MIT LAr Studies in Bo & Tall Bo

M. Toups, MIT

10/29/14

Outline

- MIT LAr studies program and Bo
- Completed Studies
- Next Years
- Conclusion

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MIT LAr Studies Program

- We have performed both experiment-specific and generic R&D with the Bo high purity test stand over the past 2 years
- We are responsible for the light detection system in MicroBooNE
- We first proposed LAr light guide detectors, which are integral to the LBNE reference design

arXiv:1101.3013v1 [physics.ins-det]

Why Bo at the PAB is important

- Bo reliably delivers high purity argon as will be seen in LAr-based particle physics detectors
- Bo is a stable (closed) system, which allows the injection of contaminants and dopants for study
- Bo (Tall Bo) is the right size to study light detection with 8" PMTs and O(1 m) light guides
- Expertise of scientists, engineers, and technicians at PAB allow us to constantly extend Bo's capabilities to meet the needs of ongoing R&D efforts

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- MIT LAr studies program and Bo
- Completed Studies
  - µBooNE R&D
  - Nitrogen Contamination in LAr
  - Argon/Methane Mixtures
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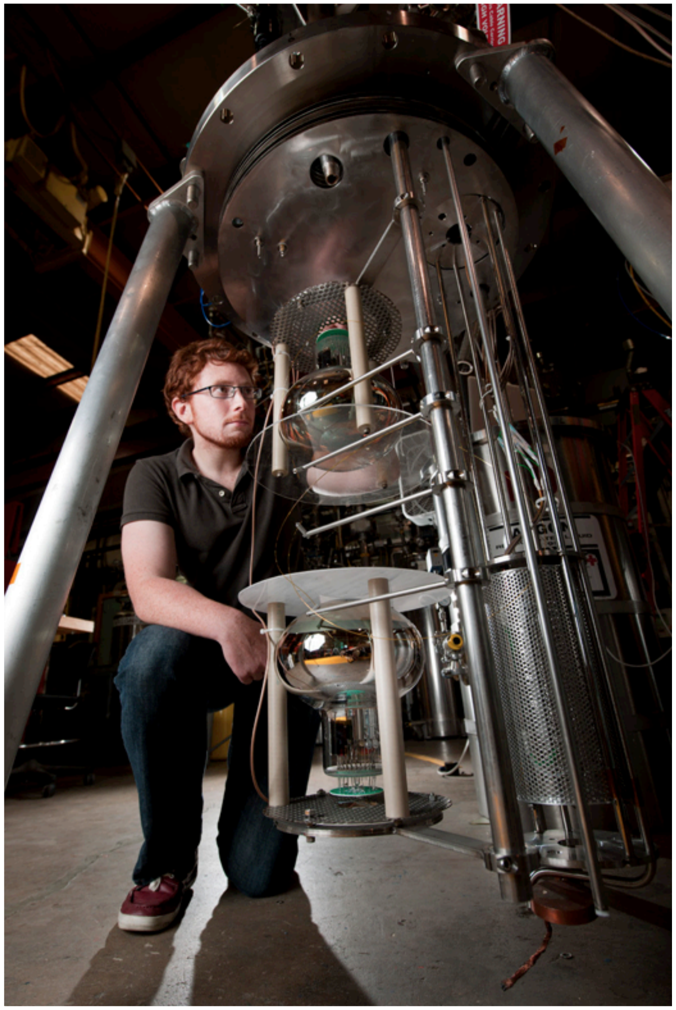
μBooNE R&D

PMT Vertical Slice Test

Bo was used to develop a full vertical slice of the µBooNE optical system, including:

- 8” PMT, base, mount, and wavelength shifting plate
- PMT cables and feed through
- PMT splitter
- High voltage + interlocks
- Readout electronics

This was an incredibly valuable resource for the development of a new LAr optical system and led to tweaks in the design of almost every item on the above list



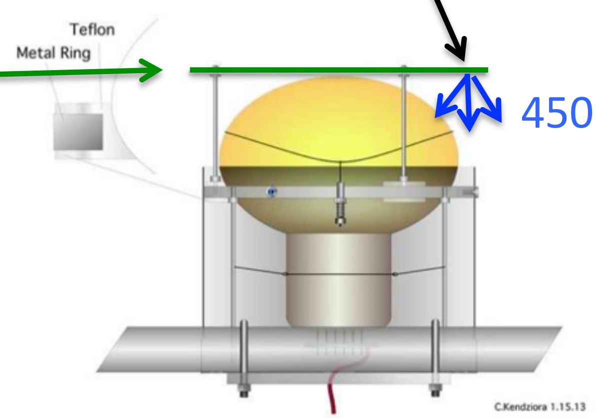
Quantum Efficiency Studies

^{210}Po source serves as standard candle (5.3 MeV alpha)

128 nm light

TPB-coated acrylic plate

450 nm light



Light yield incident on TPB plate predicted from known LAr light yield, alpha energy, and solid angle subtended by plate

Measured photo electrons then gives global efficiency (photoelectrons/incident photon) for input to MC

→ Can use this technique for other optical detectors as well

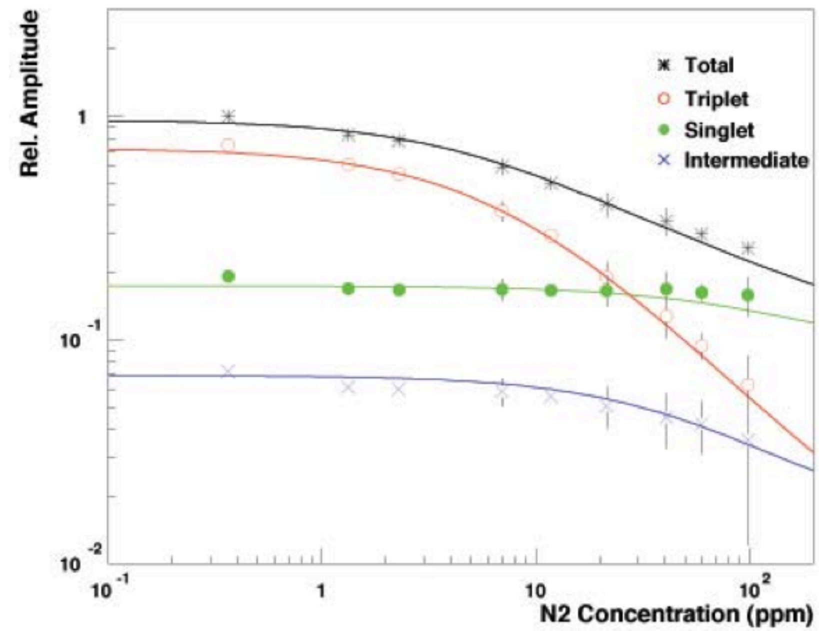
Nitrogen Contamination in LAr

Two distinct effects on light collection

- LAr scintillation light production may be quenched by impurities

- LAr scintillation light en route to a photo-detector may be absorbed by impurities in the bulk material

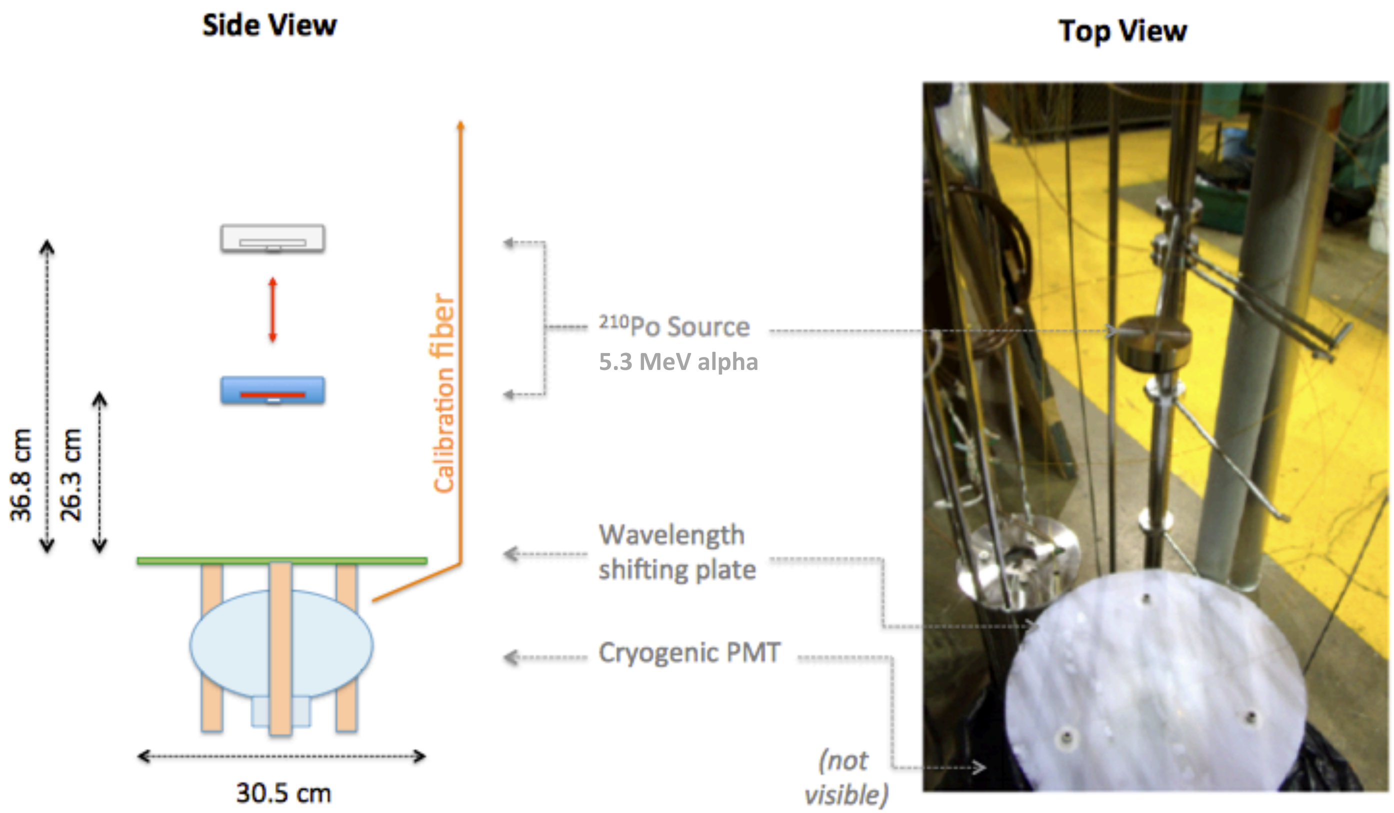
  → No measurements of this existed!



Argon Specification	Concentration of N_2
Measured N_2 concentration of clean argon for this study	37 ppb
AirGas research (grade 6) argon [25]	1 ppm
MicroBooNE cryogenic specification	2 ppm
Start of liquid recirculation phase of Liquid Argon Purity Demonstrator, Run 2 [26,27]	8 ppm
AirGas industrial (grade 4) argon [25]	100 ppm

R Acciarri *et al* 2010 *JINST* **5** P06003

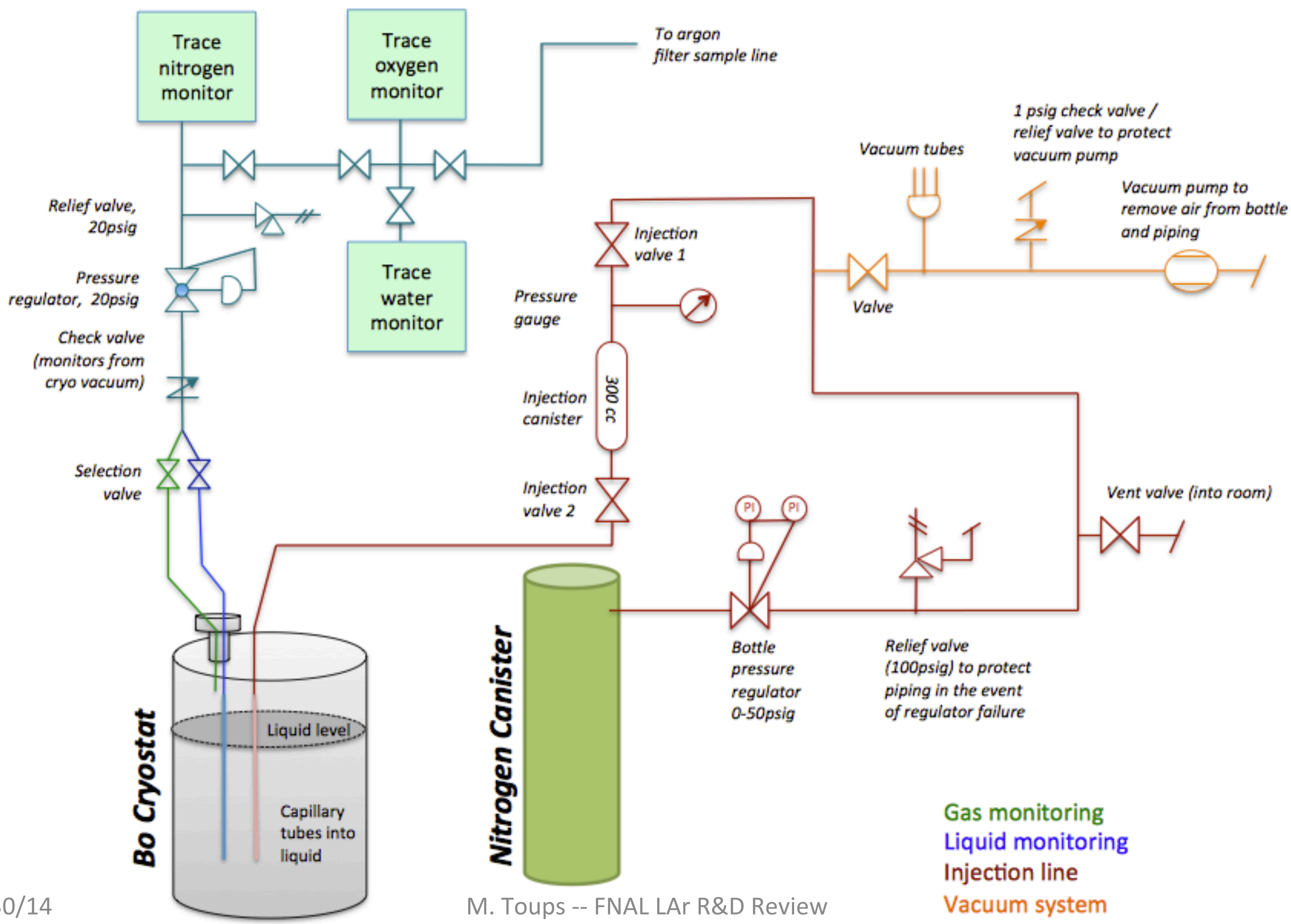
The Experiment Setup



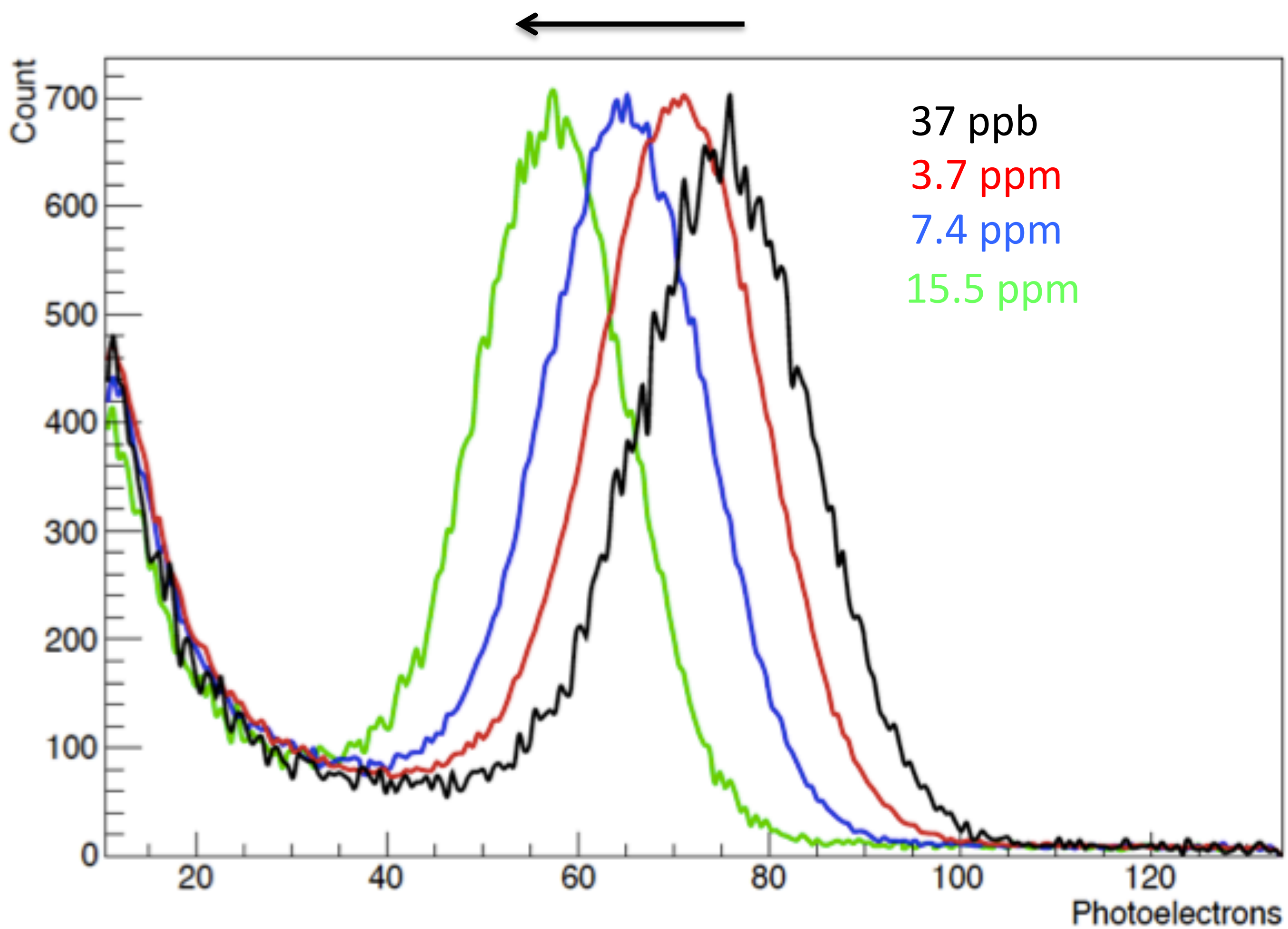
Inject controlled quantities of Nitrogen in Bo and look for:

- Differences in the relative amount of light seen from a mono-energetic alpha source as a function of Nitrogen concentration for 2 source-detector distances

Infrastructure Built at PAB for this Study

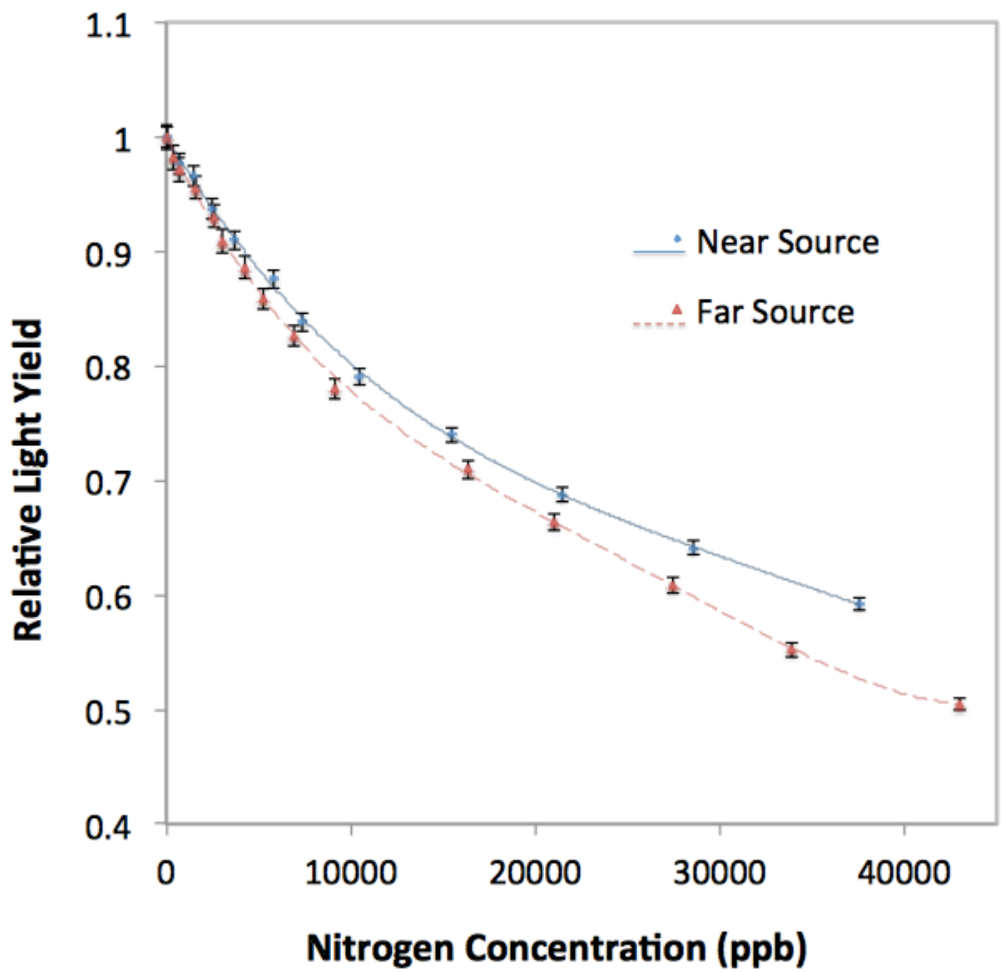


Peak of pulse area distributions decreases as a function of nitrogen concentration



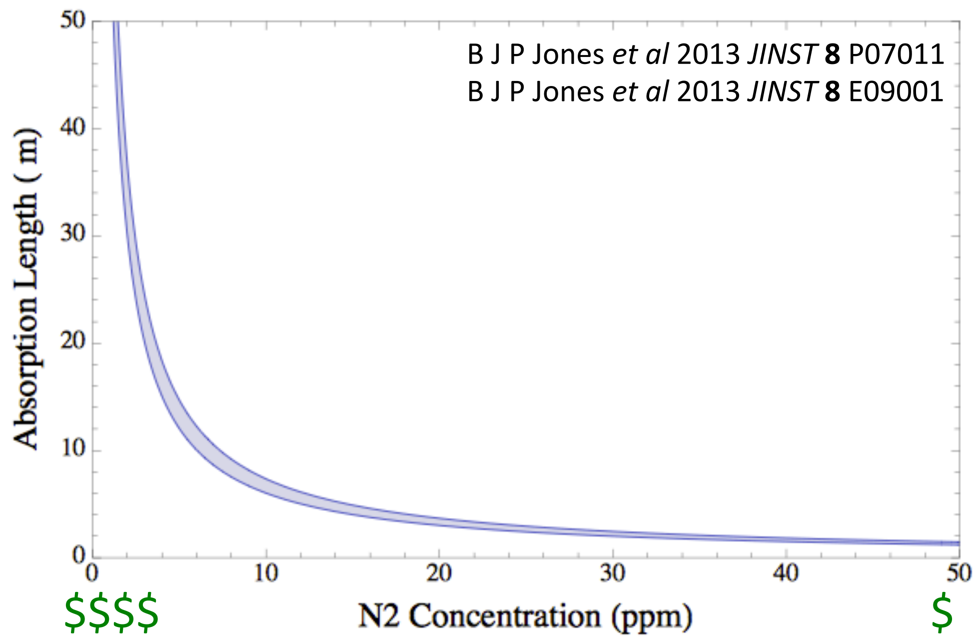
For a given nitrogen concentration, quenching has the same effect on both source configurations

The fact that the two curves diverge tells us there is a distance-dependent light loss mechanism at play



Relatively loose purity specifications of ppm-level nitrogen contamination required by current- and next-generation LAr particle physics experiments

Argon Specification	Concentration of N_2	Absorption Length
Measured N_2 concentration of clean argon for this study	37 ppb	1790 ± 160 m
AirGas research (grade 6) argon [25]	1 ppm	66 ± 6 m
MicroBooNE cryogenic specification	2 ppm	30 ± 3 m



Argon/Methane Mixtures

Why Study Light Production in CH_4-doped LAr?

- Long electron drift distances demonstrated for CH_4 concentrations of several %
- Introduces inverse-beta-decay interaction channel ($\bar{\nu}_e + p \rightarrow e^+ + n$)
  - Potentially broadens low-energy neutrino physics program of LArTPCs
- Some evidence in the literature that CH_4 may act as a wavelength-shifter
- May provide an important input for LAr-based dark matter detectors that produce Ar from underground CO_2 wells and rely on light collection

ELSEVIER

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 253, Issue 2, 1 January 1987, Pages 273–277

Drifting electrons over large distances in liquid argon-methane mixtures

E. Aprile*, K.L. Giboni**, C. Rubbia

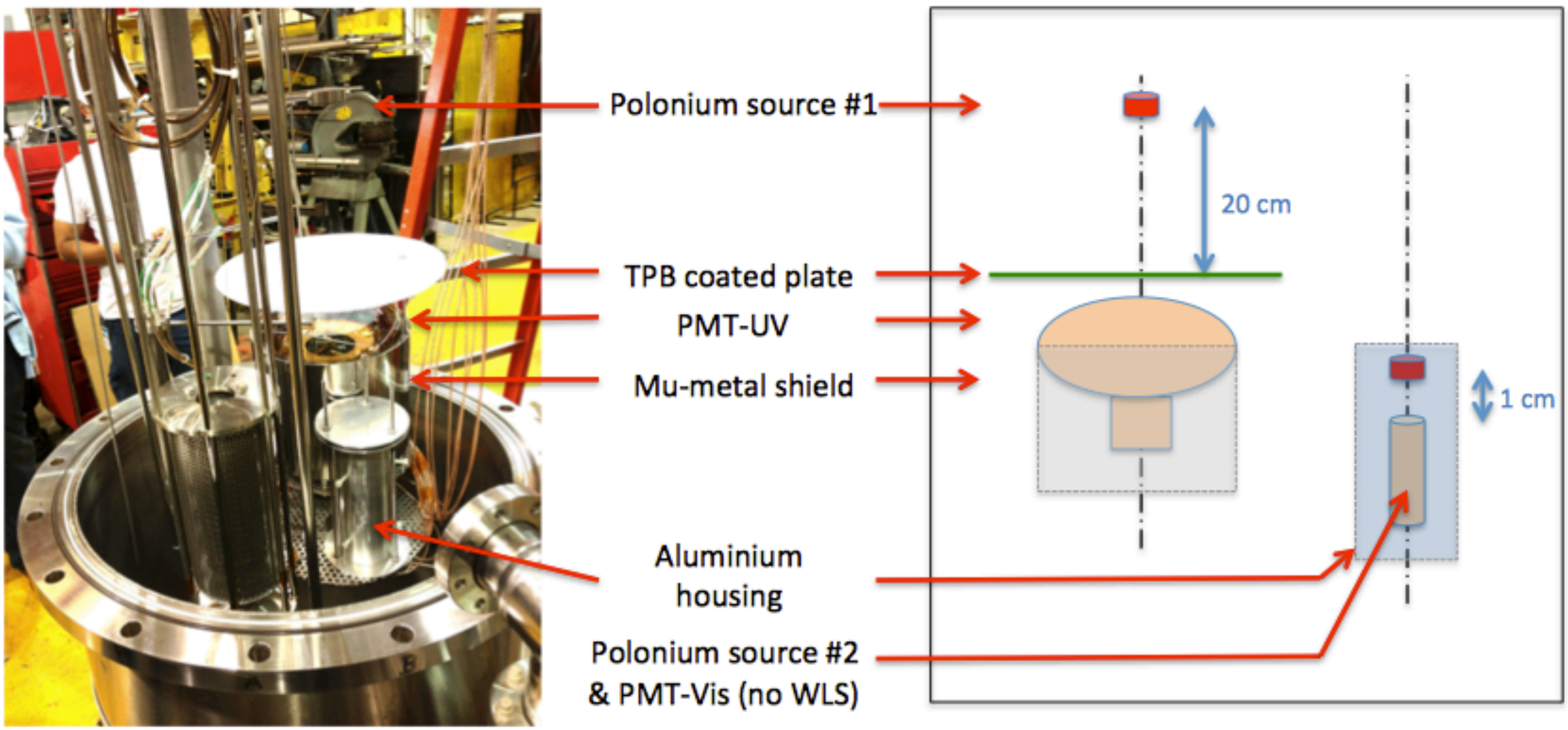
Table 2: Gas concentrations from the Kinder Morgan Doe Canyon CO_2 wells.

Gas Type	Well Concentration
Carbon Dioxide	96%
Nitrogen	2.4%
Methane	5,700 ppm
Helium	4,300 ppm
Other hydrocarbons	2,100 ppm
Water	1,000 ppm
Argon	600 ppm
Oxygen	Below sensitivity

arXiv:1204.6024v2 [astro-ph.IM]

The Experiment Setup

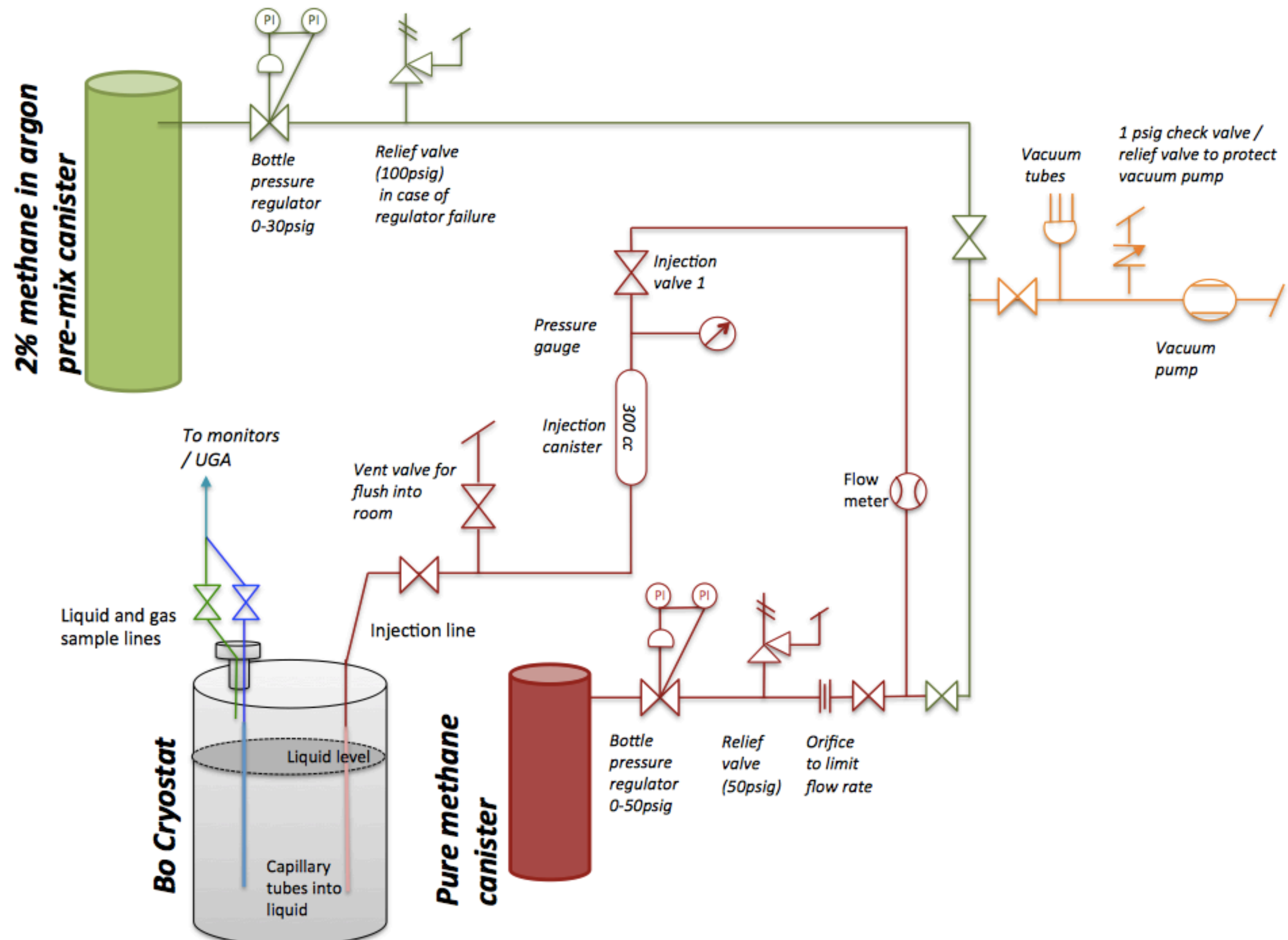
Photograph *Sketch*

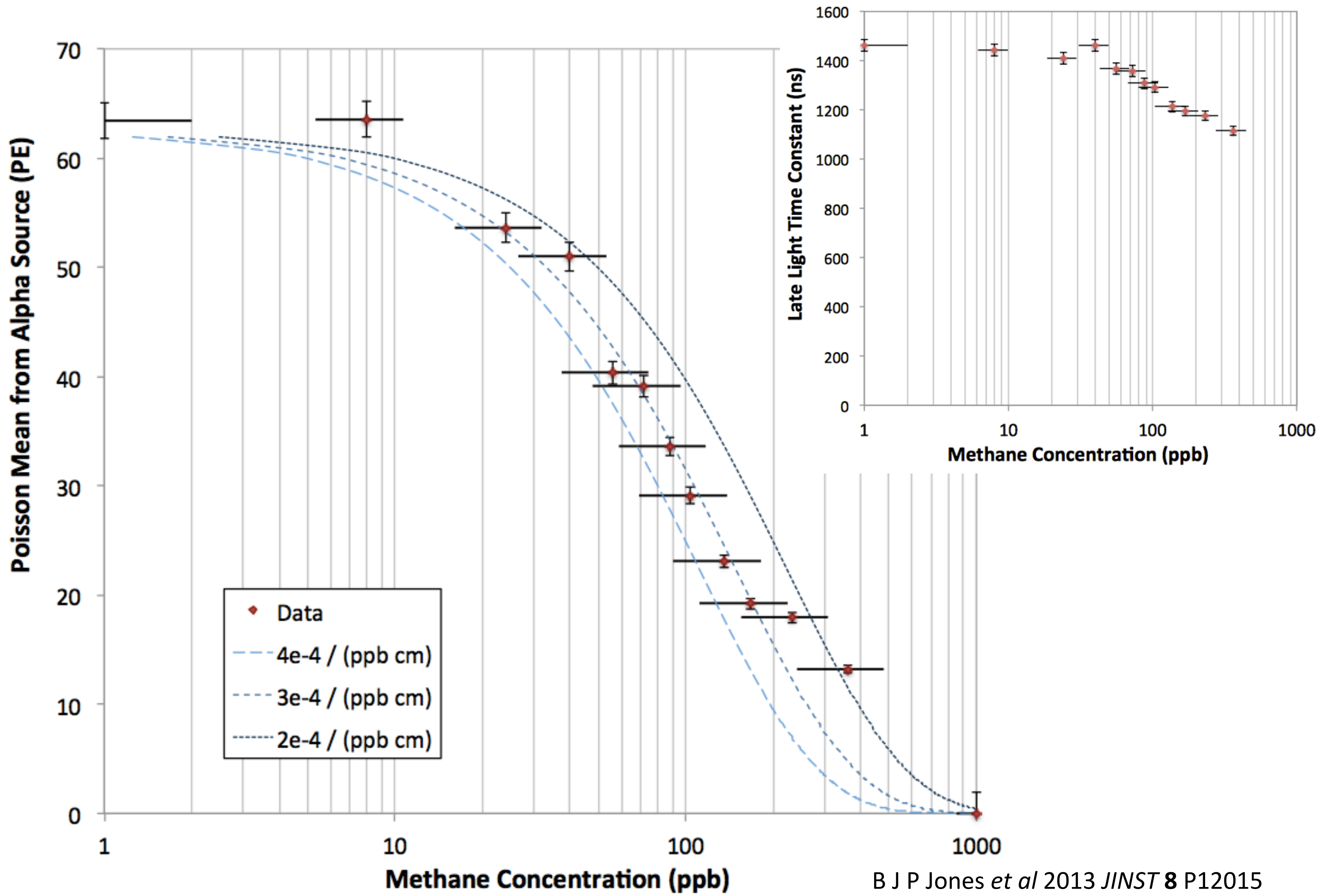


Inject controlled quantities of CH_4 in Bo and look for:

1. Quenching and/or absorption of LAr scintillation light
2. LAr scintillation light wavelength-shifted to visible light

Leveraging Infrastructure





B J P Jones *et al* 2013 *JINST* **8** P12015

- For detectors larger than O(1 cm), CH_4 concentration should be < O(100) ppb to limit absorption losses to less than a few percent
- Quenching is also at observed, but is subdominant
- No significant amount of LAr scintillation light is wavelength-shifted to visible

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- MIT LAr studies program and Bo
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- Next Years
  - Argon/Xenon Mixtures
  - ^{222}Rn Tracing in Lar
  - Rayleigh Scattering
  - Light Guide Attenuation Length Studies
- Conclusion

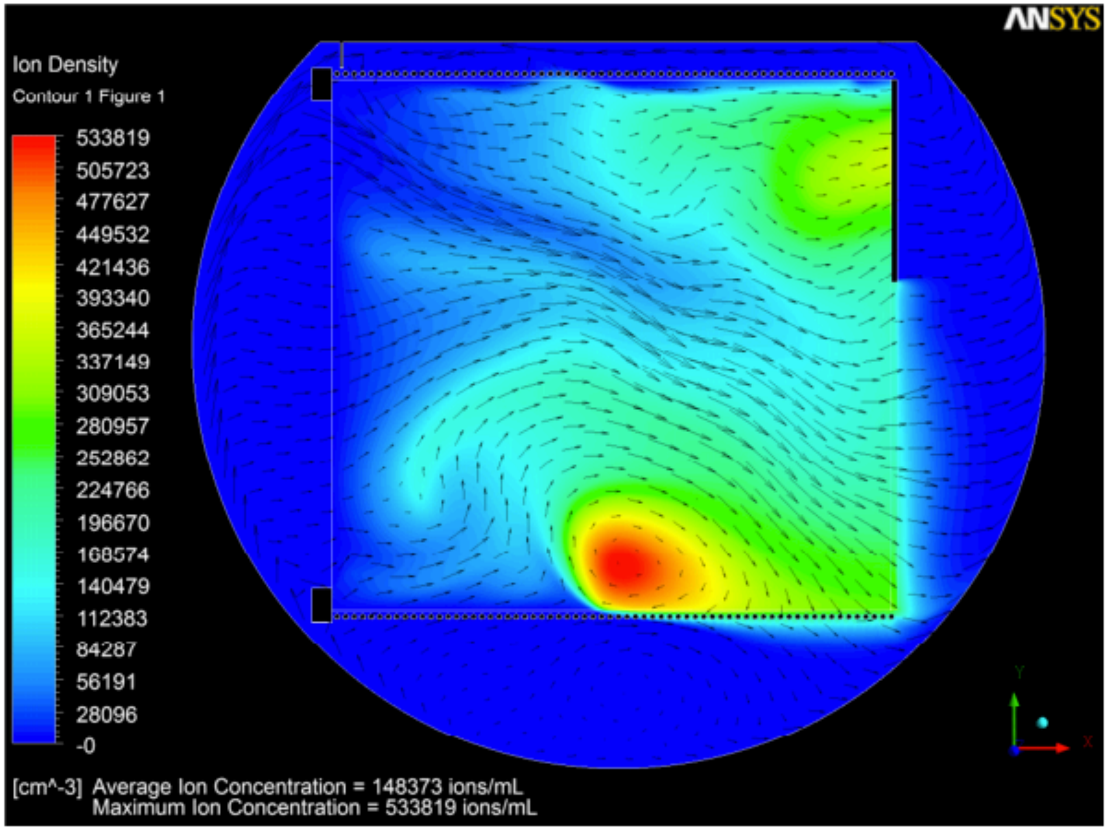
Argon/Xenon Mixtures

Adding O(10 -100 ppm) Xe to LAr

- Shifts light to earlier times
  - Roughly 3/4 of the LAr scintillation light produced by a MIP is in the slow component with $\tau = 1.6\ \mu s$
  - Doping with Xe shifts the time scale of this slow component from O(1 μs) → O(10 ns)
    - Easier to collect in a neutrino LArTPC
- Wavelength-shifts light to 175 nm
  - At concentrations of O(100 ppm) LAr scintillation (late) light is converted to 175 nm
    - More efficient detection
- We have already made one attempt to inject Xe in Bo, and we would like to pursue this further

^{222}Rn Tracing in LAr

Mapping LAr Flows

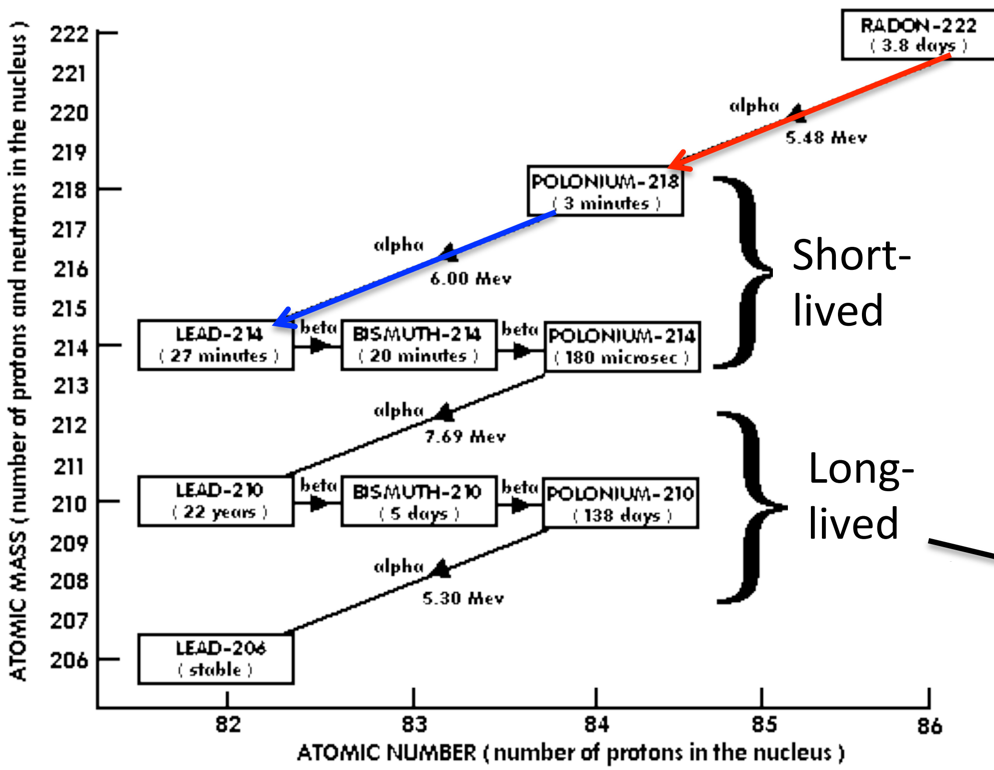


E. Voirin, for μBooNE

Ion concentration for velocity field (fluid velocity + drift velocity of 8 mm/sec)

^{222}Rn Tracing

- A new technique to map flows in a neutrino LArTPCs
- Inject ^{222}Rn into detector and look for correlated ^{222}Rn-^{218}Po decays
  - Reconstruct positions to measure flow



^{222}Rn→^{218}Po
5.48MeV alpha
3.8 days

^{218}Po→^{214}Pb
6MeV alpha
3 minutes

These will remain in your detector, but accelerator-based neutrino experiments only require negligible background in beam window

We would like to test this idea in Bo

- New infrastructure is required
  - Field cage (for drift)
  - Array of SiPMs (for position reconstruction)
  - Radon injection system

- We have already located enough Ra at FNAL to generate enough ^{222}Rn for this test!

Rayleigh Scattering

In Large ν LArTPCs Rayleigh Scattering is Important

Predicted to be 90 cm ± 35%, which is in *rough* agreement with the data

Table 3
Rayleigh scattering length for liquefied rare gases

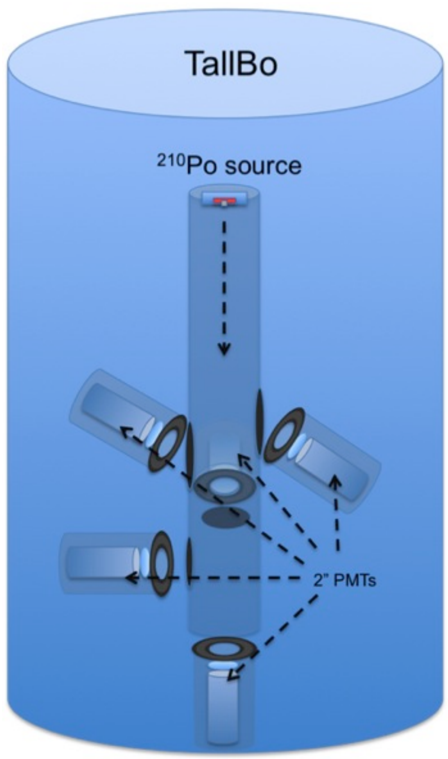
Liquid	Scintillation wavelength (nm)	Dielectric constant	Scattering length calculated (cm)	Scattering length measured (cm)
He at 4.2 K	78	1.077[a]	600	
He at 0.1 K	78	1.089[a]	2×10^4	
Neon	80	1.52[b]	60	
Argon	128	1.90[b]	90	66[d]
Krypton	147	2.27[c]	60	82[d], 100[e]
Xenon	174	2.85[c]	30	29[d], 40[f], 50[g]

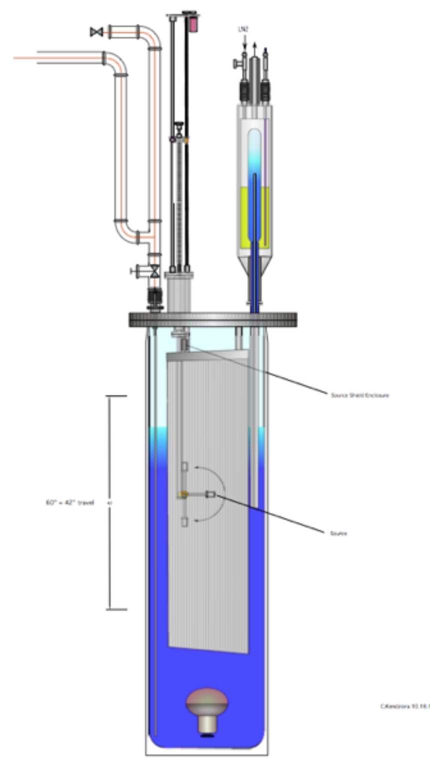
G. Seidel, et. al. NIM A489 (2002) 189-194

N. Ishida, et. al. NIM A384 (1997) 380-386.

Measuring Scattering Lengths in LAr

- We would like to study scattering lengths and angular distributions under known purity conditions in Bo
- We need a lift system to remotely articulate sources inside Bo
  - This a general-purpose tool useful for many future LAr studies
  - Design by C. Kenziora based off of system used in Luke





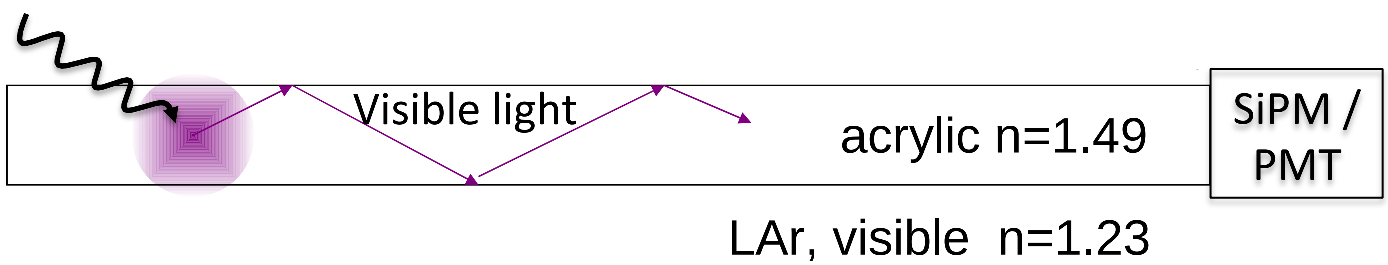
We submitted an NSF grant proposal to study this in Bo

Light Guide Attenuation Length Studies

In large neutrino LArTPCs thin profile photo-detectors are desirable to maximize TPC active regions

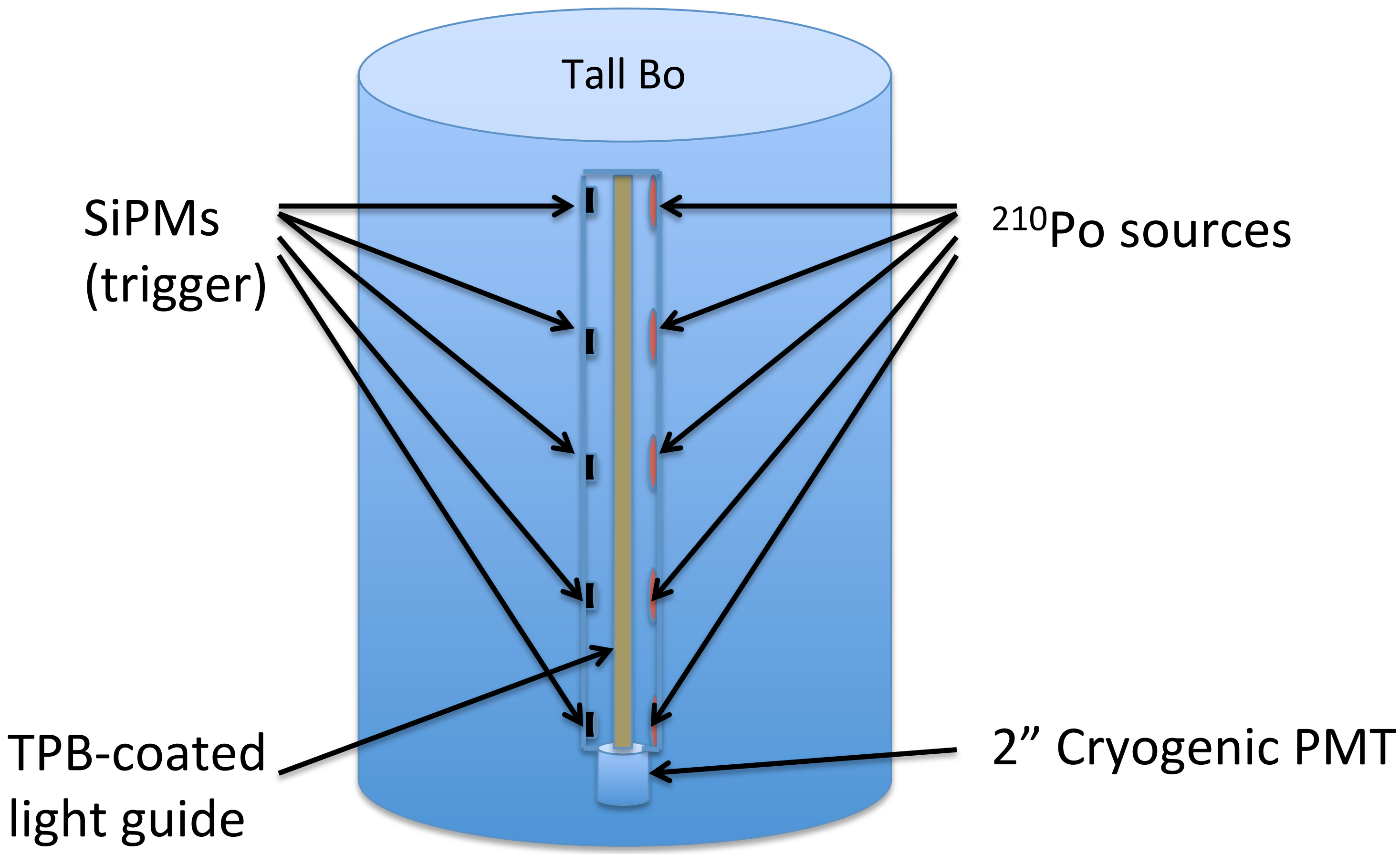
LAr scintillation light is collected by light guides coated with wavelength-shifter coupled to photo-detectors

LAr 128 nm scintillation light



Attenuation Length Measurement

- We would like to measure this with known purity conditions in Bo
  - Lift system would provide the best measurement capabilities
- Can also study the effects of cryo-cycling on light guides



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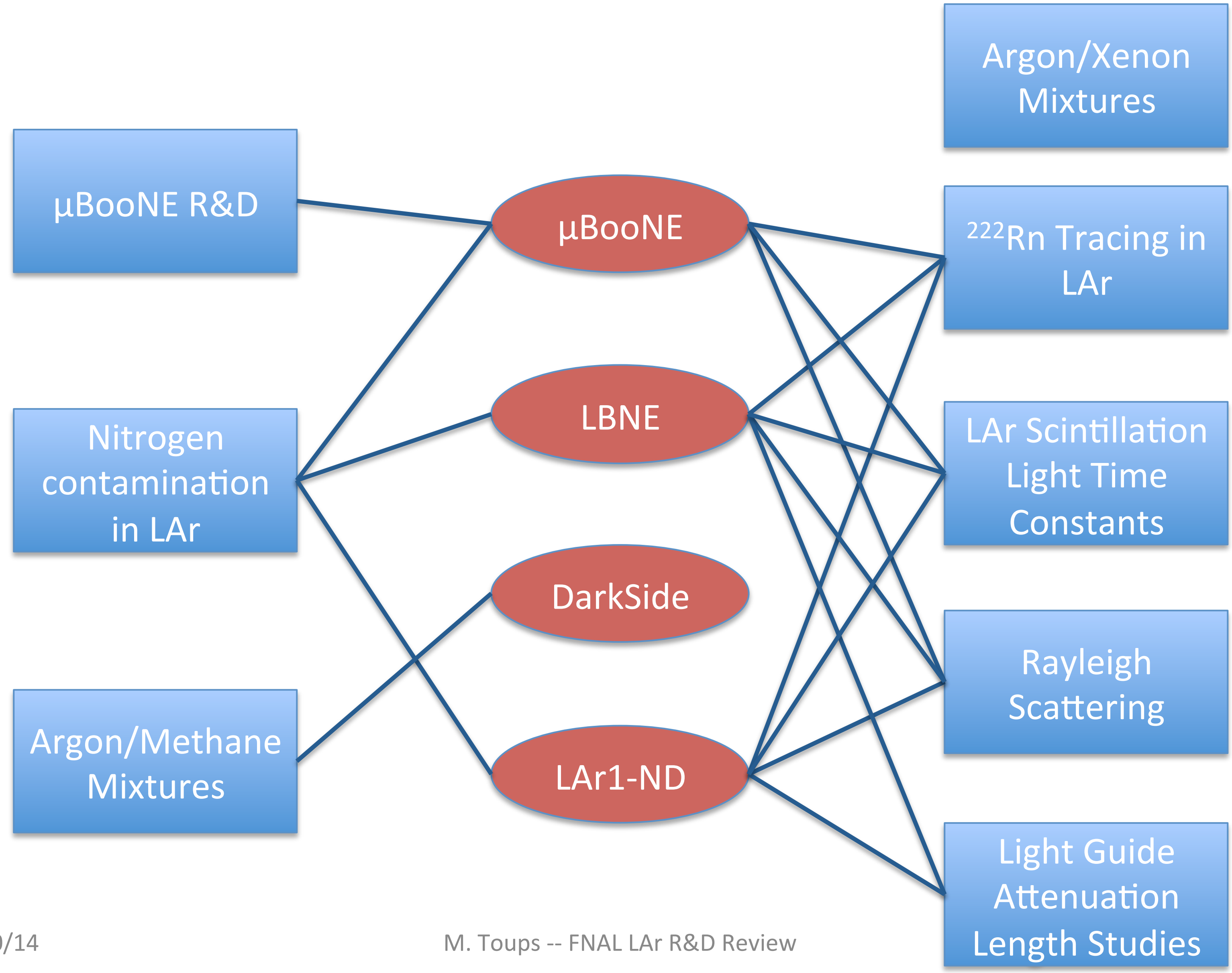
Summary of Our Program



Papers that would not have been written,
if we had not had access to the test stands at PAB to do R&D:

Published Papers

[1] B. J. P. Jones, T. Alexander, H. O. Back, G. Collin, J. M. Conrad, A. Greene, T. Katori, S. Pordes, and M. Toups, "The Effects of Dissolved Methane upon Liquid Argon Scintillation Light," JINST **8** (2013) P12015.

[2] B. J. P. Jones, C. S. Chiu, J. M. Conrad, C. M. Ignarra, T. Katori, and M. Toups, "A Measurement of the Absorption of Liquid Argon Scintillation Light by Dissolved Nitrogen at the Part-Per-Million Level," 2013 *JINST* **8** P07011

[3] T. Briese, L. Bugel, J. M. Conrad, M. Fournier, C. Ignarra, B. J. P. Jones, T. Katori, R. Navarrete-Perez, P. Nienaber, T. McDonald, B. Musolf, A. Prakash, E. Shockley, T. Smidt, K. Swanson, and M. Toups, "Testing of Cryogenic Photomultiplier Tubes for the MicroBooNE Experiment," 2013 *JINST* **8** T07005

Whitepaper for LIDINE

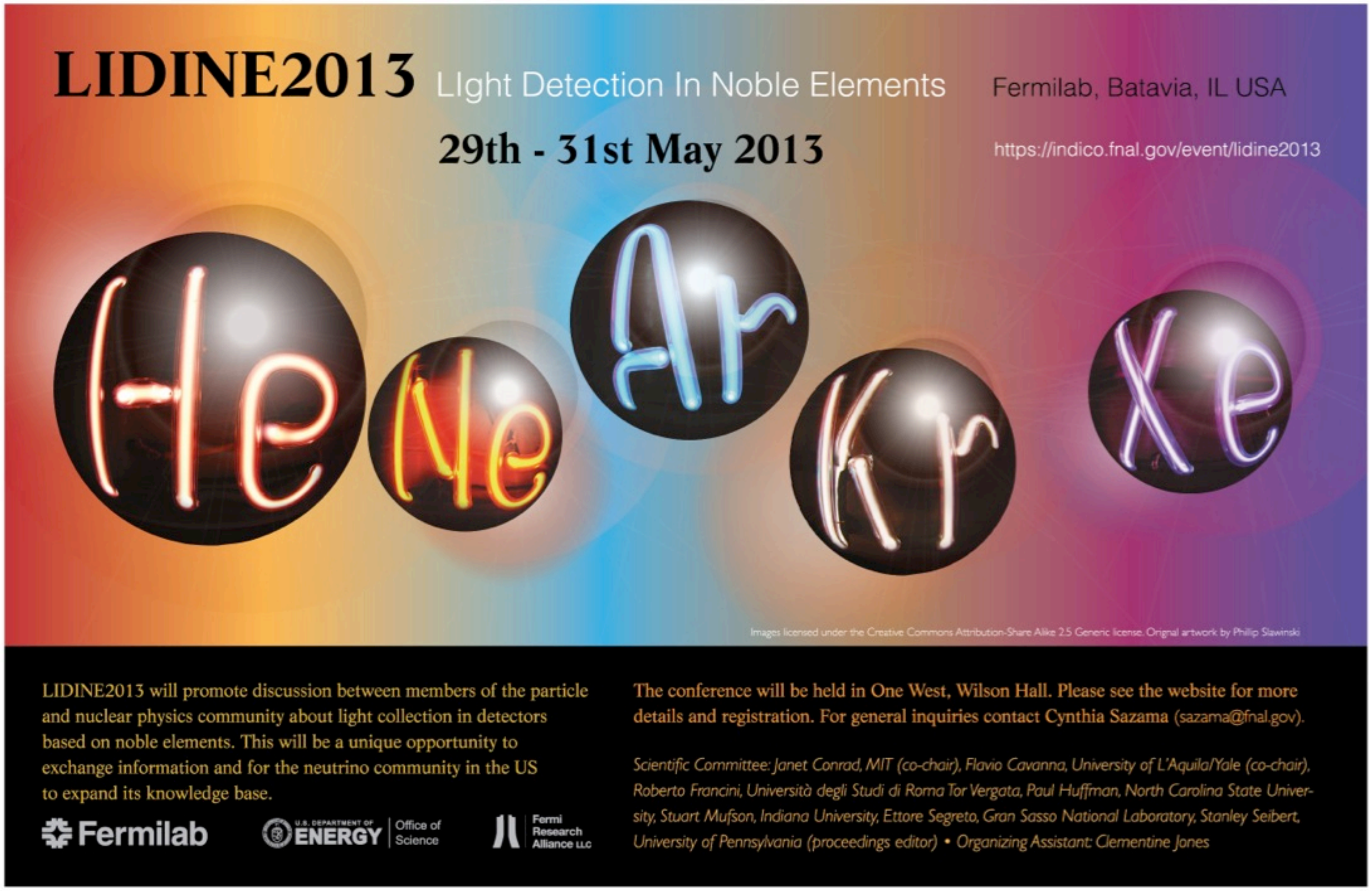
[4] B. Baptista, L. Bugel, C. Chiu, J. M. Conrad, C. M. Ignarra, B. J. P. Jones, T. Katori and S. Mufson, "Benchmarking TPB-coated Light Guides for Liquid Argon TPC Light Detection Systems," arXiv:1210.3793 [physics.ins-det].

LIDINE Proceedings (Peer Reviewed)

[5] C. M. Ignarra, "TPB-coated Light Guides for Liquid Argon TPC Light Detection Systems," JINST **8**, C10005 (2013) [arXiv:1307.8036].

[6] B. J. P. Jones, "Results from the Bo Liquid Argon Scintillation Test Stand at Fermilab," JINST **8**, C09003 (2013).

[7] B. J. P. Jones, "A simulation of the optical attenuation of TPB coated light-guidedetectors," JINST **8**, C10015 (2013) [arXiv:1307.6906].



This was a very successful conference on light collection in noble elements,
held here at Fermilab, that featured work from PAB,
and included a tour of PAB

This facility is important to the community

Final Thoughts

- The Bo high purity LAr test stand has been an invaluable resource for us
- Bo played a crucial role in the development and shake-down of the μBooNE PMT system
- We are generating important physics results, which are relevant for both future ν LArTPC experiments and dark matter experiments
- The resources at PAB are instrumental to the present and future success of the LAr community.