Neutron Dosimetry in the Presence of Strong Photon Radiation Fields

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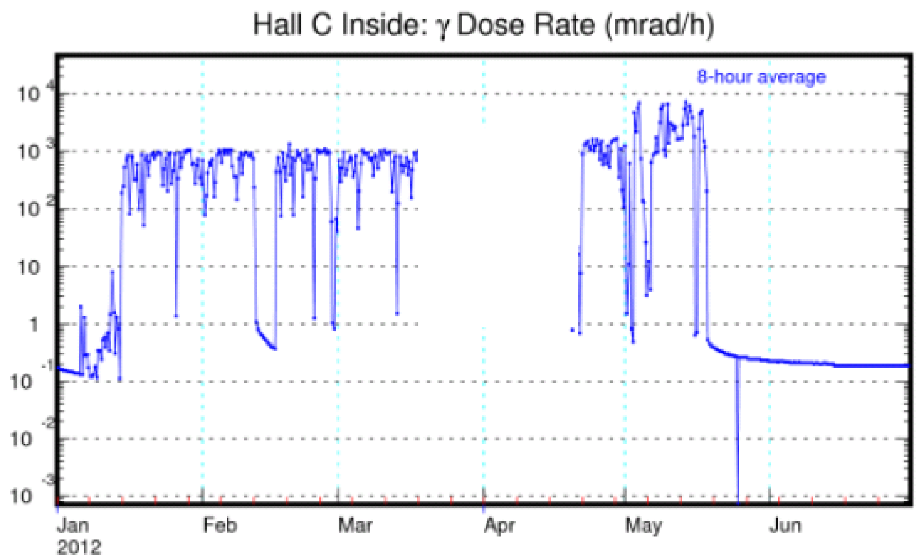
August, 2017

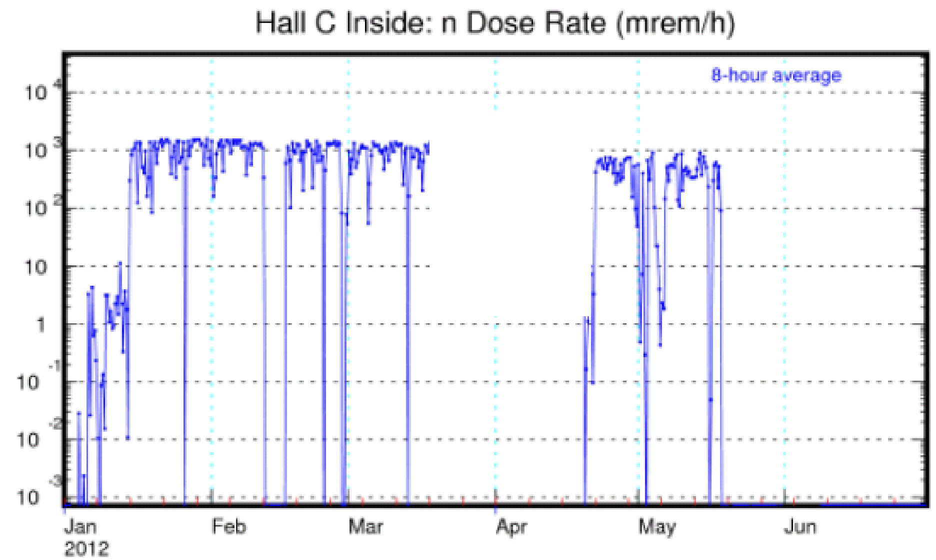
Outline

- Neutron dose rates inside High Energy electron accelerators:
  - Important for radiation safety, radiation damage, activation
  - 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:
  - On-line monitoring
  - Insensitive to photon background
  - Large dynamic range
- The new detection system (work in progress):
  - High pressure ionization chambers filled with ^{3}He and ^{4}He
  - Neutron moderator with Beryllium-loaded reflector / multiplier
  - Simulations, prototype design, preliminary results presented

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:



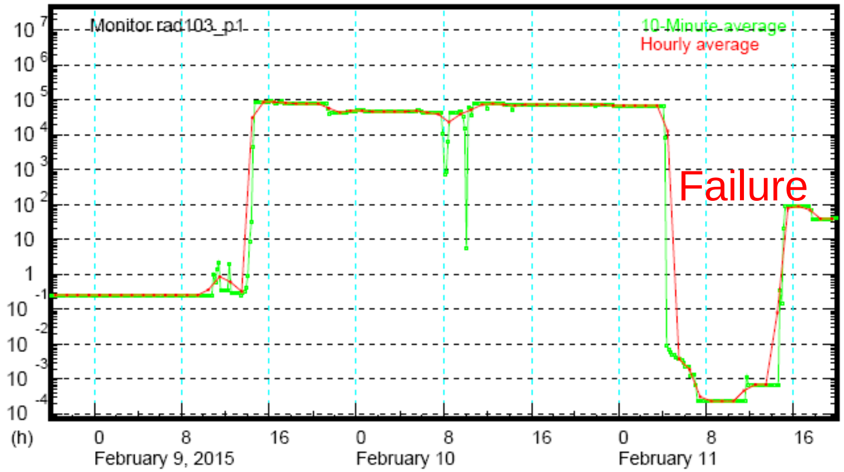


- Prompt dose rates downstream from the targets:
  - many kilorad/h photons (measured with Ion Chambers)
  - hundreds(?) rem/h neutrons (not measured)

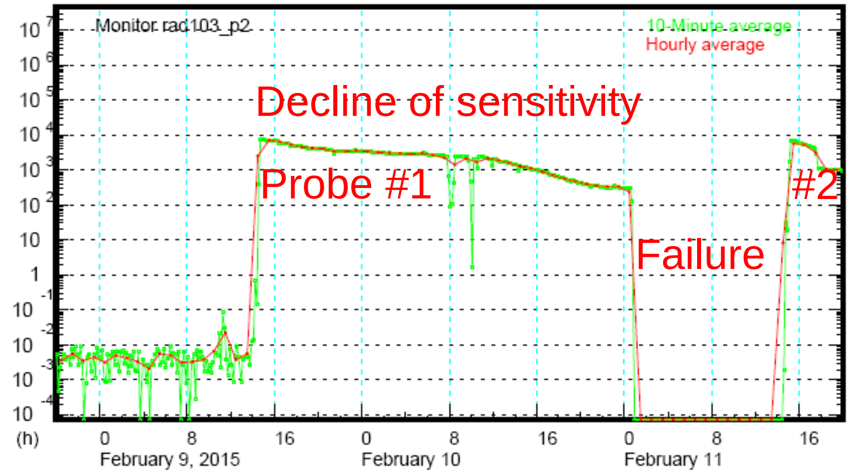
Radiation Environment at Jlab (2)

- 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



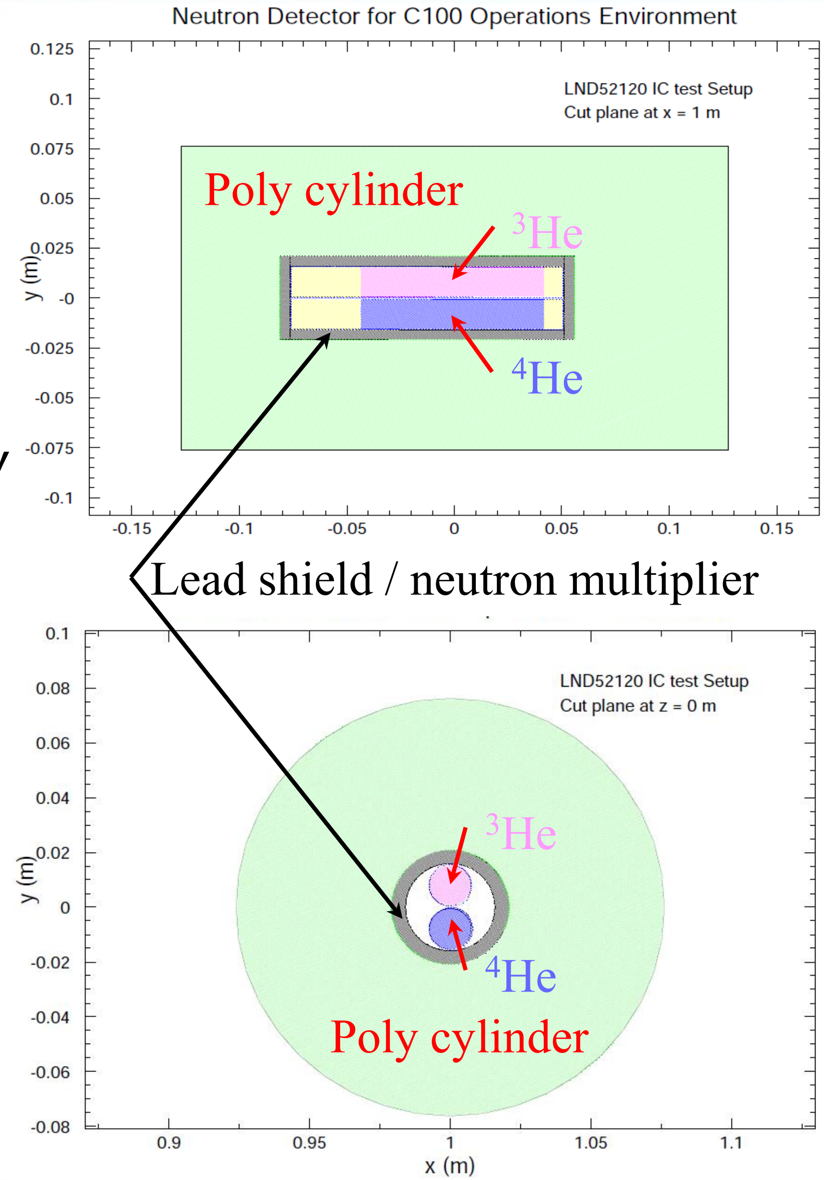
Neutrons RM-103(n probe 2) (mrem/h) - Tunnel Cryo Test



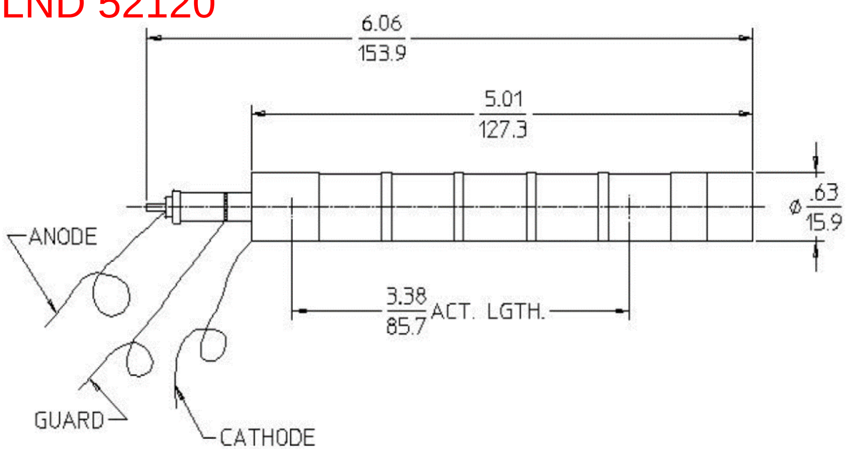
- JLab standard CARM probes do not survive for long
- Typical proportional neutron counters won't work: long cables, high rates, sensitivity to gammas
- Need radiation-hard photon- and neutron-sensitive ICs with remote front-end and DAQ electronics

Original Idea (2016)

- Propose to use two small LND ICs, filled with ^{3}He and ^{4}He (10 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

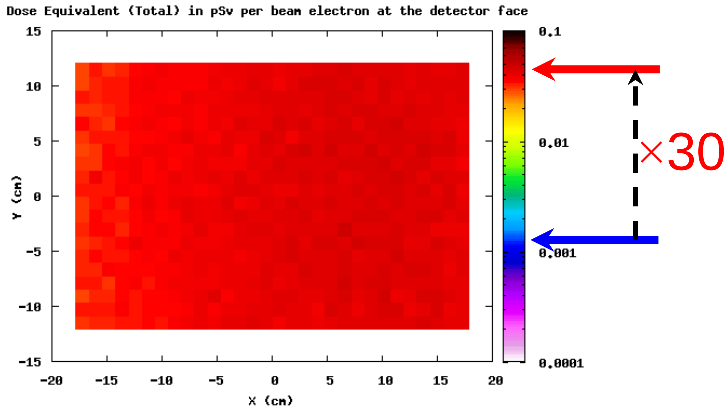


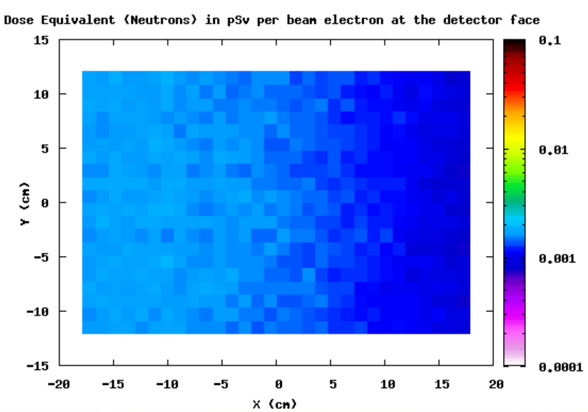
Detector next to a thick target at 2.2 GeV

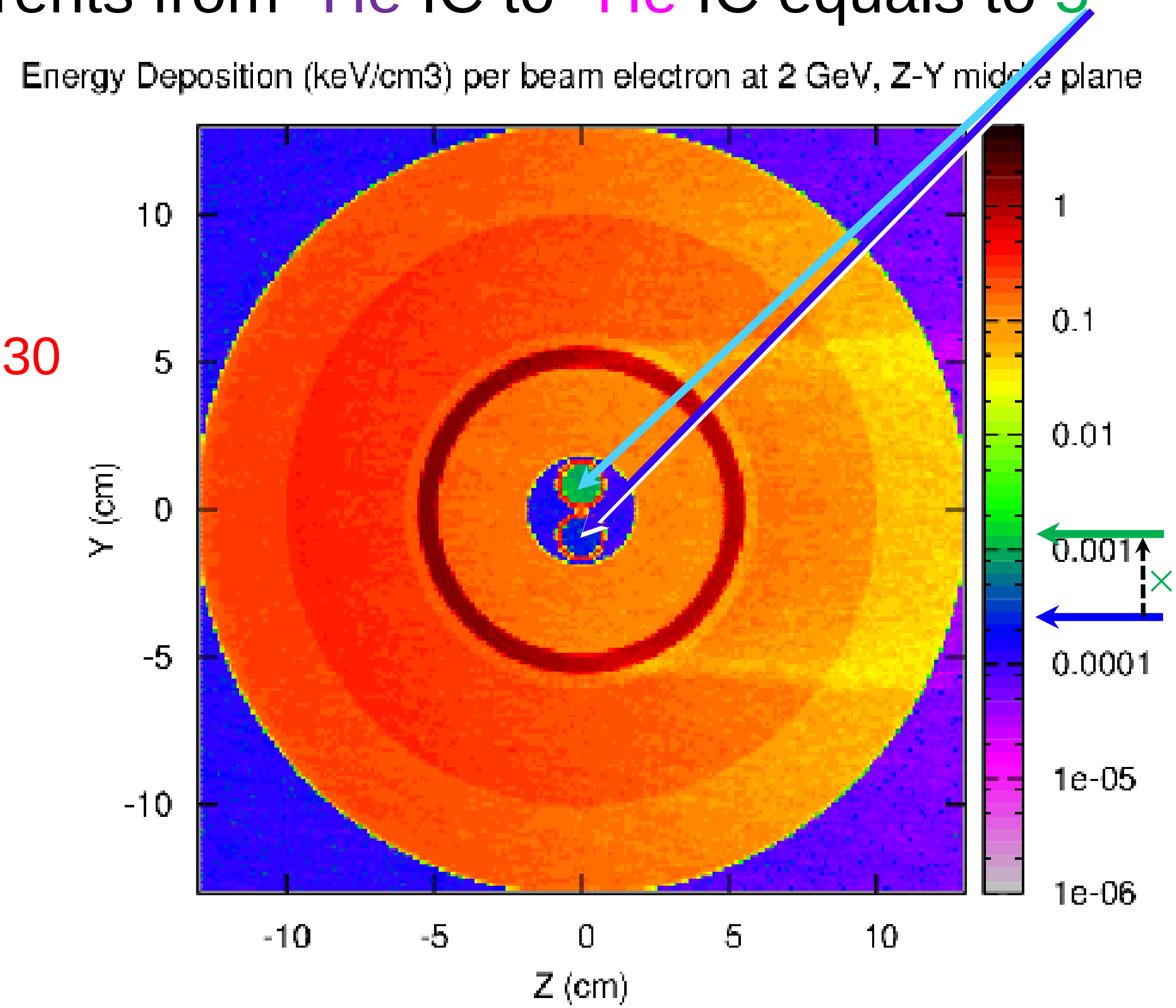
FLUKA: Showing energy density in the air, and in the detector

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

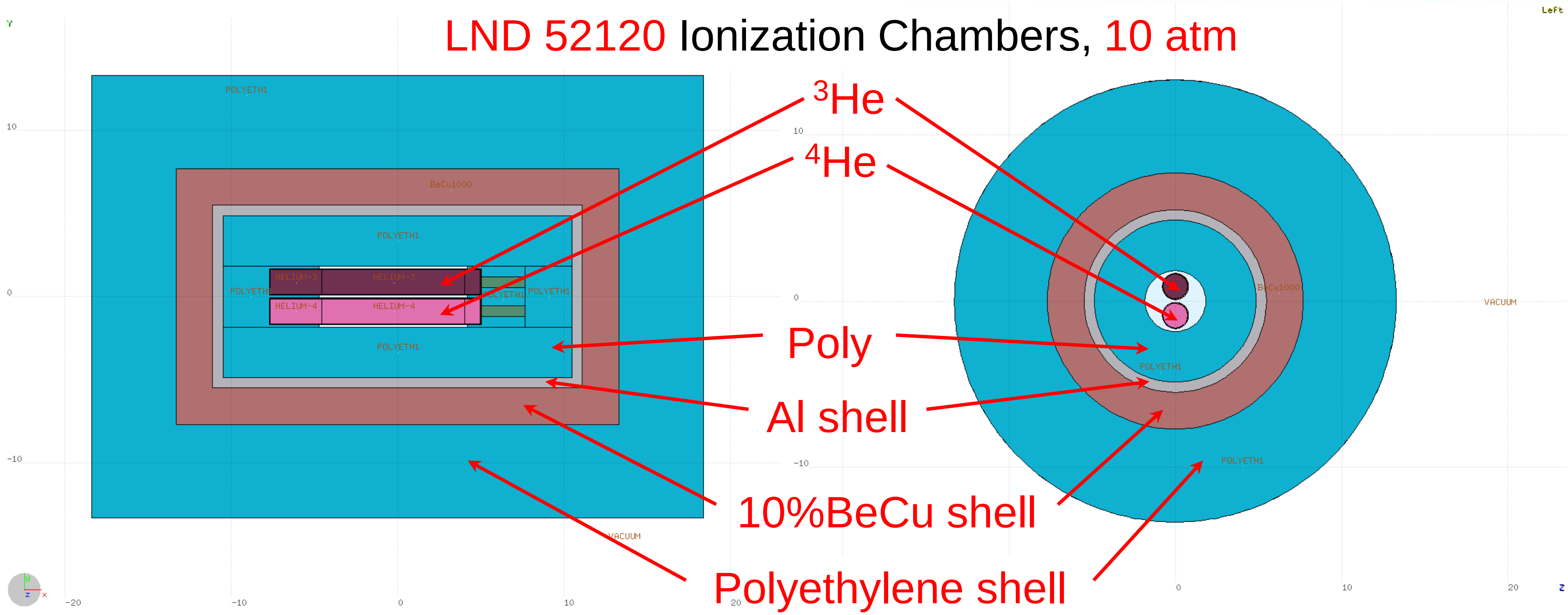
Face Dose Rates (Total and Neutron):





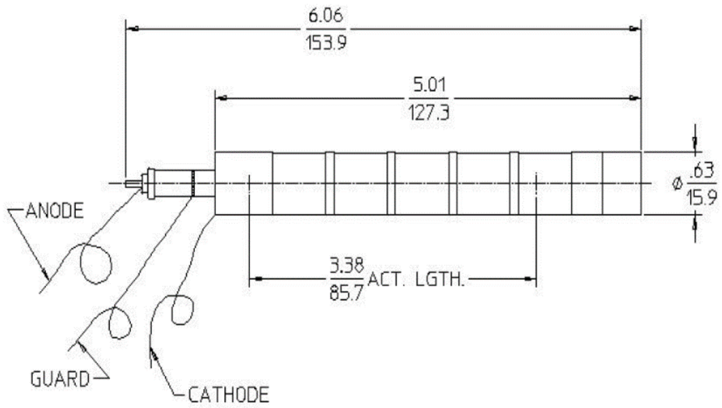


FLUKA Model, Be Loaded Moderator

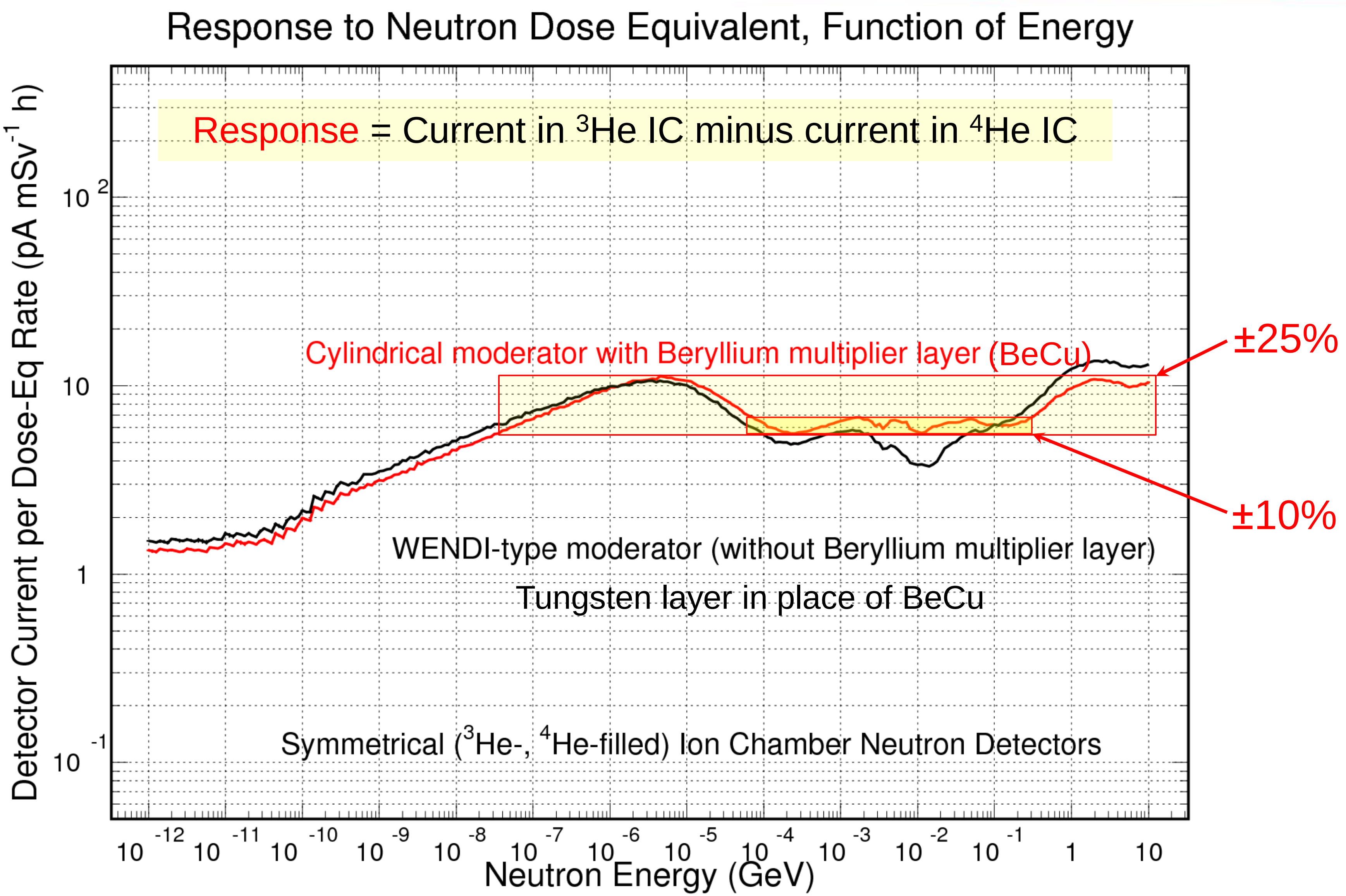


Cylindrical moderator assembly

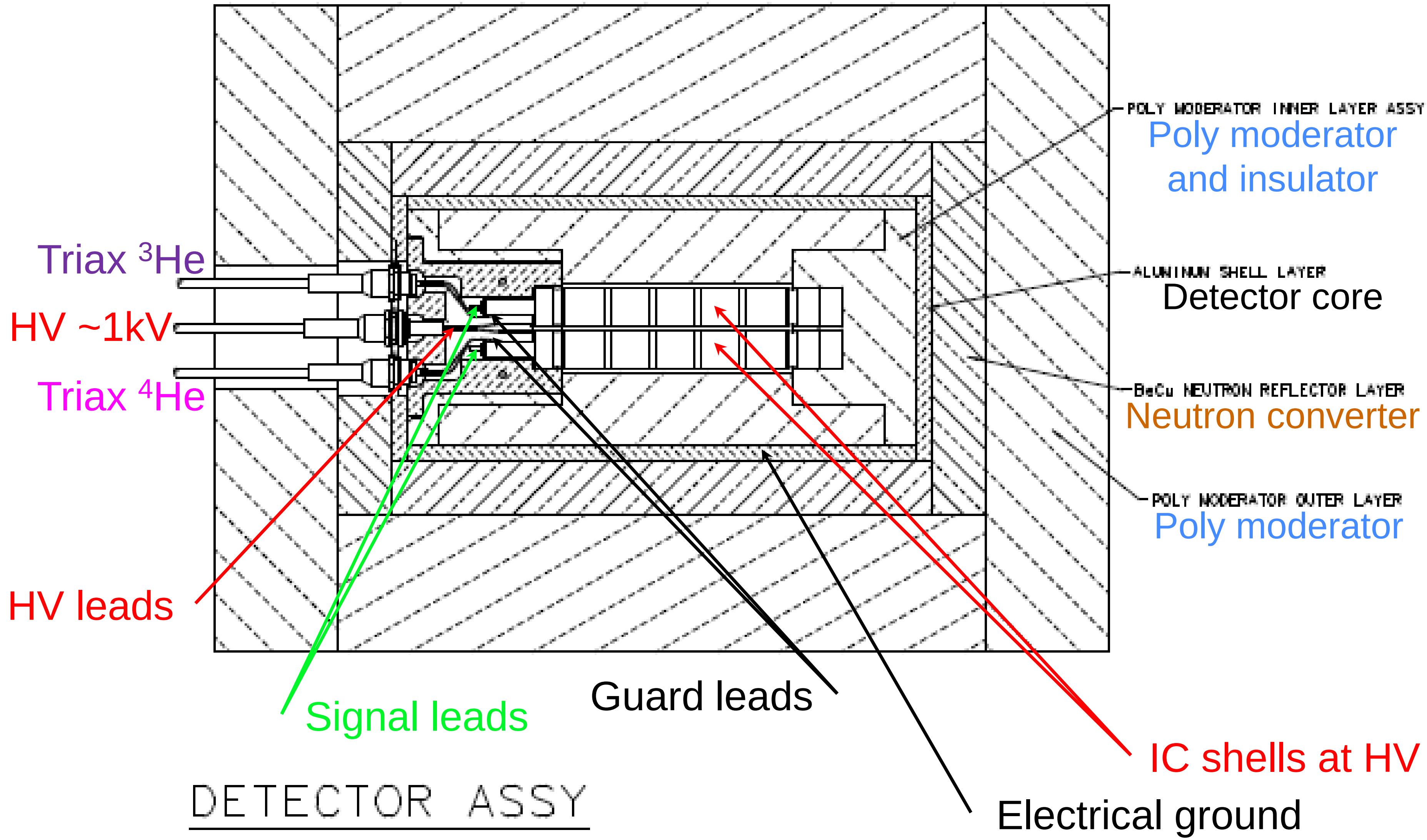
Ion Chamber Quote: $(1350+750)



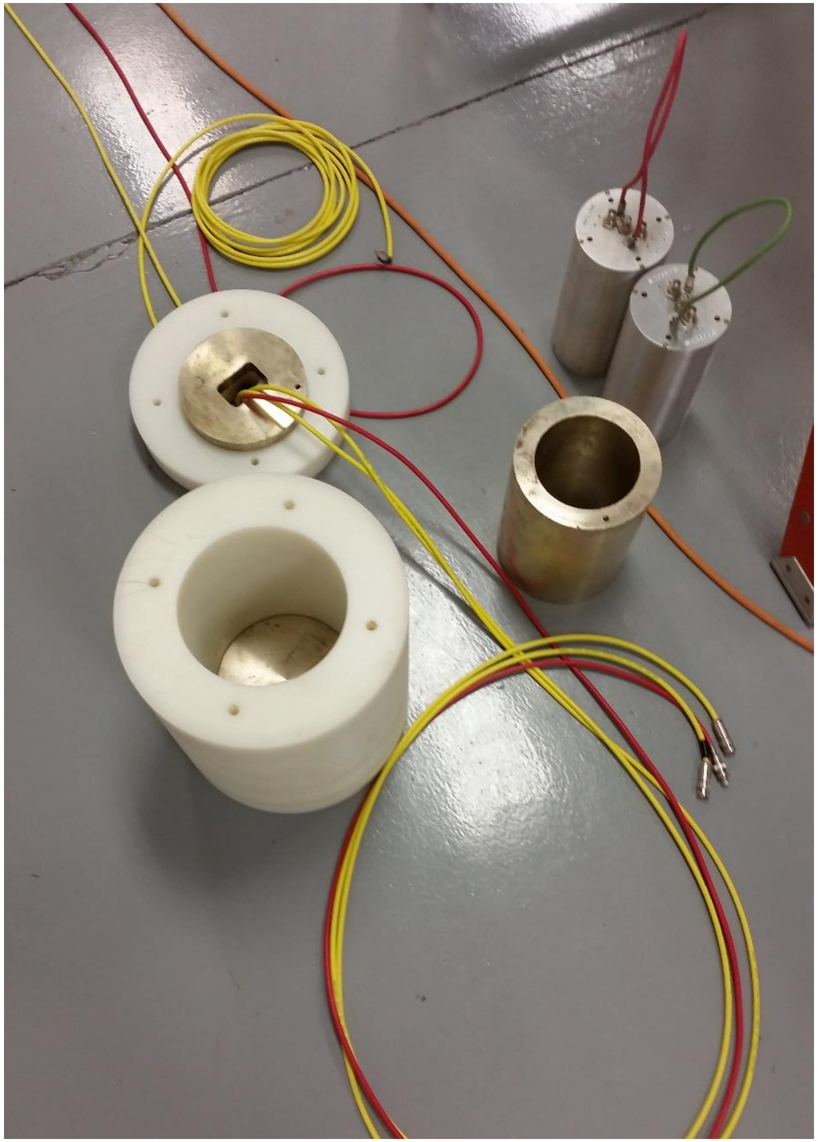
Energy Dependence of Detector Response

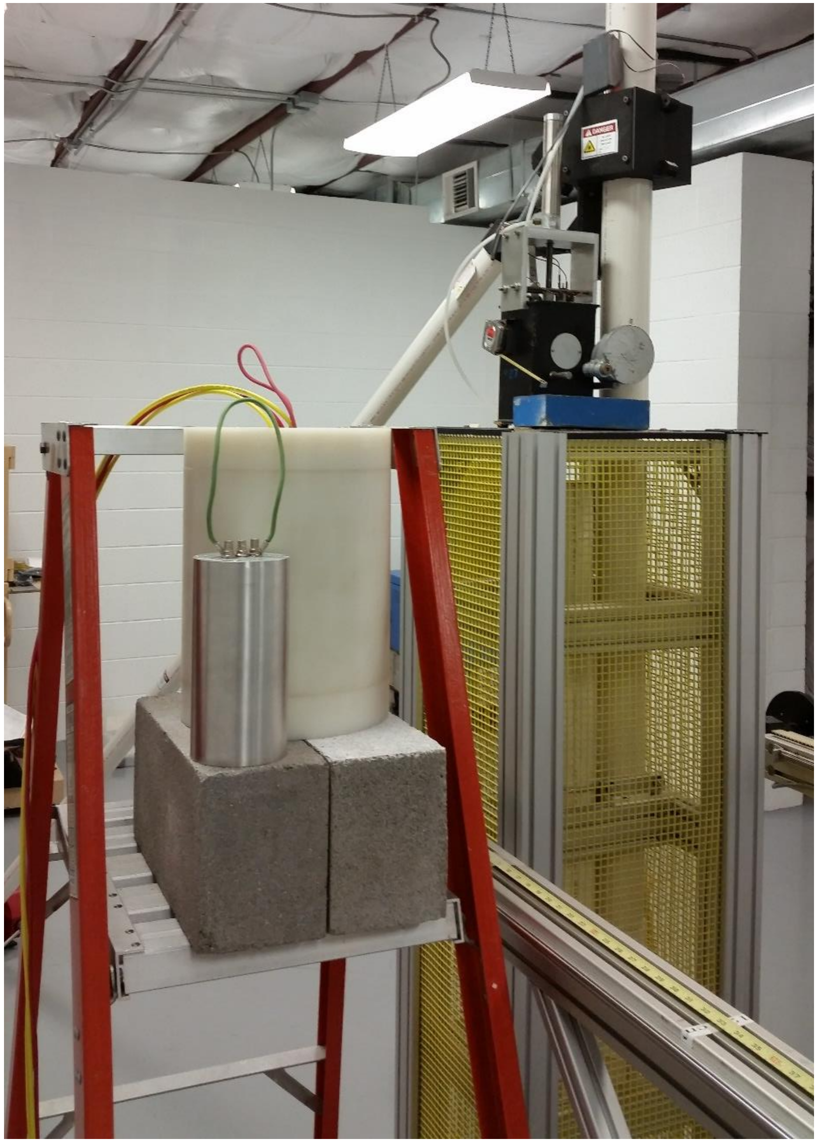


Prototype Assembly Drawings



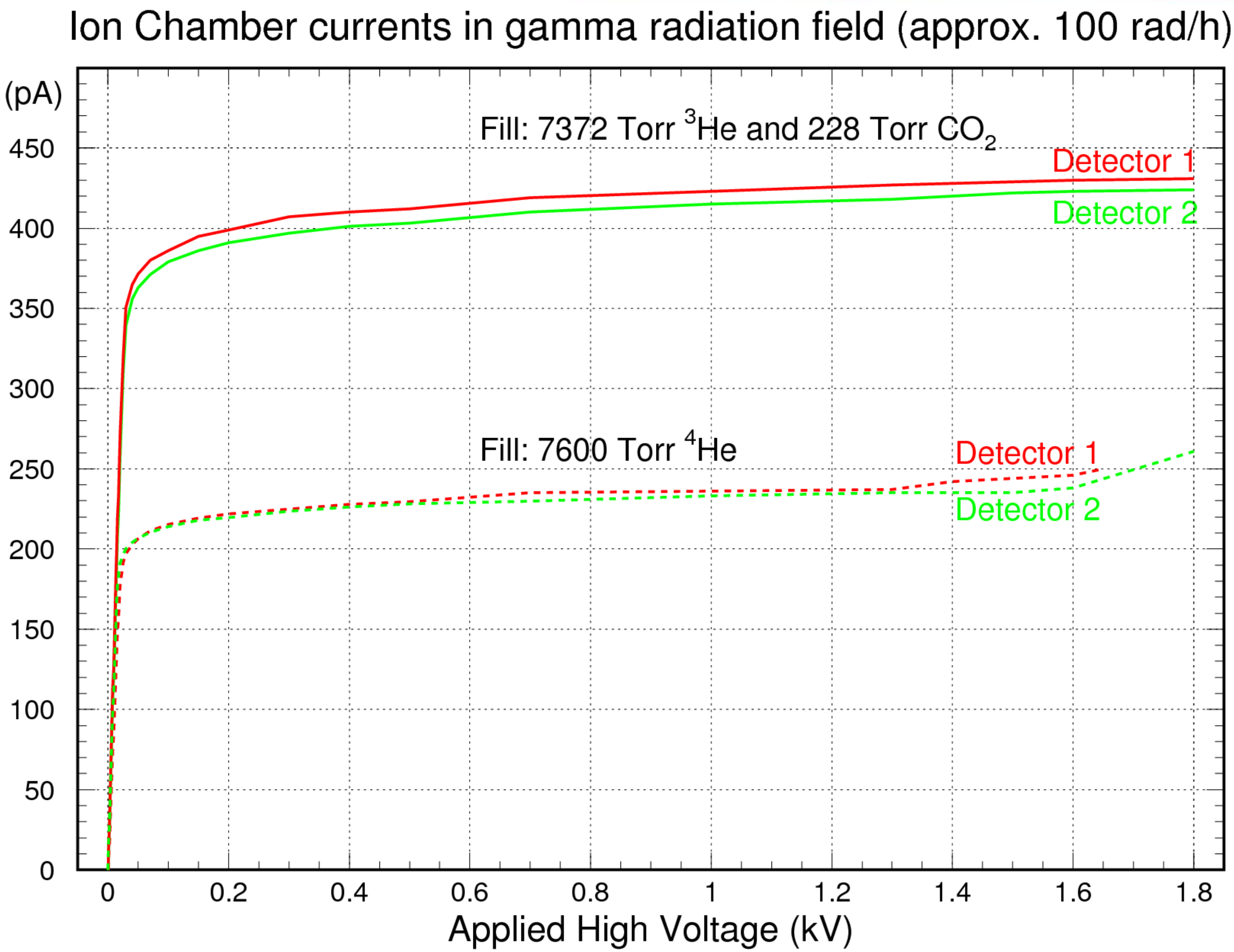
Prototype Detectors





Detector cores in ~100 rad/h photon field

Keithley 6512 electrometer



Jefferson Lab

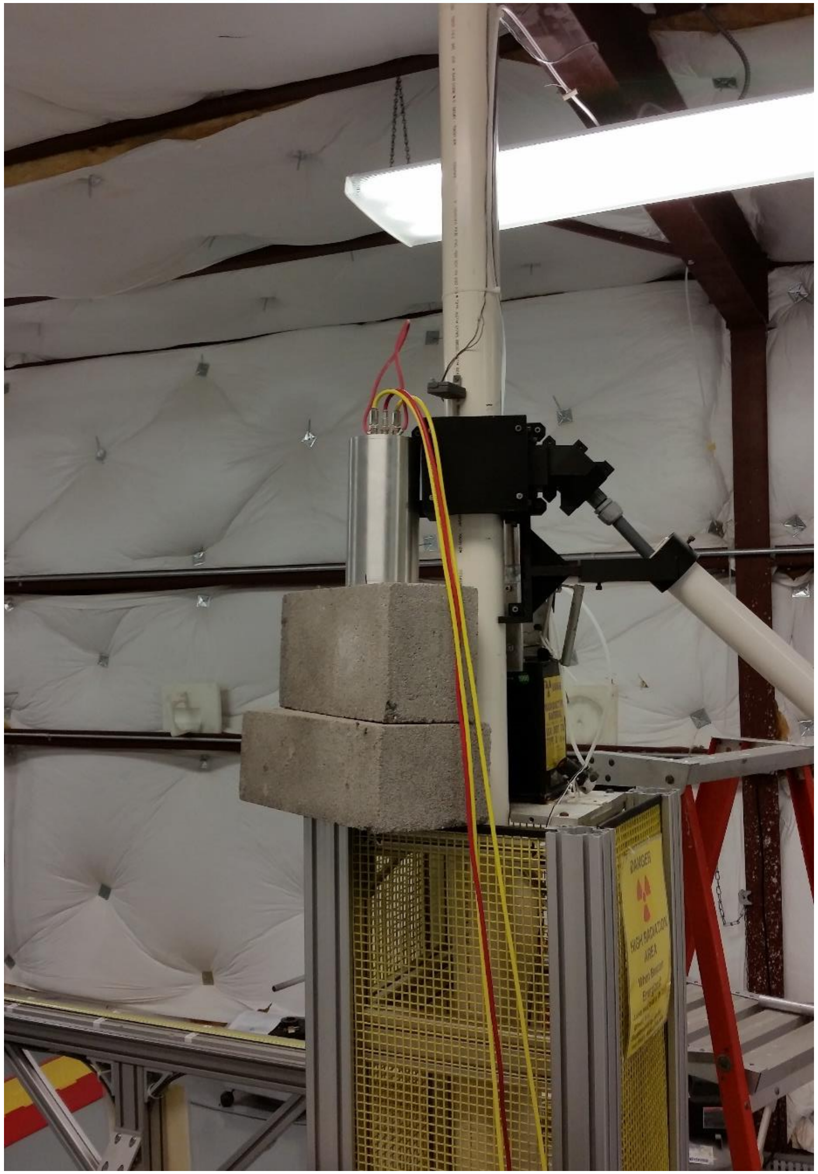
Detector cores in ~1 rem/h neutron field

^{3}He Ion Chambers: 48.0 ± 1.0 pA

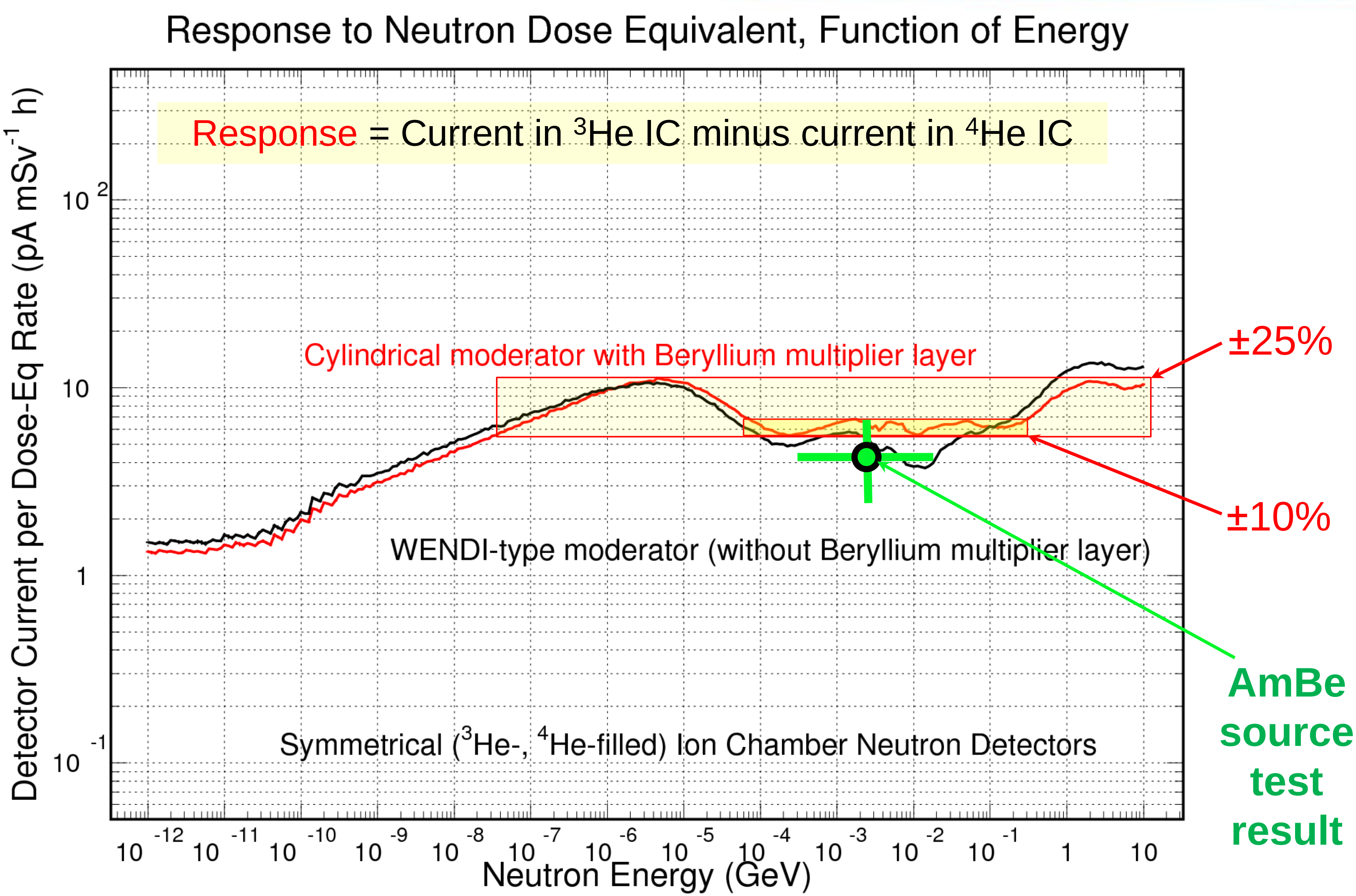
^{4}He Ion Chambers: 0.17 ± 0.03 pA

(difference of about a factor 280)

Detectors #1 and #2 agree well within the errors

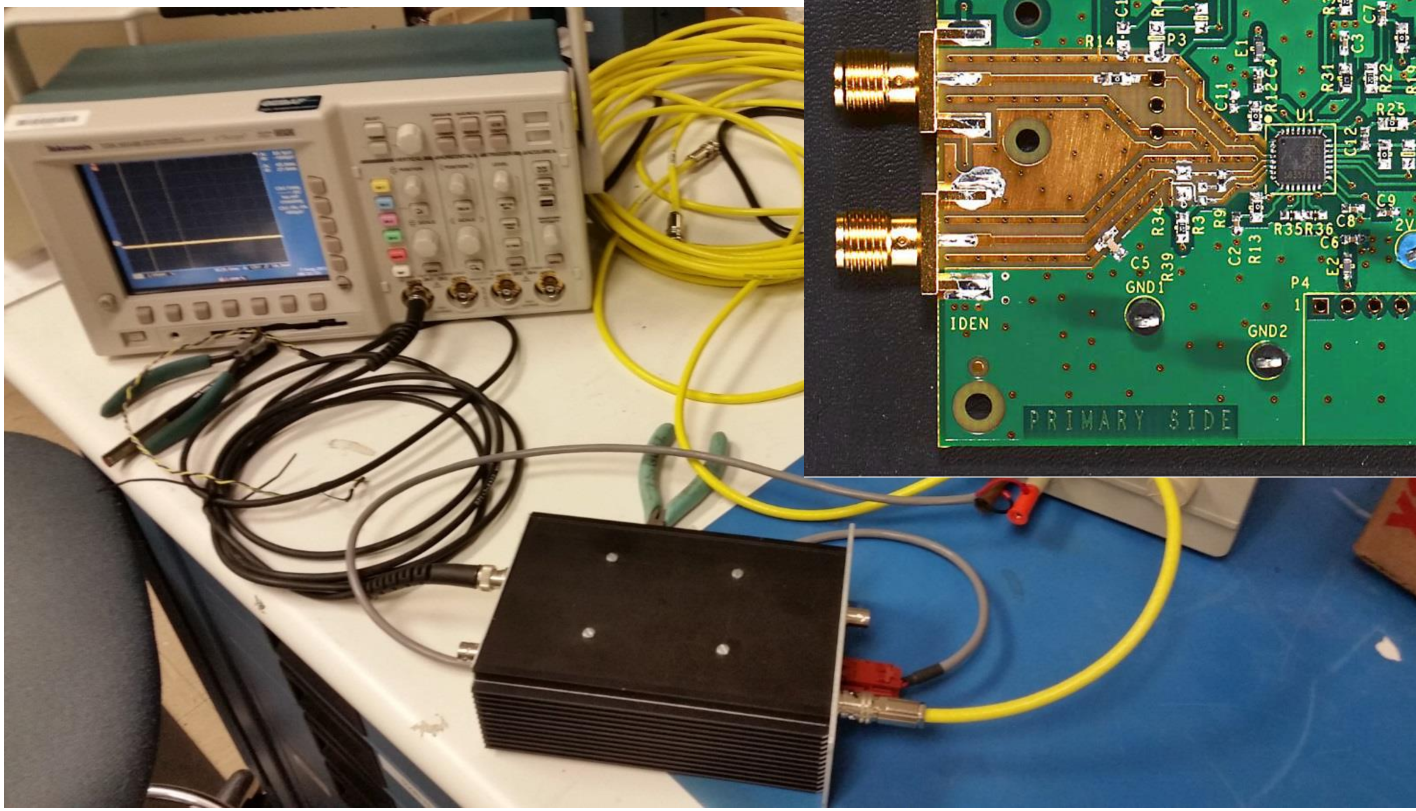


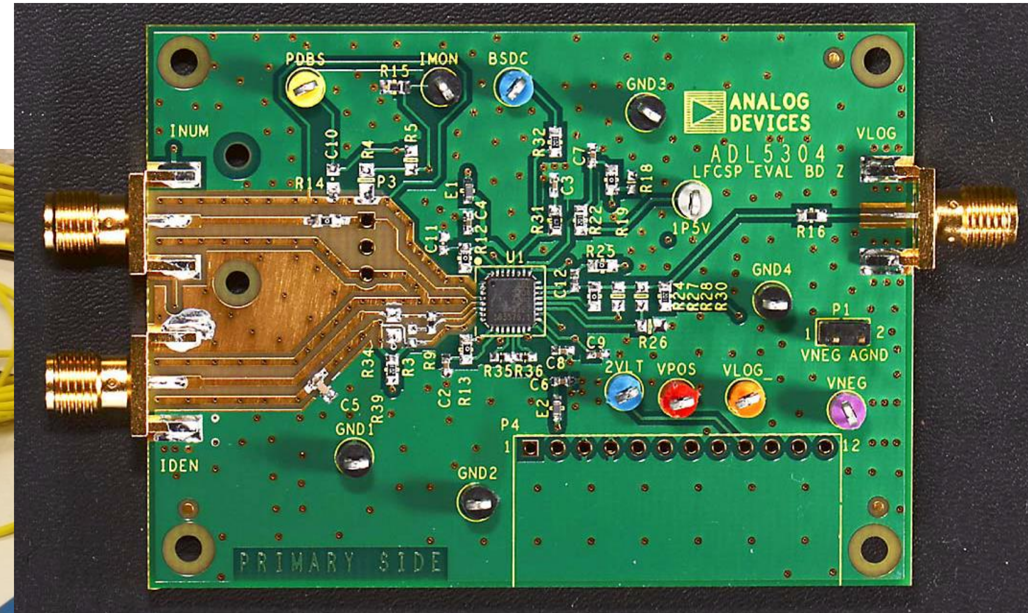
Full detector in ~10 mrem/h neutron field



Electronics front-end under development

Evaluation boards:





Logarithmic amplifiers ADL5304 by Analog Devices

Dynamic range from 1 pA to 3 mA

Summary

- Two JLab Invention Disclosures:
  - Neutron detector for use in strong gamma-radiation fields
  - Improving sensitivity and energy response of neutron detectors using moderators with embedded Beryllium-loaded materials
- Combined into the "NDX" detector design, solving the problems:
  - Neutron detection in the presence of overwhelming photon radiation fields, in particular at JLab:
    - around the C100 cryomodules at full gradients
    - at the experimental halls
  - 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
- Preliminary prototype test results are in agreement with expectations
- Plans for deployment at JLab under development

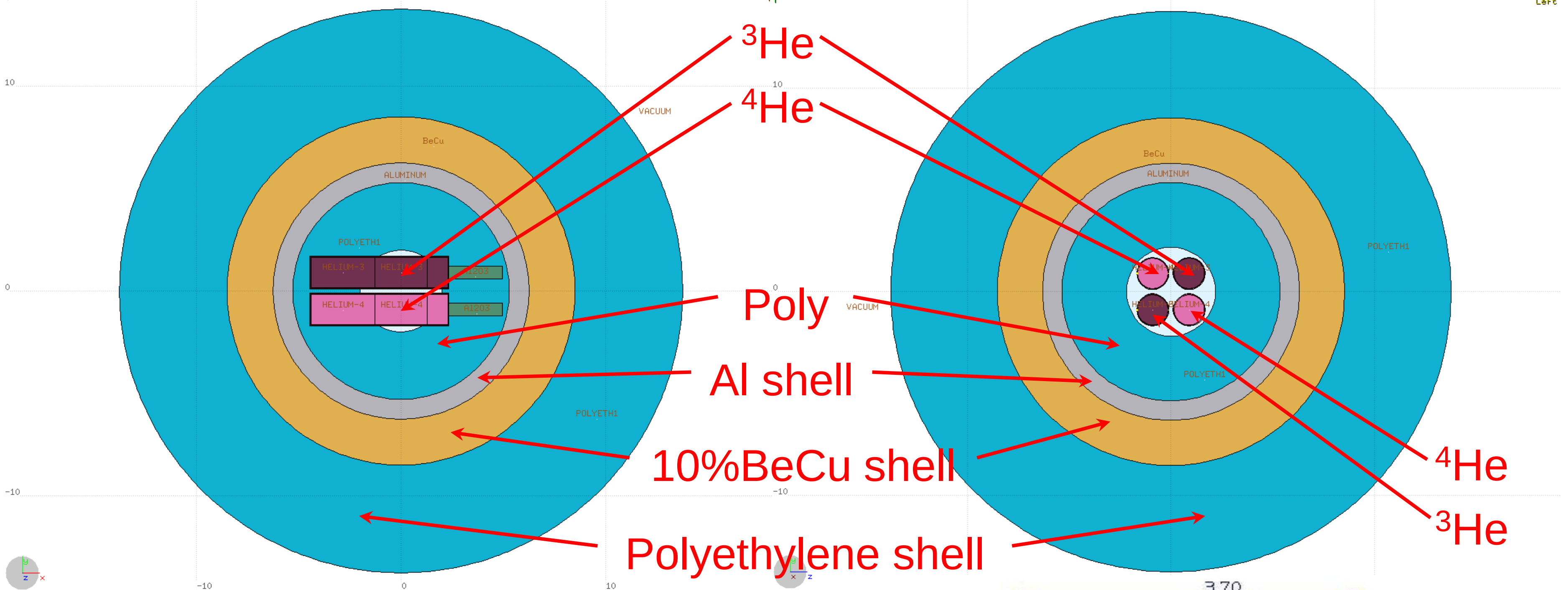
Acknowledgements

Thanks to:

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

Spherical Moderator Design

LND 52103 Ionization Chambers , 20 atm

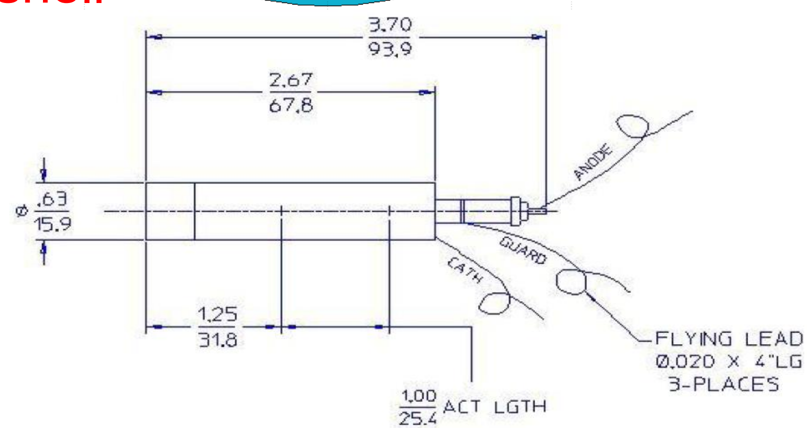


Spherical moderator assembly

Same sensitivity

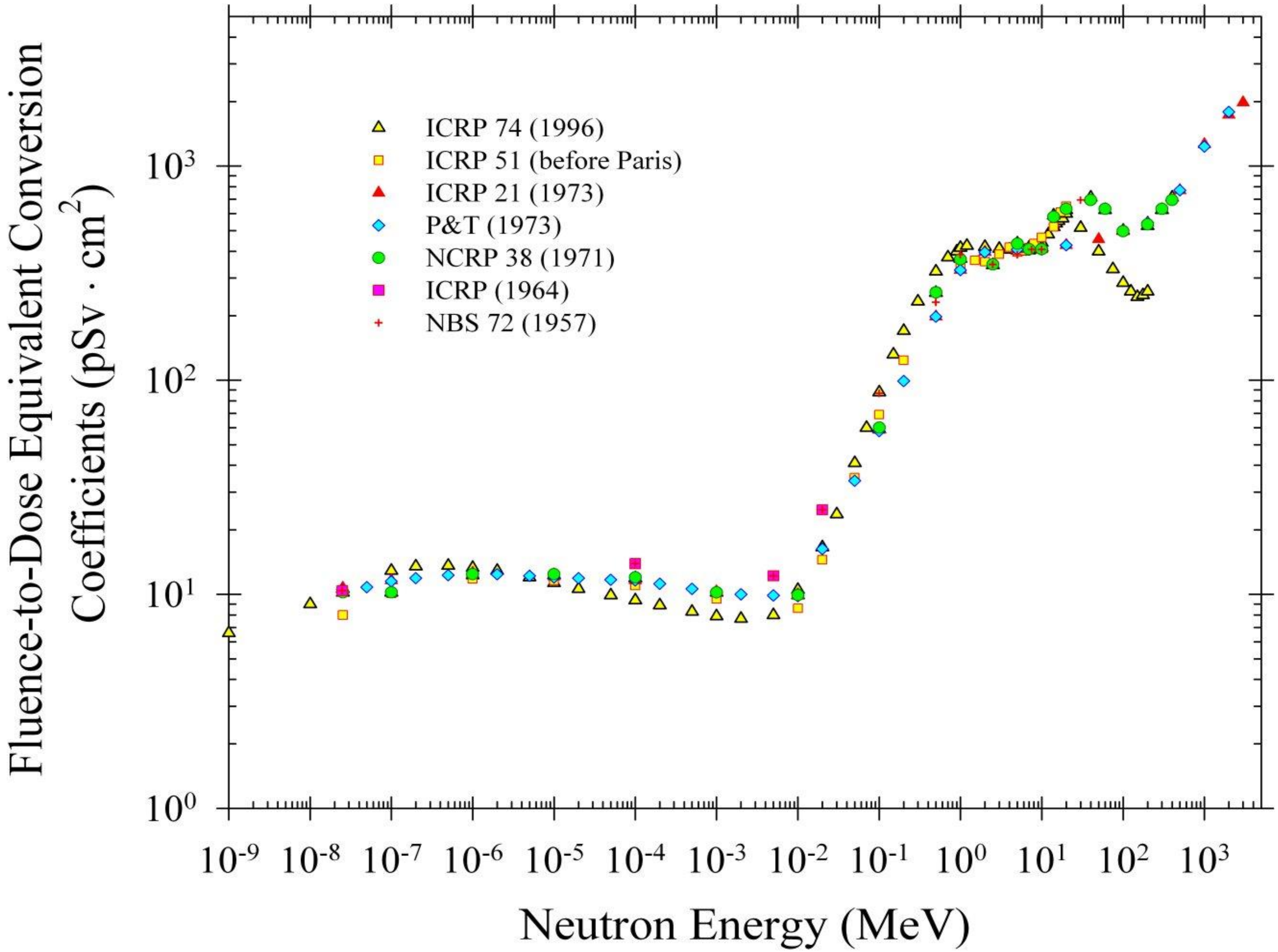
Better directional uniformity

Optimal weight of the moderator



Backup
Slide #1

Slide by Joseph C. McDonald (PNNL)



Backup Slide #2

Slide by F. Gutermuth et al. (CERN)

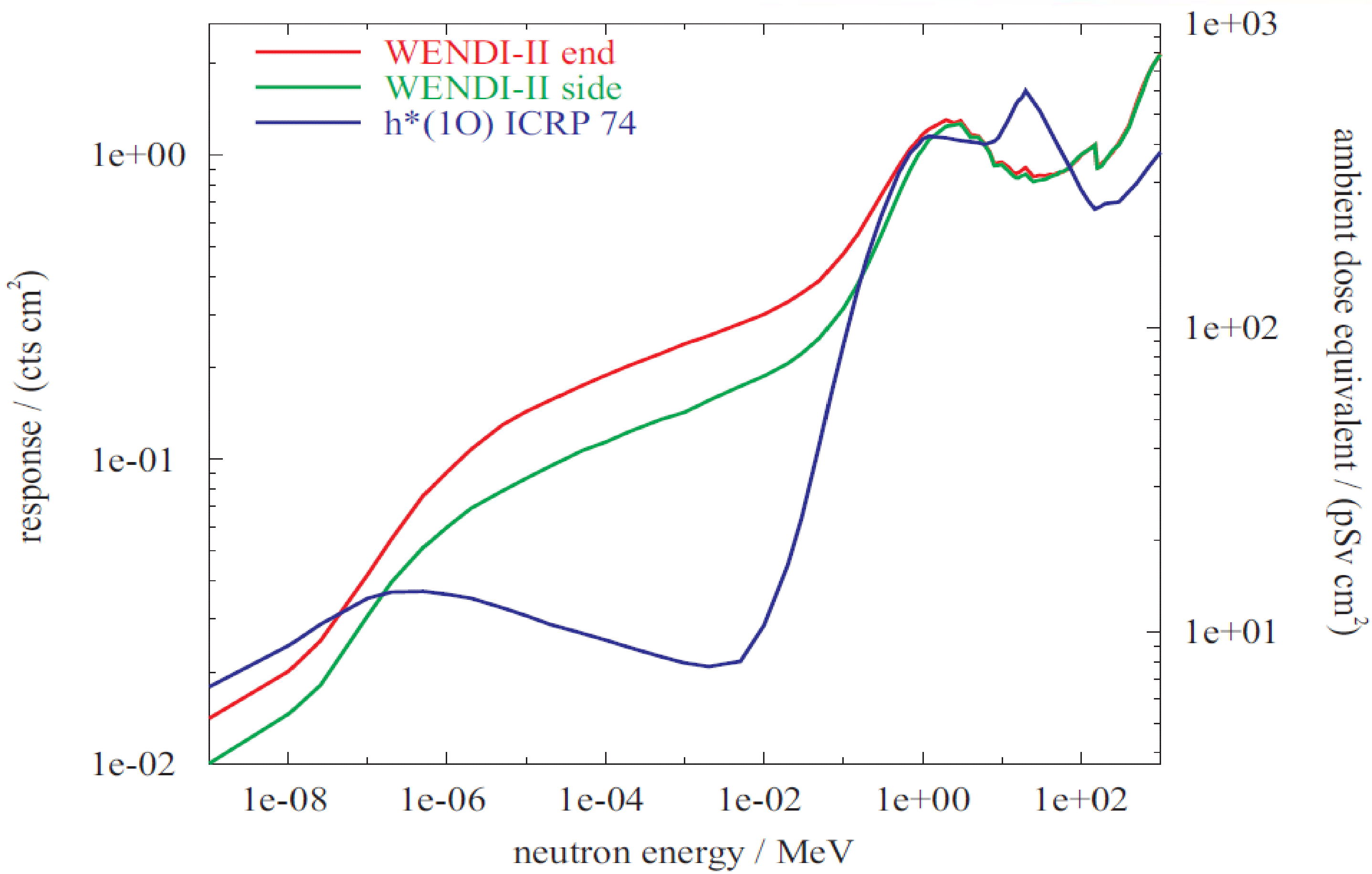


Figure 2: Response of the rem-counter WENDI-II from Thermo Eberline in comparison to the conversion function for the ambient dose equivalent. The data show the results of the MCNPX Monte-Carlo simulations from Olsher et al. [1] for the exposition of the detector from the side and from the end of the cylindrically shaped moderator.

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.

Backup
Slide #4

Extra Slide