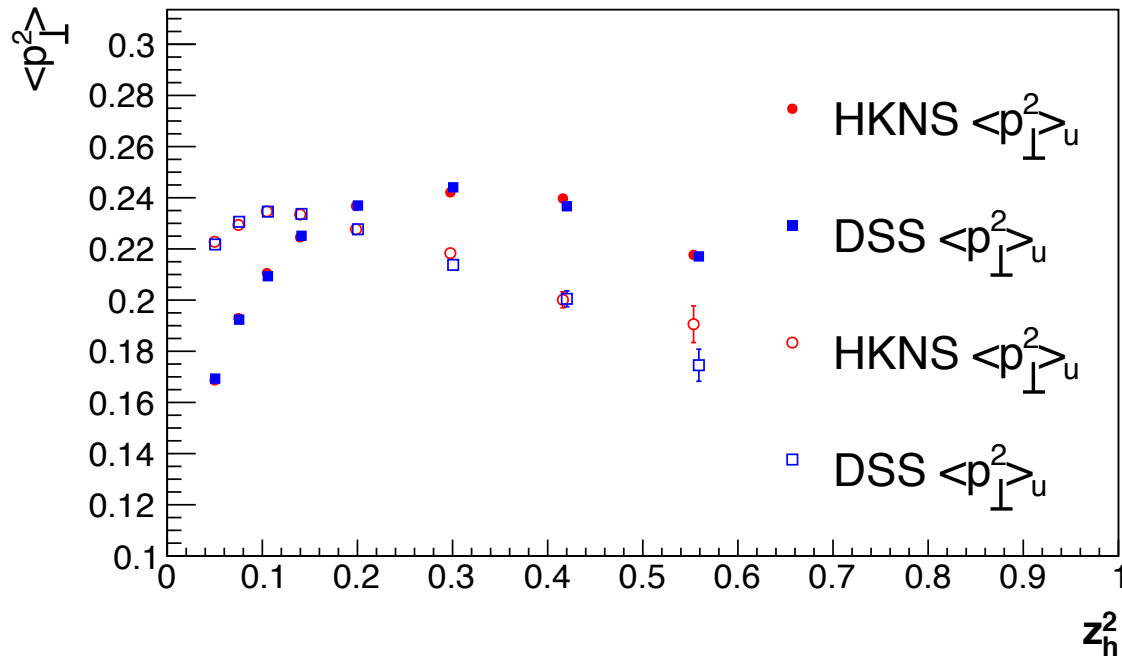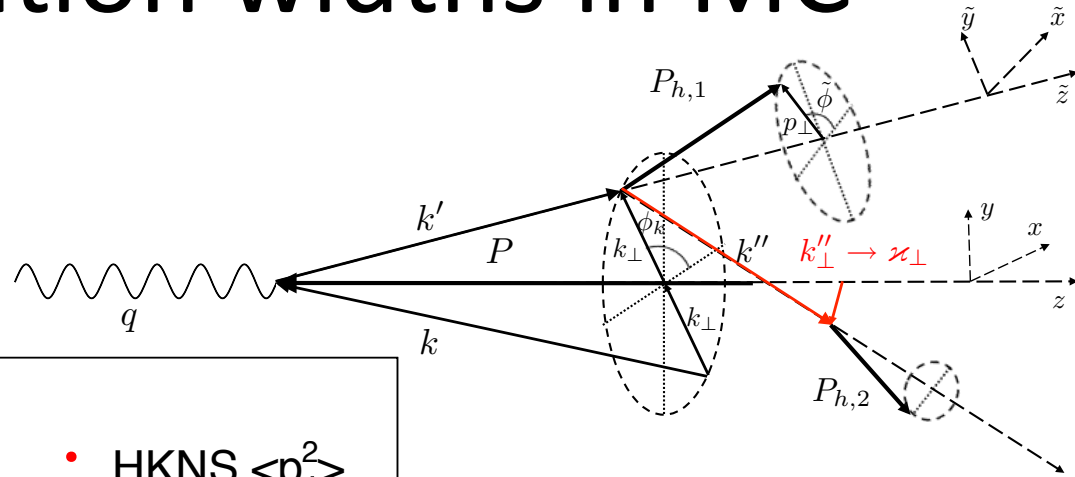change of the collinear FFs effects detected hadrons transverse widths.

Inside MC

J.H Gao, Z.T Liang, X.N. Wang, arXiv:1001.3146

Legend:
- ○ HKNS $\langle \kappa_\perp^2 \rangle_d$
- ● HKNS $\langle \kappa_\perp^2 \rangle_u$
- ■ DSS $\langle \kappa_\perp^2 \rangle_u$
- □ DSS $\langle \kappa_\perp^2 \rangle_d$
- ● $\langle k_\perp^2 \rangle_u$
- ○ $\langle k_\perp^2 \rangle_d$

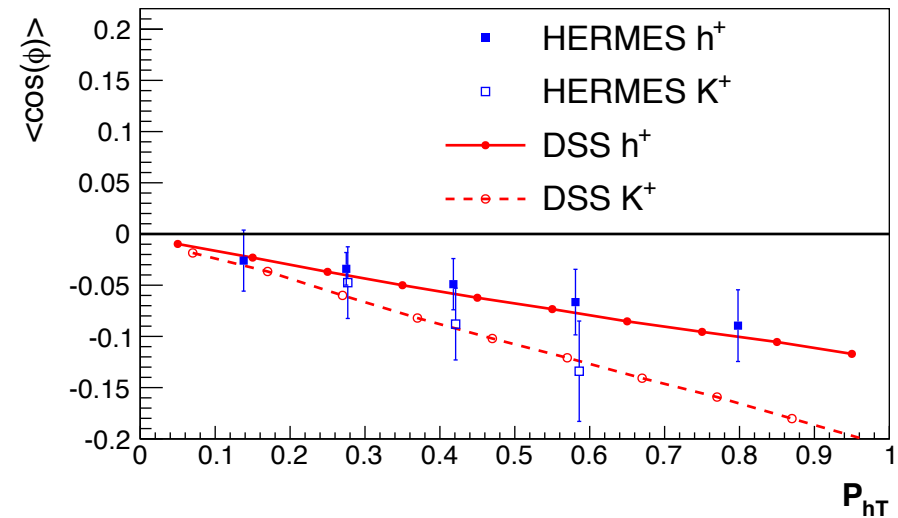y-axis: $\langle k_\perp^2 \rangle$
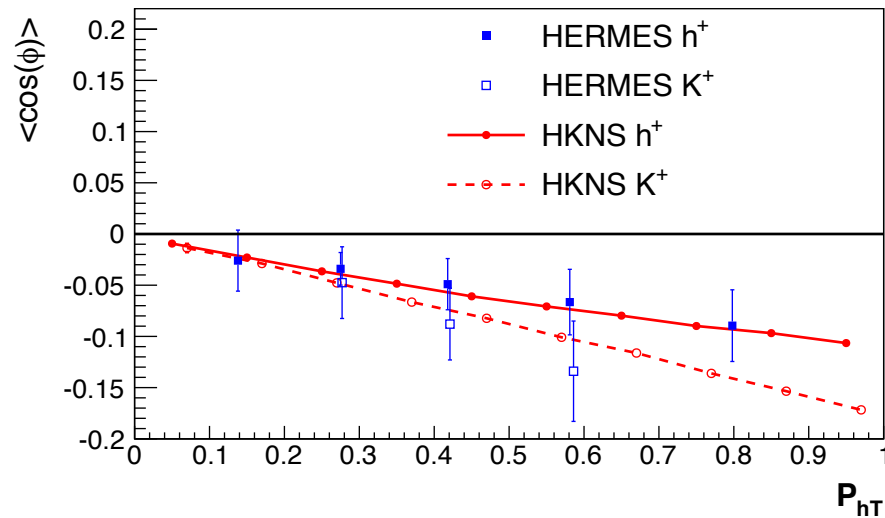
x-axis: x_B

Quarks Intrinsic transfer momenta "smearing" is in the order of factor 2- 5 times.

Fragmentation widths in MC

Transverse widths from secondary fragmentations are wider from favored FF widths only at small z.

Cahn effect from MC and <cosφ> from HERMES Data

For the same fixed input widths the outcome of MC depends on FFs.

Summary

- SIDIS data sensitive to quark "initial" intrinsic transverse momenta only at high z. (smearing due to the fragmentation dominates at low z).
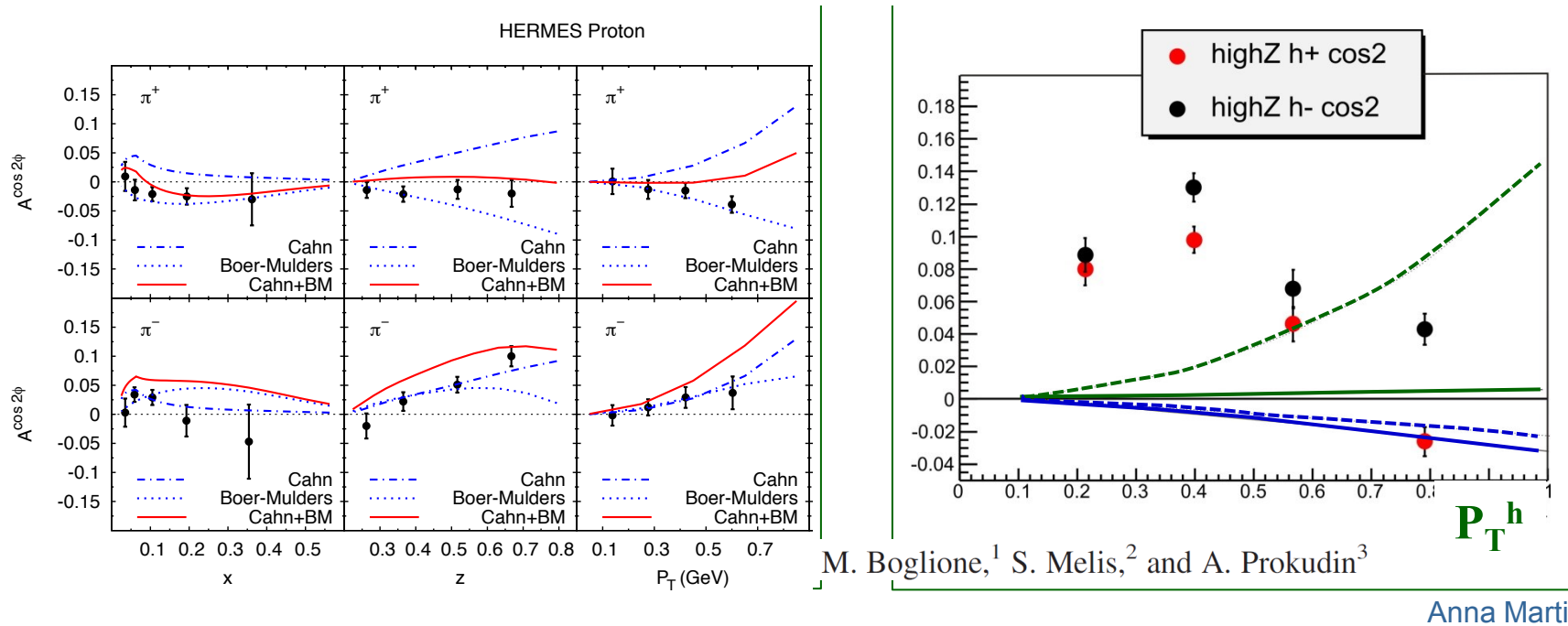
- TMD fits should be done together with collinear FFs.

Outlook

- Include resonances (need FFs model).
- Fit available unpolarized data.
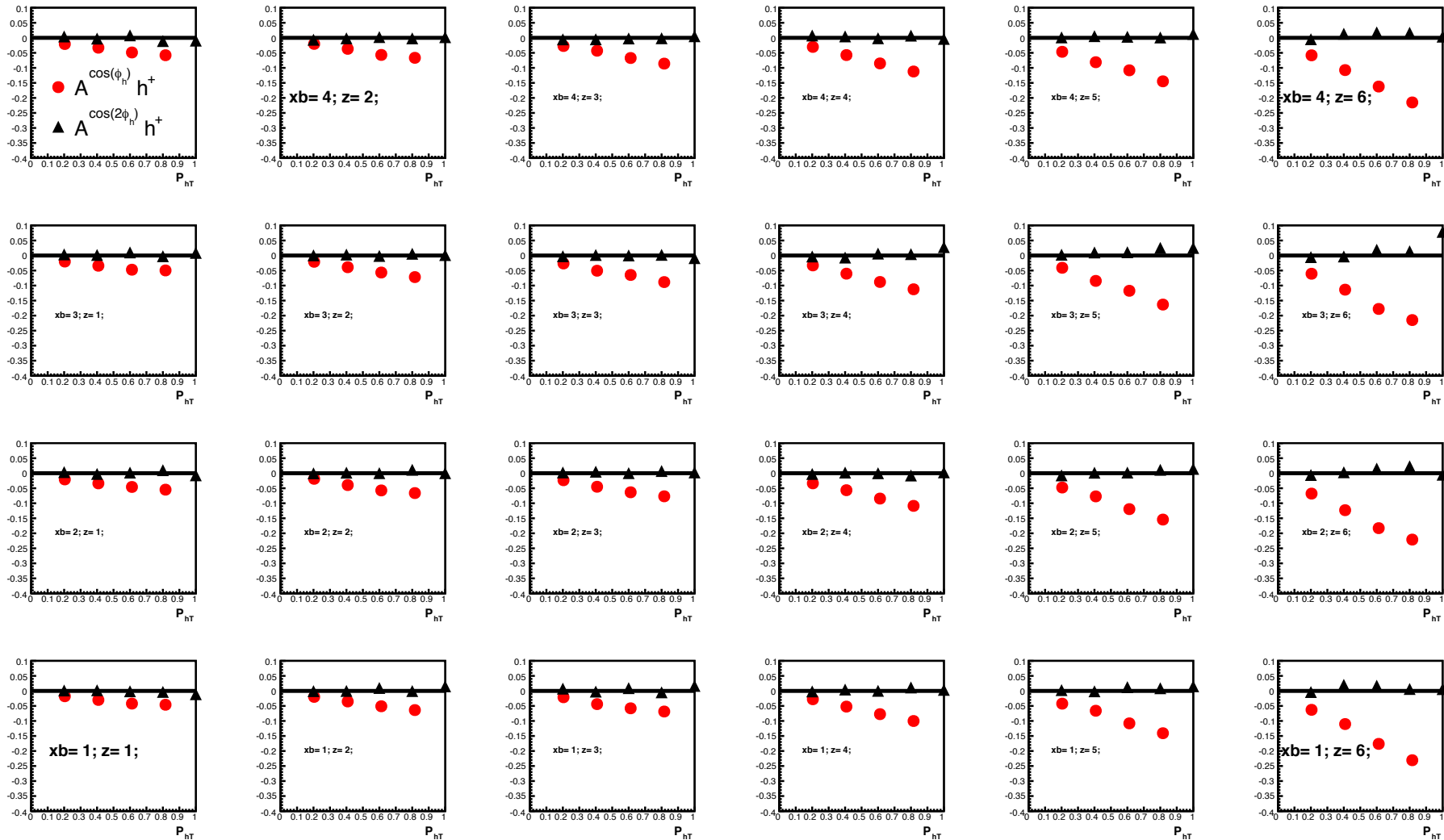- Include all 18 structure functions…

Thank you!

Support

Cos 2 ϕ_h

HERMES Proton

M. Boglione,[1] S. Melis,[2] and A. Prokudin[3]

Anna Martin

Current model calculations are not support by experimental measurements.

Cahn from MC

Cos $2\phi_h$ from Cahn for positive hadrons is consistent with zero

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