INTRODUCTION TO SCINTILLATION LIGHT IN LIQUID ARGON

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The Basics:

Light yield ~ few 10,000's of photons per MeV (dependences on E field, particle type and purity)

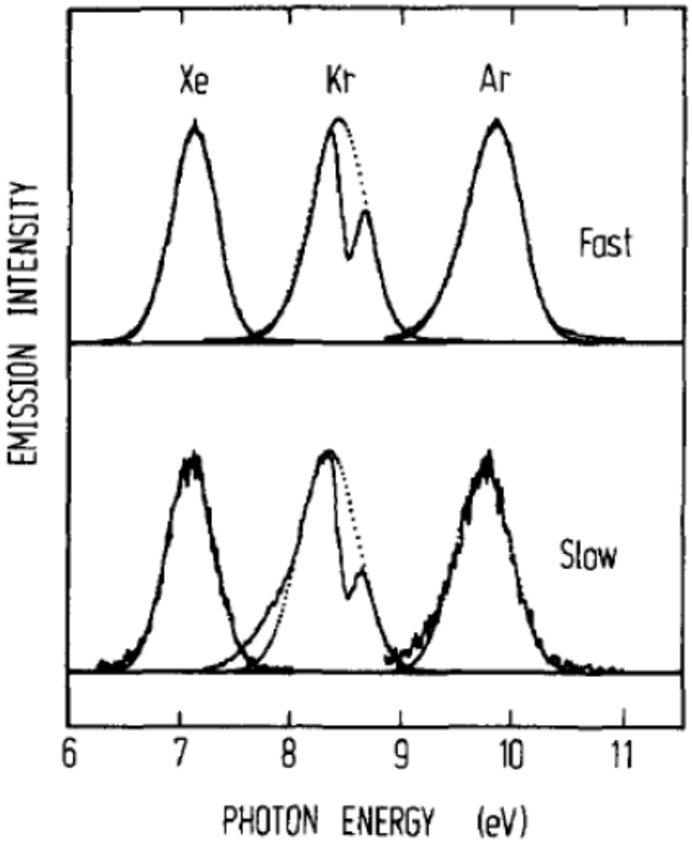
Wavelength of emission is 128nm

Light with two characteristic time constants:

- *fast component, 6 ns*
- *slow component,1500 ns*

Argon is highly transparent to its own scintillation light.

J Chem Phys vol 91 (1989) 1469 E Morikawa et al

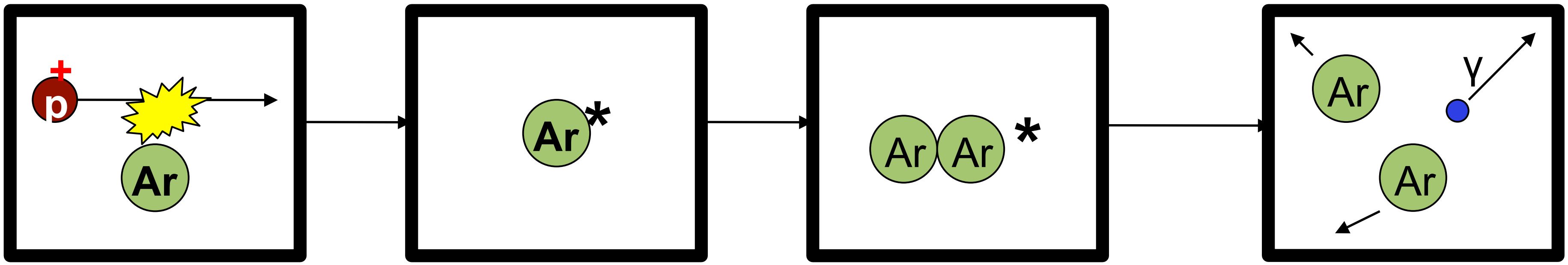


Mechanisms of Scintillation in LAr

In liquid argon, there are two important scintillation mechanisms:

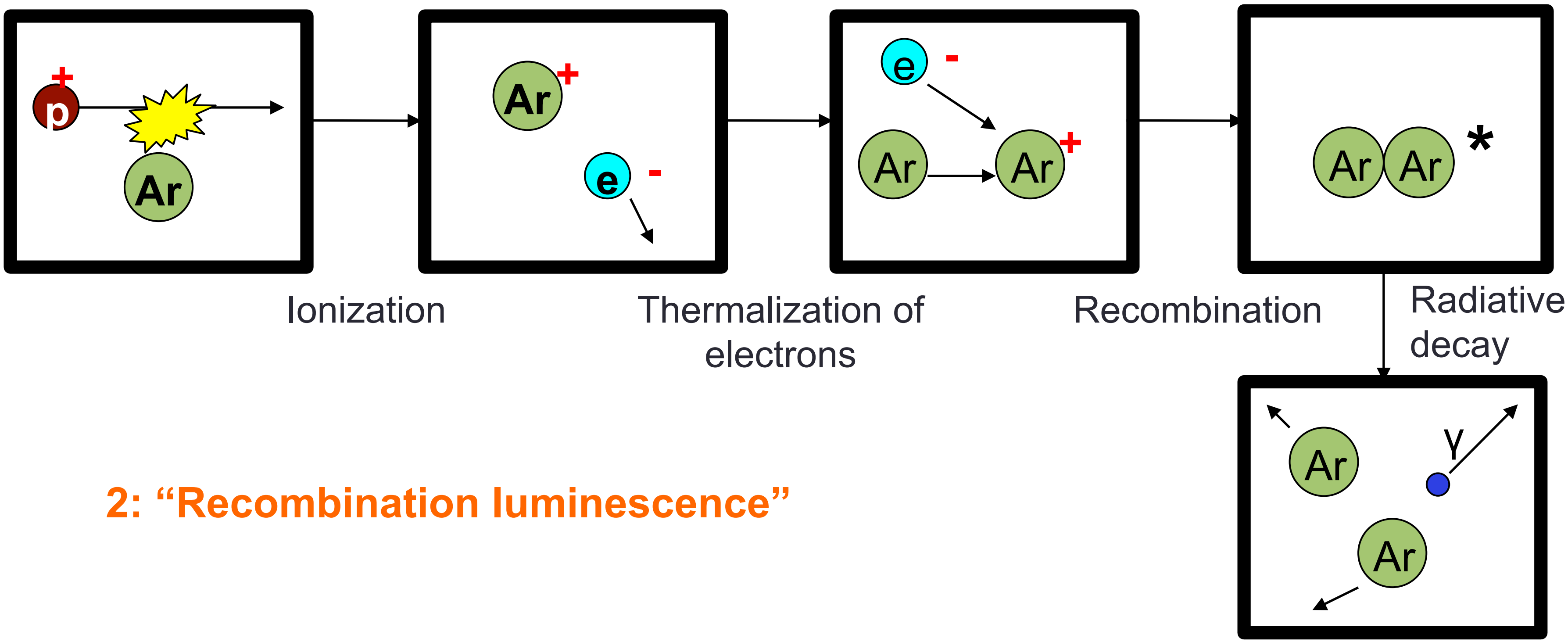
Mechanisms of Scintillation in LAr

1: "Self-trapped exciton luminescence"



Atomic Excitation Self-trapping Radiative decay

Mechanisms of Scintillation in LAr

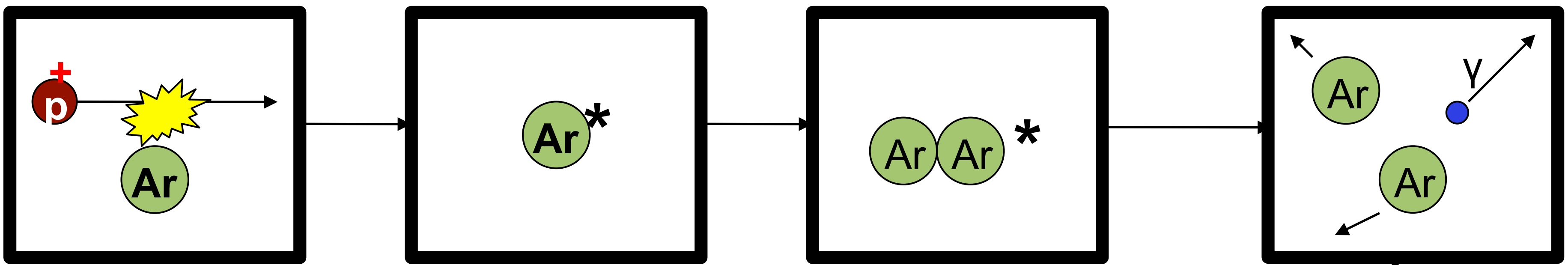


2: "Recombination luminescence"

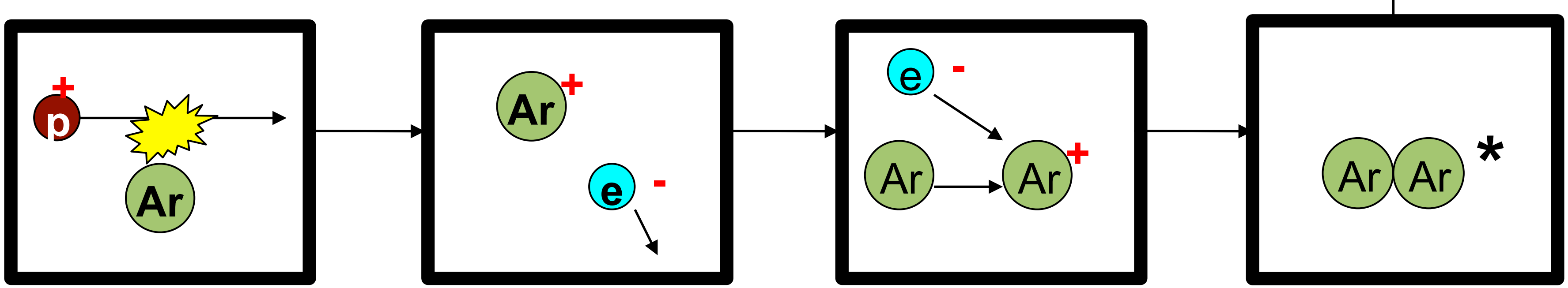
Recombination step involves an electron cloud around the track core

-> E-Field dependent scintillation yield
-> dE/dx dependent scintillation yield
-> Charge and light anti-correlation

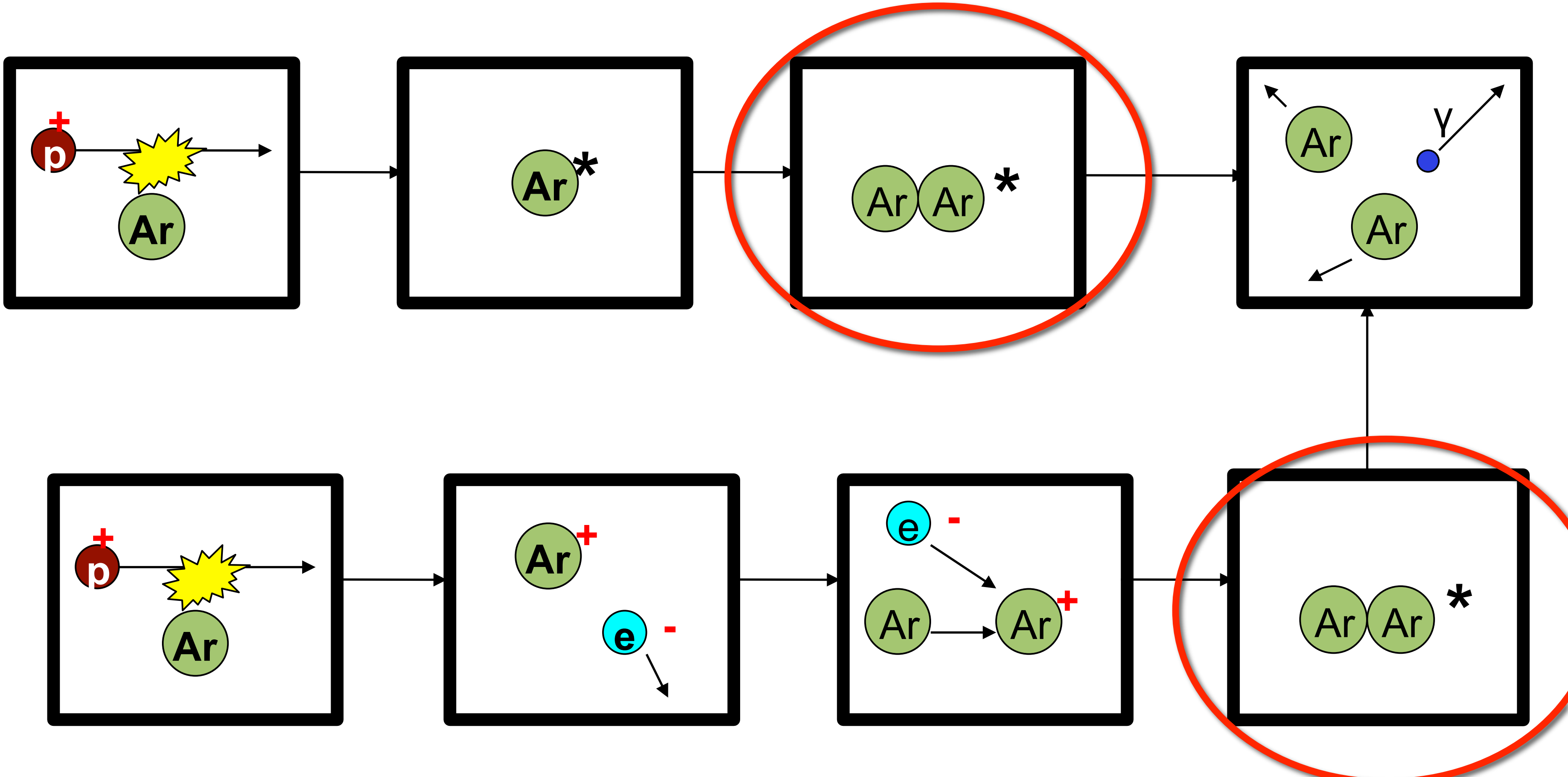
Self-trapped exciton luminescence



Recombination luminescence

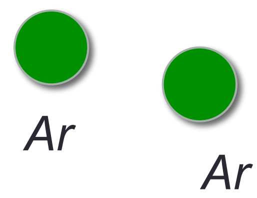


Something to note:

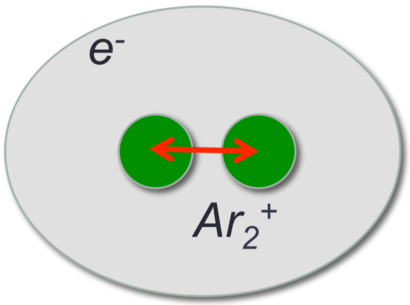


Both pathways rely on the formation of excimers

Ground state of 2 argon atoms is unbound

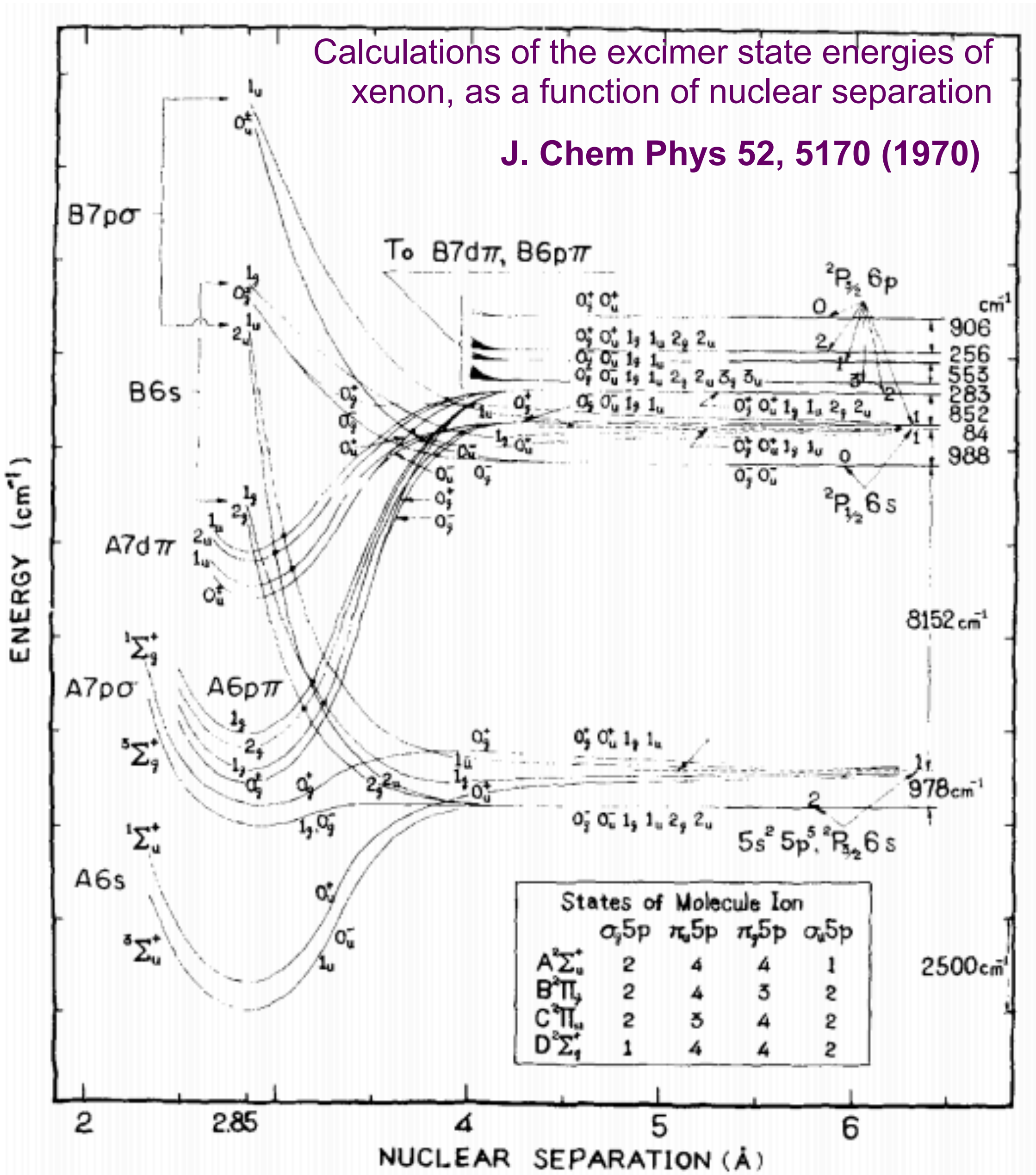


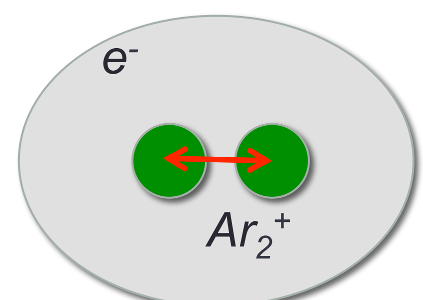
Excimer states are Rydberg states : Ar^{2+} core with a bound electron

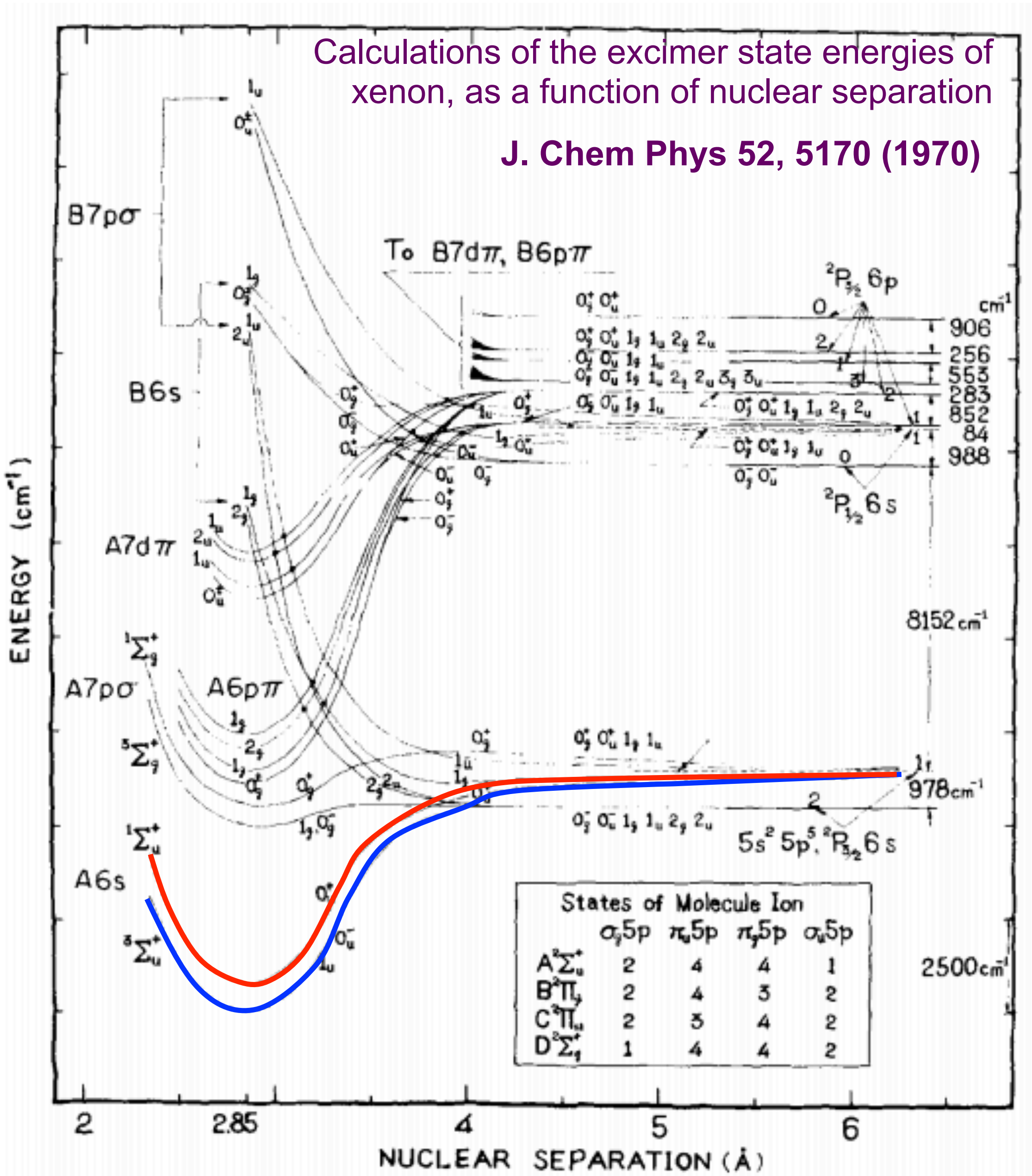


Calculations of the excimer state energies of xenon, as a function of nuclear separation

J. Chem Phys 52, 5170 (1970)





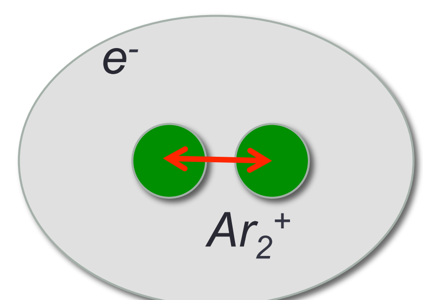


There are two low lying excited states:

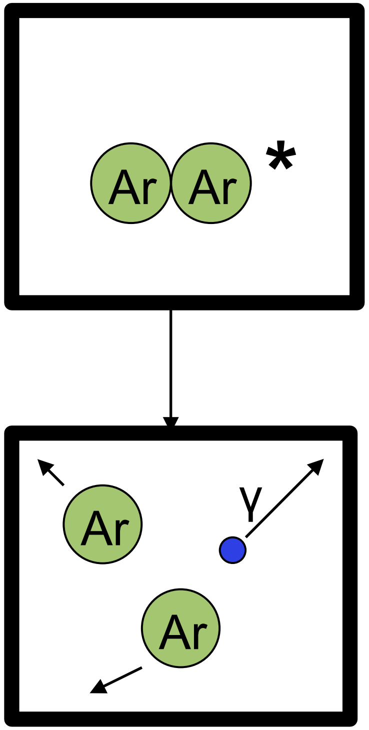
A singlet state $1\Sigma u^{+}$

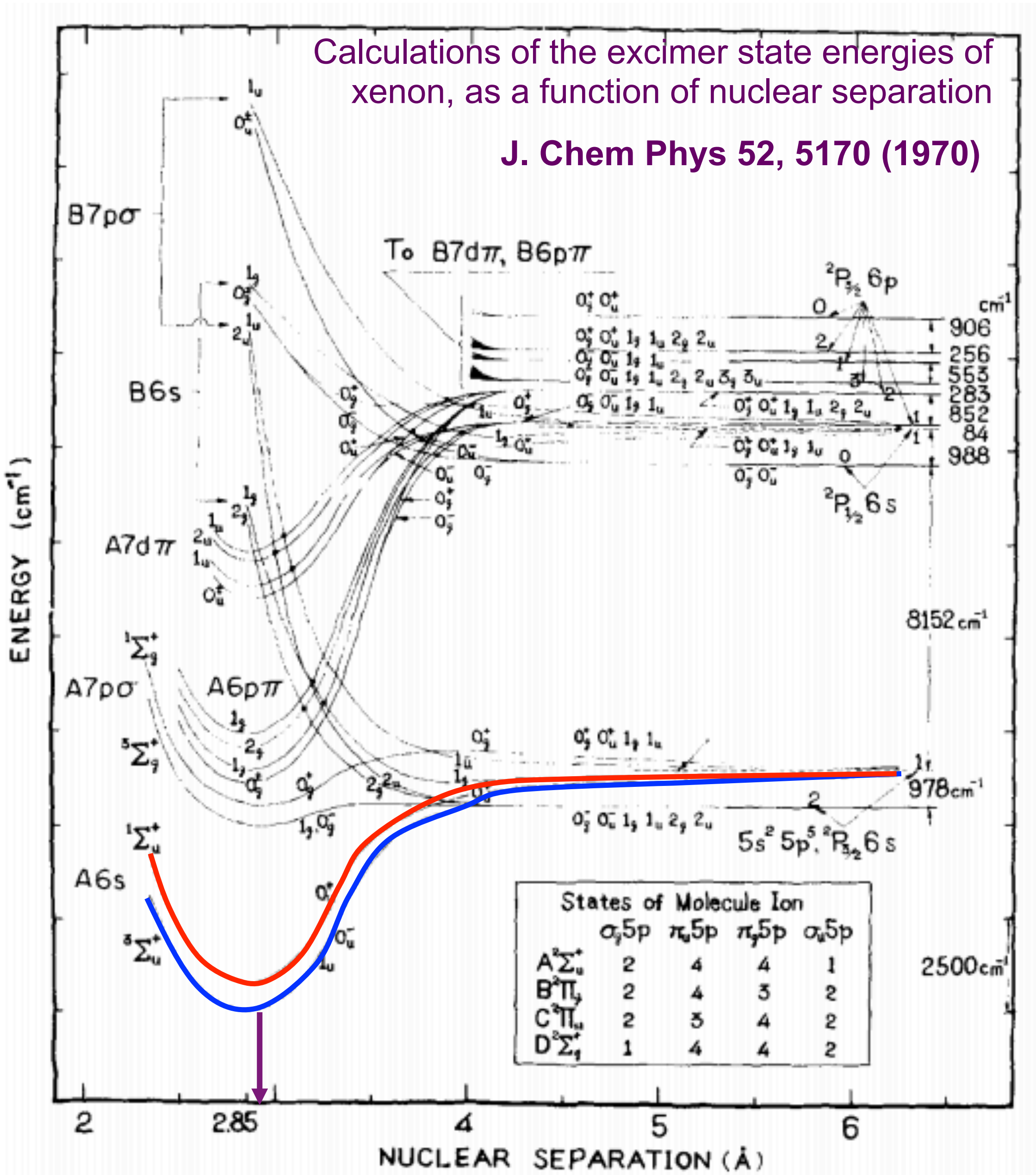
A triplet state $3\Sigma u^{+}$

Singlet and triplet refer to how the spin of the electron and argon dimer couple in the rydberg "atom".



All scintillation light comes from excimer decay



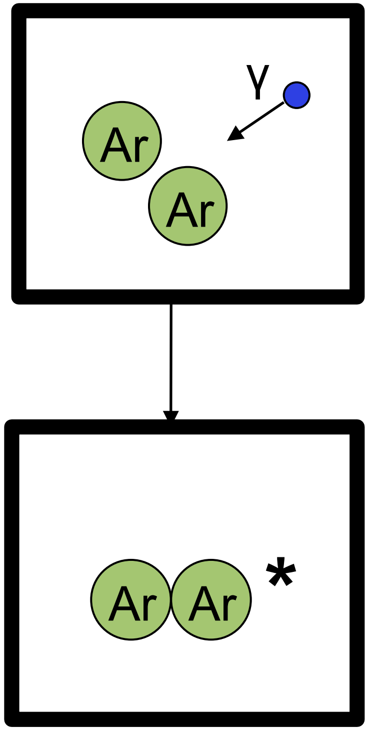


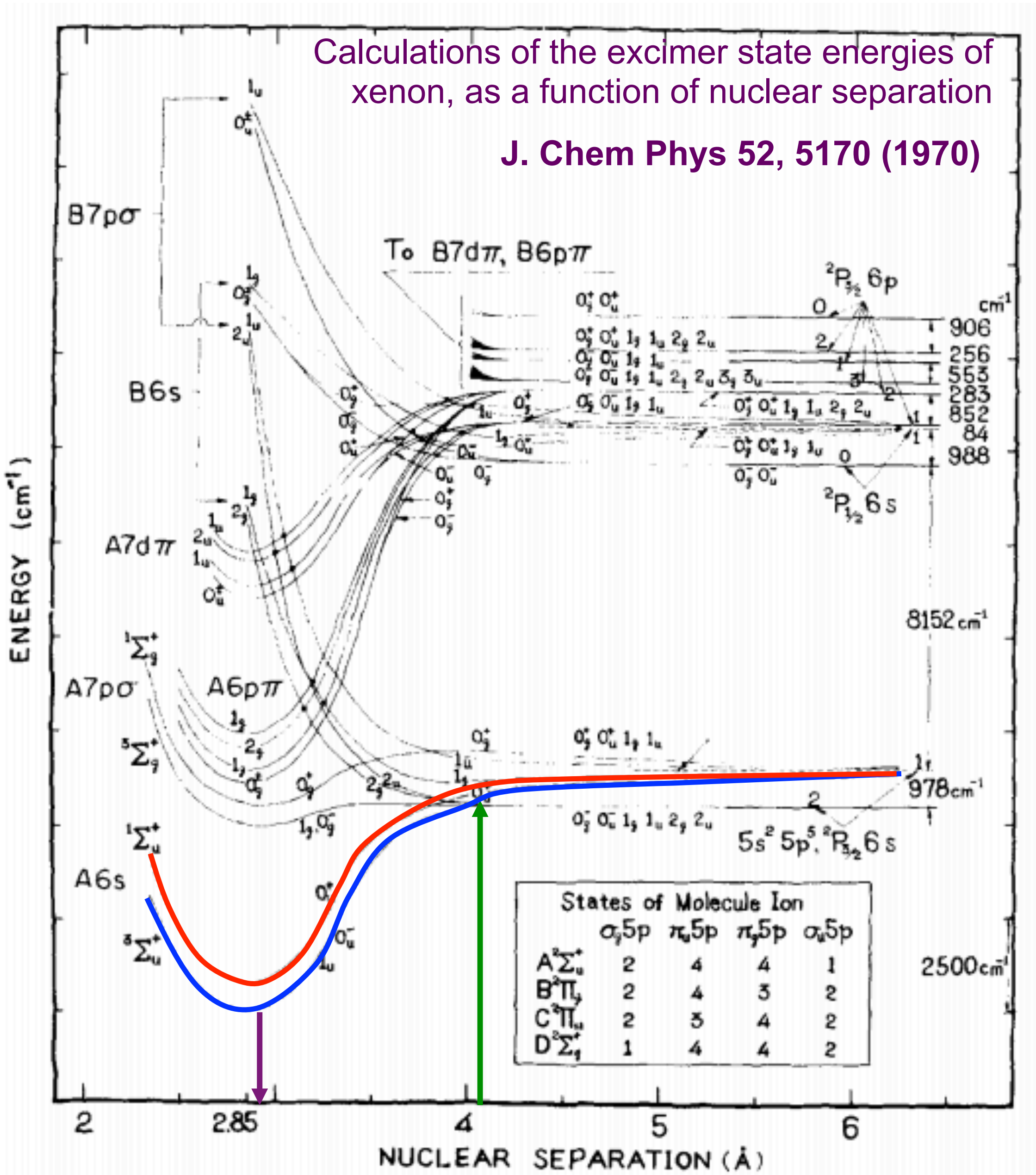
	$\sigma_g 5p$	$\pi_u 5p$	$\pi_g 5p$	$\sigma_u 5p$
$A^2\Sigma_u^+$	2	4	4	1
$B^2\Pi_g$	2	4	3	2
$C^2\Pi_u$	2	3	4	2
$D^2\Sigma_g^+$	1	4	4	2

Why are LAr / LXe transparent to their own scintillation light?

128 nm photon emission

How about the reverse process (absorption?)





Why are LAr / LXe transparent to their own scintillation light?

Typical separation in the liquid phase ground state (~4A, naively from liquid density)

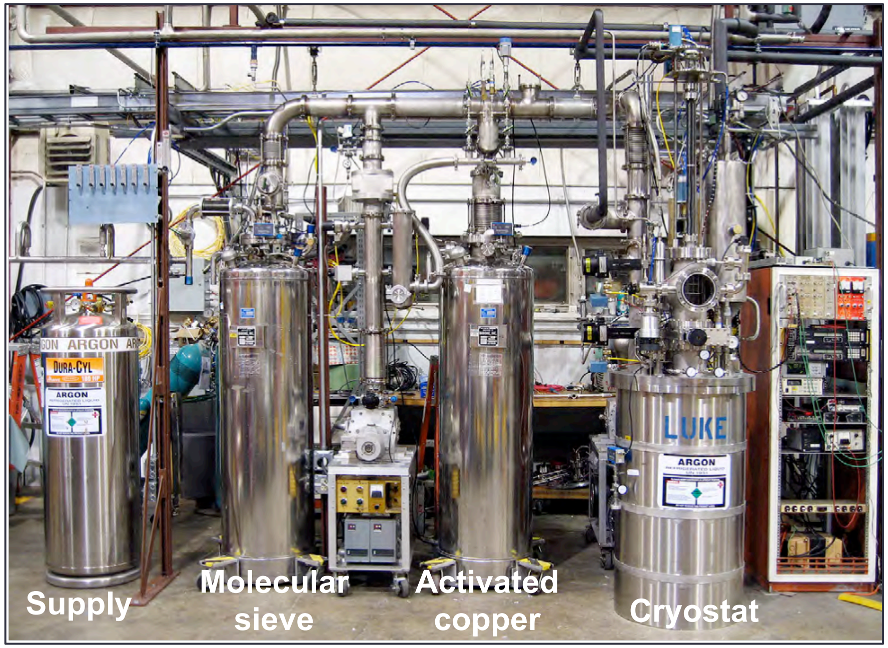
128 nm photon emission

Impurities in LAr

- Ultra-pure argon is very transparent. Dirty argon is not.
- All liquid argon will have trace impurities at some level.
- Some impurities are important for drift, some for light, some for both.
- Impurities which are difficult / expensive to remove are those which are
  - *1) present in the raw gas*
  - *2) similar in boiling point to LAr*
  - *3) not removable by regenerable filtering techniques*
- The composition of impurities depends on the source of the raw gas.

An argon isolation plant

- ***Industrial argon for large neutrino detectors***
- Large quantity required at low cost
- Raw gas : air
- Produced by industrial distillation and then purification with molecular sieves and filters
- Contaminants include ***nitrogen*** (ppm), oxygen and water (<ppb)



Flare filter + sieve system (FNAL)

- ***Underground argon for dark matter detectors***
- Low radioactivity from ^{39}Ar required
- Raw gas : CO_2 from underground wells
- Produced by VPSA, cryogenic distillation and filtering
- Contaminants include helium, ***methane***, O_2, CO_2 H_2O

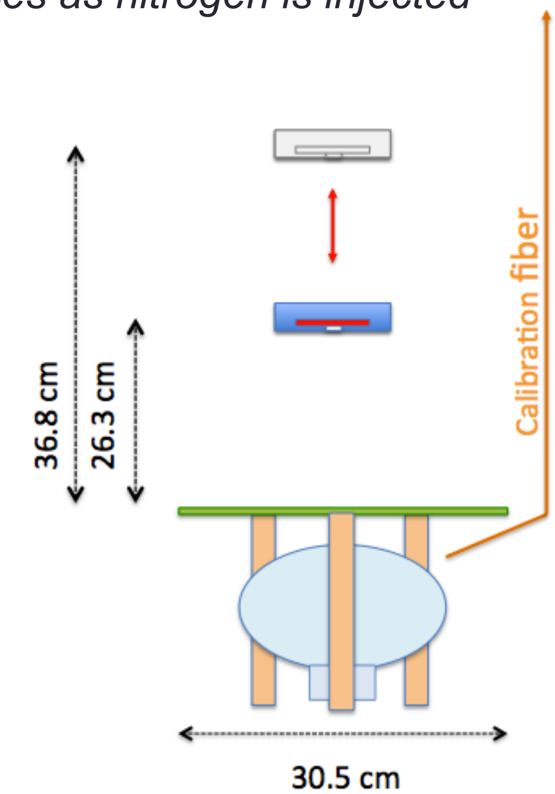
Underground argon distillation column (FNAL)

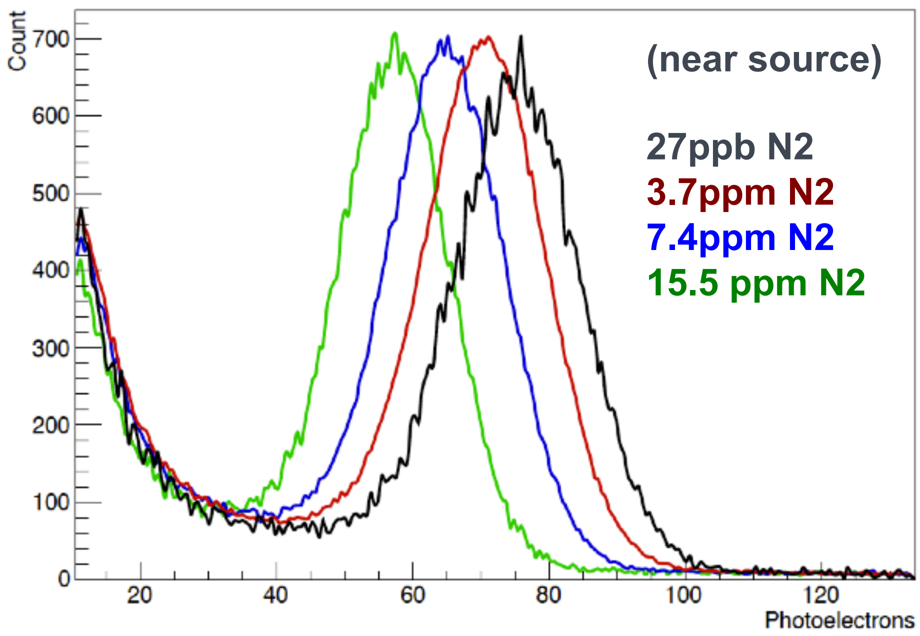
Absorption by Nitrogen

Shown at last years LArTPC workshop – absorption due to dissolved nitrogen at the ppm level:

BJPJ et al, 2013 JINST 8 P07011

Monitor light yield from 2 sources as nitrogen is injected



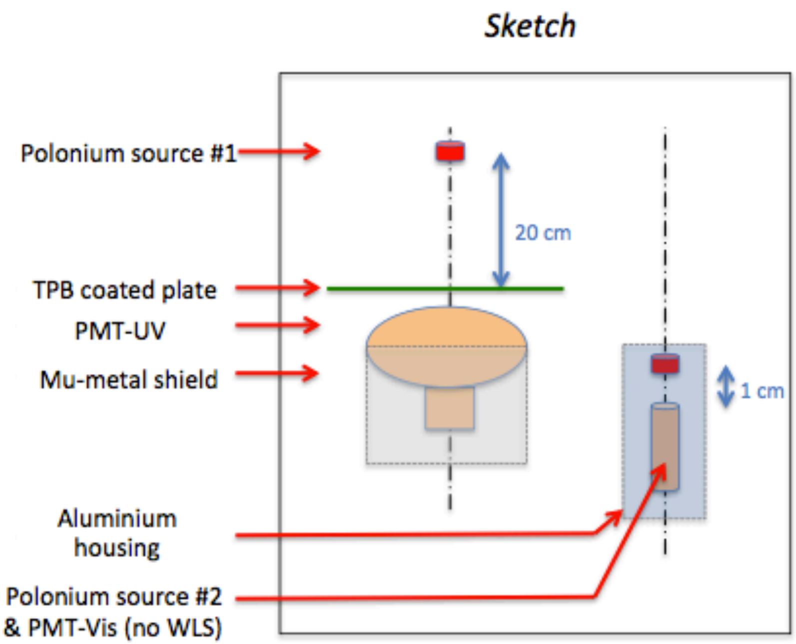


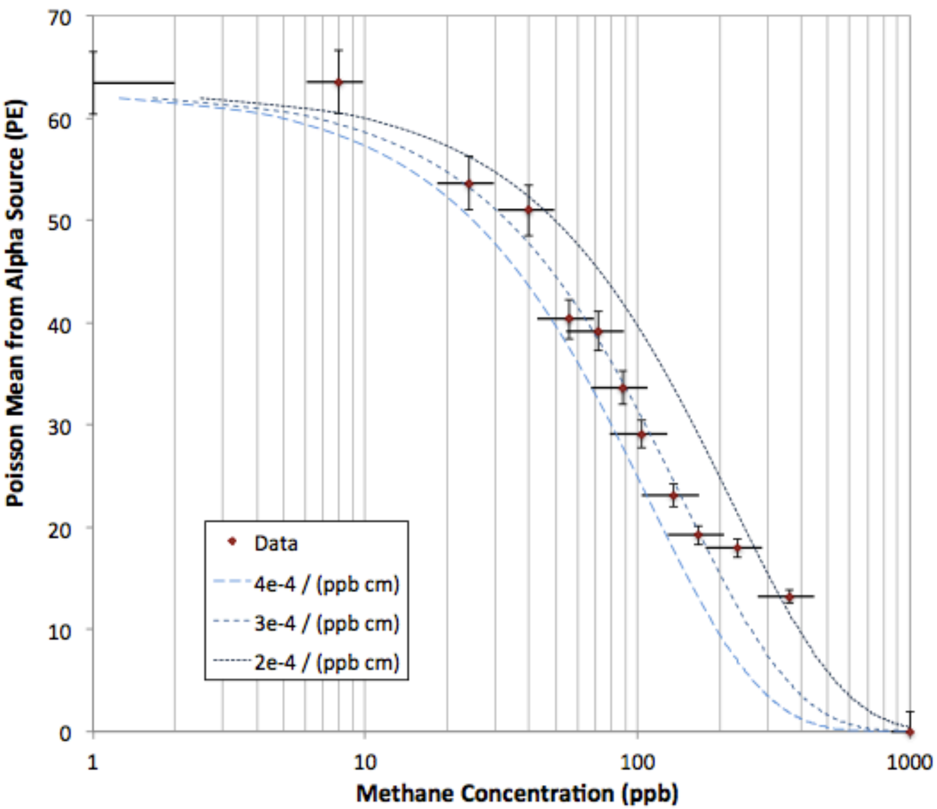
Expected attenuation length due to N2 at 2ppm (MicroBooNE cryo spec) is ~30m.

Absorption by Methane

New for this year's meeting – the effects of methane have also been studied in both visible and UV:

BJPJ et al, 2013 JINST 8 P12015

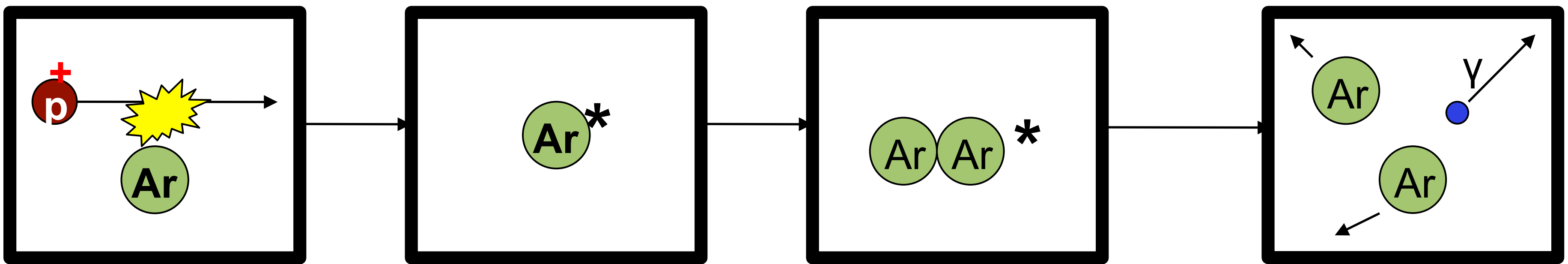




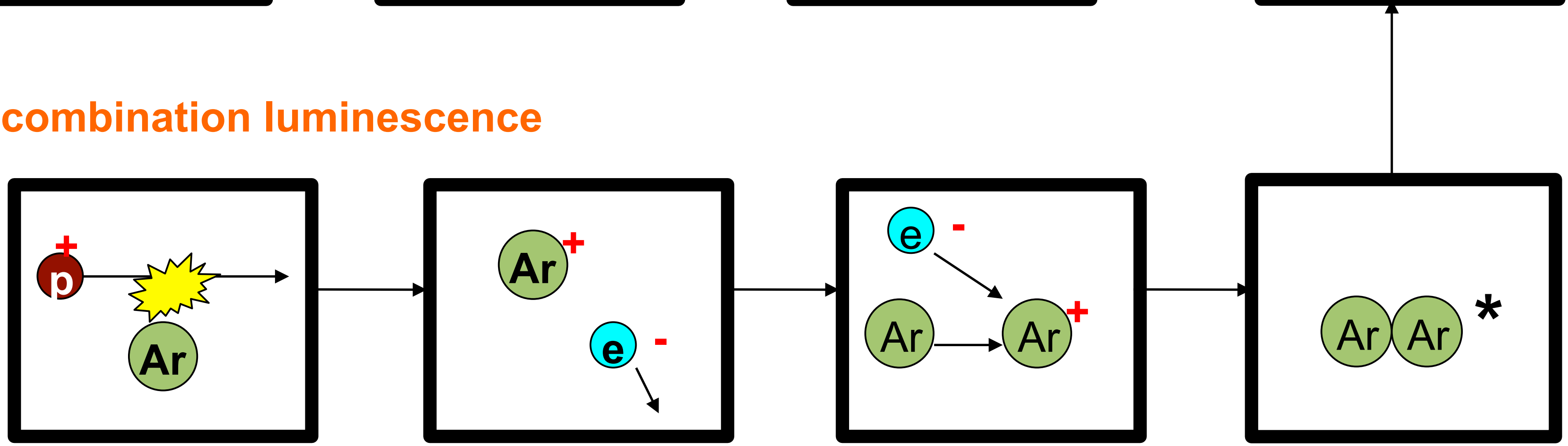
Absorption is accompanied by no visible re-emission (reported in gas phase)

<10ppb methane contamination is required for modern DM experiments.

Self-trapped exciton luminescence

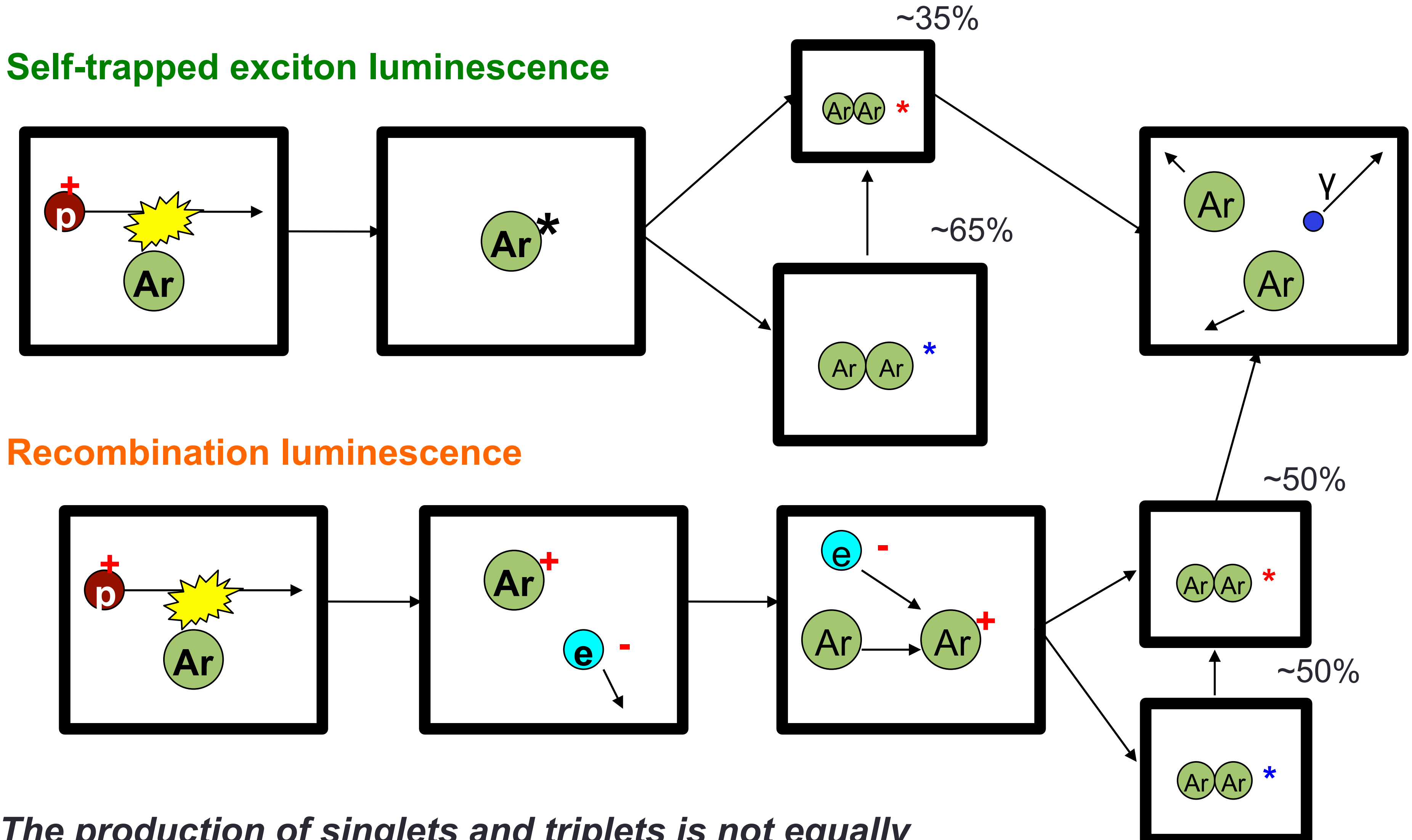


Recombination luminescence



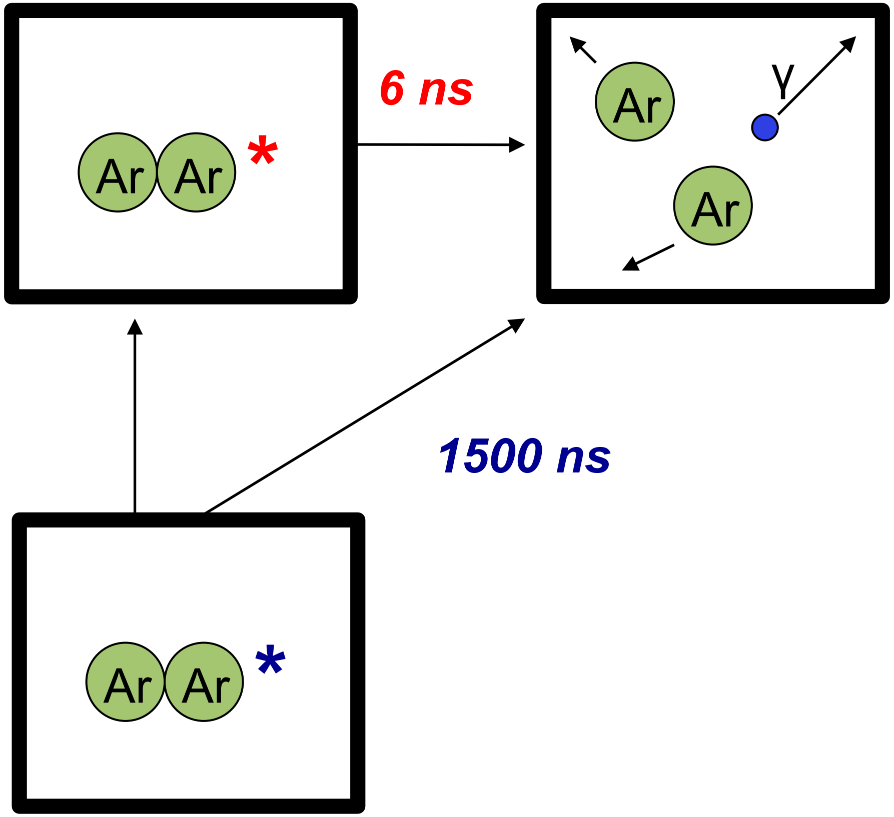
Self-trapped exciton luminescence

Recombination luminescence



The production of singlets and triplets is not equally weighted between the two processes

The fate of the excimer states

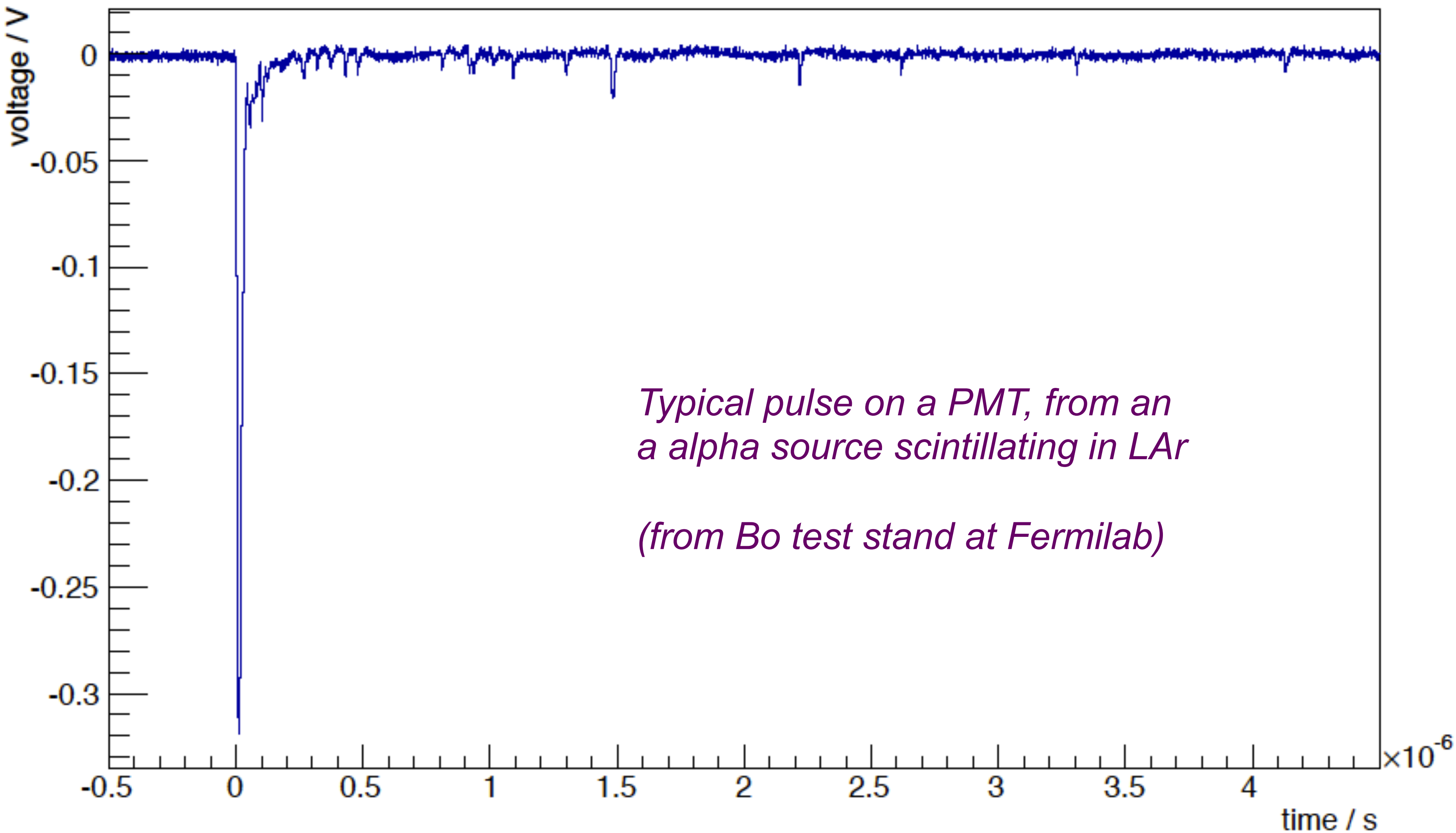


The singlet decays into two argon atoms and a photon, in 6ns

The triplet decays in ~1500 ns

Some disagreement in the literature as to whether this decay proceeds via the singlet, or directly to the ground state

Either way, time constant much longer than the singlet.



Prompt light, from singlet
(6ns time constant)

Delayed light from triplet
(1500ns, dribbling in as single photons)

Time Constants of LAr Scintillation

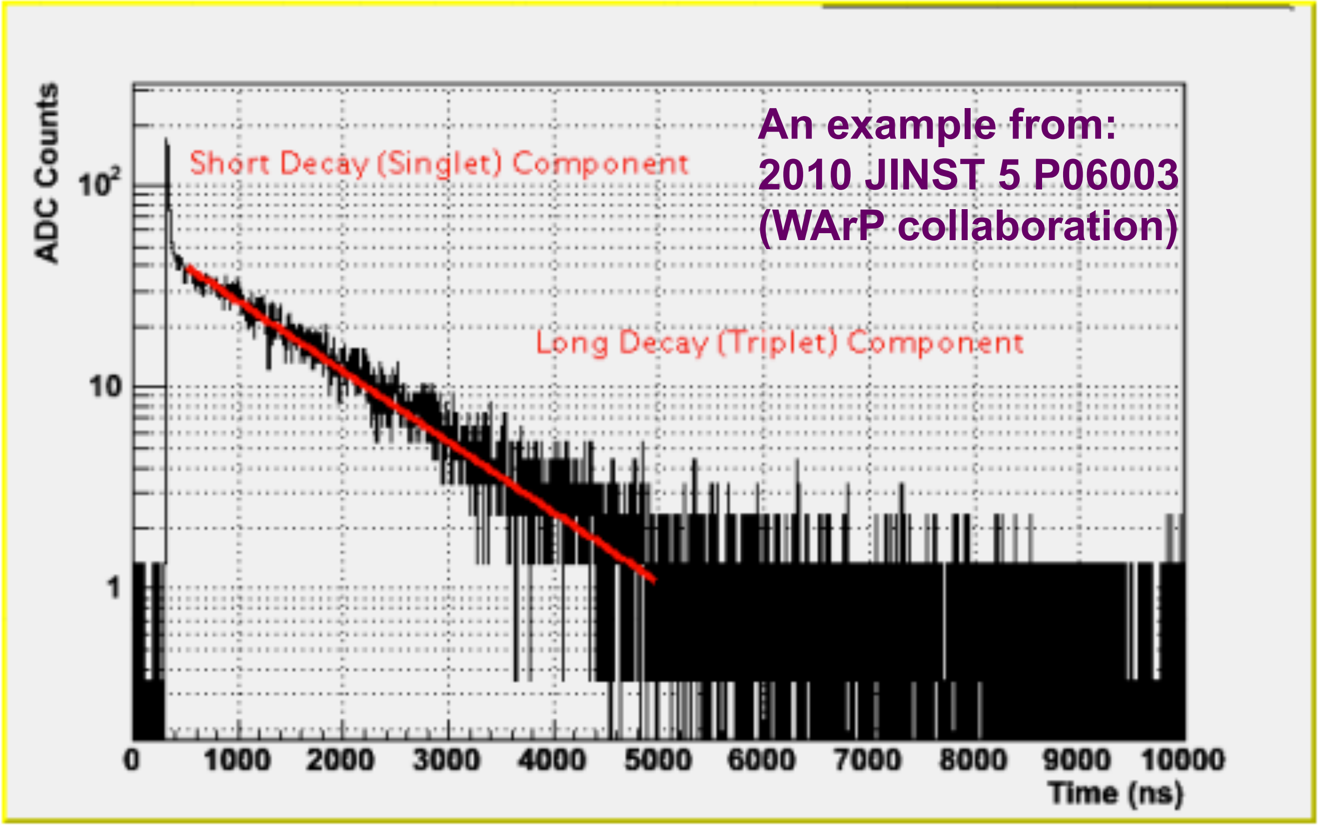
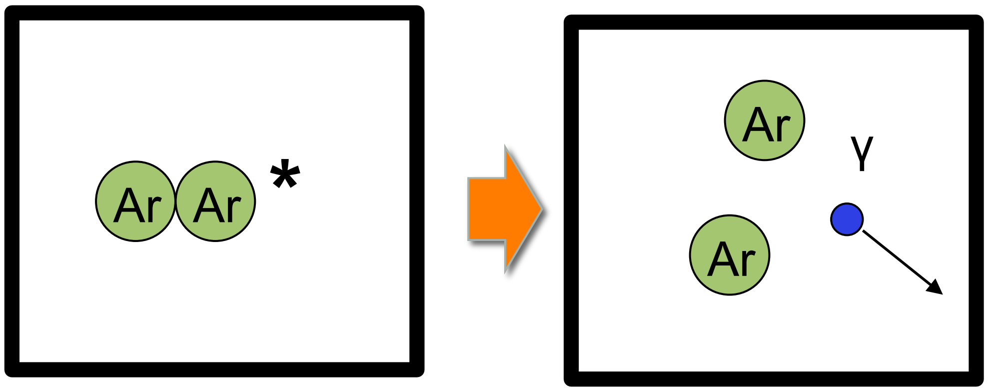


Fig. 4. *Typical (single) waveform recorded during the N_2 test. Event with large energy deposition from cosmic muon (mip) crossing the LAr cell.*

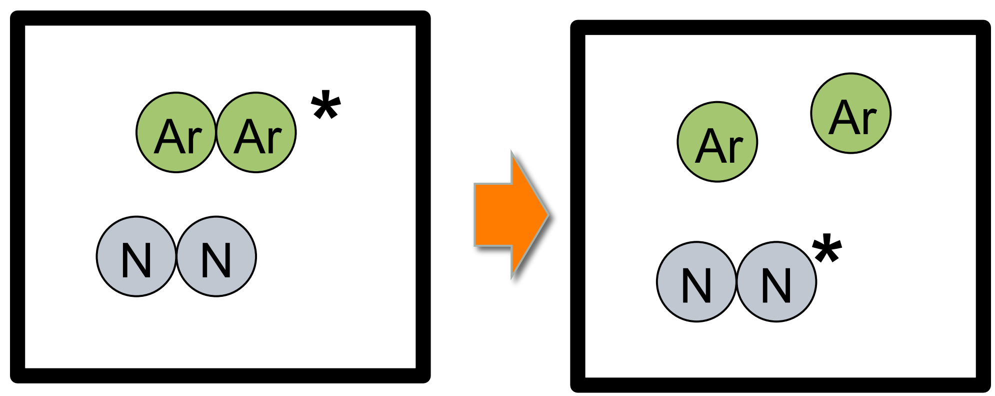
Summing up many pulses to get an average waveform, you can measure time constants

Quenching of Scintillation Light



Scintillation process

Competing Excimer Dissociation Process



Rate dependent on the density of excimers and density of impurity

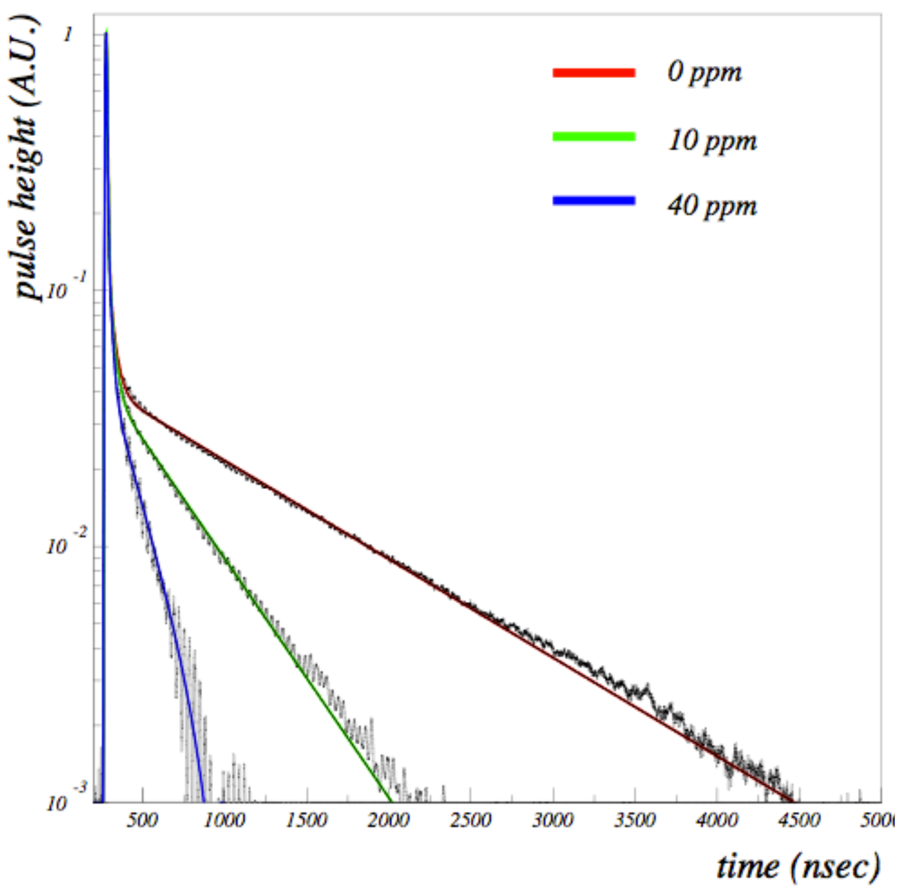
Quenching by Nitrogen

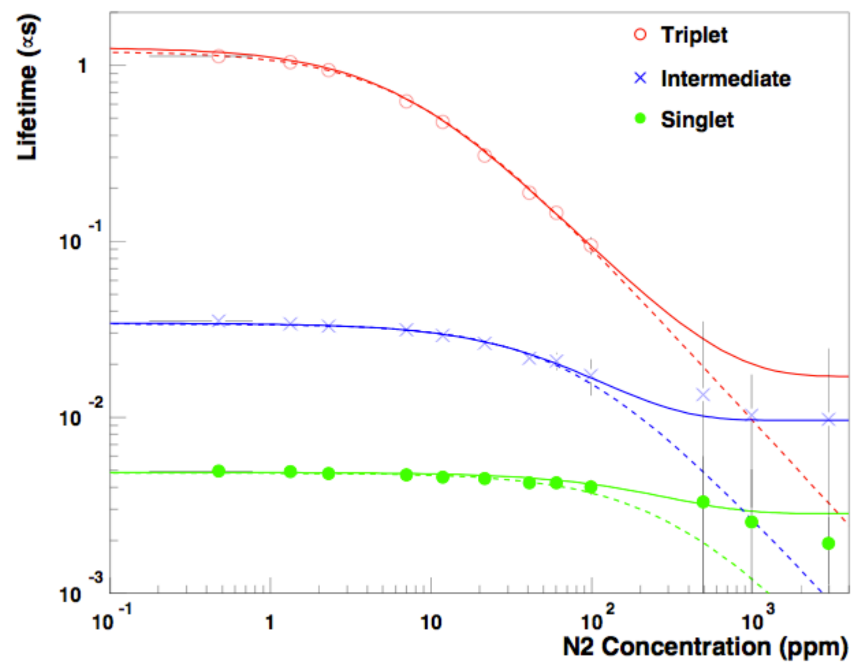
- First measured by WArP:

Acciarri et al 2010 JINST 5 P06003

Quenching shortens long time constant and reduces total scintillation yield. significant above ~2 ppm N_2

In MicroBooNE & LBNE/F, quenching and absorption may both be observable, but likely not problematic.

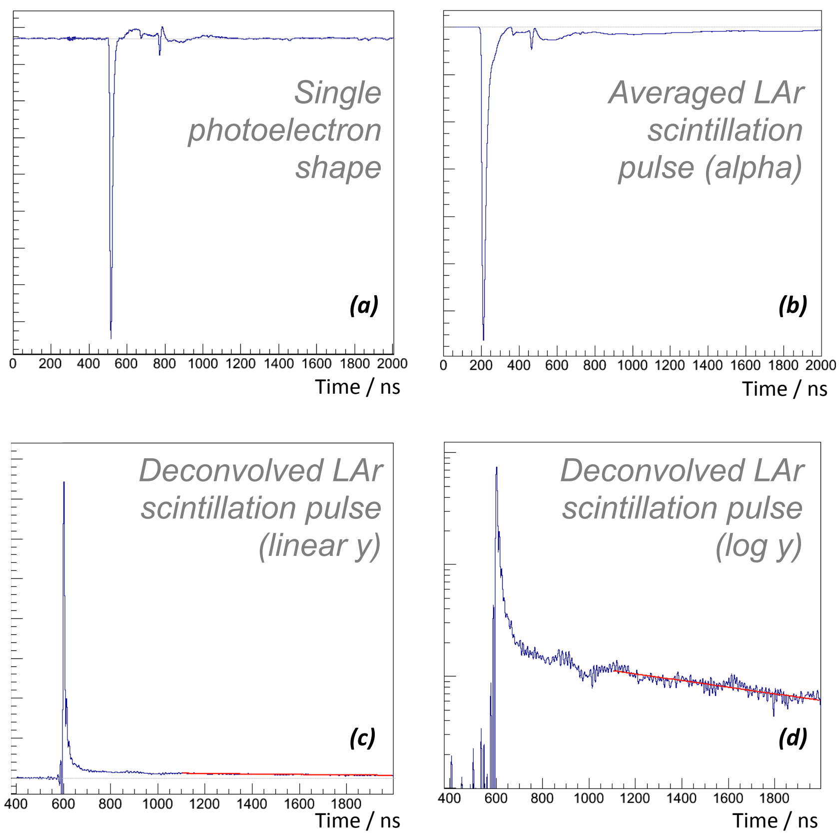


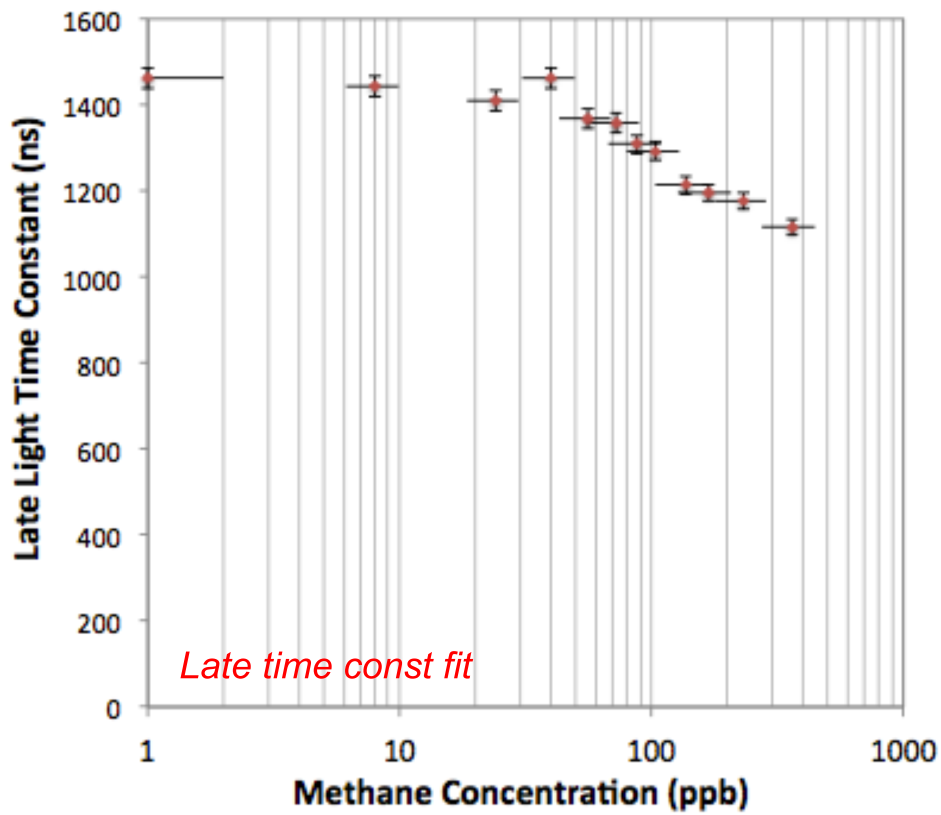


Quenching by Methane

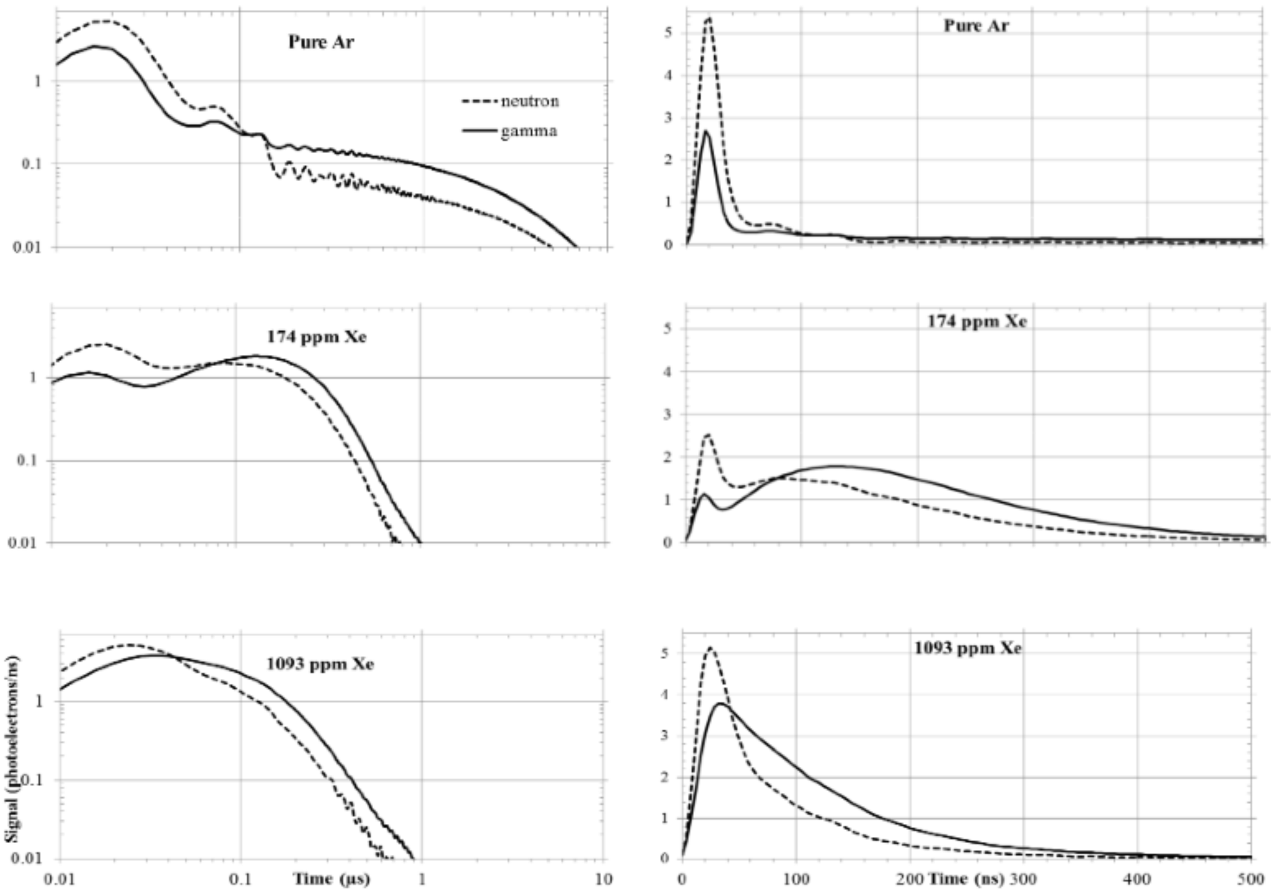
- We observed quenching by methane, but at concentrations much above where absorption is problematic

BJPJ et al, 2013 JINST 8 P12015





Excitation Transfer to Xenon



Excitation can also be transferred to a dopant which then decays with a photon.

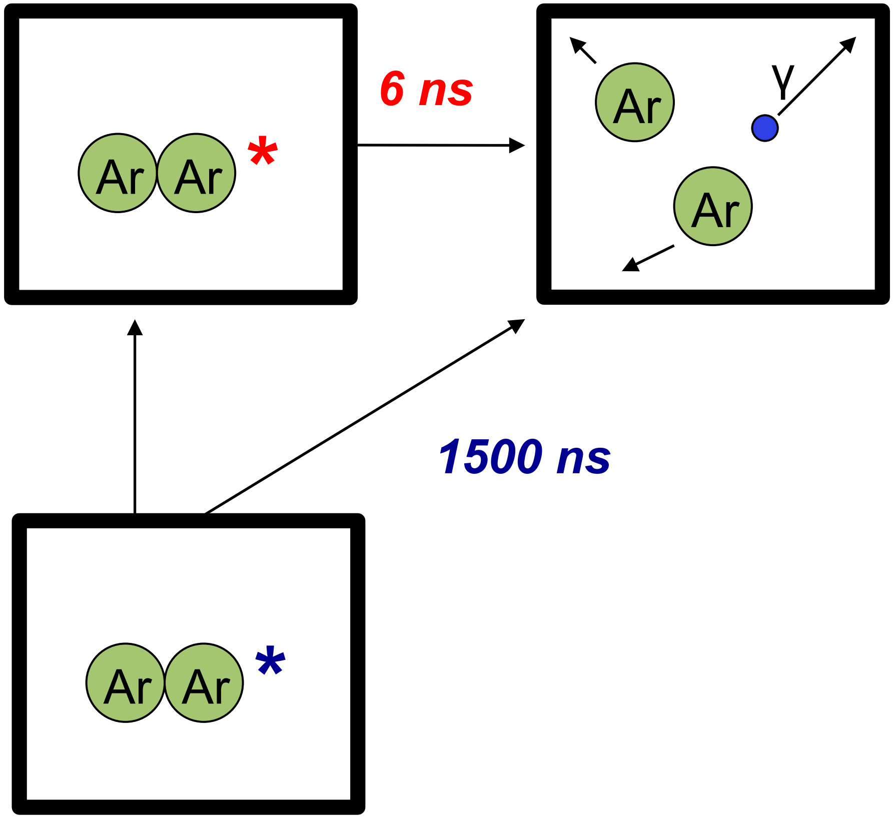
Eg xenon : first studied by ICARUS, and more recently for dark matter detection (left)

175 nm rather than 128 nm emission gives a moderate improvement to light collection capability (depends on WLS coating)

Also brings late light to shorter timescales

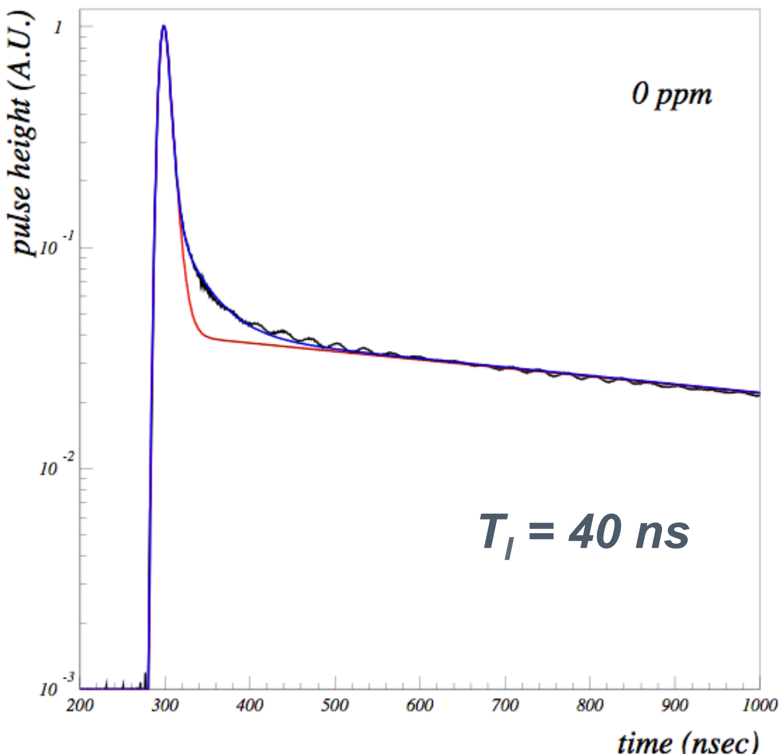
From **JINST 9 (2014) P06013**
Wahl et al

Back to pure argon :

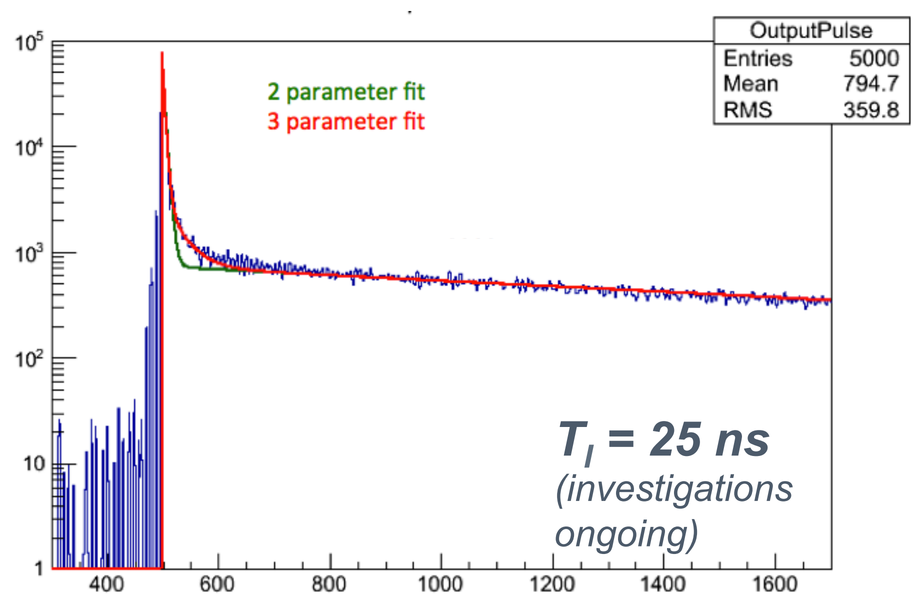


An open mystery – the Third Component

- WArP, ArDM, and BoVST, all see some activity in the “intermediate time” region of a deconvolved PMT pulse for pure argon.
- Interpretation of “intermediate component” not presently clear.
- Instrumental effect or scintillation physics?

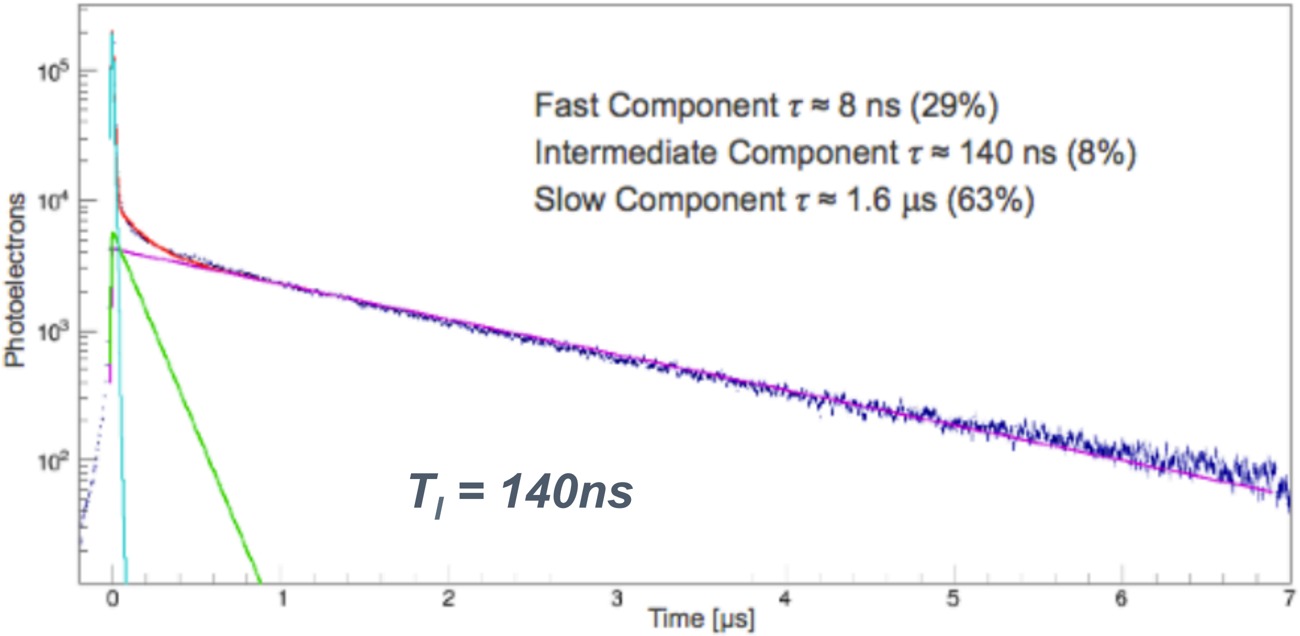


WArP deconvolution (PMT)



BoVST deconvolution (PMT)

- Different measurement methods / experiments do not presently agree on the value of the intermediate time constant or size of the component.
- A potentially interesting piece of liquid argon microphysics. What wavelength is it? Dependence on E-field? Purity? dEdx? Other??
- **Let's understand it by this session next year!**



LBNE TallBo Tests (SiPM)

D Whittington, Neutrino2014 poster

Some new and notable papers about (or relevant to) LAr scintillation physics since LArTPC2013

- Measurement of Scintillation and Ionization Yield and Scintillation Pulse Shape from Nuclear Recoils in Liquid Argon
  arXiv:1406.4825
- Observation of the dependence on drift field of scintillation from nuclear recoils in liquid argon
  Phys.Rev. D88 (2013) 9, 092006
- A study of electron recombination using highly ionizing particles in the ArgoNeuT Liquid Argon TPC
  JINST 8 (2013) P08005
- Performance of liquid argon neutrino detectors with enhanced sensitivity to scintillation light
  arXiv:1405.0848

Summary

- I discussed the mechanisms of scintillation in liquid argon
- Small concentrations of contaminants can have a detrimental impact on scintillation light
- Methane and nitrogen are problems for underground and atmospheric argon respectively, and both have been studied for absorption and quenching effects.
- There is mounting evidence of an intermediate time constant of unknown origin, which can hopefully be understood soon!

Thank you for your attention.