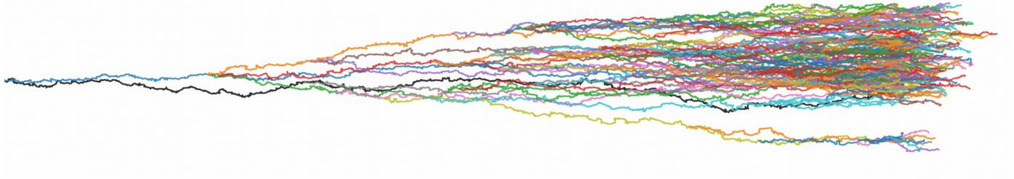
LArCADe

TRANSLATE

transport in liquid argon of near-thermal electrons



TRANSLATE - A Monte Carlo Simulation of Electron Transport in Liquid Argon

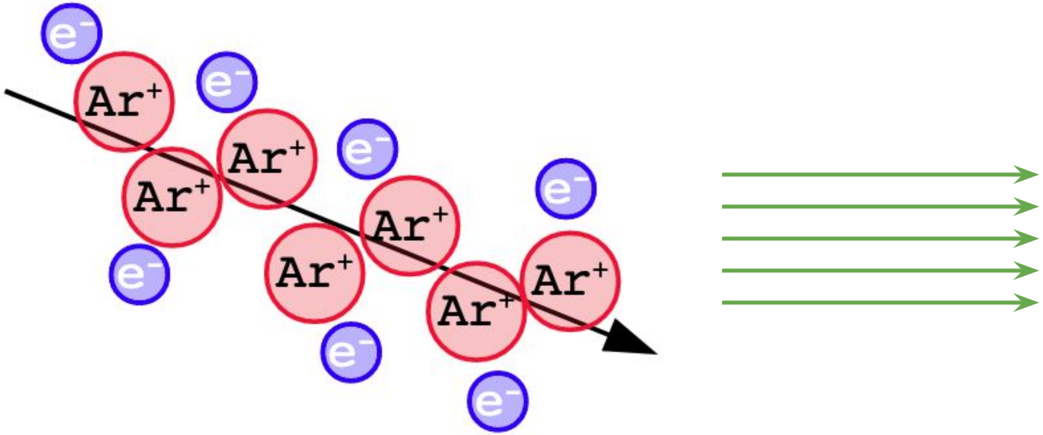
https://arxiv.org/abs/2211.12645

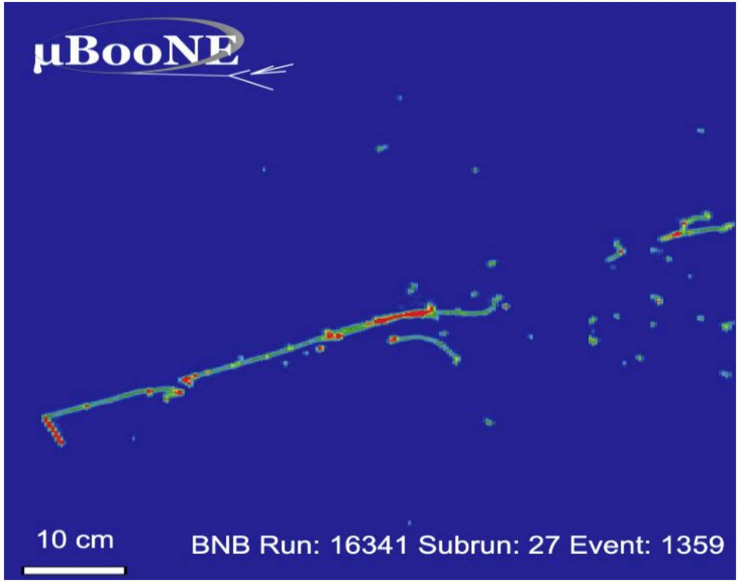
Z. Beever[a,c], D. Caratelli[c,d,*], A. Fava[c], F. Pietropaolo[b], F. Stocker[b,e], J. Zettlemoyer[c]

[a] *Boston University, Boston, MA, 02215, USA*
[b] *CERN, The European Organization for Nuclear Research, 1211 Meyrin, Switzerland*
[c] *Fermi National Accelerator Laboratory, Batavia, IL, 60510, USA*
[d] *University of California Santa Barbara, Santa Barbara, CA, 93106, USA*
[e] *Yale University, New Haven, CT, 06520, USA*

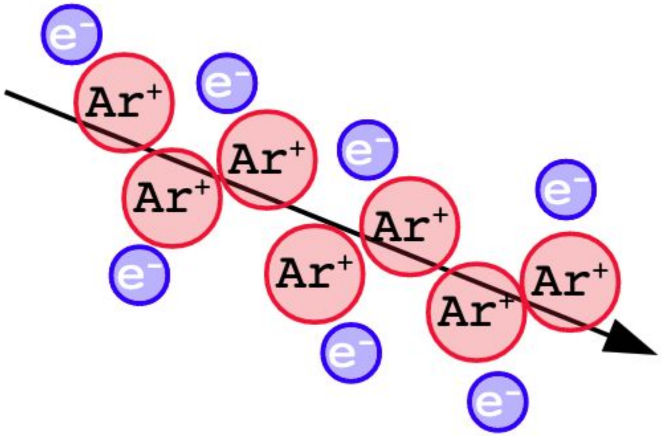
UC SANTA BARBARA

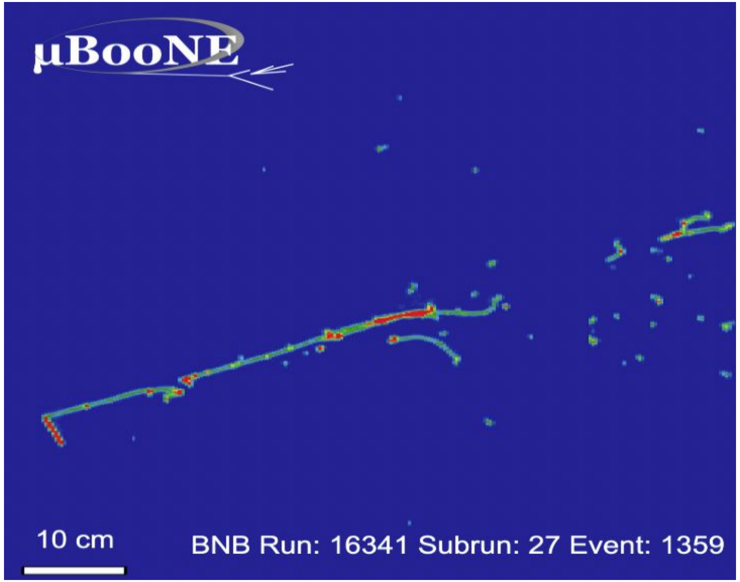
Microphysics in Noble Element Detectors





Microphysics in Noble Element Detectors

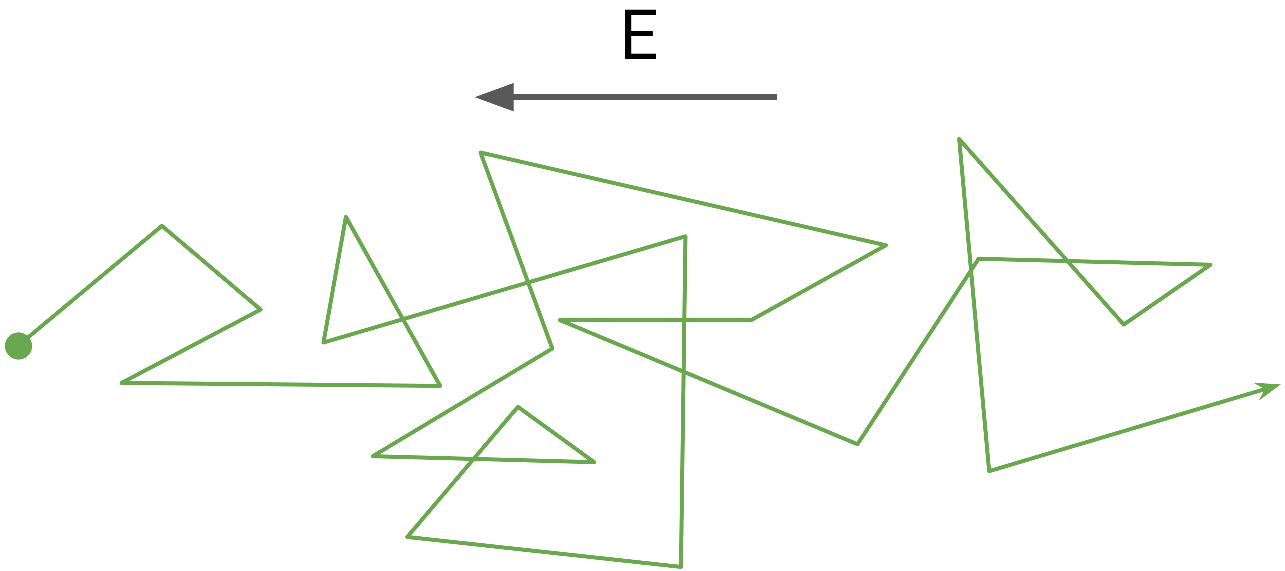




Complex microphysics at play: excitations ($\rightarrow \gamma$), ion recombination, e- – Ar scattering, secondary ionization.

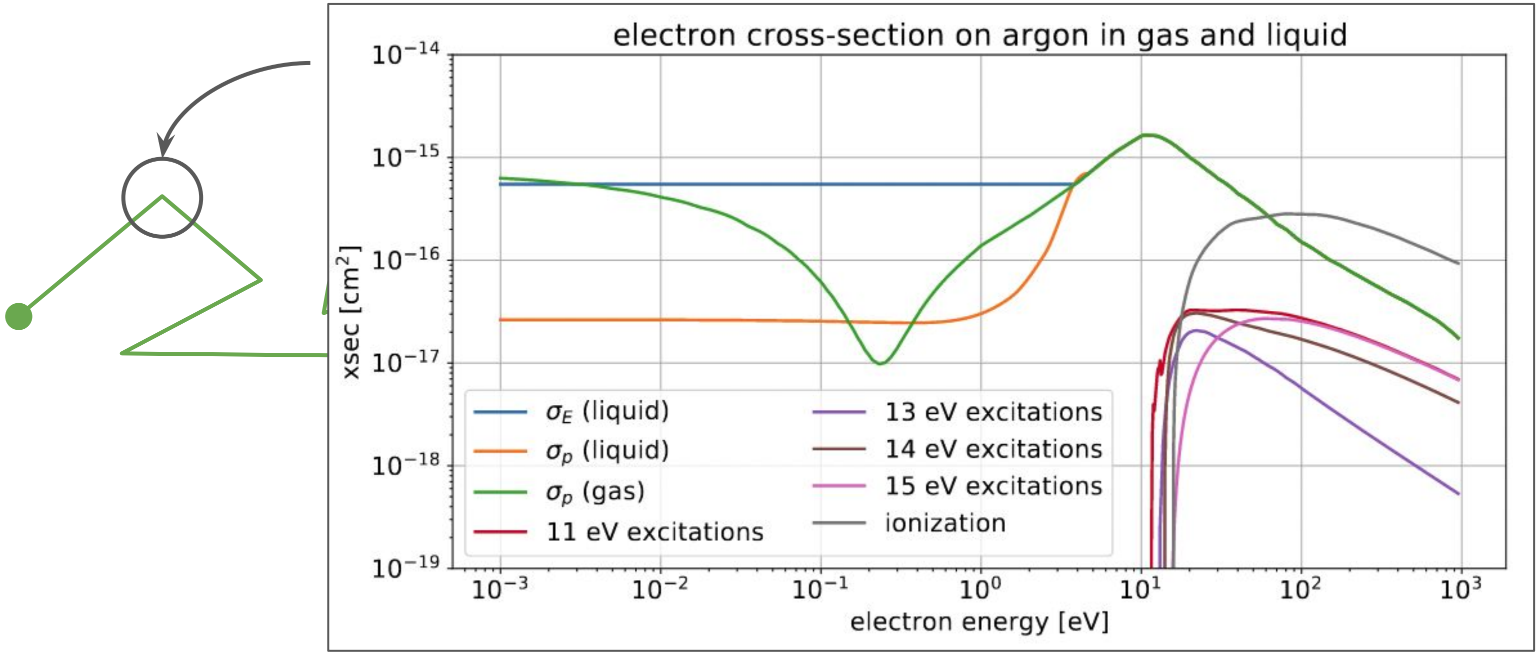
All play a critical role in determining the observables our detectors rely on: drift velocity, diffusion, charge vs. light, amplification gain, etc…

Electron Transport



Macroscopic dynamics of ionization cloud dictated by microscopic interactions of electrons in their LAr environment.

Electron Transport and Interactions



Macroscopic dynamics of ionization cloud dictated by microscopic interactions of electrons in their LAr environment.

LArCADe – Liquid Argon Charge Amplification Devices

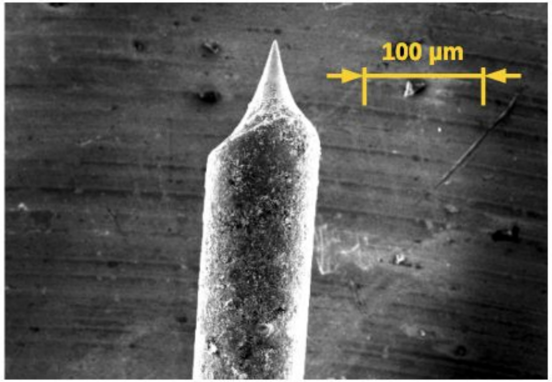
LArCADe: **L**iquid **Ar**gon **C**harge **A**mplification **De**vices

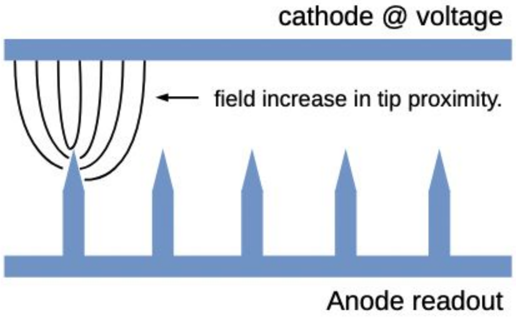
Charge amplification in gas a well established technology for low-threshold detectors. Particularly attractive for measurements of Nuclear Recoils (NRs) from Dark Matter or CEνNS interactions.

Expansion to liquid argon an exciting instrumentation development with significant R&D opportunities and challenges.

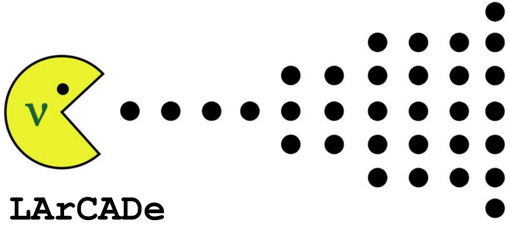
Understanding charge amplification in noble elements depends on an understanding of this same microphysics.

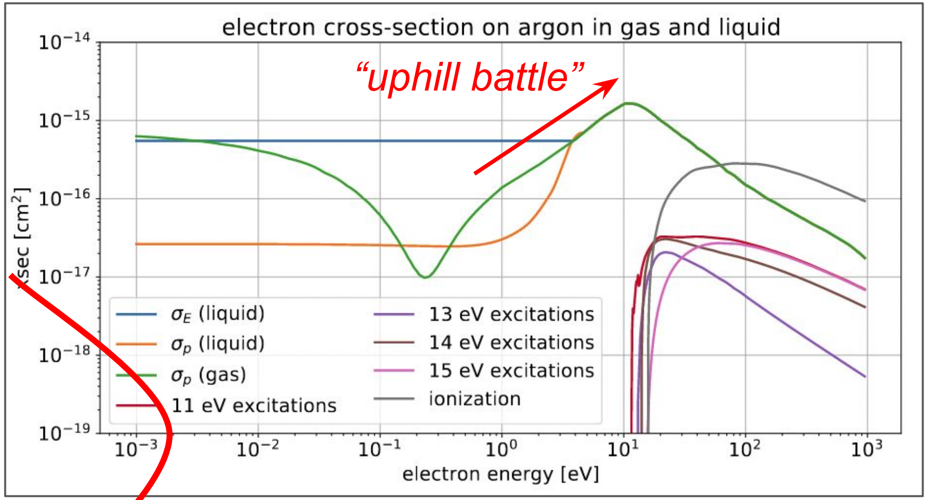
TRANSLATE simulation package arose to meet the need of quantifying expected charge amplification in LAr in complex “tip-like” geometries.

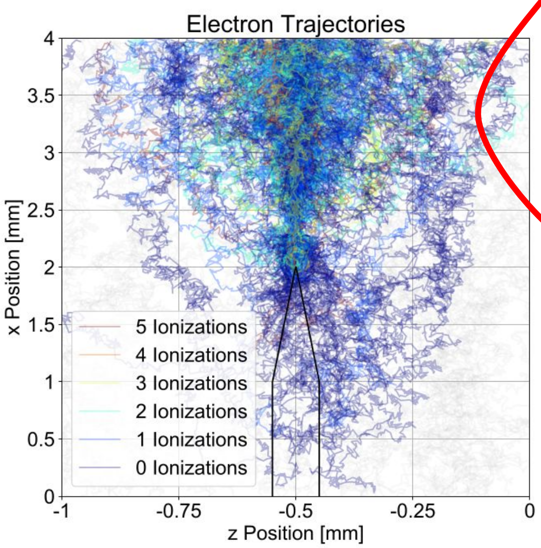


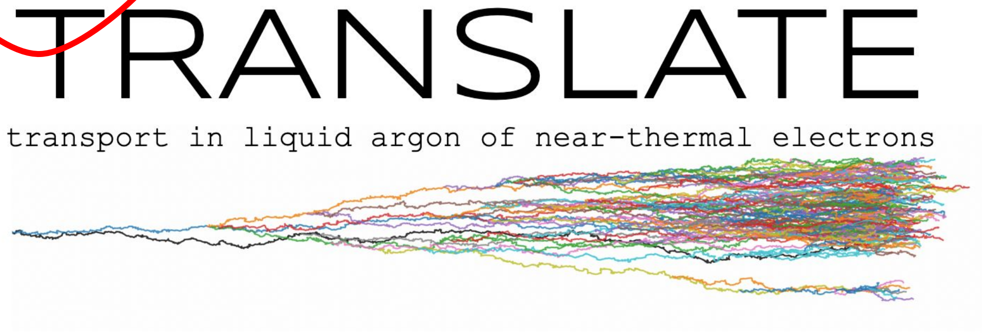


LArCADe – Liquid Argon Charge Amplification Devices









Simulation Methods

M. Wojcik, M. Tachiya / Chemical Physics Letters 379 (2003) 20–27

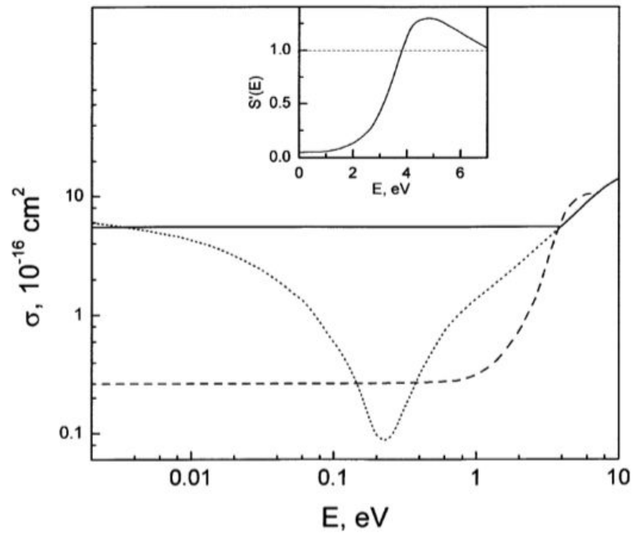
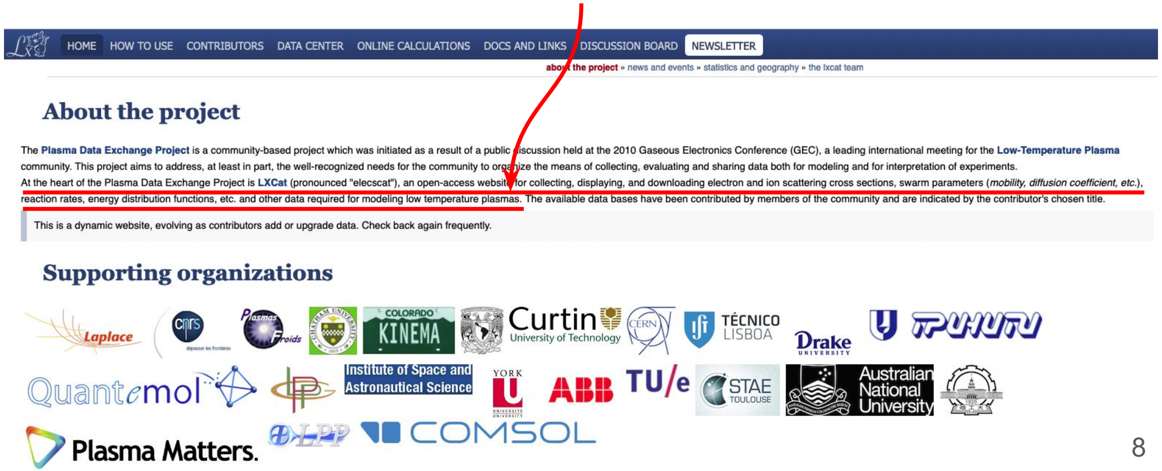


Fig. 1. Cross-sections σ_E (solid line) and σ_p (dashed line) that are used in the simulation model of electron transport in liquid argon at 87 K. The dotted line shows the momentum transfer cross-section σ_{Ar} for argon gas [28]. The inset shows the function $S'(E)$ for liquid argon [3].

LXCat – https://us.lxcat.net/home/

*"At the heart of the Plasma Data Exchange Project is **LXCat** (pronounced "elecscat"), an open-access website for collecting, displaying, and downloading electron and ion scattering cross sections, swarm parameters (mobility, diffusion coefficient, etc.), reaction rates, energy distribution functions, etc. and other data required for modeling low temperature plasmas."*



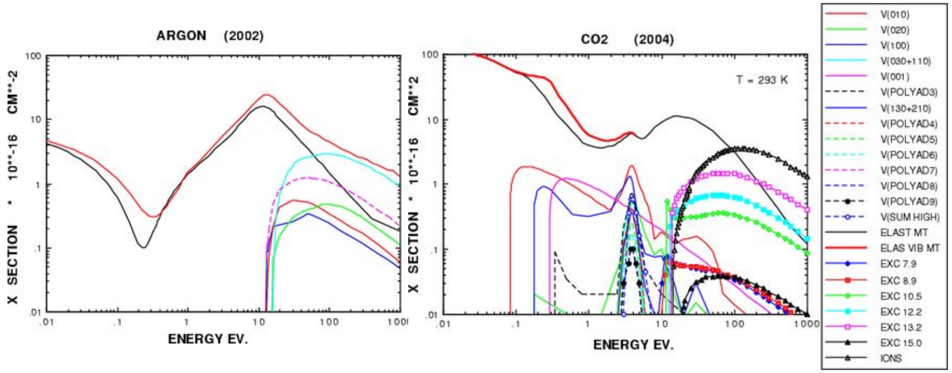
Microphysics simulation in GAr: “PyBoltz”

https://github.com/UTA-REST/PyBoltz

“Electron Transport in Gaseous Detectors with a Python-based Monte Carlo Simulation Code”
Comput.Phys.Commun. 254 (2020) 107357 [https://arxiv.org/abs/1910.06983]
B. Al Atoum, S. F. Biagi, D. Gonzalez-Diaz, B.J.P Jones, A.D. McDonald

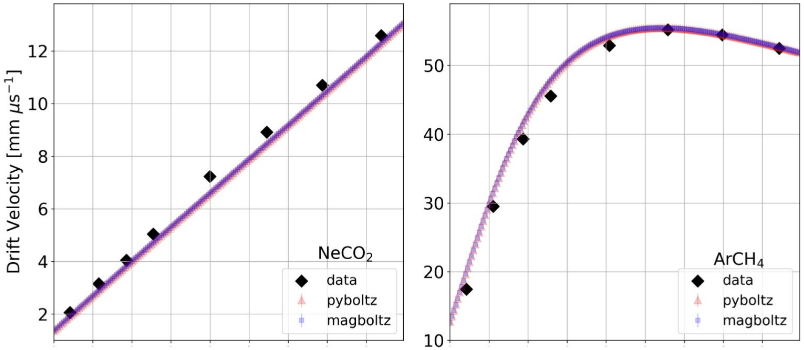
Well established Monte-Carlo based simulation package for transport in gaseous detectors. Most recent code PyBoltz builds on earlier MagBoltz simulation package.

https://magboltz.web.cern.ch/magboltz/

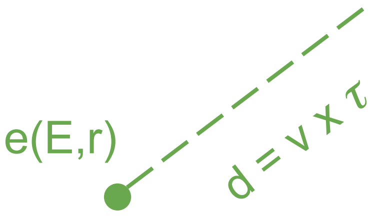


http://www.dfcd.net/projects/penningtransfer/cross.htm

Comput.Phys.Commun. 254 (2020) 107357



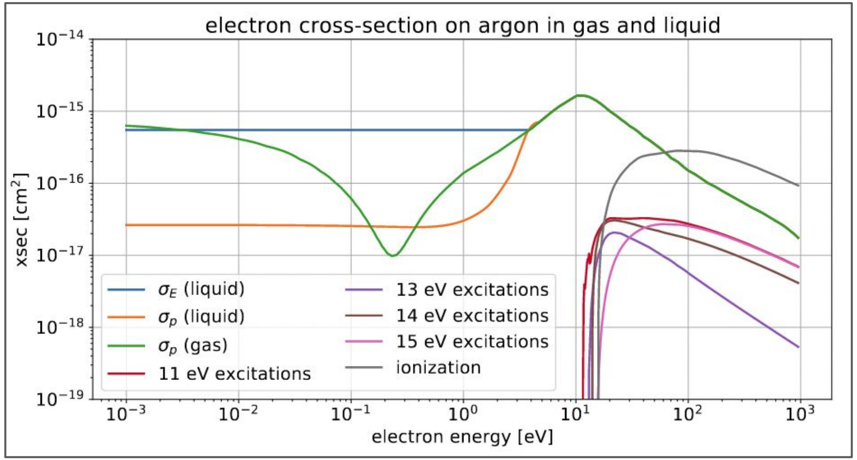
Simulation Methods

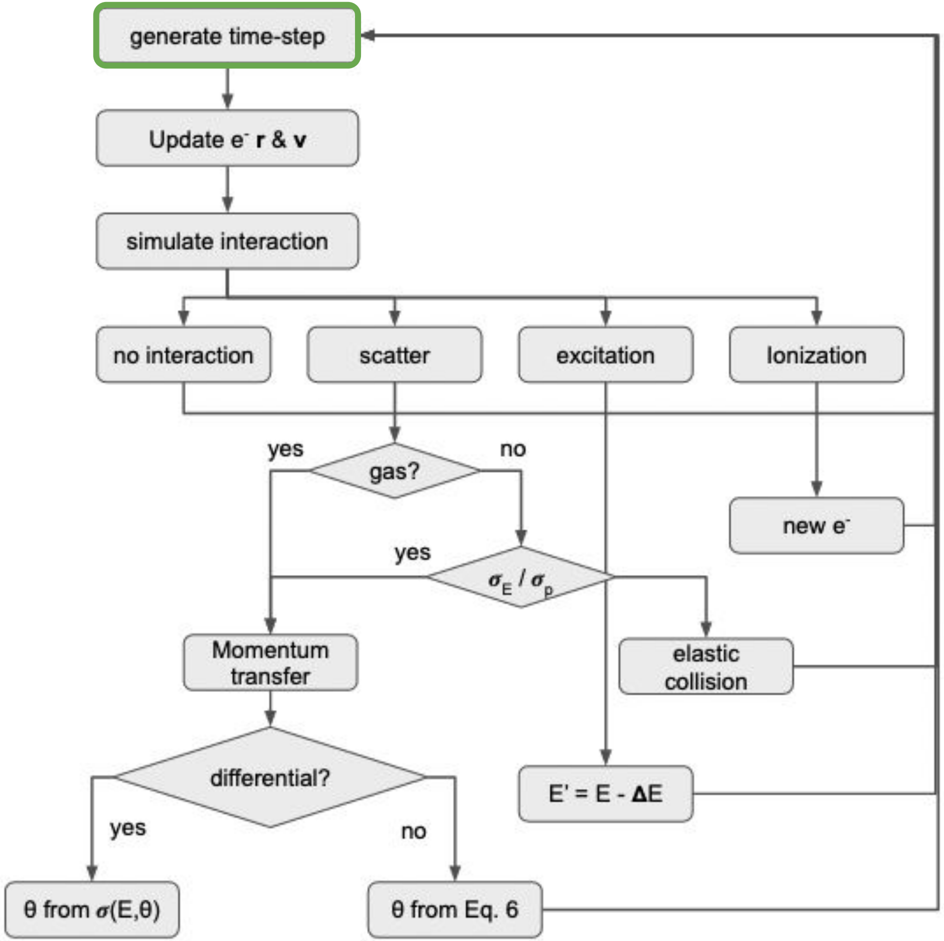


$\tau = K / 2n$

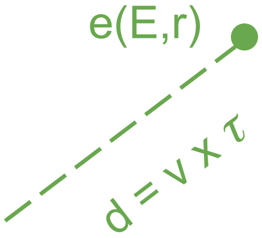
$K > \sigma_{tot}$

time-step τ appropriate given total cross-section.





Simulation Methods



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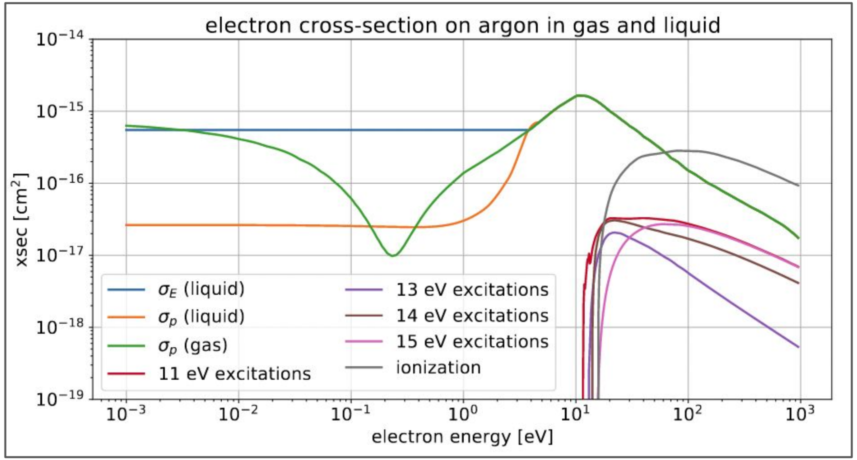
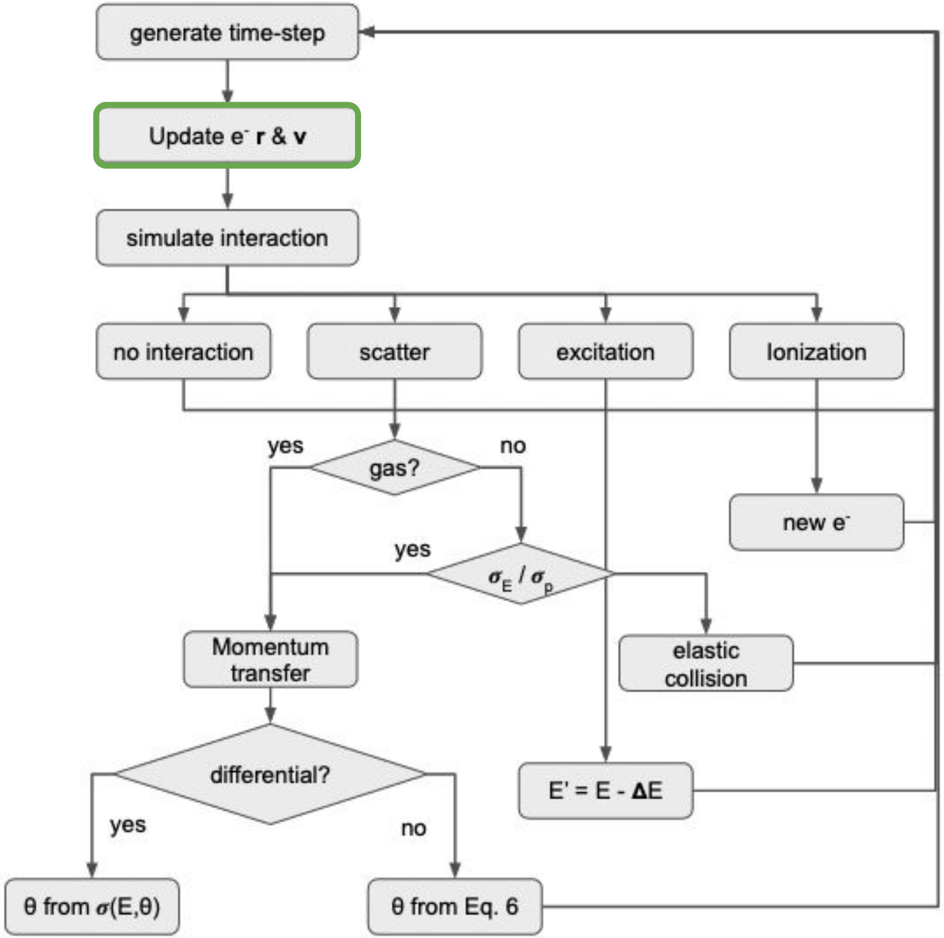
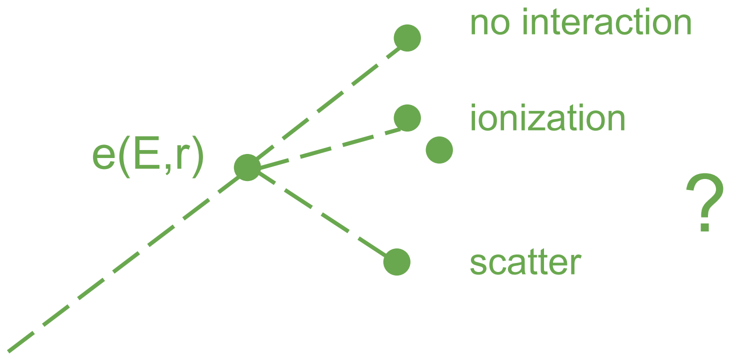
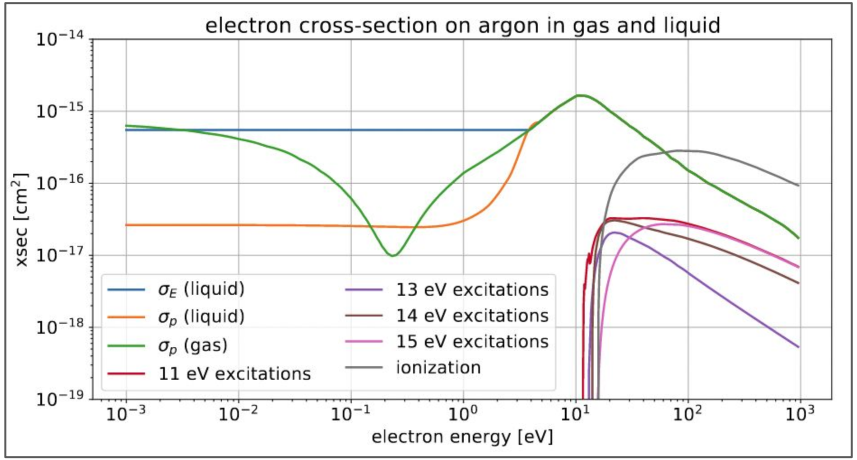
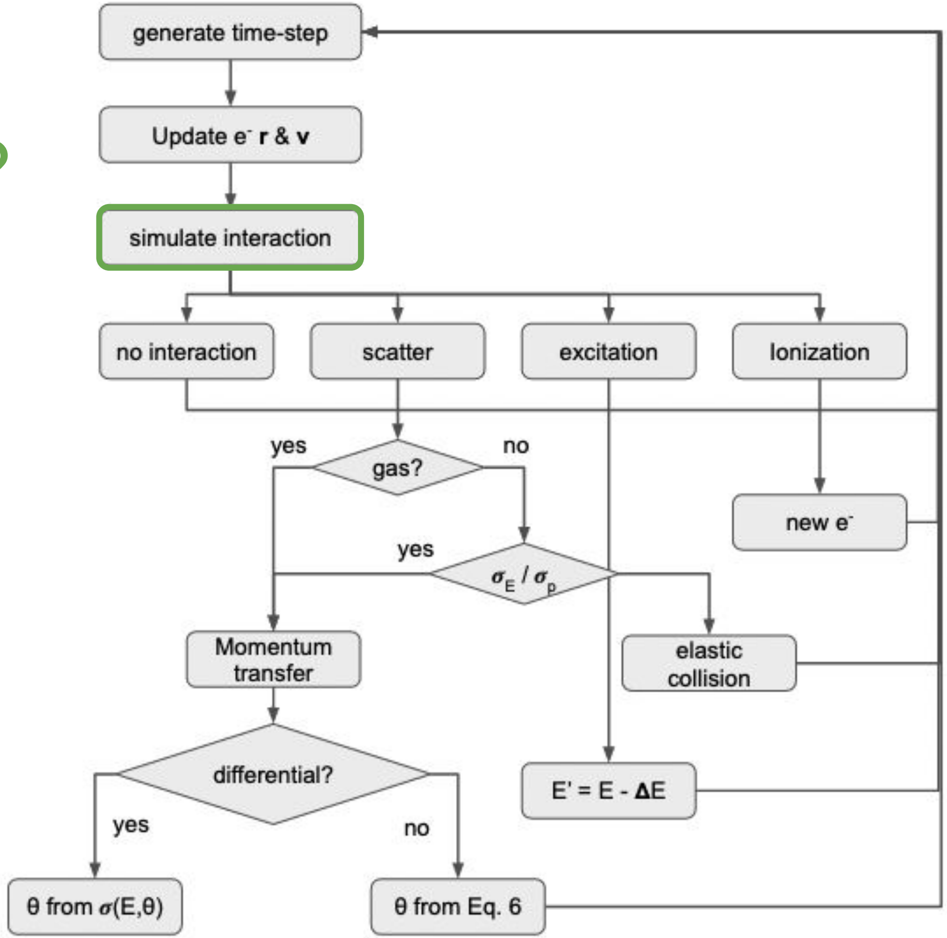




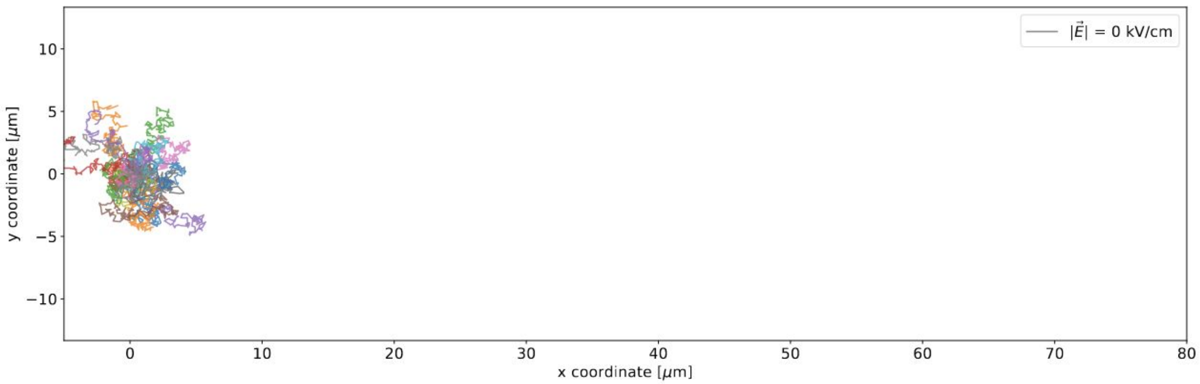


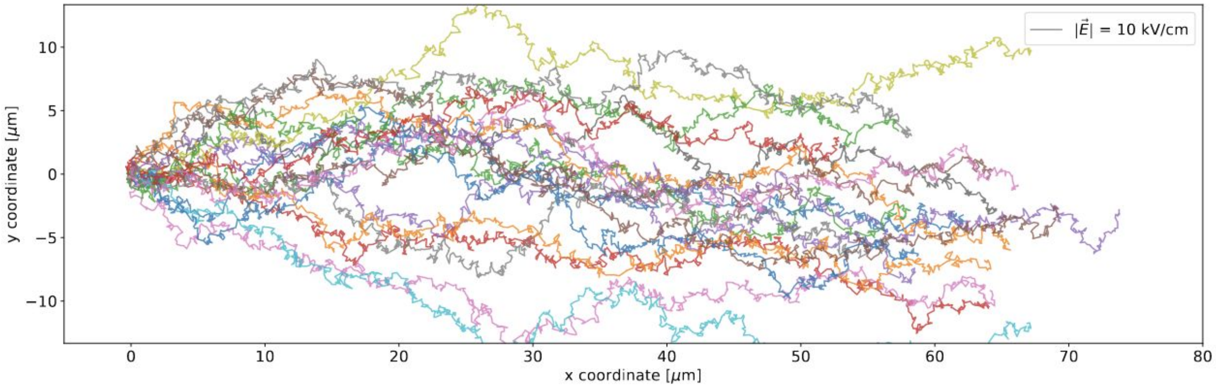
time-step τ appropriate given total cross-section.





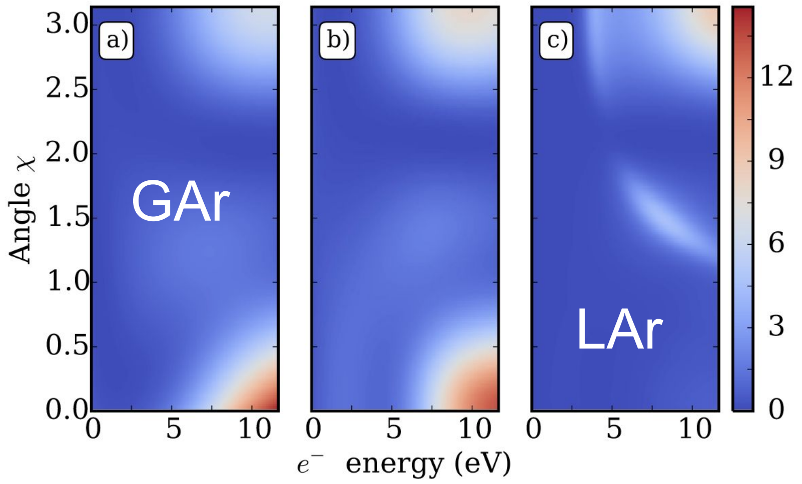
Simulation Output



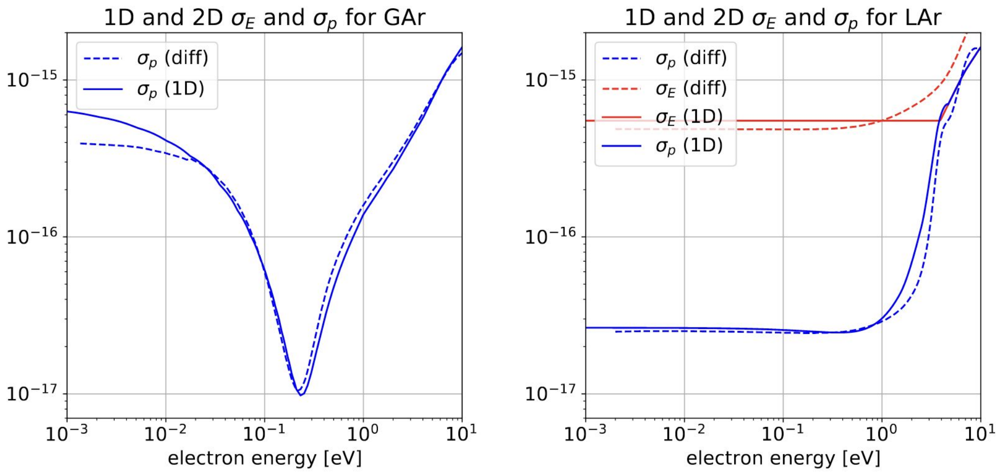


Differential Cross-Sections

J. Chem. Phys. 142, 154507 (2015)
G. J. Boyle, R. P. McEachran, D.G. Cocks, and R.D. White,
“Electron Scattering and Transport in Liquid Argon”



Differential cross-sections as implemented in TRANSLATE and compared to 1D from Wojcik & Tachiya

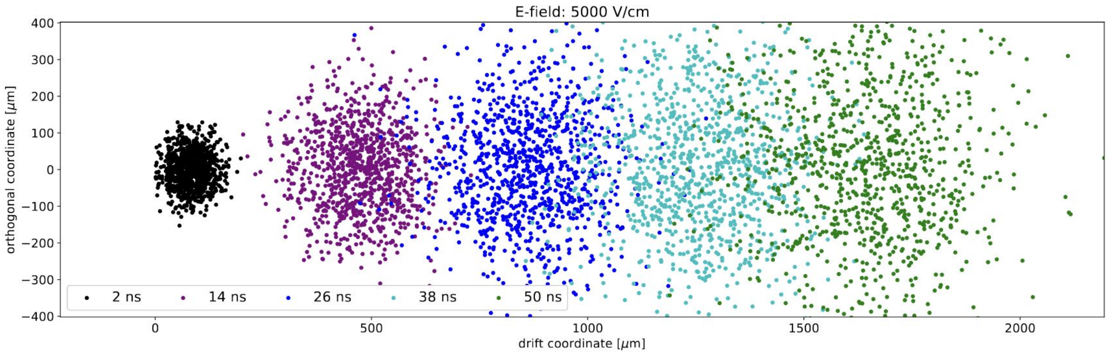


Simulation Validation: “Swarm Parameters”

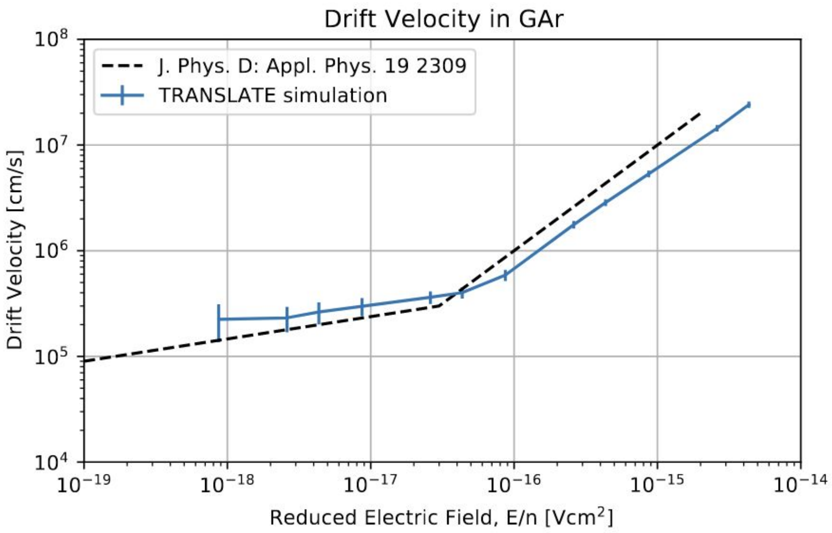
Track O(10^2 – 10^3) electrons over time intervals of 10^{-9} – 10^{-6} seconds.

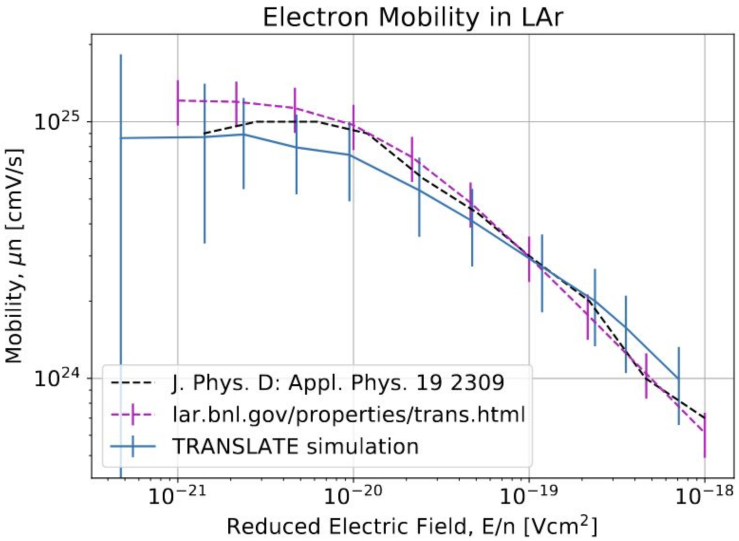
Track as a function of E-field:

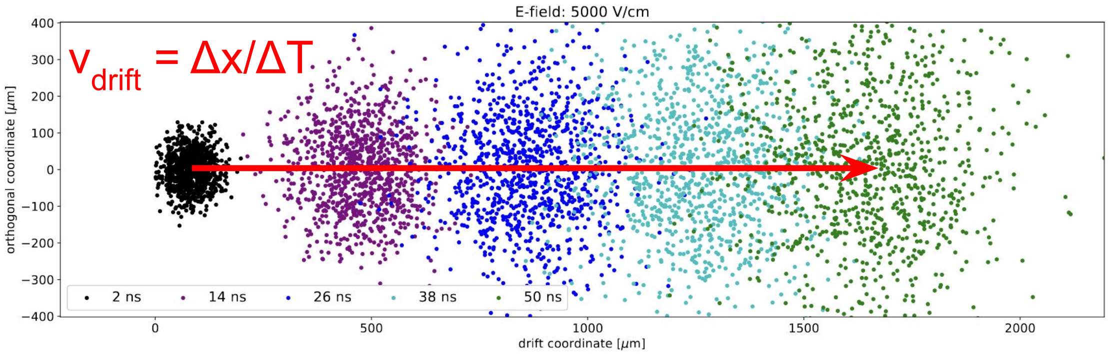
1. average distance traveled → drift velocity [GAr & LAr]
2. spread in electron clouds → diffusion [GAr & LAr]
3. Amplification [GAr]



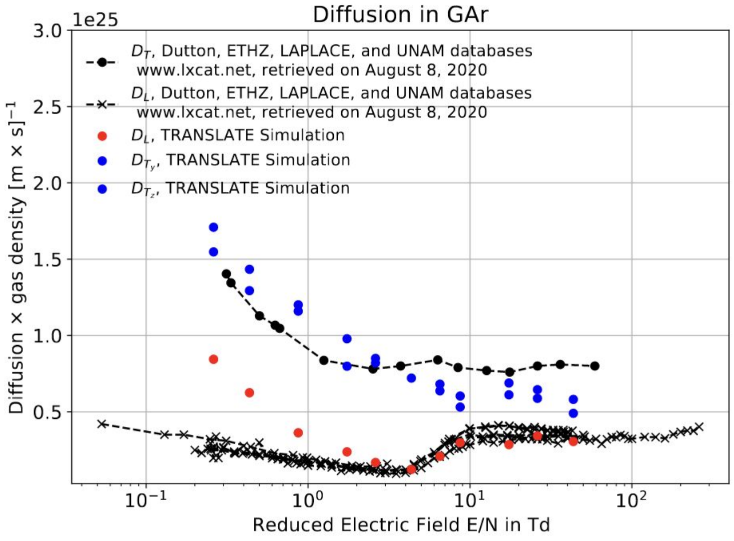
Simulation Validation: Drift Velocity

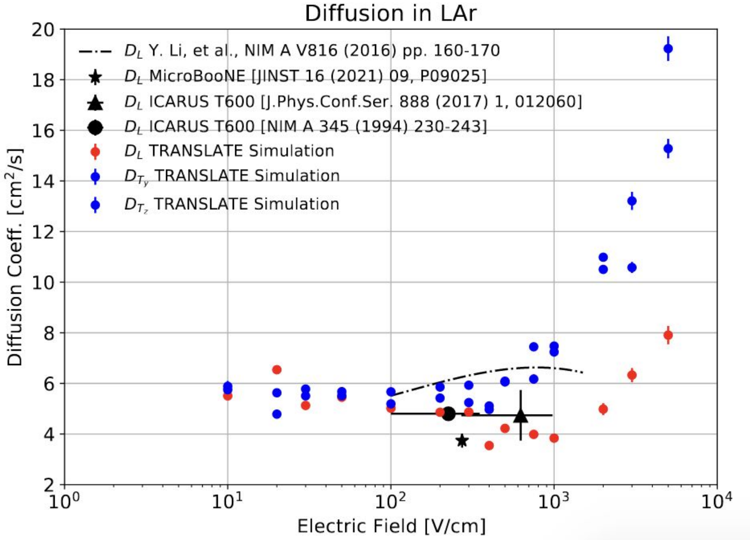


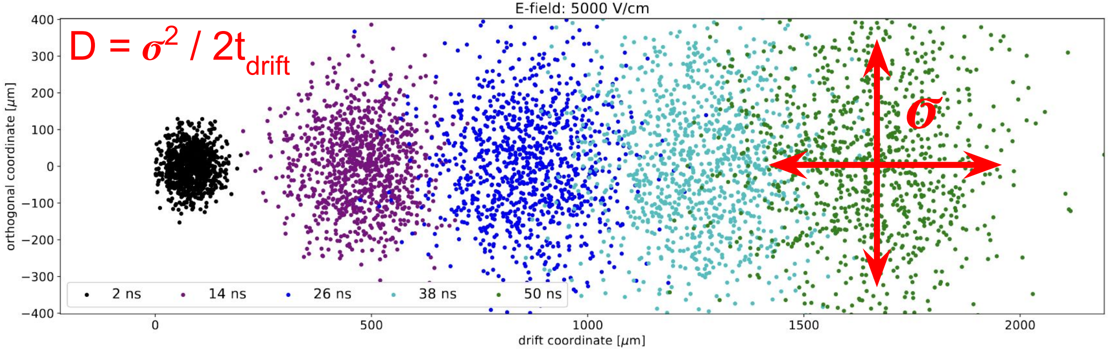




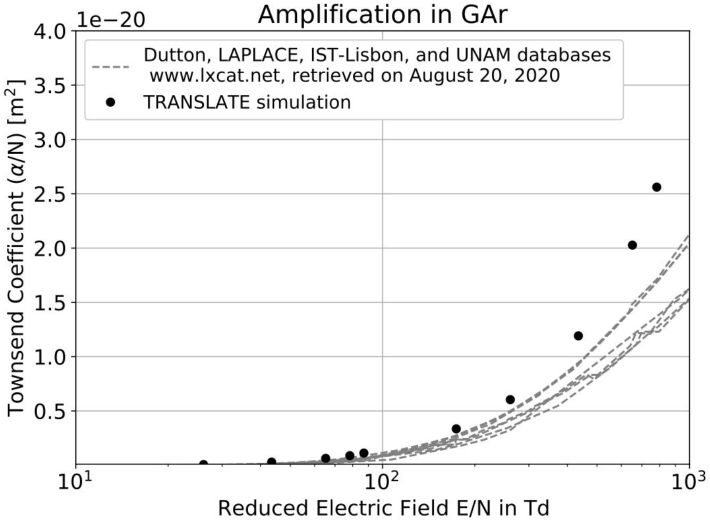
Simulation Validation: Diffusion

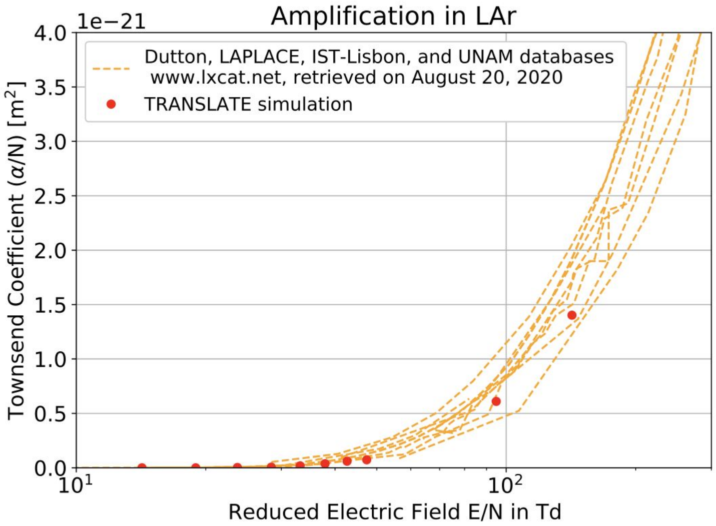


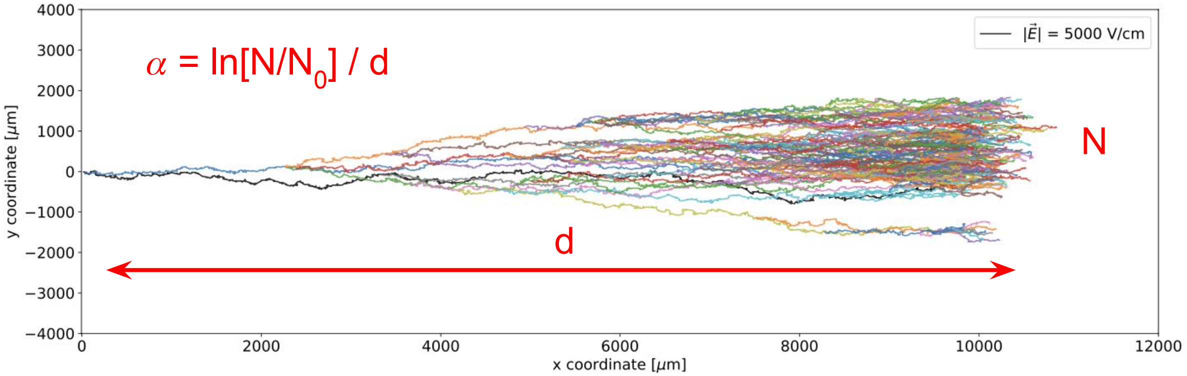




Simulation Validation: Ionization

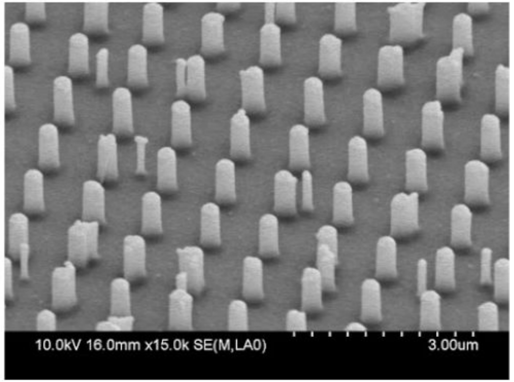


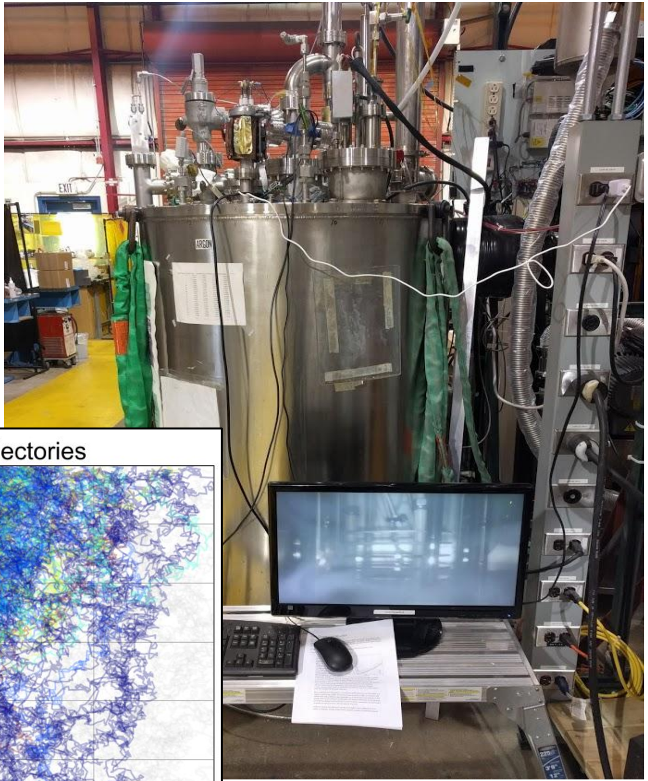


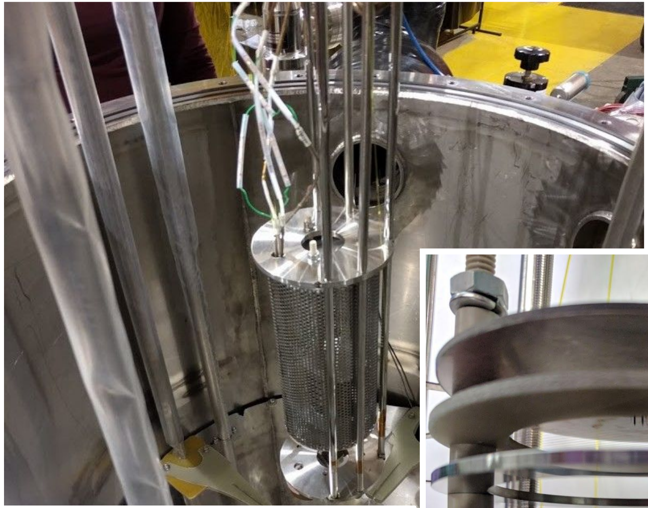


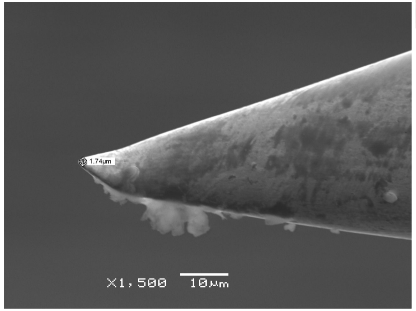
LArCADe

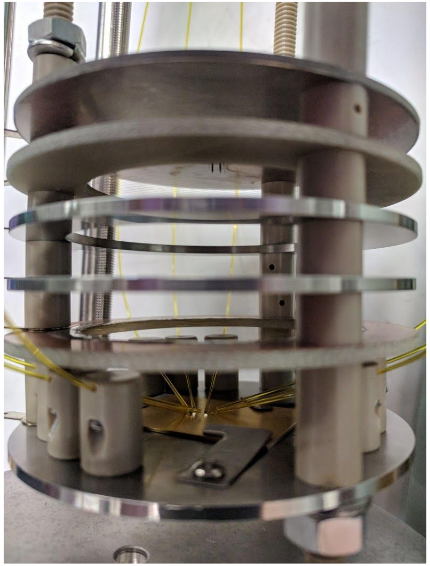
tip-array with sub µm apex produced @ BNL

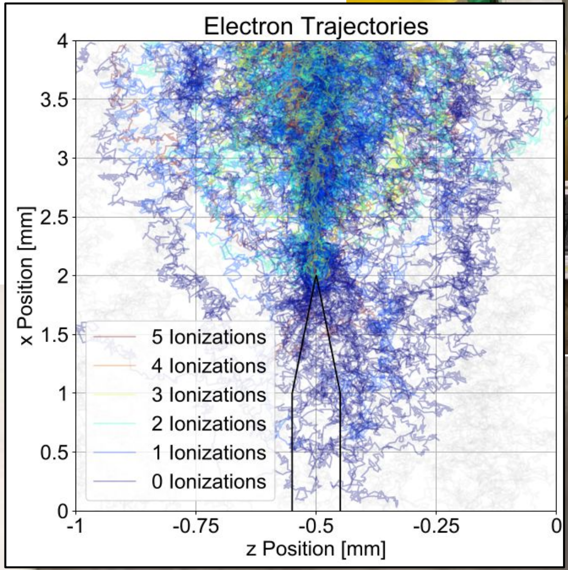




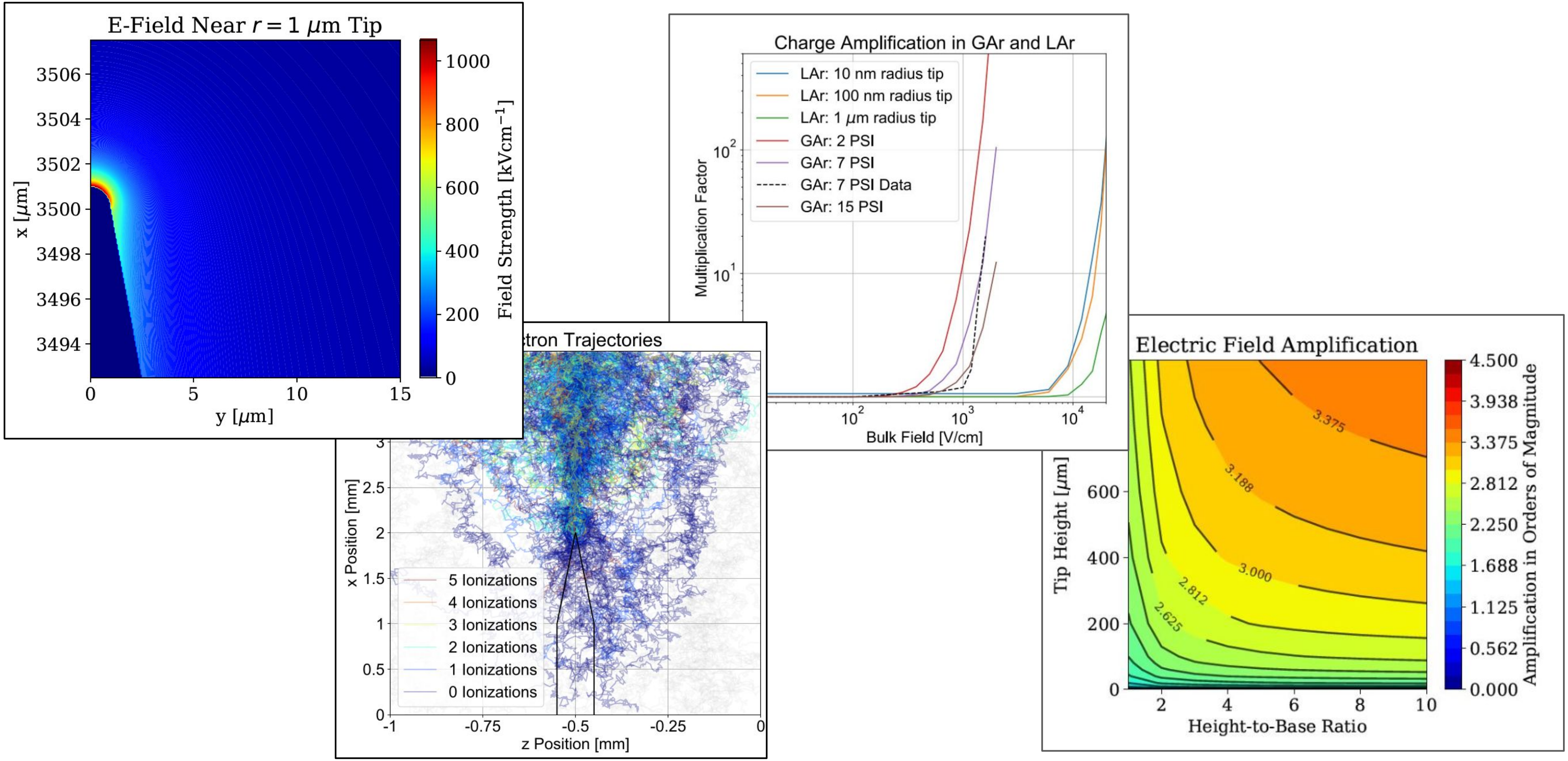








TRANSLATE → LArCADe



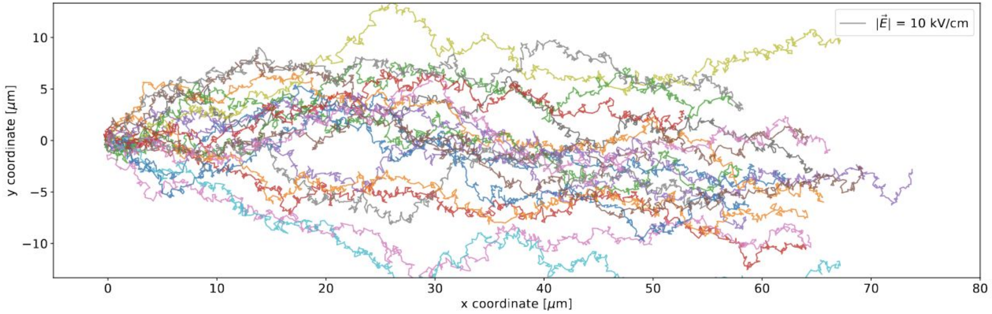
Using the **`TRANSLATE`** package

Public code repository: https://github.com/davidc1/TRANSLATE

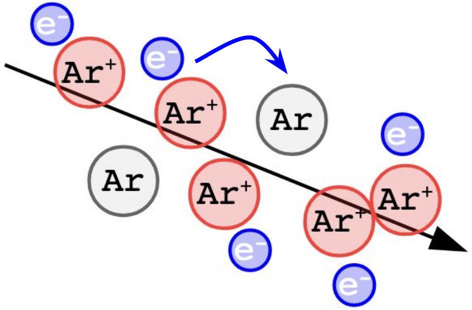
Asked to specify: gas/liquid, argon atom number density, duration of simulation in time, electric field strength, # of electrons simulated, interactions to track.

Output: txt files with position, electron energy, scattering angle, interaction mode, # of ionizations initiated.

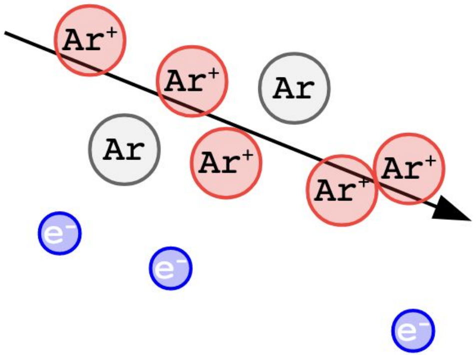
Several python Jupyter notebooks to make use of saved .txt data (e.g. trajectory plotting)



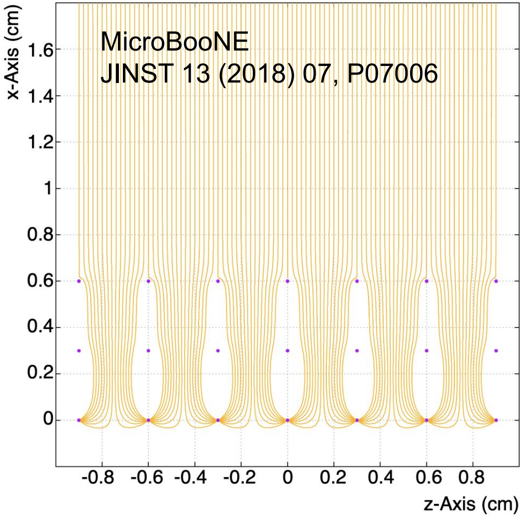
Future Opportunities with **TRANSLATE**



Ion Recombination



Impurities absorb drifting electrons



Believe this simulation package can be expanded to address numerous topics relevant to simulation / analysis of LArTPC data at all scales: R&D to full experimental program.

Welcome collaborators interested in expanding or utilizing the simulation!

Conclusions

Introduced a novel Monte Carlo simulation package for electron transport in LAr

Developed to tackle questions related to charge amplification in LAr, but much more versatile.

Interested in expanding to explore additional functionality: e.g. ion recombination, contaminants.
→ welcome collaboration and shared interests. Please reach out!

Acknowledgements:

This work was in part supported by the Fermilab LDRD LArCADe project, as well as the Fermilab Community College Internship [CCI] program.