

# SoLID Update

- SoLID Overview
- Progress in Physics Program
- Progress in Subsystem
- Summary

Ye Tian

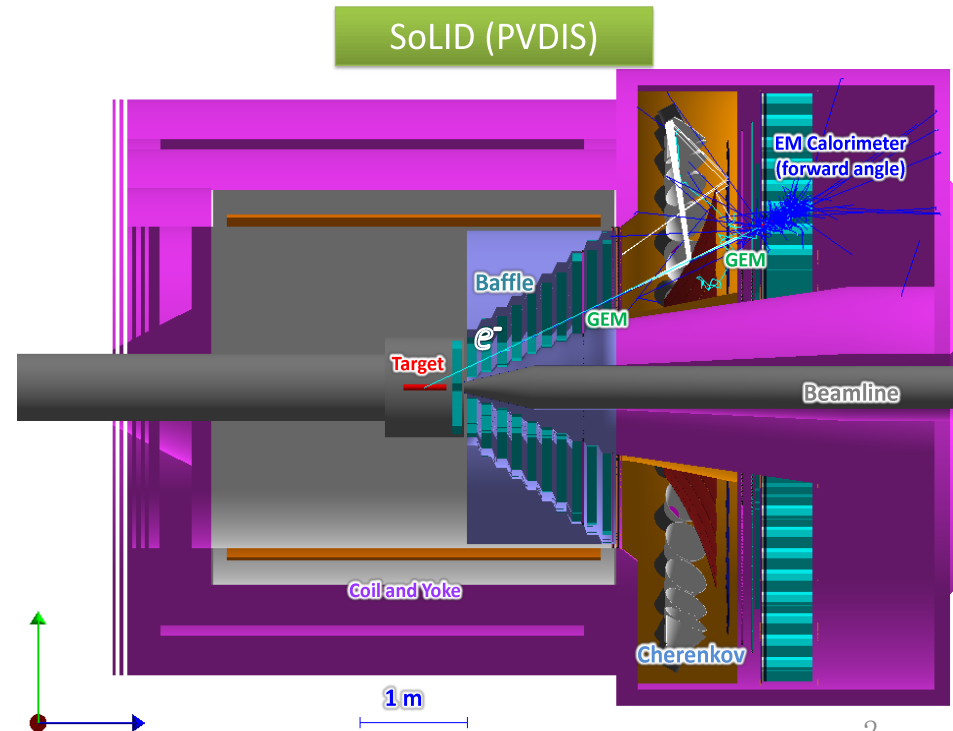
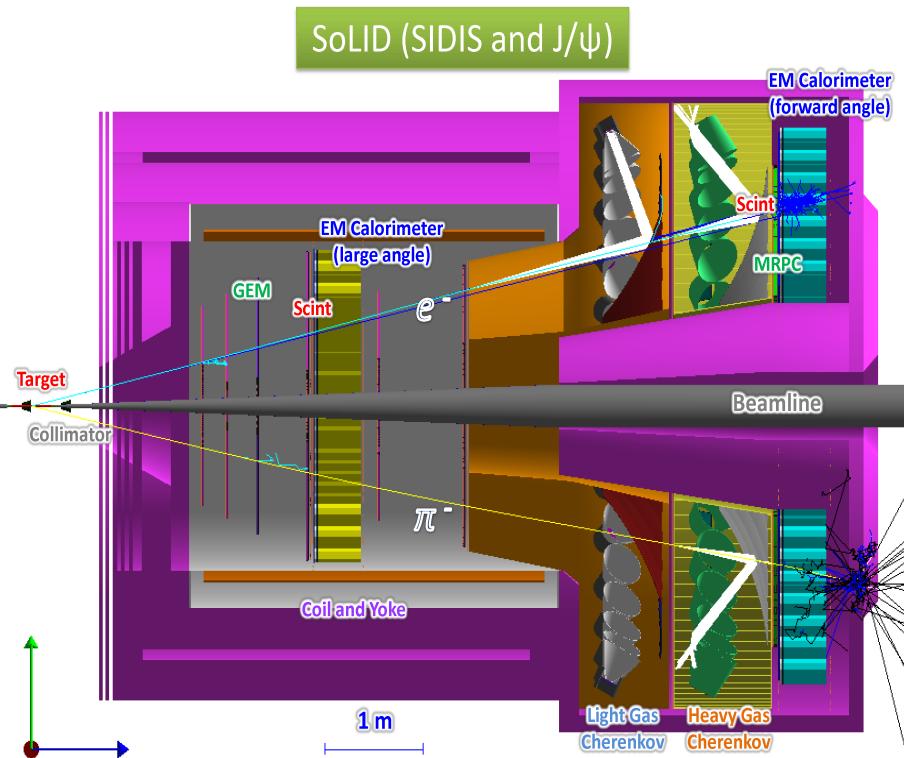
Syracuse University

For the SoLID Collaboration

# SoLID Overview

## SoLID: Solenoidal Large Intensity Device

- High Luminosity ( $10^{37}$  (SIDIS and  $J/\psi$ )  $\sim 10^{39} \text{ cm}^{-2}\text{s}^{-1}$  (PVDIS with baffles)) and,
- Large Acceptance with a full azimuthal coverage
- Take advantage of latest development in detectors, data acquisitions and simulations



# SoLID Overview

## ☑ Semi-Inclusive Deep Inelastic Scattering (SIDIS) Program:

- E12-10-006(A), Single Spin Asymmetry on Transversely Polarized  $^3\text{He}$ , 90 days
- E12-11-007(A), Single and Double Spin Asymmetry on Longitudinally Polarized  $^3\text{He}$ , 35 days
- E12-11-108(A), Single Spin Asymmetry on Transversely Polarized Proton , 120 days
- Run group experiments (Ay, Di-Hadron ...)

## ☑ Parity Violation Deep Inelastic Scattering (PVDIS) Program:

- E12-10-007 (A), Parity Violating Asymmetry in DIS with  $\text{LH}_2$  and  $\text{LD}_2$  , 169 days
- PVDIS-EMC: on  $^{40}\text{Ca}$  and PVDIS-Spin: on pol. $^3\text{He}$ , spin-flavor

## ☑ J/ $\psi$ Program:

- E12-12-006 (A-) Near Threshold Electroproduction of J/ $\psi$  at 11 GeV, 60 days

## ☑ Generalized Parton Distributions (GPDs) Programs:--Run Group Experiments

- E12-12-006A Time-Like Compton Scattering (TCS) with J/Psi configuration
- Deep Exclusive  $\pi^-$  production (DEMP) with polarized  $^3\text{He}$  target and SIDIS configuration (E12-10-006B)
- Other polarized-proton/neutron DVCS and Doubly DVCS, etc.

# SoLID Overview Progress

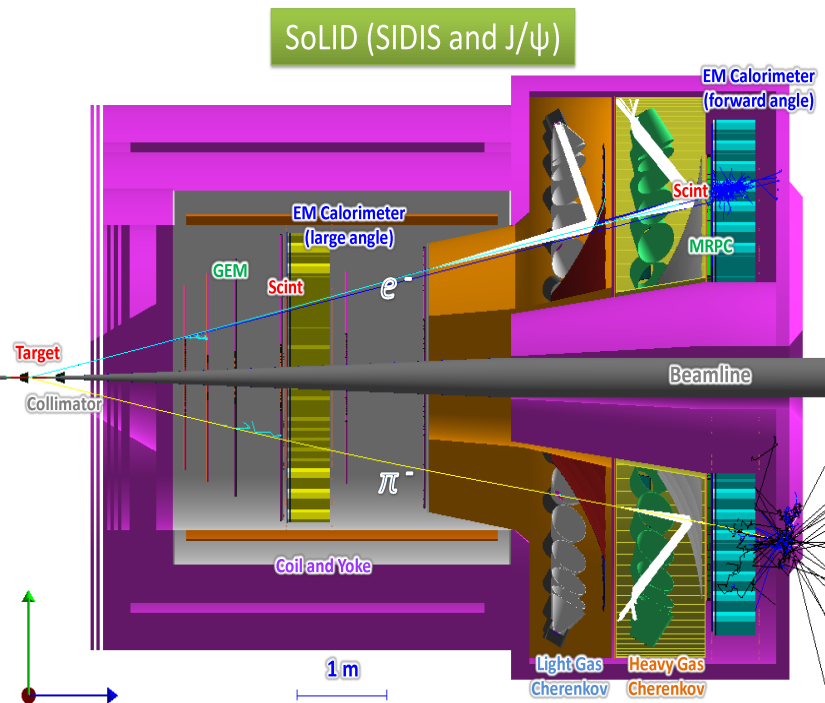
- 2015 Director's Review Recommendations were addressed and the updated preCDR (Preliminary Conceptual Design Report ) submitted in August, 2017
- Very positive Committee Report on the Updated preCDR and Responses to the Recommendations Early October, 2017. The Committee believes that **The SoLID Experiment is ready for its DOE Critical Decision Zero (CD0) Review.**

# SIDIS Program

## ☑ Semi-Inclusive Deep Inelastic Scattering:

- Study 3-D nucleon transverse momentum dependent parton distributions (TMDs)
- Extraction the tensor charge of d & u
- Provide information on quark orbital angular momentum and QCD dynamics

Luminosity  $\sim 10^{37} \text{ cm}^{-2} \text{ s}^{-1}$  (open)



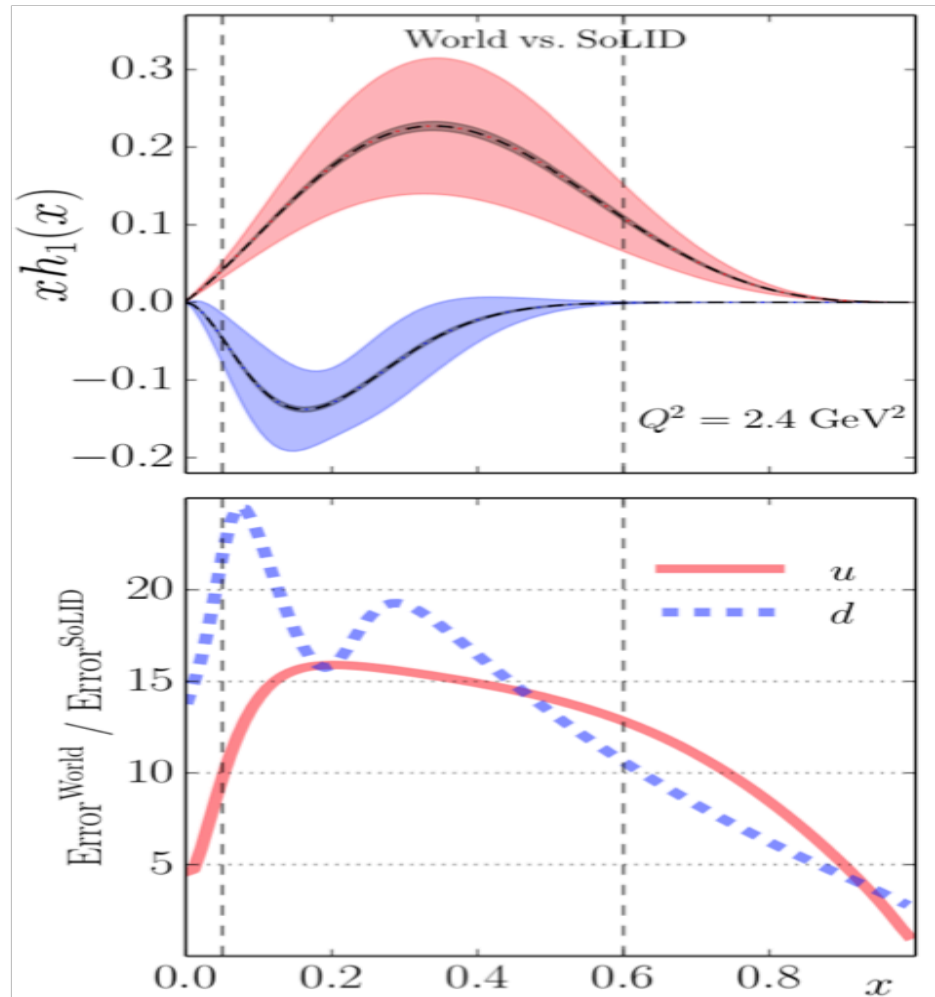
## Leading-Twist TMDs

○ → : Nucleon Spin    ○ ← : Quark Spin

		Quark Polarization		
		U	L	T
Nucleon Polarization	U	$f_1$  unpolarized		$h_1^\perp$  Boer-Mulders
	L		$g_{1L}$  helicity	$h_{1L}^\perp$  longi-transversity (worm-gear)
	T	$f_{1T}^\perp$  Sivers	$g_{1T}$  trans-helicity (worm-gear)	$h_1$  transversity $h_{1T}^\perp$  pretzelocity

# SIDIS Program Impact (**Transversity**)

- Collins Asymmetries  $\sim$  Transversity ( $x$ ) Collin Function
- Transversity: chiral-odd, not couple to gluons, **valence behavior**, largely unknown



Z. Ye et al., PLB 767, 91 (2017)

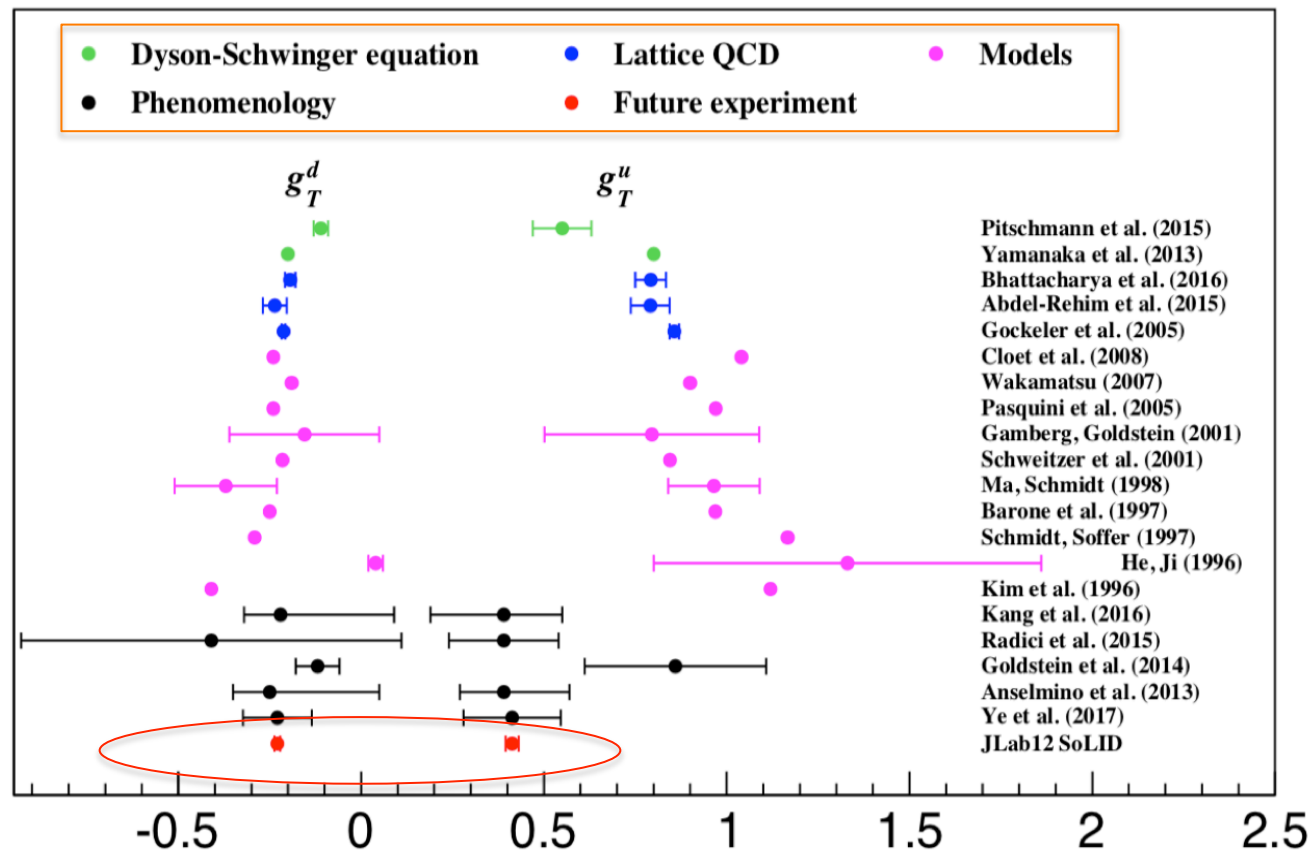
# SIDIS Program Impact (**Tensor Charge**)

## Tensor charge

$$\langle p, \sigma | \bar{\psi}_q i\sigma^{\mu\nu} \psi_q | p, \sigma \rangle = g_T^q \bar{u}(p, \sigma) i\sigma^{\mu\nu} u(p, \sigma) \quad g_T^q = \int_0^1 dx [h_1^q(x) - h_{\bar{q}}^q(x)]$$

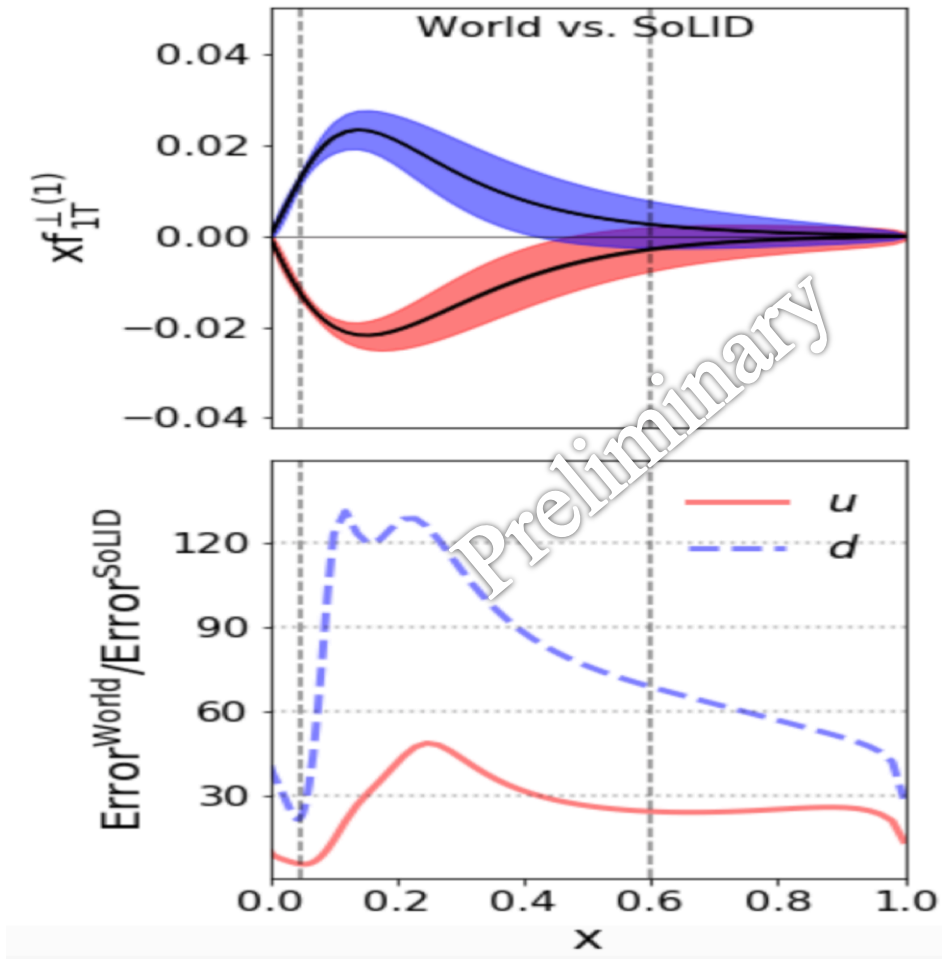
- A fundamental QCD quantity: matrix element of local operators.
- Moment of the transversity distribution: valence quark dominant.
- Calculable in lattice QCD.

❖ With both statistical and systematic errors, 1 order of magnitude improvement



# SIDIS Program Impact (**Silvers**)

New fitting method, nested sampling with Monte-Carlo simulation



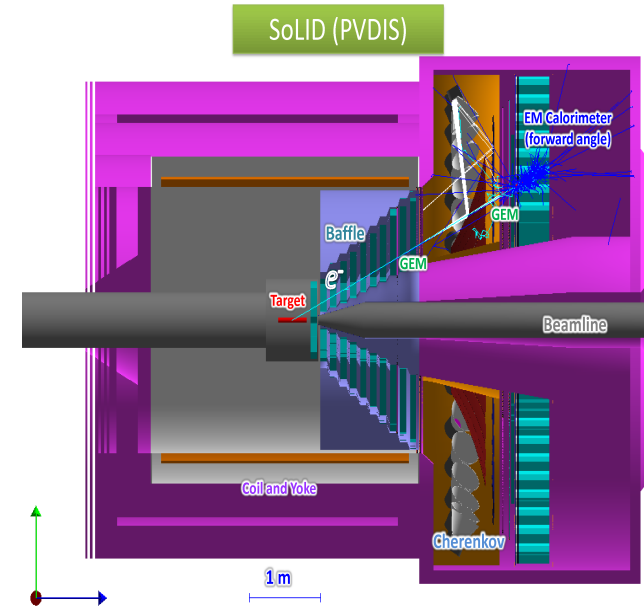
Collaboration with theory group (N. Sato, A. Prokudin, ...) on impact study



# PVDIS Program

## ☑ Parity Violation -Deep Inelastic Scattering:

- **Search for new interactions beyond the Standard Model (SM)**
- **Precision tool to study Hadron Physics:**  
Sensitive to Partonic Charge Symmetry violation (CSV) at the quark level  
Clean probe to study Higher-Twist effects from q-q correlations
- **Measure the d/u ratio for the proton at high x**



$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = - \left( \frac{G_F Q^2}{4\sqrt{2}\pi\alpha} \right) (Y_1 a_1 + Y_3 a_3)$$

$$a_1(x) = \frac{6}{5} \frac{(2C_{1u} - C_{1d})}{u^+ + d^+} \left( 1 + \frac{2s^+}{u^+ + d^+} \right),$$

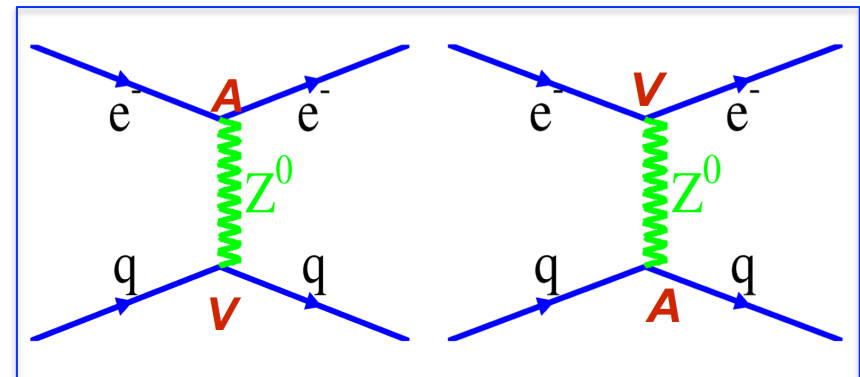
PV elastic e-p scattering, Atomic parity violation

$$a_3(x) = \frac{6}{5} \frac{(2C_{2u} - C_{2d})}{u^+ + d^+} \left( \frac{u^+ - d^+}{u^+ + d^+} \right) + \dots$$

PV deep inelastic scattering (PVDIS)

New physics

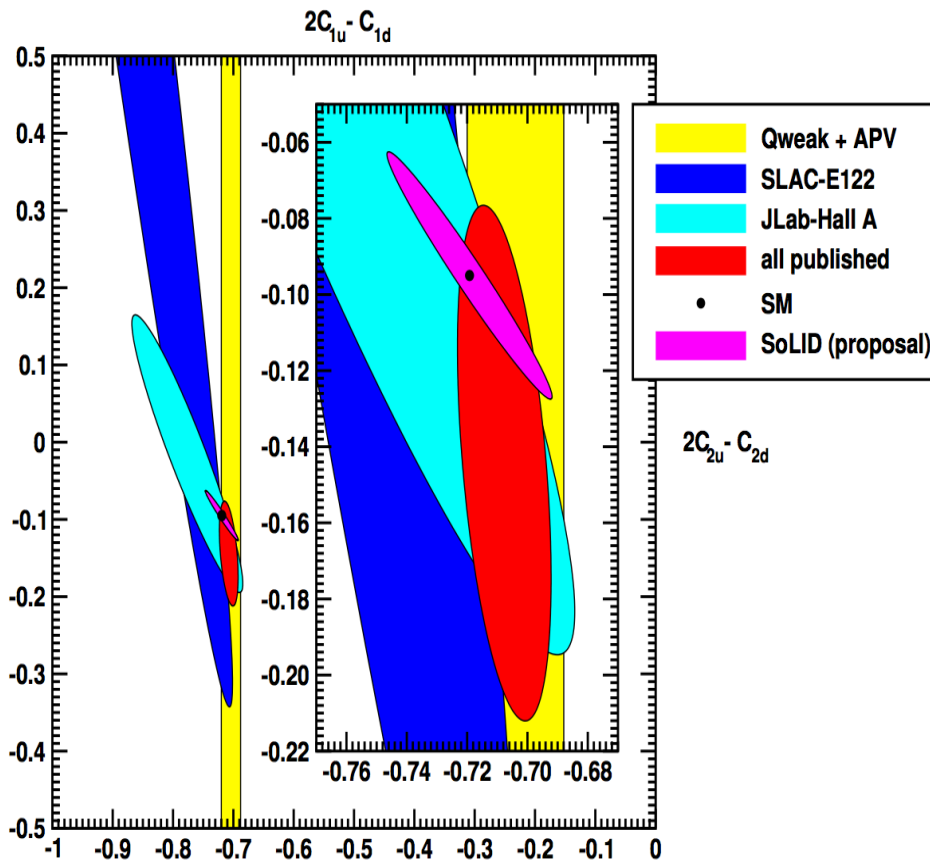
EW neutral current interaction



$$C_{1q} = 2g_A^e g_V^q$$

$$C_{2q} = 2g_V^e g_A^q$$

# New Physics

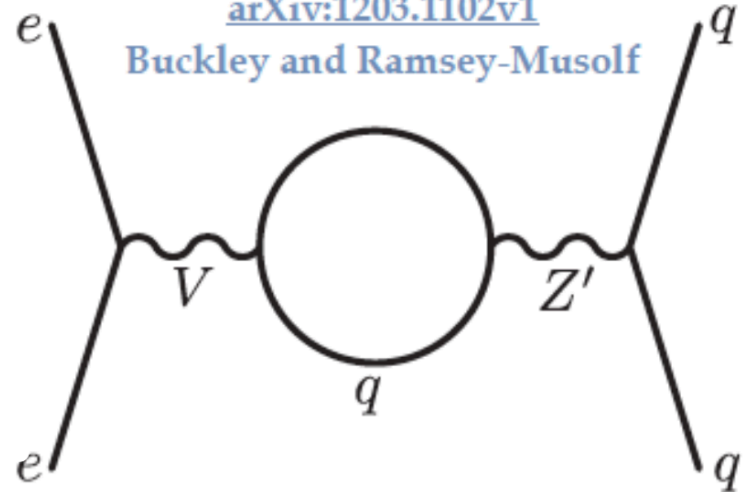


The phase-space of the linear combinations of axial-vector and vector-axial electron-quark effective coupling constants

## Leptophobic $Z'$

[arXiv:1203.1102v1](https://arxiv.org/abs/1203.1102v1)

Buckley and Ramsey-Musolf



**SOLID can improve sensitivity:  
100-200 GeV range**

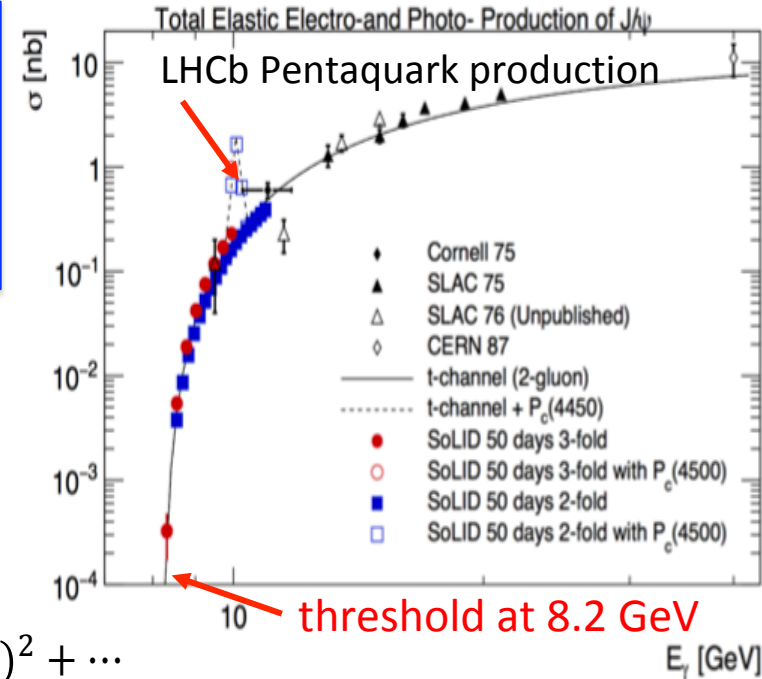
Since electron vertex must be vector, the  $Z'$  cannot couple to the  $C_{1q}$ 's if there is no electron coupling: can only affect  $C_{2q}$ 's

- Hard to see low mass leptophobic  $Z'$ 's at the LHC

# J/ψ Program

## ☑ : Near Threshold production of J/ψ

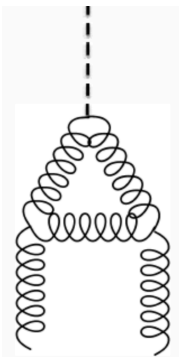
- Measure the contribution of the gluons to the **mass of the proton** directly.
- Produce and determine the quantum numbers of the LHCb pentaquark if it exist.



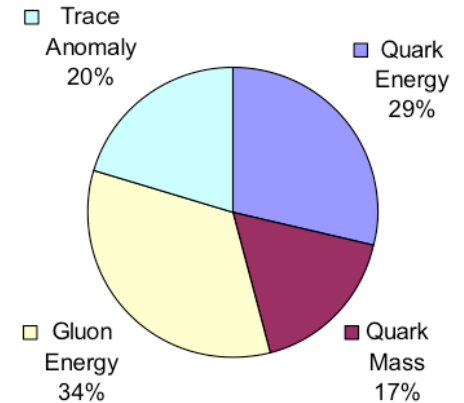
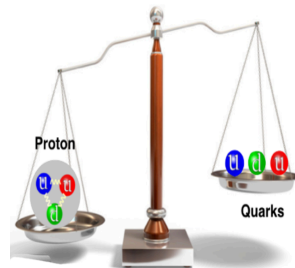
✧ Trace of the QCD energy-momentum tensor:

$$T_{\alpha}^{\alpha} = \frac{\beta(g)}{2g} G^{\mu\nu,\alpha} G_{\mu\nu}^{\alpha} + \sum_{q=u,d,s,c,b,t} m_q (1 + \gamma_m) \bar{\psi}_q \psi_q$$

QCD trace anomaly  $\beta(g) = - (11 - 2n_f/3)g^3 / (4\pi)^2 + \dots$



How does QCD generate the mass of the proton?



# SoLID Subsystem Progress

**Magnet:** Magnet modeling (Jay, JLab)

**Baffle:** Shape and material optimization

**GEM China** (USTC, CIAE, Tsinghua, Lanzhou and IMP ) continue R&D, new option uRWELL

**GEM:** R&D for Hall A 12 GeV experiments, option for readout chips (UVa)

**LGC:** Pre-R&D ongoing (Temple)

**HGC:** Conceptual design, prototyping (Duke)

**EC and SPD:** prototyping with cosmic/beam test (UVa, Shandong and Tsinghua)

**MRPC:** R&D for Kaon detection (China, funding awarded, 4.5M Chinese Yuan)

**Simulations:**

- Gean4 with all subsystems combined in the whole SoLID simulation
- More realistic estimation of acceptance, background, trigger rate ...
- GEM segmentation, LGC background, Ecal performance with background, and first round MRPC/SPD digitization software.

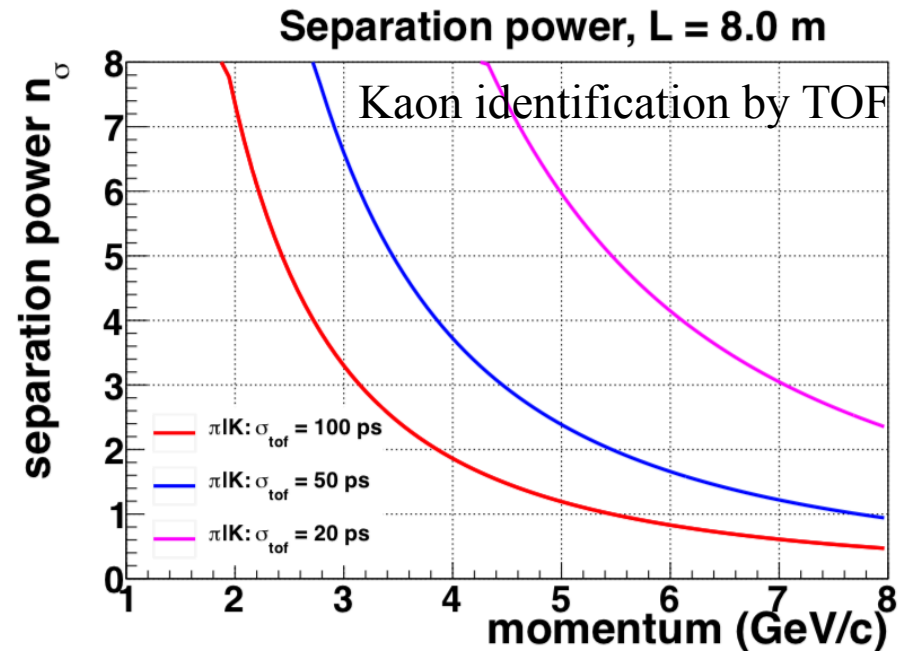
**DAQ:** Improve readout electronic systems for sub-detectors GEM and MRPC

# MRPC---R&D for Kaon Detection

Currently designed MRPC(Multi-gap Resistive Plate Chamber ) time resolution can reach 50 ps with test beam, and 80 ps in high background area.

A joint Chinese collaboration for SoLID, sPHENIX, and EIC for the next generation MRPC **aims at 20 ps time resolution.**

- Hardware, readout electronics system and the analysis frame are under prototyping.
- Beam test and finalizing of the detector and electronics design will be done in 2019

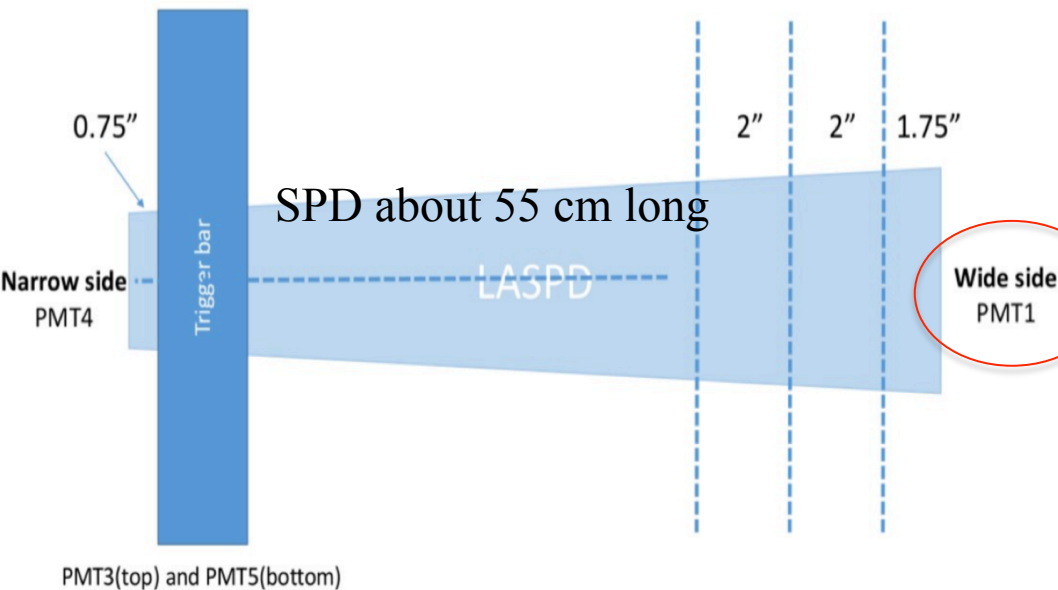


# The EC and SPD

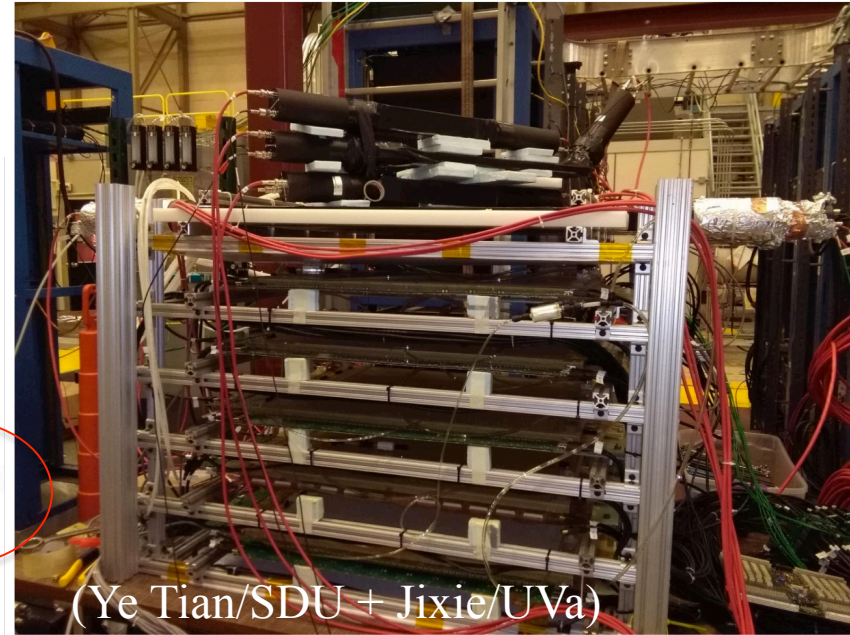
## ➤ LASPD time resolution test

The Scintillator Pad Detector (SPD) is to reduce calorimeter-based trigger rates for high-energy charged particles.

PMT0(top) and PMT2(bottom)



## Cosmic test of SPD+GEM at JLab test Lab



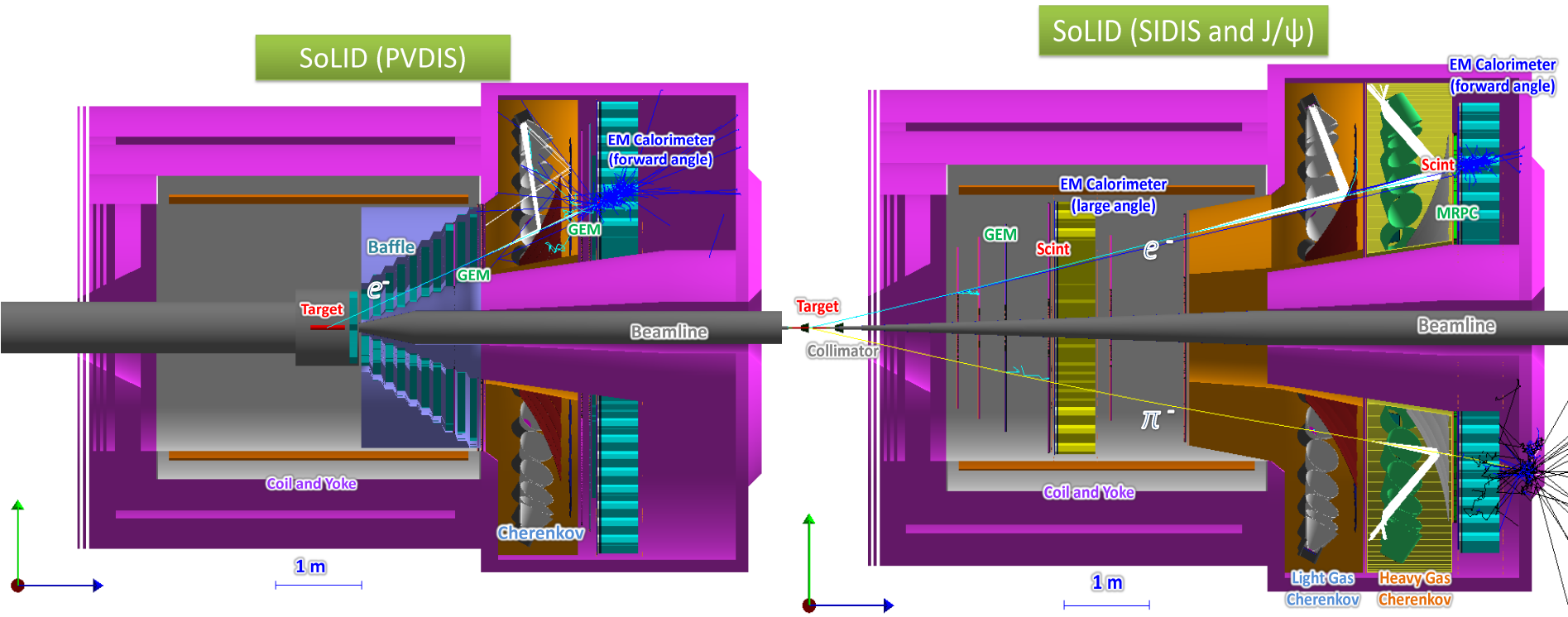
## ➤ Preparing beam test (7 shashlyk modules? )

- Prototype shashlyk modules (SDU1, 2, 3 and THU1, 2 )
- SDU is planning to construct SDU4

# Summary

- SoLID with a large acceptance detector that is capable of operating at very high luminosities will provide high-precision JLab 12-GeV measurements in QCD (TMDs,  $J/\psi$ ,  $d/u$ , GPDs), and electroweak physics.
- Active MC simulation & software developments and Prototyping on subsystem are ongoing.
- A strong and still expanding collaboration:  
250+ collaborators from 70+ institutes, 13 countries
- Looking toward the DOE science review.

# Thank you !

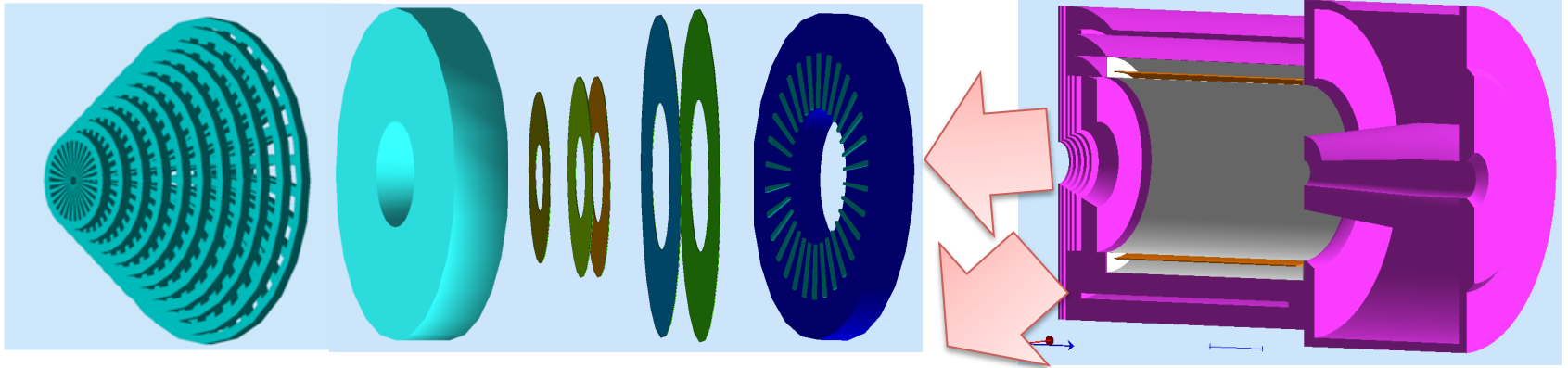




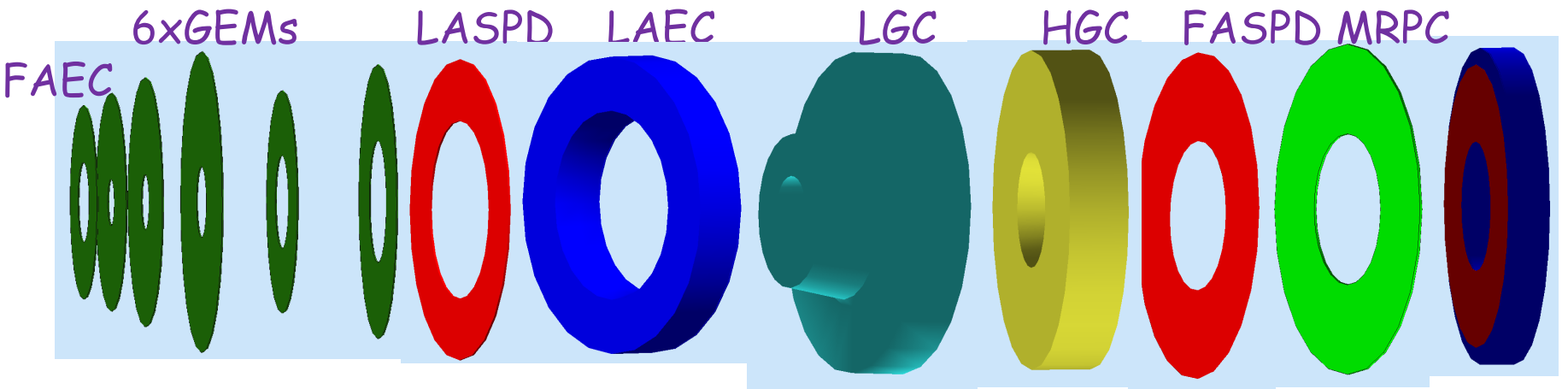
# Backup

# SoLID Detector Overview

PVDIS: Baffle LGC 5xGEMs EC



SIDIS&J/Psi:



# Parity Violation in Deep Inelastic Scattering

$$A_{LR}^{DIS} \approx -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha} \left[ a_1(x) + a_3(x) \frac{1 - (1-y)^2}{1 + (1-y)^2} \right] \quad x \equiv x_{Bjorken} = \frac{Q^2}{2M\nu}, y = 1 - \frac{E'}{E}$$

In valence quark region:

at high x

$$a_1(x) = \frac{6}{5}(2C_{1u} - C_{1d}) \left( 1 + \frac{0.6s^+}{u^+ + d^+} \right), \quad a_3(x) = \frac{6}{5}(2C_{2u} - C_{2d}) \left( \frac{u^+ - d^+}{u^+ + d^+} \right) + \dots$$

SM at tree level:

$$C_{1u} = 2g_A^e g_V^u \approx -\frac{1}{2} + \frac{4}{3} \sin^2 \theta_W \approx -0.19$$

$$C_{1d} = 2g_A^e g_V^d \approx \frac{1}{2} - \frac{2}{3} \sin^2 \theta_W \approx 0.34$$

$$C_{2u} = 2g_V^e g_A^u \approx -\frac{1}{2} + 2\sin^2 \theta_W \approx -0.030$$

$$C_{2d} = 2g_V^e g_A^d \approx \frac{1}{2} - 2\sin^2 \theta_W \approx 0.025$$

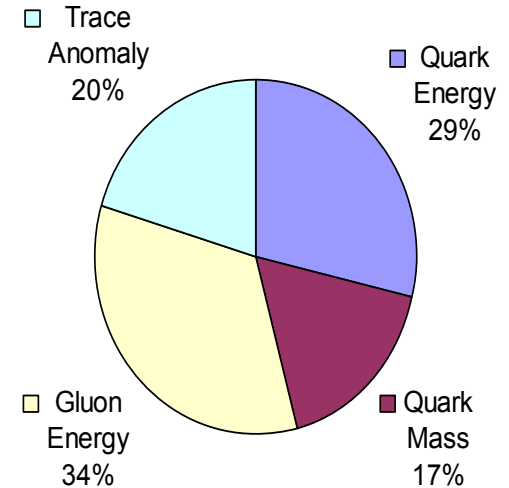
→ PV elastic e-p scattering,  
Atomic parity violation

→ PV deep inelastic scattering  
(PVDIS)

# Proton Mass: QCD energy

X. Ji, PRL741071(1995)

- One can calculate the proton mass through the expectation value of the QCD Hamiltonian,



$$H_{\text{QCD}} = H_q + H_m + H_g + H_a .$$

$$H_q = \int d^3 \vec{x} \bar{\psi} (-i \mathbf{D} \cdot \alpha) \psi, \quad \leftarrow \text{Quark energy}$$

$$H_m = \int d^3 \vec{x} \bar{\psi} m \psi, \quad \leftarrow \text{Quark mass}$$

$$H_g = \int d^3 \vec{x} \frac{1}{2} (\mathbf{E}^2 + \mathbf{B}^2), \quad \leftarrow \text{Gluon energy}$$

$$H_a = \int d^3 \vec{x} \frac{9\alpha_s}{16\pi} (\mathbf{E}^2 - \mathbf{B}^2). \quad \leftarrow \text{Trace anomaly (Dark Energy)}$$

# Hadron Physics with PVDIS

- Precision tool to study Hadron Physics
- Sensitive to Partonic Charge Symmetry Violation at large X
- Clean probe to study Higher-Twist effects from q-q correlations
- Broad kinematic coverage allows clean separation of different Physics

$$A_{DIS}^D = A_{SM} \left[ 1 + \frac{\beta_{HT}}{(1-x)^3} Q^2 + \beta_{CSV} x^2 \right]$$

	x	y	Q <sup>2</sup>
New Physics		yes	
CSV	yes		
Higher Twist	yes		yes

