Radioactive Source Deployment System (RSDS)

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James Haiston, Jason Stock
(SDSMT)

DEEP UNDERGROUND NEUTRINO EXPERIMENT

DUNE CalCI Scope Review
May 28, 2020

Motivation

- Only system to measure and scan trigger efficiency for SNB and solar neutrinos near our claimed detection threshold of 10 MeV (in particular for isolated single events)

- Well-defined physics signal at known location with known energy (with clear relation to radiological backgrounds and clearly separable from electronic noise)

- High enough energy to make multiple wire-hit Compton electron tracks with dislocated subsequent single wire-hits hits thus mimicking SNB and solar νe signature

- Allowing for EM shower calibration of beam νe and probing pair production signature

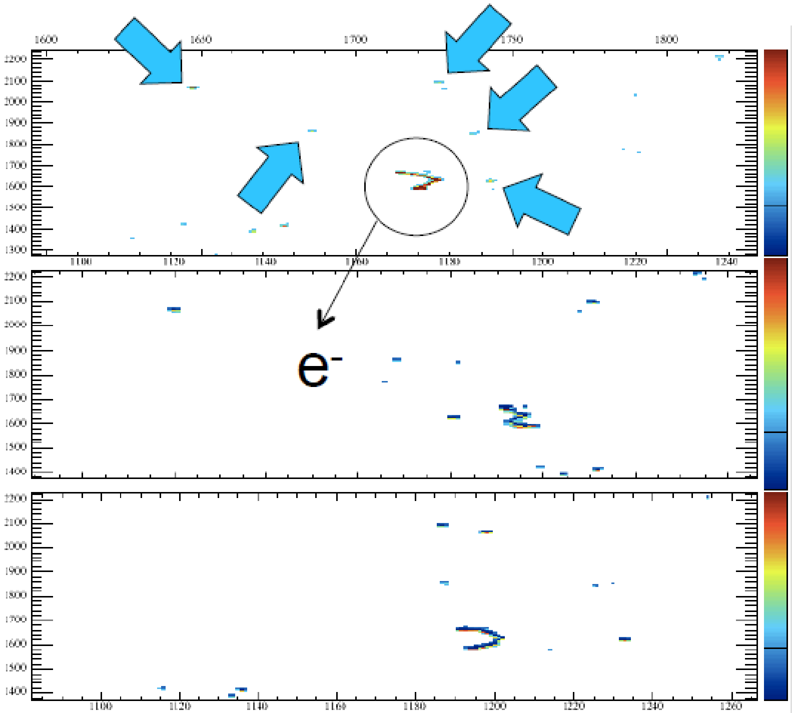
- Complementary to DD-generator calibration that probes uniformity through entire detector volume but is externally triggered and lower in γ-energies

SNB and Solar Neutrino Signature

Can we tag ν_e CC interactions in argon using nuclear deexcitation γ's?

Charged-current absorption:

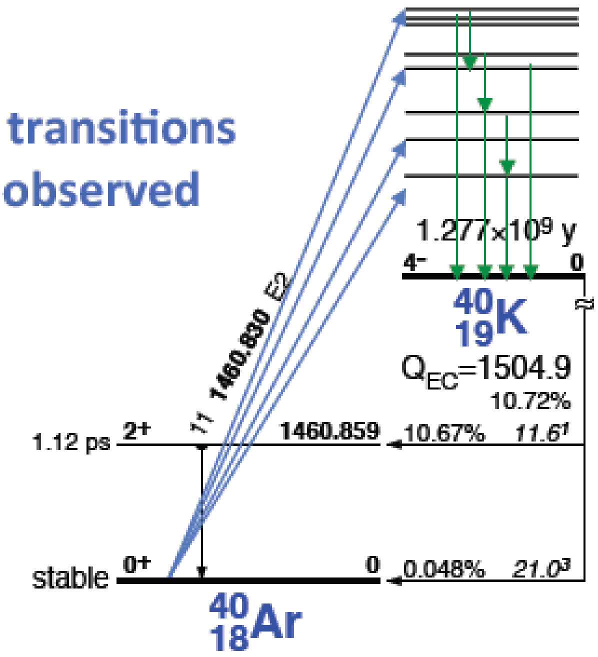
$$\nu_e + {}^{40}\text{Ar} \rightarrow {}^{40}\text{K}^* + e^-$$



MicroBooNE geometry (LArSoft)

At least 25 transitions have been observed indirectly

(g.s. to g.s. is 3rd forbidden transition)

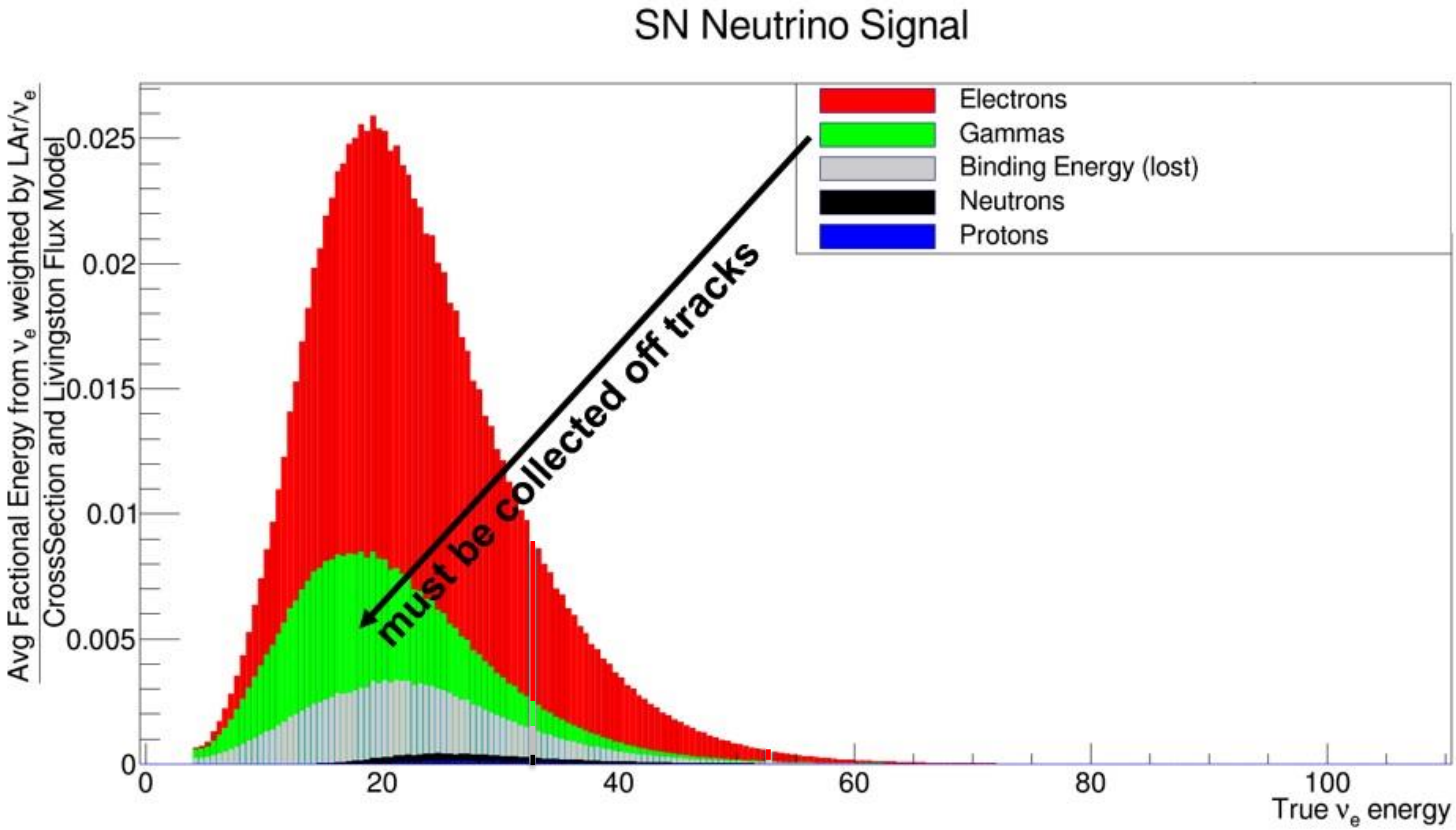


$\Rightarrow$ 9 MeV γ-rays can mimic ν_e signature:

1.) short electron track stub (^= 1st 9 MeV γ-ray Compton scatter electron)

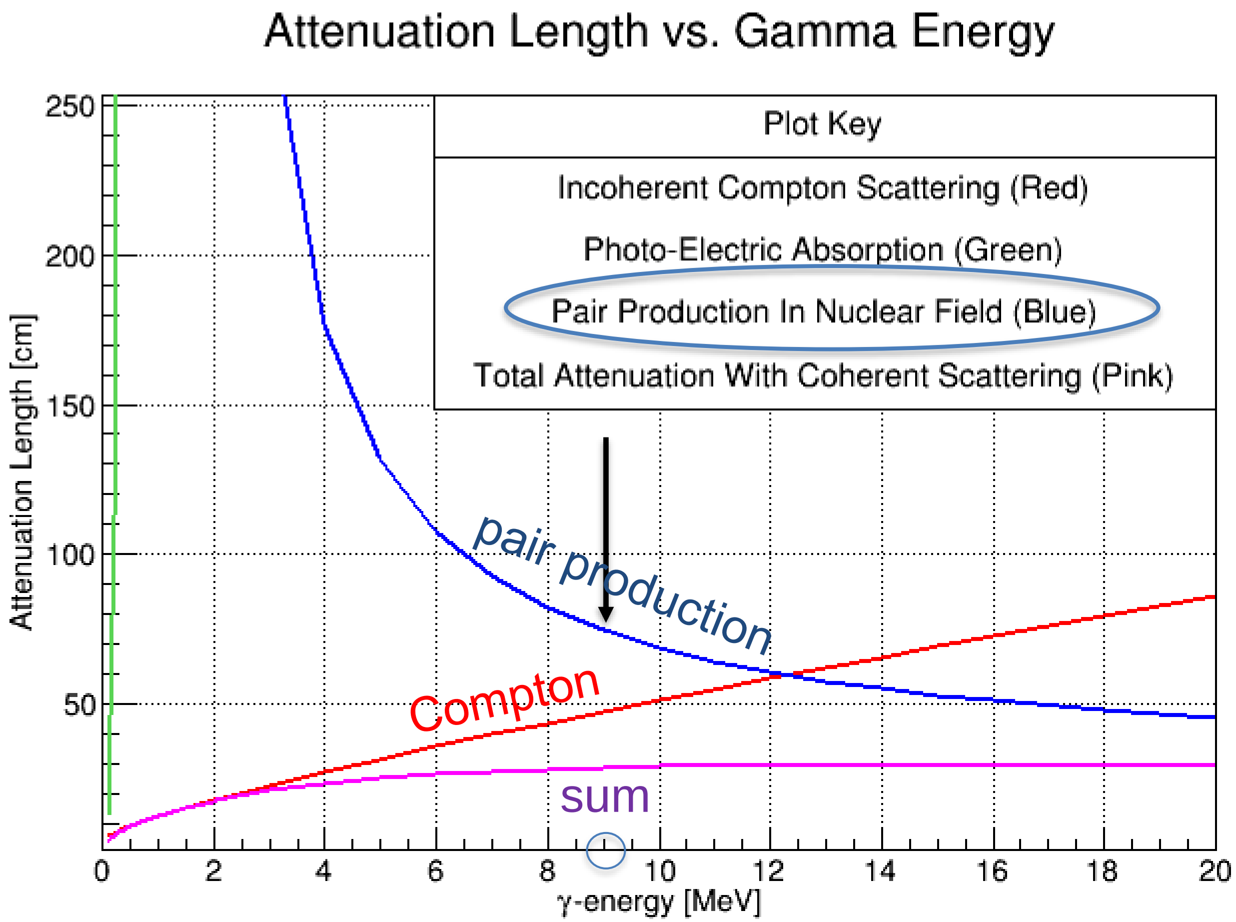
2.) several further dislocated hits from subsequent lower energy γ-ray scatters

γ-Rays from ν_e Interactions on ^{40}Ar



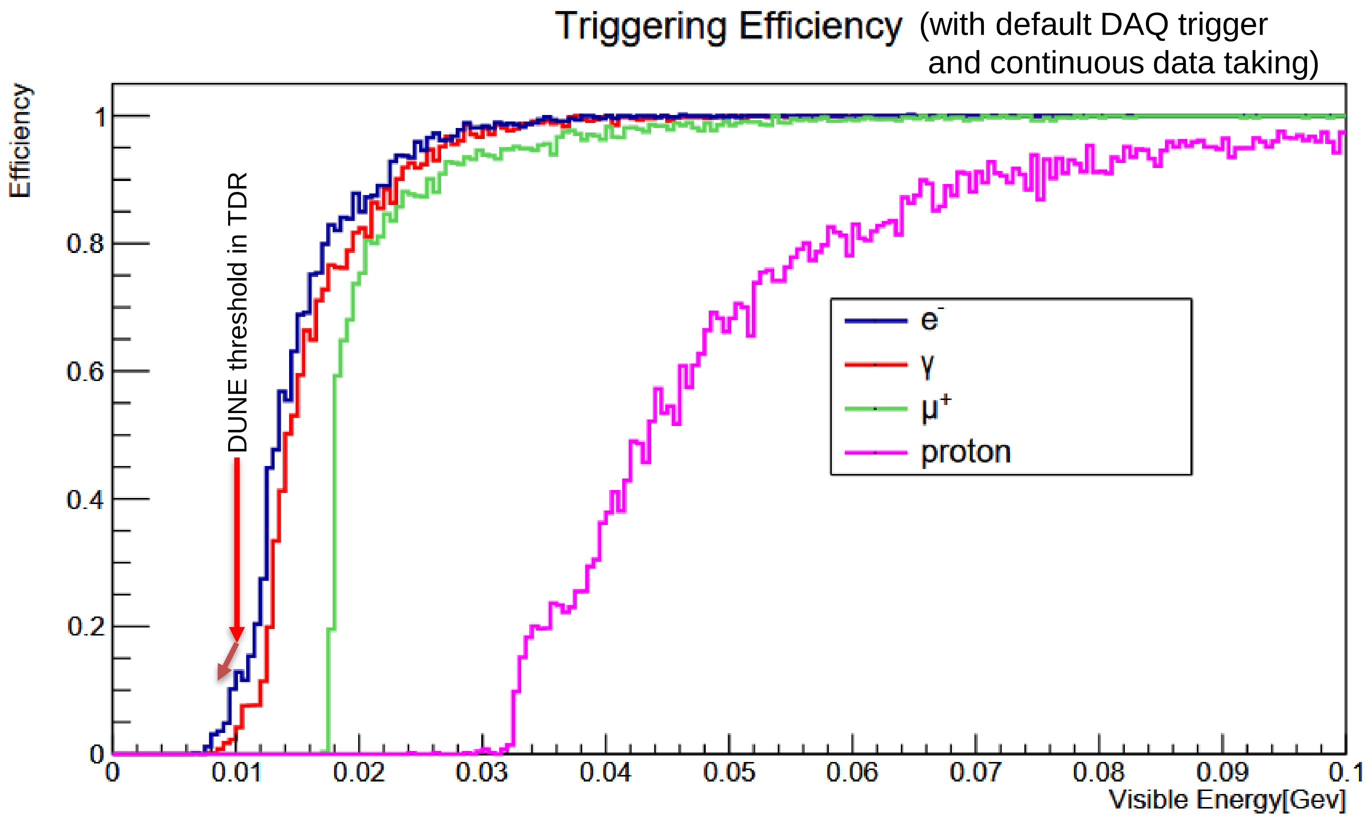
Erin Conley, Jason Stock, Steven Gardiner, Juergen

γ-Ray Interactions in LAr



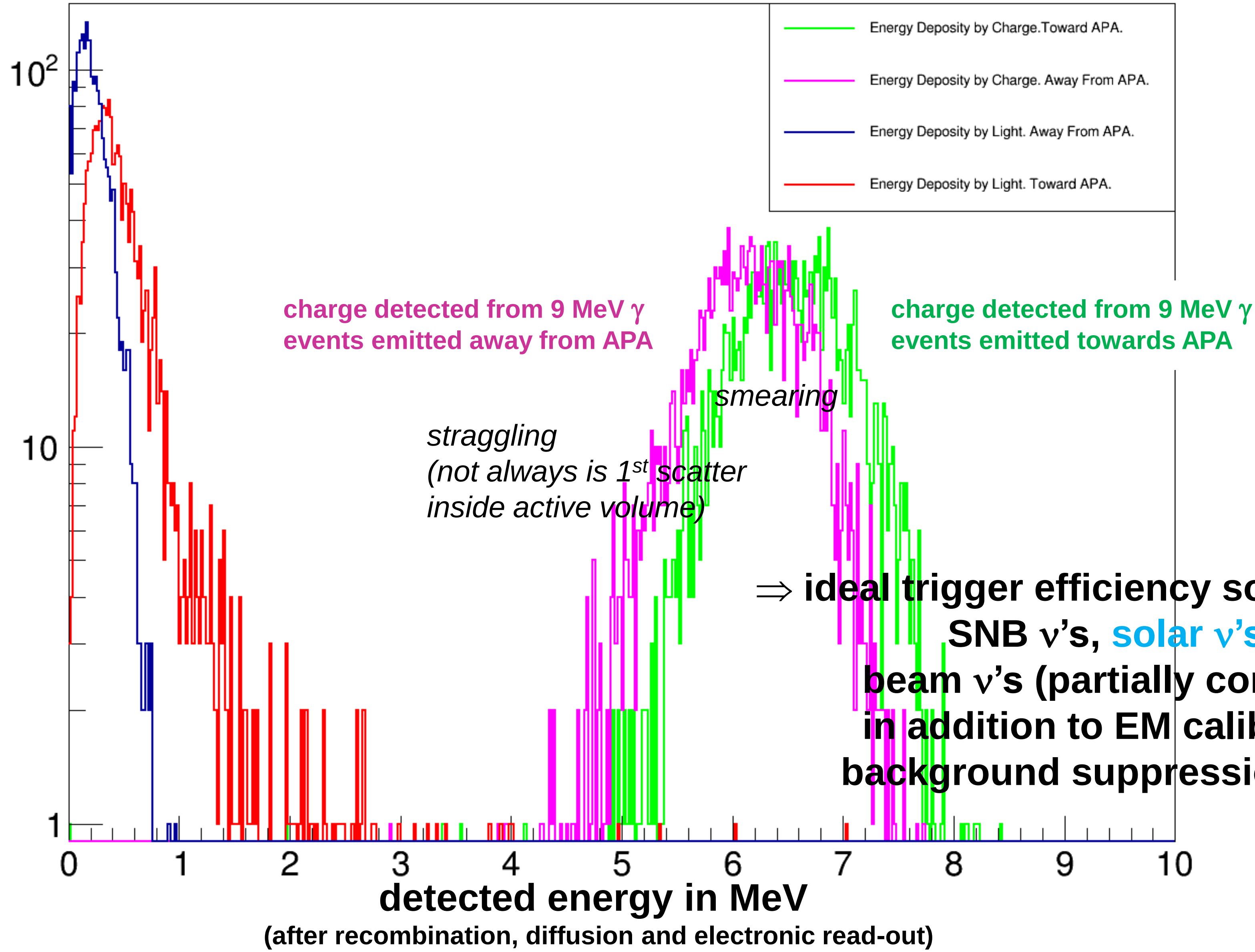
Trigger Efficiency with Electron/γ Sample

David Rivera, David Last & Josh Klein



(majority of RSDS data planned to be recorded with just one APA at a time recording ALL hits free-running
and rest of detector uses default DAQ trigger and continuous data taking w/ partitioned DAQ
-> can offline compare to the definition of efficiency for SN bursts and single solar neutrino events)

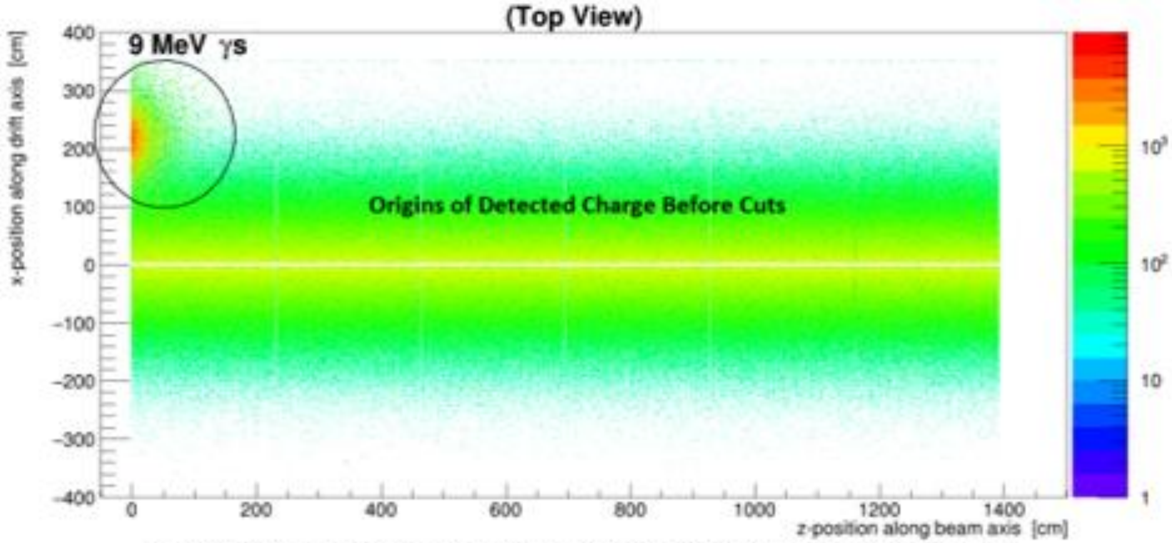
Detected Energies in Active TPC Volume



⇒ ideal trigger efficiency source for SNB ν's, solar ν's, beam ν's (partially contained) in addition to EM calibration, background suppression study

LArSoft Simulation with Expected Radiological Backgrounds

9 MeV γ-ray source deployed at 40 cm outside of the field cage, 220 cm away from the anode plane and 300 cm down from top



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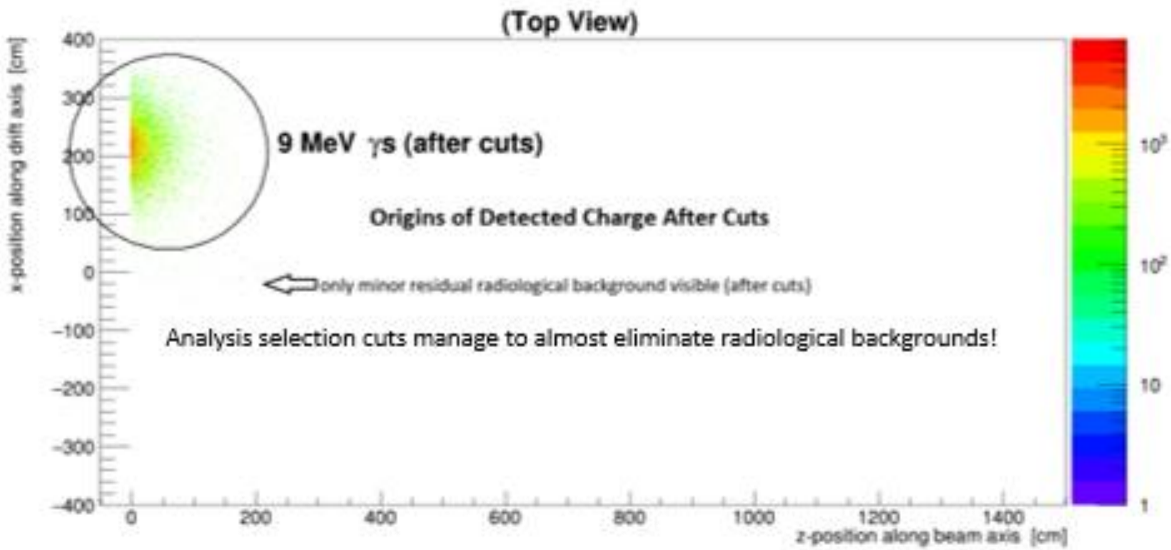

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("Virtual" RSDS already useful: Found issues in PD simulation that got fixed)

Data Analyses with Selection Cuts Using LArSoft Simulation with Expected Radiological Backgrounds

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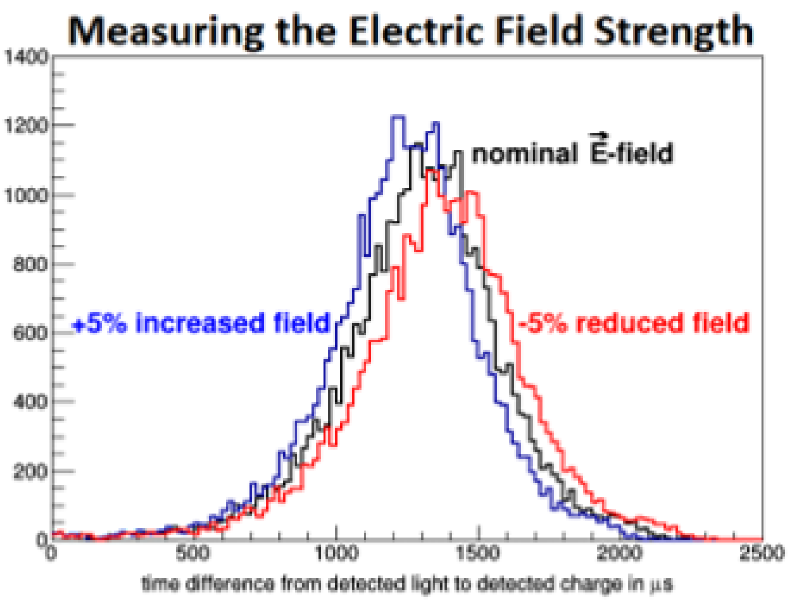
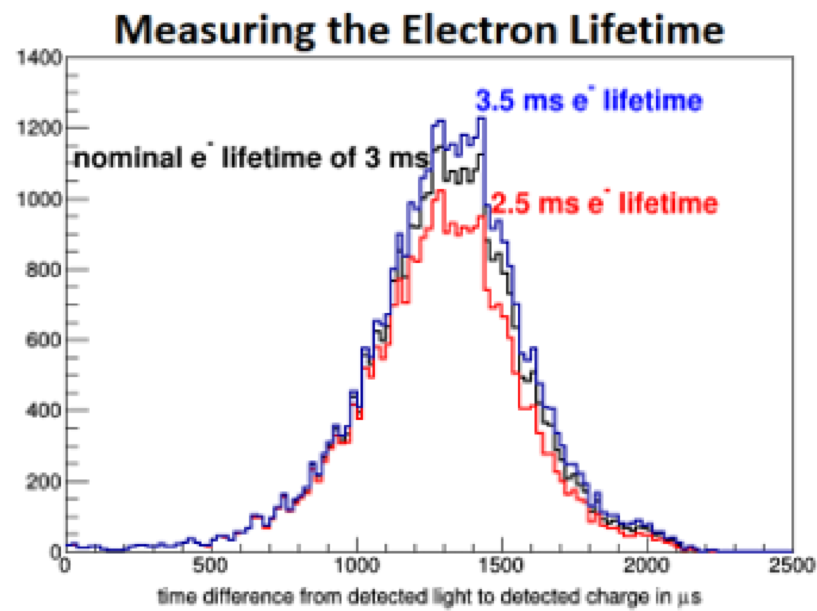
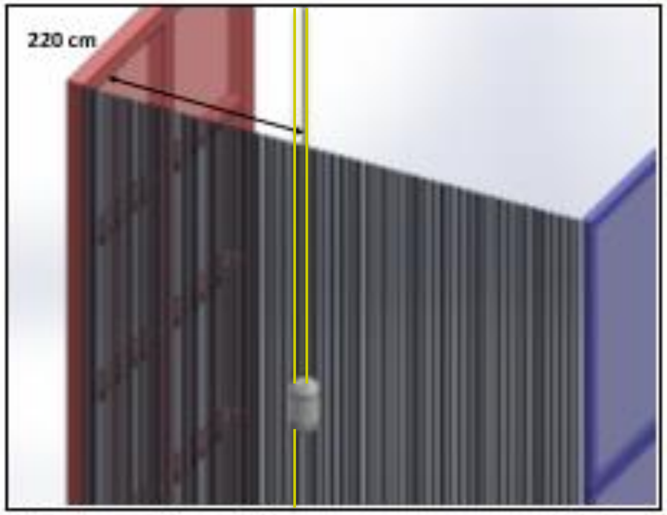


E-field

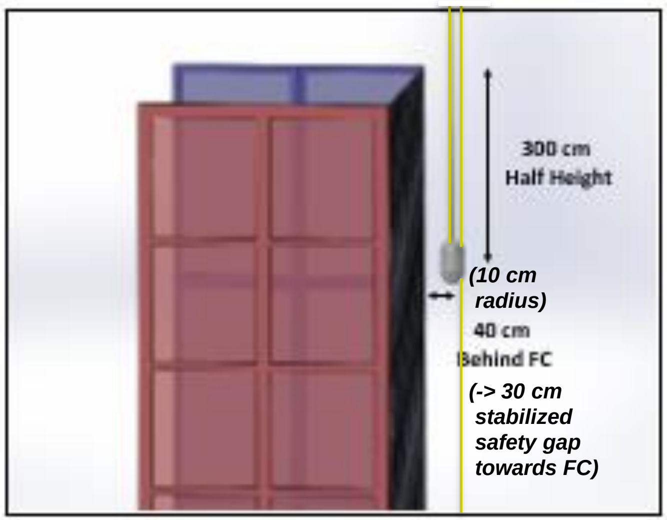


Electron-Lifetime

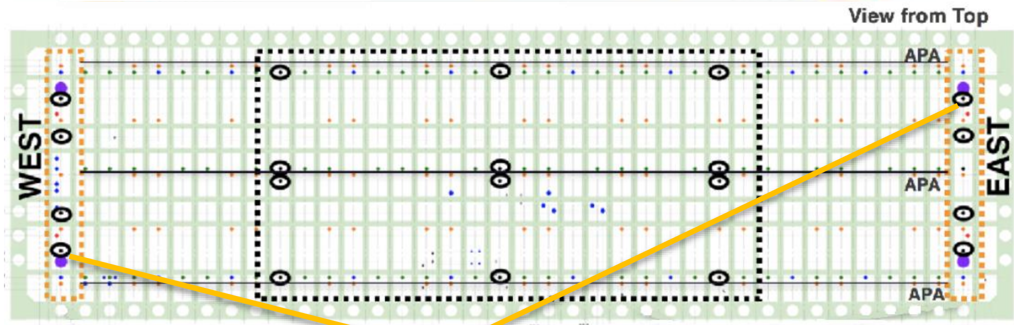
FD Deployment Locations



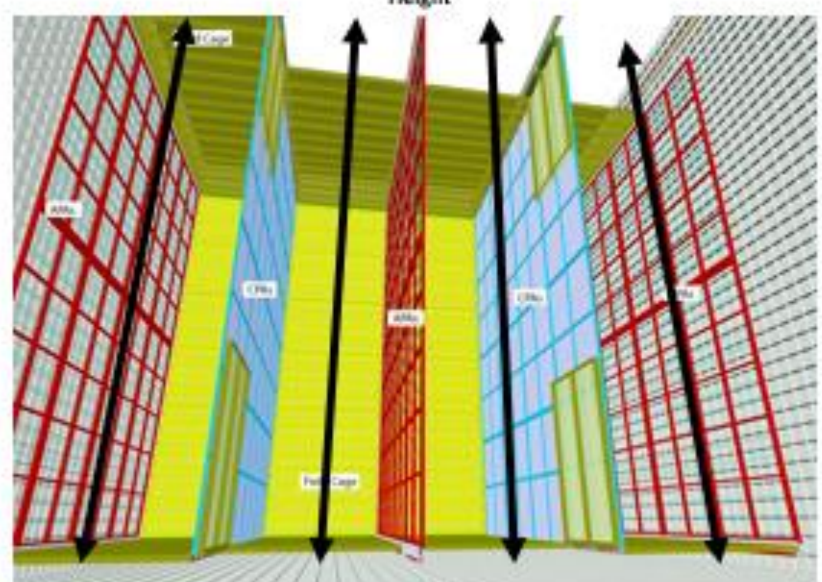
Showing position of the 9 MeV gamma source relative to anode plane assembly (red) and cathode (blue)



View of the 9 MeV gamma source from behind field cage (grey)



Baseline: use 4 penetrations at either end
(each at half-distance between an APA and a CPA)

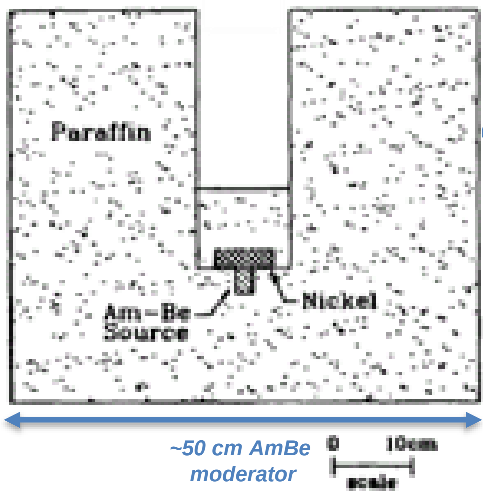


Baseline Concept of 9 MeV Gamma Source

Based on a successfully built (n,γ) source that emitted 8.97 MeV γ's.

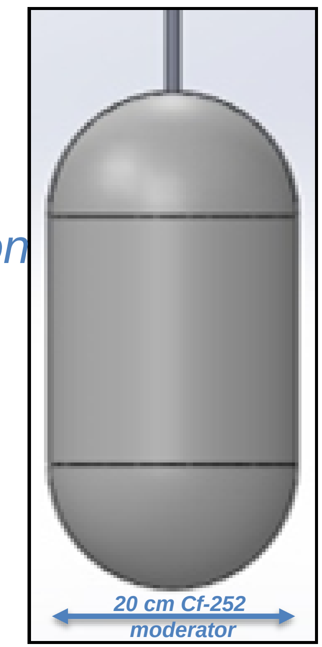
("A 7-9 MeV isotopic gamma ray source for detector testing", J. Rogers, M. Andreaco, and C. Moissan, Apr 1996)

working source design



evolution

Delrin Design with Cf-252

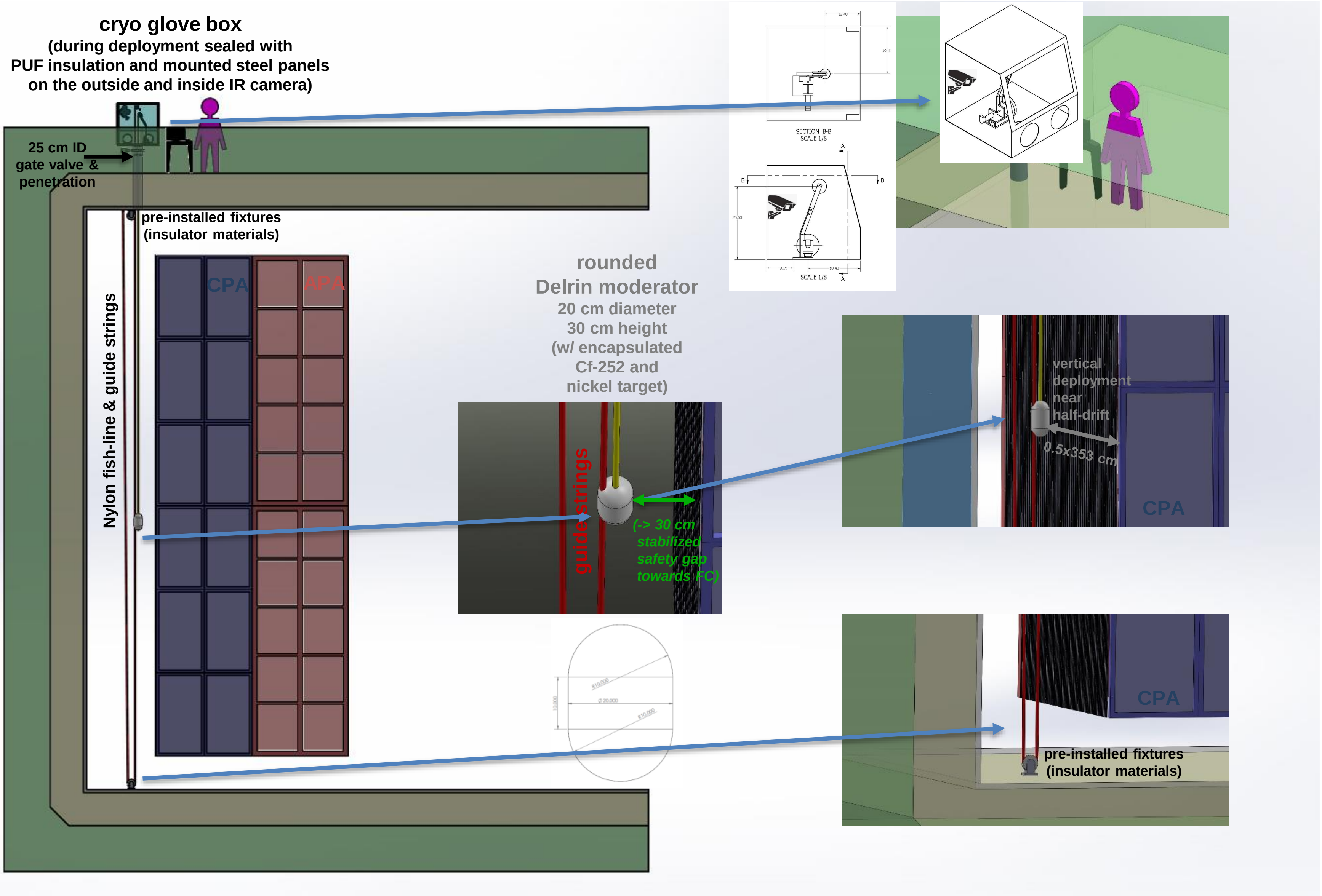


Physics Requirements of our Calibration Source

- Survivable at cryogenic liquid argon temperatures (85K)
- The entire source body does not float
- It can be deployed and retrieved through sealable flanges with 20 cm diameter at the top of the detector cryostat
- It still has enough neutron moderator material to initiate (n,γ) nuclear reactions on an encapsulated nickel target

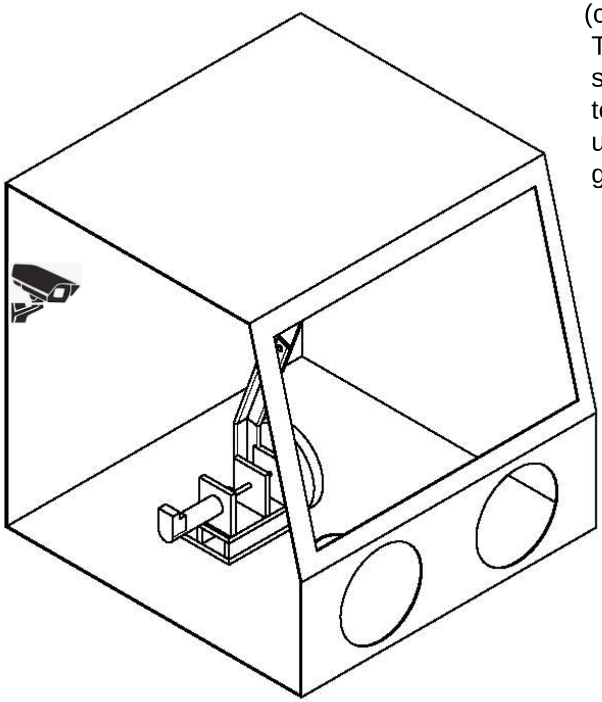
Using Cf-252 would significantly reduce size of source, such that it would fit a 25 cm diameter feed-through

Mechanical Source Deployment Scheme

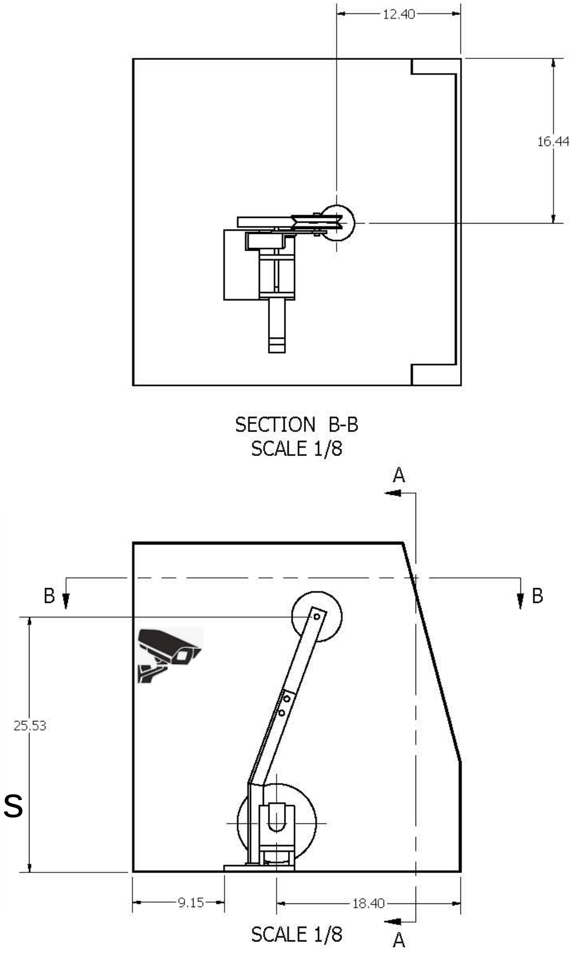


Mechanical Source Deployment System

Designed as multipurpose system (could deploy other sources, T-sensor, cameras etc.)



(cryo glovebox equipped with scroll pump, RGA, T- and p-sensors and during deployment further safely sealed by mounting PUF insulation attached to rigid steel panels on the outside and use inside IR camera to monitor interior during gate valve opening and deployment)



Based on Double Chooz system (+/- 2 mm deployment precision demonstrated over 7 m height)

- requires addition of guide strings to stabilize source wrt. FC
- new cryo-glovebox design

Deployment Operations

1.) Cool down with boil-off GAr before pumping down to vacuum, then purging again with fresh GAr before pressure equalization and gate valve opening is considered

2.) Use RGA setup (see left) to monitor e.g. O_2 concentration in GAr to be 10 ppm such that in event all GAr enters detector O_2 increase in 10 kton LAr is only 1 ppt

3.) Only then we allow the gate valve into the detector to be opened

(monitor also radon levels and have somewhat less stringent requirements for N_2 and H_2O)

Motivation of ProtoDUNE Deployment

- Primarily to demonstrate safe mechanical deployment
- Not for 9 MeV gamma-ray physics of radioactive source (overwhelming cosmic background in ProtoDUNE)
- Deploy a dummy radioactive source and possibly a camera, temperature logger
- *(In case capture rate and/or signature for neutrons are still too uncertain we might want to think about deploying a strong neutron source in ProtoDUNE)*

Timeline of Development and ProtoDUNE-SP-II Deployment

Date	Milestone
January 2020	Baseline RSDS design validation
March 2020	RSDS mock-up deployment test at SDSMT
May 2020	RSDS design review
July 2020	RSDS production readiness review (PRR)
September 2020	Start of module 0 RSDS component production for ProtoDUNE-II
February 2021	End of module 0 RSDS component production for ProtoDUNE-II
March 2021	Start of ProtoDUNE-SP-II installation
April 2021	Start of RSDS installation
April 2022	RSDS demonstration test at ProtoDUNE-SP-II

(timeline outdated due to Covid)

(ProtoDUNE-DP-II deployment would have advantage that vertical deployment height corresponds to position along drift)

Critical Path Items for ProtoDUNE-SP-II Deployment

a) Cryogenic material compatibility/survival testing in LN2 dewar & breaking strength testing on cryo testbench at SDSMT planned to finalize technical design
=> *dewar ordered (candidate materials to be ordered)*

b) High-bay testing of new guide string system at SDSMT over at least a single APA height (6 m) with deployment system
=> *scaffold tower arrived last Friday (see picture on right)*

c) Start constructing new innovative cryogenic purge box with sealable glove ports (no known design exists)
(equipped with scroll pump, RGA, T- and p-sensors and during deployment further safely sealed by mounting PUF insulation attached to rigid steel panels on the outside and use inside IR camera to monitor interior during gate valve opening and deployment)

RSDS Calibration Deliverables

Best source for this
Some limitations

Goal	Measurement	Natural sources	Laser system	Gamma sources
Determine parameters	Detector defects, alignment	Cosmics (low or 0 stats)	IoLaser, PE laser (CPA)	X
	Drift velocity/ E-field	Cosmics (low stat)	IoLaser, PE laser (int. only)	PNS, RSDS (?)
	Electron lifetime, diffusion	Cosmics (low stat), Ar39 (not in x)	IoLaser (not proven yet)	PNS, RSDS (lim. cov.)
	Recombination	Cosmics, beam	IoLaser (angular dependence ?)	PNS, RSDS ?
Measure Physics response	High energy: μ track dE/dx	Cosmics, beam: muon tracks	X	X
	High/Mid energy e/γ	Cosmics, beam: π^0 decays, Michels	X	X *(-> RSDS pair production)*
	Well-defined e/γ scale/resolution	X	X	PNS, RSDS
	Neutrons	X	X	PNS *(-> RSDS)*
	Low E singles trigger efficiency	X	X	RSDS

Conclusion

- ProtoDUNE deployment is intended to be a demonstration of the safe mechanical deployment only (with dummy source, possibly w/ camera and/or temperature logger)
- At least cryogenic material compatibility, survival, and strength testing needs to start in FY20 to avoid delaying technical design for ProtoDUNE-SP-II in FY22
- RSDS is only means to unambiguously measure trigger efficiency for SNB and solar neutrinos (isolated events)
- RSDS has well-defined physics signal at known location with known energy (with clear relation to radiological backgrounds and clearly separable from electronic noise)

Does the system have a well-justified role in facilitating the analysis of far detector data, and if so, what is the minimum amount of system scope required to fulfill this role?

- Only system to measure and scan trigger efficiency for SNB and solar neutrinos near our claimed detection threshold of 10 MeV (in particular for isolated single events)

- High enough energy to make multiple wire-hit Compton electron tracks with dislocated subsequent single wire-hits hits thus mimicking SNB and solar νe signature

- One system could suffice and could in principle be moved around

Have all technical issues related to the feasibility of the system (including those raised in the previous workshops) been resolved?

- No prototype system yet to demonstrate technical concept and performance but design based on successful system of Double Chooz

- Gas purity requirements have been addressed

- Bo Yu confirmed that even 15 cm distance to FC is safe.

- Bo pointed out that insulators are preferred inside cryostat and conductors (metal wires) should be avoided
  => braided nylon strings and Delrin fixtures

Are there any risks to overall detector performance associated with the implementation of the system, and if so, is there a plan in place for mitigating these risks?

- Gas purity requirements have been addressed
- Guide wires to ensure safe distance to field cage
- GAr cooling tests and LAr material compatibility tests defined

Is there a credible plan in place for demonstrating system performance in ProtoDUNE-II? Discussion

- see slides 15-17
- Man hole or other feedthrough could be used for test deployment
- Fixtures need to be installed before LAr filling

Does the functionality of the system justify its overall cost?

- Costs only $35k per unit:

- Get many calibration deliverables for ~10% of detector volume (detection threshold for SNB and solar, trigger efficiency, background suppression, e-lifetime, E-field, EM response, light detector calibration etc.)

Radioactive Source Deployment System				
Item	Cost/unit	Quantity	Total	Details/Comment
Material	$22,254	4	$89,016	
Packing & Shippin	$1,000	1	$1,000	U-haul is $100 a trip to SURF (x4), $600 shipping to and from CERN
Total M&S			$90,016	
Travel (CERN)	$5,000	2	$10,000	of food and lodging at CERN)
Travel (SURF)	$2,000	4	$8,000	us to go to SURF and return. 4 weeks, 5 working
Person-power				See the detailed "Person-power" table below

Cost Breakdown					
Item	Unit price ($)	Unit	Quantity	Cost	Details/Comment
Moderator+nickel	$1,000.00	each	1	$1,000.00	includes machining and misc. (like fixtures, seals)
Stepper motor assen	$4,400.00	each	1	$4,400.00	Double-Chooz z-axis deployment system (parts excl. machining, cf. technician labor in person-power)
Californium source	$5,000.00	total	1	$5,000.00	Vendor: Eckert and Ziegler (Cf-252 halflife requires replacing every 2.5 years over ten years at least)
Guidewire system	$1,000.00	total	1	$1,000.00	incl. braided wire-rope and machining of custom pulleys/tensioners/fixtures
Cryo glove-box	$4,500.00	total	1	$4,500.00	incl. machining, could be moved between ports, but 4 stationary systems preferred
Scroll pump	$4,354.00	total	1	$4,354.00	could be easier moved between different ports
System/DAQ Run Con	$2,000.00	each	1	$2,000.00	laptop with connections/interfaces/UPS (No rack space needed)
one unit (total)				$22,254.00	

$35k = $22k + $13k for RGA setup with additional turbomolecular pump

More Slides for Discussion

Next Steps

a) cryogenic material compatibility/survival/strength testing needed to start technical design

b) High-bay mock-up deployment testing at SDSMT over at least a single APA height with development of a safe guide wire system (and deploying a camera and temperature sensor with same system)

c) start developing a new innovative cryogenic purge box with sealable glove ports (no known design exists)

Steps Needed in FY20

To meet the planned timeline of a mechanical RSDS test deployment in an upcoming run of ProtoDUNE-SP-II in FY22, SDSMT should start in FY20 with the following action item:

Task a) Cryogenic Material Compatibility/Survival/Strength Testing (received modest project funds for this):

- Procure dewar for cryogenic material compatibility testing

- Perform wire-rope breaking strength test (warm and at cryogenic temperatures) at Mechanical Engineering Department at SDSMT

- Procure and test materials such as wire-rope, Delrin homopolymer acetal, Teflon, pulleys

Steps Needed Soon After FY20

- Allocate and reserve port location at ProtoDUNE

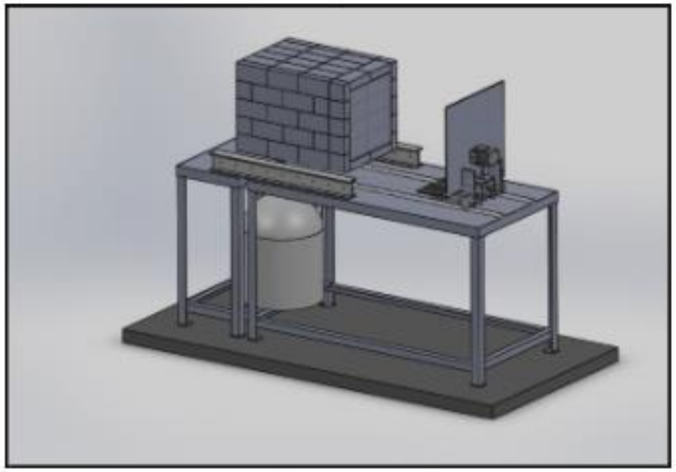
Task b) High Bay Mock Up for Mechanical Deployment Testing:

- Procure and install scaffolding of single APA height at SDSMT
- Machine source moderator cylinders made of Delrin
- Refit Double Chooz deployment system for use in ProtoDUNE

Task c) Cryo Glove Box:

- Procure and machine stainless steel sheets (SS-304) for glove-box walls
- Fit clear ultra-impact-resistant Lexan sheet as sealable glove-box window
- Large sheets of flame-retardant polyurethane foam for all around cryo insulation of glove-box
- Scroll pump for evacuating glove-box
- Vacuum metal hose, clamps, seals and feedthroughs
- Cryogenic vacuum temperature sensor
- Vacuum pressure transducer
- Develop sealed neck opening
- Develop and test guide-wire system with tensioning functionality
- Test cool down of source and entire deployment procedure

Validation of Radioactive Source Functioning



The ‘Rabbit’ germanium detector at SDSMT is of large enough size to accommodate the 9 MeV source with the bulky moderator for verification of gamma-ray yield

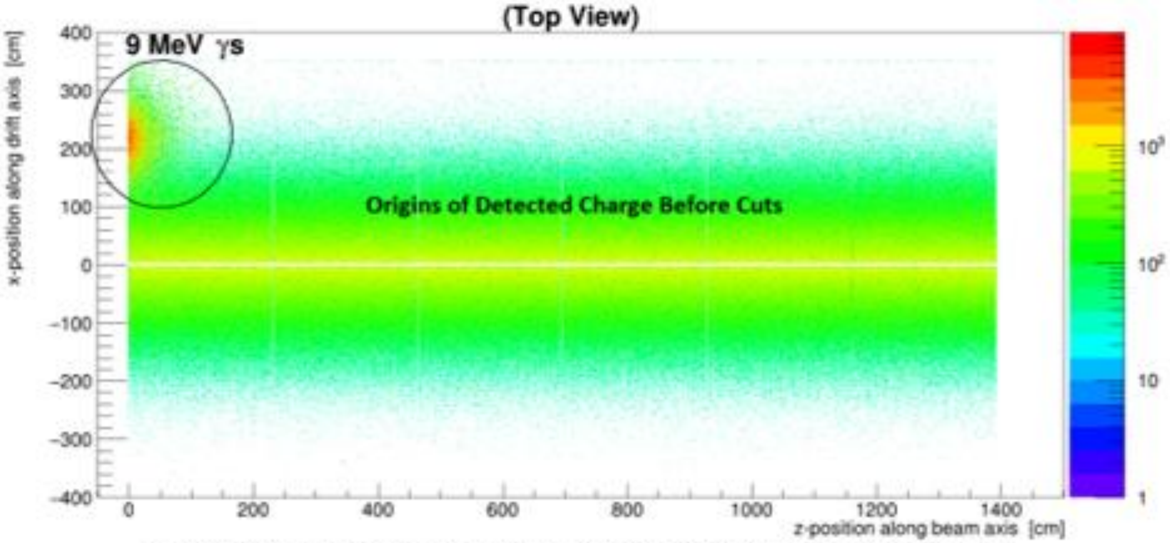
measurements of gamma-ray rate

and escaping neutrons

Validation with He-3 based hodoscope underground at SURF to check for escaping of neutrons from the moderator of the radioactive calibration source

LArSoft Simulation with Expected Radiological Backgrounds

9 MeV γ-ray source deployed
at 40 cm outside of the field cage,
220 cm away from the anode plane
and 300 cm down from top



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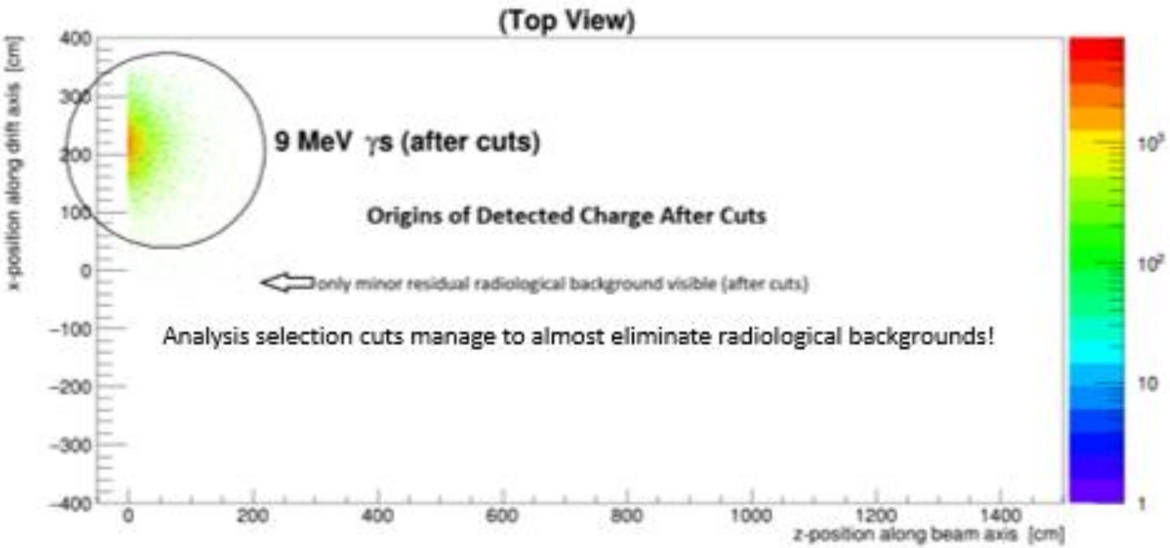

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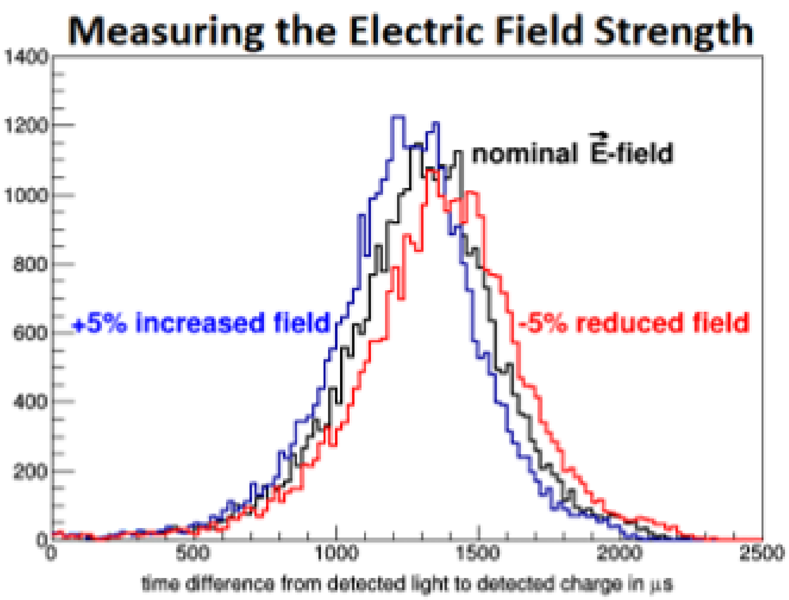
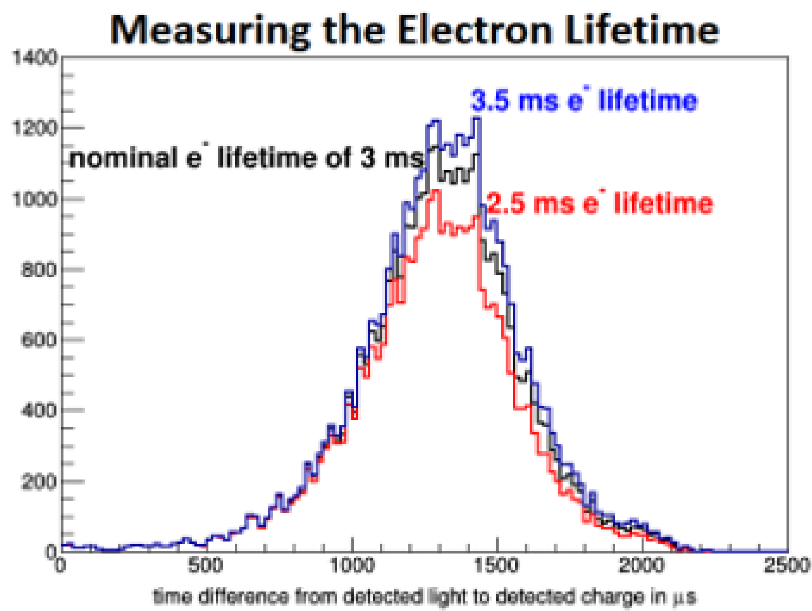
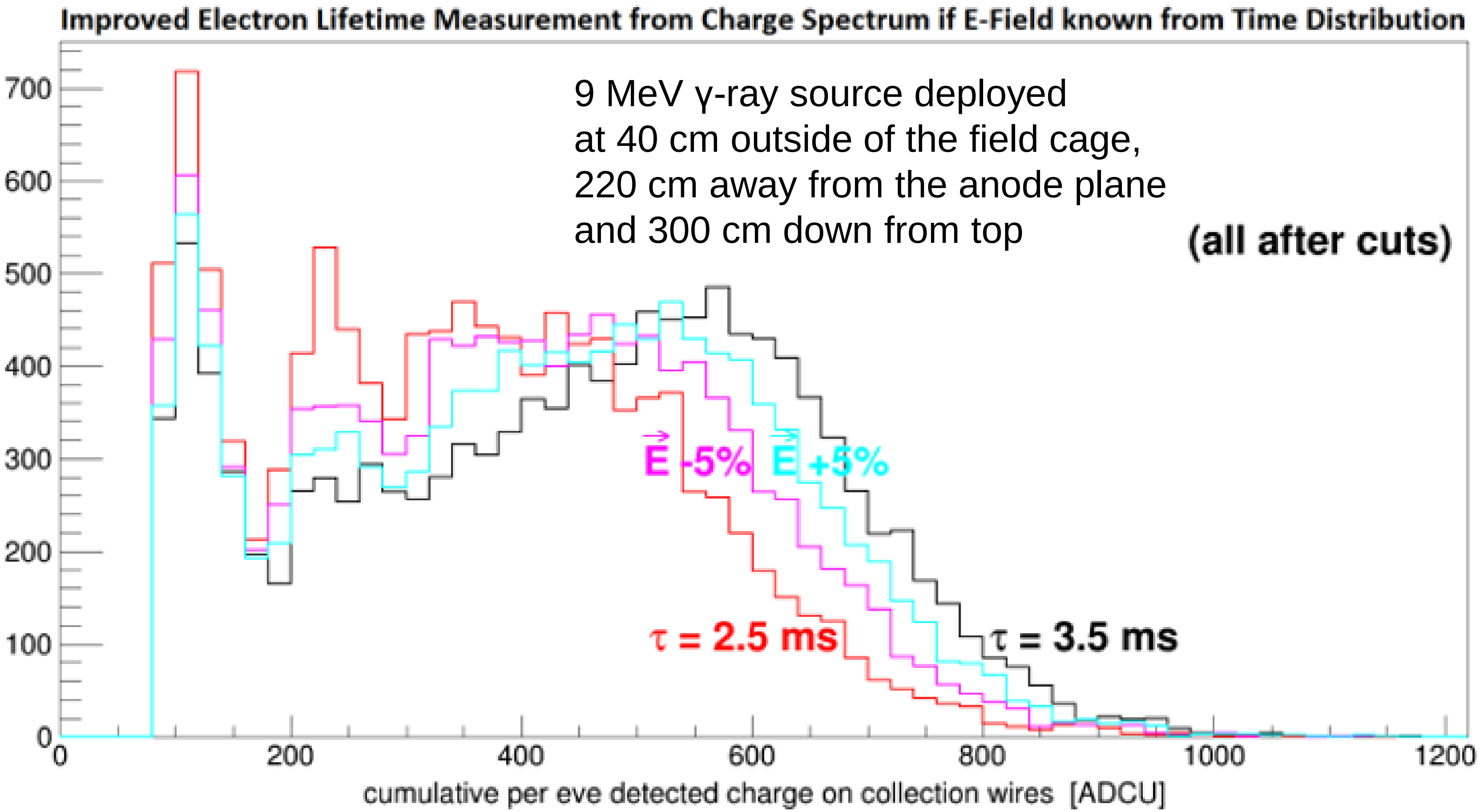


E-field



Electron-Lifetime

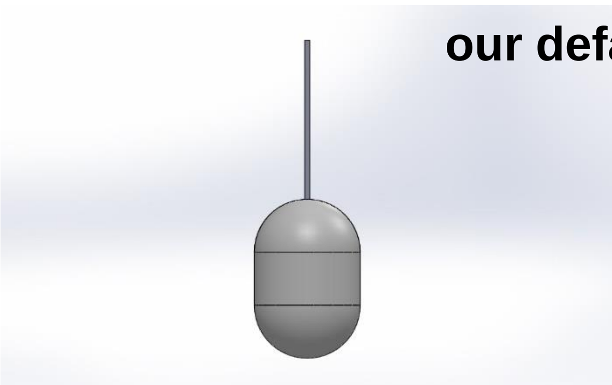
LArSoft Simulation with Expected Radiological Backgrounds



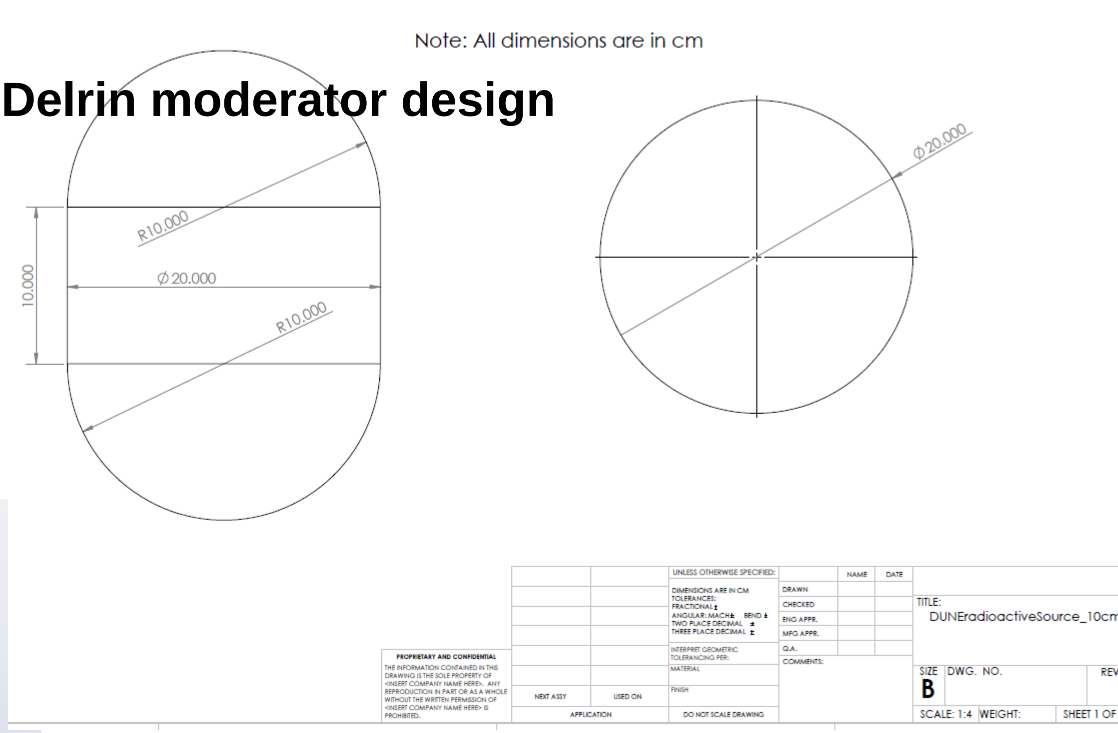
When electric field is unambiguously known from drift-time distribution the electron lifetime can then be very precisely measured from charge distribution.

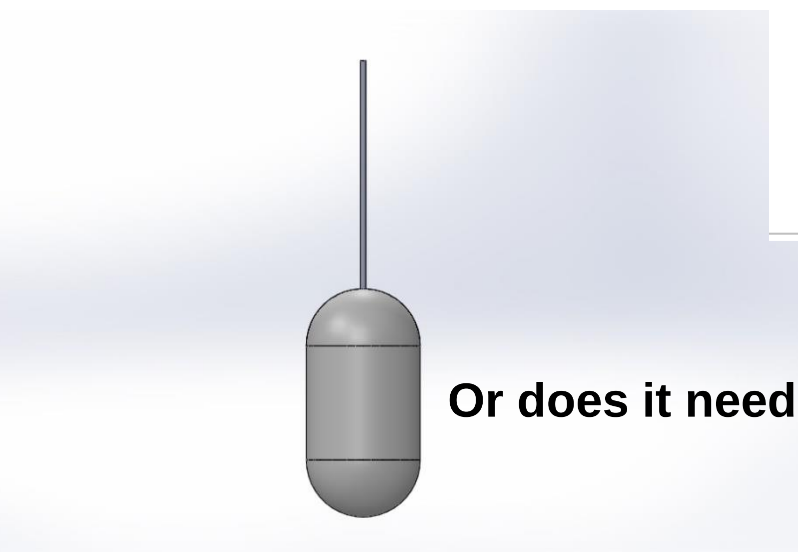
Radioactive Source Status/Plans 1 (Simulations)

- Explore tolerable neutron level spilling in from gamma source using simulations
  -> will define minimum required radius of moderator (and its cylinder height)



our default Delrin moderator design





Or does it need to be e.g. higher?

CalibrationTree

The DUNE CalibrationTree

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October 3, 2018

Abstract

Charge and Light are handled in separate simulation paths in **dunetpc/LArSoft**. As a result of these chains, and the shortcuts used to simulate light efficiently, it becomes extremely difficult to disambiguate truth in large events. This is especially problematic for low energy physics events simulated with the full radiological background, where there is simply too much information in the readout for the user to easily disambiguate it themselves. With our groups recent updates to the **PhotonBackTracker**, combined with the addition of the **ParticleInventory** and earlier update of the **BackTracker**, a simple path appears to do charge and light matching to MCParticles and MCTruth.

Perform consistency checks before official release

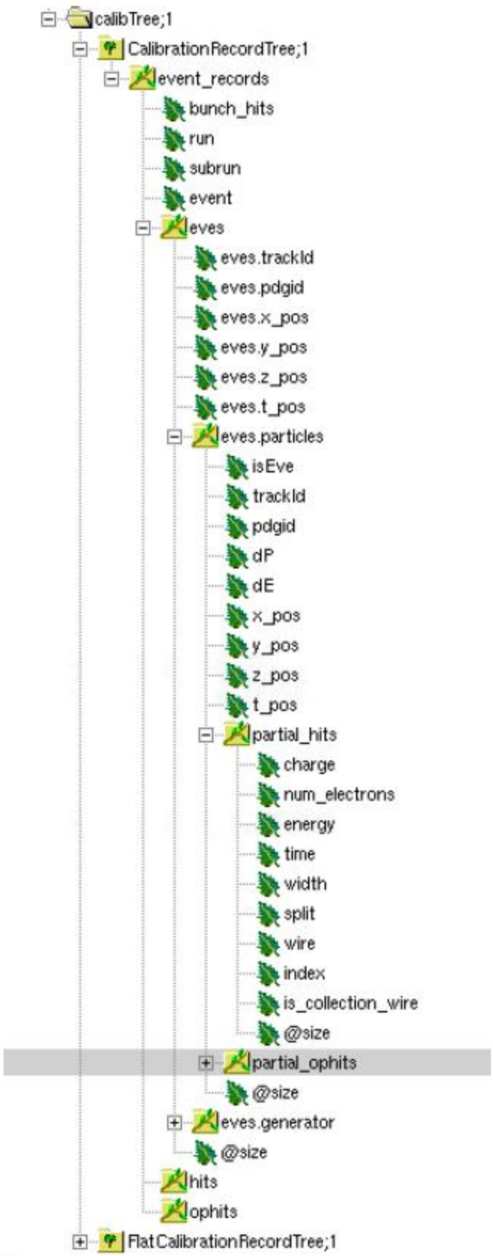
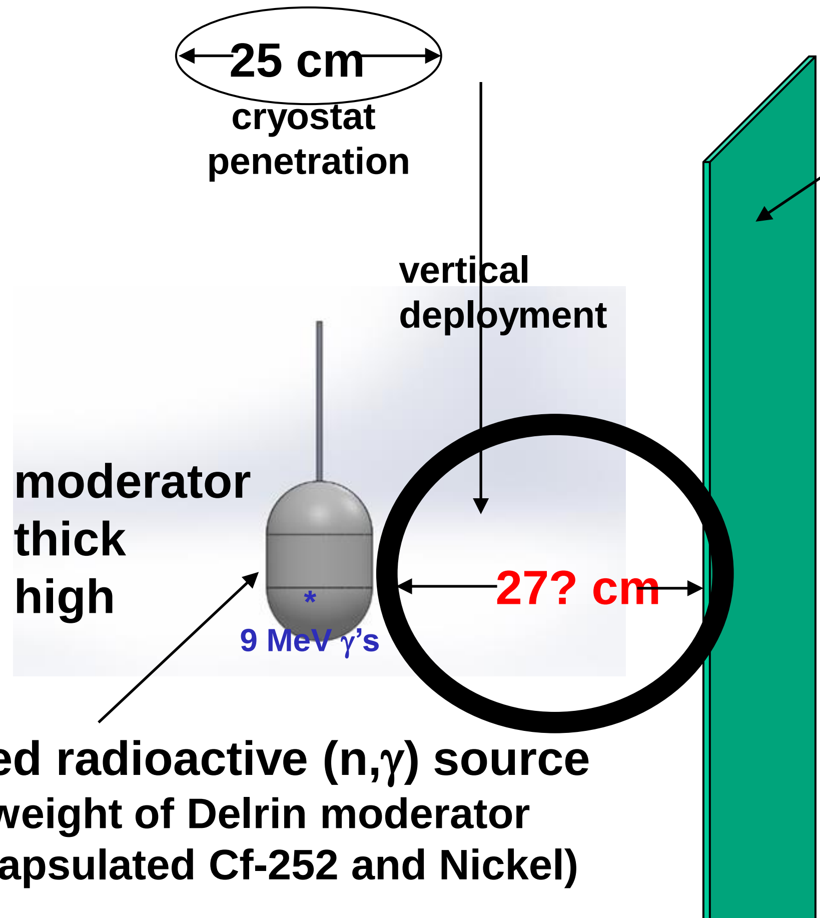


Figure 3: *The structure of the CalibrationTree.*

Does Recent TPC Translation Jeopardize This Deployment Scheme?

318.66 mm - (250 mm diameter / 2) + ~80 mm shrinkage = 273.66 mm



Field cage at sides of TPCs

⇒ Only ~5% of 9 MeV γ's enter the active TPC volume (~2 interaction lengths and about half the solid angle)

⇒ If we aim at 10 Hz rate in TPC to avoid pile-up in drift window, it means a source rate of ~200 γ's per sec

⇒ renders a tagged Cf-252 source useless for an external trigger signal b/c of ~400 Hz free-running rate (1/2.25 ms)

Delrin moderator
20 cm thick
30 cm high

Deployed radioactive (n,γ) source
(~10 kg weight of Delrin moderator with encapsulated Cf-252 and Nickel)

Do we need guide-wires or guide-tubes?
(check on currents with fluid dynamic sims of SDSU)
Would be one of first things installed in cryostat
due to access restrictions at east (or west) end inside cryo

In Charge and Light Detected Energies in Active TPC Volume