Dihadron Beam Spin Asymmetries and Helicity-Dependent Fragmentation in SIDIS at CLAS

Christopher Dilks

For the CLAS Collaboration

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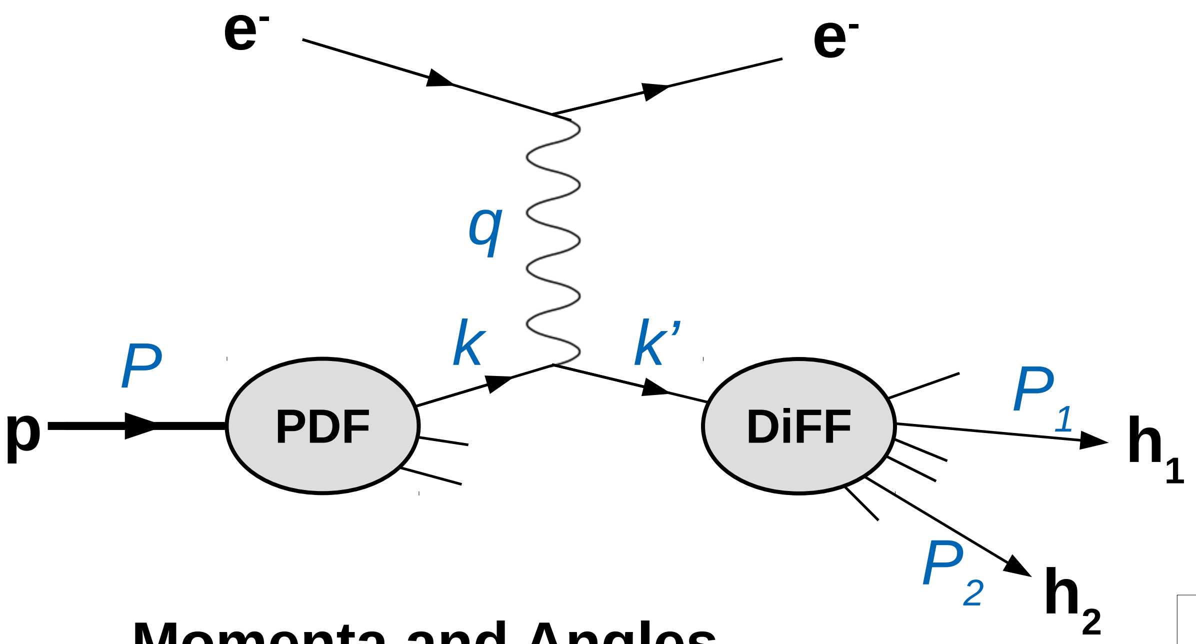
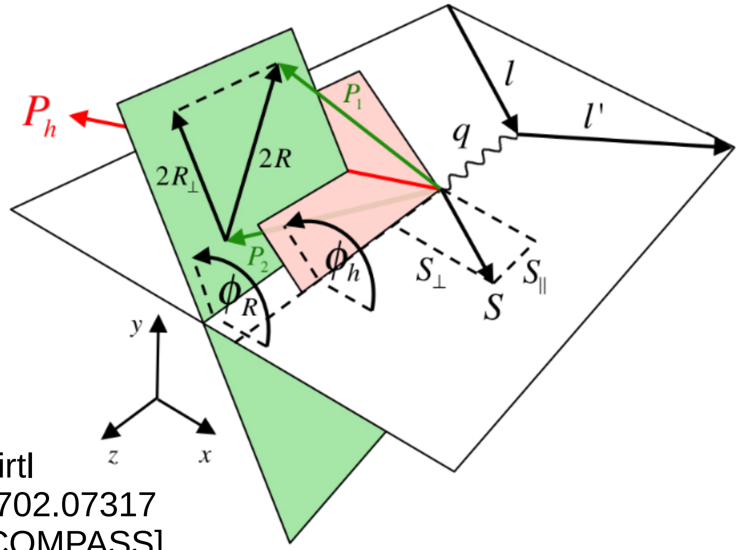
Arlington, VA

Duke UNIVERSITY

clas

SIDIS Dihadron Production: $e^- p \rightarrow e^- h_1 h_2 X$





Sirtl
1702.07317
[COMPASS]

Momenta and Angles

$$P_h = P_1 + P_2 \;\rightarrow\; \phi_h$$

$$R = \frac{1}{2}(P_1 - P_2) \;\rightarrow\; \phi_R$$

Kinematics:

- Scale: Q^2
- Bjorken-x: x
- Invariant Mass: M_h
- Fragmentation fraction: z

Helicity Dependent Dihadron Fragmentation: $G_1^\perp$

Handedness / Helicity-Dependent DiFF

$$G_1^\perp =$$

$$d^9\sigma_{LU} = -\sum_a \frac{\alpha^2 e_a^2}{2\pi Q^2 y}\,|\lambda_e|\,C(y)\,\frac{|\vec{R}_T|}{M_h}\left\{\sin(\phi_h-\phi_R)\,\mathcal{I}\left[\frac{\vec{k}_T\cdot\hat{P}_{h\perp}}{M_h}\,f_1\,G_1^\perp\right]+\cos(\phi_h-\phi_R)\,\mathcal{I}\left[\frac{\hat{P}_{h\perp}\wedge\vec{k}_T}{M_h}\,f_1\,G_1^\perp\right]\right\}$$

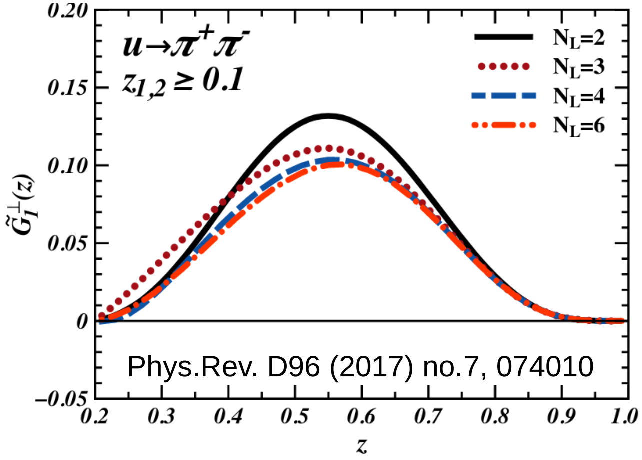
Accessible in the $\sin(\Phi_h - \Phi_R)$ modulation in dihadron longitudinal single spin asymmetries, weighted by $P_h^\perp / M_h$

$$A_{LU}(x,y,z,M_h) = \frac{\langle P_h^\perp \sin(\phi_h-\phi_R)/M_h\rangle_{LU}}{\langle 1\rangle_{UU}}$$

$$= \lambda_l \frac{C'(y)}{A'(y)} \frac{\sum_a e_a^2 \boxed{f_1^a(x)}\, z\, \boxed{G_1^{\perp a}(z,M_h^2)}}{\sum_a e_a^2\; f_1^a(x)\; D_1^a(z,M_h^2)}$$

$$f_1(x)\cdot G_1^\perp(z,M_h)$$

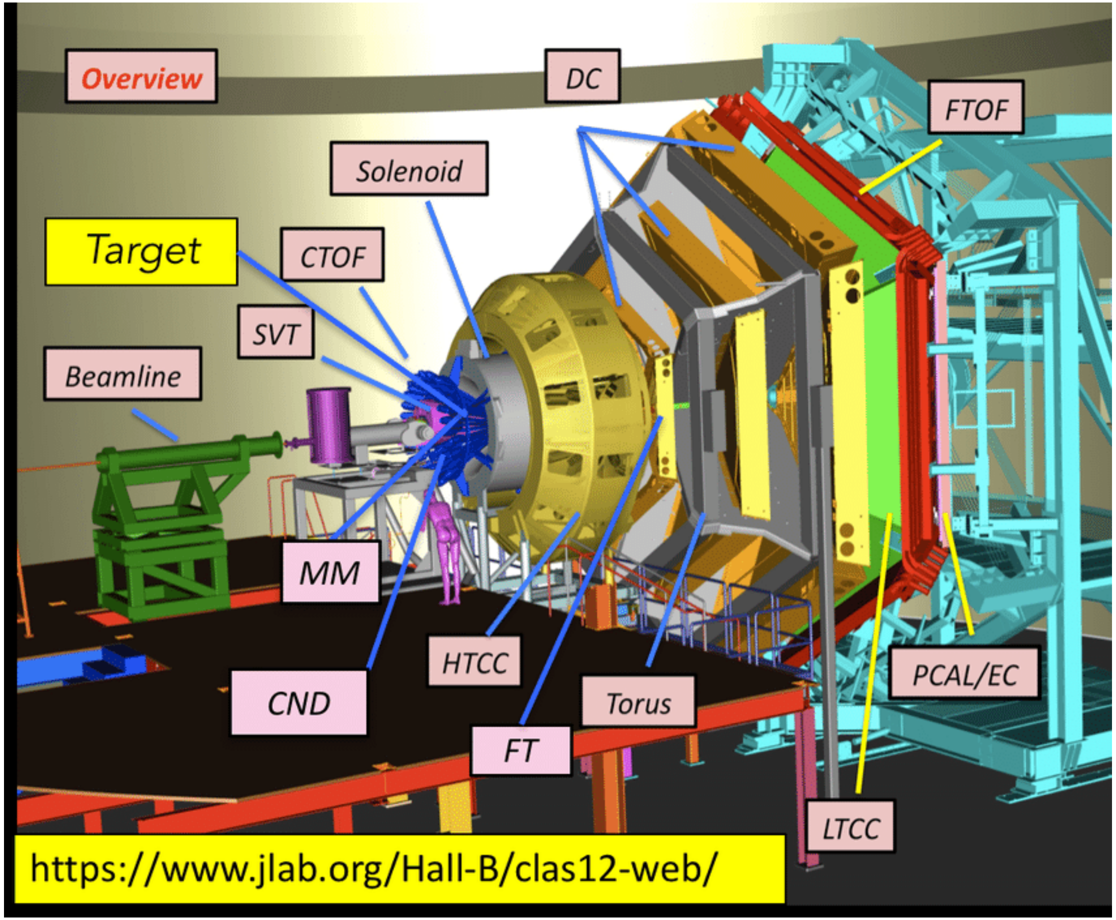
$$\tilde{G}_1^\perp(z) \equiv \frac{1}{M_1 M_2} G_1^\perp(z)$$ (integrated over M_h)



C. Dilks

Matevosyan, et al.
– Phys.Rev. D96 (2017) no.7, 074010
– PoS DIS2018 (2018) 150

CLAS Detector



Central Detector:

- Solenoid Magnet
- Barrel Silicon Tracker (SVT)
- Micromegas Vertex Tracker (MM)
- Central Time of Flight (CTOF)
- Central Neutron Detector (CND)

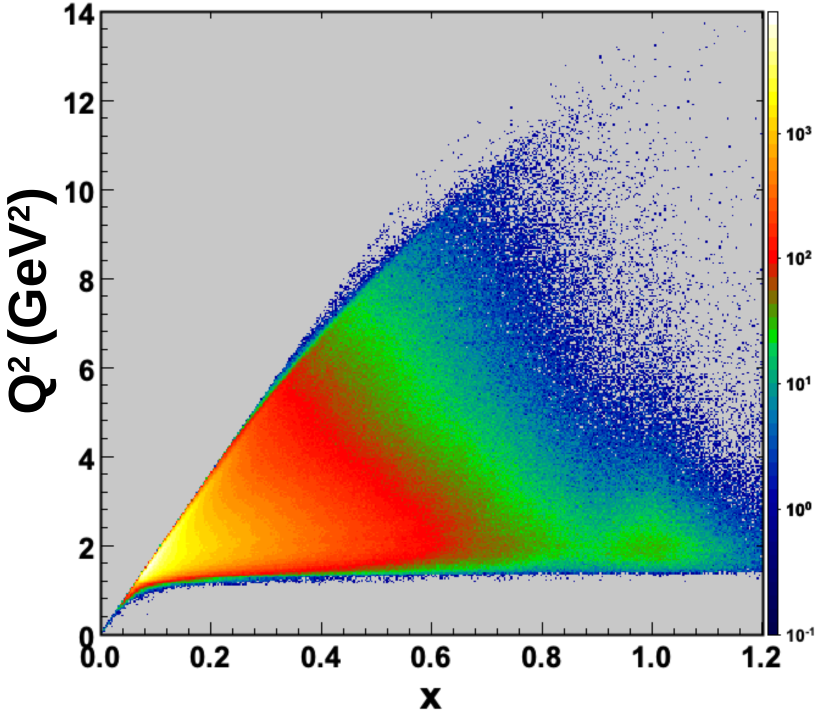
Forward Detector

- Torus Magnet
- Drift Chamber (DC)
- Forward Time of Flight (FTOF)
- High-threshold Cherenkov Counter (HTCC)
- Low-threshold Cherenkov Counter (LTCC)
- Ring Imaging Cherenkov Detector (RICH)
- Preshower + Electromagnetic Calorimeter (PCAL/EC)
- Forward Tagger (FT)

Data

- **Longitudinally Polarized Electron Beam**
  - E = 10.6 GeV
  - P = 86%
- **Unpolarized Liquid H_2 Fixed Target**
- Torus magnet → electrons inbending
- ~3% of available fixed H_2 target data analyzed
- Liquid D_2 target data → Flavor separation
- Plans for a polarized target in the near future

CLAS12 Kinematic Reach



Event Selection

Inclusive $\pi^+\pi^-$ dihadrons

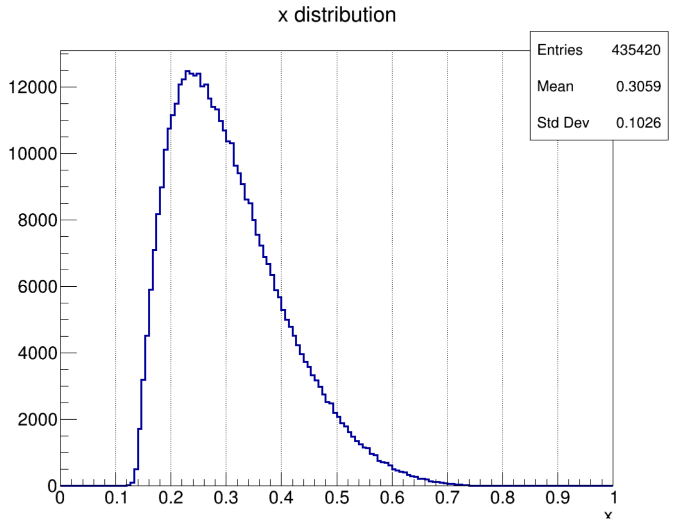
$$e^- p \rightarrow e^- \pi^+ \pi^- X$$

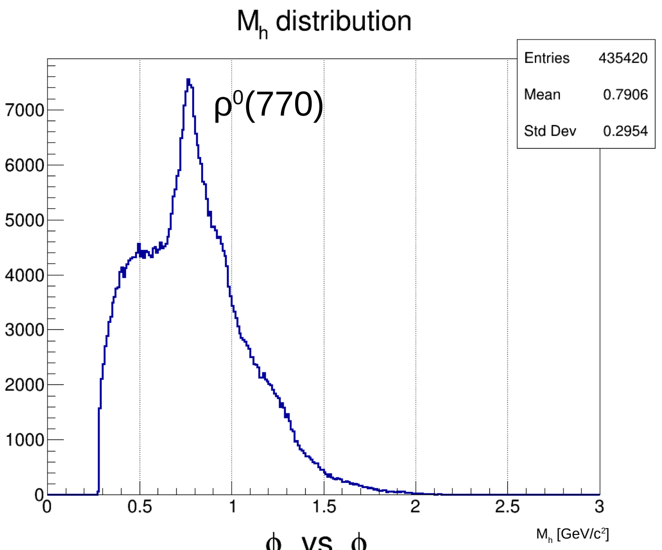
- Both pions in CLAS Forward Detector
- Scattered e^- in DC and PCAL fiducial volume

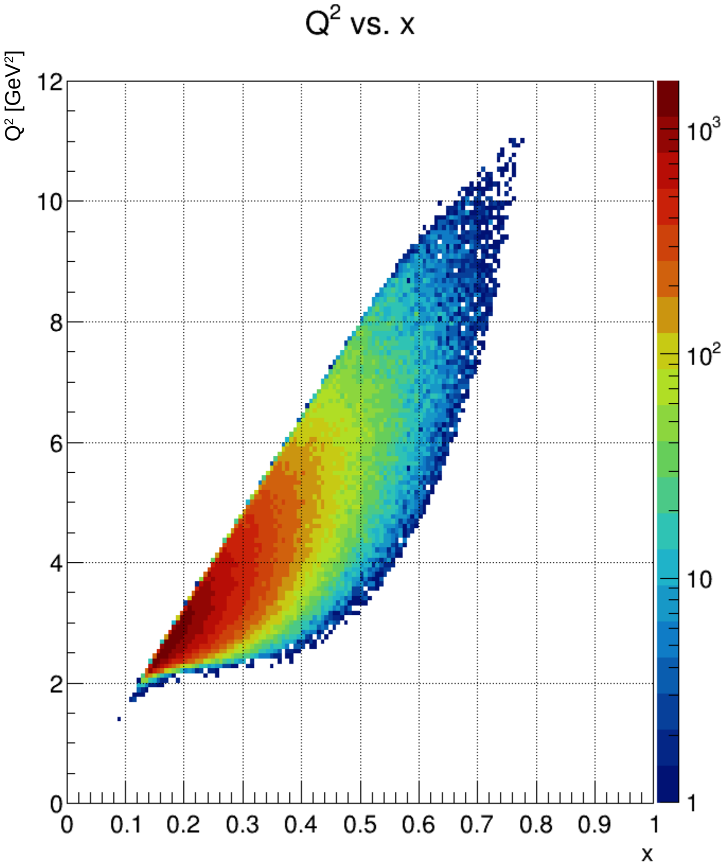
Kinematic cuts:

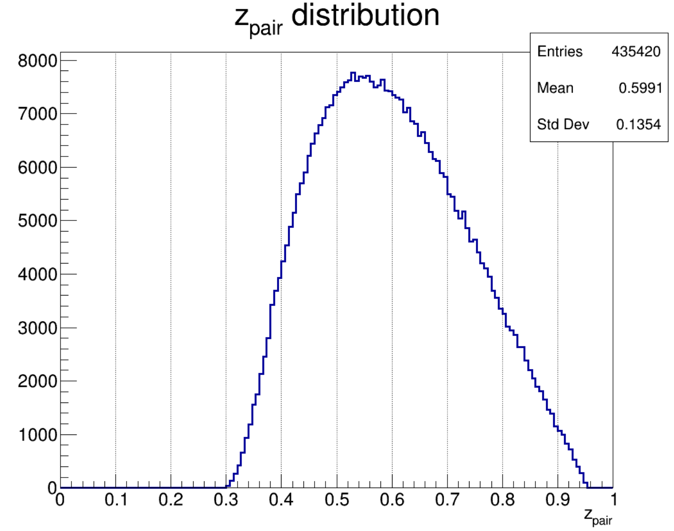
DIS cuts	$Q^2 > 1$ GeV^2 $W > 2$ GeV
Omit radiative region	$p_\pi > 1.25$ GeV
Omit exclusive region	$M_X > 1.05$ GeV
Current fragmentation region	$x_F > 0$ $y < 0.8$ $z_\pi > 0.1$ $z_{\text{pair}} < 0.95$
Vertex cuts	$-8 < v_{z,e} < 3$ cm $-8 < v_{z,\pi} < 3$ cm

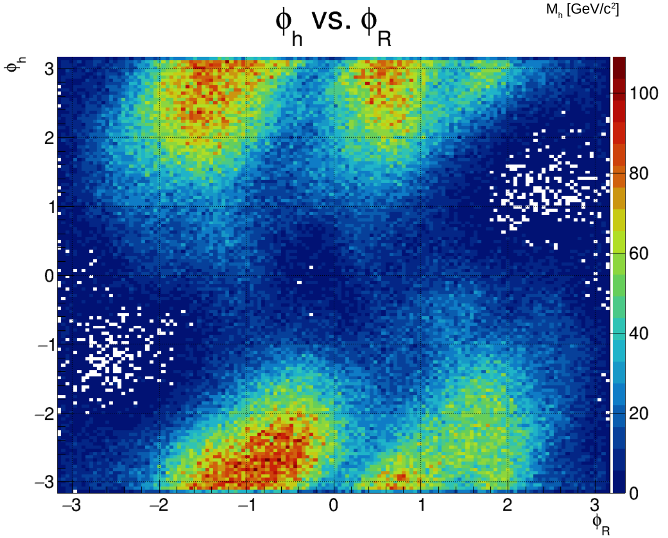
Kinematic Distributions





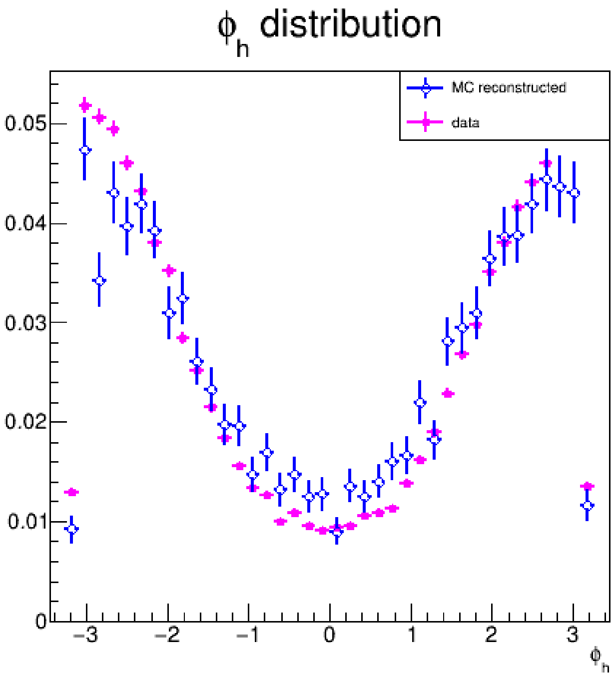


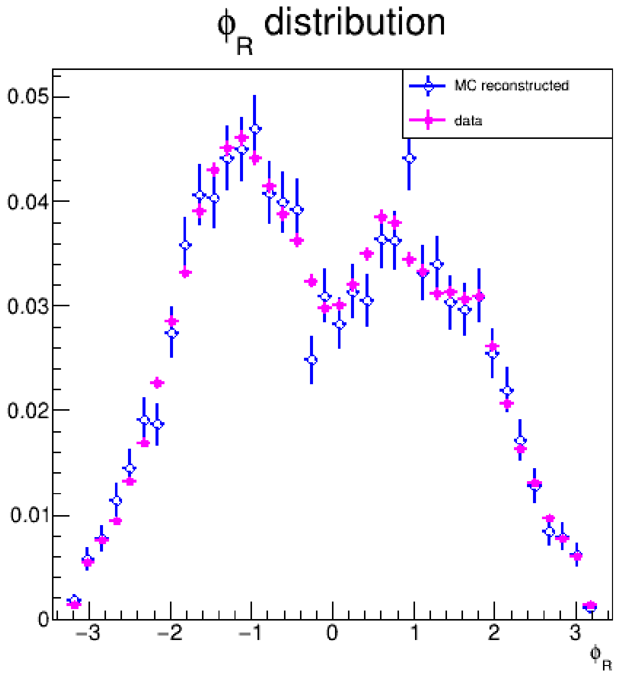


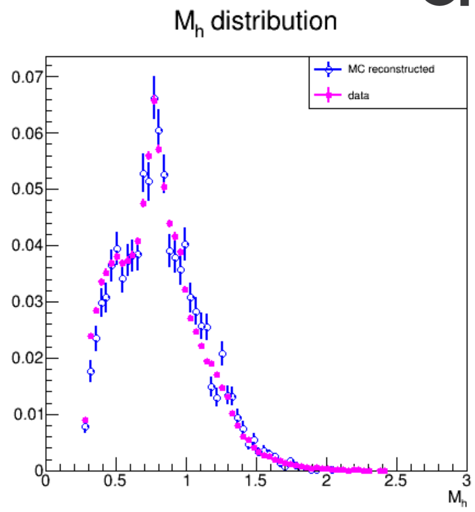


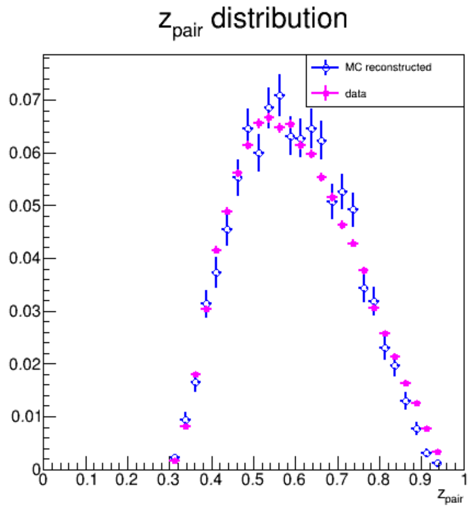
Data and Monte Carlo Comparison

- MC dihadrons generated uniformly in ϕ_h and ϕ_R
- Data ϕ_h and ϕ_R distributions reproduced in reconstructed MC data, as well as other kinematics
- Plan to use for acceptance studies and asymmetry validation









Asymmetry Extraction

Unbinned maximum likelihood method

$$\sigma_{h_e h_p} = \frac{\sigma}{4}\left(1 + h_e A_{LU} + h_p A_{UL} + h_e h_p A_{LL}\right)$$

σ_{LU}

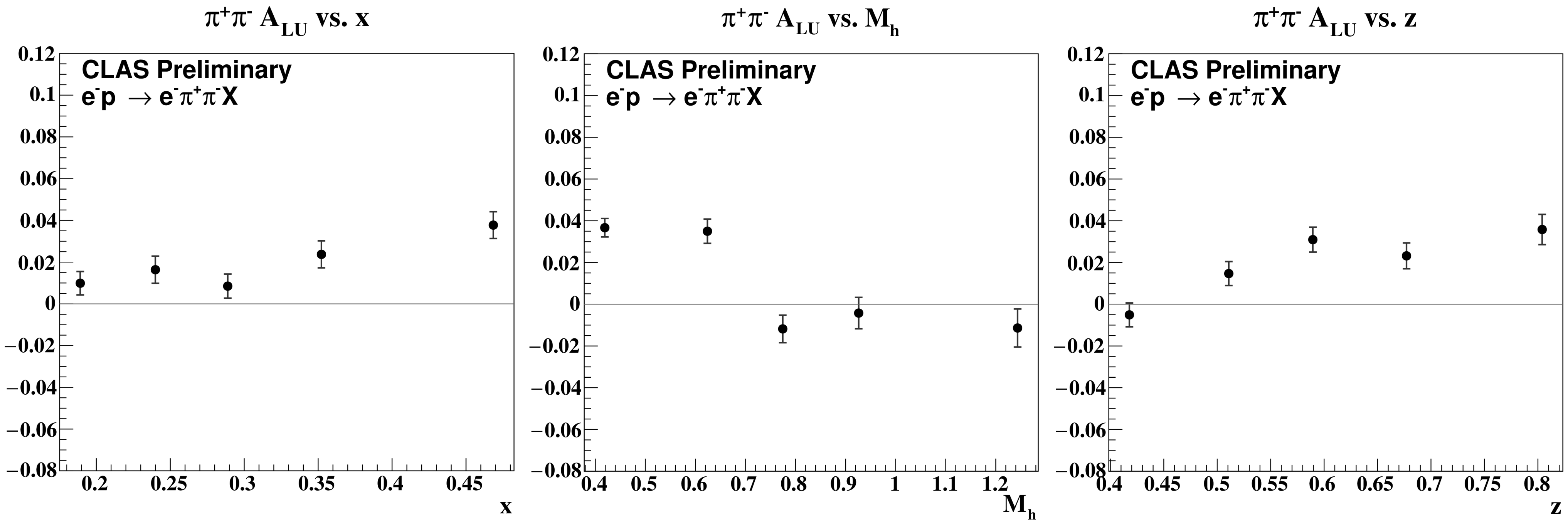
- $h_e = -1,+1$
- $h_p = 0$

PDF for building likelihood: $p_{\pm}\left(\phi_h, \phi_R; \hat{A}_{LU}\right) \propto \frac{L_{\pm}}{L}\left(1 \pm P\hat{A}_{LU}\right)$

Can use $\hat{A}_{LU}\left(\phi_h, \phi_R\right) = A_{LU}\sin\left(\phi_h - \phi_R\right)$ or any other (combination of) modulation(s)

- **Each analyzed dihadron is weighted by $P_h^{\perp} / M_h$ which is on average 0.85**
- Use MINUIT to minimize the –log likelihood
- Agrees well with linear fit to $A_{LU}\sin(\phi_h - \phi_R)$

π+π- Asymmetries



- Slow rise in x and z
- Positive at low M_h, and drops at the ρ mass
- Quantile binning, error bars are statistical
- ±3.8% polarization scale uncertainty

Additional Modulations

- **Dihadron structure functions:**

- **twist 2** $F_{LU,T}^{P_{\ell,m}\sin(m(\phi_h-\phi_{R_\perp}))} = -\mathcal{I}\left[2\cos\left(m(\phi_h-\phi_p)\right)f_1 G_1^{|\ell,m\rangle}\right]$

$\boxed{m = 1 \;\rightarrow\; A_{hR}\sin(\phi_h - \phi_R)}$

- **twist 3** $$F_{LU}^{P_{\ell,m}\sin((1-m)\phi_h+m\phi_{R_\perp})} = \frac{2M}{Q}\mathcal{I}\Bigg[-\frac{|\boldsymbol{p}_T|}{M_h}\cos\left((1-m)\left(\phi_p-\phi_h\right)\right)\left(xe\,H_1^{\perp|\ell,m\rangle}+\frac{M_h}{M}f_1\frac{\tilde{G}^{\perp|\ell,m\rangle}}{z}\right) + \frac{|\boldsymbol{k}_T|}{M}\cos\left((m-1)\phi_h+\phi_k-m\phi_p\right)\left(xg^\perp D_1^{|\ell,m\rangle}+\frac{M_h}{M}h_1^\perp\frac{\tilde{E}^{|\ell,m\rangle}}{z}\right)\Bigg]$$

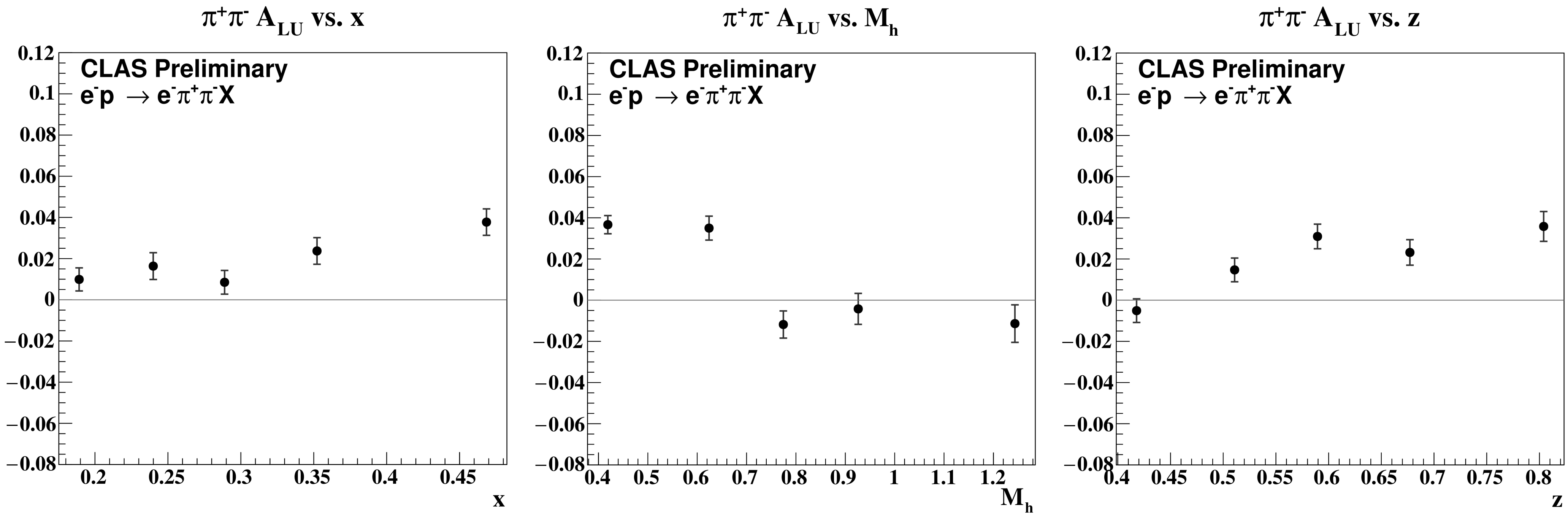
$m = 1 \rightarrow A_R\sin\phi_R$	$m = 0 \rightarrow A_h\sin\phi_h$	$m = -1$ tested, but excluded (~0)

(see T. Hayward's talk)

$$A_{hR}\sin(\phi_h-\phi_R) \;+\; A_R\sin\phi_R \;+\; A_h\sin\phi_h$$

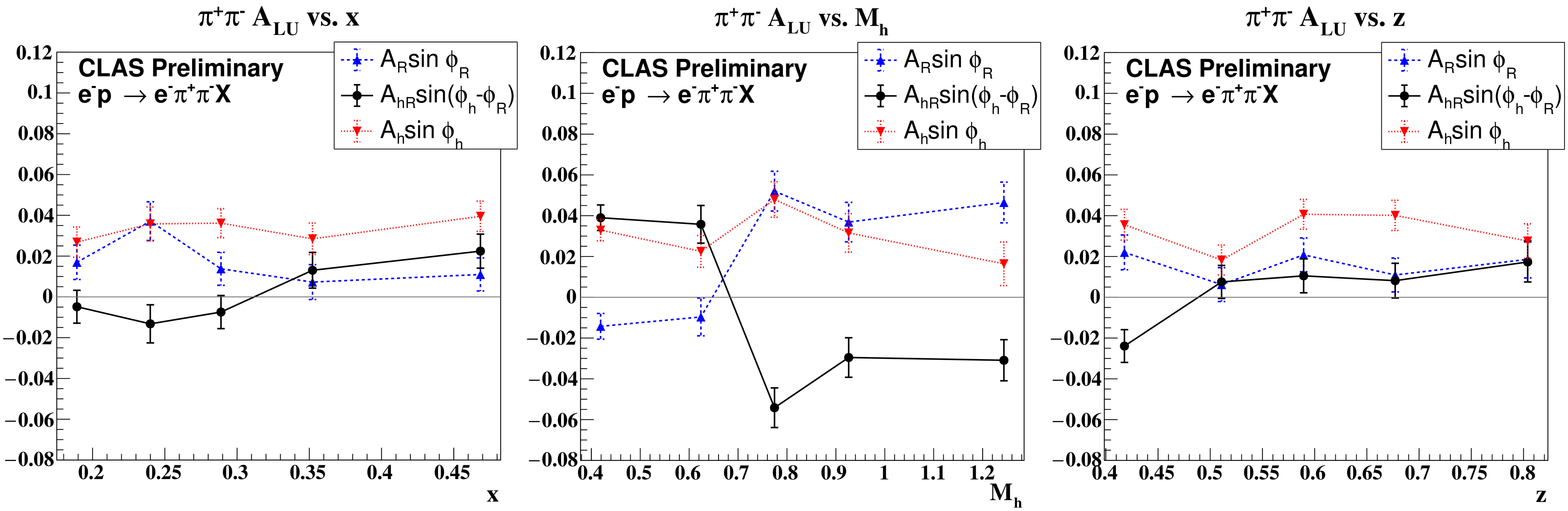
Gliske, Bacchetta, Radici
Phys.Rev. D90 (2014) no.11, 114027

π+π- Asymmetries



$A_{hR}\sin(\phi_h-\phi_R)$

π+π- Asymmetries

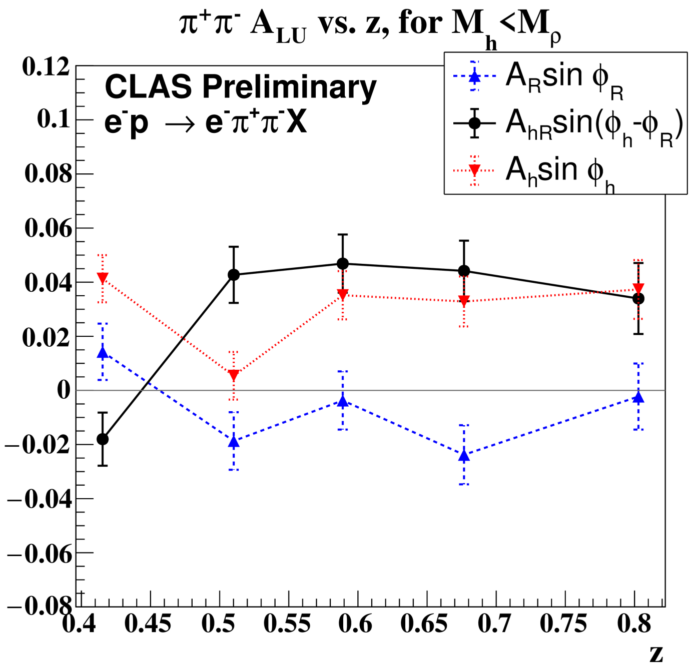


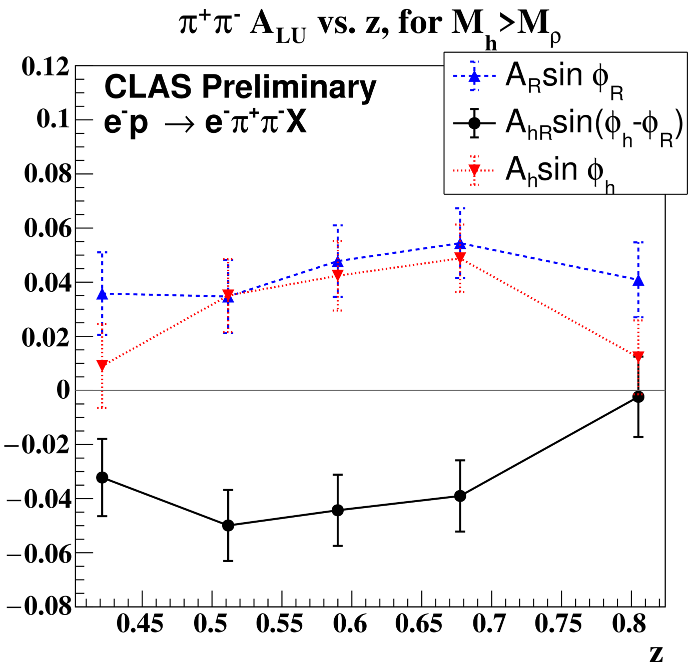
- Including additional modulations reveals more to the story
- There appears to be a sign change near M_ρ
- A_R has opposite M_h dependence to A_{hR}
- A_h is a constant 3-4%
- ±3.8% polarization scale uncertainty

$$\boxed{A_{hR}\sin(\phi_h-\phi_R) \;+\; {\color{blue}A_R\sin\phi_R} \;+\; {\color{red}A_h\sin\phi_h}}$$

π+π- Asymmetries

$M_h < M_\rho$





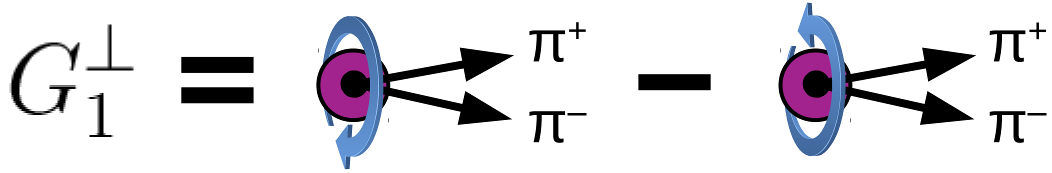
$M_h > M_\rho$

- z-dependence above and below the ρ mass
- Below M_ρ: A_{hR} is positive, A_R near zero
- Above M_ρ: A_{hR} is negative, A_R is positive

$$\boxed{A_{hR}\sin(\phi_h-\phi_R) \;+\; A_R\sin\phi_R \;+\; A_h\sin\phi_h}$$

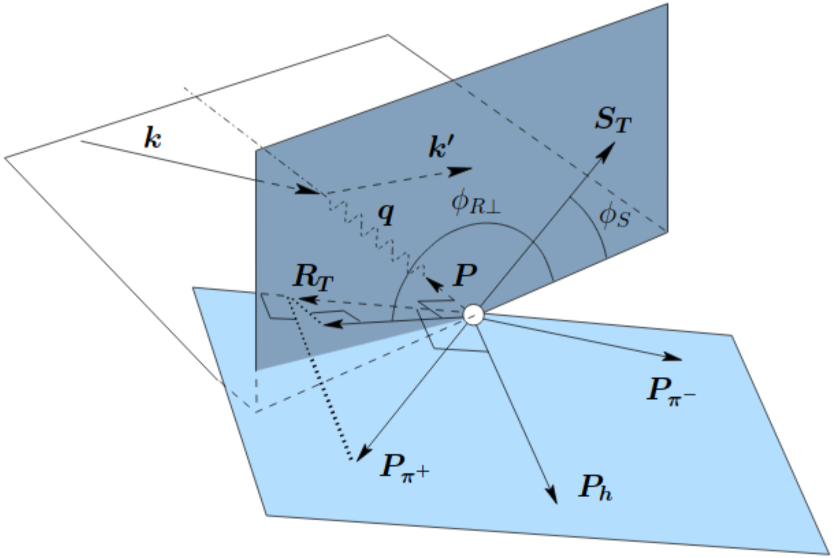
Summary

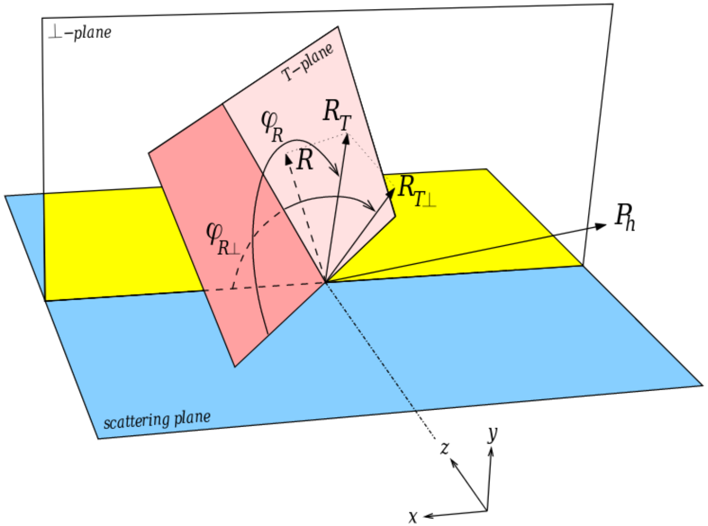
- Measuring π+π- beam spin asymmetries sensitive to helicity DiFF $G_1^\perp$
- Including additional modulations may be a necessity
- Possible sign change at the ρ mass
- Outlook
  - MC acceptance and asymmetry validation
  - Extend to additional pion and kaon channels
  - Partial wave amplitudes



Backup Slides

Dihadron Angle ϕ_R





$$\phi_{R_\perp} = \frac{(\boldsymbol{q} \times \boldsymbol{l}) \cdot \boldsymbol{R}_T}{|(\boldsymbol{q} \times \boldsymbol{l}) \cdot \boldsymbol{R}_T|} \arccos \frac{(\boldsymbol{q} \times \boldsymbol{l}) \cdot (\boldsymbol{q} \times \boldsymbol{R}_T)}{|\boldsymbol{q} \times \boldsymbol{l}|\,|\boldsymbol{q} \times \boldsymbol{R}_T|}$$

$$\boldsymbol{R}_T = \frac{z_2 \boldsymbol{P}_{1\perp} - z_1 \boldsymbol{P}_{2\perp}}{z}$$

arXiv:0803.2367

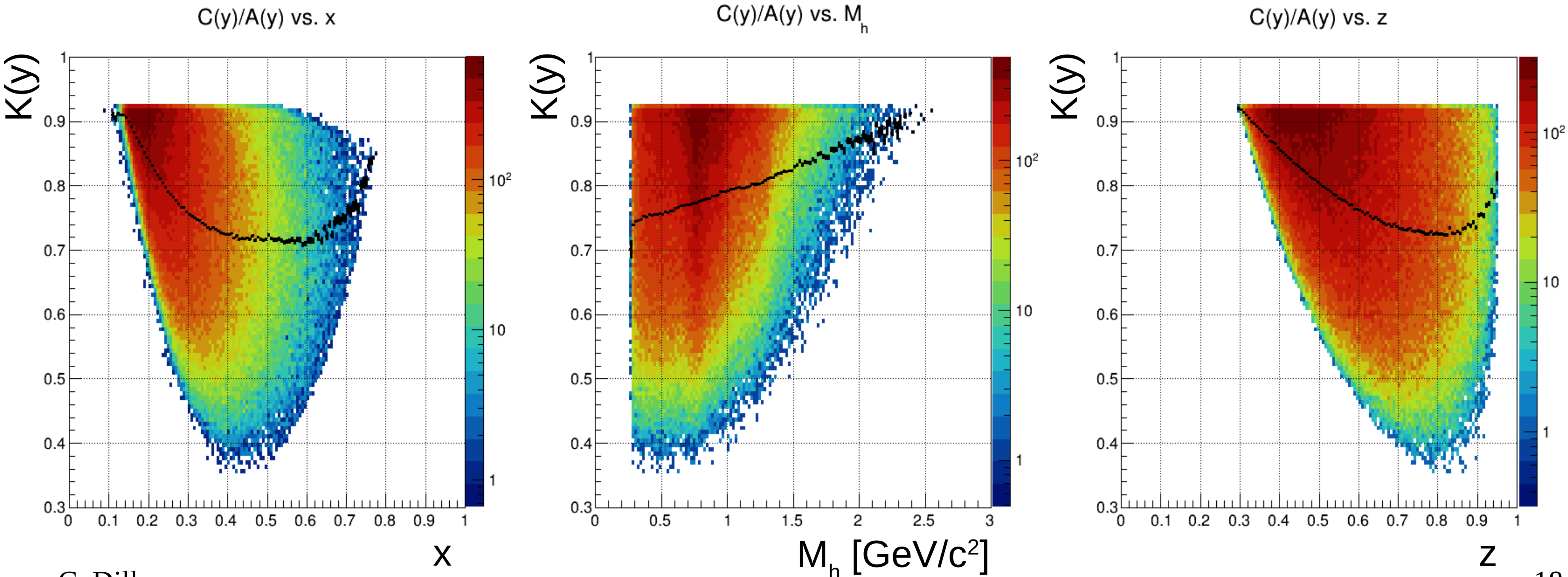
arXiv:1408.5721

hep-ph/0311173

Kinematic Factor

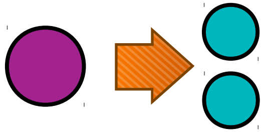
$$A_{LU} = \lambda_l K \frac{\sum_a e_a^2 z f_1^a G_1^{\perp a}}{\sum_a e_a^2 f_1^a D_1^a}$$

Kinematic factor: $K(y) = \frac{C(y)}{A(y)} \approx \frac{y\,(1 - y/2)}{1 - y + y^2/2}$



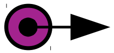
Dihadron Fragmentation Functions (DiFFs)

Unpolarized DiFF

$$D_1 =$$ 

Handedness / Helicity-Dependent DiFF

$$G_1^{\perp} =$$ 

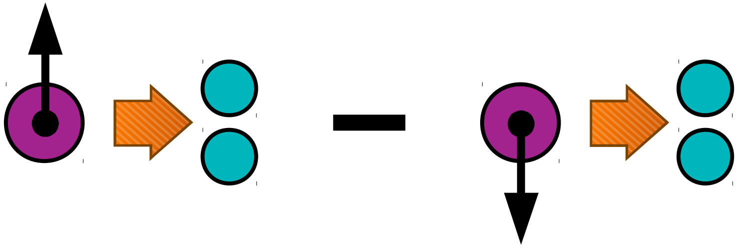
 correlated with vector product of hadrons' transverse momenta

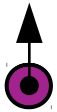
Interference Fragmentation Function

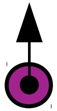
$$H_1^{\sphericalangle}$$

Collins-like DiFF

$$H_1^{\perp}$$

$$=$$ 

 correlated with relative p_T of the pair

 correlated with dihadron's total p_T