Status of Field Calculations

Weighting Potential

Shockley-Ramo construction:

1. Identify one electrode, k.
2. Set to unit voltage, all others set to 0V.
3. Calculate its *weighting* potential $\phi_{weight,k}$ in the volume.
4. Calculate the associated E-field $\vec{E}_{weight,k}$.
5. Calculate the overall *drift* potential and E-field $\vec{E}_{drift}$.

Induced current on the electrode k from charge q moving with velocity $\vec{v}$:

$$i_k = q\vec{E}_{weight,k} \cdot \vec{v}$$

And, electron drift velocity, for given mobility μ:

$$\vec{v} = \mu\vec{E}_{drift}$$

Boundary Element Method for Electrostatic Potential

1. Discretize (mesh) boundary electrodes.
2. Define potential on each mesh element.
3. Integrate Laplace $\nabla\phi = 0$.
4. Fit integral equations to boundary values.
5. Evaluate solution on points in the volume.

Element Methods: Boundary vs. Finite

BEM

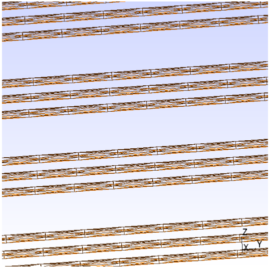
- Meshes the surfaces.
- Fast for low surface-to-volume.
- Performance relies on relatively new math discoveries.
- Relatively few software implementations.

FEM

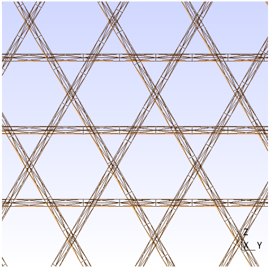
- Meshes the volume.
- Fast for high surface-to-volume.
- Adaptive meshes can improve performance.
- Many implementations, heavily used in industry.

Status of Field Calculations

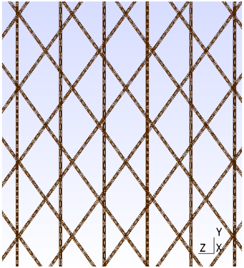
Wires Meshes



"Parallel":
3mm pitch and gap
all wires parallel

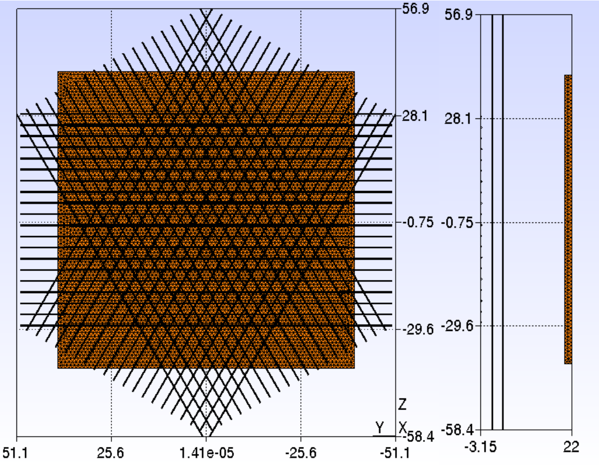


"MicroBooNE":
3mm pitch and gap
60° angles for U/V.



"DUNE":
5mm pitch and gap
35.7° angles for U/V.

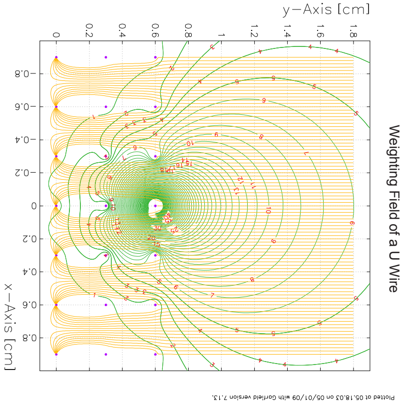
Add Cathode (MicroBooNE)



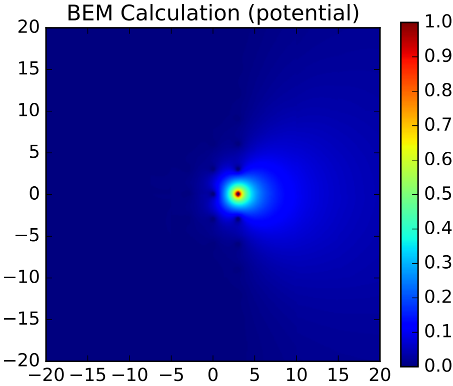
- “Cathode” is near wires with voltage adjusted to give 500V/cm.
- Do calculations at center, far enough away from edge effects.

Status of Field Calculations

Weighting Potential - 2D vs “2D”



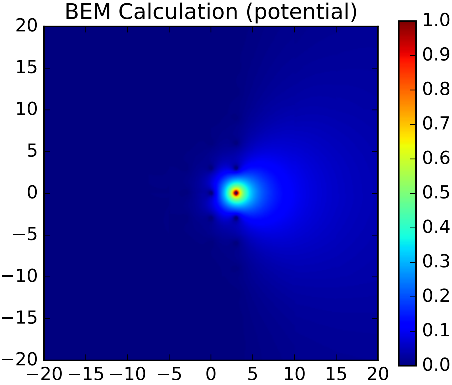
Garfield 2D calculation from Bo



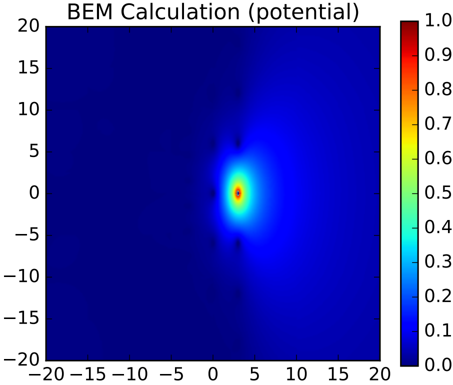
3D BEM, parallel wires, sliced at Y=0.

Initial, qualitative agreement. More checks needed.

Weighting Potential - 2D vs. 3D wire pattern



Parallel wires

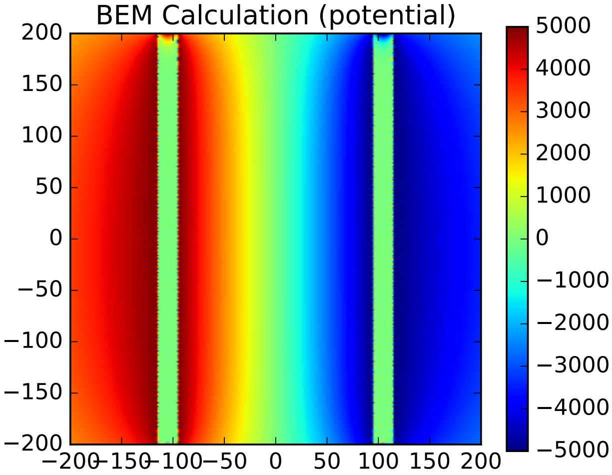


MicroBooNE wires.

Clear distortion in extent and shape. Not surprising.

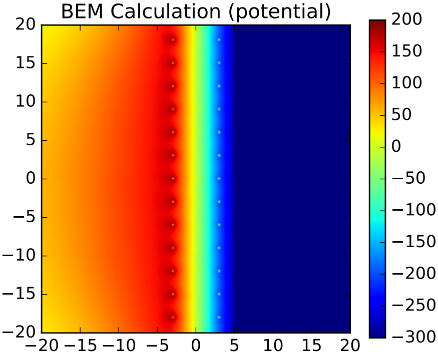
Status of Field Calculations

Capacitor

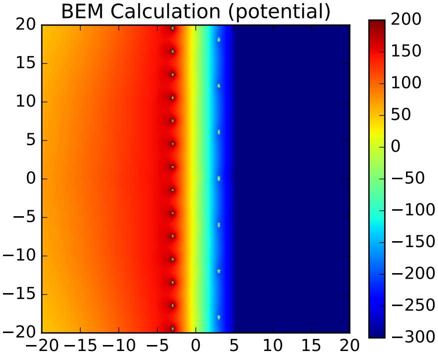


Simple test with parallel-plates at +/-5000V.

Drift Potential - 2D vs. 3D wire pattern



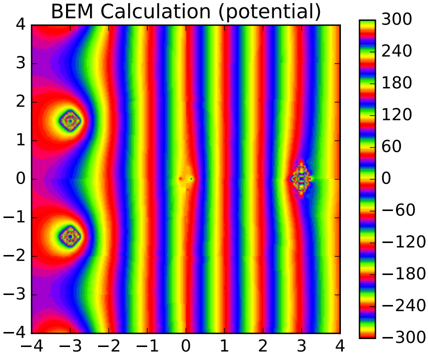
Parallel wires



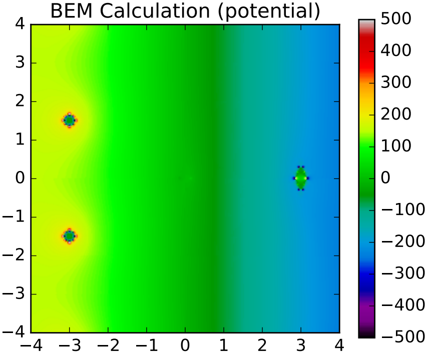
MicroBooNE wires.

Electrodes (from left-to-right) W $\rightarrow$ V $\rightarrow$ U $\rightarrow$ Cathode (off scale)

Some Issues - Mesh Granularity



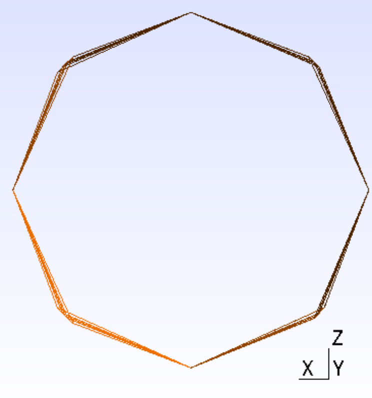
Major features look okay.



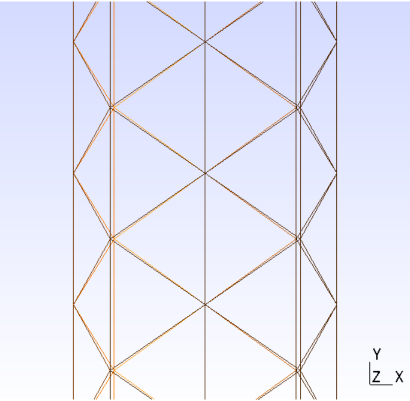
Large +/- fluctuations near wires.

- Drift potential has large fluctuations right near the wires.

Wire Mesh Closeup



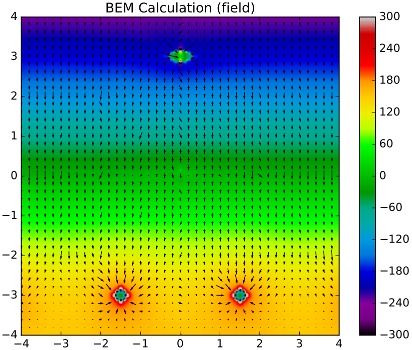
Wire cross section.



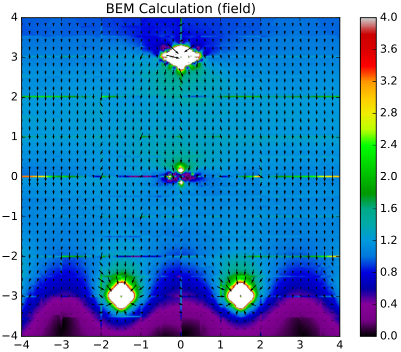
Wire side view.

- Trade-off between mesh granularity and CPU time.

An Initial E-Field Calculation



E-field lines on top of potential.



E-field lines on top of $\left|\vec{E}\right|$.

- Trade-off between mesh granularity and CPU time.

Status of Field Calculations

Main Dependencies

BEM++

- Solves Laplace, Helmholtz and Maxwell eqns using BEM
- C++ with Python interface.
- General, but low-level. Requires some understanding.
- Multithreaded.

GMSH

- 3D Grid generator and visualization.
- Volume and surface meshes.
- Interactive and scripted geometry definition.

Python:

- NumPy, Matplotlib and **LARF**

LARF - Liquid ARgon TPC Field Calculator

For now, code lives at:

https://github.com/brettviren/larf

```
$ larf mesh -o uboone.msh ubone
$ gmsh uboone.msh     # <-- to visualize the generated mesh
$ larf solve -d 11 -g near -o uboone-near-d11.npz uboone.msh
$ larf plot -p near -o uboone-near-d11.pdf uboone-near-d11.npz
```

Processing directed by a `larf.cfg` configuration file, specify things like:

geometry naming the mesh generators and parameters

problem to solve (weighting vs drift)

gridding to use for both the solution and and any plots

plot describing what plotting code to apply to a solution

- Solution results are saved as Python NumPy array files.
- Will extend this as the to-do list is tackled.

Status of Field Calculations

Much Still To Do

- Include calculations for DUNE detector geometry.
- Visualize E-fields, do more careful comparisons to 2D results.
- Go from 2D slices to full 3D volumetric data.
- Dynamics:
  - Charge drifting and wire-current signal generation.
  - Let's make a new simulated animation!
- Responses as a function of position.
  - Repeat Yichen's study on intra- and inter-wire-regions
- Finally, develop some response functions for signal extraction.
  - How detailed? (per-plane?, per wire?)
  - How to validate?
- Other ideas:
  - Jim: Edge effects near field cage, TPC-TPC gaps, inside APA.
  - Milind: calculate transparency of induction planes.
  - Others?

Other Efforts - FEM

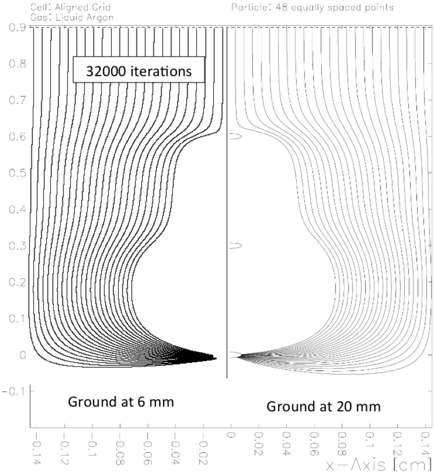
Leon Rochester @ SLAC

- MicroBooNE DocDB 5892
- FEM using custom code ("DIY Garfield")
- C++ rewritten from ICARUS FORTRAN.
- Good looking initial results on drift field and with particle stepping.
- I expect we will do a systematic comparison at some point.

Manhong Zhao @ BNL

- Initial discussions to do FEM using ANSYS + the "multi physics" module.
- Beefy workstation on order.

Not to forget hardware-based measurements!



Left half is Leon's FEM after 32k iterations with Garfield 2D on right half.