Track3P - 3D Parallel Tracking Code for Multipacting and Dark current Simulation

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Overview

- **Track3P Introduction**
  - ACE3P
  - Track3P - Parallel Particle Tracking code
  - Multipacting
  - MP module in Track3P
  - MP simulation procedure and code capabilities
  - Applications and benchmark
- **Examples:**
  - Pill box (field obtained from Omega3P)
    - Quarter structure
    - 10 degree slice structure
  - Coax waveguide (field obtained from S3P)
    - One mode
    - Combined mode
  - Coupler with window

Parallel Finite Element EM Code Suite ACE3P

Over more than a decade, SLAC has developed the conformal, higher-order, C++/MPI-based parallel finite-element suite of electromagnetic codes

ACE3P Modules		– Accelerator physics application
Frequency Domain:	Omega3P	– Eigensolver (nonlinear, damping)
	S3P	– S-Parameter
Time Domain:	T3P	– Transients & Wakefields
	Pic3P	– EM Particle-In-Cell
Particle Tracking:	Track3P	– Dark Current and Multipacting
	Gun3P	– Space-Charge Beam Optics
Multi-Physics:	TEM3P	– EM-Thermal-Mechanical

Visualization: ParaView – Meshes, Fields and Particles

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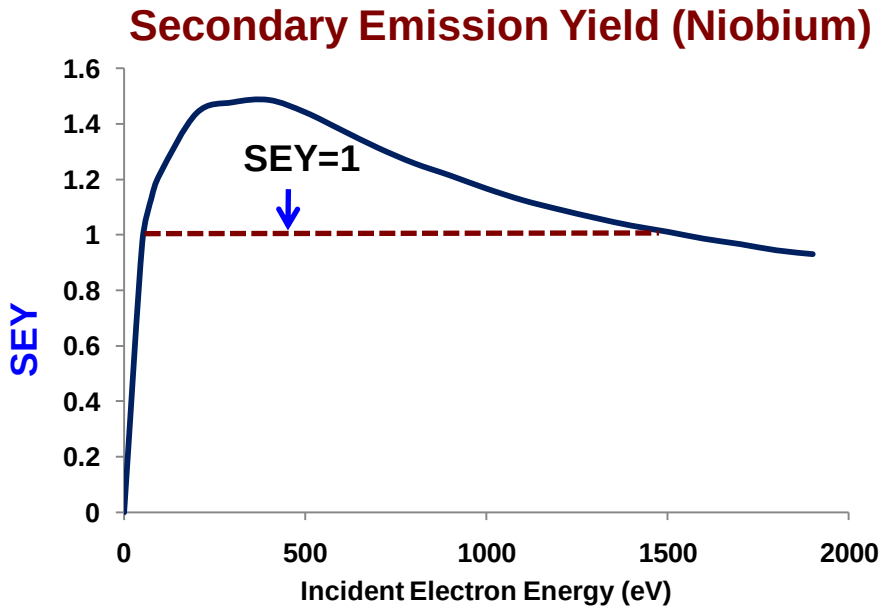
Track3P – Particle Tracking Code

- 3D parallel high-order finite-element particle tracking code for dark current and multipacting simulations (developed under SciDAC)
- Provides accurate and efficient simulation for multipacting
  - *High-resolution EM fields:* Load RF and external fields from other ACE3P modules such as Omega3P, S3P and T3P
  - *High-fidelity geometry representation:* Quadratic curved surface built in the finite-element method allows realistic modeling of particle emission on cavity wall
  - *Realistic SEY curve:* Obtain multipacting maps using accurate SEY curves provided by experiments
  - *Versatile postprocessing:* Identify onset of multipacting through various parameter scans

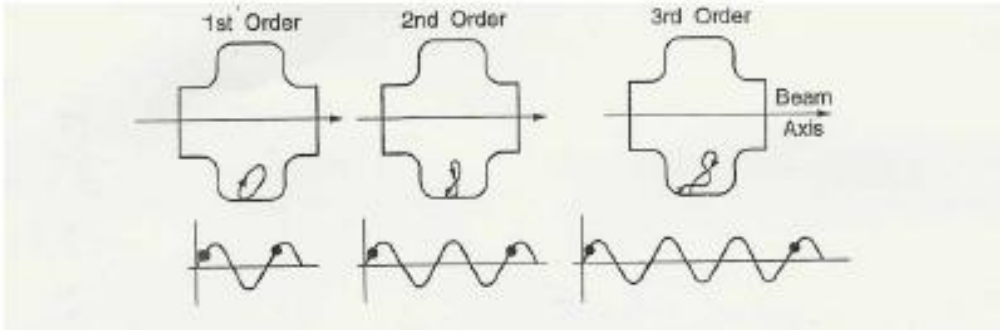
Multipacting

- Electrons are released from RF surface
- Secondary emitted electrons are in resonance with the RF fields
- Impact energies of the secondary electrons fall within the **SEY** (secondary emission yield) curve > 1
  - **SEY :** the number of secondary electrons emitted per incident particle
- The number of resonant electrons multiplies exponentially, leading to a phenomenon of electron avalanche



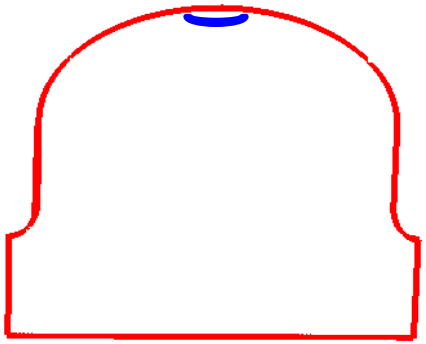
Multipacting Classification

One-point Multipacting



Two points Multipacting

small regions near the equator of elliptical cavity



- **Order:** the number of full RF-cycles it takes an resonant electron to return to its original emission site
- **Points:** the number of impact sites of the resonant trajectories

MP Module In Track3P

Launch Electrons

- Energy, angle
- RF field, location, phase, …

Track particles in electromagnetic fields

- Determine impact positions
- Generate secondary electrons
- Continue tracking for a specified number of RF cycles

Postprocess

- Determine “resonant” trajectories
- Construct MP susceptible zone
- Particles’ trajectory

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MP simulation Procedure and Capabilities

Simulation Procedure:

1. Generate geometry model (CUBIT)
2. Generate mesh (CUBIT)
3. Calculate EM Field (Omega3P/S3P)
4. MP simulation (Track3P)
    1. Construct MP map: scan all the field levels
    2. Particles trajectory at one single field level
5. Post process (Paraview)

Capabilities:

1. 3D complicated structure
2. Traveling wave, standing wave, different combined modes, exterior magnetic field, …
3. Coupler with window
4. …

Applications

- ICHIRO (KEK)
- TTF3 coupler (SLAC)
- CLIC structures (SLAC)
- SNS coupler (Oak Ridge National Lab)
- Muon cooling cavity (BNL, LBNL)
- LSBK coupler
- FRIB HWR(MSU)
- …

Example One: Pill box

Example files location: cw10/track3p/pillbox/quarter

Mesh and Field

1. Generate geometry model:

Journal files: Step1-Make-sw1.jou, Round-to-rtop.jou
Output files: sw0.sat, sw1.sat, rtop.sat

2. Generate mesh:

Journal files: Mesh-rtop.jou
Output file: rtop.gen
Mesh conversion: acdtool mesh convert cubitq netcdf rtop.gen rtop.ncdf
Mesh check: acdtool mesh stats rtop.ncdf
acdtool mesh check rtop.ncdf

3. Calculate EM Field (Omega3P):

Input file: rtop.o3p
Command line: omega3p rtop.o3p
Output files:
mode.l0.m0000.1.3138149e+09.mod
mode.l0.m0001.2.3291330e+09.mod
Eigen mode directory: vector1

Track3P input file-pillbox.track3p

Parameters related to Field

```
//Field scan parameters
FieldScales:
{
Type: FieldGradient    // Three types:
                       // FieldGradient: average field gradient as field scale parameter, unit: v/m
                       // InputPortPower: input port power as field scale parameter, unit: W.
                       // StorEnergy: store energy as field scale parameter, unit: Joul.

ScanToken: 1           // 1: scan, 0: no scan
Minimum: 25.0e+6       // Field scan range:  Minimum <= field <= Maximum
Maximum: 30.0e+6
Interval : 1.0e+6      // Field scan interval
Scale: 20.00e+6        // when scan token = 0, which means no field scan, Track3P runs on this single field level
}

// When average field gradient as field scale parameter, this block is used to normalize average field gradient between StartPoint
and EndPoint
NormalizedField:
{
  StartPoint: 0.0 0.0 -0.068
  EndPoint: 0.0 0.0 0.068
}

// specify the location of EM field
Domain:
{
  PostprocessFile: ./vector1/postprocess.in
}
```

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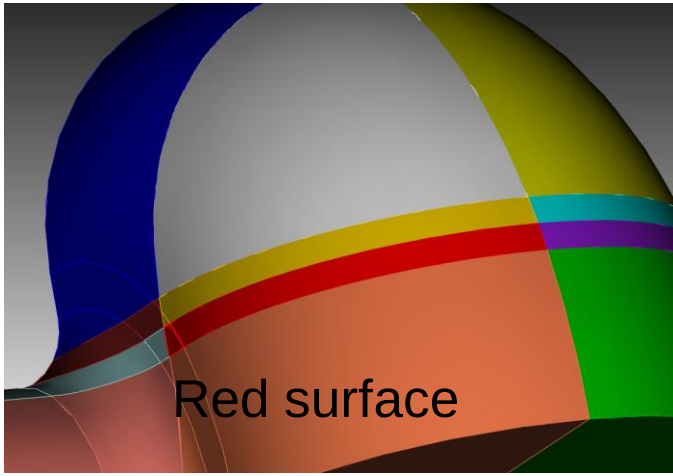
Track3P input file -continue

Emitter: **particle emission parameters. Primary particles are created by emitters, which defines what time period the emitter will be active, the type of emitter, and the boundary surface ID and bounding box to that emitter.**

You can have multiple emitters defined on a single mesh surface.

```
// Particles emitter

Emitter:
{
// time period the emitter will be active: from t0 to t1 in RF period, default value: t0: 0, t1: 1
  t0: 0
  t1: 1
  Type:  2 // Emitter type,  default is 2
         // 2: Exterior Surface
         // 5: Solid Electronic surface, for example on ceramic window
         // 7: Field Emission, for dark current simulation
  BoundaryID: 6      // particles emit from BoundaryID exterior surface
// particles emit from x0 <= x <= x1; y0 <= y <=y1; z0 <= z <= z0 bounding box
  x0: -0.03
  x1: 0.035
  y0: 0.04
  y1: 0.1
  z0: -0.045
  z1: 0.0
}
```



Track3P input file -continue

Material of each wall on the surface: **If a wall does not have an assoicated material, then a particle hitting it will simply be lost. Materials may not represent a physical reality, a symmetry wall can be defined, representing a plane of symmetry for a particle to bounce off**

```
// Test material for energy watching:
// Four types of Material
//
// 2(Absorber): when particle hit on this surface, it will be dead
// 3(Secondary):when particle hit on this surface, seondary particles will be emitted.
// 4(Primary): Primary particles can be emitted from this surface
// 5(SymmetryPlane):Symmetry plane, particles can be bounced back when hitting this plane

// Material of each wall on the surface
//
Material:
{
  Type: Primary
  BoundarySurfaceID: 6
}


Material:
{
  Type: Secondary
  BoundarySurfaceID: 6
}

Material:
{
  Type: SymmetryPlane
  BoundarySurfaceID: 1 2
}
```

Track3P input file -continue

Post process parameters

```
OutputImpacts: on  // record all impact particles information
Postprocess:
{
Toggle: on
ResonantParticles:{
        Token: on
        }

}
```

Run Track3P

Components needed for running Track3P:

1.Mesh
2.EM Field directory
3.Track3P input file
4.Executable Track3P code

Command for running Track3P

mpirun –np number ./Track3P ./inputfile job

1.-np specifies the number of processors to run on. For now, just put 1
2.Track3P is the executible file
3.inputfile is the input file you created.
4.Job is the space for save Track3P results.

Run Track3P on Pill Box Cavity

1. **Files needed for running Track3P:**
   Mesh file: rtop.ncdf
   EM field directory: vector1
   Track3P input file: pillbox.track3p

2. **Command line for running Track3P:**
   mpirun –np 1 Track3P pillbox.track3p job
   mpirun –np 1 Track3P 2.5MV.trak3p j

Track3P generated files

All data files are in the ./job directory:

1.Screen output: record.txt

2. Record all the startup parameters, including default values:

InputParameters

3. Record total running time: multipacting_performance.out

4. Impact particles information at all scanned field levels:

./job/ImpactsInfo_XXX

5. Resonant particles information:

./job/OUTPUT/MPParticlesXXX

./job/OUTPUT/resonantparticles

6. Particles trajectory at single field level: Switch ScanToken to 0, re-run Track3P to get particles trajectories information at single field level, particles emission and information at each step are saved

./job/PARTICLES/0/emissionevents_tsXXX.ascii

./job/PARTICLES/0/partpath_tsXXX.ncdf

Record.txt

Screen output

```
Leaving Emitter::findEmittingFaces(), rank 0, number of all emitting faces = 25
 scan, Minimum field: 2.500000000000e+07 Maximum field: 3.000000000000e+07 interval: 1.000000000000e+06
scale 2.509233405798e+05 Field 2.500000000000e+07
TS 0 my rank 0 Sim time: 0.000000000000e+00
TS 100 my rank 0 Sim time: 7.611397188032e-10
TS 200 my rank 0 Sim time: 1.522279437606e-09
…
Done
```

Multipacting_performance.out

Total run time: 147.365

Format of ./job/ImpactsInfo_XXX

Record all impact particles information at the field level XXX
Example for ImpactsInfo_1.2e+07

#InitialID ImpactOrder Initial_x Initial_y Initial_z Impact_x Impact_y Impact_z InitialPhaseinRFcycle ImpactPhaseinRFcycle ImpactEnergy Initial momentum_x momentum_y momentum_z ImpactFaceID ParticleType volID

20 0 -7.819021e-04 9.876826e-02 1.043925e-02 -7.819021e-04 9.876826e-02 1.043925e-02 0.000000e+00 0.000000e+00 2.000000e+00 0.000000e+00 5.883542e-27 -7.431003e-25 -1.772260e-25 6 15620840 1
50 0 -8.142427e-04 9.446314e-02 2.161697e-02 -8.142427e-04 9.446314e-02 2.161697e-02 0.000000e+00 0.000000e+00 2.000000e+00 0.000000e+00 5.775896e-27 -6.700199e-25 -3.669901e-25 6 15620840 1
60 0 -8.302425e-04 9.126924e-02 2.663040e-02 -8.302425e-04 9.126924e-02 2.663040e-02 0.000000e+00 0.000000e+00 2.000000e+00 0.000000e+00 5.601796e-27 -6.158025e-25 -4.521036e-25 6 15620840 1

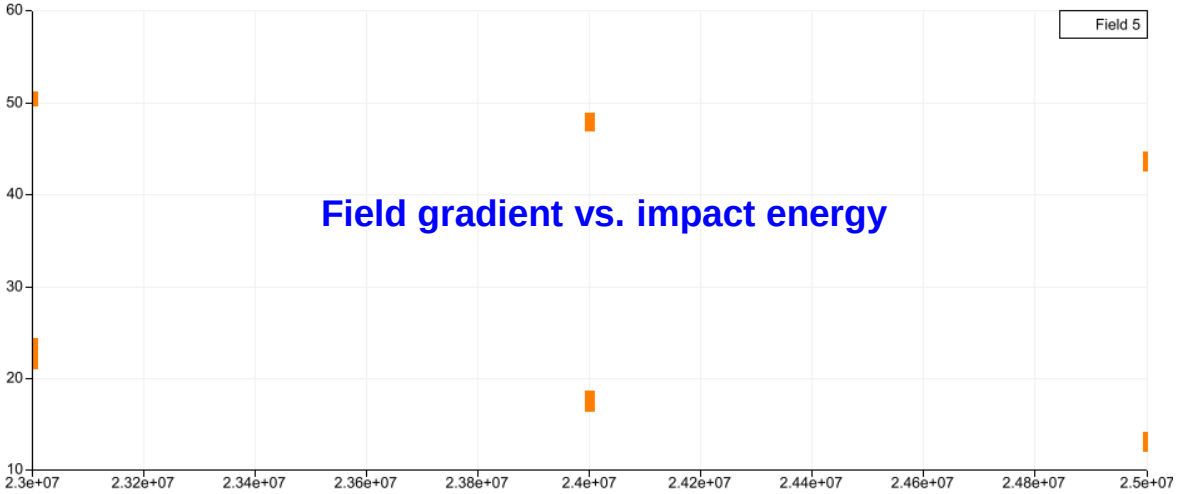
Format of ./job/resonantparticles

Record resonant particles information for all the field levels, from it one can get MP map

First colum: Field level
Second colum: particle ID
Third colum: the x coordinator of particle's impact position;
Fourth colum: the y coordinator of particle's impact position;
Fifth colum: the z coordinator of particle's impact position;
Sixth colum: particle's impact energy in eV;
Seventh colum: particle's impact phase;
Eighth colum: particle's impact time in RF cycle;
Ninth colum: particle's impact number;

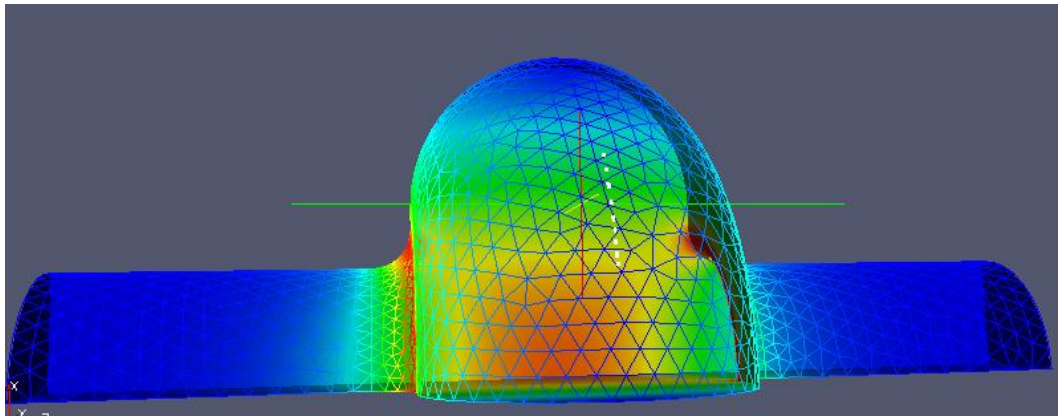
Field Level	ID	X	Y	Z	Energy	Phase	Phase in RF cycle	Impact_num
16000000	4310	-0.00079	0.100003	-0.00017	10.58931	1.48E-08	19.41	39
16000000	4310	0.00079	0.100003	0.000168	10.50246	1.52E-08	19.91	40
…								
17000000	4500	-0.00078	0.100008	-0.00017	15.45694	1.48E-08	19.39	39
17000000	4500	-0.00078	0.100008	0.000175	15.46824	1.51E-08	19.89	40
…								
18000000	10901	-0.00078	0.100005	-0.00017	20.42707	1.47E-08	19.37	38
18000000	10901	-0.00078	0.100006	0.000178	20.46064	1.51E-08	19.87	39

Visualize ./job/resonantparticles



Field Gradient vs. Impact energy

Impact positions for all the field levels



Format of ./job/OUTPUT/MPParticlesXXX

Record resonant particles each impact information at field level XXX, Example:./job/OUTPUT/MPParticles2.5e+07

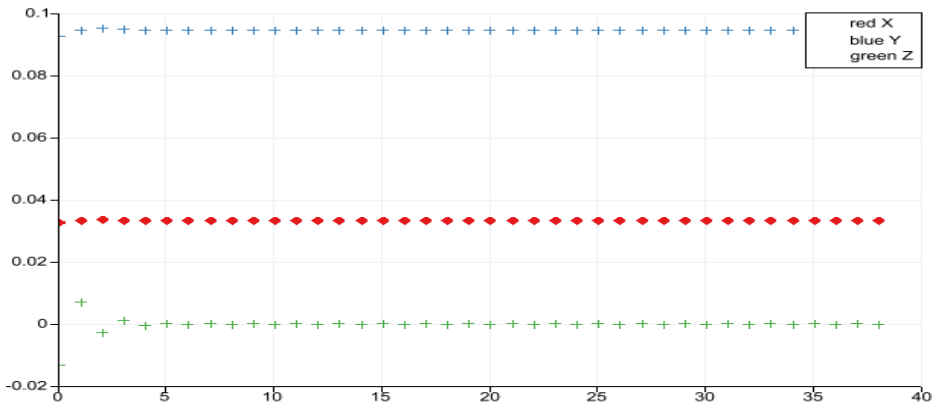
Particle ID 15270 total 39 impacts
0 3.24930503e-02 9.24500794e-02 -1.32822897e-02 2.00000000e+00 7.60000000e-01
1 3.31078646e-02 9.41994655e-02 6.97152626e-03 1.21726883e+05 1.29000000e+00
2 3.33431452e-02 9.48612128e-02 -2.87518818e-03 3.19717119e+04 1.79000000e+00
3 3.32024139e-02 9.44719591e-02 1.15149943e-03 6.04297833e+03 2.29000000e+00
4 3.31588769e-02 9.43470431e-02 -4.61342963e-04 9.72167408e+02 2.79000000e+00
5 3.31690615e-02 9.43779915e-02 1.34353079e-04 1.55416372e+02 3.30000000e+00
6 3.31612961e-02 9.43550548e-02 -1.09295111e-04 3.93742319e+01 3.80000000e+00
7 3.31589153e-02 9.43490694e-02 3.60063029e-05 1.84484892e+01 4.30000000e+00
8 3.31584108e-02 9.43470069e-02 -8.26929047e-05 1.42338645e+01 4.80000000e+00
9 3.31578999e-02 9.43462376e-02 2.93813810e-05 1.30780131e+01 5.30000000e+00
10 3.31582054e-02 9.43464984e-02 -8.21950578e-05 1.30208340e+01 5.80000000e+00
11 3.31580896e-02 9.43468549e-02 2.97321288e-05 1.30389427e+01 6.30000000e+00
12 3.31582272e-02 9.43466355e-02 -8.18215914e-05 1.30975625e+01 6.80000000e+00
13 3.31579726e-02 9.43465947e-02 2.94329286e-05 1.29568261e+01 7.30000000e+00
14 3.31583811e-02 9.43471440e-02 -8.21396500e-05 1.30891306e+01 7.80000000e+00
15 3.31578899e-02 9.43464324e-02 2.90352995e-05 1.30013316e+01 8.30000000e+00
16 3.31584767e-02 9.43474878e-02 -8.23101849e-05 1.30526859e+01 8.80000000e+00
17 3.31580997e-02 9.43471079e-02 2.90545816e-05 1.30958614e+01 9.30000000e+00
18 3.31579783e-02 9.43461547e-02 -8.12820906e-05 1.29484481e+01 9.80000000e+00
19 3.31577585e-02 9.43462064e-02 2.95249577e-05 1.28242962e+01 1.03000000e+01
20 3.31581198e-02 9.43466256e-02 -8.22913068e-05 1.30494213e+01 1.08000000e+01
21 3.31579169e-02 9.43467338e-02 2.96275196e-05 1.30413552e+01 1.13000000e+01
22 3.31582267e-02 9.43470026e-02 -8.20496018e-05 1.31070112e+01 1.18000000e+01
23 3.31576272e-02 9.43459784e-02 2.89681532e-05 1.29398116e+01 1.23000000e+01
24 3.31582474e-02 9.43471323e-02 -8.25463651e-05 1.30004088e+01 1.28000000e+01
25 3.31578105e-02 9.43465769e-02 2.92124947e-05 1.30752074e+01 1.33000000e+01
26 3.31582996e-02 9.43473547e-02 -8.22163380e-05 1.30675799e+01 1.38000000e+01
27 3.31576325e-02 9.43461415e-02 2.87850450e-05 1.29857781e+01 1.43000000e+01
28 3.31580938e-02 9.43468451e-02 -8.22722901e-05 1.29467166e+01 1.48000000e+01
29 3.31576759e-02 9.43463394e-02 2.92850245e-05 1.30023119e+01 1.53000000e+01
30 3.31579487e-02 9.43465078e-02 -8.21173930e-05 1.29991024e+01 1.58000000e+01
…

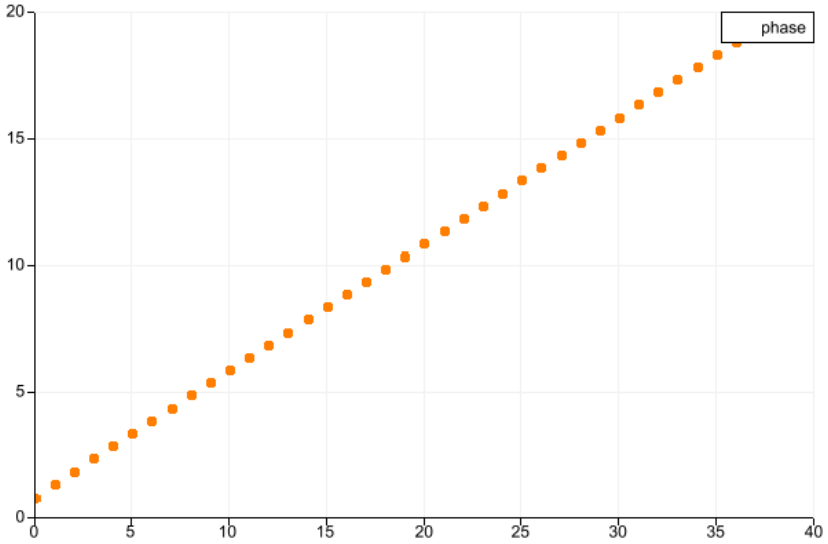
Visulize ./job/OUTPUT/MPParticlesXXX

MPParticlesXXX record each resonant particles impact position, phase and impact energy. Before visualize one single particle's information, one should dump its data to another file

MPParticles2.5e+07, ID: 15270, file: impactpostion-15270

0 3.24930503e-02 9.24500794e-02 -1.32822897e-02 2.00000000e+00 7.60000000e-01
1 3.31078646e-02 9.41994655e-02 6.97152626e-03 1.21726883e+05 1.29000000e+00
2 3.33431452e-02 9.48612128e-02 -2.87518818e-03 3.19717119e+04 1.79000000e+00
3 3.32024139e-02 9.44719591e-02 1.15149943e-03 6.04297833e+03 2.29000000e+00
4 3.31588769e-02 9.43470431e-02 -4.61342963e-04 9.72167408e+02 2.79000000e+00
5 3.31690615e-02 9.43779915e-02 1.34353079e-04 1.55416372e+02 3.30000000e+00
6 3.31612961e-02 9.43550548e-02 -1.09295111e-04 3.93742319e+01 3.80000000e+00
7 3.31589153e-02 9.43490694e-02 3.60063029e-05 1.84484892e+01 4.30000000e+00
8 3.31584108e-02 9.43470069e-02 -8.26929047e-05 1.42338645e+01 4.80000000e+00
9 3.31578999e-02 9.43462376e-02 2.93813810e-05 1.30780131e+01 5.30000000e+00
10 3.31582054e-02 9.43464984e-02 -8.21950578e-05 1.30208340e+01 5.80000000e+00
11 3.31580896e-02 9.43468549e-02 2.97321288e-05 1.30389427e+01 6.30000000e+00
12 3.31582272e-02 9.43466355e-02 -8.18215914e-05 1.30975625e+01 6.80000000e+00
13 3.31579726e-02 9.43465947e-02 2.94329286e-05 1.29568261e+01 7.30000000e+00
14 3.31583811e-02 9.43471440e-02 -8.21396500e-05 1.30891306e+01 7.80000000e+00
15 3.31578899e-02 9.43464324e-02 2.90352995e-05 1.30013316e+01 8.30000000e+00
16 3.31584767e-02 9.43474878e-02 -8.23101849e-05 1.30526859e+01 8.80000000e+00
17 3.31580997e-02 9.43471079e-02 2.90545816e-05 1.30958614e+01 9.30000000e+00
18 3.31579783e-02 9.43461547e-02 -8.12820906e-05 1.29484481e+01 9.80000000e+00
19 3.31577585e-02 9.43462064e-02 2.95249577e-05 1.28242962e+01 1.03000000e+01
20 3.31581198e-02 9.43466256e-02 -8.22913068e-05 1.30494213e+01 1.08000000e+01
21 3.31579169e-02 9.43467338e-02 2.96275196e-05 1.30413552e+01 1.13000000e+01
22 3.31582267e-02 9.43470026e-02 -8.20496018e-05 1.31070112e+01 1.18000000e+01
23 3.31576272e-02 9.43459784e-02 2.89681532e-05 1.29398116e+01 1.23000000e+01
24 3.31582474e-02 9.43471323e-02 -8.25463651e-05 1.30004088e+01 1.28000000e+01
25 3.31578105e-02 9.43465769e-02 2.92124947e-05 1.30752074e+01 1.33000000e+01
26 3.31582996e-02 9.43473547e-02 -8.22163380e-05 1.30675799e+01 1.38000000e+01
27 3.31576325e-02 9.43461415e-02 2.87850450e-05 1.29857781e+01 1.43000000e+01
28 3.31580938e-02 9.43468451e-02 -8.22722901e-05 1.29467166e+01 1.48000000e+01
29 3.31576759e-02 9.43463394e-02 2.92850245e-05 1.30023119e+01 1.53000000e+01
30 3.31579487e-02 9.43465078e-02 -8.21173930e-05 1.29991024e+01 1.58000000e+01
31 3.31579057e-02 9.43470718e-02 2.98210279e-05 1.30375176e+01 1.63000000e+01
32 3.31578992e-02 9.43464435e-02 -8.16305495e-05 1.30899204e+01 1.68000000e+01
33 3.31579333e-02 9.43472262e-02 2.98226129e-05 1.29715646e+01 1.73000000e+01
34 3.31580577e-02 9.43469667e-02 -8.16862755e-05 1.31377076e+01 1.78000000e+01
35 3.31575440e-02 9.43461866e-02 2.90088100e-05 1.28944034e+01 1.83000000e+01
36 3.31579890e-02 9.43468436e-02 -8.22948585e-05 1.29792780e+01 1.88000000e+01
37 3.31576125e-02 9.43464563e-02 2.93573790e-05 1.30131600e+01 1.93000000e+01
38 3.31582808e-02 9.43477424e-02 -8.25088857e-05 1.31180901e+01 1.98000000e+01

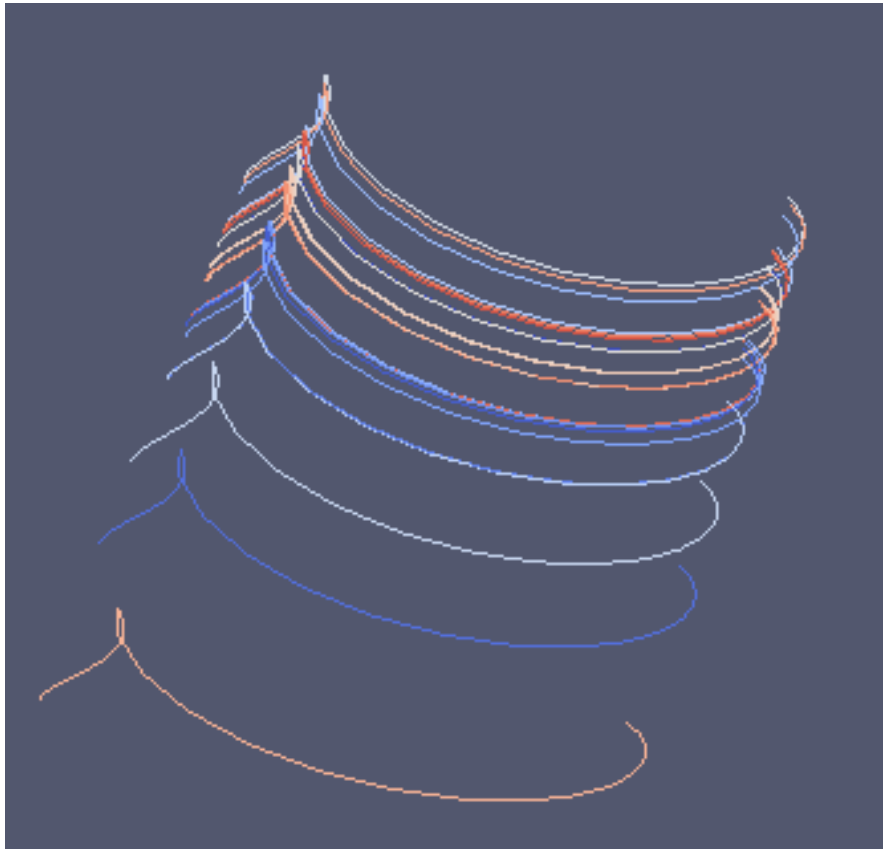




Particles Trajectory

Run Single field to get particles trjectory
Command: Mpirun –np 1 ./Track3P 2.5MV.track3p j

Parview to visualize the whole particles trajectory at field level 2.5 MV/m



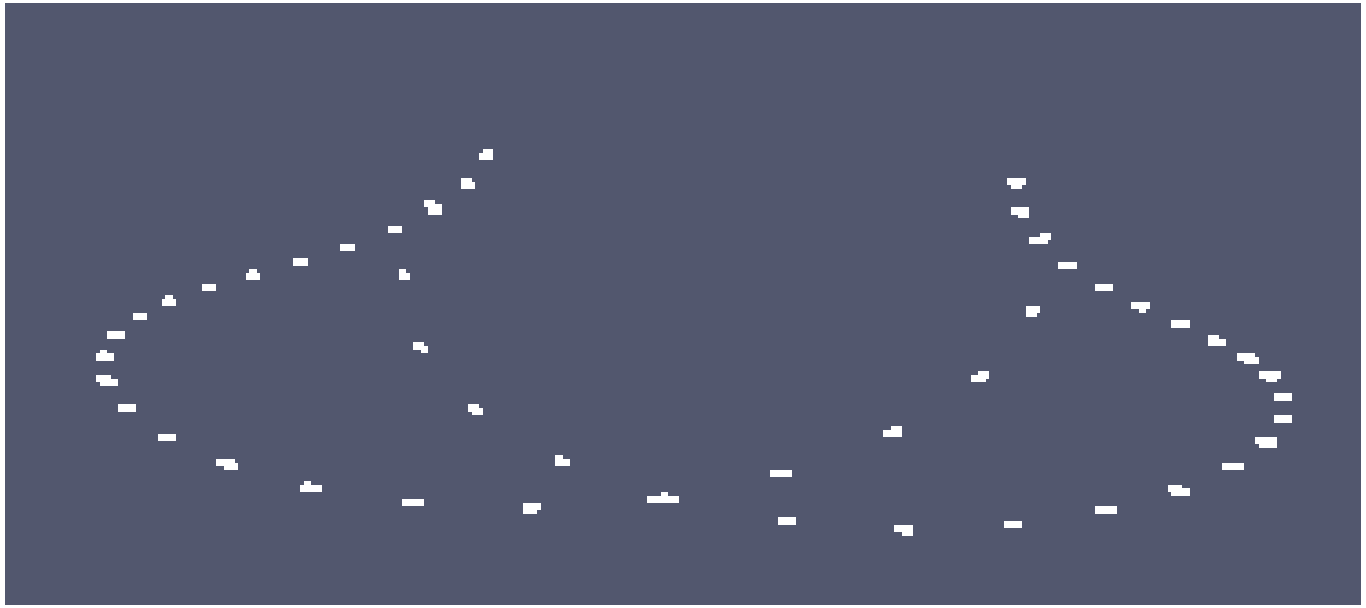
SLAC NATIONAL ACCELERATOR LABORATORY

Particles Trajectory

Extract one single particle's trajectory:

Trajectory –o 15870 –PID 15870 -particlesFileName ./j/PARTICLES/0/partpath_ts*.ncdf

Paraview to visulize particles trajectory



SLAC NATIONAL ACCELERATOR LABORATORY

Exercise: Pill Box 10 degree slice

Aim: save computing time and provide higher accuracy solution

Example files location: cw10/track3p/pillbox/10degree

Mesh and Field

1. Generate geometry model:

Journal files: model.jou
Output files: model0.sat model1-rtop.sat model1.sat

2. Generate mesh:

Journal files: mesh.jou
Output file: pillbox.gen
Mesh conversion: acdtool mesh convert cubitq netcdf pillbox.gen mesh.ncdf
Mesh check: acdtool mesh stats mesh.ncdf
acdtool mesh check mesh.ncdf

3. Calculate EM Field (Omega3P):

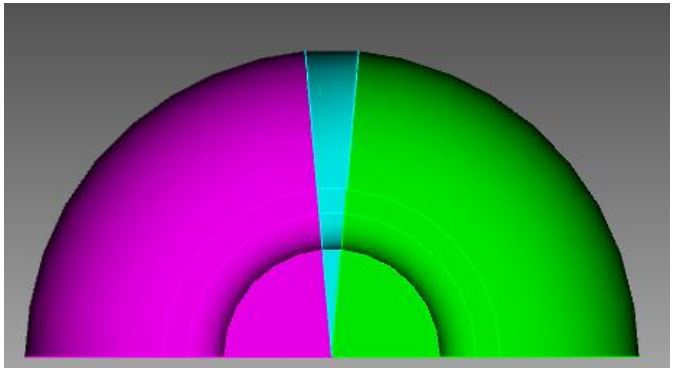
Input file: pillbox.o3p
Command line: omega3p pillbox.o3p
Output files:
field.l0.m0000.1.3138189e+09.mod
field.l0.m0001.2.3913342e+09.mod
Eigen mode directory: vector1

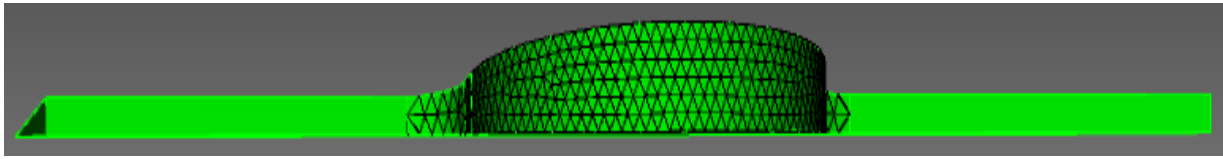
Mesh generation, conversion, check and fix

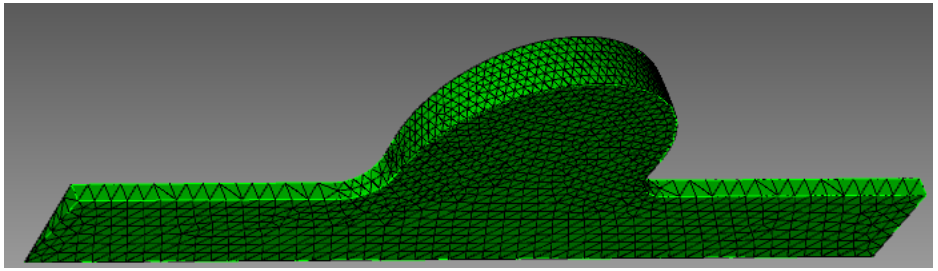
Journal file : mesh.jou

Mesh conversion: acdtool meshconvert cubitq netcdf mesh.gen mesh.ncdf
Mesh statistics: acdtool mesh stats mesh.ncdf
Check: acdtool mesh check mesh.ncdf
Fix: acdtool mesh fix mesh.ncdf

```
reset
import acis "model1-rtop.sat"
volume 1  copy reflect x
unite all
webcut volume 1  with plane xplane offset 0 rotate 5 about z noimprint nomerge
webcut volume 1  with plane xplane offset 0 rotate -5 about z noimprint nomerge
imprint all
merge all
delete volume 1
delete volume 3
compress ids
volume all scheme Tetmesh
surface 5 6 7 10 11 size 3
mesh surface 5 6 7 10 11
vol 1 size 6
mesh vol 1
Sideset 1 surface 1
Sideset 2 surface 2
Sideset 3 surface 8
sideset 4 surface 3
Sideset 6 surface all except 1 2 8 3
block 1 volume all
block 1 element type tetra10
volume all scale 0.001
export Genesis  "pillbox.gen" block all overwrite
quality vol all distortion high 0.0 draw mesh
```







SLAC NATIONAL ACCELERATOR LABORATORY

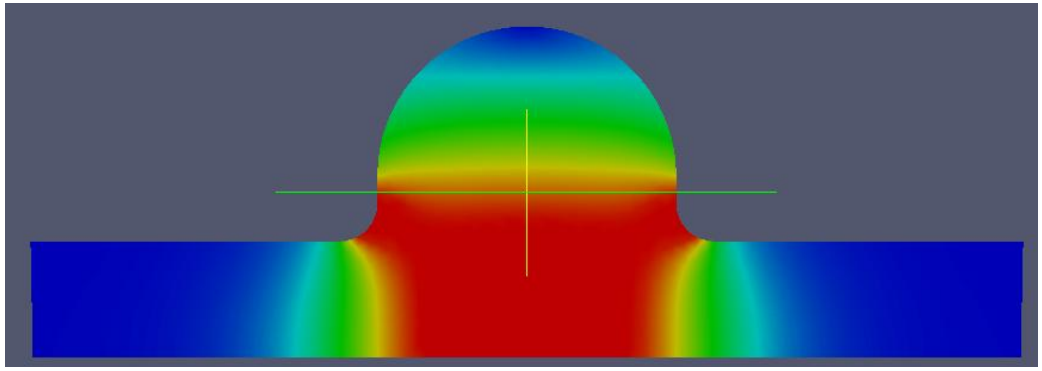
EM Field Calculation

Omega3P input file

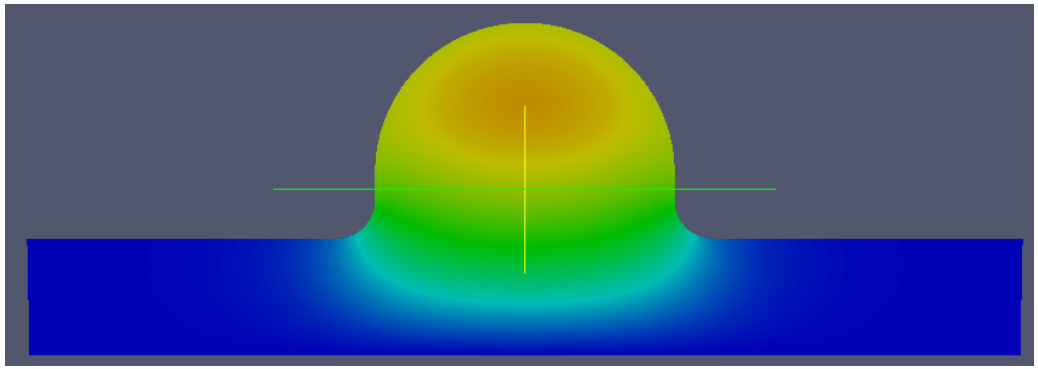
```
ModelInfo : {
 File: ./mesh.ncdf
 BoundaryCondition : {
   Magnetic: 1, 2
   Electric: 3, 4
   Exterior: 6
 }
 SurfaceMaterial : {
   ReferenceNumber: 6
   Sigma: 5.8e7
 }
}
FiniteElement: {
 Order:          2
 CurvedSurfaces: on
}
EigenSolver : {
 NumEigenvalues: 2
 FrequencyShift:  0.5e9
}
PostProcess : {
 Toggle: on
 ModeFile: field

 SymmetryFactor: 1
}
CheckPoint: {
  Directory: vector1
  Act:       save
}
```

Electric Field



Magnetic Field



field.l0.1.313819E+09.m0

field.l0.2.391335E+09.m1

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Track3P input file need to modify

Emitter: emitting location changed
Material: no SymmetryPlane

```
// Particles emitter

Emitter:
{
// particles emit from x0 <= x <= x1; y0 <= y <=y1; z0 <= z <= z0 bounding box
  x0: -0.001
  x1: 0.001
  y0: 0.09
  y1: 0.12
  z0: -0.068
  z1: 0.068
}

Material:
{
  Type: Absorber
  BoundarySurfaceID: 1 2 3 4
}
```

SLAC NATIONAL ACCELERATOR LABORATORY

Run Track3P

1. **Files needed for running Track3P:**

   Mesh file: mesh.ncdf

   EM field directory: vector1

   Track3P input file: pillbox.track3p

2. **Command line for running Track3P:**

   mpirun –np 1 Track3P pillbox.track3p job

   mpirun –np 1 Track3P pillbox.single job20MV

3. **Postprocess:**

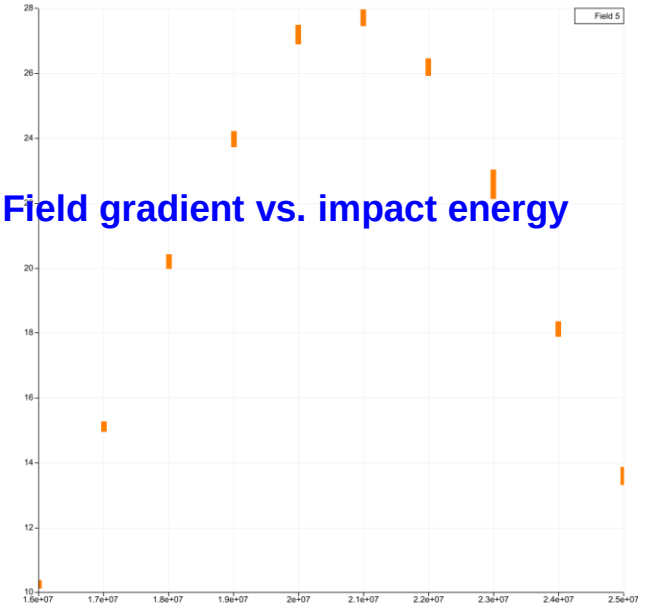
   Single particles trajectory:

   Trajectory -o 7470 -PID 7470 -particlesFileName ./job20MV/PARTICLES/0/partpath_ts*.ncdf

   Paraview

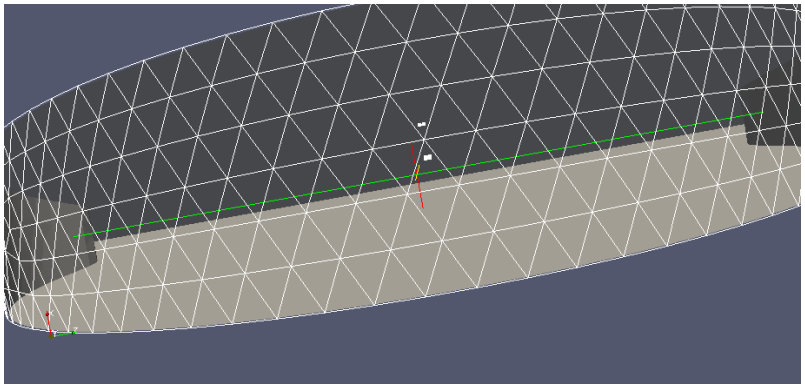
Visualize ./job/resonantparticles

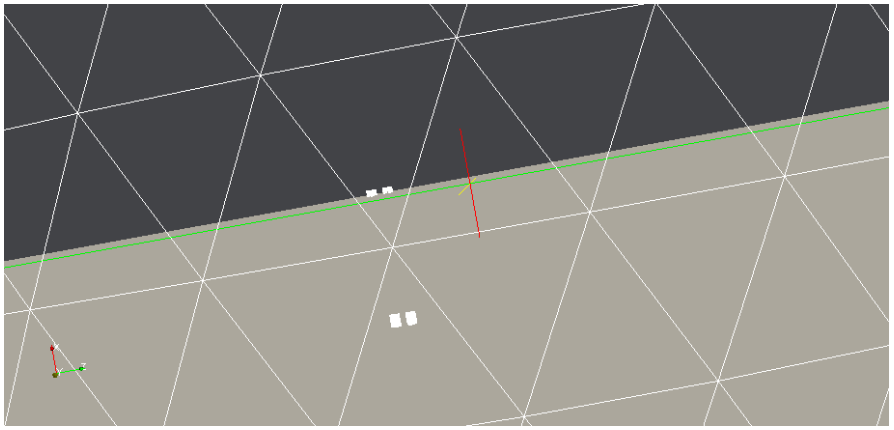
Paraview to visualize data



Field gradient vs. impact energy

Impact positions for all the field levels





Format of ./job/OUTPUT/MPParticlesXXX

Record resonant particles each impact information at field level XXX

Particle ID 10420 total 40 impacts

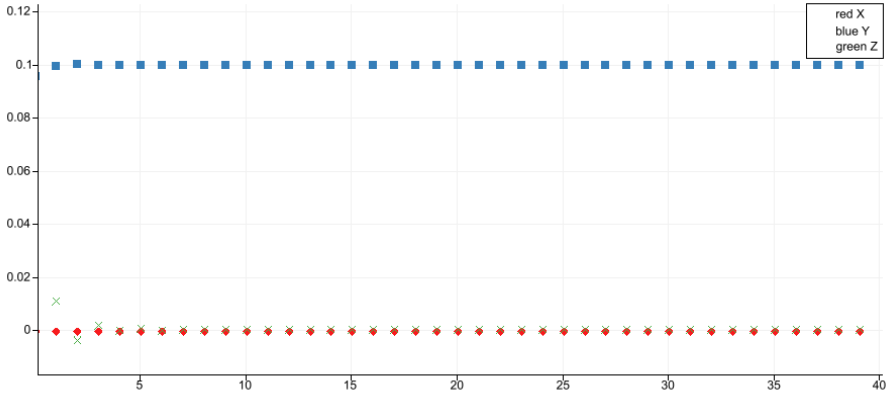
0 -8.07628999e-04 9.69904278e-02 -1.61688370e-02 2.00000000e+00 3.40000000e-01
1 -8.28503166e-04 9.94624598e-02 7.84868862e-03 1.51249826e+05 7.90000000e-01
2 -8.39854023e-04 1.00587791e-01 -3.28168750e-03 3.98418570e+04 1.29000000e+00
3 -8.30590066e-04 1.00170492e-01 1.29875657e-03 7.77206924e+03 1.79000000e+00
4 -8.30776972e-04 9.99990555e-02 -5.03537402e-04 1.21042497e+03 2.29000000e+00
5 -8.31669445e-04 1.00040213e-01 1.86251407e-04 2.01361984e+02 2.80000000e+00
6 -8.31196853e-04 1.00009912e-01 -9.29521600e-05 4.82937360e+01 3.30000000e+00
7 -8.31296515e-04 1.00002115e-01 6.83411479e-05 2.09831643e+01 3.80000000e+00
8 -8.31124832e-04 1.00000709e-01 -5.89134156e-05 1.52139534e+01 4.30000000e+00
9 -8.31263784e-04 1.00000098e-01 5.98993143e-05 1.39759895e+01 4.80000000e+00
10 -8.31114401e-04 1.00000717e-01 -5.71115001e-05 1.36992880e+01 5.30000000e+00
11 -8.31246964e-04 9.99993950e-02 5.89329447e-05 1.36080903e+01 5.80000000e+00
12 -8.31101630e-04 1.00000466e-01 -5.72242000e-05 1.35027861e+01 6.30000000e+00
13 -8.31240354e-04 9.99998487e-02 5.92895727e-05 1.36604868e+01 6.80000000e+00
14 -8.31085313e-04 9.99995795e-02 -5.66616122e-05 1.34929326e+01 7.30000000e+00
15 -8.31231808e-04 1.00000149e-01 5.99095800e-05 1.35767719e+01 7.80000000e+00
16 -8.31080637e-04 1.00000467e-01 -5.69263367e-05 1.36784245e+01 8.30000000e+00
17 -8.31219384e-04 9.99998878e-02 5.92476044e-05 1.36150592e+01 8.80000000e+00
18 -8.31063426e-04 9.99994830e-02 -5.65800885e-05 1.34782053e+01 9.30000000e+00
19 -8.31212286e-04 1.00000336e-01 6.00266631e-05 1.35778038e+01 9.80000000e+00
20 -8.31057059e-04 1.00000091e-01 -5.66790139e-05 1.36685368e+01 1.03000000e+01
21 -8.31205209e-04 1.00000639e-01 5.97365091e-05 1.36322812e+01 1.08000000e+01
22 -8.31043359e-04 9.99994647e-02 -5.61493742e-05 1.35718279e+01 1.13000000e+01
23 -8.31192298e-04 1.00000368e-01 5.99459135e-05 1.35093116e+01 1.18000000e+01
24 -8.31036245e-04 9.99999954e-02 -5.65882041e-05 1.36470522e+01 1.23000000e+01
25 -8.31172188e-04 9.99993370e-02 5.92997061e-05 1.35024309e+01 1.28000000e+01
26 -8.31028128e-04 1.00000585e-01 -5.73993424e-05 1.35723710e+01 1.33000000e+01
27 -8.31164202e-04 9.99996459e-02 5.91841600e-05 1.36745223e+01 1.38000000e+01
28 -8.31013576e-04 9.99999932e-02 -5.69388947e-05 1.35077086e+01 1.43000000e+01
29 -8.31149787e-04 9.99993286e-02 5.93771678e-05 1.35592104e+01 1.48000000e+01
30 -8.31006006e-04 1.00000626e-01 -5.74486102e-05 1.35887970e+01 1.53000000e+01
…

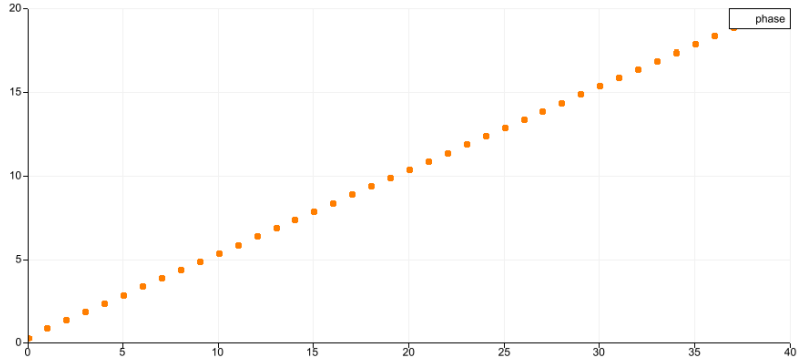
SLAC NATIONAL ACCELERATOR LABORATORY

Visulize ./job/OUTPUT/MPParticlesXXX

MPParticlesXXX record each resonant particles impact position, phase and impact energy. Before visualize one single particle's information, one should dump its data to another file

0 -8.21720042e-04 9.58174864e-02 -1.89355456e-02 2.00000000e+00 2.60000000e-01
1 -8.60021849e-04 9.97443409e-02 1.07902979e-02 1.70461121e+05 8.30000000e-01
2 -8.67732411e-04 1.00414053e-01 -3.97535667e-03 4.53701553e+04 1.32000000e+00
3 -8.62343915e-04 9.99747854e-02 1.39392090e-03 6.46759917e+03 1.82000000e+00
4 -8.64269497e-04 1.00035492e-01 -4.79747905e-04 7.82391106e+02 2.33000000e+00
5 -8.64457539e-04 1.00004447e-01 2.36708343e-04 1.28065093e+02 2.83000000e+00
6 -8.64196877e-04 1.00001102e-01 -1.69970751e-04 4.58537856e+01 3.33000000e+00
7 -8.64370244e-04 1.00001034e-01 1.56463083e-04 3.17149960e+01 3.83000000e+00
8 -8.64191196e-04 1.00001759e-01 -1.50058167e-04 2.87186485e+01 4.33000000e+00
9 -8.64357730e-04 1.00000831e-01 1.51055877e-04 2.79884302e+01 4.83000000e+00
10 -8.64181487e-04 1.00001502e-01 -1.48493582e-04 2.76716957e+01 5.33000000e+00
11 -8.64352233e-04 1.00001105e-01 1.50860073e-04 2.77199845e+01 5.83000000e+00
12 -8.64169981e-04 1.00000952e-01 -1.48037336e-04 2.75820029e+01 6.33000000e+00
13 -8.64345817e-04 1.00001296e-01 1.50959628e-04 2.76130417e+01 6.83000000e+00
14 -8.64165281e-04 1.00001384e-01 -1.48307991e-04 2.76816615e+01 7.33000000e+00
15 -8.64338848e-04 1.00001323e-01 1.50974798e-04 2.77066697e+01 7.83000000e+00
16 -8.64157801e-04 1.00001352e-01 -1.48288973e-04 2.76819581e+01 8.33000000e+00
17 -8.64332149e-04 1.00001382e-01 1.51013381e-04 2.77087666e+01 8.83000000e+00
18 -8.64149832e-04 1.00001244e-01 -1.48218849e-04 2.76787737e+01 9.33000000e+00
19 -8.64318652e-04 1.00000776e-01 1.50623226e-04 2.75976029e+01 9.83000000e+00
20 -8.64143403e-04 1.00001535e-01 -1.48407148e-04 2.75933336e+01 1.03300000e+01
21 -8.64313188e-04 1.00001029e-01 1.50782112e-04 2.76964448e+01 1.08300000e+01
22 -8.64132563e-04 1.00001088e-01 -1.48117810e-04 2.75804655e+01 1.13300000e+01
23 -8.64305087e-04 1.00001046e-01 1.50795891e-04 2.76040987e+01 1.18300000e+01
24 -8.64124021e-04 1.00001039e-01 -1.48084626e-04 2.75778714e+01 1.23300000e+01
25 -8.64297729e-04 1.00001136e-01 1.50853190e-04 2.76064491e+01 1.28300000e+01
26 -8.64114741e-04 1.00000875e-01 -1.47978183e-04 2.75728521e+01 1.33300000e+01
27 -8.64292434e-04 1.00001436e-01 1.51047477e-04 2.76153936e+01 1.38300000e+01
28 -8.64108887e-04 1.00001128e-01 -1.48140516e-04 2.76733999e+01 1.43300000e+01
29 -8.64280547e-04 1.00000990e-01 1.50760887e-04 2.76034350e+01 1.48300000e+01
30 -8.64100692e-04 1.00001143e-01 -1.48152077e-04 2.75812630e+01 1.53300000e+01
31 -8.64271887e-04 1.00000947e-01 1.50730721e-04 2.76008954e+01 1.58300000e+01
32 -8.64092979e-04 1.00001223e-01 -1.48203946e-04 2.75833751e+01 1.63300000e+01
33 -8.64262213e-04 1.00000799e-01 1.50634958e-04 2.75964345e+01 1.68300000e+01
34 -8.64086488e-04 1.00001495e-01 -1.48380061e-04 2.75916038e+01 1.73300000e+01
35 -8.64257265e-04 1.00001104e-01 1.50830234e-04 2.76985247e+01 1.78300000e+01
36 -8.64075032e-04 1.00000951e-01 -1.48028732e-04 2.75762868e+01 1.83300000e+01
37 -8.64250894e-04 1.00001299e-01 1.50958586e-04 2.76115783e+01 1.88300000e+01
38 -8.64070321e-04 1.00001382e-01 -1.48305303e-04 2.76811516e+01 1.93300000e+01
39 -8.64243971e-04 1.00001330e-01 1.50978529e-04 2.77067396e+01 1.98300000e+01





Particles Trajectory

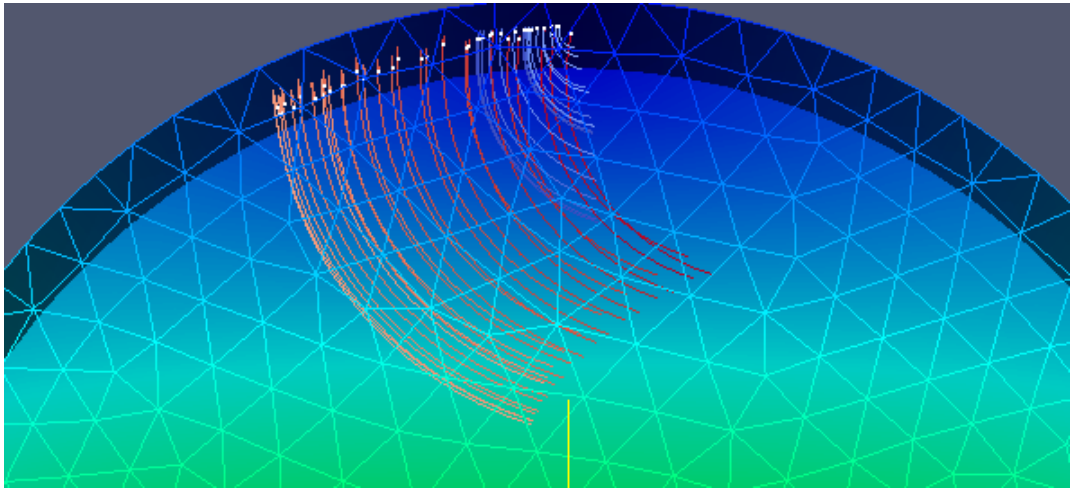
Run Single field (20 MV/m) to get particles trjectory

Command: Mpirun –np 1 ./Track3P pillbox.single job20MV

Input File:

```
ParticlesTrajectories:
{
 ParticleFile: p
 Skip: 2
// Start: 10
// Stop: 100000
}

FieldScales:
{
Type: FieldGradient
ScanToken: 0 // 1: scan, 0: no scan
Scale: 20.00e+6
}
```

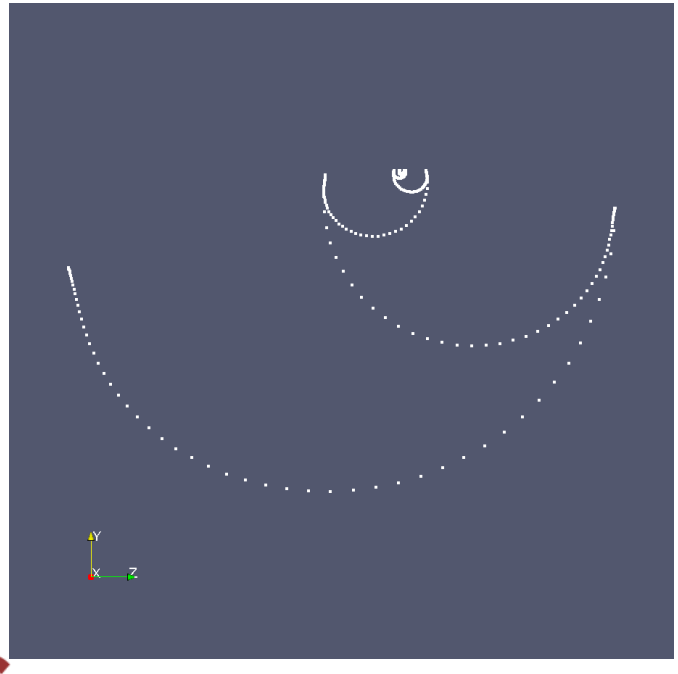


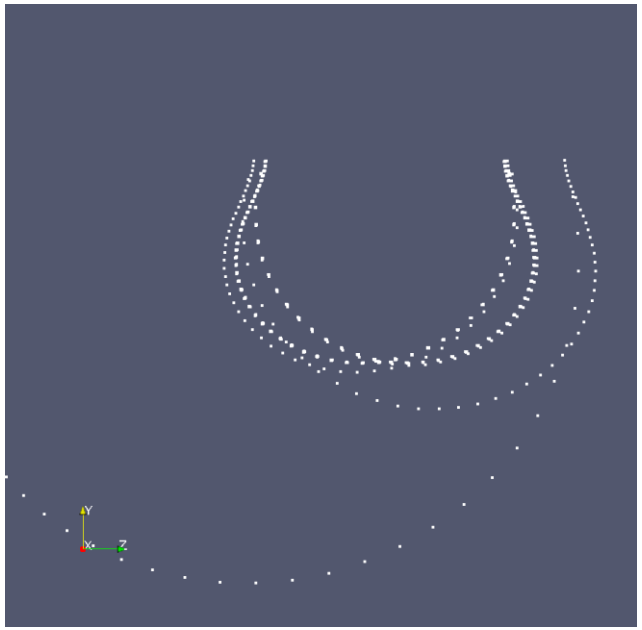
Particles Trajectory

Extract one single particle's trajectory:

Trajectory -o 7470 -PID 7470 -particlesFileName ./job20MV/PARTICLES/0/partpath_ts*.ncdf

Paraview to visulize particles trajectory





Example Two: Coax waveguide

Features: 1. Field calculated by s3p
2. Combined modes
3. Input port power as field scale

Example files location: cw10/track3p/coax/

Mesh and Field

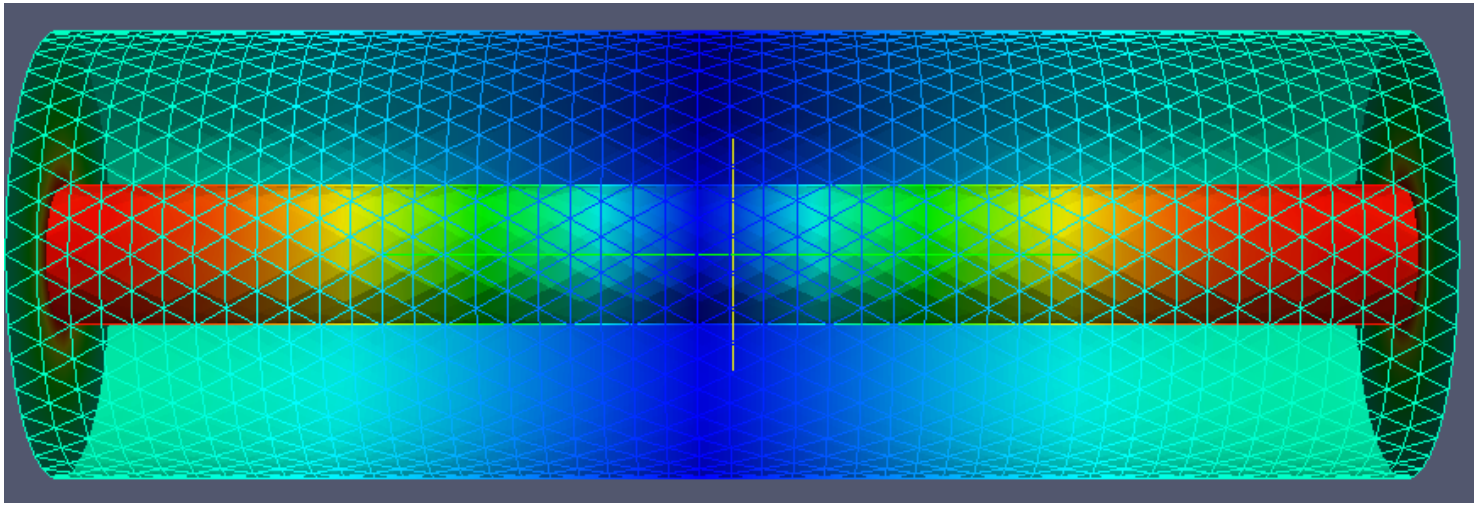
1. Generate geometry model and mesh:

Journal files: mesh.jou
Output file: mesh.gen
Mesh conversion: acdtool mesh convert cubitq netcdf mesh.gen mesh.ncdf
Mesh check: acdtool mesh stats mesh.ncdf
acdtool mesh check mesh.ncdf

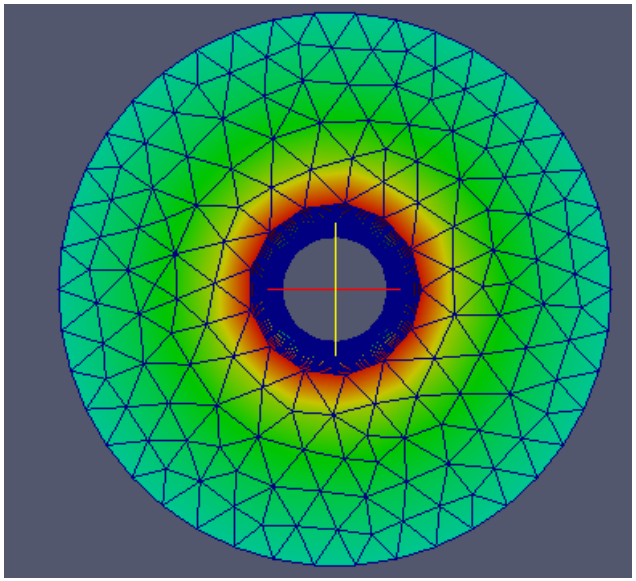
2. Calculate EM Field (S3P):

Input file: s3p.in
Command line: s3p pillbox.o3p
Output files:
mode.m0.1.300000E+09
mode.m1.1.300000E+09
Eigen mode directory: SAVE

Geometry model, mesh & Field



Total lengenth: 120mm
Outer radius: 20mm
Inner radius:6.25mm



Run Track3P on single mode

1. **Files needed for running Track3P:**
   Mesh file: mesh.ncdf
   EM field directory: SAVE
   Track3P input file: mode0.track3p

2. **Command line for running Track3P:**
   Scan: mpirun –np 1 Track3P mode0.track3p job0
   Single field particles' trajectory: mpirun –np 1 Track3P mode0-3.3MV.track3p job0-3.3

3. **Extract Single particles trajectory:**
   Trajectory –o {outputfile} –PID {ParticleID} –particlesFileName {particles file}

4. **Paraview to visualize and analyze results**

Track3P input file

Parameters need to modifiy

FieldScales:

```
{
Type: InputPortPower
Minimum: 25.0e+6
Maximum: 3.2e+6
}
```

Domain:

```
{
  PostprocessFile: ./SAVE/postprocess.in
}
```

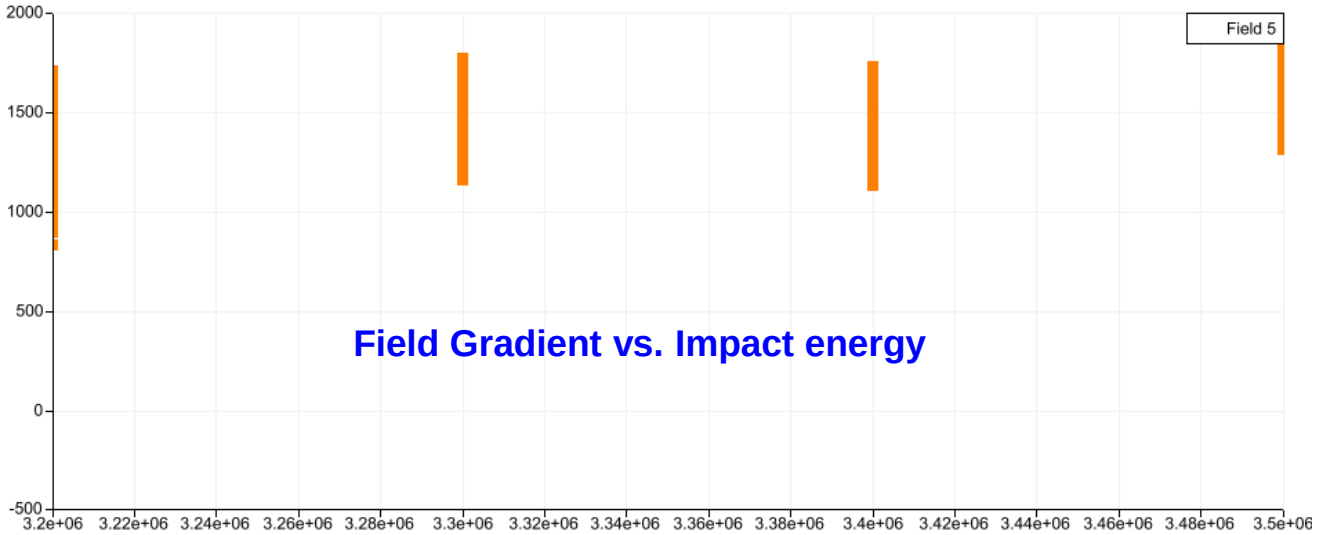
Emitter:

```
{
x1: 0.002
  y0: 0.0
  y1: 0.021
  z0: -0.01
  z1: 0.01
}
```

Material:

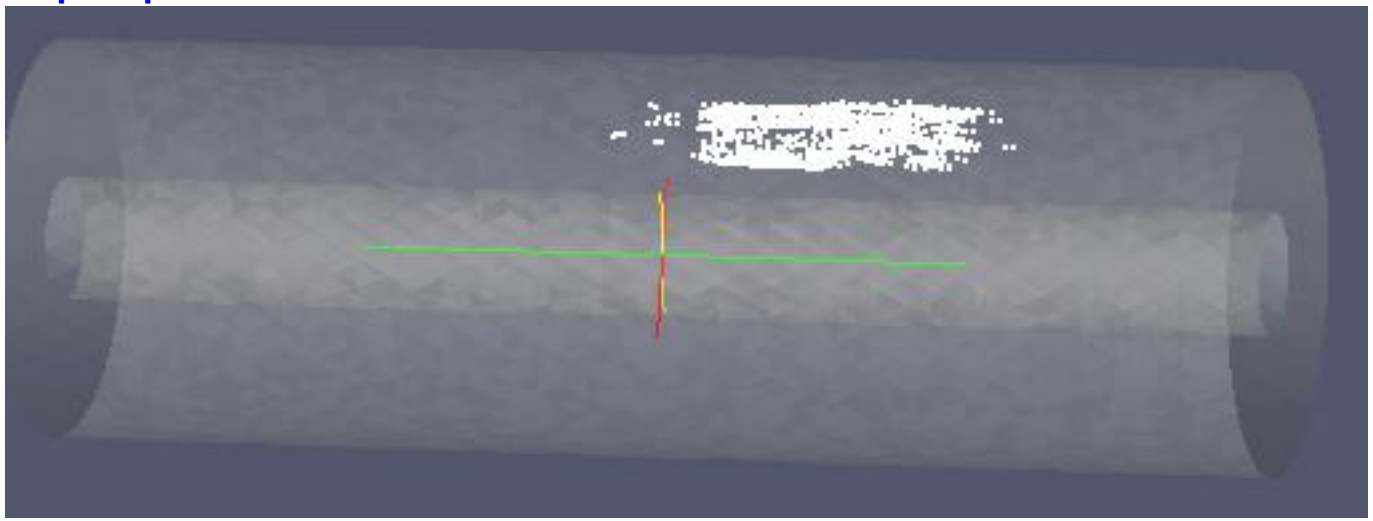
```
{
 Type: Absorber
  BoundarySurfaceID: 3 4
}
```

Visualize ./job/resonantparticles



Field Gradient vs. Impact energy

Impact positions for all the field levels



Particles Trajectory

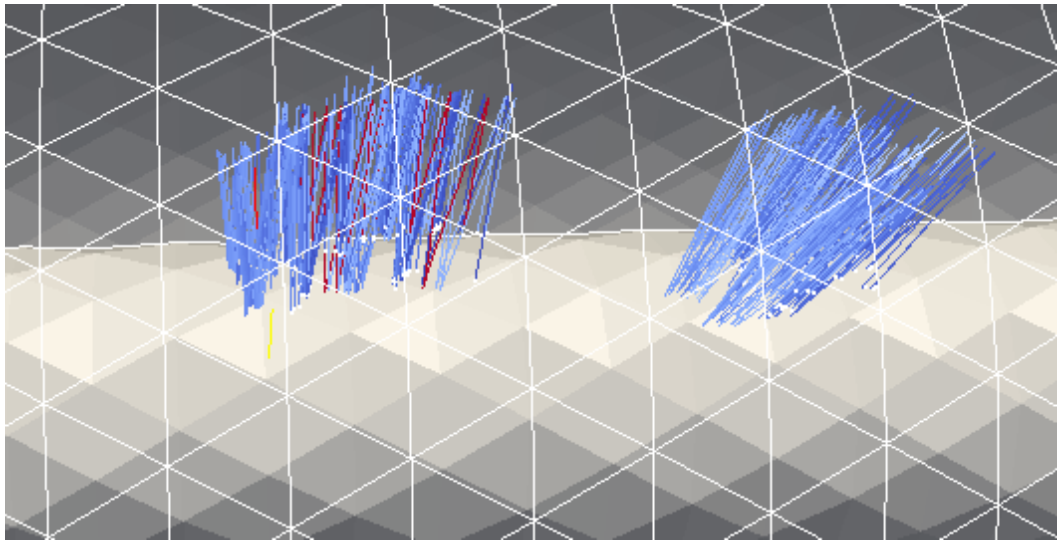
Run Single field (3.3 MV/m) to get particles trjectory

Command: Mpirun –np 1 ./Track3P mode0-3.3MV.track3p job0-3.3

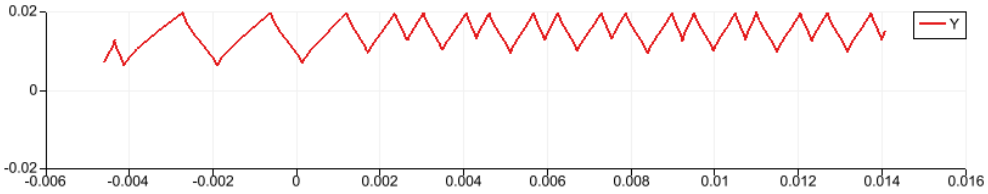
Input File:

```
ParticlesTrajectories:
{
 ParticleFile: p
 Skip: 10
 Start: 10
 Stop: 100000
}

FieldScales:
{
Type: InputPortPower
ScanToken: 0 // 1: scan, 0: no scan
Scale: 3.3e+6
}
```



Single particle's trajectory



SLAC NATIONAL ACCELERATOR LABORATORY

Run Track3P on combined modes

1. **Files needed for running Track3P:**
   - **Mesh file: mesh.ncdf**
   - **EM field directory: SAVE**
     - **Track3P input file: combine.track3p/combine-1MV.track**
2. **Command line for running Track3P:**
   - **mpirun –np 1 Track3P combine.track3p job0-1**
   - **mpirun –np 1 Track3P combine-1MV.track3p job0-1-1MV**
3. **Extract Single particles trajectory:**
   - **Trajectory –o {outputfile} –PID {ParticleID} –particlesFileName {particles file}**
4. **Paraview to visualize and analyze results**

Track3P input file

Parameters need to modifiy

FieldScales:

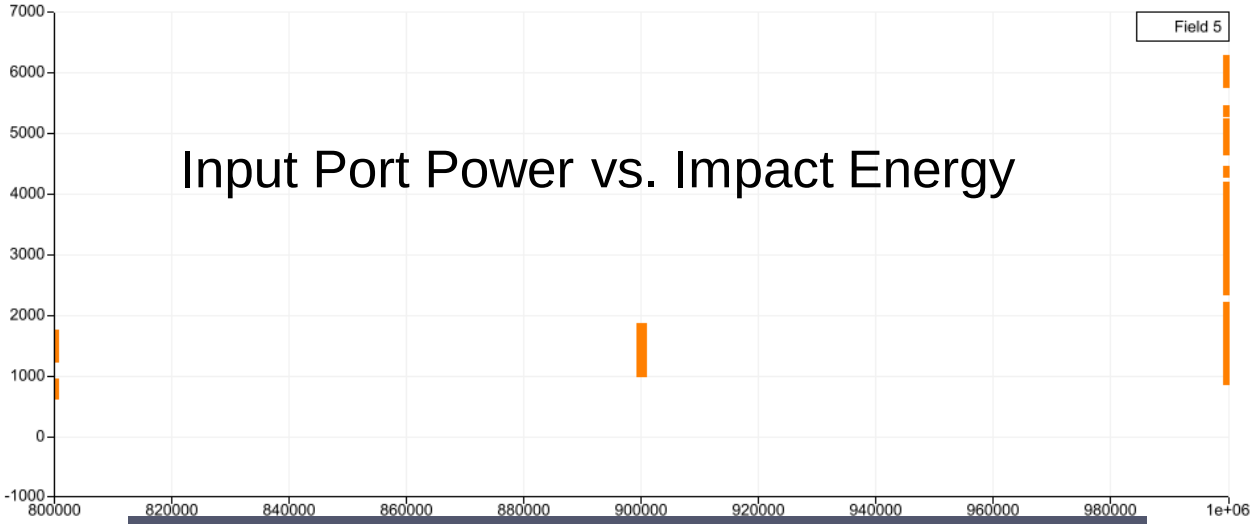
{
Minimum: 0.80e+6
Maximum: 1.0e+6
}

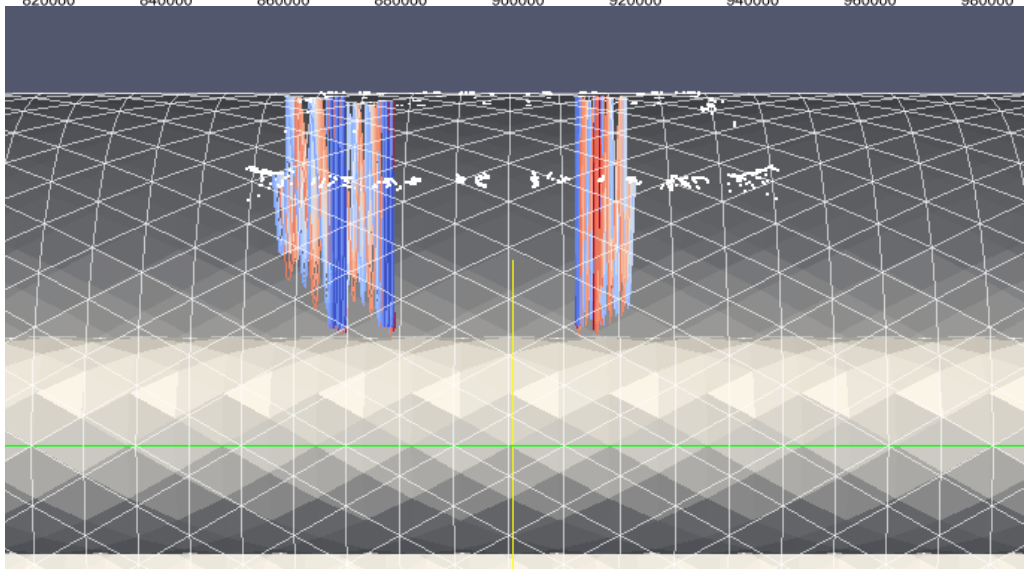
Domain:

{
ModeID1: 0
ModeID2: 1
CombineRatio: 1.0 0.0

}

Visulization





Particles trajectory at 1MW input port power

Exercise on coax waveguide

1. Geometry: One small slice of coax waveguide
2. Modes: Different ratio to combine the mode

Example Three: coupler with window

Example files location: cw10/track3p/coupler-window

Mesh and Field

1. Generate geometry model:

Journal files: make-window.jou
Output files: win.sat

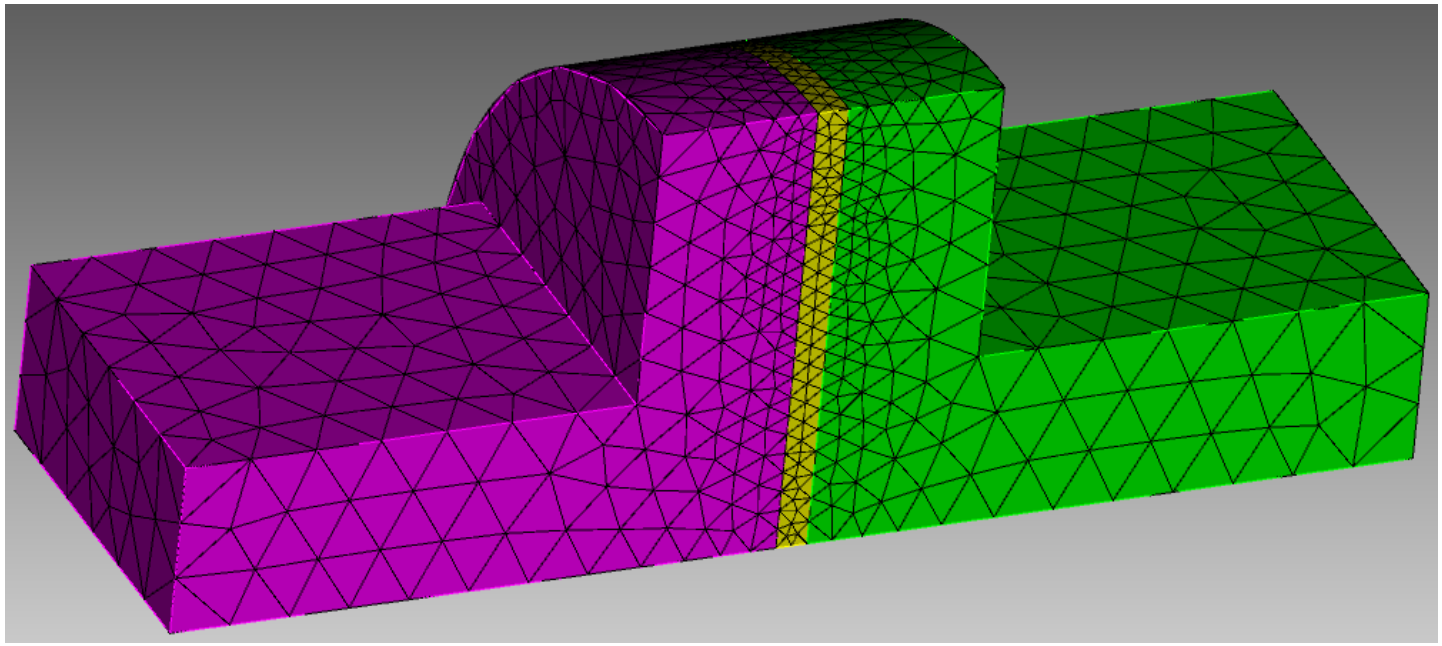
2. Generate mesh:

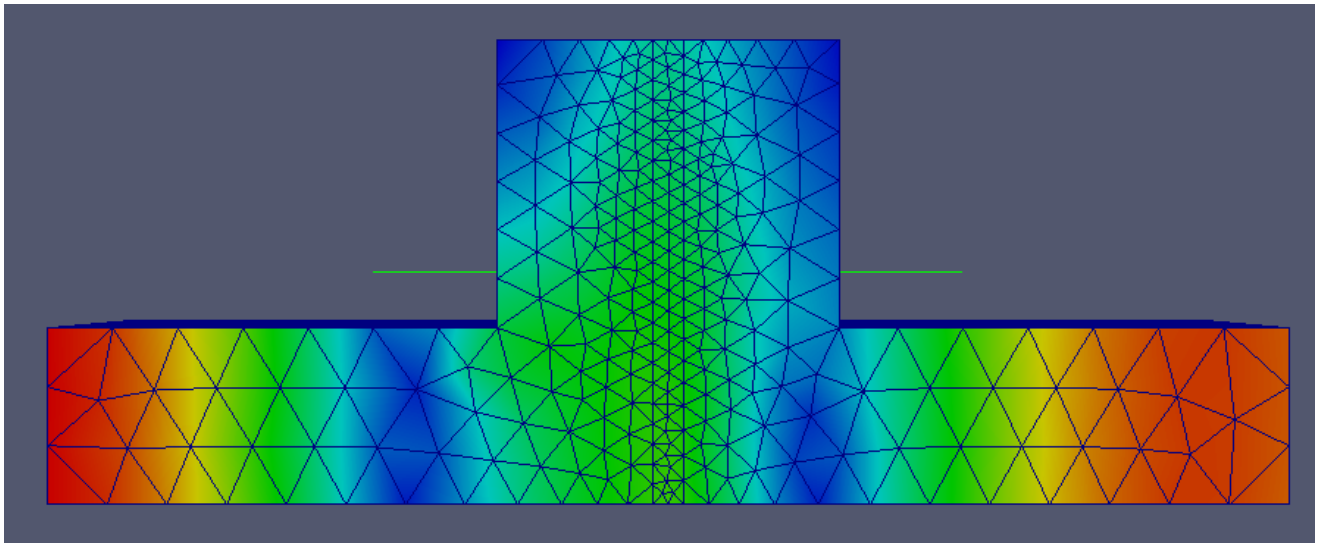
Journal files: mesh-window.jou
Output file: win.gen
Mesh conversion: acdtool mesh convert cubitq netcdf win.gen win.ncdf
Mesh check: acdtool mesh stats win.ncdf
acdtool mesh check win.ncdf

3. Calculate EM Field (S3P):

Input file: s3p.in
Command line: s3p s3p.in
Output files:
Eigen mode directory: vector1

Model, Mesh & Field





Run Track3P

1. **Files needed for running Track3P:**
   Mesh file: win.ncdf
   EM field directory: vector1
   Track3P input file: track3p.window
2. **Command line for running Track3P:**
   mpirun –np 1 Track3P track3p.window job

3. **Paraview to visualize and analyze results**

Track3P input file

Domain:

```
{
  SolidRegion: 2
  VacuumRegion: 1
}
```

Two types Emitter:

Emitter:

```
{
  Type: 5
   x0: 0.0
  x1: 0.04
  y0: 0.0
  y1: 0.04
  z0:  -0.002
  z1:  0.0
  BoundaryID: 6
}
 Emitter:
 {
    x0: 0.0
   x1: 0.04
   y0: 0.0
   y1: 0.04
   z0: -0.06
   z1: 0.002
  BoundaryID: 6
 }
```

Material:{

  Type: Primary
  SolidBlockID: 2

}

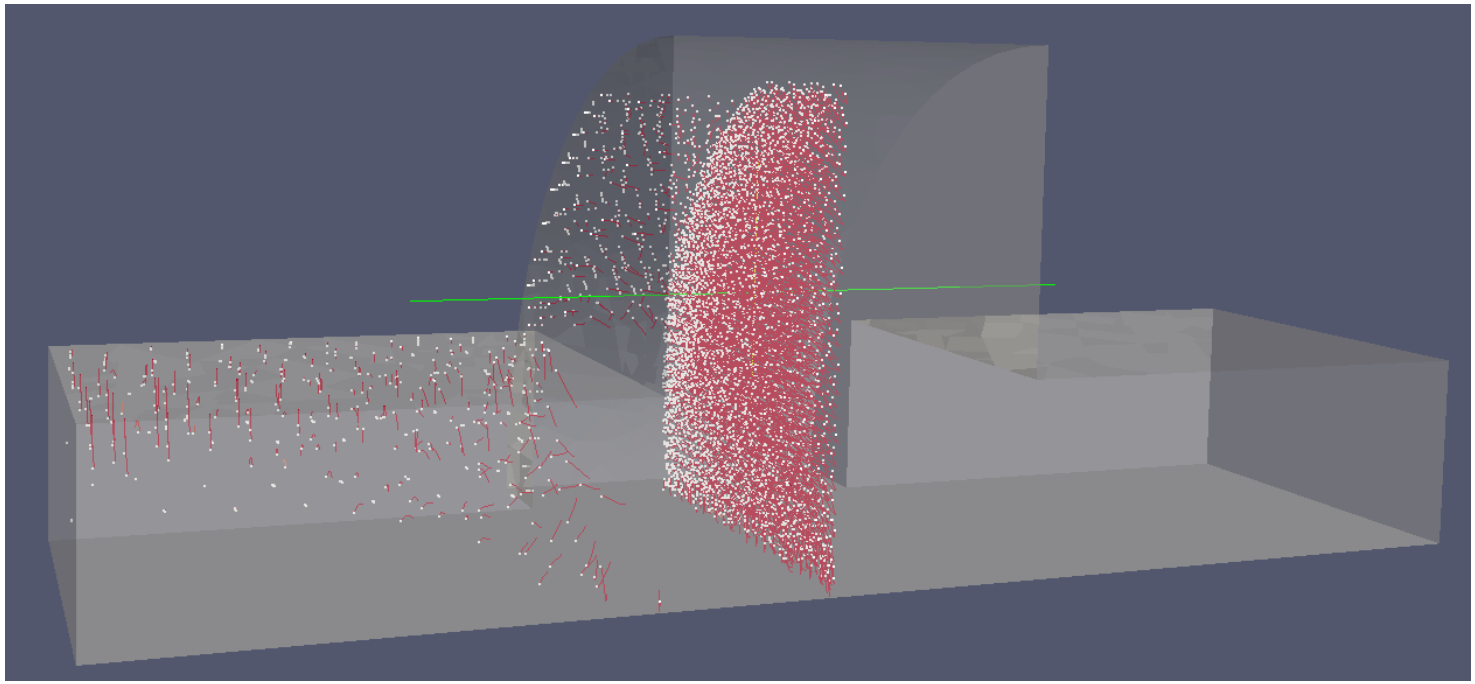
Material:{

  Type: Secondary
  SolidBlockID: 1

}

Visualization

Particles are emitted at all the surface on the left side of window



Exercise on coupler with window

1. Initial particles distribution: particles can be emitted at different regions
2. Field level scan: modify scan field levels