Target and Capture Simulations

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MUTAC Review

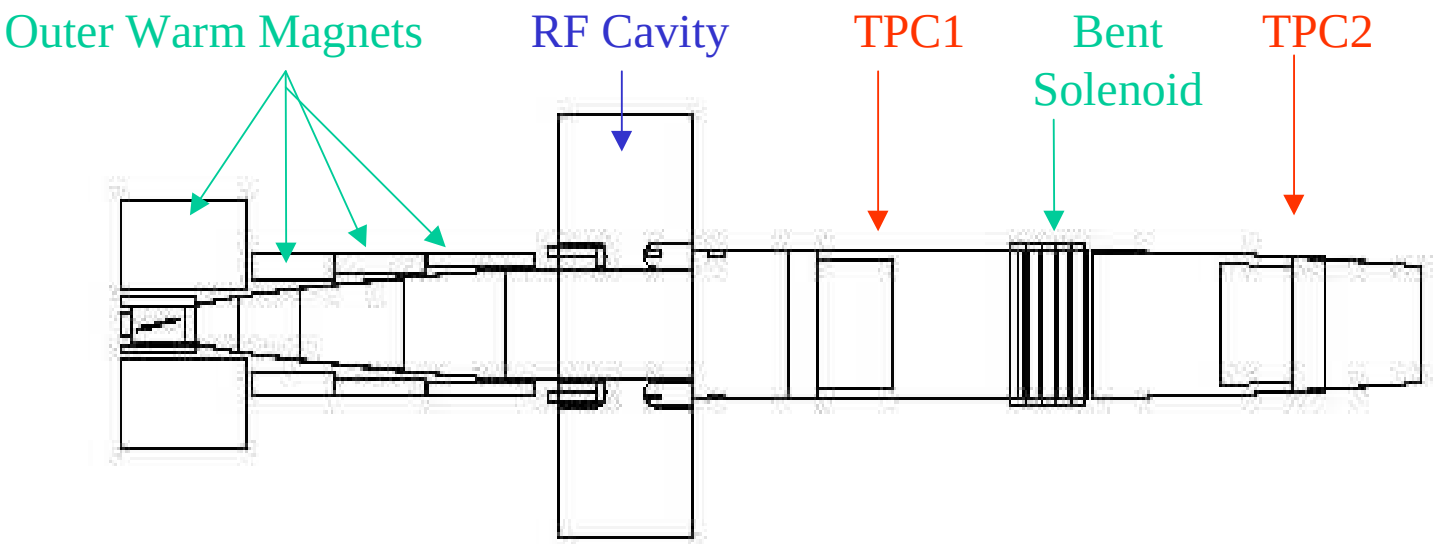
15 June 2000

Simulation Topics

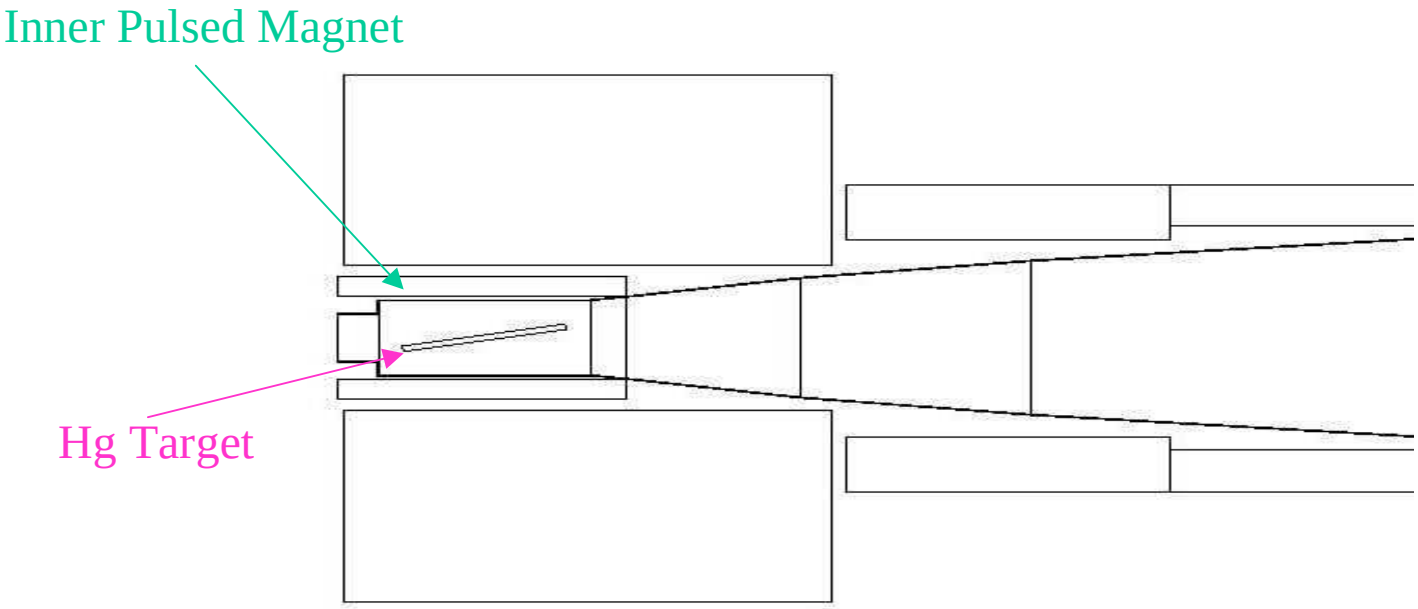
- Particle transport simulations:
  - Using MARS (N. Mokhov, H. Kirk)
  - Using GEANT (S. Kahn, Y. Fukui, I. Stumer)
- Thermodynamics and Structural Aspects of the Target:
  - Using ANSYS/Acoustic for Hg target (N. Simos)
  - Using ANSYS/Structural for solid target (P. Drumm)
  - Using FronTier (R. Samulyak)
  - Using SWHIFT (A. Hassanein)
- Hydrodynamics of liquid jet in a magnetic field.
  - Using ANSYS/FLOTRAN (C. Lu)

Particle Transport Codes Studies

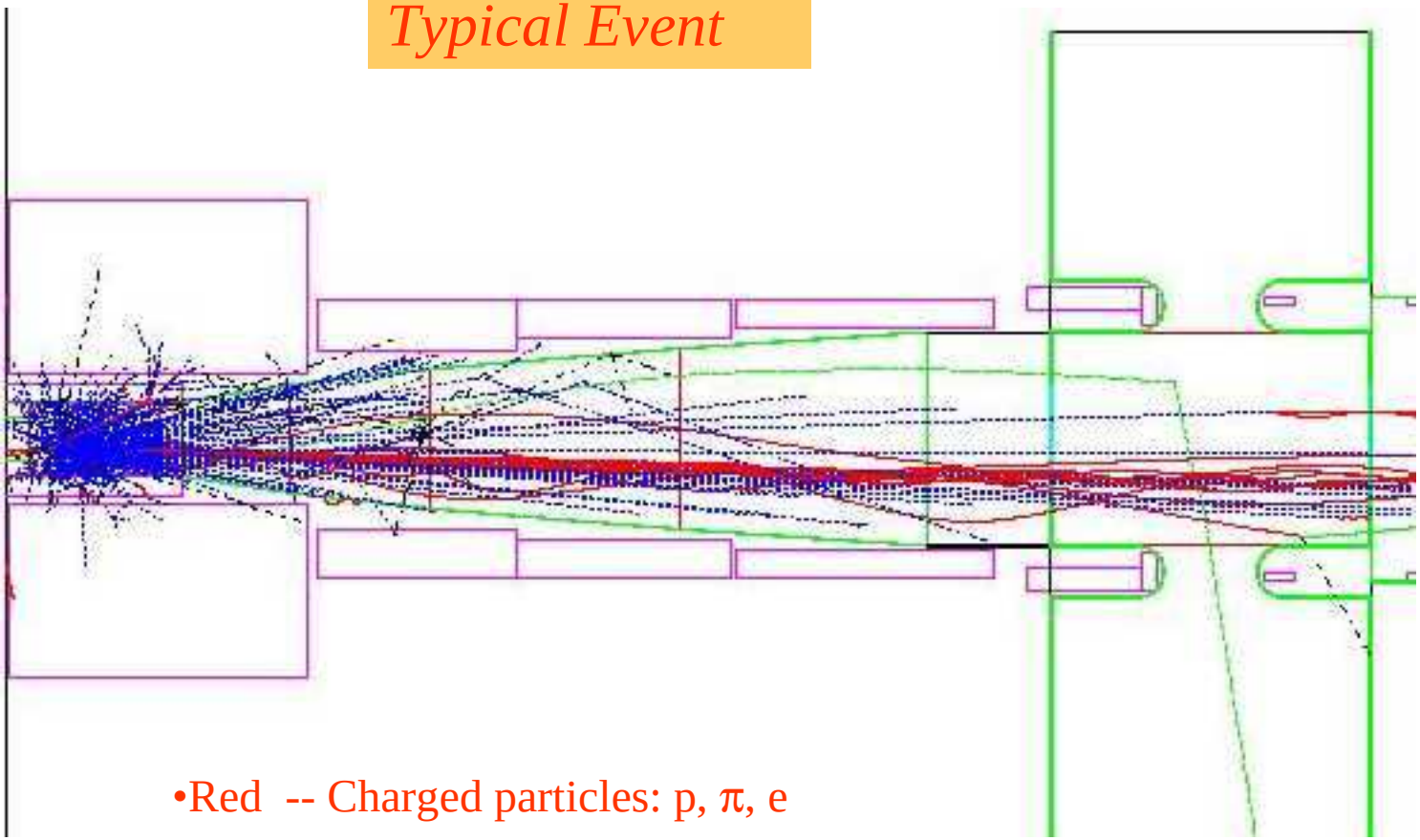
- Use has been made of both **MARS** and **GEANT** in targeting studies.
  - They have been applied both to the feasibility study at FNAL and to the E951 experiment at BNL.
- These code have been and will be used to study:
  - Deposition of energy in the target environment.
  - Particle flux for radiation damage studies.
  - Muon yield to optimize design of capture system.
  - Detection aspects of targeting experiment.
  - Particle phase space.



GEANT drawing of E951 geometry



Typical Event



- Red -- Charged particles: p, π, e
- Blue -- Photons
- Black -- Neutral particles: n
- Green -- Muons

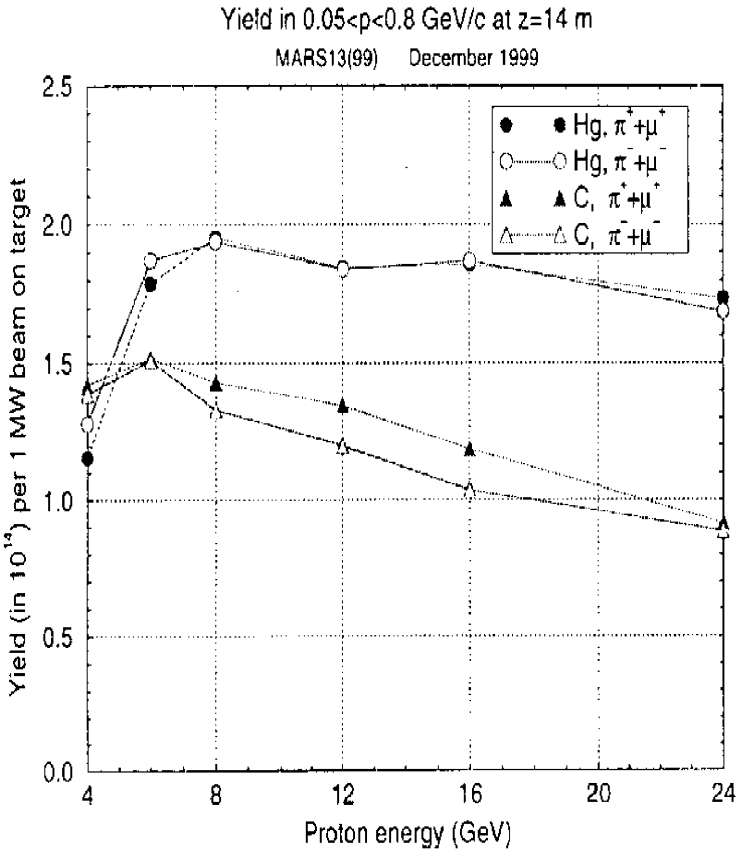
Particles Exiting Target

- Target parameters:
  - 2 λ_{int} Hg target.
  - Target inclined 150 mrad to axis.
  - 24 GeV incident proton beam.
  - 7 mm target radius.
  - 20 tesla solenoid field.
- Typical proton on target produces:
  - ~7 πs of which only 3 have $p_{\perp} < 225$ MeV/c.

Type	Kin Energy per Incident Proton (GeV)	Fraction of KE	Number per Incident Proton
E depos	3.511	0.1637	
Photons	2.296	0.1067	502.68
Electrons	0.753	0.0352	32.92
Mesons	5.152	0.2434	6.92
Protons	6.251	0.2803	5.26
Neutrons	3.712	0.1738	63.78
Total	22.614	1	
Pp cut			0.0001
Pe cut			0.0001
Pn cut			2.15E-12
mucut			0.0001

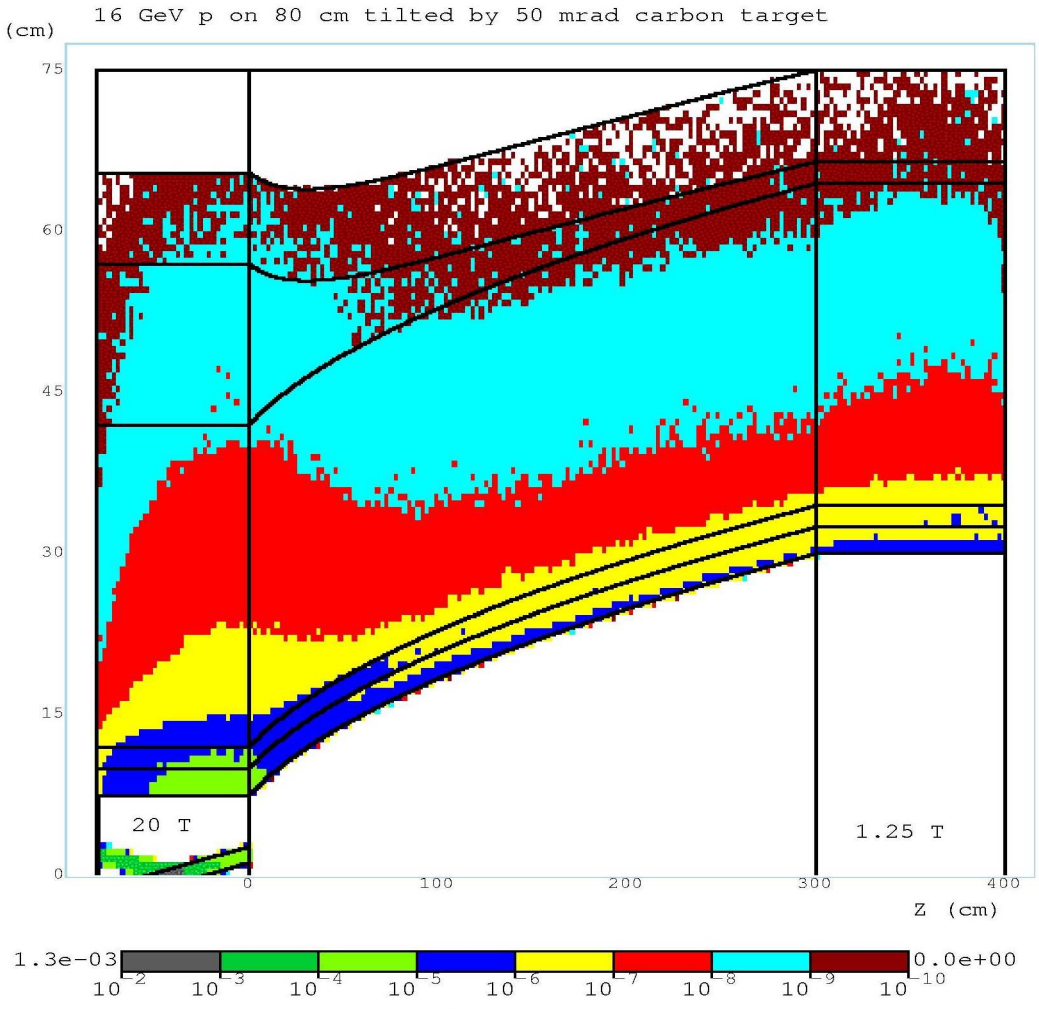
•16% of energy remains to heat the target.

Meson Yields for Hg and C Targets for 16 GeV Protons

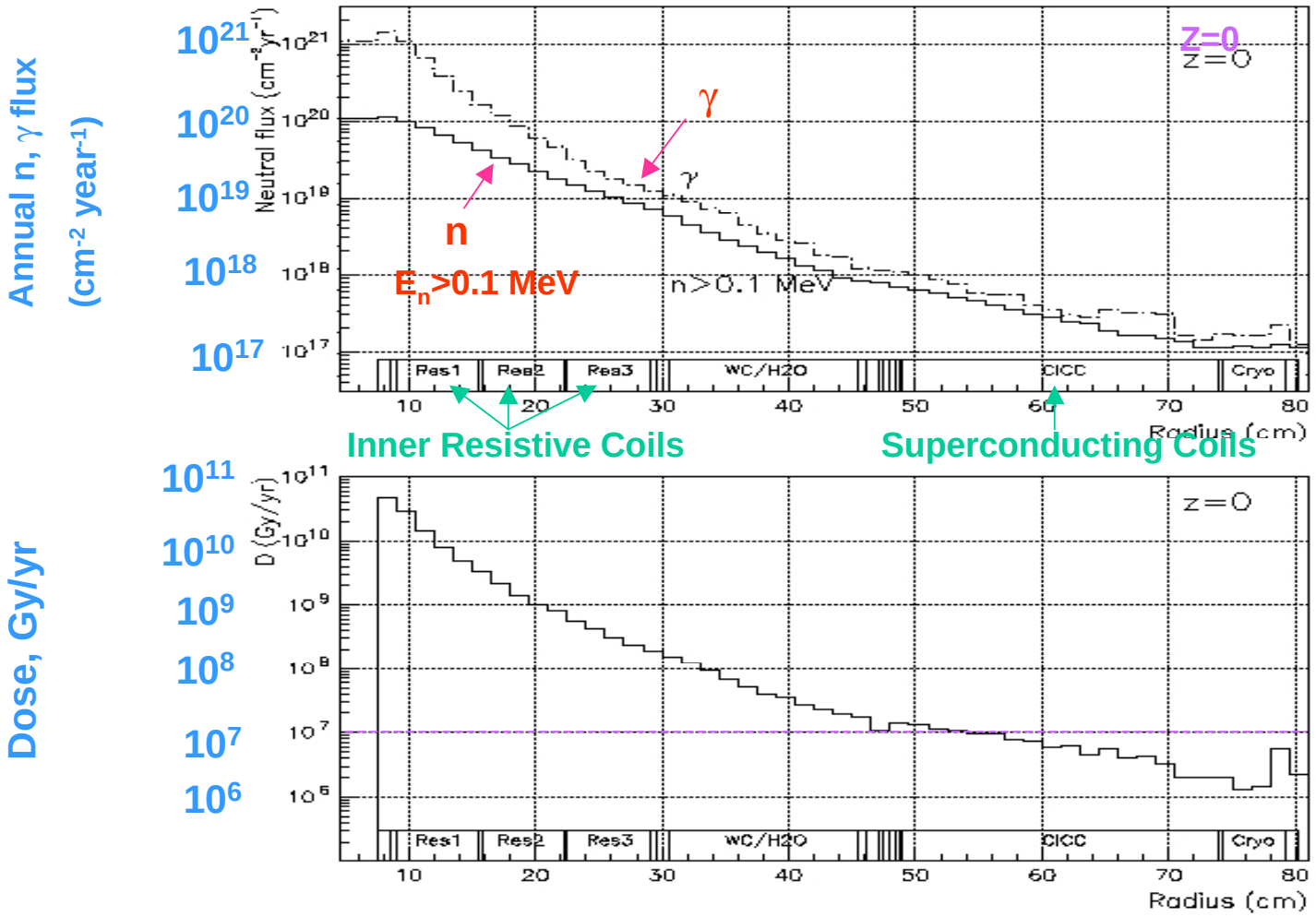


- Yield per beam power:
  - Approx constant for **Hg** target.
  - ~30% falloff for **C** target.
- Yield is ~30% larger for 50 mrad tilted target than no tilt.
- Capture yield saturates at 1.5 λ_{int}. Choose 2 λ_{int} to reduce punch thruough.
- For 16 GeV, 1 MW power:
  - 117 kw in **Hg** target.
  - 24 kw in **C** target.

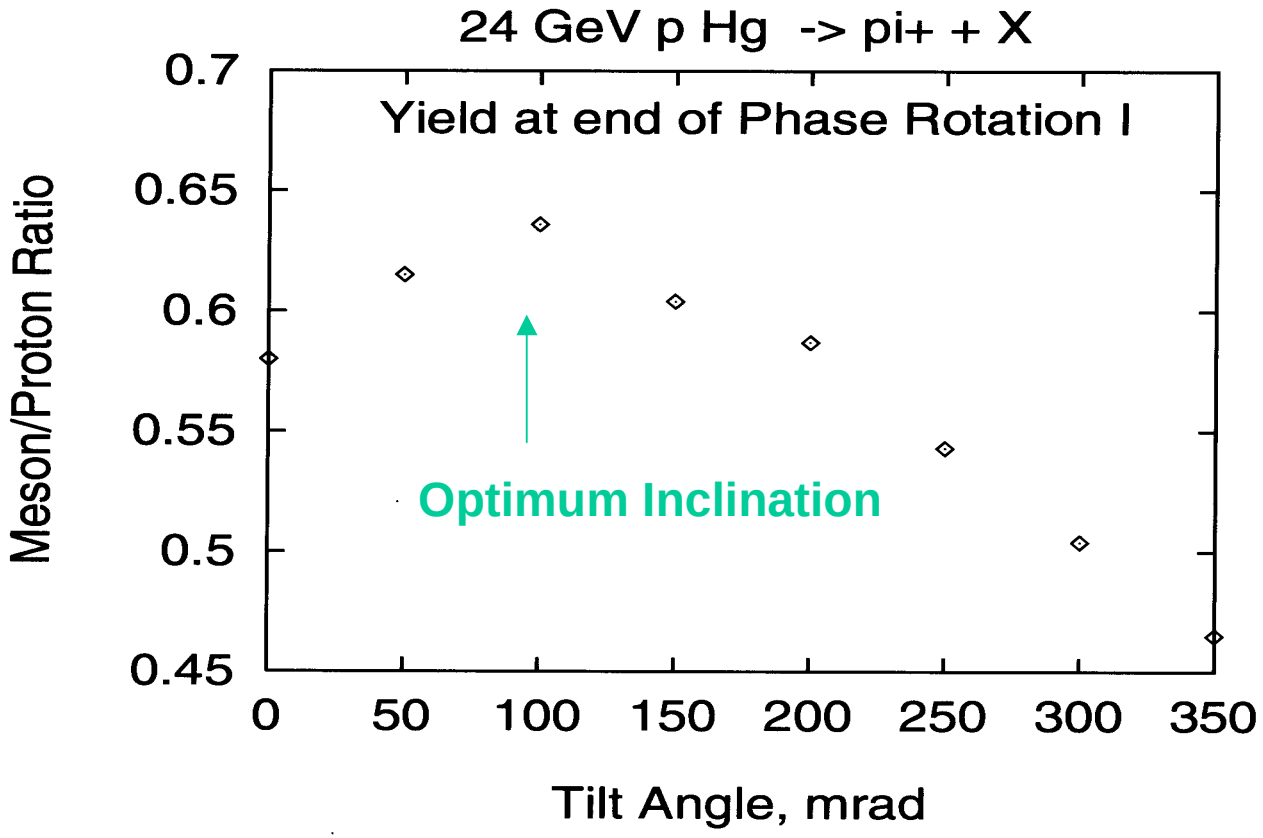
Energy Deposition Near Target



Radial Distribution of n and γ flux

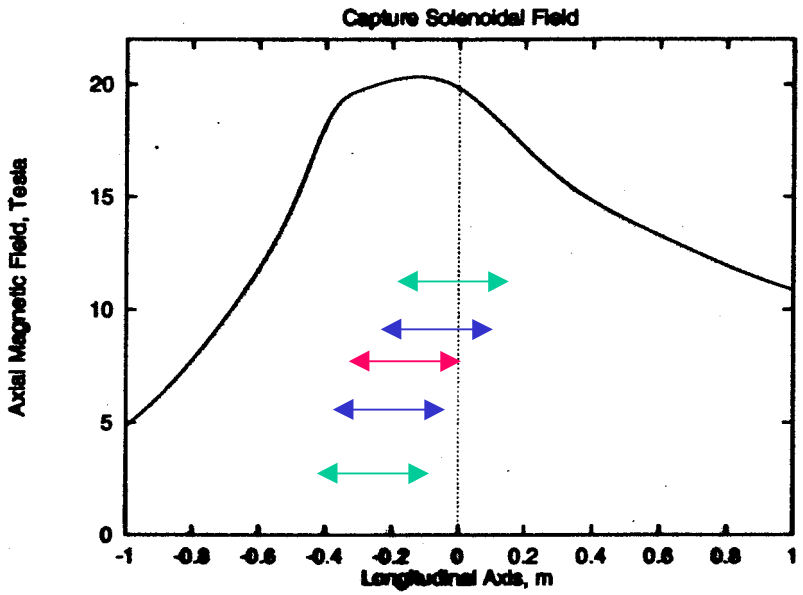


Variation of Target Inclination at 24 GeV



Alignment of Target with Magnetic Field

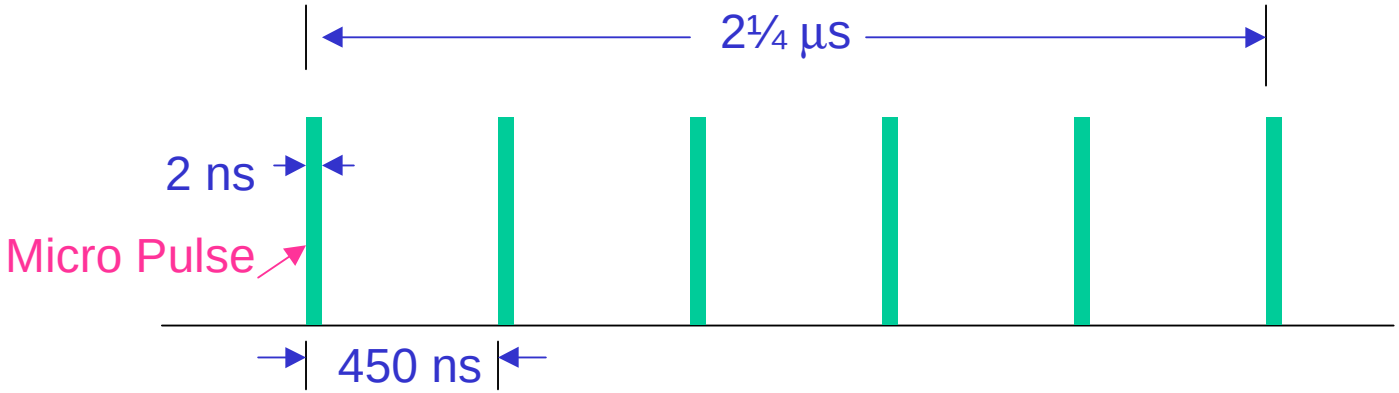
Target Region Magnetic Field



30cm Hg Target Positioning

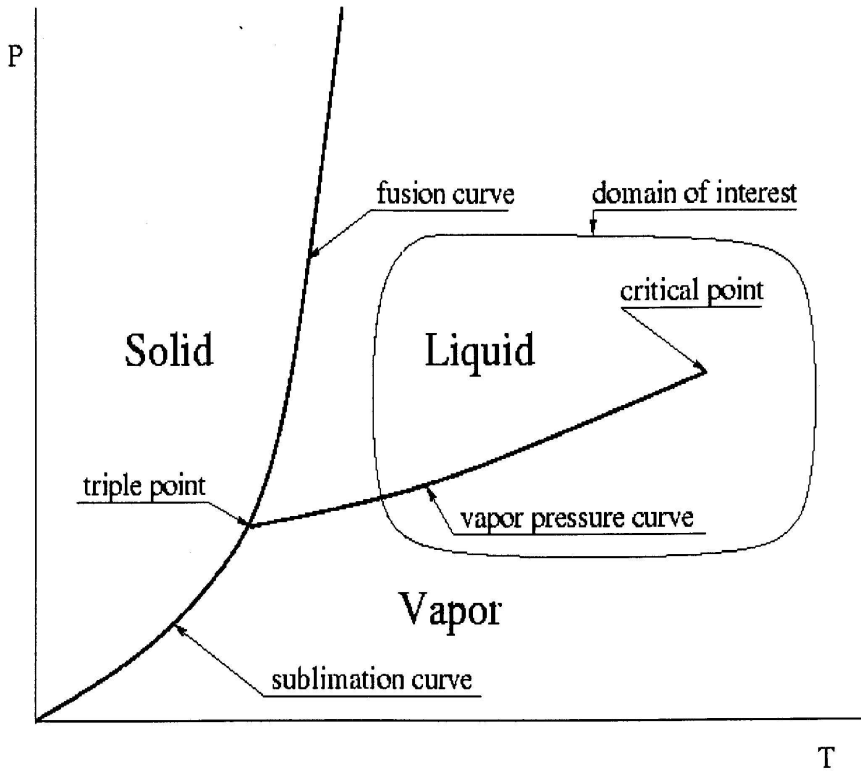
Target Shift cm	B_z T	Meson/Proton Yield End of Target	Meson/Proton Yield End of PR I
10	18.65	1.108	0.573
5	19.30	1.092	0.565
0	19.83	1.139	0.604
-5	20.17	1.035	0.538
-10	20.32	1.030	0.518

Time Structure of the AGS Beam



- 50 TP (total) of 24 GeV protons are deposited in 6 micro-pulses.
- Peak energy per micro-pulse is 87.36 joule/gram.

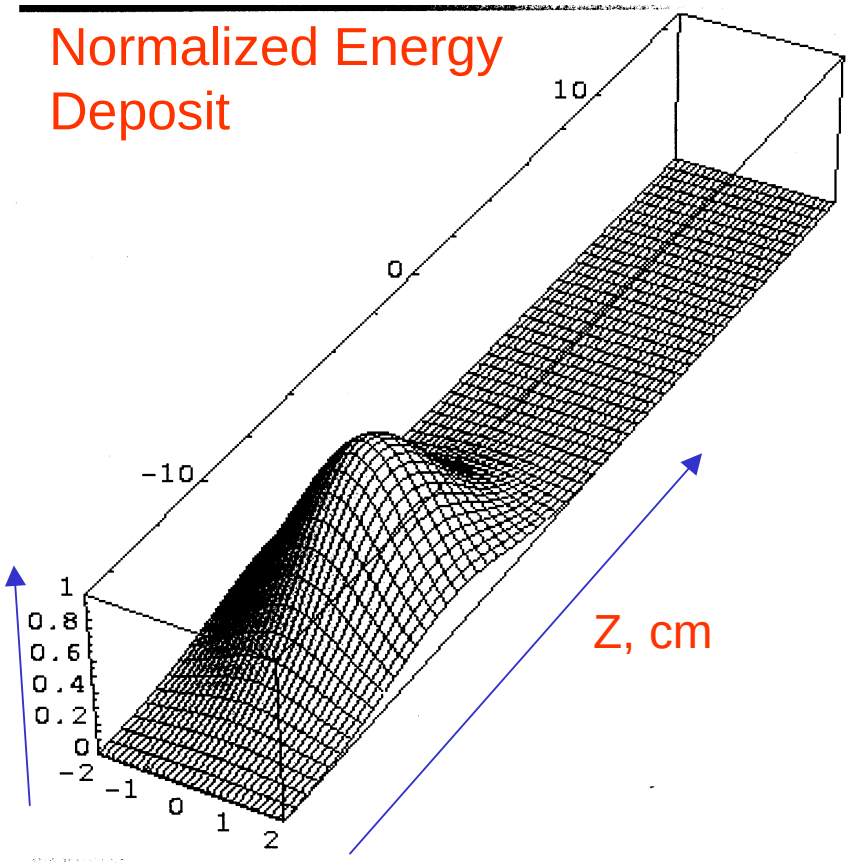
Mercury Phase Diagram



- Critical Point:
  - T_c=1750 K
  - P_c=172 Mpa
  - 43 cm^3/mole
- Boiling Point:
  - T_b=629.84 K
  - P_b= 0.1 Mpa
  - ρ = 13.546 g/cm^3
- Analytical Expression for vapor pressure:
  - $P=133.3\ e^{(18.41-7318/T)}$ in Pa

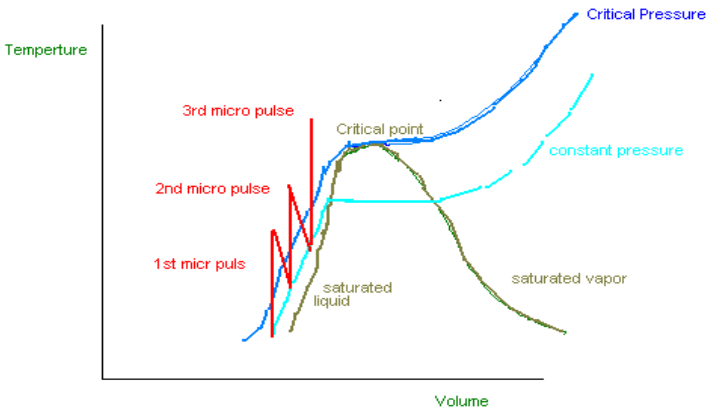
Beam Energy Deposition in Hg Target

- The distribution of energy deposit comes from MARS calculation.
- The distribution is normalized to unity. Peak $E_{deposit}$ is 87.36 j/g for a *micro-pulse.*
- This distribution is used in both ANSYS and FronTier calculations.

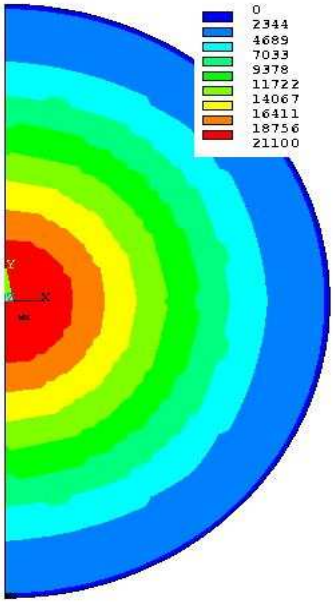


Basic Assumptions

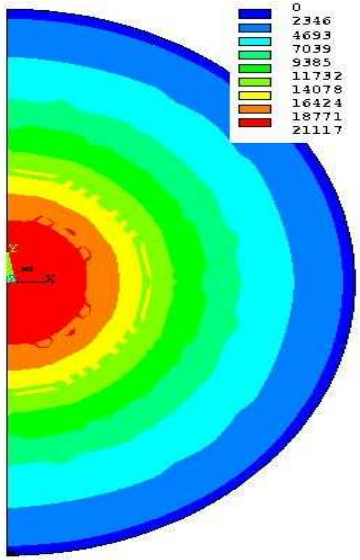
- A single micro-pulse would raise the Hg temperture above boiling *if the Hg could expand.* In the first 2 ns we assume constant volume.
- Between micro-pulses there is a pressure wave expansion at ~v_s=1.45 mm/μs.



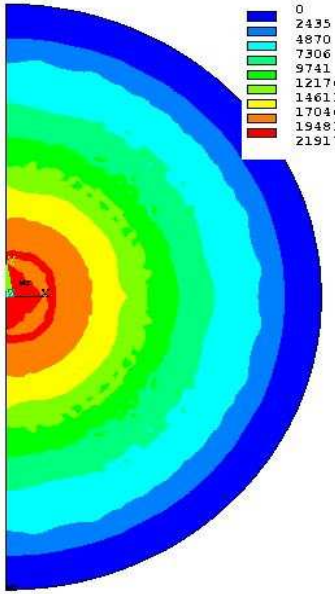
- Temperture is above critical after 3rd micro-pulse.
- Pressure wave will not hit boundary in 2.25 μsec.



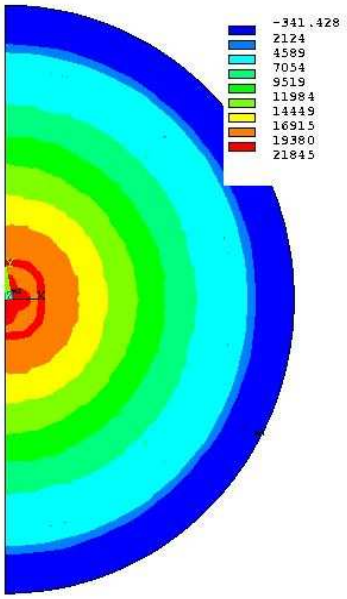
0 sec 1st μpulse



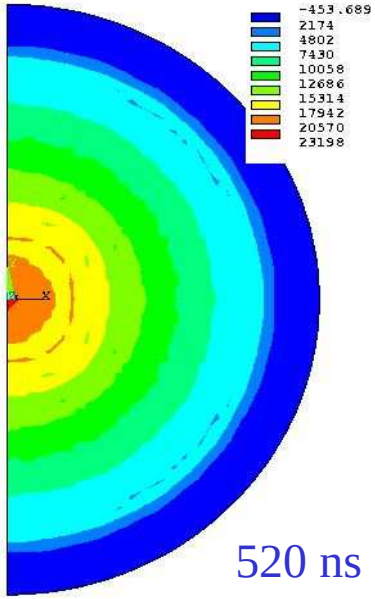
80 ns



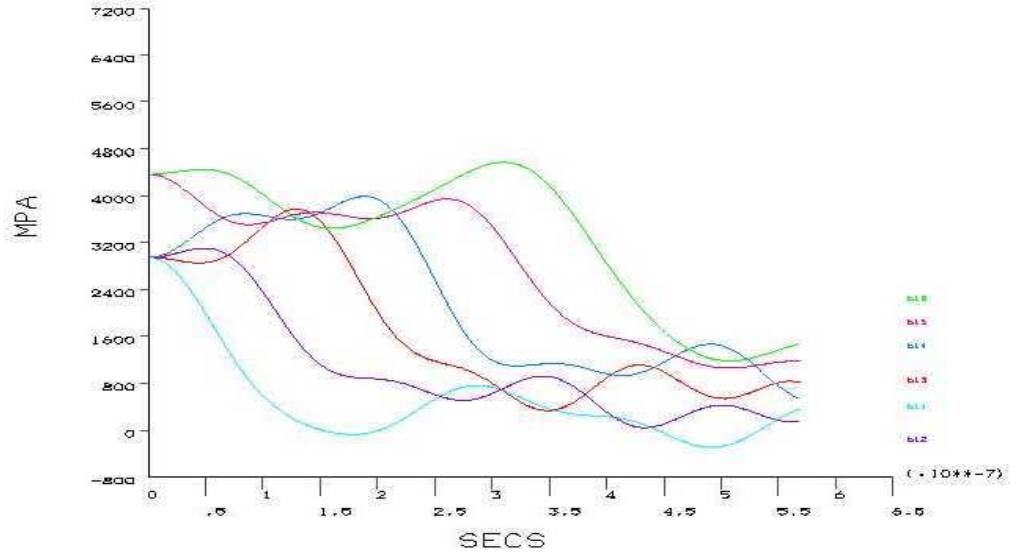
400 ns before 2nd μpulse



460 ns after 2nd μpulse



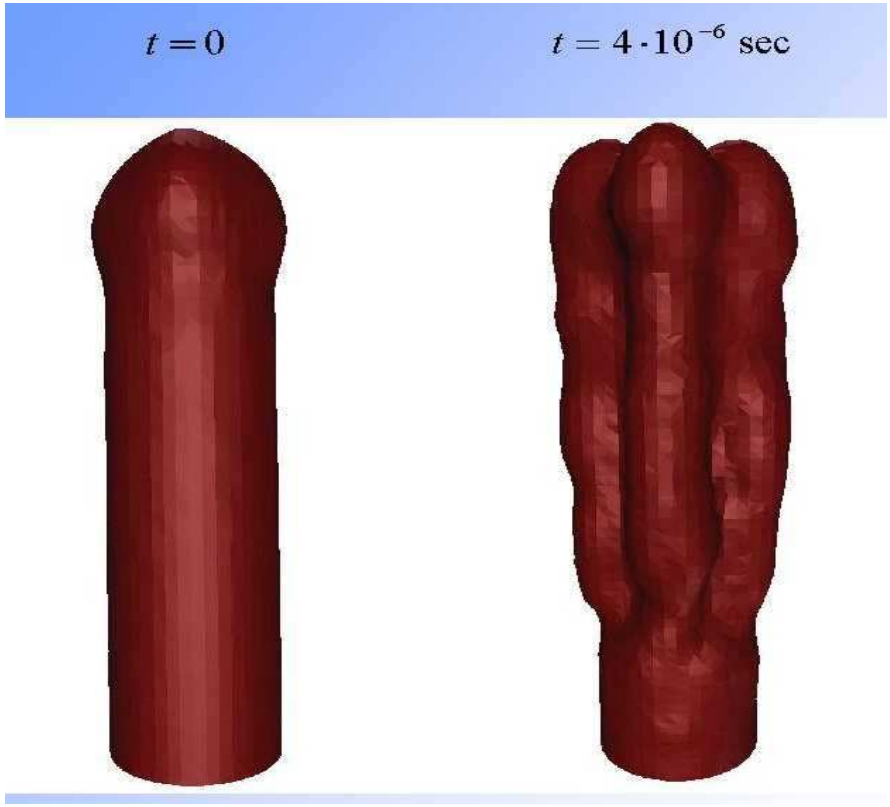
520 ns



The FronTier Code

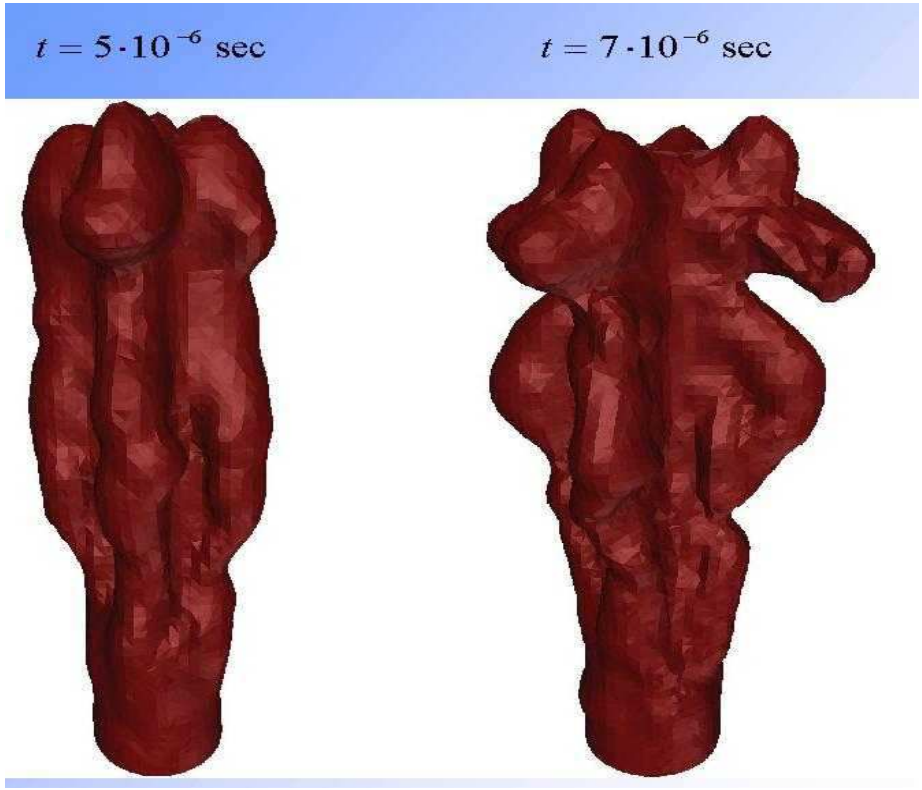
- "The *FronTier* code is based on *front tracking*, a numerical method for solving systems of *conservation laws* in which *evolution of discontinuities* is determined through the solution of the *Riemann problem.*"
  - Used to solve thermodynamic Equation of Sate
  - Does not require a highly refined mesh.
  - Ideal for problems where discontinuities are an important feature, such as with two states.
- **SESAME EOS** library from Sandia Lab provide physical and thermodynamic properties for Hg. (Used also in previous Ansys calculation.)

Shape of Hg Target from Interaction with Beam



Before 1st Pulse

Just Before 2nd Pulse

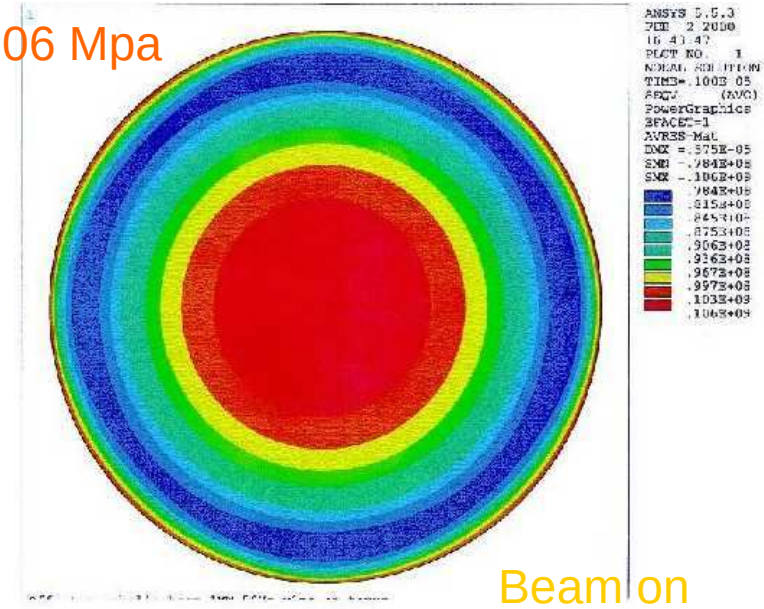


Just After 2nd Pulse

After 2nd Pulse

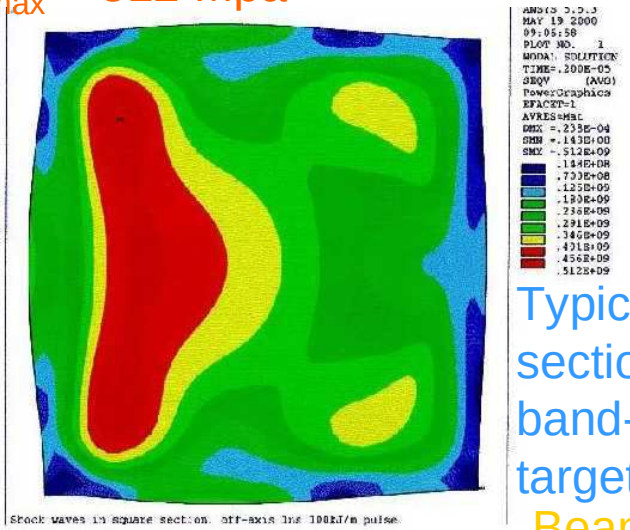
Shock Stresses in a Solid Target

σ_{max}=106 Mpa



Beam on axis

σ_{max} = 512 Mpa

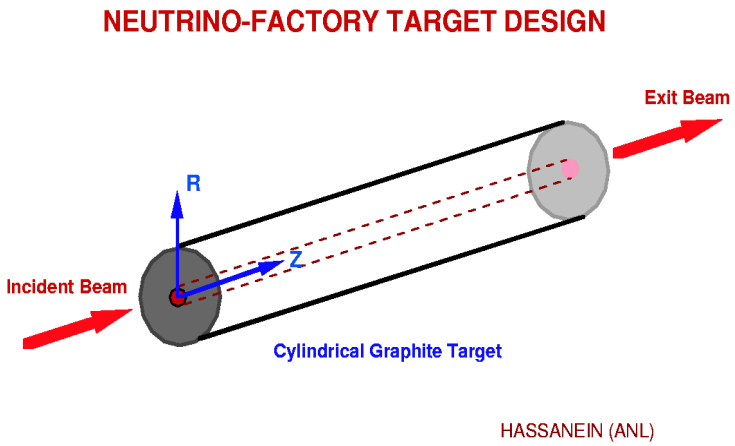


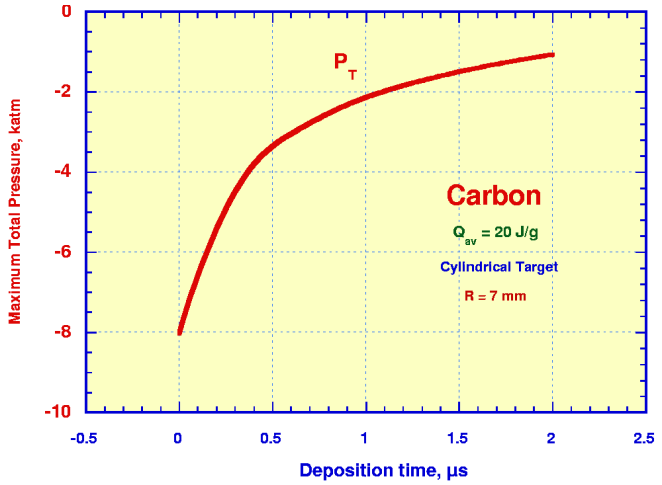
Typical section of band-saw target

Beam off center

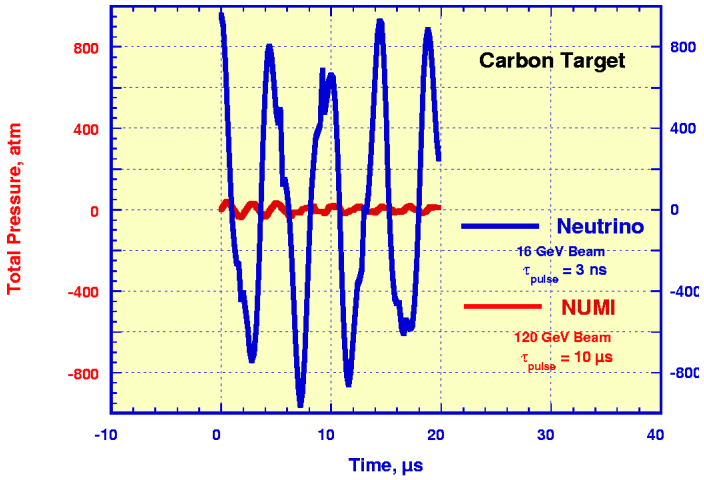
- 1 MW beam power at 50 Hz (200 kJ in 1 ns) on tantalum target
- Von Mies stress on target cross section after 1-2 μs.
- Larger σ_{eqv} on square target due to off center beam and reflected stress wave from boundary.

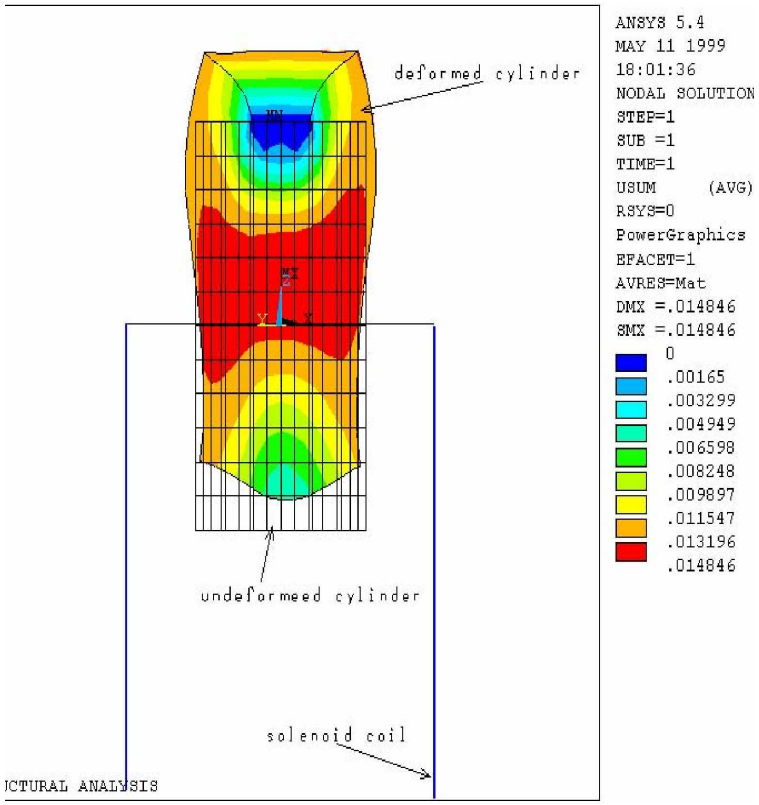
Carbon Target for a Neutrino Factory





- We see P_{total} ~90 MPa for 16 GeV beam giving 20 J/g in the target. This is sufficiently below the yield limit of the target.



Simulation of Hg Moving in B field

- Will a Hg jet distort as it enters into a magnetic field due to Eddy currents?
- Will non-axial components of the field destabilize the Hg jet?
- We will need simulations of liquid jets in a **B** field to understand the future tests at NHMFL where a Hg jet will be inserted into the solenoid.
- Both ANSYS and FronTier have capabilities that could be used for such a study.
- Initial studies using ANSYS with FLOTRAN have started. Results are premature at this point.