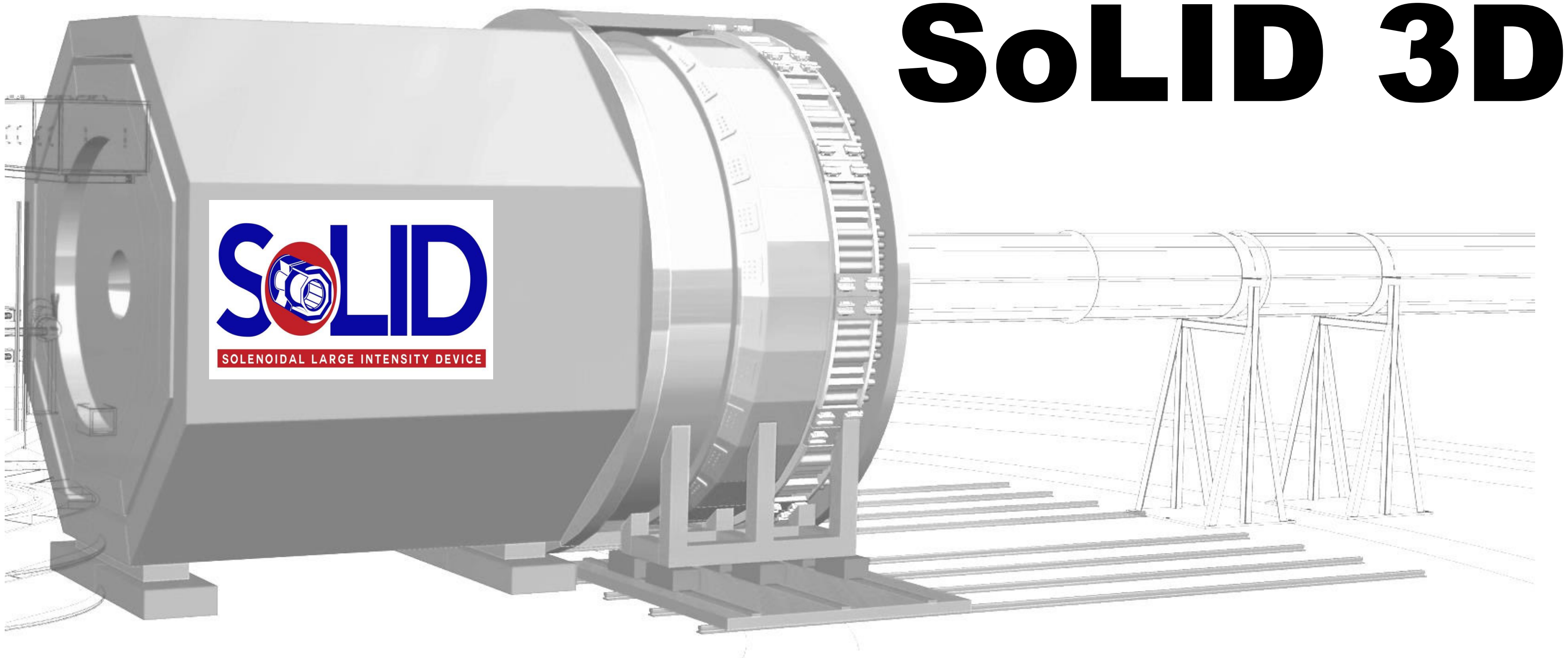
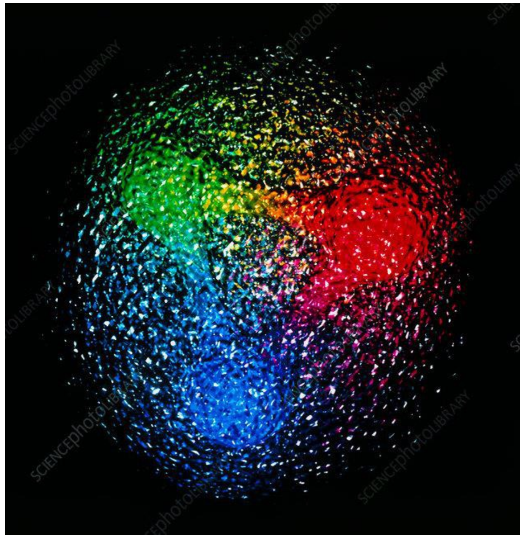
SoLID 3D Program





Zhihong Ye

Department of Physics, Tsinghua University, Beijing China

On behalf of SoLID Collaboration

Hall-A Winter Meeting, 01/26-01/27/2023

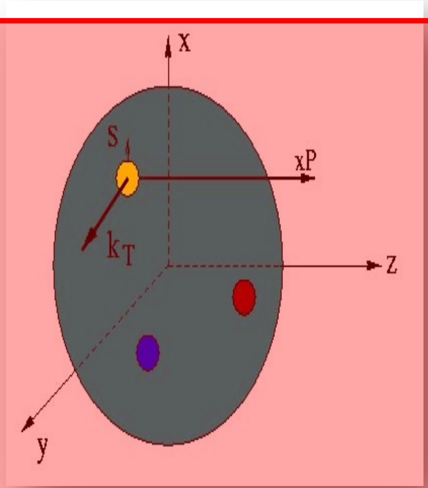
清華大學
Tsinghua University

Nucleon's 3D Structure

$W_p^u(x, k_T, \boldsymbol{r_T})$ Wigner distributions

5D

(X. Ji, D. Mueller, A. Radyushkin)



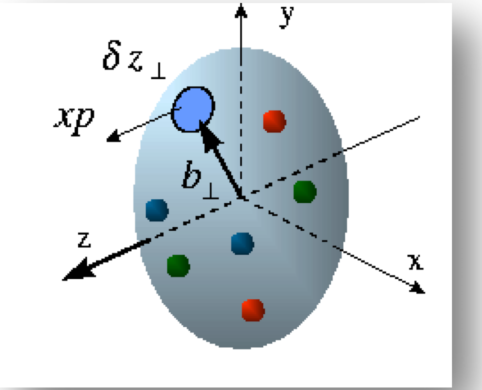
$d^2\boldsymbol{r_T}$

d^2k_T

TMD
$f_1^u(x,k_T)$, $h_1^u(x,k_T)$,…

3D

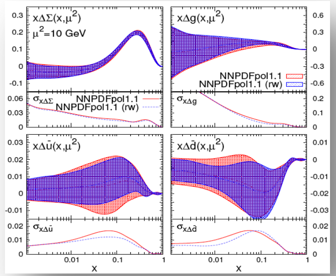
GPDs/IPDs
$H^u, E^u, \widetilde{H}^u, \widetilde{E}^u$



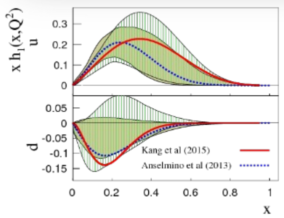
d^2k_T

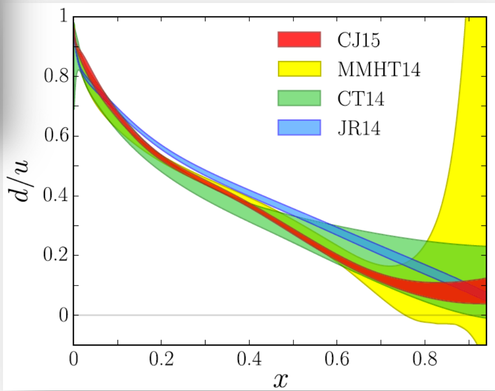
d^2r_T

dx & Fourier Transformation



A. Accardi et. al.
B. Phys. Rev. D 93, 114017 (2016)

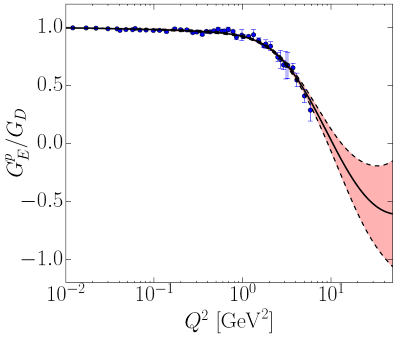


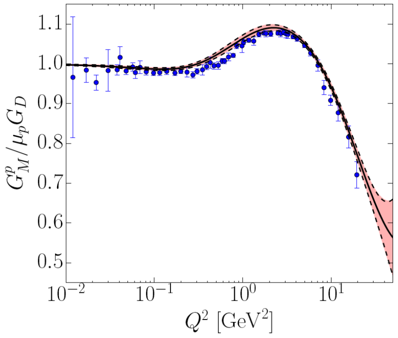


PDFs
$f_1^u(x)$, $g_1^u(x)$,
$h_1^u(x)$,…

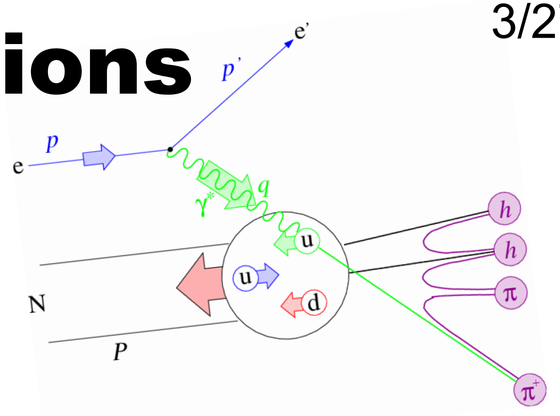
1D

Form Factors
$G_E(Q^2)$,
$G_M(Q^2)$





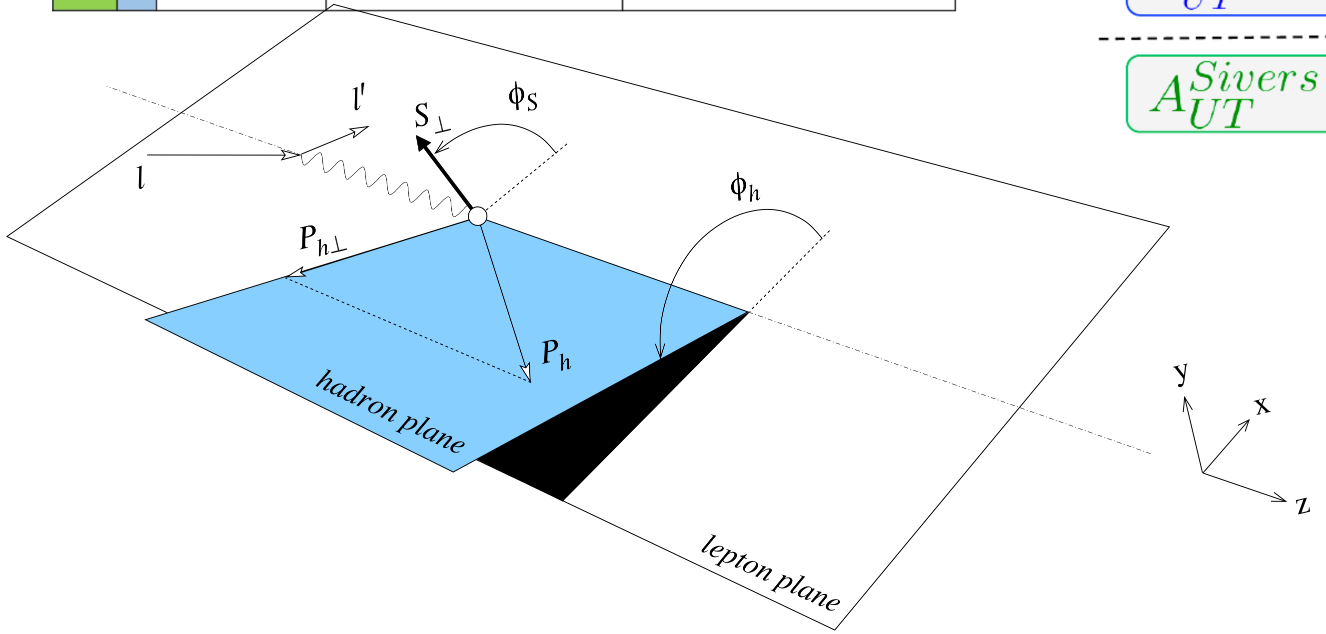
Transverse Momentum Distributions



➢ Semi-Inclusive Deep Inelastic Scattering (SIDIS) with polarized targets:

8 Quark-TMDs (leading twist)

Leading Twist TMDs		Quark Polarization: Unpolarized (U)	Quark Polarization: Longitudinally Polarized (L)	Quark Polarization: Transversely Polarized (T)
Nucleon Polarization	U	$f_1(x,k_T^2)$ Unpolarized		$h_1^\perp(x,k_T^2)$ Boer-Mulders
	L		$g_1(x,k_T^2)$ Helicity	$h_{1L}^\perp(x,k_T^2)$ Long-Transversity
	T	$f_{1T}^\perp(x,k_T^2)$ Sivers	$g_{1T}(x,k_T^2)$ Trans-Helicity	$h_1(x,k_T^2)$ Transversity; $h_{1T}^\perp(x,k_T^2)$ Pretzelosity



❑ Single-Spin Asymmetry (SSA)

$$A_{UT}(\phi_h,\phi_S) = \frac{1}{P_{t,pol}}\frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow}$$

$$= A_{UT}^{Collins}\sin(\phi_h+\phi_S) + A_{UT}^{Pretzelosity}\sin(3\phi_h-\phi_S) + A_{UT}^{Sivers}\sin(\phi_h-\phi_S)$$

$$\boxed{A_{UT}^{Collins}} \propto \langle\sin(\phi_h+\phi_S)\rangle_{UT} \propto h_1 \otimes H_1^\perp$$

$$\boxed{A_{UT}^{Pretzelosity}} \propto \langle\sin(3\phi_h-\phi_S)\rangle_{UT} \propto h_{1T}^\perp \otimes H_1^\perp$$

Collins fragmentation function from e⁺e⁻ collisions

$$\boxed{A_{UT}^{Sivers}} \propto \langle\sin(\phi_h-\phi_S)\rangle_{UT} \propto f_{1T}^\perp \otimes D_1$$

Unpolarized fragmentation function

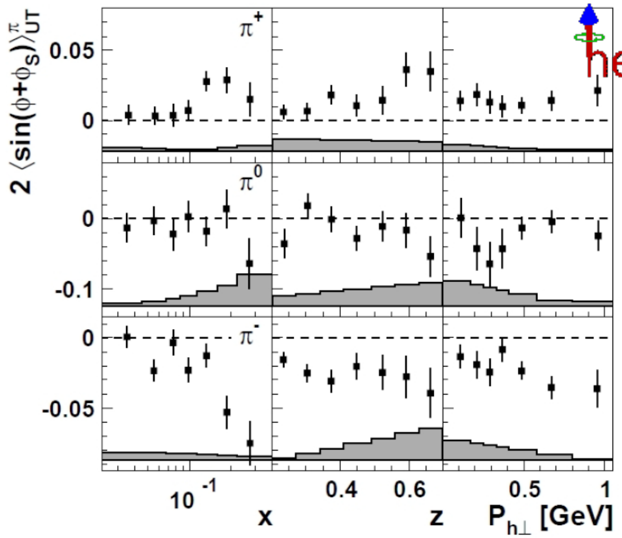
❑ Double-Spin Asymmetry (DSA)

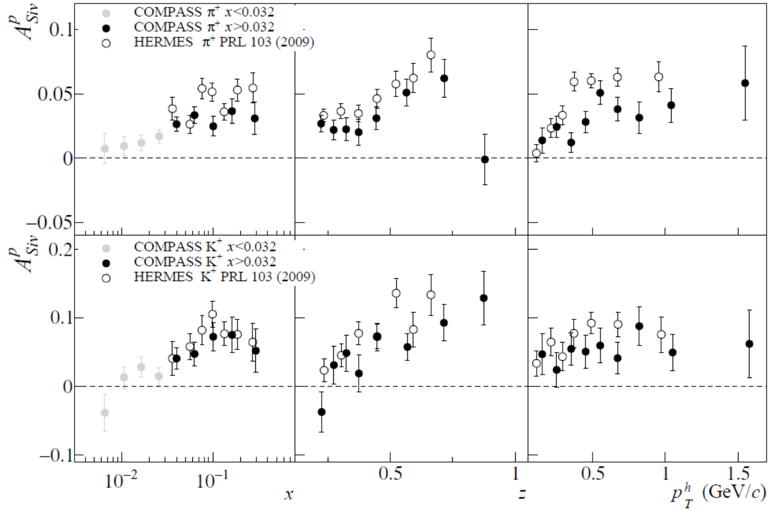
$$A_{LT}^{Worm-Gear} \propto \langle\cos(\phi_h-\phi_s)\rangle_{LT} \propto g_{1T} \otimes D_1$$

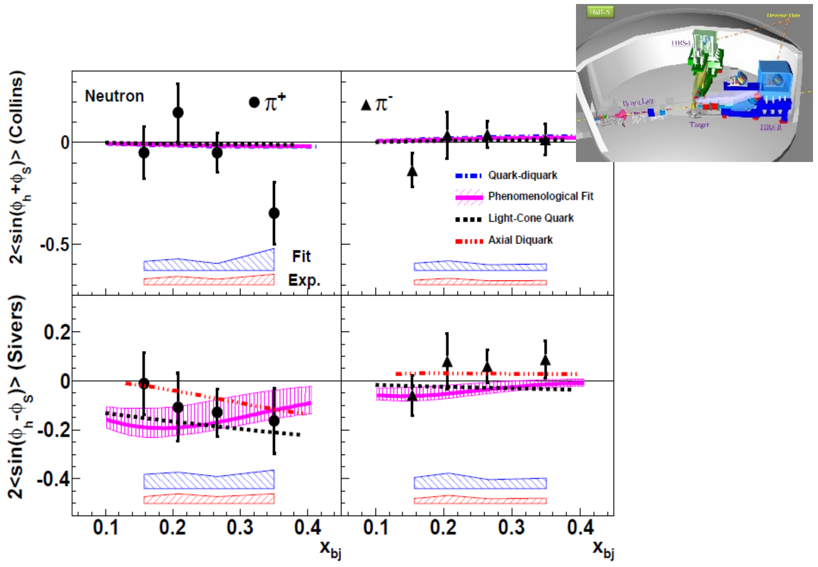
Worm-Gear

Transverse Momentum Distributions

- Existing world data:



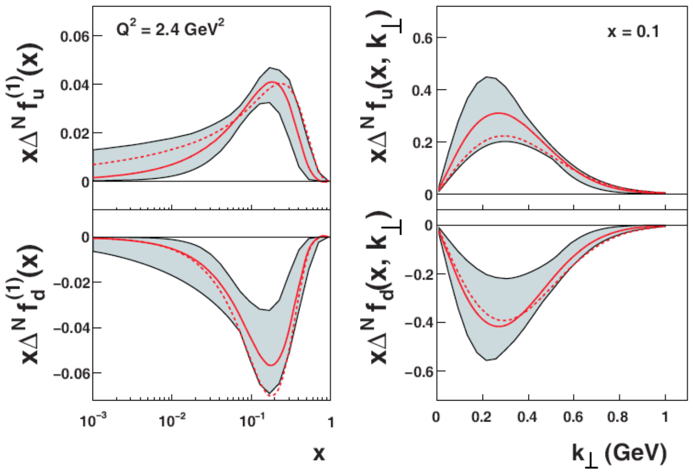




X. Qian et al., PRL107, 072003(2011)

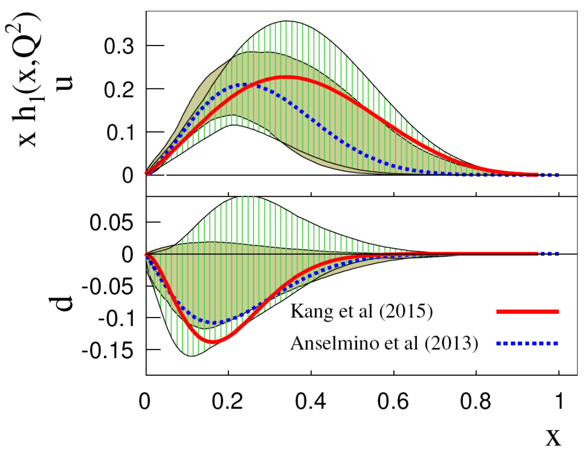
- Global analysis show big errors:

Sivers Moment



Anselmino et al. , Eur. Phys. J. A39, 89-100 (2009)

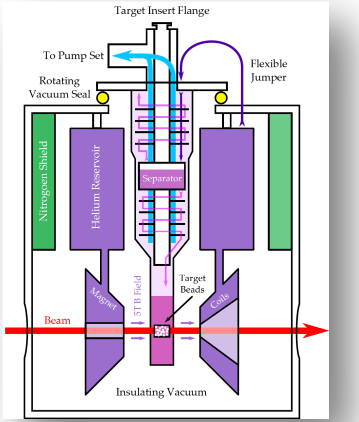
Transversity

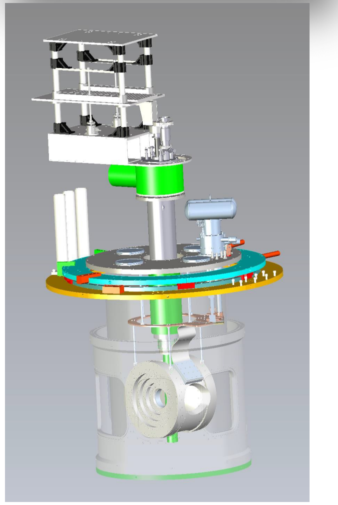


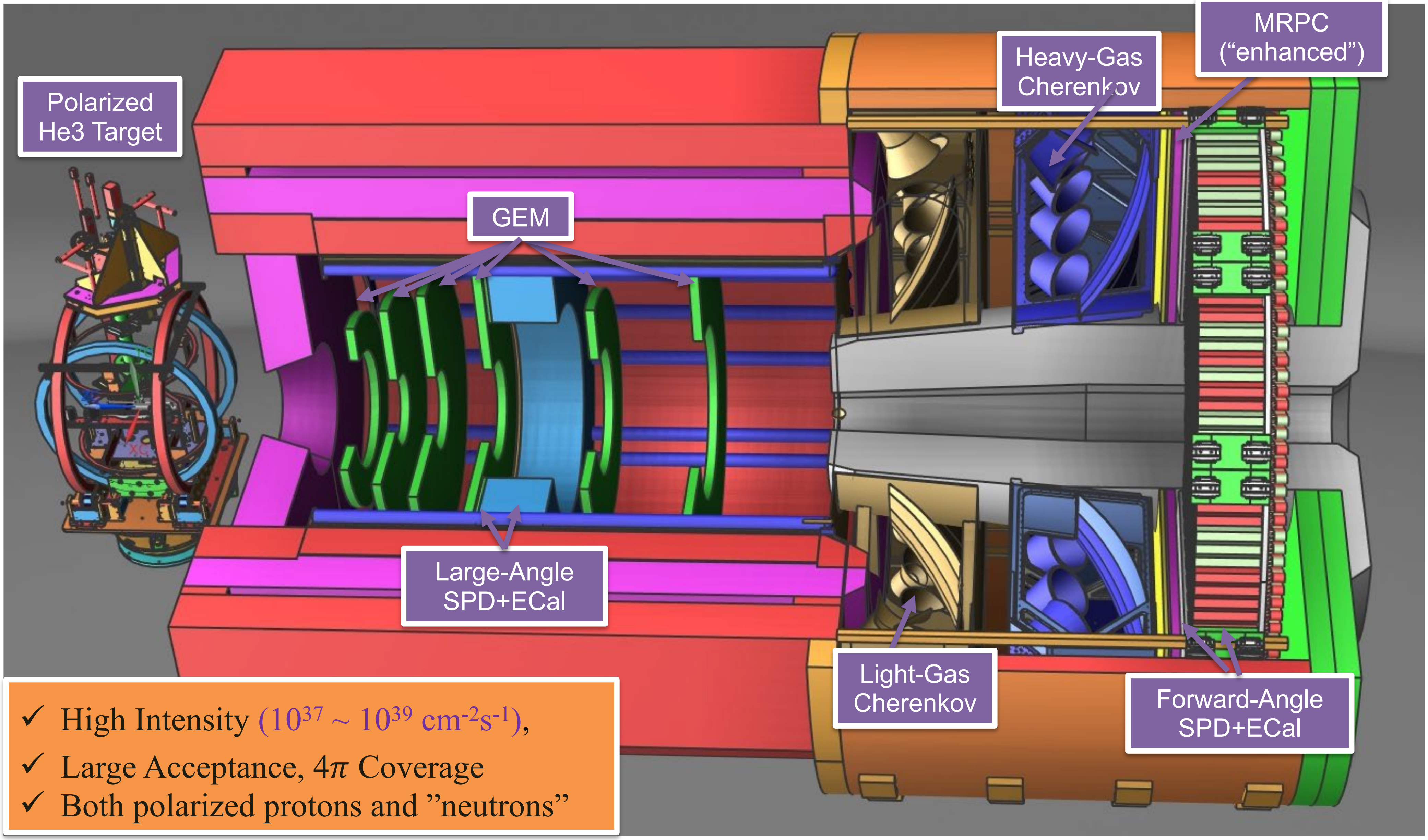
Z.-B. Kang, et. al., PRD 93 014009 (2016)

SoLID-SIDIS(&J/Psi) Configuration

Polarized NH3 (DNP) Target







- ✓ High Intensity ($10^{37} \sim 10^{39}$ cm^{-2}s^{-1}),
- ✓ Large Acceptance, 4π Coverage
- ✓ Both polarized protons and ”neutrons”

SoLID-SIDIS Programs

- Three initial SIDIS proposals:
  - **E12-10-006:** Single Spin Asymmetries on Transversely Polarized 3He @ 90 days

    J.P. Chen, H. Gao (contact), J.C.Peng, X.Qian, **Rating A**
  - **E12-11-007:** Single and Double Spin Asymmetries on Longitudinally Polarized 3He @ 35 days

    J.P. Chen (contact), J. Huang, C. Peng, W.B. Yan, **Rating A**
  - **E12-11-108:**Single Spin Asymmetrieson Transversely Polarized Proton @ 120 days

    J.P. Chen, H. Gao (contact), V. Khachatryan, X.M. Li, Z.-E. Meziani, **Rating A**

- Run-Group (same beam time / configuration):
  - SIDIS Dihadron with Transversely Polarized 3He (E12-10-006A)

    J.-P. Chen, A. Courtoy, H. Gao, A. W. Thomas, Z. Xiao, J. Zhang
  - SIDIS in Kaon Production with Transversely Polarized 3He T. Liu (E12-10- 006D)

    S. Park, Z. Ye, Y. Wang, Z.W. Zhao, Approved as run group
  - Ay with Transversely Polarized 3He (E12-10-006A)

    T. Averett, A. Camsonne, N. Liyanage, Approved as run group
  - g2 n and d2 n with Transversely and Longitudinally Polarized 3He (E12-10-006E)

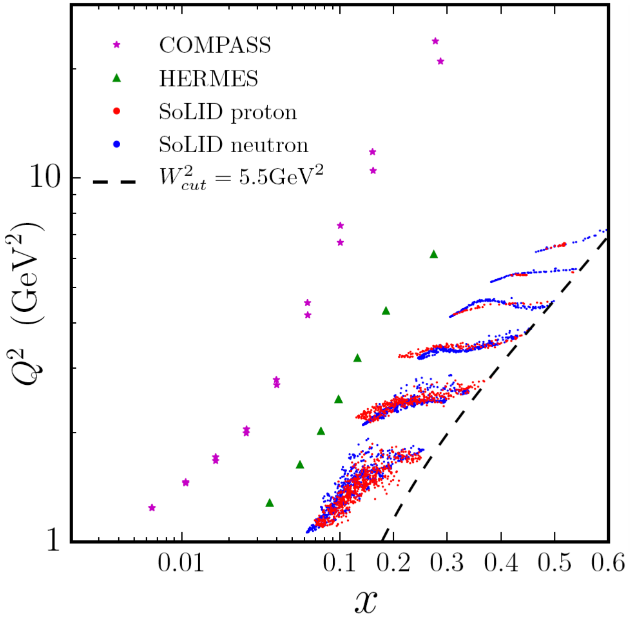
    C. Peng, Y. Tian, Approved as run group
  - Deep exclusive $\pi-$ Production with Transversely Polarized 3He (E12-10-006B)

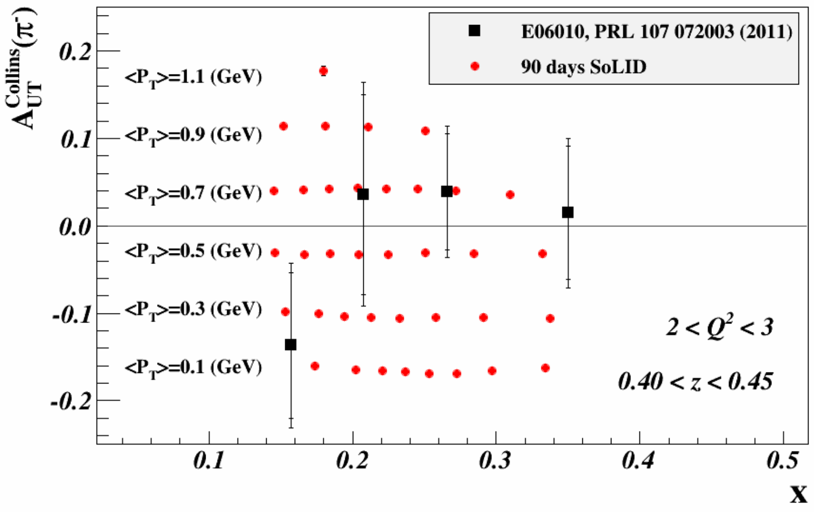
    Z. Ahmed, G. Huber, Z. Ye, Approved as run group

SoLID-SIDIS Projections

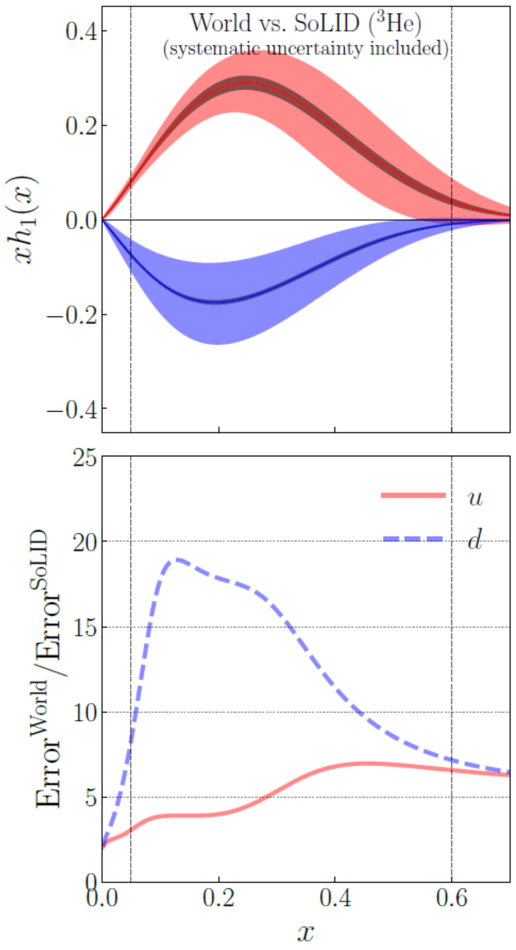
- Phase-space and Statistics of SSA:
  - ✓ Much wider phase-space to cover the valance quark region
  - ✓ High statistics for 4D binning in (x, p_T, Q^2, z)

    Overall >1000 bins for neutron and >600 bins for proton

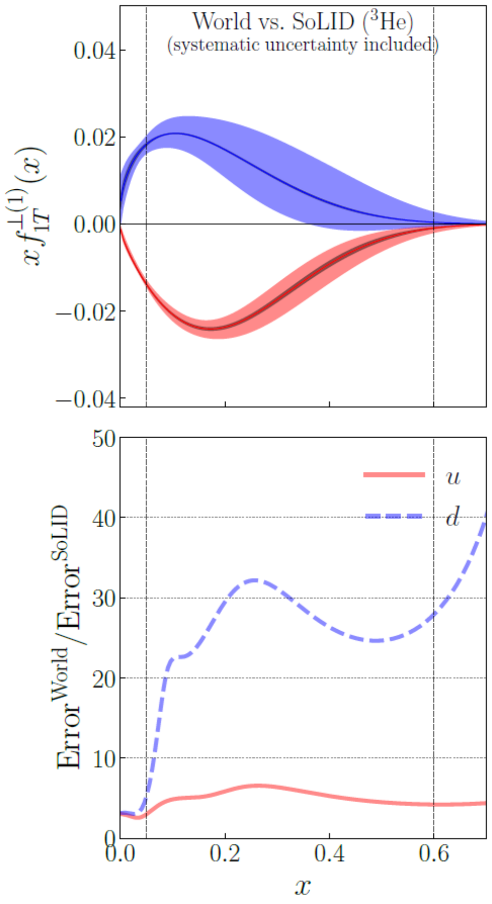




Transversity



Sivers



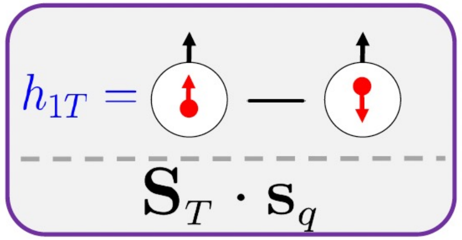
D'Alesio et al., Phys. Lett. B 803 (2020)135347
Z. Ye, N. Sato et al, Phys. Lett. B 767, 91 (2017), based on Z. Kang et. al.

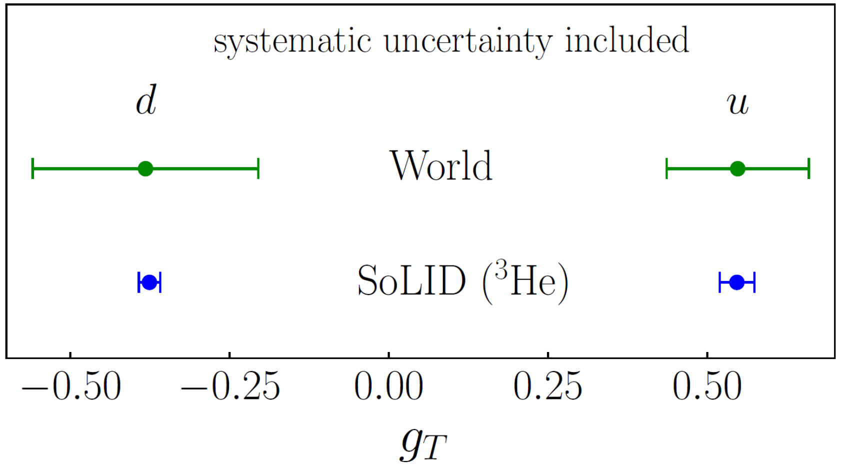
SoLID-SIDIS Projections

- Transversity & Tensor-Charge from SSA:

Z. Ye, N. Sato et al, Phys. Lett. B 767, 91 (2017)
H. Gao, T. Liu and Z. Zhao, PRD 97, 074018 (2018)

- ❑ Transversity





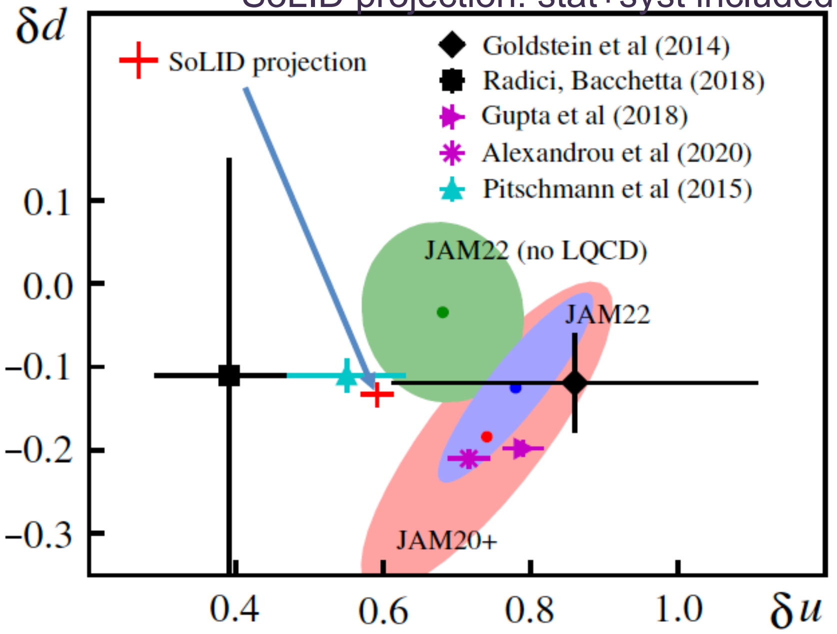
- ❑ Access Tensor charge: $g_T^q = \int_0^1 \left[h_1^q(x) - h_1^{\bar{q}}(x)\right] dx$

- ❑ Tensor charge is also connected to neutron and proton EDMs:

$$d_n = g_T^d d_u + g_T^u d_d + g_T^s d_s$$

- ✓ A fundamental QCD quantity dominated by valence quarks
- ✓ Precisely calculated on the lattice
- ✓ SoLID allows for high-precision test of LQCD predictions
- ✓ A unique opportunity for SM tests and new physics

SoLID projection: stat+syst included

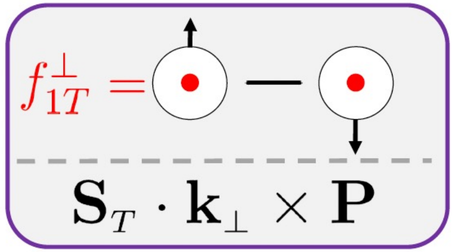


J. Cammarota et al, PRD 102, 054002 (2020) (JAM20+)
L. Gamberg et al., arXiv:2205.00999 (JAM22)

SoLID-SIDIS Projections

➢ Sivers & Prezelocity from SSA:

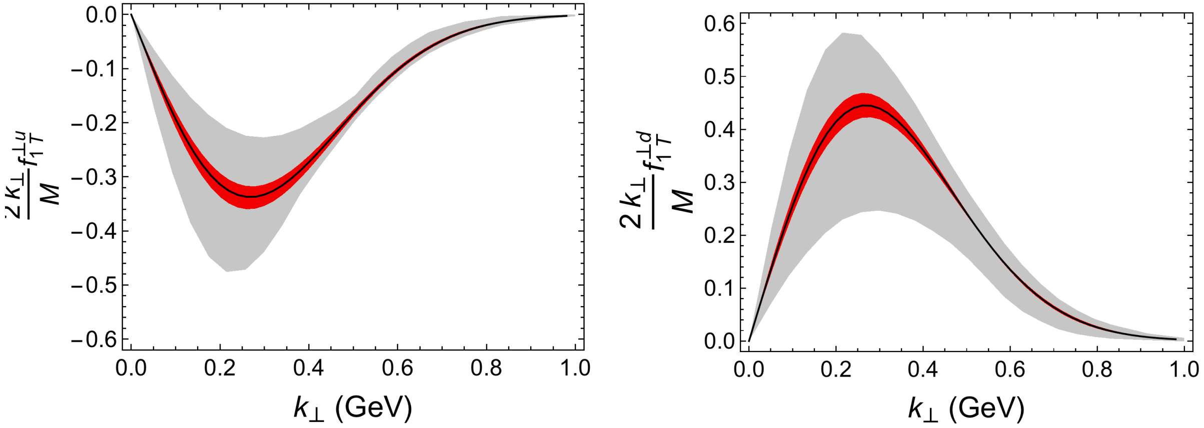
❑ Sivers distribution



- naively time-reversal odd (sign-change vs DY)

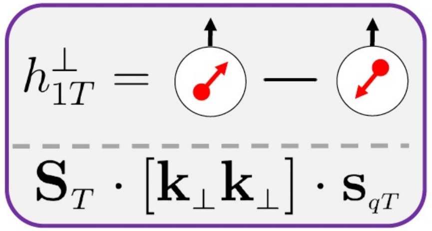
$$f_{1T}^{\perp q}(x,k_\perp)\Big|_{\mathrm{SIDIS}} = -f_{1T}^{\perp q}(x,k_\perp)\Big|_{\mathrm{DY}}$$

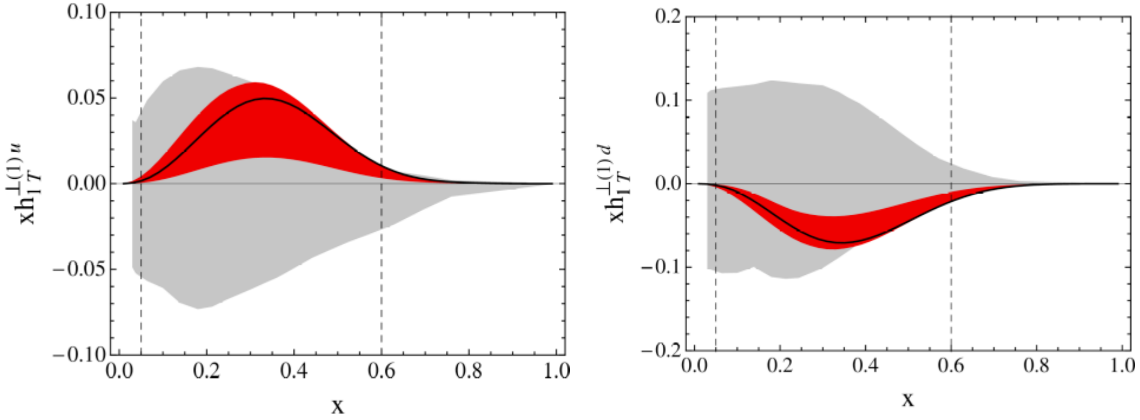
- SoLID projection with transversely polarized n/p



Parametrization by M. Anselmino et al., EPJ A 39, 89 (2009)

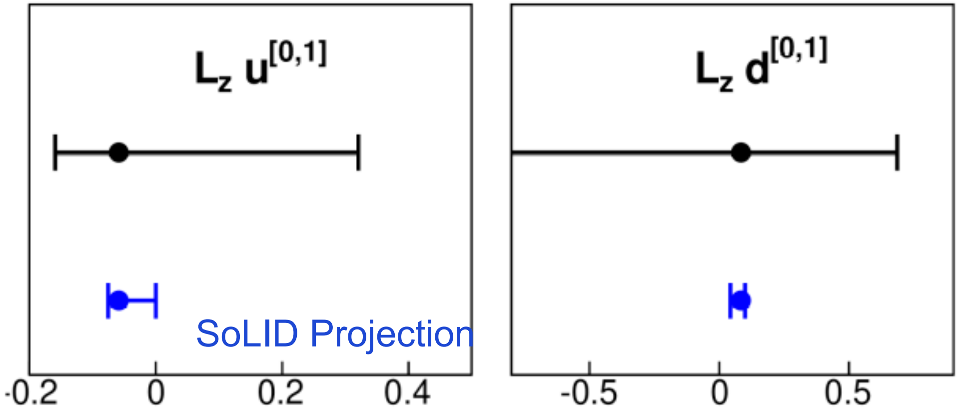
❑ Pretzelocity distribution





- Relation to OAM (canonical)

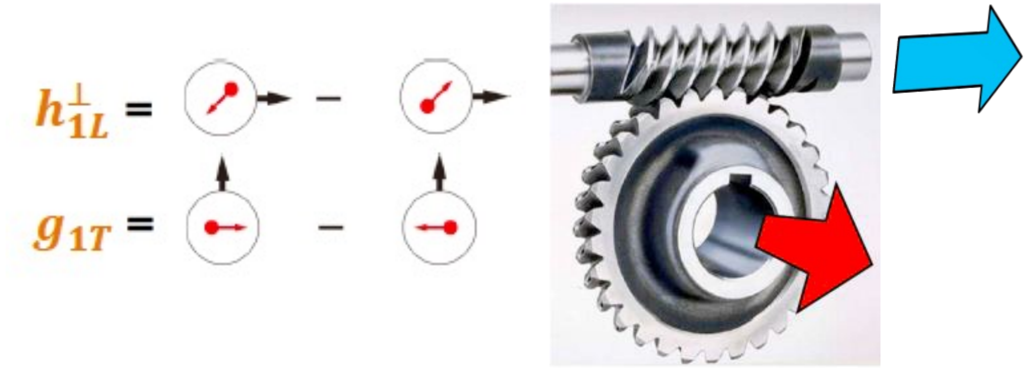
$$L_z^q = -\int dx d^2\mathbf{k}_\perp \frac{\mathbf{k}_\perp^2}{2M^2} h_{1T}^{\perp q}(x,k_\perp) = -\int dx h_{1T}^{\perp(1)q}(x)$$

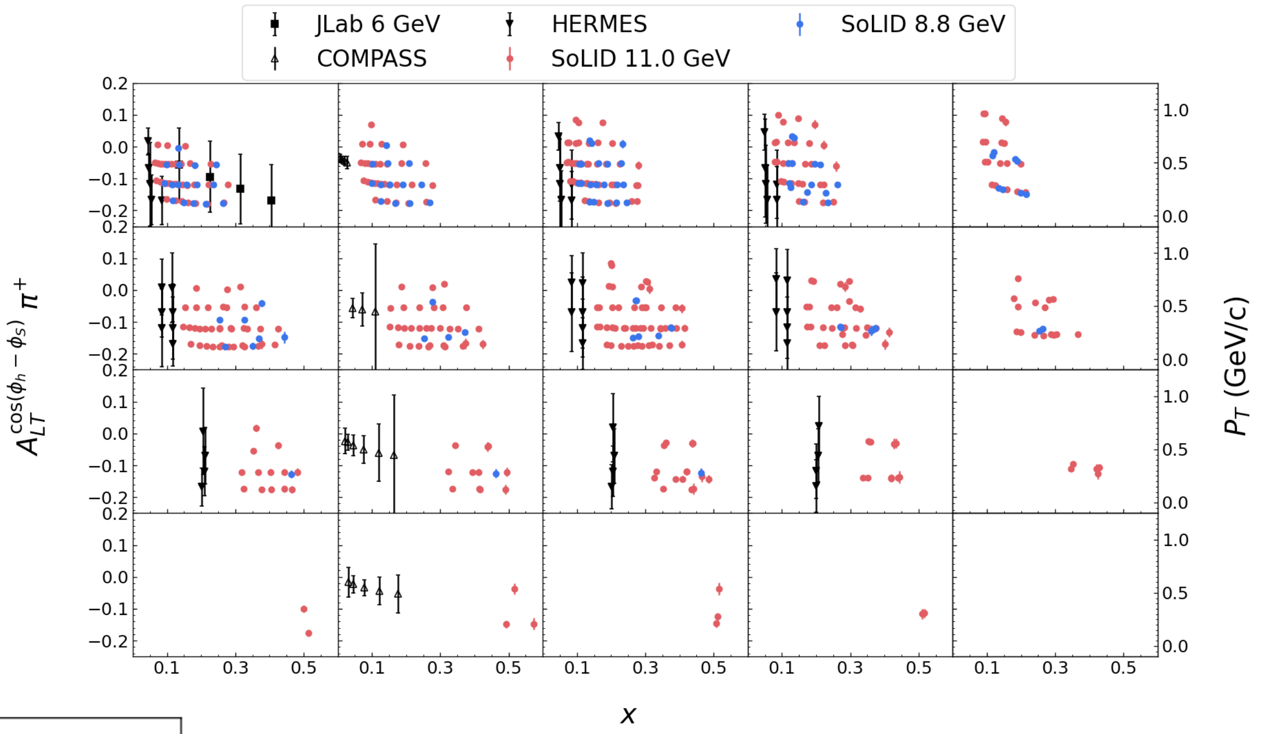


Lefky and Prokudin PRD 91, 034010 (2015)

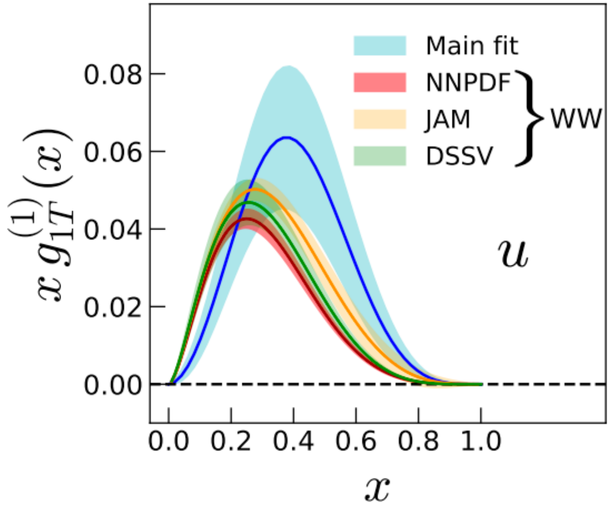
SoLID-SIDIS Projections

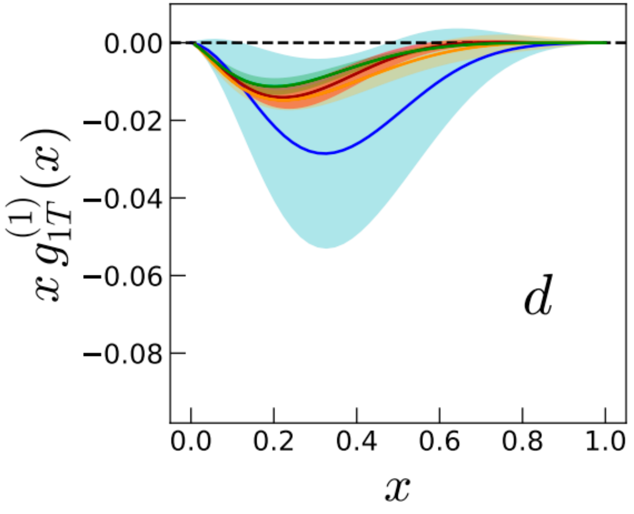
- Worm-Gear TMDs from DSA:





- ❑ Dominated by interference between wave function components that differ by one unit of quark OAM
- ❑ A genuine sign of intrinsic transverse motion



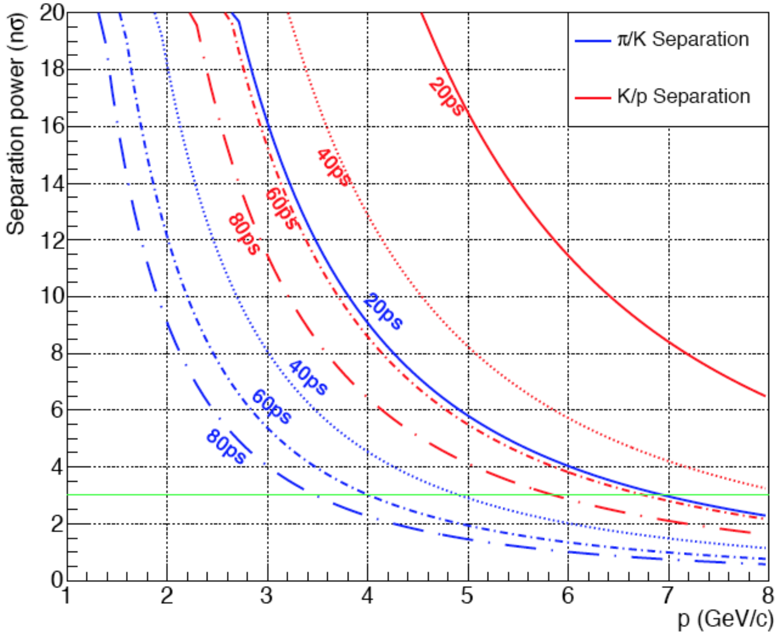


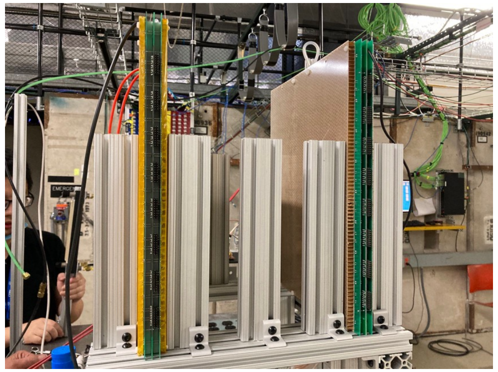
S. Bhattacharya et al.,
Phys. Rev. D105, 034007 (2022)

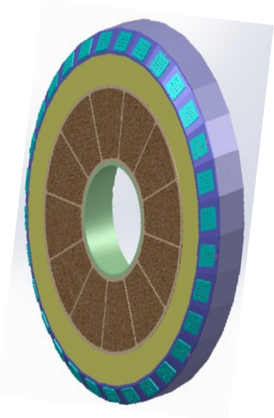
SoLID-SIDIS Projections

➢ Kaon-SIDIS:

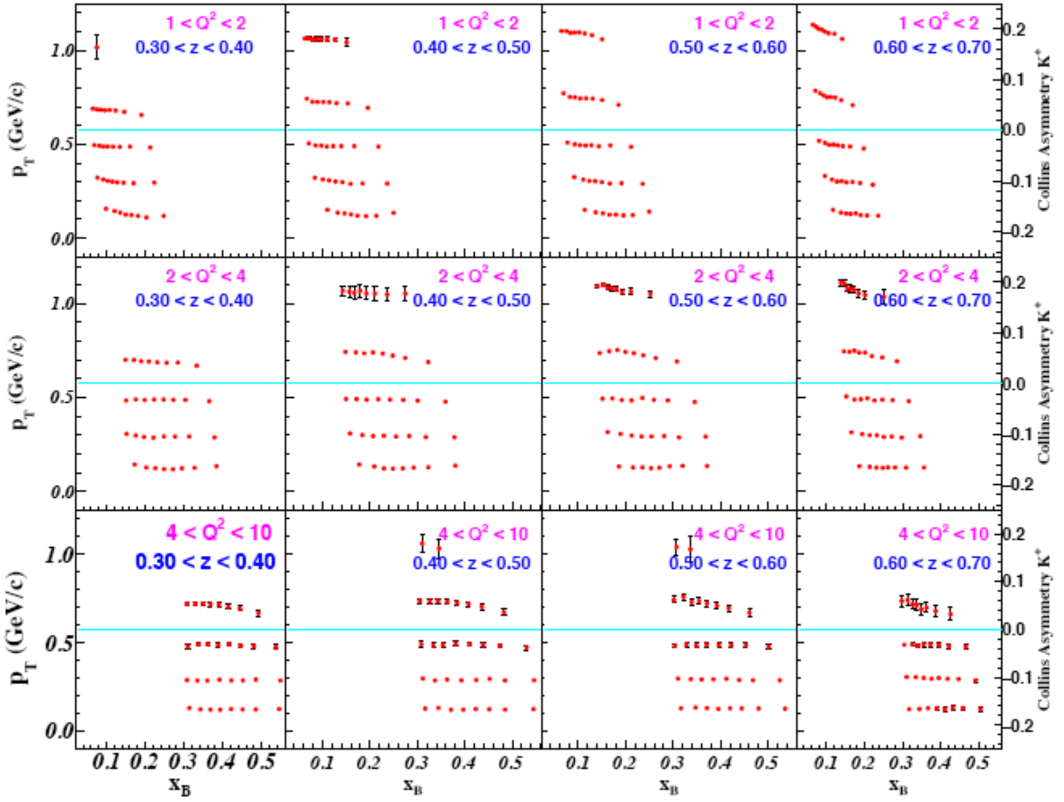
- ❑ Look for $K^{\pm}$ production in SIDIS using both the transversely polarized 3He and NH3 Targets
- ❑ Extract $K^{\pm}$ Collins, Sivers and other TMD asymmetries
- ❑ Flavor decomposition of u, d and sea quarks' TMDs
- ❑ Kaon-Identification: HGC + 30ps MRPC-TOF







Projection on Collins K+



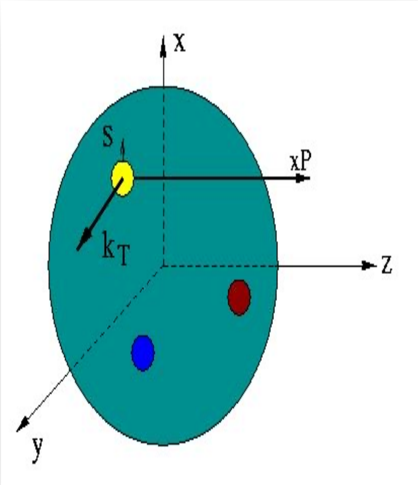
(a) $\vec{n}(e, e'K^{+})X$

❑ Enhanced configuration

- ✓ MRPC modules contributed by Chinese resources (Tsinghua, USTC, etc.)
- ✓ High-time resolution Readout electronics possibly contributed by other US funding resources (UIC, etc.)

Nucleon’s 3D Structure

$W_p^u(x,k_T,\boldsymbol{r_T})$ Wigner distributions **5D**



$d^2\boldsymbol{r_T}$

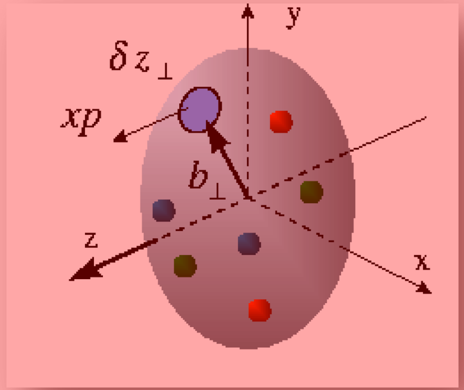
TMD
$f_1^u(x,k_T)$, $h_1^u(x,k_T)$,…

d^2k_T

(X. Ji, D. Mueller, A. Radyushkin)

3D

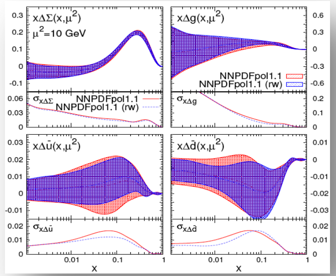
GPDs/IPDs
$H^u, E^u, \widetilde{H}^u, \widetilde{E}^u$

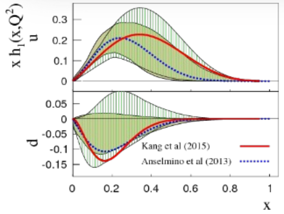


d^2r_T

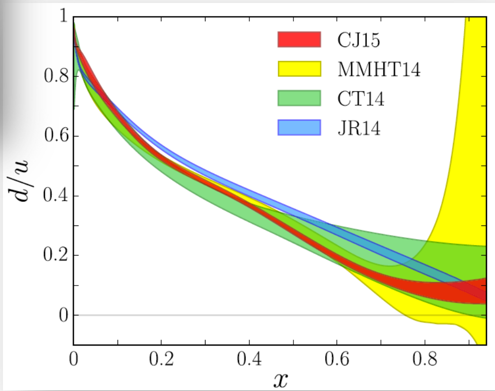
d^2k_T

dx & Fourier Transformation





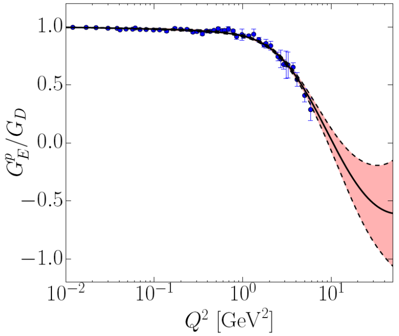
A. Accardi et. al.
B. Phys. Rev. D 93, 114017 (2016)

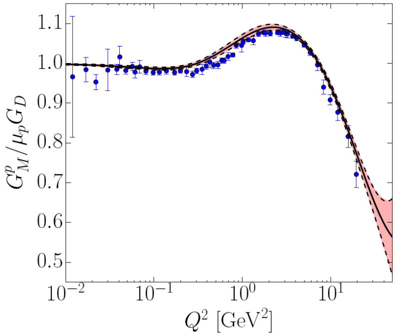


PDFs
$f_1^u(x)$, $g_1^u(x)$,
$h_1^u(x)$,…

1D

Form
Factors
$G_E(Q^2)$,
$G_M(Q^2)$





Generalized Parton Distributions

- 8 Leading-Twist GPDs:

Chiral Even $H^{q/g}, E^{q/g}, \widetilde{H}^{q/g}, \widetilde{E}^{q/g}$

Chiral Odd $H_T^{q/g}, E_T^{q/g}, \widetilde{H}_T^{q/g}, \widetilde{E}_T^{q/g}$

		Quark Polarization		
		Unpolarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Nucleon Polarization	U	H		$2\widetilde{H}_T + E_T$
	L		$\widetilde{H}$	$\widetilde{E}_T$
	T	E	$\widetilde{E}$	$H_T, \widetilde{H}_T$

- Access parton distributions in 3D

X. Ji, PRL 78, 610 (1997)
M. Diehl, Physics Reports 388 (2003) 41–277,
Belitsky, Radyushkin, Physics Reports 418 (2005) 1–387

- Connect to FF & PDFs: e.g.

$$\int_{-1}^{1} dx H^q(x,\xi,t) = F_1^q(t)$$
$$\int_{-1}^{1} dx E^q(x,\xi,t) = F_2^q(t)$$

Dirac&Pauli Form Factors

$$\int_{-1}^{1} dx \widetilde{H}^q(x,\xi,t) = G_A^q(t)$$
$$\int_{-1}^{1} dx \widetilde{E}^q(x,\xi,t) = G_P^q(t)$$

Axial&Pseudoscaler Form Factors

$$H^q(x,0,0) = q(x), x > 0$$
$$\widetilde{H}^q(x,0,0) = \Delta q(x), x > 0$$

PDFs

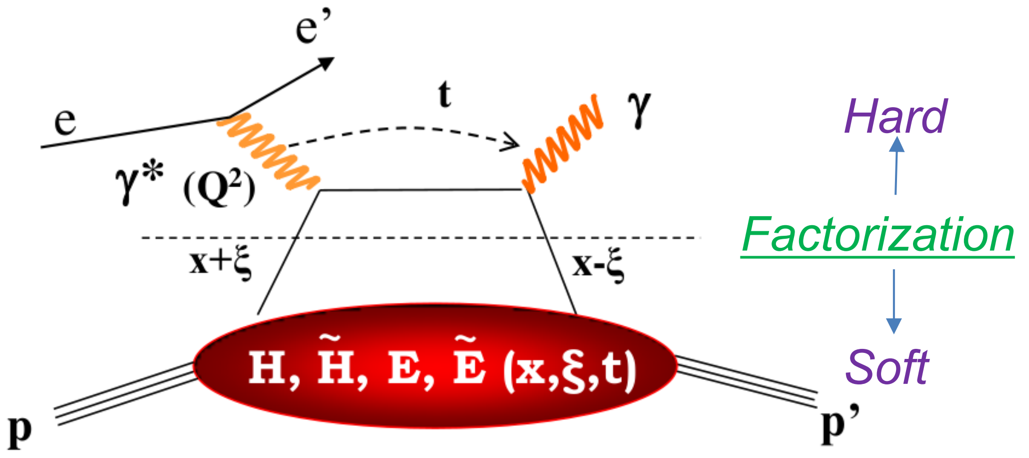
- How to access Angular Momenta?
  - ✓ Ji's Sum Rule (X. Ji, PRL 78, 610 (1997)

$$J_{q/g} = \lim_{t,\xi\to 0} \frac{1}{2} \int x dx \left[\boldsymbol{H^{q/g}}(x,\xi,t) + \boldsymbol{E^{q/g}}(x,\xi,t) \right]$$

Generalized Parton Distributions (GPD)

Generalized Parton Distributions

➢ Deep Virtual Compton Scattering (DVCS):



- ❑ Golden channel to study GPD

- ❑ DVCS only measures Compton Form Factors (CFFs):

$$\tau_{DVCS} \propto \int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi \mp i\varepsilon} dx = \overbrace{P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi} dx}^{\mathrm{Re}(\mathcal{H})} \overbrace{- i\pi H(\pm\xi,\xi,t)}^{\mathrm{Im}(\mathcal{H})},$$

(8 CFFs for $H, E, \widetilde{H}, \widetilde{E}$)

- ❑ Asymmetry: $A = \frac{I}{|\tau_{DVCS}|^2 + I + |\tau_{BH}|^2} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$

  ✓ Decouple GPDs by angular modulations:

$$d\sigma^{I}_{UU} = \frac{-K_I}{\mathcal{P}_1(\phi)\,\mathcal{P}_2(\phi)} \sum_{n=0}^{3} c^{I}_{n,\mathrm{unp}} \cos(n\phi), \qquad d\sigma^{I}_{LU} = \frac{-K_I}{\mathcal{P}_1(\phi)\,\mathcal{P}_2(\phi)} \sum_{n=1}^{2} s^{I}_{n,\mathrm{unp}} \sin(n\phi),$$

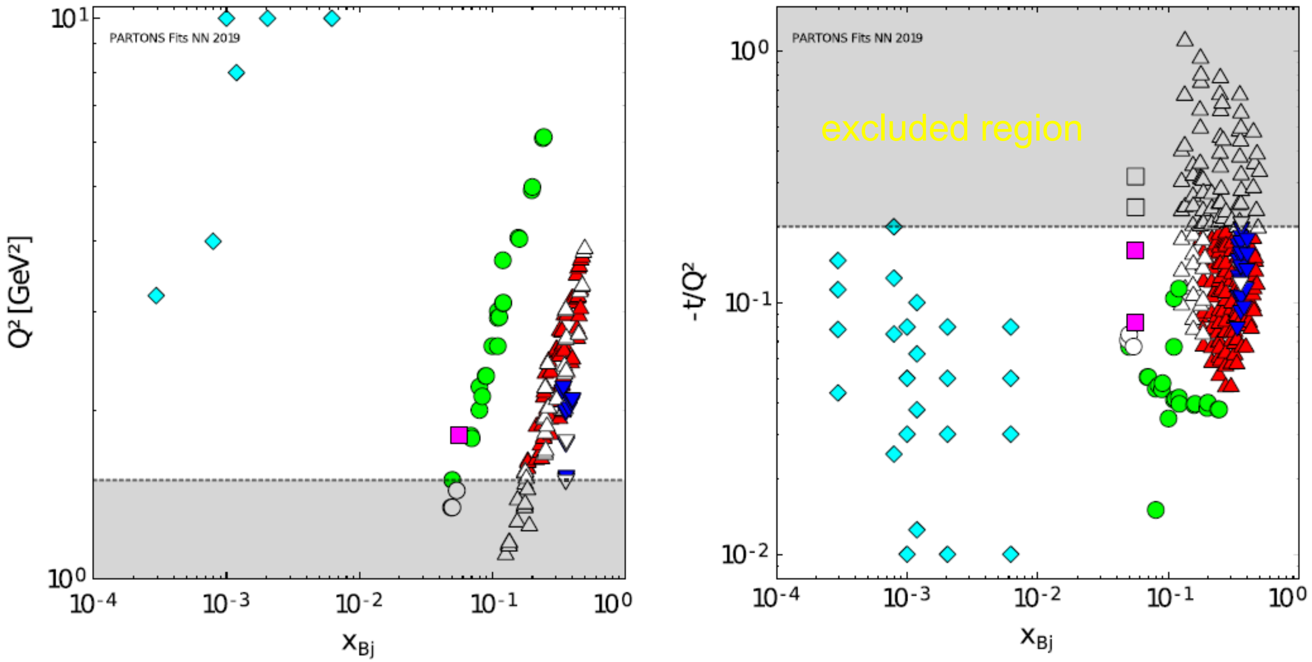
$$d\sigma^{\mathrm{DVCS}}_{UU} = \frac{1}{Q^2} \sum_{n=0}^{2} c^{\mathrm{DVCS}}_{n,\mathrm{unp}} \cos(n\phi), \qquad d\sigma^{\mathrm{DVCS}}_{LU} = \frac{1}{Q^2} s^{\mathrm{DVCS}}_{1,\mathrm{unp}} \sin\phi,$$

Polarization	Asymmetries	CFFs
Longitudinal Beam	A_{LU}	$Im\{\mathcal{H}_p, \widetilde{\mathcal{H}}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \widetilde{\mathcal{H}}_p, \mathcal{E}_n\}$
Longitudinal Target	A_{UL}	$Im\{\mathcal{H}_p, \widetilde{\mathcal{H}}_p\}$ $Im\{\mathcal{H}_n, \mathcal{E}_n, \widetilde{\mathcal{E}}_n\}$
Long. Beam + Long. Target	A_{LL}	$Re\{\mathcal{H}_p, \widetilde{\mathcal{H}}_p\}$ $Re\{\mathcal{H}_n, \mathcal{E}_n, \widetilde{\mathcal{E}}_n\}$
Transverse Target	A_{UT}	$Im\{\mathcal{H}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \mathcal{E}_n\}$
Long. Beam +Trans.Targt	A_{LT}	$Re\{\mathcal{H}_p, \mathcal{E}_p\}$ $Re\{\mathcal{H}_n, \mathcal{E}_n\}$

Generalized Parton Distributions

➢ **Current Status:**

❑ Exploration stage (CLAS, Hall-A, COMPASS, HERMES, ZEUS, H1)

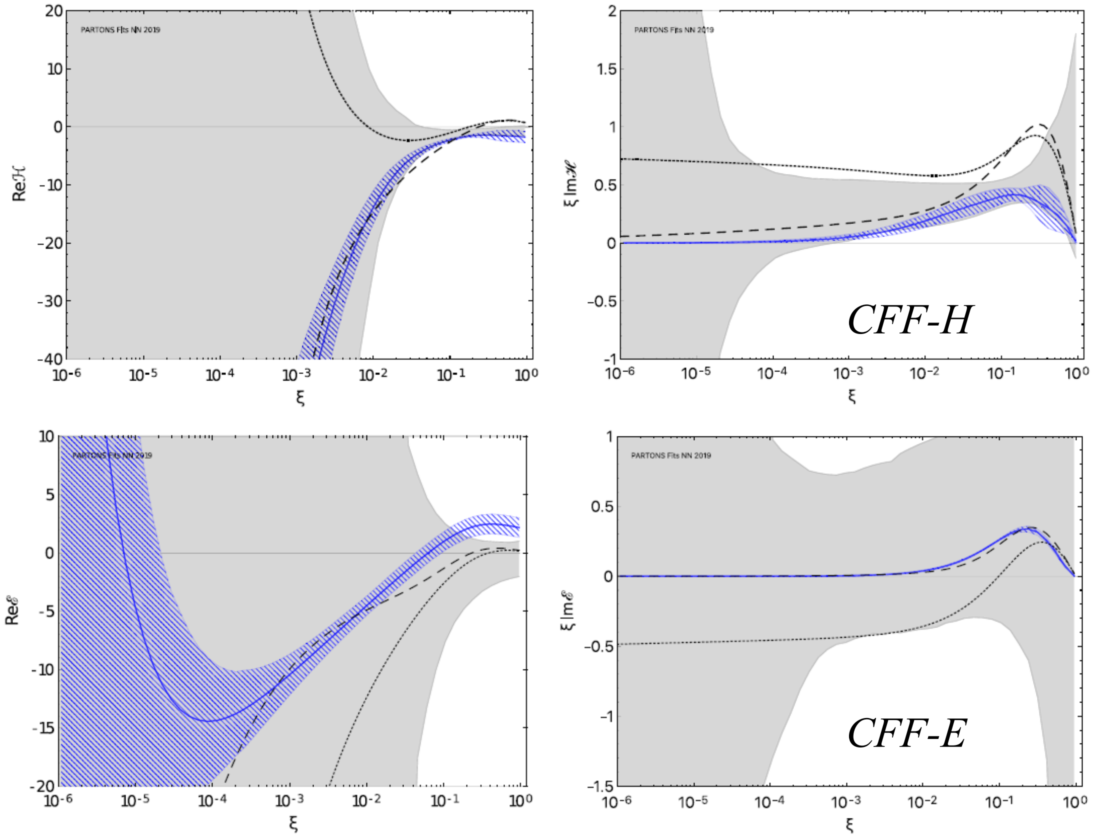


Guidal, Moutarde Vanderhaeghen, Rep. Prog. Phys. 76 (2013)
d' Hose, et. al., Eur. Phys. J. A (2016) 52: 151
X. Ji, National Science Review, 213-223 (2017)

❑ More data needed!

❑ Global Fits

Blue: fit with modle-constrain, Moutarde et. al. EPJ (2018)
Gray: unbias fit by PARTONS Collaboration, EPJ (2019)

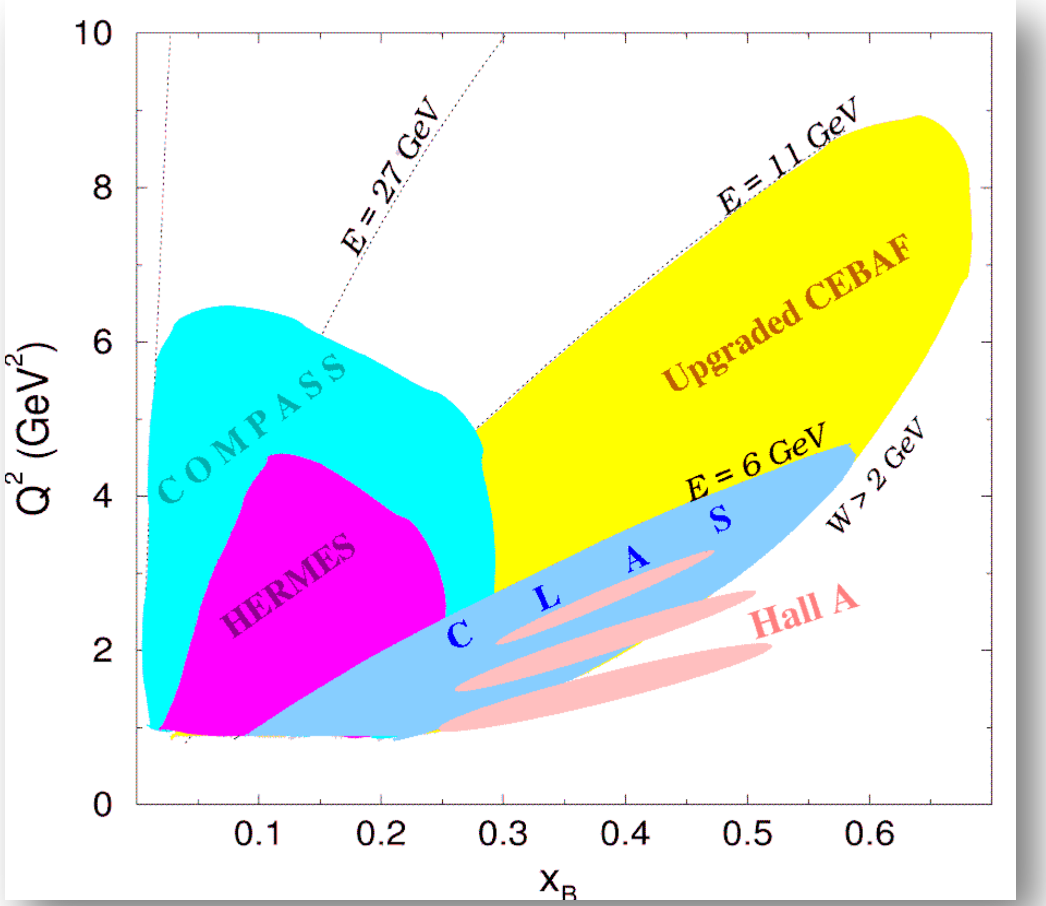


Generalized Parton Distributions

- **Jlab12GeV DVCS Experiments:**
  - ❑ DVCS not directly sensitive to flavor → proton & neutron needed for u & d
  - ❑ Need multiple observables to decouple 8 CFFs, → XS, BSA, TSA, DSA
  - ❑ 3D → wide kinematic-coverage + high rate

Approved 12GeV DVCS experiments:

- E12-16-010B (Hall-B): unpol. proton, XS
- E12-11-003 (Hall-B): unpol. Deuteron, BSA
- E12-06-119 (Hall-B): long-pol proton, BSA, TSA,
- C12-12-010 (Hall-B): *conditional approved*, trans. pol. Proton, TSA,BSA
- C12-15-004 (Hall-B): *conditional approved*, long. pol. Deuteron, TSA, BSA
- E12-06-114 (Hall-A&C): unpol. proton, XS & BSA, limited coverage
- E12-13-010 (Hall-C): unpol. proton, XS,
- E12-15-001 (Hall-C): proton, XS
- ***LOI:*** nDVCS w/ TDIS setup (Hall-A), tagged neutron, XS



❖ SoLID (SIDIS configuration) will provide:

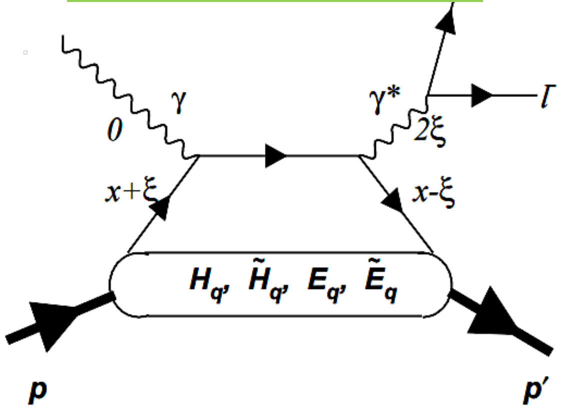
- ✓ DVCS asymmetries w/ polarized beam & target data
- ✓ DVCS neutron data (Deuteron or He3)

Generalized Parton Distributions

- **Three additional exclusive processes →Crucial to fully extract GPDs**

Timelike Compton Scattering:

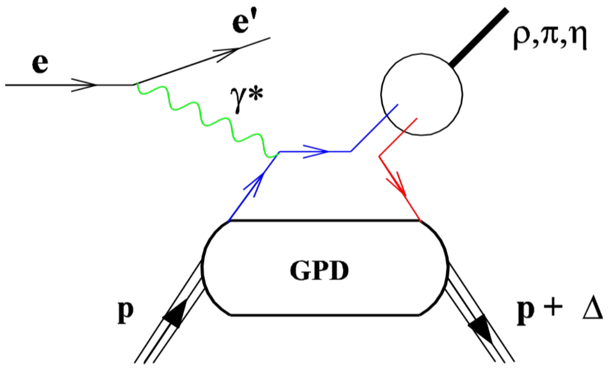
$\gamma + N \rightarrow N + l^{+} + l^{-}$



- ✓ Inverse of the space-like DVCS
- ✓ Extract the real part of CFFs
- ✓ Complimental to DVCS
- ✓ New experiments: CLAS12, SoLID

Deep Virtual Meson Production

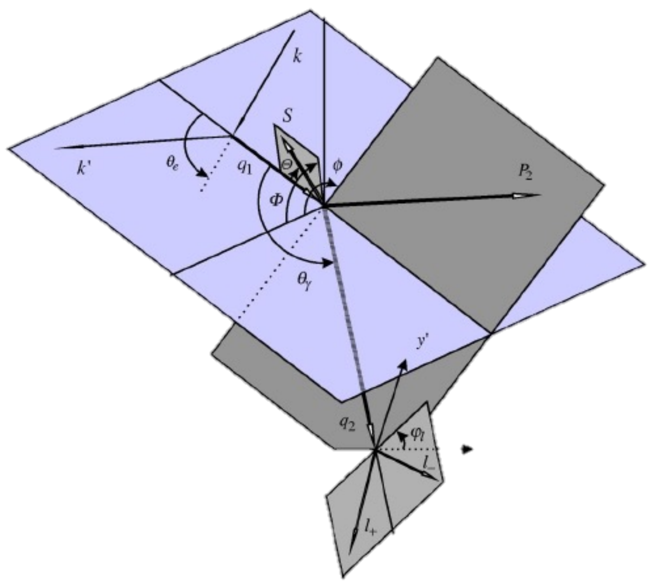
$e + N \rightarrow e' + N' + \pi^{0,\pm}\ (K^{0,\pm}, \eta, \rho, \omega, \ldots)$



- ✓ Vector mesons sensitive to H, E.
- ✓ Pseudoscalar mesons sensitive to $\tilde{H}$ and $\tilde{E}$.
- ✓ neutron + pseudoscalar uniquely sensitive to $\tilde{E}$
- ✓ sensitive to chiral-odd GPDs (H_T, E_T, $\tilde{H}_T$, $\tilde{E}_T$)
- ✓ New experiments: CLAS12, SoLID, Hall-C, COMPASS

Double-DVCS:

$e + N \rightarrow e' + N + l^{+} + l^{-}$



- ✓ Lepton pairs in the final states
- ✓ Access GPDs ***beyond the x=ξ limit***
- ✓ New experiments: NONE

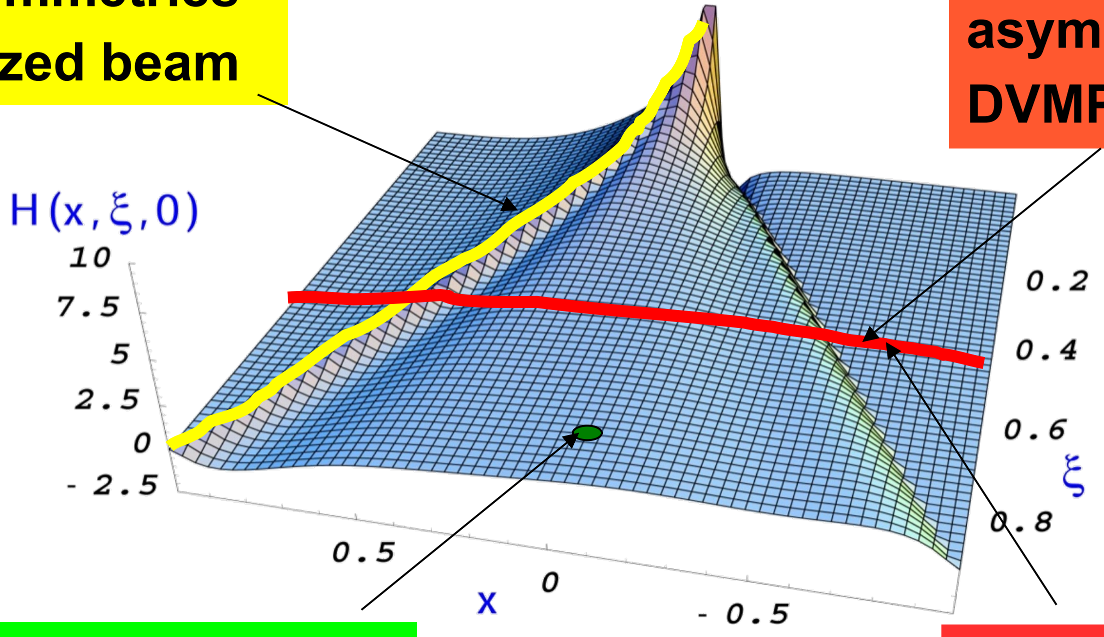
❑ Rarely done!

Generalized Parton Distributions

- **Three additional exclusive processes →Crucial to fully extract GPDs**

(Re)
DVCS: charge asymmetry
TCS: cross-section, lin beam asymmetry
DVMP: cross-section, asymmetries

(Im, x=ξ)
DVCS: spin asymmetries
TCS with polarized beam

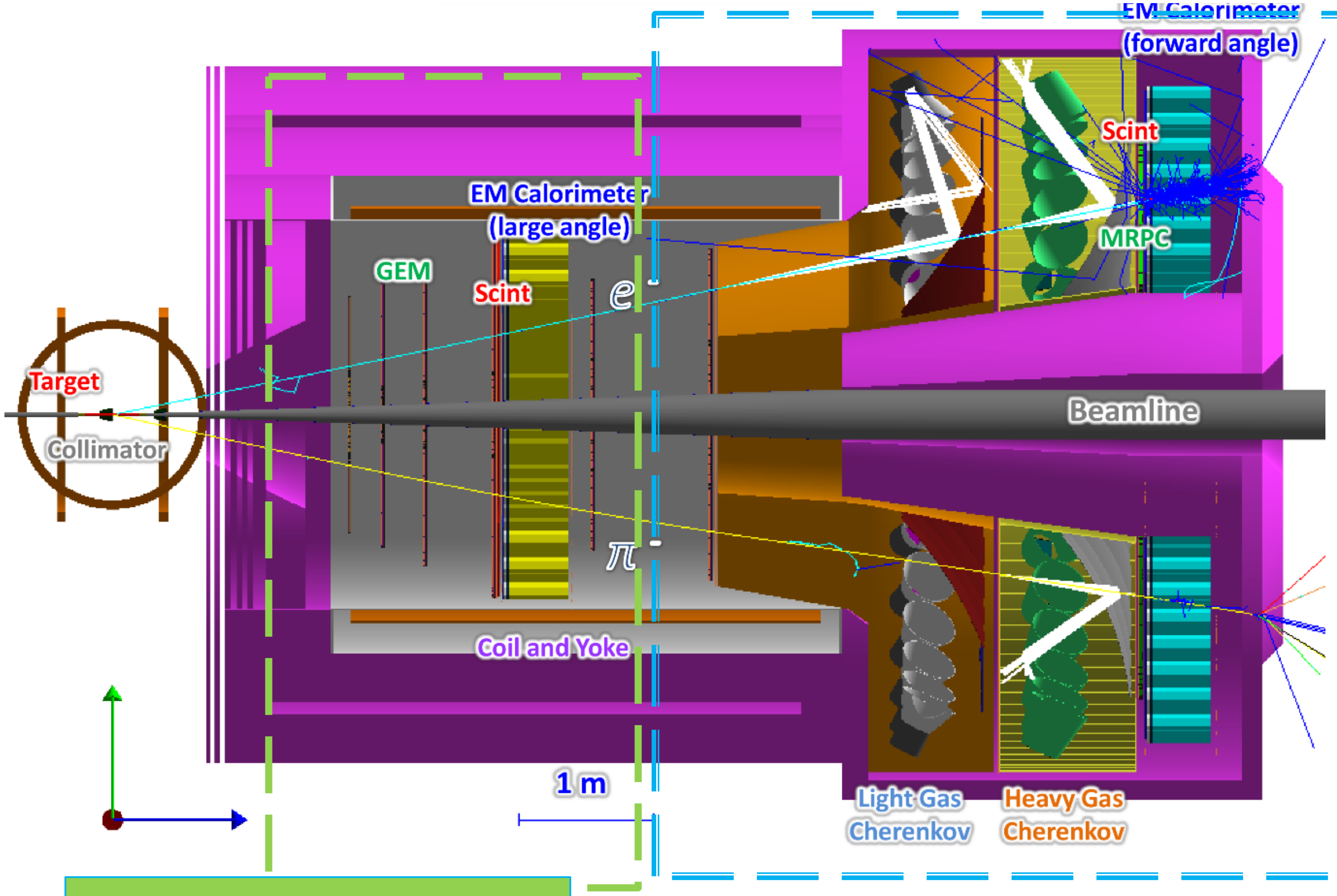


(Im, x ≠ ξ, x < |ξ|)
Double DVCS

($|Im|^2$+$|Re|^2$)
DVCS: cross section
DVMP: cross-section, asymmetries

GPDs on SoLID

- **Exclusive Measurement based on SIDIS/JPsi Setup**



Forward-Angle : electrons, pion, photons and proton

Large-Angle→electrons, photons and proton

GPDs on SoLID

➢ **SoLID-TCS:** (E12-12-006A, M. Boer, P. Nadel-Turonski, J. Zhang, Z. Zhao)

❑ Time-Like Compton Scattering (TCS):

✓ Different angular moments for TCS & BH Interference-terms

$$\sigma_{INT}^{TCS,unpol} \propto \cos\varphi Re\widetilde{M}^{--},\ \sigma_{INT}^{TCS,cir-pol} \propto \sin\varphi Im\widetilde{M}^{--}$$

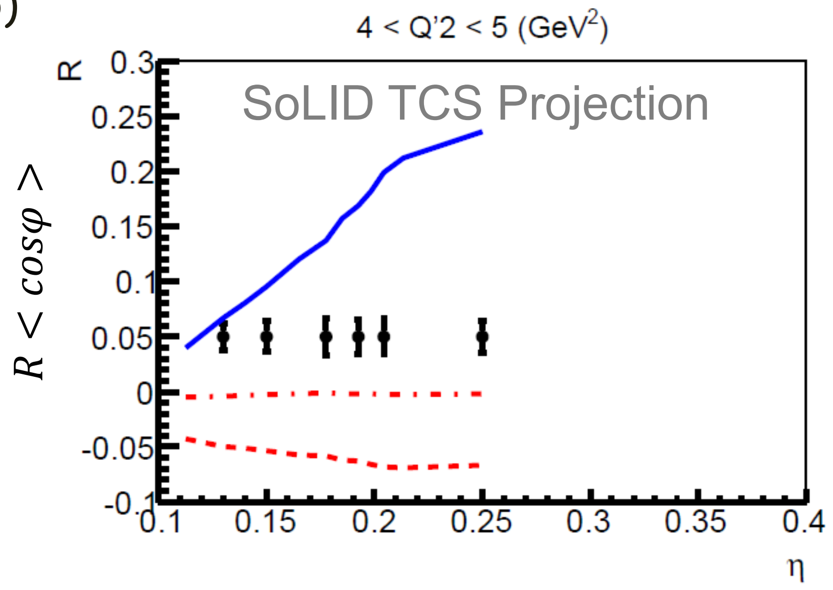
$$\tilde{M}^{--} = \frac{2\sqrt{t_0 - t}}{M}\frac{1-\eta}{1+\eta}\left[F_1\mathcal{H}_1 - \eta(F_1+F_2)\tilde{\mathcal{H}}_1 - \frac{t}{4M^2}F_2\mathcal{E}_1\right]$$

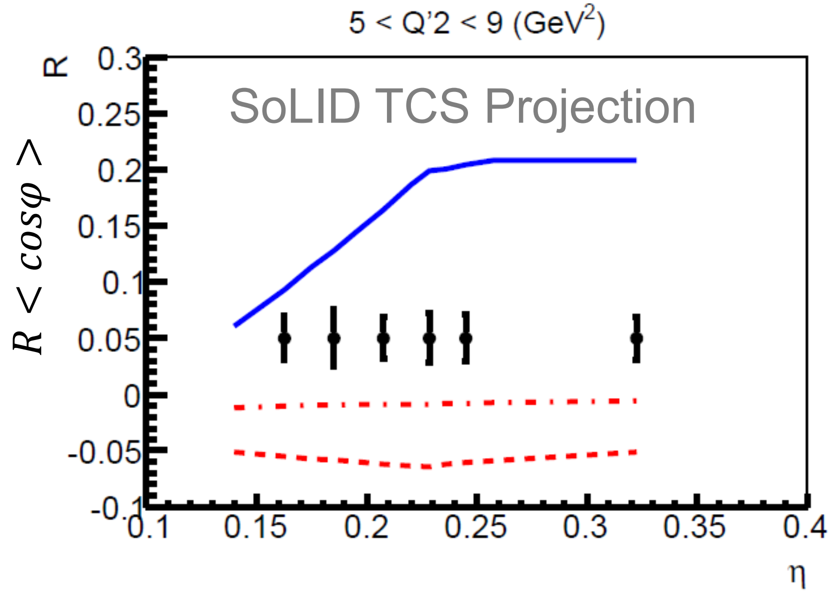
❑ SoLID-TCS: Parallel data taking with J/Psi

✓ Unpolarized 1H target

✓ Indirect photon-production

✓ Extract $cos\varphi$ and sinφ modules





GPDs on SoLID

- **SoLID-DVMP:** (E12-10-006B, Z. Ahmed, G. Huber, Z. Ye)

❑ Asymmetry : $A(\phi,\phi_s) = \frac{d^3\sigma_{UT}(\phi,\phi_s)}{d^2\sigma_{UU}(\phi)} = -\sum_k A_{UT}^{\sin(\mu\phi+\lambda\phi_s)_k} \sin(\mu\phi+\lambda\phi_s)_k$

✓ $A_{UT}^{\sin(\phi-\phi_S)}$ has significant contributions from $\tilde{E}$

✓ $A_{UT}^{\sin(2\phi-\phi_S)}$, $A_{UT}^{\sin(\phi_S)}$ sensitive to transverse GPD

✓ Other angular modules sensitive to TT terms etc.

❑ Analyze angular modules to decouple LT contribution

$$A_{UT}^{\sin(\phi-\phi_s)} \sim \frac{d\sigma_{00}^{+-}}{d\sigma_L\binom{++}{00}} \sim \frac{\mathrm{Im}(\tilde{E}^*\tilde{H})}{|\tilde{E}|^2} \text{ where } \tilde{E} \gg \tilde{H}$$

$$A_{UT}^{\sin(\phi_S)} \sim \mathrm{Im}[M_{0+++}^* M_{0-0+} - M_{0-++}^* M_{0+0+}],$$

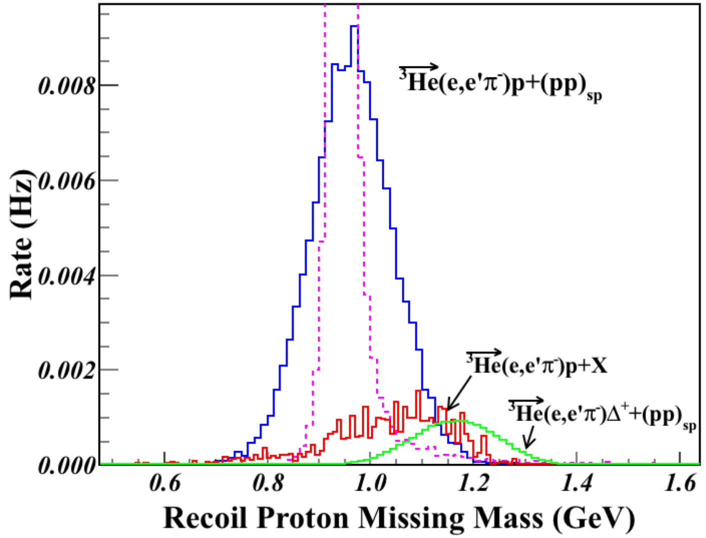
helicities: [pion, neutron, photon, proton]

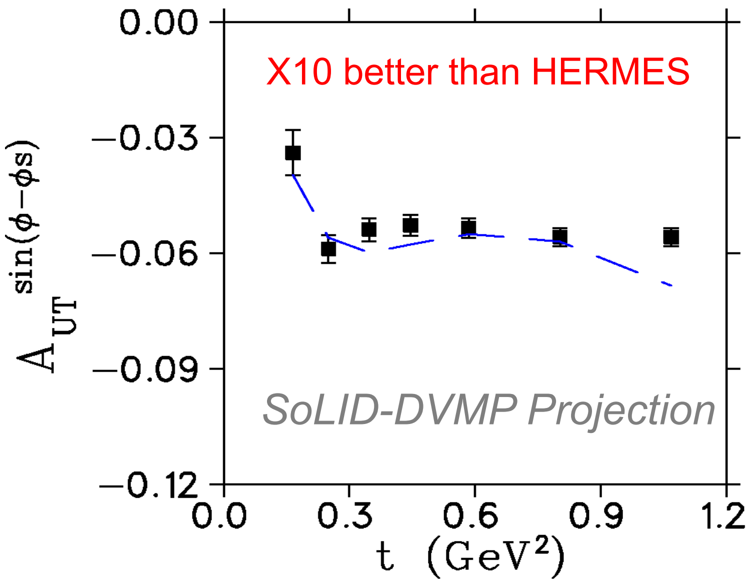
$$\mathcal{M}_{0-,++} = e_0\sqrt{1-\xi^2}\int \mathrm{d}x\mathcal{H}_{0-,++}H_T,$$

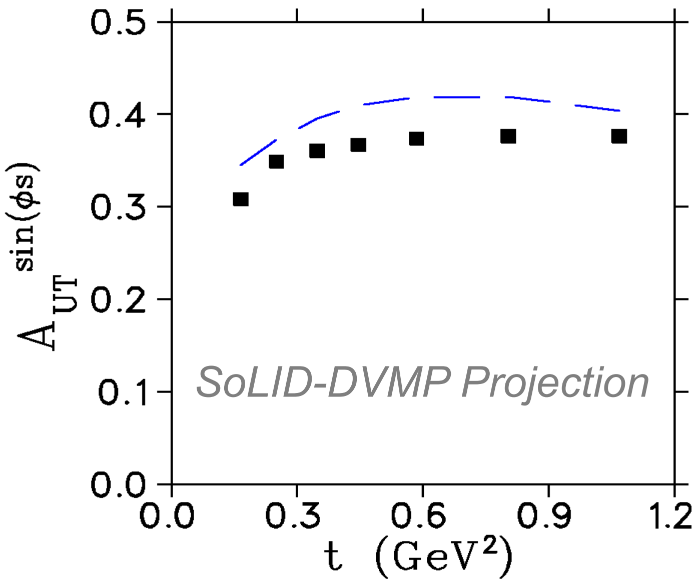
$$\mathcal{M}_{0+,\pm+} = -e_0\frac{\sqrt{t_{\min}-t}}{4m}\int \mathrm{d}x\mathcal{H}_{0-,++}\bar{E}_T.$$

❑ First neutron DVMP asymmetries

❑ Reconstruct DVMP events via Missing Mass from SIDIS data



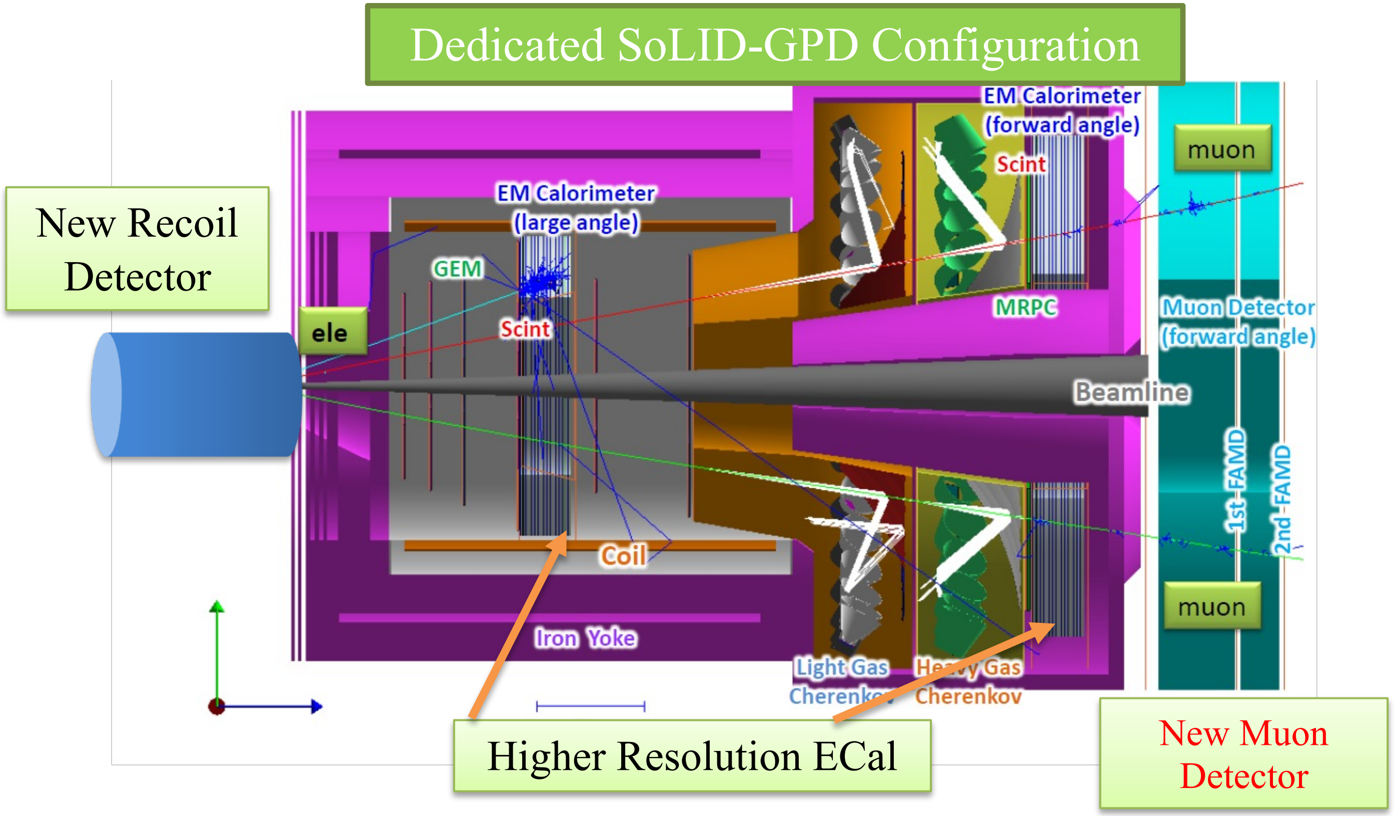


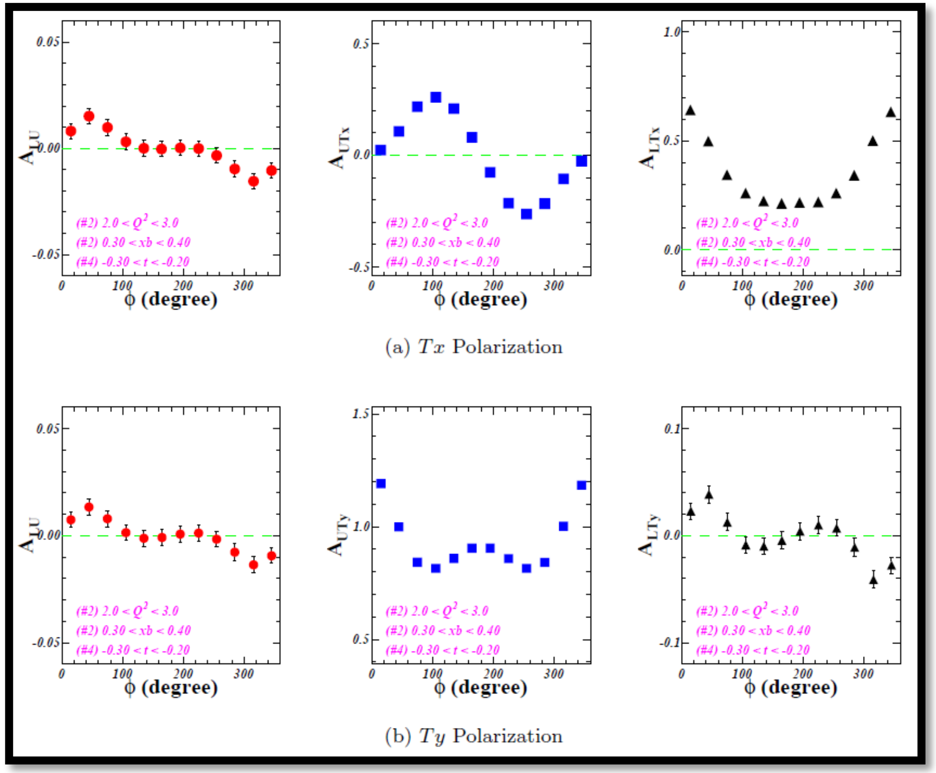


❑ Pioneer study before EIC

GPDs on SoLID

- **Dedicated Setup for New GPD Experiments**
  - SoLID is optimized for charged particle detection
  - Detector upgrade to unlock its full power of GPD measurements



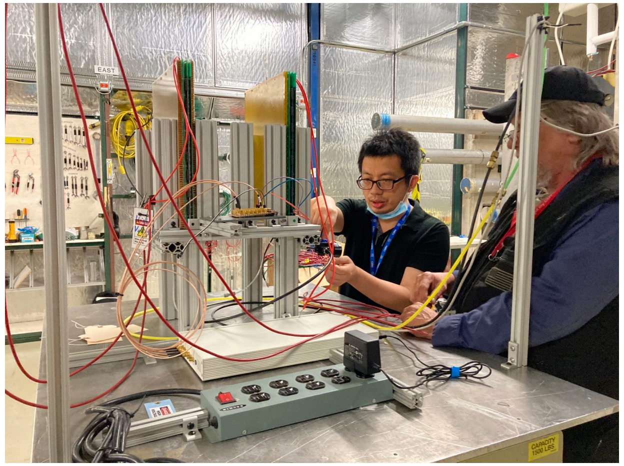


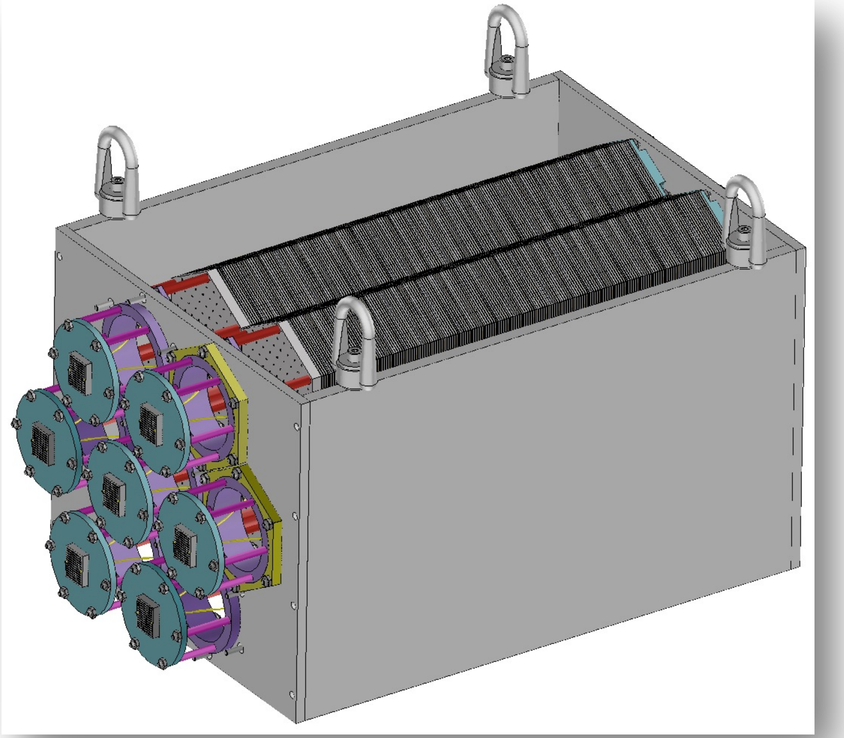
SoLID DVCS with Polarized He3 Projection: one typical (Q2, x, t) bin out of 1000+ bins

- ✓ DDVCS with J/Psi +muon detectors → New proposal under development (LOI 12-12-005)
- ✓ DVCS with polarized He3 & SIDIS → better ECal resolution + recoil proton detector

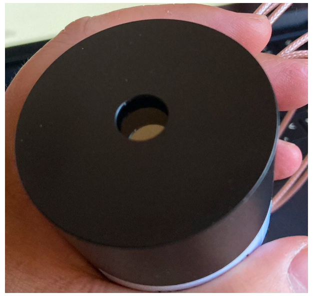
SoLID Detector R&D

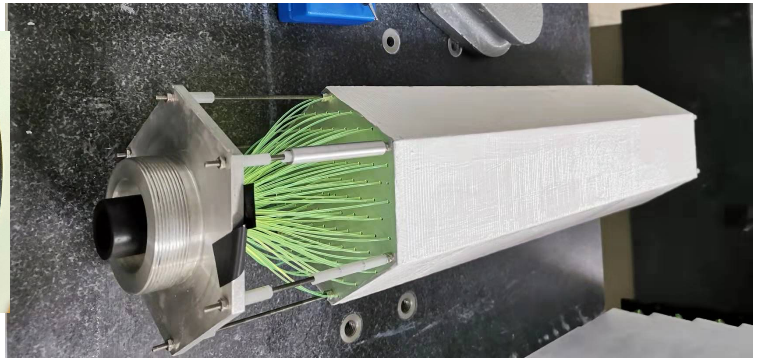
- ❑ 2022 Jlab Test for Ecal+GEM+Cherenkov (see Xinzhan's talk)
- ❑ 2022 FermiLab MRPC & MCP-PMT Test (Tsinghua +UIC)
  - ✓ Plan on 2023 test at Jlab: 4 MRPC at UIC now, high-rates MRPC to be sent to Jlab soon; Test fast electronics





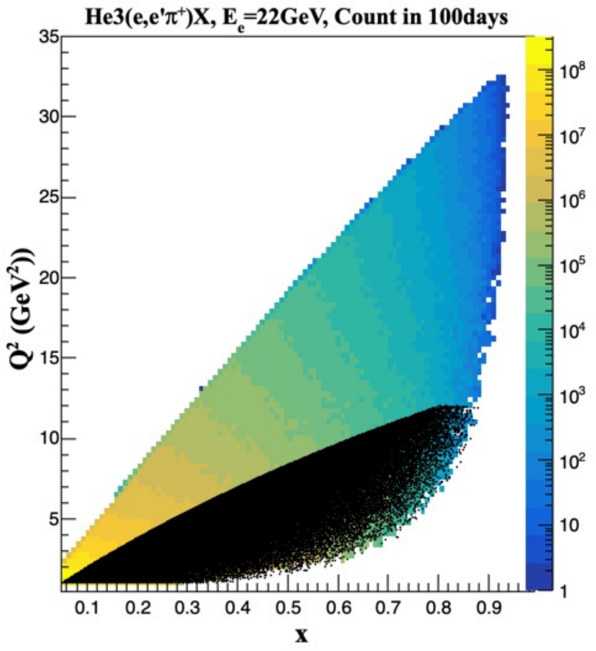
- ❑ Jlab 2023 Test of Ecal super-modules+MCP (Tsinghua & Shabndong Univ)

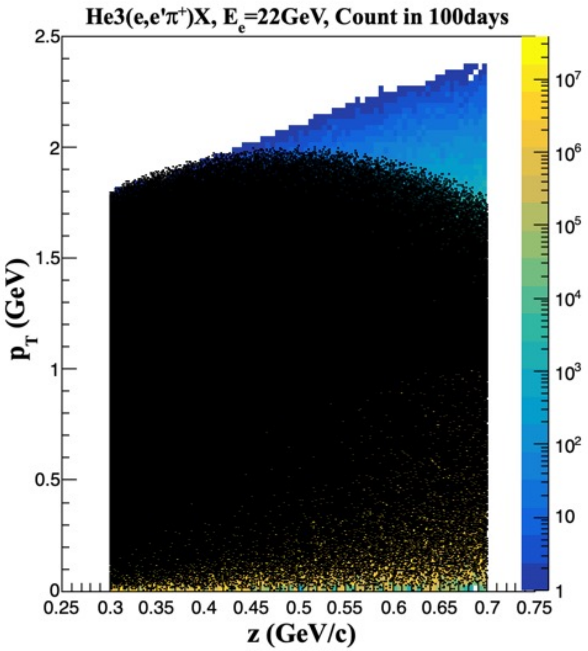




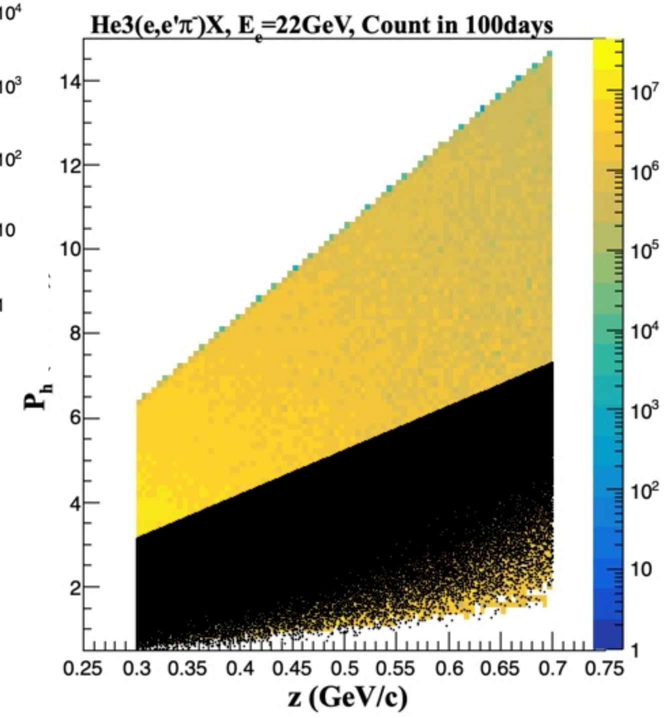
SoLID-SIDIS at 22GeV

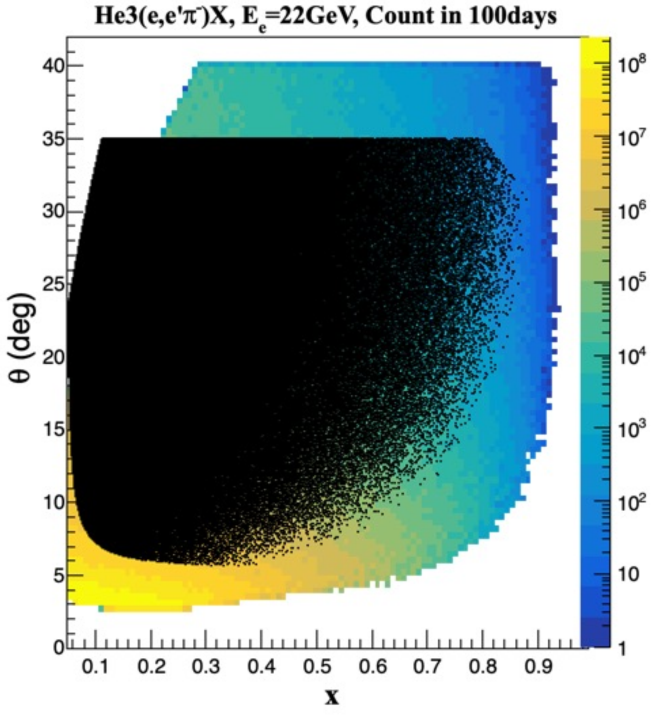
- Larger Phase-Space





Back dots→11GeV
Color dots→22GeV



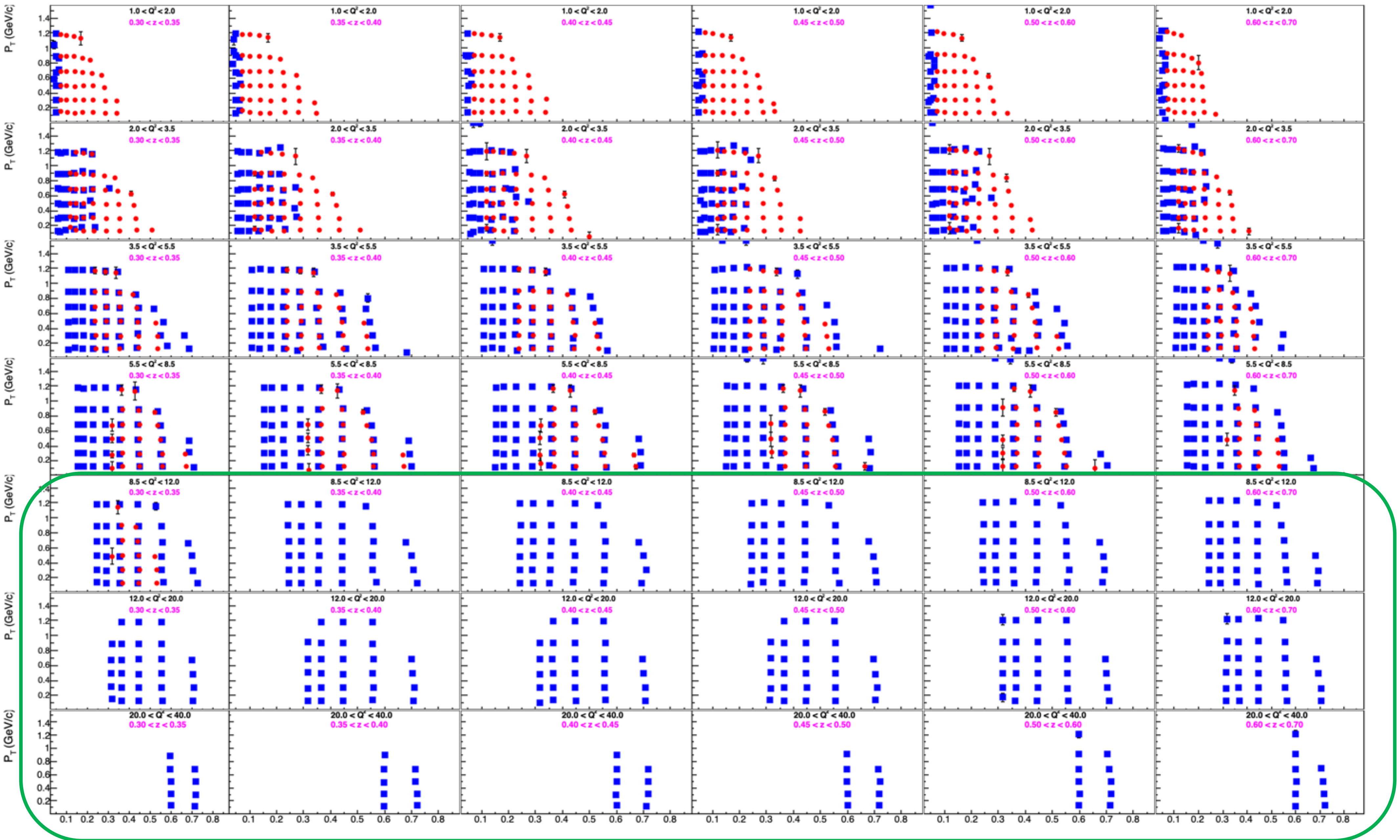


SoLID-SIDIS at 22GeV

Pio-SIDIS Projection

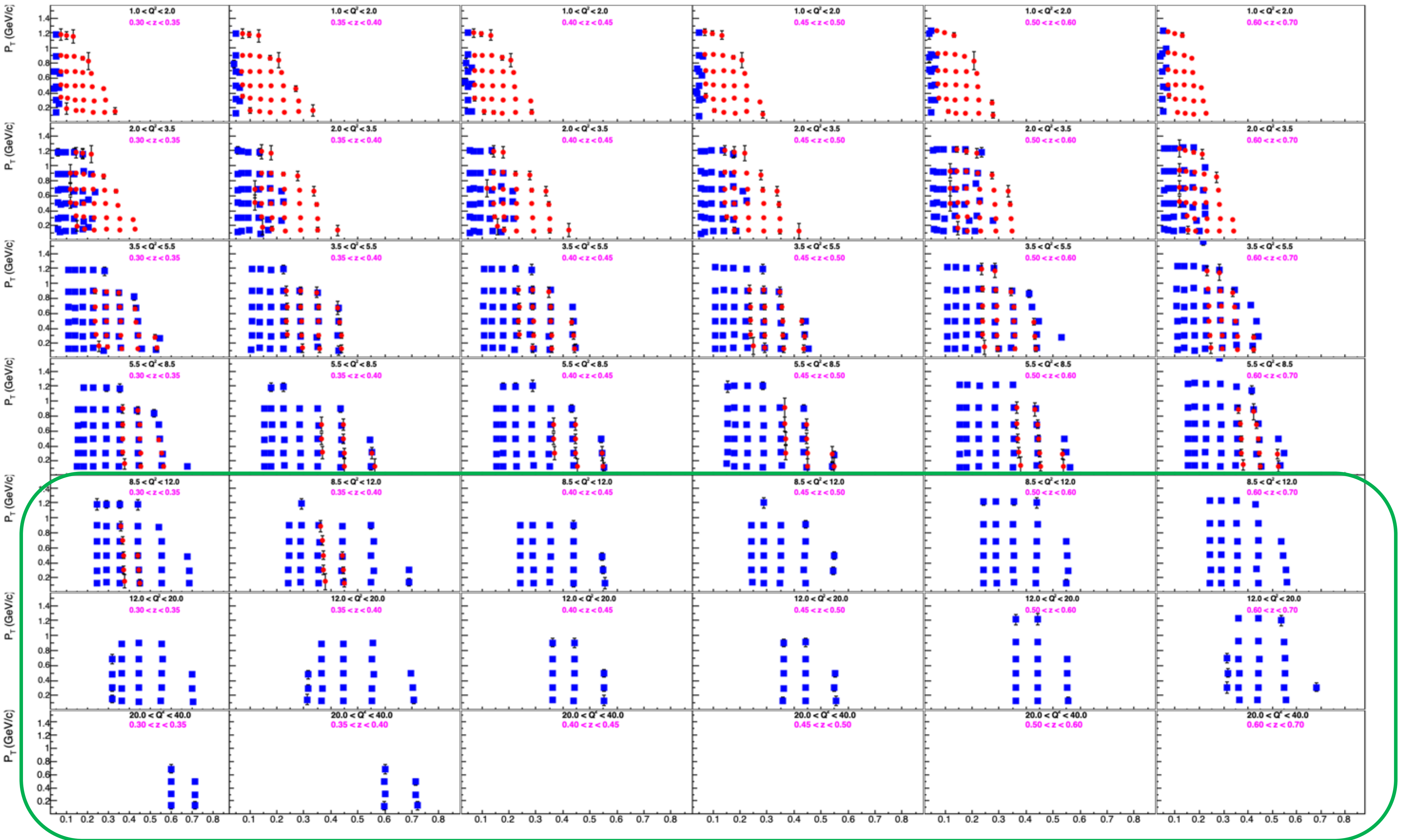
- 11GeV
- 22GeV

→Lumi~$10^{37}cm^{-2}s^{-1}$,
→1-day w/ SoLID



SoLID-SIDIS at 22GeV

Kaon-SIDIS Projection



- 11GeV
- 22GeV

→Lumi~10^{37}cm^{-2}s^{-1},
→1-day w/ SoLID

Summary

- TMD & GPD get access to 3D info of nucleons and orbital angular momentum
- SoLID detector provides both high luminosity & large acceptance, with both polarized neutron and proton targets
- SIDIS programs will greatly improve measurements of Collins, Sivers, Prezelocity & Worm Gear; Precisely obtain tensor-charge for searching new physics
- All SIDIS programs receive high recommendation in PAC50 (maintaining A-rating)
- Approved GDP programs (TCS & DVMP) in run-group with SIDIS & J/Psi setup
- Future detector updates for dedicated GPD study (DVCS & DDVCS)
- Great potential at 22GeV

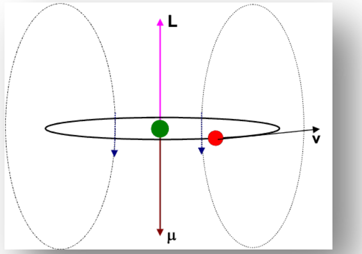
Backup Slides

Transverse Momentum Distributions

- **Transverse Momentum Distribution Functions (TMDs) →** describe 3D motion in momentum space of all quarks & gluons in a nucleon

3D = 1D Longitudinally Momentum + 2D Transverse Momentum

✓ Spin contributions from valance quarks, sea quarks and gluons



✓ Also contributed by quarks & gluons' orbital angular momenta (OAM)

Key Features of TMDs:

✓Represent the intrinsic confined motion of quark & gluons

✓Off-Diagonal TMDs vanish if no orbital angular momentum

✓Most of TMDs are due to the spin-orbit correlations

8 Quark-TMDs (leading twist)

Leading Twist TMDs		Quark Polarization: Unpolarized (U)	Quark Polarization: Longitudinally Polarized (L)	Quark Polarization: Transversely Polarized (T)
Nucleon Polarization	U	$f_1(x,k_T^2)$ Unpolarized		$h_1^{\perp}(x,k_T^2)$ Boer-Mulders
Nucleon Polarization	L		$g_1(x,k_T^2)$ Helicity	$h_{1L}^{\perp}(x,k_T^2)$ Long-Transversity
Nucleon Polarization	T	$f_{1T}^{\perp}(x,k_T^2)$ Sivers	$g_{1T}(x,k_T^2)$ Trans-Helicity	$h_1(x,k_T^2)$ Transversity $h_{1T}^{\perp}(x,k_T^2)$ Pretzelosity

Other TMDs are ZERO after integrating over k_T

Unpolarized Density Function:

$$f_1(x) = \int d^2\boldsymbol{k}_\perp \, f_1(x,k_\perp)$$

Helicity Function:

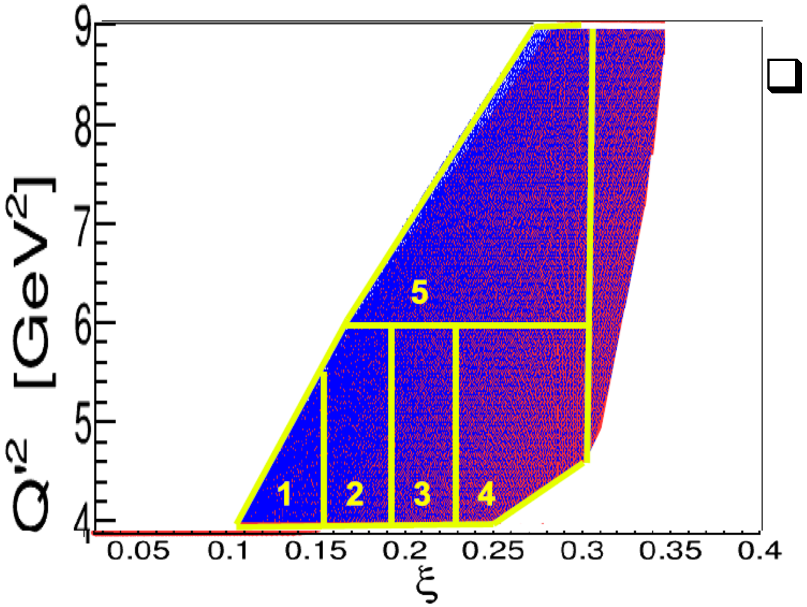
$$g_1(x) = \int d^2\boldsymbol{k}_\perp \, g_{1L}(x,k_\perp)$$

Transversity Function:

$$h_1(x) = \int d^2\boldsymbol{k}_\perp \, [h_{1T}(x,k_\perp) + \frac{k_\perp^2}{2M^2} h_{1T}^{\perp}(x,k_\perp)]$$

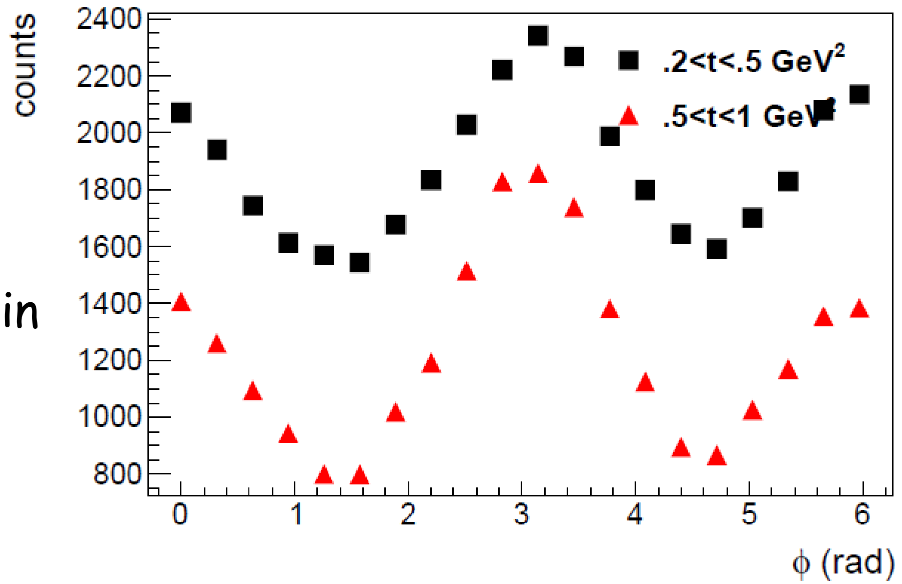
GPDs on SoLID

➢ **SoLID-TCS:** (E12-12-006A, M. Boer, P. Nadel-Turonski, J. Zhang, Z. Zhao)

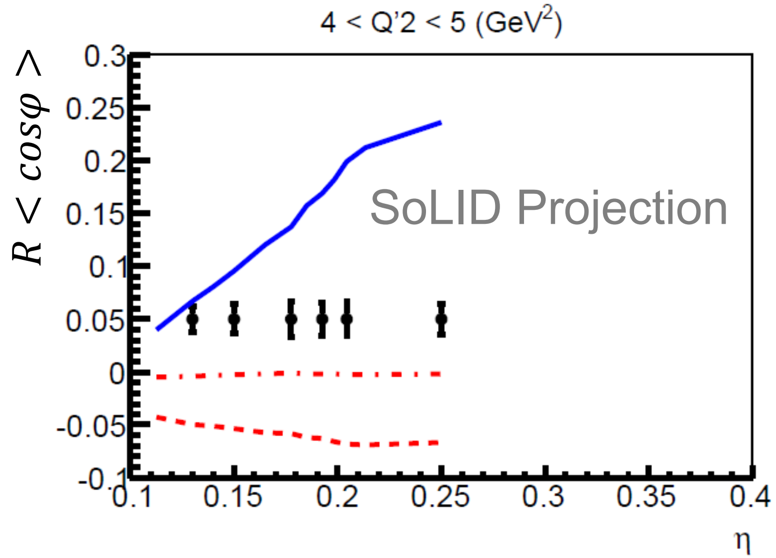


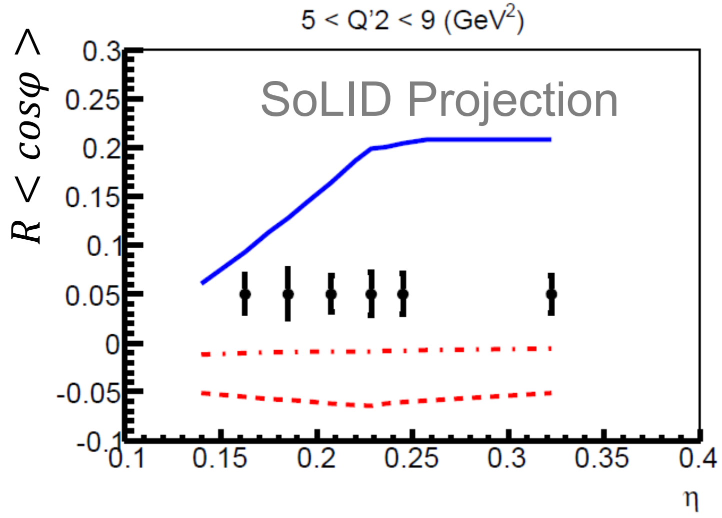
❑ Proper Q2 and ξ binning

❑ Fit to the angular distribution in each bin



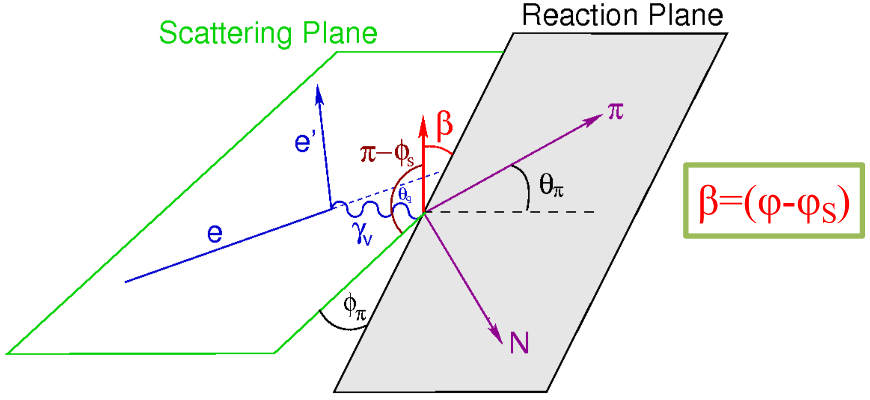
❑ Projections of two highest bins





GPDs on SoLID

- **SoLID-DVMP:** (E12-10-006B, Z. Ahmed, G. Huber, Z. Ye)



DVMP advantages:

- ✓ Direct probe of quark flavor
- ✓ Vector mesons sensitive to ***H*** and ***E***
- ✓ Pseudoscaler mesons sensitive to $\tilde{H}$ and $\tilde{E}$ (uniquely w/ neutron)
- ✓ Sensitive to transverse GPDs ($H_T, E_T, \tilde{H}_T, \tilde{E}_T$)

DVMP disadvantages:

- ✓ Usually requires Q^2 >10 GeV^2 for factorization
- ✓ Higher twist contaminations
- ✓ Long. photons to link to GPD (LT separation)

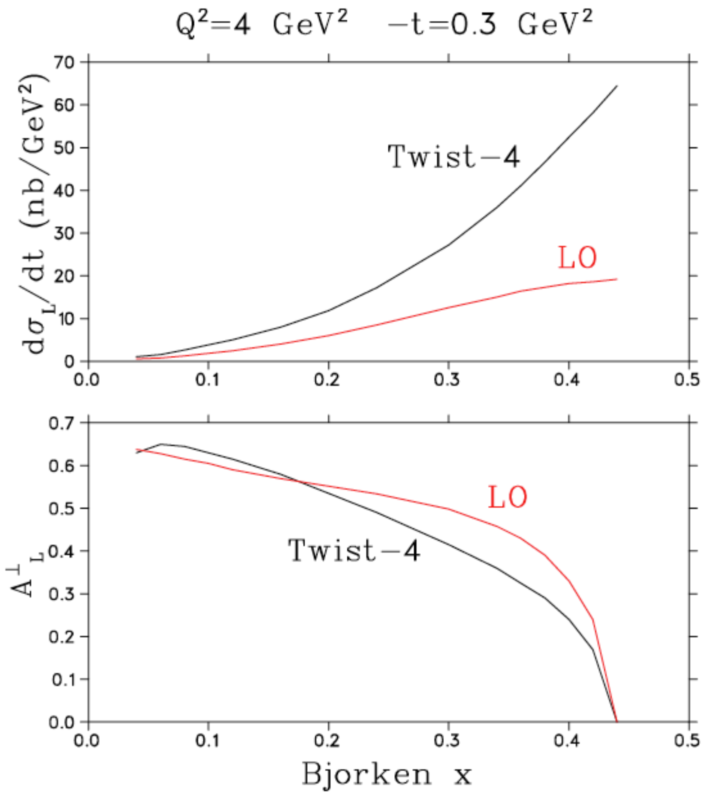
$$2\pi\frac{d^2\sigma}{dtd\phi}=\epsilon\frac{d\sigma_L}{dt}+\frac{d\sigma_T}{dt}+\sqrt{2\epsilon(\epsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi+\epsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi$$

DVMP w/ asymmetries:

Belitsky & Műller PLB 513(2001)349, CIPANP 2003).

- ✓ $A_L^{\perp}$ displays factorization even at only Q^2~2-4 GeV^2:

$$A_L^{\perp}=\frac{\sqrt{-t'}}{m_p}\frac{\xi\sqrt{1-\xi^2}\,\mathrm{Im}(\tilde{E}^*\tilde{H})}{(1-\xi^2)\tilde{H}^2-\frac{t\xi^2}{4m_p}\tilde{E}^2-2\xi^2\mathrm{Re}(\tilde{E}^*\tilde{H})}.$$



Generalized Parton Distributions

➢ Deep Virtual Compton Scattering (DVCS):

❑ With polarization: $\sigma^{BH+I+DVCS} = \underbrace{\sigma_{UU}}_{unpol} + \underbrace{P_L\sigma_{LU}}_{beam\ pol} + \underbrace{S_{L,T}\sigma_{UL,UT}}_{target\ pol} + \underbrace{P_L S_{L,T}\sigma_{LL,LT}}_{double\ pol}$

❑ Asymmetry: $A = \dfrac{I}{|\tau_{DVCS}|^2 + I + |\tau_{BH}|^2} = \dfrac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$

Polarization	Asymmetries	CFFs
Longitudinal Beam	A_{LU}	$Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \tilde{\mathcal{H}}_p, \mathcal{E}_n\}$
Longitudinal Target	A_{UL}	$Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ $Im\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$
Long. Beam + Long. Target	A_{LL}	$Re\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ $Re\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$
Transverse Target	A_{UT}	$Im\{\mathcal{H}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \mathcal{E}_n\}$
Long. Beam +Trans.Targt	A_{LT}	$Re\{\mathcal{H}_p, \mathcal{E}_p\}$ $Re\{\mathcal{H}_n, \mathcal{E}_n\}$

Belitsky, Mueller, PRD (2009,2010), NPB (2014)

❑ Decouple by angular modulations:

$$d\sigma^{I}_{UU} = \frac{-K_I}{\mathcal{P}_1(\phi)\,\mathcal{P}_2(\phi)} \sum_{n=0}^{3} c^{I}_{n,\mathrm{unp}} \cos(n\phi), \qquad d\sigma^{I}_{LU} = \frac{-K_I}{\mathcal{P}_1(\phi)\,\mathcal{P}_2(\phi)} \sum_{n=1}^{2} s^{I}_{n,\mathrm{unp}} \sin(n\phi),$$

$$d\sigma^{\mathrm{DVCS}}_{UU} = \frac{1}{Q^2} \sum_{n=0}^{2} c^{\mathrm{DVCS}}_{n,\mathrm{unp}} \cos(n\phi), \qquad d\sigma^{\mathrm{DVCS}}_{LU} = \frac{1}{Q^2} s^{\mathrm{DVCS}}_{1,\mathrm{unp}} \sin\phi,$$

H ony

$H + \tilde{H}$

$H + \tilde{H} + E$

BH

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