Heavy Ion Fusion Modeling Update*

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ARIES e-Meeting
October 17, 2001

*** This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.**

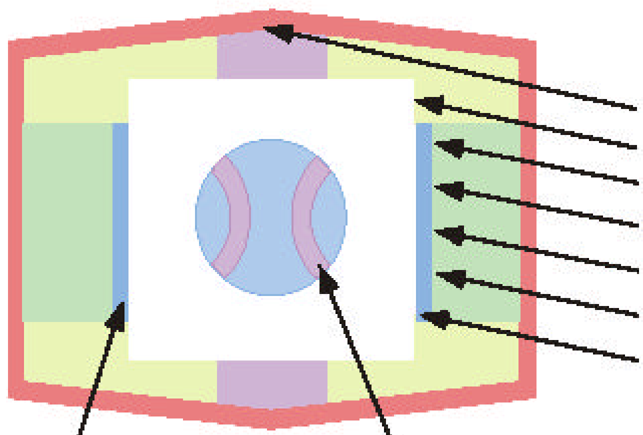
Outline

- Review some info presented at HIF-IFE meeting held at LLNL in July.
- Recent progress on update to driver model
- Expected next steps that will feed into ARIES work

A preliminary power plant design point for HIF was in July

- Goal is a starting point for updated, self-consistent HIF power plant design
- Based on the Hybrid target design
- Target gain scaling from Lasnex calculated target at 6.7 MJ
- HYLIFE-II chamber and BOP cost scaling
- IBEAM driver cost and efficiency scaling
- 1000 MWe net power as base case

The Hybrid target uses internal hohlraum shields to allow larger spots sizes

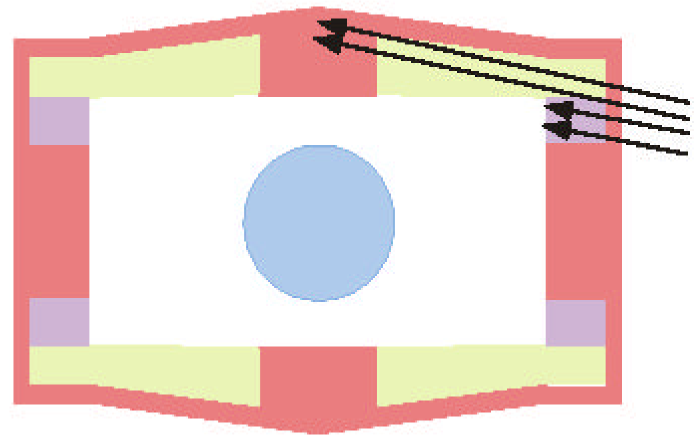


shine shield to control P_2

radiation shim to control early time P_4

Beam spot: 3.8 mm x 5.4 mm
Effective radius: 4.5 mm

6.7 MJ beam energy
Gain = 58



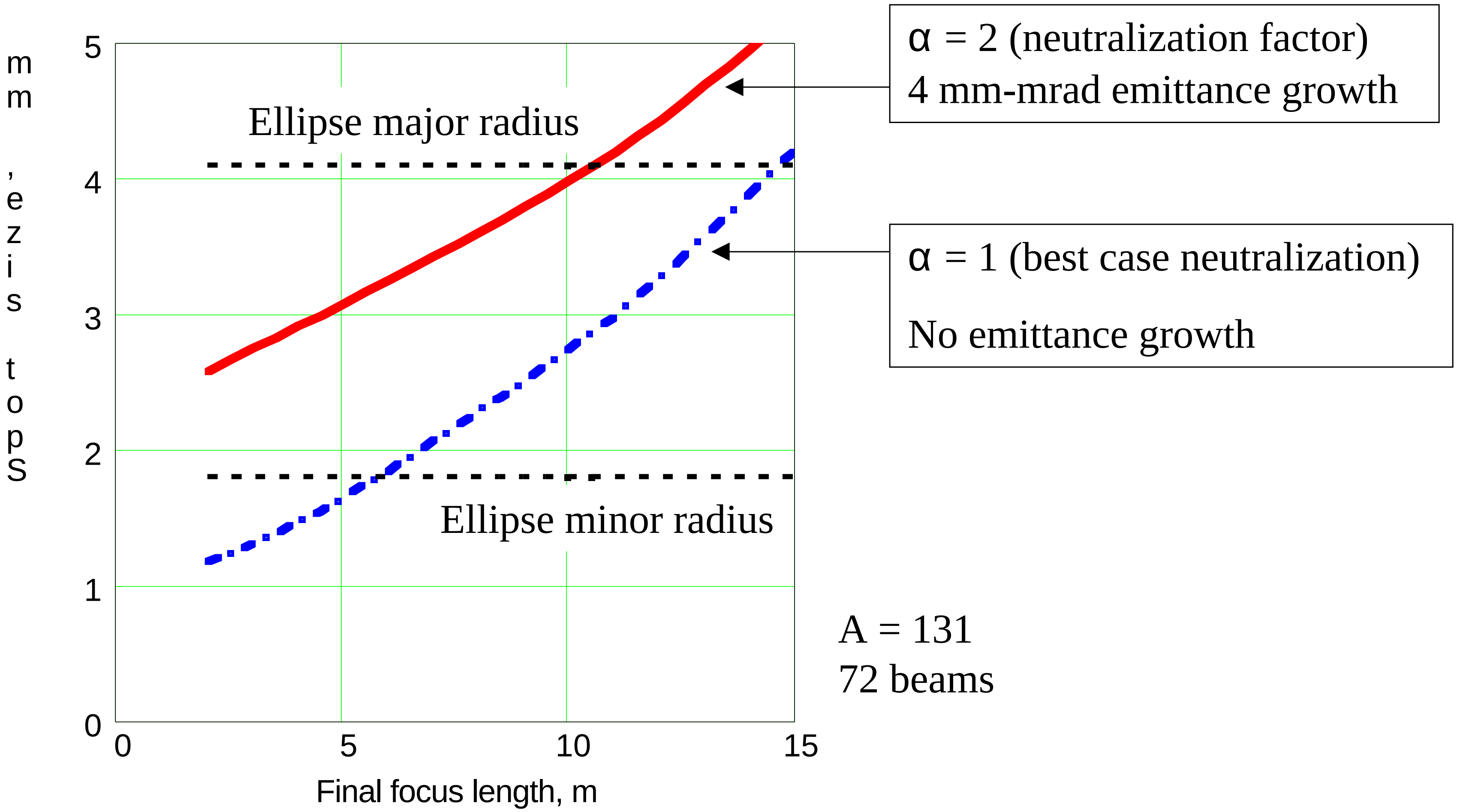
original distributed radiator target

Beam spot: 1.8 mm x 4.1 mm
Effective radius: 2.7 mm

5.9 MJ beam energy
Gain = 68

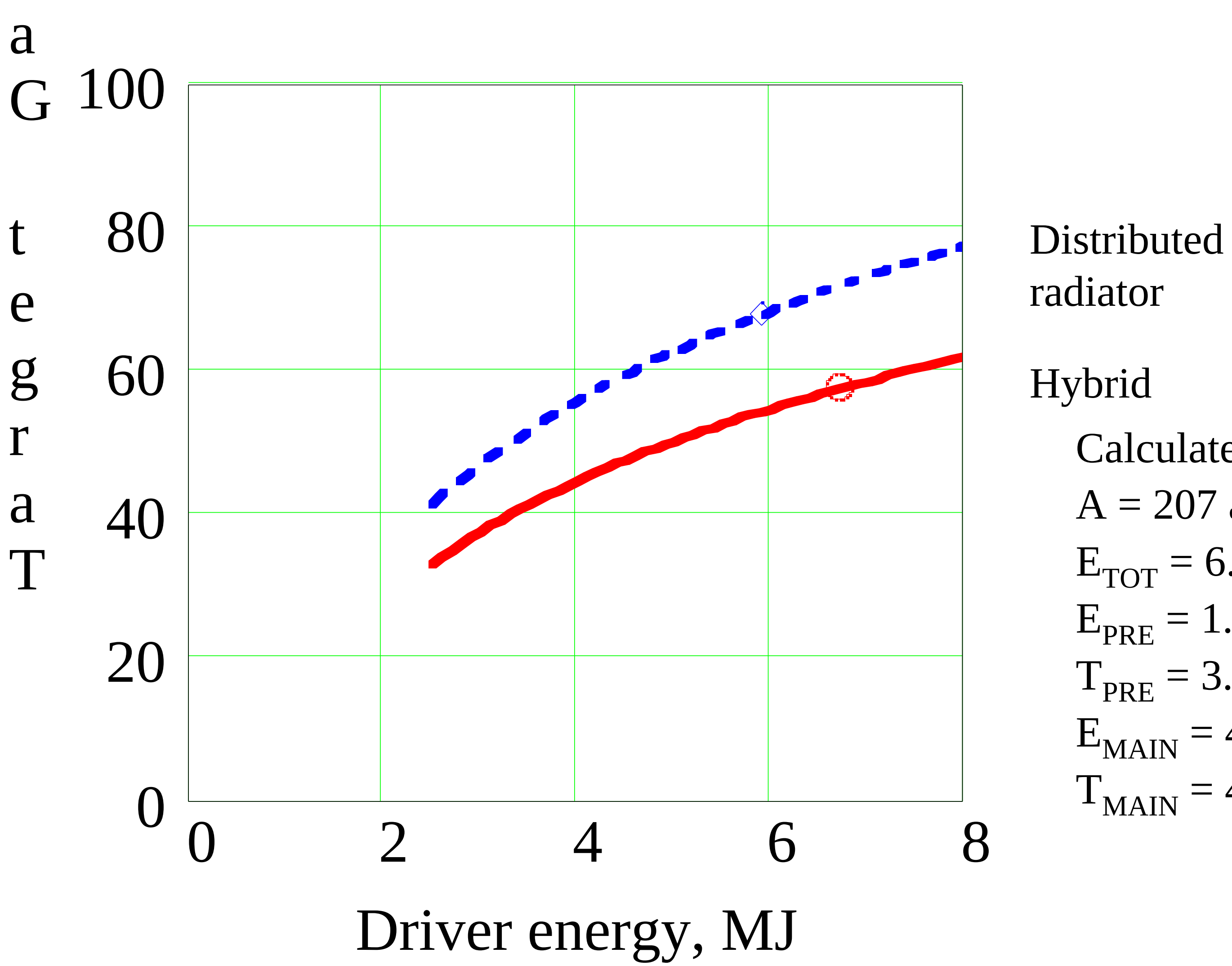
Hybrid target can accept circular beam spots. Estimated radius is 5 mm for 6.7 MJ case. Spot size likely to scale between square root and cube root of driver energy. (re: D. Callahan-Miller)

The distributed radiator target will require very small spot size if based on ellipse minor radius



A = 131
72 beams

Target gain was assumed to scale similarly to distributed radiator targets



Calculated pt.

A = 207 amu

E_{TOT} = 6.7 MJ

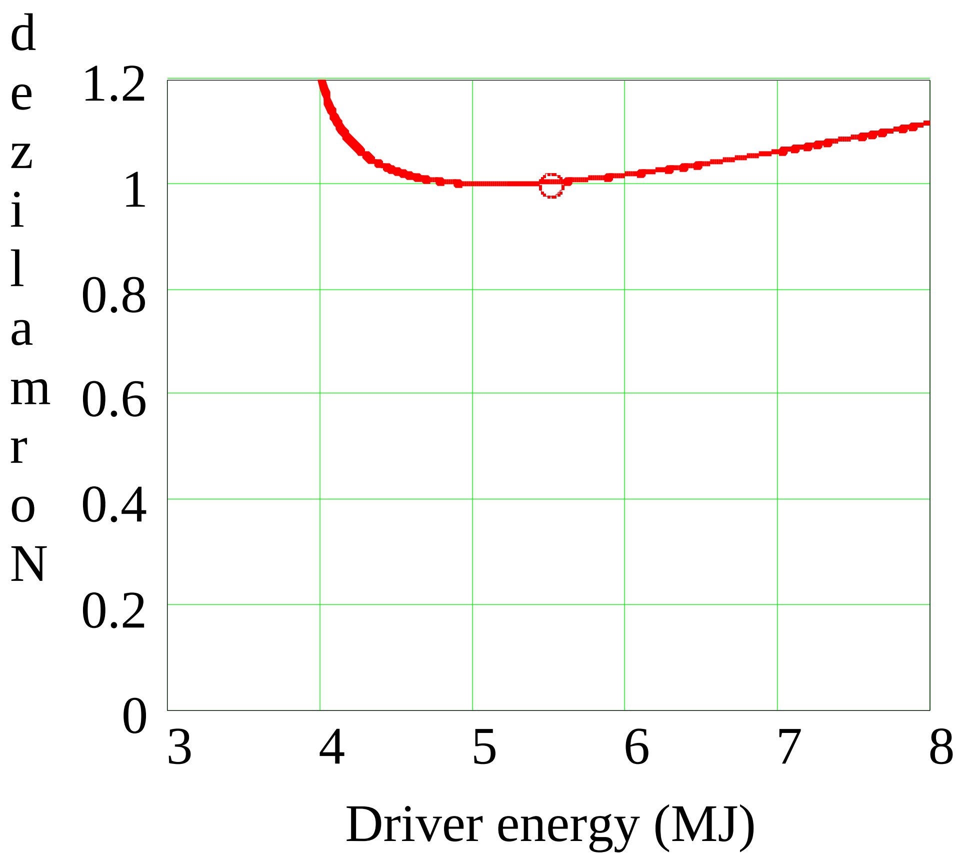
E_{PRE} = 1.9 MJ

T_{PRE} = 3.0 GeV

E_{MAIN} = 4.8 MJ

T_{MAIN} = 4.5 GeV

Preliminary cost studies indicate a flat minimum COE at driver energy ~ 5.0 - 5.5 MJ



I selected higher end of range to keep rep-rate somewhat lower (8.6 Hz at 5.5 MJ vs. 10.4 Hz at 5.0 MJ). Is there a rep-rate constraint?

1000 MWe
A = 131 amu (Xe)
(driver cost ~ 30% lower than for Pb)

Caveat: Systems model needs improvements in many areas including target gain scaling, driver costing, and HYLIFE plant models.

Key power plant design point parameters

Ion mass = 131 (Xe)
Charge state = +1
Total beam energy = 5.5 MJ
Target gain = 53
Target yield = 290
Rep-rate = 8.6 Hz
Fusion power = 2490 MWt
Total thermal = 2940 MWt
Gross electric = 1264 MWe (thermal efficiency = 43%)
Driver power = 104 MWe (driver efficiency = 45%)
Pumping power = 108 MWe
Other power = 51 MWe (4% of gross electric)
Net power = 1000 MWe

Target requirements for 5.5 MJ using Xe (A = 131) ions

	Prepulse	Main pulse
Final ion energy, GeV	1.90	2.48
Beam energy, MJ	1.56	3.94
Pulse duration, ns	30	8
Charge, mC	0.82	1.38
Spot radius, mm	4.6	4.6

Note: Energy split scaled from 6.7 MJ target. Resulting charge split would give 26.8 prepulse beams out of 72 – therefore need to slightly adjust pre/main pulse energies to get even number of each for two-sided illumination.

Key issues: What does it take to get small spot size?

- Driver example: Xe^{+1} (A = 131), E_{TOT} = 5.5 MJ,

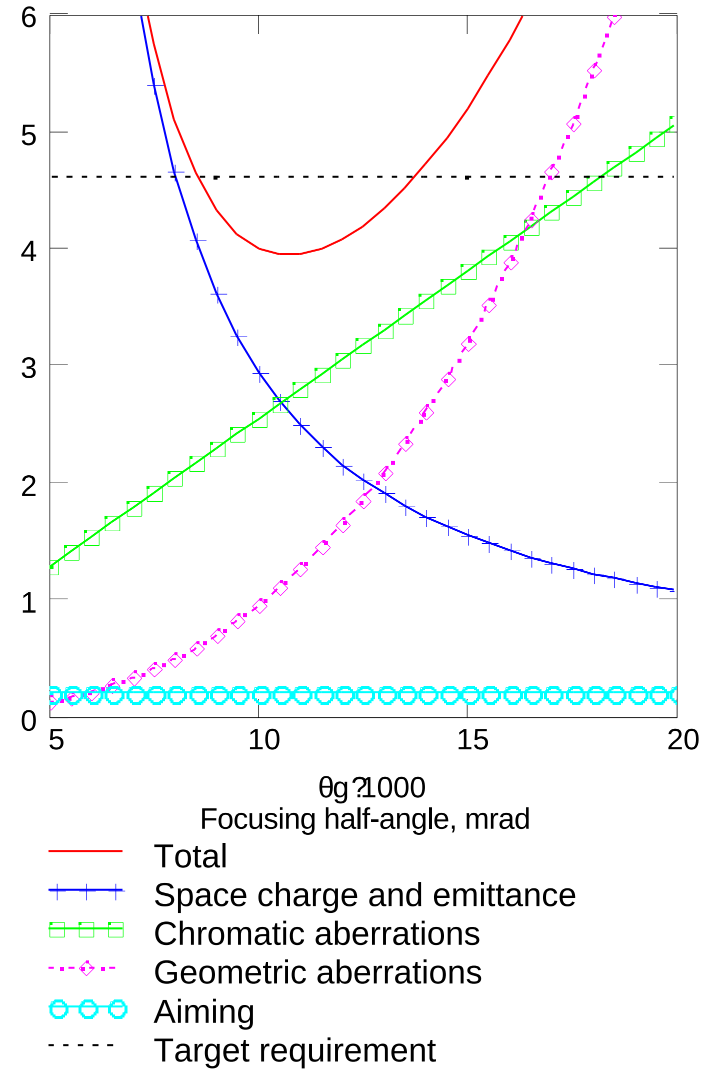
  E_{MAIN} = 3.94 MJ (2.48 GeV), E_{PRE} = 1.56 MJ (1.90 GeV)

  ~ 4.6 mm spot radius needed = 5 mm • $(5.5\ \text{MJ}/6.7\ \text{MJ})^{0.4}$
- Following design variables are examined (reference case values in parenthesis)
  - Number of beams (72)
  - Initial pulse duration (25 μs)
  - Neutralization factor (α = 2)
  - Normalized emittance growth (4 mm-mrad)
  - Final focus length (10 m)
  - Final focus beam half-angle (10 mrad)
- R_{spot} = 4.0 mm for the reference case values

Contributions to spot size for reference case vs. focus half-angle of each beam

rspotmp(Nbo , τ0o , Ao , α o , Lfo , θg , εGo , Lmo)?mm
rsmp(Nbo , τ0o , Ao , α o , Lfo , θg , εGo)?mm
rcamp(τ0o , Ao , Lfo , θg)?mm
rgeom(Lfo , θg , Lmo)?mm
raim?mm
rgoal

θ = 10 mrad selected as reference case



Recent work is focused on improved spot size models

Spot size contribution due to **chromatic aberrations**:

- This is due to the fact the the entire beam is not at exactly the same ion energy
- spot size contribution ~ focal length (L_f), beam half angle (θ), and fractional momentum spread ($\Delta p/p$):

$$\Delta r = 6 \cdot L_f \cdot \theta \cdot (\Delta p/p)$$

- L_f and θ are design optimization variables (as before)

- New model calculates $\Delta p/p$ based on the estimate voltage errors on the injector gap and the acceleration gaps along the accelerator. Thus it is now a function of the number of acceleration gaps and length of the accelerator.

Spot size model improvements (cont.)

- Beam **emittance** is related to beam temperature (i.e., ions have a transverse velocity component). Depends on source characteristics and growth during acceleration and beam manipulations.

- For a perfectly neutralized beam, emittance contribution to spot size is proportional to the normalized emittance and inversely proportional to the focus half angle

$$\Delta r_e = \varepsilon_n / \theta$$

- Emittance model has been changed in two ways:

1) Now integrates growth along the accelerator (function of length)

2) Allows elliptical beam shape with separate x-y emittance values

Next steps

- Complete driver code modifications
- Re-run for distributed radiator target
- Propose new HYLIFE point design for ARIES consideration
- New point design will also be basis for HIF VNL and VLT work on interface design issues (liquid jet configuration, final magnet shielding update, vacuum pumping, target material recovery, etc.)