BDX: Simulation of Beam-Related Backgrounds

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Outline

- Challenges in the simulation of beam-related backgrounds in dark-matter searches at accelerators
- The brute force approach: GEANT4 simulation of a beam dump experiment
- Extrapolations to full luminosity
- Alternative approaches: MCNP simulations
- Summary and conclusions

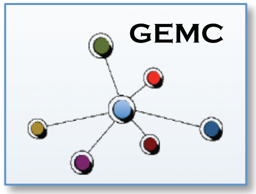
Challenges and Issues

- Goal: estimate backgrounds created by beam interaction with the dump via MC simulations
- BDX run conditions:
  - Electron energy in the GeV range
  - 10^{22} electrons on target (EOT)
  - 100 uA electron beam on dump for 6 months running
- Challenges and Issues:
  - Computing limitations:
    - Combination of very large number of incoming particles and very massive absorbers makes full-luminosity simulations prohibitive
    - Extrapolation over several order of magnitudes needed
  - Physics issues:
    - Accurate modeling of physics interaction from GeV to eV, including low energy nuclear reactions and neutron transport

GEANT4 Simulations

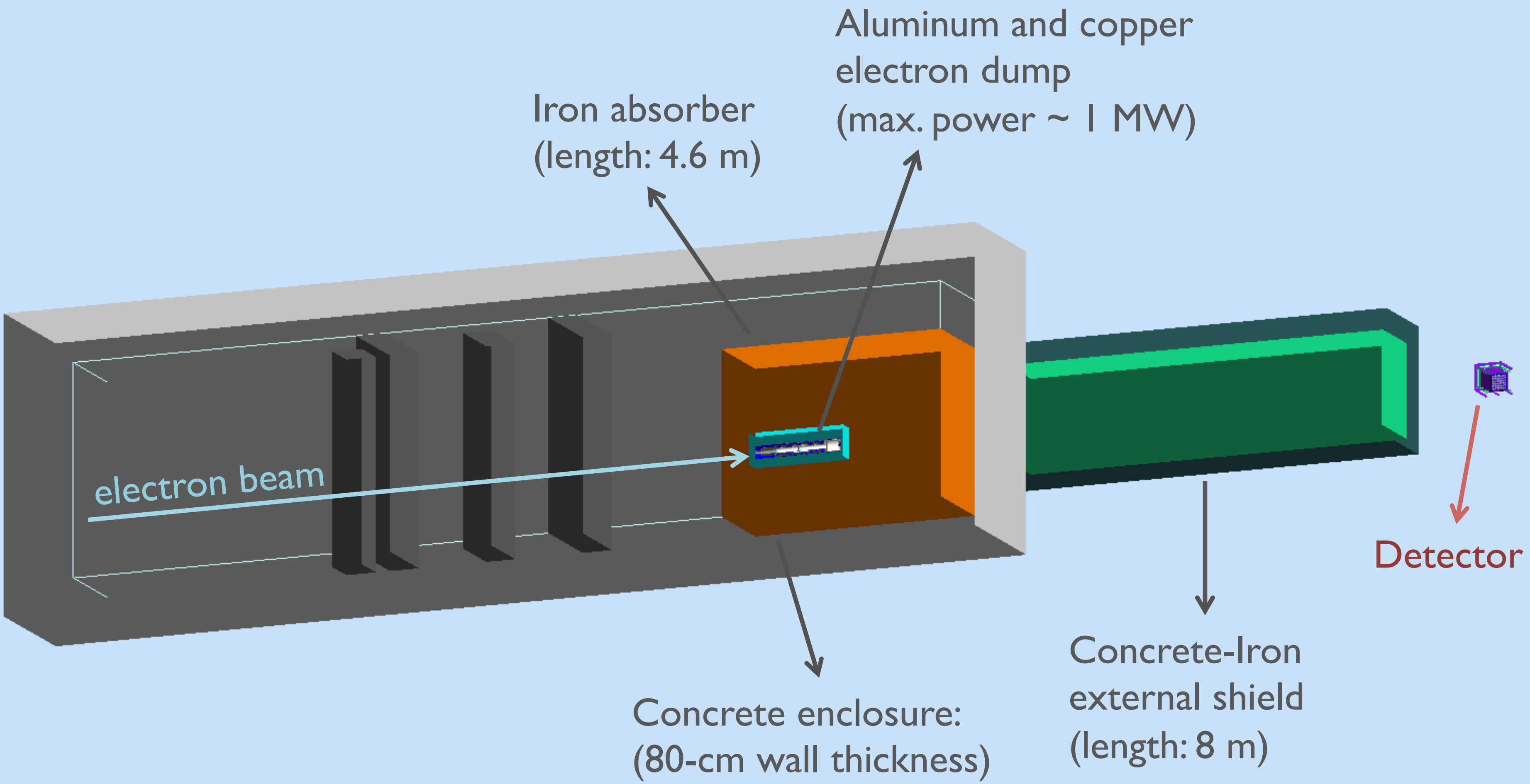
- A brute force approach:
  - Model beam dump geometry and materials
  - Use Geant4 to simulate the interaction of the electrons in the dump
  - Determine fluxes of particles exiting from the dump and reaching the detector locations

- GEANT4 setup:
  - Simulation based on GEMC (GEant4 Monte Carlo):



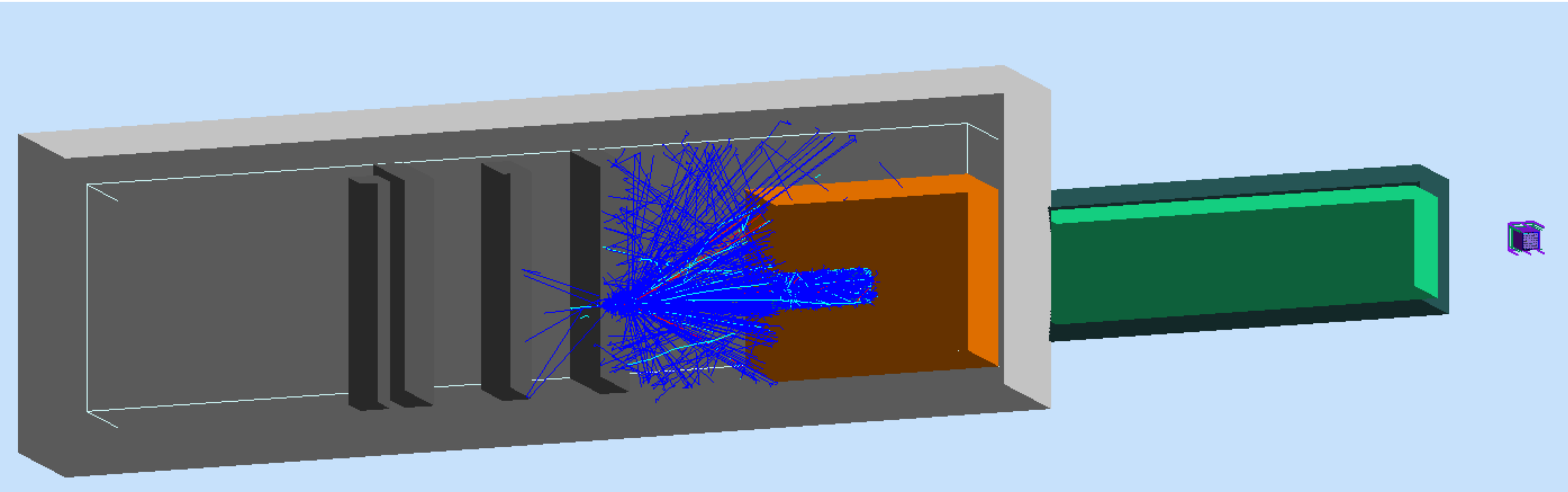
    - simulates passage of particles through matter based on Geant4 libraries
    - simulation parameters (geometry, materials fields, etc.) defined in databases (MYSQL, TXT, GDML, C++ plugins)
    - same gemc executable can be used for different detectors and experiments
    - can simulate beam structure (beam bunches, repetition rate, …)
    - more info at gemc.jlab.org
  - Use high precision physics lists (QGSP_BERT_HP + EM_HP)

BeamDump Geometry



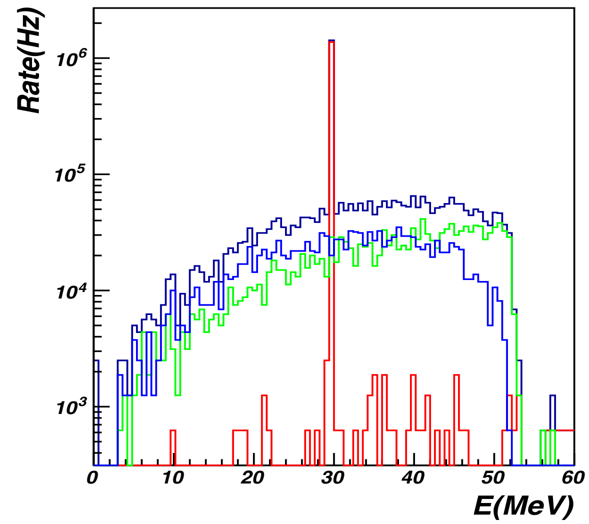
Computing resource usage

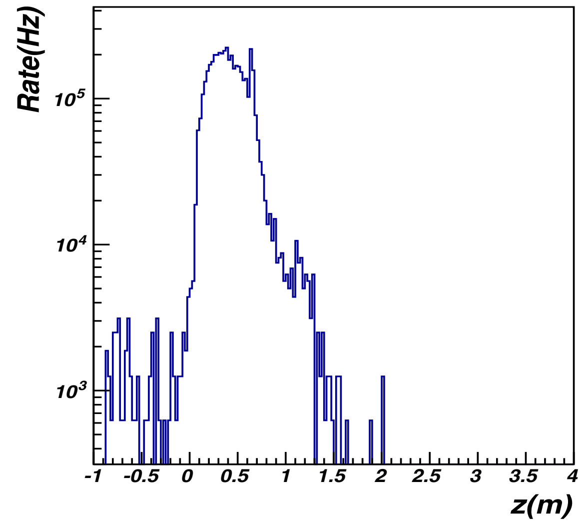
- 10000 EOT (12 GeV) ⬄ 16 ps of beam on target at 100 uA
- ~3000 s computing time on a Intel Xeon (E5530) 2.4 GHz
- 1 month of simulations on a 200 cores farm (~3600 HepSpec2006) equivalent to $2x10^9$ EOT (3.2 us of beam on target at 100 uA)
- Results would need to be extrapolated by more then 12-13 orders of magnitude to reach the desired experiment luminosity



First results

- Particle fluxes estimated at the detector location:
  - Only particles observed are neutrinos and very low energy gammas (E<eV)
  - Neutrinos originates from pion decay at rest within the main iron absorber
    - Energies: 0-60 MeV
    - Flux scales with primary beam energy and square of dump-detector distance
  - Neutrino flux on a 40x40 cm^2 surface, 15 m from the dump: 2.2 $x10^7$ Hz/uA
  - Neutrino background rate: $6x10^{-8}$ Hz/uA (100 events @ 10^{22}EOT)
    - 1 m^3 detector, ~1 m length
    - Cross section of ~ 10^{-40} cm^2 (CC interaction)
    - 50% detection effiency for 1MeV threshold





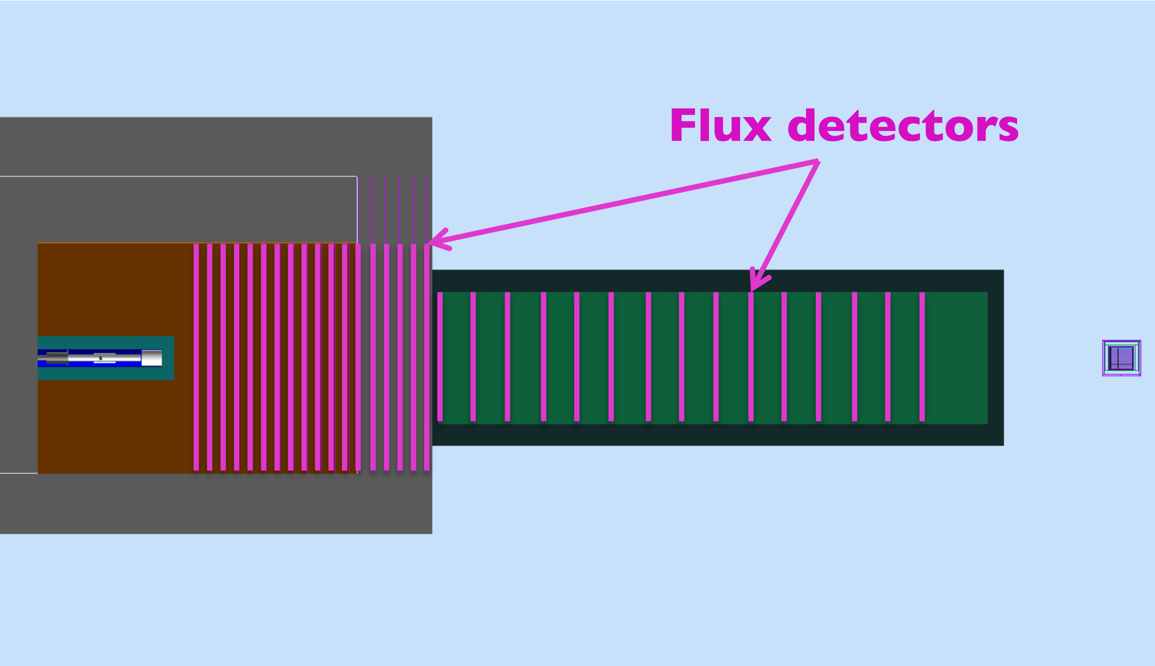
Backgrounds at full luminosity

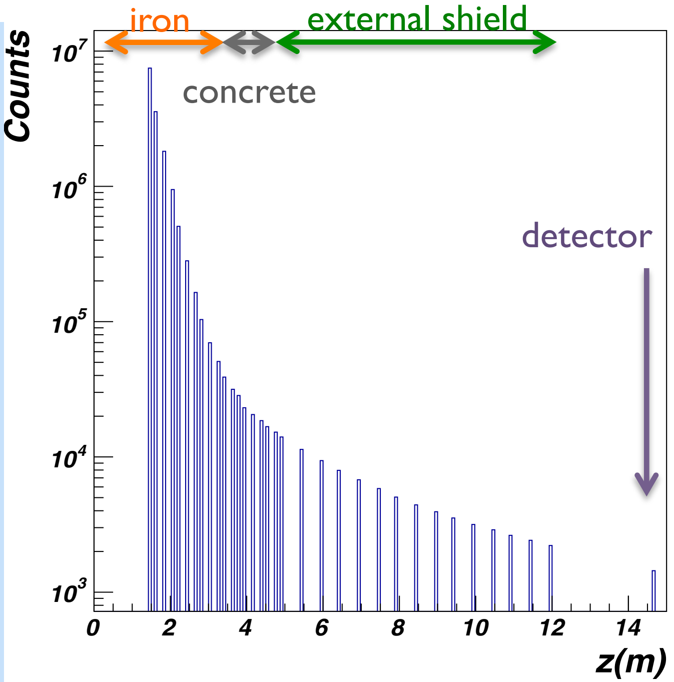
- Estimated neutrino rates can be extrapolated to full luminosity
- Zero rates observed for neutrons and gammas only allows setting an upper limit
- Increase of computing power or efficiency can gain few order of magnitudes but cannot reach 10^{22} EOT

- A different approach is needed:
  - Rely on GEANT4 for treatment of high energy (GeV to MeV) interactions
  - Sample particle fluxes at different depths within the dump absorbers to study the flux profile and find non-zero values
  - Extrapolate non-zero fluxes to full luminosity based on flux profile
  - Validate results for low energy neutrons/gamma with different simulation tools (MCNP) and using variance reduction techniques

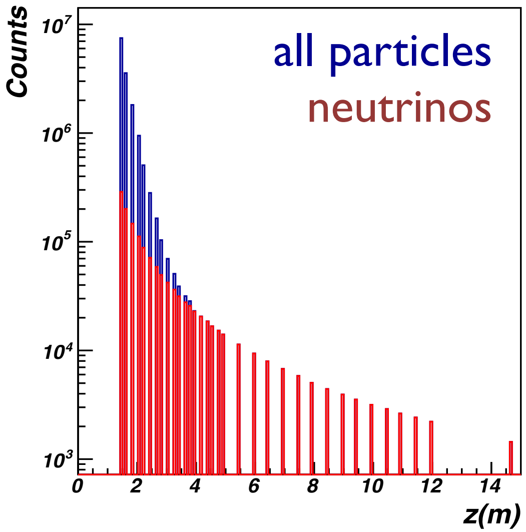
Extrapolation to full luminosity

- Sampled particles crossing XY planes at different position along the beam direction with "flux" detectors
- Checked particle types and energy spectra as a function of depth within the dump absorbers

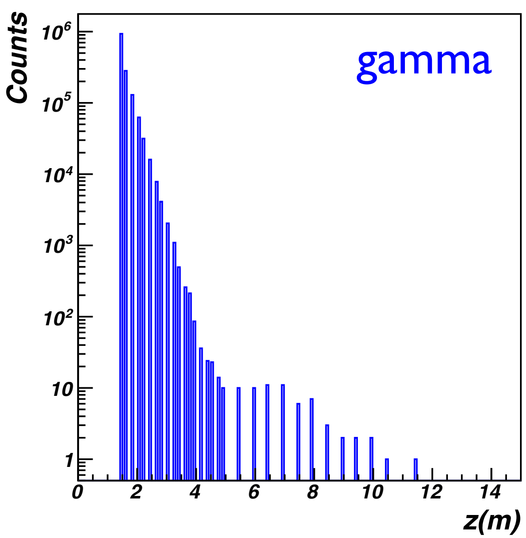


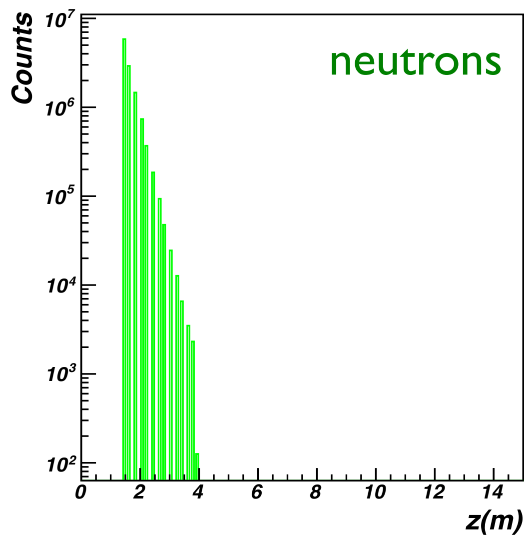


Results @ 2.5 x 10^8 EOT



- Overall particle flux is dominated by gamma and neutrons for the first 2 m and by neutrinos at larger depths
- Gamma:
  - Flux reduction of factor 3600 in 2.2 m of iron
  - Gamma detected after the iron absorber < keV energies
  - Further reduction using time correlation with beam bunches





- Neutrons:
  - Attenuation of factor ~1700 in 2.2 m iron
  - Attenuation of factor ~4.3 in 10 cm of concrete
  - <1 neutron @ 10^{22}EOT after ~3.5 m of concrete
  - Further reduction using time correlation with beam bunches
  - Attenuation depends on energy spectrum
  - Residual flux dominated by thermal neutrons: validation is needed

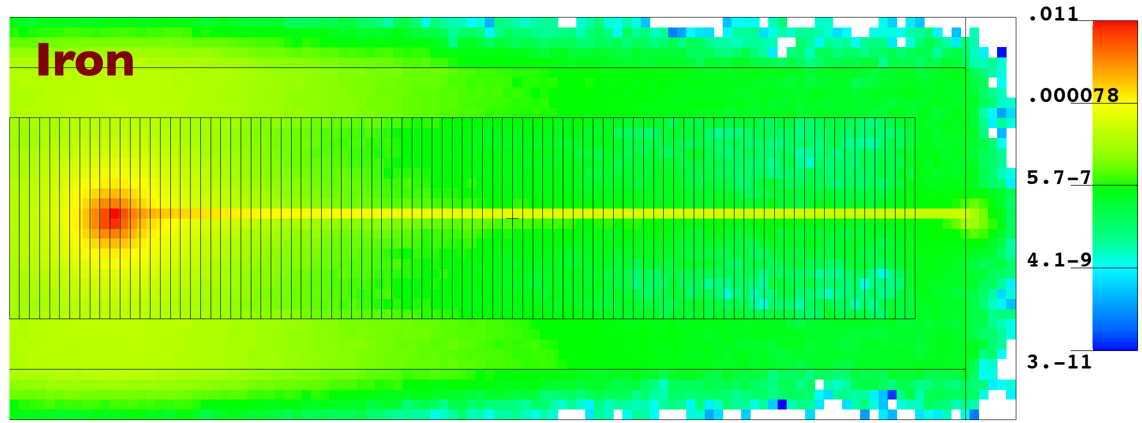
Monte Carlo N-Particle (MCNP)

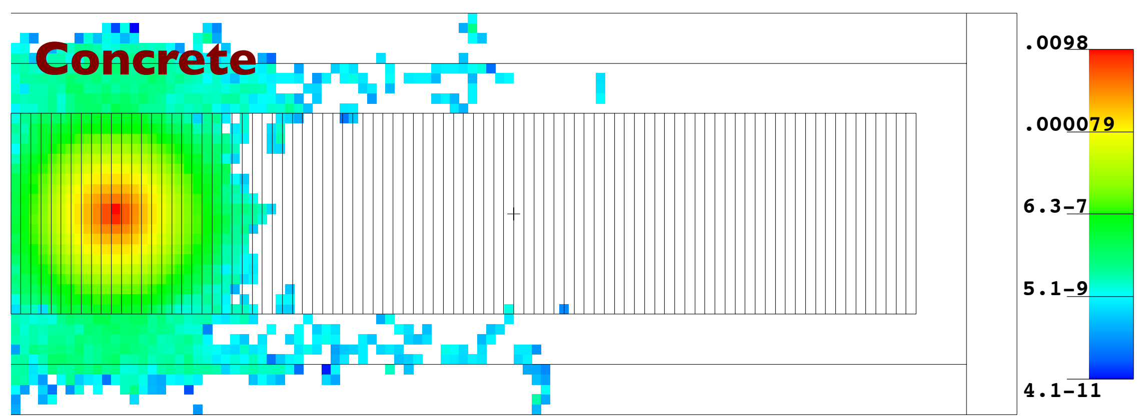
- General Transport Code developed at Los Alamos
- specific areas of application include radiation protection and dosimetry, radiation shielding, fission and fusion reactor design, decontamination and decommissioning
- can be used for neutron, photon, electron transport
- relies on point-wise cross-section data
- neutron interactions includes all reactions given in a particular cross-section evaluation (such as ENDF/B-VI)
- neutron transport is described both by both the free gas and S(alpha,beta) models
- provides variance reductions tools (non-analog Monte Carlo based on truncation, population control, modified sampling and partially deterministic methods)
- https://laws.lanl.gov/vhosts/mcnp.lanl.gov/index.shtml

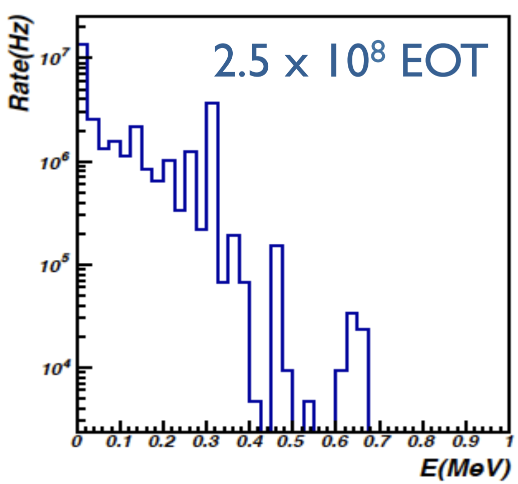
MCNP results

Neutron flux in iron or concrete absorbers

- Initial neutron spectrum from GEANT4 simulations
- Large attenuation of neutron flux in concrete is confirmed
- Actual value strongly depends on neutron energy
- Final flux reaching the detector may be dominated by gaps in the dump structure: realistic geometry is needed





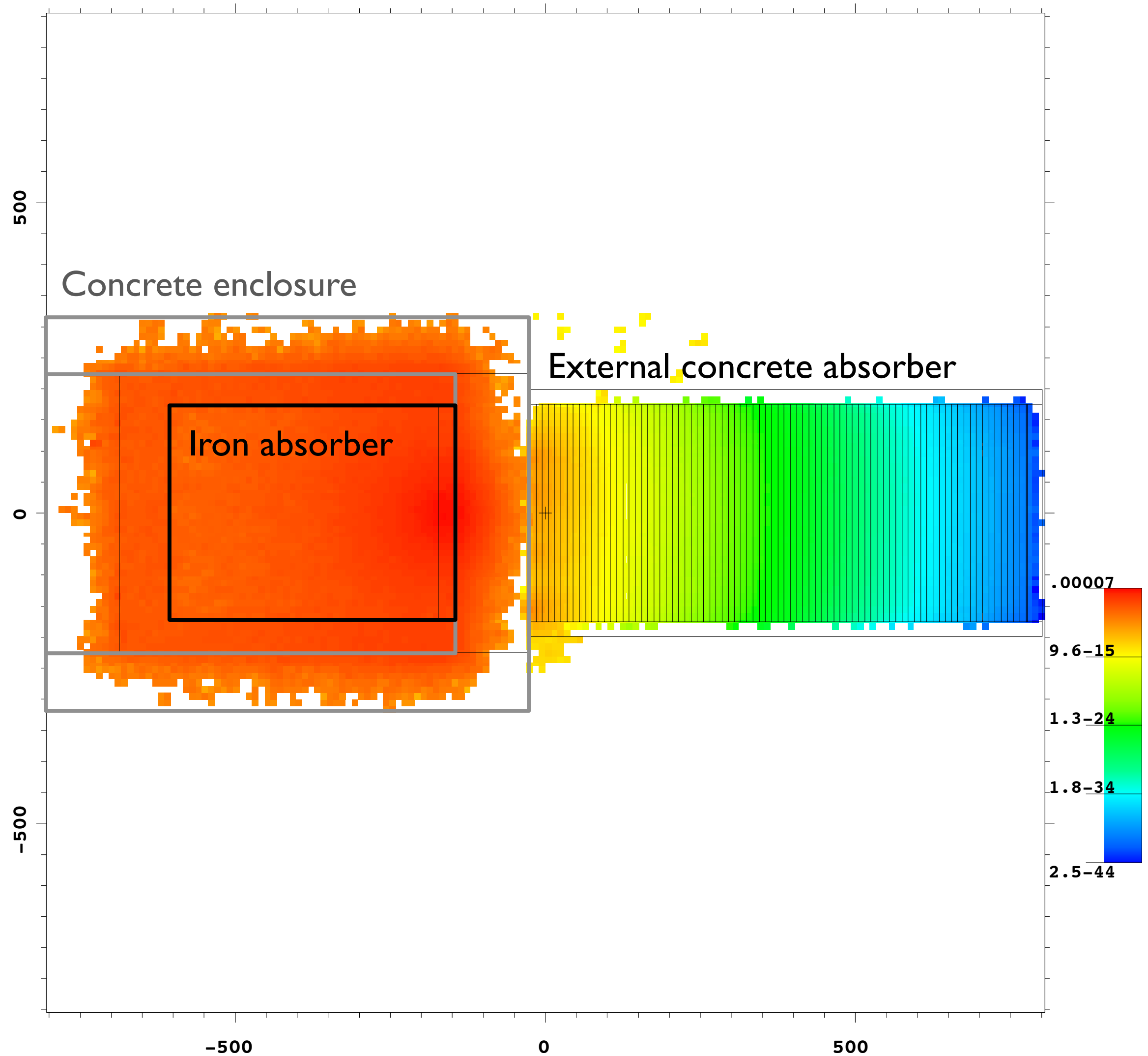


Input neutron spectrum after 2 m of Iron

MCNP results

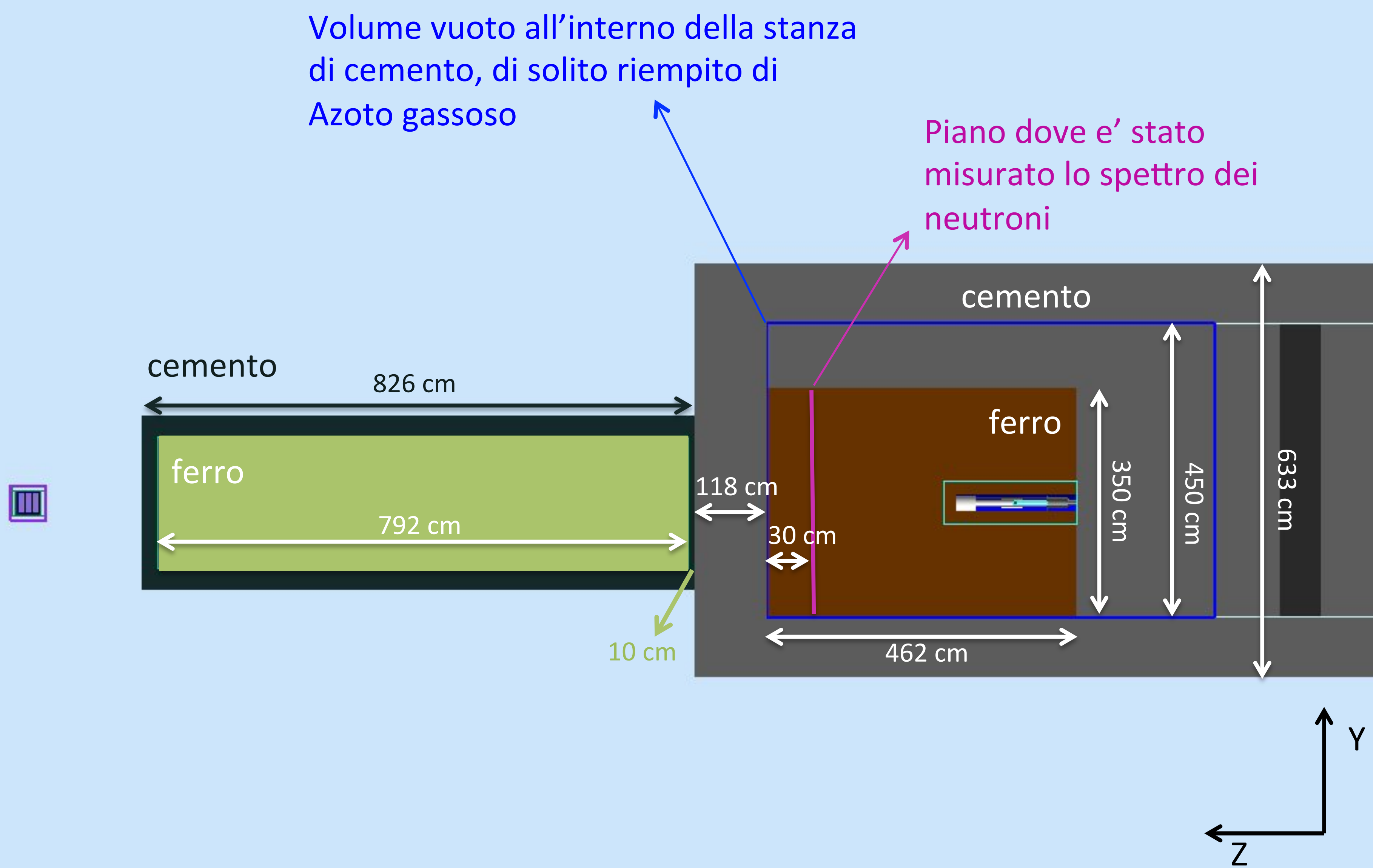
First results for neutron rates with full dump geometry and variance reduction

- Initial neutron spectrum in iron absorber from GEANT4 simulations
- Only thermal neutrons exiting from the concrete enclosure
- Neutron flux attenuated by factor ~2.5 every 10 cm
- <1 neutron @10^{22} EOT after 3 m of concrete



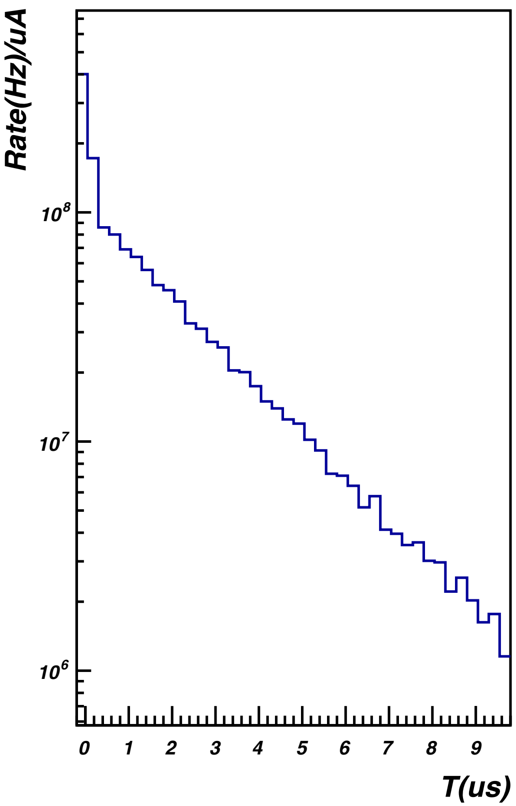
Summary and Perspectives

- Simulations of beam-related backgrounds in dump experiments present difficult challenges both for the choice of simulation tools and for the required computing power
- A brute force approach based on analog MC does not allow to reach the planned experiment luminosity
- Extrapolations based on flux profile studies and variance reduction techniques are necessary
- Background for a typical BD experiment was estimated based on a combined GEANT4-MCNP study:
  - Dominant beam background is due to neutrinos produced from pion decay
  - Neutron and gamma background may be significant depending on the experiment geometry, detector threshold and beam time structure
  - Neutron and gamma fluxes can be attenuated down to natural bg levels within few meters of iron/concrete absorbers
- Final estimates can be done with the proposed approach for specific BD configurations

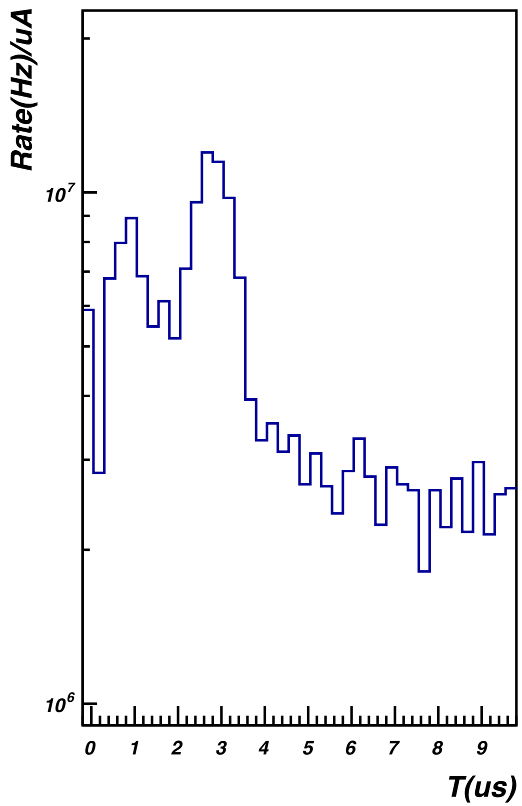

Volume vuoto all'interno della stanza di cemento, di solito riempito di Azoto gassoso
Piano dove e' stato misurato lo spettro dei neutroni
cemento
cemento
826 cm
ferro
792 cm
ferro
118 cm
30 cm
10 cm
462 cm
350 cm
450 cm
633 cm
Y
Z

Background Time Distributions

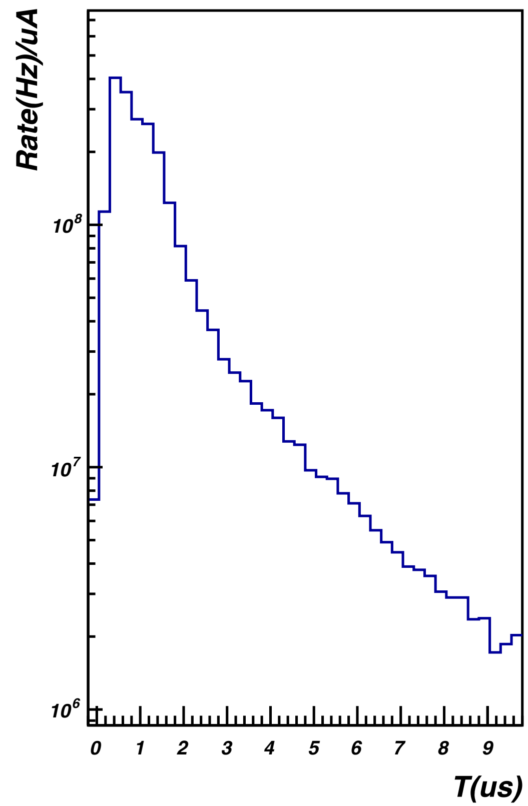
Neutrino



Gamma



Neutron



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