T3P Examples - Overview

- Example 1: Taper
  - Short-range wakefield and loss factor
  - Moving window technique
- Example 2: Cavity with coupling waveguide
  - Trapped modes and damping
- Example 3: Beam position monitor (BPM)
  - Loss factor, trapped modes and signal sensitivity
- Example 4: Cavity with absorber

Example 1: Taper

Tutorial 1 – Short-Range Wakefield

Tutorial 2 – Moving Window Technique

Taper – Mesh Generation

- Journal file for Cubit: taper.jou
- Run cubit to generate the mesh genesis file: taper.gen
- Convert genesis format to netcdf format

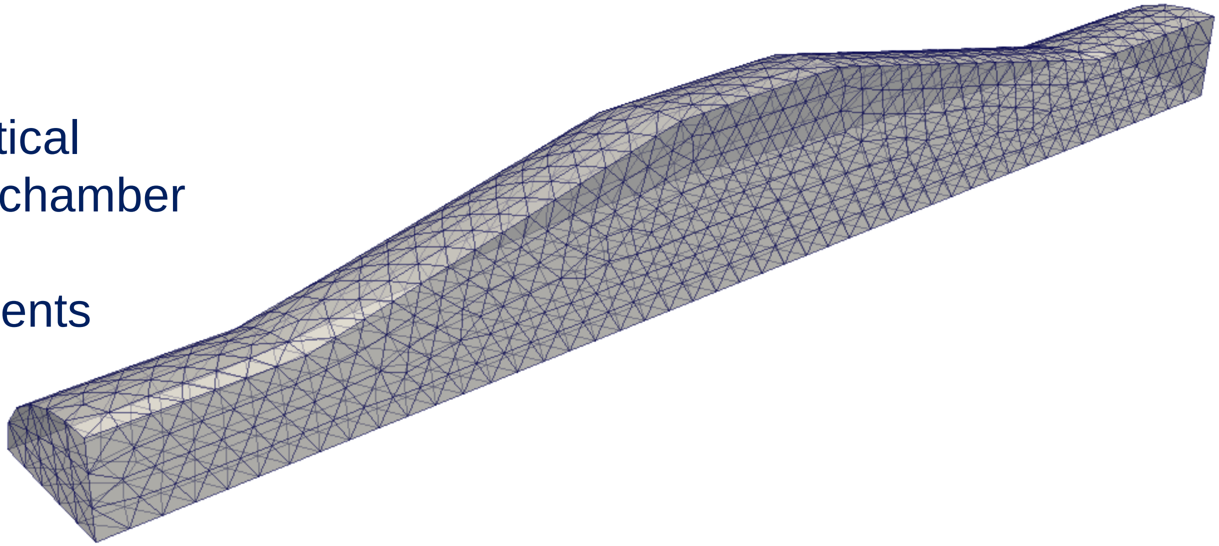
  acdtool meshconvert cubitq netcdf taper.gen taper.ncdf

- Check the mesh

  acdtool mesh check taper.ncdf
  acdtool mesh stats taper.ncdf

Mesh of ¼ taper model

•Tapers connecting elliptical beampipes and circular chamber
•Element size =7.5 mm
•Mesh size = 8888 elements



Beam Excitation in T3P

- Gaussian bunch represented by

$$\lambda(s) = \frac{1}{\sigma\sqrt{2\pi}} \exp[-\frac{(s-s_0)^2}{2\sigma^2}]$$

- Frequency spectrum of Gaussian bunch

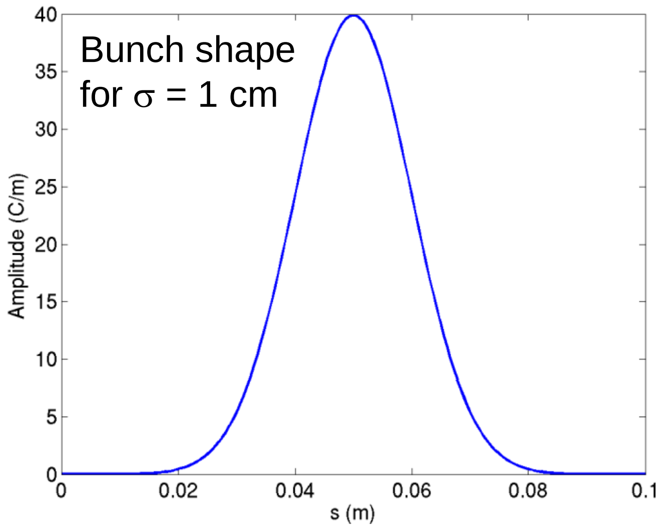
$$F(\omega) \sim \exp[-\frac{1}{2}(\frac{\omega}{c})^2\sigma^2]$$

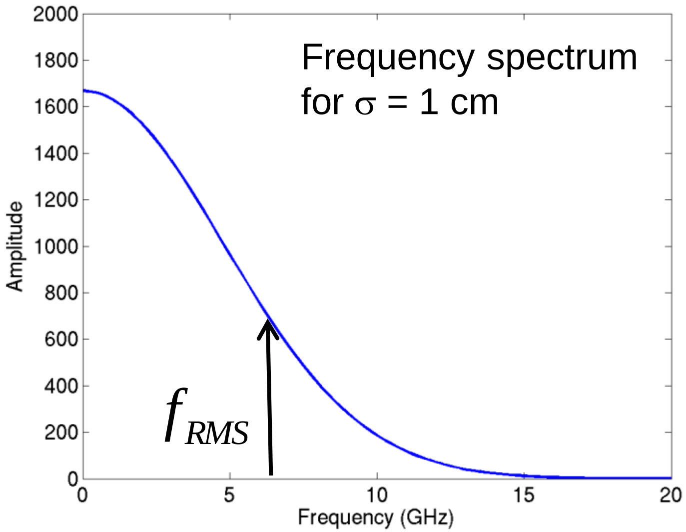
- RMS frequency

$$f_{RMS} = \frac{c}{\sqrt{2\pi}\sigma} = 6.75 \text{ GHz} / [\sigma/\text{cm}]$$

- Time step should be small enough to resolve frequency

$$\Delta t \le 1/(75 f_{RMS}) = 2 \text{ ps} \times [\sigma/\text{cm}]$$





Taper - T3P Input

```
ModelInfo:
{
  File:  ./taper.ncdf
  BoundaryCondition:
  {
    Exterior: 5
    Absorbing: 1 2
    Magnetic: 3 4
  }
}

FiniteElement:
{
  Order: 2
  CurvedSurfaces: on
}
```

```
LoadingInfo:
{
  Bunch:
  {
    Type: Gaussian
     Sigma: 0.01
     Number of sigmas: 5
     Charge: 1.e-12
   }
   SymmetryFactor: 4 //matches bc
   StartPoint: 0.0, 0.0, -0.175
   Direction: 0.0, 0.0, 1.0
   BoundaryID: 1
}

TimeStepping:
{
   MaximumTime: 1.6e-9
   DT: 2e-12
}
```

Taper – T3P Input (Cont'd)

```
Monitor:
{
  Type: FieldNodeVolume
  Name: mymon
  TimeStart: 0e-9
  TimeEnd: 1.6e-9
  TimeStep: 3.2e-11
}

Monitor:
{
   Type: WakeField
   Name: wakefield
   StartContour: -0.175
   EndContour:  0.175
   Smax: 0.45
}

LinearSolver:
{
  Solver: MUMPS
  //  Solver: CG
  //  Preconditioner: CHOLESKY
  // QuietMode: 1
  //  Tolerance: 1e-12
}
```

Taper – T3P Run & Wakefield

- Input file for T3P: taper.t3p
- Run T3P

  t3p taper.t3p

- Postprocess t3p output to obtain longitudinal wakefield

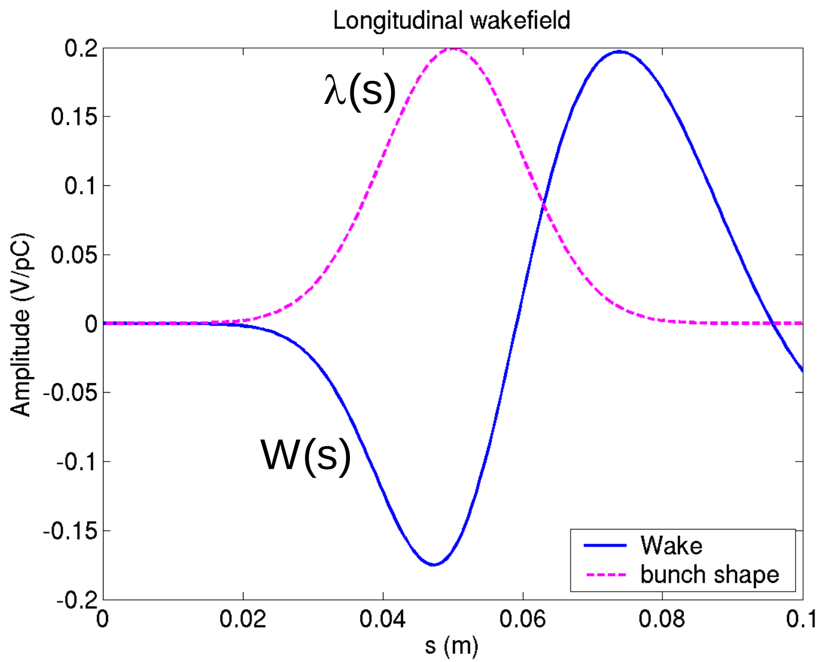
  cd OUPTUT
  acdtool postprocess wake_new wakefield.bnd wakefield.z.all.dat 0. 0.

  – Wakefield data in output file wakes_new.out, in which 1st and 2nd columns are s [m] and W [V/pC], respectively

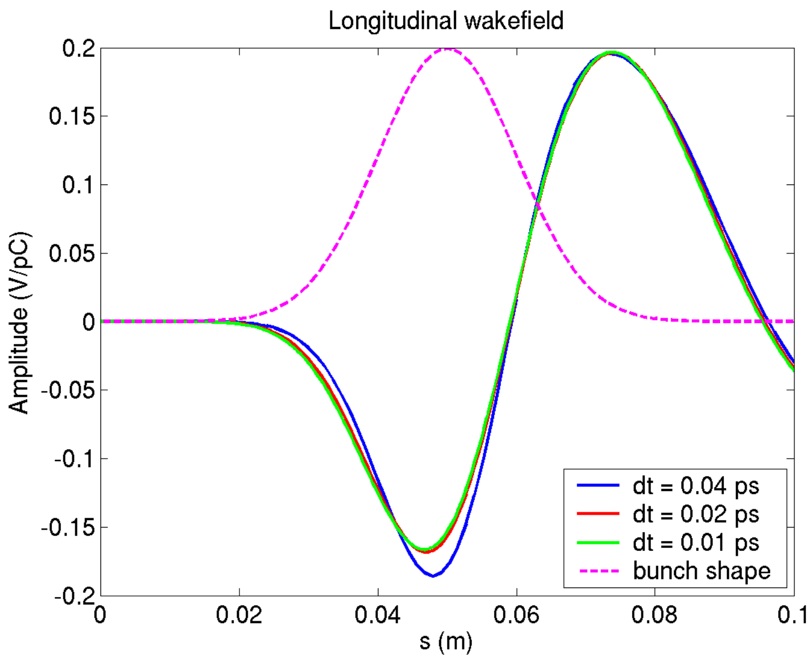
- Plot the wakefield and calculate the loss factor

$$k = \int W(s)\lambda(s)ds$$

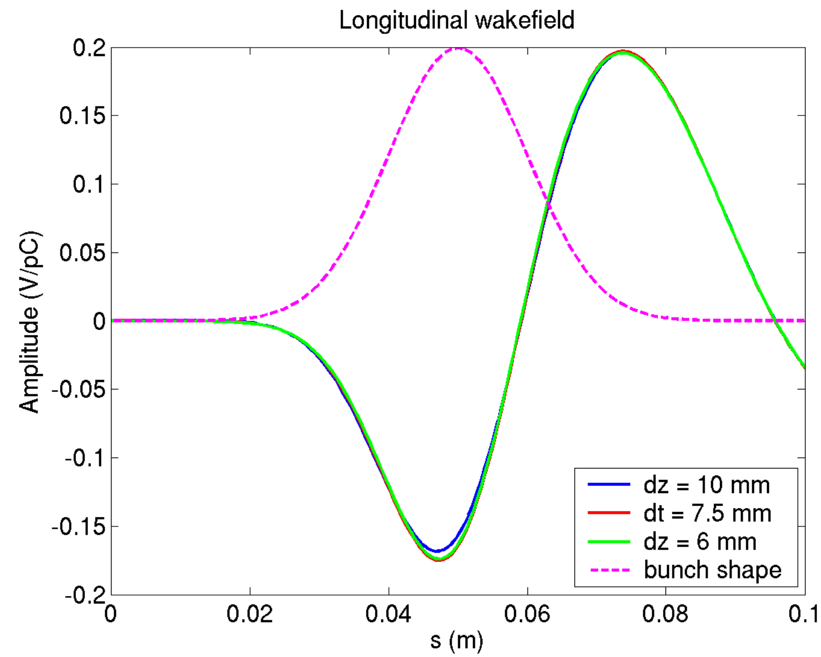
$= 0.081$ V/pC



Taper – Convergence of Calculation



Time step convergence



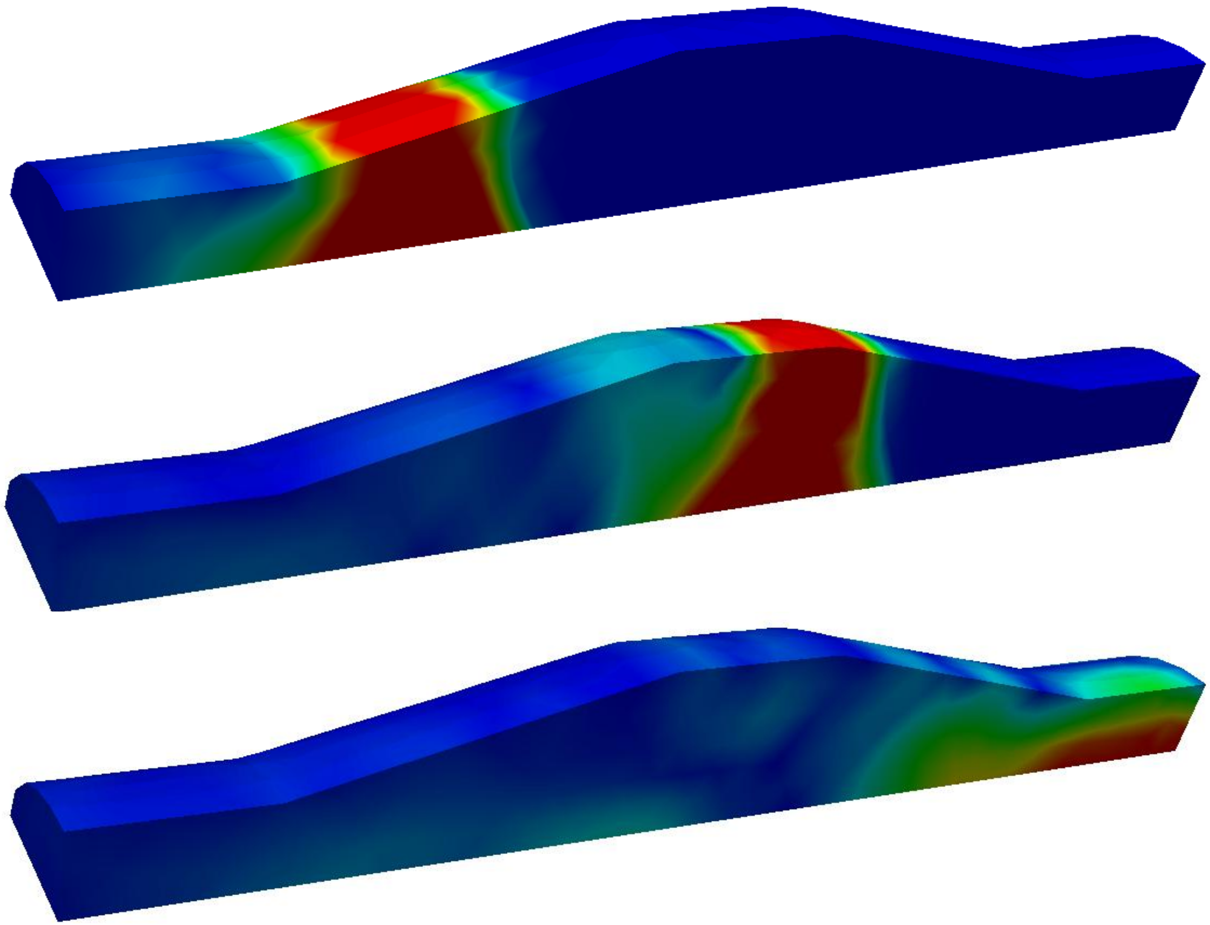
Mesh convergence

Taper - Field Visualization

- Postprocess data for ParaView

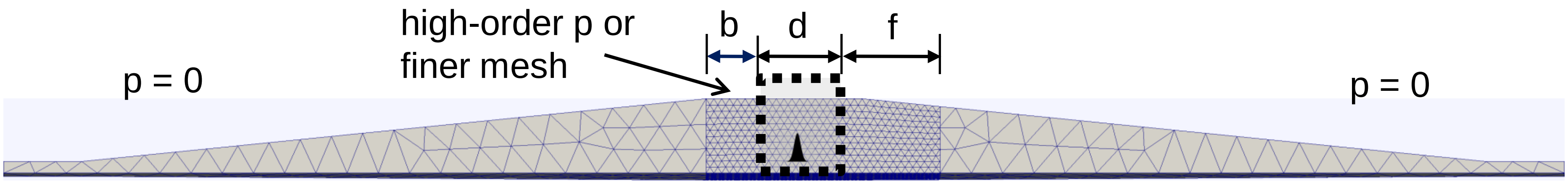
  acdtool postprocess volmontomode taper.t3p

  – Create mymonts_t*fs.out.mod in OUTPUT directory



Field snapshots of beam transit

Taper – Moving Window Technique

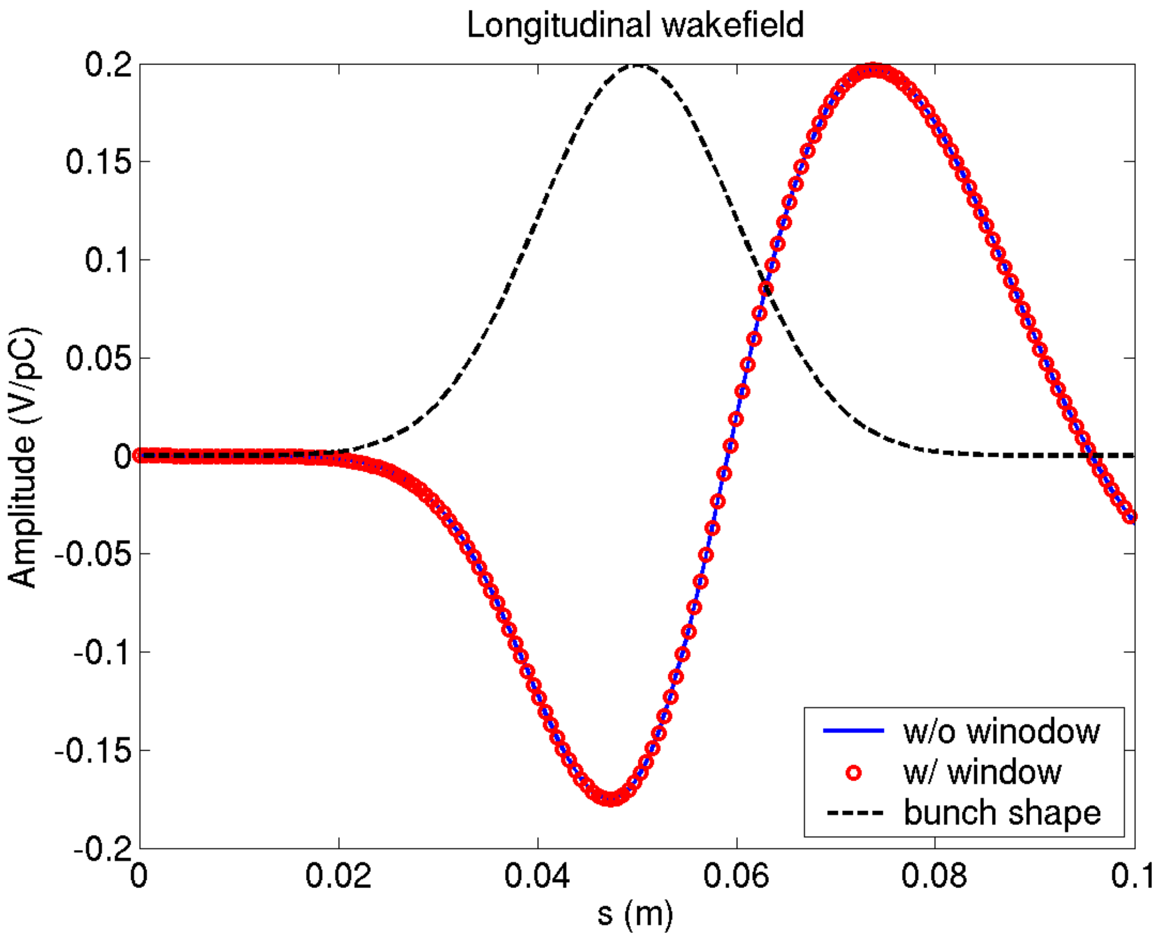


- Changes in T3P input file

```
FiniteElement:
{
  Order: 0                          // set to 0 outside  window
  CurvedSurfaces: on
}

PRegion:
{
  Type: AutomaticMovingWindow
  Order: 2                          // set to 2 inside window
  Back:  0.005
  Front: 0.1
  StructureEnd: 0.175
}
```

Taper – Wakefield w/ & w/o Moving Window



- w/o moving window, runtime 211 s
- w/ moving window (a total of 4 windows), runtime 132 s

Example 2: Cavity w/ Coupling Waveguide

Tutorial 1 – Wakefield w/ Closed Waveguide

Tutorial 2 – Wakefield w/ Open Waveguide

Cavity + Wavdguide – Mesh Generation

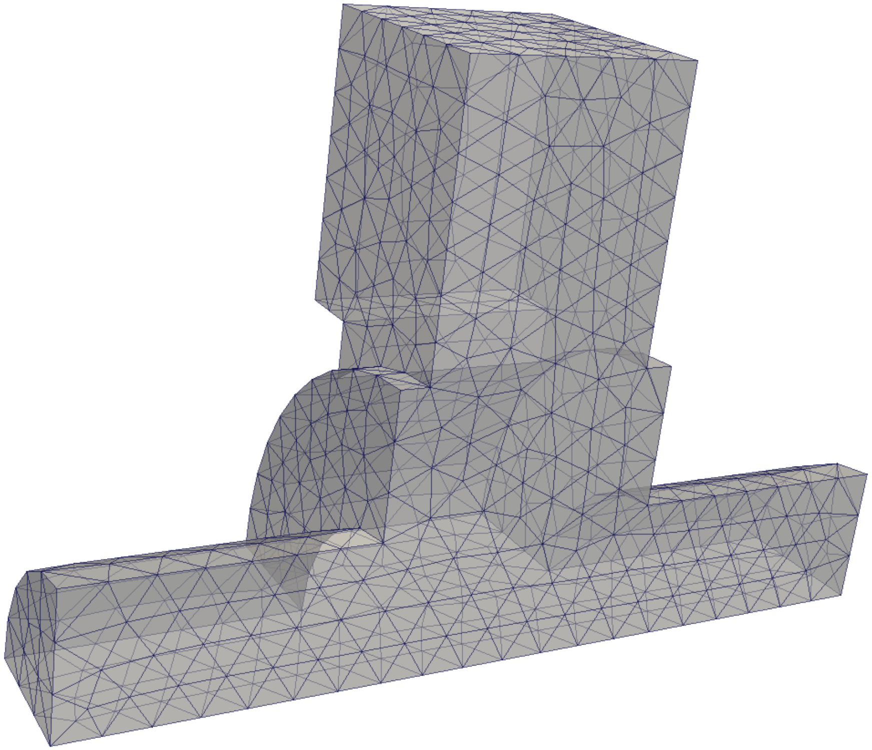
- Journal file for Cubit: pillboxwg.jou
- Run cubit to generate the mesh genesis file: pillboxwg.gen
- Convert genesis format to netcdf format

  acdtool meshconvert cubitq netcdf pillboxwg.gen pillboxwg.ncdf
- Check the mesh

  acdtool mesh check pillboxwg.ncdf
  acdtool mesh stats pillboxwg.ncdf

Mesh of ¼ model

•Pillbox cavity connected to rectangular waveguide through iris
•Element size =7.5 mm
•Mesh size = 5052 elements



Cavity + Waveguide (Closed) – T3P Input

```
ModelInfo:
{
  File:  ./pillboxwg.ncdf
  BoundaryCondition:
  {
    Exterior: 6 5
    Absorbing: 3 4
    Magnetic: 1 2
  }
}

FiniteElement:
{
  Order: 1
  CurvedSurfaces: on
}
```

```
LoadingInfo:
{
  Bunch:
  {
    Type: Gaussian
     Sigma: 0.01
     Number of sigmas: 5
     Charge: 1.e-12
   }
   SymmetryFactor: 4 //matches bc
   StartPoint: 0.0, 0.0, -0.075
   Direction: 0.0, 0.0, 1.0
   BoundaryID: 3
}

TimeStepping:
{
   MaximumTime: 5.e-9
   DT: 2e-12
}
```

Cavity + Waveguide (Open) – T3P Input (Cont'd)

```
Monitor:
{
  Type: FieldNodeVolume
  Name: mymon
  TimeStart: 0e-9
  TimeEnd: 5.e-9
  TimeStep: 1.e-10
}

Monitor:
{
   Type: WakeField
   Name: wakefield
   StartContour: -0.075
   EndContour:  0.075
   Smax: 1.4
}
```

```
LinearSolver:
{
  Solver: MUMPS
}
```

Cavity + Waveguide (Closed) – T3P Run & Wakefield

- Input file for T3P: pillboxwg-closed.t3p (in directory “closed”)
- Run T3P

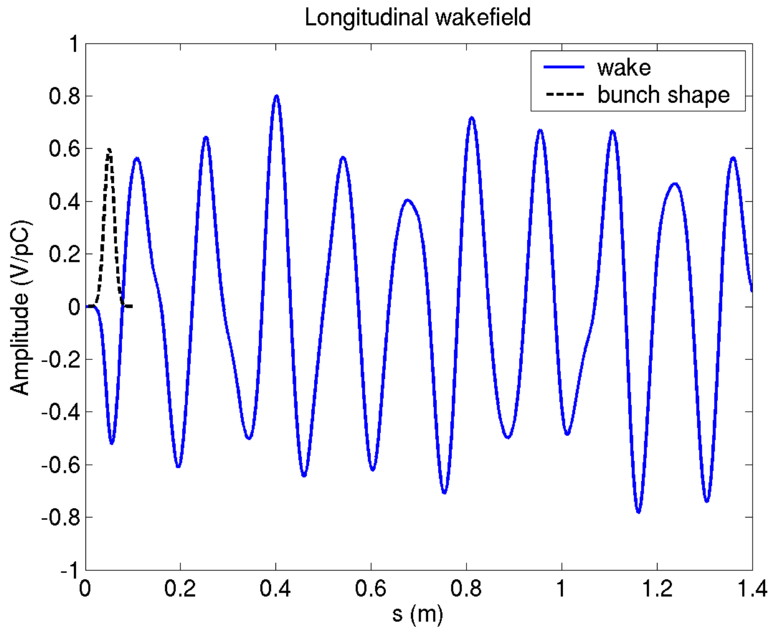
  t3p pillboxwg-closed.t3p

- Postprocess t3p output to obtain longitudinal wakefield

  cd OUPTUT
  acdtool postprocess wake_new wakefield.bnd wakefield.z.all.dat 0. 0.

  – Wakefield data in output file wakes_new.out, in which 1st and 2nd columns are s [m] and W [V/pC], respectively

- Plot the wakefield



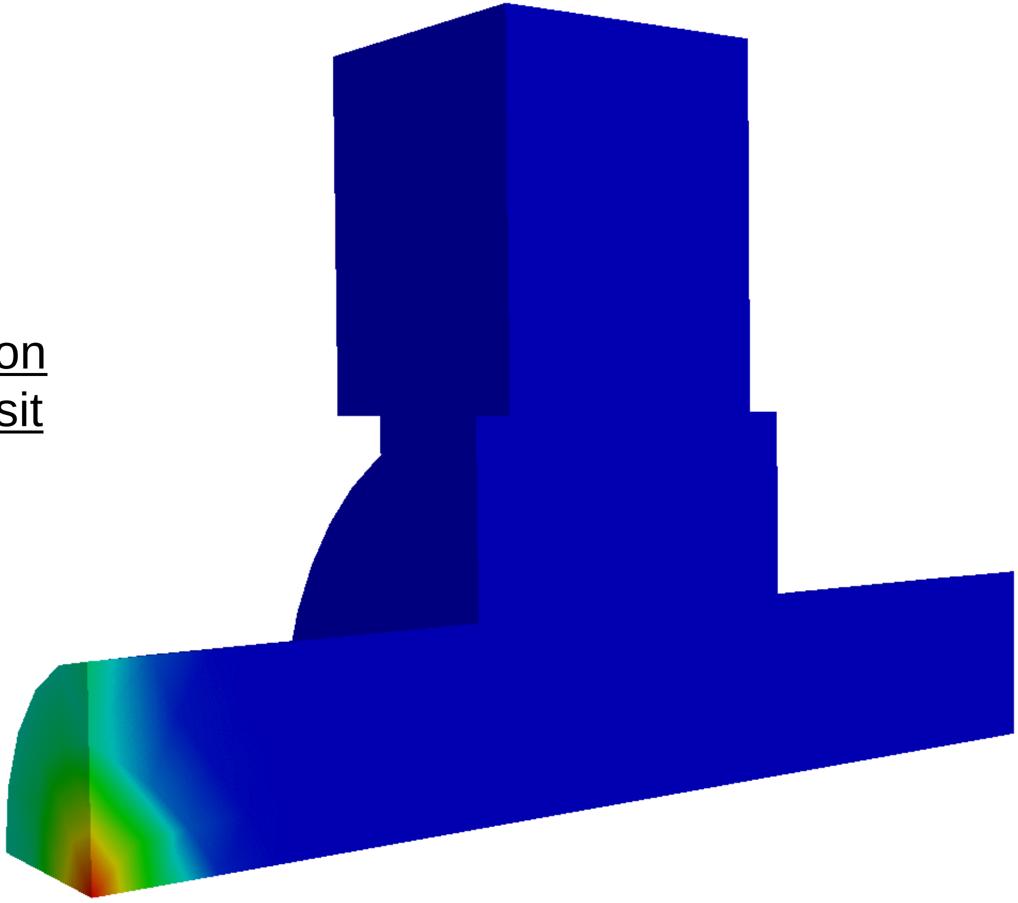
Cavity + Waveguide (Closed) - Field Visualization

- Postprocess data for ParaView

  acdtool postprocess volmontomode pillboxwg-closed.t3p

  – Create mymonts_t*fs.out.mod in OUTPUT directory

Field animation of beam transit



Cavity + waveguide (Open) –T3P Input

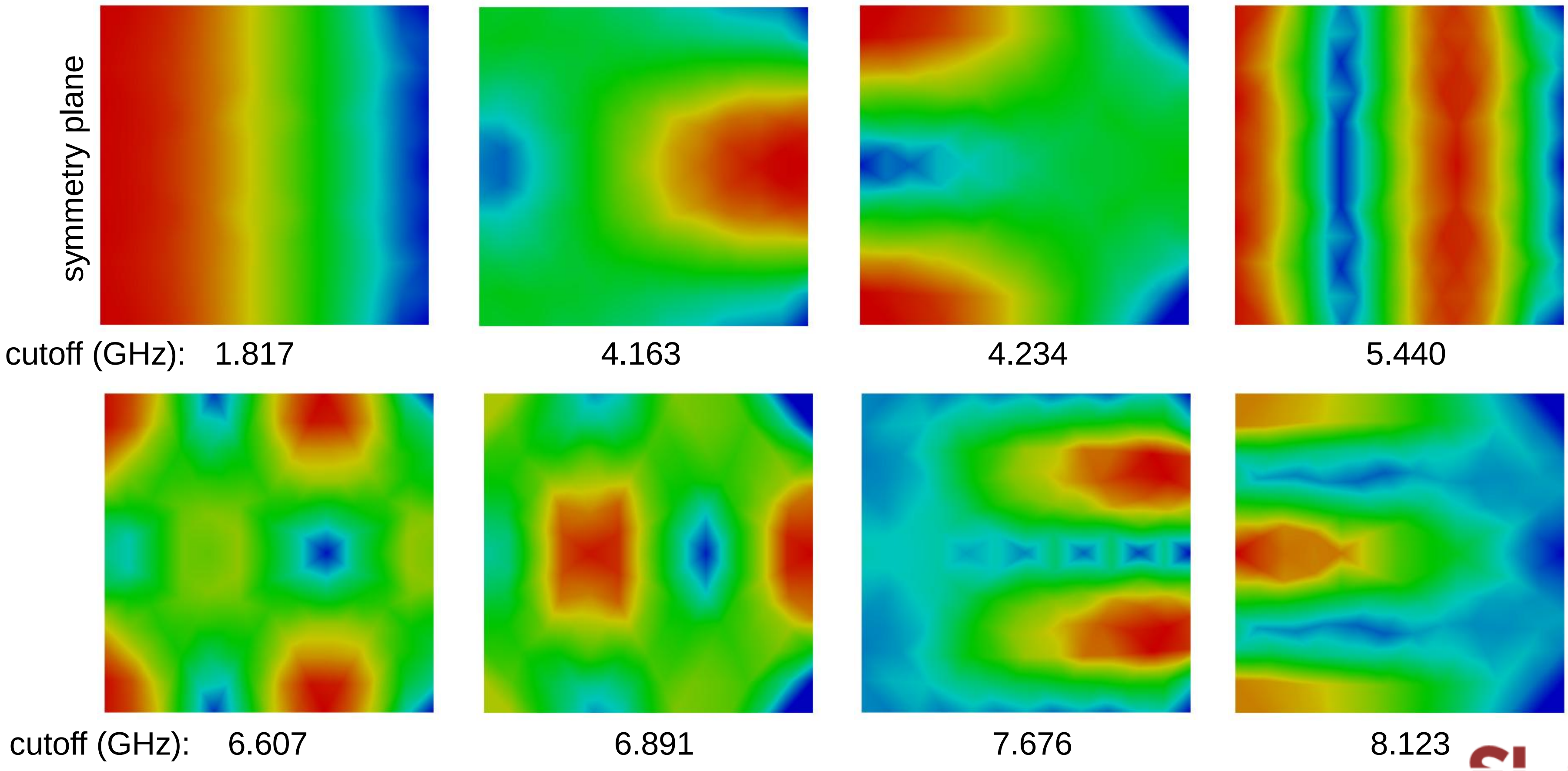
- Changes in T3P input file

```
ModelInfo:
{
  File:  ./pillboxwg.ncdf
  BoundaryCondition:
  {
   Exterior: 6
   Waveguide: 5                        // Boundary ID 5 was set to Exterior in "closed" case
   Absorbing: 3 4
   Magnetic: 1 2
  }
}
```

Cavity + Waveguide (Open) – Port Modes

- Use ParaView to visualize the waveguide modes at the waveguide port
- The mode files are *.vtu in OUTPUT/wpbc_port_5

Waveguide modes at waveguide port



Cavity + Waveguide (Open) – T3P Run & Wakefield

- Input file for T3P: pillboxwg-open.t3p (in directory "open")
- Run T3P

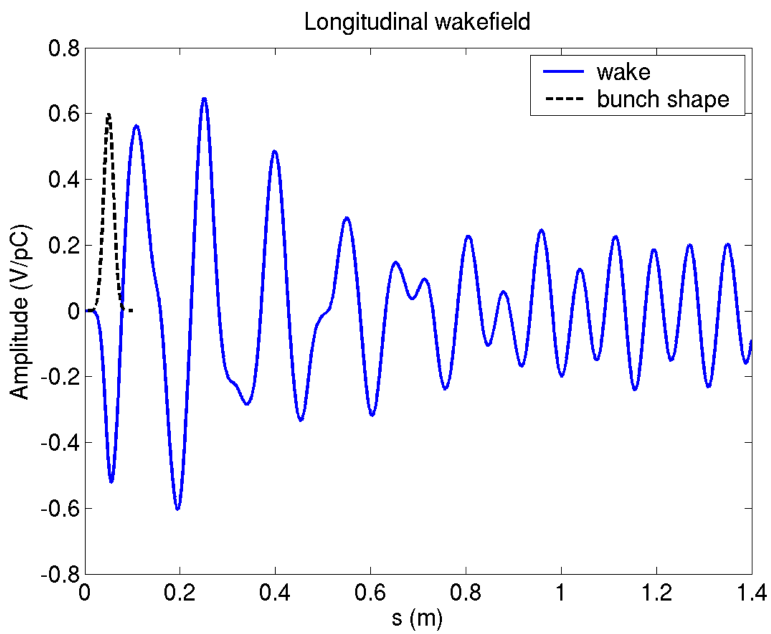
  t3p pillboxwg-open.t3p

- Postprocess t3p output to obtain longitudinal wakefield

  cd OUPTUT
  acdtool postprocess wake_new wakefield.bnd wakefield.z.all.dat 0. 0.

  – Wakefield data in output file wakes_new.out, in which 1st and 2nd columns are s [m] and W [V/pC], respectively

- Plot the wakefield



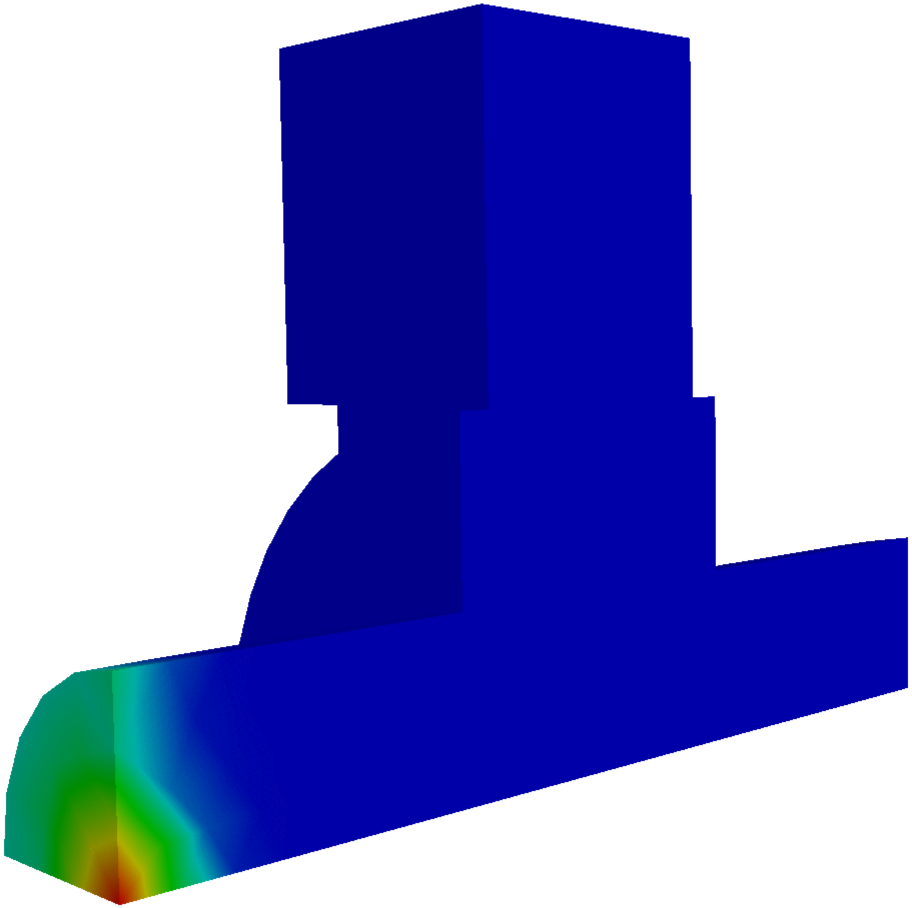
Cavity + Waveguide (Open) - Field Visualization

- Postprocess data for ParaView

  acdtool postprocess volmontomode pillboxwg-open.t3p

  – Create mymonts_t*fs.out.mod in OUTPUT directory

Field animation of beam transit



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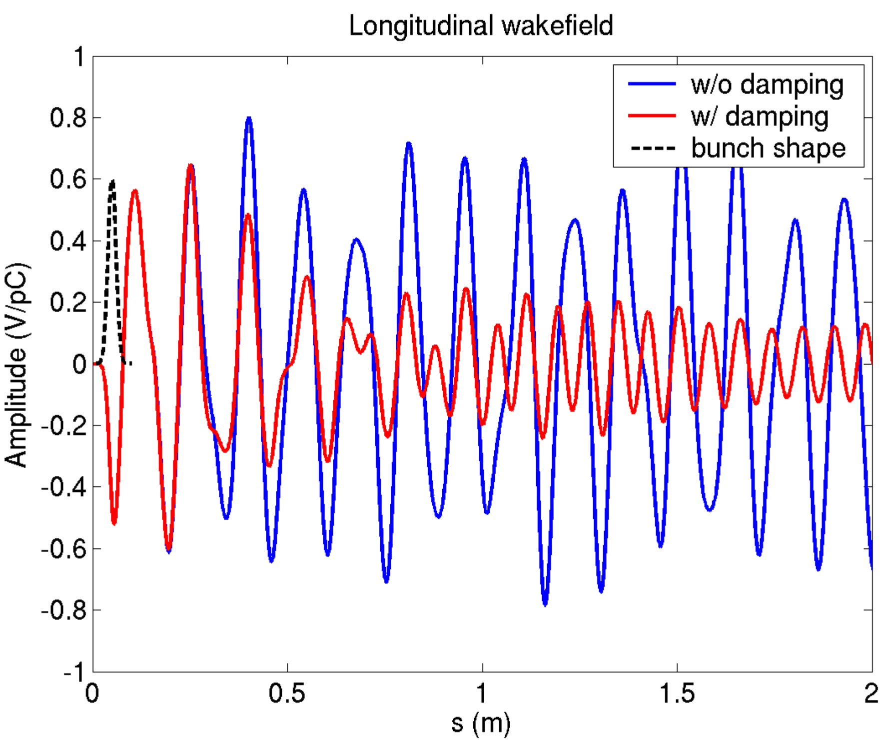
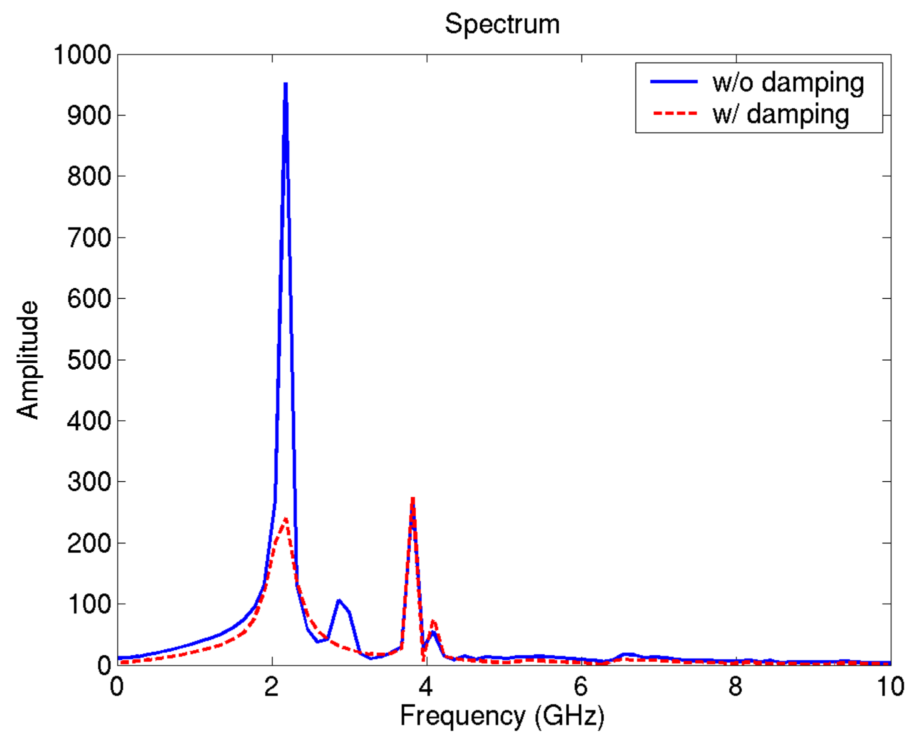
Cavity + Waveguide - Comparision

Comparison of runs with closed and open waveguides



Longitudinal wakefield

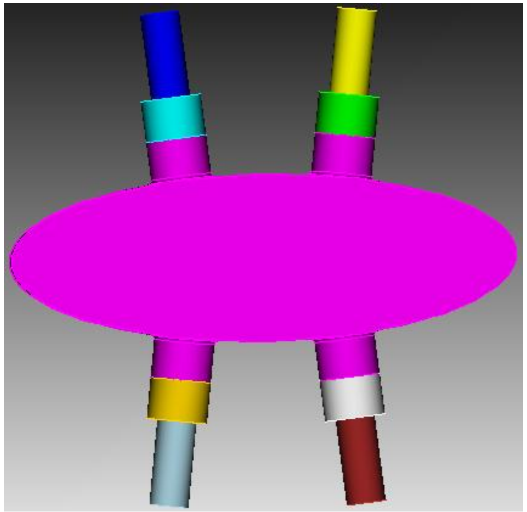


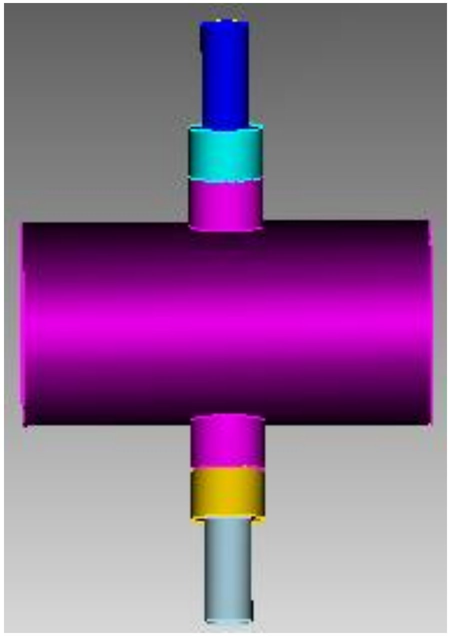
Mode Spectrum

Example 3 – Beam Position Monitor

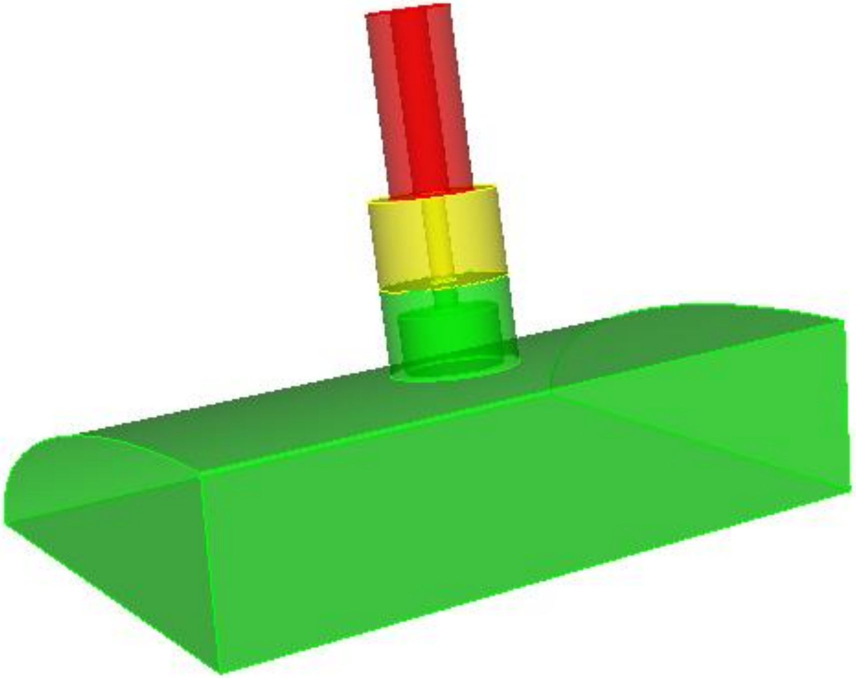
Wakefield, Trapped Modes & Signal Sensitivity

BPM Model





Cubit: make-pepx-bpm.jou



Coax cable: Z=50ohm, εr=1

Ceramic window: Z=50ohm, εr=4.9

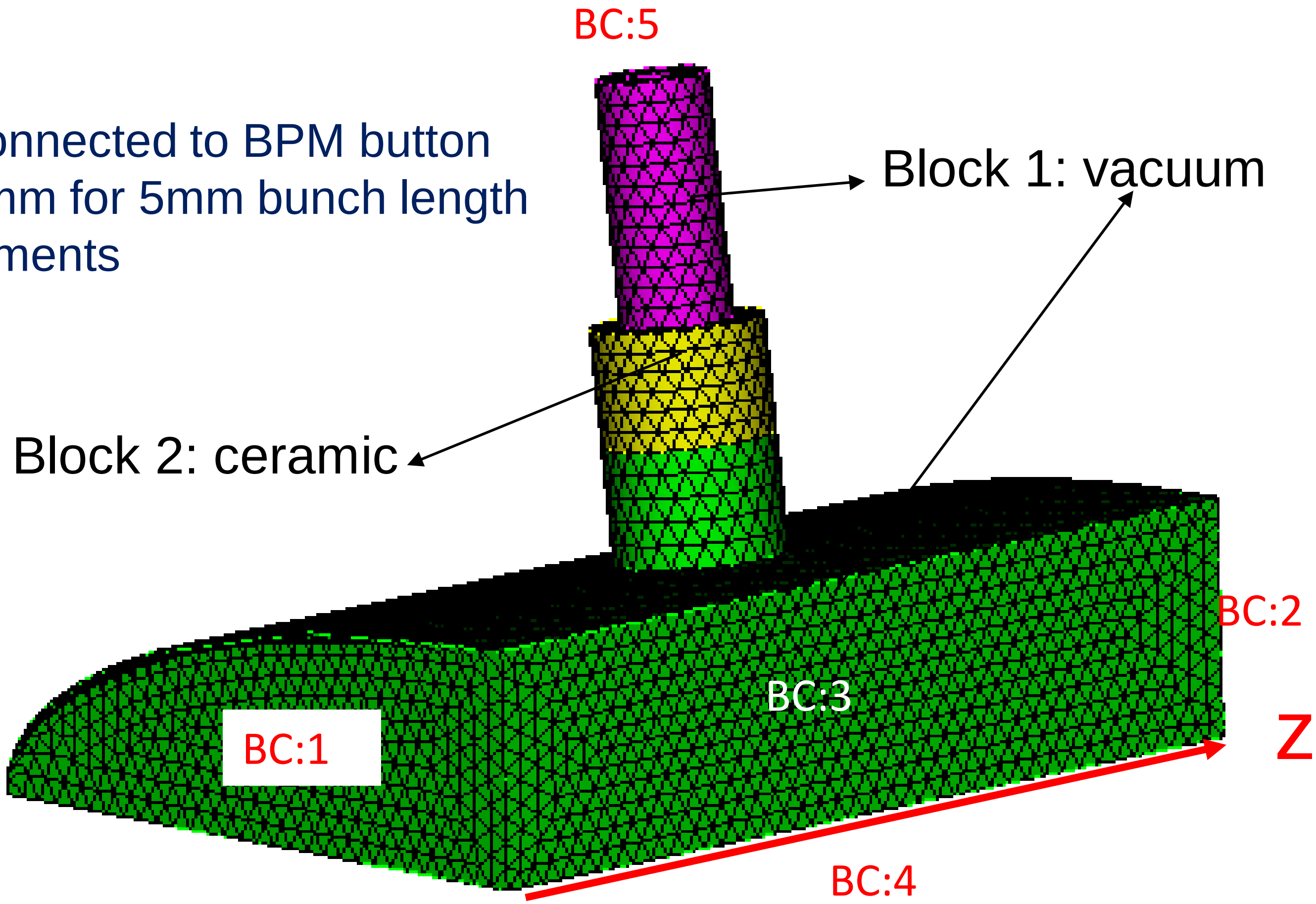
BPM button: diameter=7mm

BPM – Mesh

Cubit: mesh-pepx-bpm.jou

Mesh of ¼ model

•Elliptical chamber connected to BPM button
•Element size = 2.5 mm for 5mm bunch length
•Mesh size = 11k elements



BPM- Mesh (Cont'd)

acdtool

- Convert genesis format to netcdf format
  acdtool meshconvert cubitq netcdf pepx-bpm.gen pepx-bpm.netcdf

- Check the mesh
  acdtool mesh stats pepx-bpm.netcdf
  acdtool mesh check pepx-bpm.netcdf
  (found invalid tetrahedral elements)

- Eliminate invalid tetrahedral elements by
  acdtool mesh fix pepx-bpm.netcdf pepx-bpm-fix.netcdf
  acdtool mesh check pepx-bpm-fix.netcdf
  (invalid tetrahedral elements free)

BPM - T3P Input File

Bpm.input

```
ModelInfo: {
 File: pepx-bpm-fix.netcdf
 BoundaryCondition:
 {
  Exterior: 6
  Absorbing: 1 2 5 //(without reflection)
  Magnetic: 3 4   //(for monopole only)
 }

 Material : {
  Attribute: 1  //(vacuum)
  Epsilon:   1.0
  Mu:        1.0
 }

 Material : {
  Attribute: 2  //(ceramic window)
  Epsilon:   4.9
  Mu:        1.0
 }
}
```

```
LoadingInfo: {
 Bunch:
 {
  Type: Gaussian
  Sigma: 0.005  //(bunch length)
  Nsigmas: 5
  Charge: 1.e-12
 }
  SymmetryFactor: 4
  StartPoint: 0.0 0.0 -0.025
  Direction: 0.0, 0.0, 1.0
  BoundaryID: 1
}

TimeStepping:
{
 MaximumTime: 0.4e-9   //short-range
 DT: 1.e-12
}
```

BPM - T3P Input File (Cont'd)

```
Monitor:
{
 Type: Point
 Name: point
 Coordinate:  0.01 0.01 0.
}

Monitor:
{
 Type: Volume
 Name: volume
 TimeStart: 0.000e-9
 TimeEnd:   1e-9
 TimeStep:  0.05e-9
}

Monitor:
{
 Type: Power
 ReferenceNumber: 5
 Name: port
 TimeStart: 0.000e-9
 TimeEnd:   5e-9
 TimeStep:  1e-12
}

Monitor:
{
 Type: WakeField
 Name: wake
 Start contour: -0.0051
 End contour:   0.0051
 Smax: 0.07   //(short-range)
}
```

BPM – T3P Run

- Run T3P: **t3p bpm.input**
- Postprocess t3p output to obtain longitudinal wakefield

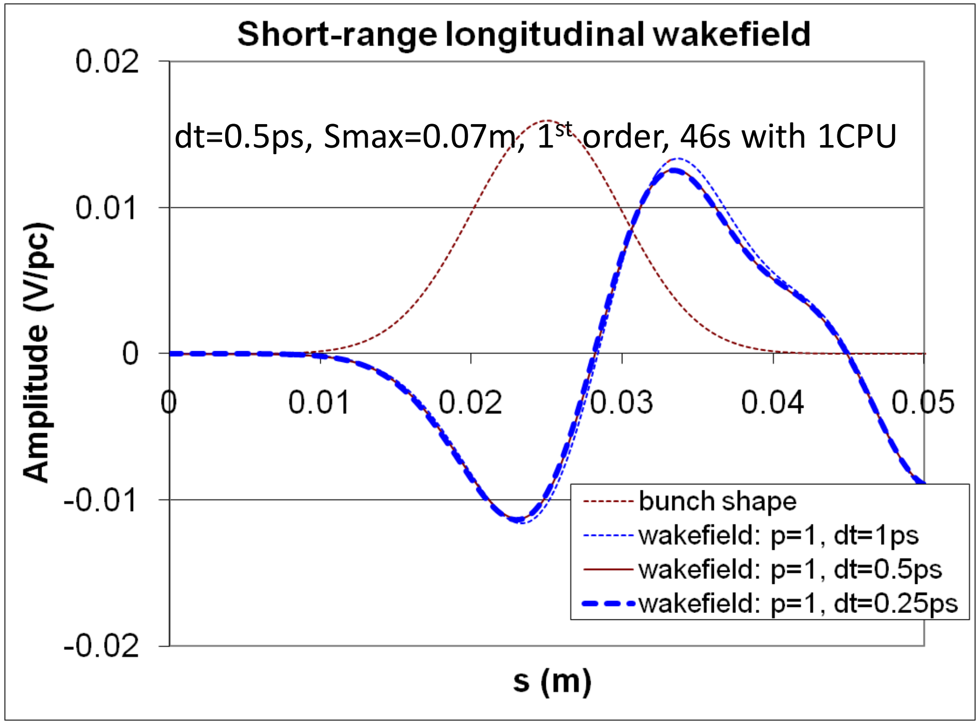
  cd OUPTUT

  acdtool postprocess wake_new wake.bnd wakefield.z.all.dat **0. 0**.

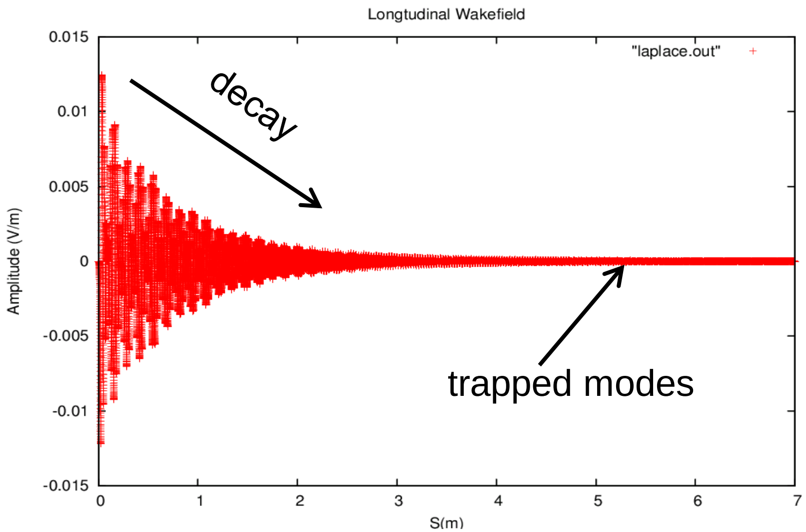
  – Wakefield data in output file ***wakes_new.out***,

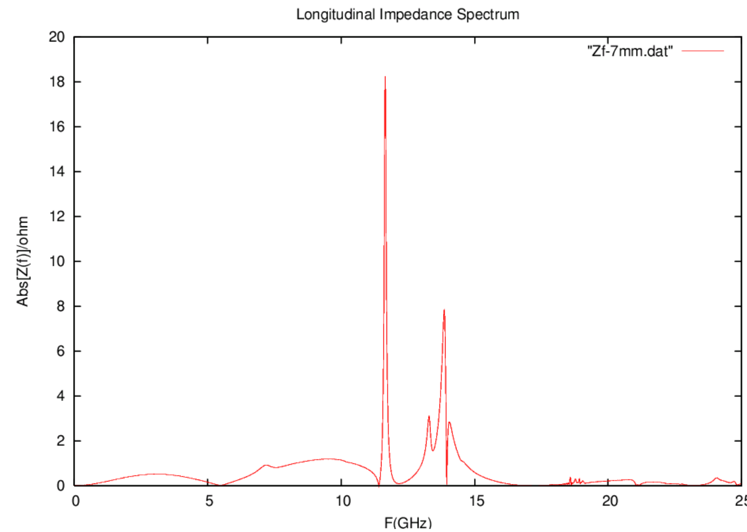
- Plot the wakefield

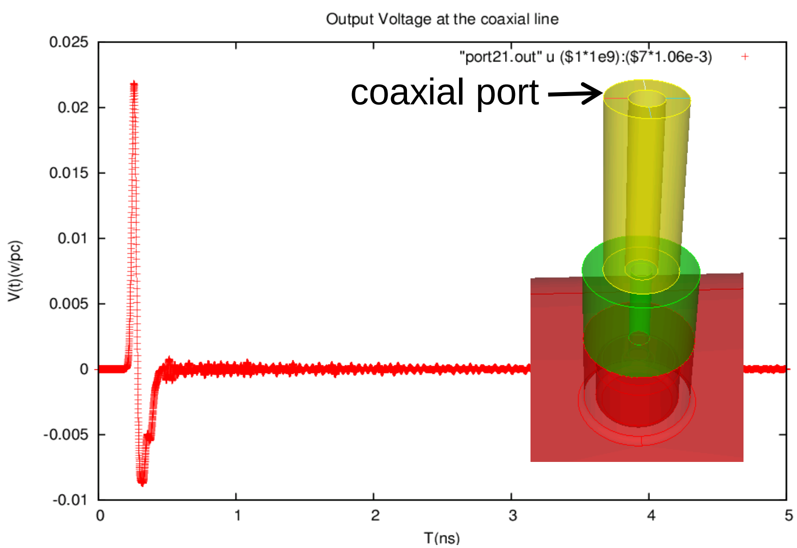
Loss factor = 0.0037 V/pC

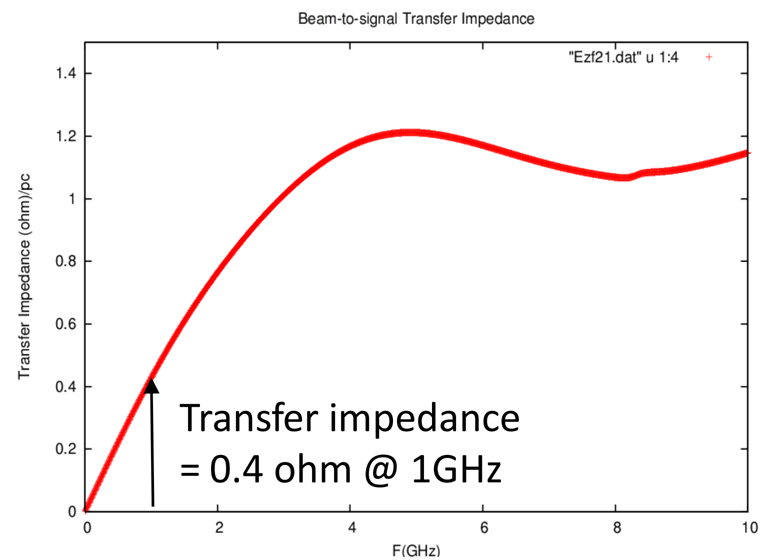


BPM Trapped Modes & Signal Sensitivity









Identification of trapped modes and determination of signal sensitivity from time signals and their Fourier transforms.

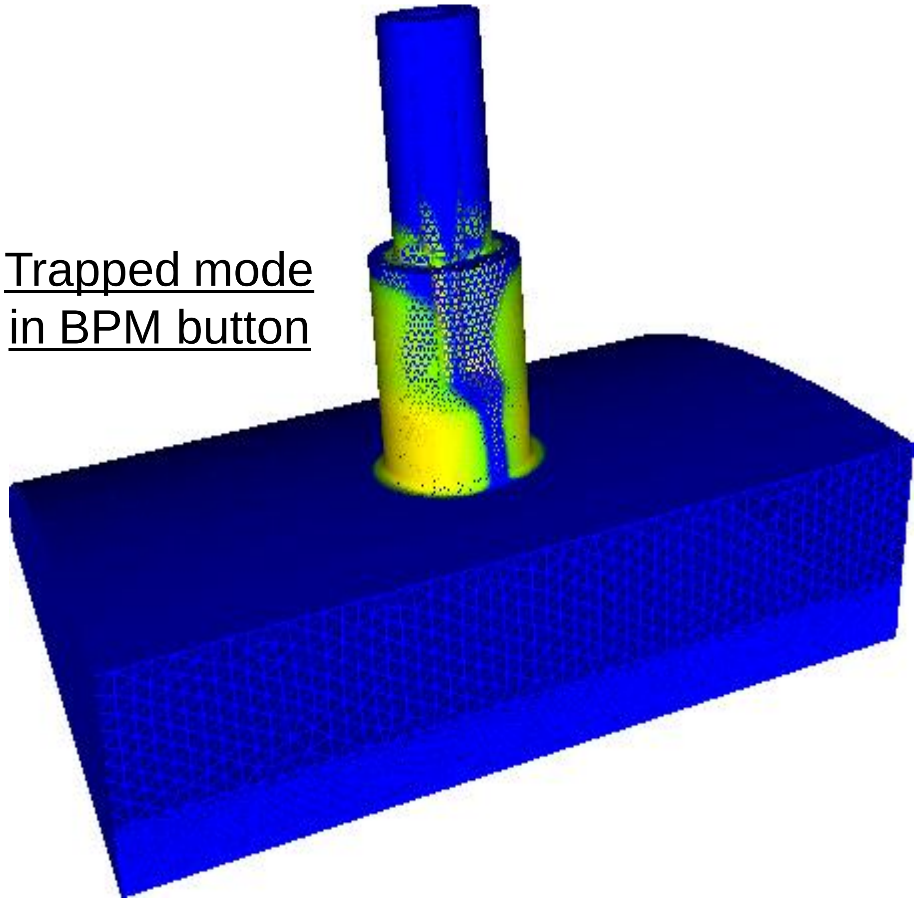
BPM - Field Visualization

- Postprocess data for ParaView

  acdtool postprocess volmontomode bpm.input

  – Create *fs.out.mod in OUTPUT directory

Trapped mode
in BPM button



BPM – T3P Run

0. In your working dir., make sure you have

   make-pepx-bpm.jou, mesh-pepx-bpm.jou, and bpm.input.

1. Run Cubit

   play **make-pepx-bpm.jou ->** pepx-bpm.sat

   play **mesh-pepx-bpm.jou ->** pepx-bpm.gen

2. Run acdtool

   acdtool meshconvert cubitq netcdf pepx-bpm.gen pepx-bpm.netcdf
   acdtool mesh stats pepx-bpm.netcdf
   acdtool mesh check pepx-bpm.netcdf
   acdtool mesh fix pepx-bpm.netcdf pepx-bpm-fix.netcdf
   acdtool mesh check pepx-bpm-fix.netcdf (optional)

BPM - T3P Run (Cont'd)

3. Run T3P:

   t3p bpm.input

4. Postprocess (cd OUTPUT)

   acdtool postprocess wake_new wake.bnd wakefield.z.all.dat 0. 0.

   ↓

   wakes_new.out

5. Run gnuplot

   Plot **wakes_new.out**

If you want to get the long-range wakefields, you need to increase the MaximumTime T & Smax in bpm.input file.

Example 4 – Cavity w/ Absorber

Wakefield Damping

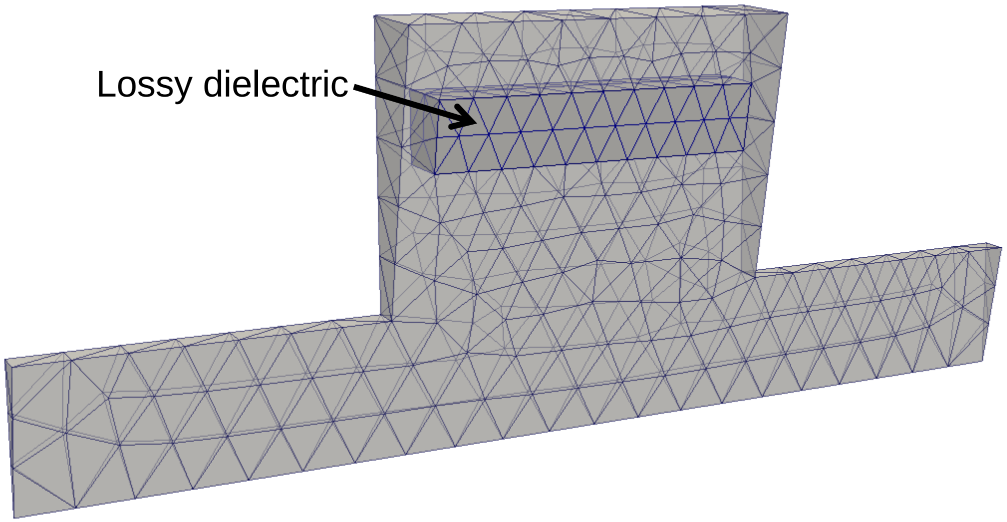
Lossy Cavity – Mesh Generation

- Journal file for Cubit: absorber.jou
- Run cubit to generate the mesh genesis file: absorber.gen
- Convert genesis format to netcdf format

  acdtool meshconvert cubitq netcdf absorber.gen absorber.ncdf

- Check the mesh

  acdtool mesh check absorber.ncdf
  acdtool mesh stats absorber.ncdf



Mesh of 10-degree model

•Lossy dielectric in pillbox cavity ris
•Element size 7.5 mm in vacuum, 5 mm in lossy dielectric
•Mesh size = 1632 elements

Cavity + Absorber – T3P Input

```
ModelInfo:
{
  File:  ./absorber.ncdf
  BoundaryCondition:
  {
   Exterior: 6
   Magnetic: 1, 2
   Absorbing: 3, 4
  }
  Material:
  {
   Attribute: 2
   Epsilon: 15.0
   Mu: 1.0
   Sigma: 0.667
   }
}

FiniteElement:
{
  Order: 2
  CurvedSurfaces: on
}
```

```
LoadingInfo:
{
  Bunch:
  {
    Type: Gaussian
     Sigma: 0.01
     Number of sigmas: 5
     Charge: 1.e-12
   }
   SymmetryFactor: 36 //matches bc
   StartPoint: 0.0, 0.0, -0.08
   Direction: 0.0, 0.0, 1.0
   BoundaryID: 3
}

TimeStepping:
{
   MaximumTime: 7.e-9
   DT: 2e-12
}
```

Cavity + Absorber – T3P Input (Cont'd)

```
Monitor:
{
  Type: FieldNodeVolume
  Name: mymon
  TimeStart: 0e-9
  TimeEnd: 8e-9
  TimeStep: 1.3e-10
}

Monitor:
{
   Type: WakeField
   Name: wakefield
   StartContour: -0.08
   EndContour:  0.08
   Smax: 2.0
}

LinearSolver:
{
  Solver: MUMPS
}
```

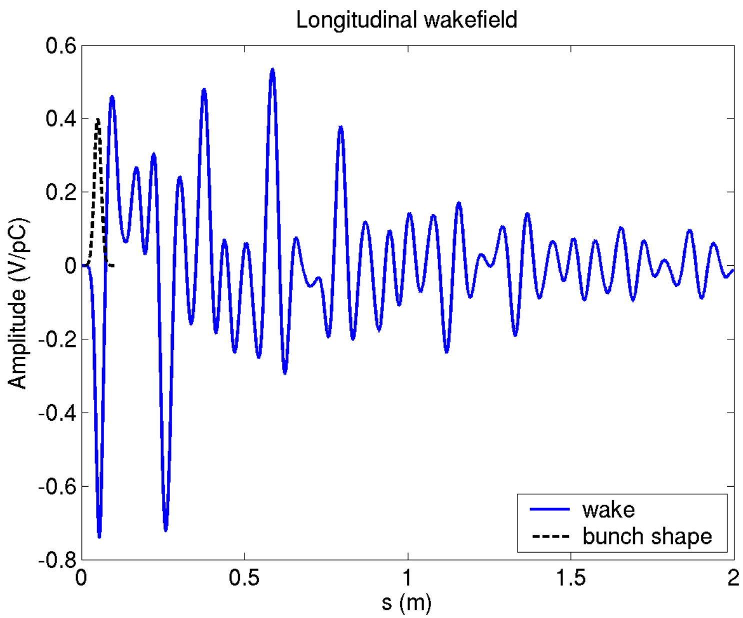
Taper – T3P Run & Wakefield

- Input file for T3P: taper.t3p
- Run T3P

  t3p absorber.t3p
- Postprocess t3p output to obtain longitudinal wakefield

  cd OUPTUT
  acdtool postprocess wake_new wakefield.bnd wakefield.z.all.dat 0. 0.

  – Wakefield data in output file wakes_new.out, in which 1st and 2nd columns are s [m] and W [V/pC], respectively
- Plot the wakefield



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Taper – Field Visualization

- Postprocess data for ParaView

  acdtool postprocess volmontomode absorber.t3p

  – Create mymonts_t*fs.out.mod in OUTPUT directory

<u>Field animation of beam transit</u>