SAND2021-14143C

INLINE STUDY OF LOW-MODE ASYMMETRY INDUCED BY POLARIZED CROSS-BEAM ENERGY TRANSFER INTERACTION IN LASER-DIRECT-DRIVE SPHERICAL IMPLOSIONS ON OMEGA

APS-DPP 2021

SEP 29TH, 2021

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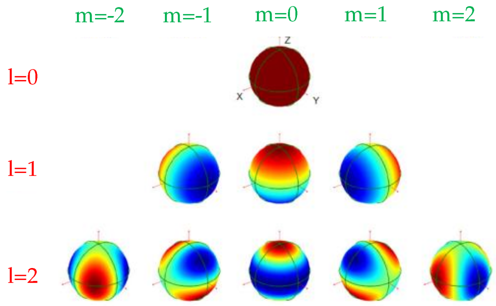
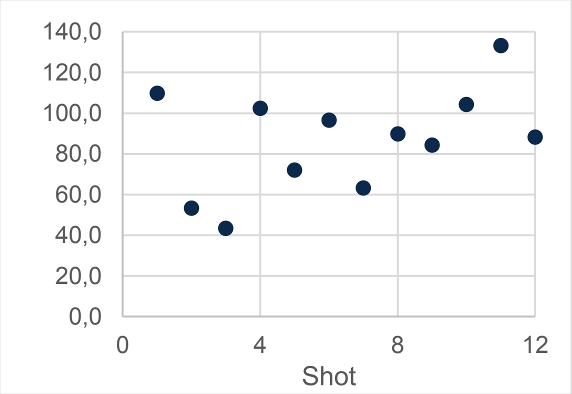
OMEGA EXPERIMENT IN THEIR BEST SETUP STILL EXHIBIT SIGNIFICANT FLOW ANOMALIES

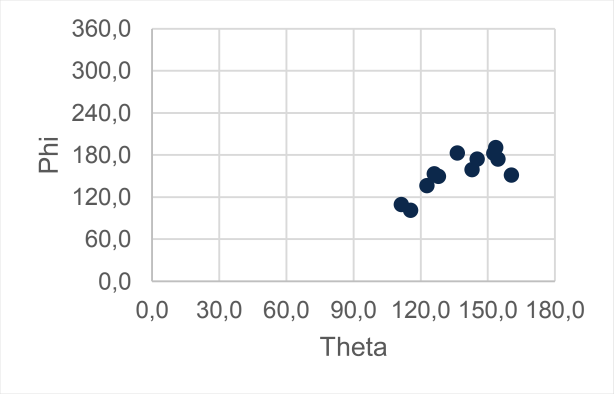
For 2019-2020 shots on OMEGA, selecting only shots with:
- good ice thickness uniformity
- good ice surface roughness
- low pointing error (<2% l=1, <2% l=2 to <1% l =1)
- low power imbalance
- low target offset (< 5 microns to < 1 micron)

… there remain a significant mode 1 assymetry in the DT flow at stagnation, that does not seem correlated to mispointing error

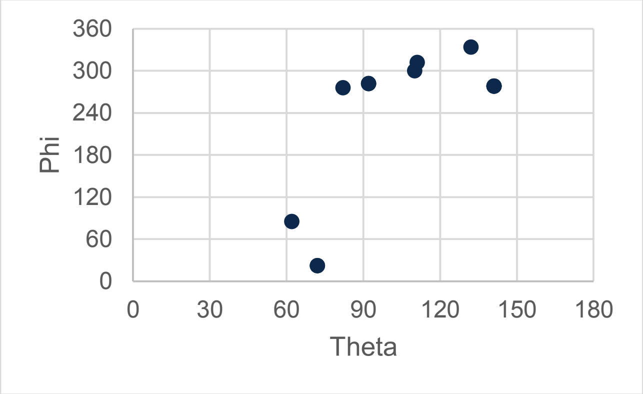




Flow velocity (km/s)



Flow direction



Mispointing L=1 orientation

[see S. Regan talk, CO04.00011]

MANY SOURCES OF LOW MODES CONTRIBUTE TO IMPLOSION DYNAMICS AND CAN COUMPOUND ON EACH OTHER

Chamber geometry

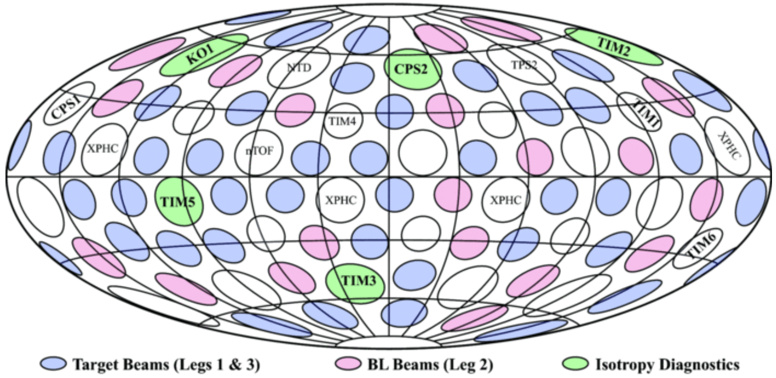
Pointing error

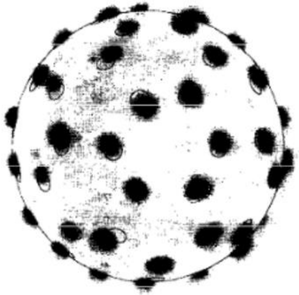
Beam balance

Target offset

Cross Beam Energy Transfer

Polarization effects





XPC H7 View

[M. Manuel et al. RSI 83 (2012)]
[T. R. Boehly et al. Opt Com 133 (1997)]

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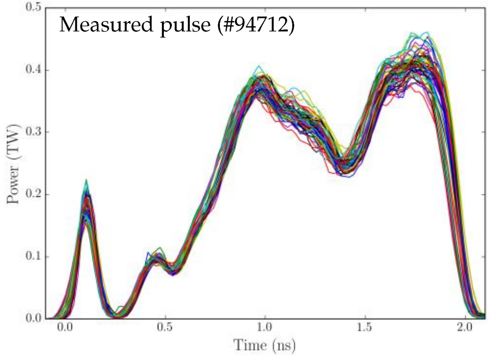
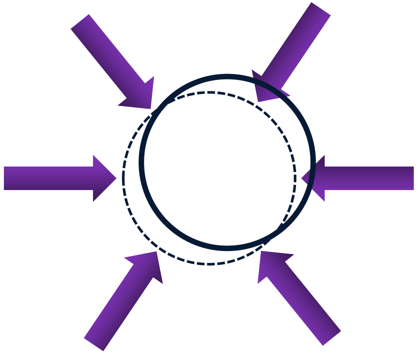


Typically in the 2-3% level



Ranging from 0 (ideal) to ~ 40 microns (bad performance)

MANY SOURCES OF LOW MODES CONTRIBUTE TO IMPLOSION DYNAMICS AND CAN COUMPOUND ON EACH OTHER

Chamber geometry

Pointing error

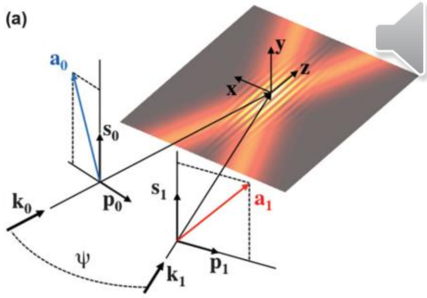
Beam balance

Target offset

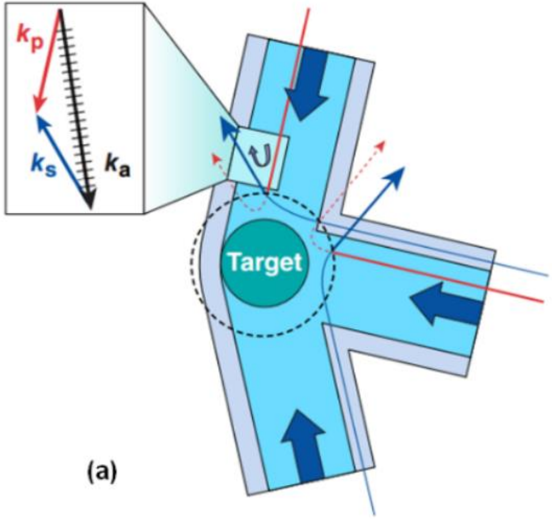
Cross Beam Energy Transfer

Polarization effects

Cross Beam Energy Transfer (CBET) transfers energy between beams through a shared IAW grating



[P. Michel et al. PoP 17 (2010)]



[A. K. Davis et al. PoP (2016)]

In direct-drive, reflected beams “steal” energy from incident beams

If the laser configuration is **perfectly symetric**, the unpolarized CBET also remains symmetric

MANY SOURCES OF LOW MODES CONTRIBUTE TO IMPLOSION DYNAMICS AND CAN COUMPOUND ON EACH OTHER

Chamber geometry

Pointing error

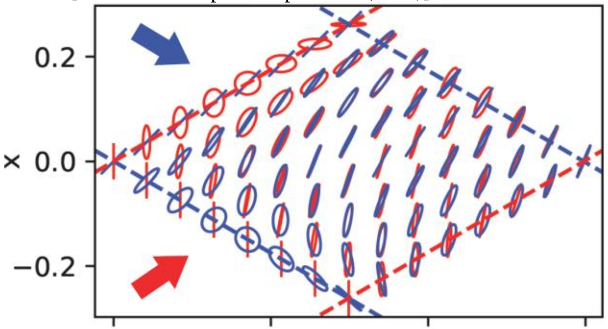
Beam balance

Target offset

Cross Beam Energy Transfer

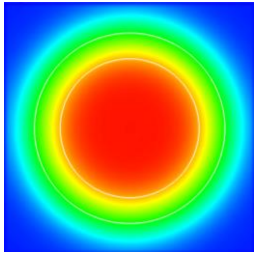
Polarization effects

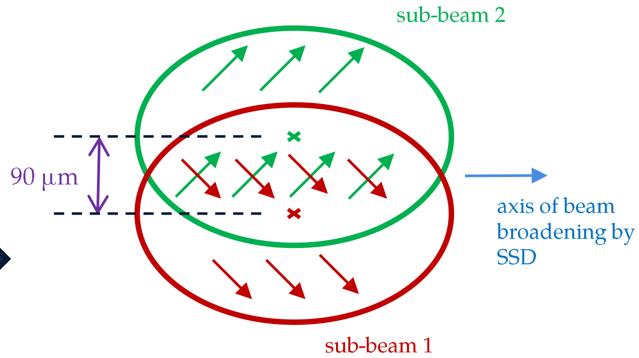
[E. Kur et al. Optics Express 29 (2021)]



CBET:
- is sensitive to the polarization of the crossing beams
- rotates the polarization of the seed towards that of the pump
- induces ellipticity in the polarizations through the IAW grating

"Average" symmetric SG5 beam usually modeled, accounting for SSD broadening and DPR separation





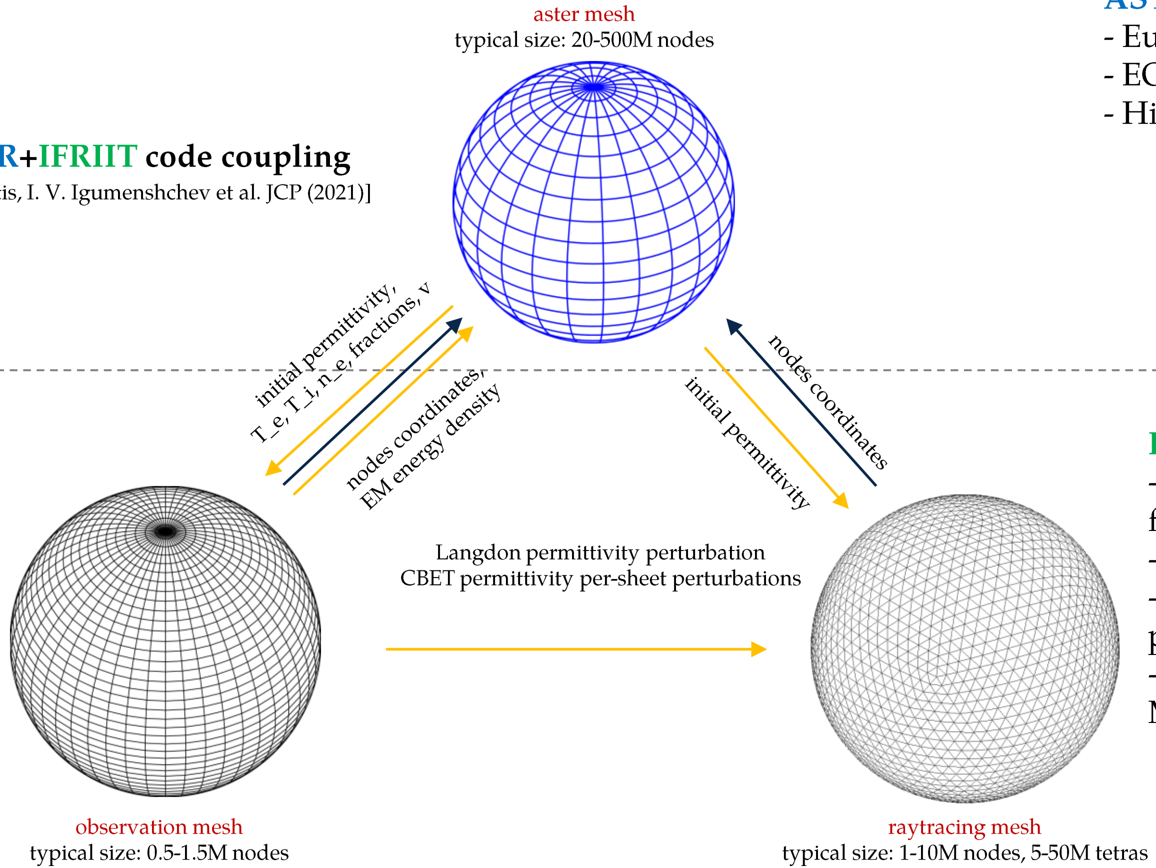
Real configuration

- The DPR system splits the SSD-smoothed elliptical beam into two sub-beams (1 & 2) with orthogonal polarization and 90 μm offset, resulting in non-uniform polarization mixing and slight non-roundness
- For collisional absorption or unpolarized CBET, the use of the detailed spot only introduces low level of medium L modes (2-25) that do not change yield nor induce significant stagnation flow

COMPLETE MODELING OF OMEGA IMPLOSIONS ARE CARRIED OUT WITH THE ASTER+IFRIIT COUPLED CODE

ASTER+IFRIIT code coupling

[A. Colaïtis, I. V. Igumenshchev et al. JCP (2021)]



ASTER 3-D radiative hydrodynamics code
- Eulieran spherical moving grid
- EOS, heat transport, radiation, hydro…
- High resolution, block-decomposed MPI

[I. V. Igumenshchev et al. PoP (2016),
I. V. Igumenshchev et al. PoP (2017)]

IFRIIT 3-D laser propagation code
- Inverse Ray Tracing for fast and low noise field computations
- Caustic modeling with Etalon Integrals
- CBET with many physics models, including polarization
- Adaptive resolution, domain-duplicated MPI/OpenMP

[A. Colaïtis et al., PoP 26(3) (2019),
A. Colaïtis et al., PoP 26(7) (2019)]

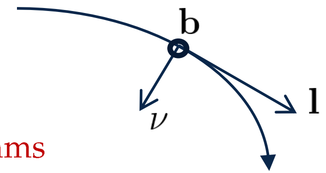
IFRIIT IMPLEMENTS THE FIRST 3D POLARIZED CBET CODE THAT CAN BE RUN INLINE

Unpolarized CBET
- Track the incident and reflected field of each beam
- Use an angle-dependant "unpolarized" coefficient for the interaction

Polarized CBET
- Transport the s/p basis of the rays that rotates due to refraction
- Track 2 complex polarizations for both the incident and reflected components of each beam
- For DPR modeling: split each beam into two sub-beams

CBET coefficients: 60 beams x 2 fields x N_gridpoints => CBET coefficients: 60 beams x 2 fields x 2 sub-beams x 2 components x 2 x N_gridpoints

Frenet reference frame



$$K = |\nabla n/n \times \mathbf{l}|$$

$$b = (1/K)\mathbf{l} \times \nabla n/n$$

$$\mathbf{b} = \mathbf{l} \times \nu$$

Complex s/p components in the Frenet frame

Sum over all incident/reflected fields of all sub-beams

$$\partial_{l_n} \begin{pmatrix} a_{n,\nu_n} \\ a_{n,b_n} \end{pmatrix} = \sum_{m=1,m\neq n}^{N} (\imath/(8k_n))K^{\star}_{nm}k^2_{bnm}.M_{mn} \begin{pmatrix} a_{n,\nu_n} \\ a_{n,b_n} \end{pmatrix}$$

Complex kinetic plasma response
Langdon and Dewandre effect
Real part: induces ellipticity
Imaginary part: depletion or gain

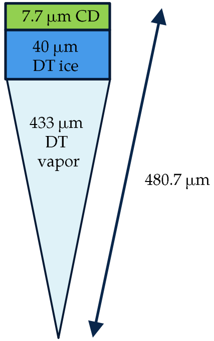
$$M_{mn} = \begin{pmatrix} a^2_{m,\nu_n} & a^{\star}_{m,b_n}a_{m,\nu_n} \\ a_{m,b_n}a^{\star}_{m,\nu_n} & a^2_{m,b_n} \end{pmatrix}$$

Matrix responsible for polarization rotation and ellipticity

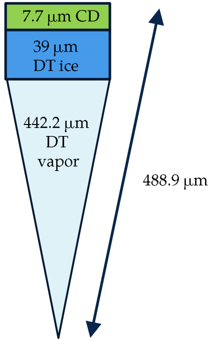
The Polarized CBET code was validated against BeamletCrosser*

*[D. Edgell, LLE]

TWO CRYOGENIC SHOTS WERE CONSIDERED TO ASSESS THE EFFECTS OF LOW MODES ON IMPLOSIONS



Cryo Shot 94712
Offset: ~ 7 µm*
Pointing: 7% mode l = 1
Measured hot-spot velocity: 146.3 km/s



Cryo Shot 94343
Offset: 3.5 µm +/- 2.2 µm
Pointing: 1.7% mode l=1
Measured hot-spot velocity: 109.8 km/s

We studied two cryo shots:
- shot 94712 with bad pointing
- shot 94343 with good pointing, low offset and low beam imbalance

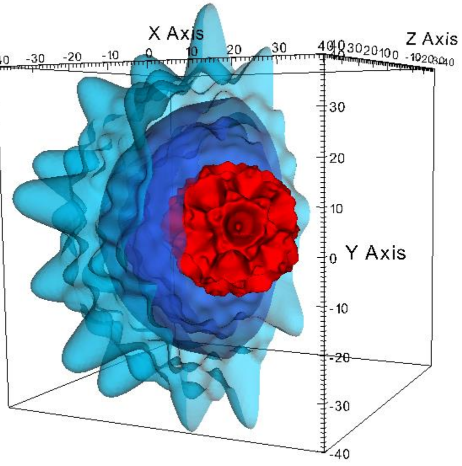
All simulations use kinetic plasma response for IAW, no saturation clamp, no CBET multiplier
All simulations use 15% flux limitation in picket, and no limitation in rest of the pulse

*degraded data from 30s before shot with 45kg preload on the shroud

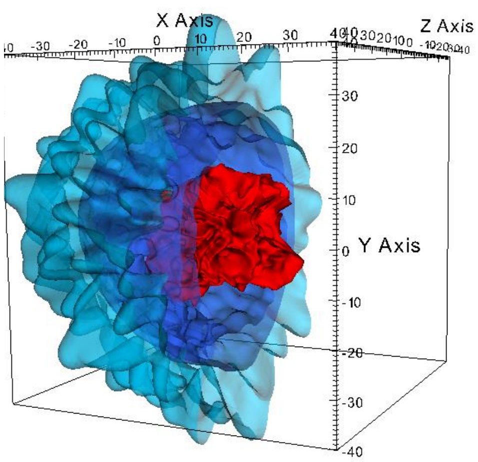
IN THE ABSENCE OF CBET, THE BEST POINTING/BALANCE PERFORMANCES STILL PRODUCE HIGH FLOWS AND LOW YIELD COMPARED TO IDEAL

Cryo shot #94343

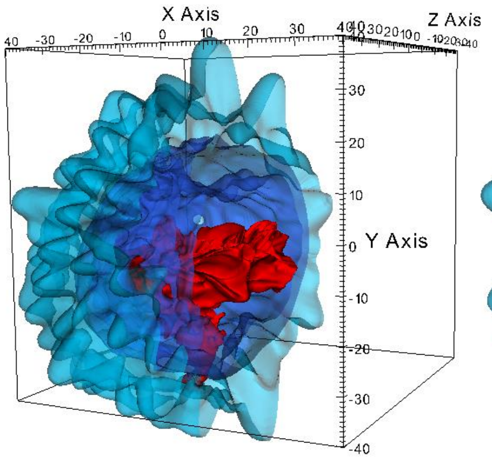
10 g/cc isocontour 50 g/cc isocontour 50/50 DT ice/gas interface



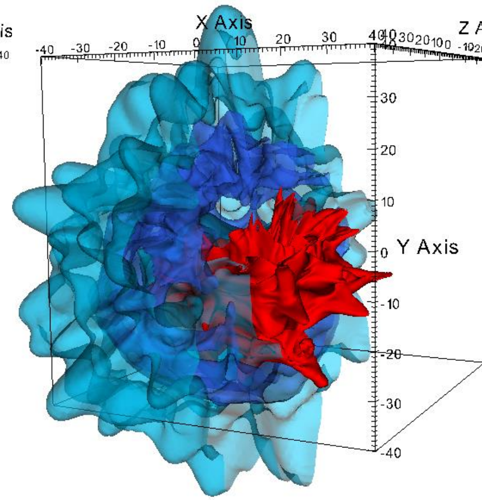
<u>No CBET</u>
Ideal Pointing
Ideal Balance
No Offset
$\text{Yield}_{\text{ideal}}$= 7.72e14
Flow vel. = 0.37 km/s



<u>No CBET</u>
Ideal Pointing
Real Balance
No Offset
Yield = 6.17e14
= 80% $\text{Yield}_{\text{ideal}}$
Flow vel. = 78.48 km/s



<u>No CBET</u>
Real Pointing
Real Balance
No Offset
Yield = 3.41e14
= 44% $\text{Yield}_{\text{ideal}}$
Flow vel. = 171.6 km/s

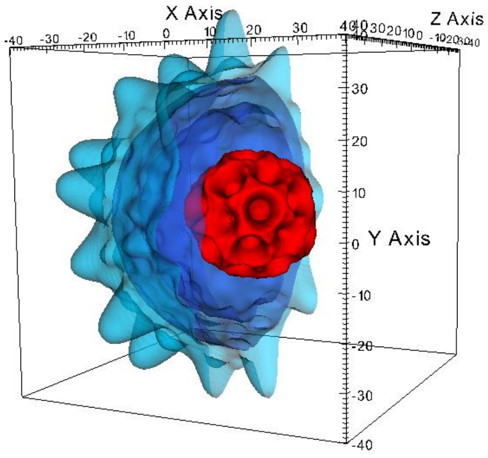


<u>No CBET</u>
Real Pointing
Real Balance
3.5μm offset
Yield = 2.22e14
= 29% $\text{Yield}_{\text{ideal}}$
Flow vel. = 156.6 km/s

- If we could mitigate CBET perfectly, current levels of pointing and balance errors still produce a yield of 29% of ideal

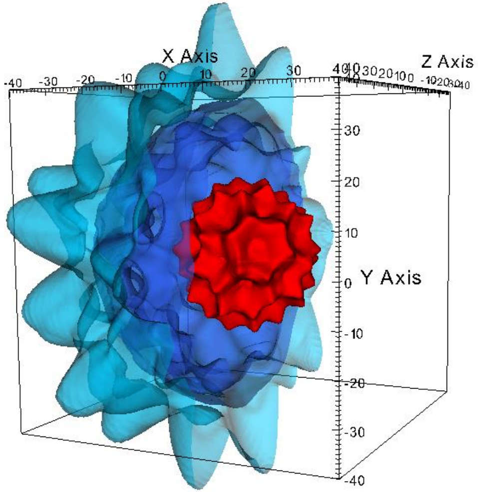
IN THE IDEAL CASE, POLARIZED CBET DOES INDUCE A SIGNIFICANT FLOW AND YIELD DECREASE COMPARED TO UNPOLARIZED CBET

Cryo shot #94712

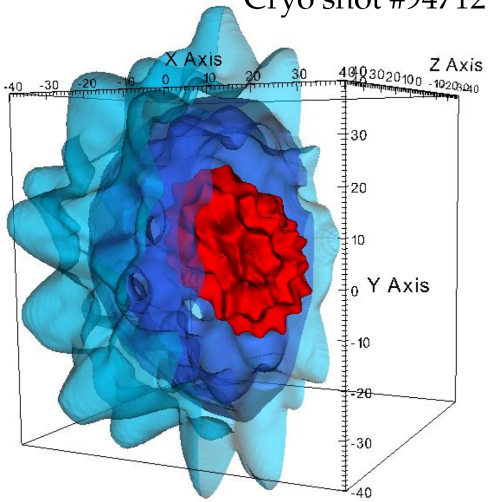


No CBET
Ideal Pointing
Ideal Balance
$\text{Yield}_{ideal} = 10.e14$

Absorption frac. = 86.6%
Flow vel. = 0.37 km/s



Unpolarized CBET
Ideal Pointing
Ideal Balance
Yield = 3.58e14
$= 36\%\ \text{Yield}_{ideal}$
Absorption frac. = 72.3%
Flow vel. = 1.18 km/s

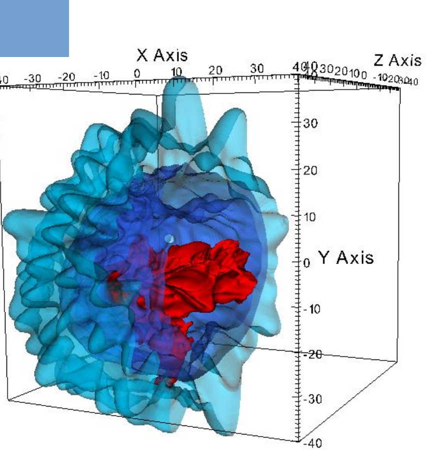


Polarized CBET
Ideal Pointing
Ideal Balance
Yield = 3.02e14
$= 30\%\ \text{Yield}_{ideal}$
Absorption frac. = 71.6%
Flow vel. = 86.9 km/s

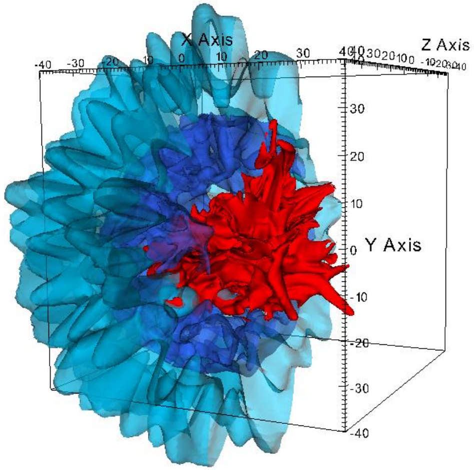
Yield decrease due to unpolarized CBET comes from loss of coupling. Flow comes from the DPR configuration.
Polarized CBET induces a mucher stronger low mode and significant velocity at stagnation
Compared to unpolarized CBET, the polarized CBET interaction with ideal conditions degrades the yield by 17%

IN PRESENCE OF POINTING AND BALANCE ERRORS, CBET DOES NOT SIGNIFICANTLY CHANGE FLOW OR YIELD

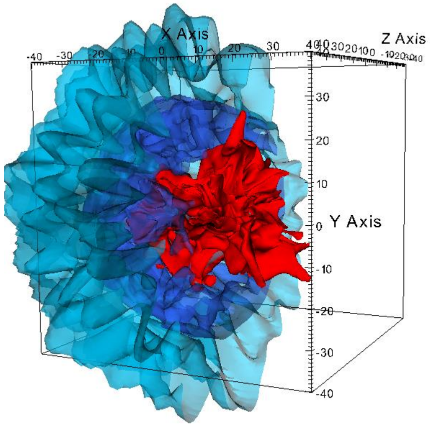
Cryo shot #94343



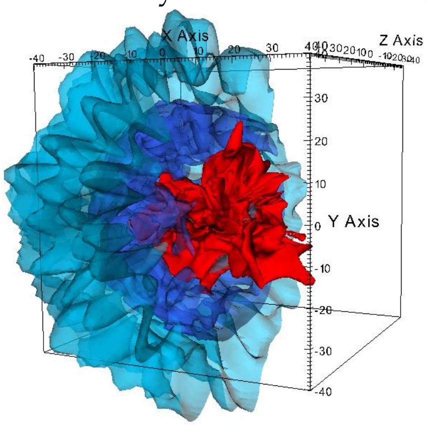
<u>No CBET</u>
Real Pointing
Real Balance
No Offset
Yield_{real} = 3.41e14
Flow vel. = 171.6 km/s



<u>Unpolarized CBET</u>
Real Pointing
Real Balance
No Offset
Yield = 1.74e14
= 51% Yield_{real}
Flow vel. = 96.35 km/s



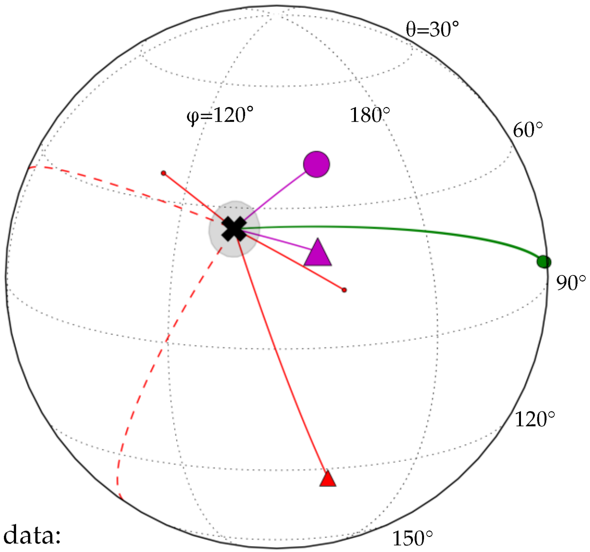
<u>Polarized CBET</u>
Real Pointing
Real Balance
No Offset
Yield = 1.54e14
= 45% Yield_{real}
Flow vel. = 110 km/s



<u>Polarized CBET</u>
Real Pointing
Real Balance
3.5μm offset
Yield = 1.51e14
= 44% Yield_{real}
Flow vel. = 114 km/s

- CBET mitigates the effect of pointing and balance, reducing significantly the flow velocity
- Yield goes down because of decreased coupling
- Polarized CBET L=1 mode is comparable to already existing modes (flow direction does change)
- The level of offset for that shot does not modify flow/yield

FOR THE POINTING-ERROR DOMINATED SHOT #94712, THERE IS GOOD AGREEMENT BETWEEN THE FULL MODELING AND THE DATA



94712 data:
Offset: ~ 7 µm (not simulated for 94712)
Pointing: 7% mode l = 1

DT flow direction as measured from neutron data

Ideal balance and pointing
Real balance
Real balance and real pointing

o unpolarized CBET model
Δ polarized CBET model
⋆ no CBET

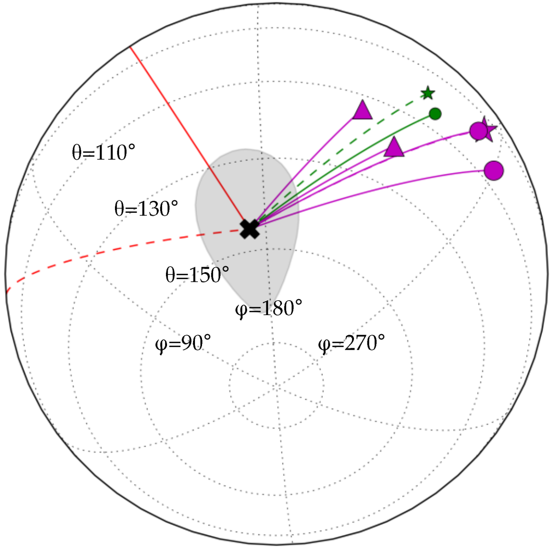
— with CBET
- - - without CBET

Symbol size ∝ flow velocity
Grey shade: error bar

- Angular anomaly dominated by **pointing**
- Closest point is polarized CBET with real balance and pointing (18° angular distance)
- Fuel aging (not modeled), is estimated to account for another 30% drop in yield
- Small-scale mixing may account for the remaining yield degradation

case	abs frac	peak neutron rise (ps)	yield (1e14) DT neutrons	l=1 areal mass mod. at stag. (microns)	final integrated flow velocity (km/s)	final integrated flow polar direction (°)	final integrated flow azimuthal direction (°)	Angular distance to measurement (°)
polarized CBET + DPR	71.1%	2107	1.51	4.28	168.2	69.4	152.9	18
data	N.A.	2081 +/- 50	0.77 +/- 0.054	N.A.	146.3 +/- 12	64.6 +/- 7	133.6 +/- 5	0

FOR THE BEST SETUP SHOT #94343, A DISAGREEMENT REMAINS IN TERM OF DT FLOW DIRECTION, ALL ELSE BEING IN GOOD AGREEMENT



DT flow direction as measured from neutron data

Ideal balance and pointing
Real balance
Real balance and real pointing

o unpolarized CBET model
Δ polarized CBET model
⋆ no CBET

— with CBET
- - - without CBET

Symbol size ∝ flow velocity
Grey shade: error bar

- Balance and pointing induce similar flow directions
- Both pointing and balance contribute to flow velocity (here constructively)
- Closest point is still the polarized CBET case with full input
- Pointing can drift during a shot day by 90°, which may explain the remaining discrepancy

94343 data:
Offset: ~ 3.5 µm
Pointing: 1.7% mode l = 1

case	abs frac	peak neutron rise (ps)	yield (1e14) DT neutrons	l=1 areal mass mod. at stag. (microns)	final integrated flow velocity (km/s)	final integrated flow polar direction (°)	final integrated flow azimuthal direction (°)	Angular distance to measurement (°)
polarized CBET + DPR	73.5	2219	1.54	0.44	110.1	114	204.3	38
data	N.A. ?	2213 +/- 50	0.746 +/- 0.052	N.A.	109.8 +/- 15	145.3 +/- 18	174 +/- 18	0

SUMMARY

- OMEGA implosions in their “best setup” exhibit significant mode 1 flow anomaly at stagnation*

- We have conducted full 3-D inline radiative hydrodynamics calculations with the ASTER+IFRIIT code, including many sources of low mode assymetry

- The study highlights that:
  1. In ideal conditions, Polarized CBET** alone induces flows up to 90 km/s and reduces yield by 15% compared to unpolarized CBET
  2. In a shot with “best setup” for pointing, imbalance and offset errors;
     i. Without CBET, yield is 29% of that of the ideal situation (without errors)
     ii. Polarized CBET has a same order of magnitude contribution to flow anomaly compared to the other sources of errors

- Simulations with measured pointing, imbalance and offset errors with polarized CBET match the data for bang time, flow velocity magnitude, and are close to reproduce the flow direction, for which pointing drift is thought to be responsible for the remaining discrepancy

[*see S. Regan talk, CO04.00011] [**see D. Edgell talk, ZI02.00005]