Application of LHC and SPS (HiRadMat) to Study High Energy Density States in Matter

By

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Design Parameters of the LHC Beam

LHC will provide two counter rotating 7 TeV proton beams

Each beam will consist of 2808 proton bunches

Each bunch will contain 1.15×10^{11} protons

Total number of protons is 3×10^{14}

Bunch length = 0.5 ns, Separation between bunches = 25 ns

Total length of the bunch train = 89 μs

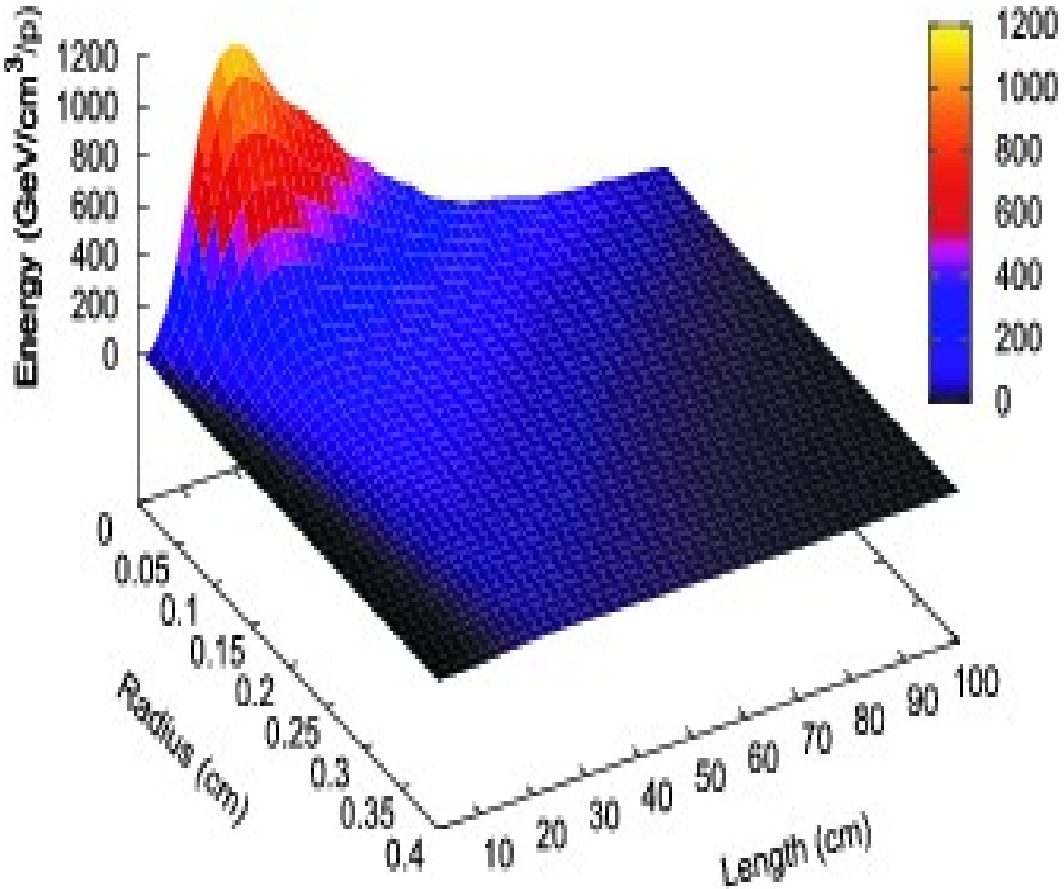
Transverse intensity distribution: Gaussian with $\sigma = 0.2$ mm

362 MJ energy / beam sufficient to melt 500 kg copper

First Step: Energy loss of 7 TeV protons in solid copper target is calculated using the FLUKA Code

Target Geometry:

- **Solid Cu Cylinder**
  L = 5 m, r = 1 m
- **Peak energy deposition**
  1200 GeV/proton/cm^3

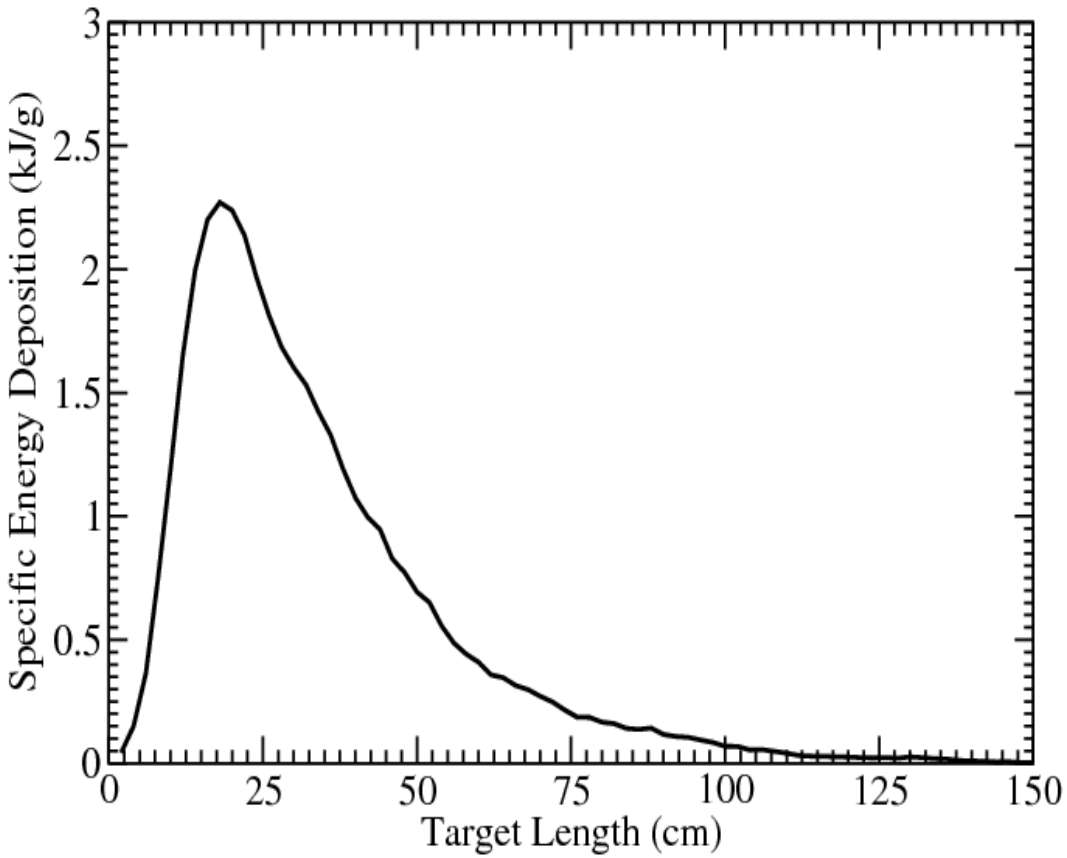


Second Step:

This energy loss data is converted into kJ/g and is used as input to a 2D hydrodynamic computer code, BIG2.

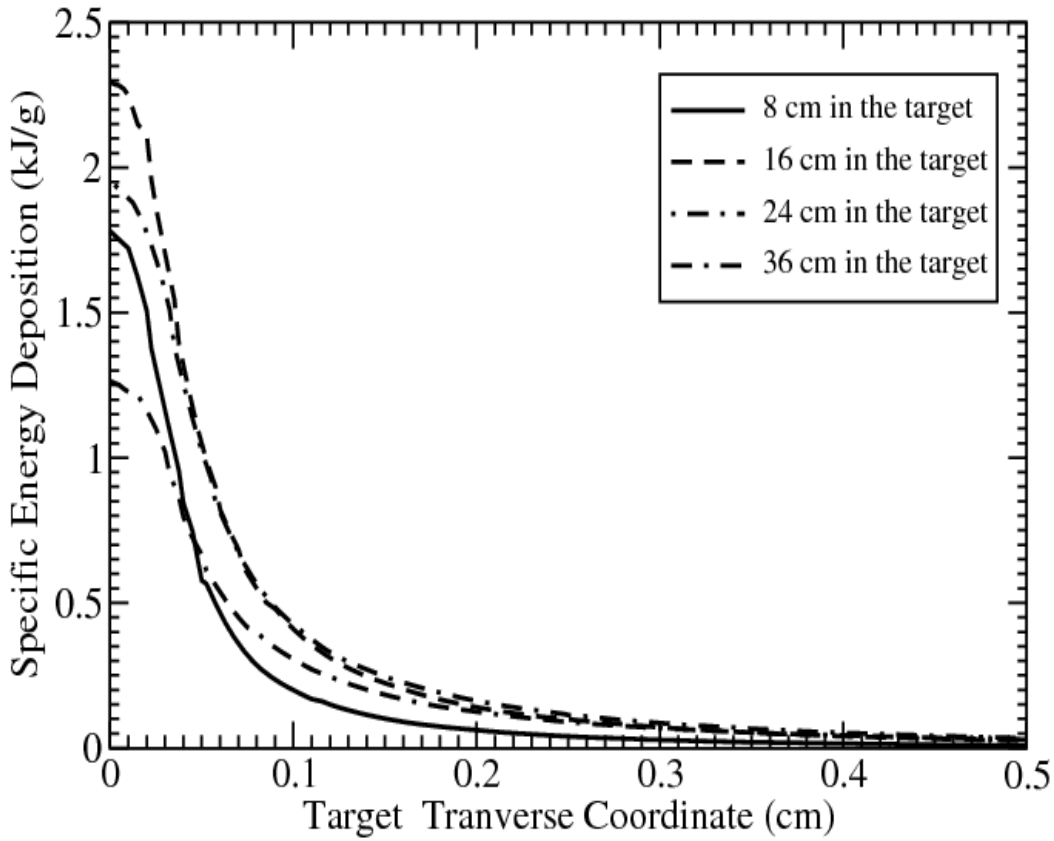
Specific Energy Deposition by a Single Bunch in Solid Copper [FLUKA Calculations]

- Specific energy (**kJ/g**) deposited by one bunch of protons along L at r = 0.
- Maximum deposition of about **2.3 kJ/g** occurs at **L ~ 16 cm.**



Specific Energy Deposition in Radial Direction Along the Target Axis

Specific energy deposition (**kJ/g**) vs radius at, L = 8 cm, **16 cm**, 24 cm and 36 cm, by a single proton bunch.

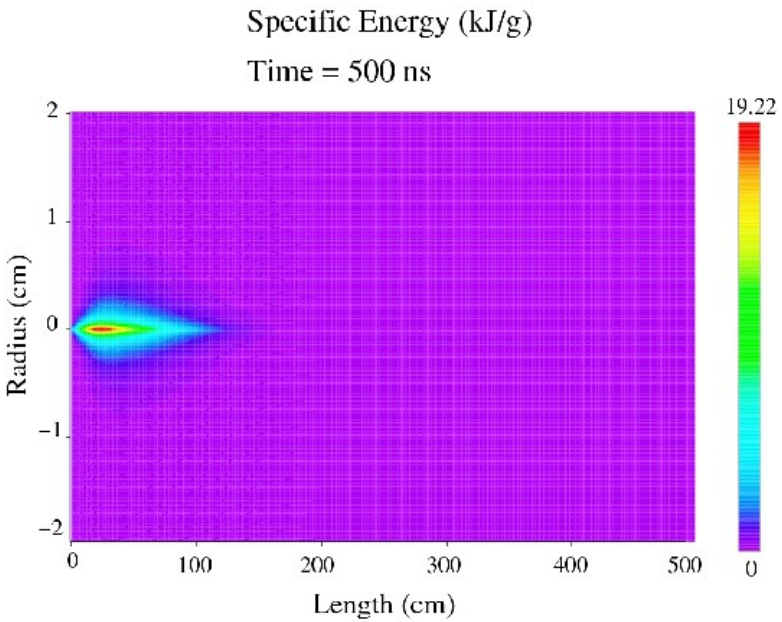


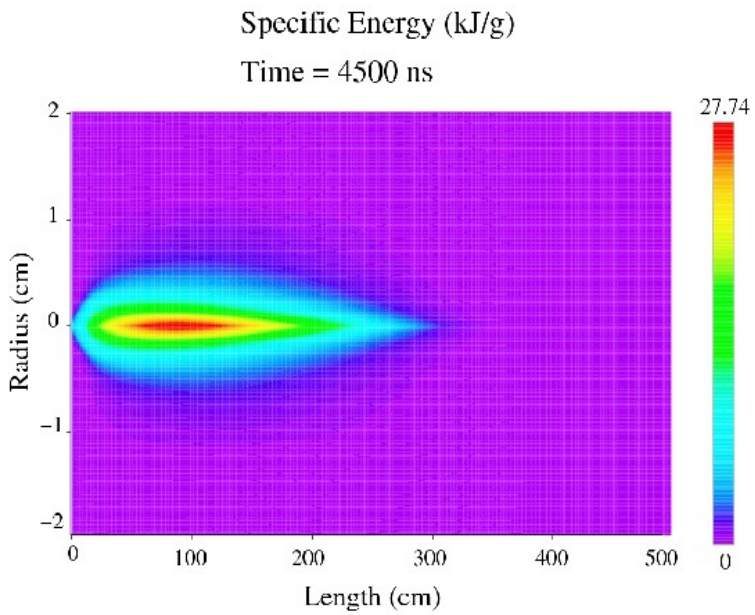
- **The target is studied in r-Z geometry.**
- **Specific energy deposition in each simulation cell at every timestep is normalized with respect to the line density along the axis.**
- **This allows for reduction of specific energy deposition in low density part of the target.**
- **This model allows for studying the proton "Tunneling Effect".**

I : <u>LHC Beam on a Solid Copper Cylinder</u>

L = 5 m

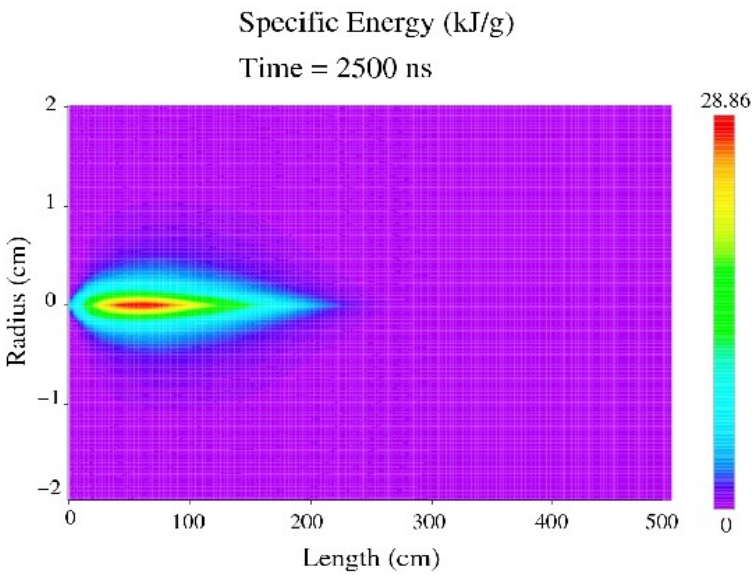
r = 5 cm

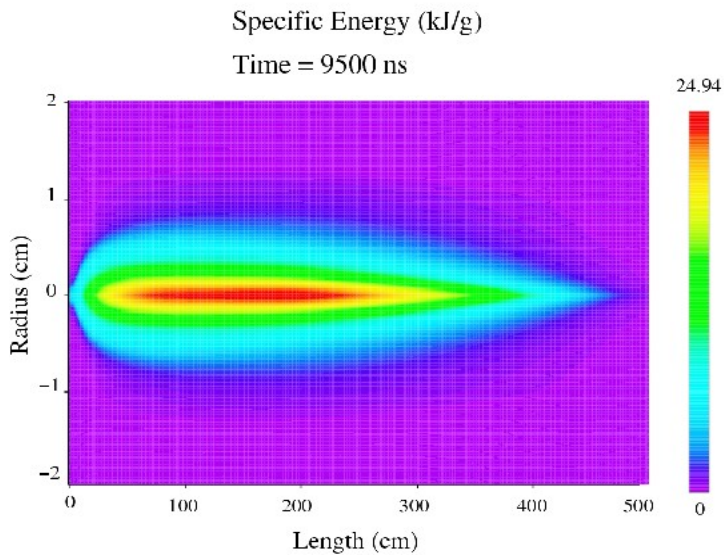


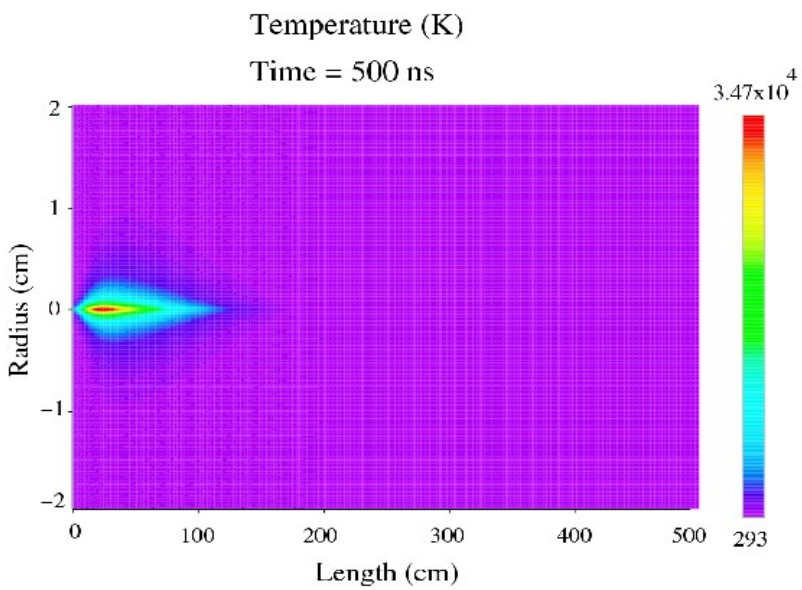


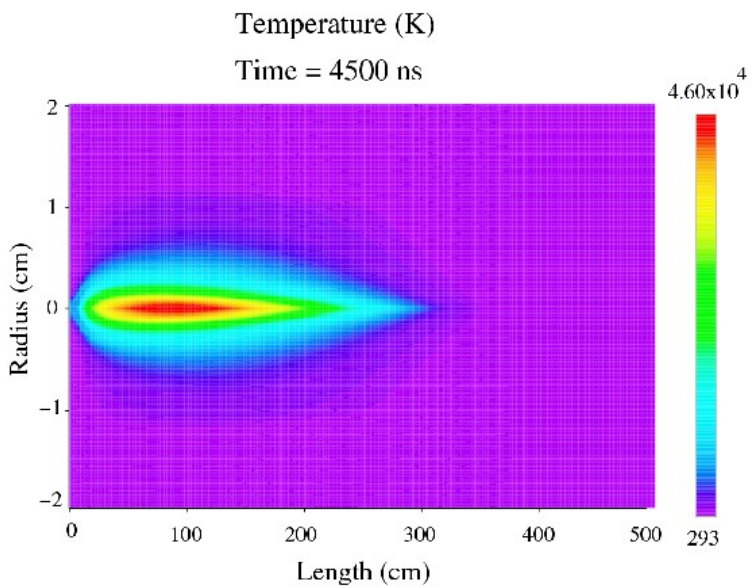
Specific Energy Deposition

Saturates to 25 kJ/g



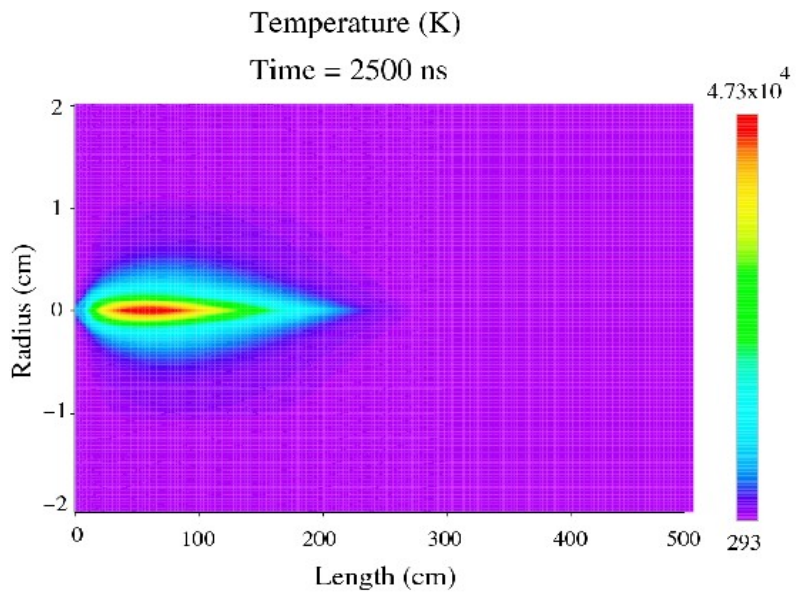


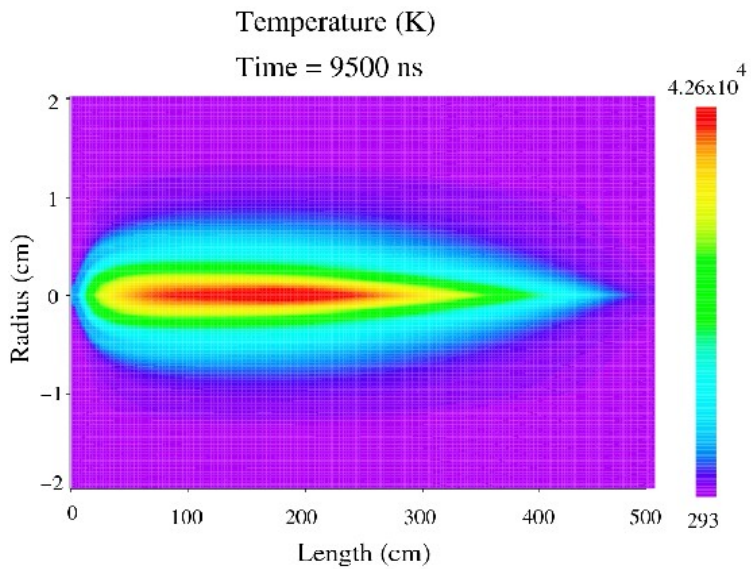


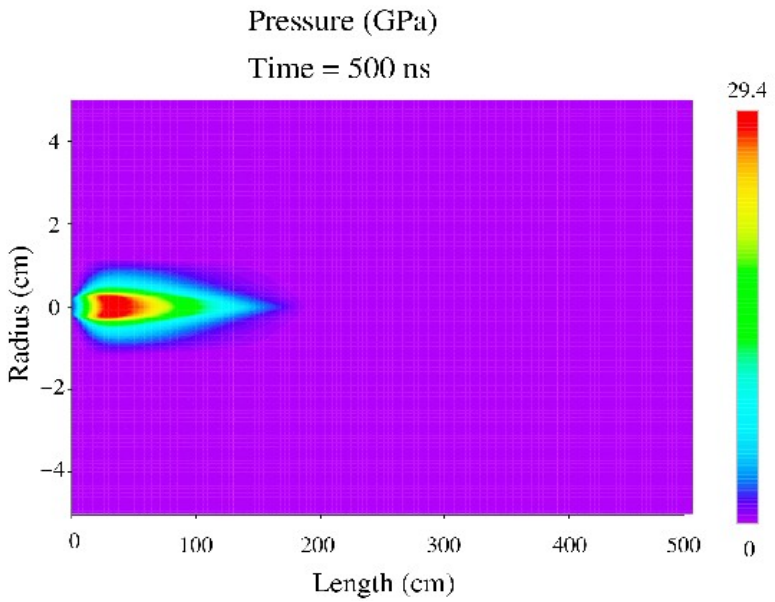


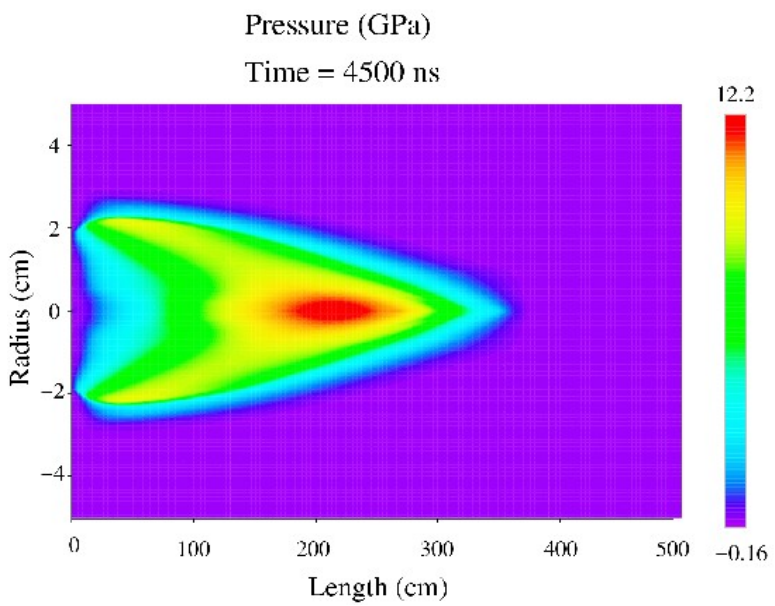
Temperature

$4x10^4$ K



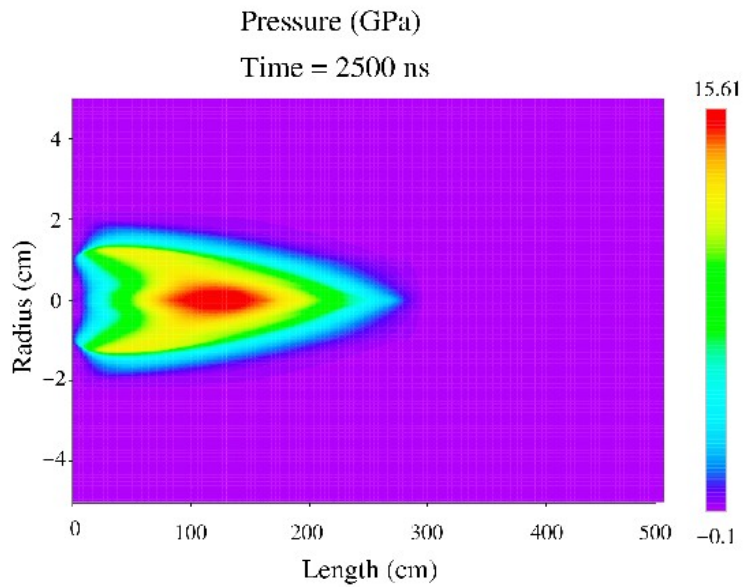


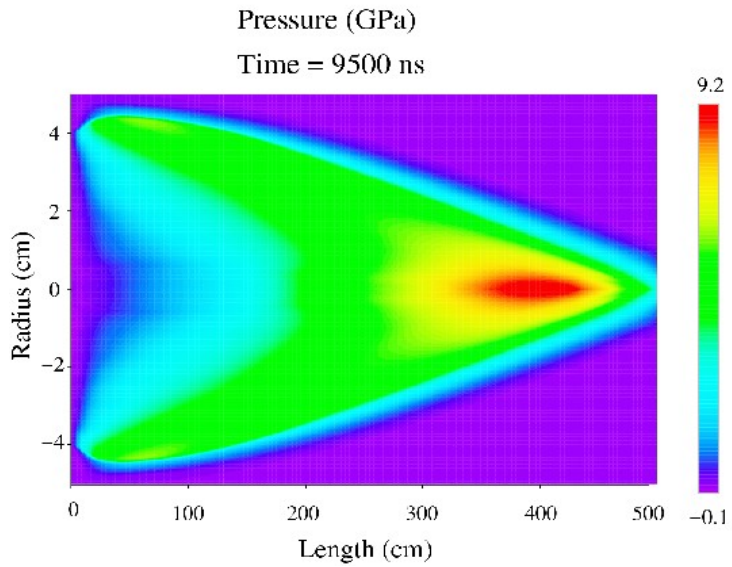




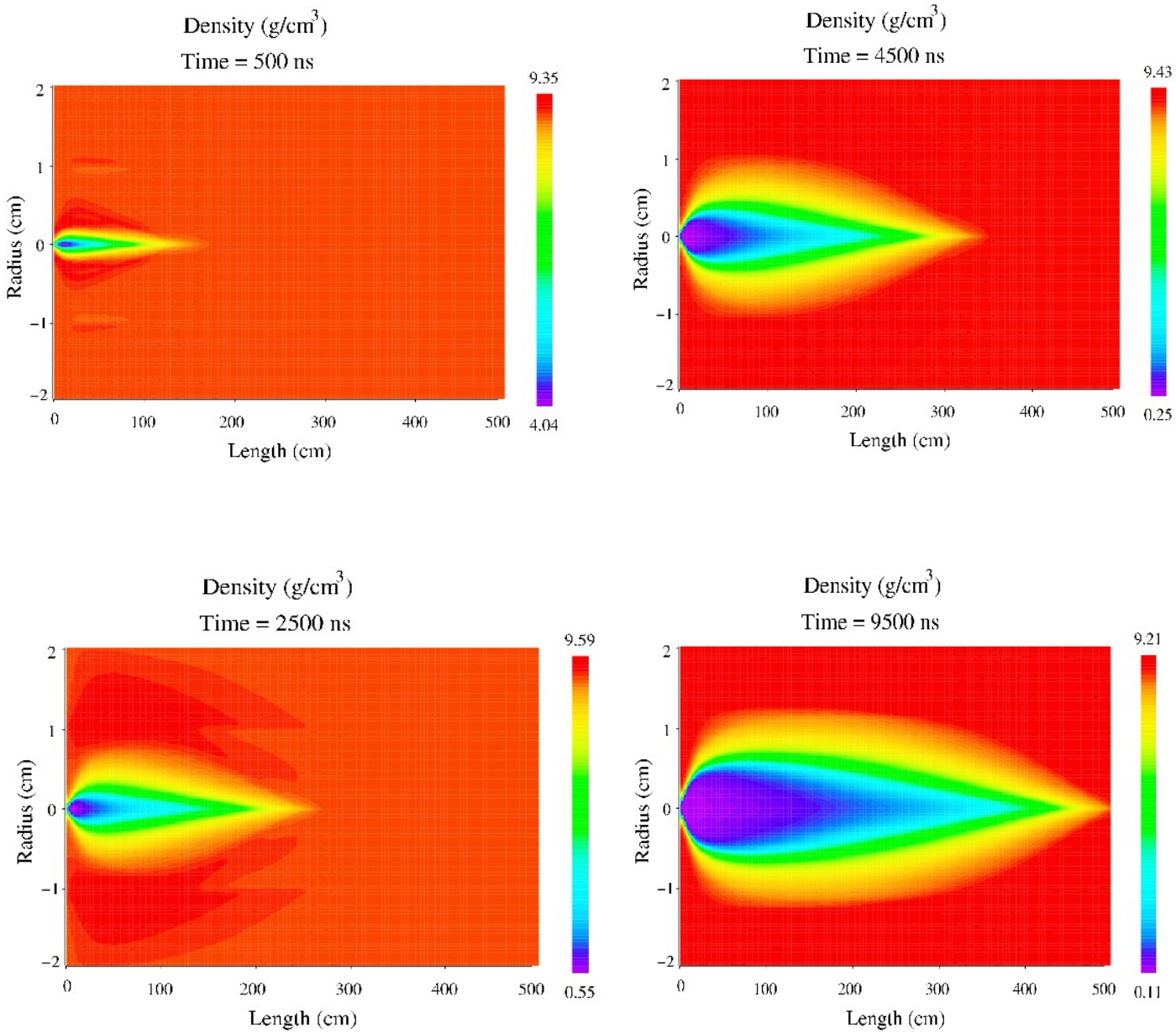
Pressure

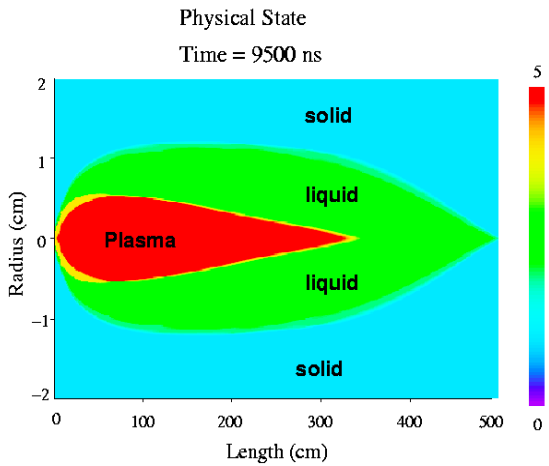
30 GPa





HEDP States





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- ***JAP 97 (2005) 083532.***
- ***PRL 94 (2005) 135004.***
- ***PRE 79 (2009) 046410.***

Penetration depth = 35 m

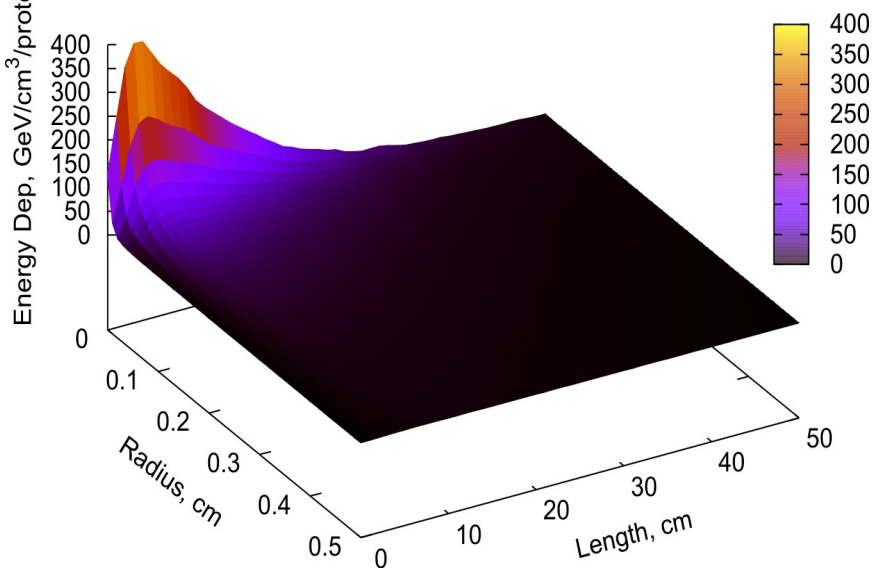
II: SPS Beam on a Tungsten Target (HiRadMat Facility)

- SPS Beam accelerates protons to 450 GeV
- 288 bunches in the beam
- Each bunch contains 1.15×10^{11} protons
- Total number of protons is about 3×10^{13}
- Bunch length = 0.5 ns, Separation between bunches = 25 ns
- Total length of the bunch train ~ 7 μs
- Transverse intensity distribution: Gaussian with
  σ = 0.088 mm, 0.28 mm and 0.88 mm

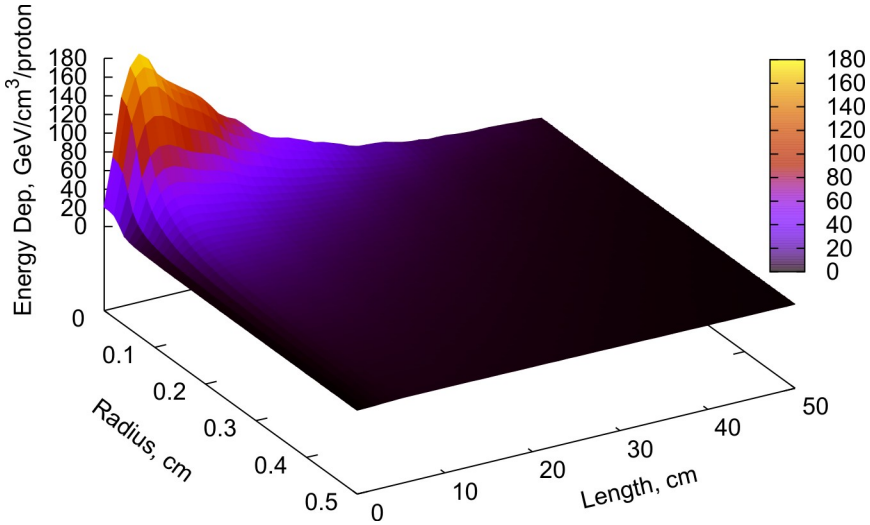
Solid tungsten cylindrical target facially irradiated

FLUKA Energy Loss Calculations [GeV/cc/p]

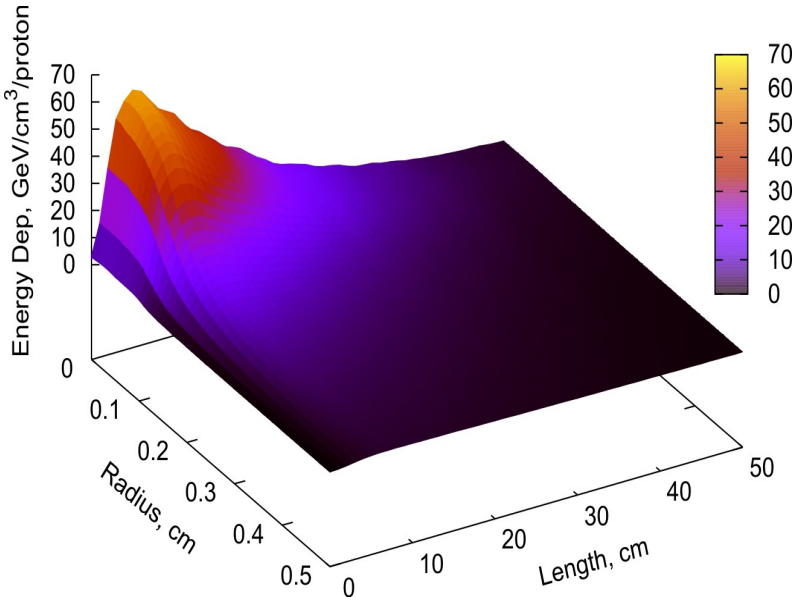
σ = 0.088 mm



σ = 0.28 mm

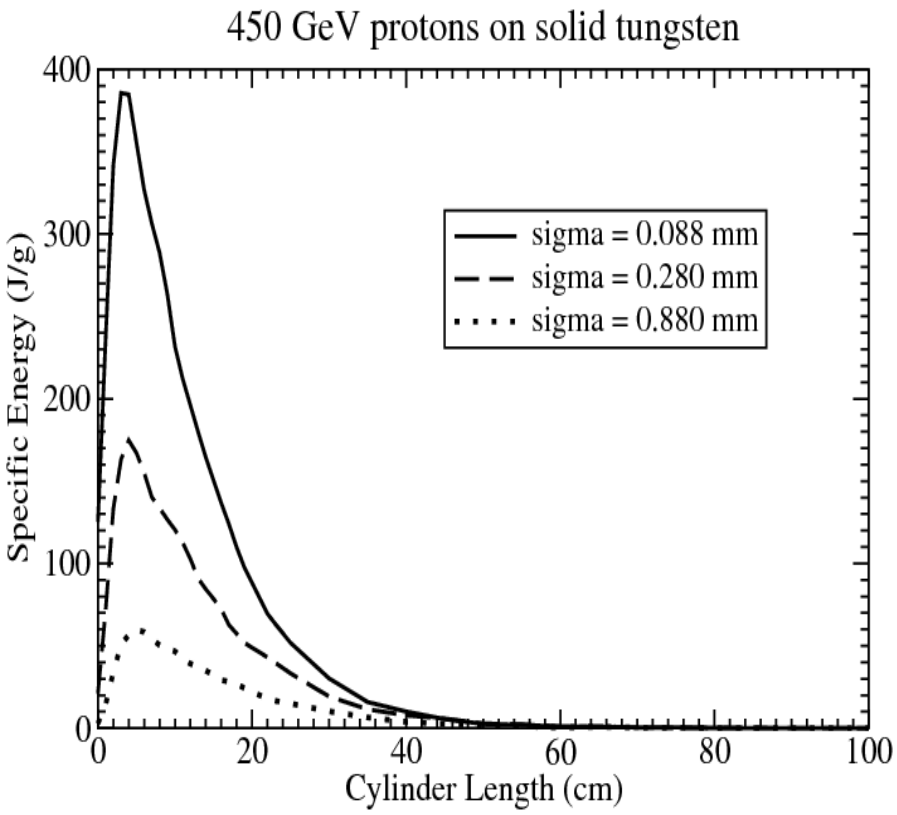


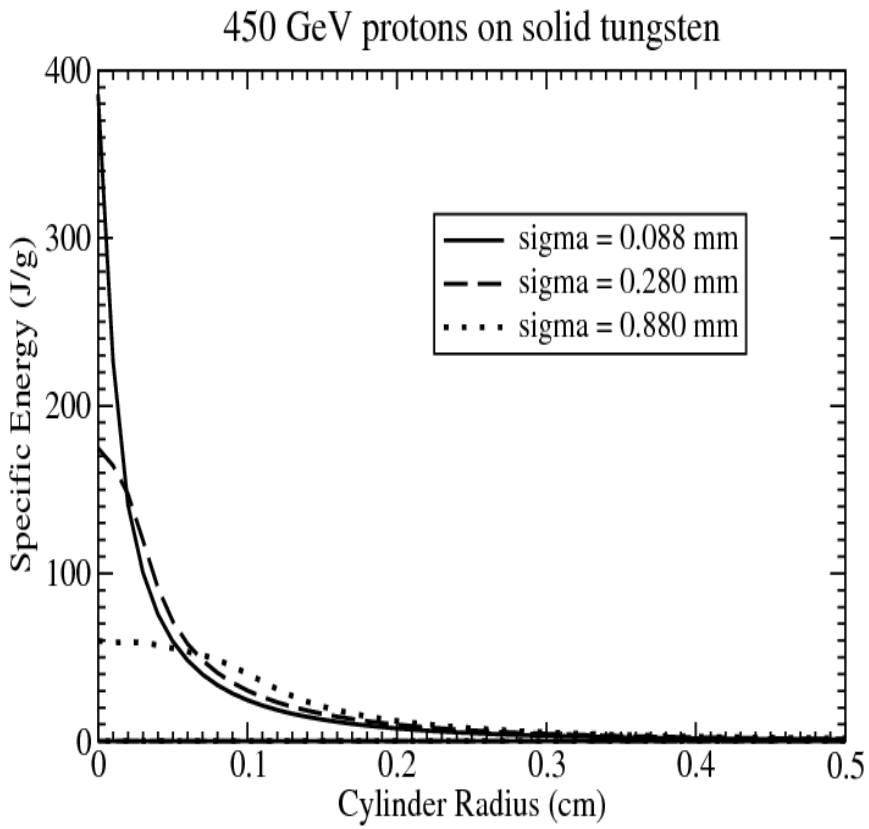
σ = 0.88 mm



FLUKA Calculations of Energy Loss

Specific Energy Deposition per Bunch

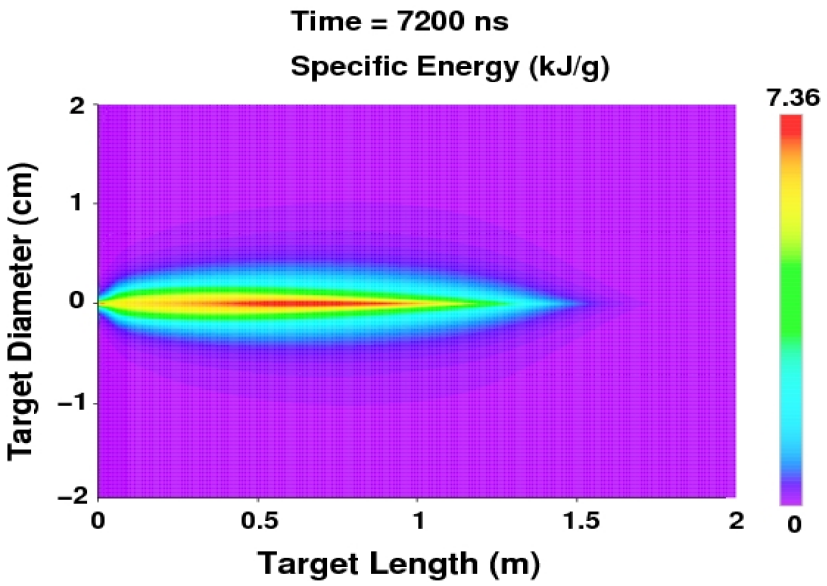




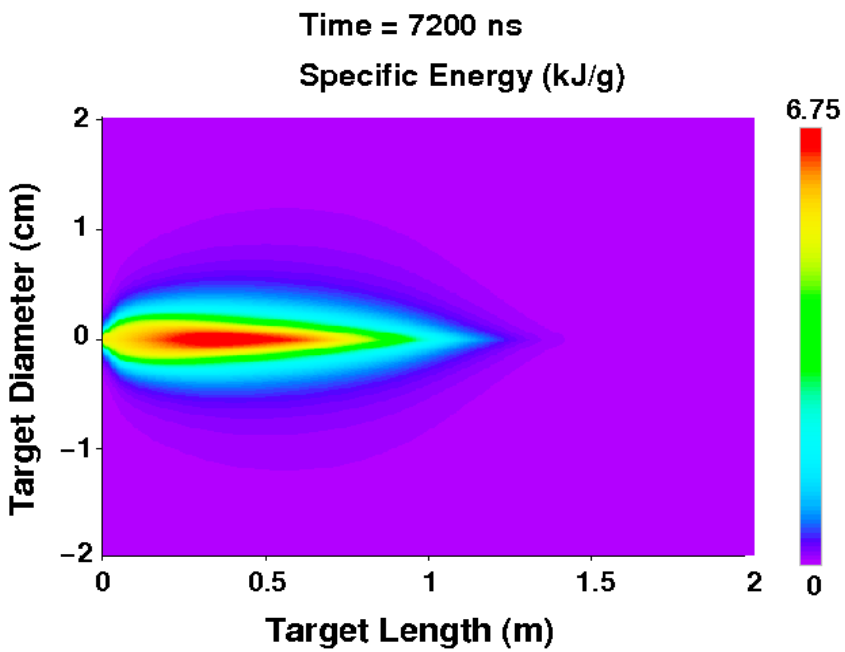
Solid tungsten cylinder L = 2 m, r = 5 cm

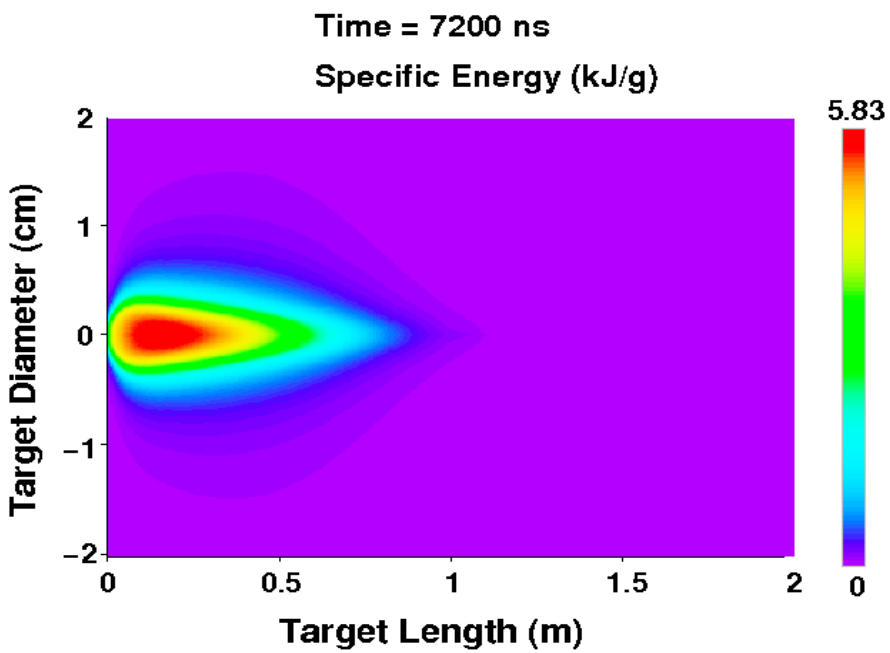
Facially irradiated by the SPS beam

Specific Energy Deposition (7.2 μs)

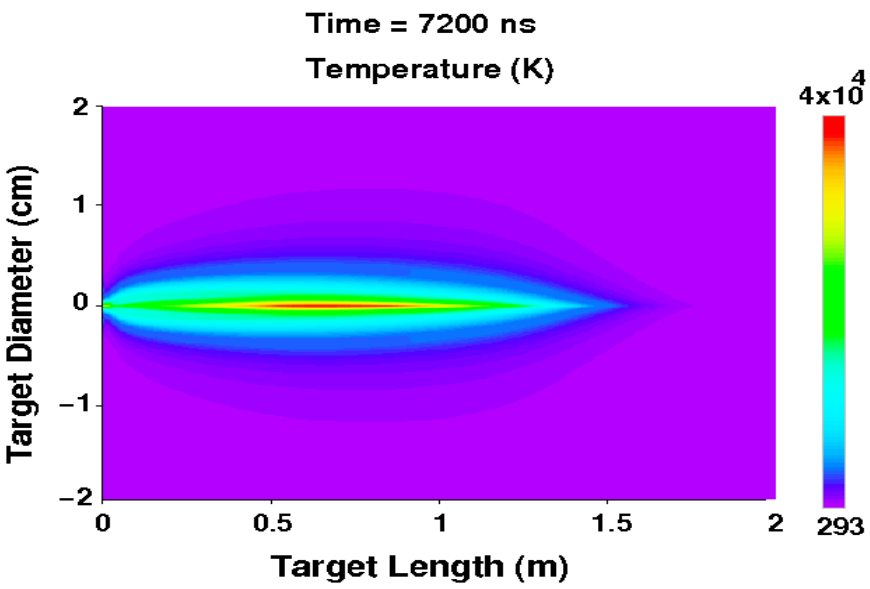


σ (mm)	E_s (kJ/g)
0.088	7.4
0.280	6.75
0.880	5.83

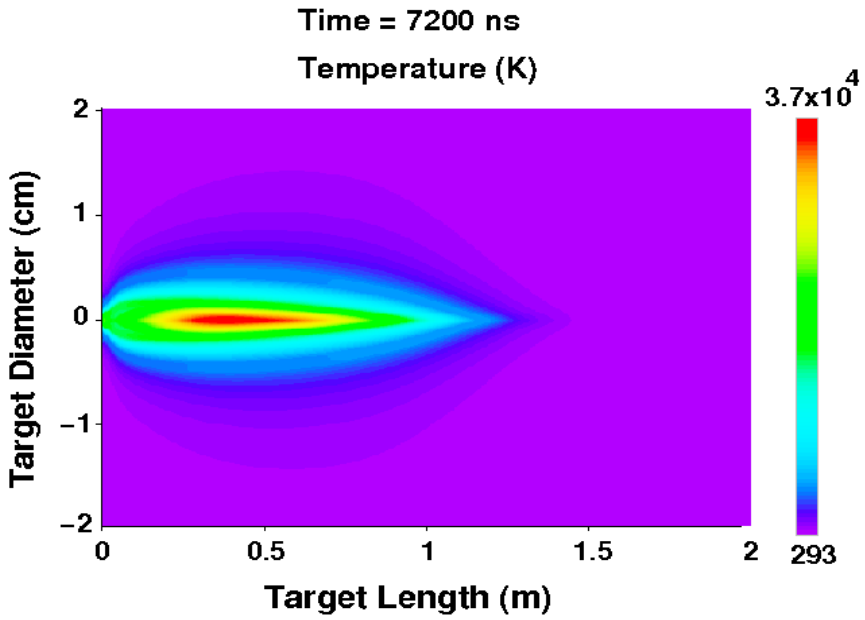


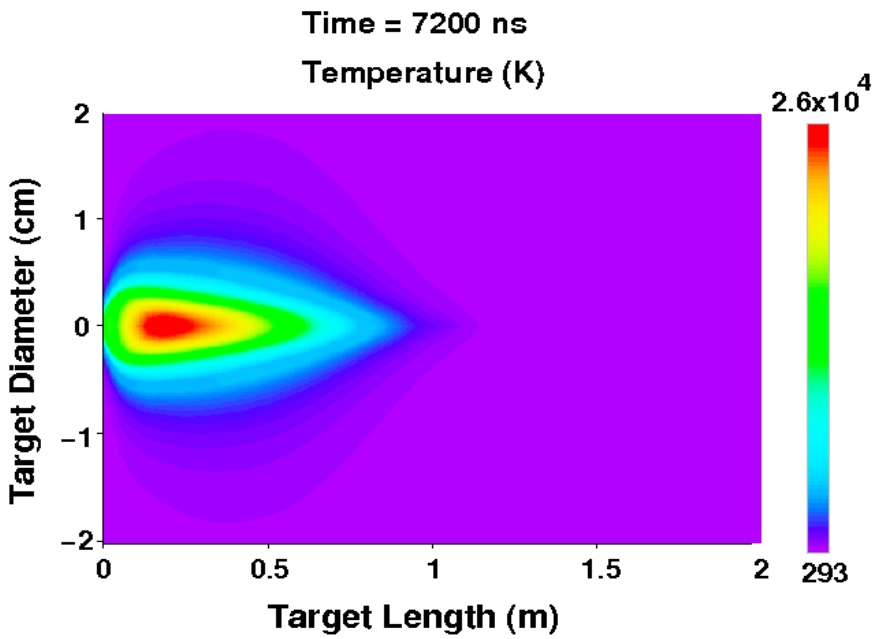


Temperature (7.2 μs)

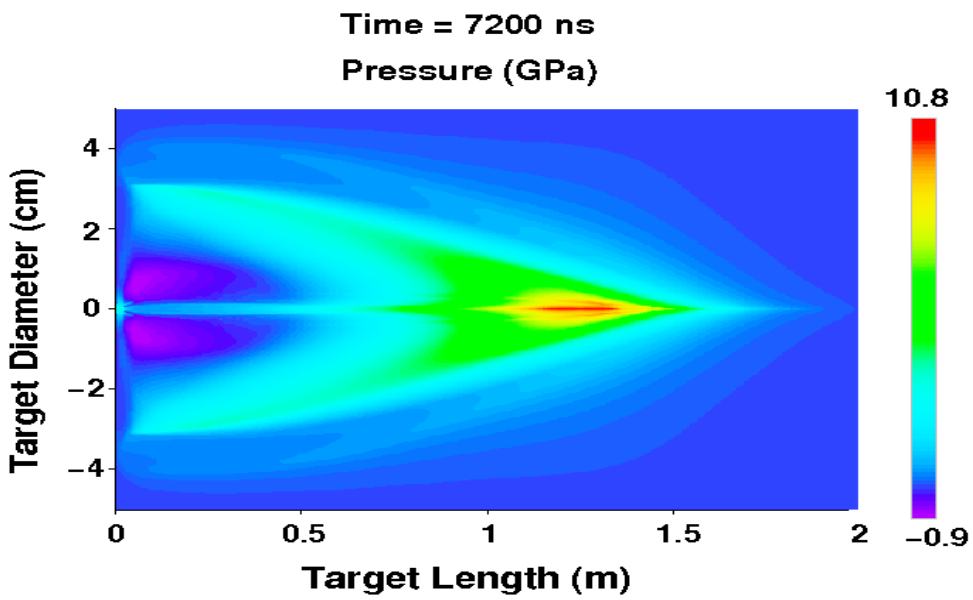


σ (mm)	T(10^4 K)
0.088	4.0
0.280	3.7
0.880	2.6

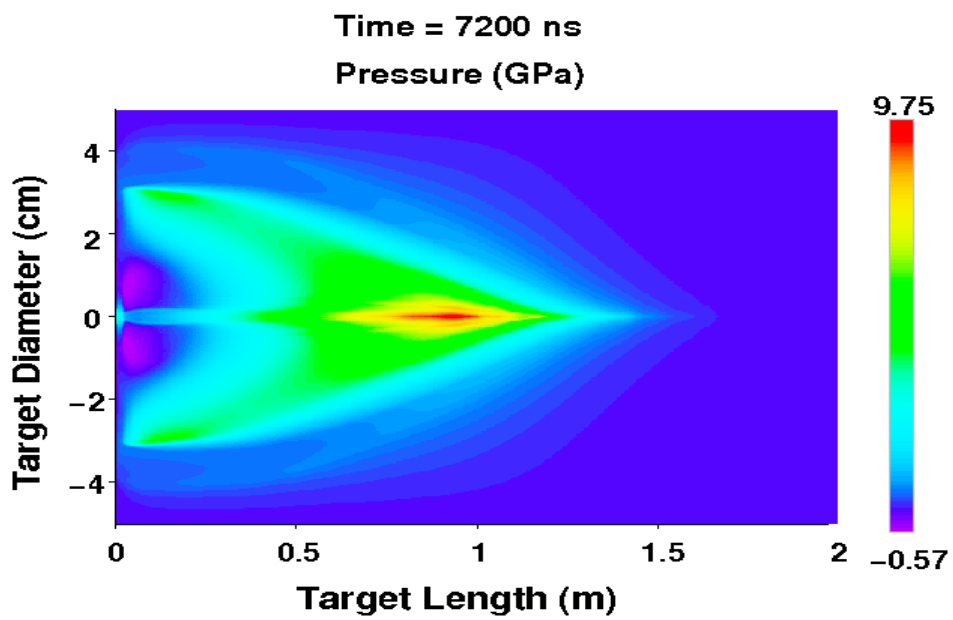


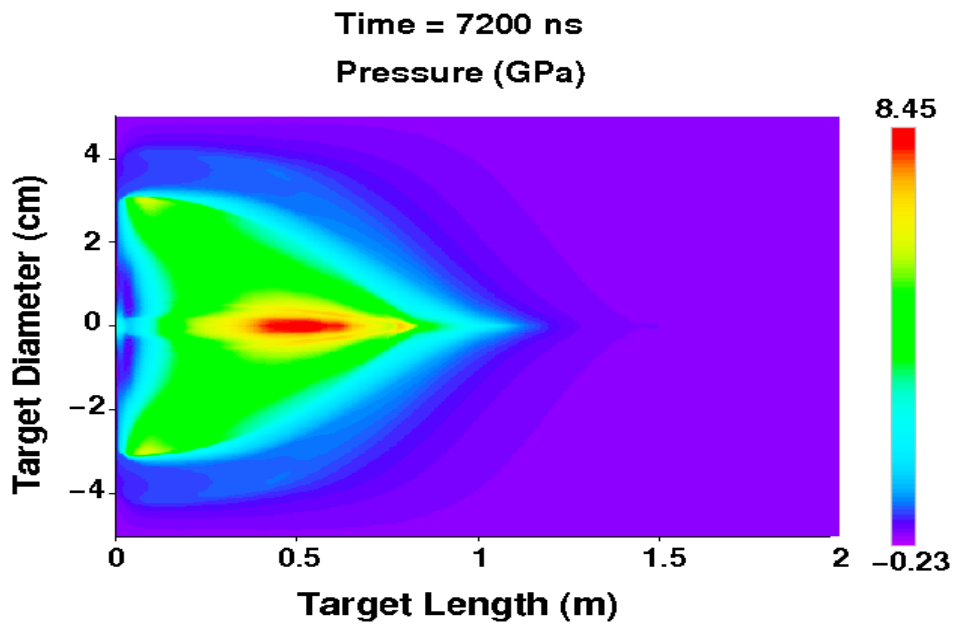


Pressure (7.2 μs)

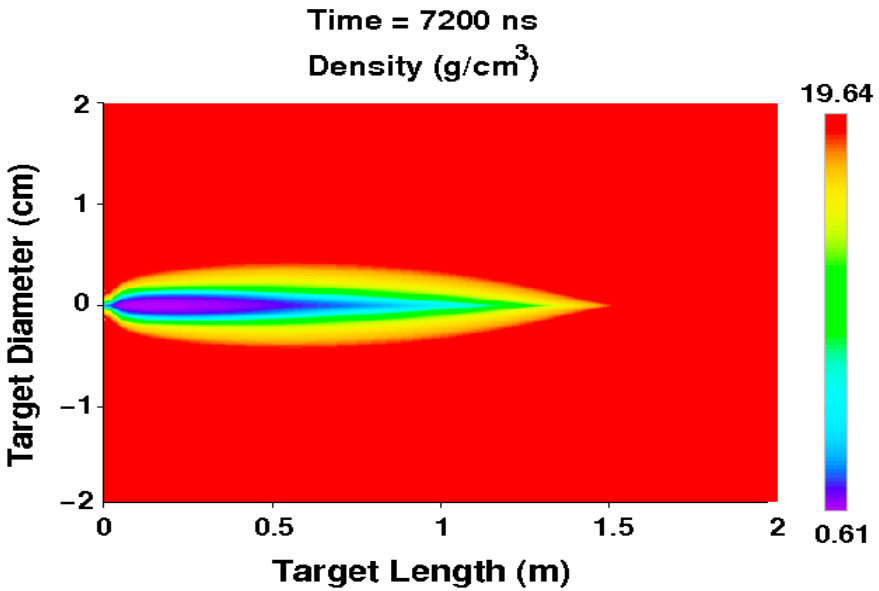


σ (mm)	P(GPa)
0.088	10.8
0.280	9.75
0.880	8.45

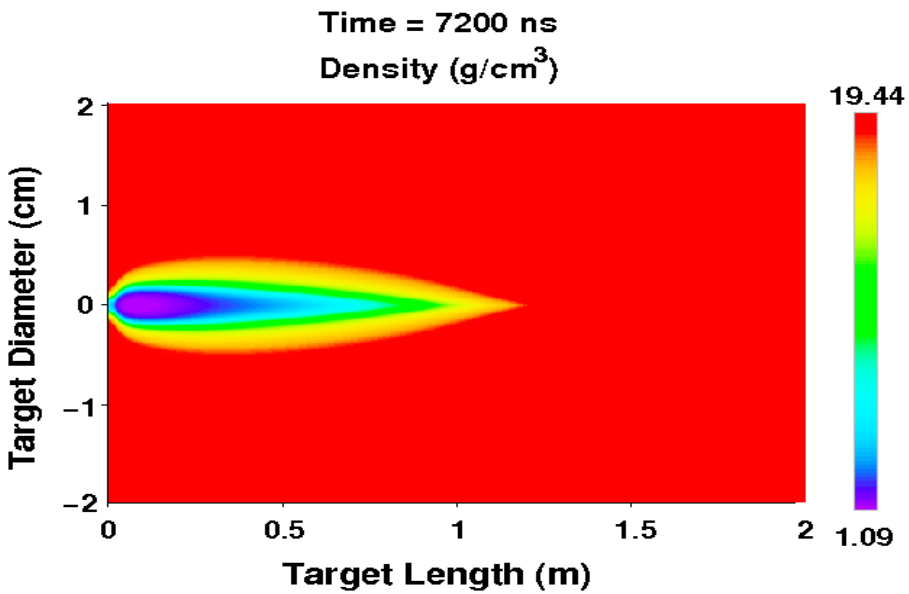


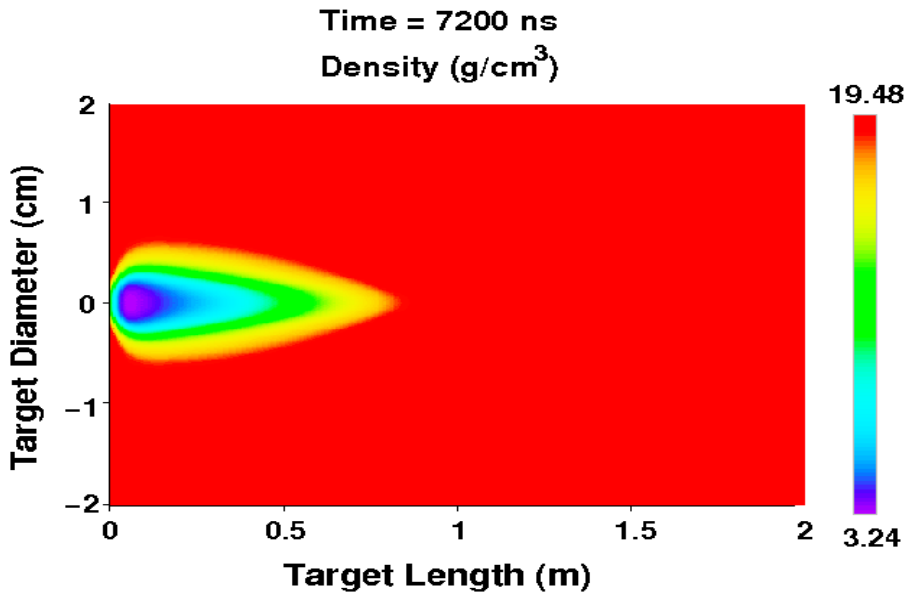


Minimum Density (7.2 μs)

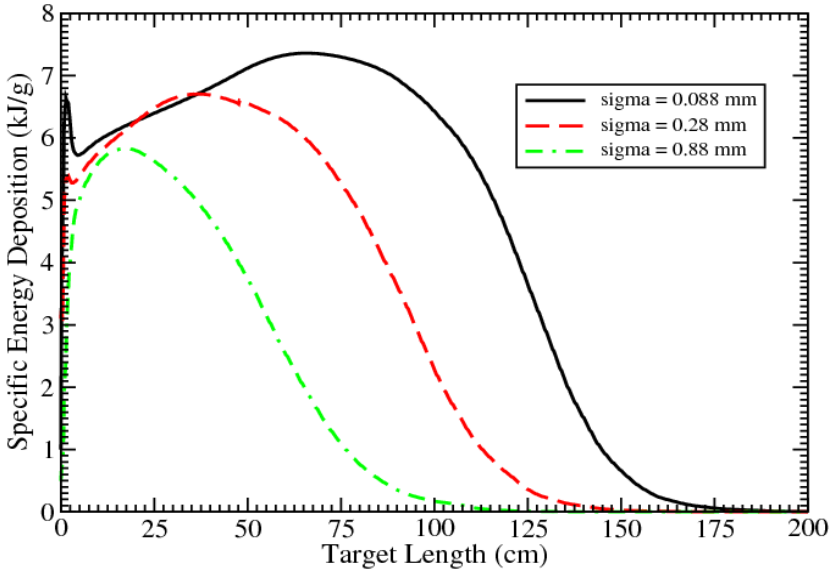


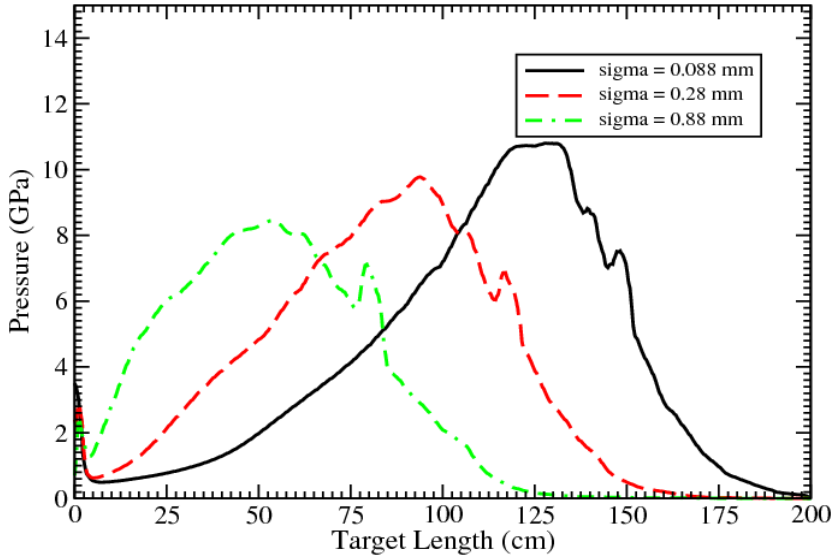
σ (mm)	ρ (g/cm^3)
0.088	0.61
0.280	1.09
0.880	3.24

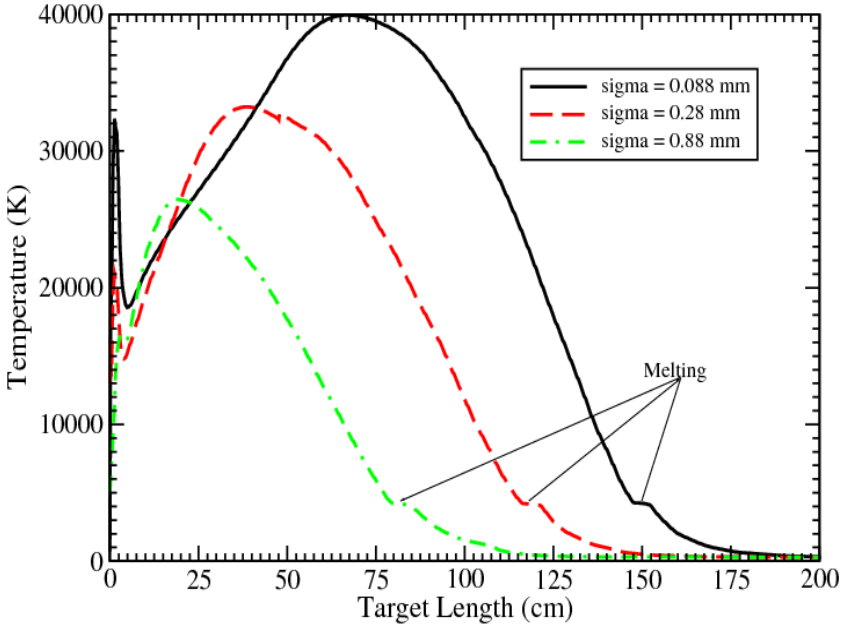


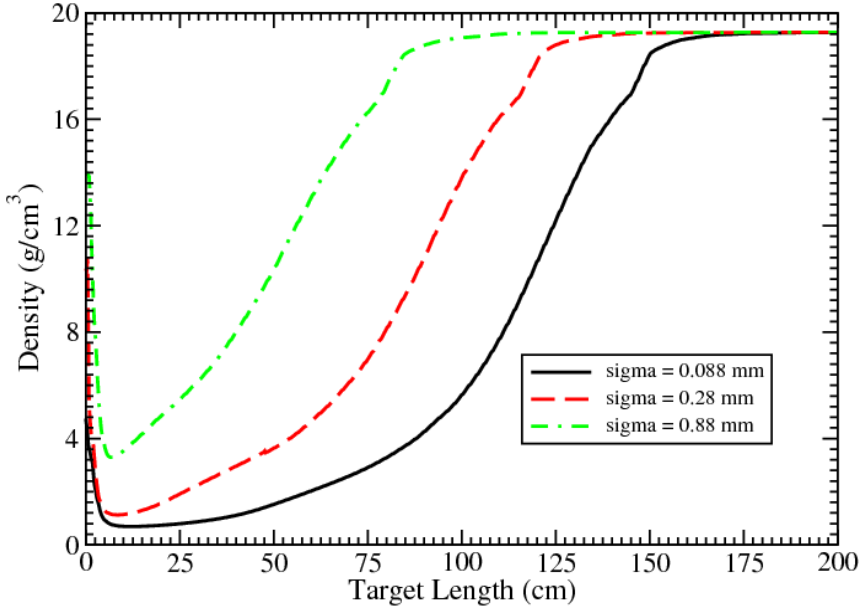


Profiles at t = 7.2 μs









Conclusions

- **Numerical simulations of full impact of LHC and SPS beams on solid targets have been carried out.**

- **It is seen that in both cases the target is severely damaged.**

- **Penetration depth of the projectile particles is much longer than predicted by a static model.**

- **An additional application of the LHC as well as SPS can be to study HED physics**

- **Fully integrated simulations with FLUKA coupled to BIG2 are required.**