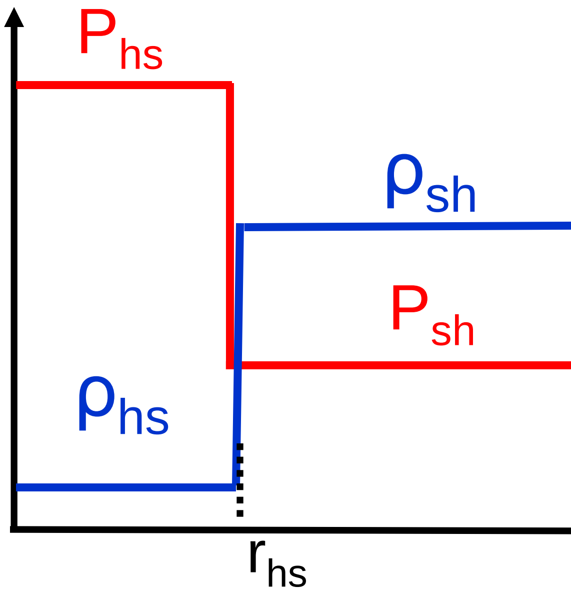
On the fielding of a High Gain Shock Ignition Target on NIF

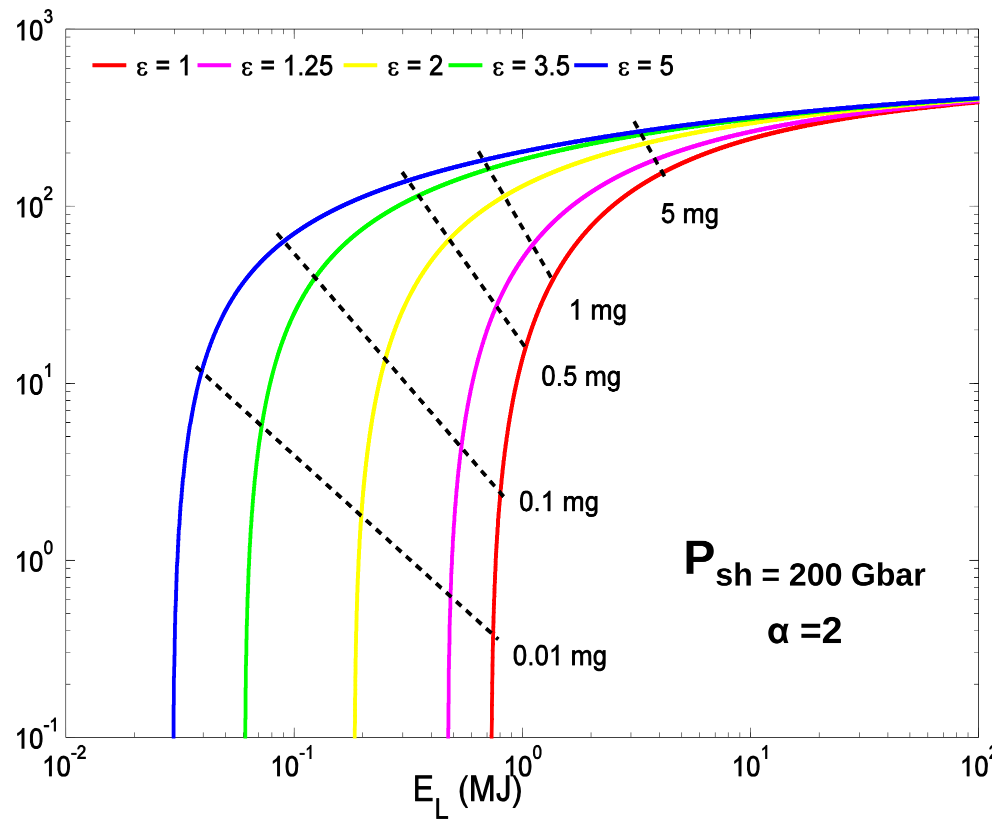
G. Schurtz,X. Ribeyre, A Casner, M. Lafon, J.Perkins,
S. Craxton, W.Theobald
S. Atzeni
CELIA/LLNL/LLE/Un. Roma

Shock Ignition is Shock Assisted Central Ignition
Idea : boost up central pressure➔ non isobaric HS



$$\epsilon = \frac{P_{hs}}{P_{sh}}$$

Non-isobaric parameter



$$G \propto \frac{\varepsilon^{0.27}}{\alpha^{0.9}} E_L^{\,0.17} \left(1 - \frac{\mathrm{cst}}{E_L}\right)$$

α adiabat at stagnation

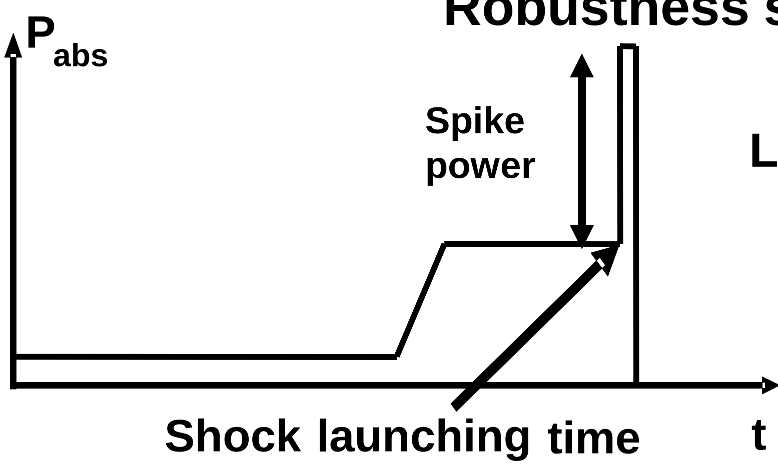
E_L laser energy

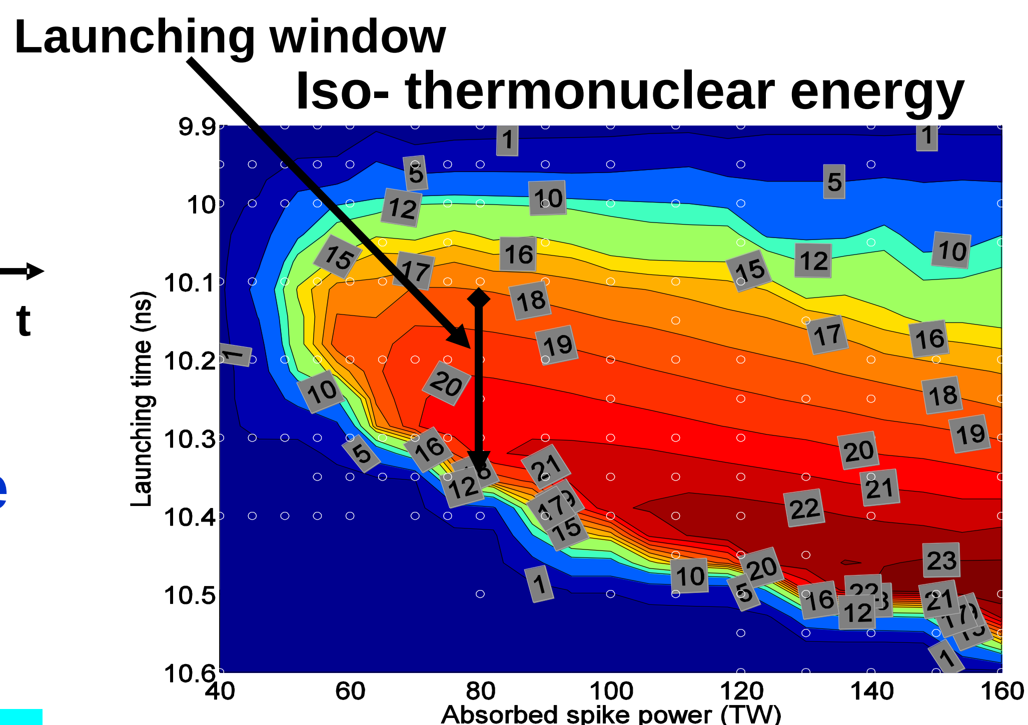
Rosen model shows the low threshold and high gain possibility of a non-isobaric configuration

(1) M.D. Rosen and J.D. Lindl (1984) UCRL-50021-83

The Ignition Shock is produced by a high intensity spike in the laser drive

Robustness study





250 ps confidence interval at 80 TW

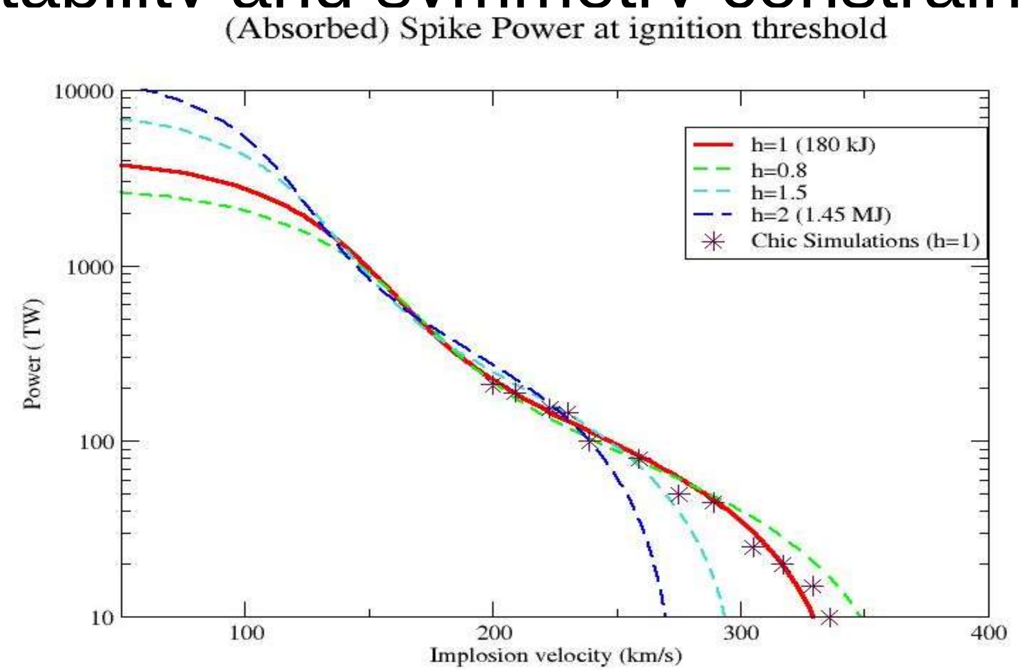
HIPER TARGET : 180 kJ, 10 ns - 50 TW for compression (3ω)
+
70-100 kJ, ≈ 500 ps – 150-200 TW for ignitor (3ω)

20 MJ (TN) : Gain ~ 80

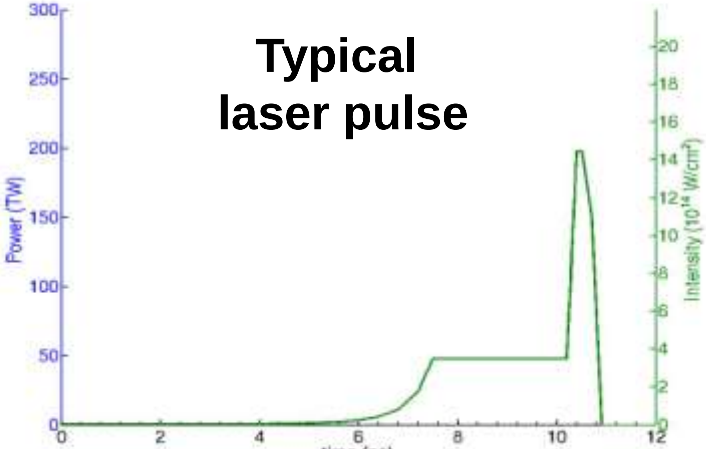
(1) Ribeyre et al. : PPCF (2009)

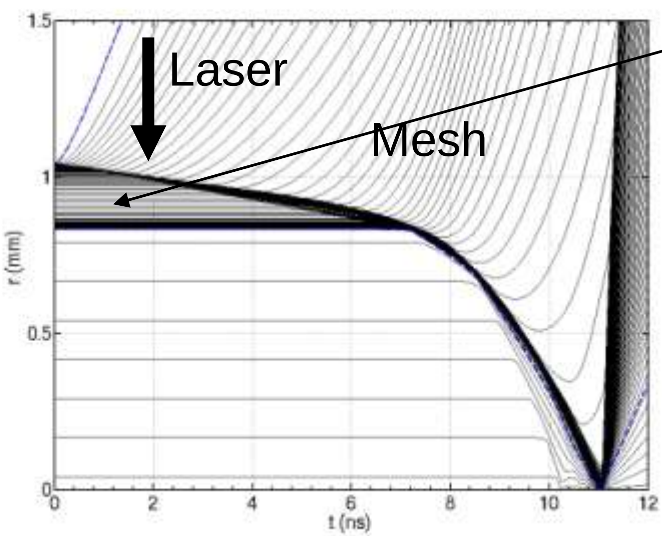
AS FI, SI separates Ignition from compression

- \+ Requires only standard laser technology
  - – ➔ achievable on NIF/LMJ class laser
- \- Needs higher implosion velocity than FI
  - – ➔ Stability and symmetry constraints apply



Absorbing > 100 TW requires dedicated beams focused at $R_0/2$





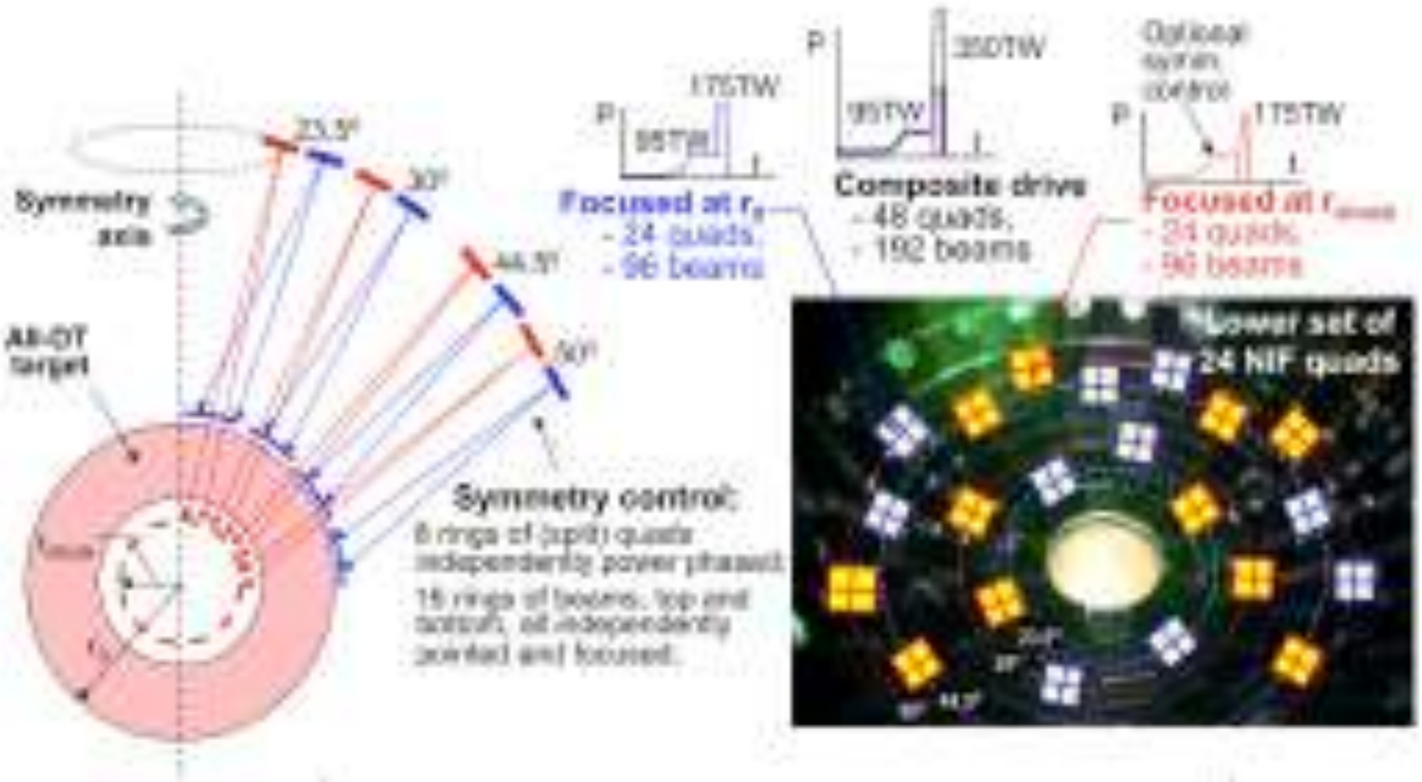
Compression beams focused at R_0

Ignition beams focused at ~ $R_0/2$

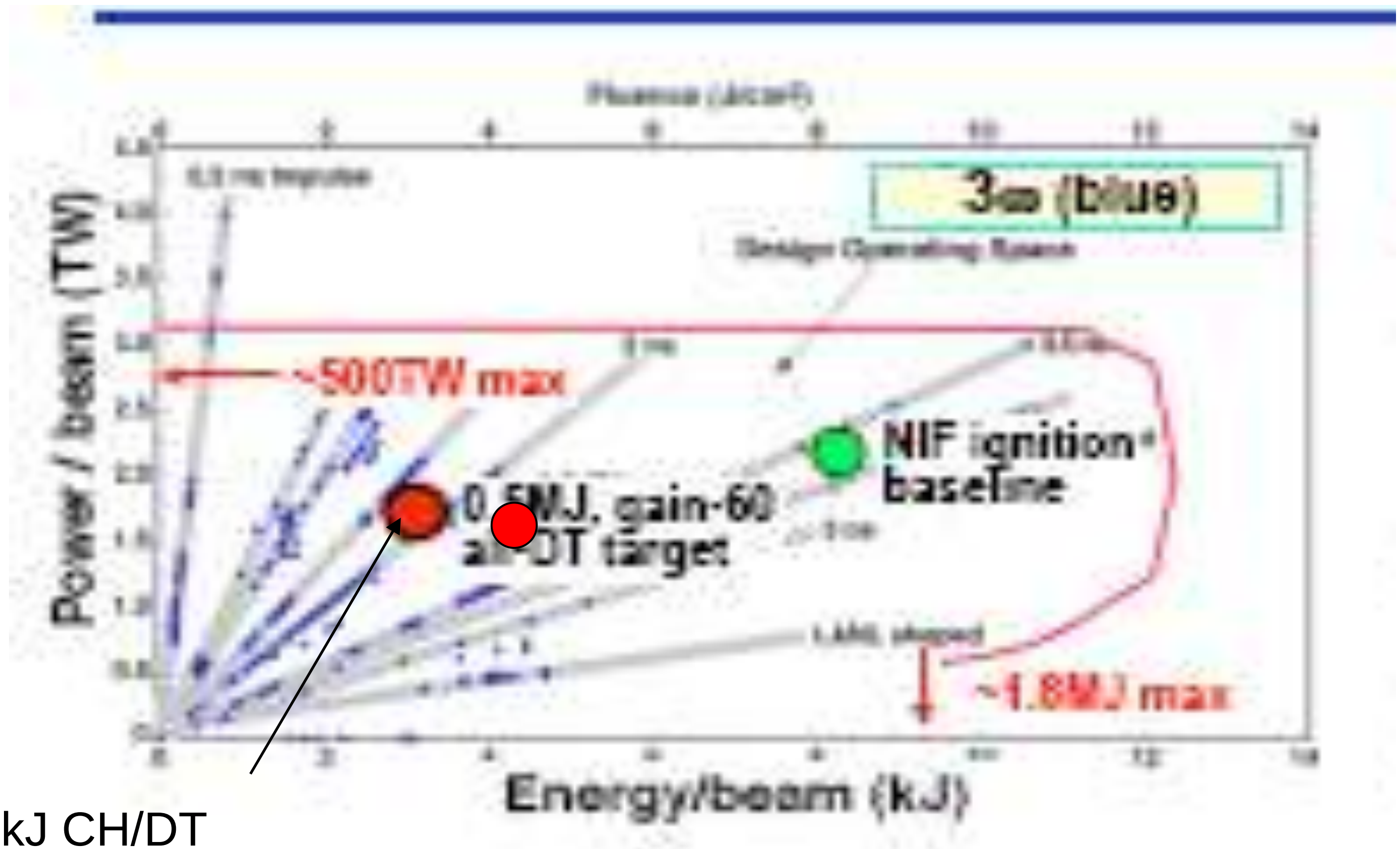
➔ Allows 75% reduction in incident power

(1) Betti R. et al. : PRL 98 (2007)

using a composite drive on NIF limits the power requirement to 350 TW

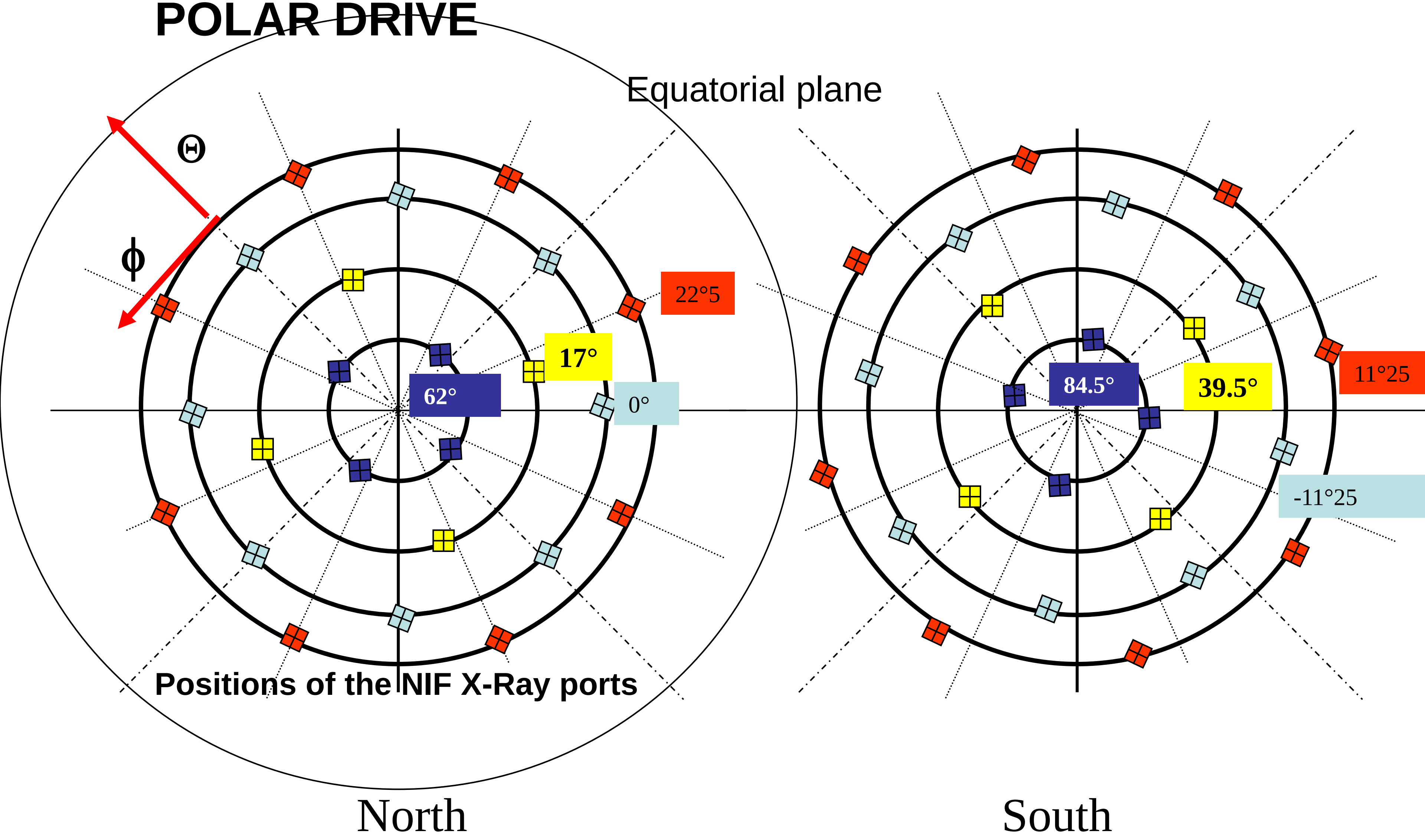


SI on NIF is achievable at low damage threshold (<1.8 TW/beam)



350 kJ CH/DT design

A SYMMETRIC COMPRESSION REQUIRES POLAR DRIVE



Design Constraints

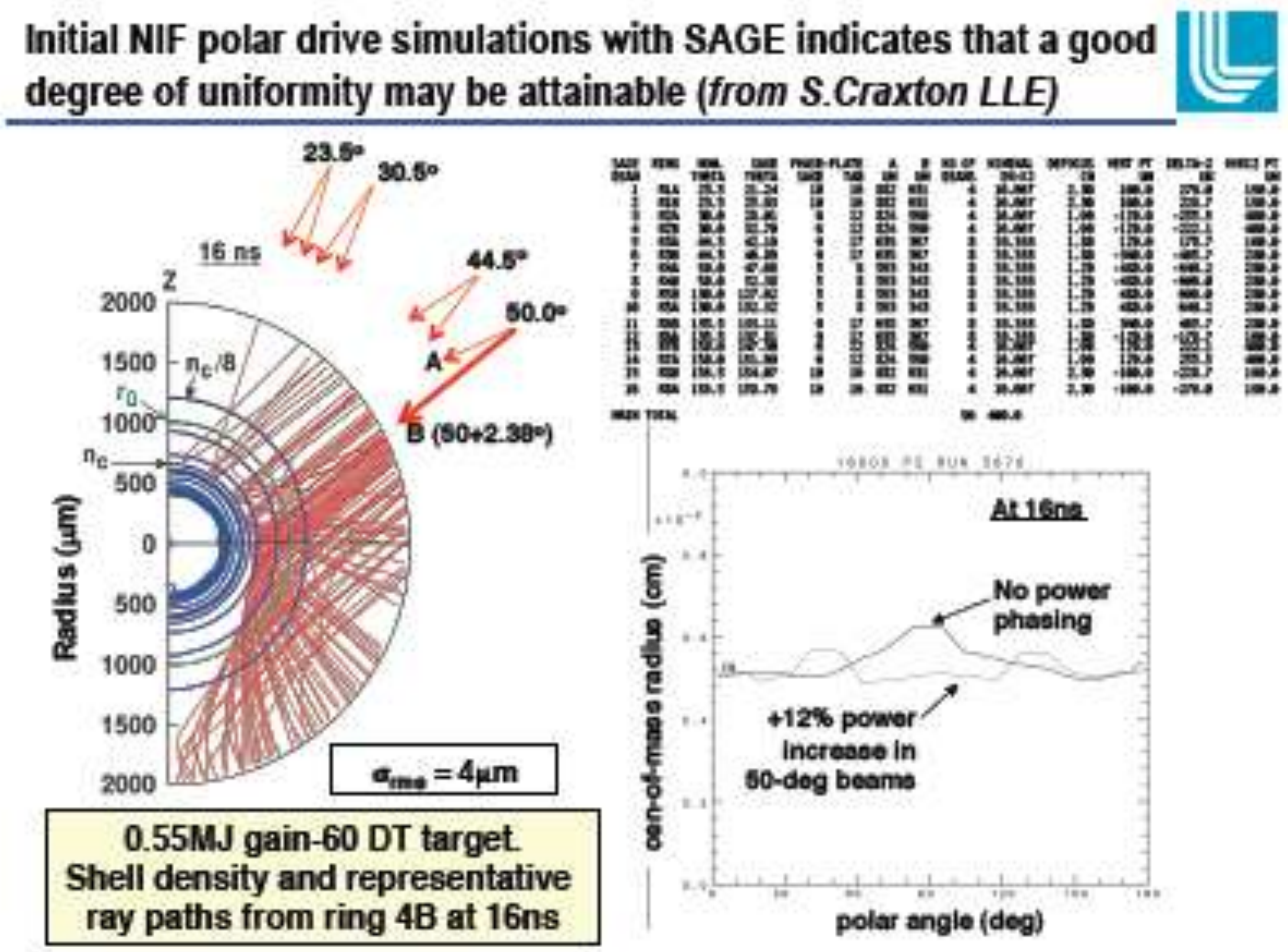
- Composite drive
  - $R_c \sim R_0/2$ at launch time
    - ➔ Spike beams on small focal spots : $R_{sp}=R_c$
    - ➔ Compression beams on best focal spots for uniformity : R_{comp}
- ~200 TW are required for ignition
  - Maximum power / beam is 1.8 TW (350/192)
  - ~96 ignition beams required + contribution from compression beams
  - ➔ total « 1D equivalent » power

$$W = 1.8\,(N_{sp} + (192 - N_{sp})(R_{sp} / R_{comp})^2)$$

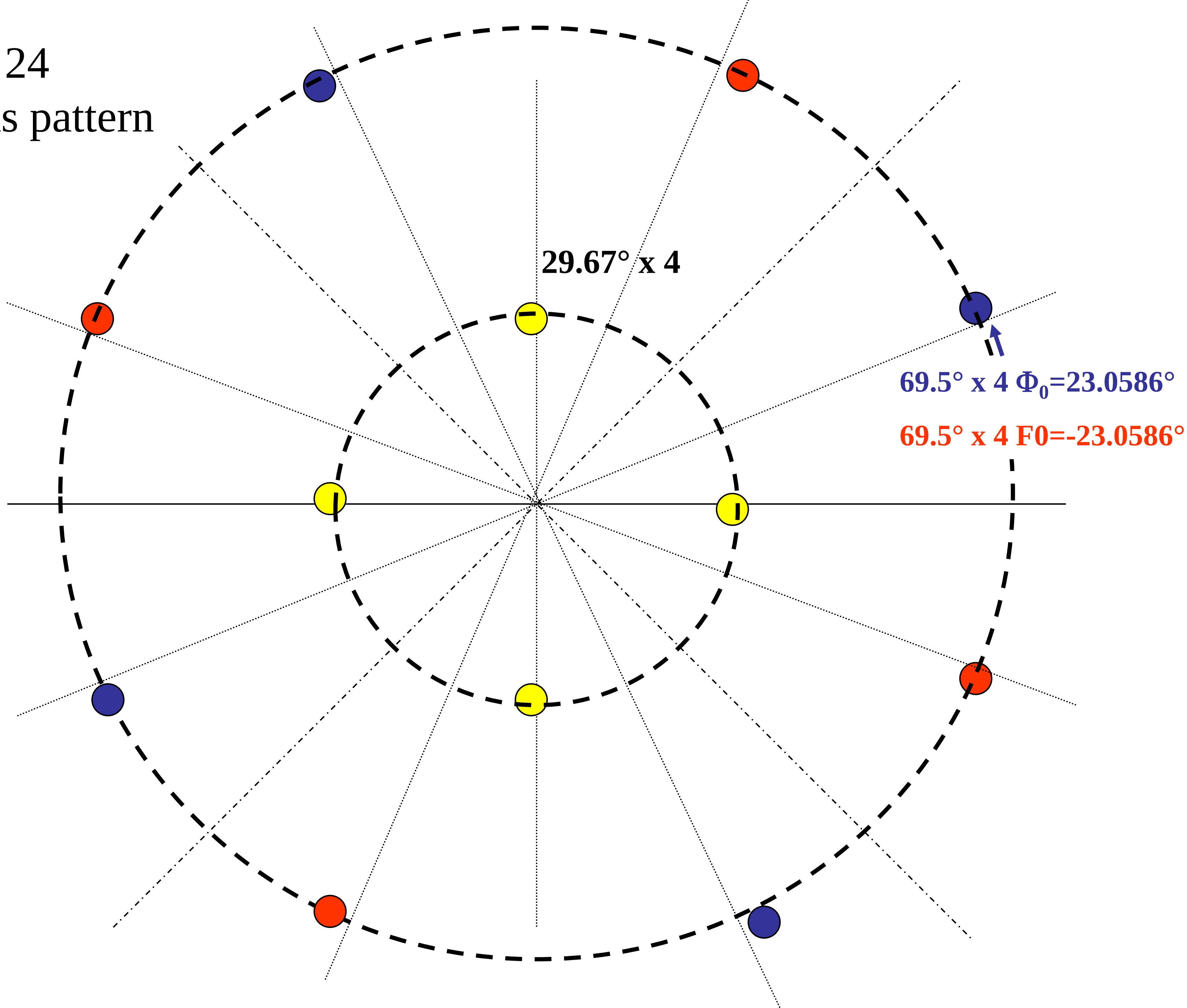
  - Eg : $N_s=N_c=96$, $R_{sp}=R_{comp}/2$ ➔ $W_{eq}=216$ TW

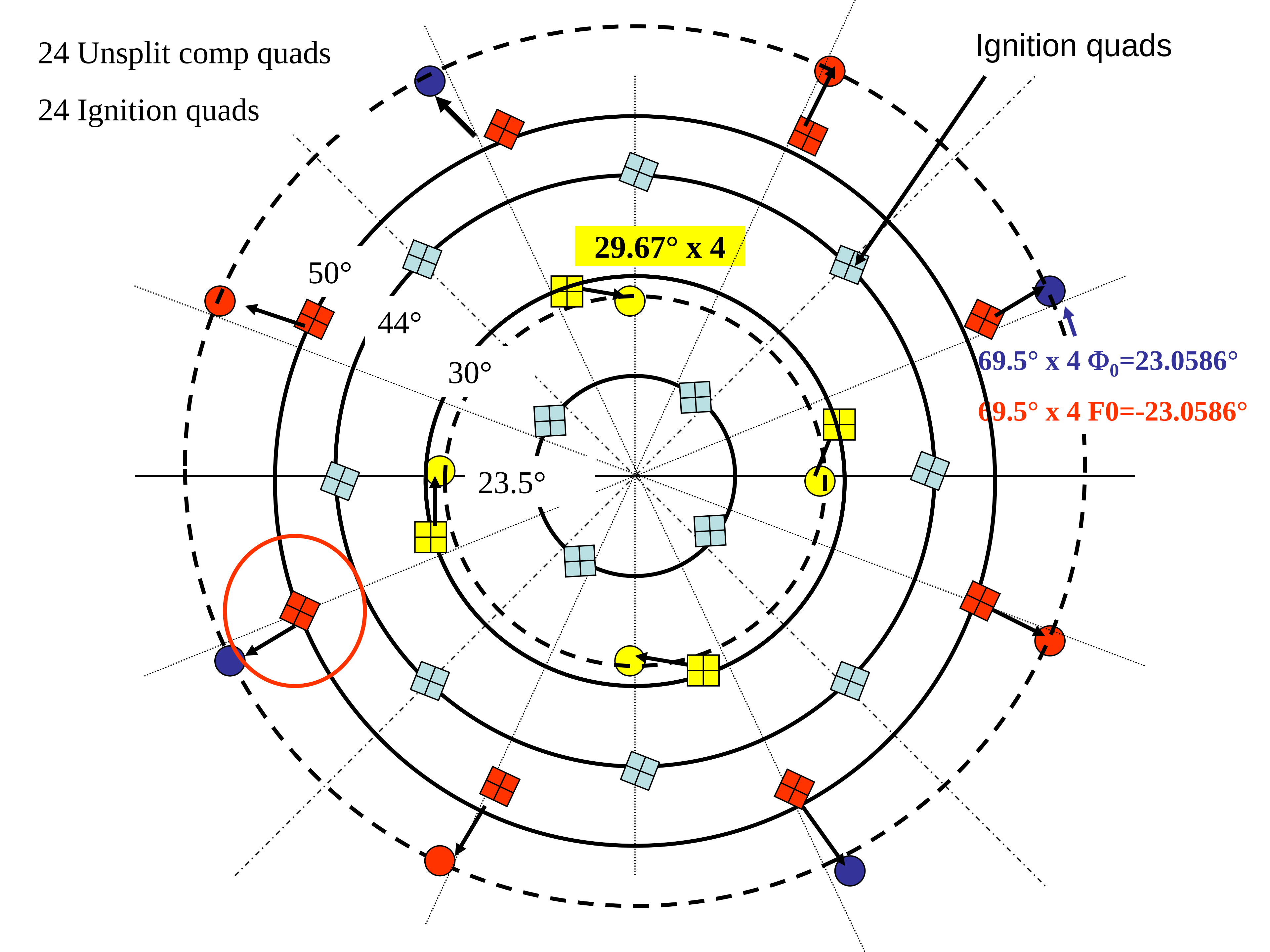
- Quads must have same pulse shape

We are now studying various PDD designs for SI



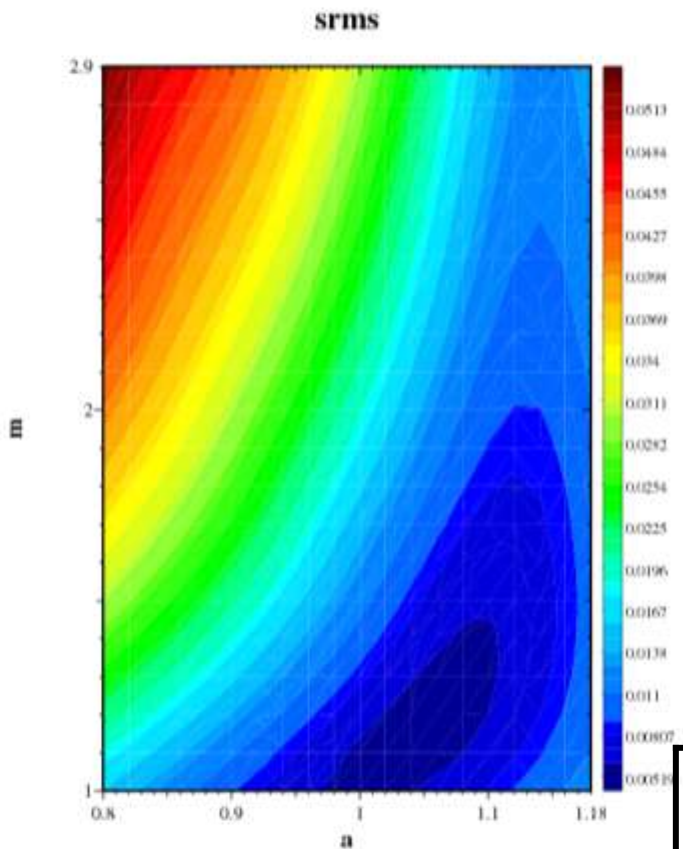
Ideal 24 beams pattern





24 Unsplit comp quads
24 Ignition quads
Ignition quads
29.67° x 4
50°
44°
30°
23.5°
69.5° x 4 Φ_0=23.0586°
69.5° x 4 F0=-23.0586°

24 spots with 96 beams



σ_{rms} < 1% for a > 0.9 (Gaussian)

Indicators

R_{spot}=0.95

σ_{rms} : 0.84% (1.5% P4)

Geom Abs : 63%

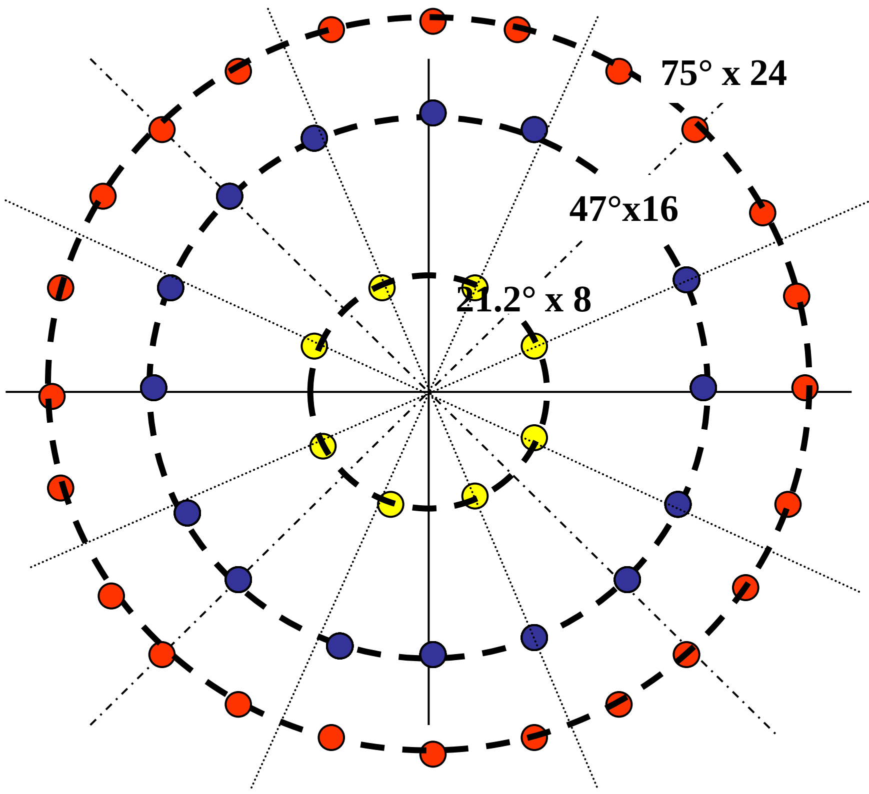
R_{spot}=1.9 (spike)

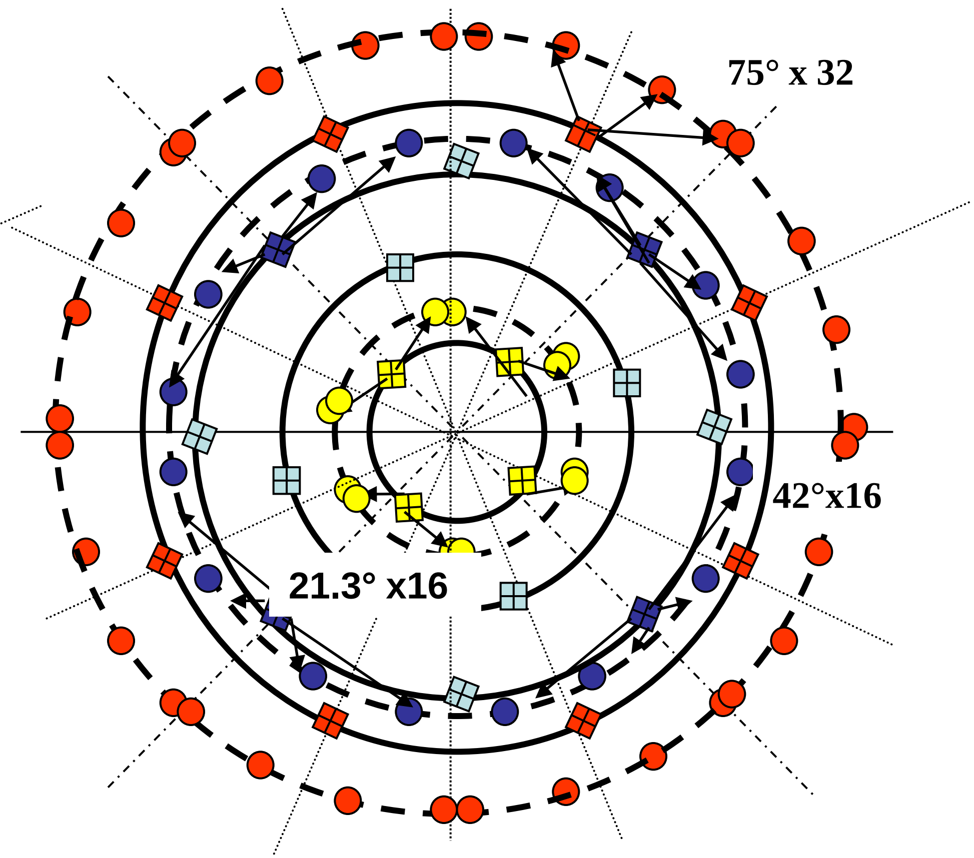
Abs = 24% (~ 42TW)

=> Total spike=217 TW

Cone	Repointing	Power/beam at 100 TW
30°	**30° unsplit**	**0.7**
50°	**69.5° : 4+4 unsplit**	**1.2**

48 and 96 beams patterns go 1/2/4 : cannot be directly achieved with 24 quads





Ideal 96 beams pattern → Approximated by 32 quads, 128 beams

128 comp beams + 64 ign beams

Cone	Repointing	Power/beam at 100 TW
23°5	**23°5 : 16 splitted**	**0.56**
44°5	**44°5 : 16 splitted**	**0.65**
50°	**75° : 32 splitted**	**0.95**

Indicators for R_{spot}=0.75

σ_{rms} : 0.82%

Abs efficiency : 73%

SPIKE

1.8x64 = 115 TW

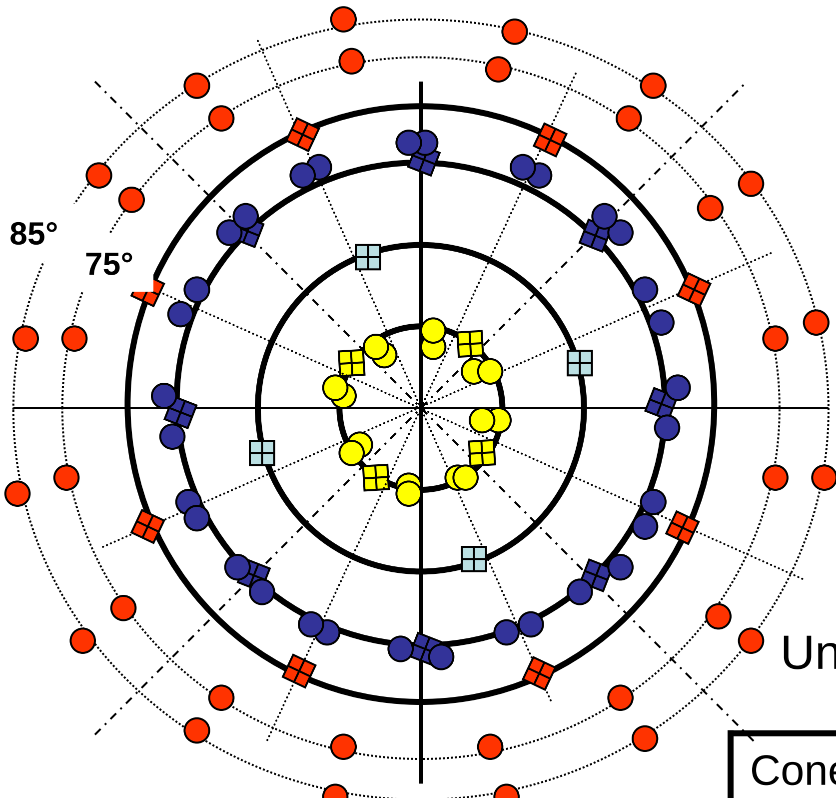
R_{spot}=1.5 R_{spike}

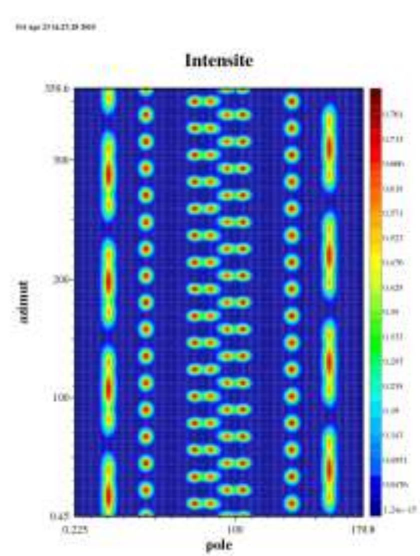
Abs = 32% (~75 TW)

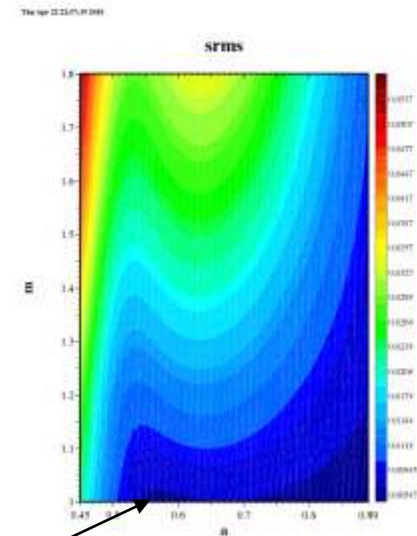
=> Total spike=190 TW

40 quads / 160 Compression beams :

mixed Polar/direct drive







Uniformity : < 1% rms for $0.52 < R_{spot}/R_0 < 1$

Indicators for R_{spot}=0.6

σ_{rms} : 0.64%

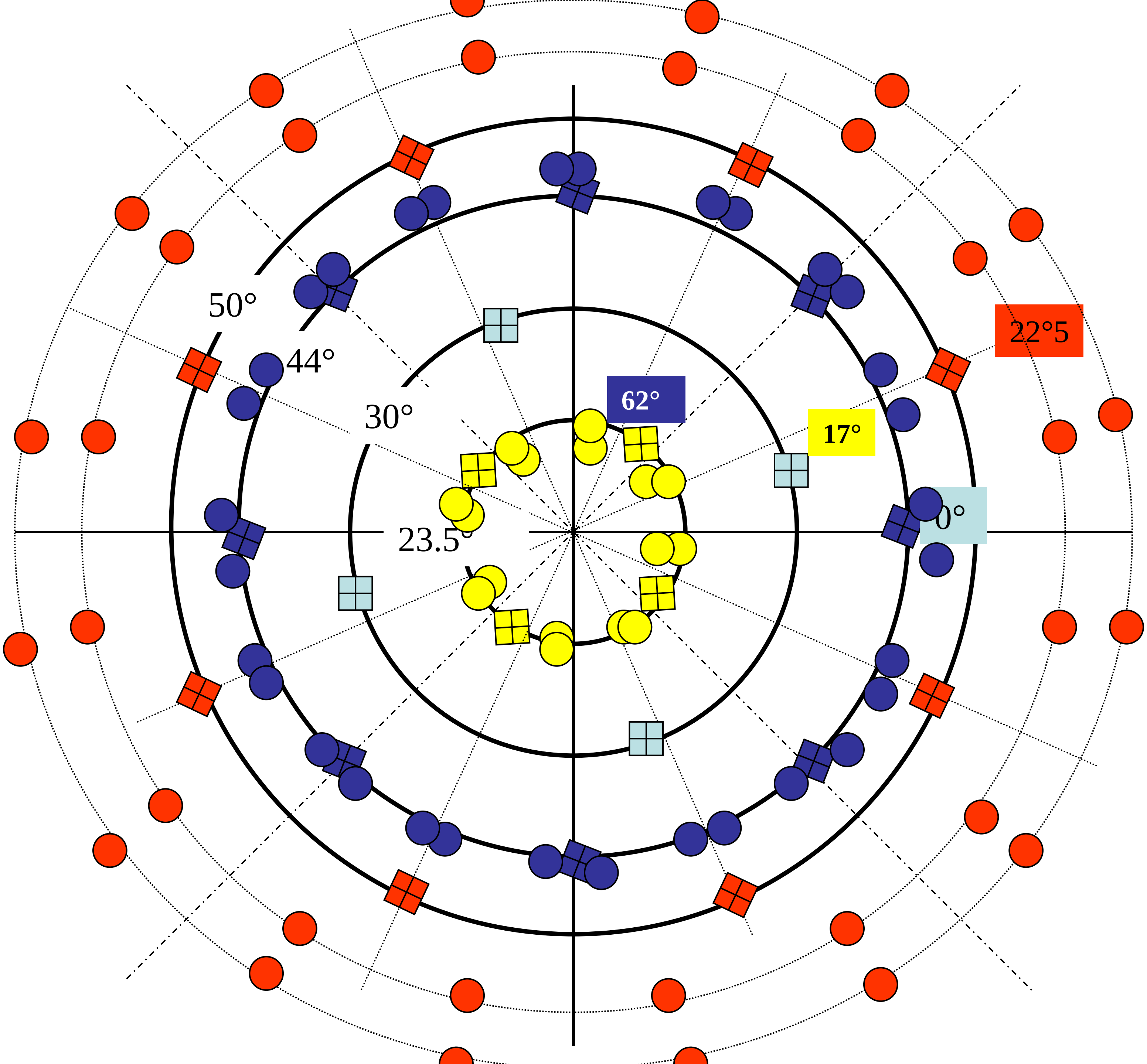
Abs efficiency : 88%

R_{spot}=1.2 R_{spike}

Abs = 60% (~170 TW)

=> Total spike=230 TW

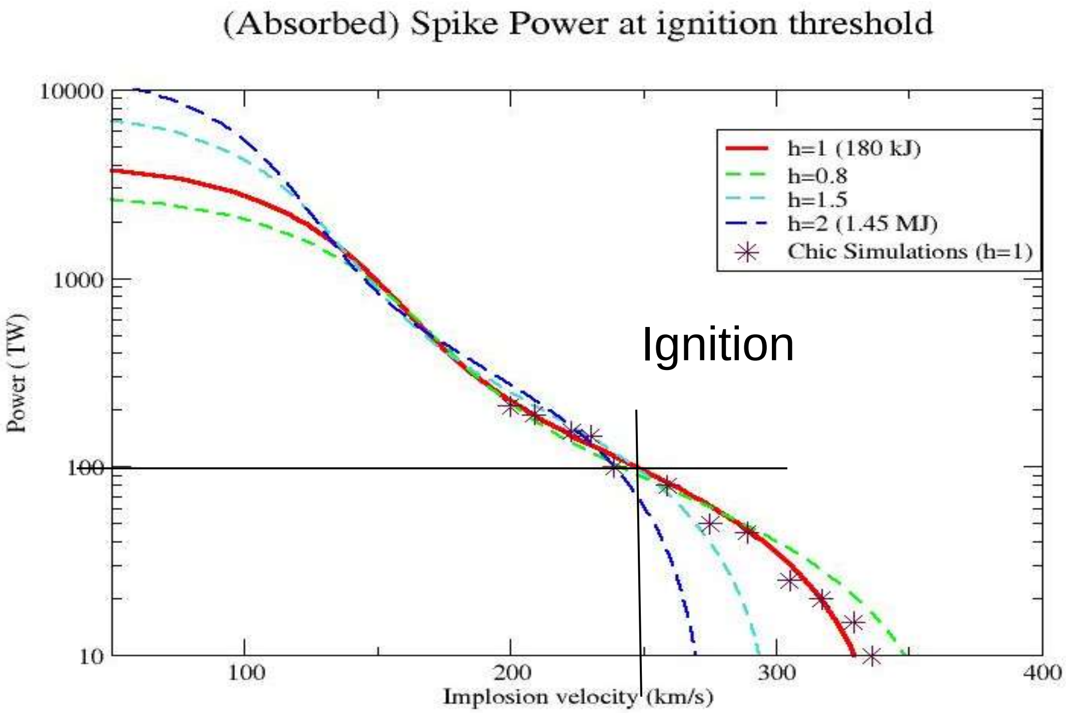
Cone	Repointing	Power/beam at 100 TW
23°5	**23°5 : 16 splitted**	**0.49**
44°5	**44°5 : 16 splitted** **16 direct**	**0.60**
50°	**75° : 16 splitted** **85° : 16 splitted**	**0.93**



50°
44°
30°
23.5°
62°
17°
0°
22°5

Consequences for target design

- P_{spike}~200 TW
  ➔Implosion velocity>250 km/s



- 200 TW, 250 km/s is close to threshold if τ_{abs}=50%
  - Absorption must be > 60 % ➔ CH , CHDT, SiO2 ablator
  - DT will need 270 km/s

Little space remains for target design

power

- Conf 1 (24 spots, 2cones, 69° PDD).
  - External beams require 1.9 TW for 100 TW comp
- Conf 2, 3
  - 1TW for 100 TW but extra margin required for time dependant symmetry

➔ Compression power < 90 TW

LPI issues : limit compression intensity to ~ 8 10^{14} W/cm^2

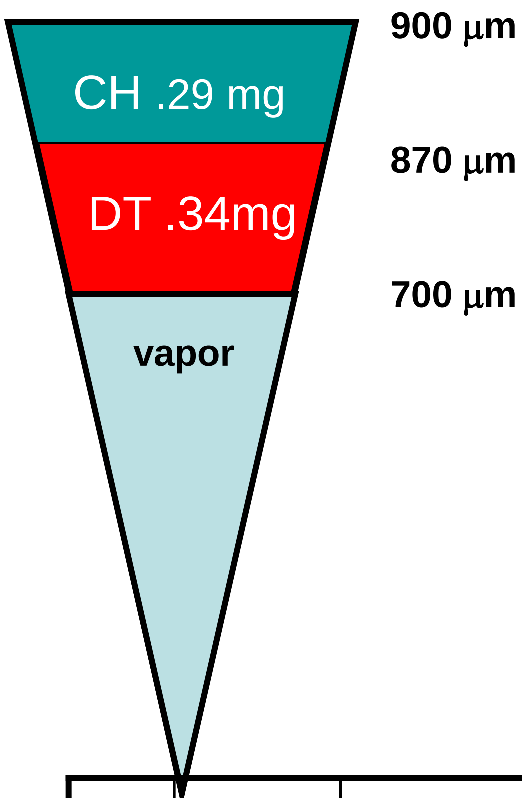
➔ Target Radius $R_{100\mu m} \geq P_{TW}^{1/2}$

~.9 mm for 80 TW

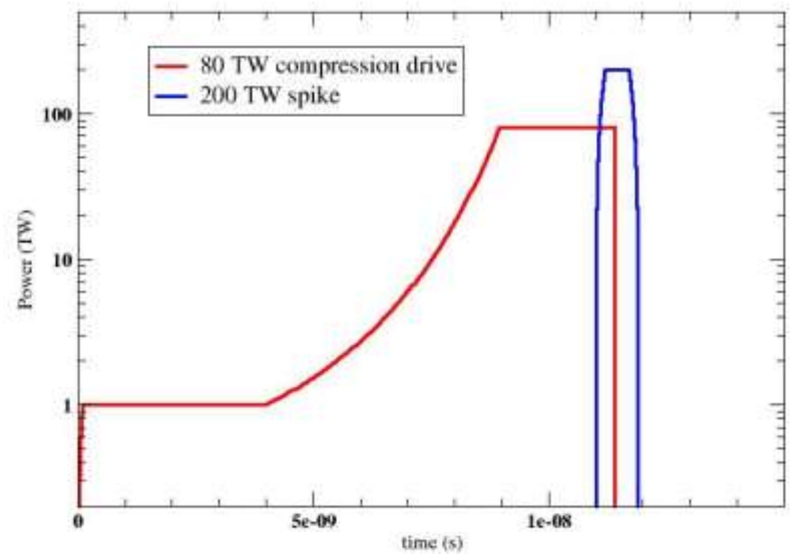
Velocity ~ 250 km/s ➔ target mass ~0.7 mg

3.5 < AR<4

NIF PDD Shock Ignition target



250 kJ comp+ 100 kJ shock



I_c=8x10^{14} W/cm^2

I_c=8x10^{15} W/cm^2

1D Performances (CHIC code)

α	AR	Vimp Comp. only	Abs. Eff. comp	Abs. Eff. spike	Yield	Gain	Ign Window
1.1	if< 37 t_0 : 4	255 km/s	92%	72%	30 MJ	85	400 ps

PDD Summary

Conf	N_{comp}	N_{spike}	R_{comp}/R_0	σ_{rms} %	τ_{abs} %	P_{comp} TW	P_{spike} TW	
Unsplit Ω_{like}	**4x24**	**96**	**0.95**	**0.84**	**63** **24**	**80**	**217**	**bipolar**
96-like	**128**	**64**	**0.75**	**0.82**	**73** **32**	**100**	**190**	
mix	**160**	**32**	**0.6**	**0.64**	**88** **60**	**100**	**230**	**Needs CH**

PDD

-2 rings PDD is the simplest, but will need a 24 quads bipolar shock drive

-3 rings PDD involves more than 24 quads

-Mix drive gives the best uniformity for the smallest focal spots.

➔Uneven (as 40/8) composite drives may perform better than even 24/24

➔**192 compression beams with R_{comp}=0.55 gives >200TW for the spike !**

Target

.7mg, AR=3.3 seems the limit. .64mg, AR=4 performs well at 80 TW

30 microns CH performs better than 10 (absorption, X-ray shielding)

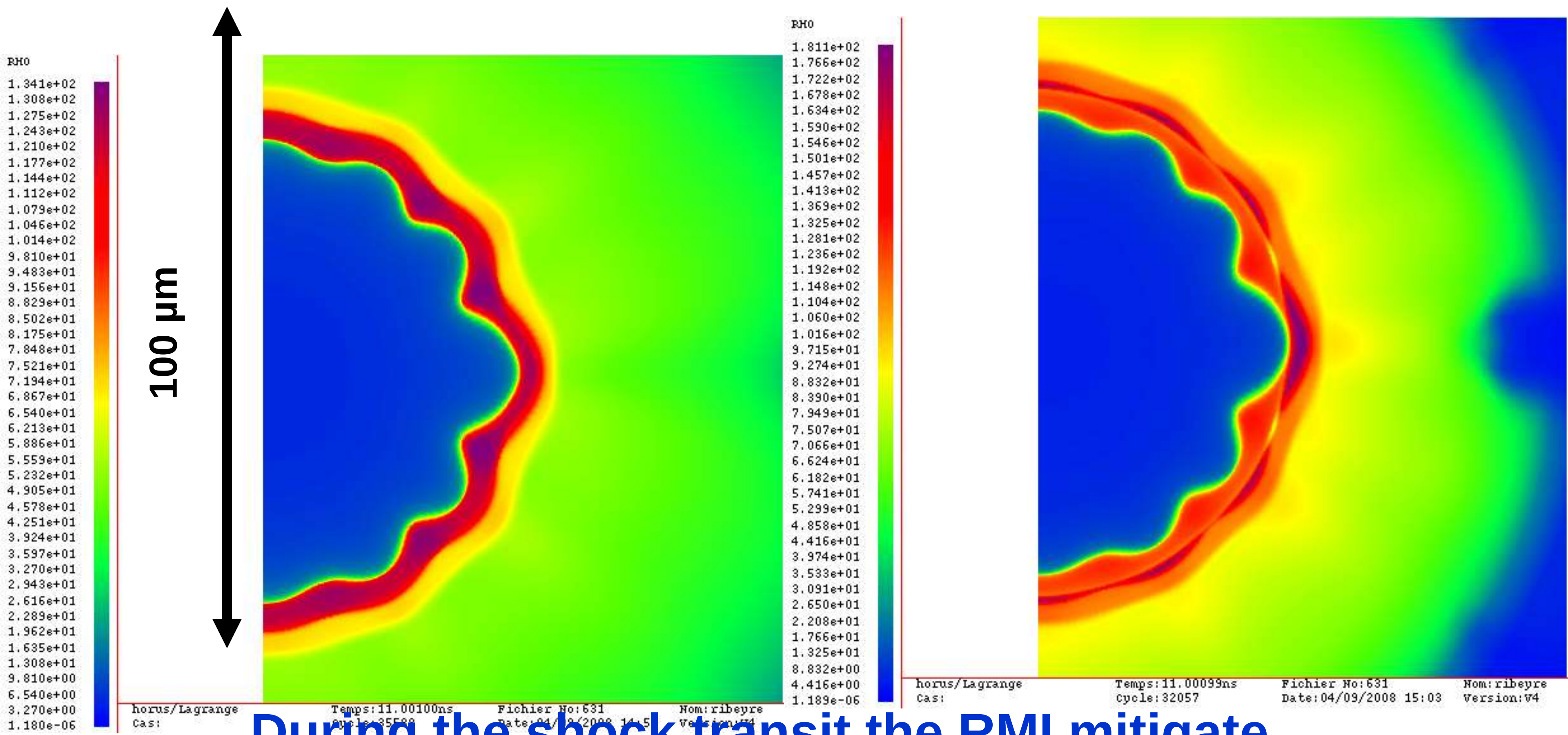
Amenable to Br or Ge doping if an Au IR protection is used

2D issues

Rayleigh-Taylor instability (RTI) for low mode asymmetry (irradiation)

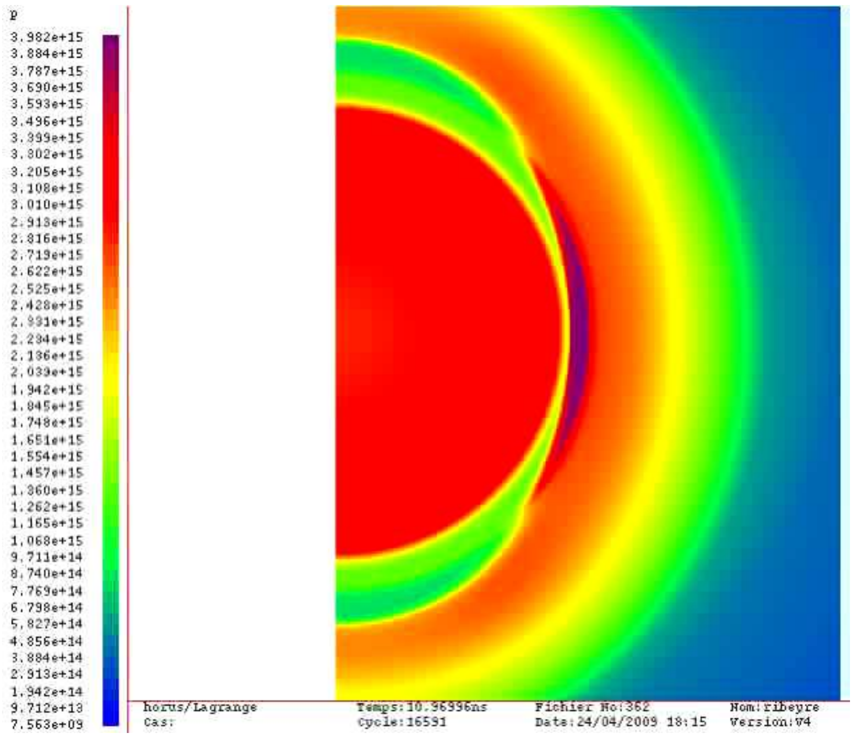
Density evolution during the stagnation

Without shock **With shock**

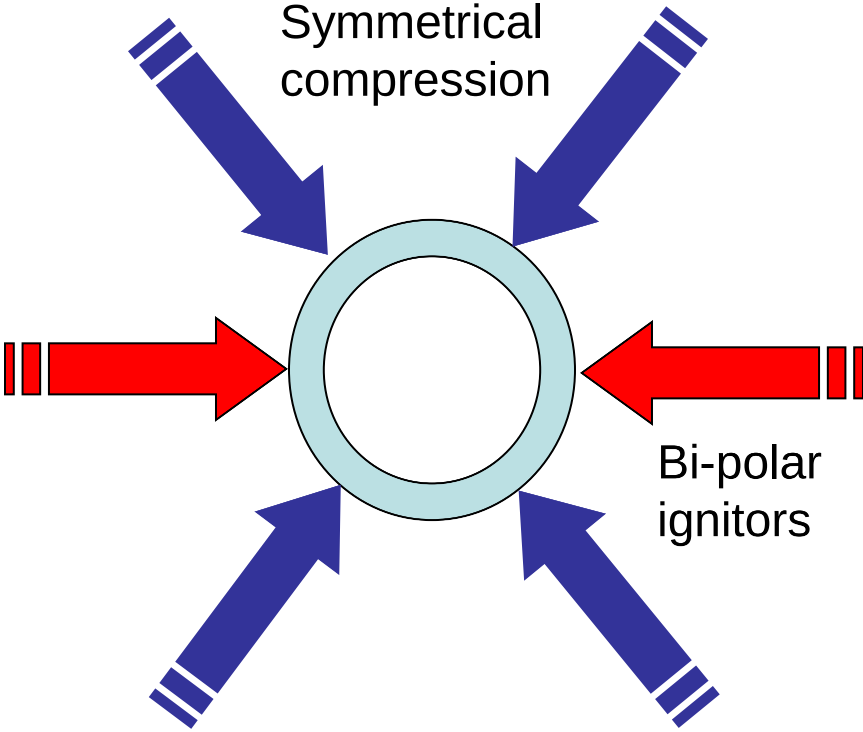


During the shock transit the RMI mitigate the RTI before the burning phase

A Symmetrical shock may be obtained from a non uniform drive



Cloudy Day model



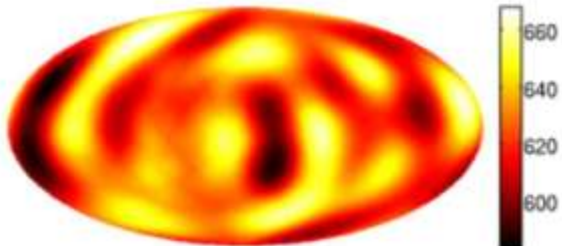
$$a_l(R_{ab}) \prec a_l(R_{cri})\left[\frac{R_a}{R_c}\right]^l$$

$$\frac{R_a}{R_c} \approx 0.5$$

Shock Symmetry issues will be investiated on Omega

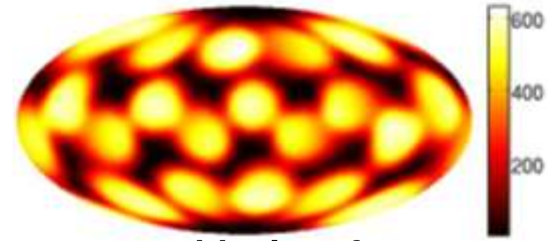
40 + 20 beams: June 2010 Omega experiment - Best symmetry

40 beams : 2.6 % non-uniformity: best symmetry



Incident on target after beam repointing

20 beams: on Dodecaedron vertices: best symmetry

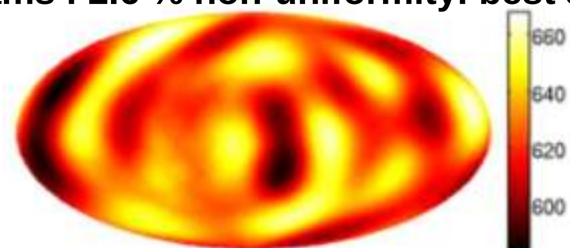


On critical surface

2 rings :
- 5 beams 37.4°
- 5 beams 79.2°

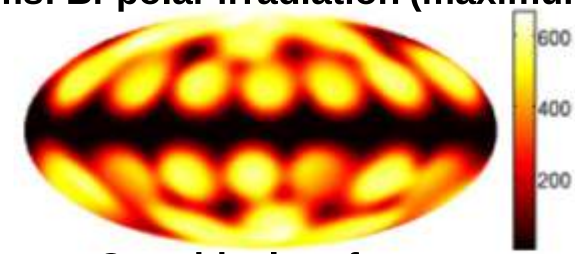
40 + 20 beams: 2011 proposal Omega experiment – Bipolar Shock irradiation

40 beams : 2.6 % non-uniformity: best symmetry



Incident on target after beam repointing

20 beams: Bi-polar irradiation (maximum near the pole)

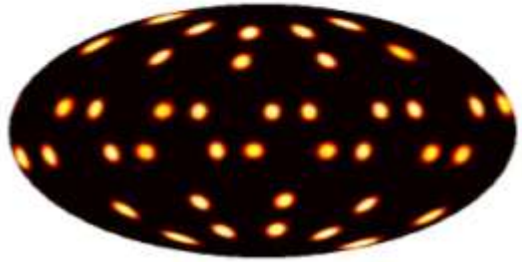


On critical surface

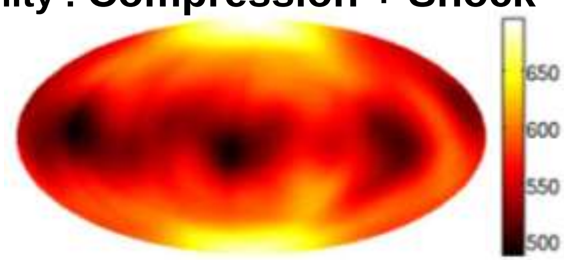
2 rings :
- 3 beams 21.4°
- 7 beams 58.8°

40 beams: 2011 proposal Omega experiment: NIF PDD like

40 beams : NIF PDD irradiation : ~5 % non-uniformity : Compression + Shock



NIF-PDD position: 3 rings (21.4°, 44.5°, 77.5°)



Incident on target

Summary

- Shock Ignition is considered for HiPER as well as Fast Ignition
  - ➔ needs demonstration
  - ➔ down selection on a risk/cost analysis basis
- NIF is achievable in the near term on NIF using D1 hardware : X-Ray pattern + RPP
- Main Physical issues are investigated on Omega