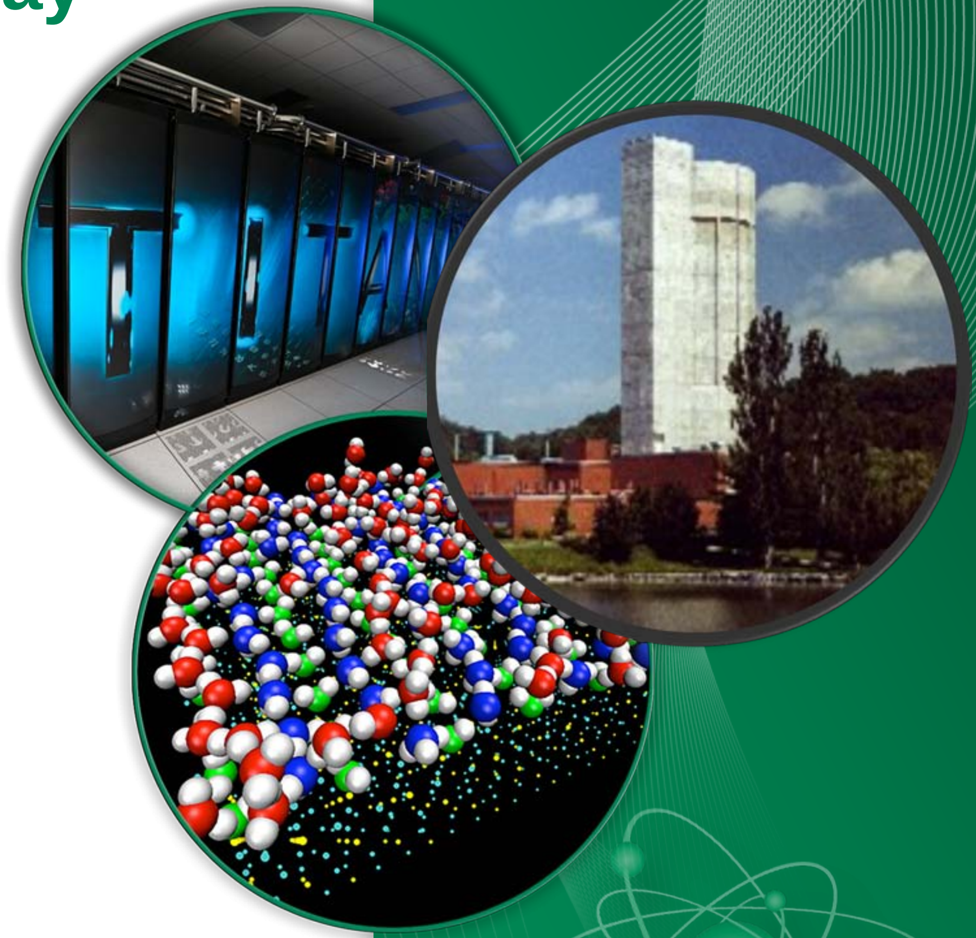
BRIKEN:
Beta-delayed neutron array at RIKEN



Krzysztof Rykaczewski

ORNL

Workshop on beta-delayed neutron emission experiments at RIBF

RIKEN, Wako

30th July 2013

Detector needs for decay studies of exotic beta-delayed neutron emitters produced in fragmentation reactions at RIKEN

- RIKEN has the best production rates of very exotic neutron-rich nuclei.
- Counting of identified ions helps to determine absolute branching ratios.
- High efficiency and granularity of the **βn-array** help to determine **β1n** and **β2n branching ratios**

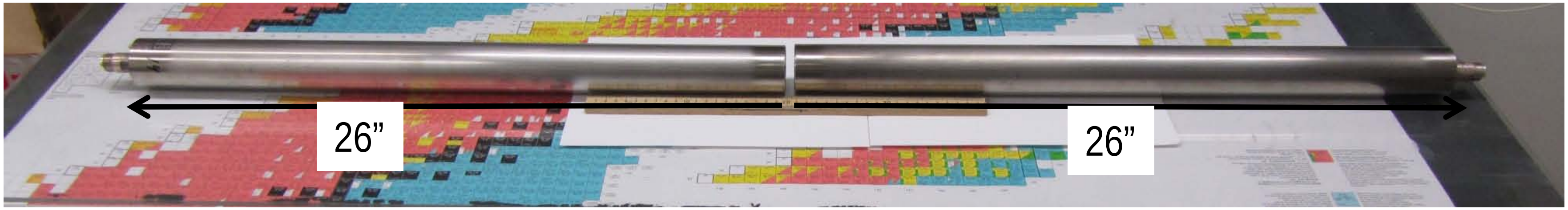
  high ε_n efficiency helps to identify/correlate observed radiation with implanted ions.

  (ε_n might be larger in comparison to ε_β compensating smaller branching ratio)
- Ion-beta-neutron correlations offer great selectivity for γ-radiation assignment.
- Hybrid design helps to include high energy-resolution gamma counting in time correlations with emitted neutrons and electrons. **Neutron-gamma** correlations validate the assignment of new gamma transitions, nuclear structure info can be gained from identifying new γ-transitions.

BRIKEN: beta-delayed neutron array at RIKEN

BRIKEN can be assembled with a “world supply” of 3He counters and provide high efficiency for correlating emitted neutrons with exotic ions, beta and gamma radiation.

The following BRIKEN design simulations are basing on two 3He tubes (2” or 1” diameter) filling one HDPE 4-foot long channel, till we run out of tubes.



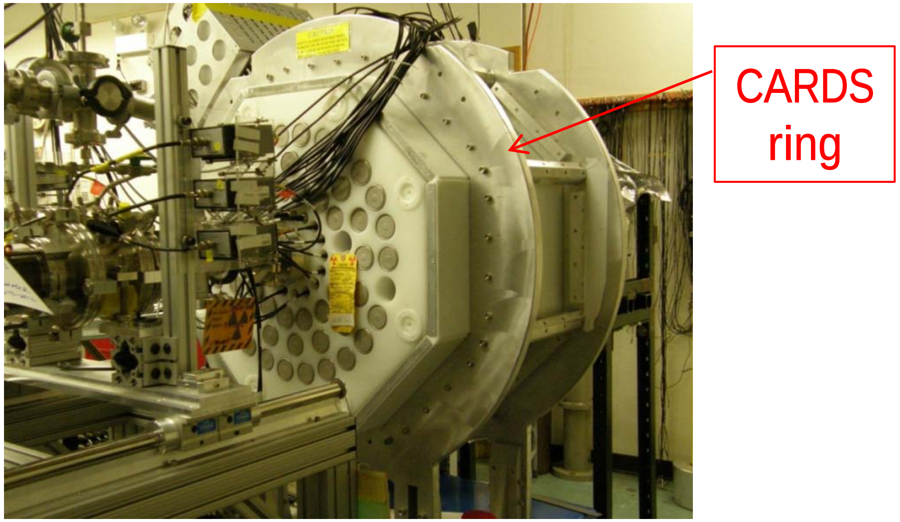
Longer array compensates some of the solid angle losses for opening needed to accommodate the implantation Si-array (AIDA). Modular design allows for relatively easy array modification, when clovers are added.

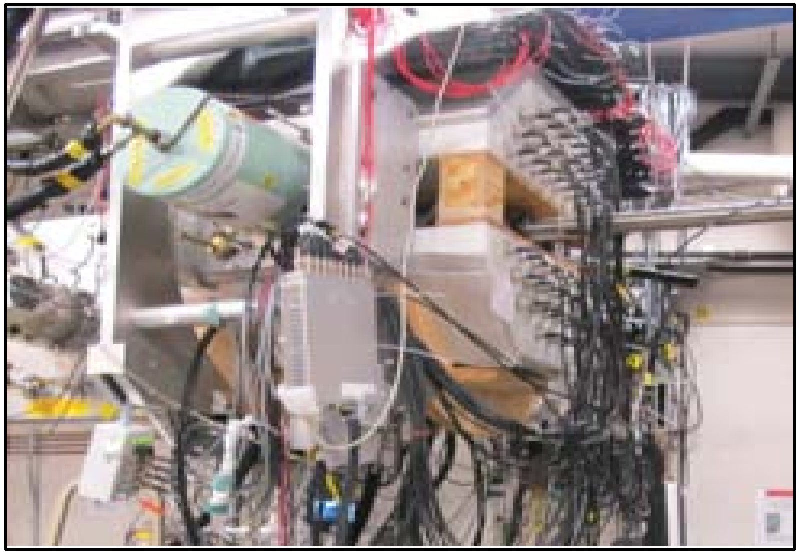
At ORNL, we do have fifty-eight 2” diameter 10 atm tubes now, and next nine are on order
→ sixty seven 2” 10 atm tubes.

And sixteen 1” diameter, 10 atm, position sensitive (two connectors) 2-foot tubes are available

BRIKEN: beta-delayed neutron array at RIKEN

The design uses ORNL 3Hen holding frames (CARDS) and Cd-HDPE shielding plates. We already have the support structures getting the beam axis of CARDS between 66” and 69” height. It means CARDS height-adjustable support standing on a floor and matching RIKEN beam height of 67” is ready.





CARDS has matching clovers mounts, but we would like to minimize the space taken by clovers in “hybrid BRIKEN”.

It means the HDPE cuts making 4” square opening and matching rectangular clover shapes. Clover holding from the top can be supported by the HDPE and the bottom clover can be supported by clover holder structure on the floor. HDPE comes in blocks 4” thick, so we need two blocks with 2” by 4” cuts added as two middle HDPE sectors to ‘maximum efficiency’ setup.

BRIKEN simulations by Charlie Rasco (LSU)

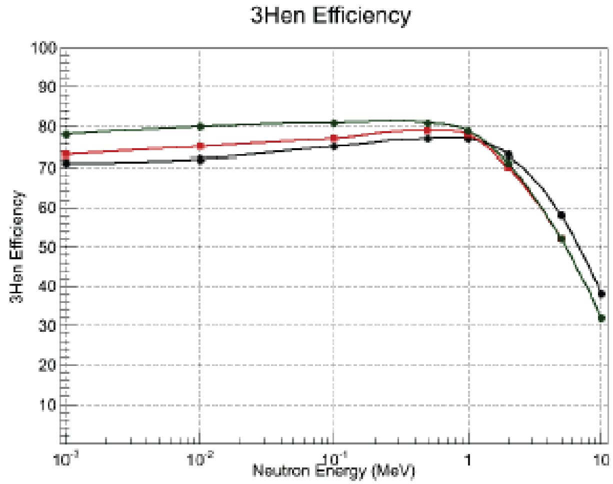
previous credits: simulations for νSNS, VANDLE, LENS, MTAS

(+ *iPod's version of "Pirates of the Caribbean" game*)

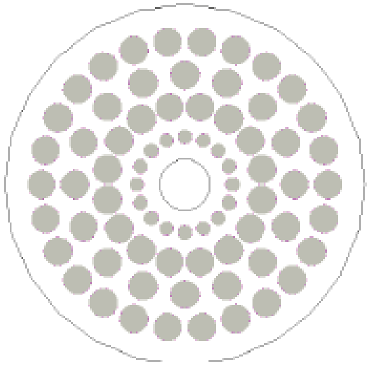
Charlie also contributed to the online analysis of the silicon tracker for SAMURAI at RIKEN.

Oak Ridge ^{3}Hen Resimulation

Current Simulation Results



Total calculated efficiency of the original ^{3}Hen design (Red is CH_2, Green is C_2H_3, Black is CH_3).



Original Simulation Results

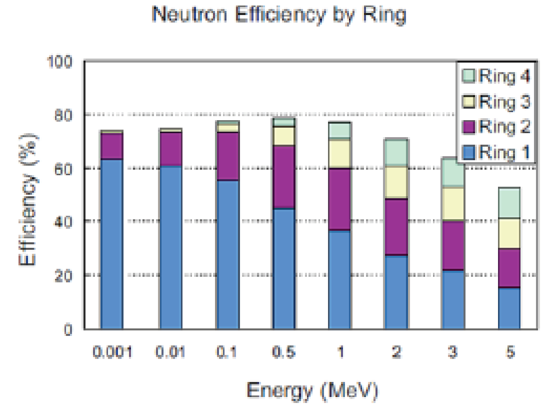
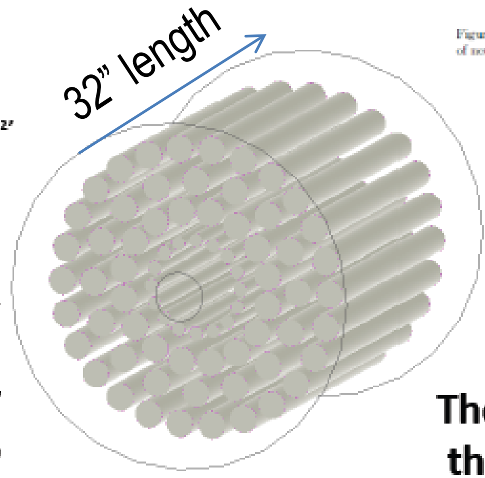


Figure 8: The efficiency-per-ring for neutron detection of proposed neutron counter, as a function of neutron energy. The simulations were made within Geant4 code.

Changing the chemical makeup of HDPE changes the efficiency of ^{3}Hen. More hydrogen slows down all neutrons quicker. But for low energy neutrons this means slows down too fast and stops in the HDPE.



25.2" diameter (32 cm radius)

The new simulation (Red) and the original simulation agree to within a few percent.

Oak Ridge ^{3}Hen Resimulation

On previous slide there was no time cut for the efficiency. For higher energy neutrons, E > 500 keV, there is a small correction for ^{3}He Tube detection times greater than 100 μsec. For energies less than 500 keV many of the neutrons are detected after 100 μsec. For neutrons with energy around 1 keV only 70% of the neutrons are detected faster than 100 μsec. For times less than 1 millisecond almost all of the low energy neutrons are detected.

^{3}Hen has a fair amount of HDPE in between each tube in the radial direction. This makes 3Hen better optimized to detect higher energy neutrons more efficienctly.

BRIKEN simulations

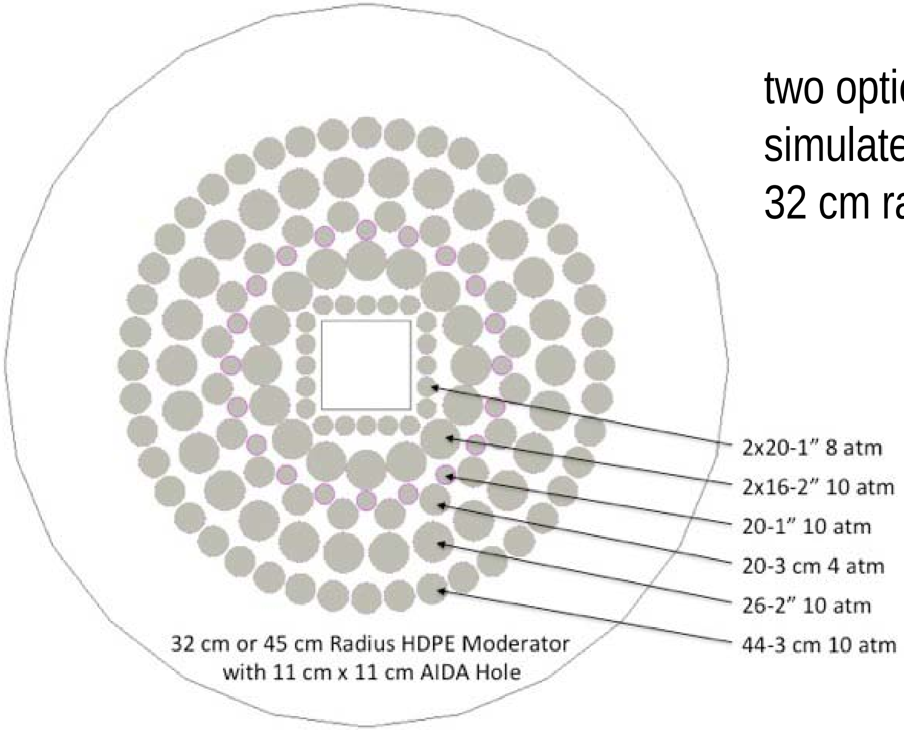
The HDPE shell was made of 3Hen diameter of 25.2”, and of double-length 64”.
It has 110 mm by 110 mm central square opening for AIDA.
We can provide the stands keeping such HDPE structure around AIDA, so called CARDS rings.
We have Cd-HDPE shielding plates for one 3Hen length of 32”.

On next slides there are no time cuts for the efficiency. The time cuts for most of these setups are less than for the 3Hen since the 3He tubes are closer packed. For higher energy neutrons, E > 500 keV, there is a small correction for ^{3}He Tube detection times greater than 100 μsec. For energies less than 500 keV many of the neutrons are detected after 100 μsec. For neutrons with energy around 1 keV almost all of the neutrons that are detected are for times less than .4 milliseconds.

All point are evaluated with 10,000 simulated neutron events. This gives an uncertainty of at least a percent or two for all of the data points on the graphs. This is an approximate error.

BRIKEN design *(as a Big Brother of 3Hen)*

- Available 3He tubes allow to reach superior efficiency with BRIKEN, up to ~ 90% for low energy neutrons and ~ 50% for 5 MeV energy of emitted neutron, with AIDA setup inside BRIKEN.
- The construction following 3Hen barrel shape can profit from ready support structures and neutron shielding plates.
- The transition to ion-beta-gamma-neutron hybrid BRIKEN made out two 3Hen-like HDPE barrels is relatively easy, requires two extra 4” HDPE plates with 4” by 4” clover holes. Rectangular shape ORNL clovers can be used for hybrid BRIKEN.

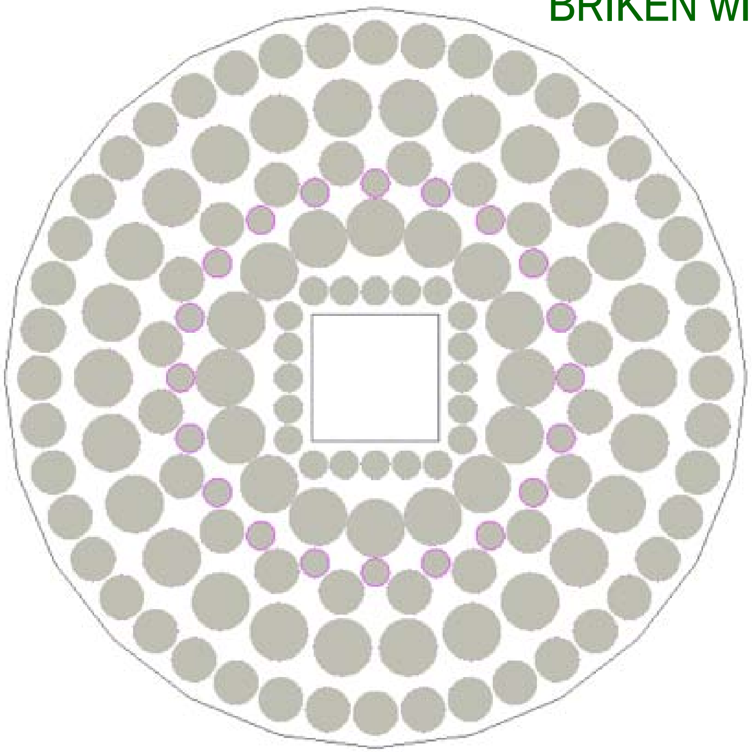


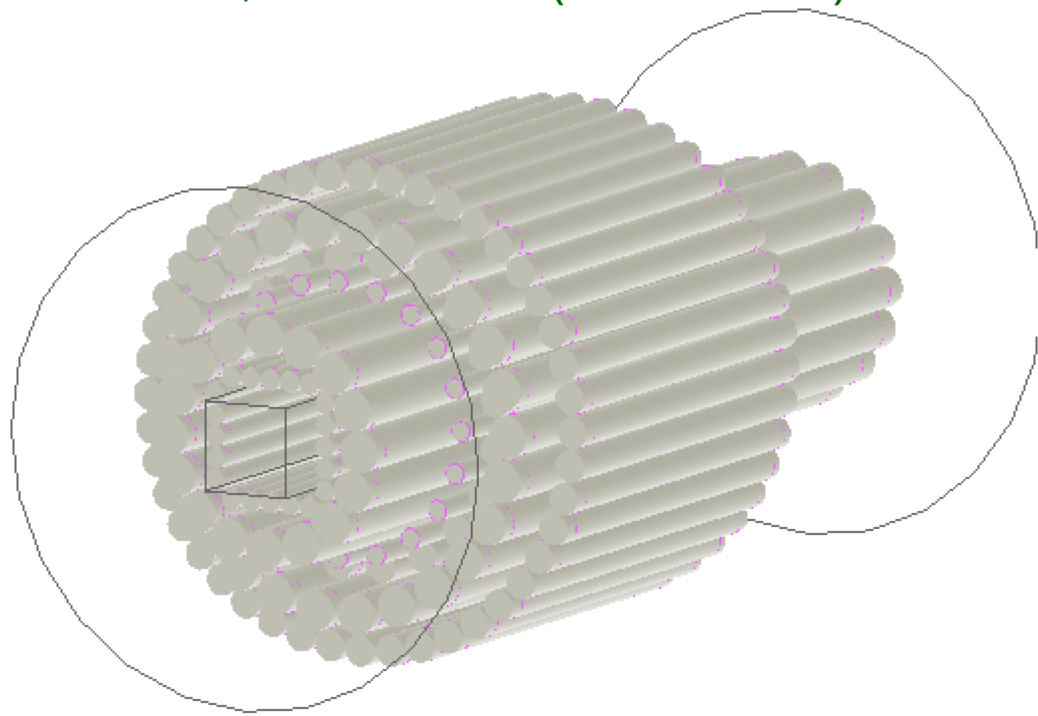
two options for HDPE moderator were simulated for efficiency comparison
32 cm radius (3Hen) and 45 cm radius

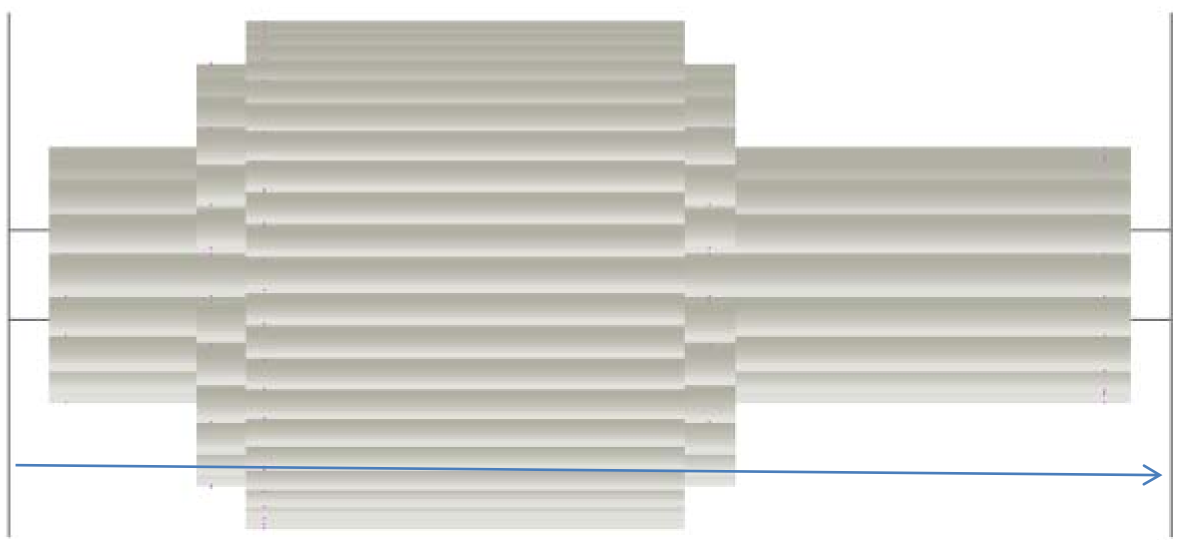
58 2” 10 atm tubes (ORNL)
40 1” 8 atm (Barcelona)
20 1” 10 atm (GSI-ORNL)
64 3 cm 4 atm (JINR)
or 26 1” 5 atm RIKEN tubes

simulations by Charlie Rasco (LSU)

BRIKEN with two 3Hen barrels, ~ 32 cm radius (25.2” diameter)

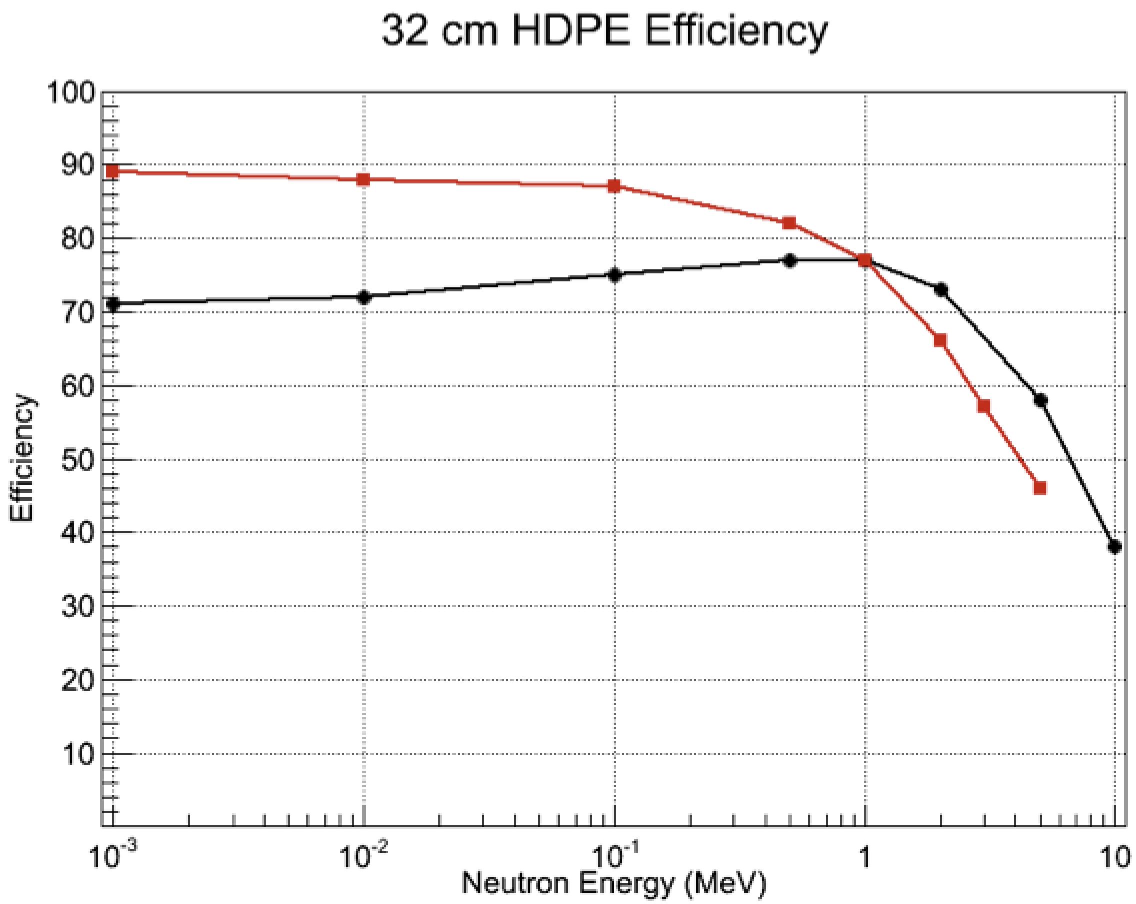






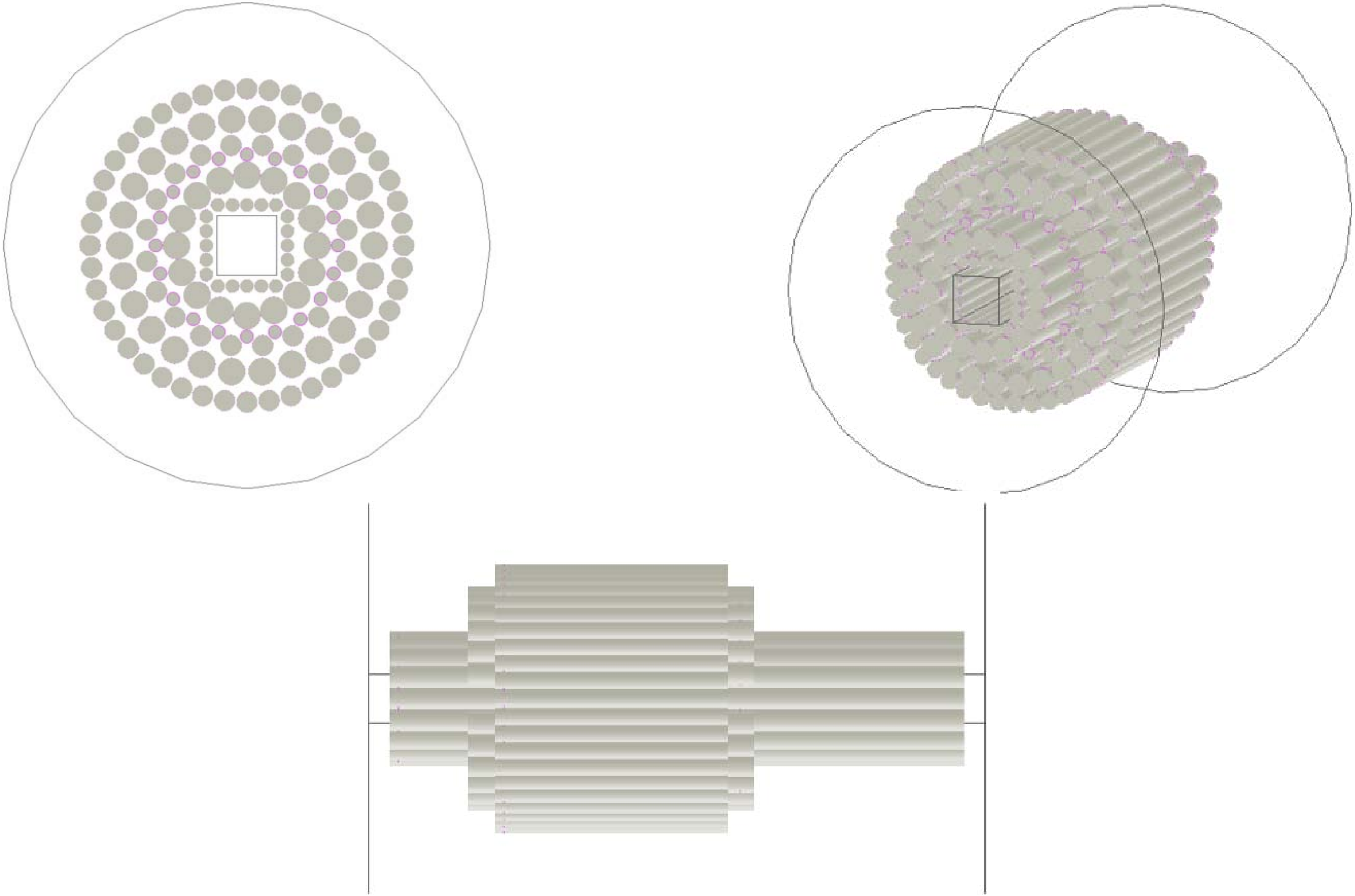
length 64” = sixteen 4” thick HDPE blocks

simulations by Charlie Rasco (LSU)

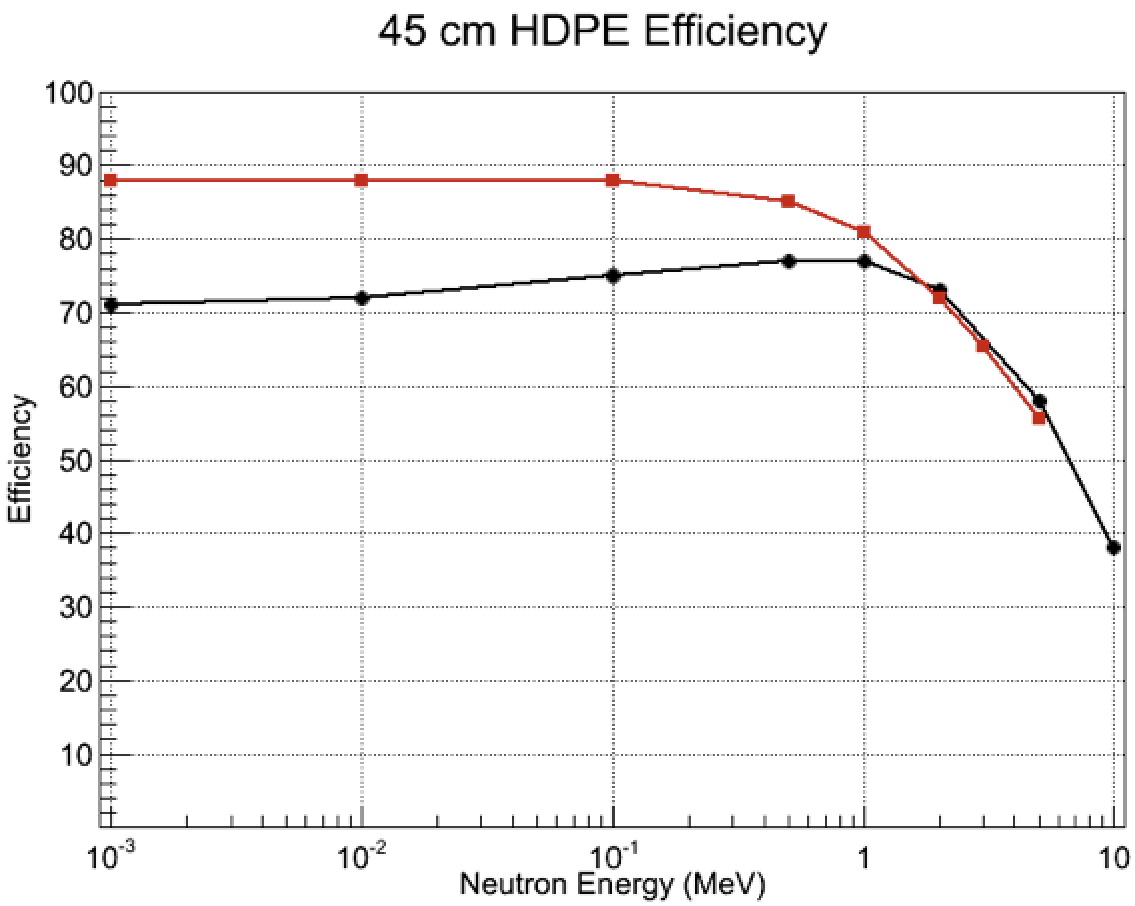


simulations by Charlie Rasco (LSU)

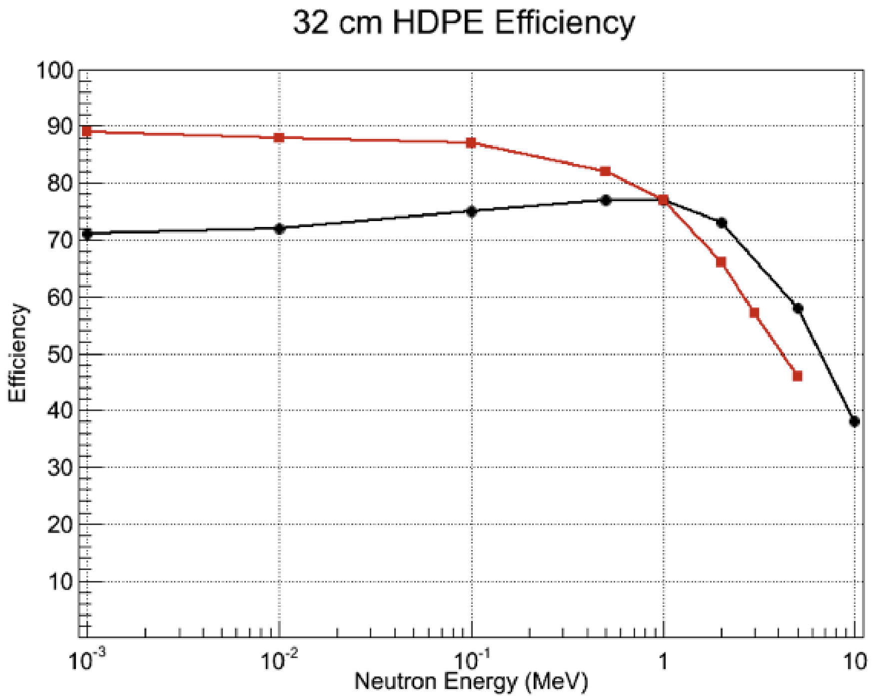
BRIKEN with 45 cm HDPE radius



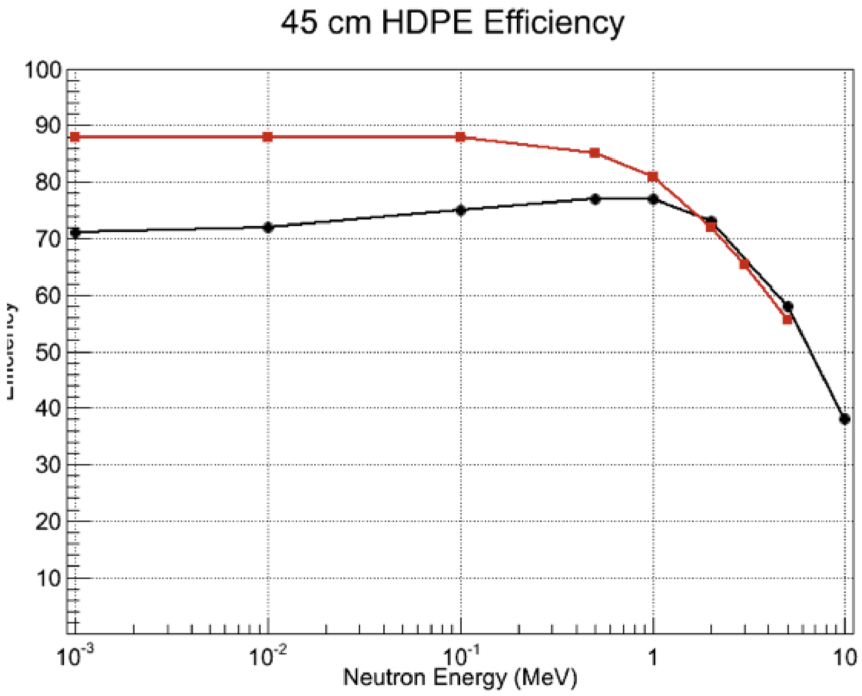
simulations by Charlie Rasco (LSU)



simulations by Charlie Rasco (LSU)

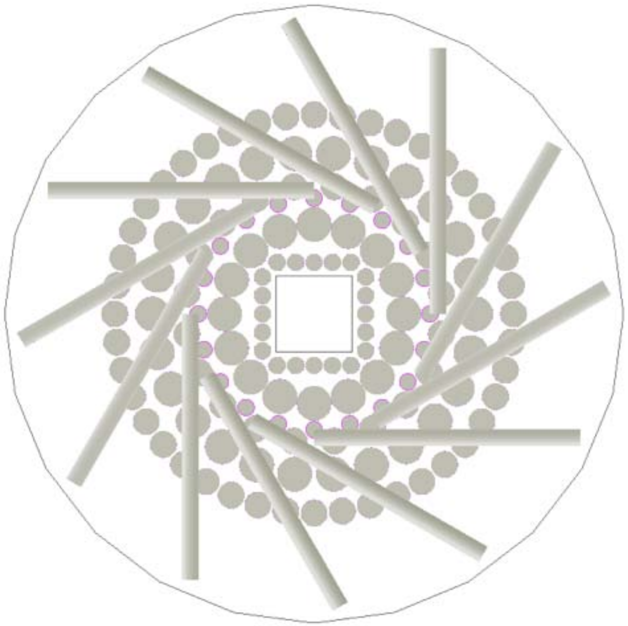


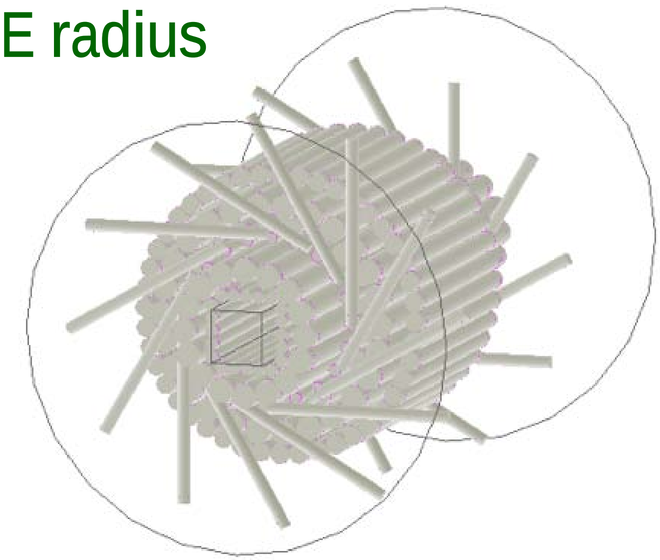
32 cm HDPE Efficiency
Efficiency
Neutron Energy (MeV)

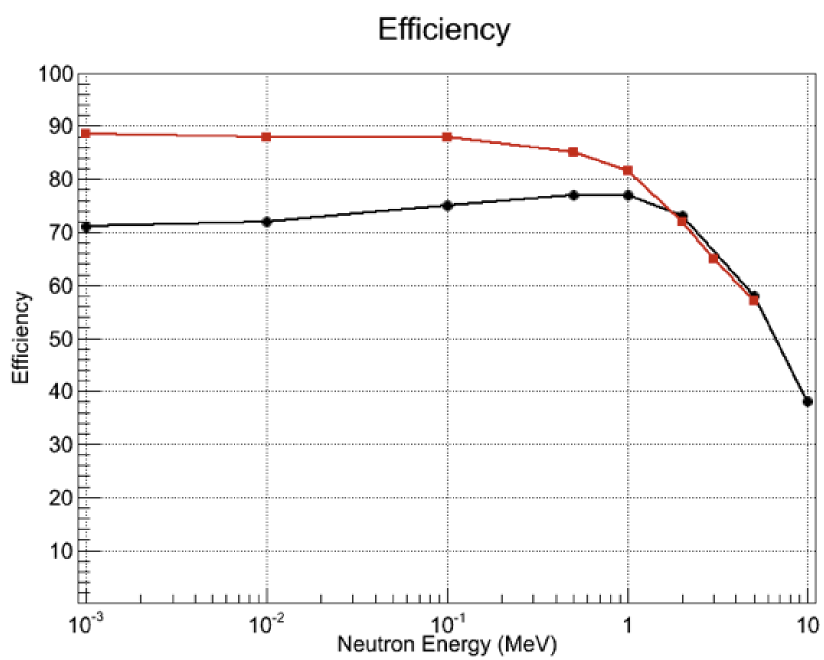


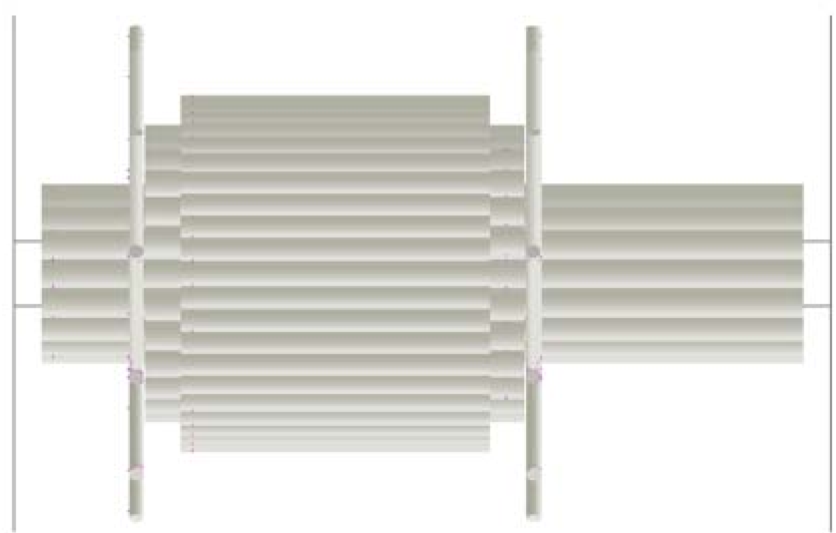
45 cm HDPE Efficiency
Neutron Energy (MeV)

Next design option for BRIKEN with 45 cm HDPE radius







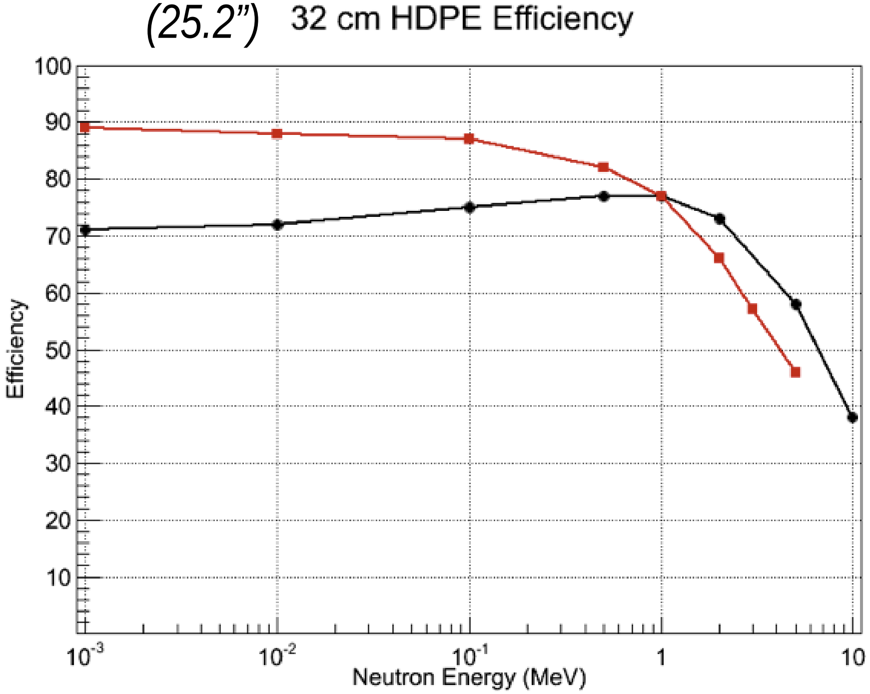


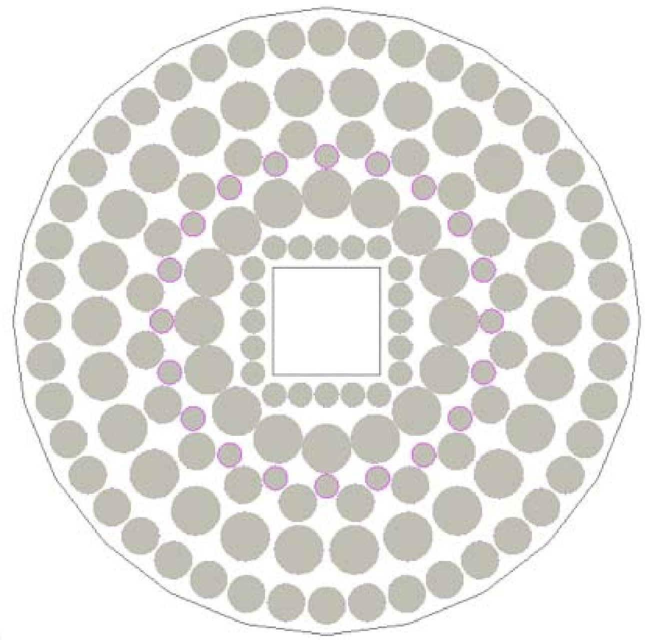
simulations by Charlie Rasco (LSU)

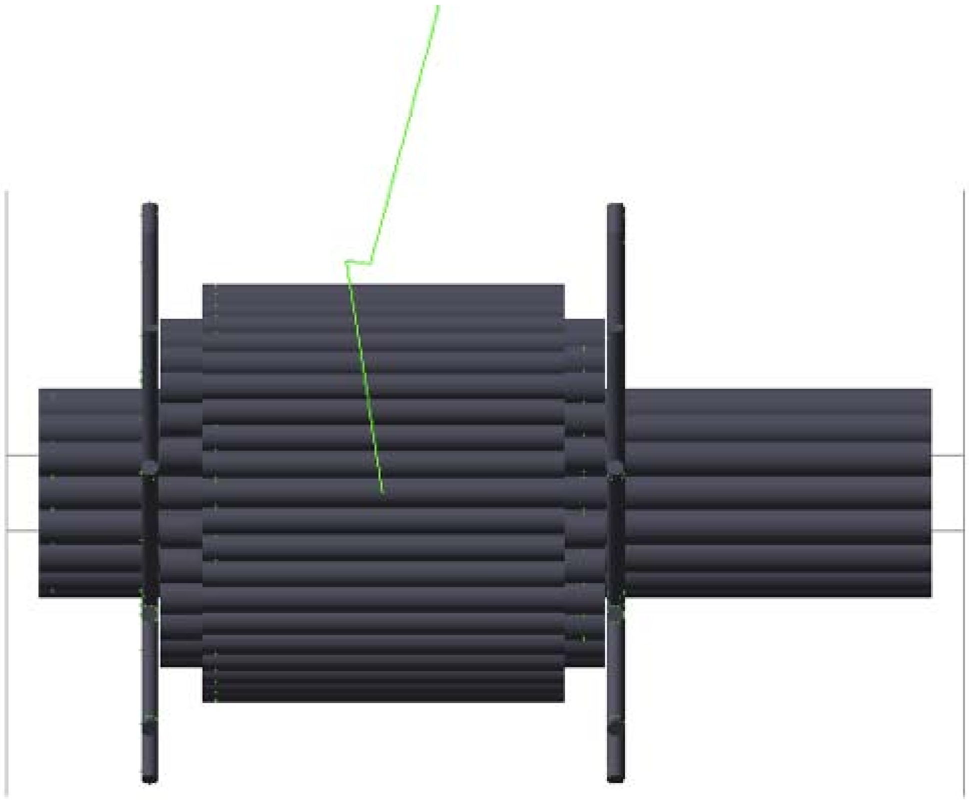
Summary: simulations for BRIKEN with “AIDA opening”

- Large number of 3He allows to reach unprecedented efficiency for 1n and multi-n signals
- Two-3He tubes in one HDPE channel and modular HDPE design (blocks 4” thick) allow for hybrid-BRIKEN with reasonable n-γ efficiency
- The design following 3Hen 25” diameter (32 cm radius) may profit from ready mounting structures and Cd-HDPE shields
- Increasing HDPE diameter, e.g., from 25” to 35 “, helps to increase the efficiency for high energy neutrons

(25.2”)





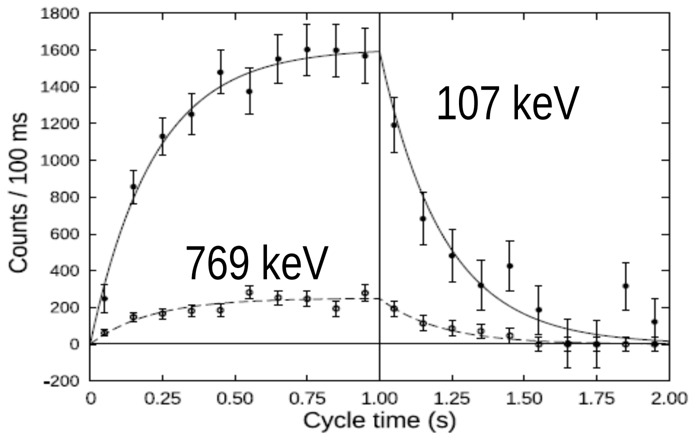


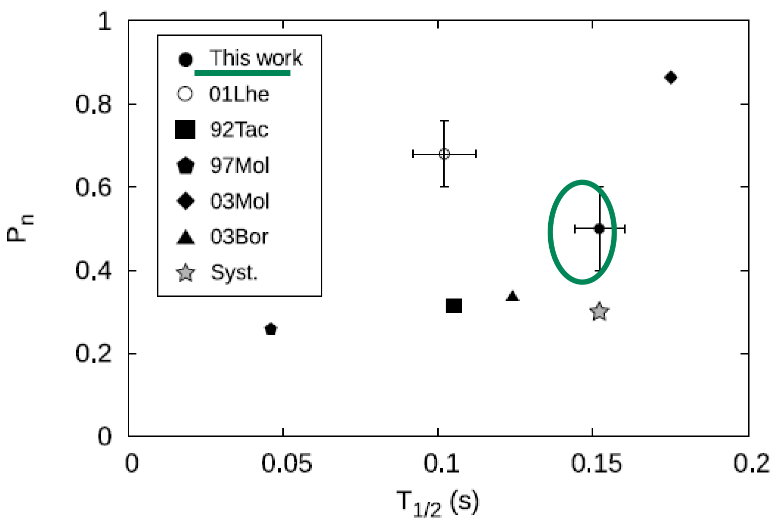
Example of corrected β-decay data: ^{93}Br decay

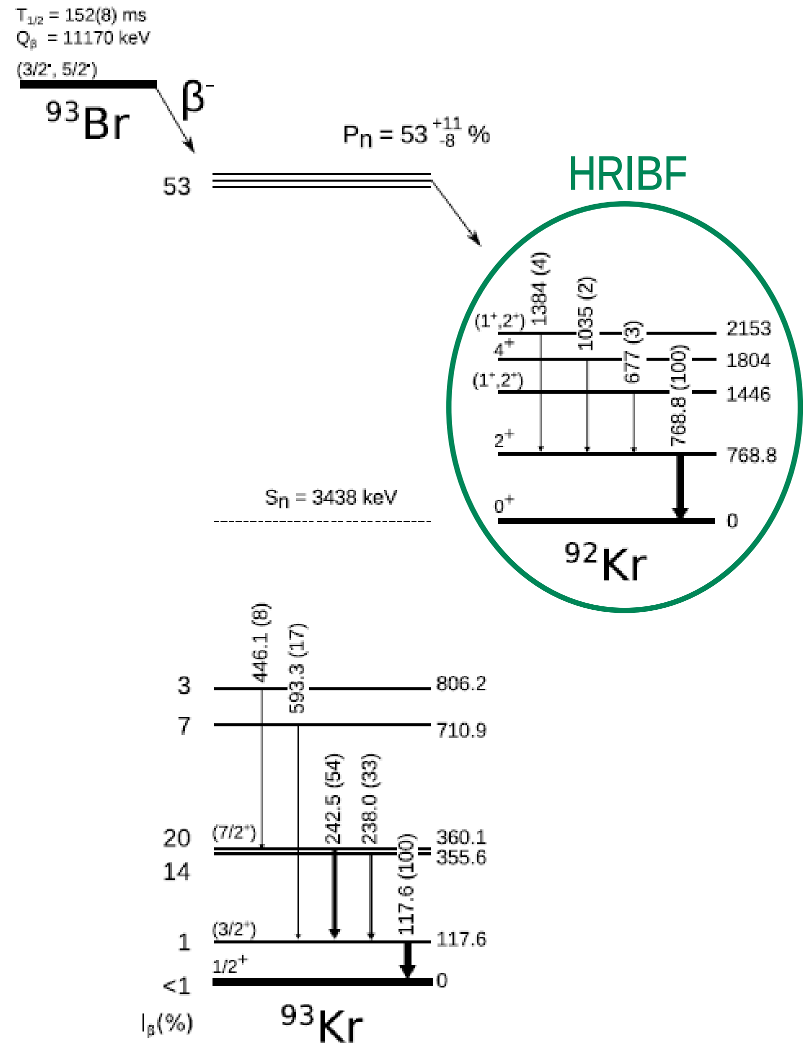
K. Miernik et al, PR C88, 014309, 2013

Previous two papers on ^{93}Br decay listed a half-life of 102(10) ms without giving an experimental evidence, and Pn branching ratios of 10(5) % and 68(7)% based on the same data. Only β0n-γ data were presented.

$T_{1/2}(^{93}Br)$ = 152(8) ms



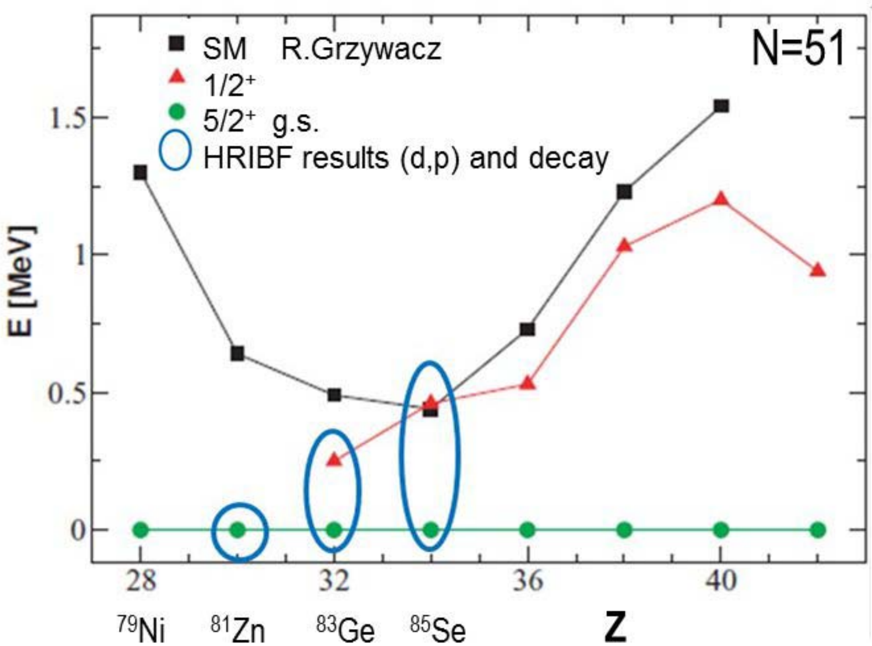


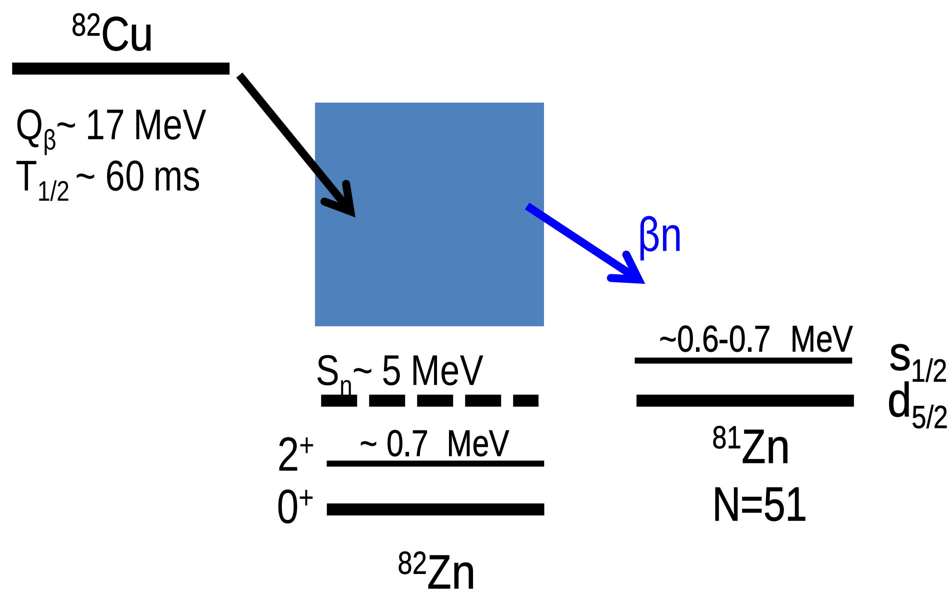


Evolution of neutron single-particle states for N > 50

search for a potential sub-shell closure $\nu 2d_{5/2}$ - $\nu 3s_{1/2}$

Padgett et al., Phys. Rev C **82**, 064314, 2010

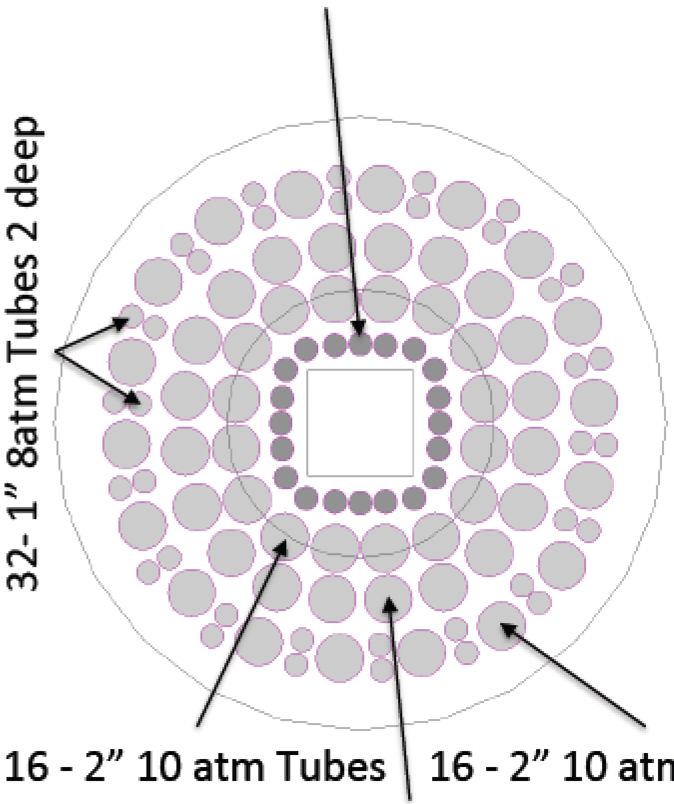




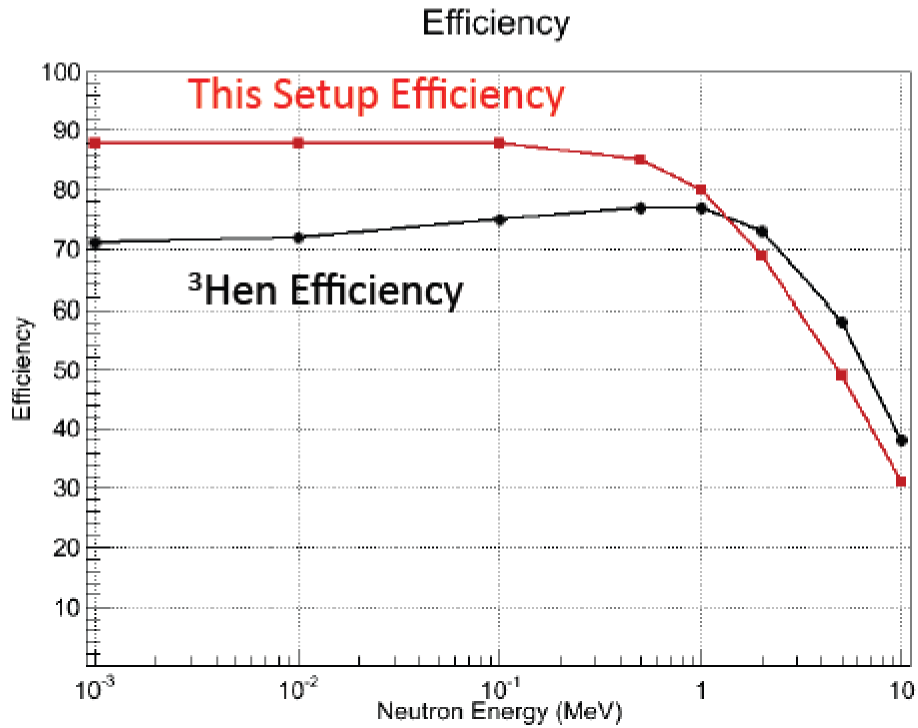
- Energy gap at N=56 or at N=58 or no gap beyond ^{78}Ni ?
- Single particle energy of $3s_{1/2}$ vs $2d_{5/2}$ in N=51 ^{79}Ni ?

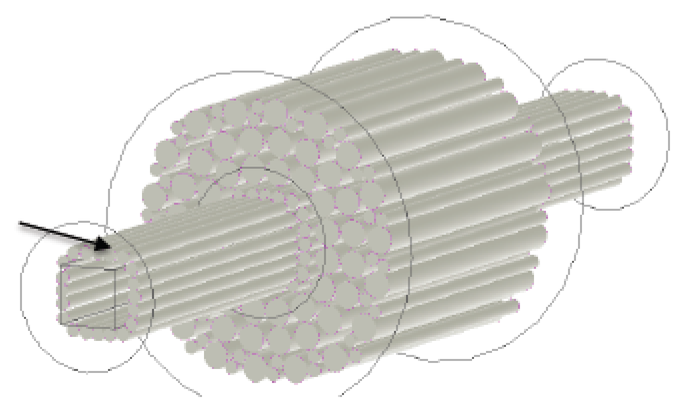
- **Answer → ^{81,82}Cu β-n-γ exp at RIKEN and ^{79,80}Co β-n-γ exp at FRIB**

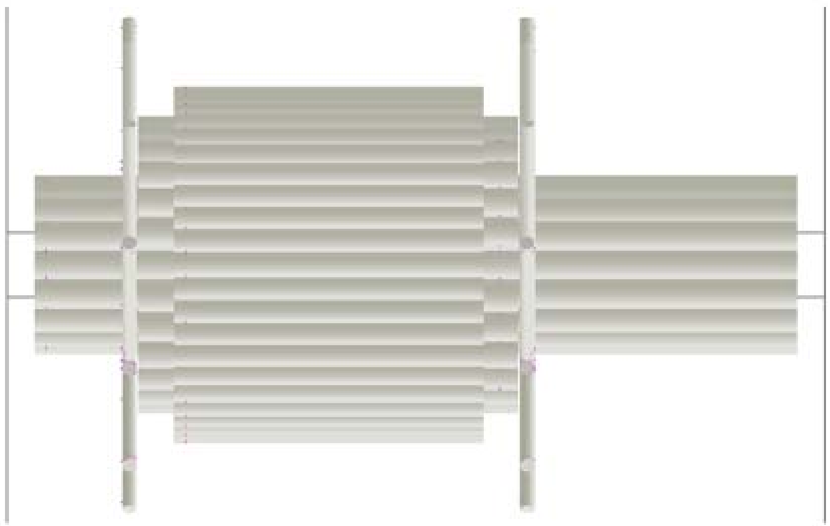
40 - 1” 8atm Tubes 2 deep on ends
+ 20 - 1” 10 atm Tubes in Center



HDPE Shell is 32”x 25.2”⌀
End shells are 25”x 11”⌀.



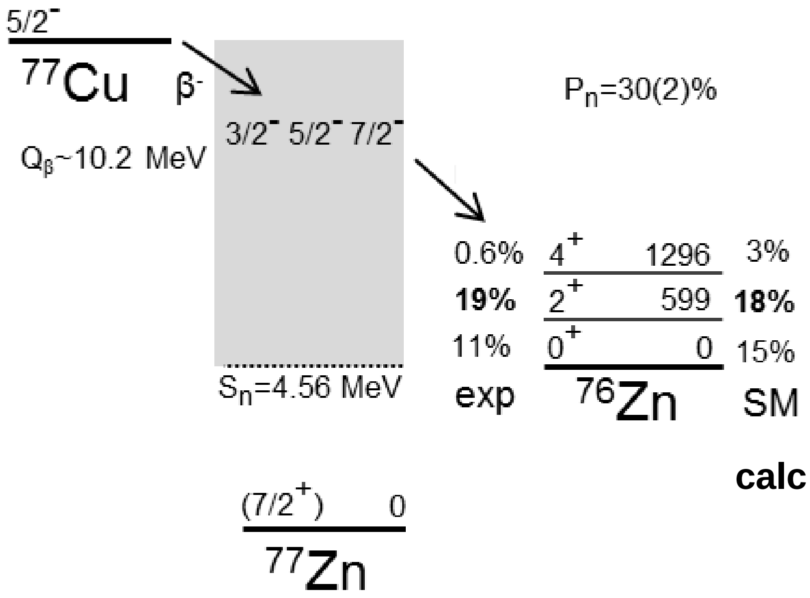


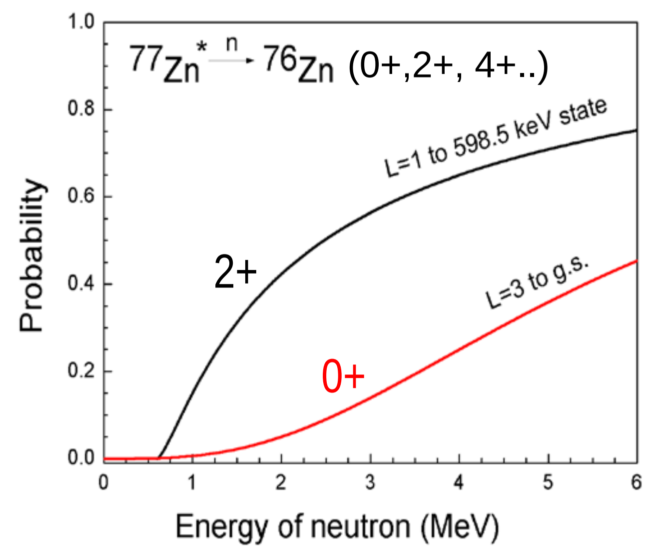


Beta-Delayed Neutron Emission

A. Korgul et al., Phys. Rev. C 86, 024307, 2012

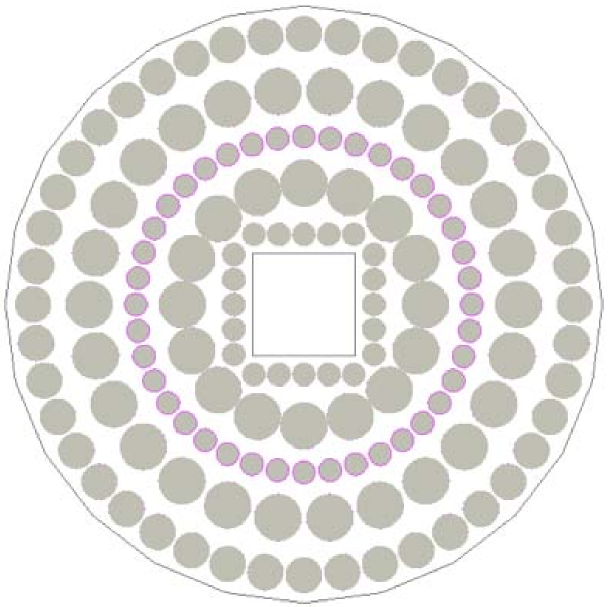
- Fine structure in βn-emission detected in several precursors, e.g. $^{75-79}$Cu, $^{83-86}$Ga
- GT β-strength distribution followed by neutron emission to final states calculated
- *ℓ=1* vs *ℓ=3* neutron competition explains large 2$^+$ state feeding in ^{77}Cu→^{77}Zn*→^{76}Zn (0$^+$,2$^+$,4$^+$)
- but βn-feeding of 2$^+$ state in ^{79}Cu→^{79}Zn*→^{78}Zn (0$^+$,2$^+$) largely over-predicted in calculations



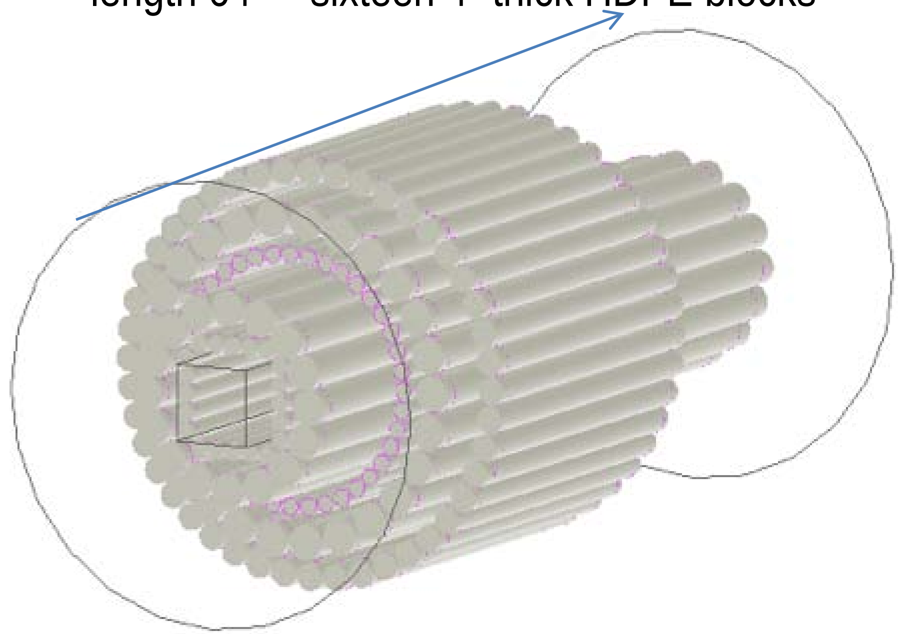


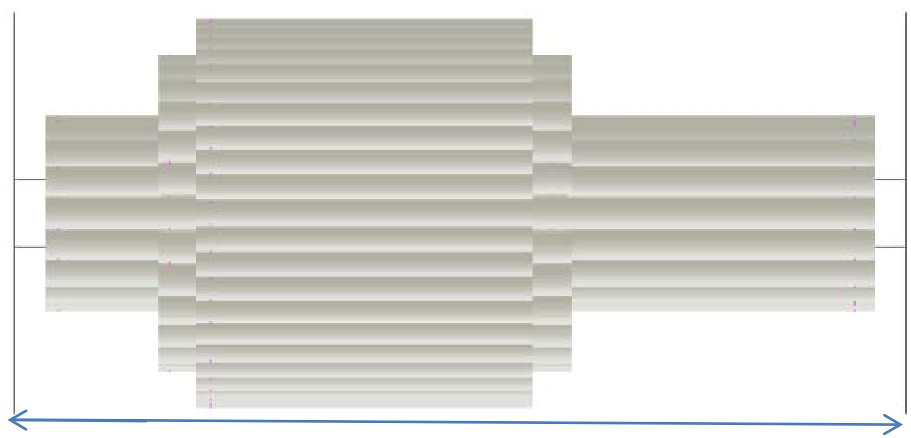
BRIKEN simulations

diameter 25.2”



length 64” = sixteen 4” thick HDPE blocks



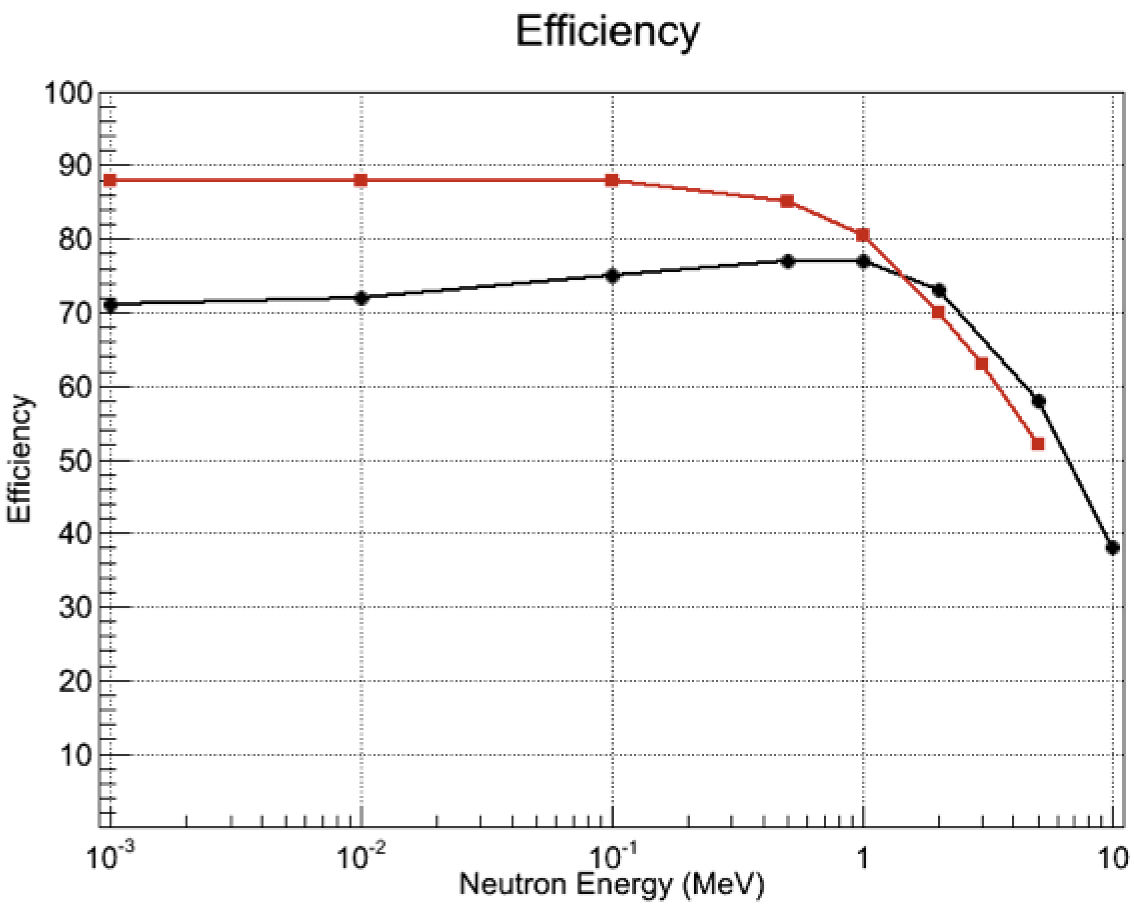


diameter 25.2”

length 64”

simulations by Charlie Rasco (LSU)

BRIKEN simulations



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