INERTIAL FUSION ENERGY SUMMARY

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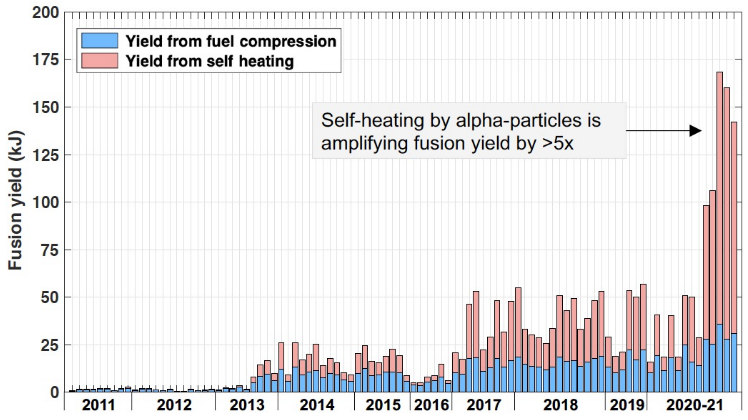
Laboratoire pour l'Utilisation des Lasers Intenses

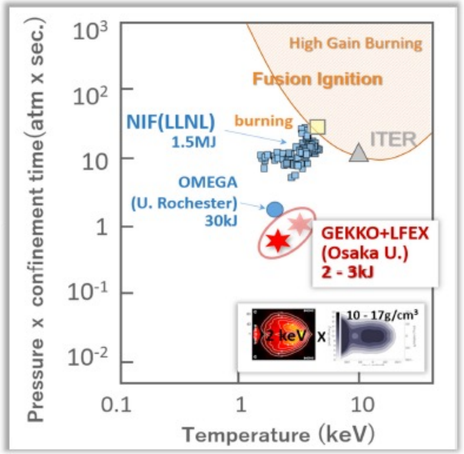
IAEA Fusion Energy Conference 2020

Significant progresses toward ignition are being made across ignition schemes

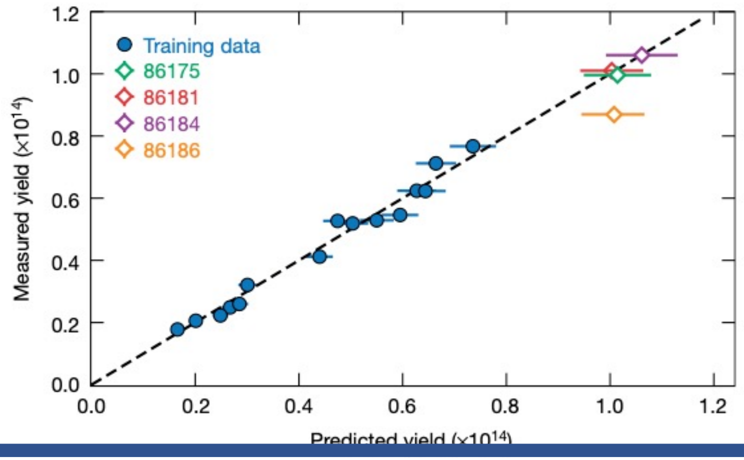
Indirect drive



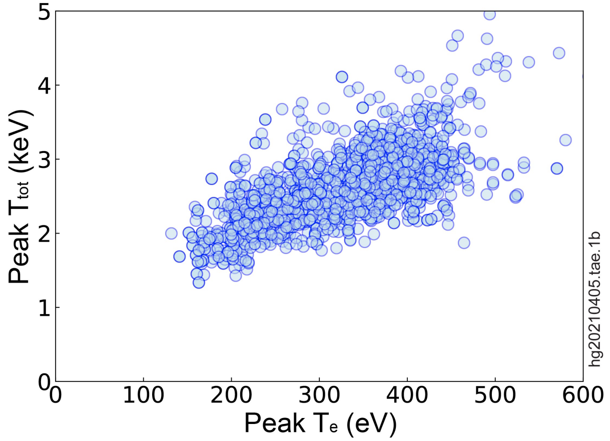
Fast Ignition



Direct drive



Beam driven FRC plasma



Significant progresses toward ignition are being made across ignition schemes

Indirect drive

increase energy coupling to the capsule using new hohlraums geometry and « old tricks »

- rugby hohlraums
- low gas fill hohlraums + CBET
- Iraums

Fast Ignition

Improve capsule stability and electron beam divergence

- External B field
- Solid capsule
- Improved laser contrast

Direct drive

Optimized shock sequence and target thickness using statistical approach

Gopalaswamy, IFE/P1-6

Beam driven FRC plasma

Advanced plasma and machine optimizations, through:

- Optometrist Algorithm utilization (human + AI)
- sophisticated active plasma controls on magnets, edge biasing, beams, and gas fueling.

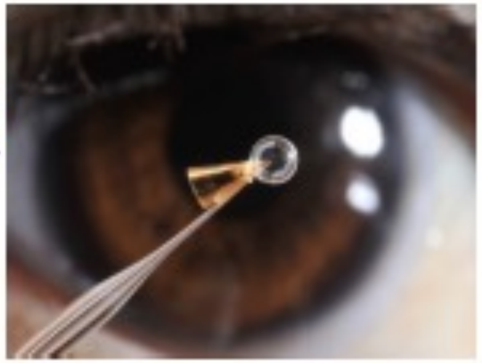
Fast Ignition

2022-2026 For the Next 50 YEARS

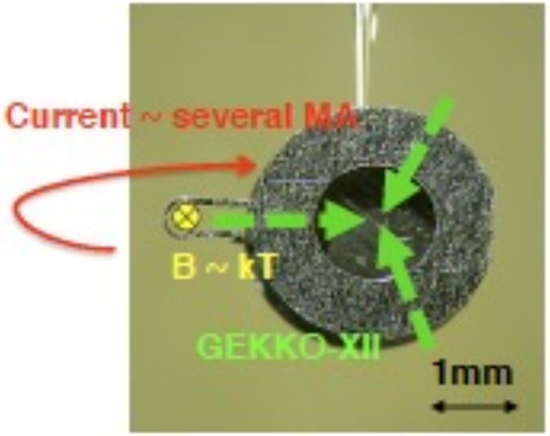
大阪大学
OSAKA UNIVERSITY

Innovative approaches to the FI schemes is proving successful

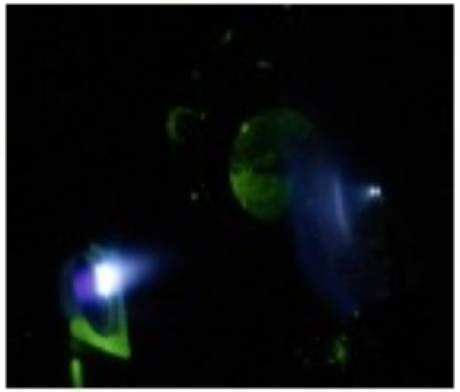
Guiding cone
for laser-absorption
R. Kodama+, Nature 2004.



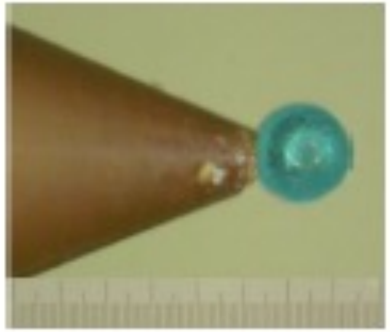
Capacitor-coil
for REB manipulation
S. Fujioka+, Sci. Rep. 2013.



Plasma mirror
for cooling REB
Y. Arikawa+, Appl. Opt. 2016.



Solid ball
for stable fuel compression
S. Fujioka+, Phys. Rev. E, 2015.

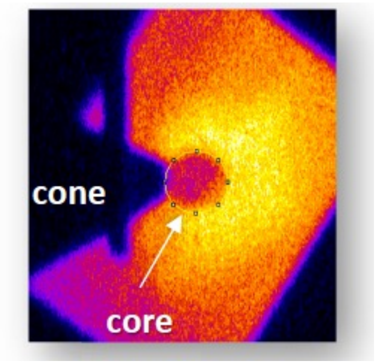


Realization of efficient plasma heating to Peta-Pascal level

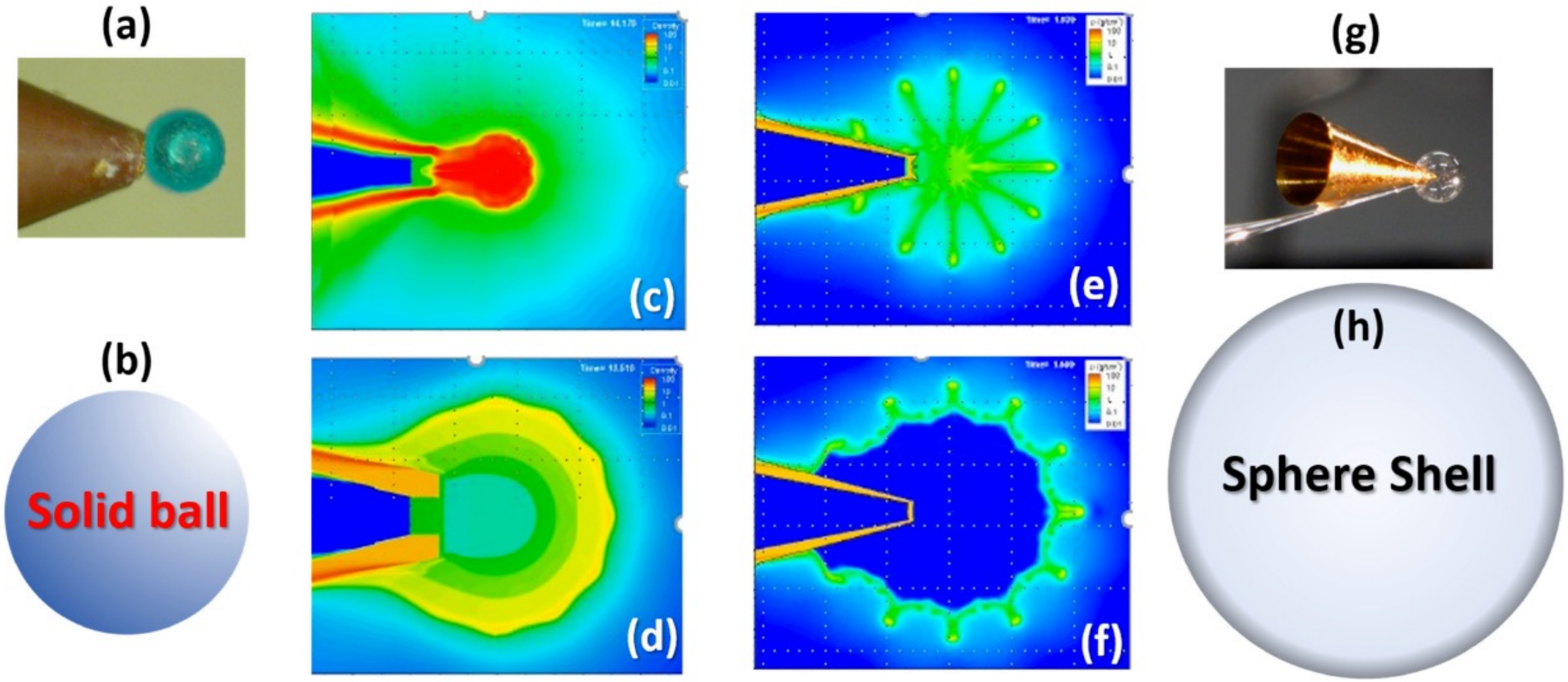
Fujioka, IFE/P1-9

Hydrodynamic instabilities growth can be controlled using a solid sphere

2D Hydro simulations

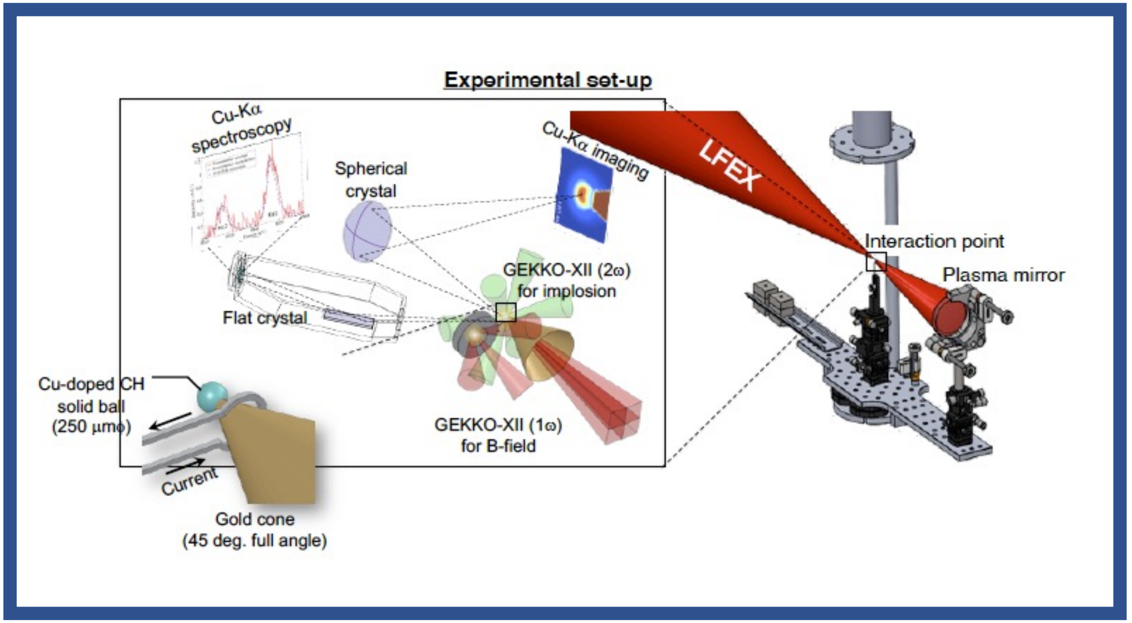


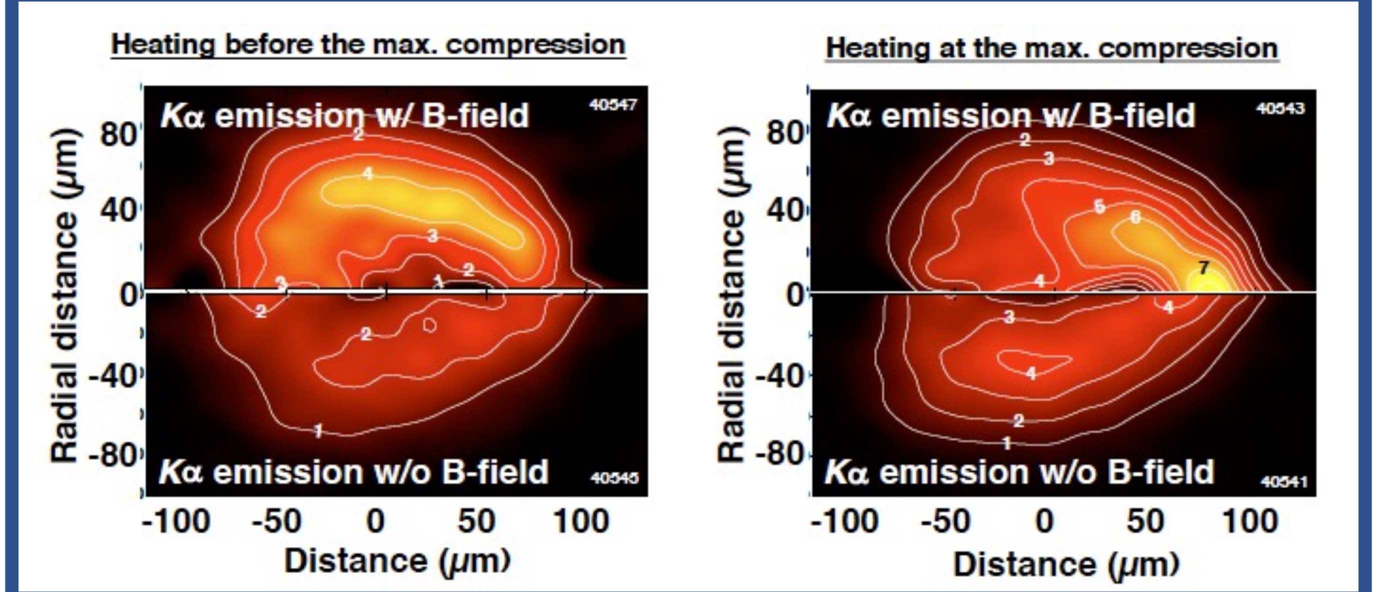
X ray radiography of solid sphere @ omega

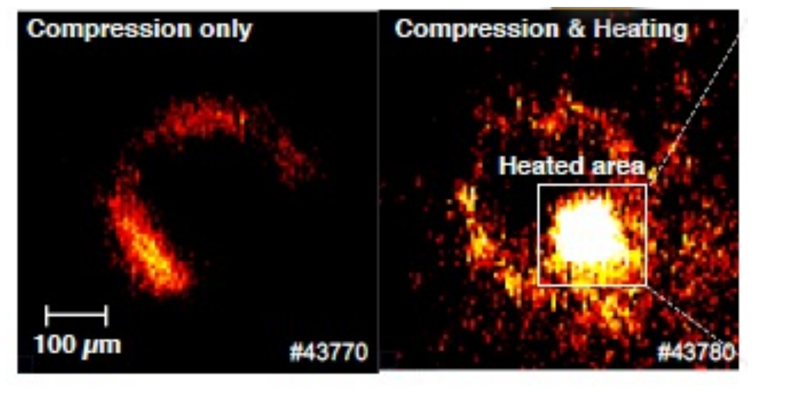


Kodama, IFE/1-1

External magnetic field improved electron coupling to the core



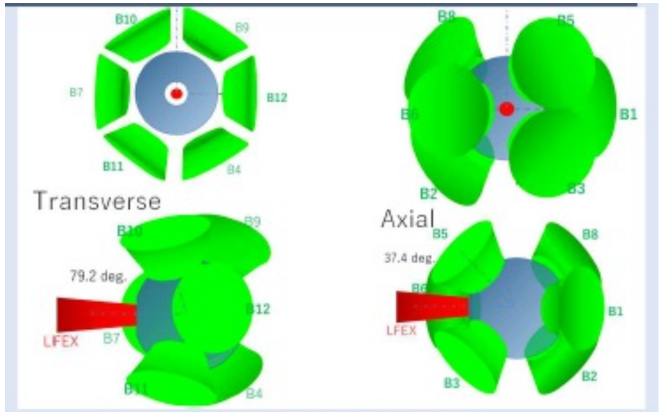




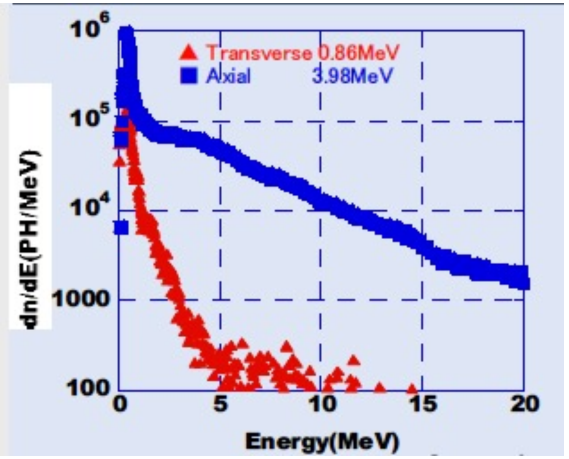
Fujioka, IFE/P1-9

Hot electron spectra can be optimized for coupling resulting in a 2-3 increase in heating

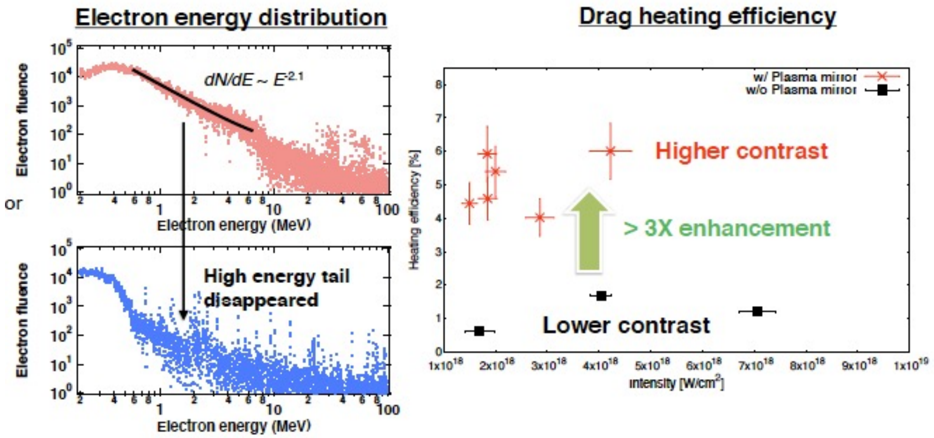
Reduced plasma blow off

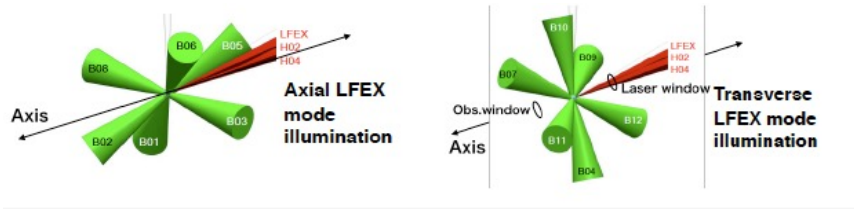


Irradiation arrangement

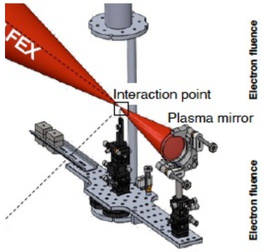


Higher laser contrast



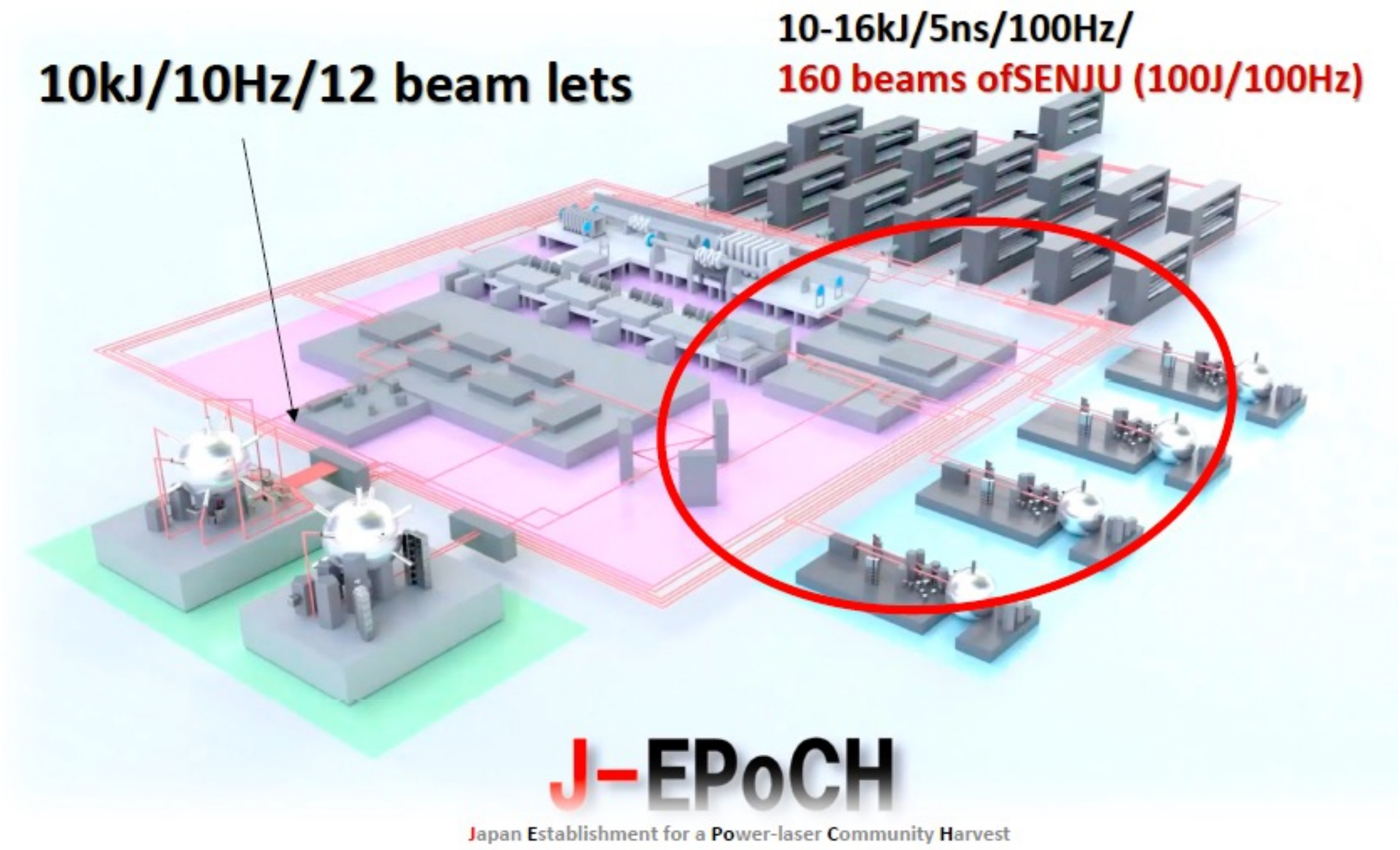


Ozaki, IFE/P1-14 Kitagawa, IFE/P1-15

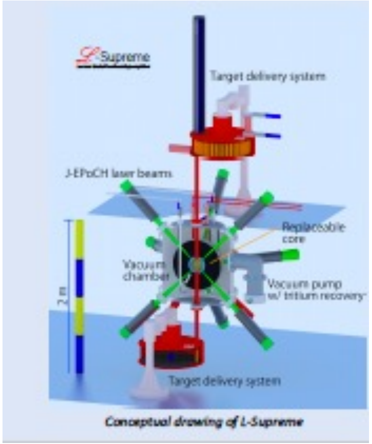


Fujioka, IFE/P1-9

Japan is thinking about the futur IFE fusion reactor

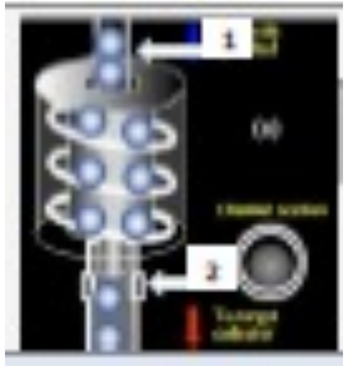


Kodama, IFE/1-1 Kawanaka, IFE/1-3



Design of sub-critical research reactor

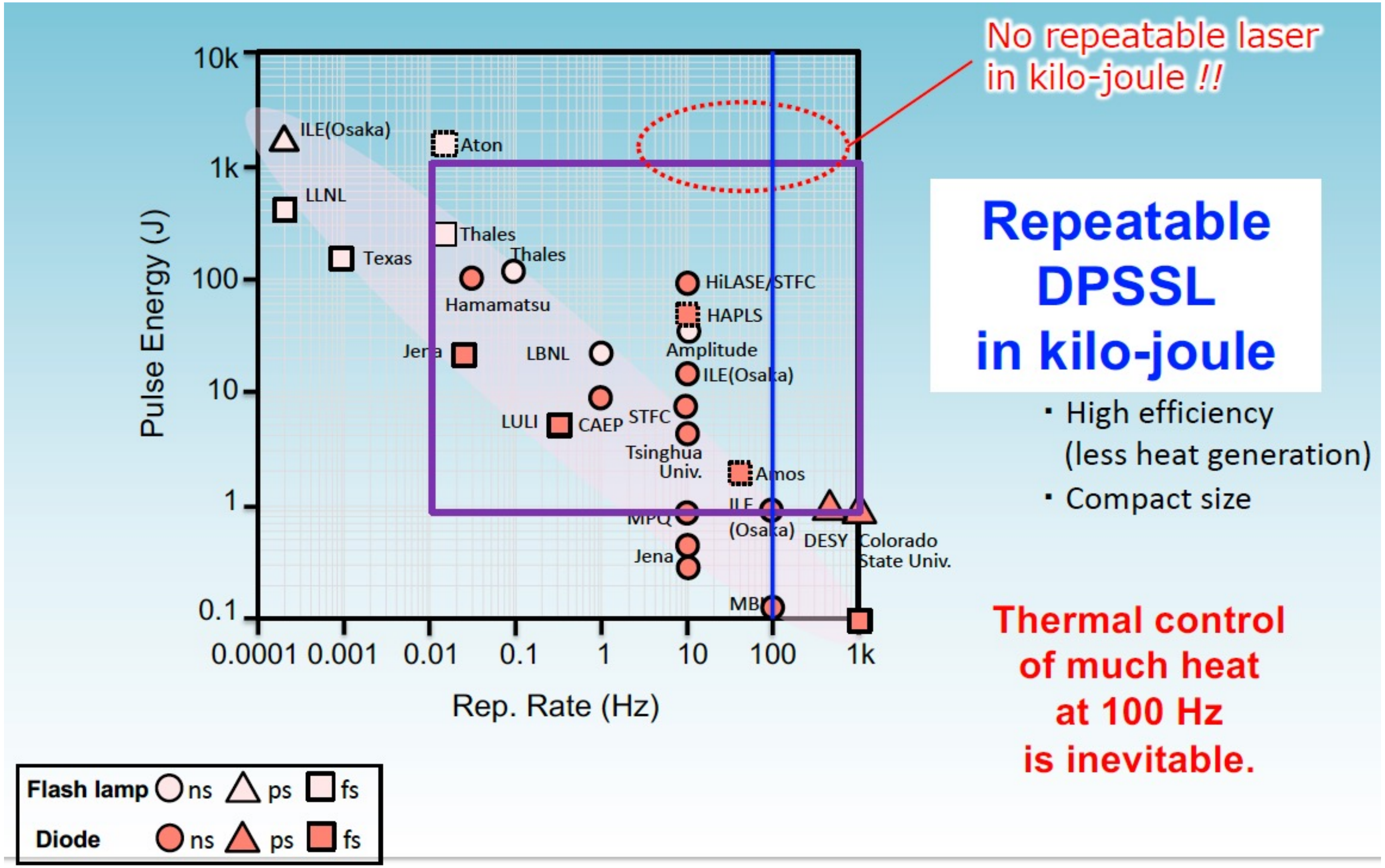
Iwamoto IFE/P4-17



Advanced target facility

Aleksandrova, IFE 1540

The challenge is to design a high rape rate kJ laser

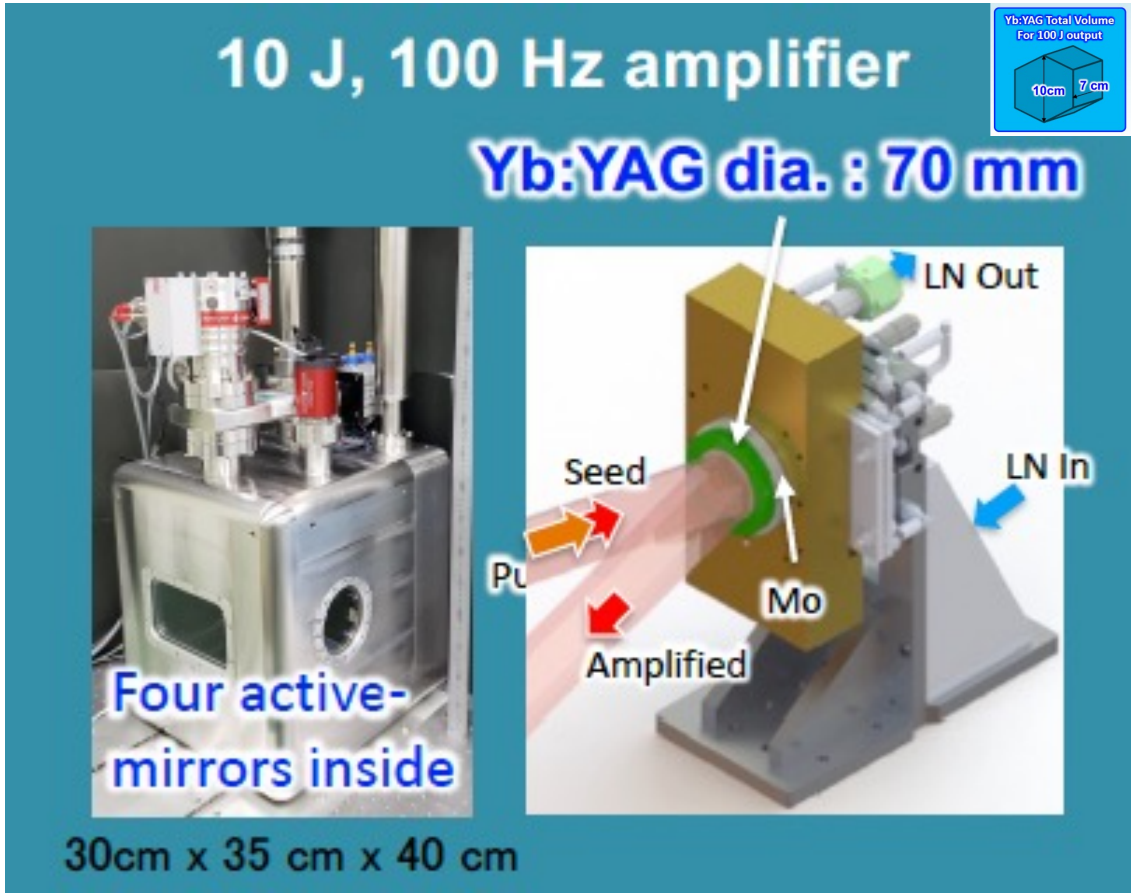


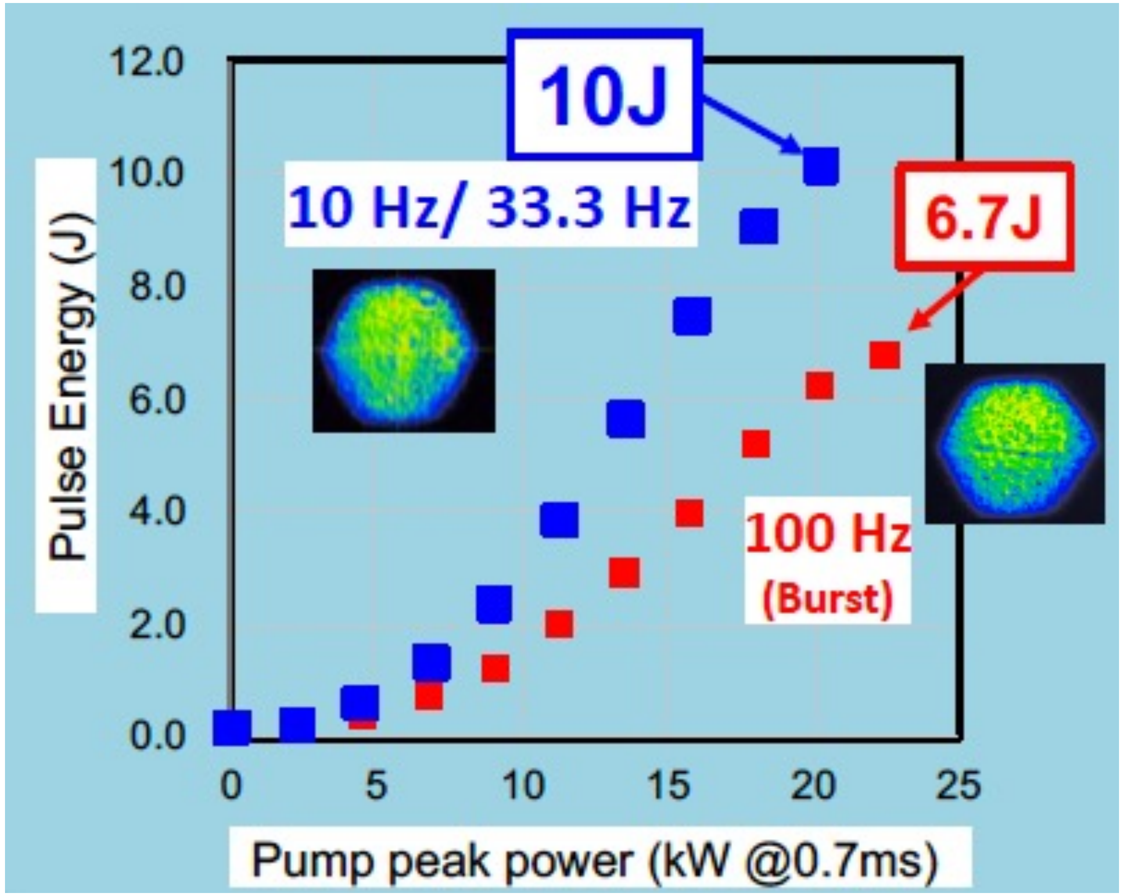
At 100 Hz, much heat induces strong internal stress in the laser materials.

- Wavefront distortion
- Birefringence

Kawanaka, IFE/1-3

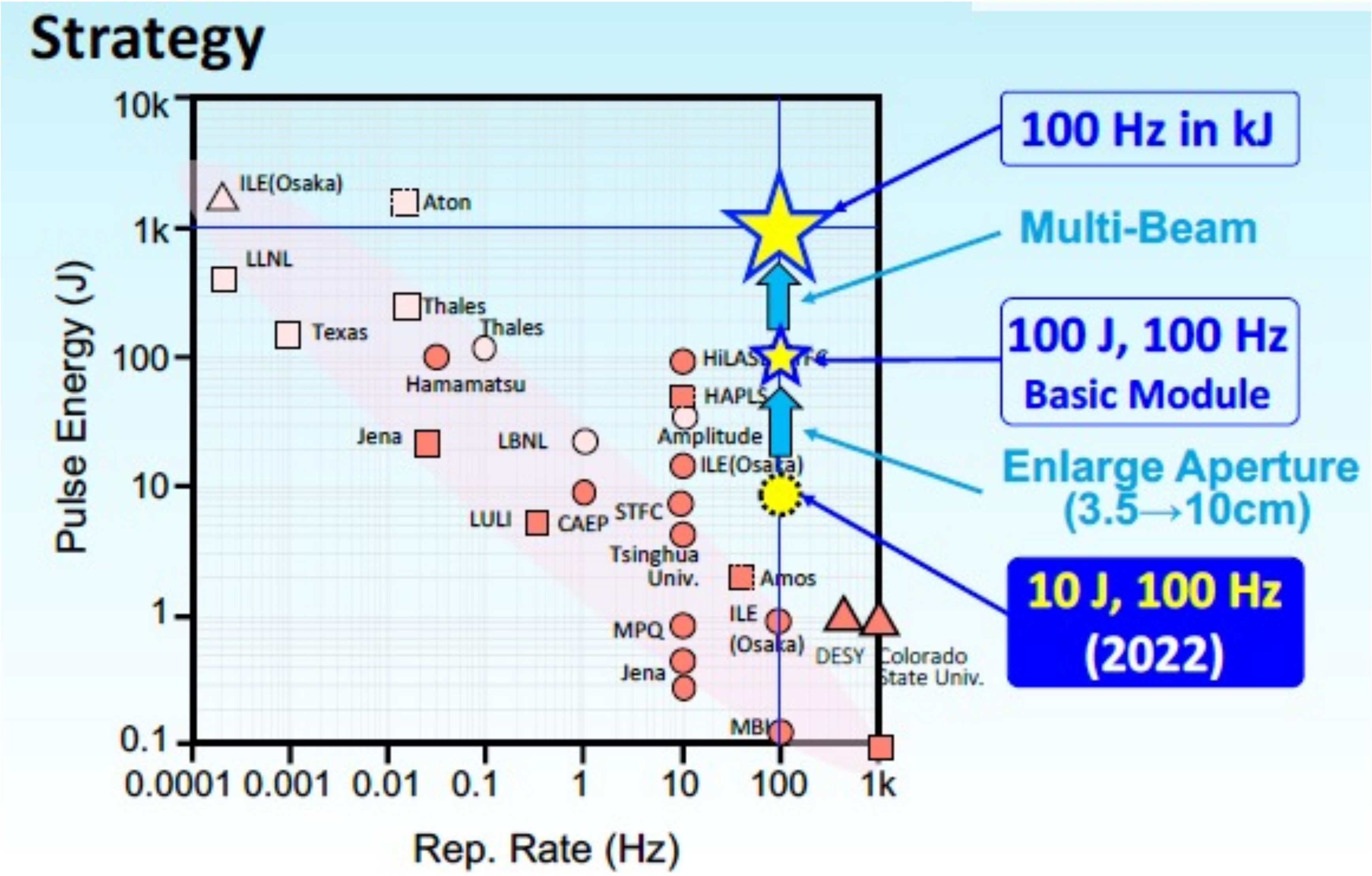
The use of cryogenic Yb:YAG coupled with active mirrors results in 10J @ 10 Hz





Kawanaka, IFE/1-3

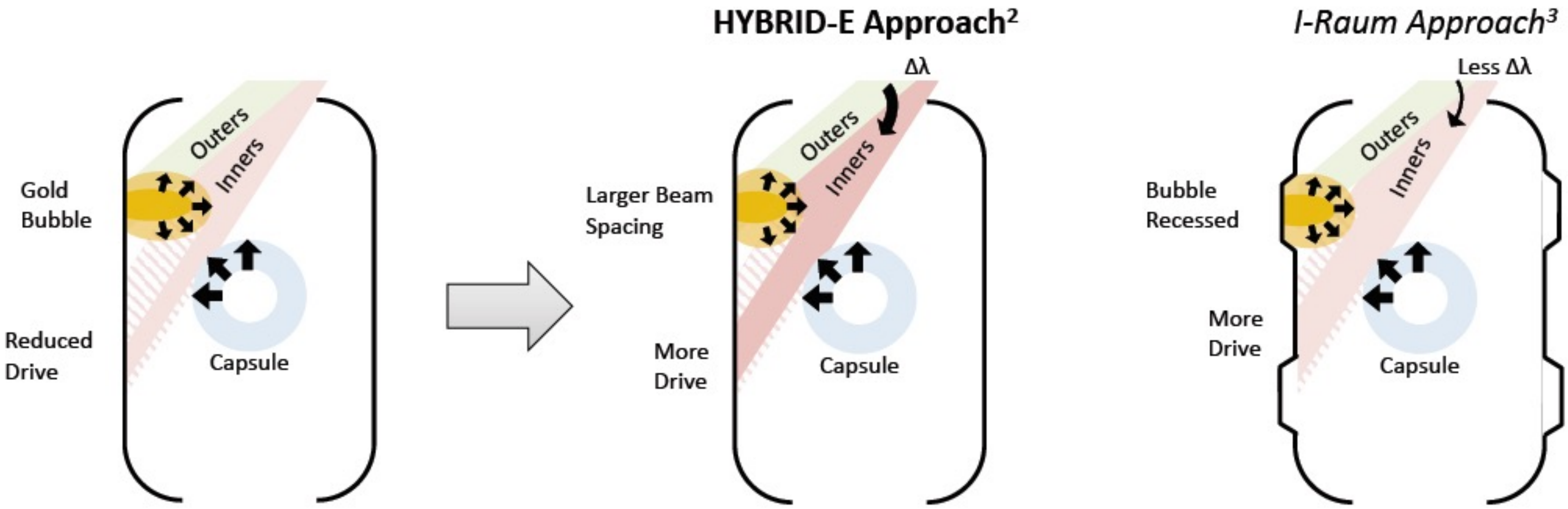
Raodmap to a kJ high rape rate laser



Kawanaka, IFE/1-3

Indirect Drive Ignition

The goal is to increase hohlraum to capsule coupling -> increase capsule size by 15 to 20 % with similar hohlraum size

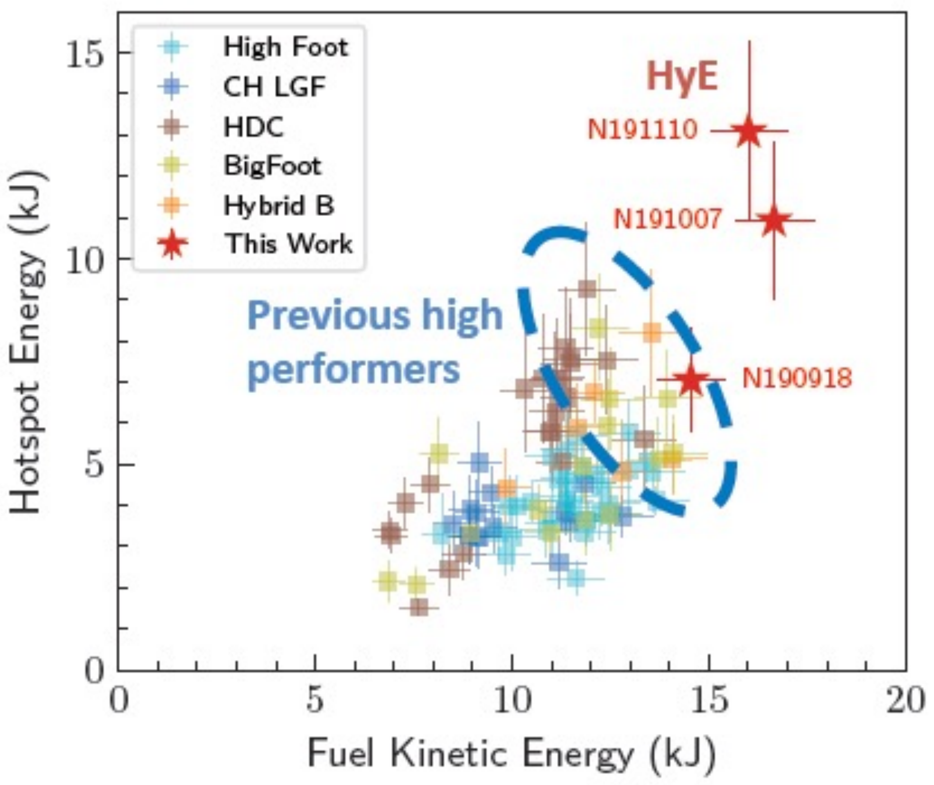


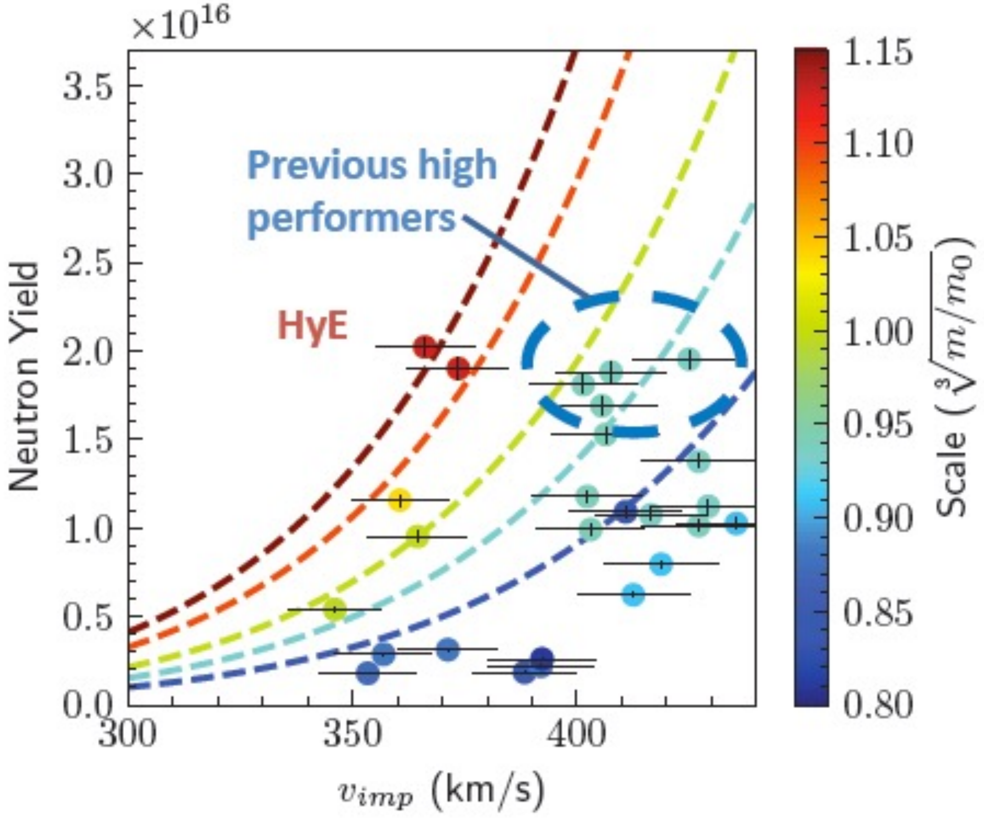
Converging plasma blow-off from the wall and capsule block inner beam propagation to the hohlraum waist[1]

Detuning the outer and inner wavelengths (Δλ) transfers power from outers to inners, increasing waist drive

Pockets displace the bubble radially outwards, giving more time for inner beams to deliver power to the waist

Initial experiment led to higher hohlraum to capsule coupling (60%) but similar yield

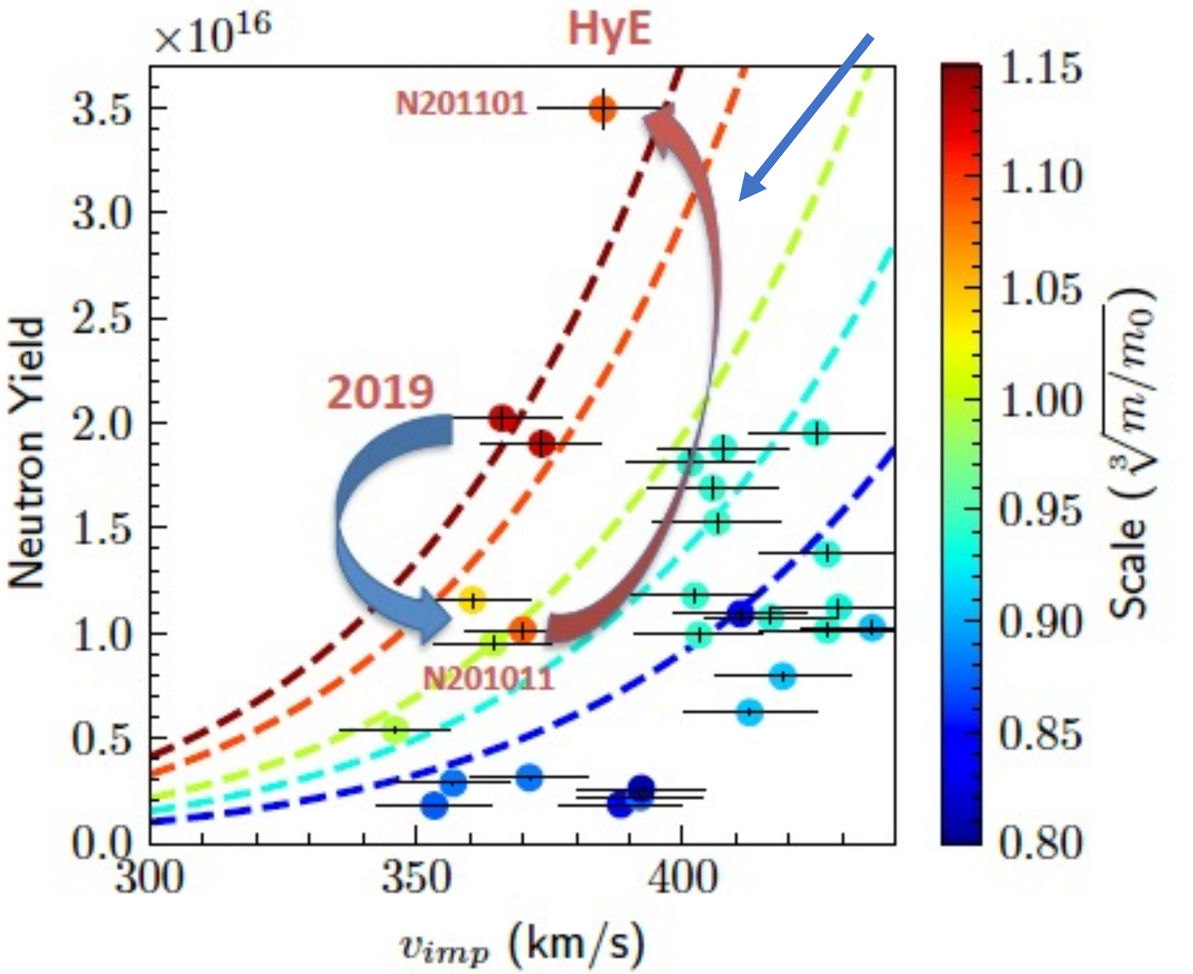




Zylstra, IFE/1-4

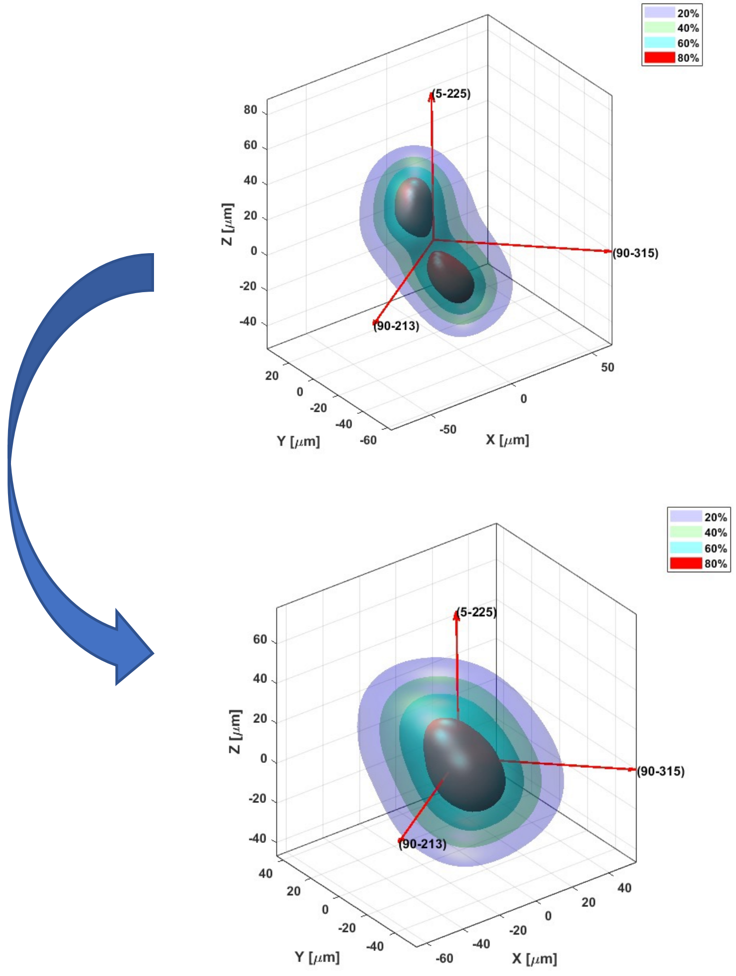
Faster implosion and better shape led to record yield (170 kJ)

Higher velocity, lower cost 100 kJ



Neutron source

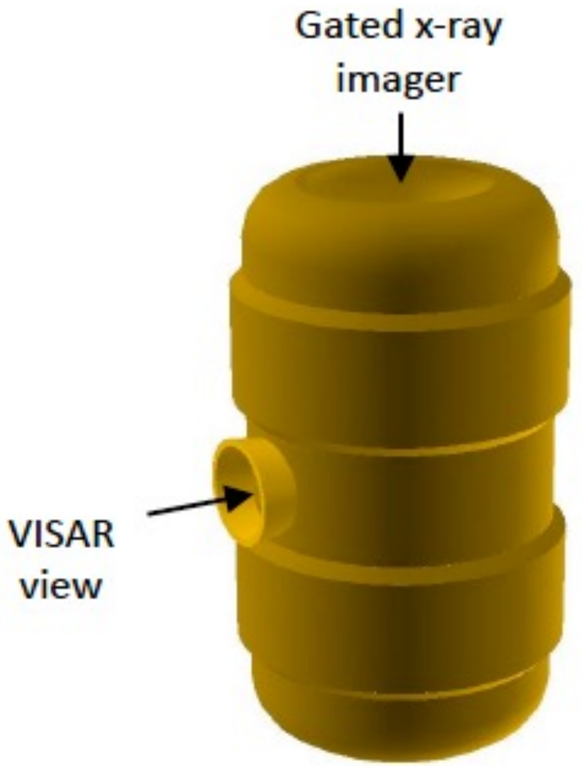
Better shape 170 kJ

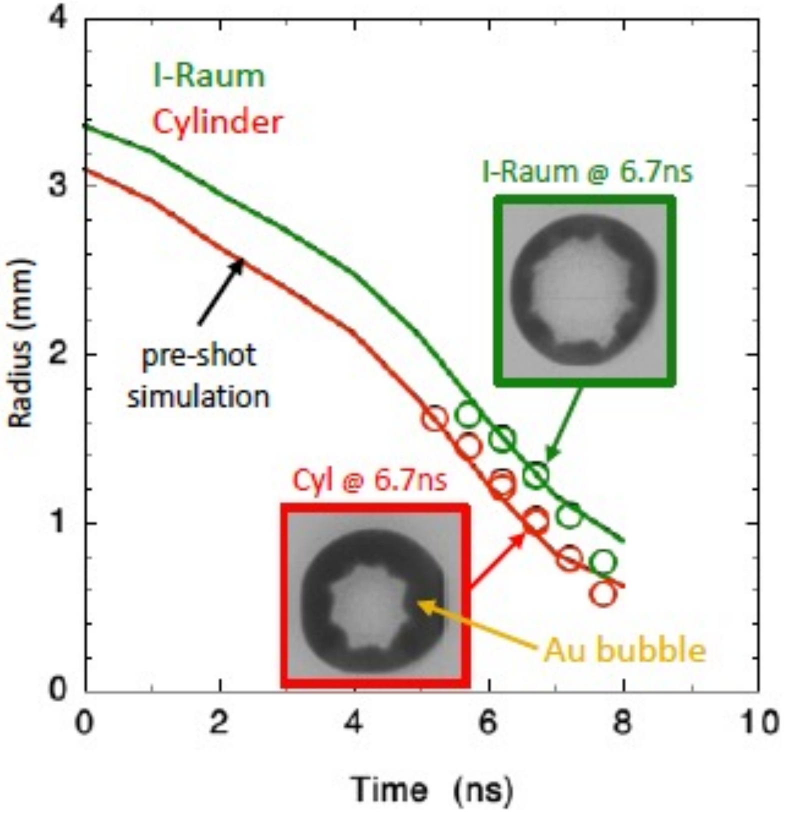


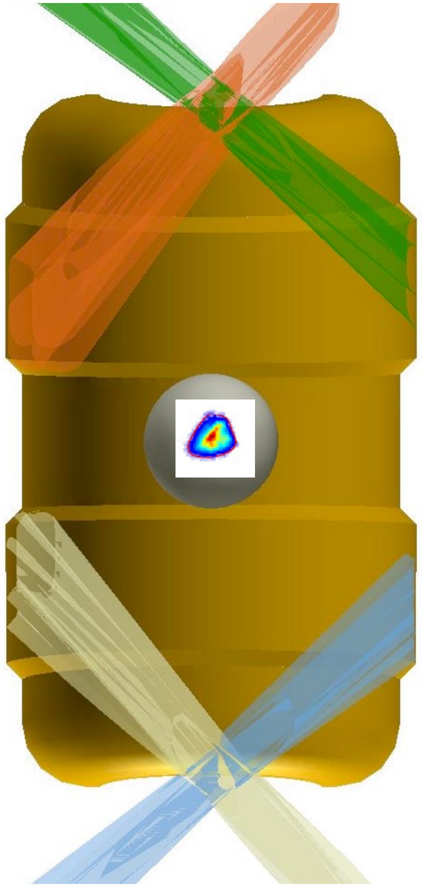
Zylstra, IFE/1-4

Iraums target are also a promising route, the most recent shot produced 170 kJ of neutron yield

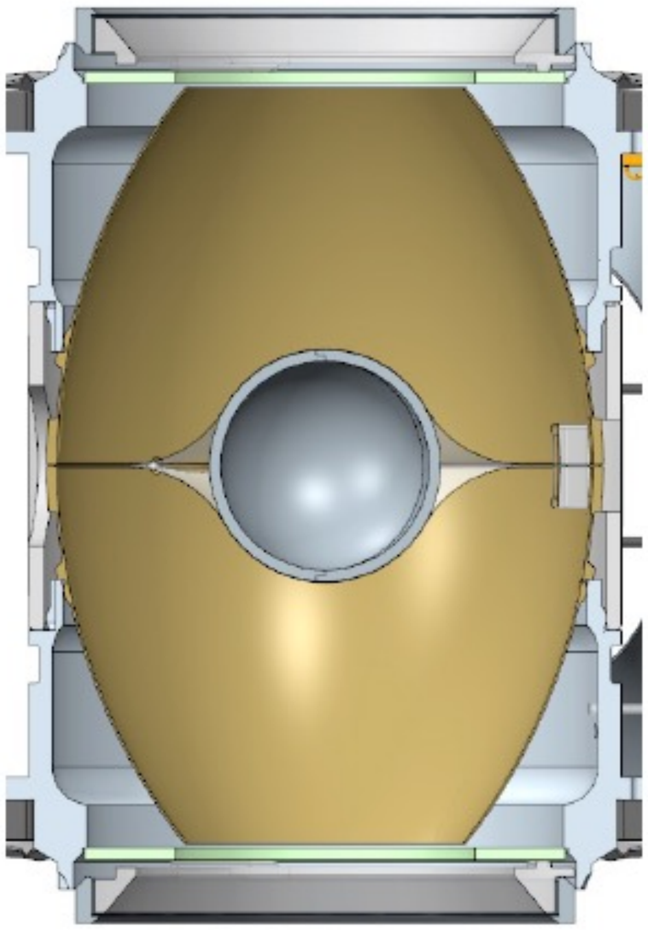
Measurements confirm the I-Raum delays bubble motion by 700 ps, allowing for a longer laser pulse.





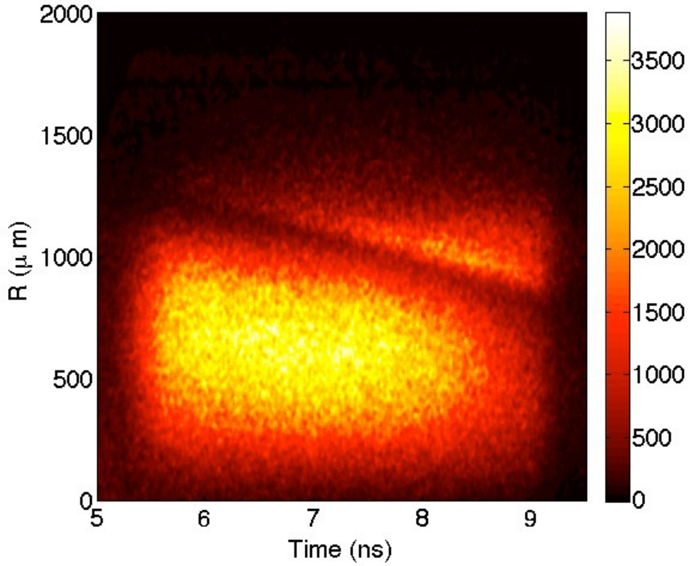


Larger capsule (3 mm) in Rugby hohlraum led to a doubling in hohlraum to capsule coupling (30%)



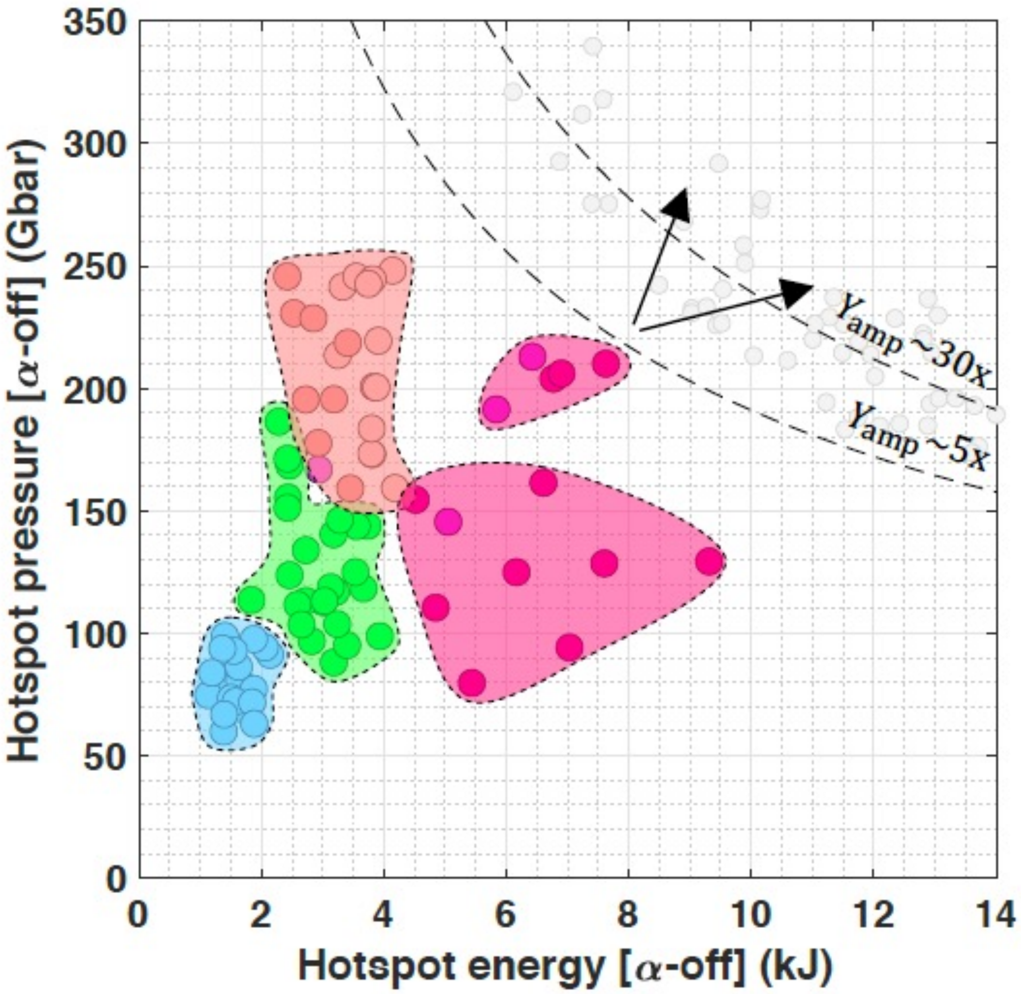
Shell velocity measurement and post shot simulation
Indicated 30% of coupled energy

	Measured	Simulated
Peak Tr (eV)	248 ±3	248
At 8.4ns		
Shell velocity (μm/ns)	151 ±8	144
<R> (μm)	890 ±20	884
<ρR> (mg/cc)	3.3 ±0.7	4.3
Shell FWHM (μm)	89 ±14	100
Mass (mg)	3.0 ±0.2	3.67
Shell kinetic energy (kJ)	34 ±4	38
At 10.6ns		
<R> (μm)	550 ±20	538



Ping, IFE/1-2

There are several path forwards for closing the gap to the ignition boundary



Improving implosion quality (pressure)

- Reducing low-mode asymmetry
- Reducing ablator mix in hotspot
- Increasing compression ratio
- Reducing 3D perturbations may enable driving implosions at higher velocity, increasing 1D margin

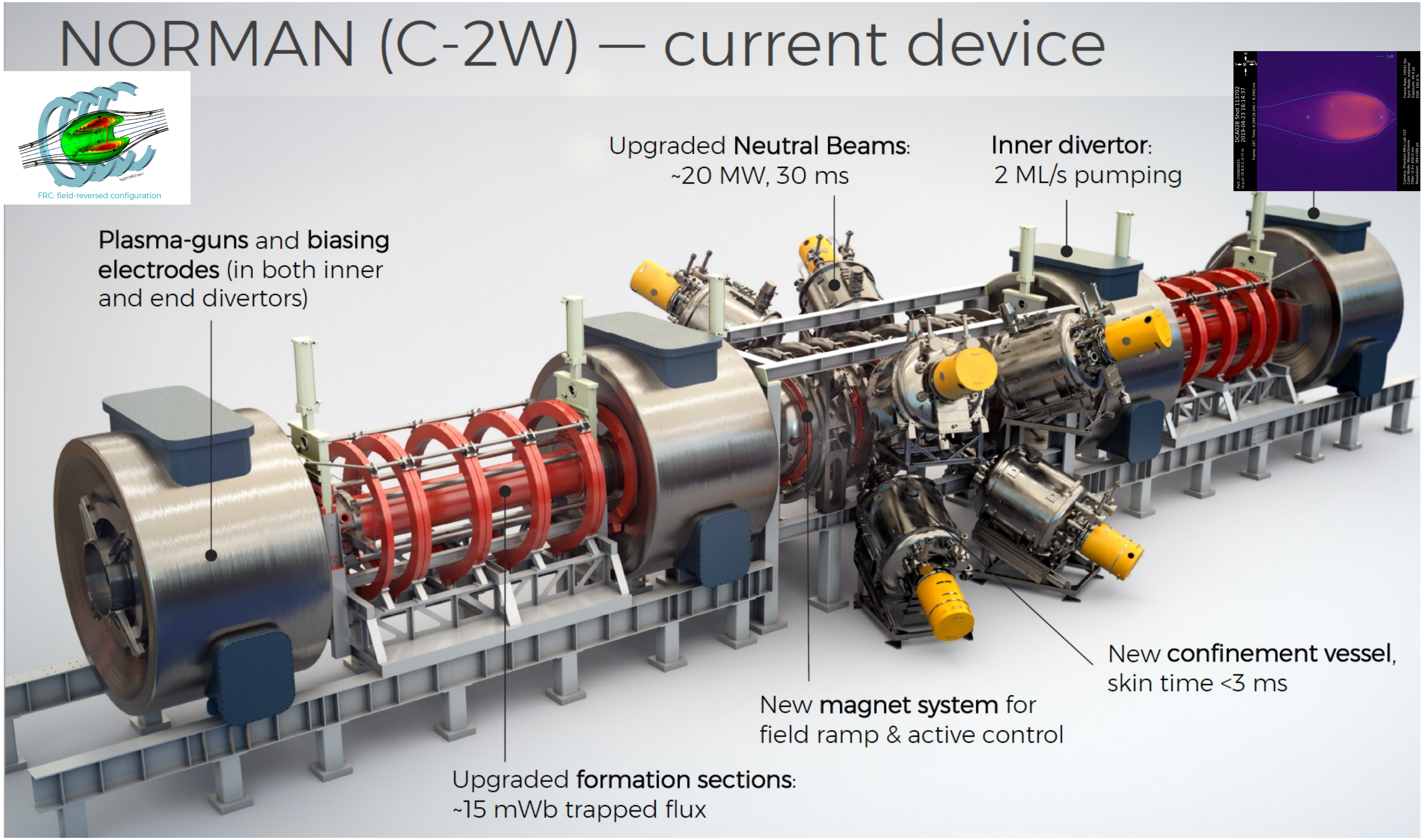
Increasing implosion scale (energy)

- Increase capsule size with fixed NIF laser energy through more efficient hohlraum designs
- Increase capsule and hohlraum size with additional NIF laser energy (exploring up to 2.6 MJ)

Patel, OV/3-1

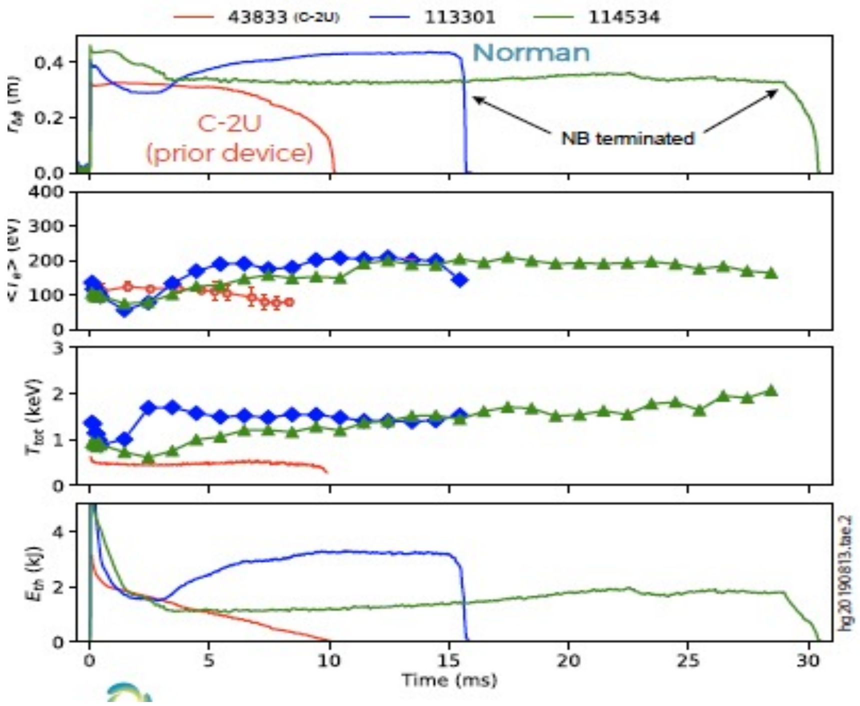
Beam driven FRC plasma

Significant progesses are made on the Norman Beam-Driven FRC device



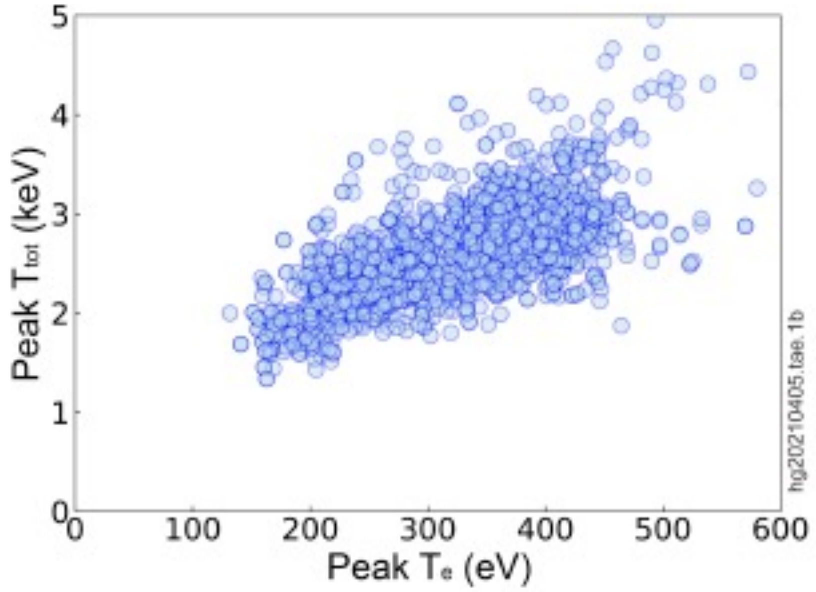
FRC sustainment up to 30+ ms achieved on Norman device

- Compared to prior C-2U device
  - 3x longer plasma lifetime
  - 4-5x higher temperature
  - 4x higher plasma energy



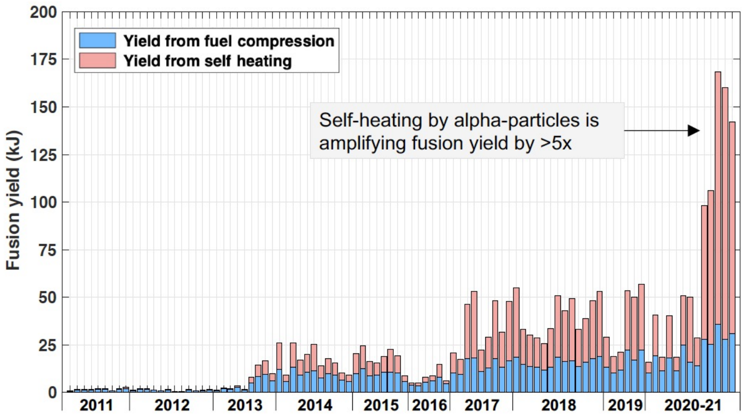
T_e >0.5 keV, T_{tot} >3 keV

- Norman can produce a wide range of T_e & n_e: T_e >0.5 keV (measured by Thomson scattering)
- Plasma temperature T_{tot} >3 keV – estimated by interpretive plasma reconstruction using experimental measurements

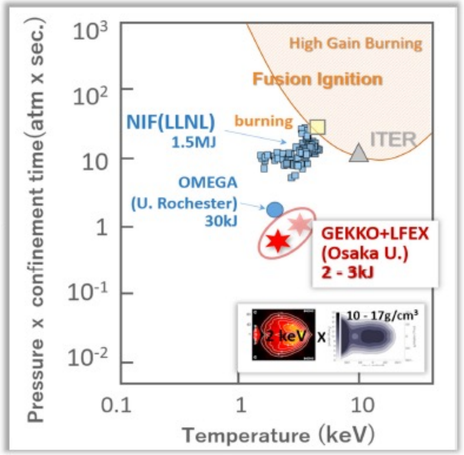


Conclusion: significant progresses toward ignition are being made across ignition schemes

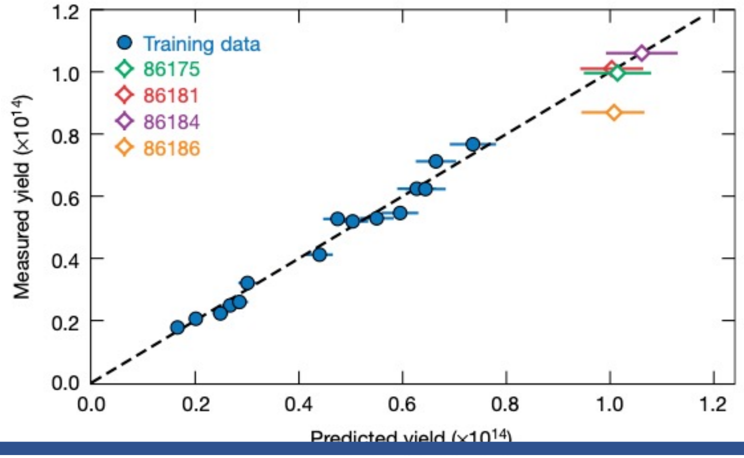
Indirect drive



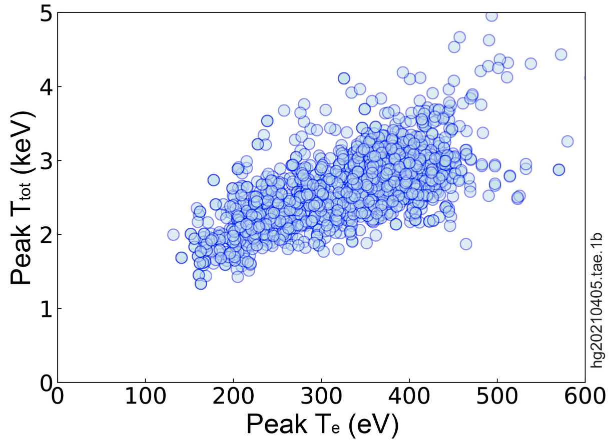
Fast Ignition



Direct drive

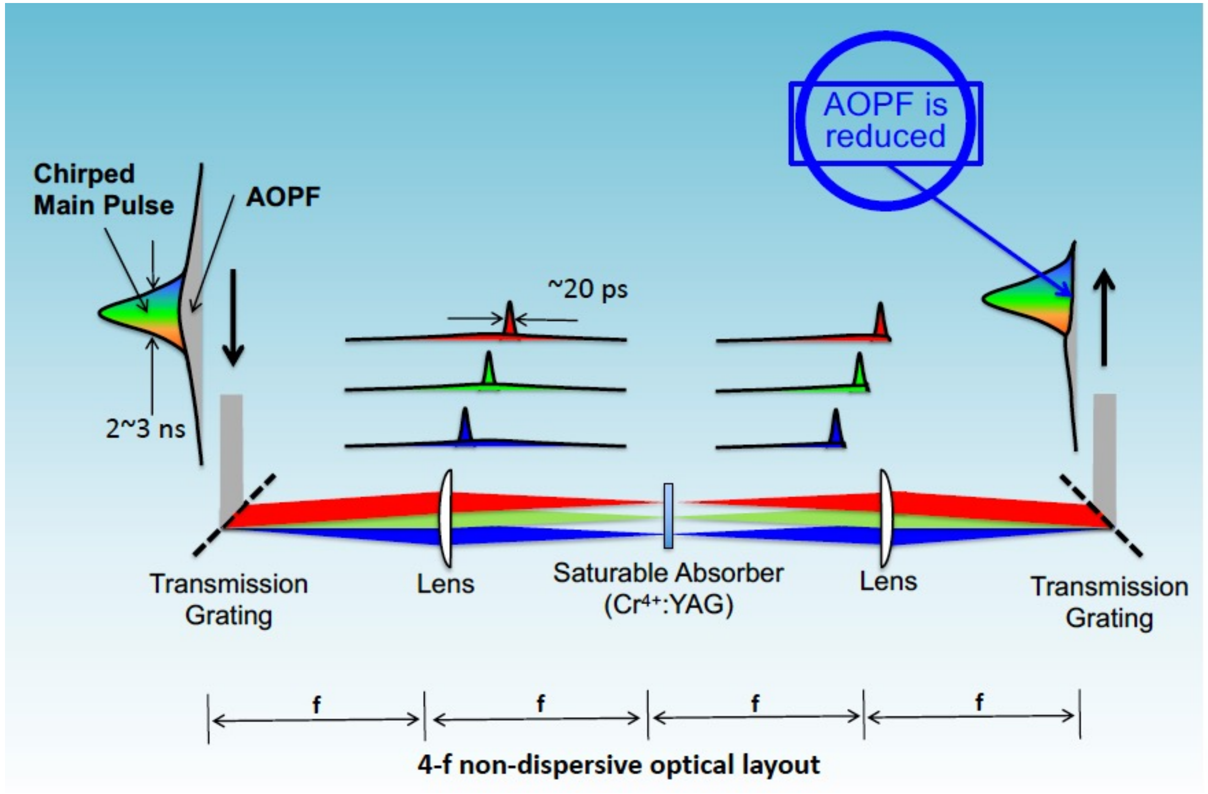


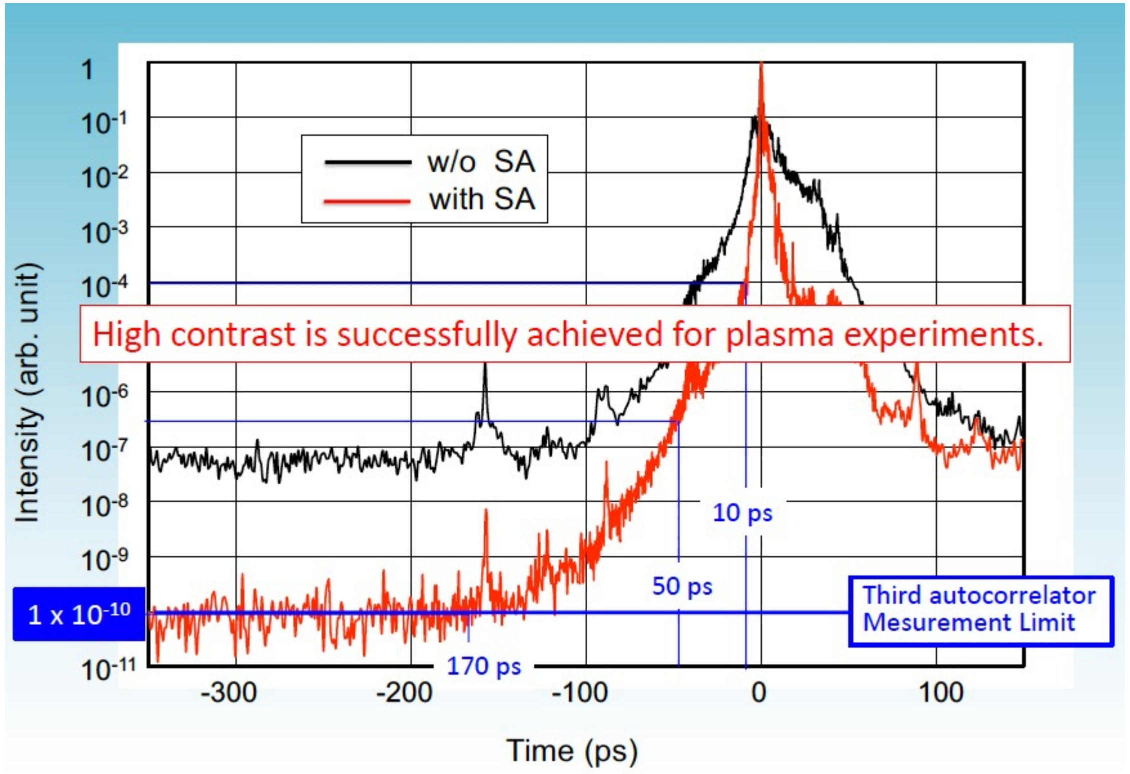
Beam driven FRC plasma



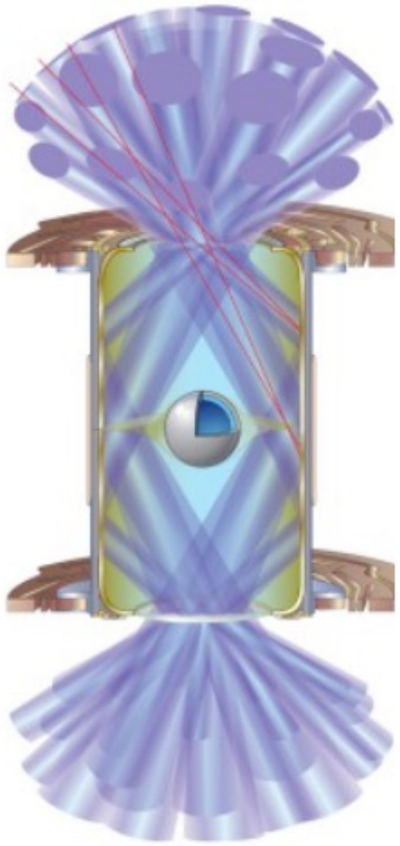
Conclusion

Fast ignition requires a high contrast, high energy short pulse





Kawanaka, IFE/1-3



Capsule increased by 15-20% but hohlraum only
increased by 3% vs HDC -> higher efficiency

Converging plasma blow-off from the wall and capsule block inner beam propagation to the hohlraum waist