Detector Simulation in Garfield++ with Open-Source Finite Element Electrostatics

Josh Renner
UC Berkeley / LBNL
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Collaborators (LLNL): Adam Bernstein, Mike Heffner, Peter Sorensen, Melinda Sweany

Background:

- Garfield and Garfield++ support simulations of electron/ion drift in finite-element fields

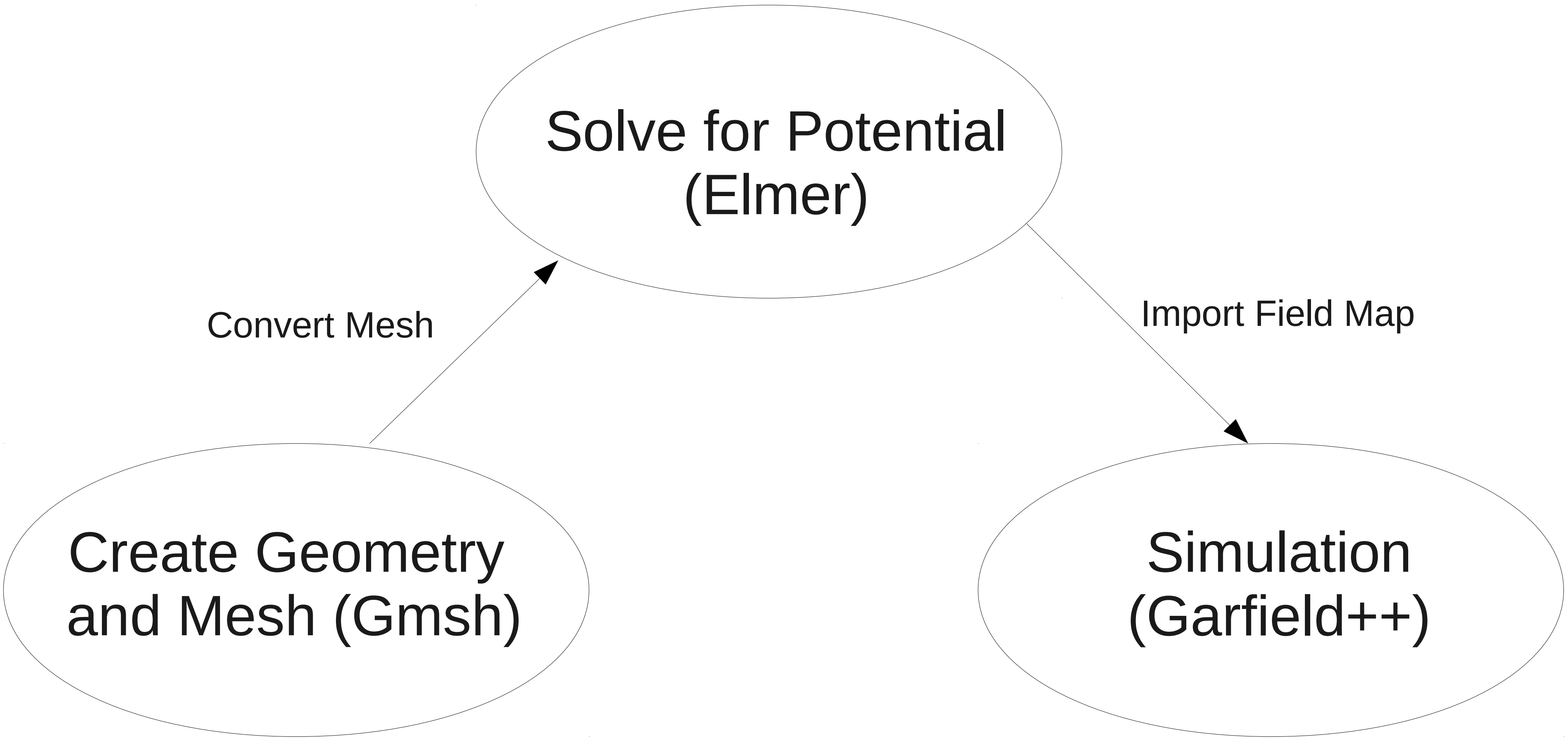
- We describe a process by which the open-source tools Gmsh (http://geuz.org/gmsh) and Elmer (http://www.csc.fi/english/pages/elmer) can be used with Garfield to perform such simulations

- This effort started at LLNL in simulations the Negative Ion TPC (discussed later).

- See accompanying writeup and code: http://garfieldpp.web.cern.ch/garfieldpp/examples/elmer/

Background:

- Overview of Procedure



Geometry:

- Gmsh - parameterized geometry input
  - ➔ Define parameters

```
x=0; y=0; z=0; d=1;
```

  - ➔ Create points

```
p1 = newp; Point(p1) = {x,y,z};
p2 = newp; Point(p2) = {x+d,y,z};
p3 = newp; Point(p3) = {x,y+d,z};
...
```

  - ➔ Connect with lines

```
l1 = newl; Line(l1) = {p1, p2};
l2 = newl; Line(l2) = {p2, p3};
l3 = newl; Line(l3) = {p3, p1};
...
```

  - ➔ Define surfaces

```
lp = newll; Line Loop(lp) = {l1, l2, l3};
s = news; Plane Surface(s) = {lp};
...
```

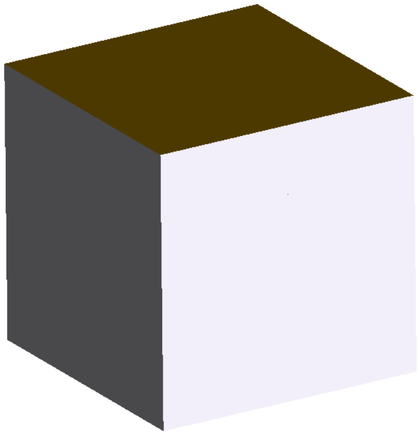
  - ➔ Define volumes

```
s_loop = newsl; Surface Loop(s_loop)
  → = {s1, s2, s3, s4, s5, s6};
vol = newv; Volume(vol) = {s_loop};
...
```

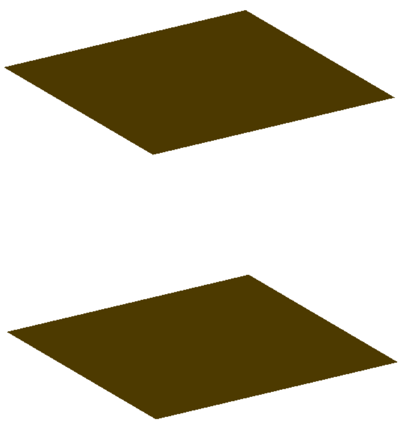
Geometry:

- Potentials and materials
  - Physical volumes specify materials to be assigned a dielectric constant

```
physv_dielectric = n_physv;
Physical Volume(physv_dielectric) = {vol_inner};
```



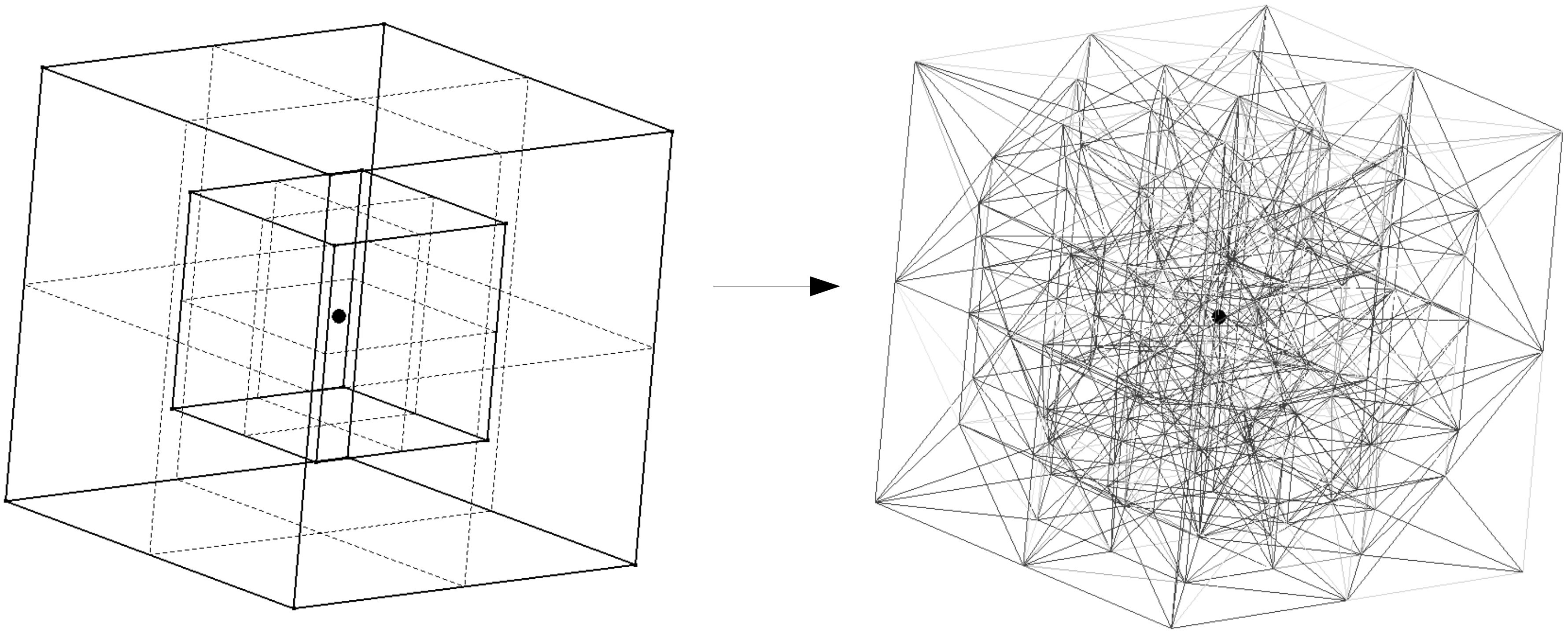
  - Physical surfaces specify areas to be assigned specific potentials



```
physs_top_plate = n_physs;
Physical Surface(physs_top_plate) = {s_top_plate};
physs_bottom_plate = n_physs;
Physical Surface(physs_bottom_plate) = {s_bottom_plate};
```

Mesh:

- Mesh geometry with Gmsh



- ➔ Sizes of mesh elements can be varied at each point
- ➔ Any region in which the field will be calculated must be meshed
- ➔ Later convert to Elmer format for electrostatics calculation
- ➔ Note: Gmsh can also import geometries from CAD programs, though this may complicate meshing and assignment of potentials/materials

Electrostatics:

- Elmer called with an input file:

  - Specify solver and options

```
Solver 1
  Equation = Stat Elec Solver
  Variable = Potential
  Variable DOFs = 1
...
```

  - Specify boundary conditions

```
Boundary Condition 1
  Target Boundaries = 1
  Potential = 0
End
...
```

* Physical surface identifier

  - Specify dielectric constants

* Physical volume identifier

```
Body 1
  Equation = 1
  Material = 1
End

Material 1
  Relative Permittivity = 1
End
...
```

Simulation/visualization:

- Results of the calculation imported into Garfield++, along with Elmer-formatted mesh

```
ComponentElmer * elm
= new ComponentElmer(
  "sample_map/mesh.header",          // Mesh
  "sample_map/mesh.elements",
  "sample_map/mesh.nodes",
  "sample_map/dielectrics.dat",      // List of dielectrics
  "sample_map/sample_map.result",    // Elmer results
  "cm");                             // Units
```

- Assign a drift medium

```
elm->SetMedium(0,gasArCO2);
```

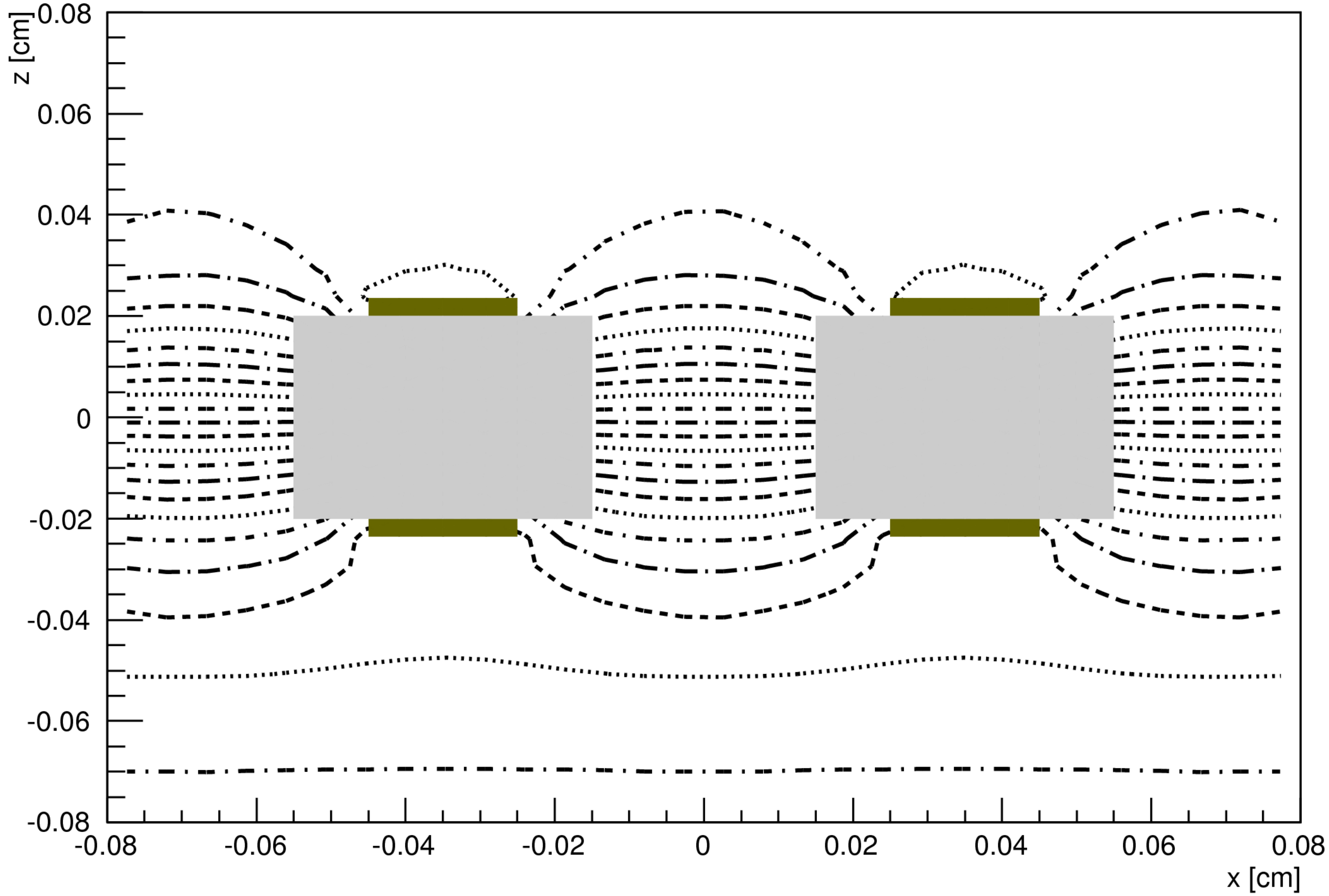
Ready for simulation

Simulation/visualization:

- ViewFEMesh class
  - ➔ Draws finite elements according to fill and color options
  - ➔ Can draw drift lines produced in simulations with ViewDrift
  - ➔ Can be drawn over a plot made by ViewField

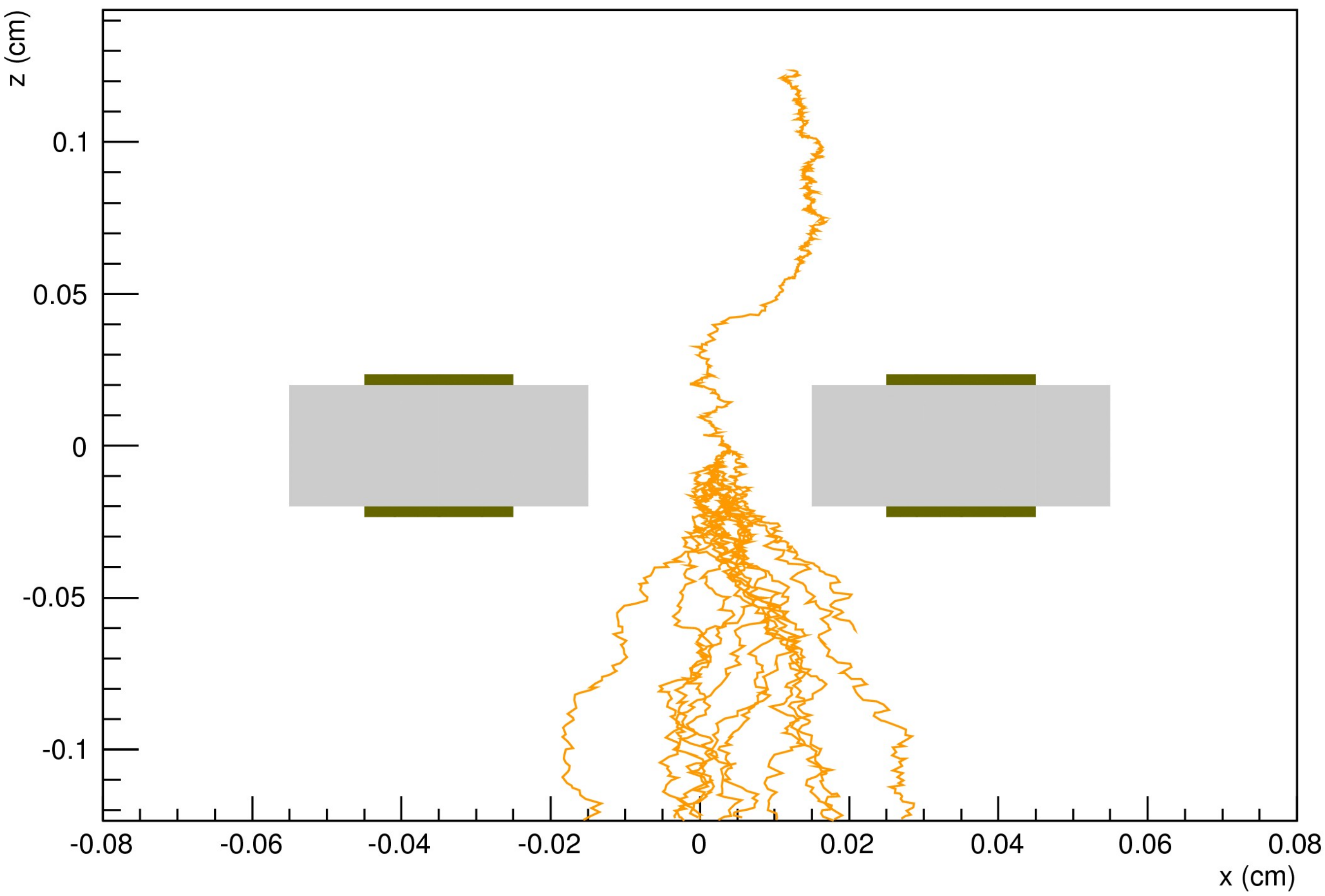
Simulation/visualization:

- ViewFEMesh + ViewField: contours for a LEM



Simulation/visualization:

- ViewFEMesh + ViewDrift: avalanche in a LEM



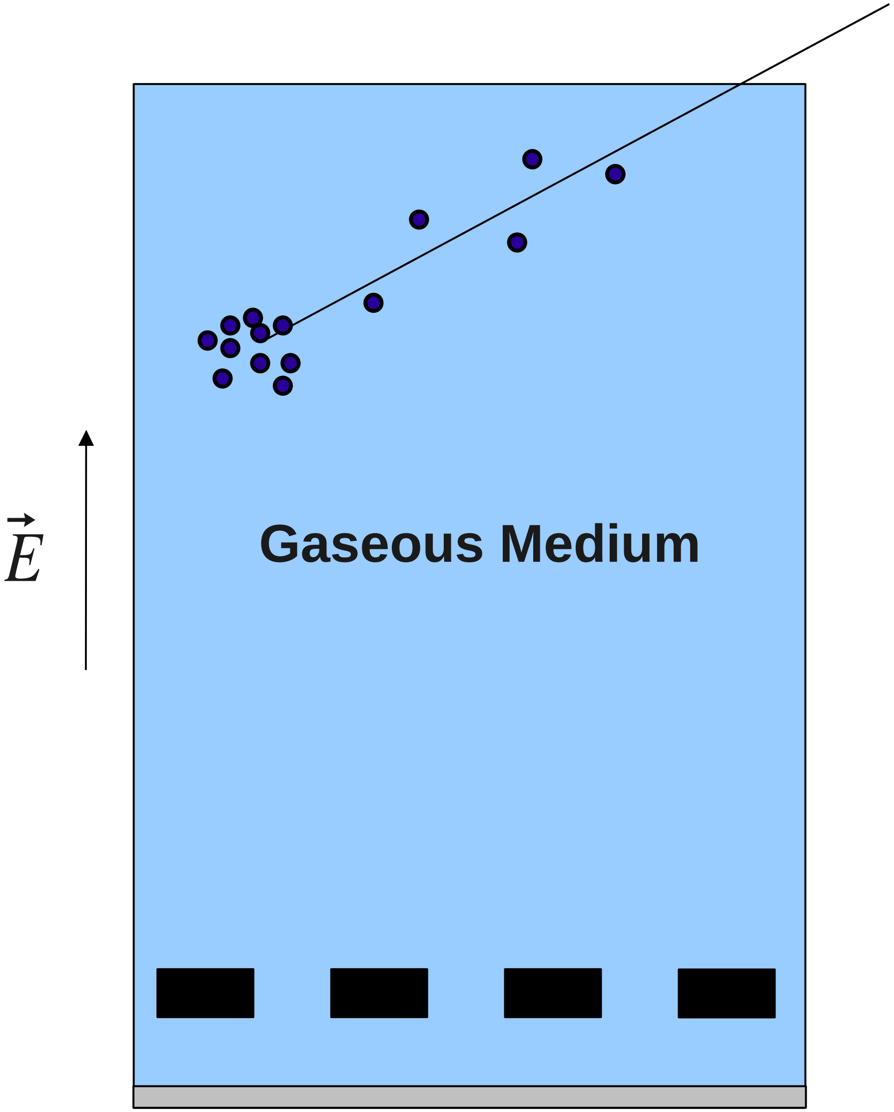
Application: Negative Ion TPC*

- Drift ionization in the form of negative ions
- Advantages include reduced diffusion and potentially intrinsic energy resolution (electrons are counted one by one)
- Garfield++ and finite element used to simulate and understand LEM-based readout process

*** References:**

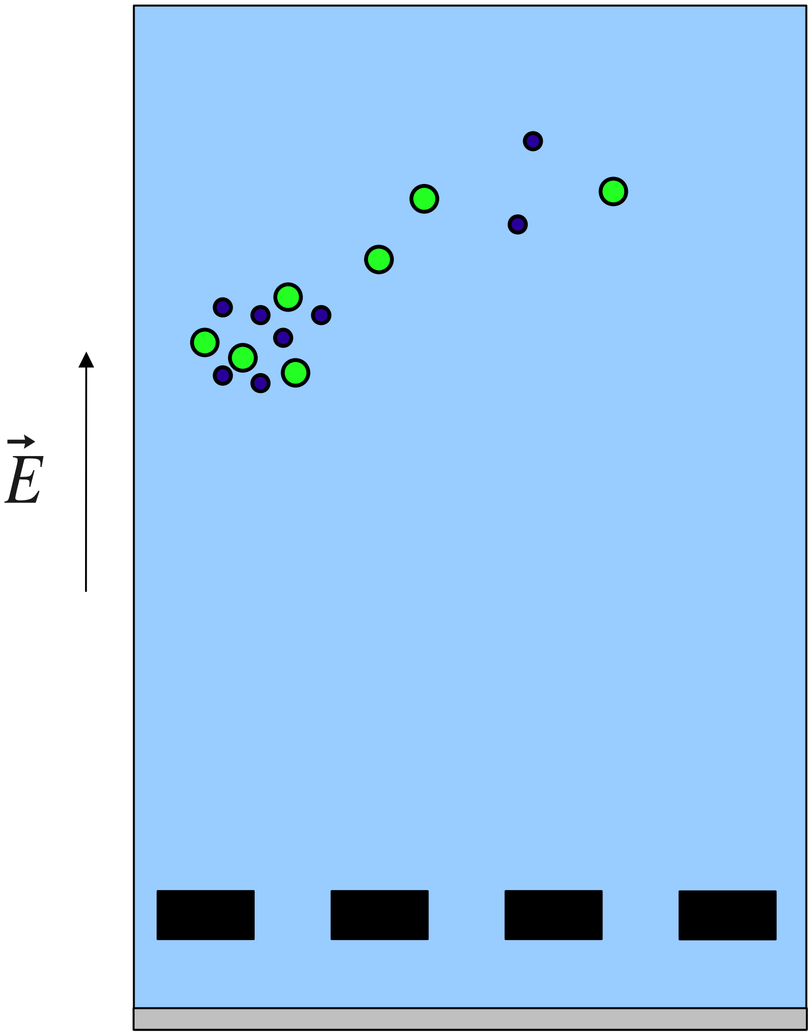
1. C. J. Martoff *et. al.* Nucl. Instr. Meth. A 440, 355 (2000).
2. For further analysis, see D. Nygren. J. Phys. Conf. Series 65 (2007) 012003.
3. P. Sorensen et. al. arXiv:1205.6427v1. (http://dx.doi.org/10.1016/j.nima.2012.05.078)

Application: Negative Ion TPC



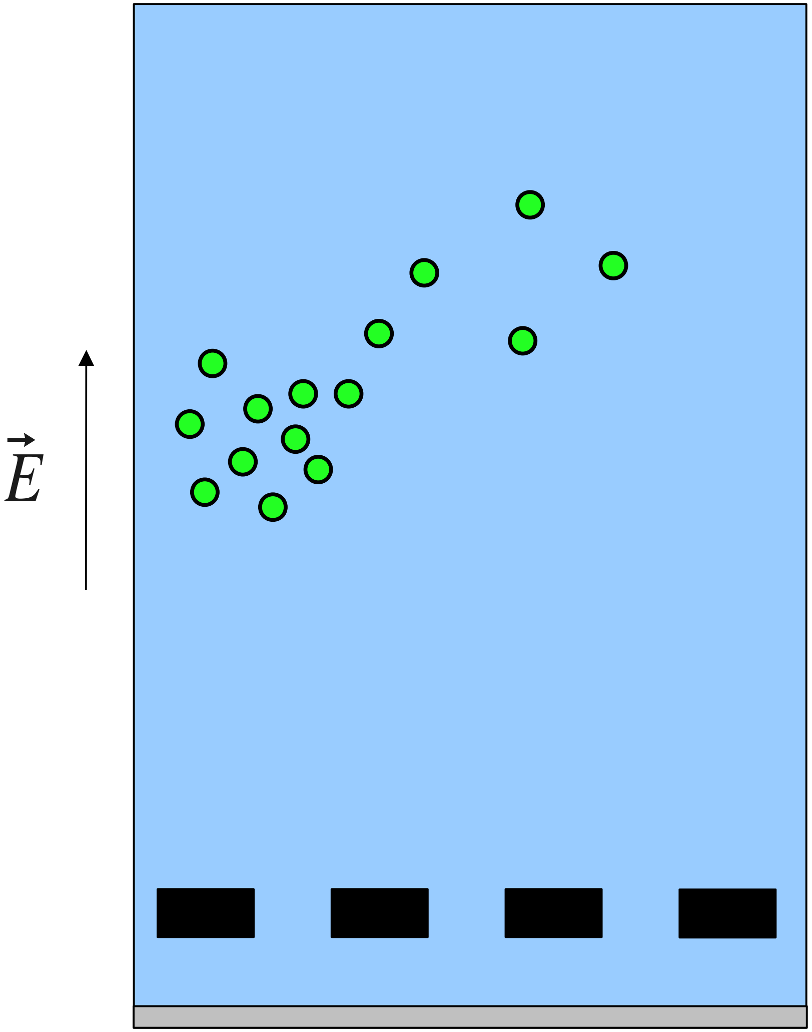
- Incident particle deposits energy through ionization

Application: Negative Ion TPC



- Incident particle deposits energy through ionization
- Electrons are drifted until they attach to impurities to form negative ions

Application: Negative Ion TPC



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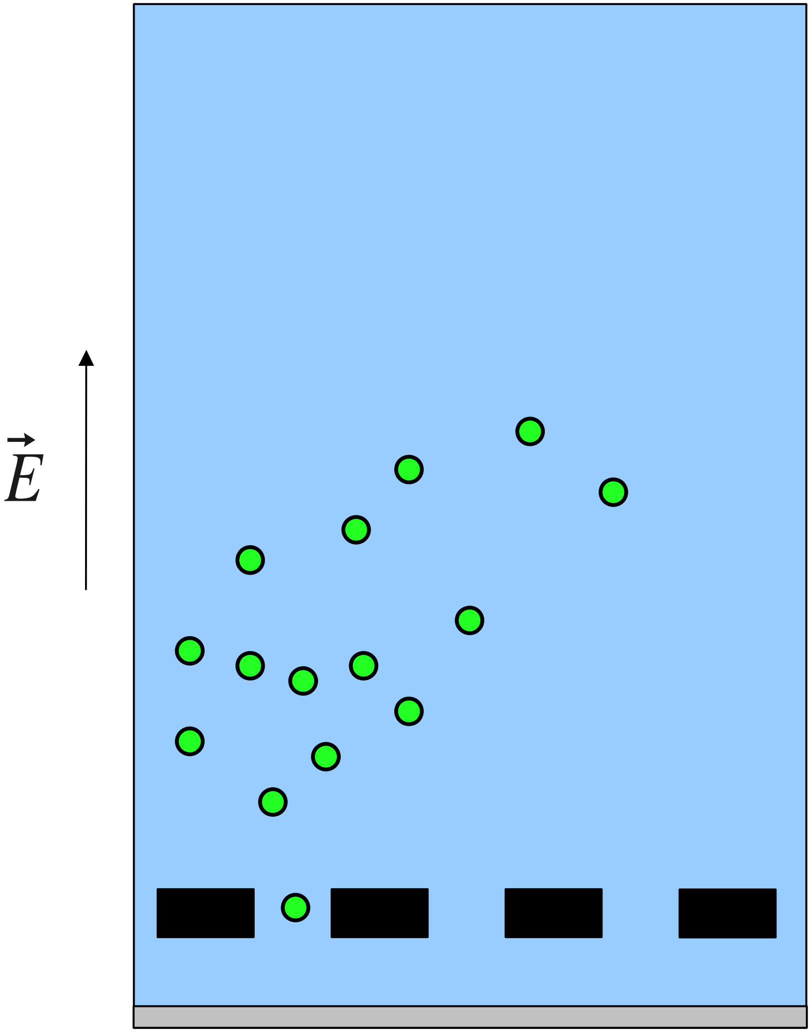

- Incident particle deposits energy through ionization
- Electrons are drifted until they attach to impurities to form negative ions
- These ions are drifted to a plane...

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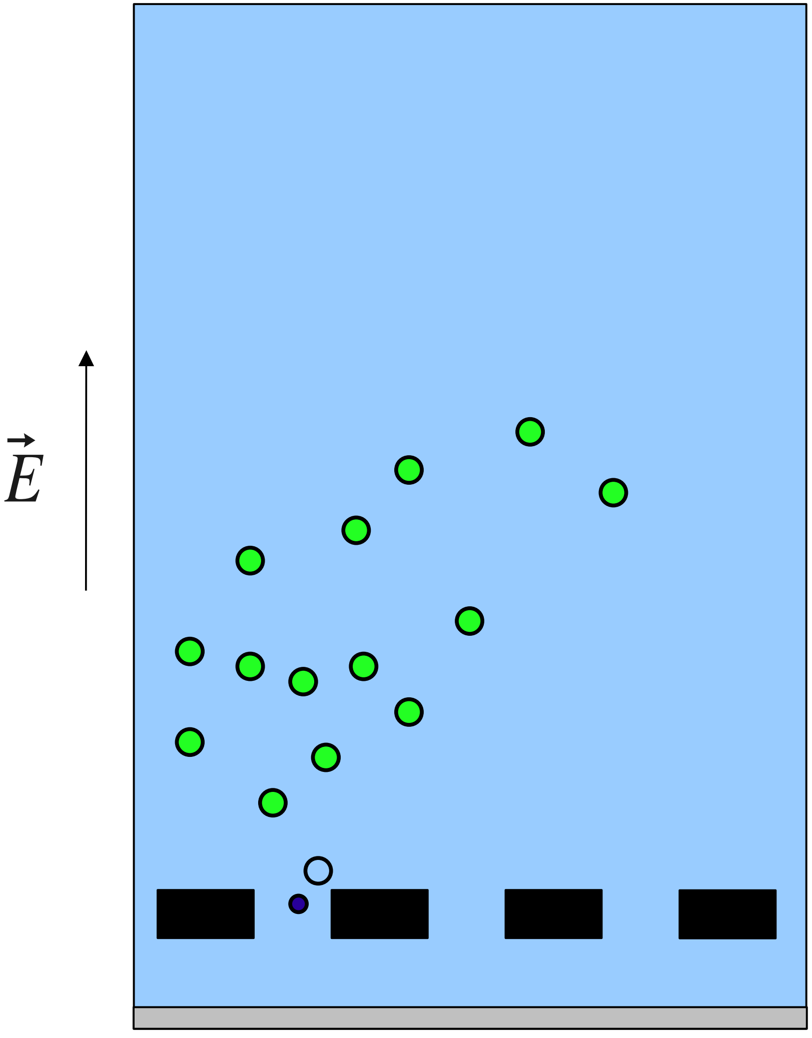

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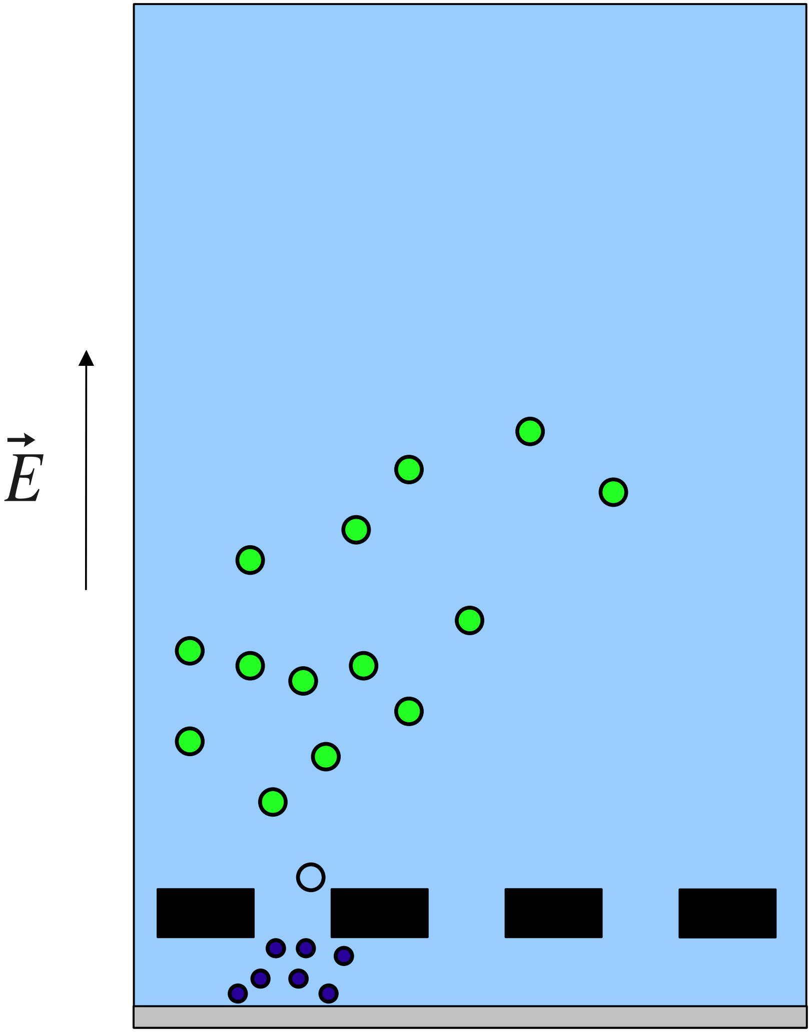
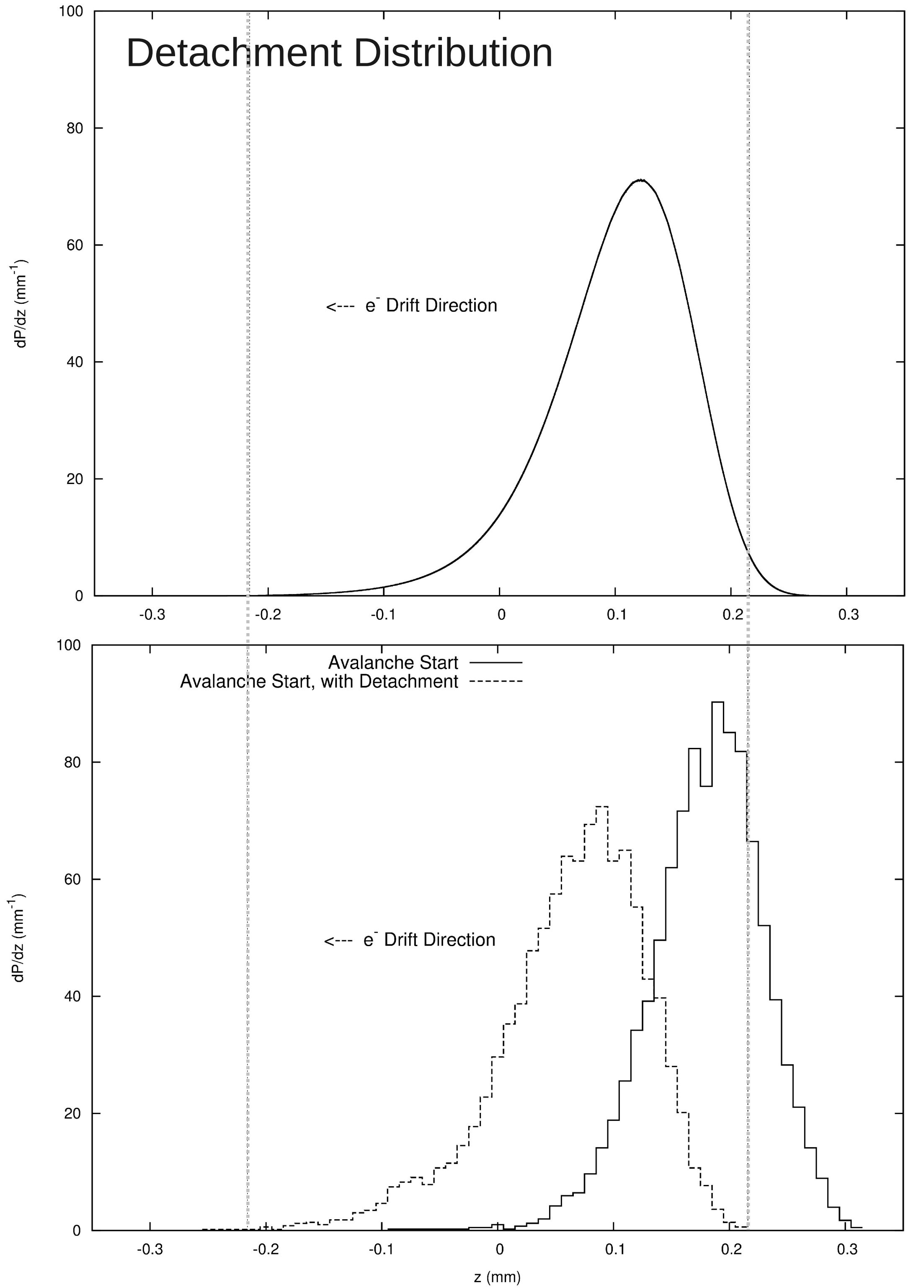


- Incident particle deposits energy through ionization
- Electrons are drifted until they attach to impurities to form negative ions
- These ions are drifted to a plane... where each has its electron removed by the high field in a LEM
- This electron multiplies in the high field yielding one detectable signal for each ion

Application: Negative Ion TPC

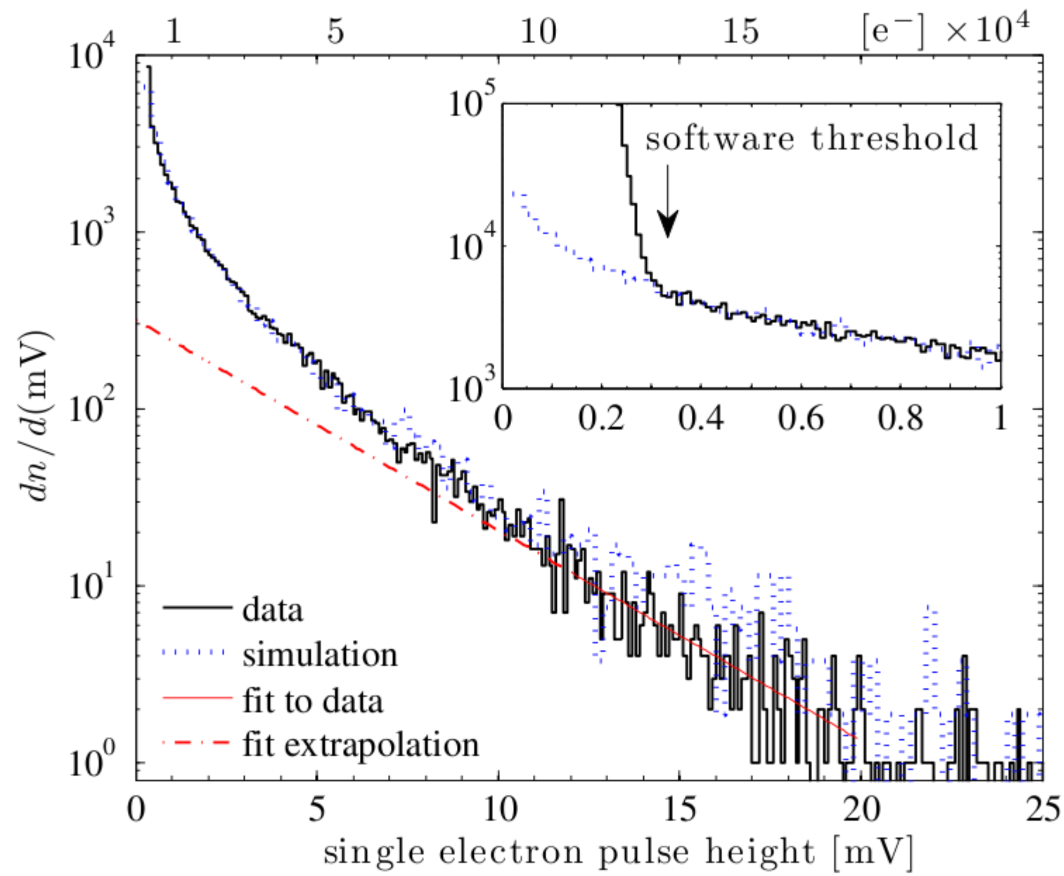
- Avalanche in the presence of detachment
  - ➔ Place electrons according to a calculated detachment distribution
  - ➔ Drift and mark first ionization in avalanche
  - ➔ Uses Garfield++ class: AvalancheMicroscopic
  - ➔ Similar calculation presented in [1]

[1] P. Sorensen et. al. arXiv:1205.6427v1.



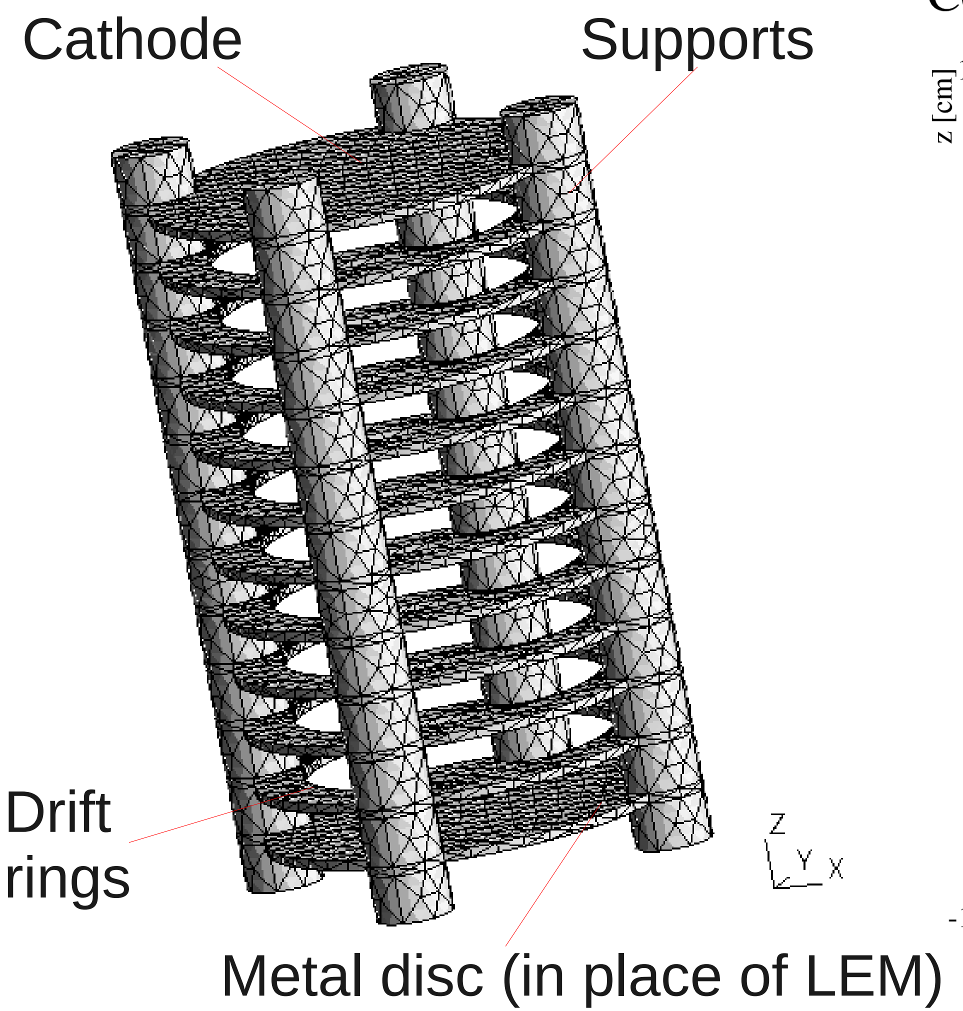
Application: Negative Ion TPC

- LEM gain curve modified due to variation in avalanche start location (expect exponential)
  - Effectively simulates avalanches initiated by negative ions
  - Uses AvalancheMC
  - Deviation from exponential due to detachment
  - Used modified Townsend coefficient (enlarged by 19%) to match gain of LEM

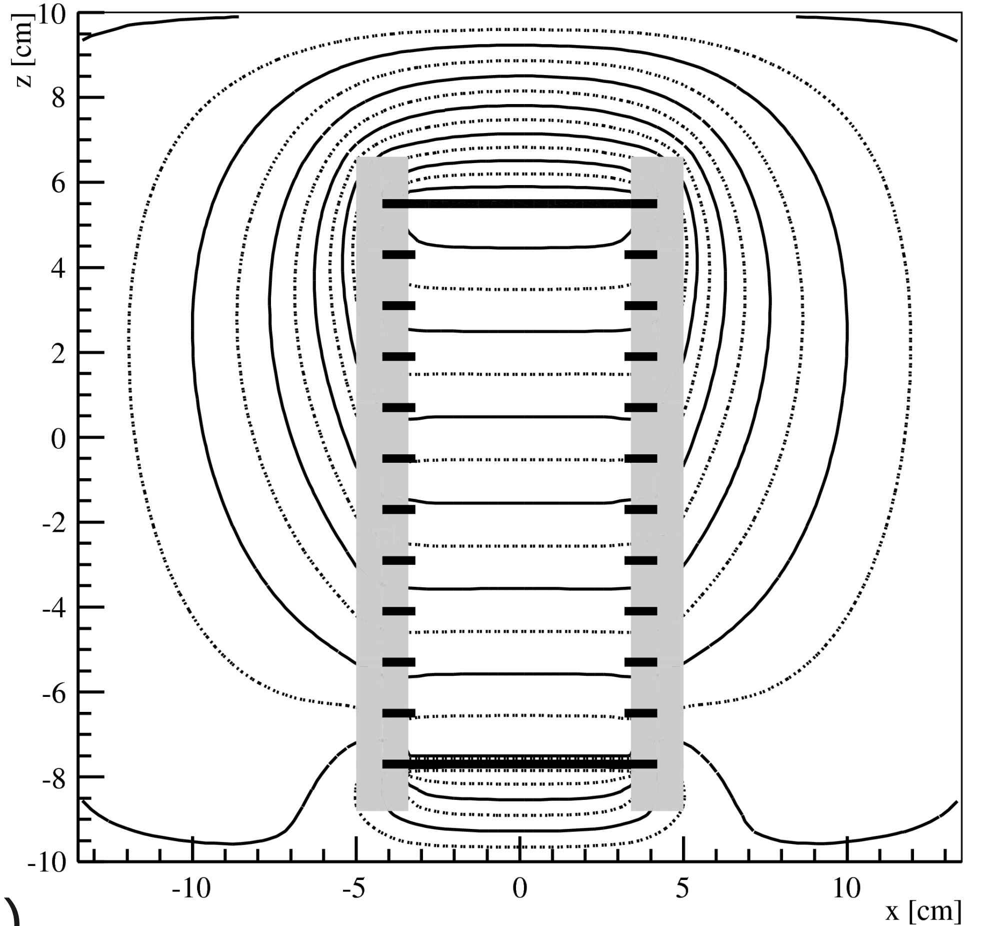


From Sorensen et. al. arxiv 1205.6427v1

- Negative Ion TPC detector geometry

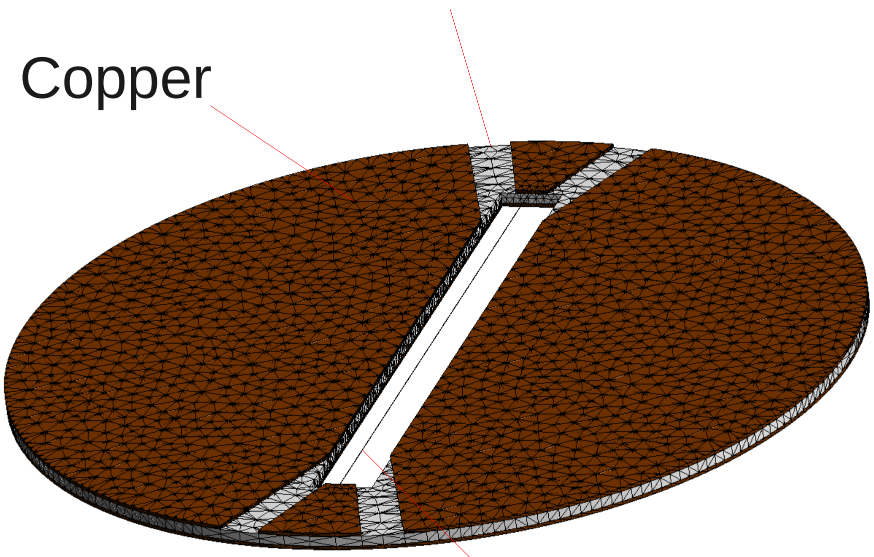


Contours of the potential

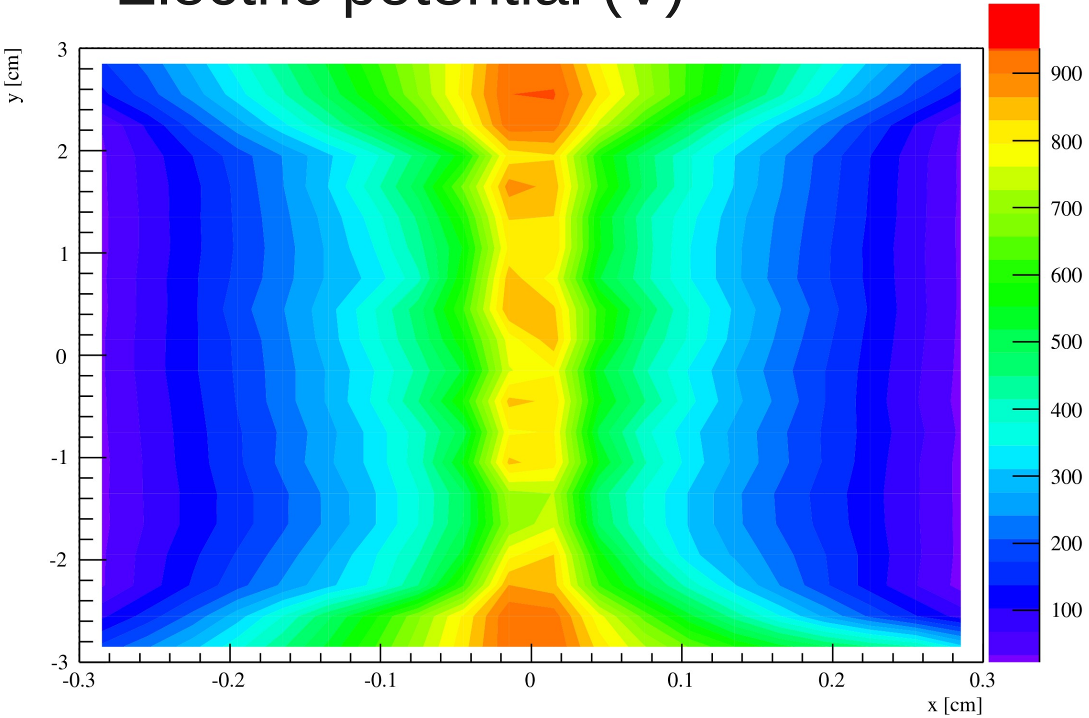


Other Finite Element Examples

- Single-wire alternate to LEM readout



Electric potential (V)



Summary

- Finite element tools
  - Geometry (Gmsh), Electrostatics (Elmer), Simulation/visualization (Garfield++)
  - Open-source
  - Parameterized geometry input: adjustments in dimensions can be made quickly

- Possible improvements to consider
  - Initial geometry input and large changes require significant effort
  - Difficult to mesh geometries with large variations in dimensions (may require a very large mesh)

Acknowledgements

- LLNL Negative Ion Group
- Garfield++ team; especially Heinrich Schindler and Rob Veenhof
- LBNL Xenon Group and NEXT Collaboration; especially Azriel Goldschmidt
- DOE NNSA Stewardship Science Graduate Fellowship