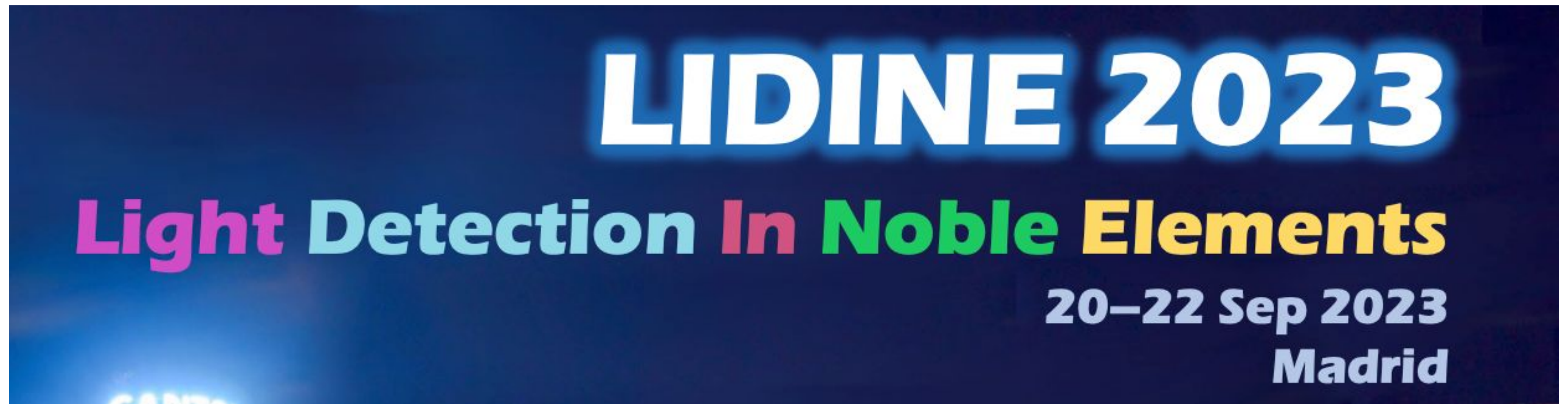
Xenon-Doped Liquid Argon Scintillation Light

DEPARTMENT OF PHYSICS & ASTRONOMY

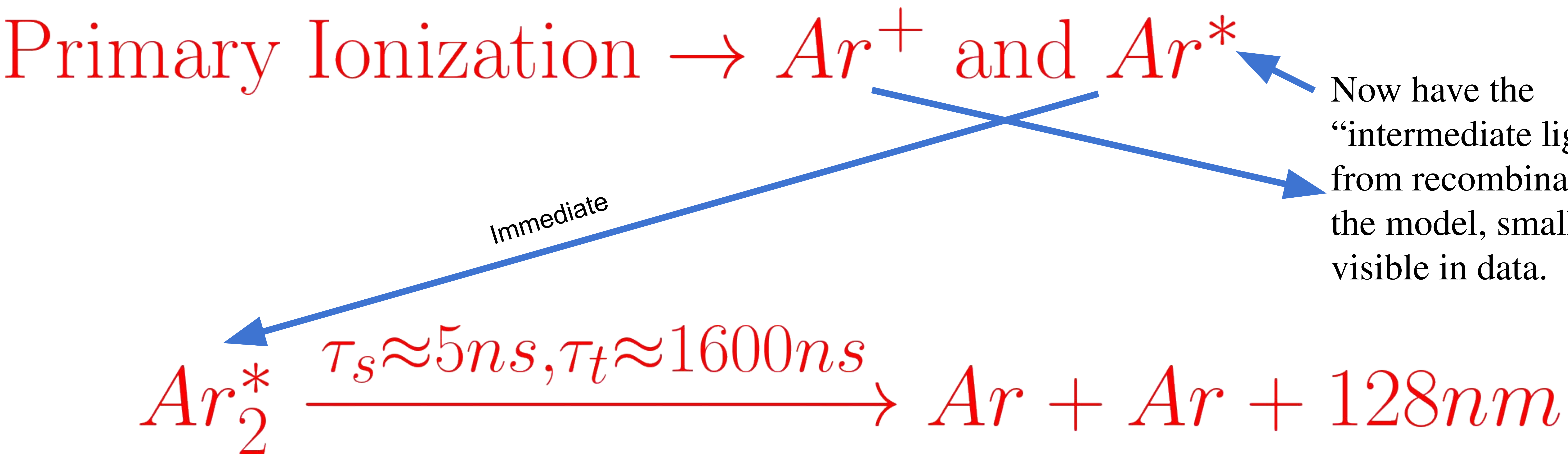
D.E. Fields, M. Gold, T. Reza, Luis Flores-Sanchez (UNM)
S.R. Elliott, R. Massarczyk, A. Mazumdar, C. Romo Luque, T. Thorpe, N. O’Brien, B. Turner (LANL)

Los Alamos NATIONAL LABORATORY

https://arxiv.org/pdf/2009.10755.pdf



Evolution of Our Understanding: *Pure* LAr



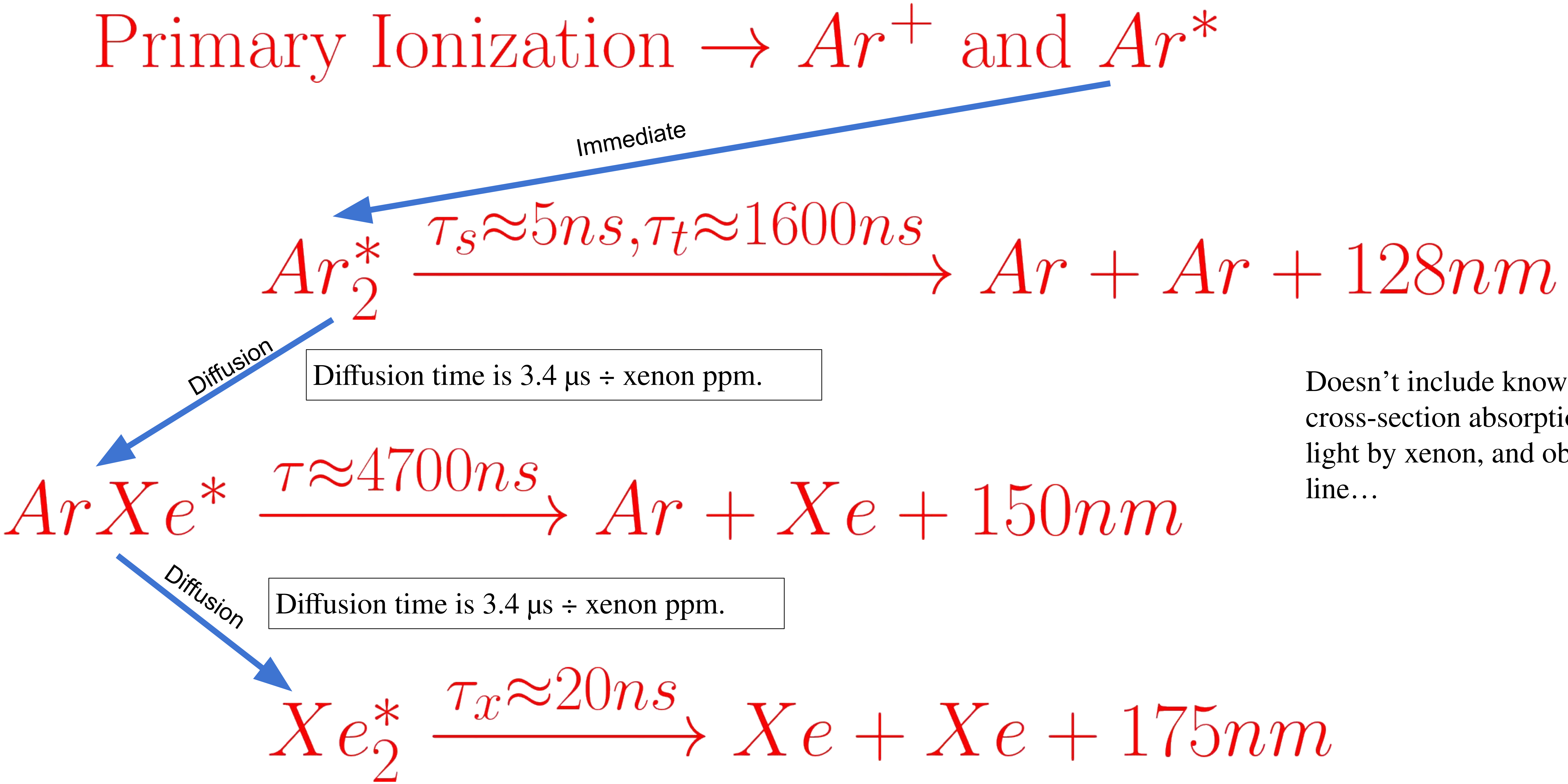
$$\text{Primary Ionization} \rightarrow Ar^{+} \text{ and } Ar^{*}$$

$$Ar_2^{*} \xrightarrow{\tau_s \approx 5ns, \tau_t \approx 1600ns} Ar + Ar + 128nm$$

Now have the “intermediate light” from recombination in the model, small, but visible in data.

Very different measurements of the long, triplet lifetime from 1100 to 2100 ns. Ratio of triplet to singlet different for different ionizing particles and can change in the presence of an electric field. Doping with xenon has dramatic effects…

Evolution of Our Understanding: *Xe-doped* LAr



$$\text{Primary Ionization} \rightarrow Ar^+ \text{ and } Ar^*$$

$$Ar_2^* \xrightarrow{\tau_s \approx 5ns, \tau_t \approx 1600ns} Ar + Ar + 128nm$$

Diffusion time is 3.4 µs ÷ xenon ppm.

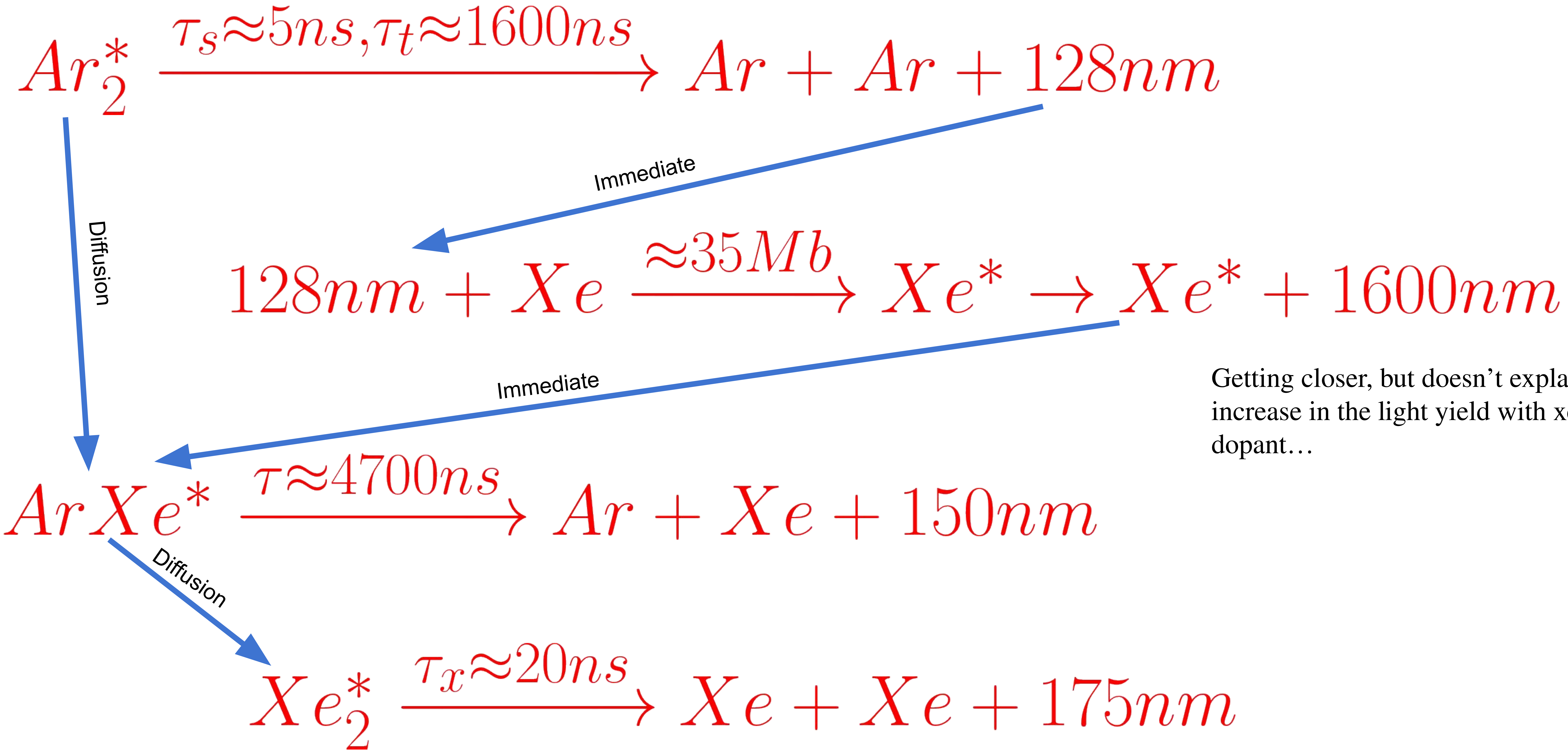
$$ArXe^* \xrightarrow{\tau \approx 4700ns} Ar + Xe + 150nm$$

Diffusion time is 3.4 µs ÷ xenon ppm.

$$Xe_2^* \xrightarrow{\tau_x \approx 20ns} Xe + Xe + 175nm$$

Doesn’t include known, large cross-section absorption of the 128 nm light by xenon, and observed 1600 nm IR line…

Evolution of Knowledge: Absorption



$$Ar_2^* \xrightarrow{\tau_s \approx 5ns, \tau_t \approx 1600ns} Ar + Ar + 128nm$$

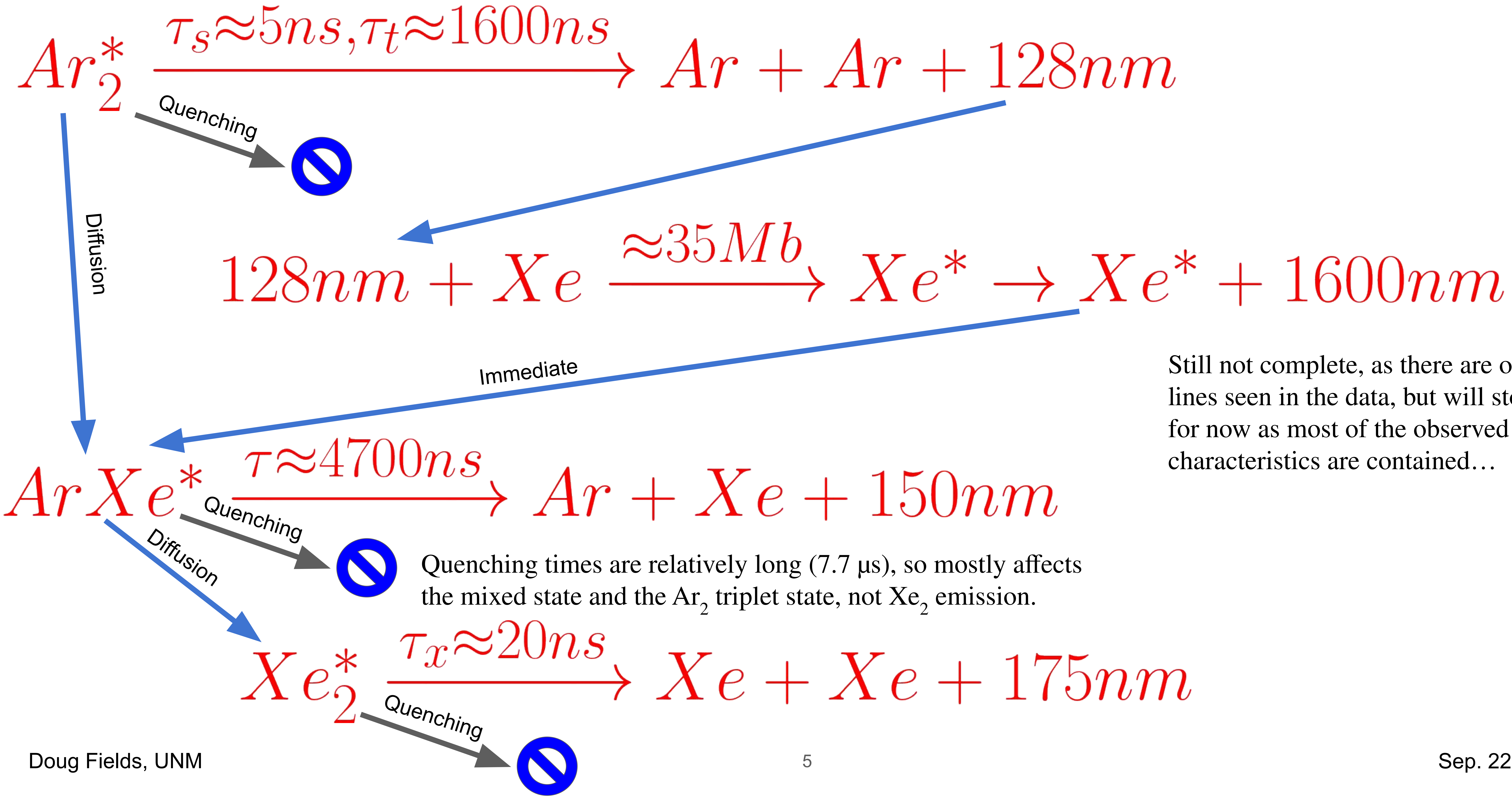
$$128nm + Xe \xrightarrow{\approx 35Mb} Xe^* \rightarrow Xe^* + 1600nm$$

$$ArXe^* \xrightarrow{\tau \approx 4700ns} Ar + Xe + 150nm$$

$$Xe_2^* \xrightarrow{\tau_x \approx 20ns} Xe + Xe + 175nm$$

Getting closer, but doesn’t explain increase in the light yield with xenon dopant…

Evolution of Knowledge: Quenching



$$Ar_2^* \xrightarrow{\tau_s \approx 5ns, \tau_t \approx 1600ns} Ar + Ar + 128nm$$

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$$ArXe^* \xrightarrow{\tau \approx 4700ns} Ar + Xe + 150nm$$

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Still not complete, as there are other IR lines seen in the data, but will stop here for now as most of the observed characteristics are contained…

Quenching times are relatively long (7.7 μs), so mostly affects the mixed state and the Ar_2 triplet state, not Xe_2 emission.

Absorption is not straightforward

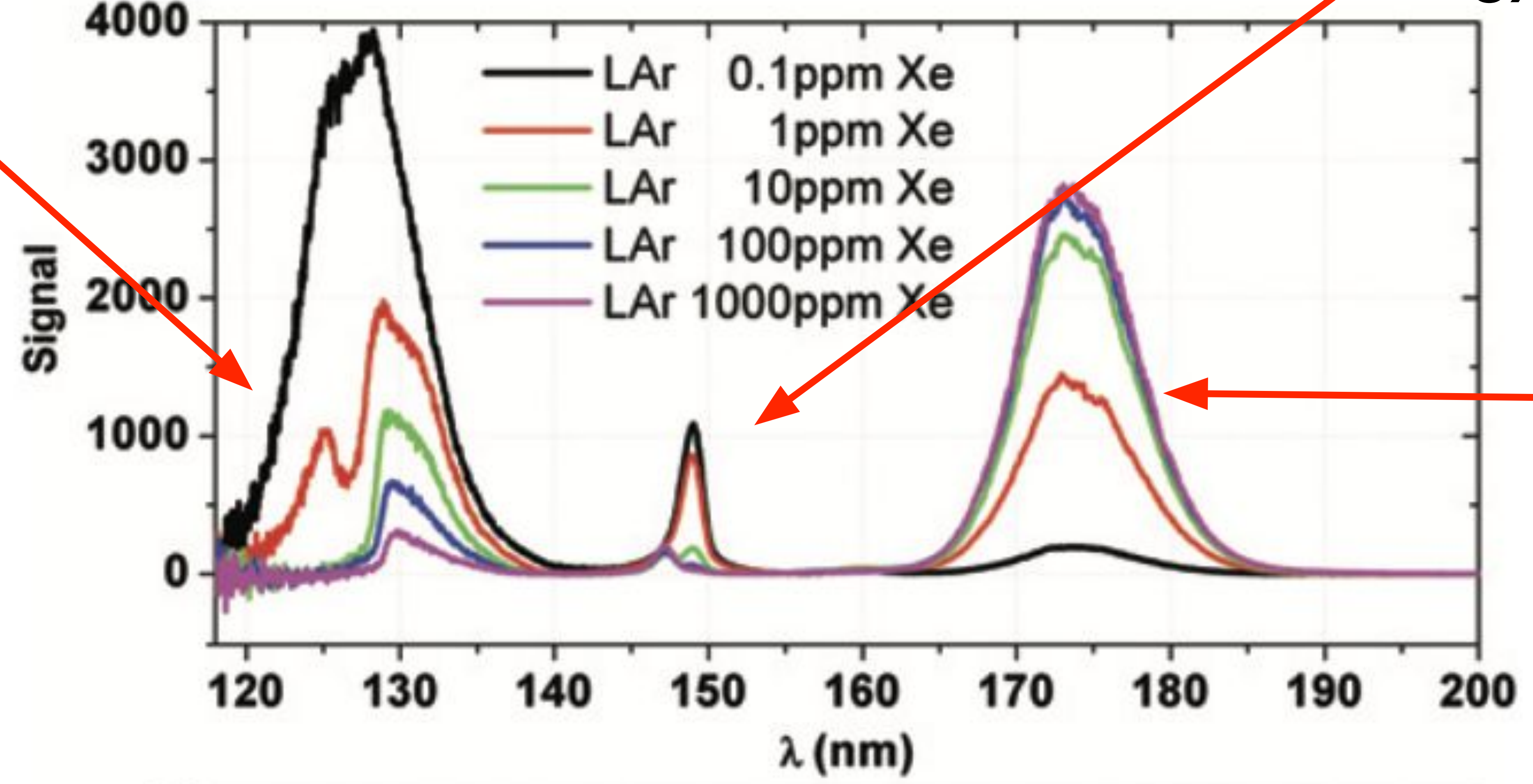
A. Neumeier *et al.*

Argon eximer

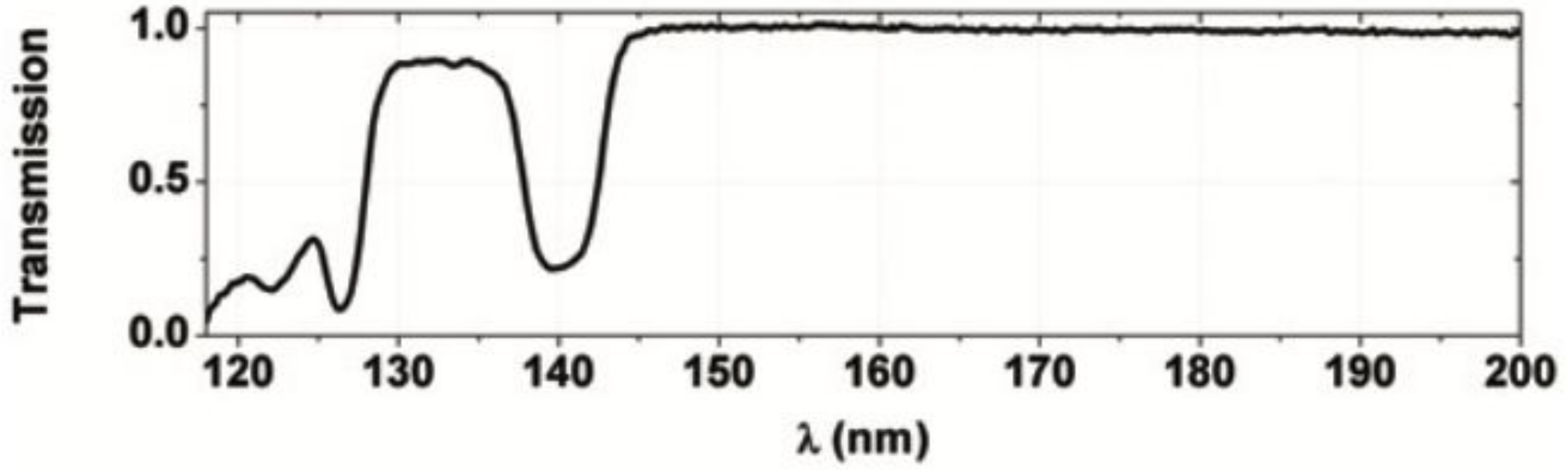
Mixed (ArXe) excimer

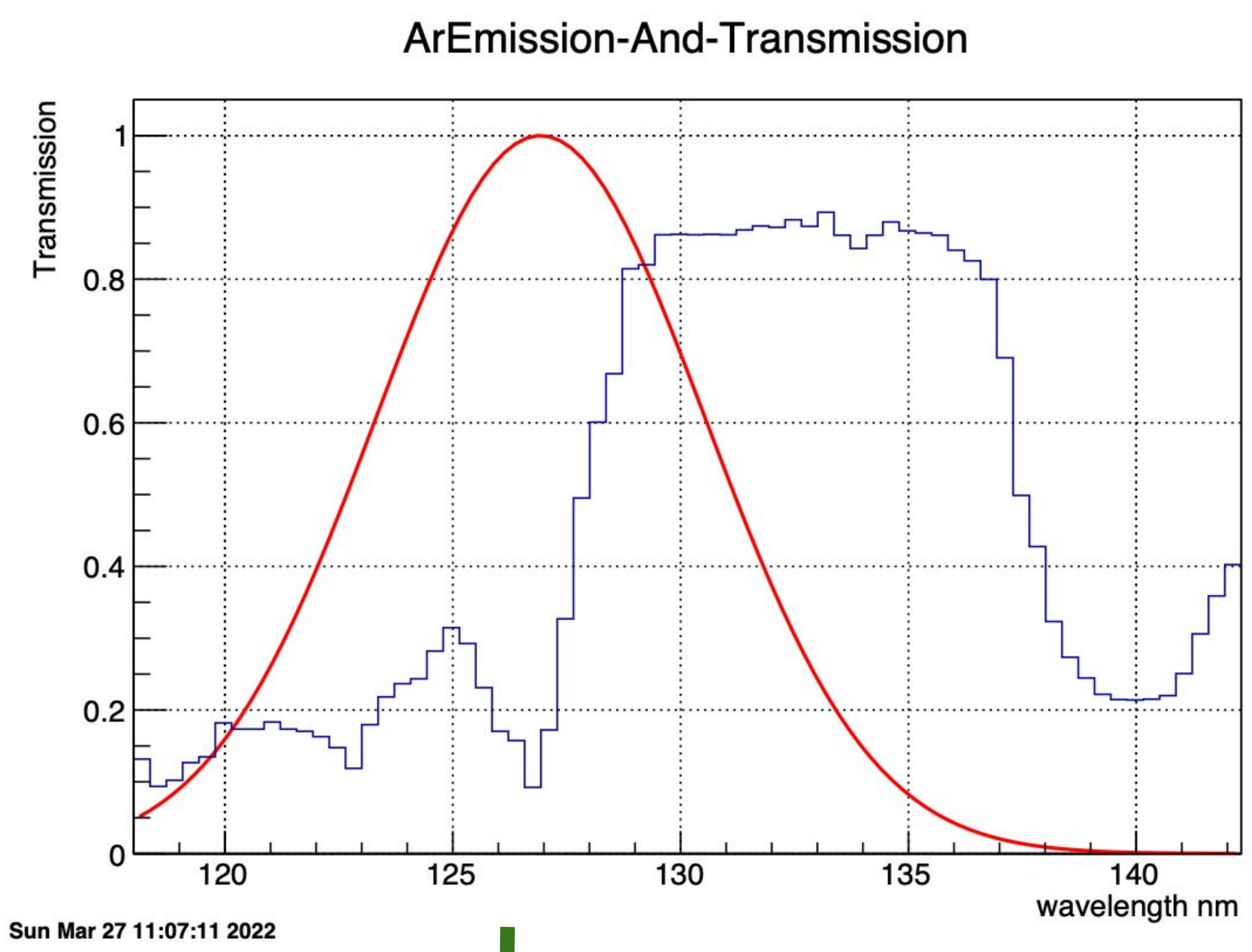
Xenon excimer

The VUV emission of electron-beam excited liquid argon doped (2 mm)

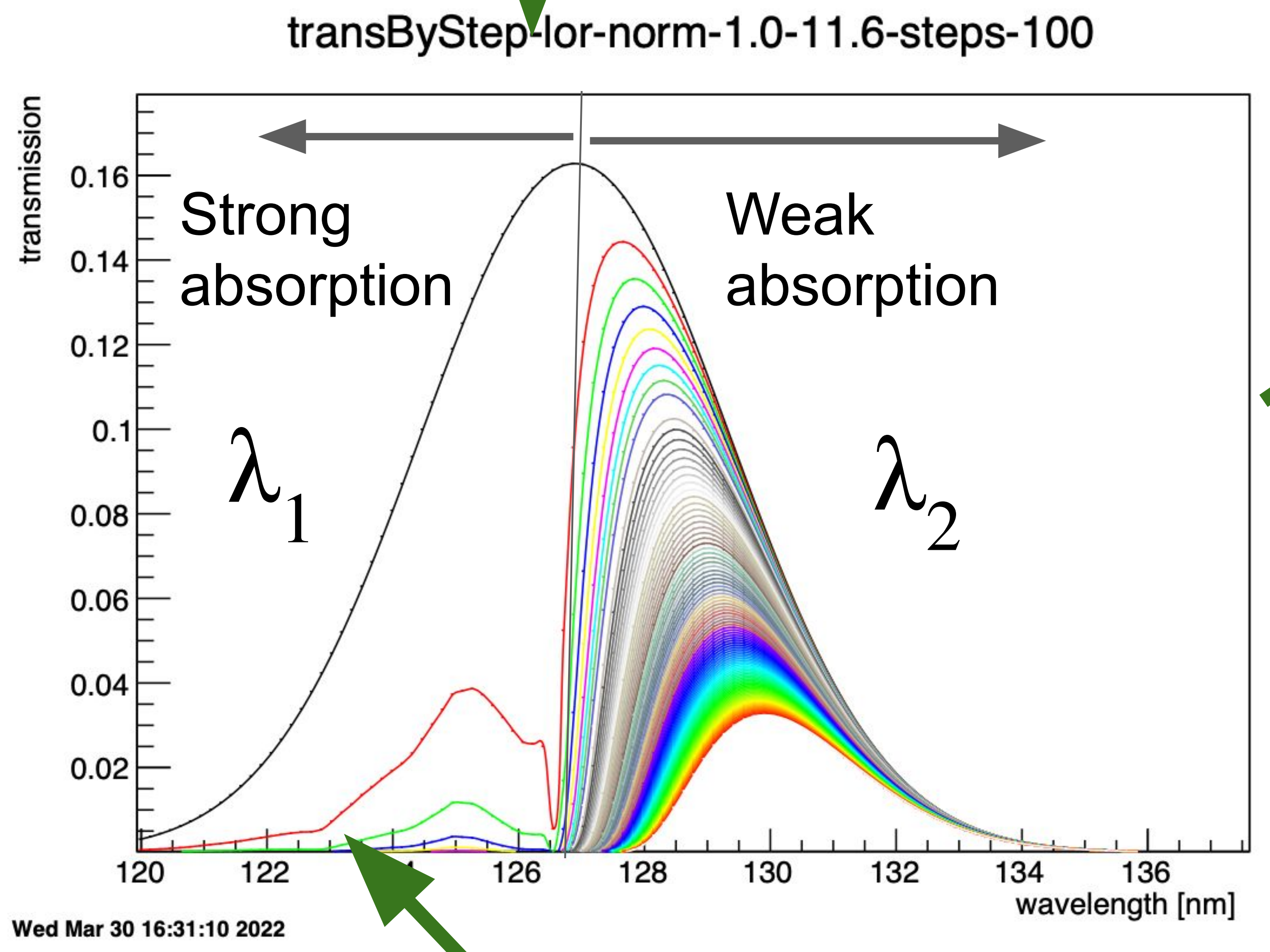


Transmission of liquid argon doped with 0.1 ppm xenon measured with a deuterium light source and a length of the optical path of 11.6 cm



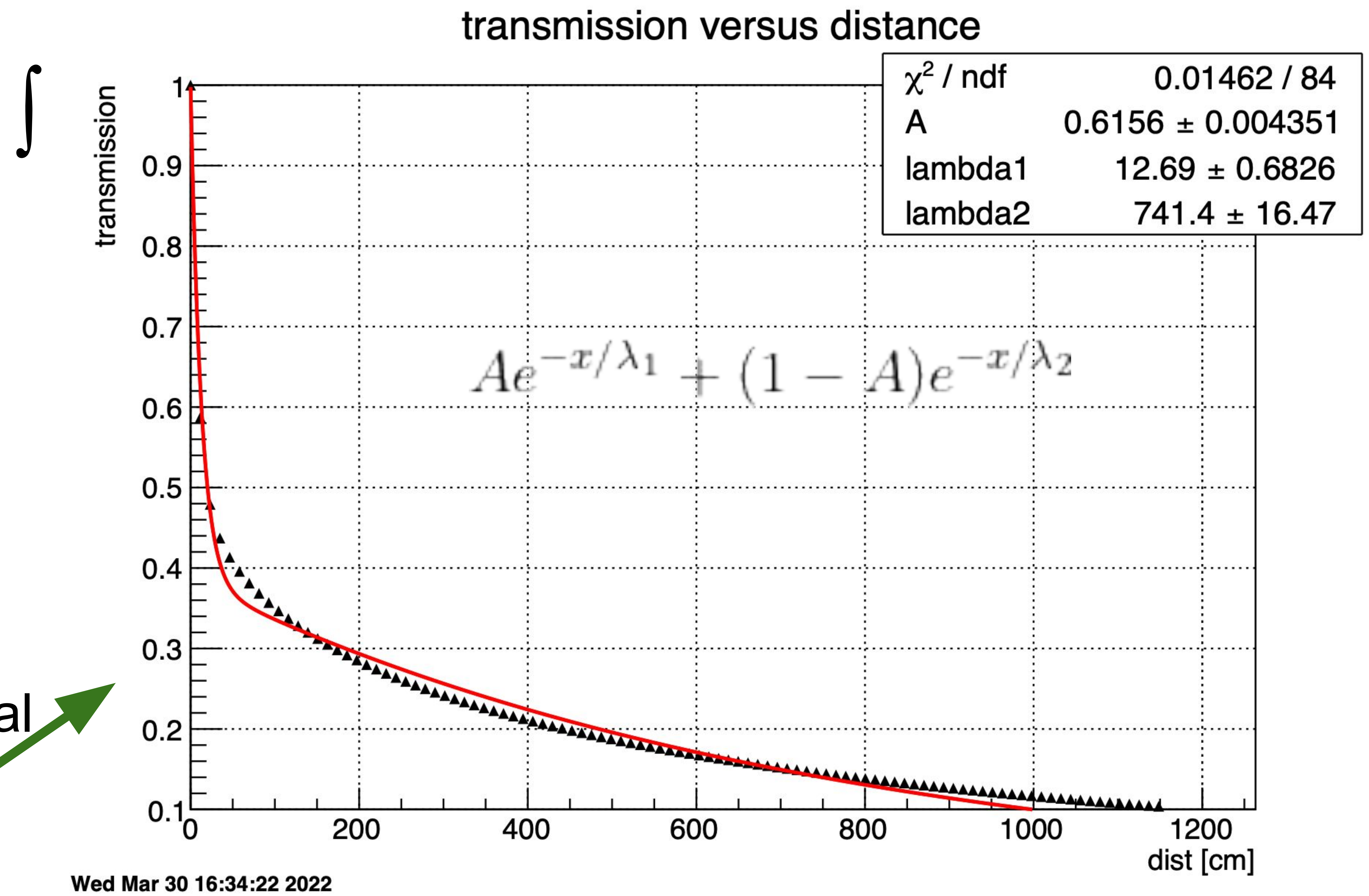


Iterate convolution



Red curve is 11.6 cm (0.1 ppm Xe), green is 23.2 cm, etc.

Integral



For λ_1 = 12.7 cm,

σ_{abs} = 47.6/(12.7 cm)/(0.1 ppm)= 37.5 Mb

in agreement with Calvo *et al.* ArDM

Our Model

k_x is calculated diffusion limited reaction rate in LAr for Ar, to Xe (scales with Xe concentration) $k_x = 2.9 \times 10^{-4}$ x [ppm] ns^{-1}

time dependencies of the different states. Our model consists of the following coupled differential equations for the number of molecules as a function of time t for the dimer states argon singlet $S(t)$, argon triplet $T(t)$, mixed $M(t)$ and xenon $X(t)$:

$$\dot{S} = -S/\tau_S - (k_x + k_q) S \equiv -\lambda_1 S \tag{1}$$

$$\dot{T} = -T/\tau_T - (k_x + k_q) T \equiv -\lambda_3 T \tag{2}$$

$$\dot{M} = -\left(1/\tau_M + k_x + k'_q\right) M + \left(k_x + A/\tau_S\right) S + \left(k_x + A/\tau_T\right) T \tag{3}$$

$$\dot{X} = -X/\tau_x + k_x M \tag{4}$$

Note: Below 0.5 ppm, quenching is faster than diffusion.

Note: We are adding the intermediate light in the model (can see the effect).

We take A from the fit to the absorption curve.

$k_{q'} \sim k_q = 1.3 \times 10^{-4}$ ns^{-1} are quenching rates (Segreto, *Phys.Rev.D* 103 (2021) 4, 043001)

Light yield (time)

Then these equations are easily integrated giving S(t), T(t), M(t) and X(t), and the light seen (128 nm + 150 nm + 175 nm) is given by:

$$\ell(t) = N_1 \boxed{(1-A)}\, e^{-t\lambda_1}/\tau_S + N_3 \boxed{(1-A)}\, e^{-t\lambda_3}/\tau_T + M(t)/\tau_M + X(t)/\tau_X$$

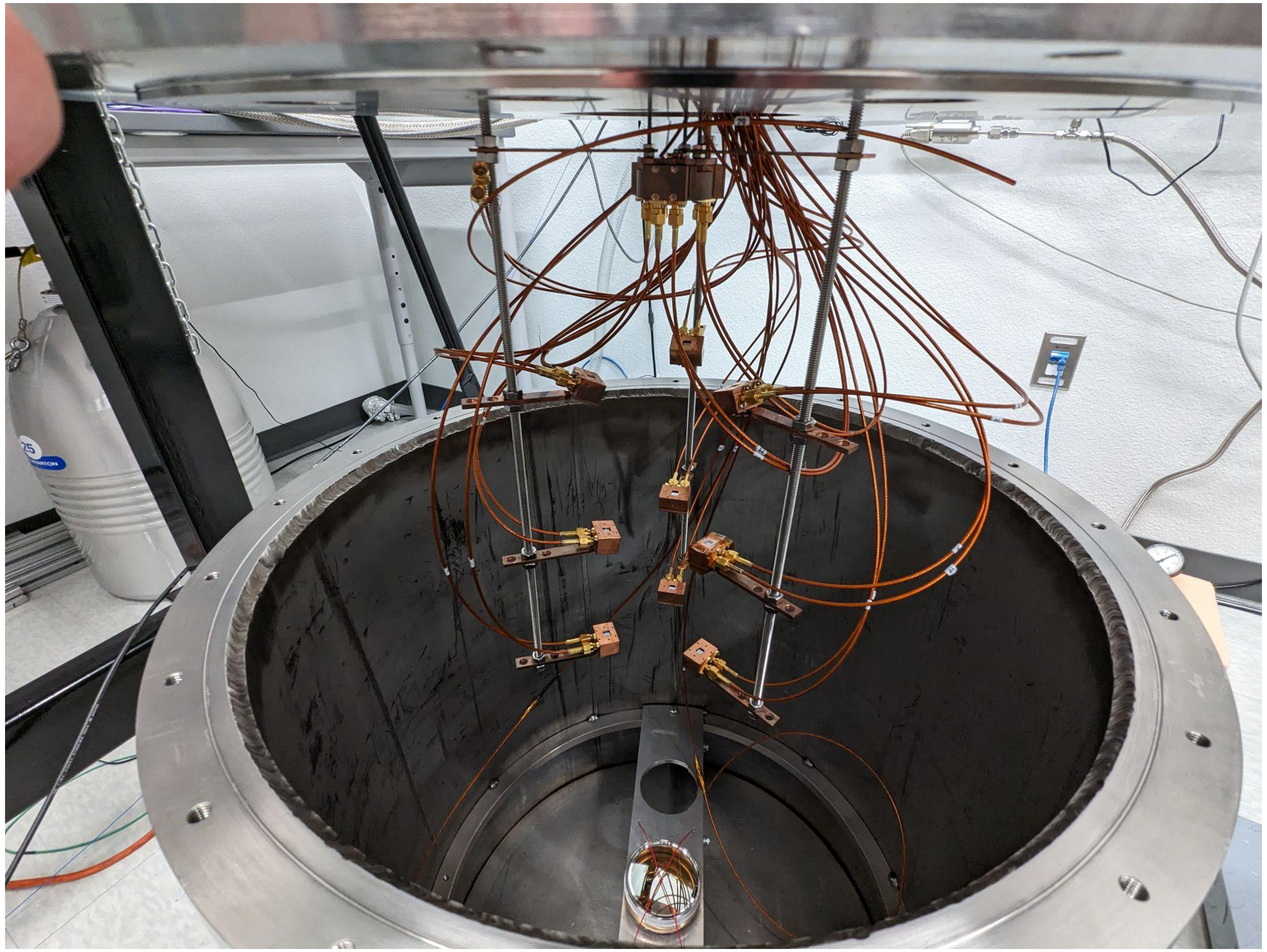
In terms of singlet fraction (sfrac) N_1 = N*sfrac, N_3 = N(1-sfrac)

N is the total number of dimers created by initial ionization

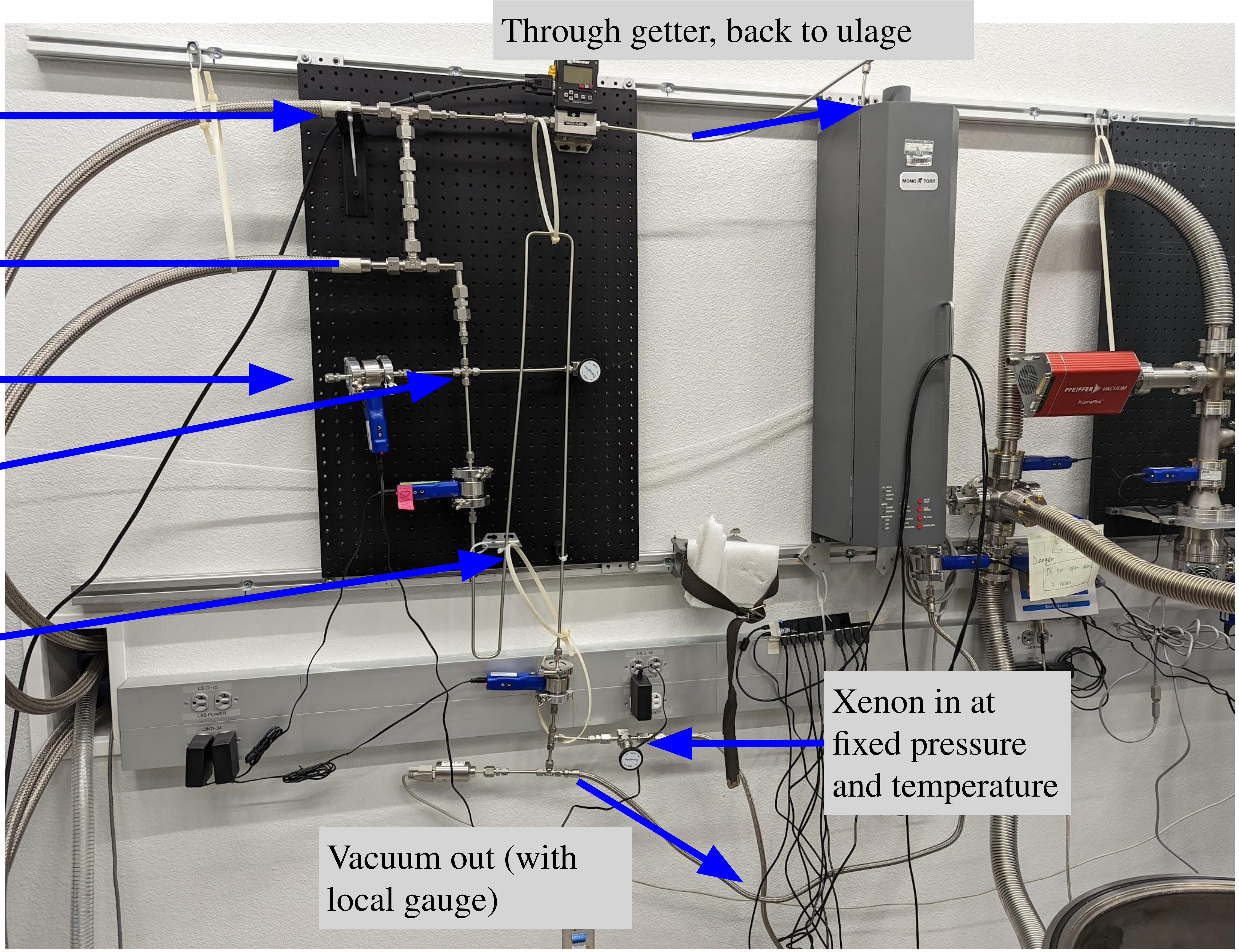
Similar to Segretto, but includes absorption, and is based on diffusion times

New Setup

- One Hamamatsu R11410 (sensitive to 175 nm, but not 128 nm).
- Triggered ^{241}Am source aka Llama (LEGEND LAr monitoring system from TUM).
- Three levels of 3 SiPM (Hamamatsu 13370) detectors sensitive to both 128 nm and 175 nm.
- One SiPM covered with Suprasil glass to block 128 nm light.



Doping Procedure



In from recirculation pump

Out to recirculation pump

In from LAr ulage

Mixes with ulage

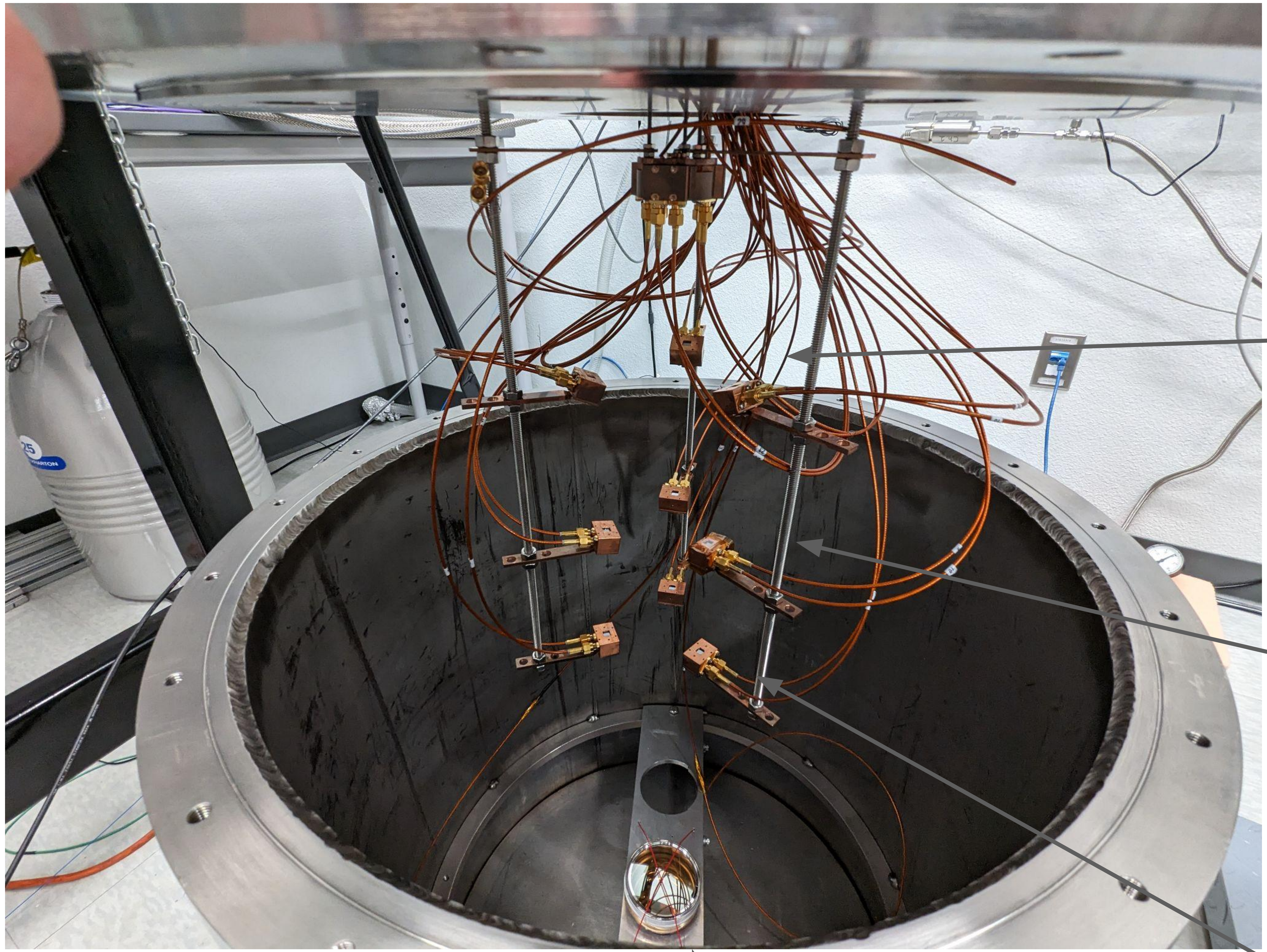
U-tube (fixed volume)

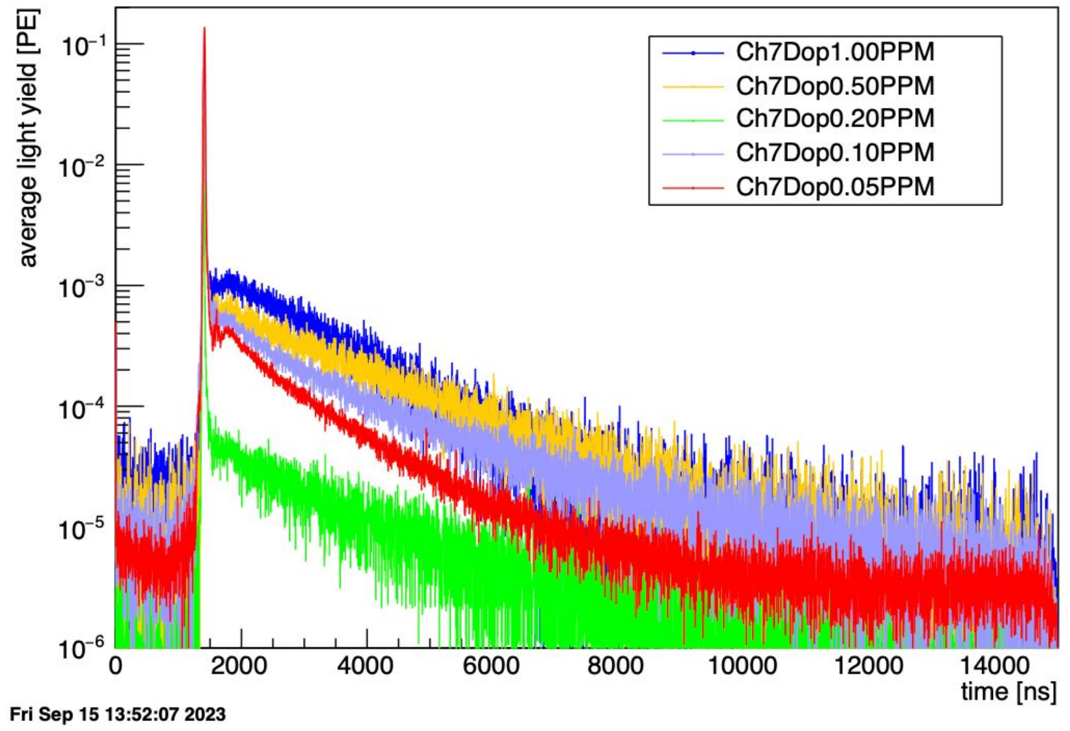
Through getter, back to ulage

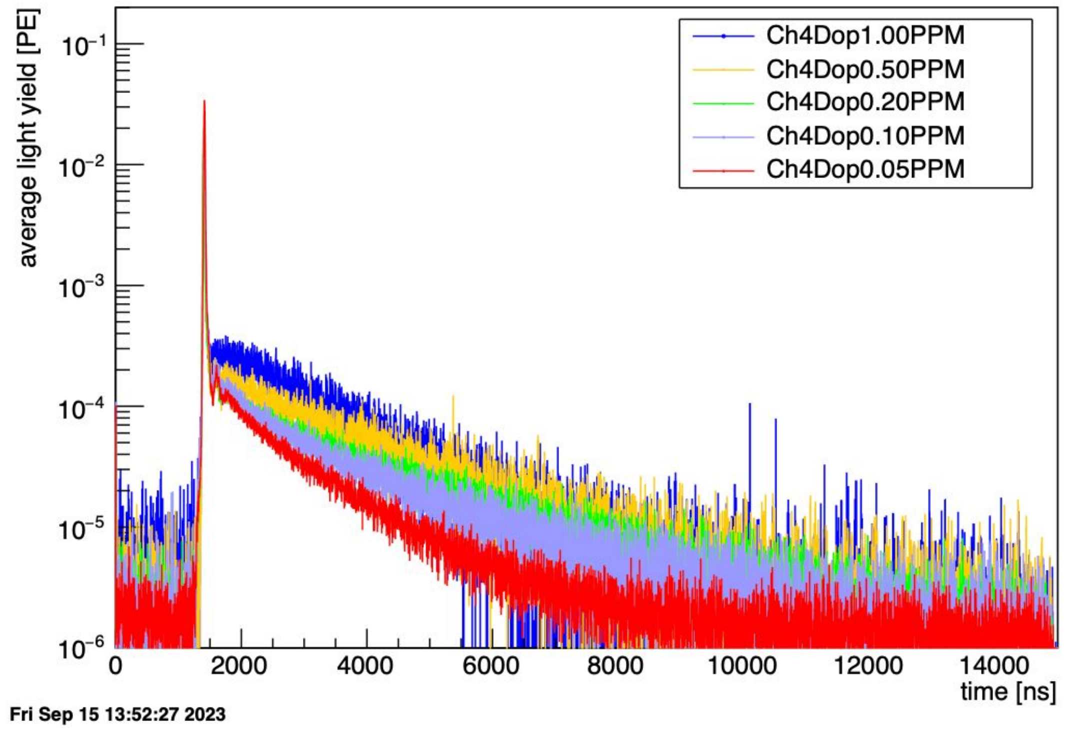
Xenon in at
fixed pressure
and temperature

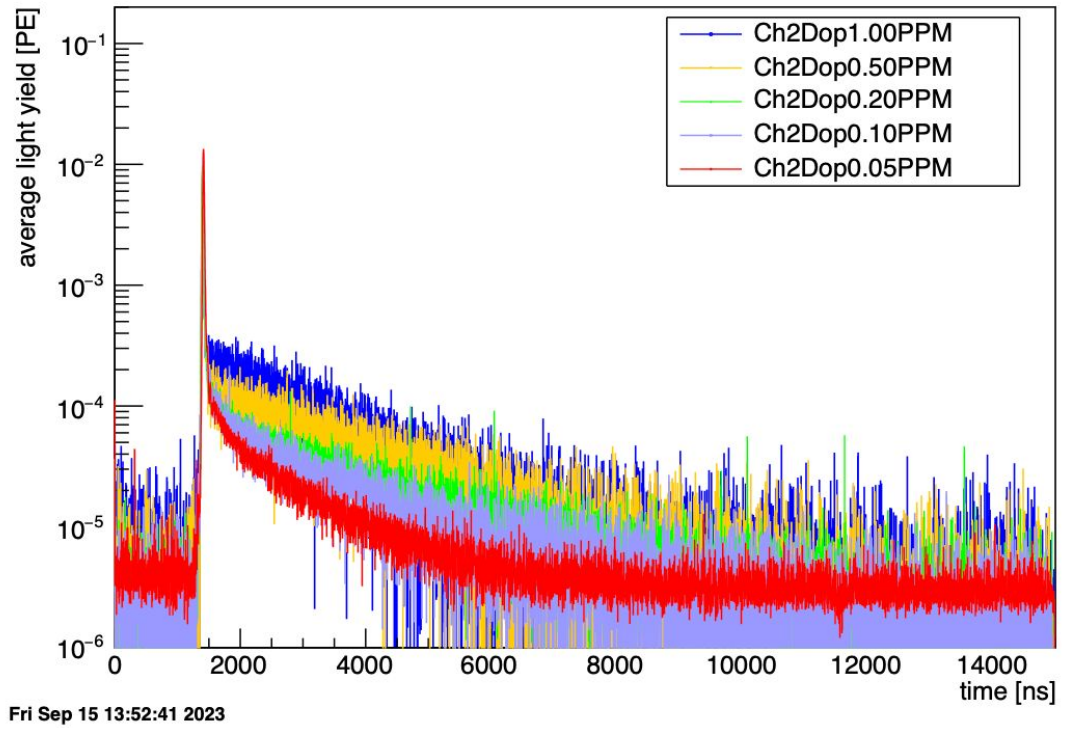
Vacuum out (with
local gauge)

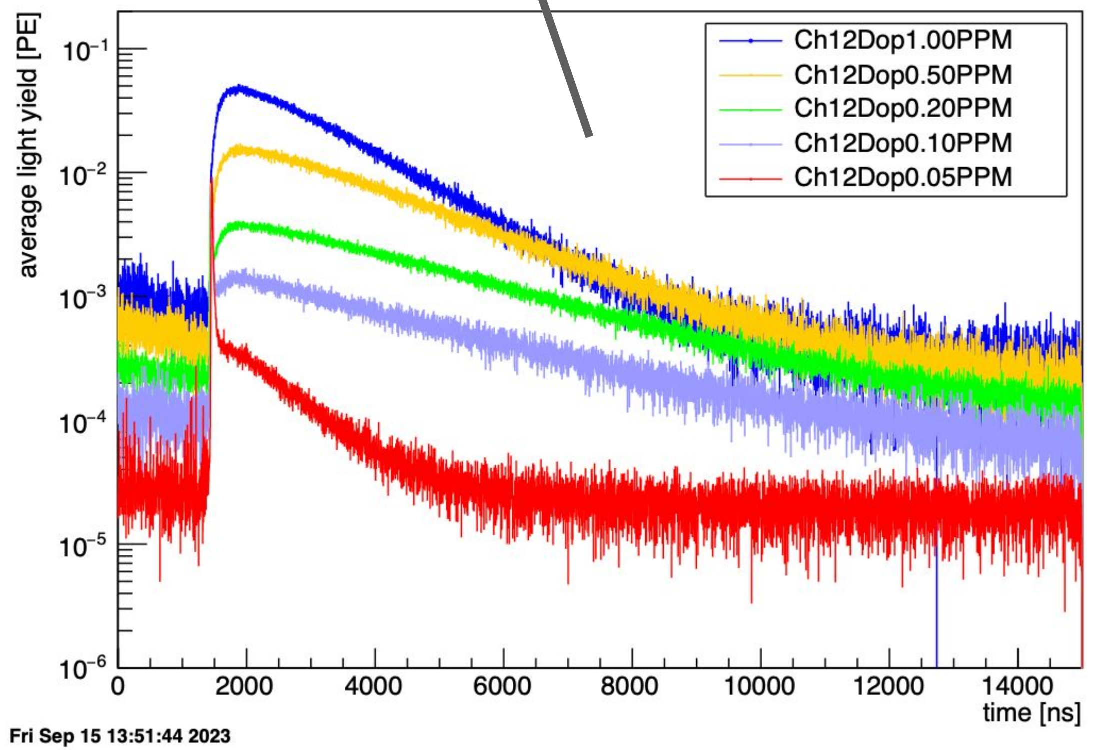
Preliminary Data











Undoped 0.01 - 0.07 ppm

Doped 0.1 ppm

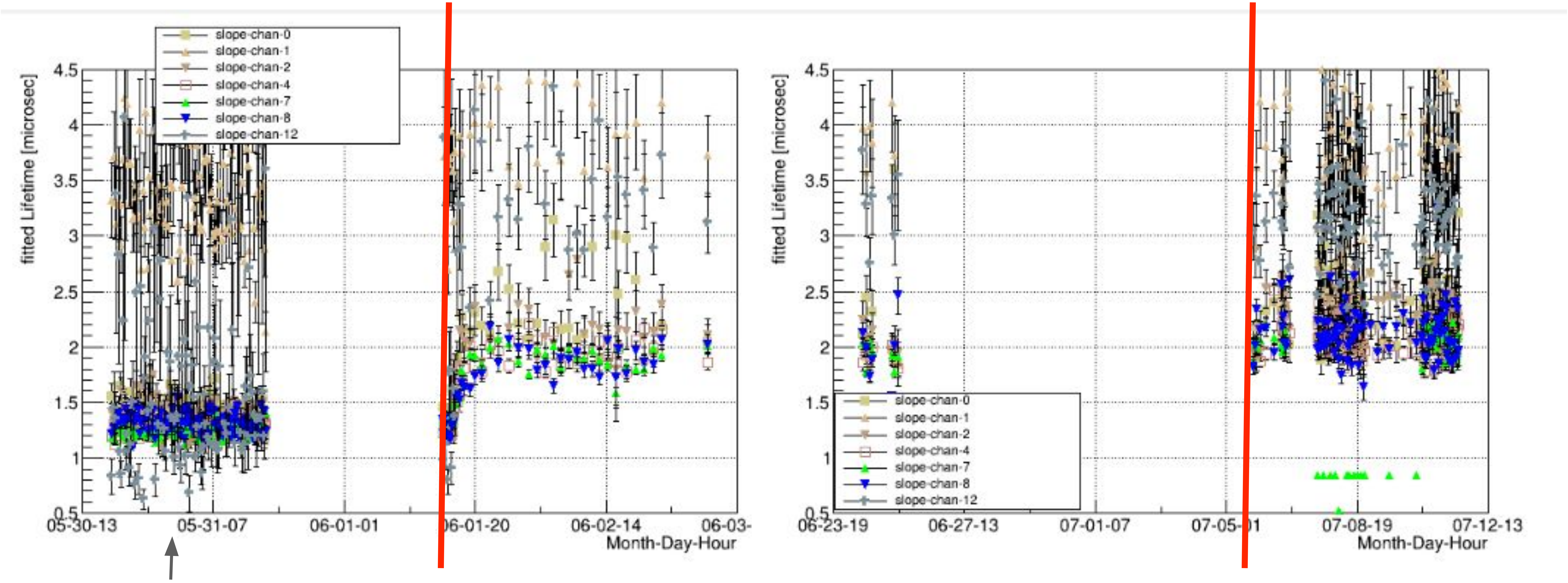
Doped 0.2 ppm

Doped 0.5 ppm

Doped 1.0 ppm

Preliminary Xe-Doping Data

Slopes from ~1.5 μs after singlet to 5 μs



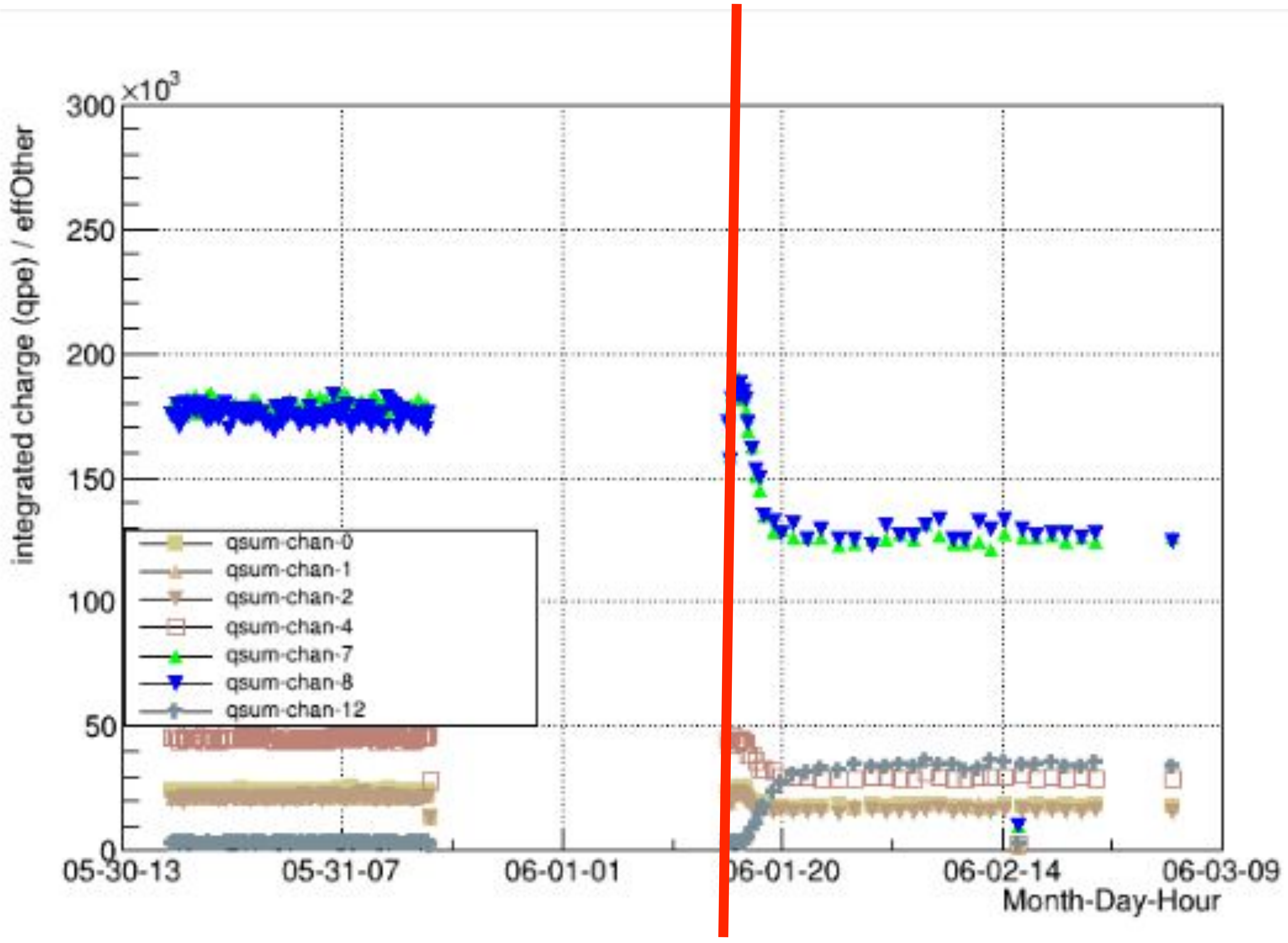
initial xenon concentration in ulage measured to be 0.01 +/- 0.07 ppm

0.1 ppm (added to initial)

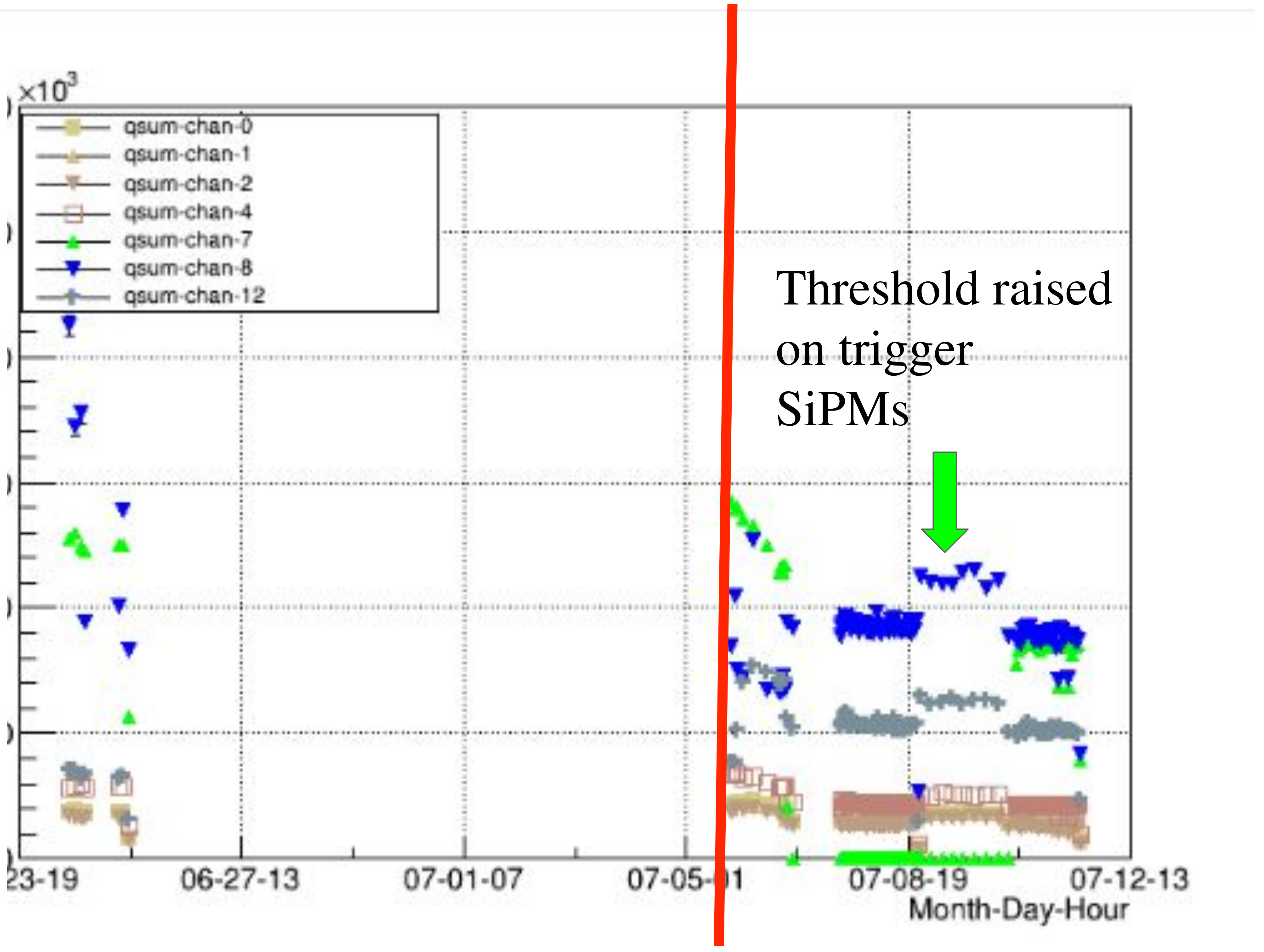
0.2 ppm total added

Preliminary Xe-Doping Data

Integrated charge from ~1.5 μs after singlet to 5 μs



0.1 ppm (added to initial)

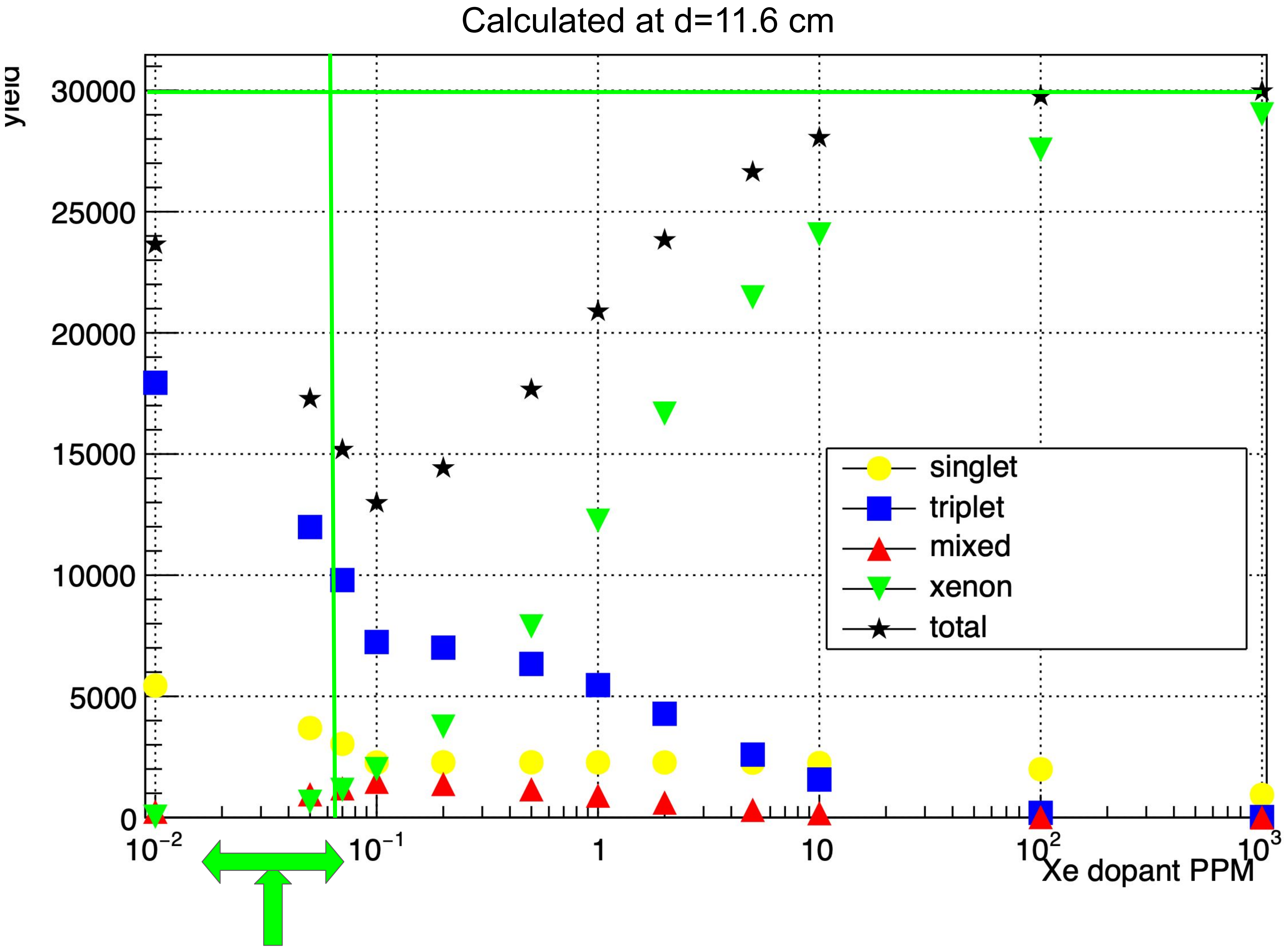


Threshold raised on trigger SiPMs

0.2 ppm total added

Model Prediction (NOT yet tuned to data)

- At doping levels greater than 0.1, we take A to be constant (as in our fits), but at very low PPM, the assumption of constant absorption is no longer valid, so we use values of A from the previous fit.
- From the model we can understand the increase in light given the initial concentration of Xe in the LAr.
- Notice that there is still very strong reduction in light at 0.1 ppm Xe
- Even at 0.01 ppm, the yield is still only 80% of original (number of excitons).
- At 10 ppm Xe, light is recovered to >90% of original.



Initial Xe concentration

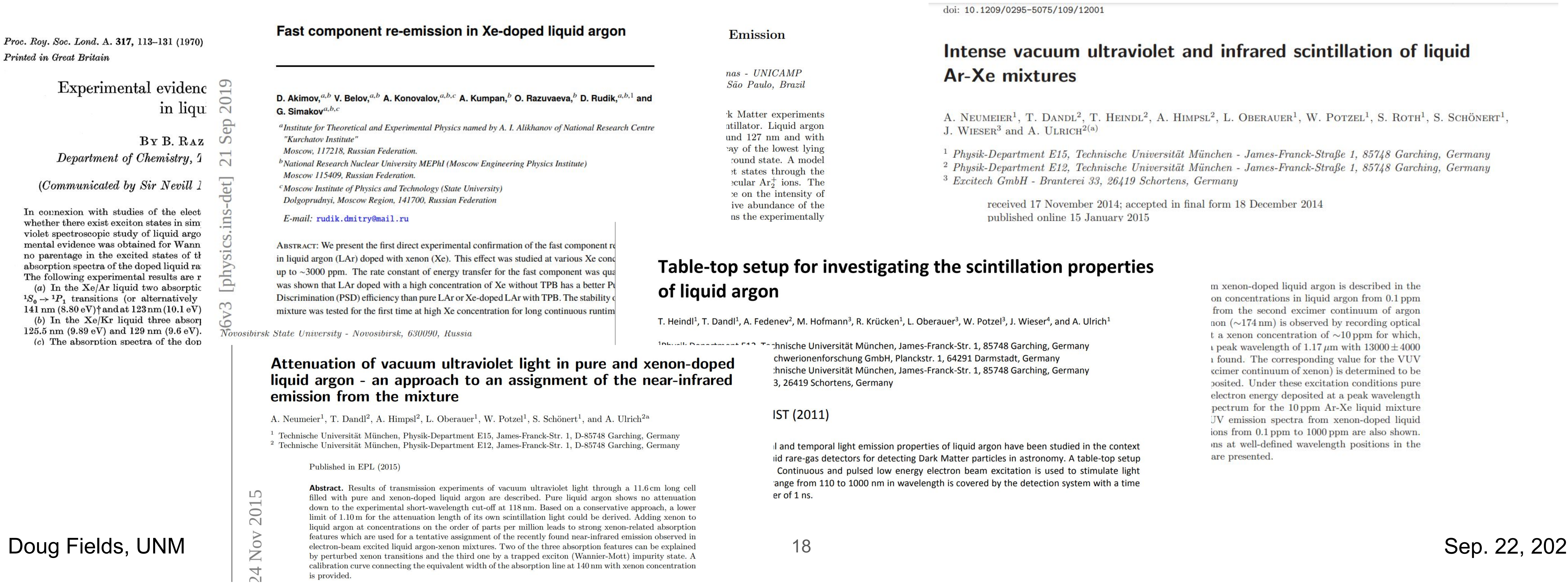
Conclusions

- Xenon absorption of Argon 128 nm scintillation light is complicated and has a significant effect on the time spectra of emission and light yields even at very low concentrations.
- Quenching of long-lived states can account for increased light yields at Xe doping levels above 1 ppm.
- Our upcoming runs should narrow the parameter space for lifetimes and quenching times, and we can examine the effect on the fast/slow ratio for PID.
- Can also add N_2, etc. to the model…
- Thank you for staying to the end!

Backup

Scintillation light in LAr

There have been many papers and much work done to characterize and understand the amount and time distribution of scintillation light in liquid argon…



Proc. Roy. Soc. Lond. A. **317**, 113–131 (1970)
Printed in Great Britain

Experimental evidenc
in liqu

By B. Raz
Department of Chemistry, 7

(*Communicated by Sir Nevill 1*

In connexion with studies of the elect
whether there exist exciton states in sim
violet spectroscopic study of liquid argo
mental evidence was obtained for Wann
no parentage in the excited states of tl
absorption spectra of the doped liquid ra
The following experimental results are r
(*a*) In the Xe/Ar liquid two absorptic
$^1S_0 \rightarrow {}^1P_1$ transitions (or alternatively
141 nm (8.80 eV)† and at 123 nm (10.1 eV)
(*b*) In the Xe/Kr liquid three absor
125.5 nm (9.89 eV) and 129 nm (9.6 eV).
(*c*) The absorption spectra of the dop

6v3 [physics.ins-det] 21 Sep 2019

Fast component re-emission in Xe-doped liquid argon

D. Akimov,[a,b] V. Belov,[a,b] A. Konovalov,[a,b,c] A. Kumpan,[b] O. Razuvaeva,[b] D. Rudik,[a,b,1] and G. Simakov[a,b,c]

[a] *Institute for Theoretical and Experimental Physics named by A. I. Alikhanov of National Research Centre "Kurchatov Institute"*
Moscow, 117218, Russian Federation.
[b] *National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)*
Moscow 115409, Russian Federation.
[c] *Moscow Institute of Physics and Technology (State University)*
Dolgoprudnyi, Moscow Region, 141700, Russian Federation

E-mail: rudik.dmitry@mail.ru

Abstract: We present the first direct experimental confirmation of the fast component re
in liquid argon (LAr) doped with xenon (Xe). This effect was studied at various Xe conc
up to ~3000 ppm. The rate constant of energy transfer for the fast component was qua
was shown that LAr doped with a high concentration of Xe without TPB has a better Pu
Discrimination (PSD) efficiency than pure LAr or Xe-doped LAr with TPB. The stability c
mixture was tested for the first time at high Xe concentration for long continuous runtim

Novosibirsk State University - Novosibirsk, 630090, Russia

Emission

nas - UNICAMP
São Paulo, Brazil

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doi: 10.1209/0295-5075/109/12001

Intense vacuum ultraviolet and infrared scintillation of liquid Ar-Xe mixtures

A. Neumeier[1], T. Dandl[2], T. Heindl[2], A. Himpsl[2], L. Oberauer[1], W. Potzel[1], S. Roth[1], S. Schönert[1], J. Wieser[3] and A. Ulrich[2(a)]

[1] *Physik-Department E15, Technische Universität München - James-Franck-Straße 1, 85748 Garching, Germany*
[2] *Physik-Department E12, Technische Universität München - James-Franck-Straße 1, 85748 Garching, Germany*
[3] *Excitech GmbH - Branterei 33, 26419 Schortens, Germany*

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published online 15 January 2015

m xenon-doped liquid argon is described in the
on concentrations in liquid argon from 0.1 ppm
from the second excimer continuum of argon
non (~174 nm) is observed by recording optical
t a xenon concentration of ~10 ppm for which,
ı peak wavelength of 1.17 μm with 13000 ± 4000
ı found. The corresponding value for the VUV
xcimer continuum of xenon) is determined to be
posited. Under these excitation conditions pure
electron energy deposited at a peak wavelength
pectrum for the 10 ppm Ar-Xe liquid mixture
UV emission spectra from xenon-doped liquid
ions from 0.1 ppm to 1000 ppm are also shown.
ns at well-defined wavelength positions in the
are presented.

Table-top setup for investigating the scintillation properties of liquid argon

T. Heindl[1], T. Dandl[1], A. Fedenev[2], M. Hofmann[3], R. Krücken[1], L. Oberauer[3], W. Potzel[3], J. Wieser[4], and A. Ulrich[1]

chnische Universität München, James-Franck-Str. 1, 85748 Garching, Germany
chwerionenforschung GmbH, Planckstr. 1, 64291 Darmstadt, Germany
chnische Universität München, James-Franck-Str. 1, 85748 Garching, Germany
3, 26419 Schortens, Germany

IST (2011)

l and temporal light emission properties of liquid argon have been studied in the context
id rare-gas detectors for detecting Dark Matter particles in astronomy. A table-top setup
Continuous and pulsed low energy electron beam excitation is used to stimulate light
ange from 110 to 1000 nm in wavelength is covered by the detection system with a time
er of 1 ns.

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24 Nov 2015

Attenuation of vacuum ultraviolet light in pure and xenon-doped liquid argon - an approach to an assignment of the near-infrared emission from the mixture

A. Neumeier[1], T. Dandl[2], A. Himpsl[2], L. Oberauer[1], W. Potzel[1], S. Schönert[1], and A. Ulrich[2a]

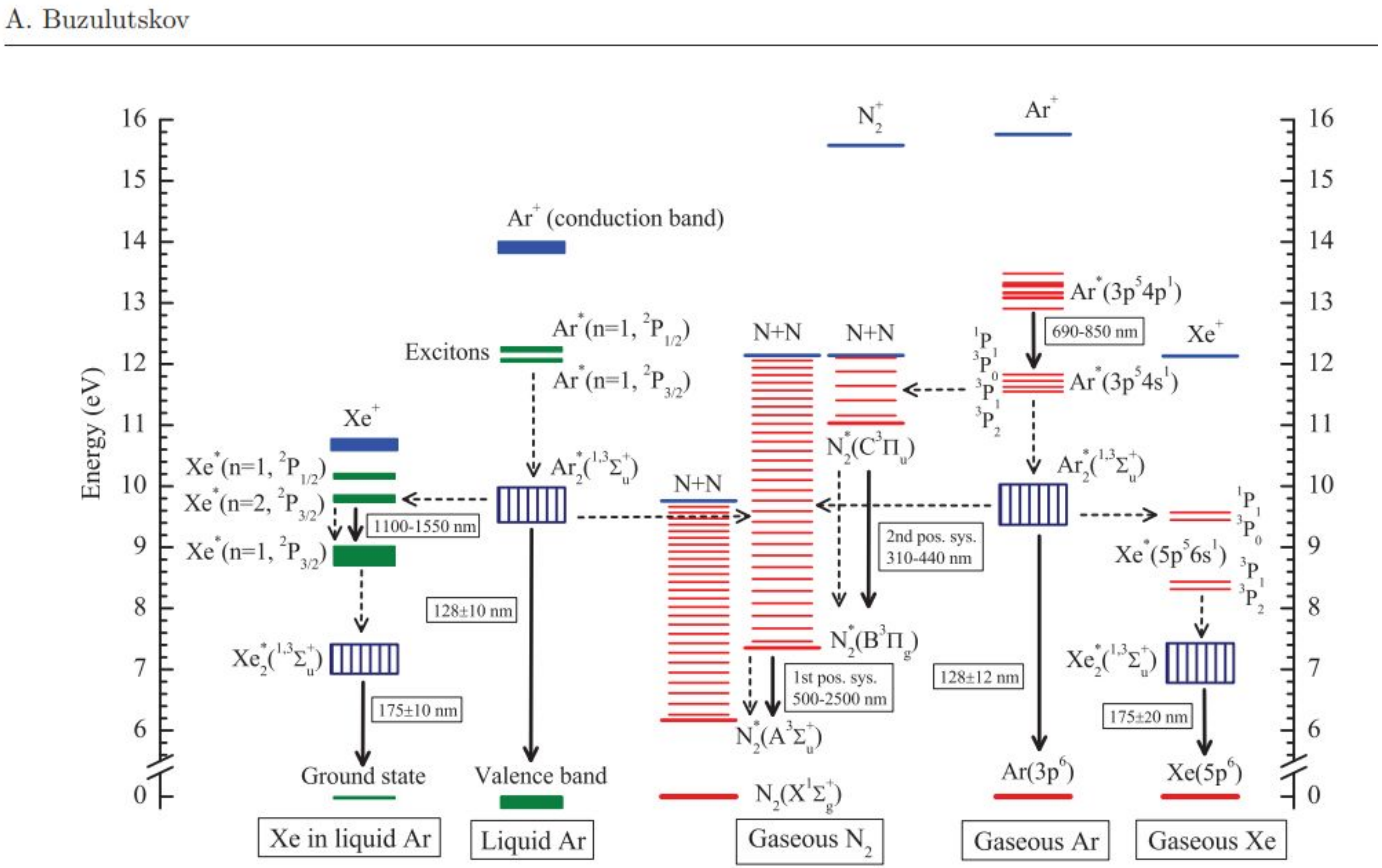
[1] Technische Universität München, Physik-Department E15, James-Franck-Str. 1, D-85748 Garching, Germany
[2] Technische Universität München, Physik-Department E12, James-Franck-Str. 1, D-85748 Garching, Germany

Published in EPL (2015)

Abstract. Results of transmission experiments of vacuum ultraviolet light through a 11.6 cm long cell filled with pure and xenon-doped liquid argon are described. Pure liquid argon shows no attenuation down to the experimental short-wavelength cut-off at 118 nm. Based on a conservative approach, a lower limit of 1.10 m for the attenuation length of its own scintillation light could be derived. Adding xenon to liquid argon at concentrations on the order of parts per million leads to strong xenon-related absorption features which are used for a tentative assignment of the recently found near-infrared emission observed in electron-beam excited liquid argon-xenon mixtures. Two of the three absorption features can be explained by perturbed xenon transitions and the third one by a trapped exciton (Wannier-Mott) impurity state. A calibration curve connecting the equivalent width of the absorption line at 140 nm with xenon concentration is provided.

Starting Point

Not working in an (academic) vacuum, but until now, noone has put all the pieces together…


A. Buzulutskov

Plus Nitrogen

- The addition of Nitrogen involves a complicated cascade of reactions, some of which emit in the IR and UV…
- BUT, decay times are very long (from 10 μs to several ms), hence collisional quenching dominates and one can take excitation energy transfer to Nitrogen excimers as non-photonic.
- So, one could just add another loss term with a time constant equal to the diffusion time times the nitrogen concentration.