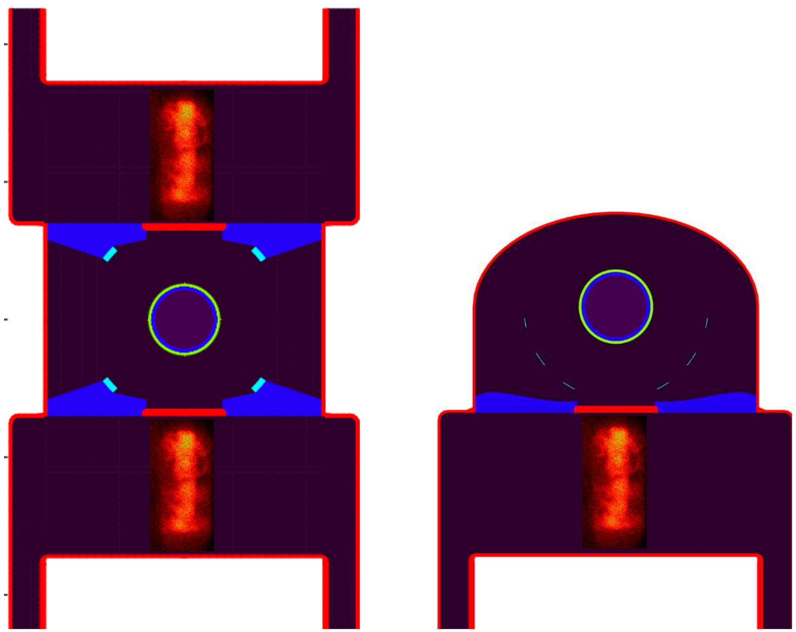
SAND2008-7824C

Application of variably-doped ablators to a single-sided drive ICF hohlraum



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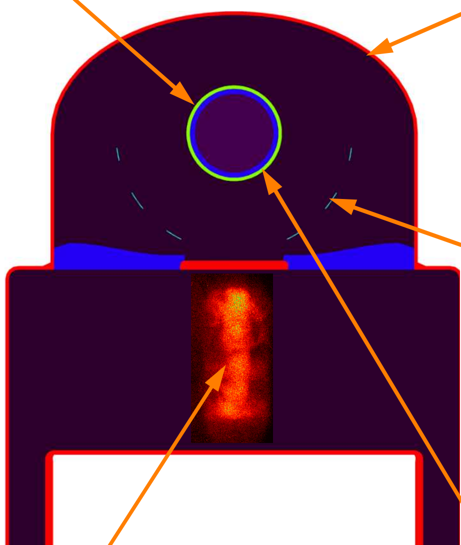
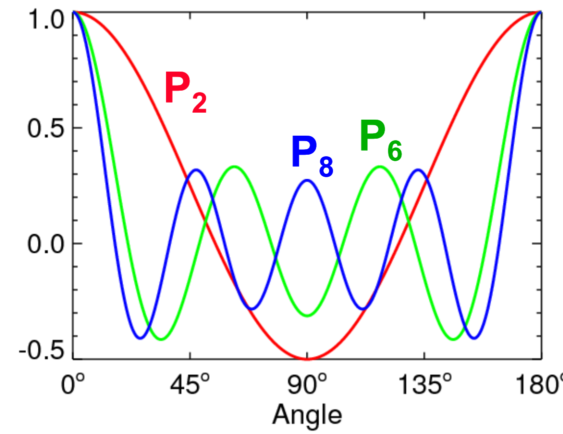
Ignition of a high yield capsule in a single-sided hohlraum will require aggressive symmetry control

High yield ICF capsule



Hohlraum geometry
(dimensions, shaping)

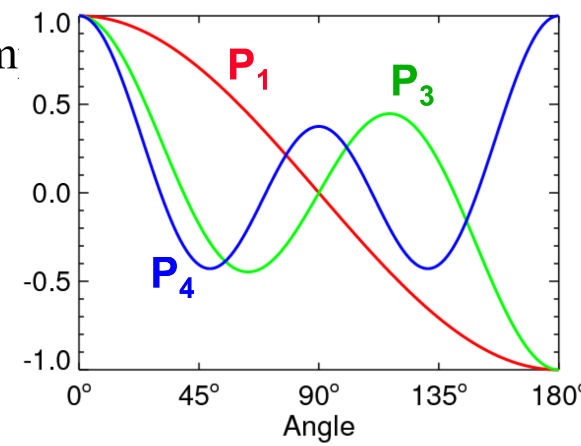
Minimize P_2, P_6, P_8



Symmetry shield(s)
(position, com

Reduce P_1, P_3

Minimize P_4



High power, high energy z-pinch x-ray source

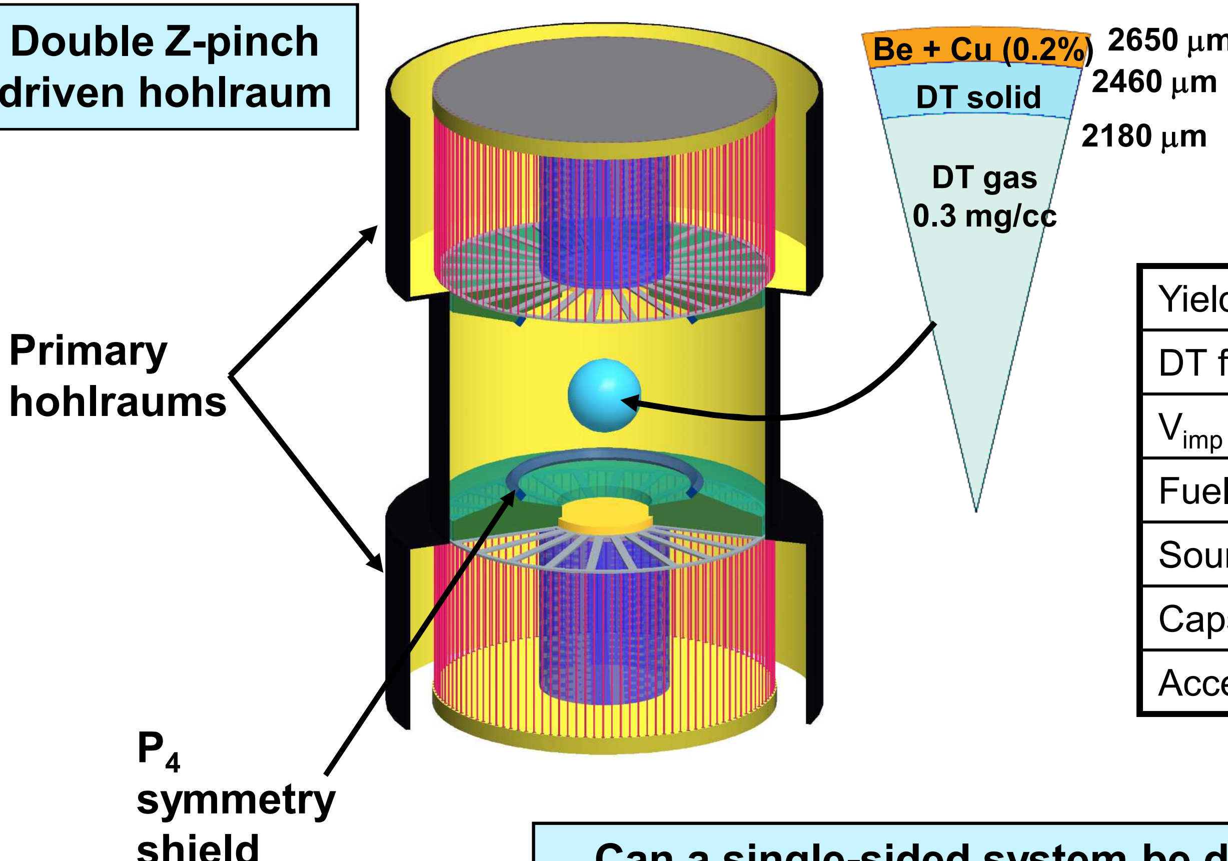
Capsule modifications

Compensates for residual asymmetry

Ignition in 2D capsule simulations

A reference design for a 2-sided z-pinch driven high yield system has been published[1]

Double Z-pinch driven hohlraum



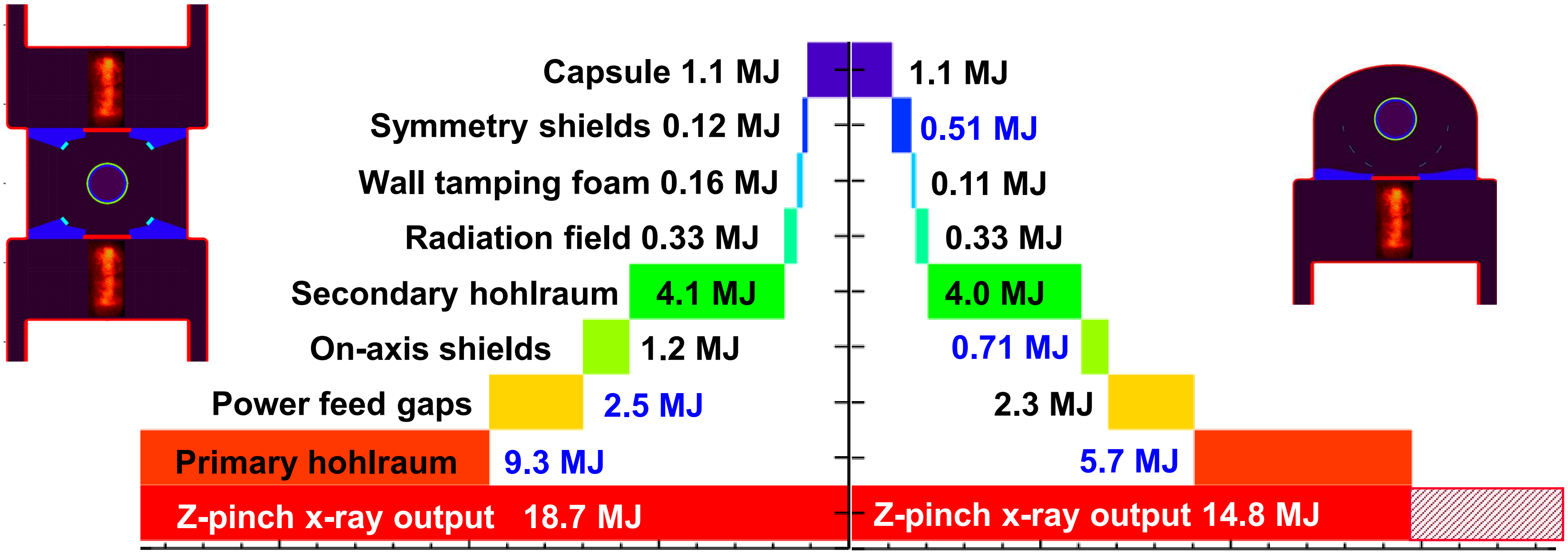
System parameters

Yield	**520 MJ**
DT fuel mass	**4.74 mg**
V_{imp} (cm/μs)	**26.0**
Fuel KE margin	**29%**
Source x-ray energy	**19 MJ**
Capsule absorbed energy	**1.2 MJ**
Accelerator stored energy	**~400 MJ**

Can a single-sided system be designed that allows high yield with higher efficiency ?

[1] R. A. Vesey, M. C. Herrmann, R. W. Lemke, *et al.*, *Phys. Plasmas* **14**, 056302 (2007)

Preliminary LASNEX simulations show x-ray source energy savings with a 1-sided configuration



Advantages:

- Avoids mistiming or power imbalance issues associated with 2 pinch sources
- Simpler and more efficient pulsed-power accelerator design
- Better access for diagnostics, cryogenics, experimental packages

Issues:

- Higher performance required for the single z-pinch
- **Inherent P_1 > 20%, P_3 of -8%, P_4 of -2% must be addressed**

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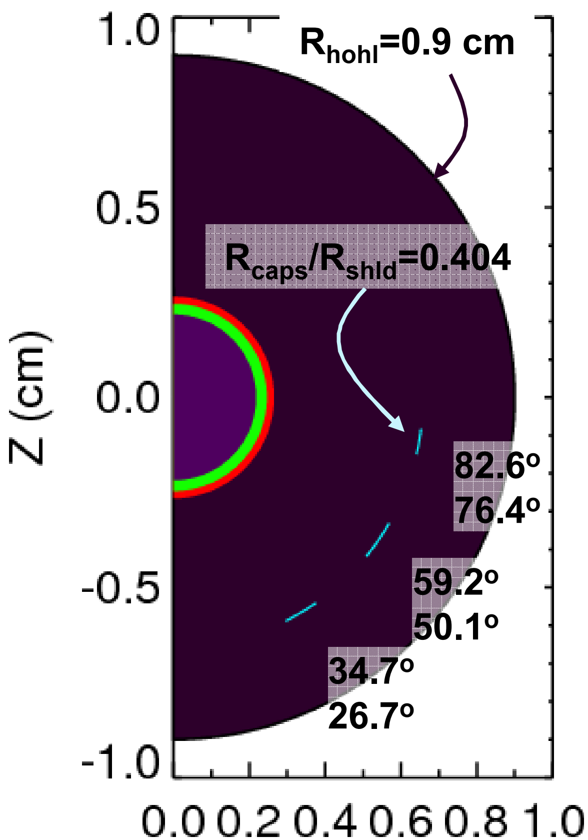
Multi-dimensional optimization[1] of shields reduces $P_1 \rightarrow P_{10}$ to low levels in a model problem

Model problem



Hohlraum source asymmetry applied in P_1, P_3, P_4:

At capsule, P_1 = 25%, P_3 = -8%, P_4 = -2%

Viewfactor optimization procedure:

- Shield Legendre mode content $a_{n,shield}$ are parameters
- Solve equations for angular extent of shields
- Call viewfactor routine to calculate flux to capsule
- Evaluate mode content in flux at capsule, $a_{n,caps}$

Optimized shields give P_1 - P_{10} < 1% in both viewfactor and 2D LASNEX for the sphere-in-sphere model problem

However, recent 2D hohlraum simulations using these 3 shields show excessive perturbation of the hohlraum environment → non-optimum symmetry control

[1] R. A. Vesey, S. A. Slutz, M. C. Herrmann, *et al.*, *Phys. Plasmas* **15**, 042704 (2008)

(r,θ) *variable doping*[1] of the capsule ablator compensates for residual hohlraum asymmetry

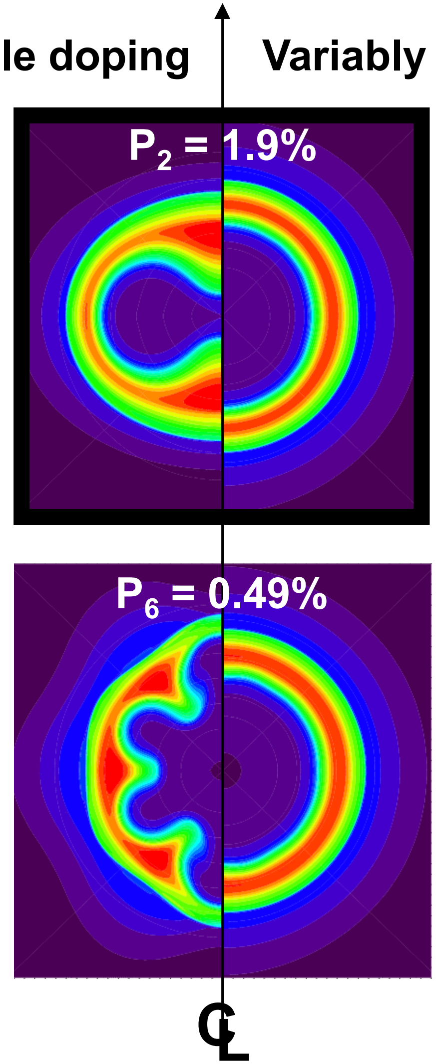
Concept is to use high-Z dopant to achieve spatially uniform ablation pressure for a known non-uniform radiation flux distribution

Simulations found the ablation pressure P_{abl} as a function of $I=T_r^4$ and Au dopant fraction in Be ablator

→ f_{Au} (T_r, $\delta I/I$) at constant P_{abl}

Use 1D simulation to map the drive $T_r(t)$ onto depth of ablation front

→ Known asymmetry modes $P_n(t)$ determine $f_{Au}(r,\theta)$ in ablator



Uncompensated capsule is near failure threshold.

Compensated capsule implosion is nearly spherical

⇒ much higher radiation asymmetries can be accepted as part of the target design

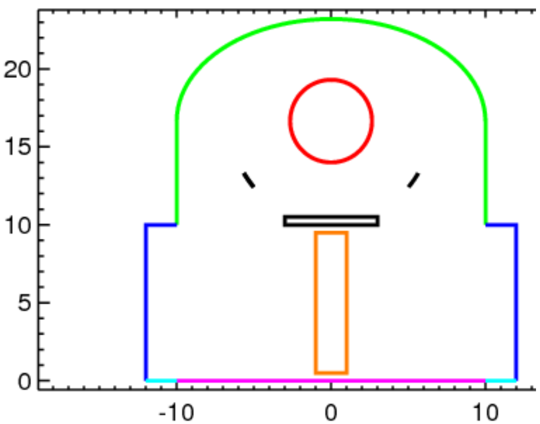
With higher order corrections, compensation for (individual) modes was successful for:

P_1	**18.5 %**	(1.2%)
P_2	**20.0 %**	(2.0%)
P_4	**10.5 %**	(1.5%)
P_6	**8.5%**	(0.48%)

[1] S. A. Slutz, R. A. Vesey, and M. C. Herrmann, *Phys. Rev. Lett.* **99**, 175001 (2007)

Combine hohlraum shaping, shields, and variable ablator doping to symmetrize the implosion

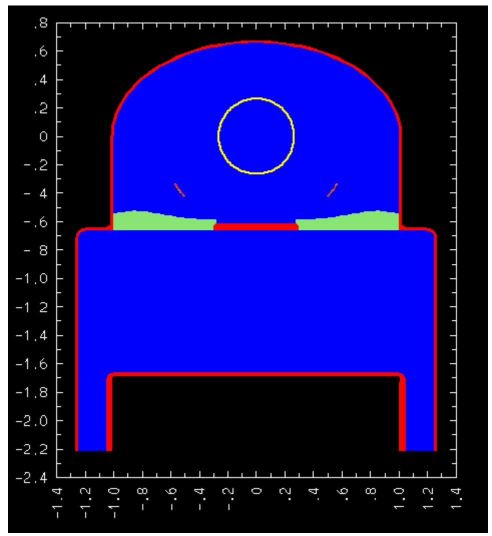
Incorporate shields in viewfactor optimization of 1-sided hohlraum → **Evaluate asymmetry in 2D LASNEX without capsule implosion** → **Design variably-doped capsule to compensate for residual asymmetry**



Optimize $[\theta_1, \theta_2]$ range(s)

Iterations are fast

Imperfect guide



Most complete hohlraum physics

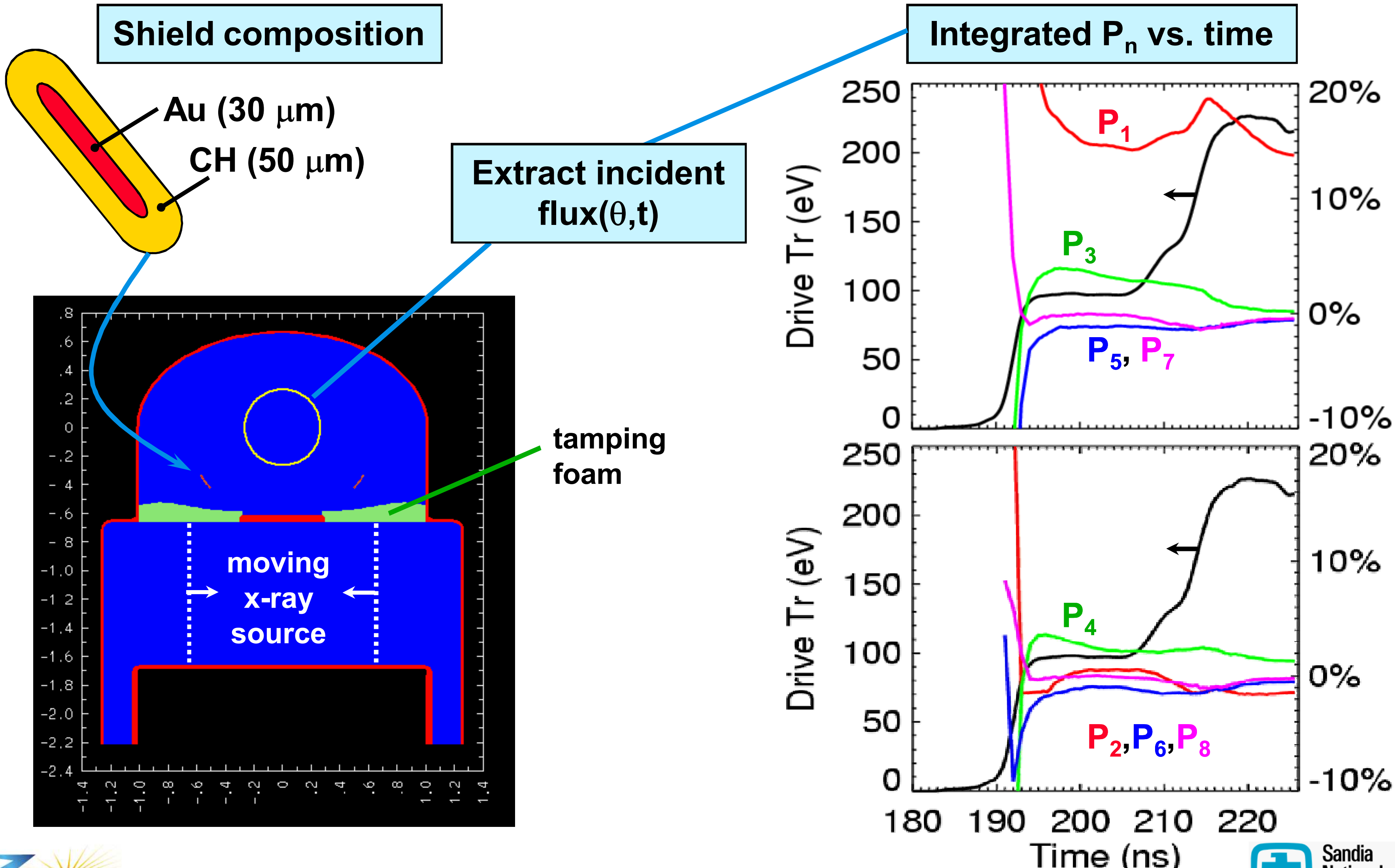
Model benchmarked at Z conditions

Specify $f_{Au}(r,\theta)$ in ablator

Run 2D LASNEX capsule-only with time-dependent drive asymmetry

Evaluate implosion quality and ablation pressure asymmetry

A single ring shield reduces P_1 from > 20% to 14% in 2D LASNEX simulations



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The Be ablator is doped as a function of (r,θ) at levels from 0% to 0.2% Au to symmetrize implosion

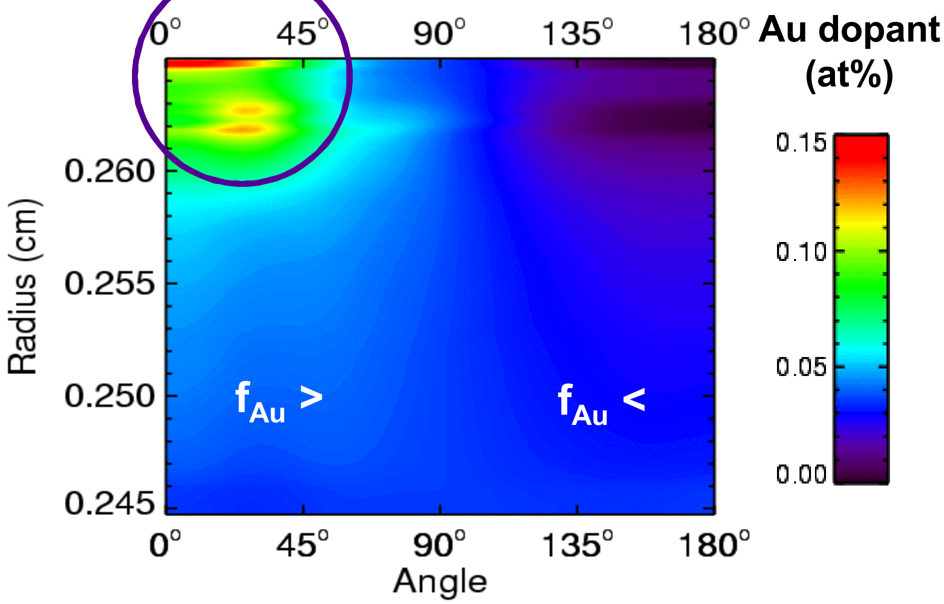
Use full knowledge of time-dependent asymmetry

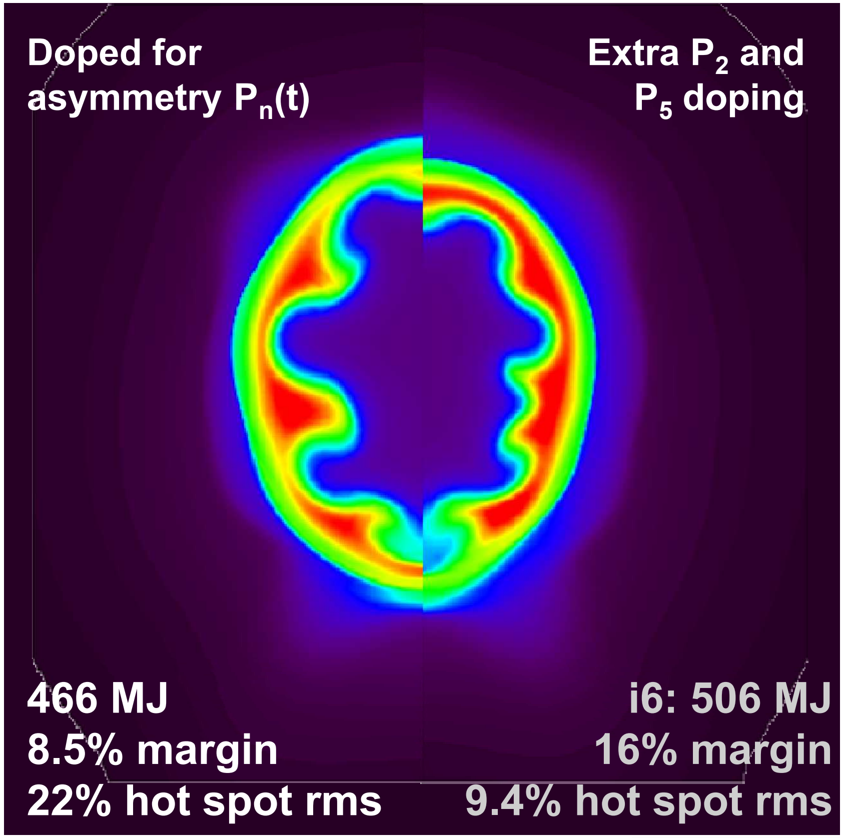
Include time shift: dope for ablation front at time t according to asymmetry at time t + 4 ns

2D LASNEX capsule density plots at ignition

low / high

Higher f_{Au} near bottom pole for early P_1>0





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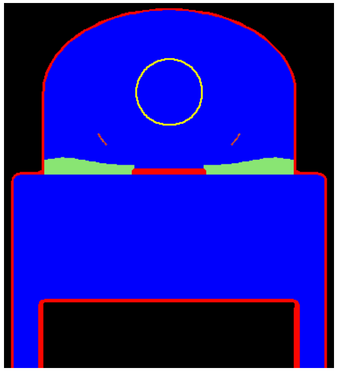
Ignition of a high yield capsule in a single-sided hohlraum will require aggressive symmetry control



Current approach uses shields to reduce asymmetry to levels that can be compensated for using variable (r,θ) doping of the capsule ablator

A single ring shield in the secondary hohlraum reduces the P_1 asymmetry to 14% while also keeping other modes small

- further improvements may be possible
- not clear that shields alone can provide a full solution

Variable ablator doping is predominantly P_1-shaped in θ, and is successful in producing ignition and full burn in 2D LASNEX simulations, using knowledge of time-dependent asymmetry

Single-sided hohlraum requires 20% less source x-ray energy than double-sided hohlraum driving the same capsule

More compact x-ray sources will allow even larger gains in efficiency for either 2-sided or 1-sided systems

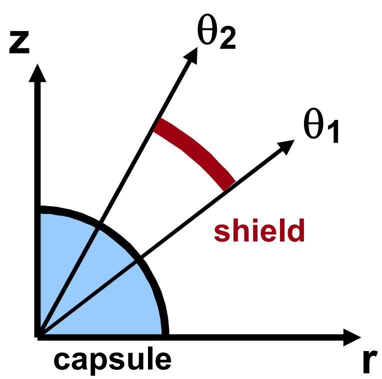
extras

Mode-selective shields are an important part of the double z-pinch high yield target design

Control the Legendre mode content of transmission past the shield

Specify positive P_4 content to counteract inherent $-P_4$ flux in hohlraum

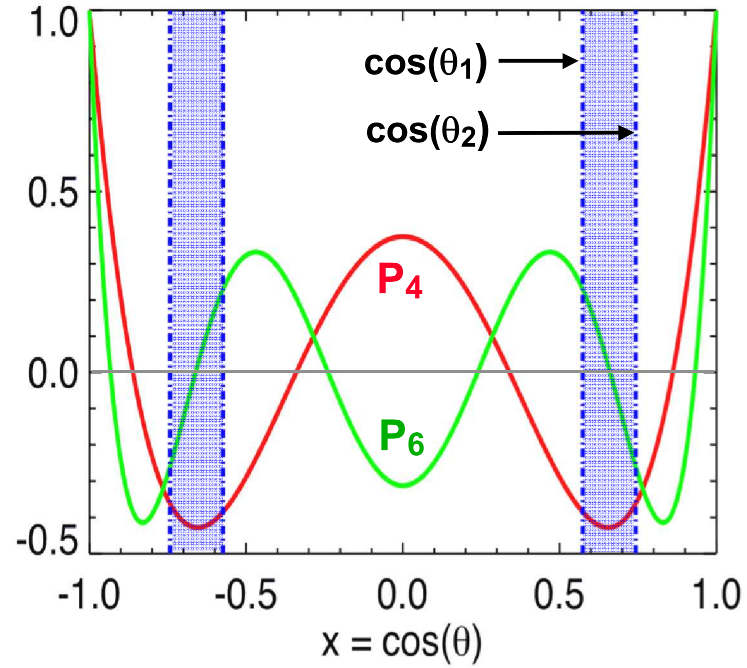
Specify zero P_6 content



$$x = \cos(\theta)$$

$$a_{6,shield} \propto \int_{-1}^{1} T(x) P_6(x)\, dx = 0$$

$$a_{4,shield} = \frac{9}{2} \int_{-1}^{1} T(x) P_4(x)\, dx > 0$$



Family of (θ_1,θ_2) solutions with P_4 effect $\propto \Delta\theta$

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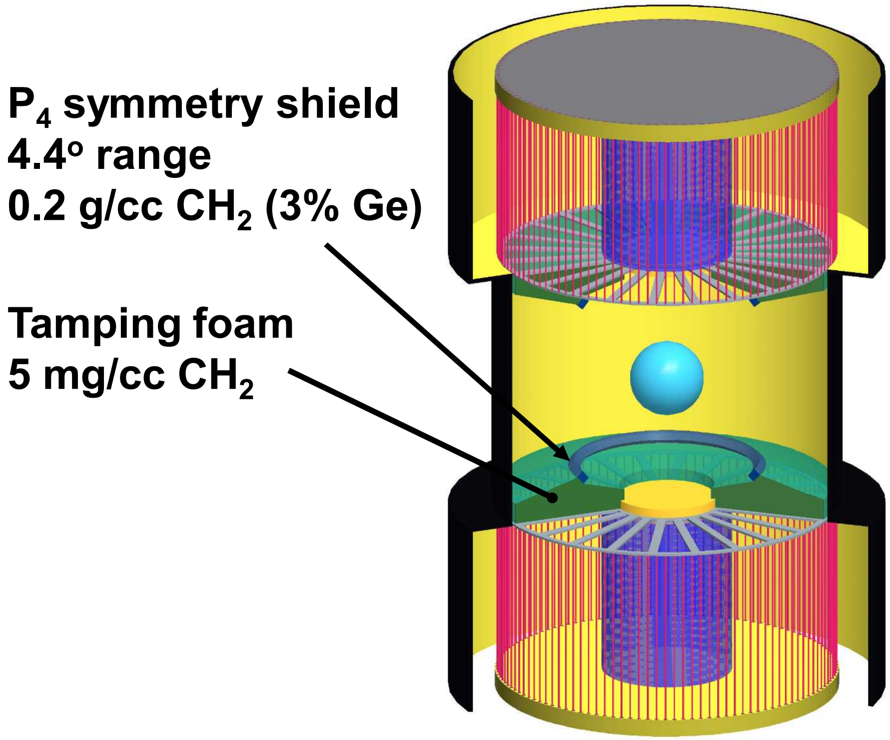
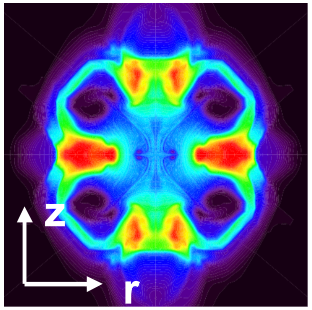
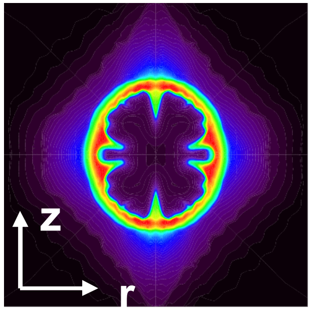
Mode-selective shields provided adequate symmetry control for 2D ignition & burn



Mode-selective shields minimize P_4 without enhancing P_6 or P_8





No structures	With P_4 shield
P_4 = -3.3%	P_4 = -0.5%
Yield = 0.040 MJ	Yield = 470 MJ

Result can be generalized to N shields to control 2N modes *in principle*

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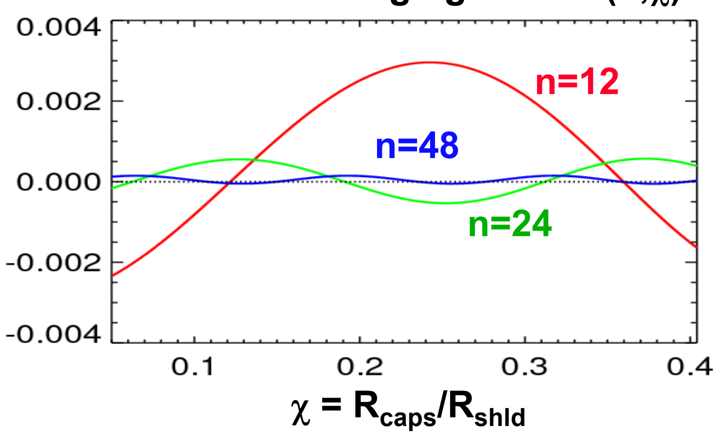
Geometric averaging reduces the effects of the inherent high-mode content of the shields

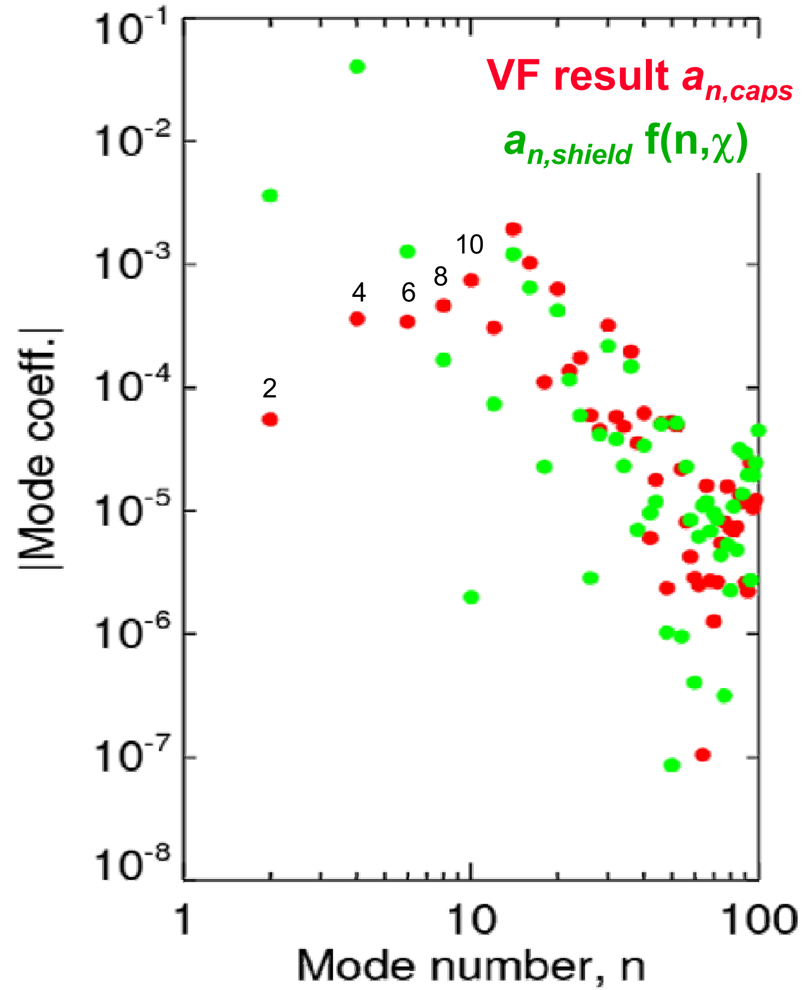
Example: applied asymmetry -5% P_4
Optimized shields minimize $P_{2,4,6,8,10}$
High resolution viewfactor result in red
Estimate $a_{n,shield}$*$f(n,R_{caps}/R_{shld})$ in green

Time-varying R_{caps}/R_{shld}
As capsule implodes, χ decreases
Time-averaged geometric averaging
reduces average $a_{n,caps}$ for most modes

Geometric averaging factor $f(n,\chi)$



Simple estimate is good for n>10



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