Developments of polarized ^{7}LiD target system for spin-dependent EMC effect experiments at CLAS12

Tsuneo Kageya

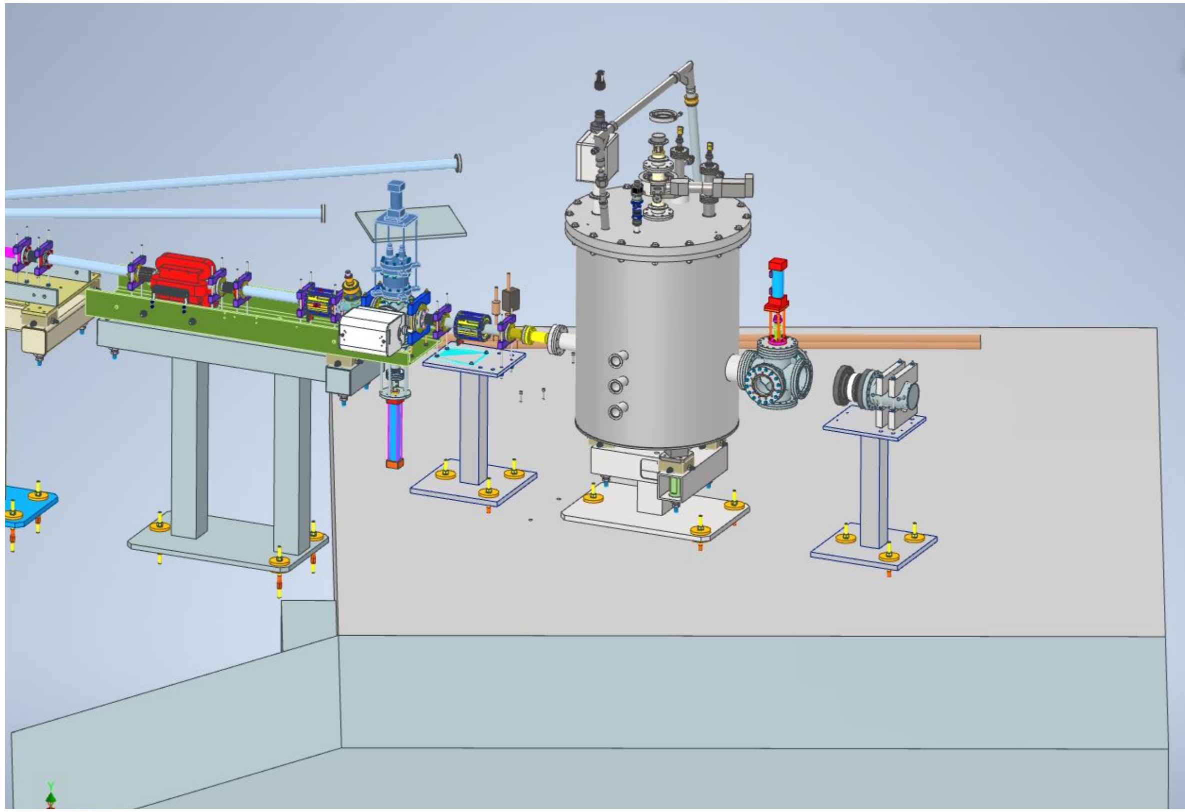
Thomas Jefferson National Accelerator Facility (JLab)

D. Akers, J. Brock, C. Carlin, G. Dezern,
C. Flanagan, D. Griffith, M. Hoegerl,
P. Hood, C. Keith, J. Maxwell, S. Madlock,
D. Meekins (JLab Target Group)

P. Dobrenz, X. Wei (Jlab Hall B)

J. Creel, B. Mastracci (JLab Engineering Division)

P. Dobrenz, M. Poelker, E. Pozdeyev (JLab Accelerator Division)



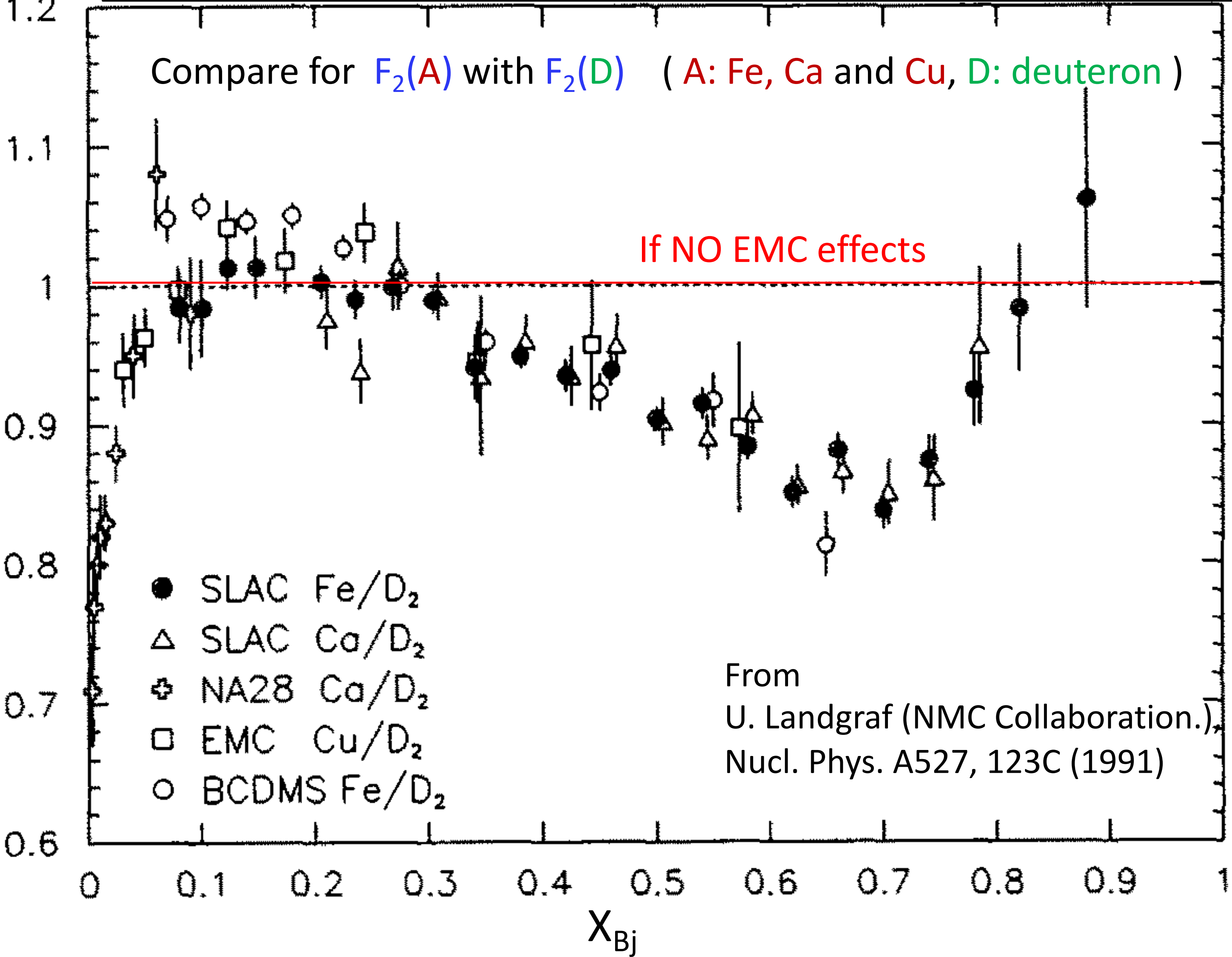
Related talks: J. Brock, “A Solid Polarized Target Development Facility at Jefferson Lab.” (Tue.)
X. Wei, “Preparation at Jefferson Lab. for Spin Polarized Fusion Program” (Thurs.)

1. EMC effects (European Muon Collaboration)

Quark's momentum distributions accessed by DIS: different for light and heavy nuclei ⇒ Not anticipated results

$$\frac{F_2(A)}{F_2(D)}$$

F_2: unpolarized structure function



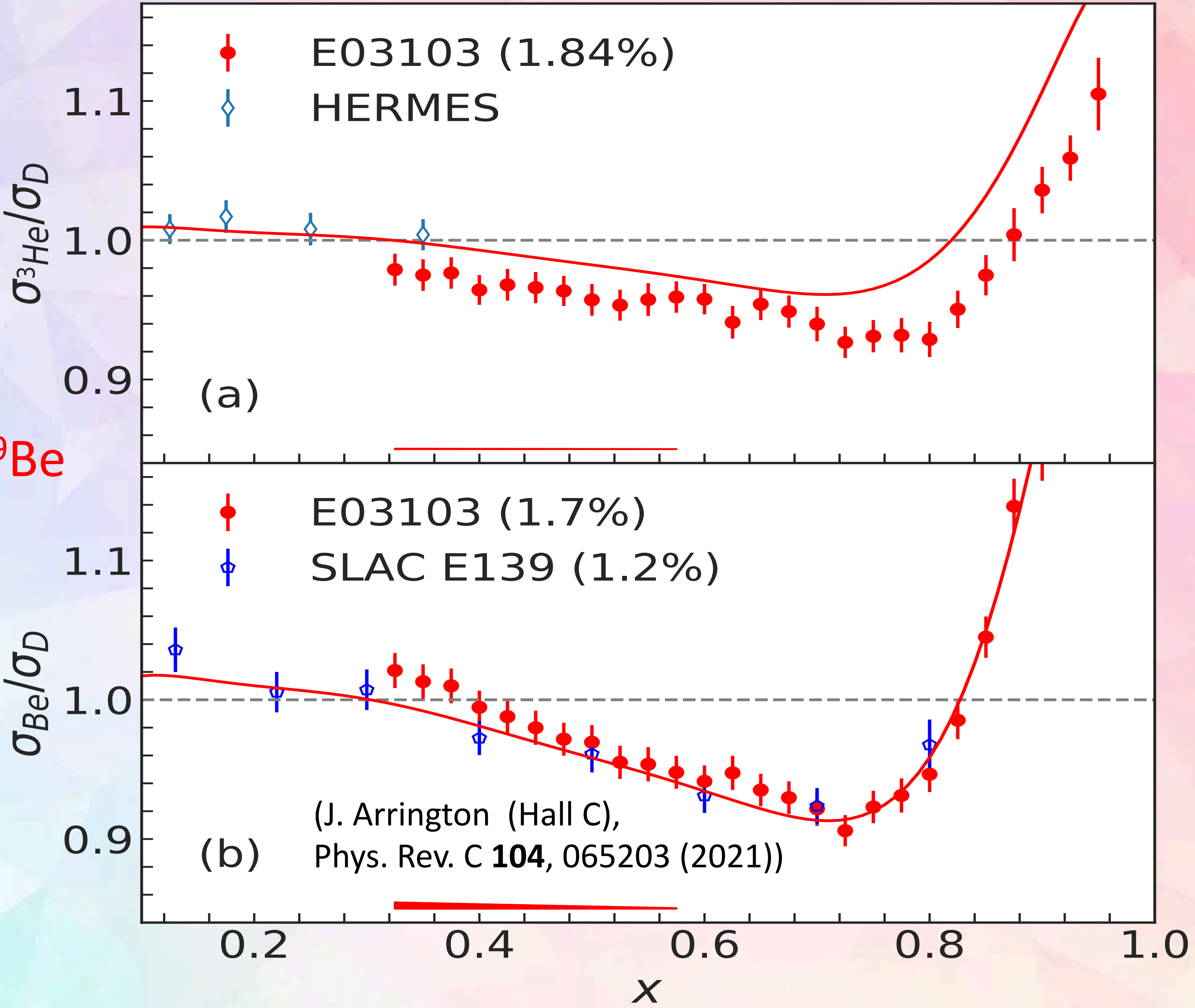
From
U. Landgraf (NMC Collaboration.),
Nucl. Phys. A527, 123C (1991)

1. EMC effects observed for light nuclei

$\frac{^3He}{D}$

^7LI : between ^3He and ^9Be

$\frac{^9Be}{D}$



(J. Arrington (Hall C), Phys. Rev. C **104**, 065203 (2021))

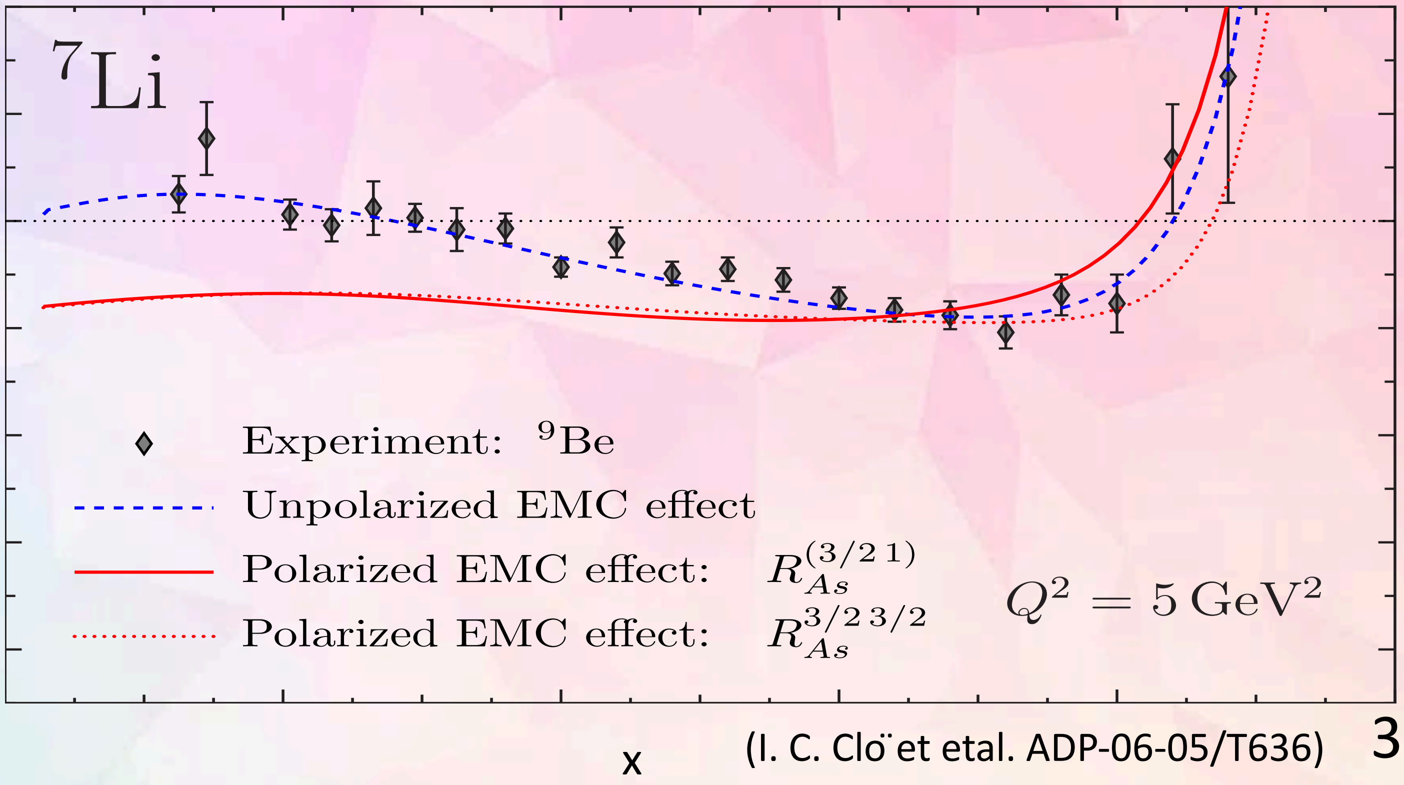
1. Polarized (Spin-Dependent) EMC effects

Proposed experiments (Hall B, (PR12-14-001)) for Spin dependent EMC effects:

- measure and compare spin dependent structure function g_1 from bound proton (p in $^7\overrightarrow{Li}$) with free proton (three H in N$\vec{H}_3$) at same experimental setup

An example of theoretical prediction for polarized EMC for ^{7}Li

Polarized EMC effect could be more enhanced than unpolarized ← Theoretical predictions



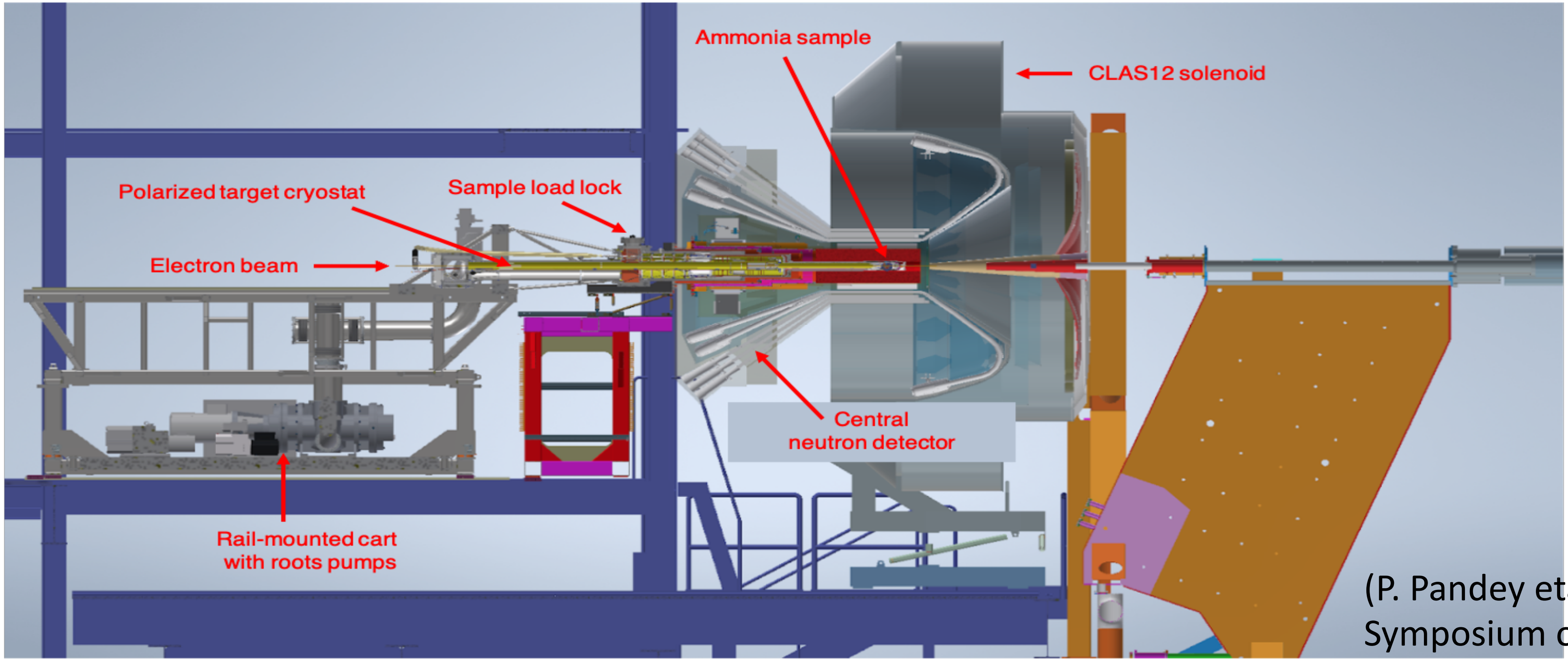
(I. C. Clo¨et etal. ADP-06-05/T636)

1. Longitudinally Polarized Solid Target for Spin dependent EMC effect at Hall B

Use the same setup of target system as Run Group C (Run in 2022-23).

DNP at 5 Tesla (Solenoid) and 1 K (^{4}He evaporation cryostat)

Use Longitudinally polarized e^- beams (11 GeV)



(P. Pandey etal, Proc. of 25th Int. Symposium of Spin Physics. 2023, 211)

Side view of the polarized target installed in Hall B. A few elements of the CLAS12 spectrometer are shown.

2. Advantages of using polarized solid ^{7}LiD and NH_3 targets for Spin dependent EMC effects

No so much data for ^{7}LiD; use data from ^{7}LiH, ^{6}LiD and ^{6}LiH

Solid ^{6}LiD has been used as polarized targets in the past experiments: its performances are rather well known, ^{7}LiD is supposed to perform similarly.

a. Low mass nuclei like ^{7}Li; detailed structure of nuclei is well known

b. ^{7}LiD and NH_3 can be highly polarized with DNP

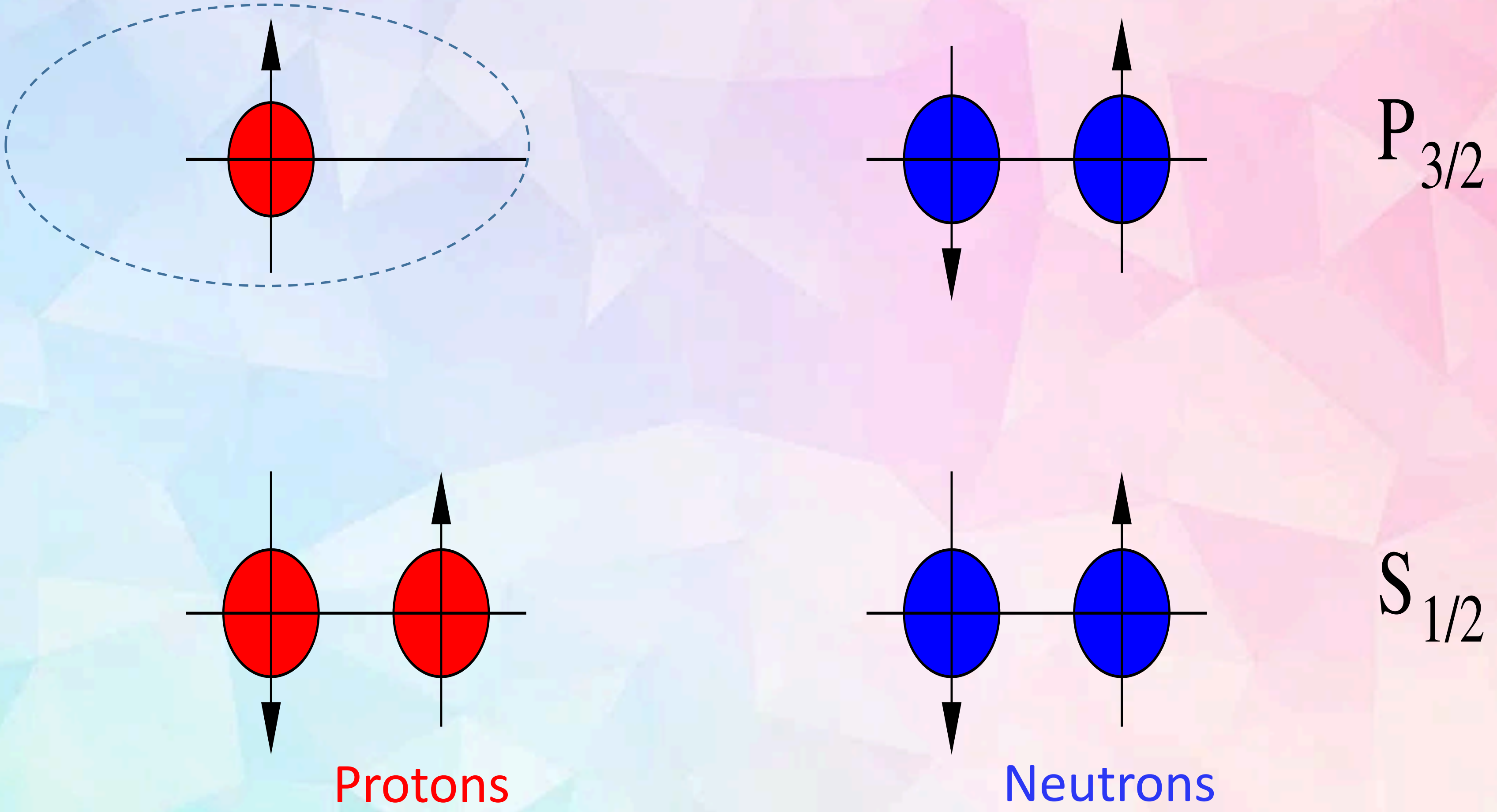
c. ^{7}LiD and NH_3 are highly radiation resistant on electron beams

d. Reasonable Dilution Factor

a. Low mass nuclei like ^{7}Li; detailed structure of nuclei is well known

Structure of ^{7}Li in a simple shell model picture

^{7}Li: p (∽ 87 % of Li spin)[1,2] + n + n (– 0.04 %)[1,2] + ^{4}He (zero pol.)



(From proposal PR12-14-001)

(1 : Shell model; S. Cohen, D. Kurath, Nucl. Phys. 73 (1965) 1.
2: Quantum Monte Carlo calculations; B.S. Pudliner etal., Phys. Rev. C 56 (1997) 1720)

b. ^{7}LiD and NH_3 can be highly polarized with DNP

Polarization past records; as high as (at 5 Tesla and 1K on beam line)

* ^{7}Li (in ^{7}LiH) : $\sim$ 60 %

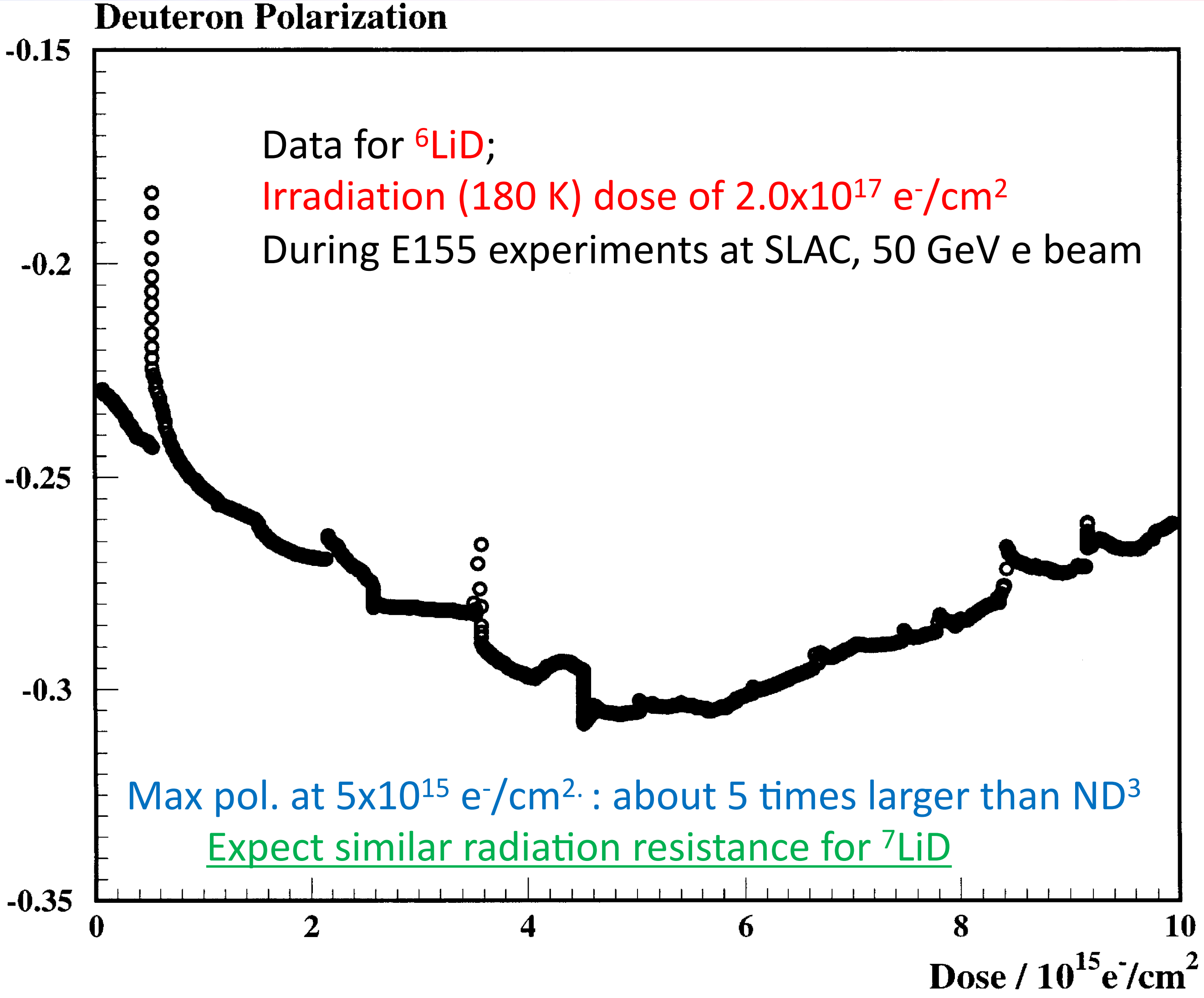
(S. Bueltzmann etal. Nucl. Instr. and Meth. A 425 (1999) 23)

* H (in NH_3) : $\geq$ 90 %

(from past experiments at JLab)

c. Radiation resistance for ^{6}LiD (No data for ^{7}LiD nor ^{7}LiH)

S. Bültmann et al. / Nuclear Instruments and Methods in Physics Research A 425 (1999) 23–36 35



Data for ^{6}LiD;

Irradiation (180 K) dose of 2.0×10^{17} e^-/cm^2

During E155 experiments at SLAC, 50 GeV e beam

Max pol. at 5×10^{15} e^-/cm^2. : about 5 times larger than ND^3

Expect similar radiation resistance for ^{7}LiD

d. Acceptable dilution factor for ^{7}LiD and NH_3

$$\text{Ratio } (^{7}\text{LiD}) \approx \frac{\text{Number of polarizable bound proton}}{\text{Total number of nucleons}} = \frac{1}{9} = 0.11$$

$$\text{Ratio } (\text{NH}_3) \approx \frac{\text{Number of polarizable free protons}}{\text{Total number of nucleons}} = \frac{3}{17} = 0.18$$

Other nuclei candidates with a single valence polarized proton;
^{11}B (5p, 6n), ^{15}N (7p, 8n), ^{19}F(9p, 10n) and ^{27}Al (13p, 14n), for example.
Heavier nuclei: smaller dilution factor.

3. Three processes of producing and testing polarized target materials of ^{7}LiD

I. Fabrications of a disc from ^{7}LiD powder

II. Irradiation of ^{7}LiD on CEBAF injector beam line

III. Polarization measurements at 5 Tesla and 1 K

I. Fabrications of a disc from ^{7}LiD powder

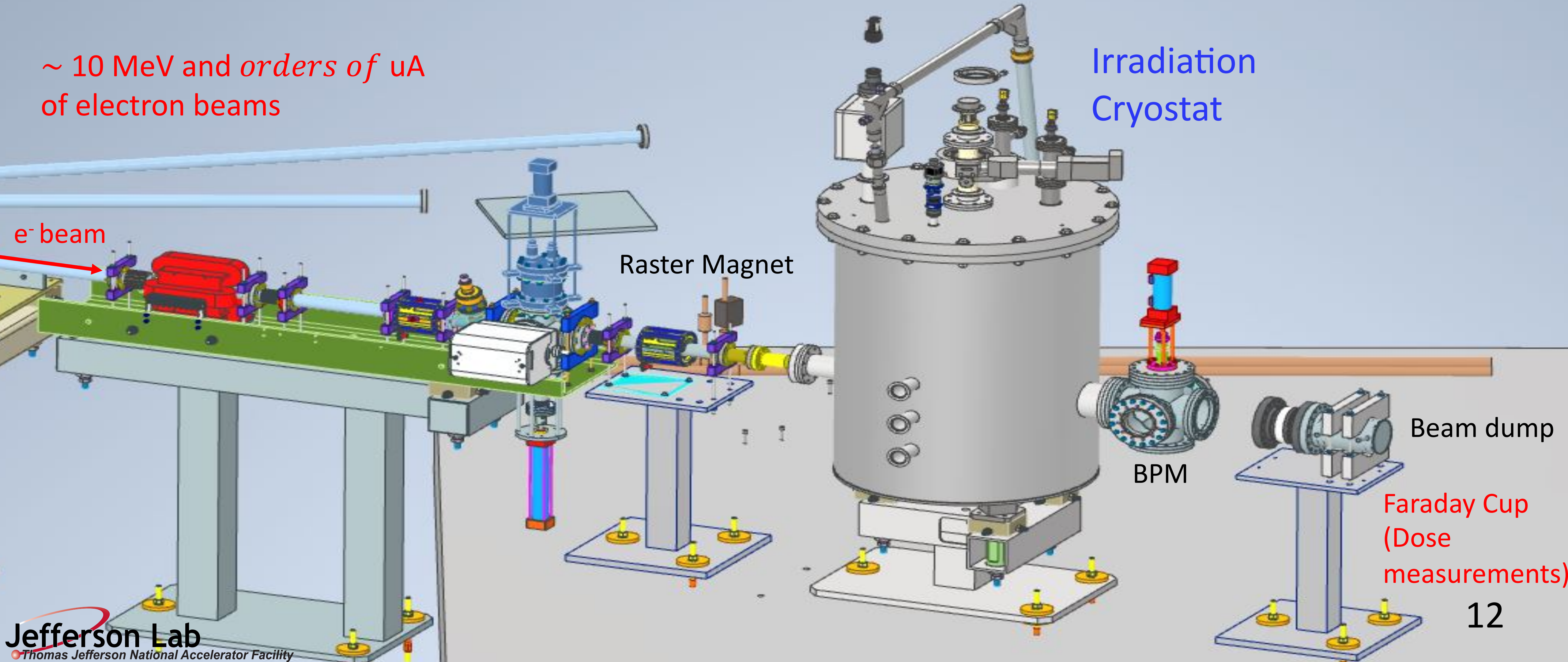
* ^{7}LiD powder is commercially available on the following conditions

- Isotopic purity of Lithium, ^{7}Li : ∽ 93 % and ^{6}Li : ∽ 7 %
- Isotopic purity of Deuterium, D : ∽ 98 % and H : ∽ 2 %
- Chemical purity, $\leq$ 5 % of impurities (LiOD, LiOD-H_2O, Li_2CO_2 …)
  (Analysis of ^{7}LiH powder (from a commercial company) by a group of LLNL (C.G. Bustillos etal., Annals of Nuclear Energy 185 (2023) 109709))

* Requesting service work to Y12 to fabricate disc (2 cm diameter and 2 mm thick)

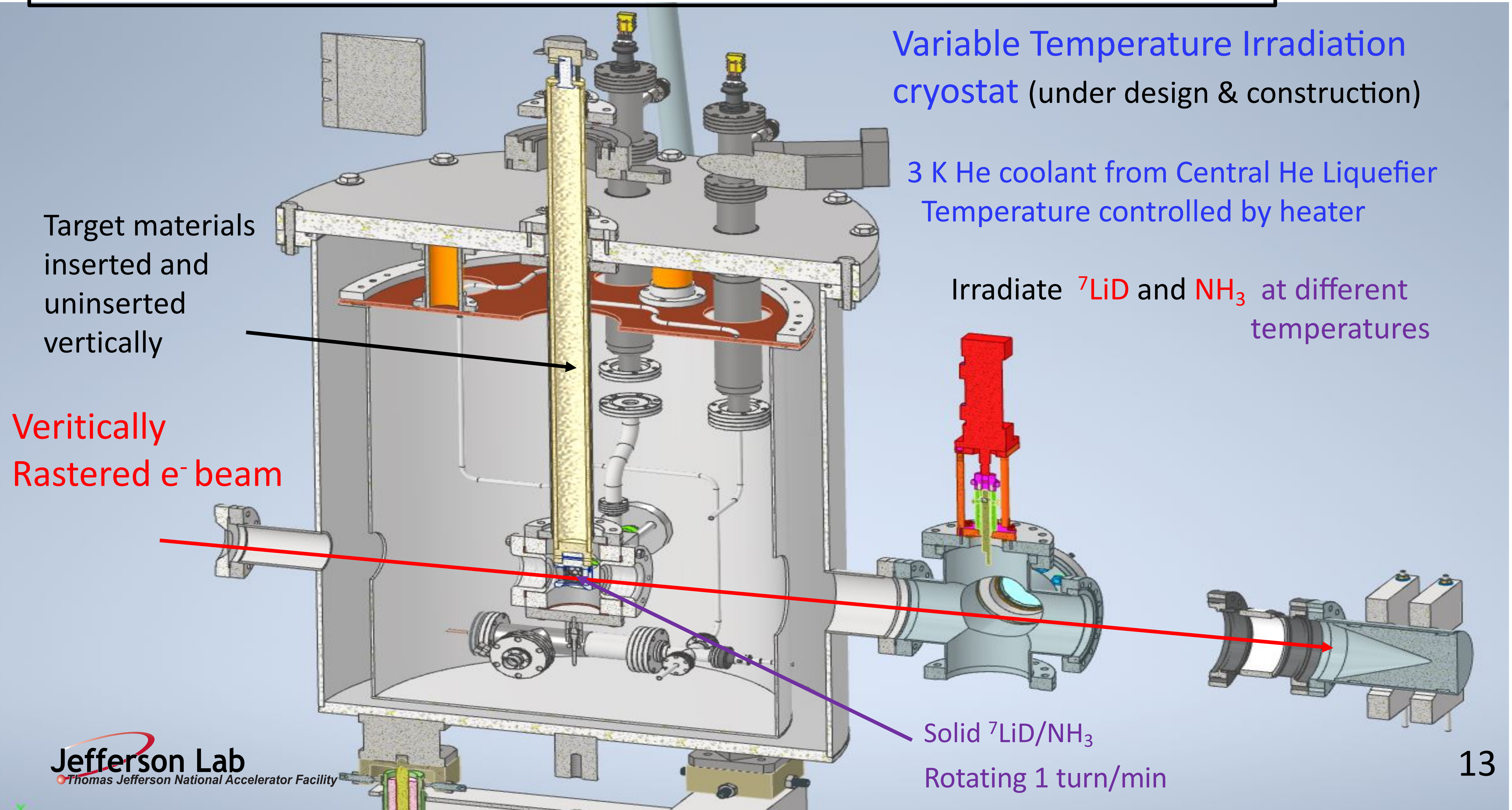
II. Irradiation of ^{7}LiD on CEBAF injector beam line (JLab) : New

NH^3 and ND^3 had been irradiated at NIST with collaboration of UVA target group in the past



Jefferson Lab
Thomas Jefferson National Accelerator Facility

II. Irradiation Cryostat (detail)



Variable Temperature Irradiation cryostat (under design & construction)

3 K He coolant from Central He Liquefier

Temperature controlled by heater

Irradiate ^{7}LiD and NH_3 at different temperatures

Target materials inserted and uninserted vertically

Veritically Rastered e^- beam

Solid ^{7}LiD/NH_3

Rotating 1 turn/min

II. Irradiation conditions for ^{7}LiD (higher polarization and shorter polarization building Time)

Some noteworthy past records for ^{7}LiH & ^{6}LiD (different irradiation temperatures and option)

	Group	T_{irrad} (K)	E_{e-} (MeV)	Dose (X 10^{17} e/cm^2)	P_{Li}(%)	T_{Build}	T(K)	B(Tesla)	Year & note
(1)	Bonn[1]	180	20	1	12	50 min	1	2.5	1995 (^{7}LiH)
					15	8 min			Ad. Irad. 1K 10^{15} e-

← Standard

(1) Additional irradiations at Lower Temperature (3K): can increase P_{max} and shorten T_{build}

	Group	T_{irrad} (K)	E_{e-} (MeV)	Dose	P_{Li}(%)	T_{Build}	T(K)	B(Tesla)	Year & note
(2)	SLAC[2]	183 $\pm$3	30	1.3 – 4.5	~ 60		1	5	1999 (^{7}LiH)

(2) ^{7}Li in ^{7}LiD is expected to polarize as high as 60 % at 5 Tesla (may optimize dose)

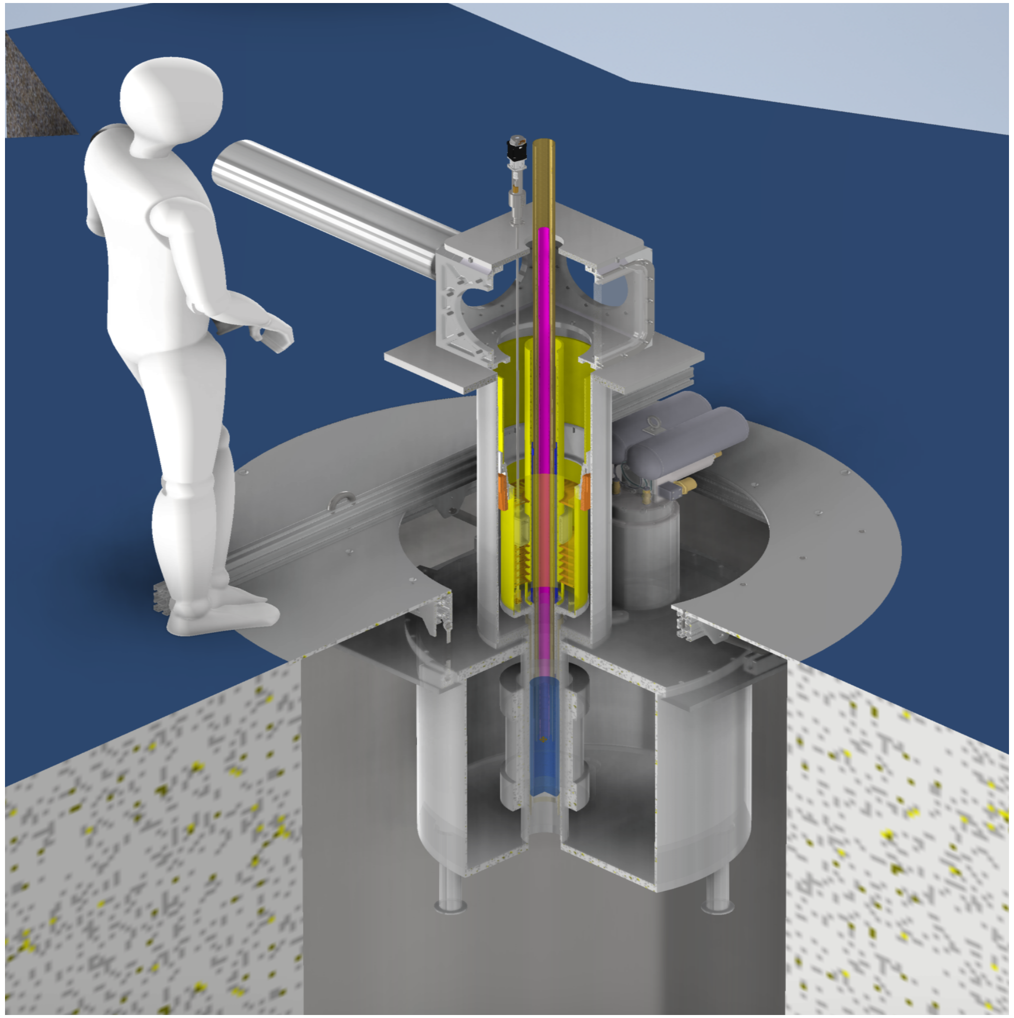
	Group	T_{irrad} (K)	E_{e-} (MeV)	Dose	P_{Li}(%)	T_{Build}	T(K)	B(Tesla)	Year & note
(3)	Bochum[3]	190	20	0.1	-17.8	220 min	1	2.5	2001 (**^{6}LiD)**
		140		1	-17.9	60 min	1	2.5	Warm RT

(3) ^{6}LiD at room temperature for 10 min; as od as on standard and may shorten T_{build}

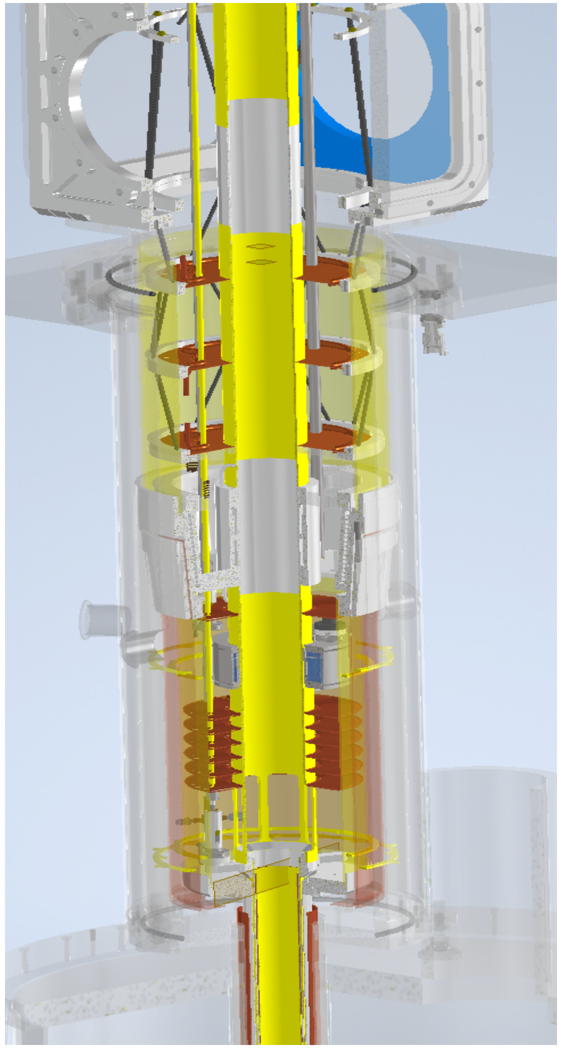
* Irradiate NH_3 at 80 K (standard irradiation temperature) and 3 K (low temperature as (1)) in prior to 11 GeV beam. NH_3 materials will be supplied by Univ. New Hampshire group.

1. S. Goertz etal., Nuclear Instruments and Methods in Physics Research A 356 (1995) 20
2. S. Bueltmann etal. Nuclear Instruments and Methods in Physics Research A 425 (1999) 23
3. A. Meier, 6LiD for the polarized target of the COMPASS experiment, PhD. Thesis, Ruhr-University Bochum 2001

III. DNP cryostat with 5 Tesla and 1 Kelvin (under design and construction)



Cryomagnetics Cryo-Free 5 T Warm Bore Magnet



Vertical 1 K cryostat

(Refer J. Brock's presentation)

Summary

1. We are developing polarized ^{7}LiD target system for Spin dependent EMC effect experiments at Hall B.

2. For this purpose, designing and constructing irradiation and polarizing cryostats.

3. Plan to irradiate and polarize ^{7}LiD target materials in the middle of 2025. Test materials and optimize parameters to obtain higher polarization and shorter building up time of polarization on the beamline.

Backup Slides

II. Irradiation of ^{7}LiD (higher polarization and shorter polarization building Time)

Summary of some past records; T_{irrad}, Pol_{Max}, $Time_{Build}$ and polarizing conditions for ^{7}LiH

Group	T_{irrad}(K)	E_{e-} (MeV)	Dose (e/cm²)	P_{Li}(%)	P_{H}(%)	BuildT	T(K)	B(Tesla)	Year
Abragam[1]	77	3	2×10^{17}	80	95	50 h	0.2	6.5	1978
Saclay[2]	183	300-650	1	50	70	24 h	0.2 – 0.4	5	1985-87
	183	300-650	2	47	56	6 h	0.2 - 0.4	2.5	1985-87
PSI[3]	180	3	2	90			0.2 - 0.4	2.5	1990
Saclay[4]	184 ± 4	30	0.5	31	42	3 h	0.2 – 0.4	2.5	1992
Bonn[5]	180	20	1	12		50 min	1	2.5	1995
				15		8 min			Ad. Irad. 1K 10^{15} e-
SLAC[6]	183 ± 3	30	1.3 – 4.5	~ 60			1	5	1999

Optional procedure: after irradiation keep ^{6}LiD at room temperature for 10 min.

Group	T_{irrad}(K)	E_{e-} (MeV)	Dose (e/cm²)	P_{Li}(%)	P_{H}(%)	BuildT	T(K)	B(Tesla)	Year
Bochum[7]	190		0.1	-17.8	-18.6	220 min	1	2.5	2001
	140		1	-17.9	-18.7	60 min	1	2.5	Warm RT

1. A. Abragam etal., J. Physique Let. 41 (1980) L-309
2. P. Chaumette etal. Proc. of 8th Int. Symposium of High Energy Spin Physics. 1988, 1275
3. S. Mango etal. Proc. of 9th Int. Symposium of High Energy Spin Physics, 1990, 320
4. J.J. Jarmer etal., Proc. Of 10th International Symposium on High Energy Spin Physics, 1992, 363
5. S. Goertz etal., Nuclear Instruments and Methods in Physics Research A 356 (1995) 20
6. S. Bueltmann etal. Nuclear Instruments and Methods in Physics Research A 425 (1999) 23
7. A.Meier, 6LiD for the polarized target of the COMPASS experiment, PhD. Thesis, Ruhr-University Bochum 2001