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

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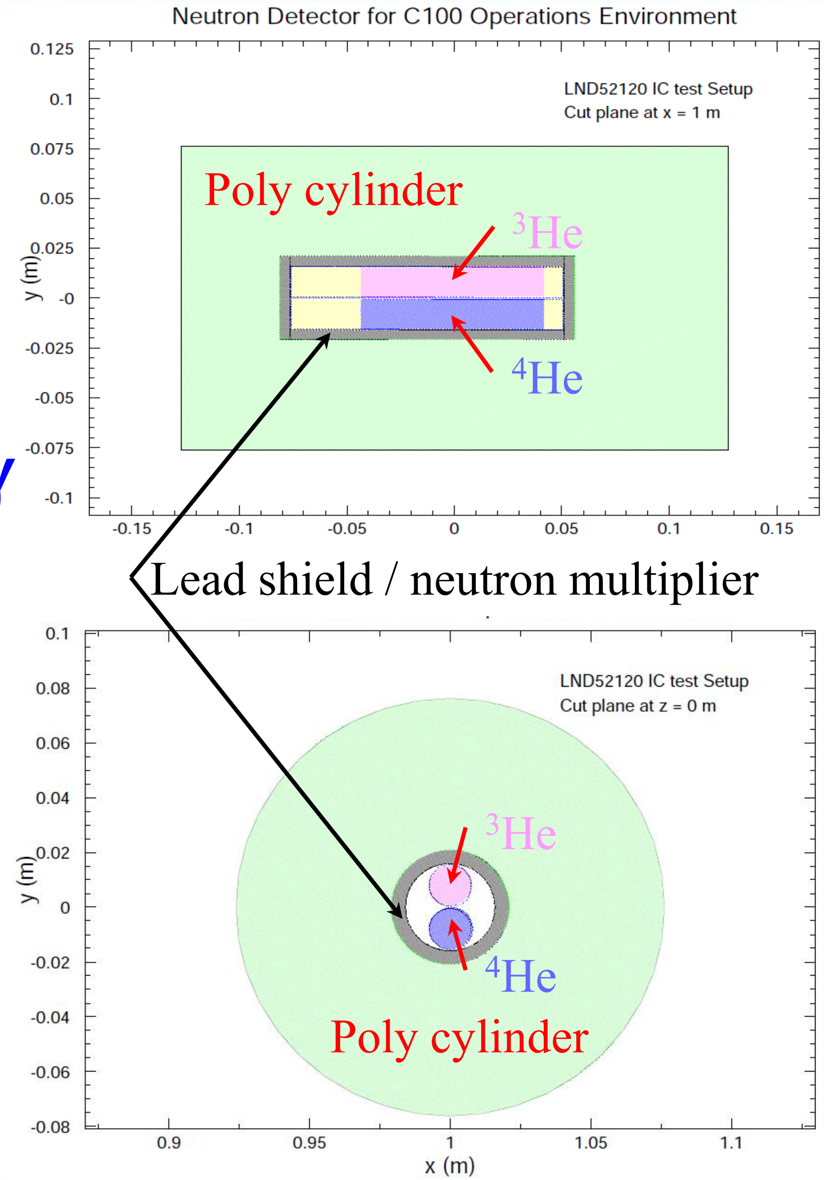
Outline

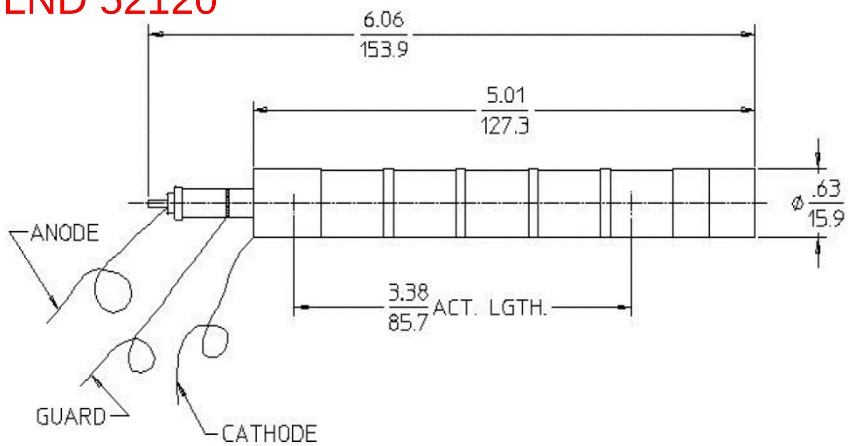
- Neutron dose rates inside High Energy electron accelerators:
  - Important for radiation safety, radiation damage, activation
  - Needed to evaluate and benchmark the simulation models
  - Difficult to measure due to overwhelming photon radiation
  - Monitors fail: radiation damage, high photon background
  - 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 ^{3}He and ^{4}He
  - Neutron moderator with Beryllium-loaded reflector / multiplier

Original Idea (2016)

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



LND 52120



Principle of Operation

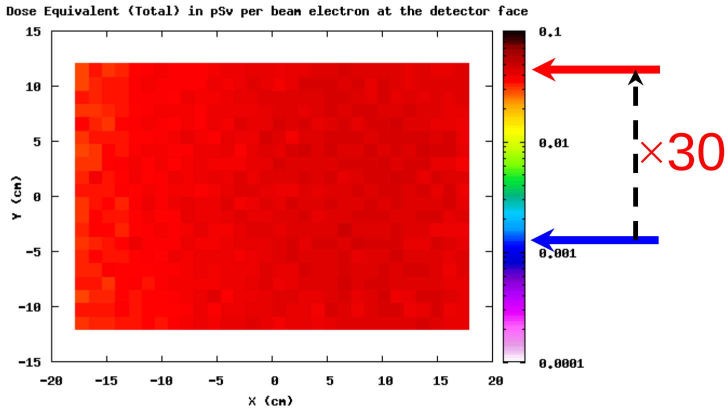
- Captured moderated thermal neutrons produce measurable current in the ^{3}He-filled ion chamber, and photons produce small symmetrical response in both ^{3}He- and ^{4}He-filled ion chambers.
- A sensitive electrometer-type current readout needed, with a long-term stability in pA range.
- Using Beryllium-Copper 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.

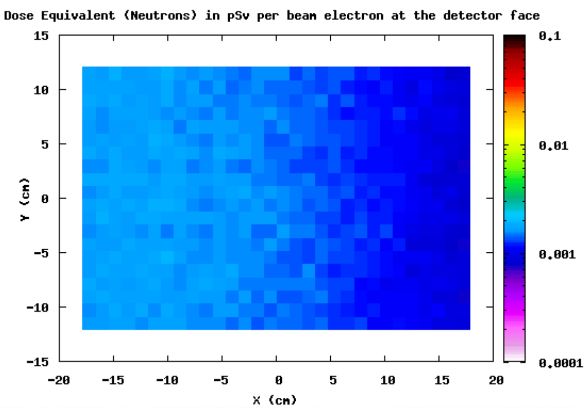
Detector next to a thick target at 2.2 GeV

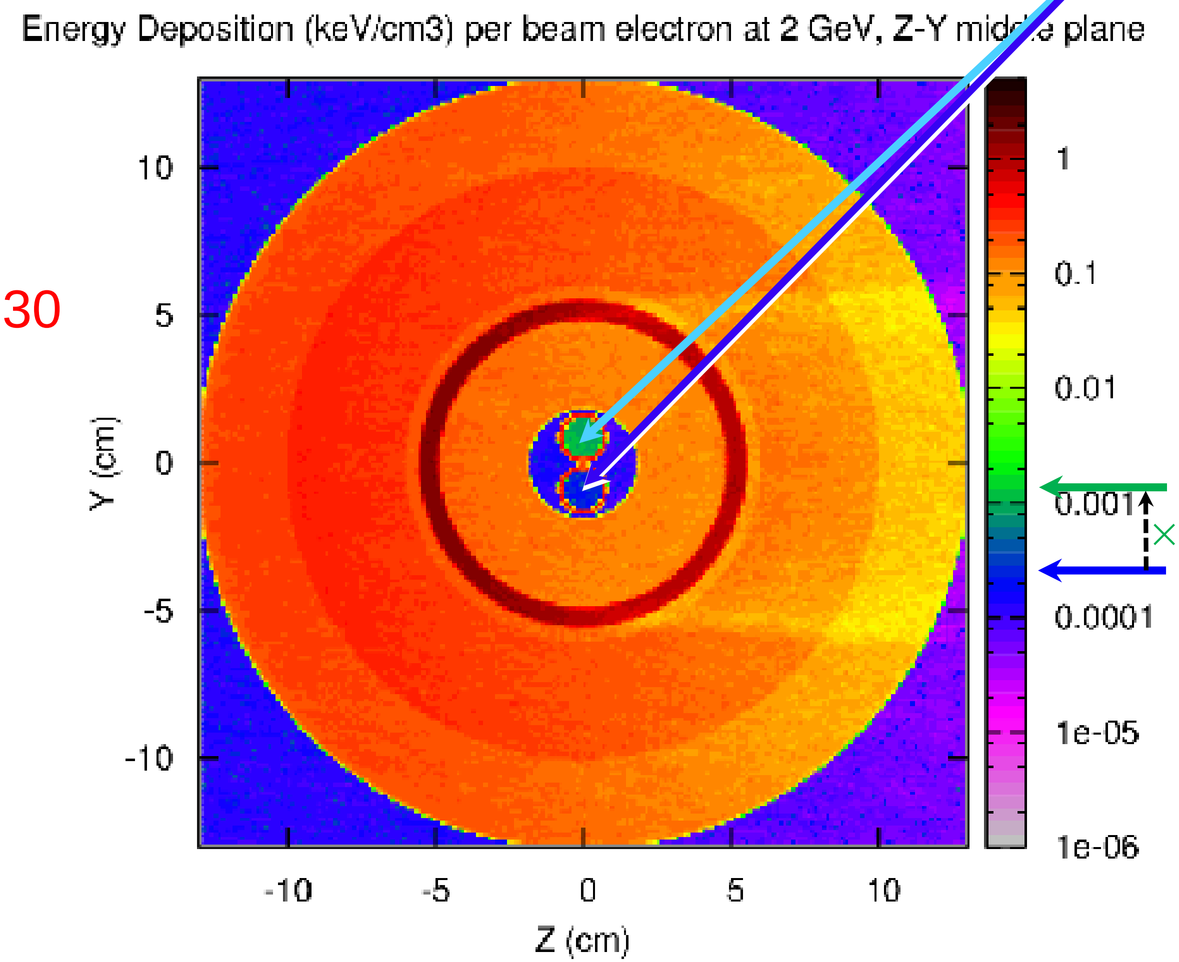
FLUKA: Showing energy density in the air, and in the detector

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

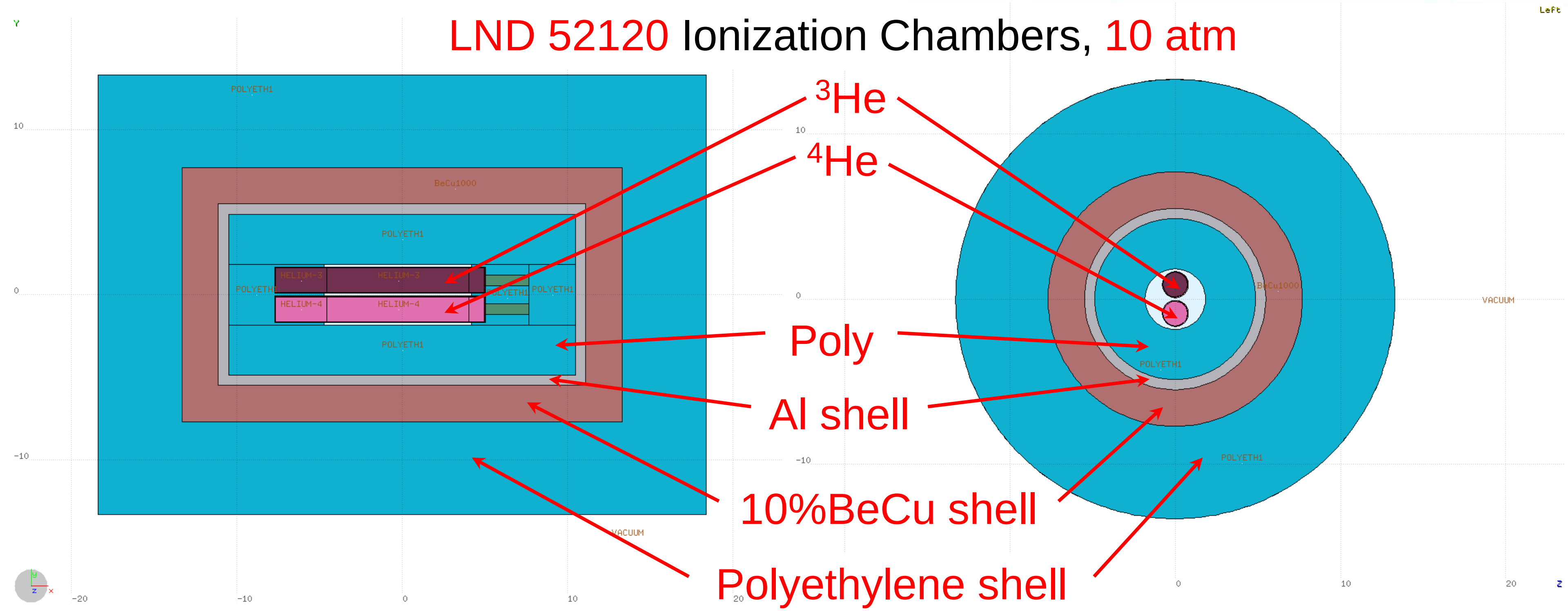
Face Dose Rates (Total and Neutron):





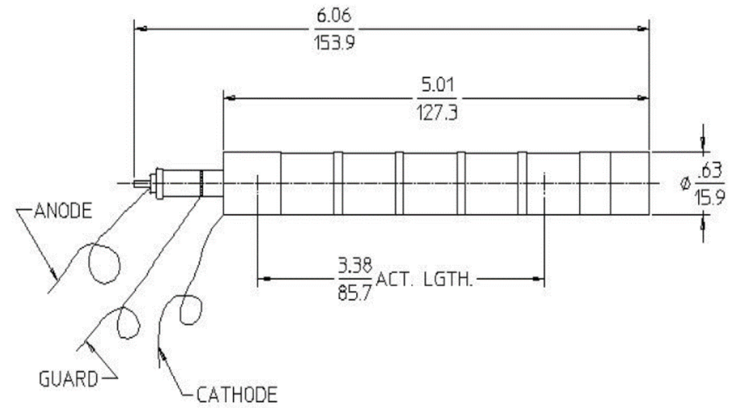


FLUKA Model, Be Loaded Moderator

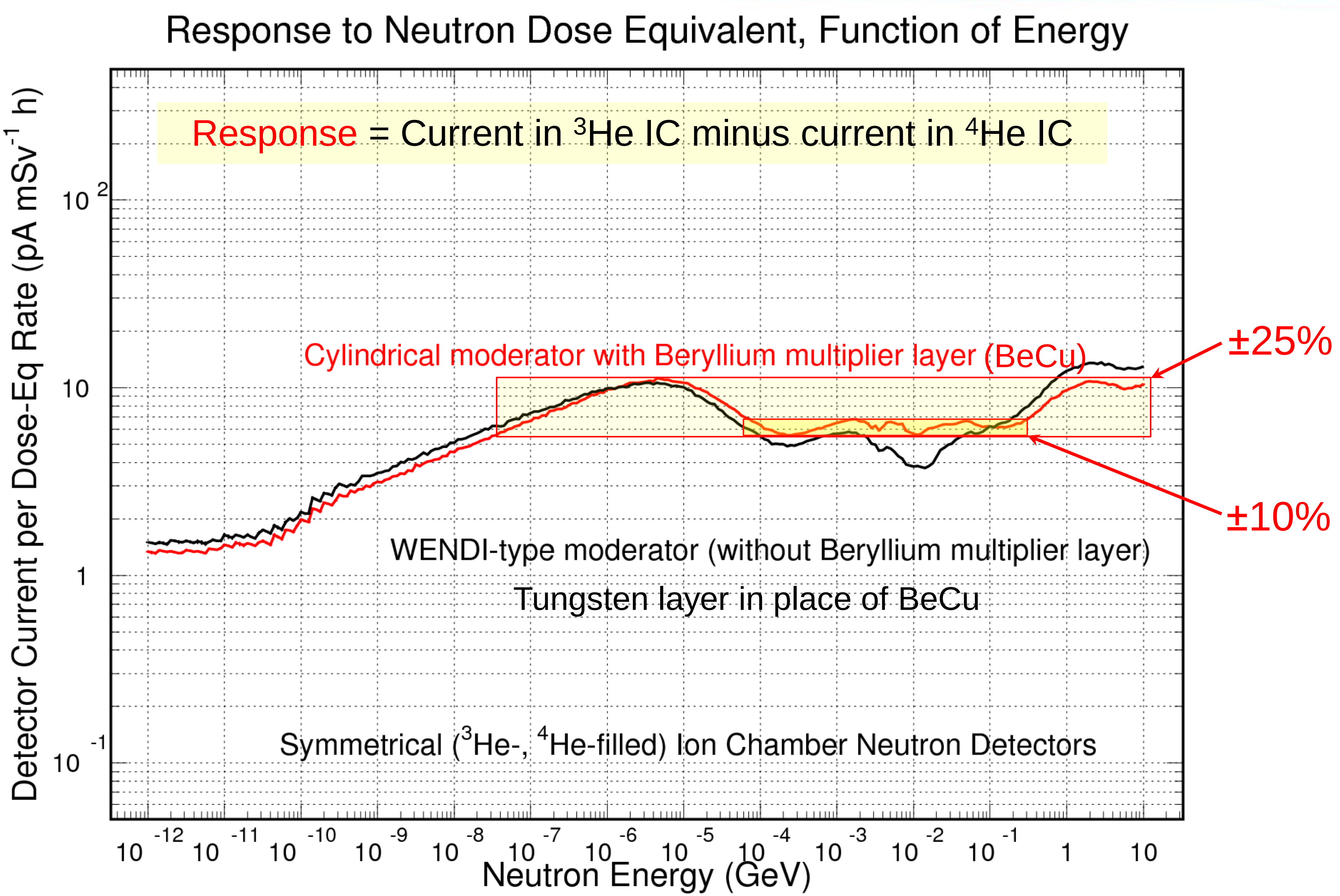


Cylindrical moderator assembly

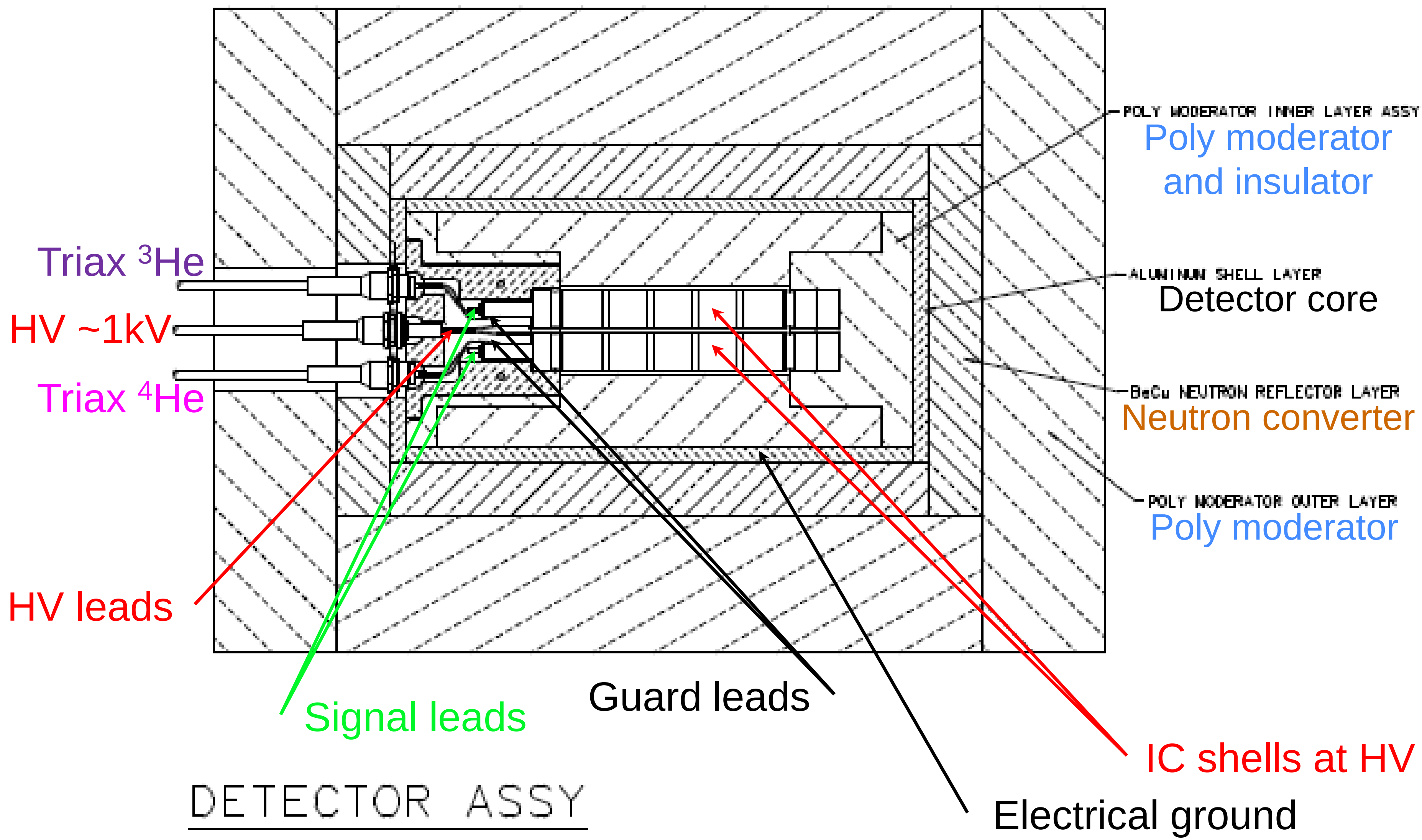
Ion Chamber Quote: $(1350+750)



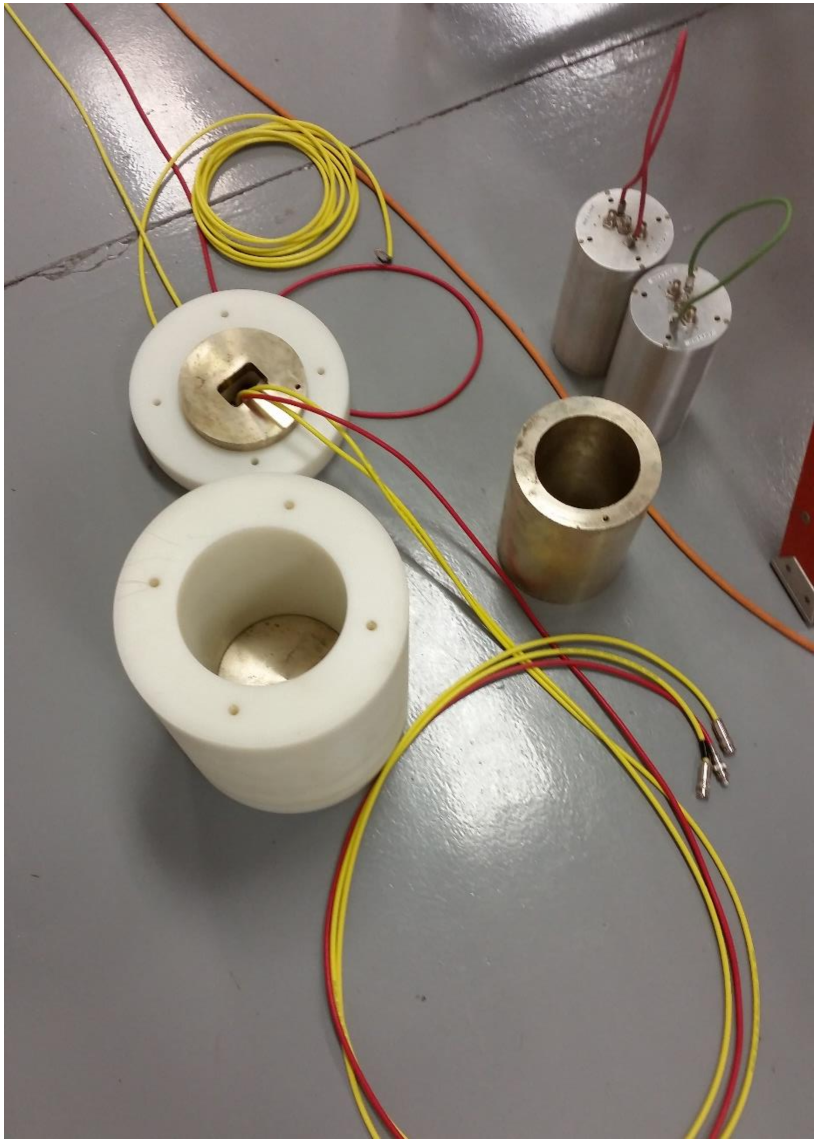
Energy Dependence of Detector Response

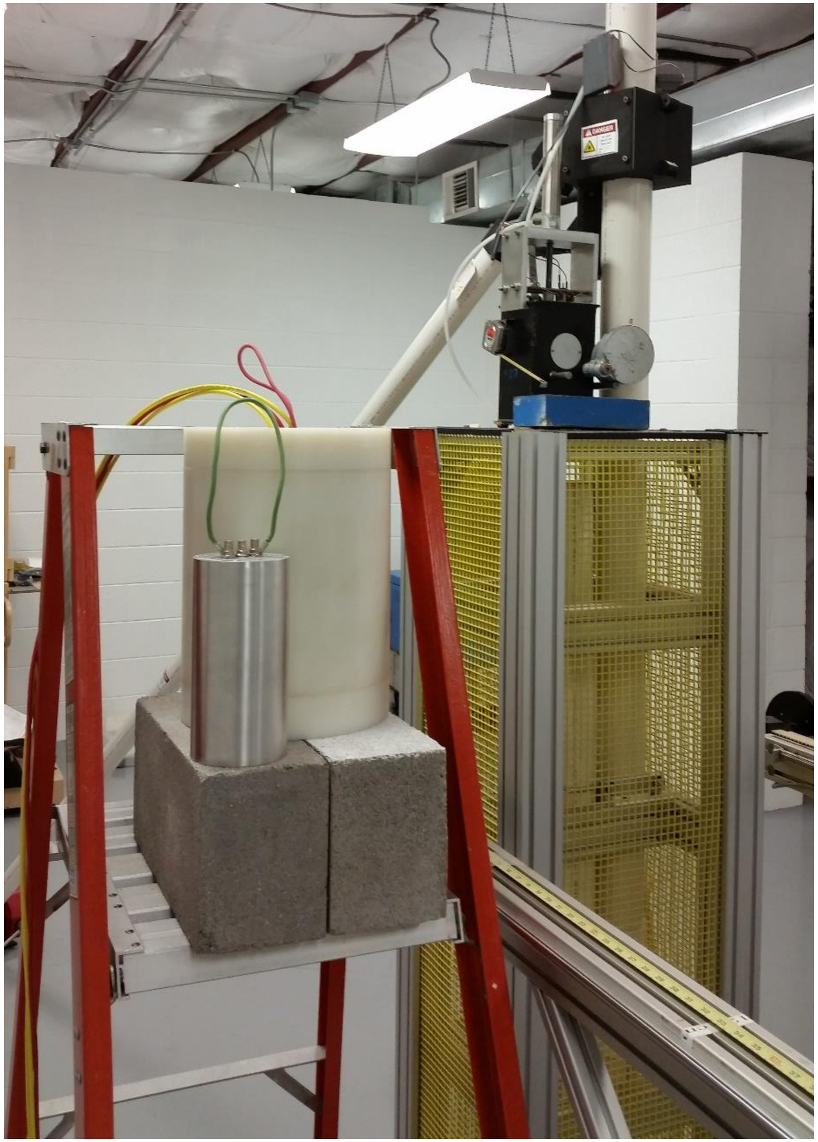


Prototype Assembly Drawings



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

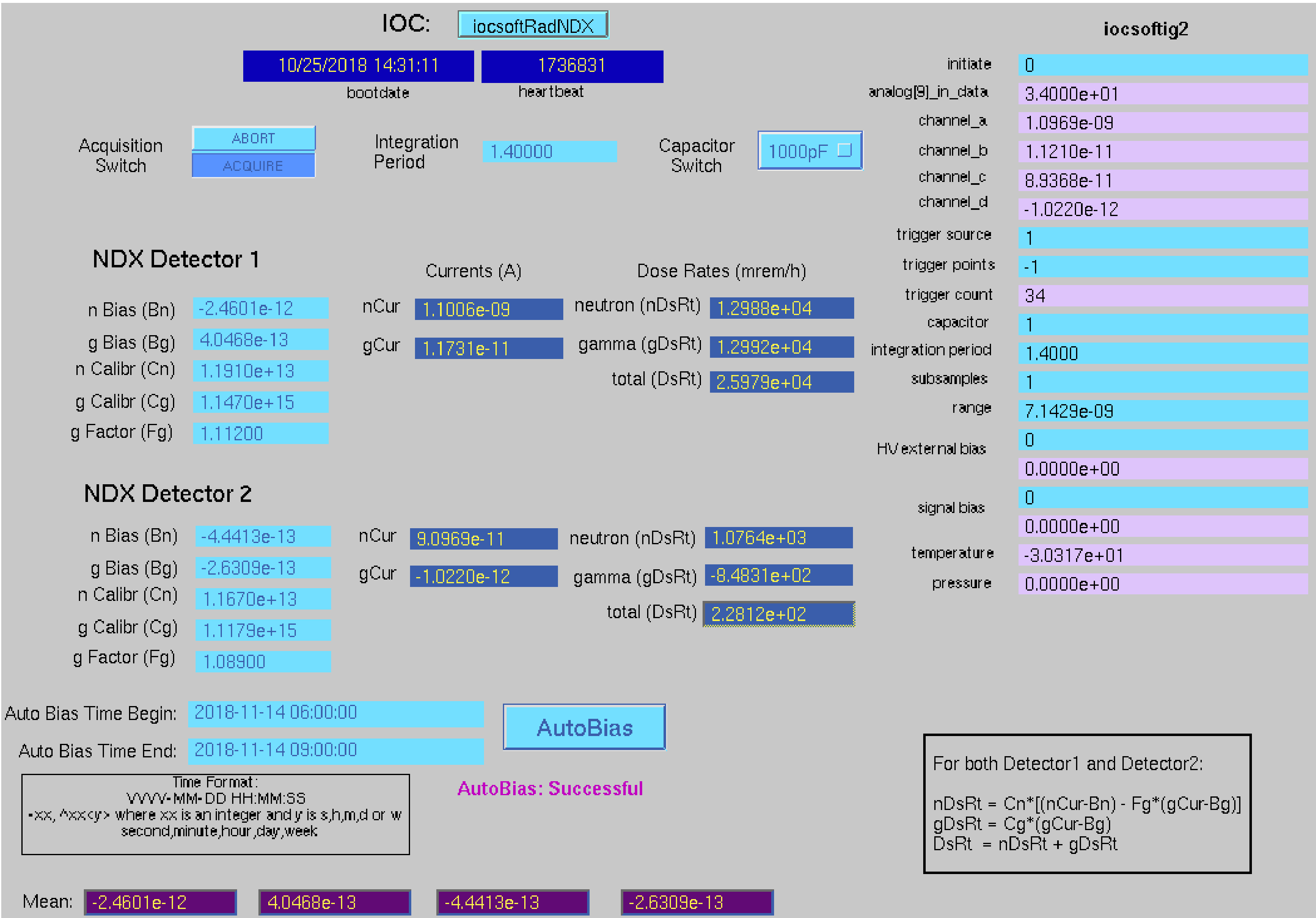
Calibration

- 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 mrem/h per pA.
- The symmetric response of the ^{3}He and ^{4}He ion chambers to high photon dose rates (~100 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



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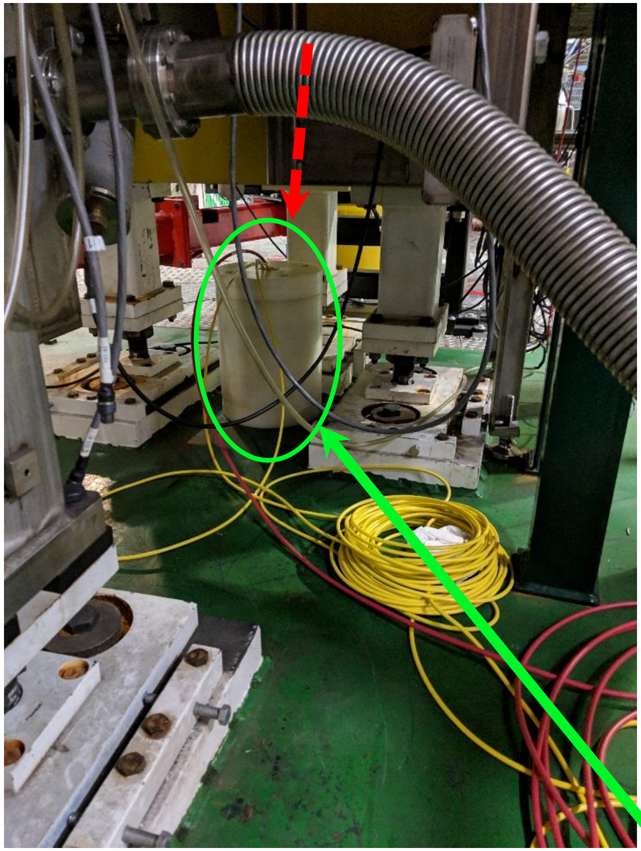
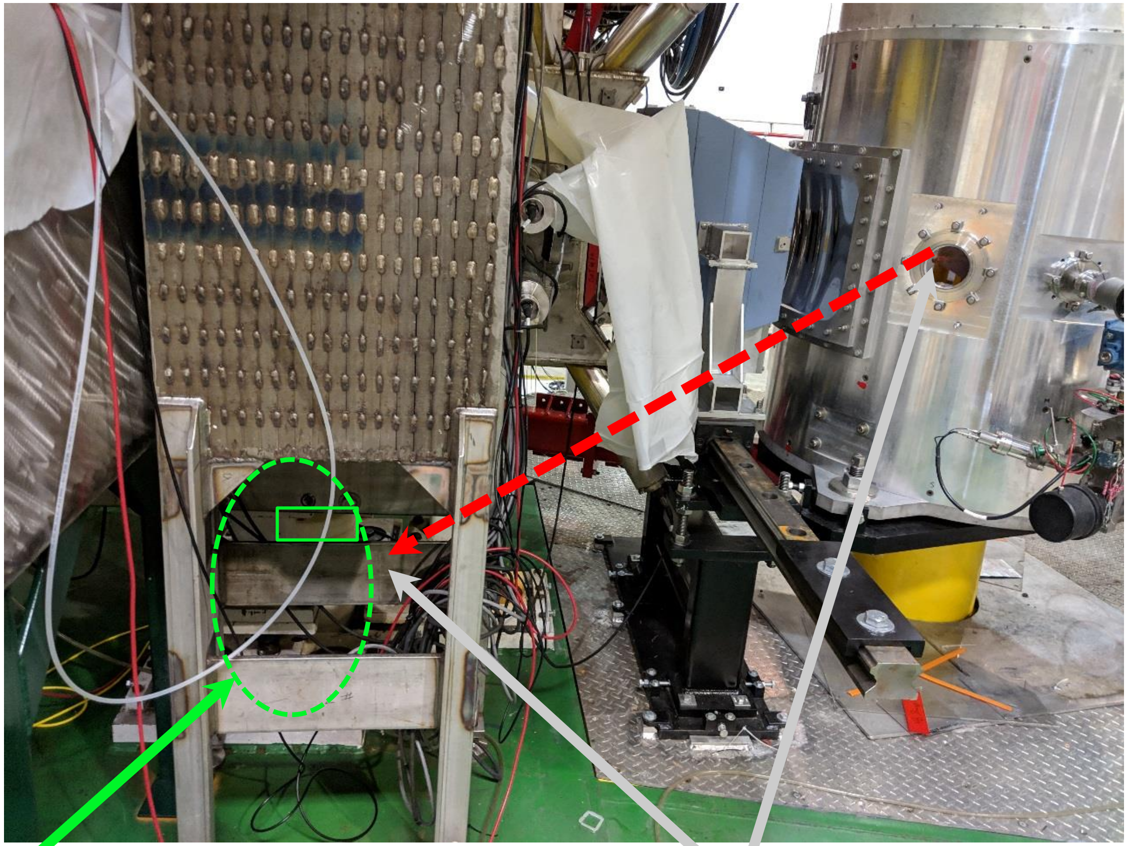
NDX-1 Detector, SHMS Platform under HB Magnet

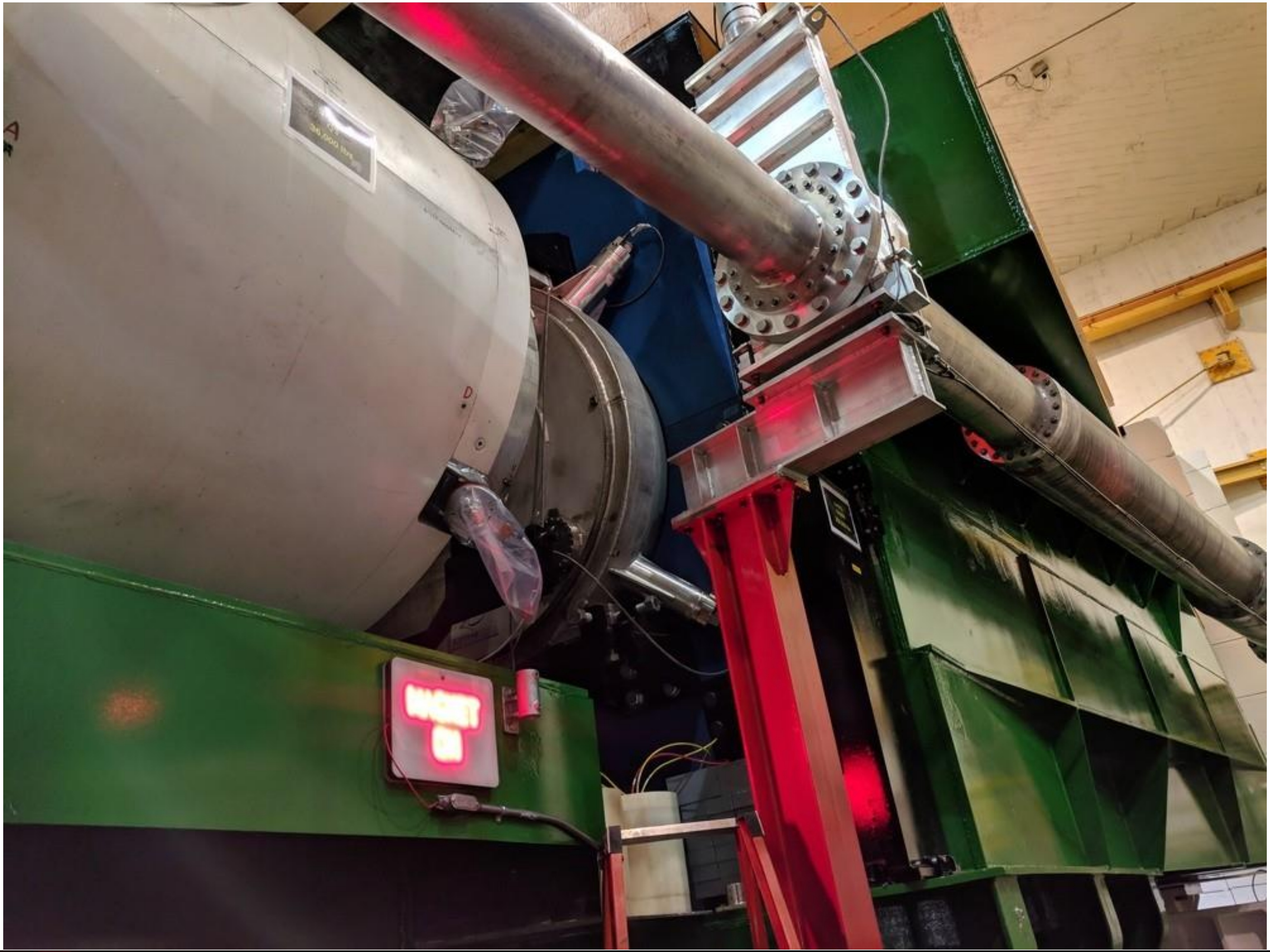




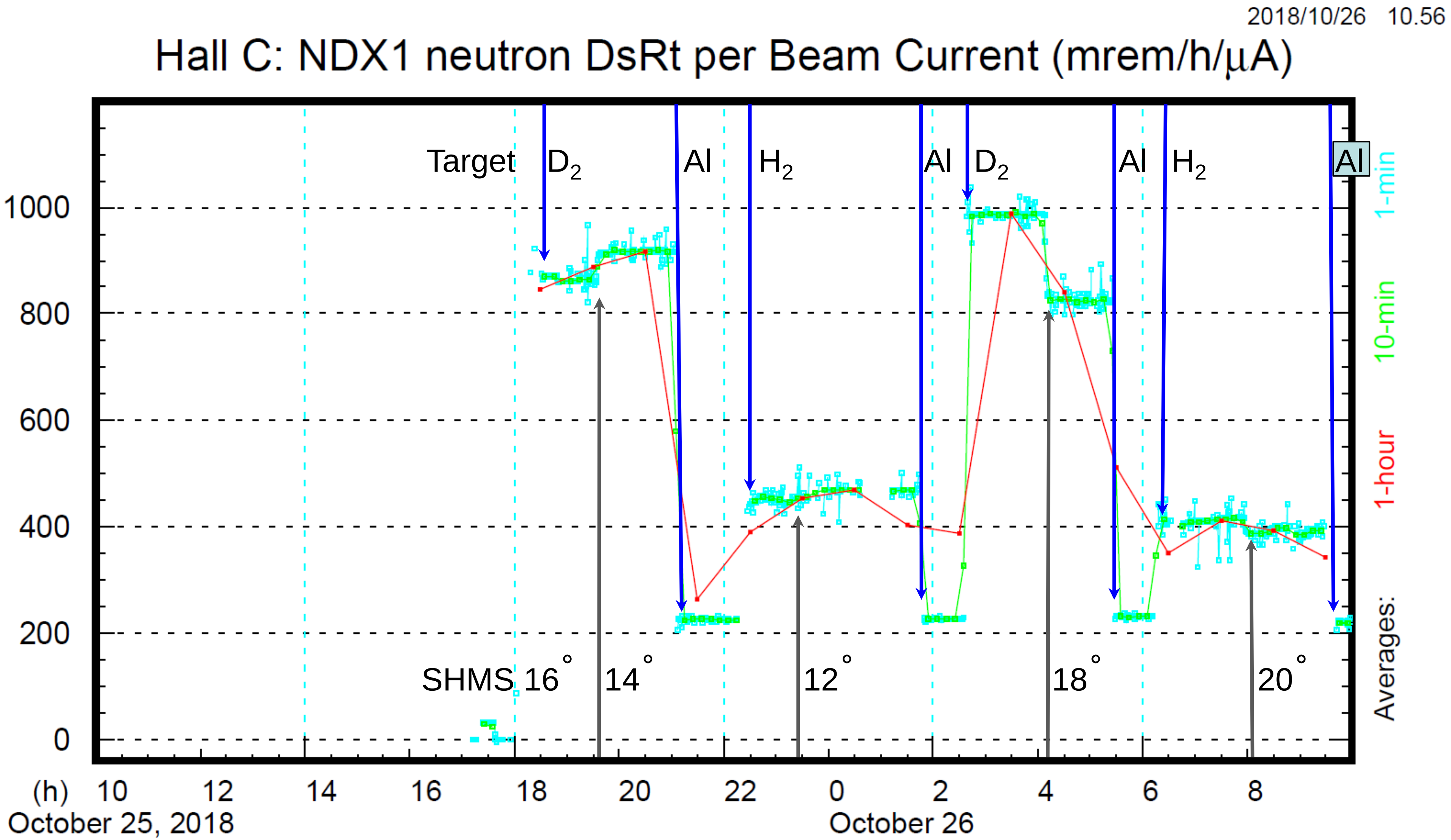
NDX01 Detector under HB magnet

Approx. 3 m from target

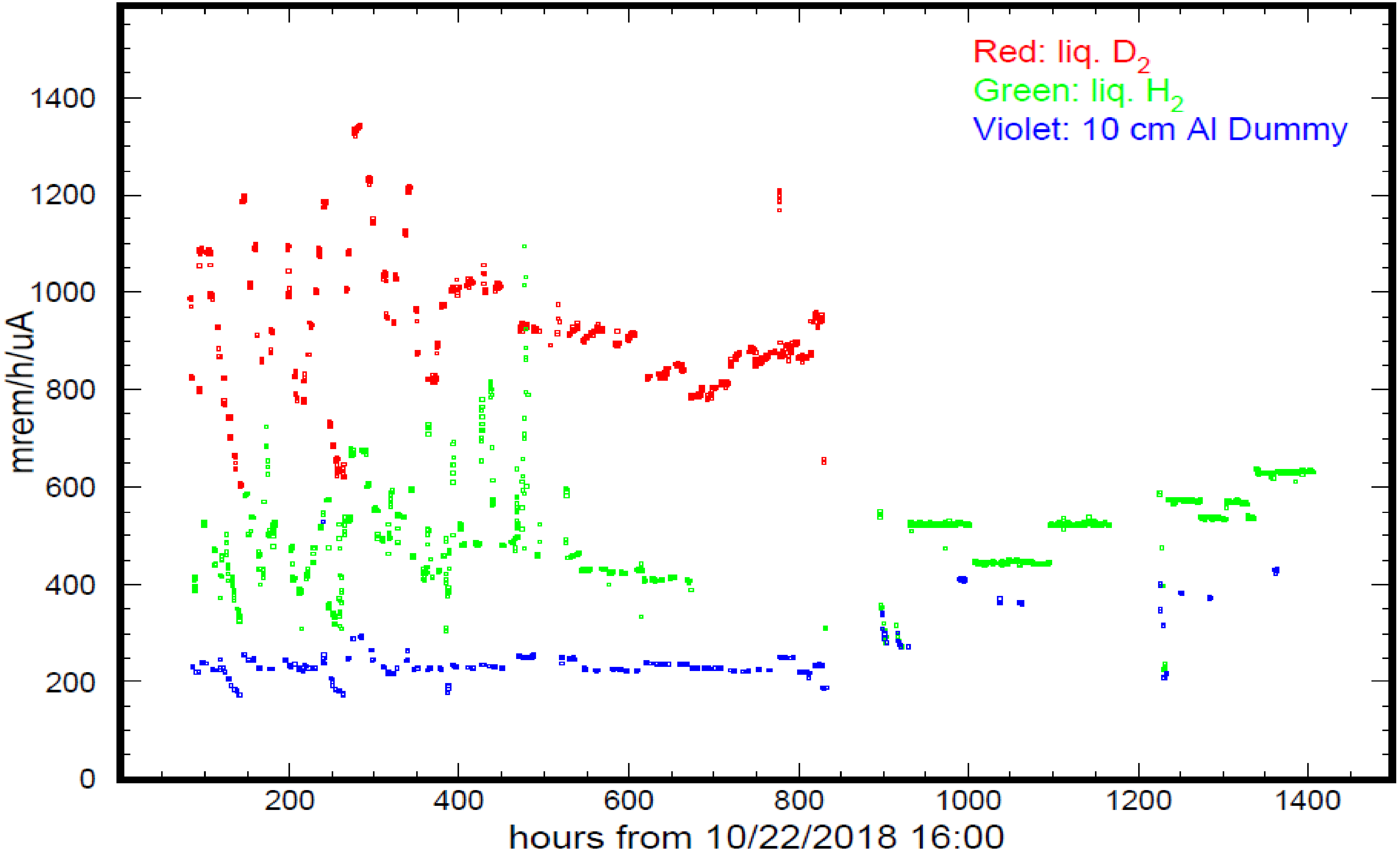
NDX-2 on SHMS Platform Downstream



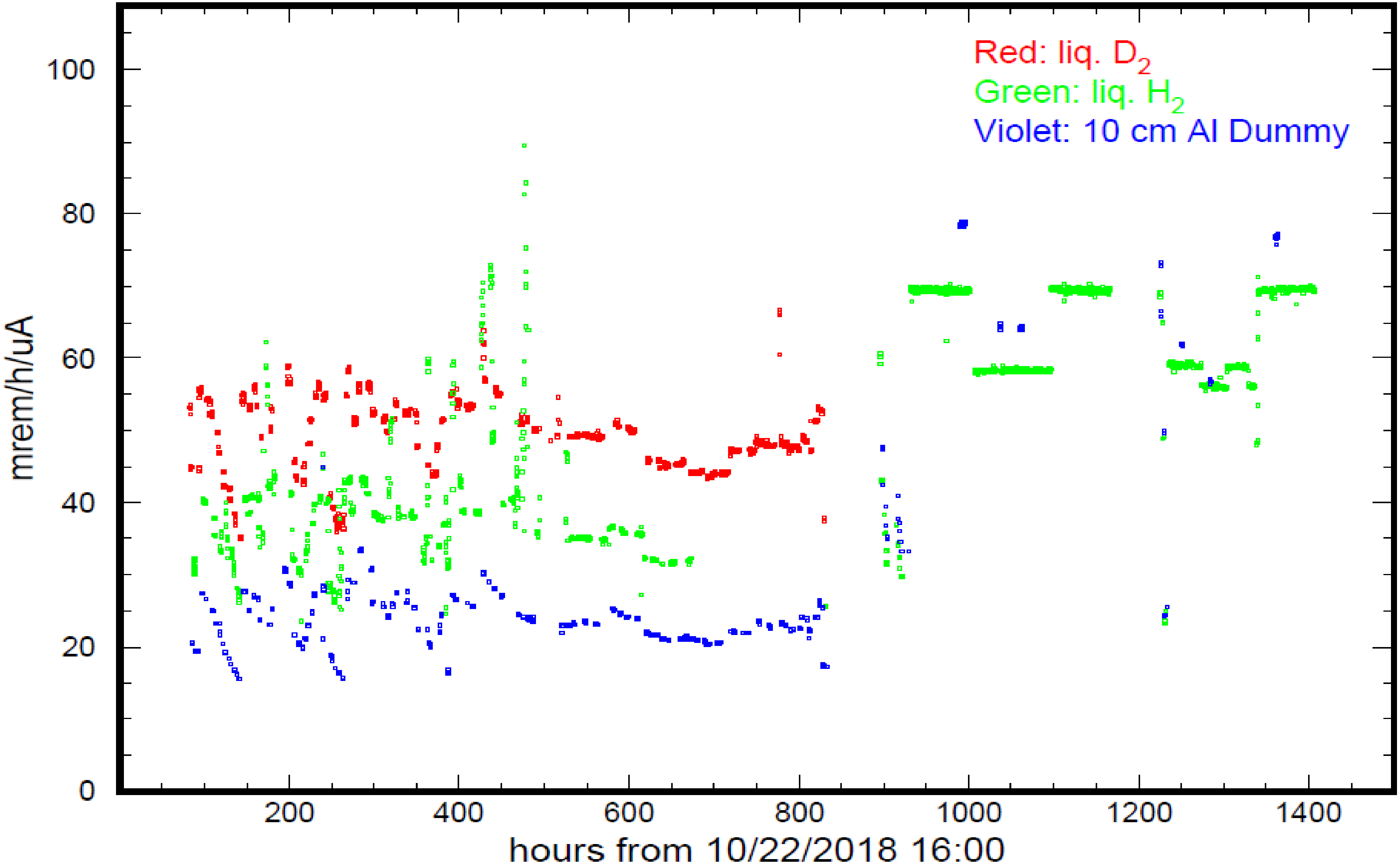
NDX1 Dose Rates per Beam Current



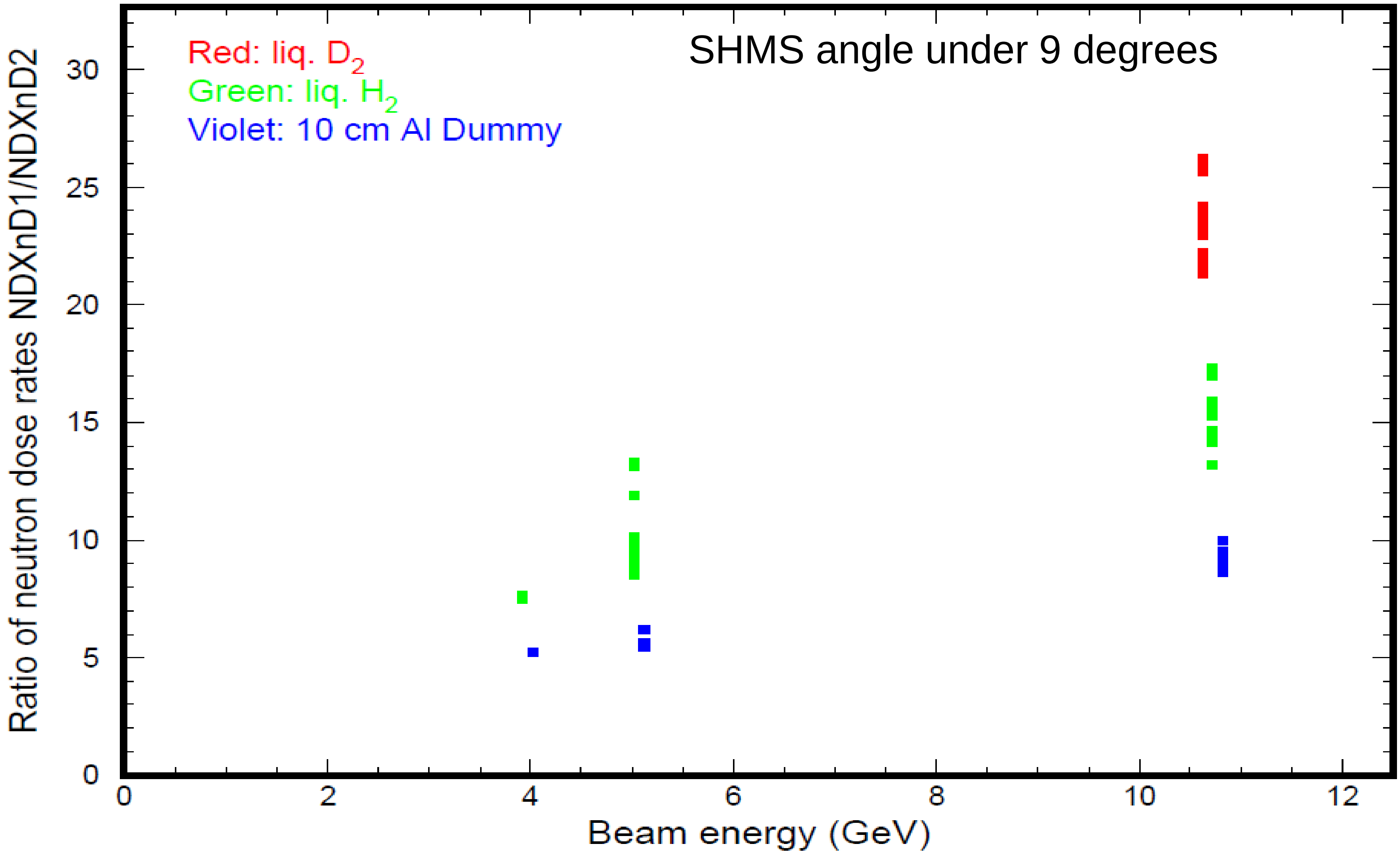
NDX1 n Dose Rates per Beam Current



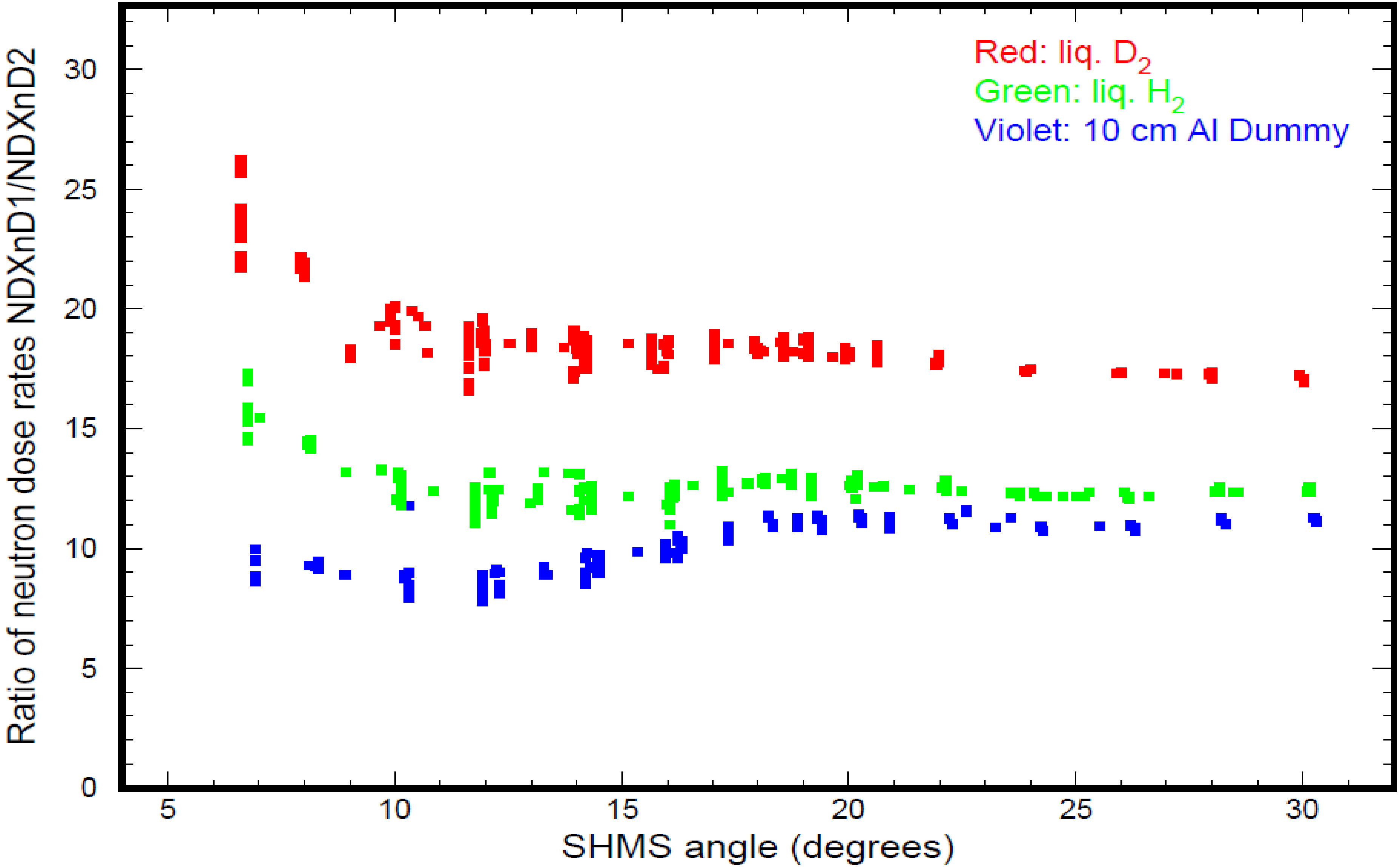
NDX2 n Dose Rates per Beam Current



nD1/nD2 Ratio vs. Beam Energy

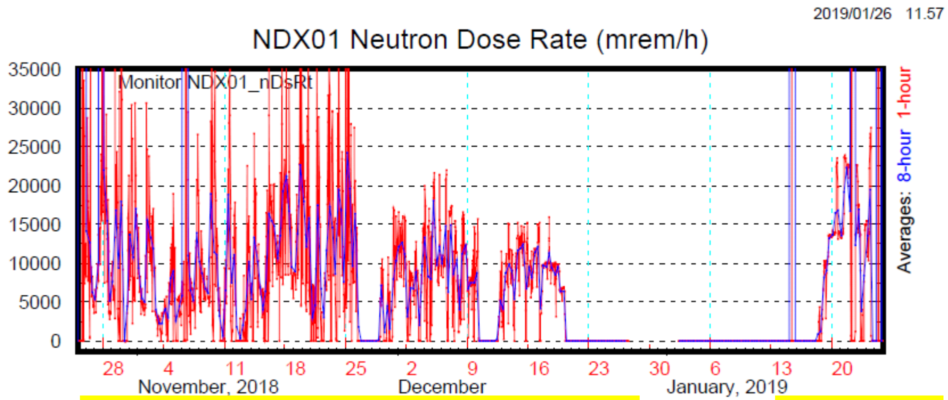


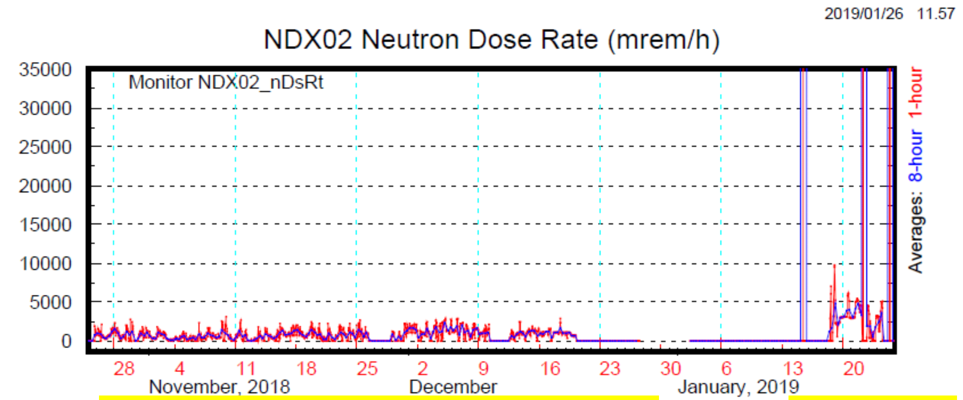
nD1/nD2 ratio vs. SHMS angle, E = 10.6 GeV



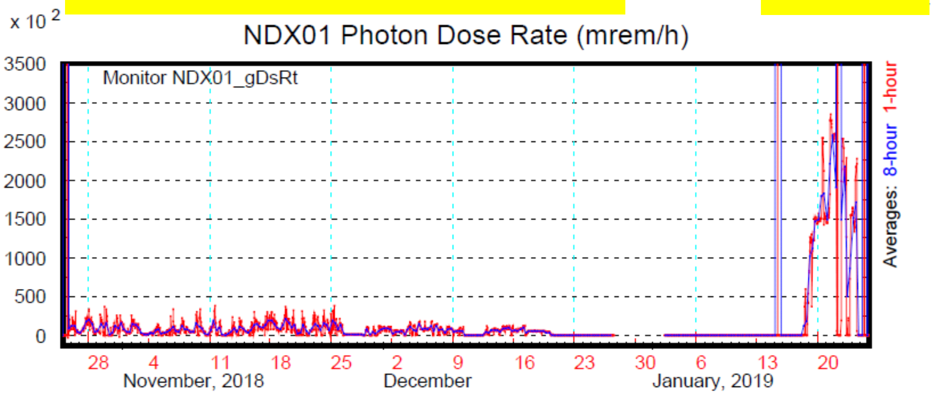
NDX Detectors: Last Three Months

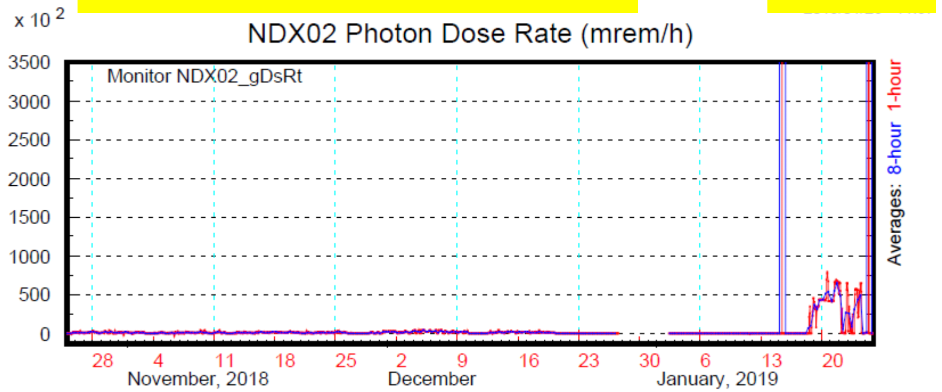
Neutron and photon dose rates measured by the NDX detectors during the last run in Hall C, and the beginning of operations in the North Linac at NL26





Hall C **NL26** **Hall C** **NL26**





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

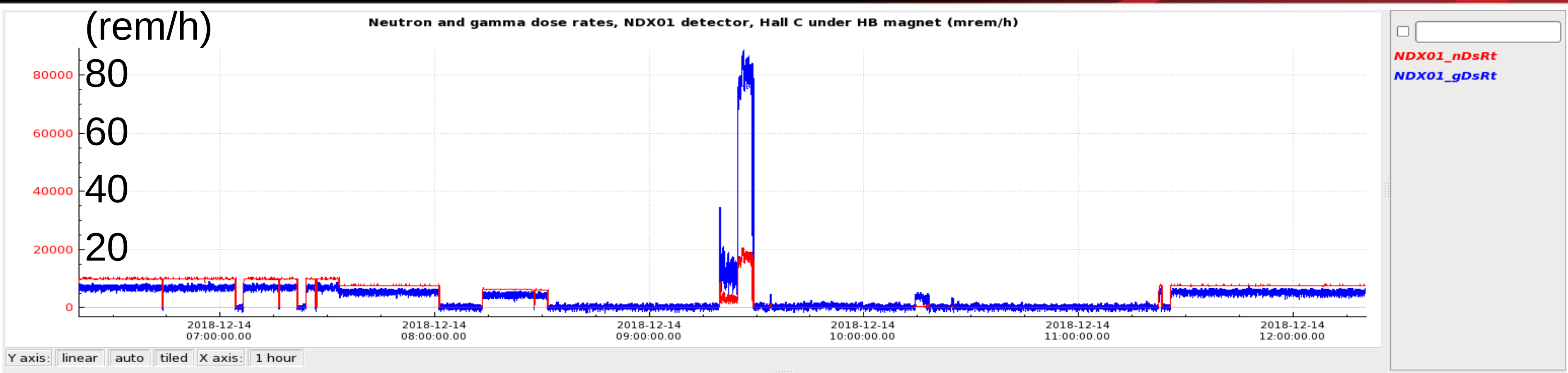
Acknowledgements

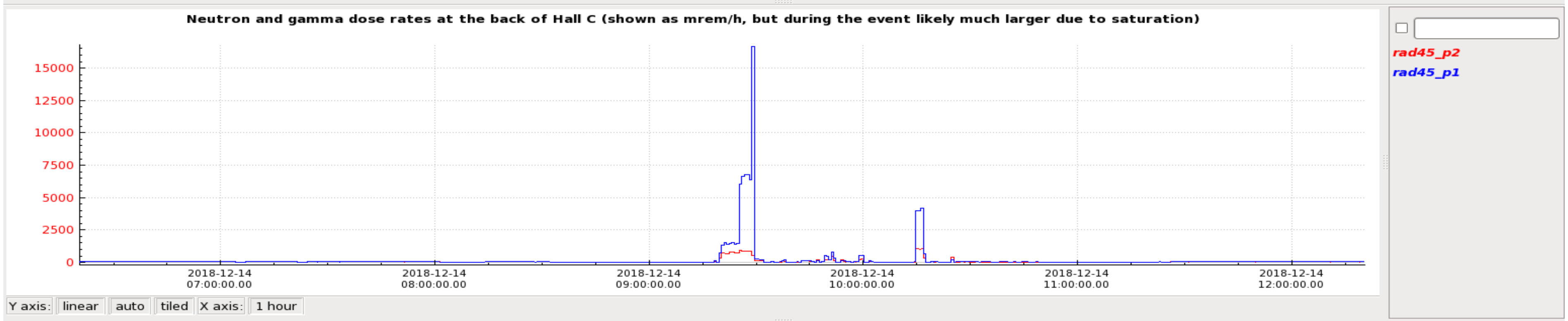
Thanks to:

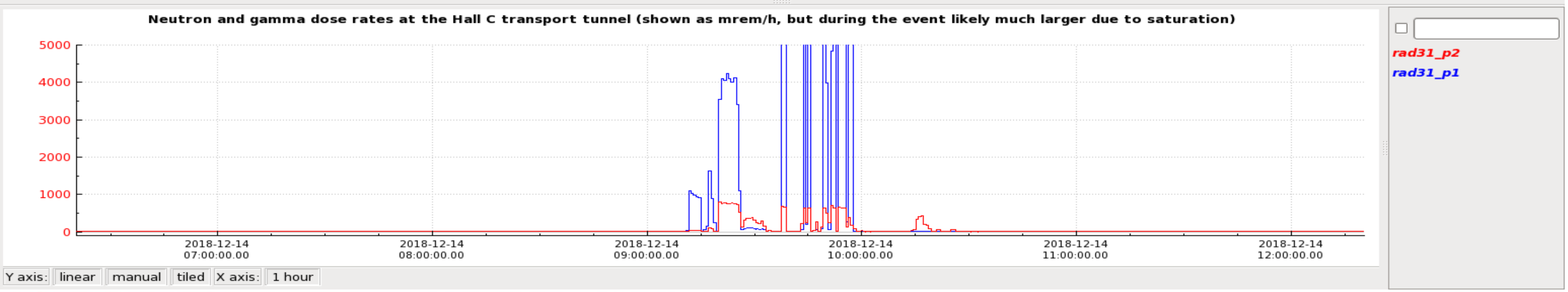
- Rolf Ent, Cynthia Keppel, Paulo Medeiros, Bogdan Wojtsekhowski, Brad Sawatzky
- Vashek Vylet, George Kharashvili, David Hamlette, Melvin Washington, John Jefferson
- Chris Cuevas, Armen Stepanyan
- Matt Poelker, Sue Witherspoon
- William Lehnert (LND, Inc.)

Extras

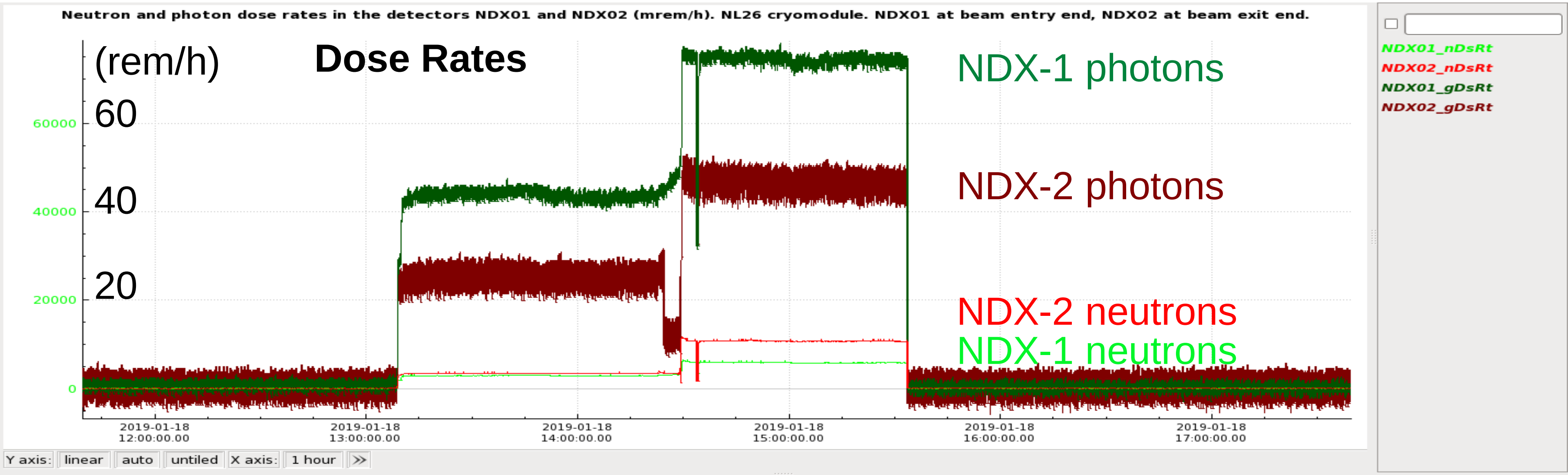
Beam Loss in Transport Tunnel on 12/14/18

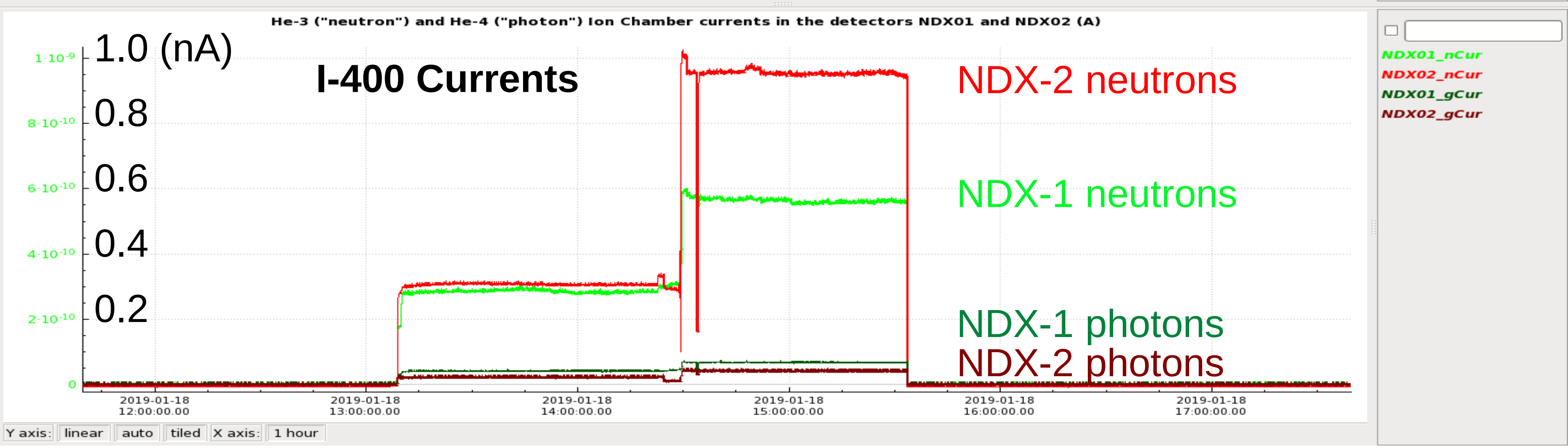






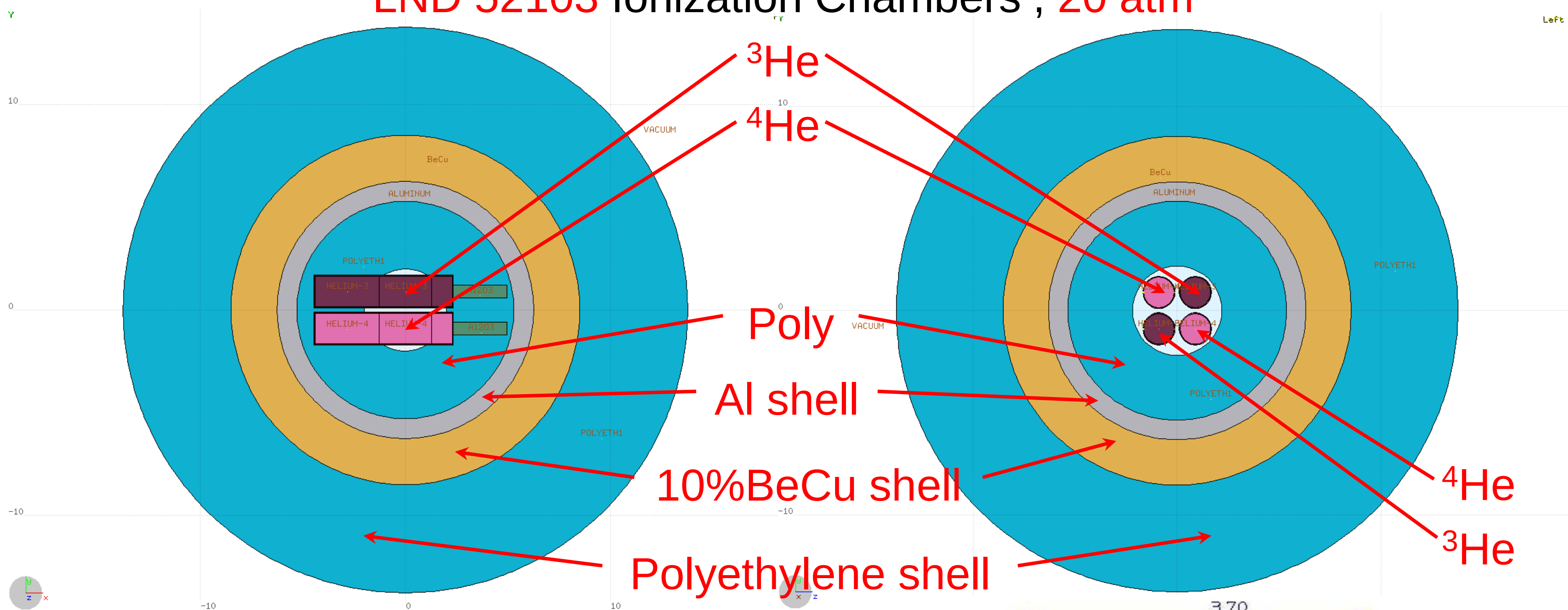
NDX Operation in North Linac, Example





Spherical Moderator Design

LND 52103 Ionization Chambers , 20 atm

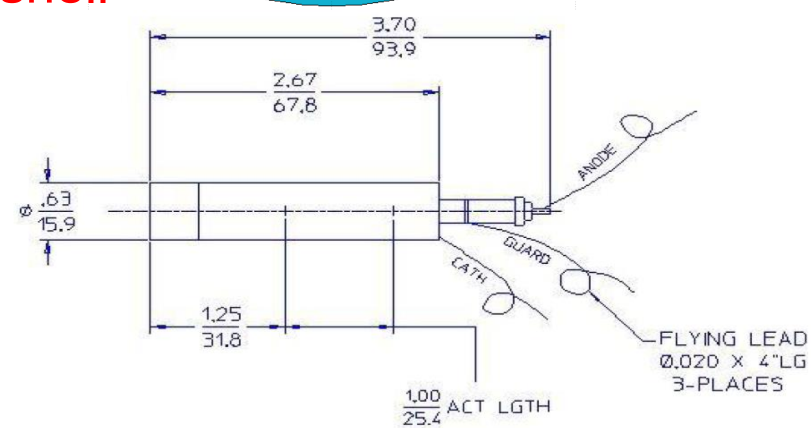


Spherical moderator assembly

Same sensitivity

Better directional uniformity

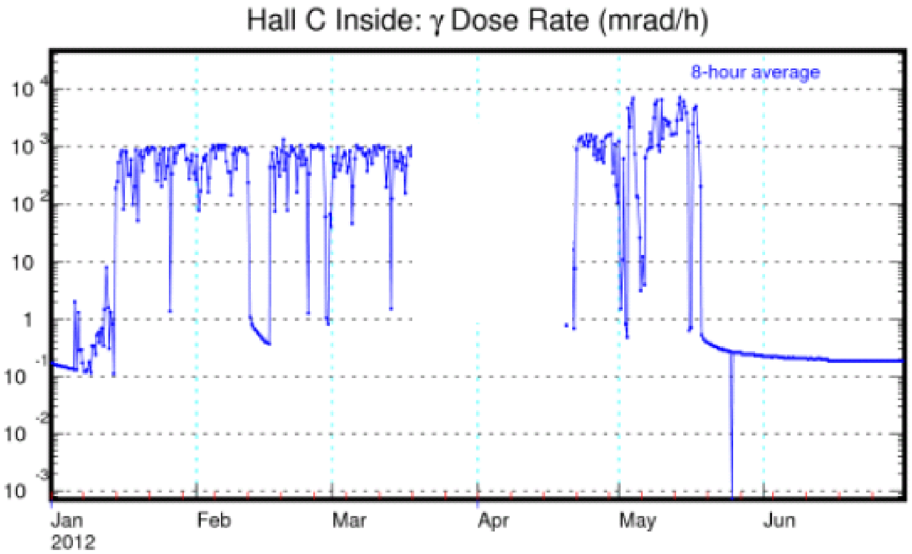
Optimal weight of the moderator

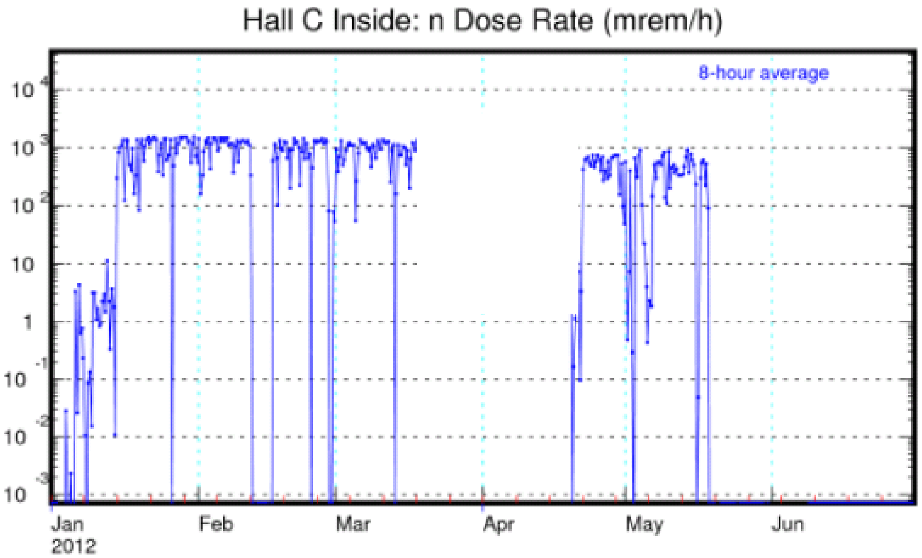


Gamma Irradiator Tests

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:



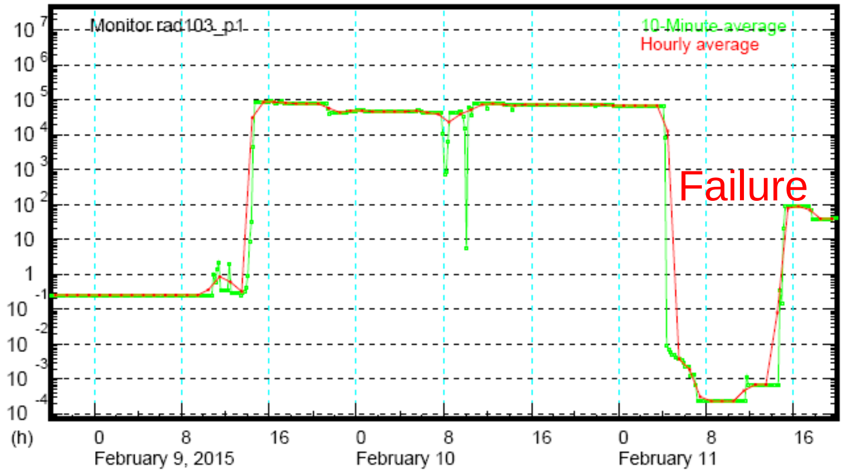


- Prompt dose rates downstream from the targets:
  - many kilorad/h photons (measured with Ion Chambers)
  - hundreds(?) rem/h neutrons (not measured)

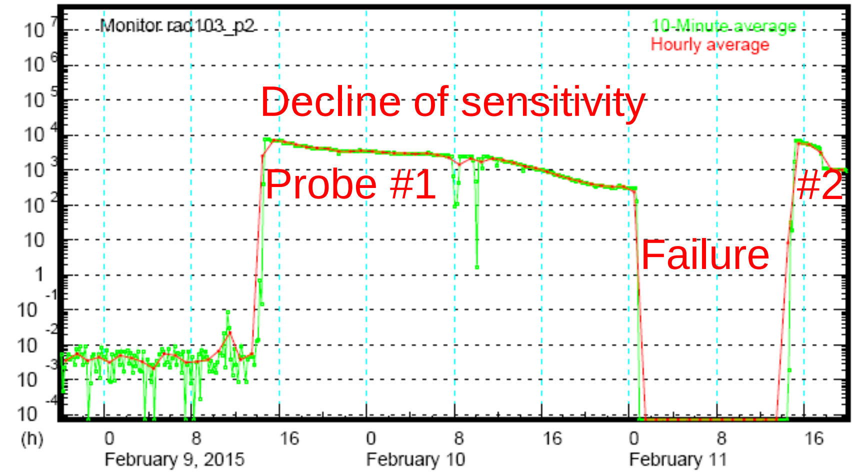
Radiation Environment at Jlab (2)

- 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

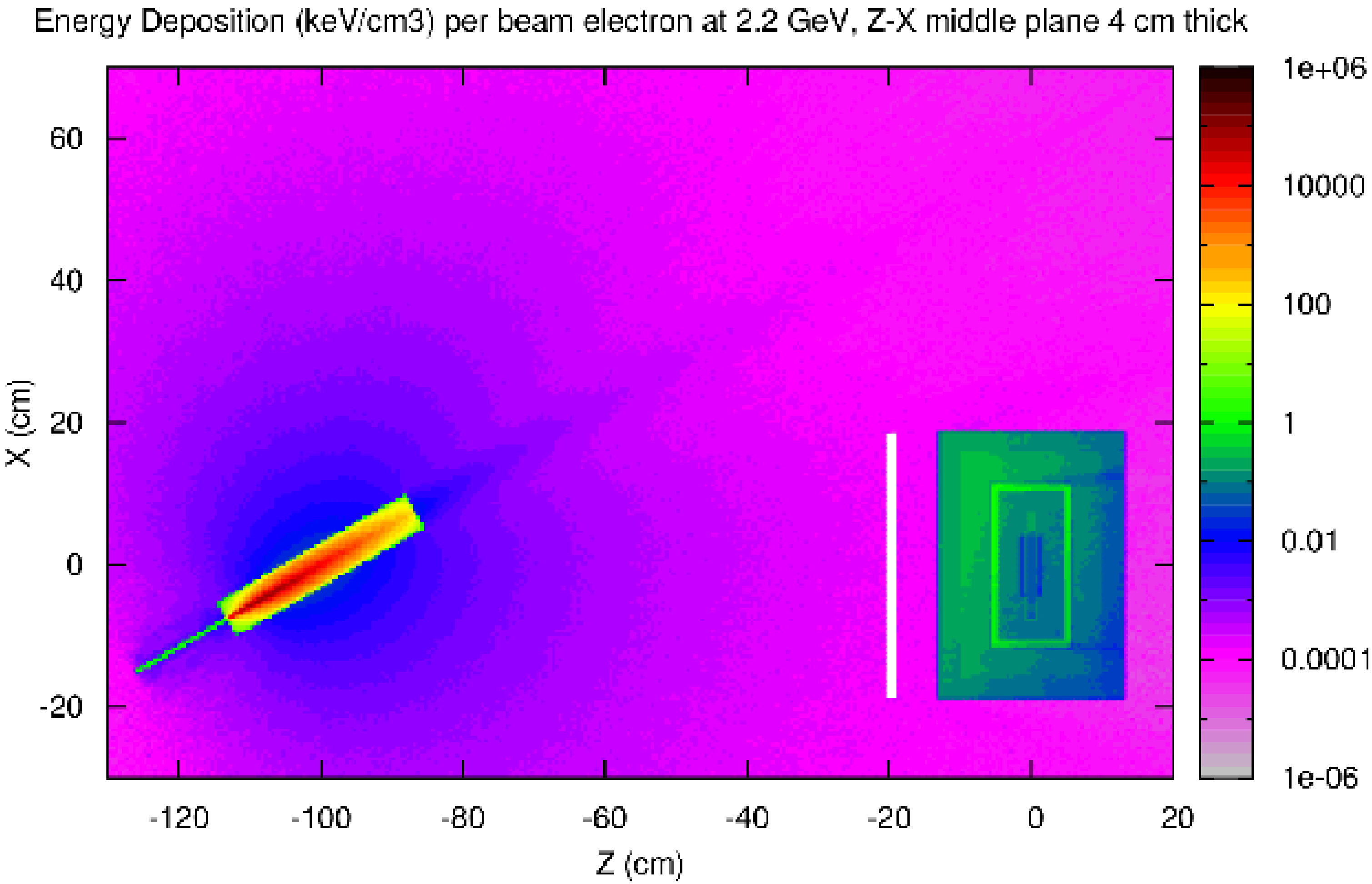


- JLab standard CARM probes do not survive for long
- Typical proportional neutron counters won't work: long cables, high rates, sensitivity to gammas
- Need radiation-hard photon- and neutron-sensitive ICs with remote front-end and DAQ electronics

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



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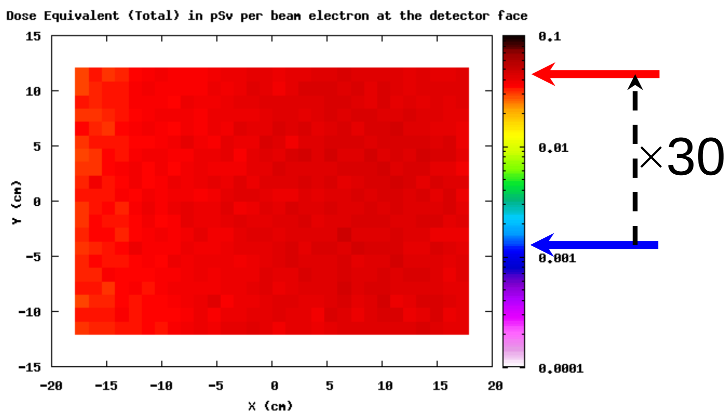
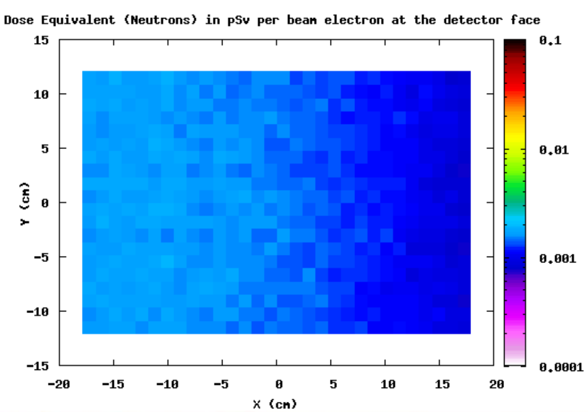
Detector next to a thick target at 2.2 GeV

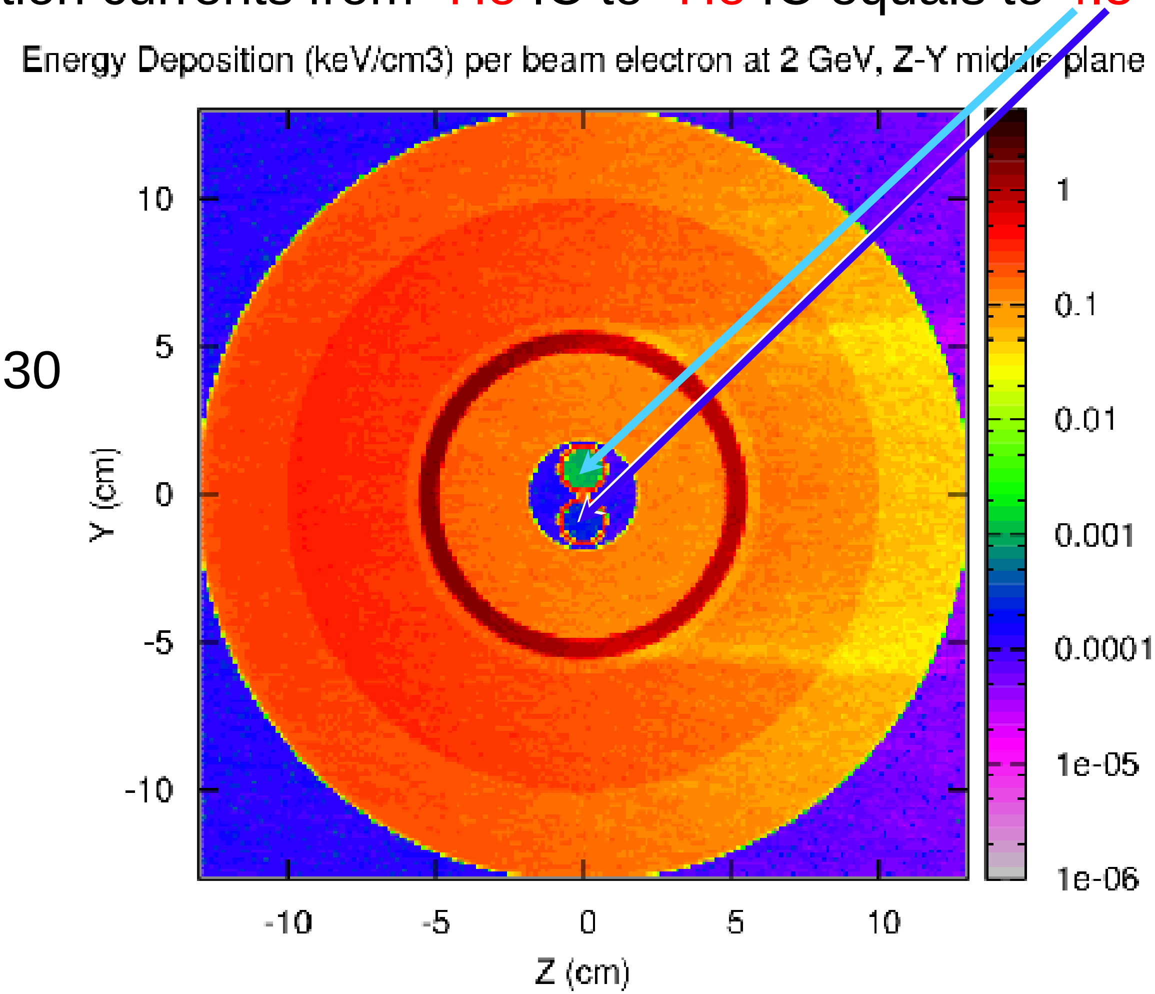
FLUKA: Showing energy density in the air around, and in the detector

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

Face Dose Rates
(Total and Neutron):



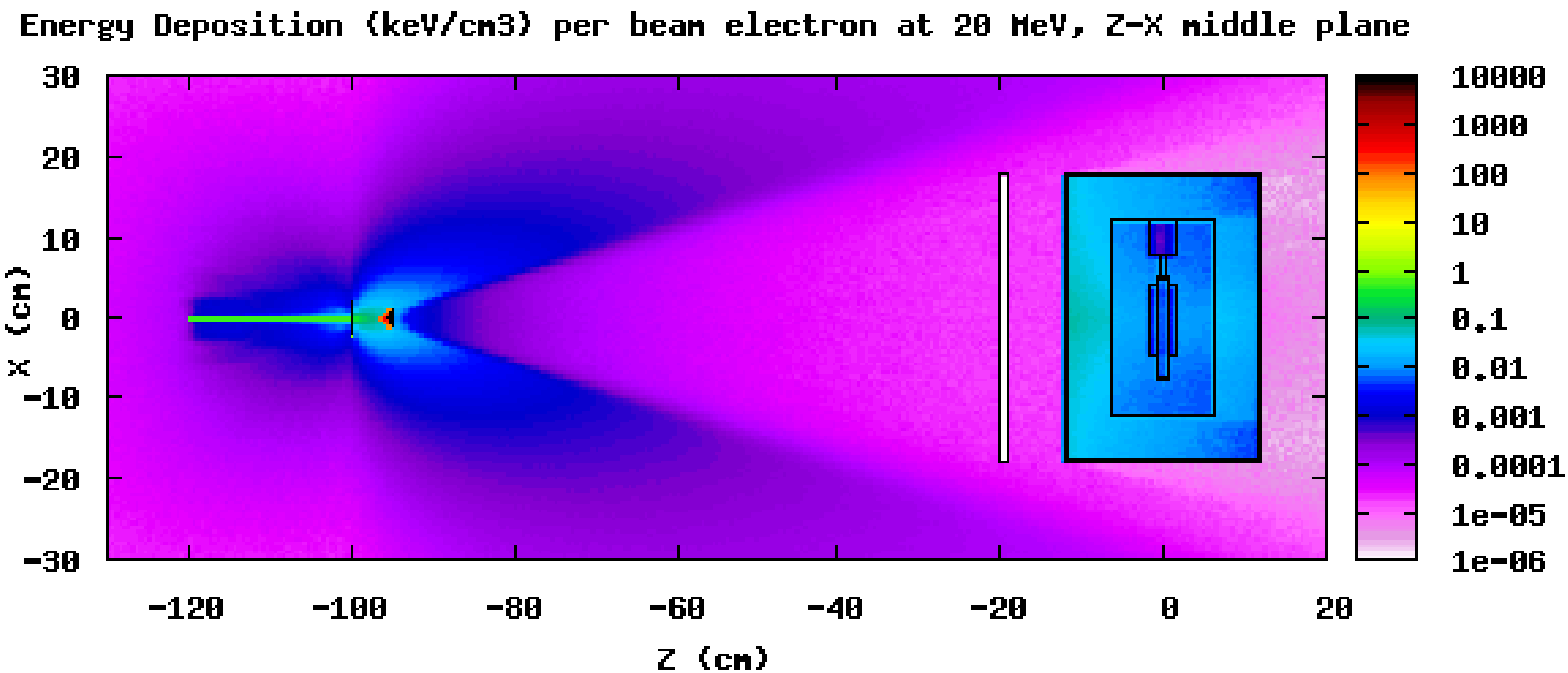




Detector in the 20 MV photon beam

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

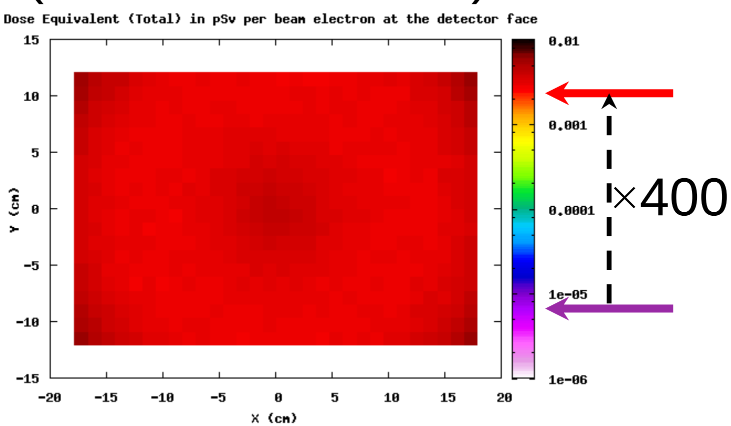


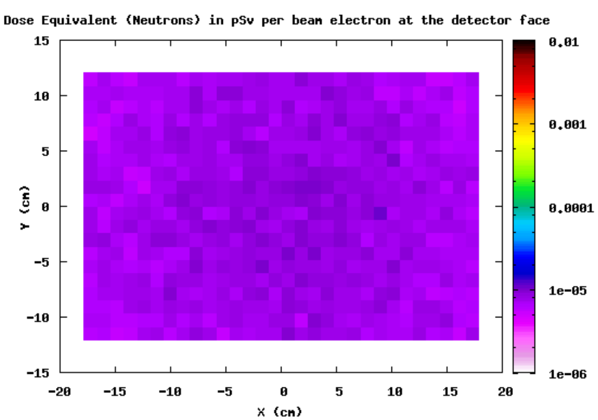
Detector in the 20 MV photon beam

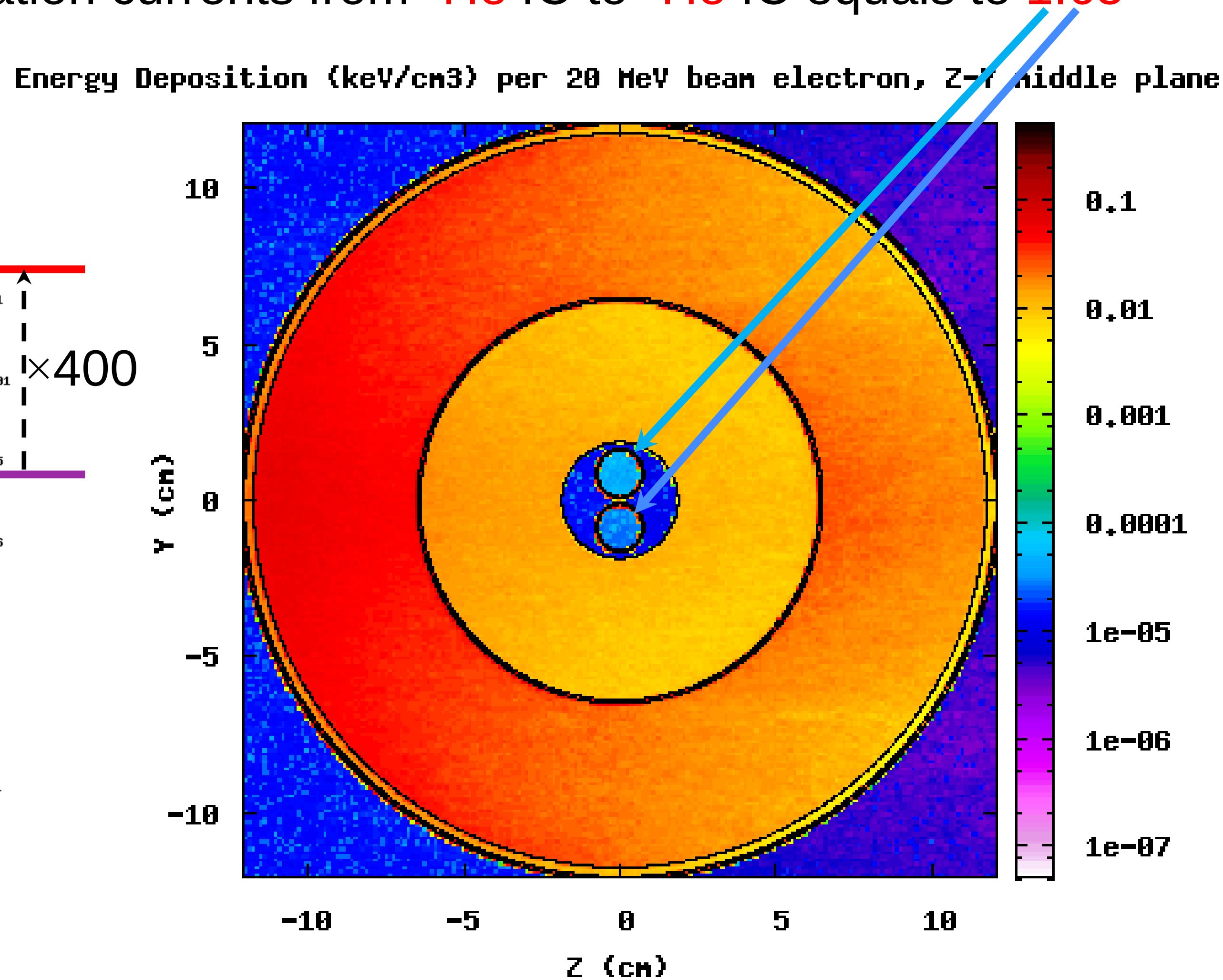
FLUKA: Showing energy density in the air around, and in the detector

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

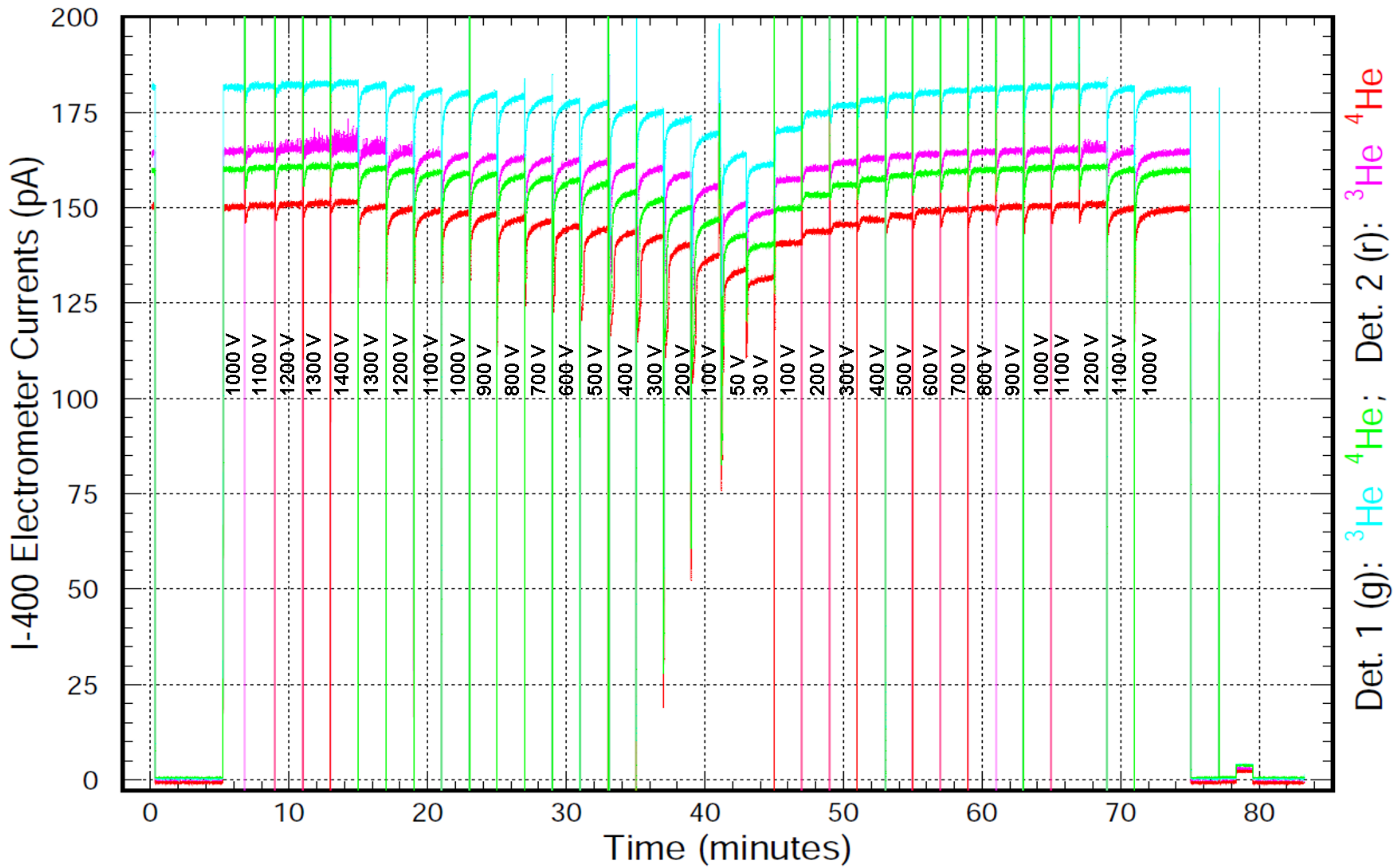
Face Dose Rates
(Total and Neutron):







HV Plateau Studies in Photon Field



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[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.