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 neutrino signature

• Allowing for EM shower calibration of beam neutrino 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 $\nu_e$ CC interactions in argon using nuclear deexcitation $\gamma$'s?

Charged-current absorption:

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

At least 25 transitions have been observed indirectly

(g.s. to g.s. is 3rd forbidden transition)
Gamma-Rays from $\nu_e$ Interactions in LAr

SN Neutrino Signal

Avg Fractional Energy from $\nu_e$, weighted by LAr/$\nu_e$

CrossSection and Livingston Flux Model

must be collected off tracks

Electrons
Gammas
Binding Energy (lost)
Neutrons
Protons

True $\nu_e$ energy
Gamma-Ray Interactions in LAr

Attenuation Length vs. Gamma Energy

Plot Key

- Incoherent Compton Scattering (Red)
- Photo-Electric Absorption (Green)
- Pair Production In Nuclear Field (Blue)
- Total Attenuation With Coherent Scattering (Pink)

Pair production
Compton
sum
Trigger Efficiency with Electron/γ Sample

David Rivera, David Last & Josh Klein

Update (Jan 30, 2019)

(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)
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 Concept of 9 MeV Gamma Source

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

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

**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 \((n,\gamma)\) 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

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

- Deployment system used in the Double Chooz experiment can be reconfigured to safely and reliably deploy the 9 MeV calibration source in the DUNE detector.

- The automated fishline system for target deployments: +/- 4 mm precision over 14 m

- Modifications and the inclusion of guide wires may be necessary due to currents within the DUNE detector volume, which mock-up tests in a LAr column at SDSMT will probe.
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. O2 concentration in GAr to be 10 ppm such that in event all GAr enters detector O2 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 N2 and H2O)
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

<table>
<thead>
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<th>Date</th>
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<td>Baseline RSDS design validation</td>
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*(ProtoDUNE-DP-II deployment would have advantage that vertical deployment height corresponds to position along drift)*
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 neutrne 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
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

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Does the functionality of the system justify its overall cost?

- Cost for one system only $35k
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
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.

("Virtual" RSDS already useful: Found issues in PD simulation that got fixed)
Data Analyses with Selection Cuts Using 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

E-field

Electron-Lifetime
LArSoft Simulation with Expected Radiological Backgrounds

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

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

JASON STOCK, JUERGEN REICHENBACHER
South Dakota School of Mines and Technology
jason.stock@mines.sdsmte.edu

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
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

New LY much better with ARAPUCAs

⇒ ideal trigger efficiency source in addition to EM calibration for beam nu’s, SNB nu’s, solar nu’s

charge detected from 9 MeV γ events emitted away from APA

charge detected from 9 MeV γ events emitted towards APA

light detected from 9 MeV γ events emitted away from APA

light detected from 9 MeV γ events emitted towards APA