MARS SIMULATION OF CAPTURED MESON BEAM AND RADIATION IN SOLENOID AND SHIELDING

OF A MUON STORAGE RING TARGET STATION

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"Feasibility of a Neutrino Source Based on a Muon Storage Ring"

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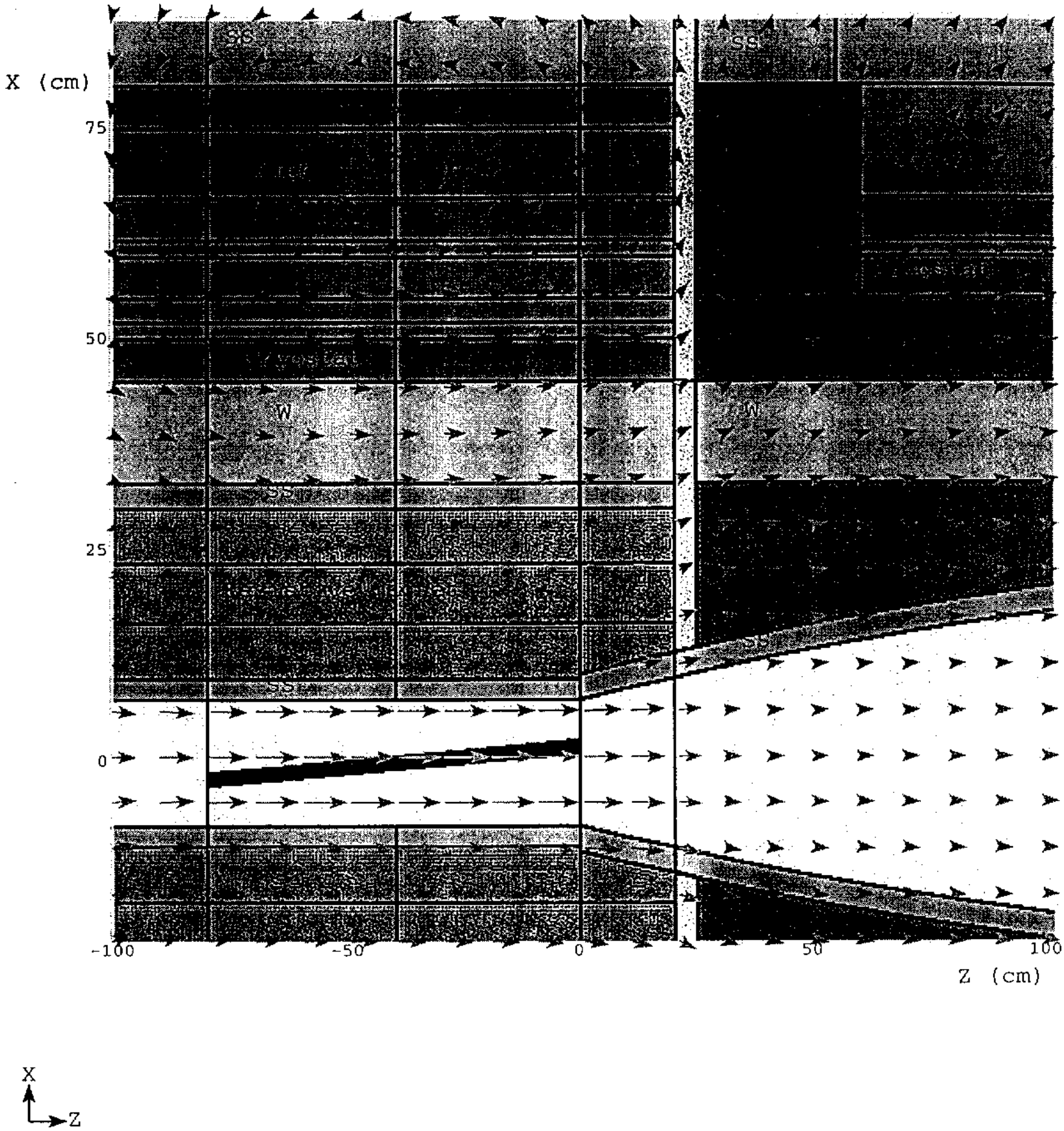
OUTLINE

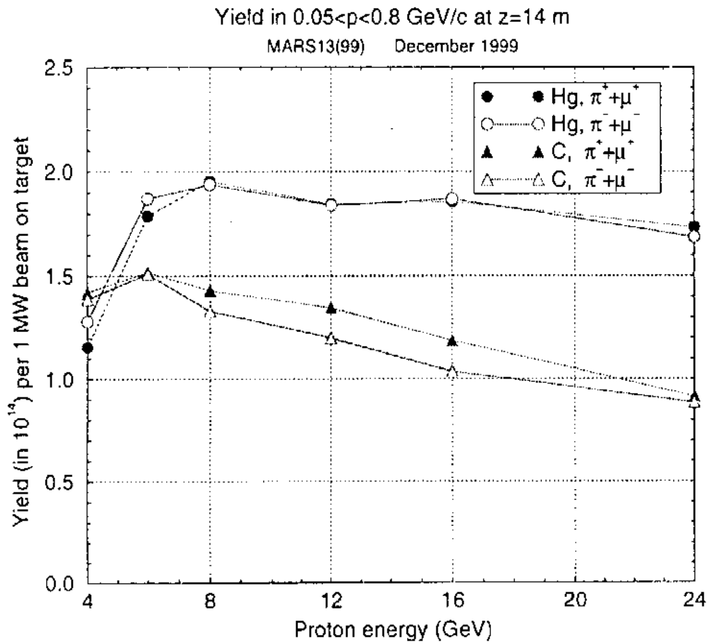
- Captured π/μ beam *vs* target and beam parameters
- Towards realistic target station and capturing system
- Particle flux, dose and residual dose rates in the system
- Radiation shielding

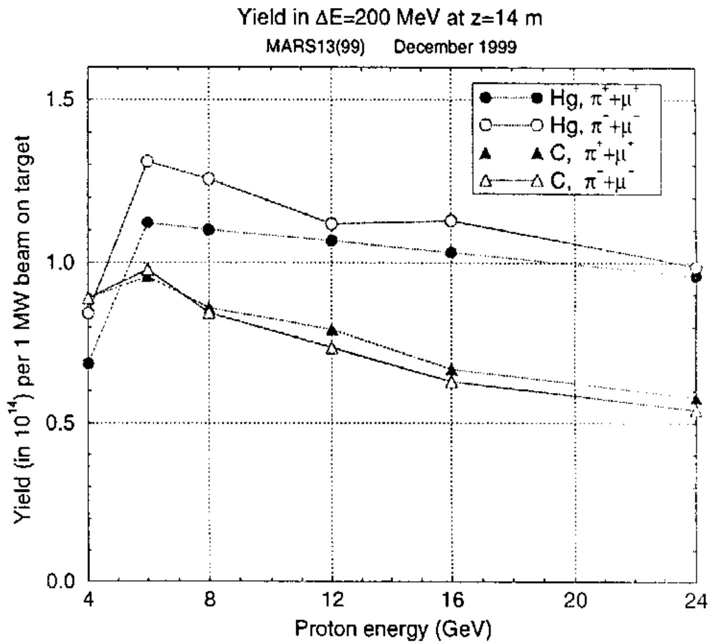
Jan. 2000

16 GeV p on 80-cm C-target (50 mrad) in FSU solenoid



MUSR TARGET: ENERGY AND MATERIAL





Meson yield at z=14 m with mercury and graphite targets: 0.05<p<0.8 GeV/c interval (left) and ±0.1 GeV at peak (right). Captured π/μ beam with the baseline C-target at 16 GeV is 0.171 (+) and 0.145 (−) compared to 0.302 (+) and 0.239 (−) for the 0.05<p<0.8 GeV/c interval.

π/μ YIELD: BEAM AND TARGET CHOICE (1)

- Proton energy E_0=6-16 GeV: yield (in the decay channel) per beam power is independent of E_0 for high-Z targets at $6< E_0 <24$ GeV and drops by 30% at 16 GeV from the 6-GeV peak for graphite. The higher E_0 reduces the number of protons on target, but results in more severe energy deposition in the target. Proton driver folk favor E_0=16 GeV, picked as the baseline energy for the feasibility study.

- For the given parameters optimization is done for the $\pm$100 MeV interval (around the spectrum maximum at $\geq$10 m from the target) to be captured by a phase rotation system.

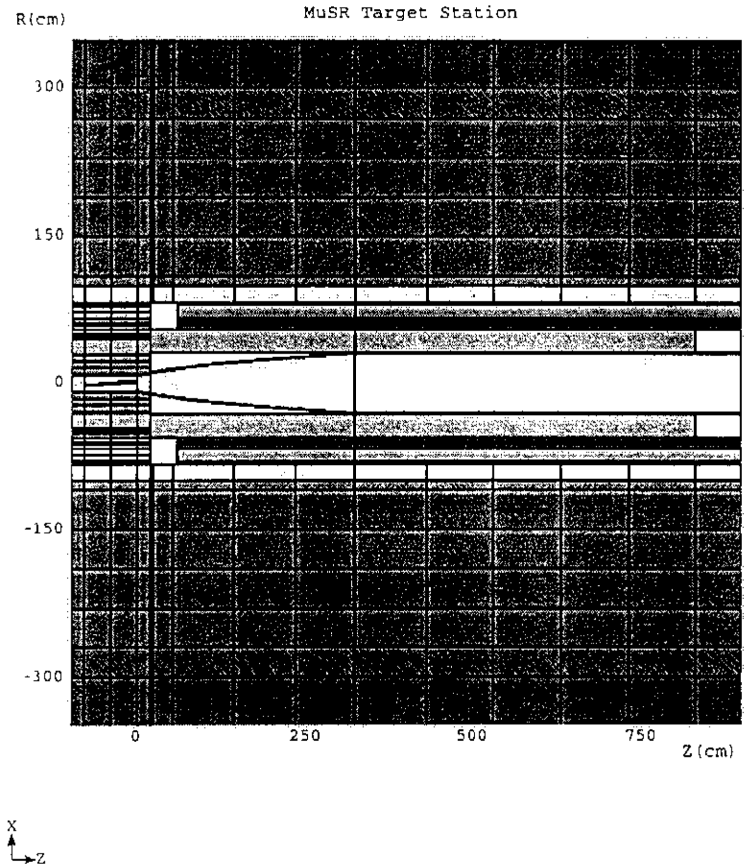
- Under these conditions the yield is higher by up to $\sim$30% for the tilted target $\rightarrow$ pick 50 mrad to have a beam dump at $\sim$6 m from the target. This is for $R_{target} = 2.5\sigma_{x,y} = 0.75$–1 cm which is optimal for both yield and power dissipation in the target and solenoid.

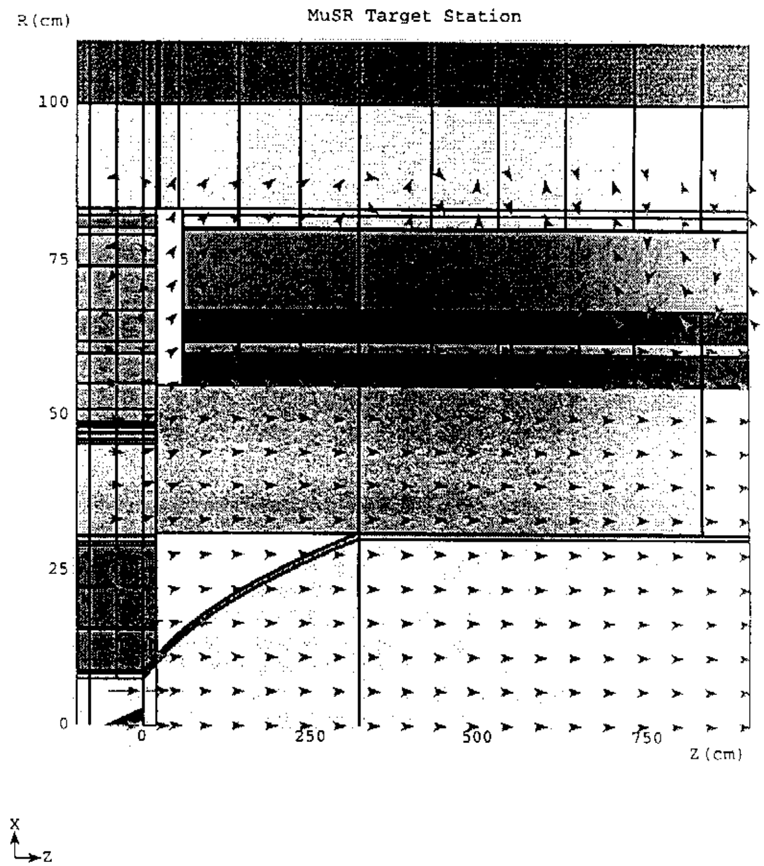
π/μ YIELD: BEAM AND TARGET CHOICE (2)

- Captured yield saturates at the target length of ~1.5 interaction length → pick 2 interaction length (80 cm of graphite or 30 cm of mercury) to mitigate beam dumping.
- October-November 1999 results and files are available on http://www-ap.fnal.gov/mokhov/mumu/target99/ (see also MUC0061 note). The present studies (January-February 2000) done for more realistic geometry, materials and magnetic field distributions provided by John Miller's group give about the same yields (5-7% lower) and allow for detailed studies of radiation fields in the entire target station.
- At 16 GeV 1 MW beam power dissipation is 117 and 24 kW in mercury and graphite targets, respectively. A solid graphite target is much simpler than a mercury jet. Pick a graphite target (stationary or movable) as a baseline for the feasibility study. The yield lower by 50% can be compensated by increasing the beam power to 1.5 MW.

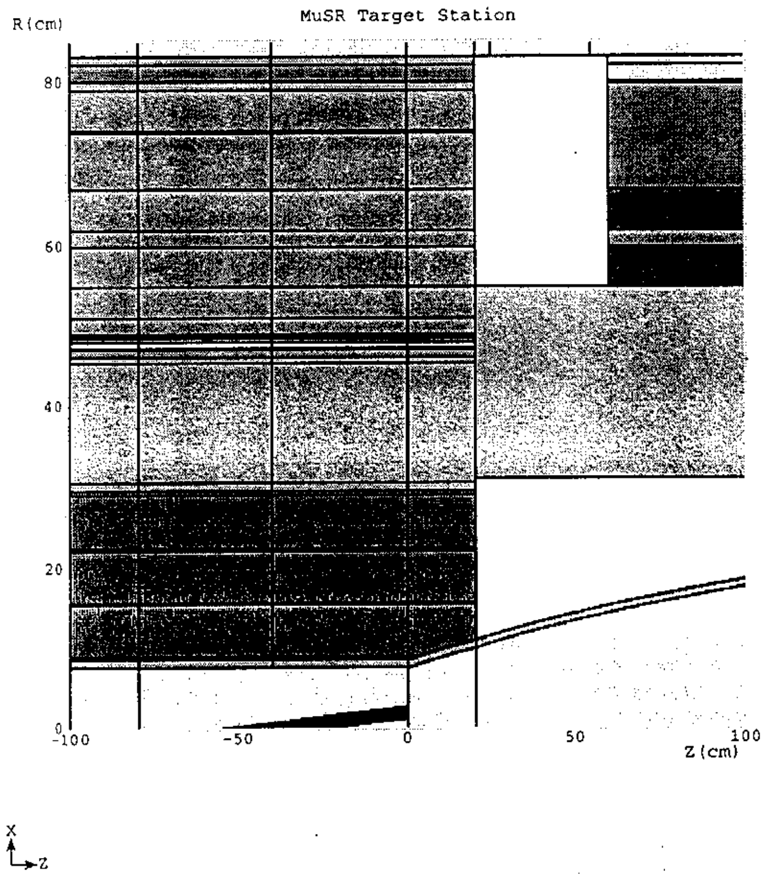
Thickness of bore tube (mm)	10	Assume 304L ss (density 7911 kg/m3)
Effective thickness of bore-tube insulator (mm)	5	50 vol% ceramic insulator (density 2000 kg/m3) and 50% water
Radial build of inner coil (mm)	64.7	90 vol% copper (density 8940 kg/m3) and 10% water
Assembly gap (mm)	3	50 vol% ceramic insulator (density 2000 kg/m3) and 50% water
Radial build of next outer coil (mm)	64.6	90 vol% copper (density 8940 kg/m3) and 10% water
Assembly gap (mm)	3	50 vol% ceramic insulator (density 2000 kg/m3) and 50% water
Radial build of outer coil (mm)	64.7	90 vol% copper (density 8940 kg/m3) and 10% water
Effective thickness of outer insulator (mm)	5	50 vol% ceramic insulator (density 2000 kg/m3) and 50% water
Thickness of outer shell of magnet housing (mm)	10	Assume 304L ss (density 7911 kg/m3)
Radial build of W/H2O shielding (mm)	150	70 vol% WC (density 15600 kg/m3) and 30% water
Thickness of cryostat bore tube (mm)	6	Assume 304L ss (density 7911 kg/m3)
Radial clearance gap, bore tube-to-cold panel (mm)	10	Assume MLI (consisting of pure Al and non-woven glass separat
Thickness of inner cold panel (mm)	3	Assume copper (density 8940 kg/m3)
Radial clearance gap, cold panel-to-vessel bore tube (n	6	Empty space
Thickness of magnet-vessel bore tube (mm)	5	Assume 304L ss (density 7911 kg/m3)
Assembly gap & ground-wall insulation (mm)	3	Empty space
Thickness of ground-wall insulation (mm)	2	GFRP (density 2000 kg/m3)
Radial build of CICC windings (mm)	250	33 vol% ss (density 7980 kg/m3) 21 vol% Cu (density 8940 kg/m3) 10 vol% non-Cu (density 8230 kg/m3) 20 vol% He (density 140 kg/m3) 16 vol% GFRP (density 2000 kg/m3)

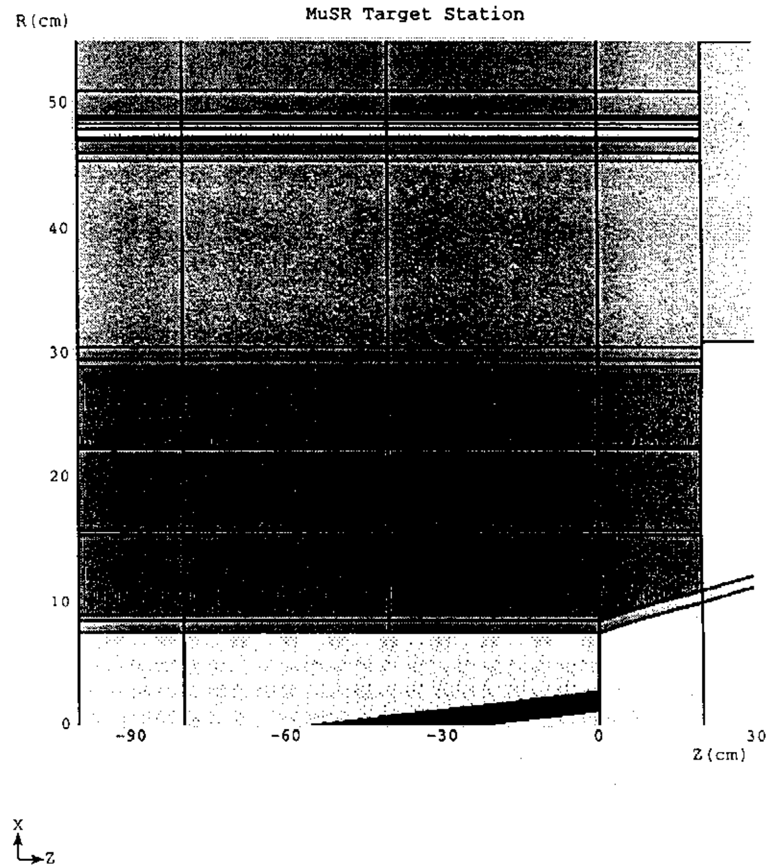
MUSR TARGET STATION: MARS MODEL(1)



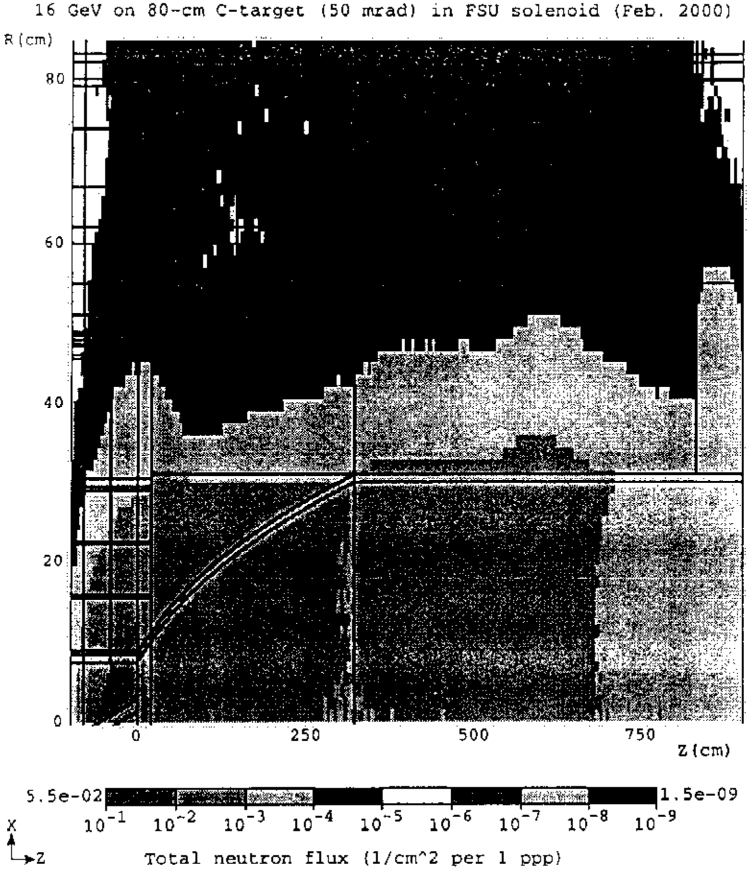


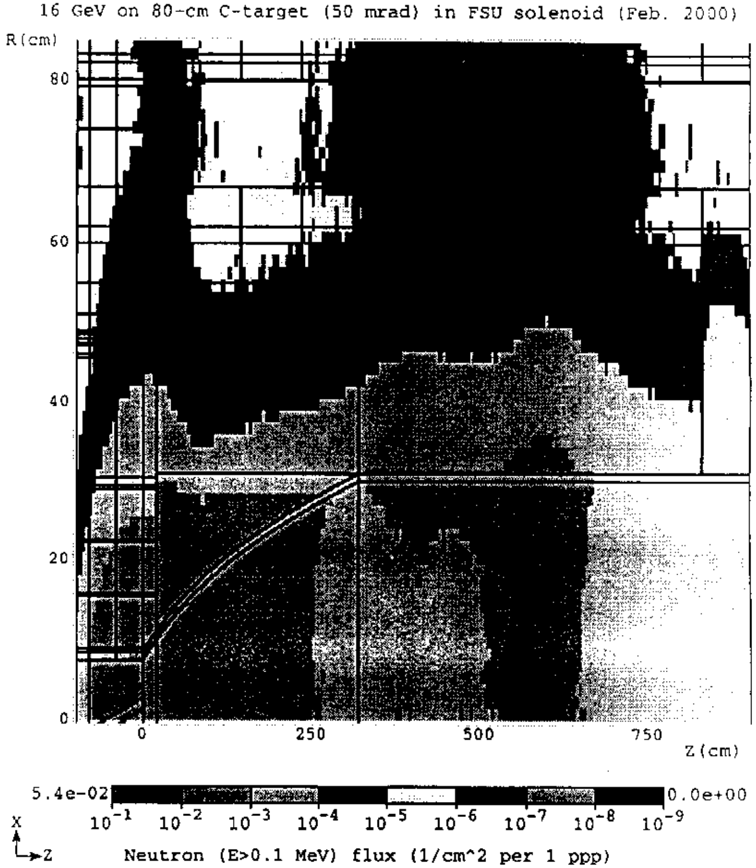
MUSR TARGET STATION: MARS MODEL(2)





MUSR TARGET STATION: NEUTRONS





Neutron flux (cm^{-2} per 1 ppp) at E> 0 (left) and E> 0.1 MeV (right)

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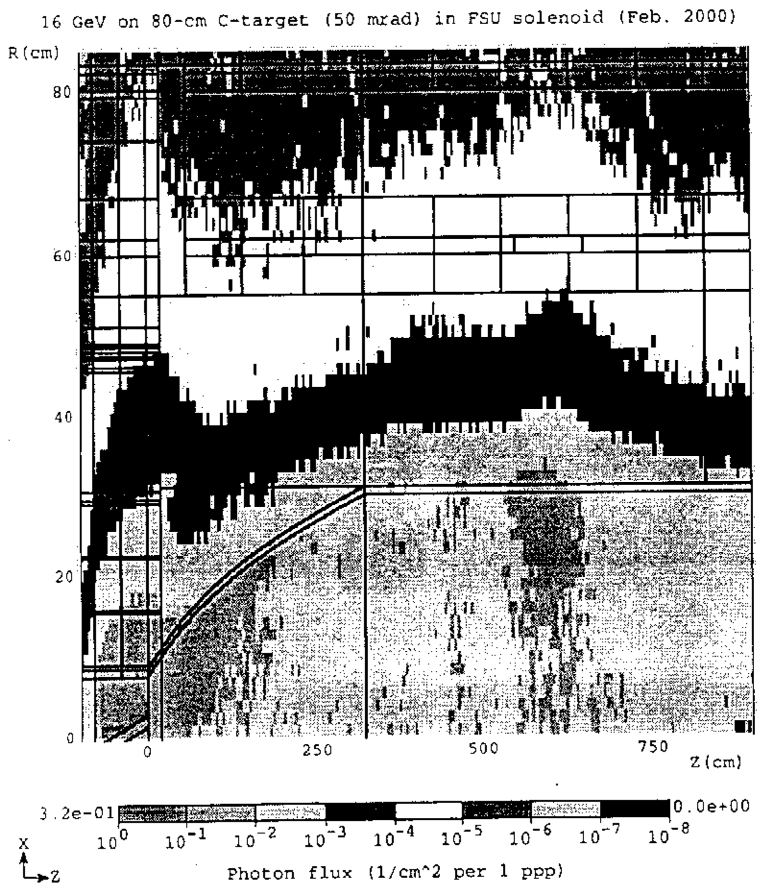
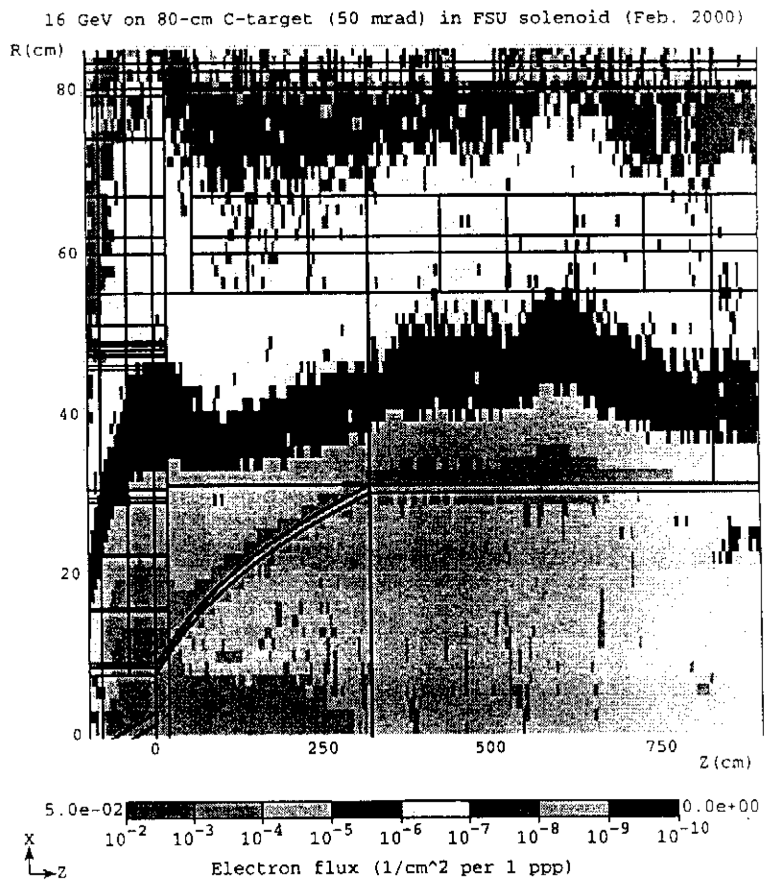
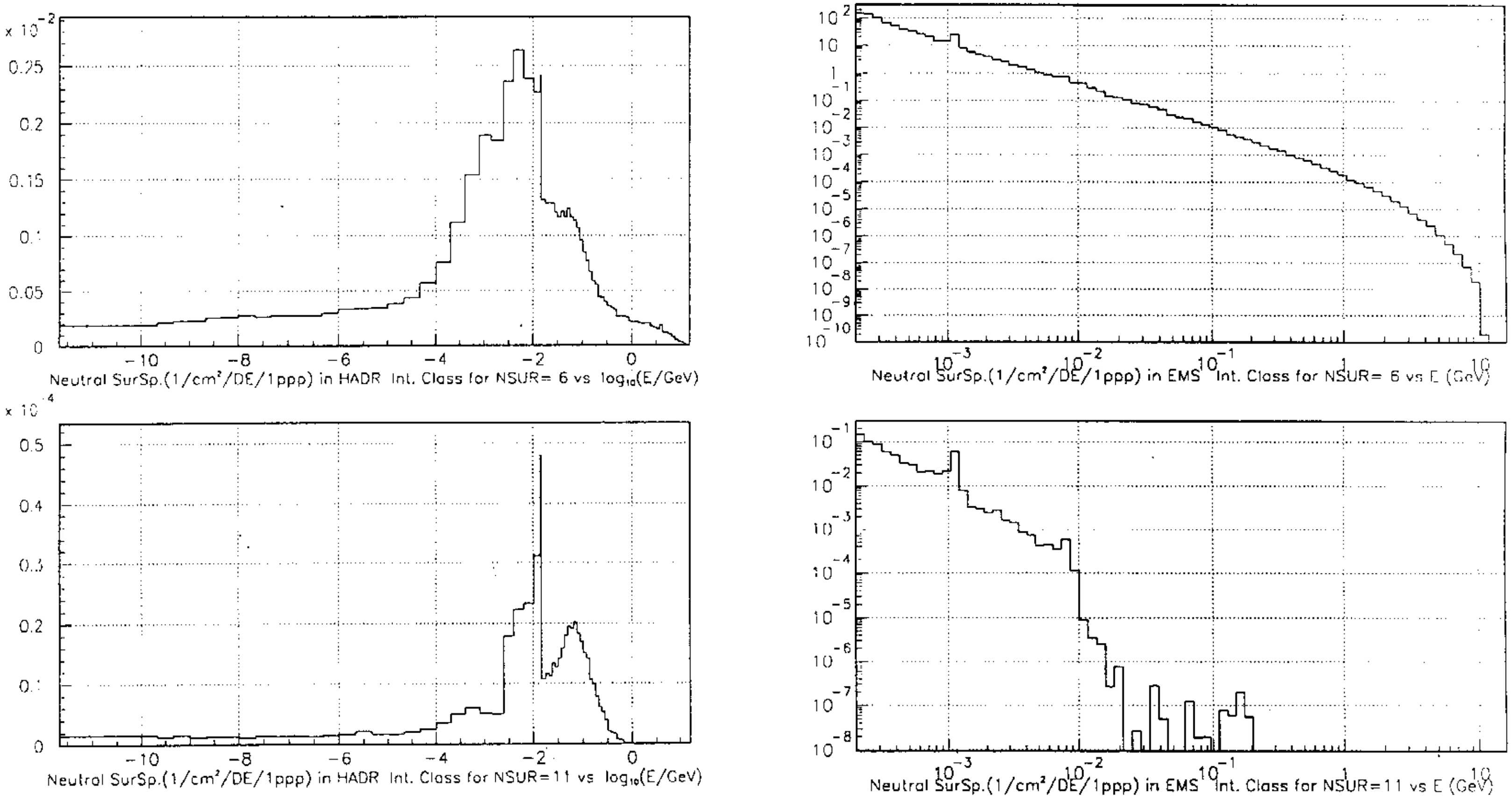
MUSR TARGET STATION: γ and $e^{\pm}$





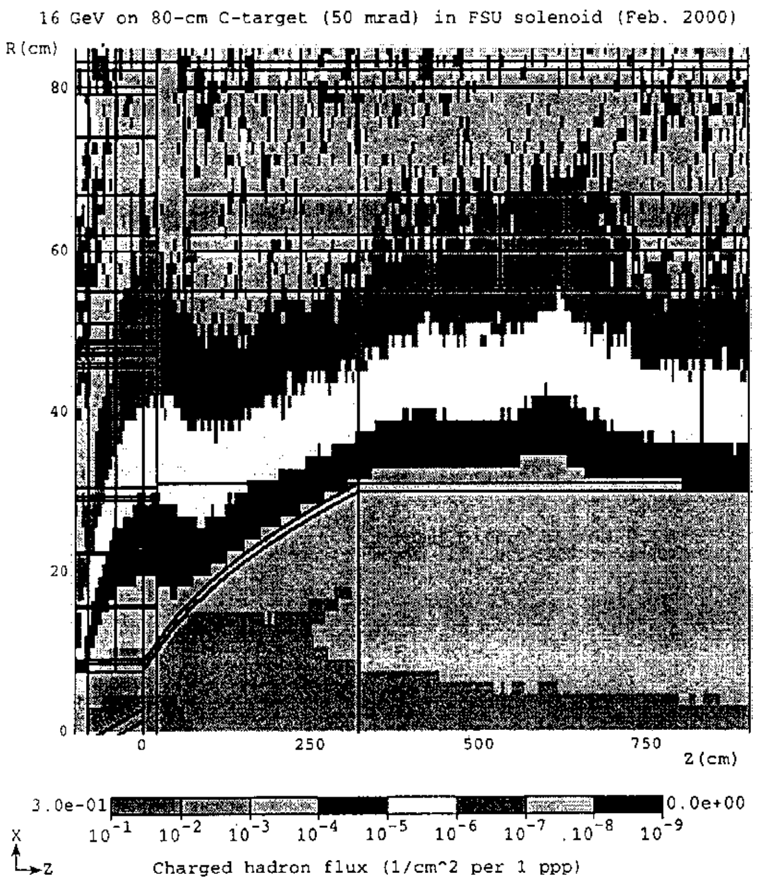
Photon (left) and electron (right) flux (cm^{-2} per 1 ppp)

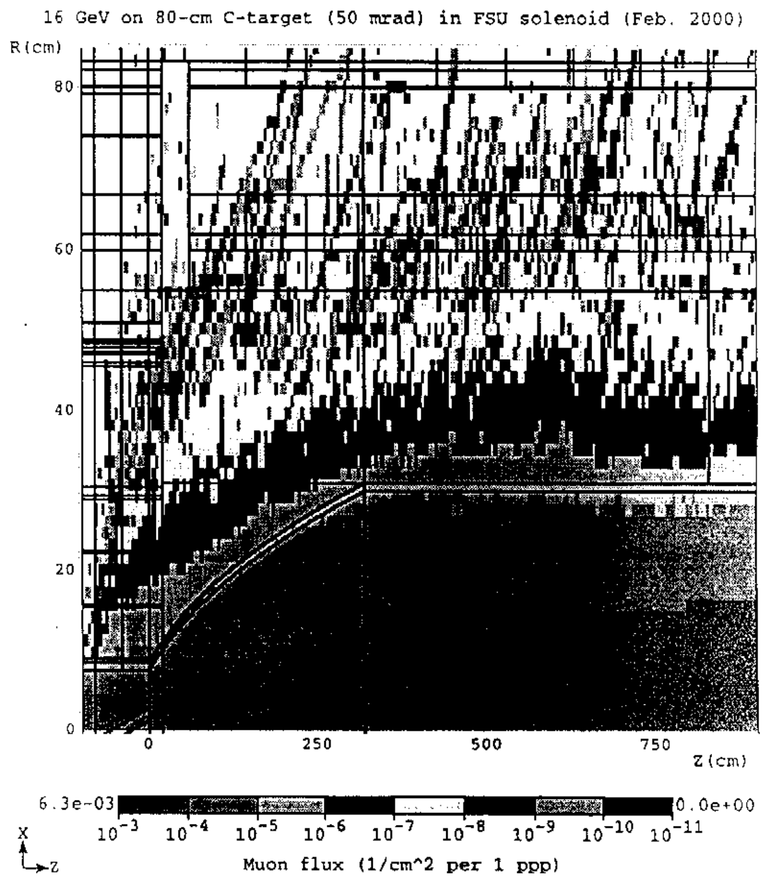
NEUTRON AND PHOTON SPECTRA AT COILS



Neutron (left) and photon (right) spectra entering the inner resistive coil at R=9 cm (top) and the CICC superconducting windings at R=49 cm (bottom) at -40<Z<20 cm.

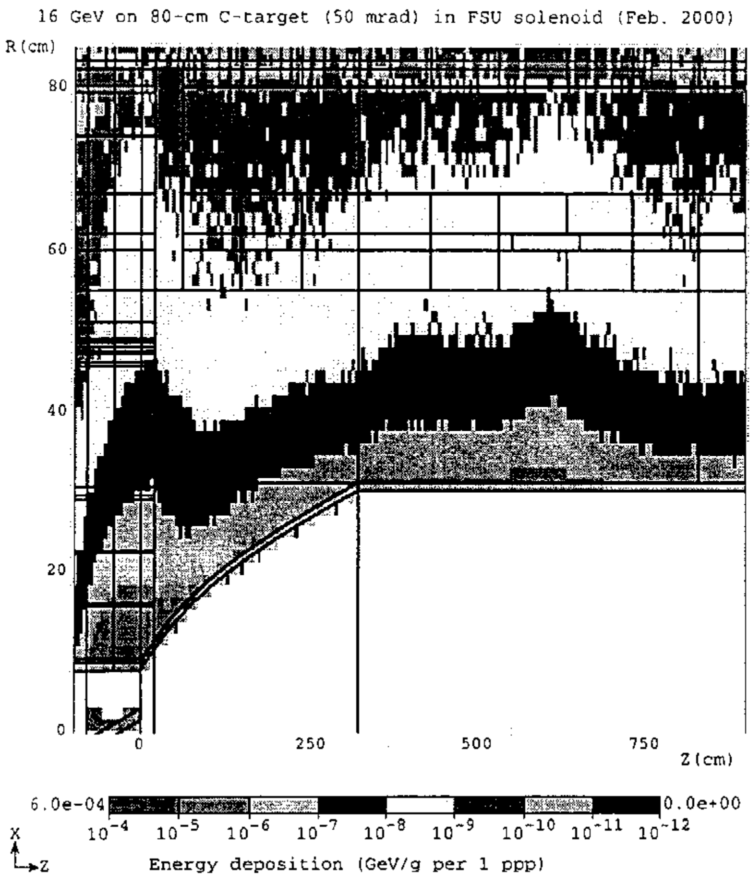
MUSR TARGET STATION: $h^{\pm}$ and $\mu^{\pm}$

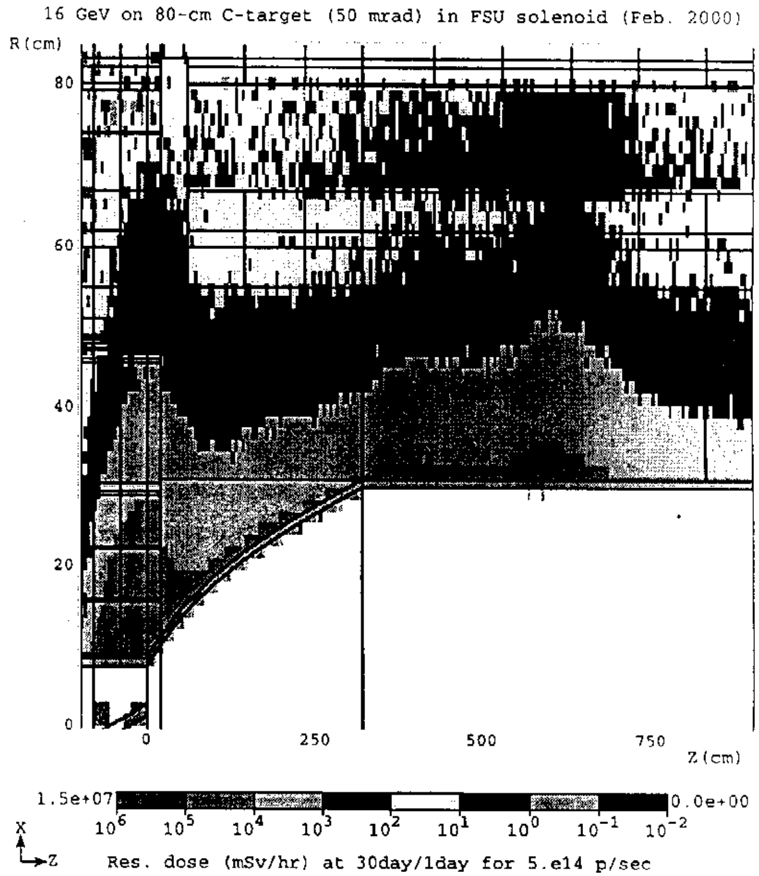




Charged hadron (left) and muon (right) flux (cm^{-2} per 1 ppp)

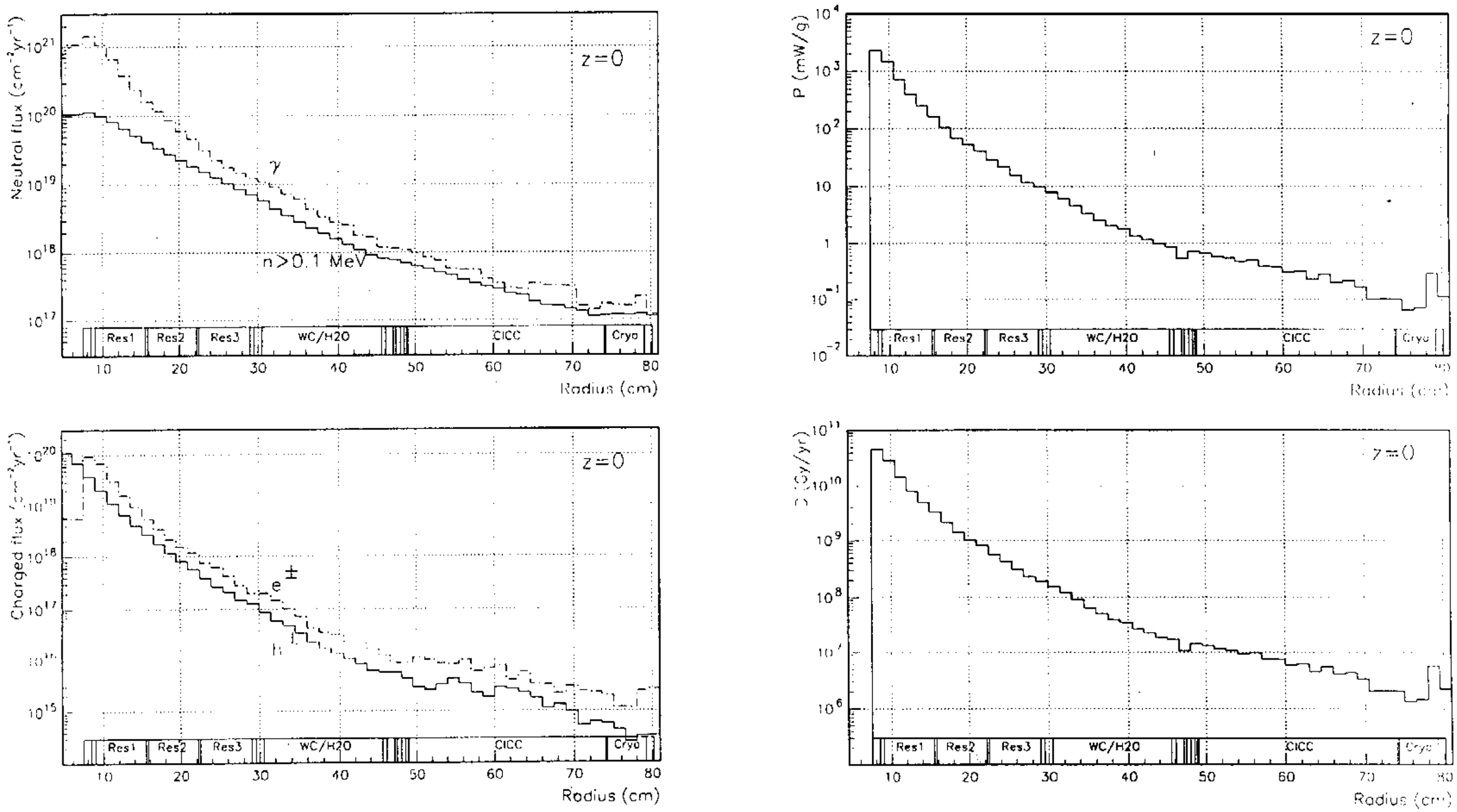
ENERGY DEPOSITION AND RESIDUAL DOSE





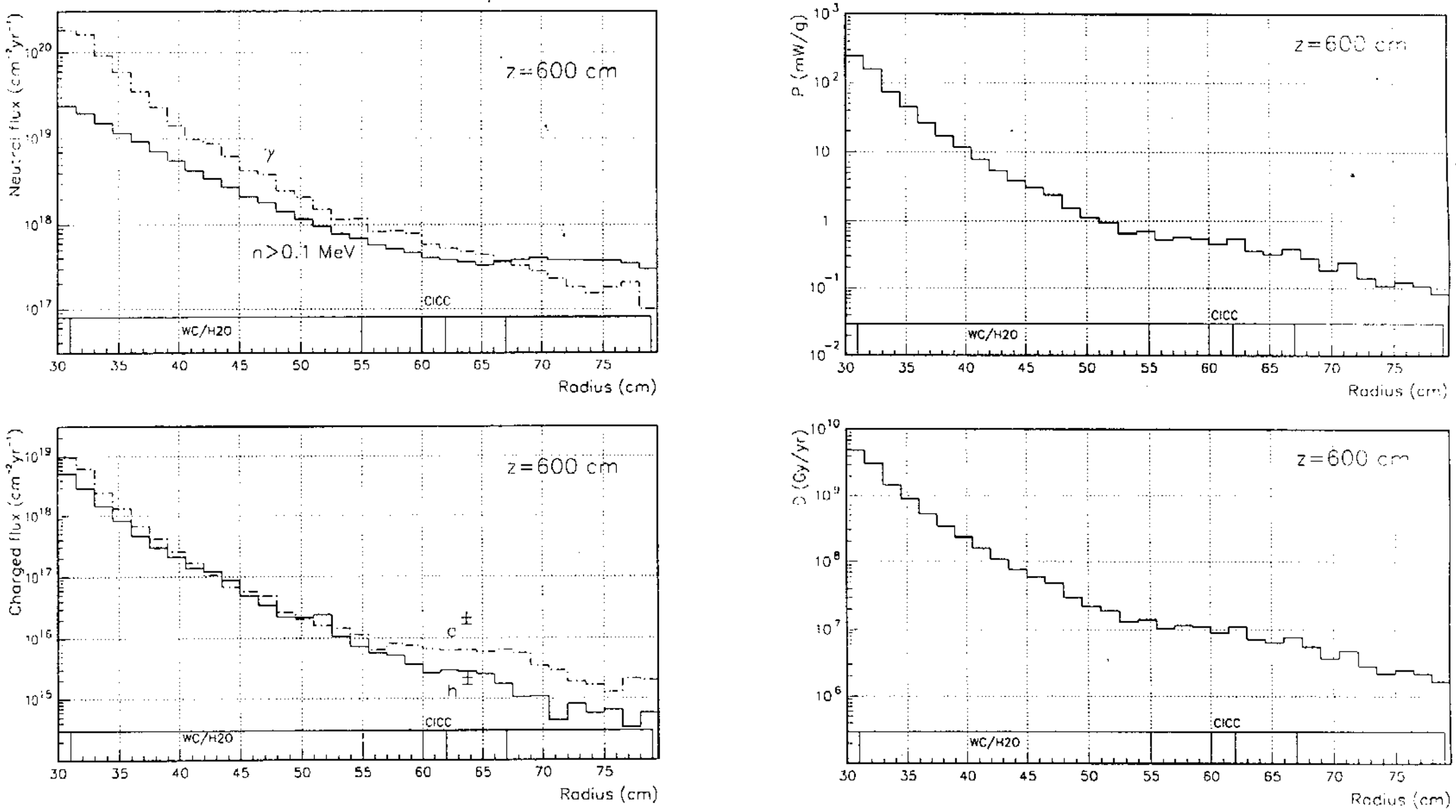
Energy deposition in GeV/g per 1 ppp (left) and residual dose rate after 30 day irradiation and 1 day cooling at 5×10^{14} p/sec (right)

MUSR TARGET STATION: FLUX AND DOSE



Radial distribution of particle flux ($cm^{-2}yr^{-1}$), power density (mW/g) and absorbed dose (Gy/yr) for 1.5 MW 16 GeV beam on target

MUSR TARGET DUMP: FLUX AND DOSE



Azimuthally averaged particle flux ($cm^{-2}yr^{-1}$), power density (mW/g) and absorbed dose (Gy/yr) at the dump for 1.5 MW 16 GeV beam

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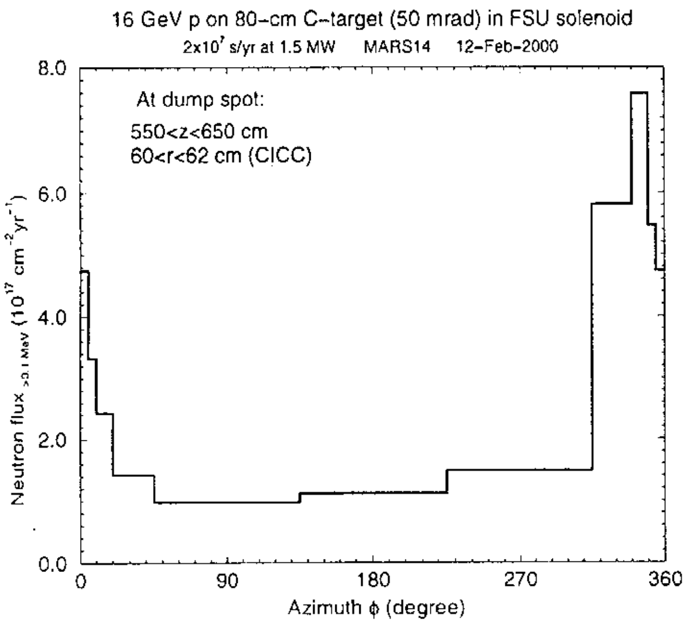
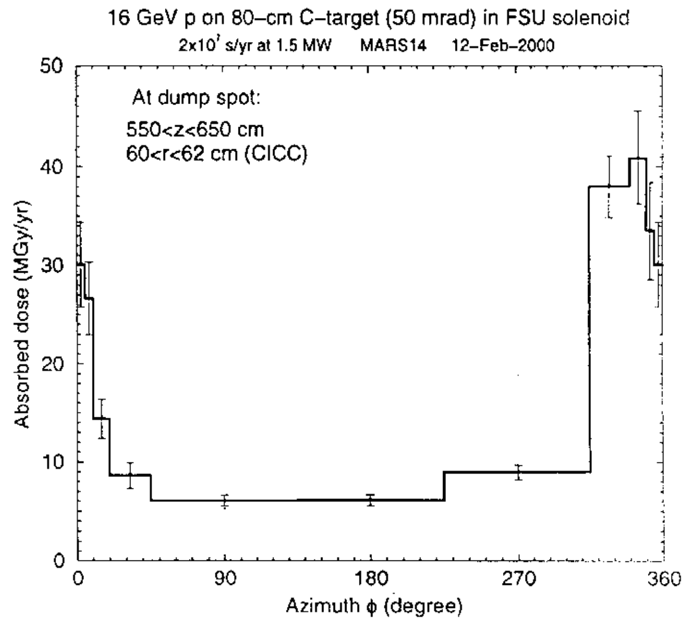
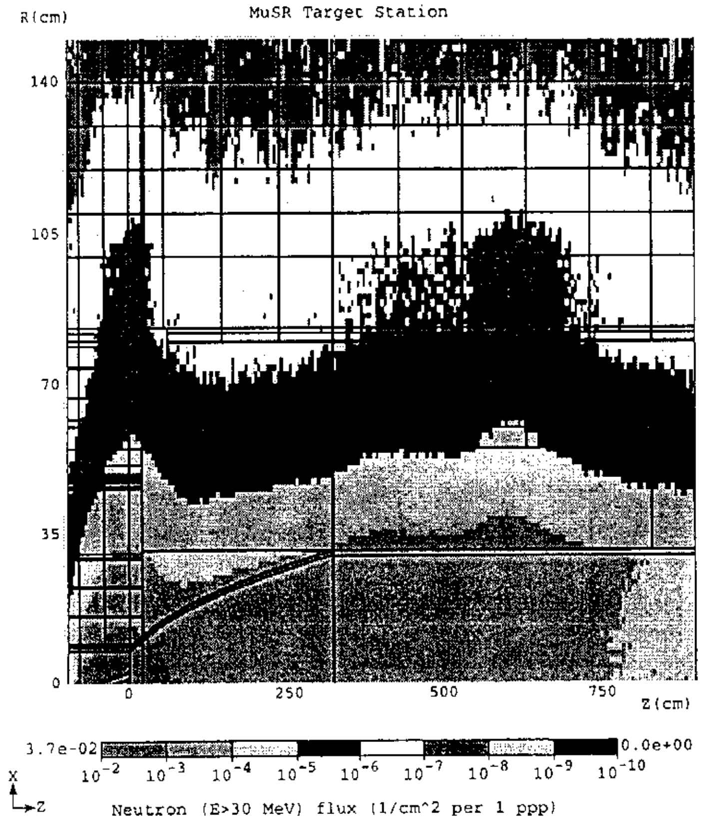
MUSR TARGET DUMP: PEAK FLUX AND DOSE

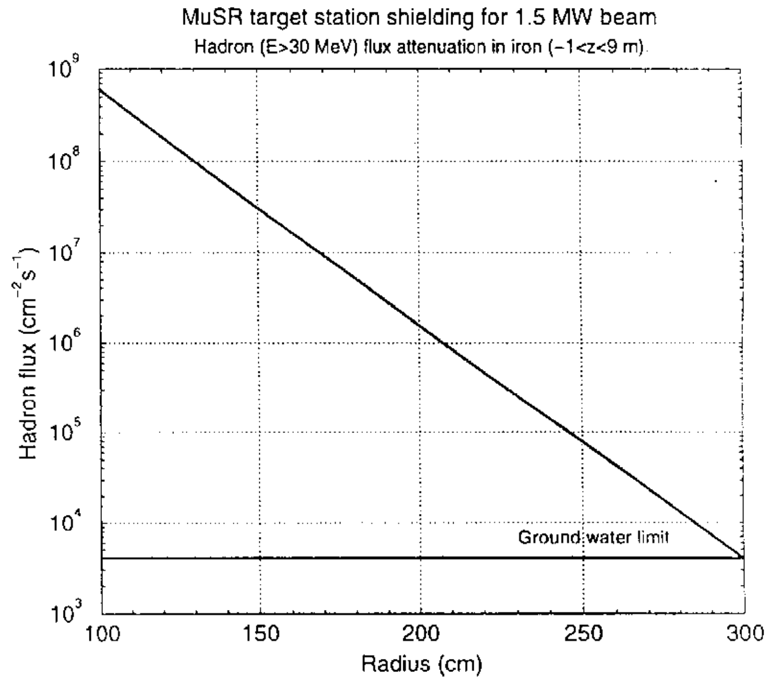




Azimuthal distribution of neutron (E>0.1 MeV) flux and absorbed dose in SC coil at the dump location for 1.5 MW 16 GeV beam

MUSR TARGET STATION SHIELDING





Neutron (E>30 MeV) isoflux (cm^{-2} per 1 ppp) (left) and total hadron (E>30 MeV) flux ($cm^{-2}s^{-1}$) for 1.5 MW 16 GeV beam on target (right). Need ~2 m of steel followed by 0.3 m concrete wall/floor with about 3 m dirt above, i.e. >6 m or 18 feet from the beam to the surface.

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SUMMARY-1

- Captured π/μ beam with the baseline graphite target at 16 GeV is 0.171 (+) and 0.145 (−) compared to 0.302 (+) and 0.239 (−) for the $0.05<p<0.8$ GeV/c interval
- There are possibilities to increase the yield ($C \rightarrow Hg$) and captured yield per beam power (16 GeV → 6 GeV)
- Annual hadron flux in the graphite target is $\sim 5\times10^{21}$cm^{-2} $\rightarrow \sim$1 month lifetime for a 1.5 MW beam on stationary target
- Annual hadron flux (E>0.1 MeV) and dose in the hottest spot of the inner resistive coil are 1.2×10^{20}cm^{-2} and 3×10^{10} Gy respectively → $\sim$3 year lifetime even for copper/ceramic (non-organic insulation etc.)

SUMMARY-2

- Annual neutron flux (E>0.1 MeV) and dose in the hottest spot of the CICC superconducting coil are 8×10^{17}cm^{-2} and 1.3×10^{7} Gy respectively $\rightarrow$ $\sim$20 year lifetime
- Annual neutron flux (E>0.1 MeV) and dose in the hottest spot of the potted superconducting coil at the beam dump are 7.6×10^{17}cm^{-2} and 4.1×10^{7} Gy respectively $\rightarrow$ $\sim$10 years
- Residual dose rates for a 1.5 MW beam are up to 10^7 mSv/hr = 10^6 R/hr on target, bore tube and inner resistive coil, 10^3 mSv/hr = 100 R/hr on CICC coil and 10^2 mSv/hr = 10 R/hr on vessel $\rightarrow$ remote control and robotics
- Radiation shielding: $\sim$2 m of steel followed by 0.3 m concrete wall/floor (to protect ground water) with about 3 m dirt above, i.e. >6 m or 18 feet from the beam to the surface