Isochoric heating of DT fuels through PW-Laser produced proton beams

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- Fast Ignition of an inertial fusion target : Protection and transport
- Main features of the MBC-ITFIP code
- Angular diffusion in dense plasmas
- Results for a specific configuration of FI
- Conclusion

LPS are specially well suited for depositing high density of energy in dense matter

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Ultralow Emittance, Multi-MeV Proton Beams from a Laser Virtual-Cathode Plasma Accelerator

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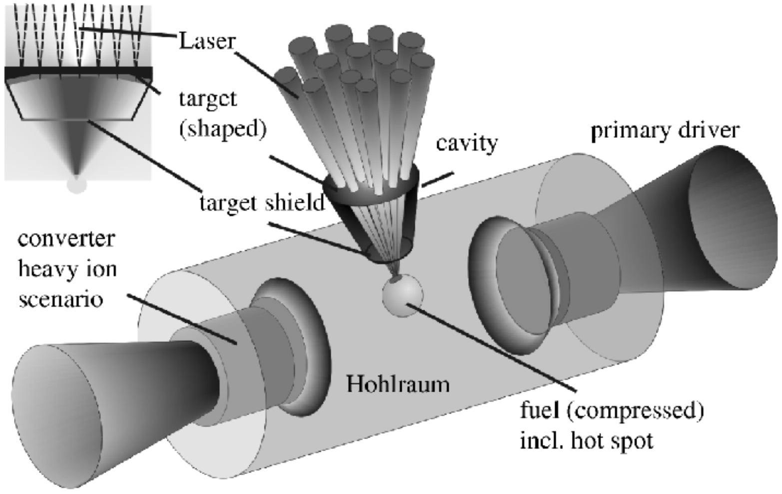
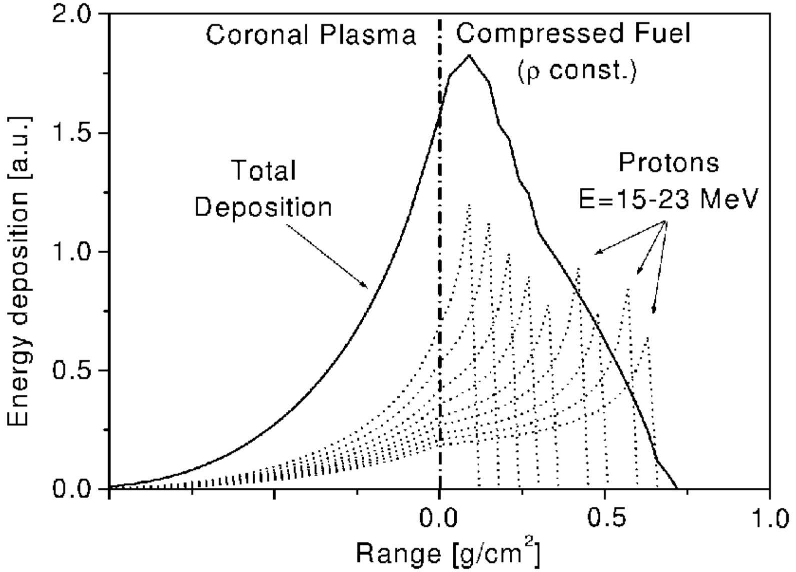
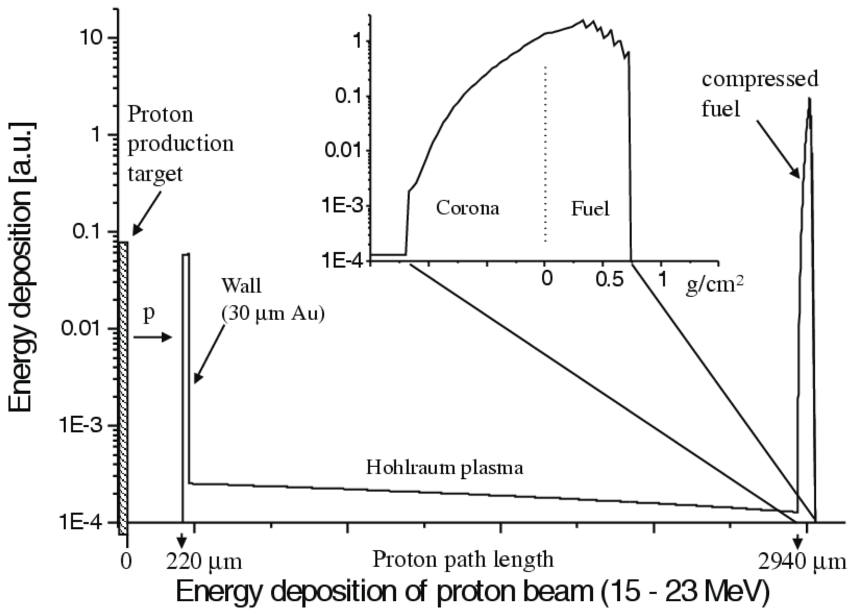
Compare to standard Fast Ignition with electrons (Tabak 94):

- Very low emittance
- Less charge and current
- Less instability, and ⊥ dispersion
- Bragg Peak
- Patel *et al*. PRL 91, 25004: T>20 eV in solid target

Fast Ignition of an Inertial Target by Proton Beams
M. Roth et al PRL 2001



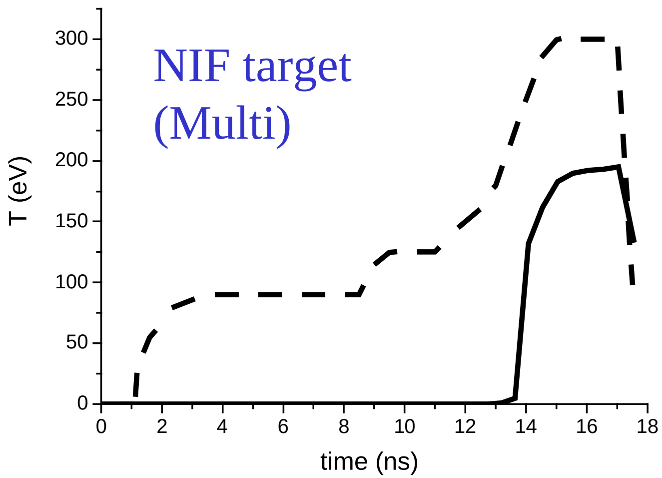


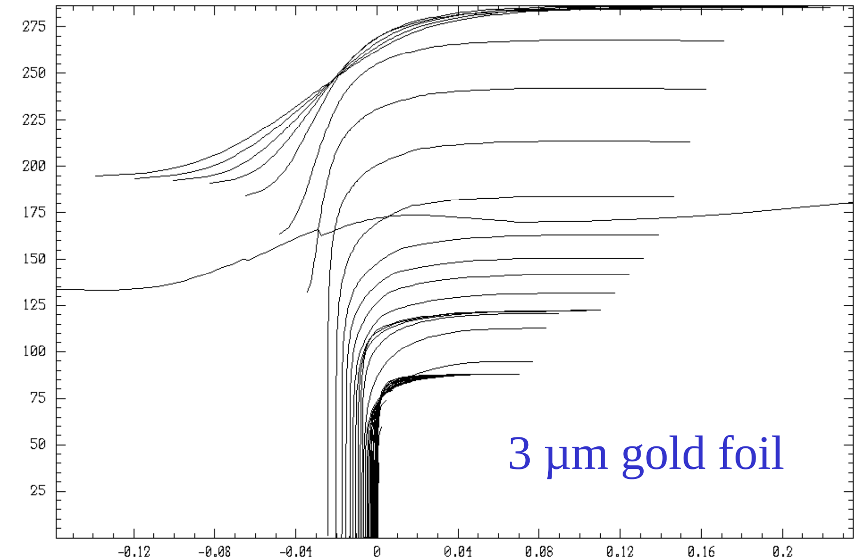


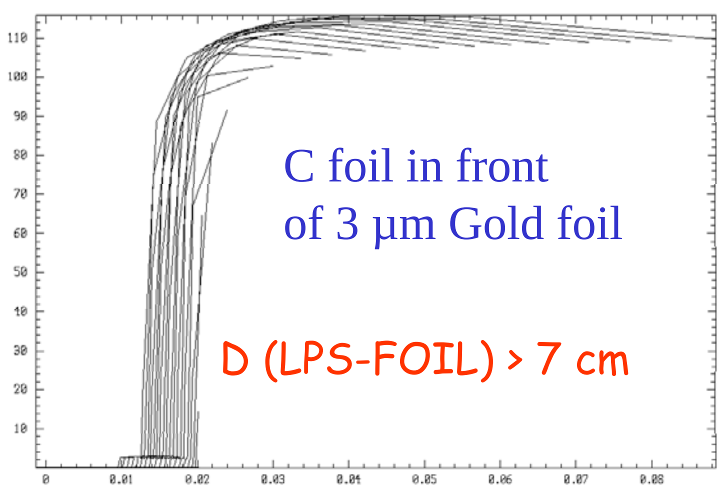
- 10 kJ, 10 ps, 15 MeV -> I>10^7A
- large distances
- the LPS should be protected
- collective effects: H. Ruhl *et al.*, Nucl. Fusion 44, 438 (2004)

An efficient protection of the LPS can require a substantial amount of heavy material on the path of the protons

MULTI2002, Rafael Ramis







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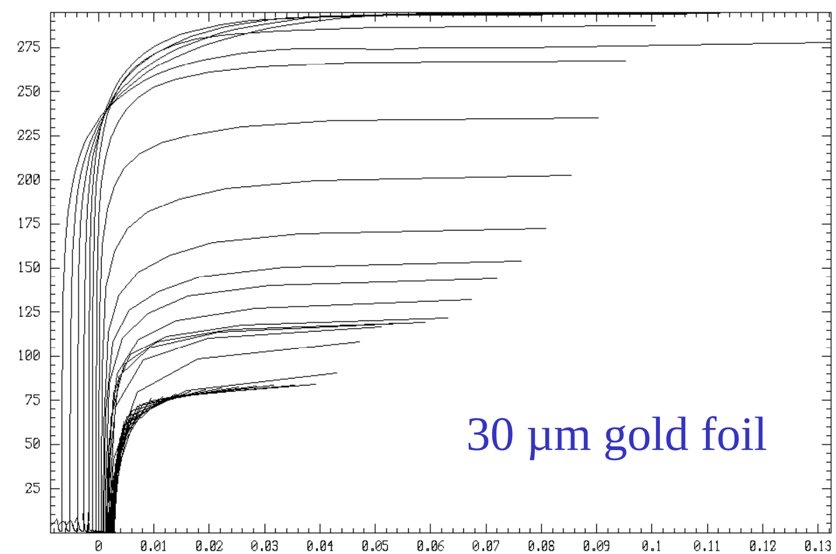


The MBC-ITFIP code is used to describe the transport of proton beams inside dense targets

- Standard Monte-Carlo method. Stopping and soft collisions as continuous forces, hard collisions as stochastic processes
- Born I dielectric formalism for stopping
- Classical collision theory for scattering (Lindhard 68, Ziegler 85)
- Average Atom Model to describe atomic physics and screening potential. R-HFS for bound electrons, R- TFD for free electrons

$$P(\Delta E) = \frac{1}{\sqrt{2\pi}} \frac{1}{\sqrt{\Omega^2 d_h}} \exp\left[-\frac{1}{2} \frac{\left(\Delta E - \overline{\Delta E}\right)^2}{\Omega^2 d} \right]$$

$$P(\theta) = \frac{1}{\sqrt{2\pi}} \frac{1}{\sqrt{\left\langle \theta^2 \right\rangle_s}} \exp\left[-\frac{1}{2} \frac{(\theta - \theta_h)^2}{\left\langle \theta^2 \right\rangle_s} \right]$$

The elastic scattering cross section is derived from the magic formula of Lindhard *et al.* 1968

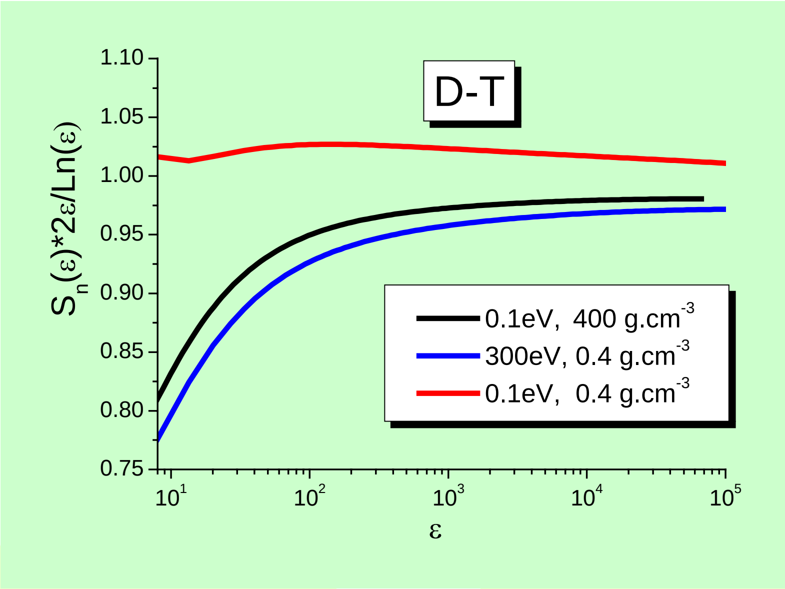
$$\frac{4}{3}\pi a^3 n_t = 1, \quad U(\rho) = \frac{e^2 Z_t}{4\pi\varepsilon_0 \rho}\phi(x = \rho / a)$$

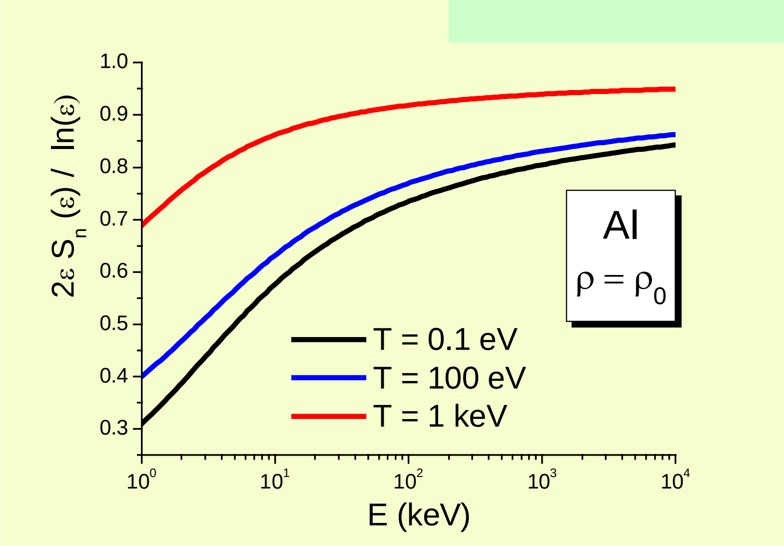
$$\varepsilon = \frac{4\pi\varepsilon_0 a M_t}{Z_t e^2 (1 + M_t)}, \quad d\sigma = \left(\frac{\pi a^2}{2}\right)\frac{f\left(t^{1/2}\right)}{t^{3/2}}dt, \quad t = \varepsilon^2 \sin^2\left(\frac{\Theta}{2}\right)$$

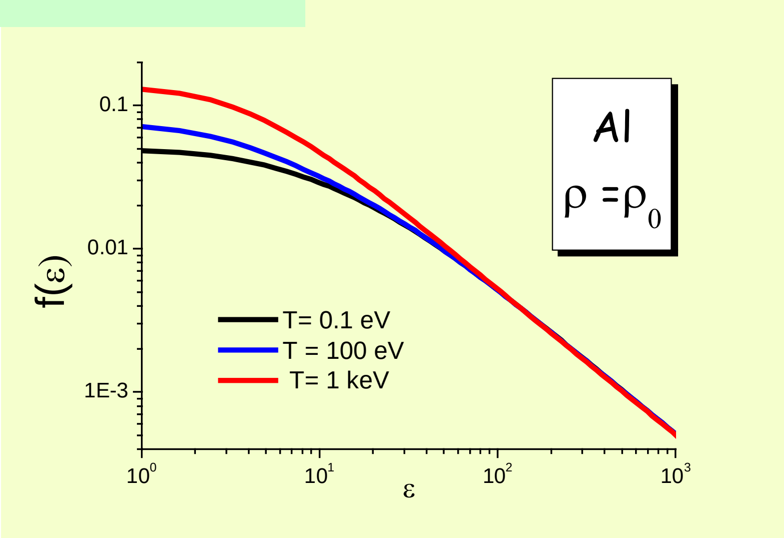
$$S_n(\varepsilon) = 2\varepsilon\int_0^\infty \sin^2\left(\frac{\Theta}{2}\right) b\,db, \quad \left\langle \vartheta^2 \right\rangle = 2\pi \frac{M_t}{1 + M_t}\frac{S_n(\varepsilon)}{\varepsilon}$$

$$f(x) = \frac{d}{dx}\left[x S_n(x)\right]$$

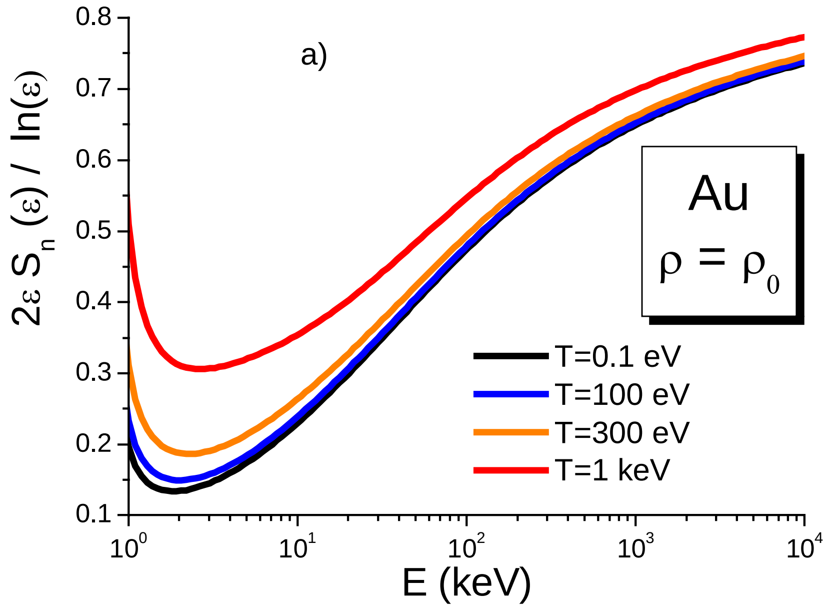
Modifications of the atomic screening are more clearly seen at low energy and for small angles

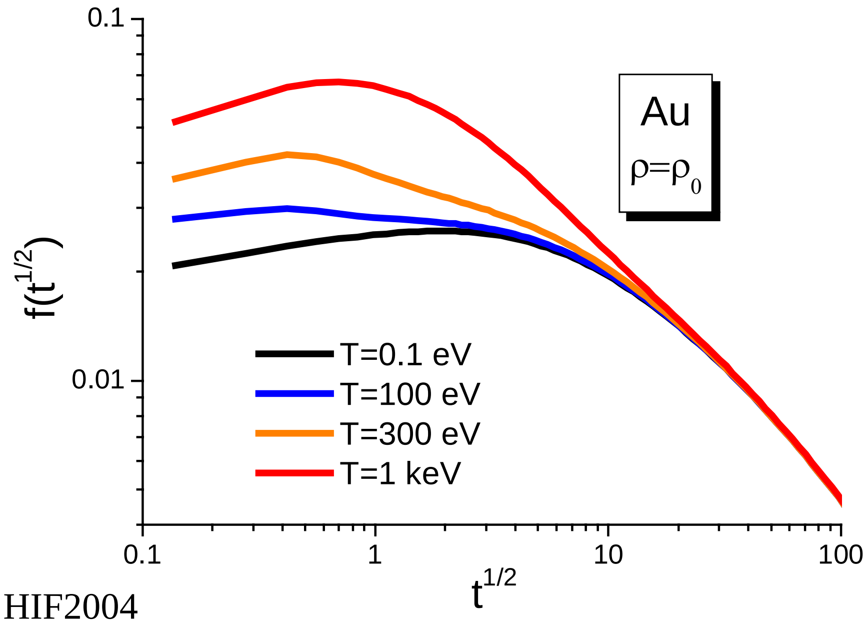




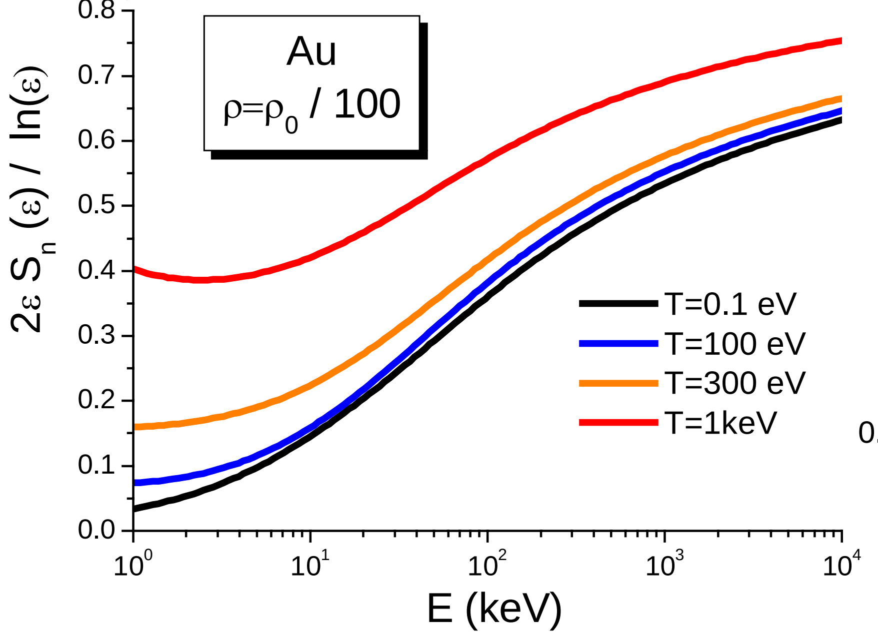


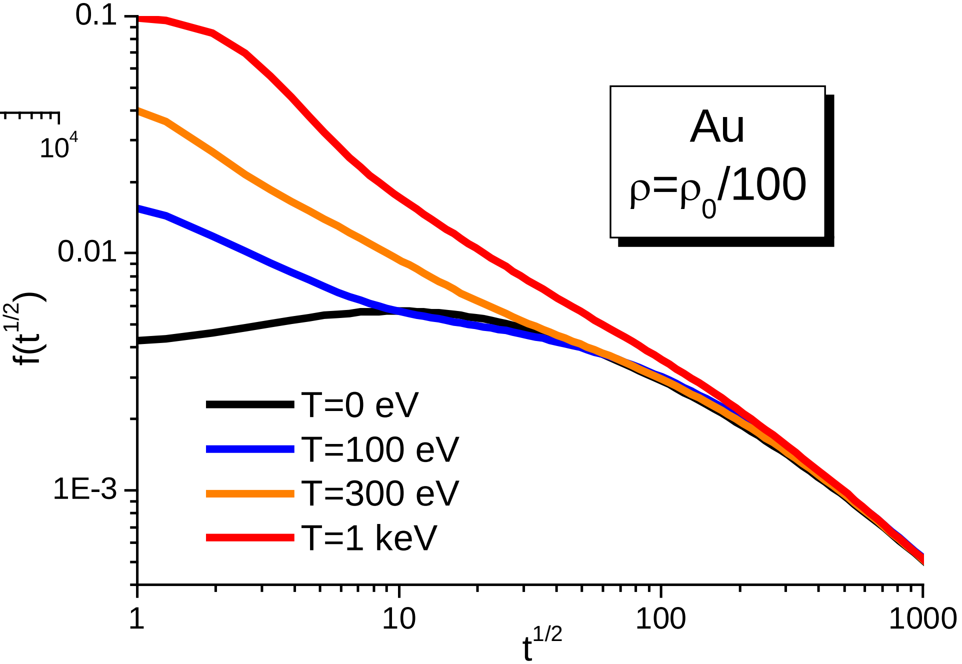
Heavy materials yield larger scattering angles, transverse diffusion is more sensitive to the plasma state





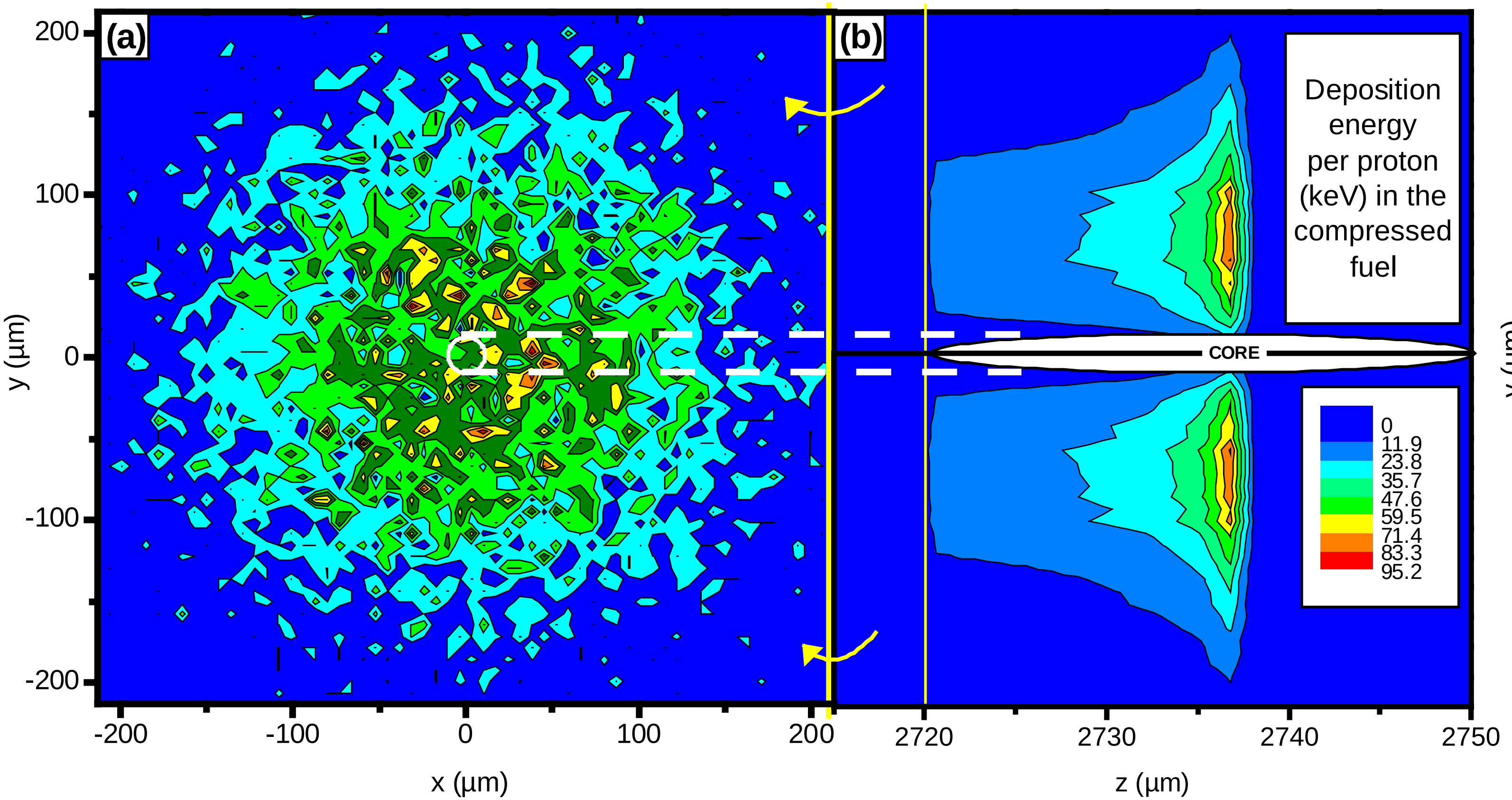
The influence of temperature is increased at low density, due to higher ionization states





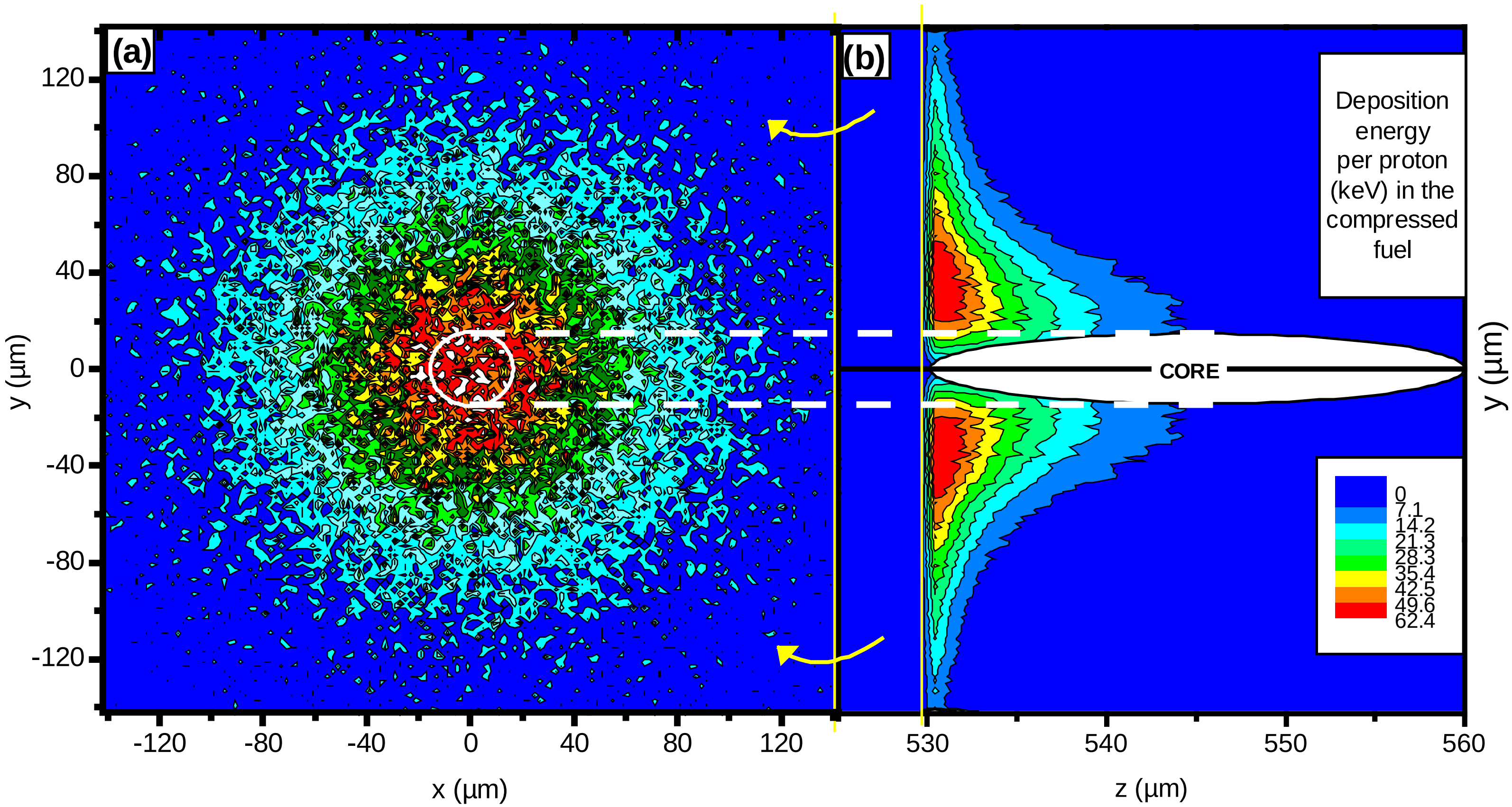
When the LPS is put outside the capsule, with a 30μm protecting gold foil, the transverse dispersion is rather large

E_p=15 MeV, D = 2.7 mm, 30μm gold foil,
99% of the protons are outside Rc (16μm)



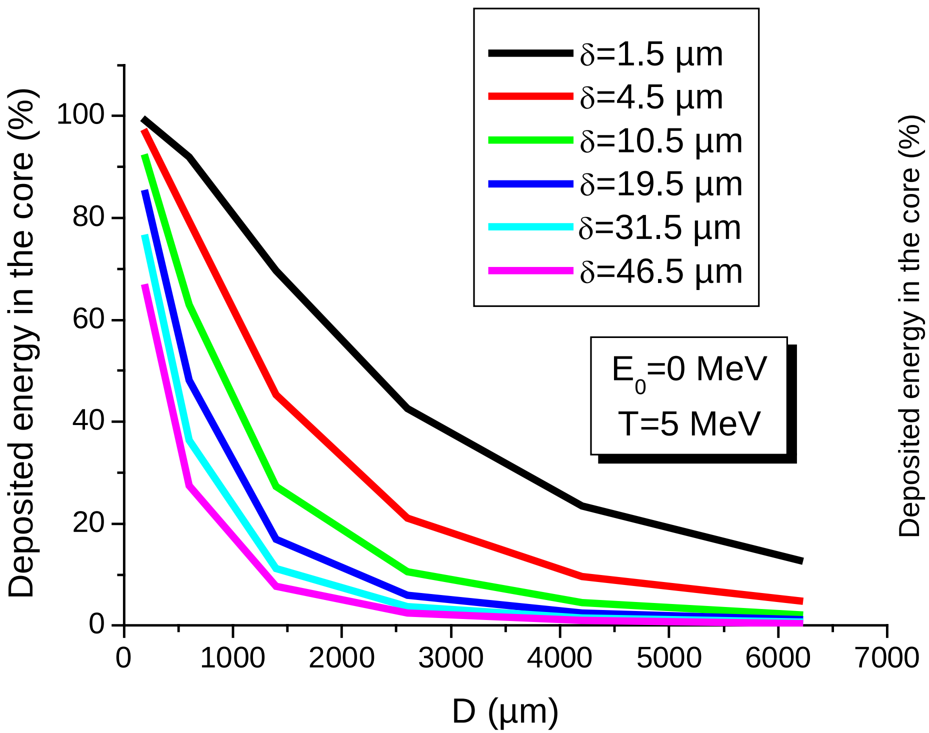
Even for a protecting foil close to the target, the dispersion is large, when considering a broad energy distribution

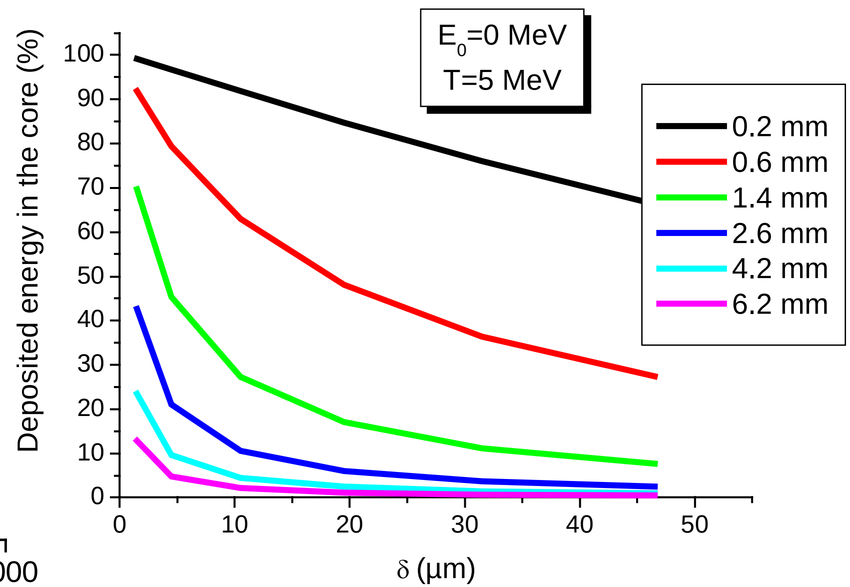
D=0.5 mm, 30 µm gold foil, energy distribution of present LULI source



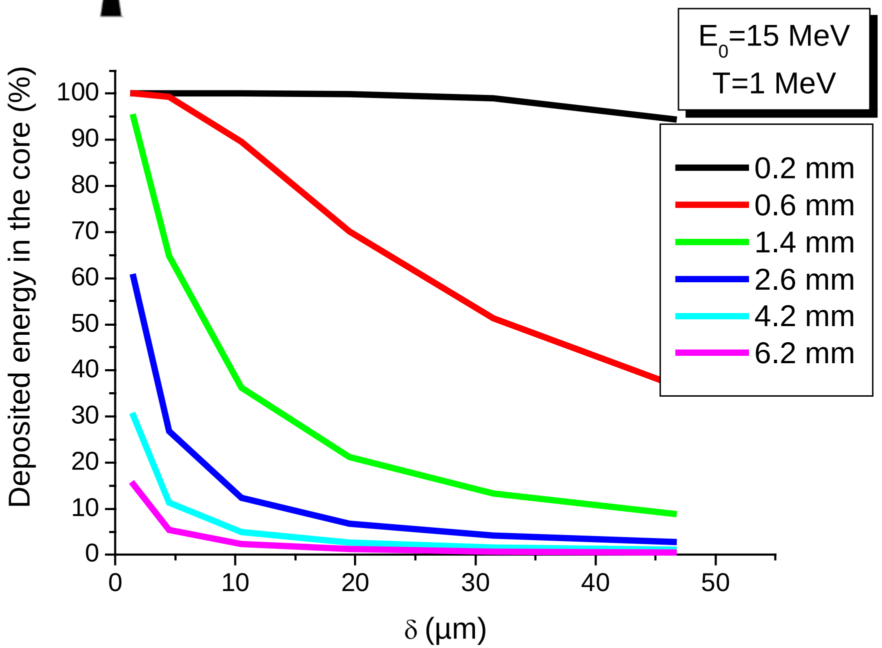
Efficiency of energy deposition can be estimated through a simple formula for the width of the distribution in the transverse plane

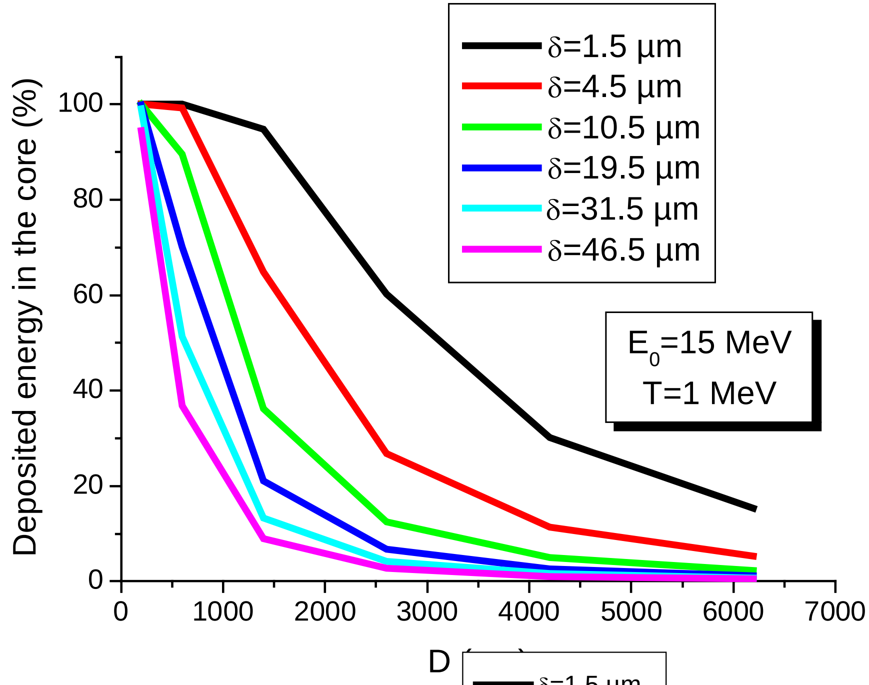
$$\sigma(\mu m) = 0.07 \frac{\sqrt{\delta(\mu m)}\,(D+\delta)(\mu m)}{E_p(MeV) - 0.15\delta(\mu m)/E_p(MeV)}$$

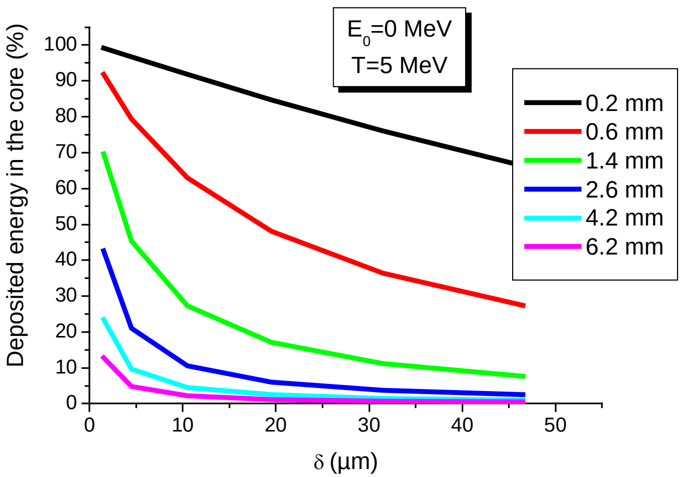


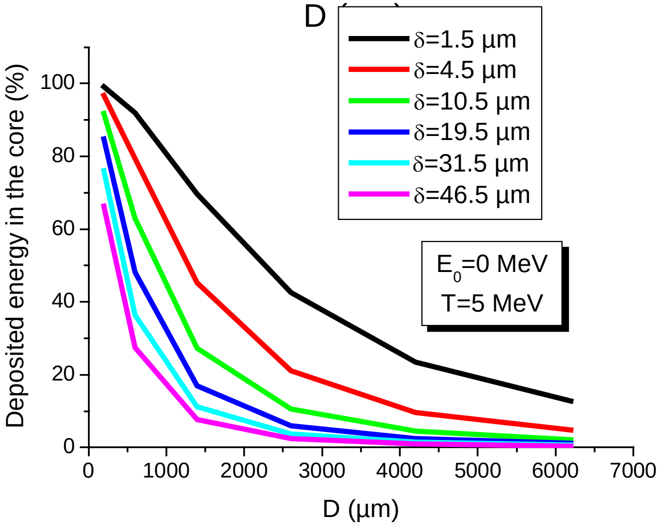


The sensitivity on the shape of the energy distribution depends on the thickness of the protecting foil









Conclusion

• The specific properties of LPS (small emittance but large energy spread) render it, more appropriate to analyze dense matter properties from angular diffusion than from energy loss.
• Looking at forward direction and for thin targets it seems possible to investigate the plasma influence on the screening of the nucleus.
• For Fast Ignition, high density of deposited energy, required a minimum growth of transverse dispersion during the travel between the LPS up to the DT. Transport is a crucial issue for proton fast ignition as it is in the electron case.
• One technical problem to solve should be to protect efficiently the LPS during the compression phase, without introducing large transverse dispersion.