Using TART to design the neutron shield for the Magnetic Recoil Spectrometer (MRS) at OMEGA

D.T. Casey, J.A. Frenje, S. Volkmer, C.K. Li, J.R. Rygg, F.H. Séguin and R.D. Petrasso[a)]

Plasma Science and Fusion Center, Massachusetts Institute of Technology

V.Yu. Glebov, D.D. Meyerhofer[b)], T.C. Sangster and C. Stoeckl

Laboratory for Laser Energetics, University of Rochester

S. Haan and S. Hatchett

Lawrence Livermore National Laboratory

[a)] **Visiting Senior Scientist at LLE**

[b)] **Dept. of Mech Eng, Phys and Astronomy**

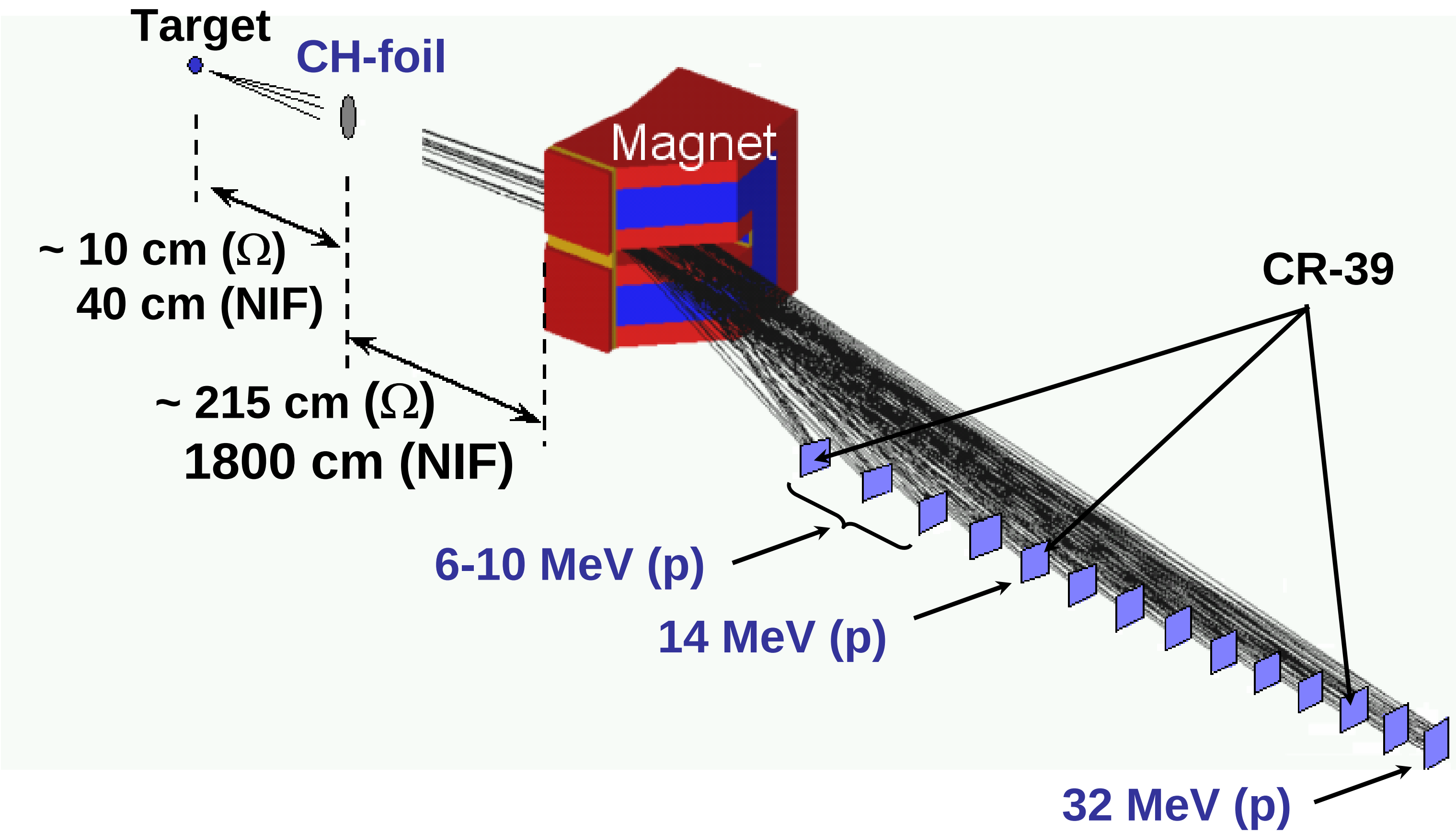
American Physical Society
47th Annual Meeting of the Division of Plasma Physics
Denver, Co
October 24-28th, 2005

Abstract

A Magnetic Recoil Spectrometer (MRS) is currently being developed, at both OMEGA and the NIF, for measurements of down-scattered neutrons from which ρR of cryogenic DT implosions can be inferred [J. A Frenje et al., Q03.00010, and J. A Frenje et al., Rev. Sci Instrum 72, 854 (2001)]. As is the case for complementary methods to measure ρR [C. K. Li *et al*, Phys. Plasmas 8, 4902 (2001)], minimizing the effect of the background is critical for its successful implementation.

CR-39 detectors will be used in the MRS, which places a set of requirements on the MRS shielding design. Our initial calculated minimum S/B of 20, folded with CR-39 neutron response, determined the tolerable background neutron fluence. The Monte Carlo code TART code is being used to calculate the transport of neutrons through the structures inside the OMEGA target bay, and in the shielding surrounding the MRS. The NIF MRS shielding design will be developed using the same method and tools. This poster presents the current status of this project. This work was supported in part by LLE, LLNL, the U.S. DoE, the Univ. of Rochester, and the N.Y.State Energy Research and Development Authority.

Magnetic Recoil Spectrometer (MRS) Principle



J. A. Frenje et al., Q03.00010

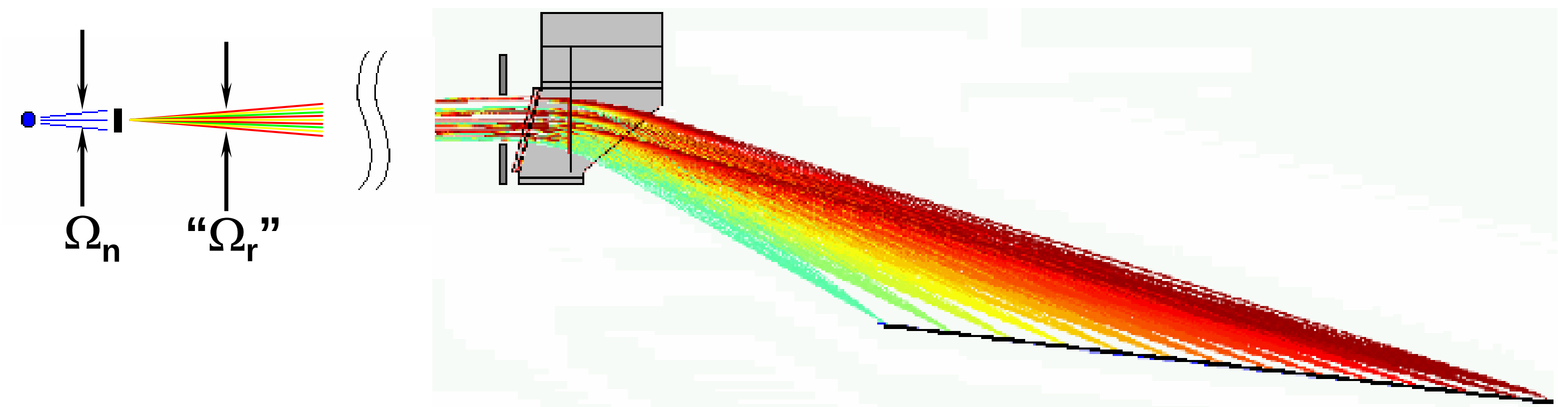
J. A. Frenje et al., NIF Ignition Diagnostics Workshop, Livermore, June 16, 2005

J. A. Frenje et al., Rev. Sci Instrum 72, 854 (2001).

(a) Detection Efficiency

- The detection efficiency (ε_{MRS})

$$\varepsilon_{MRS} = \frac{\Omega_n}{4\pi} \cdot n_i \cdot t \int^{"\Omega_r"} \frac{d\sigma}{d\Omega_{lab}} d\Omega$$



- Maximum differential cross section at forward scattering angles and focusing, which allows for a larger aperture, both significantly enhance ε_{MRS}.
- Absolute yields will be measured since Ω_n, n_i, t, $\frac{d\sigma}{d\Omega}$, and Ω_r are known.

(b) Resolution (ΔE_l)

- **Resolution (ΔE_l) is defined as:**

$$\Delta E_l \approx \sqrt{\Delta E_f^2 + \Delta E_k^2 + \Delta E_m^2}$$

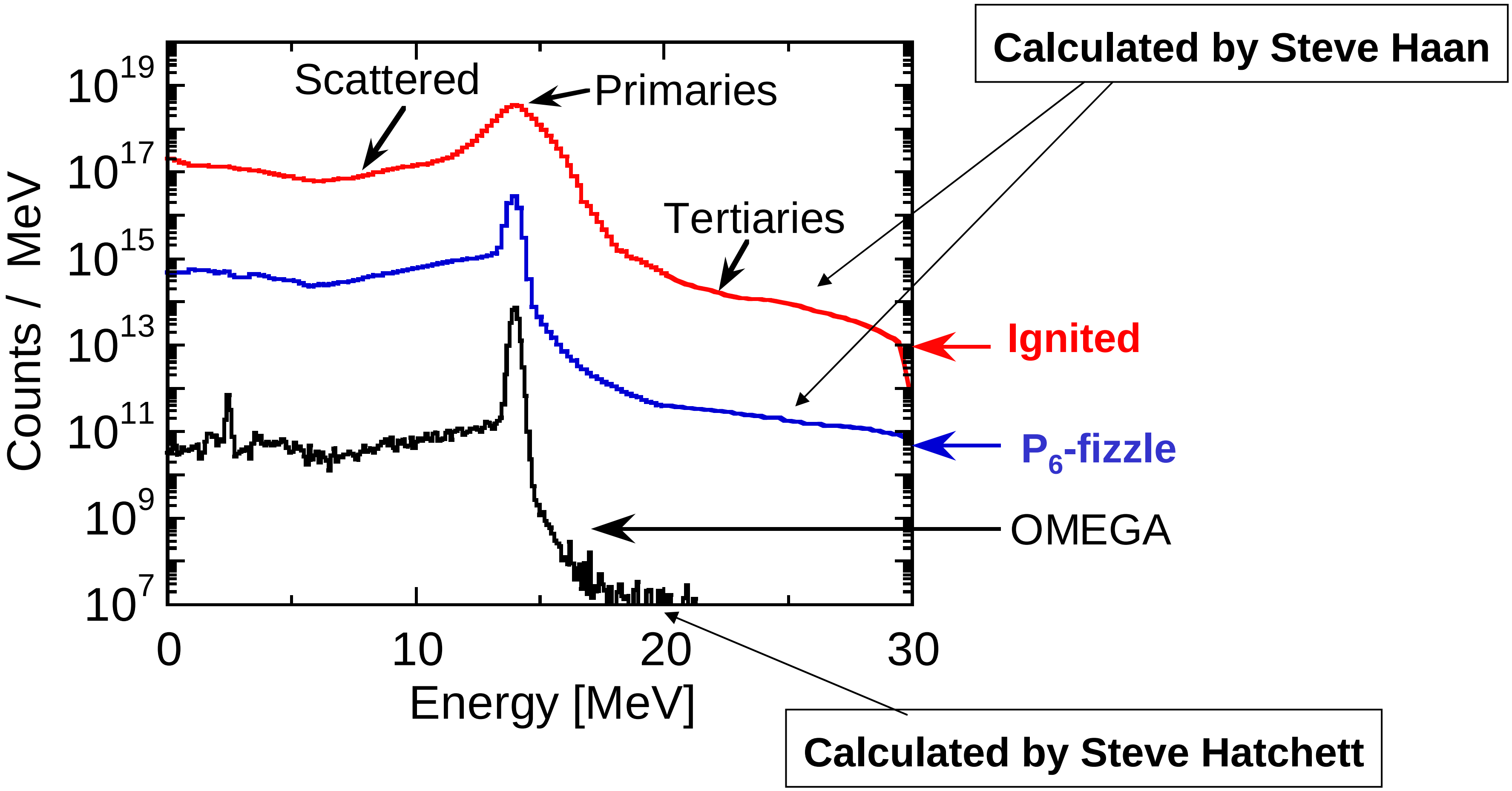
ΔE_f	=	**Energy loss in foil**	$\propto$	**foil thickness**
ΔE_k	=	**Kinematic energy broadening**	$\propto$	**foil and aperture sizes**
ΔE_m	=	**Optical energy broadening**	$\propto$	**magnet performance**

Motivation for the MRS at OMEGA and the NIF

- **Measure absolutely the neutron energy spectrum of cryo DT implosions in the range of 6-32 MeV**
- **Infer ρR from the down-scattered neutron spectrum (6-10 MeV)**
- **Measure absolute neutron yield**
- **Determine fuel ion temperature from Doppler broadened primary neutron spectrum**
- **Infer ρR from the tertiary neutron spectrum (20-32 MeV) (NIF)**

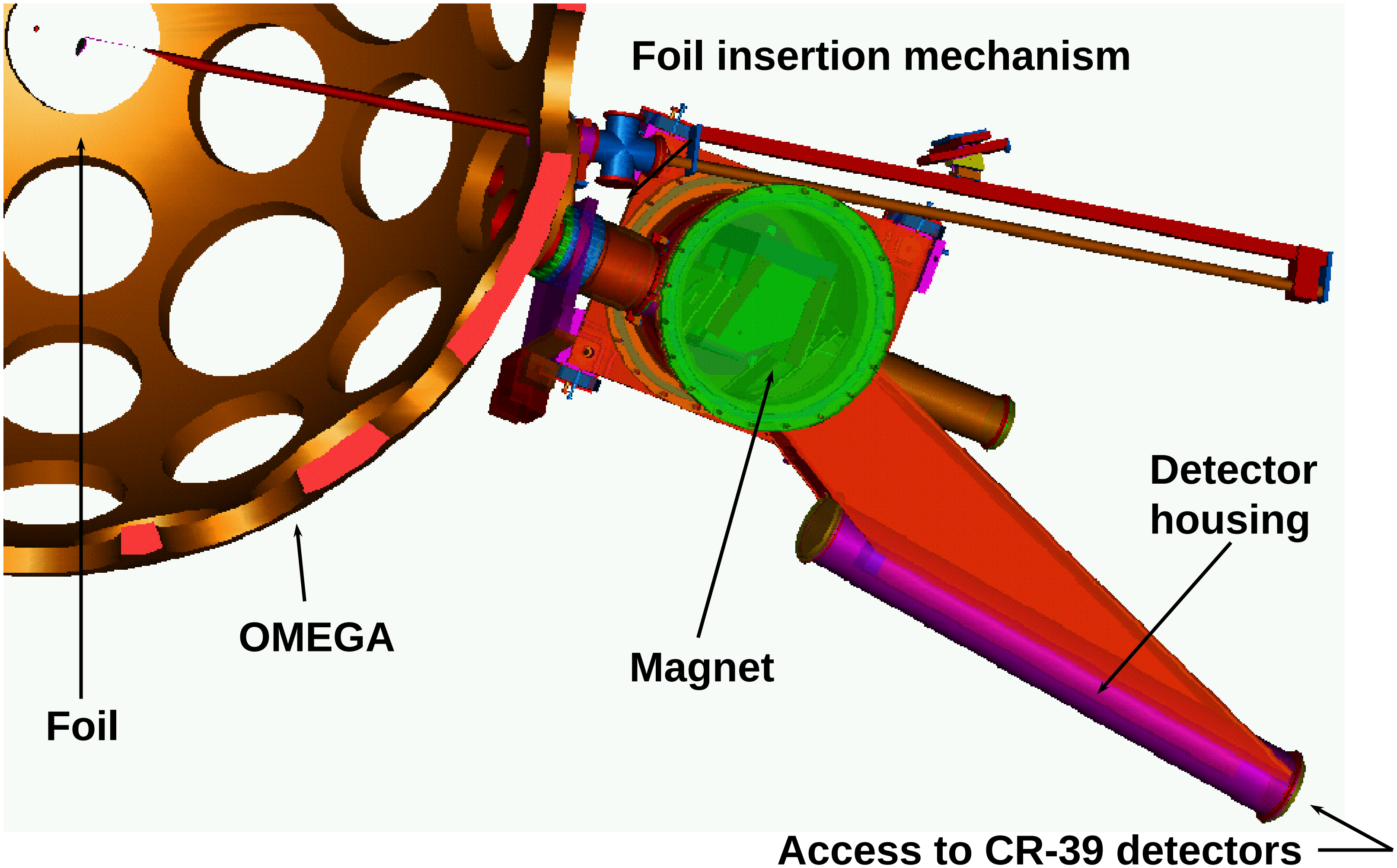
Minimizing the neutron background is critical for the successful implementation of the MRS at OMEGA and NIF

The MRS designs at OMEGA and the NIF were driven by LASNEX simulations



J. A. Frenje et al., Q03.00010

MRS on OMEGA



Foil insertion mechanism
Detector housing
Magnet
OMEGA
Foil
Access to CR-39 detectors

The required S/B > 10 for OMEGA defines the tolerable neutron fluence at the MRS detector

$$\frac{S}{B} > 10 \quad \Rightarrow \quad \frac{S}{F_n \cdot A \cdot \varepsilon_{CR39}} > 10$$

$$S \approx 2.75 \times 10^{-2} \cdot \rho R \cdot Y_{1n} \cdot \varepsilon_{MRS}$$

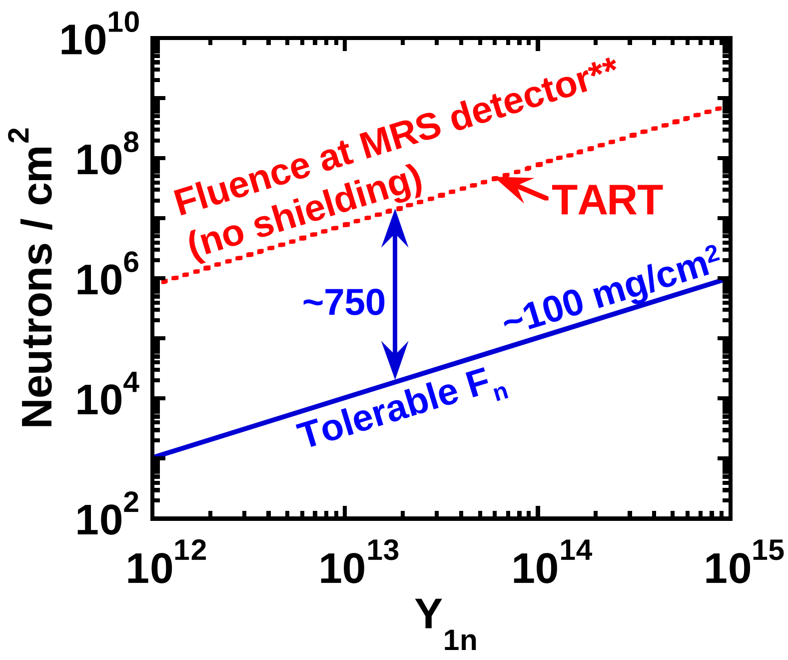
$$F_n < \frac{2.75 \times 10^{-2} \cdot \rho R \cdot Y_{1n} \cdot \varepsilon_{MRS}}{10 \cdot \varepsilon_{CR39} \cdot A}$$

OMEGA

A ~ 40 cm^2

ε_{MRS} ~ 9×10^{-9}*

ε_{CR39} ~ 6×10^{-5}** (6 hrs etch)



For a ρR~100 mg/cm^2, neutron fluence needs to be reduced ~750 times

---

* $\varepsilon_{CR\text{-}39}$ can be reduced further by selecting a certain track diameter range.

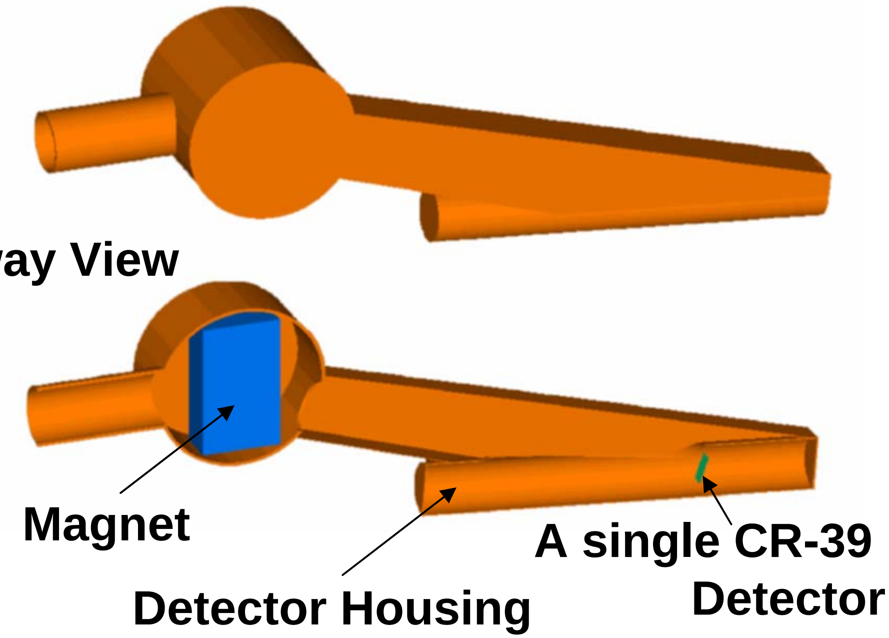
** J. A Frenje et al., Q03.00010

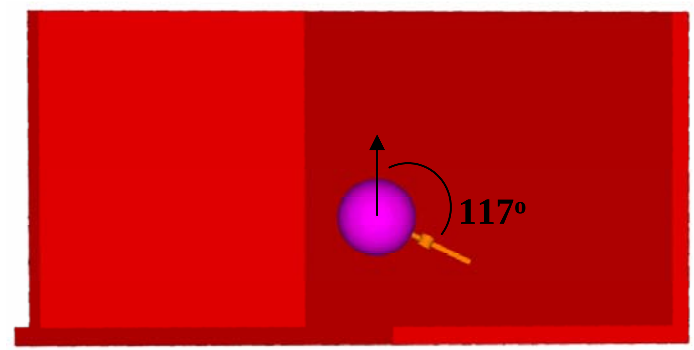
Neutron fluence at the MRS detector was determined using the neutron transport code TART

The OMEGA MRS will be positioned at the P-10 Port on OMEGA

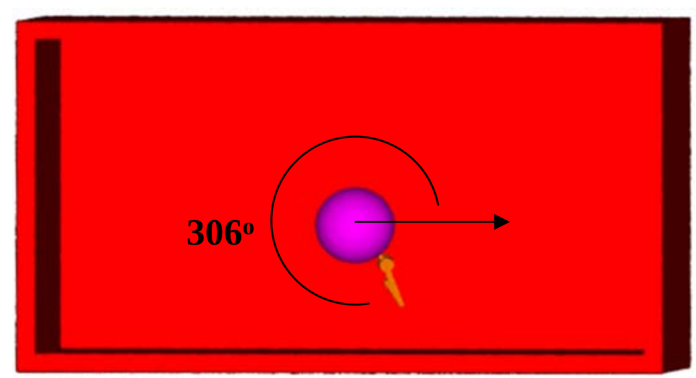
TART MRS Detector Model

Cutaway View





Looking in from side of target bay

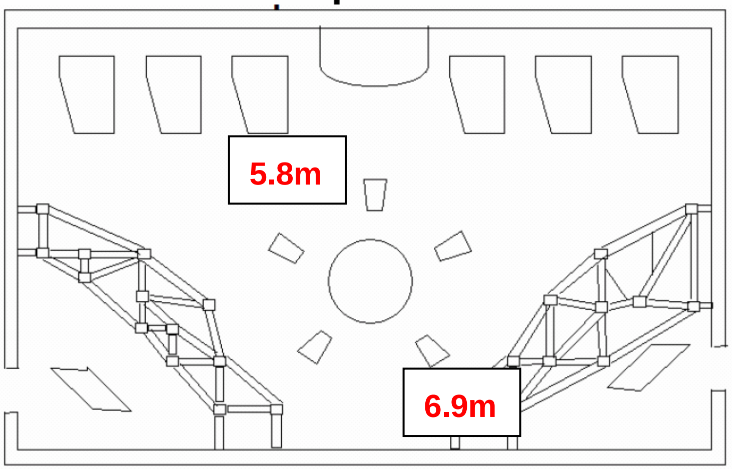


Looking down from ceiling of the target bay

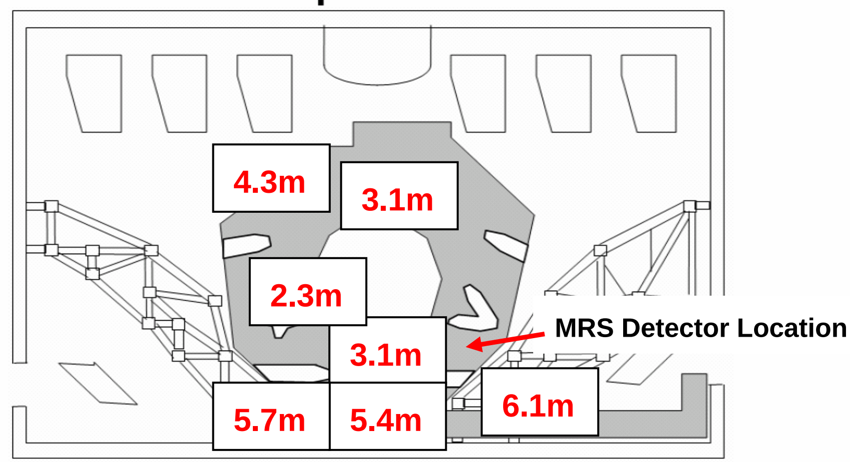
Benchmarking TART Neutron Transport Calculations with Experimental Data

Neutron fluence measurements made at different locations in the OMEGA target bay, were used to benchmark the TART calculation

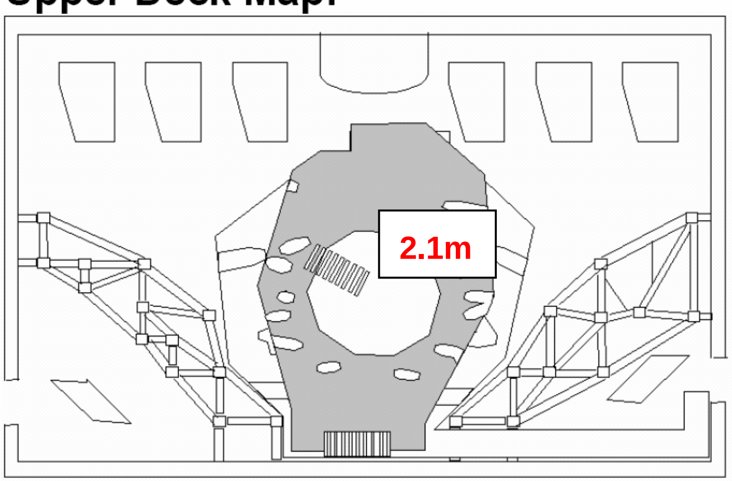
Ground Floor Map:



Center Deck Map:



Upper Deck Map:

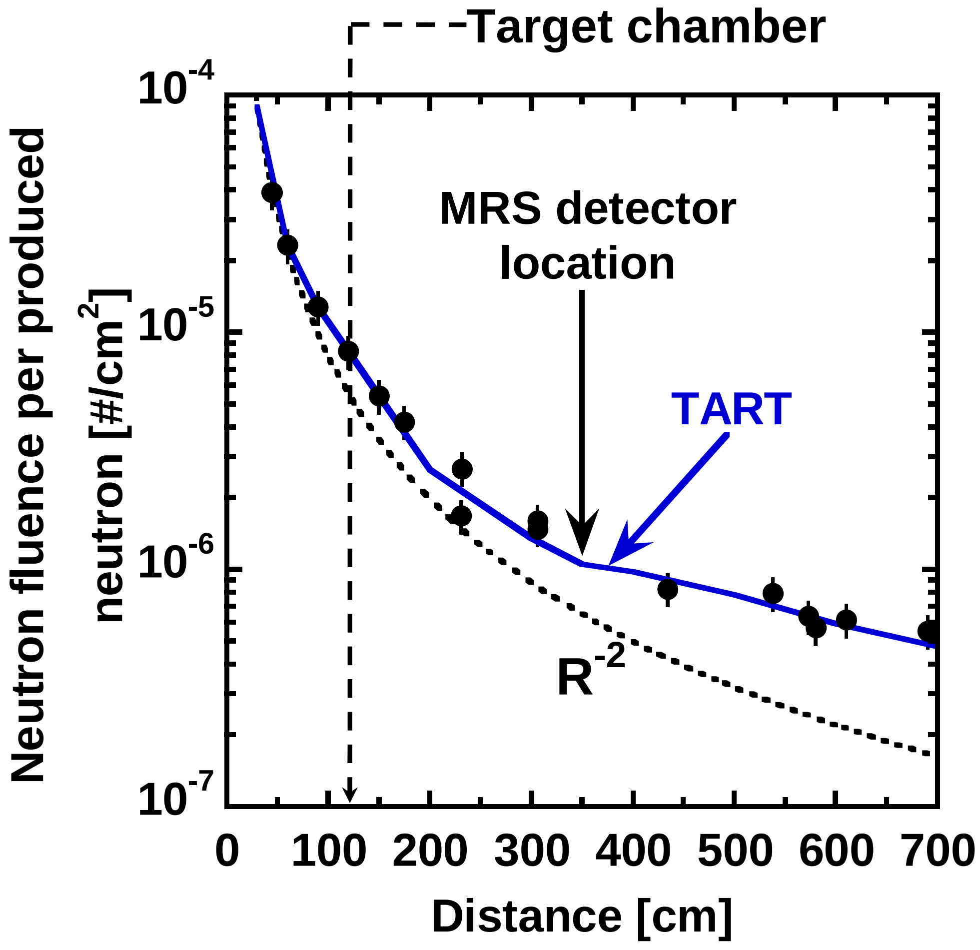


Nine high-yield DT shots on July 27th 2004 producing a total neutron yield of 5.2E14 were used

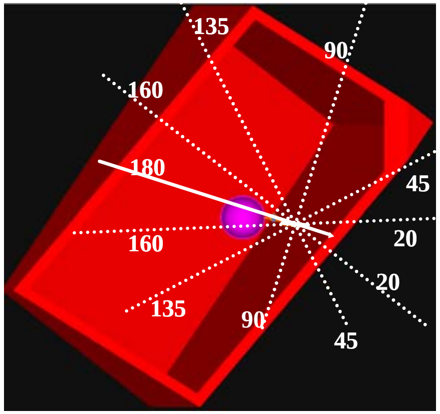
TART calculations agree with experimental data

The TART MRS model was used to calculate the neutron fluence at different distances from the target chamber center and then compared to experimental CR-39 fluence measurements.

Further benchmarking is going to be performed around the P-10 port where the MRS will be positioned.

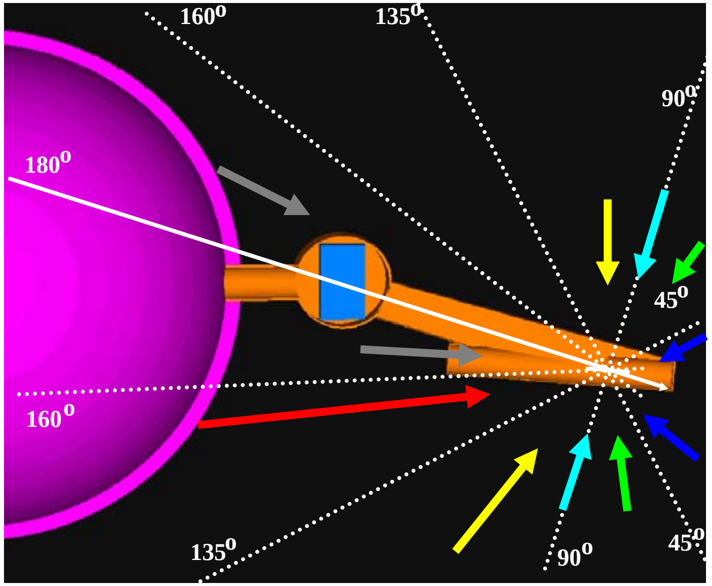


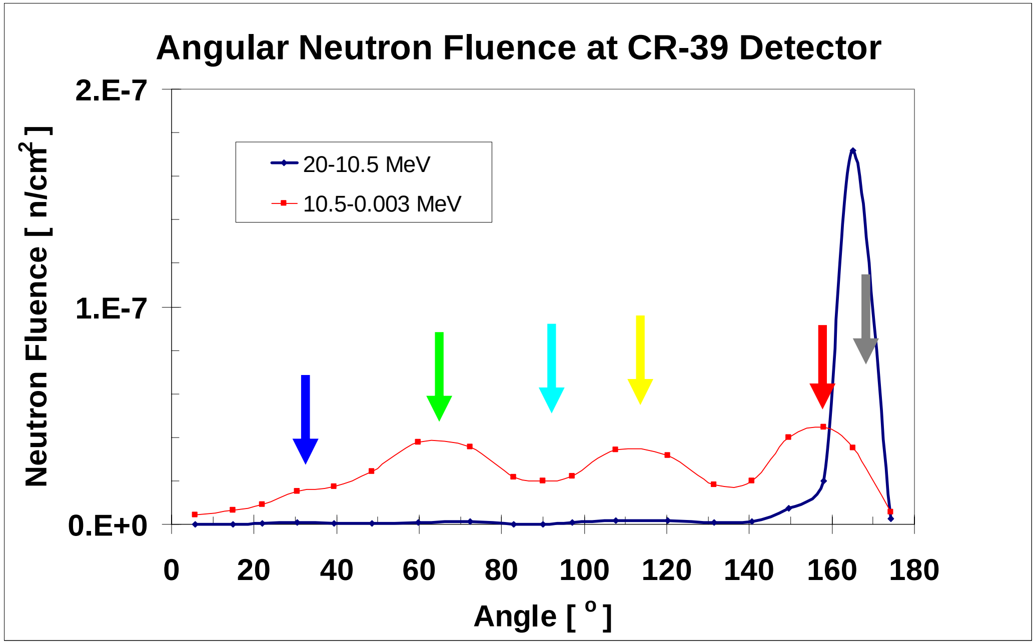
Calculated neutron fluence at the unshielded MRS detector



Background is dominated by neutrons directly from the source.

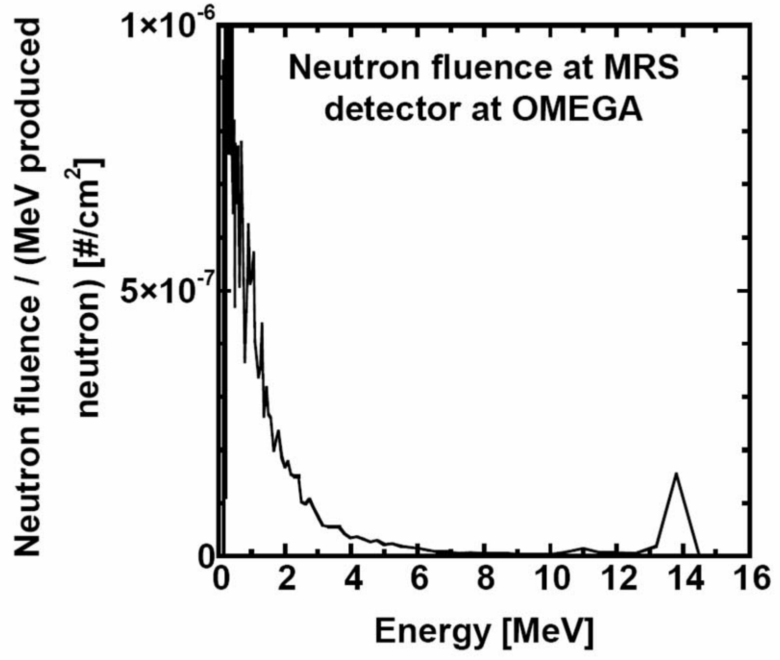
Total neutron background at MRS detector ~1 x 10^{-6} n/cm^{2}62% per produced source neutron.

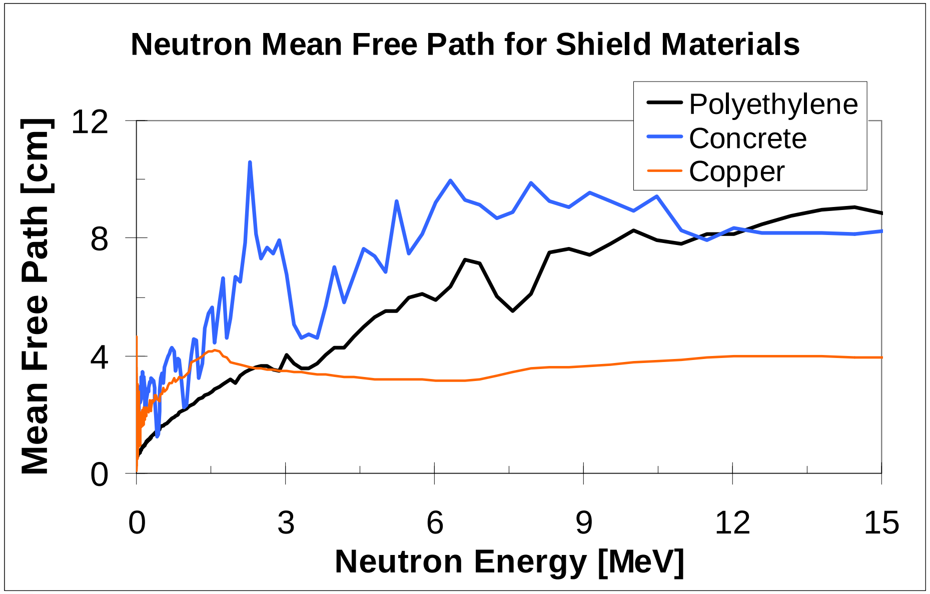




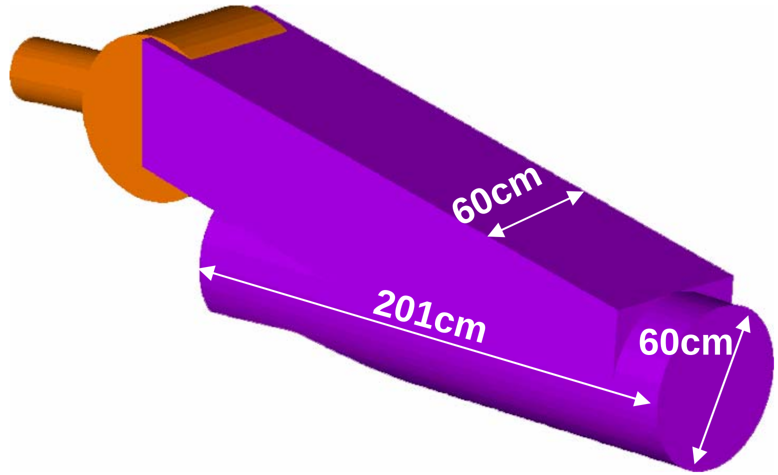
Polyethylene was selected for shielding

Polyethylene is ~2.3 times more effective than concrete and 2.4 time less dense.

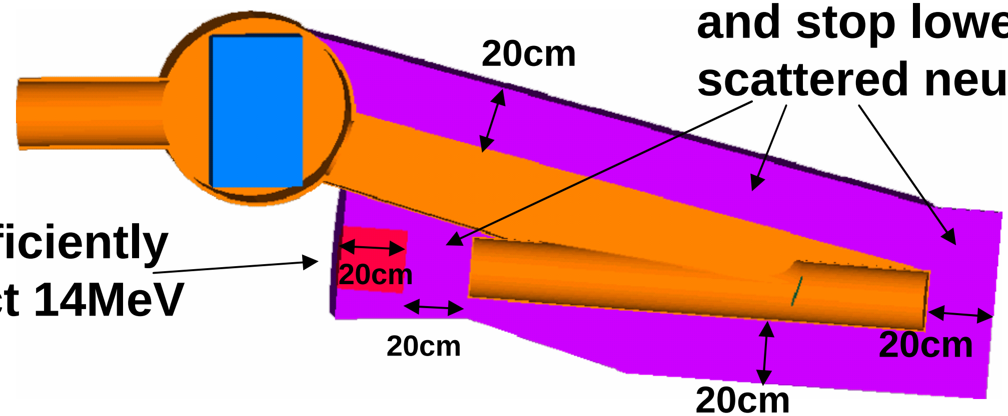




OMEGA MRS shielding point design



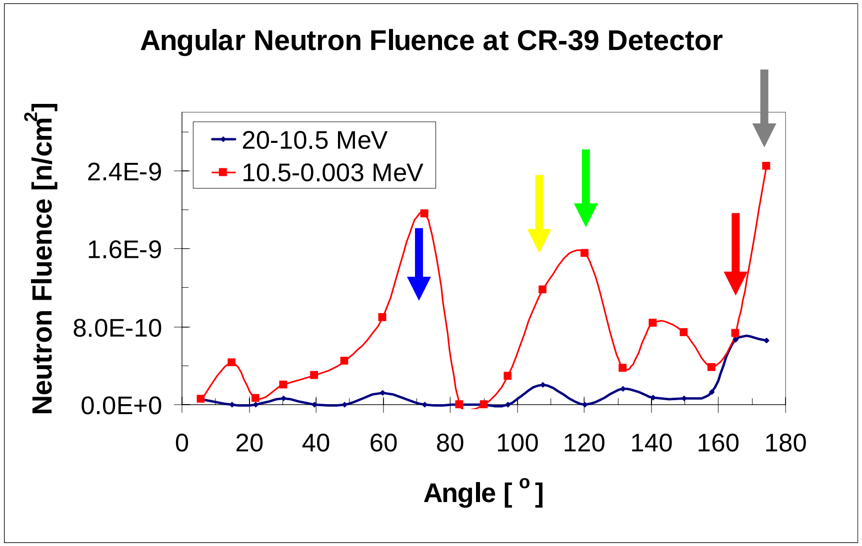
Poly is used to slow down and stop lower energy scattered neutrons

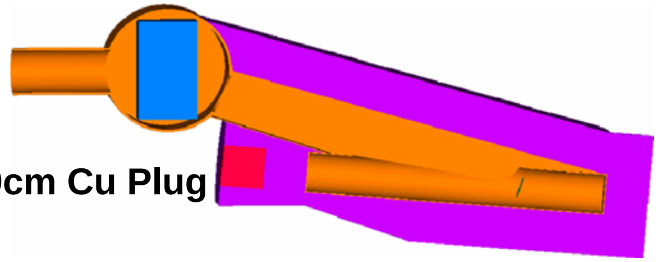


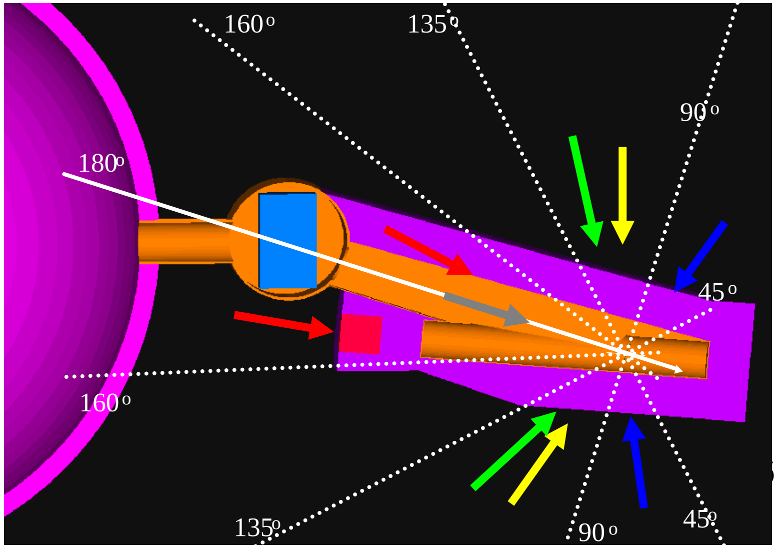
Cu is used to efficiently slow down direct 14MeV neutrons

Calculations show shielding point design will reduce neutron fluence by ~50 times

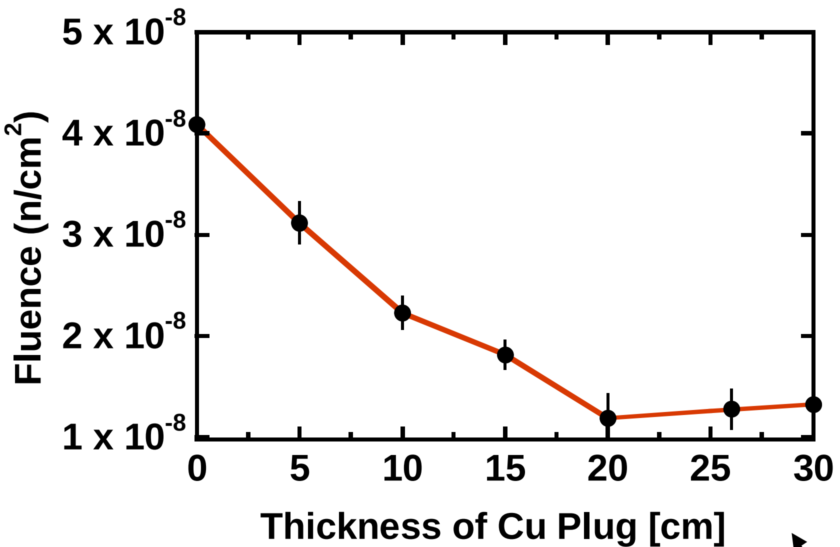
Primary neutron signal has been significantly reduced. Now neutrons scattering off walls and scattering off magnet dominate the signal. Because of space limitations no more shielding can be added.

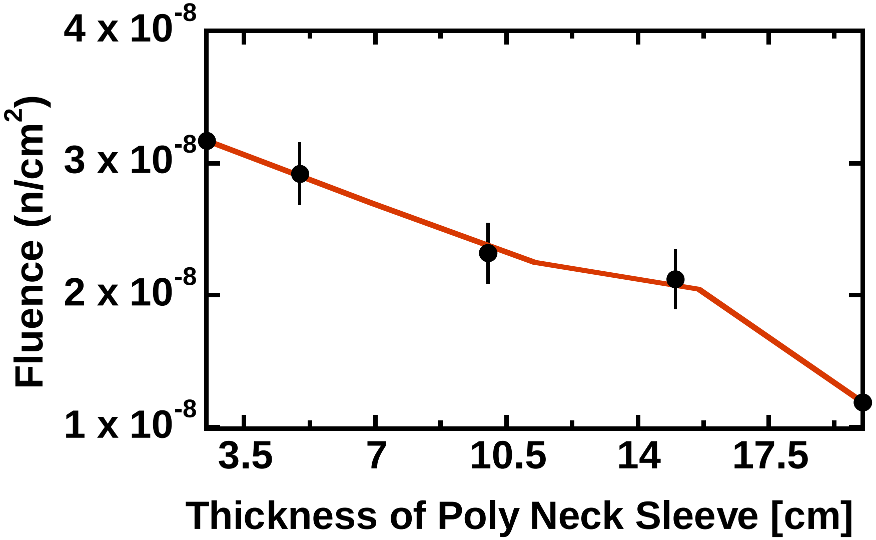


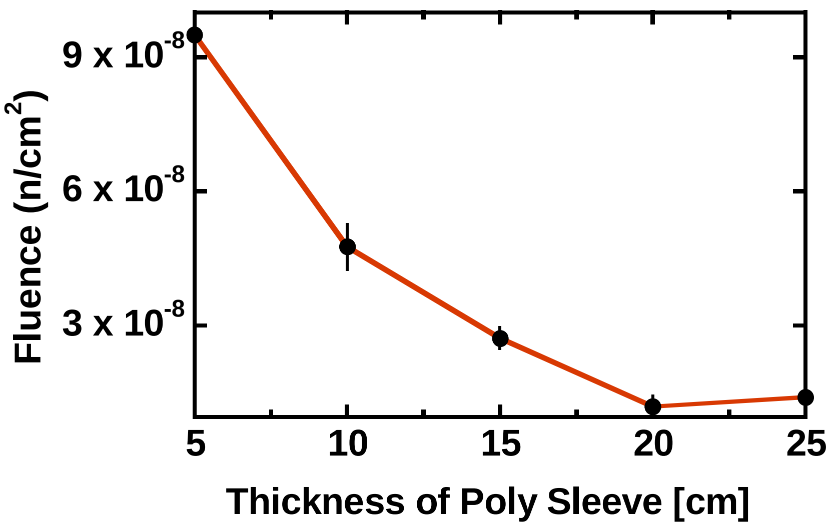


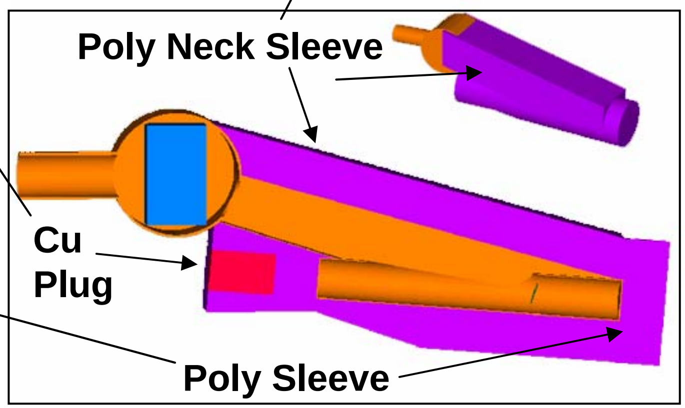


Impact of shielding parameters on total neutron fluence



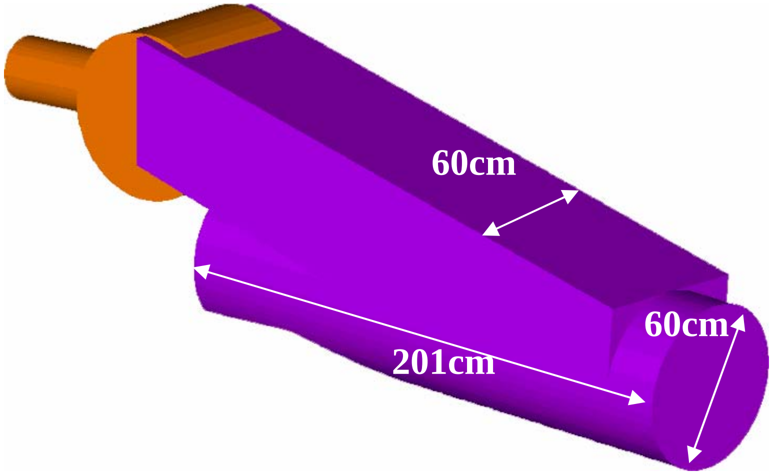


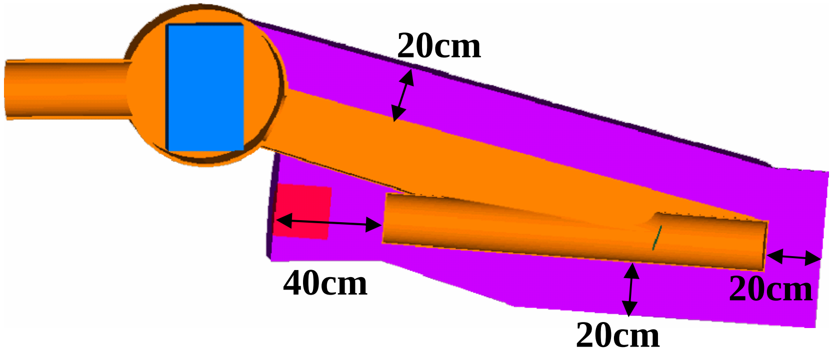




** All Fluence units normalized per source neutron

Point design installation considerations





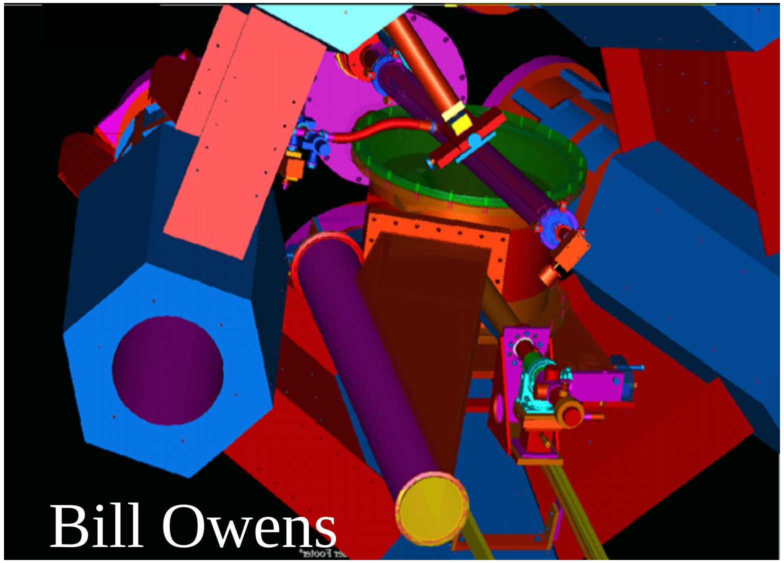
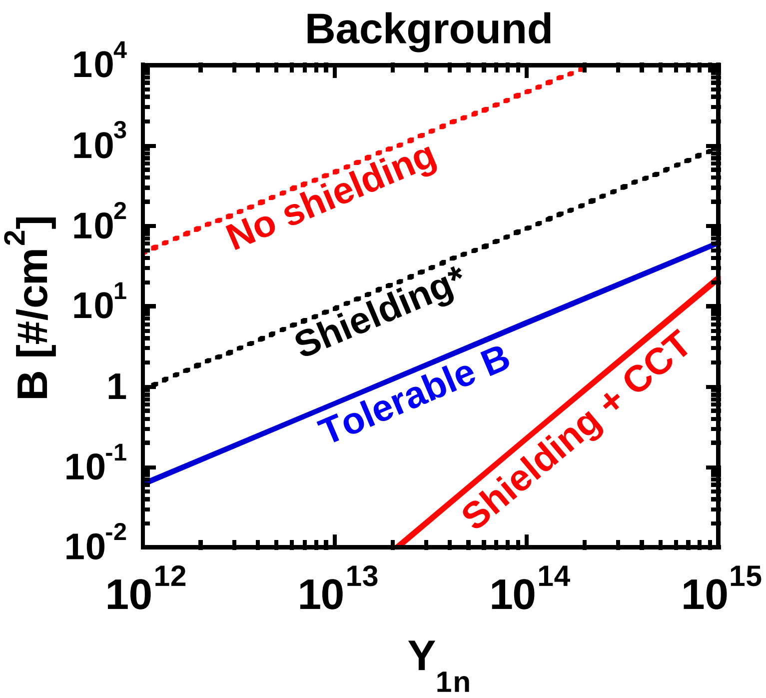
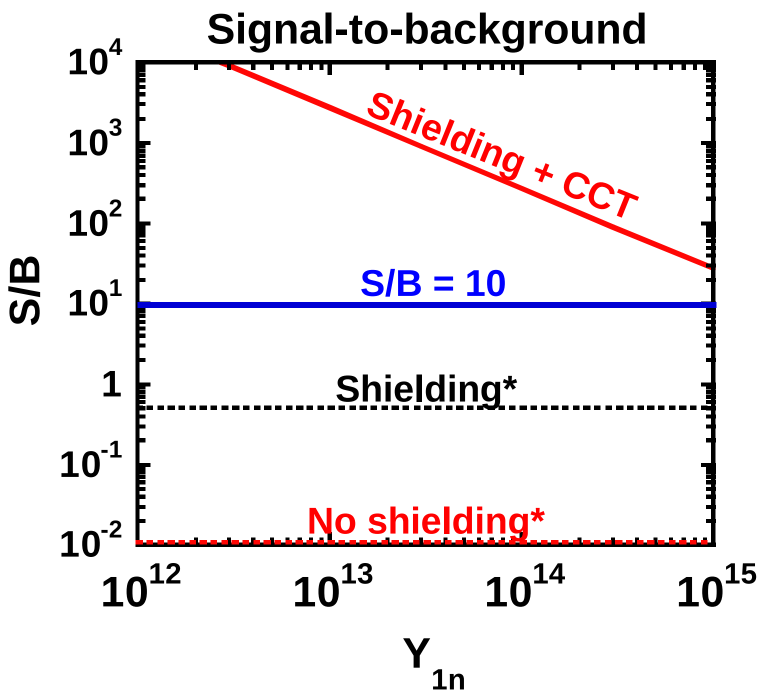


Image of MRS at the OMEGA P-10 port

The coincidence counting technique (CCT)* combined with the MRS shielding point design increases S/B >> 10





These results indicate that the MRS shielding point design can be reduced

* S. Volkmer, FP1.00007

** J. A Frenje et al., Q03.00010

Conclusions and future work

- **Shielding alone cannot reduce the neutron fluence to the required level for down-scattered neutron measurements. (The shielding point design reduces the background by ~50 times.)**

- **In combination with coincidence counting, the S/B will be increased well beyond the required level. (S. Volkmer, FP1.00007). Calculations show that the shielding could be reduced below the point design while maintaining the S/B > 10.**

- **Current shielding design probably needs to be slightly modified to fit in available space after the restrictions are clearly identified.**