DUNE Calibrations with Radioactive Sources and Intrinsic Ar-39 & Ar-42

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DEEP UNDERGROUND NEUTRINO EXPERIMENT

SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY

Calibration Workshop

Fermilab, 27-July-2017

OUTLINE

1.) Motivation for low-energy calibration in DUNE

2.) Intrinsic Ar-39 & Ar-42

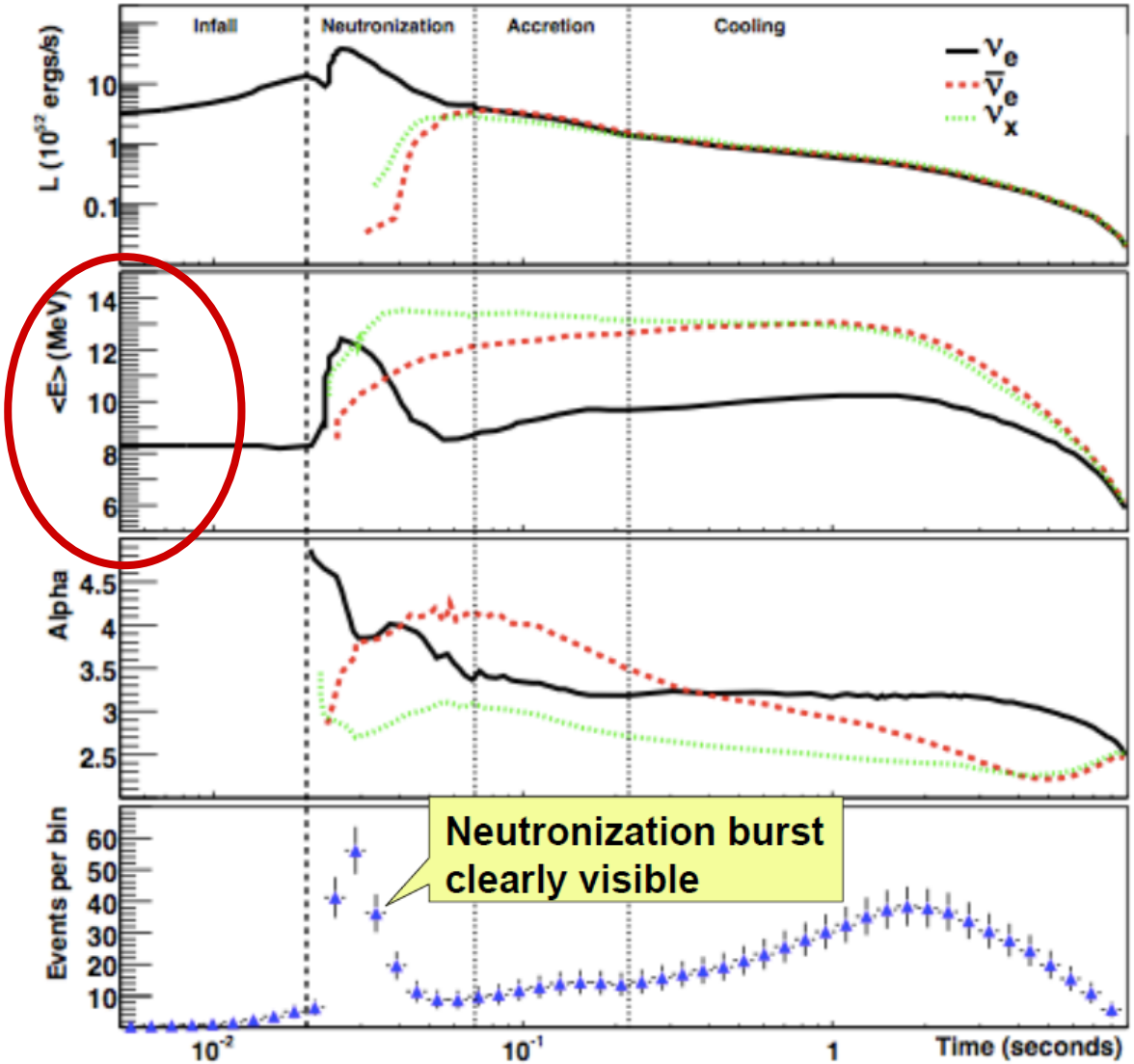
3.) External radioactive source deployments

4.) Internal fixed radioactive sources

5.) Injected short-lived radioactive sources

1.) Motivation for Low-Energy Calibrations in DUNE

Example of supernova burst signal in 34 kton of LAr



arXiv:1307.7335

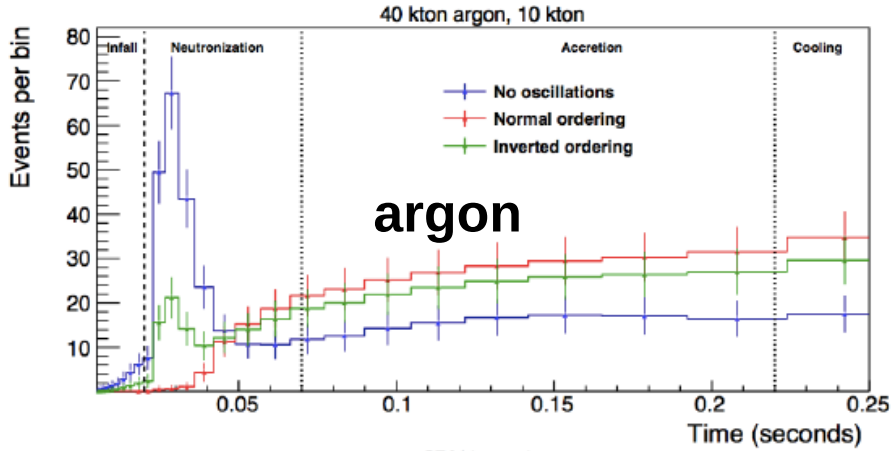
Flux from Huedepohl et. al, PRL 104 (2010) 251101 @ 10 kpc

1.) Motivation for Low-Energy Calibrations in DUNE

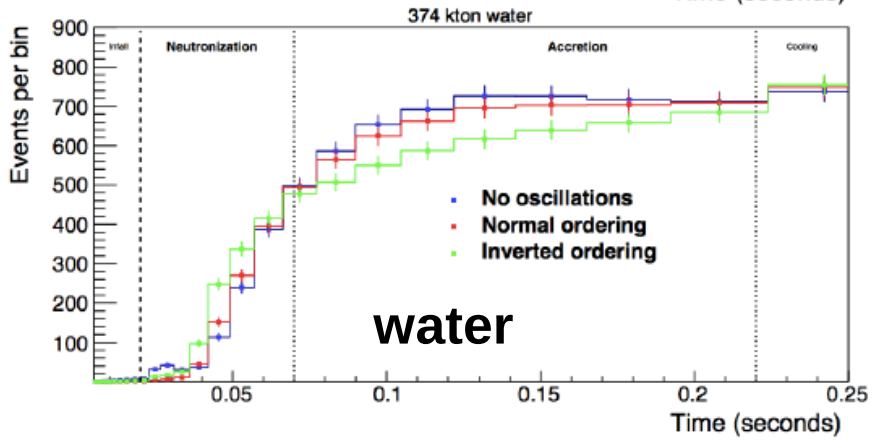
Same supernova model, other future large detectors

- neutronization burst much more visible in LAr
- time profile varies by hierarchy, differently for different detectors

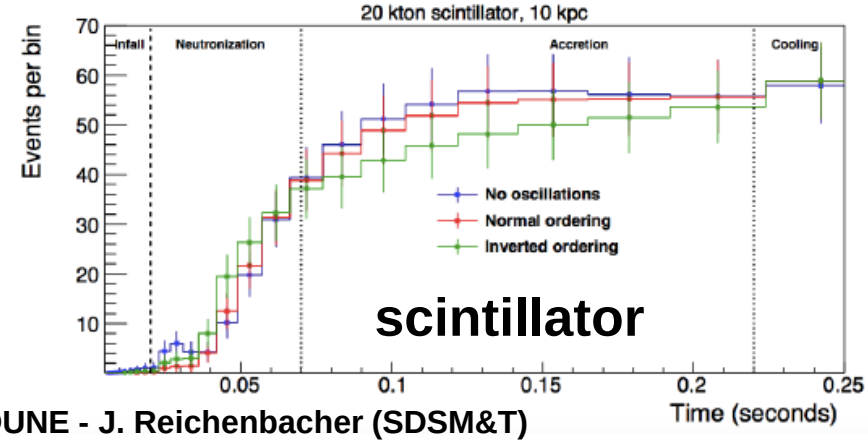
⇒ ***<u>We need LAr SNB detector!</u>***



ν_e



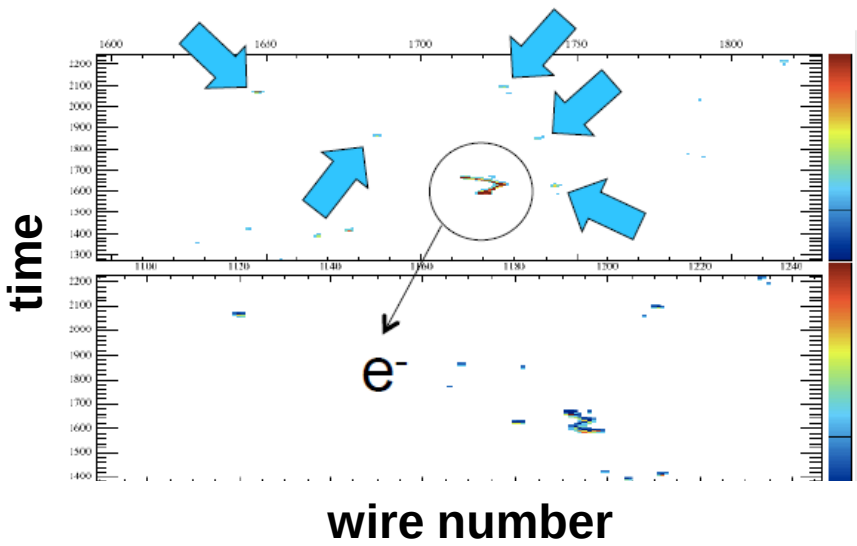
$\bar{\nu}_e$



$\bar{\nu}_e$

1.) Motivation for Low-Energy Calibrations in DUNE

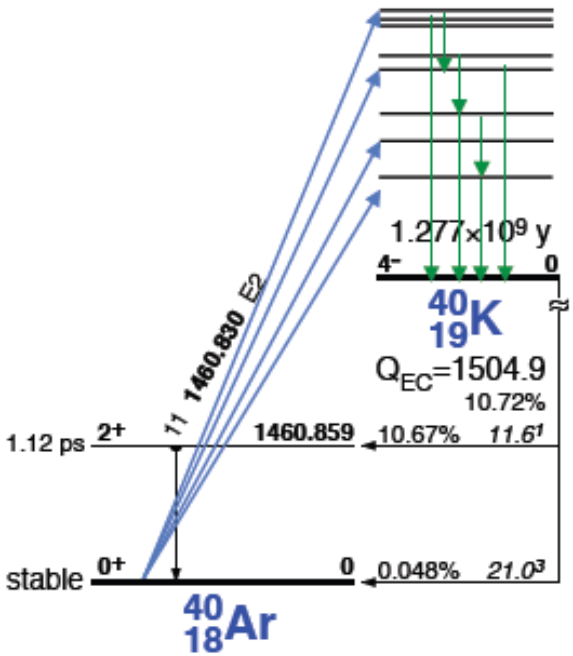
Can we tag ν_e CC interactions in argon using nuclear deexcitation γ's?



Charged-current absorption:

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

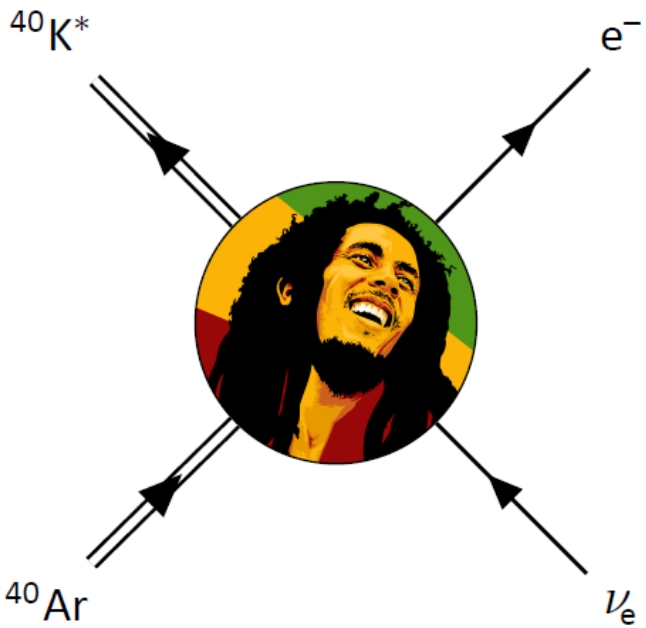
(g.s. to g.s. is 3rd forbidden transition)



20 MeV ν_e, 14.1 MeV e^-, simple model based on R. Raghavan, PRD 34 (1986) 2088
Improved modeling based on ^{40}Ti (^{40}K mirror) β decay measurements in progress
Direct measurements (and theory) needed!

MARLEY: Model of Argon Reaction Low-Energy Yields

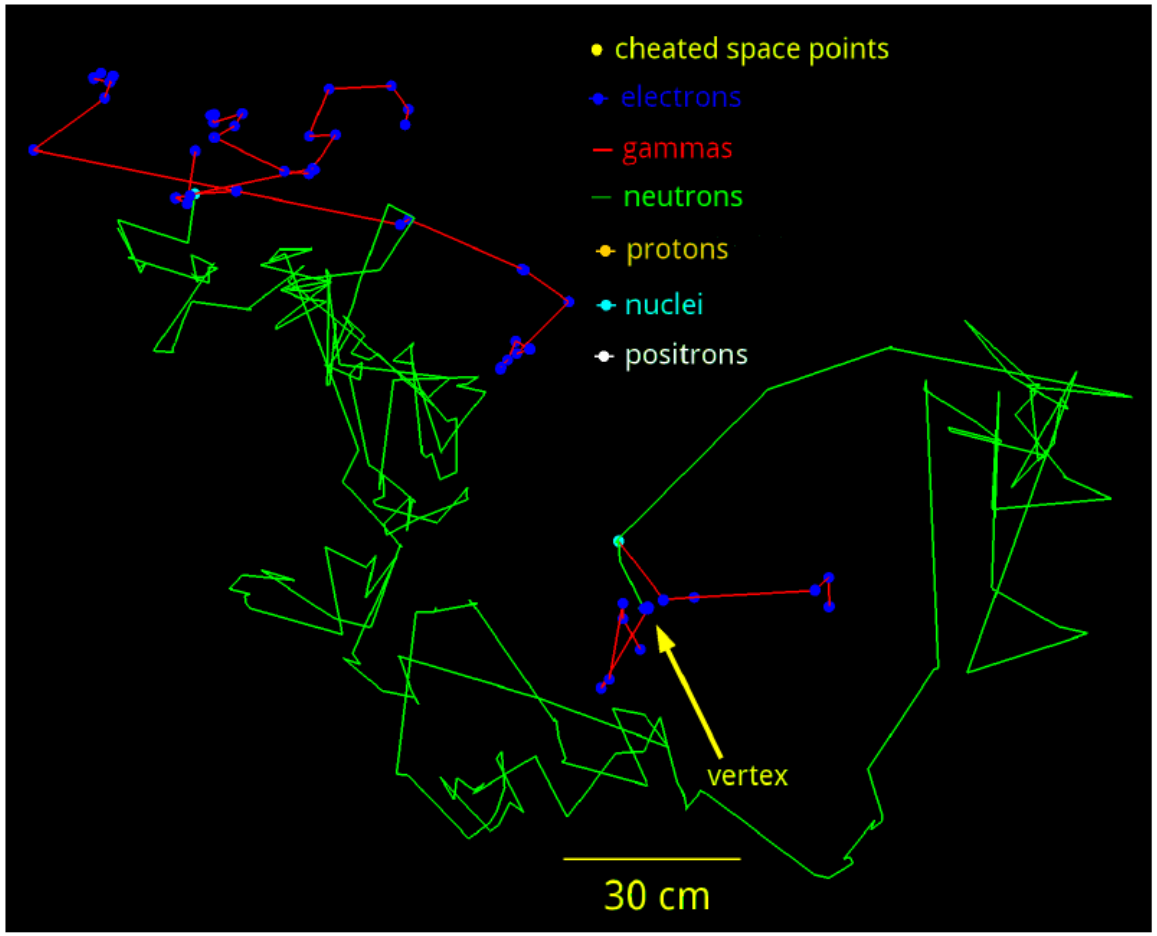
- **Goal:** determine whether "every little thing gonna be all right" for SN neutrino physics in LArTPCs
- Event generator for SN ν on ^{40}Ar
- Current version focuses on generating ν_eArCC events



R. Svoboda,
S. Gardiner (-> talk),
C. Grant & E. Pantic

Example neutron event (true trajectories)

- E_ν = 16.3 MeV
- e^- deposited 4.5 MeV
- No primary γs from vertex
- ^{39}K deposited 68 keV
- n deposited 7.6 MeV (mostly from capture γs)
- Total visible energy: 12.2 MeV
- Visible energy sphere radius: 1.44 m
- Neutrons bounce around for a long time!



-> need to control u/g neutron background!

Important: Radiological Model and Inputs from Screening

⇒ ***Requirements on Radiopurity driven by intrinsic Ar-39 level in LAr (1.01 Bq / kg)***

GERDA: 10^-4 Bq/kg of Ar-42 in LAr
(Curse and/or Blessing? Study in progress)

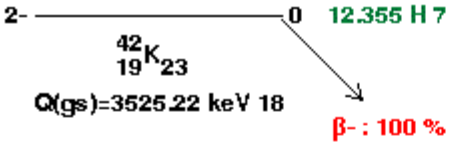
(would require Manhattan-Project style effort to mitigate for DUNE)

- **Radiological control is crucial for far detector!**

⇒ **alpha- and gamma-screening of radiologically critical detector components for far detector used as inputs for radiological model**

- **Full-blown radiological model is condensed into one LArSoft producer file and provides input for SNB, DAQ simulations, cosmogenics, atmospheric ν's, ndk etc.**

2.) Intrinsic Ar-39 & Ar-42



Author: Jun Chen and Balraj Singh Citation:Nuclear Data Sheets 135, 1 (2016)

Parent Nucleus	Parent E(level)	Parent Jπ	Parent $T_{1/2}$	Decay Mode	GS-GS Q-value (keV)	Daughter Nucleus	Decay Scheme	ENSDF file
$^{42}_{19}K$	0	2-	12.355 h 7	β^-: 100 %	3525.22 18	$^{42}_{20}Ca$		

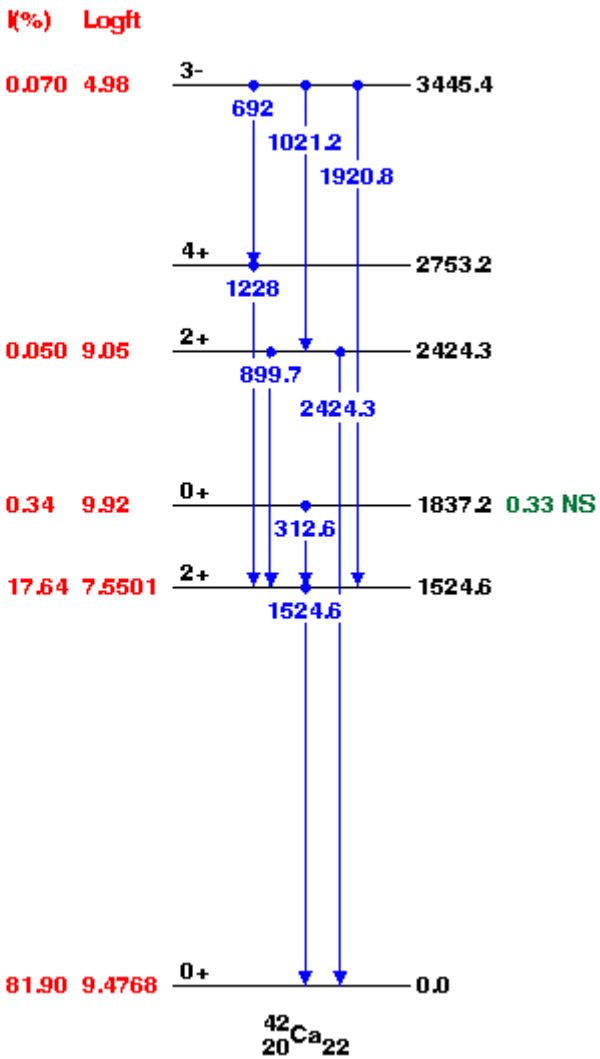
Beta-:

Energy (keV)	End-point energy (keV)	Intensity (%)	Dose (MeV/Bq-s)
21.41 21	79.8 7	0.070 % 10	1.50E-5 21
415.41 20	1100.9 4	0.050 % 10	2.1E-4 4
702.95 20	1688.0 4	0.34 % 3	0.00239 21
824.32 17	2000.6 3	17.64 % 9	0.1454 7
1565.86	3525.22 18	81.90 % 9	1.2824 14

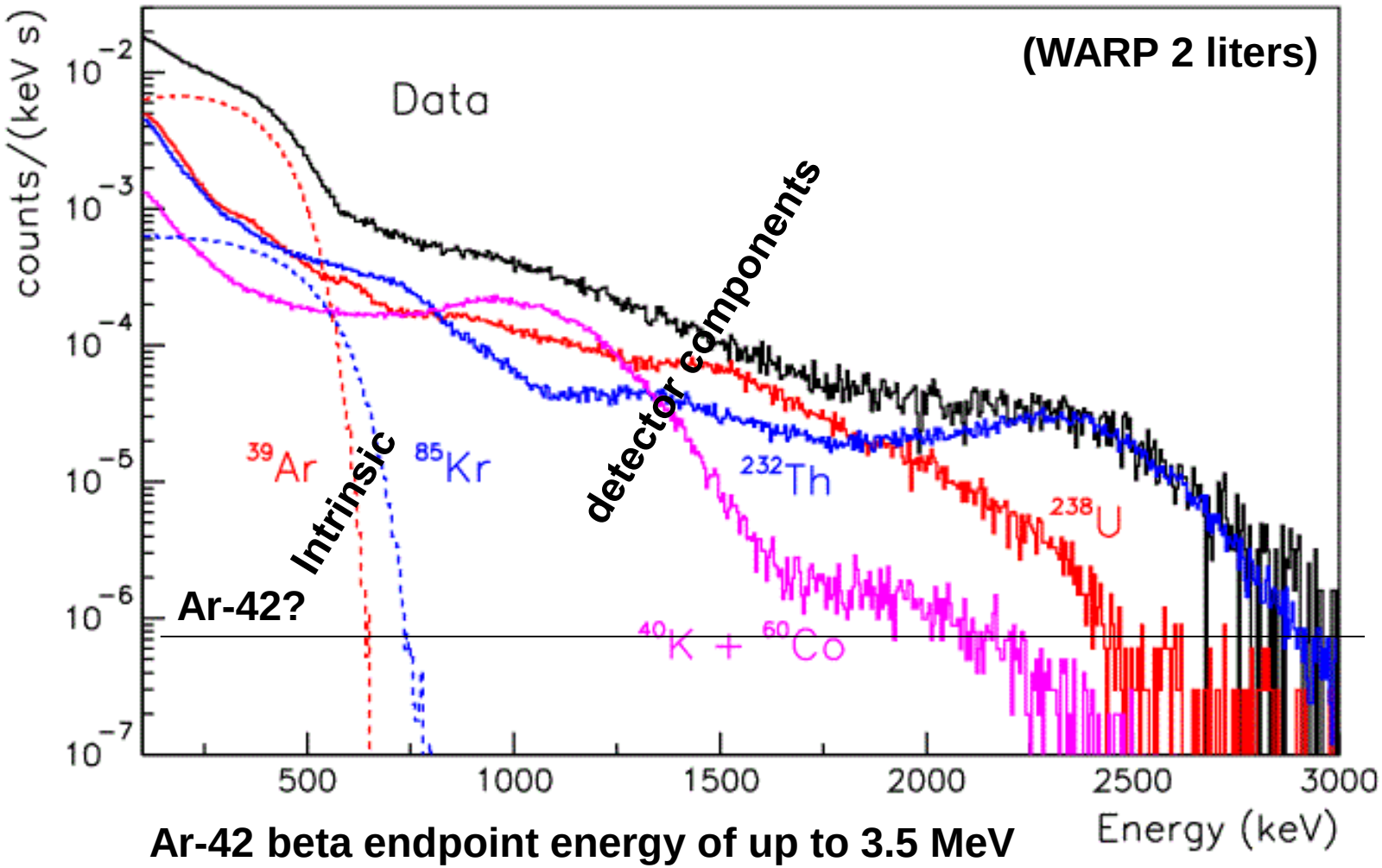
Mean beta- energy: 1430.5 keV *25*, total beta- intensity: 100.00 % *13*, mean beta- dose: 1.430 MeV/Bq-s *3*

Gamma and X-ray radiation:

Energy (keV)	Intensity (%)	Dose (MeV/Bq-s)
312.60 25	0.336 % 20	0.00105 6
692.0 8	0.0033 % 7	2.3E-5 5
899.7 4	0.052 % 3	4.64E-4 23
1021.2 9	0.0201 % 14	2.05E-4 15
1228.0 15	0.0024 % 11	2.9E-5 13
1524.6 3	18.08 %	0.2756
1920.8 10	0.041 % 4	7.9E-4 8
2424.3 7	0.020 % 3	4.8E-4 7



2.) Intrinsic Ar-39 & Ar-42

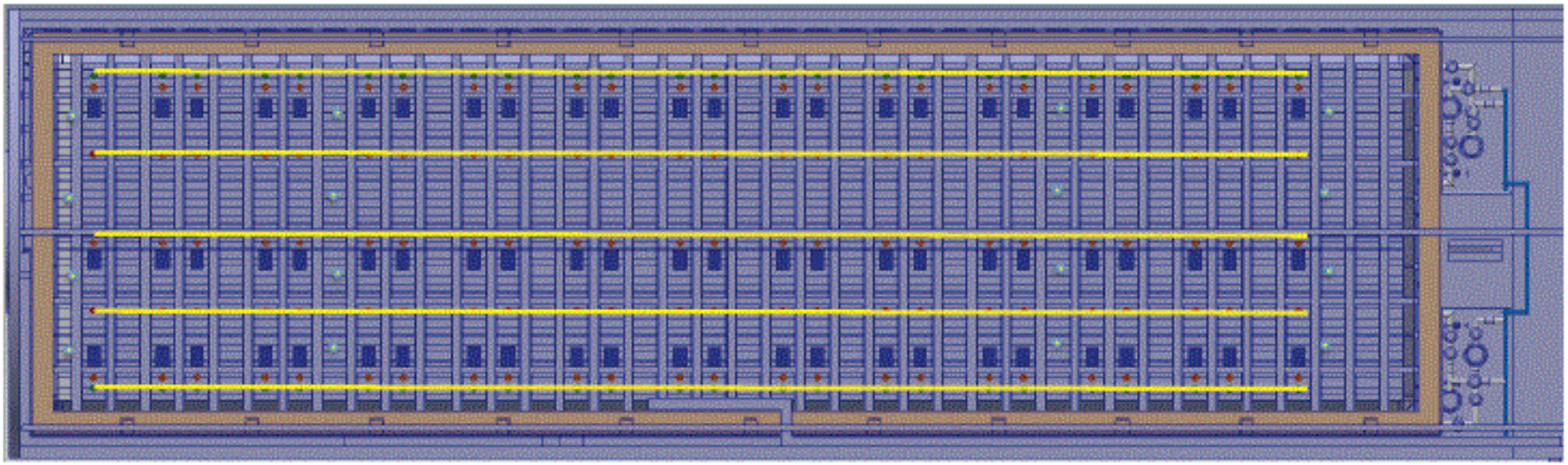


Ar-42 beta endpoint energy of up to 3.5 MeV and often correlated gammas of ~1.5 MeV+

10 kt: 10 MHz Ar-39 + 1 kHz Ar-42 (can hit 3 adjacent wires -> cal)

3.) External radioactive source deployments

Radioactive sources/movable TGradiant



- A 58Ni-252Cf source will emit 8-9 MeV gammas which are in the right range for calibration the energy response in the SN region. As absolute energy calibrations would otherwise be difficult this capacity should be foreseen.
  - A Ni source will probably need ~100mm space including N moderator.
- Dynamic T-gradient monitors should also be foreseen at the detector ends and it is reasonable to combine these functions in single larger penetrations. Assume a 250 mm crossing tube.
- 16 penetrations total. 8 roughly centered in each TPC drift and 8 at the ends of the detector. The penetrations at the ends should not be more than 0.5m from the field cage but sufficiently far away not to risk the field.
  - Need to check rate when a natural position is determined.

3.) External radioactive source deployments

$^{58}Ni(n,\gamma)^{59}Ni$

TRI-PP-96-7
Apr 1996

A 7–9 MeV isotopic gamma ray source for detector testing

Joel G. Rogers[a*], Mark S. Andreaco[b], and Christian Moisan[a]

[a]*TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., Canada V6T 2A3*
[b]*CTI, 810 Innovation Drive, Knoxville, TN 37932, U.S.A.*

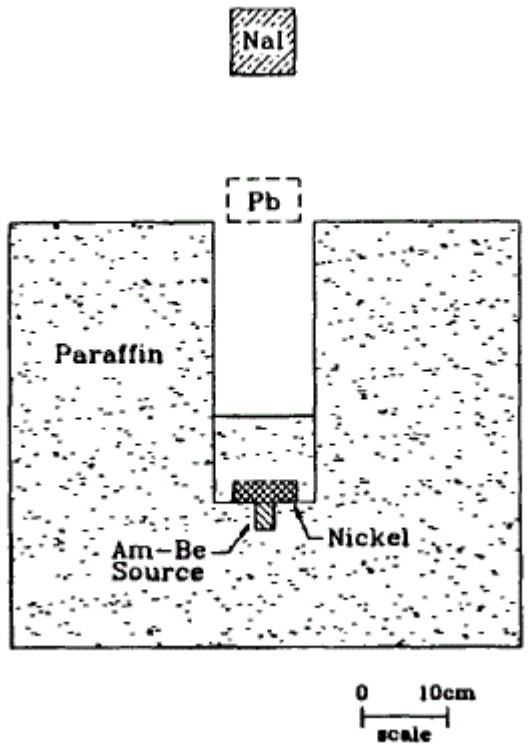


Table 1 - Thermal (n,γ) Rates from natural Ni taken from ref. [3]

Gamma Energy (MeV)	Rate (photons/100 captures)
8.997	26
8.532	11
8.119	2.5
7.817	6
7.528	4
7.22	0.4
7.05	0.6
6.839	9
6.58	2
6.34	1
6.10	1.3
5.99	0.4
5.82	3
5.70	0.6
5.31	1.3

[3] E. Troubetzkoy and H. Goldstein, "A compilation of information on gamma ray spectra resulting from thermal neutron capture", USAEC Report, ORNL-2904 Oak Ridge National Laboratory, 1960.

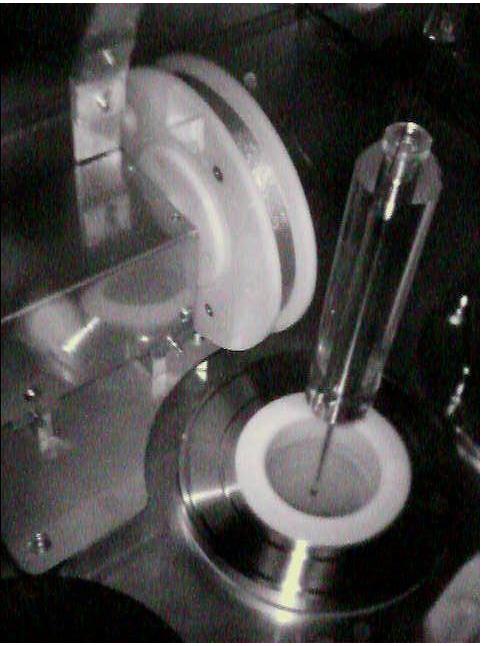
Using Cf-252 (or even better AmLi) would significantly reduce size of source, such that it would fit a 20 cm diameter feedthru

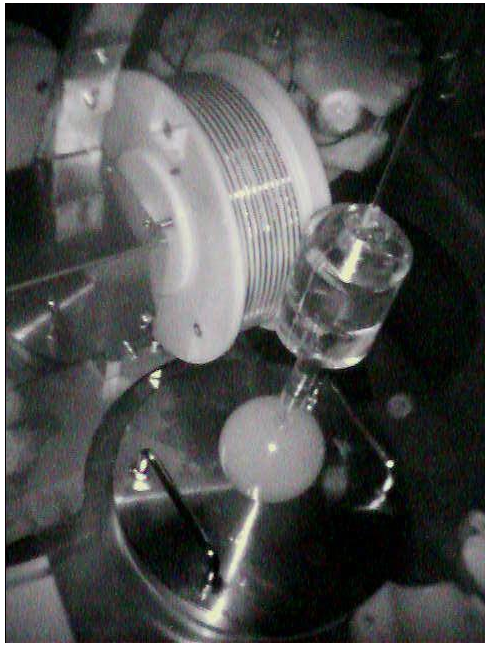
Double Chooz Calibration Deployment System inside Glove Box:

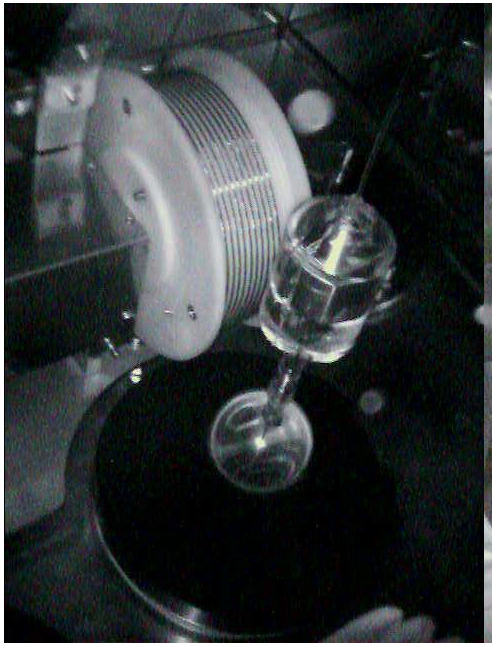
Automated fishline system for target deployments:

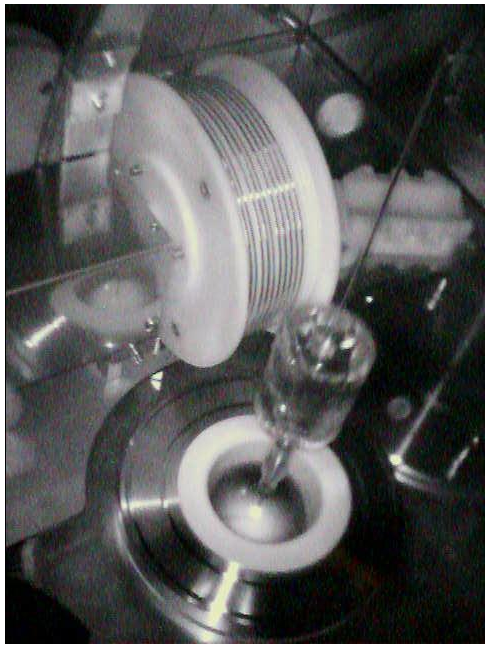
+/-2 mm precision over 7 m

radioactive source **Blue Laser** **UV Laser** **UV Laser w/ hat**

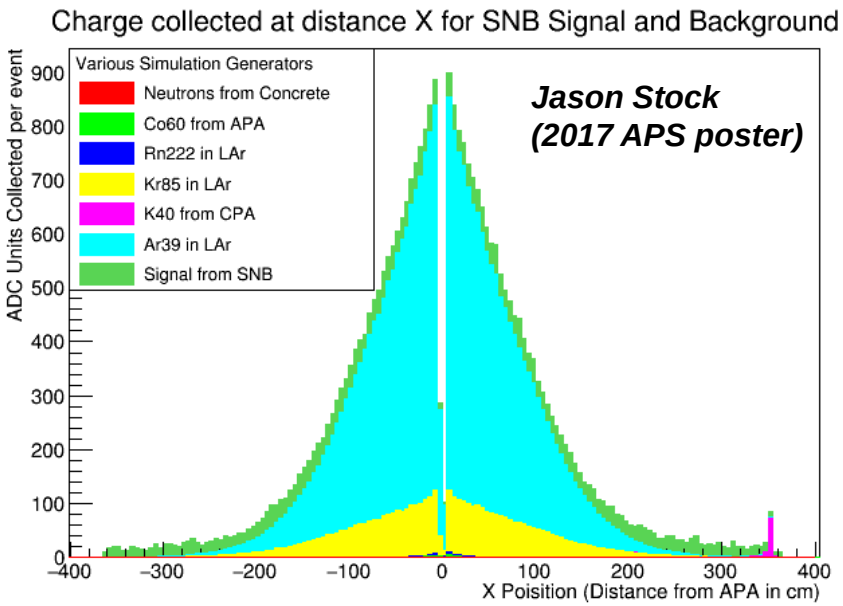


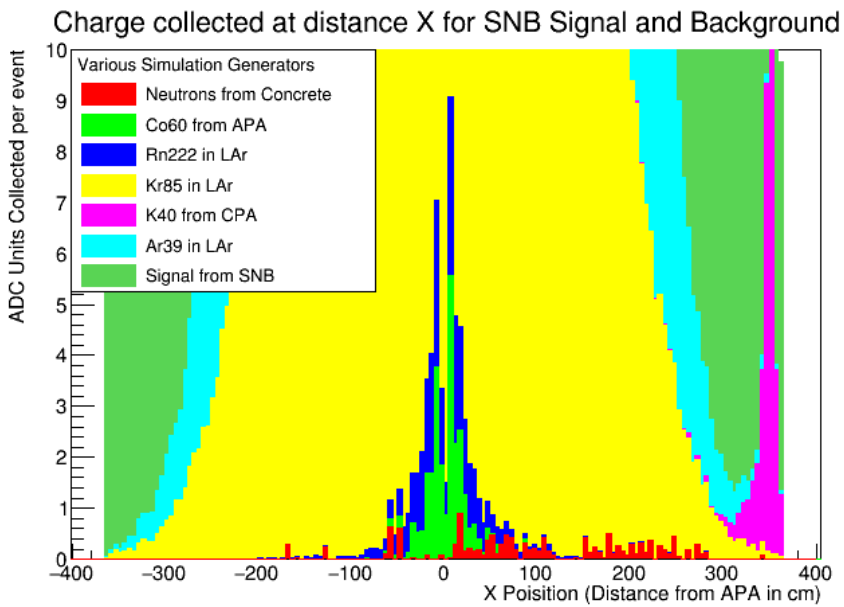






4.) Internal fixed radioactive sources

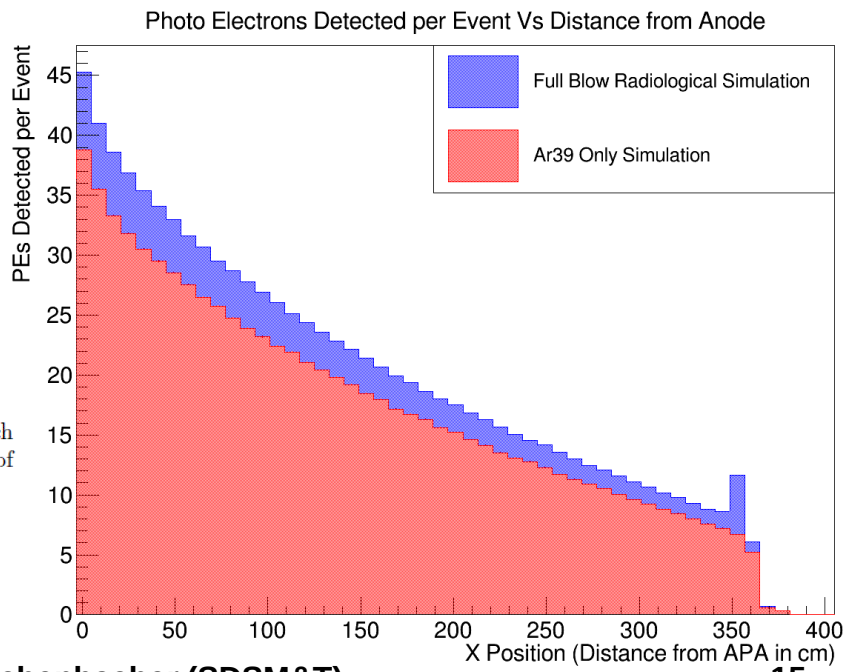




-> Spike local points on cathode and field cage (electroplating isotopes dissolved in nitric acid and final seal with thin Teflon layer)

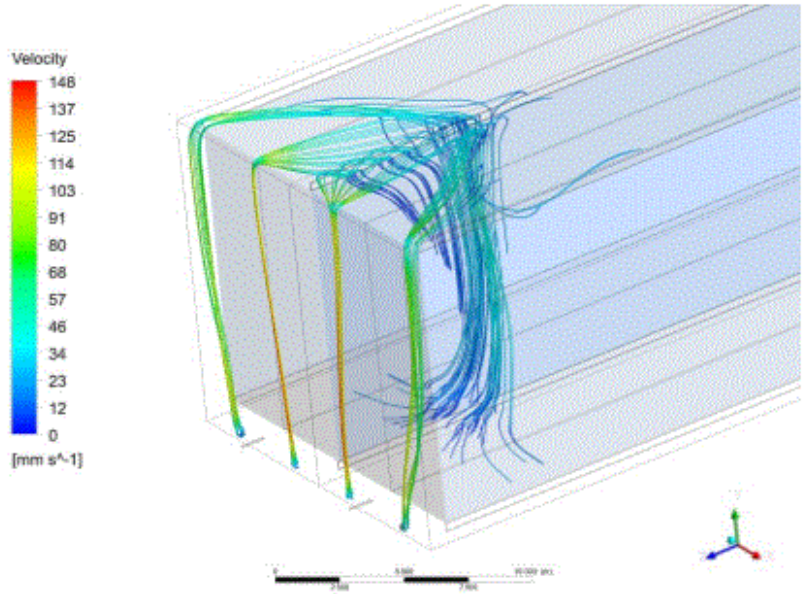
Use Thoron (-> Tl-208) or beta sources

β-sources with relatively high end point energies, such as for example ^{144}Ce (halflife of 284 d, daughter ^{144}Pr with $\beta- < 2.99$ MeV) or ^{106}Ru (halflife of 368 d, daughter ^{106}Rh with $\beta- < 3.54$ MeV).



5) Injected short-lived radioactive sources: Detector Uniformity

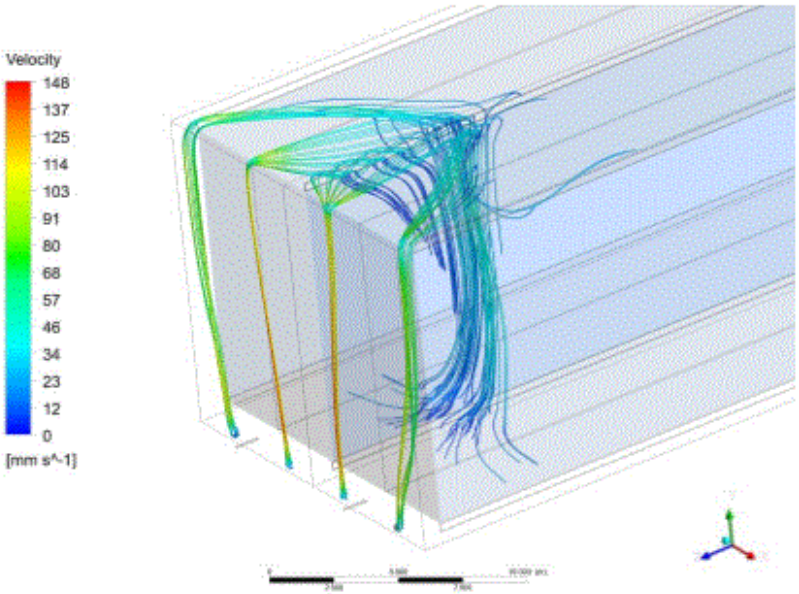
DUNE/LBNF far detector single-phase
Distribute flow to 4 locations
(one injection pump at one end + manifold

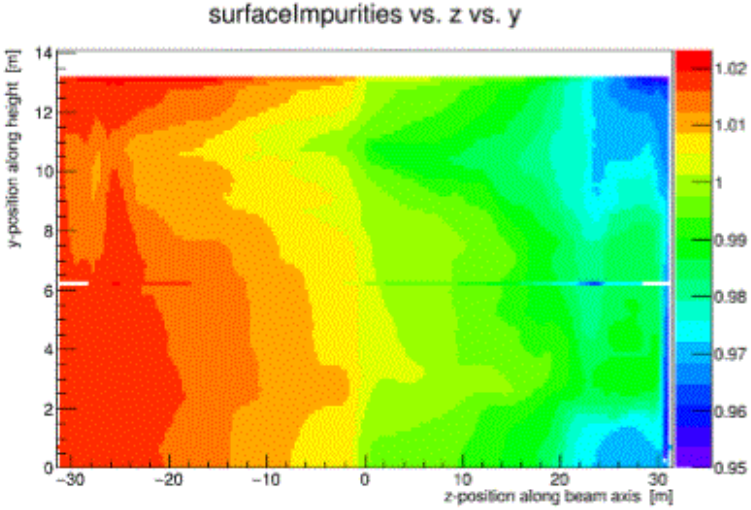


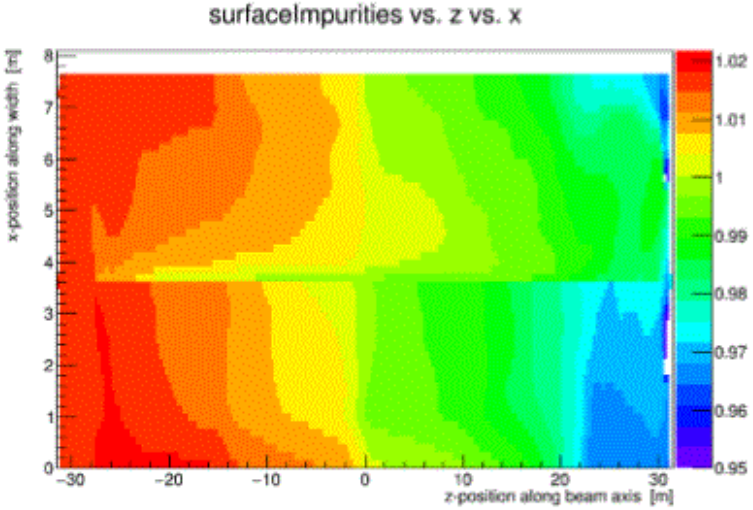
⇒ **ensure uniform detector response: purity and electron lifetime (employ purity monitors)**

⇒ **impact of complicated flow pattern checked with fluid dynamic simulation (employ RTDs)**

DUNE/LBNF far detector single-phase V3 simulation by Erik Voirin (FNAL): Distribute flow to 4 locations (one injection pump at one end + manifold, suction at opposite module end)

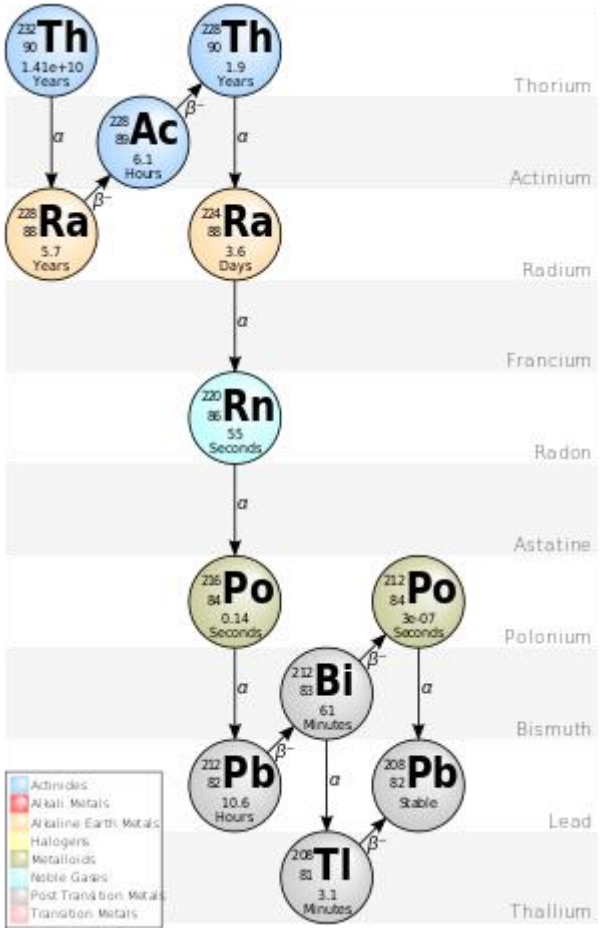






Extracted from E. Voirin's fluid flow simulation
is normalized relative surface impurities level
z vs x TProfile and z vs y TProfile
that are input for LArSoft MC reweighting
to study impact on uniformity of electron-lifetime
throughout default DUNE 10 kt module
(*J. Reichenbacher and J. Stock*)

5.) Injected short-lived radioactive sources



Tl-208 gamma of 2.615 MeV
and beta with endpoint energy of up to 1.8 MeV