

NDX detectors in Hall C: neutron dosimetry in the presence of strong photon radiation fields, first results

Pavel Degtiarenko
Radiation Physics Group at RadCon
Jefferson Lab

January, 2019

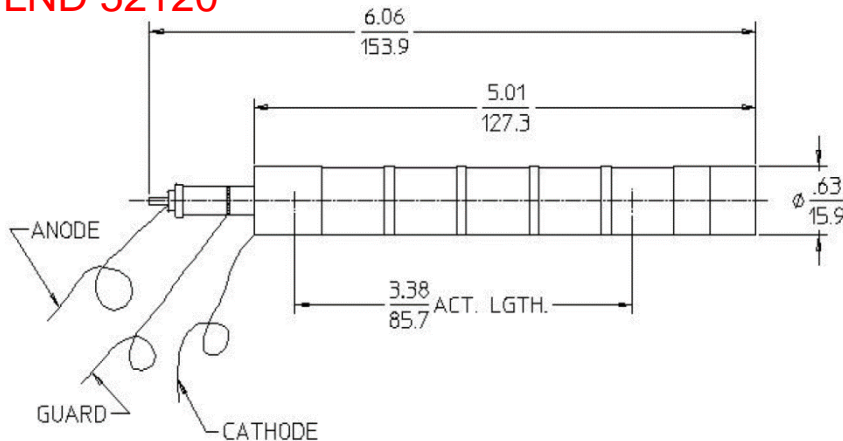
Outline

- ❑ Neutron dose rates inside High Energy electron accelerators:
 - ❖ Important for radiation safety, radiation damage, activation
 - ❖ Needed to evaluate and benchmark the simulation models
 - ❖ Difficult to measure due to overwhelming photon radiation
 - ❖ Monitors fail: radiation damage, high photon background
 - ❖ Passive dosimetry: lack of online monitoring capability, generally small dynamic range
- ❑ Need in the new neutron dosimetry techniques:
 - ❖ Online monitoring
 - ❖ Insensitive to photon background
 - ❖ Large dynamic range
- ❑ NDX: novel neutron dose rate meter with extended capabilities
 - ❖ High pressure ionization chambers filled with ^3He and ^4He
 - ❖ Neutron moderator with Beryllium-loaded reflector / multiplier

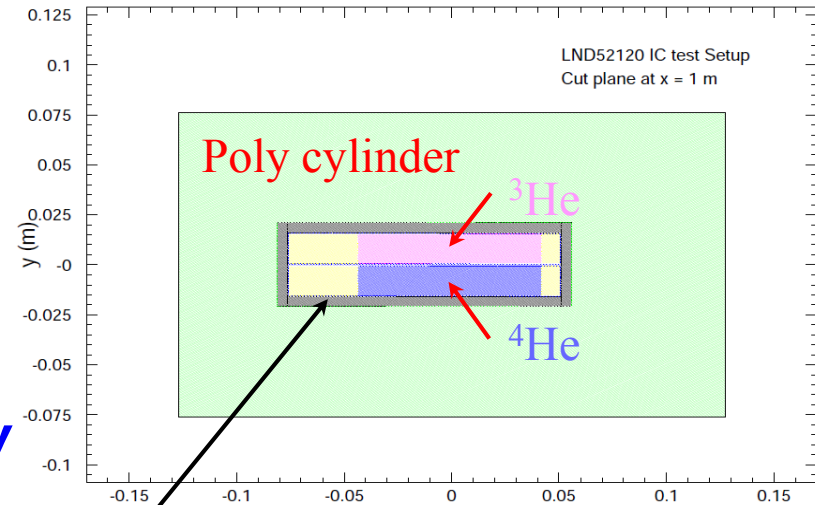
Original Idea (2016)

- Propose to use two small LND ICs, filled with ^3He and ^4He (1 atm gas pressure) placed together in a poly moderator, with lead or tungsten shield
- ^4He and ^3He : ~ 0.1 pA in 1 rad/h γ
- ^3He : ~ 10 pA in 1 rem/h neutrons

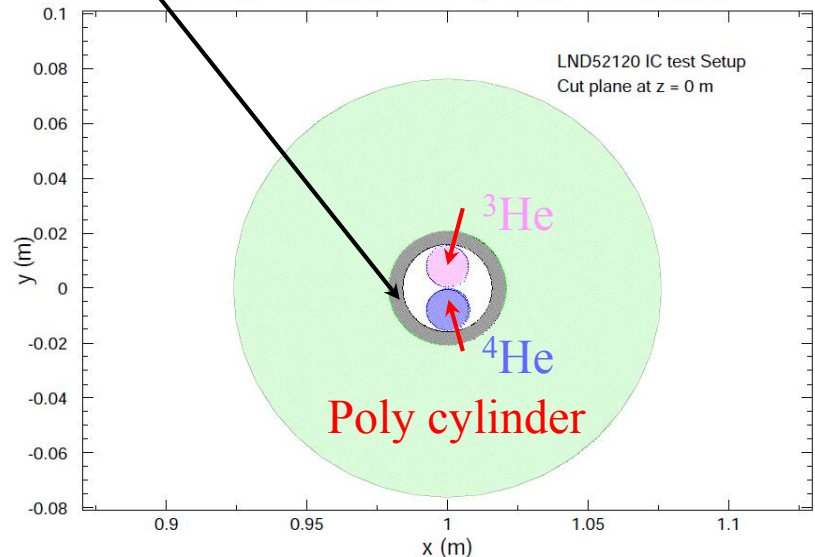
LND 52120



Neutron Detector for C100 Operations Environment



Lead shield / neutron multiplier



Principle of Operation

- Captured moderated thermal neutrons produce measurable current in the ^3He -filled ion chamber, and photons produce **small** symmetrical response in both ^3He - and ^4He -filled ion chambers.
- A sensitive electrometer-type current readout needed, with a long-term stability in pA range.
- Using Beryllium-Copper alloy layer inside the moderator improves the linearity of the neutron energy response function. Beryllium acts as a “neutron multiplier” in the energy range of **10-50 MeV**, where other neutron detectors lack response. At higher energies (**~ 0.5 -10 GeV**) neutrons interact with Copper and improve the response due to the spallation reactions.

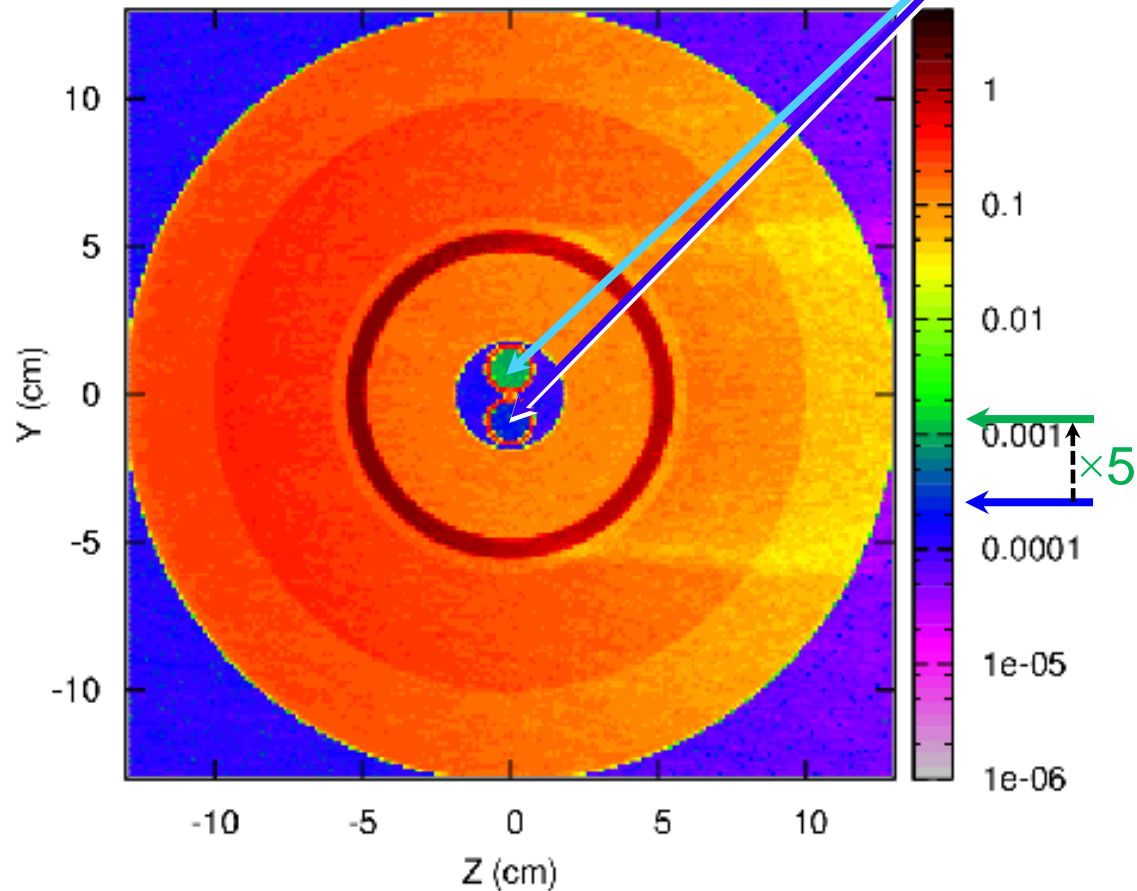
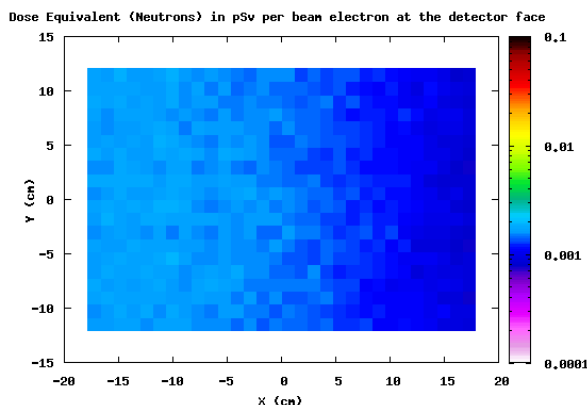
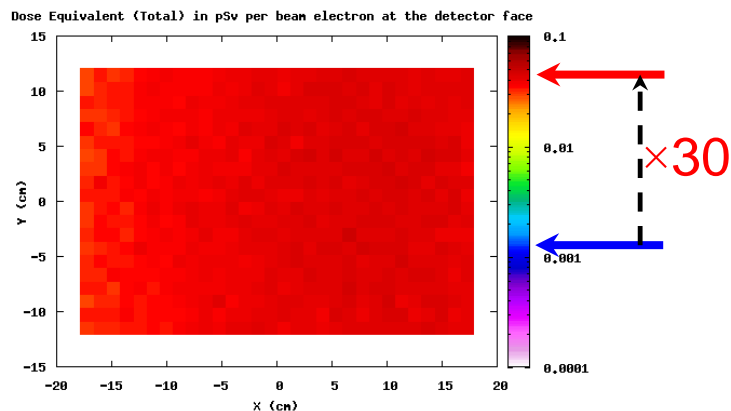
Detector next to a thick target at 2.2 GeV

FLUKA: Showing energy density in the air, and in the detector

The ratio of currents from ^3He IC to ^4He IC equals to 5

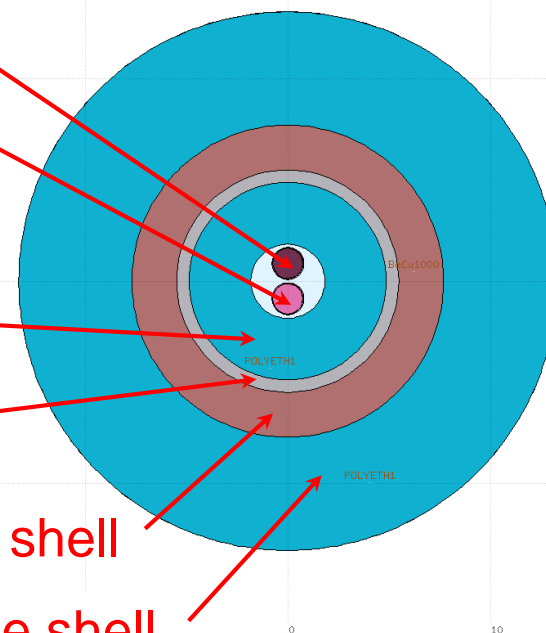
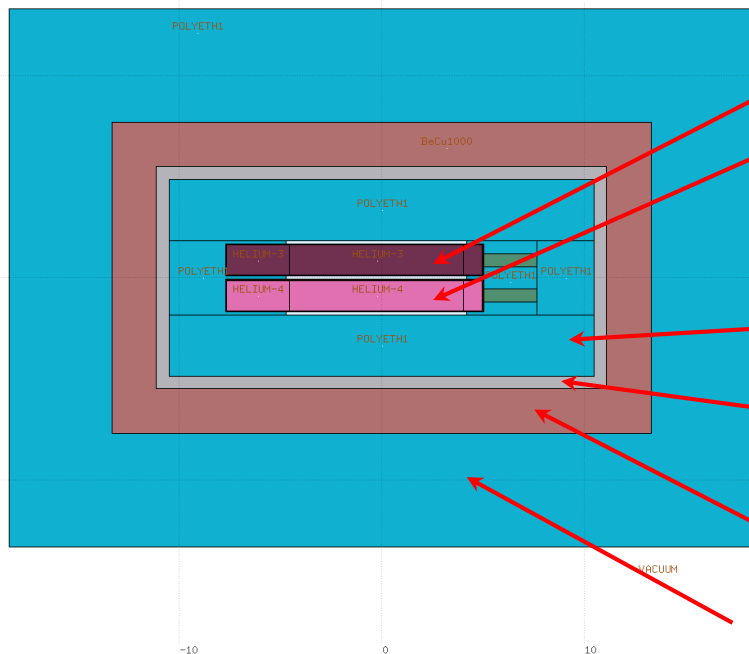
Face Dose Rates
(Total and Neutron):

Energy Deposition (keV/cm³) per beam electron at 2 GeV, Z-Y middle plane



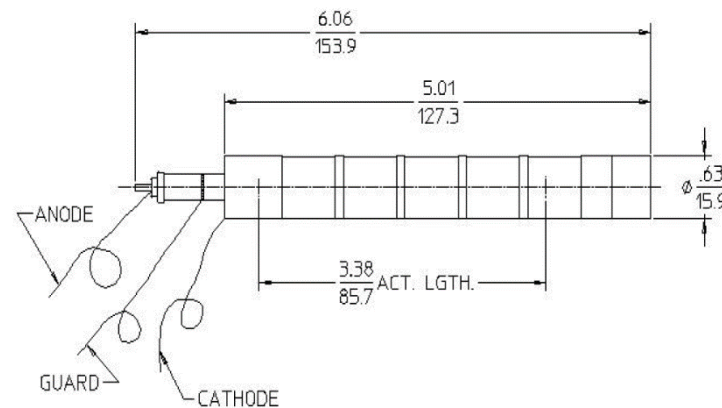
FLUKA Model, Be Loaded Moderator

LND 52120 Ionization Chambers, 10 atm



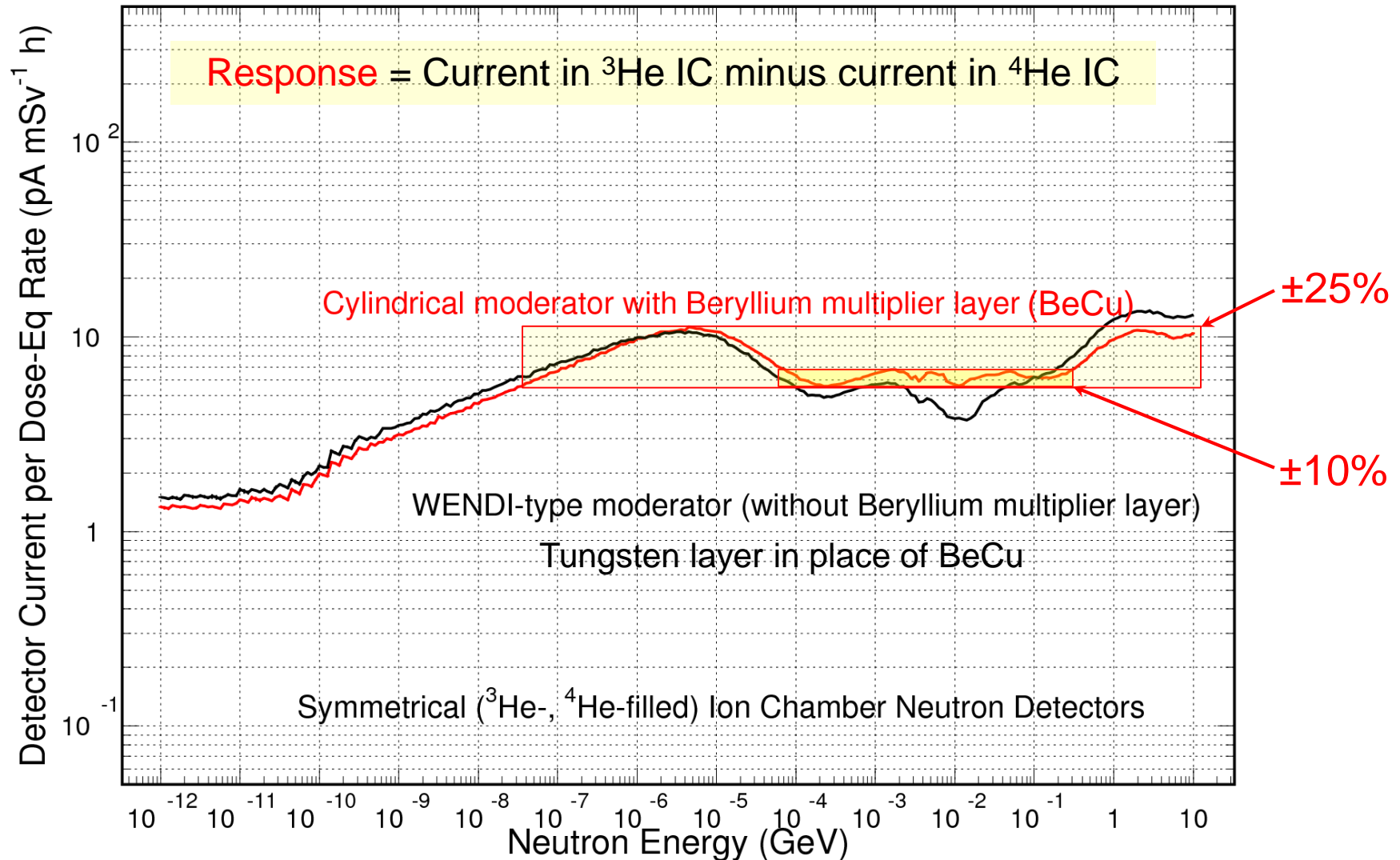
Cylindrical moderator assembly

Ion Chamber Quote: \$(1350+750)

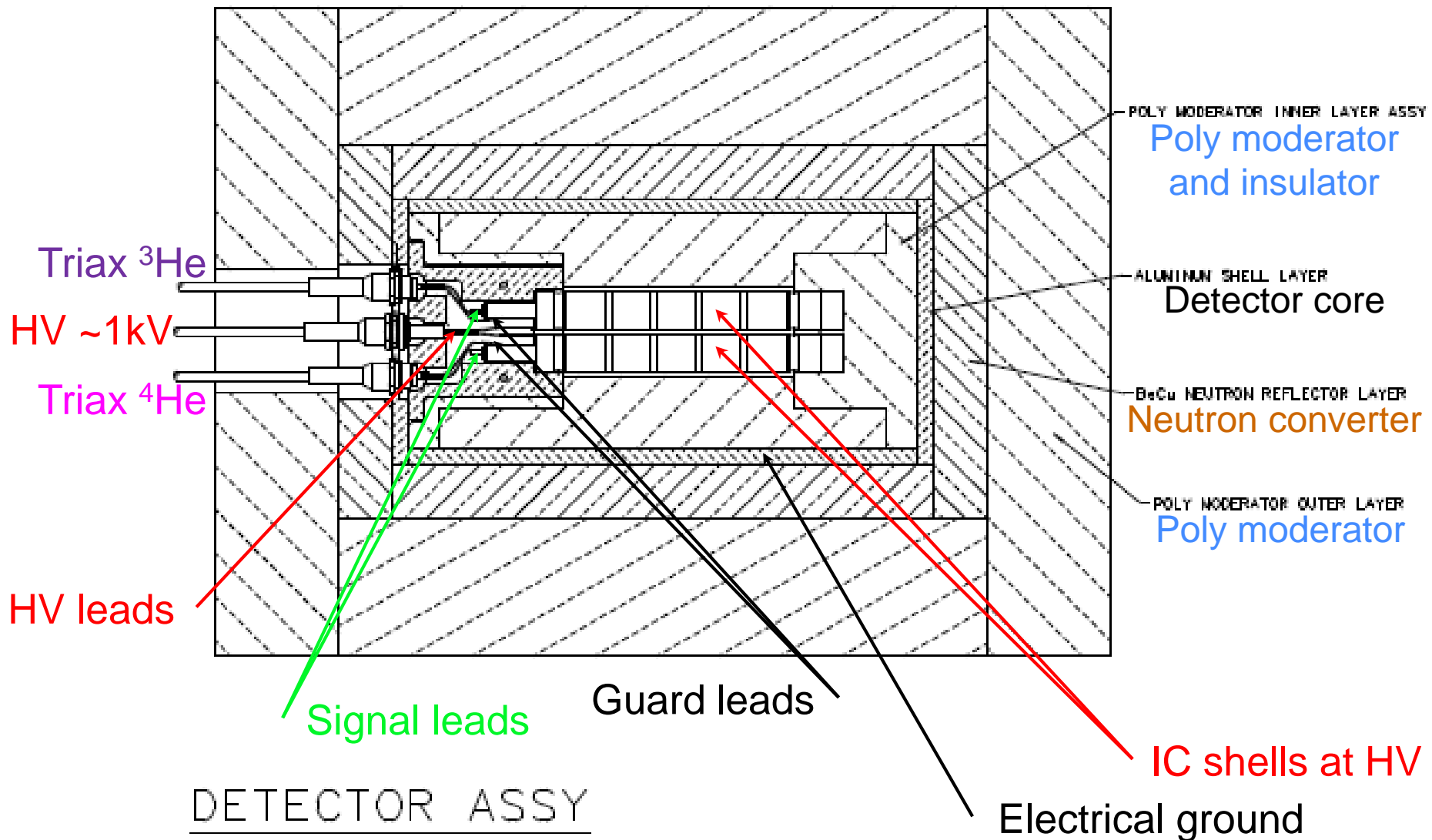


Energy Dependence of Detector Response

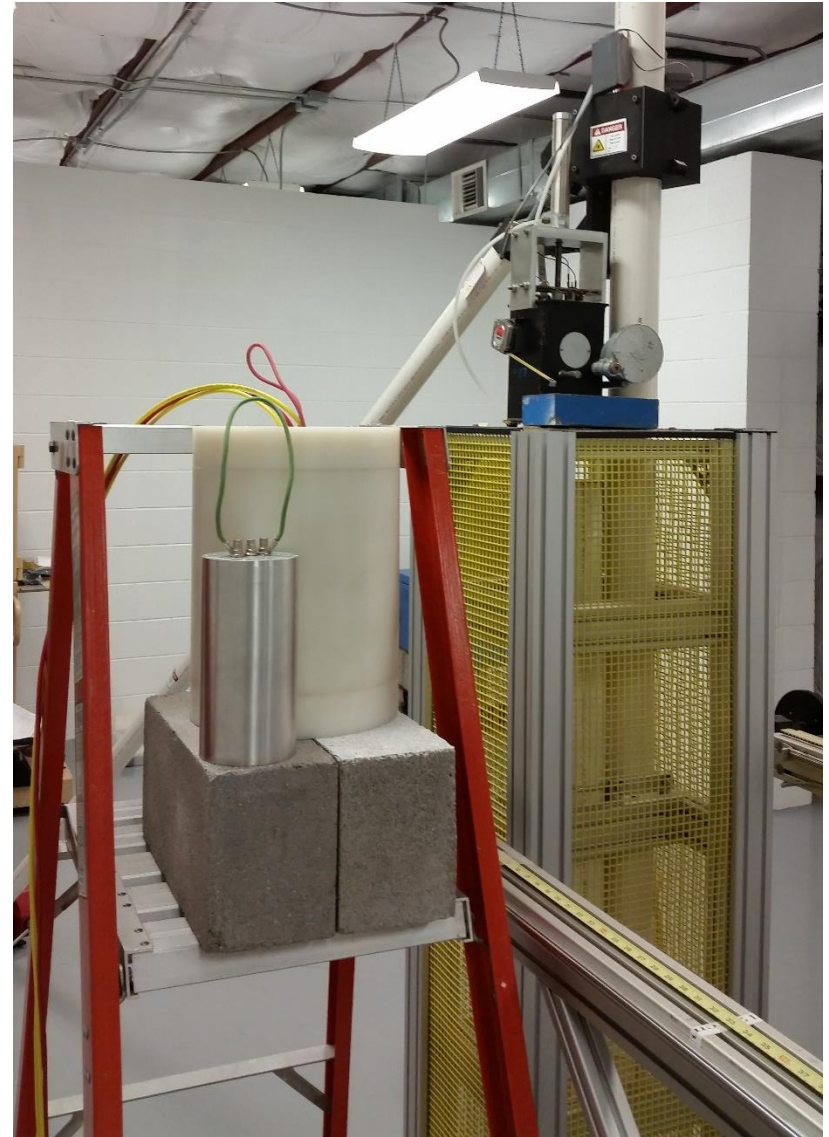
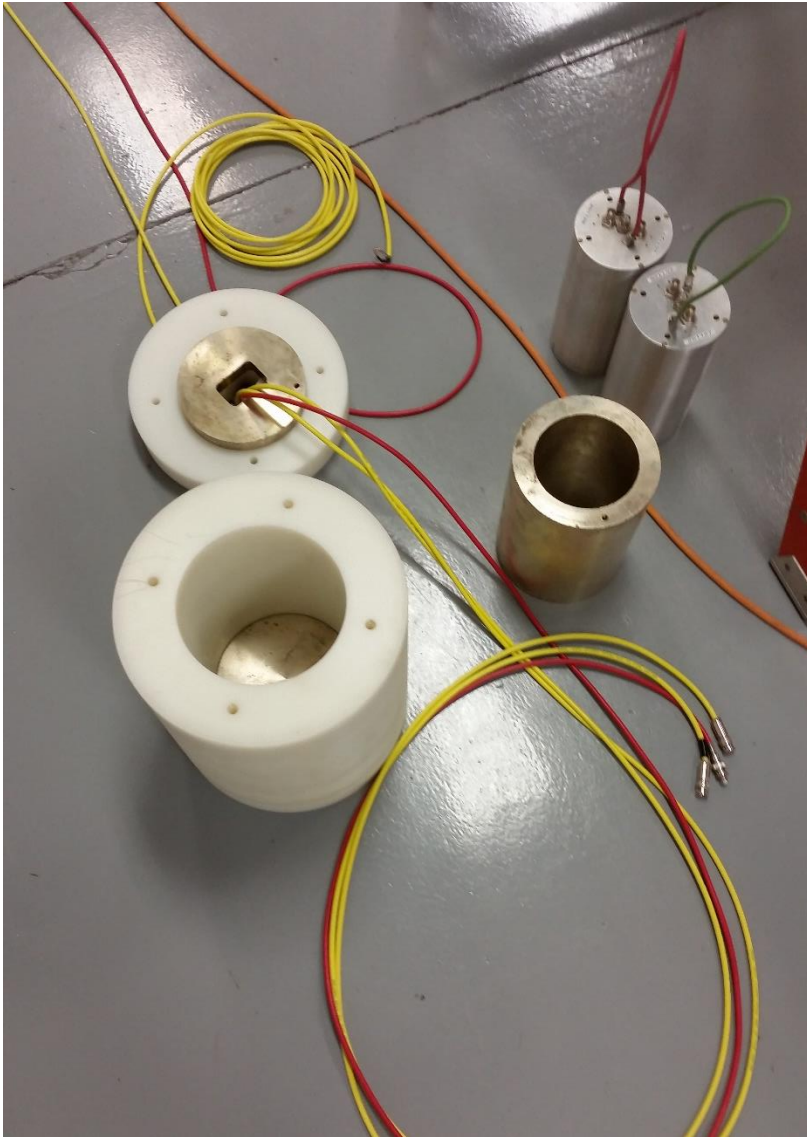
Response to Neutron Dose Equivalent, Function of Energy



Prototype Assembly Drawings



Prototype Detectors



Pyramid Front End Electronics

- ❑ Pyramid Technical Consultants, Inc.
 - ❖ Four channels
 - ❖ Sensitivity and stability down to 0.1 pA
 - ❖ Network connectivity for the data readout
 - ❖ “EPICS ready”
 - ❖ Cost at about \$6k



Calibration

- The calibration of the detectors in the test neutron fields at RadCon range (AmBe neutron source, max calibration field about 75 mrem/h) resulted in the values of the calibration coefficients of about $C_n = 12 \text{ mrem/h per pA}$.
- The symmetric response of the ^3He and ^4He ion chambers to high photon dose rates ($\sim 100 \text{ Rad/h}$) was tested in the gamma irradiator at RadCon, and the difference was found to be under 10%. This factor is used in the current subtraction procedure.
- The formulas for neutron and photon dose rates:

$$nDsRt = C_n * [(nCur - B_n) - F_g * (gCur - B_g)]$$

$$gDsRt = C_g * (gCur - B_g)$$

NDX I-400 EPICS Expert Screen

IOC: iocsoftRadNDX

10/25/2018 14:31:11

bootdate

1736831

heartbeat

Acquisition Switch

ABORT
ACQUIRE

Integration Period

1.40000

Capacitor Switch

1000pF
☐

NDX Detector 1

	Currents (A)	Dose Rates (mrem/h)
n Bias (Bn)	-2.4601e-12	nCur 1.1006e-09 neutron (nDsRt) 1.2988e+04
g Bias (Bg)	4.0468e-13	gCur 1.1731e-11 gamma (gDsRt) 1.2992e+04
n Calibr (Cn)	1.1910e+13	total (DsRt) 2.5979e+04
g Calibr (Cg)	1.1470e+15	
g Factor (Fg)	1.11200	

NDX Detector 2

n Bias (Bn)	-4.4413e-13	nCur 9.0969e-11 neutron (nDsRt) 1.0764e+03
g Bias (Bg)	-2.6309e-13	gCur -1.0220e-12 gamma (gDsRt) -8.4831e+02
n Calibr (Cn)	1.1670e+13	total (DsRt) 2.2812e+02
g Calibr (Cg)	1.1179e+15	
g Factor (Fg)	1.08900	

Auto Bias Time Begin: 2018-11-14 06:00:00

Auto Bias Time End: 2018-11-14 09:00:00

AutoBias

Time Format:
VVVV-MM-DD HH:MM:SS
-xx, ^xxx> where xx is an integer and y is s,h,m,d or w
second,minute,hour,day,week

AutoBias: Successful

Mean: -2.4601e-12

4.0468e-13

-4.4413e-13

-2.6309e-13

iocsoftig2

initiate	0
analog[9]_in_data	3.4000e+01
channel_a	1.0969e-09
channel_b	1.1210e-11
channel_c	8.9368e-11
channel_d	-1.0220e-12
trigger source	1
trigger points	-1
trigger count	34
capacitor	1
integration period	1.4000
subsamples	1
range	7.1429e-09
HV external bias	0
signal bias	0.0000e+00
temperature	-3.0317e+01
pressure	0.0000e+00

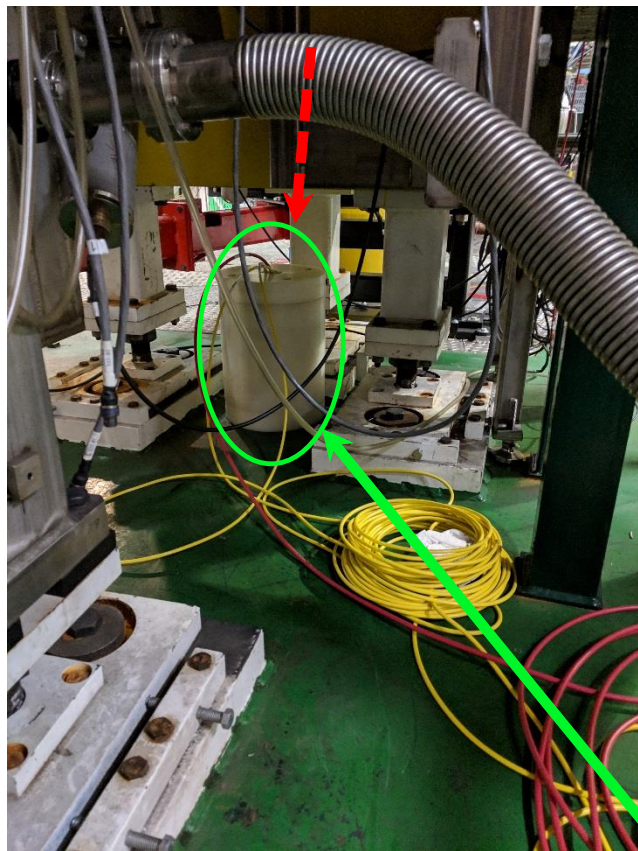
For both Detector1 and Detector2:

$$\text{nDsRt} = \text{Cn} * [(\text{nCur} - \text{Bn}) - \text{Fg} * (\text{gCur} - \text{Bg})]$$

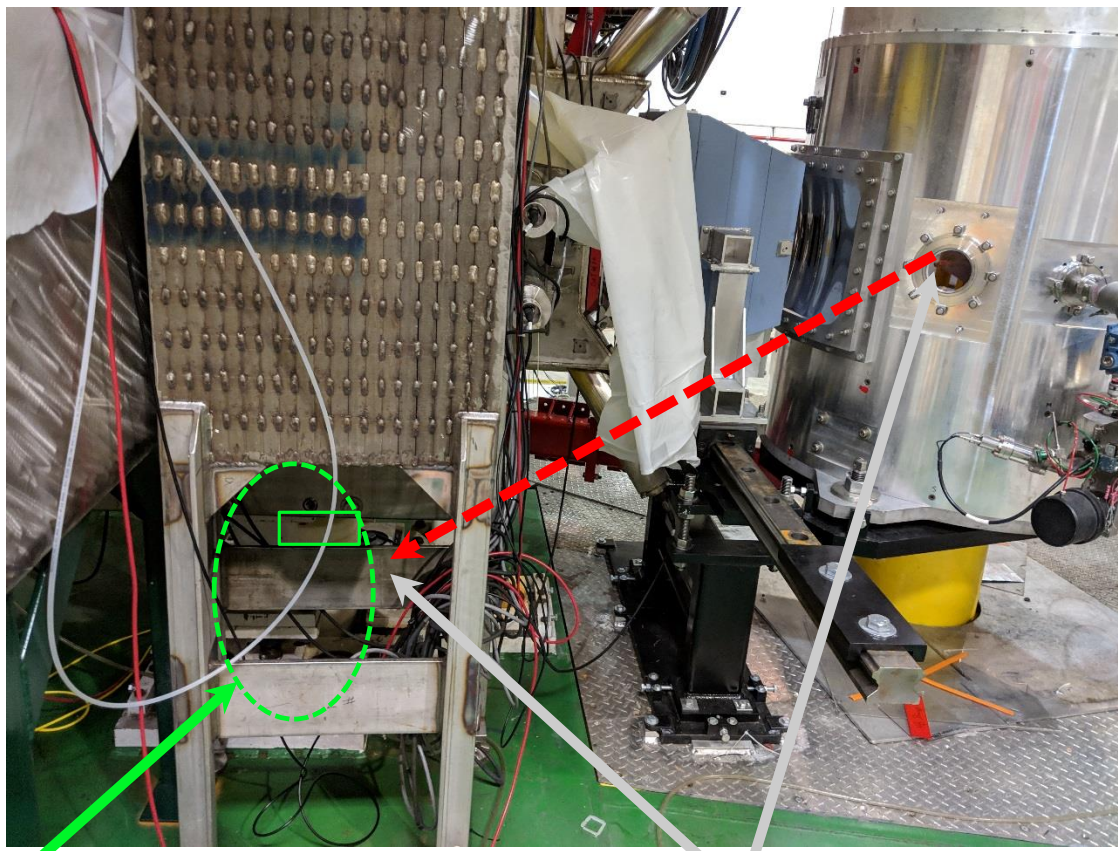
$$\text{gDsRt} = \text{Cg} * (\text{gCur} - \text{Bg})$$

$$\text{DsRt} = \text{nDsRt} + \text{gDsRt}$$

NDX-1 Detector, SHMS Platform under HB Magnet



NDX01 Detector under HB magnet



Approx. 3 m from target

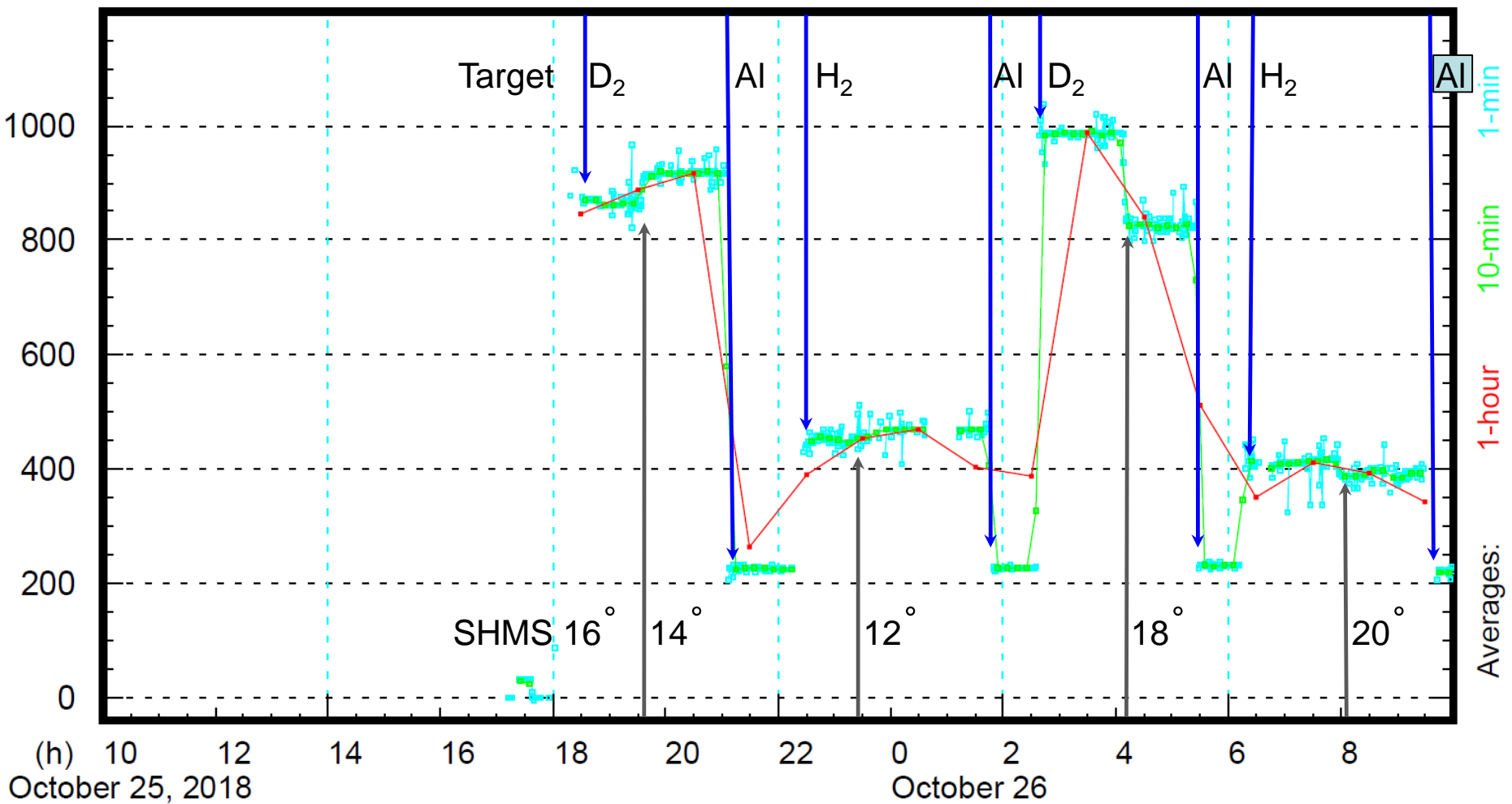
NDX-2 on SHMS Platform Downstream



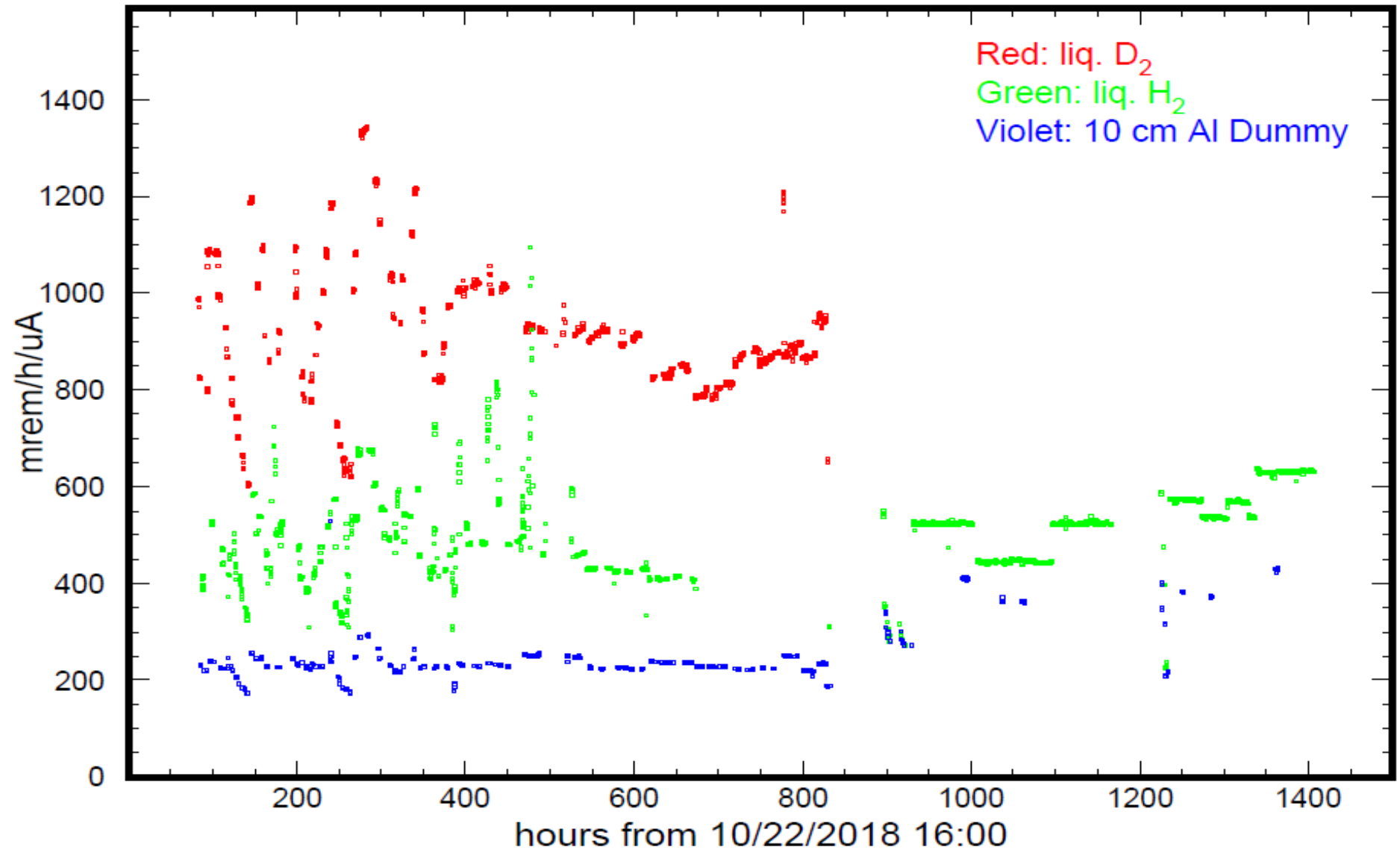
NDX1 Dose Rates per Beam Current

2018/10/26 10:56

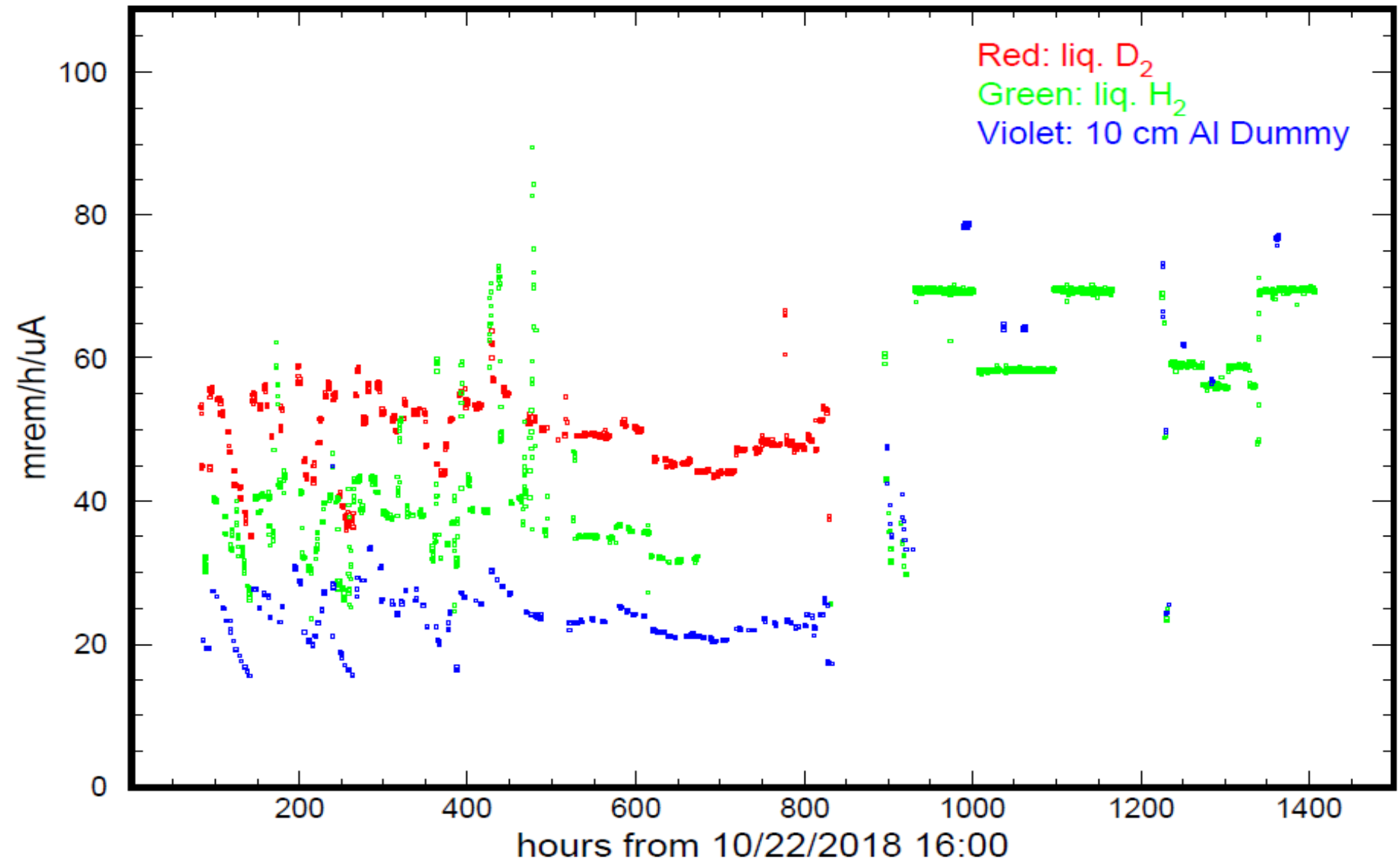
Hall C: NDX1 neutron DsRt per Beam Current (mrem/h/ μ A)



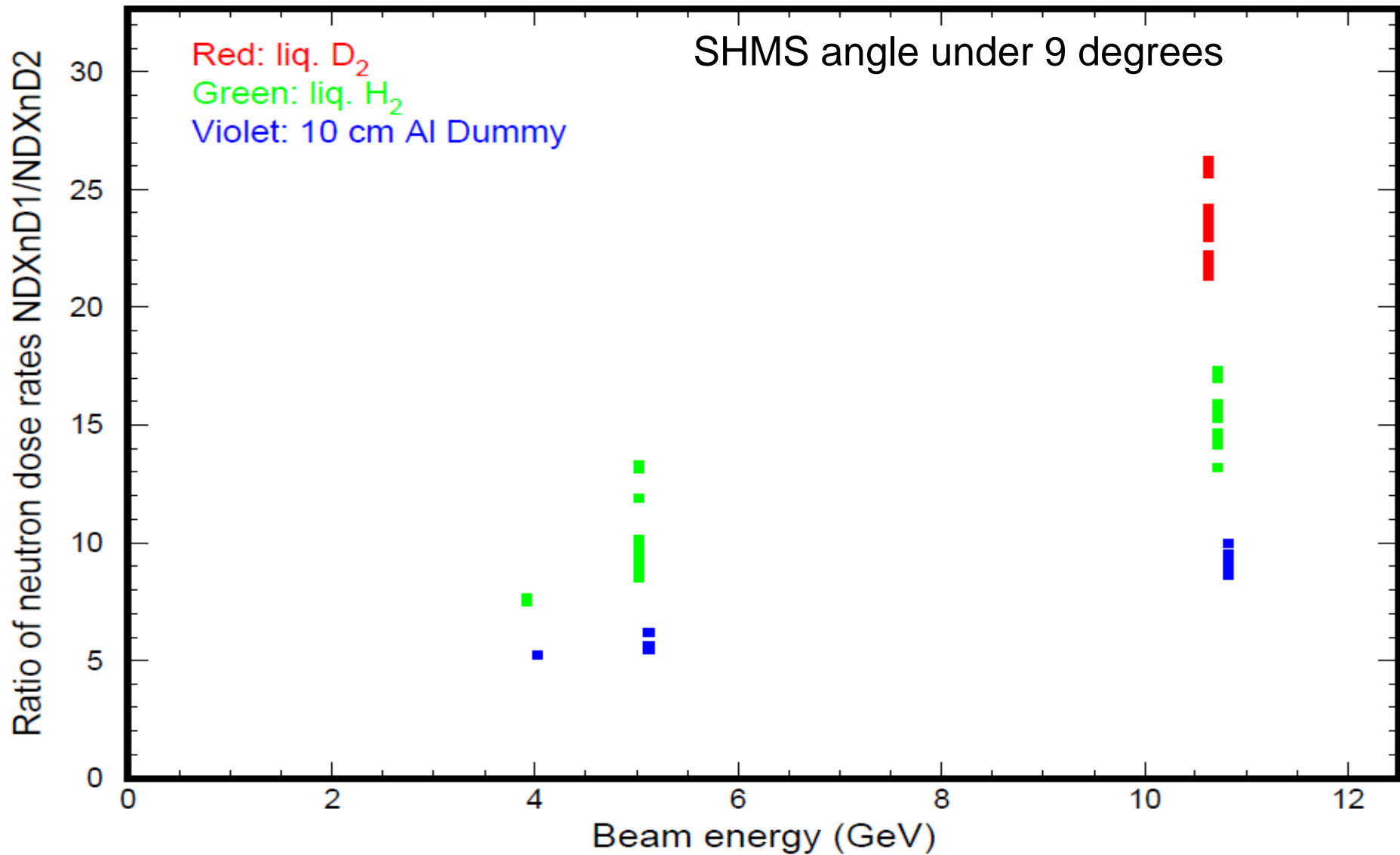
NDX1 n Dose Rates per Beam Current



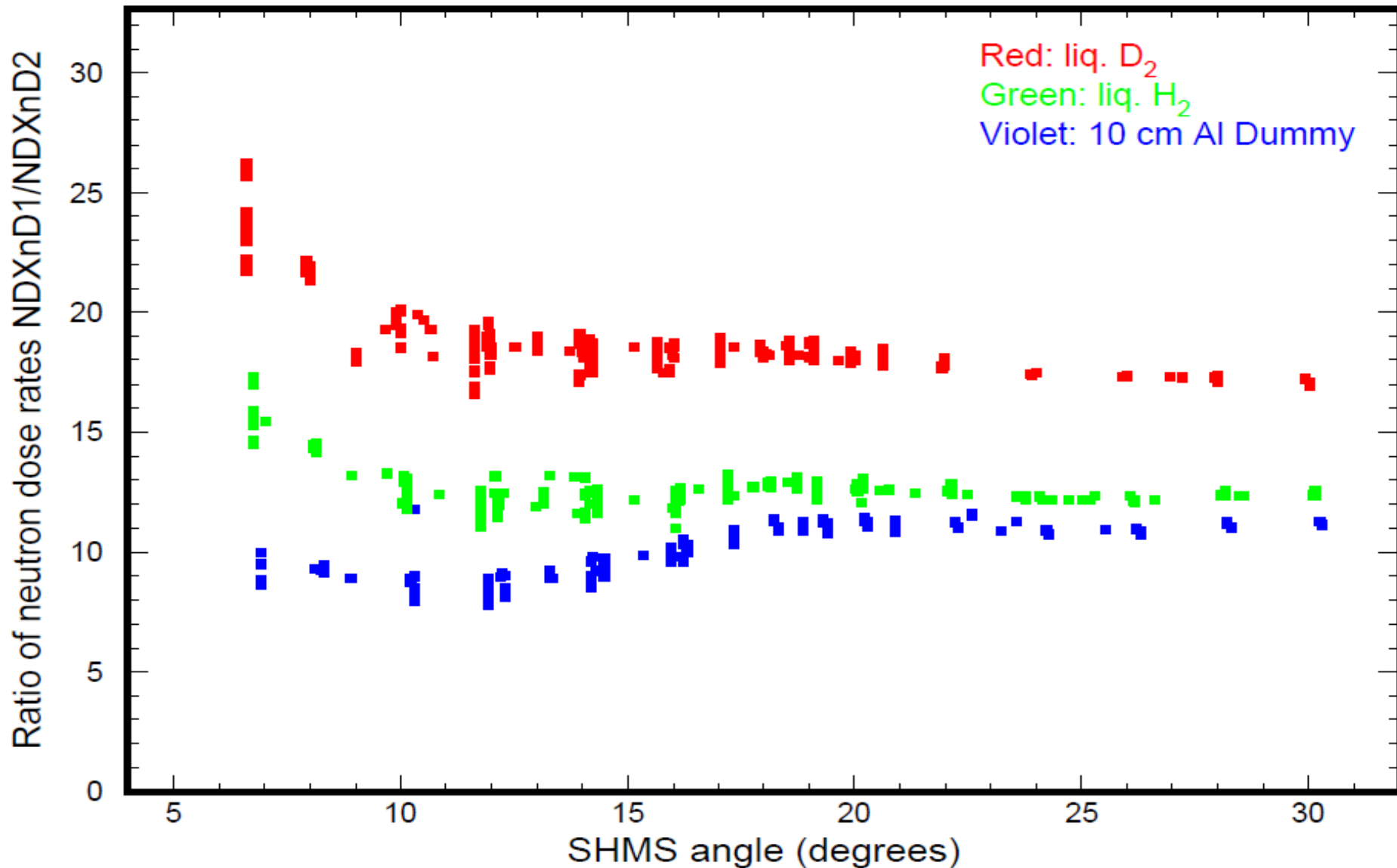
NDX2 n Dose Rates per Beam Current



nD1/nD2 Ratio vs. Beam Energy



nD1/nD2 ratio vs. SHMS angle, E = 10.6 GeV

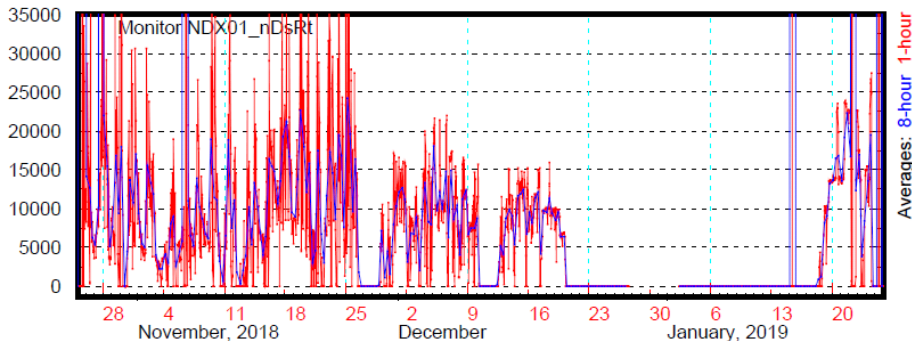


NDX Detectors: Last Three Months

Neutron and photon dose rates measured by the NDX detectors during the last run in Hall C, and the beginning of operations in the North Linac at NL26

2019/01/26 11:57

NDX01 Neutron Dose Rate (mrem/h)

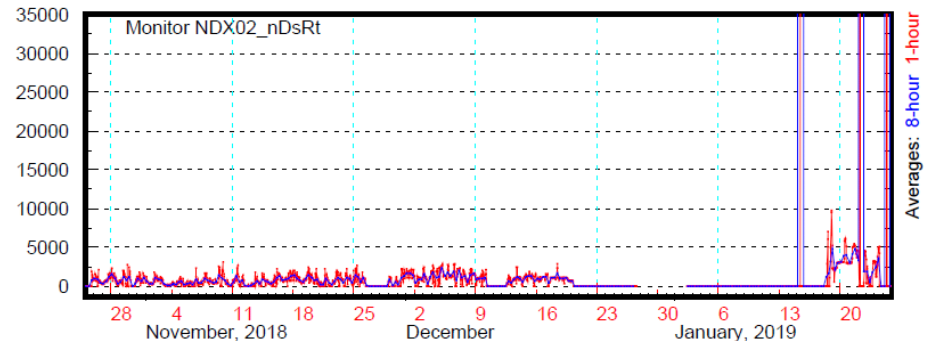


Hall C

NL26

2019/01/26 11:57

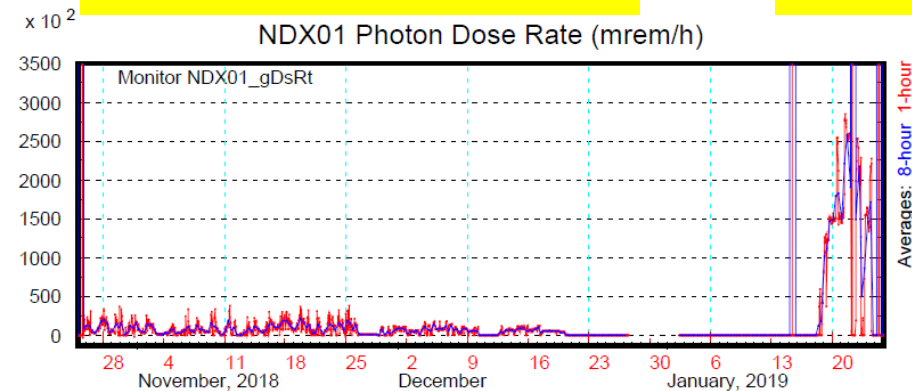
NDX02 Neutron Dose Rate (mrem/h)



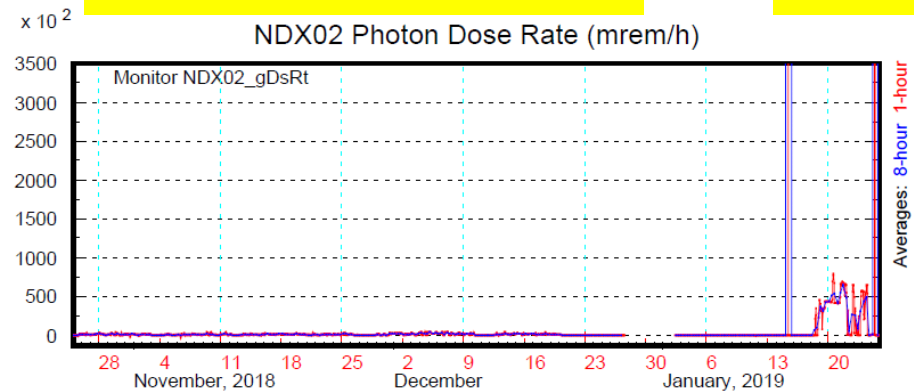
Hall C

NL26

NDX01 Photon Dose Rate (mrem/h)



NDX02 Photon Dose Rate (mrem/h)



Summary

- ❑ Stable and reliable operation of the two prototype **NDX** detectors has been demonstrated during the two-month run in Hall C, solving the problems:
 - ❖ Neutron detection in the presence of overwhelming photon radiation fields at JLab:
 - at the experimental halls
 - around the SRF cryomodules
 - possible beam loss monitoring
 - ❖ Improving quality of the neutron ambient dose equivalent measurements at high neutron energies up to 10 GeV
 - ❖ Radiation hardness, large dynamic range, stability of the neutron detection, characteristic for Ion Chamber operation
- ❑ JLab patent submitted, with possible applications in Accelerators, Photon Irradiation Facilities, Nuclear Power Plants
- ❑ List of “Lessons Learned” is compiled to take into account in the future development

Acknowledgements

Thanks to:

- ☐ Rolf Ent, Cynthia Keppel, Paulo Medeiros, Bogdan Wojtsekhowski, Brad Sawatzky
- ☐ Vashek Vylet, George Kharashvili, David Hamlette, Melvin Washington, John Jefferson
- ☐ Chris Cuevas, Armen Stepanyan
- ☐ Matt Poelker, Sue Witherspoon
- ☐ William Lehnert (LND, Inc.)

Extras

Beam Loss in Transport Tunnel on 12/14/18



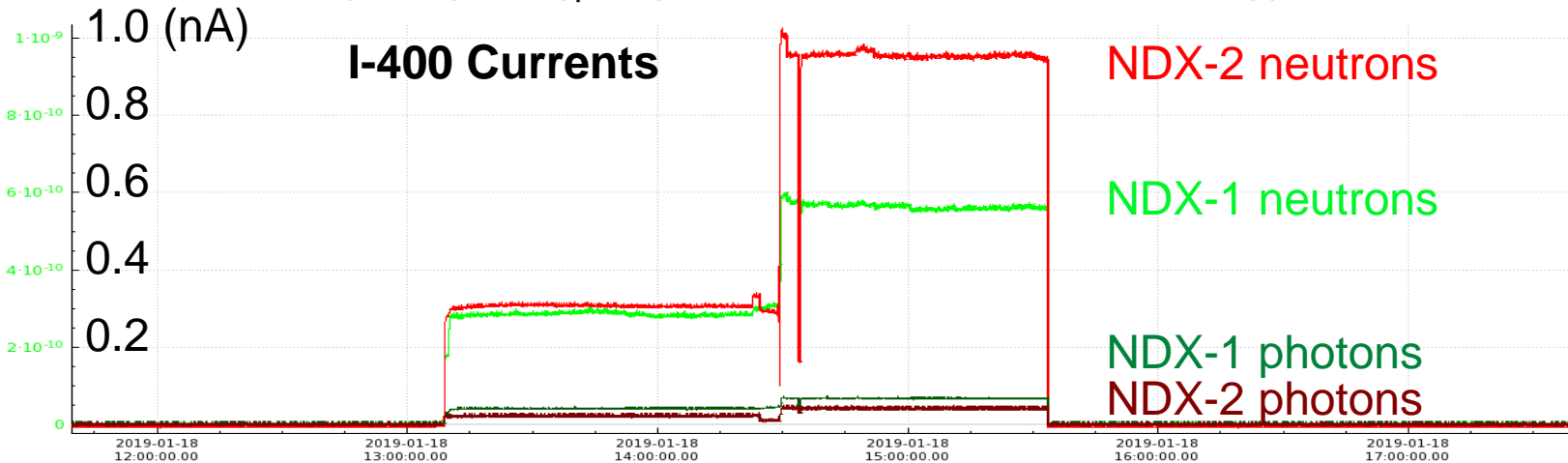
NDX Operation in North Linac, Example

Neutron and photon dose rates in the detectors NDX01 and NDX02 (mrem/h). NL26 cryomodule. NDX01 at beam entry end, NDX02 at beam exit end.



NDX01_nDsRt
NDX02_nDsRt
NDX01_gDsRt
NDX02_gDsRt

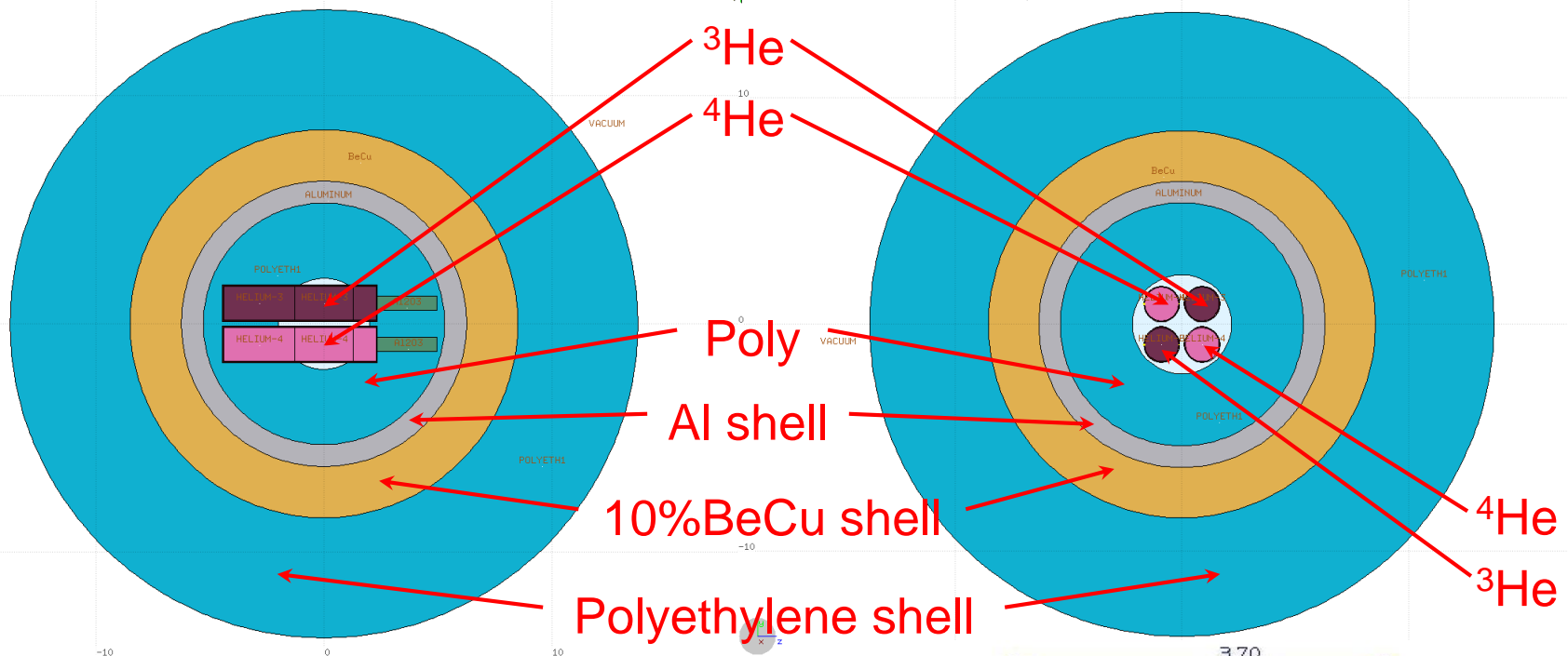
He-3 ("neutron") and He-4 ("photon") Ion Chamber currents in the detectors NDX01 and NDX02 (A)



NDX01_nCur
NDX02_nCur
NDX01_gCur
NDX02_gCur

Spherical Moderator Design

LND 52103 Ionization Chambers , 20 atm

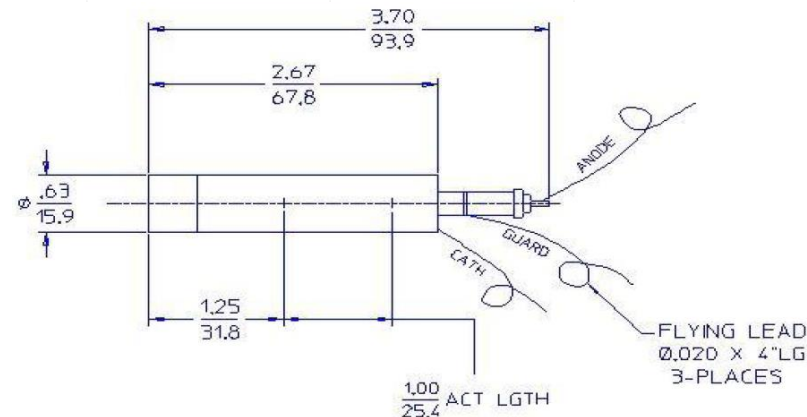


Spherical moderator assembly

Same sensitivity

Better directional uniformity

Optimal weight of the moderator



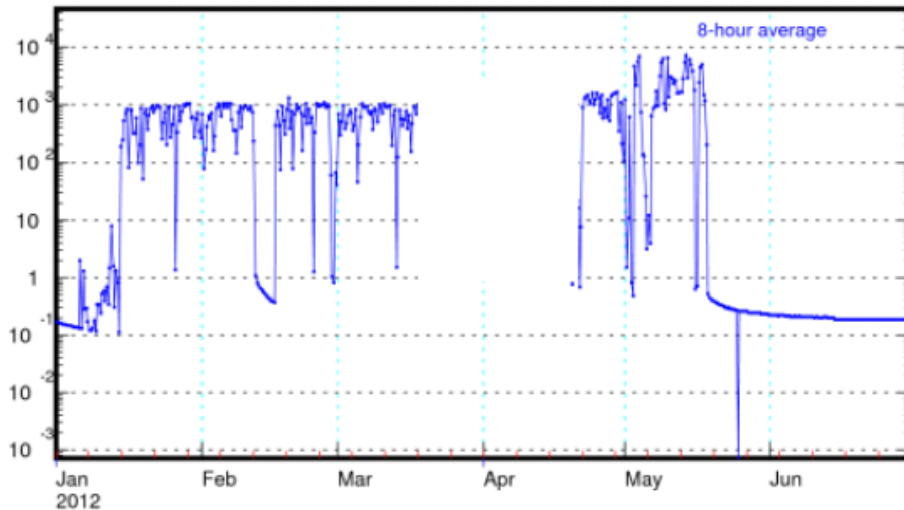
Gamma Irradiator Tests



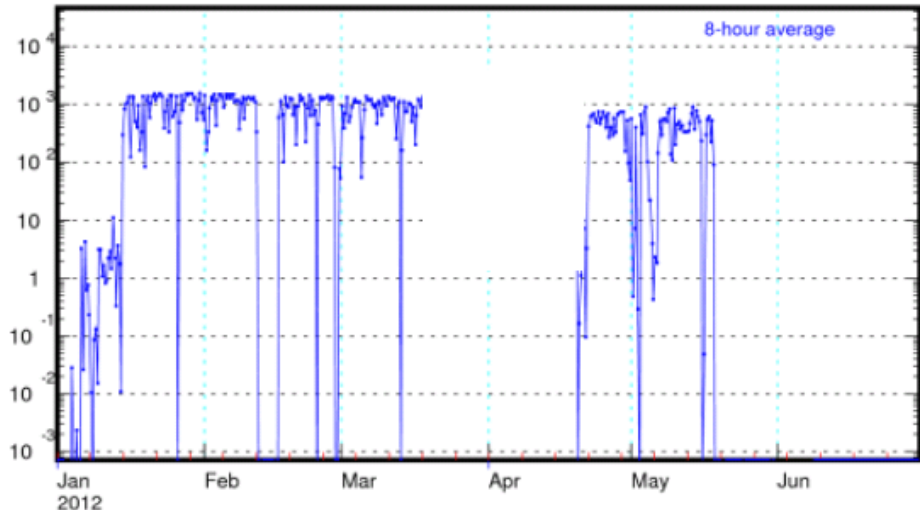
Radiation Environment at Jlab (1)

- Radiation monitoring in the Experimental Halls: γ , n
- Prompt dose rates observed at the back of the Halls: up to **~ 10 rad/h photons, ~ 1 rem/h neutrons:**

Hall C Inside: γ Dose Rate (mrad/h)



Hall C Inside: n Dose Rate (mrem/h)

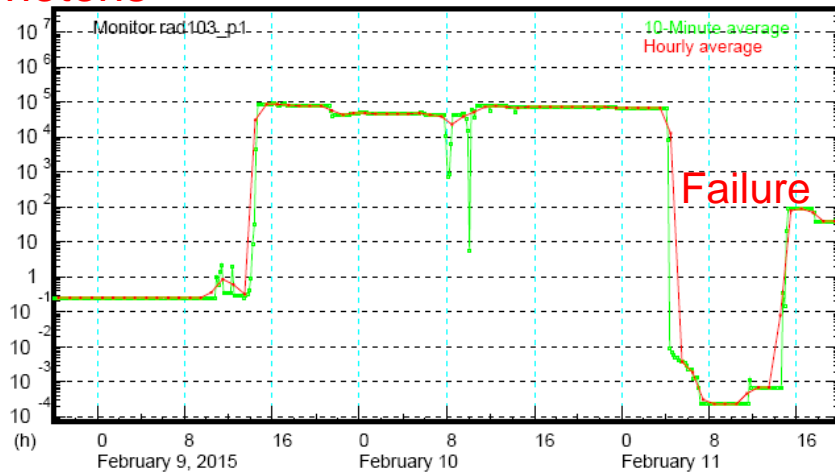


- Prompt dose rates downstream from the targets:
 - many **kilorad/h photons** (measured with Ion Chambers)
 - hundreds(?) **rem/h neutrons** (not measured)

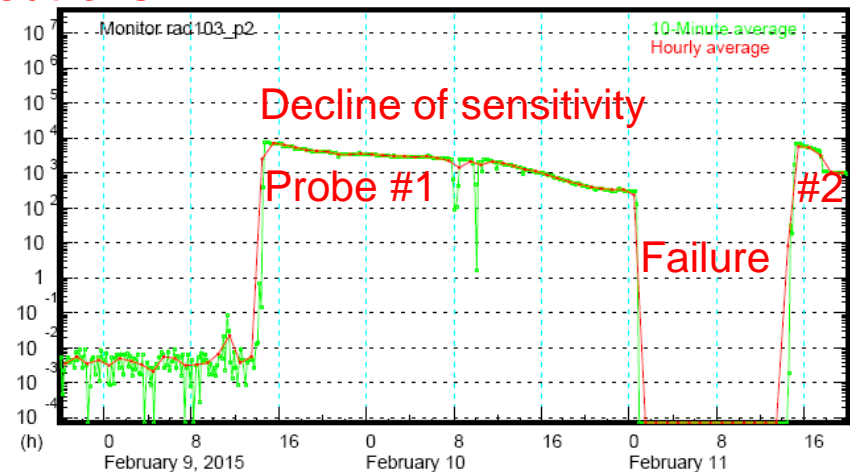
Radiation Environment at JLab (2)

- Radiation monitoring around C100 cryomodules: γ , n
- Dose rates observed at 1 foot, ~ 100 rad/h γ , ~ 10 rem/h n :

Photons RM-103(g probe 1) (mrad/h) - Tunnel Cryo Test



Neutrons RM-103(n probe 2) (mrem/h) - Tunnel Cryo Test



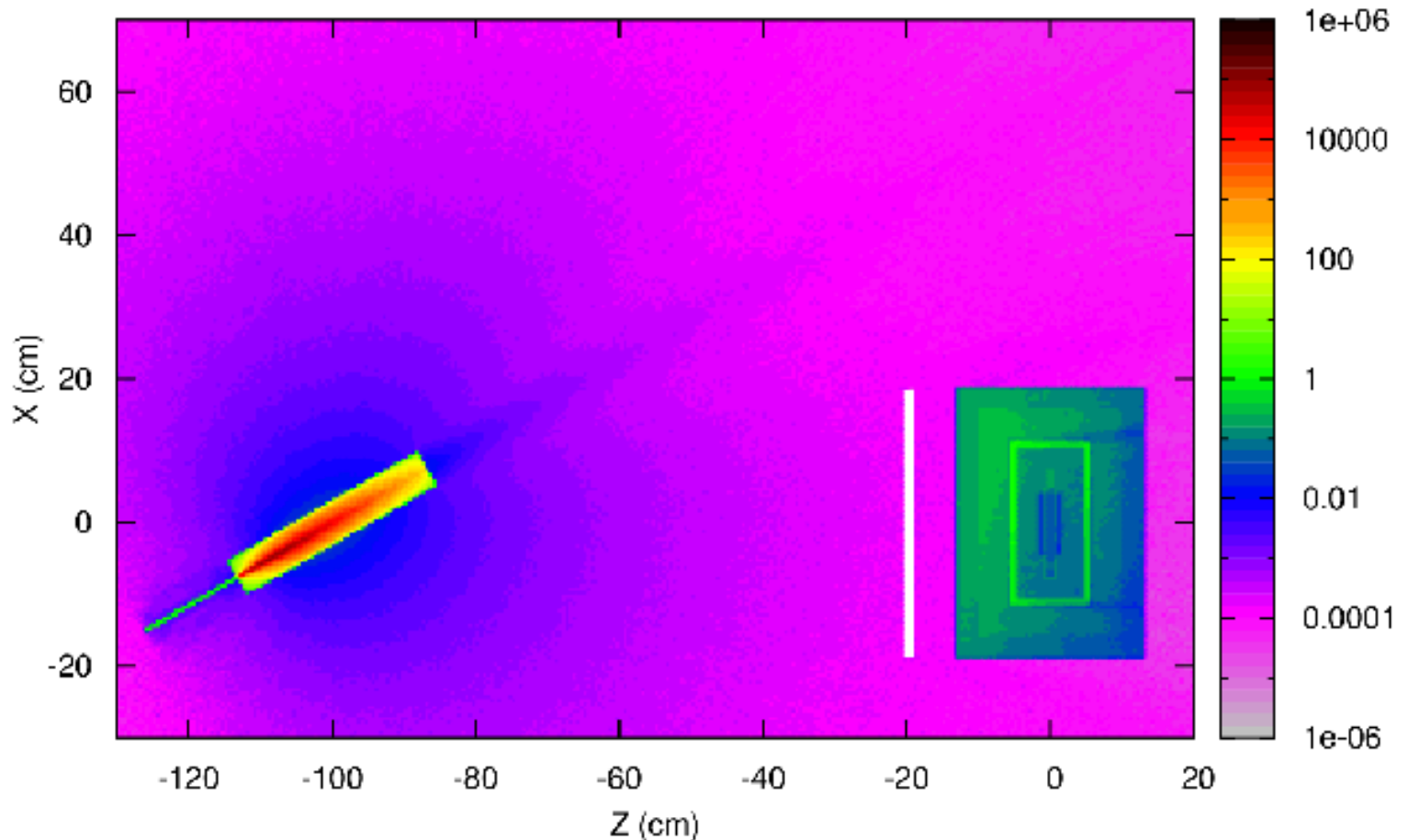
- JLab standard CARM probes do not survive for long
- Typical proportional neutron counters won't work: long cables, high rates, sensitivity to gammas
- Need radiation-hard photon- and neutron-sensitive ICs with remote front-end and DAQ electronics

Detector next to a thick target at 2.2 GeV

FLUKA: Showing energy density in the target, air around, and the detector

Neutron Dose rate estimate is about **0.036** of the **Total Dose** rate

Energy Deposition (keV/cm³) per beam electron at 2.2 GeV, Z-X middle plane 4 cm thick



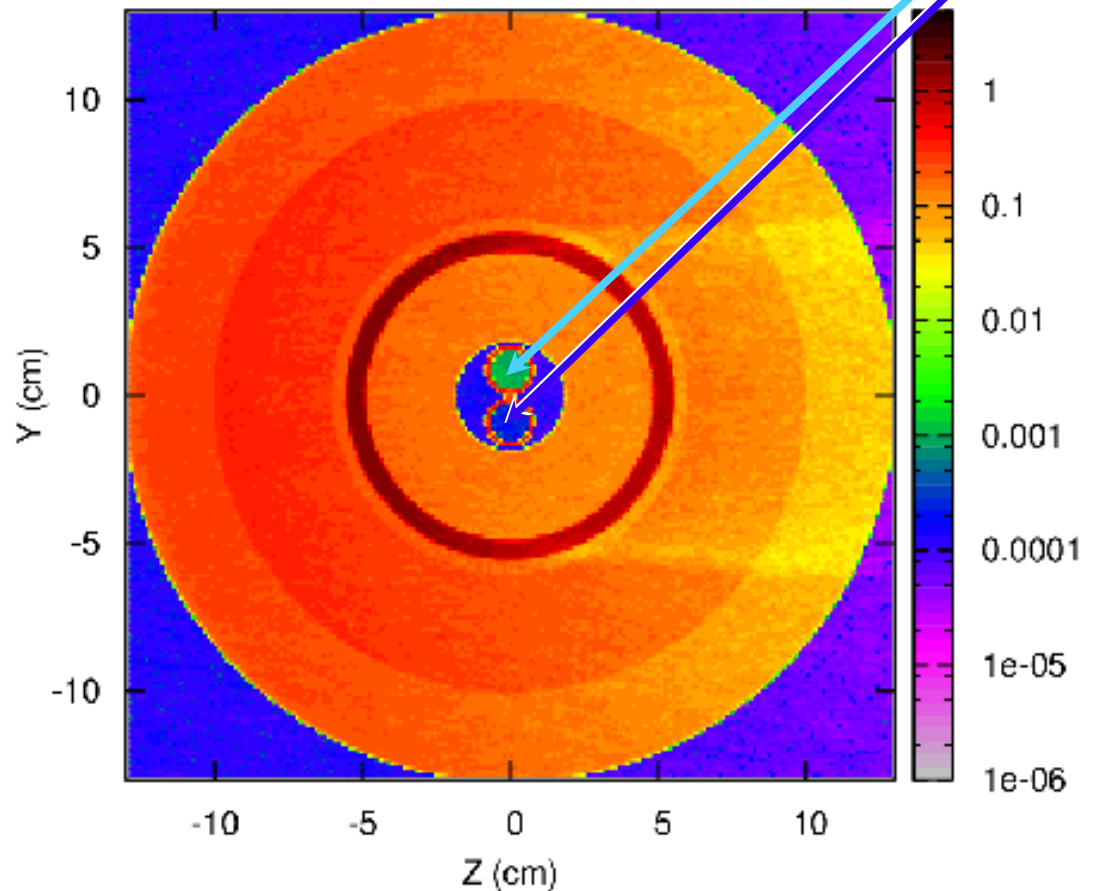
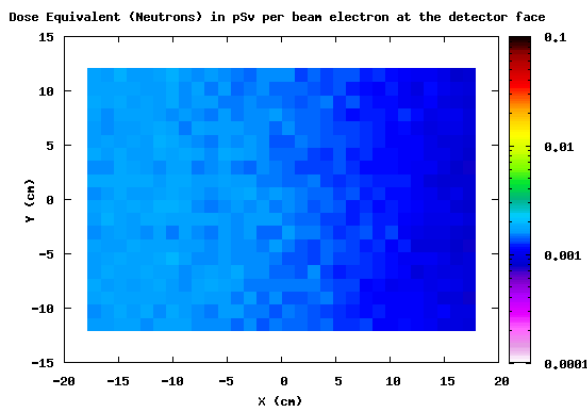
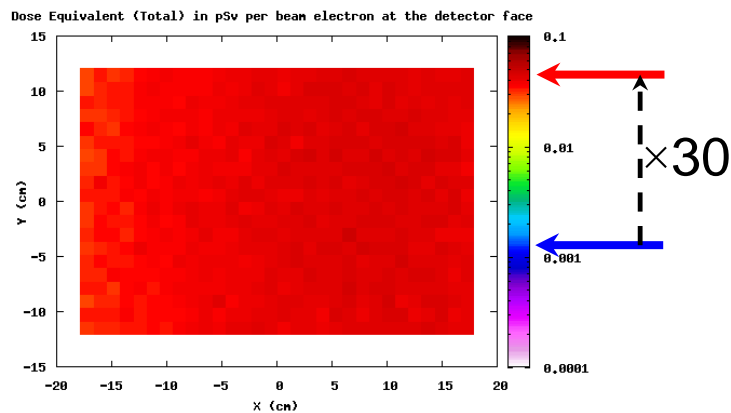
Detector next to a thick target at 2.2 GeV

FLUKA: Showing energy density in the air around, and in the detector

The ratio of ionization currents from ^3He IC to ^4He IC equals to 4.5

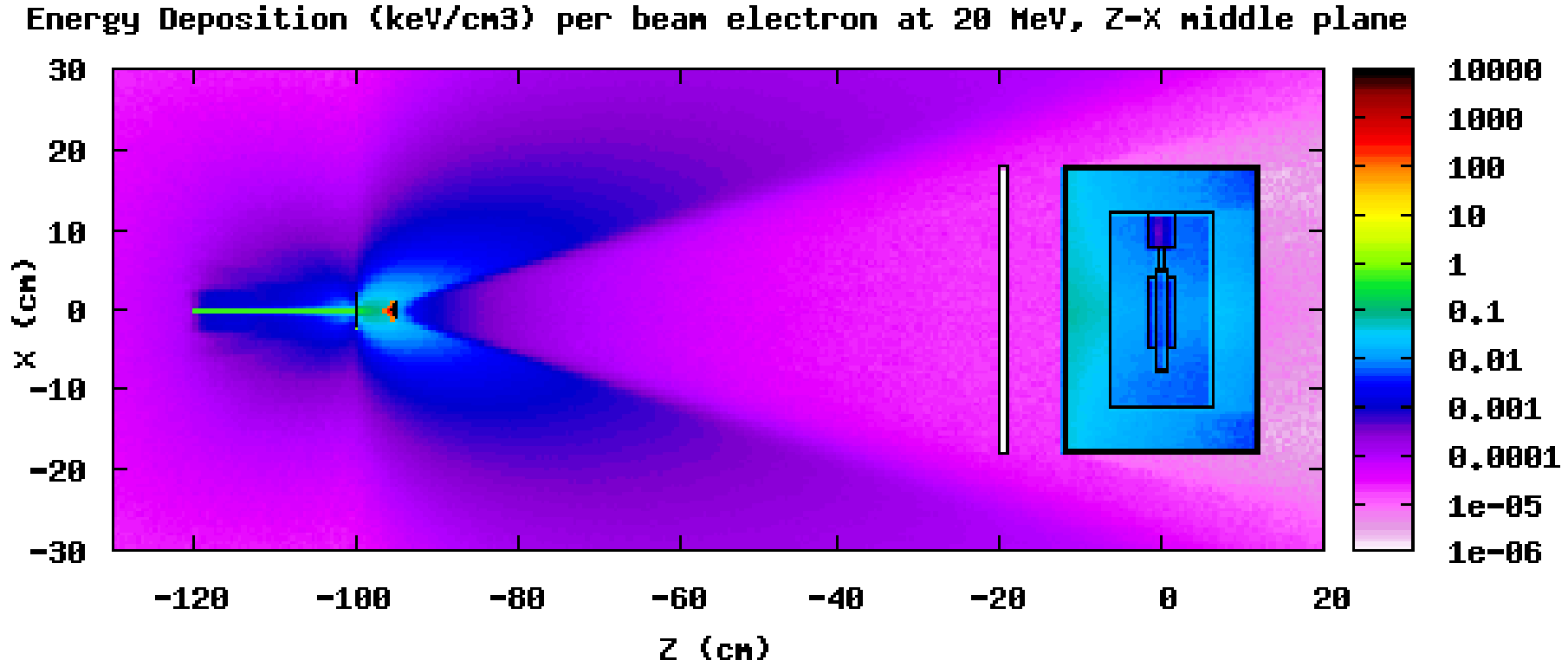
Energy Deposition (keV/cm³) per beam electron at 2 GeV, Z-Y middle plane

Face Dose Rates
(Total and Neutron):



Detector in the 20 MV photon beam

FLUKA: Showing energy density in the target, air around, and the detector
Neutron Dose rate estimate is about **0.0025** of the **Total Dose** rate



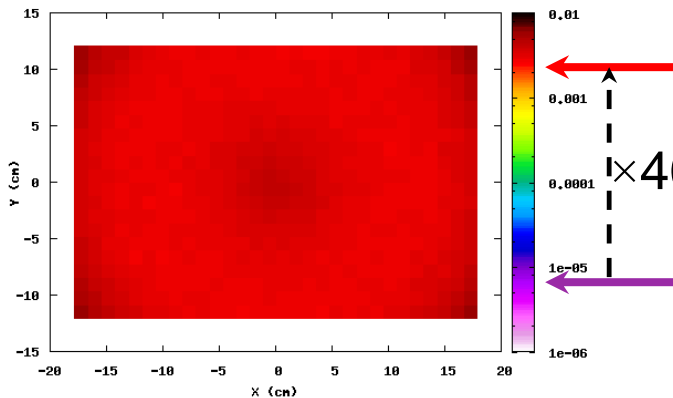
Detector in the 20 MV photon beam

FLUKA: Showing energy density in the air around, and in the detector

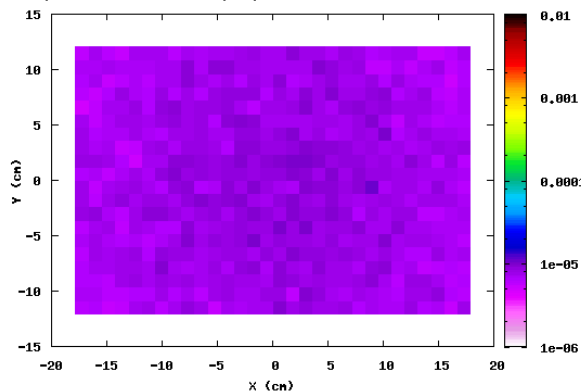
The ratio of ionization currents from ^3He IC to ^4He IC equals to 1.65

Face Dose Rates (Total and Neutron):

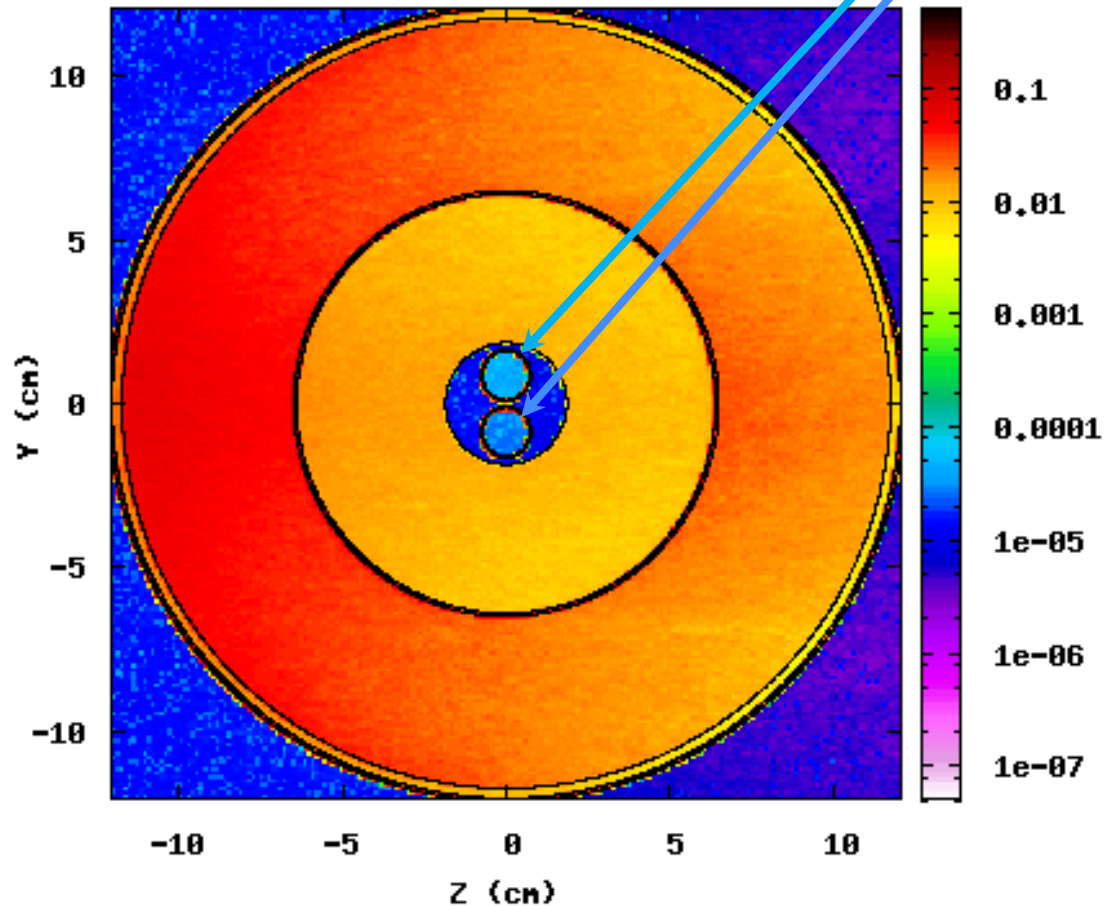
Dose Equivalent (Total) in pSv per beam electron at the detector face



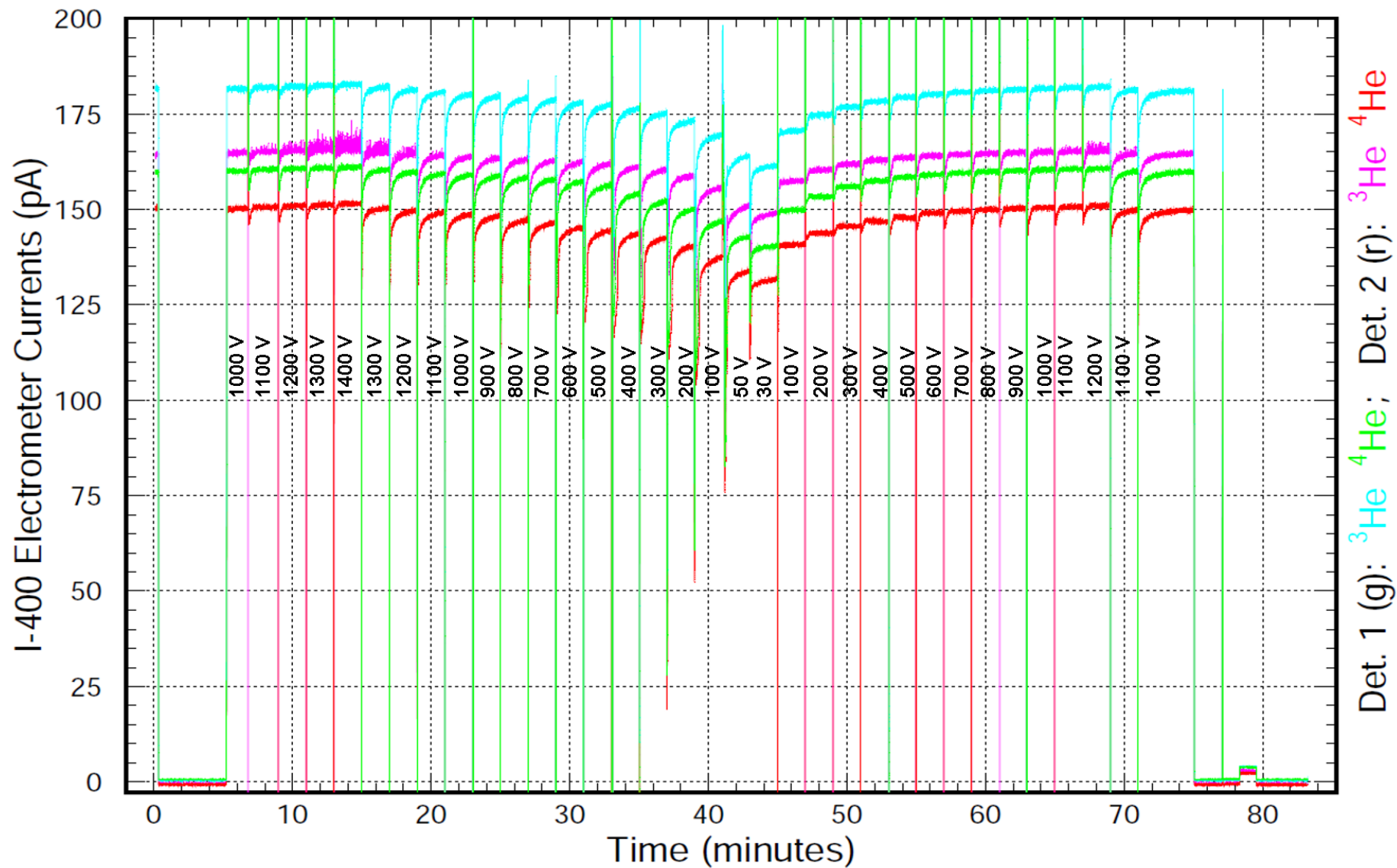
Dose Equivalent (Neutrons) in pSv per beam electron at the detector face



Energy Deposition (keV/cm³) per 20 MeV beam electron, Z-Y middle plane



HV Plateau Studies in Photon Field



References (incomplete)

- [1] F. Gutermuth, T. Radon, G. Fehrenbacher, R. Siekmann. “Test of the rem-counter WENDI-II from Eberline in different energy-dispersed neutron fields”, CERN EXT-2004-085 04/03/2004
- [2] R. H. Olsher, H.-H. Hsu, A. Beverding, J. H. Kleck, W. H. Casson, D. G. Vasilik, and R. T. Devine. “WENDI: An improved neutron rem meter”, Health Physics, 79(2):170ff, 2000.
- [3] I. O. Andersson and J. A. Braun. “Neutron rem-counter with uniform sensitivity from 0.025 eV to 10 MeV”, in: Proceedings of the IAEA Symposium on neutron dosimetry, Vienna, 2:87–95, 1963.
- [4] C. Birattari, A. Ferrari, C. Nuccetelli, M. Pelliccioni M., and M. Silari. “An Extended Range Neutron Rem Counter”, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 297:250–257, 1990.