Perspectives for Shock Ignition experiments on LMJ

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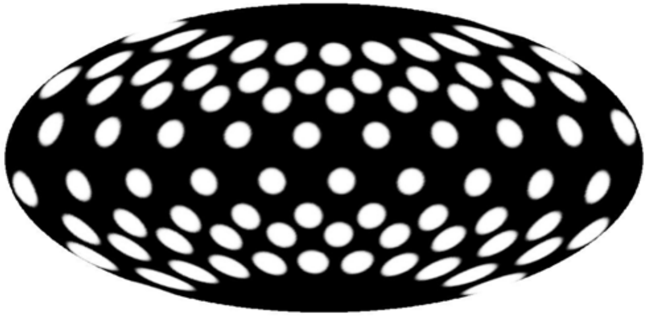
CELIA



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LMJ schedule

- PETAL+ to be commissionned end 2014
  - 8 beams of LMJ + 3.5kJ ps beams
- 2016 : 80 ns beams
- 2017 : 160 LMJ beams + 16 radiography beams
- Hiper cannot wait for completion of CEA defense programmes to enter the game
  - Need to use LMJ as it is : ID laser ports and focusing hardware
  - Use LMJ at low damage : E<600 KJ, P<300 TW

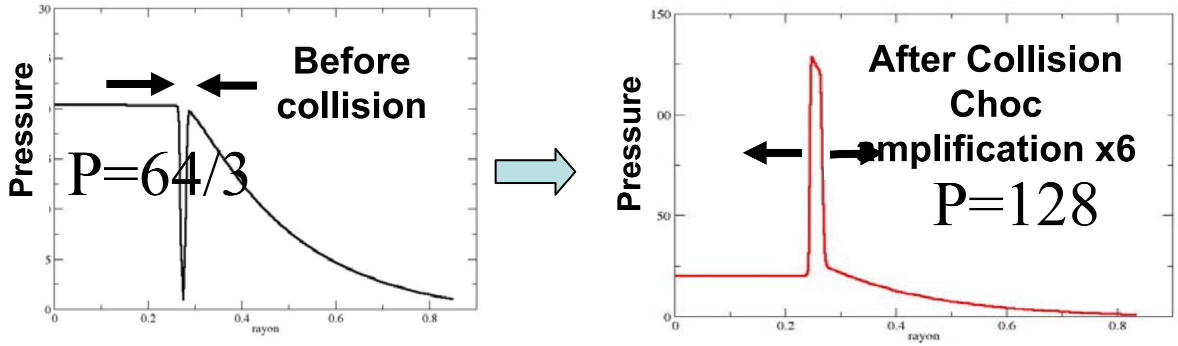
Definition of HiPER and target design have strongly evolved since 2007

- 2005-2008
  - HiPER demonstrates single shot fast ignition using 150 kJ of ns pulse + 100 kJ opcpa
  - Stefano Atzeni's target : all DT, .59 mg driven at 135kJ, 40 TW
- 2008-2011
  - HiPER addresses IFE issues, including high rep, mass production + Injection and tracking
  - Down selection of solutions on the basis of
    - Detailed specs
    - Demonstration of ignition on existing facilities : NIF, LMJ
  - Shock Ignition becomes the main line
  - CEA supports HiPER « in kind » : 20% of LMJ shots
- May be envisonned using ID hardware

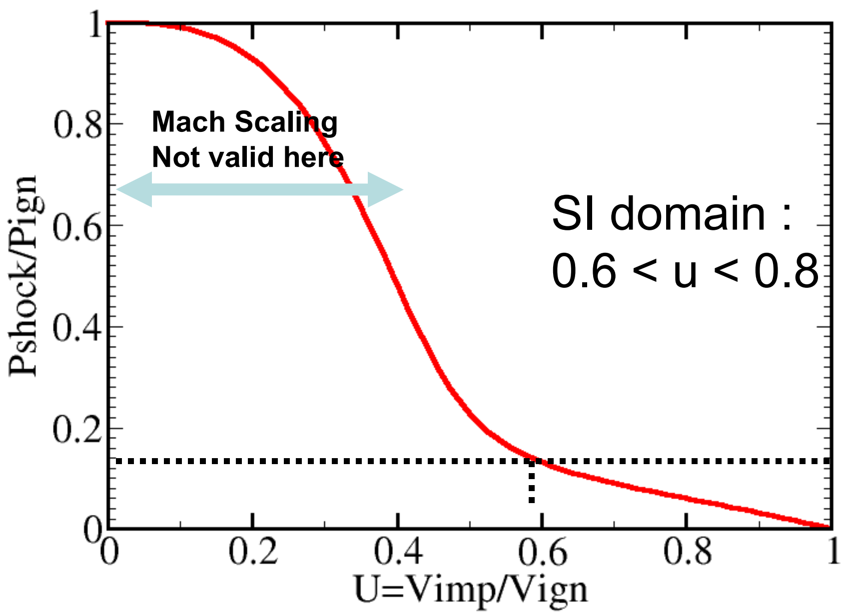
Implosion velocity for SI ranges in the 230-280 km/s interval

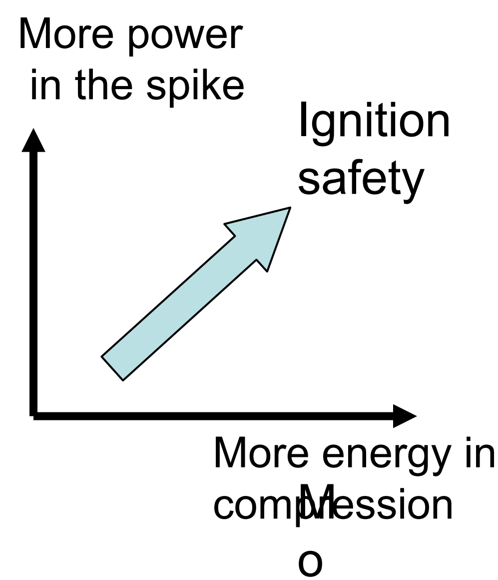
Efficient shock collision requires impedance matching

X 6 in ideal conditions



Rankine Hugoniot
+
Mach scaling



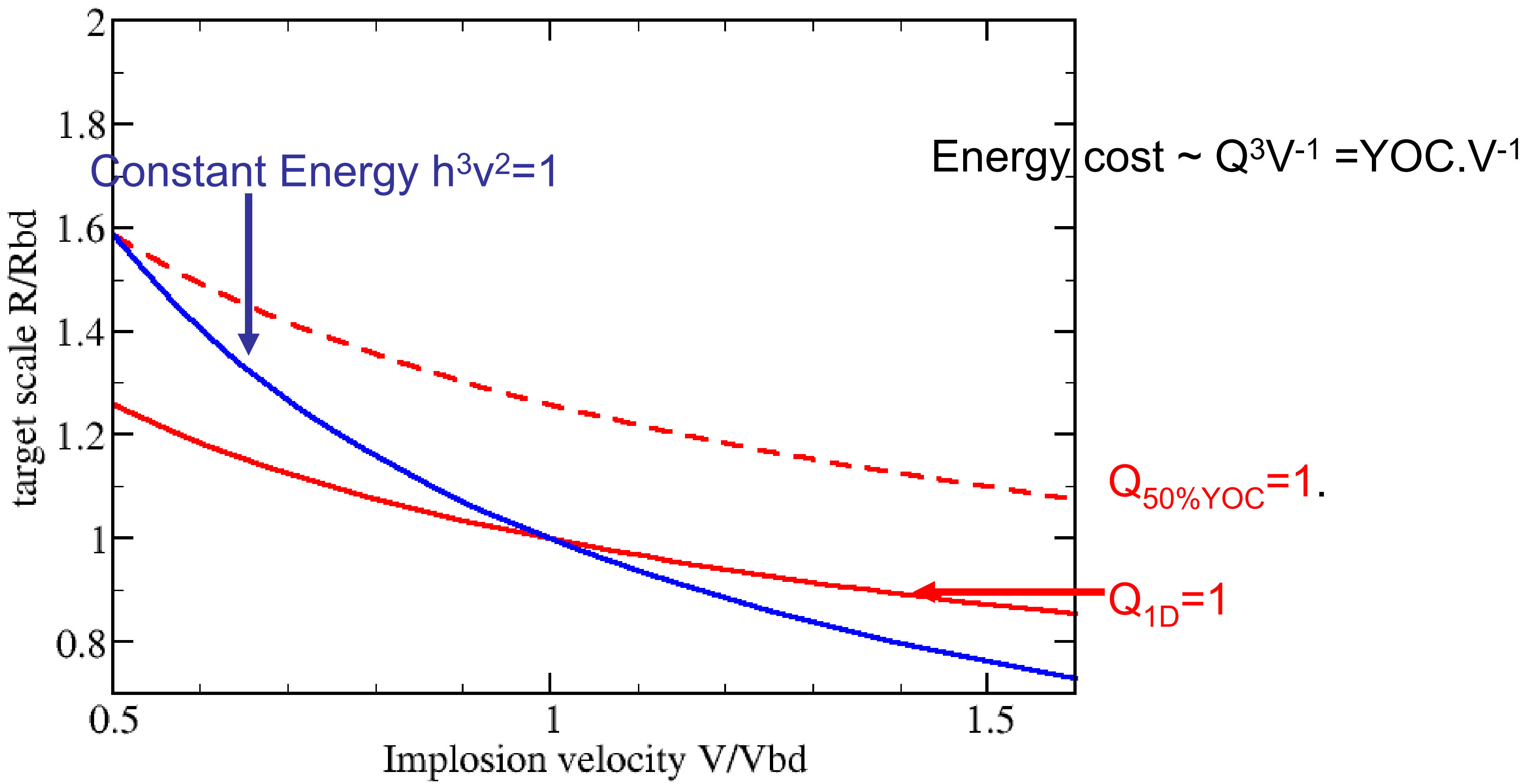


Ignition safety : back of the enveloppe modeling

Assume baseline design such as: scale h=1, Velocity V=1

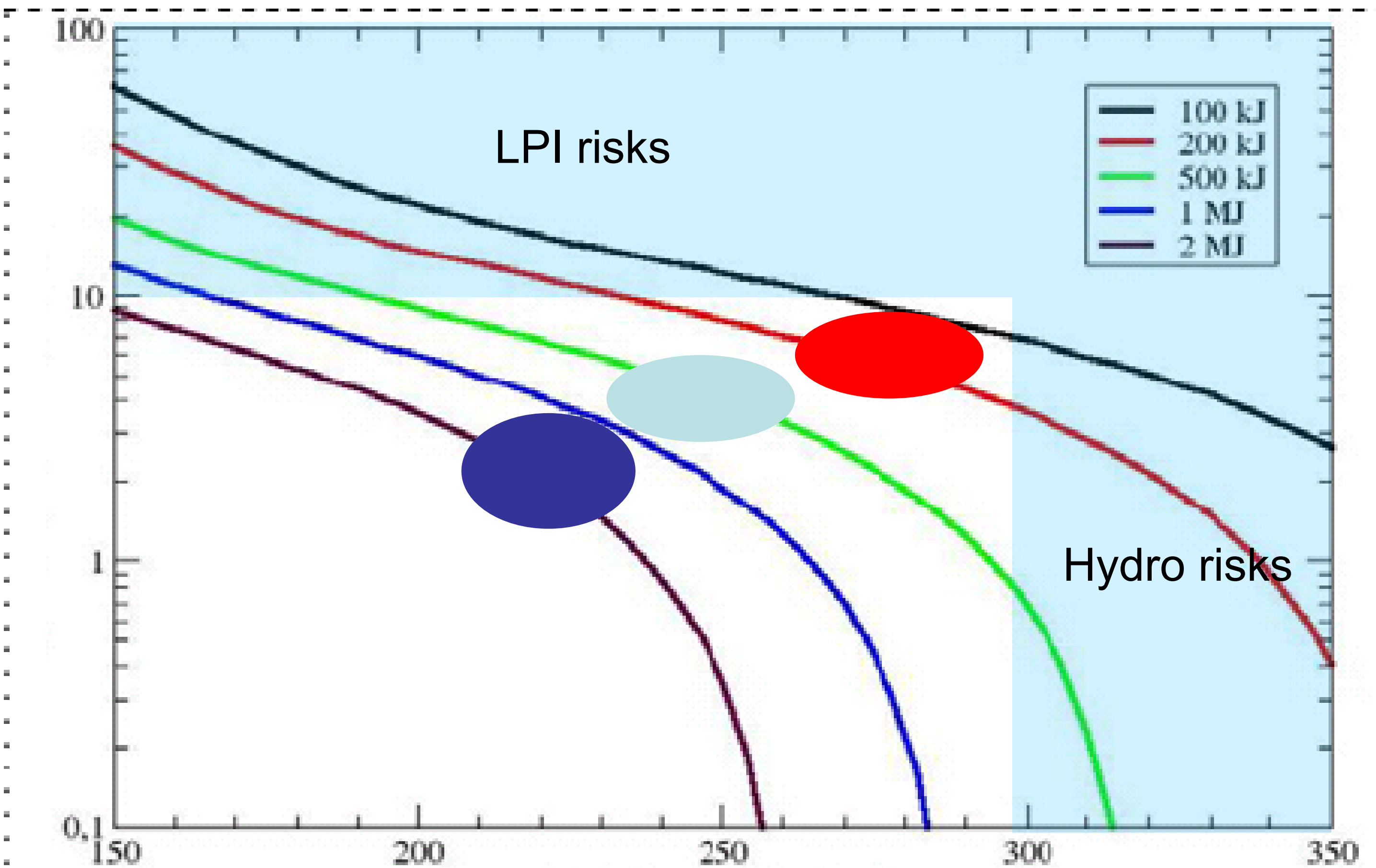
Ignition parameter Θ=p.R constant on the curve $h.V^3=1$ (for same impedance match)

YOC ~ $(R_{clean}/R_{1D})^3 \Rightarrow \Theta_{rough}=\Theta_{1D}\,YOC^{-1/3}$: 50% YOC calls for h~1.26



Ignition occurs for $P_{hs}R_{hs} > Q_0$: Trading Off Risks becomes easier at higher energy

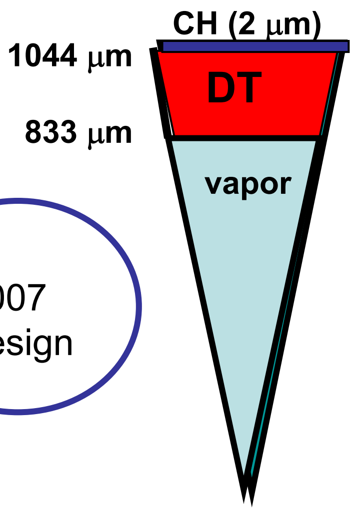
Intensity in spike (10^{15} W/cm^2)



Implosion velocity (km/s)

Curves given for the all-DT 180 kJ target

HiPER Target Design evolves towards more realism and enhanced robustness



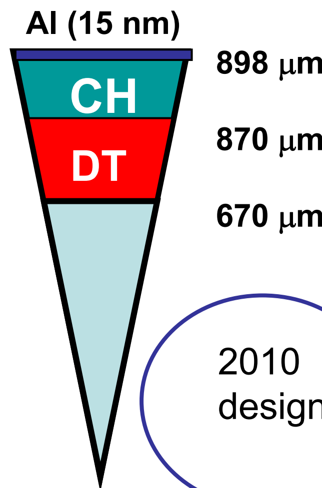
2007 design

CH ablator

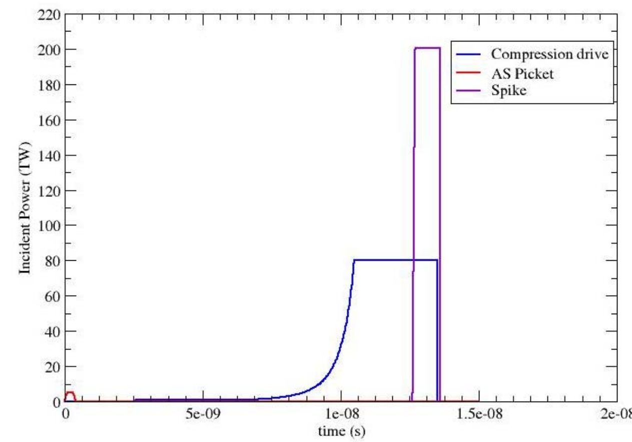
- Ease manufacturing
- Amenable to doping
- Higher collisionnality

& TPD threshold

Lower AR and hydro efficiency ➔ hydro robustness



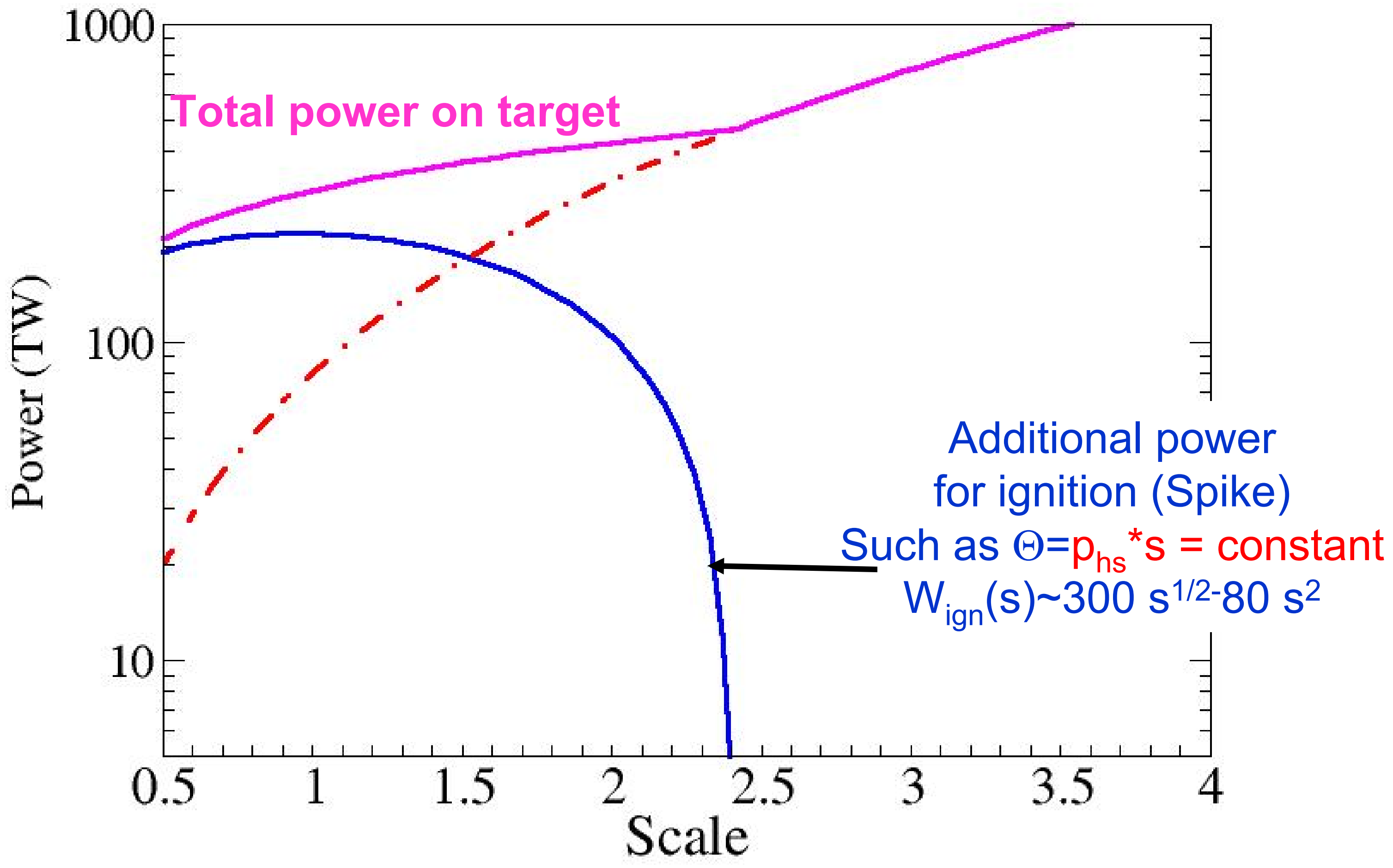
2010 design



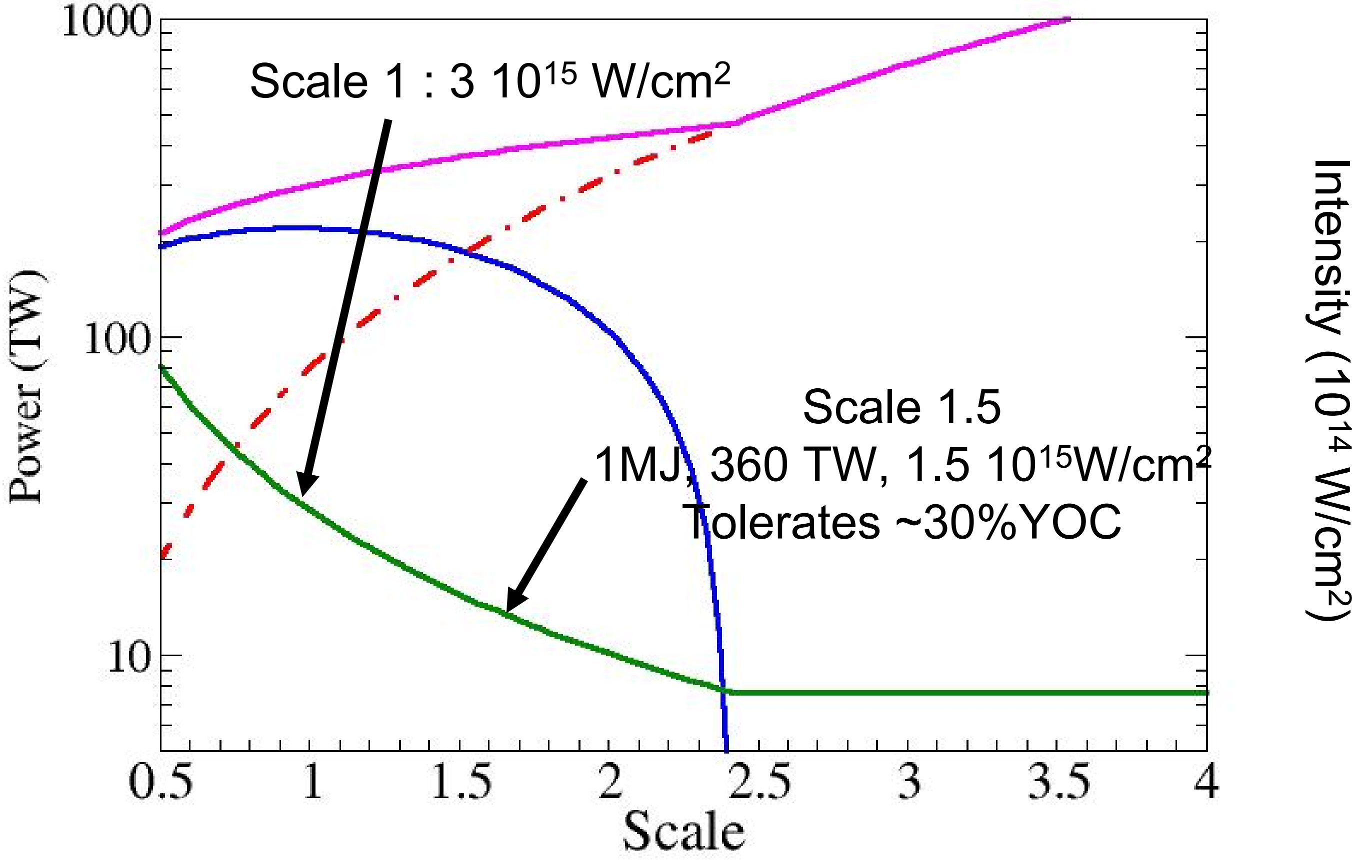
	IFAR 75%r_0	Mass	Compression	Vimplo	η %	Spike	Gain
ALL DT S.A.	4.5 (t=0) 30 (75%r_0)	.59 mg .29 fuel	180 kJ 50 TW 600 g/cc 1.5 g/cm^2	280 km/s	9%	160 TW 80 kJ	Y = 20 MJ G ~ 76
CH G.S./S.A.	3.4 (t=0) 18 (75% r_0)	.67 mg .38 mg fuel	260 kJ 80 TW 720 g/cc 1.83 g/cm2	240 km/s	5%	200 TW 150 KJ	Y = 32 MJ G ~ 80

Upscaling HiPER at constant velocity : shock requirements

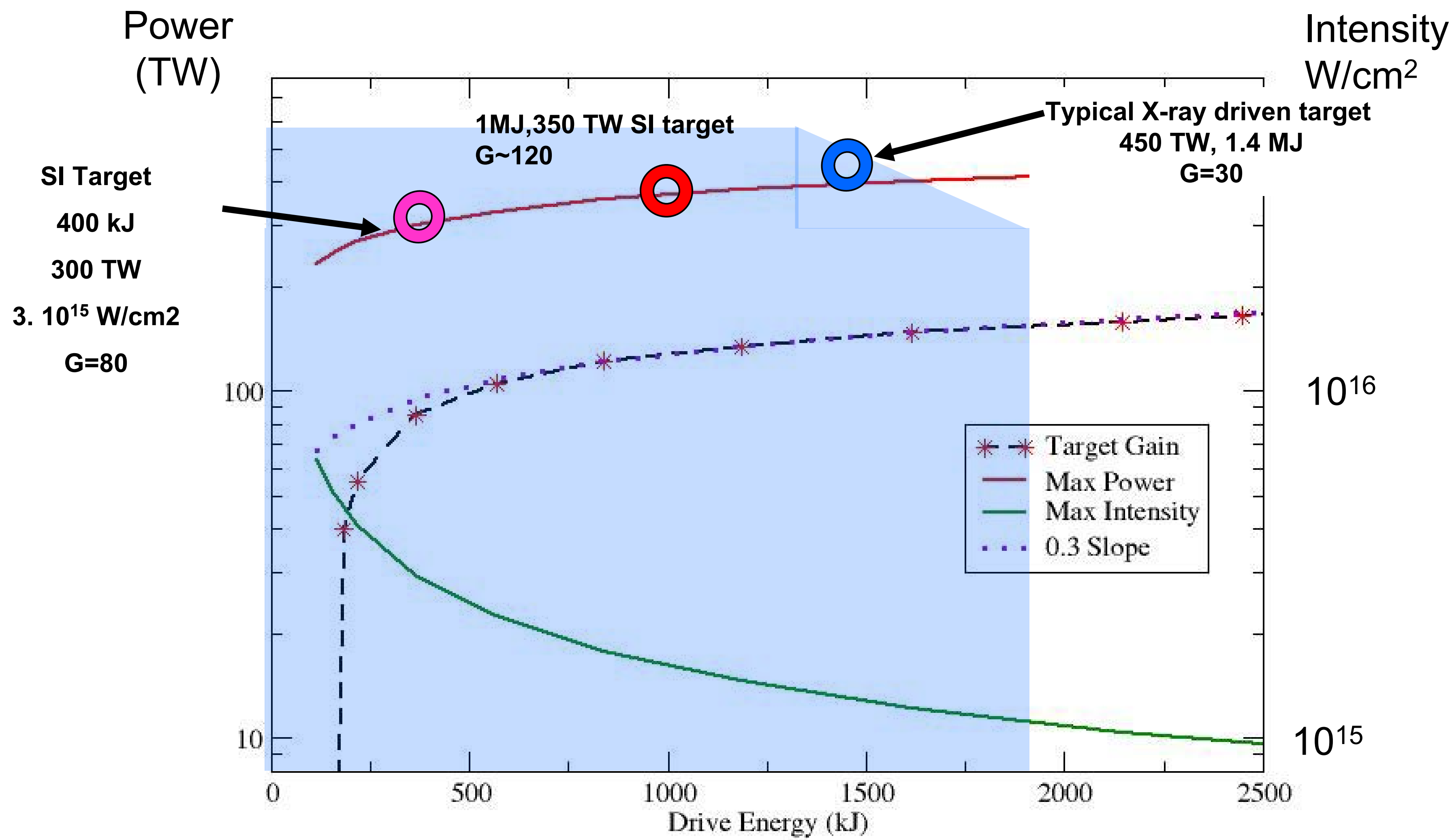
R➔ R.s , t➔ t.s , W➔ Ws², E➔ Es³, M➔Ms³ : **SAME VELOCITY AND INTENSITY**



Maximum Laser Intensity decreases with target scale



Gains > 100 may be obtained from safe SI targets on MJ class lasers

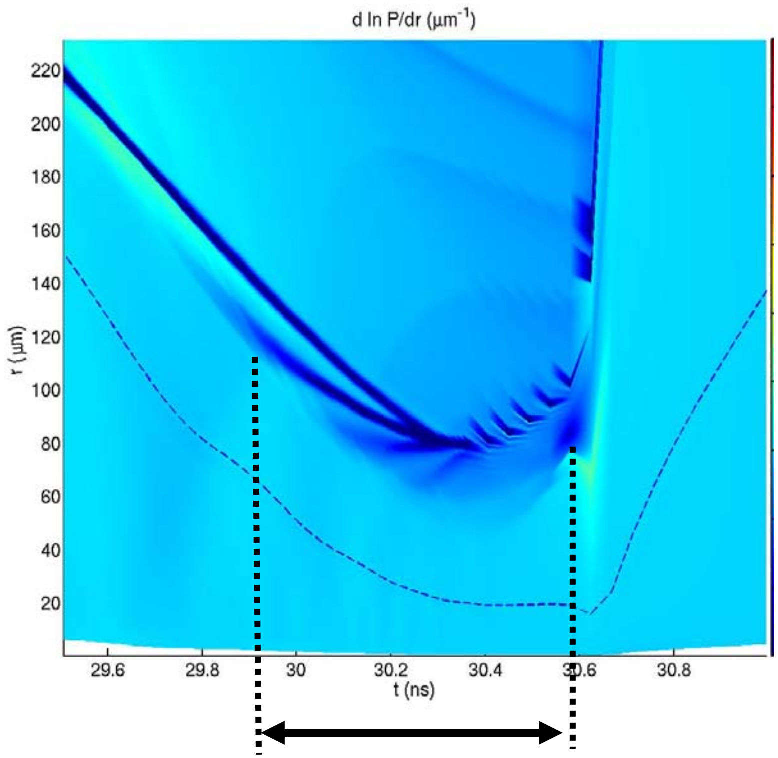


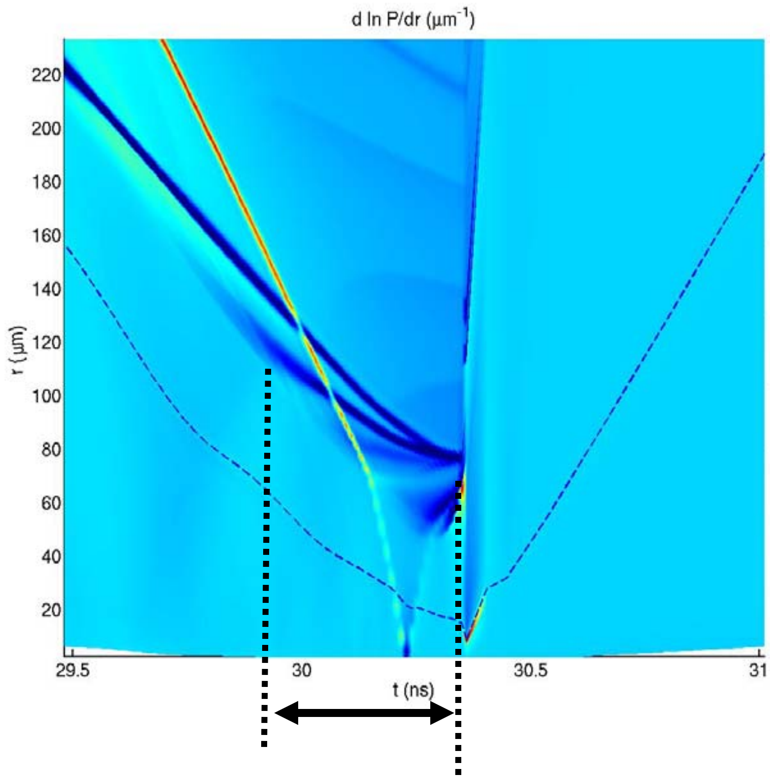
At reactor size, a shock allows control of the ignition time

A 3 MJ, G=200 CH/DT target

self ignites at 240 km/s

Same target with a shock ignites 350 ps earlier



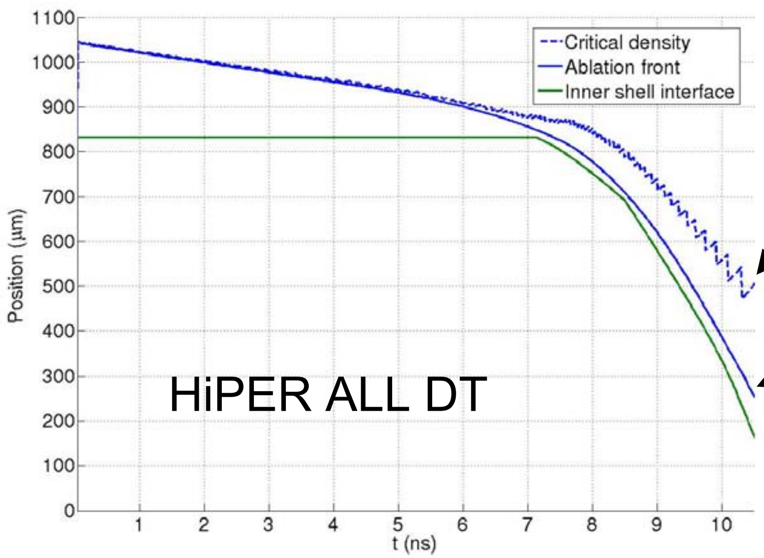


~750 ps for Rayleigh-taylor

~ 400 ps for Rayleigh-Taylor

Enhanced Ignition safety

Spike Symmetry



Critical density is half its initial value at spiketime

➔ *use specific beams for the shock*

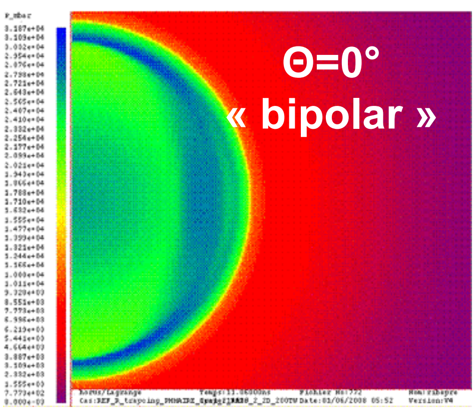
Ablation radius ~1/2 critical radius

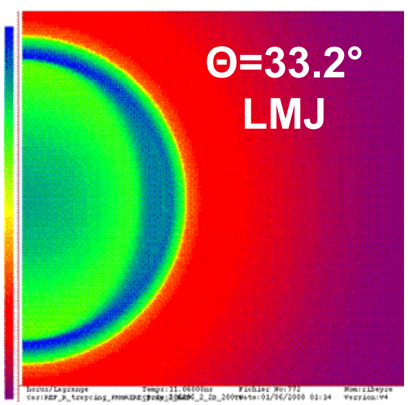
➔Efficient thermal smoothing

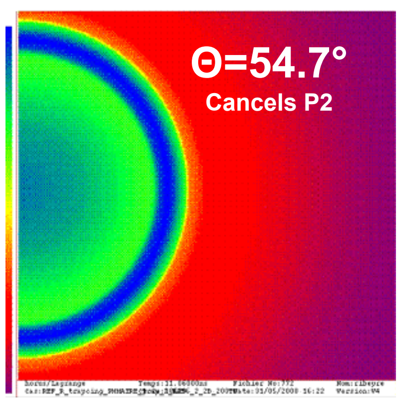
➔*Spike illumination symmetry probably not stringent*

According to 2D simulations,the Hiper target still ignites for non symmetric spikes

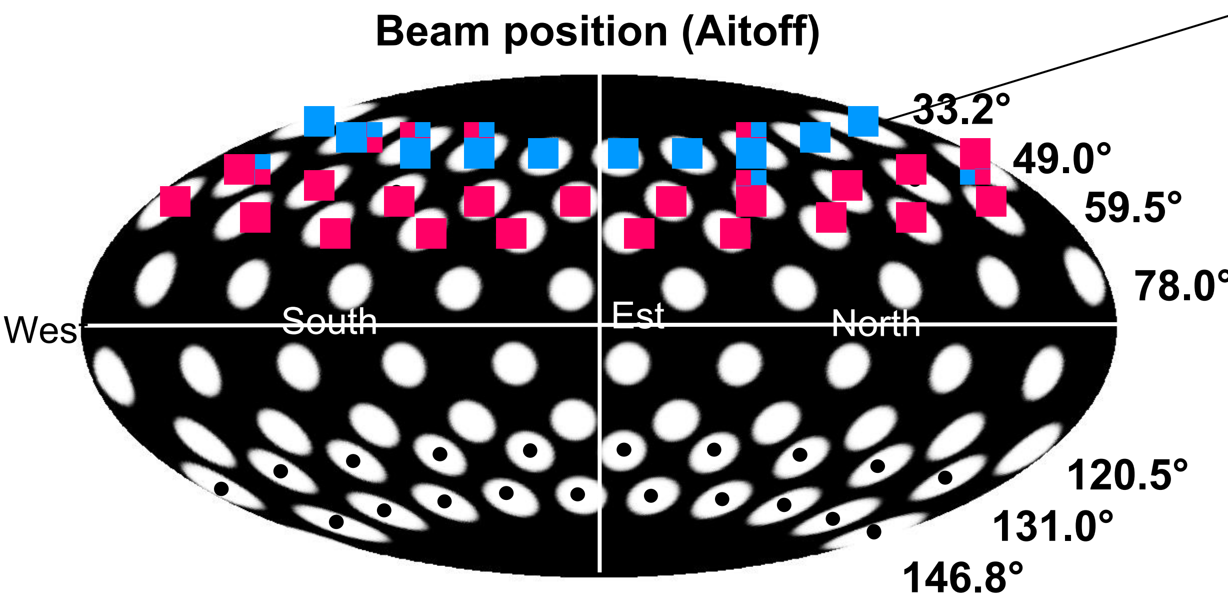
Pressure at shock launch (CHIC , DUED)

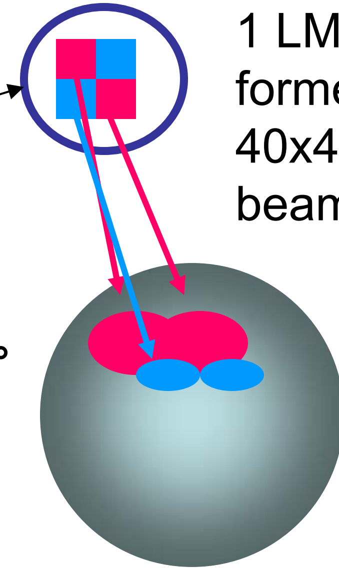






LMJ/160 beams irradiation





1 LMJ Quad formed from 4 40x40 (cm) beams

May be split and repointed on a sphere for optimal illumination

60 quads , 500 kJ, 300 TW
- no PDD nor quad splitting
- 49° + 59° +power balance 4/5 (no depointing)
- for compression+Spike
- 33° for spike

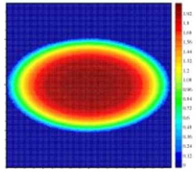
40 quads pattern : - uses quad splitting, defocusing and repointing (Polar Drive)

80 beams for compression + spike (PDD) 3.8 kJ, 1.5 TW/beam

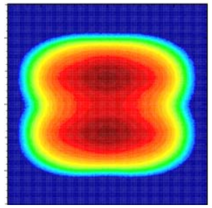
80 beams for spike only (DD, tight focus) 0.75 kJ, 1.5 TW/beam

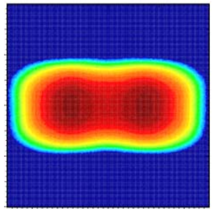
160 beams for comp. + Shock and dynamic pointing

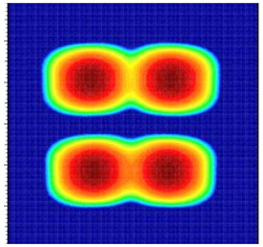
Optimize Polar Drive



- Repointing Beams

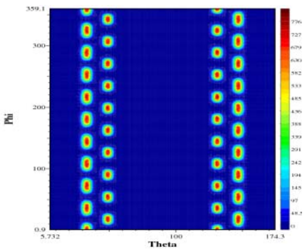


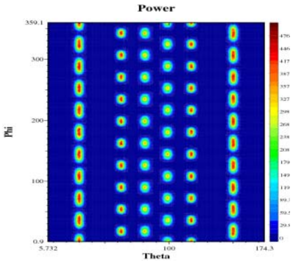




- Defocusing Beams

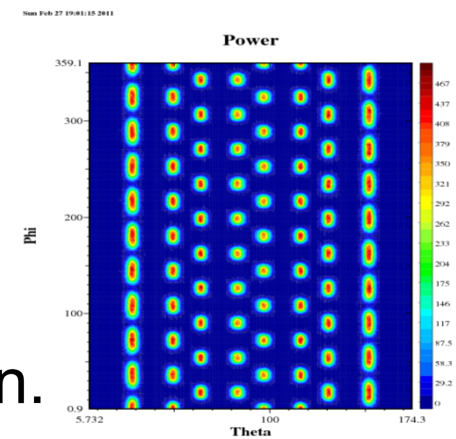
- Splitting quads





- Tuning Power Balance : w_b
  - Intensity on target is linear function of w_b: $I(\theta,\varphi)=\sum_b A_{\theta\varphi b} w_b$
  - Solve for w_b $I(\theta,\varphi)=\overline{I} \quad \Rightarrow \quad (A^\dagger . A) w_b = A^\dagger \overline{I}$

LMJ_8 cones irradiation (160 beams)

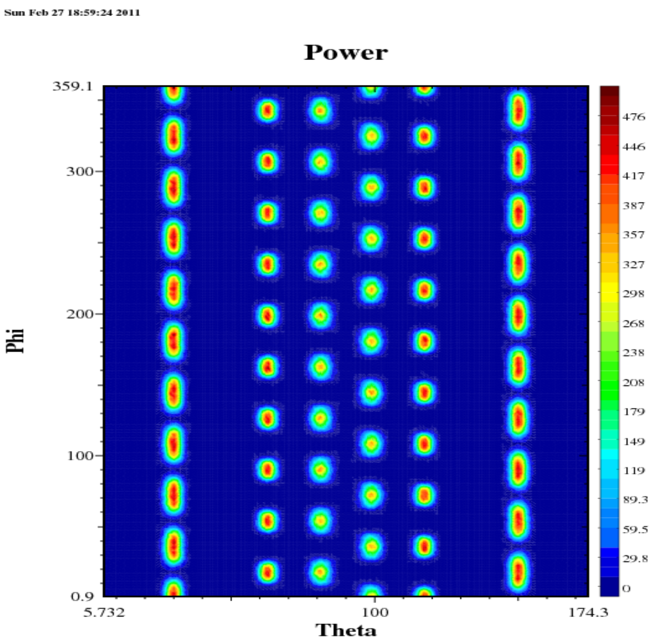


- 160 beams for compression + spike
- No azimutal depointing
- Beam balance can be time dependant
- Poor contribution of 33-b in foot, of 49a in main.

Power/beam for 100 TW on target	33-a 20 beams	33-b 20 beams	49-a 20 beams	49_b 20 beams	%rms
Θ, defocus	28°, -2	47°, -2	55°, -2	82°, -2	
R_0	.61	.61	.61	.61	3.7
R_0 + balance	.8	.25	.53	.9	1.14%
75% R_0	.7	.63	.36	.8	0.78%

LMJ-6 cones irradiation 120+40 split

- 120 beams for compression + Spike
- 33-b for spike only
- Spike irradiation is 2-sided

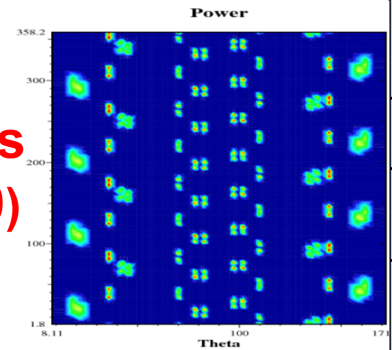


Power/beam for 100 TW on target	33-a 20 beams	49-a 20 beams	49-b 20 beams	%rms
ΔΘ, defocus	30°, -2.15	62°, -2.4	80°, -1.95	
R_0	.8	.8	.8	3.56
R_0 + balance	.9	.77	.82	0.73%
75% R_0	.81	1.13	.56	1.35%

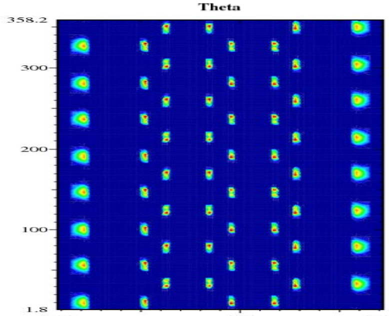
Best NIF PDD patterns do not use ring_023/ring_30

Φ 2mm target

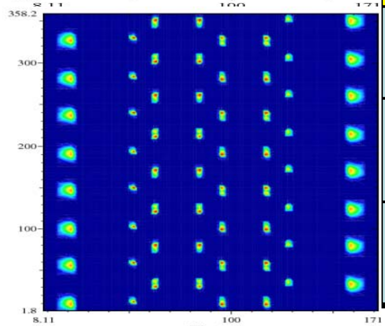
192 beams (LLE 2010)



128/64

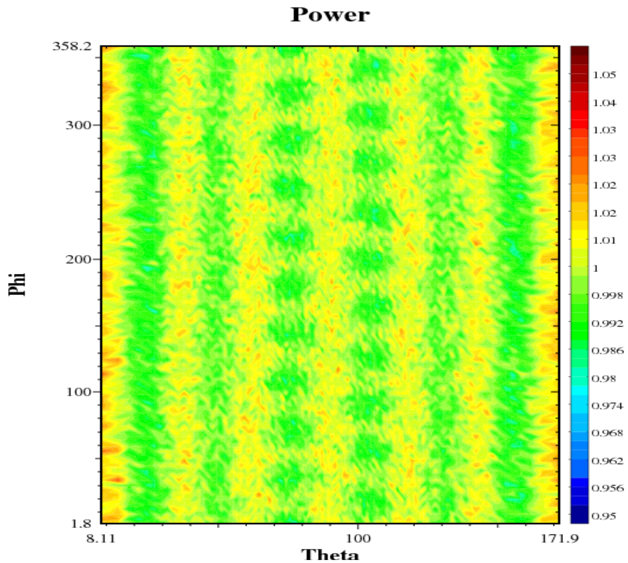


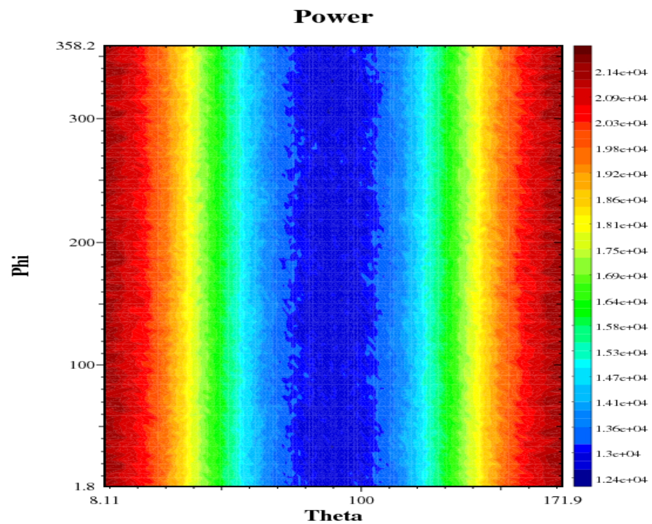
112/80



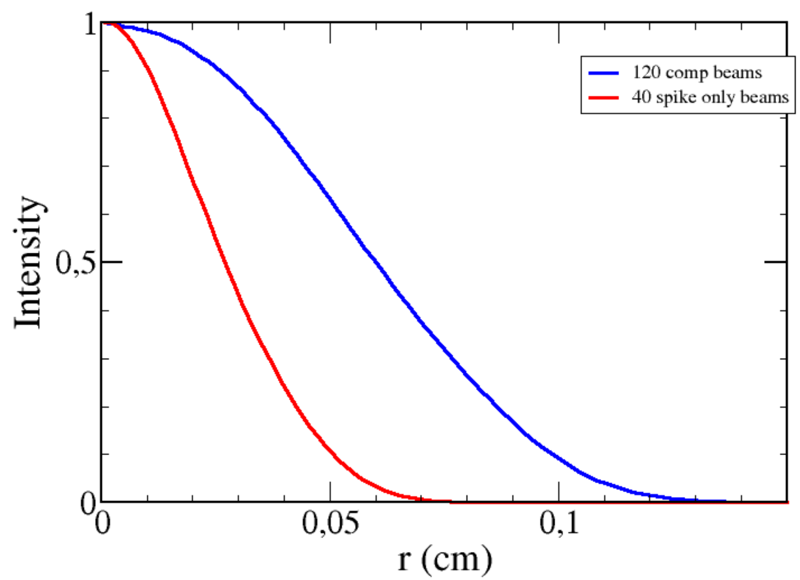
TW/beam 100 TW total	R-23	R_30	R45-a	R45-b	R50-a	R50-b	%rms
#beams	16	16	16	16	16	16	
R_0	0.52	0.52	0.52	0.52	0.52	0.52	**7%**
R_0 + bal.	0.669	0.227	0.57	1.2	-0.16	0.62	**1.03%**
75% R_0	0.53	0.4	0.57	1.28	0.38	-0.46	**1.17% (9.55)**
	0	**0**	16	16	16	16	
R_0 + bal.	0	0	0.86	0.37	0.93	0.96	**0.72% (5%)**
75% R_0			0.71	0.78	0.85	0.78	**0.67% (2.3%)**
			16	0 8	16	16	
R_0 + bal.	0	0	0.84	.96	.94	.86	**0.75% (2%)**
75% R_0			.67	1.95	0.85	0.62	**0.72% (1.7%)**

6 cones on LMJ . Energetics

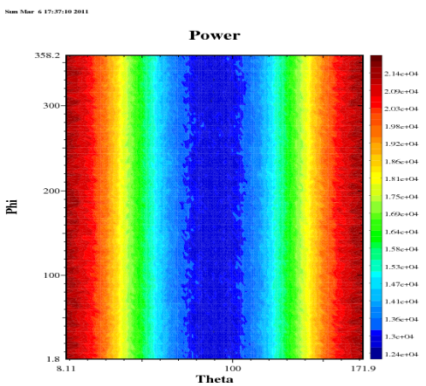


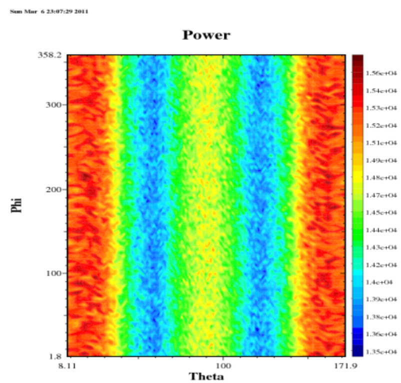


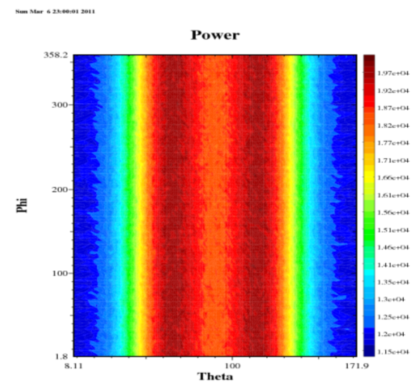
This 3D result may be accounted for in 1D simulations:
- compute the histogram of laser rays (cf S. Craxton)
-differentiate and divide by r in order to get equivalent focal spots for 1D simulations.
-This can be done for each cone if a variable power balance is used



In most cases shock will be driven from a 2-sided polar illumination





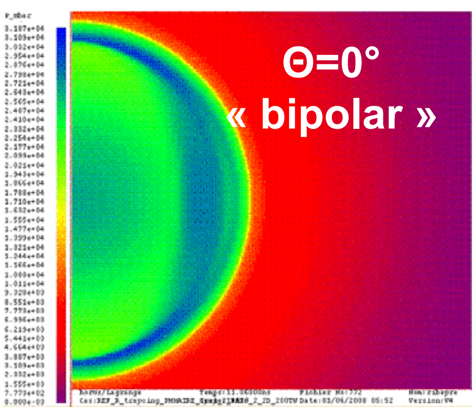


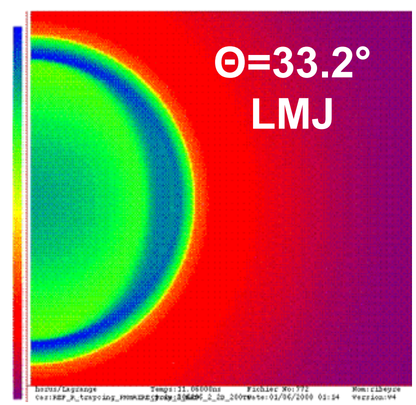
NIF 128/64
17%rms

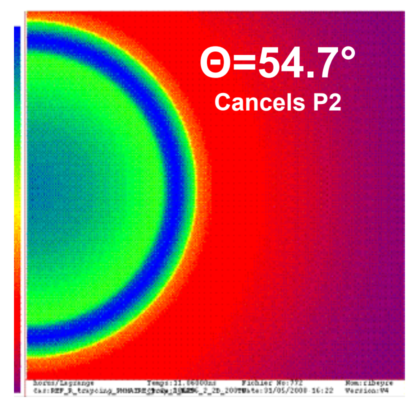
LMJ 160
3%rms

LMJ 120/40 + repointing 33a
15%rms

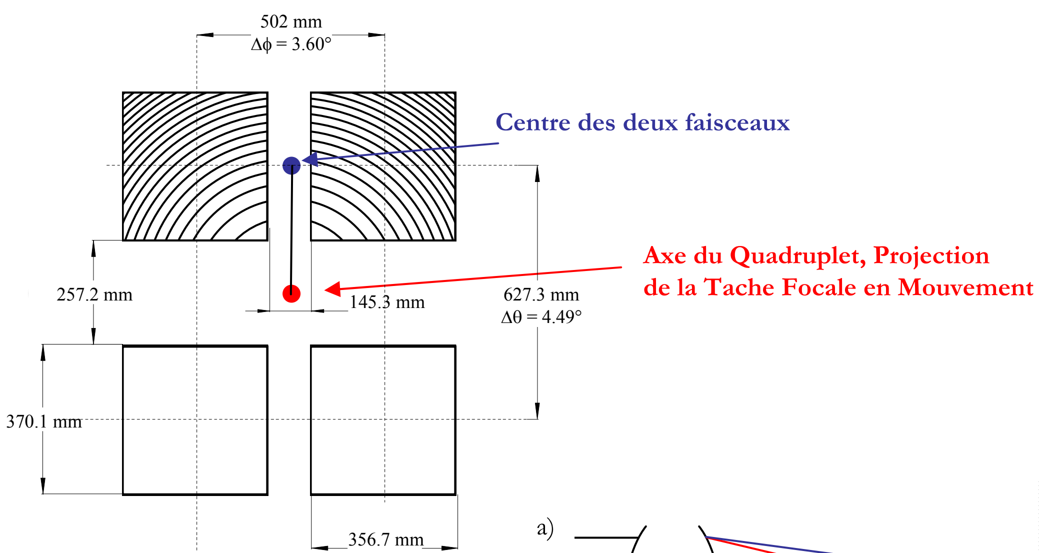
$R_{ab} \sim R_{crit}/2$: Cloudy Day model predict reduction of mode l ~ 2^{-l} at ablation front
CHIC 2D calculations predict ignition for non uniform spikes

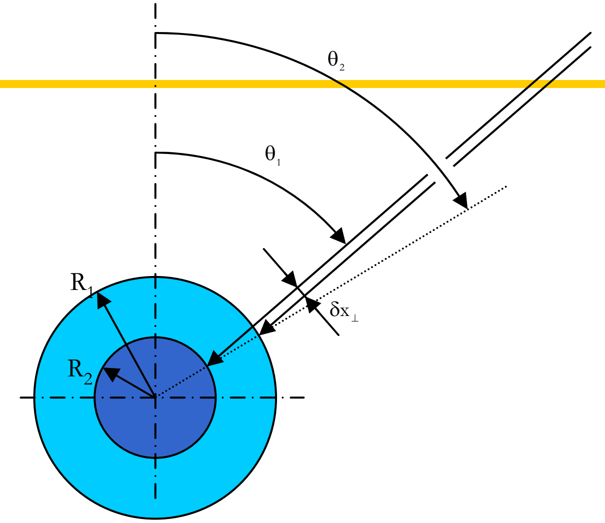




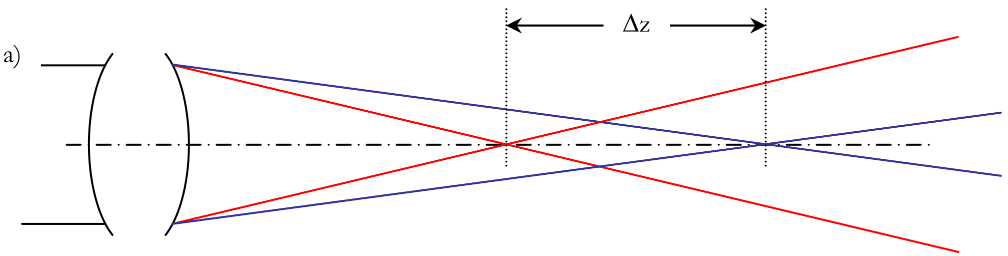


Dynamic repointing seems achievable on LMJ

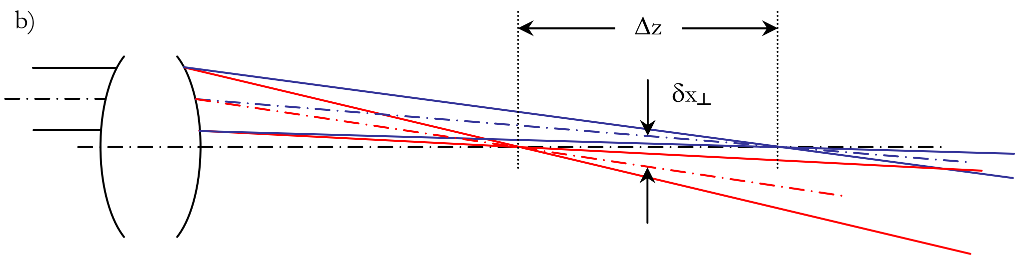




a)

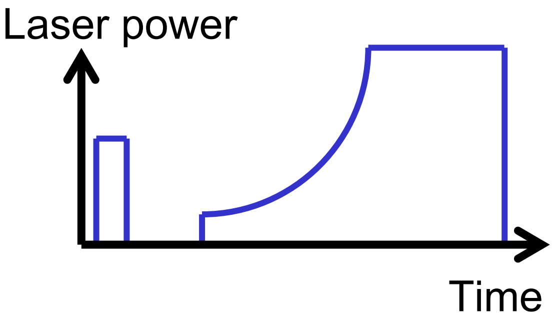


b)



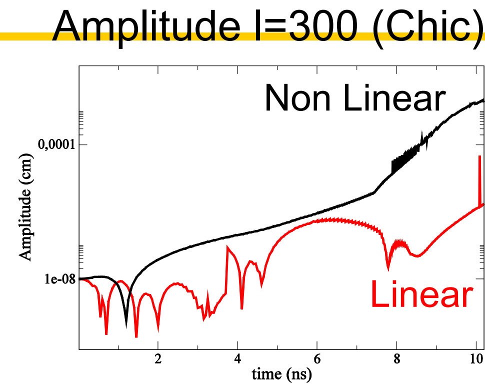
Doped Ablators may strongly reduce the growth of perturbations at ablation front

❑ Adiabat shaping (High modes)



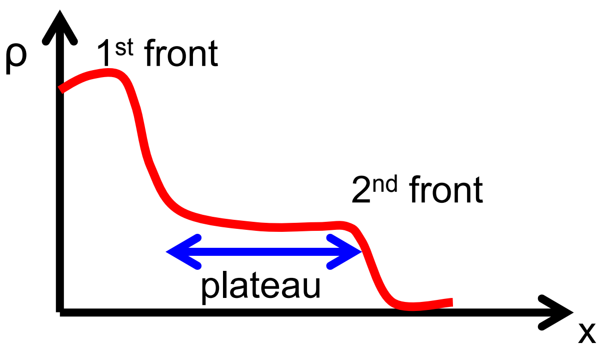
- Ablation velocity ↗
- Laser contrast ↘
- Non linear stage delayed

  (ex: HiPER target l=300)

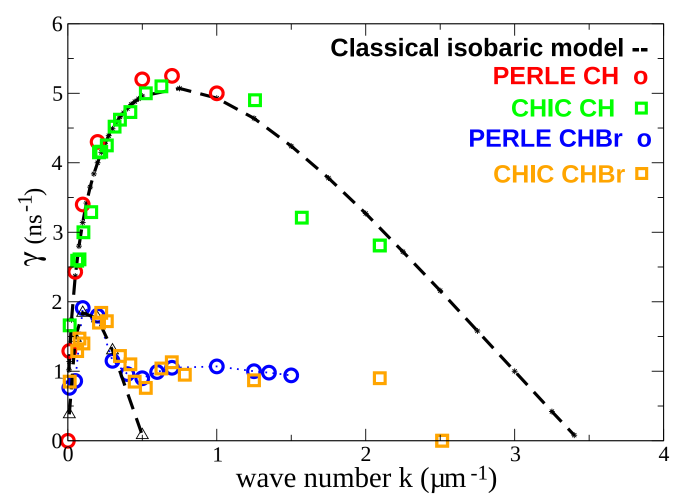


❑ Moderate-Z ablators (SiO2, CHBr…)

(Collaboration Univ. Madrid)



Stability analysis :
with realistic modeling (Chic 2D) and simplified 2T model (Perle 1D + linear perturbations)
⇒ Growth rate reduction
⇒ N



1D dynamics: Double ablation front structures

- Important role of the radiative flux
- New theoretical 2T model / Realistic simulations

  J. Sanz et al. , Phys. Plasmas 2009

  V. Drean et al., Phys. Plasmas 2010

- Other issues as LPI, RTI , discussed in further talks by S. Atzeni, O. Klimo, E. Le Bel

Numerous Physical Issues remain to be addressed

- Absorption efficiency
- How does RTI at stagnation interact with the shock ?
- What are the symmetry requirements for the spike ?
- Intensities in Spike are high : what about SRS, SBS, TPD ?
- electron transport in PDD shock ignition regime : probably non local, magnetized
- Validating PDD designs is first milestone

SI Physics roadmap - Overview

Issues	Modelling	Expts	Design Issues
PHYSICS			
LPI at I > 5 10^{15} **2w / 3w**	**2D large scale PIC** **Reduced model in codes**	**PALS/LULI/RAL/LIL** **PETAL- LMJ 16 b (2015)**	**Wavelength, target design**
e^- transport	**2D VFPL**		
Ablative RTI	**Imprint modelling** **Random material**	**Double ablation expts at GEKKO** **ICE characterization**	**Bandwidth, gain material smoothing** **DT layering techniques** **Ablator**
Proof of Principle (Ω)	Integrated ϕcs in hydro code	Down scaled implos	Predictive design code
Ignition Window		OMEGA Warm + cryo shots 60 beams Vs 40+20 b	
YOC > (TBD) %			
PDD validation	Bfields + NL transport		
Scale 1 Demo on LMJ		**2016 : 80 beams** **2018 : 160+16 beams**	Down selection of SI as HiPER main line
Compression		**PPD implos** **LMJ 80 b (2016)**	**PDD pattern, Dynamic pointing, smoothing**
Shock timing and sym.		**n imaging**	**Viability of 2 sided SI**
Ignition metrics **{ ρR ,Ti , YOC }**		**Warm targets** **Cryo Shots**	**Decision for DT shots**

SUMMARY - CONCLUSIONS

- HiPER needs to demonstrate full scale ignition before decision to construction

- A 500 kJ , CH/DT target provides robust ignition with 100 TW for compression and 150-200 TW for the shock (scale 1.1)

- Scaling up the target at constant implosion velocity reduces both hydro and LPI risks.

- The trade-off between implosion velocity and maximum power may be different on NIF and LMJ.

-A major milestone is proof of principle of high convergence PDD implosions.
  -Numerical restitution of NIF PDD PEX experiments would confort our design

- PDD solutions on LMJ and NIF are quite similar : 6 or 8 cones using the outer rings
  LLE and CELIA designs differ. Needs to be understood.

- Physics and robustness studies are ongoing within HiPER (see talks from S.Atzeni and O. Klimo)