Studies of Dihadron Electroproduction in DIS with Transversely Polarized HD Target

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Proposal **PR12-12-009**

- Measure transverse target SSA in hadron pair production in SIDIS
- Study the transversity distribution function and interference effects in hadronization

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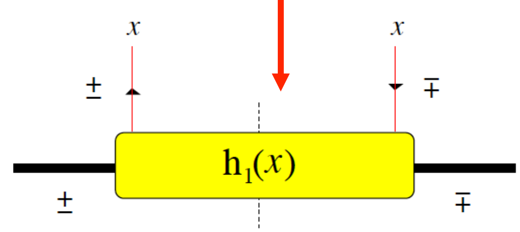
Outline

Introduction
- Di-hadron production
- Transversity distribution

Projections for 12 GeV

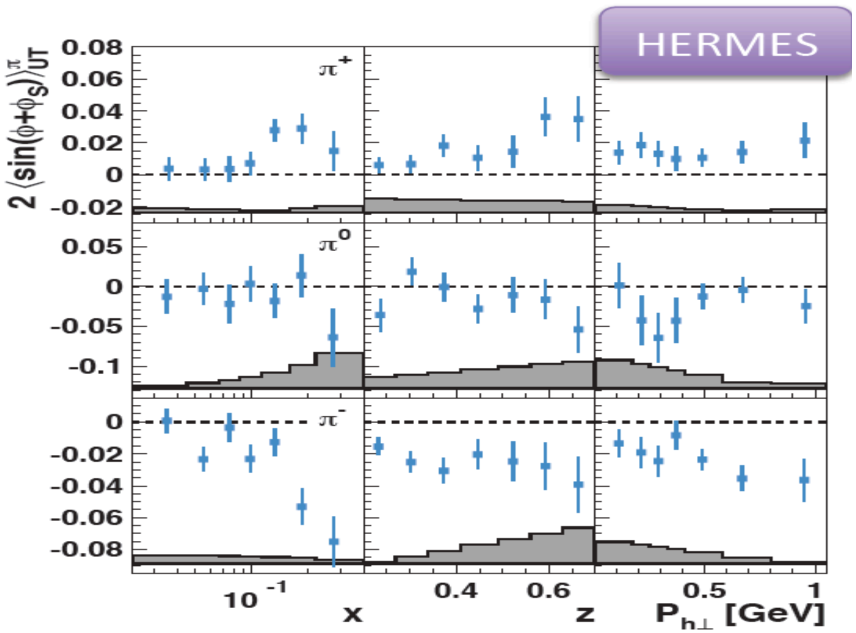
Summary

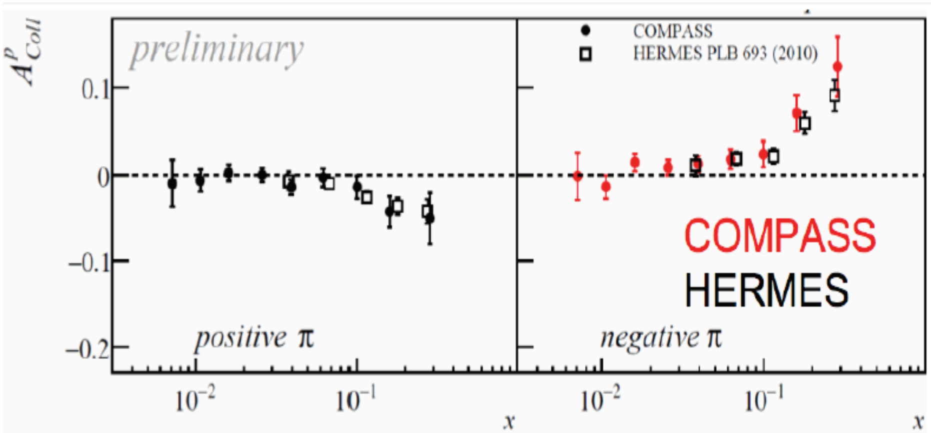
N \ q	U	L	T
U	f_1		$h_1^{\perp}$
L		g_1	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	g_{1T}	h_1 $h_{1T}^{\perp}$



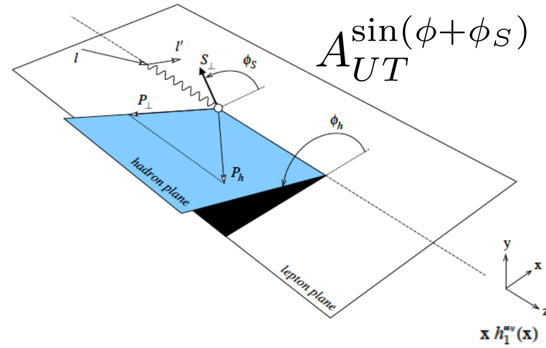
Provide, a complementary to Collins effect, measurement of the leading twist transversity distribution, h_1

Transversity: Current status from Collins asymmetries



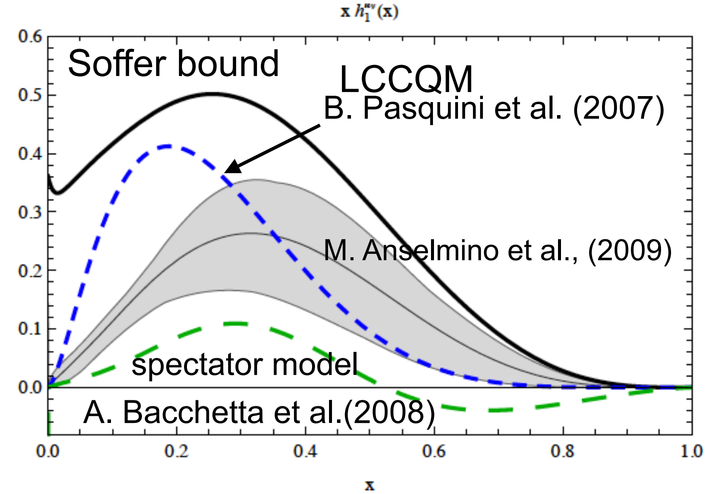


Effects large at large x



$$A_{UT}^{\sin(\phi+\phi_S)} \propto h_1^q(x) \otimes H_1^{\perp q\to h}(z)$$

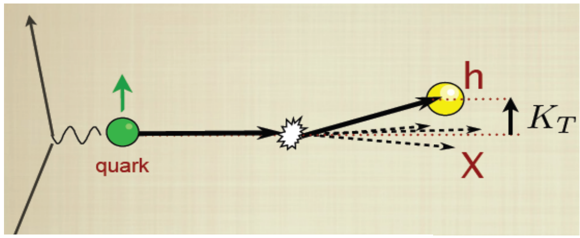
fraction of virtual photon energy carried by detected hadron



- Existing data limited to x < 0.3
- Statistics not enough to adress p_T dependence
  → gaussian ansatz
- Fragmentation extracted from high energy colliders
  → evolution properties assumed

Transversity extraction from single-hadron SSAs

No simple way to extract transversity



$$F_{UT}^{\sin(\phi_h+\phi_S)} = \mathcal{C}\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h} h_1 H_1^{\perp}\right]$$

$$\mathcal{C}\left[w\, f\, D\right] = x\sum_a e_a^2 \int d^2\boldsymbol{p}_T\, d^2\boldsymbol{k}_T\, \delta^{(2)}\left(\boldsymbol{p}_T - \boldsymbol{k}_T - \boldsymbol{P}_{h\perp}/z\right) w(\boldsymbol{p}_T, \boldsymbol{k}_T)\, f^a(x, p_T^2)\, D^a(z, k_T^2)$$

A model independent TMD flavor decomposition procedure is required to estimate the systematic error of extraction of transversity TMD.

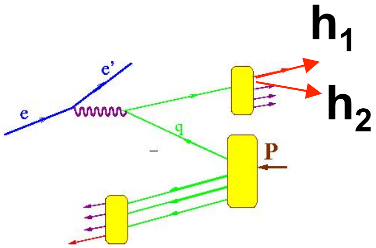
Bessel weighting procedure proposed by Boer, Gamberg, Musch &Prokudin arXiv: 1107.5294 requires detailed measurements in a wide kinematic range in x,z and P_T!

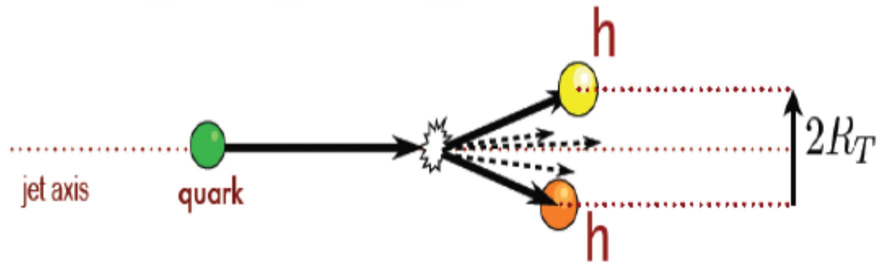
$$\int_0^{2\pi}\frac{d\phi_S}{2\pi}\int_0^{2\pi} d\phi_h\, \sin(\phi_h+\phi_S)\int_0^{\infty} d|\boldsymbol{P}_{h\perp}|\,|\boldsymbol{P}_{h\perp}|\,\frac{2J_1(|\boldsymbol{P}_{h\perp}||\boldsymbol{b}_T|)}{zM_h|\boldsymbol{b}_T|}\left[\frac{d\sigma}{dx\, dy\, d\phi_S\, dz_h\, d\phi_h\, |\boldsymbol{P}_{h\perp}| d|\boldsymbol{P}_{h\perp}|}\right]$$
$$= \frac{\alpha^2}{yQ^2}\frac{y^2}{(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)|\boldsymbol{S}_\perp|\,\varepsilon\sum_a e_a^2\, \tilde{h}_1^{(1)a}(x, z^2\boldsymbol{b}_T^2)\; \tilde{H}_1^{\perp(1)a}(z, \boldsymbol{b}_T^2)\ .$$

Fourier transforms to b_T-space

Dihadron production kinematics

z_1, z_2 - fractions of energy carried by a hadrons

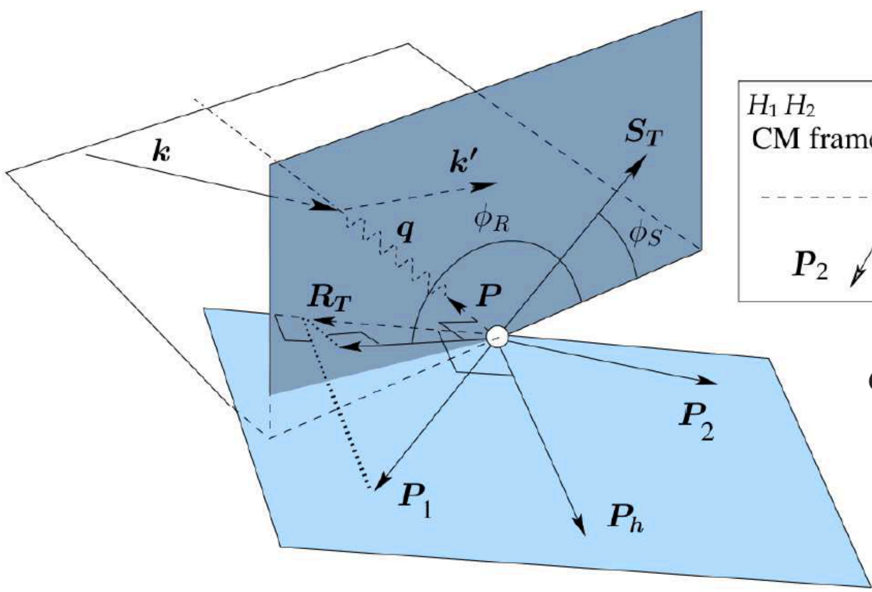


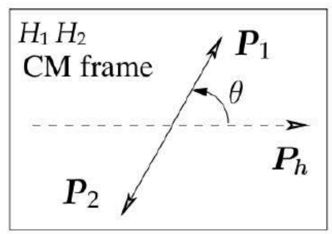


DiFF

$$\boxed{D_1^{q\rightarrow h_1,h_2}(z_1, z_2, R_T^2)}$$

- Factorization proven
- Evolution known
- Extracted at BELLE for ππ pairs, planned for πK pairs





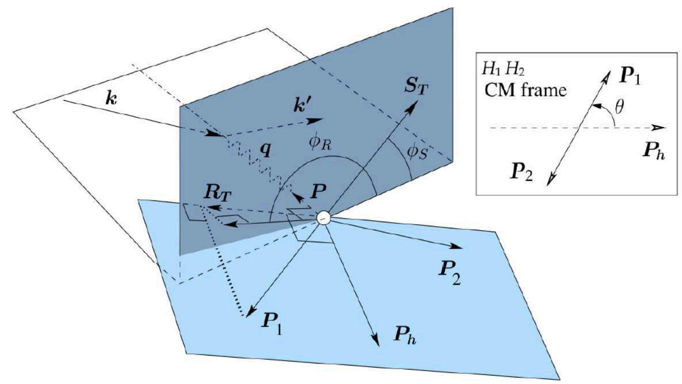
$$\phi_R \equiv \frac{(\boldsymbol{q}\times\boldsymbol{k})\cdot\boldsymbol{R_T}}{|(\boldsymbol{q}\times\boldsymbol{k})\cdot\boldsymbol{R_T}|}$$

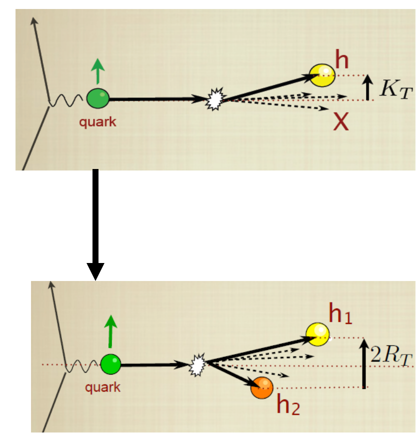
$$\boldsymbol{R_T} = \boldsymbol{R} - (\boldsymbol{R}\cdot\hat{\boldsymbol{P}}_{\boldsymbol{h}})\hat{\boldsymbol{P}}_{\boldsymbol{h}}$$

Dihadron productions offers exciting possibility to access transversity distribution as we deal with the product of functions instead of convolution

Dihadron cross sections with transverse target

$$
\begin{aligned}
\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_R\,dM_h^2\,d\cos\theta} &= \\
\frac{\alpha^2}{xy\,Q^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)&\Bigg\{F_{UU,T}+\varepsilon\,F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_R\,F_{UU}^{\cos\phi_R} \\
&+\varepsilon\cos(2\phi_R)\,F_{UU}^{\cos 2\phi_R}+\lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_R\,F_{LU}^{\sin\phi_R} \\
&+|\boldsymbol{S}_T|\Bigg[\sin(\phi_R-\phi_S)\left(F_{UT,T}^{\sin(\phi_R-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_R-\phi_S)}\right) \\
&\quad\boxed{+\,\varepsilon\,\sin(\phi_R+\phi_S)\,F_{UT}^{\sin(\phi_R+\phi_S)}}+\varepsilon\,\sin(3\phi_R-\phi_S)\,F_{UT}^{\sin(3\phi_R-\phi_S)} \\
&\quad+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_R-\phi_S)\,F_{UT}^{\sin(2\phi_R-\phi_S)}\Bigg] \\
&+|\boldsymbol{S}_T|\lambda_e\Bigg[\sqrt{1-\varepsilon^2}\,\cos(\phi_R-\phi_S)\,F_{LT}^{\cos(\phi_R-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S} \\
&\quad+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_R-\phi_S)\,F_{LT}^{\cos(2\phi_R-\phi_S)}\Bigg]\Bigg\},
\end{aligned}
$$





Similar to single hadron SIDIS with $\phi_R \rightarrow \phi_h$

Accessing transversity from target SSA

$$A_{UT}^{\sin(\phi_R+\phi_S)\sin\theta}(x,y,z,M_h,Q) = \frac{1}{|\mathbf{S_T}|}\frac{\frac{8}{\pi}\int d\phi_R\, d\cos\theta\ \sin(\phi_R+\phi_S)\left(d\sigma^{\uparrow}-d\sigma^{\downarrow}\right)}{\int d\phi_R\, d\cos\theta\,(d\sigma^{\uparrow}+d\sigma^{\downarrow})}$$

$$= \frac{\frac{4}{\pi}\varepsilon\int d\cos\theta\, F_{UT}^{\sin(\phi_R+\phi_S)}}{\int d\cos\theta\ (F_{UU,T}+\epsilon F_{UU,L})}\ . \qquad (1)$$

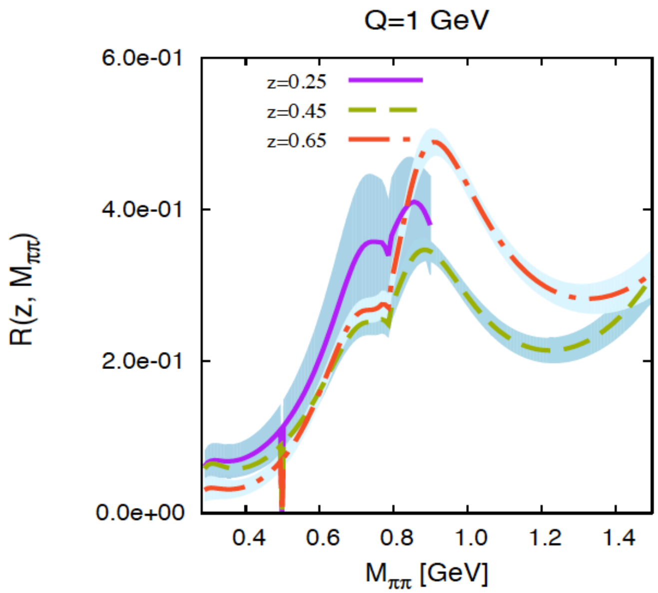
Leading twist

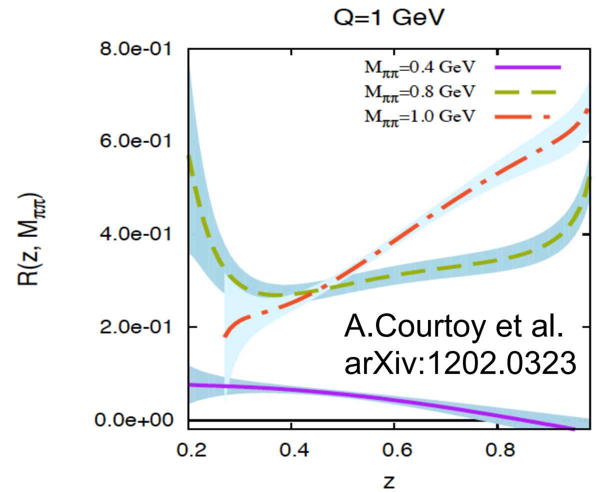
$$A_{UT}^{\sin(\phi_R+\phi_S)\sin\theta}(x,y,z,M_h,Q) = -\frac{B(y)}{A(y)}\frac{|\mathbf{R}|}{M_h}\frac{x}{x}\frac{\sum_q e_q^2\, h_1^q(x)\, H_{1,sp}^{\sphericalangle,q}(z,M_h)}{\sum_q e_q^2\, f_1^q(x)\, D_{1,ss+pp}^q(z,M_h)}$$

$$D_1^u(z,M_h) = D_1^d(z,M_h) \longrightarrow \frac{h_1^u - h_1^d/4}{f_1^u + f_1^d/4}$$

- Target spin asymmetry can be presented as a flavor sum of products of PDF and FF.
- SSA A_{UT} on proton provides access to transversity flavor sum (need interference FFs)

Dihadron Fragmentation





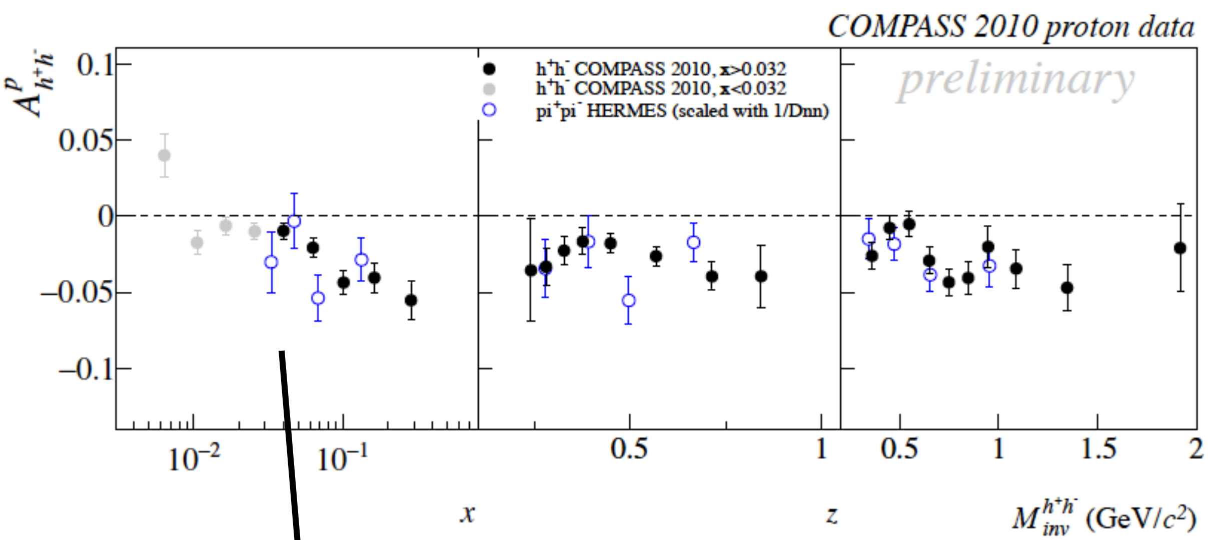
$$D_1^{u\to\pi^+\pi^-} = D_1^{d\to\pi^+\pi^-}$$

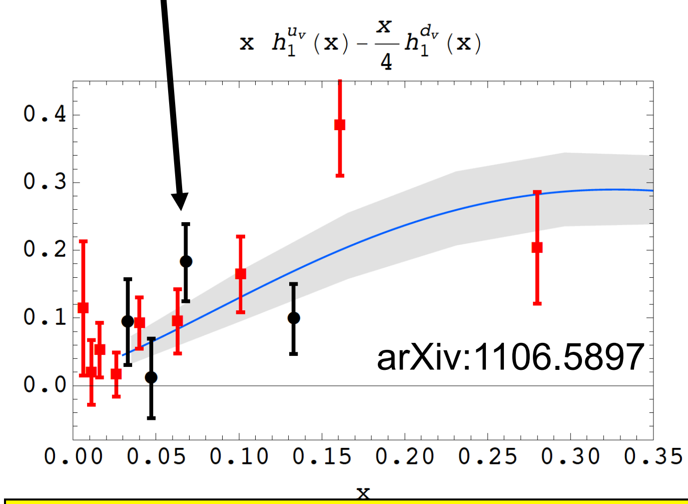
•Significant DiFF published by BELLE

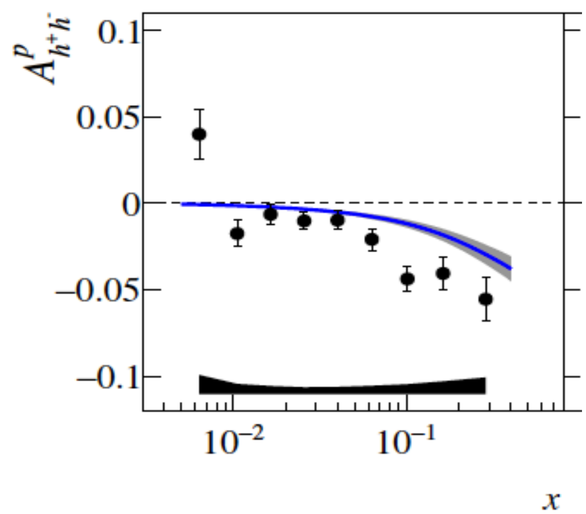
$$\frac{n^u_{H_1^{\sphericalangle}}}{n^u_{D_1}}(\sim 2\ \mathrm{GeV}^2)\Big/\frac{n^u_{H_1^{\sphericalangle}}}{n^u_{D_1}}(100\ \mathrm{GeV}^2) = 92\% \pm 8\%$$

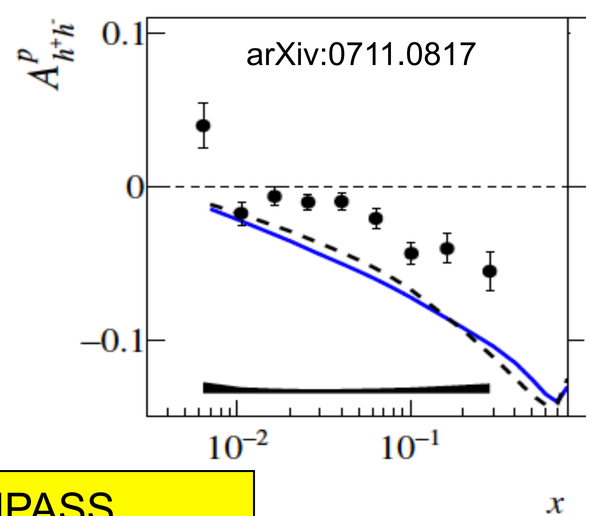
- Evolution effects small for DiFF/D_1
- DiFF represent the easiest way to measure the polarization of a fragmenting quark
- DiFF contain information on interferences between different channels (e.g., rho and continuum), which cannot be encoded in MC generators based on the Lund model

Dihadron production with transversely polarized target



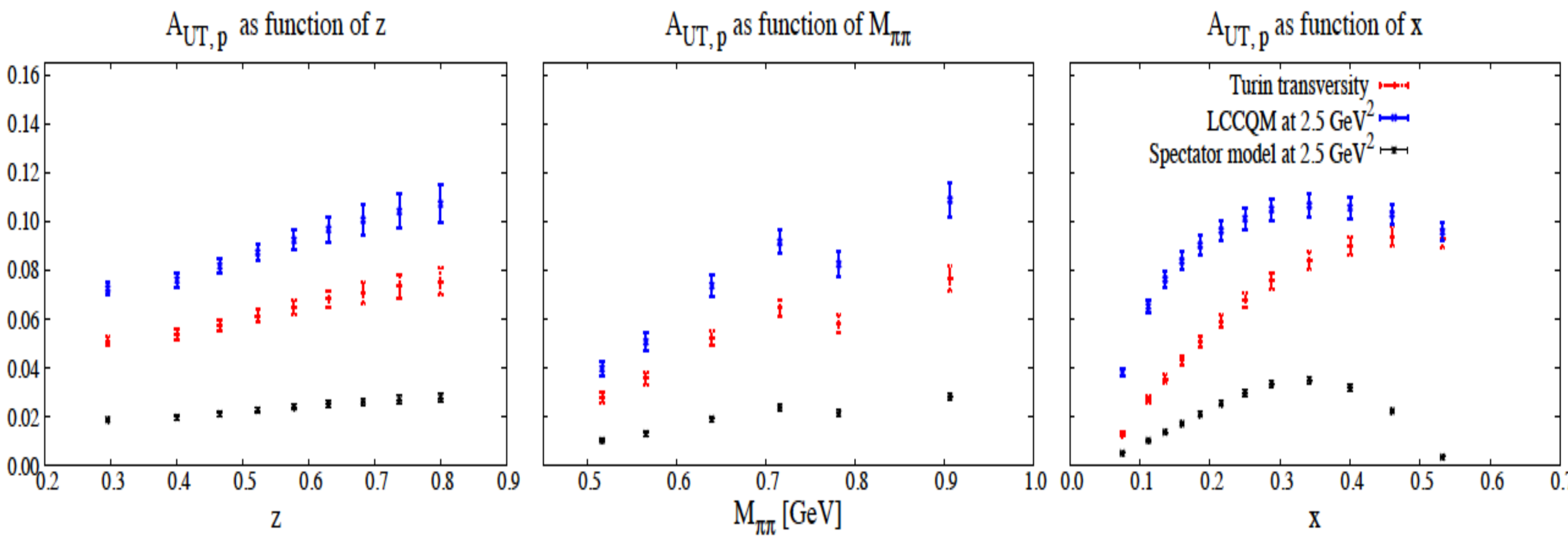






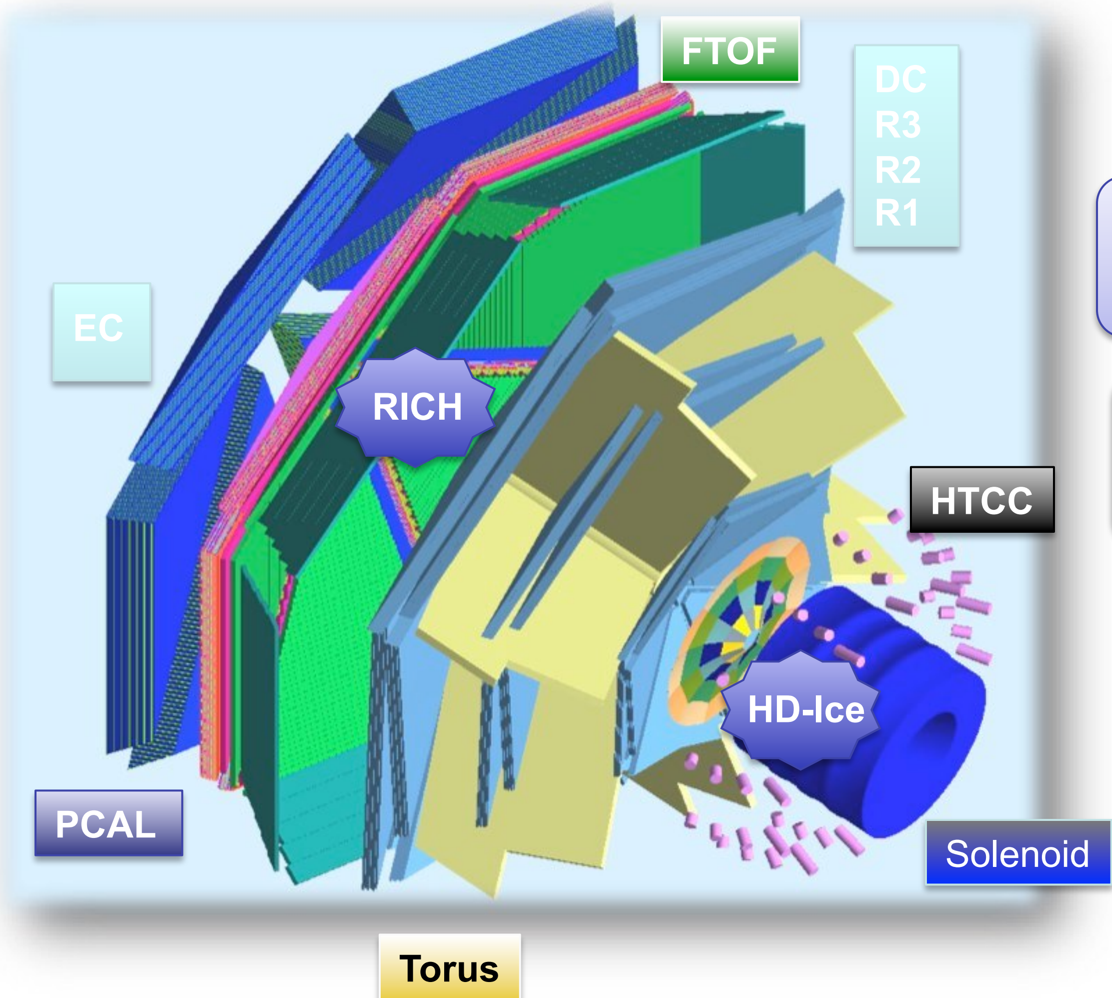
- Significant asymmetries observed at HERMES and COMPASS
- Large variations in model predictions

Model predictions: polarized target



- Large target SSA predicted for ππ pair production
- Large variations of the magnitude from different models

CLAS12 Configuration



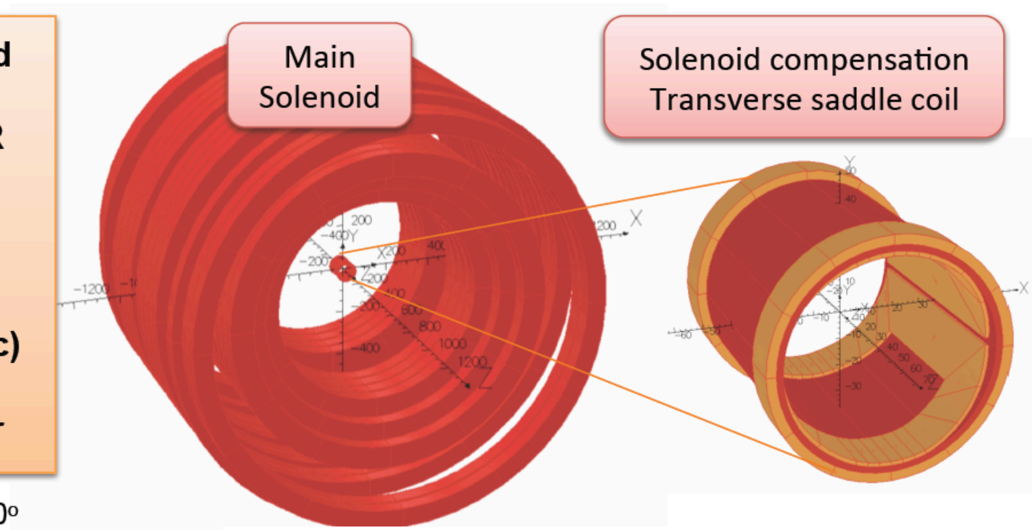
HD-Ice: Transverse Target with P=60% (common to PR12-12-010 and C12-11-111)

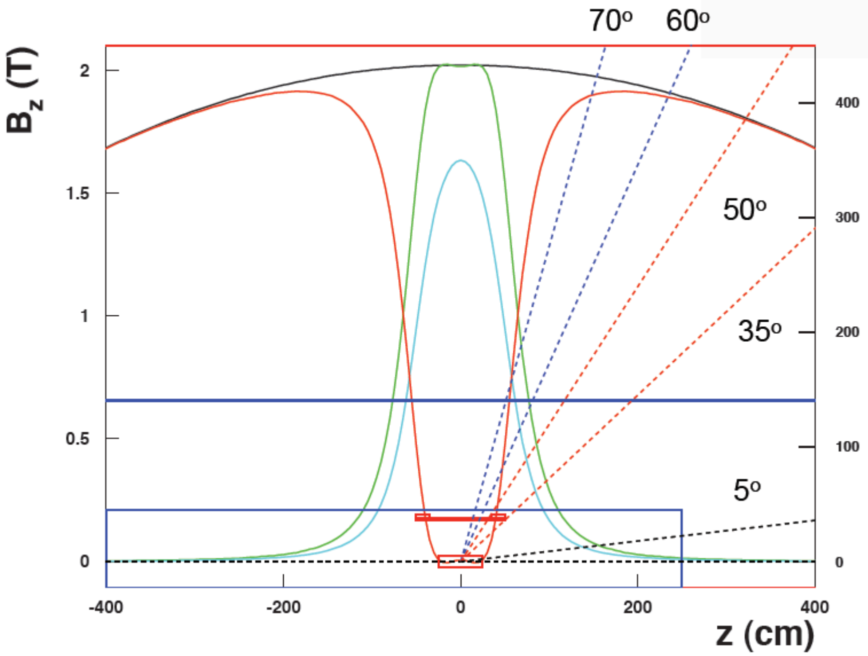
Open acceptance and high resolution important in particular for hadron pair production

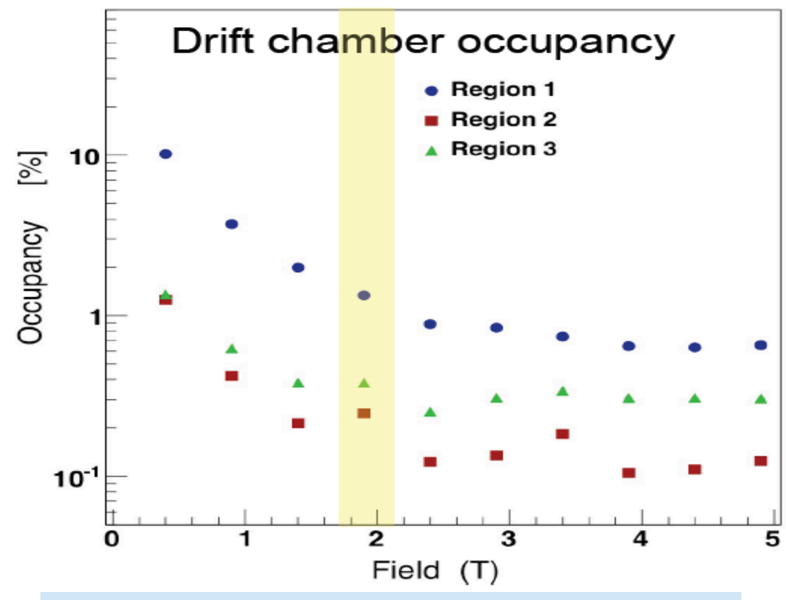
Designed for lumi $10^{35}cm^{-2}sec^{-1}$ (request $5.10^{33}cm^{-2}sec^{-1}$)

Transverse target configuration

- 2T compensating, 0.5T transverse field
- Enhanced version of the existing NMR magnet system inside HD-ice cryostat
- Free forward acceptance (up to 35°)
- Recoiling proton detection (>0.4 GeV/c)
- No impact on CLAS12 central detector

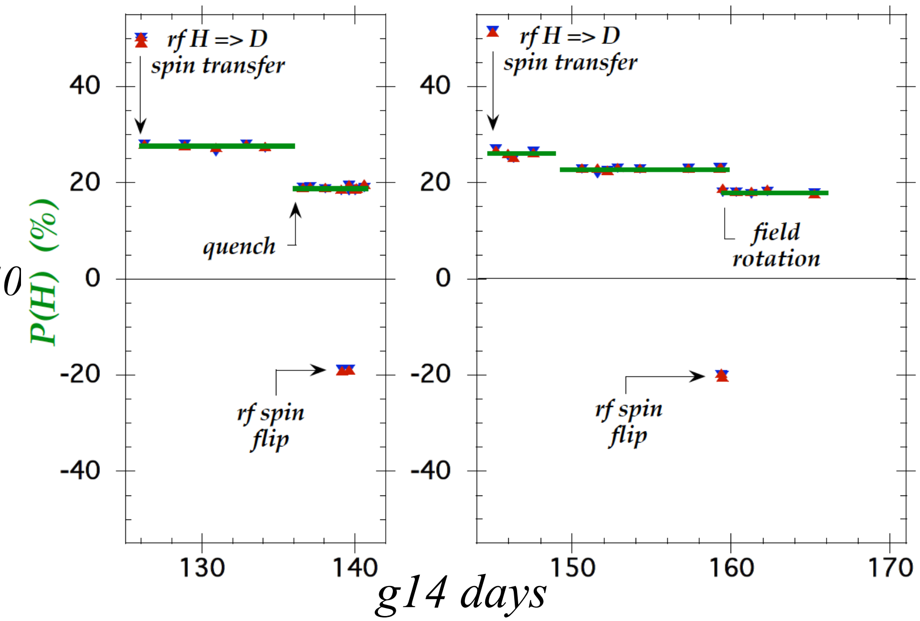






HDice target

- *HD targets condensed, polarized and aged to the Frozen-Spin state in HDice Lab*
- *transferred as solid, polarized HD between cryostats*
- *In-Beam Cryostat (IBC) operates in Hall at 50 mK, 0.9 tesla*
- *g14 ran from Nov/11 to May/12 with 15mm Ø ×50mm long HD cells*
- *γ-beam lifetimes ~ years with 10^8 γ/s*

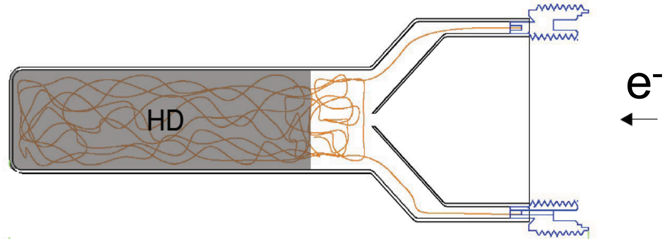


Material	gm/cm^2	mass fraction (%)
HD	0.735	78%
Al	0.139	15%
C_2ClF_3	0.065	7%

- *HD targets used for eHD tests in Feb/12 and Mar/12*

➔ *H polarization does not appear to suffer radiation damage with 1 nA; D does*

➔ *heat removal needs improvement – faster raster, larger diameter cell, shorter, additional cooling wires, …*

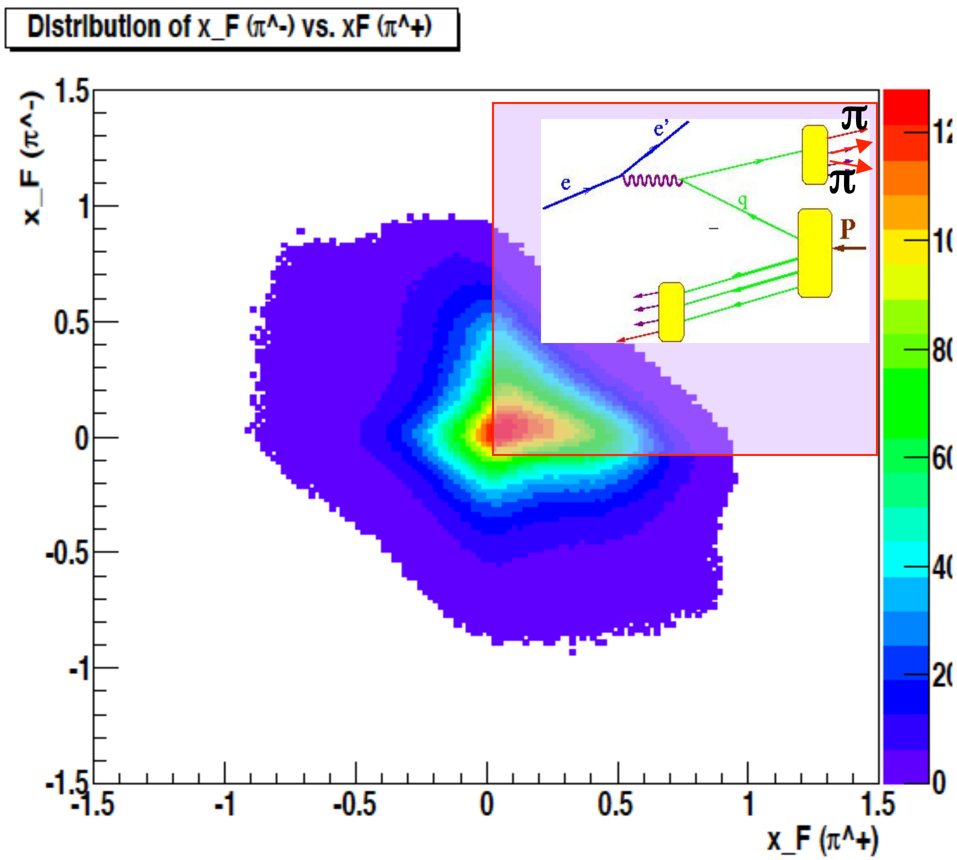


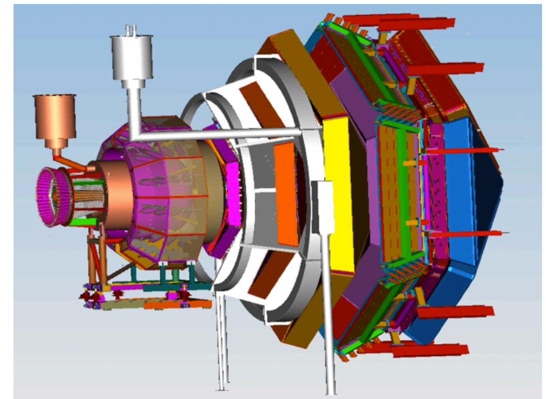
Dihadron production with CLAS12

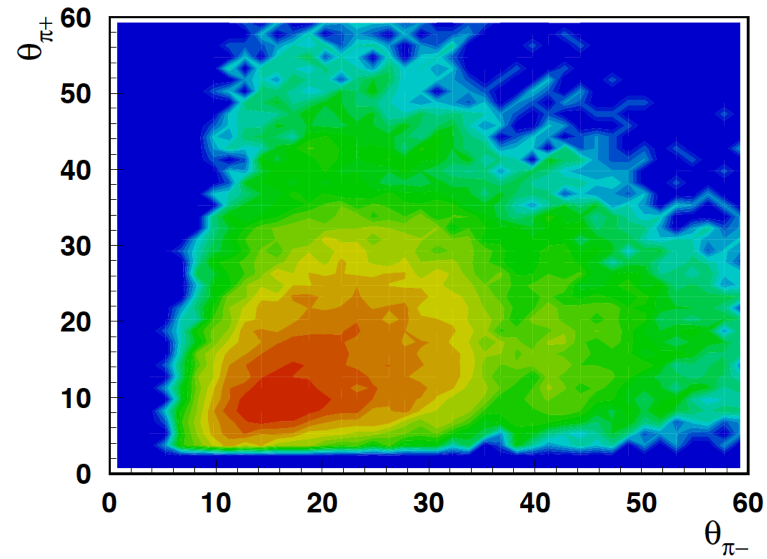
Use the clasDIS (LUND based) generator + FASTMC

to study ππ pairs

x_F - momentum in the CM frame



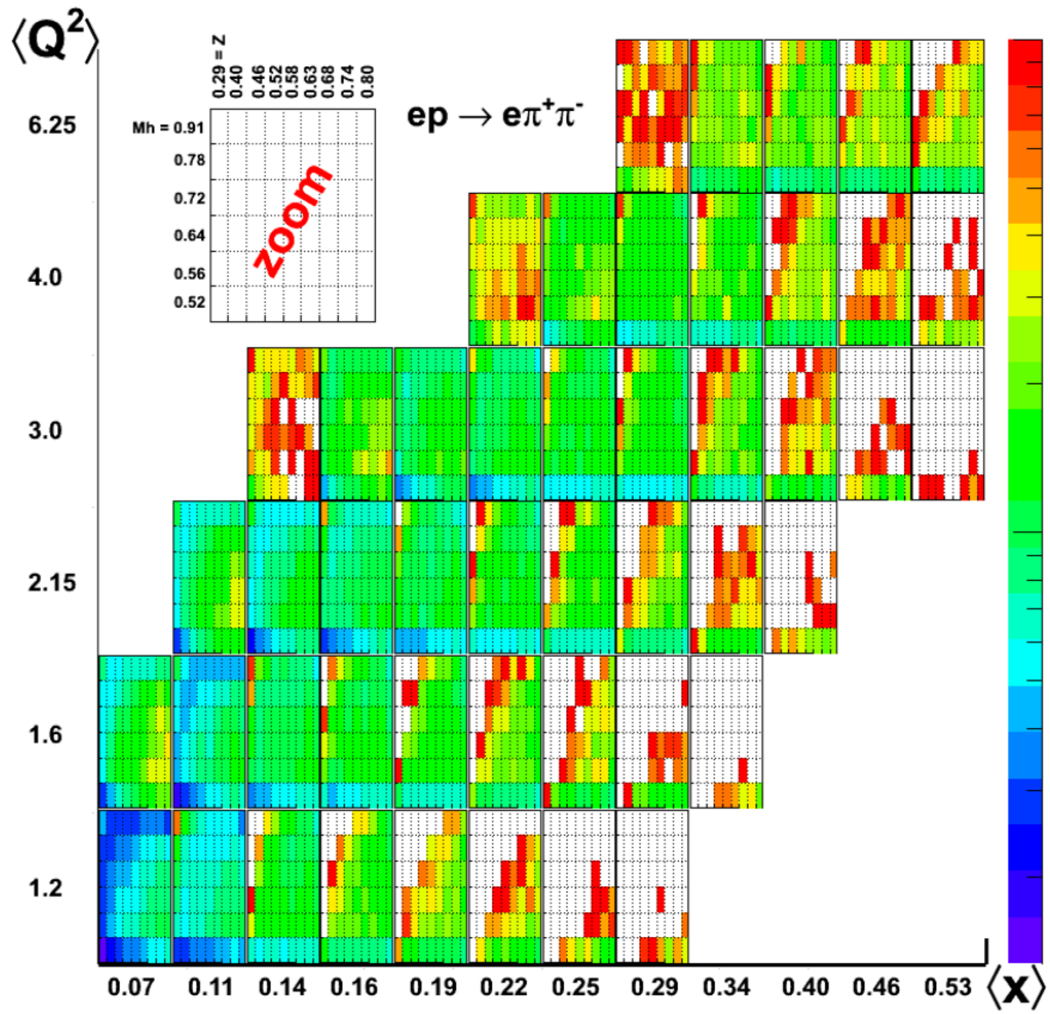


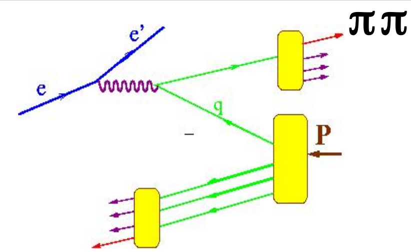


Dihadron sample defined by SIDIS cuts+x_F>0 (CFR) for both hadrons

Wide angular coverage is important

Dihadron production with CLAS12



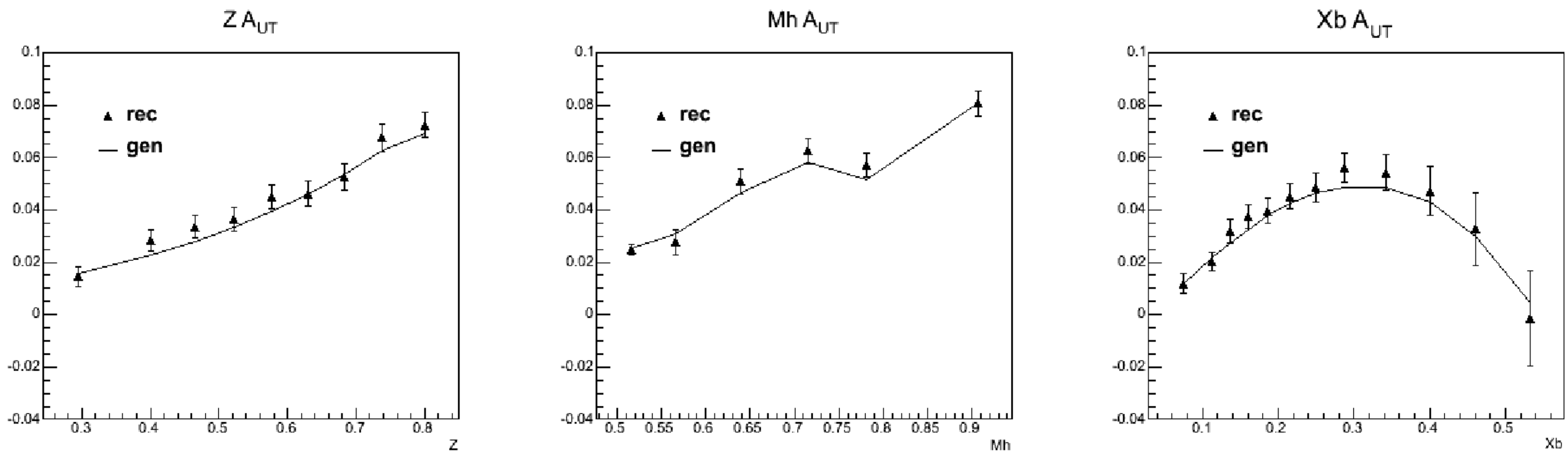


Error source	Systematic error (%)
D background	4
Target polarization P_T	4-5
acceptance corrections	5
Al background contribution	3
Radiative corrections	2
Total	~ 8

CLAS12 will provide precision measurements of target spin asymmetries in a wide range of x and Q^2 in dihadron pair production in SIDIS

Acceptance effects in dihadron production

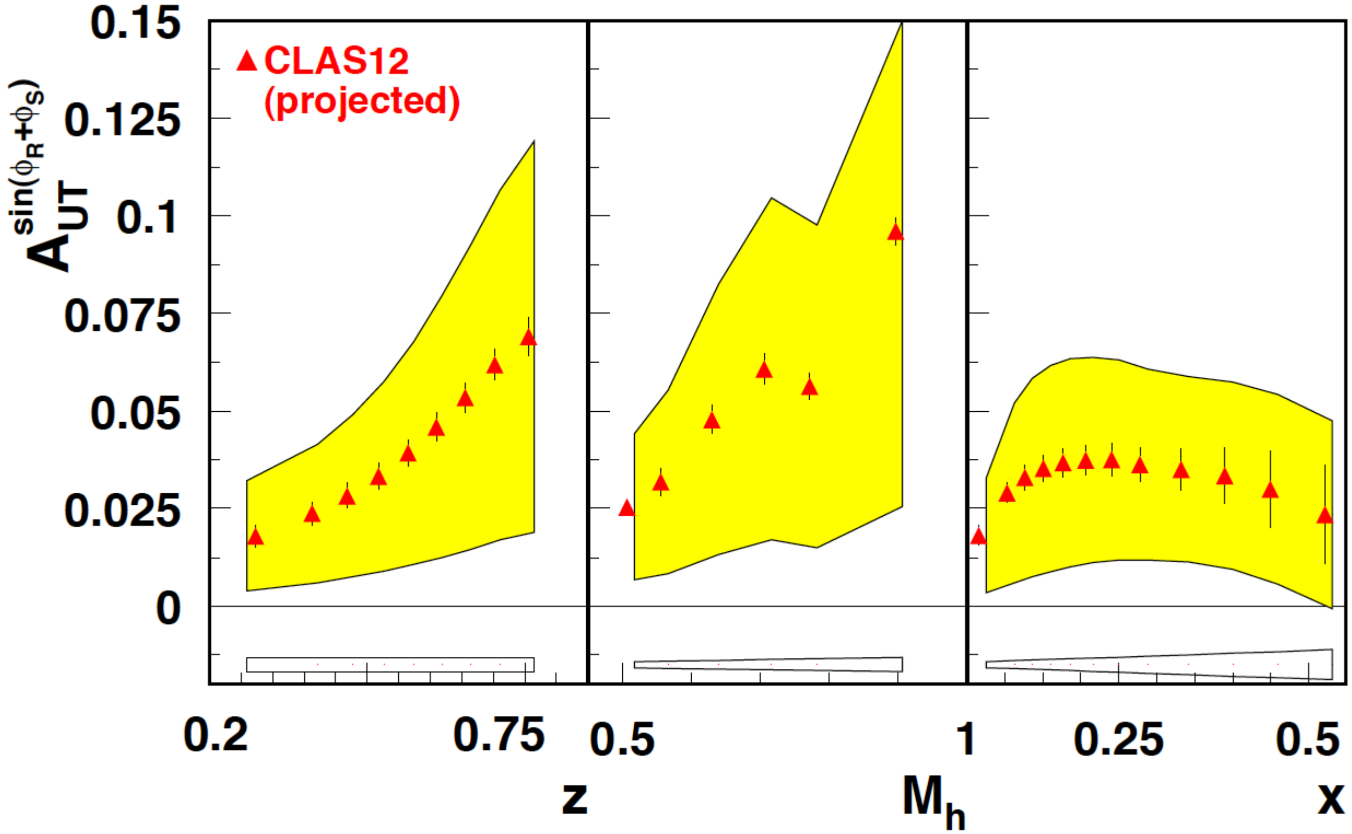
Generate events with all azimuthal modulations in PEPSI → Smearing & acceptance from FASTMC → Reconstruct $A_{UT}^{\sin(\phi+\phi_S)}$ (arXiv:1006.4221 HERMES)



Systematic errors in extraction of di-hadron asymmetries estimated using the FAST-MC with realistic input and maximum-likelihood fit

Dihadron production with CLAS12

100 days of polarized proton
P_T=60%, L=5. 10^{33} $cm^{-2}s^{-1}$



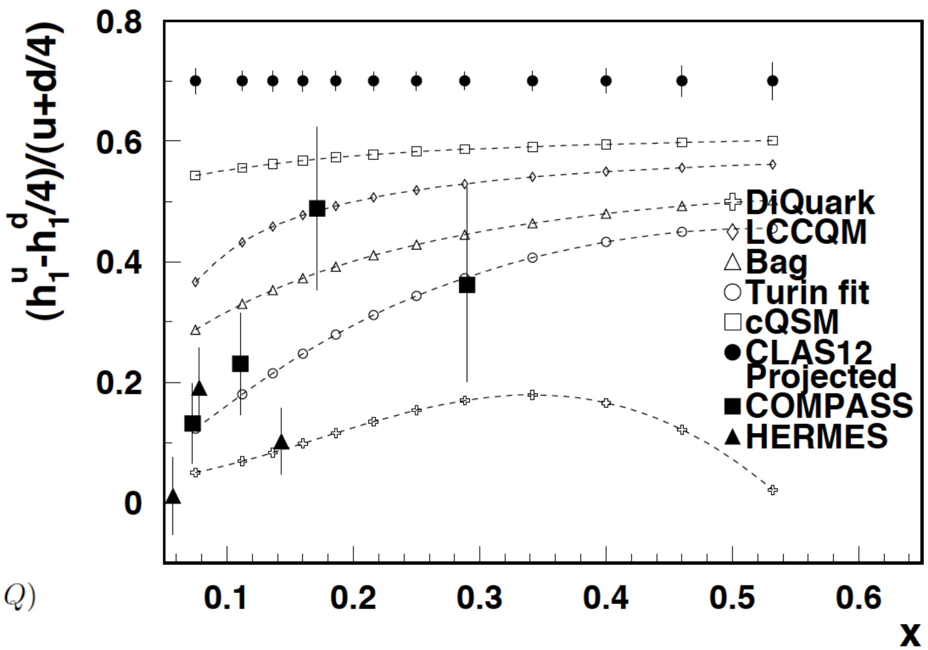
CLAS12 will provide precision measurements of single-target asymmetries in dihadron pair production in SIDIS

Dihadron production with CLAS12

$$D_1^u(z, M_h) = D_1^d(z, M_h)$$

Use Belle measurement

$$|\vec{R}| H_1^{\angle u}(z, M_h) / M_h D_1^u(z, M_h)) \longrightarrow$$



u-dominance

$$\frac{x\, h_1^u(x)}{x\, f_1^u(x)} = -\frac{A(y)}{B(y)} \left(\frac{|\mathbf{R}|}{M_h}\right)^{-1} \frac{D_1^u(z, M_h)}{H_1^{\sphericalangle,u}(z, M_h)} A_{UT}^{\sin(\phi_R+\phi_S)\sin\theta}(x, y, z, M_h, Q)$$

$$\frac{17}{18}\frac{x\, h_1^u(x)}{x\, f_1^u(x)} \models -\frac{A(y)}{B(y)} \left(\frac{|\mathbf{R}|}{M_h}\right)^{-1} \frac{D_1^u(z, M_h)}{H_1^{\sphericalangle,u}(z, M_h)} A_{UT}^{\sin(\phi_R+\phi_S)\sin\theta} \longrightarrow$$

in models extract h_1^u

100 days of transversely polarized HD will allow precision measurement of the transversity distribution.

Summary

- Significant SSA observed in hadron pair production in SIDIS
- The large acceptance of the CLAS12 provides unique possibility to study hadron pairs in electroproduction

Beam request: 100 days of **CLAS12**@ 11 GeV with $L=5.10^{33} cm^{-2} sec^{-1}$ with transversely polarized HD target (shared with E12-11-111)

Precision measurement of forward going high energy $\pi\pi$ pairs in DIS will allow us to:

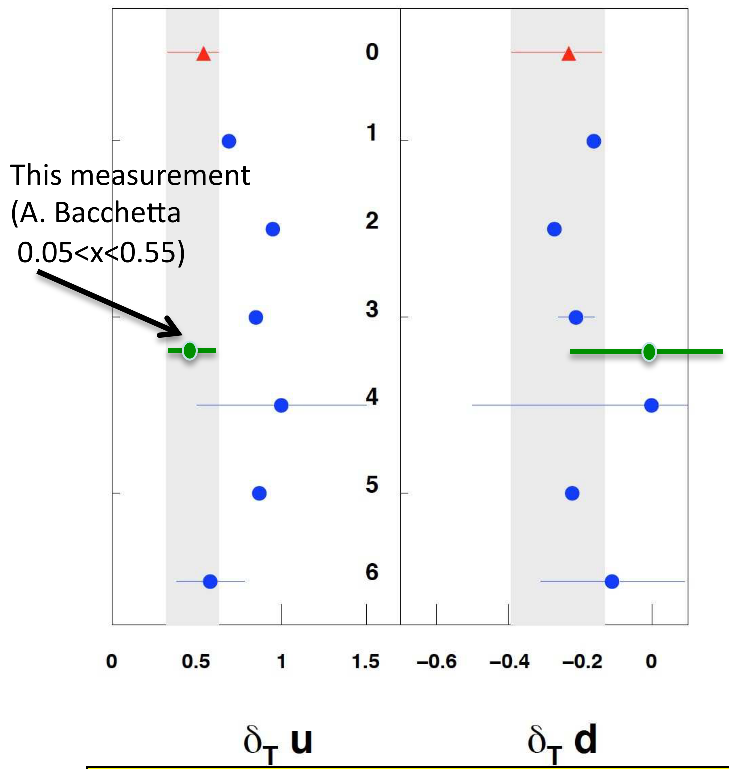
- Provide complementary measurement of the transversity distribution
- Study interference effects in hadronization

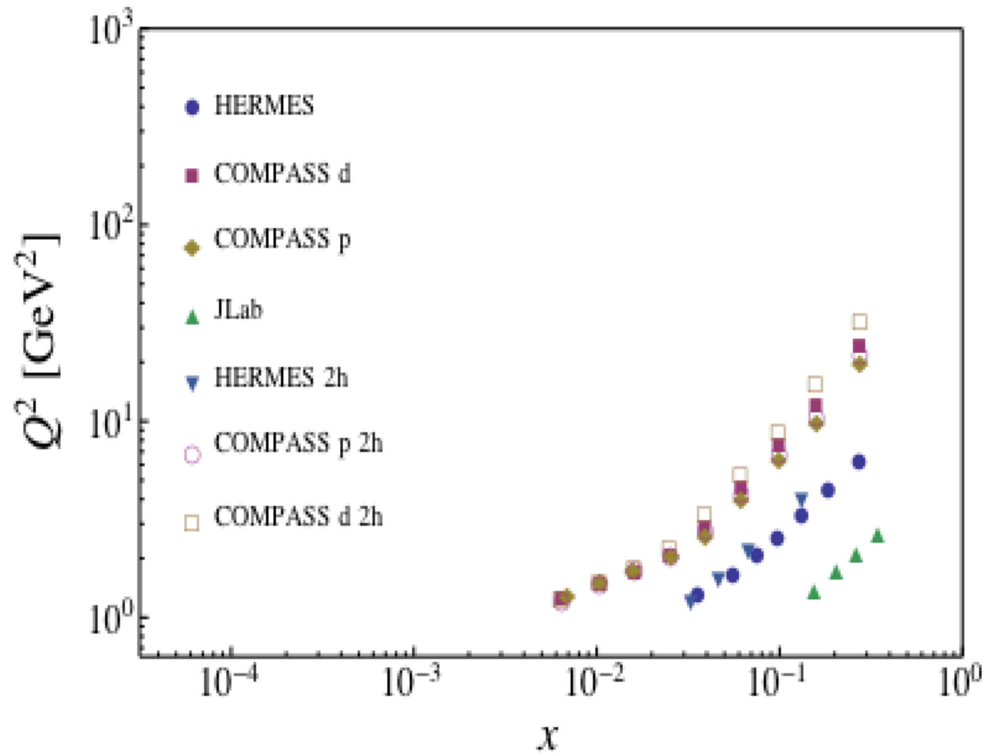
Support slides….

PAC readers comments/requests

- comparison of the proposed measurement (or its complementarity) with other proposals.
- additional complications (having a range of invariant mass and a momentum R to deal with).
- complementarity to other extractions or overlapping and their usefulness to contribute to getting the tensor charge, etc.

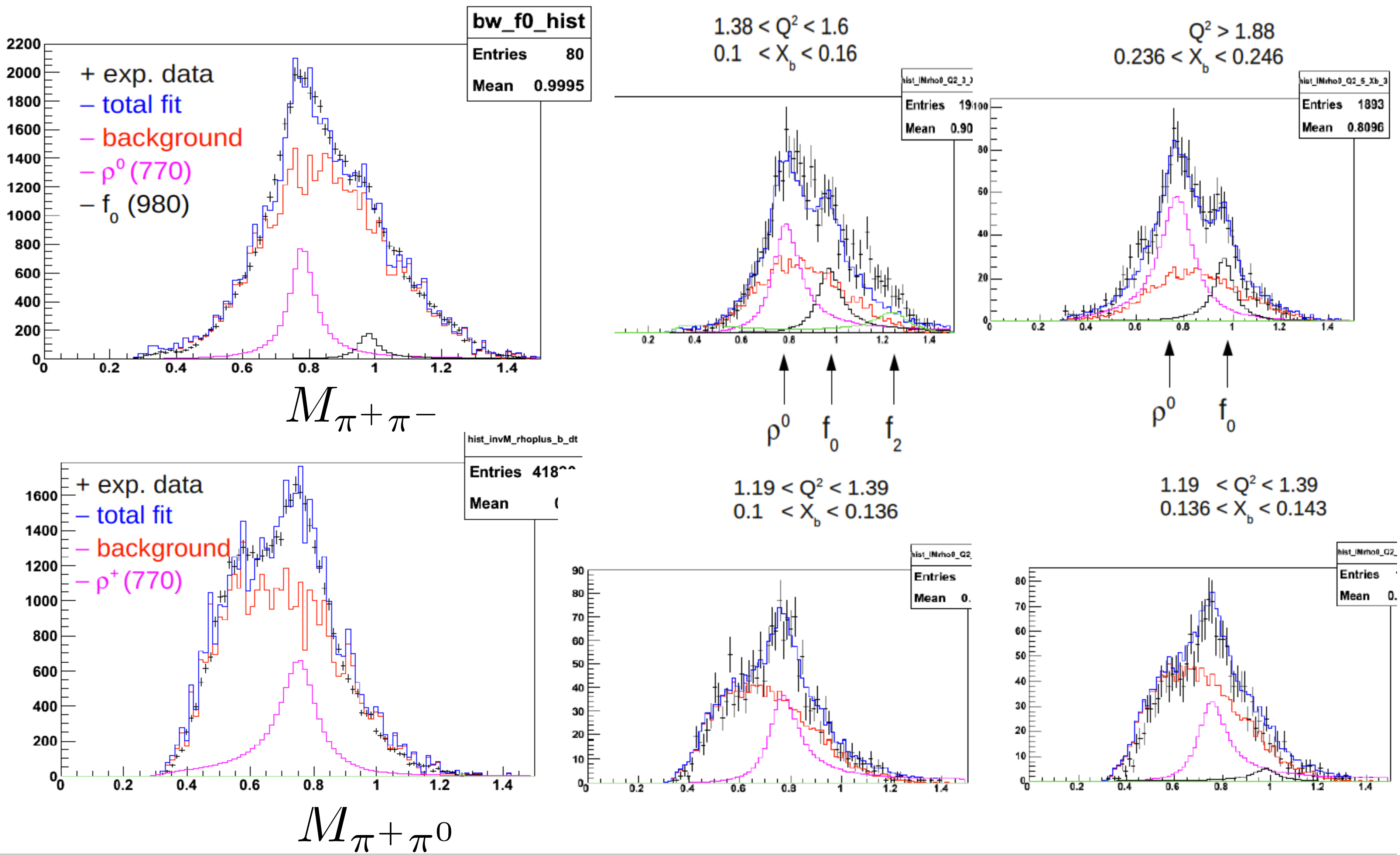
$$\int_{-1}^{1} h_1(x)dx = \int_0^1 (h_1(x) - \bar{h}_1(x))dx$$



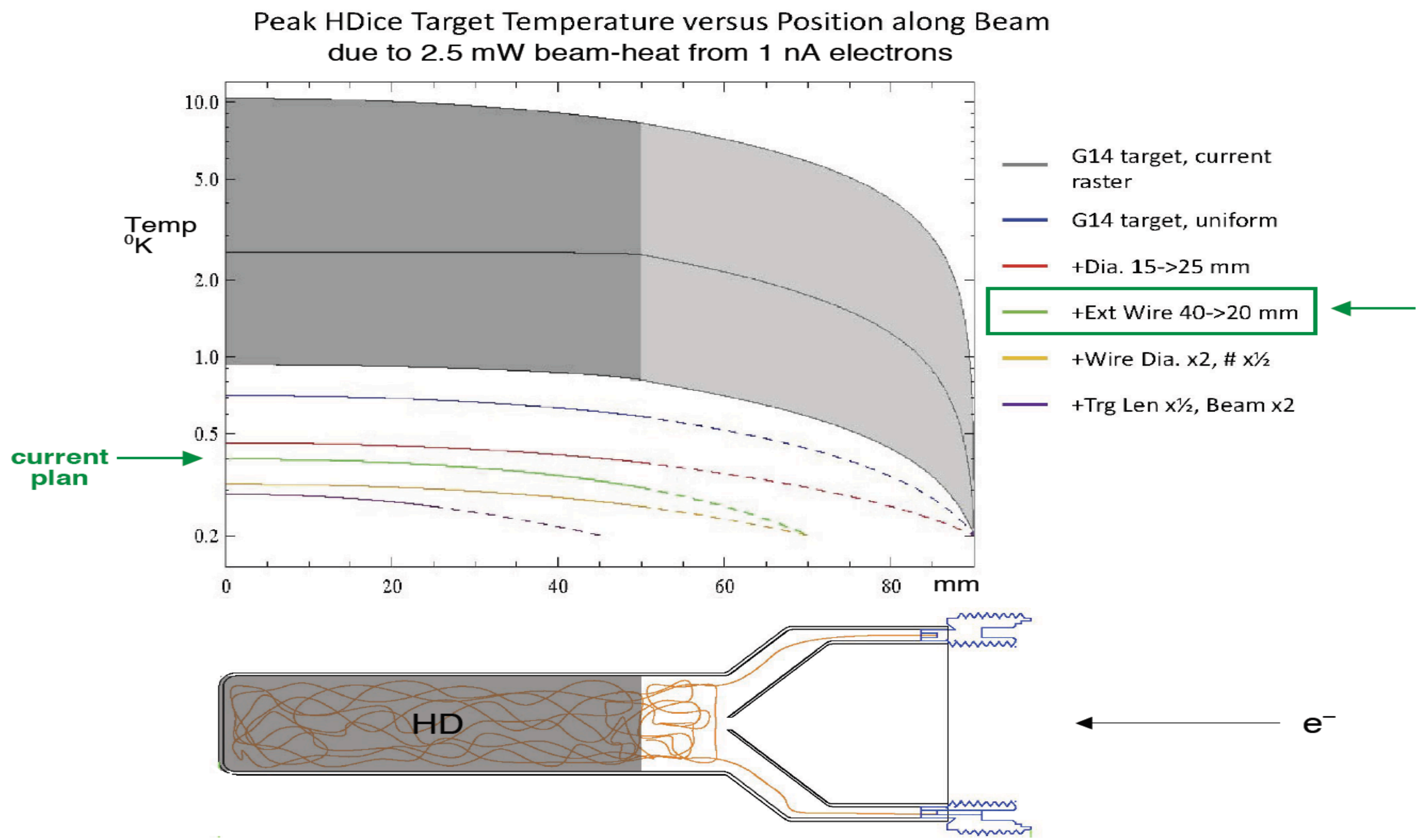


Dihadron production is not increasing the kinematical coverage accessible in single hadron production, but it provides complementary measurements

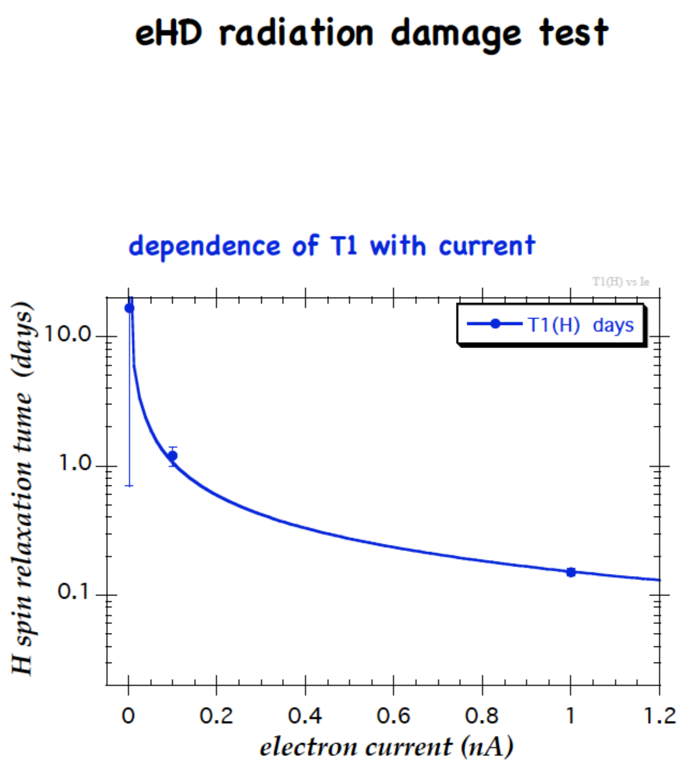
Dihadron simulations with LUND-MC @6 GeV

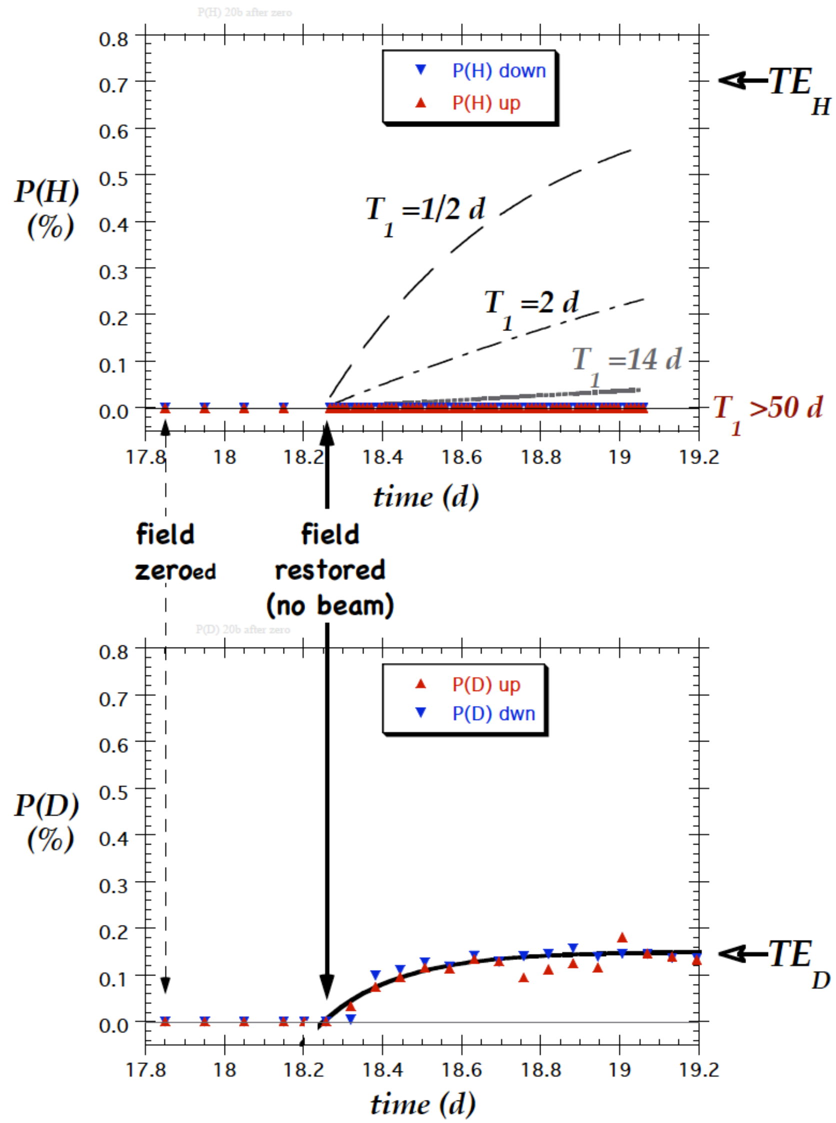


HD polarization during g14/E06-101

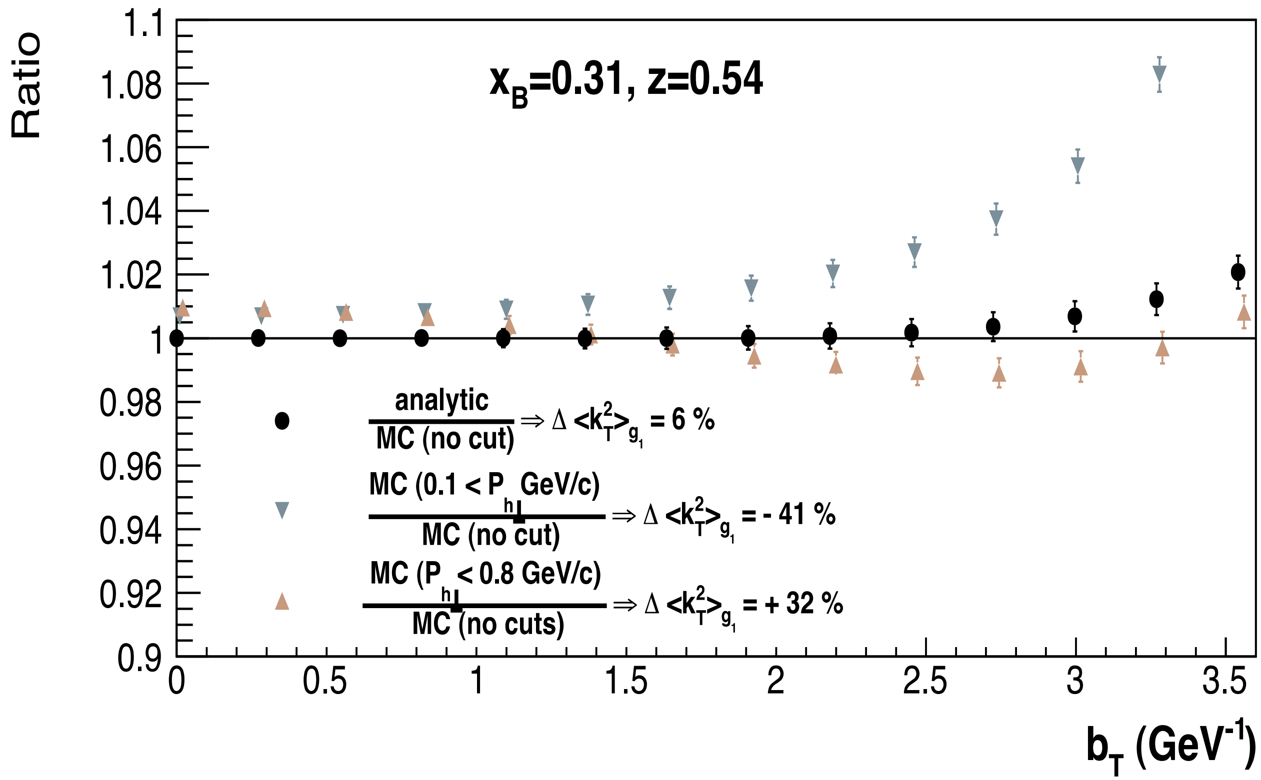


HD radiation damage test





Bessel method: sensitivity to cuts



- P_T cuts affects the value of extraction and the shape of b_T dependence!
- The correlation is direct consequence of the energy and momentum conservation when we account for intrinsic motion of the quarks
- The correlation is not sensitive to the details of the models used for the extraction.