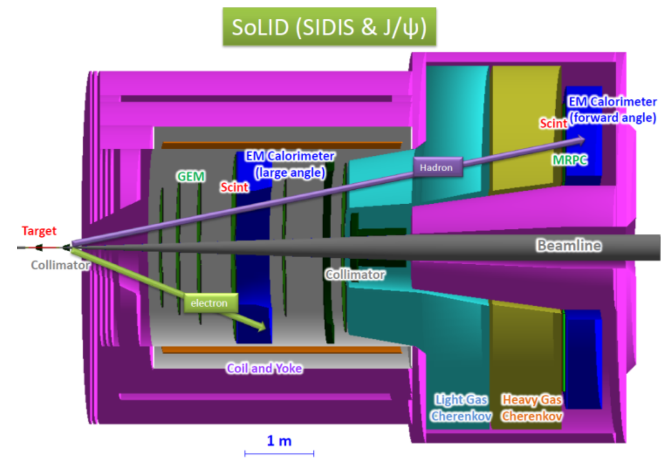
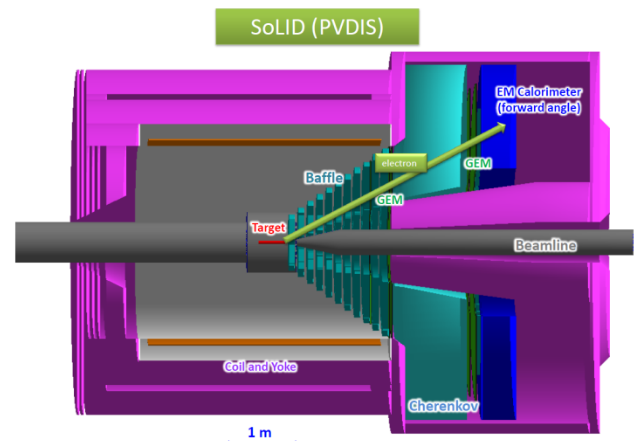
Overview of the SoLID Experiments

Jian-ping Chen, Jefferson Lab

Hadron-China2015, August 3, 2015

- Introduction
- Approved Experiments (5 + 3 run group)
  - SoLID TMD Experiments (3 + 2)
  - PVDIS (1)
  - J/ψ Threshold Production + TCS (1+1)
- Under development: GPDs, PV-EMC,…
- Current Status
- Summary



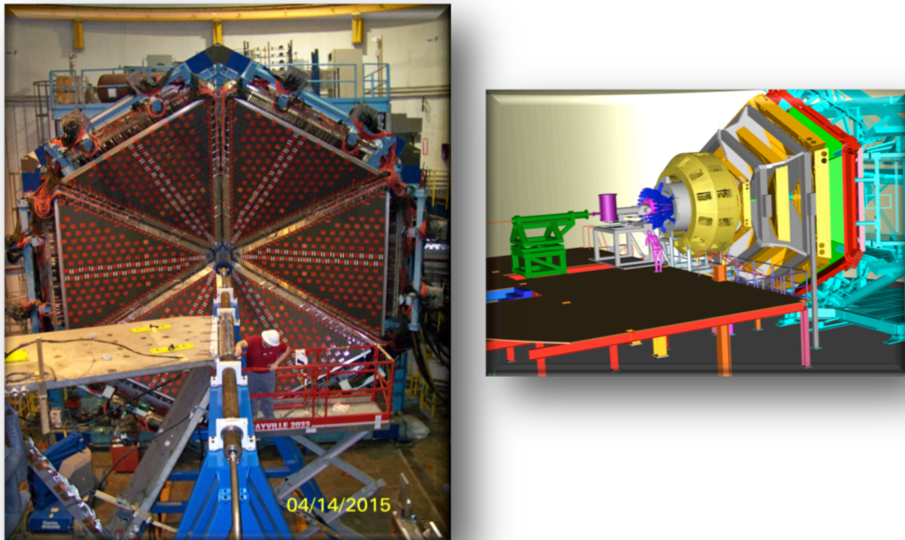


Introduction

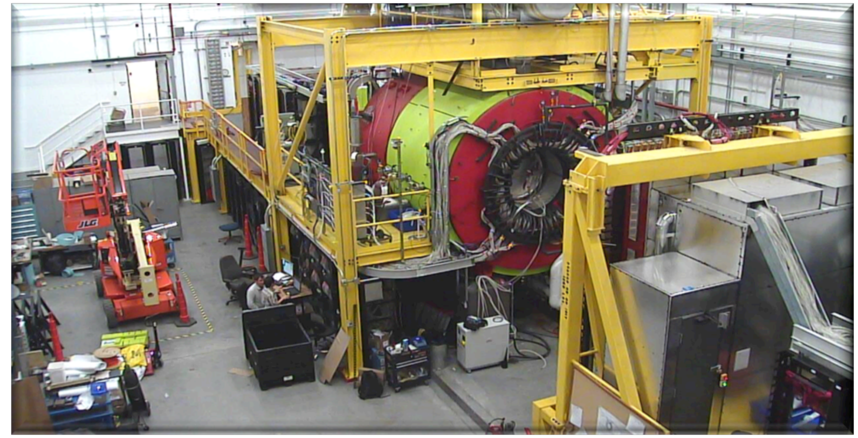
Why SoLID?

12 GeV Scientific Capabilities

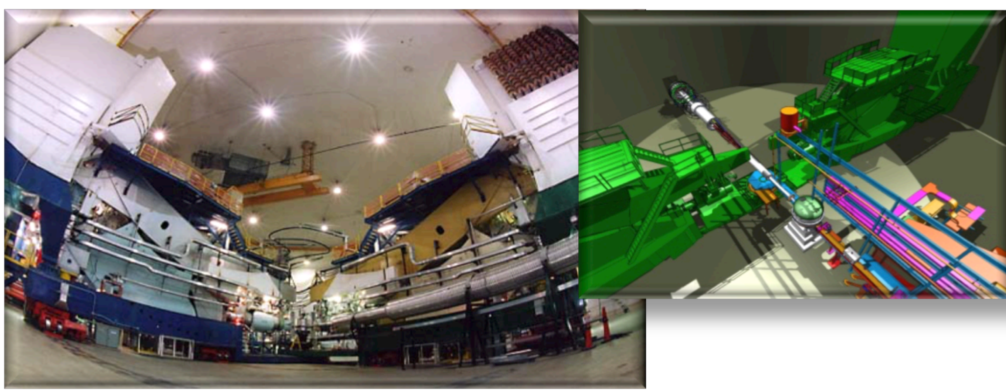
Hall B – *understanding nucleon structure via generalized parton distributions*



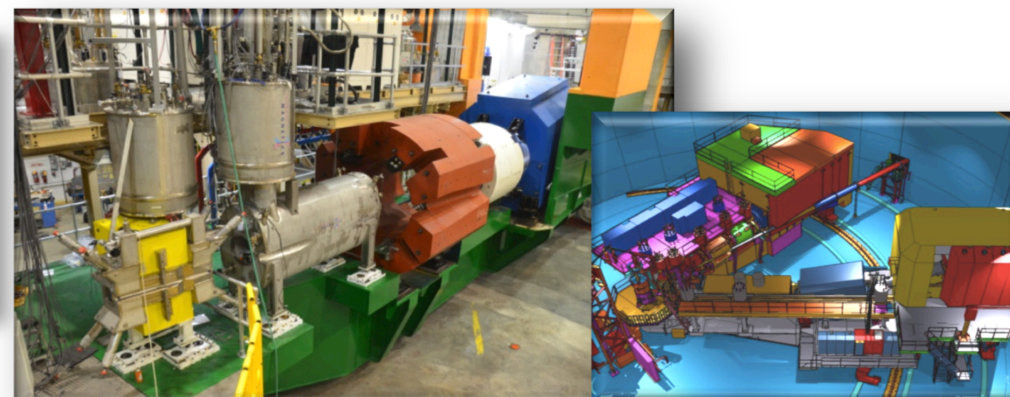
Hall D – *exploring origin of confinement by studying exotic mesons*



Hall A – *form factors, future new experiments (e.g., SoLID and MOLLER)*



Hall C – *precision determination of valence quark properties in nucleons/nuclei*



Why SoLID

- JLab 6 GeV: precision measurements

  high luminosity (10^{39}) but small acceptance (HRS/HMS: < 10 msr)

  or large acceptance but low luminosity (CLAS6: 10^{34})

- JLab 12 GeV upgrade opens up a window of opportunities (DIS, SIDIS, Deep Exclusive Processes) to study valence quark (3-d) structure of the nucleon and other high impact physics (PVDIS, J/ψ, …)
- High precision in multi-dimension or rare processes requires very high statistics → large acceptance and high luminosity
- CLAS12: luminosity upgrade (one order of magnitude) to 10^{35}
- To fully exploit the potential of 12 GeV, taking advantage of the latest technical (detectors, DAQ, simulations, …) development

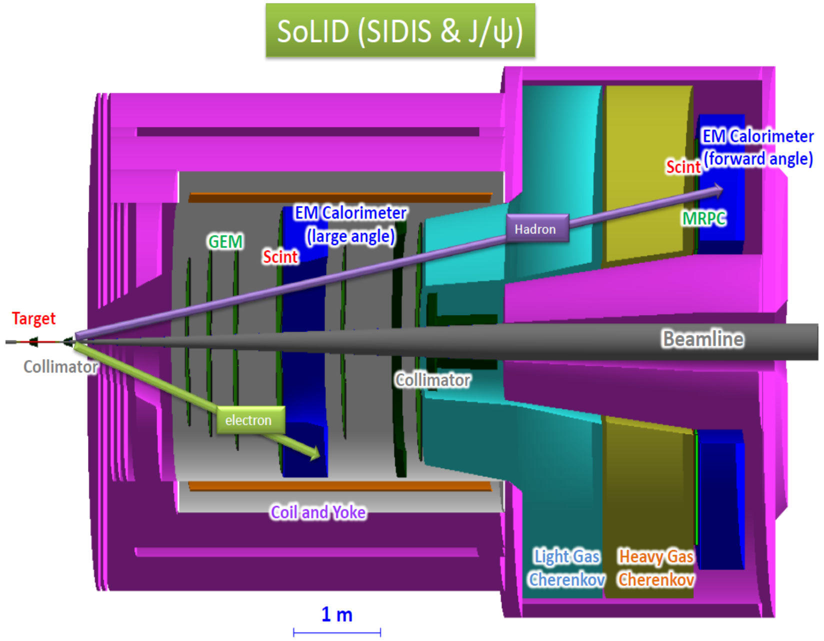
→ SoLID: large acceptance detector can handle 10^{37} luminosity (no baffles)

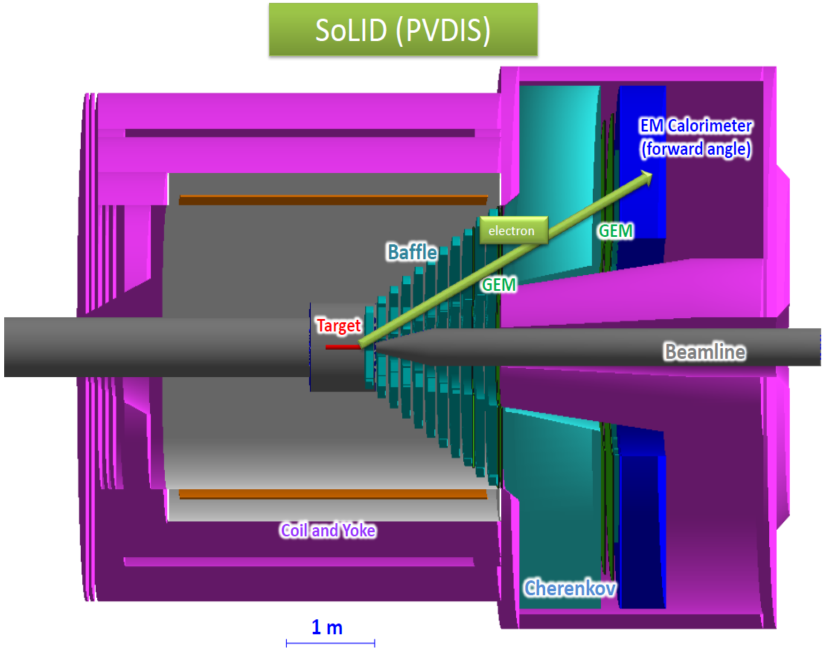
10^{39} with baffles

Overview of SoLID

Solenoidal **L**arge **I**ntensity **D**evice

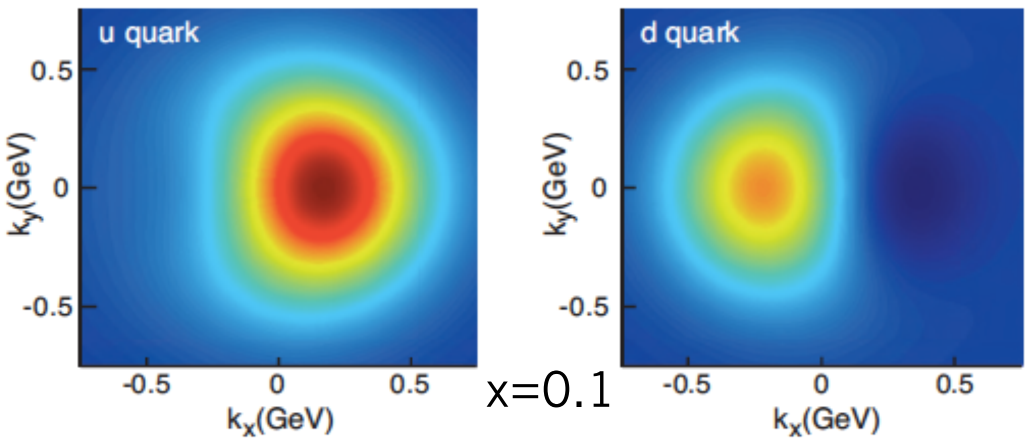
- **Full exploitation of JLab 12 GeV Upgrade**
  → A **Large Acceptance** Detector **AND** Can Handle **High Luminosity** (10^{37}-10^{39})
  Take advantage of latest development in detectors , data acquisitions and simulations
  Reach ultimate precision for SIDIS (TMDs), PVDIS in high-*x* region and threshold J/ψ
- **5 highly rated experiments approved (+3)**
  Three SIDIS experiments, one PVDIS, one J/ψ production (+ three run group experiments)
- **Strong collaboration** (250+ collaborators from 70+ institutes, 13 countries)
  Significant international contributions (Chinese collaboration)





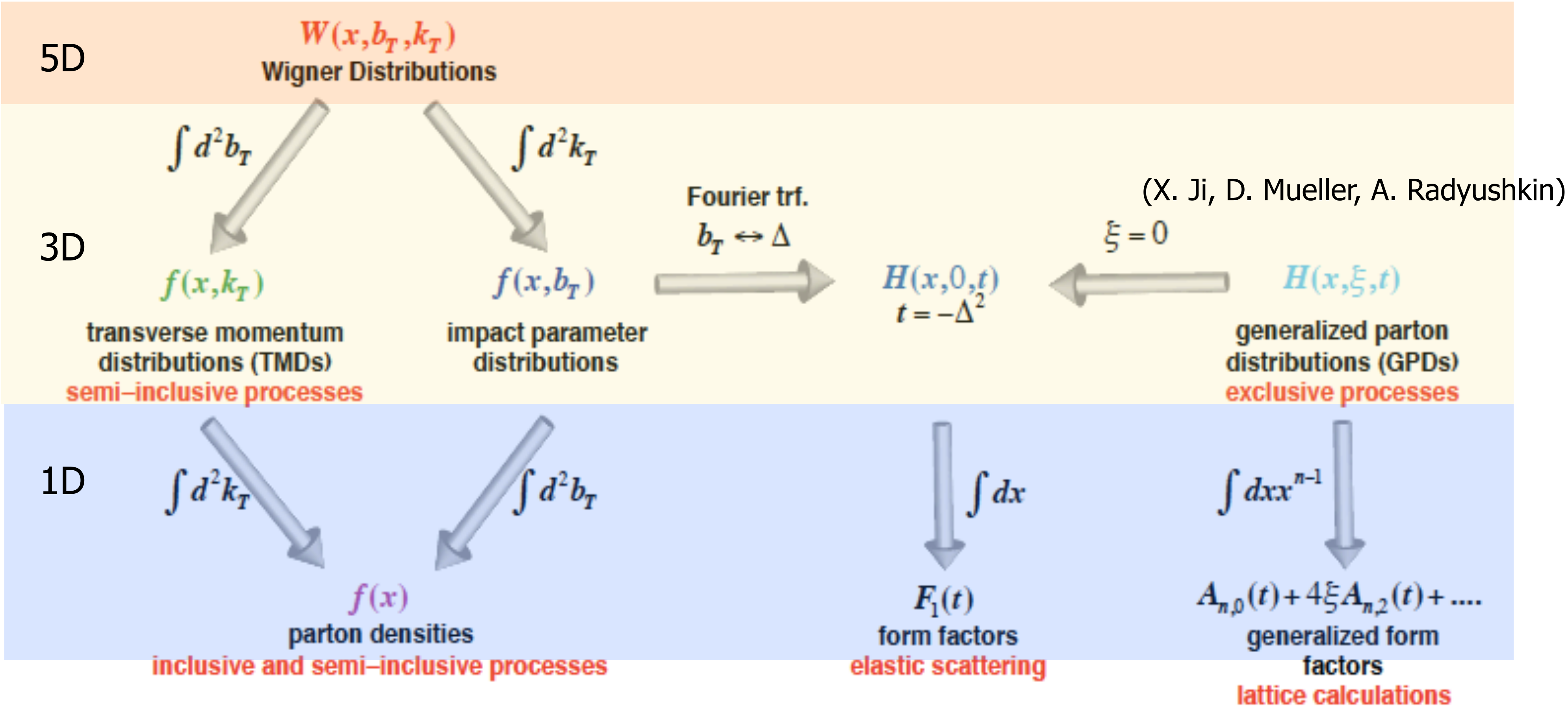
3-D Structure: TMDs

SoLID SIDIS Program



Unified View of Nucleon Structure

Wigner distributions (Belitsky, Ji, Yuan) (or GTMDs)

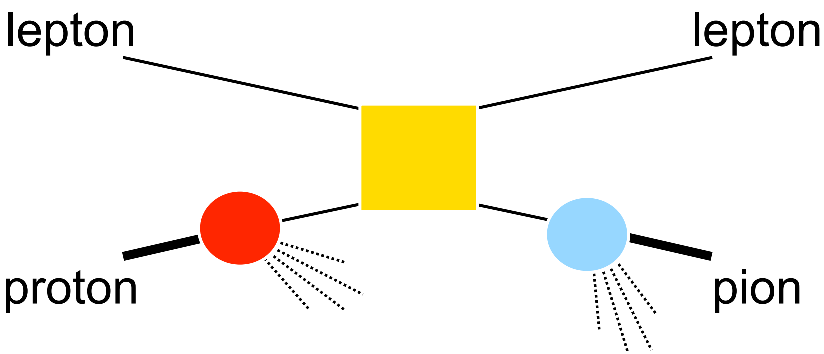


Leading-Twist TMD PDFs

Nucleon Spin
Quark Spin

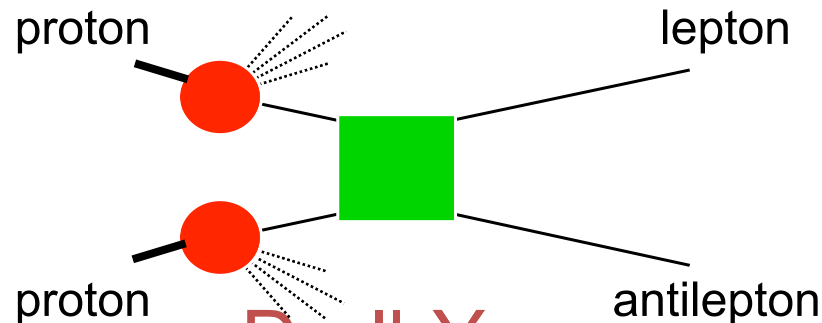
		Quark polarization		
		Unpolarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Nucleon Polarization	U	f_1		$h_1^{\perp}$ Boer-Mulders
	L		g_1 Helicity	$h_{1L}^{\perp}$ Long-Transversity
	T	$f_{1T}^{\perp}$ Sivers	g_{1T} Trans-Helicity	h_1 Transversity $h_{1T}^{\perp}$ Pretzelosity

Access TMDs through Hard Processes



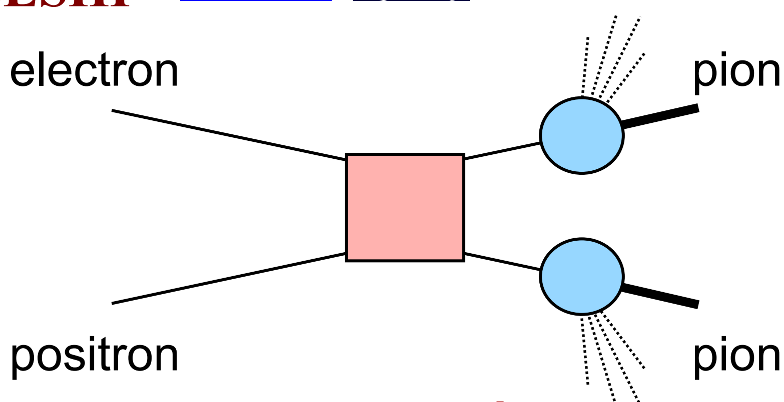
SIDIS

Wen-Chen Chang's Talk



Drell-Yan

Guangshun Wang's Talk



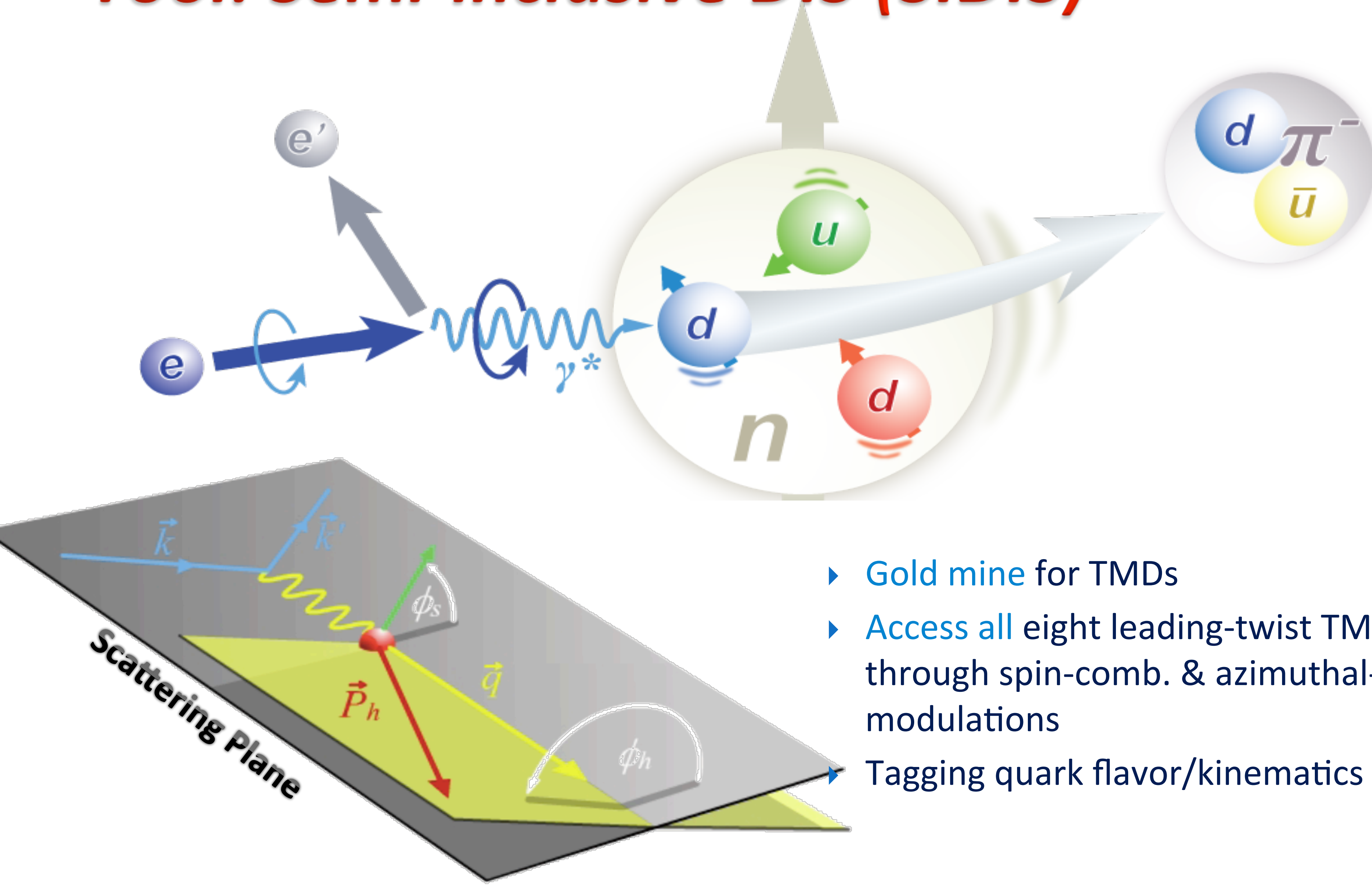
$e^{-}e^{+}$ to pions

- Partonic scattering amplitude
- Fragmentation amplitude
- Distribution amplitude

$$f_{1T}^{\perp q}(\mathrm{SIDIS}) = -f_{1T}^{\perp q}(\mathrm{DY})$$

$$h_1^{\perp}(\mathrm{SIDIS}) = -h_1^{\perp}(\mathrm{DY})$$

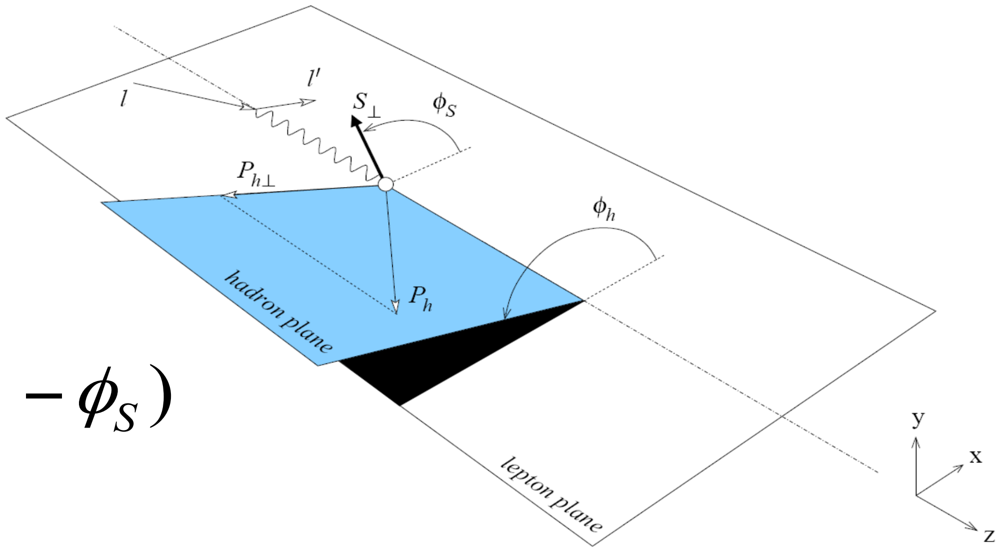
Tool: Semi-inclusive DIS (SIDIS)



- Gold mine for TMDs
- Access all eight leading-twist TMDs through spin-comb. & azimuthal-modulations
- Tagging quark flavor/kinematics

Separation of Collins, Sivers and pretzelocity effects through angular dependence

at leading-twist :



$$A_{UT}(\varphi_h^l,\varphi_S^l) = \frac{1}{P}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

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

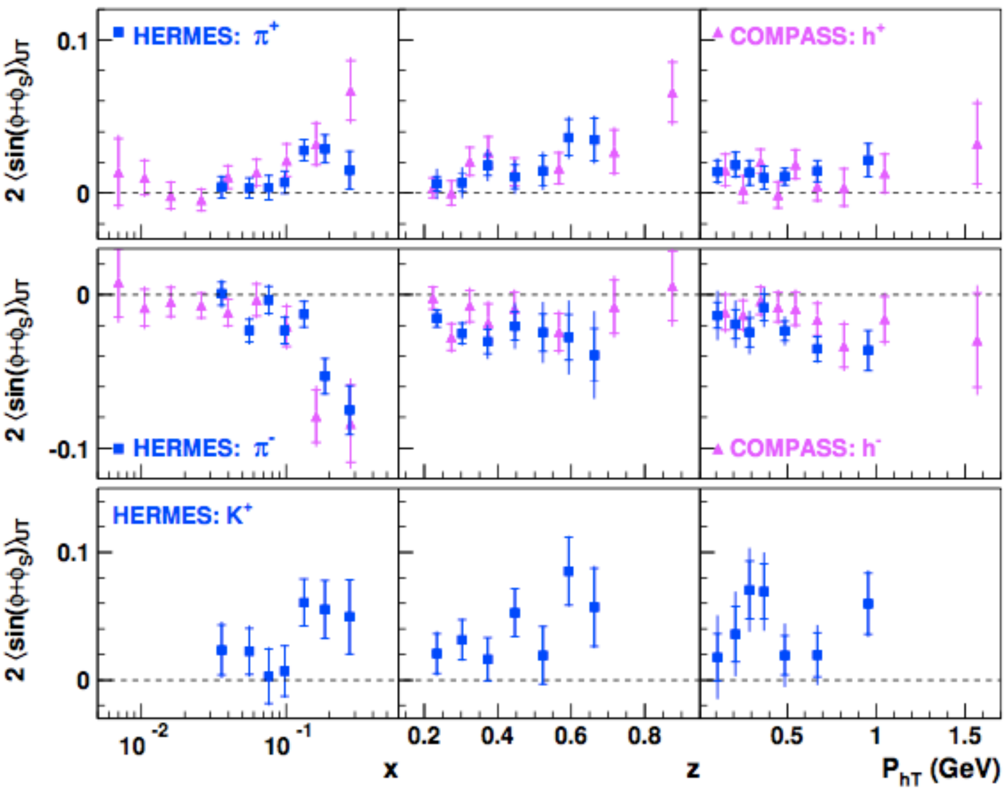
$$+ A_{UT}^{Pretzelosity}\sin(3\phi_h-\phi_S)$$

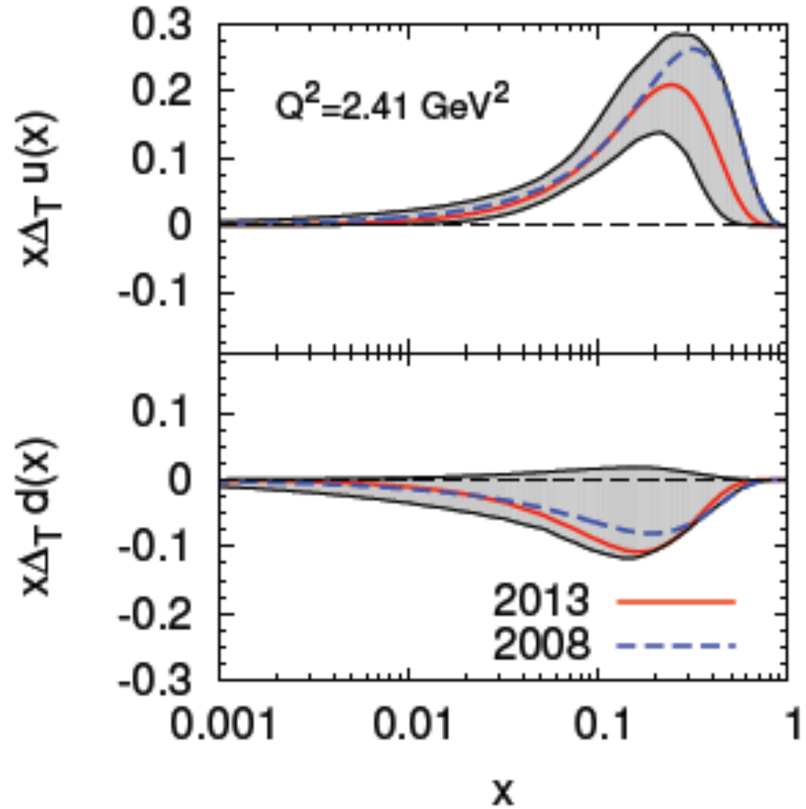
$$A_{UT}^{Collins} \propto \langle \sin(\phi_h+\phi_S)\rangle_{UT} \propto h_1 \otimes H_1^{\perp}$$

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

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

Collin Asymmetries and Transversity





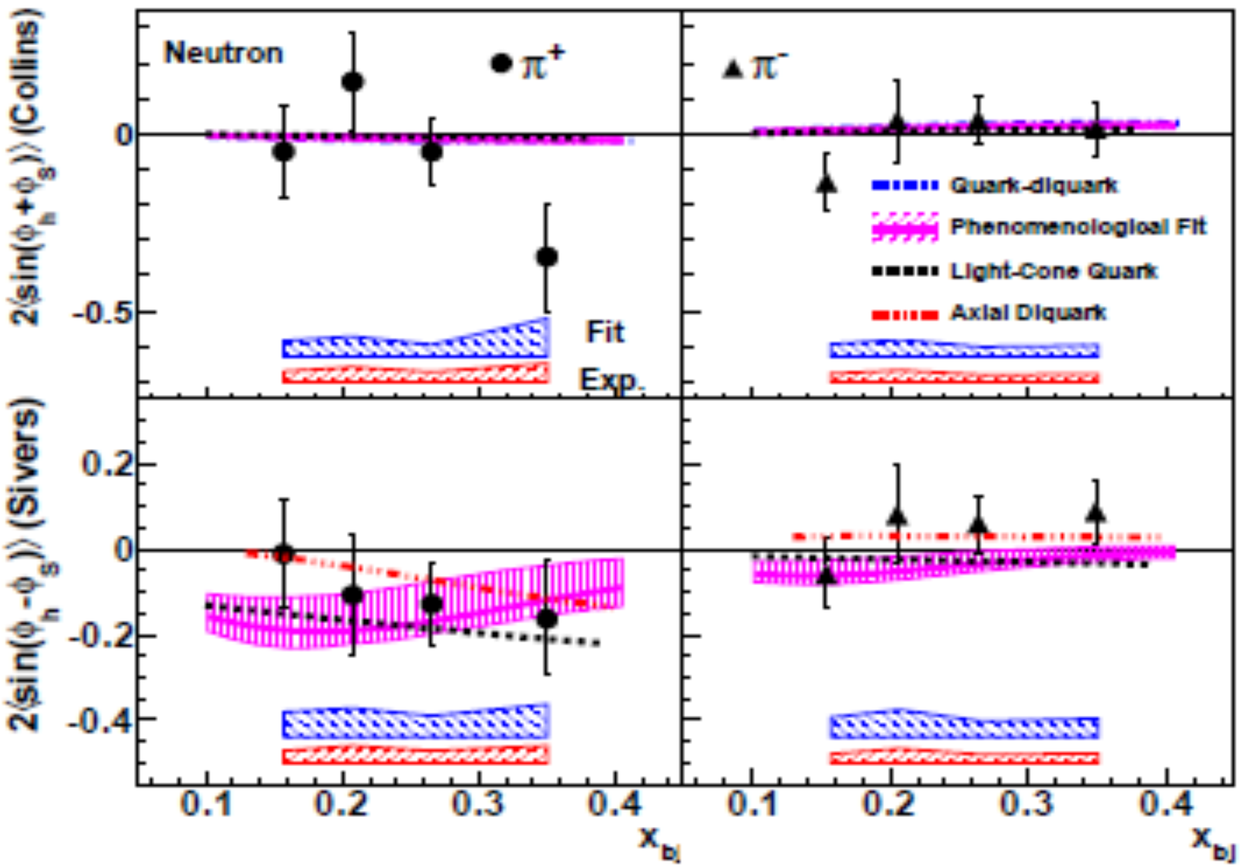
M. Anselmino, *et al.*
PRD 87, 094019 (2013)

JLab 6 GeV Exploration: ^{3}He (n) Target SSA in SIDIS

E06-010 collaboration, X. Qian *at al.*, **PRL 107:072003(2011)**

$$n^{\uparrow}(e,e'h), h = \pi^{+}, \pi^{-}$$

See Kalyan Allada/Xuefei Yan's Talks



neutron Collins SSA small
Non-zero at highest x for π+

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

neutron Sivers SSA:
negative for π^+,
Agree with Torino Fit

Blue band: model (fitting) uncertainties
Red band: other systematic uncertainties

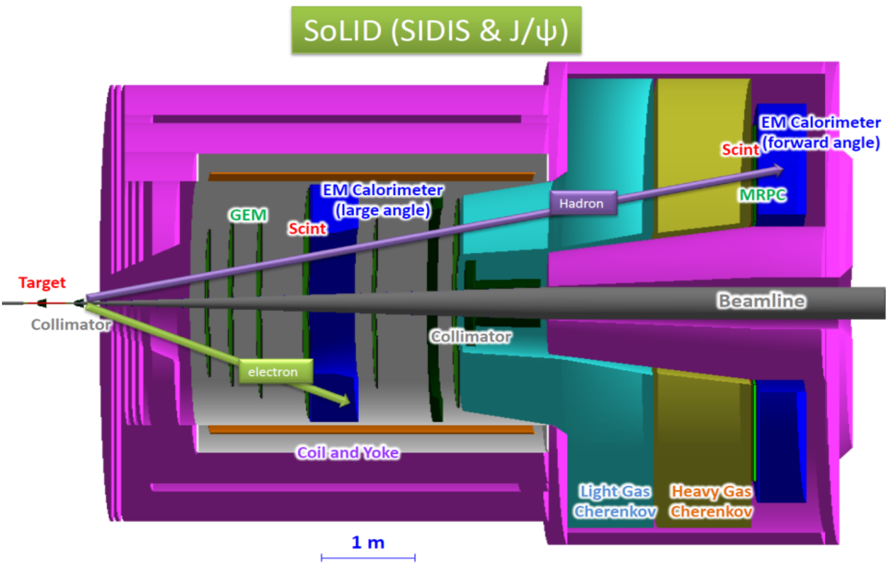
JLab 12 GeV: Precision Study of TMDs

- Explorations: HERMES, COMPASS, RHIC-spin, JLab6,…
- From exploration to precision study with 12 GeV JLab
- Transversity: fundamental *PDF*s, tensor charge
- *TMD*s: 3-d momentum structure of the nucleon

  → information on quark orbital angular momentum

  → information on QCD dynamics
- Multi-dimensional mapping of *TMD*s
- Precision → high statistics
  - high luminosity and large acceptance

SoLID-Spin: SIDIS on ^{3}He/Proton @ 11 GeV

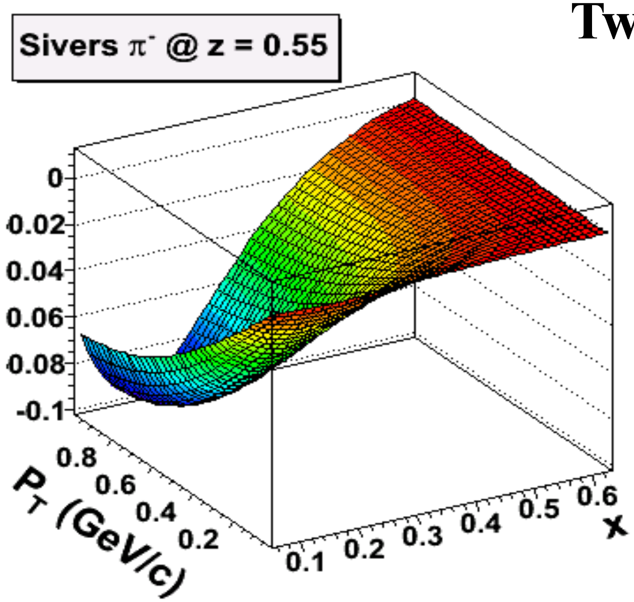


E12-10-006: Single Spin Asymmetry on Transverse ^{3}He, **rating A**

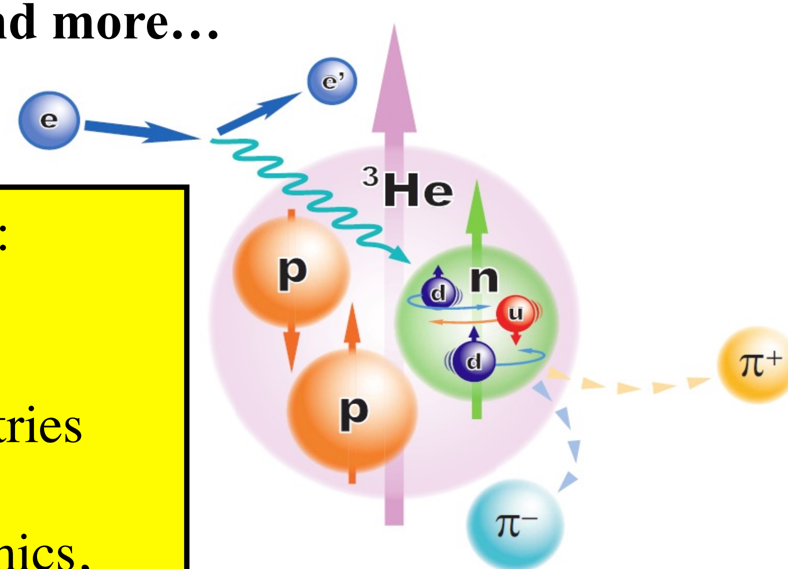
E12-11-007: Single and Double Spin Asymmetries on ^{3}He, **rating A**

E12-11-108: Single and Double Spin Asymmetries on Transverse Proton, **rating A**

Two run group experiments, and more…



Key of SoLID-Spin program:
Large Acceptance
+ High Luminosity
→ **4-D** mapping of asymmetries
→ Tensor charge, TMDs …
→Lattice QCD, QCD Dynamics, Models.

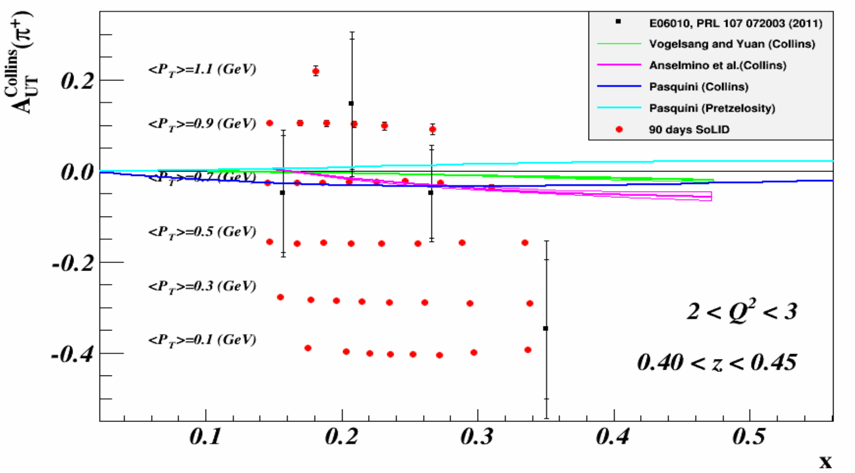


Transversity and Tensor Charge

- Collins Asymmetries ~ Transversity (x) Collin Function
- **Transversity**: chiral-odd, not couple to gluons, **valence behavior**, largely unknown
- **Tensor charge (0th moment of transversity): fundamental property**
  Lattice QCD, Bound-State QCD (Dyson-Schwinger) , Light-cone Quark Models, …
- Global model fits to experiments (SIDIS and e+e-)
- **SoLID** with **trans polarized n & p** → determination of tensor charges for **d & u**

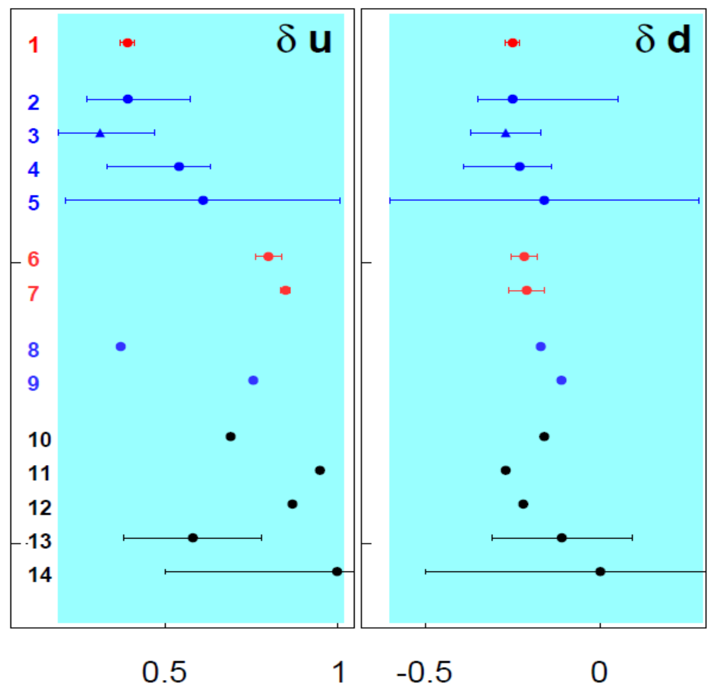
Collins Asymmetries

(Transversity (x) Collins Function)



P_T vs. x for one (Q^2, z) bin
Total > 1400 data points

Tensor Charges



SoLID projections

Extractions from existing data

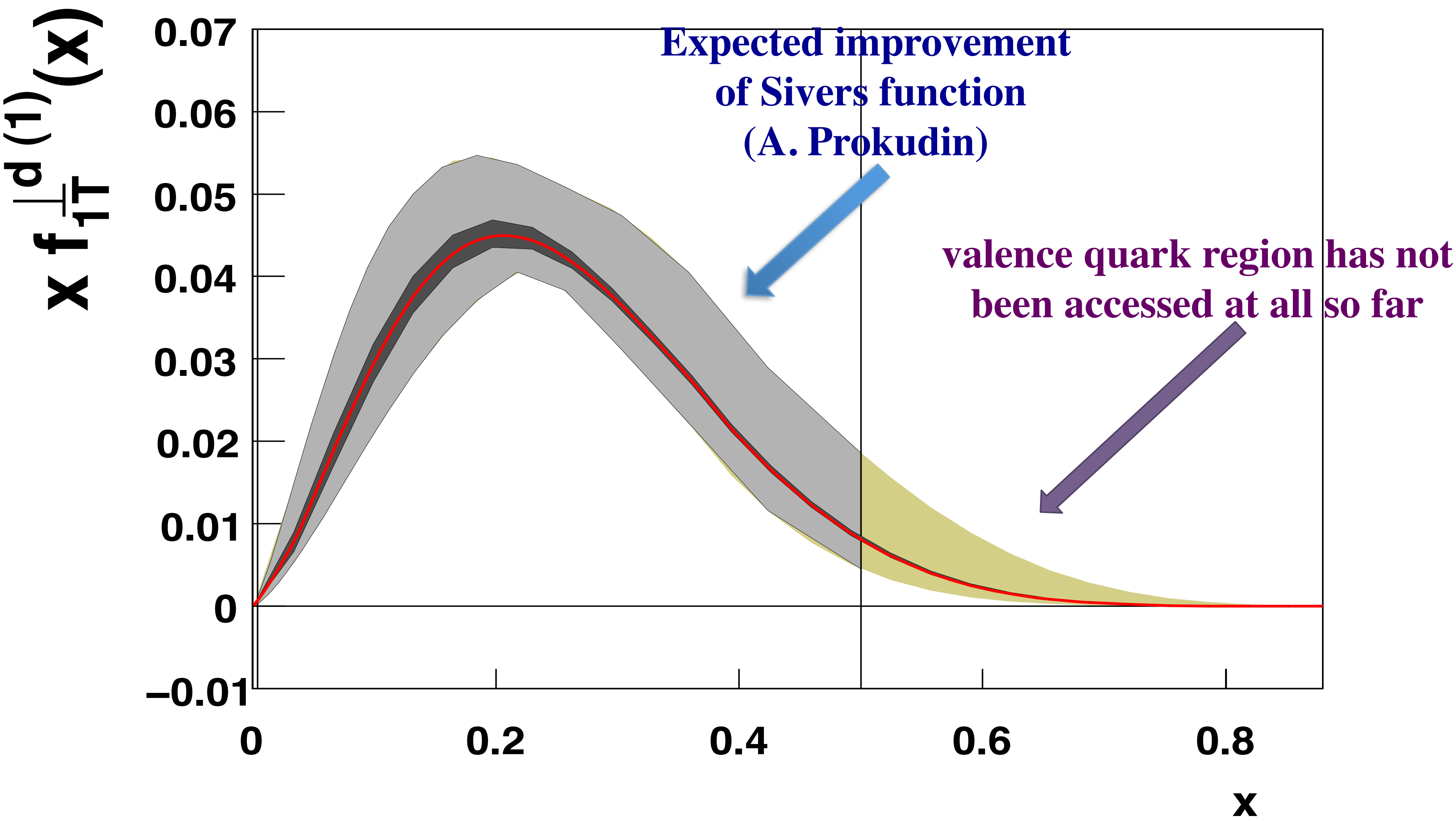
LQCD

DSE

Models

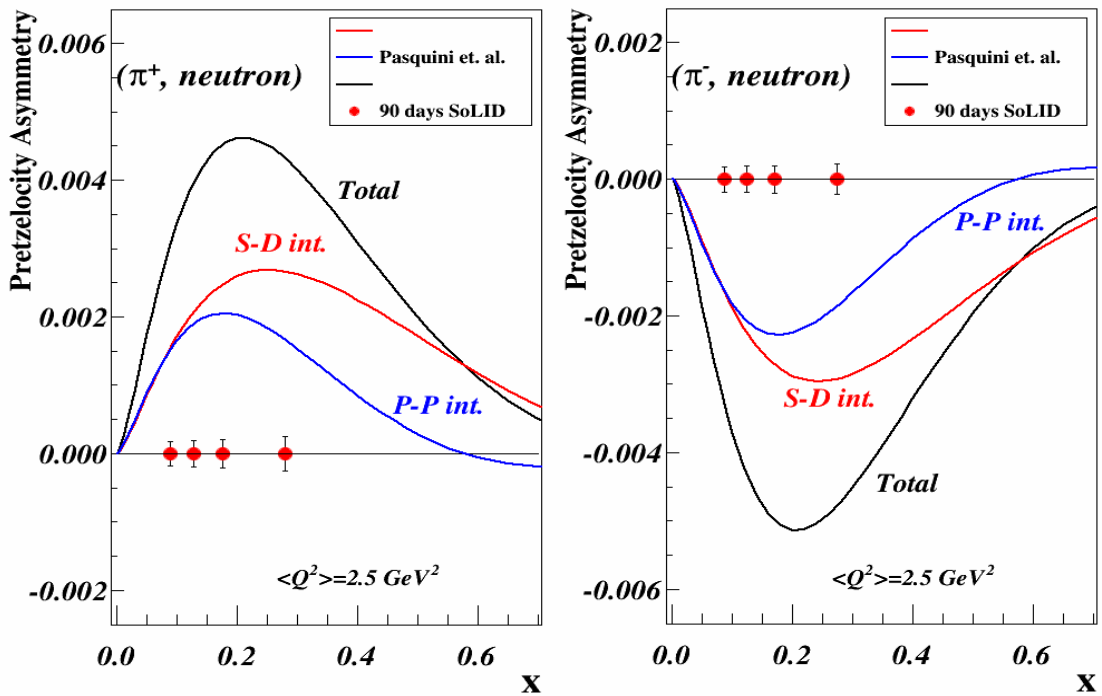
- *Projections with a model*

Projected Sivers Function



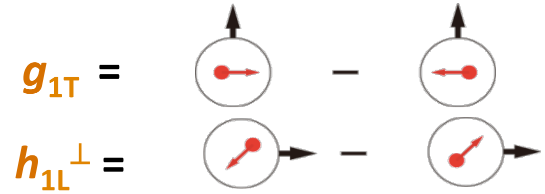
TMDs: 3-d Structure, Quark Orbital Motion

- TMDs : Correlations of transverse motion with quark spin and orbital motion
- **Without OAM, off-diagonal TMDs=0**,
  no direct model-independent relation to the OAM in spin sum rule yet
- Sivers Function: QCD lensing effects
- In a large class of models, such as light-cone quark models
  Pretzelosity: ΔL=2 (L=0 and L=2 interference , L=1 and -1 interference)
  Worm-Gear: ΔL=1 (L=0 and L=1 interference)
- **SoLID with trans polarized n/p** → **quantitative knowledge of OAM**

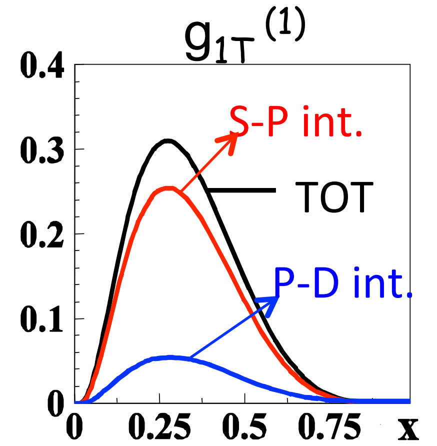


Pretzelosity

Worm-gear Functions

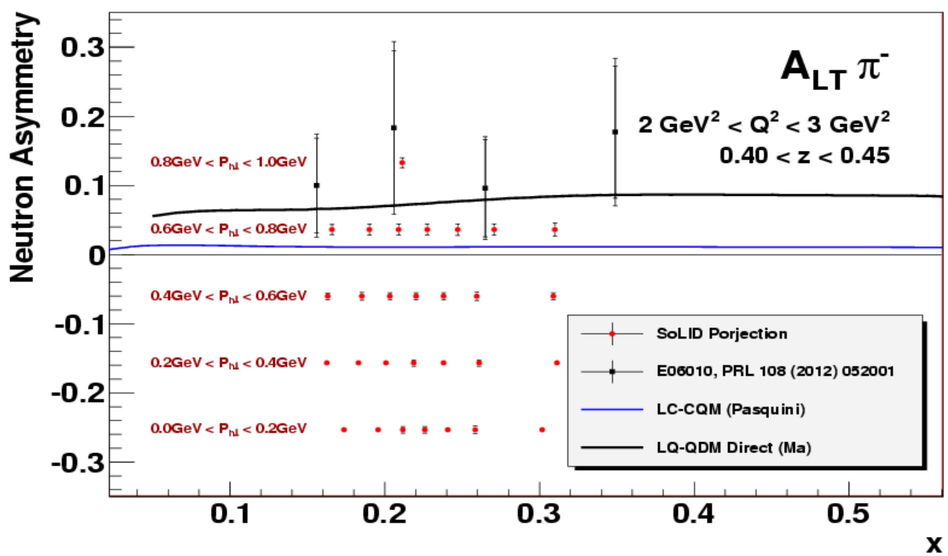


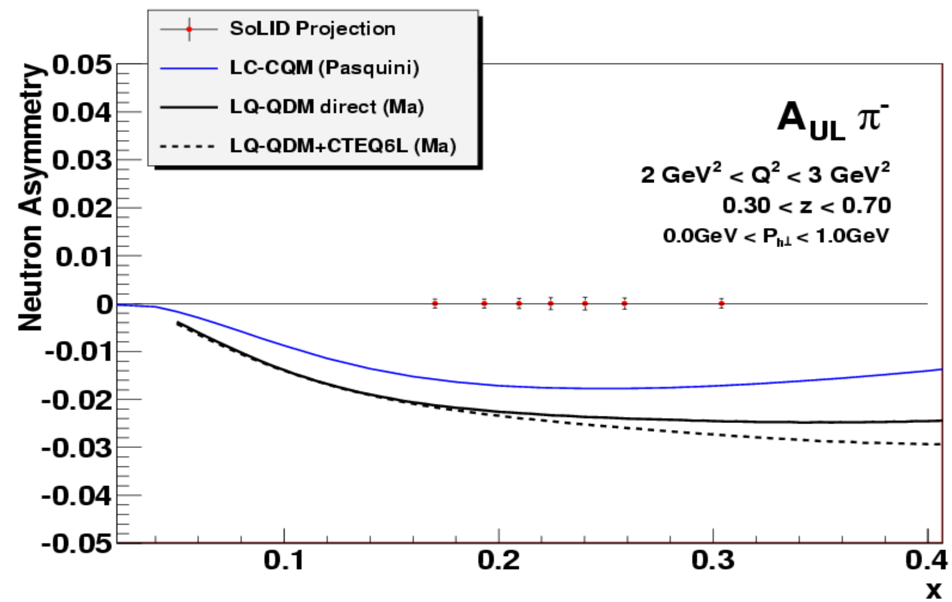
- Dominated by real part of interference between **L=0 (S) and L=1 (P) states**
- No GPD correspondence
- Exploratory lattice QCD calculation:
  Ph. Hägler et al, EPL 88, 61001 (2009)



Light-Cone CQM by B. Pasquini
B.P., Cazzaniga, Boffi, PRD78, 2008

Neutron Projections,





$$A_{LT} \sim g_{1T}(x) D_1(z)$$

$$A_{UL} \sim h_{1L}^{\perp}(x) \otimes H^{\perp}{}_1(z)$$

Summary on TMD Program

- Exploratory results from 6 GeV neutron experiment
- **Unprecedented precision *multi-d* mapping of SSA in valence quark region with SoLID at 12 GeV JLab**
- Both polarized n (^{3}He) and polarized proton

  Three "A" rated experiments approved

  + one run-group experiment on di-hadron

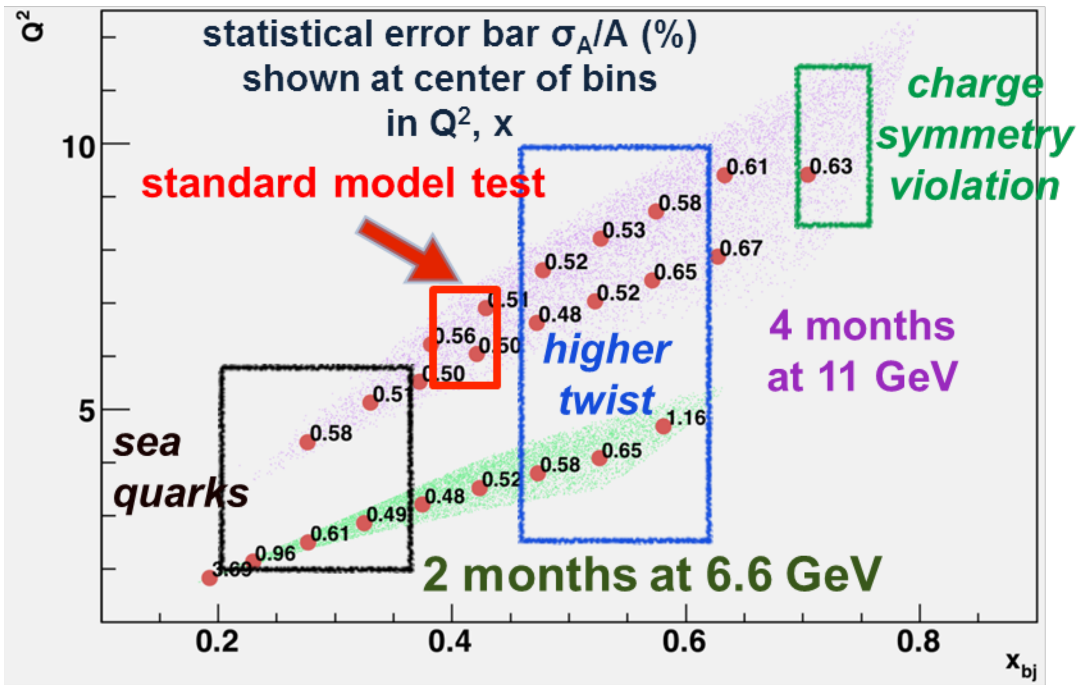
  + one run-group experiment on inclusive electron SSA
- Combining with the world data (fragmentation functions)
  - extract transversity for both *u* and *d* quarks
  - determine tensor charges
  - learn quark orbital motion and QCD dynamics
- Global efforts (experimentalists and theorists), global analysis
  - much better understanding of 3-d nucleon structure and QCD
- **Long-term future: EIC to map sea and gluon SSAs**

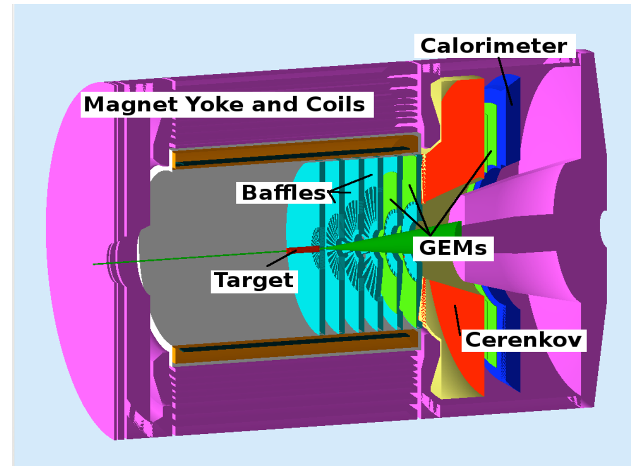
Parity Violating Deep-Inelastic Scattering

Precision Test of Standard Model
Unique Information on Nucleon Structure

See Xiaochao Zheng's Talk

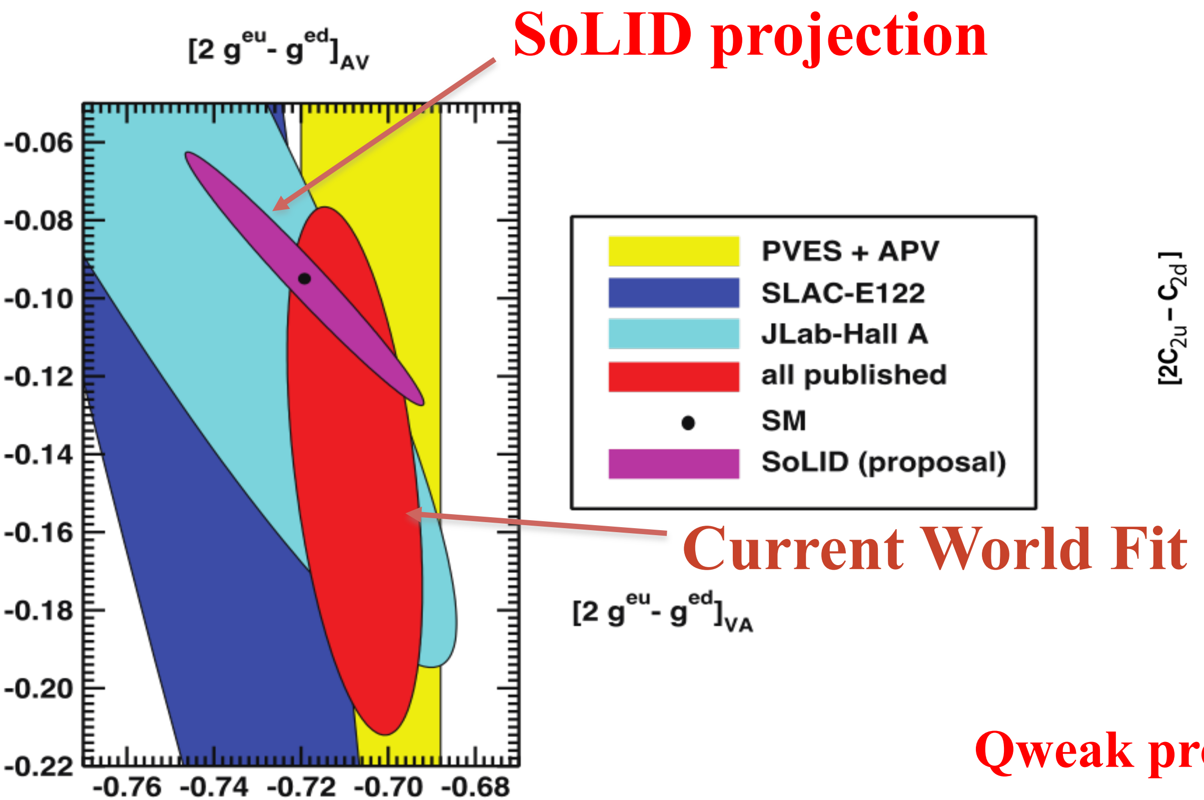
PVDIS with SoLID @ JLab12

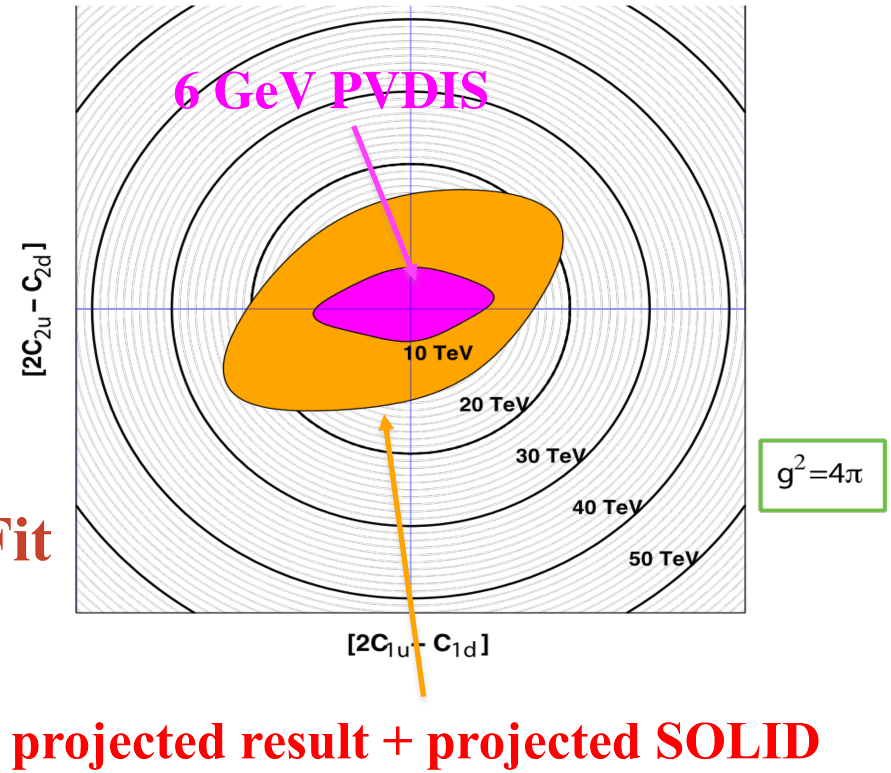




- High Luminosity on LD2 and LH2
- Better than 1% errors for small bins over large range kinematics
- Test of Standard Model
- Quark structure:
  - charge symmetry violation
  - quark-gluon correlations
  - d/u at large-x

Parity Violation with SoLID





Qweak and SOLID will expand sensitivity that will match high luminosity LHC reach with complementary chiral and flavor combinations

JLab 6-GeV PVDIS results
Wang *et al*., Nature 506, No. 7486, 67 (2014)

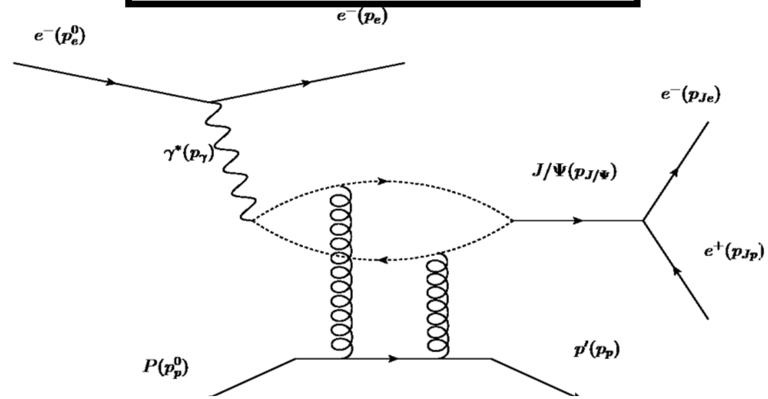
SoLID ~ 10 times improvement over 6 GeV result

Threshold J/ψ Production

Gluon Dynamics, Proton Mass, Axial Anomaly

J/ψ @ SoLID

$$\gamma^* + N \rightarrow N + J/\psi$$

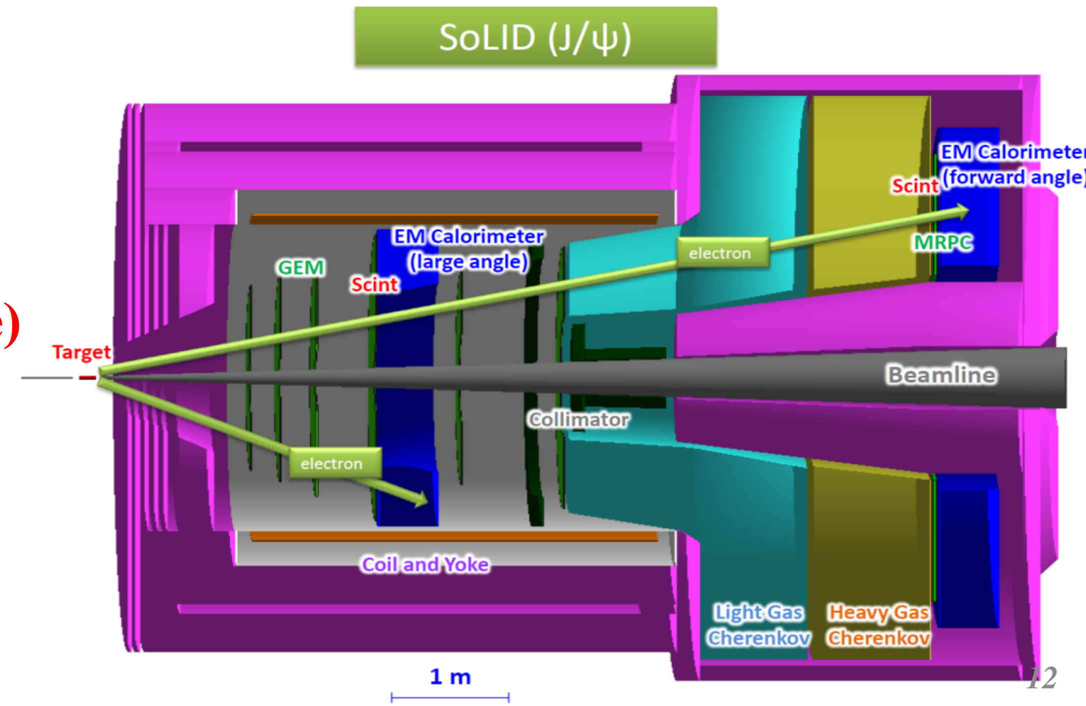


Threshold J/Ψ production, probing strong color field in the nucleon, QCD trace anomaly (important to proton mass budget)

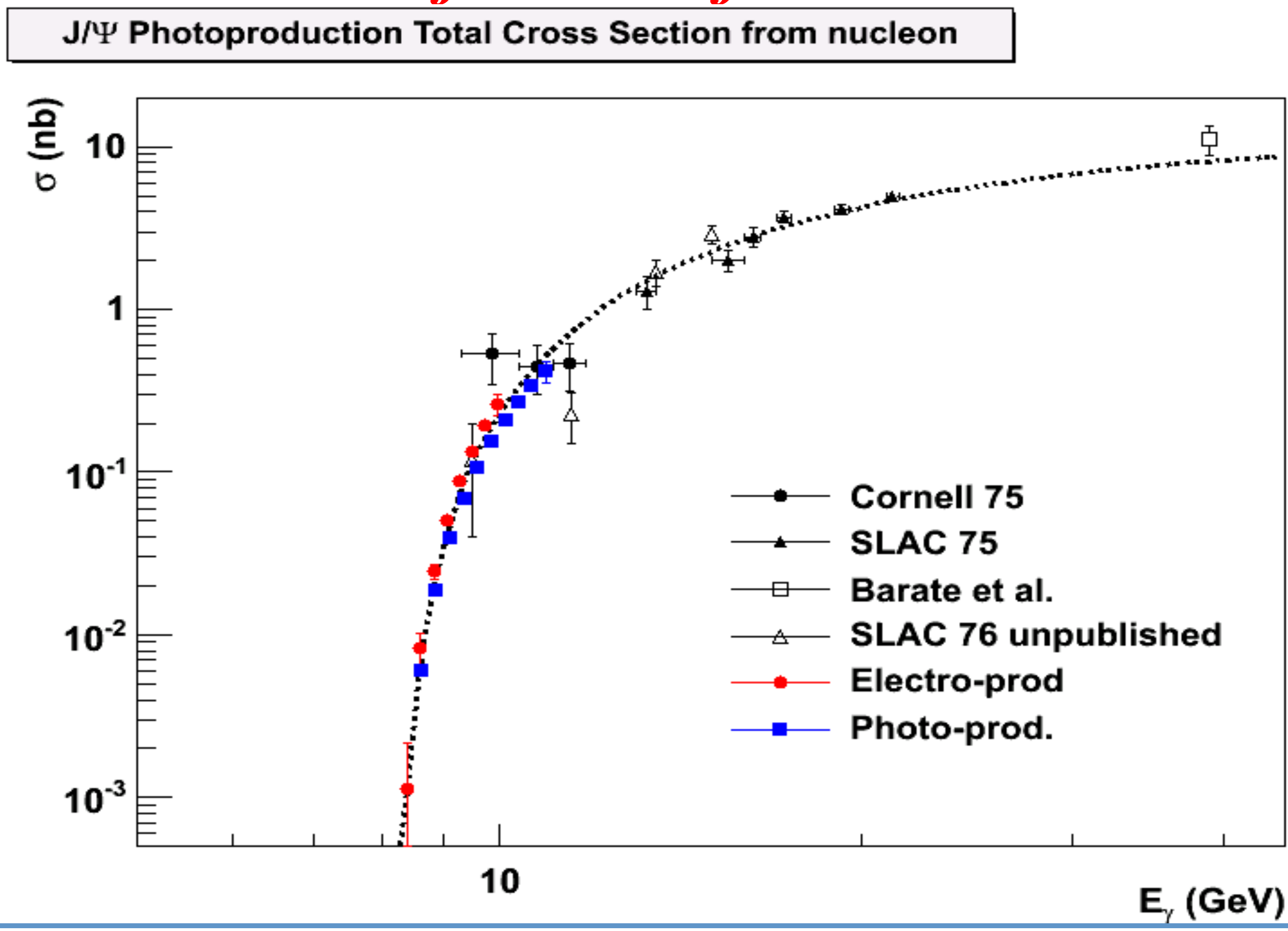
$$e\,p \rightarrow e'\,p'\,J/\psi(e^-\,e^+)$$
$$\gamma\,p \rightarrow p'\,J/\psi(e^-\,e^+)$$

Imaginary part: related to the total cross section through optical theorem

Real part: contains the conformal (trace) anomaly



Projection of Total Cross Section



Lumi $1.2*10^{37}/cm^2/s$
11GeV 3uA e- on 15cm LH2
50 Days

No competition in statistics

Study the threshold behavior of cross section with high precision **could shed light on the conformal anomaly**

3-D Structure II: GPD Study with SoLID

- A run-group proposal to PAC43: Time-like DVCS, Z. Zhao, *et al.*
  recently reviewed and approved by the SoLID collaboration

- A new letter-of-intent to PAC43: Double-DVCS, A. Camsonne, *et al.*
  submitted, presented at SoLID collaboration meeting

- A future proposal: DVCS with transversely polarized 3He,
  Z. Ye, et al.
  work on-going, presented at SoLID collaboration meeting,
  for PAC next year?

- A future proposal: Deep Virtual Neutral-Meson production,
  G. Huber, et al.
  work on-going, presented at SoLID collaboration meeting,
  for PAC next year?

Status of SoLID

Time Line, pre-R&D, pCDR, Subsystems

SoLID Timeline and Status

- 2010-2012 Five SoLID experiments approved by PAC (4 A, 1 A- rating)
  3 SIDIS with polarized ^{3}He/p target, 1 PVDIS, 1 threshold J/ψ
- 2013: CLEO-II magnet formally requested and agreed
- 2014: Site visit, plan transportation to JLab (2016?)

2010-2014: Progress

- Spectrometer magnet, modifications
- Detailed simulations
- Detector pre-R&D
- DAQ

✓ 2014: pre-CDR submitted

✓ 2015: Director's Review

What's next:

- ○ Continue pre-R&D, full simulation, pCDR → TDR
- ○ Prepare MIE proposal: 2015-2016?
- ○ DOE Science Review: soon?

Director's Review

Director's Review in February 2015: Successful

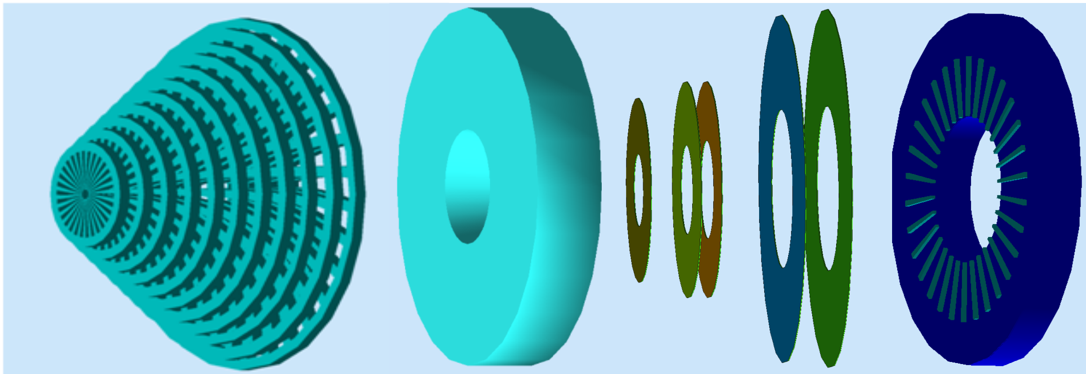
- Executive Summery of the Review Committee Report:

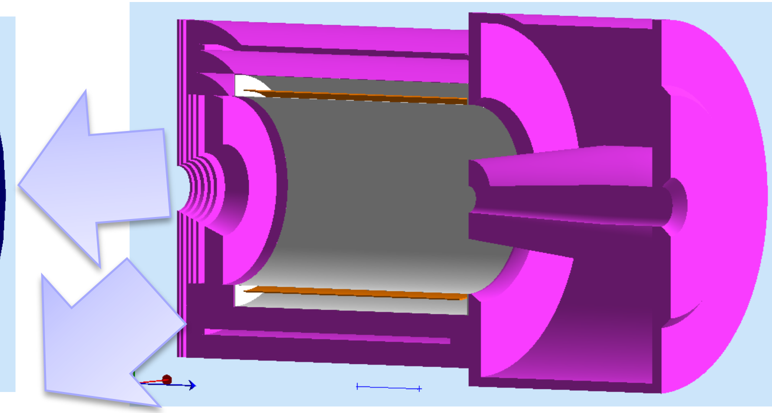
"Overall the committee members were very impressed with the quality of the material presented and the state of the project as presented. The committee was very impressed with the high level of international contributions in SoLID. The collaboration should be commended on the international nature of their effort. The committee felt that the project was in a good state to move forward, but also identified a number of areas where additional work will be needed. "

SoLID Detector Overview

See Talks Wednesday Afternoon

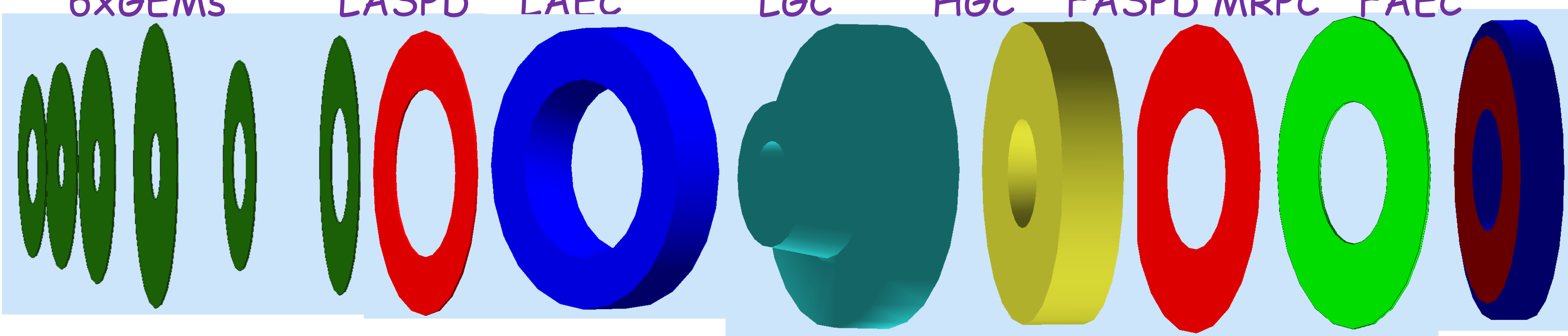
PVDIS: Baffle LGC 5xGEMs EC



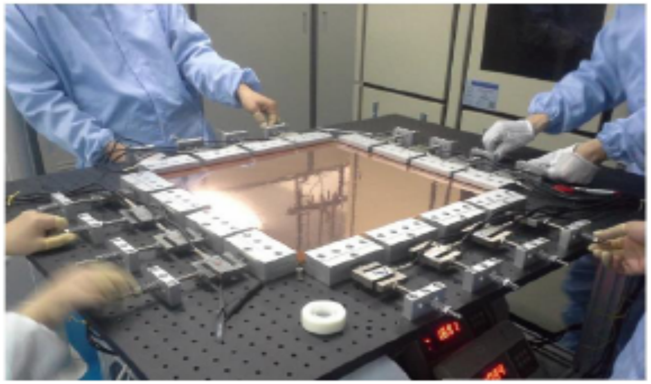


SIDIS&J/Psi:

6xGEMs LASPD LAEC LGC HGC FASPD MRPC FAEC

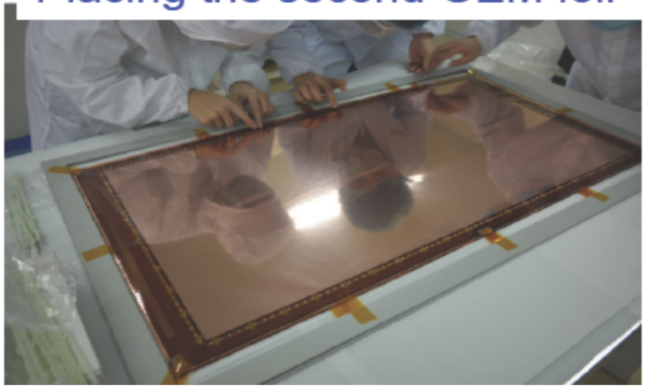


GEM Detector R&D Progress (China)



Fabricated 45 cm X 45 cm GEM chamber (Tsinghua and IMP)

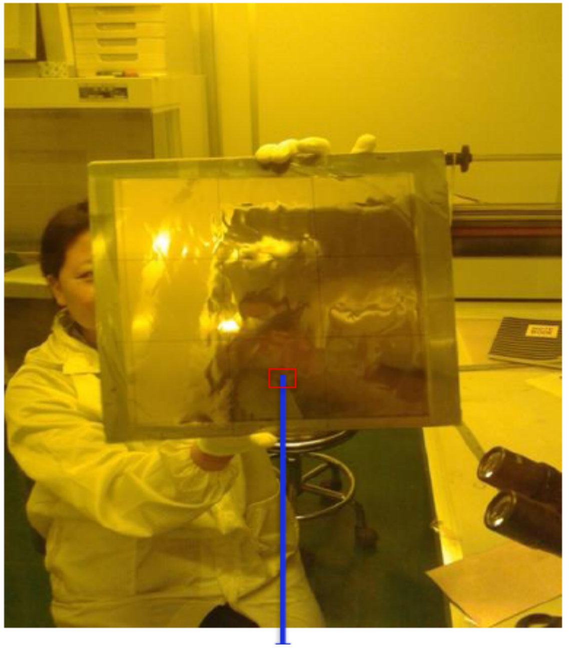
Placing the second GEM foil



Designing and Building full size 1 m X 0.5 m (USTC)

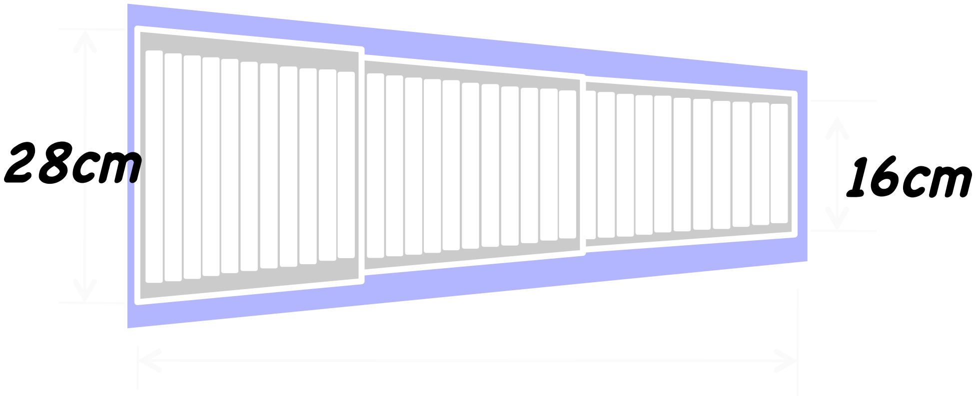
Produced 30cmX30cm GEM foil with double masking
Produced 40cmx40cm GEM foil with single masking (CIAE)

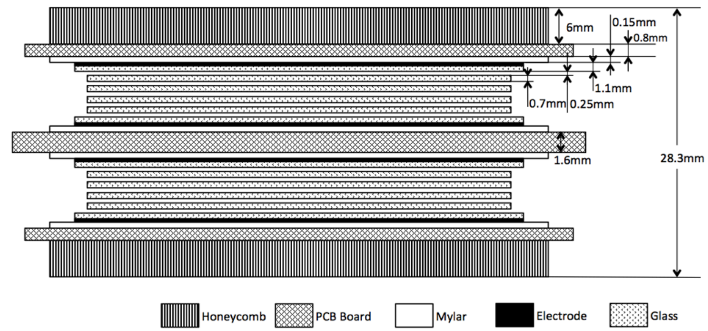
A 30cm*30cm GEM foil

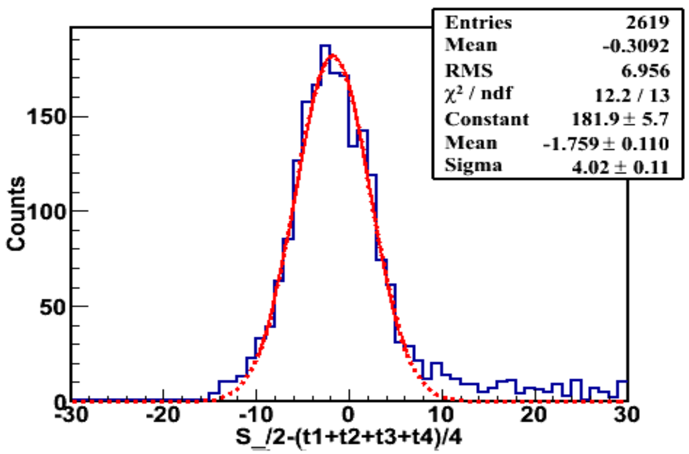


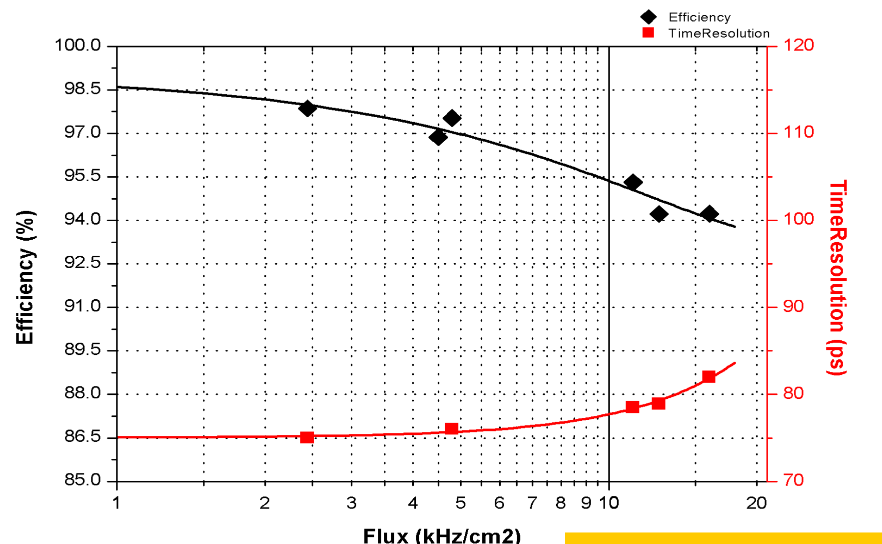
Successfully tested GEM chambers with INFN readout (CIAE)
R&D on readout system (USTC/Tsinghua)

MRPC R&D and Testings (China)









Time Resolution: ~75ps

Cosmic Ray test:
Efficiency > 95% @ 96kV/cm (6.0kV)
Time resolution: ~ 52ps

A MRPC prototype for SoLID-TOF in Jlab, Y. Wang et al. JINST 8 (2013) P03003

中国原子能科学研究院
China Institute of Atomic Energy

中国科学技术大学
University of Science and Technology of China

黄山學院
Huang Shan XueYuan

蘭州大學

華中科技大學
HUAZHONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

北京大學
PEKING UNIVERSITY

華大

昆山杜克大学
DUKE KUNSHAN UNIVERSITY

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Chinese Academy of Sciences
IMP
www.impcas.ac.cn

中国科学院近代物理研究所
titute of Modern Physics,Chinese Academy of Sciences

山东大学
SHANDONG UNIVERSITY

Summary

Full exploitation of JLab 12 GeV Upgrade

→ **SOLID:** A **Large Acceptance** Detector that can handle **High Luminosity** (10^{37}-10^{39})

Rich, vibrant and important physics program to address some of the most fundamental questions in Nuclear Physics

SoLID will provide the community with a large acceptance detector capable of operating at very high luminosities making high-precision JLab 12-GeV measurements in QCD (TMD, J/ψ, d/u), and electroweak physics. It also provides access to a broad set of other reactions.

Strong Chinese Collaboration.

SoLID could be the 1st detector for future EIC.

Detailed information: see the SoLID whitepaper: arXiv:1409.7741; and http://hallaweb.jlab.org/12GeV/SoLID/