Target and Capture Simulations

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MUTAC Review

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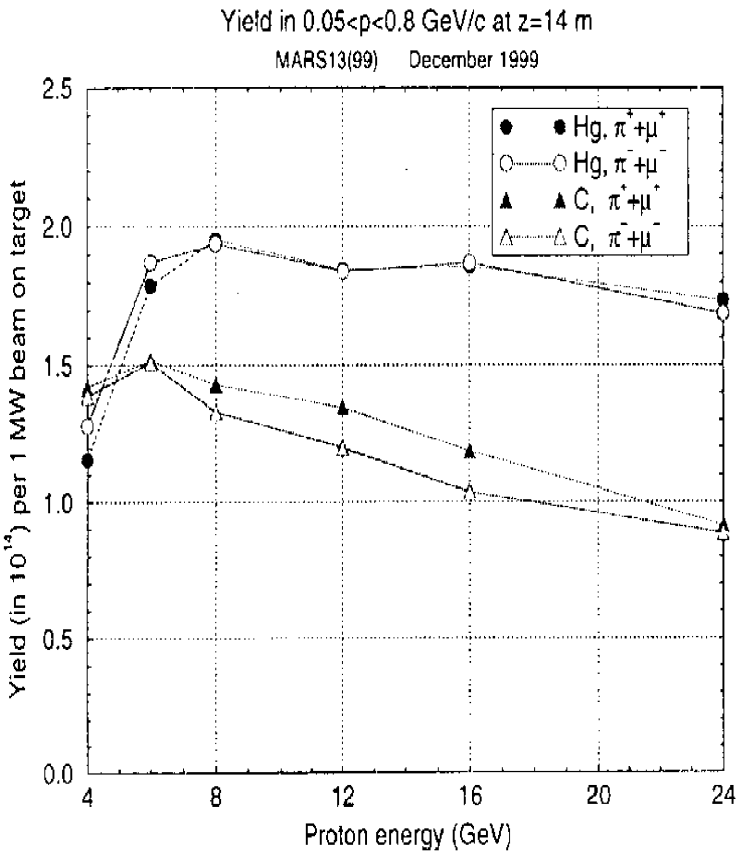
Simulation Topics

- 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)

Production and 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 codes 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.
  - Charged particle flow (other than π, μ) down the beam channel.
  - Detection aspects of E951 targeting experiment.
  - Particle phase space.

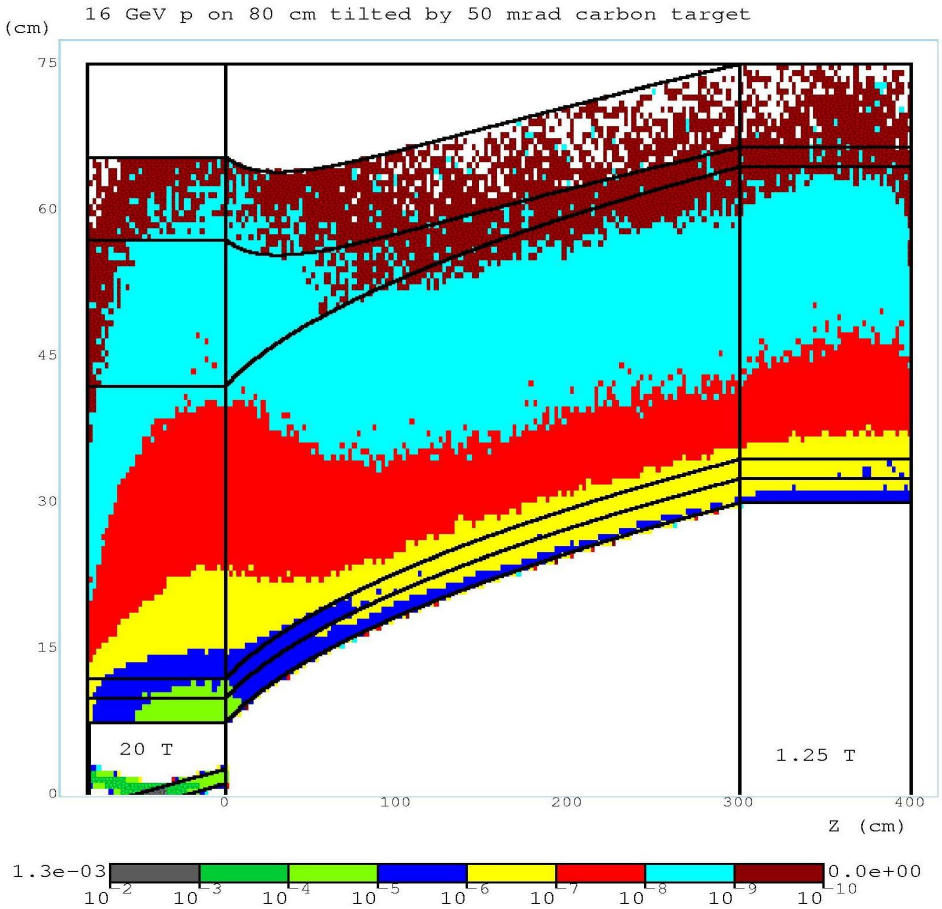
Meson Yields for Hg and C Targets for 16 GeV Protons



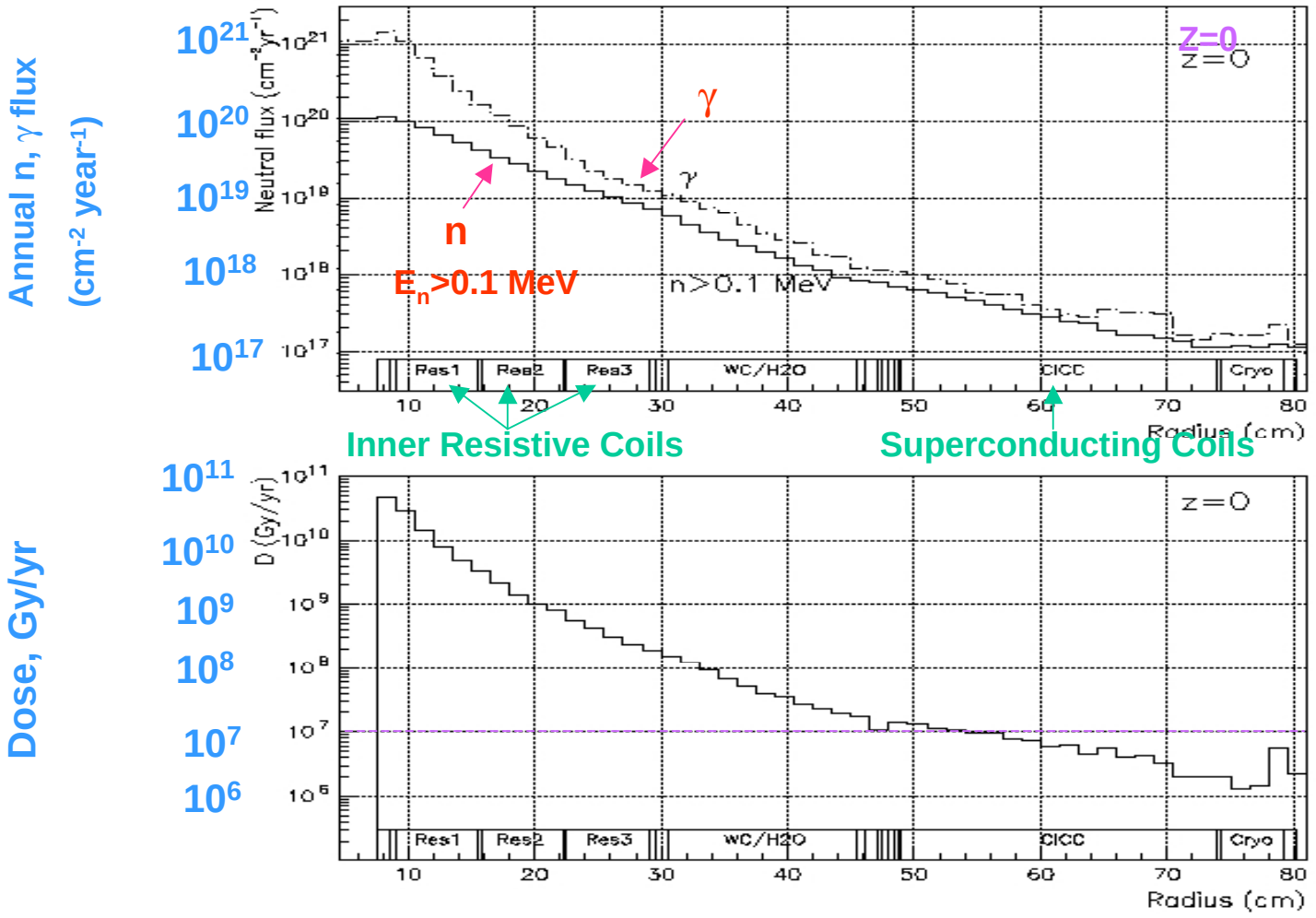
- Yield per beam power:
  - Approx constant for **Hg** target.
  - ~30% falloff for **C** target.
  - **Hg** target provides approx. twice the yield as **C** target at 24 GeV
- Yield is ~30% larger for 50 mrad tilted carbon target than no tilt.
- Capture yield saturates at 1.5 λ_{int}. Choose 2 λ_{int}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

Energy Deposition Near Carbon Target

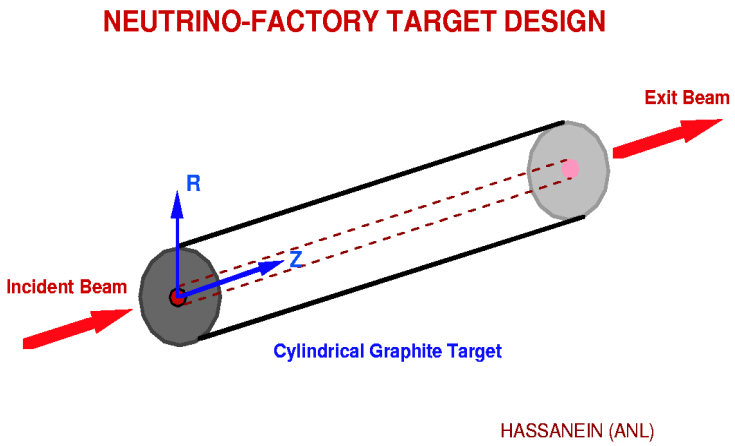
- 1.5 MW 16 GeV proton beam on a 50 mrad tilted carbon target

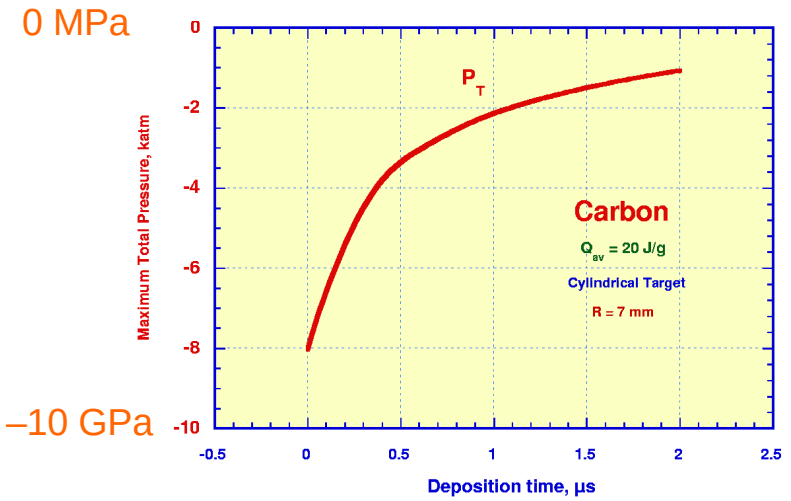


Radial Distribution of n and γ flux

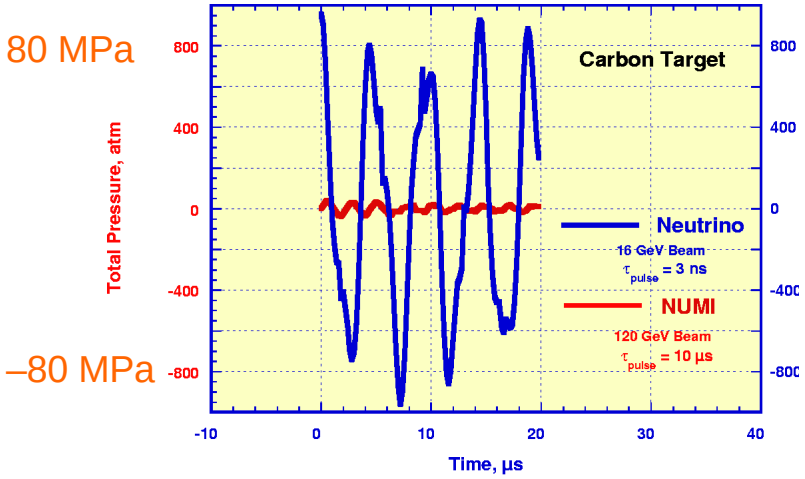


Carbon Target for a Neutrino Factory

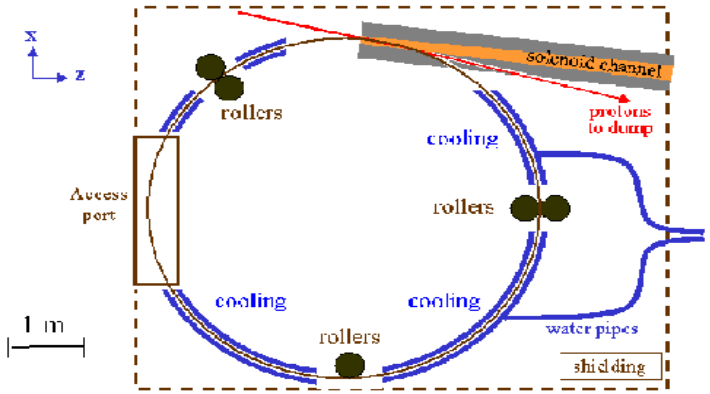




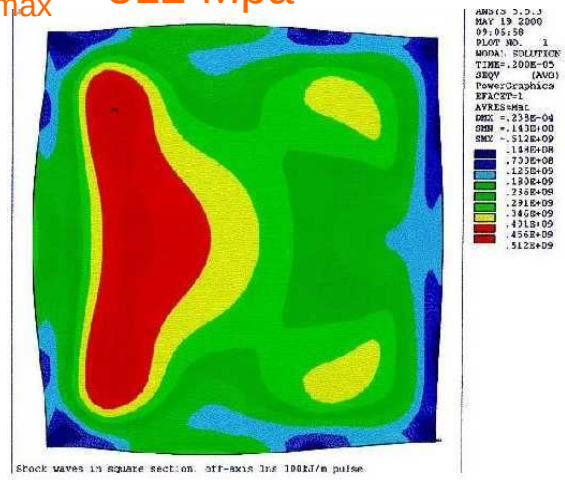
- We see P_{total} ~90 MPa for 16 GeV beam giving 20 J/g in the target. This is sufficiently below the yield limit of the target.



Shock Stresses in a Rotating Band Target



σ_{max} = 512 Mpa

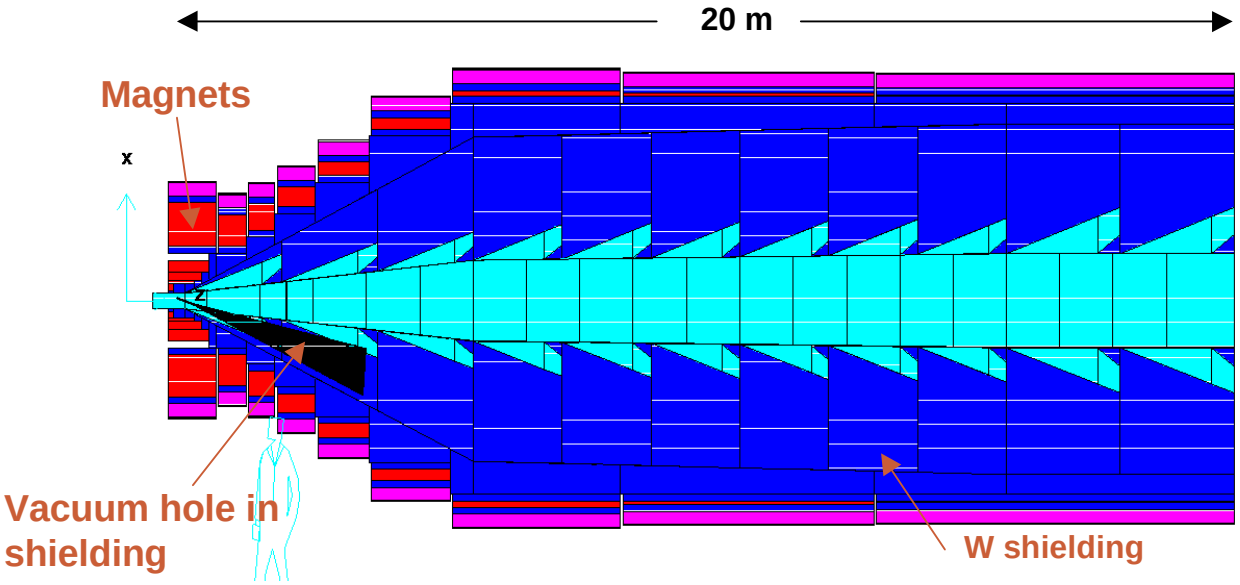


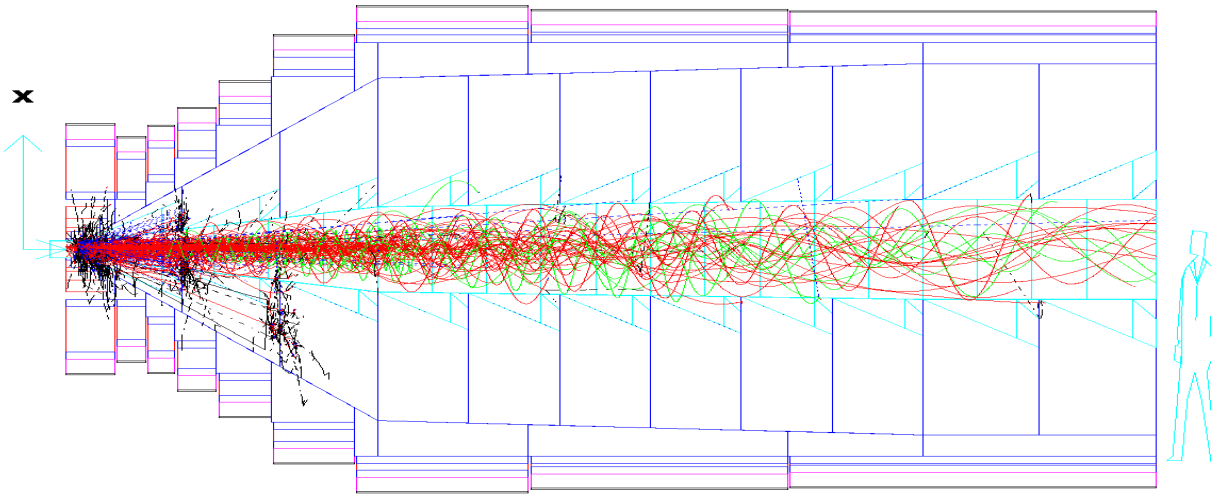
- Typical section of a rotating band target.
- 1 Mw beam power at 50 Hz (200 kJ in 1 ns) on tantalum target
- Plot shows Von Mises stress on target cross section after 2 μs.
- Large σ_{eqv} on square target due to the beam being off center and the reflected stress wave from the boundary.

Hg as an alternate to a C target

- The *feasibility study I* has shown that a **C** target appears workable solution up to 1.5 Mw.
- A high Z target could increase the μ yield by a factor of 2 at the same beam power.
  - The increased energy deposition in a high Z material favors the selection of a liquid metal target. Also a liquid target may potential go to a higher beam power than a solid target.
  - As **Hg** has a high resistivity, it is a desirable candidate.
- There are technological challenges associated to a **Hg** target. Much of the **Hg** target simulation studies is *work in progress*. A survey of these studies is presented.

GEANT Study of Hg Target Environment





- Lower figure shows typical proton on target.
- All particles have p>10 MeV/c
- Low energy neutrons not show for clarity.
- Significant charged particle flow down beam cavity:
  - **Desired μ and π.**
  - **Less desired p and e**

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

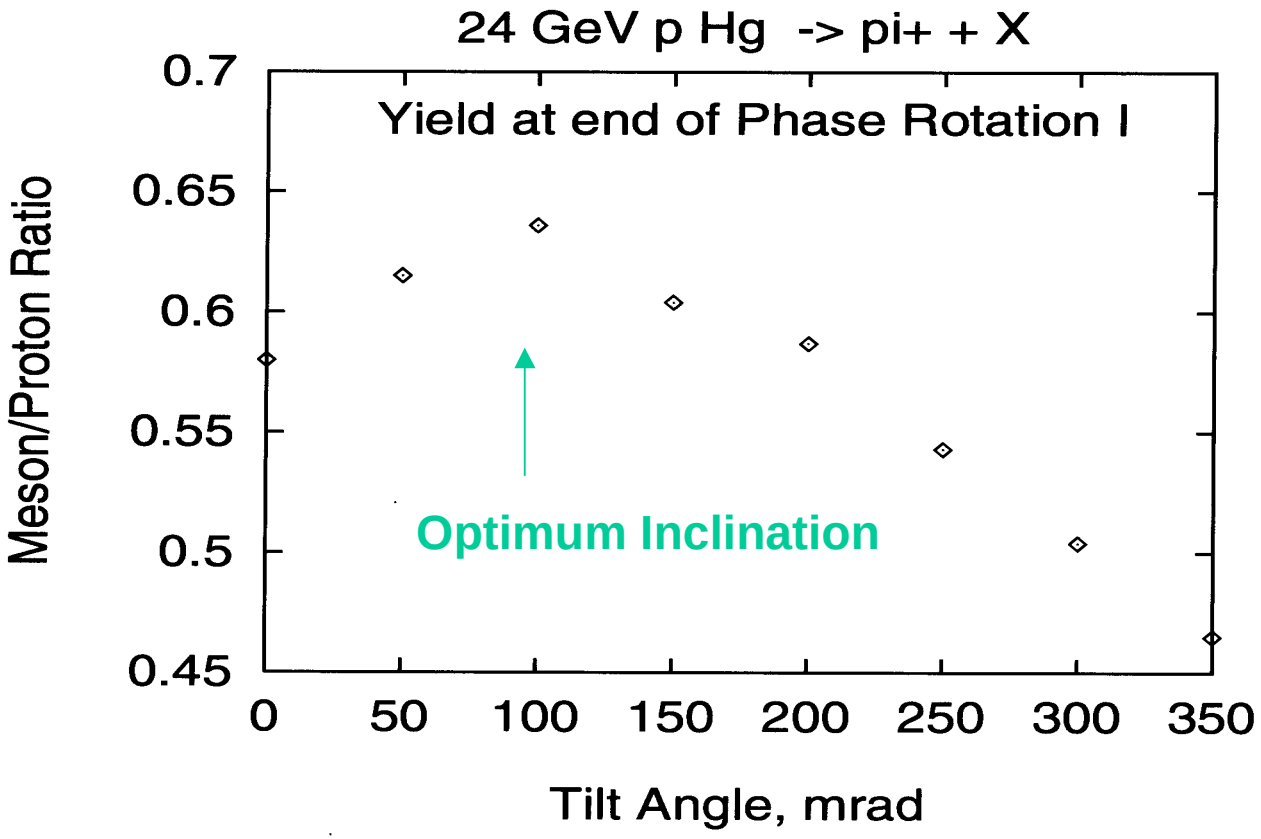
Particles Exiting Target

- 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.
- GEANT with FLUKA used
- 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. Expected to be less with 5 mm target.

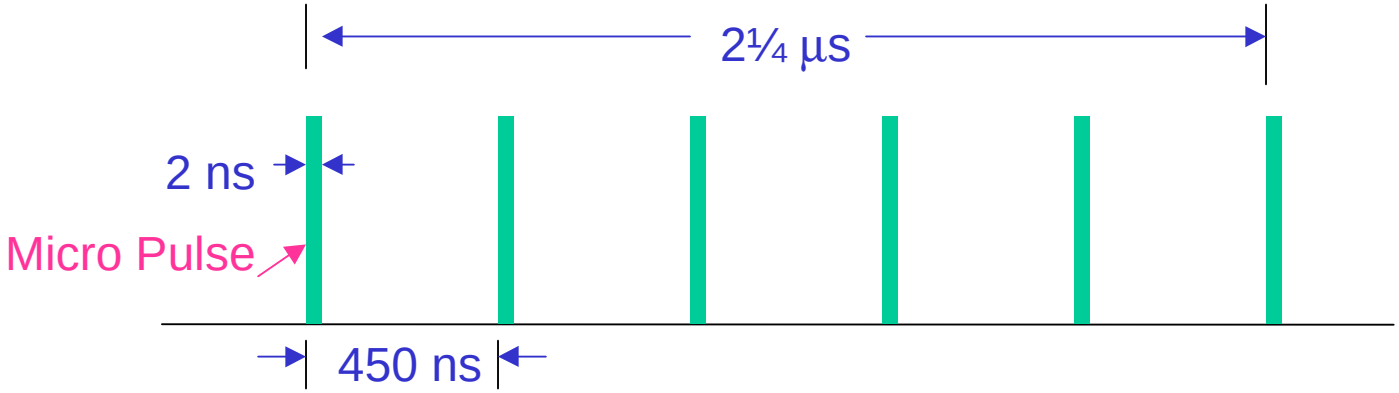
Variation of Target Inclination at 24 GeV



Study uses MARS for production and ICOOL for transport.

Time Structure of the AGS Beam

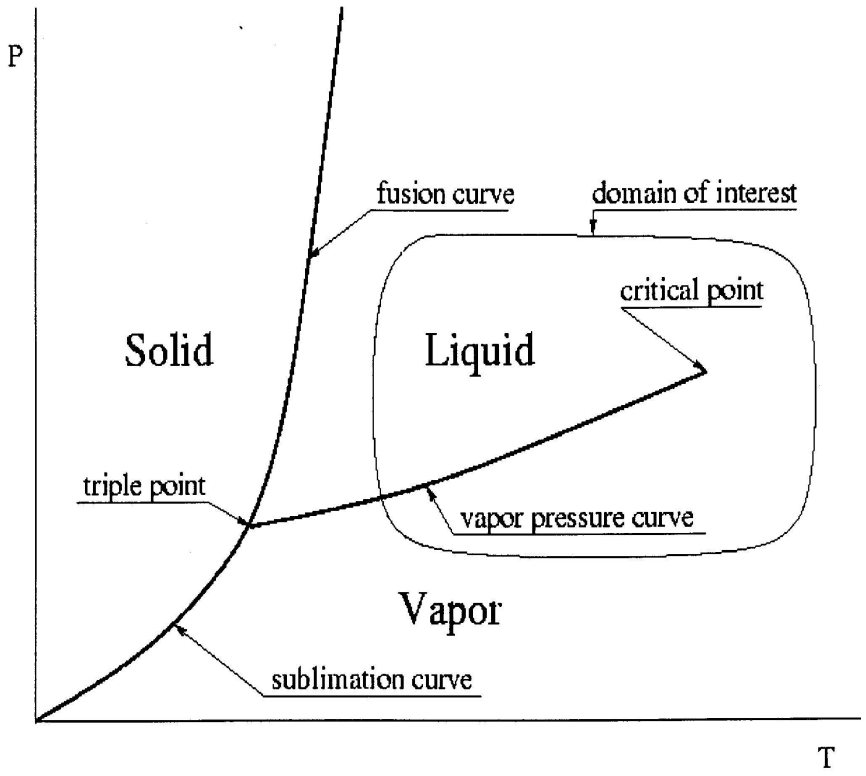
•For the simulations of the Hg target, a beam with the time structure of the AGS has been used. A micro-pulse structure tends to increase the instantaneous pressures in the target.



•100 TP (total) of 24 GeV protons are deposited in 6 micro-pulses.

•Peak energy per micro-pulse is 87.36 joule/gram.

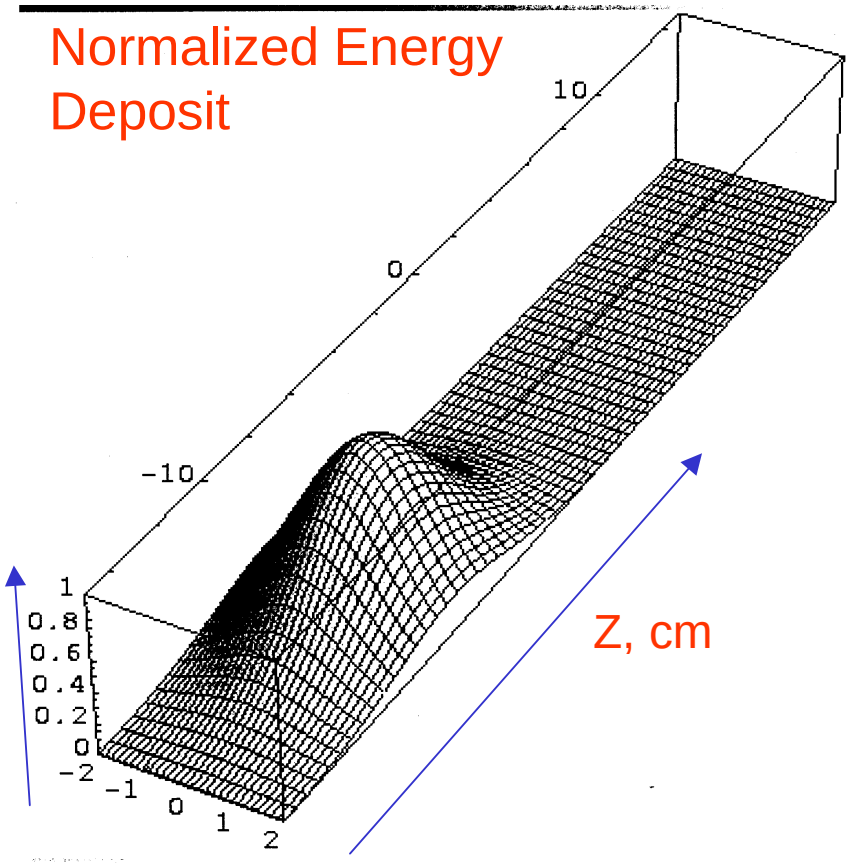
Mercury Phase Diagram



- 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

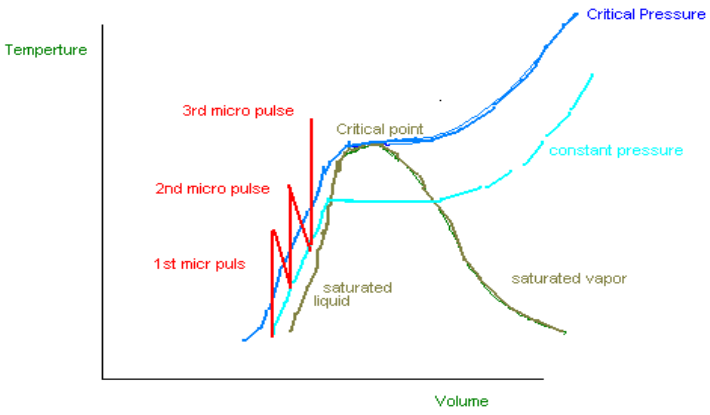
Beam Energy Deposition in Hg Target

- 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 temperature 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.

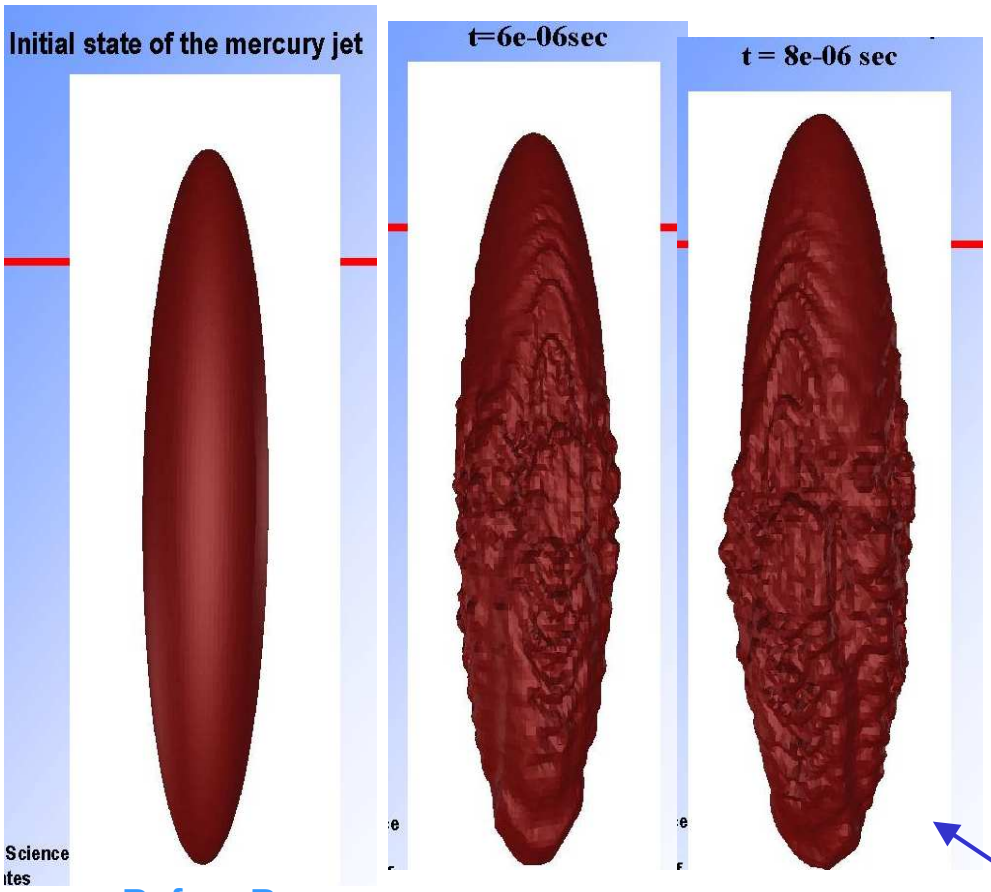


- Temperature is above critical after 3rd micro-pulse.
- Pressure wave will not hit boundary in 2.25 μsec.

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 State
  - 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

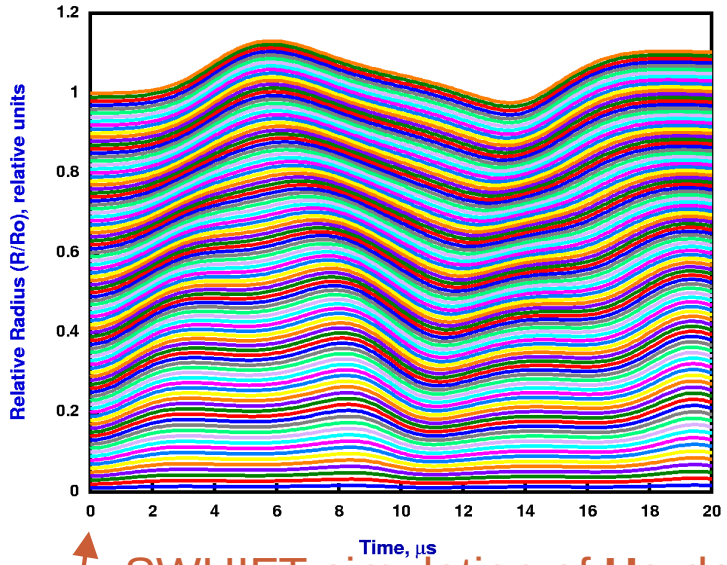


Before Beam Pulse

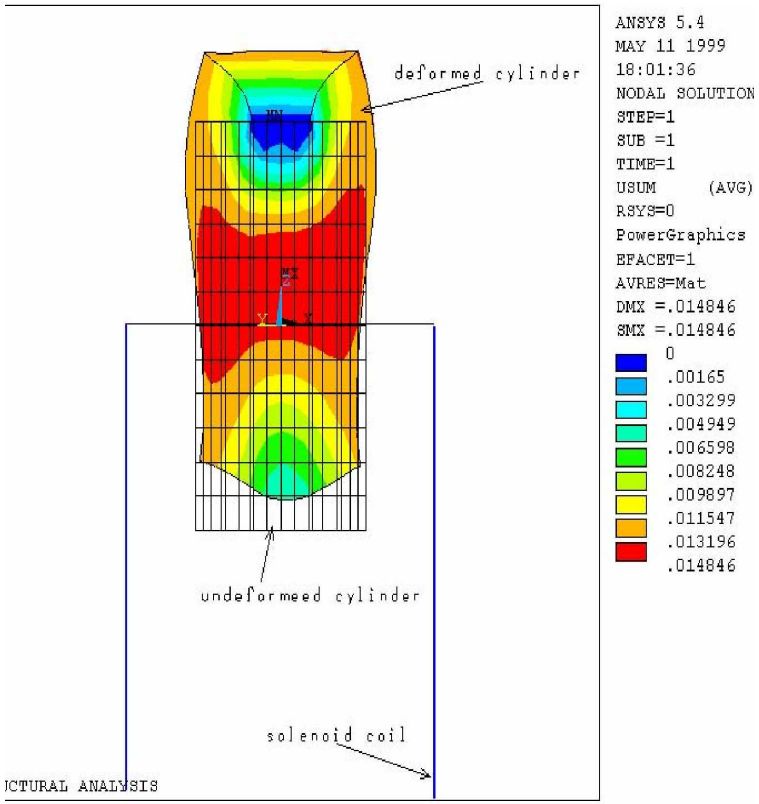
After Beam Pulses

FronTier simulation of time evolution of **Hg** target

Mercury Jet with 4 mm Beam and B-field Diffused in



SWHIFT simulation of **Hg** density (r/r_o) as a function of time. This shows acoustic stock waves.

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.