Measurement of Longitudinal Electron Diffusion in Liquid Argon

BROOKHAVEN NATIONAL LABORATORY

Yichen Li[1], Thomas Tsang[2], Craig Thorn[1], Xin Qian[1], Milind Diwan[1], Jyoti Joshi[1], Steve Kettell[1], William Morse[1], Triveni Rao[2], Jim Stewart[1], Wei Tang[1], Brett Viren[1]

1. *Physics Department, Brookhaven National Laboratory, Upton, NY 11973, USA*

2.*Instrumentation Division, Brookhaven National Laboratory, Upton, NY 11973, USA*

Abstract

We report the measurement of longitudinal electron diffusion coefficients in liquid argon for electric fields between 100 and 2000 V/cm with a gold photocathode as a bright electron source. The measurement principle, apparatus, and data analysis are described. Our results, which are consistent with previous measurements in the region between 100 to 350 V/cm reported by ICARUS, are systematically higher than the theoretical prediction of Atrazhev-Timoshkin, and represent the world's best measurement in the region between 350 to 2000 V/cm. A paper on the results were submitted to NIM and available on arXiv: 1508.07059.

Introduction

•LArTPCs are now the preferred technology for many accelerator neutrino and dark matter experiments. At present, two LArTPCs have been constructed and operated for neutrino physics measurements: the ICARUS and ArgoNeut detector. Meanwhile, two other LArTPCs have been constructed for dark matter searches: Darkside and WArP detectors. Recently, the MicroBooNE experiment, with a 170 ton LArTPC has begun operation in the US. In the future, a set of LArTPCs will be installed at Sanford Underground Research Facility (SURF) for the Deep Underground Neutrino Experiment (DUNE) to search for CP violation in the lepton sector and to determine the neutrino mass hierarchy. For the near-term neutrino program, a three-LArTPCs configuration will be implemented at Fermilab to search for a light sterile neutrino and to precisely measure neutrino-argon interaction cross sections.

•LArTPCs are attractive detectors for neutrino experiments. As the most abundant noble gas (1.3% by weight) in the atmosphere, argon is commercially available in large quantities. The low cost and relative high density (1.4 g/mL at 87 K) make LAr an ideal material for the massive TPCs needed for neutrino-induced rare processes.

•Knowing electron diffusion after long drift distance of meters is crucial for understanding track resolution.

Electron Diffusion in Liquid Argon

The development of a point source of charge at the origin with a constant field in the drift direction is described by a Gaussian distribution

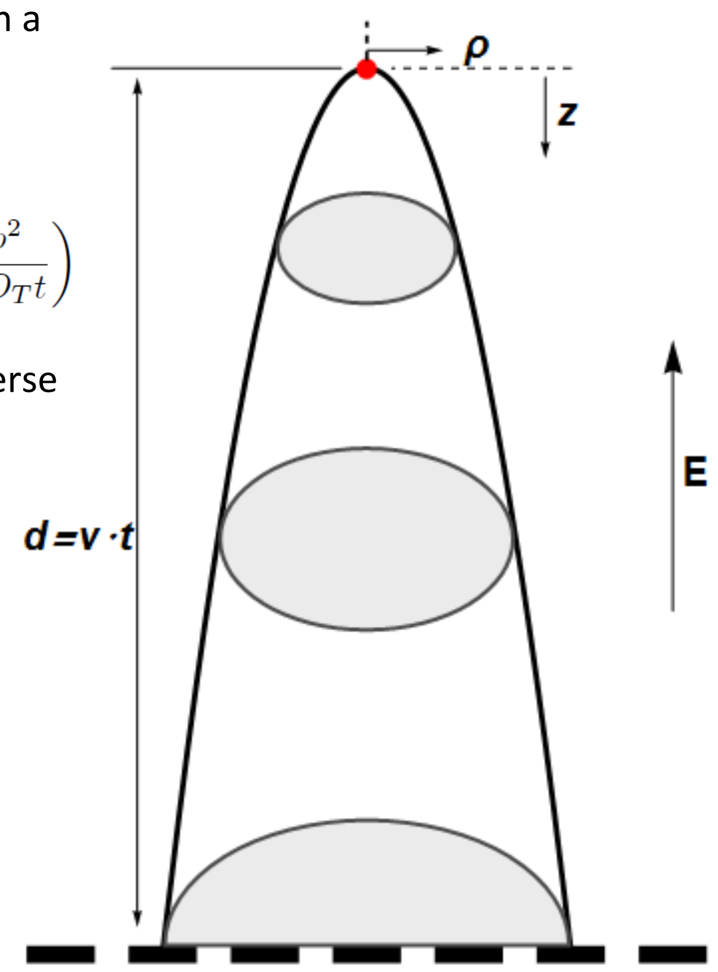
$$n(\rho,z,t)=\frac{n_0}{4\pi D_T t\sqrt{4\pi D_L t}}\exp\left(-\frac{(z-vt)^2}{4D_L t}-\lambda v t\right)\exp\left(-\frac{\rho^2}{4D_T t}\right)$$

longitudinal transverse

The diffusion of electrons in strong electric fields is generally not isotropic. Therefore, longitudinal and transverse diffusion require separate measurements.

Measurements have been reported previously of longitudinal diffusion at electric fields 0.1-0.35 kV/cm and of transverse diffusion at electric fields above 1.5 kV/cm.

No direct measurement so far for both longitudinal and transverse diffusion at 0.5 kV/cm which is the operating field of most LArTPCs.



Drift/Diffusion process

The drift velocity is measured by the time-of-flight and drift distance from the original to the anode

$$v=\frac{d}{t_p}$$

Where *d* the drift distance, t_p is the drift time.

The diffusion is the standard deviation in the time of this charge distribution after the swarm has drifted

$$\sigma_{L(T)}=\sqrt{2D_{L(T)}\cdot t_p/v^2}$$

The diffusion coefficient is given by Einstein-Smoluchowski relation

$$D=\frac{kT}{e}\mu$$

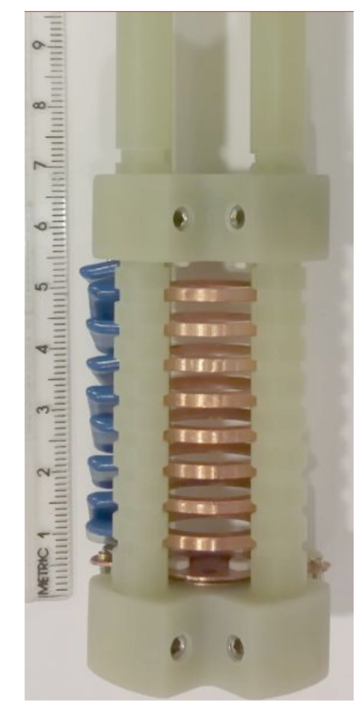
where *kT* the electron temperature, μ is the mobility.

The ratio of longitudinal to the transverse diffusion coefficient can be expressed as:

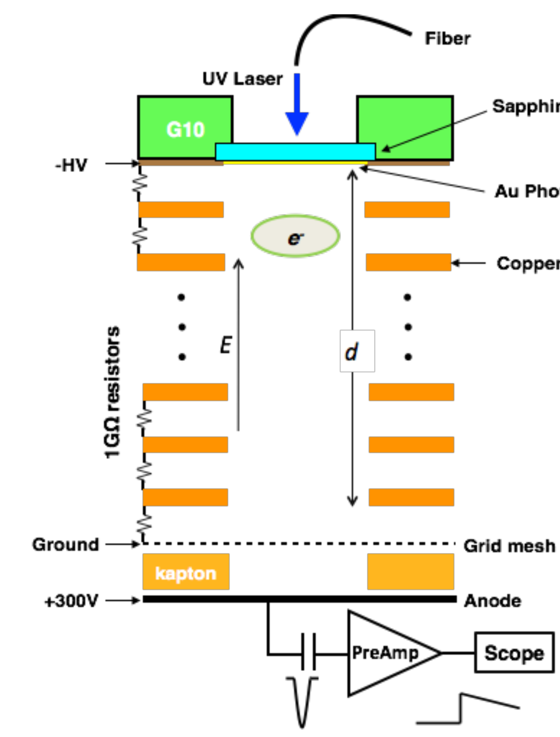
$$\frac{D_L}{D_T}=1+\frac{E}{\mu}\frac{\partial\mu}{\partial E}$$

Experimental Setup

•The Au photocathode is vacuum evaporated on a sapphire substrate, the Au film thickness is 22nm.
•266nm UV pulsed laser is guided into the chamber with fiber.
•The drift stack is built to create uniform electric field.
•Electrons are collected by a copper anode fed into a preamp in ambient and readout by a oscilloscope.
•A grid mesh is installed 300 μm from the anode to screen the slow rise signal.



Drift Stack

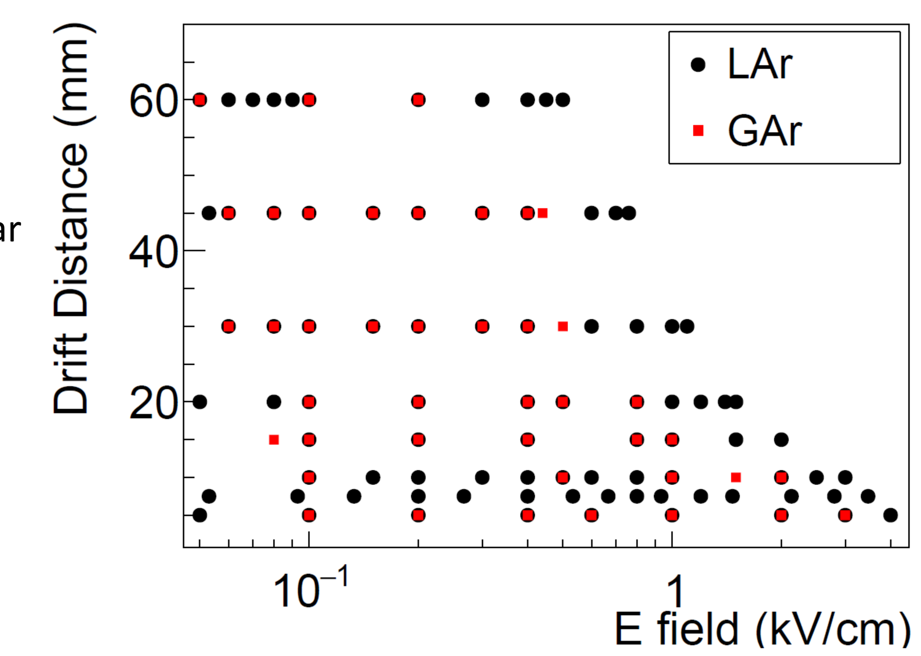


Schematic of experimental setup

Measurements

•The test chamber is purged and baked (~90C).
•The system is pumped down to vacuum first for quantum efficiency measurement.
•GAr data is filled at room temperature with 1.5bar pressure .
•LAr is then formed by cooling down the chamber with liquid nitrogen and dry ice bath at 87K.
•The anode charge signals measured at multiple drift distances with all achievable HVs until breakdown for both GAr and LAr.

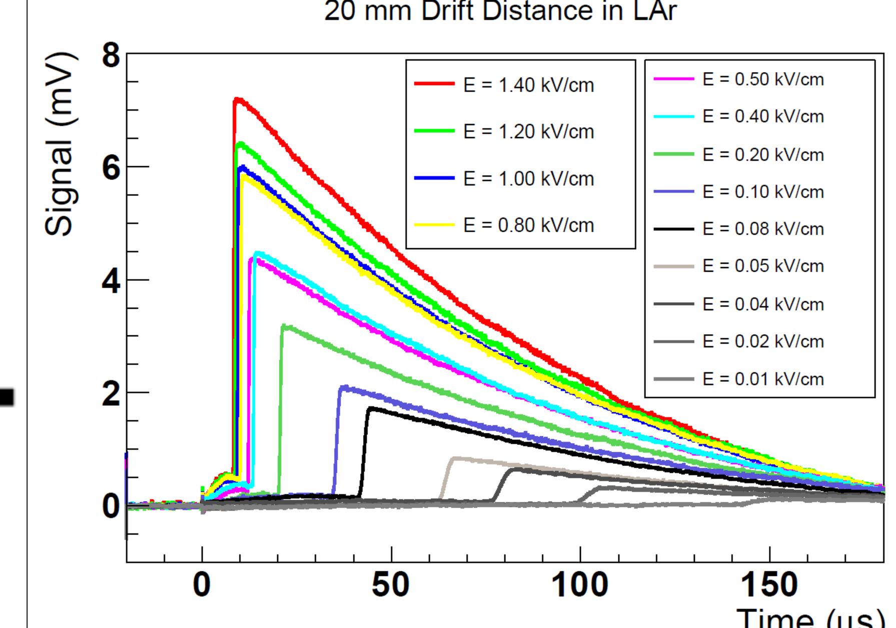
Mapped Parameter Space



The raw signal is fitted by a convolution of a Gaussian function containing the information of the electron swarm and a step response function with damping representing the response of the pre-amplifier.

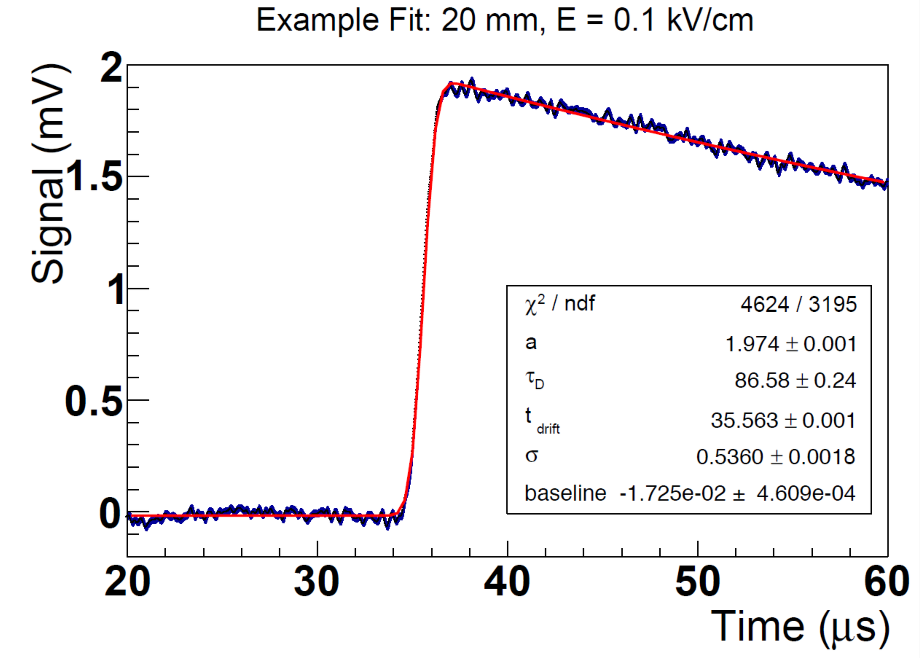
$$f(t,\sigma,\tau_D,a)=a\cdot e^{\frac{\sigma^2-2t\cdot\tau_D}{2\tau_D^2}}\cdot\left(1+\mathrm{Erf}\left(\frac{-\sigma^2+t\cdot\tau_D}{\sqrt{2}\tau_D\cdot\sigma}\right)\right)$$

20 mm Drift Distance in LAr



Raw signal shape for 20mm data

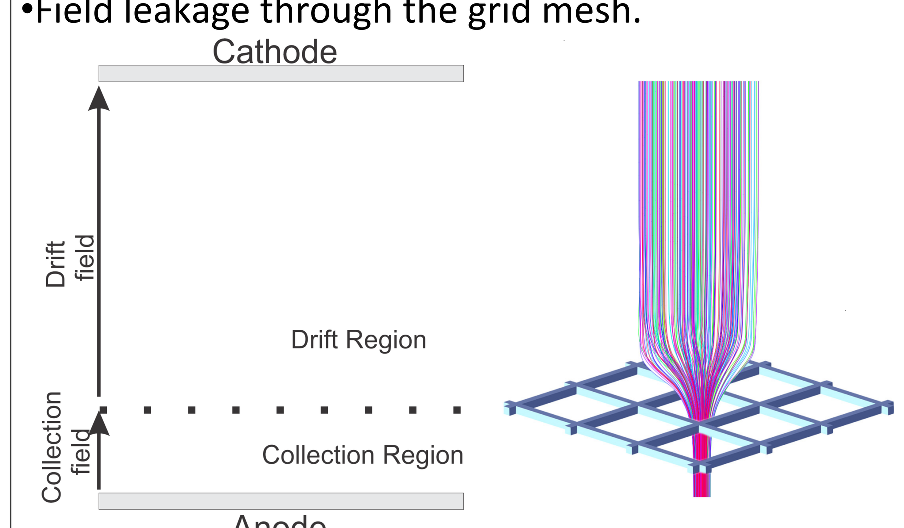
Example Fit: 20 mm, E = 0.1 kV/cm



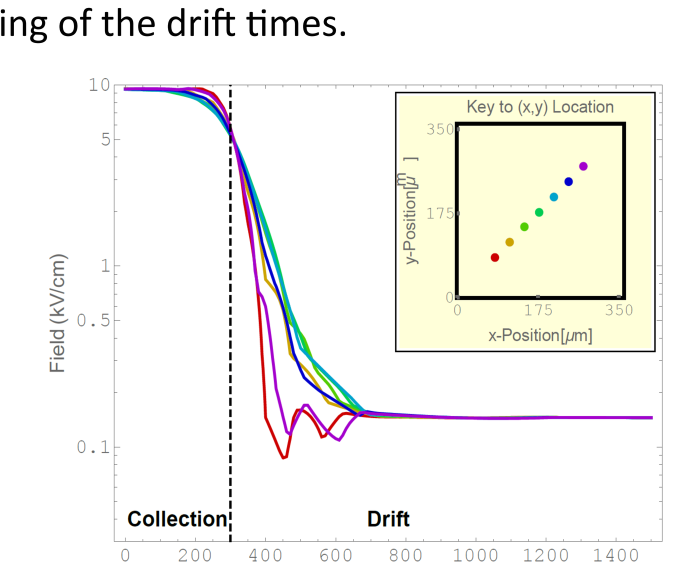
Fit to a single trace

Systematic Uncertainties

•Additional drifting distance between the grid mesh.
•Electronics response time(measured).
•The tightly focused bundle of trajectories lead to a spreading of the drift times.
•Field leakage through the grid mesh.



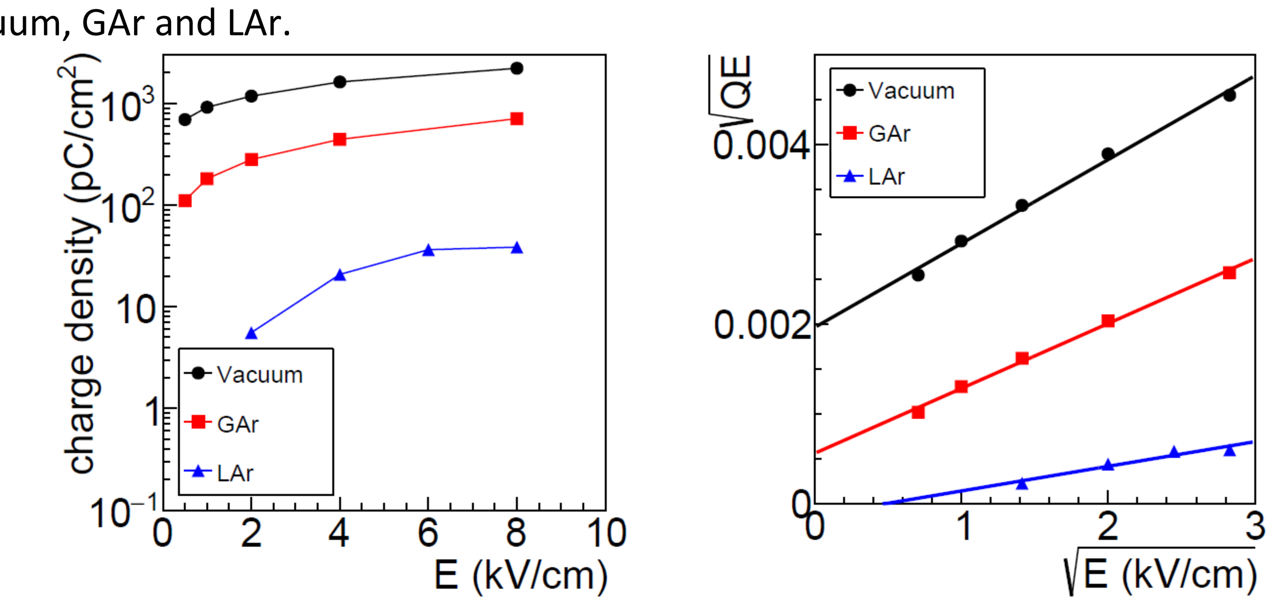
Ray tracing with field simulated by Maxwell 3D



Electric field calculated near the grid

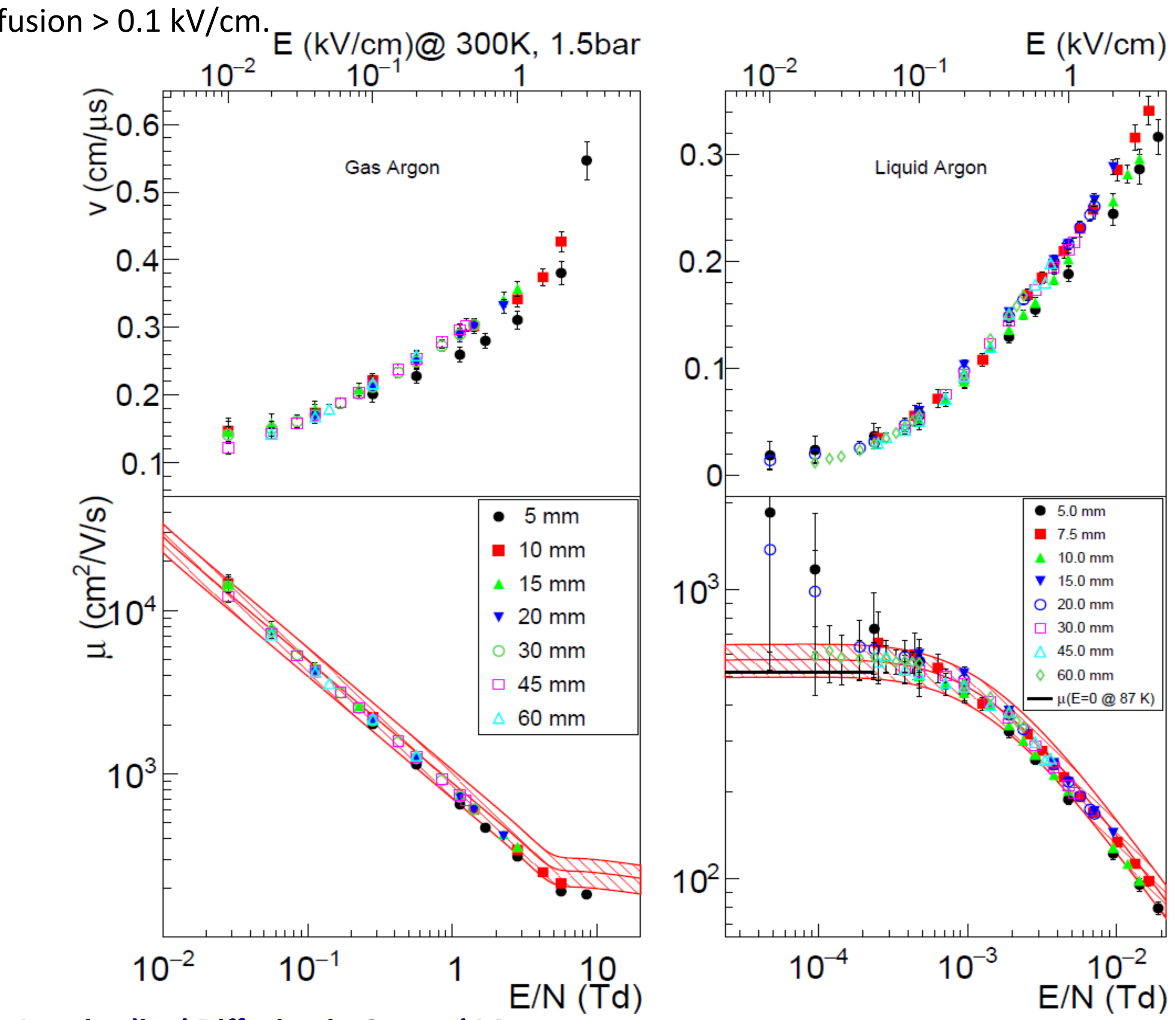
Results: Au Photocathode Quantum Efficiency

•The quantum effeciency (QE) is defined as the number of electrons leaving the photocathode per number of UV photons irradiating the back surface of the photocathode. It is measured for vacuum, GAr and LAr.



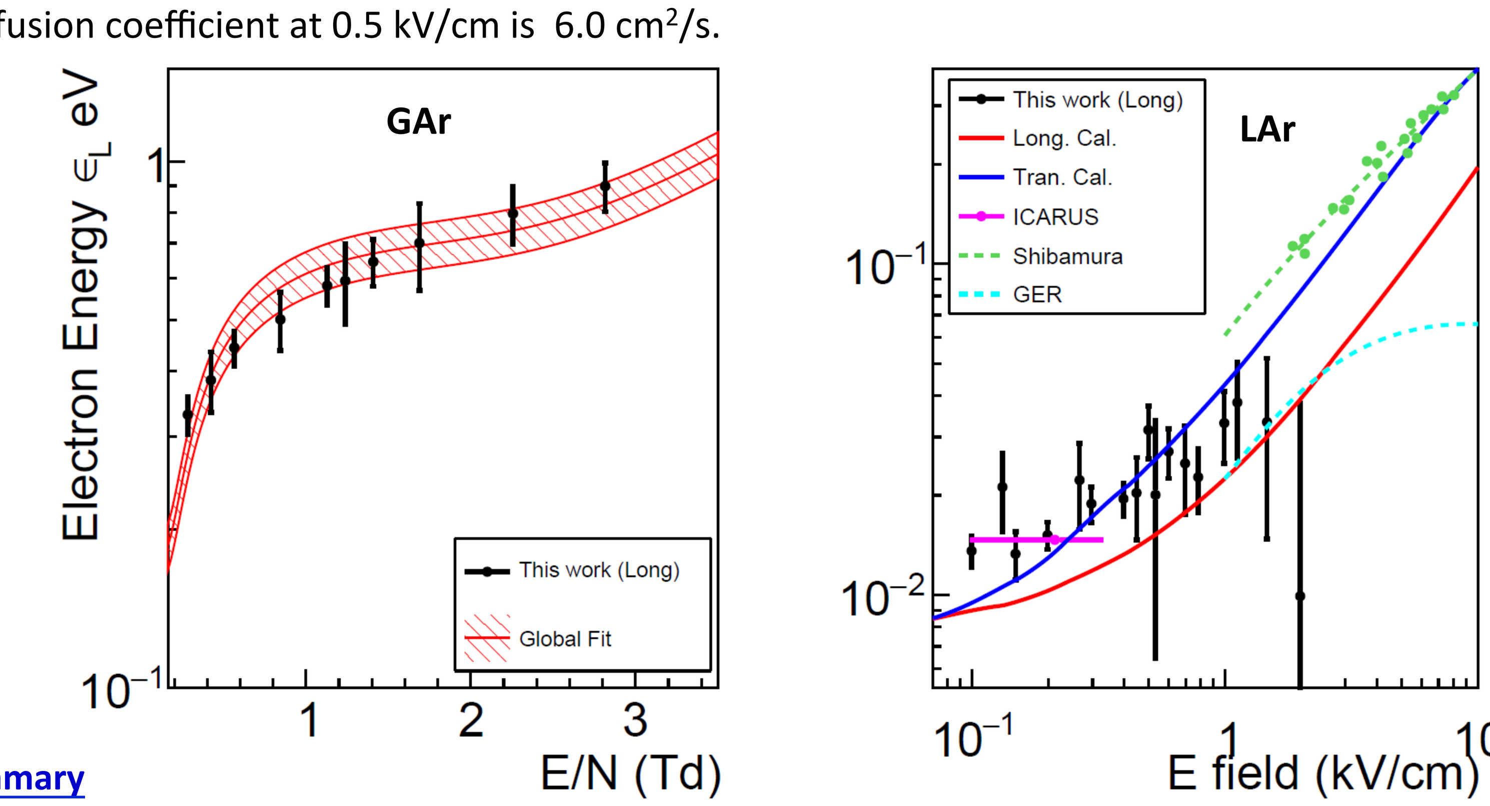
Results: Drift Velocity and Mobility in GAr and LAr

•The mobility is compared to a global fit of world data found in references. $v=\frac{d}{t}=\mu\cdot E$
•Our results agree with the global fit of previous measurements.
•The discrepancy on mobility at low field is caused by the field leakage effect, so we only report the diffusion > 0.1 kV/cm.



Results: Longitudinal Diffusion in Gar and LAr

•After subtracting the instrumental effects, our longitudinal diffusion measurement results are systematically higher than the theoretical prediction of Atrazhev's.
•We also agree with ICARUS' previous results.
•We are limited by systematic uncertainties. $\epsilon_L=eD_L/\mu$
•Diffusion coefficient at 0.5 kV/cm is 6.0 cm²/s.



Summary

❑We reported the world's best measurement on longitudinal diffusion in LAr 0.35 – 2 kV/cm.
❑A new setup with improved design has been constructed. Improved measurements are expected soon.
❑Transverse diffusion will also be measured with the new setup.

Acknowledgements

❑ This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of High Energy Physics and Early Career Research program under contract number DE-SC0012704.