&

The CLAS12 Physics Program

Keith Griffioen

College of William & Mary
Helmholtz Institute Mainz

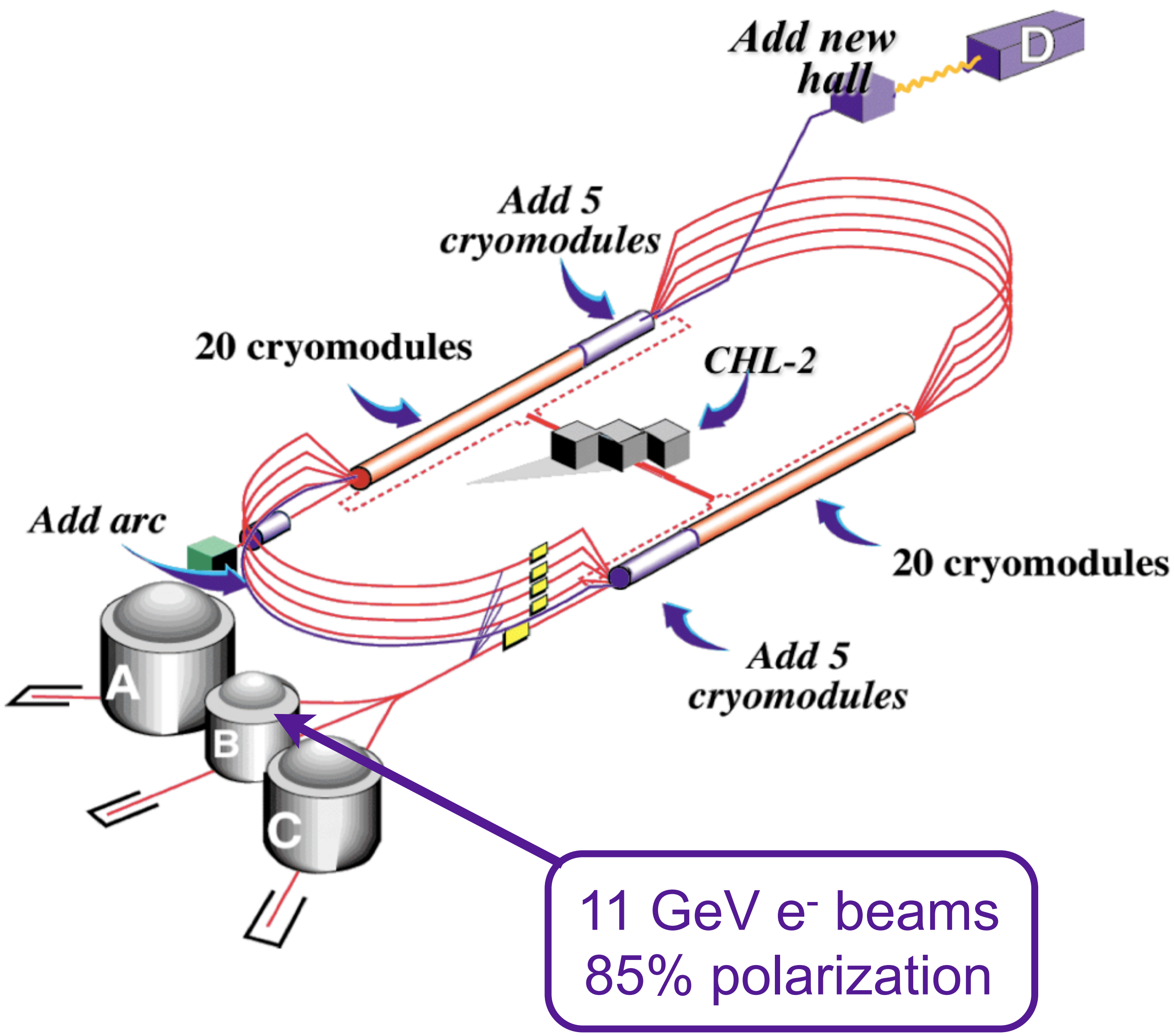
for the CLAS12 Collaboration

griff@physics.wm.edu

XX International Workshop on Deep-Inelastic Scattering and Related Subjects

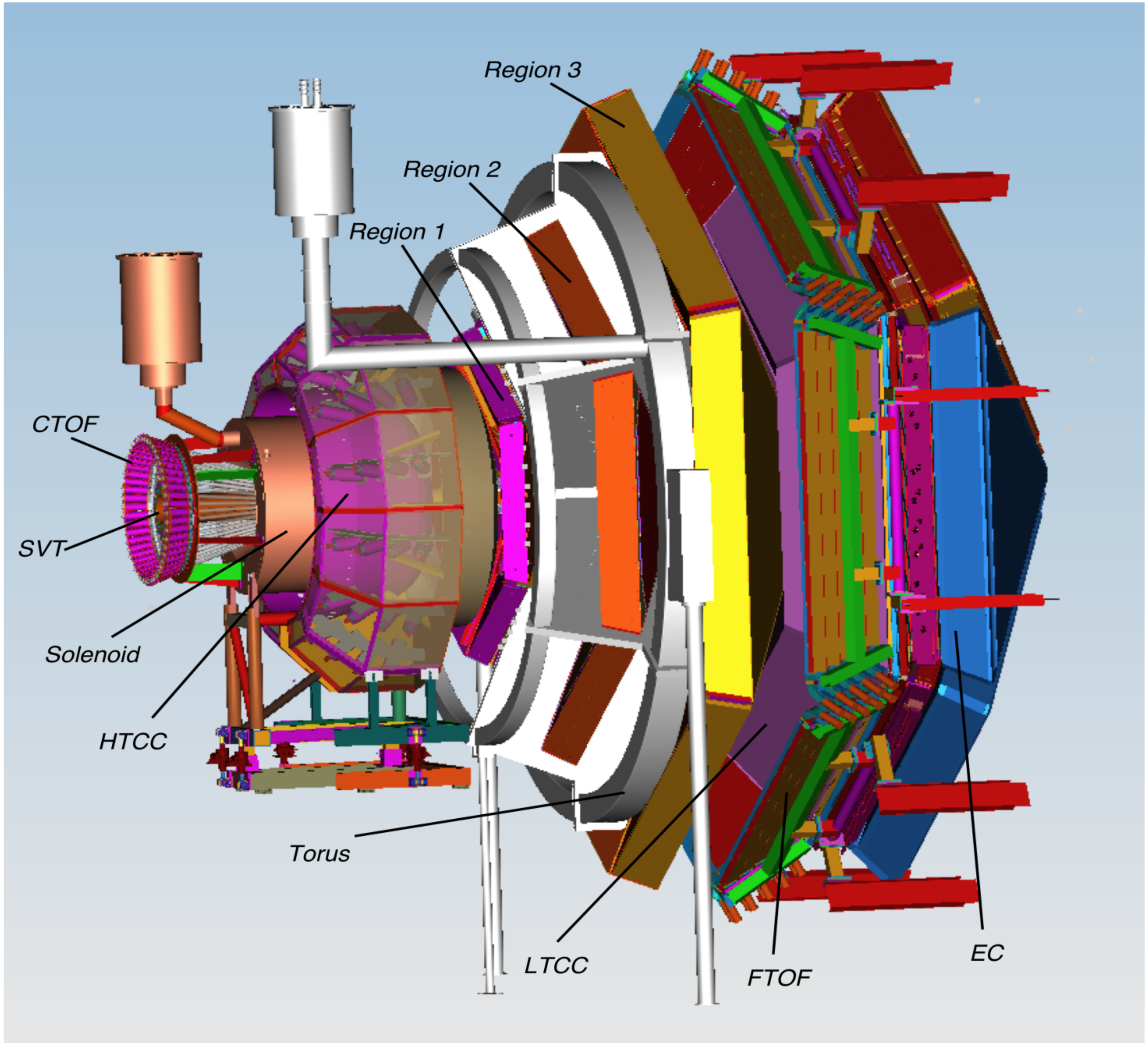
Bonn, 27 March 2012

JLab 12 GeV Upgrade

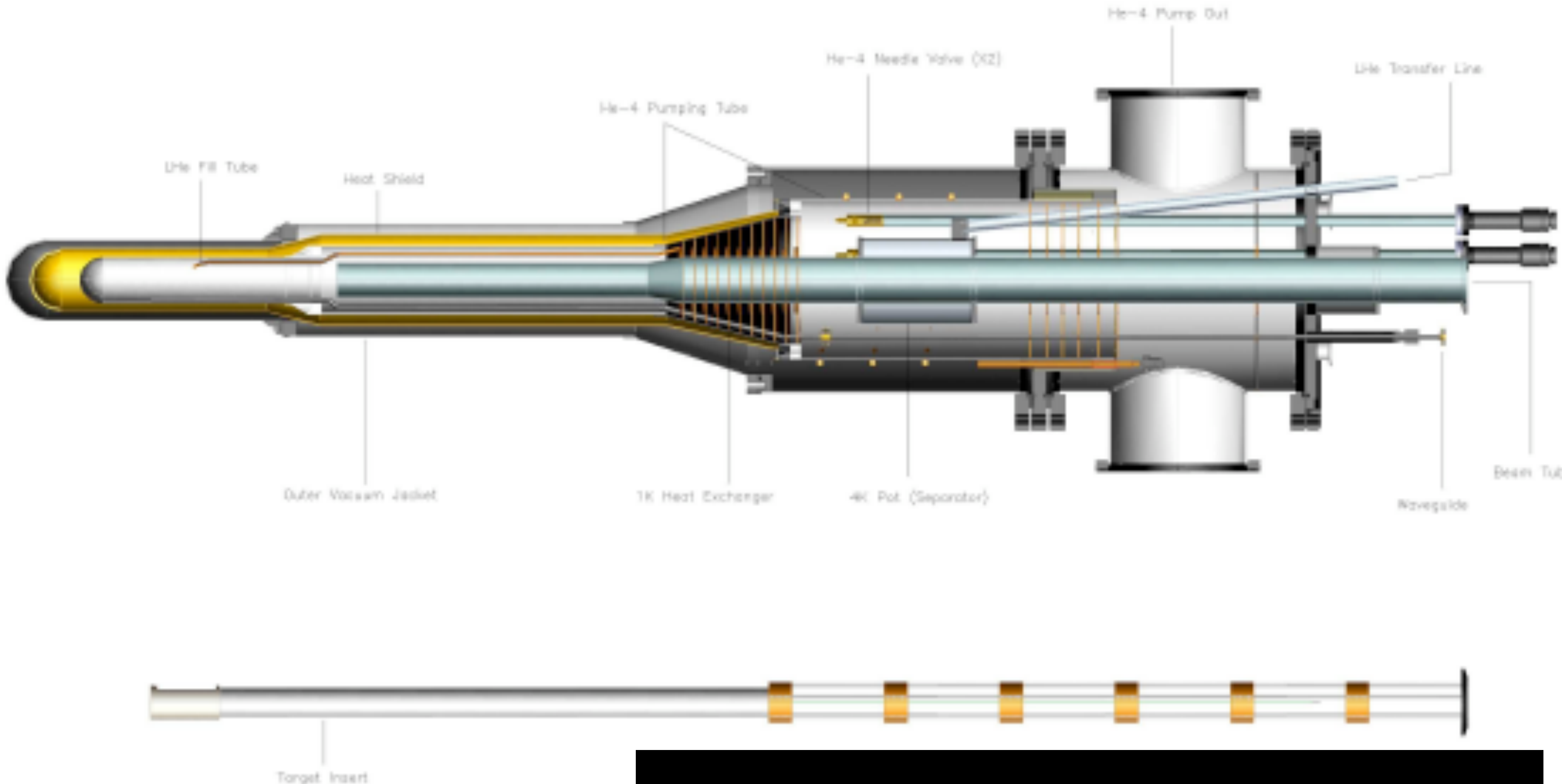


CLAS12 Detector

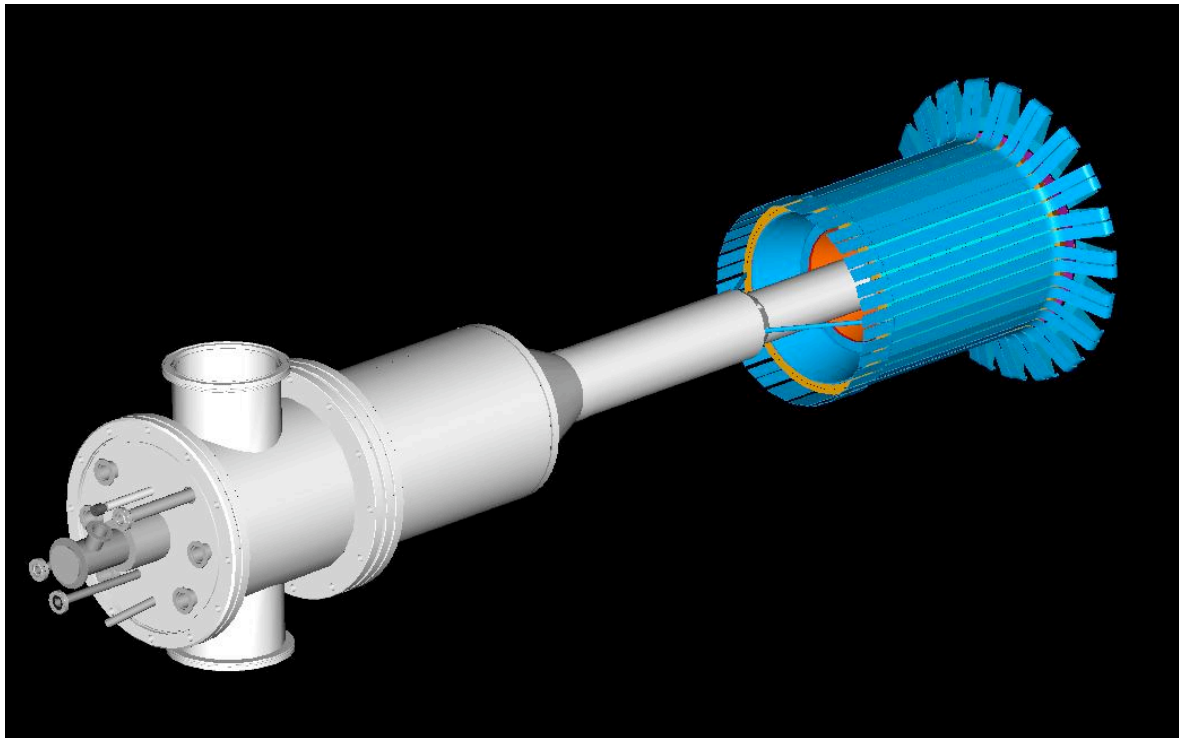
- Region 1,2,3 drift chambers
- **CTOF**: central time-of-flight
- **SVT**: silicon vertex tracker
- Superconductiong solenoid (5 T)
- **HTCC**: high threshold Cherenkov counter
- Superconducting torus
- **LTCC**: low threshold Cherenkov counter
- **FTOF**: forward time-of-flight detector
- **EC**: electromagnetic calorimeter
- Upgrades: **RICH**, **CND**: central neutron detector, forward tagger, micromegas



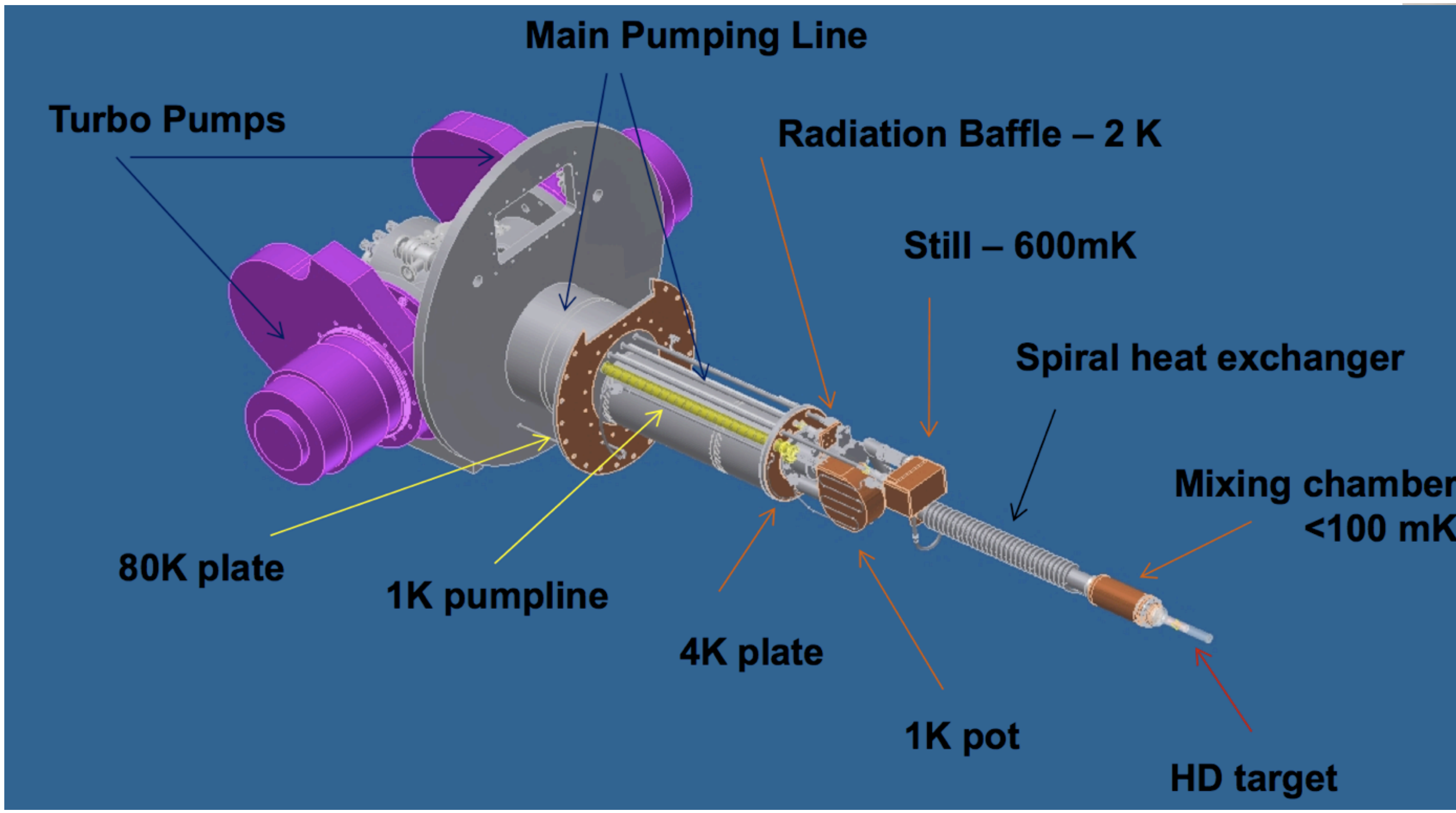
Polarized Target (L)

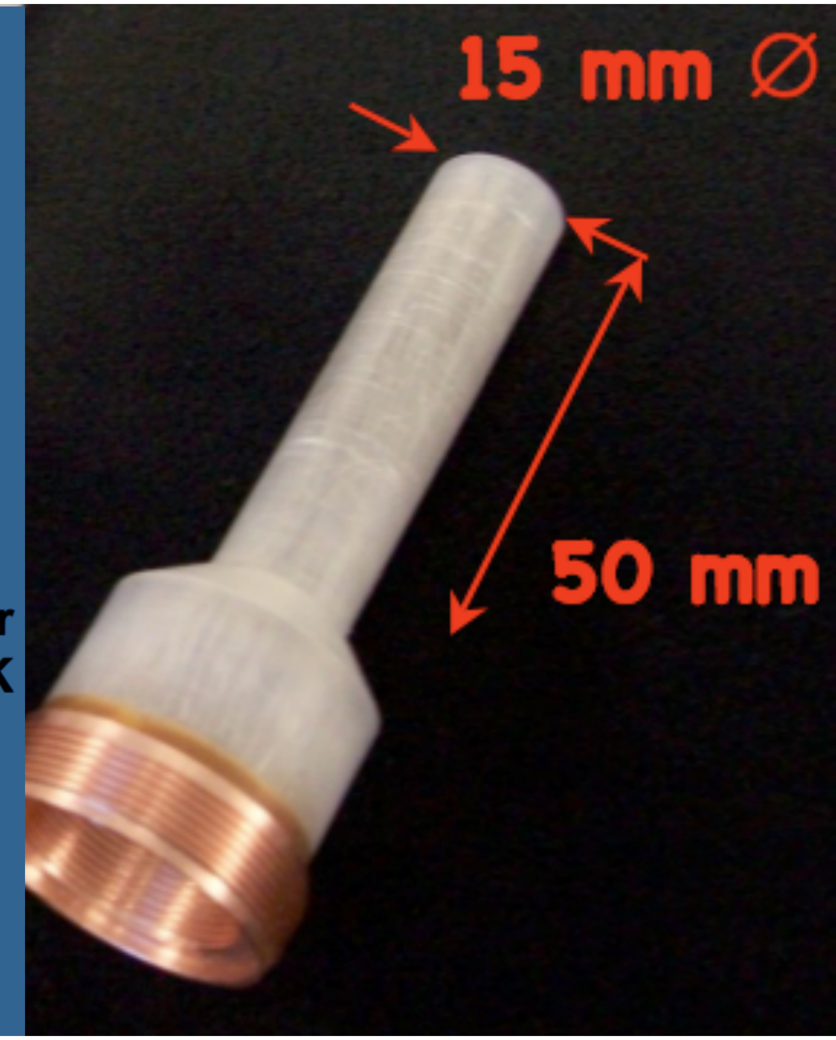


- 3.3 cm long NH_3 and ND_3 targets (plus C)
- 5 T longitudinal field, 140 GHz microwaves
- Dynamic Nuclear Polarization
- P_T = 80% for p and 40% for d
- raster over the 3 cm diameter



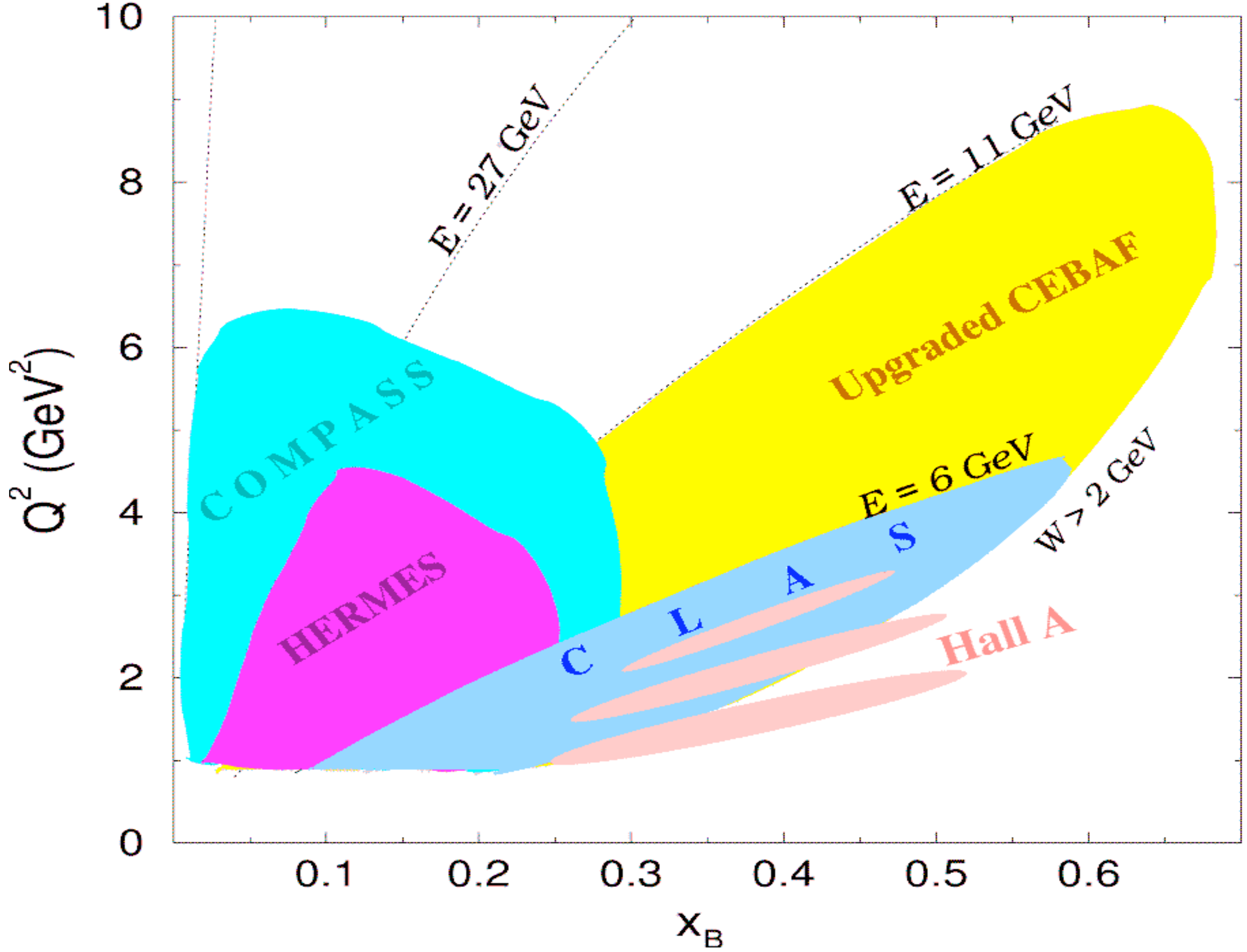
Polarized Target (T)





- HD Ice Target
- Polarize small amounts of H_2 and D_2
- o-H_2 and p-D_2 spin-exchange polarizes HD
- Frozen-spin achieved in a few months
- 0.05 K cryostat
- Low holding field (0.01-0.5 T)
- P_T = 75% for p and 40% for d
- Initial tests are promising for use with electron beam

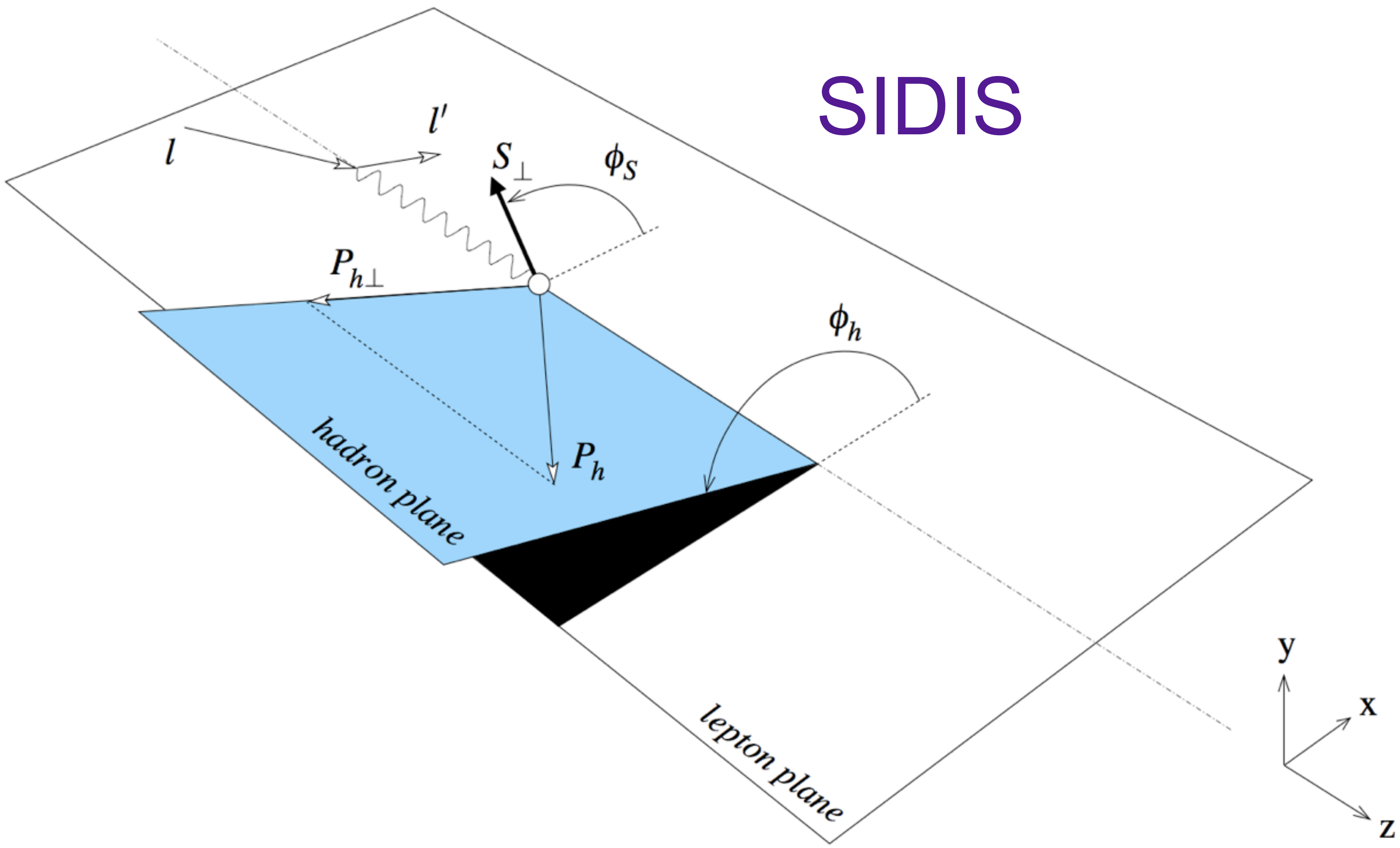
Kinematic Coverage

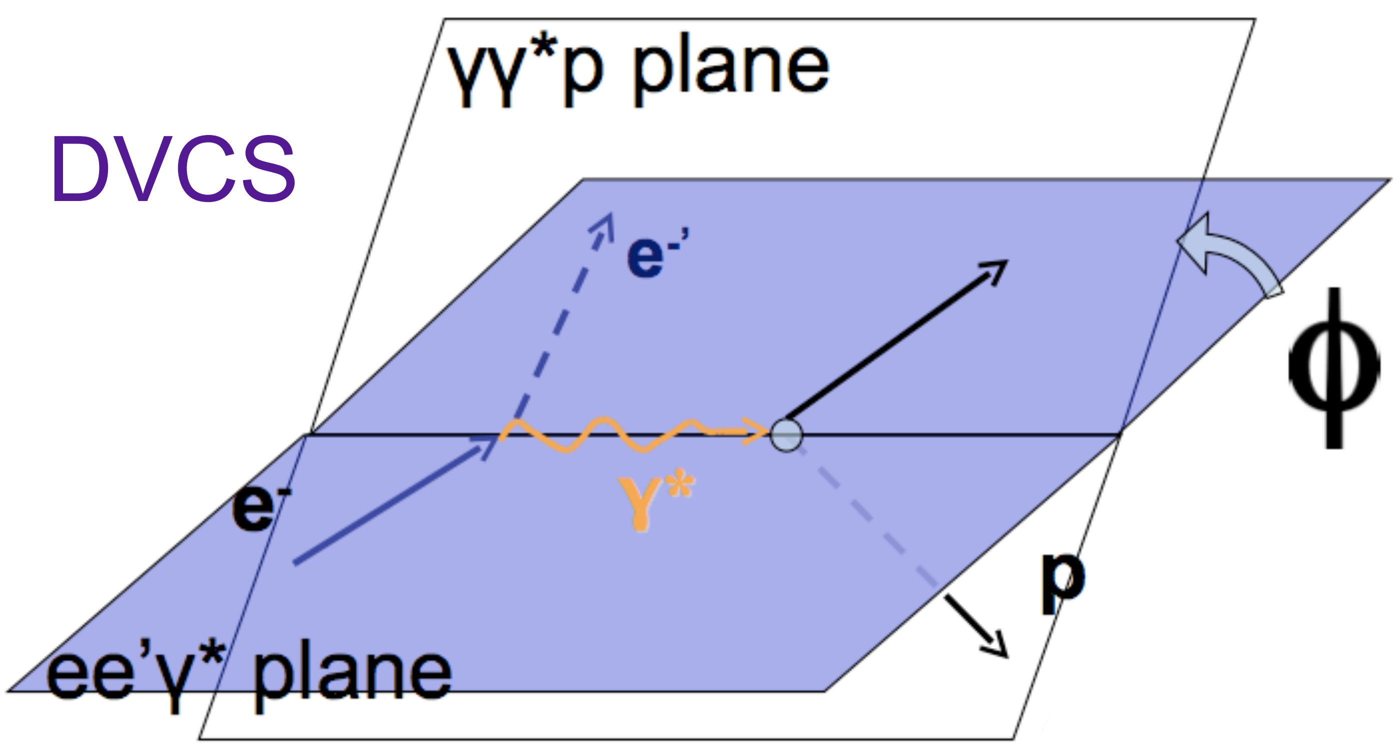


CLAS12 Program

- Nucleon structure (p & d targets)
  - Exploring projections of the Wigner Distribution
    - Form Factors (FFs)
    - Parton Distribution Functions (PDFs)
    - Generalized Parton Distributions (GPDs)
    - Transverse Momentum Distributions (TMDs)
- Nuclear QCD
  - Color transparency
  - Quark propagation and hadronization in nuclei
  - Short-range correlations
  - Effects of binding on nucleon structure
- Hadron spectroscopy

Kinematics





- $Q^2 = -(\nu, \mathbf{q})^2$: virtual photon γ* 4-momentum
- x: momentum fraction
- $y = \nu/E_{beam}$: fractional energy of virtual photon
- $\phi_{(h)}$: azimuthal angle between lepton scattering and final-state particle emission planes
- $z = E_h/\nu$: fractional energy of hadron:
- $\mathbf{p}_T$: quark transverse momentum
- $\mathbf{P}_{h\perp}$: hadron transverse momentum
- $\mathbf{k}_T$: transverse momentum from hadronization
- $\mathbf{S}_\perp$: target polarization ⊥ **q**
- ϕ_S: angle $\mathbf{S}_\perp$ makes with the scattering plane

Nucleon Structure

	γ	π^+/π^-	π^0	K^+/K^-	η	ρ/ω/φ
Exclusive						
SIDIS						

Target Polarization

Beam Polarization

	U	L	T
U			
L			

Wigner Projections

Pasquini, *et al.*

$X(x, \xi, \mathbf{p}_T^2, \mathbf{b}_T^2, \mathbf{p}_T \cdot \mathbf{b}_T)$ Wigner

↓ FT

$X(x, \xi, \mathbf{p}_T^2, \mathbf{\Delta}_T^2, \mathbf{p}_T \cdot \mathbf{\Delta}_T)$ GTMD

$\xi = 0$, $\mathbf{\Delta}_T = 0$ → TMD: $q(x, \mathbf{p}_T^2)$

$\int \mathbf{p}_T$ → GPD: $H(x, \xi, \mathbf{\Delta}_T^2)$

From $q(x, \mathbf{p}_T^2)$: $\int \mathbf{p}_T$ → PDF: $q(x)$

From $H(x, \xi, \mathbf{\Delta}_T^2)$: $\mathbf{\Delta}_T = 0$ → PDF: $q(x)$

From $H(x, \xi, \mathbf{\Delta}_T^2)$: $\int dx$ → FF: $F(\mathbf{\Delta}_T^2)$

- x: quark momentum fraction
- ξ: ½ of quark momentum fraction transfer
- $\mathbf{p}_T$: quark transverse momentum
- $\mathbf{b}_T$: quark transverse location

CLAS12 Experiments

Proposal	Physics	Contact	Rating	Days	Group	New equipment	Energy	Group	Target
E12-06-108	Hard exclusive electro-production of π^0, η	P. Stoler	B	80	119	RICH IC Forward tagger	11	**RG-A** **F. Sabatié**	liquid H_2
E12-06-112	Proton's quark dynamics in SIDIS pion production	H. Avakian	A	60					
E12-06-119	Deeply Virtual Compton Scattering	F. Sabatie	A	80					
E12-09-103	Excitation of nucleon resonances at high Q^2	R. Gothe	B+	40					
E11-005	Hadron spectroscopy with forward tagger	M. Battaglieri	A-	119					
PR12-11-103	DVMP of ρ, ω, φ	M. Guidal		D					
E12-07-104	Neutron magnetic form factor	G. Gilfoyle	A-	30	90	Neutron detector RICH IC	11	**RG-B** **K. Hafidi**	liquid D_2 target
PR12-11-109 (a)	Dihadron DIS production	Avakian		D					
E12-09-007a	Study of partonic distributions in SIDIS kaon production	K. Hafidi	A-	56					
E12-09-008	Boer-Mulders asymmetry in K SIDIS w/ H and D targets	M. Contalbrigo	A-	TBA					
11-003	DVCS on neutron target	S. Niccolai	A	90					
E12-06-109	Longitudinal Spin Structure of the Nucleon	S. Kuhn	A	80	170	Polarized target RICH IC	11	**RG-C** **S. Kuhn**	NH_3 ND_3
E12-06- 119(b)	DVCS on longitudinally polarized proton target	F. Sabatie	A	120					
E12-07-107	Spin-Orbit Correl. with Longitudinally polarized target	H. Avakian	A-	103					
PR12-11-109 (b)	Dihadron studies on long. polarized target	H. Avakian		D					
E12-09-007(b)	Study of partonic distributions using SIDIS K production	K. Hafidi	A-	110					
E12-09-009	Spin-Orbit correlations in K production w/ pol. targets	H. Avakian	B+	103					
E12-06-106	Color transparency in exclusive vector meson production	K. Hafidi	B+	60	60		11	**RG-D**	Nuclear
E12-06-117	Quark propagation and hadron formation	W. Brooks	A-	60	60		11	**RG-E**	Nuclear
E12-10-102	Free Neutron structure at large x	S. Bueltman	A	40	40	Radial TPC	11	**RG-F**	Gas D_2
PR12-11-109	SIDIS on transverse polarized target	M. Contalbrigo		C2		Transverse target	11	**RG-G**	HD
TOTAL run time				1231	539				

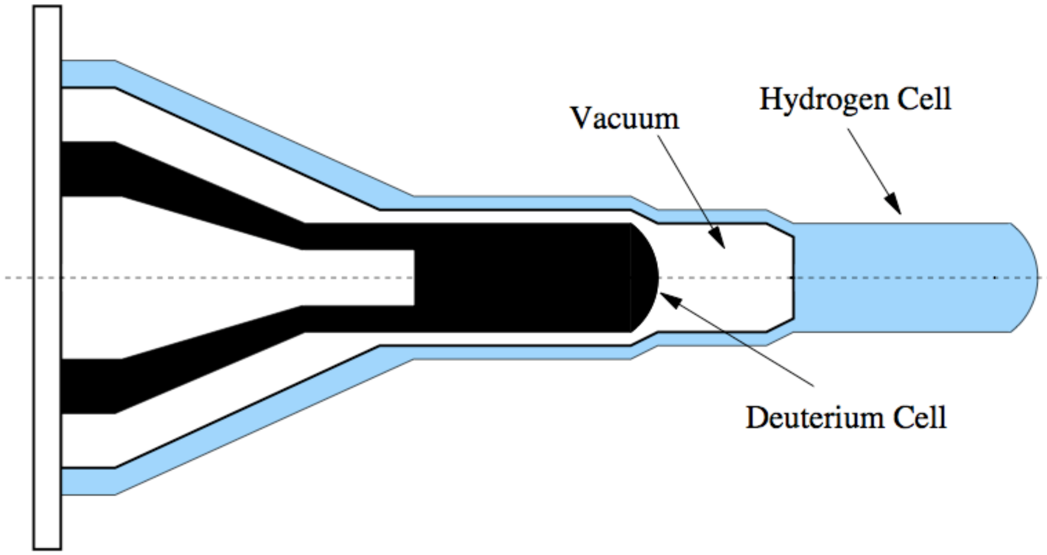
	U	L	T
U			
L			

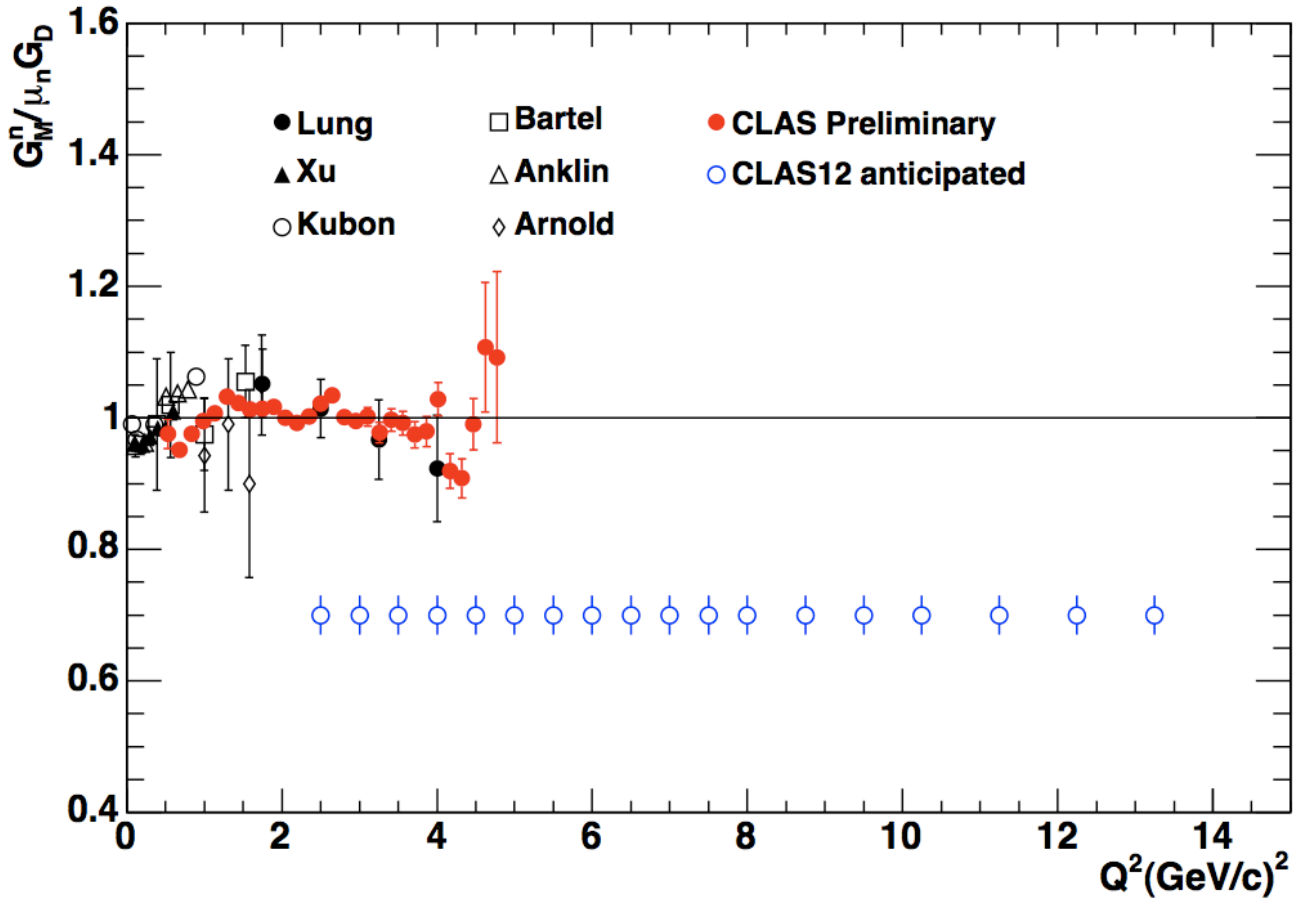
Measure of the Neutron Magnetic FF at High Q^2

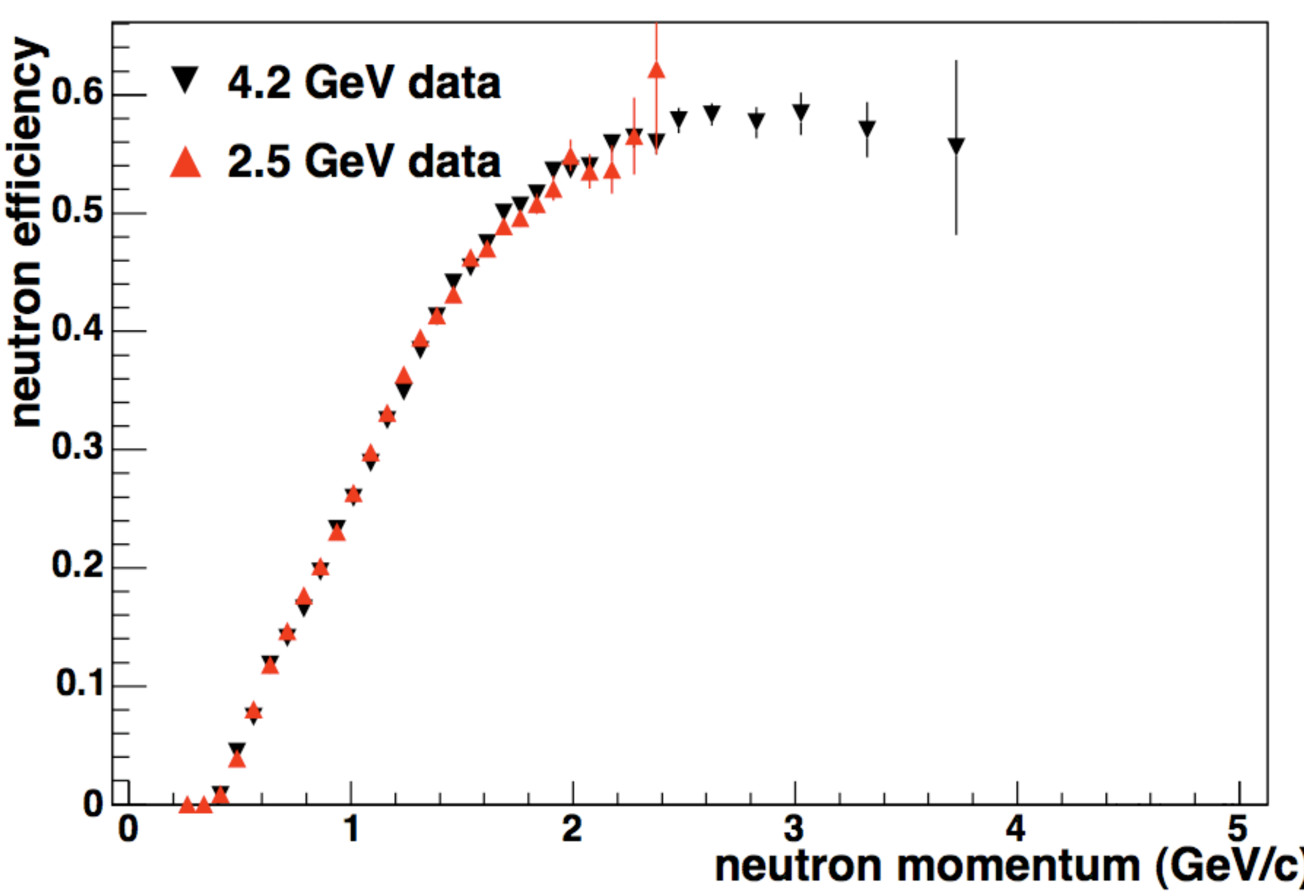
PR12-07-104

$$R = \frac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\frac{d\sigma}{d\Omega}(D(e,e'p))}$$

$$R = a(Q^2)\frac{\sigma^n_{mott}\left({G^n_E}^2 + \frac{\tau_n}{\epsilon_n}{G^n_M}^2\right)\left(\frac{1}{1+\tau_n}\right)}{\sigma^p_{mott}\left({G^p_E}^2 + \frac{\tau_p}{\epsilon_p}{G^p_M}^2\right)\left(\frac{1}{1+\tau_p}\right)}$$

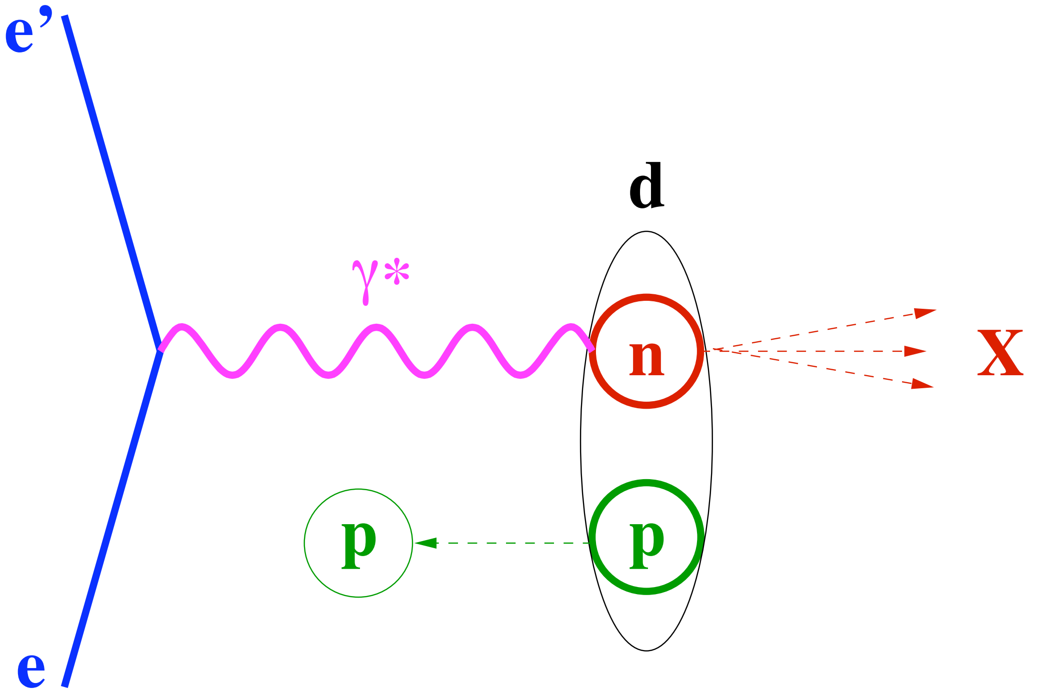






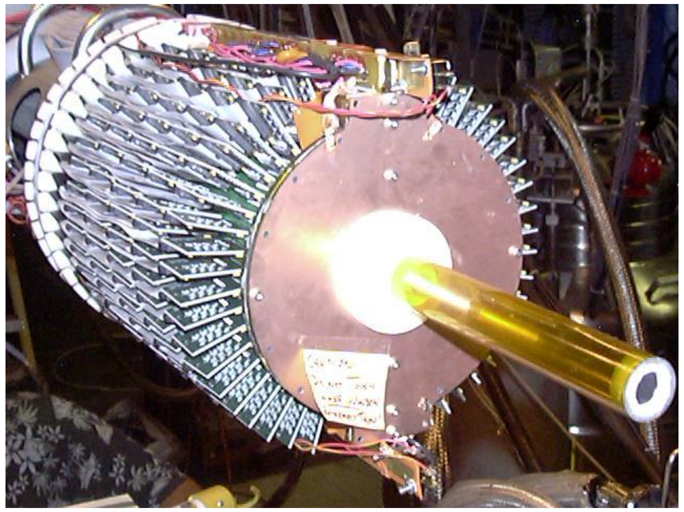
Structure of the Free Neutron at Large Bjorken x

PR12-06-113

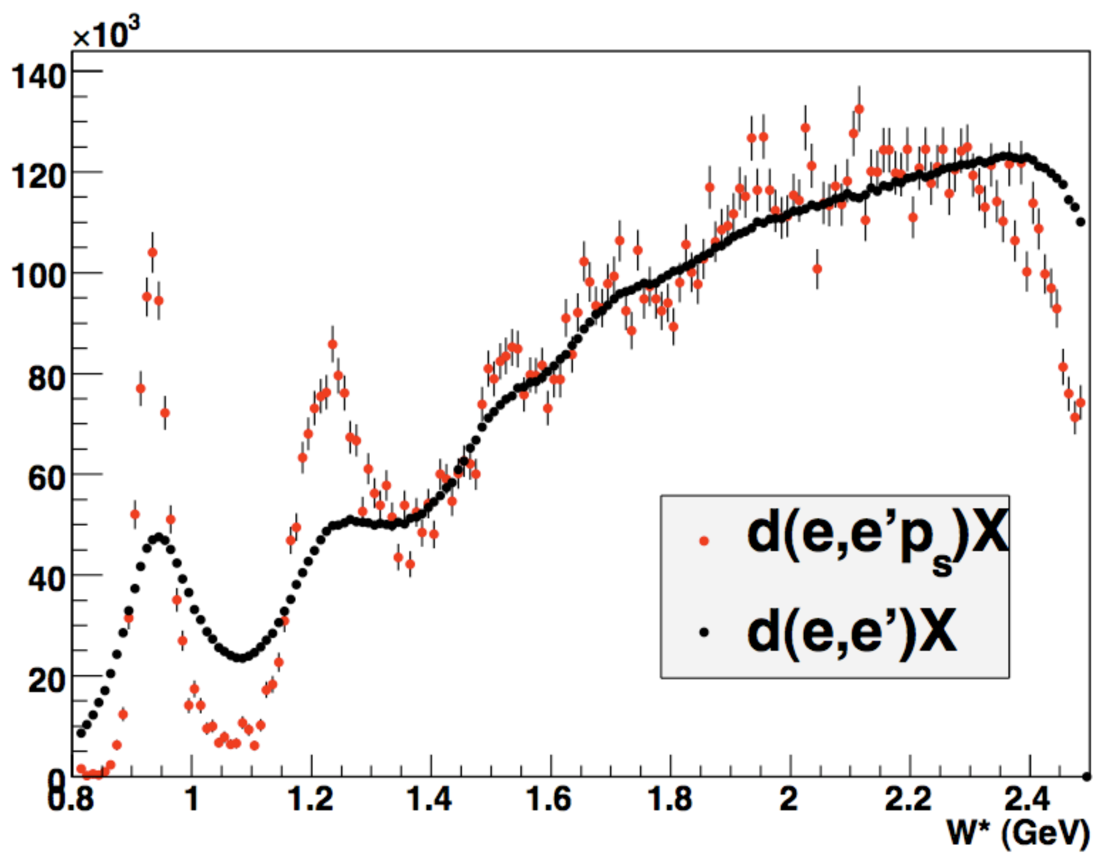


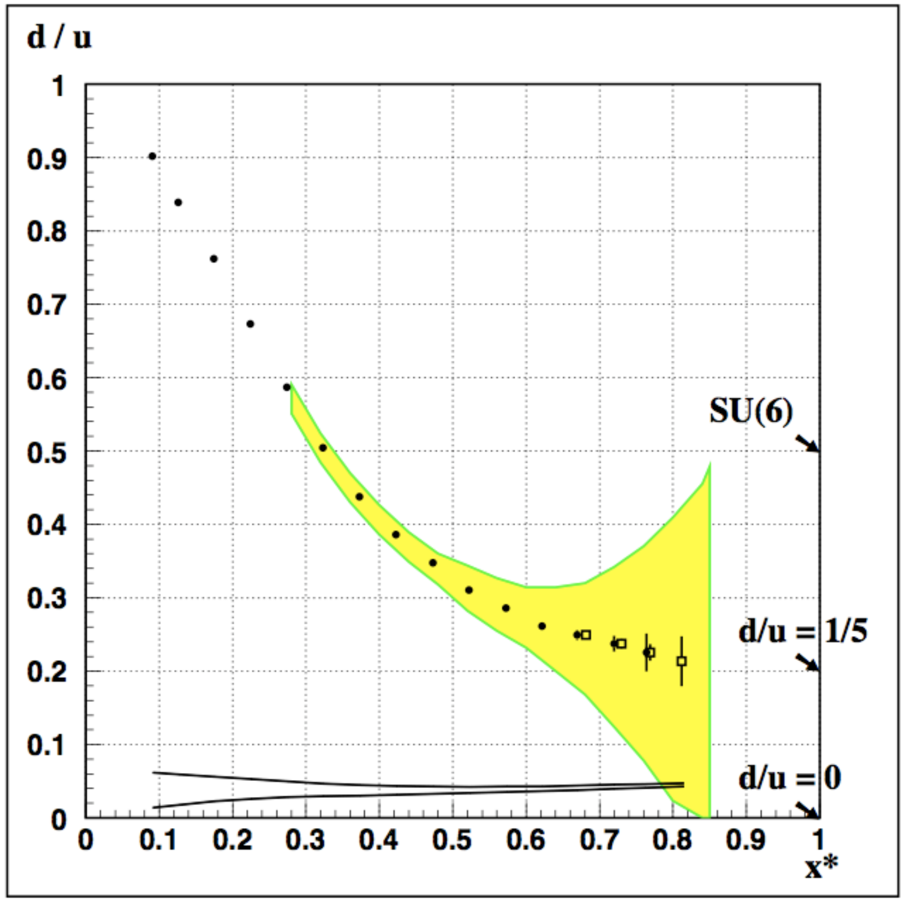
$$\frac{F_2^n}{F_2^p} = \left(\frac{F_2^n}{F_2^d}\right)\left(\frac{F_2^d}{F_2^p}\right)_{\text{model}}$$

d(e,e'p_s)X / d(e,e')X



Radial TPC: 70 < p_s <100 MeV/c





	U	L	T
U			
L			

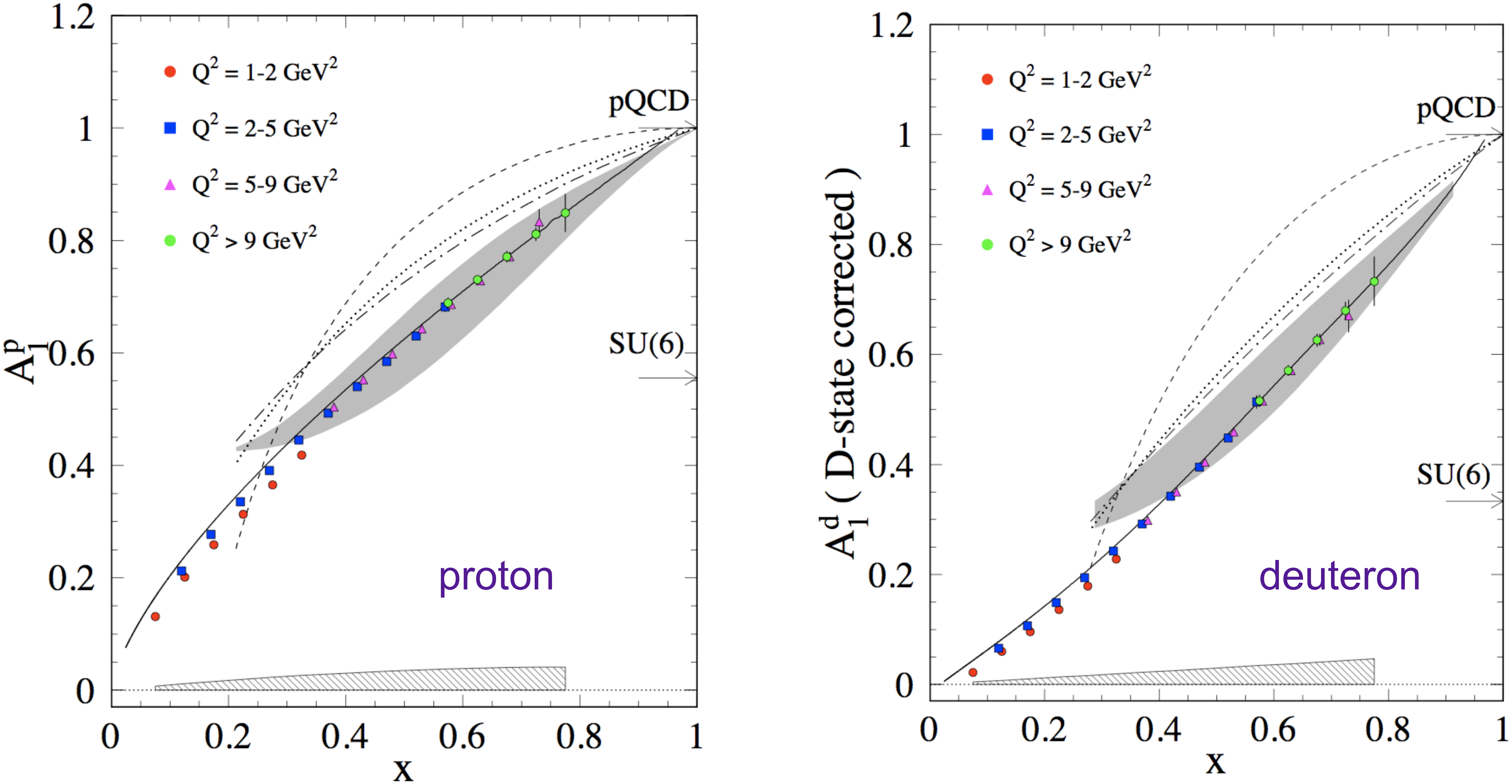
Longitudinal Spin Structure of the Nucleon

PR12-06-109

$$\frac{d\sigma}{dx\,dy\,d\psi} = \frac{2\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\Big\{F_T + \varepsilon F_L + S_\parallel \lambda_e \sqrt{1-\varepsilon^2}\,2x\left(g_1 - \gamma^2 g_2\right) - |\boldsymbol{S}_\perp|\lambda_e\sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_S\,2x\gamma\left(g_1+g_2\right)\Big\}$$

Inclusive double spin asymmetries, esp. at high x

$A_1=2x(g_1-\gamma^2 g_2)/F_T$

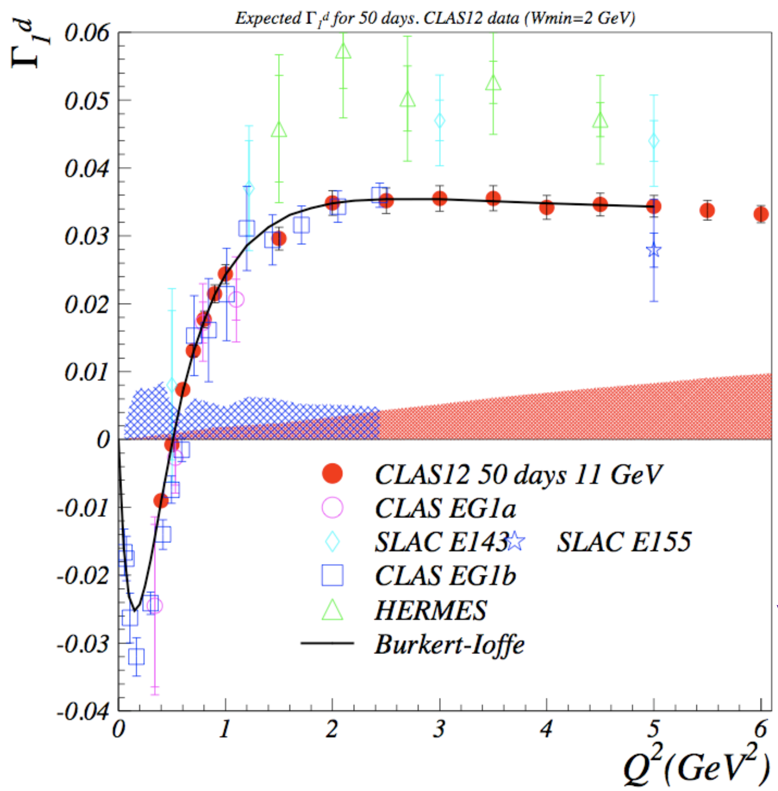


DIS: A_{LL}

	U	L	T
U			
L			

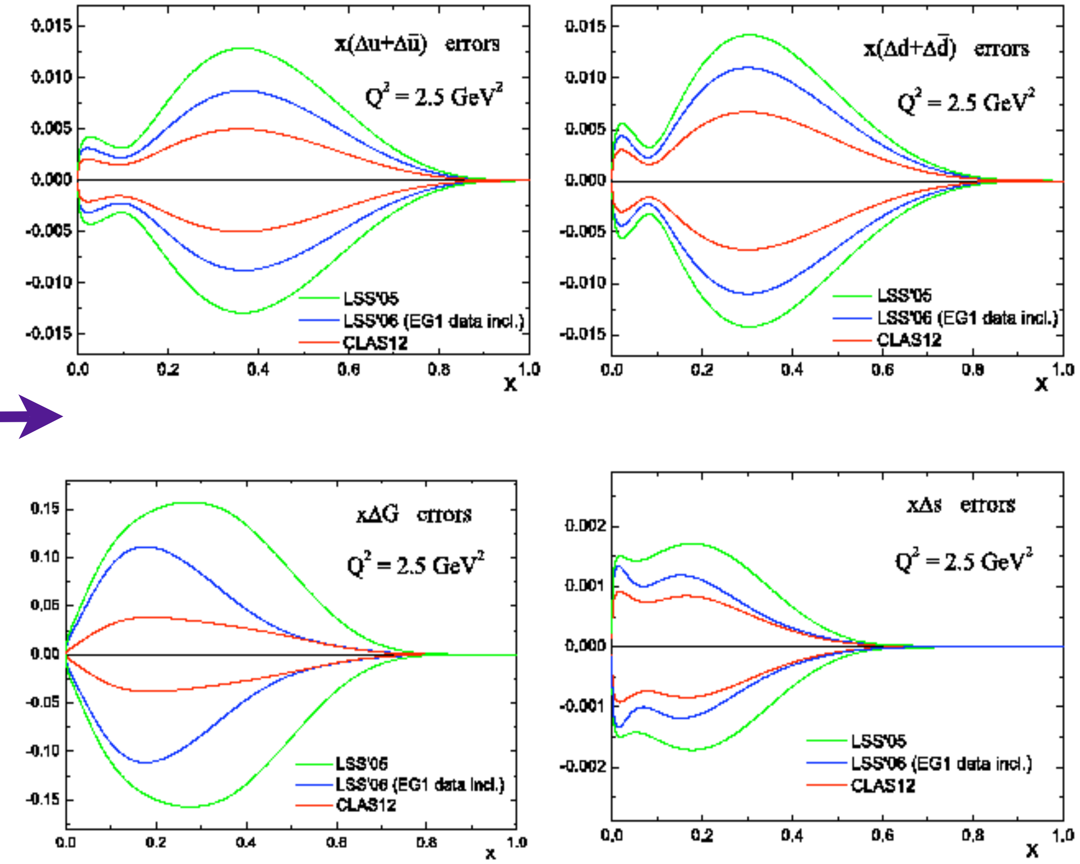
Longitudinal Spin Structure of the Nucleon

PR12-06-109

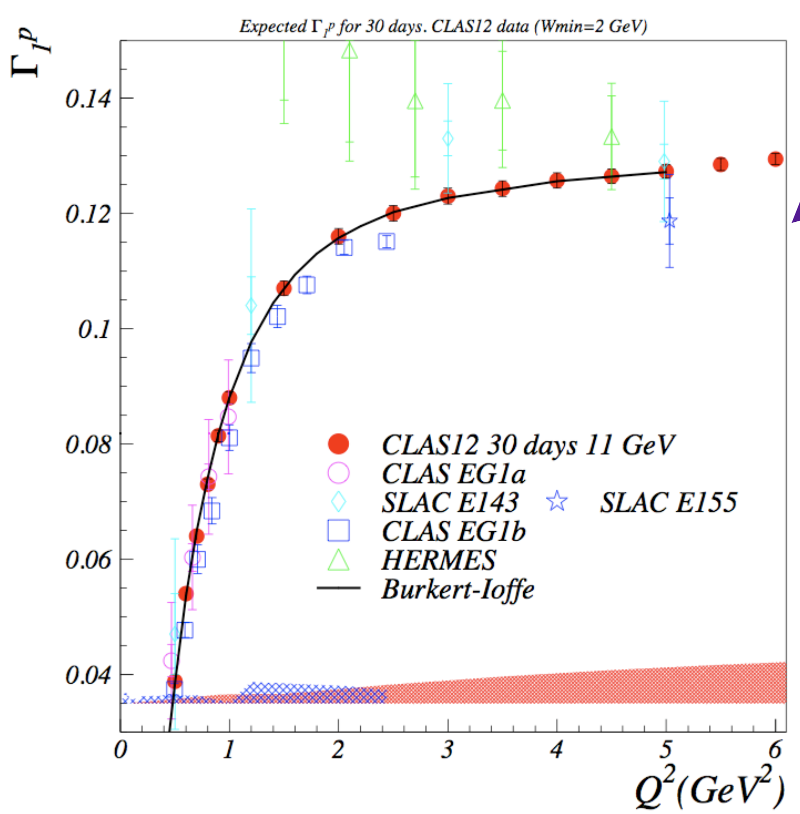


$A_1 \sim g_1/F_1$

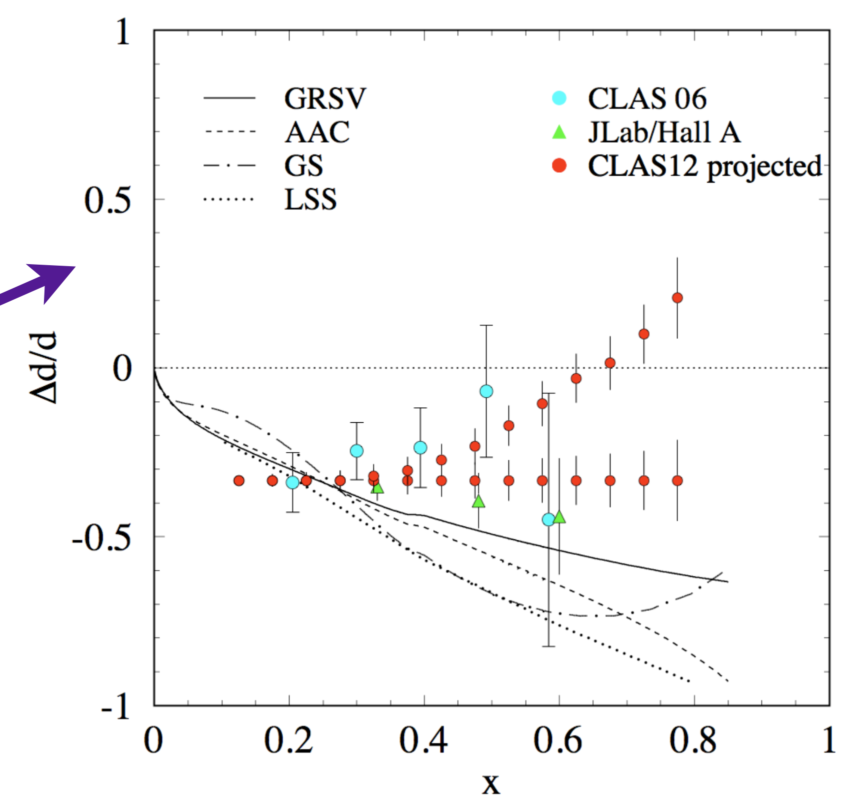
NLO fits to PDFs improve greatly with CLAS12 data



$\Gamma_1 = \int dx\, g_1(x)$



$\Delta d(x)/d(x)$ significantly improved at high x



Hard Exclusive Electroproduction of π^0 and η

PR12-06-108

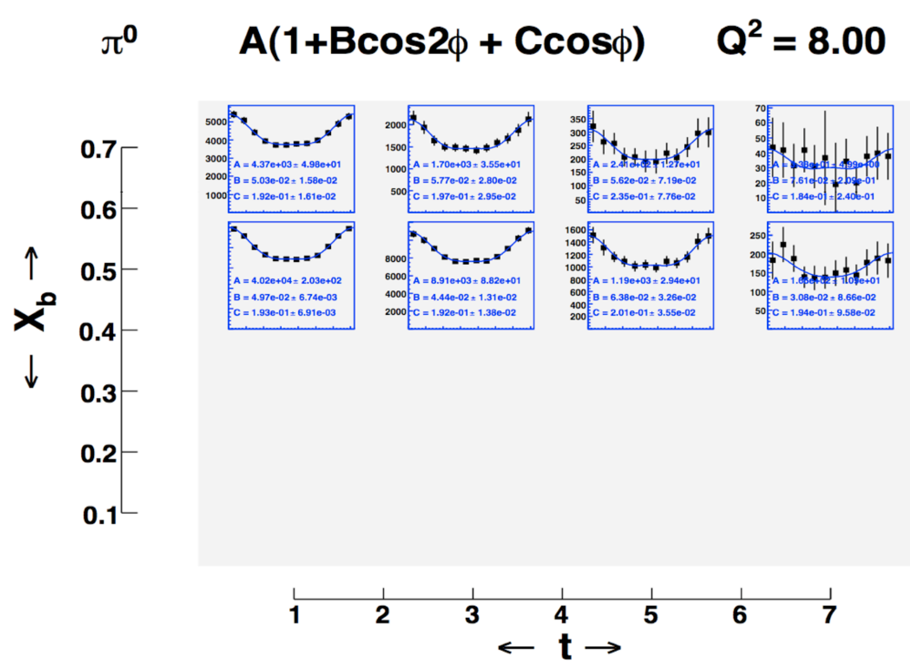
$$\frac{d\sigma}{d\Omega} = \sigma_T + \epsilon \sigma_L + \sqrt{2\epsilon(1+\epsilon)} \cos\phi\, \sigma_{LT} + \epsilon \cos 2\phi\, \sigma_{TT} + \lambda_e \sqrt{2\epsilon(1-\epsilon)} \sin\phi\, \sigma_{LT'}$$

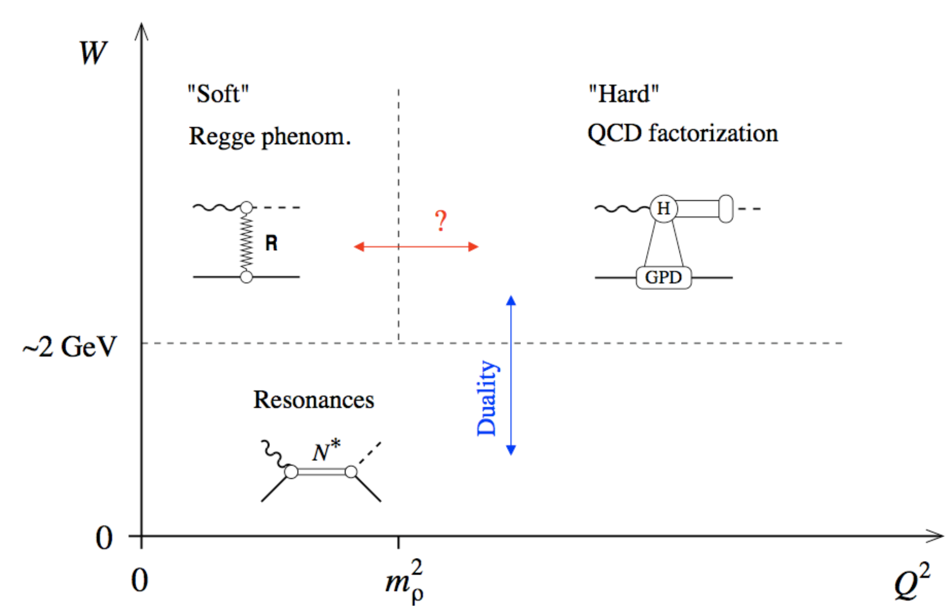
$$\tilde{H}(x,0;0) = \Delta q(x) \quad \text{for} \quad x > 0$$

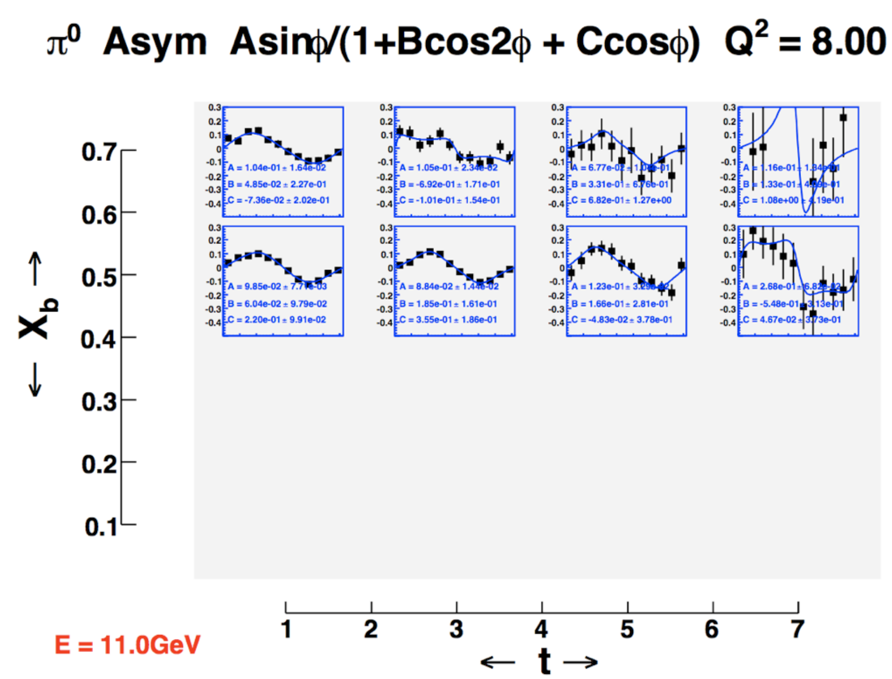
$$\pi^0 : \qquad 2\Delta u - \Delta d,$$

$$\eta : \qquad 2\Delta u + \Delta d,$$

- p(e,e'π^0)p and p(e,e'η)p
- W>2 GeV; 1<Q^2<10 GeV^2
- L/T separation for limited Q^2
- Measure LT interference by azimuthal dependences
- Sensitive to $\tilde{H}$ and $\tilde{E}$







&

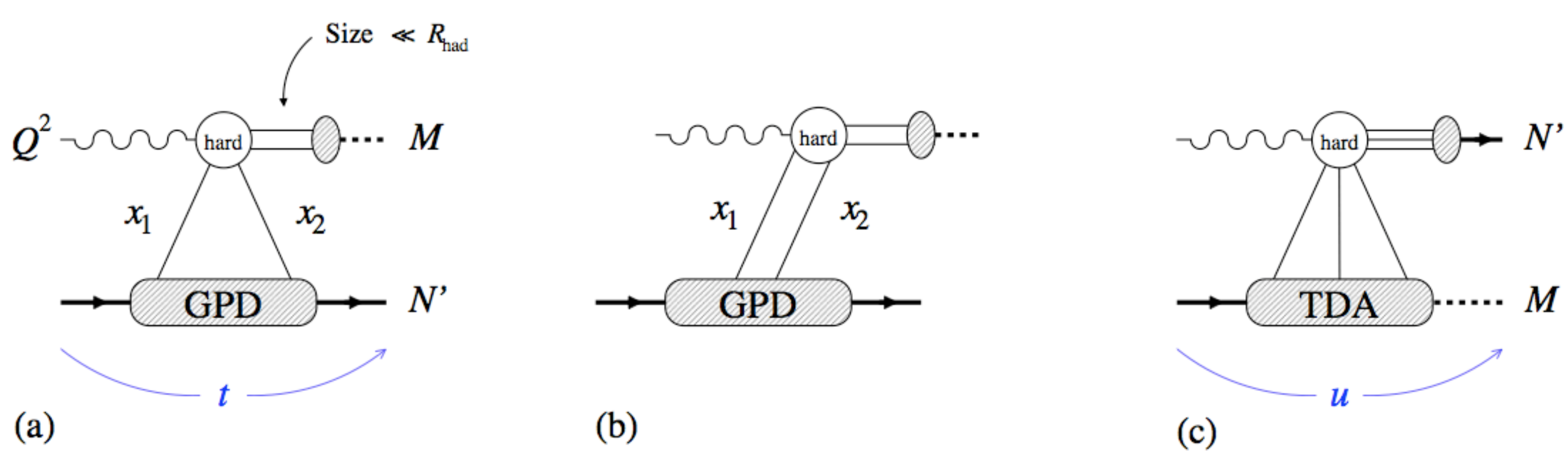
DVMP σ_{UU} & σ_{LU}

	U	L	T
U			
L			

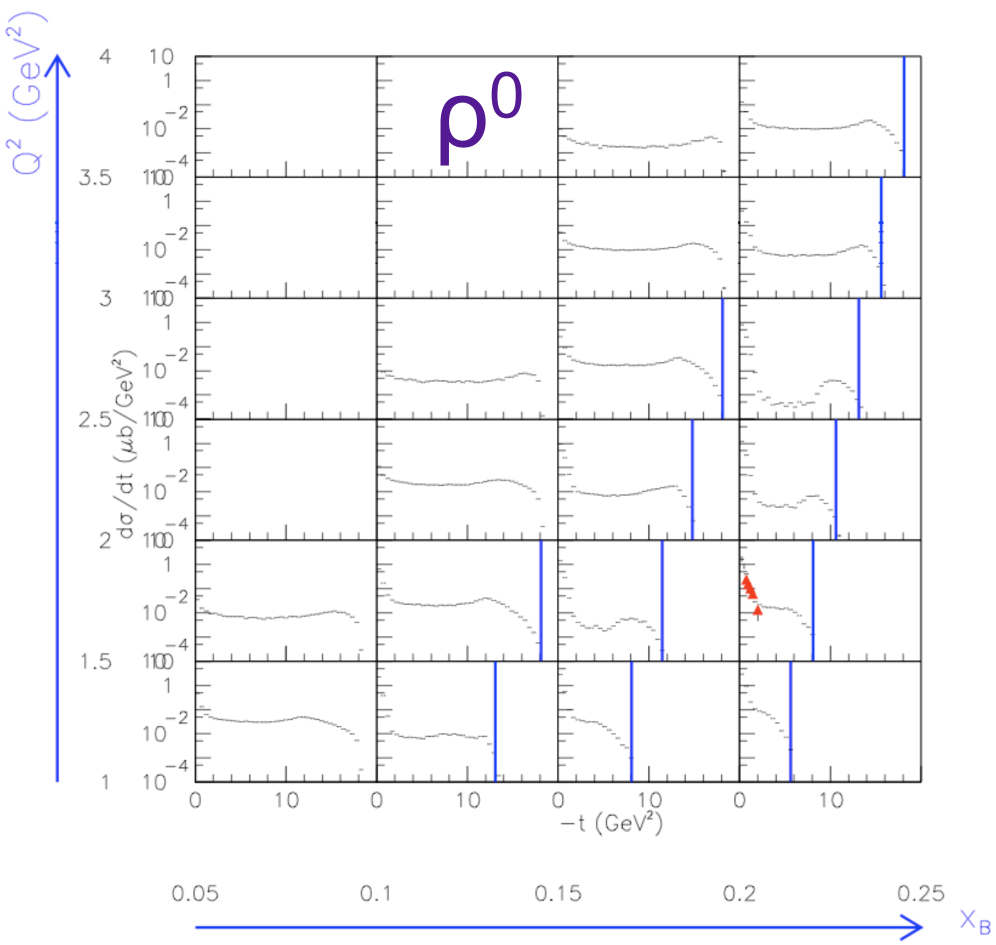
Exclusive Vector Meson Electroproduction

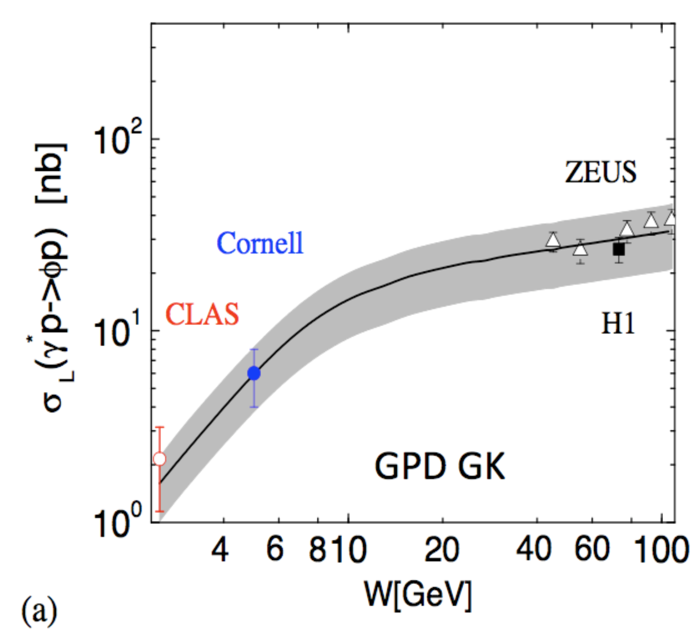
PR12-11-103

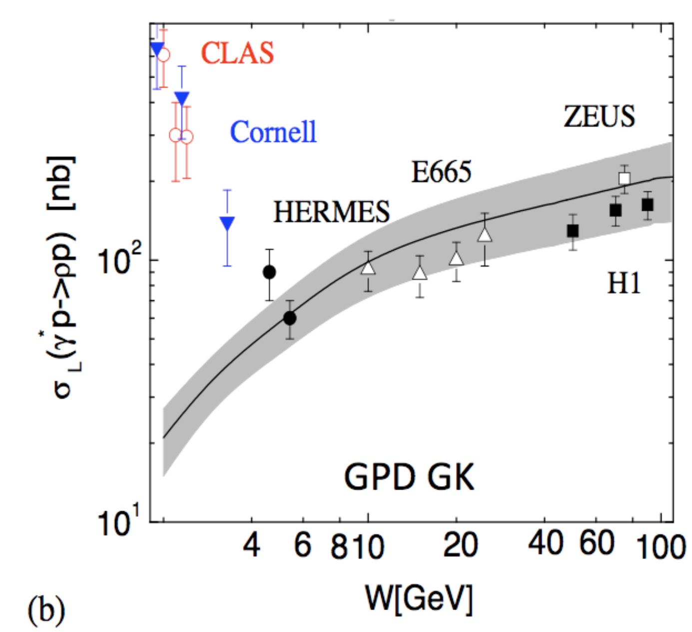
$$\frac{d\sigma}{d\Omega} = \sigma_T + \epsilon\sigma_L + \sqrt{2\epsilon(1+\epsilon)}\cos\phi\,\sigma_{LT} + \epsilon\cos 2\phi\,\sigma_{TT} + \lambda_e\sqrt{2\epsilon(1-\epsilon)}\sin\phi\,\sigma_{LT'}$$



- (a) Low t; high Q^2; x_1/x_2 have same sign
- (b) Low t; high Q^2; x_1/x_2 have opposite sign (q-qbar)
- (c) high Q^2; low u (i.e. backwards meson)
- (d) ρ^+, ρ^0, ϕ, ω
- (e) $2<W<5$ GeV; $1<Q^2<12$ GeV^2; -t to 15 GeV^2





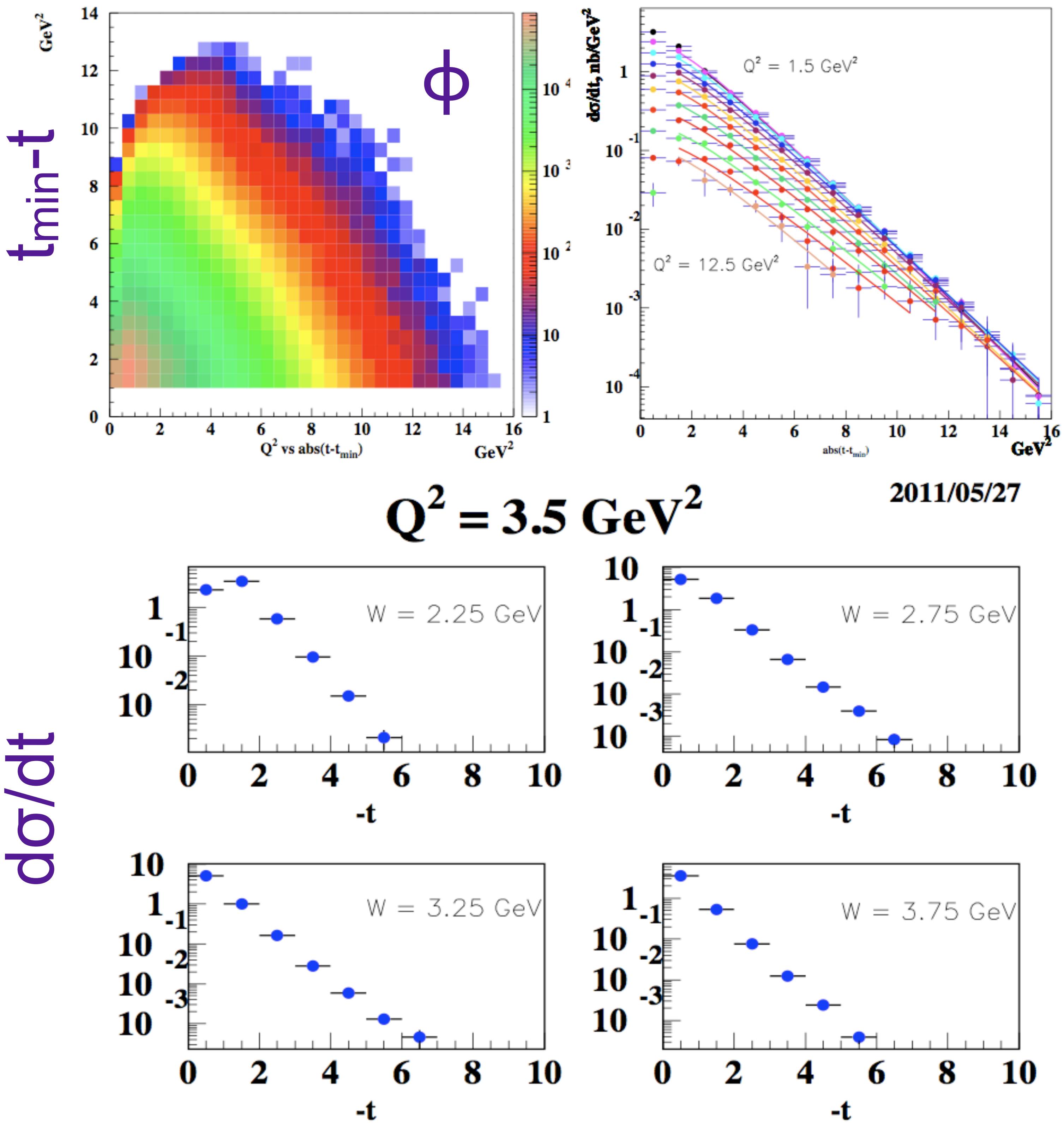


DVMP σ_{UU} & σ_{LU}

	U	L	T
U			
L			

Exclusive Vector Meson Electroproduction

PR12-11-103



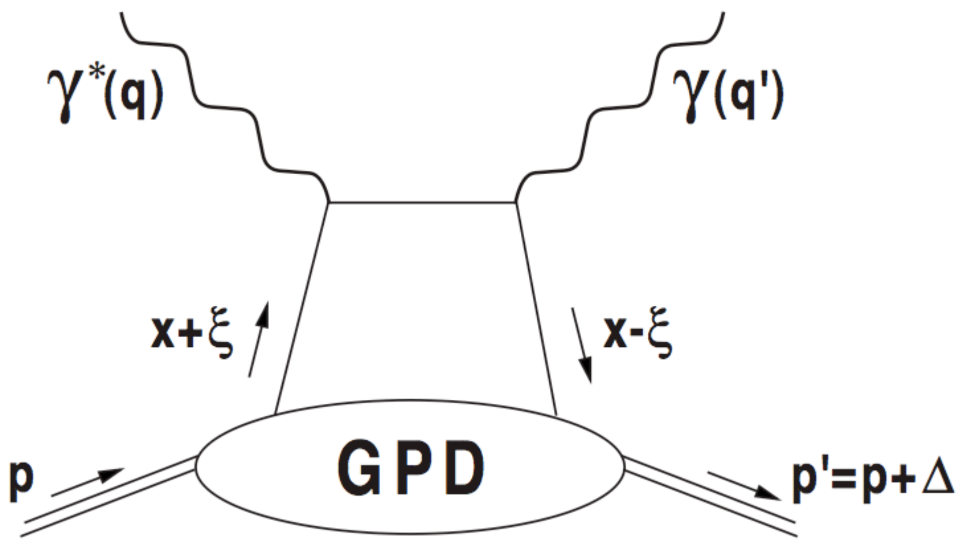
(a) Q^2 vs t_{min}-t event distribution for φ (mostly $\kappa^+\kappa^-$)
(b) dσ/dt for bins in Q^2
(c) dσ/dt at $Q^2 = 3.5$ GeV^2 and W = 2.25, 2.75, 3.25 and 3.75 GeV

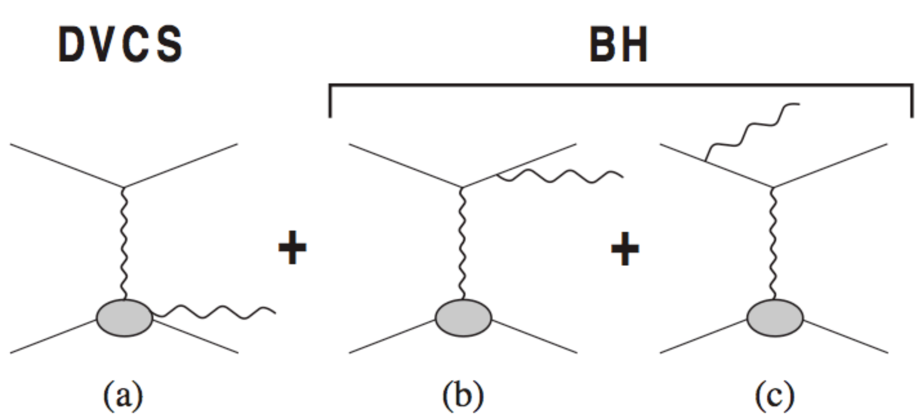
DVCS: A_{LU} & A_{UL}

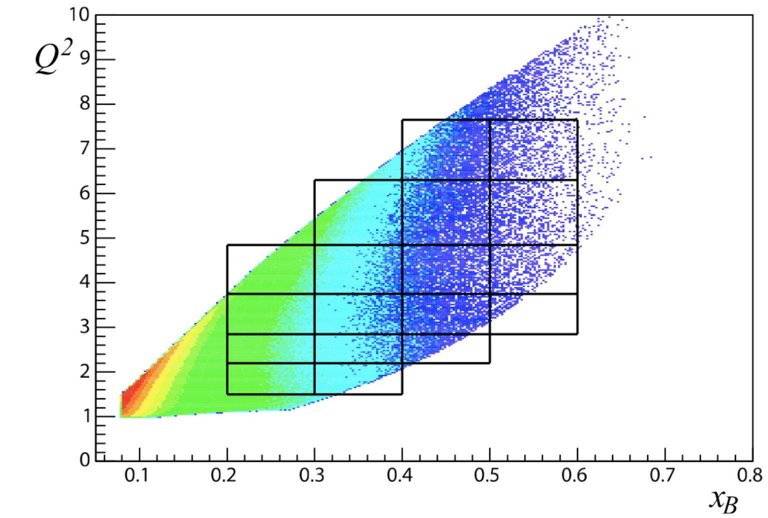
	U	L	T
U		■	
L	■		

Deeply Virtual Compton Scattering

PR12-06-119







$$\frac{1}{2} = J_q + J_g$$

$$J_q = \frac{1}{2}\Delta\Sigma + L_q$$

$$\sum_q \frac{1}{2}\int_{-1}^{+1} dx\, x[H^q(x,\xi,t=0) + E^q(x,\xi,t=0)] = J_q$$

$$\mathcal{H}(\xi,t) = \sum_q \left[\frac{e_q}{e}\right] \left\{ i\pi\left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t)\right] + \mathcal{P}\int_{-1}^{+1} dx \left[\frac{1}{\xi - x} - \frac{1}{\xi + x}\right] H^q(x,\xi,t)\right\}$$

Compton FF

$$d\sigma^{\rightarrow} - d\sigma^{\leftarrow} = 2\cdot\mathcal{T}_{BH}\cdot Im(\mathcal{T}_{DVCS})$$

$$d\sigma^{\rightarrow} + d\sigma^{\leftarrow} = |T_{BH}|^2 + 2\cdot\mathcal{T}_{BH}\cdot Re(\mathcal{T}_{DVCS})$$

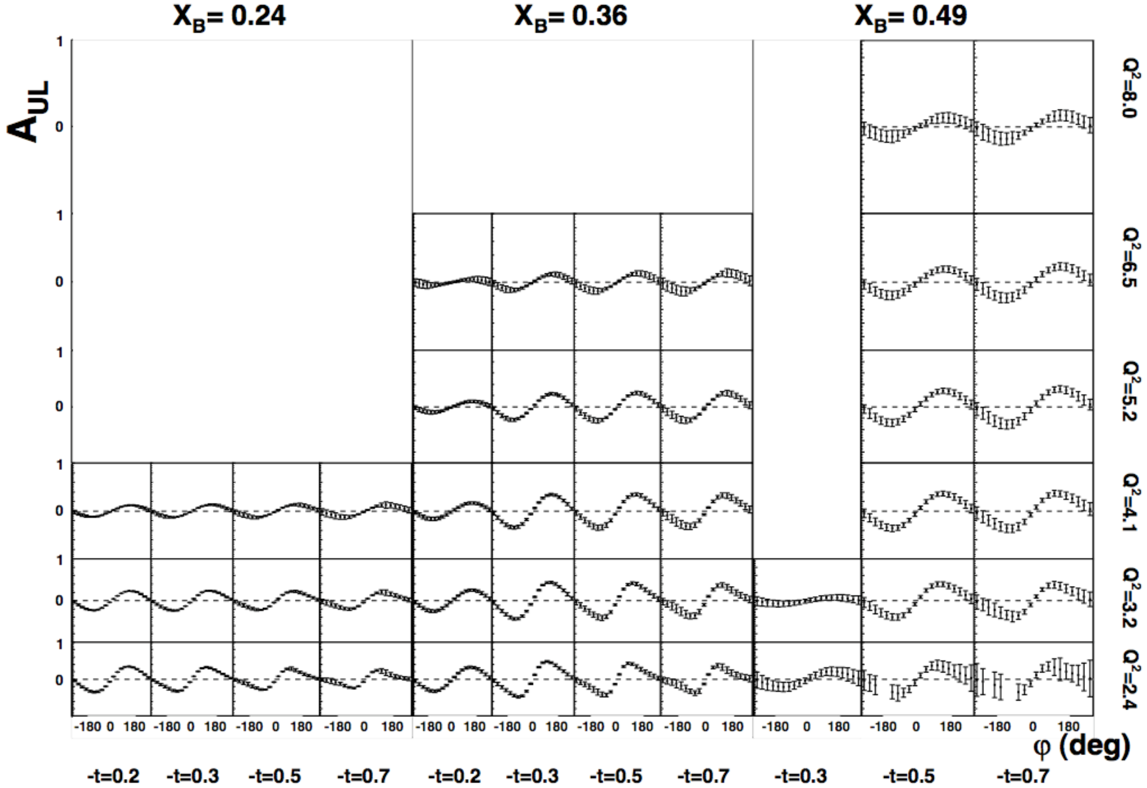
$$A \simeq \Gamma_A \frac{s_1^I}{c_0^{BH}}\sin\varphi \qquad s_{1,unp}^I = Im\left\{F_1\mathcal{H} + \frac{x_B}{2-x_B}(F_1+F_2)\widetilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}\right\}$$

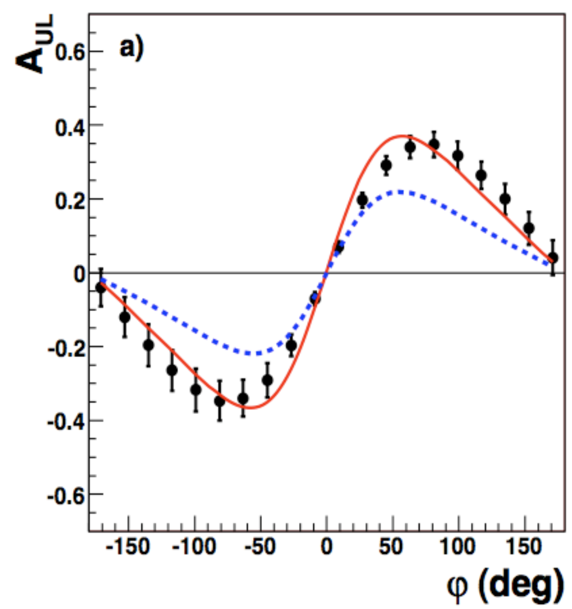
$$s_{1,LP}^I = Im\left\{F_1\widetilde{\mathcal{H}} + \frac{x_B}{2-x_B}(F_1+F_2)\left(\mathcal{H} + \frac{x_B}{2}\mathcal{E}\right) - \frac{x_B}{2-x_B}\left(\frac{x_B}{2}F_1 + \frac{t}{4M^2}F_2\right)\widetilde{\mathcal{E}}\right\}$$

DVCS: A_{LU} & A_{LU}

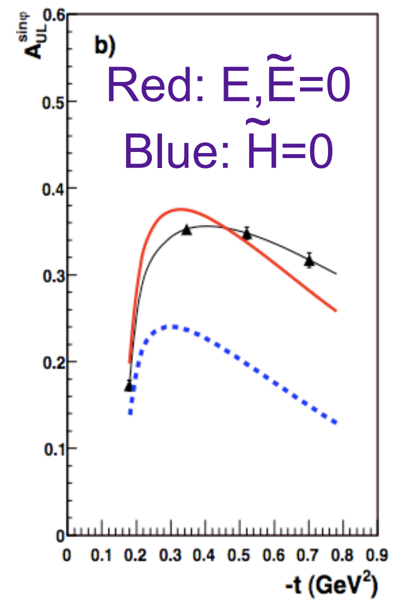
	U	L	T
U			
L			

PR12-06-119

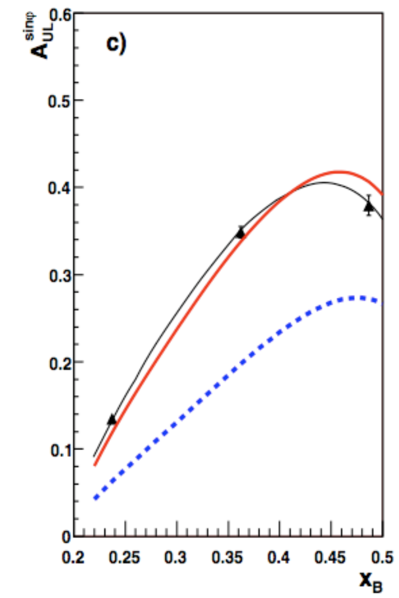




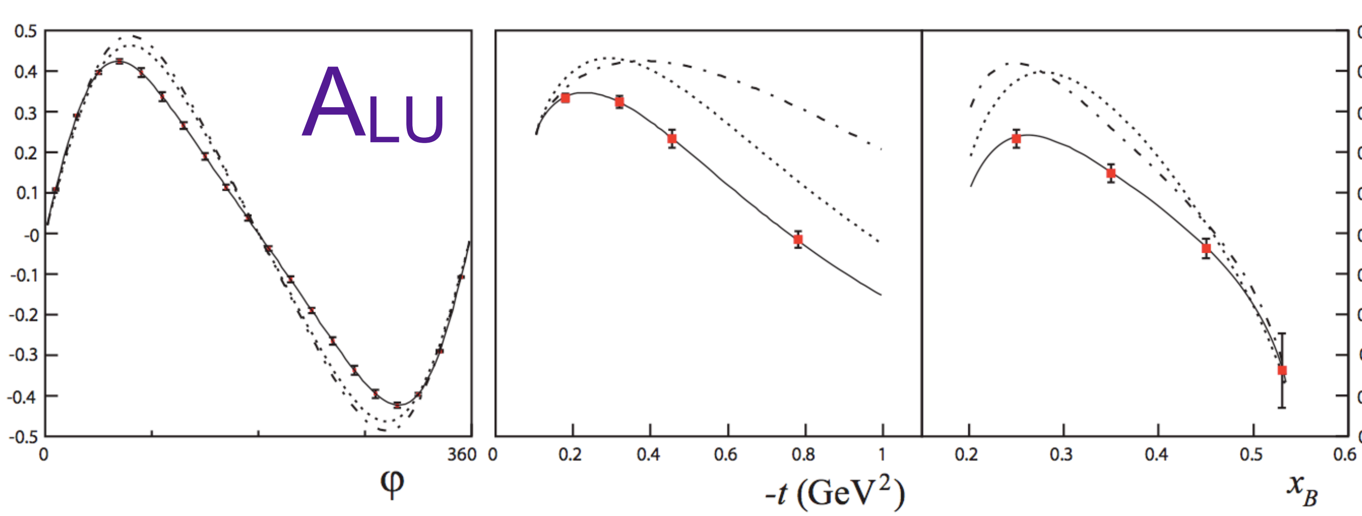
x=0.36
Q^2=4.1 GeV^2
-t=0.52 GeV^2



x=0.36
Q^2=4.1 GeV^2
sinϕ moment



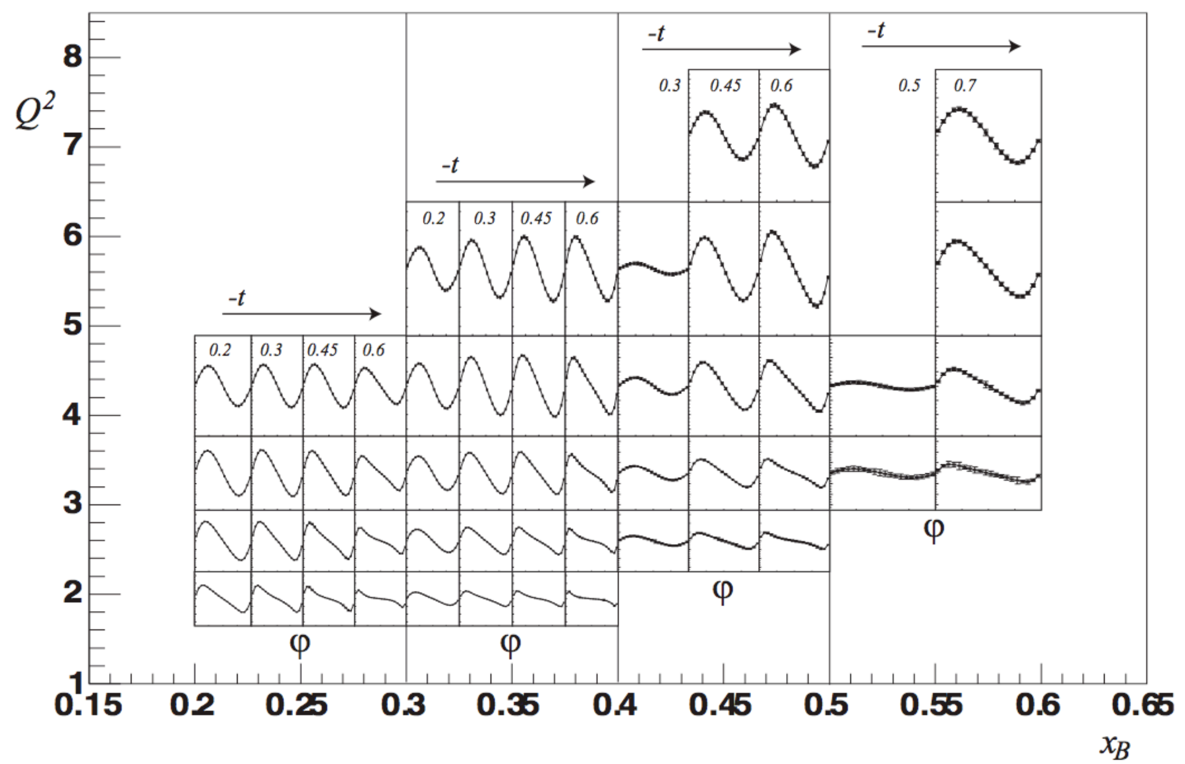
t=0.52 GeV^2
Q^2=4.1 GeV^2
sinϕ moment



x=0.2
Q^2=3.3 GeV^2
-t=0.45 GeV^2

x=0.2
Q^2=3.3 GeV^2
ϕ=90^o

t=0.45 GeV^2
Q^2=3.3 GeV^2
ϕ=90^o



DVCS: A_{LU}

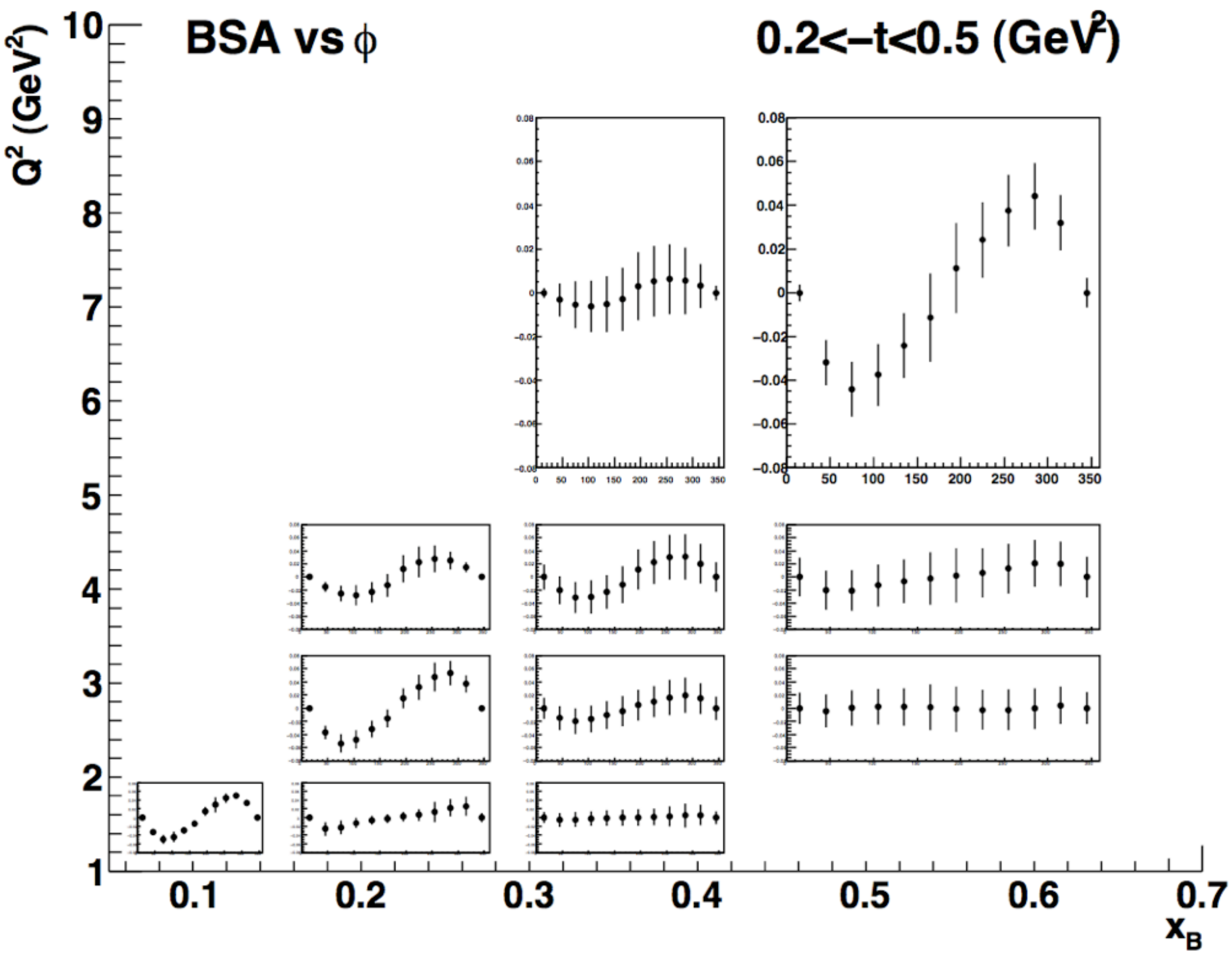
	U	L	T
U			
L			

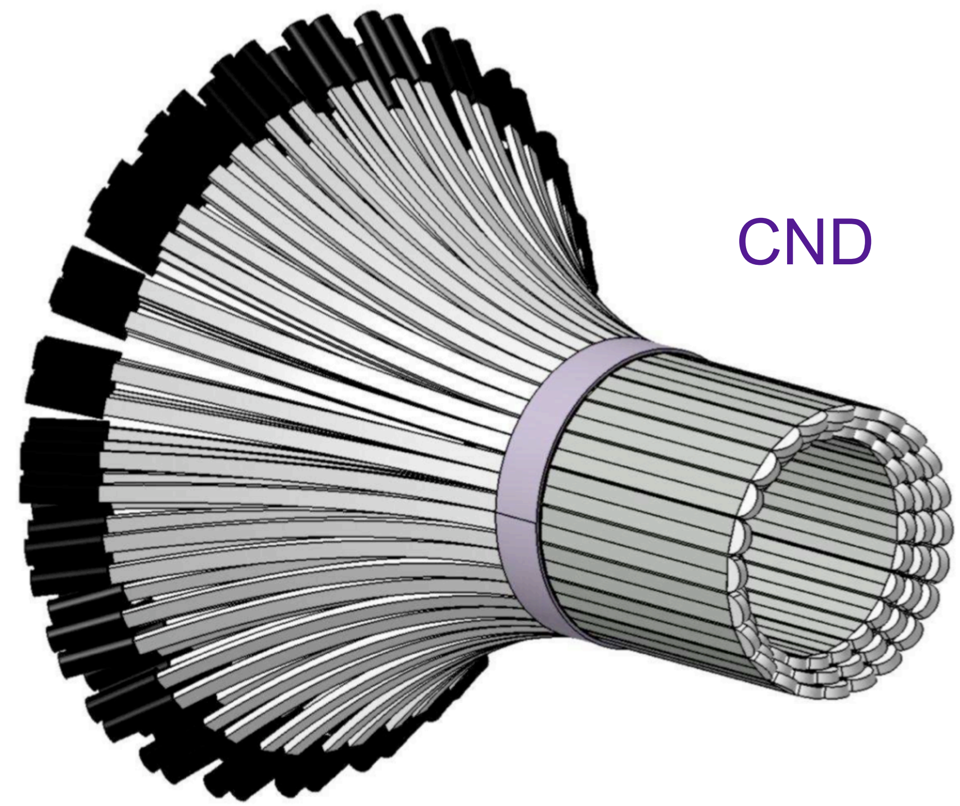
DVCS on the Neutron

PR12-11-103

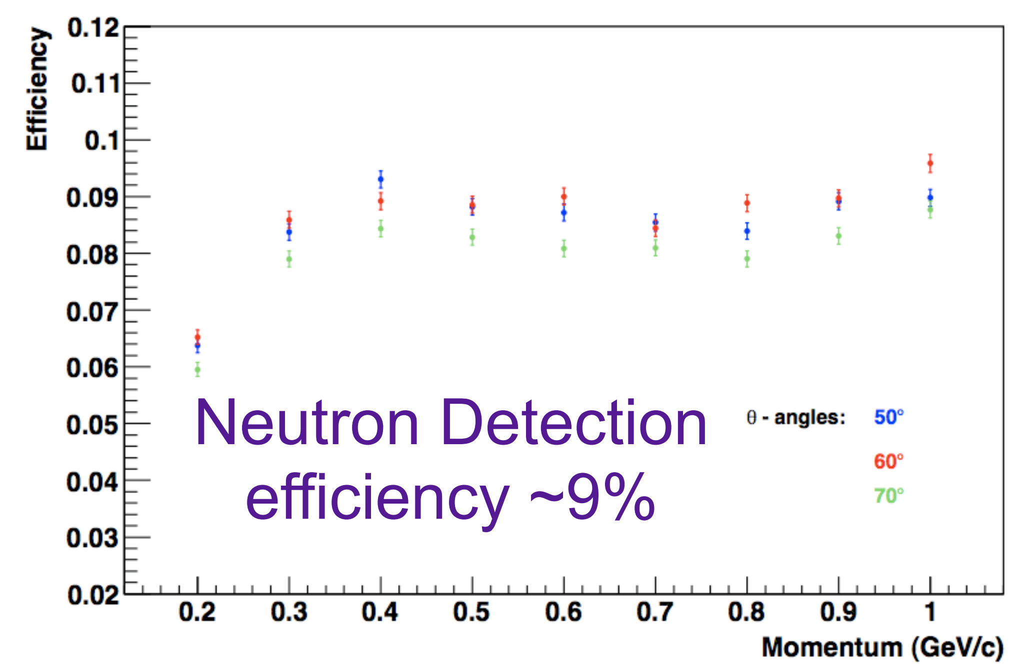
$$ed \to e'n\gamma(p)$$

Beam spin asymmetry for 1 of 4 t-bins



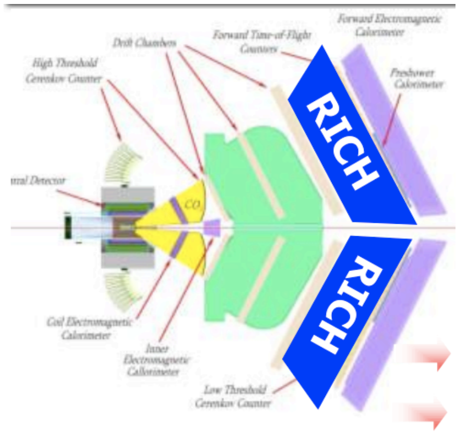


CND



Parton Distributions from SIDIS with Kaons

PR12-09-107



$$A_1^h(x,Q^2,z) = \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)} = \sum_q \mathcal{P}_q^h(x,Q^2,z)\frac{\Delta q(x,Q^2)}{q(x,Q^2)}$$

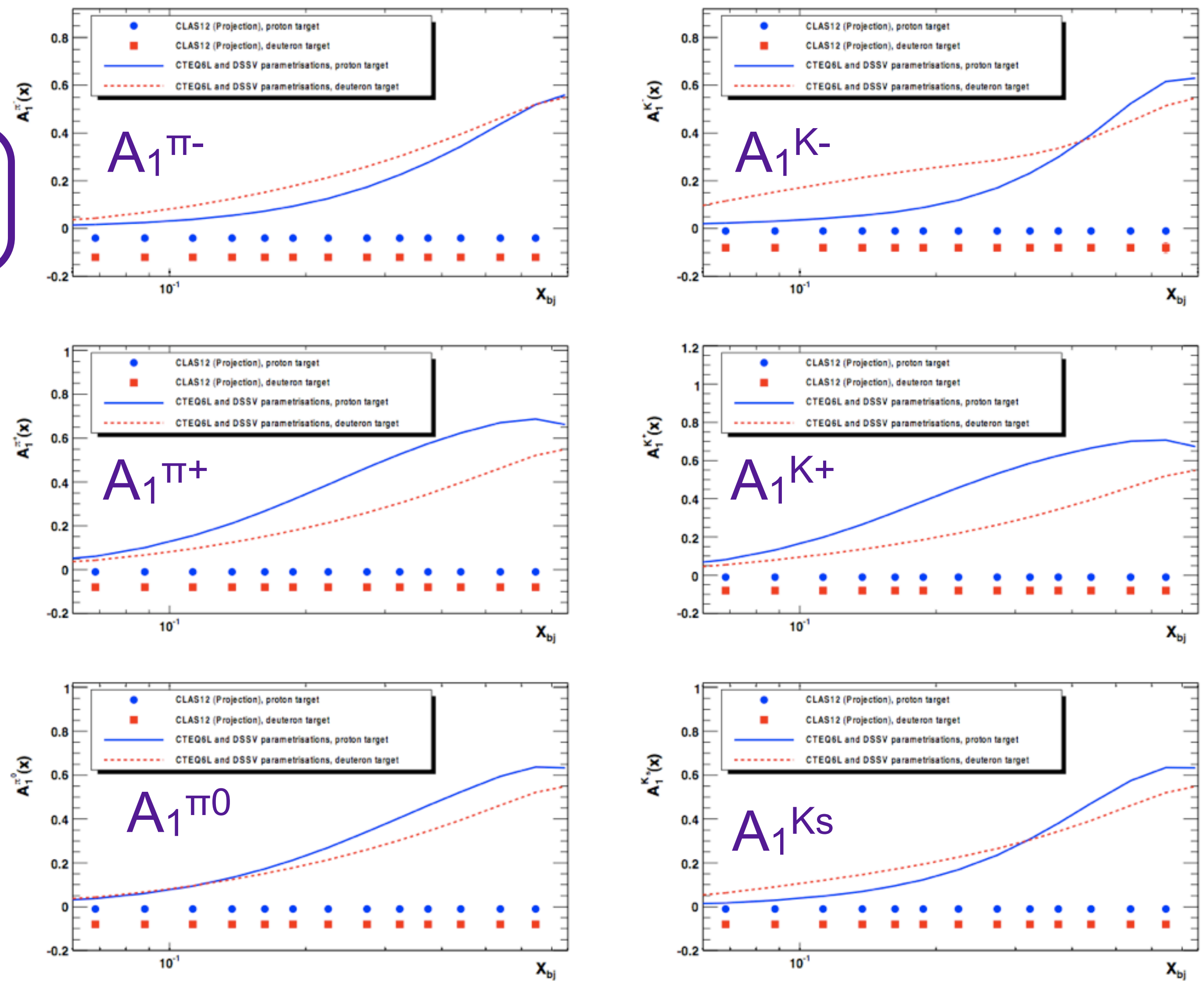
$$\vec{\mathcal{A}}(x,Q^2) = (A_{1p}, A_{1p}^{\pi^+}, A_{1p}^{\pi^-}, A_{1p}^{K^+}, A_{1p}^{K^-}, A_{1p}^{K_s^0}, A_{1d}, A_{1d}^{\pi^+}, A_{1d}^{\pi^-}, A_{1d}^{K^+}, A_{1d}^{K^-}, A_{1d}^{K_s^0})$$

$$\mathcal{P}_q^h(x,Q^2,z) = \frac{e_q^2 q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}$$

$$\vec{\mathcal{Q}}(x,Q^2) = (\frac{\Delta u}{u}, \frac{\Delta d}{d}, \frac{\Delta s}{s}, \frac{\Delta \bar{u}}{\bar{u}}, \frac{\Delta \bar{d}}{\bar{d}}, \frac{\Delta \bar{s}}{\bar{s}})$$

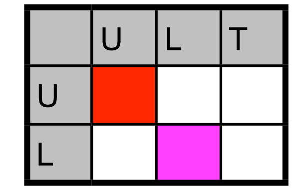
$$\vec{\mathcal{A}}(x,Q^2) = \mathcal{P}(x,Q^2) \cdot \vec{\mathcal{Q}}(x,Q^2)$$

$A_1 \sim F_{LL}/F_{UU} = A_{LL}$



- Purities determined from unpolarized data
- Proton and deuteron targets
- Kaon detection is crucial
- RICH detector needed for this

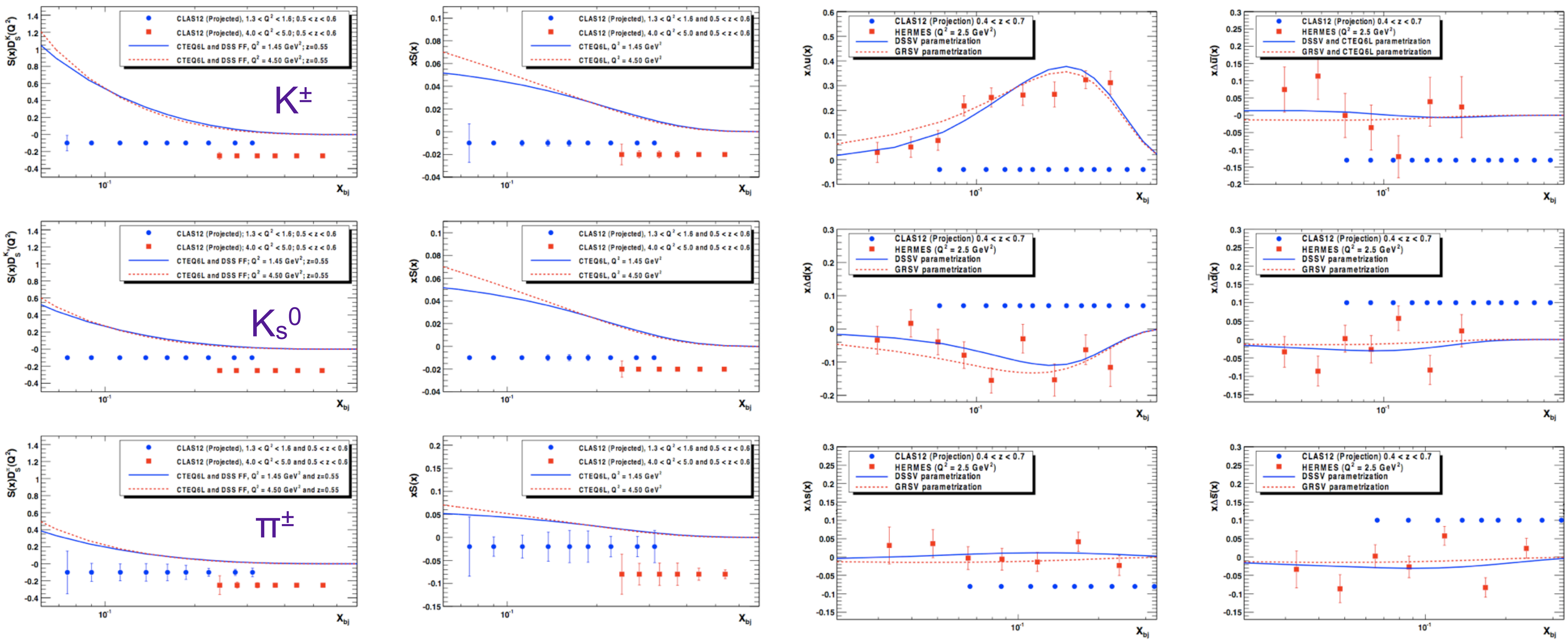
SIDIS: F_{UU} & F_{LL}



Parton Distributions from SIDIS with Kaons

PR12-09-107

$0.5 < z < 0.6$; Q^2=1.45 & 4.5 GeV^2



s(x)D(z) for $K^{\pm}$, K_s^0, $\pi^{\pm}$

xs(x) for $K^{\pm}$, K_s^0, $\pi^{\pm}$

$\Delta u(x)$, $\Delta d(x)$ $\Delta s(x)$

$\Delta\bar{u}(x)$, $\Delta\bar{d}(x)$, $\Delta\bar{s}(x)$

Primary TMDs

Red: T-odd

Black: survive p_T integration

Yellow box: chiral-odd

quark pol. / nucleon pol.

	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1,\ h_{1T}^\perp$

Twist-2 TMDs

$f_1(x,p_T)$ → f_1

Helicity → g_{1L}

Sivers → $f_{1T}^\perp$

Worm Gear → g_{1T}, $h_{1L}^\perp$

Transversity → h_1

Boer-Mulders → $h_1^\perp$

Pretzelocity → $h_{1T}^\perp$

higher twist → (e), (h_L)

SIDIS Cross Section

Bacchetta, et al., JHEP 2(2007)093

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\varepsilon F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h}$$

$$+\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

$$+S_\parallel\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right]$$

$$+S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]$$

$$+|\boldsymbol{S}_\perp|\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)$$

$$+\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big]$$

$$+|\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}$$

$$+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\},$$

Leading Twist

Sub-Leading Twist (extra factor of 1/Q)

0 (i.e. $R=\sigma_L/\sigma_T=0$)

A_{UL} = {UL terms} / {UU terms}

A_{LL} = {LL terms} / {UU terms}

etc.

f_1		$h_1^\perp$ (e)
	g_{1L}	$h_{1L}^\perp (h_L)$
$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

SIDIS A_{UU} & A_{LU}

	U	L	T
U			
L			

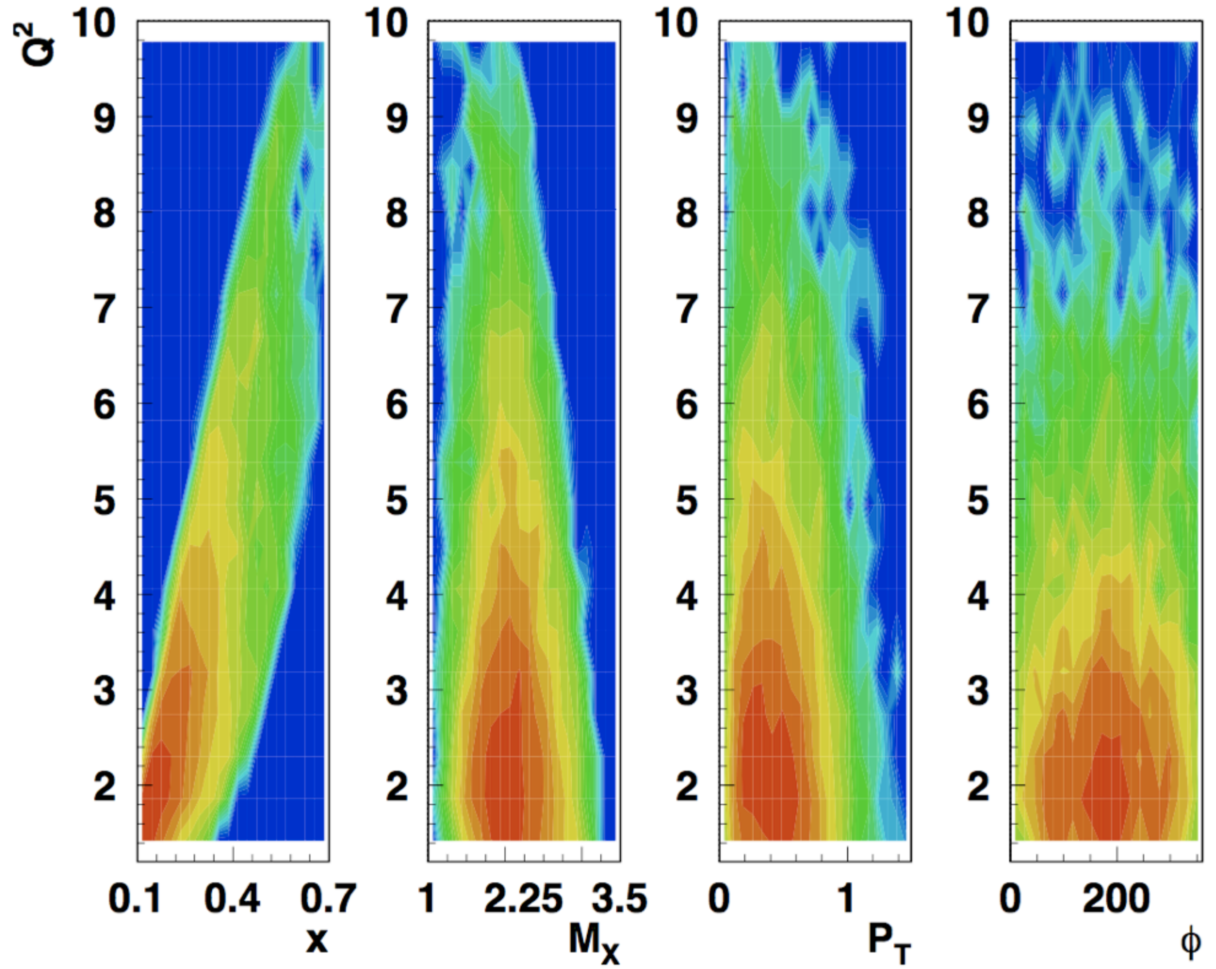
Proton Quark Dynamics in SIDIS π Production

PR12-06-112

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)\times$$

$$\left\{F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \epsilon\cos 2\phi_h F_{UU}^{\cos 2\phi_h} + \lambda_e\sqrt{2\epsilon(1-\epsilon)}\sin\phi_h F_{LU}^{\sin\phi_h}\right\}$$

$$f\otimes D = x\sum_q e_q^2\int d^2\mathbf{p}_T d^2\mathbf{k}_T \delta^{(2)}(\mathbf{p}_T - \mathbf{k}_T - \mathbf{P}_{h\perp}/z)w(\mathbf{p}_T,\mathbf{k}_T)f^q(x,p_T^2)D^q(z,k_T^2)$$



$$F_{UU,T} \sim f_1(x,p_T^2)\otimes D_1(z,k_T^2)$$

$$F_{UU}^{\cos 2\phi_h} \sim h_1^\perp(x,p_T^2)\otimes H_1^\perp(z,k_T^2)$$

$$F_{UU,L} \to 0$$

$$F_{UU}^{\cos\phi_h} \sim h(x,p_T^2)\otimes H_1^\perp(z,k_T^2)$$

$$F_{LU}^{\sin\phi_h} \sim e(x,p_T^2)\otimes H_1^\perp(z,k_T^2)$$

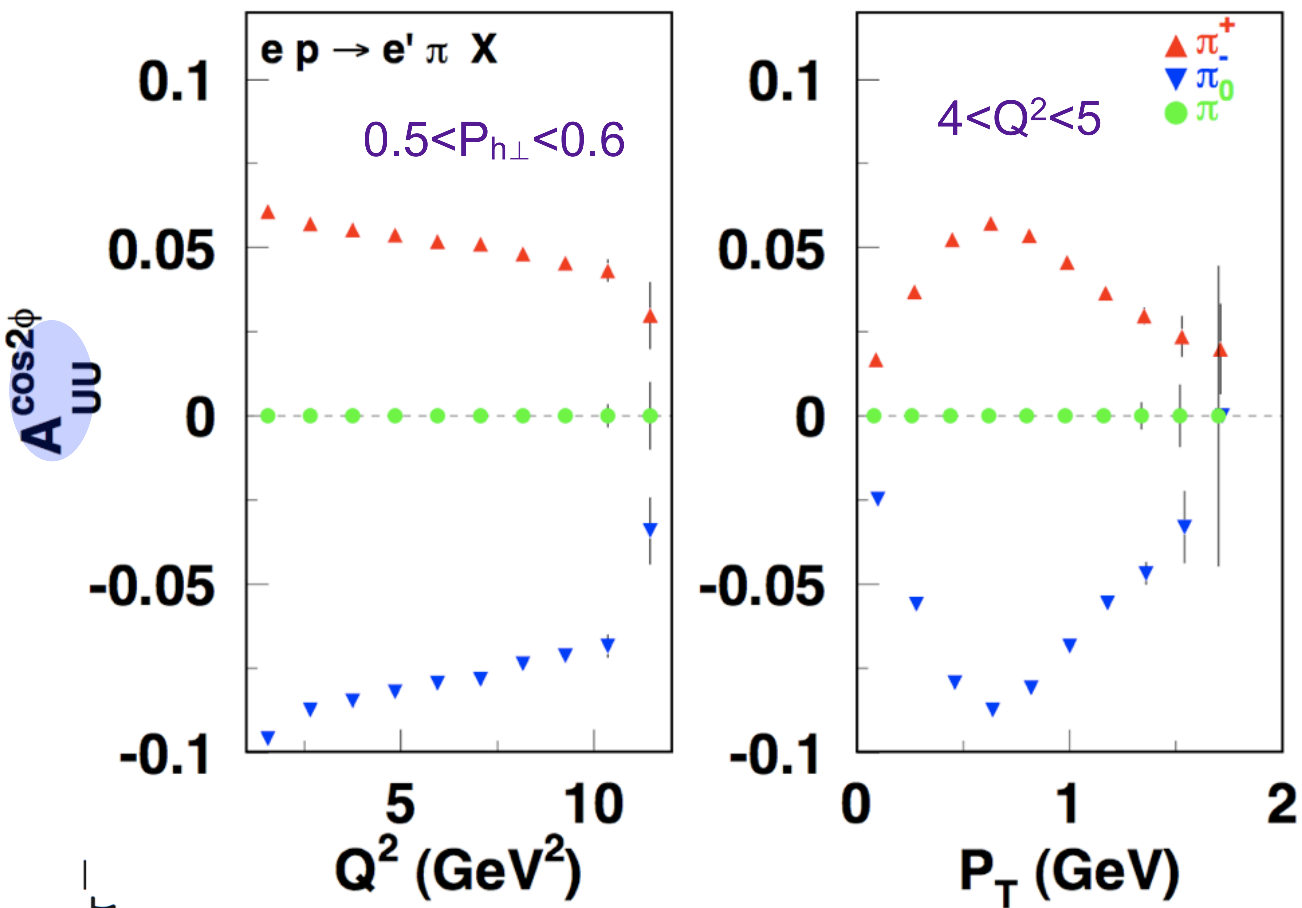
$$A_{LU} = \frac{F_{LU}}{F_{UU}} = \frac{\sigma^{\uparrow 0} - \sigma^{\downarrow 0}}{\sigma^{\uparrow 0} + \sigma^{\downarrow 0}}$$

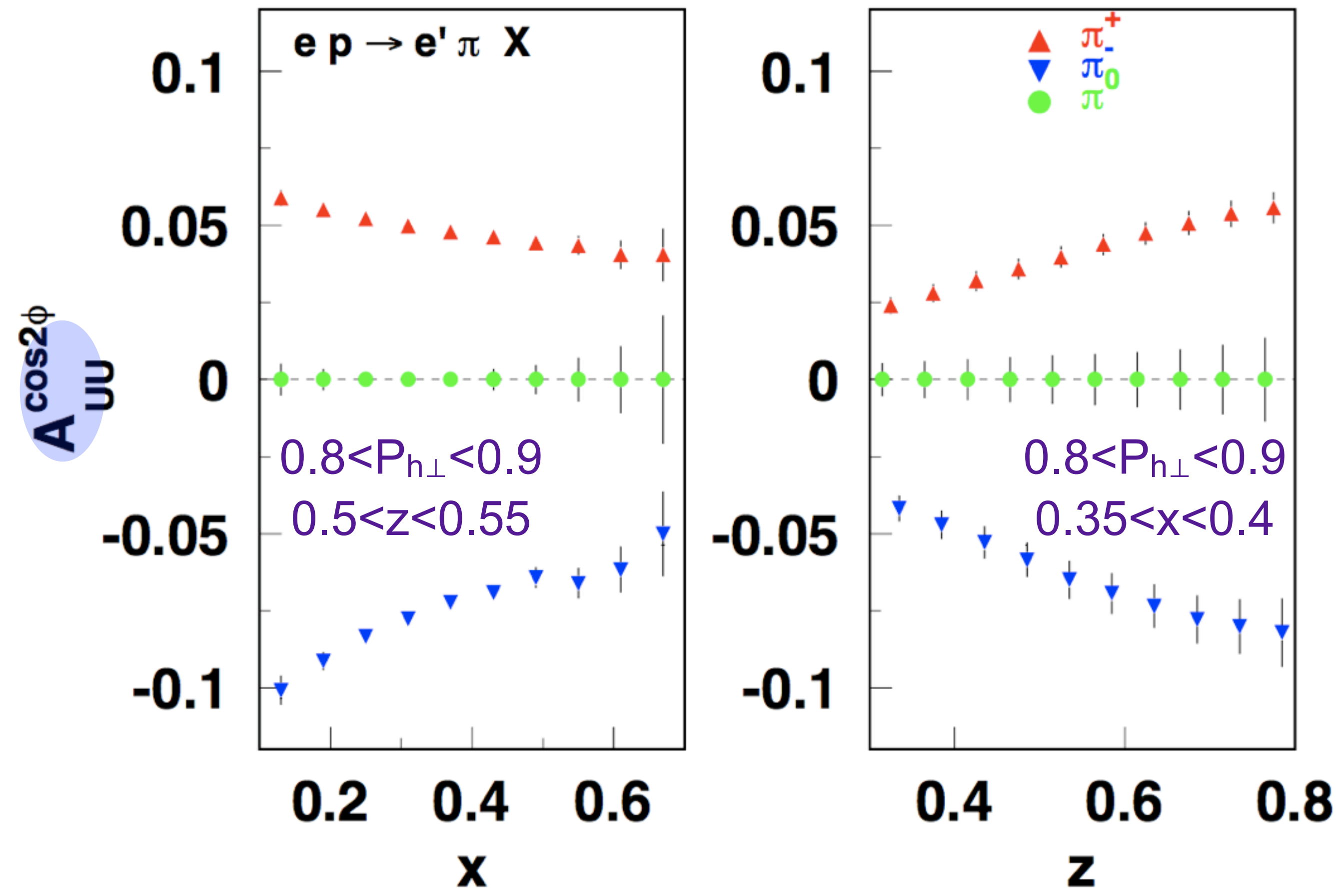
f_1		$h_1^{\perp}$ (e)
	g_{1L}	$h_{1L}^{\perp}(h_L)$
$f_{1T}^{\perp}$	g_{1T}	$h_1,\ h_{1T}^{\perp}$

SIDIS A_{UU} & A_{LU}

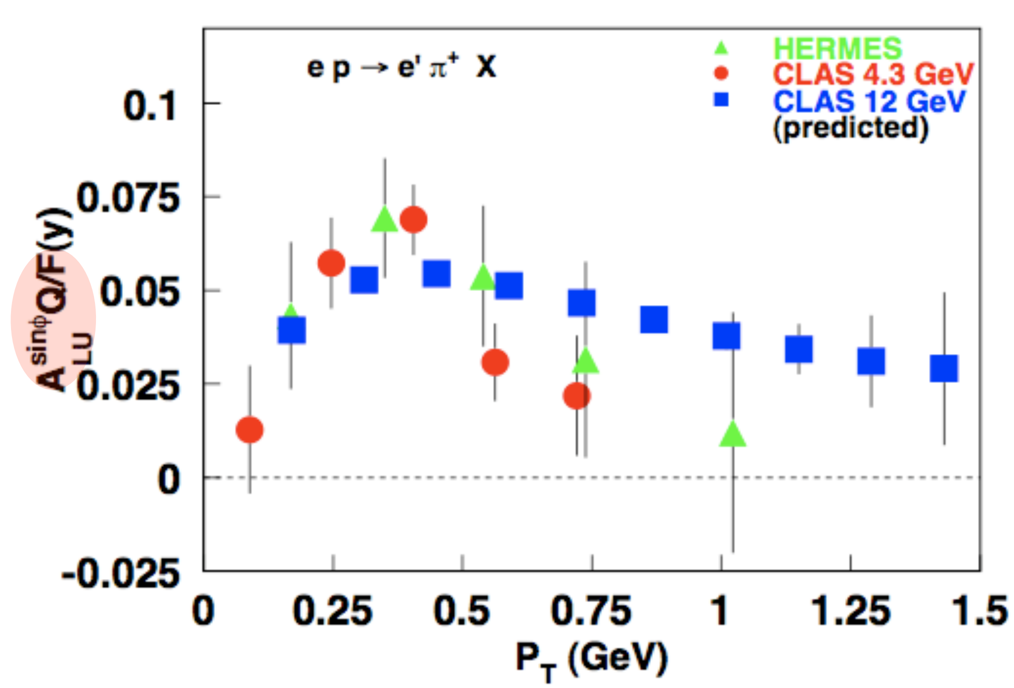
	U	L	T
U			
L			

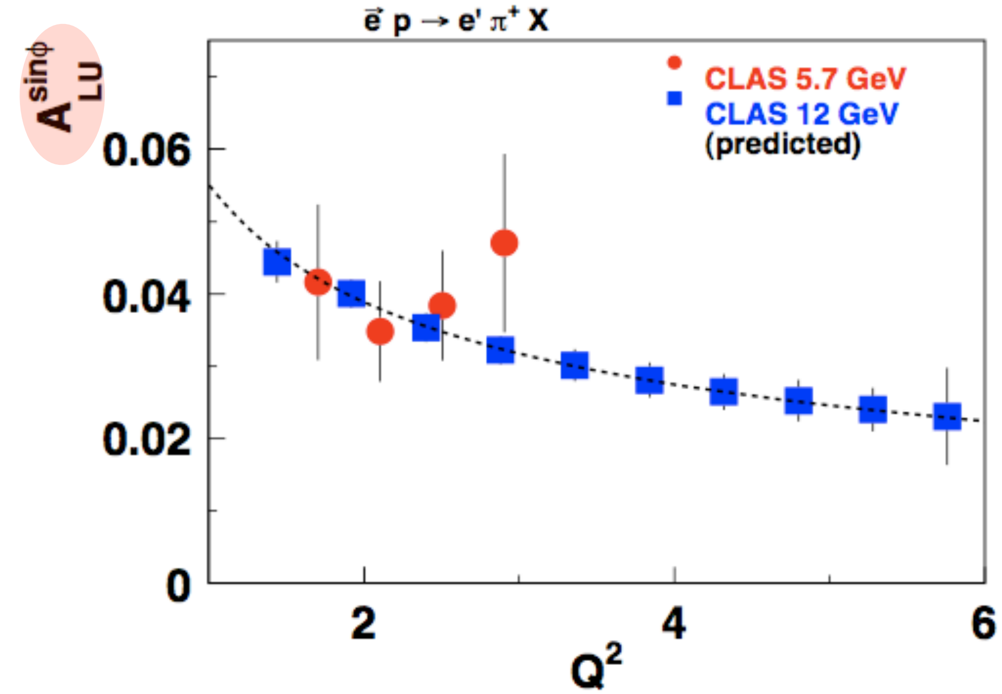
PR12-06-112





$$H_1^{\perp u\to\pi^+} = -H_1^{\perp u\to\pi^-}$$





f_1		$h_1^\perp$
	g_{1L}	$h_{1L}^\perp$
$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

SIDIS: F_{UU}

	U	L	T
U			
L			

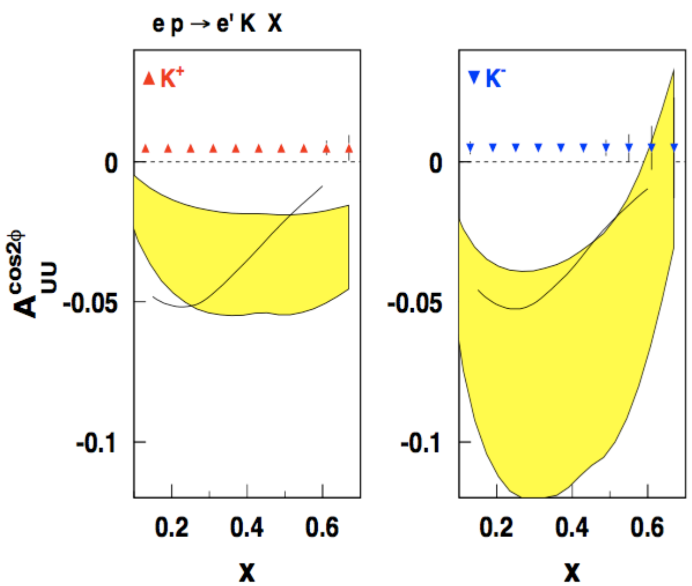
Boer-Mulders Function with Kaons

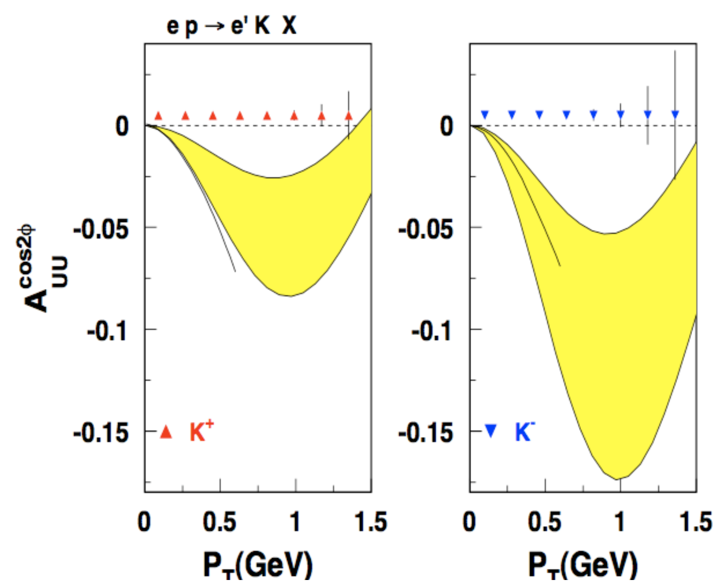
PR12-09-108

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)\times$$

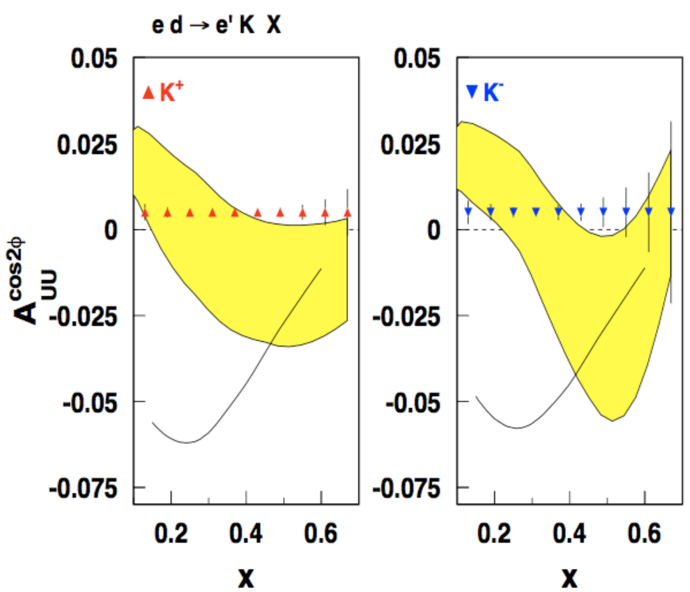
$$\left\{F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \epsilon\cos 2\phi_h F_{UU}^{\cos 2\phi_h} + \lambda_e\sqrt{2\epsilon(1-\epsilon)}\sin\phi_h F_{LU}^{\sin\phi_h}\right\}$$

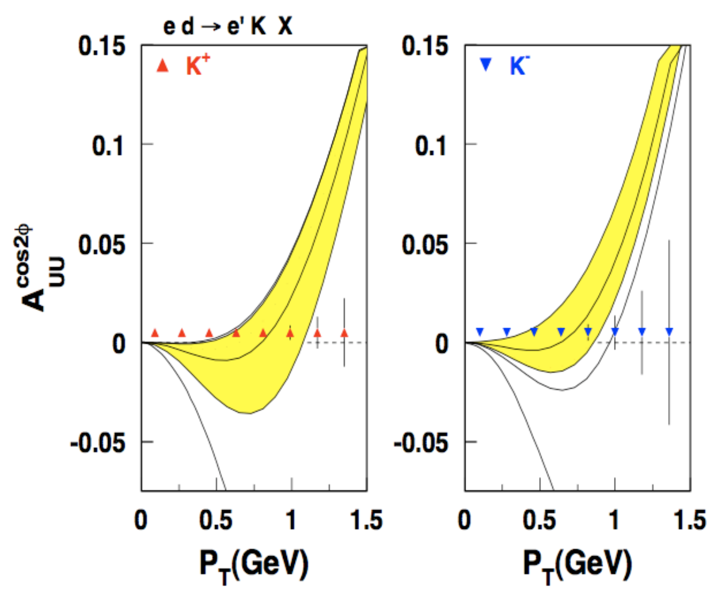
$$F_{UU}^{\cos 2\phi_h} \sim h_1^\perp(x, p_T^2) \otimes H_1^\perp(z, k_T^2)$$





Proton target
K^+ (left) & K^- (right)





Deuteron target
K^+ (left) & K^- (right)

f_1		$h_1^\perp$
	g_{1L}	$h_{1L}^\perp$
$f_{1T}^\perp$	g_{1T}	$h_1,\ h_{1T}^\perp$

SIDIS: A_{LL} & A_{UL}

	U	L	T
U			
L			

Spin-Orbit Correlations with Polarized Target (L)

PR12-07-107

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\left\{\ldots + S_\parallel\left[\sqrt{2\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h} + \varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right]\right.$$

$$\left. + S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL} + \sqrt{2\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]\right\}$$

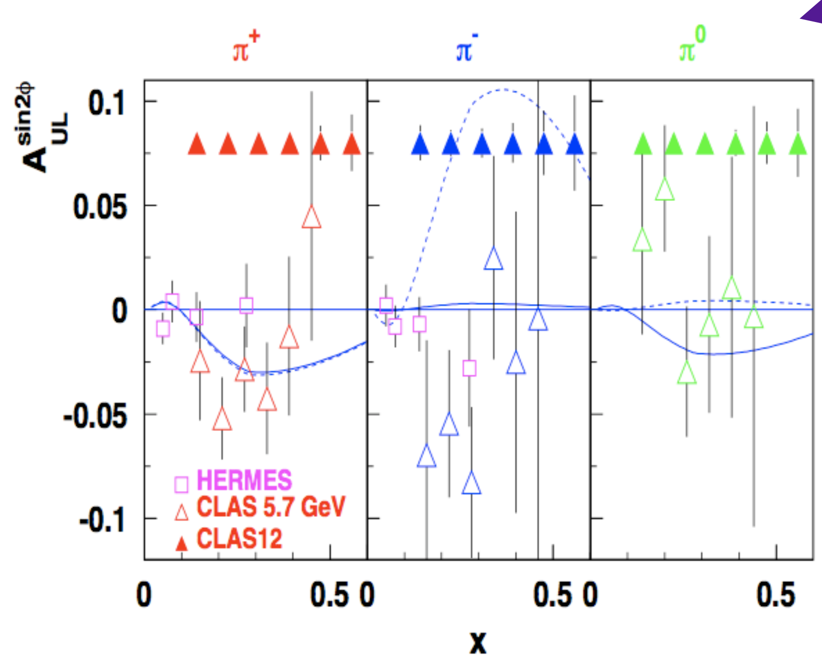
$$F_{LL} \sim g_{1L}(x,p_T^2) \otimes D_1(z,k_T^2)$$

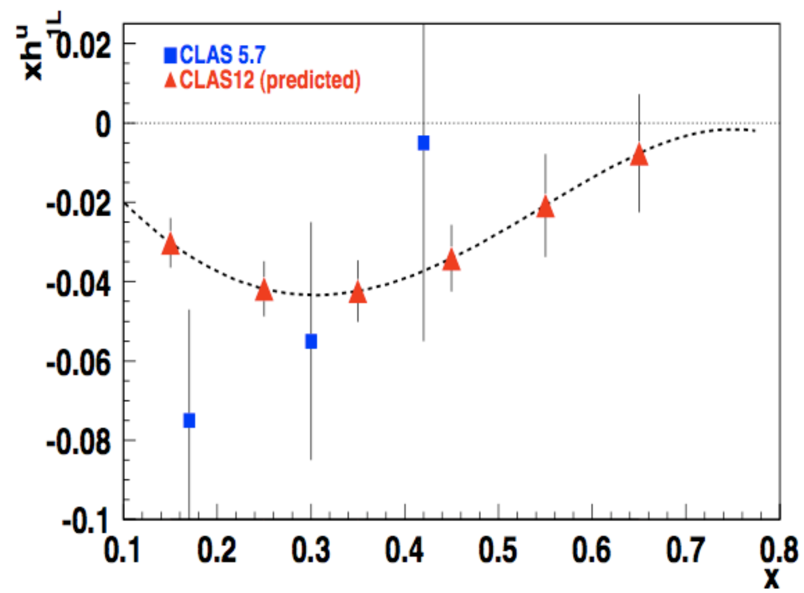
$$F_{UL}^{\sin\phi_h} \sim h_L(x,p_T^2) \otimes H_1^\perp(z,k_T^2)$$

$$F_{UL}^{\sin 2\phi_h} \sim h_{1L}^\perp(x,p_T^2) \otimes H_1^\perp(z,k_T^2)$$

$$F_{LL}^{\cos\phi_h} \sim e_L(x,p_T^2) \otimes H_1^\perp(z,k_T^2)$$

See Avakian PRL**105**(2010)262002 for final CLAS data





f_1		$h_1^\perp$
	g_{1L}	$h_{1L}^\perp$
$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

f_1		$h_1^\perp$ (e)
	g_{1L}	$h_{1L}^\perp(e_L)$
$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

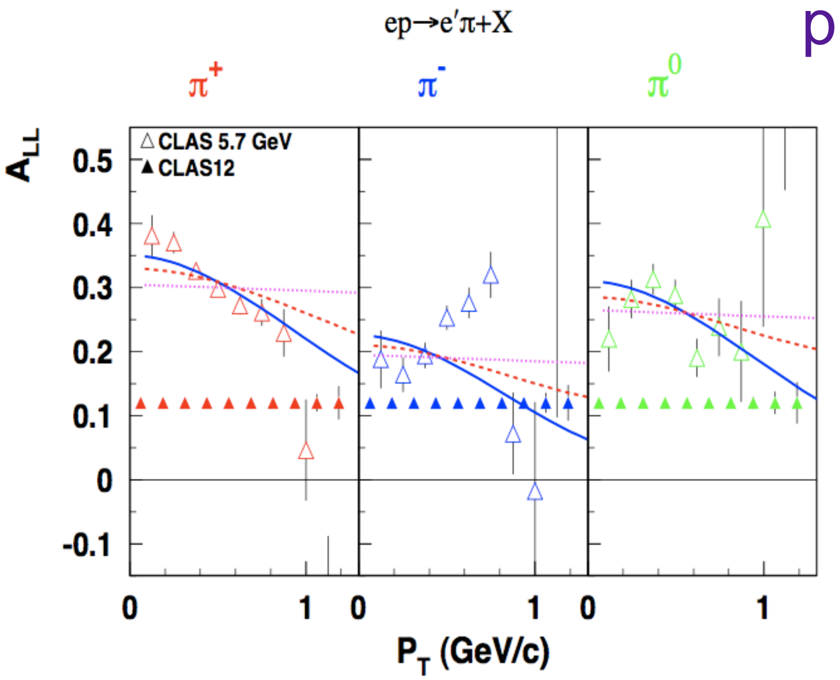
SIDIS: A_{LL} & A_{UL}

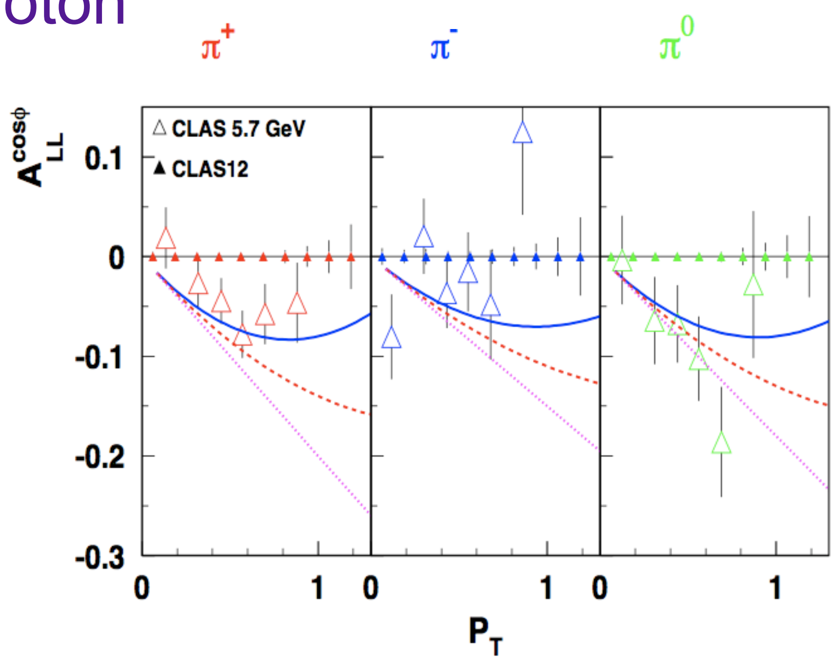
	U	L	T
U			
L			

Spin-Orbit Correlations with Polarized Target (L)

PR12-07-107

proton



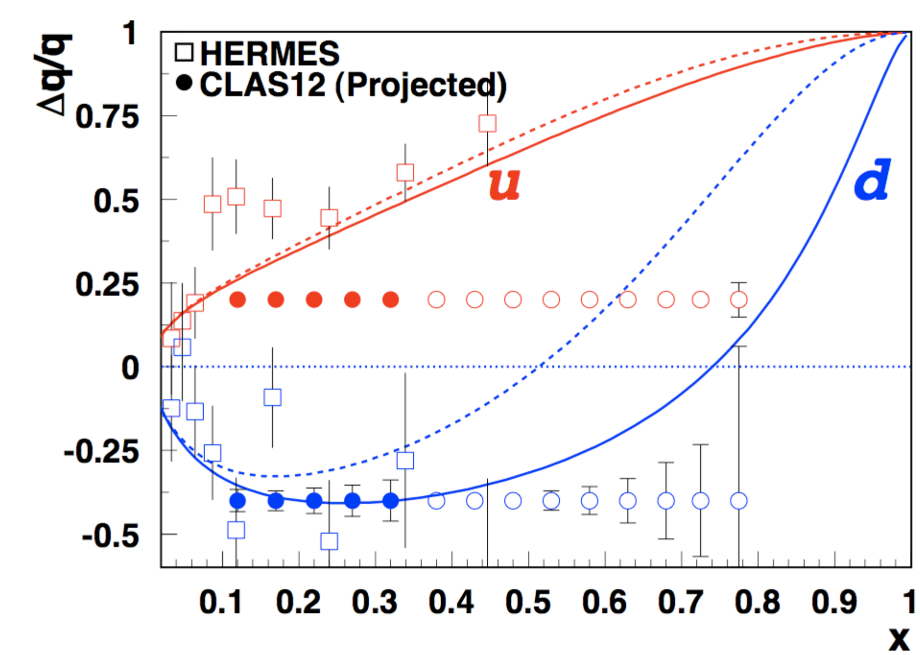


$$F_{LL} \sim g_{1L}(x,p_T^2) \otimes D_1(z,k_T^2)$$

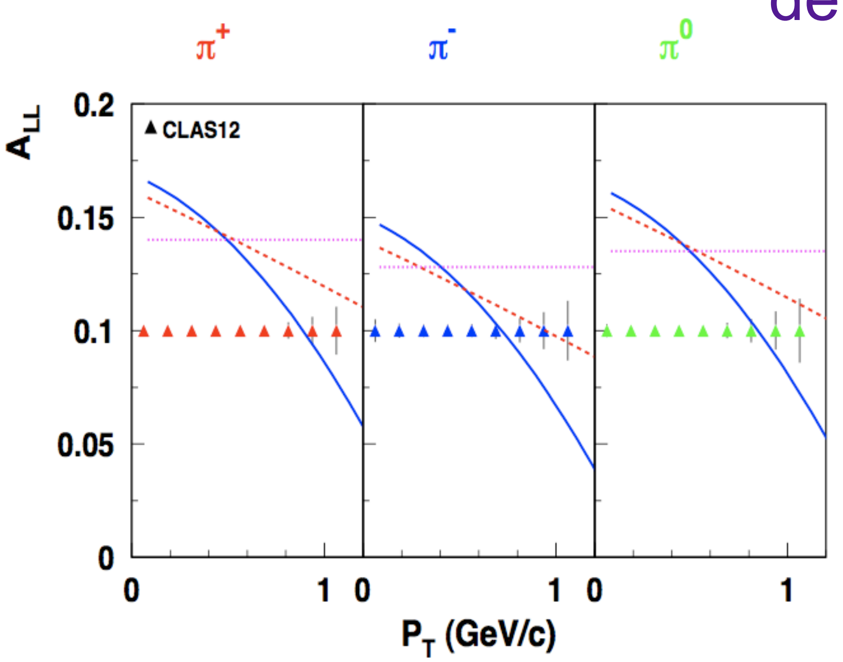
$$F_{LL}^{\cos\phi_h} \sim e_L(x,p_T^2) \otimes H_1^\perp(z,k_T^2)$$

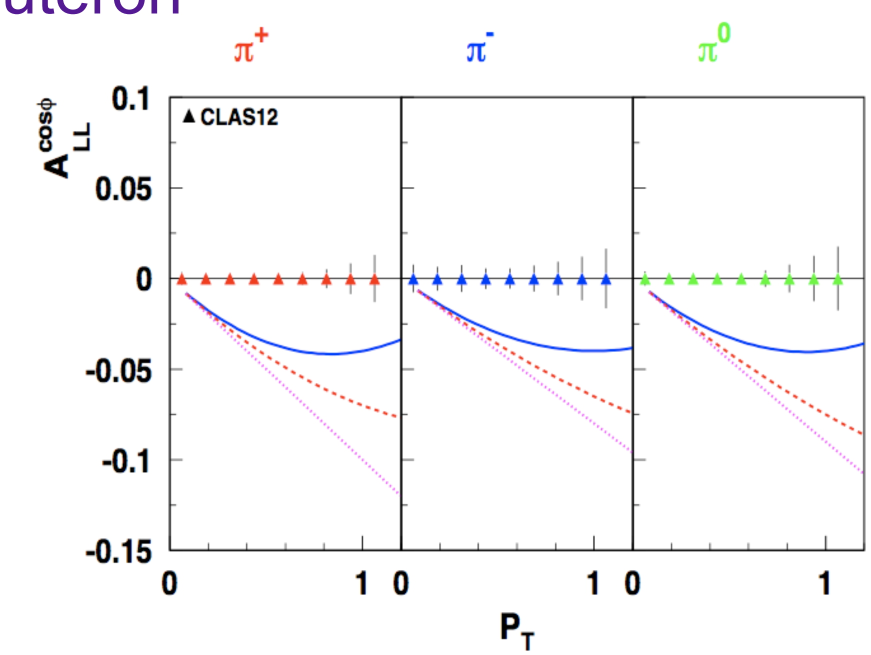
See Avakian PRL**105**(2010)262002 for final CLAS data

Δd/d and Δu/u



deuteron





SIDIS: A_{LL} & A_{UL}

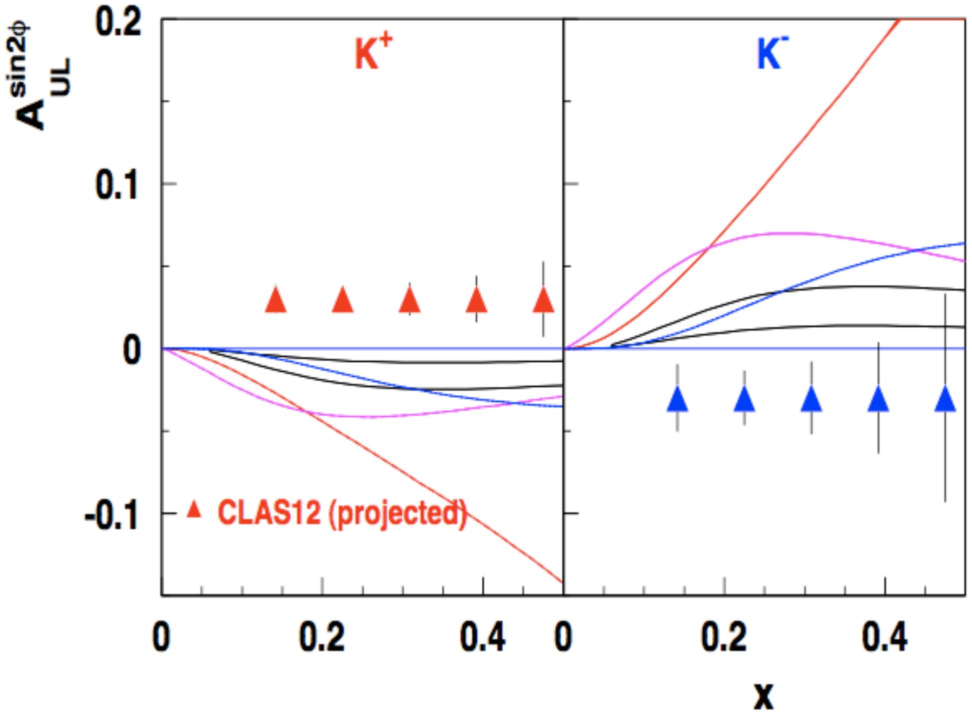
f_1		$h_1^\perp$
	g_{1L}	$h_{1L}^\perp$
$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

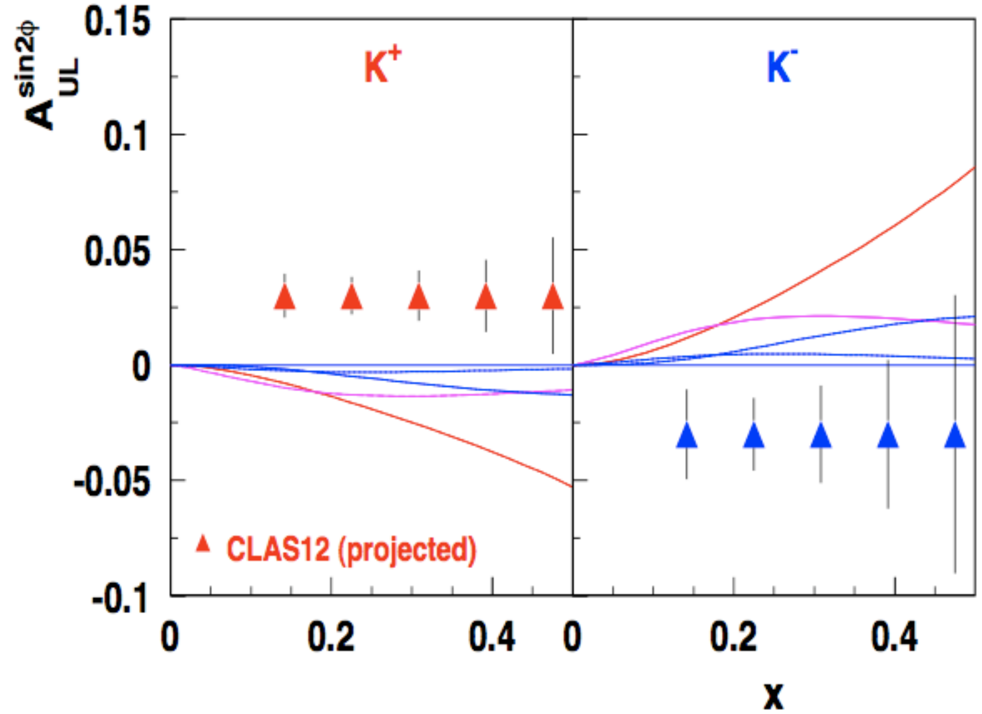
f_1		$h_1^\perp$
	g_{1L}	$h_{1L}^\perp$
$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

	U	L	T
U			
L			

Spin-Orbit Correlations with Kaons (L)

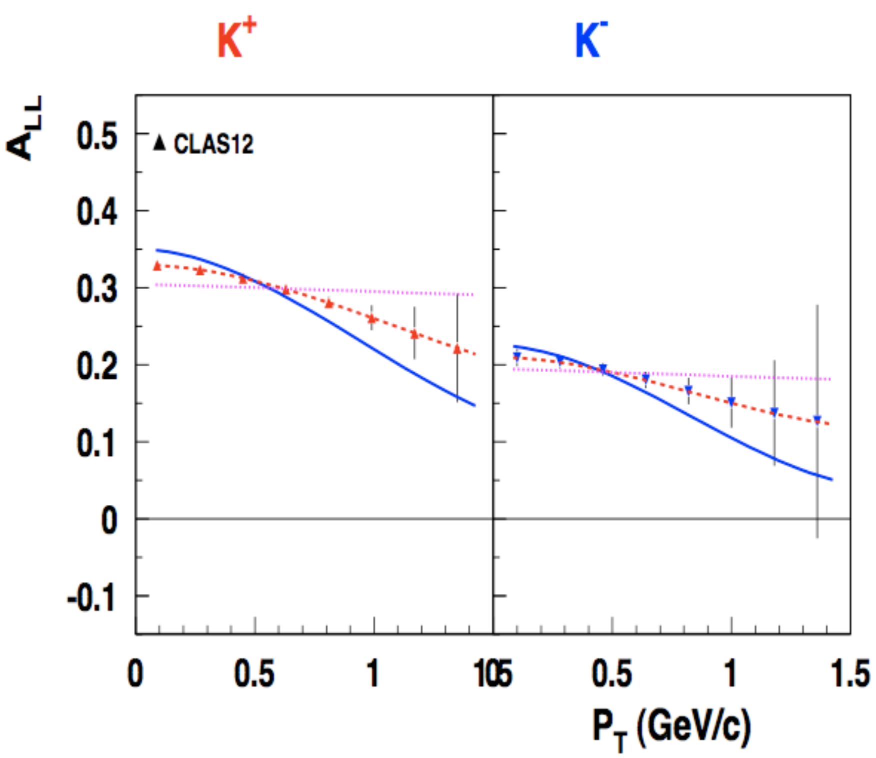
PR12-09-109

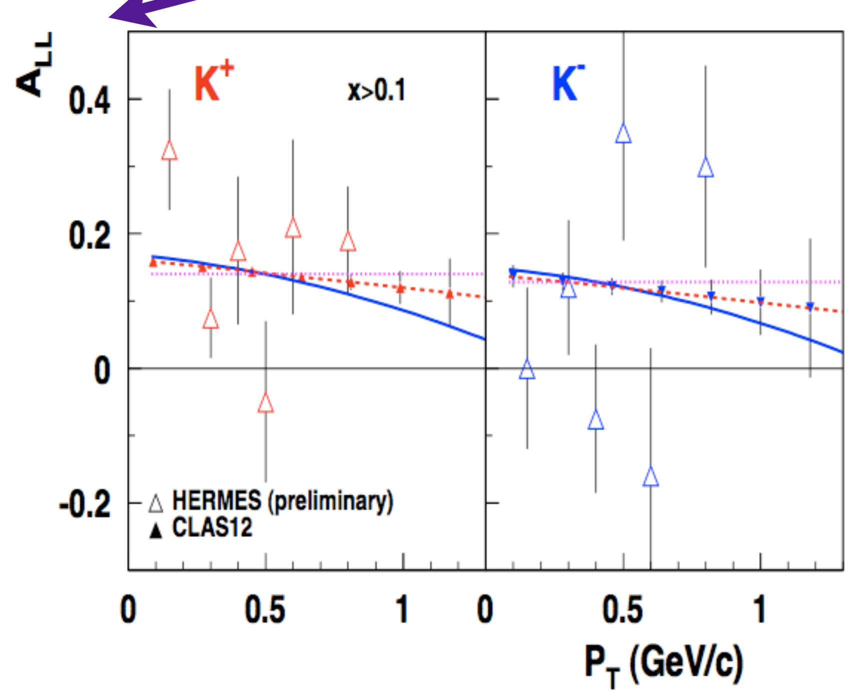




$$F_{UL}^{\sin 2\phi_h} \sim h_{1L}^\perp(x, p_T^2) \otimes H_1^\perp(z, k_T^2)$$

$$F_{LL} \sim g_{1L}(x, p_T^2) \otimes D_1(z, k_T^2)$$





	U	L	T
U			
L			

Dihadron Electroproduction in DIS

PR12-11-109

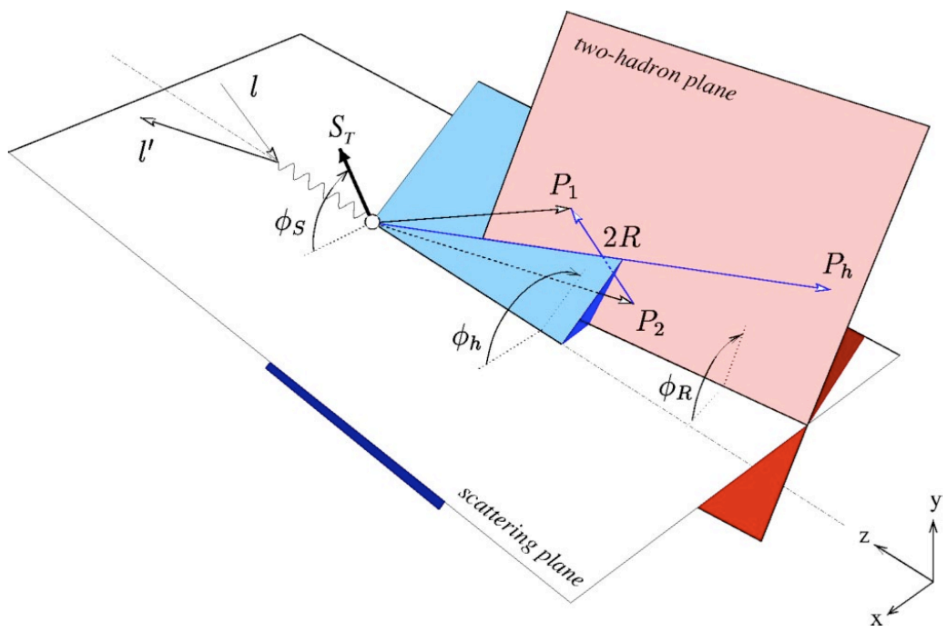
$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_R\,dM_h^2\,d\cos\theta} =$$

$$\frac{\alpha^2}{xy\,Q^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\,\varepsilon(1+\varepsilon)}\cos\phi_R\,F_{UU}^{\cos\phi_R}$$

$$+\,\varepsilon\cos(2\phi_R)\,F_{UU}^{\cos 2\phi_R} + \lambda_e\sqrt{2\,\varepsilon(1-\varepsilon)}\sin\phi_R\,F_{LU}^{\sin\phi_R}$$

$$+\,S_L\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\sin\phi_R\,F_{UL}^{\sin\phi_R} + \varepsilon\sin(2\phi_R)\,F_{UL}^{\sin 2\phi_R}\right]$$

$$+\,S_L\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL} + \sqrt{2\,\varepsilon(1-\varepsilon)}\cos\phi_R\,F_{LL}^{\cos\phi_R}\right]\Big\}$$



$$F_{LL}^{\cos\phi_R} = -x\frac{|\boldsymbol{R}|\sin\theta}{Q}\frac{1}{z}\,g_1^q(x)\,\widetilde{D}^{\sphericalangle q}(z,\cos\theta,M_h)$$

$$F_{UU,T} = x f_1^q(x)\,D_1^q(z,\cos\theta,M_h)$$

$$F_{UU}^{\cos\phi_R} = -x\frac{|\boldsymbol{R}|\sin\theta}{Q}\frac{1}{z}\,f_1^q(x)\,\widetilde{D}^{\sphericalangle q}(z,\cos\theta,M_h)$$

$$F_{LL} = x g_1^q(x)\,D_1^q(z,\cos\theta,M_h)$$

$$F_{UL}^{\sin\phi_R} = -x\frac{|\boldsymbol{R}|\sin\theta}{Q}\left[\frac{M}{M_h}\,x\,h_L^q(x)\,H_1^{\sphericalangle q}(z,\cos\theta,M_h) + \frac{1}{z}\,g_1^q(x)\,\widetilde{G}^{\sphericalangle q}(z,\cos\theta,M_h)\right]$$

$$F_{LU}^{\sin\phi_R} = -x\frac{|\boldsymbol{R}|\sin\theta}{Q}\left[\frac{M}{M_h}\,x\,e^q(x)\,H_1^{\sphericalangle q}(z,\cos\theta,M_h) + \frac{1}{z}\,f_1^q(x)\,\widetilde{G}^{\sphericalangle q}(z,\cos\theta,M_h)\right]$$

f_1		$h_1^\perp$ (e)
	g_{1L}	$h_{1L}^\perp(h_L)$
$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

f_1		$h_1^\perp$ (e)
	g_{1L}	$h_{1L}^\perp(h_L)$
$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

SIDIS: A_{UL}, A_{LU}, A_{LL}

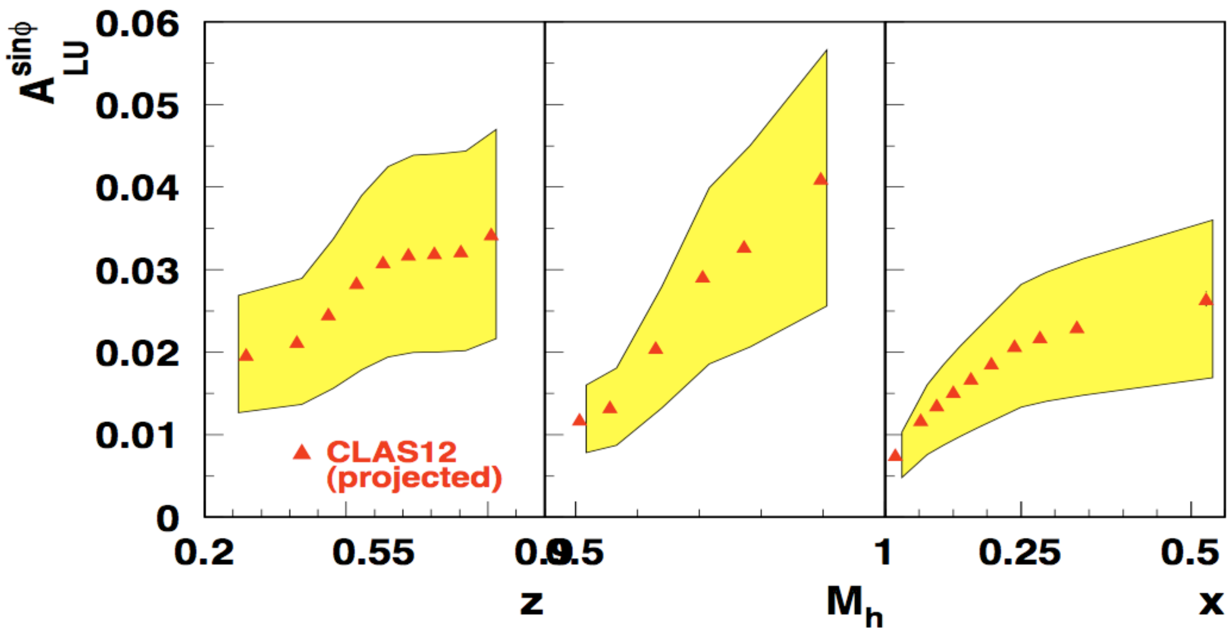
	U	L	T
U			
L			

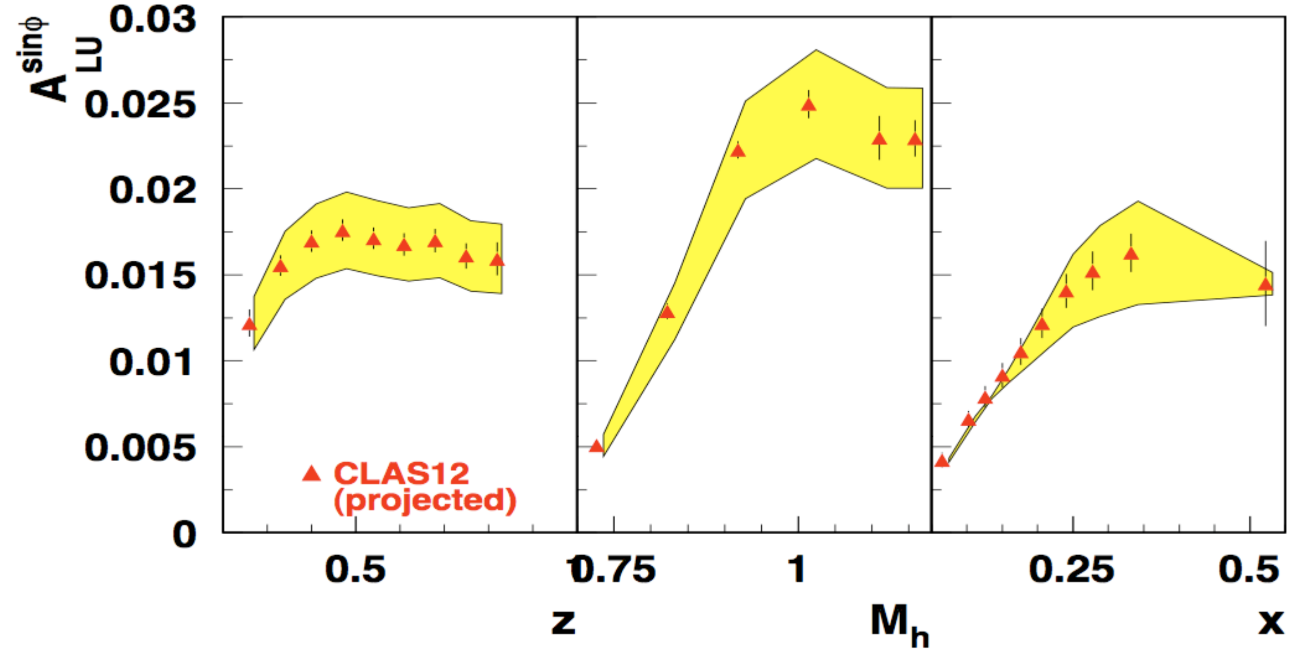
Dihadron Electroproduction in DIS

PR12-11-109

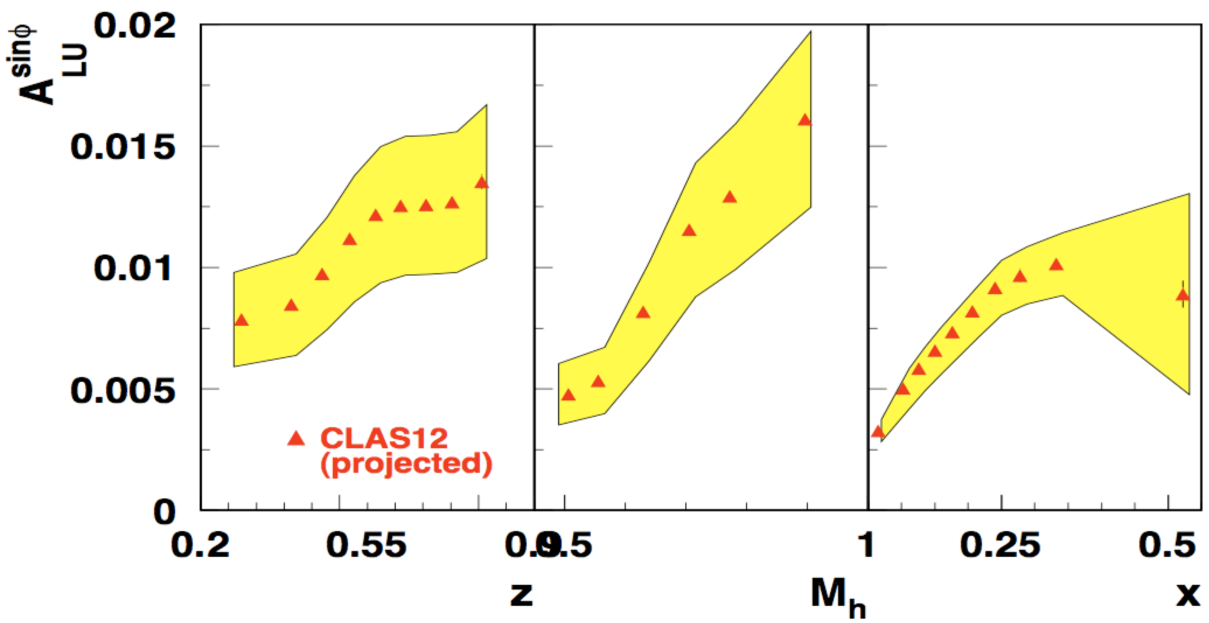
e, h_L ~ twist-3

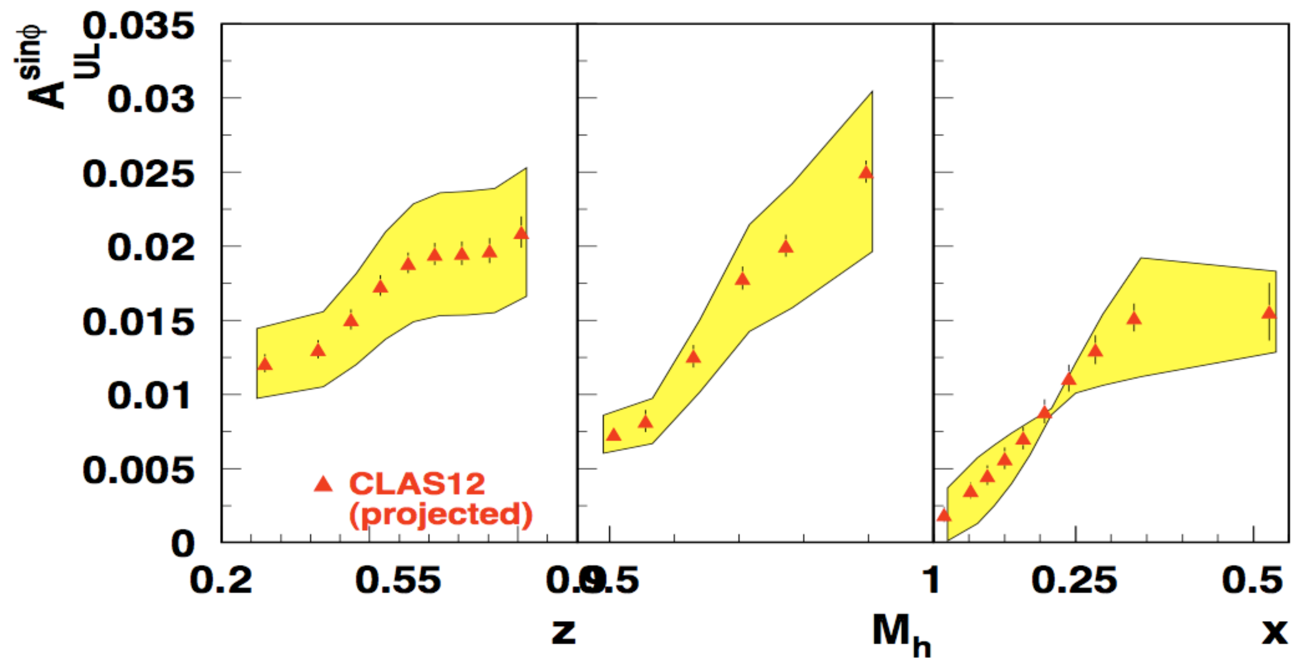
p: $\pi^+ \pi^-$ e(x) yellow: spread in models p: $K^+ \pi^-$ e(x)





d: $\pi^+ \pi^-$ e(x) e(x) related to χ symmetry breaking d: $\pi^+ \pi^-$ h_L(x)





f_1		$h_1^\perp$
	g_{1L}	$h_{1L}^\perp$
$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

SIDIS: A_{UT} & A_{LT}

	U	L	T
U			
L			

SIDIS with Transversely Polarized Target (T)

PR12-11-111

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{\ldots+|\boldsymbol{S}_\perp|\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)$$

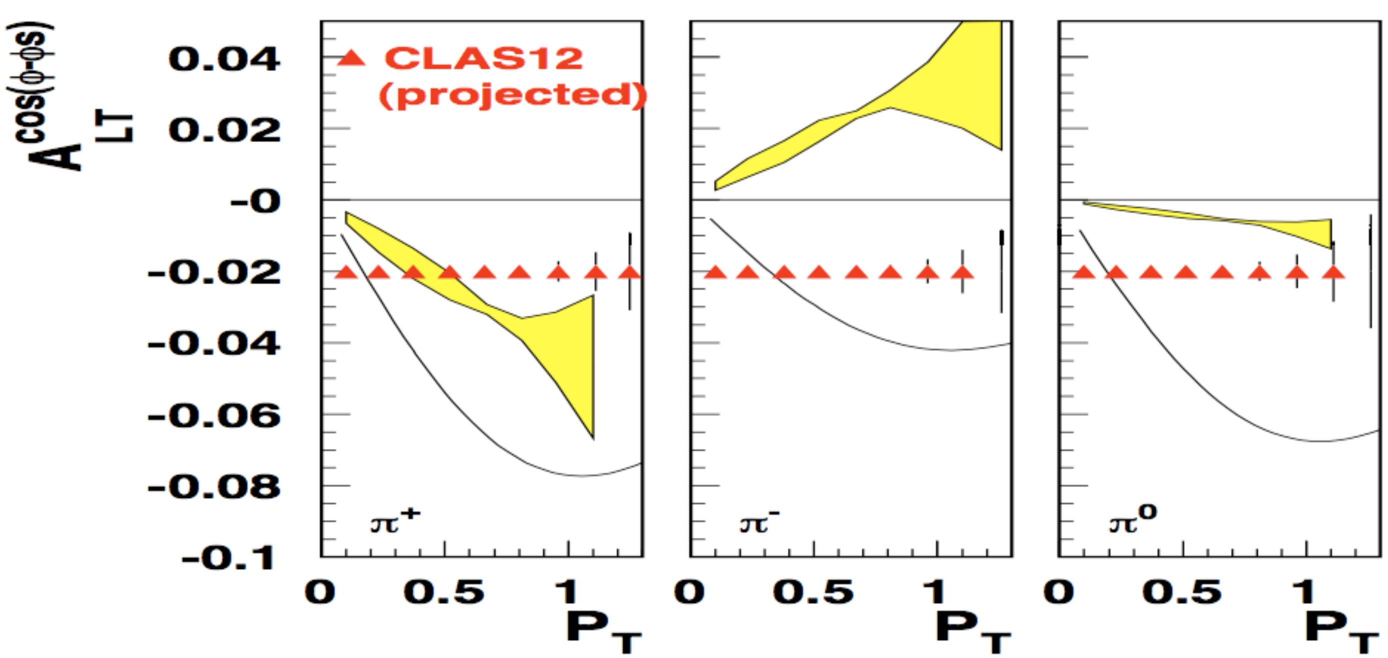
$$+\varepsilon\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+\sqrt{2\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big]$$

$$+|\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}$$

$$+\sqrt{2\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\},$$

$$F_{LT}^{\cos(\phi_h-\phi_S)} \sim g_{1T}(z,p_T^2)\otimes D_1(z,k_T^2)$$



f_1		$h_1^\perp$
	g_{1L}	$h_{1L}^\perp$
$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

f_1		$h_1^\perp$
	g_{1L}	$h_{1L}^\perp$
$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

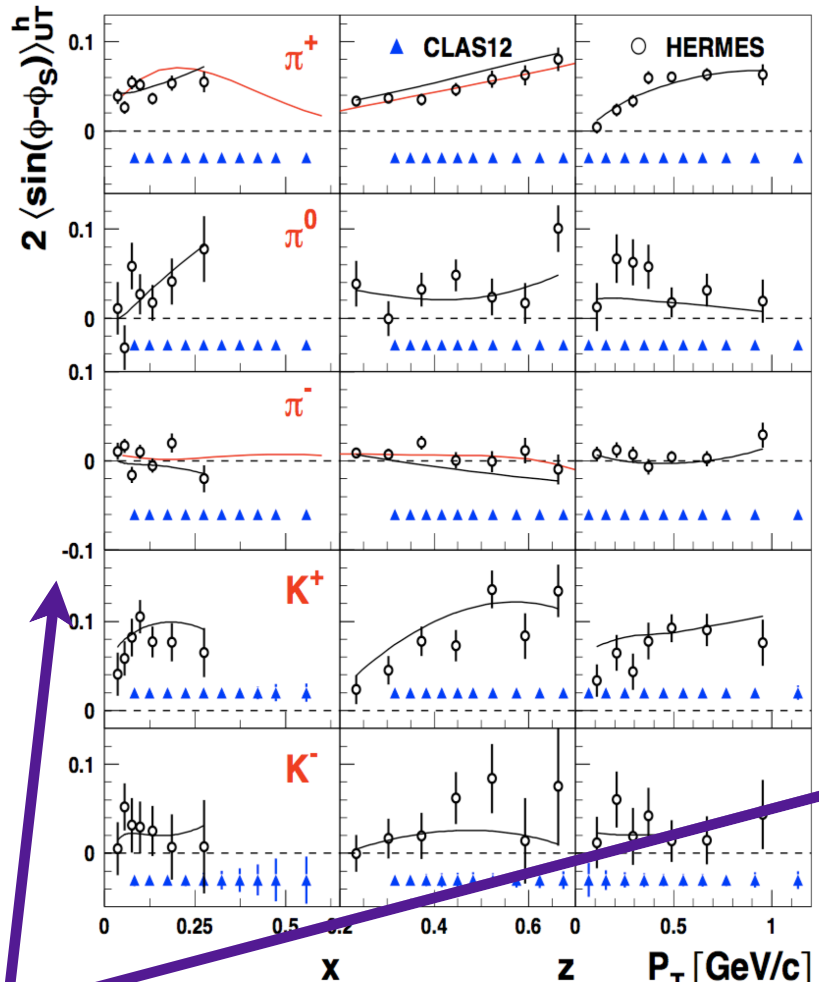
SIDIS: A_{UT} & A_{LT}

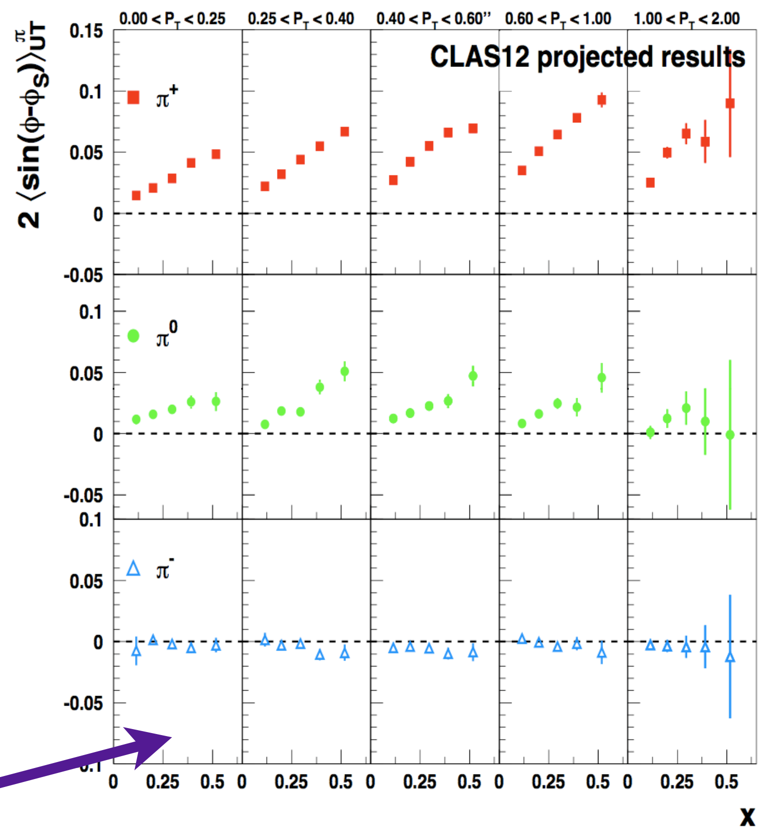
	U	L	T
U			
L			

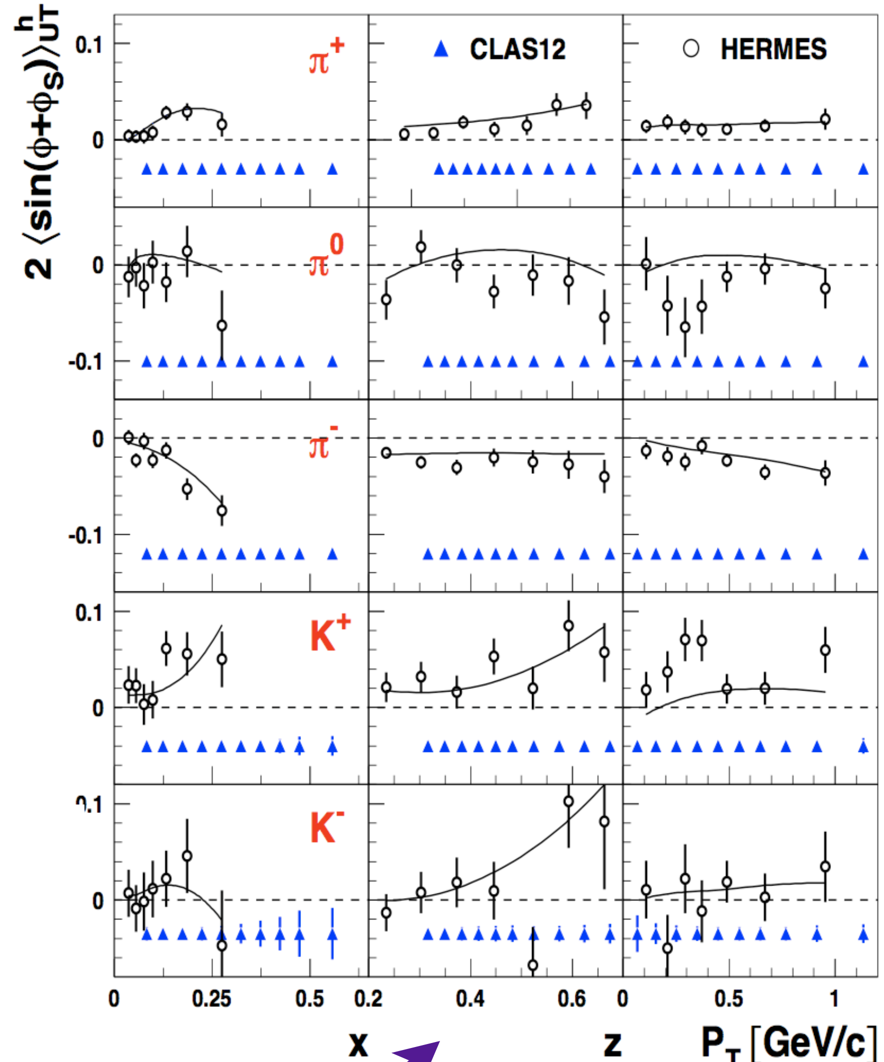
SIDIS with Transversely Polarized Target (T)

PR12-11-111

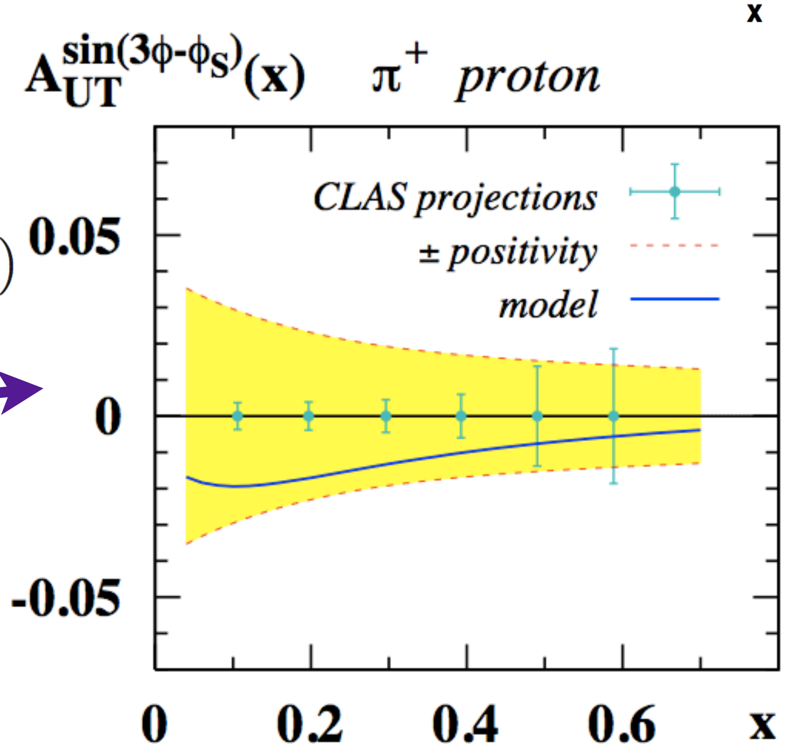
proton







$$F_{UT,T}^{\sin(\phi_h-\phi_S)} \sim f_{1T}^\perp(x,p_T^2) \otimes D_1(z,k_T^2)$$



$$F_{UT}^{\sin(3\phi_h-\phi_S)} \sim h_{1T}^\perp(x,p_T^2) \otimes H_1^\perp(z,k_T^2)$$

$$F_{UT}^{\sin(\phi_h+\phi_S)} \sim h_1(x,p_T^2) \otimes H_1^\perp(z,k_T^2)$$

Conclusions

- CLAS12 is scheduled to begin data-taking in mid-2015
- A diverse program of nucleon structure function measurements using p and d targets, U and L polarized beams, U, L and T polarized targets are approved.
- This program centers on DIS, SIDIS, DVCS and DVMP.
- The combined weight of these experiments will significantly enhance our understanding of GPDs, TMDs and PDFs.