TMD Studies and More with SoLID at JLab

Solenoidal Large Intensity Device

Jian-ping Chen (陈剑平), Jefferson Lab, Virginia, USA

Spin2014, Beijing, China, October 24, 2014

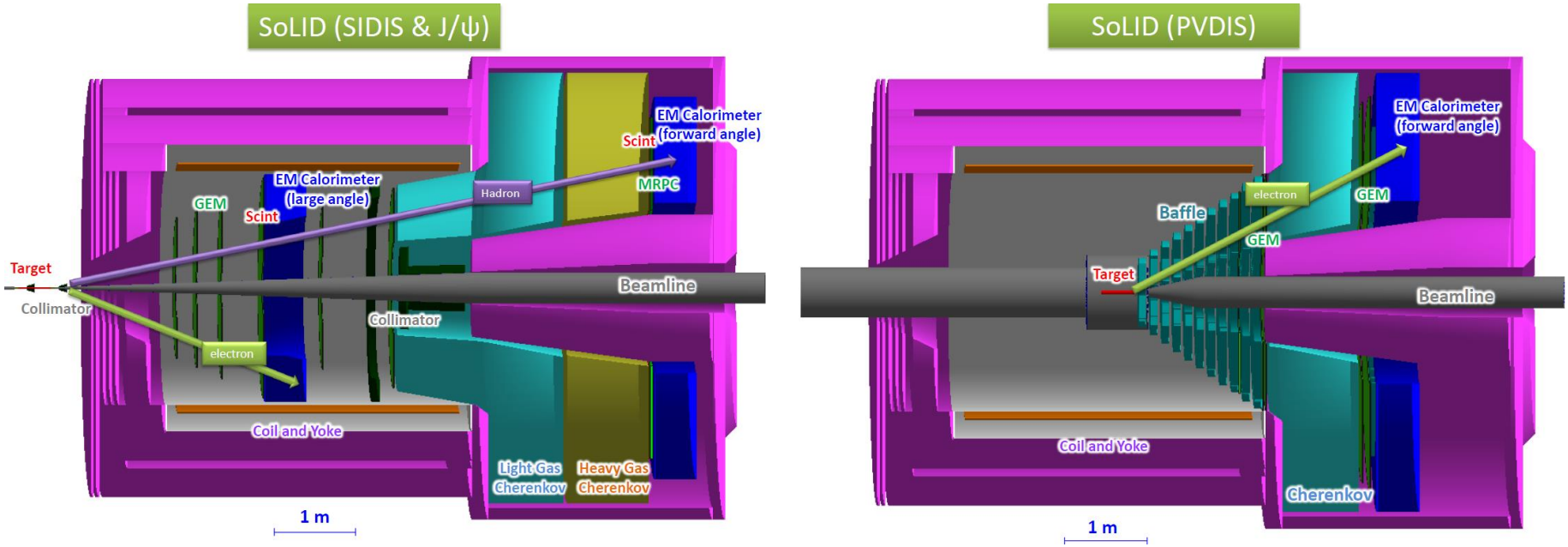
- **SoLID Physics Program @ 12 GeV JLab**
  - Transverse Spin and Transverse Structure: TMDs
  - Parity Violating DIS
  - J/ψ threshold production
- **SoLID Instrumentation: Status and Plan**

Acknowledgement: many slides provided by my SoLID collaborators

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**
  - Three SIDIS experiments, one PVDIS, one J/ψ production
  - Bonus: di-hadron, Inclusive-SSA, and much more …
- **Strong collaboration** (200+ collaborators from 50+ institutes, 11 countries)
  - Significant international contributions



SoLID Physics Program (I)

Transverse Spin and Transverse Structure: TMDs

Leading-Twist TMD PDFs

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

Nucleon Spin

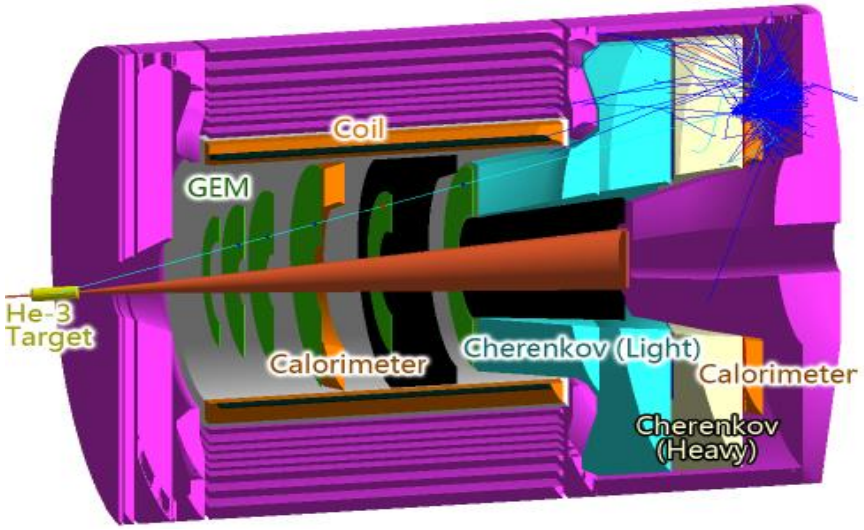
Quark Spin

: Survive trans. Momentum integration

JLab 12 GeV: Precision Study of *TMD*s

- Experimental explorations: HERMES, COMPASS, JLab, RHIC, …
- From exploration to precision study with 12 GeV JLab
- Transversity: fundamental *PDF*s, tensor charge
- *TMD*s: 3-d momentum structure of the nucleon
- → Quark orbital angular momentum
- Multi-dimensional mapping of *TMD*s
  - 4-d (x,z,$P_\perp$,Q^2)
  - Multi-facilities, global effort
- Precision → high statistics
  - high luminosity and large acceptance

Nucleon Structure (TMDs) with SoLID



Solenoidal Large Intensity Device (SoLID)

Semi-inclusive Deep Inelastic Scattering program:

Large Acceptance + High Luminosity
+ Polarized targets
→ **4-D** mapping of TMD asymmetries
→ Tensor charge, TMDs …
→ Benchmark test of Lattice QCD, probe QCD Dynamics and quark orbital motion

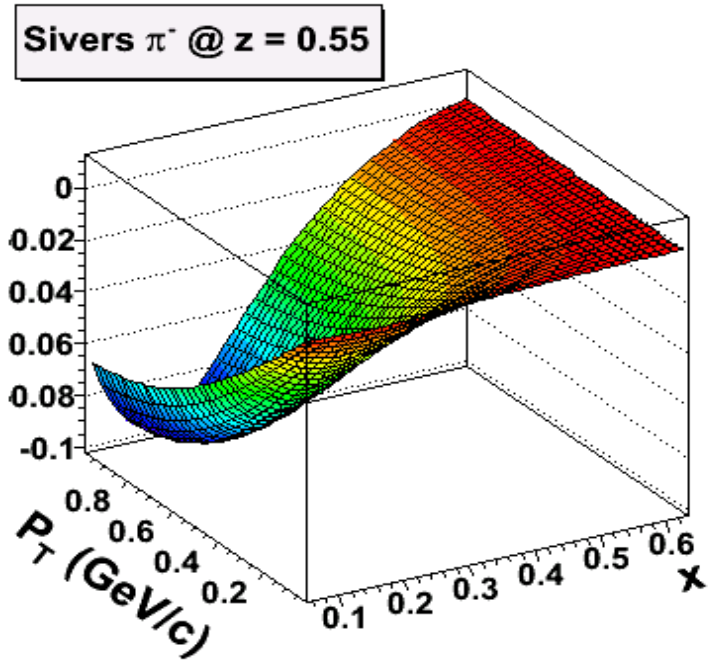
International collaboration, 11 countries

Rapid Growth in US-China Collaboration

Chinese Hadron collaboration
(USTC, CIAE, PKU, Tsinghua U, Lanzhou, IMP,+)

- large GEM trackers
- MRPC-TOF

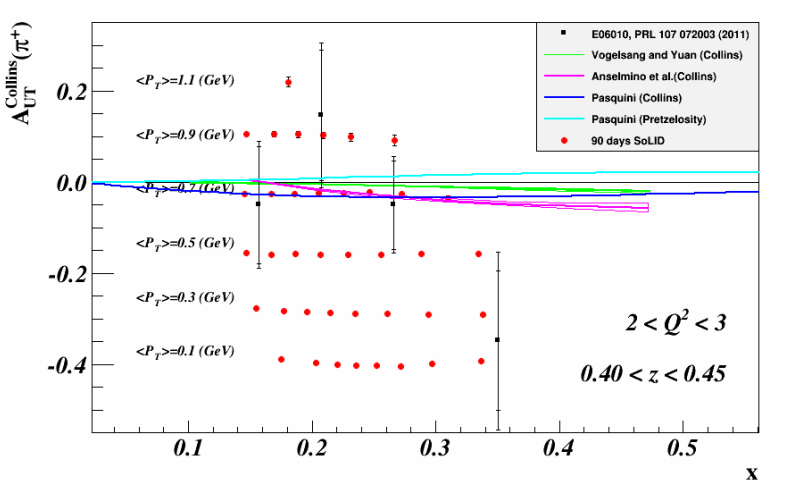
3 A rated SIDIS experiments approved for SoLID
+ 2 bonus experiments
with 3 having Chinese collaborators as co-spokesperson (Li from CIAE, Yan from USTC and Xiao from Tsinghua)



Transversity and Tensor Charge

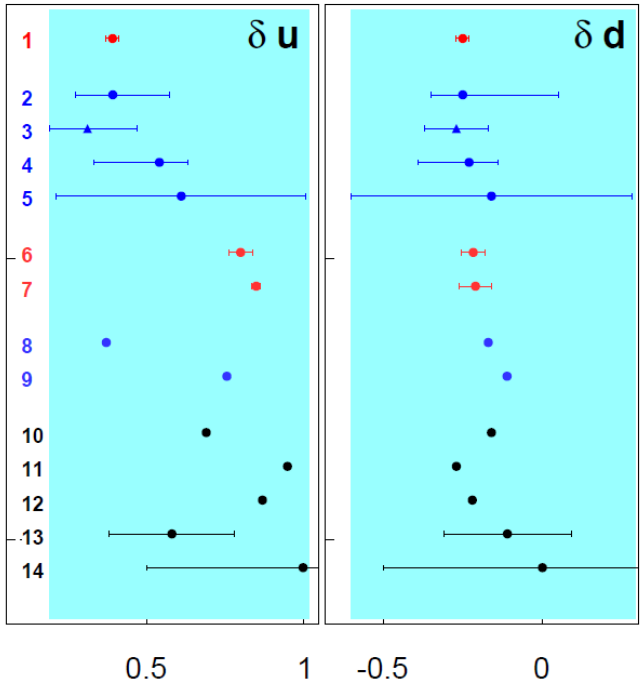
- Collins Asymmetries ~ Transversity (x) Collin Function
- **Transversity**: chiral-odd, not couple to gluons, **valence behavior**, largely unknown
- **Tensor charge (0th moment of transversity): fundamental property**
  Lattice QCD, Bound-State QCD (Dyson-Schwinger) , Light-cone Quark Models, …
- Global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

Collins Asymmetries



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

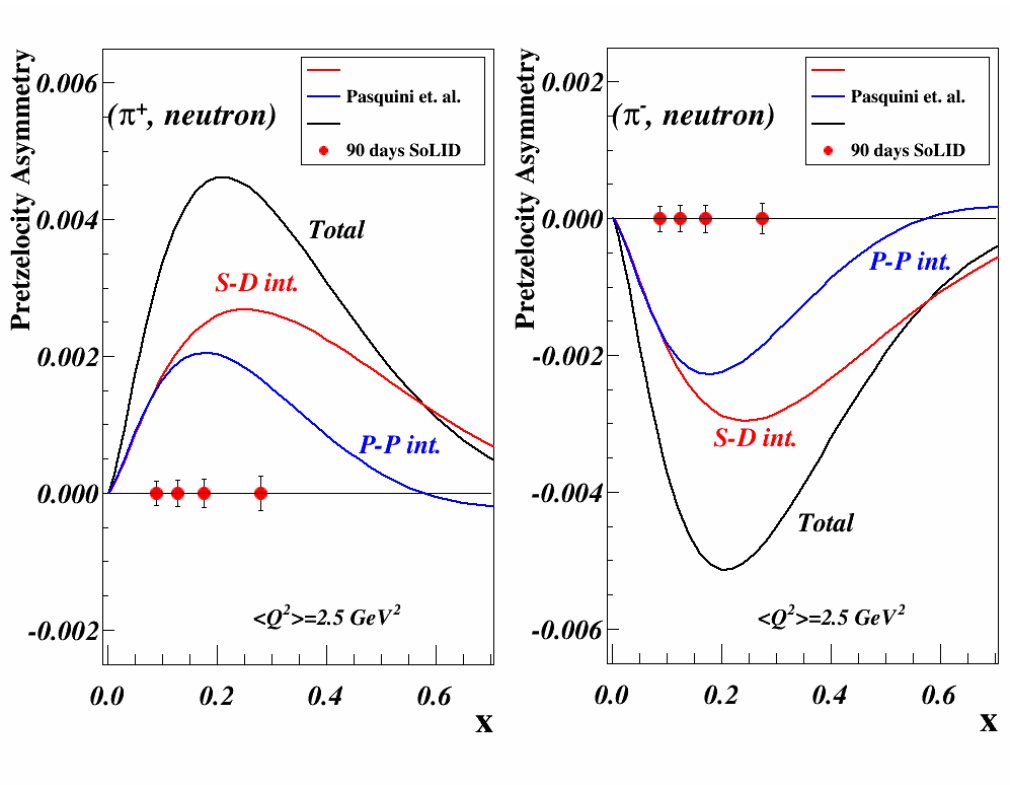
Tensor Charges



- ***Projections with a model***
- ***There are un-measured regions***
- ***QCD evolutions being worked***

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**

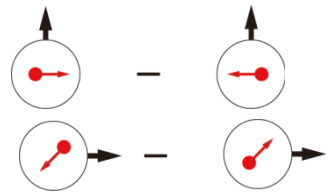


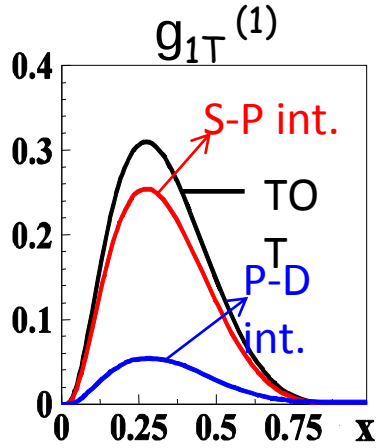
Pretzelosity

Worm-gear Functions

g_{1T} =

$h_{1L}^{\perp}$ =

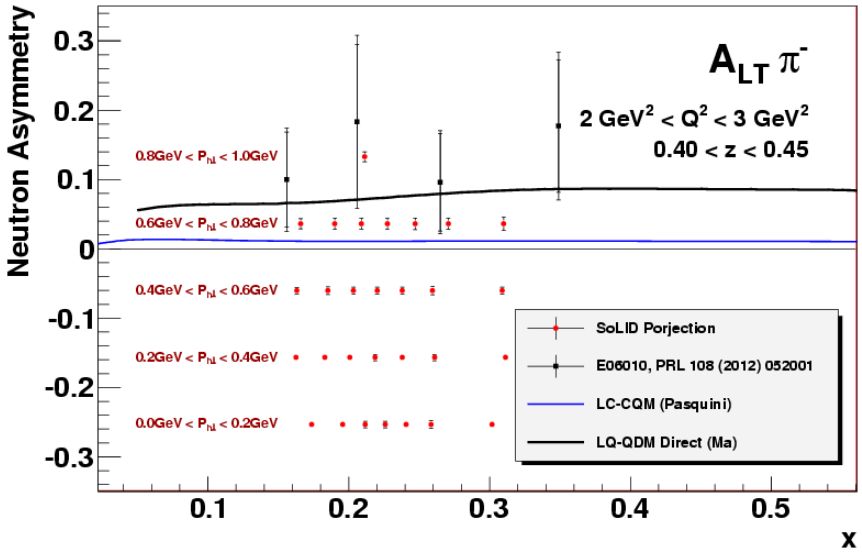


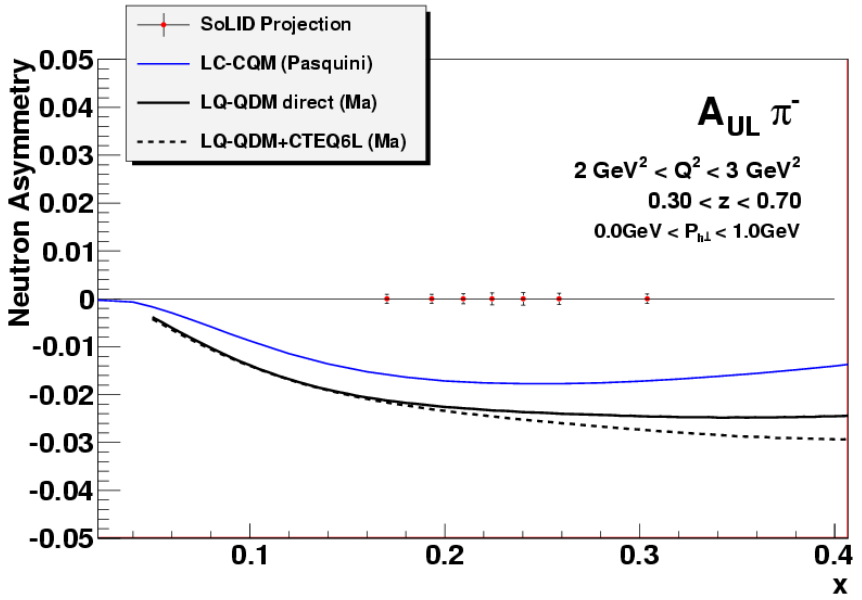


- Dominated by real part of interference between L=0 (S) and L=1 (P) states
- No GPD correspondence
- Exploratory lattice QCD calculation:
  Ph. Hägler et al, EPL 88, 61001 (2009)

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

Neutron Projections,





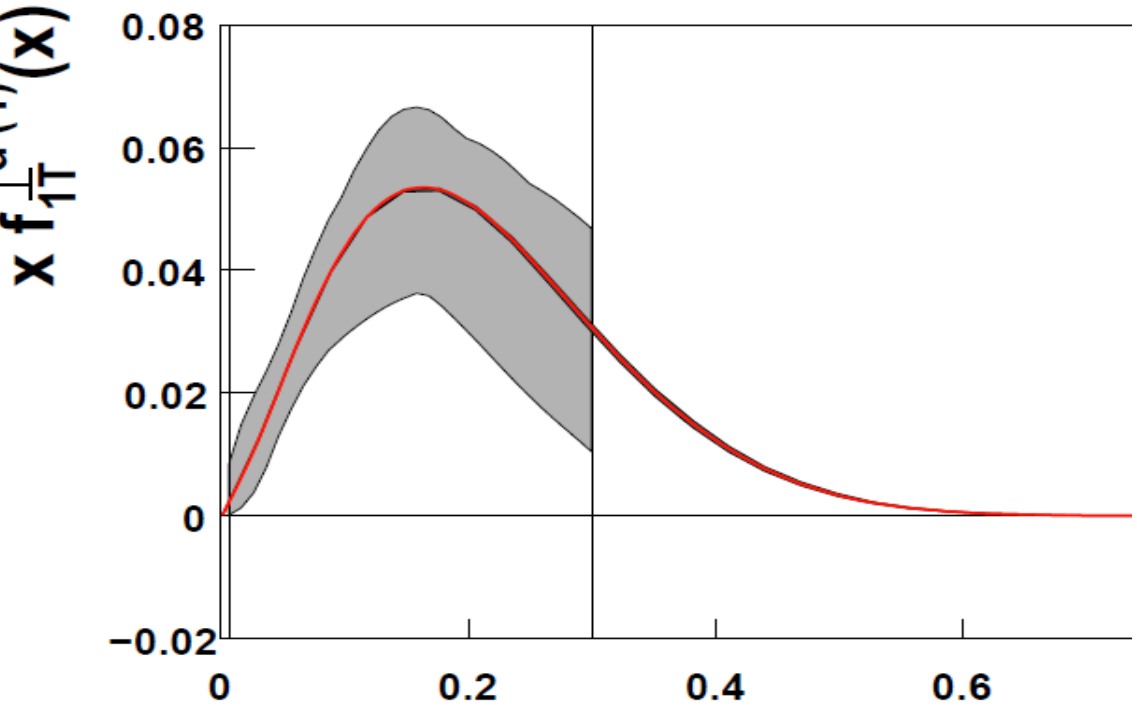
$$A_{LT} \sim g_{1T}(x) D_1(z)$$

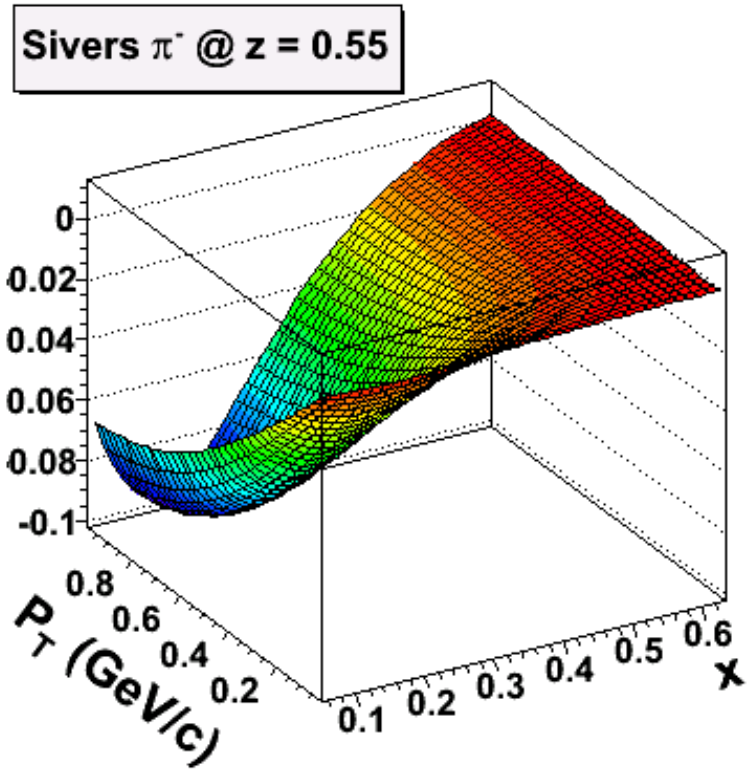
$$A_{UL} \sim h_{1L}^{\perp}(x) \otimes H^{\perp}{}_1(z)$$

Sivers Function

$f_{1T}^{\perp}$ =  –

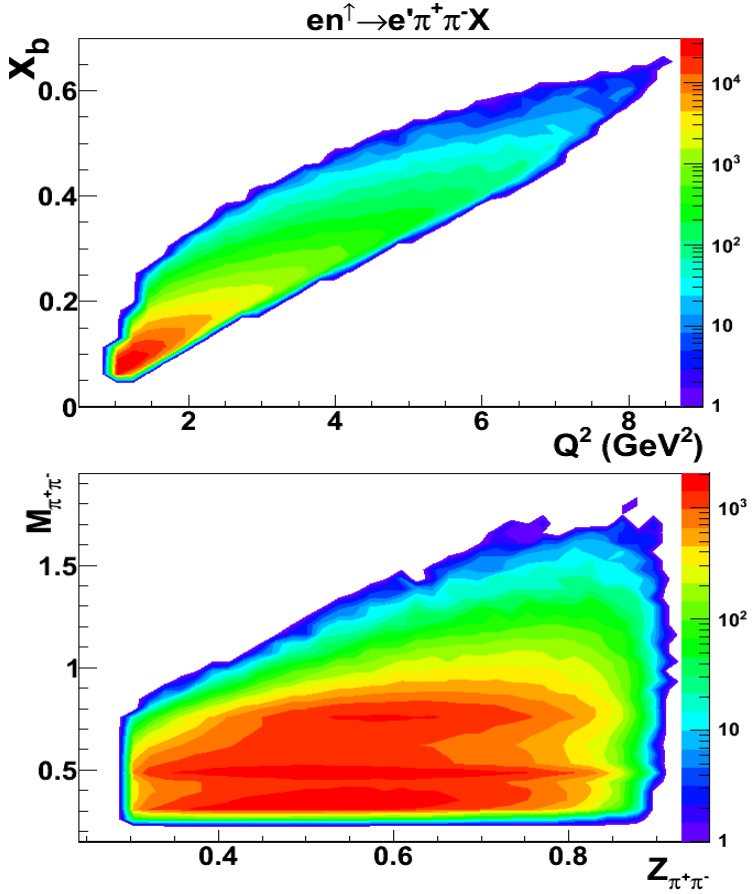
- Significant Improvement in the valence quark (high-x) region
- Illustrated in a model fit (from A. Prokudin)



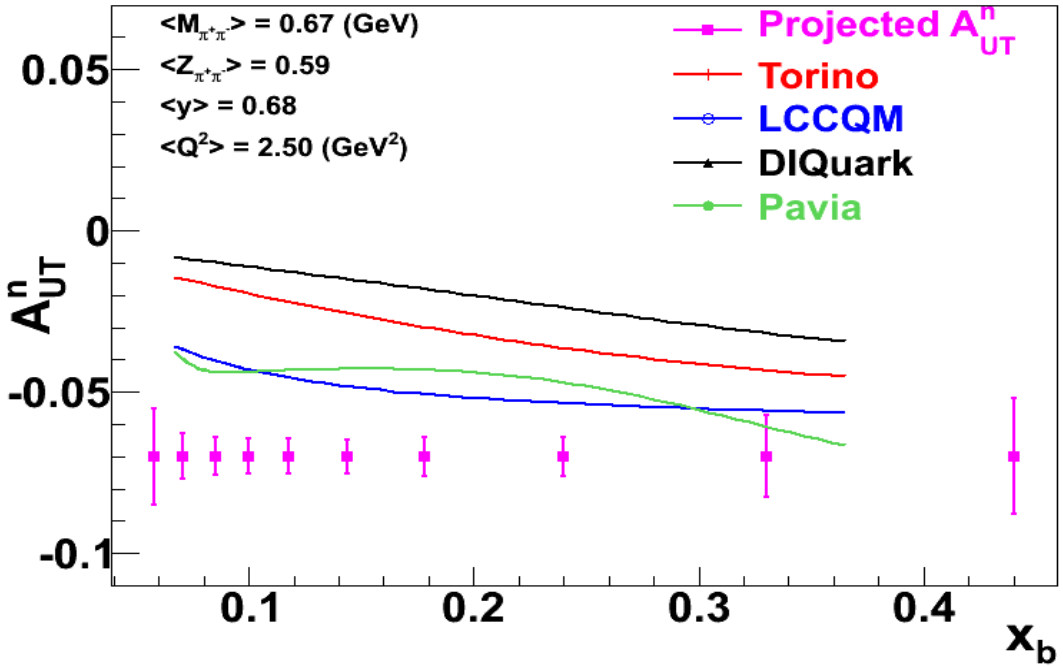


Measure Transversity via Dihadron with SoLID

- Precision dihadron (π+/π-) production on a transversely polarized ^{3}He (n)
- Extract transversity on neutron
- Provide crucial inputs for flavor separation of transversity



Wide x_b and Q^2 coverages



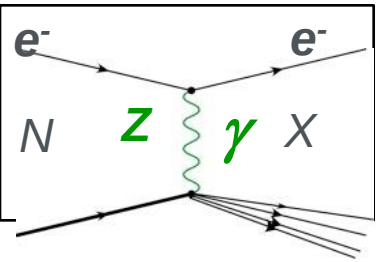
Projected Statistics error for one ($M_{\pi\pi}$,$z_{\pi\pi}$) bin, integrated over all y and Q^2.

Discussion

- **Unprecedented precision *4-d* mapping of SSA**
  - Collins and Sivers
  - π^+, π^- and K^+, K^-
- **Three "A" rated SIDIS experiments (p and n) with SoLID + dihedron**
  - Reach ultimate precision: high luminosity and large acceptance
- **Combining with the world data**
  - extract transversity for both *u* and *d* quarks
  - determine tensor charges
  - study TMDs in the valence region
  - study quark orbital angular momentum and QCD dynamics
- **Global efforts (experimentalists and theorists), global analysis**
  - much better understanding of multi-d nucleon structure and QCD
- **Long-term future: EIC to map sea and gluon SSAs**

SoLID Physics Program (II)
Parity Violating Deep Inelastic Scattering

Precision Test of Standard Model
and Precision Study of Hadron Properties



JLab 6 GeV Results on PVDIS

Wang et al., Nature 506, no. 7486, 67 (2014)

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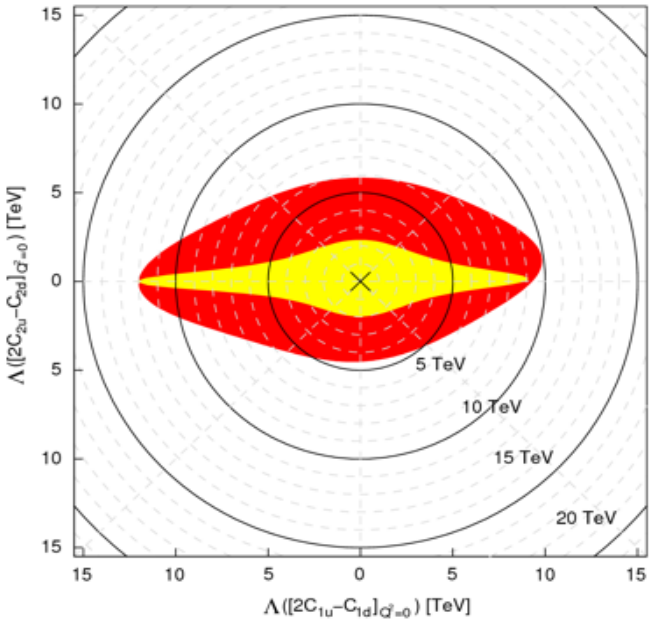
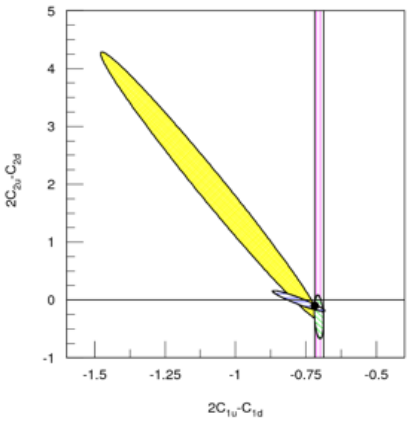
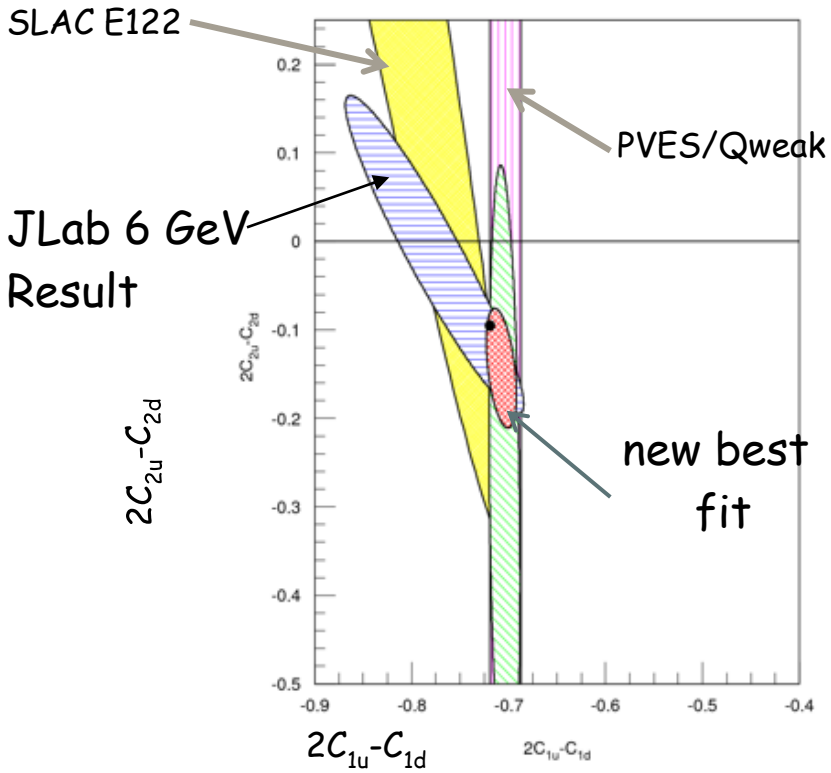
日本語要約

Measurement of parity violation in electron–quark scattering

The Jefferson Lab PVDIS Collaboration

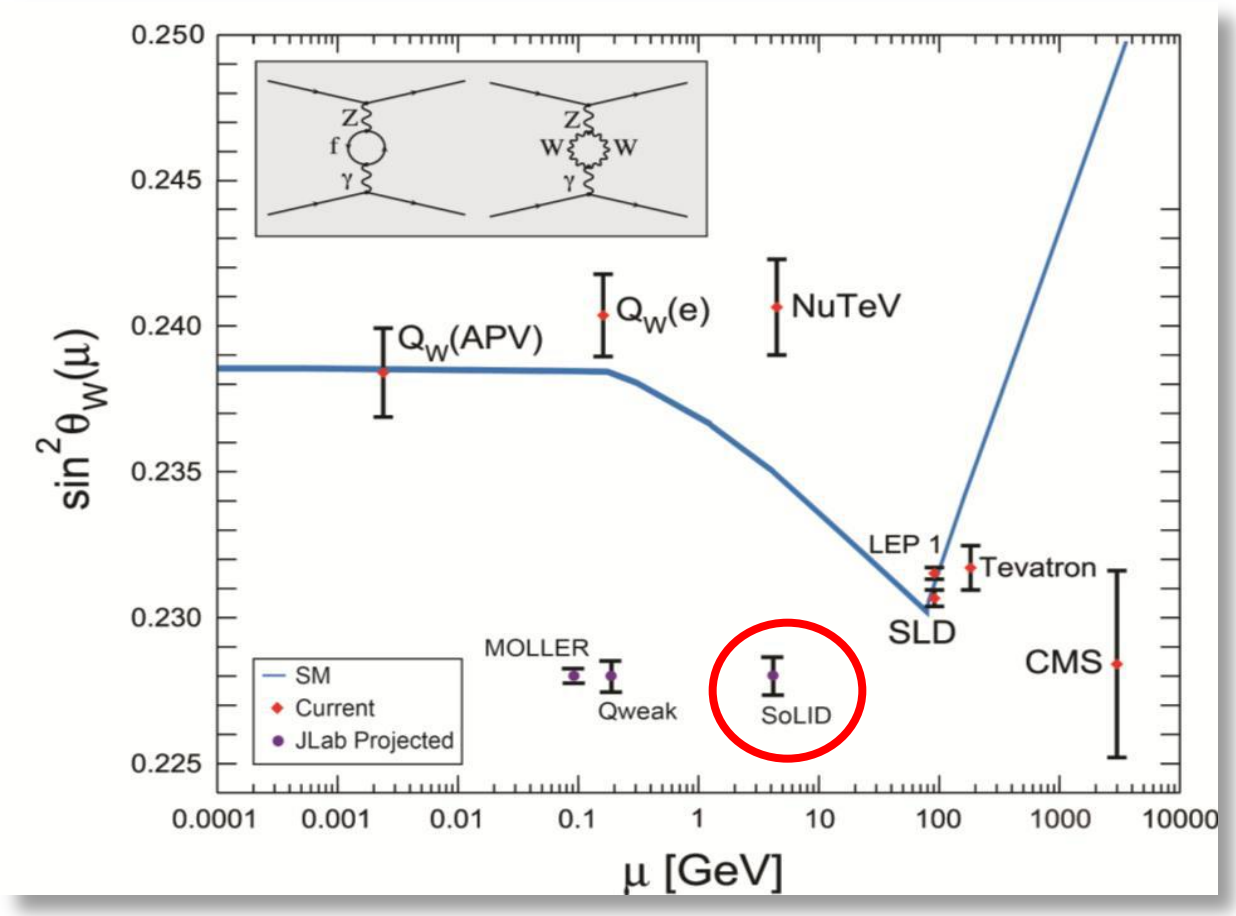


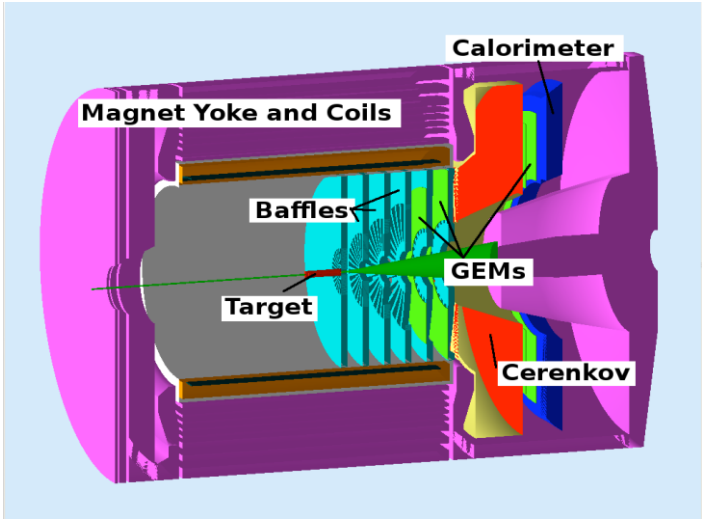




first experimental determination that an axial quark coupling combination is non-zero (as predicted)

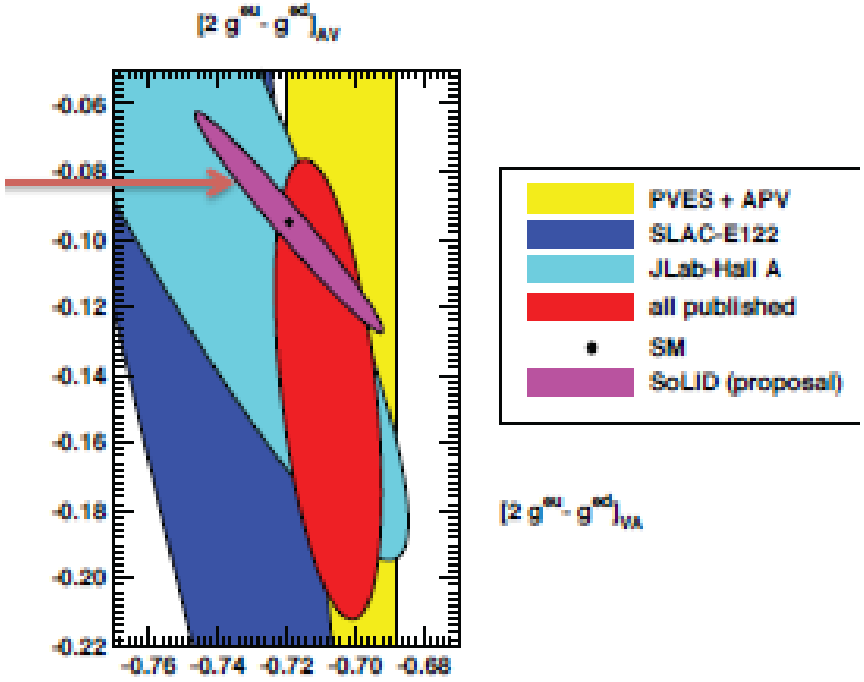
PVDIS with SoLID

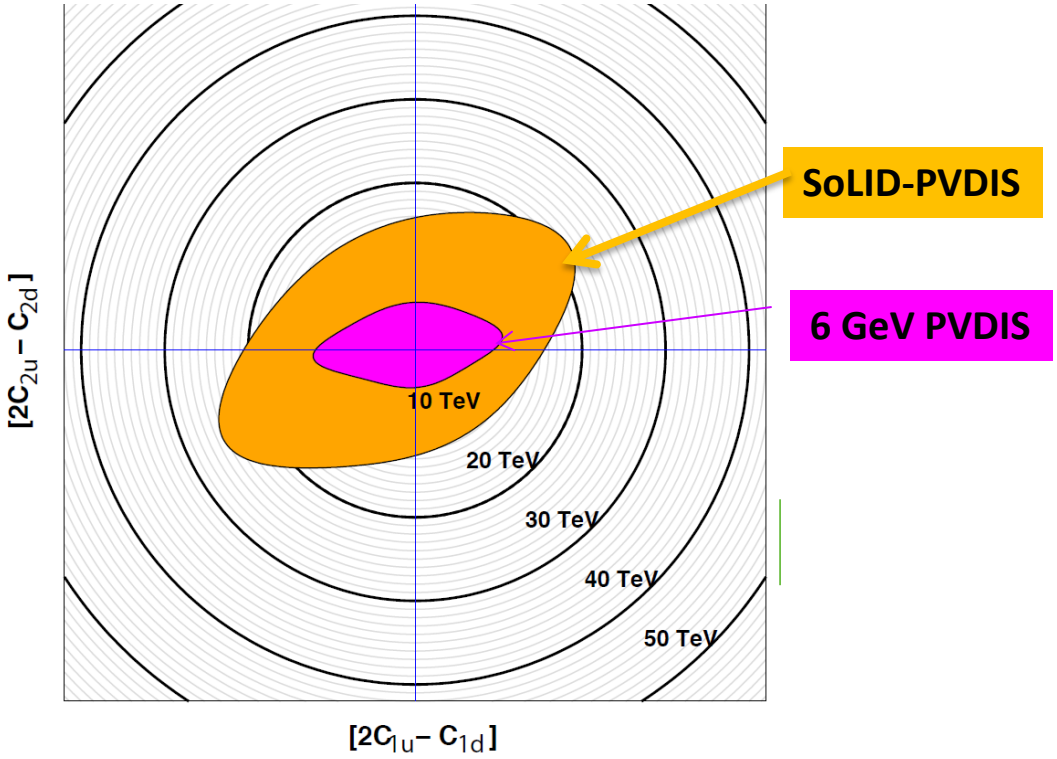




- High Luminosity on LD2 and LH2
- Better than 1% errors for small bins over large range kinematics
- Test of Standard Model
- Quark structure:
  - charge symmetry violation
  - quark-gluon correlations
  - d/u at large-x

Parity Violation with SoLID





PVDIS asymmetry has two terms:

1) $\mathbf{C_{2q}}$ weak couplings, test of Standard Model

2) Unique precision information on **quark structure of nucleon**

Mass reach in a composite model

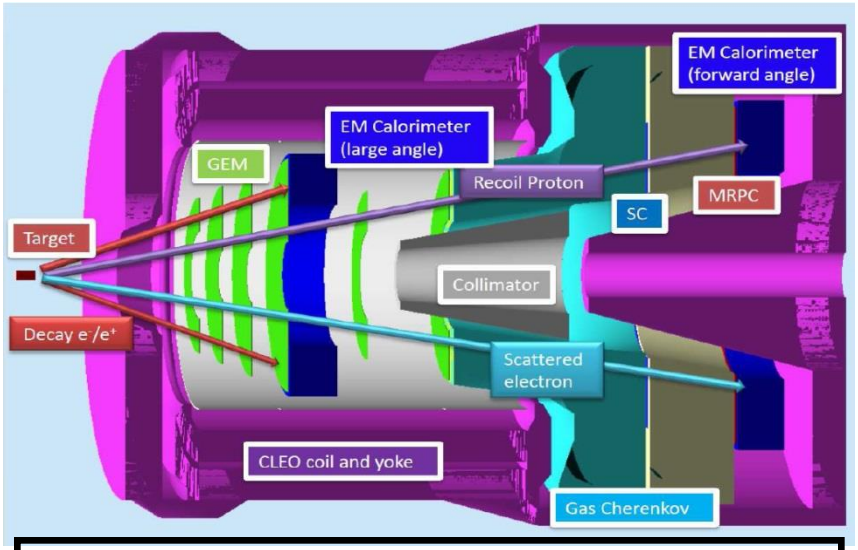
SoLID-PVDIS ~ 20 TeV (LHC scale)

SoLID-J/ψ: Study Non-Perturbative Gluons

J/ψ: ideal probe of non-perturbative gluon

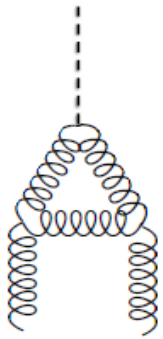
The high luminosity & large acceptance capability of SoLID enables a unique "precision" measurement near threshold

- **Search for threshold enhancement**
- **Shed light on the conformal anomaly**

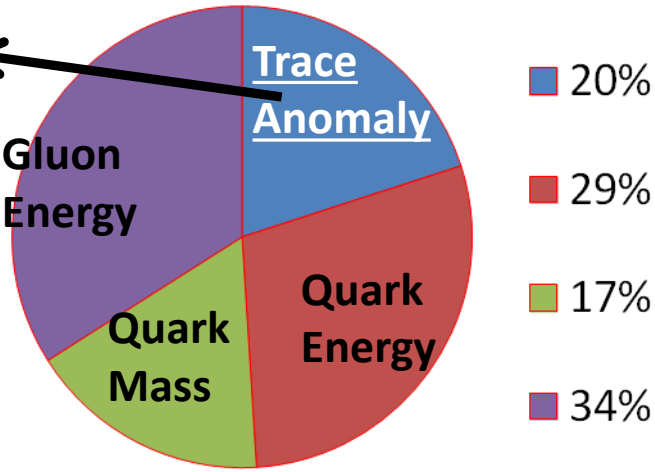


$$\gamma^* + N \rightarrow N + J/\psi$$

$$G^{\alpha\beta\gamma} G^{\gamma}_{\alpha\beta}$$

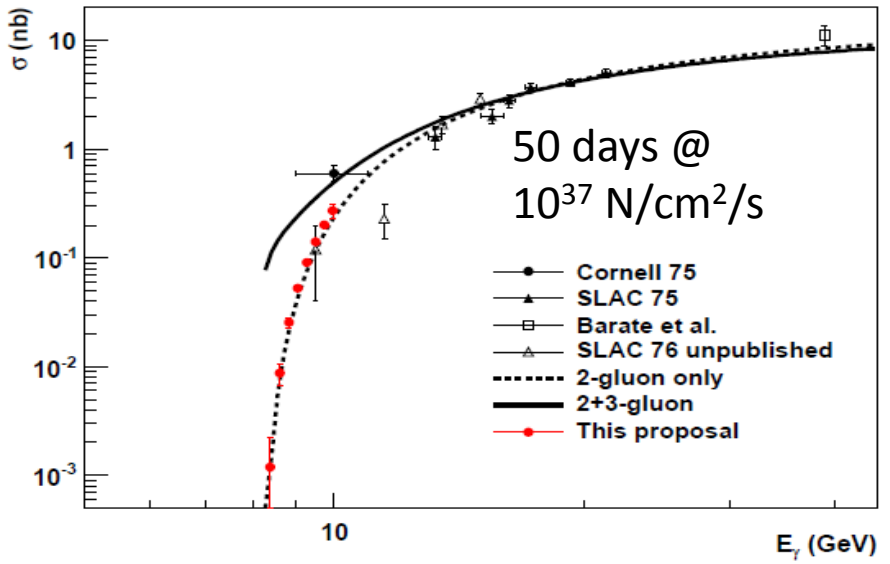


Proton Mass Budget



X. Ji PRL 74 1071 (1995)

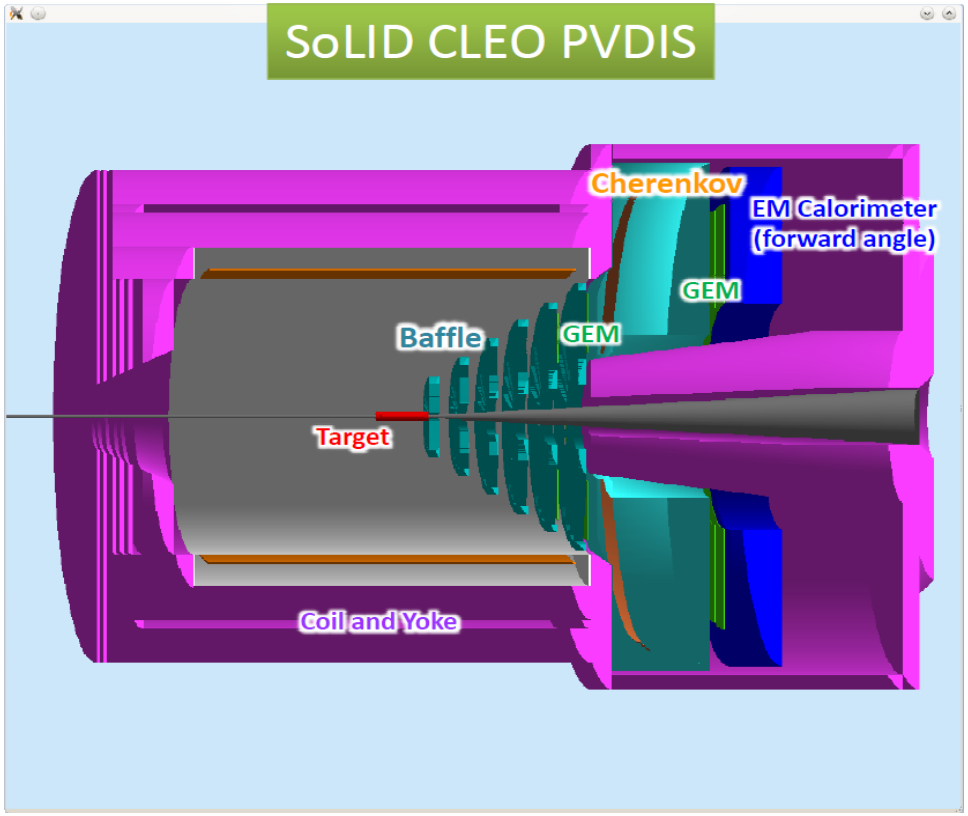
J/Ψ Photoproduction Total Cross Section from nucleon

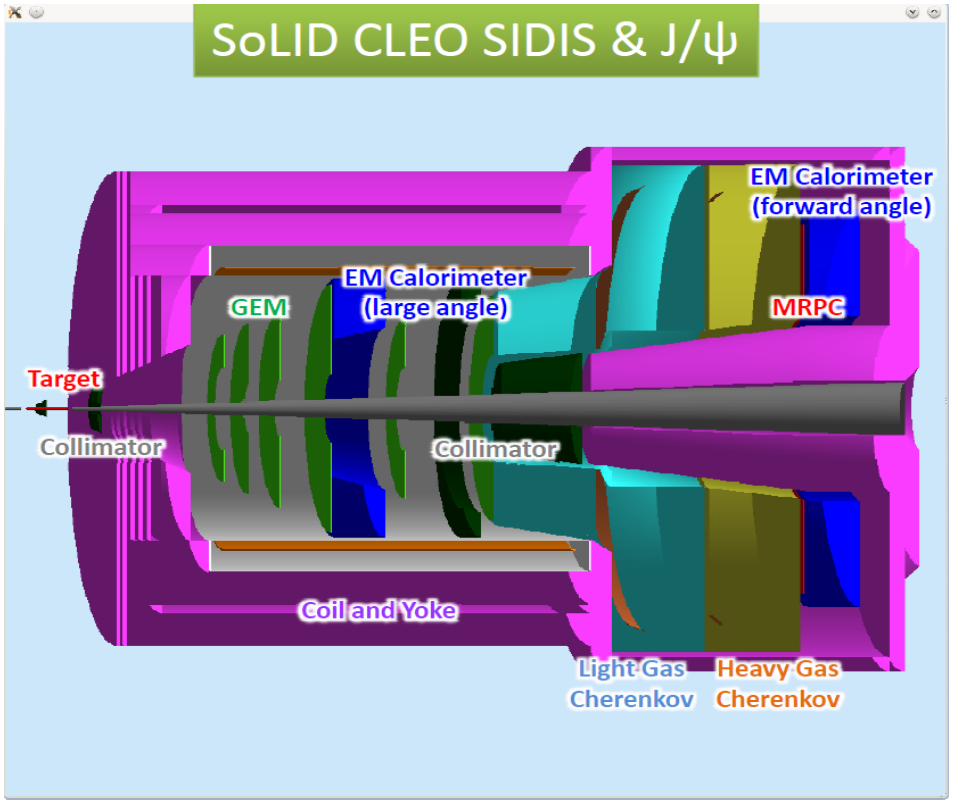


SoLID Instrumentation

Magnet, Detectors, DAQs, Simulations

SoLID Instrumentation





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**

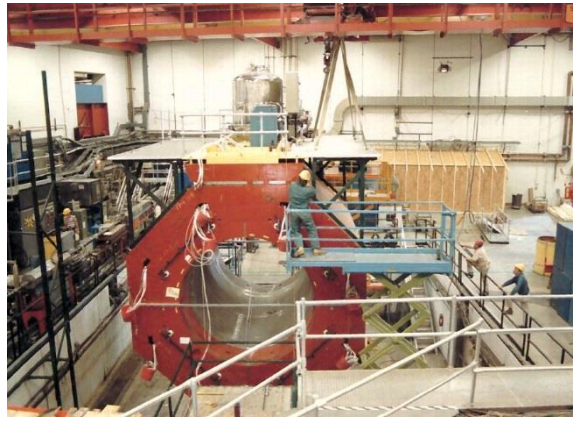
- 2013: **CLEO-II magnet formally requested and agreed**

- 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** for JLab Director's Review



CLEO-II magnet

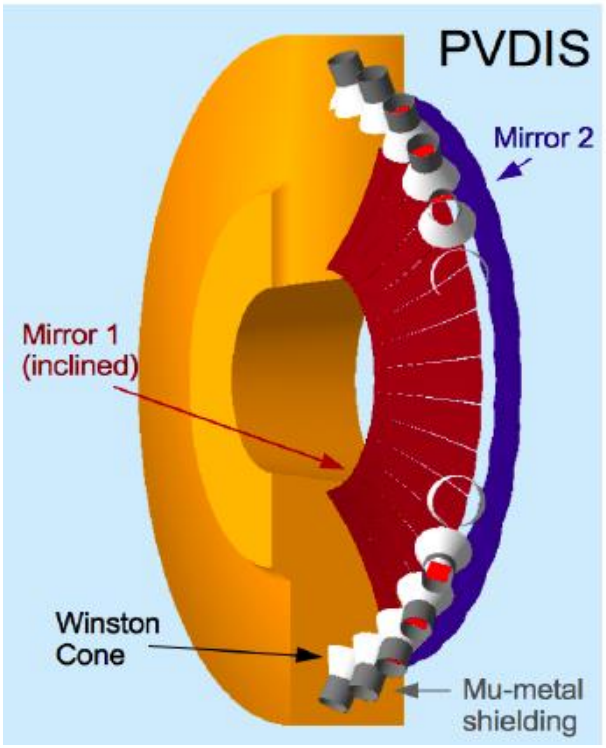
Active collaboration,

200+ physicists from 50+ international institutions

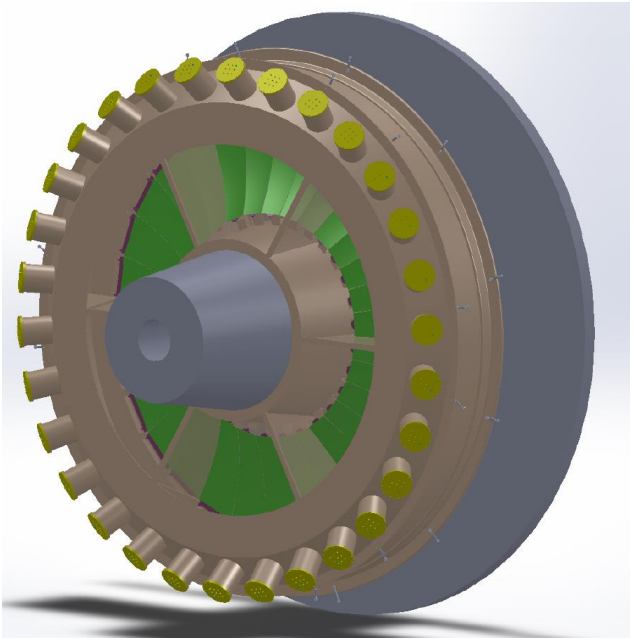
significant international contributions (China)

SoLID Detector Development

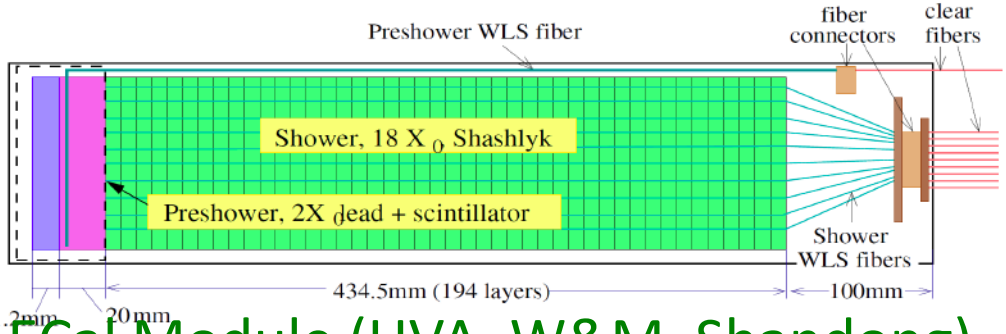
Simulations now with realistic backgrounds



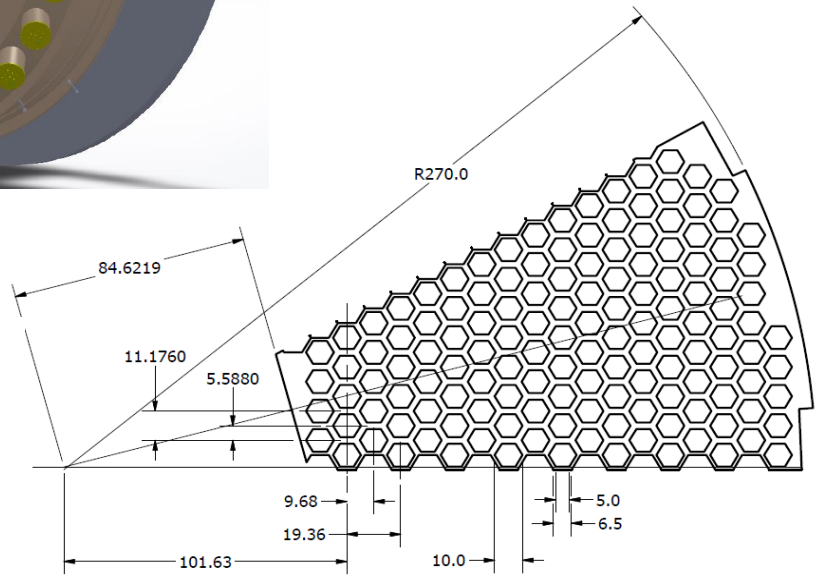
Light Gas Cerenkov (Temple)



Heavy Gas
Cerenkov (Duke)



ECal Module (UVA, W&M, Shandong)

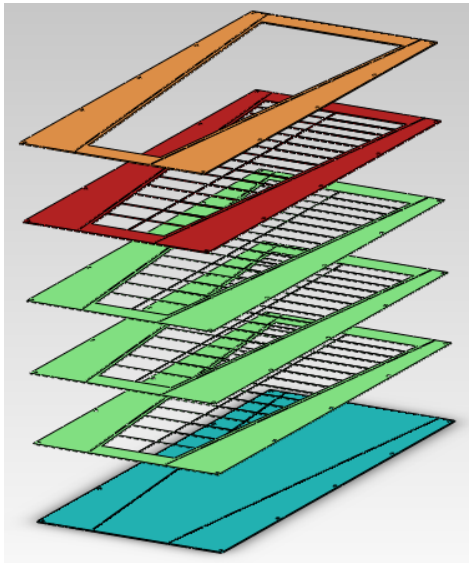


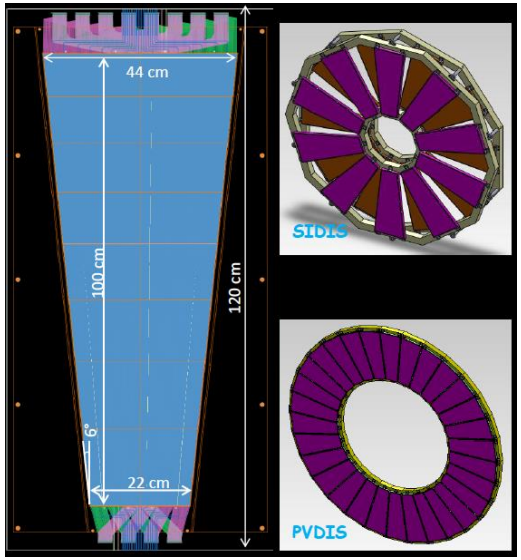
ECal Mounting Design (ANL)

GEM Progress

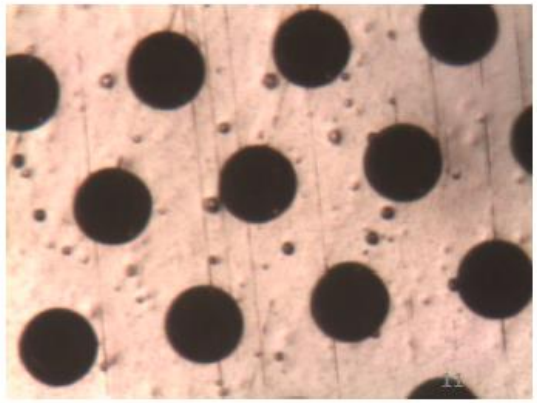
Chinese Collaboration

- First full size prototype assembled at **UVA**, tested in beam (Fermi Lab)
- 30x30 cm prototype constructed, readout tested (**CIAE/USTC/Tsinghua/Lanzhou**)
- GEM foil production facility under development at **CIAE** (China)





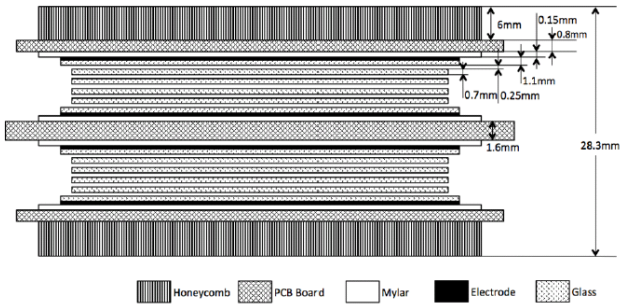
GEM foils made at CIAE

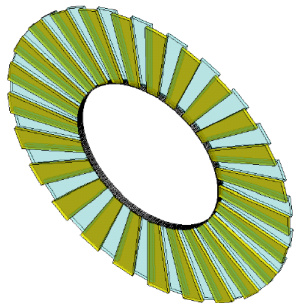


MRPC – High Resolution TOF

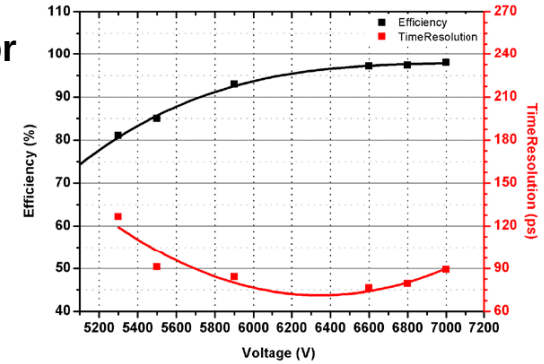
> 95 % efficiency

Timing resolution ~ 85 ps





A MRPC prototype for SOLID-TOF in JLab
Y. Wang, *et al.* **JINST 8 (2013) P03003**
(Tsinghua, USTC)



Summary

- A challenge: Understand Strong QCD
  - Needs multi (transverse) dimension
  - Need high precision: high luminosity and large acceptance
- **SoLID @ JLab 12 GeV: exciting physics program**

  4 “A” rated, 1 “A-” rated experiments approved
  - SIDIS: Precision extraction of transversity/tensor charge/ TMDs
  - PVDIS: low energy test of standard model and hadron properties
  - J/ψ threshold production: study gluons
  - Bonus experiments: di-hadron, Ay
  - Exciting new opportunities

New collaborators welcome