Precision Physics with SoLID and MOLLER

Hot and Cold QCD Town Meeting

September 23, 2022

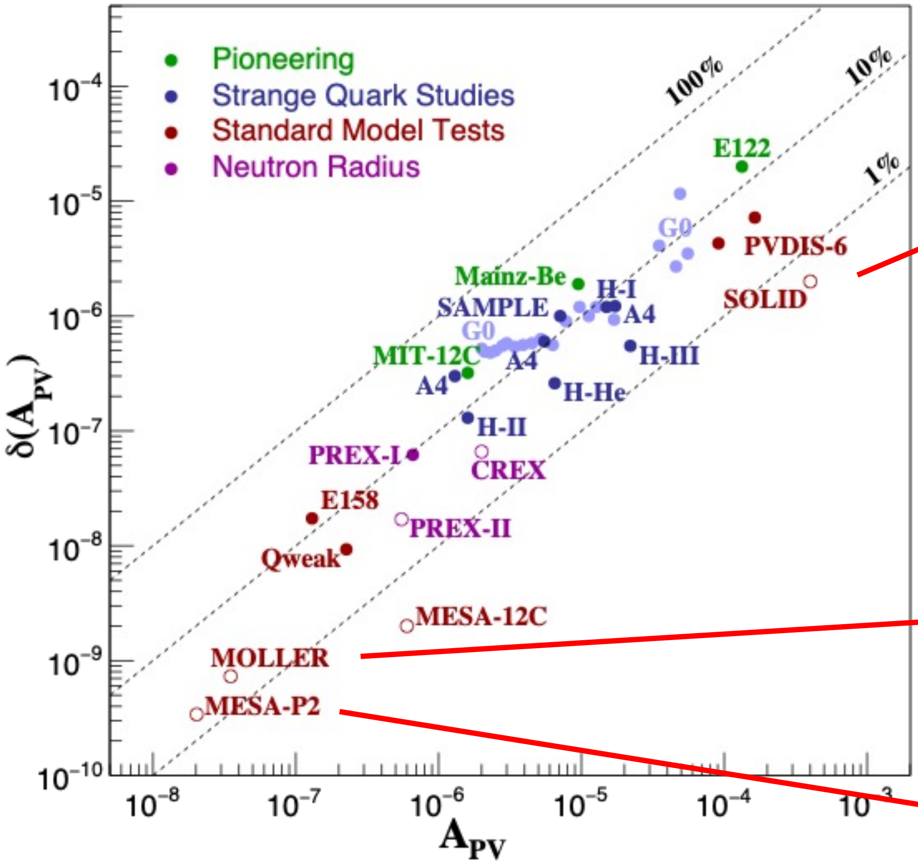
SoLID
SOLENOIDAL LARGE INTENSITY DEVICE

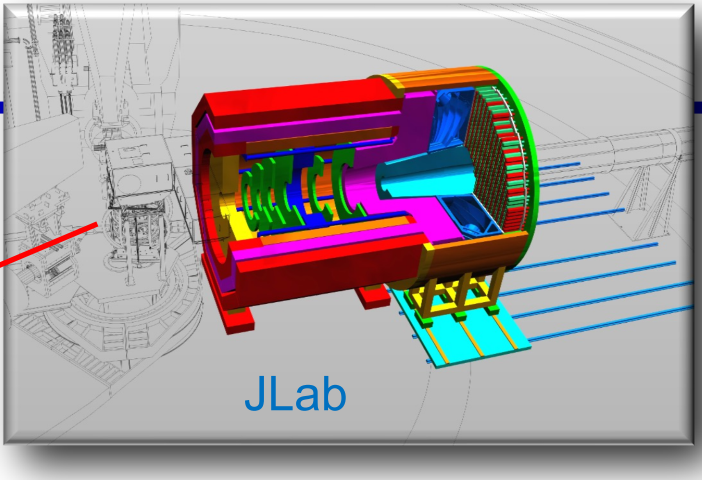
MOLLER

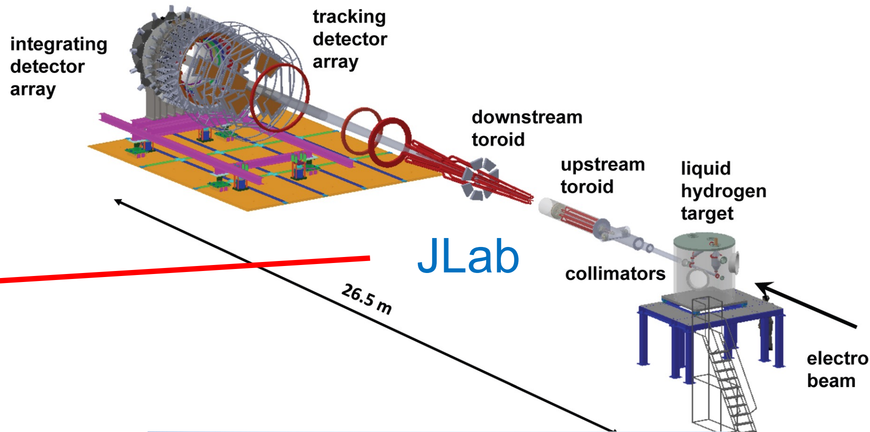
Paul Souder

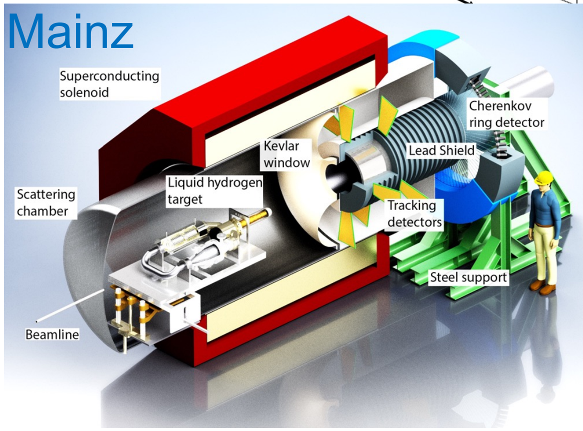
Syracuse University

BSM PVES Experiments





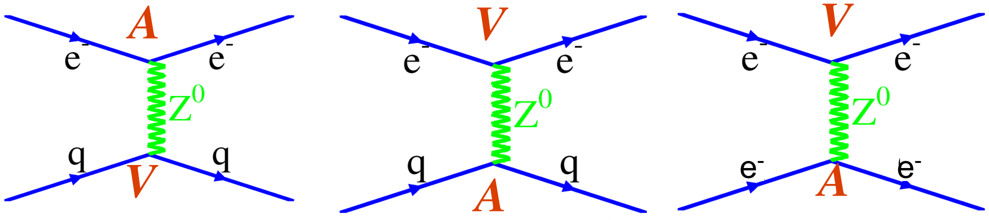




	A	δA	δA/A(%)
SoLID	500 ppm	3 ppm	0.6
MOLLER	0.035 ppm	0.0008 ppm	2.2
P2	0.020 ppm	0.0004 ppm	2.0

MOLLER, SoLID, and P2 all improve precision

Goals of SoLID, MOLLER, (and P2)



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

Goal: Measure all the C's as precisely as possible

$$A_{PV} = Q_W^e \frac{Q^2 G_F}{\sqrt{2}\pi}\left(\frac{1-y}{1+y^4+(1-y)^4}\right)$$

Moller (Simple formula)

$$A_{PV} = \frac{G_F Q^2}{\pi \sqrt{2}}\left(Q_W^p + A_M + \cancel{A_s + A_A}\right)$$

P2: e P and ^{12}C elastic
(Simple formula at low E and θ)

$$A^{PV} = \left(\frac{G_F Q^2}{4\sqrt{2}\pi}\right)(Y_1 a_1 + Y_3 a_3)$$

$$a_1^d = \frac{6}{5}(2C_{1u} - C_{1d}); \quad a_3^d = \frac{6}{5}(2C_{2u} - C_{2d})$$

SoLID PVDIS (Simple for d at large E and θ, only way to get C_2's)

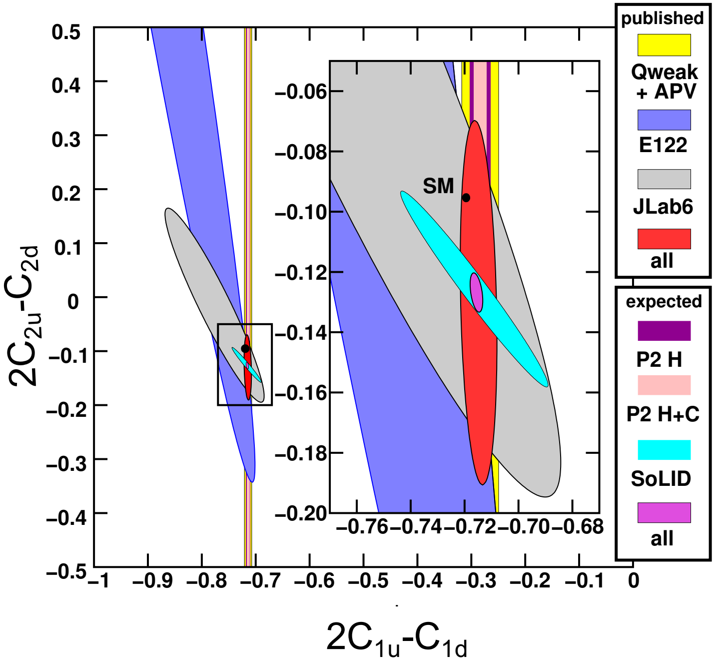
$$Q_W(Z,N) = -2[C_{1u}(2Z+N) + C_{1d}(Z+2N)]$$

$$Q_W(e) = -2Cee$$

Goals of PVDIS with SoLID

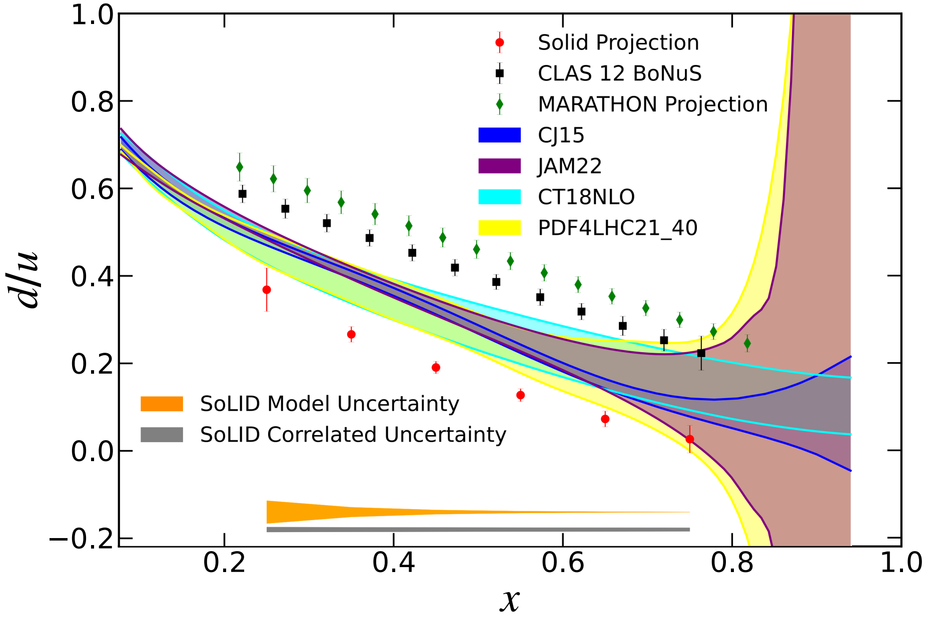
A_{PV} with the Deuteron

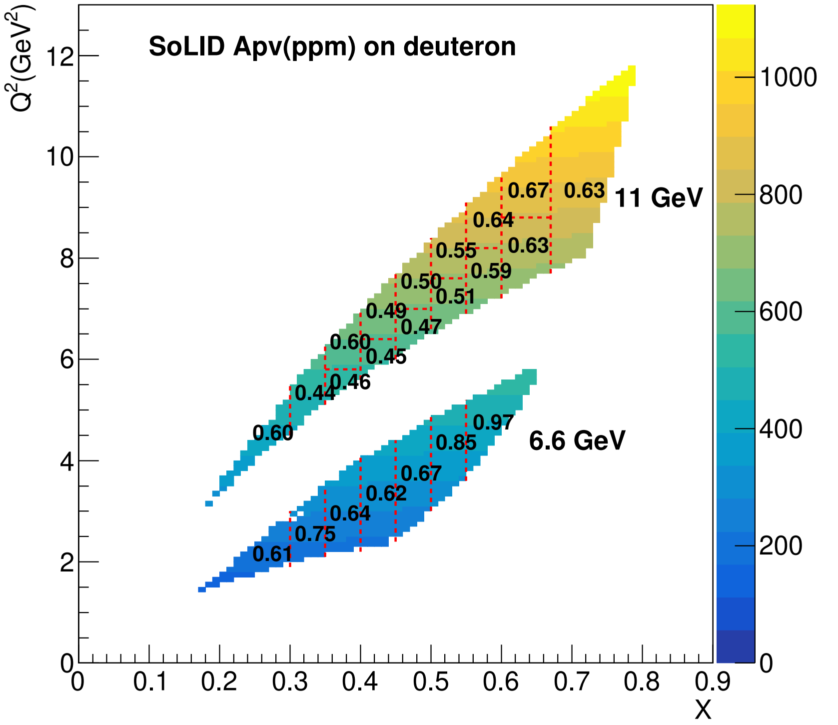
1. Search for BSM physics at a high energy scale.
2. Search for CSV at the quark level
3. Search for quark-quark higher twist effects



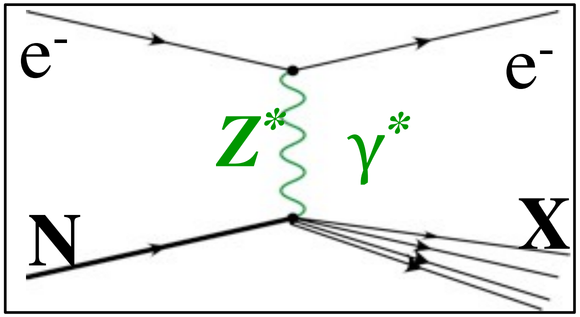
A_{PV} with the Proton

1. Help determine d/u PDF's
2. Insight into nuclear effects at high x





PVDIS for eD Scattering



$$A_{PV} = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\left[g_A \frac{F_1^{\gamma Z}}{F_1^{\gamma}} + g_V \frac{f(y)}{2}\frac{F_3^{\gamma Z}}{F_1^{\gamma}}\right]$$

$x \equiv x_{Bjorken}$

$y \equiv 1 - E'/E$

$Q^2 >> 1$ GeV², $W^2 >>$ 4 GeV²

$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[a(x) + f(y)b(x)\right]$$

$$A_{\text{iso}} = \frac{\sigma^l - \sigma^r}{\sigma^l + \sigma^r} = \left(\frac{3G_F Q^2}{\pi\alpha 2\sqrt{2}}\right)\frac{2C_{1u} - C_{1d}(1+R_s) + Y(2C_{2u} - C_{2d})R_v}{5 + R_s}$$

Unique feature: sensitivity to C_2's

$$R_s(x) = \frac{2S(x)}{U(x)+D(x)} \xrightarrow{\text{Large } x} 0$$

$$R_v(x) = \frac{u_v(x)+d_v(x)}{U(x)+D(x)} \xrightarrow{\text{Large } x} 1$$

At high x, A_{iso} becomes independent of pdfs, x & W, with well-defined SM prediction for Q^2 and y

SM Effective Field Theory (SMEFT) and LHC Data

$$\mathcal{L} = \sum_d \sum_{ij} \frac{C_d^{ij}}{\Lambda^{d-4}} \mathcal{O}_d^{ij}$$

$$\mathcal{O}_d^{ij} = \bar{e}_i \gamma_\mu e_i \bar{f}_j \gamma^\mu f_j$$

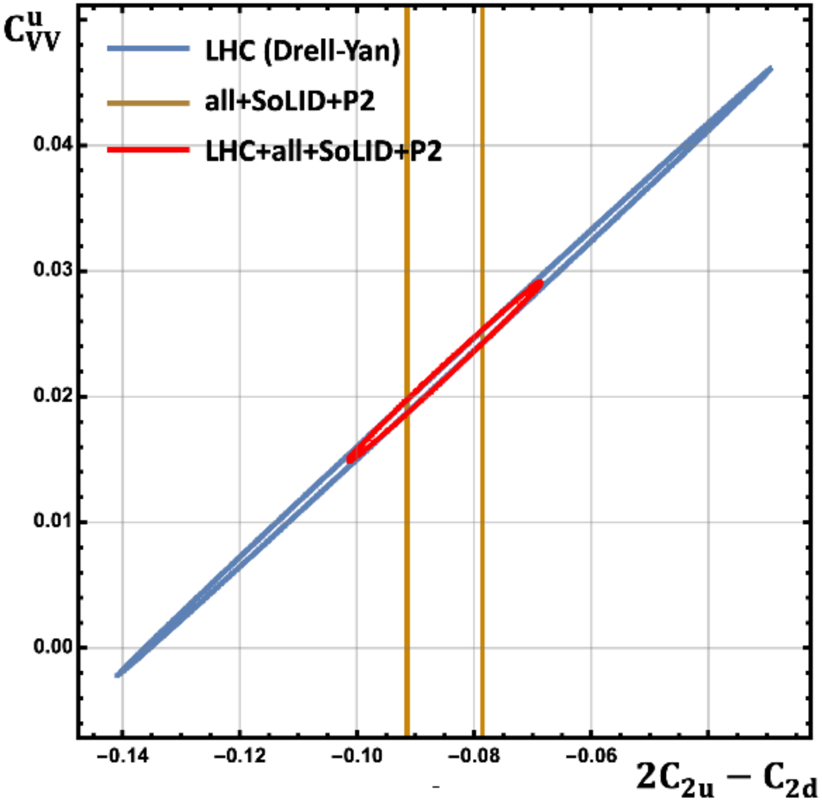
$$e_{L/R} = \frac{1}{2}(1 \mp \gamma^5)\psi_e$$

$$\mathcal{O}_d^{ij} = LL_f,\ LR_f,\ RL_f,\ RR_f$$

New Drell-Yan LHC data measures a combination of parity conserving and parity violating couplings.

Goal: Measure each C_d^{ij} as precisely as possible (Nobody really knows where the new physics is.)

Figure courtesy of Frank Petriello…



SoLID and LHC data are complementary

Dark Boson Z_d and other Sub-TeV BSM Models

- *Davoudiasl, et al. Phys.Rev.D* 92, (2015) 5, 055005
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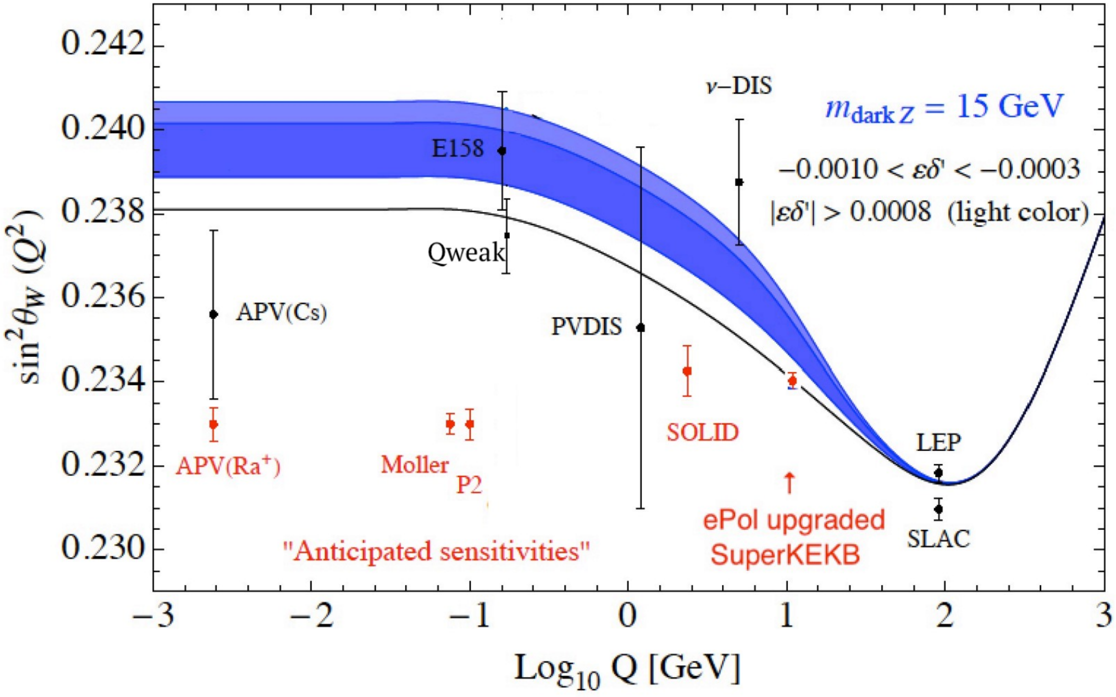
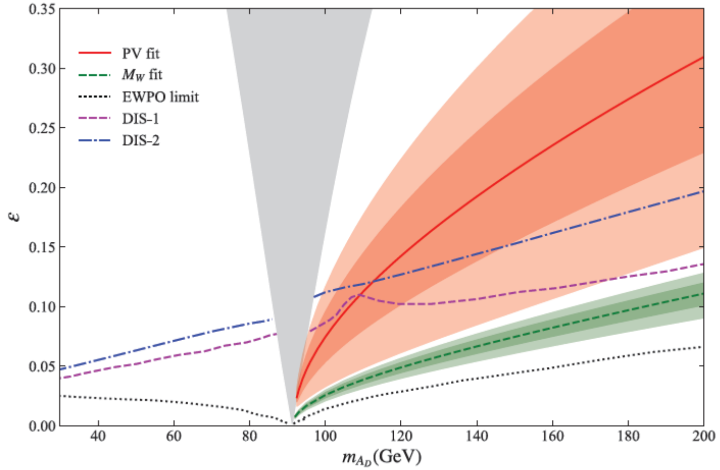


A. W. Thomas and X. G. Wang, [arXiv:2205.01911 [hep-ph]];
A. W. Thomas, X. Wang and A. G. Williams, Phys. Rev. Lett. **129**, no.1, 011807 (2022)

Constraints of new W mass versus PV

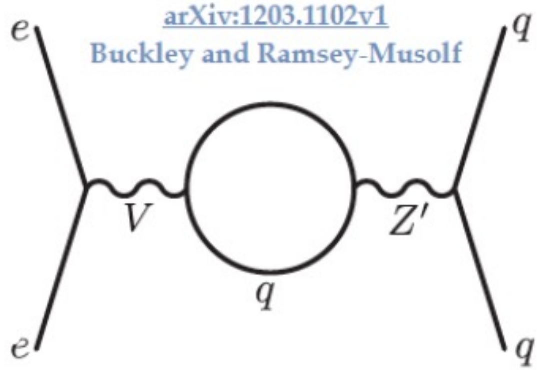
Thomas and Wang, arXiv: 2205.01911



Leptophobic Z'

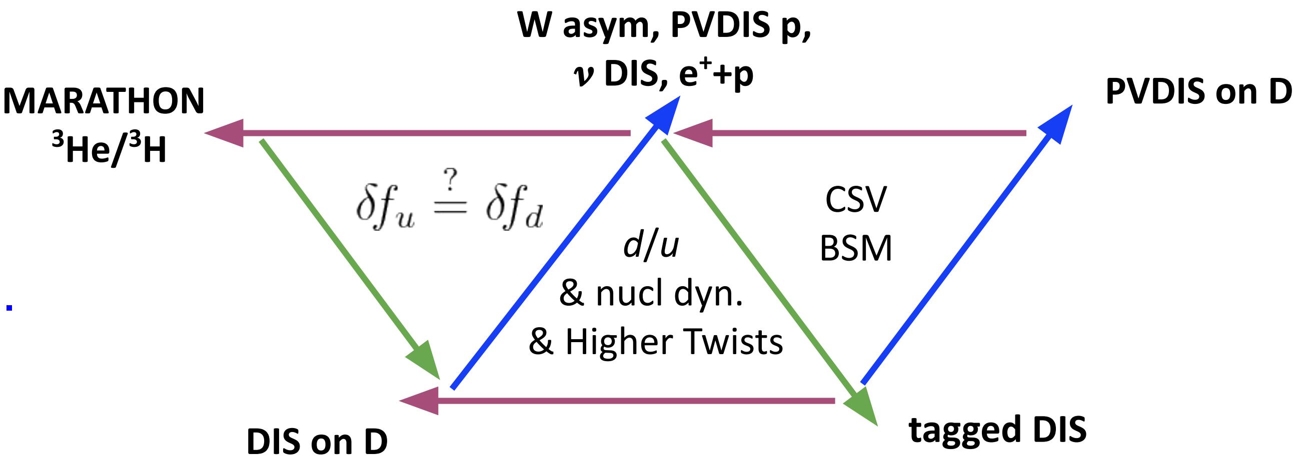
arXiv:1203.1102v1

Buckley and Ramsey-Musolf



PVDIS with the Proton

Figure courtesy of A. Accardi



W asym, PVDIS p,
ν DIS, e^++p

MARATHON
^{3}He/^{3}H

PVDIS on D

$\delta f_u \overset{?}{=} \delta f_d$

d/u
& nucl dyn.
& Higher Twists

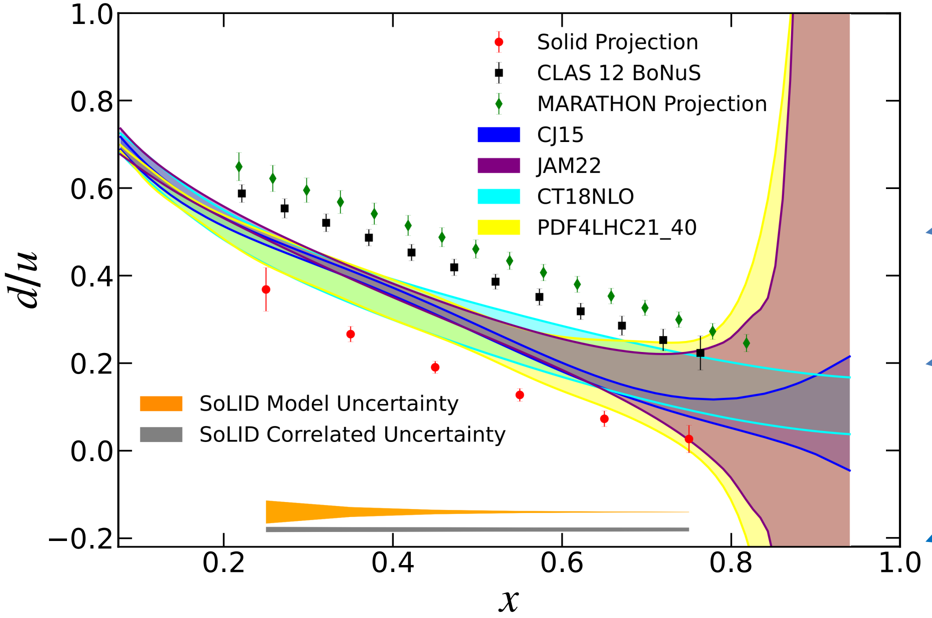
CSV
BSM

DIS on D

tagged DIS

PVDIS is complementary to
the rest of the Jlab d/u program.
Only PVDIS has
no nuclear effects

The MARATHON Data on d/u has different interpretations. Hence as many targets as possible should be studied: PVDIS, BONUS (D), and MARATHON



Phys.Rev.Lett. 127 (2021) 24, 242001
Phys.Rev.Lett. 128 (2022) 13, 132003

SU(6)

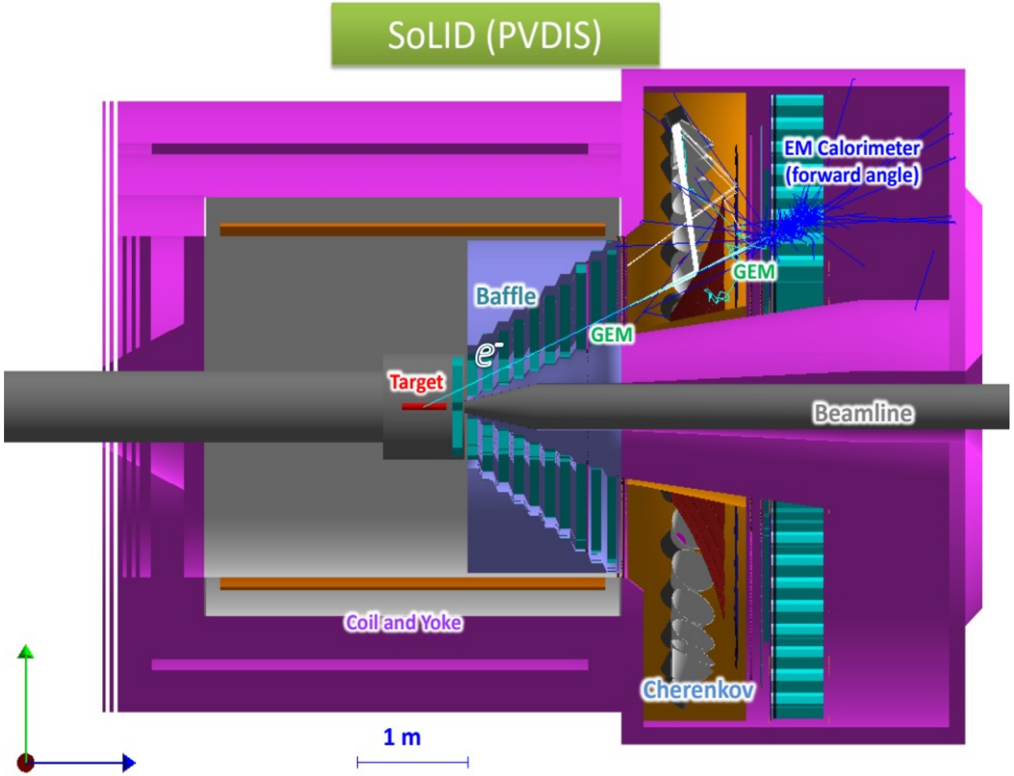
Helicity Conservation

Scalar Diquarks

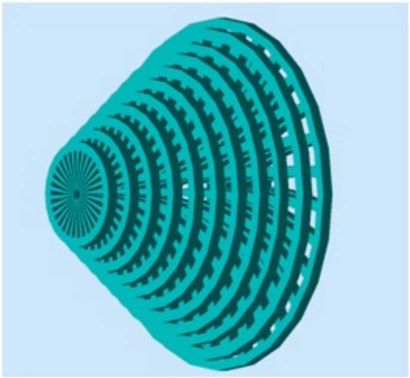
SoLID PVDIS Apparatus Described in Pre-CDR

Achieving High Luminosity

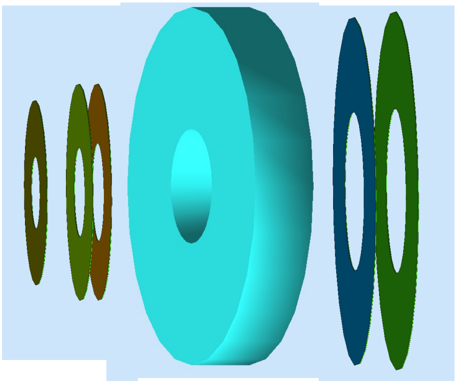
- 50 μA beam current.
- 40 cm LD_2\LH_2 target
- ~40% azimuthal coverage with baffles which provide curved channels that block positive and neutral background particles
- Azimuthally symmetric.
- High-rate GEM tracking Chambers



Baffles



GEM Chambers

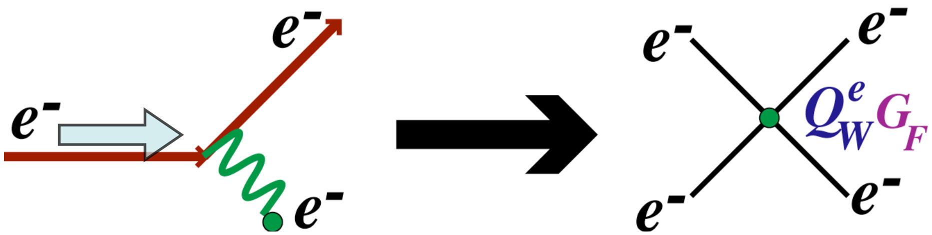


Magnet from CLEO experiment at Cornell is at JLab. Cold test is expected to be completed by October.

MOLLER – World leading measurement of A_{PV}

11 GeV, 65 μA 90% beam polarization

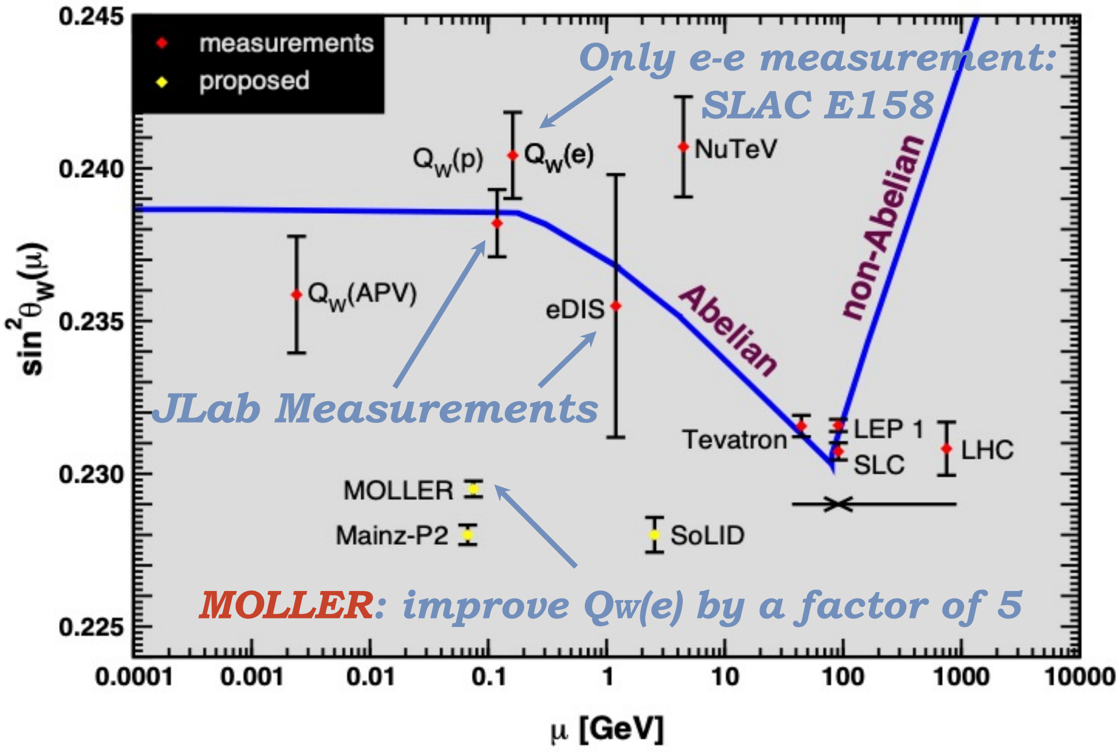
Special opportunity with the 12 GeV upgrade



A_{PV} ~ 32 ppb ***δ(A_{PV}) ~ 0.8 ppb***

δ(Q^e_W) = ± 2.1 % (stat.) ± 1.1 % (syst.)

δ($\sin^2\theta_W$) = ± 0.00023 (stat.)
± 0.00012 (syst.) ⇨ *~ 0.1%*



Only e-e measurement: SLAC E158

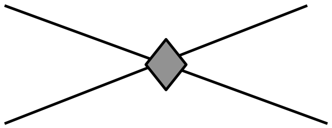
JLab Measurements

MOLLER: improve Qw(e) by a factor of 5

Search for new flavor diagonal neutral currents

Look for tiny but measurable deviations from precisely calculable prediction for SM processes

A_{new}



$$\frac{1}{\Lambda^2}\mathcal{L}_6$$

Unique (purely leptonic) new physics reach

MOLLER Reach

$$\Lambda^{ee}_{RR-LL} \sim 38\ \text{TeV}$$

Discovery space comparable to a 500 GeV lepton collider

Fixed target MOLLER versus LEP 200

$$\frac{\Lambda}{\sqrt{|g_{RR}^2 - g_{LL}^2|}} = \frac{1}{\sqrt{\sqrt{2}G_F|\Delta Q_W^e|}}$$

$$\simeq \frac{246.22\text{ GeV}}{\sqrt{0.023 Q_W^e}} = 7.5\text{ TeV}.$$

Model	η^f_{LL}	η^f_{RR}	η^f_{LR}	η^f_{RL}
$LL^\pm$	±1	0	0	0
$RR^\pm$	0	±1	0	0
$LR^\pm$	0	0	±1	0
$RL^\pm$	0	0	0	±1
$VV^\pm$	±1	±1	±1	±1
$AA^\pm$	±1	±1	∓1	∓1
$VA^\pm$	±1	∓1	±1	∓1

Conventional Collider Contact Interaction Analysis:

→ $|g^2_{RR} - g^2_{LL}| = 4\pi$

95%
C.L.
Limits

LEP200

$\Lambda^{ee}_{LL} \sim 8.3$ TeV

$\Lambda^{ee}_{RR} \sim 8.2$ TeV

$\Lambda^{ee}_{VV} \sim 17.7$ TeV

$\Lambda^{ll}_{LL} \sim 12.8$ TeV

$\Lambda^{ll}_{RR} \sim 12.2$ TeV

$\Lambda^{ll}_{VV} \sim 22.2$ TeV

E158 Reach (actual limits asymmetric)

$\Lambda^{ee}_{LL} \sim 12$ TeV

$\Lambda^{ee}_{RR-LL} \sim 17$ TeV

LEP-200 insensitive

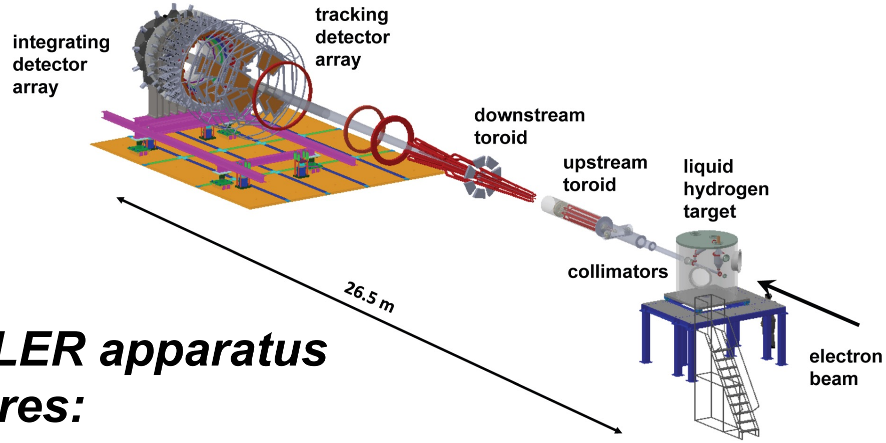
MOLLER Reach

$\Lambda^{ee}_{LL} \sim 27$ TeV

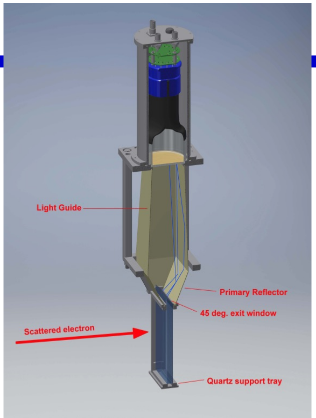
$\Lambda^{ee}_{RR-LL} \sim 38$ TeV

MOLLER is accessing discovery space that cannot be reached until the advent of a new lepton collider

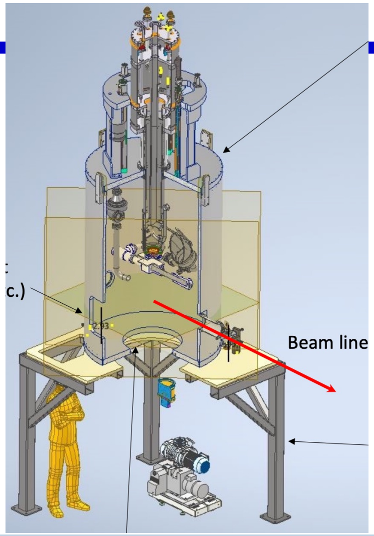
MOLLER PROJECT



Single channel

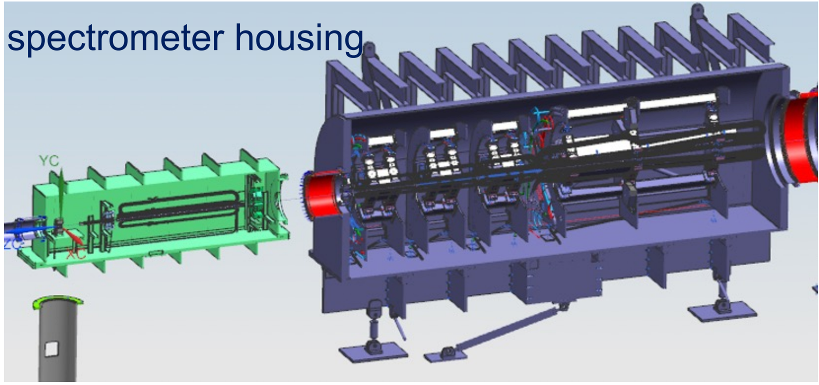


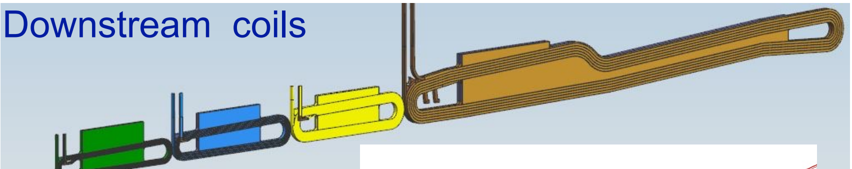
Liquid Hydrogen Target



MOLLER apparatus features:

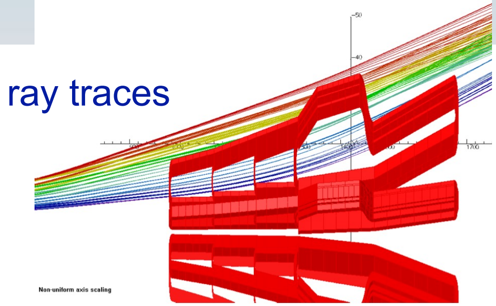
- **High intensity polarized electron source**
- **1 nm control of beam centroid on target**
- **~ 9 gm/cm^2 (1.25 m) liquid hydrogen target**
- **Full Azimuthal acceptance w/ θ_{lab} ~ 5 mrad**
- **~ 134 GHz scattered electron rate**
- **Robust & Redundant 0.4% beam polarimetry**





***DOE MIE** (Office of Nuclear Physics):*

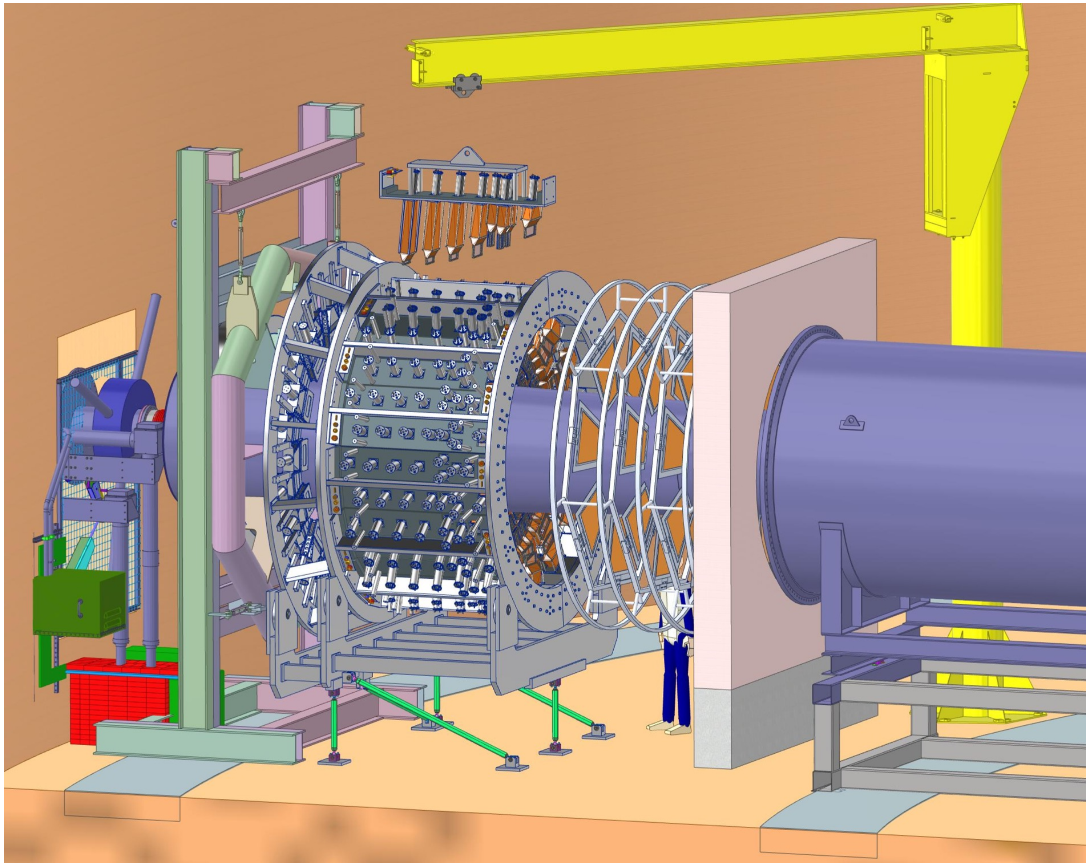
- **Full project team in place since January 2019**
- **Prototyping/construction/installation (2022-25)**
- **DOE OPA CD-1 Approval: December 2020**
- **CD-2/CD-3 Review~Summer 2023**

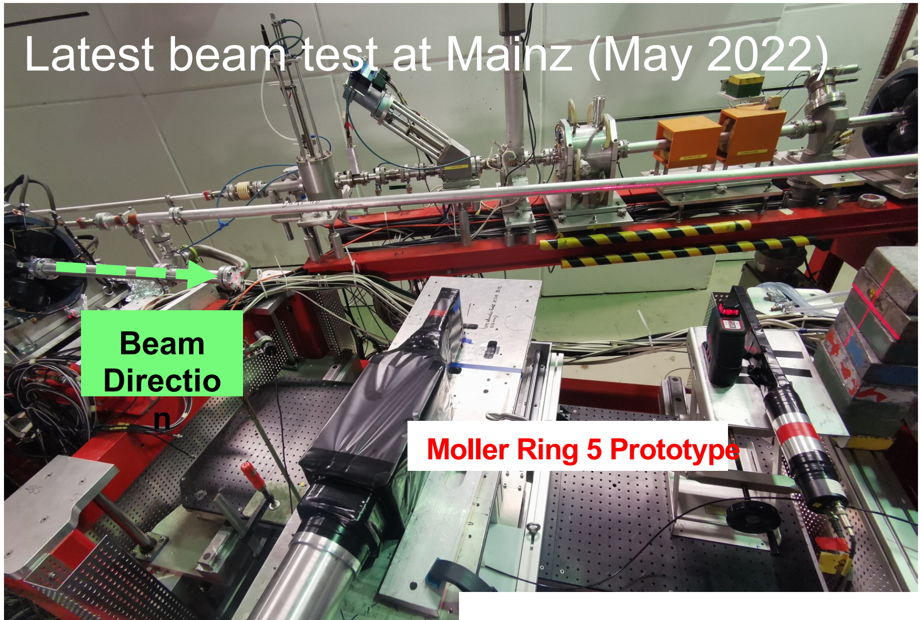


Detector Assembly Engineering Design Progress and Tests

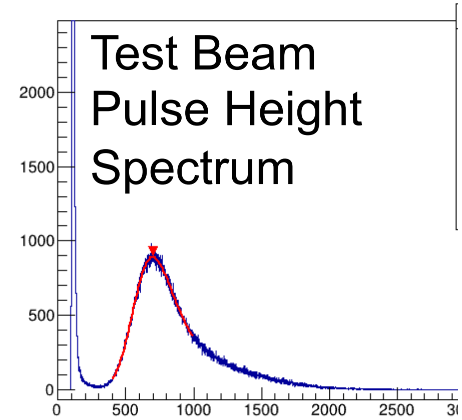
- Main detectors and Shower-Max integrated on “rotator” so all modules can be installed from above rather than needing complex materials handling to insert, e.g. from underneath the structure

Engineering CAD of Main Detector Assembly





Prototype Ring 5 and Ring 6 modules evaluated in test beam



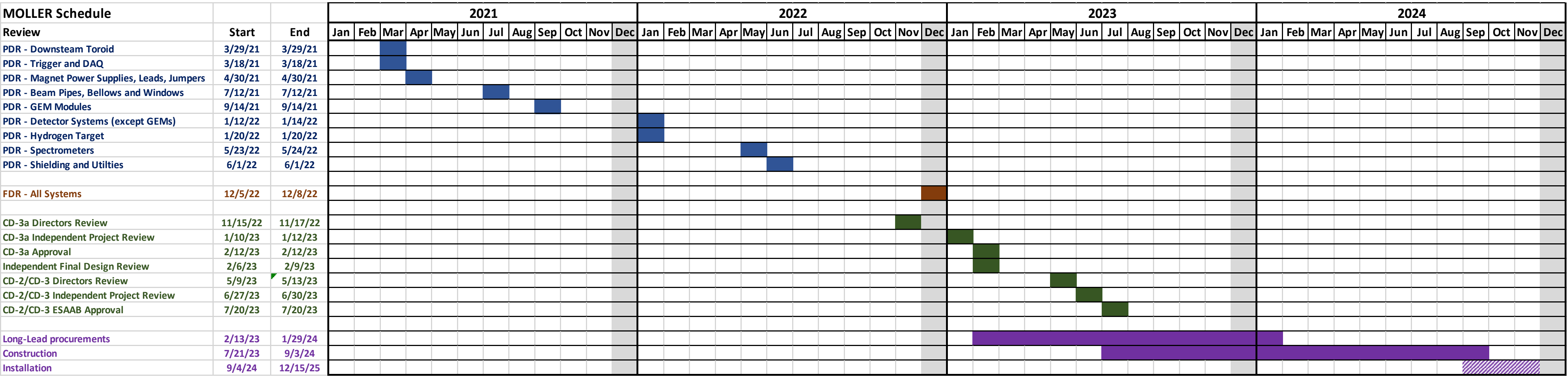
SoLID and MOLLER MIE Project

SoLID

- Successful DOE Science Review, March 2021
- Successful PAC review for all previously approved experiments: July 2022

MOLLER MIE Project Schedule

- Wrapped up all Preliminary Design Reviews in June 2022
- Targeting Final Design Review(s) in late CY2022 to support spring 2023 CD-2/3 approval
- Technically driven schedule is then ~15 months construction and ~18 months installation
- Now fully funded



MOLLER Schedule		
Review	**Start**	**End**
PDR - Downsteam Toroid	3/29/21	3/29/21
PDR - Trigger and DAQ	3/18/21	3/18/21
PDR - Magnet Power Supplies, Leads, Jumpers	4/30/21	4/30/21
PDR - Beam Pipes, Bellows and Windows	7/12/21	7/12/21
PDR - GEM Modules	9/14/21	9/14/21
PDR - Detector Systems (except GEMs)	1/12/22	1/14/22
PDR - Hydrogen Target	1/20/22	1/20/22
PDR - Spectrometers	5/23/22	5/24/22
PDR - Shielding and Utilties	6/1/22	6/1/22
FDR - All Systems	12/5/22	12/8/22
CD-3a Directors Review	11/15/22	11/17/22
CD-3a Independent Project Review	1/10/23	1/12/23
CD-3a Approval	2/12/23	2/12/23
Independent Final Design Review	2/6/23	2/9/23
CD-2/CD-3 Directors Review	5/9/23	5/13/23
CD-2/CD-3 Independent Project Review	6/27/23	6/30/23
CD-2/CD-3 ESAAB Approval	7/20/23	7/20/23
Long-Lead procurements	2/13/23	1/29/24
Construction	7/21/23	9/3/24
Installation	9/4/24	12/15/25

SoLID and MOLLER Collaboration

SoLID PVDIS Collaboration

~ 247 authors, 62 institutions, 13countries

P. A. Souder: Contact
P. Reimer: Co-spokesperson
X. Zheng: Co-spokesperson

MOLLER Collaboration and Project

~ 160 authors, 37 institutions, 6 countries

K. Kumar: Contact
J. Fast: Project Manager

Backup

Backup