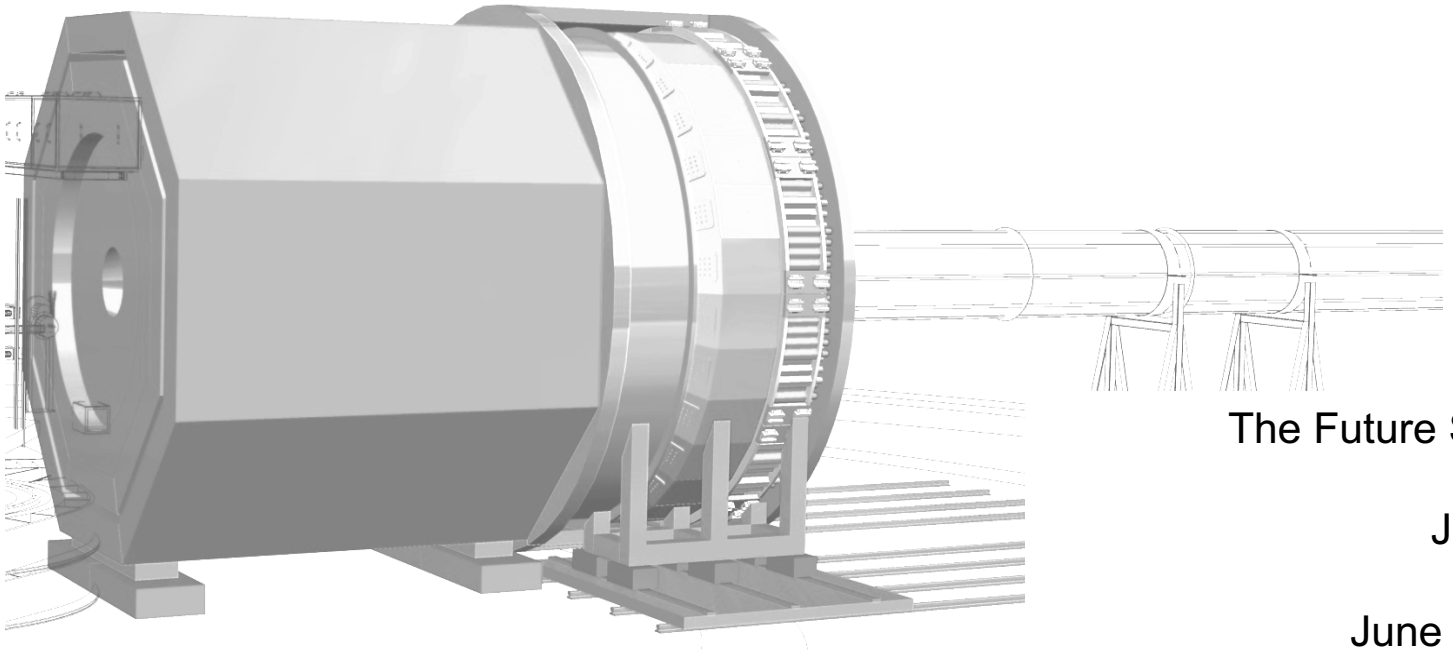
SoLID



The Future SoLID Program

JULO

June 23, 2020

Paul Souder

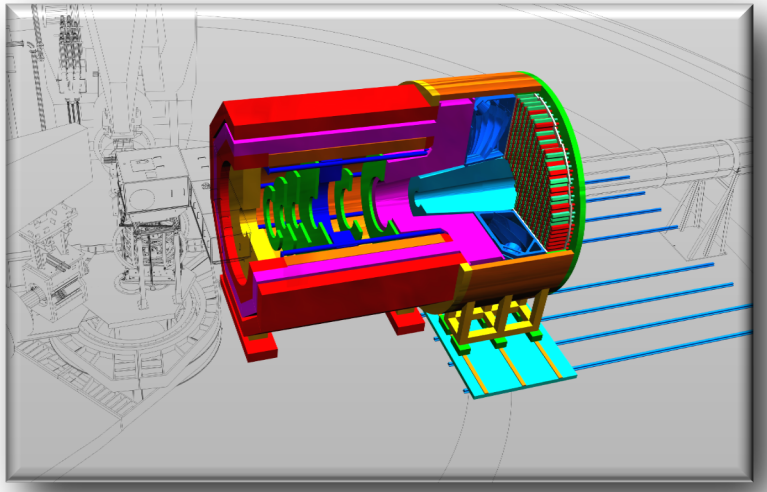
Syracuse University

(for the SoLID Collaboration)

SOLENOIDAL LARGE INTENSITY DEVICE

Outline

1. Physics reach of Solid
2. The Solid Spectrometer
3. Status of the experiment

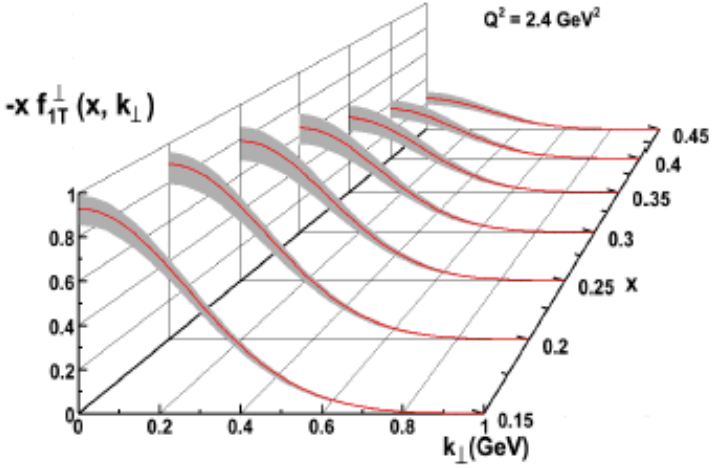


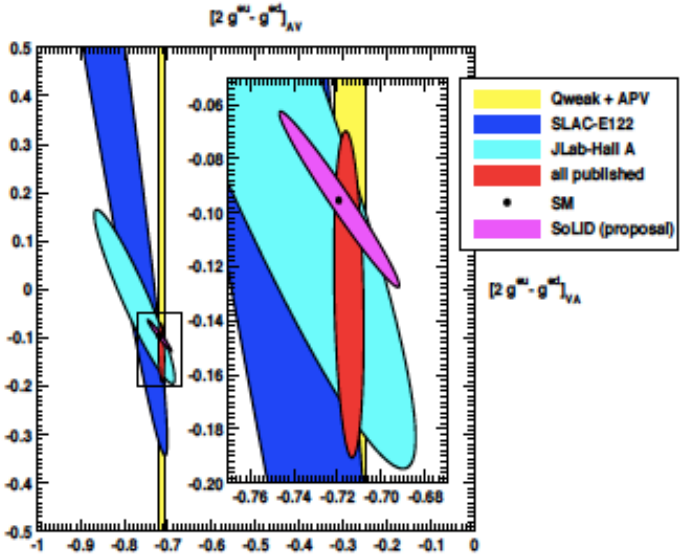
SoLID Physics Overview QCD at the intensity frontier

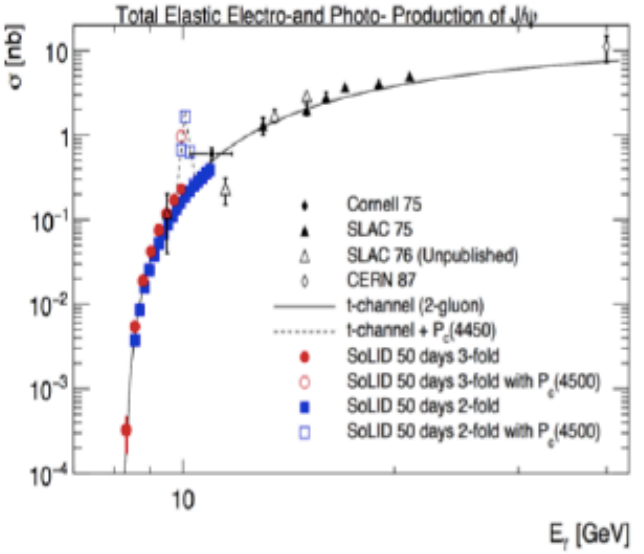
- **Full exploitation of JLab 12 GeV Upgrade to maximize scientific return**

A Large Acceptance Detector AND Can Handle High Luminosity (10^{37}-10^{39})

- SIDIS - reaching ultimate precision for tomography of the nucleon (E12-10-006, E12-11-007, E12-11-108)
- PVDIS in high-x region - providing sensitivity to new physics at 10-20 TeV (E12-10-007)
- Threshold J/ψ - probing strong color fields in the nucleon and the origin of its mass (trace anomaly) (E12-12-006)





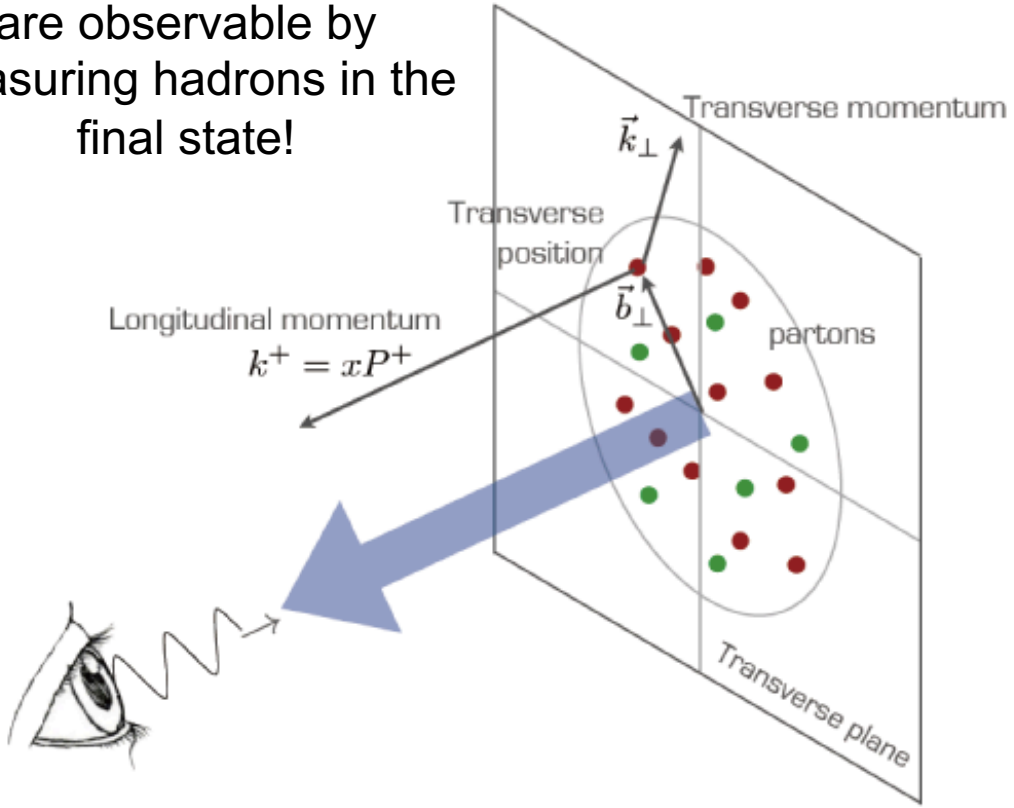


- **2015 LRP recommendation IV**

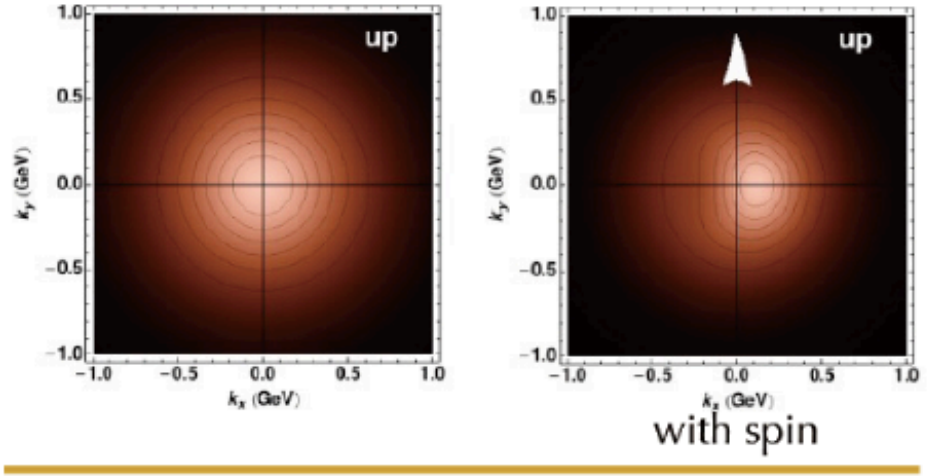
- We recommend increasing investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories – **SoLID – mid-scale project**

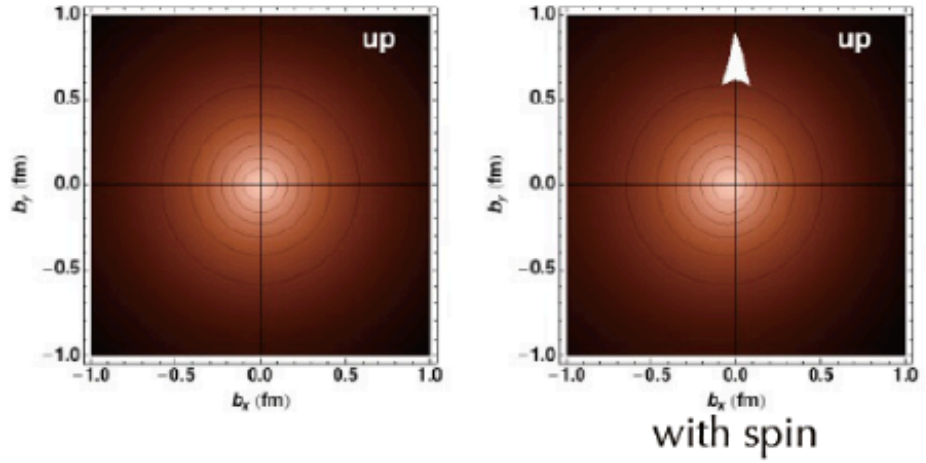
3D Nuclear Structure

Transverse momentum and spin of struck quark are observable by measuring hadrons in the final state!



Effects are big!

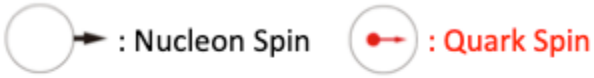




Generalized parton distribution (GPD)
Transverse momentum dependent parton distribution (TMD)

Reminder: TMD's

Leading Twist TMDs



Nucleon Polarization	Quark polarization: Un-Polarized (U)	Quark polarization: Longitudinally Polarized (L)	Quark polarization: Transversely Polarized (T)
U	f_1 =		$h_1^\perp$ = − Boer-Mulder
L		g_1 = − Helicity	$h_{1L}^\perp$ = −
T	$f_{1T}^\perp$ = − Sivers	$g_{1T}^\perp$ = −	h_{1T} = − Transversity $h_{1T}^\perp$ = −

SoLID SIDIS Projection: Major Improvement in Precision

Compare SoLID with World Data

Fit Collins and Sivers asymmetries in SIDIS and e^+e^- annihilation

World data from HERMES, COMPASS and JLab-6 GeV

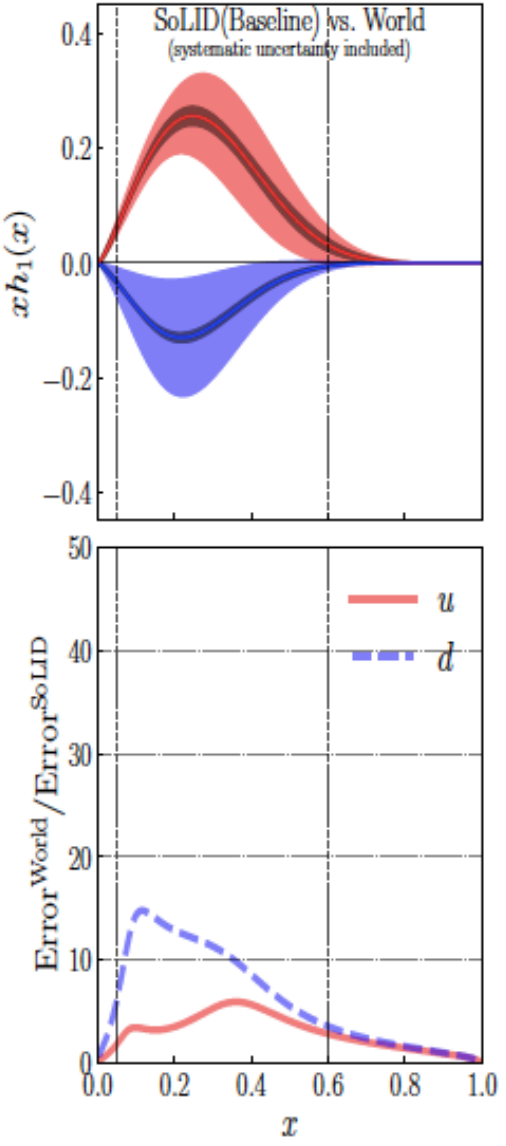
e^+e^- data from BELLE and BABAR

Monte Carlo method with nested sampling algorithm is applied

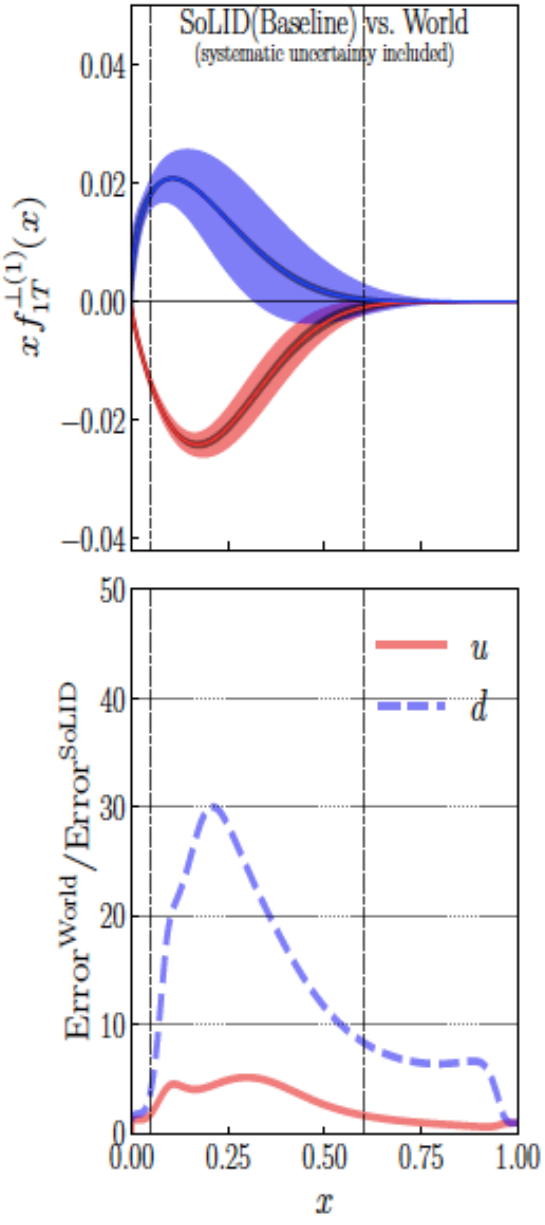
Including both systematic and statistical uncertainties

Ref: Z. Ye *et al*, Phys. Lett. B 767, 91 (2017)

Transversity



Sivers

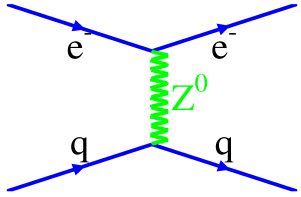


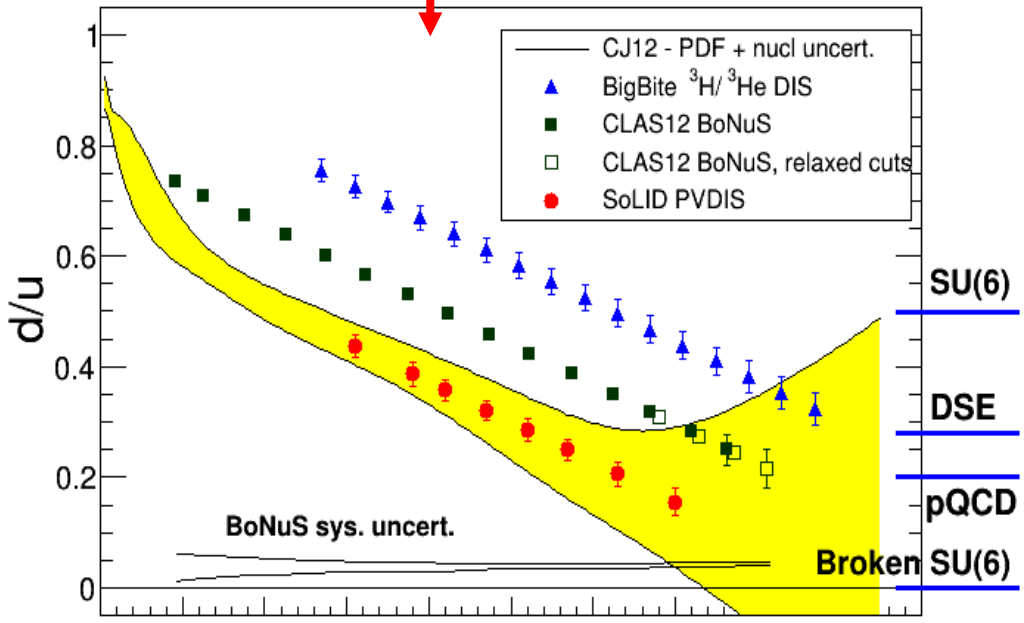
SoLID baseline used

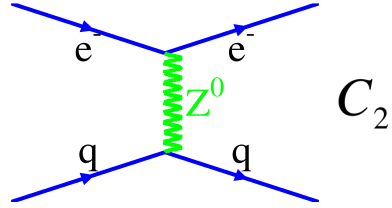
PVDIS: Physics Program

1. Beyond Standard Model test
2. Charge symmetry violation
3. Quark-quark correlations
4. d/u with no nuclear corrections

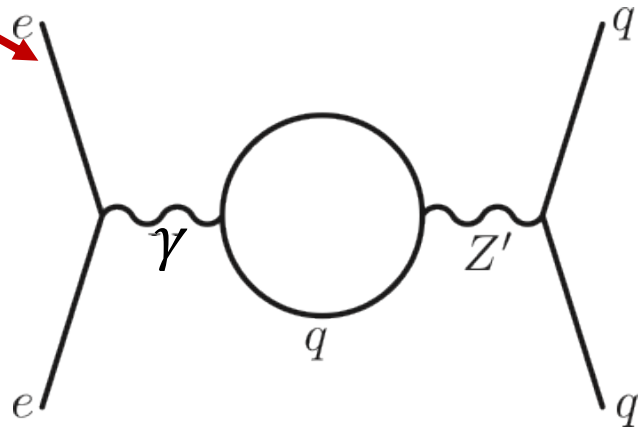
$$C_{1i} \equiv 2 g_A^e g_V^i$$







$$C_{2i} \equiv 2 g_V^e g_A^i$$

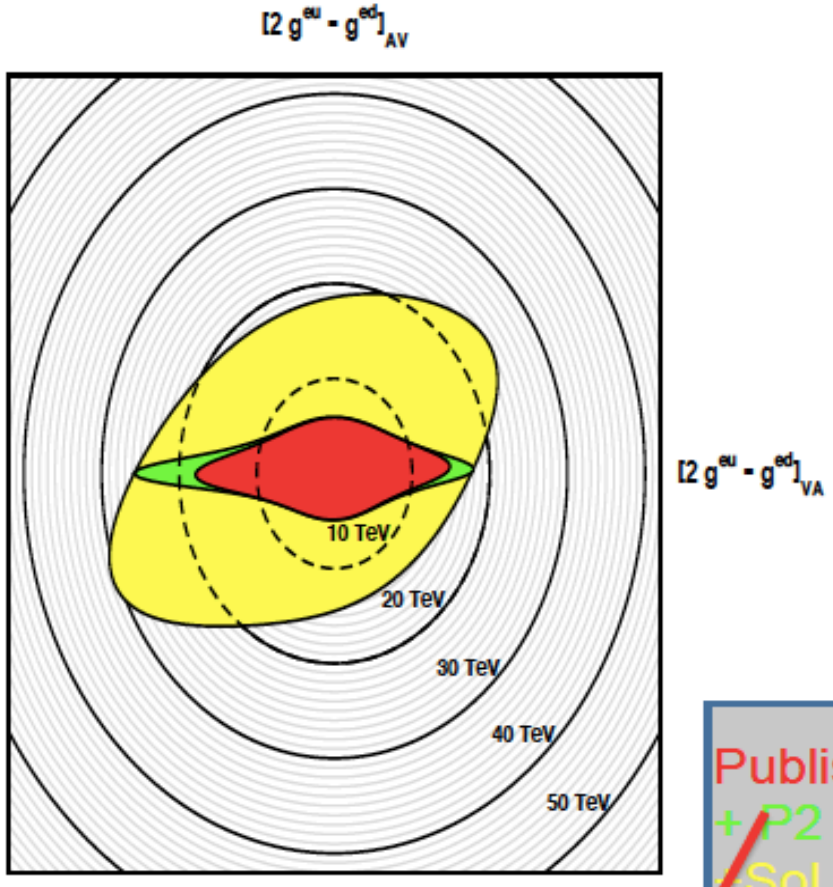


Phys.Lett. B712 (2012) 261-265

This radiative correction diagram for a BSM leptophobic Z' can only affect C_{2q}*'s*

PVDIS: BSM with SMEFT

PVDIS in high-x SoLID has high-energy reach complimentary with the LHC.



Published data
+ P2 at Mainz
+SoLID

Nature **557**, no. 7704, 207 (2018)

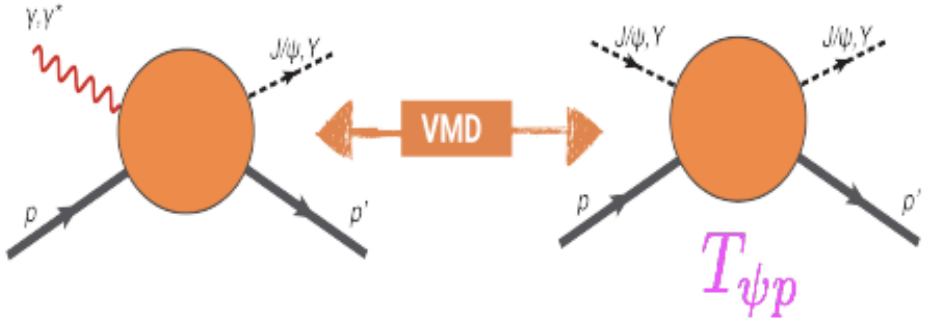
Nature **506**, no. 7486, 67 (2014)

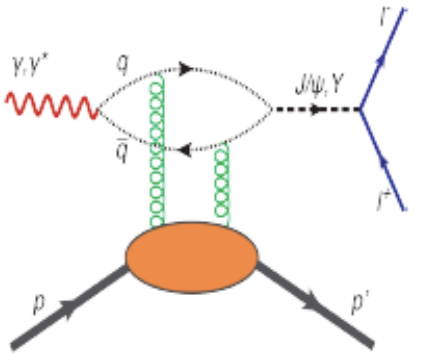
SMEFT Lagrangian is used for general BSM searches:

$$\mathcal{L} = \sum_{d}^{6,8\ldots} \sum_{ij} \frac{C_d^{ij}}{\Lambda^{4-d}} \mathcal{O}_d^{ij}$$

C_{2i} from SoLID provides a unique constraint on the C^{ij}_6

J/ψ Production: Relationship to Proton Mass





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

Heavy quark – dominated by two gluons

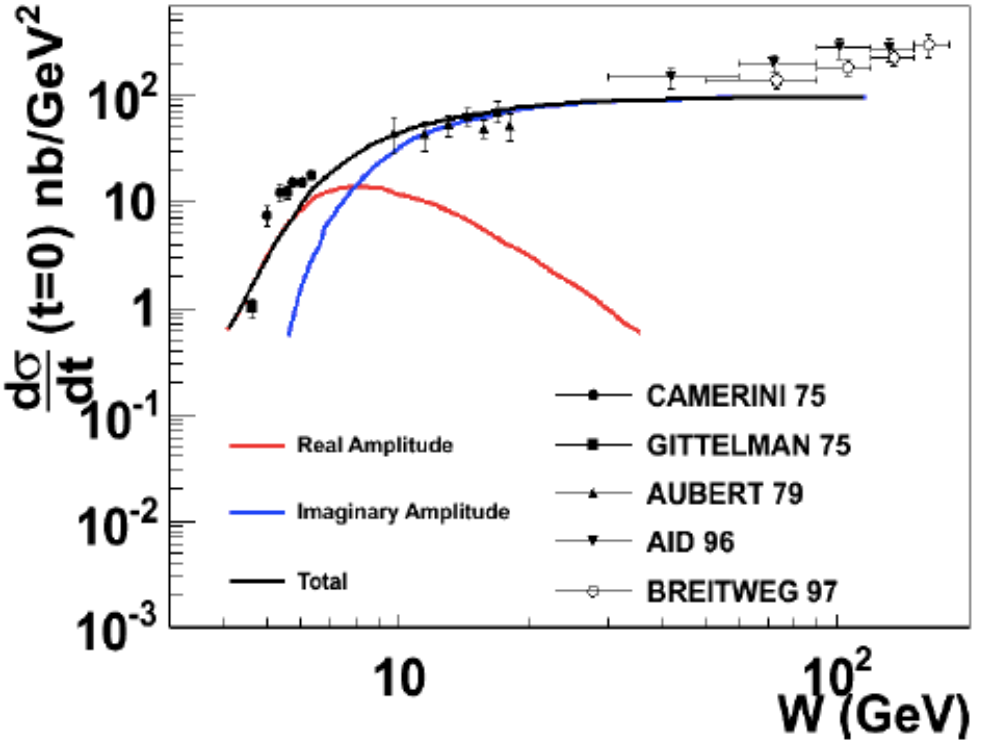
$$\langle P|T^{\alpha}_{\alpha}|P\rangle = 2P^{\alpha}P_{\alpha} = 2M_p^2$$

$$\frac{d\sigma_{\gamma N\to\psi N}}{dt}(s,t=0) = \frac{3\Gamma(\psi\to e^+e^-)}{\alpha m_\psi}\left(\frac{k_{\psi N}}{k_{\gamma N}}\right)^2 \frac{d\sigma_{\psi N\to\psi N}}{dt}(s,t=0)$$

$$\frac{d\sigma_{\psi N\to\psi N}}{dt}(s,t=0) = \frac{1}{64\pi}\frac{1}{m_\psi^2(\lambda^2-m_N^2)}|\mathcal{M}_{\psi N}(s,t=0)|^2$$

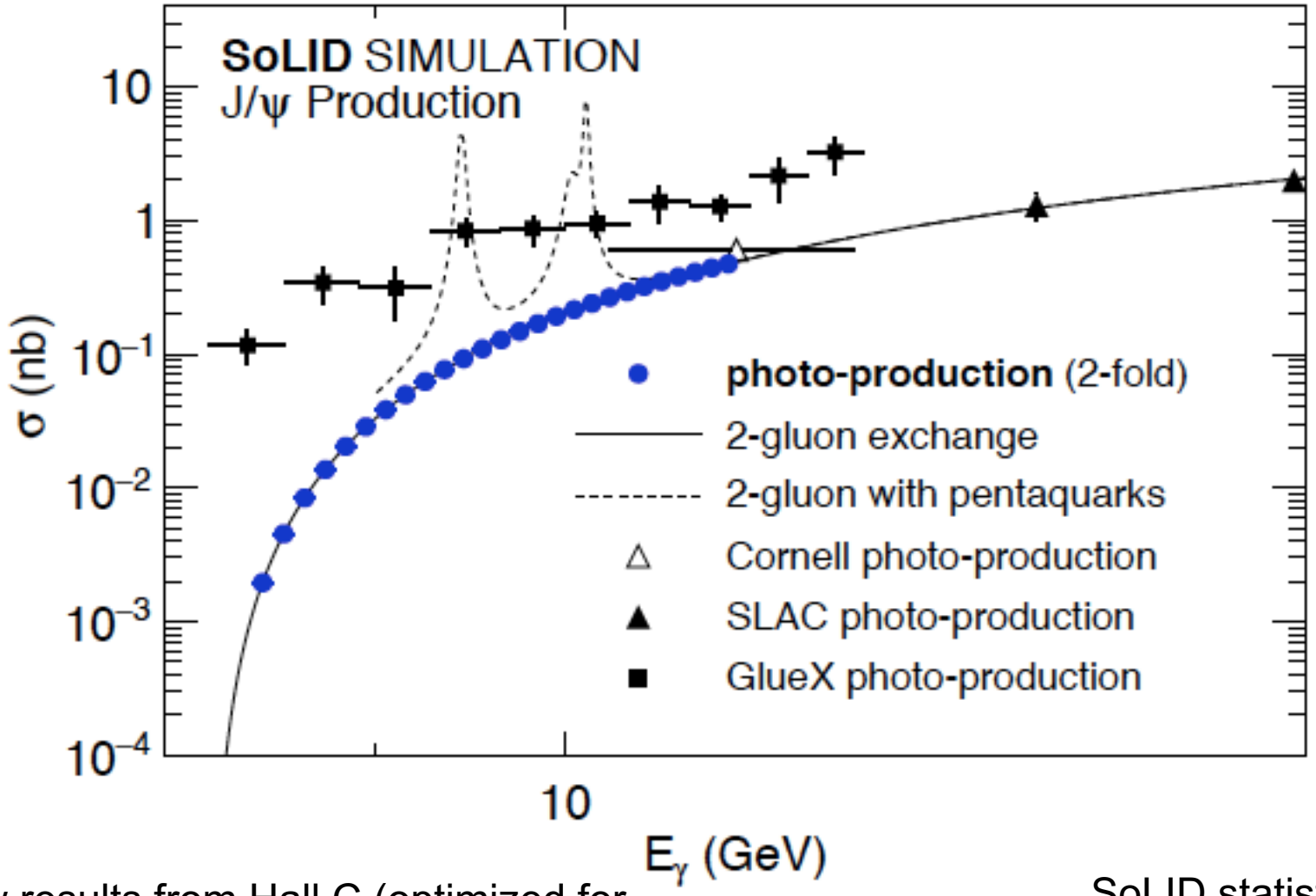
VMD relates photoproduction cross section to quarknium-nucleon scattering amplitude

- **Imaginary part** is related to the total cross section through optical theorem
- **Real part contains the conformal (trace) anomaly;** Dominate the near threshold region and constrained through dispersion relation



A measurement near threshold could allow access to the trace anomaly

LHCb Pentaquark?



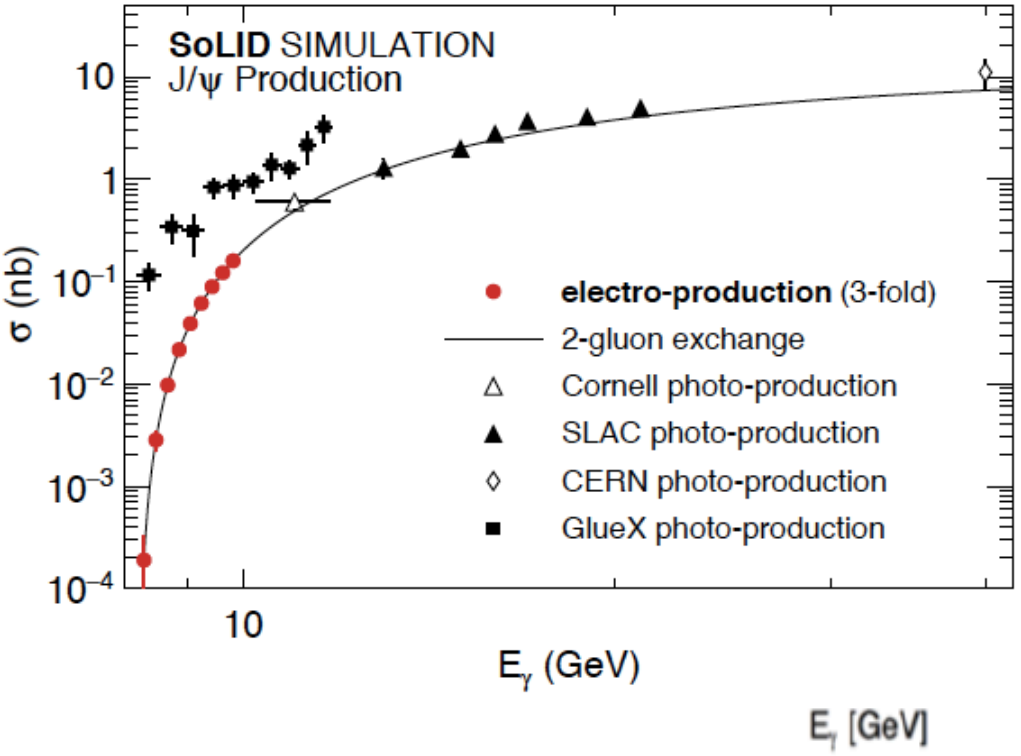
New results from Hall C (optimized for pentaquark search) expected this spring

SoLID statistics allow us to explore Q2 and t dependence

J/ψ with SoLID vd Upsilon Production at the EIC

SoLID with J/ψ

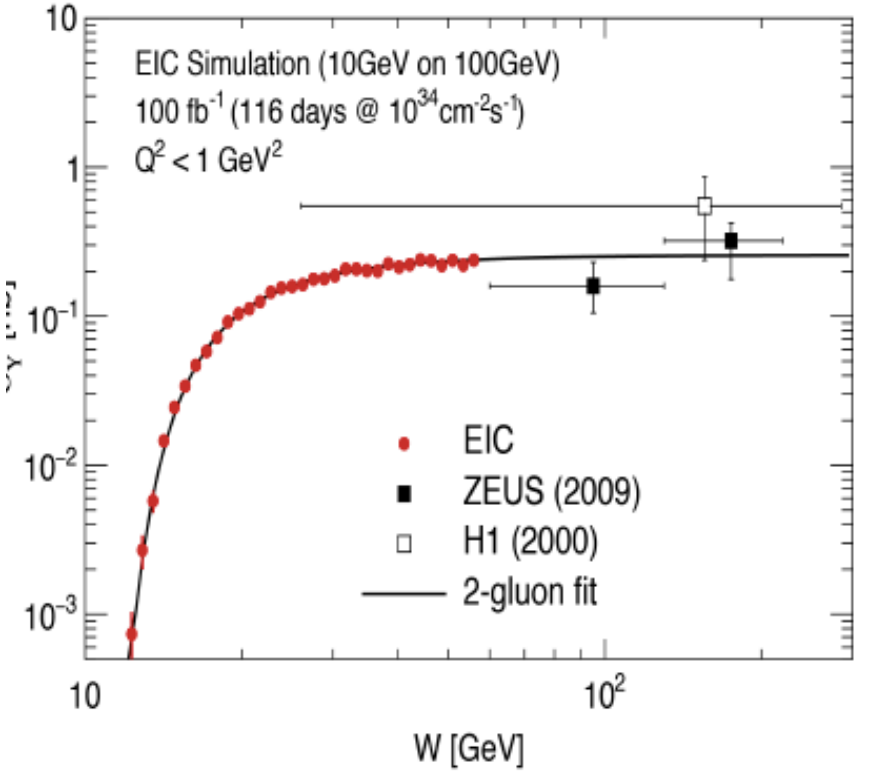
Total elastic electro and photo-production of J/psi



E_γ [GeV]

EIC with Upsilon

Total elastic electro and photo-production of Upsilon



Trace of EMT proportional to Quarkonium-proton scattering amplitude
to be measured at JLab with J/psi at SoLID or Upsilon at EIC

Both SoLID and EIC are needed to confirm the trace anomaly extraction and could lead to a solution of the nucleon mass puzzle

Synergy Between SoLID and the EIC

A. Physics
   1. Proton Mass
   2. Proton Spin
   3. 3D Imaging (Complementary range in x)

B. Experimental Techniques
   1. Streaming Readout
   2. Machine Learning for tracking
   3. Large Scale DAQ

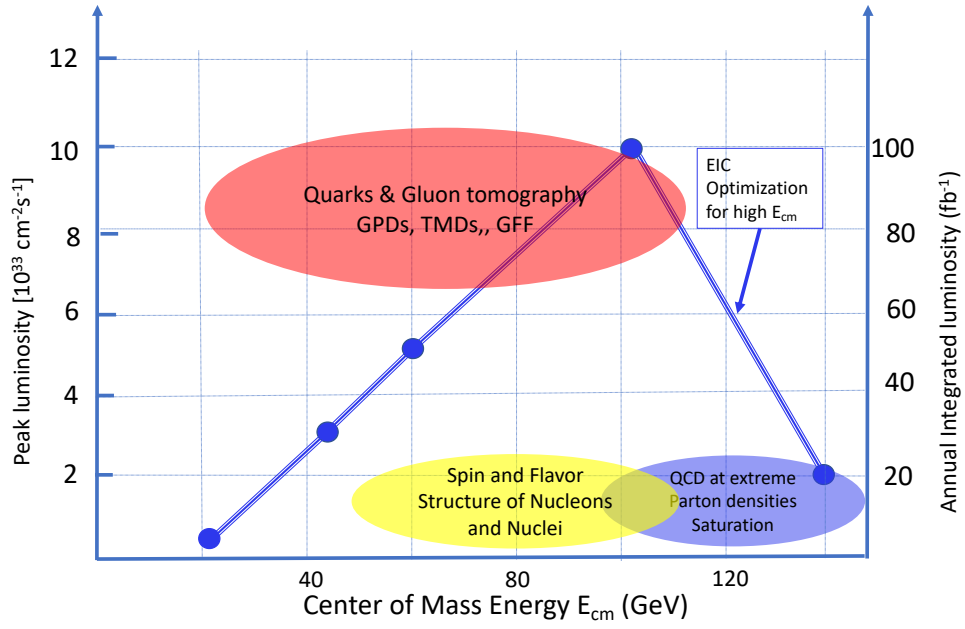
SoLID will be a bridge that helps train the workforce for the EIC.

EIC: QCD energy frontier

✓ luminosity ($10^{33\text{-}34}$ /cm^2/s)

✓ variable center-of-mass energy **(20-140 GeV)**

✓Sea quark and gluon region



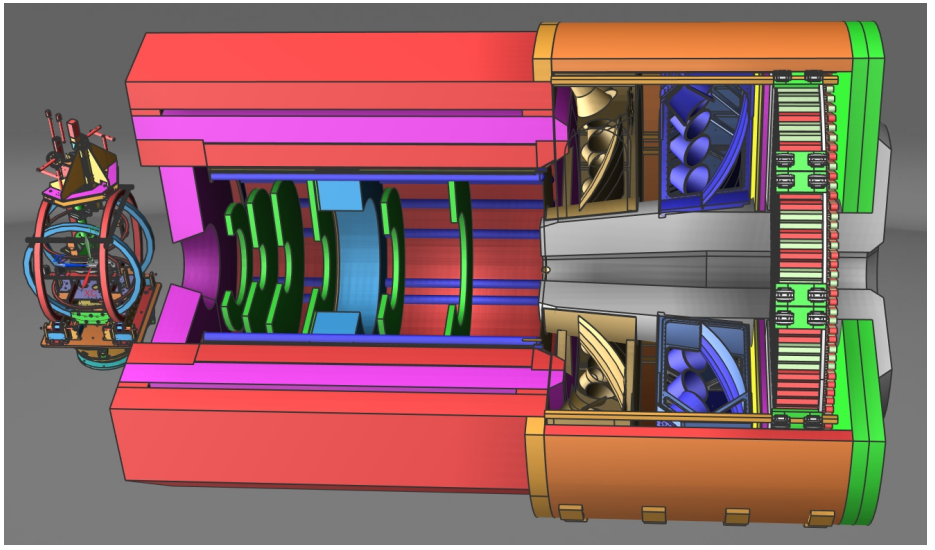
(Figure credit: Volker Burkert)

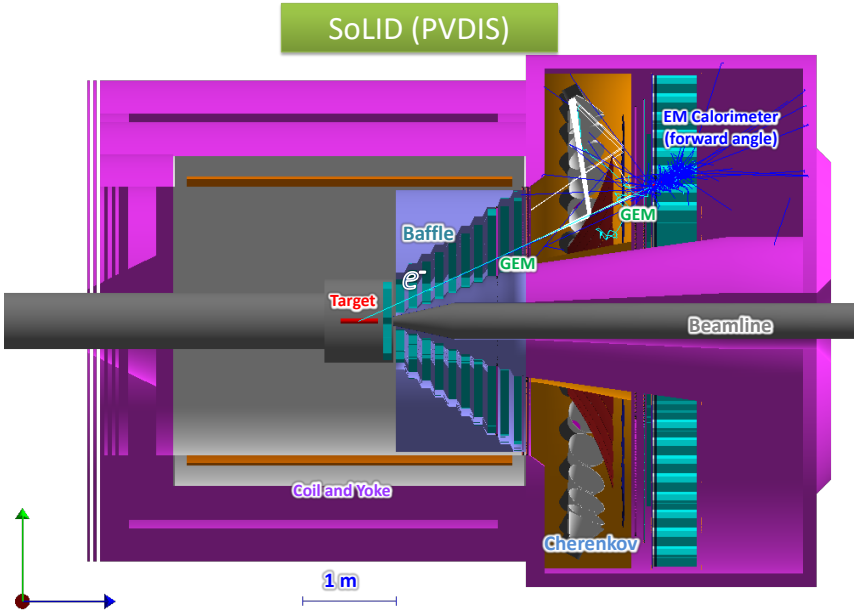
SoLID Apparatus

Requirements are Challenging

- High Luminosity (10^{37}-10^{39})
- High data rate
- High background
- Low systematics
- High Radiation
- Large scale (Like RHIC)
- New Technologies
  - GEM's
  - Shashlyk Ecal
  - Pipeline DAQ

Polarized ^{3}He (``neutron") @ SoLID





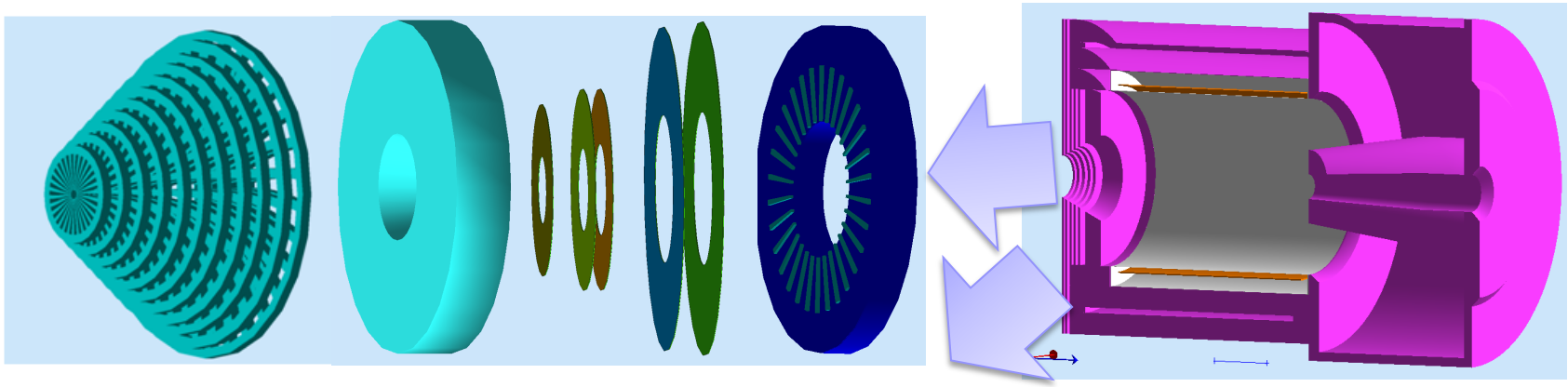
Timeline and Proposed Schedule

- Since 2010: Five SoLID experiments approved by PAC with high rating
  3 SIDIS with polarized ^{3}He/p target, 1 PVDIS, 1 threshold J/ψ
  Five run-group experiments approved
- 2013: CLEO-II magnet requested, agreed, arrived at JLab 2016,
  steel arrived August 2019.
- **2014: pCDR submitted to Jlab with cost estimation and proposed schedule**
  estimation based on Hall D and CLAS12 experience
- 2015: Director's Review, positive with many recommendations
- 2017: Updated pCDR submitted to JLab with responses to the recommendations
- 7/2018: DOE NP visit and discussion: → **update cost estimation**
- 1/2019: **Updated cost estimation (updated pCDR) submitted to the lab**
- **8/2019: New cost estimation with WBS structure and proposed schedule**
- 9/2019: Director's Review 9/9-9/11 with WBS structure and proposed schedule
- 11/2019 Pre-R&D Plan Funded

SoLID MIE Submission to DOE	February 2020
Science Review – proposed	late 2020?
CD0 – proposed	2Q FY21?
CD1 – proposed	1Q FY22?
CD2/3A –proposed	2Q FY23
CD3 – proposed	2Q FY24
CD4 – proposed	4Q FY28

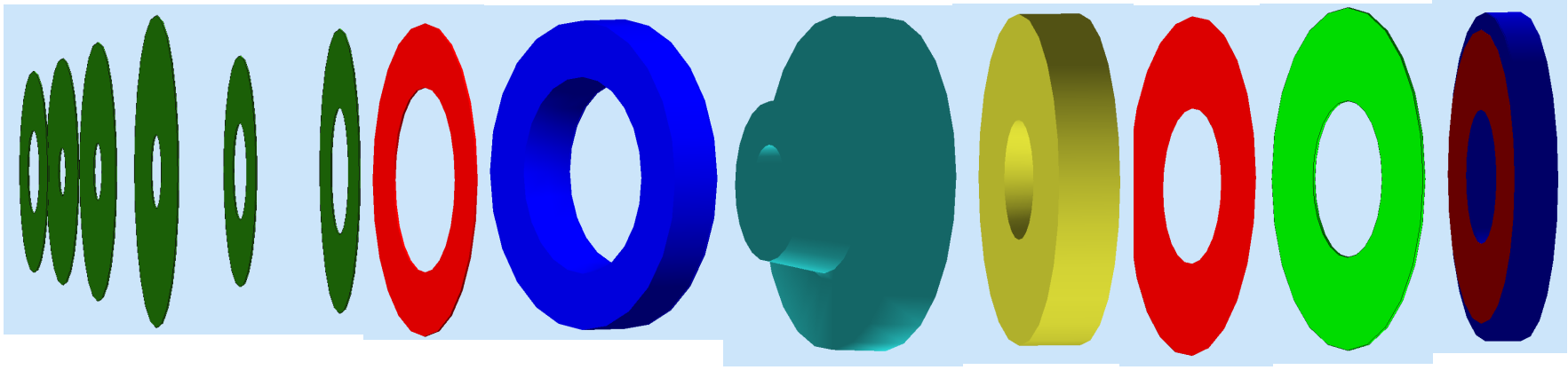
SoLID Detector Subsystems

PVDIS: Baffle LGC 5xGEMs EC



SIDIS&J/Psi:

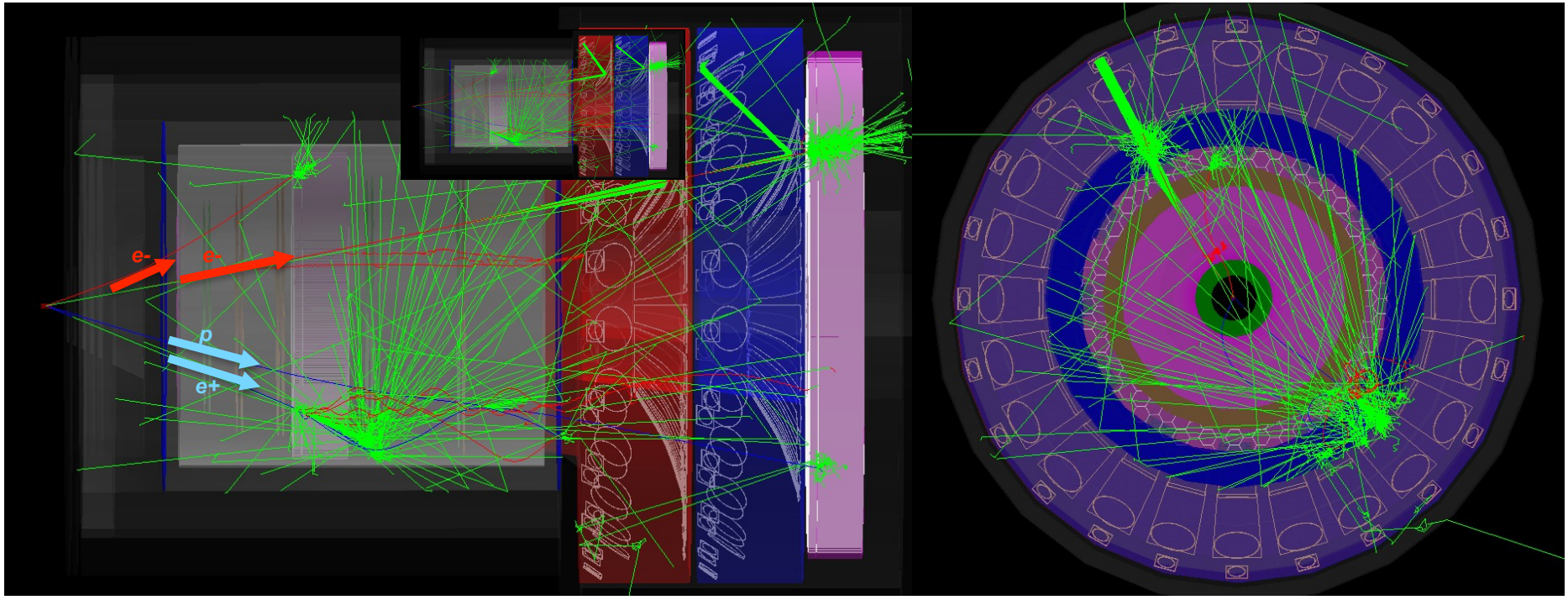
6xGEMs LASPD LAEC LGC HGC FASPD MRPC FAEC



Uses full capability of Jlab electronics

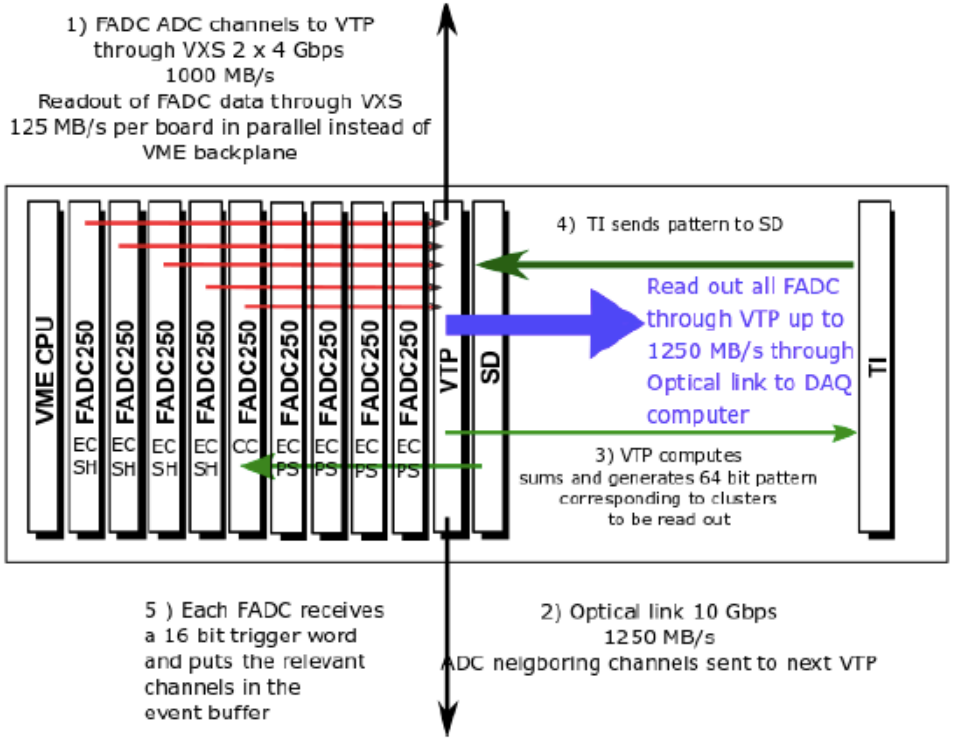
New DD4HEP Software

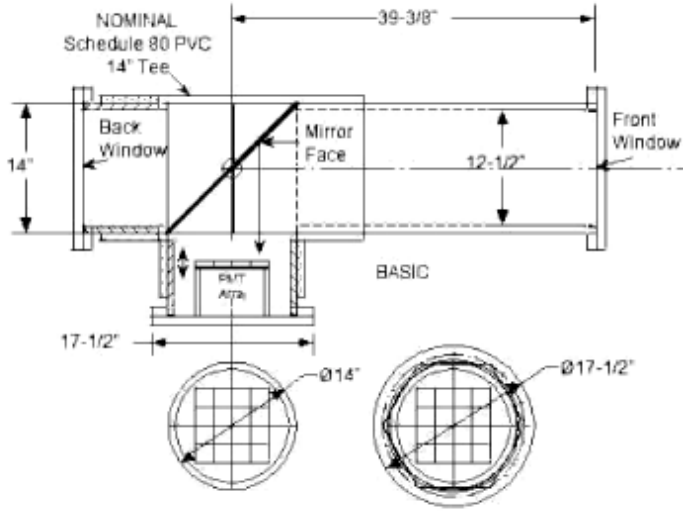
J/Ψ event with 4-fold coincidence



Allows Simulation and reconstruction
within the same framework

Pre-R&D Plan Part A-Electronics Part B-Cerenkov



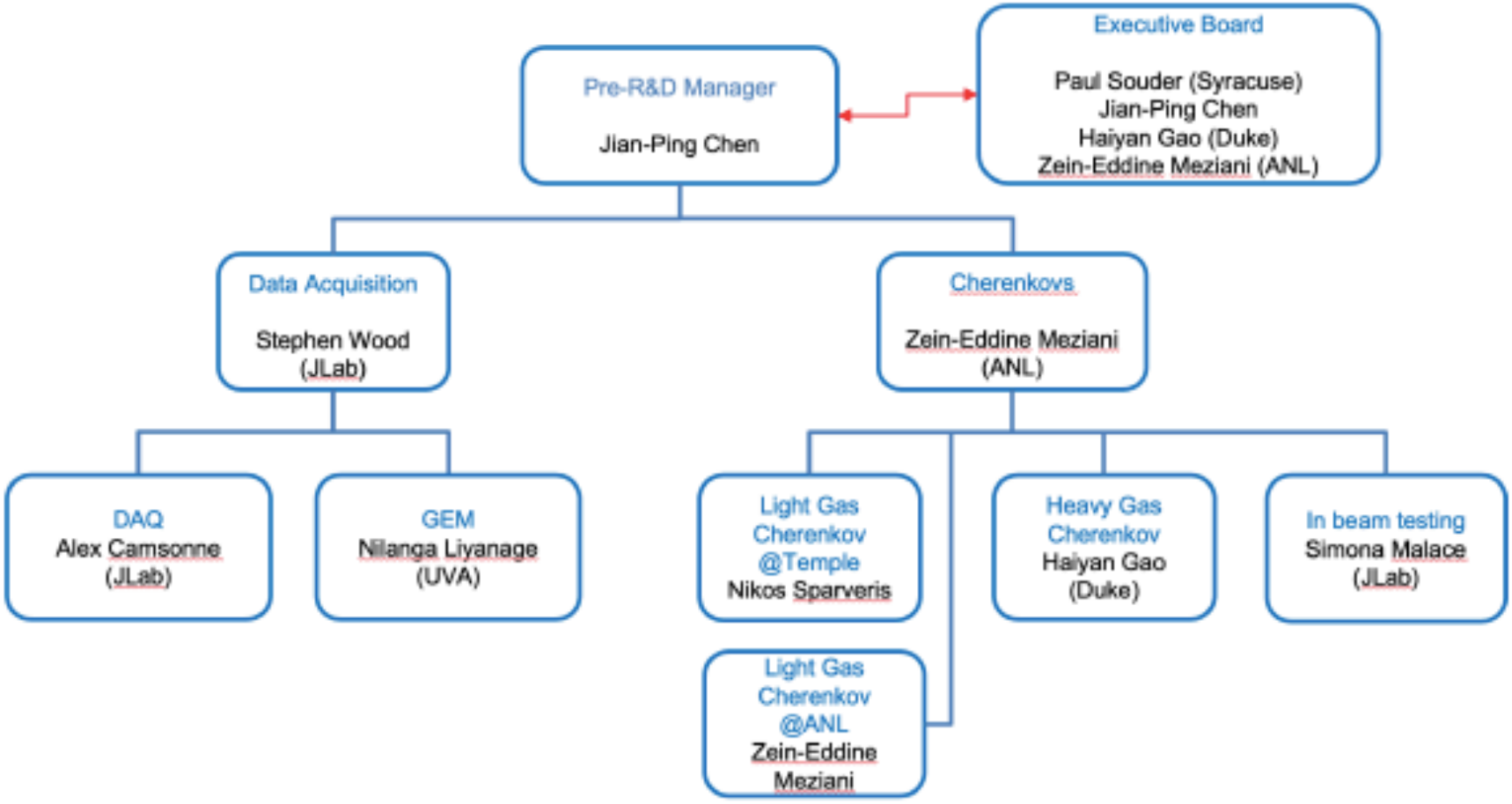


Uses full capability of Jlab FADC electronics

Equipment to be tested: MAPMT, wavelength shifter, summing and MAROC electronics

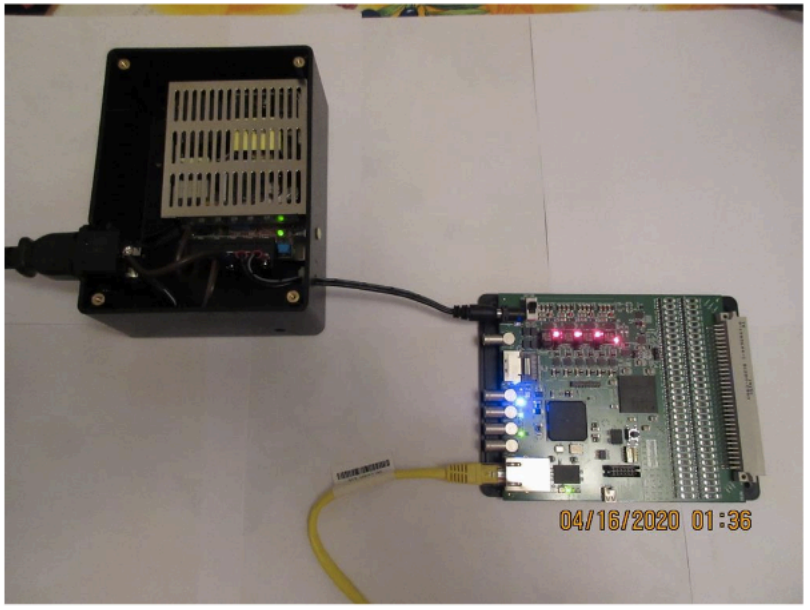
SoLID: You are Welcome to Get Involved

Example: Pre-R&D Plan. Contact anyone on the chart to start.



Recent Progress

- Simulations/Software
  - Tracking: with new GEM readout VMM for PVDIS, SIDIS-He3 and SIDIS-proton cases
  - Background study for SIDIS-proton case
  - Simulation in support of in-beam Cherenkov tests
  - Developing end-to-end simulation in synergy to EIC development
  - J/ψ case study with new simulation package
  - Hadron event generator validation with date
- Detectors
  - LGC/HGC: in-beam test of prototype Cheronkov
  - HGC: gas handling system study, window study
  - GEMs: testing new readout system (VMM)
  - ECal: testing and optimize efficiency
- DAQ
  - JLab DAQ group support
  - Design readout board with VMM for GEM readout
  - Setup prototype DAQ test stand
    - Testing rate limitation with FADC
    - Tesiting readout system for TOF detector.



VMM3 Evaluation Board Testing

Summary

1. Exciting, varied physics program
2. State-of-the-art apparatus
3. Gateway to the EIC
4. Now is a good time to get involved