TRIUMF

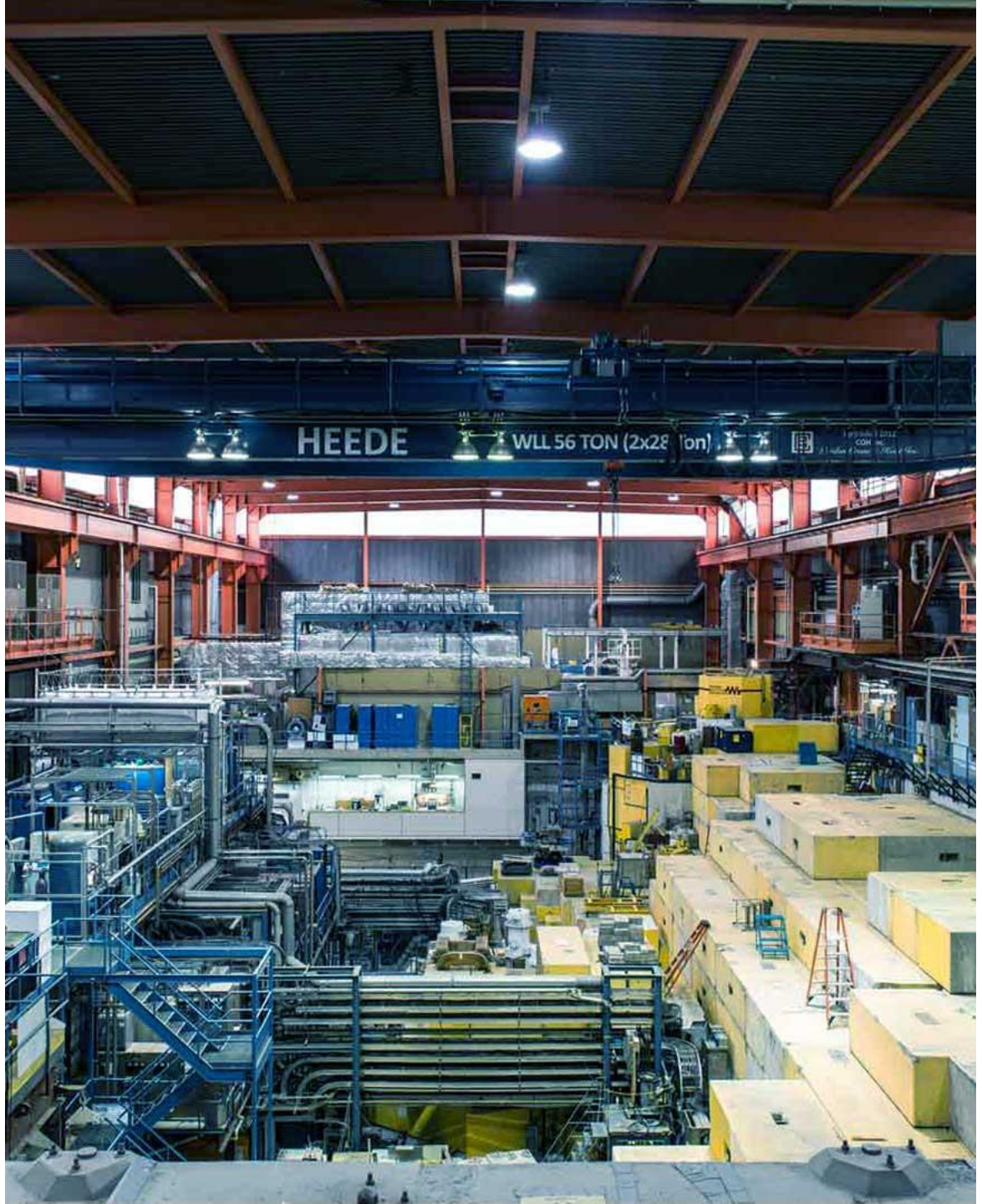
Ba-ion mobility simulations in LXe for Ba-tagging at TRIUMF

Megan Cvitan

CAP Congress, June 8th 2022

Supervisors: Annika Lennarz & Alan Chen

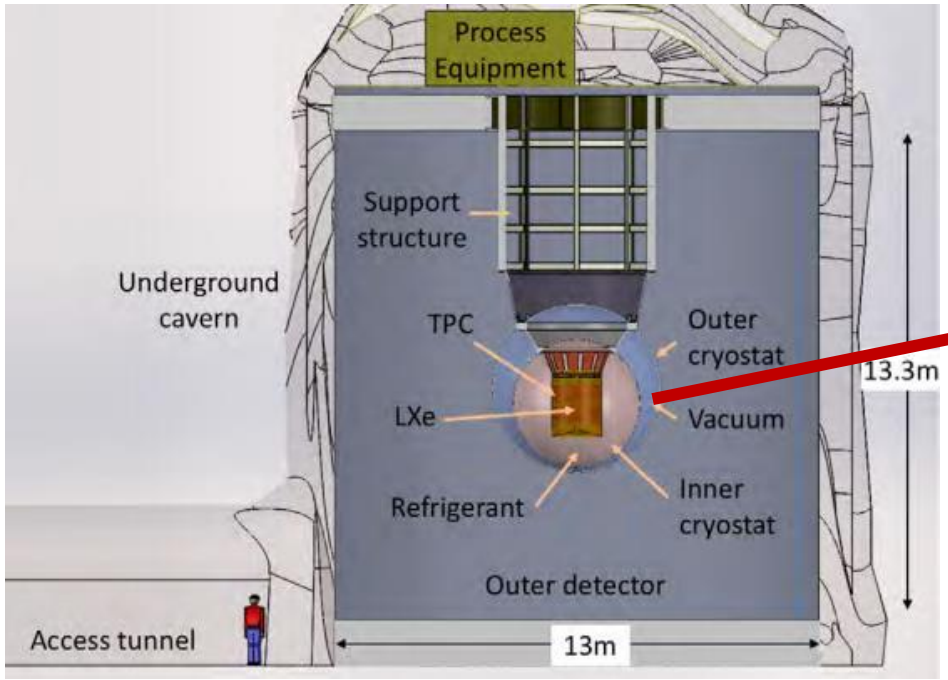
McMaster University



Discovery, accelerated

The nEXO Experiment

- Proposed next generation 5-tonne Liquid Xe Time Projection Chamber (TPC)
- Search for 0νββ in ^{136}Xe as a tool to study neutrino mass
- Using scintillation and ionization to detect event location and multiplicity



arXiv:1805.11142v2

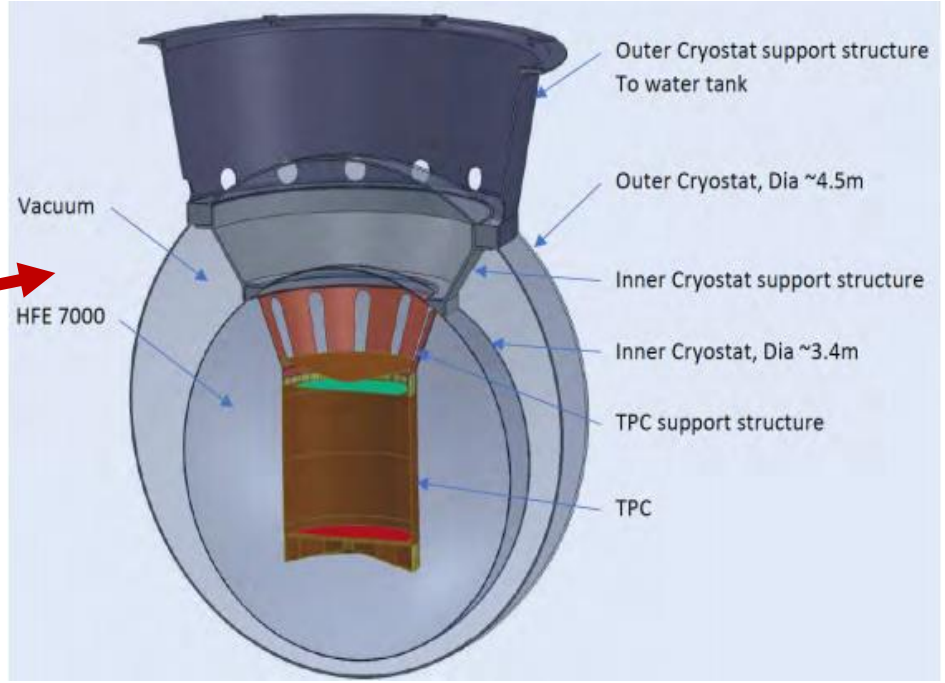
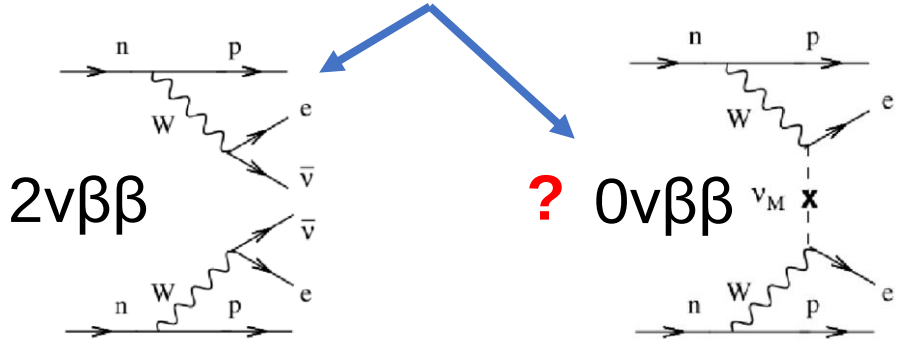


Illustration of the nEXO detector, demonstrating the placement of the LXe TPC and cryostat

A Proposed Future nEXO Upgrade with Ba-tagging

$^{136}Xe \longrightarrow {}^{136}Ba^{++} + 2e^{-}$

Identify ββ decay product in ^{136}Xe



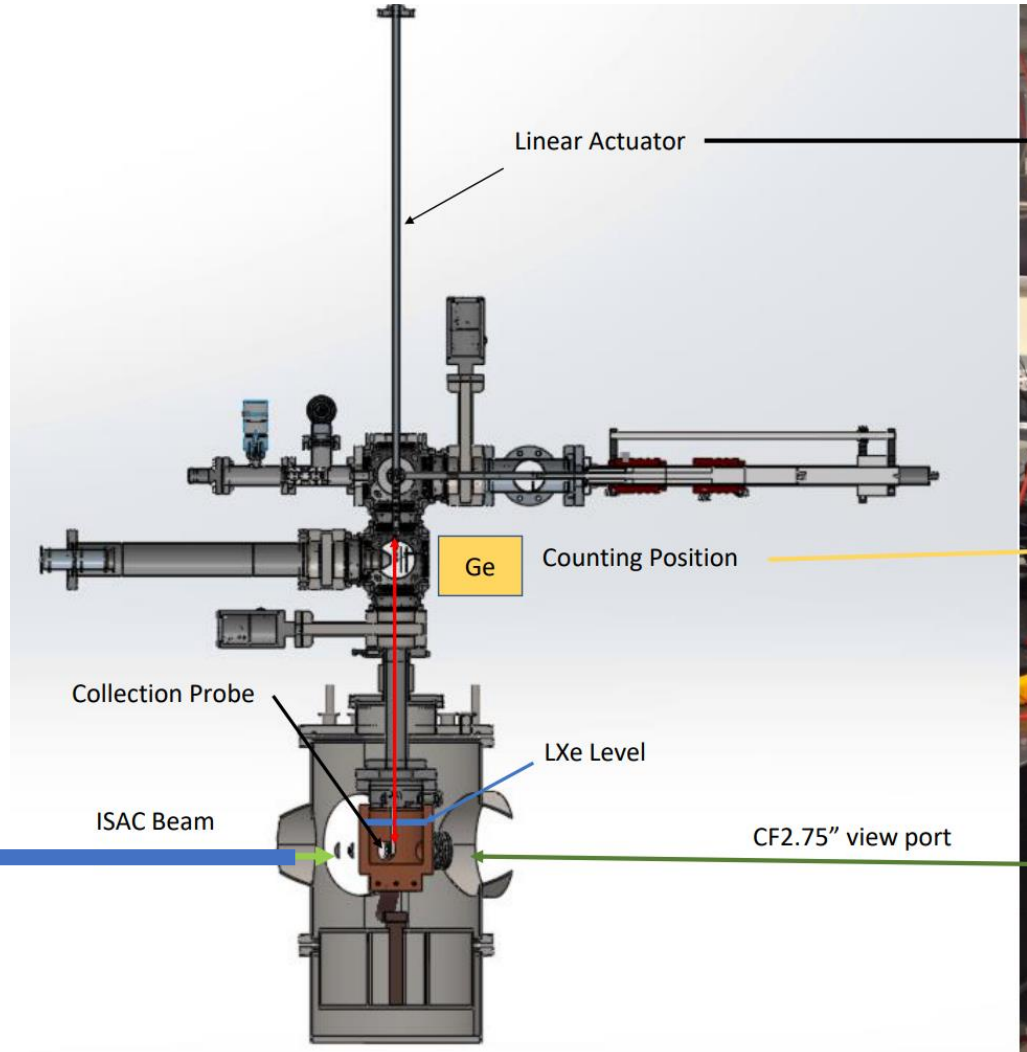
1. Localize event
2. Event of interest? Near Q-value?
3. Extract ion from xenon volume
   - Not well-understood yet
   - Create new tools to explore this step
4. Identify ion, is it Ba?

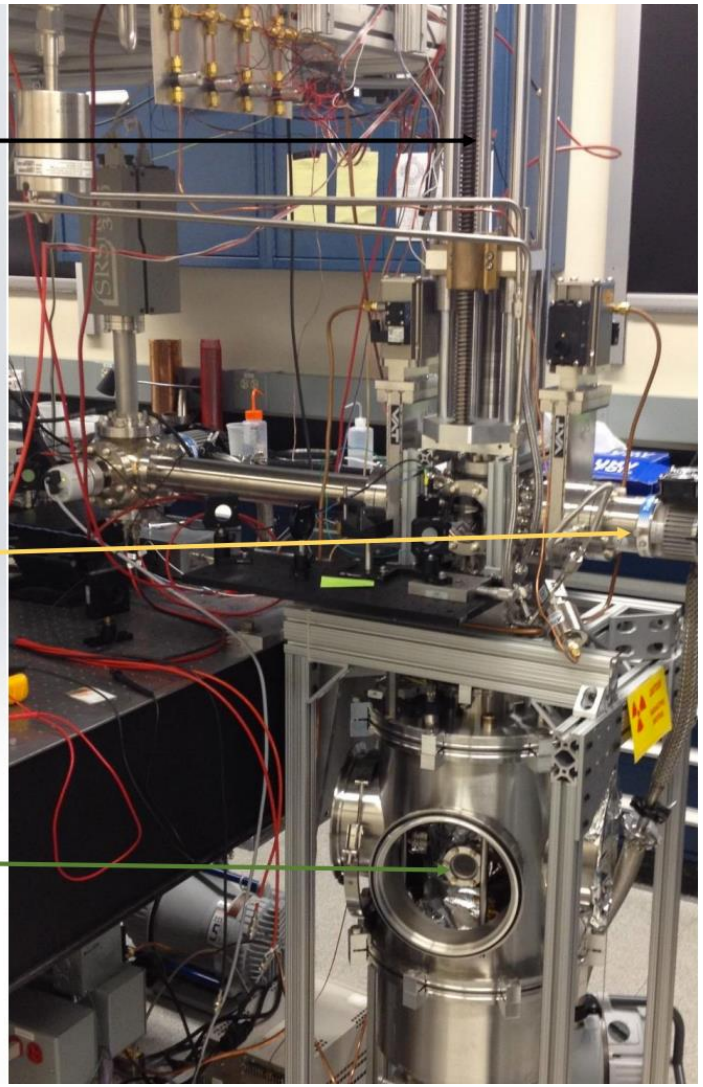
Need reliable, high-quality in-liquid Xe Ba source
→ Need ISAC-II at TRIUMF

Ba-tagging at TRIUMF Overview

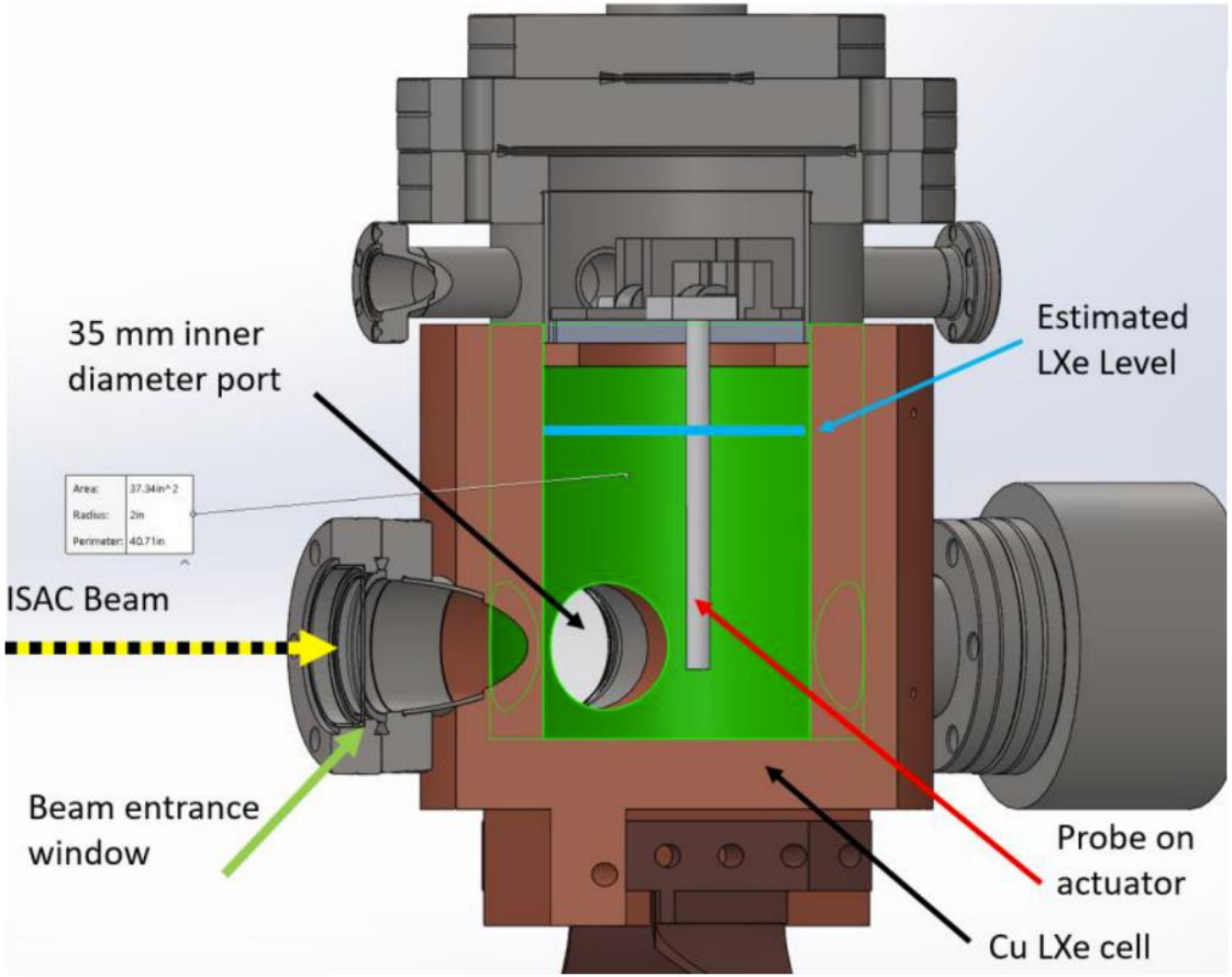
Novel radioactive beam approach for ion implantation into LXe volume & subsequent extraction

Coupled to TRIUMF beam

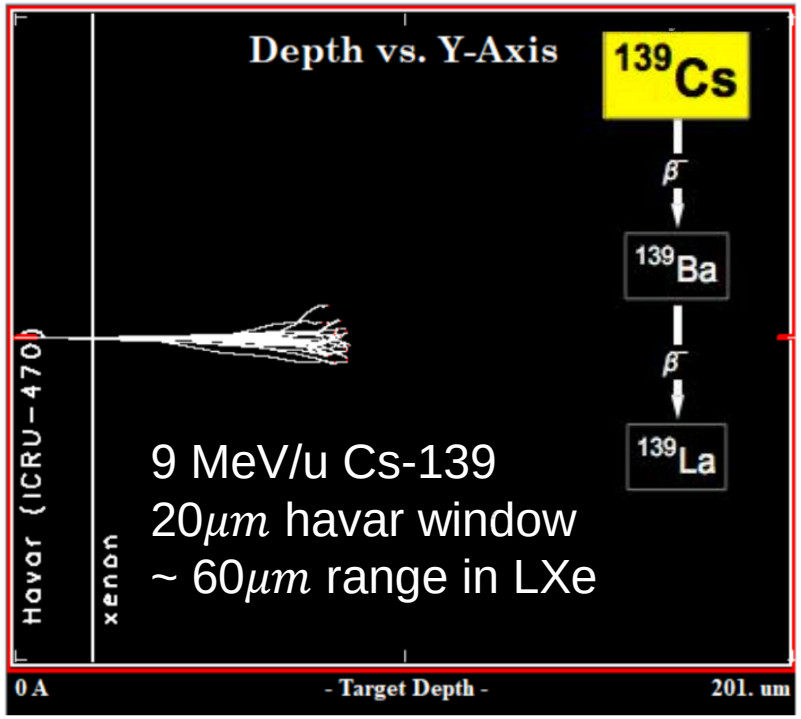




Closer look at the Liquid Xe Chamber



- 2 - 10 MeV/u beam energy
- Beam intensity ~10^5 pps
- Havar/mylar beam window
- Ions will not travel far
- ~10x10x10 cm^3 LXe volume
- LXe at ~1000 Torr, 165 K
- Ge detector for counting radiation



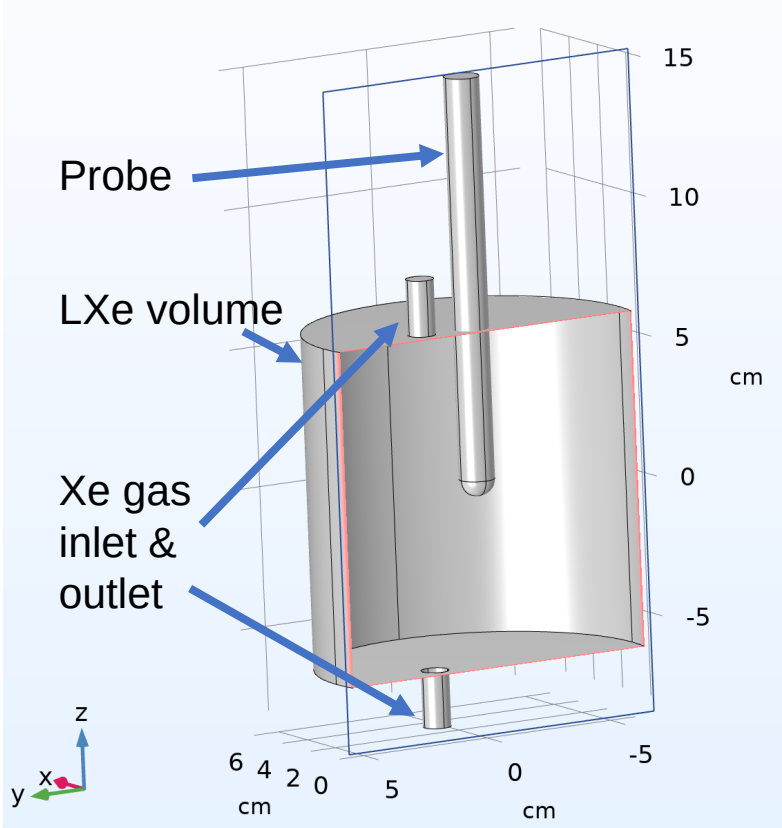
COMSOL Multiphysics Simulation Overview

- Finite element analysis simulation software
- Commonly used for fluid flow, thermal physics, electromagnetics... the possibilities are endless!

How to attract ions onto a DC biased probe for extraction purposes?

Parameters to consider

- Ba ion mass, charge, initial position and velocity
- LXe temperature, pressure, fluid & electrical properties
- Probe type: placement, material, shape?



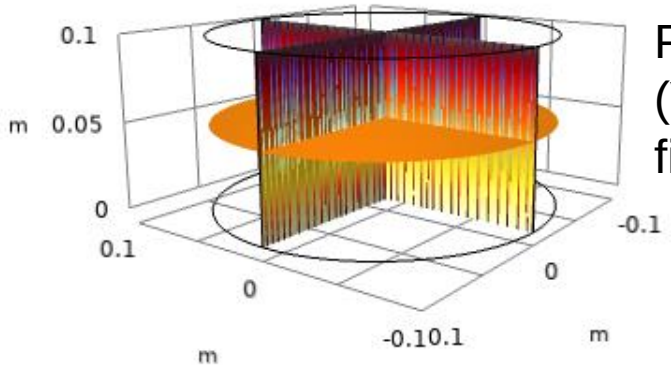
First, a Simple Model for Ion Mobility in Liquid Xenon

- Can compare experimentally measured μ with simulated value to **validate** the model
- Important milestone in Ba-tagging, μ = 2.11e-4 cm^2/Vs

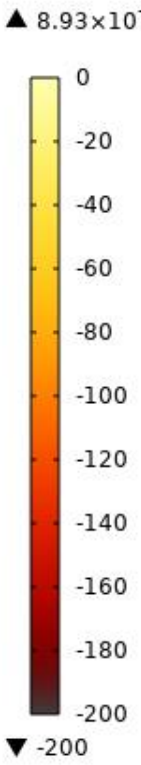
  → Possibility to follow a Ba^+ daughter ion from ββ-decay in LXe [S-C Jeng et al 2008]

$$v = \mu E$$

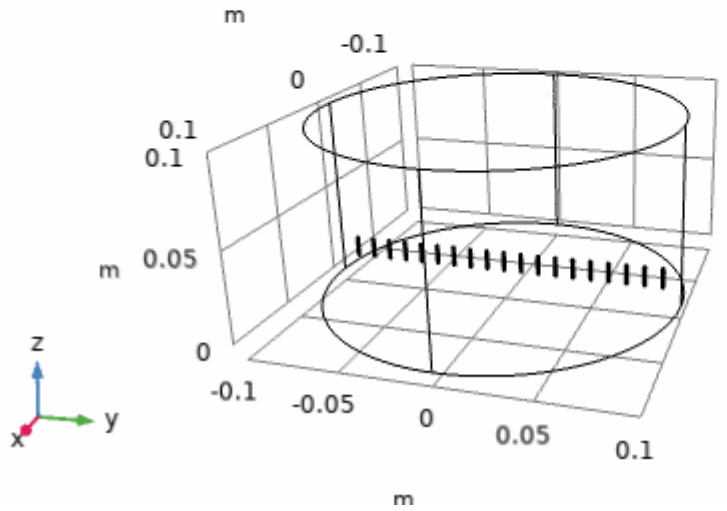
μ = ion mobility (m^2/Vs)
E = electric field (V/m)
v = ion drift velocity (m/s)

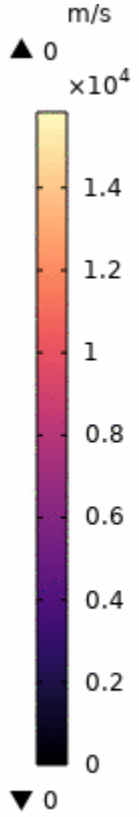


Potential (V) and field lines



Ba+ ion trajectories in uniform electric field





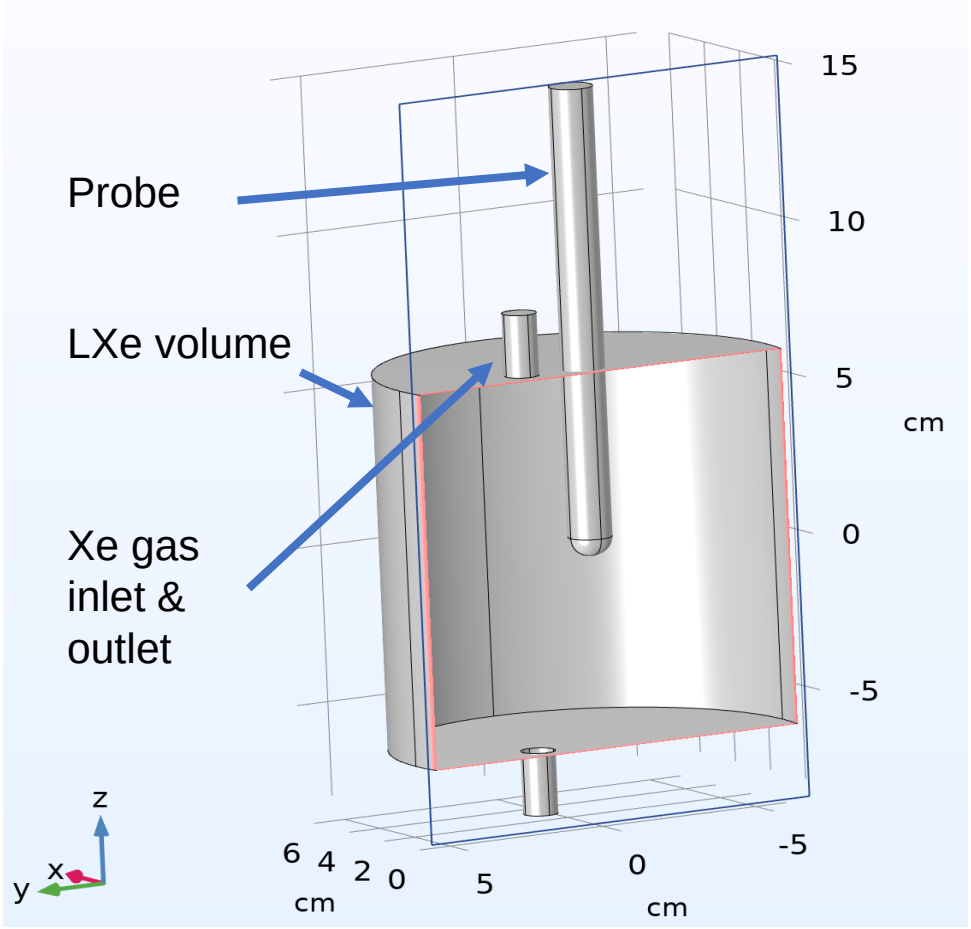
COMSOL Multiphysics Simulation Components

How to attract charged ions onto a DC biased probe for extraction purposes?

Need to solve:

✓ Steady State Fluid/Electrostatics

✓ Time Dependent Particle Tracing



Geometric assumptions

- No copper vessel surrounding the LXe for now
- Inlet and outlet for convergence reasons

COMSOL Simulation Environment: Creeping Flow

- Ideally, fluid is near rest, not circulating Xe during experiment

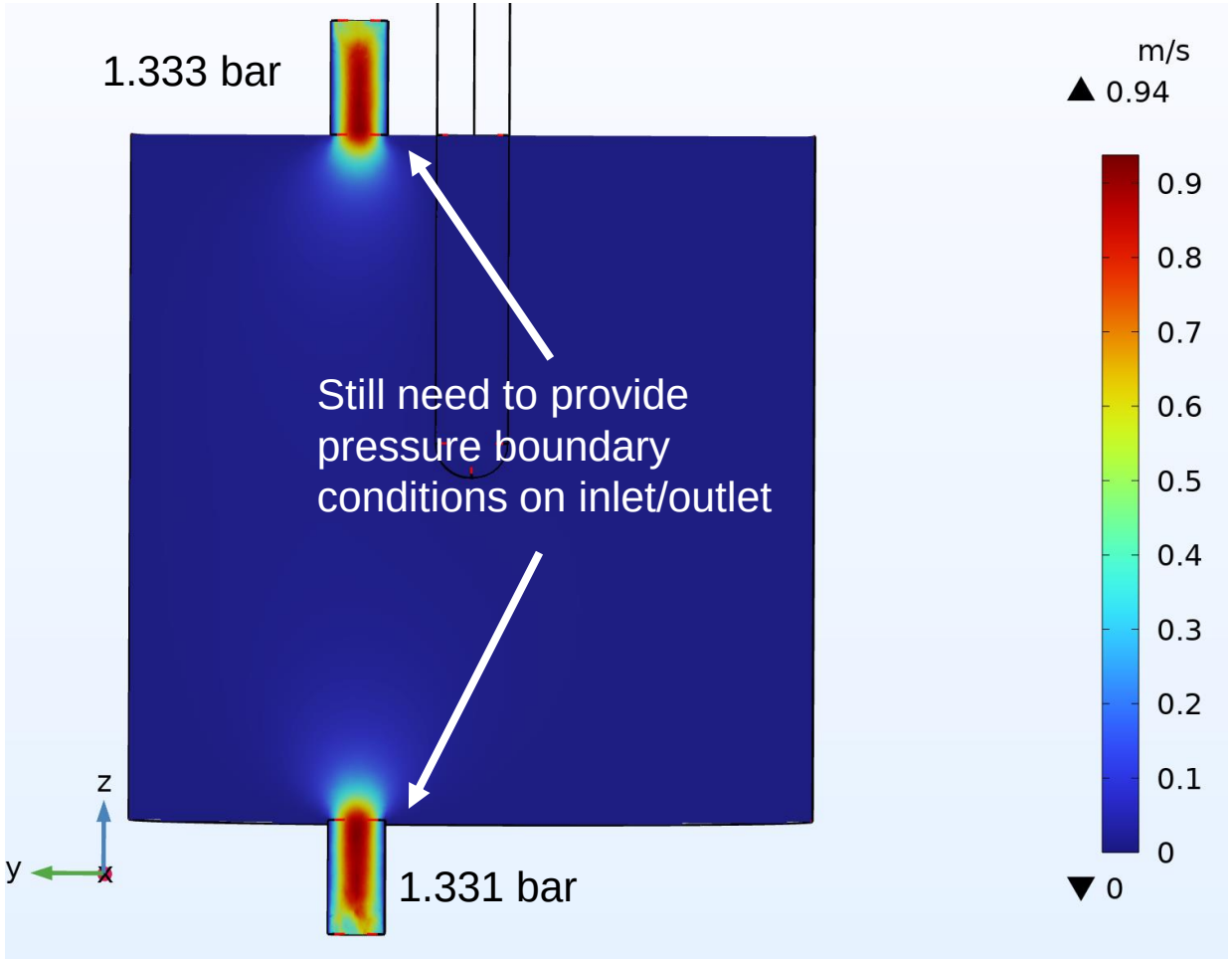
- Most computationally heavy part of this simulation, even without turbulence (but 3D)

Why do we need to solve the fluid dynamics?

- **Stokes drag force on Ba ions**
- Convenient initial velocity for Ba ions once stopped in LXe

$$F_D = 6\pi\mu R v$$

F_D = drag force on spherical object
μ = dynamic viscosity
R = particle radius
v = flow velocity relative to particle

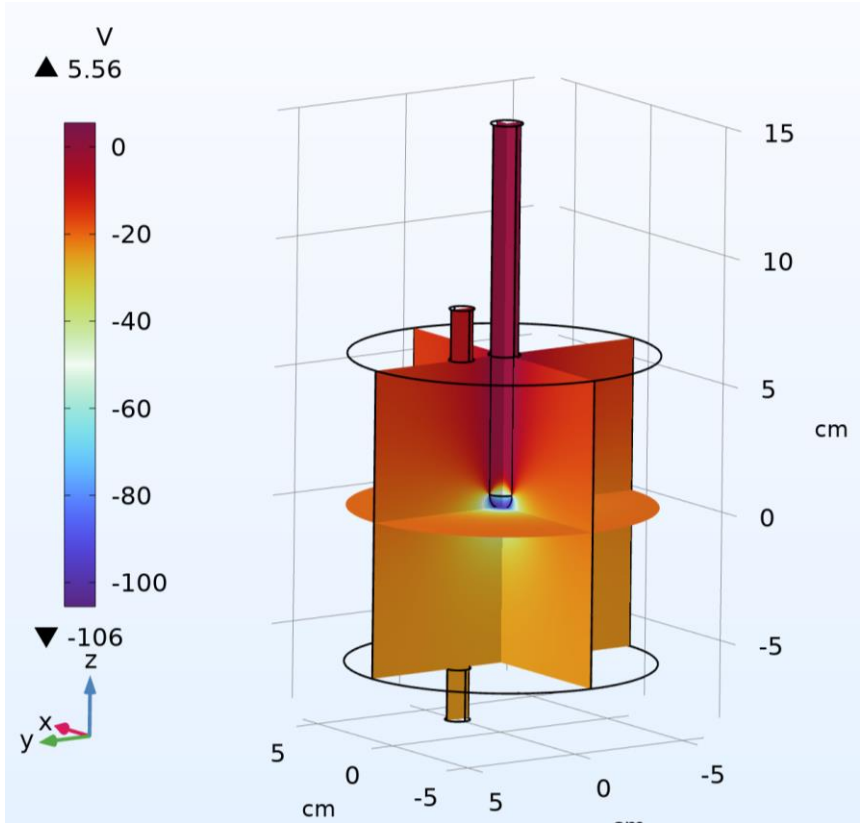


LXe velocity magnitude (m/s)

COMSOL Simulation Environment: Electrostatics

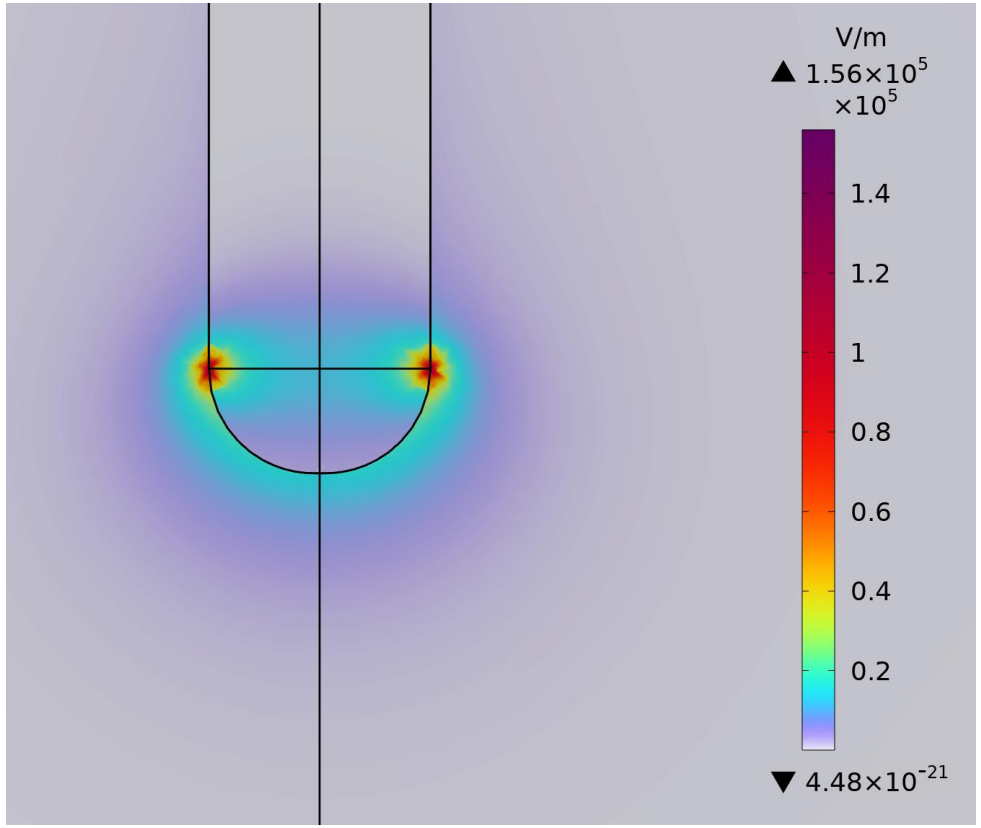
- Solve for E field that will **drift ions** onto stainless steel probe
- Dielectric constant of LXe ~1.87
- Field shaping rings?

Potential on probe tip ~ -100 to -300 V



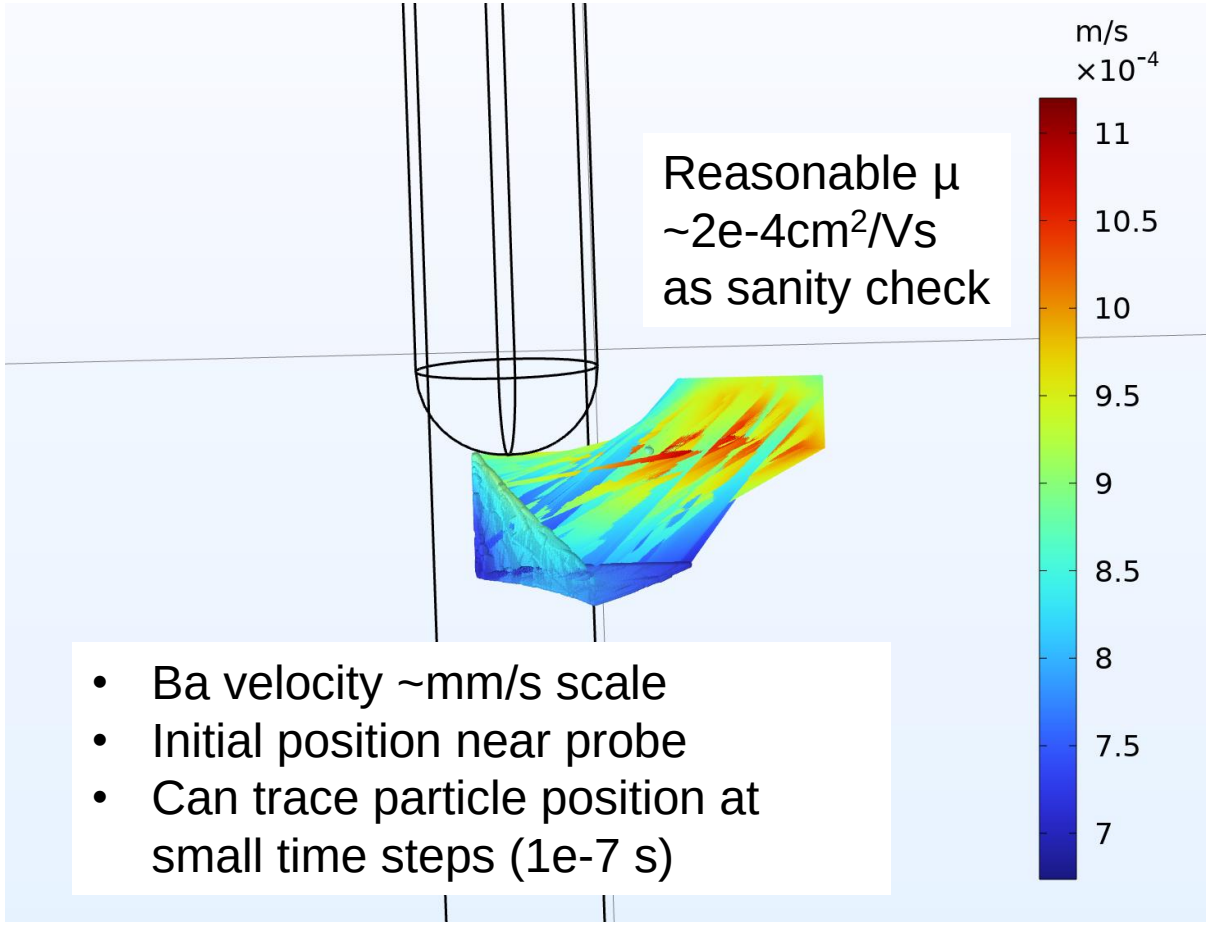
Electric Potential (V)

Stationary, non-uniform electric field



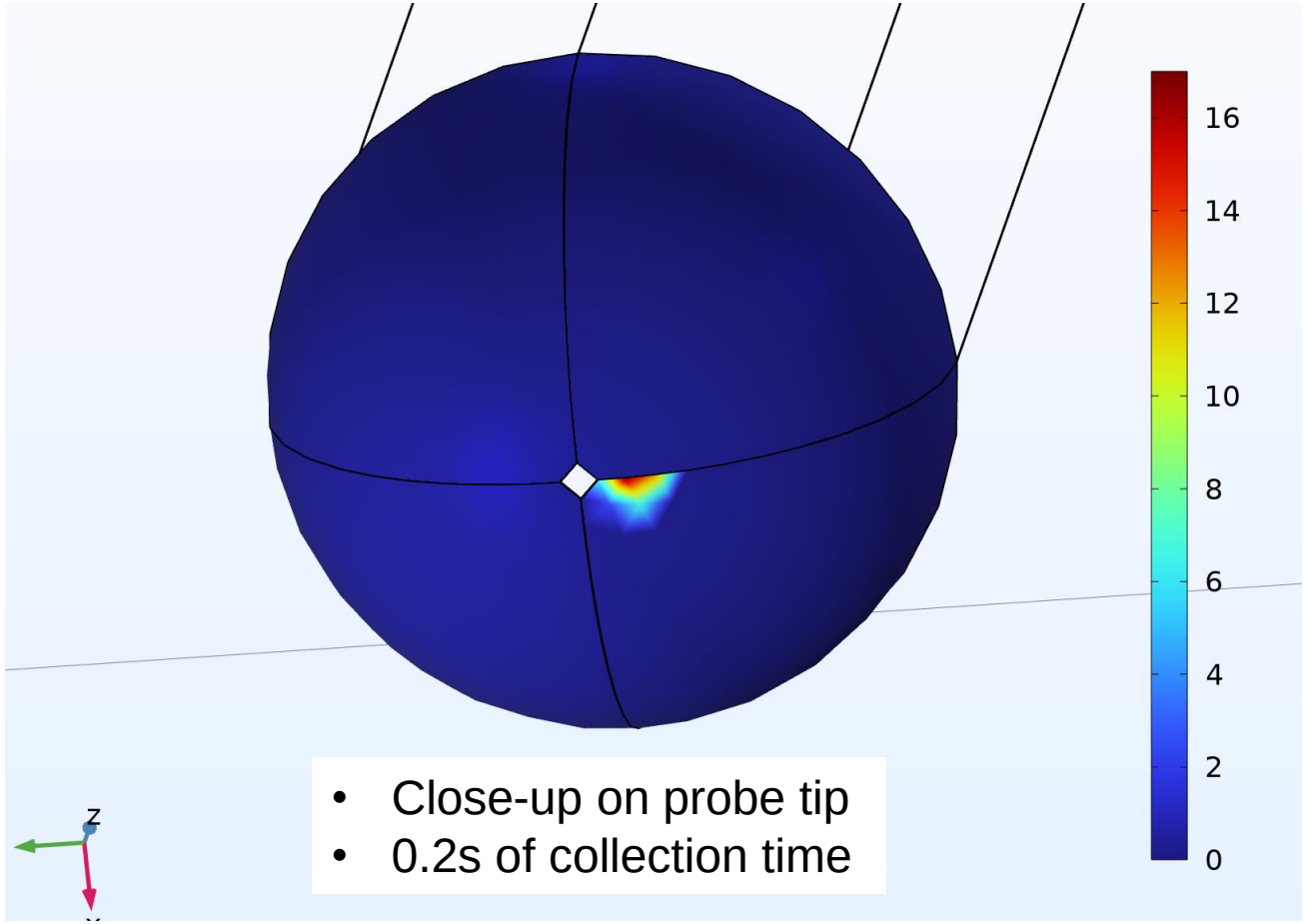
Electric Field Norm (V/m)

COMSOL Particle Trajectories Towards Probe



Reasonable μ
~2e-4cm^2/Vs
as sanity check

- Ba velocity ~mm/s scale
- Initial position near probe
- Can trace particle position at small time steps (1e-7 s)



- Close-up on probe tip
- 0.2s of collection time

Summary

- Ba tagging R&D studies at TRIUMF for potential nEXO upgrade
  - Novel approach with radioactive ion beams in LXe
  - Single Ba ion source in LXe to study Ba-tagging process
  - Comparison of ion mobility in LXe using COMSOL with experiment to validate models
    - Preliminary results: working model validated by reproducing Ba^+ ion mobility in LXe
    - Next steps: charge effects, liquid Argon, ion extraction efficiencies, electrode placement in LXe chamber, field shaping rings

TRIUMF

Thank you
Merci

Special thanks to Dr. Robert Collister for his COMSOL expertise!

www.triumf.ca

Follow us **@TRIUMFLab**

Discovery, accelerated