Radioactive Source Deployment System (RSDS) Proof of Principle

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SOUTH DAKOTA MINES

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

DUNE CALCI Working Group

Nov. 30, 2023

Formerly Optimized Geometric Configuration with Standalone G4 Simulations for Most Effective 9 MeV γ-Ray Production

Optimized RSDS configuration:

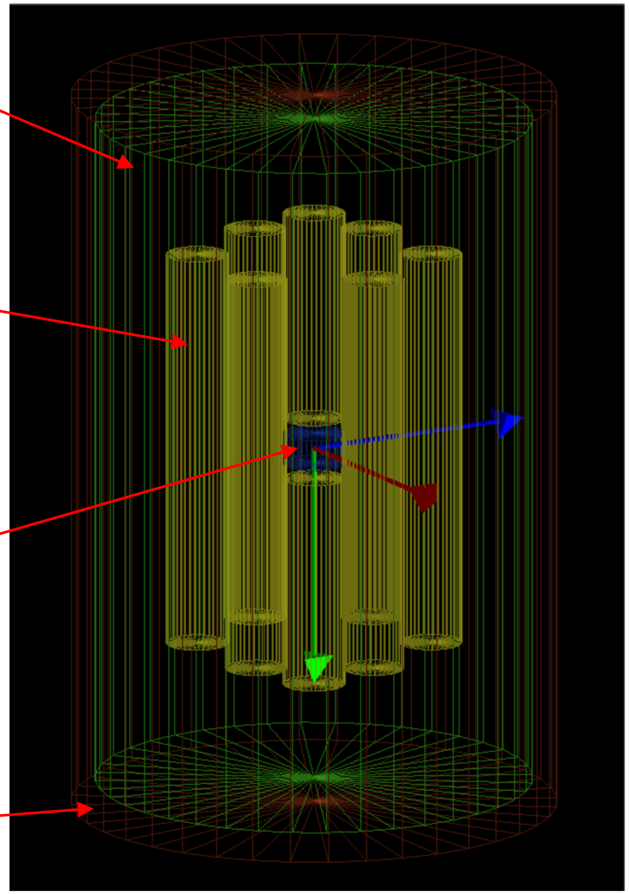
⇒ needs to be implemented in LArSoft geometry/simulation

Delrin Moderator (green)

Ni-200 target rods (yellow)

AmLi neutron Source (blue)

30% wt Boron 70% wt Delrin Moderator (red)



Specifications of Winning RSDS Geometry:

Optimized Configuration using **6 Radial Rods**

Radial Distance of Rods = 4.8 cm

Height of Radial Rods = 16.5 cm

Height of Upper and Lower Rods = 8.73 cm each

Shell Composition is 30% wt Boron 70% wt Delrin

Shell Thickness = 1.0 cm

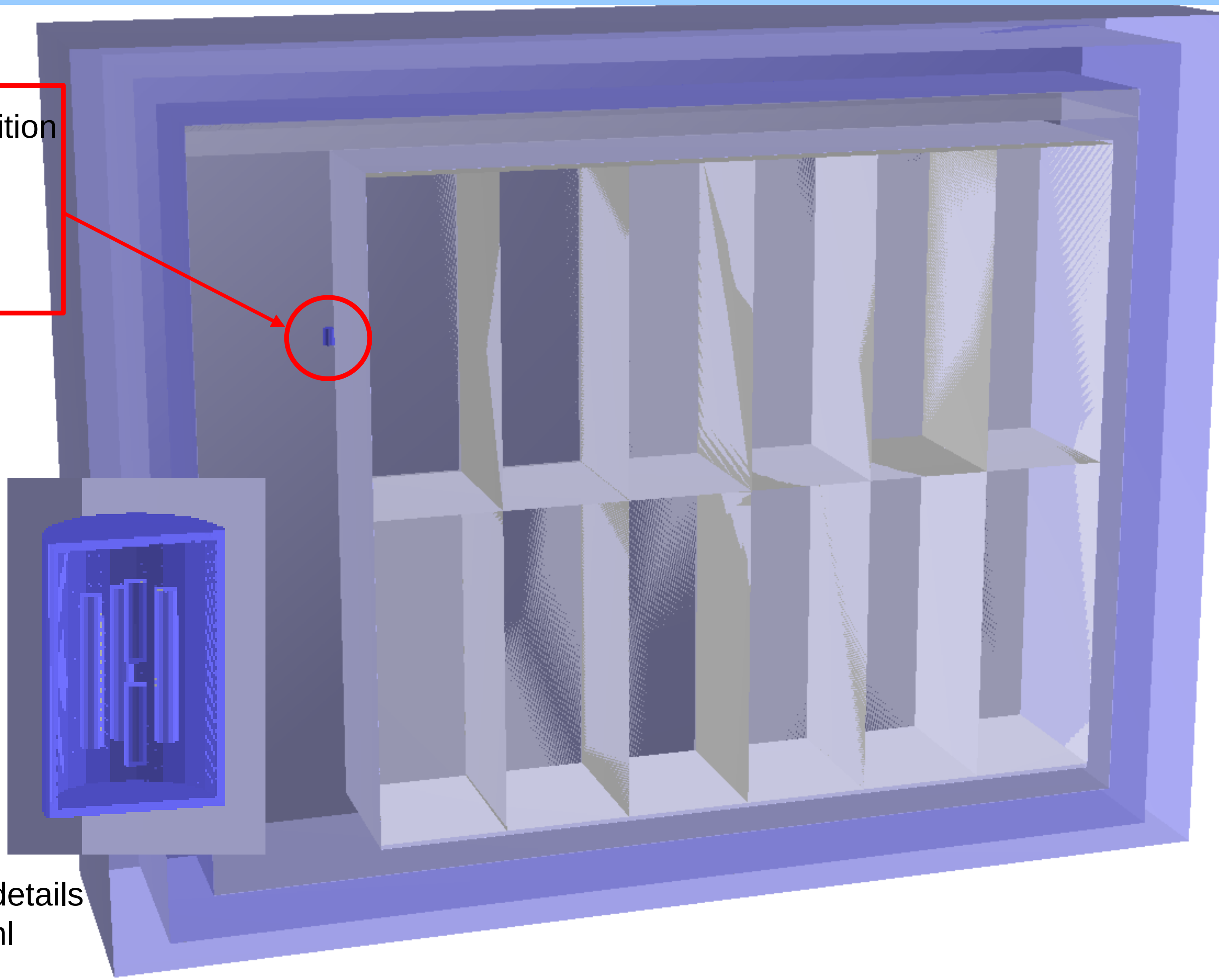
Weight of RSDS = 14.75 kg

FOM = 8.400 ± 0.039 @ 1.0 cm shell thickness

RSDS Only Near Top Deployed But Sim Check at Half Height of Upper APA (TGeo Validation/Screenshots of Implementation of RSDS in <dune10kt_1x2x6_v4.gdml> for LArSoft Input)

Fixed RSDS position in gdml:

- x = 220 cm
- y = 300 cm
- z = -40 cm

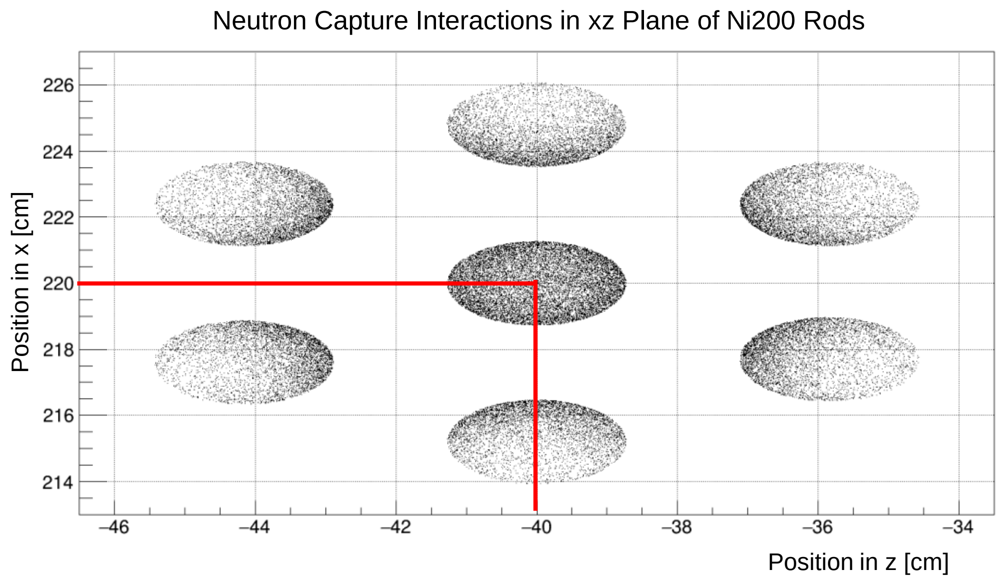


Close-up of RSDS details implemented in gdml for LArSoft

Neutron Capture Locations in Ni200 Rods from LArSoft RSDS Simulation
Validating Physics & Correct Placement of RSDS in dune10kt_1x2x6v4.gdml

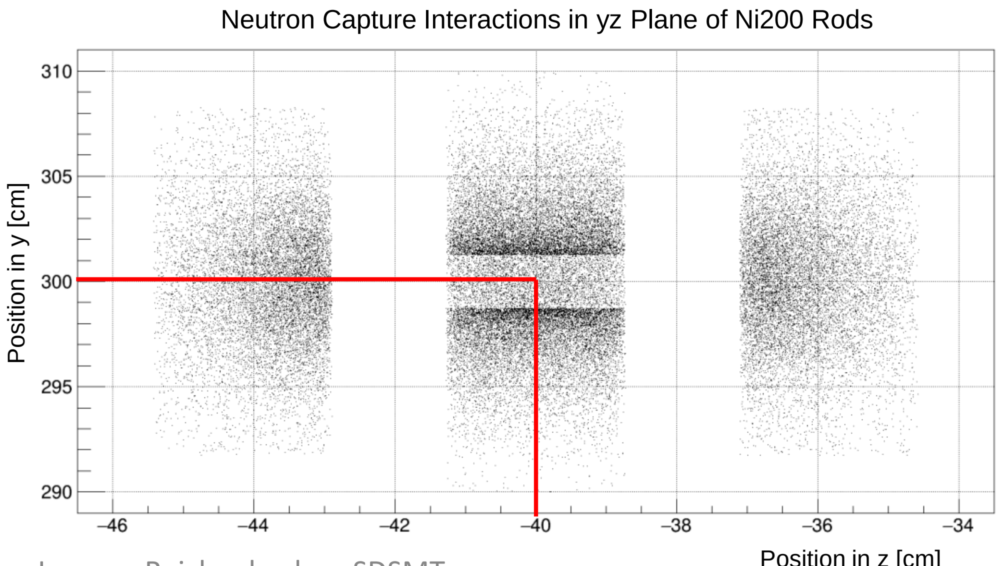
Correct placement at x=200 cm

Correct placement at z=-40 cm



Correct placement at x=300 cm

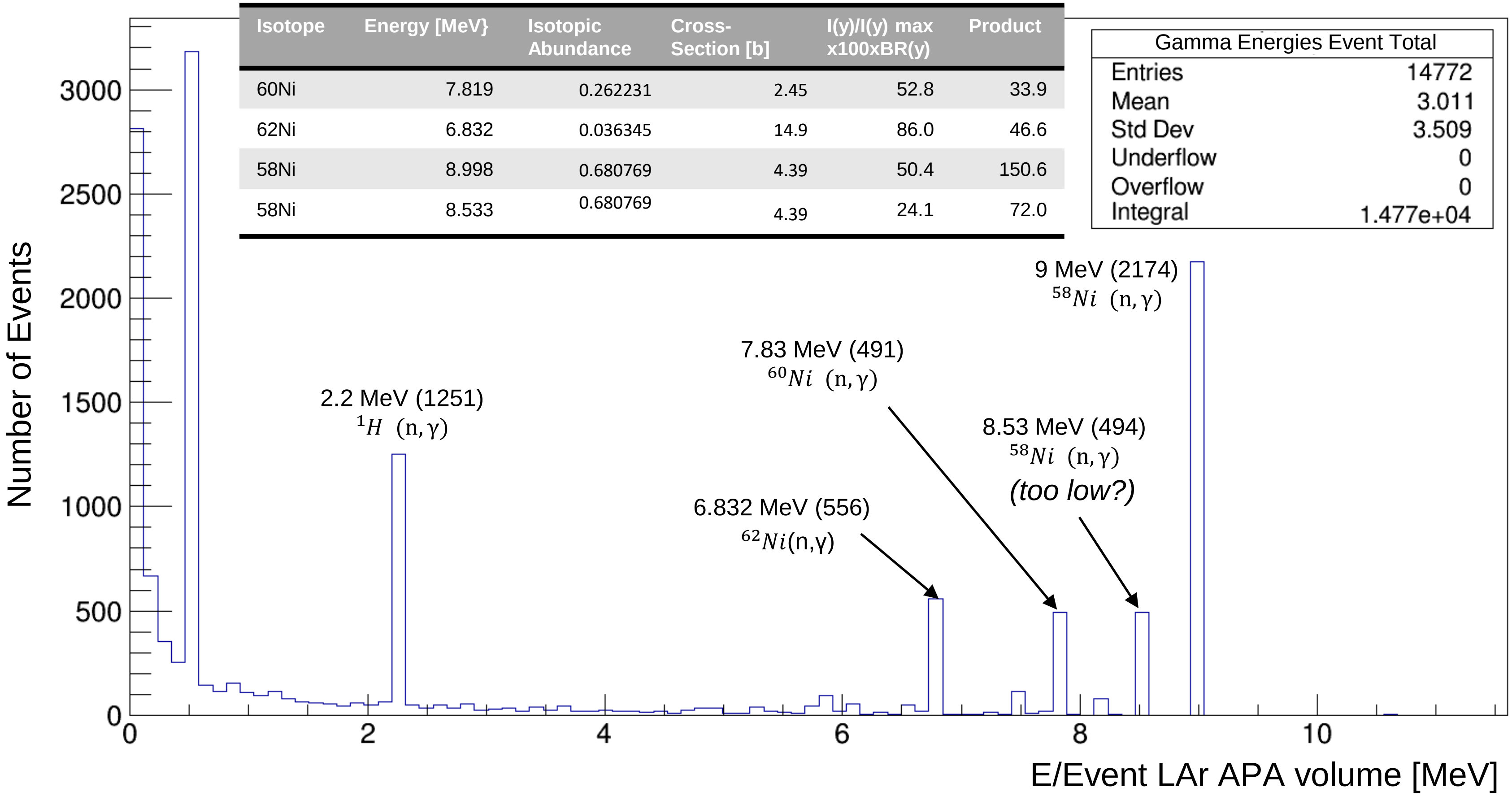
Correct placement at z=-40 cm



Resulting Energy Spectrum of γ-Rays Making it into the APA Volume in LArSoft RSDS Simulation

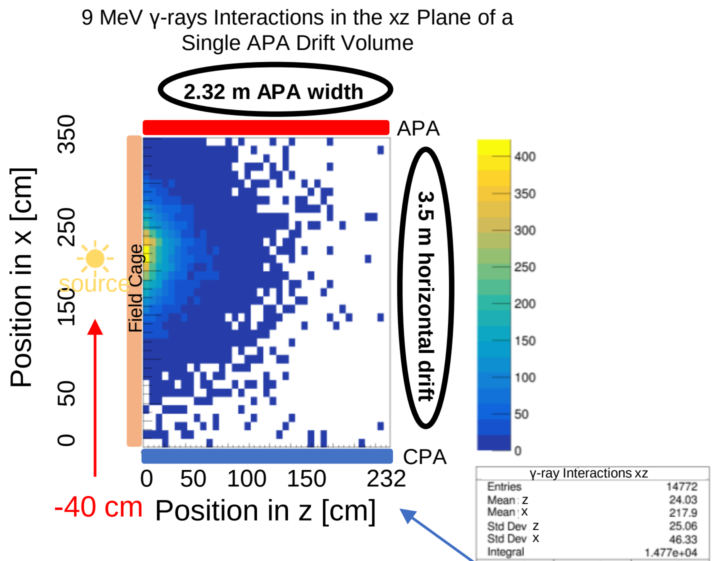
Total Gamma-Ray Energy per Event Deposited Inside APA Volume:

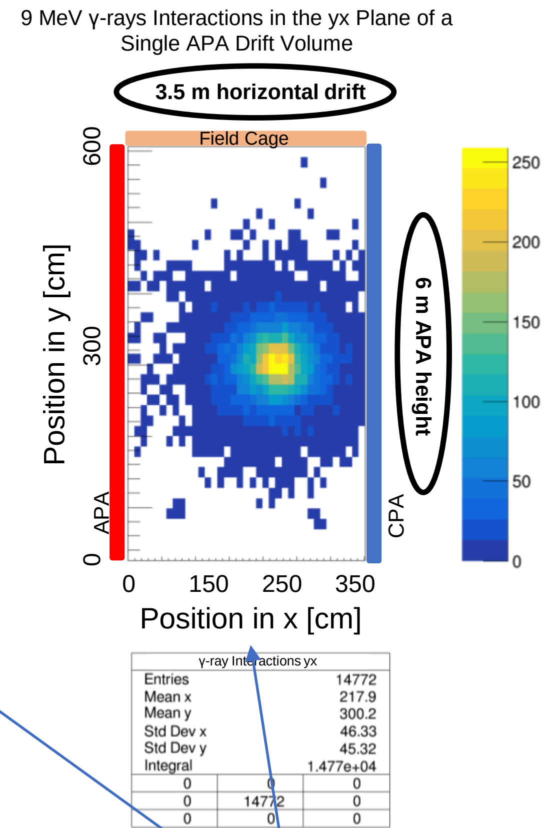
Isotope	Energy [MeV}	Isotopic Abundance	Cross-Section [b]	I(y)/I(y) max x100xBR(y)	Product
60Ni	7.819	0.262231	2.45	52.8	33.9
62Ni	6.832	0.036345	14.9	86.0	46.6
58Ni	8.998	0.680769	4.39	50.4	150.6
58Ni	8.533	0.680769	4.39	24.1	72.0

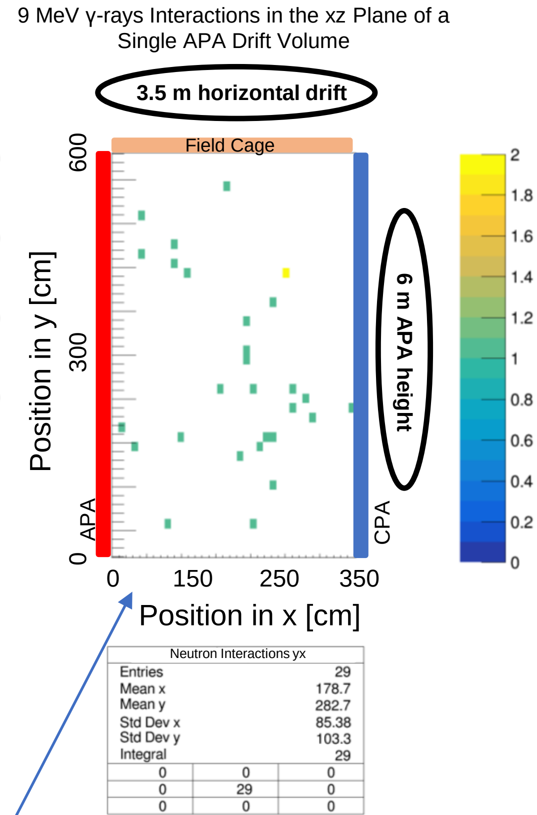


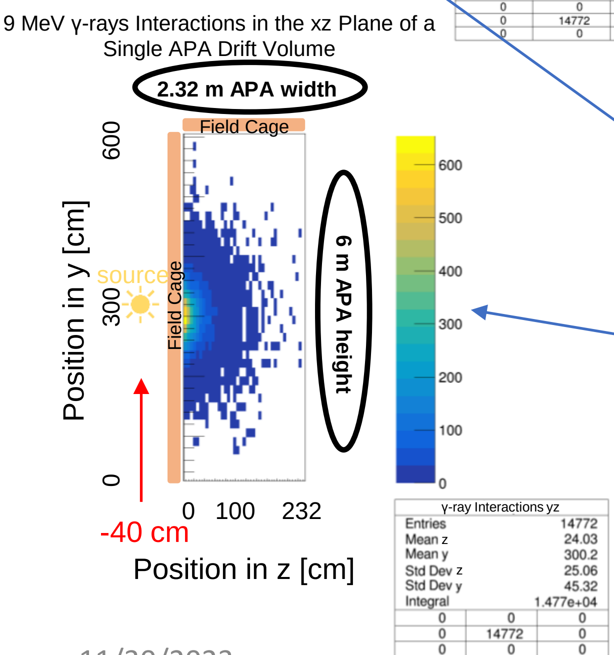
82k neutrons generated with AmLi source at RSDS center result in 2.2k 9 MeV gamma-rays inside the single APA volume:
=> 2.6% efficiency despite half of solid angle available only and two attenuation lengths min. path to enter APA!

Resulting RSDS Interactions in Single APA Drift Volume with LArSoft RSDS Simulation Using 1x2x6 Geometry with RSDS Implementation:





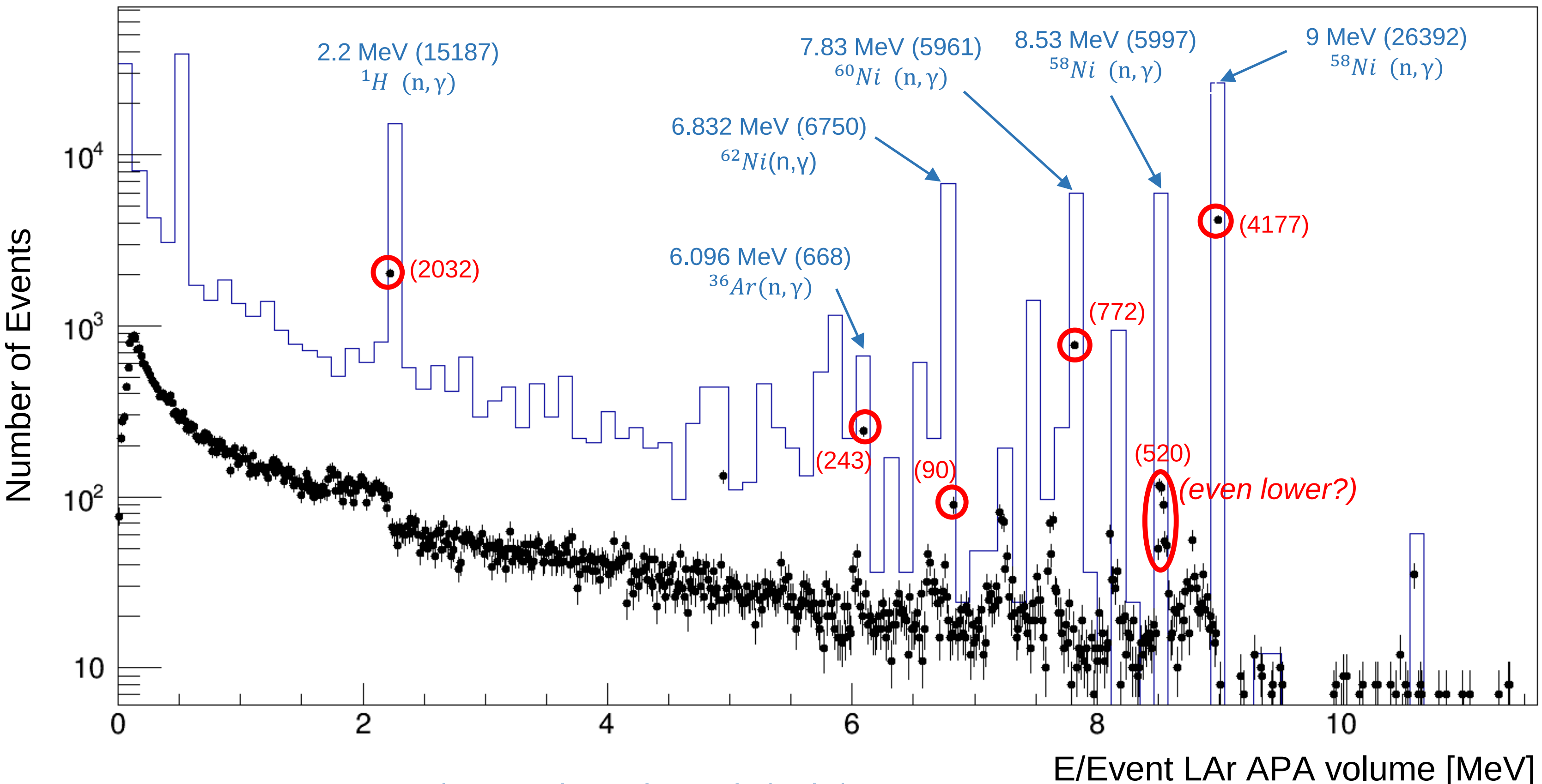




9 MeV γ-ray Vs. neutron energy deposits in fiducial single APA drift volume from LArSoft simulation of RSDS in dune10kt_1x2x6_v4.gdml

Comparison of γ-Ray Spectra inside APA Volume:
Geant4-10-06-p02 Standalone RSDS Simulation
Vs. LArSoft v08_60_00 e19:prof RSDS Simulation

Total Gamma-Ray Energy per Event Deposited in APA Volume:



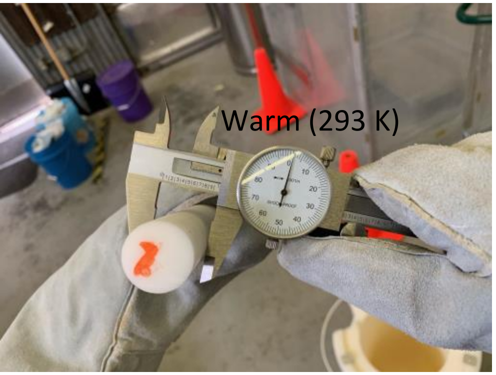
γ-ray spectrum in APA volume of LArSoft simulation

γ-ray spectrum in APA volume of standalone Geant4 simulation
(re-normalized by number of generated neutrons (1,000,000 G4 / 82,410 LArSoft = 12.13 down-scaling factor)

=> Accounting issue in standalone G4 RSDS simulation got resolved

Successful Cryo Testing of RSDS Components at SD Mines

Thermal expansion measured 1% for Delrin (<2% MSDS)

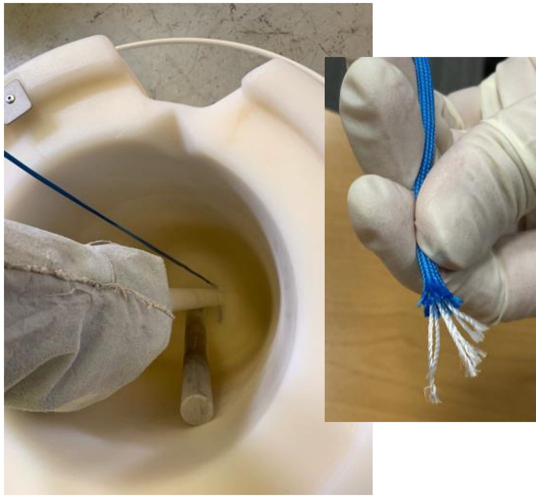


Successful mechanical strength tests before/after LN2:

Submerge in LN2 (85 K) in dewar::

Thermal expansion measured 0.5% for nickel rod:

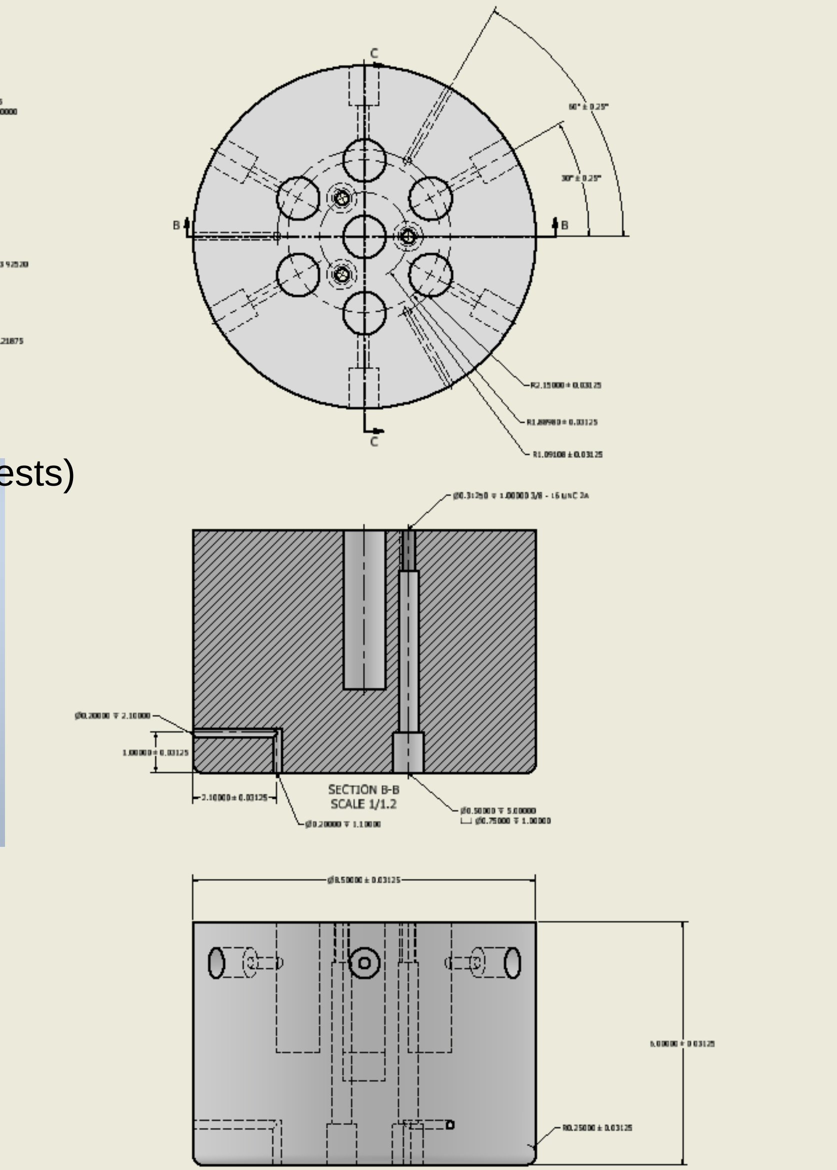
Diamond braid nylon lanyard worked great (cryo elastic, very stable strength)!



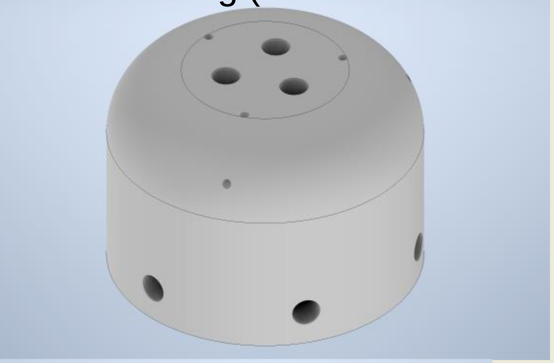
Anchor nylon line got too stiff:

-> Prepared ASTM tests for cryogenically tested & selected parts: Braided paracord, Delrin bar & fishline

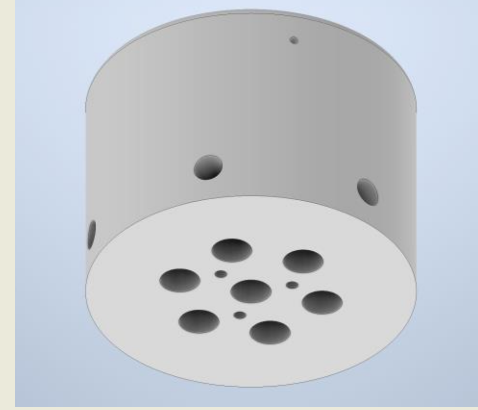
Top Half of Business End of RSDS with 3 Paracord Attachments



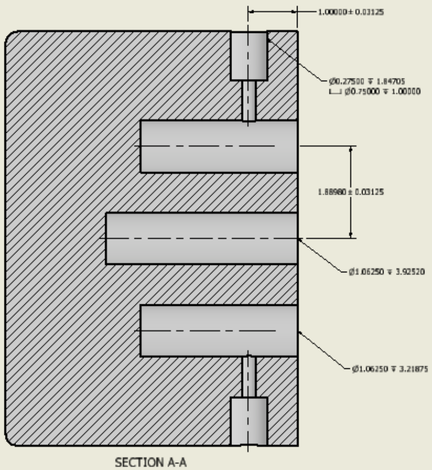
Final rounding (after successful tests)

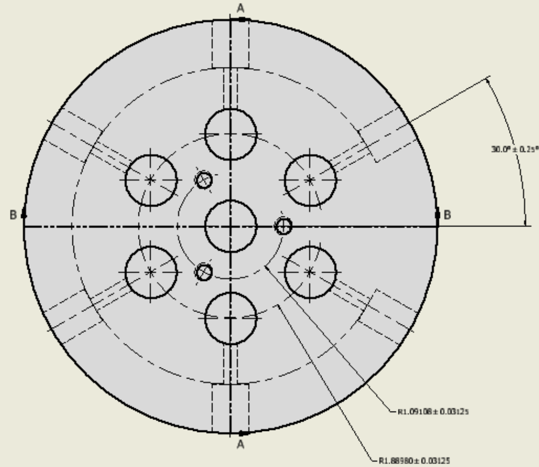


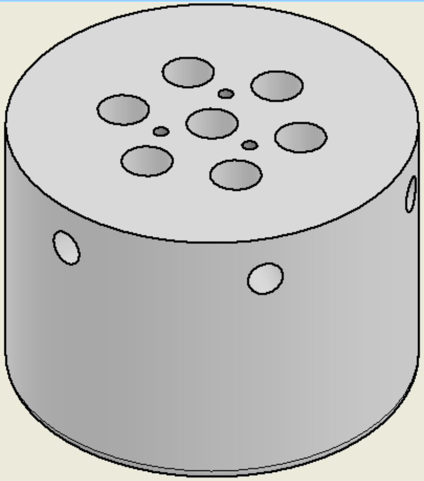
Initial version (before tests)



Bottom Half of Business End of RSDS

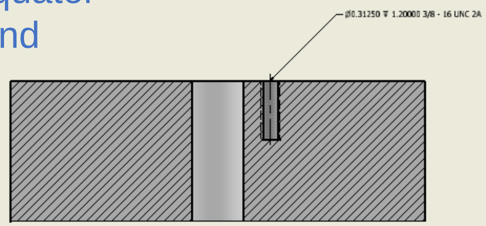


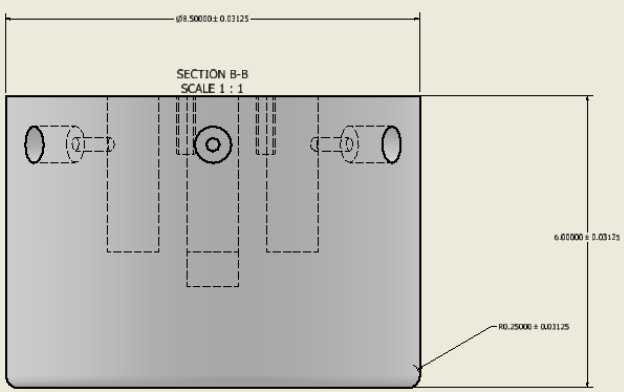




Initial version (before tests)

Solid attachments to nickel rods near equator
Such that nickel rods carry the weight and
to eliminate shrinkage gap at equator
and to provide a very solid joint of
upper and lower Delrin halves

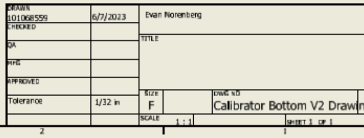




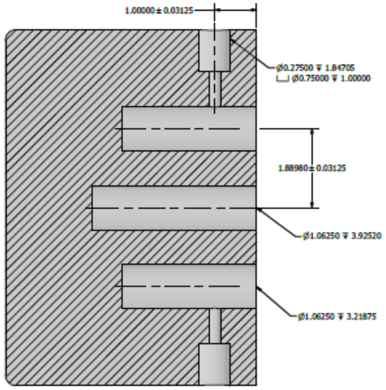
Final rounding (after successful tests)

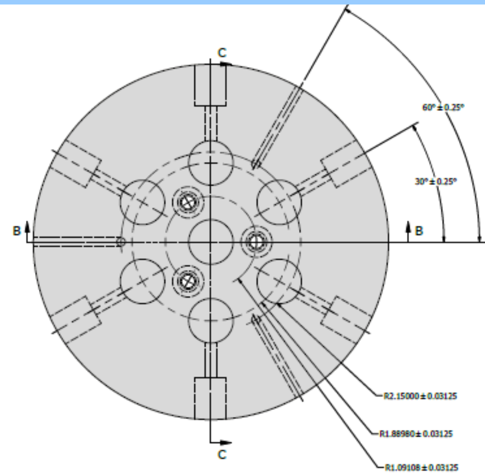
Drawing has 8.5" diameter of Delrin as delivered (original spec was only 8.0" but 8.5" will be used for this work piece).

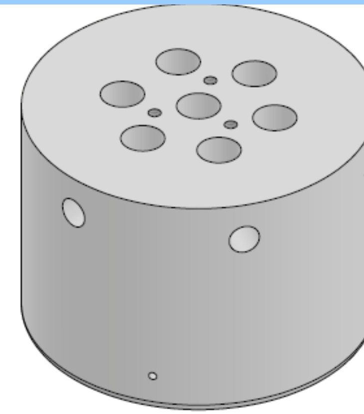
Threads need not be cut.

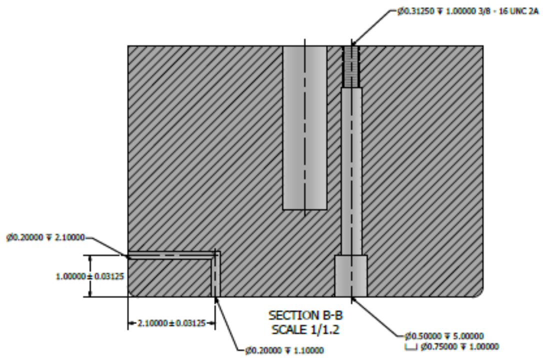


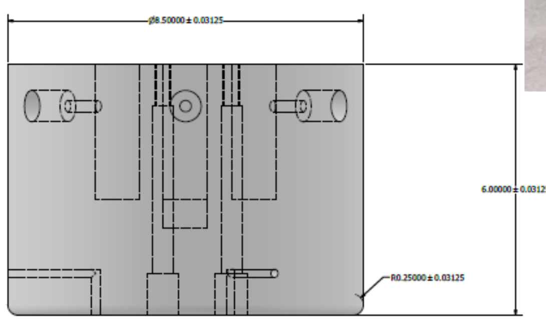
Fabricated Business End of RSDS with Cut and Inserted Nickel Rods









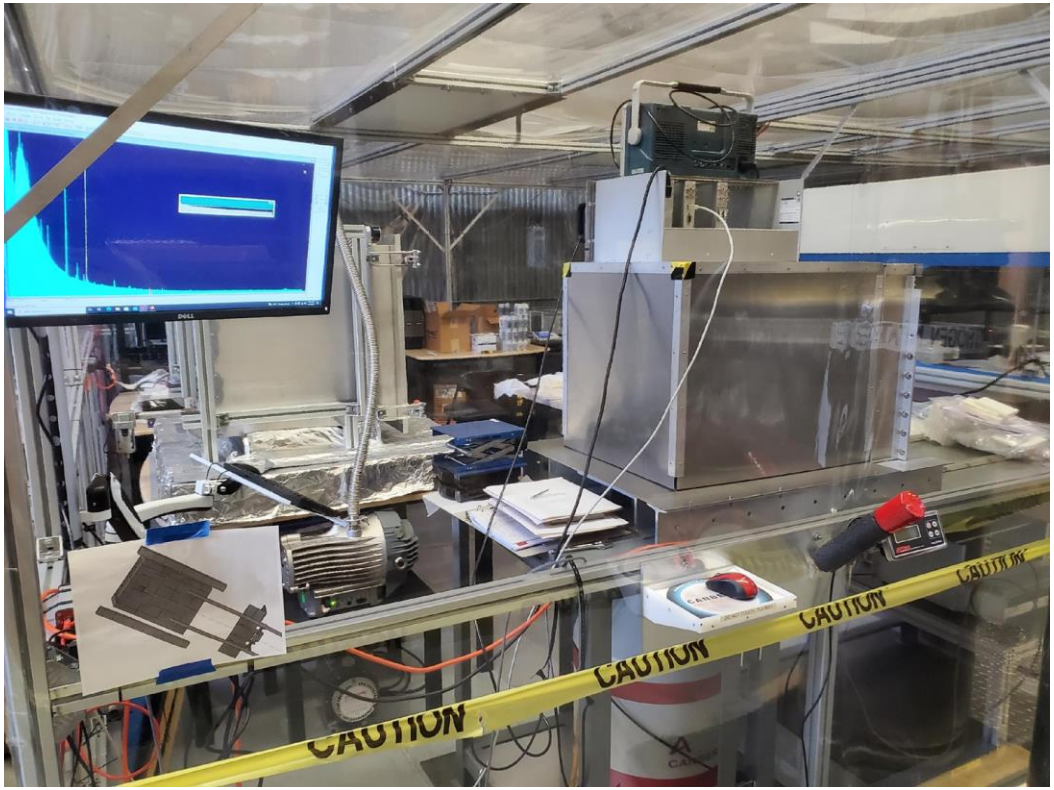


Drawing has 8.5" diameter of Delrin as delivered (original spec was only 8.0" but 8.5" will be used for this work piece).

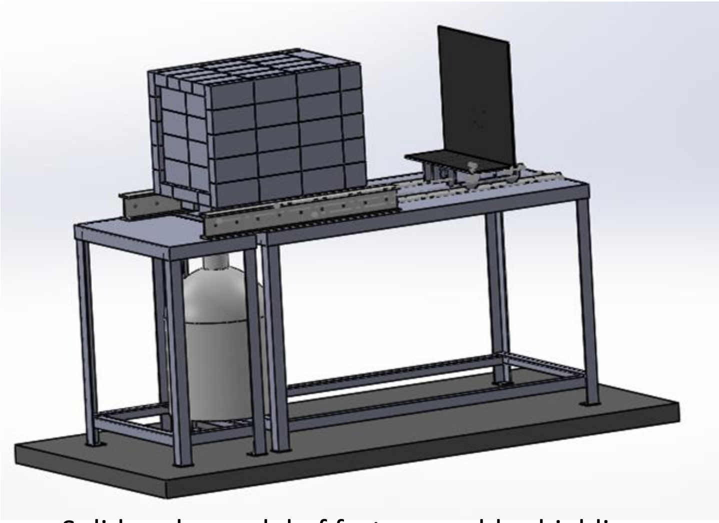
Threads need not be cut.

DRAWN 101068559	6/7/2023	Evan Norenberg
CHECKED		TITLE
QA		
MFG		
APPROVED		
Tolerance	1/32 in	SIZE F · DWG NO Calibrator Top V5 Drawing · SCALE 1/1.2 · SHEET 1 OF 1

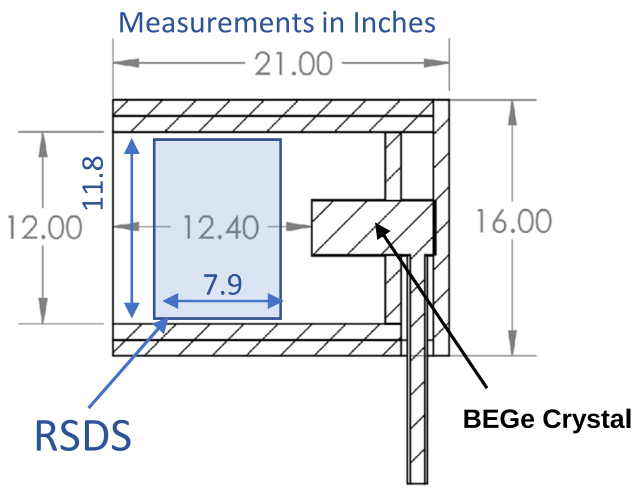
Current Step: Validate High Energy γ-Ray Yields of RSDS



Physical setup of 'Rabbit' γ-ray BEGe detector



Solidworks model of fast moveable shielding (using rails) with cryostat of 'Rabbit' detector

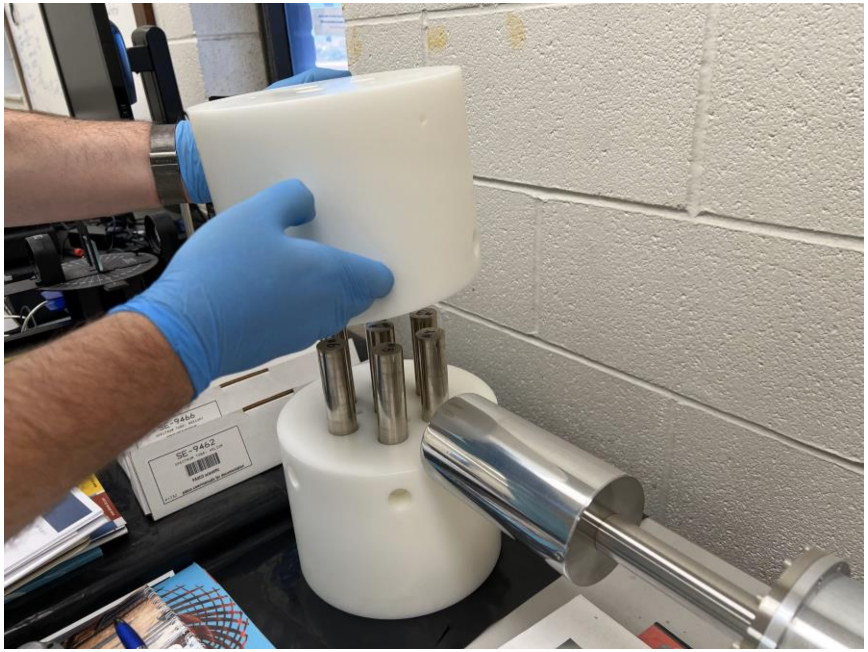


Solidworks drawing of 'Rabbit' γ-ray BEGe detector with shielded inner assay chamber

Our 'Rabbit' BEGe detector provides a uniquely large sample chamber of 12" x 12" x 12.4". This will provide the space required to assay the bulky RSDS' γ-ray emission.

=> Use existing Cf-252 neutron source instead for initial test (and other Ge-detector)

Current Step: Validate High Energy γ-Ray Yields of RSDS

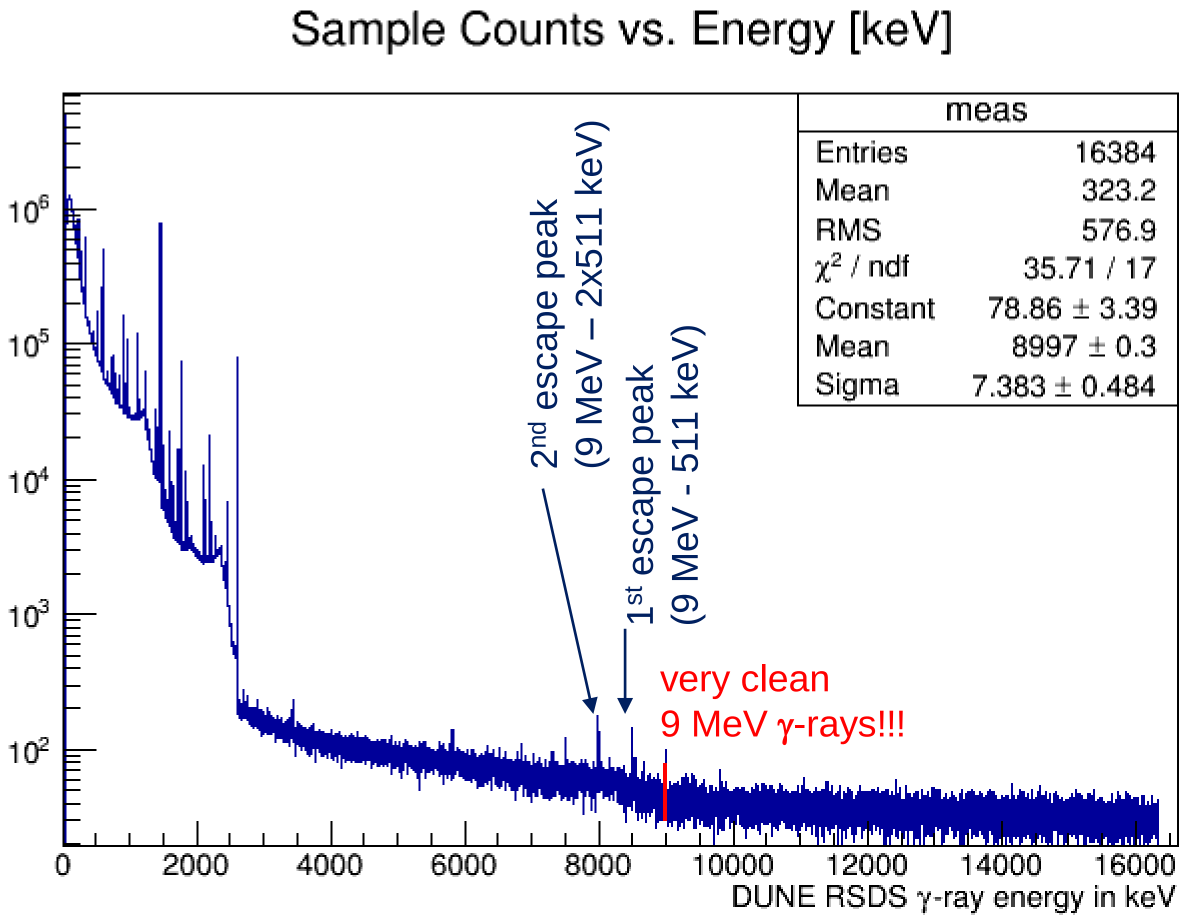



Physical setup at our cryo-pulser-cooled Ge-detector at SD Mines

⇒ ***Use existing Cf-252 neutron source instead of AmLi (-> costs) for initial test and our available 2nd Ge-detector ('Rabbit' is fully occupied with DUNE assays)***

⇒ ***Use LUX AmBe source to calibrate with 4.4 MeV γ-rays the clear signature of pair-production in our Ge-detector (dominant interaction as for 9 MeV γ-rays)***

Proof of Principle Measurement Successful!

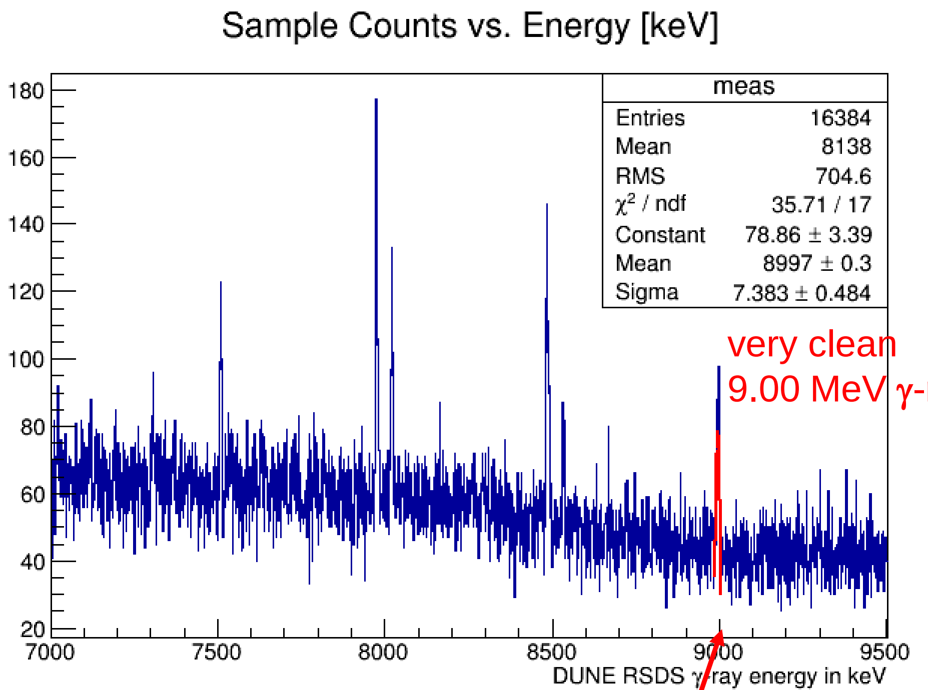


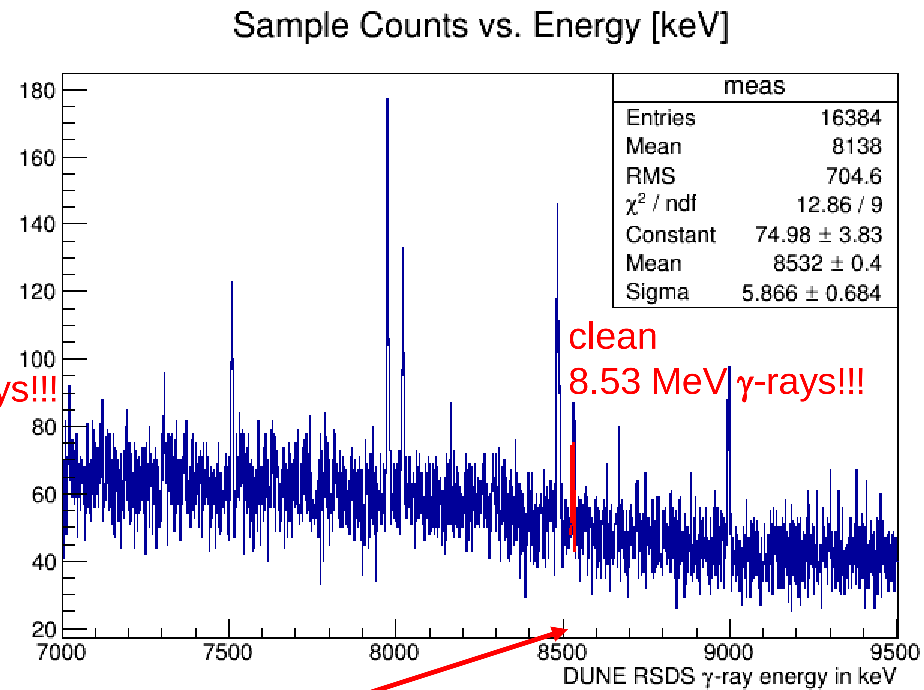
⇒ ***Proof of Principle Measurement** already with existing Cf-252 neutron source (57 n/s)*

⇒ ***Will be even better with lower energy AmLi source -> costs justified now***

Used ^{40}K & ^{208}Tl γ-lines for energy scale in addition to LUX AmBe source to calibrate with 4.4 MeV γ-rays the clear signature of pair-production in our Ge-detector (dominant interaction as for 9 MeV γ-rays)

Proof of Principle Measurement Close-Up!



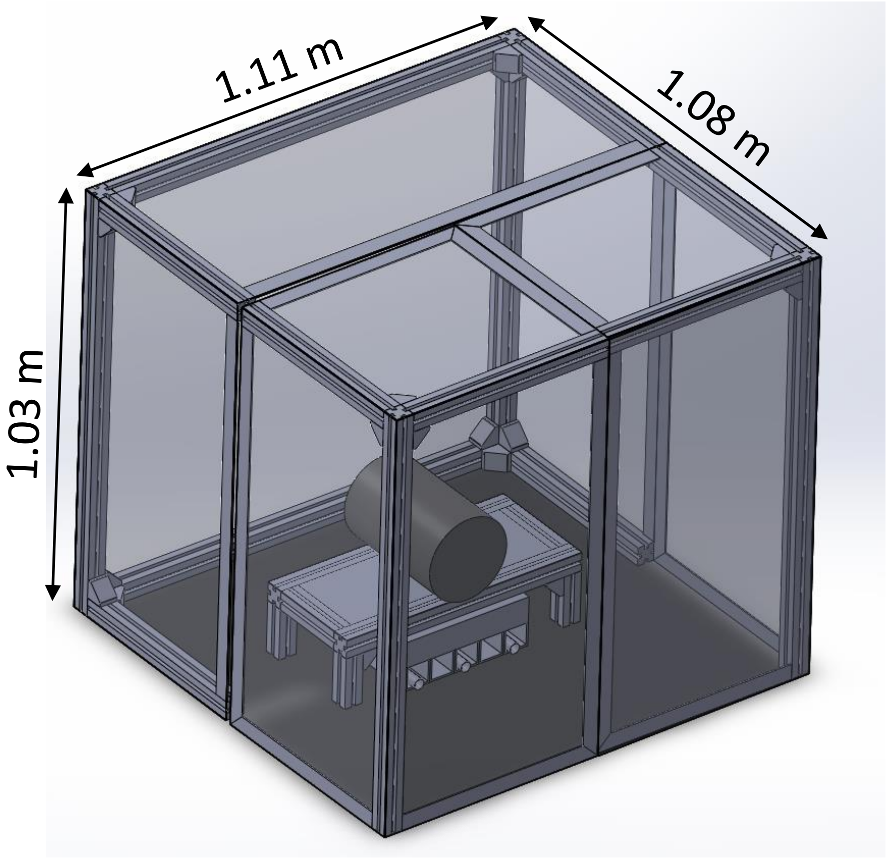


Type	E(γ) (keV)	ΔE(γ) (keV)	I(γ)/I(γ)max × 100	Δ(I(γ)/I(γ)$_{max}$)
Primary	7697.30	*0.06*	2.4832	*0.0490*
Primary	8120.75	*0.07*	8.5014	*0.1888*
Primary	8533.71	*0.07*	47.8386	*0.9982*
Primary	8998.63	*0.07*	100.0000	*2.0365*

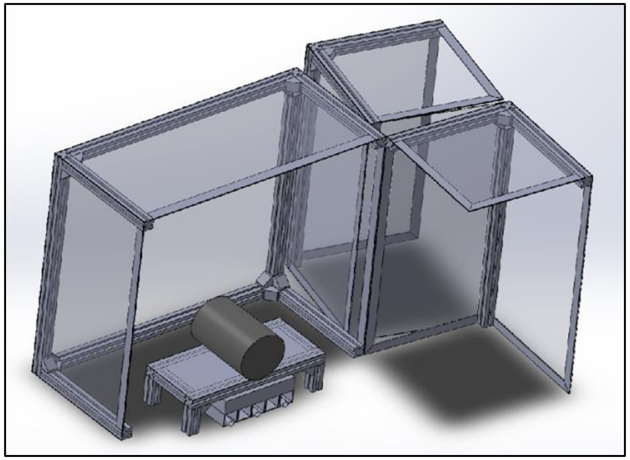
⇒ ***Measured very clean 9.00 MeV γ-rays at about twice the rate as the clean 8.53 MeV γ-rays [as expected from capGam 58Ni(n, g)59Ni data]***

⇒ ***Ideal calibration source to measure trigger efficiency at DUNE FD threshold and E-resolution with two clear pair production peaks that should be separable!***

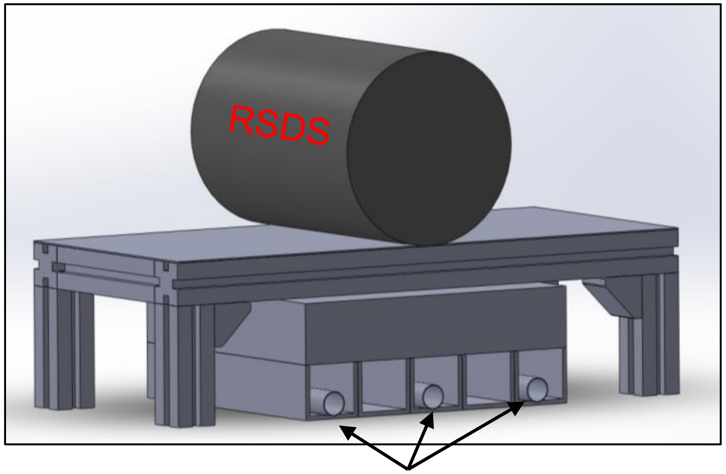
Next Step: Underground Testing of RSDS for Residual Neutron Emission at SURF



SDSMT previously developed He-3 hodoscope for LZ experiment with test stand enclosure to be used in assaying of the residual neutron emission rate of the RSDS optimized configuration



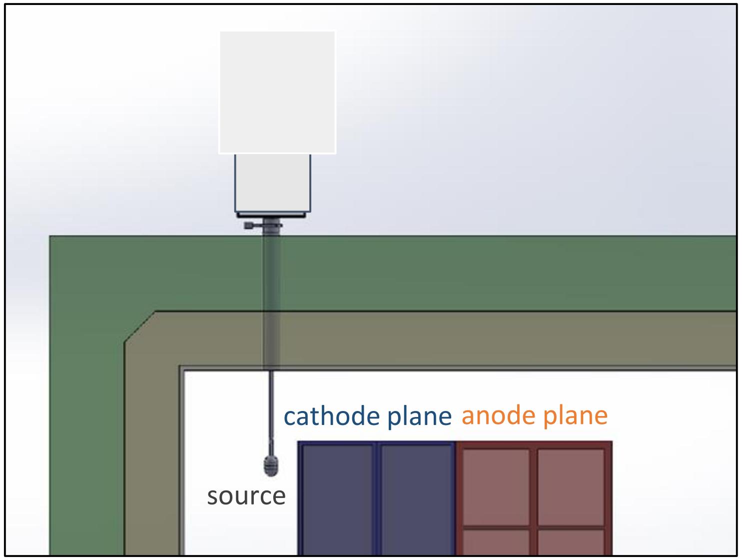
Accordion-like construction allows for safely locking up source during long measurement (SURF requirement)



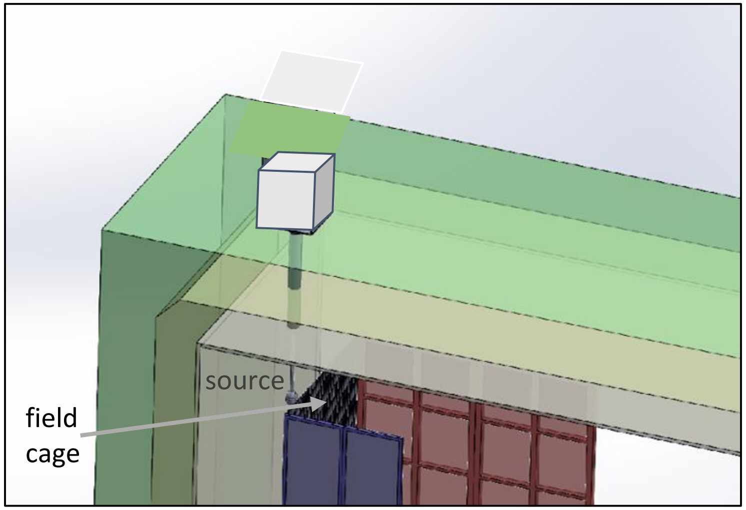
He-3 proportional counters

Planned Deployment Testing of RSDS in our High-Bay Lab at SD Mines

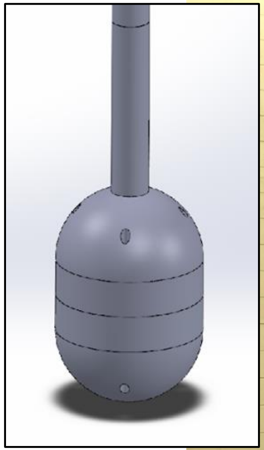
Side view of source deployment into cryostat:



Rotated side view of source deployment into cryostat:



Scaffold tower in our high bay for mechanical mock-up testing:

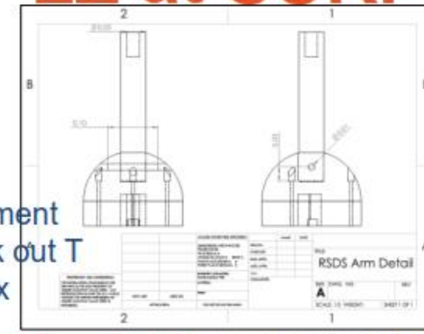


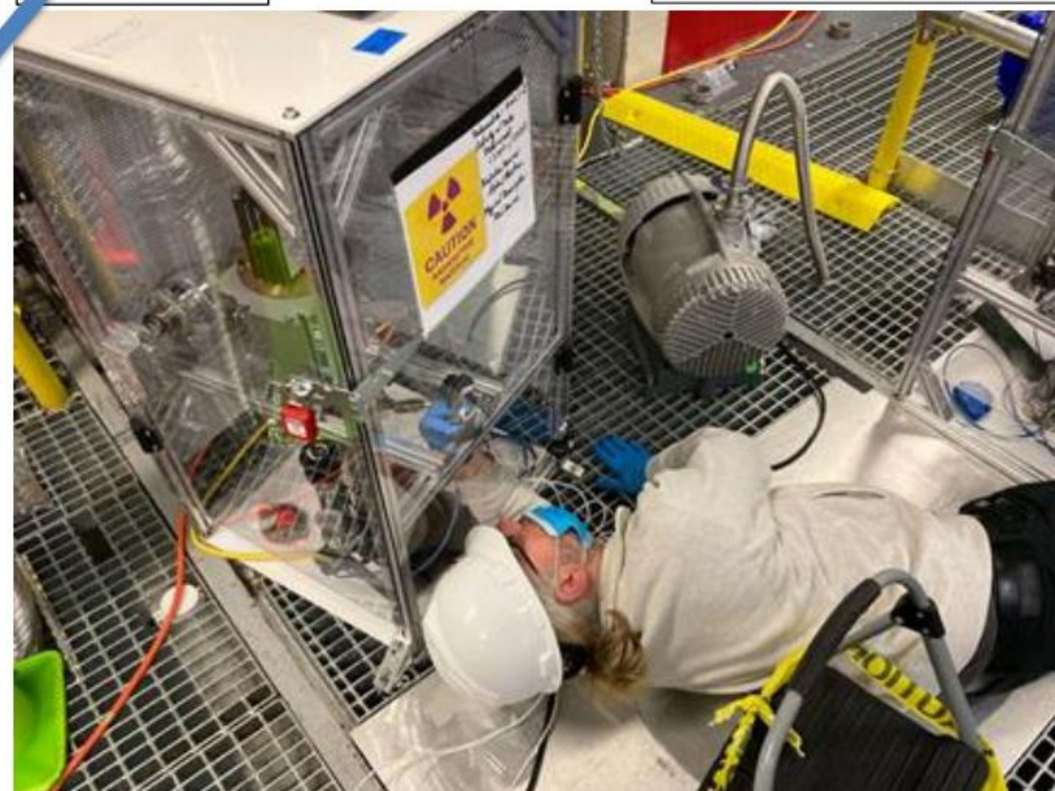
Business end of RSDS (<u>R</u>adioactive <u>S</u>ource <u>D</u>eployment <u>S</u>ystem)

=> Plan also external deployment of RSDS business end outside of small LArTPC

Neck extension with our RSDS deployment box mounted above gate valve as we did for LZ at SURF

OD 200 source
< ID 250 port
w/ deployment arm
for insulated rope attachment
hoisted by motor in break out T
at side of deployment box





Summary and Outlook

- Successful implementation of the RSDS geometry into the 1x2x6 geometry GDML file, and successful simulation of RSDS in LArSoft by generating AmLi neutrons at center of RSDS.
- LArSoft RSDS simulation demonstrates that 9 MeV gamma-rays are produced at a very efficient rate per AmLi neutron. However, more checks on physics list need to be done for both for standalone G4 and LArSoft simulation.
- RSDS materials required for a physical RSDS have been acquired

  => cryo testing of materials/RSDS has been successful!

  => machining of RSDS business end is done!
- Underground neutron test bed ready with safety officer approved enclosure structure for SURF. Germanium based gamma-spectrometer is calibrated with high energy gamma-rays from tagged AmBe neutron source

  => γ-ray measurement of RSDS w/ inner Cf-252 source is successful Proof of Principle!
- Cf-252 (5 kBq – 10 kBq already on SDSMT and SURF license) with Delrin moderator seems to be a viable fast interim solution for RSDS demonstrator (proof of principle) to be employed exteriorly at small test LArTPC (Fermilab u/g 2x2?, LArPix?, CSU?)