LA-UR-17-30411
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Intended for: Mark-IV Target Neutronics Design Review

Issued: 2017-11-13

Lujan Mark-4

Physics design proposal

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Nov 15, 2017

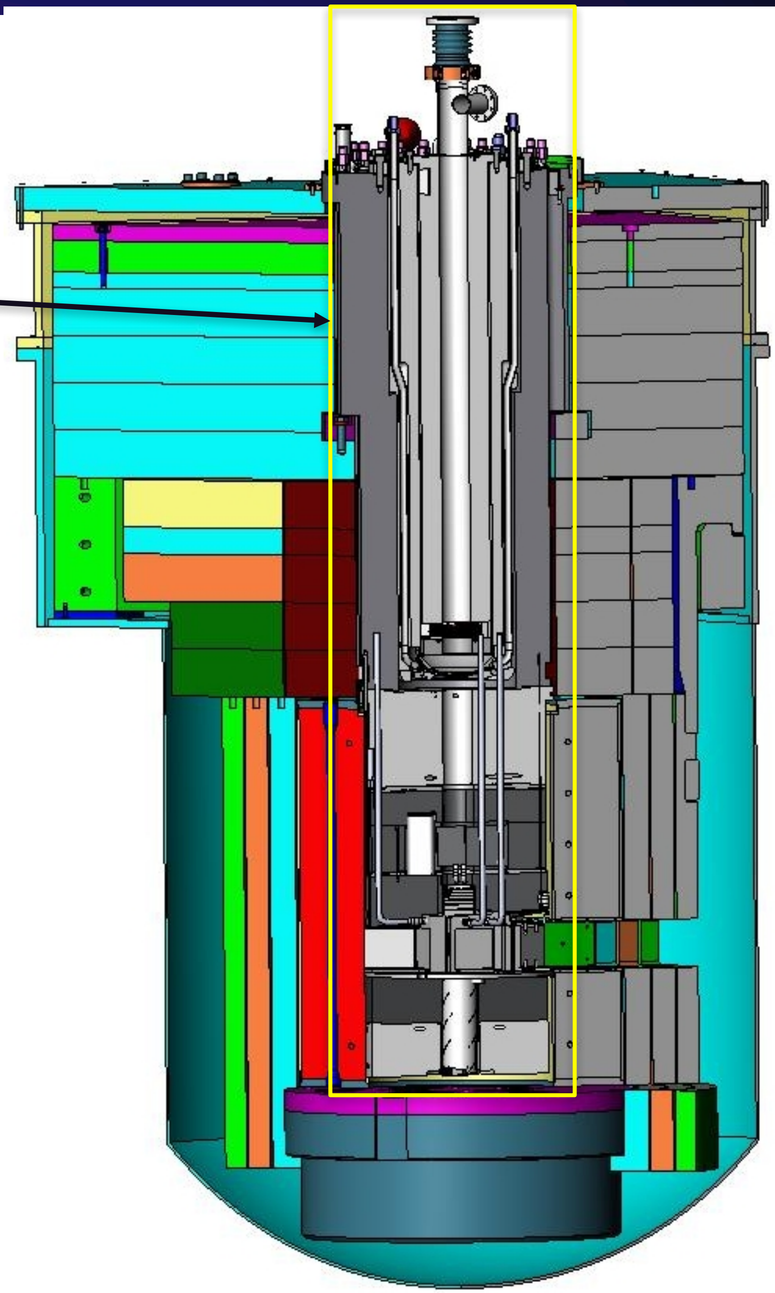
Los Alamos NATIONAL LABORATORY EST. 1943

Lujan TMRS: historical perspective

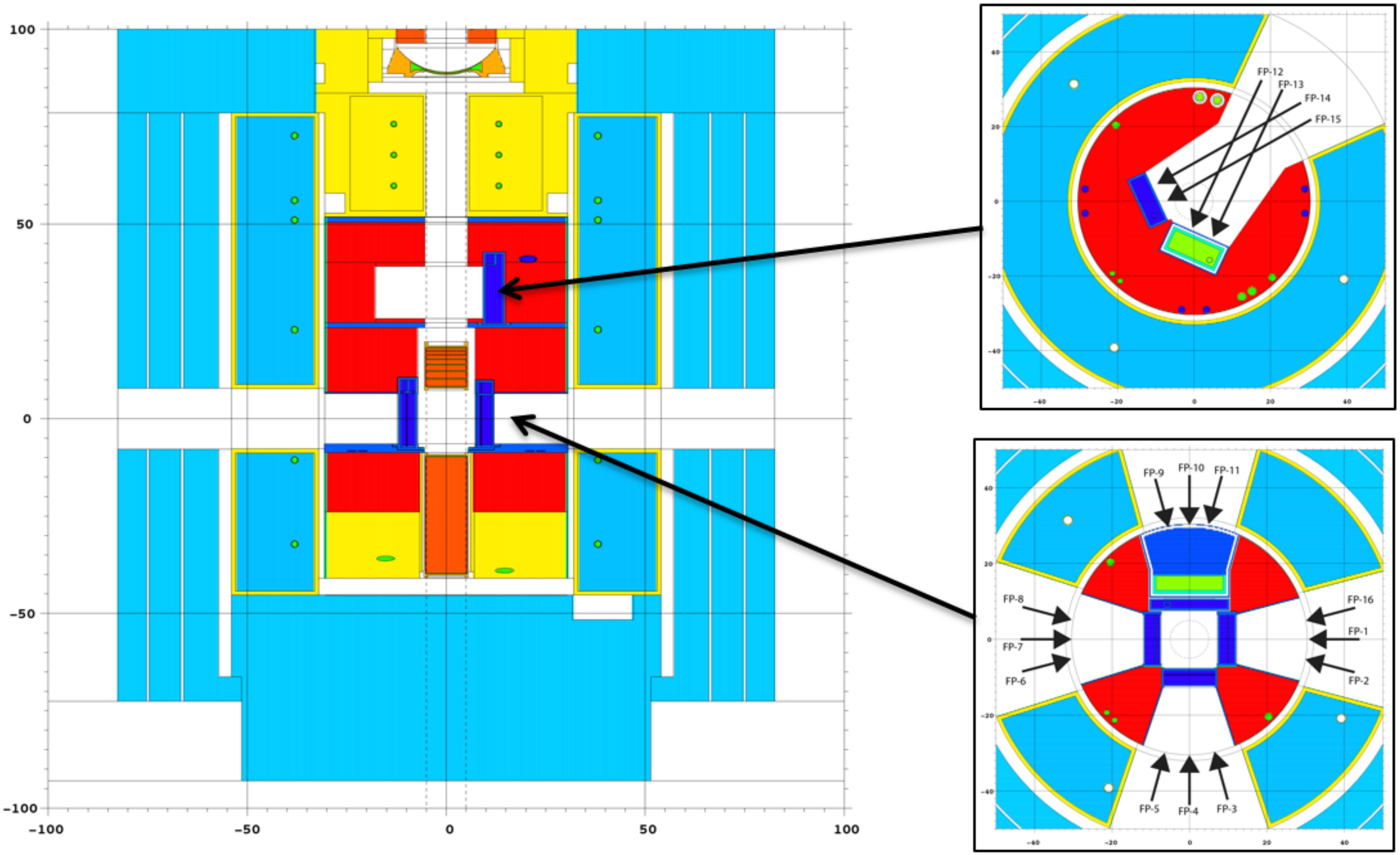
- **Mark-0: first attempt (1995-1998)**
- **Mark-I: rather short lifetime (1998-2001)**
  - Lead reflector cooling failure
- **Mark-II: minor changes from Mark-I (2002-2010)**
  - Lead reflector replaced by beryllium
  - Degradation of performance in last two years of operation
- **Mark-III: (2010-today)**
  - Ta-clad tungsten targets
  - Cold Be reflector-filter
  - Other small optimizations (MACOR, pre-moderators)
- **Mark-IV: planned for installation during 2020 outage**
  - Major redesign of the upper tier, offering harder neutron spectra for upper-tier FPs
  - Redesign of the high-resolution (HR) moderator
  - Preserve the rest of Mark-III features (Ta-clad tungsten targets, cold be reflector-filter)

Lujan TMRS Mark-III: facts

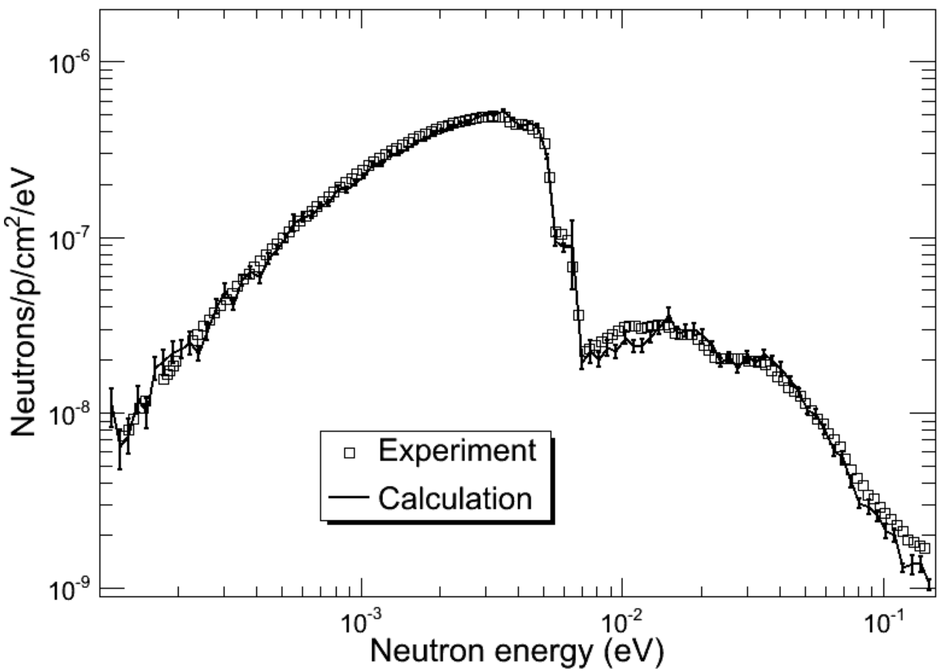
- **TMRS assembly**
  - 3 meters tall
  - 60 cm in diameter
- **Split tungsten target**
  - Ta-clad, water cooled
- **Vertical proton beam delivery**
- **16 neutron flight paths in two horizontal planes**
- **Upper tier:**
  - 2 FPs water moderator
  - 2 FPs liquid hydrogen moderator
- **Lower tier:**
  - 9 FPs three water moderators
  - 3 FPs liquid hydrogen moderator coupled with beryllium reflector-filter

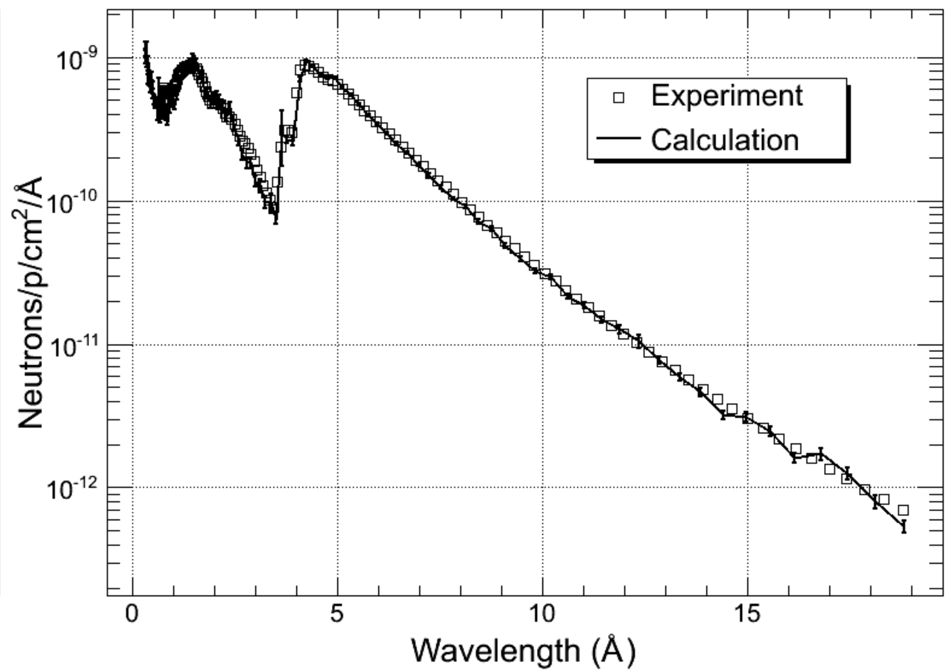


Lujan TMRS: detailed MCNP model



Validation: cold neutron spectra

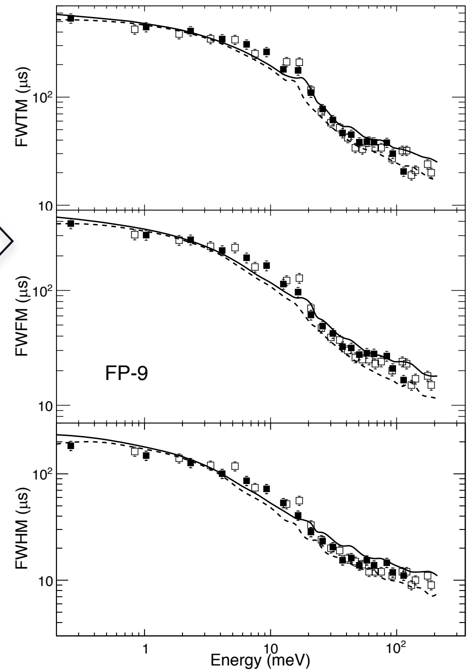




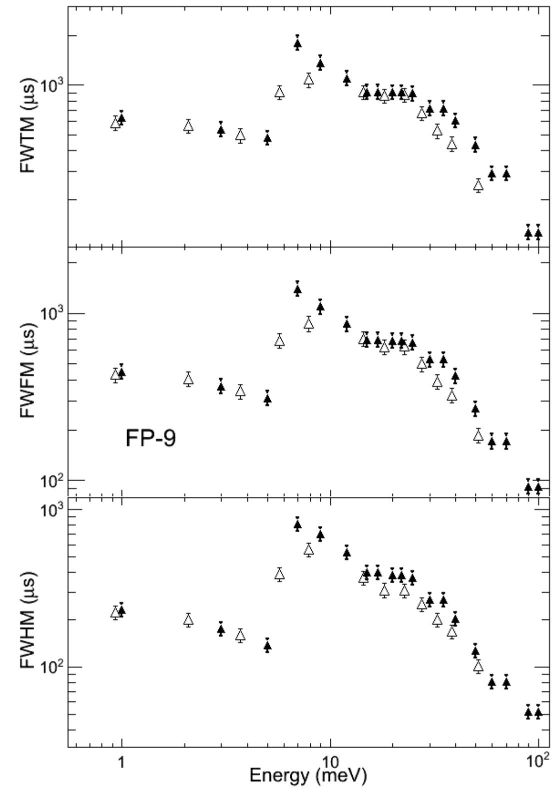
M. Dubey, M. S. Jablin, P. Wang, M. Mocko, J. Majewski; Eur. Phys. J. Plus 126 (2011) p110

Validation: time emission spectra

Mark-II
FP-9

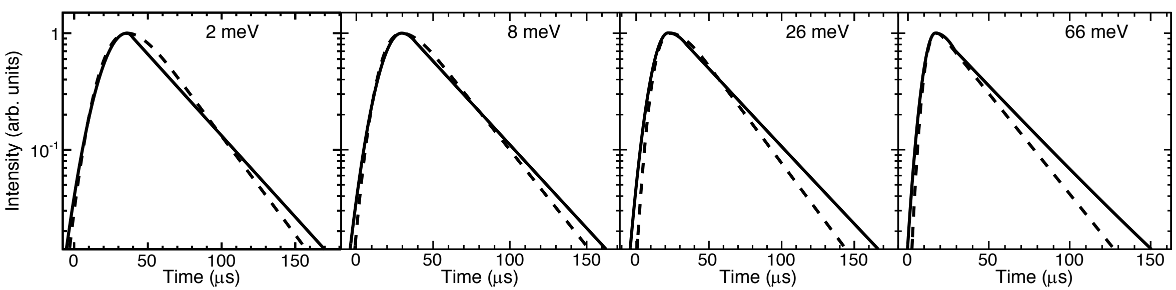


Mark-III: FP-9



M. Mocko and G. Muhrer, NIMA 704 (2013) 27-35

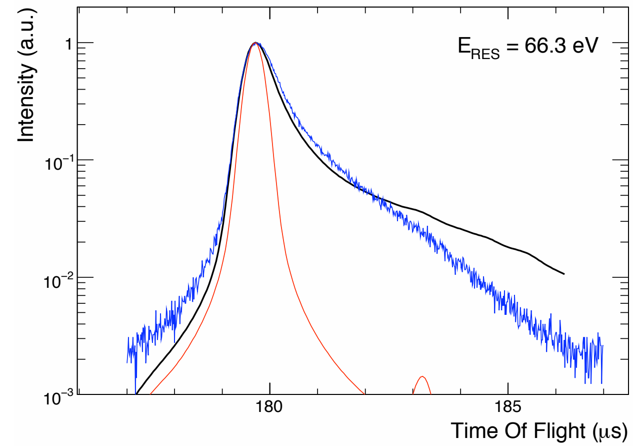
FP-5 time emission spectra (Mark-II)

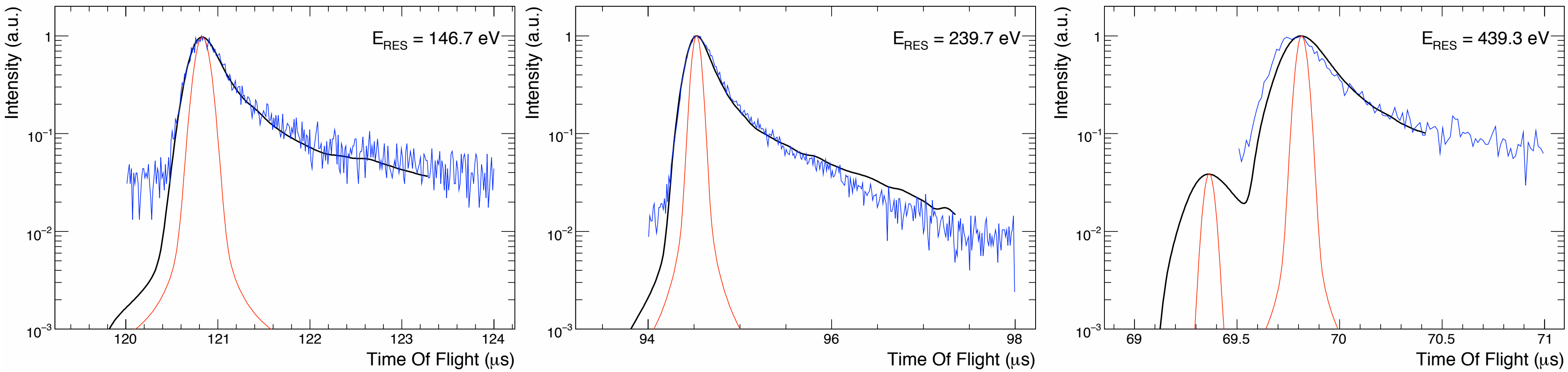


M. Mocko et al., NIMA 632 (2011) 101-108

Validation: response function FP-14 simulations

- **Better understand the resolution and energy calibration**
- **Detailed simulations with real proton pulse distribution for FP-14**
- **Time emission spectra 1 eV - 1 keV**
- **Experimental data for $^{238}U(n,g)^{239}U$**

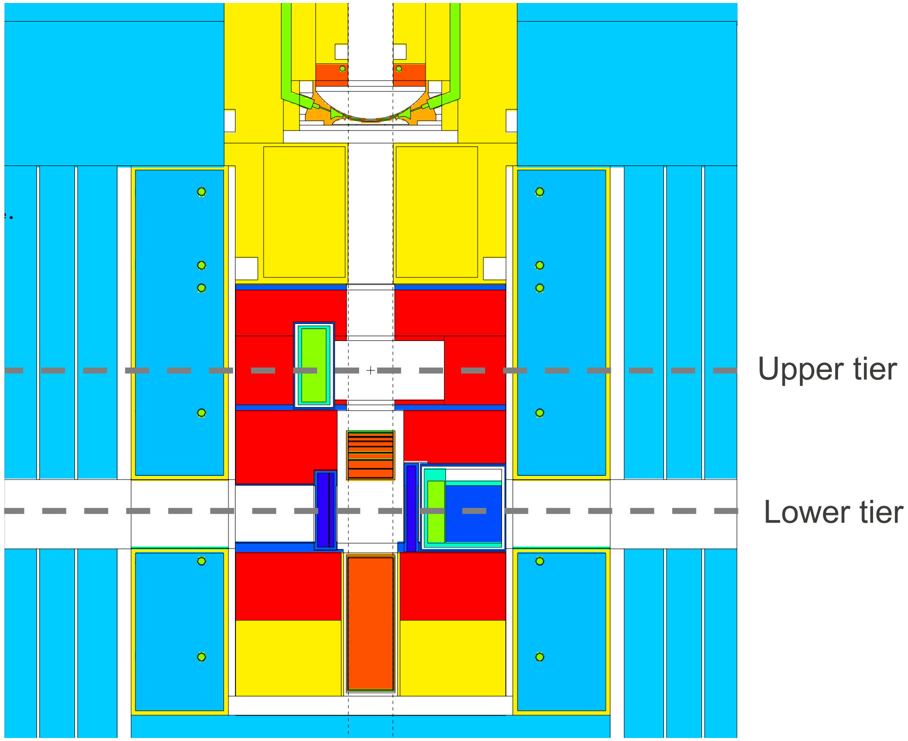




Data
ENDF
ENDF⊗SIM

Lujan TMRS Mark-IV design philosophy

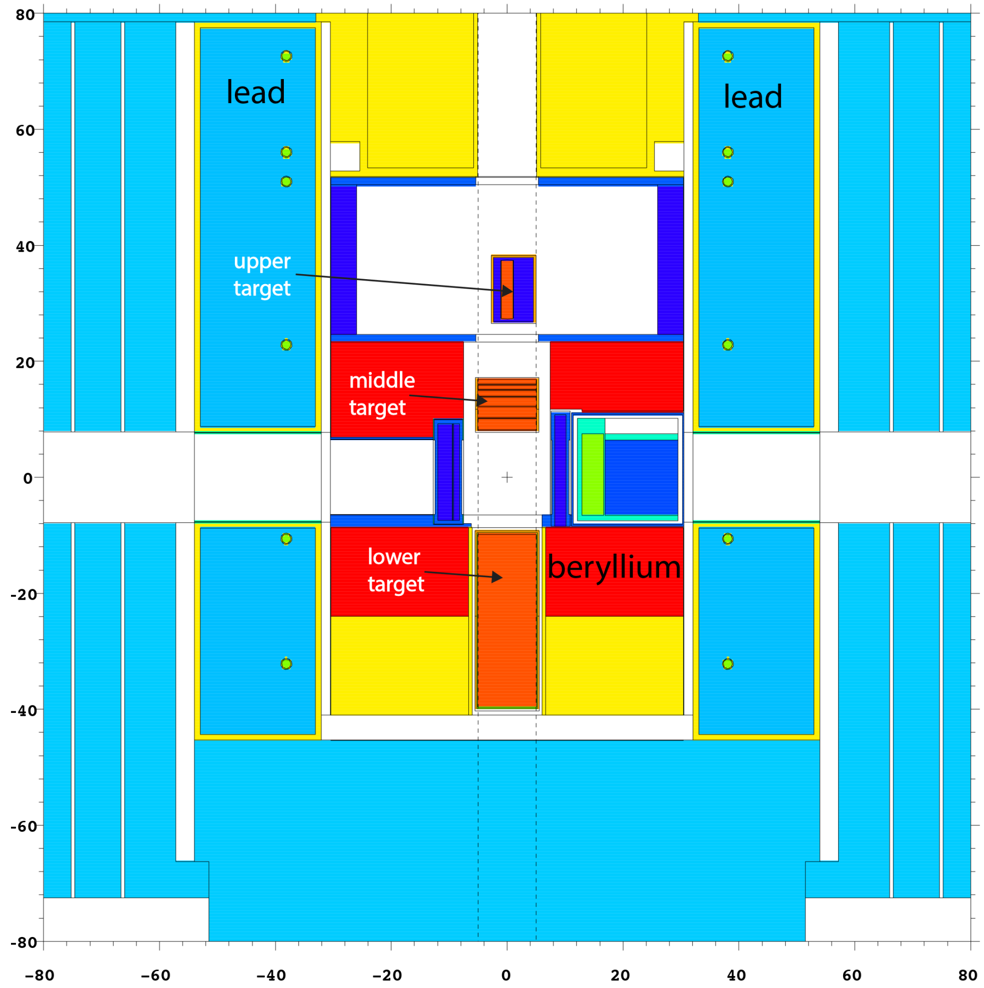
- **Growth areas emerging in nuclear science fields**
- **Fundamental challenges**
  1. TMRS is optimized for superior thermal and cold neutronic performance (material science)
  2. Emerging applications need more medium energy neutrons (nuclear physics)
- **How do we retain (1) and enable new experiments (2) at the same time?**



GOOD: Two-tiered design naturally lends itself to serve two very different customer bases.
BAD: We are not producing more neutrons overall!

Lujan Mark-IV: proposed design changes

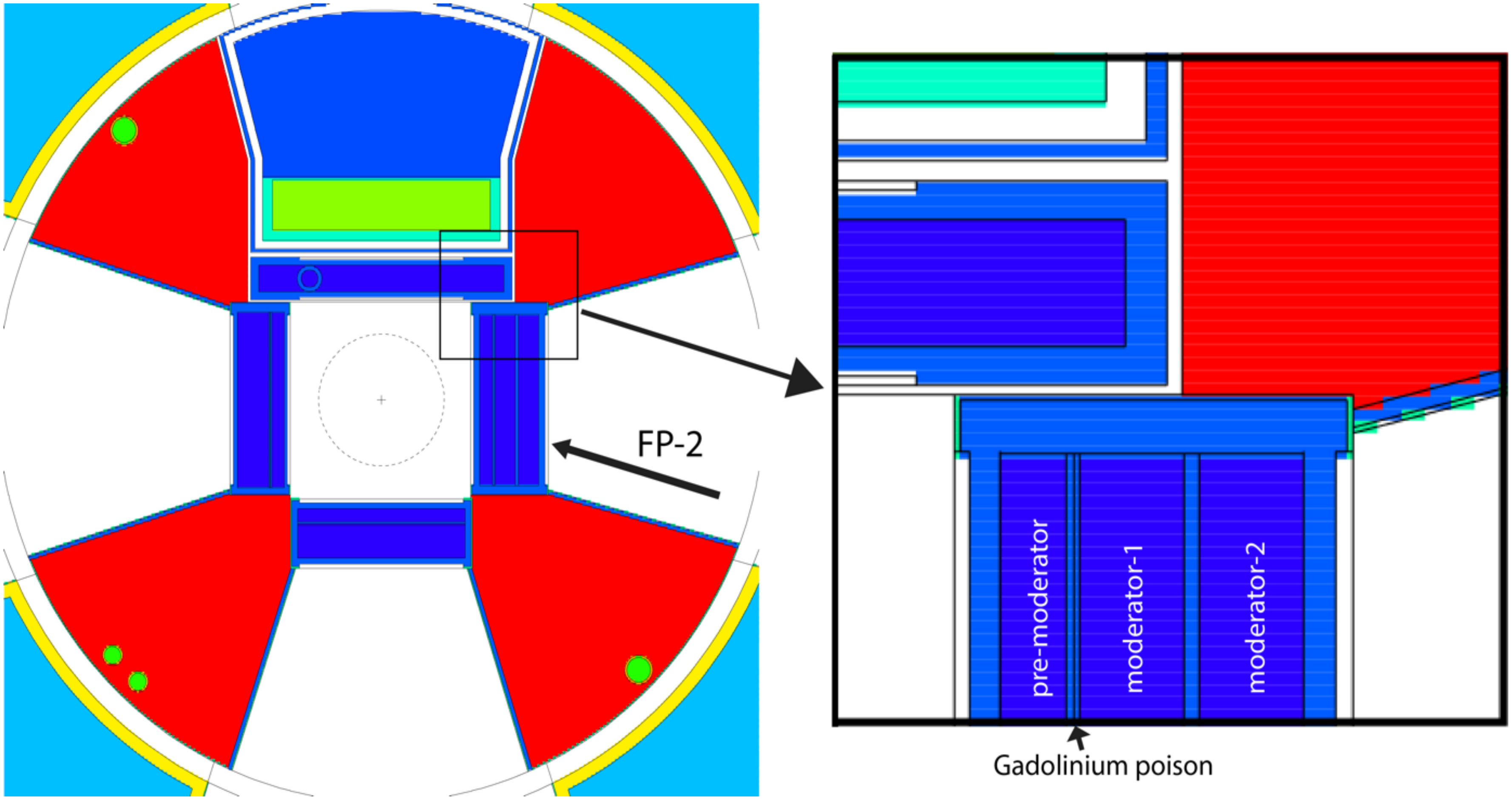
- **Lower tier:**
  - Redesigning the High-Resolution moderator, offers more flexibility (two modes of operation)
  - Optimizing the middle target thickness and position
- **Upper tier:**
  - Complete redesign main components:
    - Moving the upper target into the field of view
    - Removing beryllium reflector
    - Water liner for outer lead reflector
    - Water liner separating the lower from upper tier neutronically
  - Compact target with moderator wings



Lower tier design changes

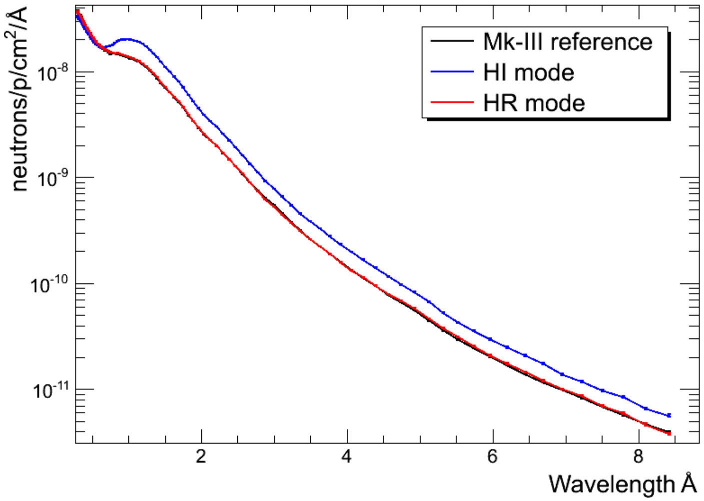
- **High-resolution moderator redesign**
  - Thinner pre-moderator
  - Additional volume that could be filled with water upon demand
  - Changes enable two modes of operation: high resolution and high intensity
  - High-resolution mode
    - Small increase (6%) in thermal neutron intensity over Mark-III
  - High-intensity mode
    - 60% increase in thermal neutron intensity over Mark-III
    - Resolution worsening by about 10%
- **Rest of lower-tier moderators intact**
  - Two water high-intensity moderators
  - Partially-coupled liquid hydrogen moderator with Be reflector-filter
- **Middle target**
  - Taller (thicker) middle target yields slightly higher neutron output for lower tier

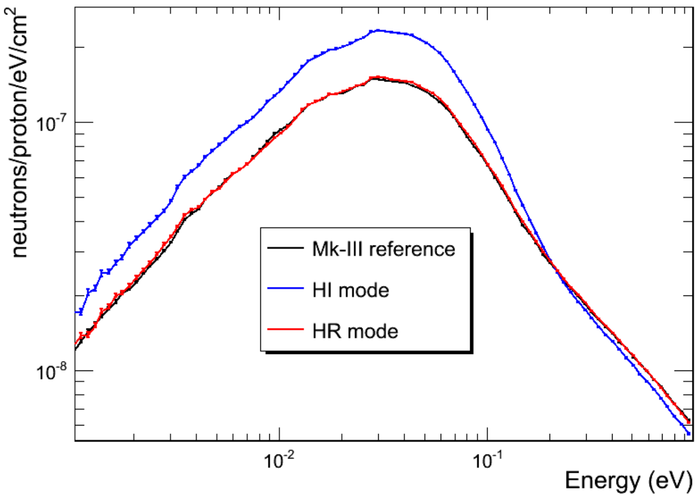
High resolution moderator redesign



Moderator-2 filled with water: HI-mode
Moderator-2 filled with helium: HR-mode

HR moderator performance



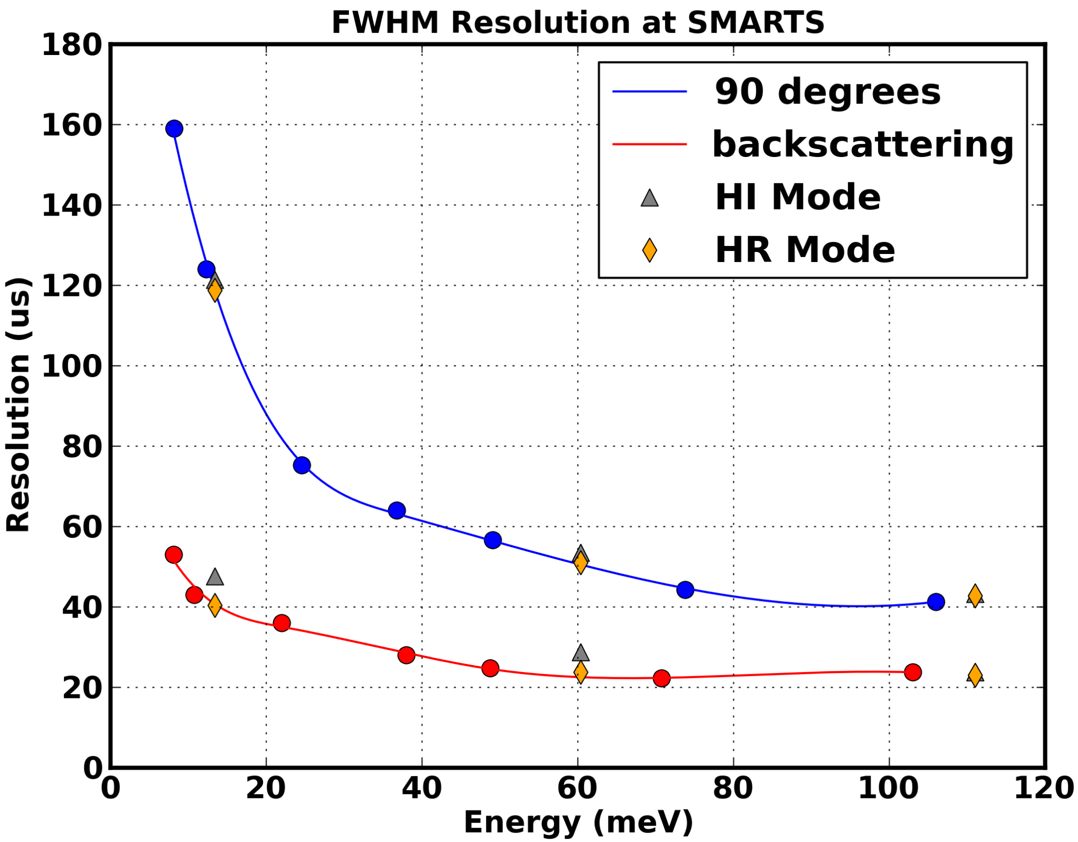


Ratio at maximum flux:	
HI Mode	HR Mode
1.84	1.06

Total gain in thermal flux:	
HI Mode	HR Mode
57%	6.1%

Increase in background (E_n > 0.5 eV):	
HI Mode	HR Mode
-0.3%	13.7%

HR moderator performance



Change in resolution: (backscattering)

Energy (meV)	HI Mode (us)	HR Mode (us)
13.4	+7.0	-0.4
60.4	+6.3	1.2
111.0	+1.0	0.2

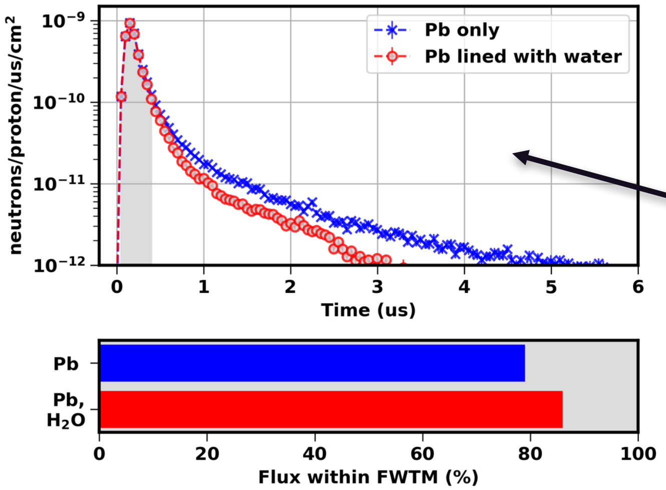
Change in resolution: (backscattering)

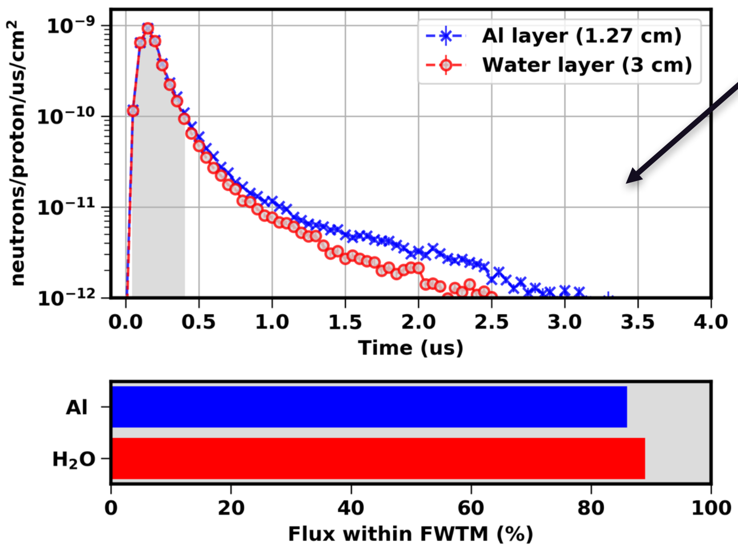
Energy (meV)	HI Mode	HR Mode
13.4	+17.1%	-0.9%
60.4	+27.9%	+5.5%
111.0	+4.6%	+1.1%

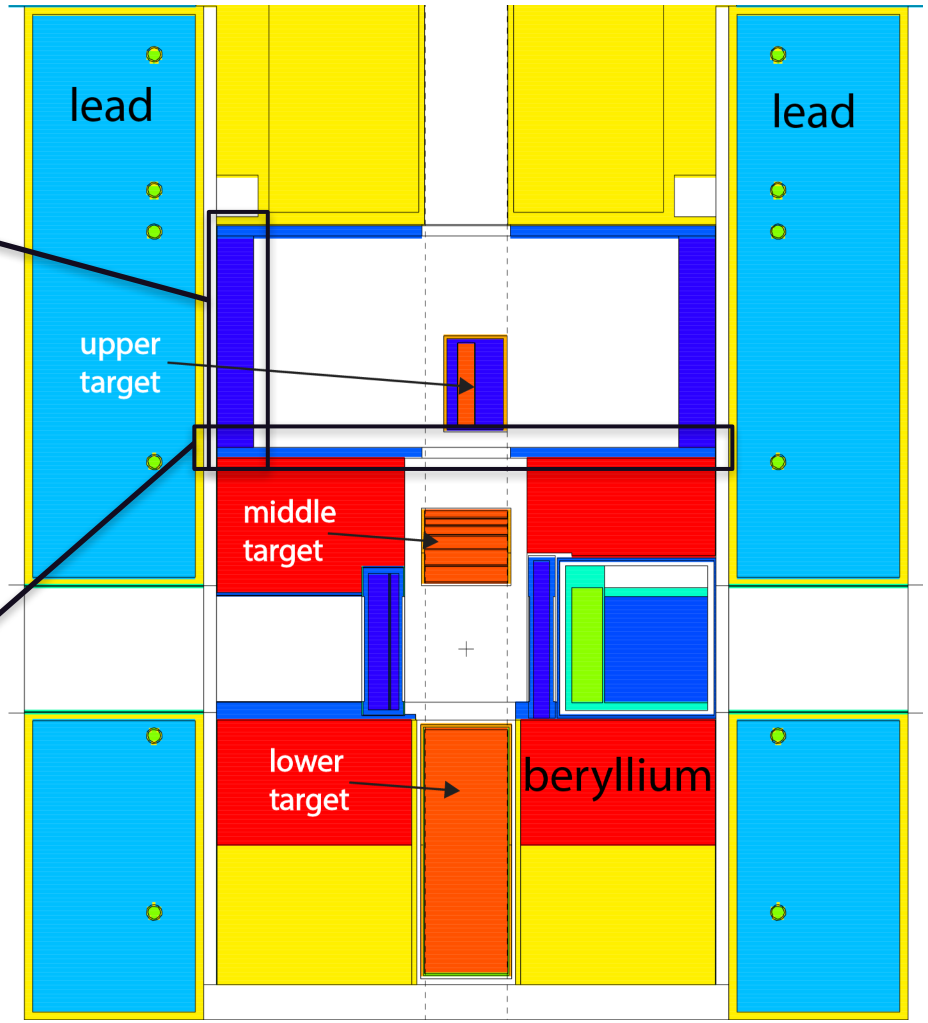
Upper-tier design

- **Improving performance in keV region (1 eV to 100 keV)**
- **Increasing neutron flux:**
  – Undermoderated system
  – Production region in line of sight of neutron FPs
- **Improving resolution:**
  – eliminating reflector material
  – small neutron production region
- **Resulting design**
  – Removing beryllium reflector and upper-tier moderators
  – Compact spallation target
  – Small moderator covering the field-of-view
  – Water layers neutronically separating the outer reflectors, lower tier from the upper-tier flight paths

Minimizing reflector influence

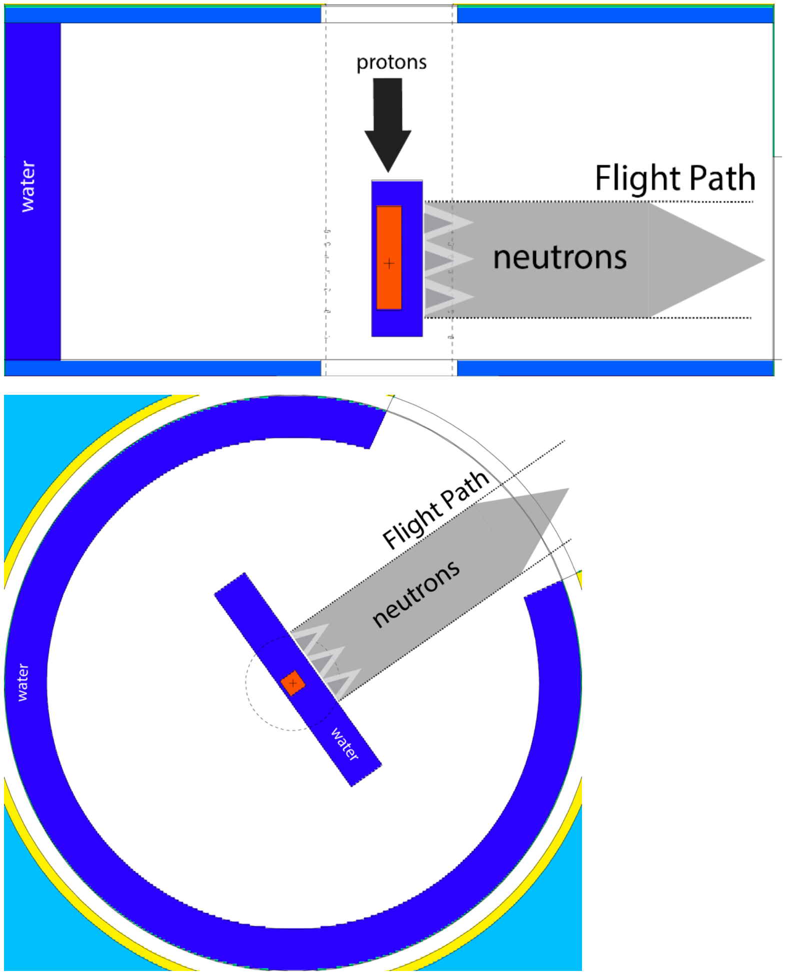




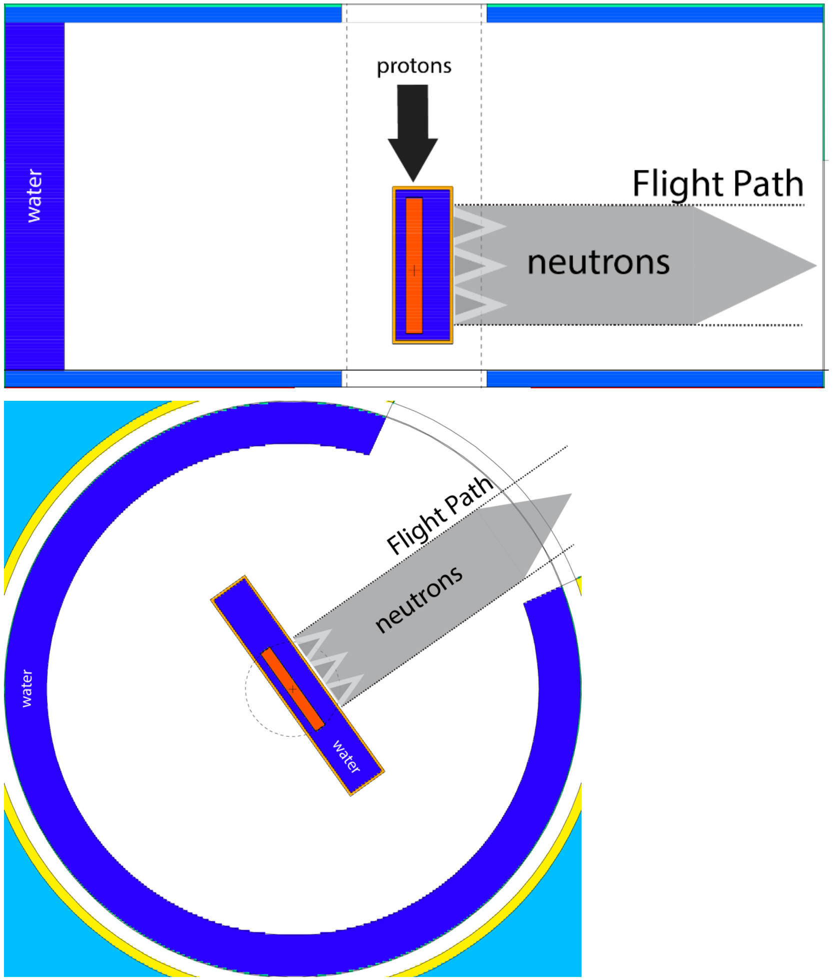


Compact target-moderator assembly

"rod" design

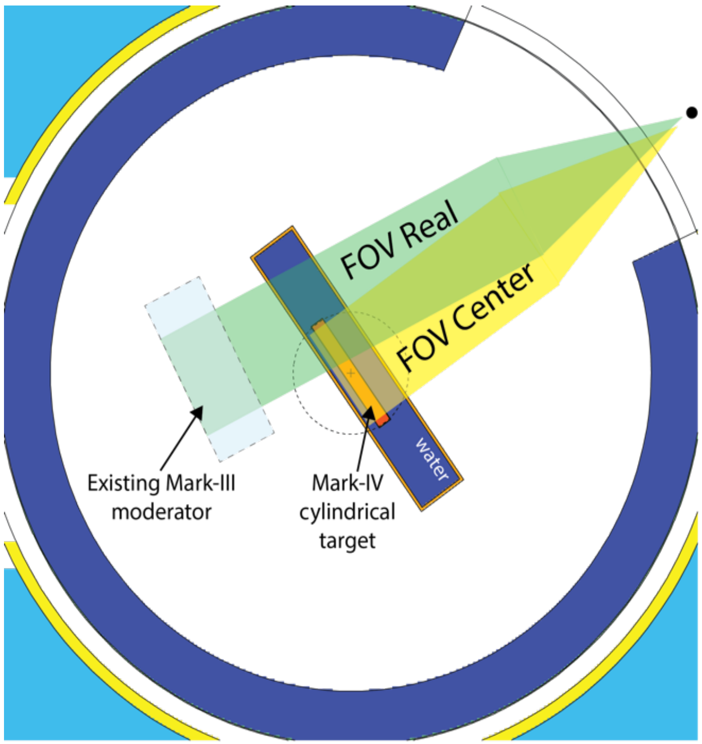


"disk" design

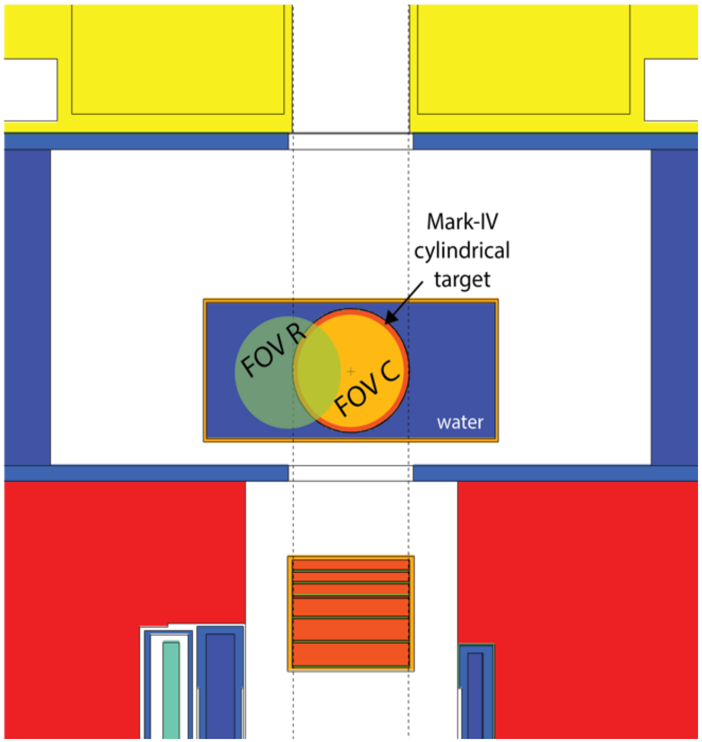


Upper tier field of view discussion

plane view



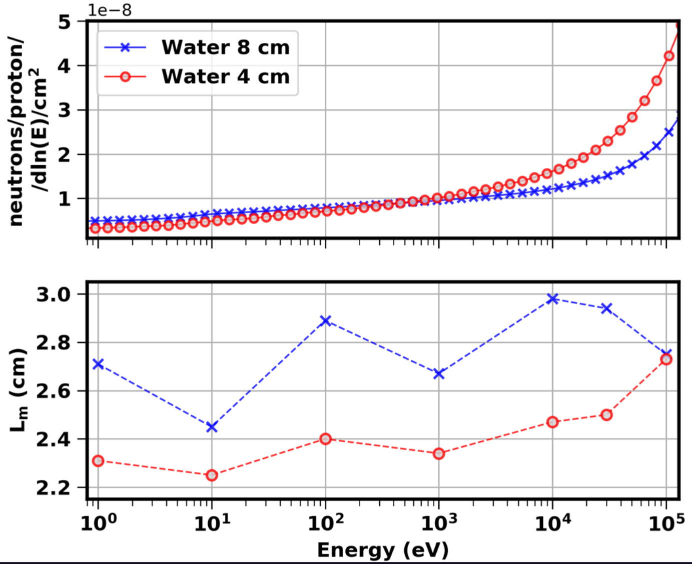
elevation view



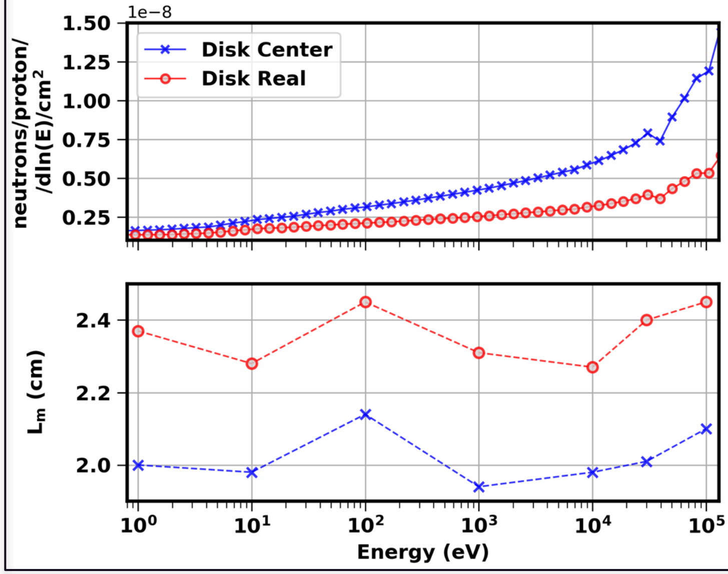
- **FOV Real: Existing upper-tier flight paths**
- **FOV Center: Requires flight path reconfiguration**

Optimization studies

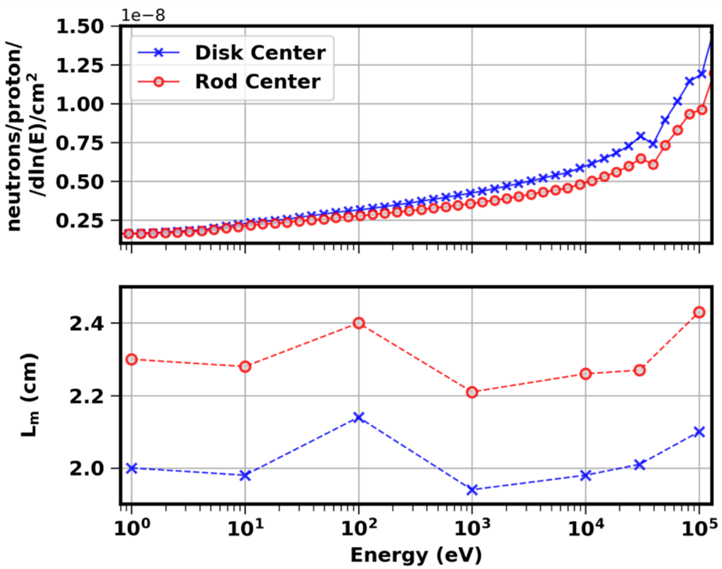
Moderator thickness



Field-of-view

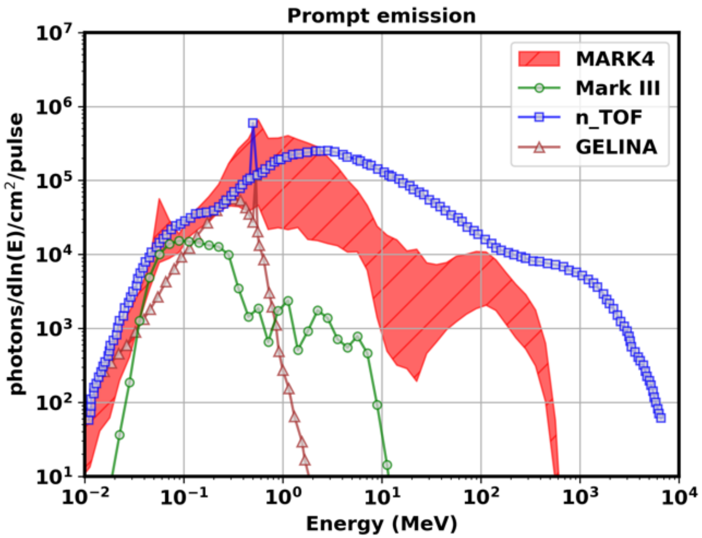


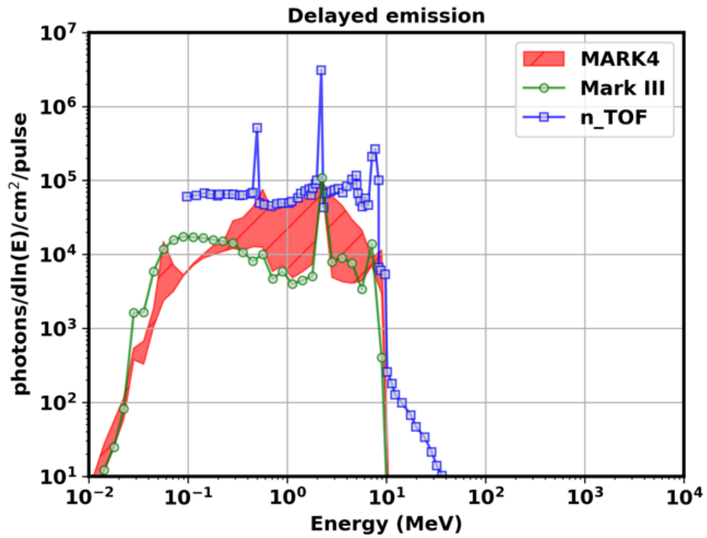
Disk versus Rod geometry

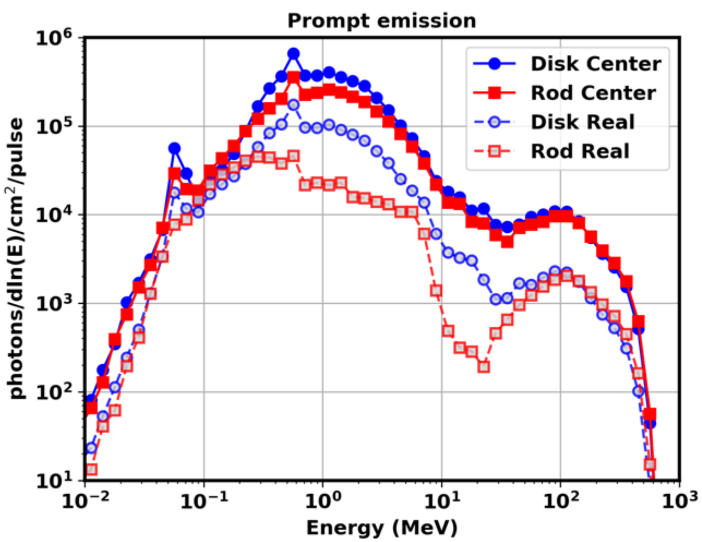


L_m is flight path length uncertainty calculated from FWHM of time emission spectra

Measure of background: gamma emission

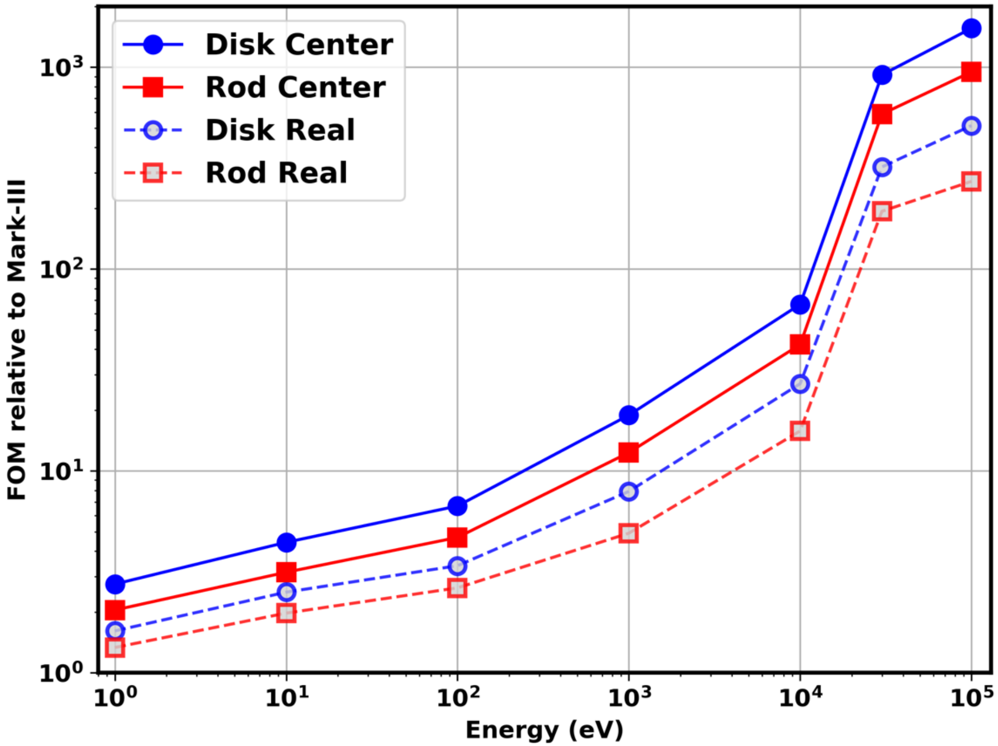






Prompt emission = gamma flash (<1 μs)
Delayed emission = everything else (after 1 μs)

Upper tier design: conclusions

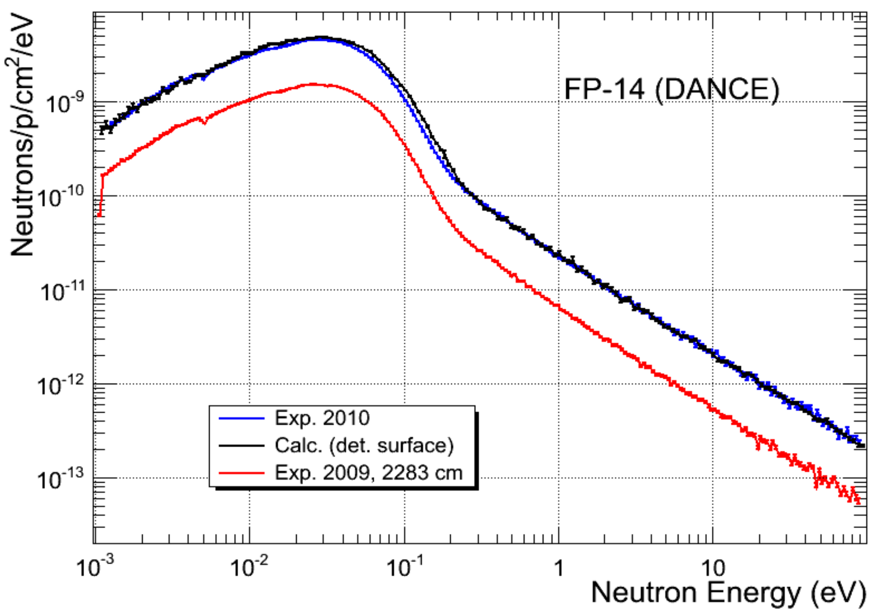


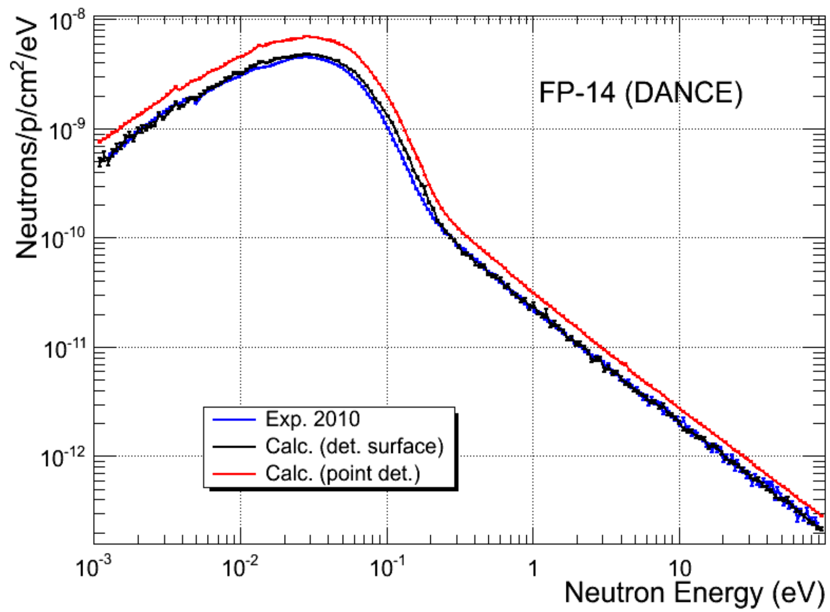
$$FOM(E) = \frac{\phi(E)}{FWHM^2(E)}$$

Design	FOV	FOM ratio	g-ray background ratio (prompt : delayed)	M4/M3 lower-tier flux (%)
Disk	Center	4	9 : 2	72
	Real	2	2 : 2	72
Rod	Center	2	6 : 2	74
	Real	1	1 : 1	74

Backup slides

Validation: thermal neutron spectra





Excellent reproduction of experimental data. Difference between Exp. 2009 and Exp. 2010 corresponds to end-of-life Mark-II versus Mark-III, demonstrating degradation of performance.

Excellent reproduction of experimental data when simulating the experimental setup. The results obtained with point detector over-estimate the experimental data due to uncertainty in beam spot area determination.