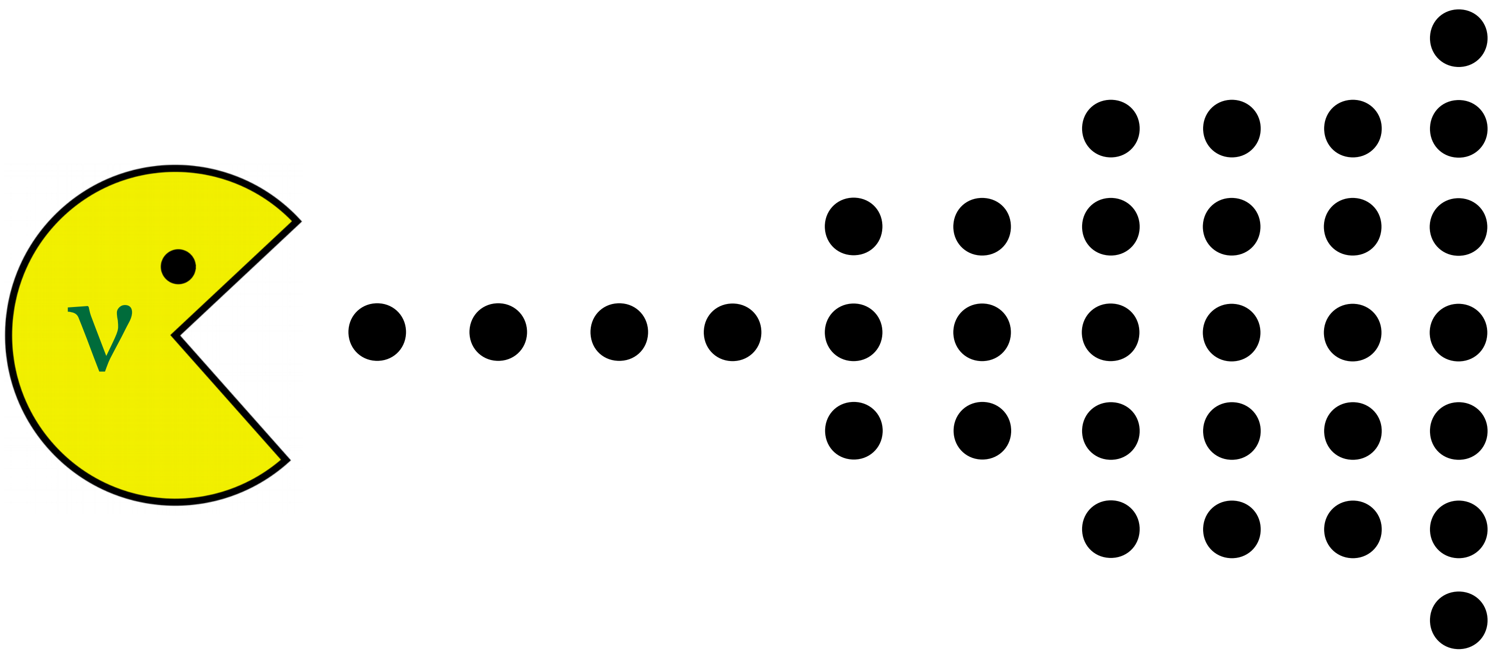
LArCADe: lowering thresholds in LArTPC detectors

Magnificent CEvNS – UChicago – November 3rd, 2018



Fermilab

David Caratelli & Angela Fava

LArCADe: **L**iquid **Ar**gon **C**harge **A**mplification **De**vices

David Caratelli @ Magnificent CEvNS, UChicago, 03/11/18

LDRD project @ Fermilab started in spring ‘18

Investigate feasibility of obtaining stable e⁻ charge amplification in LAr.

→ past attempts, non-conclusive.

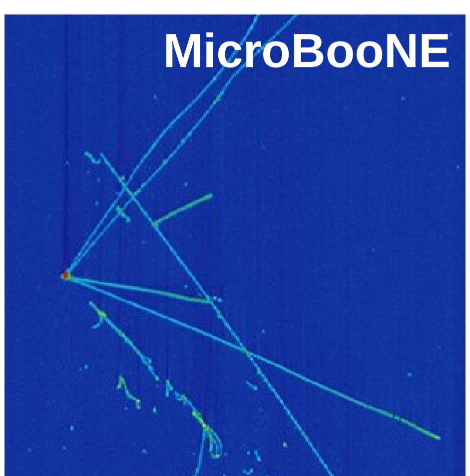
With the goal of trying to further expand the physics reach of large-scale LArTPCs

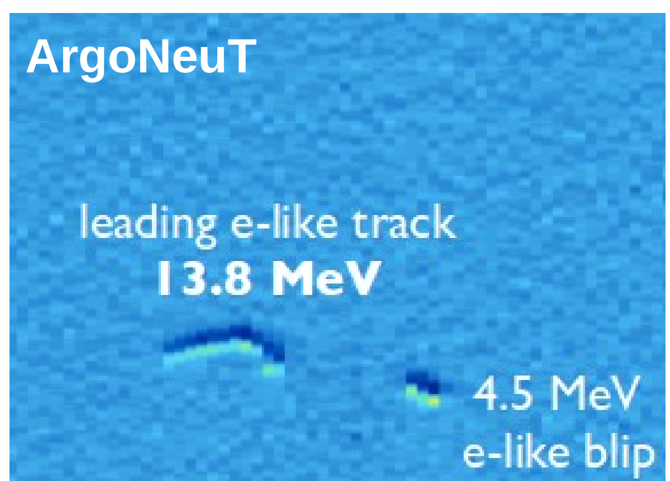
This talk:

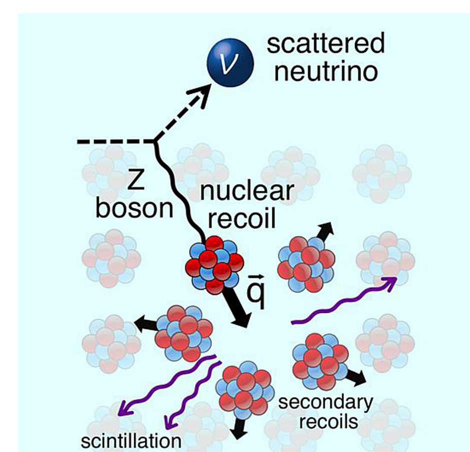
1) Project overview + CEvNS as physics motivation.

2) Results in gas + future plans for LAr.

Single-phase LArTPCs







Science 10.1126 aao0990 (2017)

GeV MeV keV

Charge Amplification in LAr

Few attempts at obtaining charge amplification in liquid argon.

Electron amplification has been observed but unstable.

Challenges: amplification gain / bubble formation / e^- vs Ar^+ drift.

Advantages: single-phase / scalable / position resolution / complementary to scintillation light.

Our goal is to explore in more detail the feasibility of obtaining stable, proportional charge amplification in liquid argon.

Electron avalanches in liquid argon mixtures

J.G. Kim[a], S.M. Dardin[a], R.W. Kadel[a,*], J.A. Kadyk[a], V. Peskov[b], W.A. Wenzel[a]

[a] *Lawrence Berkeley, National Laboratory, Berkeley, CA 94720, USA*
[b] *Royal Institute of Technology, Stockholm, Sweden*

Received 18 March 2004; accepted 8 June 2004
Available online 6 August 2004

Abstract

We have observed stable avalanche gain in liquid argon when mixed with small amounts of xenon (xe) in the high electric field (>7 MV/cm) near the point of a chemically etched needle in a point–plane geometry. We identify two gain mechanisms, one pressure dependent, and the other independent of the applied pressure. We conclude that the pressure-

Electron multiplication in liquid argon on a tip array

G. Bressi [a], M. Cambiaghi [a], G. Carugno [b], E. Conti [c] and E. D'Uscio

[a] *INFN, Sezione di Pavia, Via A. Bassi, 6 - Pavia, Italy*
[b] *INFN, Laboratori Nazionali di Legnaro, Via Romea, 4 - Legnaro PD, Italy*
[c] *Università di Padova, Dipartimento di Fisica and INFN, Sezione di Padova, Via F. Marzolo, 8 - Pa*

Received 29 April 1991 and in revised form 17 July 1991

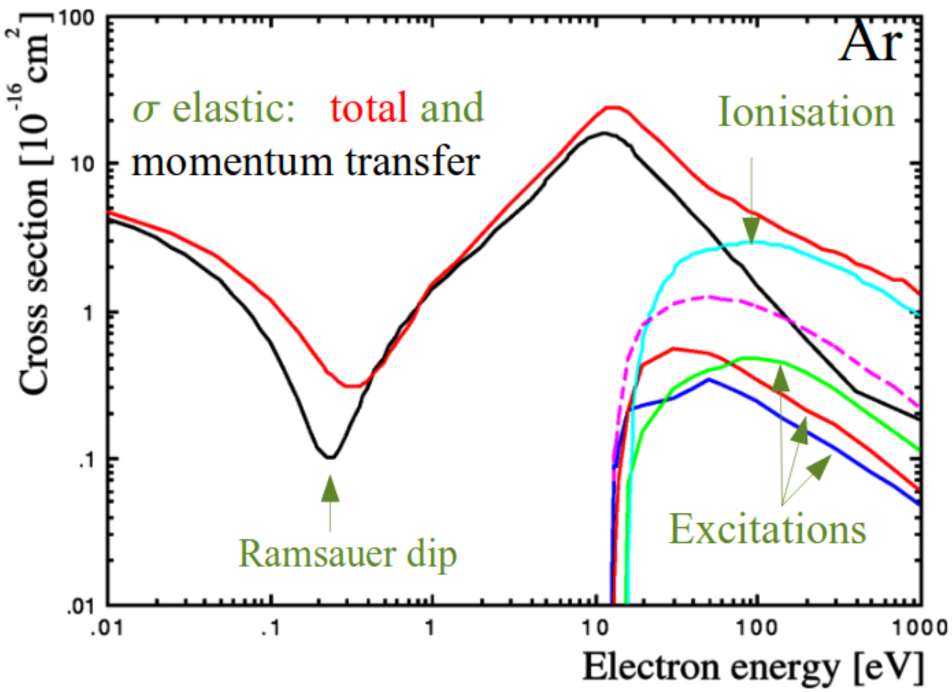
We have carried out a systematic study of the electron multiplication in liquid argon on an ar
multiplication factor for a single tip of at least 100 and a plateau region in the counting-rate vs t
The results make us hopeful in exploiting such mechanism for a new kind of detectors.

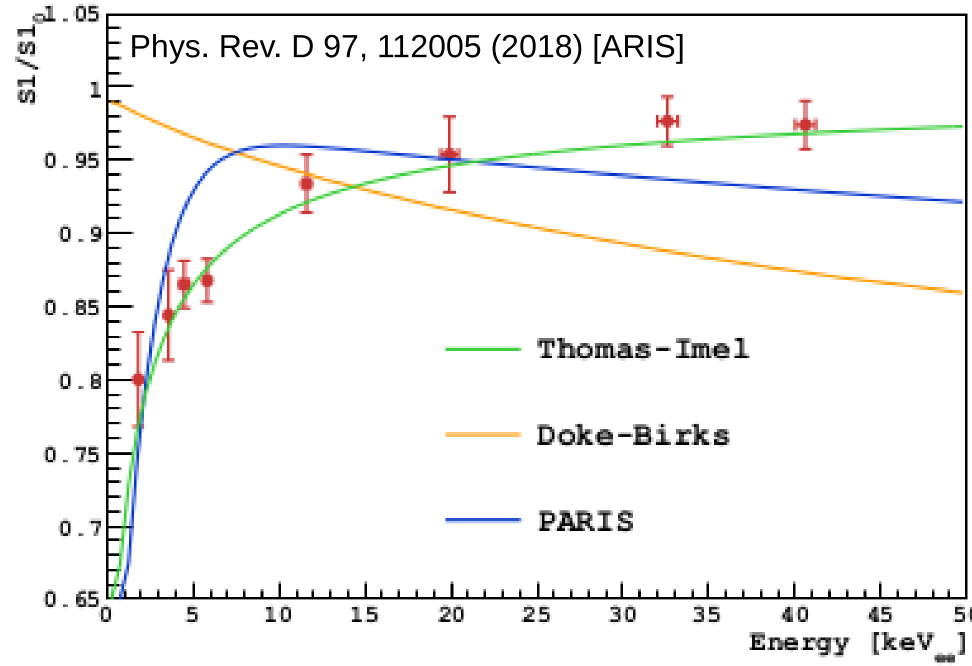
LBNL-47794 1

Studies of Electron Avalanche Behavior in Liquid Argon

J.G. Kim, S.M. Dardin, K.H. Jackson, R.W. Kadel, J.A. Kadyk, V. Peskov, W.A. Wenzel

Challenges for e⁻ signature





Making it to ionization energy before electrons have scattered elastically in the denser medium (i.e. shorter pathlength)

Significant quenching of charge (80-90%) due to ion recombination.

Significant variation in models.

amplification @ ~ 10^6 V/cm

"detectable" electrons

NR vs. ER quenching

Ion recombination

$$N_e = L_{\mathrm{eff}} \frac{E_{\mathrm{dep}}}{W} \frac{1-R}{1+\alpha}$$

1 for NR

NR e- signature:

Phys. Rev. D 97, 112005 (2018) [ARIS]
arXiv:1707.05630 [DarkSide]
Phys. Rev. D 91, 092007 (2015) [SCENE]

Ar xsec:

Phys Rev A, V65, 042713
J Chem Phys 142, 154507 (2015)

CevNS: e^- signature in LArTPC

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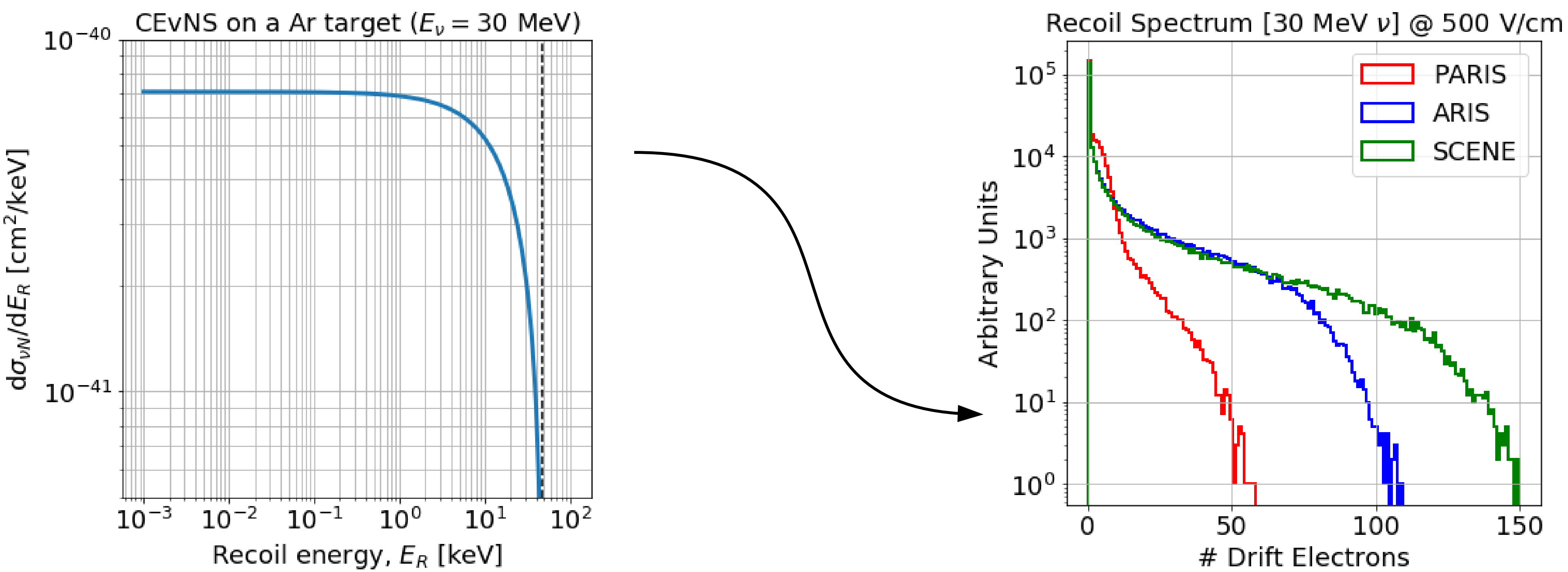
What is required to detect ionization charge from Ar recoil?

1) wire-readout single-phase LArTPCs have noise @ 400 e^- level, using cold electronics.

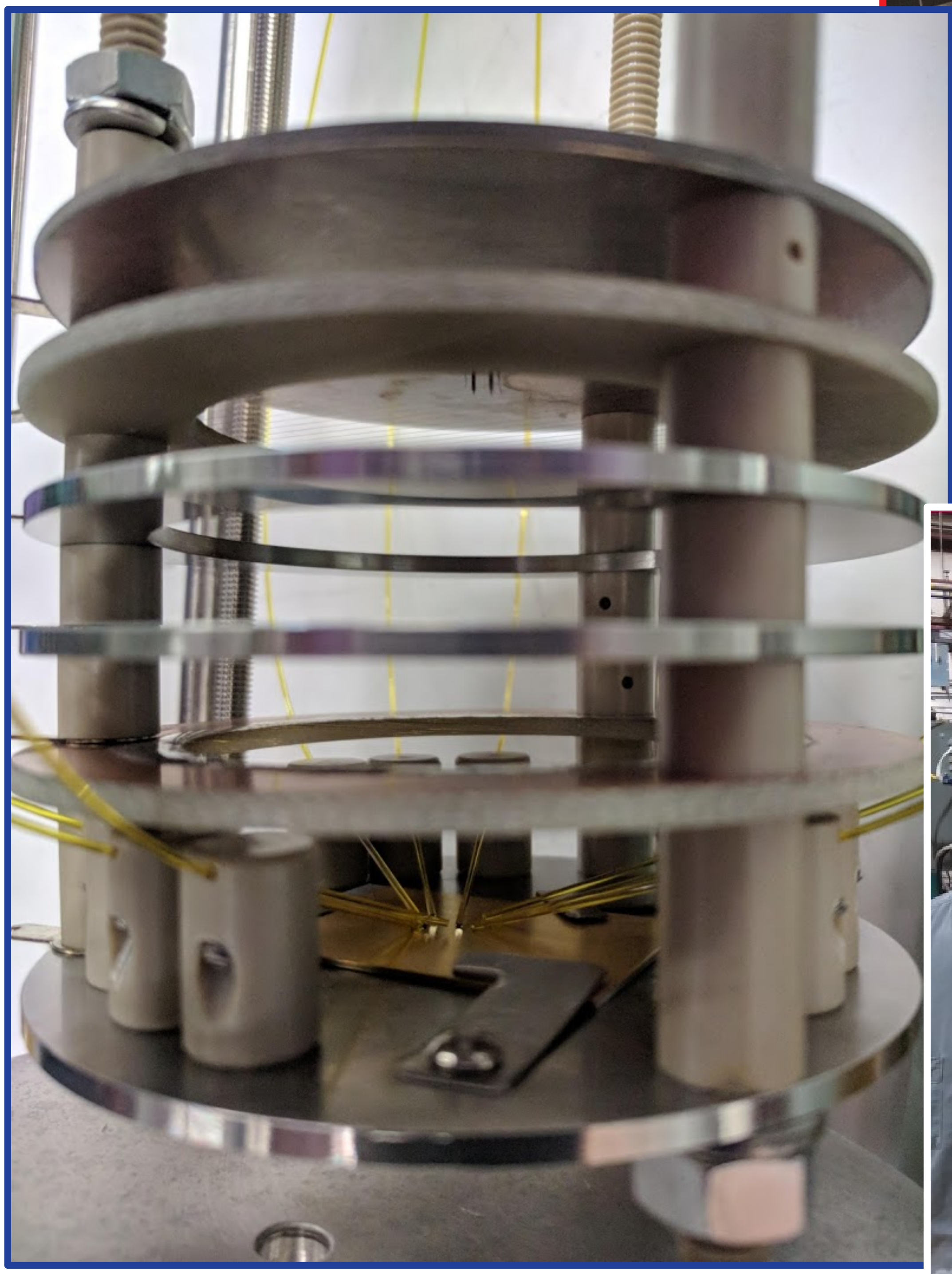
2) signature of 10s of MeV CEvNS → 10s – 100 e^-.

Factor of x100 amplification brings S:N close to that of MIP signatures for current LArTPCs

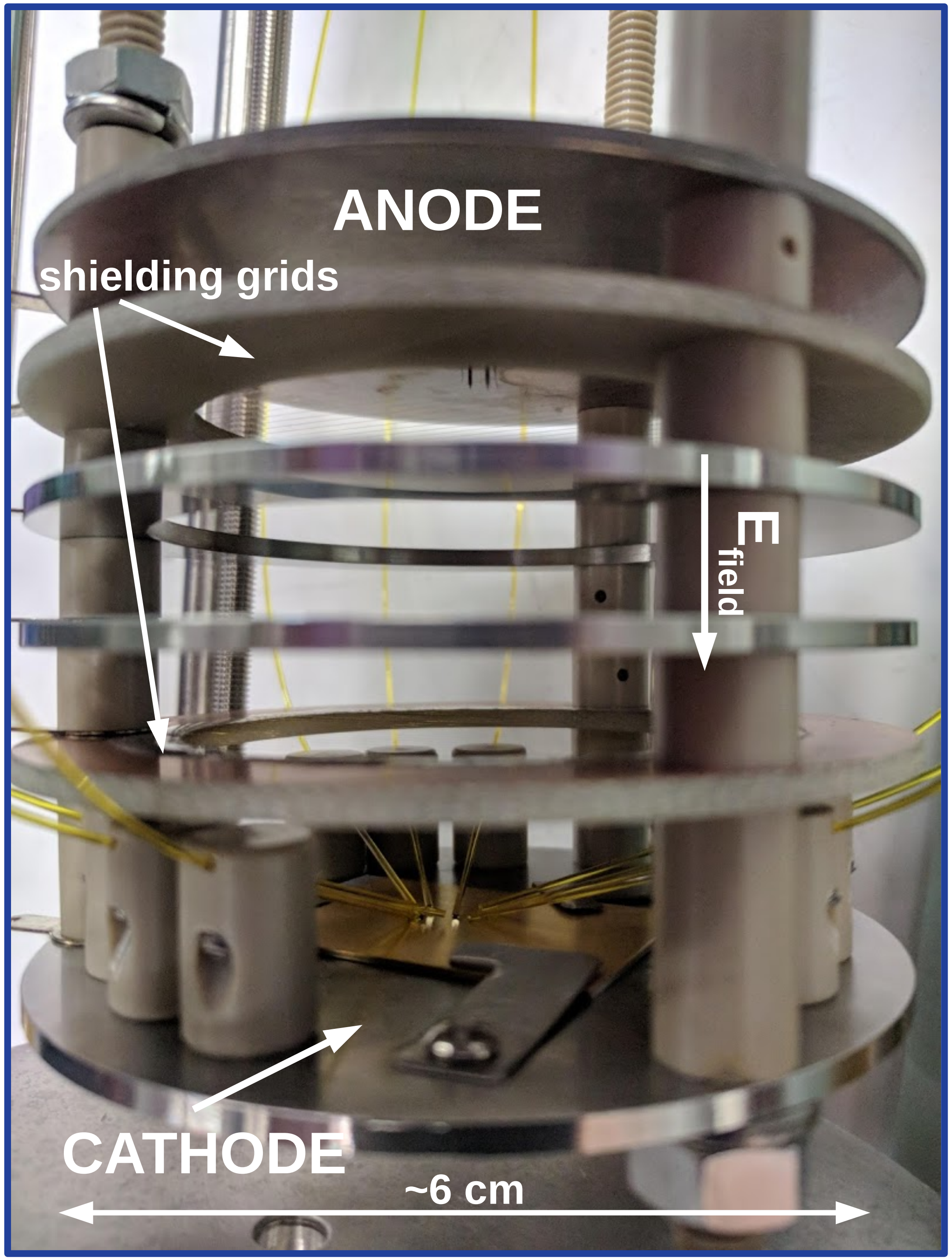


ttps://github.com/bradkav/CEvNS

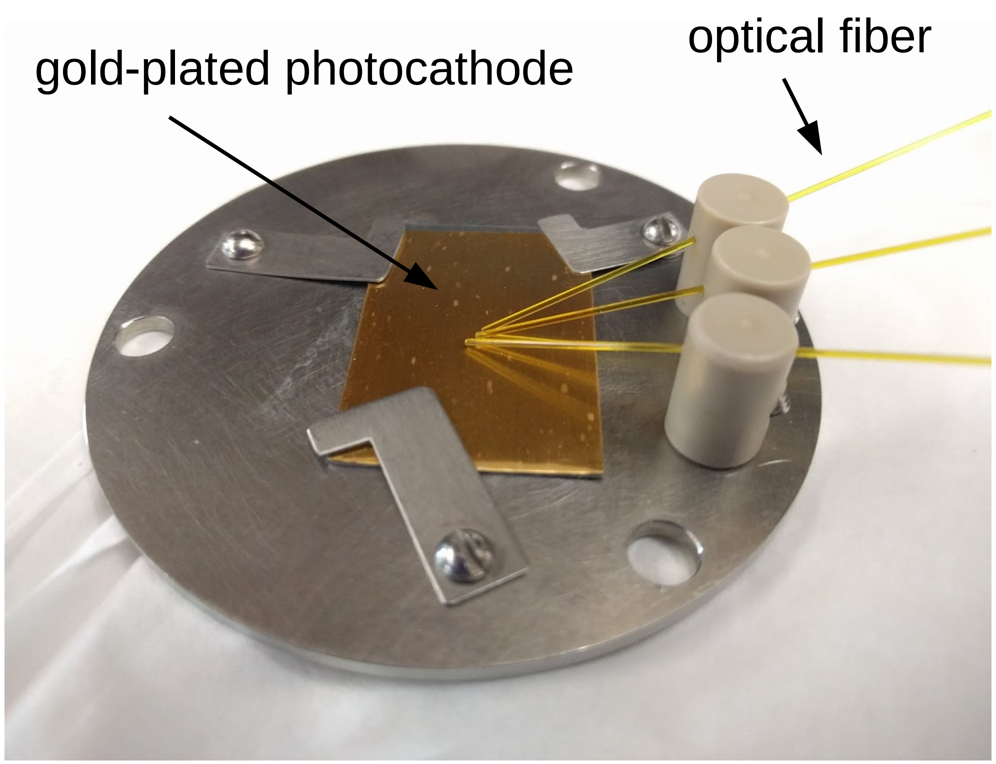
LArCADe Project



LArCADe Setup



~5cm drift purity monitor operated @ Fermilab's PAB facility.



LArCADe Setup

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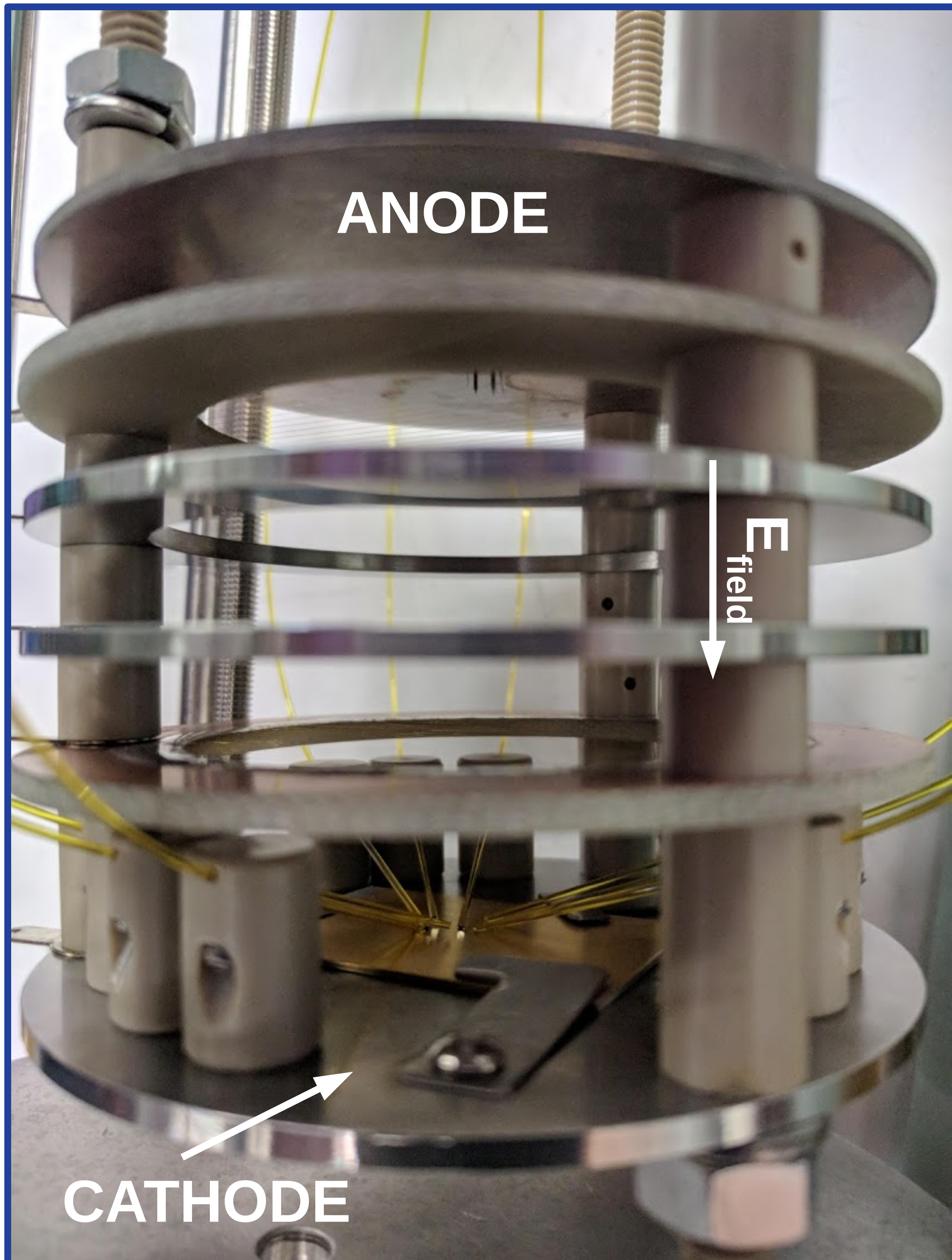
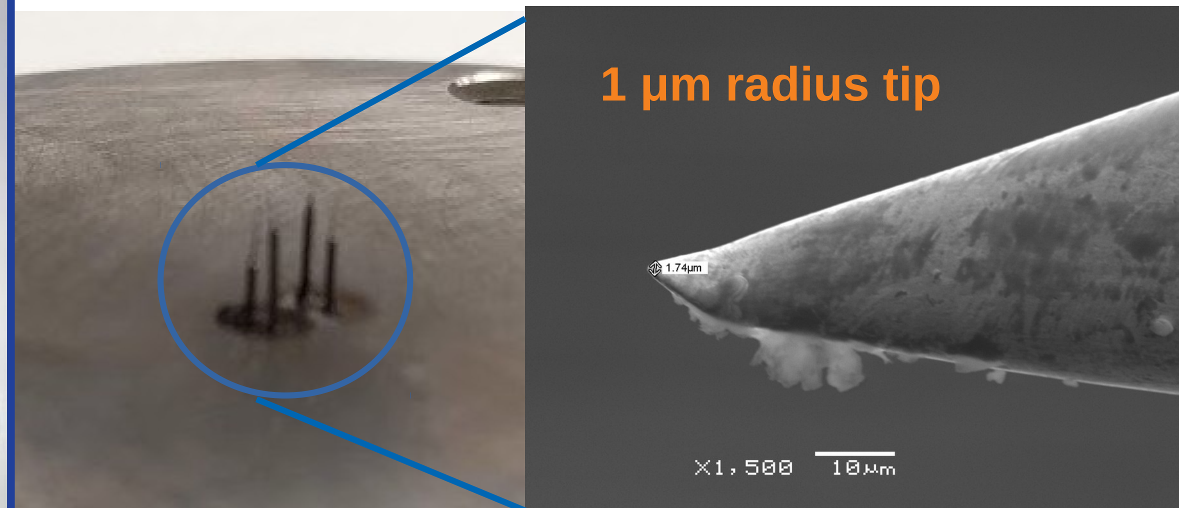
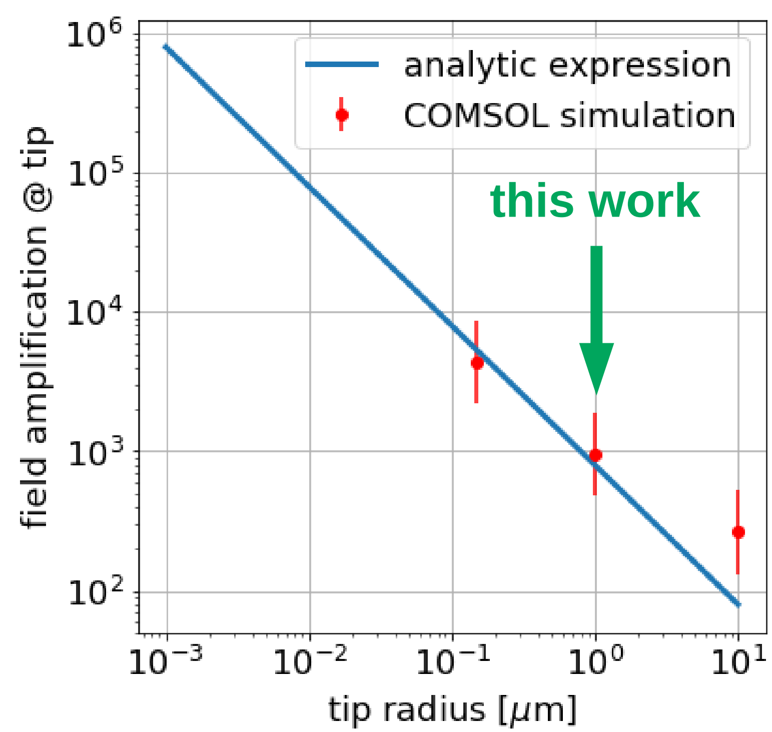




Collect charge @ anode on small tips
Intense field in tip proximity



source for analytic expression: NIM A 534 (2004) 376-396

Simulation

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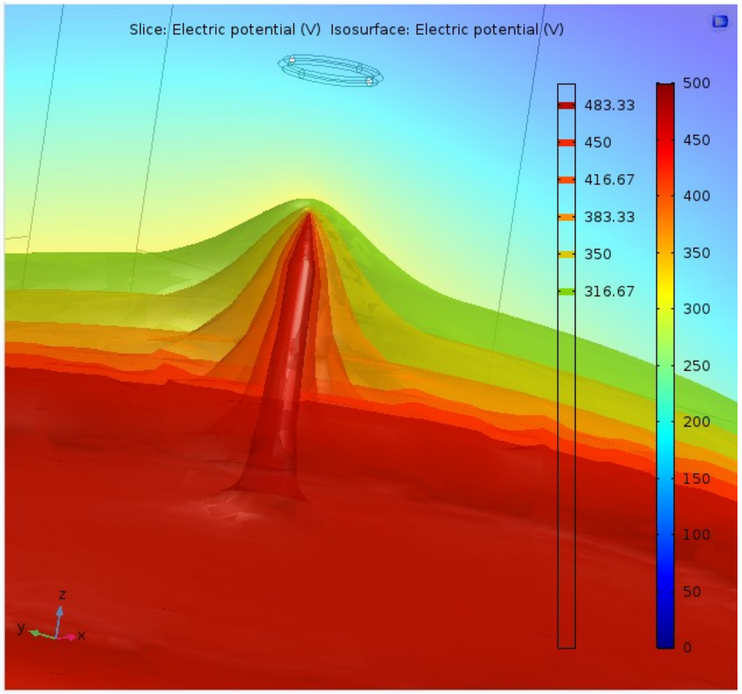

COMSOL simulation tool to model electric field in detector geometry and simulate electron drift.

Rely on literature to extract expected amplification for gas in function of local field and pressure.

M represents the multiplication factor. In the general case of a non-uniform electric field, $\alpha = \alpha(x)$, Eq. (23) has to be modified in the following way:

$$\frac{\alpha}{P} = A\,e^{-BP/E} \qquad M = \exp\left[\int_{x_1}^{x_2} \alpha(x)\,dx\right]. \qquad (24)$$

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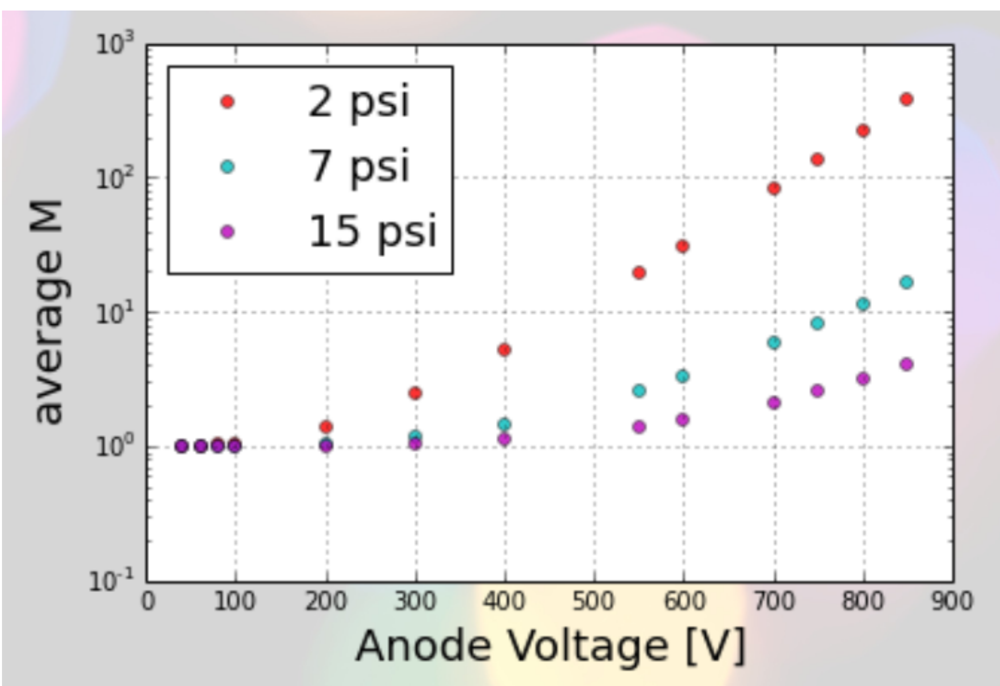
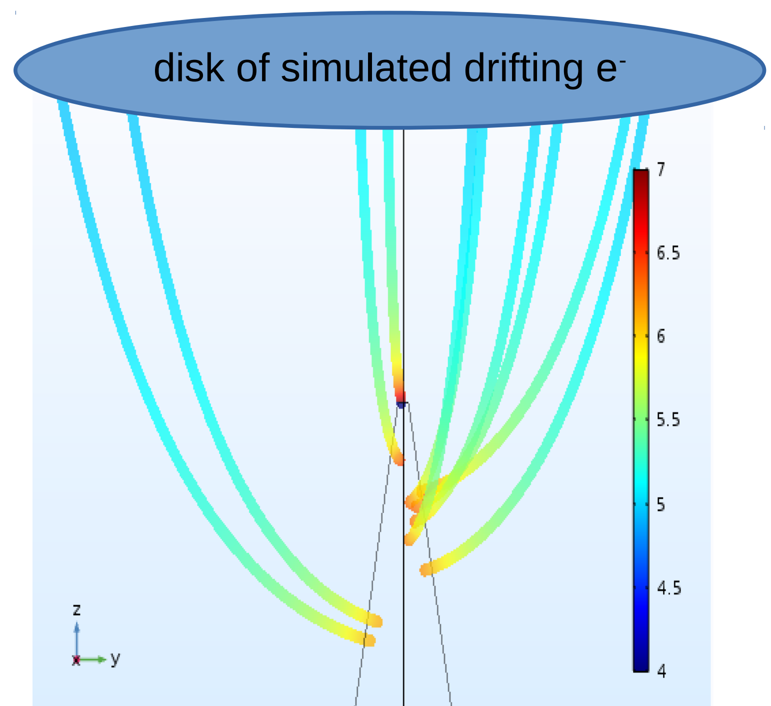
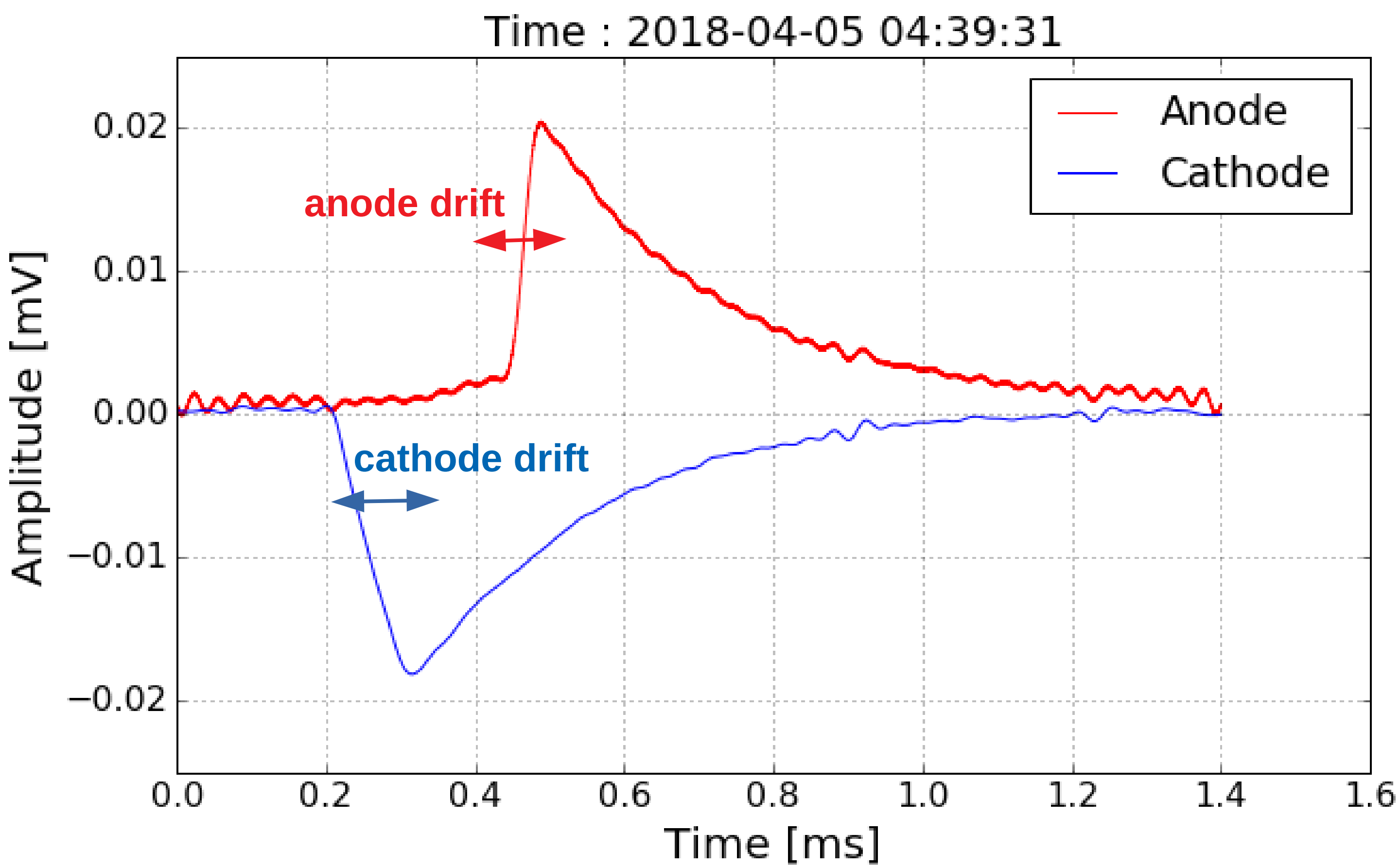
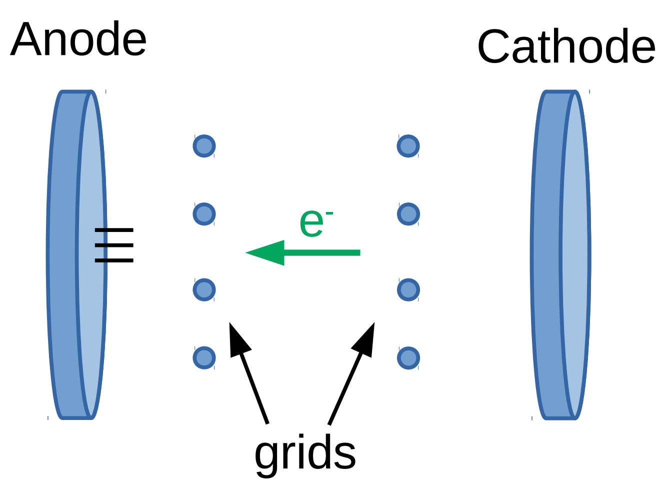




Data Analysis

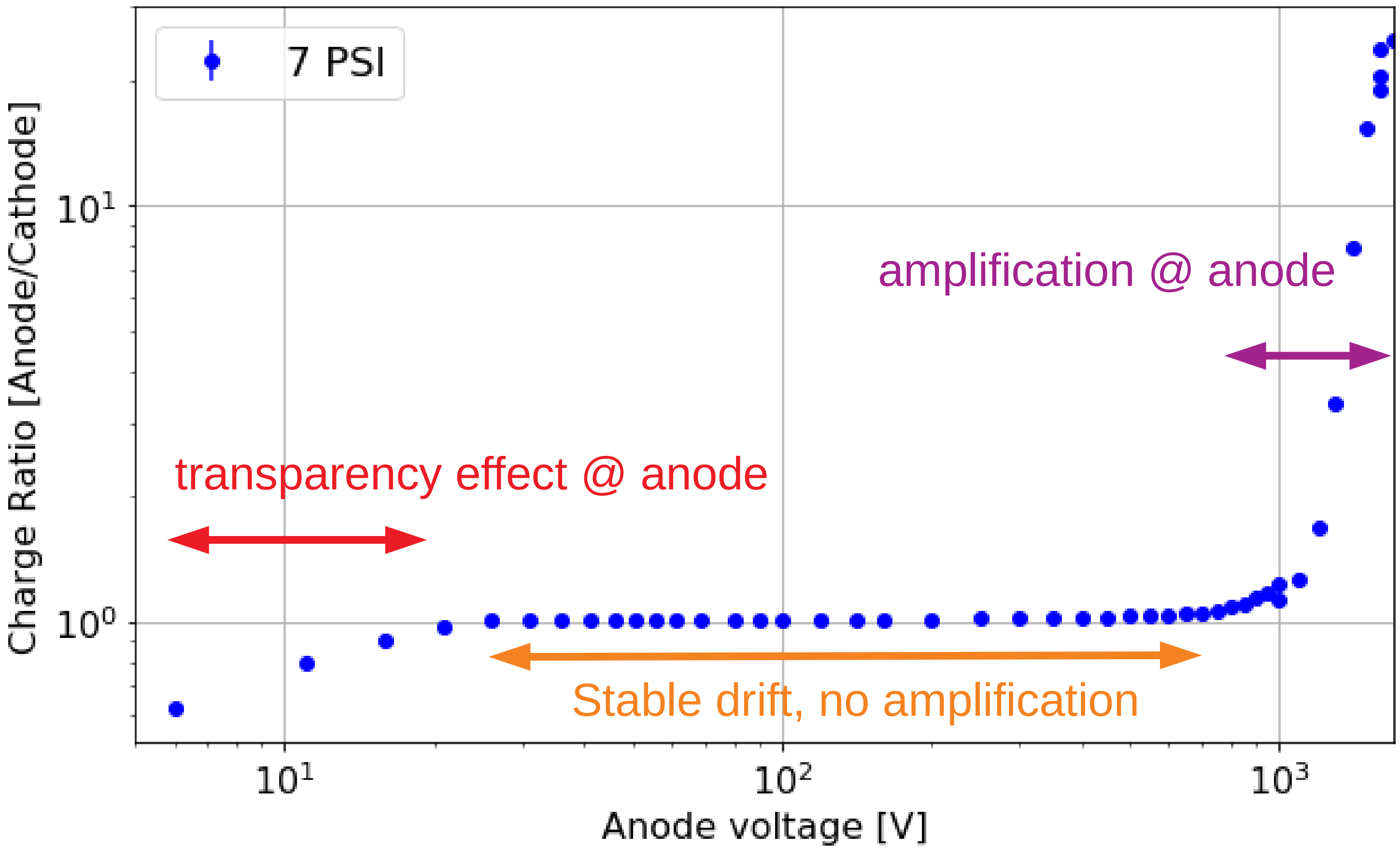




Cathode signal provides a reference of original electron cloud.

Comparison with anode used to study possible amplification.

Data Analysis [gas runs]



Data Analysis [gas runs]

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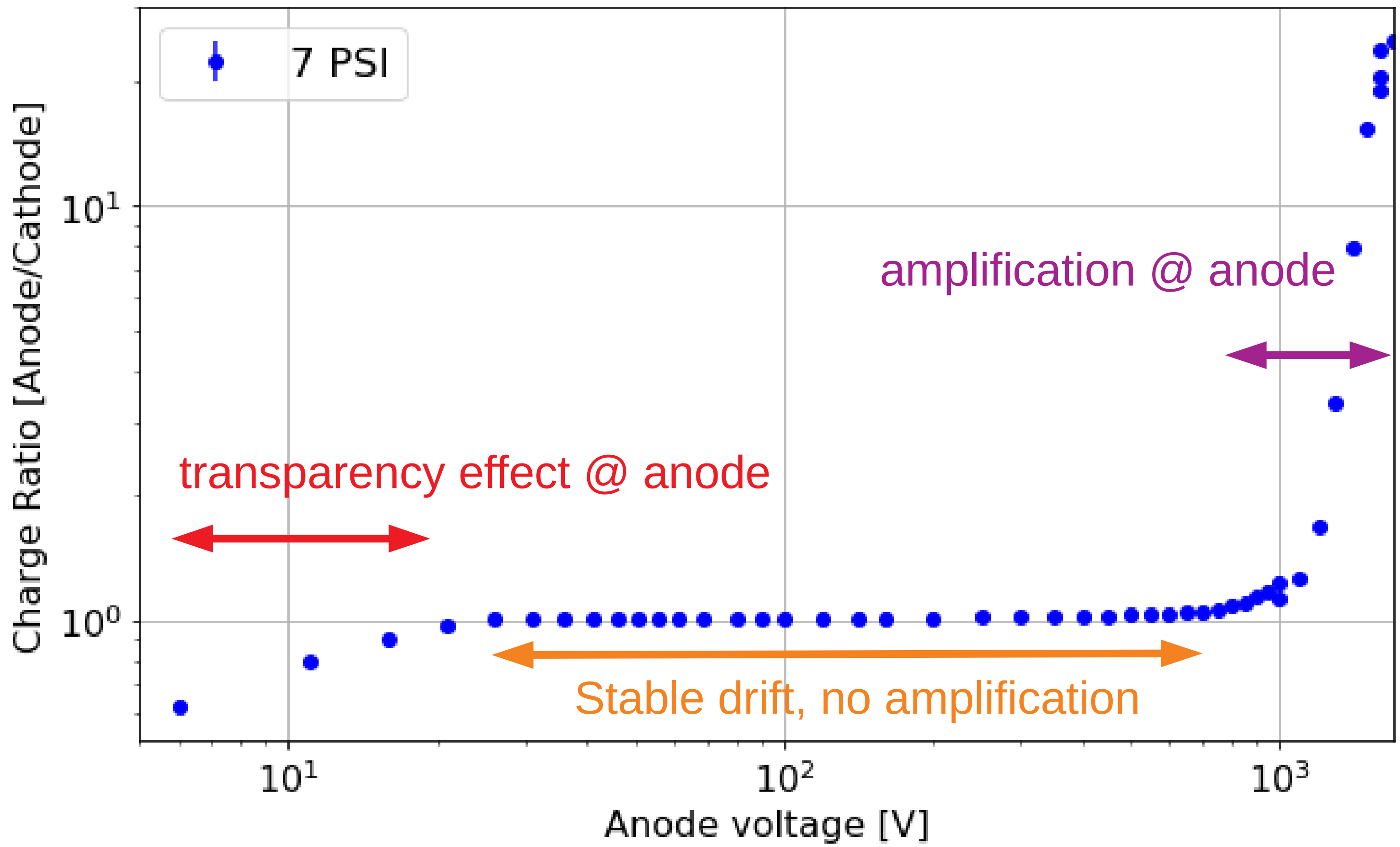

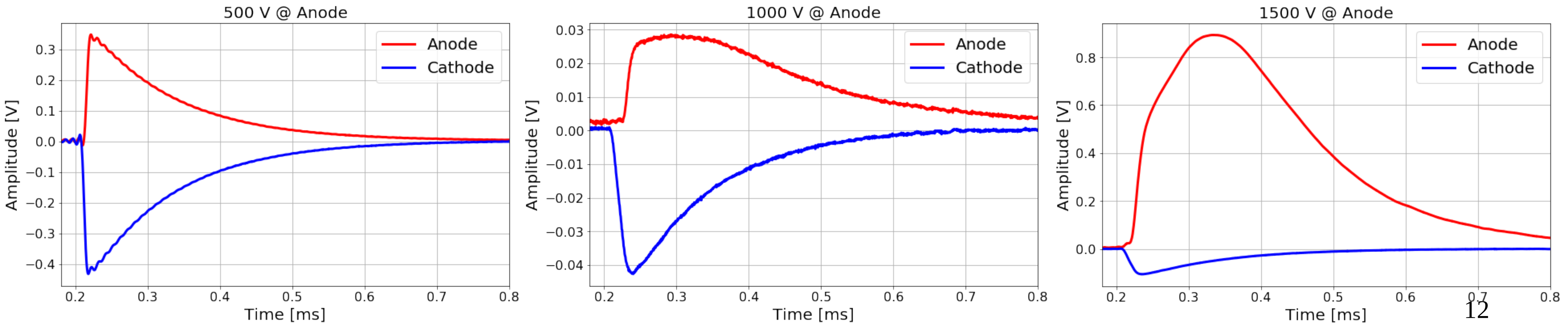

Data Analysis [liquid argon]

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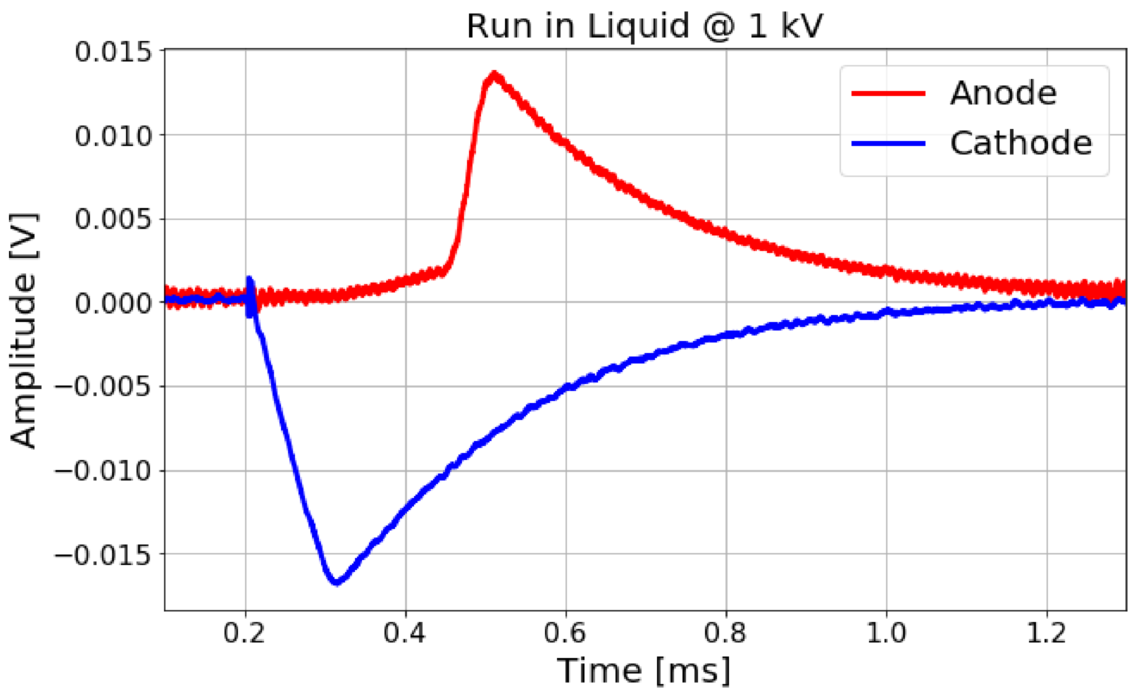
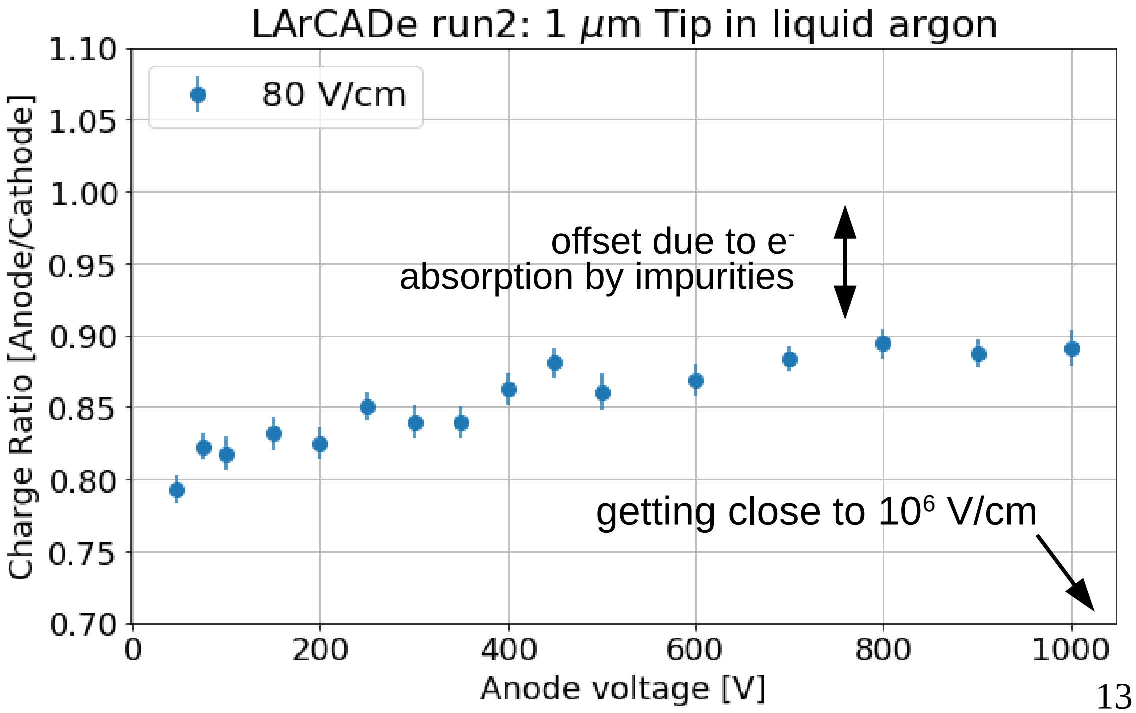
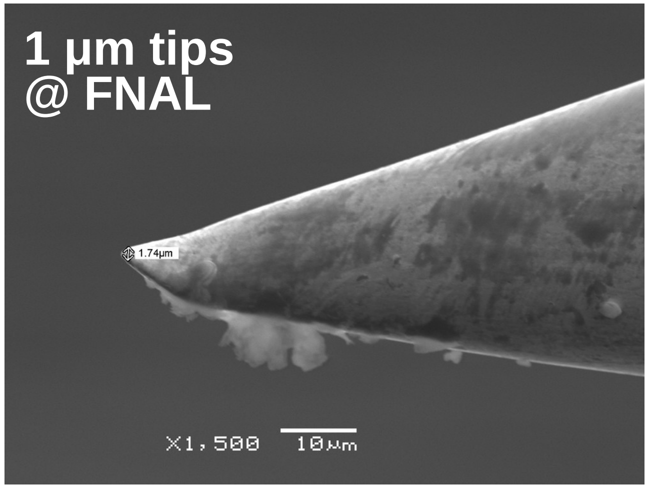


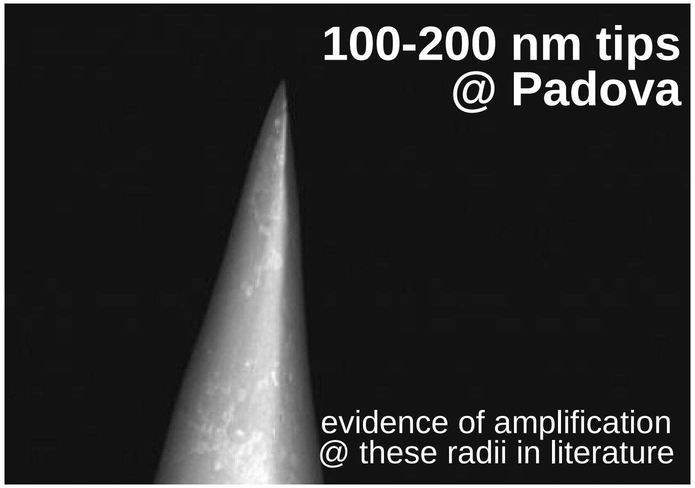
Decreased signal strength in liquid

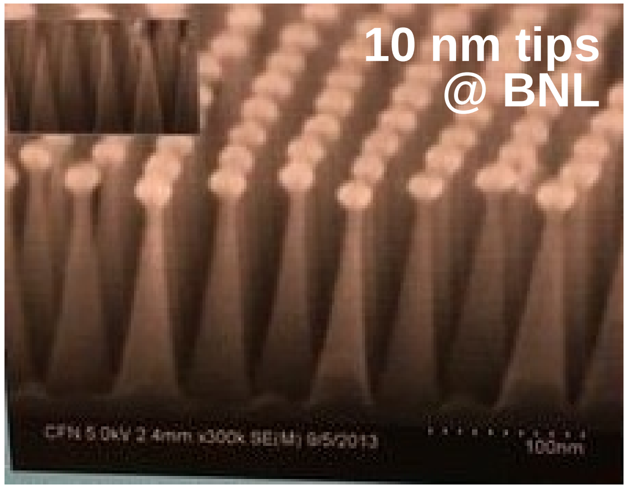
No sign of amplification
[not unexpected at these fields]



Next Steps



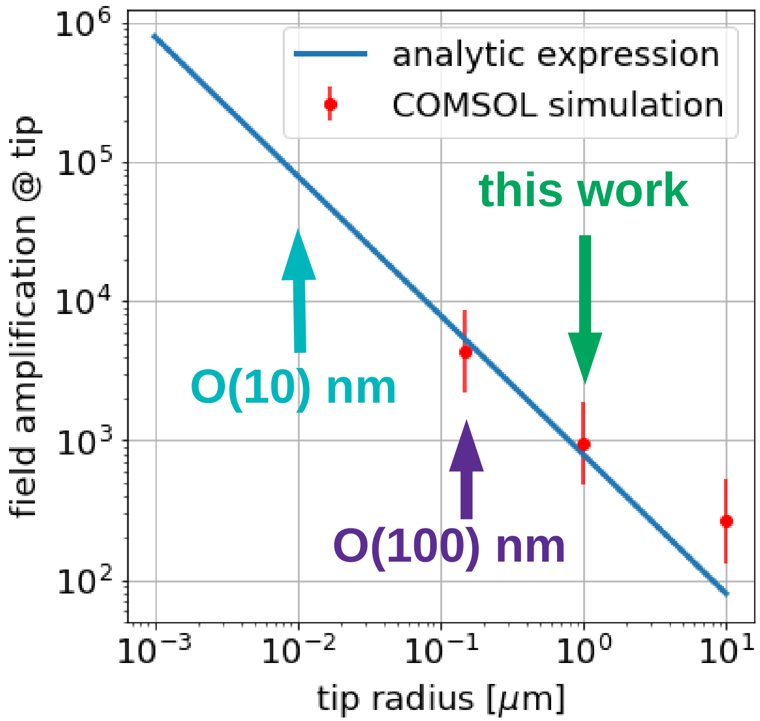




Move from 1 um to tips of 100 and 10 nm.

Study impact of tip / grid geometry on absolute gain determination.

Investigate possibility of moving to using micro-strip arrays for a scalable device.

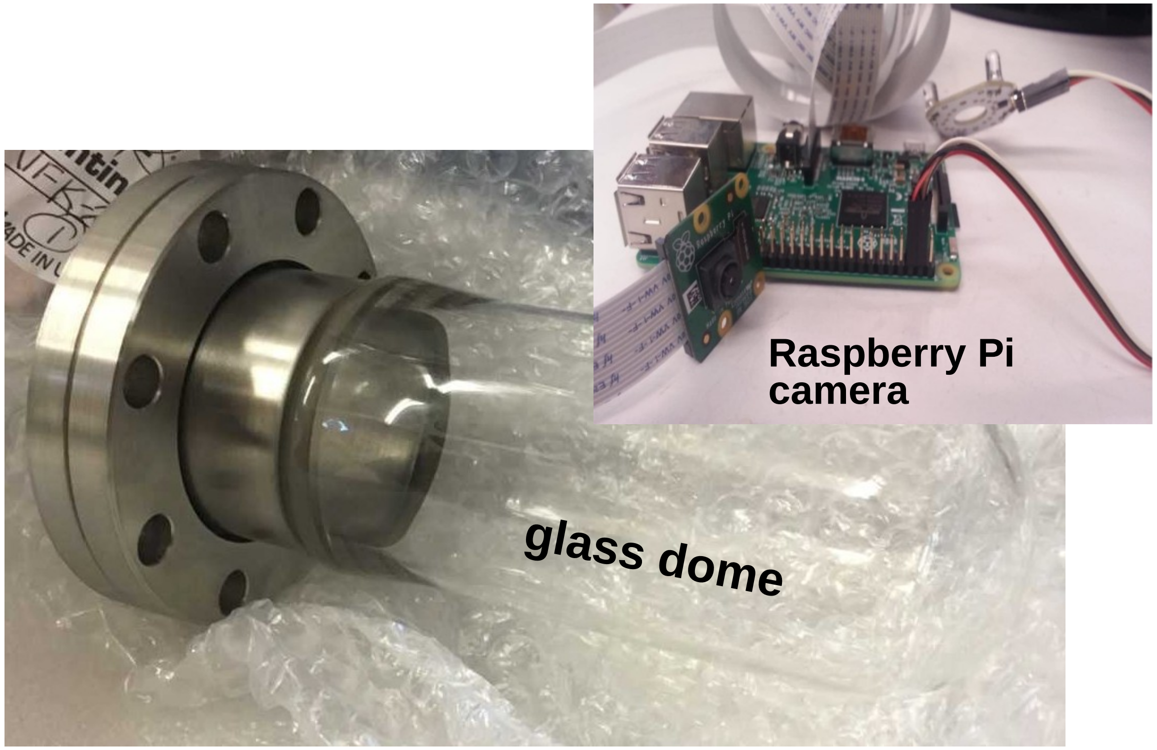


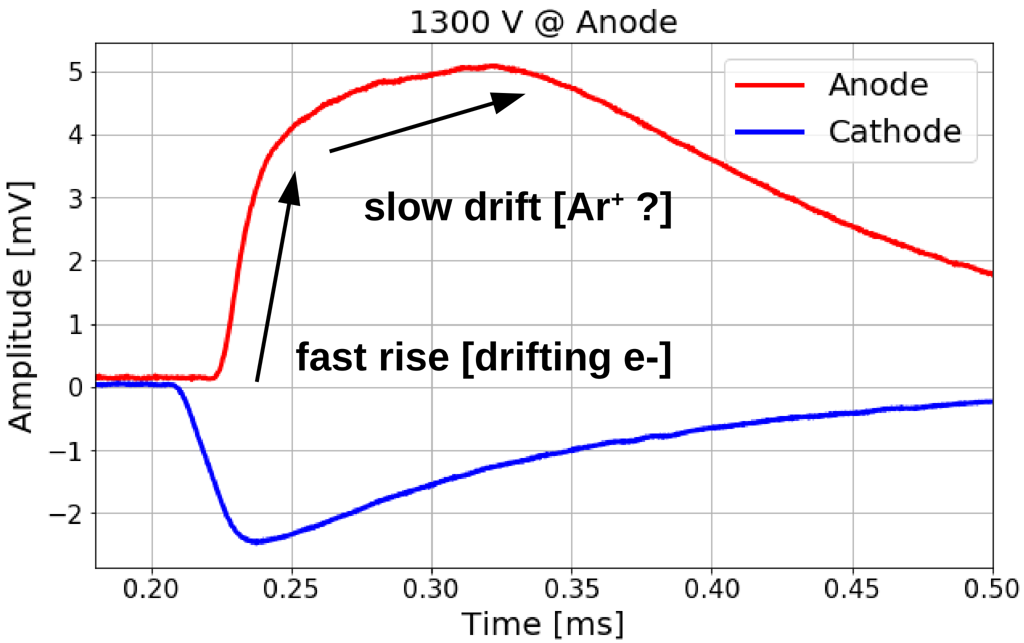
Challenges for Amplification

High E-field can induce gas bubbles in the vicinity of tips.

Induce undesired and unstable gas amplification.

Investigate bubble formation with a raspberryPi camera





Amplification occurs in tip's proximity

→ space charge effect of e^- / Ar^+

Observe in gas slow drift, possibly caused by Ar^+ ions.

Would be problematic in liquid.

Summary

1. Single-phase LArTPCs currently limited to O(1 MeV) energy thresholds by noise levels.

   [for wire/pixel detectors reading out drift e^- charge]

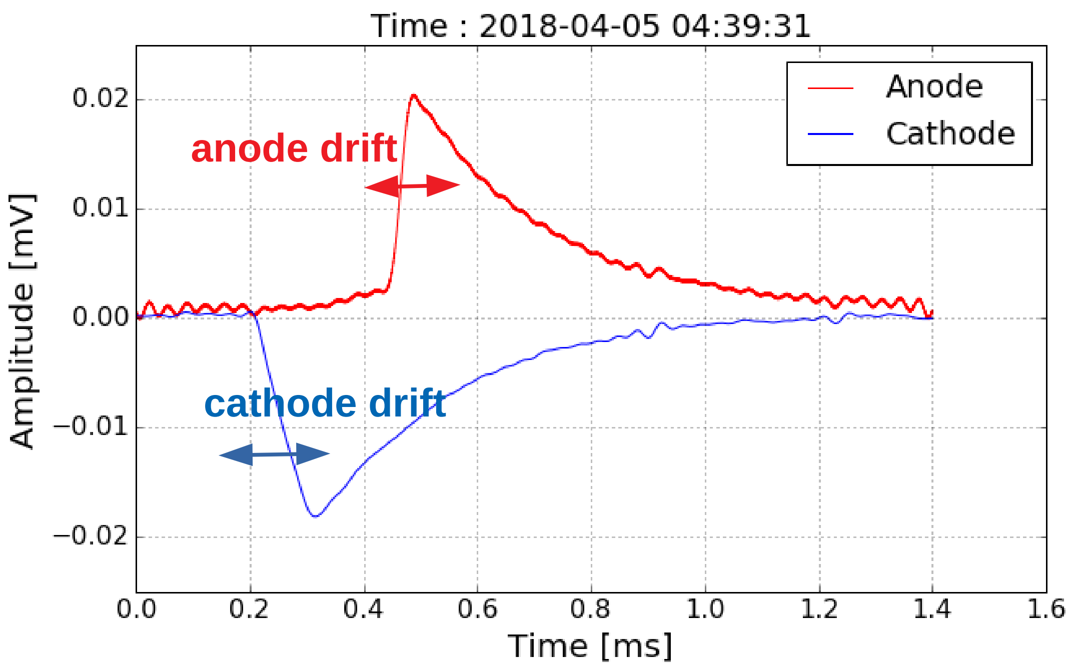
2. Amplification in liquid could expand physics reach to nuclear recoils & CEvNS.

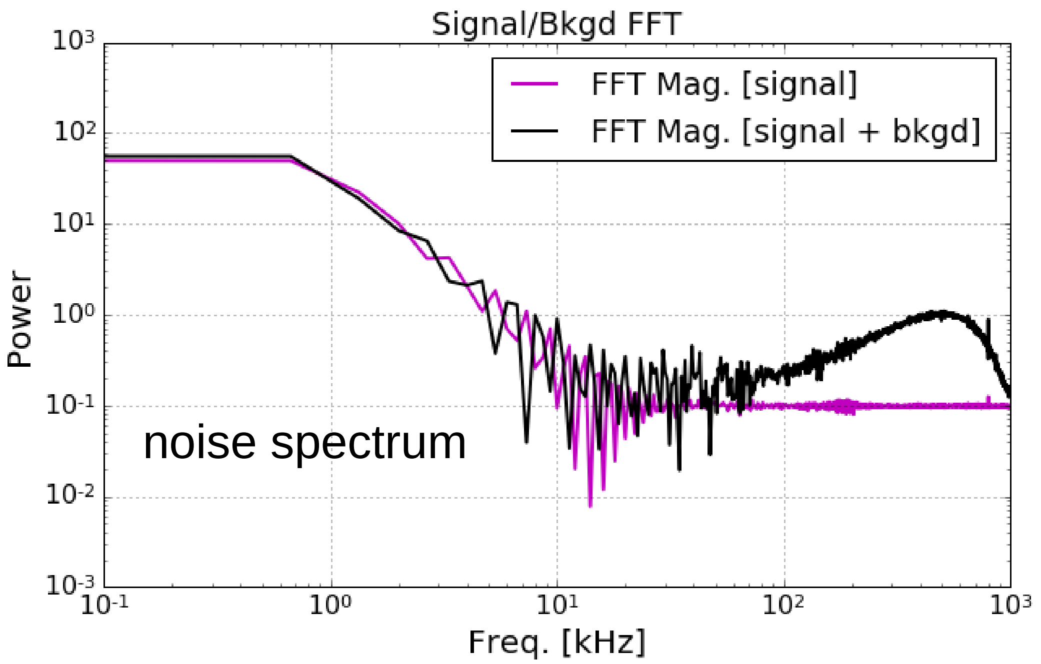
3. LArCADe program aims to explore the feasibility of obtaining stable amplification in LAr.

   1) Gained understanding of setup performance in gas.
   2) Moving to measurements in liquid with different tip configurations.
   3) Aiming to investigate effects impacting the feasibility stable amplification.

Backup

Signal Processing





Electroncs Noise in LArTPCs

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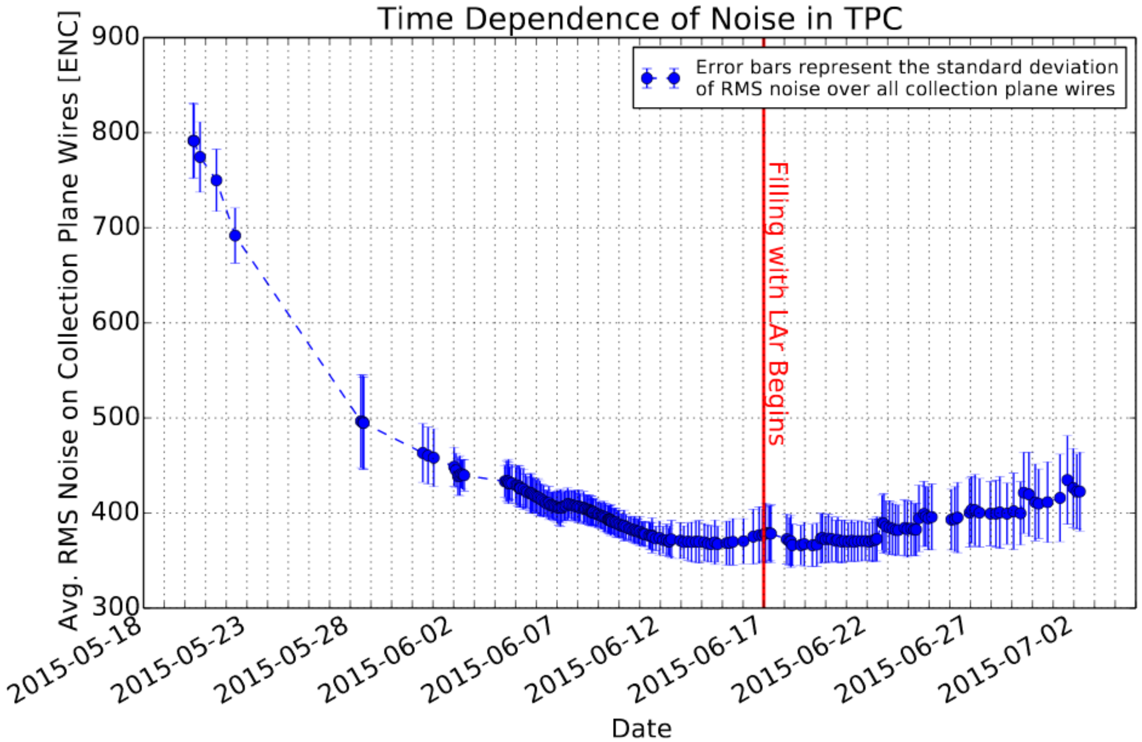

MicroBooNE: http://microboone.fnal.gov/wp-content/uploads/MICROBOONE-NOTE-1001-TECH.pdf

Pressure Dependence in Gas

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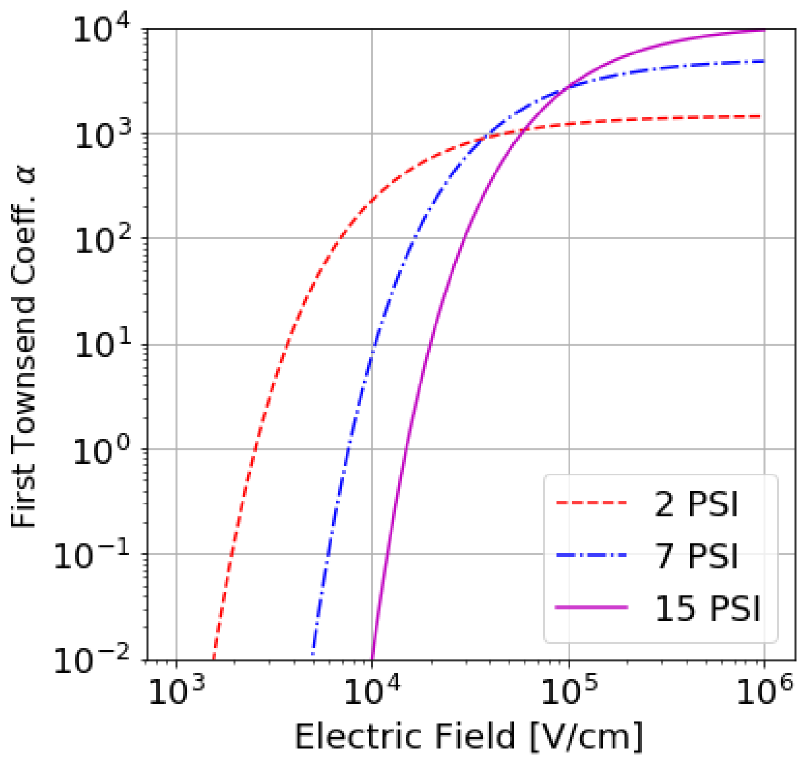
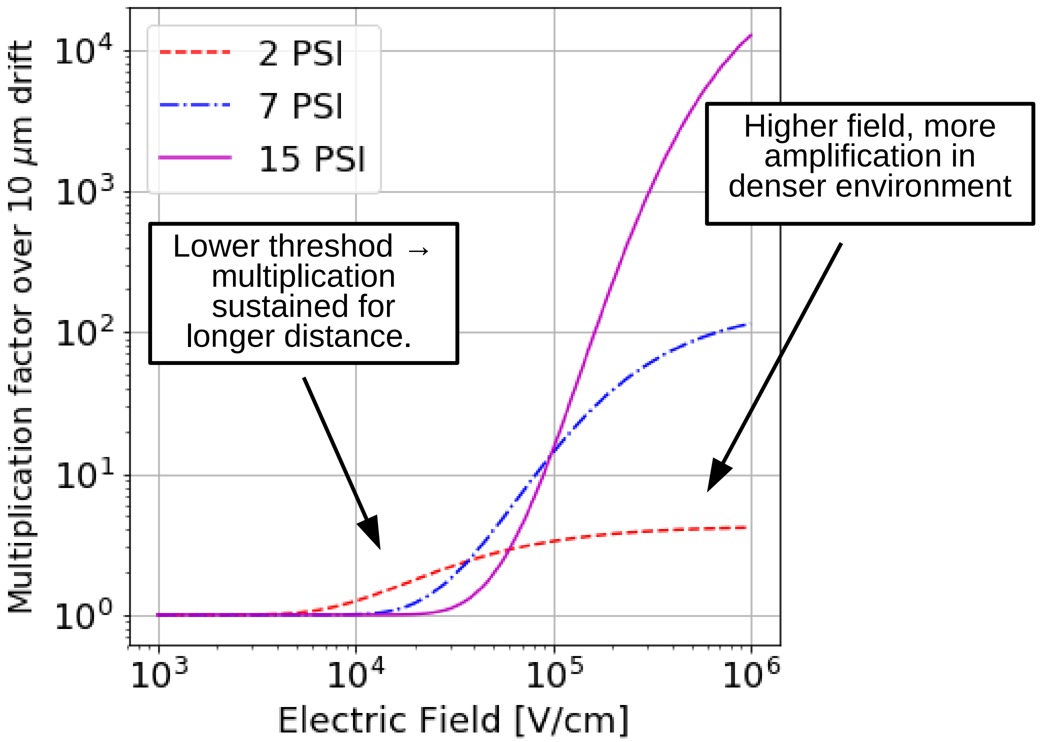
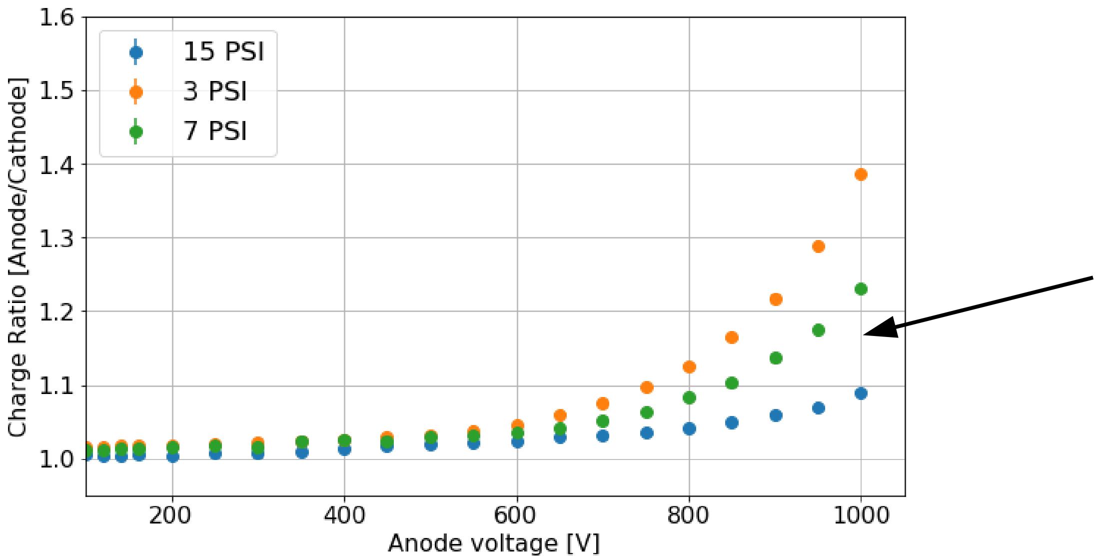






Observe different regimes of amplification.

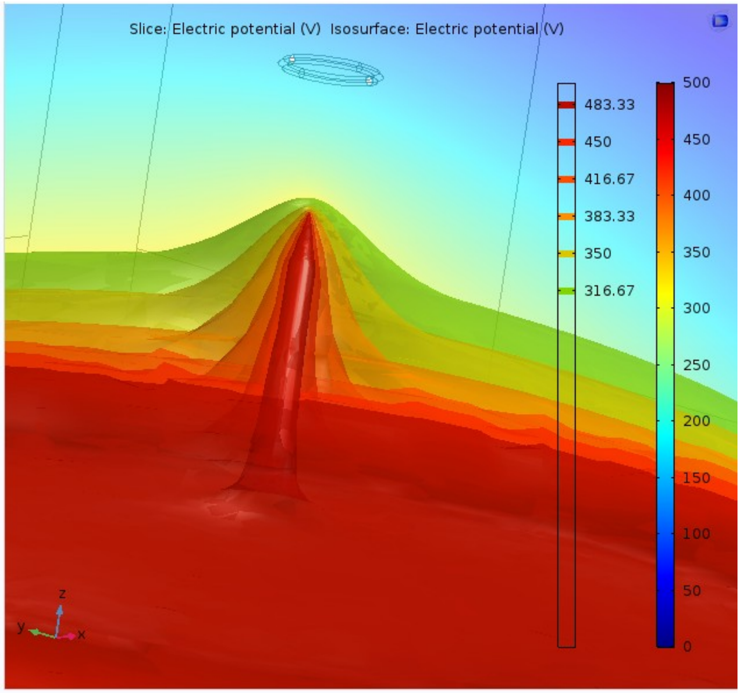
Pressure dependence significantly impacted by tip geometry.

Project Overview

- Measure gain amplification factor in gas when running with FNAL-produced tips.

Two-steps:

1) Simulate E-field and e- trajectory in COMSOL.



2) Calculate amplification factor from analytic expression.

M represents the multiplication factor. In the general case of a non-uniform electric field, $\alpha = \alpha(x)$, Eq. (23) has to be modified in the following way:

$$M = \exp\left[\int_{x_1}^{x_2} \alpha(x)\, dx\right] . \qquad (24$$

$$\frac{\alpha}{P} = A\, e^{-BP/E}$$

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α = Townsend coeff. → Inverse of ionization mean free path, or, number of ions produced per unit distance.

Amplification Calculation

M represents the multiplication factor. In the general case of a non-uniform electric field, $\alpha = \alpha(x)$, Eq. (23) has to be modified in the following way:

$$M = \exp\left[\int_{x_1}^{x_2} \alpha(x)\, dx\right] . \qquad (24$$

$$\frac{\alpha}{P} = A\, e^{-BP/E}$$

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What to expect based on this model.

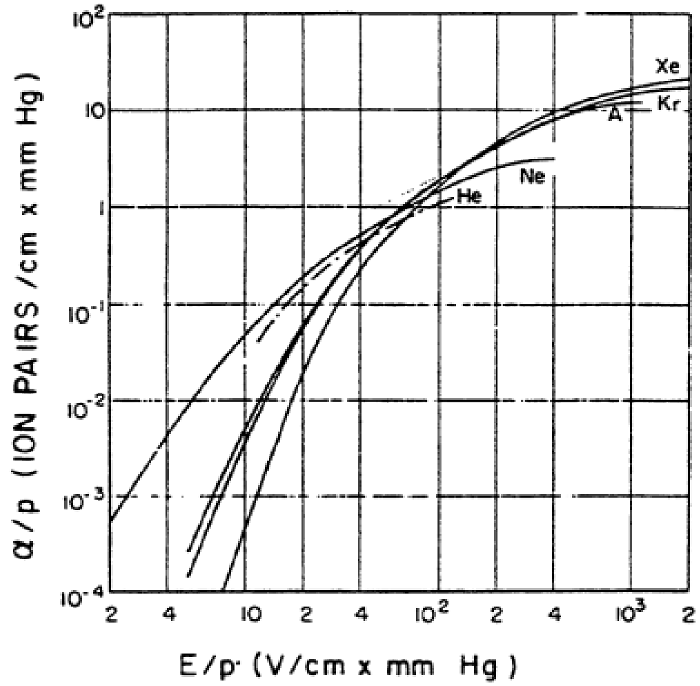
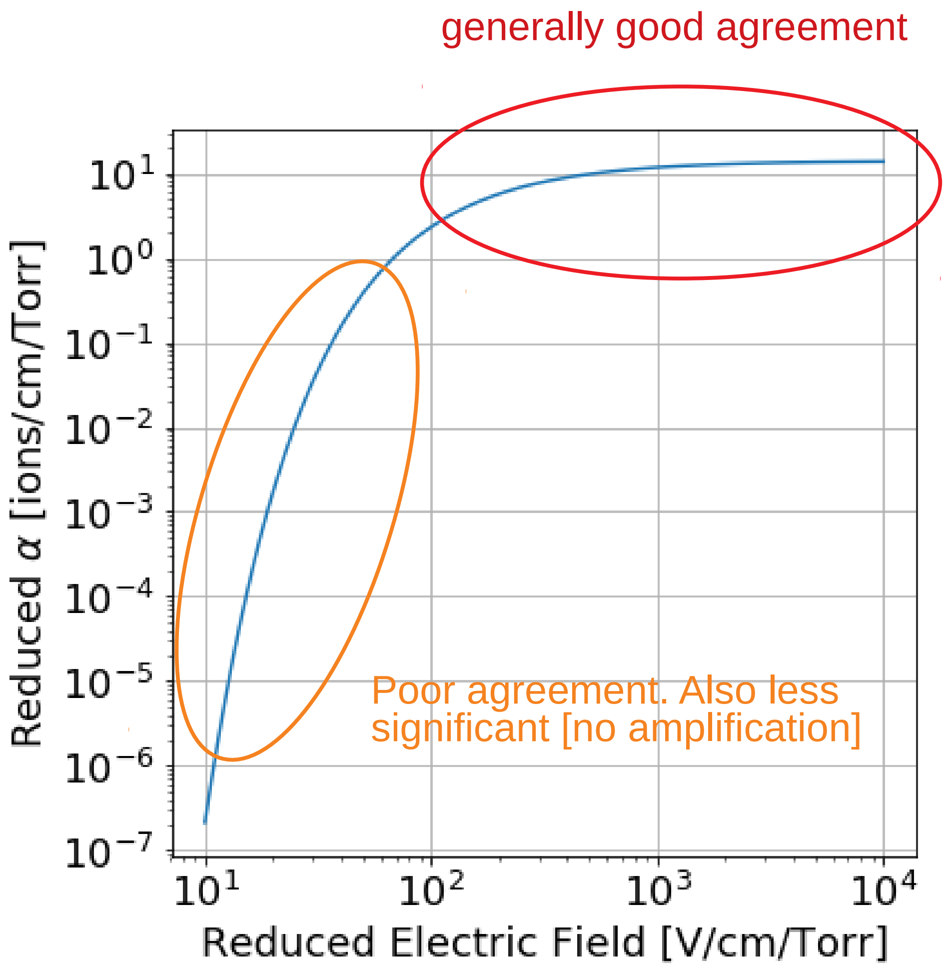
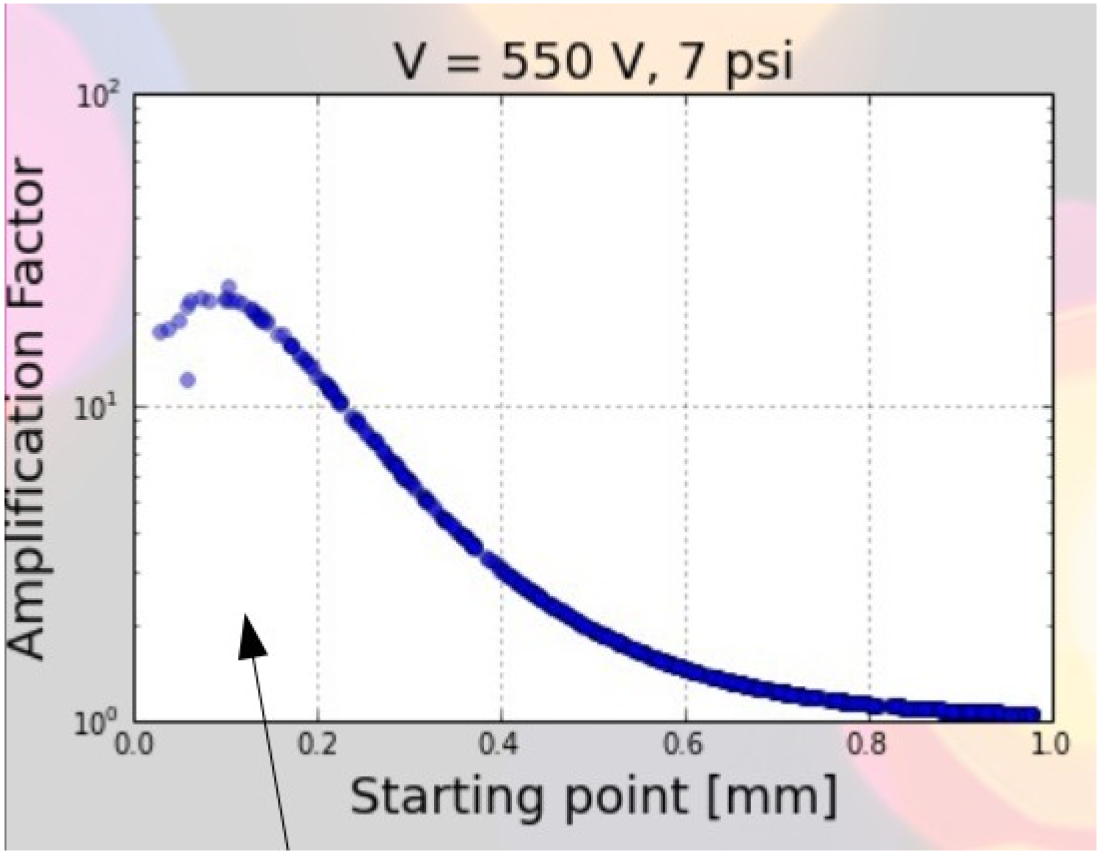
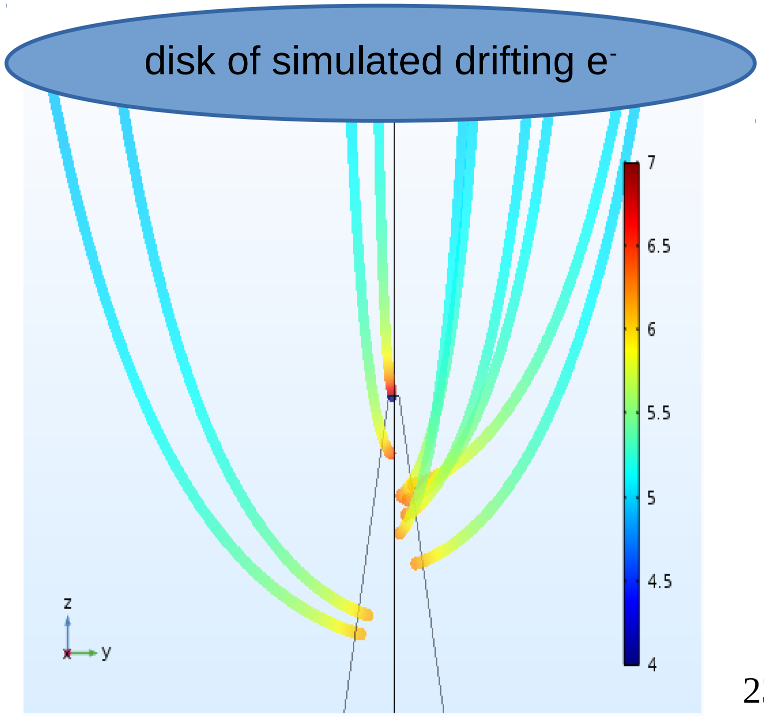


Fig. 44 First Townsend coefficient as a function of the reduced electric field, for noble gases[22])

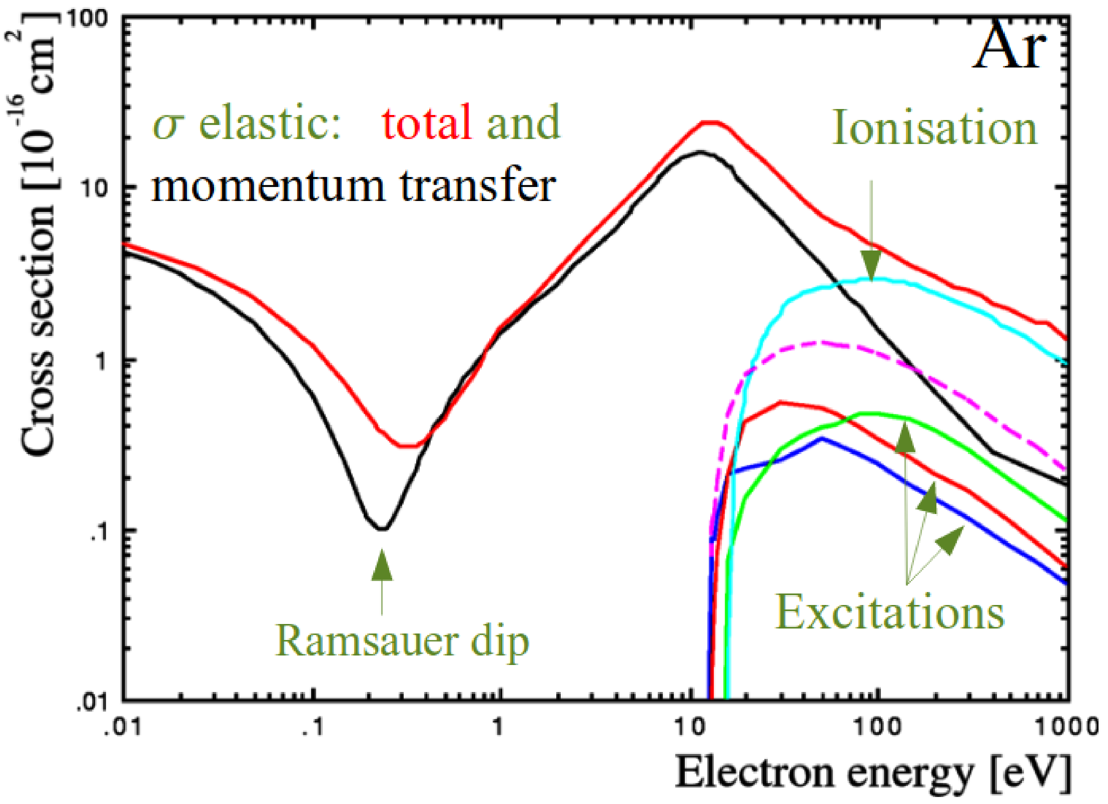


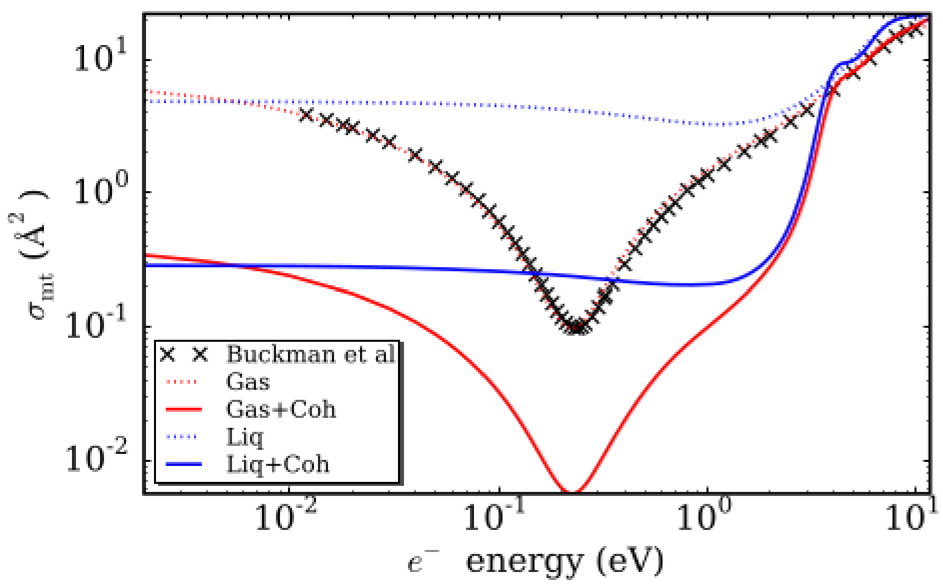
Impact of Anode / Tip geometry





e⁻ scatter / ionization in LAr





Ar xsec:

Phys Rev A, V65, 042713
J Chem Phys 142, 154507 (2015)

L_{eff}

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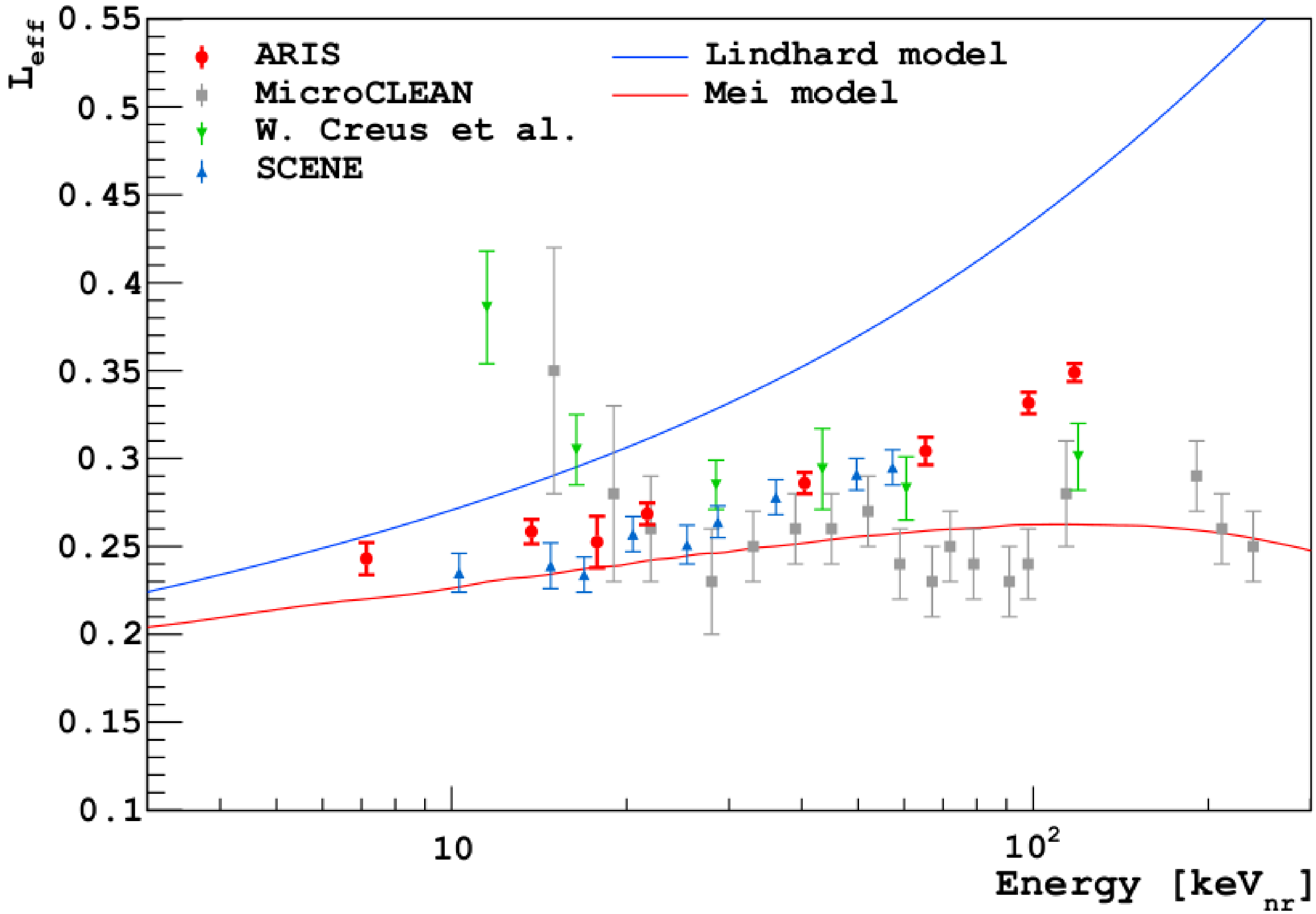

FIG. 14. $\mathcal{L}_{eff}$ dependence on NR energy as measured by this work and compared with other data sets [14–16] and models [18, 19].

Phys. Rev. D 97, 112005 (2018) [ARIS]