Constraining the effective mass dependence of the Nuclear Symmetry Energy

Kyle Brown

September 7th, 2017

This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University. Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

Outline

otivation

evious Experimental Work

w Experimental Setup

iRA Upgrade

icroball

eutron Wall

harged-particle Veto Wall

tlook

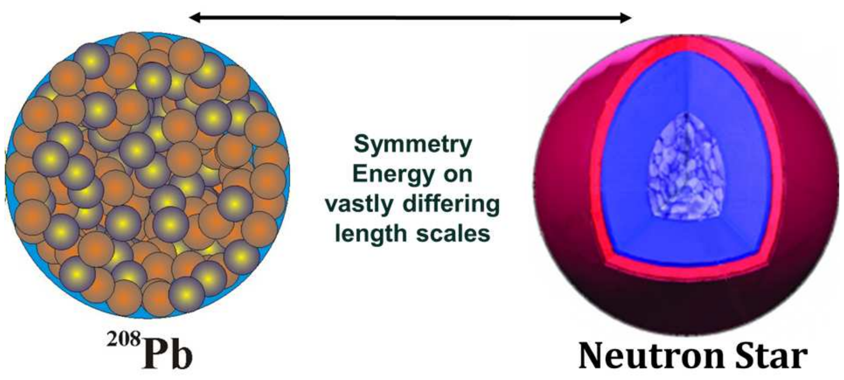
Motivation

Nuclear Equation of State

$$\frac{E}{A}(\rho,\delta)=\frac{E}{A}(\rho,\delta=0)+E_{sym}(\rho)\delta^2$$

$$\delta=\frac{\rho_n-\rho_p}{\rho_n+\rho_p}$$

***Symmetry Energy*: cost for N≠Z**
(largest EoS uncertainty)



C.J. Horowitz, J. Piekarewicz, Phys. Rev. Lett. 86 (2001) 5647

Symmetry Energy affects

- Neutron Skin Thickness
- Fragment Flow
- Yield Ratios
- Isospin Diffusion

Astrophysics

- Neutron star cooling
- Mass-radius relation in neutron stars
- Production of r-process nuclei

Effective Mass

e isovector effective mass describes how the potential energy depen
the momentum

$$m^* = \frac{m}{1 + \frac{m}{p}\frac{\partial V}{\partial p}}$$

saturation density this reduction is ~70% from the free nucleon mass

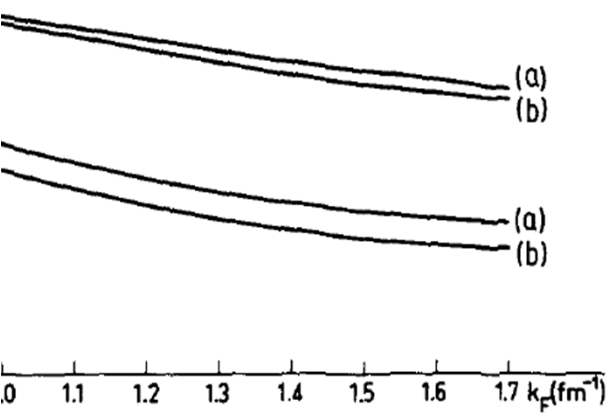
asymmetric matter the potentials that neutrons and protons feel are
pected to be different → effective-mass splitting

$$\Delta m^*_{np} = \frac{m^*_n - m^*_p}{m_N}$$

Effective-Mass Splitting

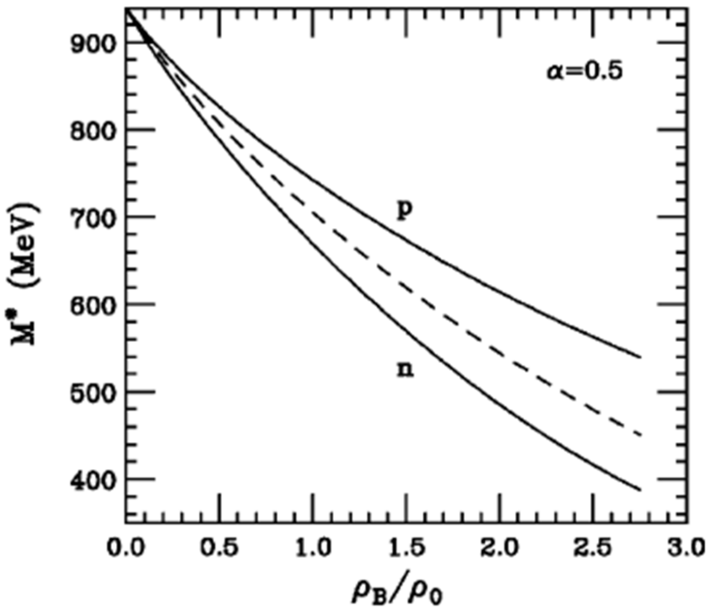
- Neutron rich systems show effective-mass splitting
- Greater isospin asymmetry leads to more mass splitting

dau-Fermi Liquid Theory

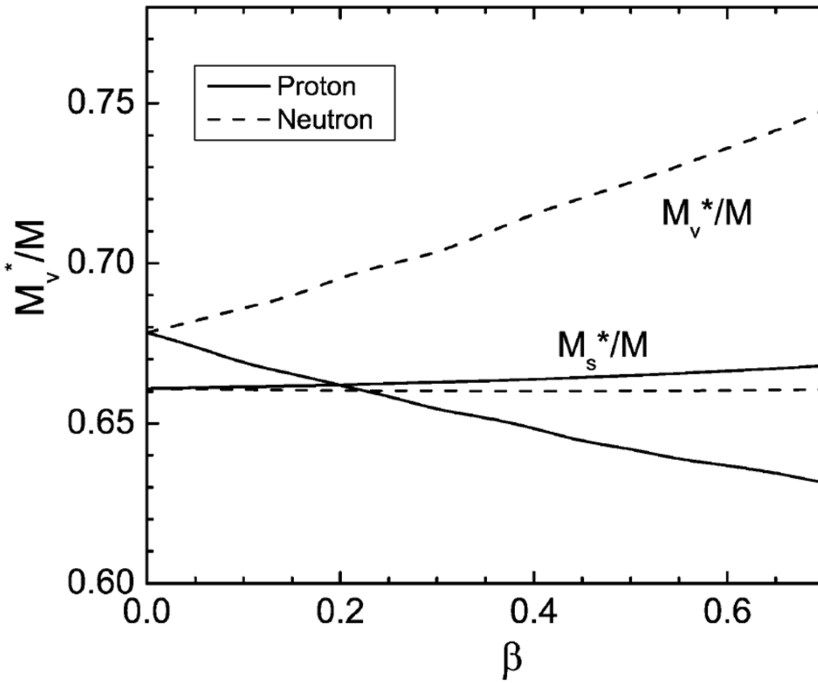


Sjoberg, Nuc Phys A265, 511-516 (1976)

RMFT



B. Liu, et al Phys Rev C65, 045201, (2002)



M. Zhong-Yu et al, Phys Lett B, 606 170-174, (2004)

Theoretical models disagree whether $m_p^* > m$ or $m_n^* > m_p^*$

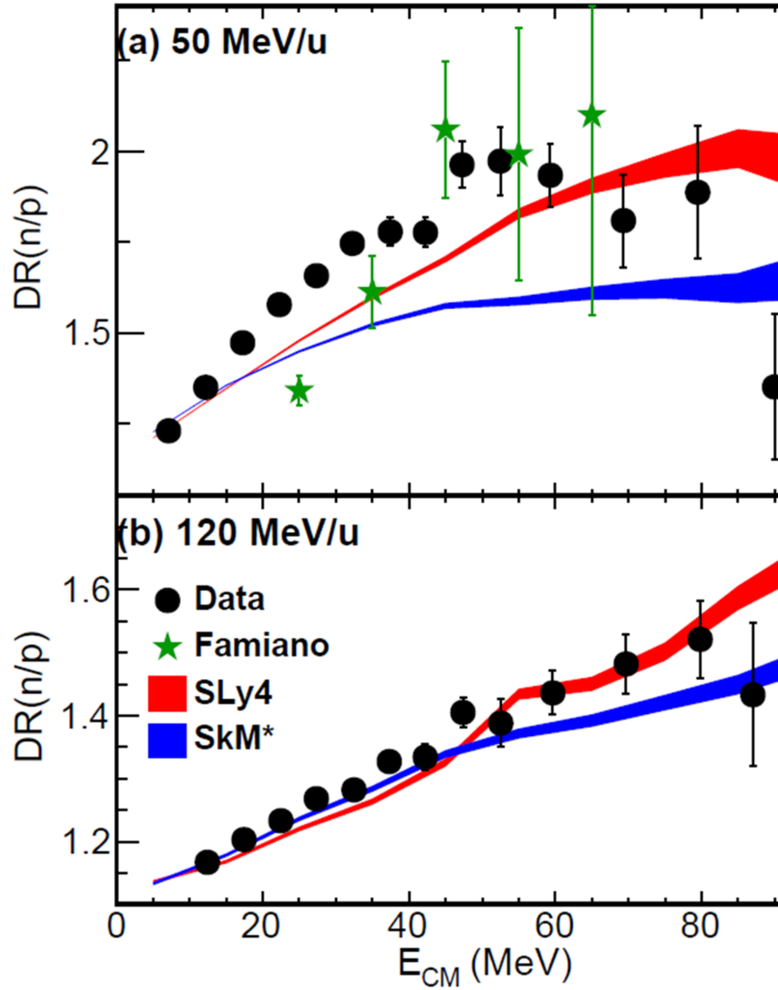
Experimentally Constraining Δm^*_{np}

evious work:

- ivide n/p ratios for two reactions
- inimize systematic uncertainties in detection fficiencies of neutrons and charged particles
- educes effects from the Coulomb force
- ncertainties large between theory and experiment

ture Improvements:

- ingle ratio has better sensitivity BUT need better nderstanding of experimental system → NPTool imulations
- eed to probe at higher energies
  - Requires upgrade to our experimental setup



D. D. S. Coupland *et al*, PRC **94**, 011601 (R) (201

Experimentally Constraining Δm^*_{np}

4030 & e15190

lan to measure the n/p ratio for the near symmetric systems ^{40,48}Ca +
,^{64}Ni and the very asymmetric systems ^{40,48}Ca + ^{112,124}Sn at 50, 140
eV/A

ne light, symmetric systems:

Can make extensive comparisons with nearly all transport models → E_{sym} and m
constraints

ne asymmetric systems:

More sensitive to momentum dependence and less sensitive to density depende
of mean field potential

nese data will add to the heavy, mass symmetric (^{112,124}Sn+^{112,124}Sn,
oupland et al) already measured at 50, 120 MeV/A

Upgrading the Experimental Setup

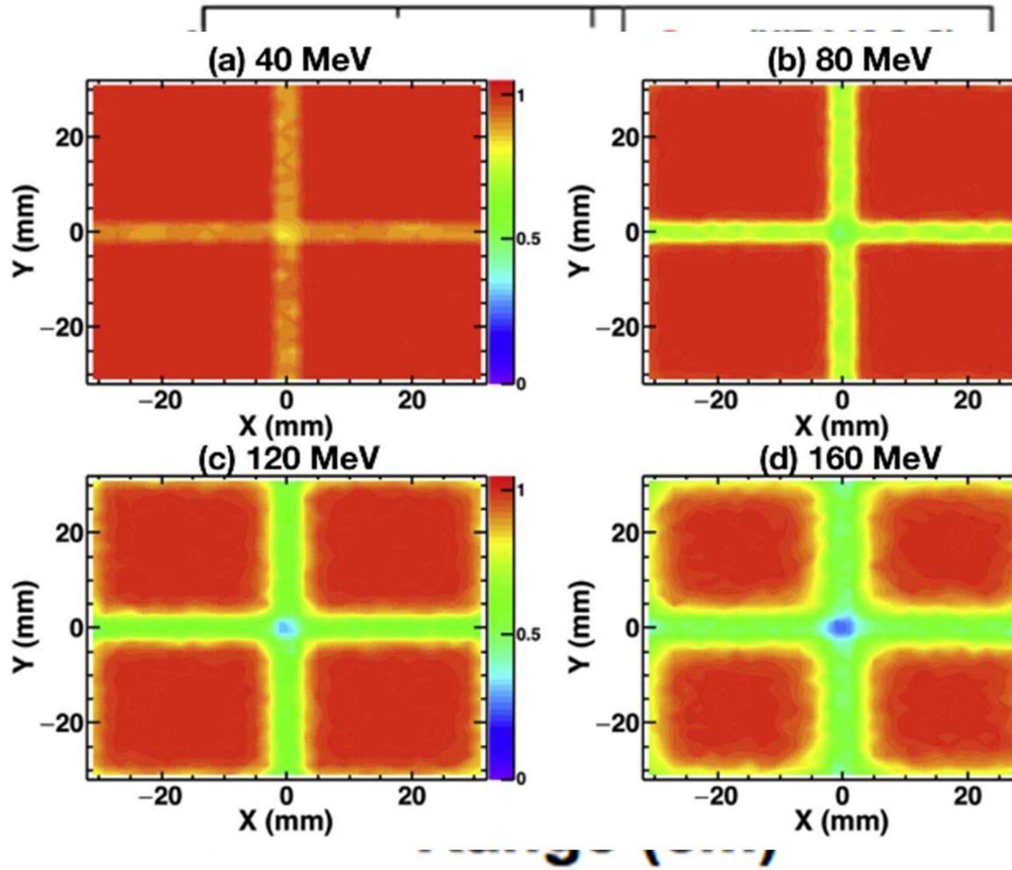
HiRA Upgrade

are exchanging the 4-cm-long CsI(Tl) stals for 10 cm crystals -> increased amic range

Isotope	4 cm CsI (MeV)	10 cm CsI (MeV)
p	116	200
d	157	265
t	186	314

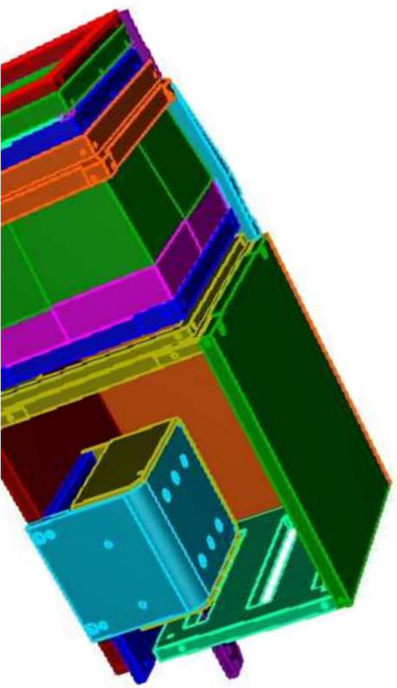
s increase comes at the cost of loss in ciency due to out-scattering and nuclear ctions

s efficiency is also a function of energy, so most dramatic losses will occur for the hest energy particles

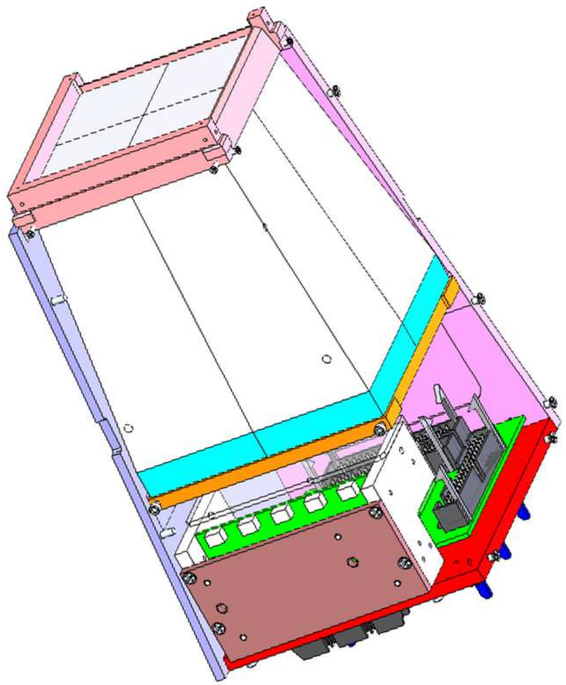


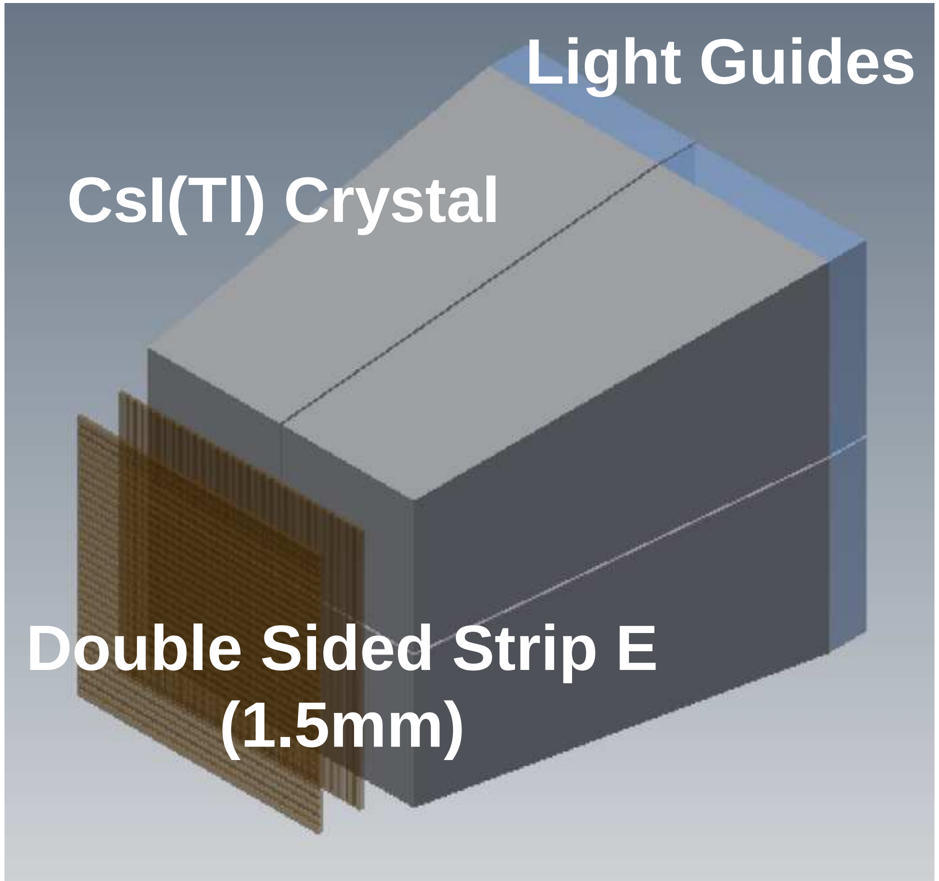
HiRA Upgrade

ld HiRA



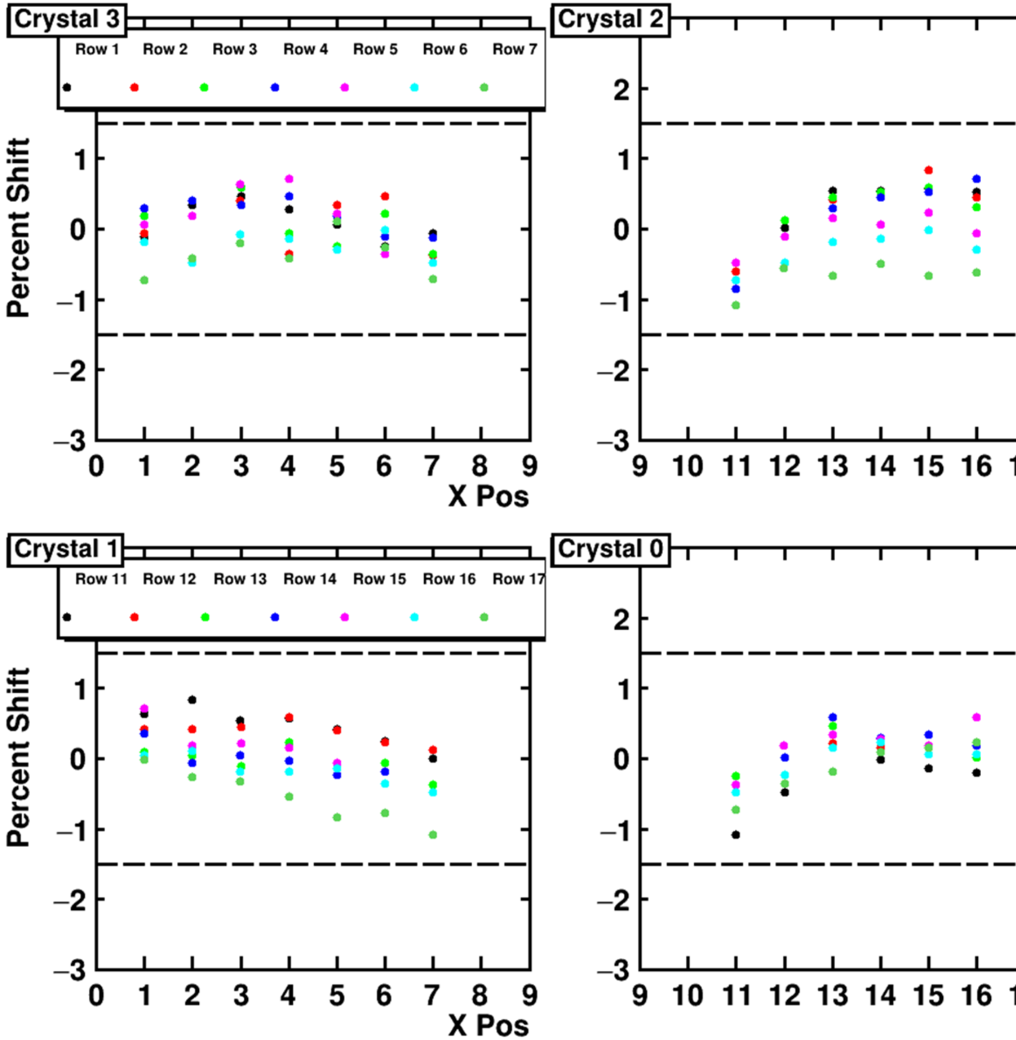
HiRA Upgrade



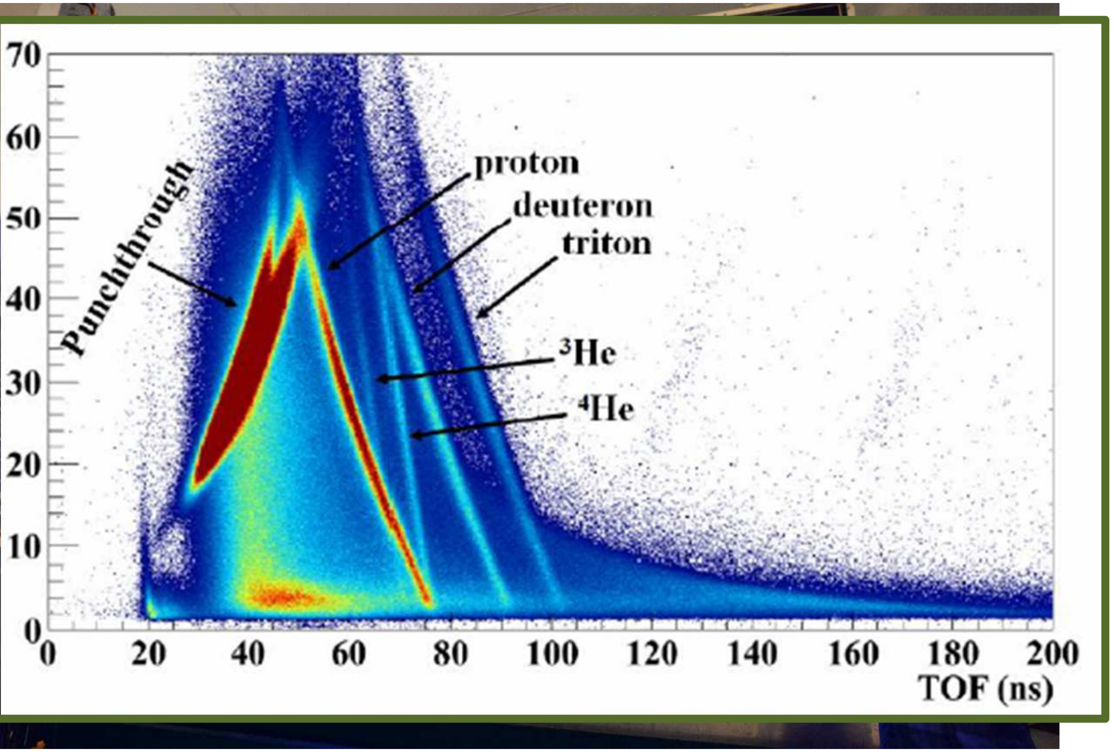


Testing for Uniformity

Shift = $100*(\mu_i-\mu_{av})/\mu_{av}$

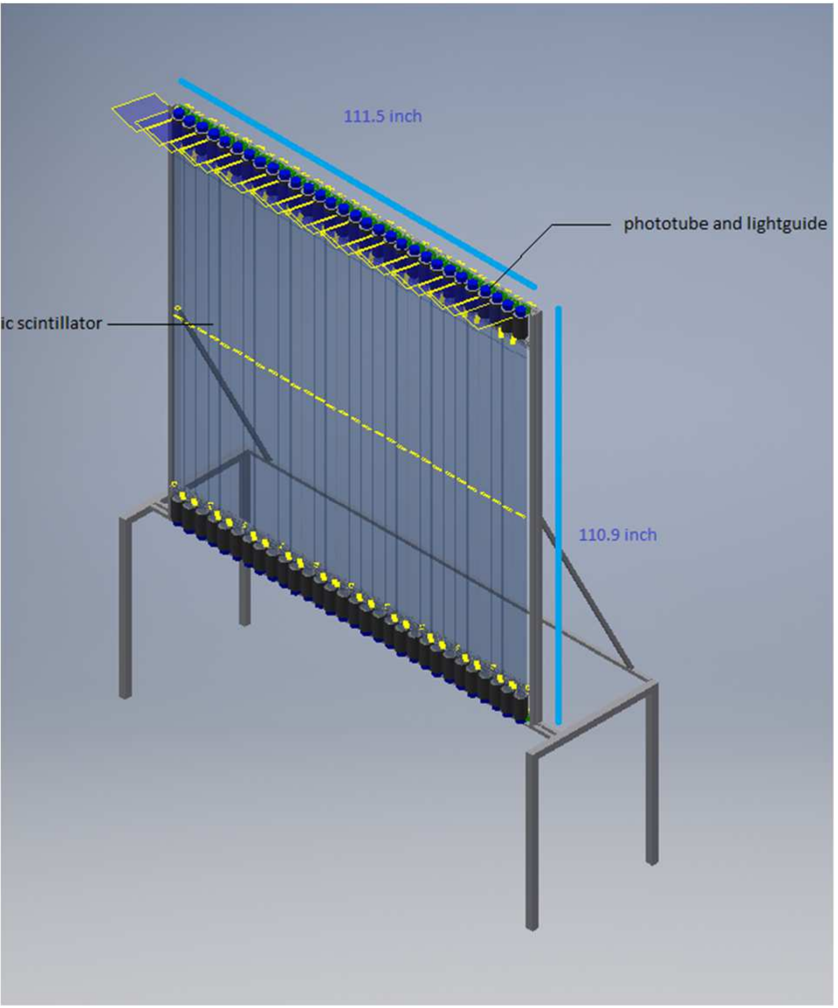


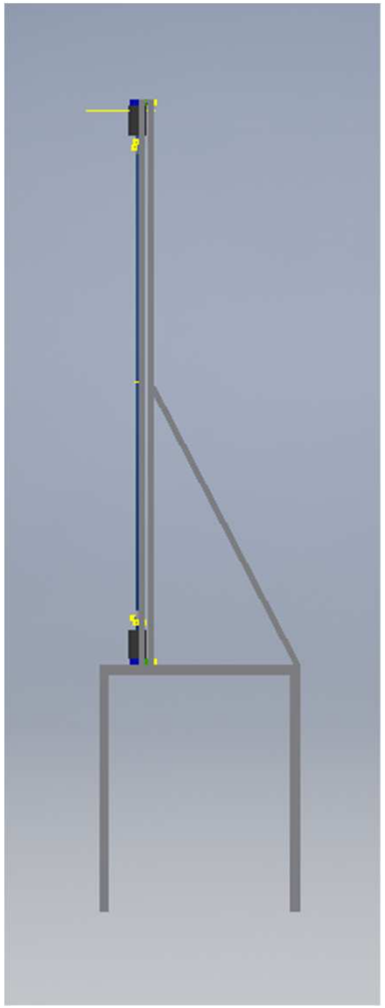
Large Area Neutron Array (LANA)

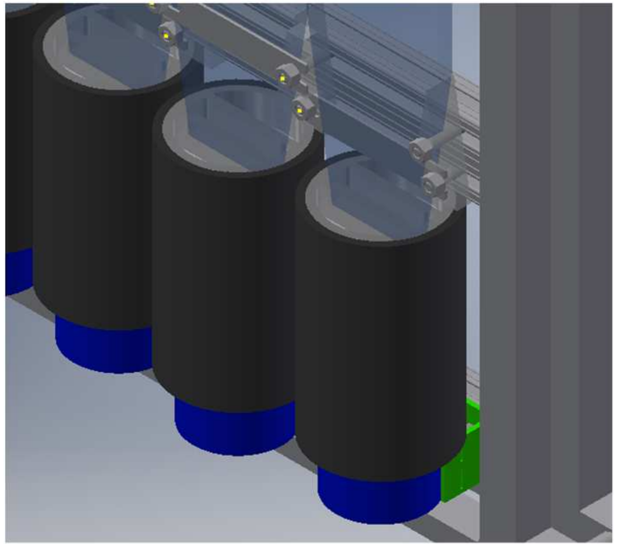


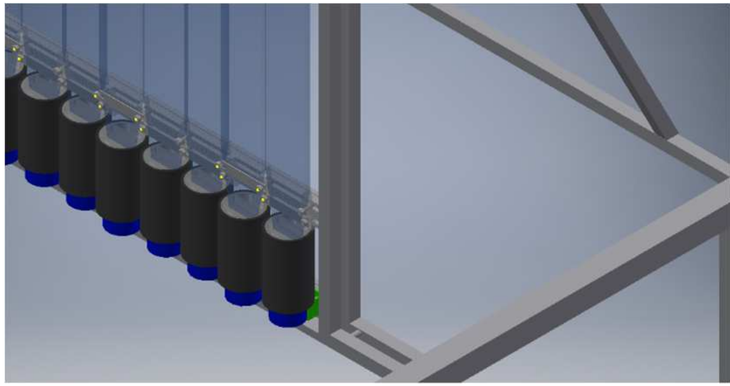
- We are recommissioning LANA to use to detect the neutron energy spectra
- LANA is comprised of:
  - Two Walls of 25 scintillator bars
    - » 2 meters long, 7.7 cm square cross-section
    - » NE-213 liquid scintillator
- In previous work, the veto of charged par was not perfect
  - The veto detector was small, close to the ta and did not have position information in 2D
  - Not all of the charged particles could be reje

Construction of a new Veto Wall



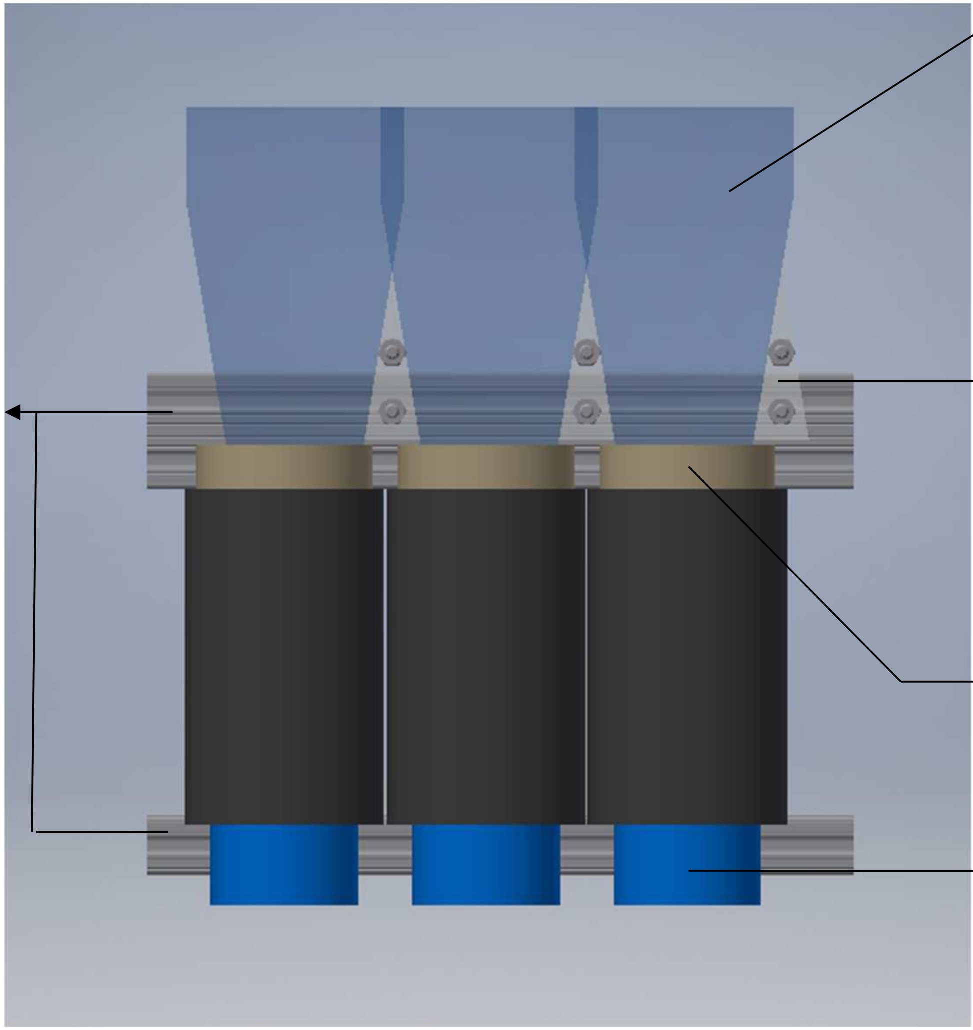




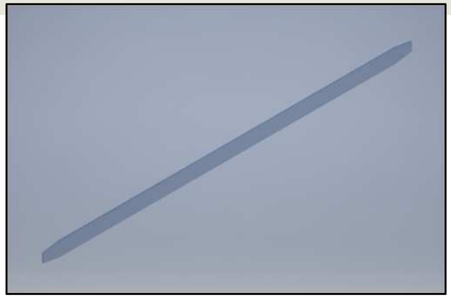


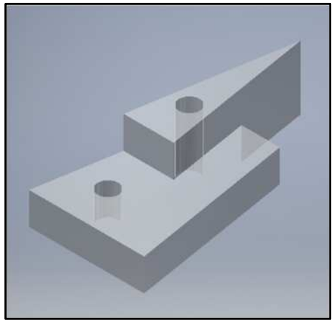
Construction of a new Veto Wall

otted
inum
usions

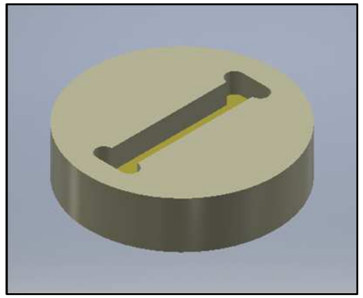


Plastic Scintillator





Supporting Wedge

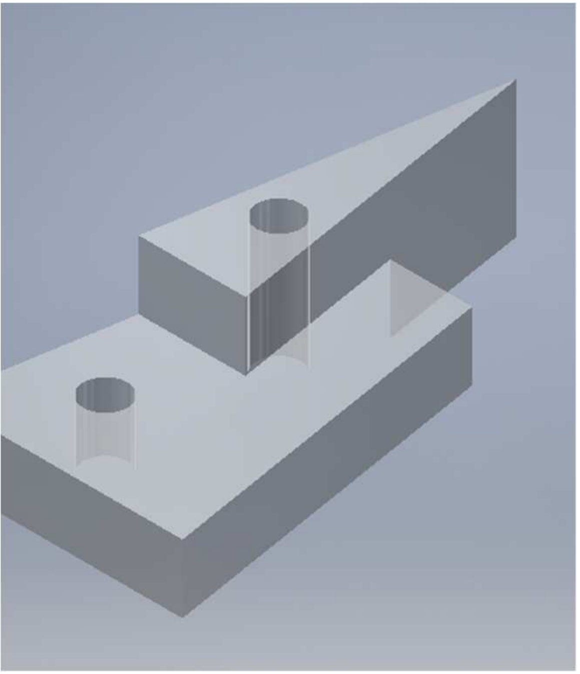


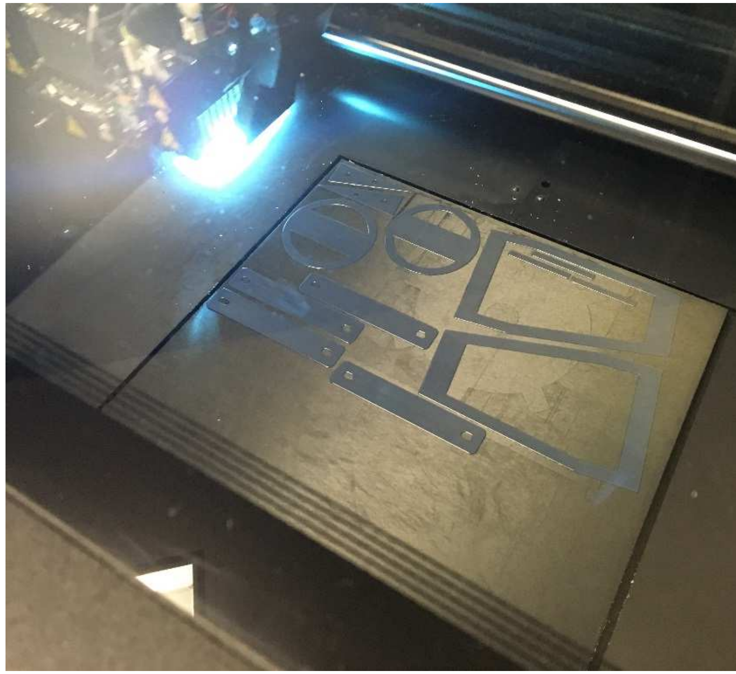
Light Guide

Phototube socket and black mu-shell

Slide from Kuan Zhu

Construction of a new Veto Wall





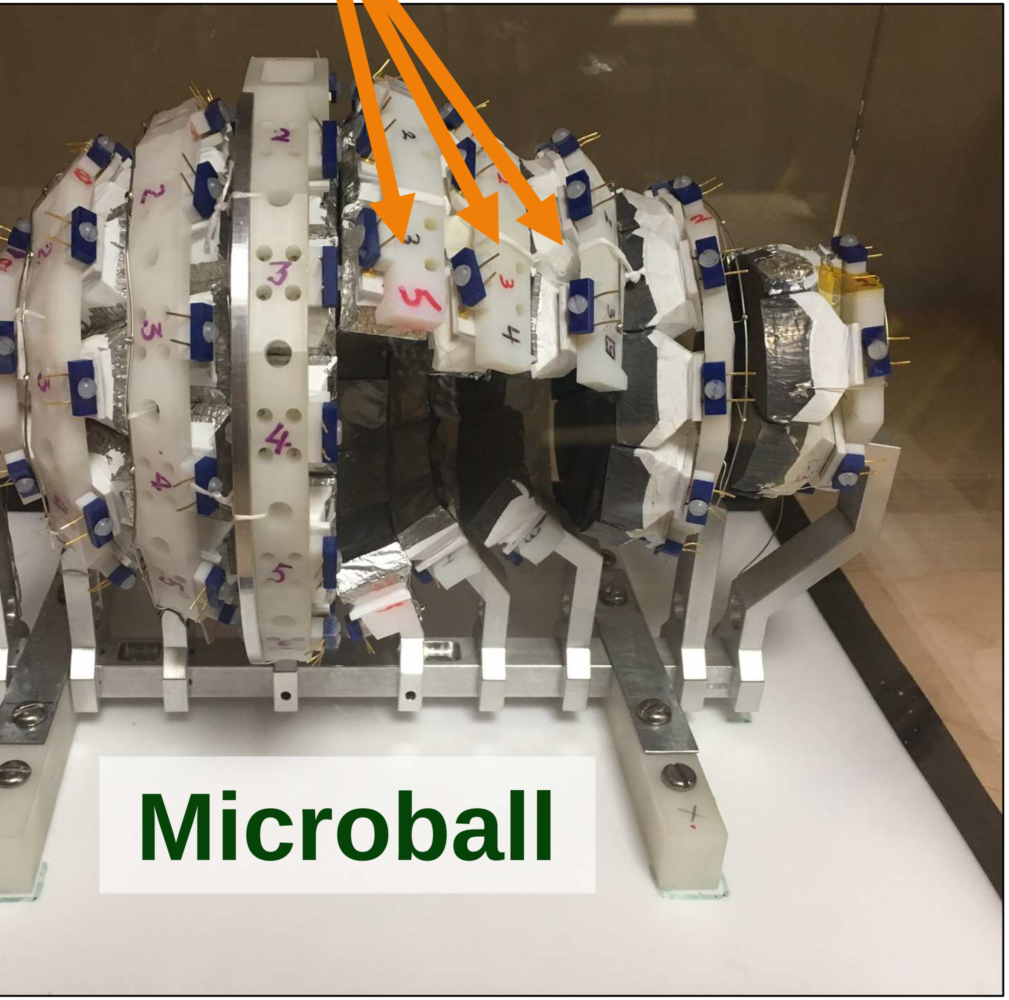
Objet Connex350 Multi Material 3D Printing System

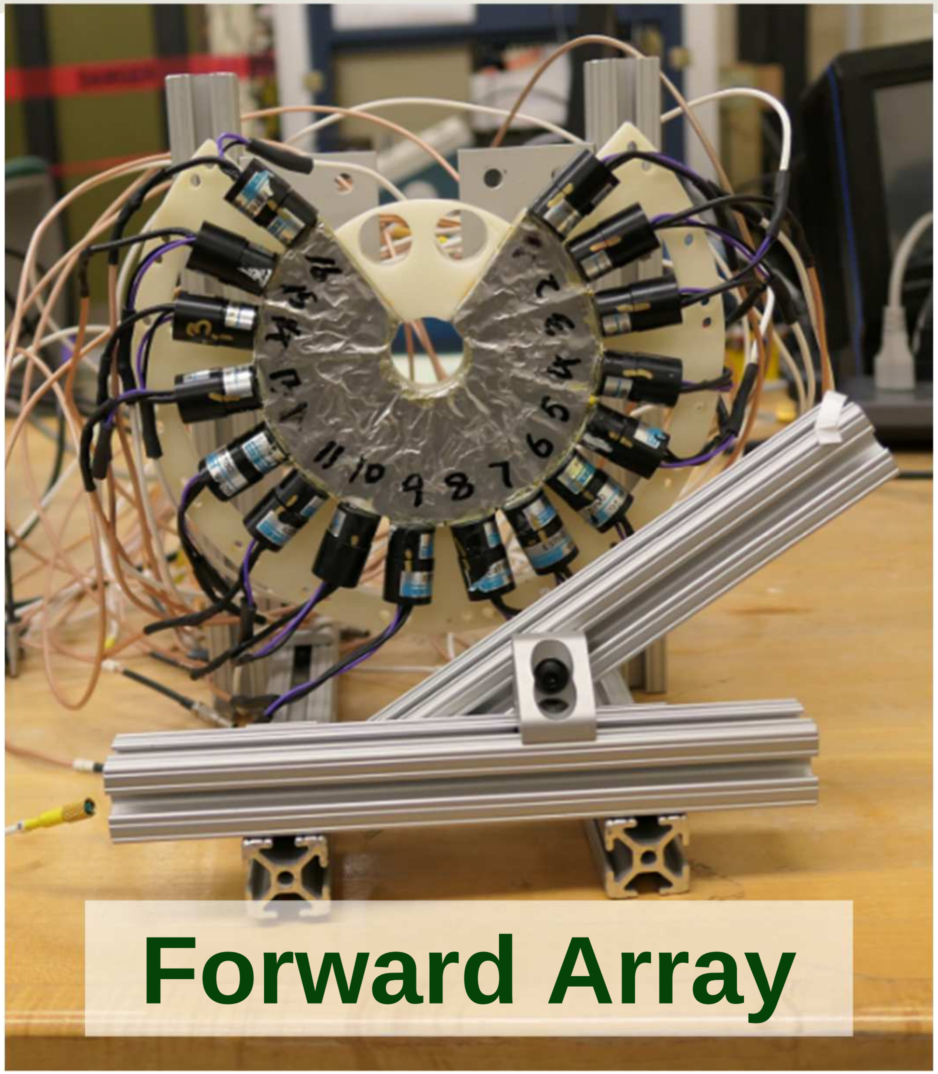
3D Printing

Construction of a new Veto Wall

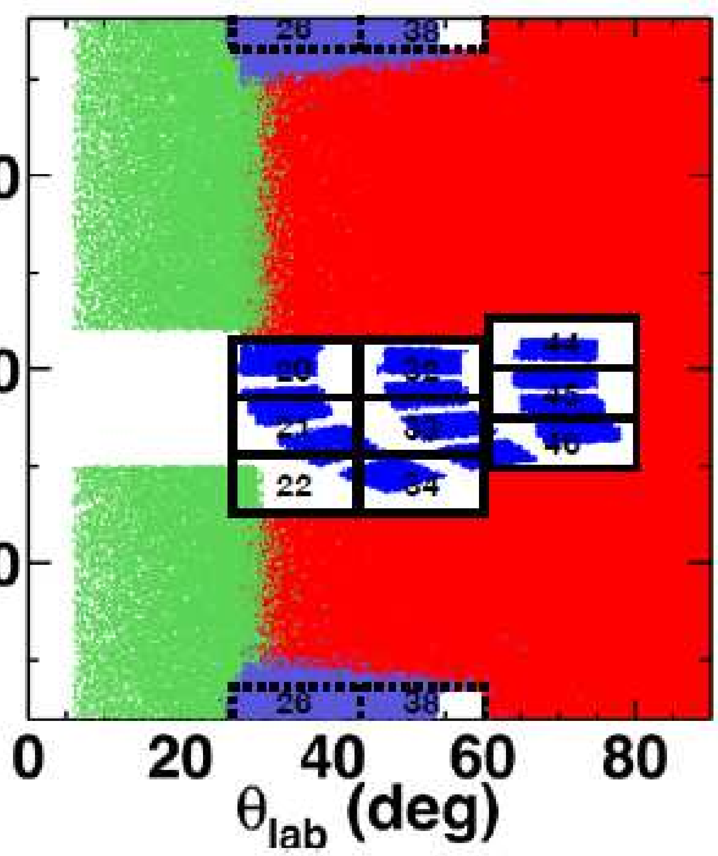
Other Detector Systems

3-D Printed!



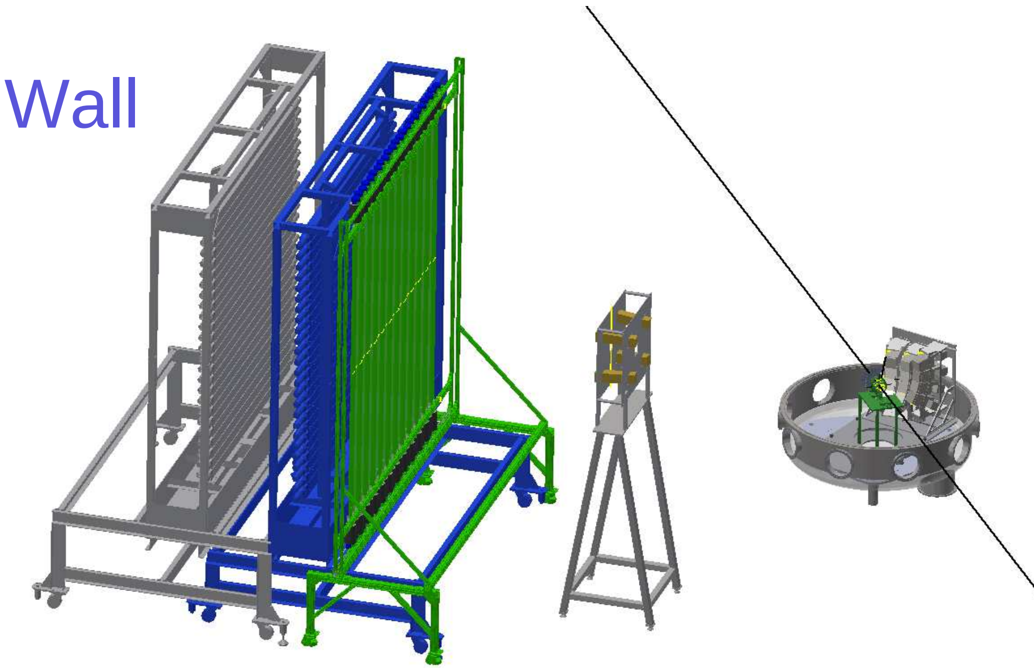


Putting it all together

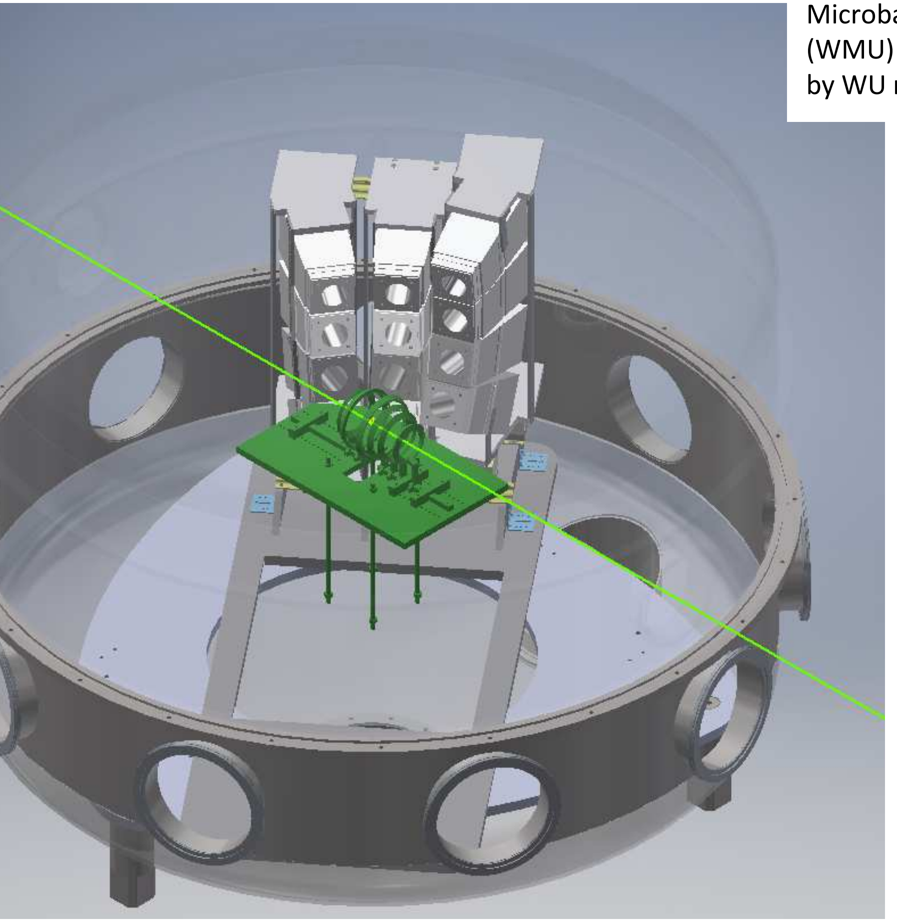


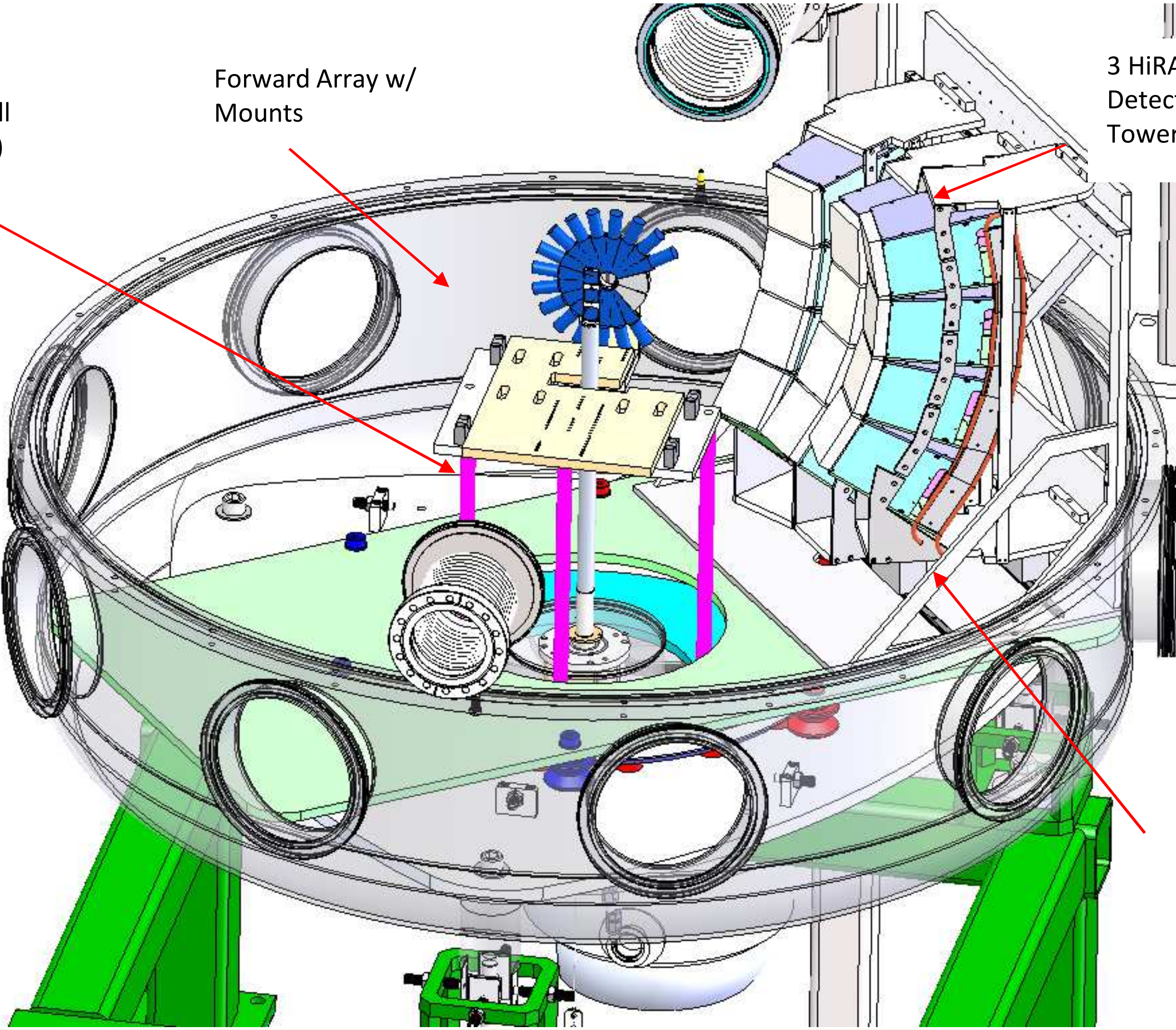
Removed Microball crystals for neutron side
Crystal 10 in ring 3 (crystal 26)
Crystal 10 in rint 4 (crystal 38)

- Space for all of these detector systems is quite tight
  - Forward Array
  - Microball
  - HiRA10
  - Neutron Wall



Putting it all together





Run Schedule

- te December → HiRA10 calibration, Veto/Neutron Wall mmissioning and shakedown (3 days)
- bruary → $^{40}Ca + ^{112,124}Sn, ^{58,64}Ni$ (18 days) @ 50,140 MeV/A
- arch → HiRA10 calibration (3 days)
- arch → $^{48}Ca + ^{112,124}Sn, ^{58,64}Ni$ (18 days) @ 50,140 MeV/A

Summary and Outlook

e effective mass of nucleons is an important piece in the Symmetry ergy puzzle.

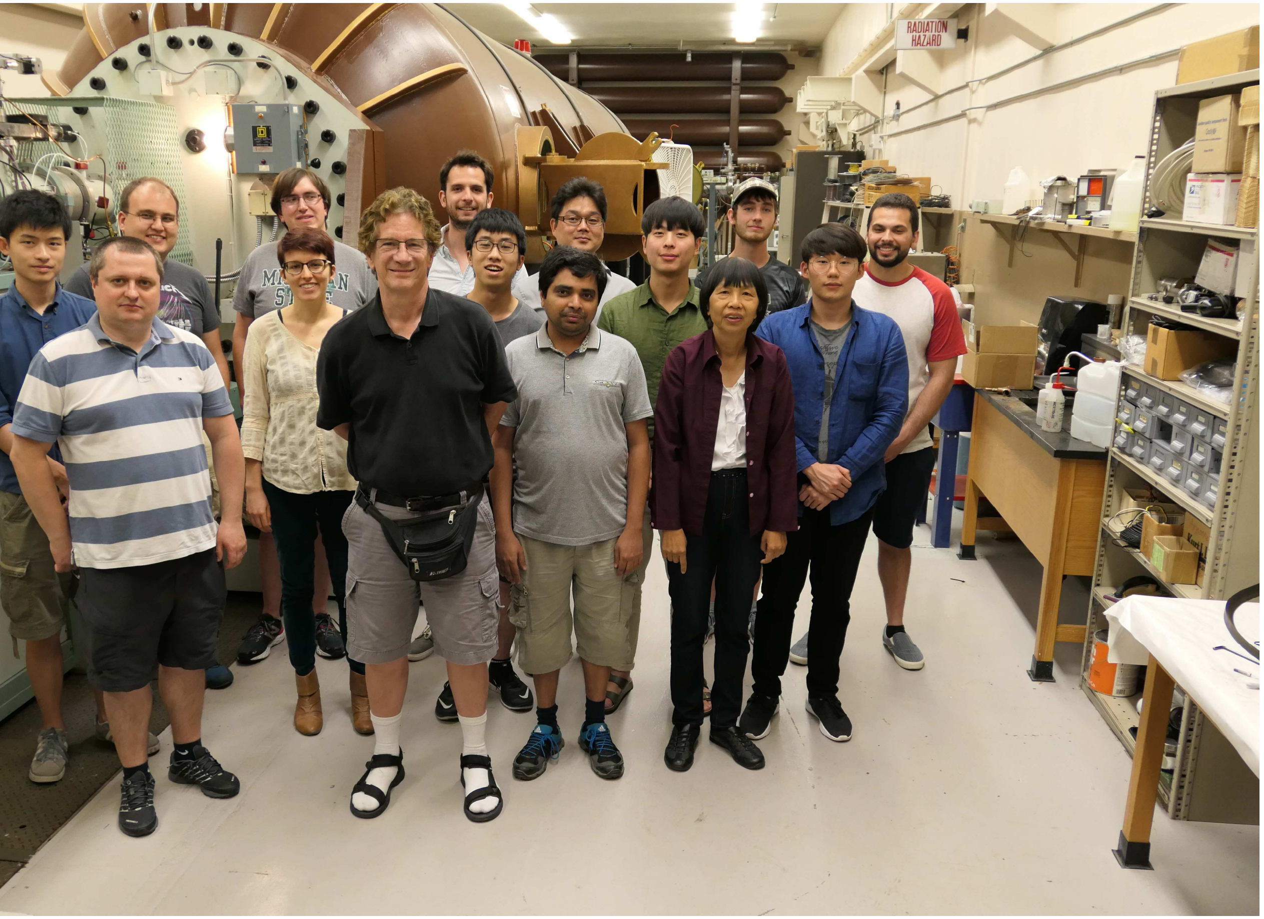
utron-to-proton energy spectra from heavy-ion collisions are a sensit servable for constraining the effective mass of nucleons in heavy nuc

grades to the **Hi**gh **R**esolution **A**rray (HiRA) will allow us to nearly uble the energy range of detected protons

nstruction of the new Charged-Particle Veto Wall will enable us to m anly measure the energy distribution of the neutrons

ay tuned for results from our upcoming beam time

Collaboration



NSCL FRIB WESTERN MICHI UNIVERSITY

KOREA UNIVERSITY 1905

Washington University in St. Louis