Radiation Environment and Shielding Design Optimization at MEIC

Pavel Degtiarenko
Radiation Physics Group
Radiation Control Department, JLab

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Radiation Environment at MEIC

- Radiation Source Terms at the MEIC
  - Regular beam losses by the protons, heavy nuclei, and electrons
    - Beam lines, Limiting apertures, Beam removal / dumps, etc.
    - Impact:
      - ✓ High level of prompt radiation dose rates inside
      - ✓ Limited/delayed access due to areas of activation
  - Environmental
    - Prompt radiation through shielding walls and penetrations
    - Neutron and gamma skyshine, dose rates at the boundaries
    - Activated air, ground water
    - Impact:
      - ✓ Defines shielding needs and limits for the site boundary
  - High energy muon production
  - Synchrotron radiation
  - Field emission in superconducting high-gradient cryomodules

Radiation Physics Processes at MEIC

- Electromagnetic interactions of electrons and gammas
  - E-M cascades in thin and thick targets
  - Muon production
- Nuclear interactions of electrons and gammas
  - Source for prompt neutrons and material activation
  - Prompt hadron and muon production at the EIC interaction points
- Nuclear interactions of protons and nuclei
  - Source for prompt hadrons, material activation, and muon flux
- Combinations of the processes in real geometries, particle cascades
  - Typical examples:
    - Beam losses in the tunnel
    - Electron-Ion collisions at the interaction point and consequent interaction of the products in the narrow beam line apertures
    - Full beam absorption in a beam dump device
    - Production of ^{3}H and ^{22}Na in the ground water

Critical Project Cost Impact Areas

- Beam losses in the main tunnel define requirements on the wall thickness and the thickness of the berm cover on top
  - Regular beam losses
    - Ground water activation
    - Radiation production outside
    - Direct and skyshine dose rates at the boundary
  - Accidental beam losses
    - Max instantaneous dose
- Endpoints of the linear portions of the tunnel will require extra shielding to stop/range out the muon flux generated as a result of the regular and accidental beam losses in the tunnel
- Interaction Regions will require adequate thickness of the roofs to limit the neutron skyshine dose rates at the boundary
- Beam Removal / Beam Dump areas will require special design to limit the ground water activation, and limit exposures to activated materials

Facility Design Guidelines: 10CFR835

- §835.1001 rule: maintain radiation exposure in controlled areas ALARA through engineered and administrative controls

- §835.1002 specifies objectives for facility design and modifications:
  - Use of optimization methods to achieve ALARA in developing and modification of facility design and physical controls
  - The design objective for controlling personnel exposure: keep the dose accumulation ALARA, and below 1 rem in a year
  - Avoid releases of airborne radioactive material to the workplace atmosphere under normal conditions
  - Include in the design, and in material selection, features that facilitate operations, maintenance, decontamination, and decommissioning

Facility Design Goals at JLab

- Jefferson Lab has established action levels and design goals consistent with ALARA principle. Action levels are set to be below the statutory limits. The Design Goals are lower than Action Levels and are intended to provide assurance that ALARA principle is included in the basic design and operation.
- JLab Radiological Control Policy (ES&H Manual, Radiation Control Supplement §111-06, §211-05) sets the Design Goals:
  - maintaining individual worker dose less than
    - 250 mrem per year (Radiological Workers)
    - 10 mrem per year (General Employees, General Population)
  - preventing degradation of groundwater quality
  - controlling contamination by engineered means where possible
  - minimizing the generation of radioactive material

General Approach to Shielding Design

- Design approach
  - Preferably use realistic model calculations for evaluation of the radiation source terms and beam conditions if practical, otherwise apply conservative empirical approach
  - Use collaboration of RadCon with Physics, Accelerator, and Engineering Divisions in producing ALARA optimized designs
  - Use an iterative design process:
    - Conceptual plans are reviewed for radiological impact
    - Results feed back into subsequent design revisions
- Practical Design Criteria based on the Design Goals
  - Routine Continuous Beam Operations
    - Below 250 mrem to radiation worker in a 2000 hours work year
    - Below 10 mrem to non-radiation worker in a work year
    - Below 10 mrem a year to public beyond the fence 24/7/365
  - Maximum Credible Accident: limit 15 rem for a single occurrence

Design Methods

- Design methods implemented and available:
  - Analytical/semi-empirical (Shield11 code, Thick Shielding approximations, algorithms for dose propagation through labyrinths, Neutron Skyshine parameterizations)
  - Monte-Carlo Simulation programs, including:
    - GEANT3
    - Geant4
    - FLUKA
    - MARS
- Independent different approaches in combination used to increase reliability
- External reviews for the large-scale projects, like MEIC

MEIC Shielding Packages

- Evaluation of the shielding packages
  - Main tunnel linear portions
  - Tunnel Arcs
  - Beam removal / dumping
  - Interaction Regions / Experimental Halls
  - Beam transport lines, Injector, Booster
- Each package should consider operational radiation source terms, as well as accident scenarios
- To evaluate the source terms we have to assume realistic and conservative average beam losses in the machine, and the frequency of the accidental and planned beam removals
- For every package, there will be an iterative process of evaluating the radiological impact, suggesting and finding solutions to satisfy radiological limitations, optimizing the costs and implementing changes

MEIC Tunnel Design (example)

- MEIC tunnel represents a significant portion of the project cost
- Environmental radiation production limits thickness of shielding berm
- Ground water activation limits thickness of walls
- Beam losses may be evaluated conservatively using the published MEIC project operating parameters:
  - Proton beam: 100 GeV, 0.5 A, 15 hours beam live time
  - Electron beam: 11 GeV, 3.0 A, 4 hours beam live time
- Assume uniform beam loss along the beam line
- Use model design of the existing CEBAF tunnel in the first iteration
  - 3x3 m^2 square tunnel, 1500 m long, “figure eight”
  - 60 cm concrete walls
  - 4.5 m berm cover
  - GEANT3 model of the tunnel in the ground
  - Realistic atmosphere above to model radiation skyshine
  - Beam line modeled as an “optimal” 4x4 cm^2, long iron target

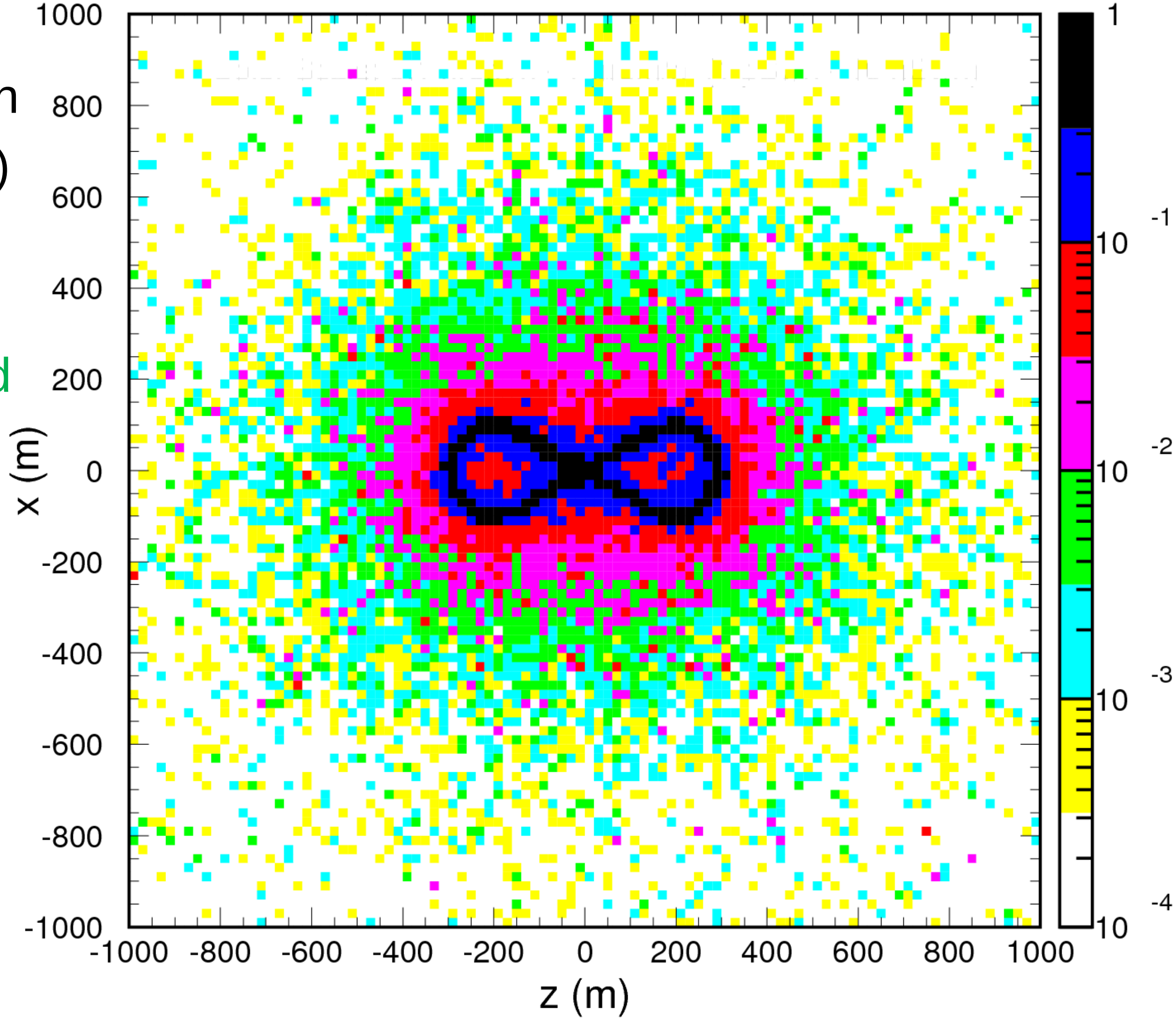
Environmental Radiation Dose Rates

Color scale (log):

0.1 nrem/h – 1 μrem/h

(1 pSv/h – 10 nSv/h)

- Less than ~20% of natural background



Preliminary Results for the MEIC Tunnel

- CEBAF-style main tunnel (60 cm concrete walls, 4.5 m of soil above) seems to be sufficient shielding for the regular beam losses in MEIC
- 100 GeV proton beam is the main contributor
- Linear tunnel sections may use thinner walls
- Ends of the linear sections would need thicker walls and end cups to stop forward directed hadrons and muons generated by the beams
- Further cross-checks and refinements needed
  - Use of other simulation packages (FLUKA, MARS)
  - Other methods of ground water activation calculation
  - Refine beam loss model parameters
  - Contribution to the tunnel radiation source terms from the accidental beam losses and from beam removal processes should be evaluated

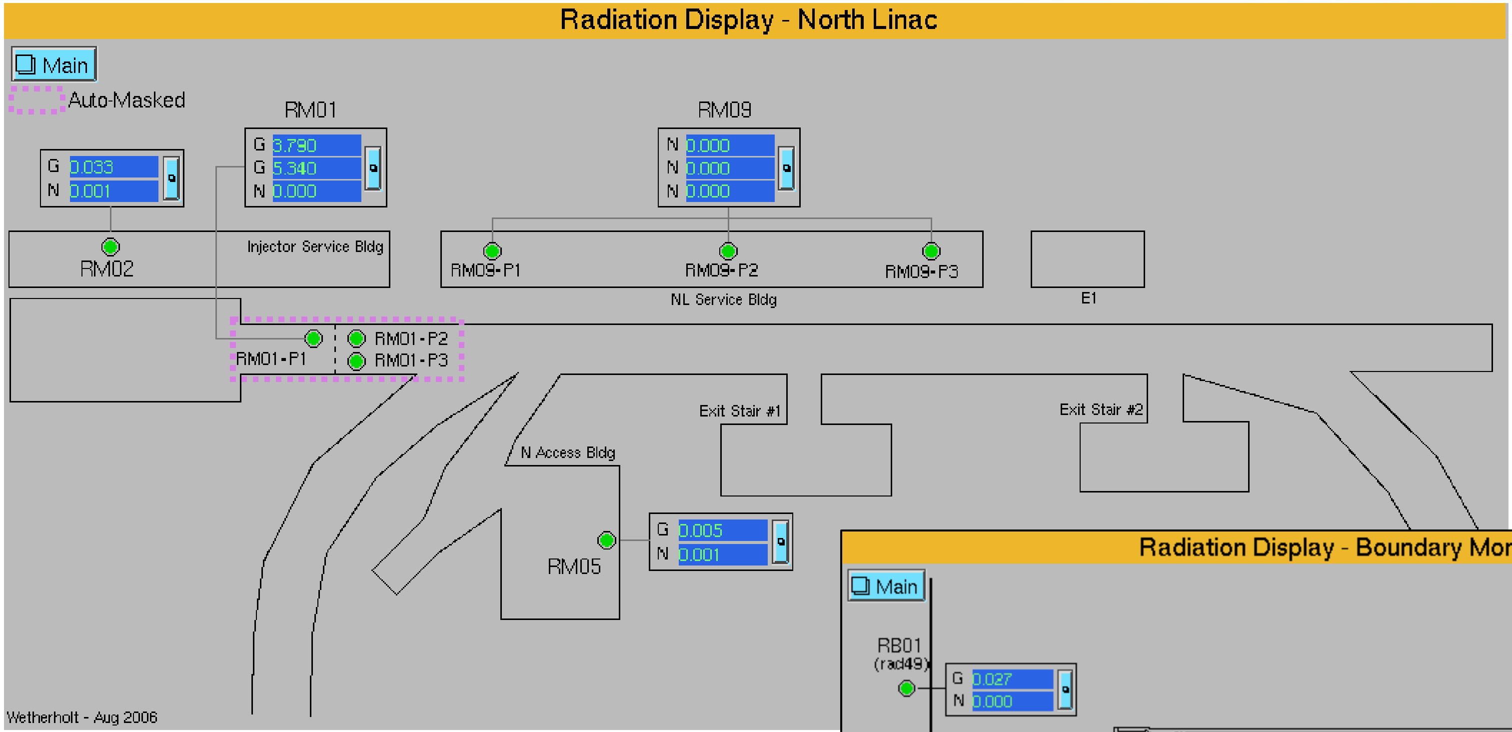
More Shielding Packages

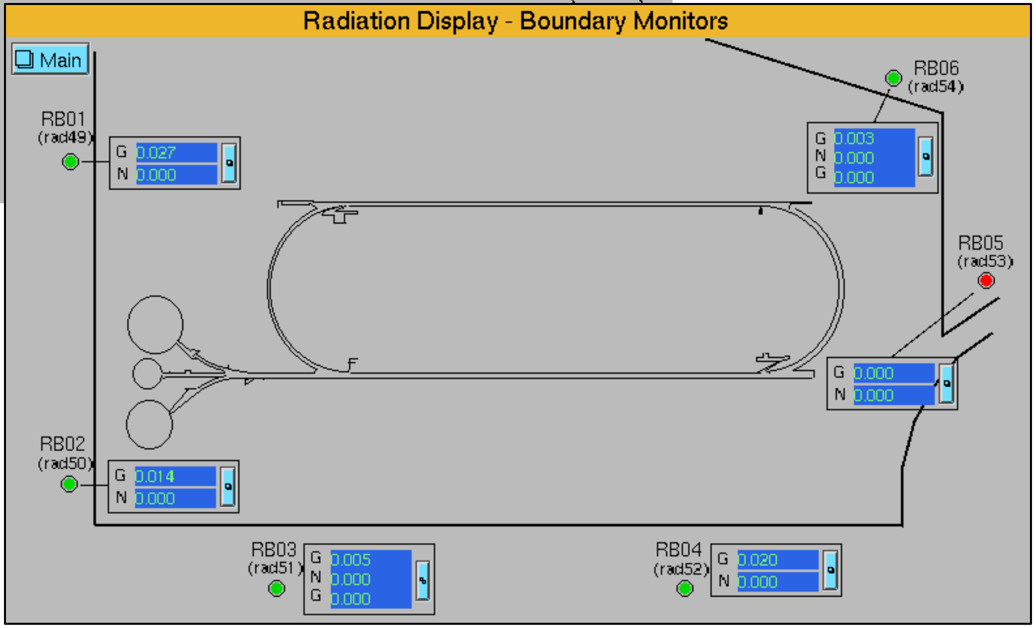
- Beam Removal and Dumping
  - Design details and parameters needed for both beams:
    - Location, timing parameters, critical apertures, dump design
- Interaction Regions
  - Select appropriate source term models: FLUKA, CHIPS, MARS…
  - Need more details of the geometry:
    - beam lines, exit apertures, experimental Hall volumes
- Injector, Booster, Beam Transport Lines
  - Will design the shielding packages "to specifications"
  - Need detailed parameters for the source terms for each package
- Elements of Infrastructure
  - Access ways, various tunnel penetrations, labyrinths, doors, etc.
- Each package will consider operational radiation source terms, as well as accident scenarios

Control and Monitoring of Radiation Fields

- Radiation Monitoring at MEIC will be vitally important, specifically the environmental part
- Jefferson Lab has established Environmental Radiation Control program, showing good track record during our 20 years of operations
- The program includes planning stage in which every upcoming experiment is evaluated for its contribution to the environmental radiation. Designs and run parameters are optimized at this stage.
- Monitoring and data archiving system is set up to measure and document radiation fields at the strategic places on and around the CEBAF site.
- Semiannual reports are issued during periods when the machine operates.

Radiation Monitoring Online at CEBAF



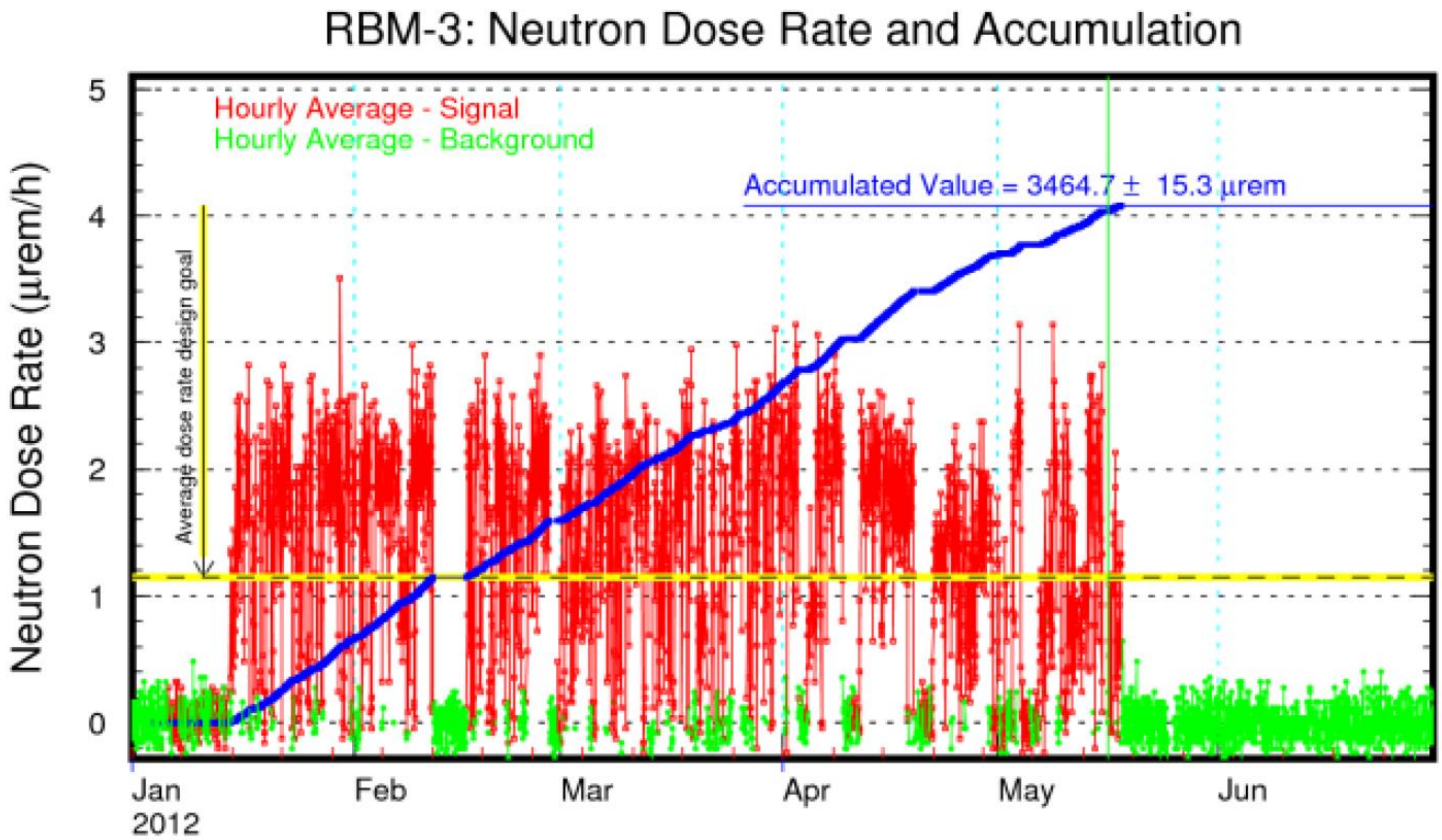


Two examples of the online radiation monitoring screens:

- North Linac area
- Boundary Monitors

Environmental Neutron Dose Rates

Measurements in January – June, 2012



RBM-3 location at CEBAF boundary closest to Hall C (90 m)

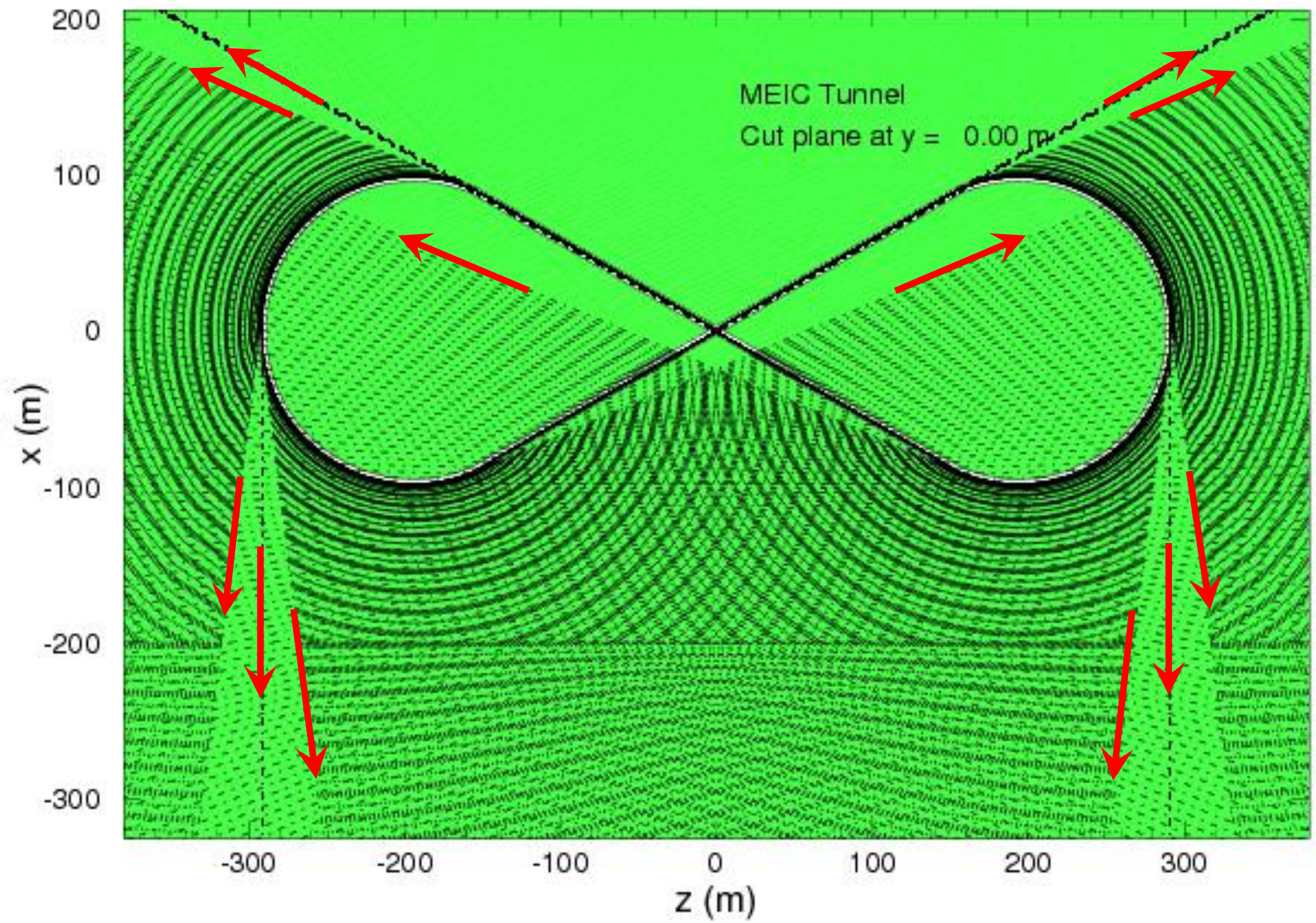
RadCon plans for MEIC CDR-0 report

– Two-year plan, if funded –

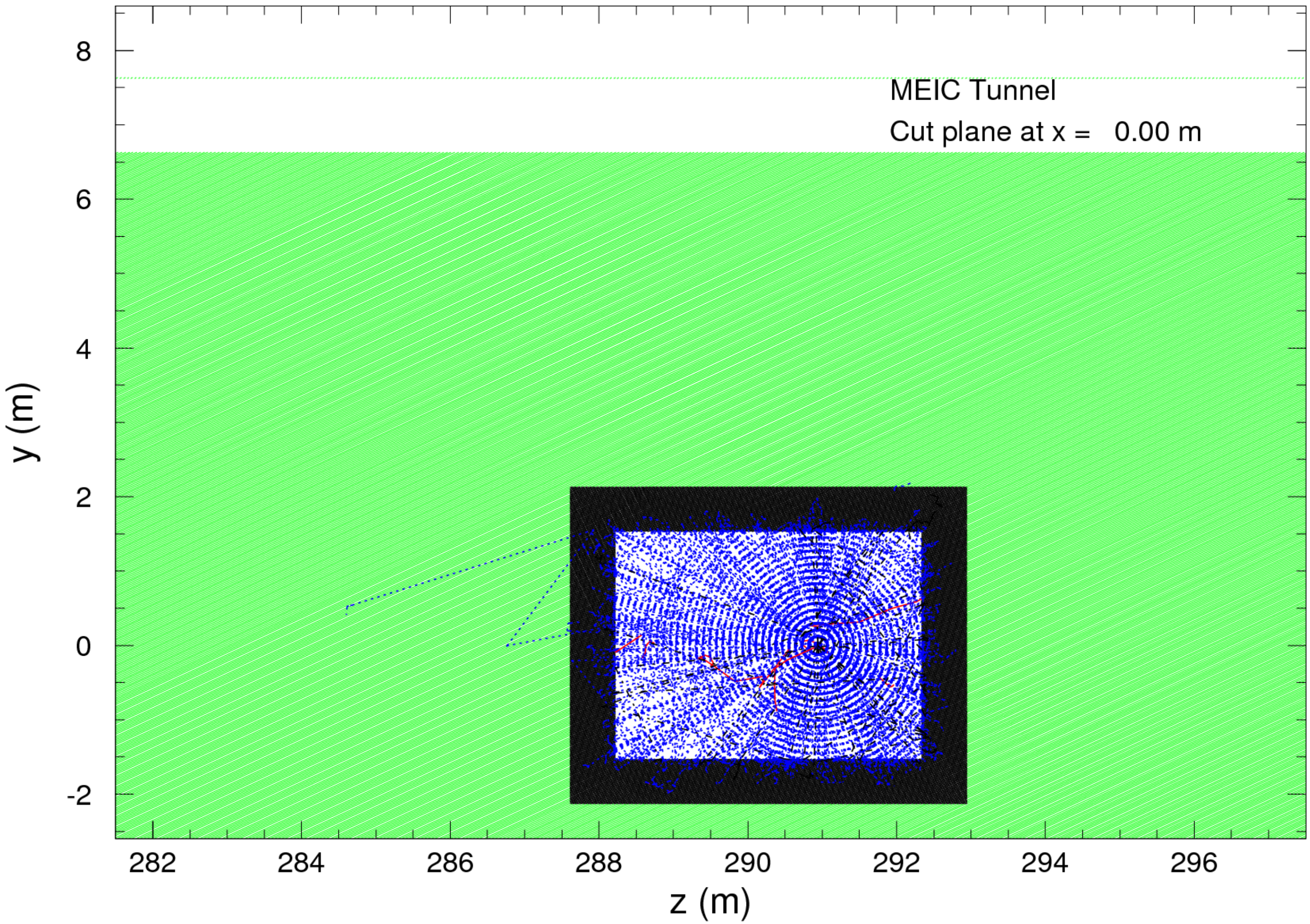
- Develop the list of radiation sources in and around the MEIC complex, radiological issues and critical machine parameter envelopes.
- Iteratively develop the radiological models describing the potential radiation sources, evaluate the need for extra mitigation measures (shielding, labyrinths, geometry and material choices, etc). Estimate groundwater activation, generation and release of radioactive and noxious gases, environmental radiation impact, radiation damage.
- Evaluate material activation based on final preliminary design; prepare draft decommissioning plan for the machine
- Evaluate and plan deployment of radiation detection systems, associated communication infrastructure and DAQ as applicable for area, boundary and environmental monitoring
- Document the efforts and produce the radiation shielding design report ready for the external review

Extra Slides

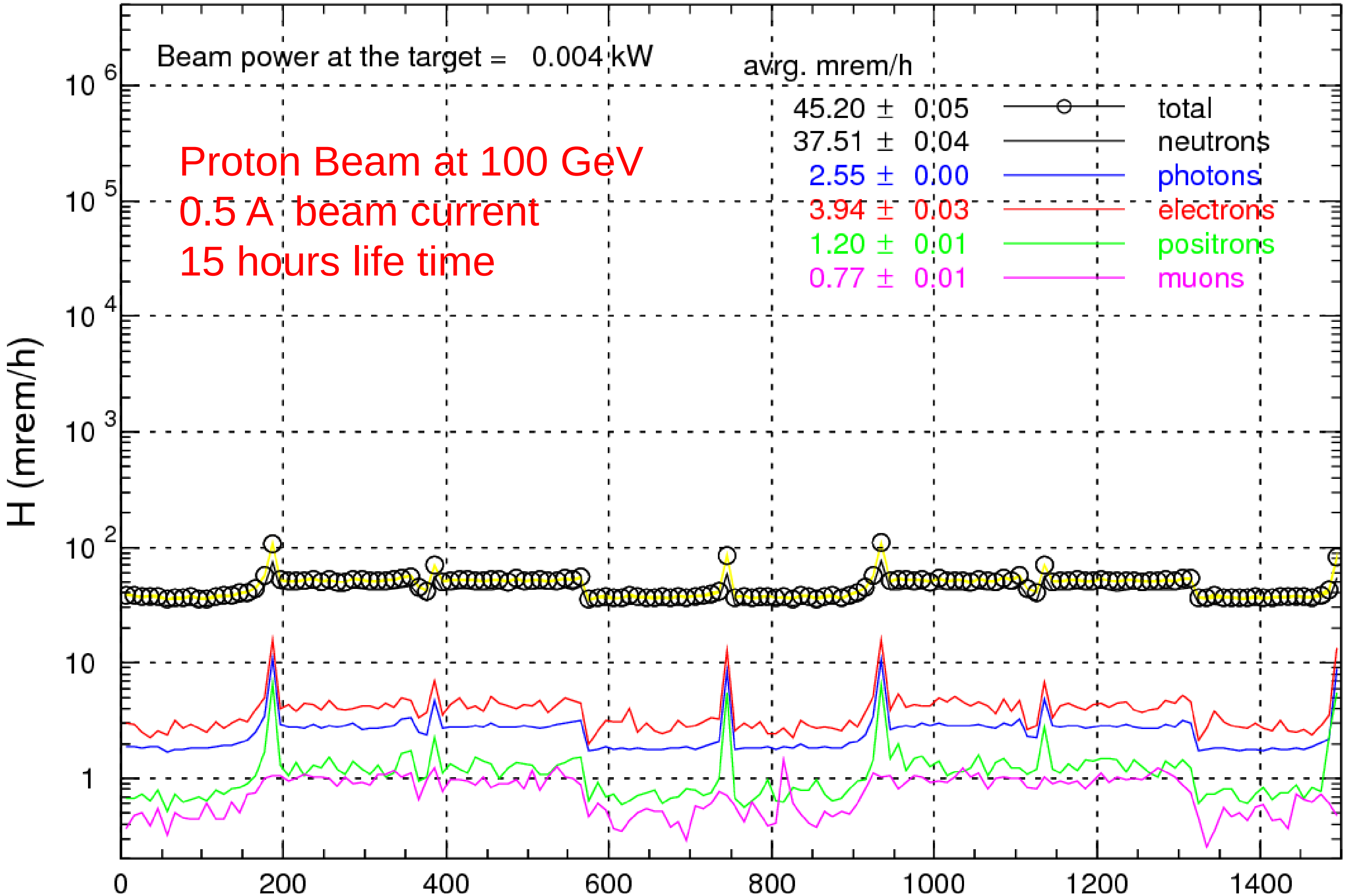
Continuous Beam Loss Source Term



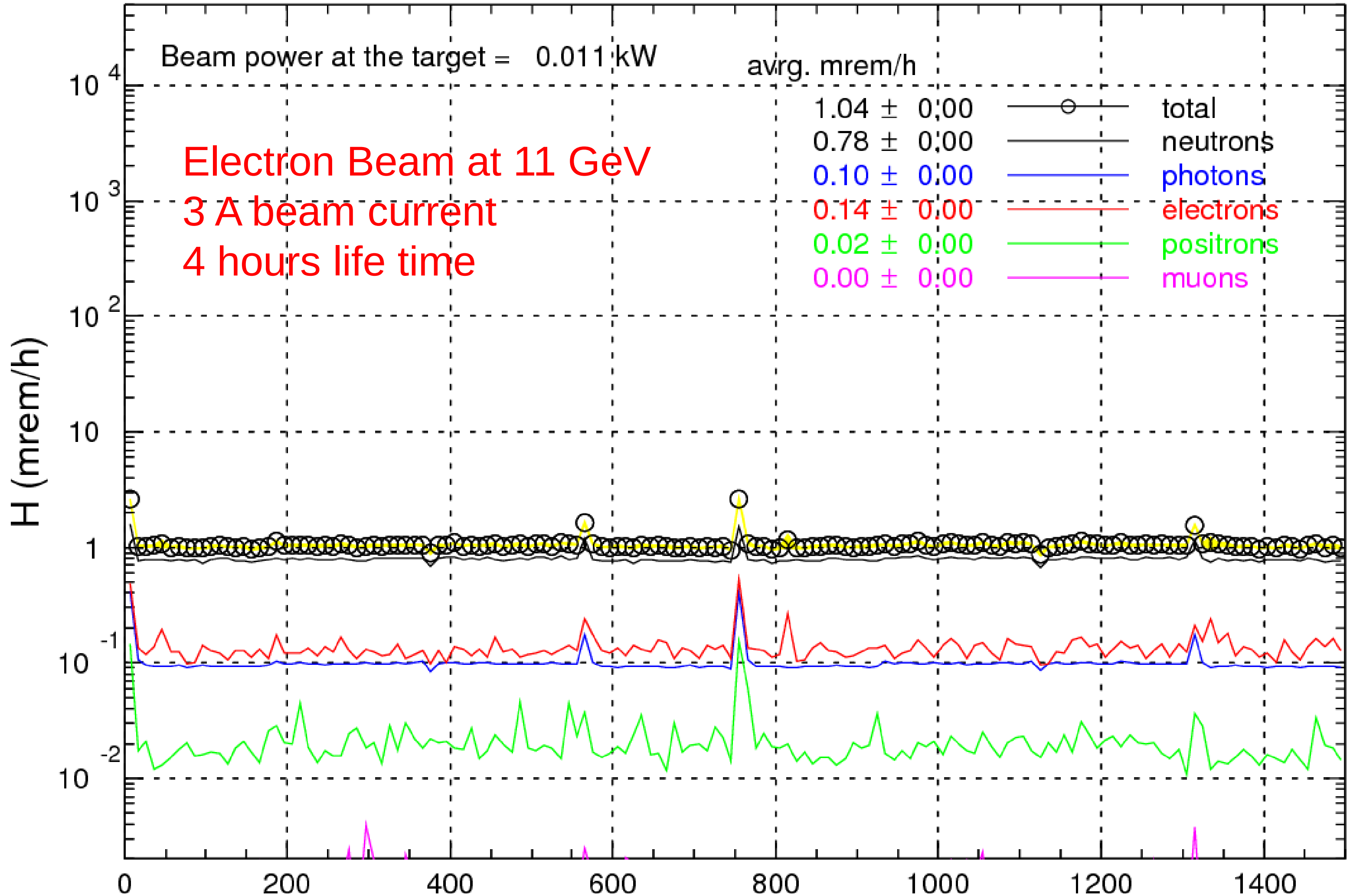
Vertical Cut View of the Tunnel



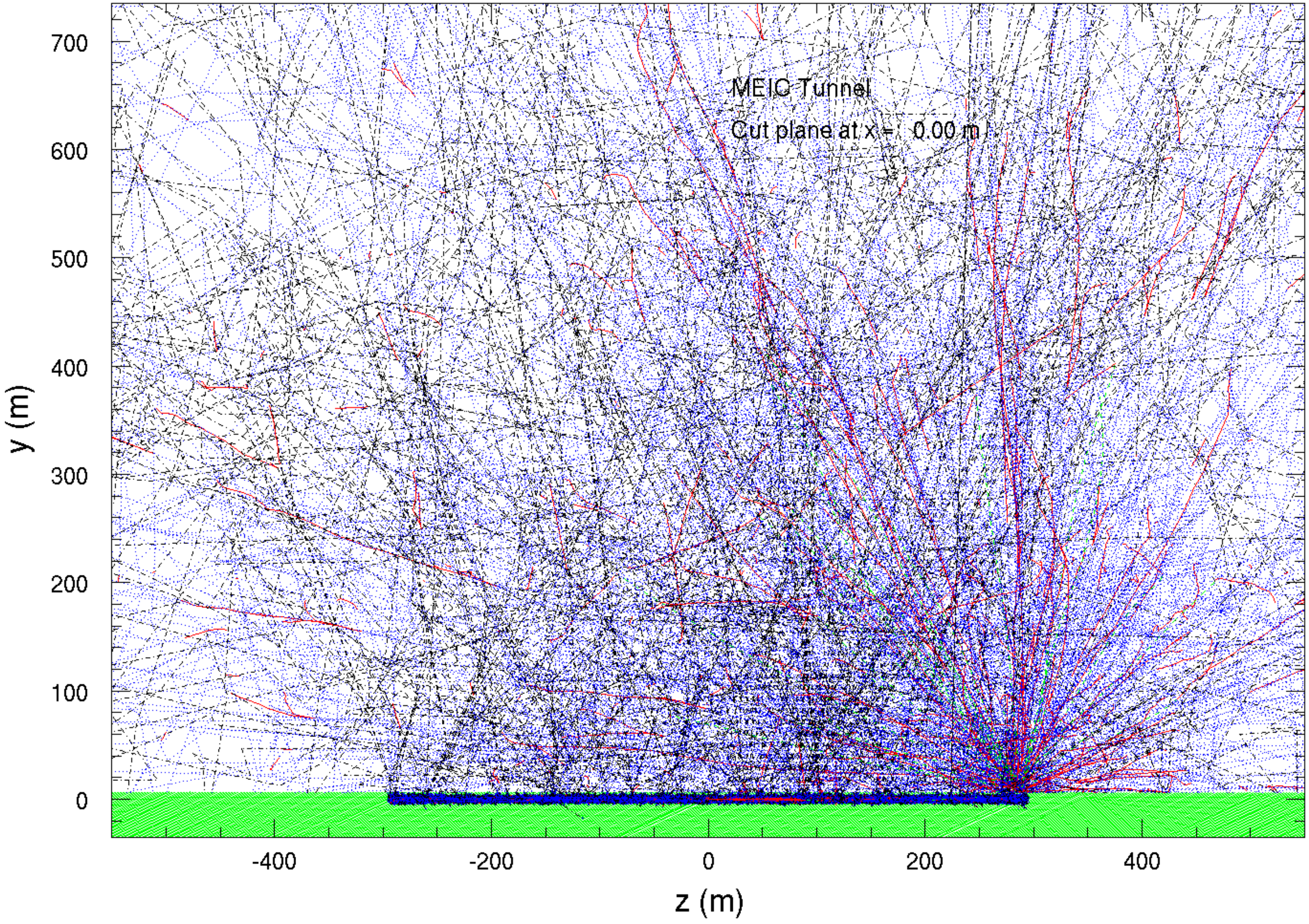
Dose Rates Outside the Tunnel Walls



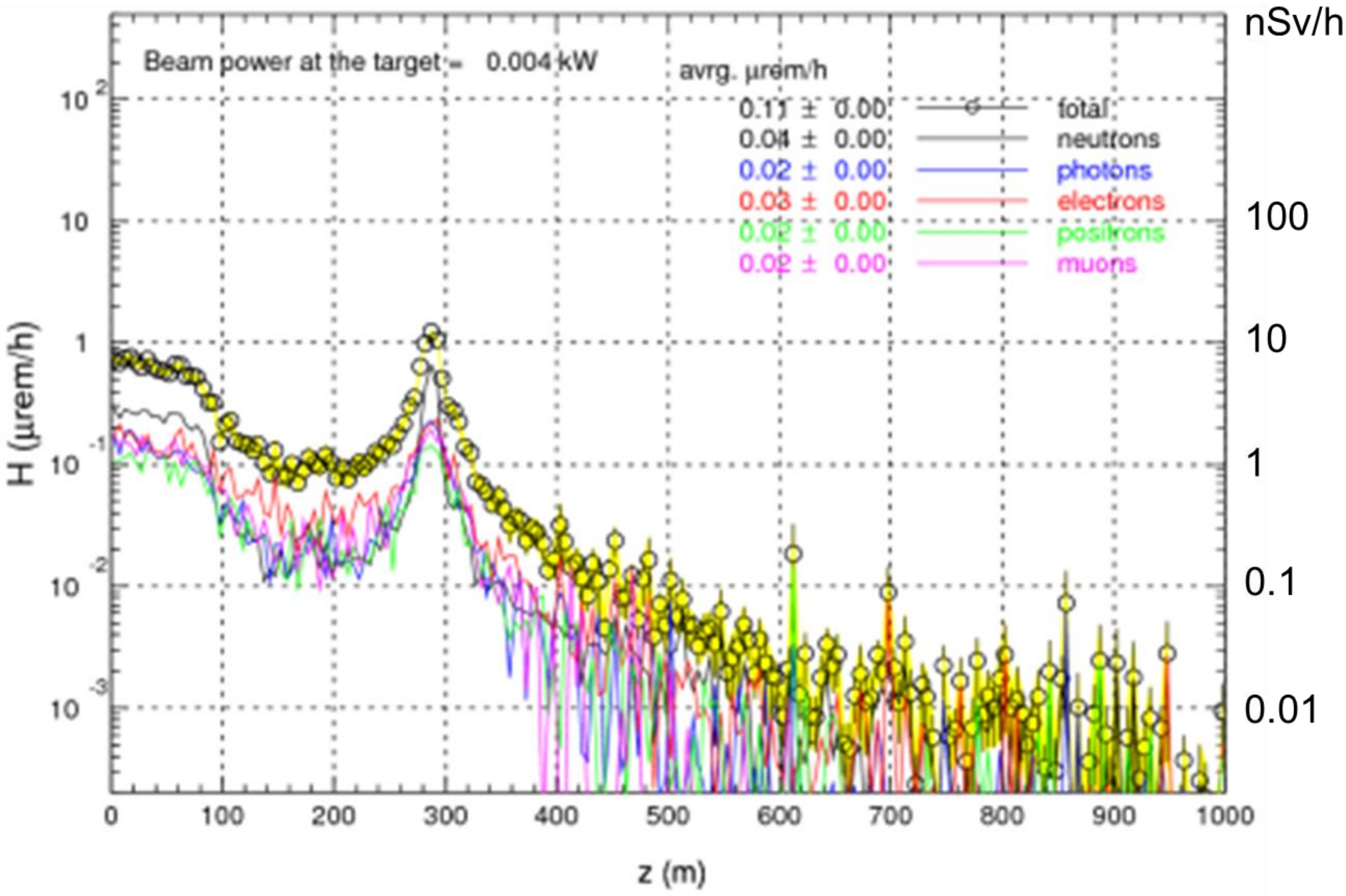
Dose Rates Outside the Tunnel Walls



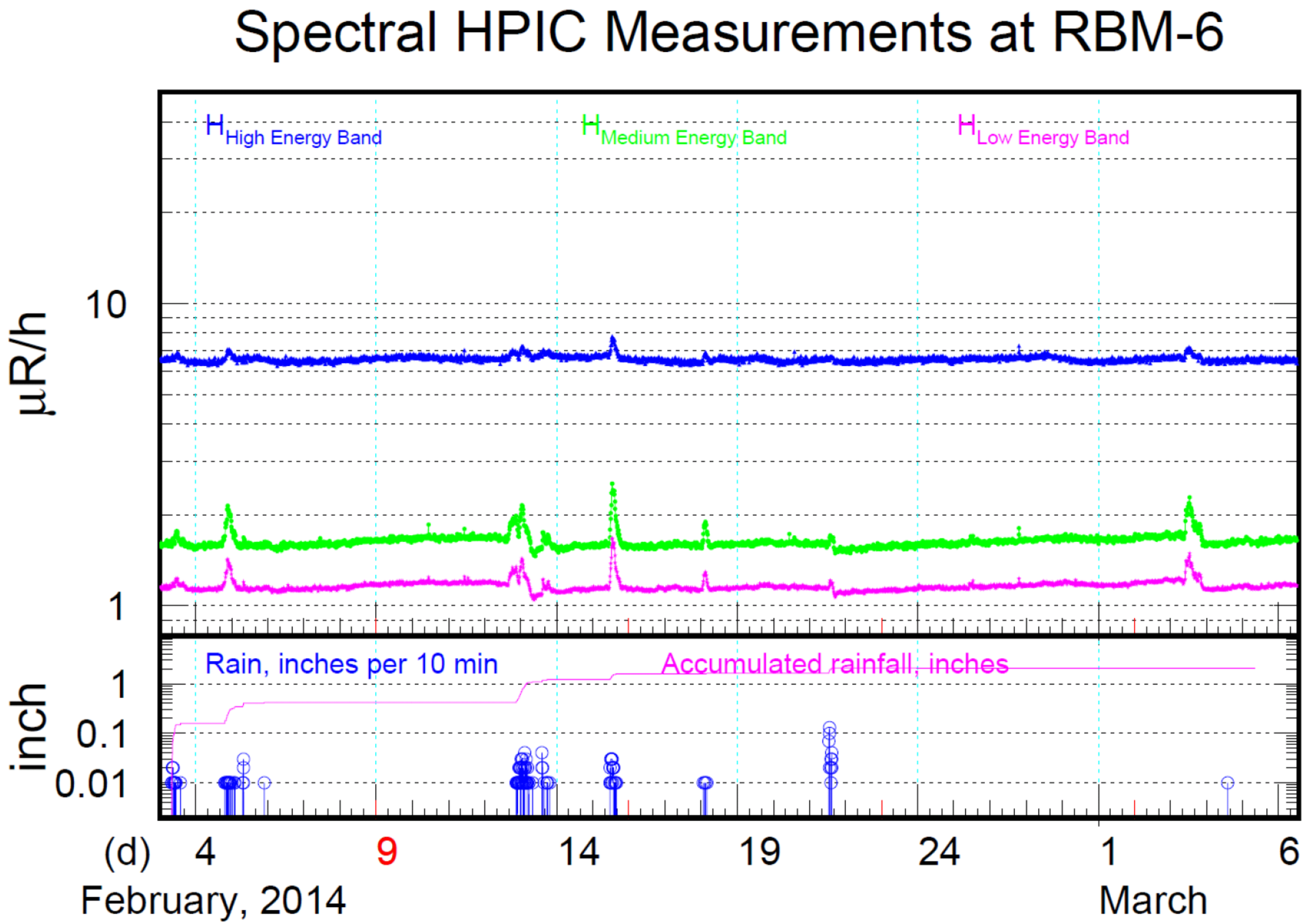
Radiation Skyshine above MEIC Site



Environmental Radiation Dose Rates



Last Month's Gamma Dose Rates



Environmental Gamma Dose Rates

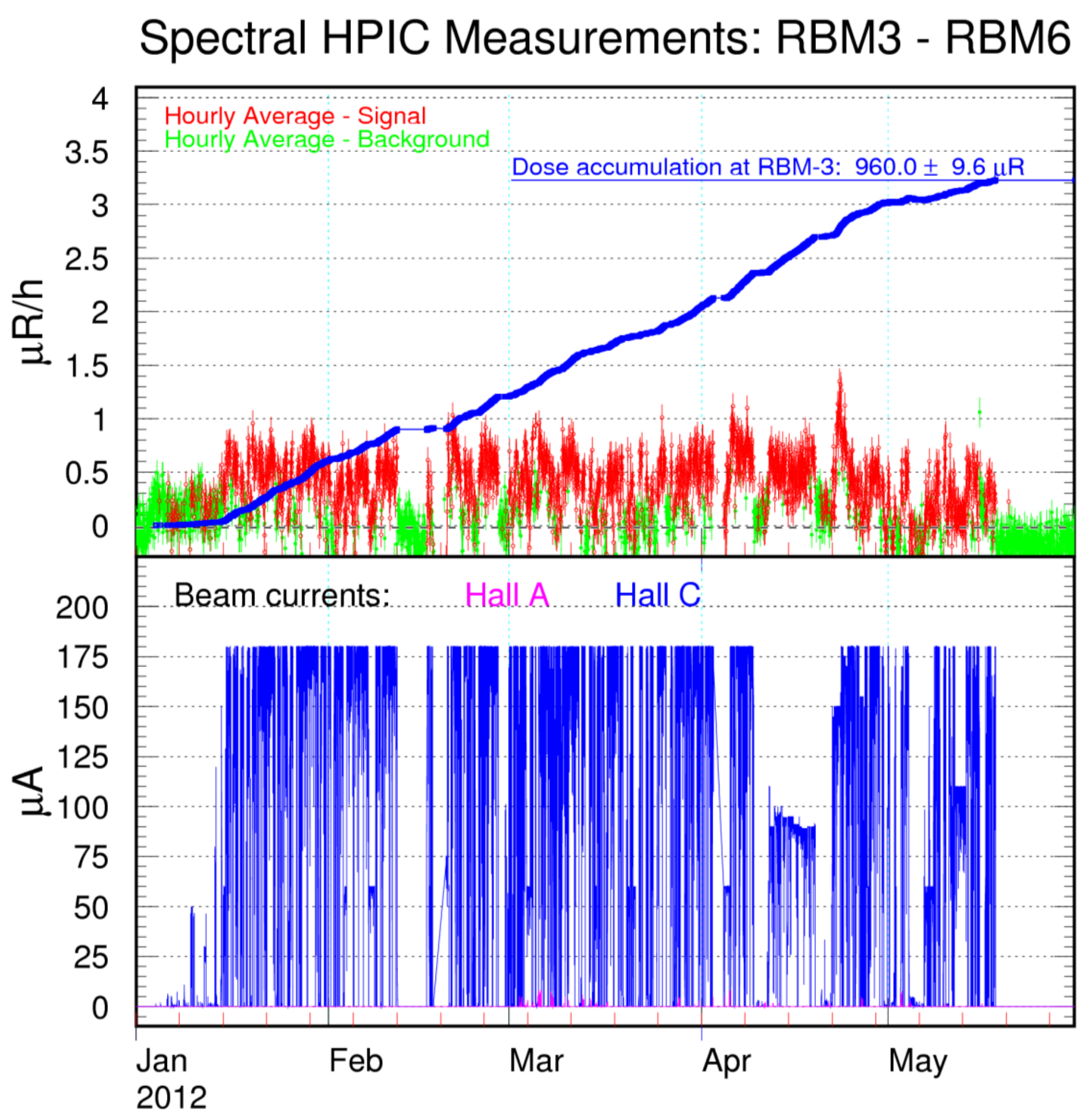
Environmental Spectroscopic High Pressure Ionization Chambers at the boundary: RBM-3 and RBM-6 sites

Difference
"Signal IC – Background IC"
= SHPIC3 – SHPIC6

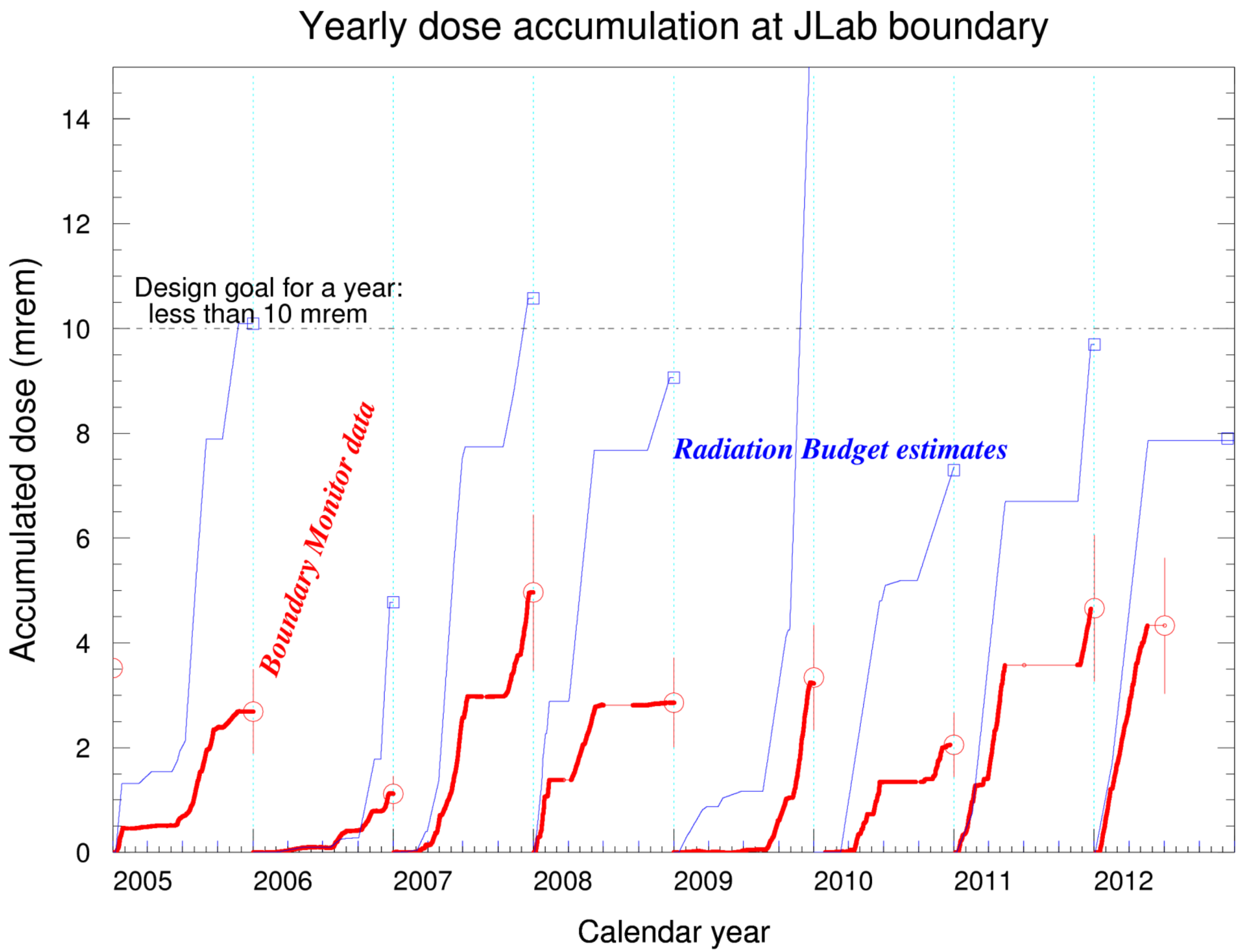
Same background subtraction technique applied as in the case for neutrons

Dose rates from operations visible at a level of few percent of natural background

Gamma contribution to the dose at the boundary: ≈20%



Environmental Dose History 2005-2012



Conclusions

- Radiological protection issues for the future EIC are critical to the design, construction and operations of the new facility
- Preliminary study indicates that the proposed MEIC complex can be installed at Jefferson Lab site in a tunnel similar to CEBAF tunnel
- Radiation Physics Group at JLab will collaborate with the System and Facility designers and Accelerator physicists at MEIC to find and address radiation protection problems at early stages of the development in order to find and implement optimized solutions
- All final solutions will be subject to independent external reviews
- Radiation Control Department at JLab has over 20 years of successful experience of monitoring and controlling radiation environment on site and around
- New radiation monitoring systems will be developed and deployed around the future MEIC site, emphasizing reliable control over the environmental and site boundary radiation produced by the new machine