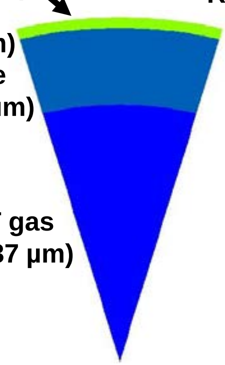
1D PDD shock ignition design for NIF/LMJ demonstration

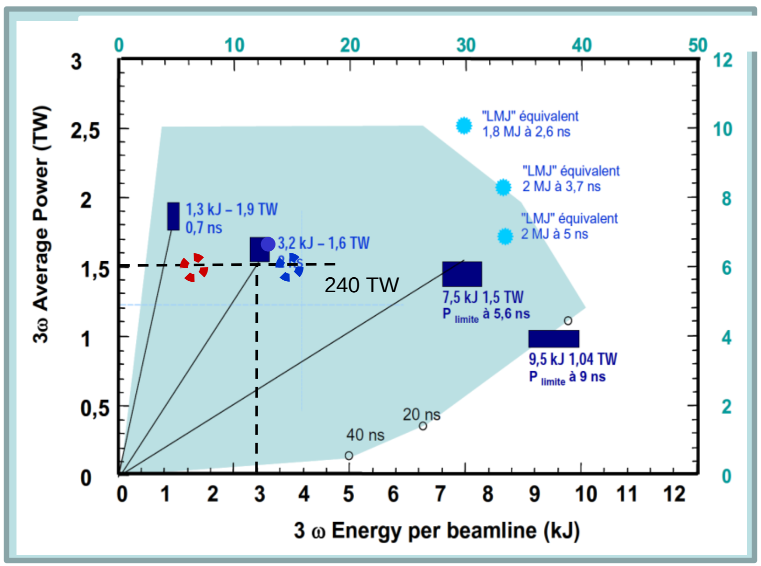
Investigated Total Laser Power slot ~ 250 TW
CH Low Aspect Ratio Target Family @ 240 km/s
G_{1D} > 90 @ 500 kJ and more

Large spots
Small spots

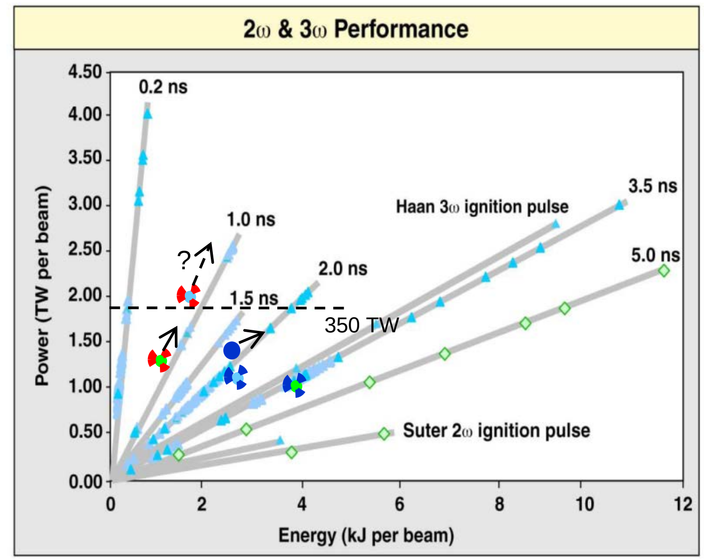


LMJ 160 b step: Composite 80 120b-40b; Integrated 160b

NIF 192 b: Separate 96b-96b; Composite 80 160b-32b; Integrated 192b



International Workshop
on
ICF Shock Ignition
March 2011
LLE
Rochester University



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Context

- HiPER project : toward DD IFE : HiPER
  - Robust Target design need for high rep.
- Two main ignition schemes :
  - Shock ignition
  - Fast ignition
- NIF/LMJ: Shock ignition demonstration - need PDD

- NIF : 350 TW available ? 192 b : 1.82 TW / b max ?
- LMJ is under construction CEA CESTA center : first contacts with CEA for SI demo step @ 160 b SSD 1D ID phase plates, request low impact on optics and minor mod of facility (cryo tarpos…) Hypothesis of present work / CELIA : P ~ 1.5 TW / b, P_L~ 250 TW - E_L < 600 kJ

- Hiper Low aspect ratio CH targets family @ low speed 240 km/s

- Study NIF configurations in the continuity of the last join SI proposal

- Evaluate SI first LMJ configurations under a projection of future Facility constrains

PDD Shock Ignition Windows on NIF

☑ CH low aspect targets (CELIA design)

☑ 1D CHIC simulations including Craxton's laser impact parameters for **large** and **small** laser spots for SI PDD fusion experiments on NIF

☑ Investigated cases :

- ☒ **Separate :** 2×96 vs 160-32 : without spike on compression pulse
  - **1×96** or *1×160* beams for **compression drive 80 TW** - **Large spots - PDD**
  - **1×96** or *1×32* beams for **spike** - **Small spots - DD**
- ☒ **Composite :** 2×96 vs 160-32 : with spike on compression pulse
  - **1×96** or *1×160* beams for **compression drive 80 TW + spike 50(80) TW** - **Large spots - PDD**
  - **1×96** or *1×32* beams for **spike** - **Small spots - DD**
- ☒ **Integrated 192** :
  - **1×192** beams for **compression drive 80TW** + **spike** - **Large spots - PDD**

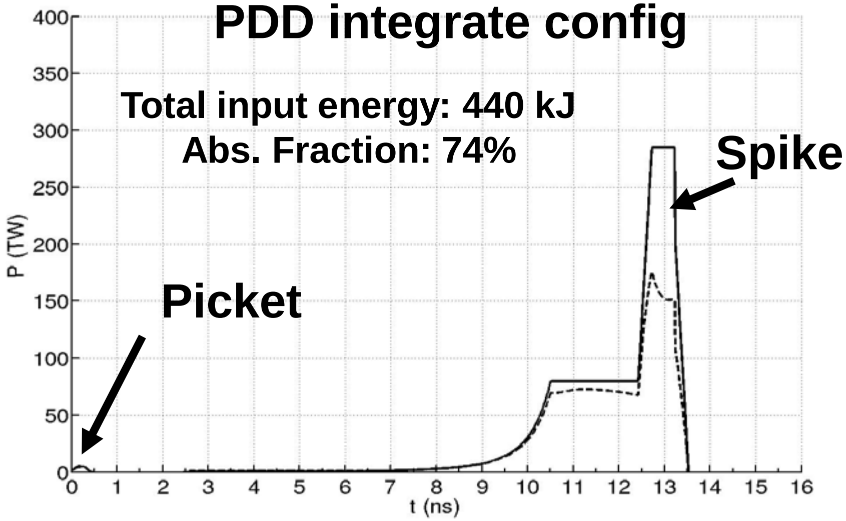
☑ Parameters :

- ☒ SI scaled NIF windows with euler hydrodynamic equivalent target scaling for scales x = 0.9 - 1.0 - **1.1** – **1.2** – 1.4 – 2.0
- ☒ Spike pulse rise and fall duration of **300** ps is invariant
- ☒ Spike pulse duration **500** ps follow the scaling in time i.e. FWHM-ps=(500 × x)+300
- ☒ ± Δt ps delay between spikes of large and small spots drives (composite)

☑ Output of 1D study :

- ☒ 1D confidence SI windows, Gain -Yield performances, laser energy balance
- ☒ 3ω NIF SI performances per beam
- ☒ additional results @ scale 1.1 for a new NIF symmetry design (112-80) and LMJ (120-40)

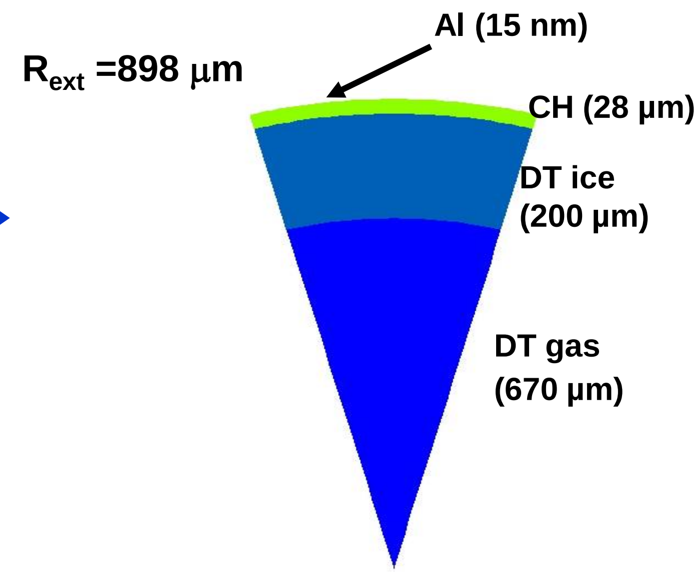
A robust target designed for NIF/LMJ class lasers



(scale x=1)

Fat target

Mass: 0.67 mg



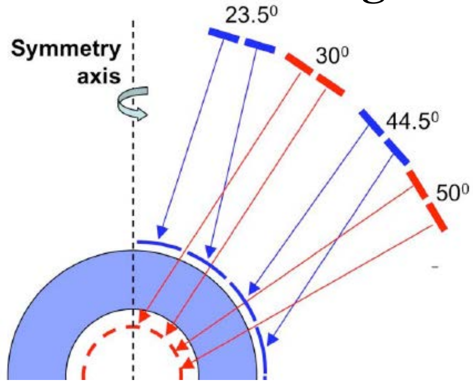
- Low aspect ratio + Picket: Improves Target Stability
  - => peak IFAR ~ 33 IFAR and $0.75R_{inner}$ =17
- Al coating : Target protection from IR and prepulse
- CH ablator : Higher Absorption fraction

$\langle \alpha_{if} \rangle$ =1.2

Compression	Implosion velocity	Performances	Shock Spike	Implosion velocity with shock	Absorption	Yield t_s=12.425ns	Gain	Stable Ignition window
80 TW 272 kJ	240 km/s	625 g/cc 1.83 g/cm² Rho $_{Peak}$ 720 g/cc	205 TW 164 kJ	265 km/s	74 %	32 MJ	75	120 ps

The 96/96 pattern uses repointing and quad splitting as proposed by LLE + distribution of ray impact parameters for 1D calculations

NIF Polar Direct-Drive configuration

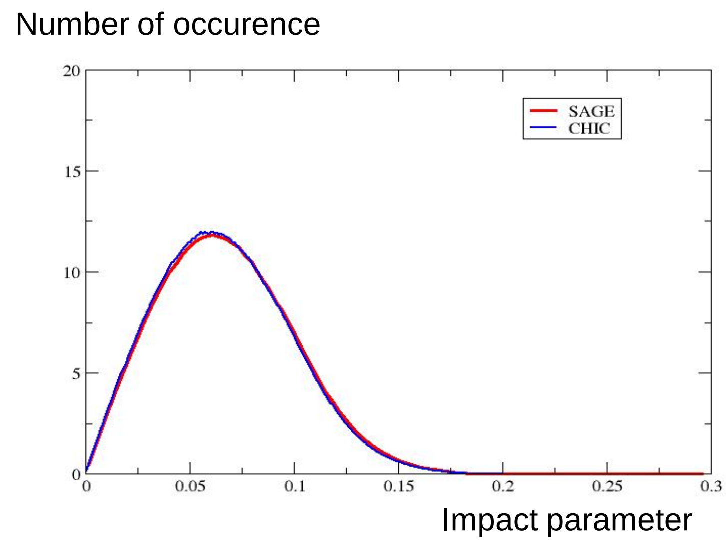


The polar-drive design for the 96 main beams has 24 pointing and focusing parameters

UR LLE

SAGE beam	Ring	Nom. *θ*	*SAGE* *θ*	*a* (μm)	*b* (μm)	# of beams	Nominal en-kJ	Defocus cm	Vert. PT (μm)	Horiz. PT (μm)
1	R1A	23.5	21.24	882	631	4	16.667	2.3	100	190
2	R1B	23.5	25.93	882	631	4	16.667	2.3	100	190
3	R2A	30.0	28.01	824	590	4	16.667	1.9	–120	400
4	R2B	30.0	32.70	824	590	4	16.667	1.9	–120	400
5	R3A	44.5	42.19	635	367	8	33.333	1.8	120	160
6	R3B	44.5	46.89	635	367	8	33.333	1.8	–340	280
7	R4A	50.0	47.68	593	343	8	33.333	1.2	–480	280
8	R4B	50.0	52.38	593	343	8	33.333	1.2	–480	280
9	R5B	130.0	127.62	593	343	8	33.333	1.2	480	280
10	R5A	130.0	132.32	593	343	8	33.333	1.2	480	280
11	R6B	135.5	133.11	635	367	8	33.333	1.8	340	280
12	R6A	135.5	137.81	635	367	8	33.333	1.8	–120	160
13	R7B	150.0	147.30	824	590	4	16.667	1.9	120	400
14	R7A	150.0	151.99	824	590	4	16.667	1.9	120	400
15	R8B	156.5	154.07	882	631	4	16.667	2.3	–100	190
16	R8A	156.5	158.76	882	631	4	16.667	2.3	–100	190
Main total						96	400.000			

From S. Craxton (SI workshop- 27/04/2010)



SAGE and CHIC give the same impact parameter

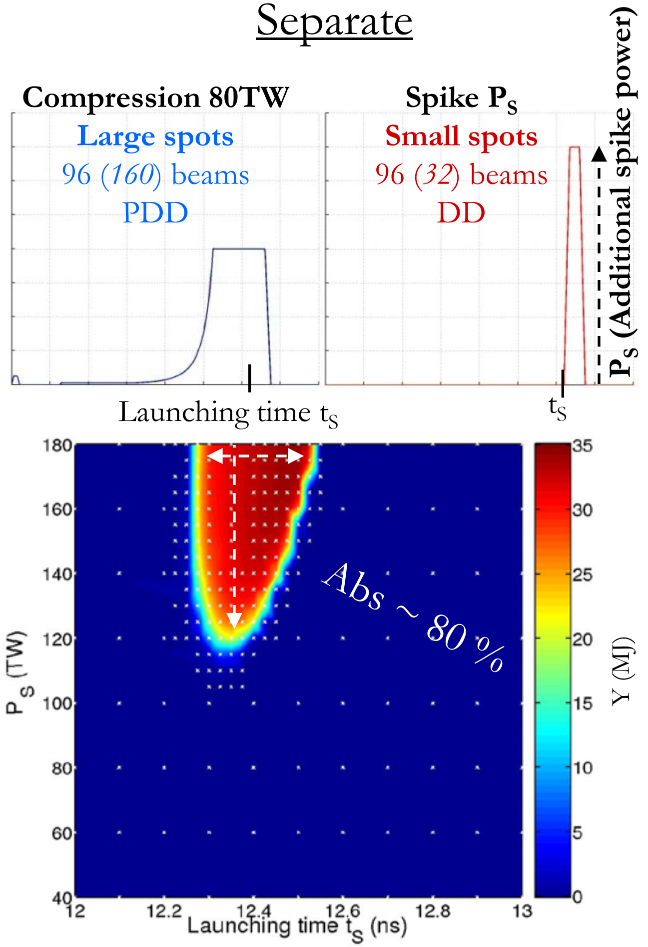
Equivalent to a super gaussian focal spot for 1D simulations

$$I(r) = e^{-\left(\frac{r}{885mm}\right)^{2.66}}$$

Shock Ignition windows on NIF – CH Target Scale 1
1D CHIC simulations using PDD laser spot Impact Parameter for large and small spots

x=1

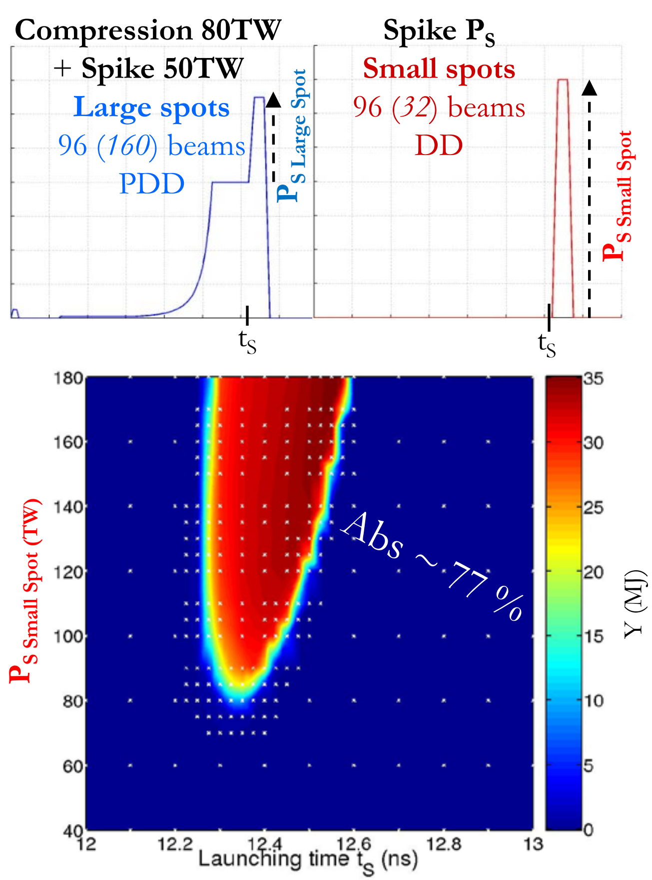
Separate



$\Delta t|_{PS=180\ TW} \sim 225$ ps

$P_{total}|_{t=12.350\ ns} = 80 + P_S > 200$ TW

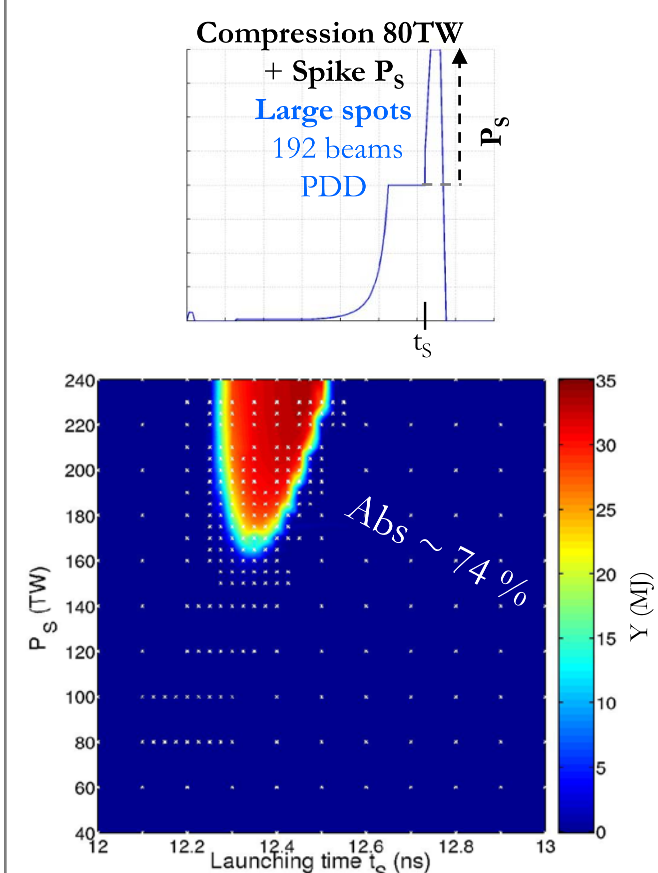
Composite



$\Delta t|_{PS=50+130=180\ TW} \sim 200$ ps

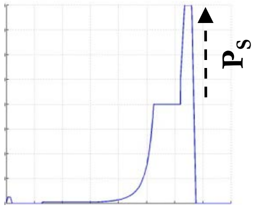
$P_{total}|_{t=12.350\ ns} = 80 + 50 + P_S > 215$ TW

Integrated



$\Delta t|_{PS=180\ TW} \sim 75$ ps

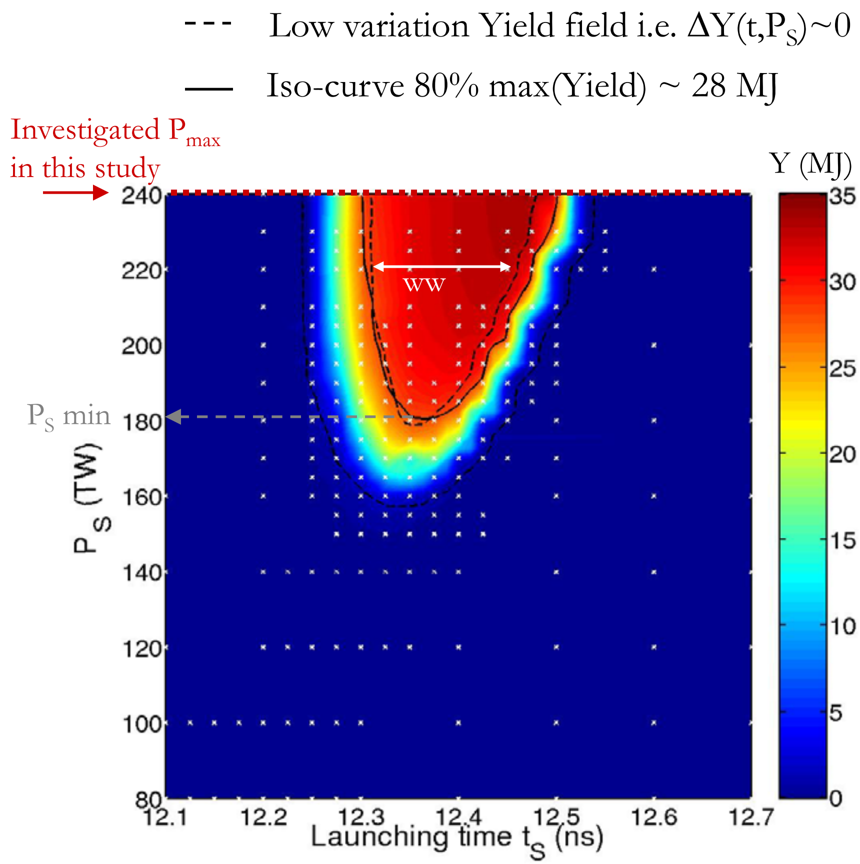
$P_{total}|_{t=12.350\ ns} = 80 + P_S > 250$ TW

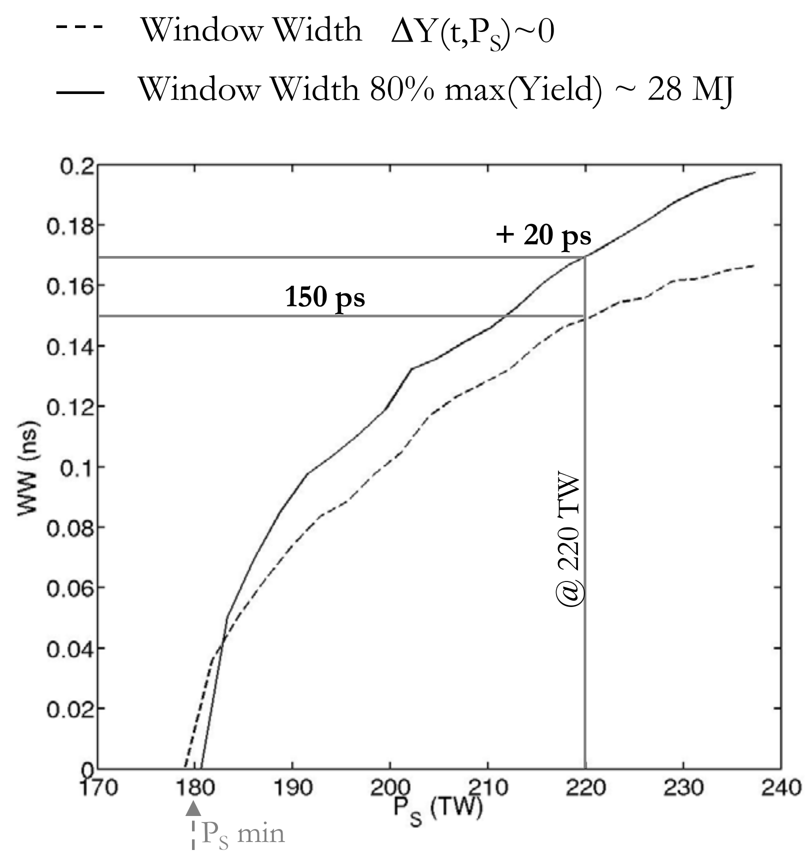


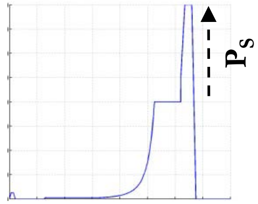
SI NIF Integrated scale 1 : we request a large stable Yield area Window Width ?

x=1

We propose to use the 80% max(Yield) as a common and simple criteria for evalute the windows width from 1D calculations (width estimated error > +10 %)

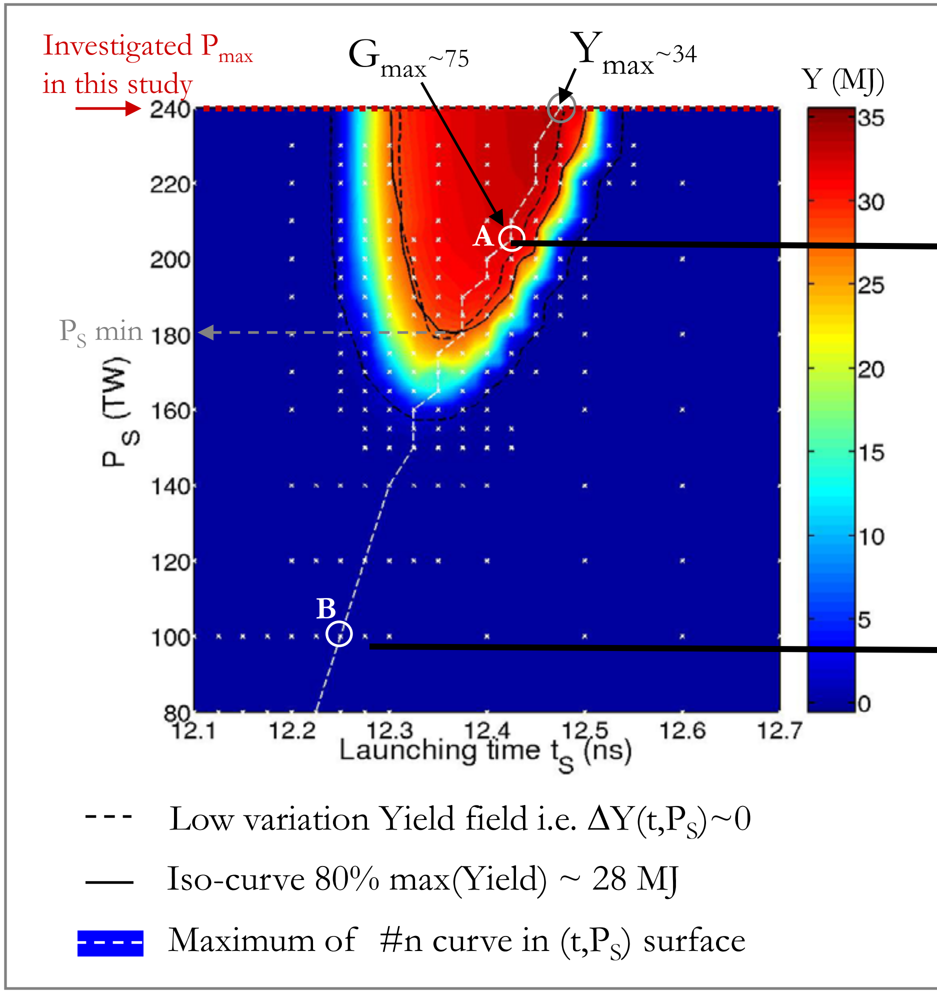


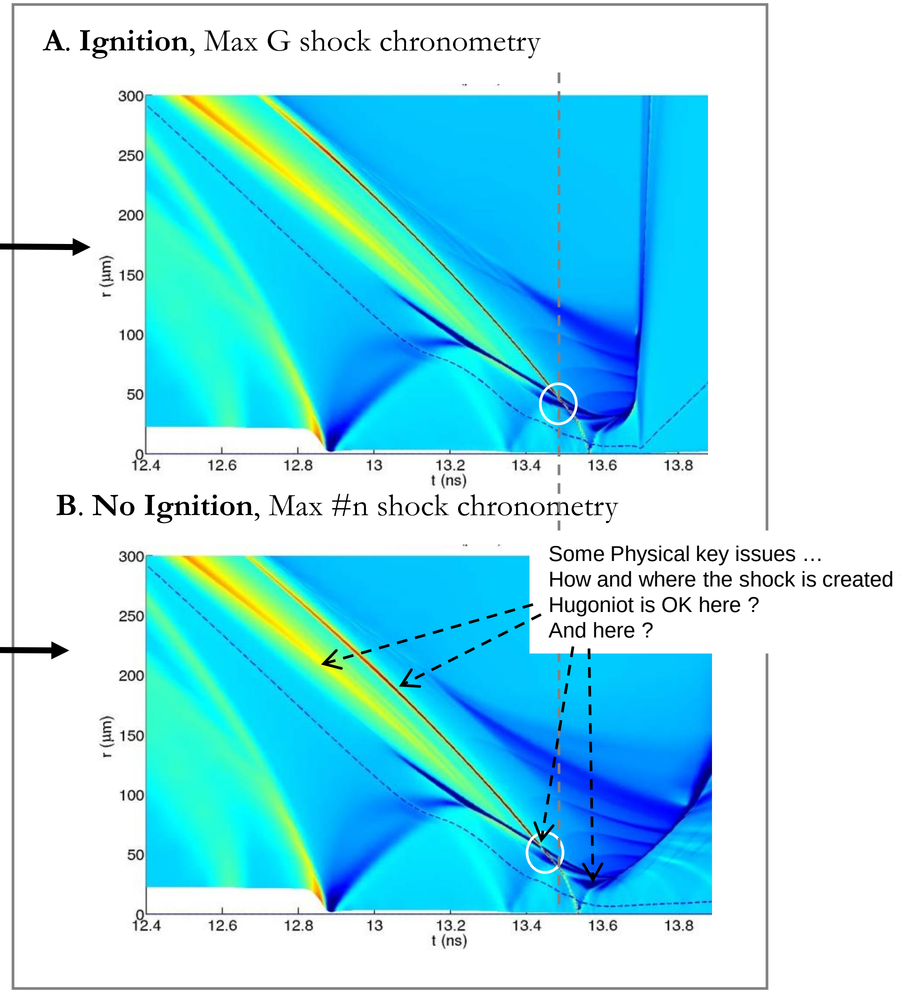




SI NIF Integrated scale 1 window
Max (Yield, Gain, #n)
x=1

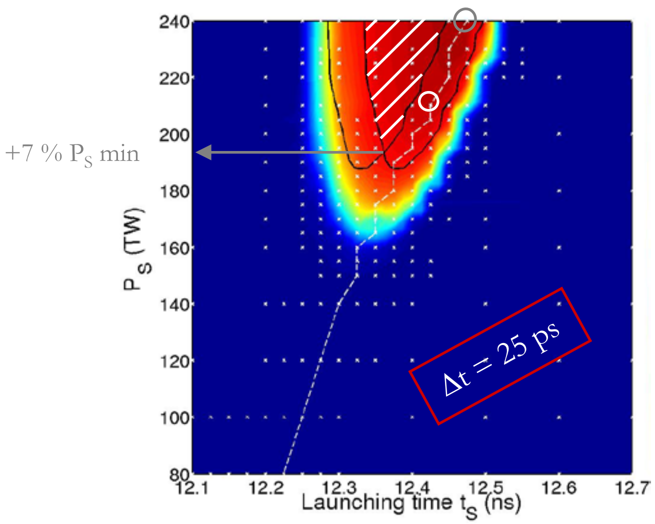
The maximum of #n curve in (t,P_S) surface is related to the most efficient shock collision condition.

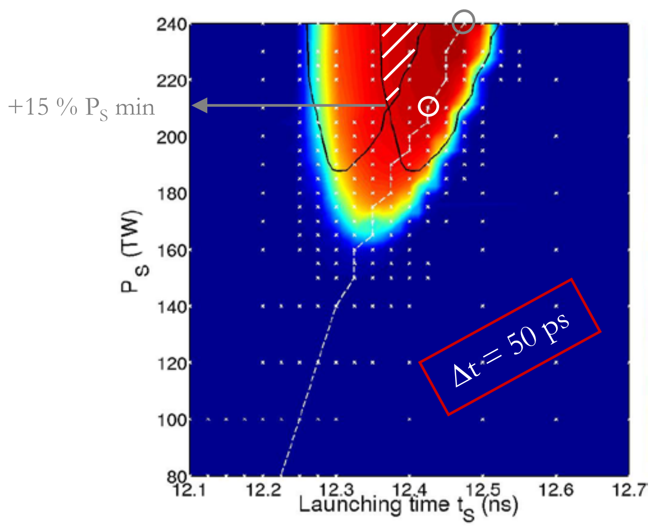


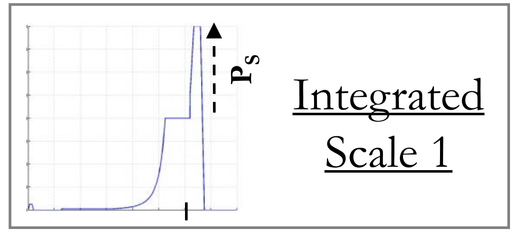


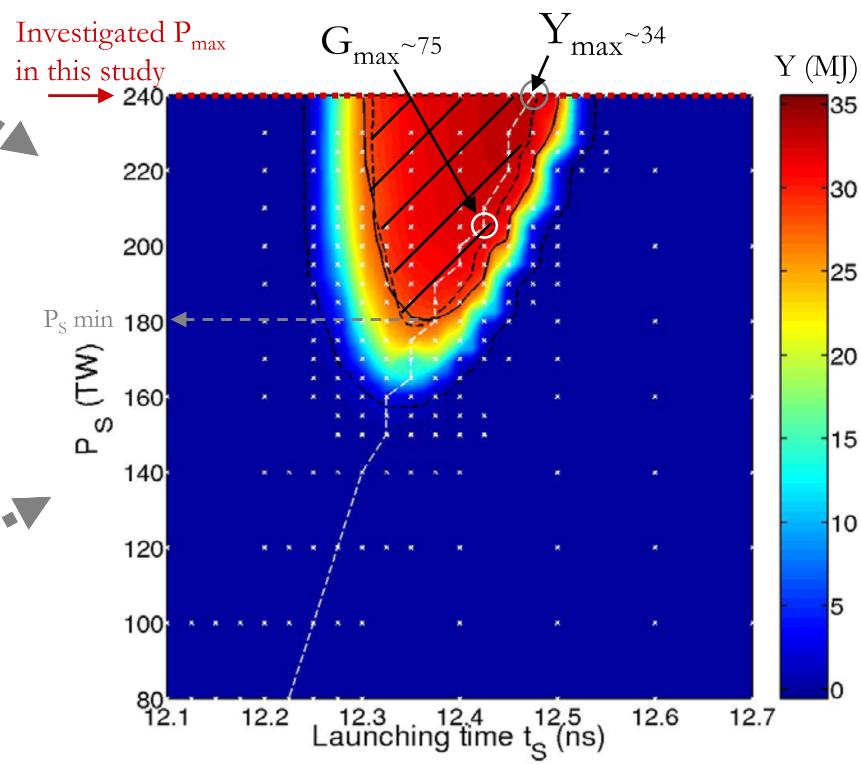
Max #n : Connection between no-ignition and ignition point design

1D SI confidence areas associated with a Facility errors ± Δt on spike launch timing and -5% for the spike power P_S required for a shot, ensure a stable 1D yield area [28-35] MJ, considering a perfect compression drive for this example.



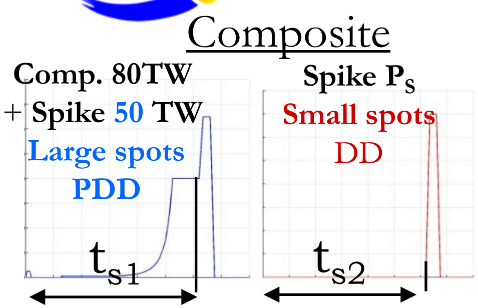






Search larger SI confidence windows : euler scaling ?

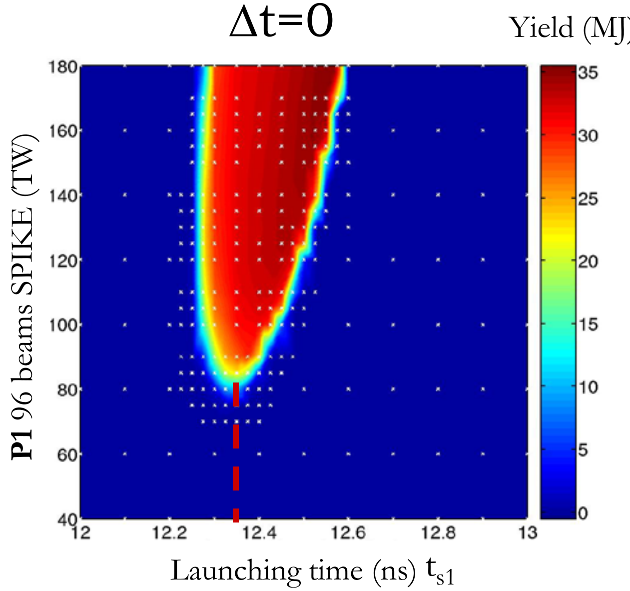
Composite admit 2 Δt jitters, one associated to the spike of the compression drive on large spots and other one for the spike on the small spots :

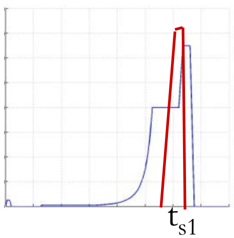


In order to give one example of evaluation of a confident window for these constraints we need to recompute the SI windows taking into account the Δt between the two spikes. The referring time is the 1x96 beams pulse with large spots compression + spike drive.

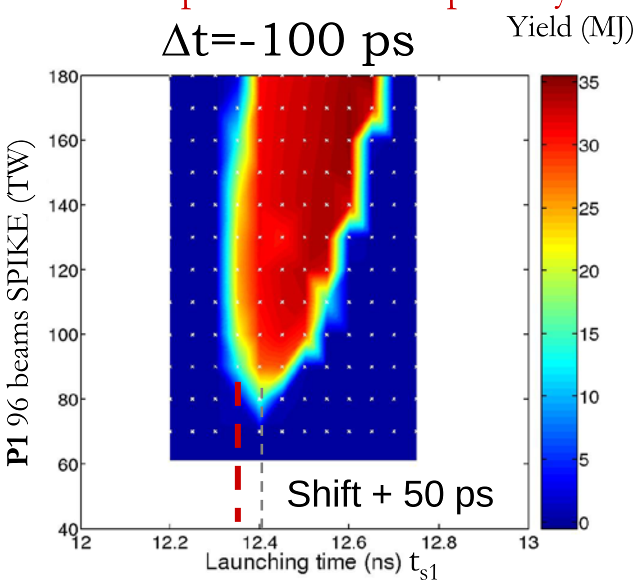
$$t_{s2} = t_{s1} + \Delta t$$

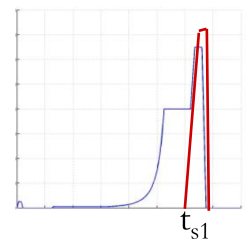
The 2x96 beams have perfect timing



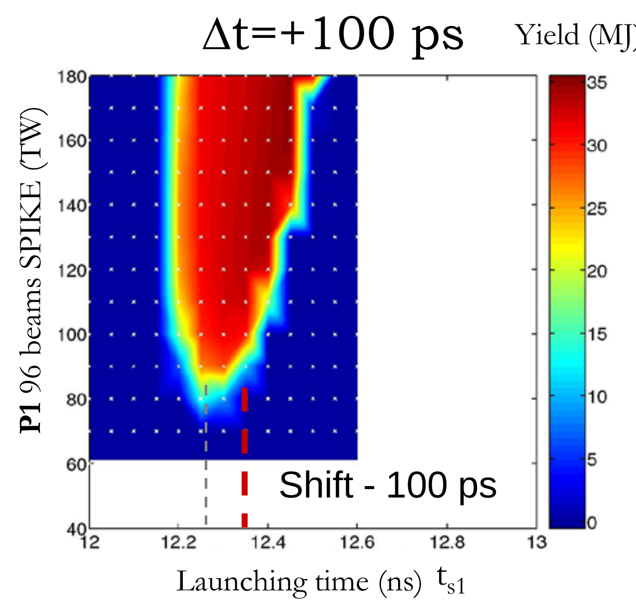


1x96 spike beams 100 ps early



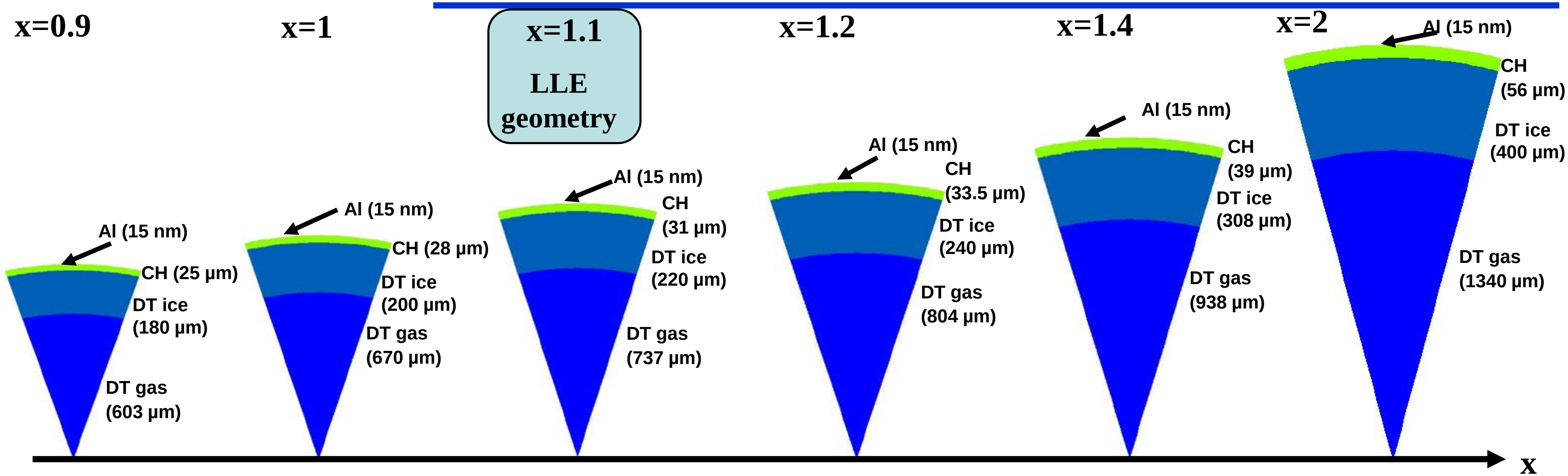


1x96 spike beams 100 ps later



SI-NIF/LMJ Target Euler Scaling

x scaling factor



Euler Scaling (no dissipative process)

$$x = \frac{r_{cible}}{r_{réf}}$$

$$M_{cible} \propto x^3 M_{réf} \qquad E_{L\,cible} \propto x^3 E_{L\,réf}$$

$$t_{cible} \propto x\, t_{ref} \qquad P_{L\,cible} \propto x^2 P_{L\,réf}$$

$$\rho R_{cible} \propto x\, \rho R_{réf}$$

$$G_{cible} \propto x\, G_{ref}$$

For all targets

I_L = 8x10^{14} W/cm²

V_I = 240 km/s

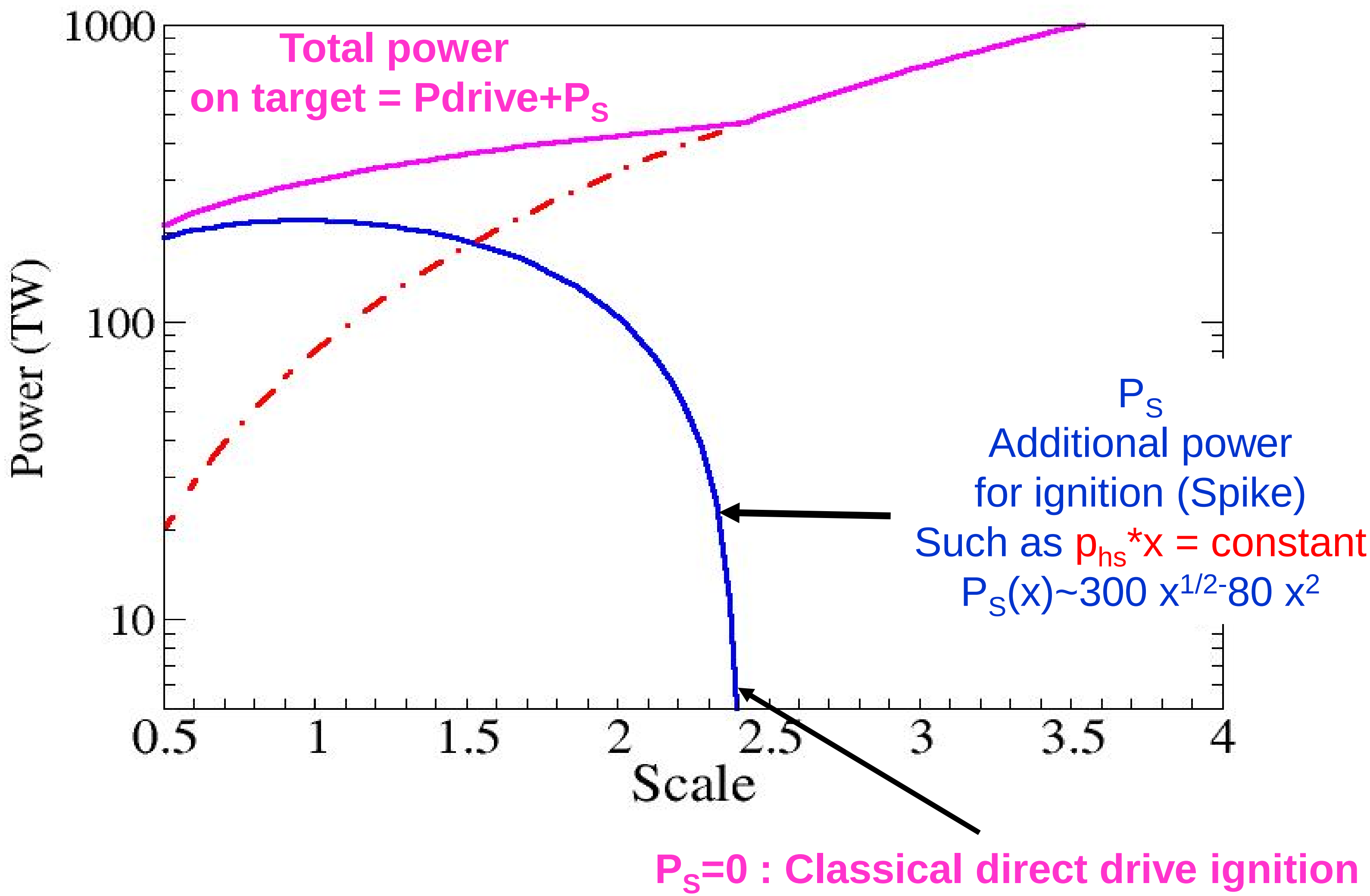
ρ_{max}= 624 g/cc

$\langle \alpha_{if} \rangle$ =1.2

x=1.1 close to LLE target geometry

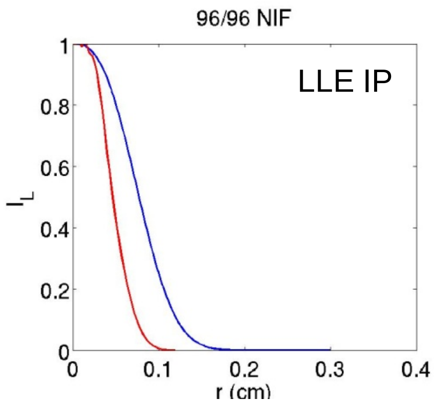
Euler Scaled targets at same ignition parameter P_{hs}*R require less intense spikes

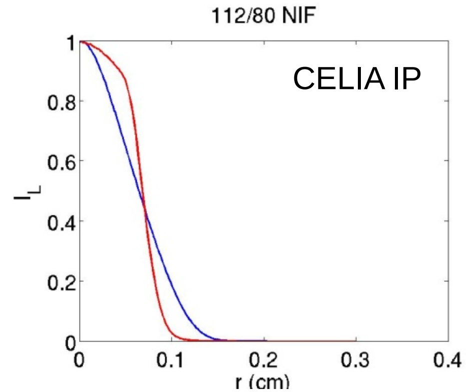
$R \rightarrow R.x$, $t \rightarrow t.x$, $P_S \rightarrow P_S x^2$, $E \rightarrow E x^3$, $M \rightarrow M x^3$: SAME VELOCITY AND INTENSITY

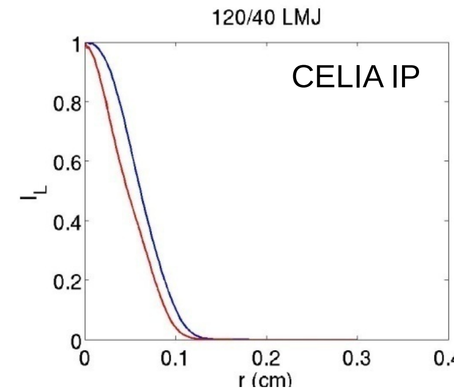


1D CHIC calculation with Impact parameters deduced from symmetry evaluation of some PDD configurations for NIF and LMJ for the scale 1.1 (E_L=500 kJ G_{1D}~90)

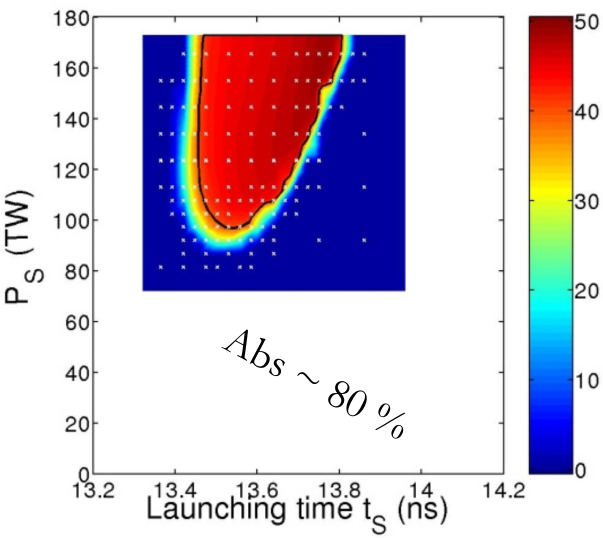
1D beam profiles of polar drive configurations for simulations



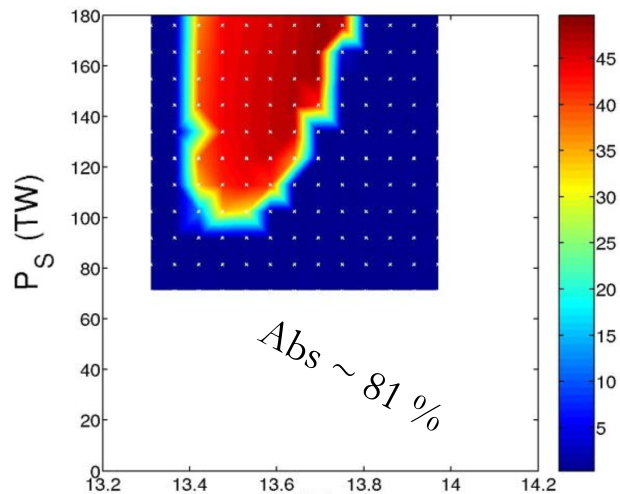




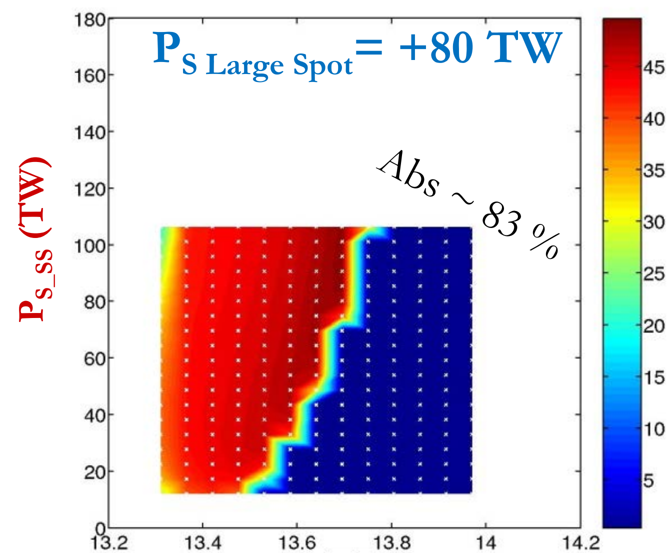
NIF 96/96 Separate



NIF 112/80 Separate

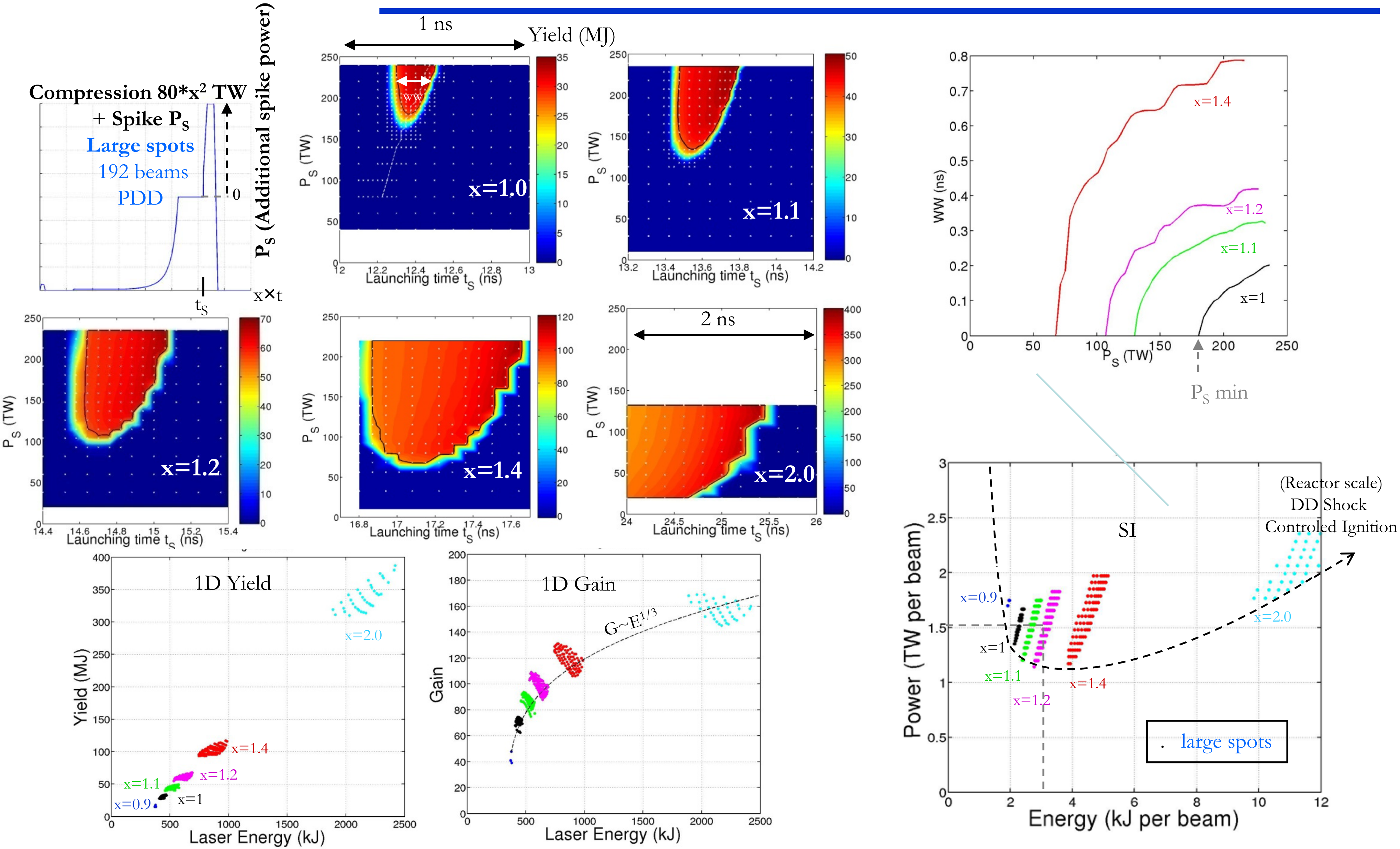


LMJ Composite 80

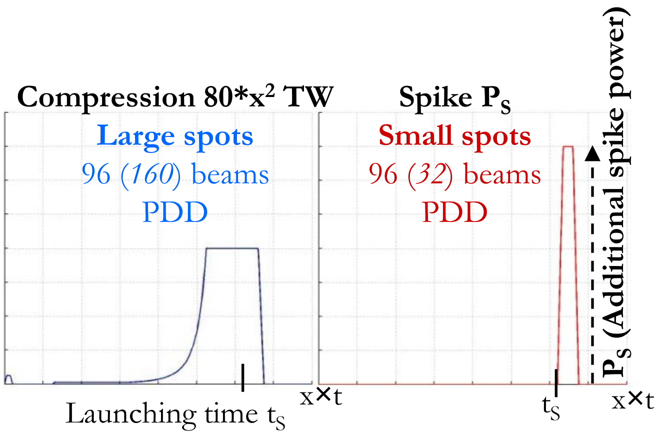


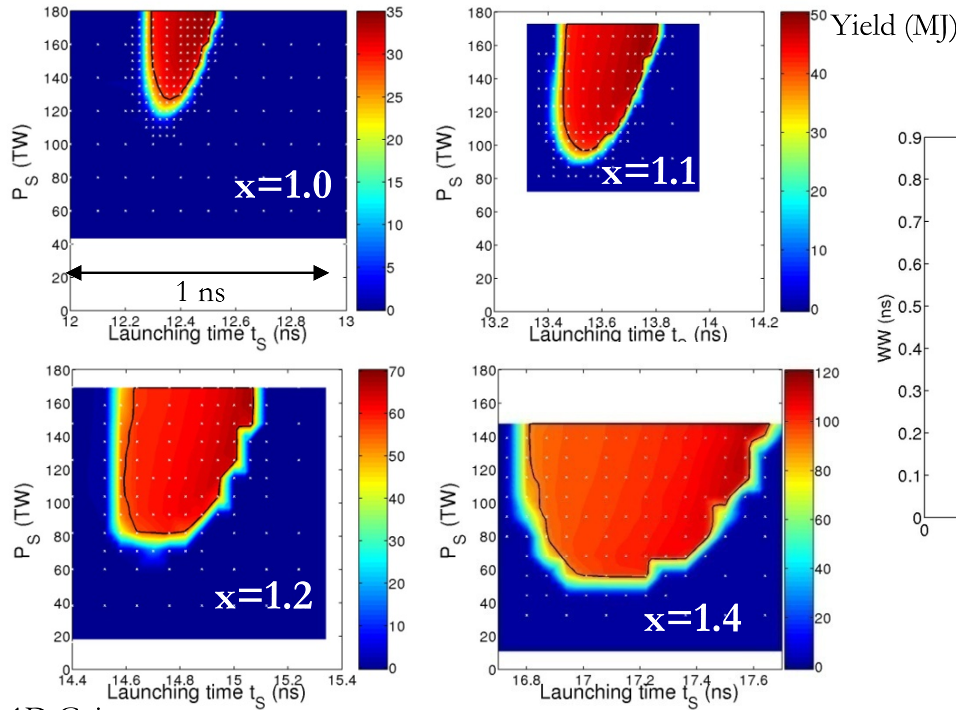
P_S (TW) = $P_{S\ Large\ Spot}$ + P_{S_ss}

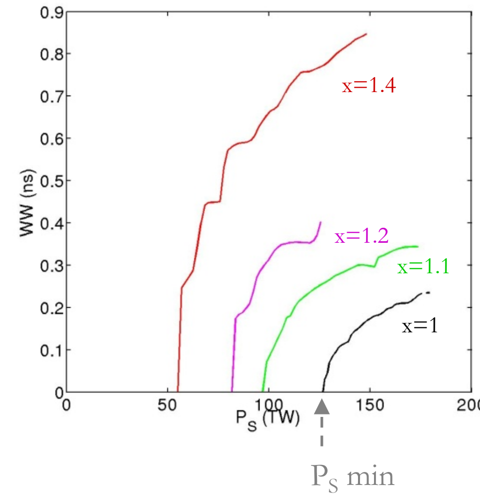
Integrated scaled NIF windows (1D CHIC PDD IP results)
192 beams 3ω NIF Performance

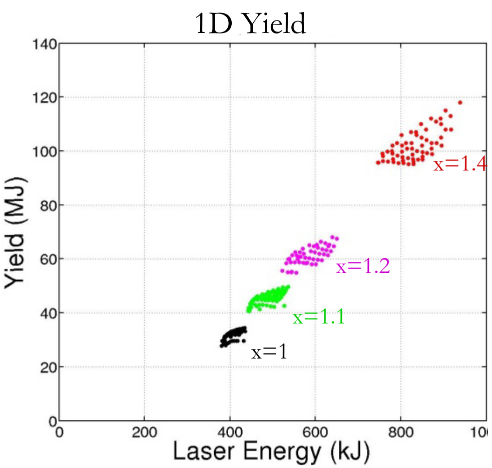


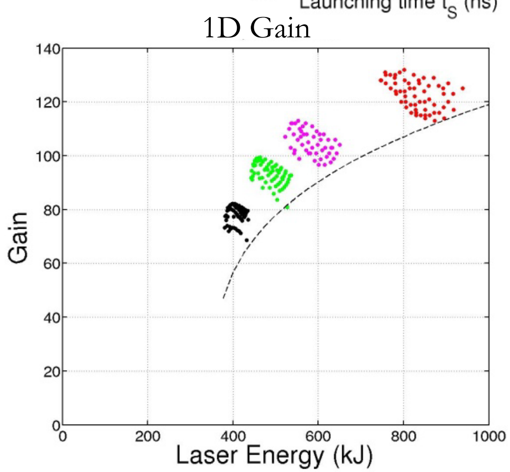
Separate scaled NIF windows (1D CHIC PDD IP results)
96-96 vs 160-32 3ω NIF Performance

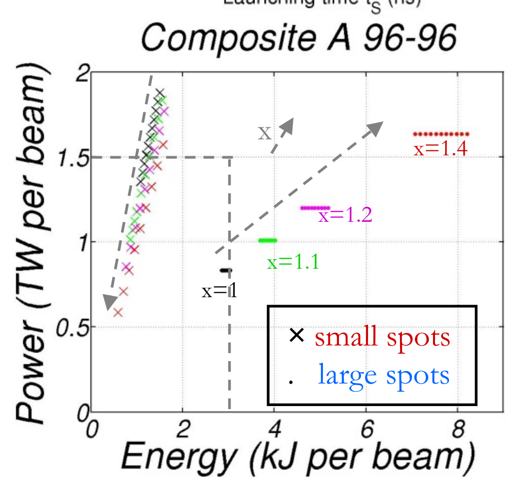


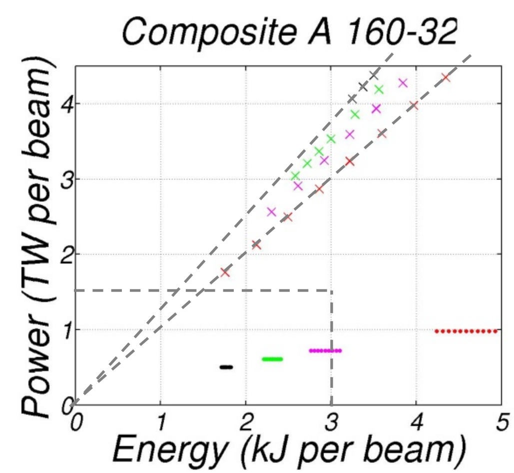




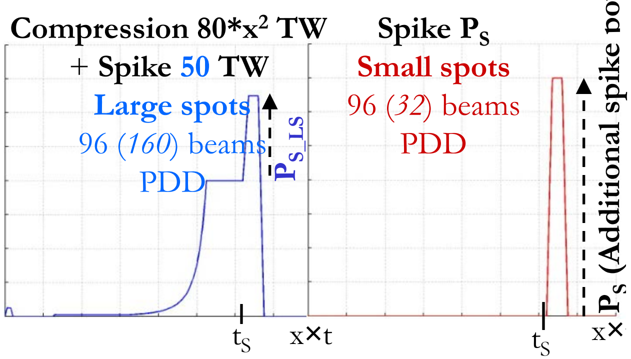




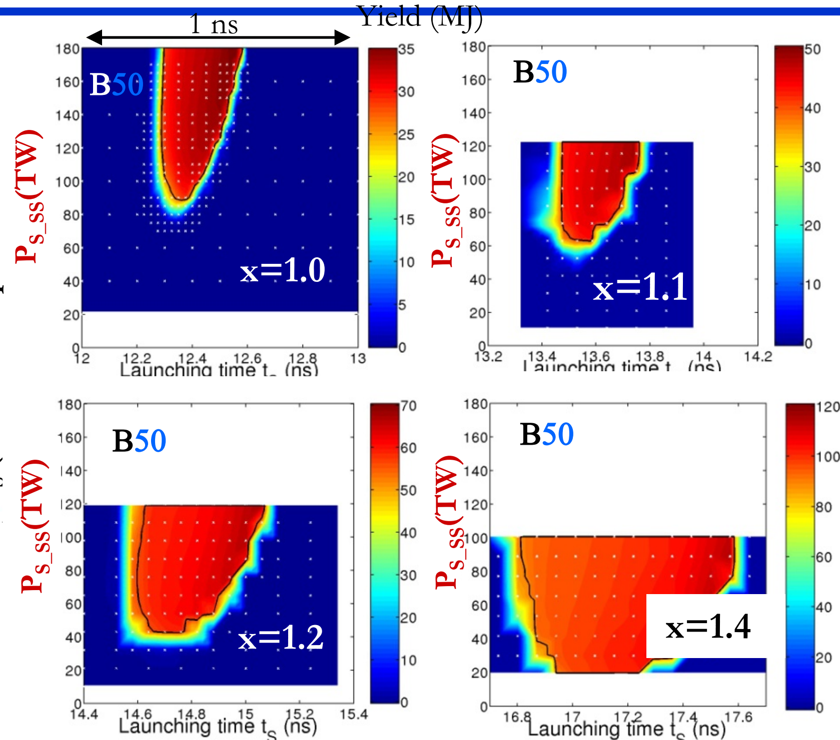


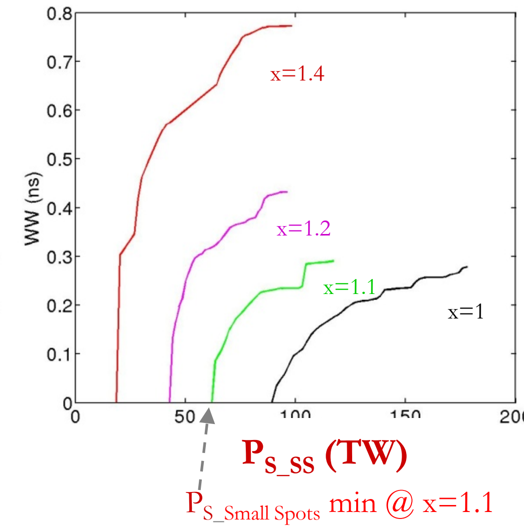


Composite 50 scaled NIF windows (1D CHIC PDD IP results)
96-96 vs 160-32 3ω NIF Performance

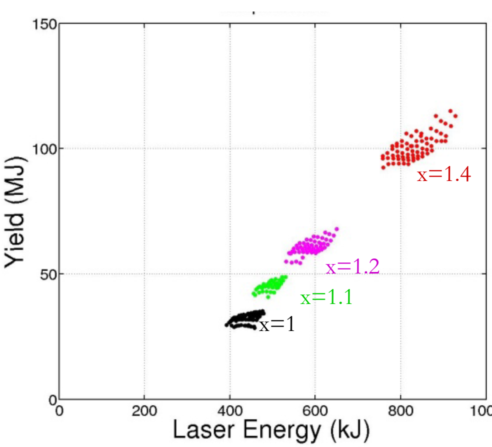


Total Additional spike power $P_S = P_{S\_LS} + P_{S\_ss}$

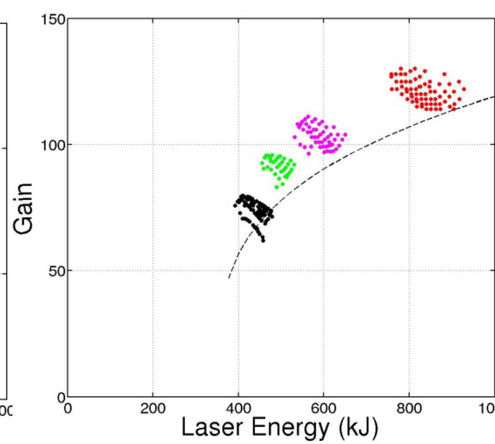




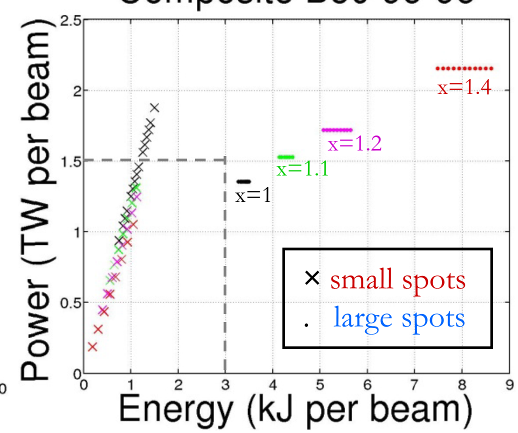
1D Yield



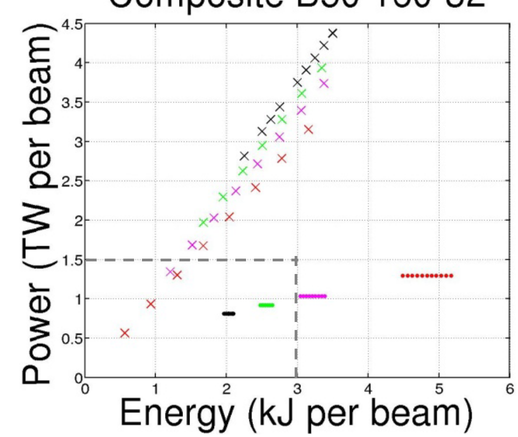
1D Gain



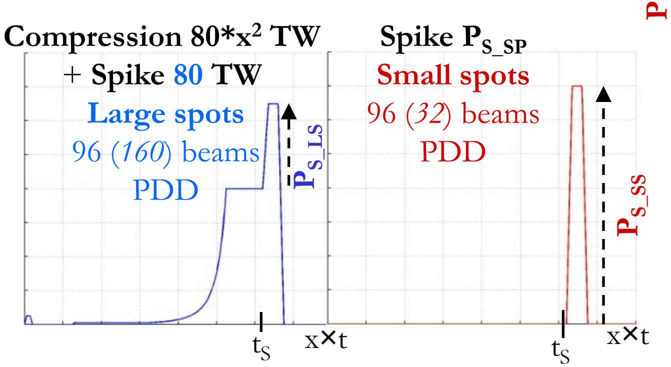
Composite B50 96-96



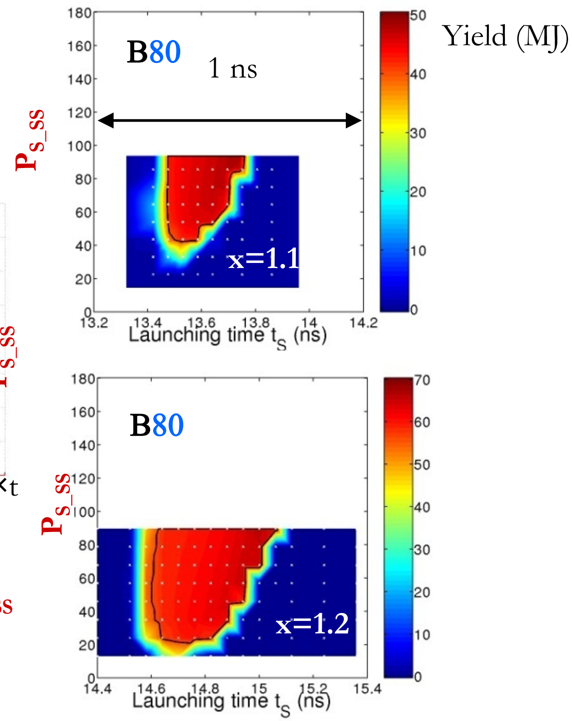
Composite B50 160-32

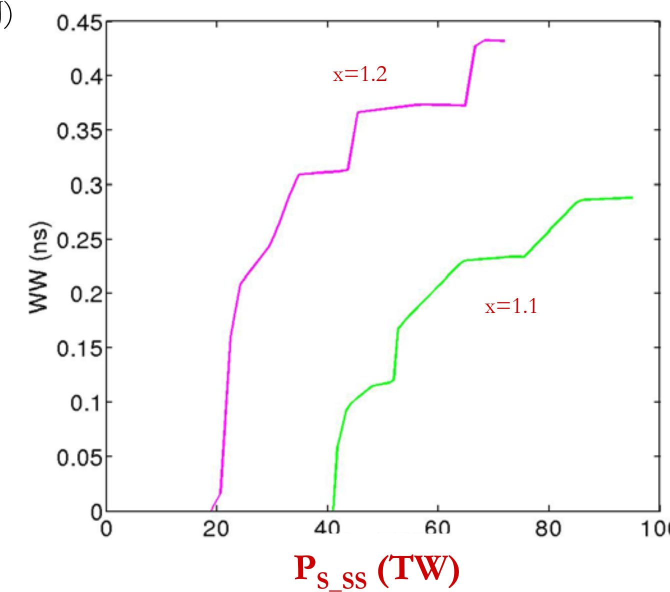


Composite 80 scaled NIF windows (1D CHIC PDD IP results)
96-96 vs 160-32 3ω NIF Performance

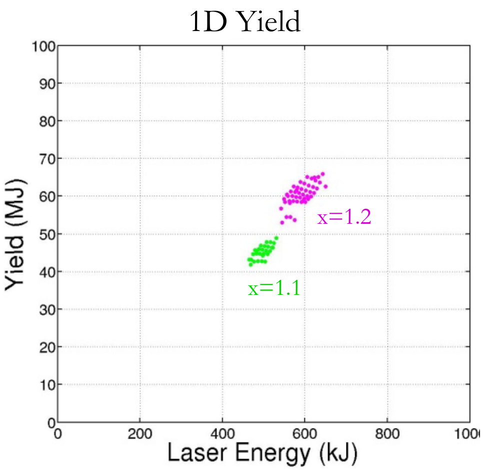


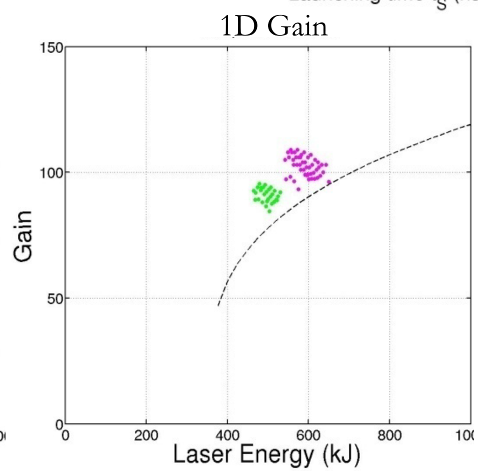
Total Additional spike power $P_S = P_{S\_LS} + P_{S\_SS}$

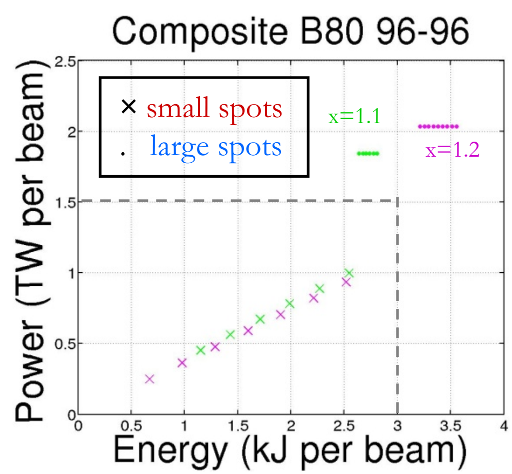


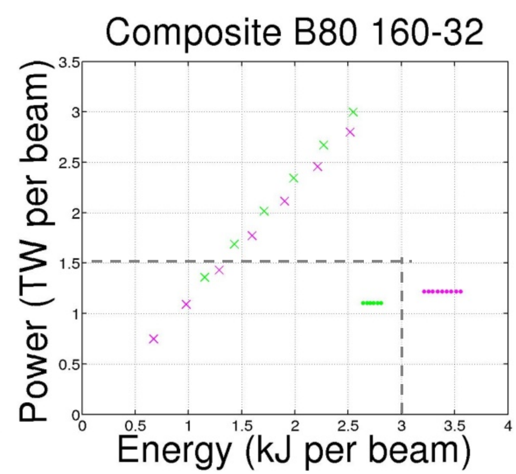


$P_{S\_Small\ Spots}$ min @ x=1.1, P_S=120 TW



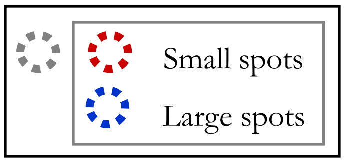


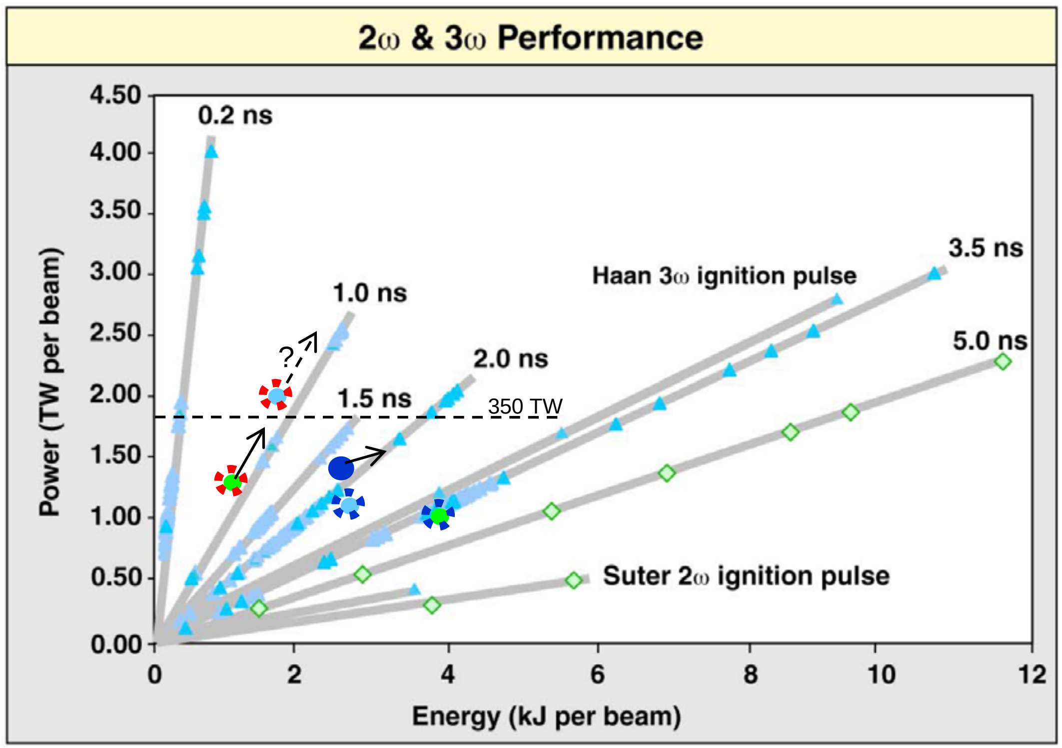




SI low aspect ratio CH target
3ω NIF PDD 1D design **x=1.1**

- Composite **A** **96b**-**96b**, P_S=125 TW, P_{Total}=220 TW, t_S=13.600 ns, **(Y46MJ-G98)$_{1D}$** @ **E_{Laser}=470 kJ**
- Composite **B80 160b-32b**, P_S=145 TW, P_{Total}=240 TW , t_S=13.600, **(Y44MJ-G94)$_{1D}$** @ **E_{Laser}=490 kJ**
- Integrated **192b**, P_S=175 TW, P_{Total}=270 TW, t_S=13.600, **(Y45MJ-G90)$_{1D}$** @ **E_{Laser}=500 kJ**





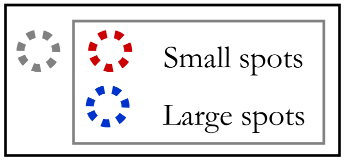
↗ design : possibility to increase spike power and then target robustness in a 1D world without hot é.

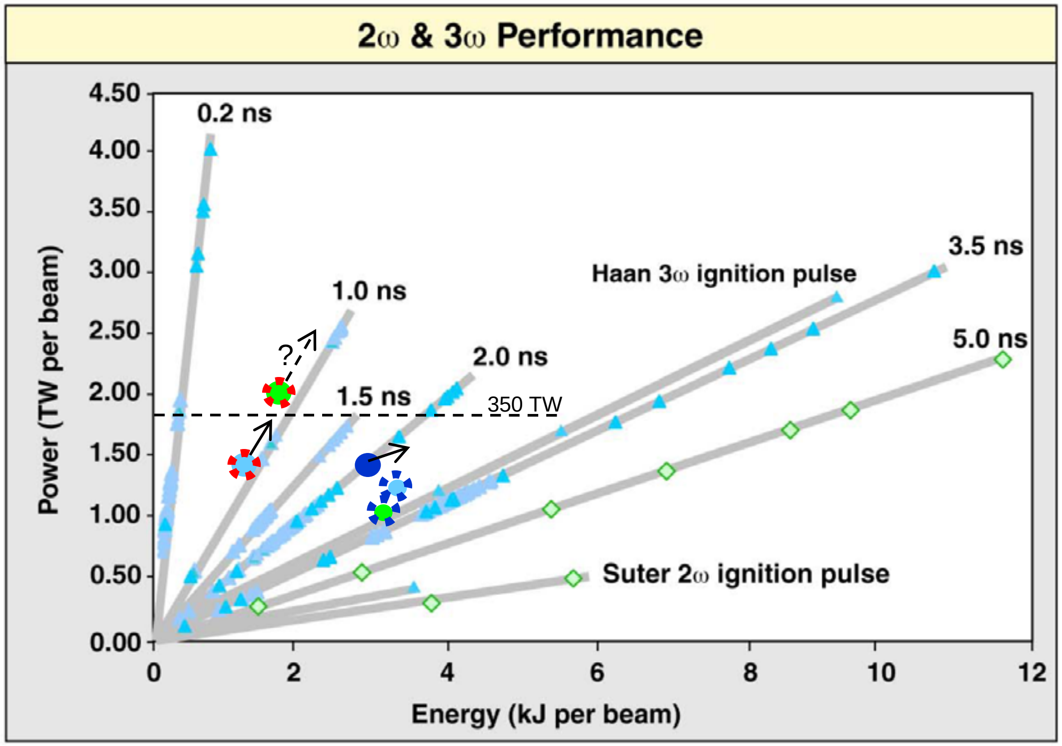
SI low aspect ratio CH target
3ω NIF PDD 1D design **x=1.2**

Composite **B50 160b-32b**, P_S=115 TW, P_{Total}=230 TW , t_S=14.750, **(Y61MJ-G107)$_{1D}$** @ **E_{Laser}=570 kJ**

Composite **B80 160b-32b**, P_S=125 TW, P_{Total}=240 TW , t_S=14.750, **(Y61MJ-G106)$_{1D}$** @ **E_{Laser}=575 kJ**

Integrated **192b**, P_S=150 TW, P_{Total}=265 TW, t_S=14.750, **(Y60MJ-G104)$_{1D}$** @ **E_{Laser}=580 kJ**



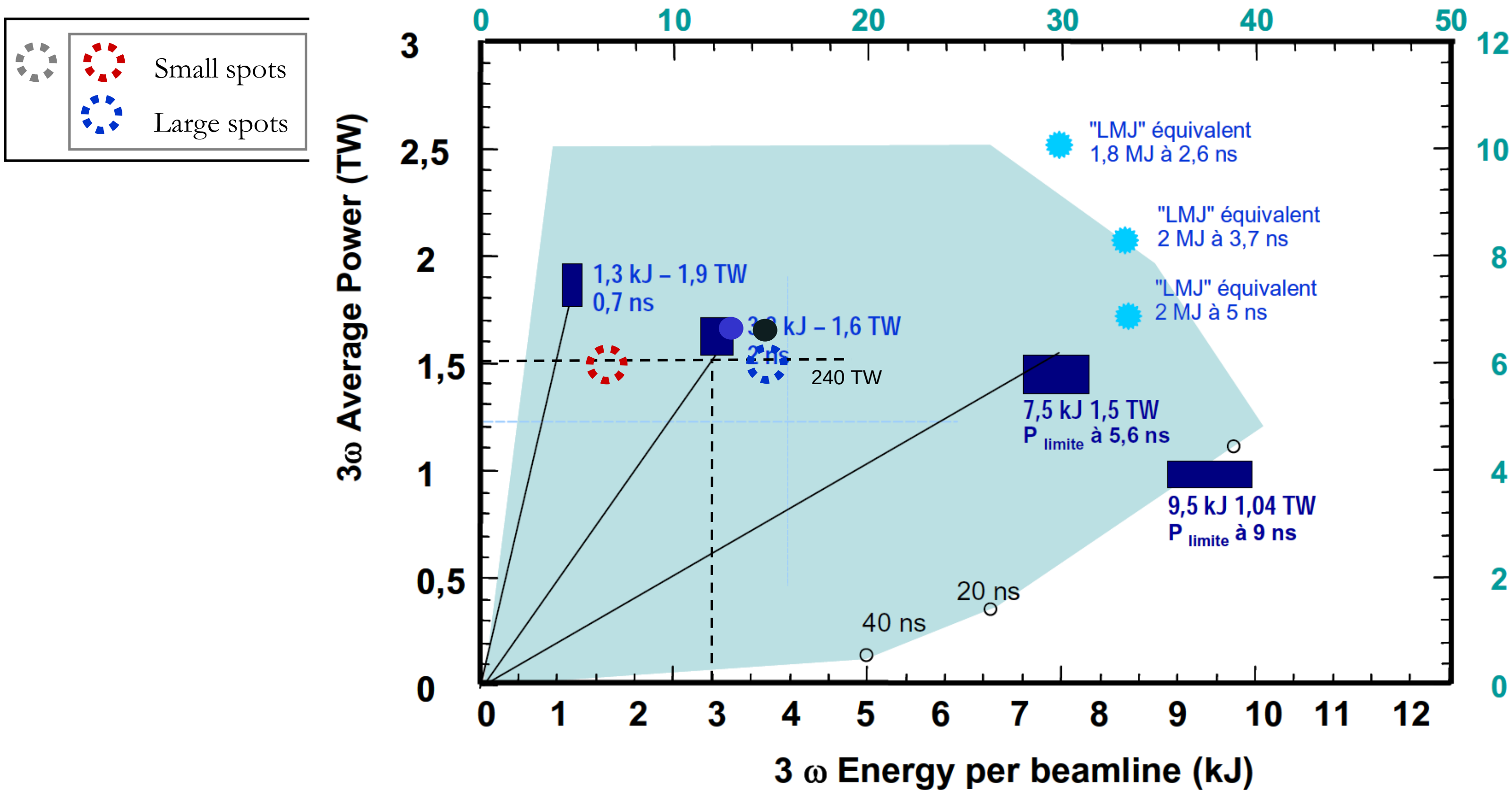


↗ design : possibility to increase spike power and then target robustness in a 1D world without hot é.

LMJ SI prospect : 3ω LIL Performance

Possible SI high gain for scales 1.1 and 1.2 on LMJ near of 1.5 TW/b hypothesis

- Composite **120b**/**40b**, scale1.1 design, P_S=150 TW, P_{Total}=245 TW, t_S=13.450, **(Y45MJ-G94)$_{1D}$** @ **E_{Laser}=490 kJ**
- Integrated **160b**, scale1.1 design, P_S=175 TW, P_{Total}=270 TW, t_S=13.600, **(Y45MJ-G90)$_{1D}$** @ **E_{Laser}=500 kJ**
- Integrated **160b,** scale 1.2 design, P_S=150 TW, P_{Total}=265 TW, t_S=14.750 ns, **(Y60MJ-G104)$_{1D}$** @ **E_{Laser}=580 kJ**



3ω LIL Performance figure : CEA/DAM 2005 - Claude Cavailler, Noel A. Fleurot, Jean-Michel Di Nicola, "LIL and LMJ laser facility status", 26th International Congress on High-Speed Photography and Photonics, edited by D. L. Paisley, S. Kleinfelder, D. R. Snyder, B. J. Thompson, Proc. SPIE, Vol. 5580, 443 (2005)

Summary

- First Goals of this study - provide 1D simulation data base in the motivation to enhance our understanding of physic of Shock Ignition - Give first simple ideas on a design strategy and how we can manage spike power on large and small spots on Facilities.

- Robust 1D SI targets with gain > (90)100 may be fielded on LMJ or NIF at ~ (500)600 kJ, 250 TW

- Different PDD irradiation solutions are considered
  - Full 192 beams for compression and spike (LMJ and NIF)
  - 96/96 composite or separate (NIF) : 2D symmetry needs confirmations
  - 160/32 composite (NIF)
  - 112/80 separate (NIF)
  - 120/40 composite (LMJ)

- Upscaled targets require less power in Spike, more power in compression
  - The optimal split : 96/96, 112/80, 128/64, 160/32, 192/0 depends of scale
  - More spots for compression enhances symmetry , abs. efficiency , and robustness from pointing errors …

- Ignition windows are used as figure of merit of robustness
  - Accounting for Facilities pulse jitters and power inaccuracies leads to select sensible 1D reference designs
  - Proposed solutions are various : separate, composite, integrate @ scale 1.1 on NIF and LMJ for a laser energy around 500 kJ with 1D G~90 or around 600 kJ for a 1D G~100

Perspectives for design

- Study NIF PDD patterns for full 192, composite or separated 112/80, 128/64, 160/32, 96/96 : test of our tools and design strategy
    - Cross check with LLE needed
- Consider Direct Drive for Spike (composite), DD bipolar or annular symmetry on NIF/LMJ using ID phase plates.
- Do we need specific SI phase plates, Multi-FM, Dynamical Pointing … ? 3ω and 2ω studies @ CELIA for Hiper on CH abblator designs
- Assess 2D robustness for LMJ and NIF design including credible facility jitters. Cross check with Rome, LLE and LLNL. Early LIL experiments welcome
- Our priority is Hydro Code with LPI reduced models experimental validation for SI design and physic needs. Interest on NIF/LMJ-like configurations tests on Omega : PDD for compression (+spike for 60b integrated), DD for Spike (composite or separated), bipolar … Is balance necessary for spike ? Multi FM, or specific phase plates ?

TY
was my first talk in a SI workshop