LANSCE Research Motivated by Particle Physics

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LANL
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Outline

- Why is particle physics concerned with WNR-energy neutrons?
  - creation of backgrounds
  - components of signal
- Double beta-decay and LANSCE
- Neutron-anti-neutron oscillation experiments and LANSCE
- Neutrino oscillation experiments and LANSCE

Particle Physics – Neutron Backgrounds

- MeV-scale physics
  - Searches for rare events in the MeV regime generally require large detectors and extremely low backgrounds
  - Detectors are run continuously – cosmic-rays are significant potential sources of backgrounds
  - Detectors are deployed underground and often still have significant shielding
  - Neutrons created by high-energy muon spallation external to the detector can enter undetected and create background
- GeV-scale physics
  - Cosmic-ray neutrons or beam-correlated neutrons can enter detectors through passive or active shielding undetected and create background
- Measurements of neutron interactions with materials in the 10's to 100's of MeV regime are crucial. WNR's well-characterized neutron beam provides a unique and crucial environment to make such measurements

Particle Physics – Neutron Signal

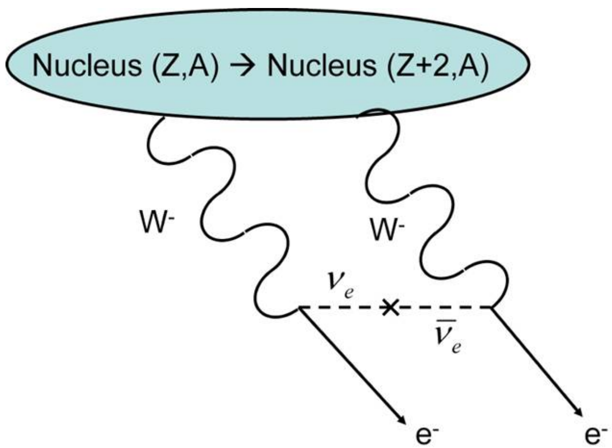
- Neutrino oscillation physics employs neutrino beams in the GeV regime
- Cross-sections and event signatures are poorly understood in this energy regime
- Neutrons of 100's of MeV of kinetic energy are often an important component of the event signature
- WNR's well-characterized neutron beam is crucial for interpreting event signatures from neutrino interactions

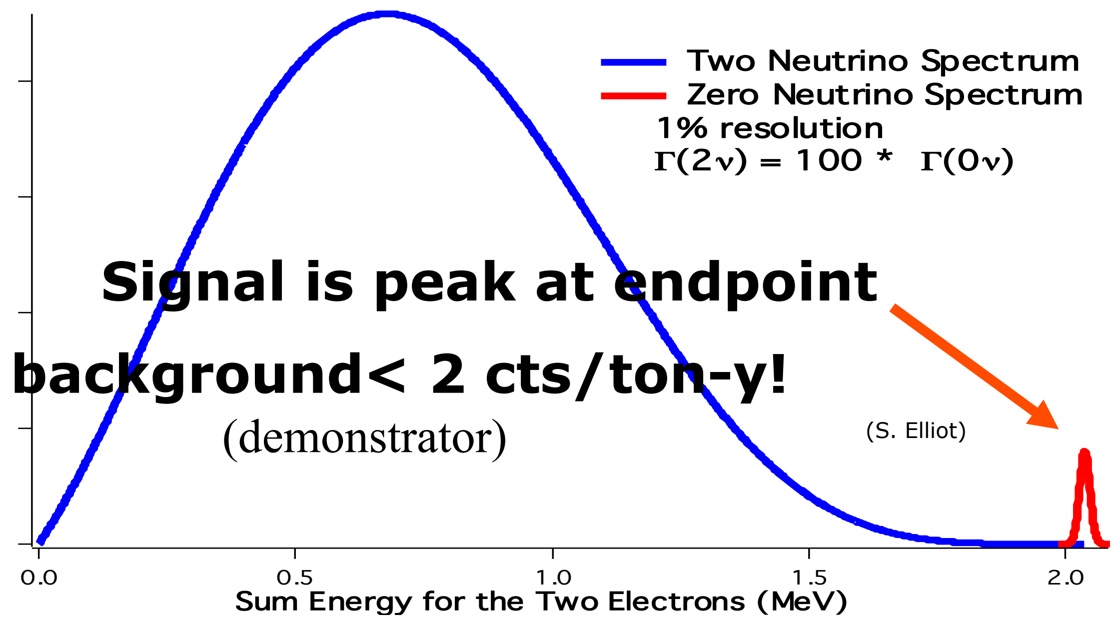
Neutrinoless double beta decay

Neutrinoless double beta decay: only occurs if neutrino is a majorana particle and lepton number is violated

A critical question for particle physics and a major component of the 2015 long range plan for nuclear physics

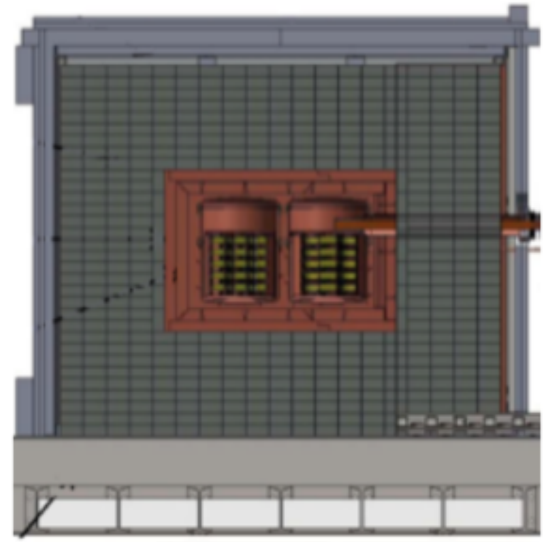
Only practical way to determine whether ν is a majorana or dirac particle

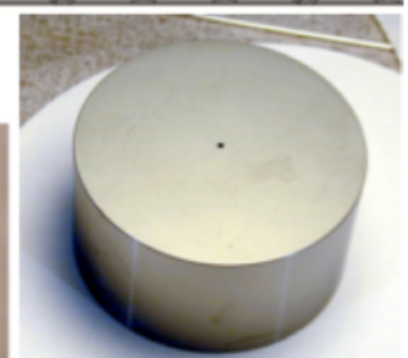




Neutron-Related Backgrounds

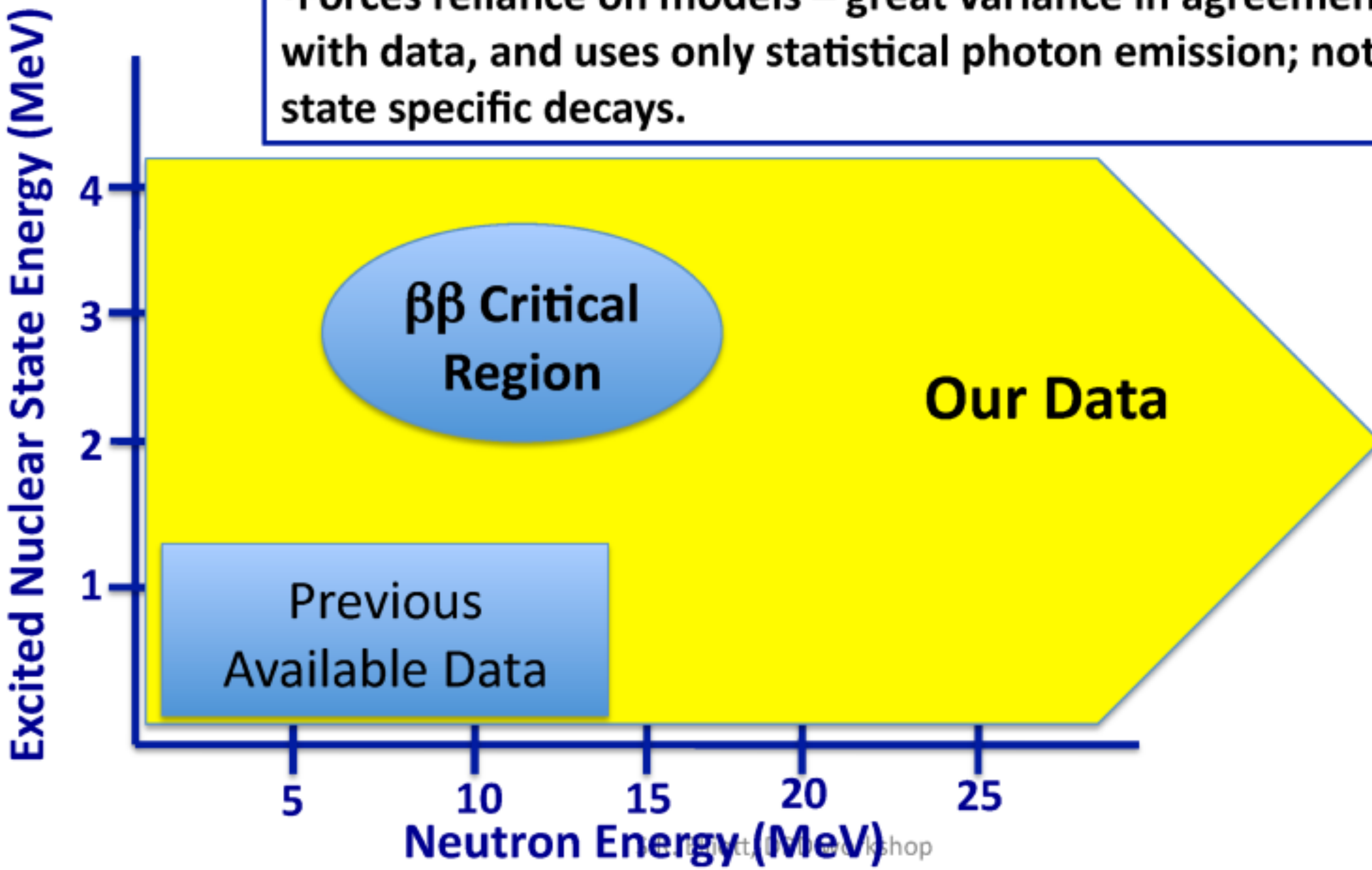
- The Majorana Demonstrator uses Ge, Cu and Pb as its 3 largest material components. GERDA uses lots of Ar (also related to our dark matter program.
- Need to measure:
  - A(n,X)A' cross sections
  - Detector Activation (MJD
  - (n,n'γ) cross sections



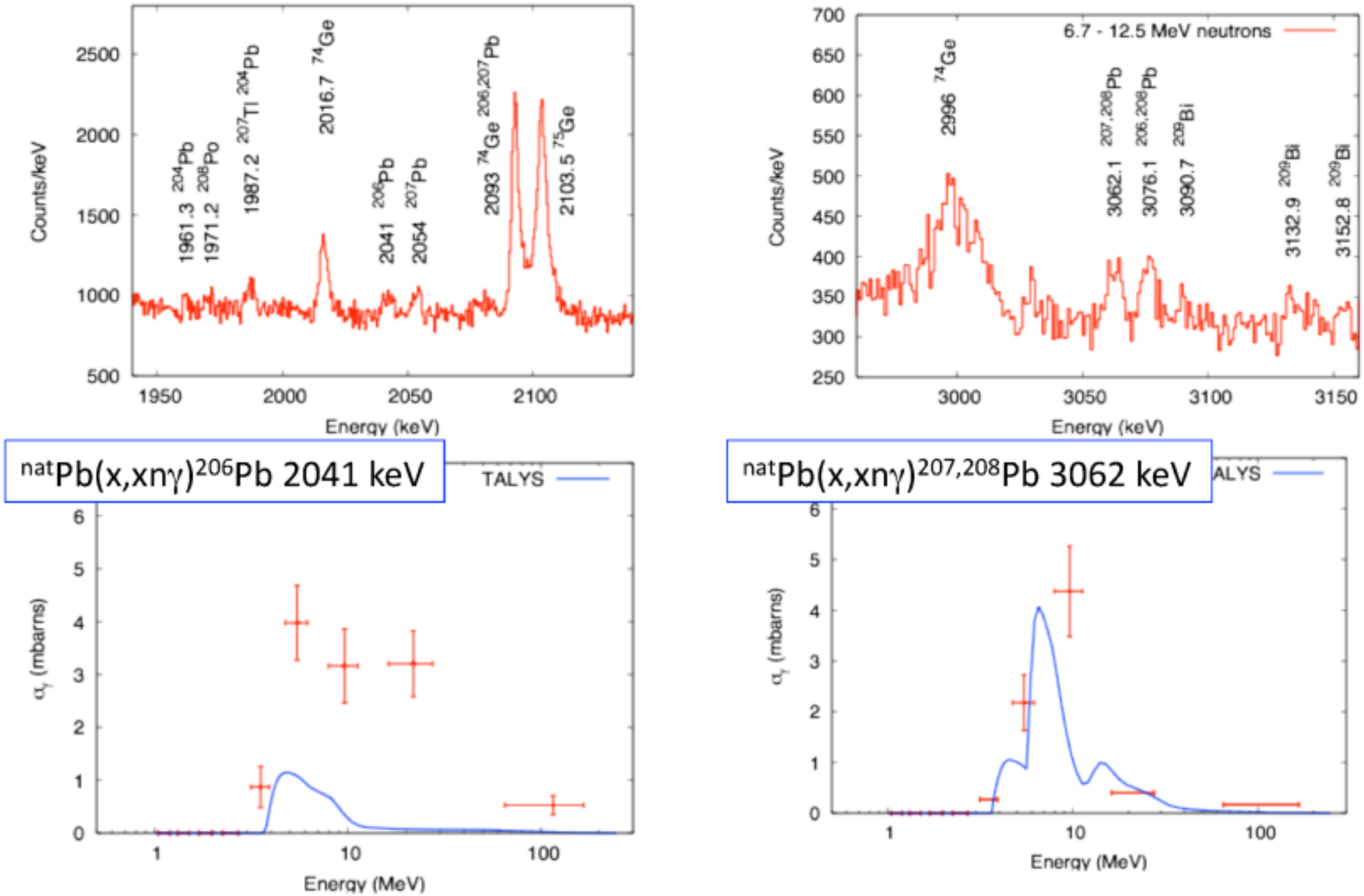


(n,n') Program

- Few measurements in ββ critical region.
- Cross sections set to zero when no measurements available.
- Forces reliance on models – great variance in agreement with data, and uses only statistical photon emission; not state specific decays.



Pb(n,n'γ) Measurements



V.E. Guiseppe *et al.* (2009) *PRC* ***79, 054604***

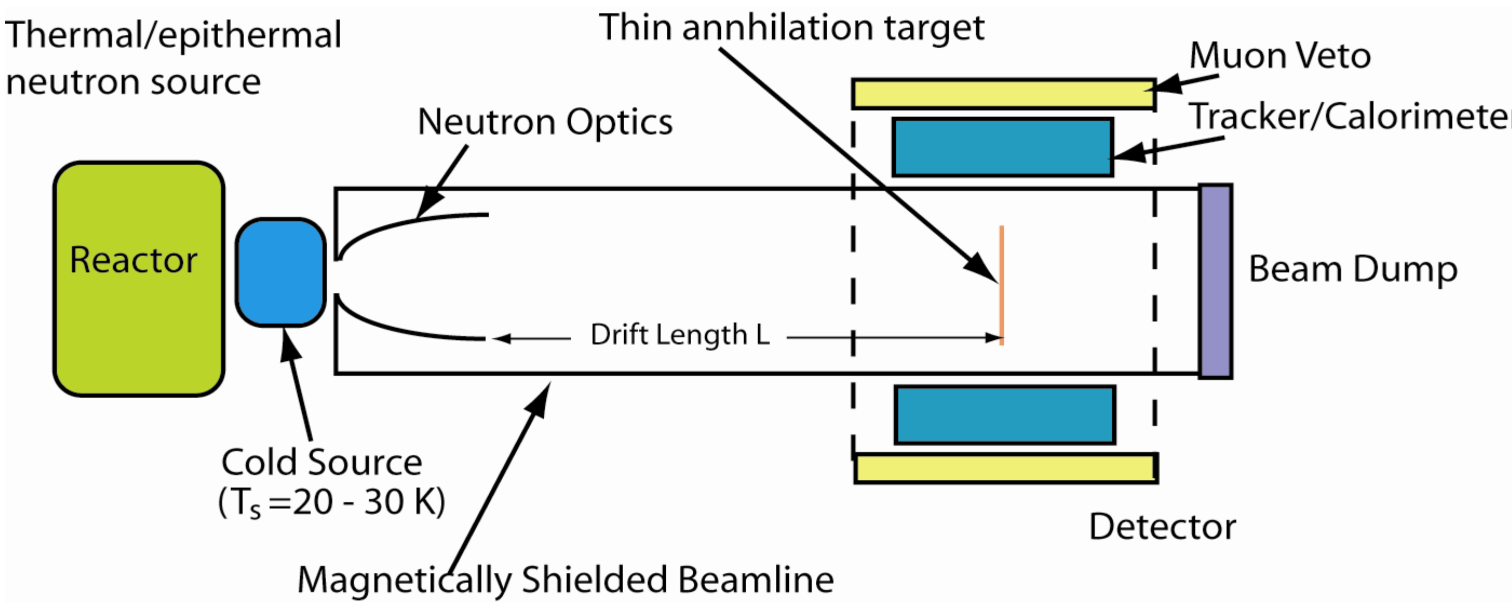
Summary of Measurements

- Pb(n,n′γ) - published
- Cu(n,n′γ) – published
- CZT(n,n′γ) – still in analysis
- ^{enr}Ge(n,n′γ) – published
- Ar(n,n′γ) – published
- Ne(n,n′γ) - published
- $^{enr}Ge(n,X)^{68}Ge$, Cosmogenic activation - published
- Pb(n,X)A, Cosmogenic activation – published
- Zn,Nb,Zr,Cd(n,X)A, Cosmogenic activation – measurements in progress
- ^{nat}Ge[HPGe]$(n,X)^{68}Ge$, Cosmogenic activation
  - Semi coax – published
  - BEGe - measurements in progress

Collaborators

- ^{enr}**Ge(n,X)**: S.R. Elliott, V.E. Guiseppe, B. LaRoque, R. Johnson, S. Mashnik
- Pb(n,X): V.E. Guiseppe, S.R. Elliott, N. Fields, D. Hixon
- Activated Detectors: D. Steele, S.R. Elliott, V.M. Gehman, V.E. Guiseppe
- Ar(n,n'γ): S. MacMullin, M. Boswell, S. Elliott, V. Guiseppe, R. Henning, B. LaRoque, M. Devlin, N. Fotiades, R. Nelson, J O'Donnell
- Pb(n,n'γ): V. E. Guiseppe, M. Devlin, S. R. Elliott, N. Fotiades, A. Hime, D.-M. Mei, R. O. Nelson, D. V. Perepelitsa
- Cu(n,n'γ): M.S. Boswell, S.R. Elliott, D.V. Perepelitsa, M. Devlin, N. Fotiades, R.O. Nelson, V.E. Guiseppe

Detector Development for a Cold Neutron Beam measurement of neutron of Neutron-Antineutron Oscillations

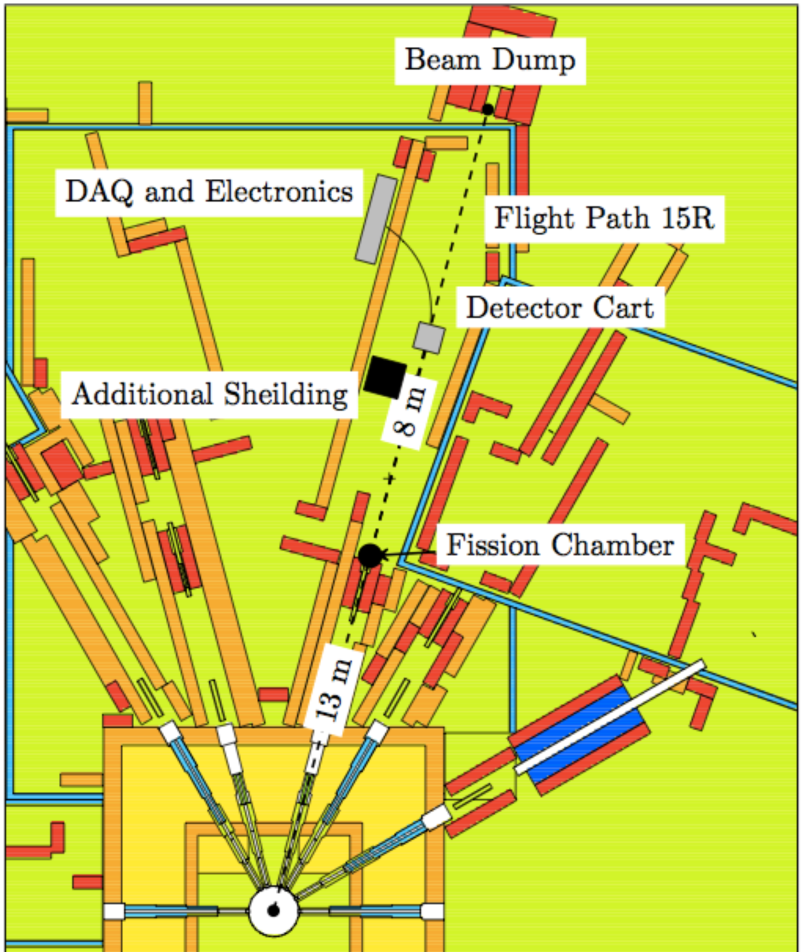


- If ΔB=2 interaction exists, can cause neutron to transform into antineutron in free flight! Connected to origin of neutrino mass, baryogenesis, extra dimensions
- Striking multi-pion signature if neutron annhilates in graphite target
- Factor of roughly 100 sensitivity improvement over all existing experiments (best limits at present from underground experiments) possible at spallation source (ESS)
- Problem: cosmic ray neutrons evade veto, critical contribution to backgrounds – but **no data on efficiency** for tracking detector components (gas detectors...)
- Some experiments propose employing beam-spallation neutron sources – response to fast neutron backgrounds is crucial

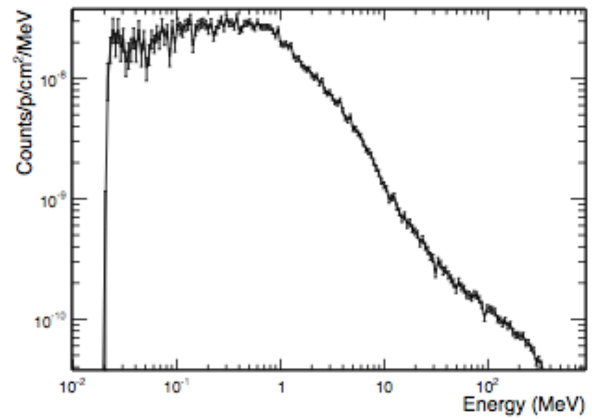
Need to measure!

WNR Tests – Absolute Detector Efficiencies for Gas Tube Counters for Neutrons from few MeV to ~500 MeV

LANL WNR-15R Beamline

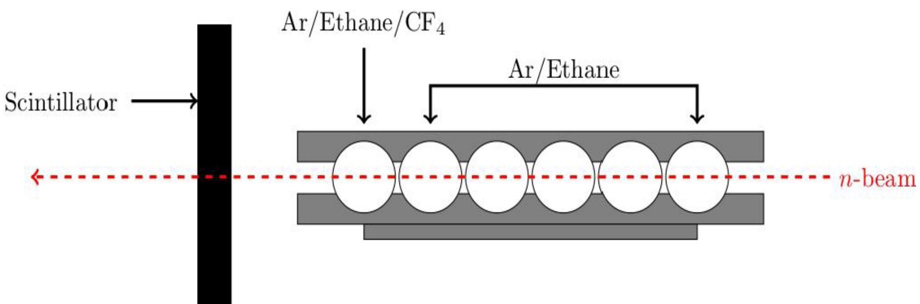


Predicted *n*-flux 20m from target



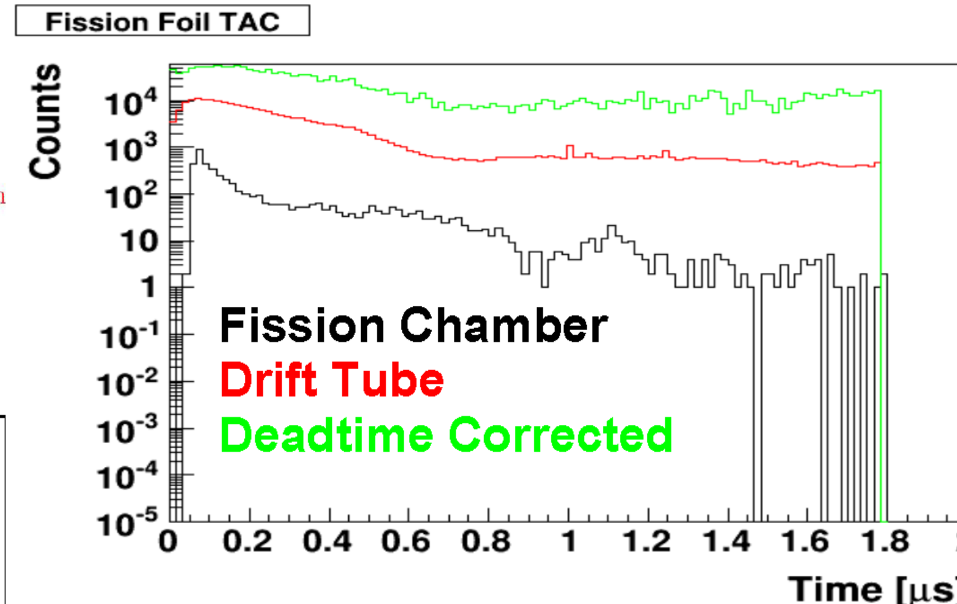
- Use carbon fiber body proportional counters filled with different gas mixes
- Directly measure the efficiency, normalizing to the measured flux as a function of energy

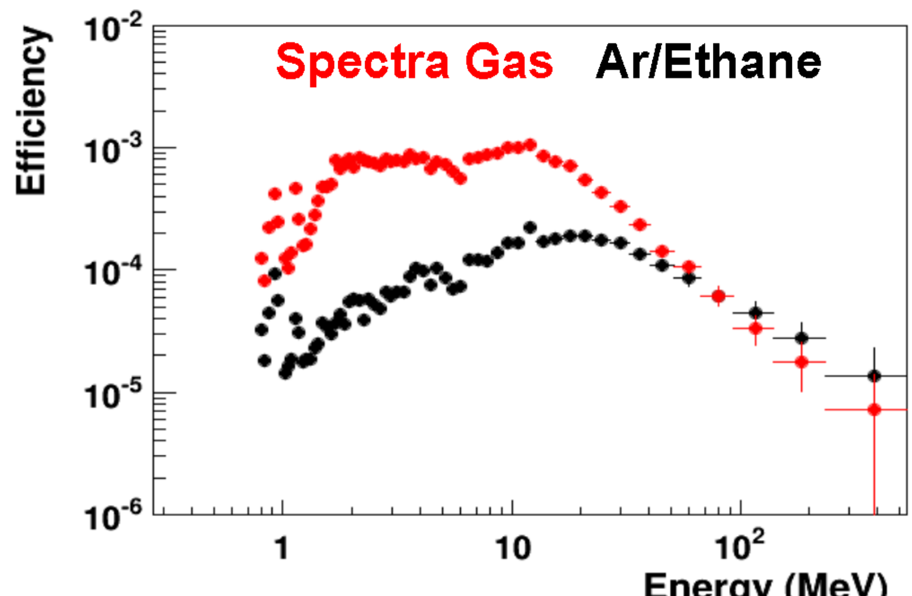
Preliminary Drift tube Efficiency Results



nominal 2" diam. neutron beam

- Efficiencies measured for two gas mixtures
- Efficiencies for neutrons confirmed to be below 10^{-4} for both mixtures above 100 MeV (good for nnbar)
- Measurements provide direct input into detector simulations!





Collaboration

Experimentalist Group

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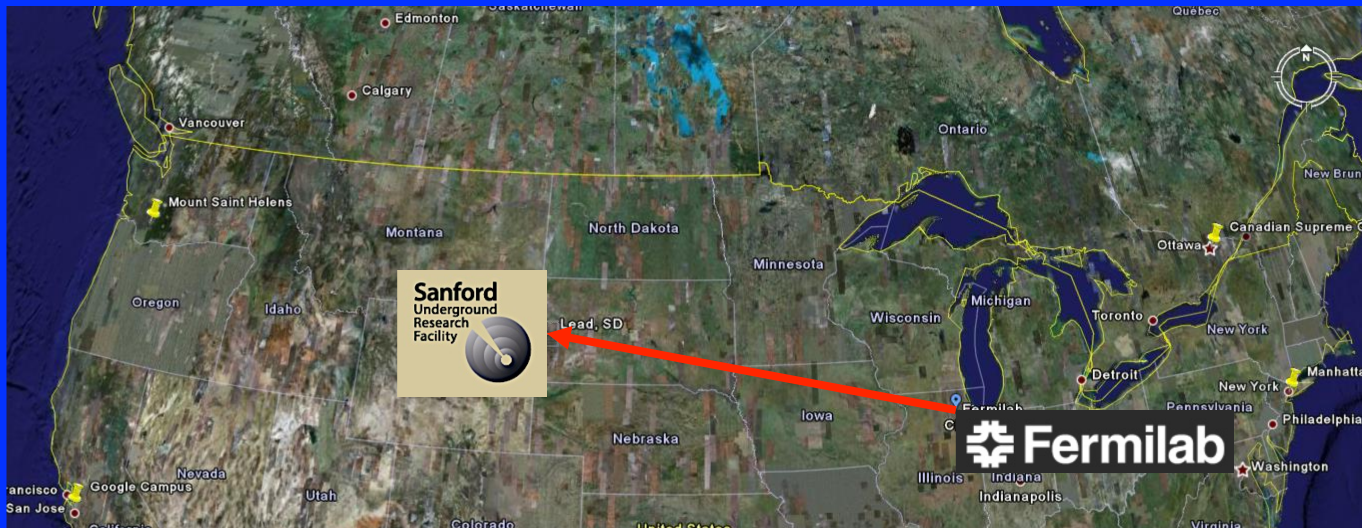
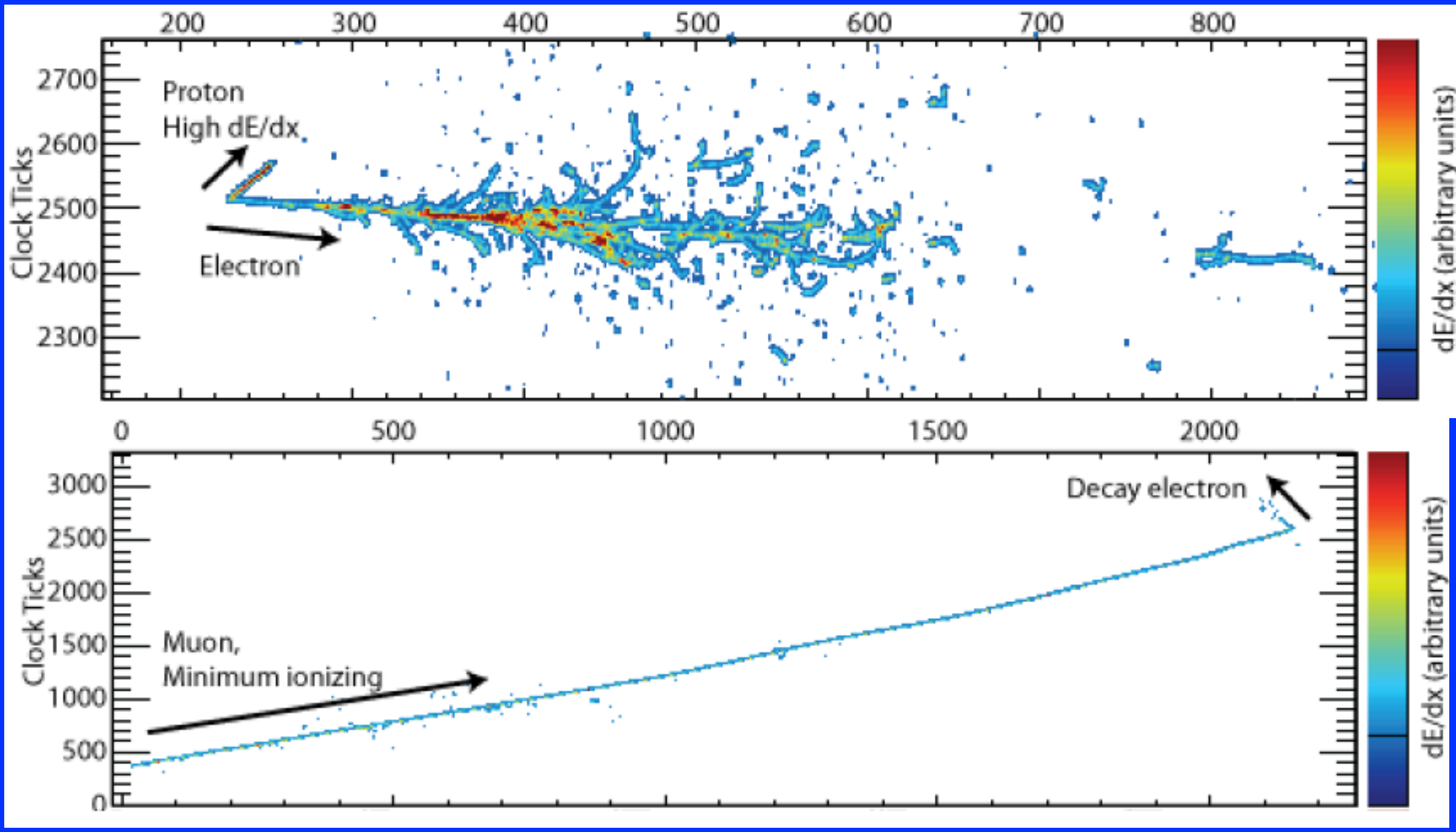
The Long-Baseline Neutrino Program



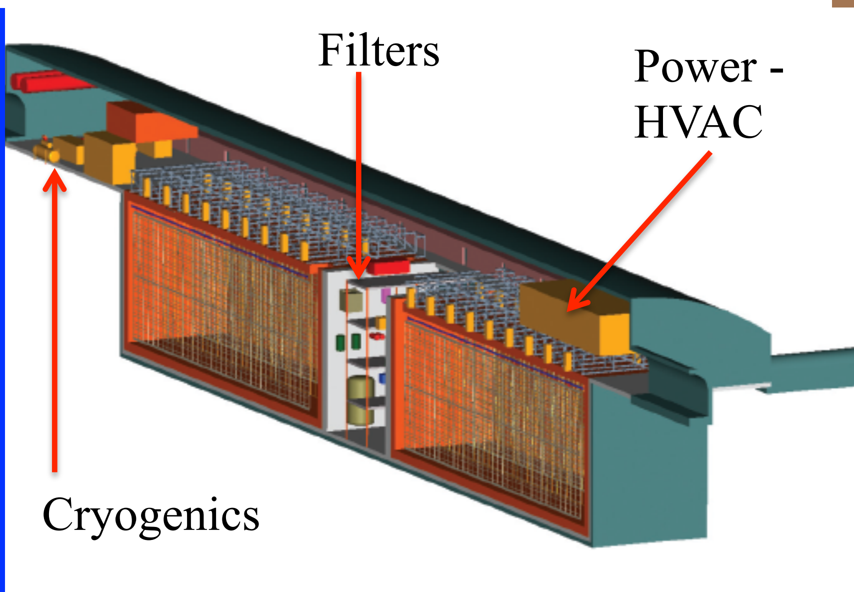
- The program consists of
  - an intense neutrino beam at Fermilab
  - near detector systems at Fermilab
  - a 40 kt liquid argon time-projection chamber (TPC) at Sanford Laboratory at 4850 foot depth – 1300 km from Fermilab
- When constructed, the experiment will have the longest manmade baseline of any neutrino experiment

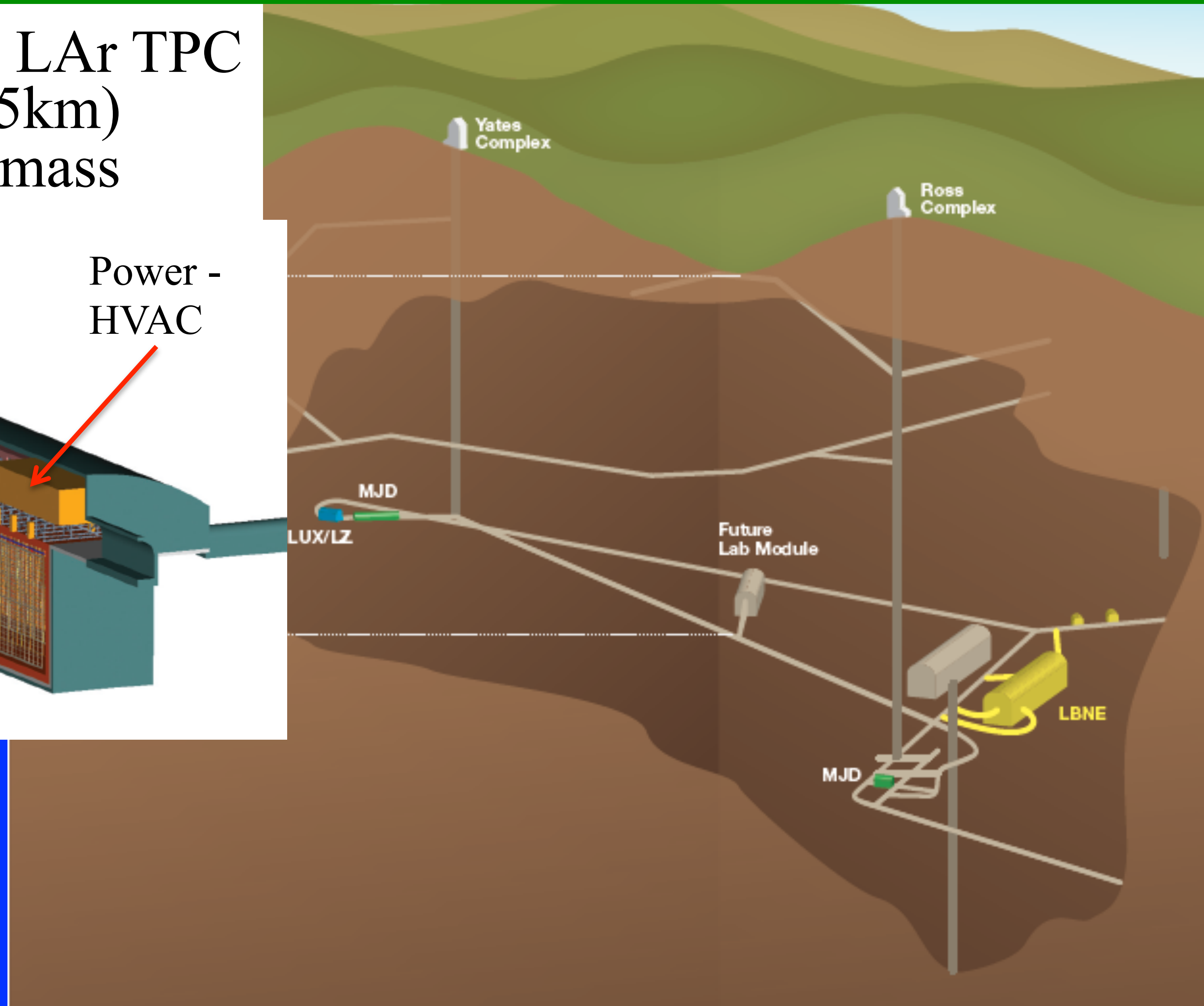
Liquid Argon TPC Performance



Far Detector Layout

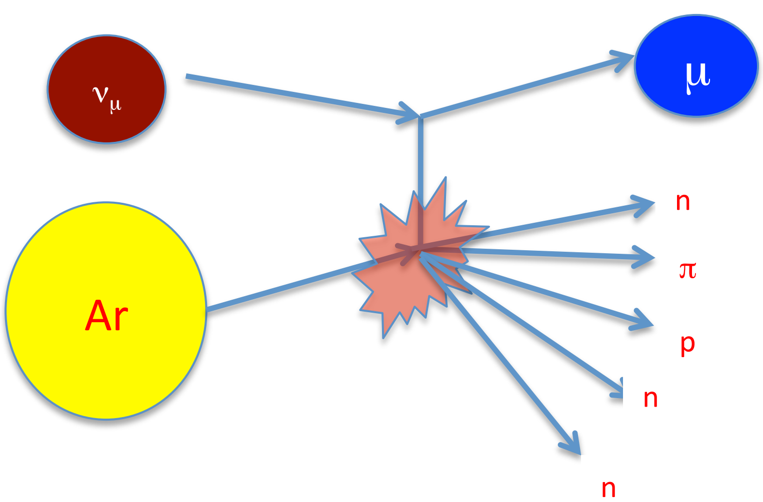
34kt fiducial mass LAr TPC
at 4850'L (1.5km)
50kt total Ar mass

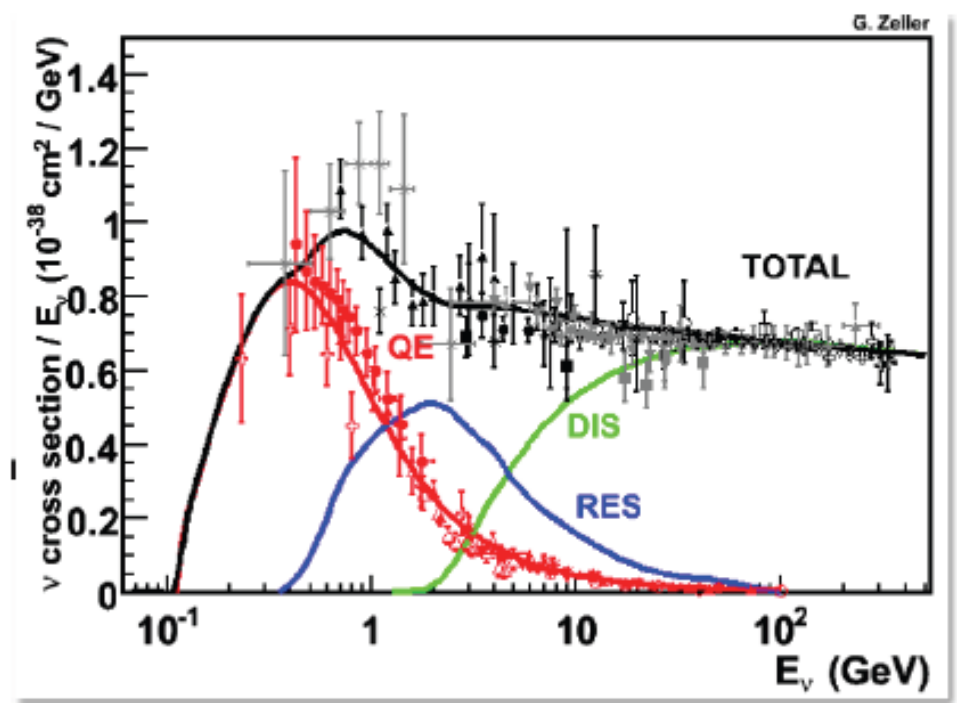




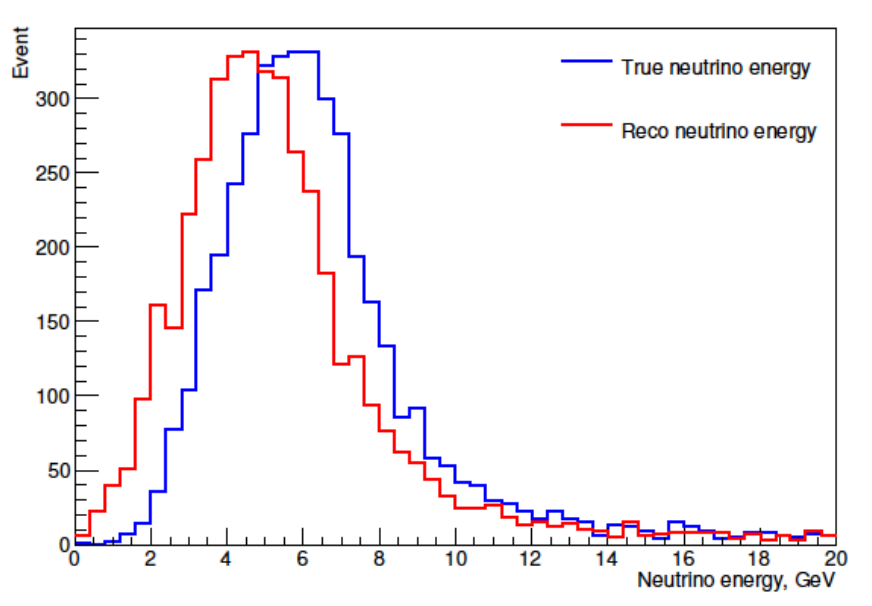
DUNE Physics Challenges – medium-energy neutrinos

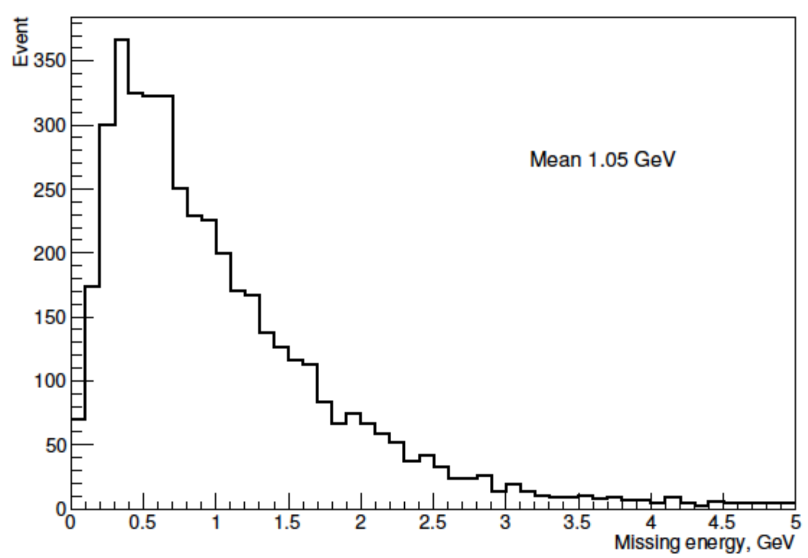
- DUNE does long-baseline physics in resonance regime (1st Oscillation Maximum at ~2.4 GeV) and resonance/DIS cross-over regime
- Atmospheric neutrinos are measured in the same neutrino energy regime
- Neutrino oscillation phenomena depend on mixing angles, masses, etc. and neutrino energy
- Critical to understand the correlation between true and reconstructed neutrino energy

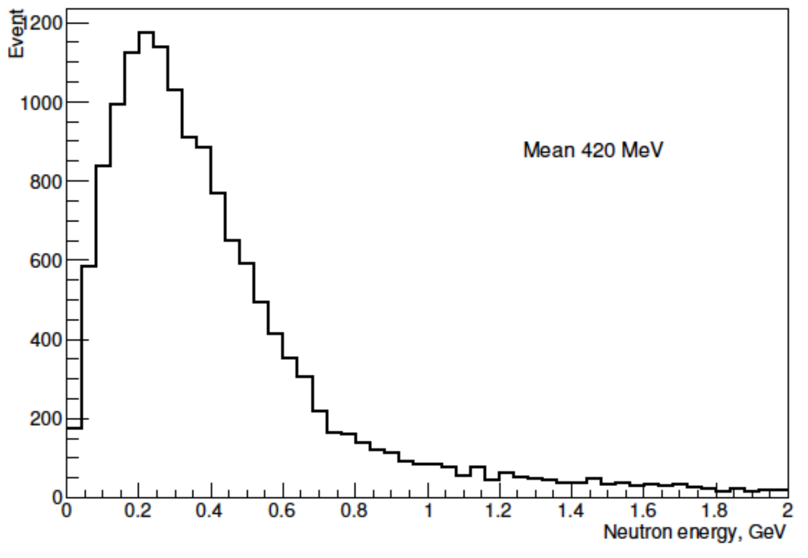




NuMI Medium Energy Tune





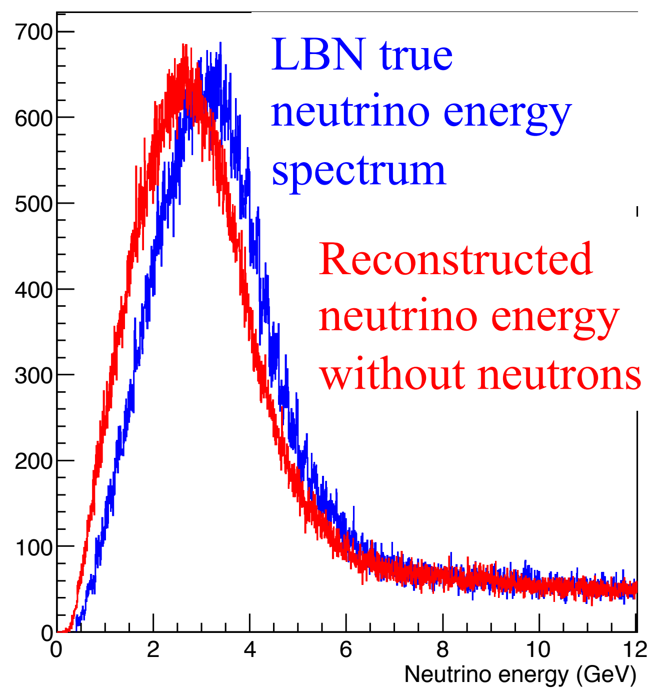


- Upper left: Blue is true neutrino energy; Red is reconstructed energy assuming no neutron reconstruction and perfect reconstruction of other particles
- Upper right: Total energy in neutrons. Note asymmetric distribution (and large uncertainties), so we cannot assume a constant ``offset'' to the neutrino energy reconstruction
- Lower right: Energy per neutrons
- All plots: NuMI medium energy tune, GENIE event generator ``out of the box''

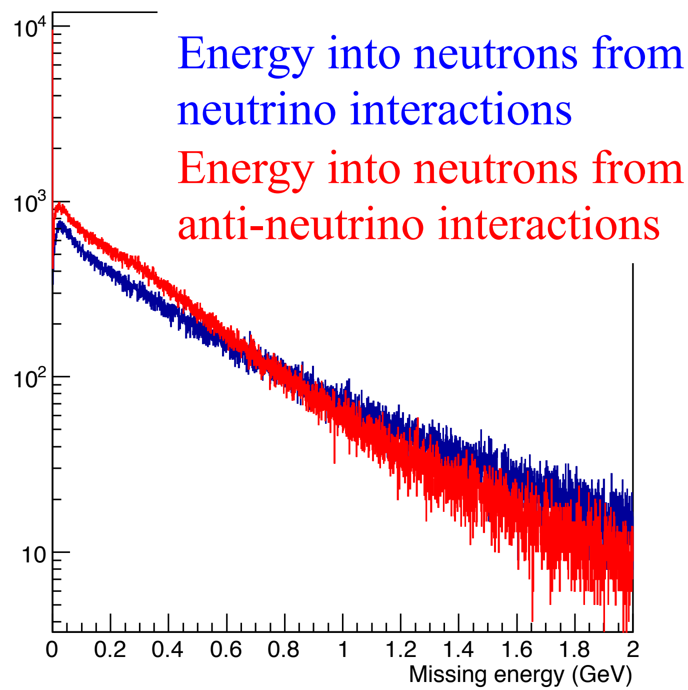
Qiuguang Liu

LBNF Beam

LBNF Neutrino Energy Spectrum



Outgoing energy in neutrons



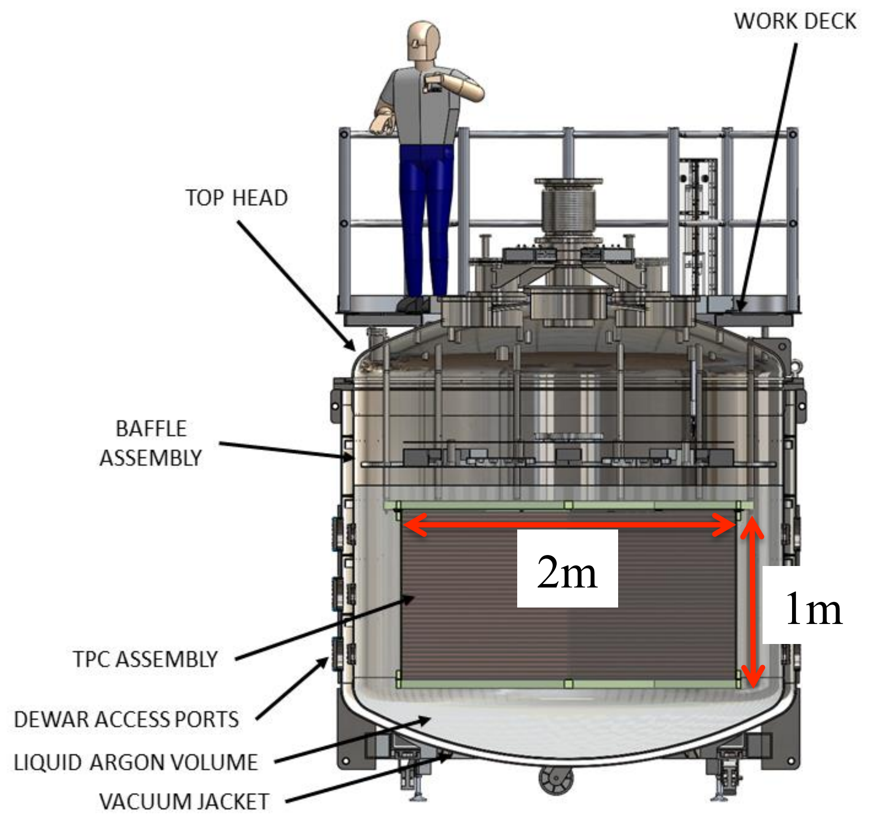
- At LBNF neutrino energies, neutrons can carry away significant energy
- Uncertainties on the energy carried away are large and unconstrained
- The energy carried away differs between neutrinos and anti-neutrinos

Elena Guardincerri

The CAPTAIN Detector

CAPTAIN: Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos

- CAPTAIN Detector
  - hexagonal TPC with 1m vertical drift, 1m apothem, 2000 channels, 3mm pitch, 5 instrumented tons
  - indium seal – can be opened and closed
  - photon detection system and laser calibration system
  - using same cold electronics and electronics chain as MicroBooNE (front end same as DUNE)
- CAPTAIN prototype – Mini-CAPTAIN
  - Hexagonal TPC with 30 cm drift, 50cm apothem, 1000 channels, 3mm pitch, 400 instrumented kg
  - Cryostat on loan from UCLA
  - more details later in the talk

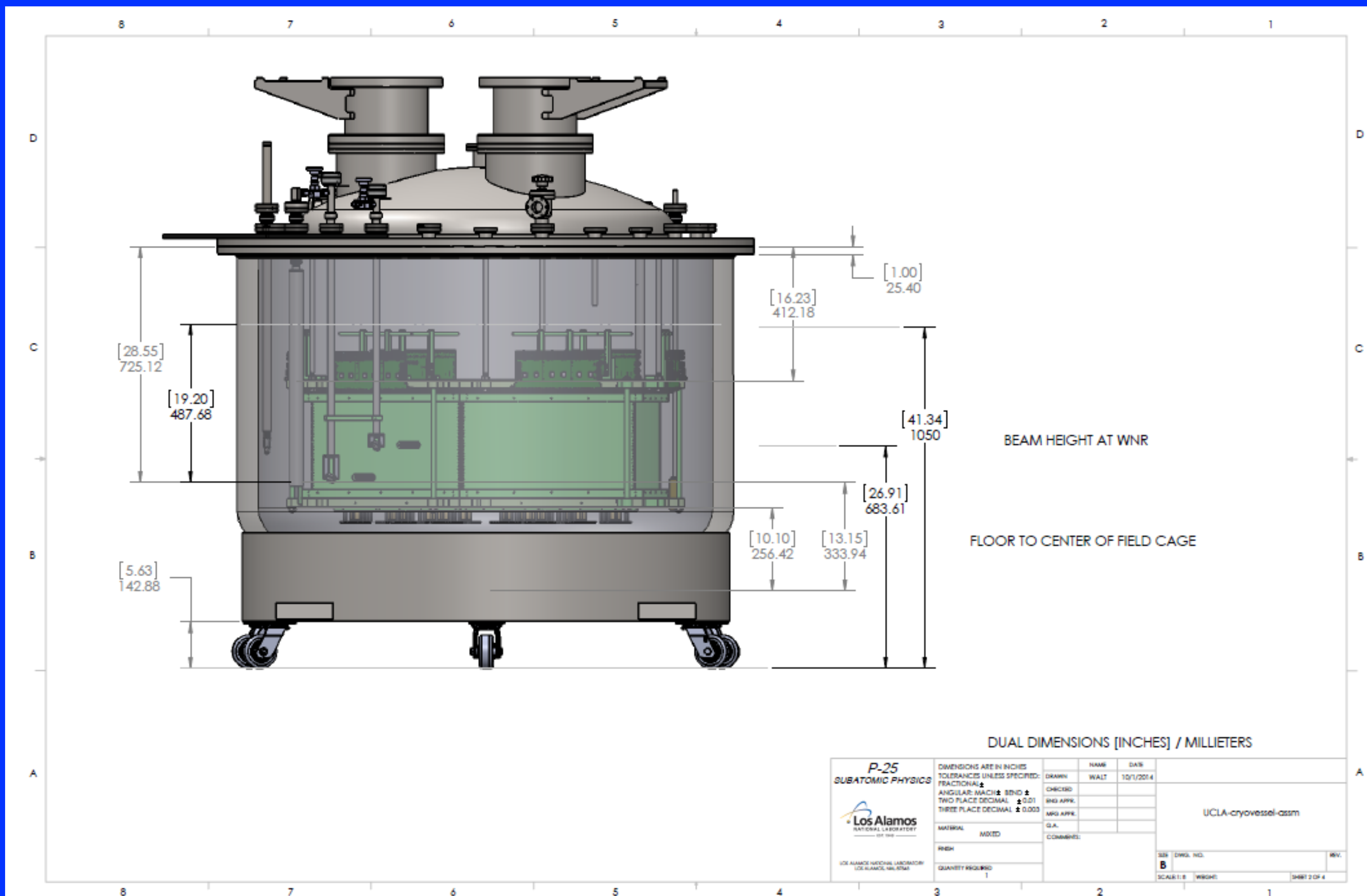


CAPTAIN Collaboration

- Alabama: Shak Fernandes, Ion Stancu
- ANL: Zelimir Djurcic
- LBL: Vic Gehman, Craig Tull
- BNL: Hucheng Chen, Veljko Radeka, Craig Thorn
- UC Davis: Hans Berns, Kyle Bilton, Daine Danielson, Steven Gardiner, Chris Grant, Emilja Pantic, Robert Svoboda, Nick Walsh
- UC Irvine: Craig Pitcher, Michael Smy
- UC Los Angeles: David Cline, Kevin Hickerson, Kevin Lee, Elwin Martin, Jasmin Shin, Artin Teymourian, Hanguo Wang
- FNAL: Oleg Prokoviev, Jonghee Yoo
- Hawaii: Jelena Maricic, Marc Rosen, Yujing Sun
- Houston: Babu Bhandari, Aaron Higuera, Lisa Whitehead, Jieun Yoo
- Indiana: Stuart Mufson
- LANL: Jeremy Danielson, Steven Elliott, Gerald Garvey, Elena Guardincerri, Todd Haines, Wesley Ketchum, David Lee, Qiuguang Liu, William Louis, Christopher Mauger, Geoff Mills, Jacqueline Mirabal-Martinez, Jason Medina, John Ramsey, Keith Rielage, Constantine Sinnis, Walter Sondheim, Ciara Sterbenz, Charles Taylor, Richard Van de Water
- Louisiana State University: Thomas Kutter, William Metcalf, Martin Tzanov
- Minnesota: Jianming Bian, Marvin Marshak
- New Mexico: Michael Gold, Alexandre Mills
- South Dakota: Chao Zhang
- South Dakota State: Robert McTaggart
- Stony Brook: Clark McGrew, Chiaki Yanagisawa

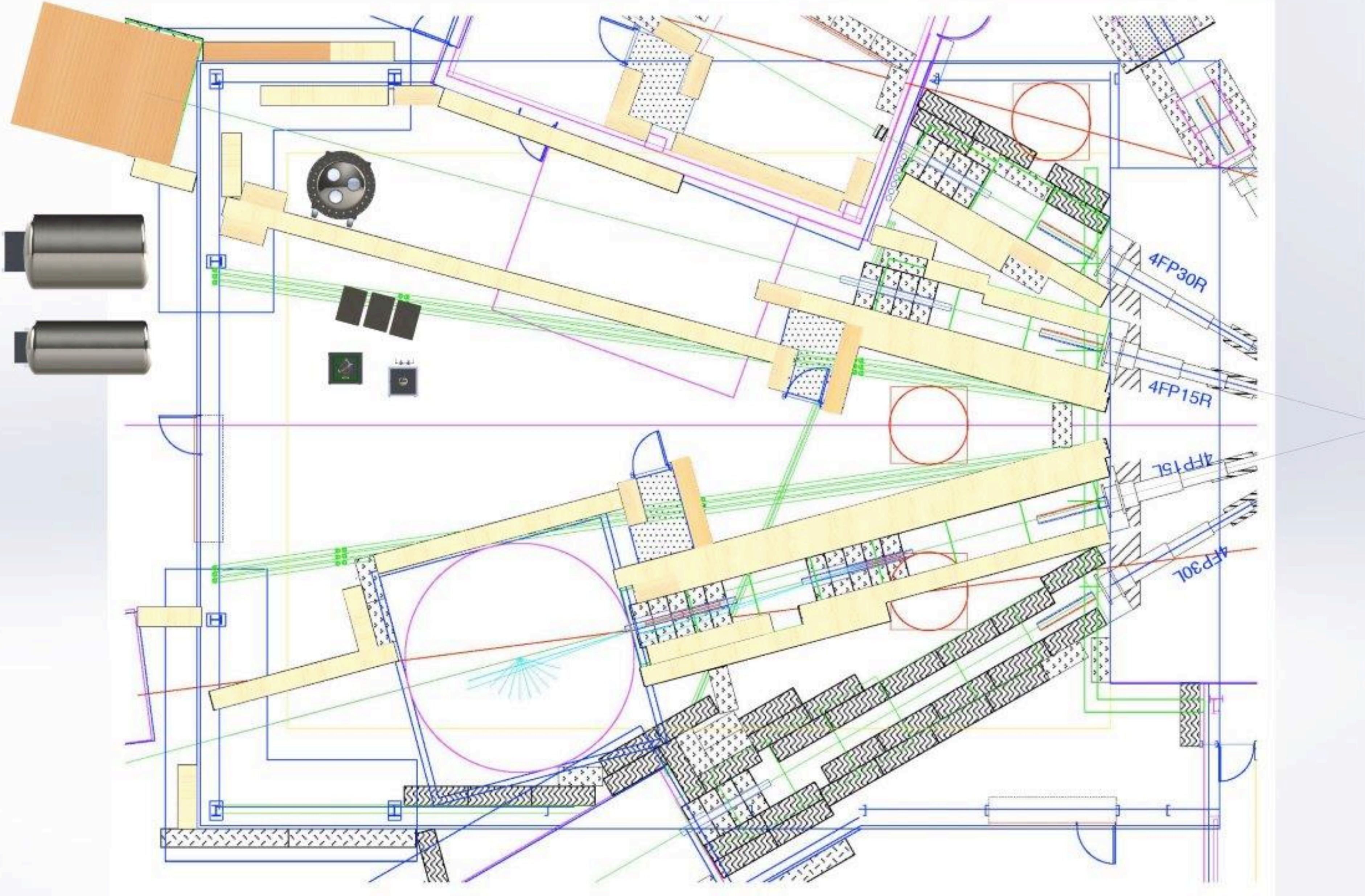
Spokesperson: Christopher Mauger; Deputy Spokesperson: Clark McGrew

Mini-CAPTAIN Detector



Mini-CAPTAIN Detector

LANL postdoc Charles Taylor prepares the prototype


4FP30R
4FP15R
4FP15L
4FP30L

Conclusions

- Neutrons can create backgrounds in a variety of particle physics experiments, so careful measurement of high-energy neutron interactions with a variety of materials and detector components is crucial – WNR is an ideal choice
- Neutrons can be an important part of the signal in particle physics experiments and thus understanding the detector response to such particles is crucial – WNR is an ideal choice for such measurements
- LANSCE will continue to be an unique and crucial resource for the development of particle physics experiments and the interpretation of their data

Thank you to Steve Elliott and Albert Young for slide contributions

Backup

CAPTAIN Physics Program

Neutron Beam
Low-Energy Neutrino Beam
Medium-Energy Neutrino Beam

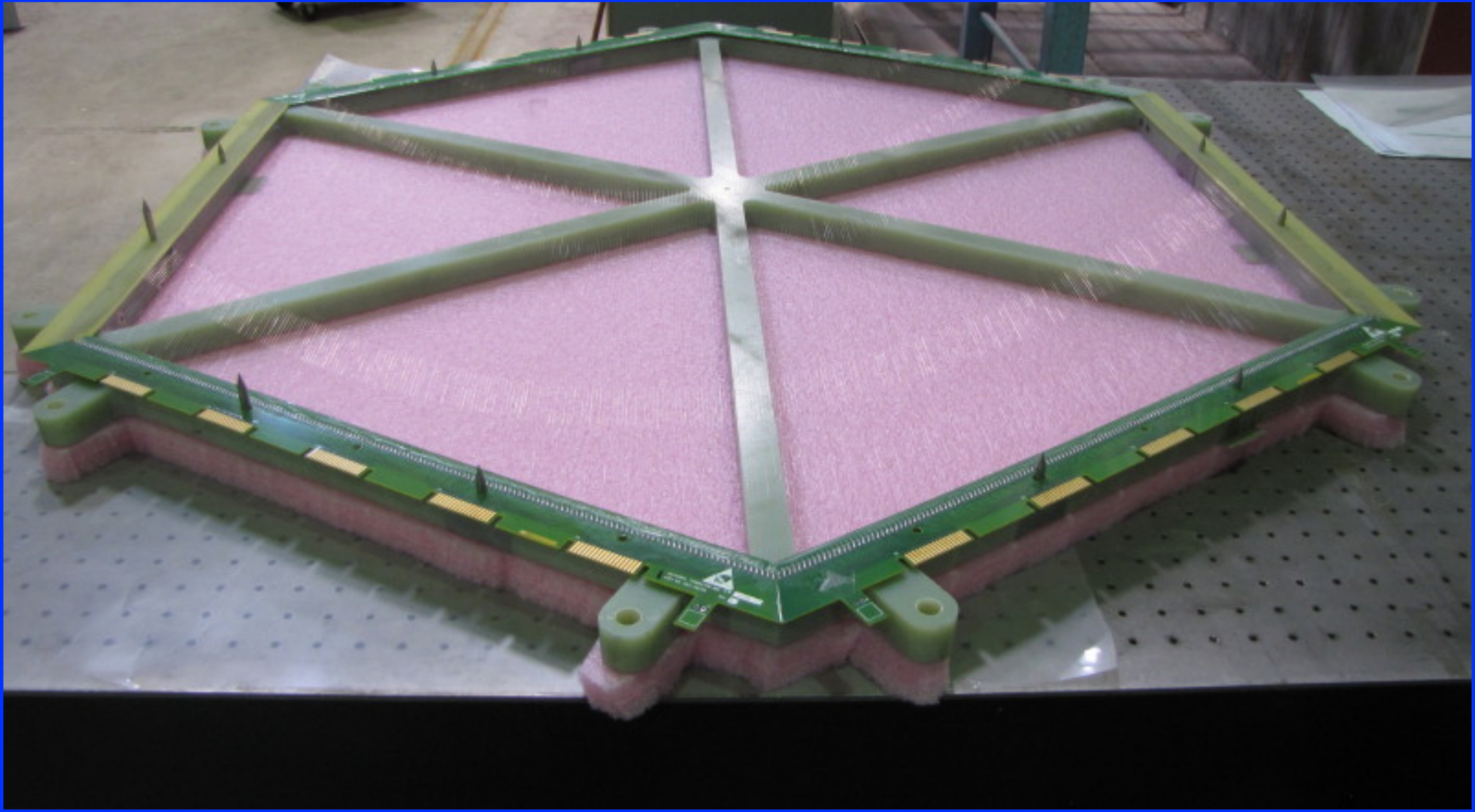
- Low-energy neutrino physics related
  - Measure neutron production of spallation products
  - Benchmark simulations of spallation production
  - Measure the neutrino CC and NC cross-sections on argon in the same energy regime as supernova neutrinos
  - Measure the correlation between true neutrino energy and visible energy for events of supernova-neutrino energies
- Medium-energy neutrino physics related
  - Measure neutron interactions and event signatures (e.g. pion production) to allow us to constrain number and energy of emitted neutrons in neutrino interactions
  - Measure higher-energy neutron-induced processes that could be backgrounds to ν_e appearance e.g. $^{40}Ar(n,\pi^0)^{40}Ar^{(*)}$
  - Measure inclusive and exclusive channels neutrino CC and NC cross-sections/ event rates in a neutrino beam of appropriate energy
  - Test methodologies of total neutrino energy reconstruction with neutron reconstruction

CAPTAIN Running Plans

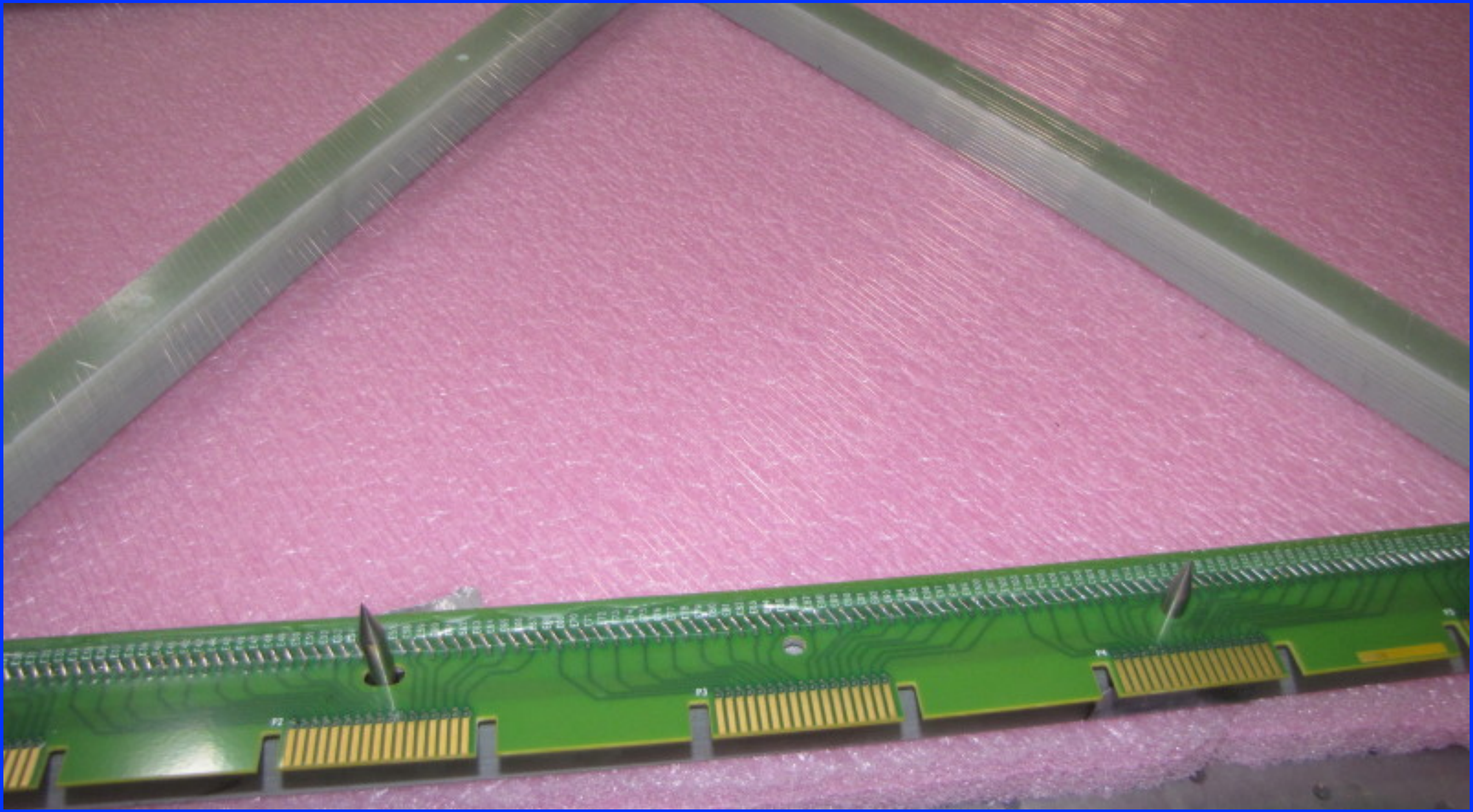
- Neutron running – Taking place at LANSCE
- CAPTAIN Minerva – Medium-energy neutrino running
  - Letter of Intent (LOI) to FNAL Physics Advisory Committee (PAC) in January of 2015
  - Proposal to PAC in June – Stage 1 approval
- CAPTAIN BNB – Low-energy neutrino running
  - LOI to FNAL PAC for running near the Booster Neutrino Beamline (BNB)
  - Proposal preparation requires beam-induced neutron background studies around the BNB – measurements in June, analysis ongoing
- Summary Plan
  - Neutron running will be done at LANL with Mini-CAPTAIN with a run in January 2016 and Autumn of 2016 (depending on approval of beam-time).
  - Neutron data will be analyzed beginning in 2016 after the January run and proceed through the end of the ER period (September 2017)
  - CAPTAIN Minerva requires completion of all elements of the CAPTAIN detector and its move to FNAL. We anticipate a surface commissioning run at FNAL prior to moving underground at NuMI
  - CAPTAIN-BNB would be subsequent to CAPTAIN Minerva

Mini-CAPTAIN field cage

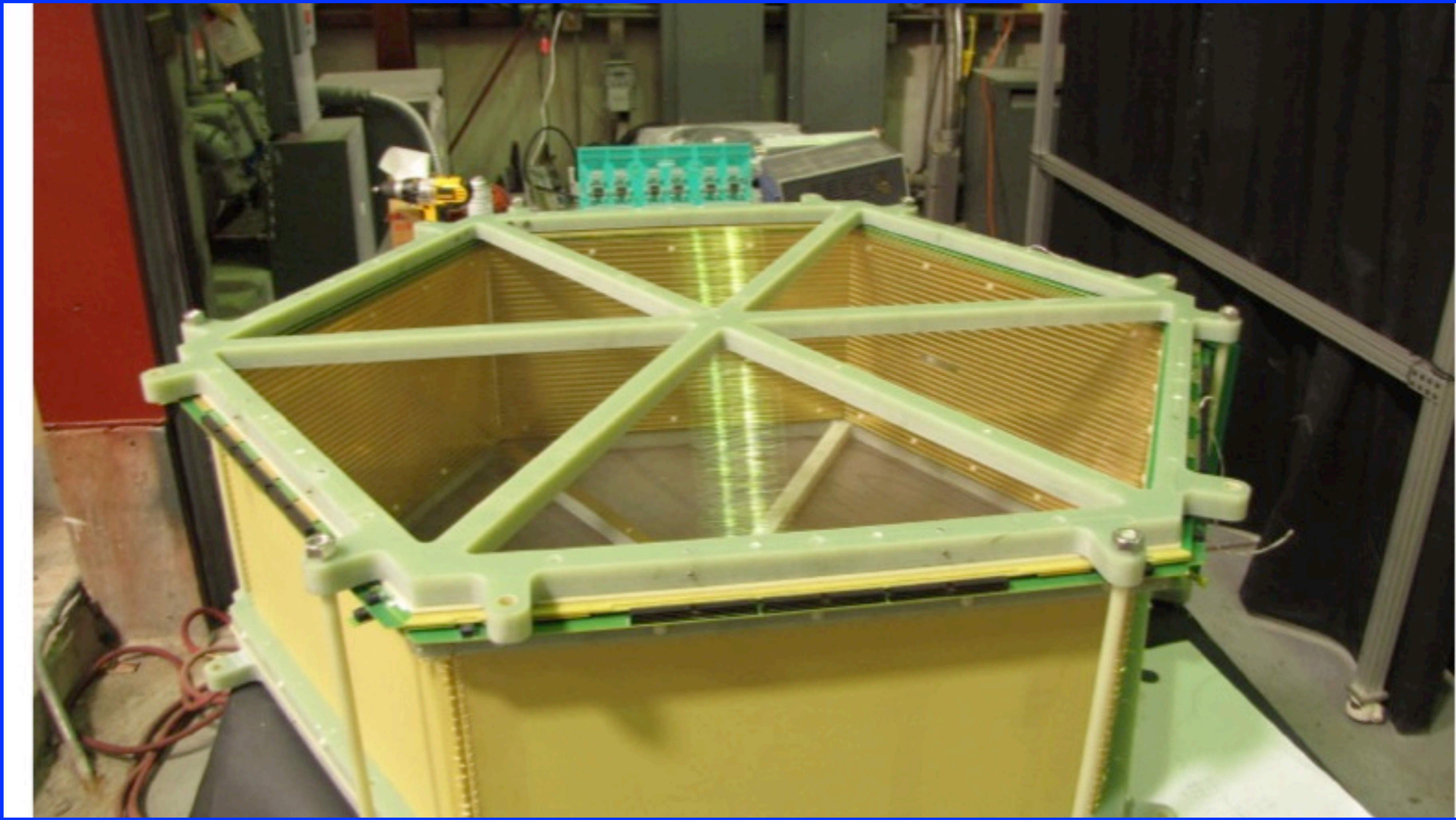
Mini-CAPTAIN wire frame



Wire-frame close-up

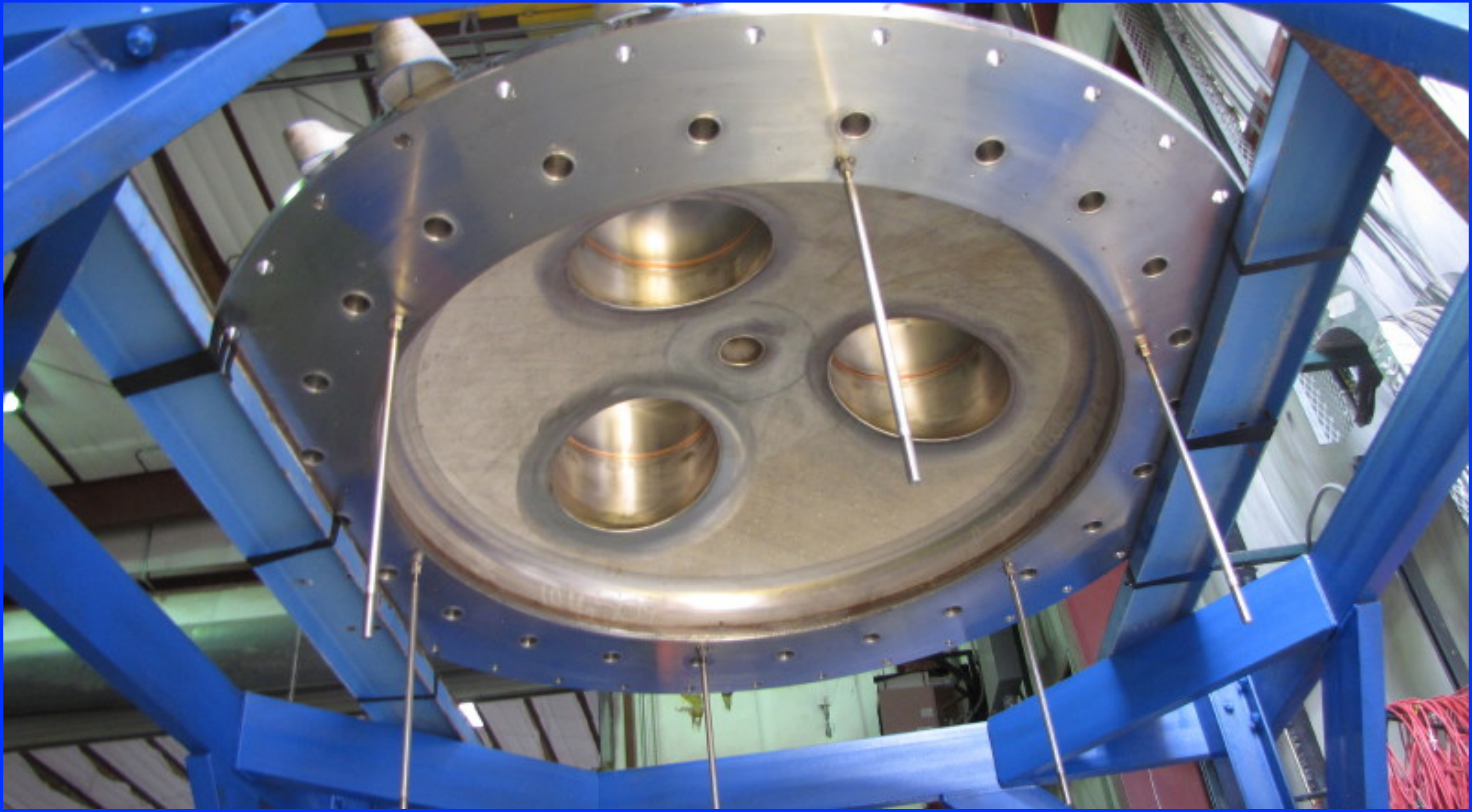


Mini-CAPTAIN TPC assembled



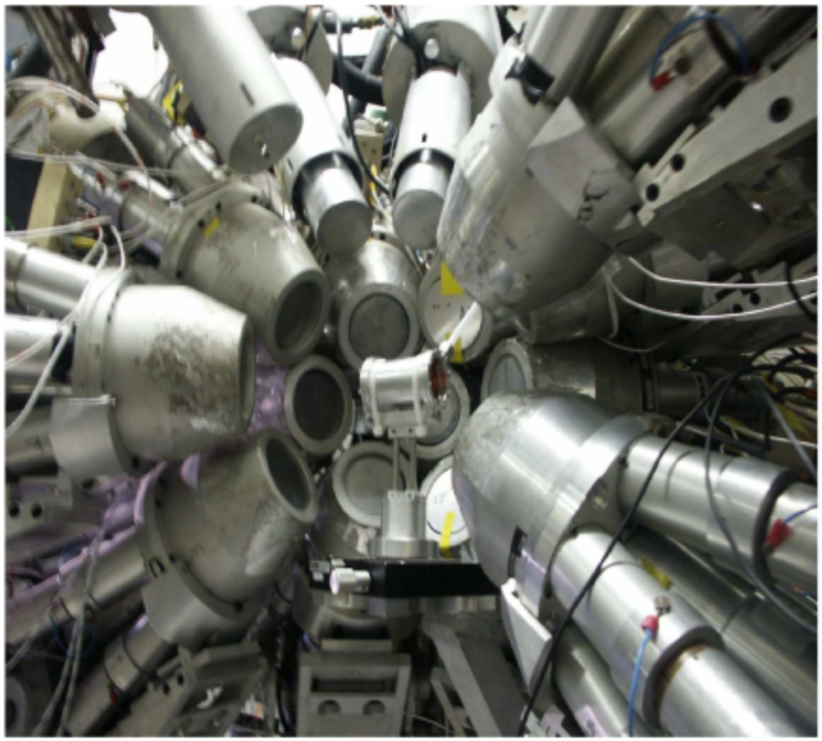
Mini-CAPTAIN cryostat

Mini-CAPTAIN lid and support stand

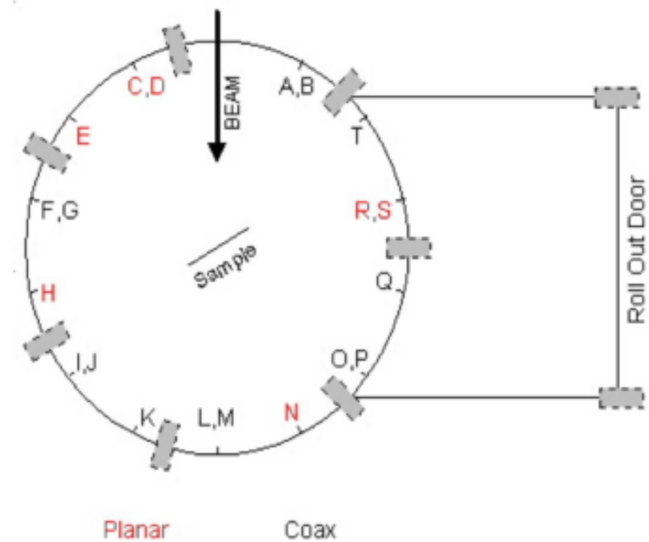


GEANIE

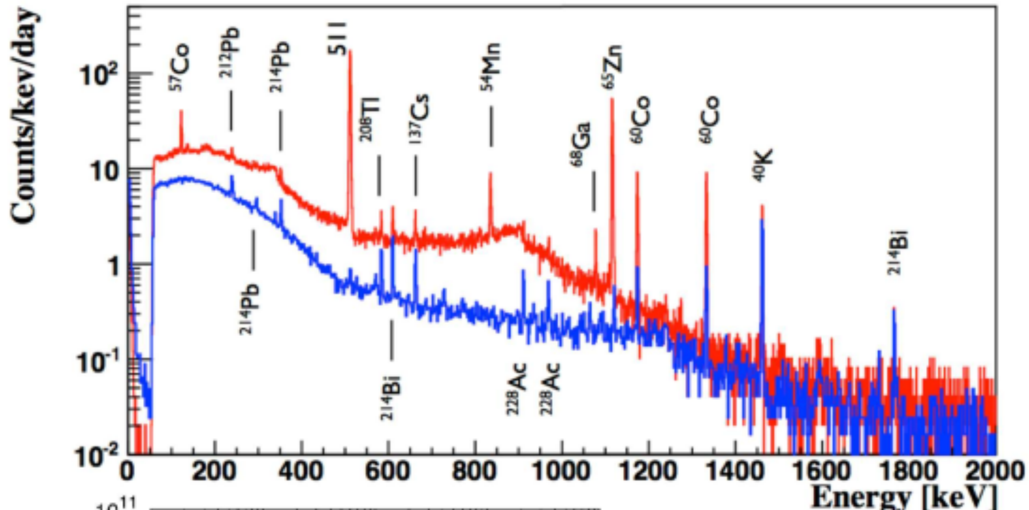
(Germanium Array for Neutron Induced Excitations)



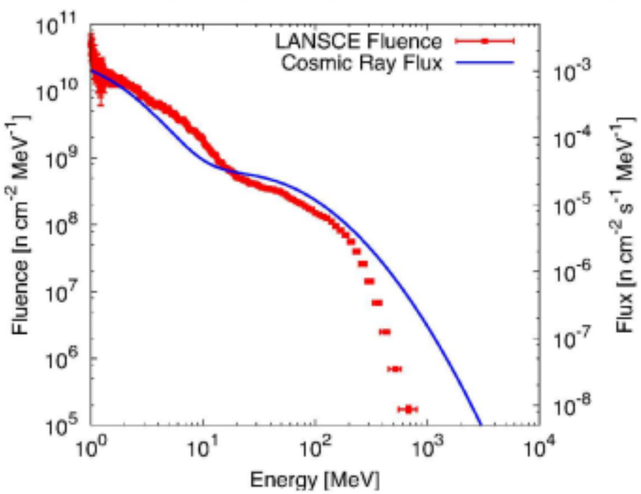
- 20 BGO suppressed HPGe detectors
  - 13 coaxial ($E_\gamma < 4$ MeV)
    - 2.2 keV at E_γ=1332 keV
    - 15 ns FWHM
  - 7 planar ($E_\gamma < 1$ MeV)
    - 0.9 keV at E_γ=122 keV
    - 10s ns FWHM

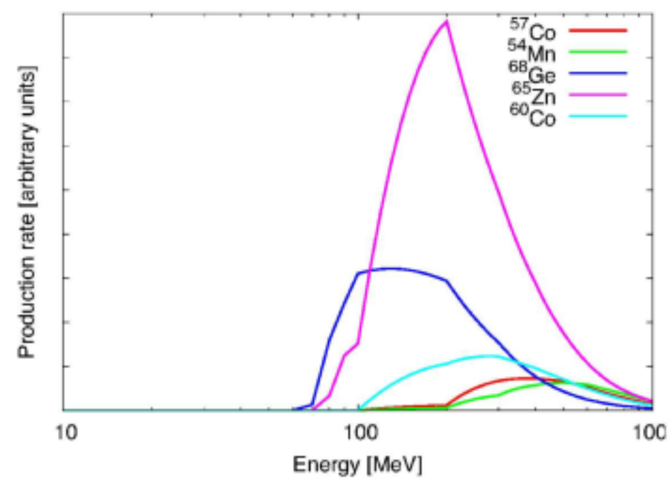


Enriched Ge activation



Enriched Ge sample activated at GEANIE, and counted on low-background Ge detector at WIPP.





^{enr}Ge Results (atoms/kg-d) (Phys Rev C **82 054610 (2010)**

Isotope	Ref. [14]	Ref. [15]	Ref. [22]	Ref. [20]	Ref. [16]	Ref. [23]	Ref. [21]	This work
^{57}Co	0.1	1.0	1.6		2.3	2.9	6.7	0.7 ± 0.4
^{54}Mn		1.4	2.3		5.4	2.2	0.87	2.0 ± 1.0
^{68}Ge	1.2	1.2		5.7	13	7.6	7.2	2.1 ± 0.4
^{65}Zn	6.0	6.4	11.0		24	10.4	20.0	8.9 ± 2.5
^{60}Co	3.5			3.3	6.7	2.4	1.6	2.5 ± 1.2

[14] H. S. Miley, F. Avignone, R. Brodzinski, W. Hensley, and J. Reeves, Nucl. Phys. B (Proc. Suppl.) 28A, 212 (1992).
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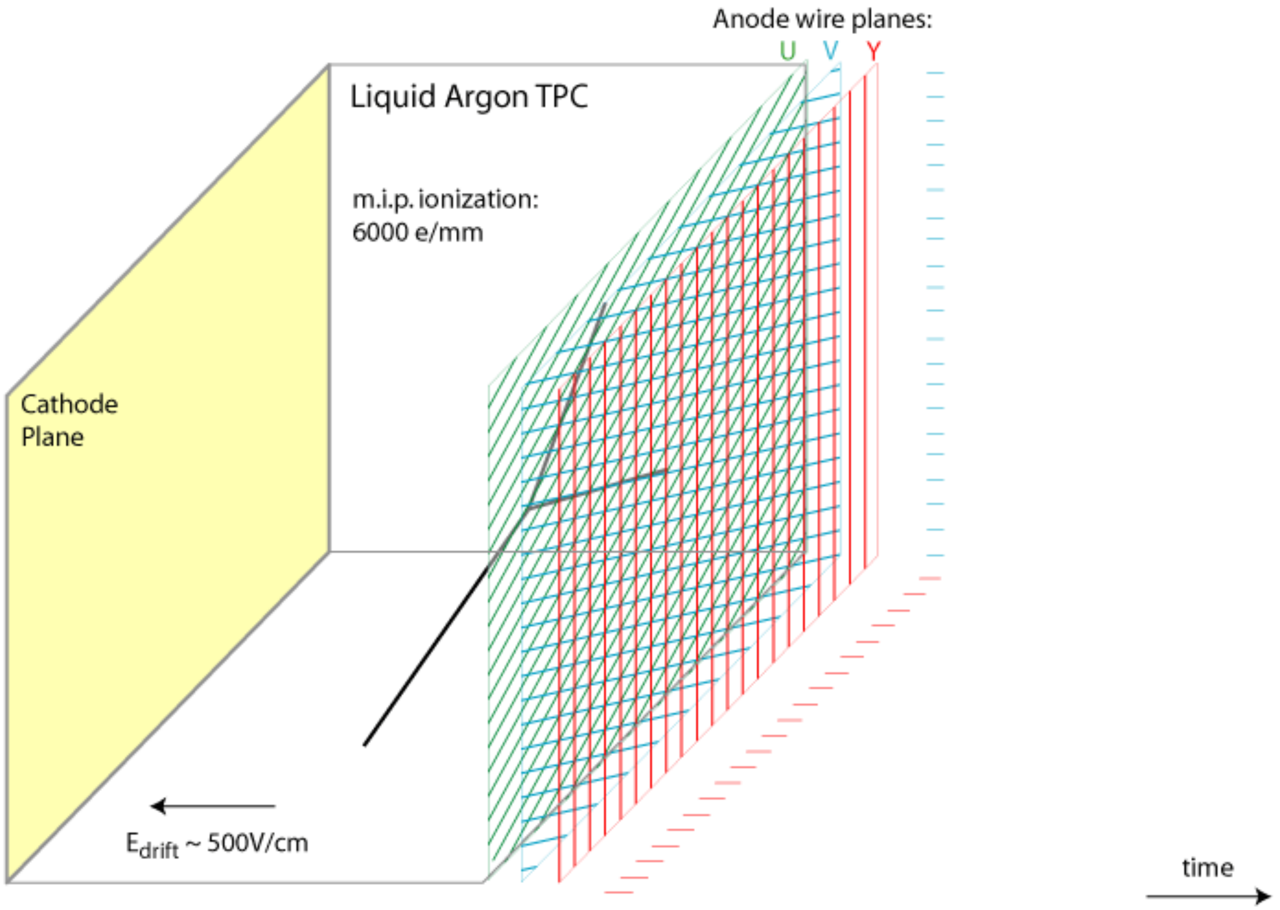
Pb(n,n'γ) near ROI

Neutron energy (MeV)	Cross section (mb)	
	$^{nat}Pb(n,xn\gamma)^{206}Pb$ 2041 keV	$^{nat}Pb(n,xn\gamma)^{207,208}Pb$ 3061,3062 keV
2.87–4.20	0.72 ± 0.44(stat.) ± 0.07 (syst.)	<0.3
4.20–6.72	4.0 ± 0.6 (stat.) ± 0.4 (syst.)	3.0 ± 0.5 (stat.) ± 0.3 (syst.)
6.72–12.50	3.6 ± 0.7 (stat.) ± 0.3 (syst.)	3.9 ± 0.8 (stat.) ± 0.4 (syst.)
12.50–31.15	3.3 ± 0.6 (stat.) ± 0.3 (syst.)	<0.4
31.15–200	0.50 ± 0.17 (stat.) ± 0.05 (syst.)	<0.2

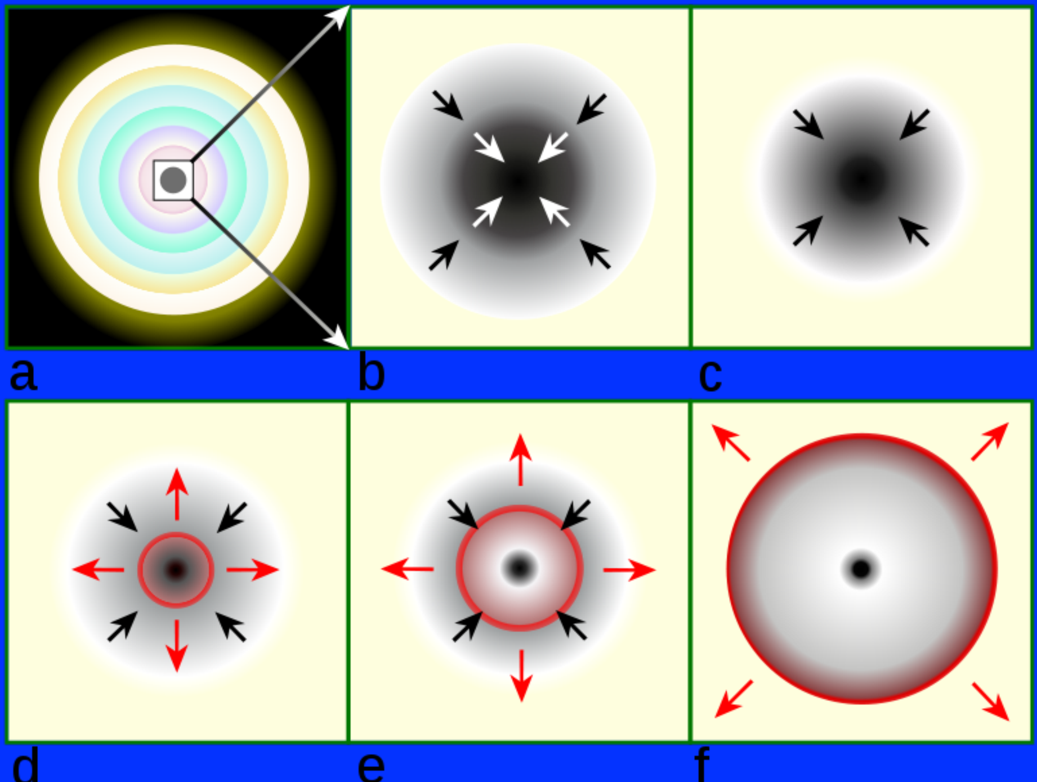
$\beta\beta$ isotope	$Q_{\beta\beta}$ (keV)	γ ray	SEP	DEP
^{76}Ge	2039.00 ± 0.05	^{206}Pb $\sigma = 3.6 \pm 0.8$ mb		^{207,208}Pb $\sigma = 3.9 \pm 0.9$ mb
^{82}Se	2995.5 ± 1.9			^{208}Pb σ NA
^{100}Mo	3034.40 ± 0.17	^{208}Pb $\sigma < 0.4$ mb	^{206}Pb $\sigma = 2.7 \pm 0.6$ mb	^{206}Pb σ NA
^{116}Cd	2809 ± 4		$\sigma = 0.69 \pm 0.49$ mb	
^{130}Te	2530.3 ± 2.0		^{208}Pb $\sigma < 0.4$ mb	
^{136}Xe	2457.83 ± 0.37	^{206,208}Pb $\sigma < 0.3$ mb		
^{150}Nd	3367.7 ± 2.2			^{207}Pb σ NA

Liquid Argon Time-Projection Chambers (TPCs)

MIP dE/dx = 2.2 MeV/cm
→ ~ 1fC/mm @ 500 V/cm
→ ~1 MeV/wire



Supernova Neutrinos



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- Cross-sections have never been measured
  - Absolute cross-sections uncertain
  - Visible energy vs. neutrino energy
- We want to measure CC electron neutrino interactions at supernova energies

- Supernova bursts in our galaxy are a fantastic source of neutrinos
- Proto-neutron star deep in the core
- Infalling matter bounces – creates shock
- Shock stalls – reheated by neutrino interactions
- Significant fluxes in < 10 seconds
- Matter effects unachievable from other sources
- Argon uniquely sensitive to CC electron neutrino interactions – complementary to water Cherenkov detectors sensitive to CC electron anti-neutrino interactions
- Galactic Supernova - Expect ~3 thousand events in DUNE