Studies on target robustness, including the effects of target positioning

S. Atzeni, A. Marocchino, A. Schiavi, A. Giannini

Dipartimento SBAI, Università di Roma “La Sapienza” and CNISM
Rome, Italy

International Workshop on ICF Shock Ignition
Rochester, NY, USA, 8-10 March 2011

Acknowledgments

For discussions and information on unpublished work:

G. Schurtz and J. Ribeyre, CELIA, Univ. Bordeaux

For development of 3D raytracing scheme

M. Temporal

For funding:

- MIUR-Italy PRIN project 20072KW45J
- HiPER project (STFC-UK and EC funding)

Summary

- Shock ignition potentials = > motivation

(mainly for the HiPER reference target)

- 1D ignition windows
- Compression stage
  - sensitivity analysis to parameter changes (1D)
  - Ablation front instabilities => need for adiabat shaping
- Irradiation nonuniformity and target misplacement
- Optimization of irradiation schemes
- Conclusions / Directions for future work

Shock ignition: pros & issues

PROS

- Implosion velocity smaller than for central ignition
  - ⇒Lower intensity, smaller RTI growth => more room for direct-drive
  - ⇒Potentially higher gain
- Ignition configuration: Non isobaric => higher gain (than central ignition)
- Spherical targets

ISSUES, DESERVING EXPERIMENTS (@ NIF, Omega?)

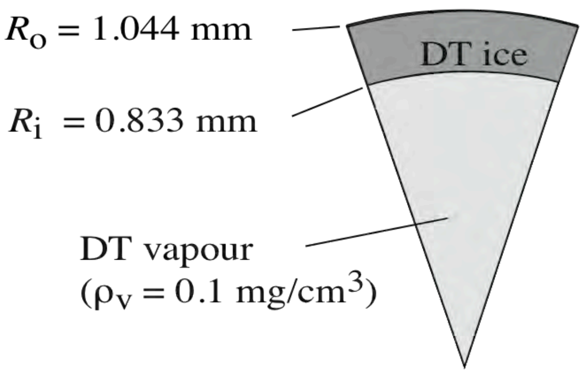
- Laser-plasma interaction at 10^{16} W/cm^2: backscattering? Hot electrons?
- Energy transport at above intensity
- Shock propagation through perturbed materials

MEANWHILE: WHAT ABOUT ROBUSTNESS?

HiPER baseline target and a target for NIF (*)

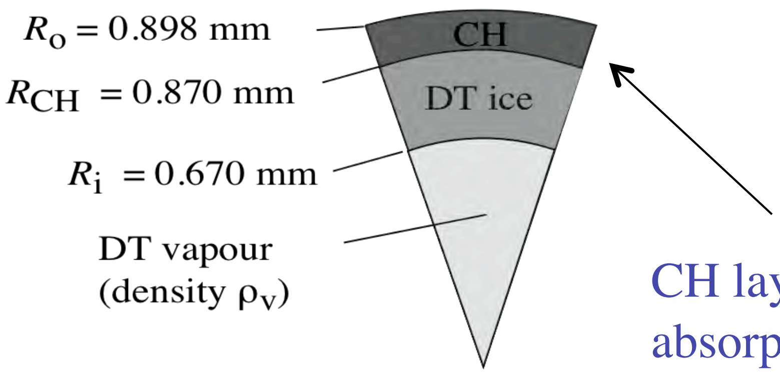
HiPER target

a)



CELIA-NIF target

b)



CH layer to increase absorption

For both targets

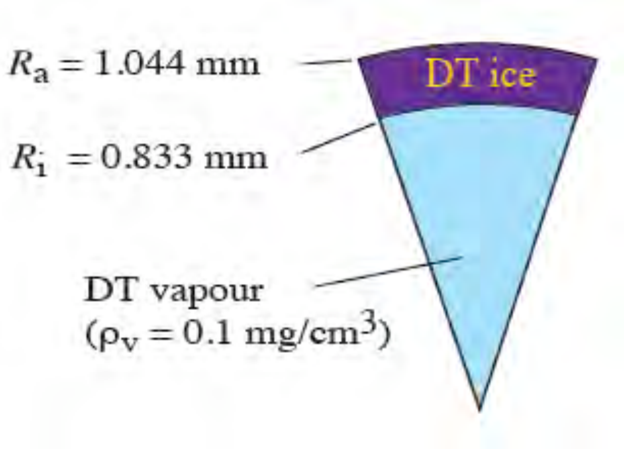
- Adiabat shaping picket
- Different focal spot for compression and ignition pulse
- laser wavelength: 0.35 μm

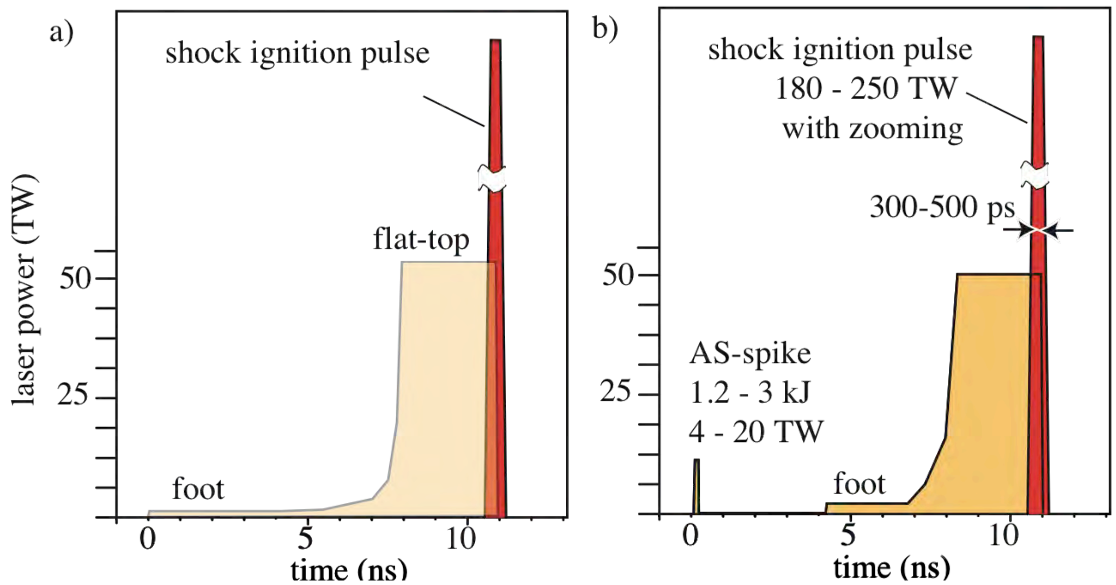
(*) Designed by G. Schurtz and X. Ribeyre, CELIA, May 2010, private communication

HiPER baseline target -- Shock-ignition

Target: HiPER baseline target

Laser wavelength = 0.35 μm
Compression energy: 180 kJ
Focal spot: 0.64 mm (compression)
0.4 mm (SI)



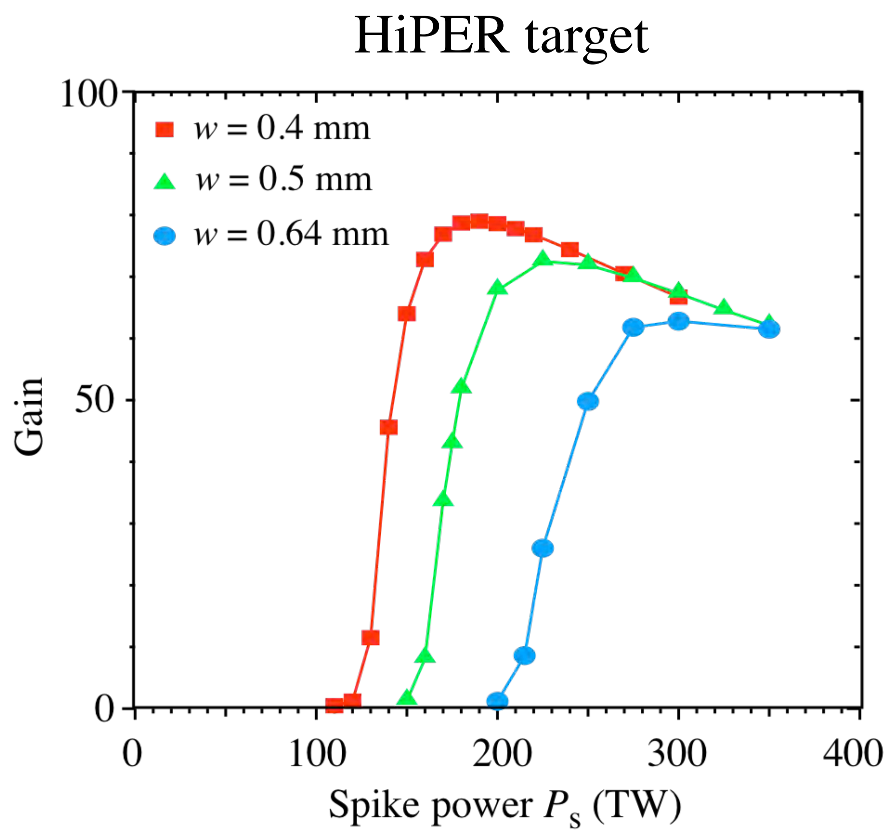


Target: S. Atzeni, A. Schiavi and C. Bellei, PoP, **15**, 14052702 (2007)
Pulses: X. Ribeyre *et a*l, PPCF **51,** 015013 (2009);
S. Atzeni, A. Schaivi, A. Marocchino, PPCF (2011)

Pulse parameters and 1D performance

	HiPER target	CELIA-NIF
Compression pulse		
• Energy	180 kJ	250 kJ
• Flat-top power	42 TW	80 TW
• Focal spot width w_c	0.65 mm	0.68 mm
Ignition pulse		
• Energy	≥ 80 kJ	≥ 70 kJ
• Power	≥ 150 TW	≥ 150 TW
• Focal spot width w_s	0.4 mm	0.345 mm
• Synchronization	120 ps (@ 170 TW)	
	250 ps (@ 270 TW)	
Fusion yield	≤ 24 MJ	≤ 33 MJ
1D Gain	**≤ 80**	**≤ 100**
Convergence ratio	35 – 42	30 – 42
vapor density	0.1 – 0.25 mg/cm^3	0.3 - 0.1 mg/cm^3

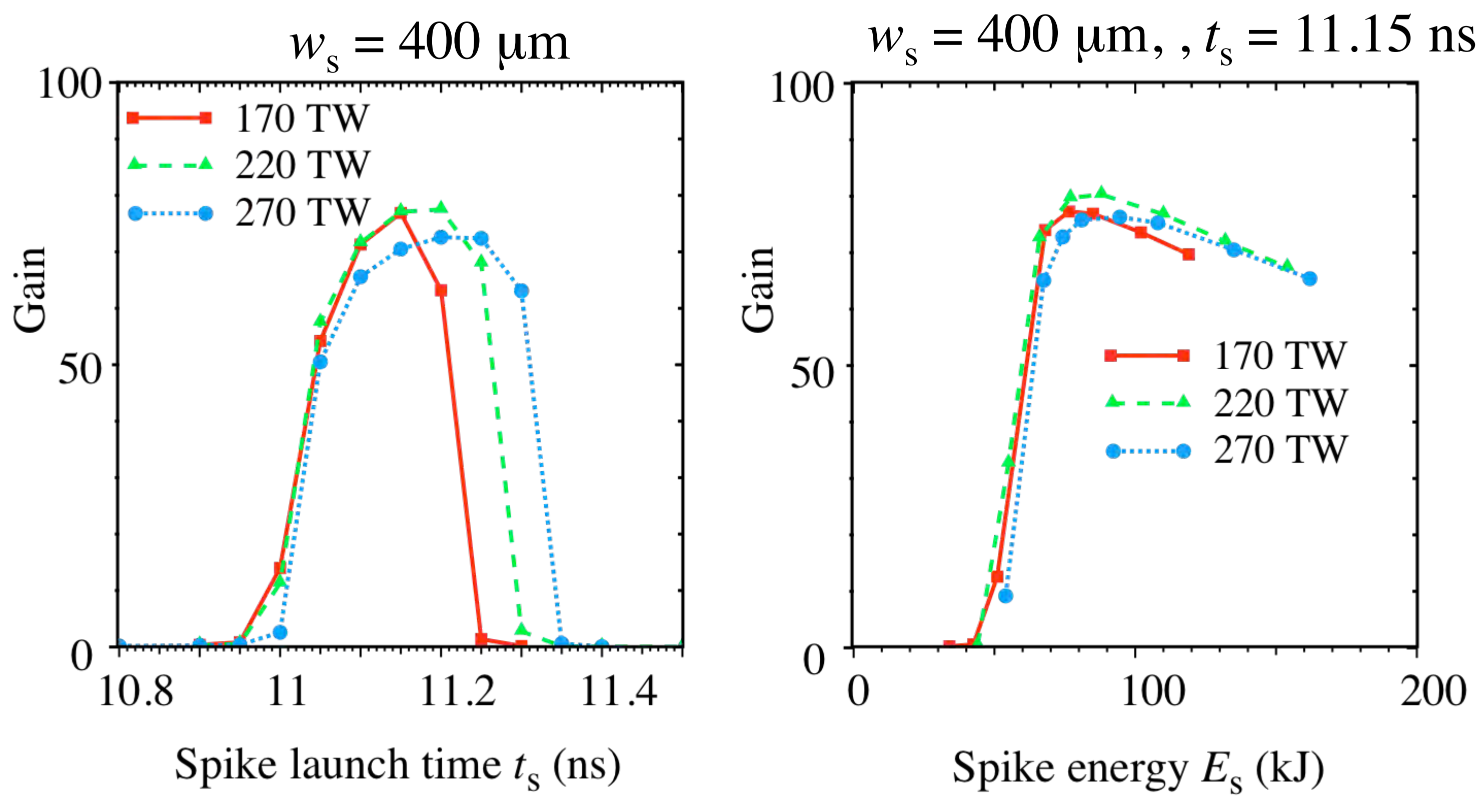
Zooming required to reduce spike power



Gaussian beams, width w_s

w_s	min. spike power
400 µm	150 TW
500 µm	200 TW
640 µm	270 TW

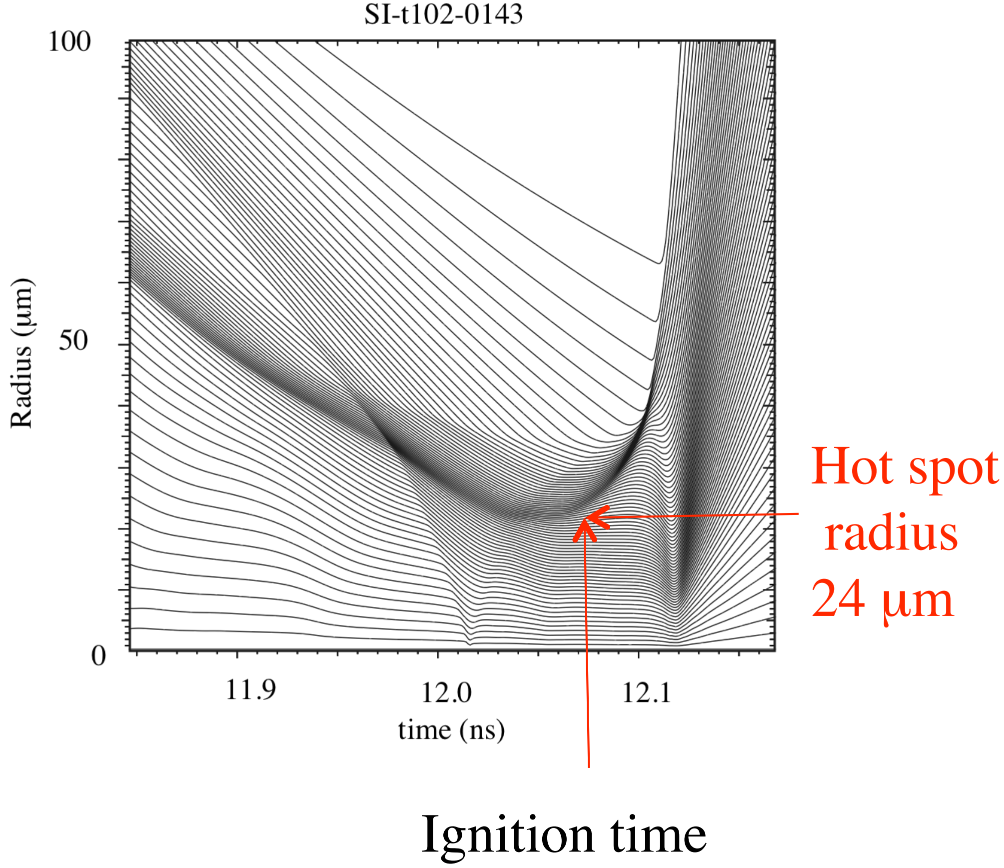
Time synchronization window enlarges with spike power, Spike energy independent of spike power



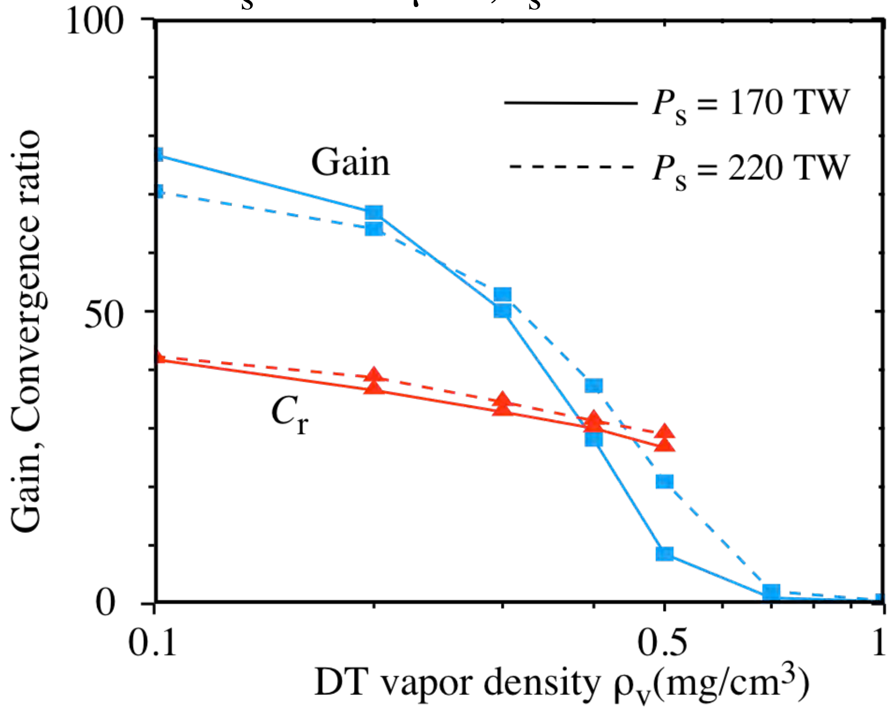
Hot spot convergence ratio is high

Some control of convergence by increasing vapour density

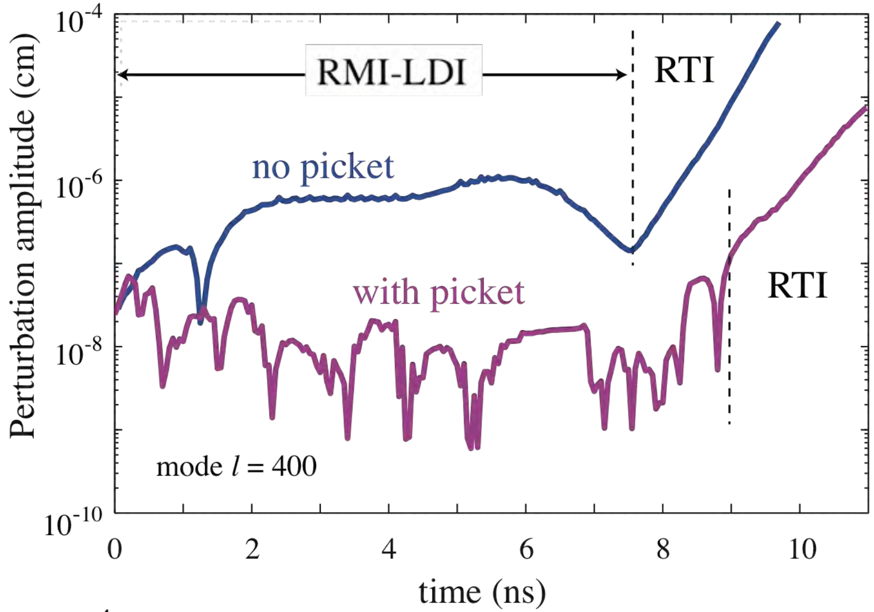
HiPER target,
initial outer radius: 1044 μm



$w_s = 400$ μm, $t_s = 11.15$ ns

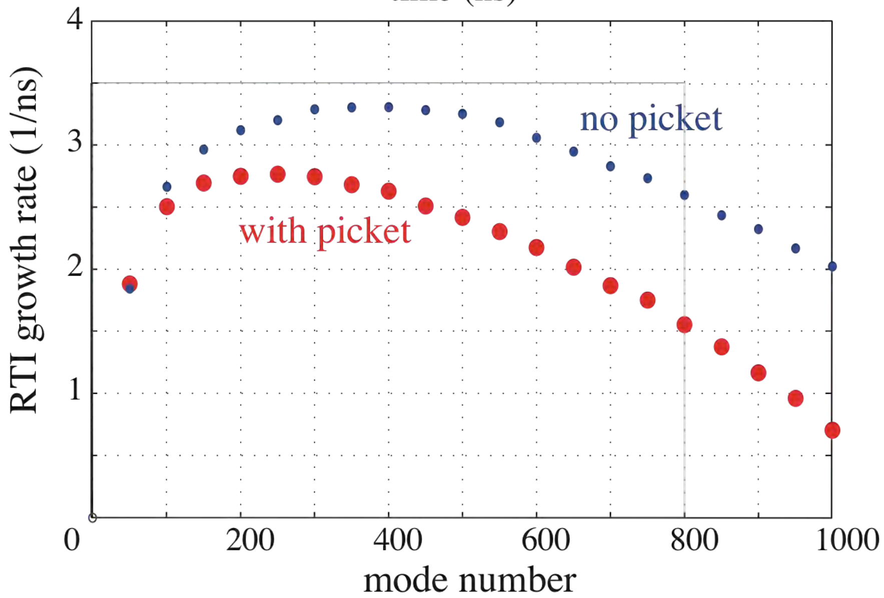


Laser pulses with **adiabat-shaping picket** reduce perturbation growth



1. Initial Richtmyer-Meshkov and Landau-Darrieus instabilities **avoided or greatly reduced**

A. Marocchino, S. Atzeni, A. Schiavi, PoP, 2010



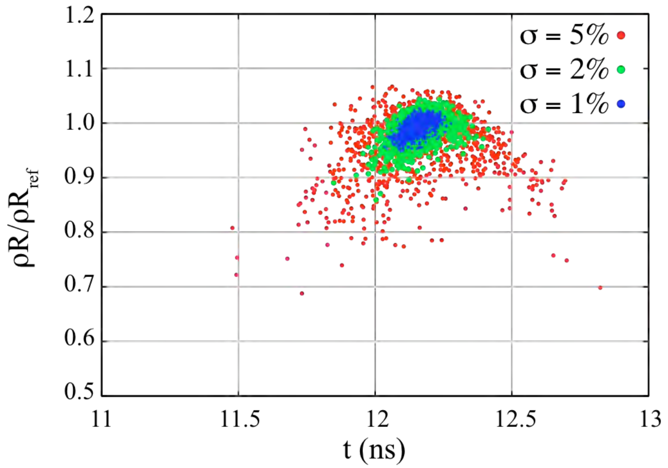
2. Linear RTI **growth reduced**; full stabilization for $l > 1200$

S. Atzeni, A. Schiavi, A. Marocchino, PPCF 2011

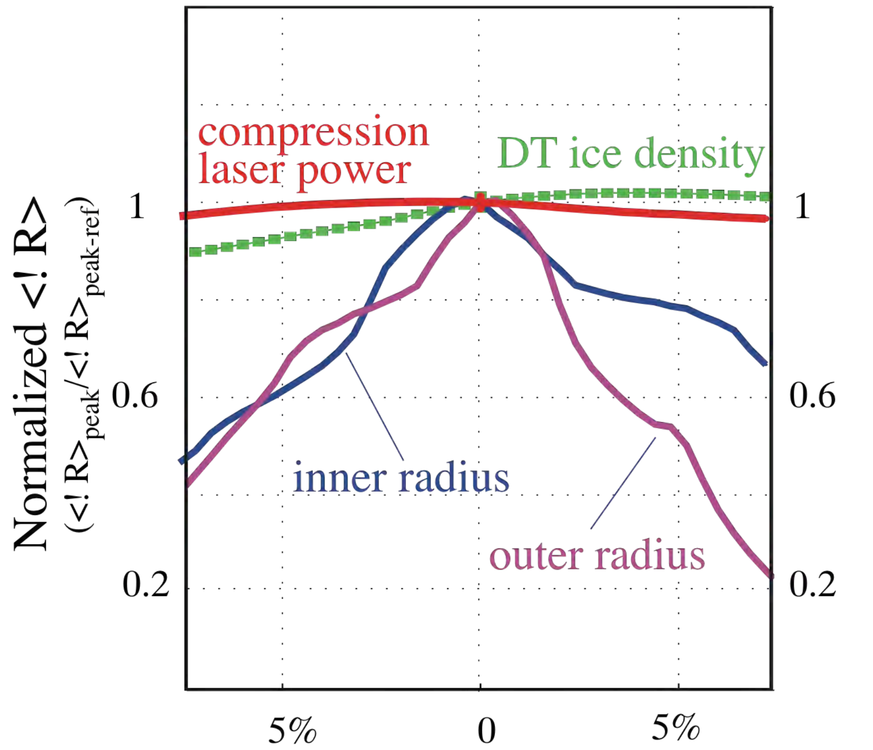
Tolerances & risk assessment – compression stage

Parametric 1-D analysis, 9 target and pulse parameters

about 3,000 1D runs, simultaneously
varying 5 parameters
(fuel density, laser energy, 3 power levels)



Varying one parameter at a time



1% errors in dimensions, few % in energy and mass, 100 ps in timing tolerated

Irradiation non uniformity and target misplacement:

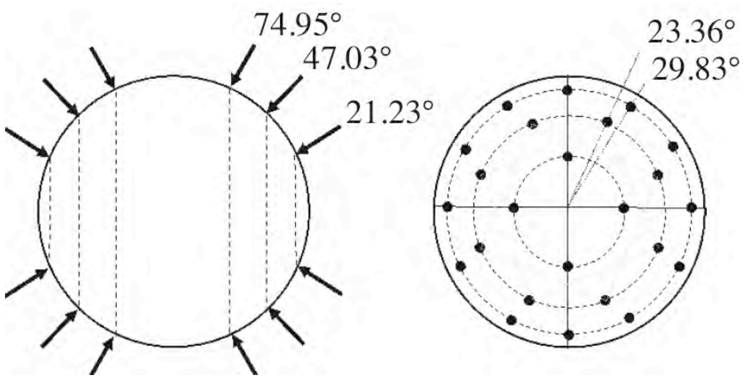
A first model study

- 2D hydro
- full code model,
  - full code model,

  - but
  - radial rays
  - time independent irradiation spectrum (Legendre modes)

The reference HiPER DD48 irradiation scheme

CELIA irradiation scheme

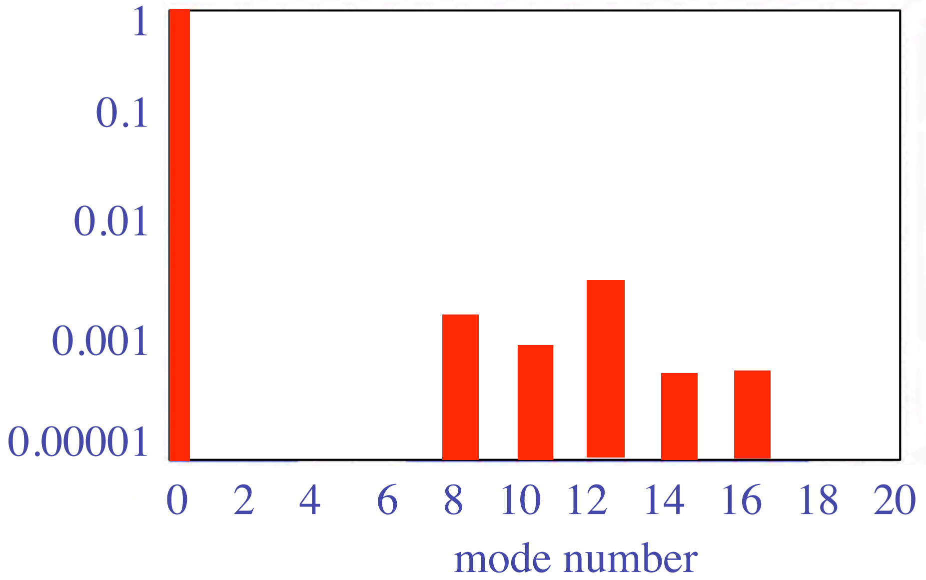


intensity profile: exp $(-r/w)^{m}$

$m = 2$ (Gaussian profile)
$w = 0.6$ * target outer radius

Optimal at $t = 0$ & no displacement

$t = 0$ illumination
2D spectrum (Legendre modes)



L. Hallo et al., 2009 (study of the HiPER baseline target)

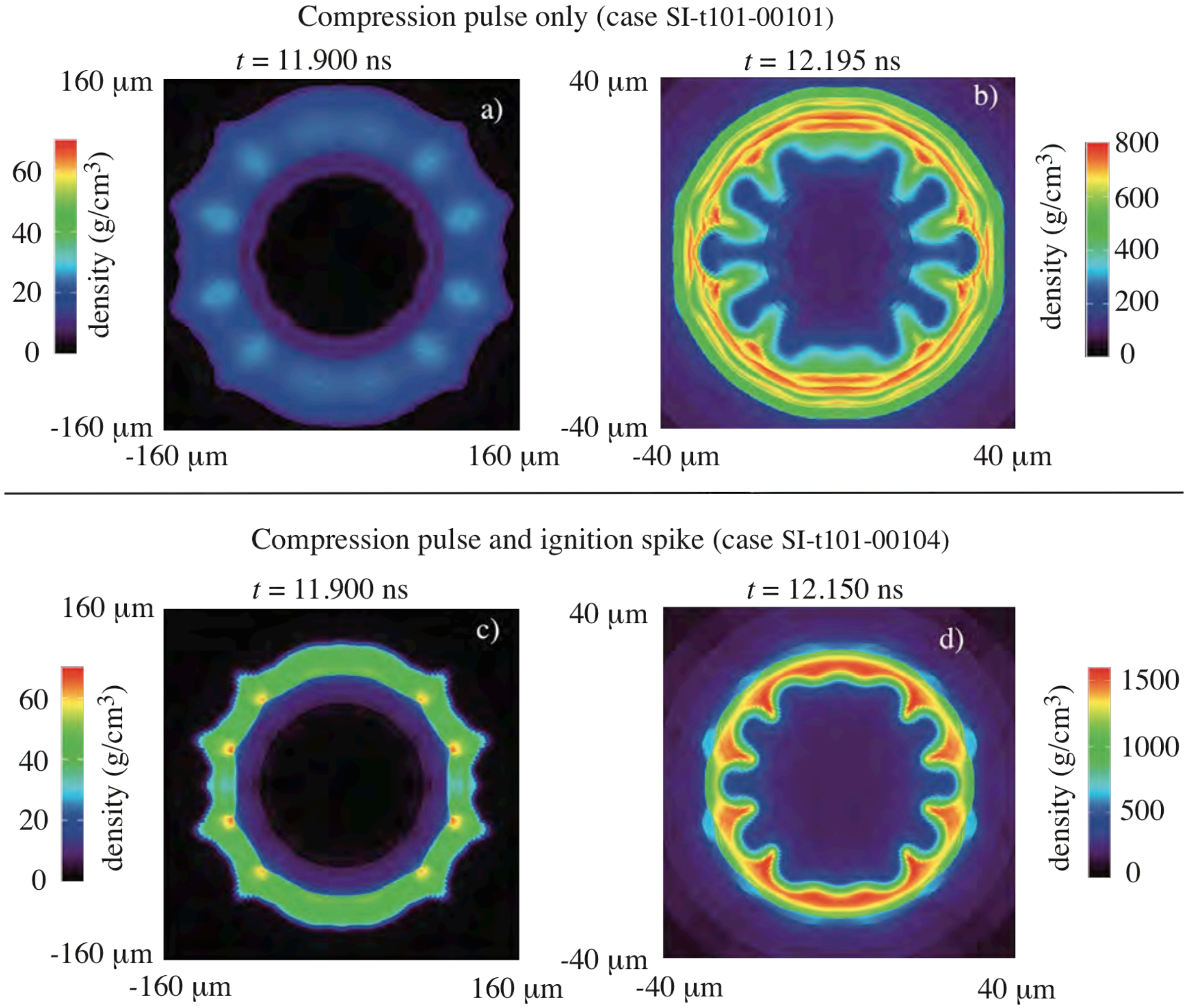
HiPER

Shock-ignition: reduced hot spot-RTI growth

No SI spike

with the CELIA rradiation spectrum

Shock ignition



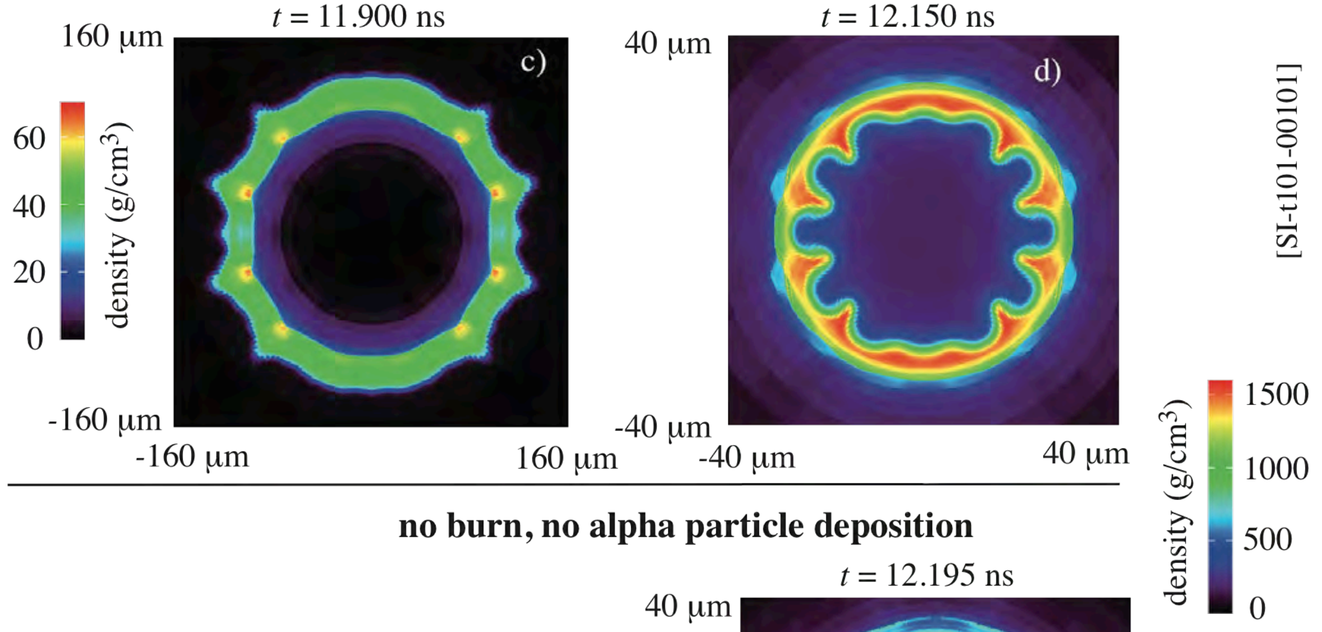
perturbation growth halts @ shock collision

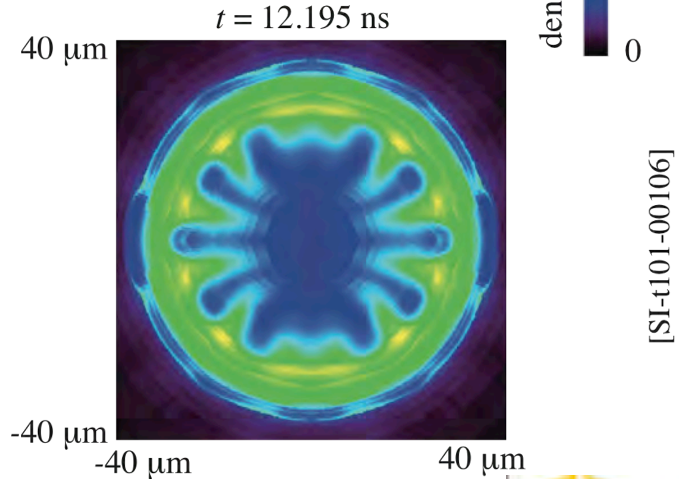
S. Atzeni, A. Schiavi, A. Marocchino, PPCF 2011.; confirms results by Ribeyre et al. PPCF 2009

RTI growth reduction due to reduced time inverval of growth and fire polishing

Full physics

with the CELIA irradiation spectrum



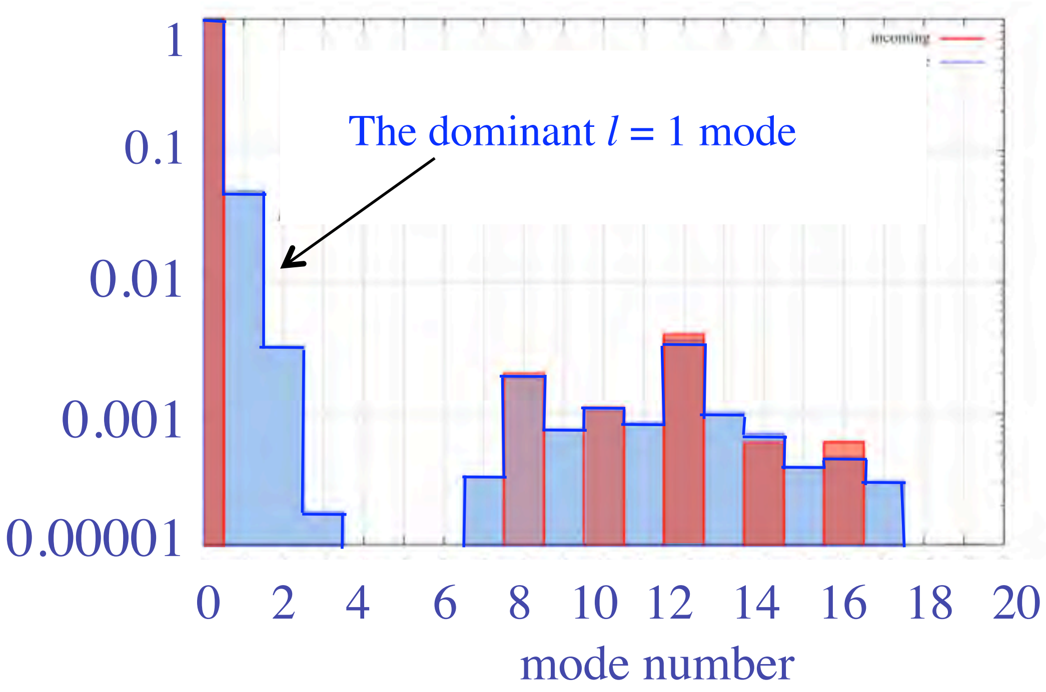


No burn,
No Alphas,

Shock does not invert phase of perturbation, growth continues as in the case without SI spike

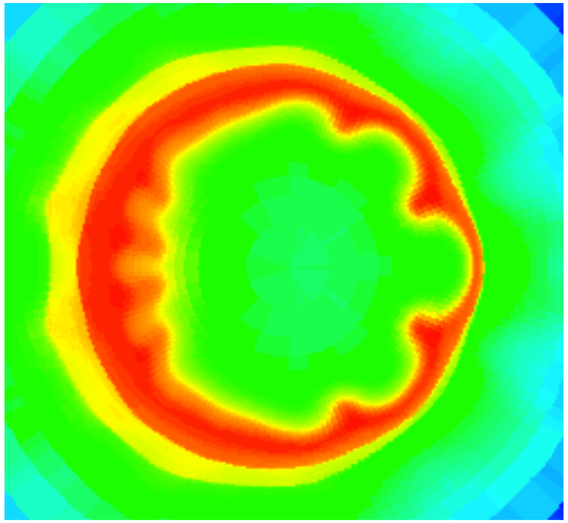
What about target misplacement?

- cylindrical symmetry
- target displaced on symmetry axis
  => initial irradiation spectrum:
  - perturbations due to finite number of beams (red)
  - *l* = 1 mode due to misplacement
  - Satellite modes due to combination of the above



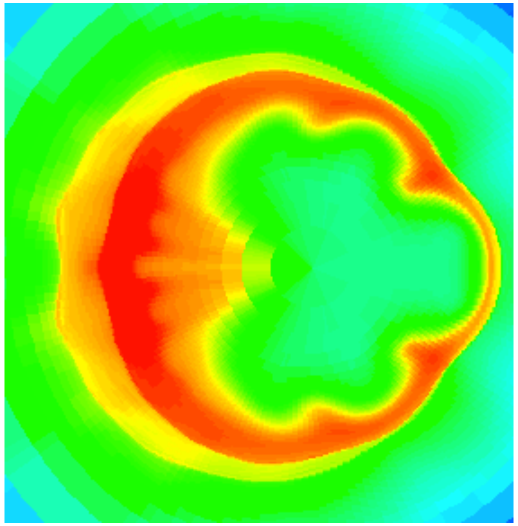
Shock-ignition: sensitive to mispositioning

Density maps when central T_{ion} = 10 keV
(80 * 80 μm)



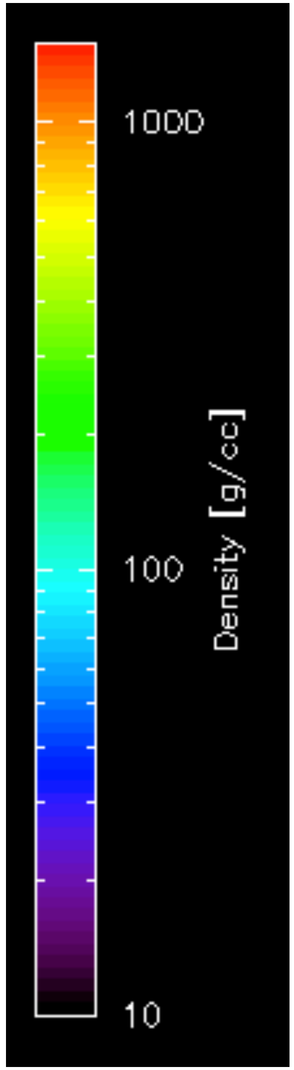
10 μm displacement

Gain = 95% of 1D gain



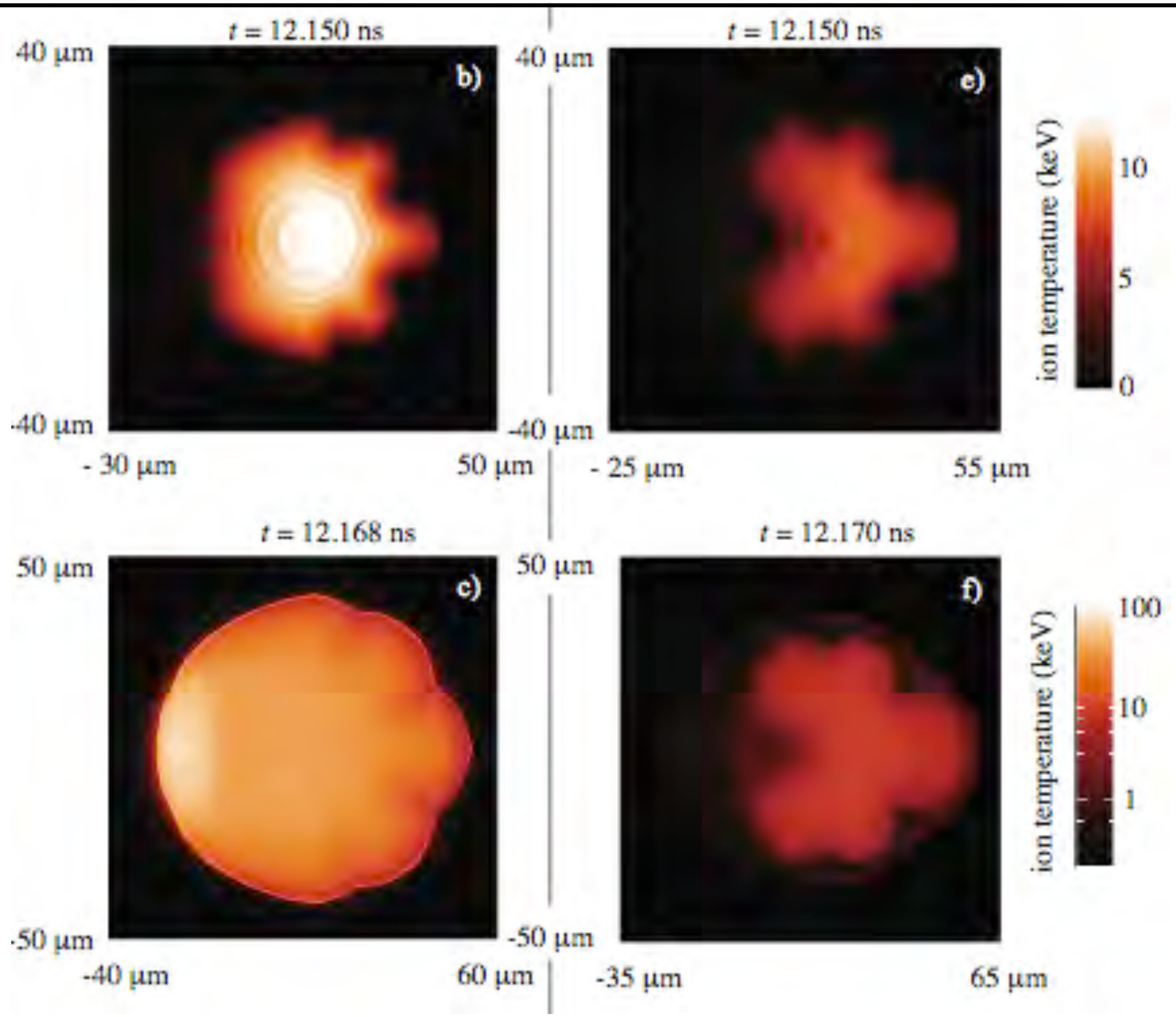
20 μm displacement

Gain = 1% of 1D gain



S. Atzeni, A. Schiavi, A. Marocchino, PPCF 2011

Shock-ignition: sensitive to mispositioning



10 μm displacement

Gain = 95% of 1D gain

20 μm displacement

Gain = 1% of 1D gain

Shock-ignition

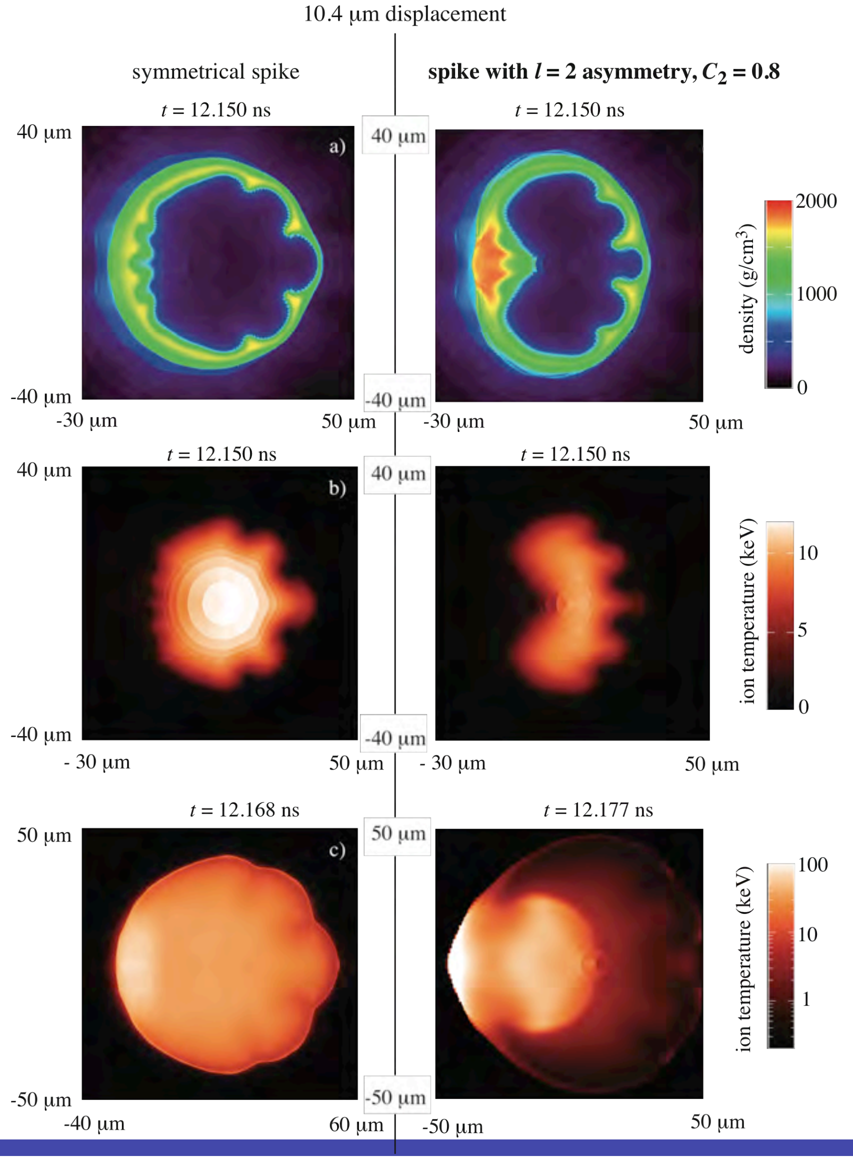
tolerates very large spike asymmetry

(warning: artifact of flux-limited SH electron conduction?)

Reference
irradiation pattern

10.4 μm
displacement

Symmetric ignition spike



Reference
irradiation pattern

10.4 μm
displacement

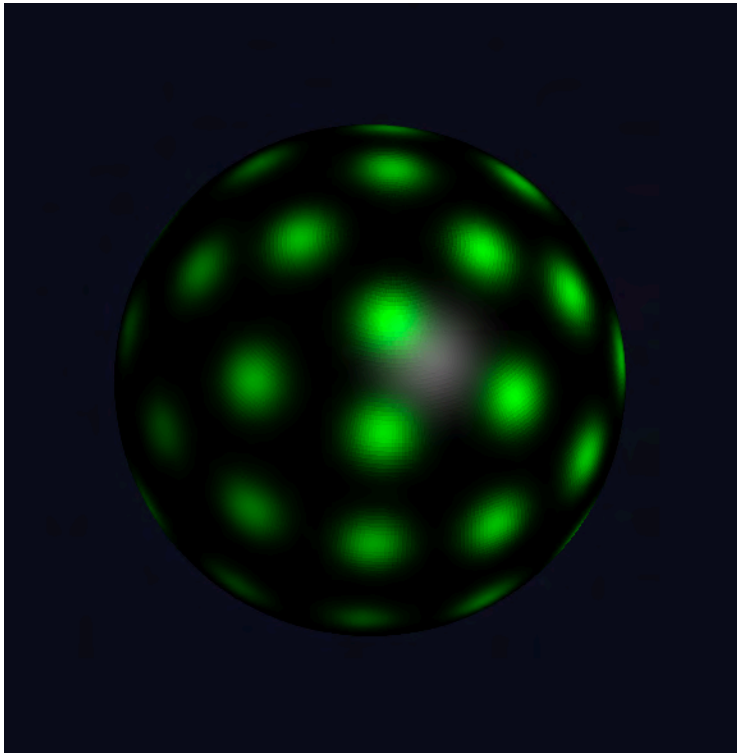
ignition spike with $l = 2$, $C_2 = 80\%$ asymmetry

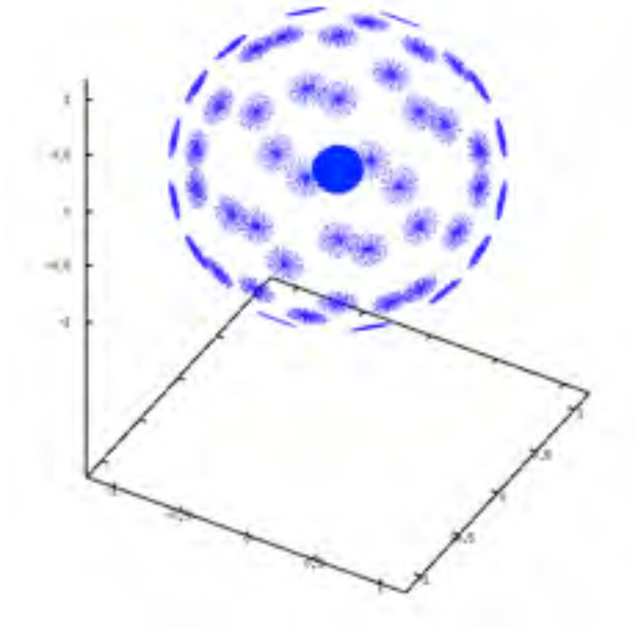
Improving the previous study

- Include **errors in irradiation scheme**, and **optimize irradiation scheme** (see next viewgraphs)
- Full 3D ray-tracing in the 2D hydro code DUED (*).
  First complete simulations from next week.
- Non-local electron transport (in progress)

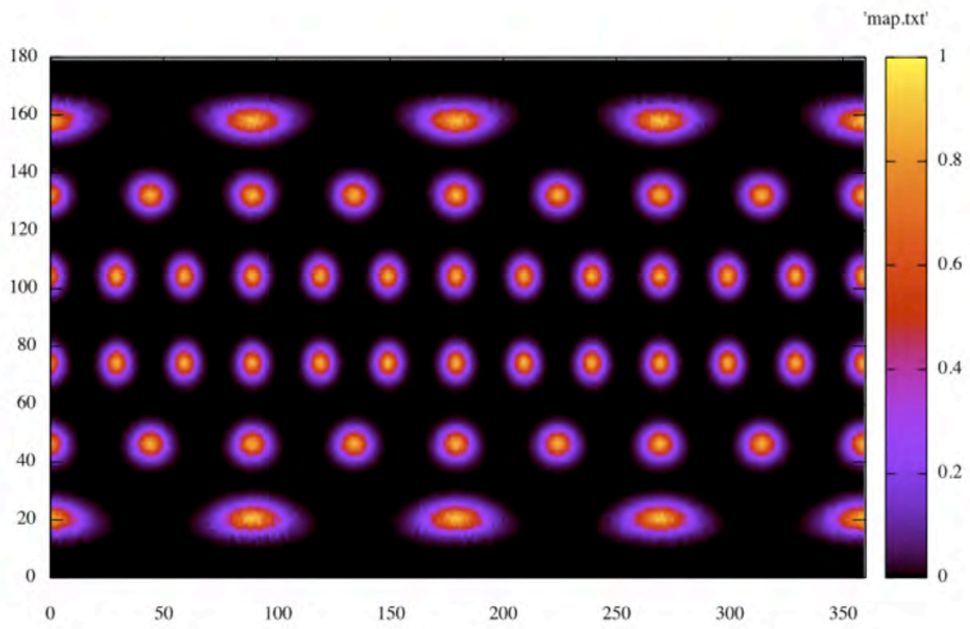
(*) In collaboration with M. Temporal, ETSIA, UP Madrid

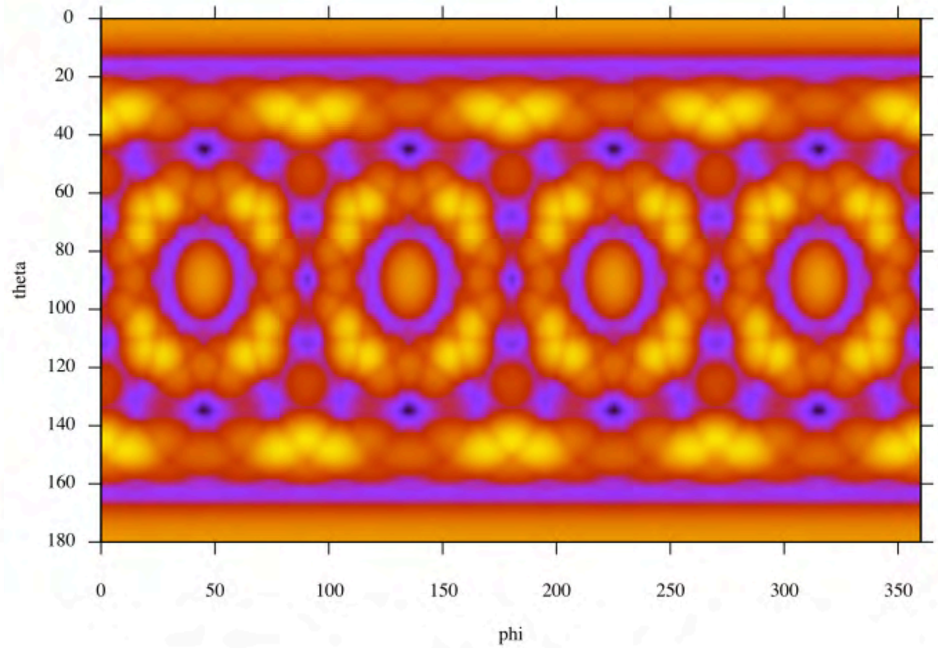
The reference DD48 HiPER irradiation scheme





HiPER - DD48 – m = 2, w/R = 0.6
Highly uniform, when no errors



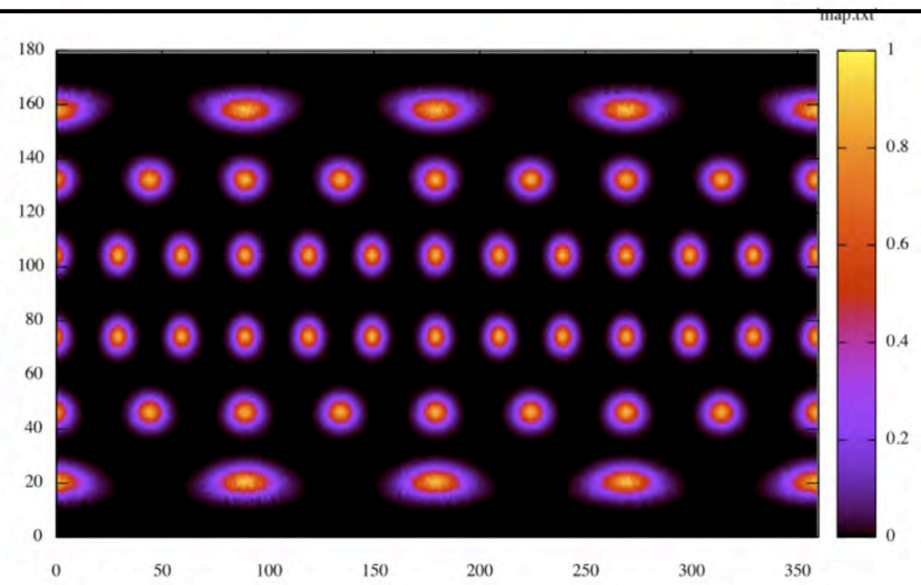


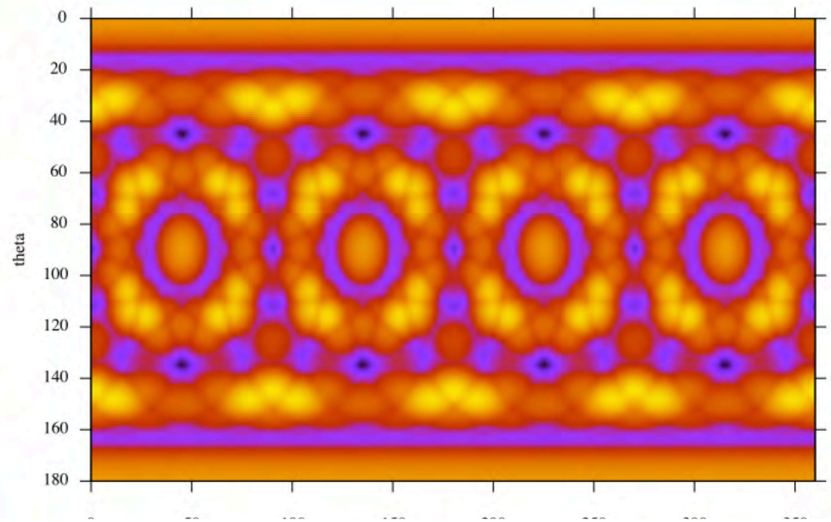
Beam centers positions on the sphere (theta-phi plane)

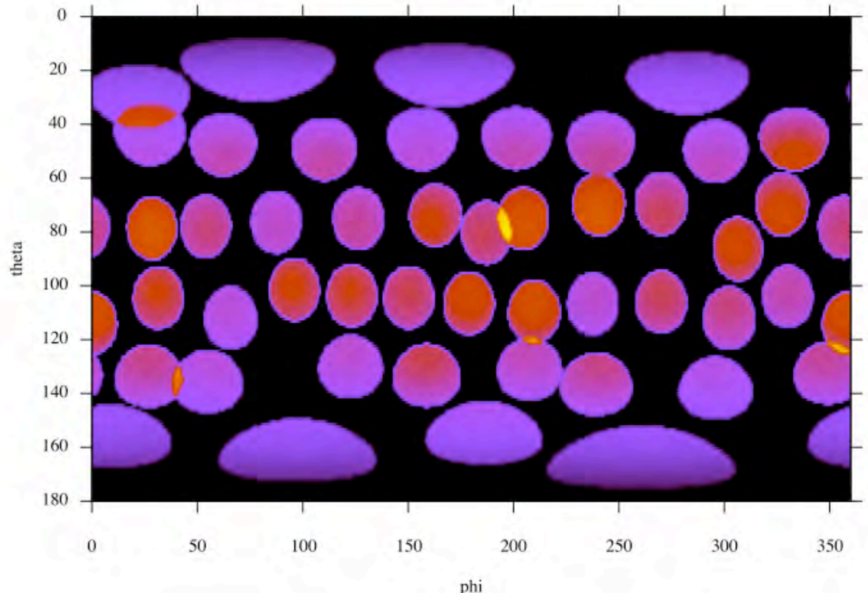
Intensity map for perfect DD48 Illumination

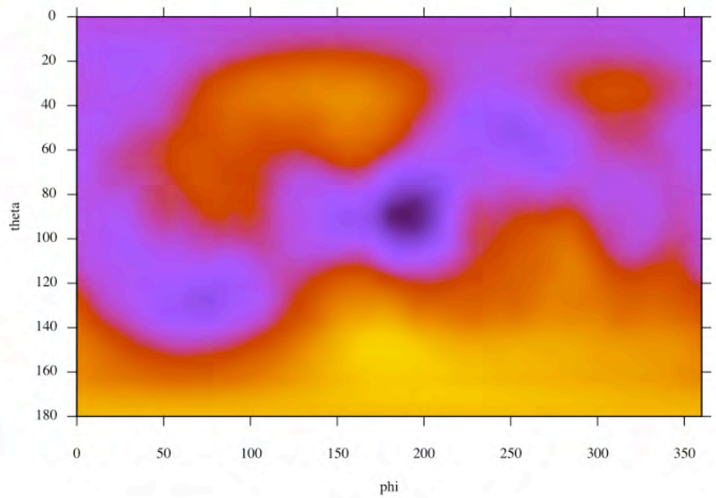
rms nonuniformity: 0.2 %

HiPER - DD48 – m = 2, w/R = 0.6
sensitive to errors!





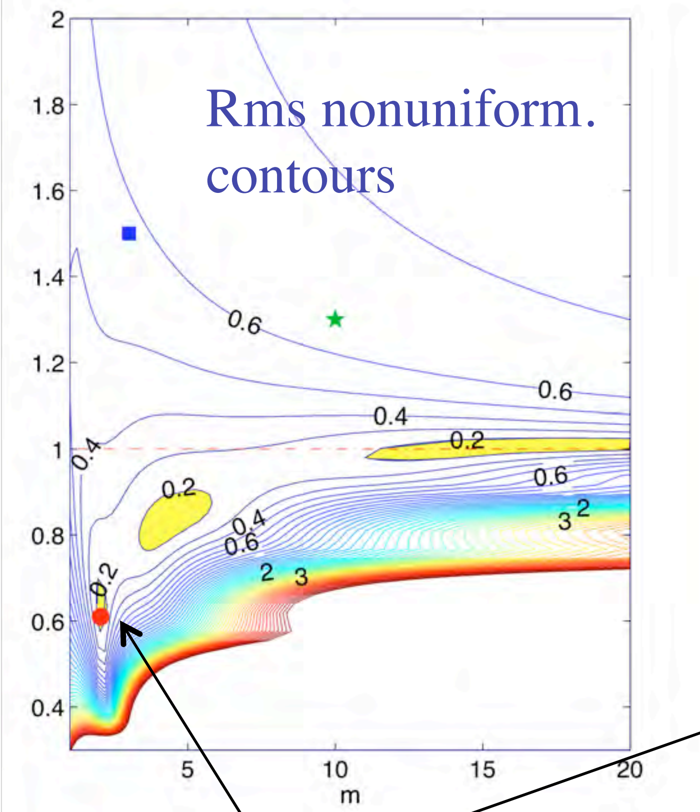




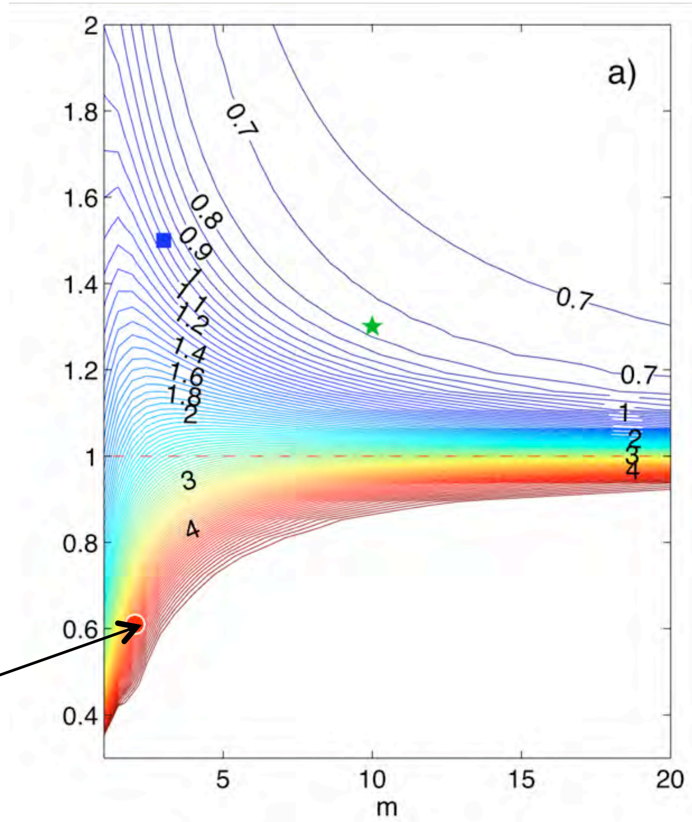
HiPER - DD48 – m = 2, w/R = 0.6highly sensitive to beam & positioning errors => better choices?

No errors

Beam width / target radius



With mispointing, imbalance, mispointing

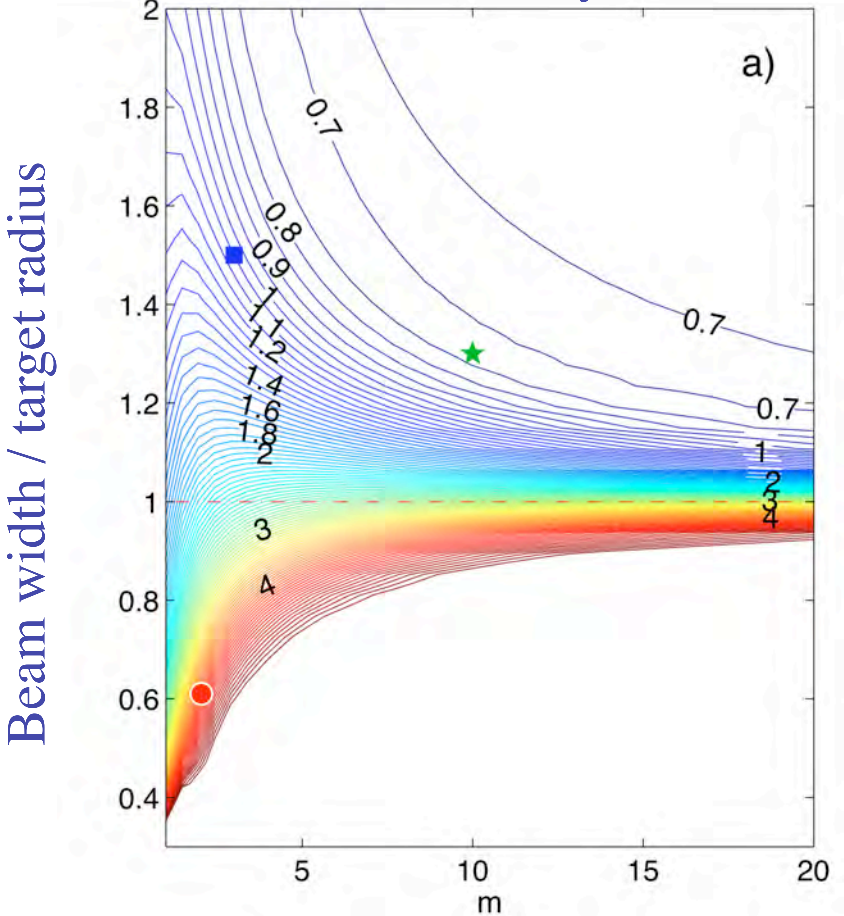


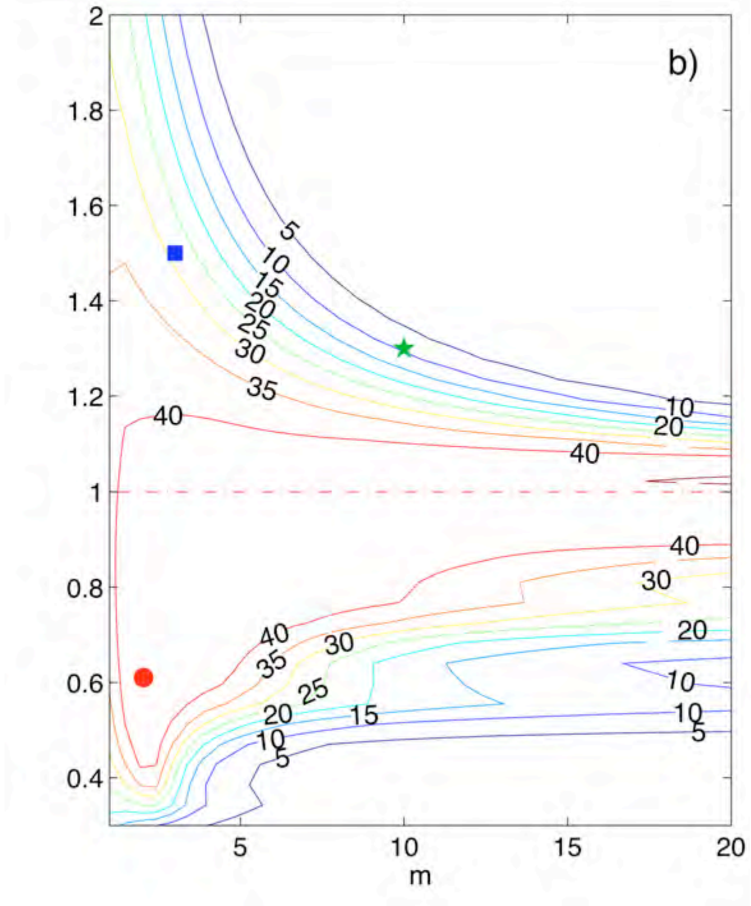
Reference irradiation scheme

m = Supergaussian index
(2=Gaussian)

Schiavi, Atzeni, Marocchino, *Europhys. Lett.* , in press

Relative fluctuactions to be taken into account too





m = Supergaussian index
(2=Gaussian)

m = Supergaussian index
(2=Gaussian)

Schiavi, Atzeni, Marocchino, *Europhys. Lett.* , in press

Conclusions

- First studies on target robustness
- capability for systematic parameter scans developed

Preliminary results:

- specifications for a few target laser parameters
- Need for adiabat shaping; (many) further studies required to define target specs (roughness, inhomogeneities, …) and laser bandwidth (to limit imprint)
- SI robust to macroscopic asymmetry; final shock seems to reduce hot spot deformation
- Target misplacement a so-far underestimated issue. Simulations with real beam geometry and 3D raytracing needed and already programmed; more robust irradiation schemes investigated