Testing TMD Extractions With Multidimensional SIDIS MC

Mher Aghasyan
LNF INFN

25 February 2014

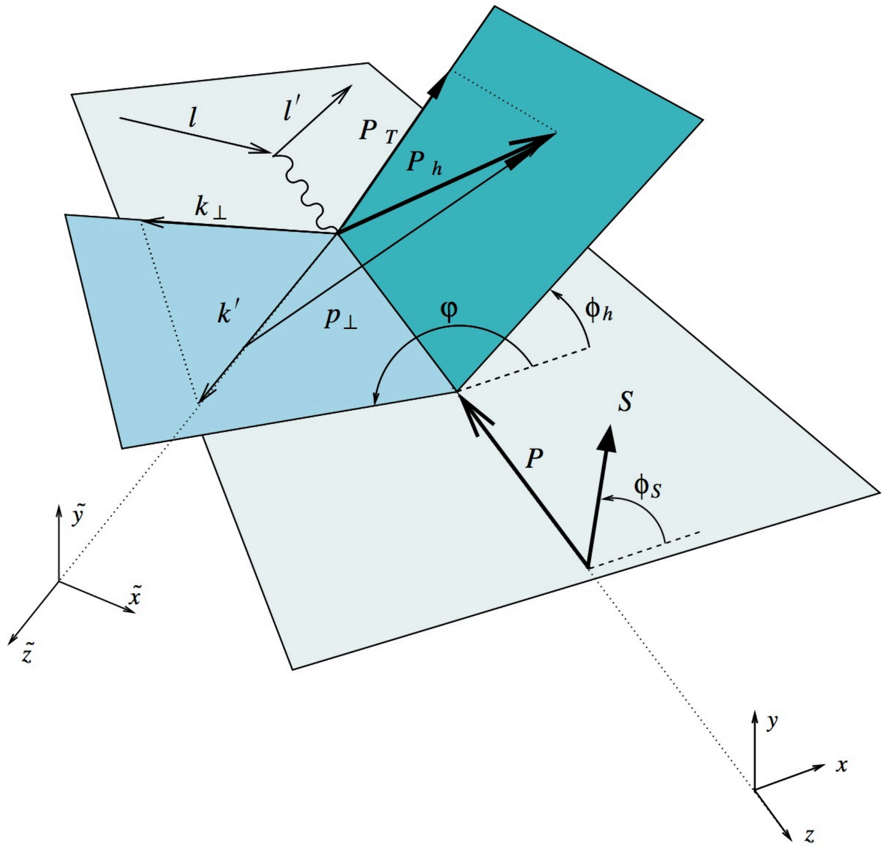
Outline

- Fully differential MC
  - ➢Only single hadron production
  - ➢Multi-hadron production
- Results
- Summary and outlook

SIDIS cross-section

$$eP \to e'hX$$

Figure from **PRD 71, 074006 (2005).**



$$\frac{d\sigma}{dxdydzd^2\mathbf{p}_\perp d^2\mathbf{k}_\perp d\phi_{l'}} =$$

Assuming single photon exchange, after integration, the lepton-hadron cross section can be expressed in a model-independent way:

$$\frac{d\sigma}{dxdydzdP_{h,T}^2 d\phi_s d\phi_h} = \ldots$$

MC should depend on parton's transverse momenta, for studying extraction accuracy.

Role of the Unpolarized Cross Section

$$A_{\vec{l},\vec{N}} \sim \frac{F_{\vec{l},\vec{N}}}{F_{UU}} \sim \frac{\sum_q PDF_q \otimes FF_q}{\sum_q e_q^2 f_1^q \otimes D_1^q}$$

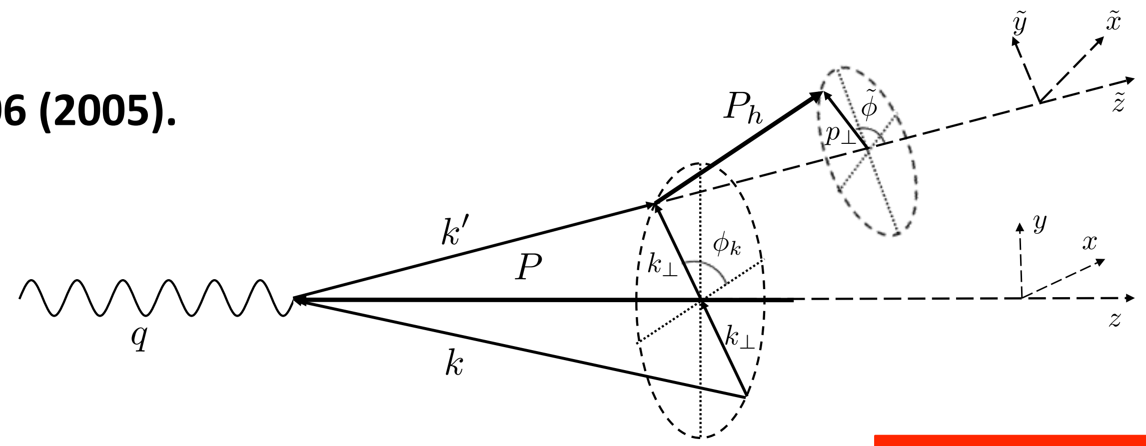
Unpolarized uPDFs/TMDs and uFFs/FFs affect spin asymmetries.
They influence the extraction accuracy.

Model in MC should be flexible to accept:

- Collinear PDF conv TMD-PDFs or un-integrated PDFs.
- Collinear FFs conv TMD-FFs or un-integrated FFs.

Model for fully differential SIDIS dedicated MC

Anselmino: PRD 71, 074006 (2005).



Quark intrinsic motion with Torino model: $M_p \neq 0 \quad x_{LC} = k^- / P^-$ ➡ $\langle k_\perp^2 \rangle \sim f(x)$

Quark inside the proton have the momentum:

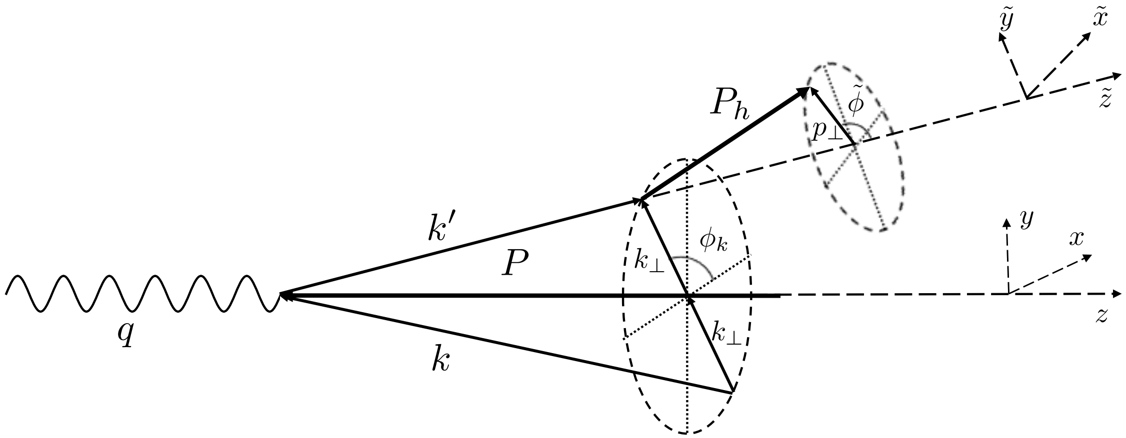
$$k = \left(x_{LC} P' + \frac{k_\perp^2}{4 x_{LC} P'}, \mathbf{k}_\perp, -x_{LC} P' + \frac{k_\perp^2}{4 x_{LC} P'} \right)$$ ⬅ Could be modified

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

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, A. Prokudin

Fragmentation



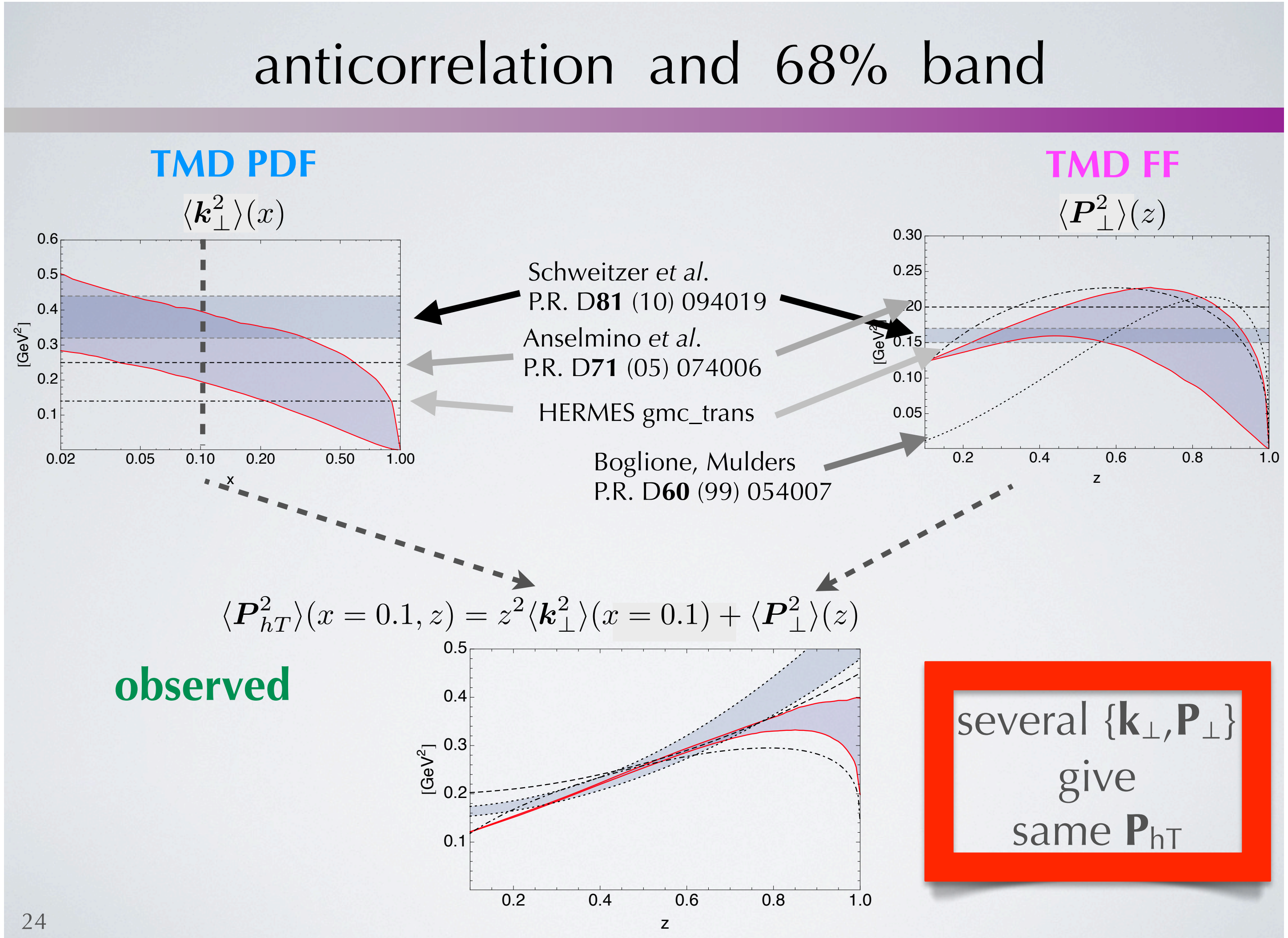
Scattered quark 4 momenta calculated: $k' = k + q$

Final hadron generated with the momentum:

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

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

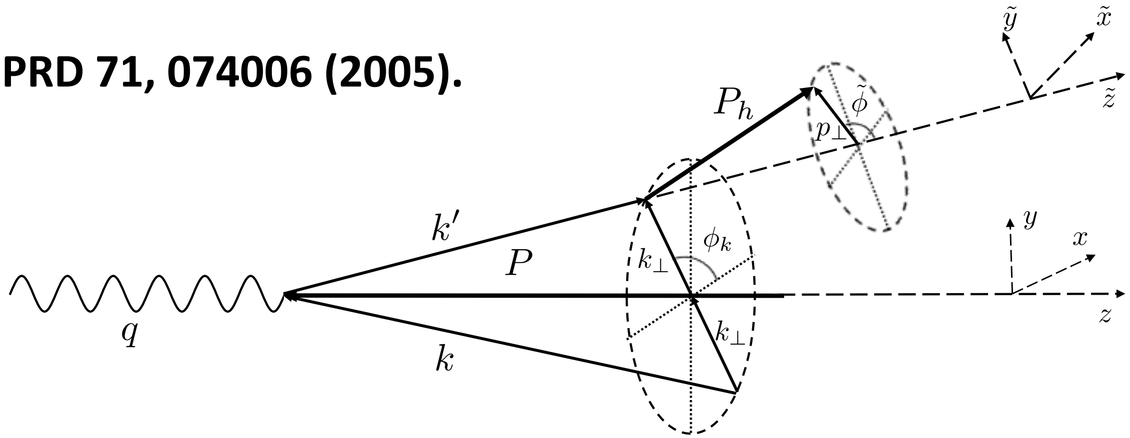
Fitting multiplicities



Slide from M. Radici: 2nd PSHP workshop at LNF, 2013

Cahn effect in MC

Anselmino: PRD 71, 074006 (2005).



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

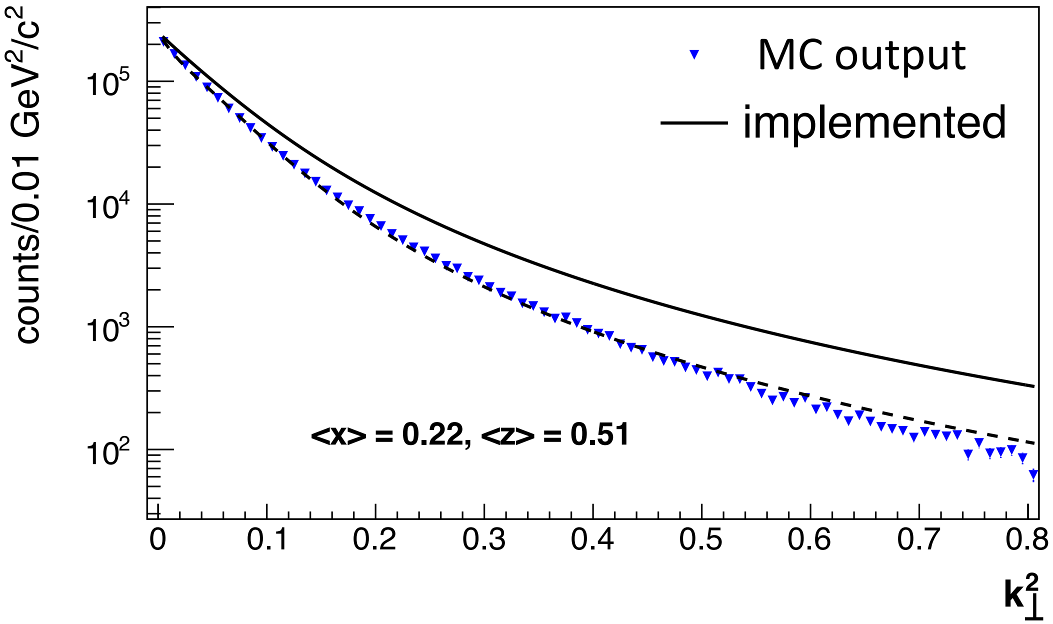
$$\hat{s} = (l+k)^2$$

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

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

Constraints from 4 momenta conservation

$\langle k_\perp^2 \rangle$ -depends on x and $\langle p_\perp^2 \rangle$ -depends on z



$k_\perp$- **is smaller than:**

a) Quarks longitudinal momenta component.
b) Smaller than total energy of quark.
c) Energy of detected hadron.

no infinity!
And no limit in MC to implement something else!

B. Pasquini $$f(k_\perp) = \left[1. + 20.82k_\perp^2 + 126.7k_\perp^4 + 1285k_\perp^6\right]^{-1}$$

Quark transverse component of the momenta is smaller than LC component which effects high $k_\perp$ tail.

Bessel-Weighted Extraction

Model independent extraction of flavor decomposition of $k_\perp$ dependent PDFs. Boer:JHEP10(2011)021

Complicated convolution

$$\sigma^h(P_{hT}) \sim \sum_q f^q(x, k_\perp) \otimes D^{q\to h}(z, p_\perp)$$

Fourier transform

$$\tilde{\sigma}^h(b_T) \sim \sum_q \tilde{f}^q(x, b_T) \cdot \tilde{D}^{q\to h}(z, b_T)$$

product

Bessel-Weighted Extraction of the Double Spin Asymmetry A_{LL}

Boer: JHEP10(2011)021

$$A_{LL}^{J_0(b_T P_{h,T})}(b_T) = \frac{\tilde{\sigma}^+(b_T) - \tilde{\sigma}^-(b_T)}{\tilde{\sigma}^+(b_T) + \tilde{\sigma}^-(b_T)} = \frac{\tilde{\sigma}_{LL}(b_T)}{\tilde{\sigma}_{UU}(b_T)} = \sqrt{1-\varepsilon^2}\,\frac{\sum_q \tilde{g}_1^q(x, z^2 b_T^2)\tilde{D}_1^q(z, b_T^2)}{\sum_q \tilde{f}_1^q(x, z^2 b_T^2)\tilde{D}_1^q(z, b_T^2)}$$

where

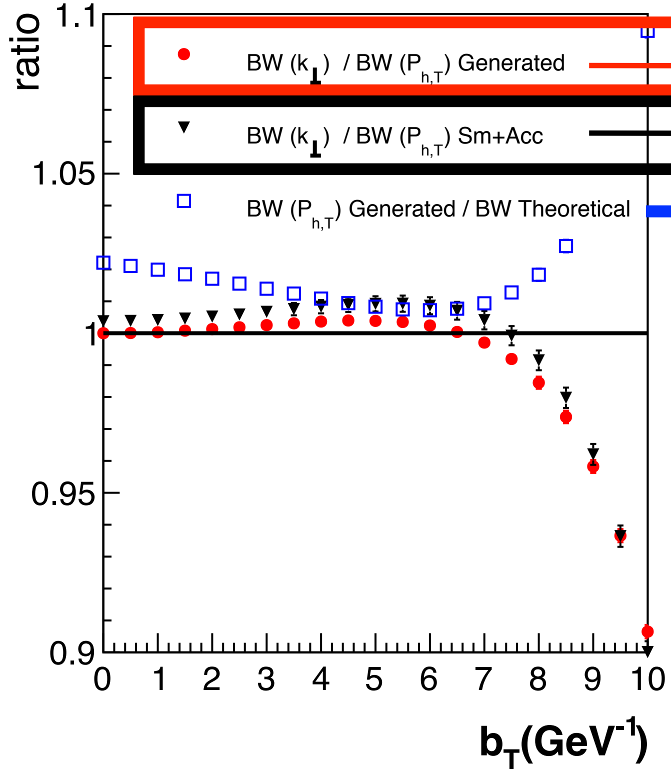
$$\tilde{\sigma}^\pm(b_T) = \int \frac{d\sigma^\pm}{dP_{h,T}} J_0(b_T P_{h,T}) P_{h,T} dP_{h,T}$$

For MC events

$$\tilde{\sigma}^\pm(b_T) \simeq S^\pm = \sum_{i=1}^{N^\pm} J_0(b_T P_{h,T,i})$$

In Fourier space convolution of TMD-DF and TMD-FF become simple products!

Extraction accuracy for BW



Systematic discrepancy due to the FF.

Systematic discrepancy due detector.

Systematic discrepancy due to the absence of 4-momenta conservation in theoretical integration (from 0 to infinity).

$$\tilde{\sigma}^{\pm}(b_T) = \int \frac{d\sigma^{\pm}}{dP_{h,T}} J_0(b_T P_{h,T}) P_{h,T} dP_{h,T}$$

Extraction accuracy for BGMP formalism acceptable only at low b_T.
See L. Gamberg's talk on Wednesday.

Short Summary

- Easy to use any collinear PDF and FF in convolution with TMDs.
- Highest systematic discrepancy is due to the integration in physical phase-space (in MC I integrate only physical phase-space that produces physical events).

- With single hadron MC due to the 4 momenta conservation there is no high P_{hT} tails.
- We are blind regarding underlying mechanisms.

Blind to Underlying Mechanism

Is parton shower + fragmentation:

Constrained?

Disordered?

Strictly ordered?

Trees have many branches (parton’s) and leaves (hadron’s we detect).

Requirements for MC

Collins,Rogers,Staśto:PRD77,085009,2009

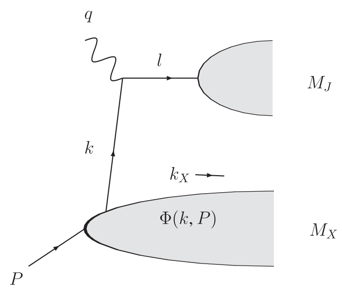
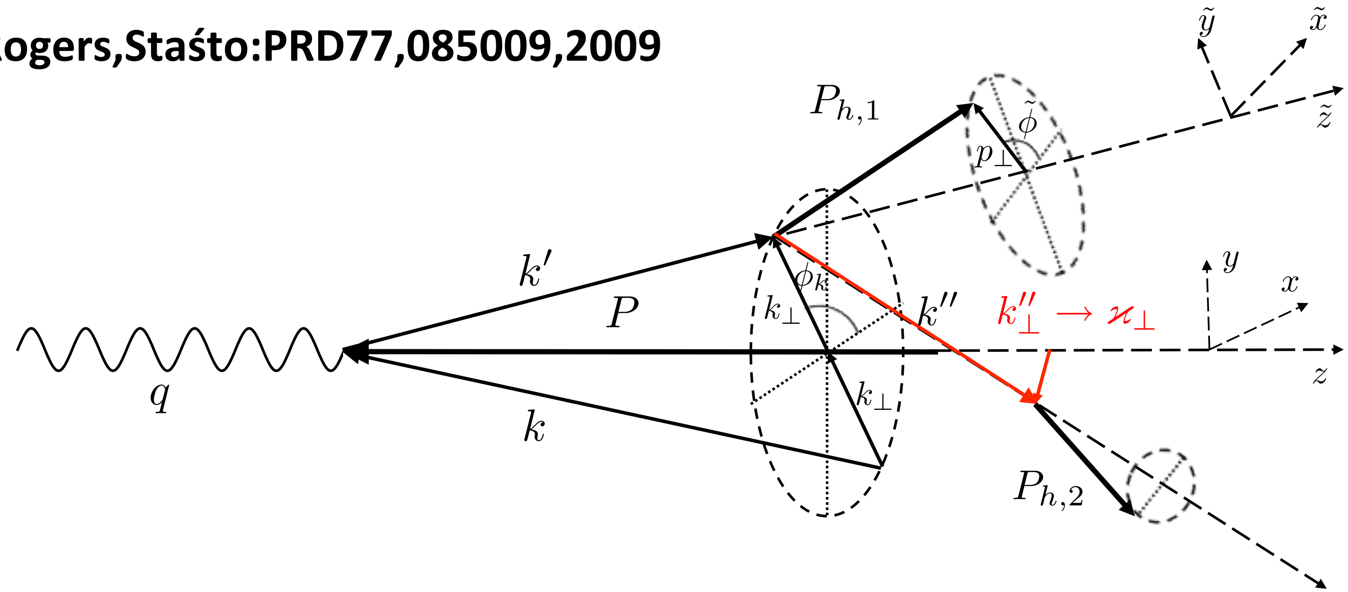


FIG. 2. The amplitude for $\gamma^* p$ scattering into two jets with fixed masses.

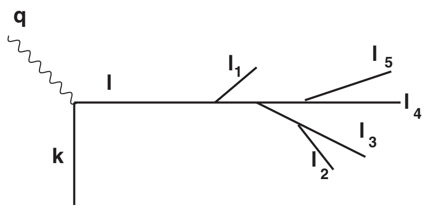
- The kinematics of the initial and final states must be kept exact.
- The sums over physical final states must be kept explicit.
- To avoid making kinematical approximations in the initial and final states, the factors need to be function of all components of parton four-momentum.
- *The hard-scattering 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



PHYSICAL REVIEW D **77,** 085009 (2008)

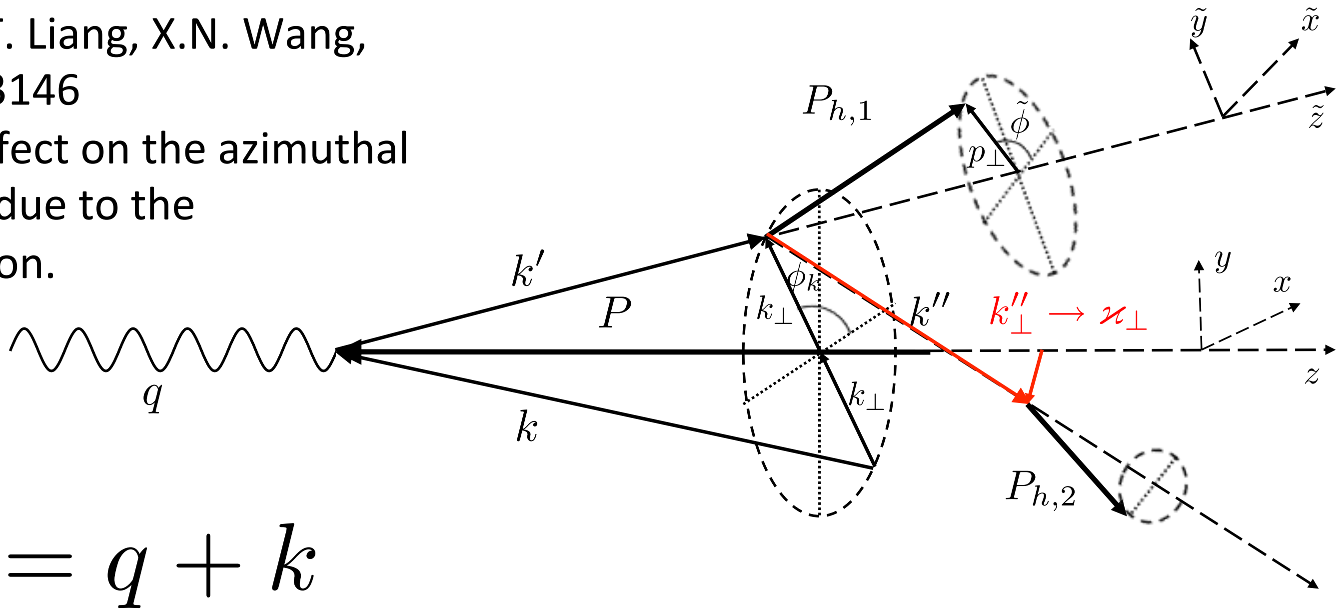


$$k' = q + k$$
$$k'' = k' - P_{h,1}$$

Four momenta conservation at each vertex.

Model for Multi-hadron Production

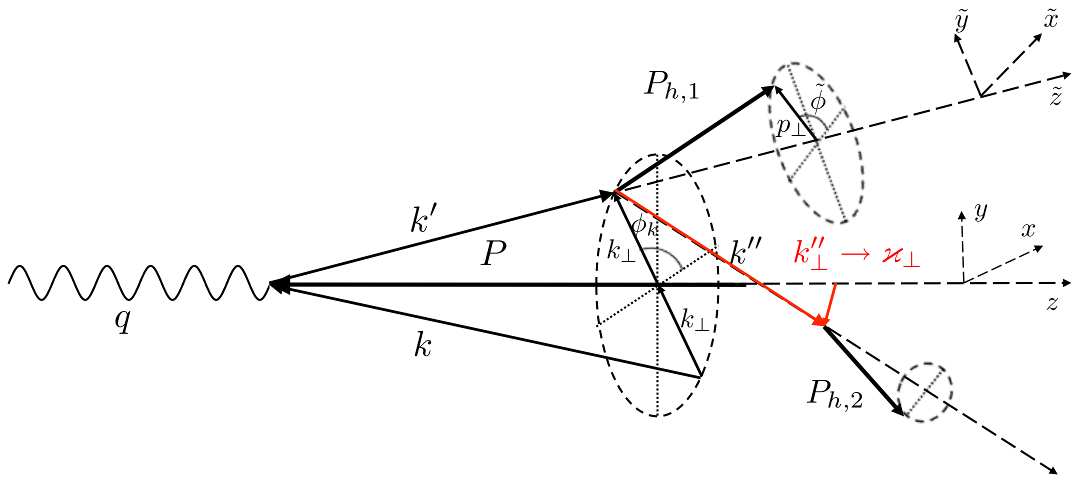
J.H. Gao, Z.T. Liang, X.N. Wang, arXiv:1001.3146
Smearing effect on the azimuthal asymmetry due to the fragmentation.



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

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

Inputs for MC



Functions to reproduce:

Collinear FFs: DSS or HKNS

Gaussian with:

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

Collinear PDFs: MSTW, NNPDF

Gaussian with:

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

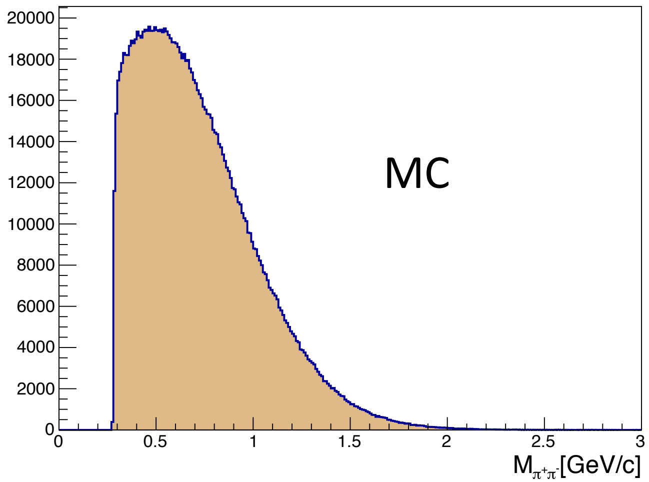
$$k' = q + k$$

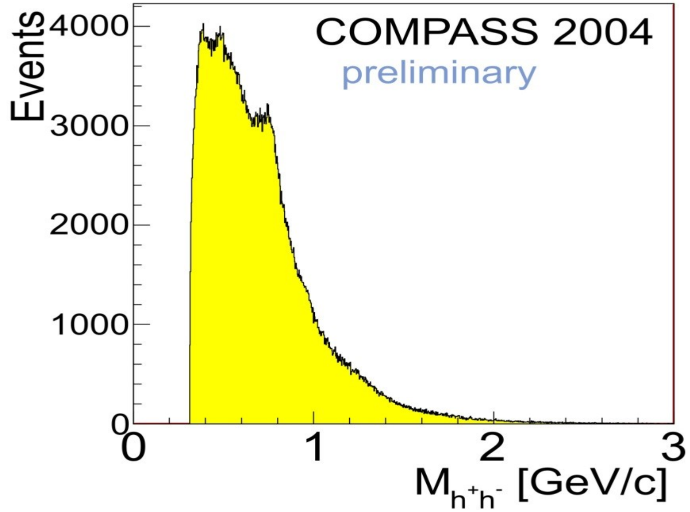
$$k'' = k' - P_{h,1}$$

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

Unfavored FF and $k''_\perp \to \varkappa_\perp$ is being calculated from four-momenta conservation.

Outcome of MC at 160 GeV



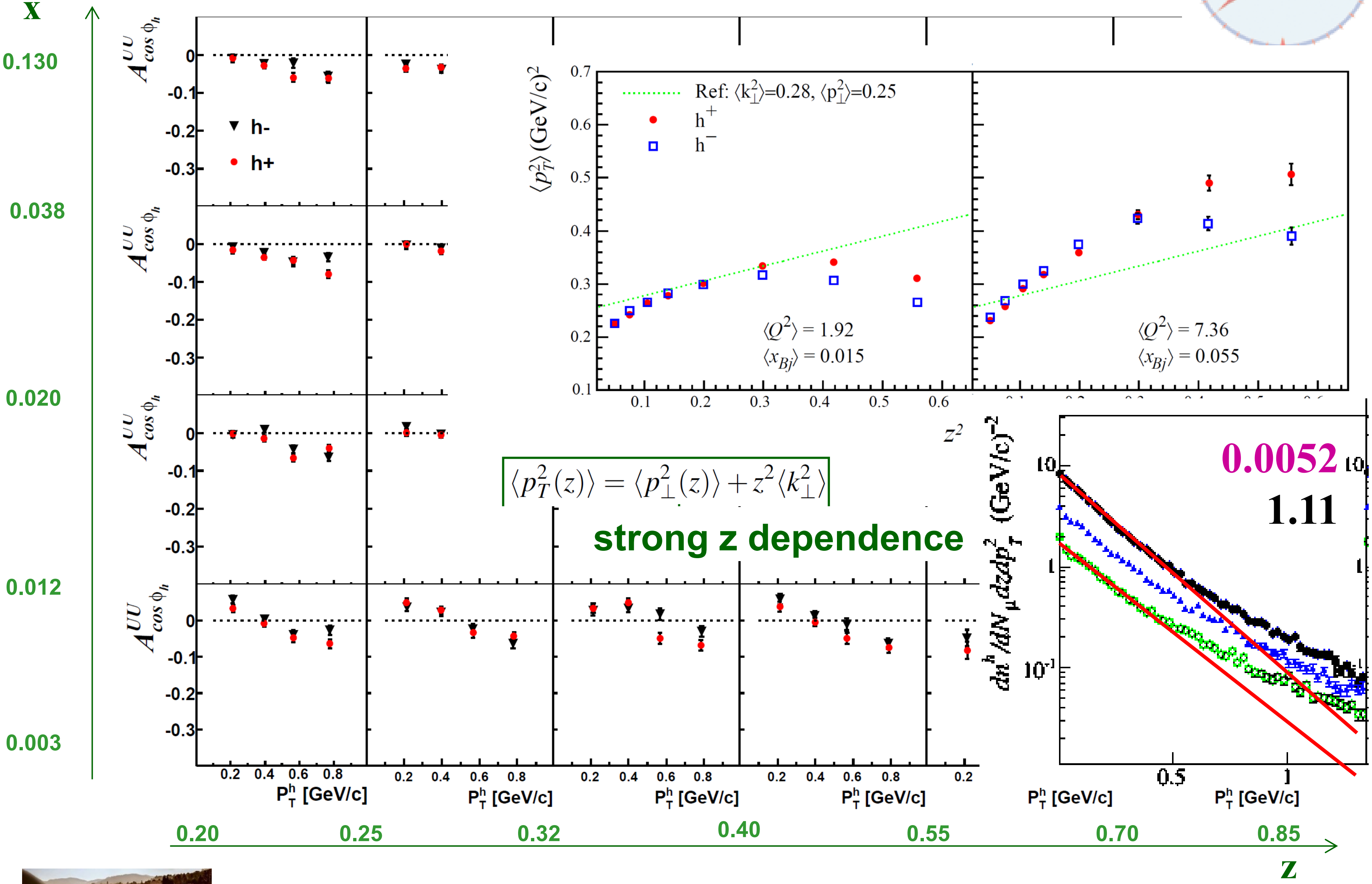


From A.Martin presentation at Como.

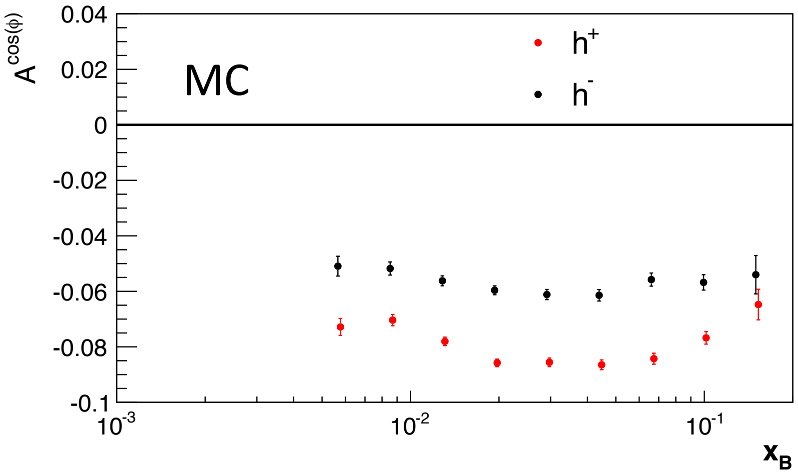
Vector meson production in MC is not included yet!

azimuthal asymmetries - cos ϕ

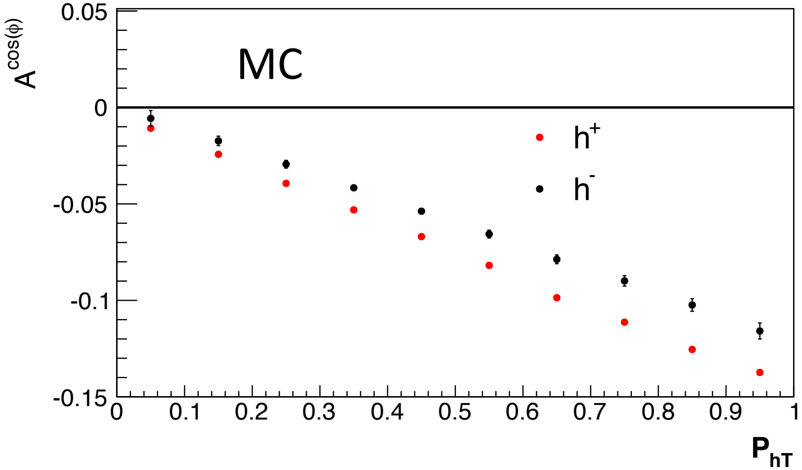
COMPASS ^{6}LiD (25% of 2004 data) preliminary

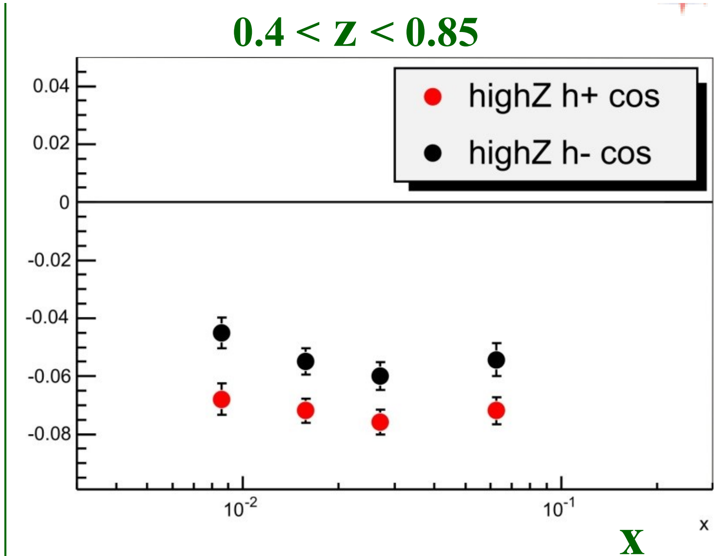


Cahn effect from MC and $A^{\cos\phi}$ from Data

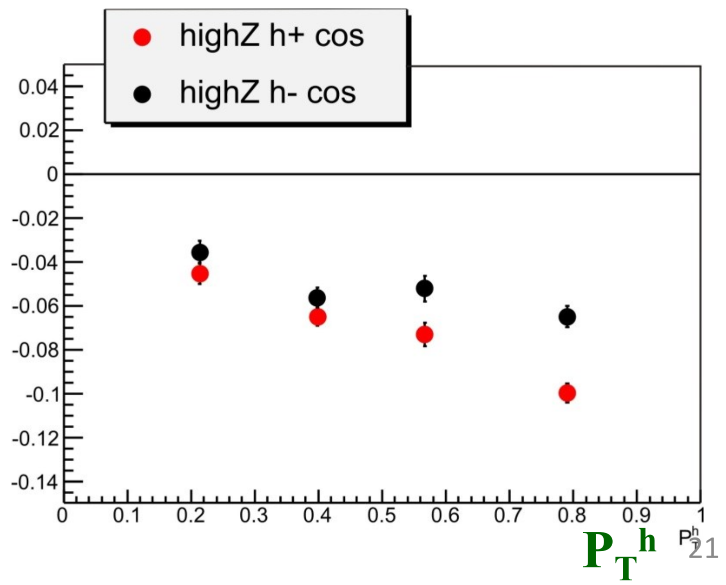


Reasonable agreement at high z

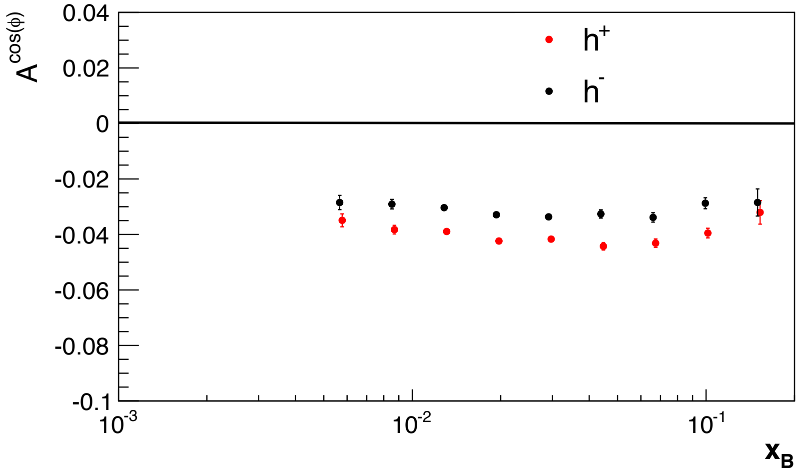


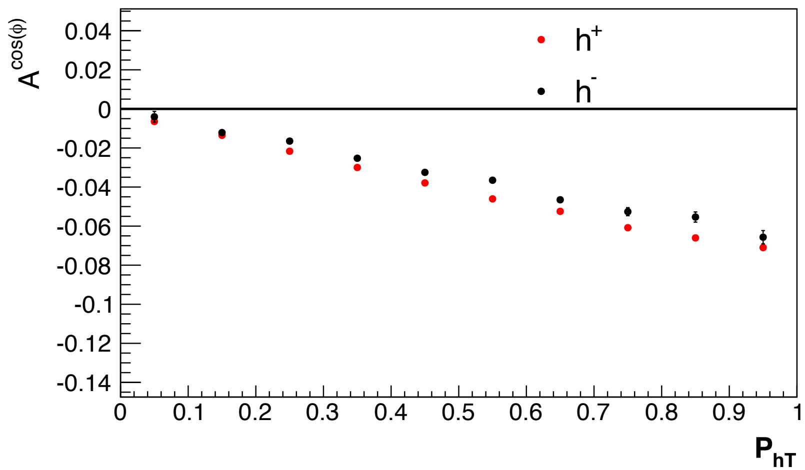


A. Martin, Como, June, 2013

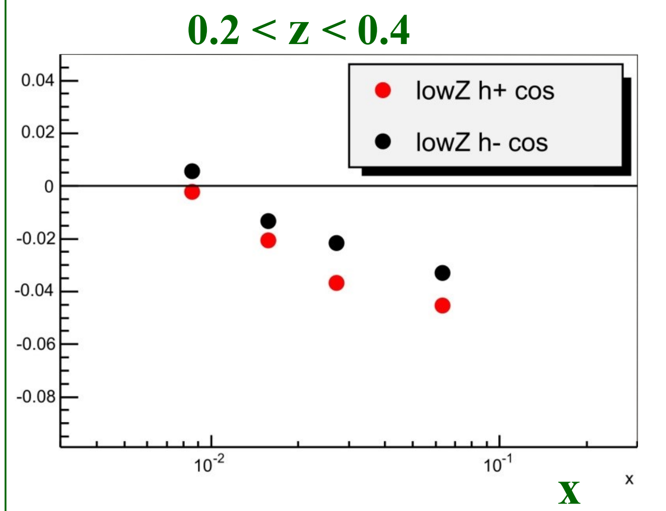


Cahn effect from MC and $A^{\cos\phi}$ from Data

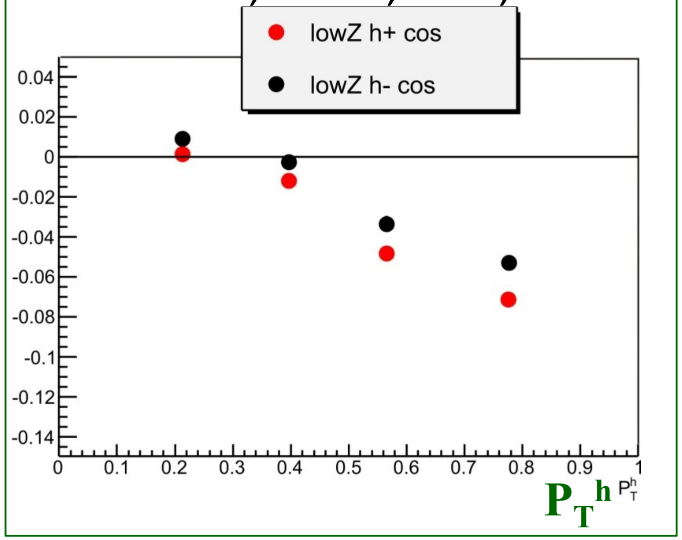




With current model I can not describe low z

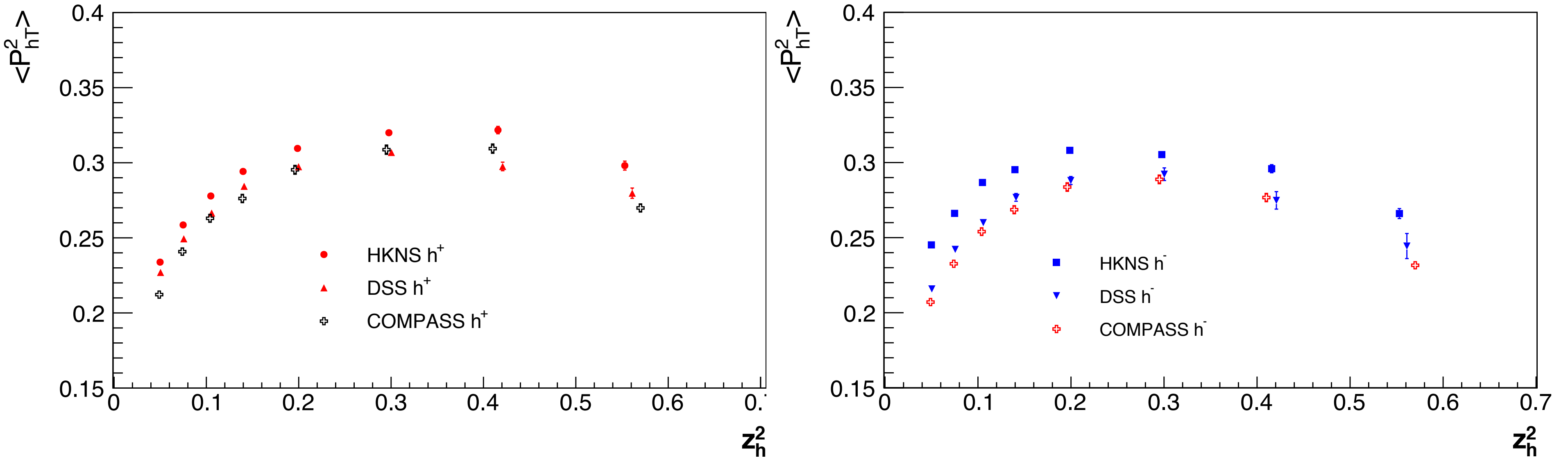


A. Martin, Como, June, 2013



MC vs COMPASS average transverse widths

$$\langle x_B \rangle = 0.0213, \langle Q^2 \rangle = 1.23 (GeV/c)^2$$



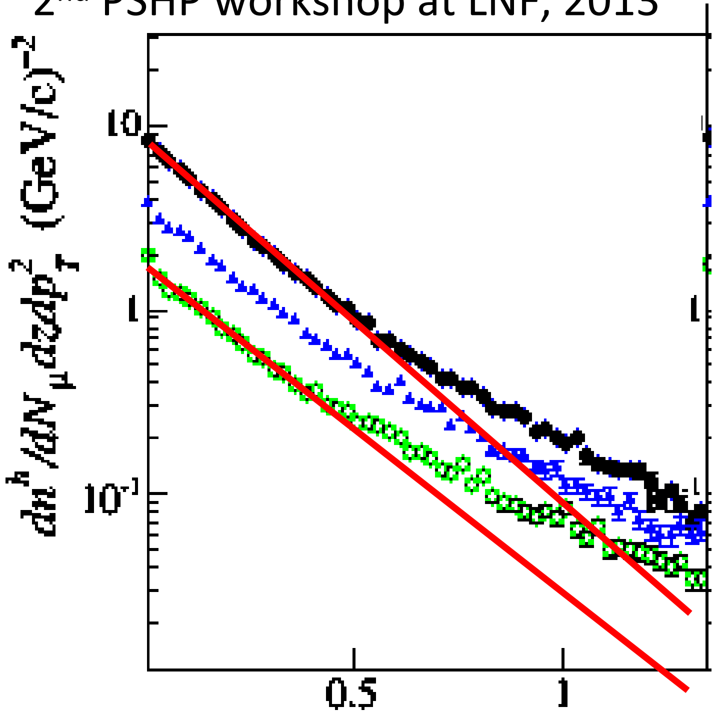
$$\langle p_\perp^2 \rangle_q = C_q \times z \cdot (1-z)^{0.9}$$

<u>For fixed input transverse widths in FF and DF:</u>

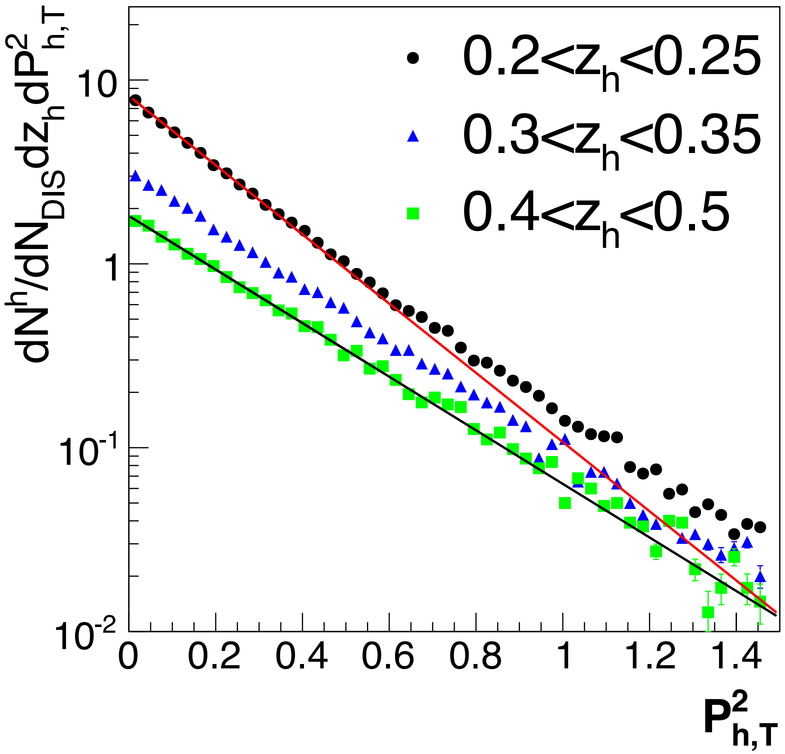
change of the FFs effects detected hadrons transverse widths.

MC vs COMPASS multiplicities

Plot from A. Martin's slide:
2nd PSHP workshop at LNF, 2013



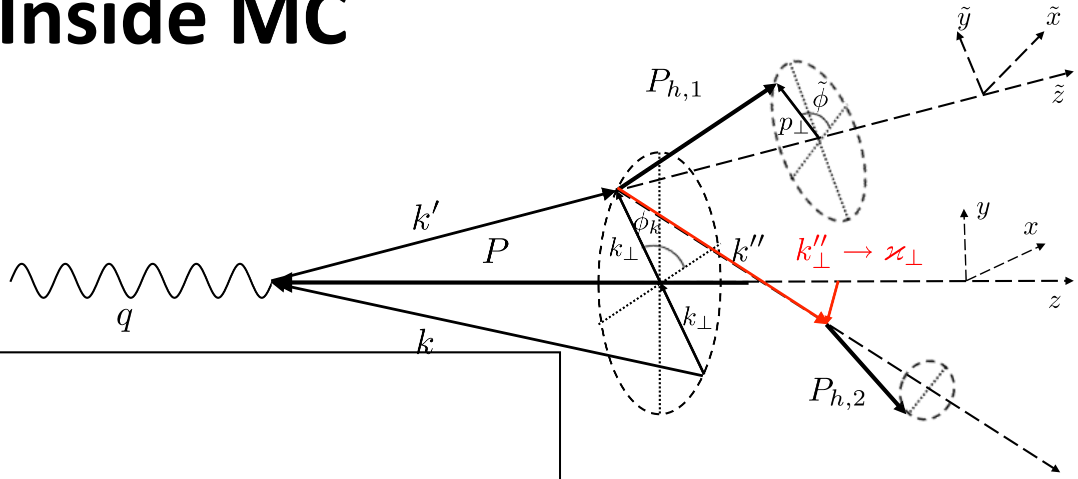
$\langle x_B \rangle = 0.0052 \quad \langle Q^2 \rangle = 1.11$

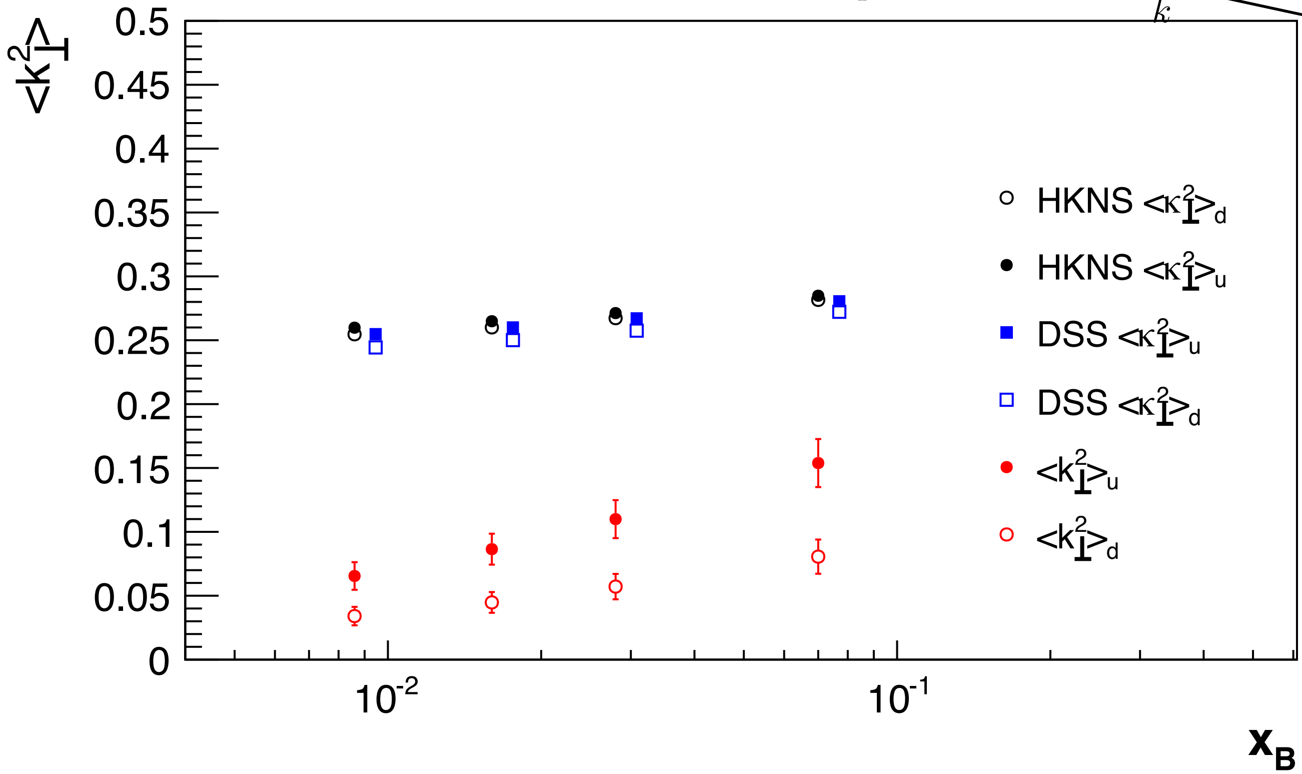


For fixed input Gaussian TMD DF and FFs MC allows high P_{hT} tail.
P_{hT} tail in data could be due to gluons, vector mesons …

Inside MC

J-H. Gao, Z-T. Liang, X-N. Wang, arXiv: 1001.3146
Smearing effect on the azimuthal asymmetry due to the fragmentation.

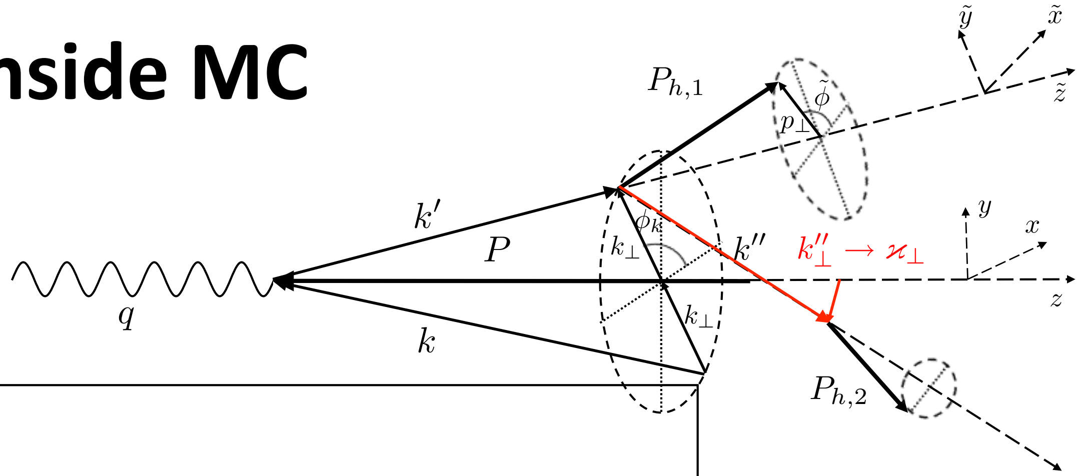




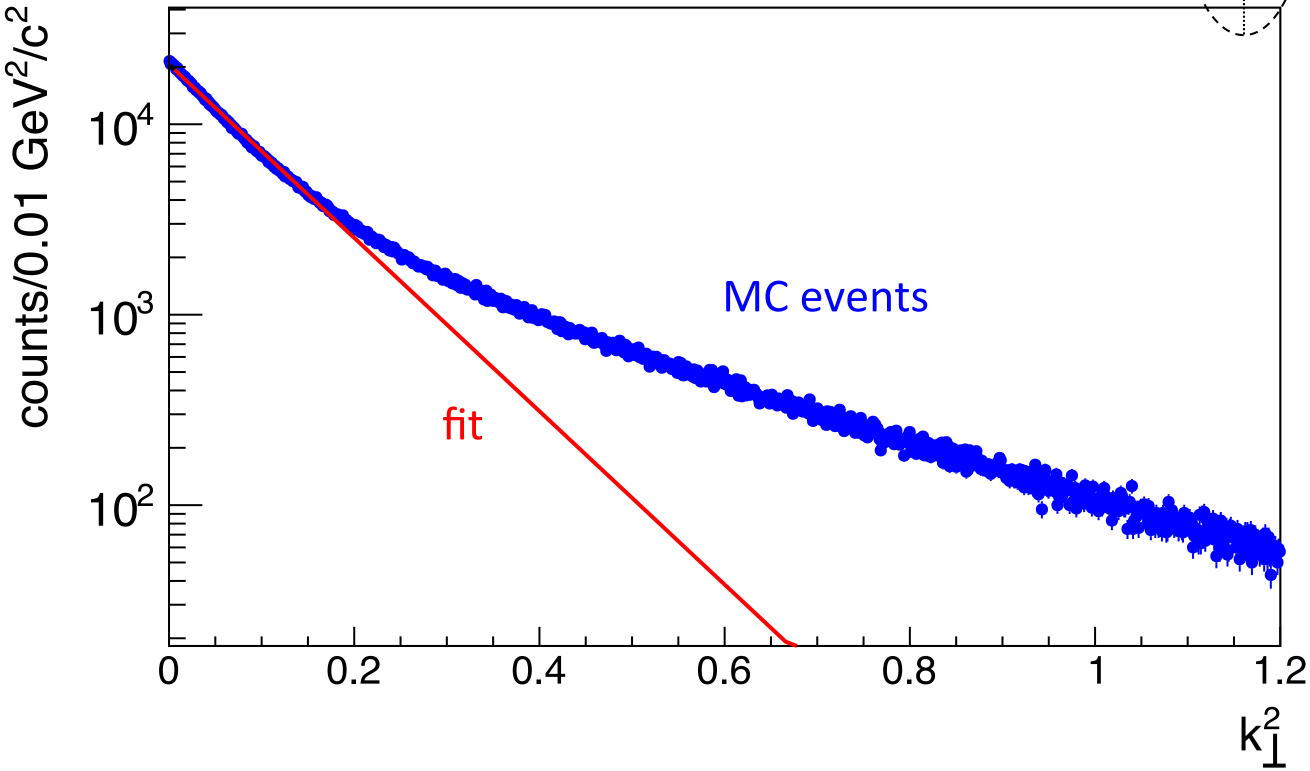
Quarks Intrinsic transfer momenta “smearing” is in the order of factor 2- 5 times.

Inside MC

$k_\perp + \varkappa_\perp$

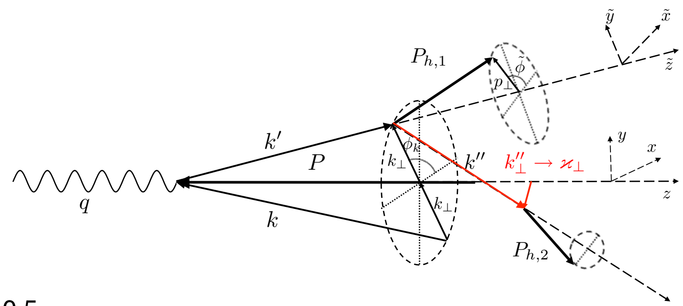


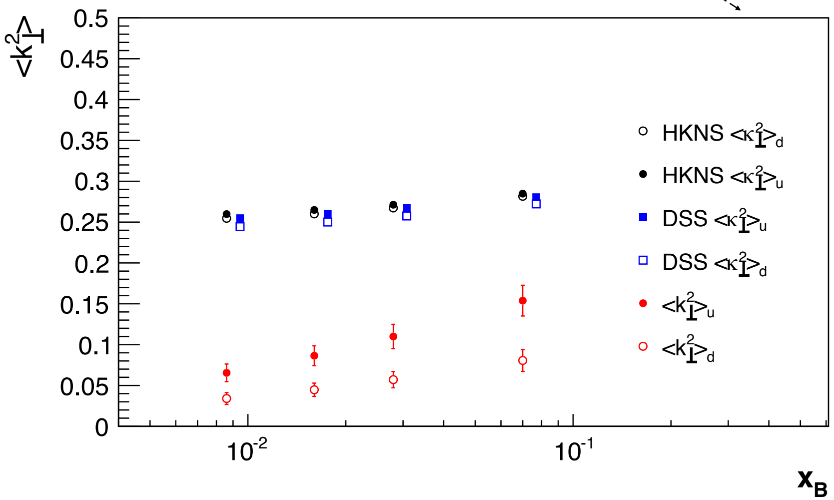
distribution for only u quarks



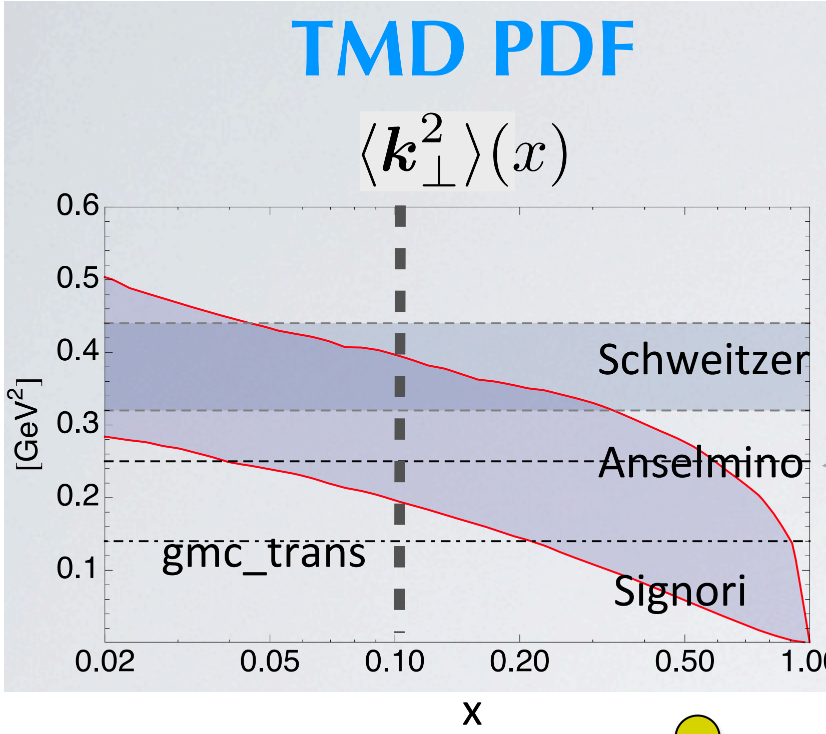
Even with Gaussian input, quarks TMD-PDF is not Gaussian, has power like tail due to multi parton production.

MC and available results





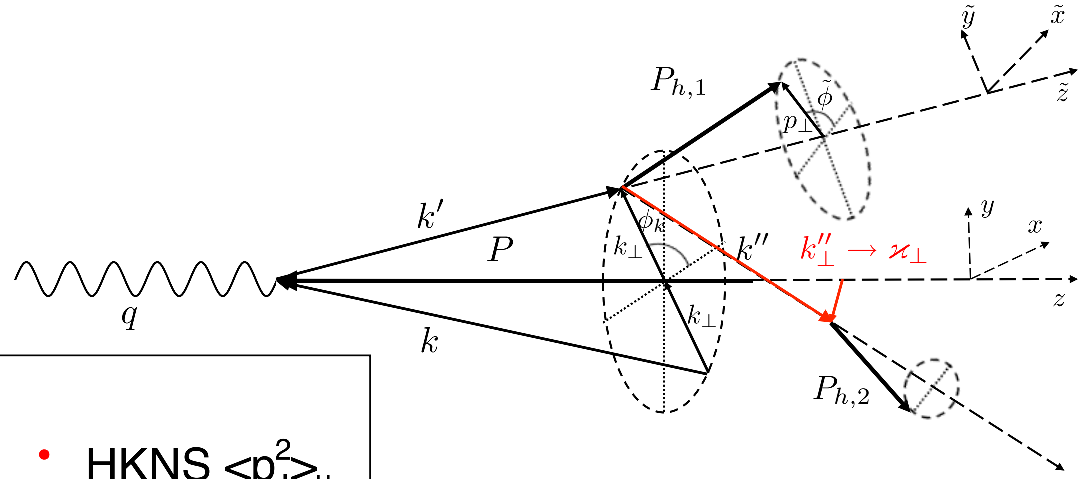
Plot is from M. Radici: 2nd PSHP workshop at LNF, 2013

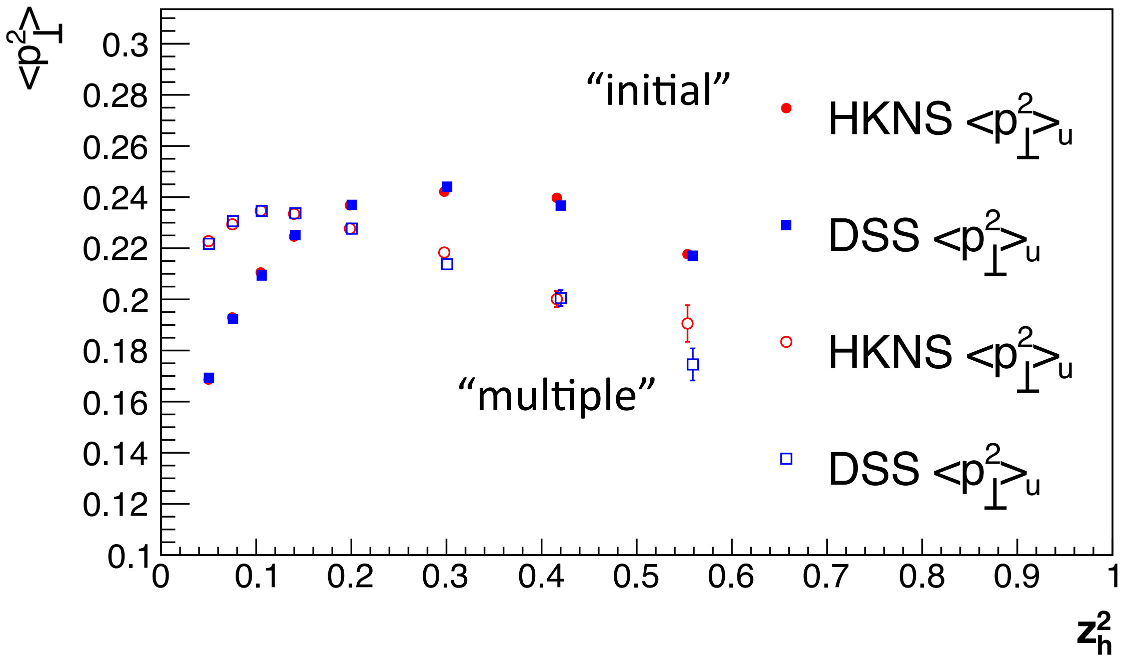


Results are consistent with: HERMES gmc_trans
Anselmino et al. PRD71(05)074006
Schweitzer et al. PRD81(10)094019
Signori et al. JHEP 1311, 194 (2013)

Fragmentation widths in MC

$u \to \pi^+$





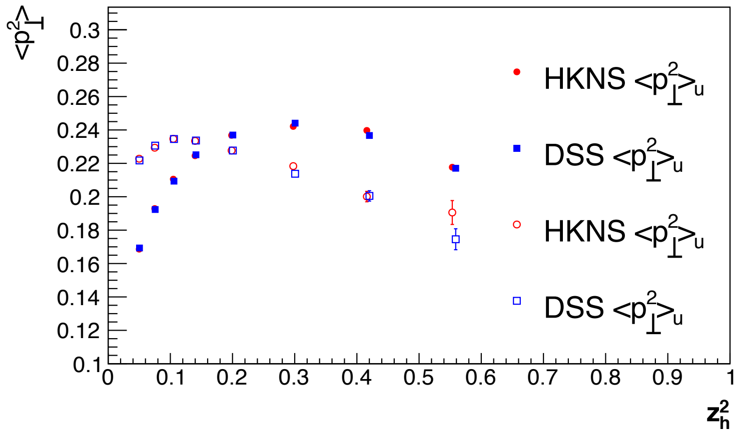
J-H. Gao, Z-T. Liang, X-N. Wang, arXiv:1001.3146
Smearing effect on the azimuthal asymmetry due to the fragmentation.

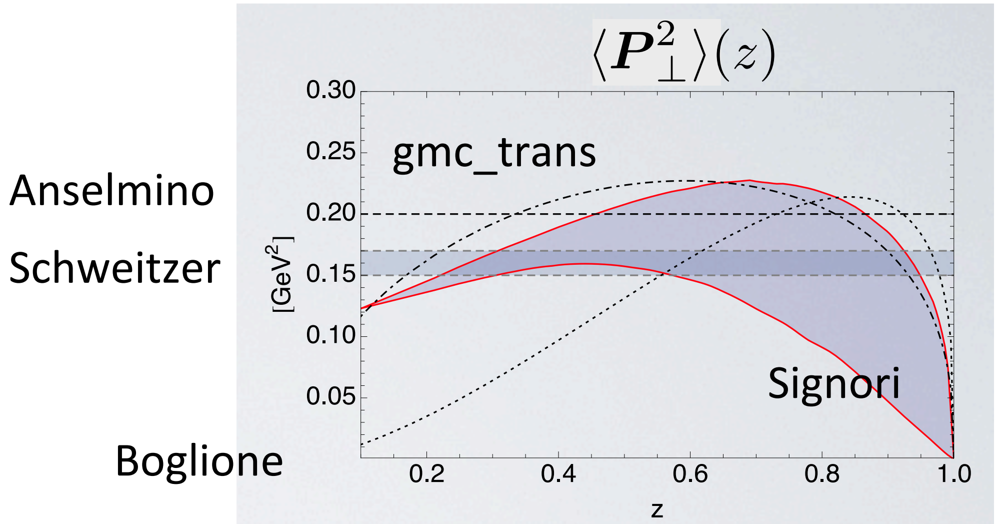
Transverse widths from "secondary" fragmentations are wider from favored "initial" FF widths only at small z.

Fragmentation widths in MC

$u \longrightarrow \pi^+$

Plot is from M. Radici: 2nd PSHP workshop at LNF, 2013

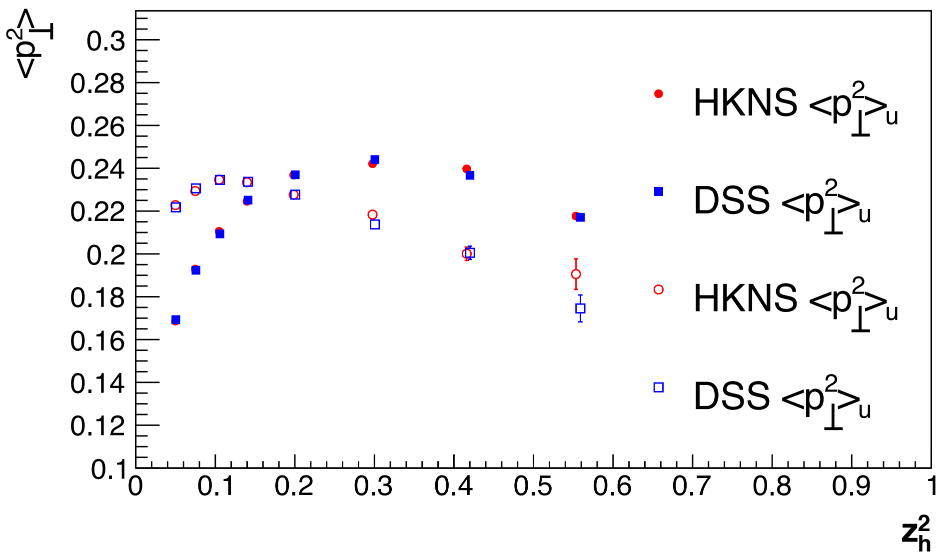


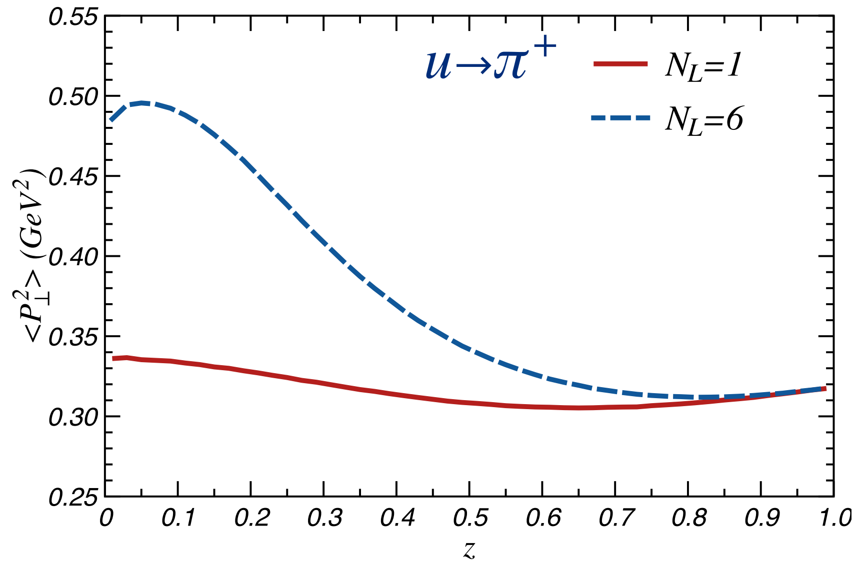


MC widths are consistent with: HERMES gmc_trans
Anselmino et al. PRD71(05)074006
Schweitzer et al. PRD81(10)094019
Signori et al. JHEP 1311, 194 (2013)
Boglione, Mulders PRD60(99)054007

Fragmentation widths in MC

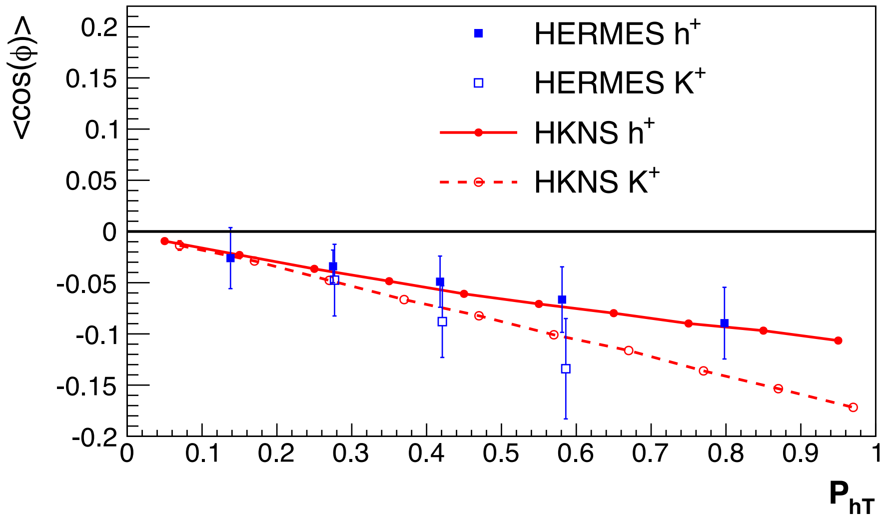
$$u \longrightarrow \pi^+$$

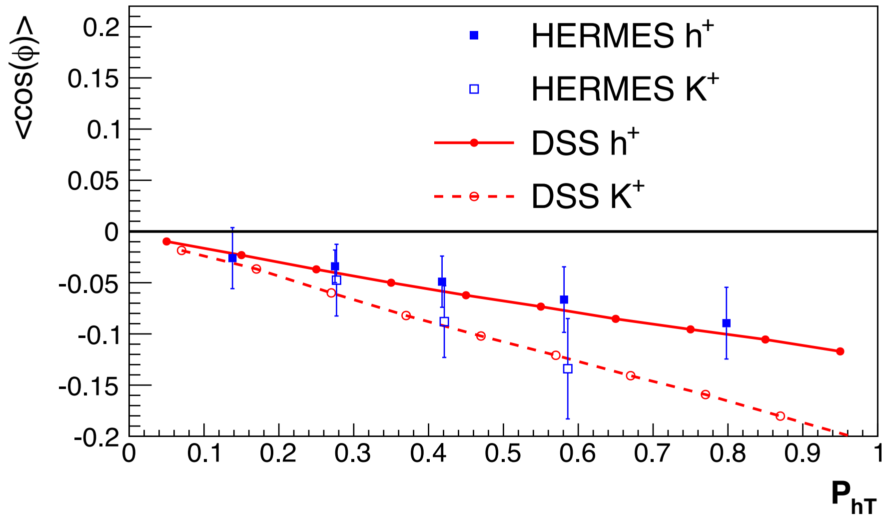




The MC results exhibit similar behavior to those from NJL-Jet.

Cahn effect from MC and <cosϕ> from HERMES Data





For the same fixed input widths the outcome of MC depends on FFs.
Reasonable agreement with HERMES with the same input parameters.

Summary

- Extraction of the Unpolarized SIDIS cross-section from global fit with different models will reduce uncertainties on polarized structure functions.
- SIDIS data sensitive to quark “initial” intrinsic transverse momenta only at high z. (smearing due to the fragmentation dominates at low z).
- Un-integrated PDFs and FFs could be (I guess should be) obtained from the fit of global data for each given model.
- Extraction accuracy varies for different models.

Outlook

- Gluons should be included in MC.
- Vector meson production should be included (only model from NJL-Jet is available in the market).
- More general formalism for parton 4 momenta implementation should be studied.
- Fit available SIDIS data for each model to have precise estimate of extraction accuracy.

Global Fit Should Include Different Underlying Mechanisms

Constrains

Disorder

Strictly ordered

Thank you!

Support

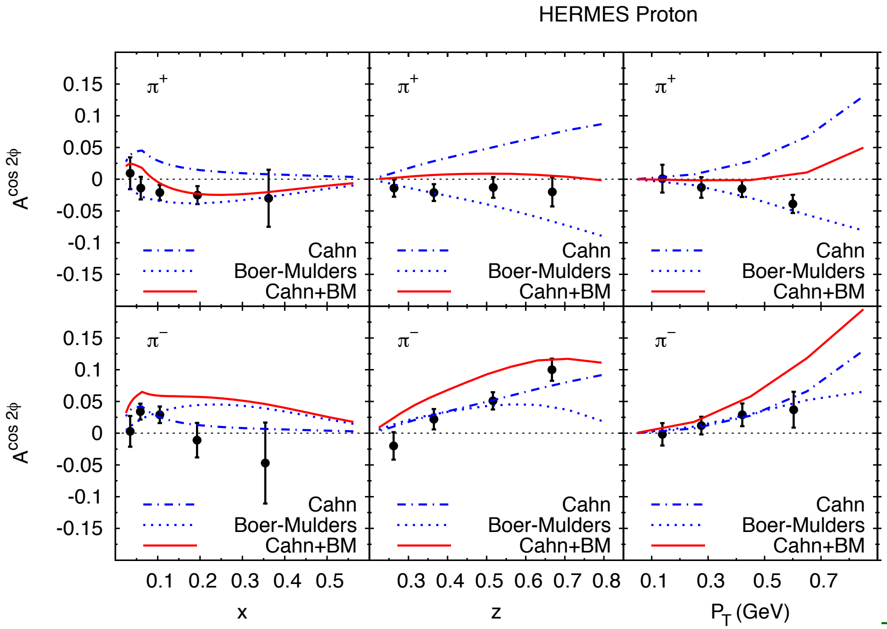
Smearing effect due to the Fragmentation

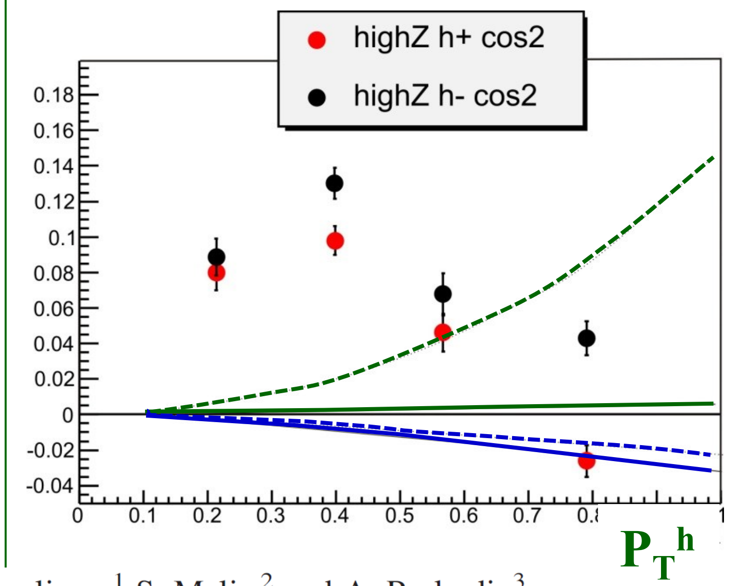
We compare the above results with those obtained without fragmentation, Eqs. (48) and (49), and see that we have a clear smearing effect on the azimuthal asymmetry in both e^-N and e^-A-scatterings. The smearing factors are given by,

$$\frac{\langle\cos\phi_h\rangle_{eN}}{\langle\cos\phi\rangle_{eN}}\Big|_{|\vec{p}_{h\perp}|=z|\vec{k}_\perp|} = \frac{\beta z^2}{\beta z^2+\alpha_F}, \tag{58}$$

$$\frac{\langle\cos\phi_h\rangle_{eA}}{\langle\cos\phi\rangle_{eA}}\Big|_{|\vec{p}_{h\perp}|=z|\vec{k}_\perp|} = \frac{(\beta+\Delta_{2F})z^2}{(\beta+\Delta_{2F})z^2+\alpha_F}. \tag{59}$$

Cos 2 ϕ_h



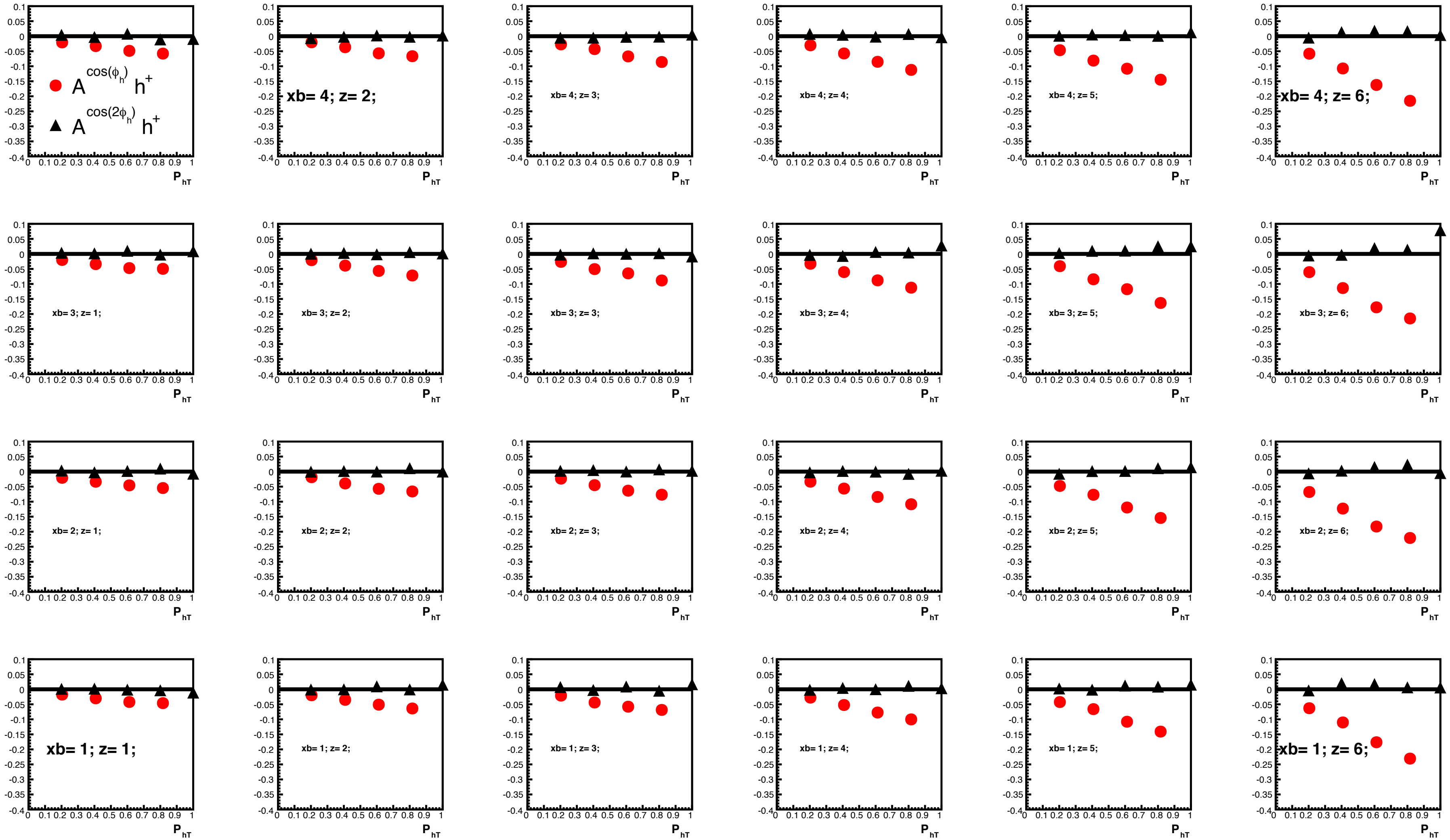


M. Boglione,[1] S. Melis,[2] and A. Prokudin[3]

Anna Martin

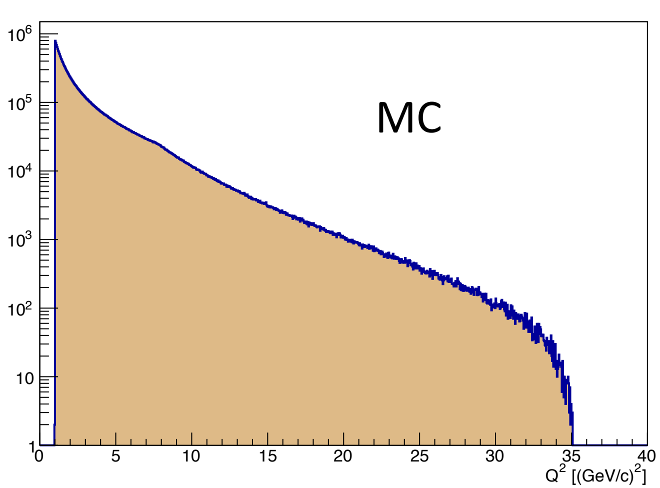
Current model calculations are not support by experimental measurements.

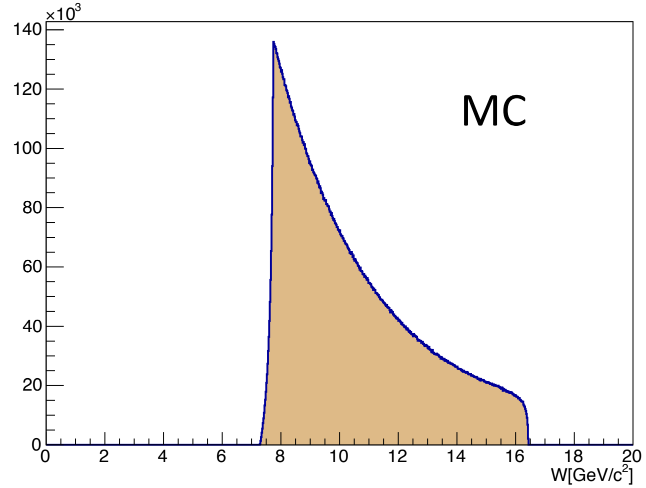
Cahn from MC



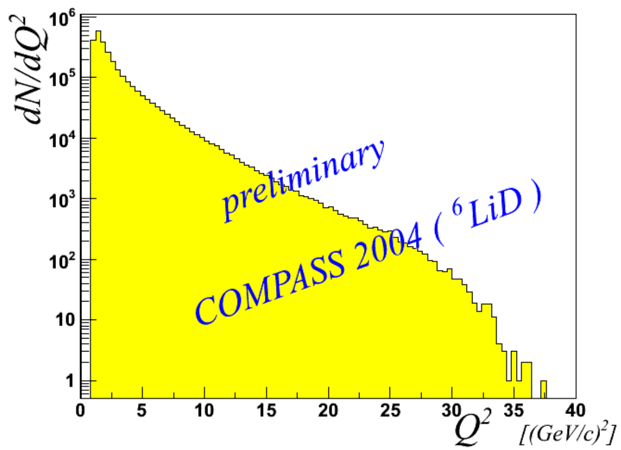
Cos $2\phi_h$ from Cahn for positive hadrons is consistent with zero

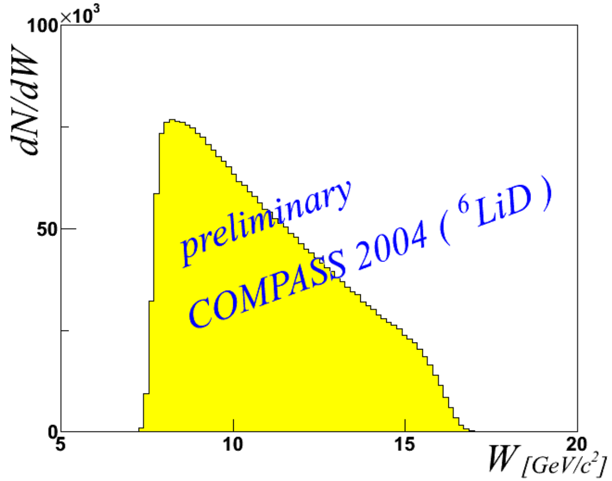
Outcome of MC at 160 GeV



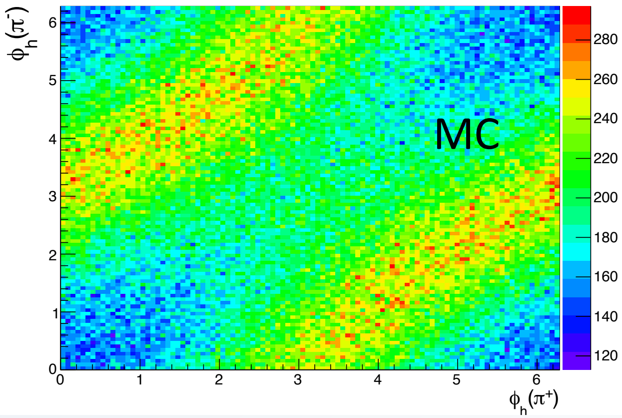


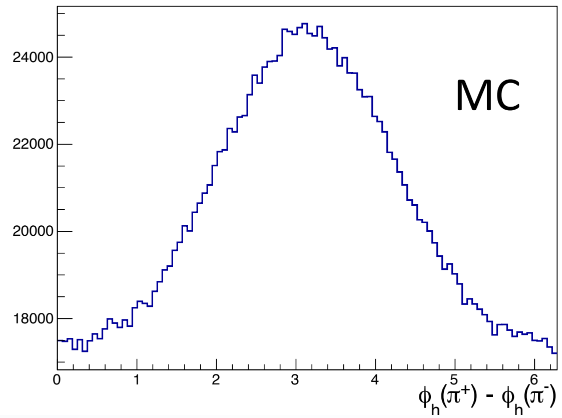
Nice agreement (COMPASS acceptance is not applied to MC)

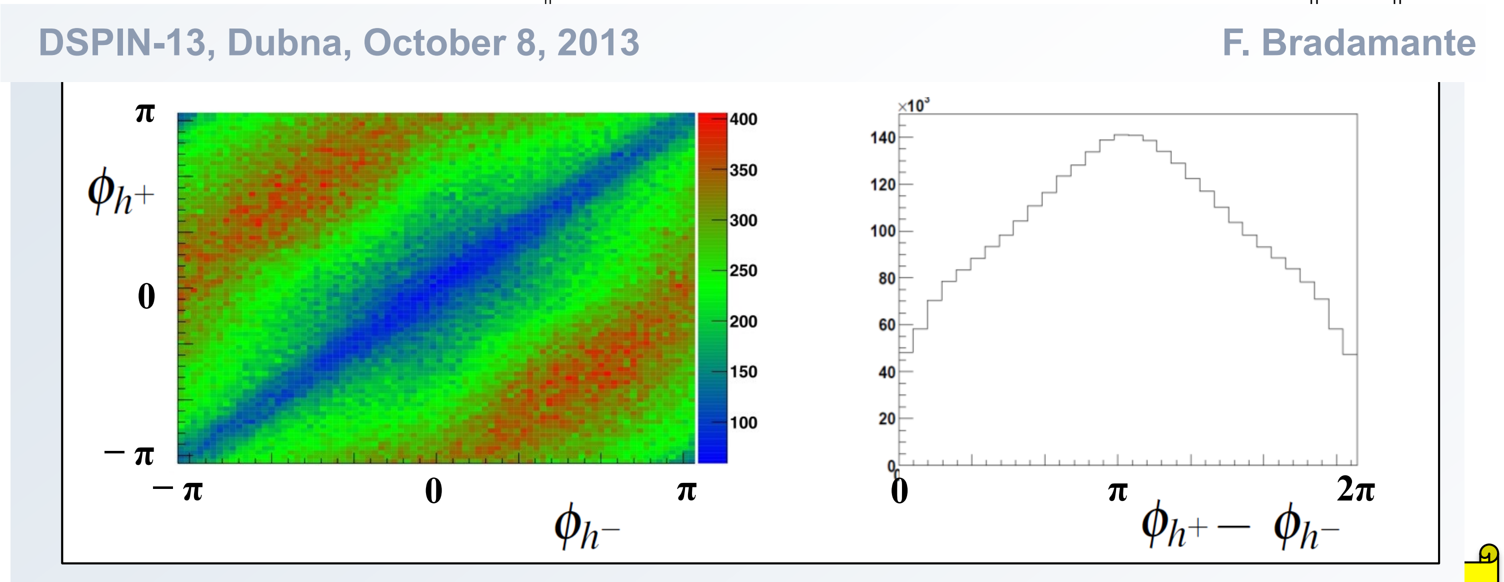




Outcome of MC at 160 GeV







Reasonable agreement even w/o COMPASS acceptance.