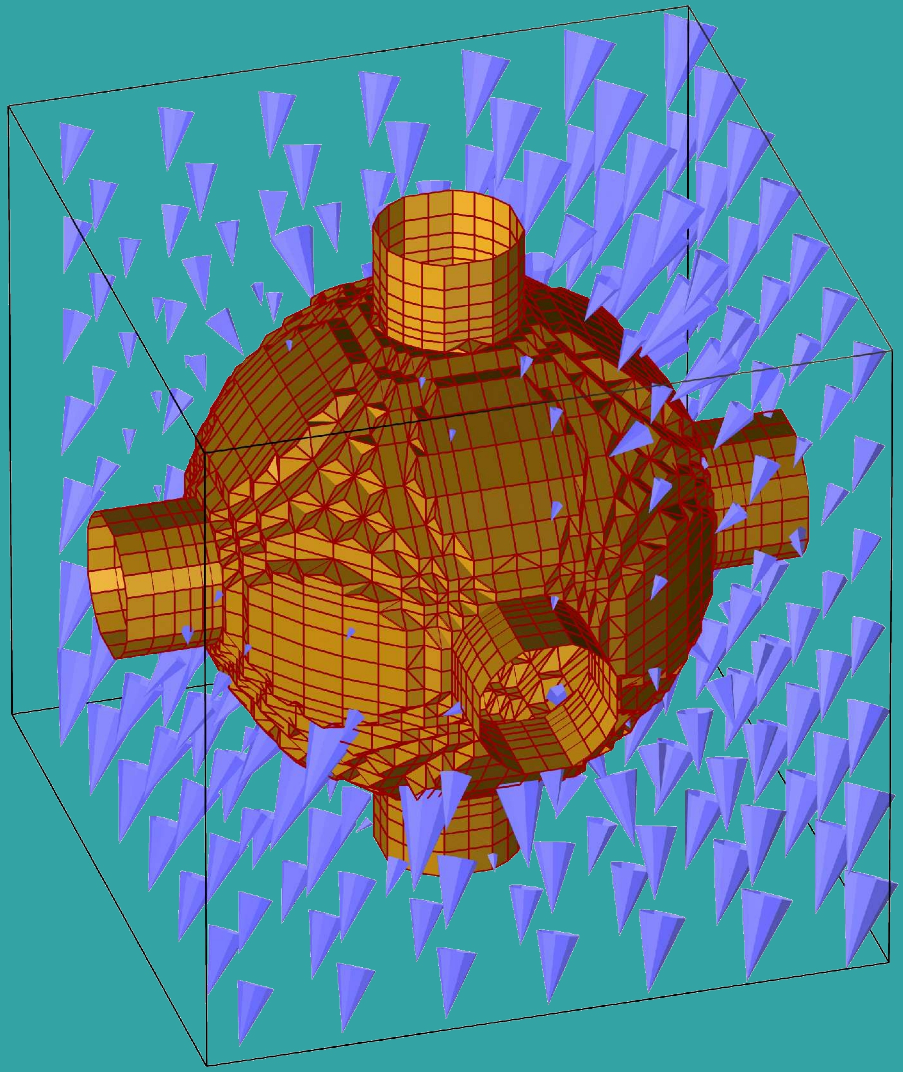
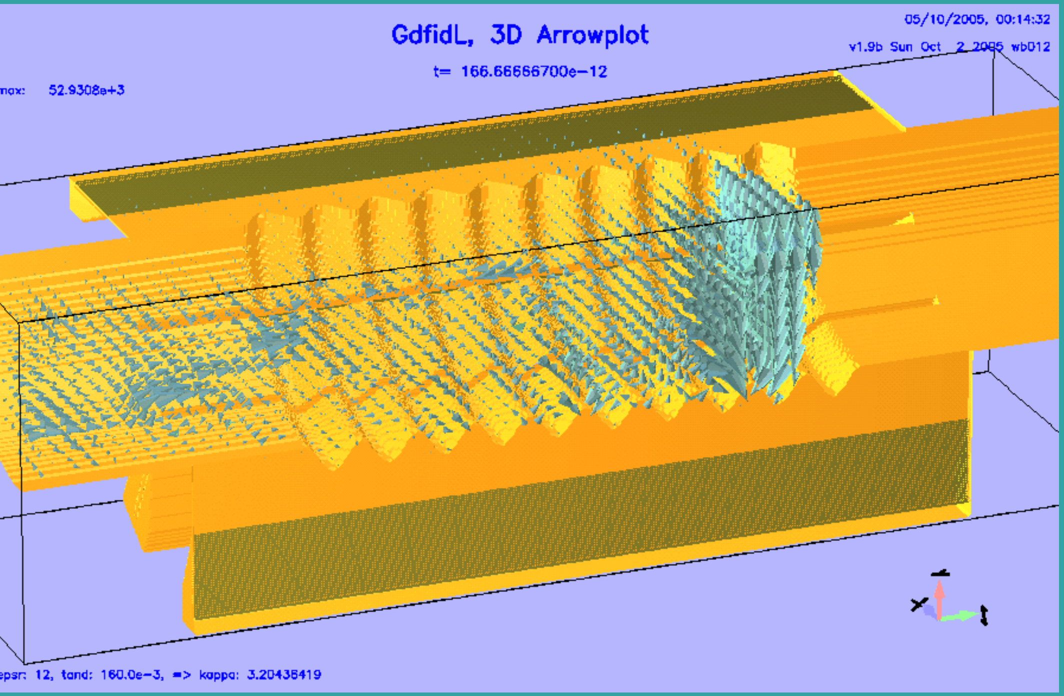
The GdfidL Electromagnetic Field Simulator



Warner Bruns

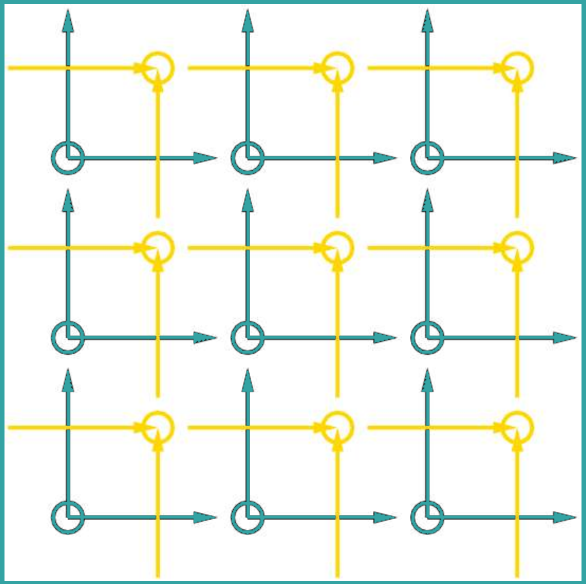
What is computed



Materials can be lossy and dispersive

- Resonant fields
  - Periodic boundary conditions
- Time dependent fields excited via
  - Relativistic line charges
  - Free moving charges
  - Portmodes

Finite Difference/ Finite Integration



- Electric/ magnetic voltages at the edges of cells

$$
\begin{aligned}
-\frac{d}{dt}h &= \int_{\Delta s'} \frac{1}{\int_A \mu dA} ds' \left(e_1 + e_2 - e_3 - e_4\right) \\
\frac{d}{dt}e &= \int_{\Delta s} \frac{1}{\int_{A'} \varepsilon dA'} ds \left(h_1 + h_2 - h_3 - h_4\right)
\end{aligned}
$$

FD-Equations

Loss free Maxwell

$$\int \frac{d}{dt}\varepsilon \vec{E}\, d\vec{A} = \oint \vec{H}\cdot d\vec{s}$$

$$-\int \frac{d}{dt}\mu \vec{H}\, d\vec{A} = \oint \vec{E}\cdot d\vec{s}$$

We approximate

$$\int \varepsilon dA' \frac{d}{dt}\vec{E}\cdot \vec{n}'_A \approx \oint \vec{H}\cdot d\vec{s}'$$

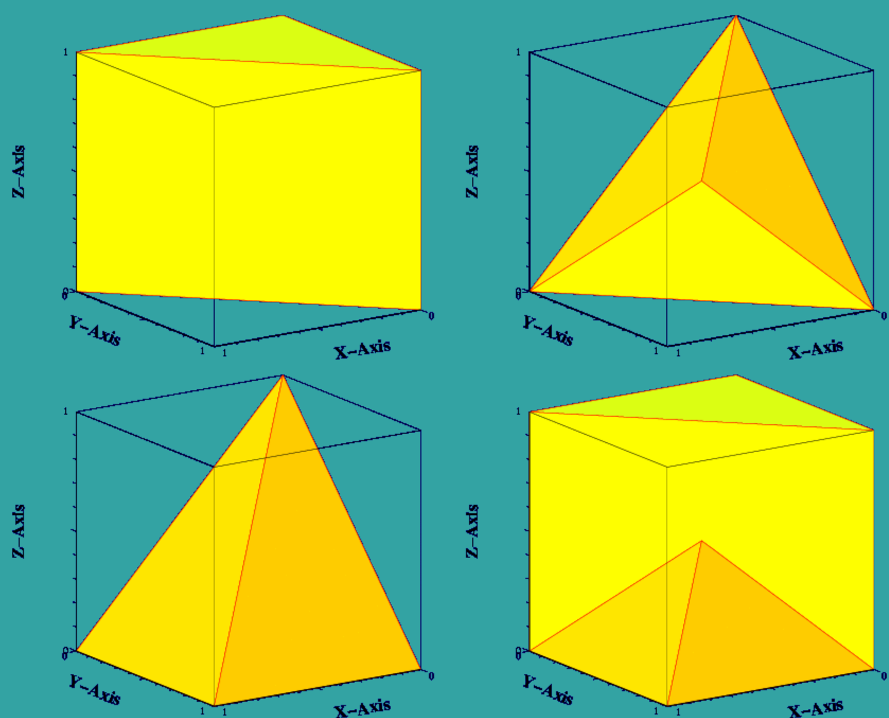
$$-\int \mu dA \frac{d}{dt}\vec{H}\cdot \vec{n}_A \approx \oint \vec{E}\cdot d\vec{s}$$

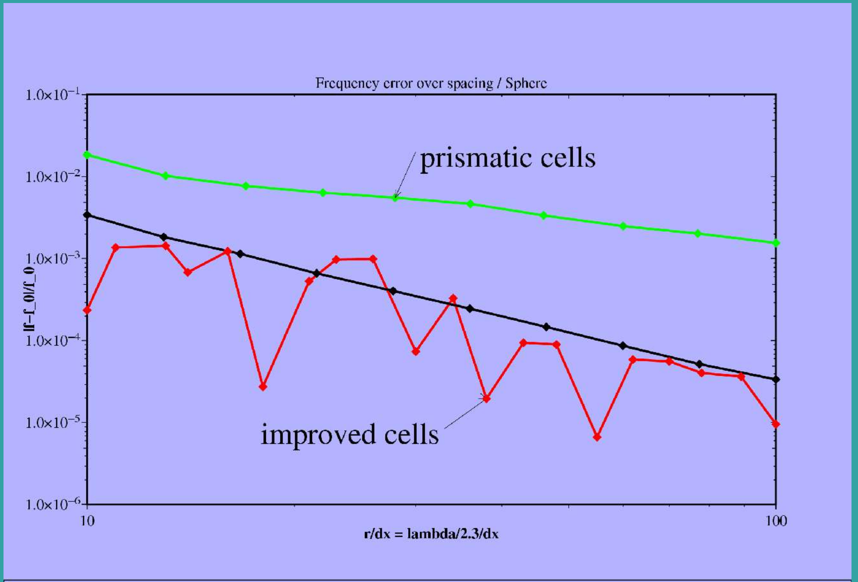
Integration gives electric/ magnetic voltages

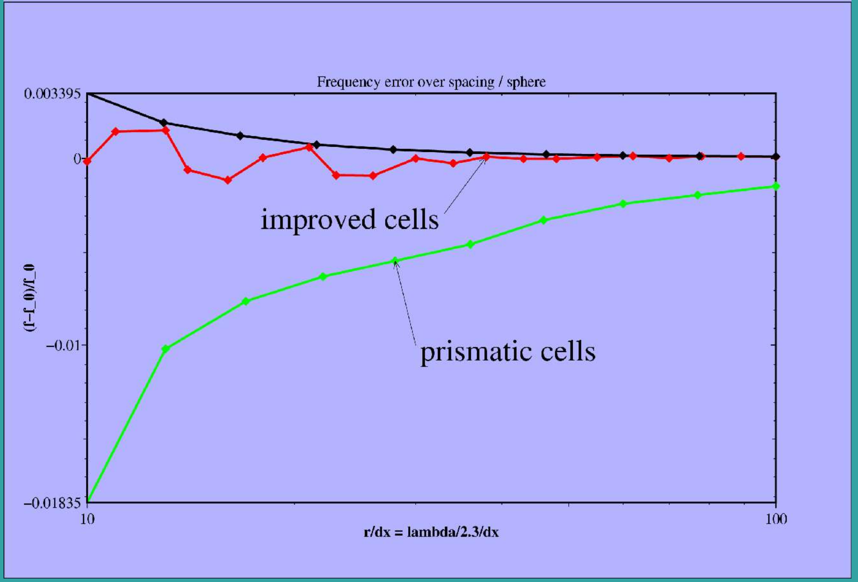
$$\frac{d}{dt}\int \vec{E}\cdot d\vec{s} \approx \frac{\int ds}{\int \varepsilon dA'}\oint \vec{H}\cdot d\vec{s}'$$

$$-\frac{d}{dt}\int \vec{H}\cdot d\vec{s}' \approx \frac{\int ds'}{\int \mu dA}\oint \vec{E}\cdot d\vec{s}$$

Generalised diagonal fillings

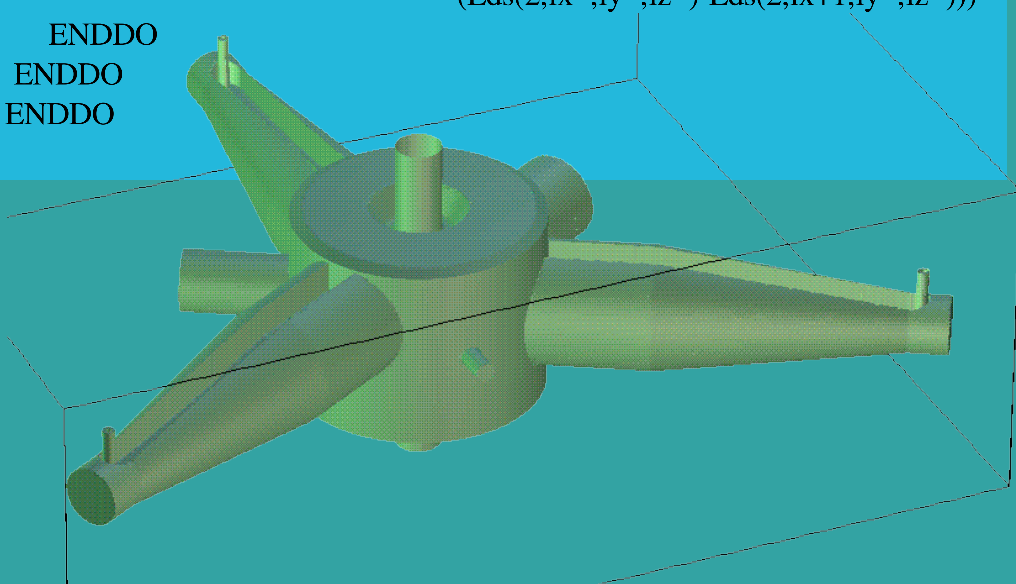






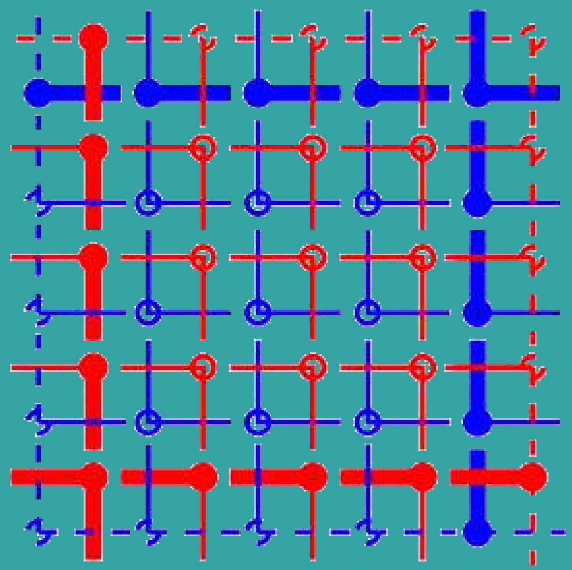
Memory and CPU-Time only for interesting Gridcells

```
REAL, DIMENSION(1:3,0:nx+1,0:ny+1,0:nz+1) :: &
    Eds, Hds, dsoEpsA, dsoMueA
DO iz= 1, nz, 1
  DO iy= 1, ny, 1
    DO ix= 1, nx, 1
       Hds(1,ix,iy,iz)= Hds(1,ix,iy,iz) &
           - dt*dsoMuA(1,ix,iy,iz) * (  Eds(2,ix   ,iy   ,iz  )-Eds(2,ix   ,iy   ,iz+1) &
                                       + Eds(3,ix   ,iy   ,iz  )-Eds(3,ix   ,iy+1,iz   ) )
       Hds(2,ix,iy,iz)= Hds(2,ix,iy,iz) &
          - dt*dsoMuA(2,ix,iy,iz) * (-(Eds(1,ix   ,iy   ,iz  )-Eds(1,ix   ,iy   ,iz+1)) &
                                      + Eds(3,ix   ,iy   ,iz  )-Eds(3,ix+1,iy   ,iz   ) )
       Hds(3,ix,iy,iz)= Hds(3,ix,iy,iz) &
          - dt*dsoMuA(3,ix,iy,iz) * (  Eds(1,ix   ,iy   ,iz  )-Eds(1,ix   ,iy+1,iz   ) &
                                      -(Eds(2,ix   ,iy   ,iz  )-Eds(2,ix+1,iy   ,iz   )))
     ENDDO
 ENDDO
ENDDO
```



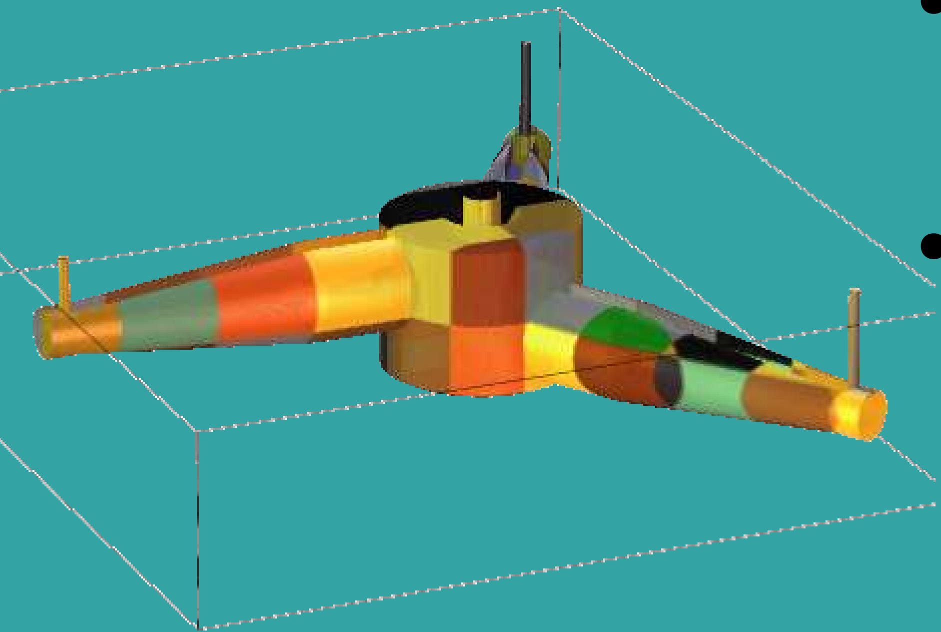
```
REAL,DIMENSION(1:3,0:NetCells) :: Eds, Hds
INTEGER, DIMENSION(0:NNetCells) :: KindofCell
INTEGER, DIMENSION(0:nx+1,0:ny+1,0:nz+1) :: NrofCell
REAL, DIMENSION(1:3,0:NDifferentCells) :: dsoEpsA, dsoMuA
DO iz= 1, nz, 1
  DO iy= 1, ny, 1
    DO ix= 1, nx, 1
       i= NrofCell(ix,iy,iz)
       IF (i .LT. 1) CYCLE
       k= KindofCell(i)
       ipx= NrofCell(ix+1,iy   ,iz   )
       ipy= NrofCell(ix   ,iy+1,iz   )
       ipz= NrofCell(ix   ,iy   ,iz+1)
       Hds(1,i)= Hds(1,i) - dt*dsoMuA(1,k) &
                 * (  Eds(2,i)-Eds(2,ipz) + Eds(3,i)-Eds(3,ipy) )
       Hds(2,i)= Hds(2,i) - dt*dsoMuA(2,k) &
                 * (-(Eds(1,i)-Eds(1,ipz)) + Eds(3,i)-Eds(3,ipx) )
       Hds(3,i)= Hds(3,i) - dt*dsoMuA(3,k) &
                 * (  Eds(1,i)-Eds(1,ipy) -(Eds(2,i)-Eds(2,ipx)))
     ENDDO
 ENDDO
ENDDO
```

Parallel Computation



For all Timesteps: DO
  Compute local H by applying the local curl operator to the local E
    For all Directions: DO
      Send tangential H to the neighbour
      Receive tangential H from the neighbour
    ENDDO For all Directions
  Compute local E
    For all Directions: DO
      Send tangential E to the neighbour
      Receive tangential E from the neighbour
    ENDDO For all Directions
ENDDO For all Timesteps

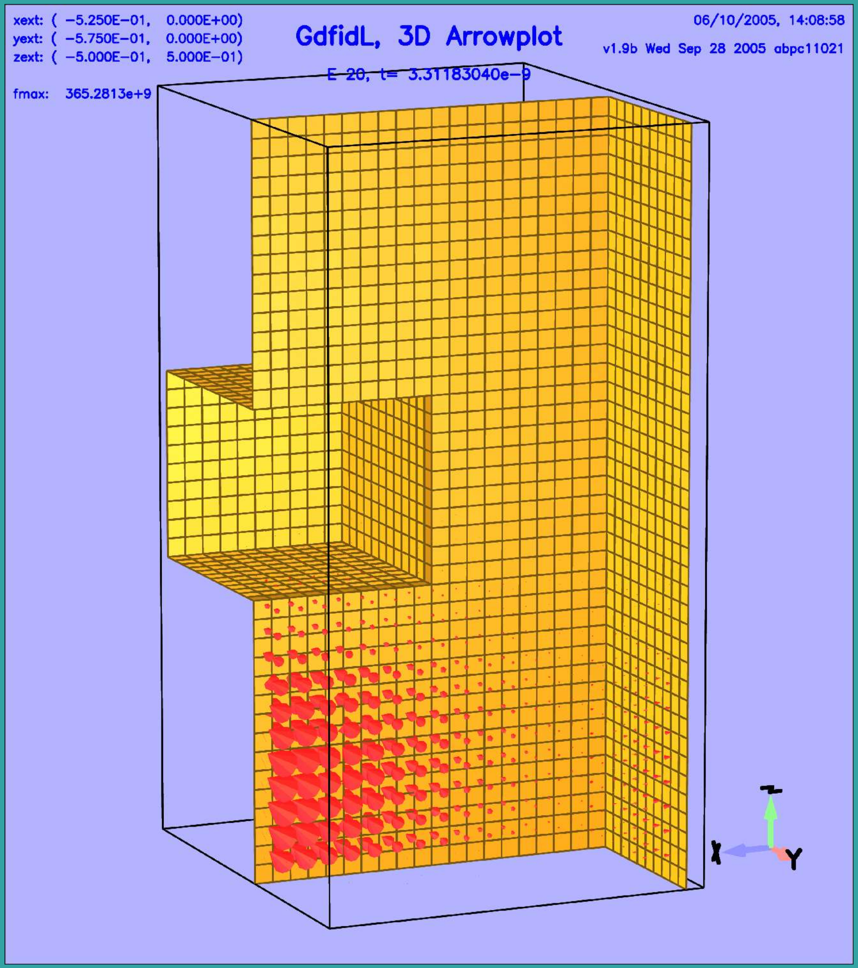
Parallel Computation, Load Balancing



Less than 10% interesting volume

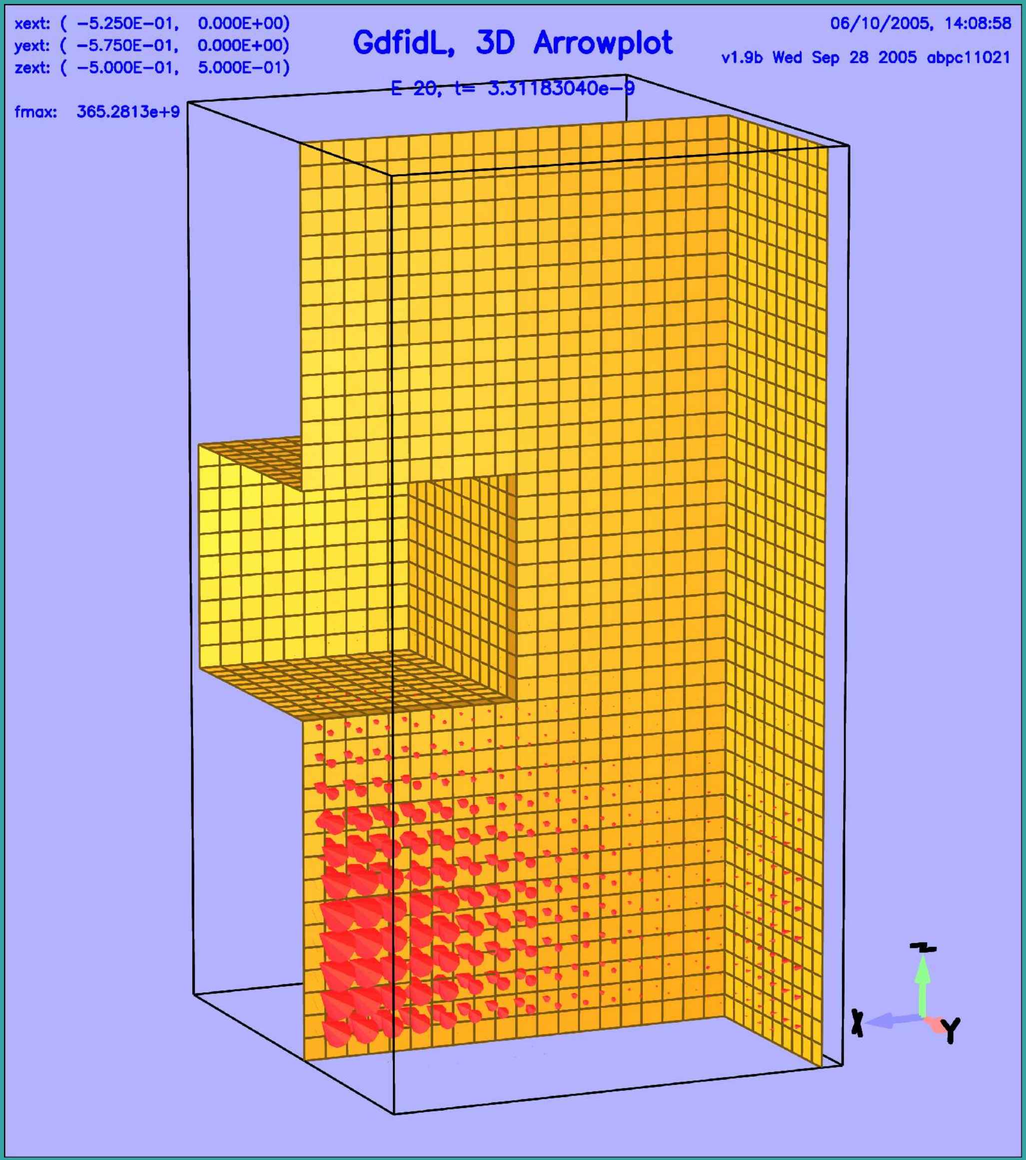
- Volume is partitioned in many subvolumes
- Interesting subvolumes are spread over the available processors.

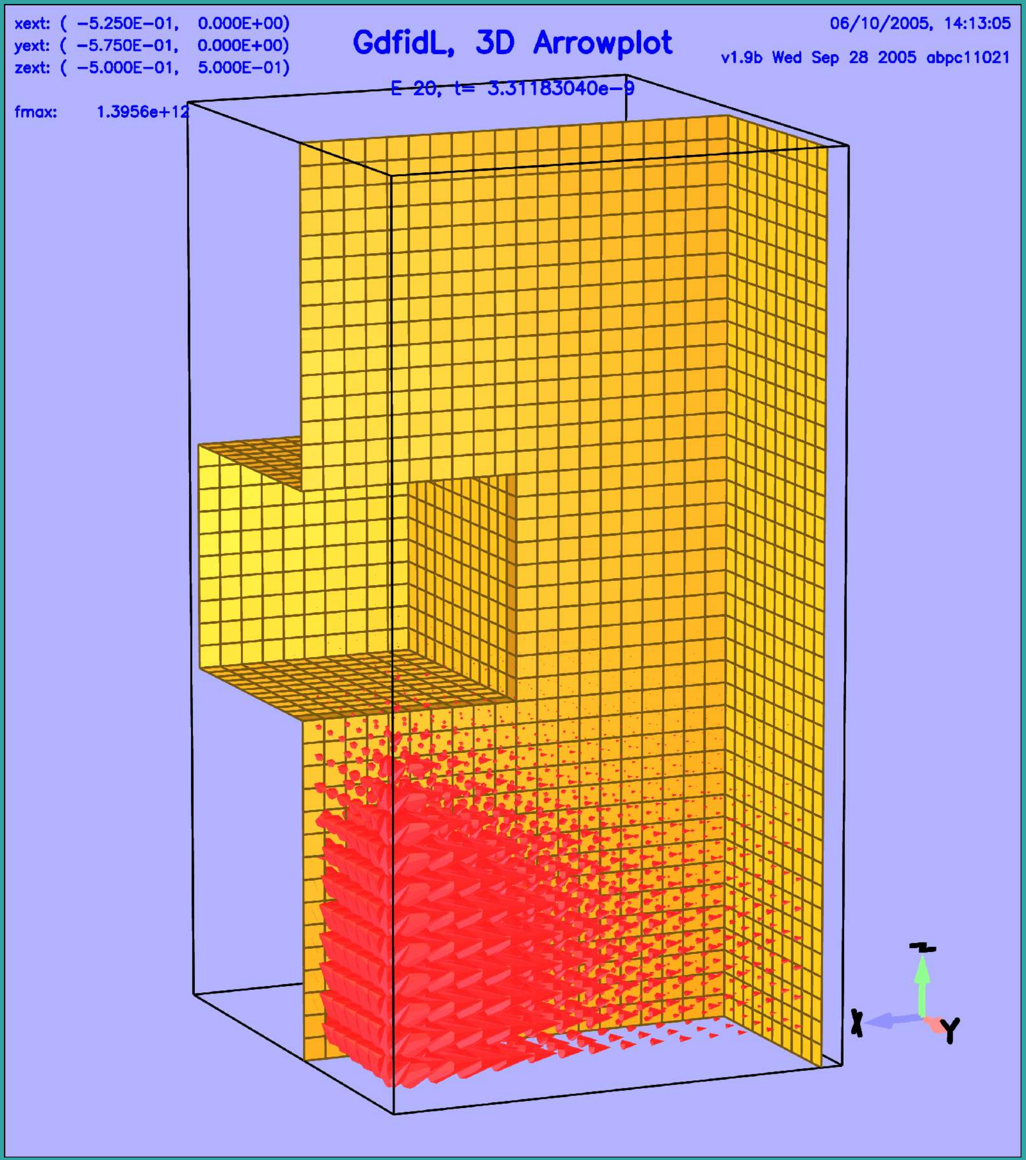
Excitation with hollow Charge



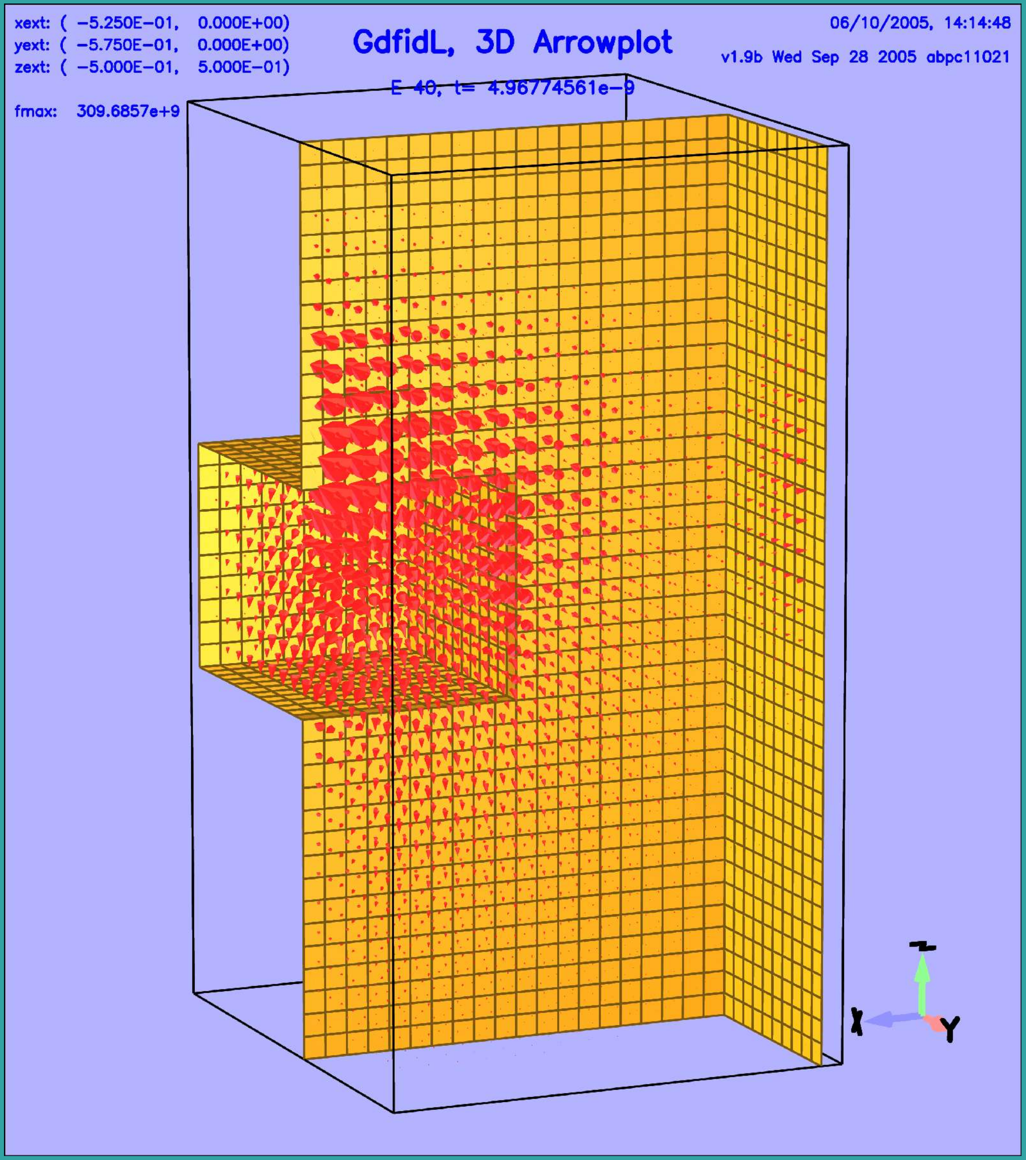
- Hollow charge very near to the beampipe
- Less dispersion error

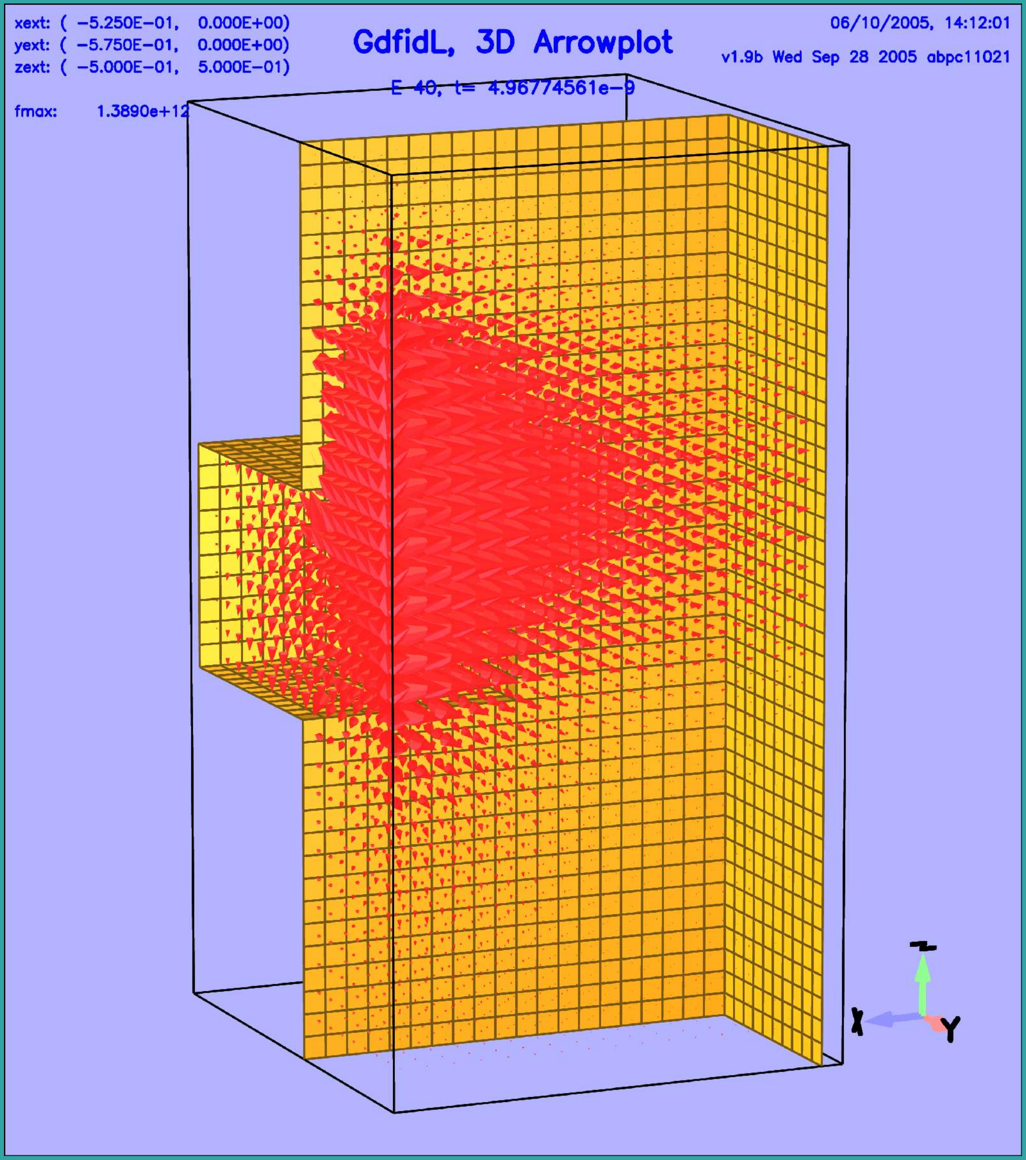
Hollow Charge



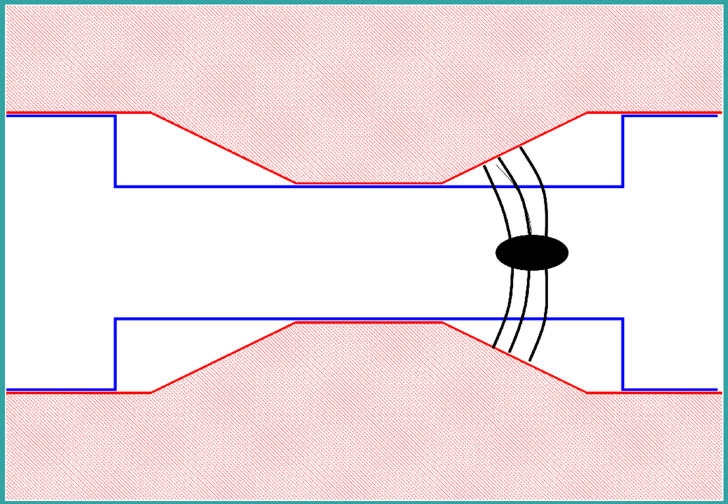


Hollow Charge





Napoly Integration in 3D



- Avoids "Catch-up Problem" also for Collimator-like structures.

$$W_z(x,y,s) = \frac{c}{Q}\int_{-\infty}^{\infty} E_z(x,y,z=ct-s,t)\,dt$$

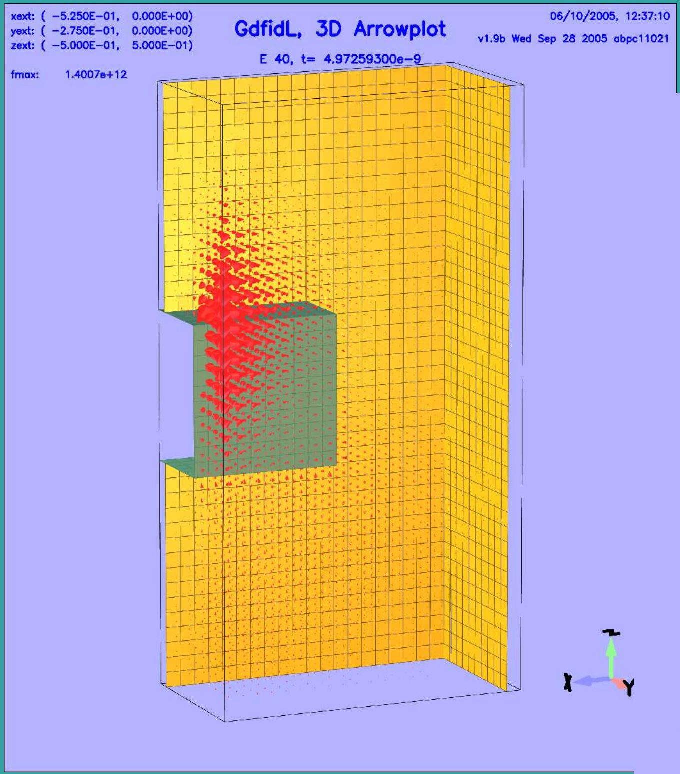
$$c\int_{t=s/c}^{\infty} E_z(x,y,z=ct-s,t)\,dt \quad = \quad \int_{\xi=x}^{x_{Max}} \left(E_x^{TM} + cB_y^{TM}\right)(x=\xi,y,z=0,t=s/c)\,d\xi$$

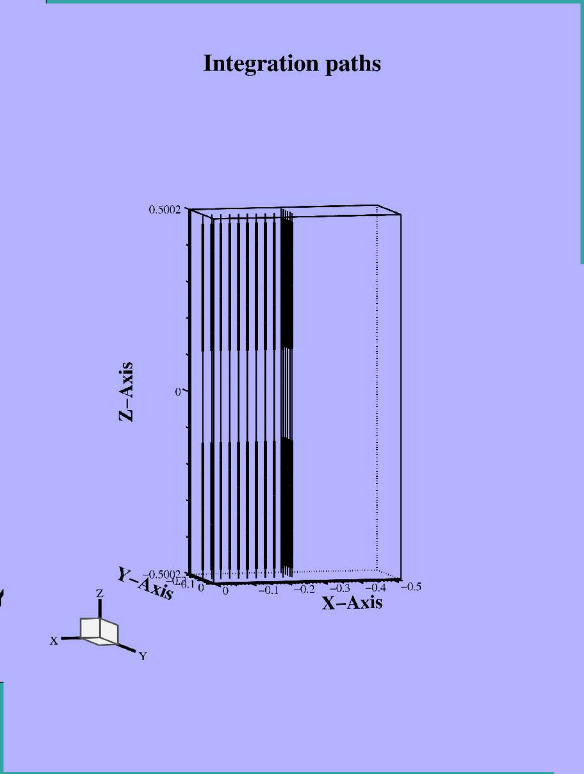
Napoly Integration in 3D

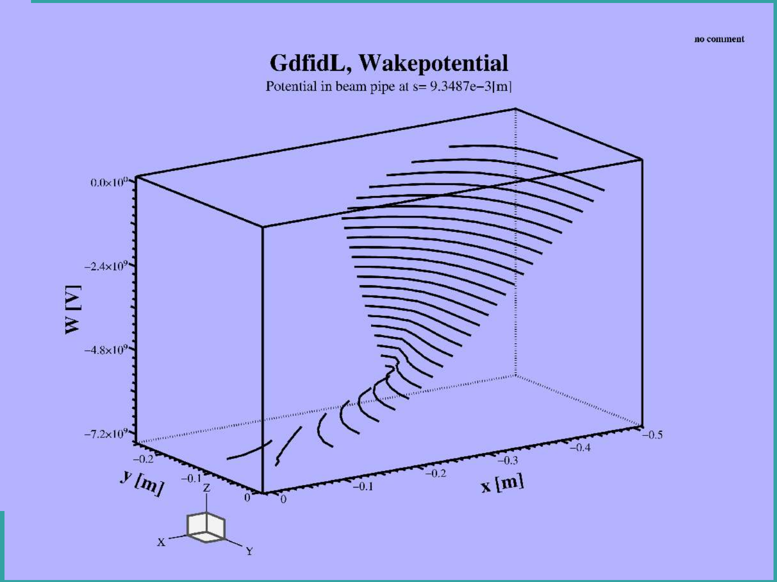
- Integration only over TM part of the field.
- Requires solution of 2D Poisson problems at each timestep

$$
\begin{aligned}
\vec{E}_t^{TM} &= \nabla_t(\varphi^{TM}) \\
\Delta_t \varphi^{TM} &= -\frac{d}{dz} E_z \\
\vec{H}_t^{TM} &= \vec{H}_t - \vec{H}_t^{TE} \\
\vec{H}_t^{TE} &= \nabla_t(\varphi^{TE}) \\
\Delta \varphi^{TE} &= -\frac{d}{dz} H_z
\end{aligned}
$$

Napoly Integration







Summary

- Computation on parallel systems
  - Incredibly large number of gridcells possible
- Wakepotentials
  - Napoly Integration for general geometries
  - Hollow beam excitation for general geometries
- Generalised diagonal fillings
- Eigenvalues of lossy structures