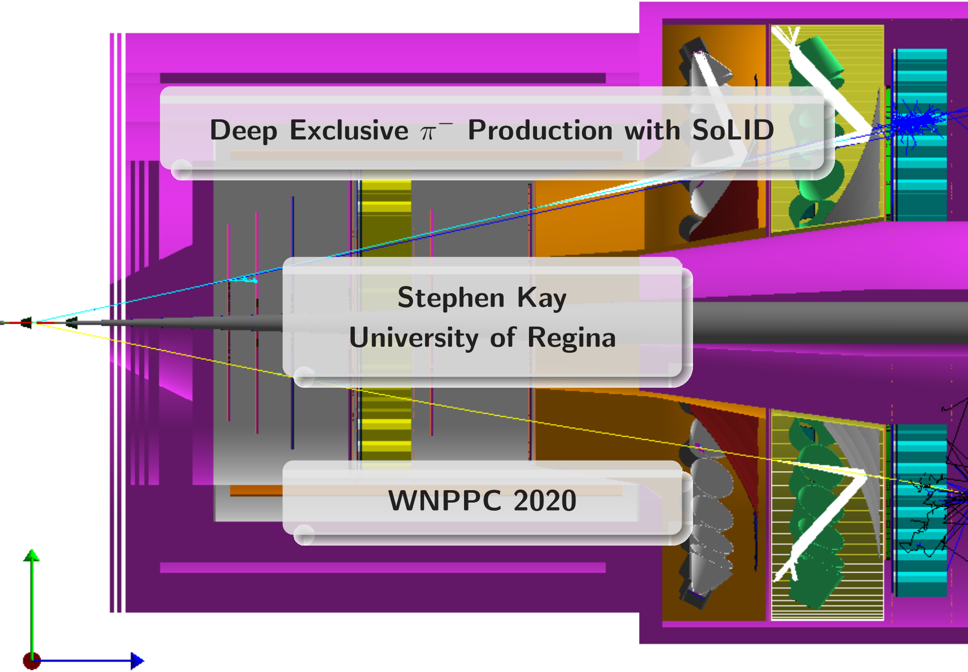
Deep Exclusive π^- Production with SoLID

Stephen Kay
University of Regina

WNPPC 2020



Overview

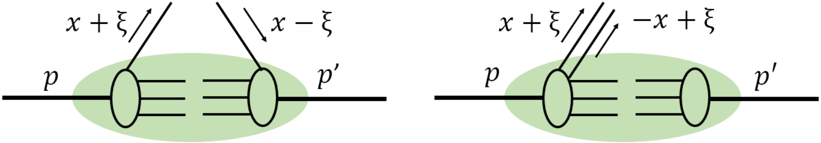
- SoLID Program
- GPDs
- Probing GPDs with DEMP
- JLab and SoLID Overview

SoLID SIDIS Program

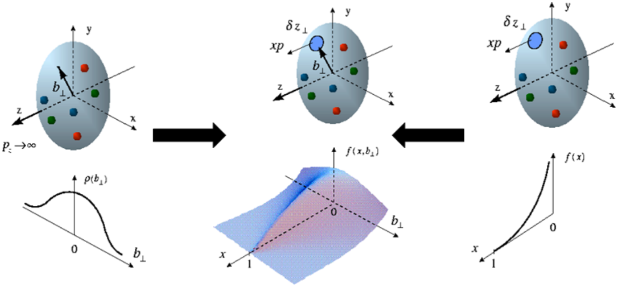
- The **So**lendoial **L**arge **I**ntensity **D**evice (SoLID) is an upcoming high acceptance detector at Jefferson Lab
- **S**emi-**I**nclusive **D**eep **I**nelastic **S**cattering (SIDIS) reaction measurements are a key part of the experimental program
  - Measure SIDIS reactions of electrons off a polarised ^{3}He target
- Data from these measurements can also be analysed to study **D**eep **E**xclusive **M**eson **P**roduction (DEMP) reactions
  - In particular, the reaction $\vec{n}(e, e'\pi^{-})p$

PDFs and GPDs

- Can represent hadron structure using **P**arton **D**istribution **F**unctions (PDFs) or **G**eneralised **P**arton **D**istributions (GPDs)
- GPDs - universal quantities which reflect the structure of the nucleon independently of the probing reaction
  - GPDs - Interference between partons with longitudinal momentum fractions $x+\xi$ and $x-\xi$, interrelating longitudinal momentum and transverse spatial structure within a fast moving hadron



Visualising Nucleons with GPDs

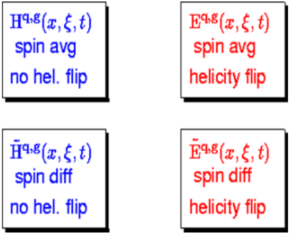


- Form factors - Transverse charge and current densities
- GPDs - Correlated quark momentum and helicity distributions in transverse space
- Structure functions - Quark longitudinal helicity and momentum distributions

Images - G.M. Huber, University of Regina

Relating GPDs to Nucleon Structure

- At leading twist-2, we have four quark chirality conserving GPDs for each quark, gluon type, E, H, $\tilde{E}$ and $\tilde{H}$



  - Related to nucleon elastic form factors through model-independent sum rules
  - $\sum_q e_q \int_{-1}^{+1} dxH^q(x,\xi,t) = F_1(t) \rightarrow$ Dirac elastic nucleon FF
  - $\sum_q e_q \int_{-1}^{+1} dxE^q(x,\xi,t) = F_2(t) \rightarrow$ Pauli elastic nucleon FF
  - $\sum_q e_q \int_{-1}^{+1} dx\tilde{H}^q(x,\xi,t) = G_A(t) \rightarrow$ isovector axial FF
  - $\sum_q e_q \int_{-1}^{+1} dx\tilde{E}^q(x,\xi,t) = G_p(t) \rightarrow$ pseudoscalar FF

Image - G.M. Huber, University of Regina

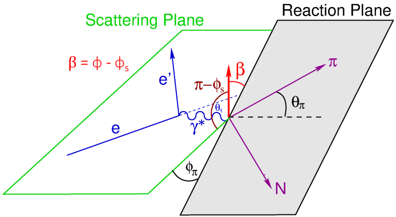
Probing $\tilde{E}$ with DEMP

- $\tilde{E}$ is not related to any already known parton distribution
- $G_p(t)$ highly uncertain, negligible at p transfer of β decay
- DEMP reactions allow us to probe the GPD $\tilde{E}$
  - New nucleon structure information, unlikely to be available from any other source
- Access $\tilde{E}$ via asymmetry moments such as $A_{UT}^{\sin\beta}$ from DEMP reactions
  - $U \rightarrow$ unpolarised beam, $T \rightarrow$ transversely polarised target

$$A_{UT}^{\sin\beta} \sim \frac{d\sigma_{00}^{+-}}{d\sigma_L(_{00}^{++})} \sim \frac{\Im(\tilde{E}^* \tilde{H})}{|\tilde{E}|^2}$$

Reaction Frame

- e^- scatters from target exchanging γ^*
- Produce π and N in reaction plane
- Measure two transverse target orientations $\rightarrow$ asymmetry A_{UT}



$$\langle A_{UT} \rangle = \frac{1}{P \eta_n d} \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

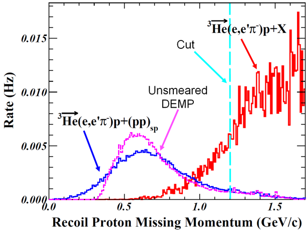
- target polarisation, effective neutron polarisation, dilution factor

- Extract asymmetry moments $\rightarrow A_{UT}^{\sin\beta}$, $A_{UT}^{\sin\phi_s}$, $A_{UT}^{\sin\phi+\phi_s}$ etc.
- $\phi_s \rightarrow$ azimuthal angle between the target nucleon polarization and the scattering plane

Refs - A.V. Belitsky, D. Mueller, PLB513 (2001) 349, L.L. Frankfurt, et al., PRD 60(1999) 014101

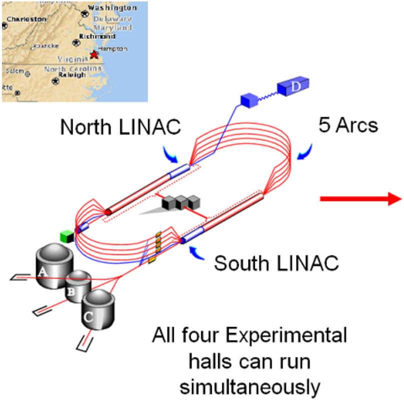
Experimental Measurement

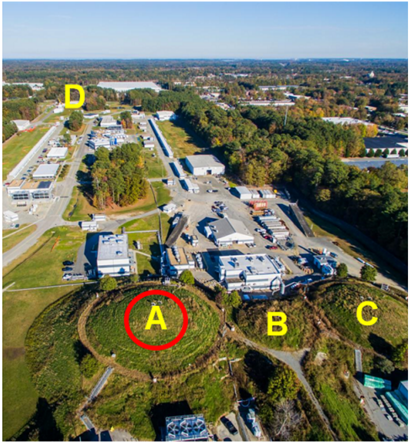
- Want to measure the reaction $\vec{n}(e, e'\pi^-)p$
- Transversely polarised ^{3}He target $\rightarrow$ polarised neutron target
  - Measure $^3\vec{\mathrm{He}}(e, e'\pi^- p)pp_{sp}$ in reality
- Trigger on $e^-\pi^-$ coincidence, apply proton missing momentum cut - $p_{miss} = |\underline{p}_e - \underline{p}_{e'} - \underline{p}_{\pi^-}| < 1.2\ GeVc^{-1}$



Missing momenta spectra for DEMP and SIDIS events.

Image - Z. Ahmed et. al, JLab Experiment E12-10-006B proposal


Washington
Charleston
Delaware
Maryland
Richmond
Hampton
Virginia
North Carolina
Raleigh
North LINAC
5 Arcs
D
South LINAC
A
B
C
All four Experimental
halls can run
simultaneously


D
A
B
C

Hall A

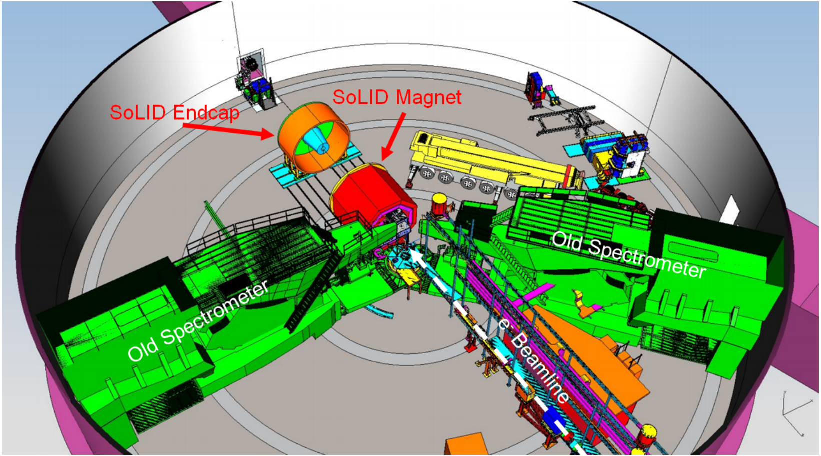


Image - SoLID PreCDR Review,
https://hallaweb.jlab.org/12GeV/SoLID/download/doc/solid-precdr-2018.pdf

SoLID Detector Overview 1/3

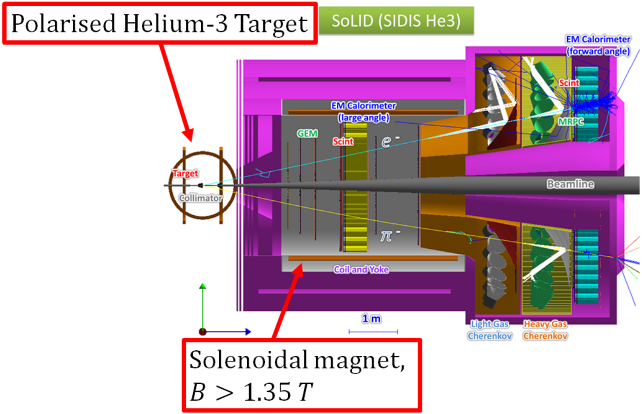
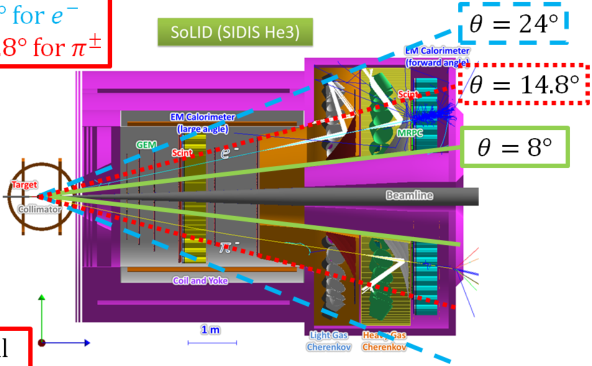


Image - Z. Zhao, Duke University

θ Acceptance –
$8^\circ < \theta < 24^\circ$ for e^-
$8^\circ < \theta < 14.8^\circ$ for $\pi^\pm$



2π azimuthal coverage

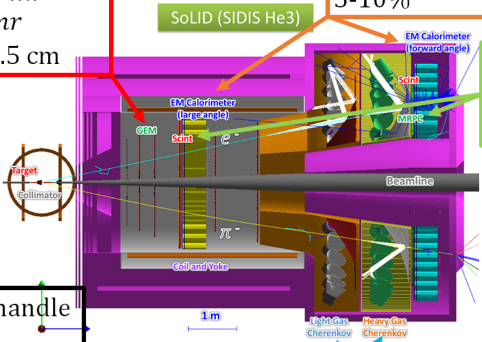
Image - Z. Zhao, Duke University

SoLID Detector Overview 3/3

Tracking – Resolution
θ – 0.6 mr
ϕ - 5 mr
Vertex - 0.5 cm

Calorimetry – Resolution
5-10%

Timing – Resolution
50 – 100 ps



Detectors to handle high rates - $\mathcal{L} \sim 10^{37} cm^{-2} s^{-1}$

PID

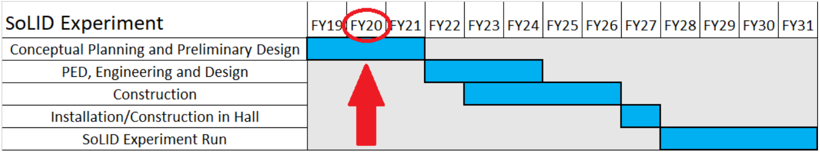
Image - Z. Zhao, Duke University

SoLID Magnet

CLEO-II was a former detector at an e^+e^- collider at Cornell.

Image - SoLID PreCDR Review,
https://hallaweb.jlab.org/12GeV/SoLID/download/doc/solid-precdr-2018.pdf

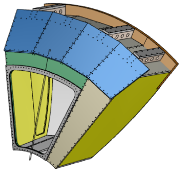
Timeline



- Installation and operation expected by mid 2020's
- Detector R&D is in full swing

Current Detector Work

- Heavy Gas Cherenkov Detector → The University of Regina and Duke University
- HGC formed of 10 sections in a ring
- Prototype, $1 + \frac{1}{3}$ sections, under construction
  - Machining of prototype tank underway
  - Thin window for HGC designed and tested
- Collaborators also progressing with testing and design of other detectors



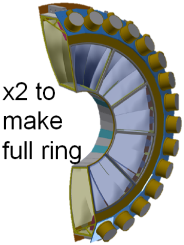


Image - G. Swift, Duke University

Summary and Outlook

- SoLID is an upcoming large acceptance, high luminosity, next generation detector at Jefferson Lab
- SoLID opens up the opportunity to study DEMP reactions in greater detail than currently available
  - Measure single-spin asymmetry moments - in particular $A_{UT}^{\sin\beta}$
  - Observables sensitive to the spin-flip GPD, $\tilde{E}$
- R&D and simulation of detectors at an advanced stage
  - University of Regina heavily involved in this effort for the HGC
- SoLID expected to be up and running by mid 2020's

Thanks for listening, any questions?

S.J.D. Kay, G.M. Huber, Z. Ahmed, H. Gao, Z. Ye, Z. Zhao, V. Kumar, A. Smith, A. Usman, B. Yu and J. Zhou
On behalf of the SoLID Collaboration.

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Unseparated Asymmetries

$$\frac{d^3\sigma_{UT}}{dtd\phi d\phi_s} = -\frac{P_\perp \cos\theta_q}{\sqrt{1-\sin^2\theta_q \sin^2\phi_s}} \left[\sin\beta \Im(d\sigma^{+-}_{++} + \epsilon d\sigma^{+-}_{00})\right.$$

$$+\sin\phi_s \sqrt{\epsilon(1+\epsilon} \Im(d\sigma^{+-}_{+0}) + \sin(\phi+\phi_s)\frac{\epsilon}{2}\Im(d\sigma^{+-}_{+-})$$

$$+\sin(2\phi-\phi_s)\sqrt{\epsilon(1+\epsilon}\Im(d\sigma^{-+}_{+0})+$$

$$\sin(3\phi-\phi_s)\frac{\epsilon}{2}\Im(d\sigma^{-+}_{+-})$$

- ϵ is the virtual photon polarisation
- $\sigma^{ij}_{mn} \rightarrow ij = (+1/2, -1/2)$, nucleon polarisations and $mn = (-1, 0, +1)$, photon polarisations
- $A^{\sin\beta}_{UT} \sim \frac{d\sigma^{+-}_{00}}{d\sigma_L(^{++}_{00})} \sim \frac{\Im(\tilde{E}^*\tilde{H})}{|\tilde{E}|^2}$

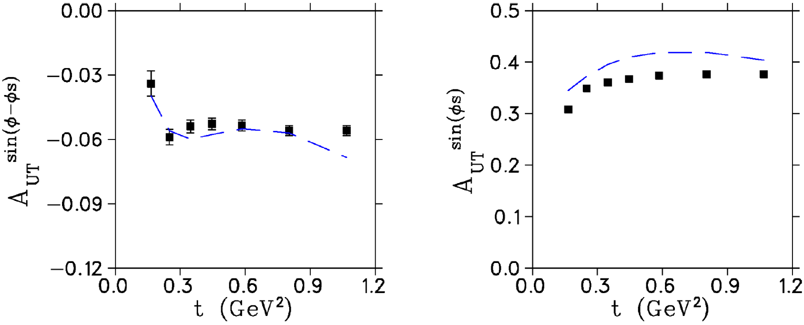
Asymmetry Moments

$$\langle A_{UT} \rangle = \frac{1}{P \eta_n d} \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

- P - target polarisation, η_n - effective neutron polarisation, d - dilution factor
- Can decompose asymmetry into asymmetry moments

$$\begin{aligned} A_{UT}(\phi, \phi_s) = {} & A_{UT}^{\sin(\phi-\phi_s)} \sin(\phi - \phi_s) + A_{UT}^{\sin(\phi_s)} \sin(\phi_s) \\ & + A_{UT}^{\sin(2\phi-\phi_s)} \sin(2\phi - \phi_s) + A_{UT}^{\sin(3\phi-\phi_s)} \sin(3\phi - \phi_s) \\ & + A_{UT}^{\sin(\phi+\phi_s)} \sin(\phi + \phi_s) + A_{UT}^{\sin(2\phi+\phi_s)} \sin(2\phi + \phi_s) \end{aligned}$$

A_{UT} Moment Projections



Projected values and uncertainties for the two dominant single spin asymmetry modulations, $A_{UT}^{\sin\beta}$ and $A_{UT}^{\sin\phi_s}$. Blue curves represent input modulation.

Image - Z. Ahmed et. al, JLab Experiment E12-10-006B proposal

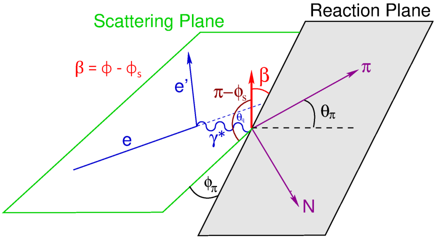
SoLID Experimental Requirements

- Solenoidal magnetic field of $> 1.35\ T$
- 2π acceptance in ϕ, $8 < \theta < 24$ polar angle acceptance
- Tracking, PID and calorimetry detectors capable of handling high rates
  - $\mathcal{L} \sim 10^{37}\ cm^{-2}s^{-1}$
- High resolution
  - 2% momentum resolution
  - 5 mr azimuthal and 0.6 mr polar angle resolution
  - 0.5 cm vertex resolution
  - $5 - 10\%$ energy resolution
  - $50 - 150$ ps timing resolution
- Polarised ^{3}He target

The Transverse Single Spin Asymmetry $A_L^{\perp}$

- The most sensitive observable to prove $\tilde{E}$ is the transverse single spin asymmetry in exclusive π production, $A_L^{\perp}$-

$$A_L^{\perp} = \frac{\int_0^{\pi} d\beta \frac{d\sigma_L^{\pi^-}}{d\beta} - \int_{\pi}^{2\pi} d\beta \frac{d\sigma_L^{\pi^-}}{d\beta}}{\int_0^{2\pi} d\beta \frac{d\sigma_L^{\pi^-}}{d\beta}}$$



- Fit $\sin(\beta) = \sin(\phi - \phi_s)$ dependence to extract asymmetry
  - ϕ_s is the azimuthal angle between the target nucleon polarization and the scattering plane

Refs - A.V. Belitsky, D. Mueller, PLB513 (2001) 349, L.L. Frankfurt, et al., PRD 60(1999) 014101

Relating $\tilde{E}$ and $A_L^\perp$

- $\tilde{E}$ and $A_L^\perp$ are related via -

$$A_L^\perp = \frac{\int_0^\pi d\beta \frac{d\sigma_L^{\pi^-}}{d\beta} - \int_\pi^{2\pi} d\beta \frac{d\sigma_L^{\pi^-}}{d\beta}}{\int_0^{2\pi} d\beta \frac{d\sigma_L^{\pi^-}}{d\beta}}$$

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

Unseparated Asymmetries

- $A_L^{\perp}$ is actually an L/T separated observable
- With SoLID, will measure an unseparated moment of this observable, $A_{UT}^{\sin\beta}$
  - U = Unpolarised beam
  - T = Transversely Polarised target
- Asymmetry diluted by $\sim$ 50% by not separating out the L/T contributions

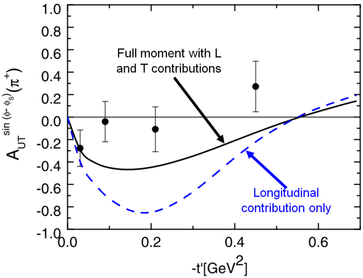


Image - Modified from S.V. Goloskokov and P. Kroll, EPJC,65(2010)137

$A_{UT}^{\sin\phi_s}$ Modulation

- Main theoretical and experimental motivation is to measure the $A_{UT}^{\sin\beta}$ asymmetry moment
- $A_{UT}^{\sin\phi_s}$ asymmetry moment also measurable with SoLID
- $A_{UT}^{\sin\phi_s}$ measures only LT interference terms
- $A_{UT}^{\sin\phi_s}$ is expected to be large