BO VST AND THE PURIFICATION OF UNDERGROUND ARGON FOR DARK MATTER EXPERIMENTS

Ben Jones, MIT

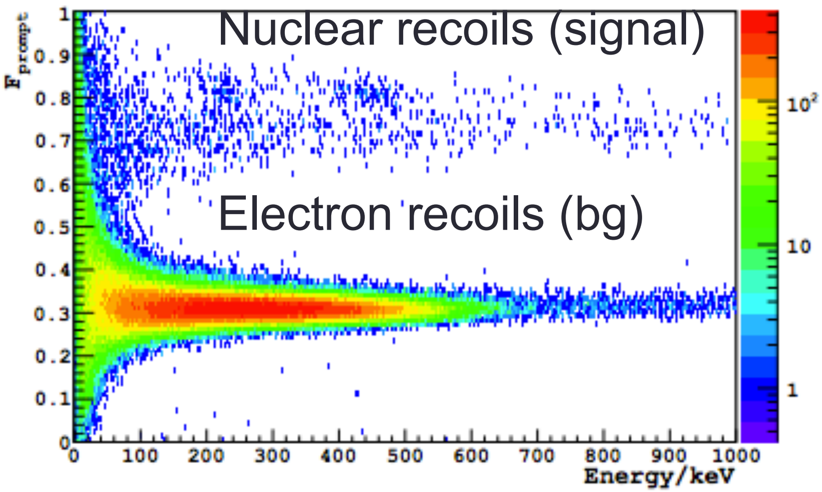
Why on earth does this topic have anything to do with MicroBooNE R&D group??

- Adding methane to liquid argon could lower the threshold for neutrino interactions in a LArTPC
- This would increase sensitivity to solar, supernova and decay-at-rest neutrinos
- And also perhaps open up coincidence IBD tagging as a possibility for LArTPCs
- We may have been able to do it as a future MicroBooNE upgrade
- Studies have been done on charge drift in these mixtures. We set out to investigate what happens to light.
- Our idea didn't work (more later)
- **But we found that our results were very interesting indeed to dark matter folks!**

MICROBOONE

A Very Short Introduction to Argon 39

- Argon 39 is an intrinsic background to argon based dark matter experiments
- Beta emitter with an endpoint of 565 keV, and present in standard argon distilled from air with activity of 1 Bq/kg
- Pulse shape discrimination was invented to suppress backgrounds just like this – the nuclear recoils from dark matter interactions look different to electron recoils from Ar39.
- And it is quite effective. WArP, DEAP, MiniCLEAN all use this technique.
- But ultimately, this background sets the “noise floor” for dark matter experiments, and limits their scale.



Why is there all this radioactive argon everywhere?

- Short answer is cosmic rays.
- Argon 39 is produced from argon 40 by cosmic ray spallation in air.
- When we distill the air for argon, we get argon 39 just as well as argon 40.
- If only someone could find some argon which hadn't seen cosmic rays in >269 years?

arXiv.org > astro-ph > arXiv:0712.0381

Astrophysics

Discovery of underground argon with low level of radioactive 39Ar and possible applications to WIMP dark matter detectors

C. Galbiati, R. Purtschert, et. al

(Submitted on 3 Dec 2007)

arXiv.org > physics > arXiv:1204.6011

Search

Physics > Instrumentation and Detectors

A Study of the Residual 39Ar Content in Argon from Underground Sources

J. Xu, F. Calaprice, C. Galbiati, A. Goretti, G. Guray, T. Hohman, D. Holtz, A. Ianni, M. Laubenstein, B. Loer, C. Love, C.J. Martoff, D. Montanari, S. Mukhopadhyay, A. Nelson, S.D. Rountree, R.B. Vogelaar, A. Wright

(Submitted on 26 Apr 2012)

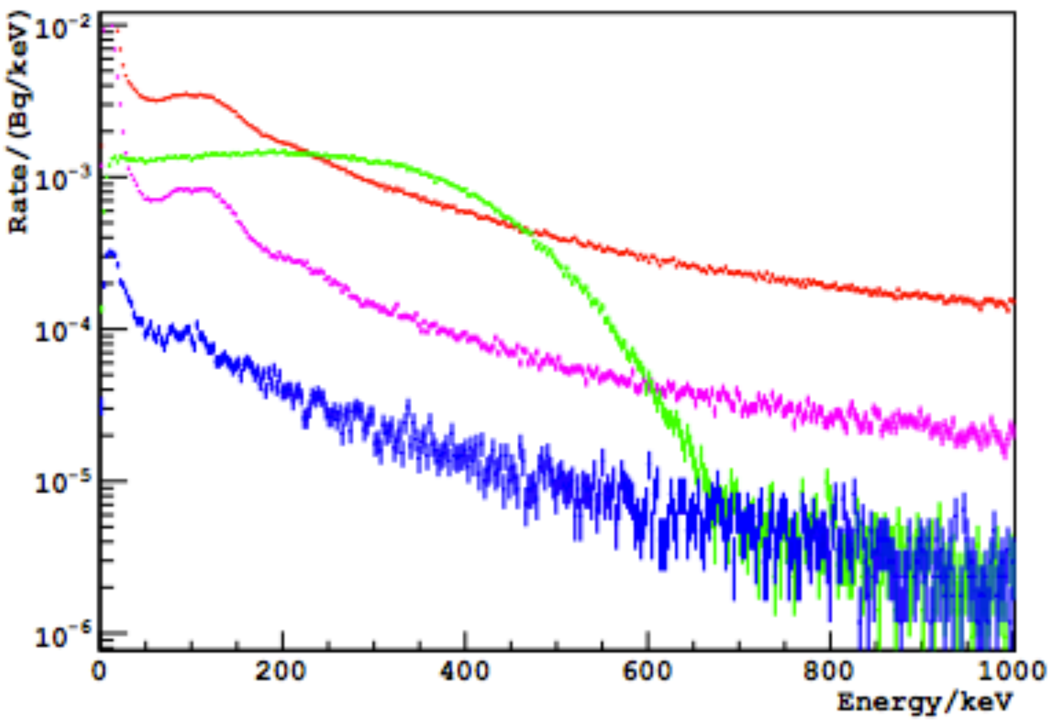


Figure 7: The energy spectra recorded in the argon detector under different conditions. Red: underground argon data at surface; purple: underground argon data at surface with an active cosmic ray veto; blue: underground argon data at KURF; green: atmospheric argon data at KURF.

How do you get it?

- The gas from the carbon dioxide well contains this crap:

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

How do you get it?

- Perform Vacuum Pressure Swing Adsorption and you get this slightly-less-crap:

arXiv.org > astro-ph > arXiv:1204.6024

Astrophysics > Instrumentation and Methods for Astrophysics

First Large Scale Production of Low Radioactivity Argon From Underground Sources

H. O. Back, F. Calaprice, C. Condon, E. de Haas, R. Ford, C. Galbiati, A. Goretti, T. Hohman, An. Inanni, B. Loer, D. Montanari, A. Nelson, A. Pocar

Figure 3: VPSA plant as-build in the Kinder Morgan CO2 facility.

Gas Type	Concentration after VPSA extraction 2010	2011
Carbon Dioxide	~0	~0
Nitrogen	70%	40%
Methane	~0	~0
Helium	27.5%	55%
Other hydrocarbons	~0	~0
Water	~0	~0
Argon	2.5%	5%
Oxygen	~0	~0

How do you get it?

- Then it comes to Fermilab, and it is distilled in a condenser tower
- This it is not a trivial process, at all, and I can’t claim to know all the details.
- But in the end you get this :

- **98% Argon**
- **2% Methane**
- **Very little else**

What about that methane? Do we care about that?

- **Nobody knows!**
- Removing methane is actually quite hard - expensive hot are getters needed, which can't be regenerated and only have a small capacity for methane.
- It has been shown that you can drift electrons just fine in argon / methane mixtures

Drifting Electrons Over Large Distances In Liquid Argon - Methane Mixtures
E. Aprile, K.L. Giboni, C. Rubbia (Harvard U.). 1987.
Published in **Nucl.Instrum.Meth. A253 (1987) 273-277**
DOI: 10.1016/0168-9002(87)90714-5

- But DarkSide, and ~everyone else, needs scintillation light. What about the that?

BoVST To The Rescue!

The Effects of Dissolved Methane upon Liquid Argon Scintillation Light

B.J.P. Jones[a*], T. Alexander[b], H.O. Back[c], G. Collin, [a], J.M. Conrad[a], A. Greene[a], T. Katori[a], S. Pordes[d], M. Toups[a].

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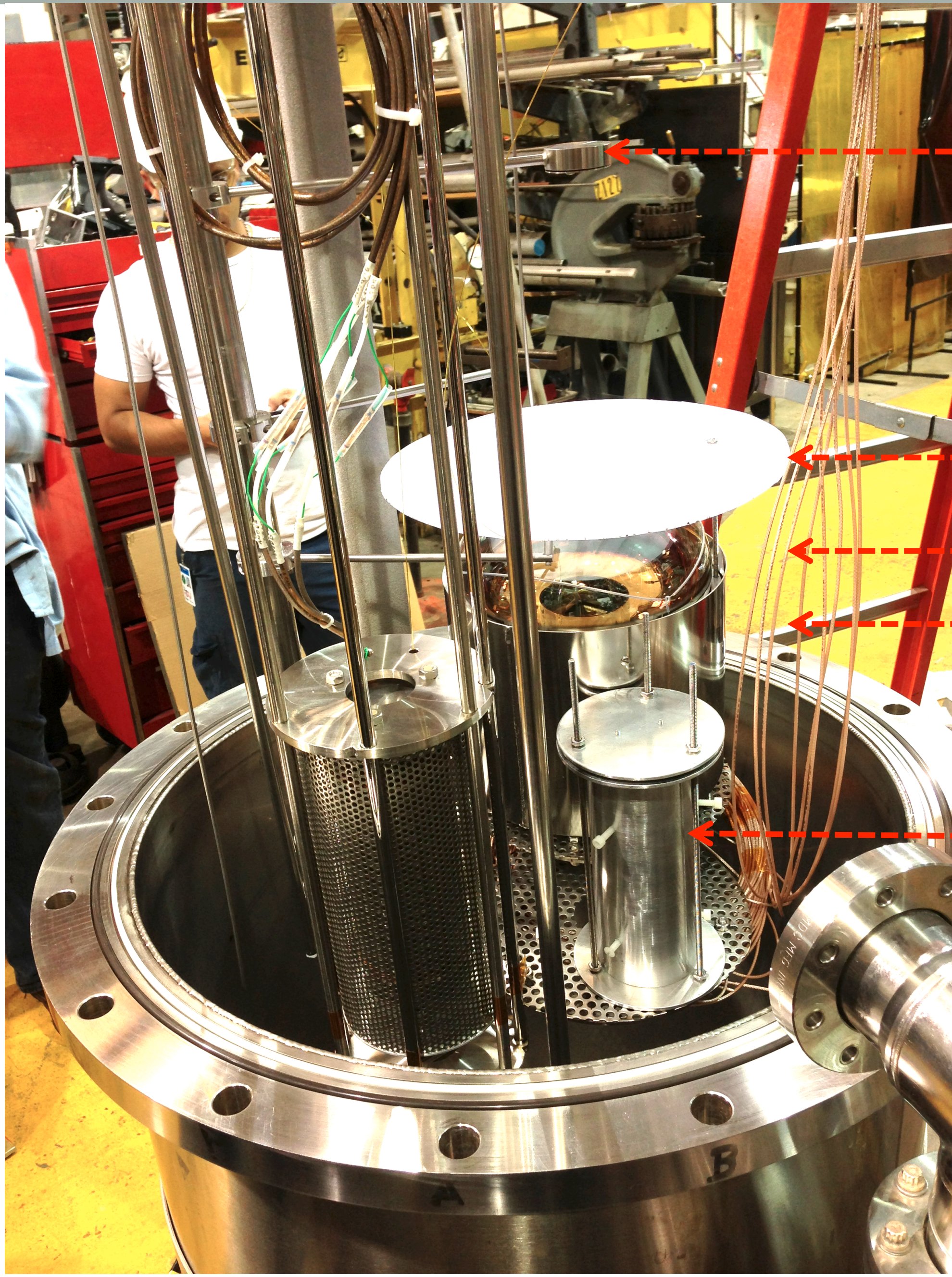
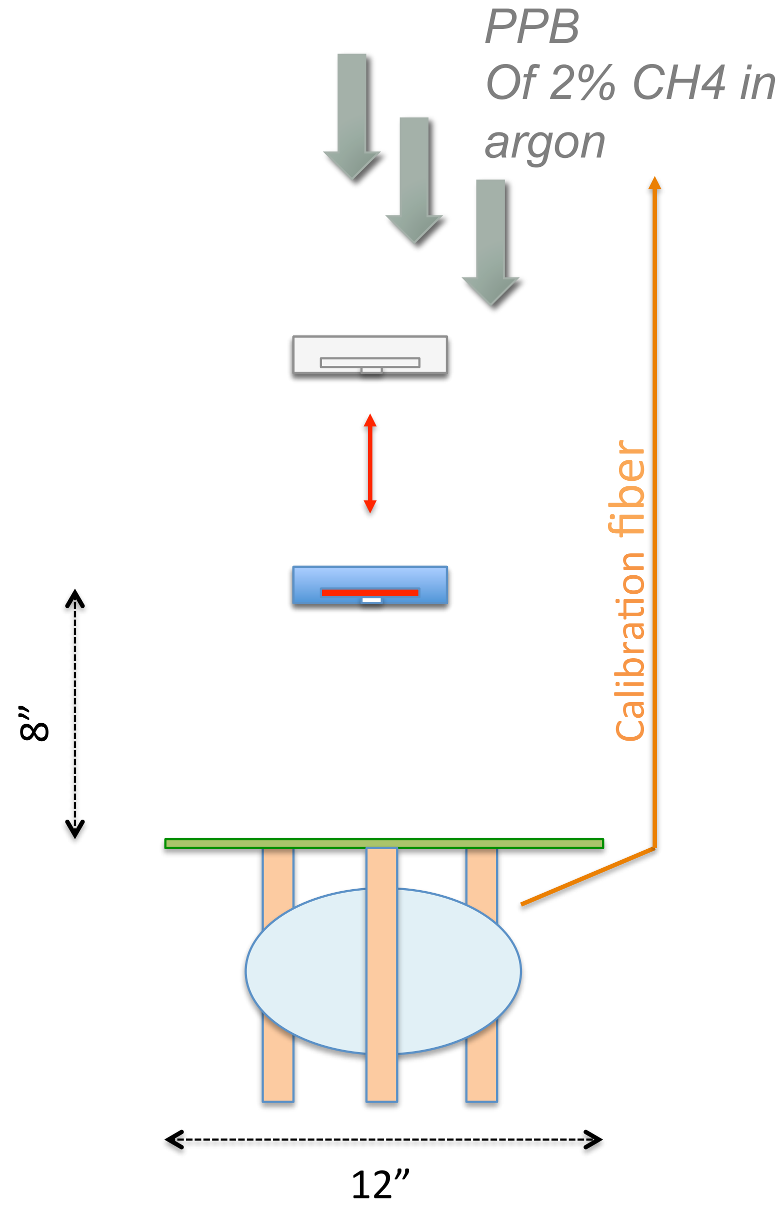
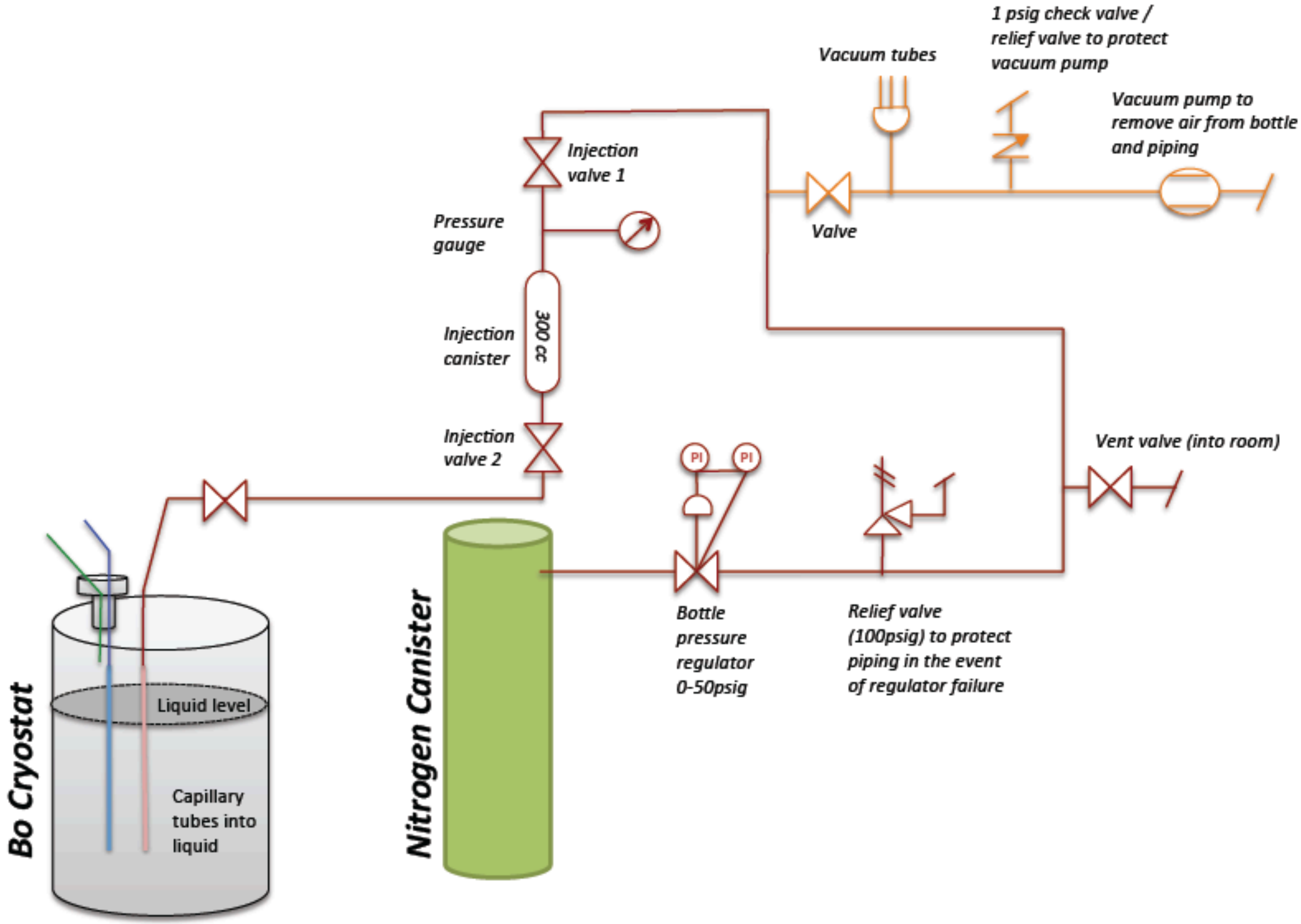
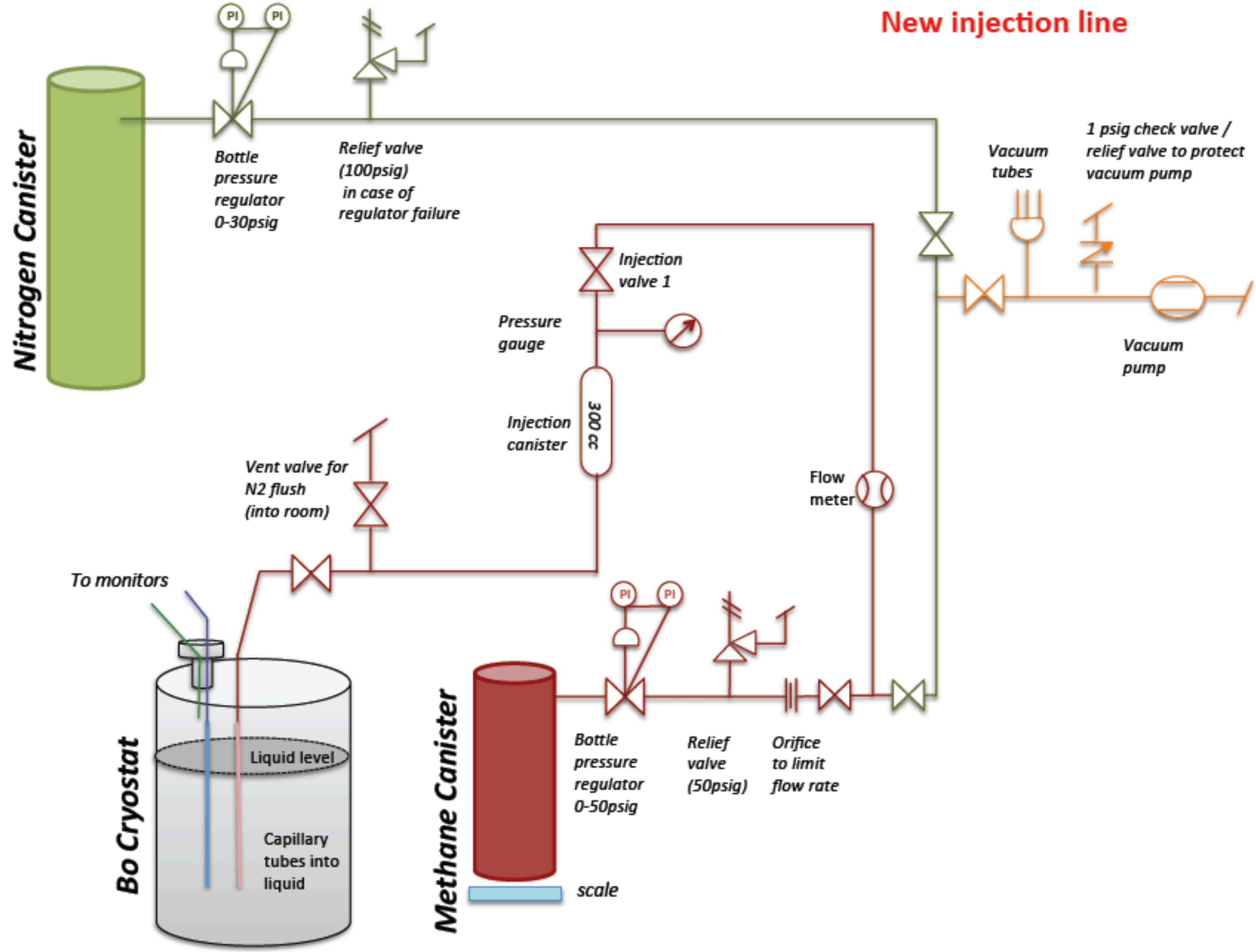

Polonium source #1
20 cm
TPB coated plate
PMT-UV
Mu-metal shield
Polonium source #2
1 cm
PMT-Vis (no WLS)
Aluminium housing

Monitor light yield as you inject methane. Simple.



Old injection line



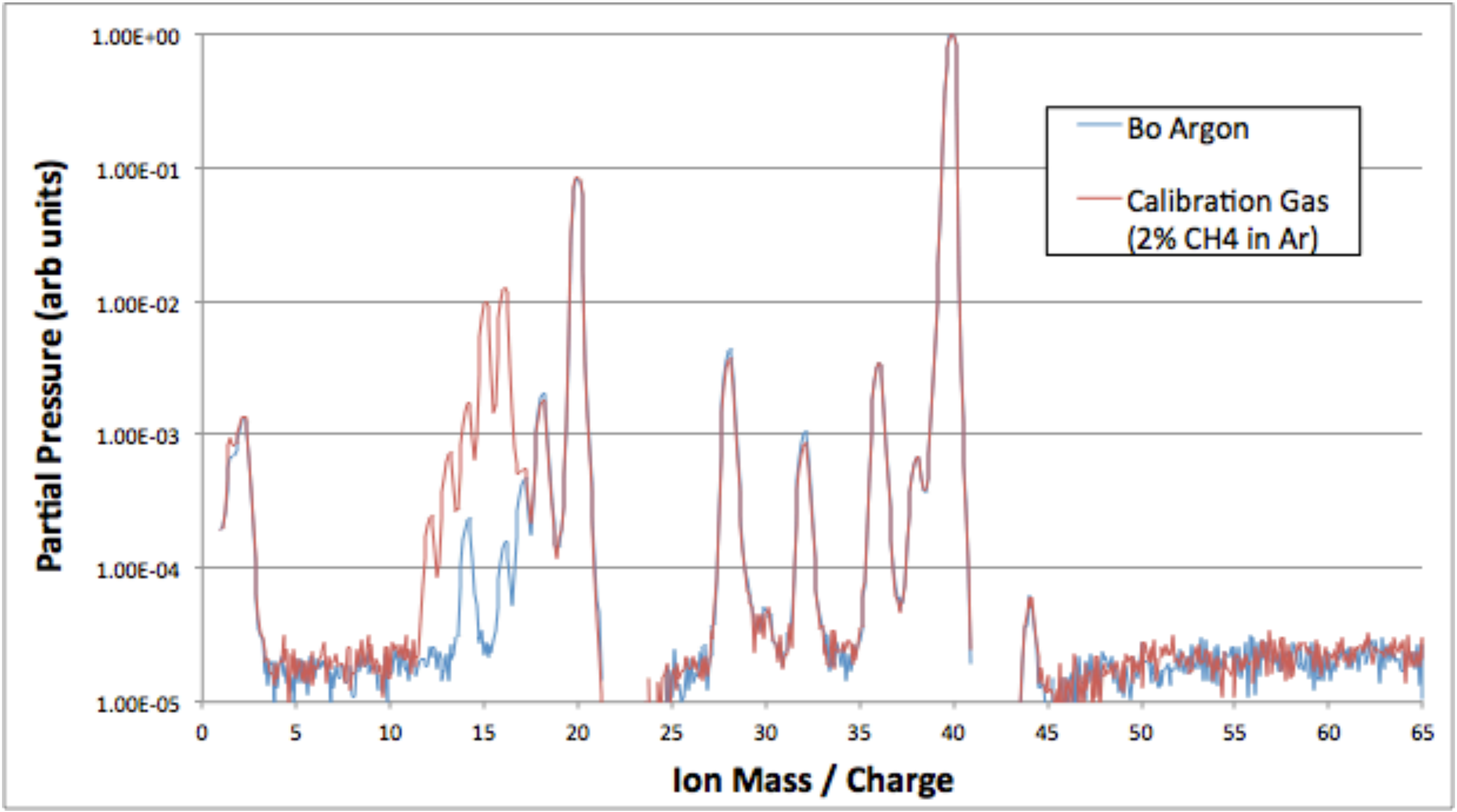


New injection line
Nitrogen Canister
Bottle pressure regulator 0-30psig
Relief valve (100psig) in case of regulator failure
Vacuum tubes
1 psig check valve / relief valve to protect vacuum pump
Injection valve 1
Pressure gauge
Vacuum pump
Injection canister
300 cc
Vent valve for N2 flush (into room)
Flow meter
To monitors
Bo Cryostat
Liquid level
Capillary tubes into liquid
Methane Canister
Bottle pressure regulator 0-50psig
Relief valve (50psig)
Orifice to limit flow rate
scale

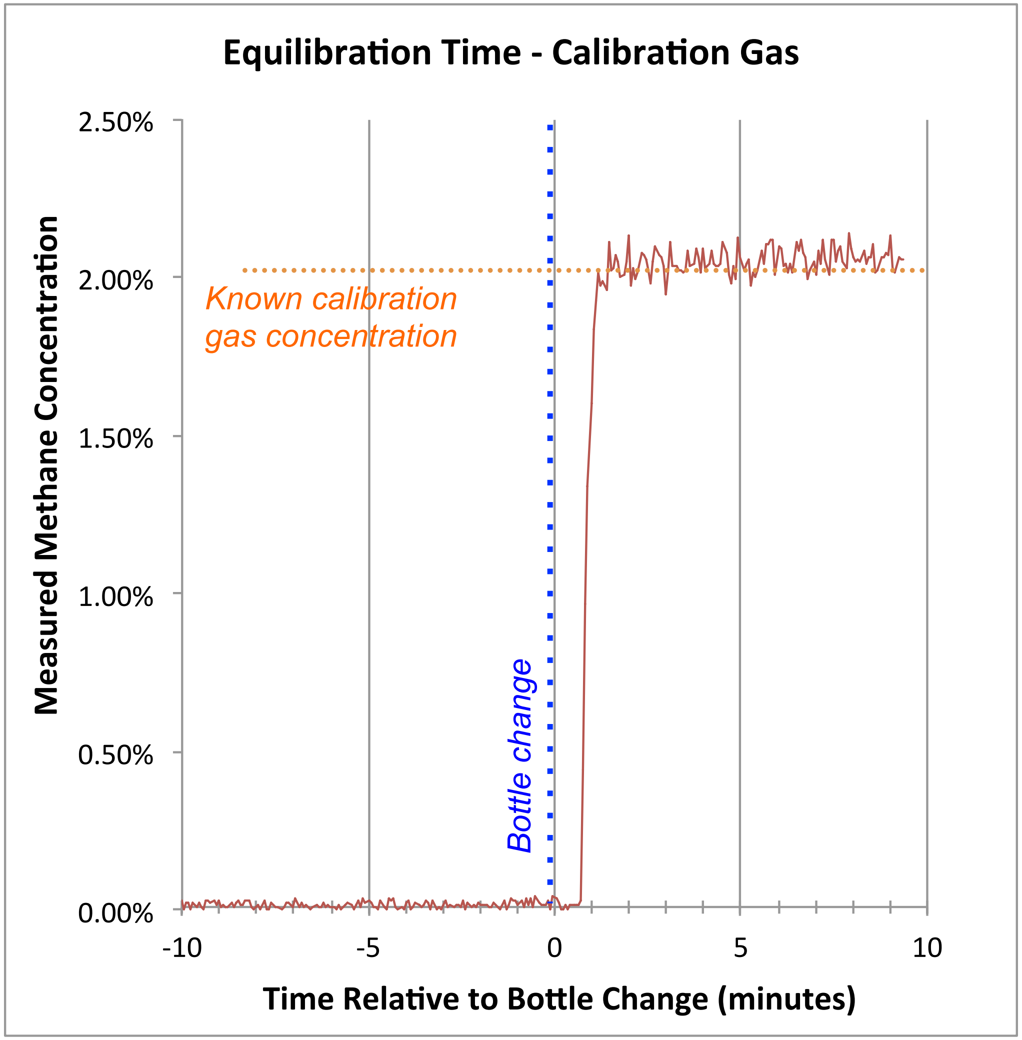
Measurement of CH_4 / Ar Equilibration time

- We inject small quantities of CH_4 gas into argon. How long does it take to mix and equilibrate?
- We can measure this using the UGA, and it informs our data taking strategy (need to know how long to leave the system between injection and light measurement)
- UGA only sensitive to ~0.01% CH_4 in Ar, so we don't use it for actual concentration measurements during the CH_4 run.

- We monitor the mass 15 peak for methane, since at 16 (actual methane mass) there is a background oxygen peak.
- Ratio of peak at 15 to peak at 40 gives CH4 / Argon ratio (after calibration)



Instrumental response time + concentration calibration



Up until time 0, Bo sample line connected @12psi.

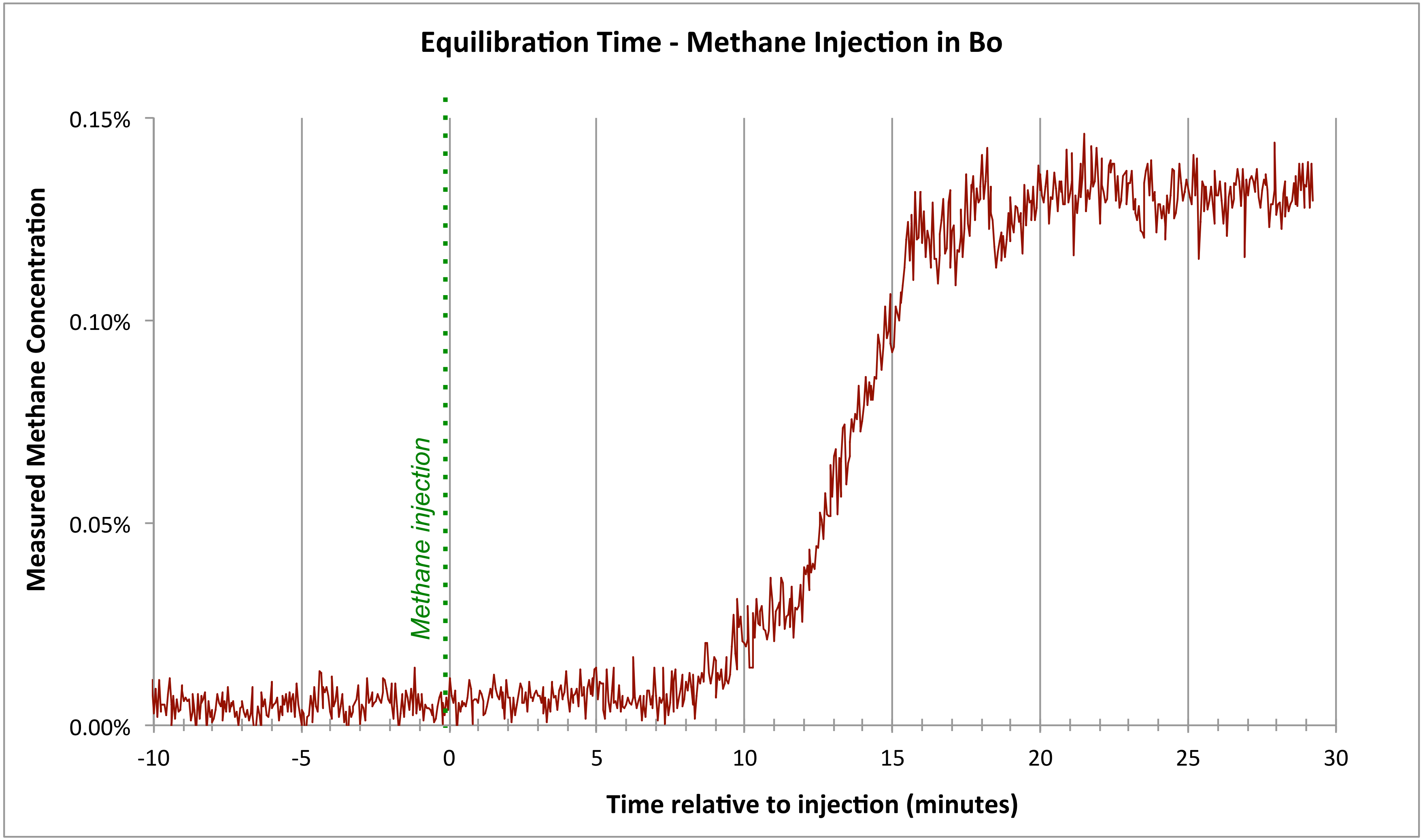
At time 0, valve to Bo closed and sample line moved to 2% methane in argon calibration gas bottle with 12psi regulator.

Measured concentration in UGA used to calibrate vertical scale

More important for us: time response shows us how long it takes for flow down 100ft sample pipe + analyzer response

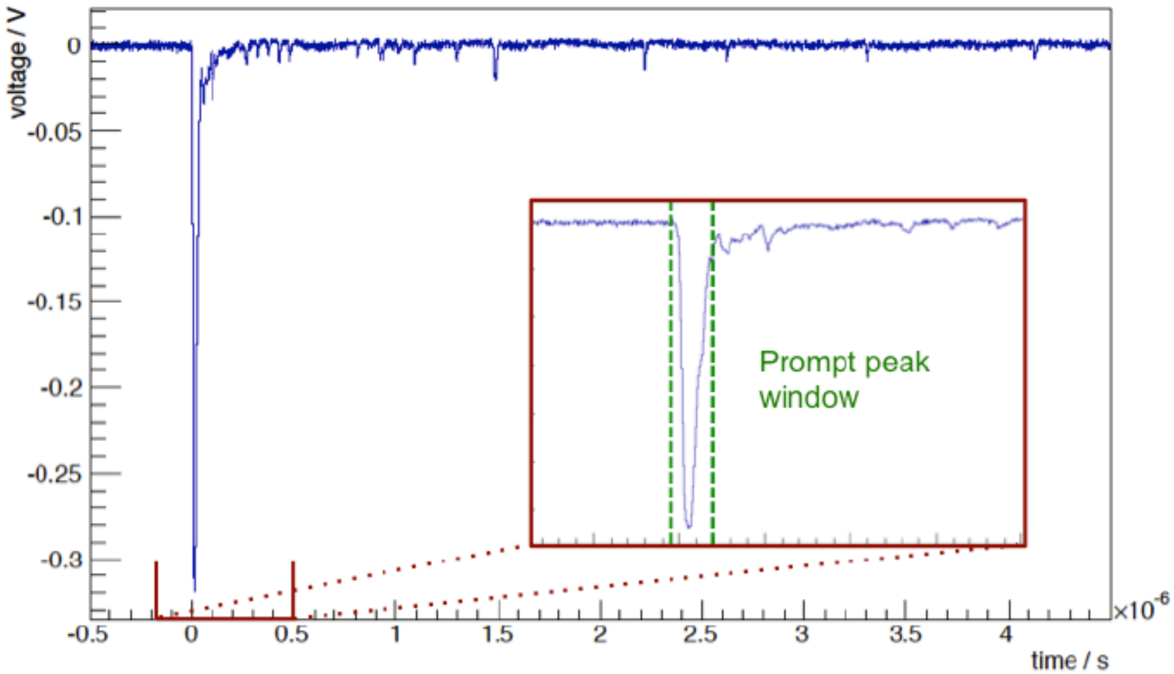
< 2 minutes response time.

- Response time following a large CH4 injection is ~20 minutes. We know the sample line and analyzer lag is <2 minutes, so this is the methane equilibration timescale.
- We always allow >40 minutes between injection and light measurement

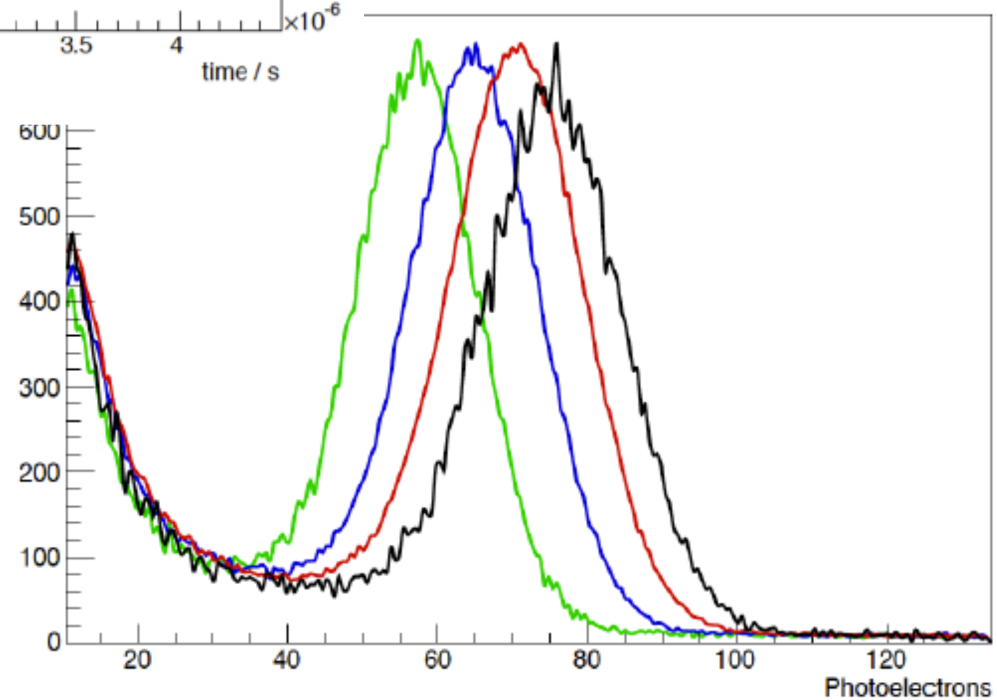


Data Taken

- Prep time for this measurement ~ few months
- Data for this run taken over a period of 1 week by Ben Jones and Tom Alexander (DarkSide)
- Scope terminated at 50Ohms, sampling at 1GS/S.
- Datasets taken:
  - 10,000 self triggered waveforms of length 2us
  - Histogram of pulse areas within a prompt window $-50 < t < 100$ ns, with >40,000 counts in each
  - Similar data from 2" tube, I'll come to that later.



There are from our N2 paper – but the same idea.



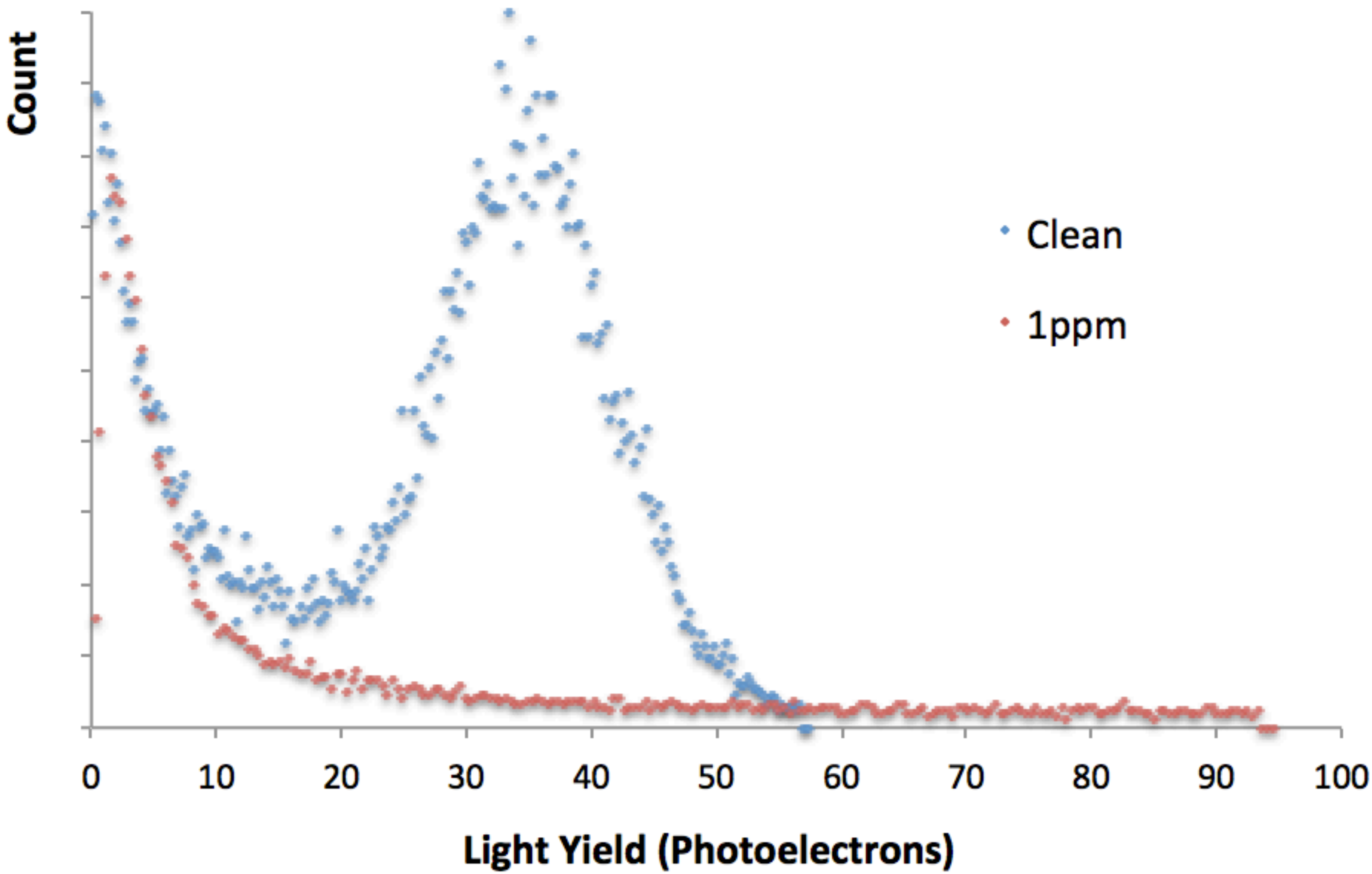
By the way, did I mention the N2 paper was published 2 days ago?

What we saw

- Remember we were at first trying to look into a mixed methane / argon TPC. So we planned a logarithmic scan, ***1ppm, 10ppm, 100ppm, 1000ppm, 0.01%, 0.1%, 1%, 5%***

- **First data point, 1ppm…**

Light Yield at PMT 1 (8" with TPB)

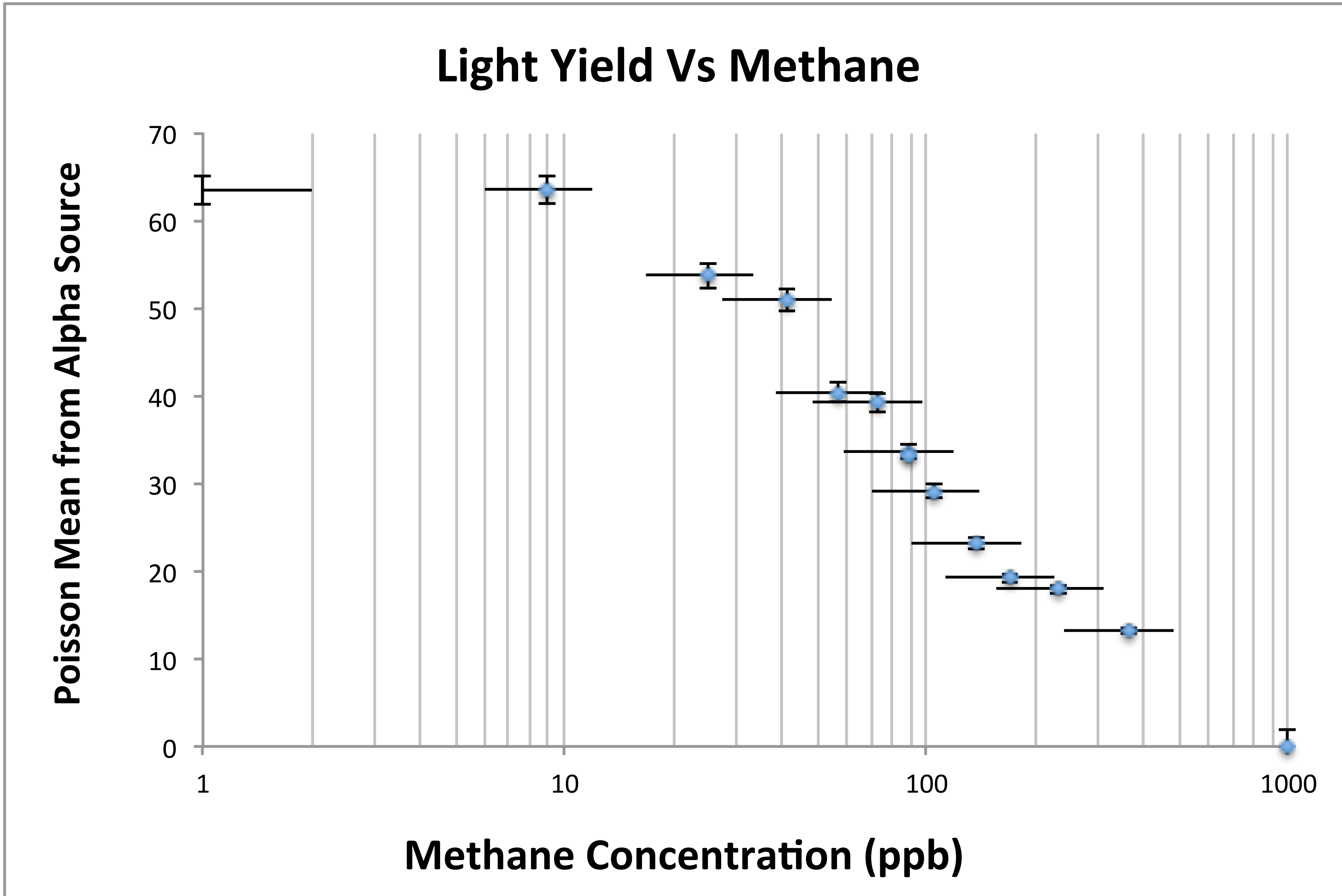


Alright then…

- So much less than 1ppm of methane, to our surprise, kills ALL scintillation light.

- This is where the dark matter folks suddenly started paying attention.

- We dumped out Bo, made a fresh fill and worked out a method to go down a couple of orders of magnitude lower…



Horizontal error bars are from injection pressure uncertainty
Vertical error bars are from SPE scale uncertainty

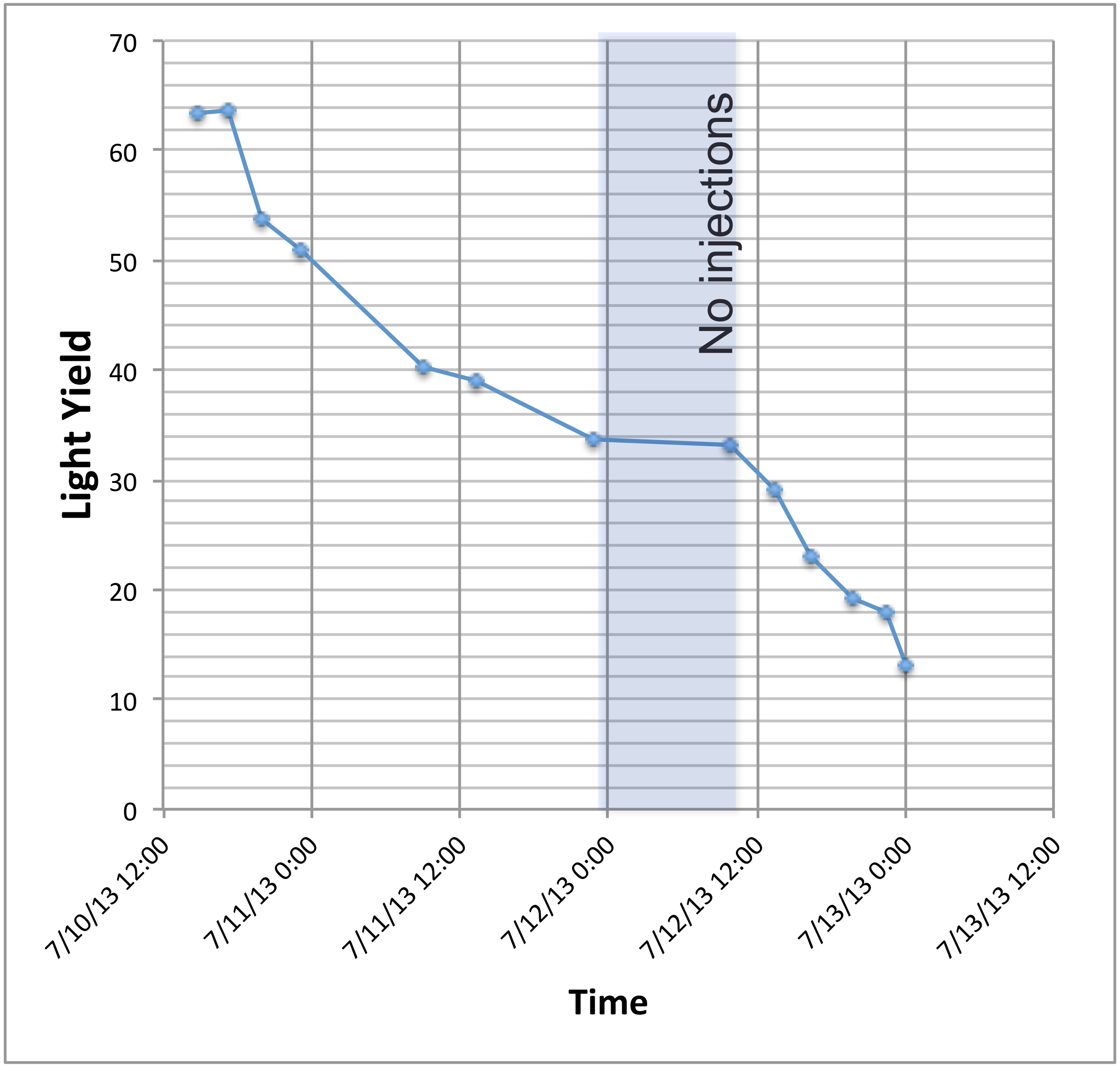
We did the usual outgassing test twice, taking the same data a few hours apart

Unfortunately one of them was a victim of the "hi-res lo-res" issue and did not come out consistent

The outgas test with both points correctly taken in hi-res mode did show stability.

This data vs time shown right.

This seems to be to be a strong enough constraint on outgassing to rule it out as an explanation for observed



So whats going on?

- We see light losses. There are basically two options:

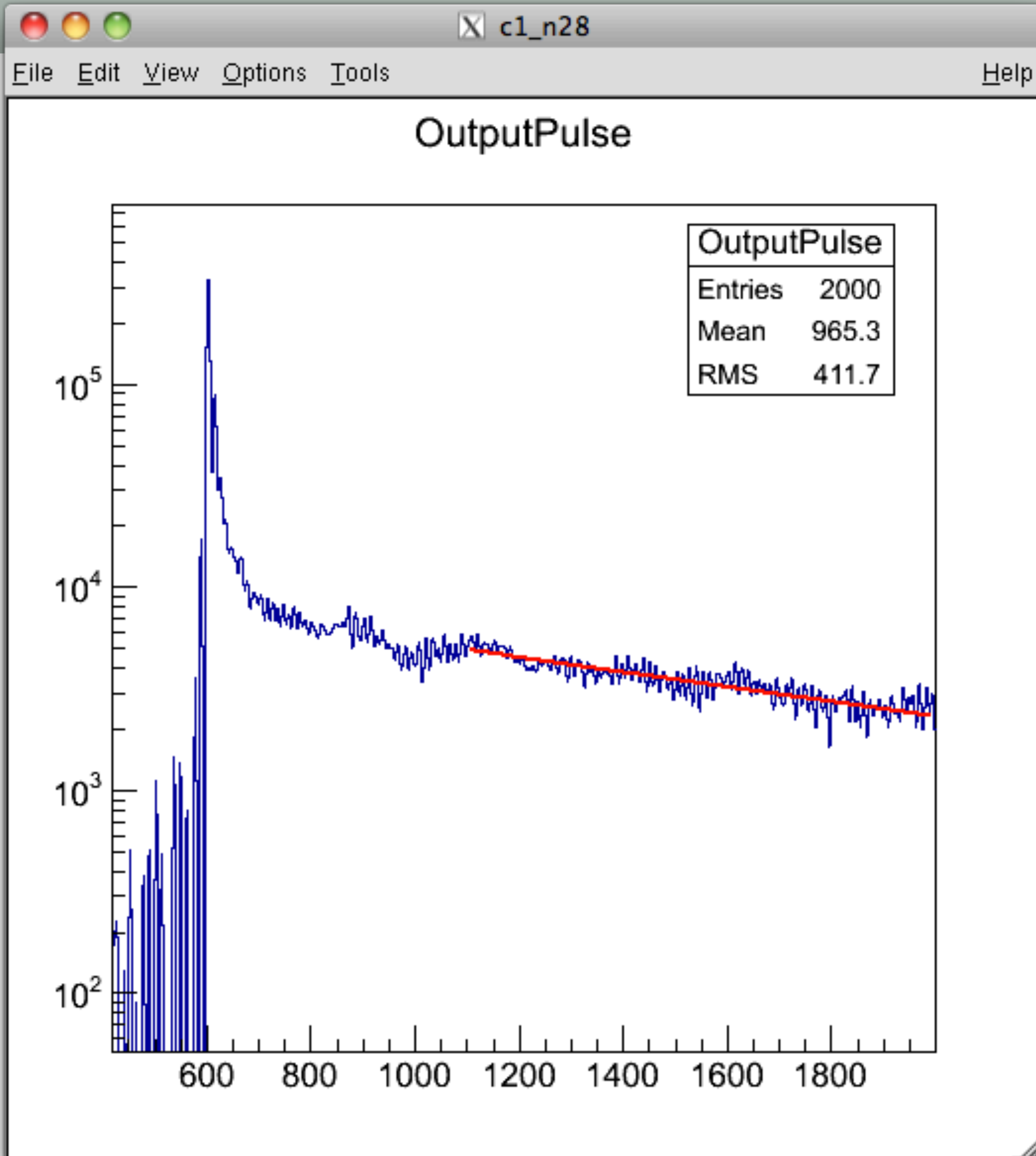
- 1) **Quenching**. Methane interfering with the argon excimers during the scintillation process
- 2) **Absorption**. Methane eating UV photons between source and detector

- We can tell the difference between these by looking at late scintillation light – quenching hurts late light much more than prompt light, and causes a drop in the time constant.

- Absorption hurts prompt and late light in the same way.

Time Constant Measurement

- As we learned in the N2 study, measuring time constants using PMT pulses has many subtleties
- We use the same method here – main question we are asking is: does the time constant change?
- Process (in summary):
  - 1) Generate deconvolution kernel using LED driven SPE sample
  - 2) Sum all alpha pulse waveforms for one sample
  - 3) Apply pre-processing, sigmoid window function, padding, baseline removal
  - 4) Deconvolve the summed waveform
  - 5) Combined weiner optimal filter and low pass filter to remove noise and artifacts

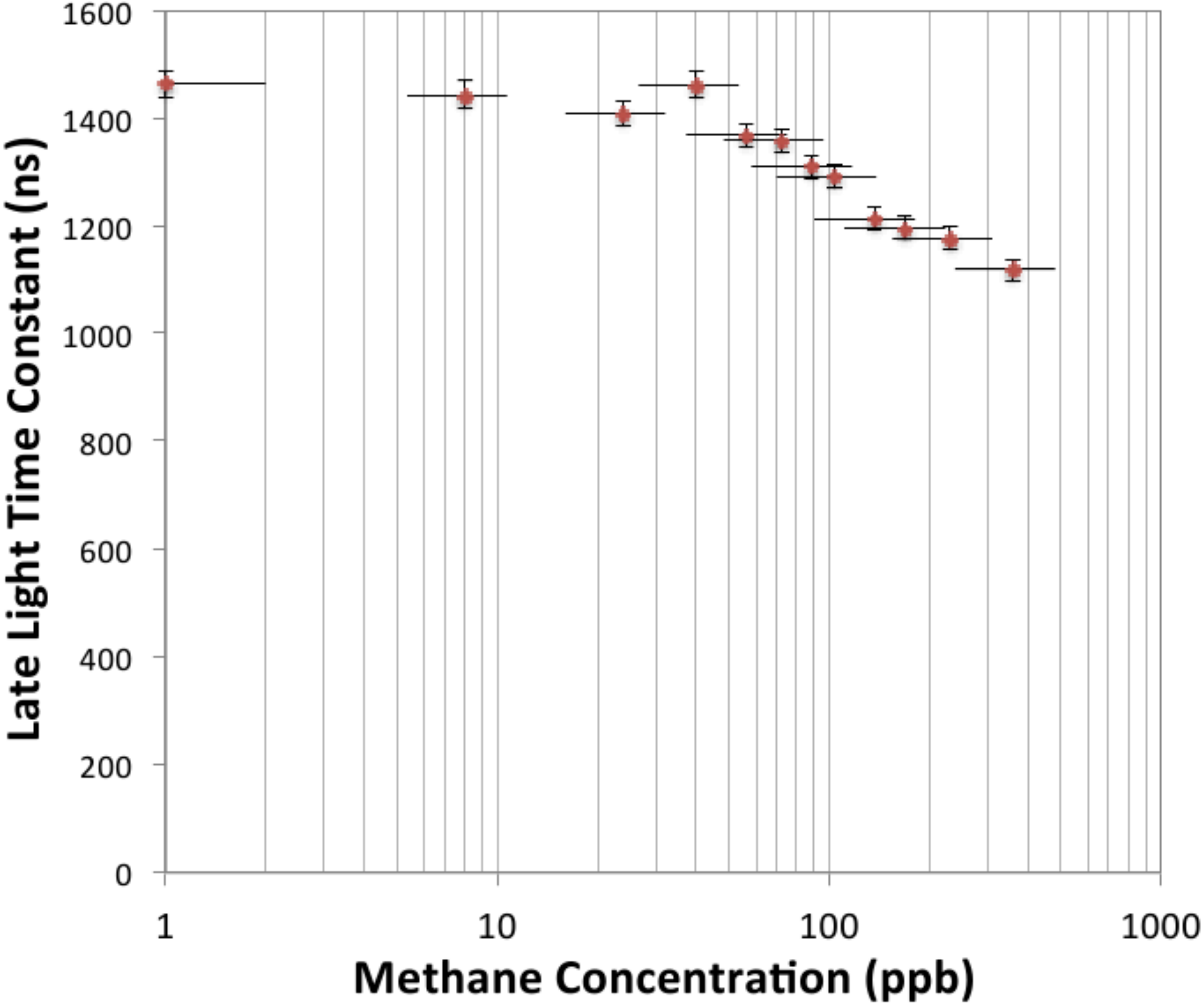


We know from our previous studies that the early part of the pulse is susceptible to nonlinearities and ringing effects

So we fit only the part of the pulse more than 500ns after the trigger

This gives a lever arm of 900ns, which should be enough

Lippincott et al recommend only fitting 1us after the trigger onwards – we don't have enough waveform for this.



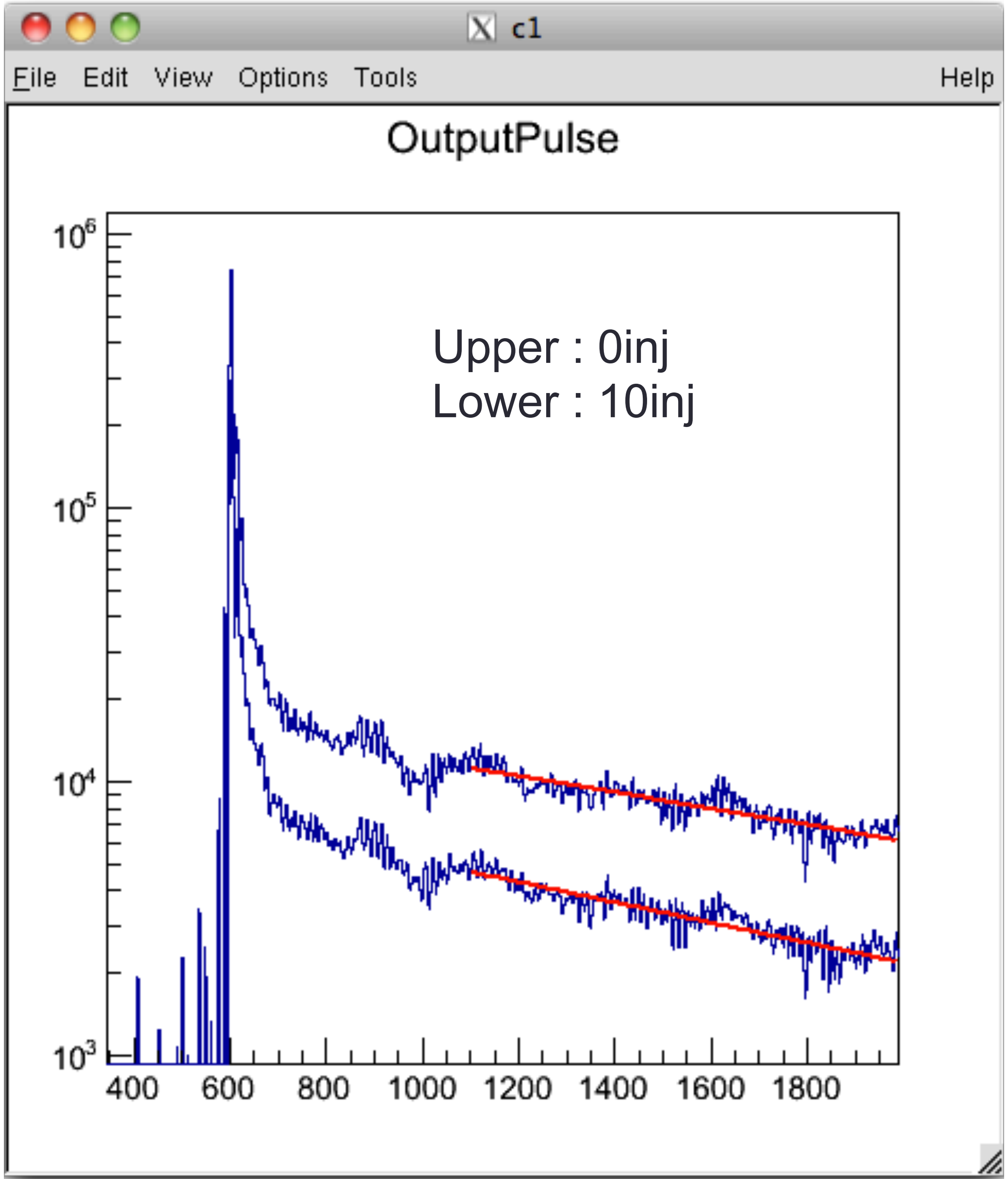
Vertical error bars are given by RMS difference between 1st and 2nd half of each 10,000 waveform dataset

The effect is very small – difficult to see by eye

Shows that the majority of the light loss is caused by absorption and not by quenching.

Next question : Can we confidently say there IS quenching?

Open question (as always) is about the effects of nonlinearities, such as pulse undershoot being different for smaller peaks, etc…



Maybe some silver (or blue) lining?

IEEE Transactions on Nuclear Science, Vol. NS-29, No. 5, October 1982

Scintillating Drift Chambers—The Nature of the Emission Process in Ar/CH_4

T. J. Sumner, G. K. Rochester, P. D. Smith, J. P. Cooch, and R. K. Sood*

established. One system which has remained unexplained is that using Ar/CH_4 mixtures. We have earlier [6] tentatively proposed a mechanism for the optical emission from scintillating drift chambers filled with this gas mixture and here we provide a more detailed account and also offer two further pieces of supporting evidence. First, an unidentified spectral feature seen by Siegmund et al[5] as the major emission component in Ar/CH_4 agrees exactly with what is predicted, and second, the presence of photoelectric emission from cathode wall material can be explained within the framework of the proposed mechanism.

Theory

a) *Pure Argon*

The basic processes are as follows:

$$e + Ar \rightarrow e + Ar^* \qquad (a)$$

$$Ar^* \rightarrow Ar + h\nu_1 \qquad (b)$$

$$h\nu_1 + Ar \rightarrow Ar^* \qquad (c)$$

$$Ar^* + Ar + Ar \xrightarrow{K_1} Ar_2^{**} + Ar \qquad (d)$$

b) *Argon-methane*

The addtion of methane will add the following processes to those listed earlier:

$$e + CH_4 \rightarrow [CH_4^*] \qquad (h)$$

$$h\nu + CH_4 \rightarrow [CH_4^*] \qquad (i)$$

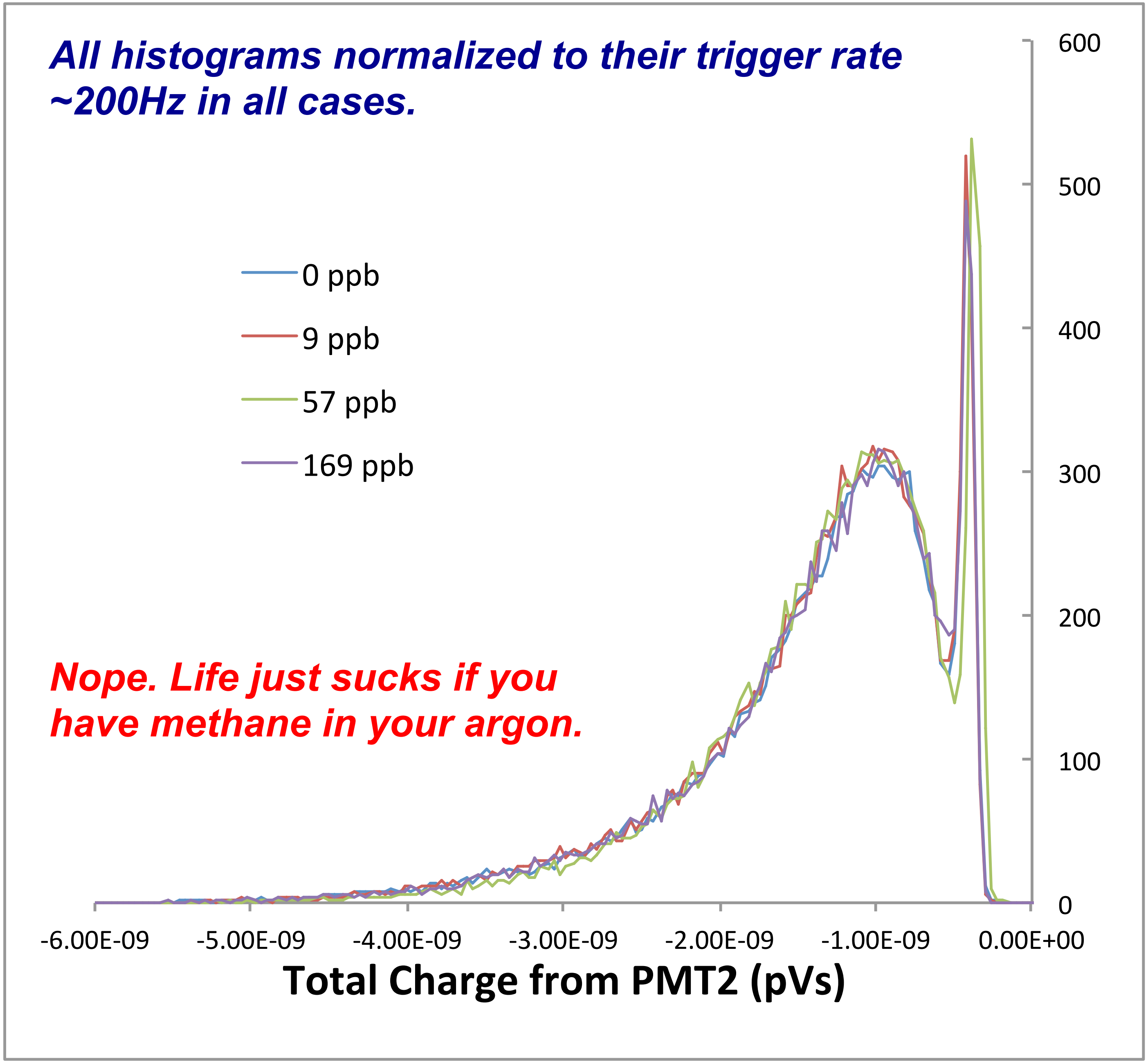
$$Ar^* + CH_4 \xrightarrow{K_3} [CH_4^*] \qquad (j)$$

$$[CH_4^*] \rightarrow CH^* + H_2 + H \qquad (k)$$

$$[CH_4^*] \rightarrow C^* + 4H \qquad (l)$$

$$[CH_4^*] \rightarrow H^* + CH + H_2 \qquad (m)$$

$$CH^* \rightarrow CH + h\nu_4 \qquad (n)$$

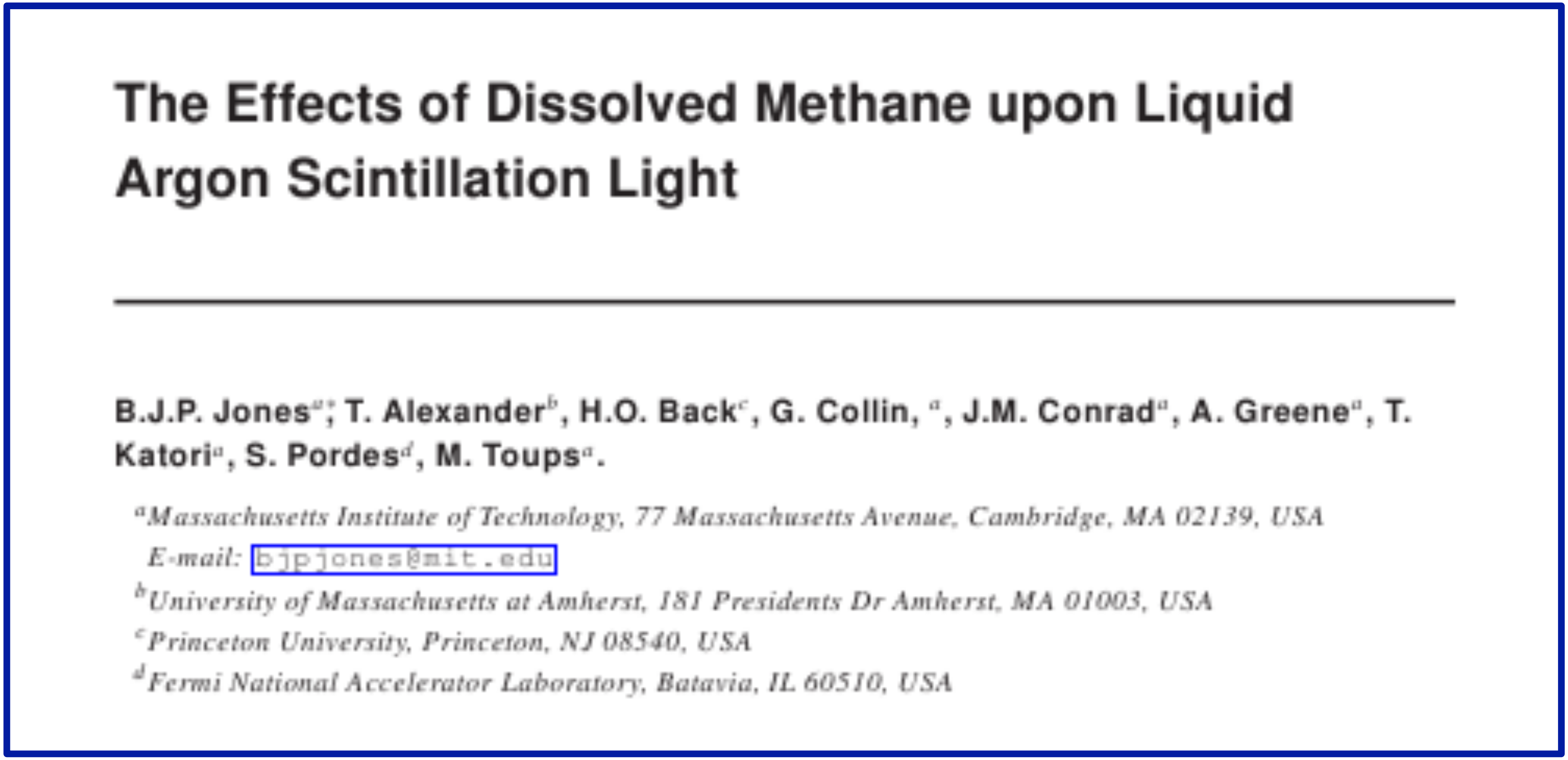


All histograms normalized to their trigger rate ~200Hz in all cases.
0 ppb
9 ppb
57 ppb
169 ppb
Nope. Life just sucks if you have methane in your argon.
600
500
400
300
200
100
0
-6.00E-09
-5.00E-09
-4.00E-09
-3.00E-09
-2.00E-09
-1.00E-09
0.00E+00
Total Charge from PMT2 (pVs)

What can we say based on this data?

- Based on this data, we can say conclusively:
  - 10s of PPB of methane significantly damages light yield in LAr detectors
  - The majority of light loss does not appear to be due to excimer quenching, since even when most of the prompt light is gone, there is still late light
  - To be used in DM experiments, underground argon should probably be purified to have <10ppb methane – challenging but not impossible!
  - There is no useful visible re-emission feature from the dissolved methane in the liquid phase
- And more speculatively:
  - We see some effect which is consistent with methane induced quenching of late light, but at higher concentrations than absorption kicks in

Most importantly : Another paper for the glory of the R&D Group!!


The Effects of Dissolved Methane upon Liquid Argon Scintillation Light

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Thanks for your attention!