Update on NIF and NIC

Presentation to

TOFE 2012, Nashville

August 30, 2012

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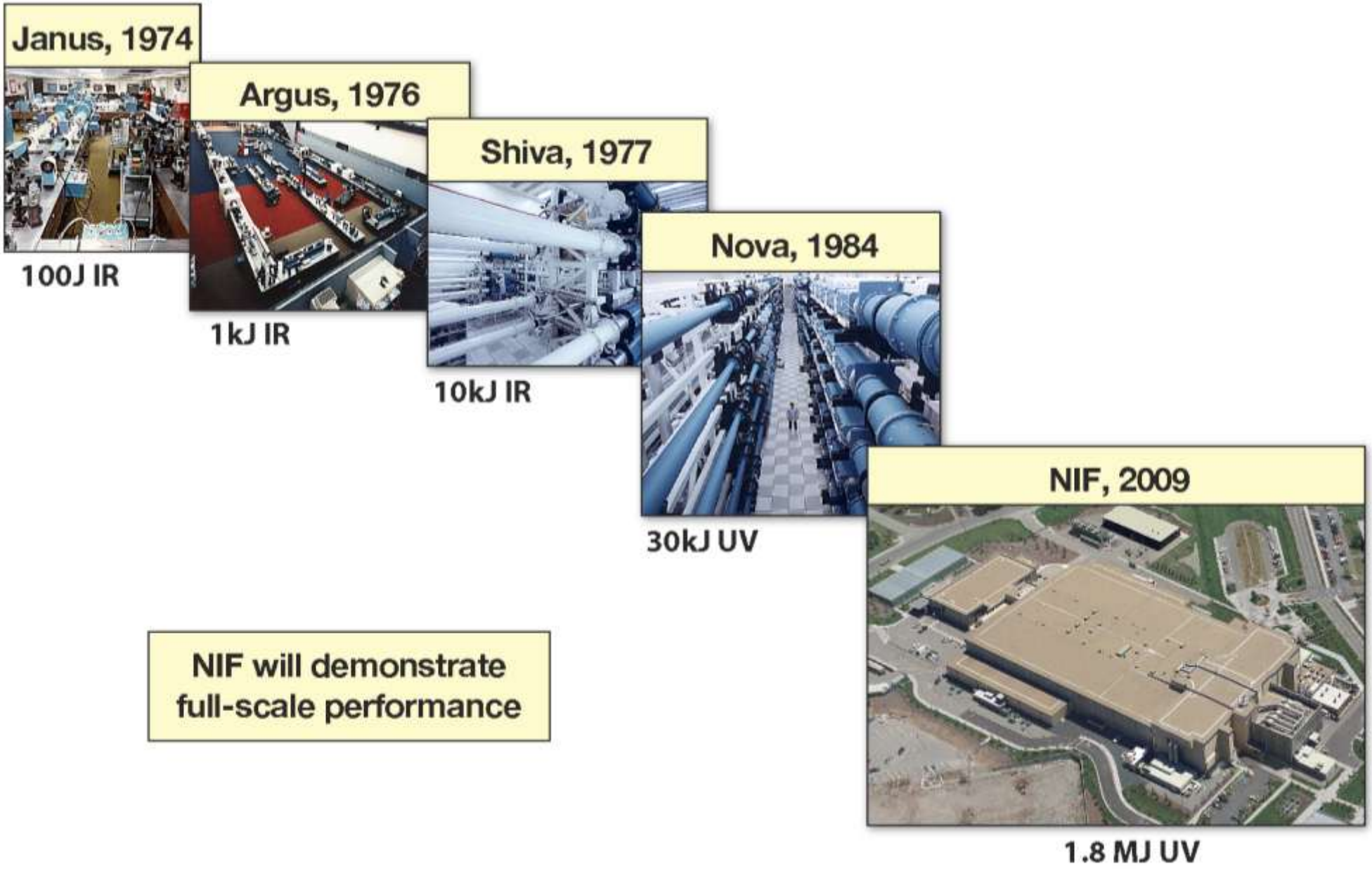
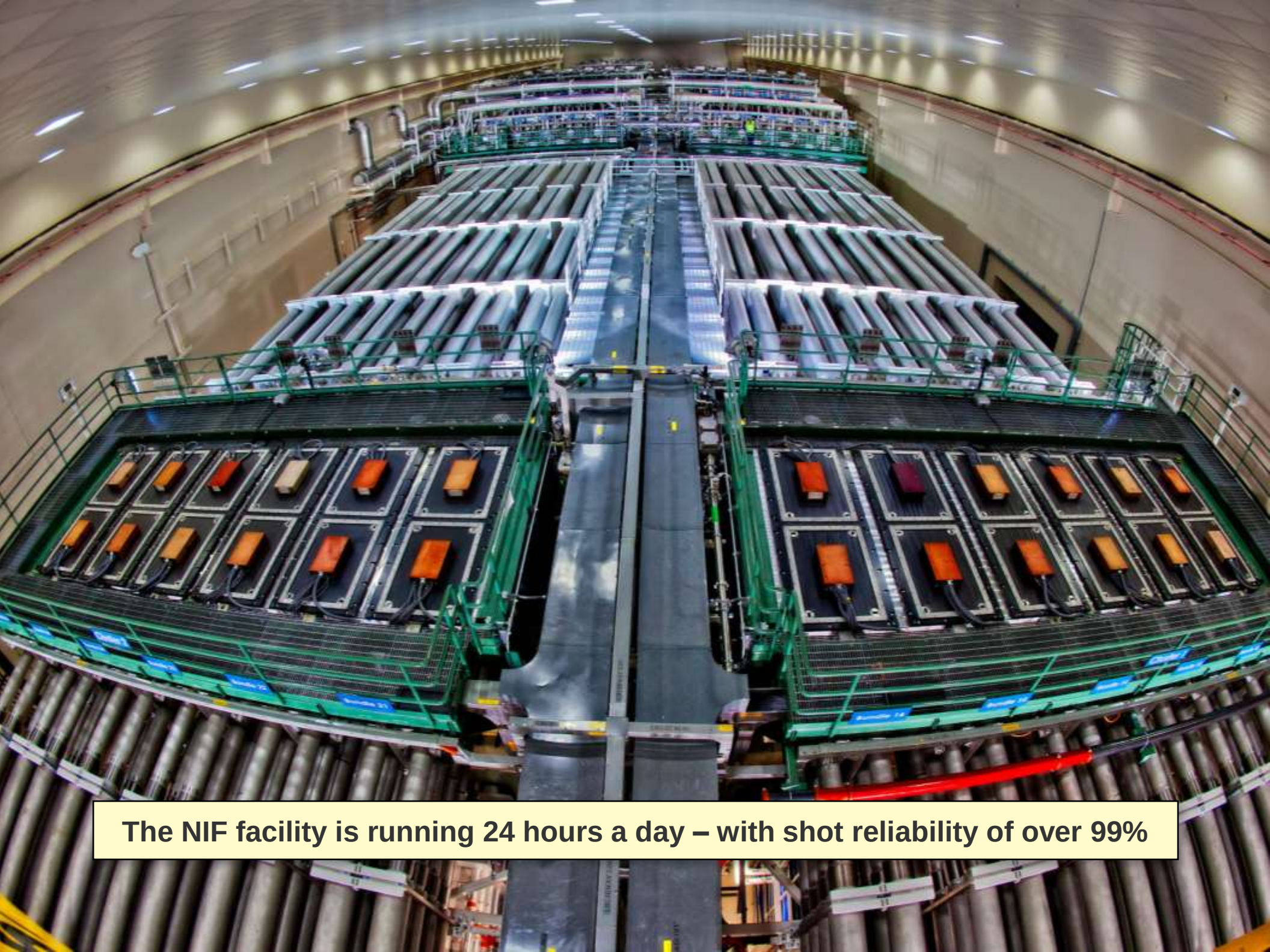
Director, Laser Fusion Energy

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

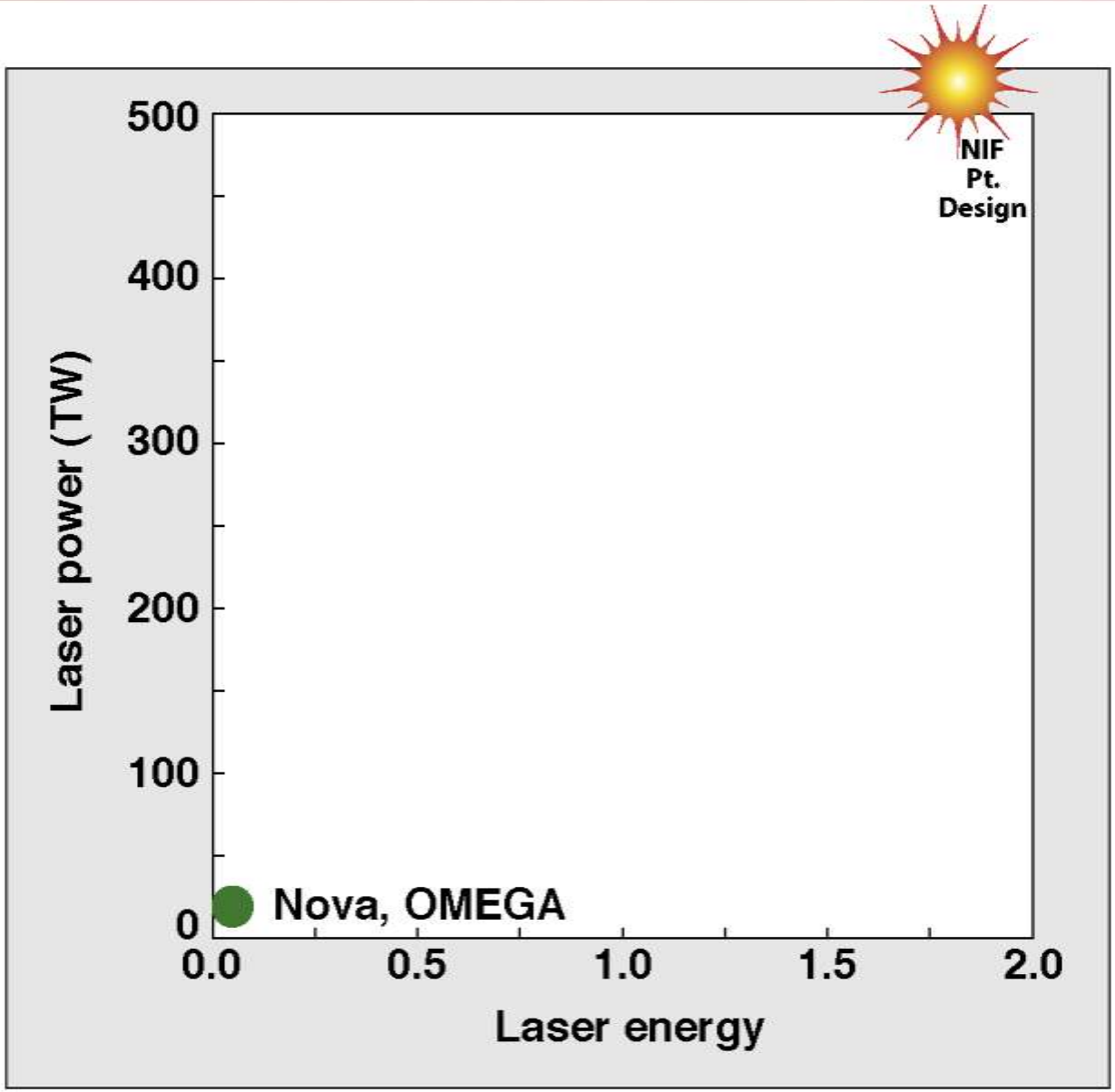
NIF is the culmination of a decades-long effort to demonstrate fusion ignition and energy gain





The NIF facility is running 24 hours a day – with shot reliability of over 99%

We are steadily increasing the laser energy and power available for ignition experiments



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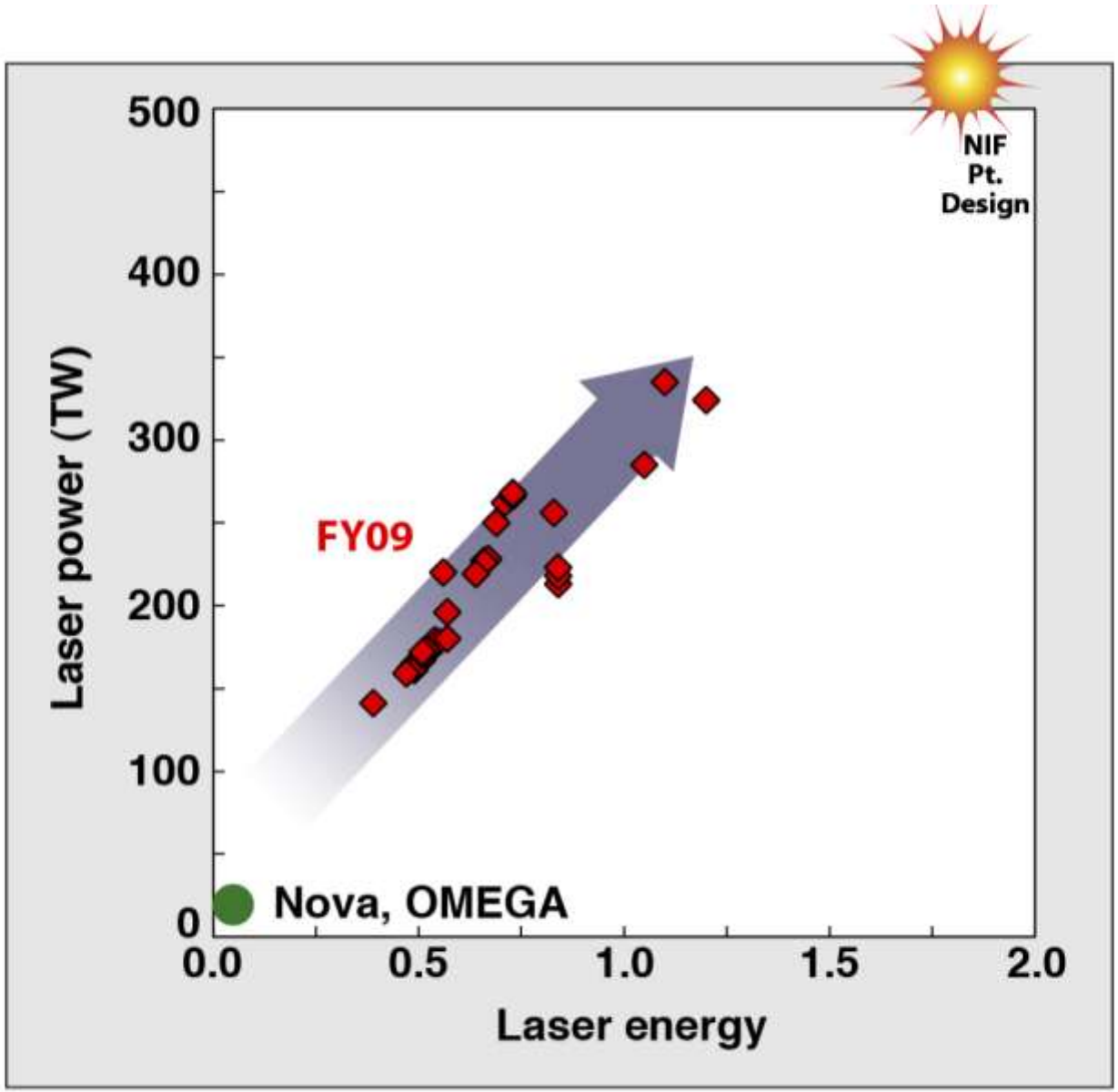

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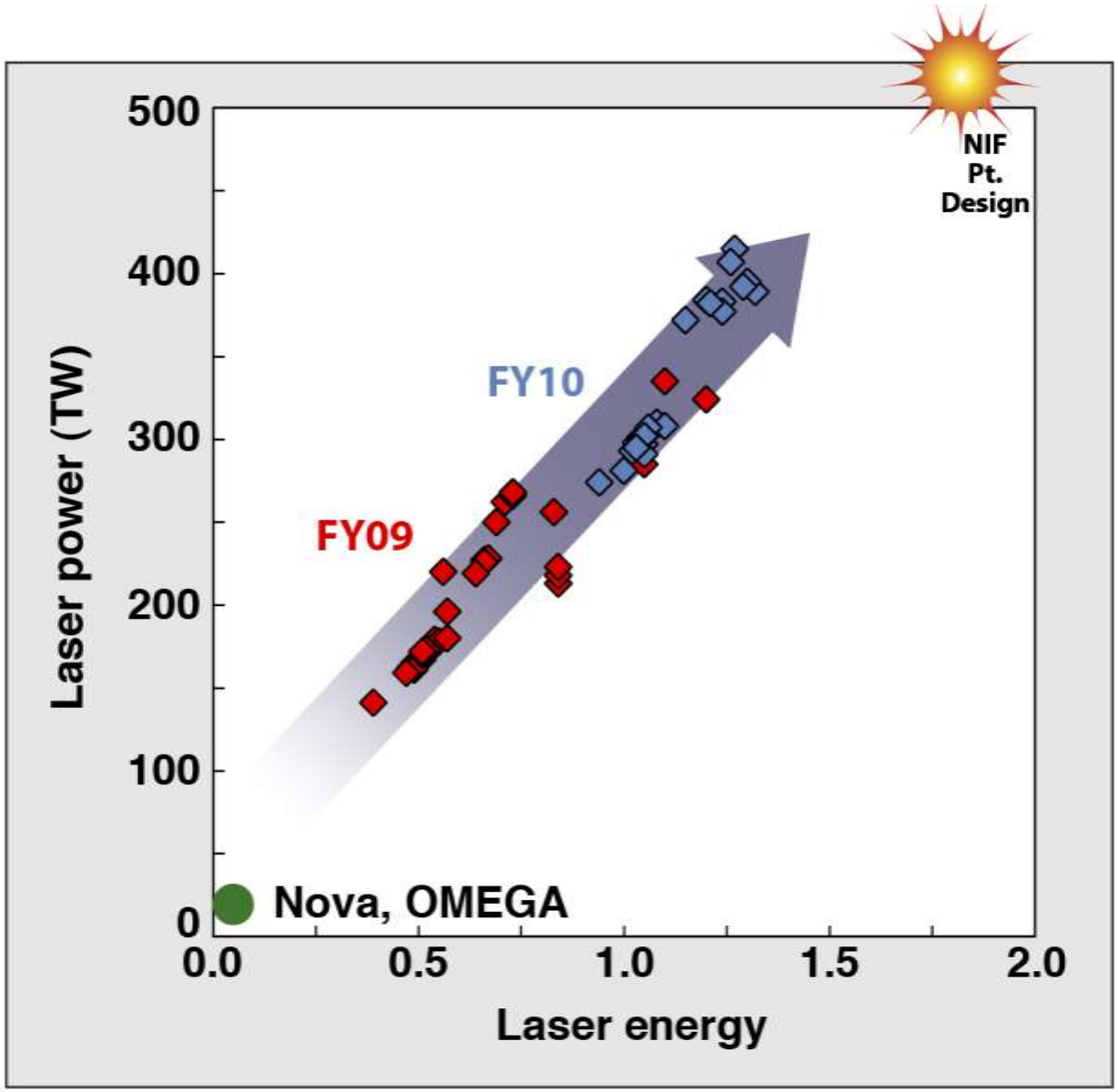

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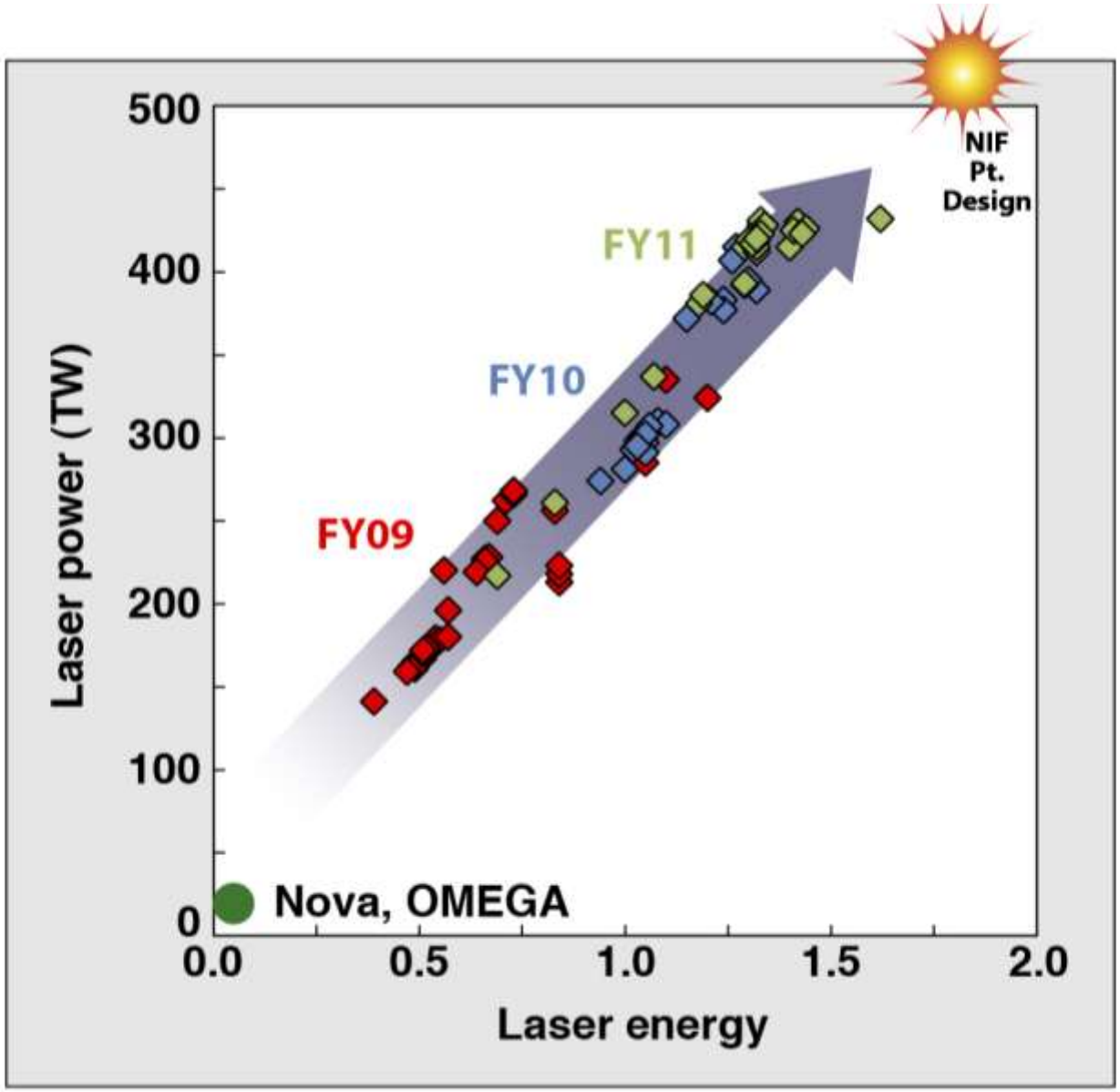
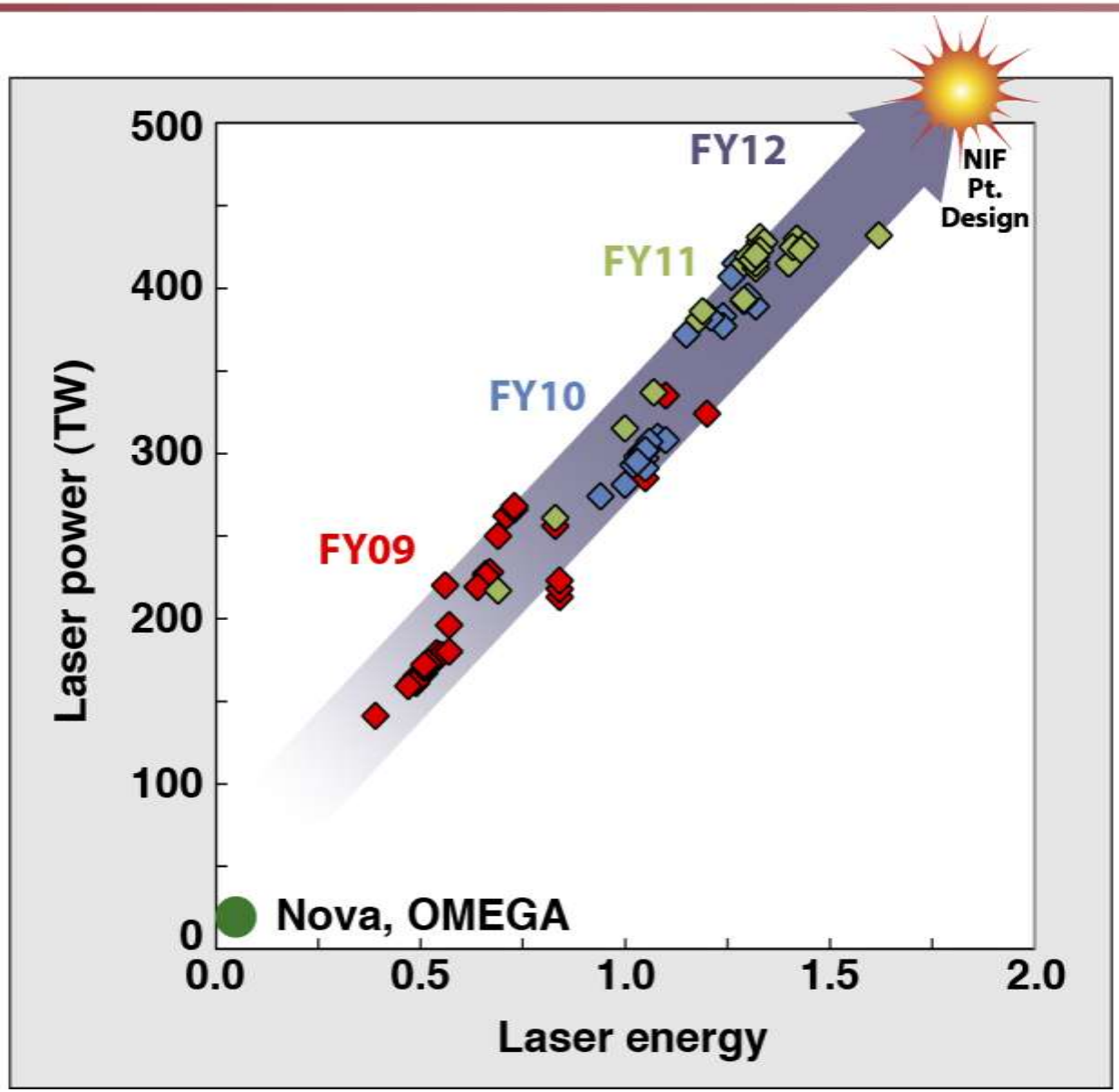


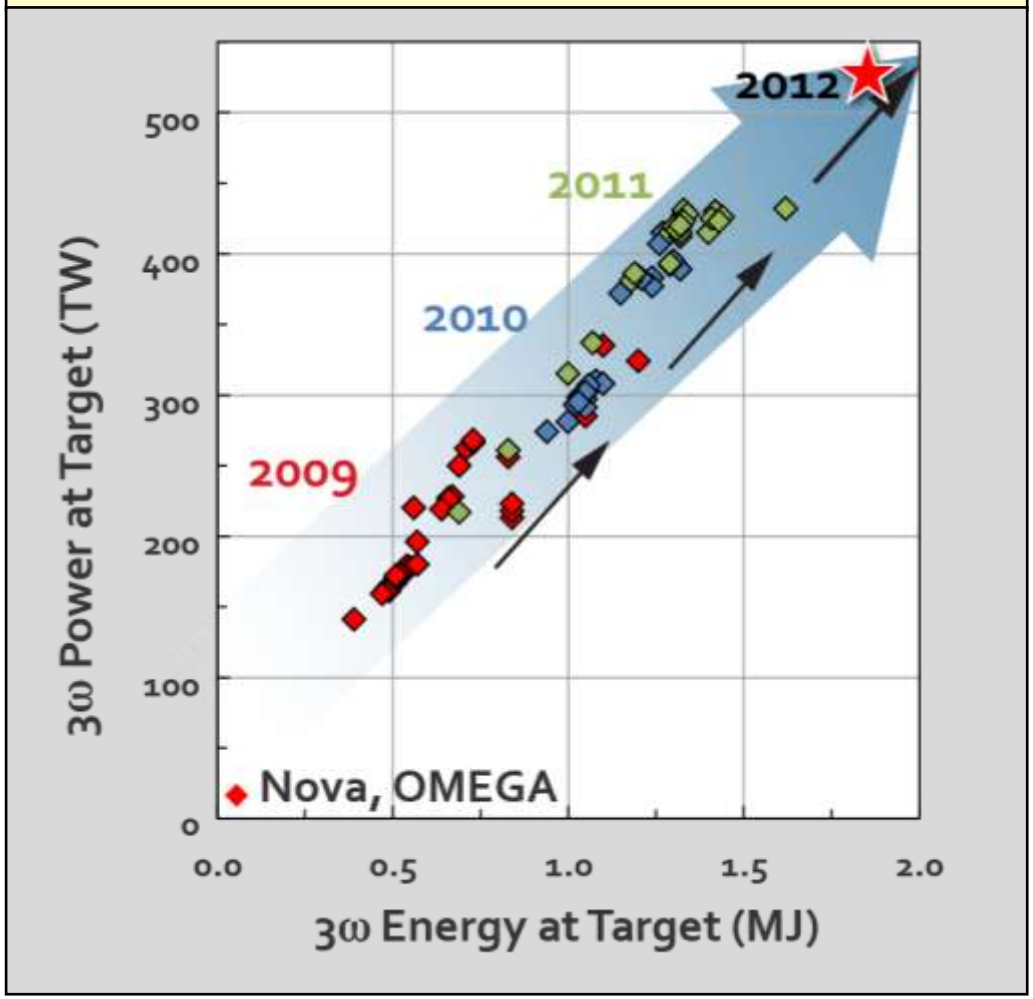
We are steadily increasing the laser energy and power available for ignition experiments 2012

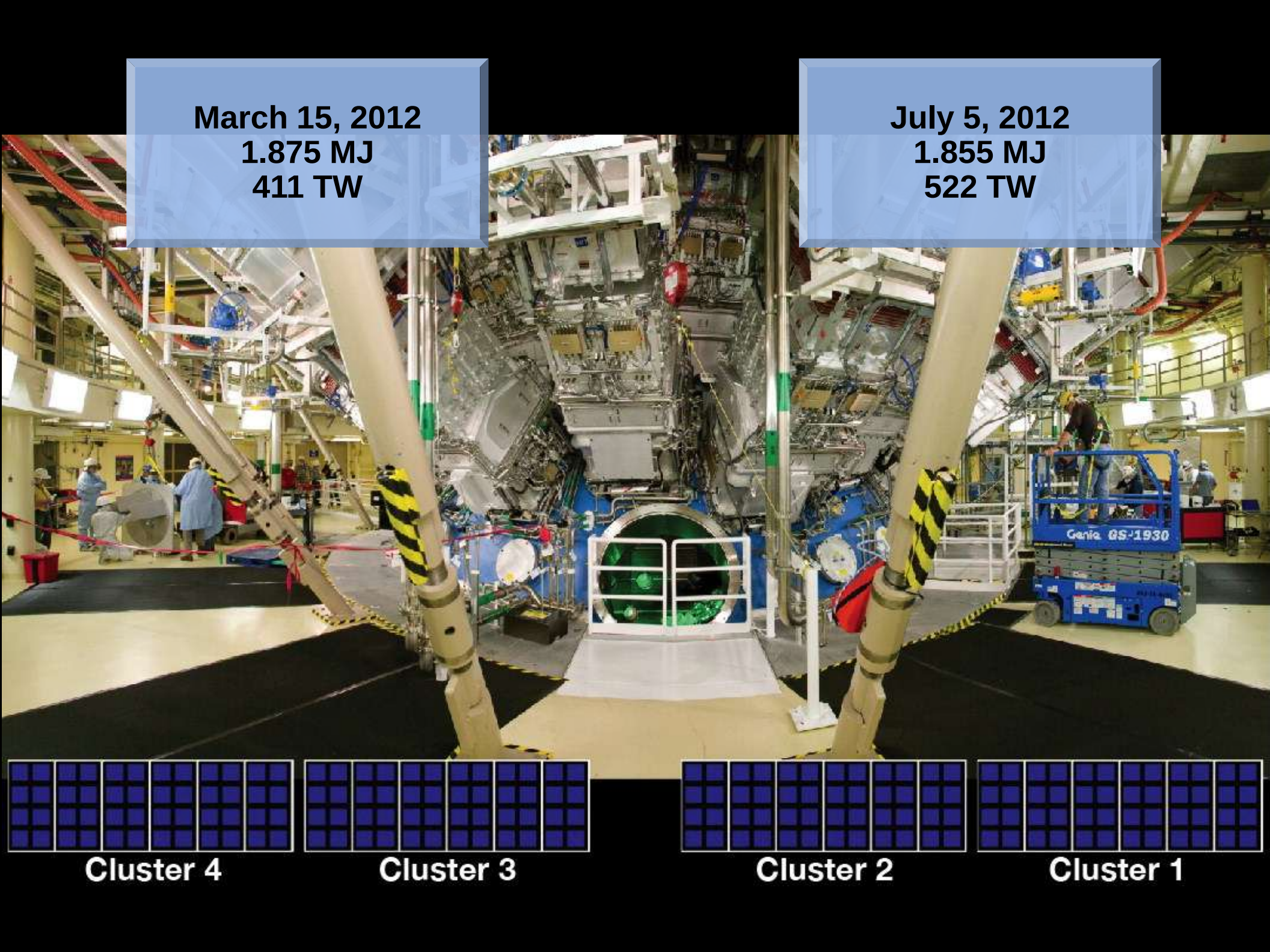


NIF recently exceeded its design goal of sustainable operations at 1.8MJ / 500TW

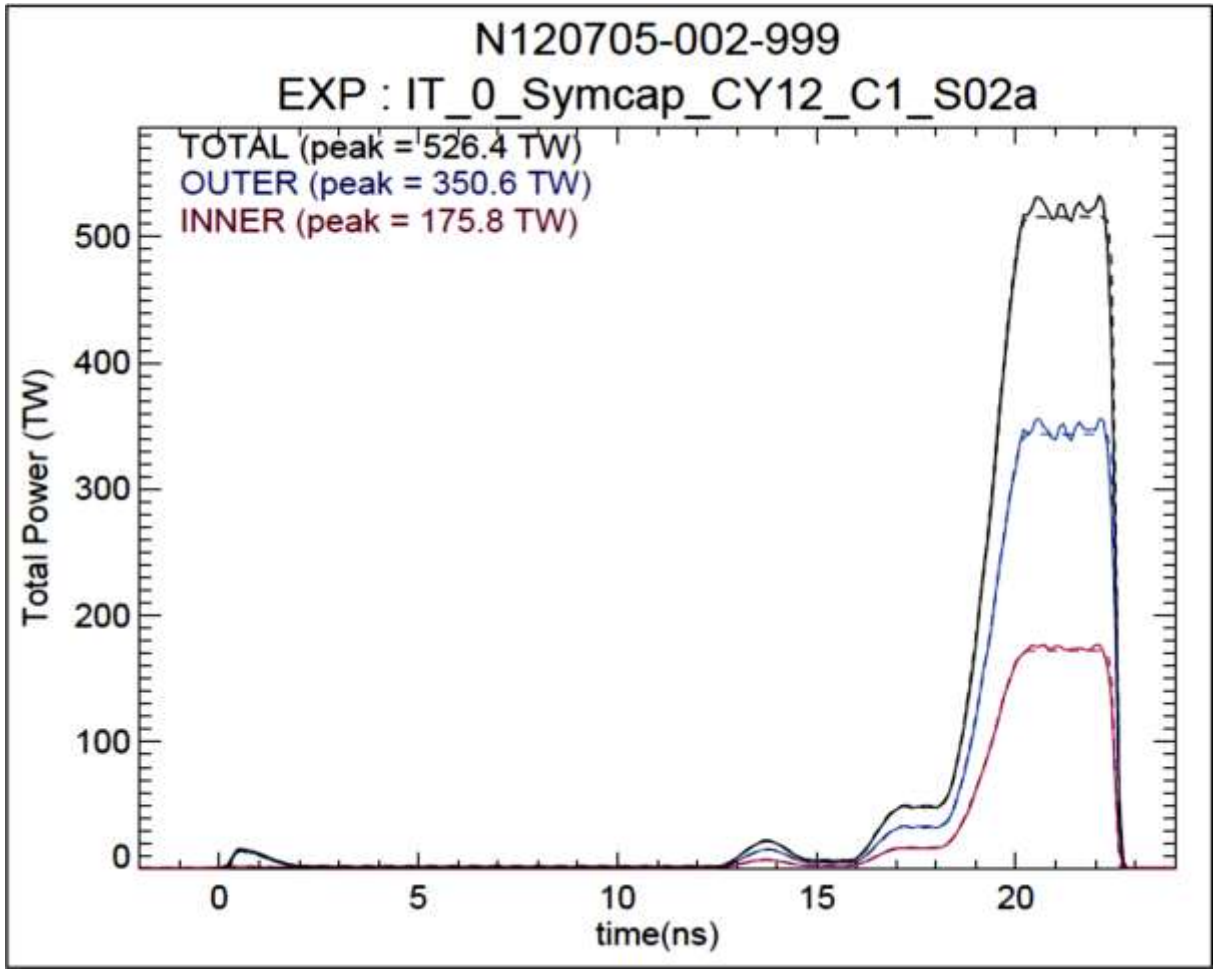
- NIF has been steadily increasing its laser energy and power
- NIF is now operating 24/7 with exceptional reproducibility and reliability (99%)
- Currently supporting the NIC in 1.4 to 1.8 MJ campaigns
- **1.855 MJ, 522 TW achieved in a NIC-relevant pulse format**
- The NIF has intrinsic capability to continue on this growth path for several more years

The laser energy and power available for experiments have been steadily increasing



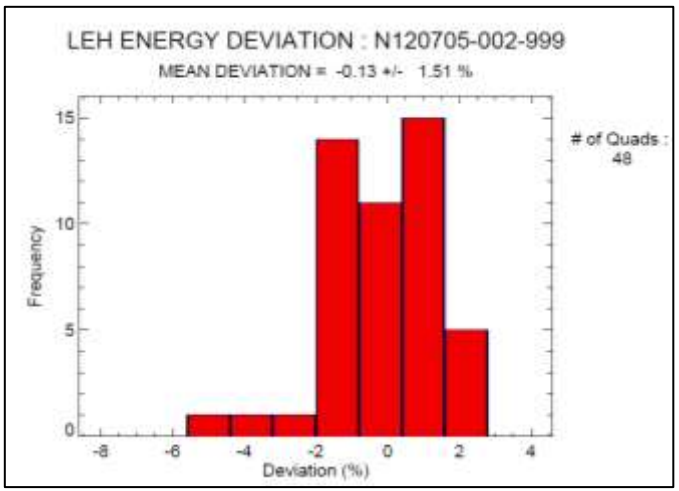

March 15, 2012
1.875 MJ
411 TW
July 5, 2012
1.855 MJ
522 TW
Genie GS-1930
Cluster 4
Cluster 3
Cluster 2
Cluster 1

Beam balance and accuracy exceeded design goals

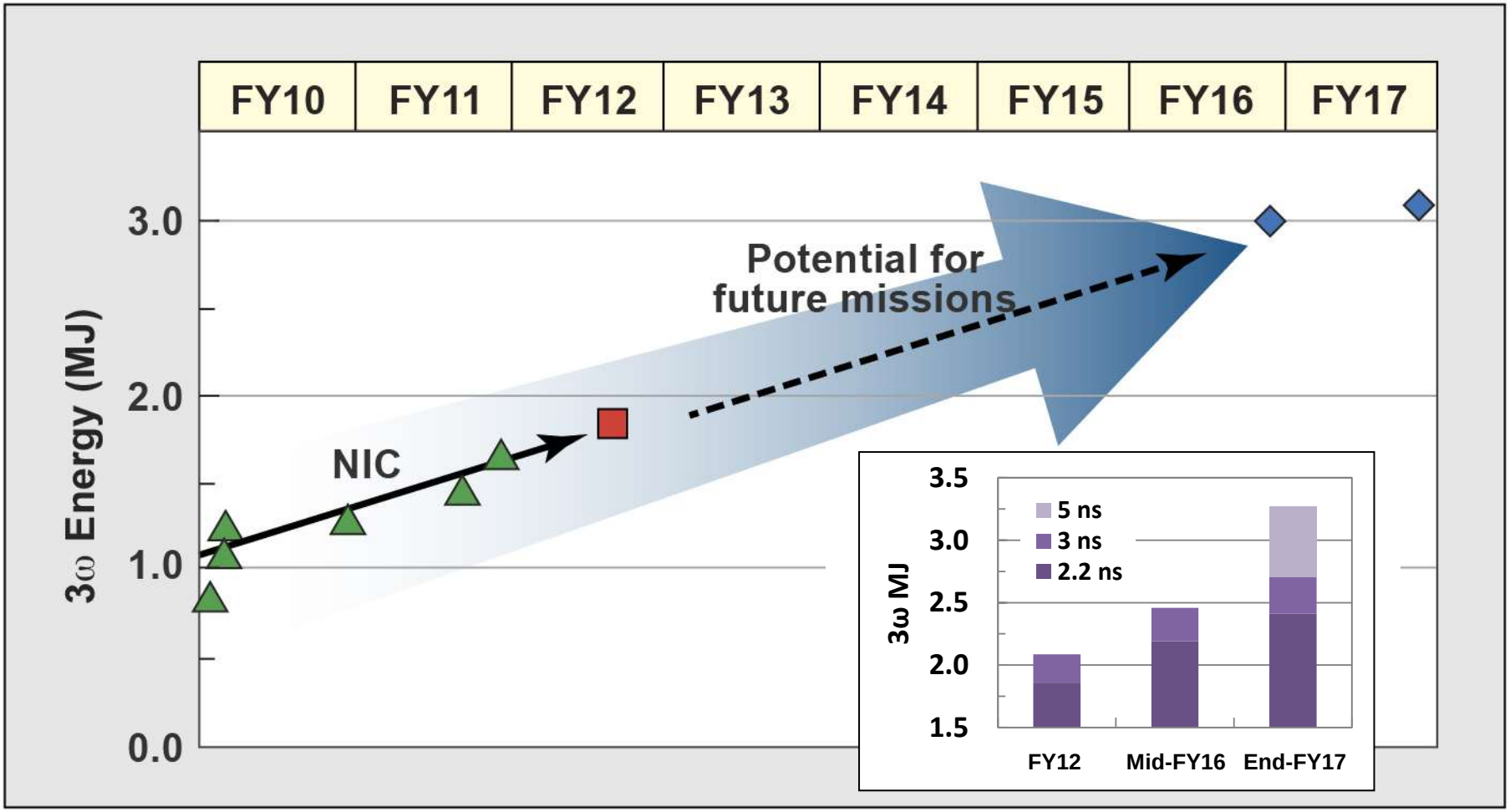


Excellent accuracy and beam balance:

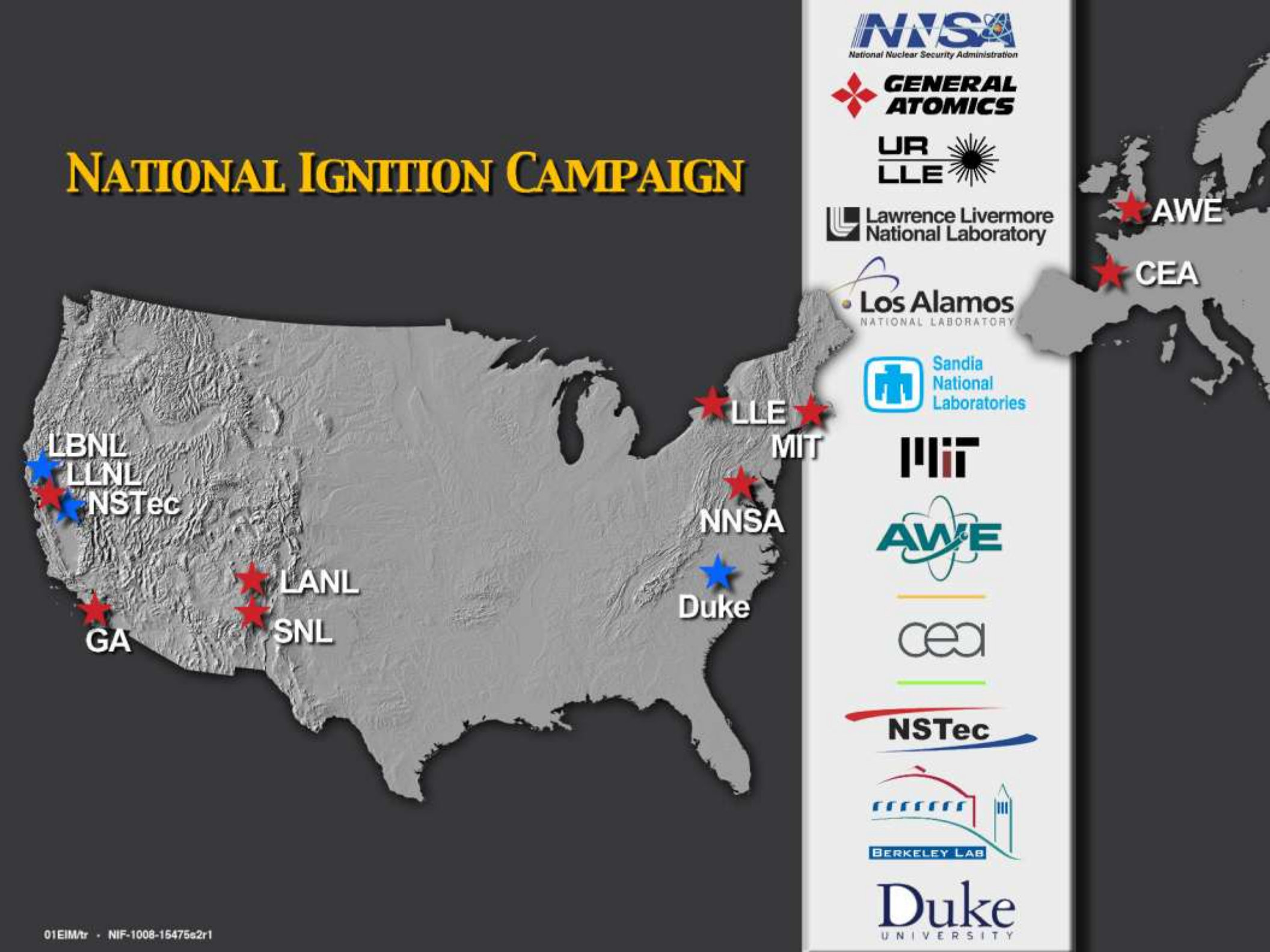
- **-0.13% deviation of total delivered energy**
- **1.5% rms deviation of individual quad energy**
- **1.6% rms quad peak power imbalance (3% goal)**



Plans are being developed for enhanced NIF performance, via incremental improvements



NATIONAL IGNITION CAMPAIGN



NNSA National Nuclear Security Administration

GENERAL ATOMICS

UR LLE

Lawrence Livermore National Laboratory

Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

MIT

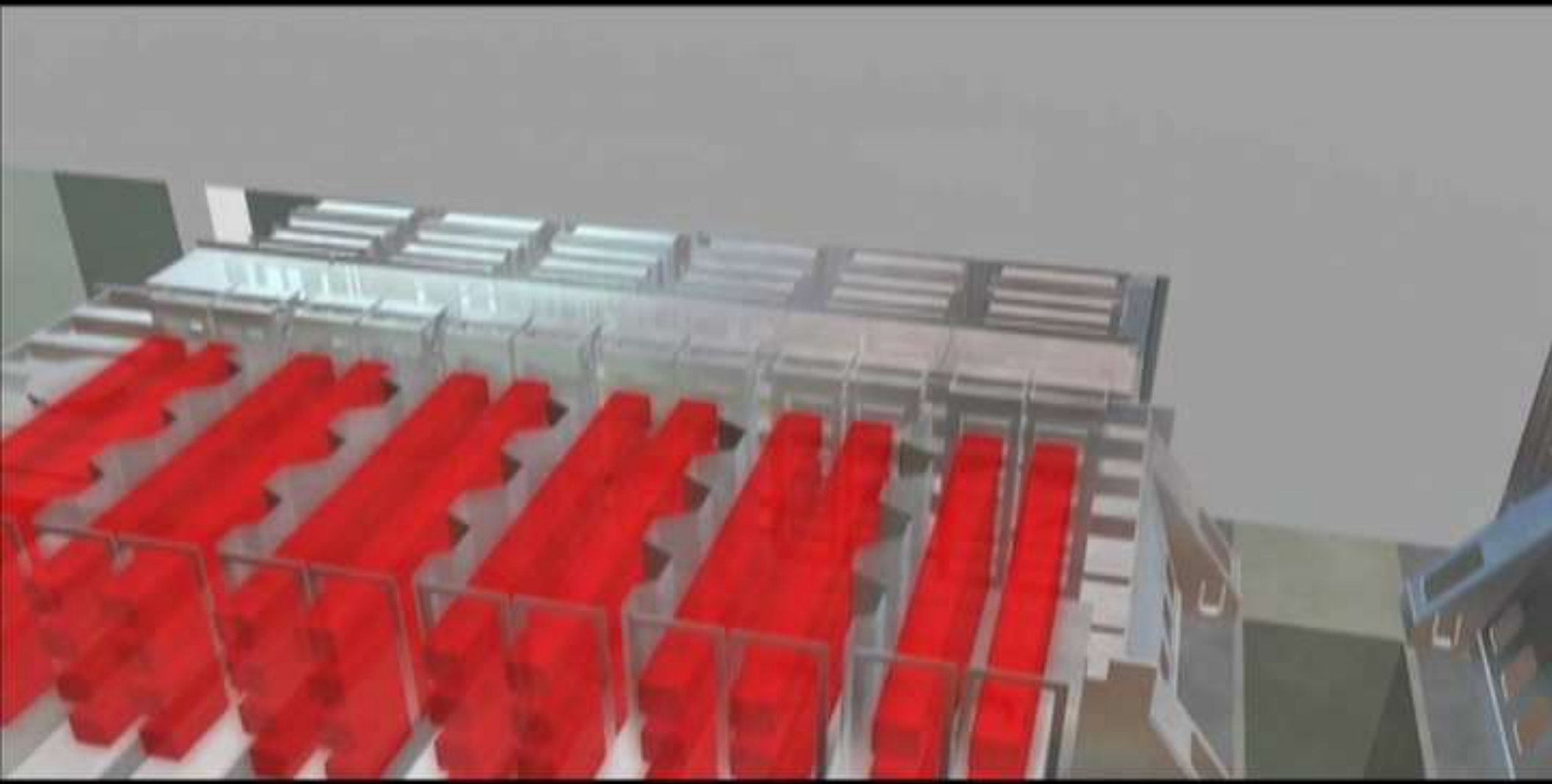
AWE

cea

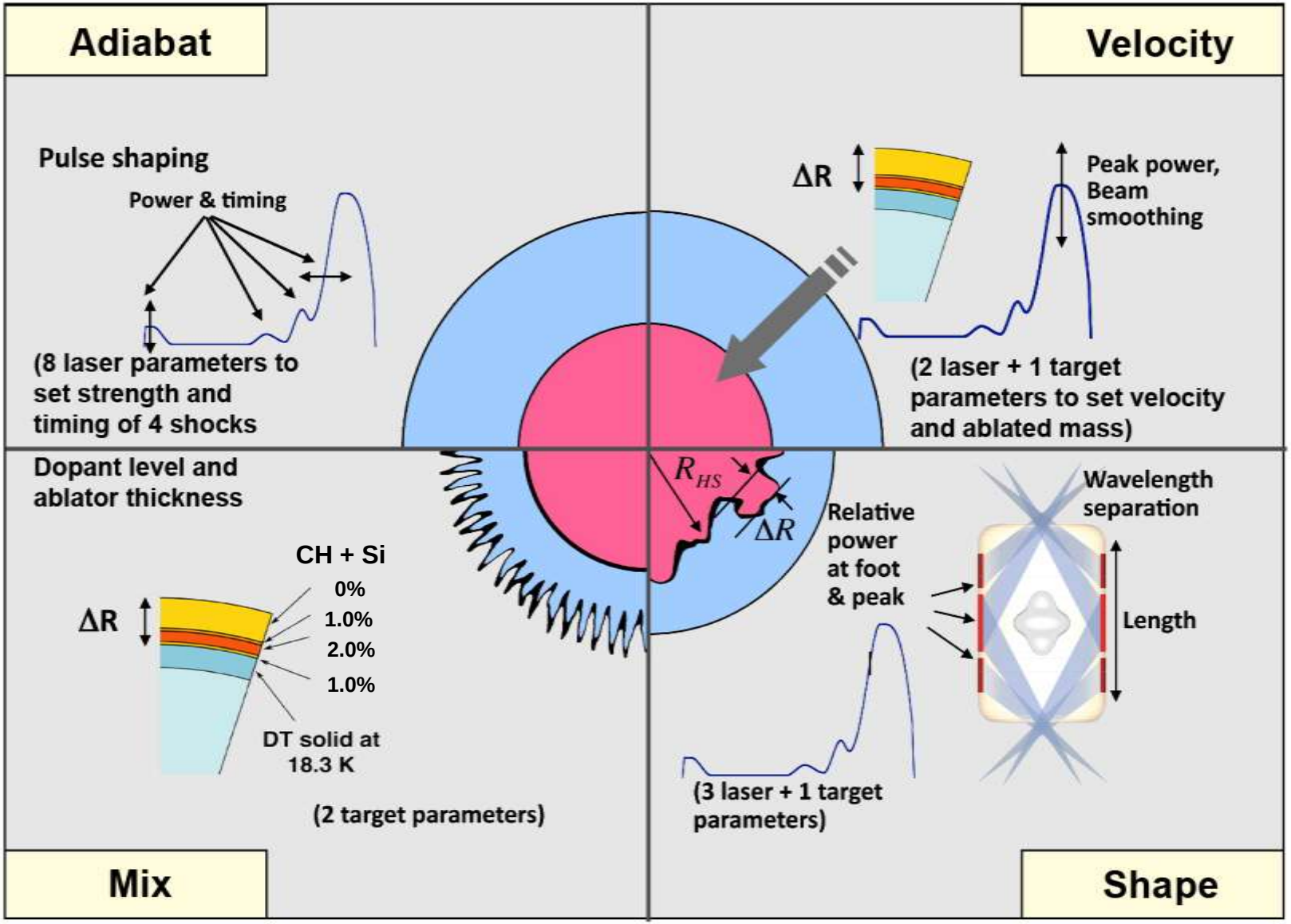
NSTec

BERKELEY LAB

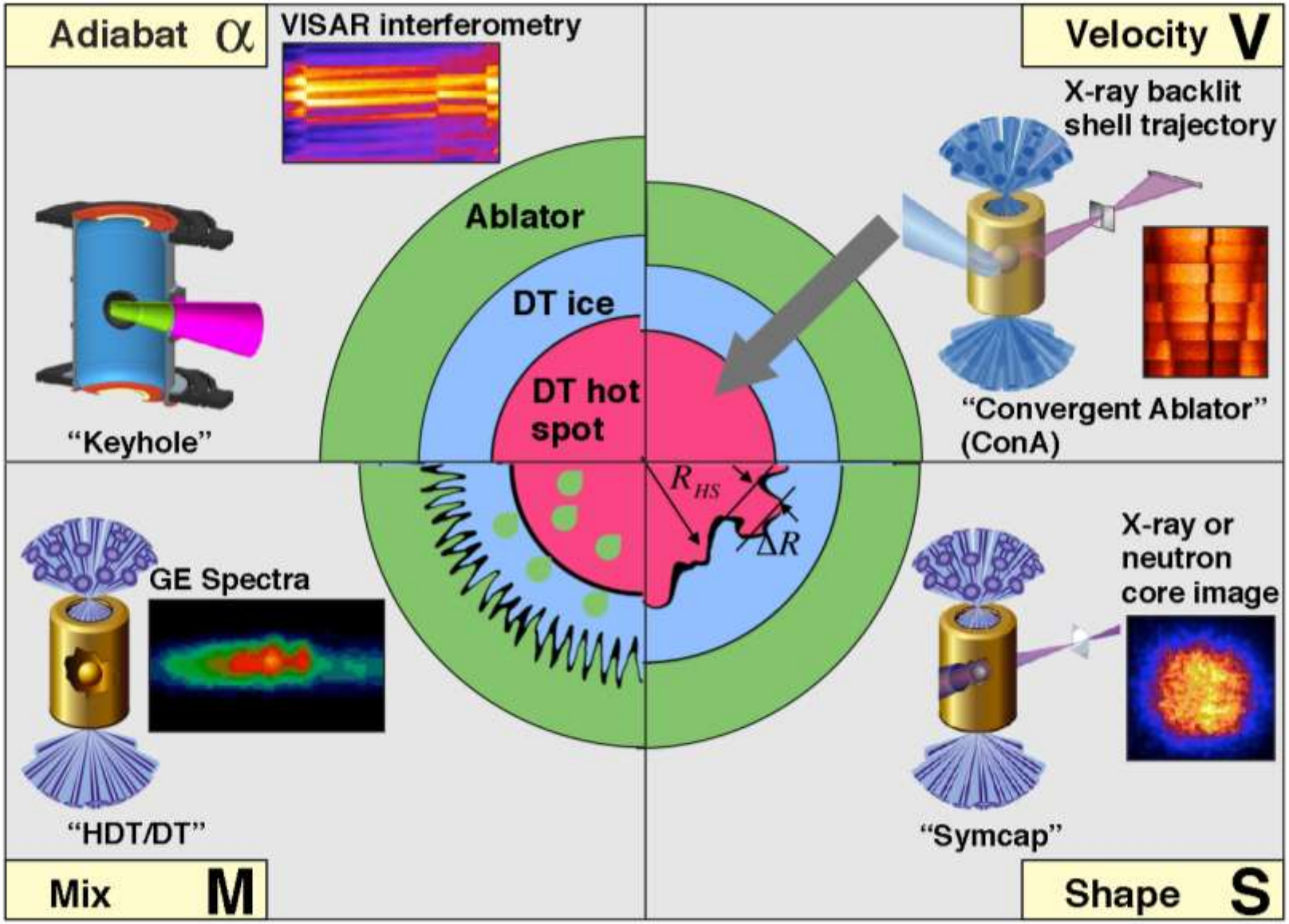
Duke UNIVERSITY



NIC performance is optimized around four key variables



We use a variety of platforms to tune the capsule shape, adiabat, velocity and mix



NIF Target diagnostics have helped build the user community – about 50 have been fielded to date

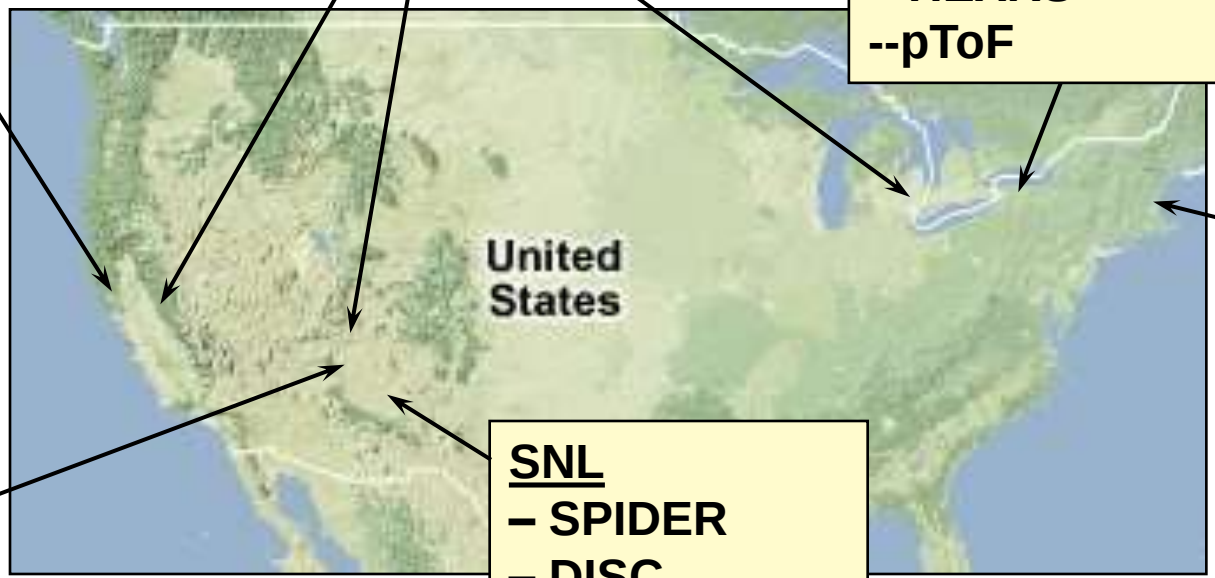
LLNL
- FABS, NBI
- Dante I & II
- VISAR
- DISC
- RAGS
- hGXI
- ARIANE
- DIXI
- NAD
- -- MRS

NSTec
- Calibration

U of M.
- HEMPI

LLE
- NToFs
- 4⎡ fidu system
- MRS, NADS
- SPBT
- HEXRS
- --pToF

AWE
- FFLEX

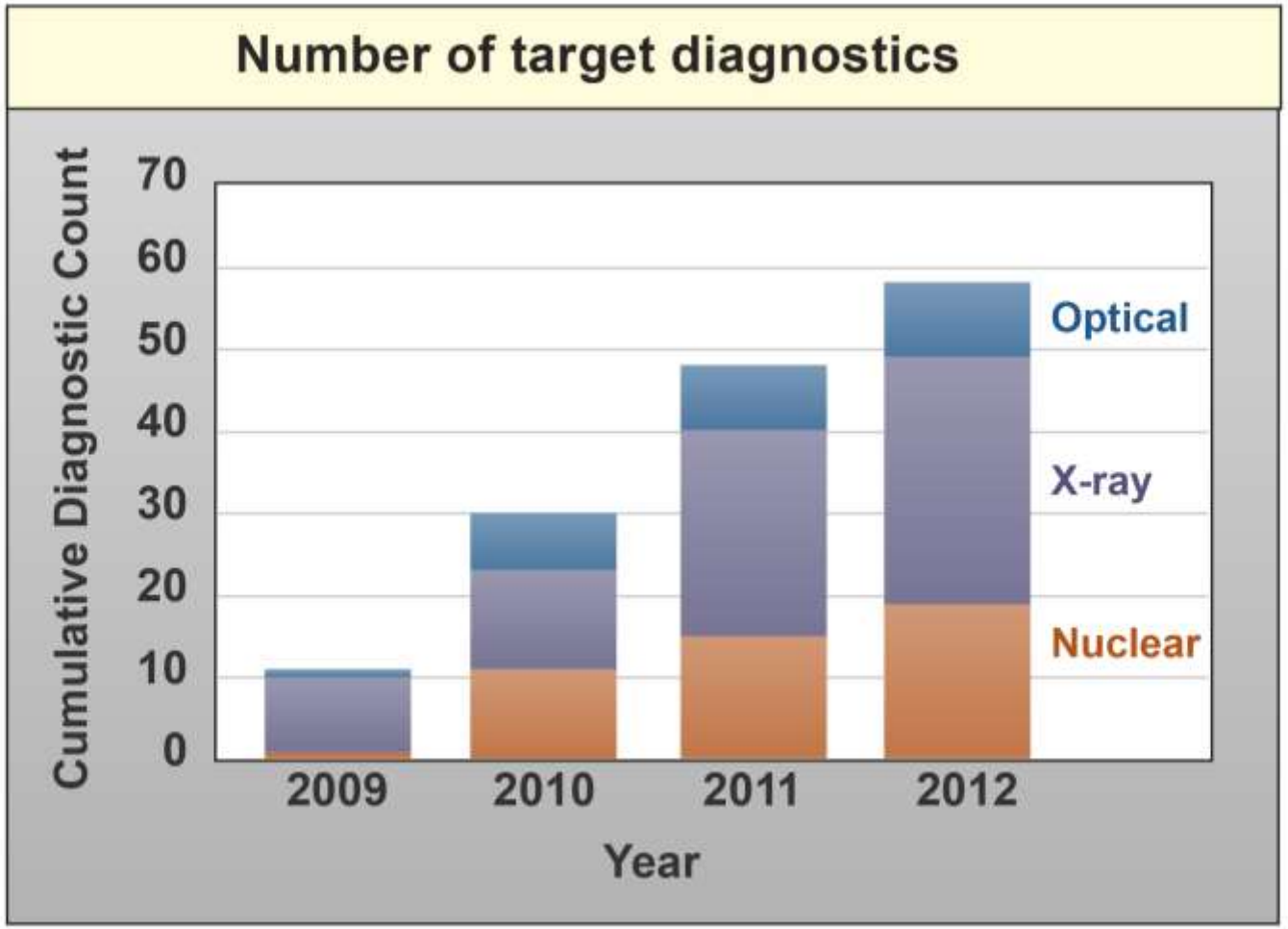


MIT
- MRS
- WRF
- PTOF

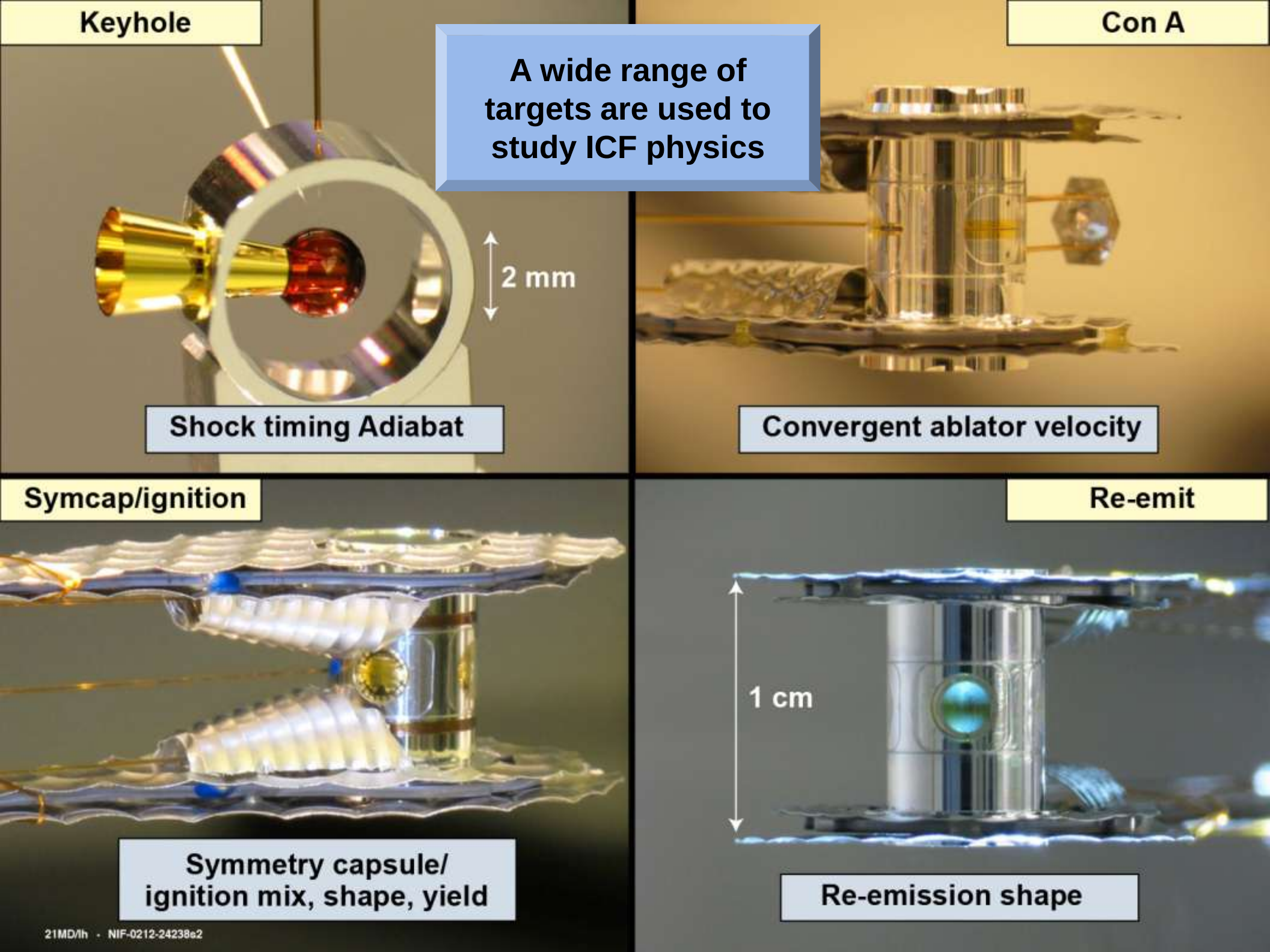
LANL
- GXD
- ©burn
- n imaging

SNL
- SPIDER
- DISC
- NAD (Cu)
- RAGS

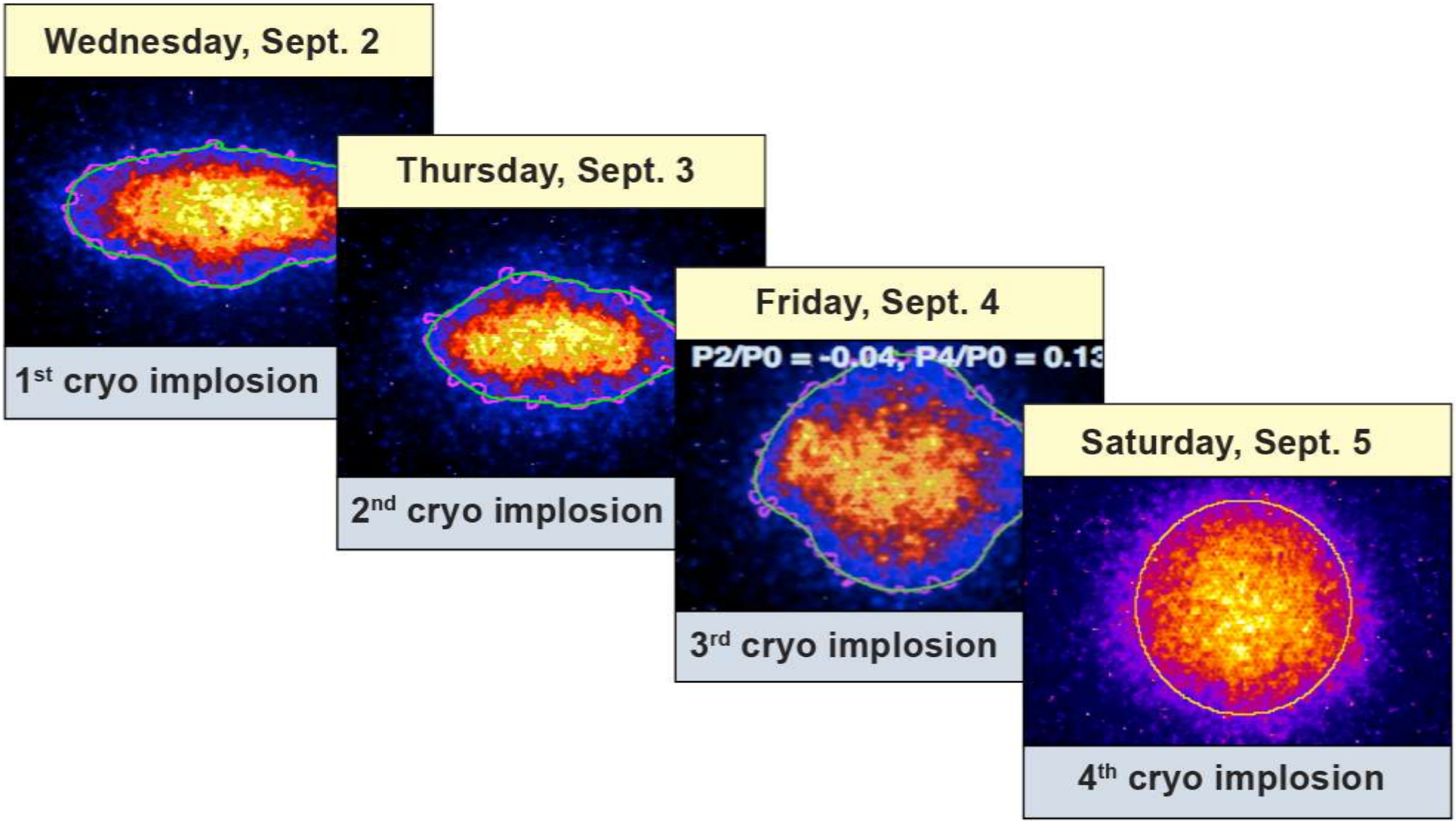
The diagnostic capabilities have grown significantly



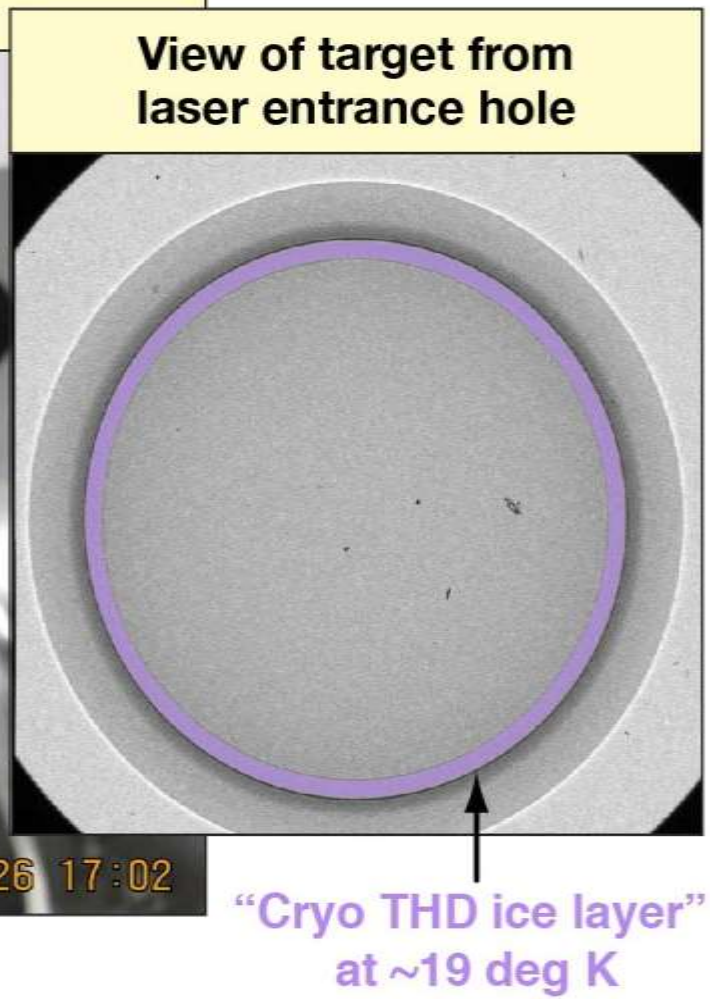
Secretary Chu


Keyhole
A wide range of targets are used to study ICF physics
Con A
2 mm
Shock timing Adiabat
Convergent ablator velocity
Symcap/ignition
Re-emit
1 cm
Symmetry capsule/ ignition mix, shape, yield
Re-emission shape
21MD/lh · NIF-0212-24238e2

On September 2, 2009 NIF conducted its first integrated hohlraum experiments



On September 29, 2010 NIC conducted the first cryo-layered target experiment on NIF

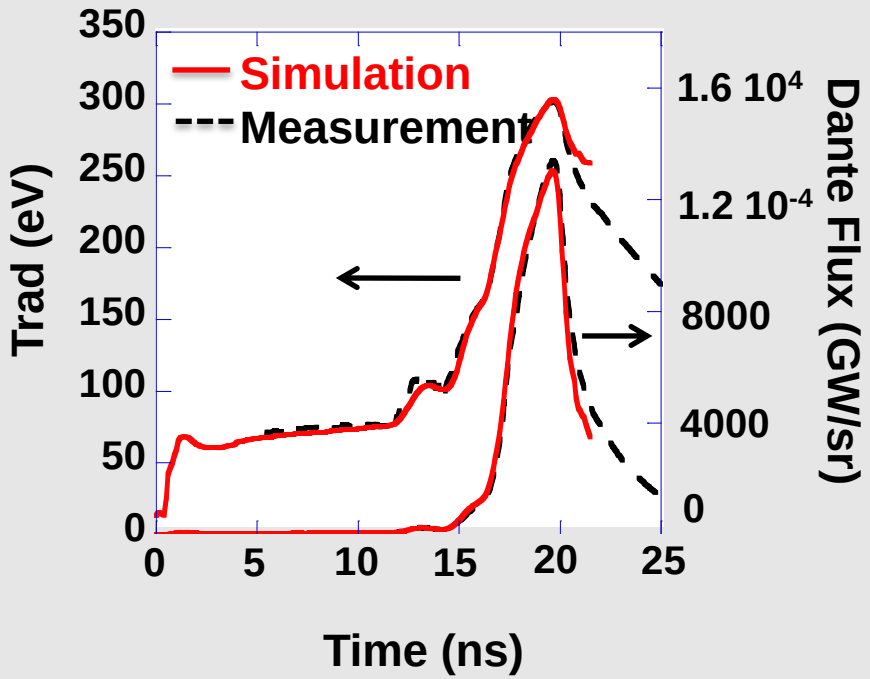


Precision tuning experiments started in May 2011

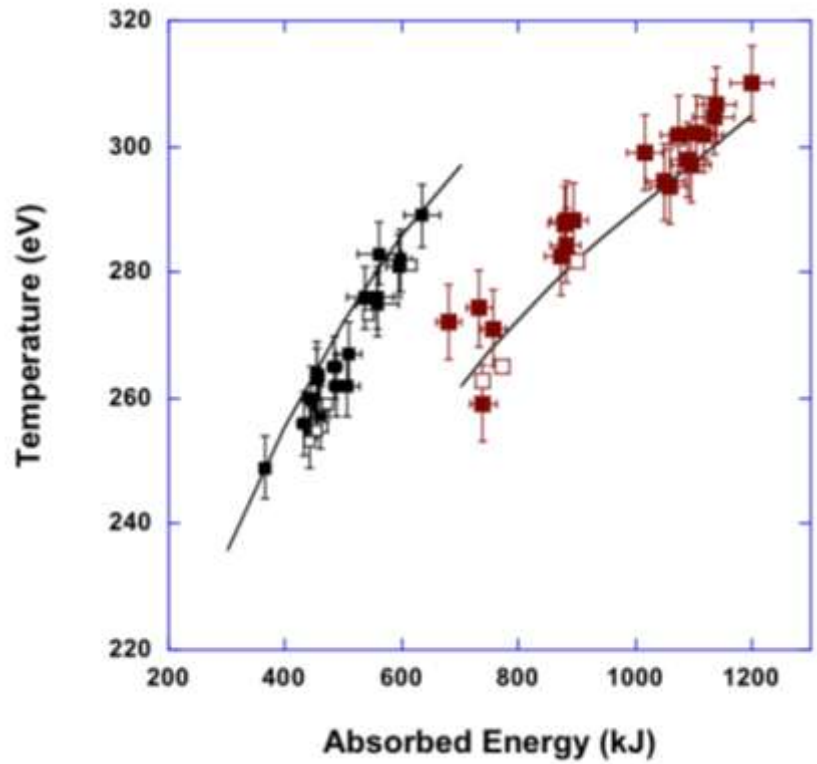
The required hohlraum temperatures have been achieved, with LPI under sufficient control

- LPI observed to be at level acceptable for ignition experiments
- Detailed dependencies different to expectations, but reproducible and tunable

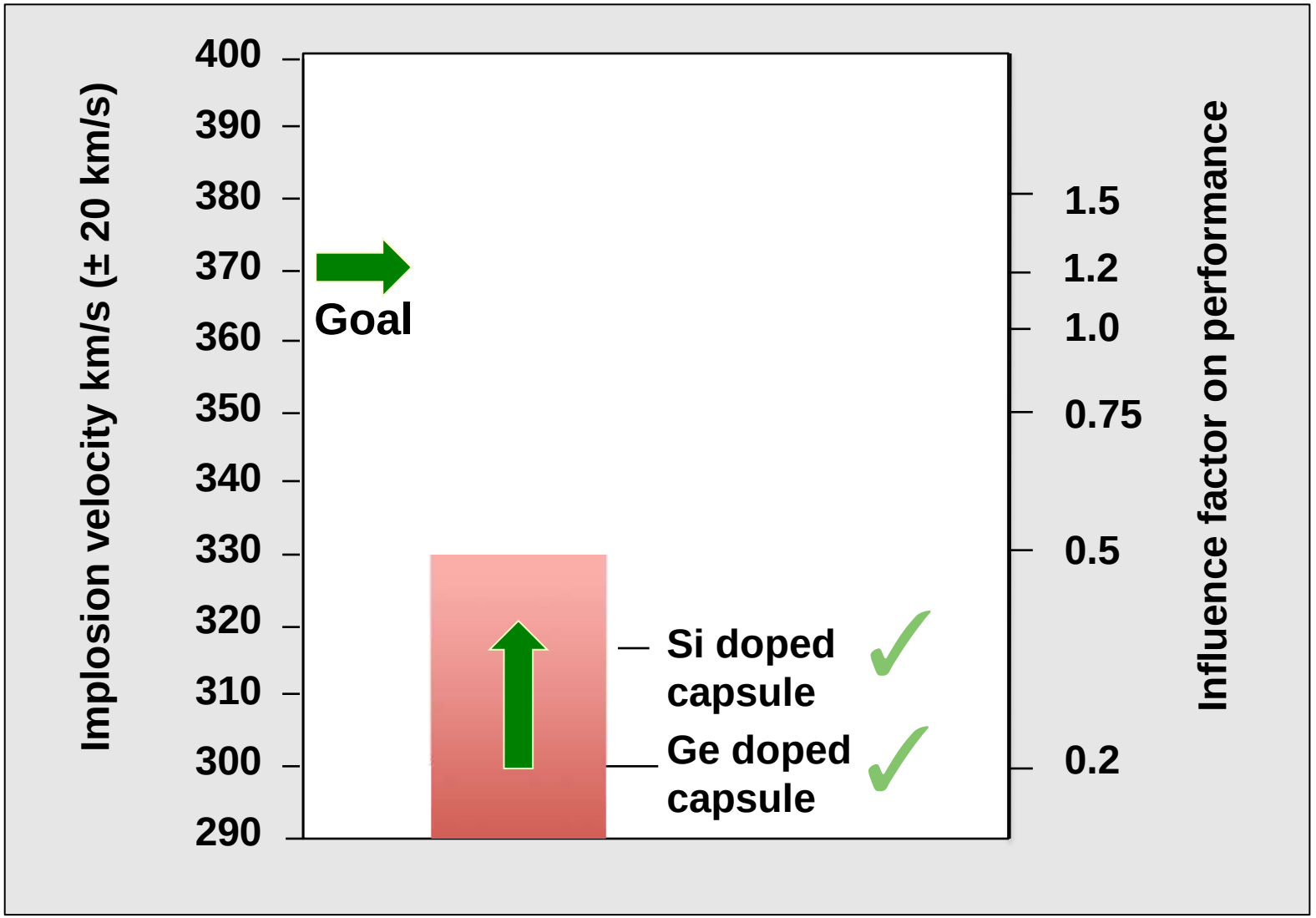
Measured vs. simulated Dante drive profile



Hohlraum Radiation Temperatures are well above 300 eV

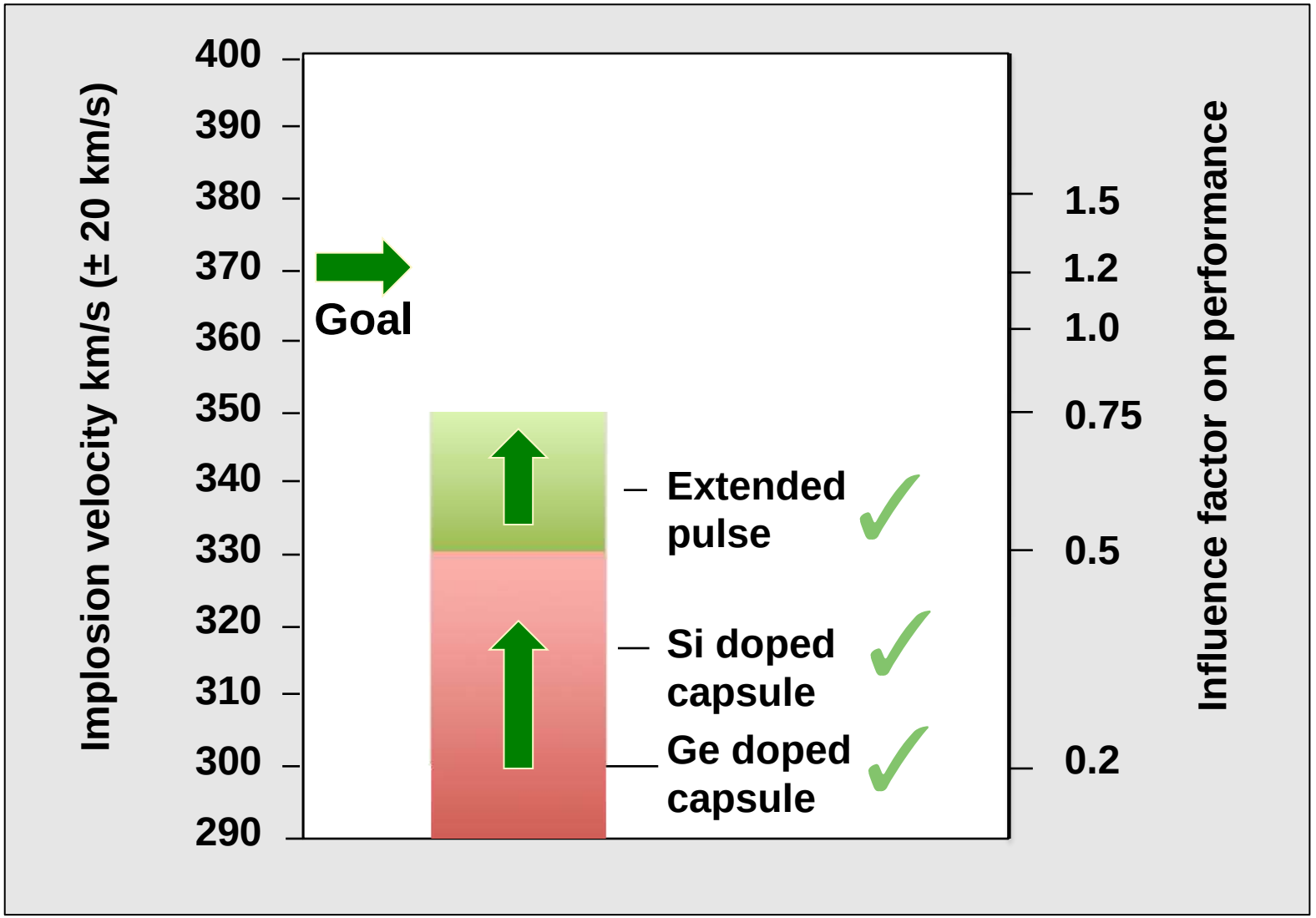


Velocity: progression from substantial deficit to an excess that can be traded against mix susceptibility



Hydrodynamic instability growth and velocity need to be balanced

Velocity: progression from substantial deficit to an excess that can be traded against mix susceptibility



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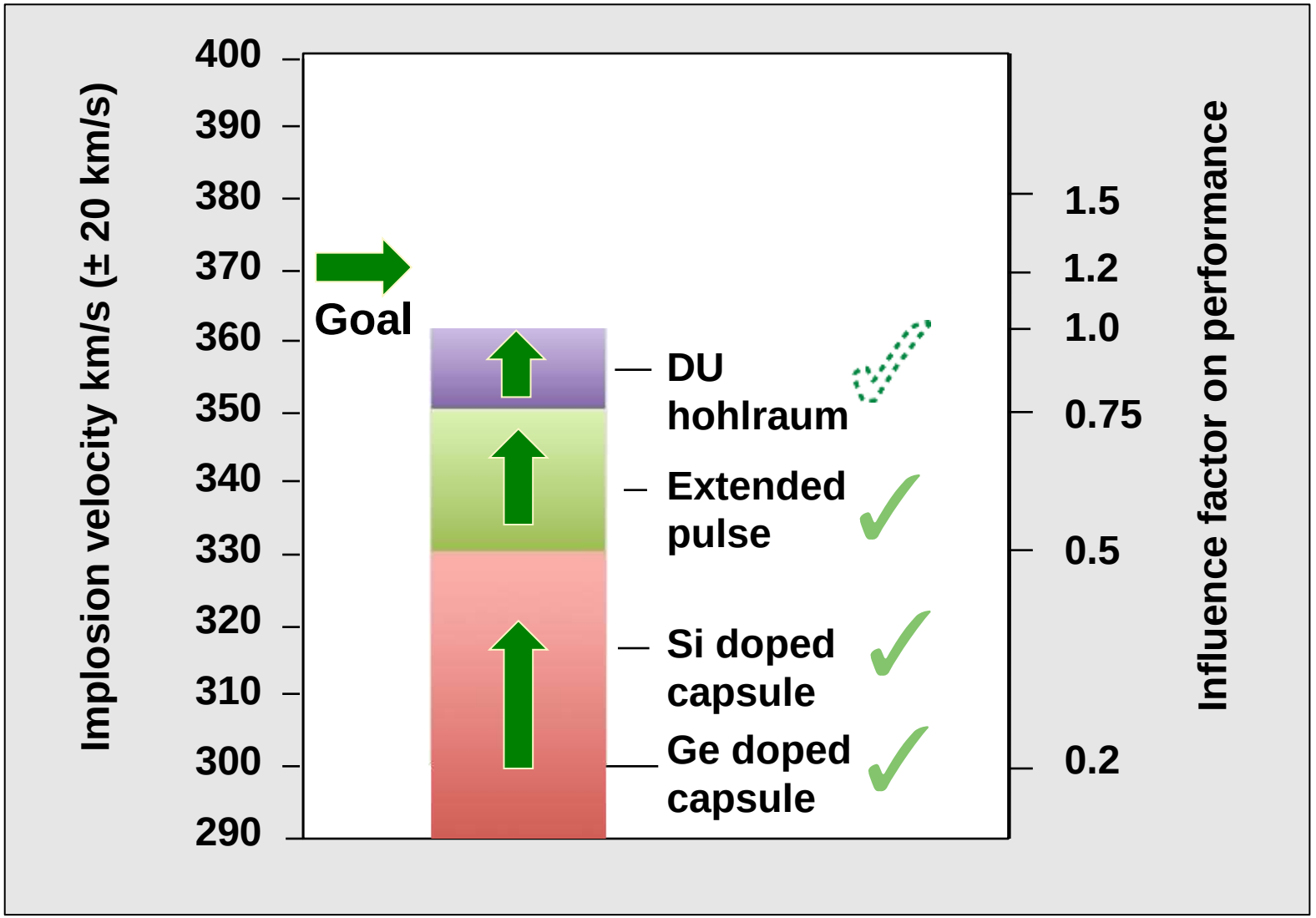

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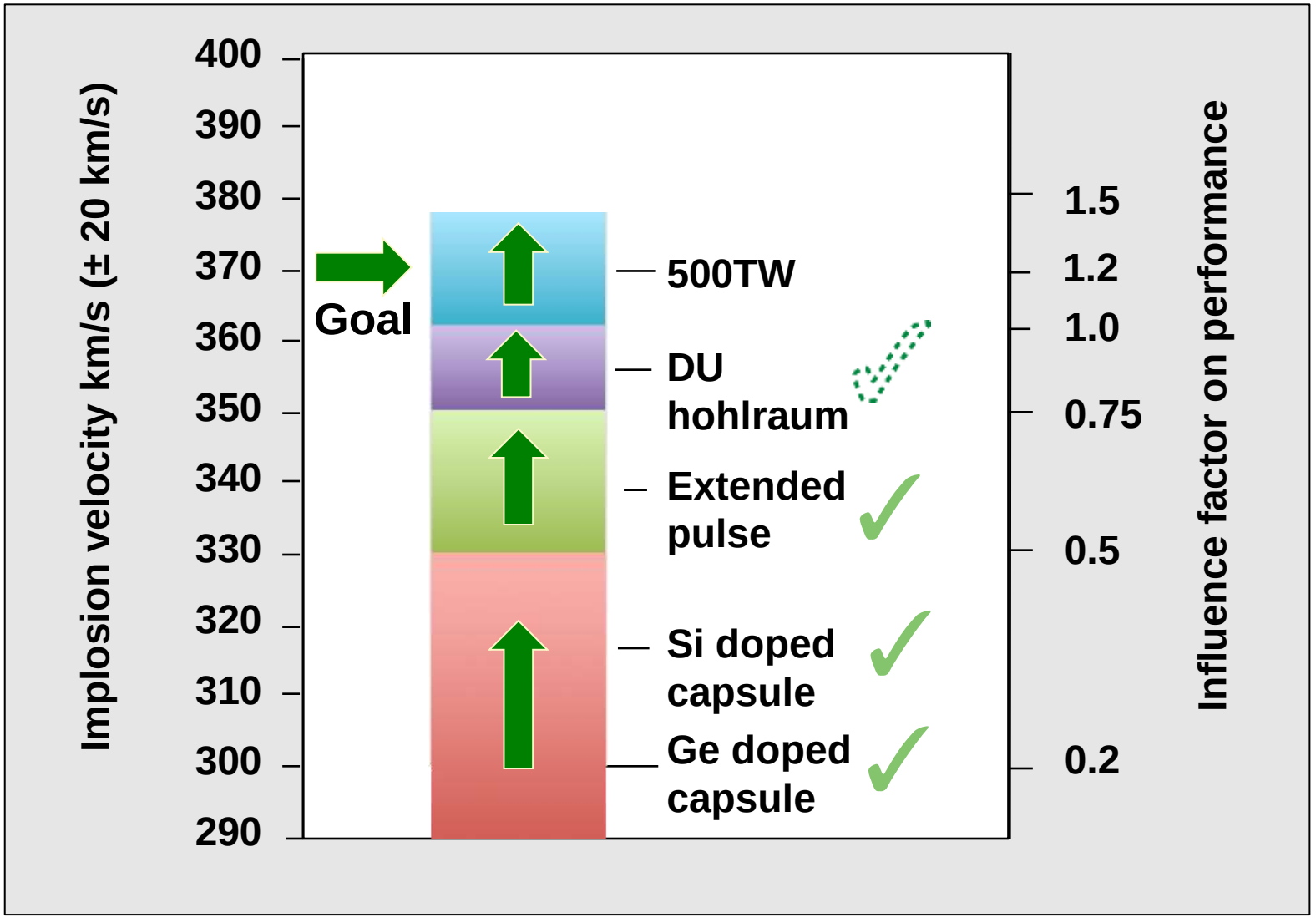

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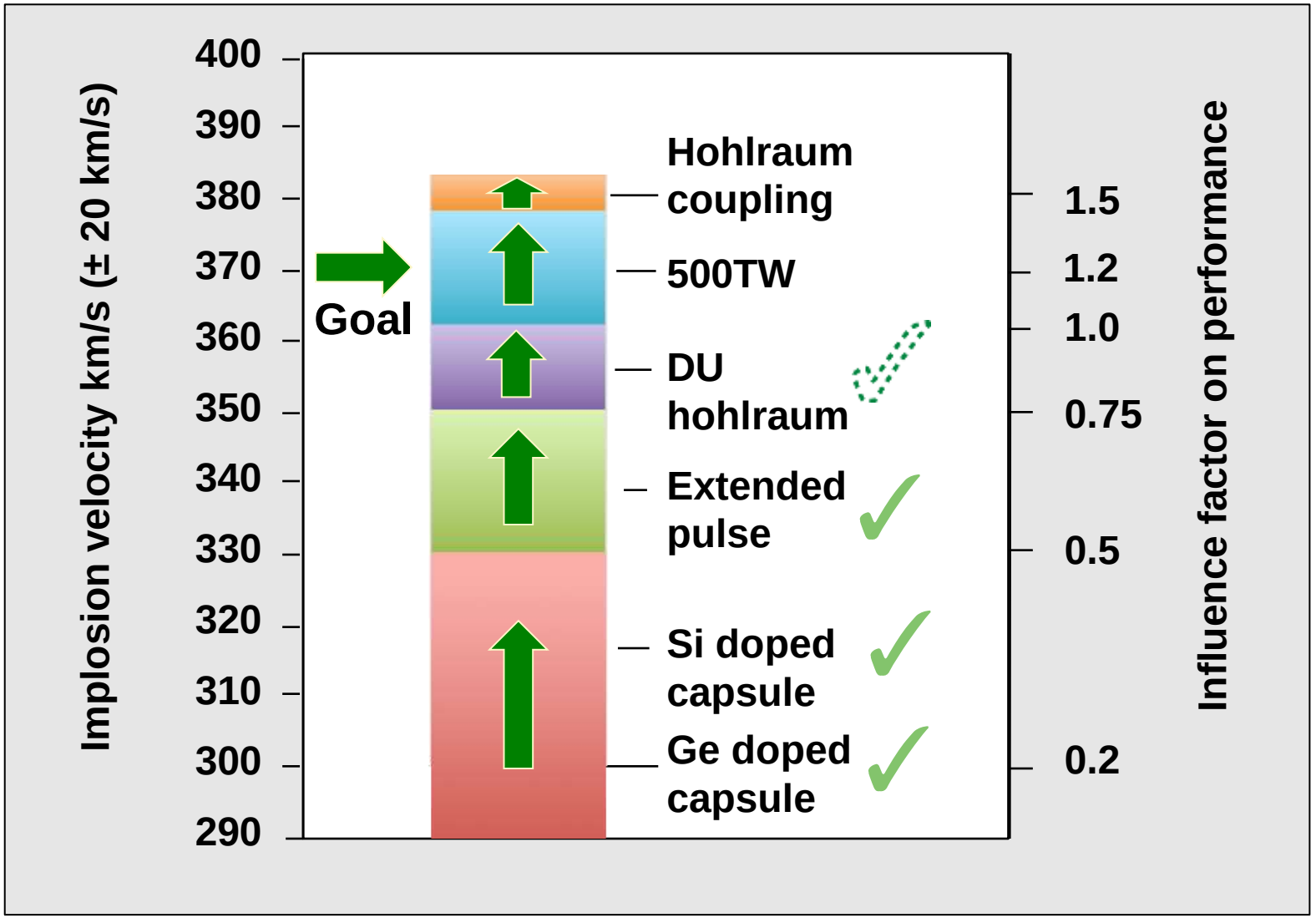

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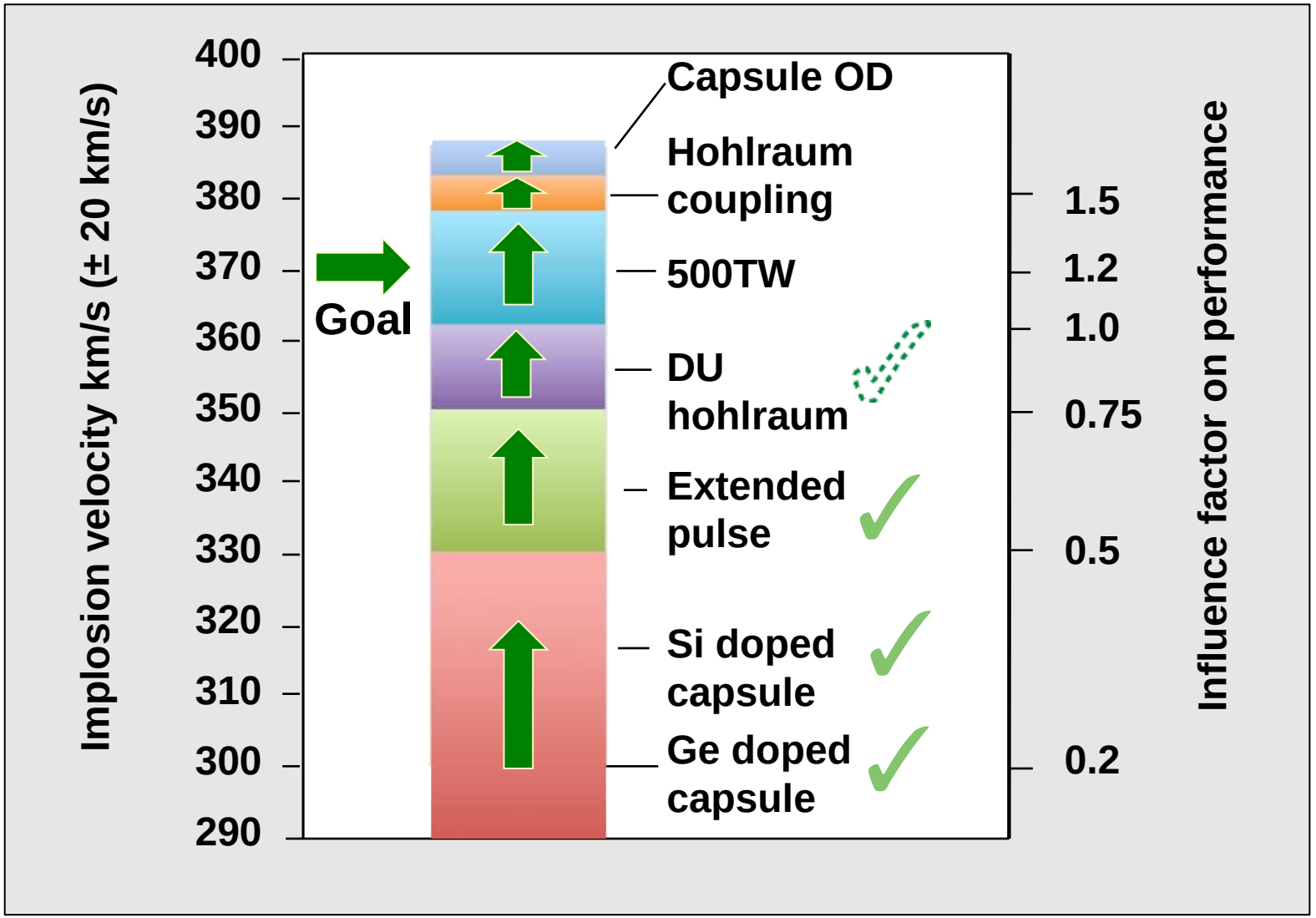
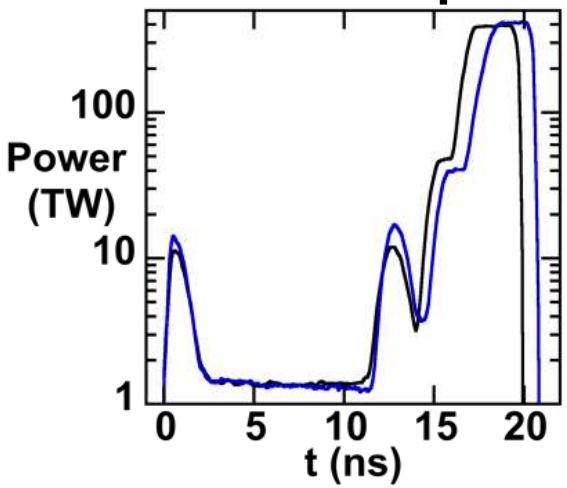
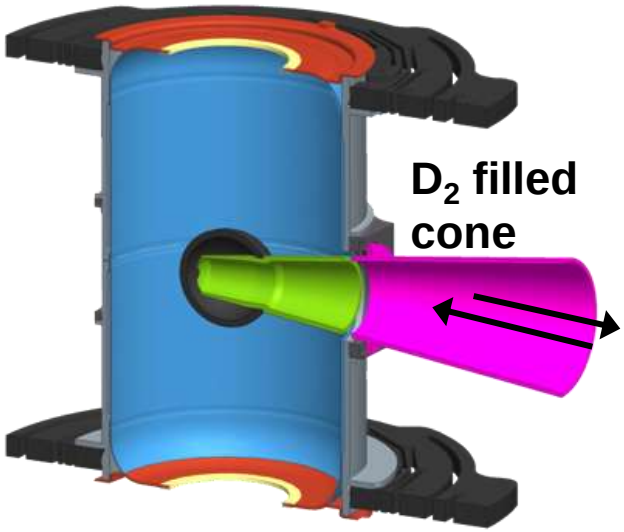


Hydrodynamic instability growth and velocity need to be balanced

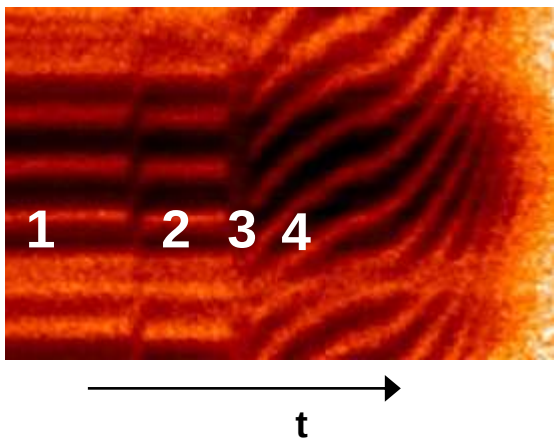
Adiabat: controlled via timing the 4-shocks; measured using a “keyhole target”

Tune laser pulse

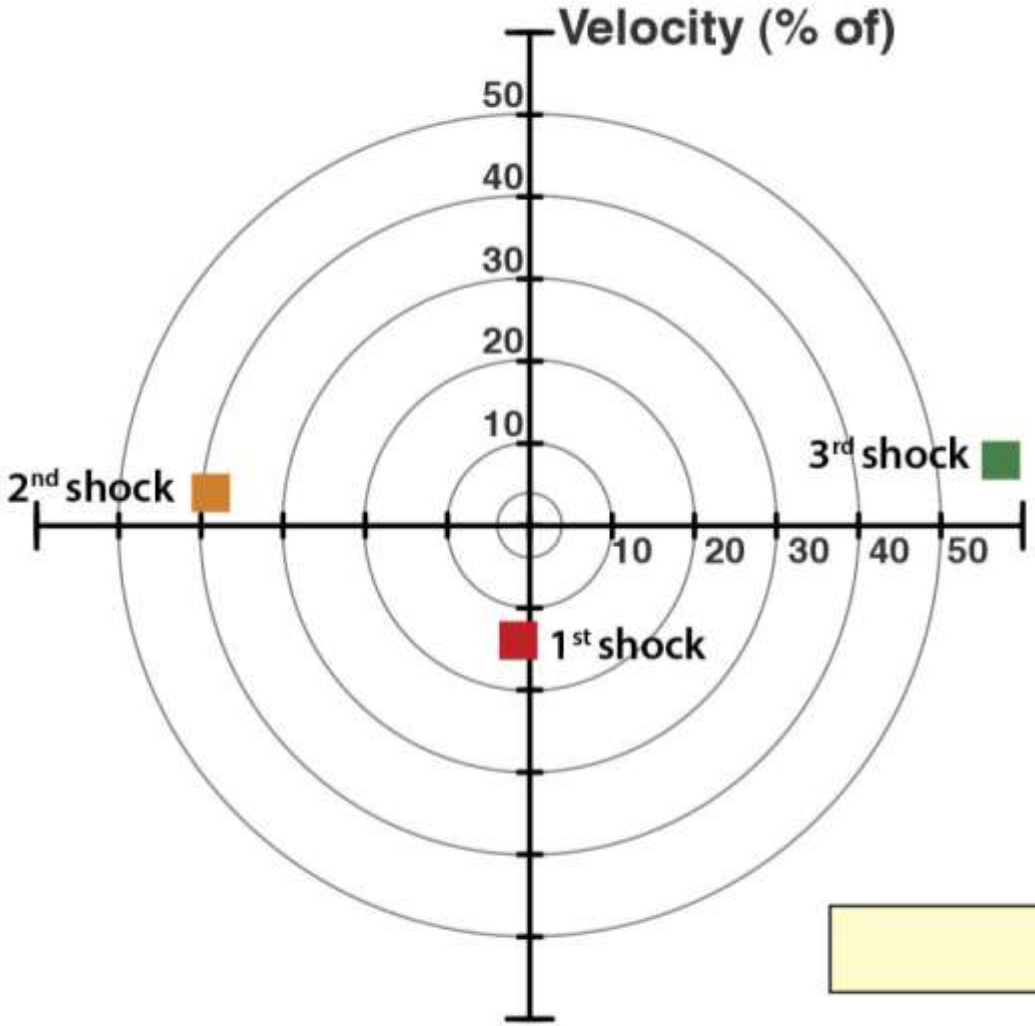


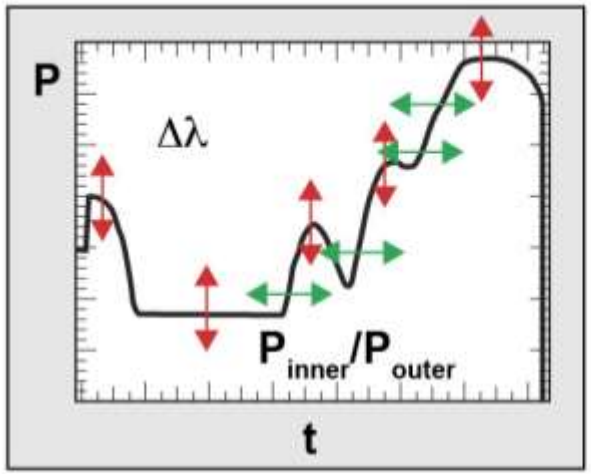


VISAR streak



Adiabat: Shocking timing shot A



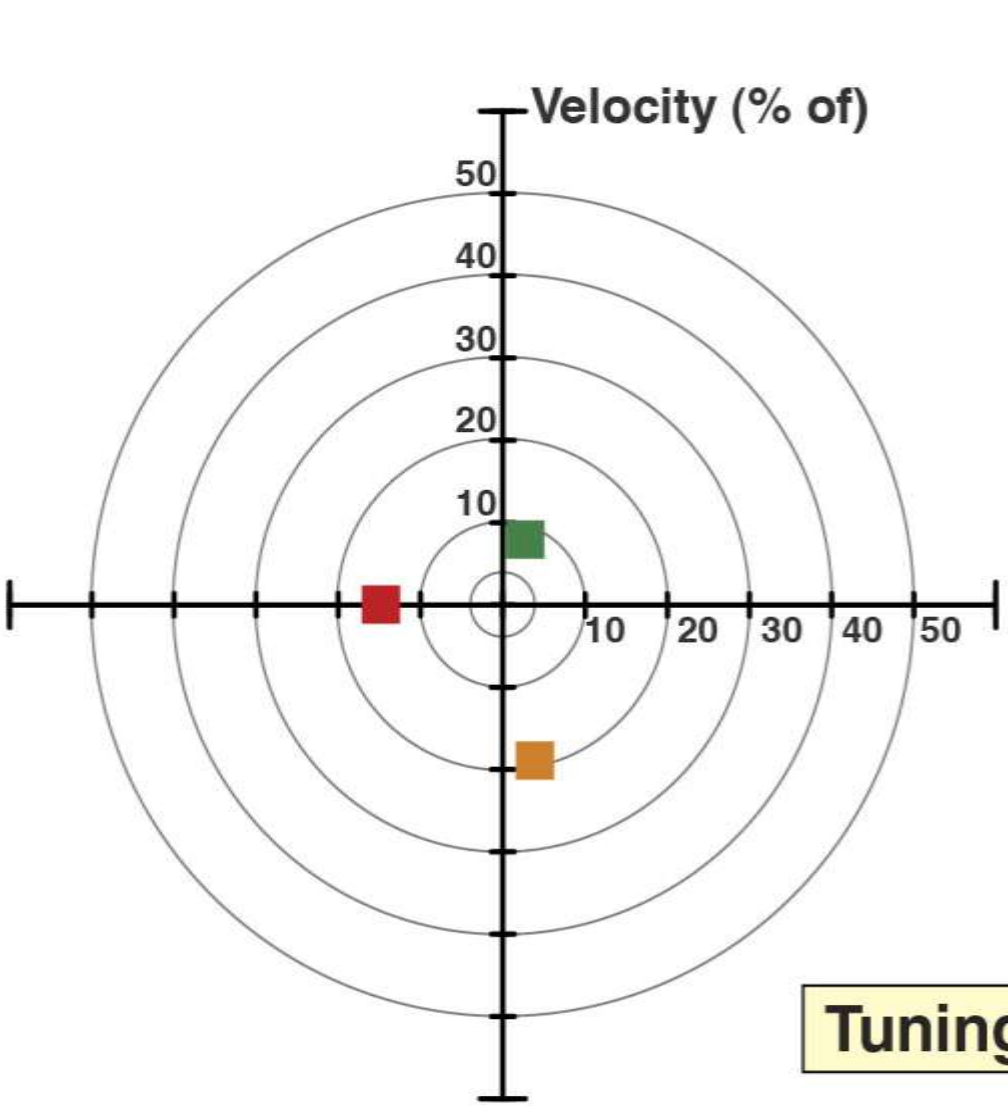


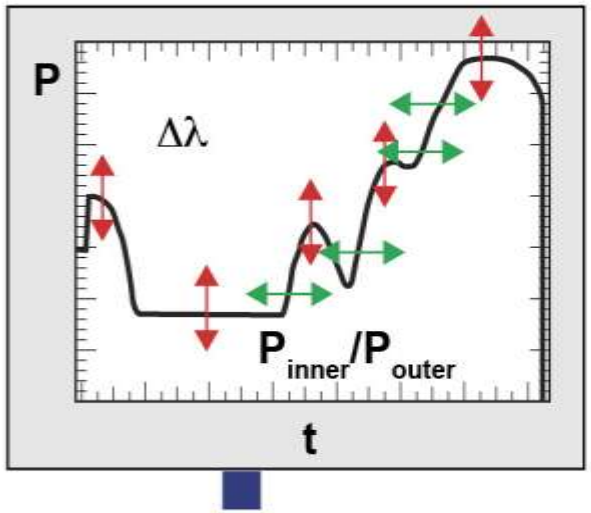
4th shock

Merged depth (% of)

Baseline shot

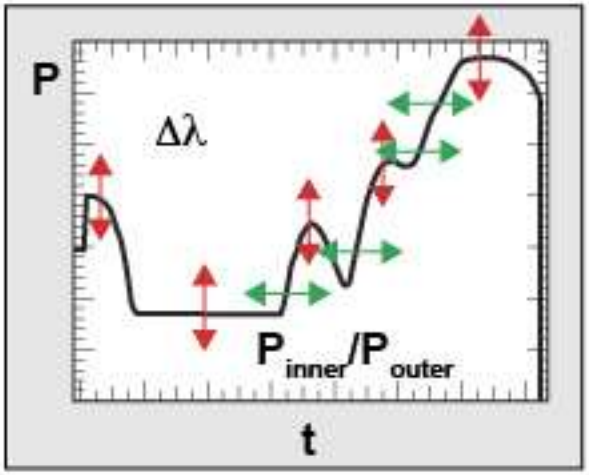
Adiabat: Shock timing shot B

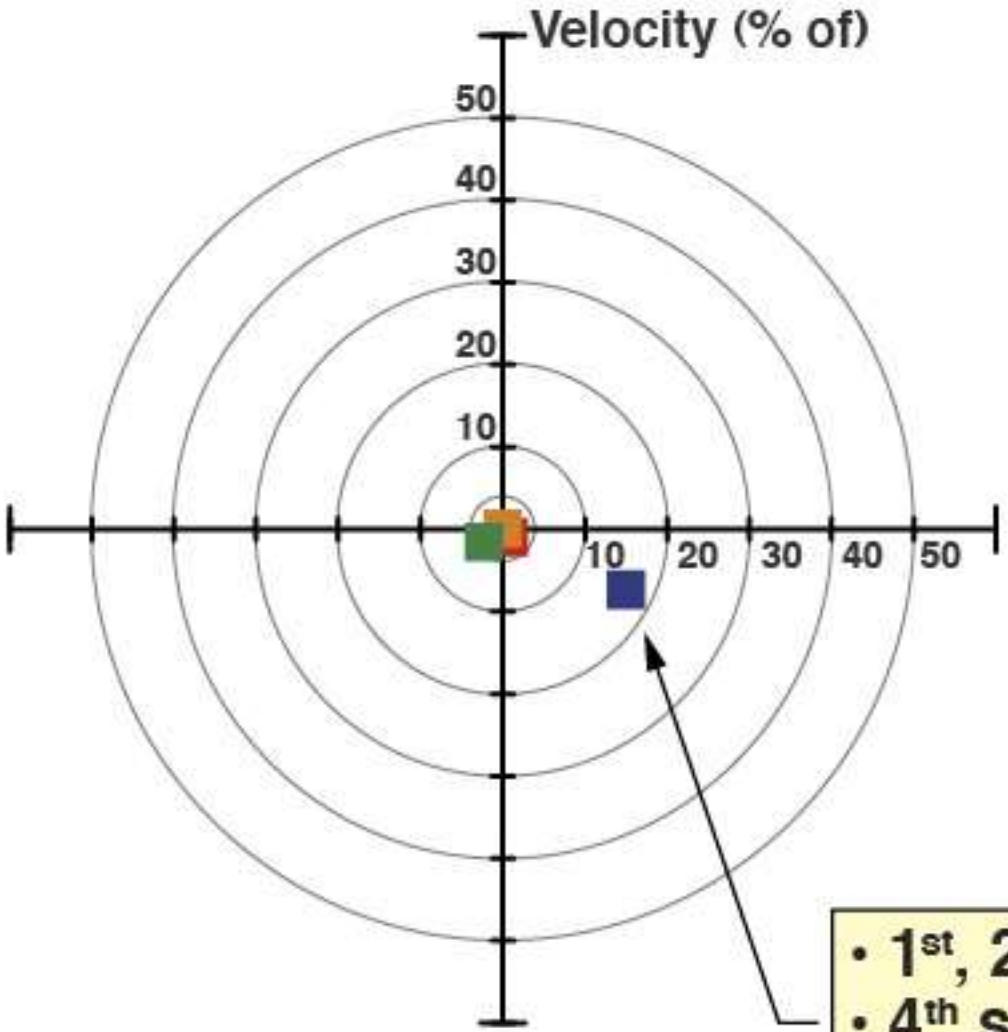




Tuning all shock timing / amplitude

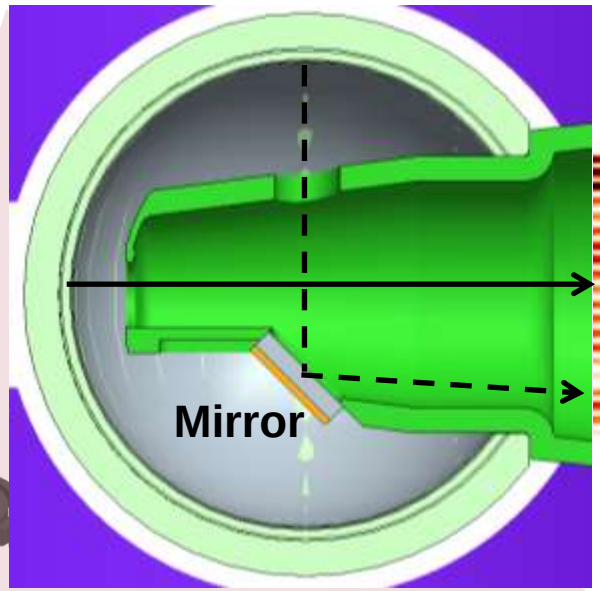
Adiabat: Shock timing shot C

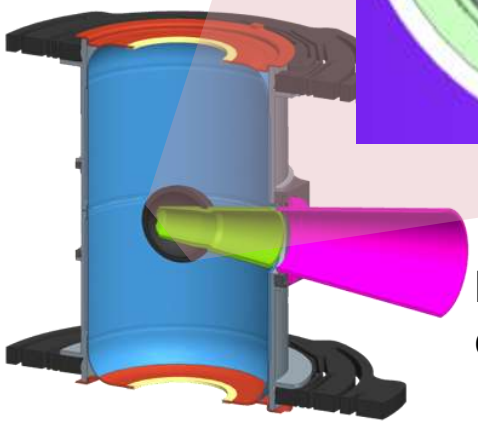




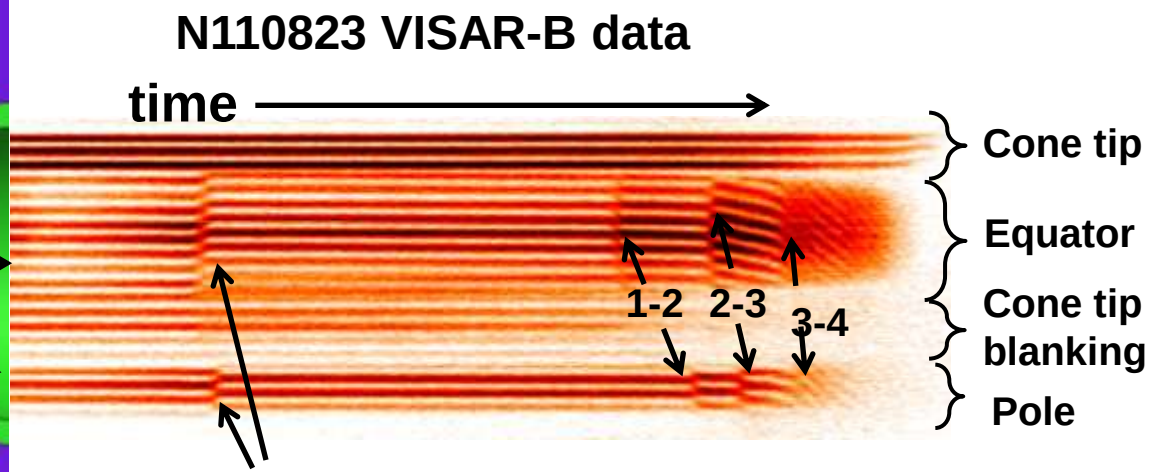
- 1st, 2nd, 3rd shocks coalescing
- 4th shock

Adiabat:
New diagnostic added to monitor shock symmetry



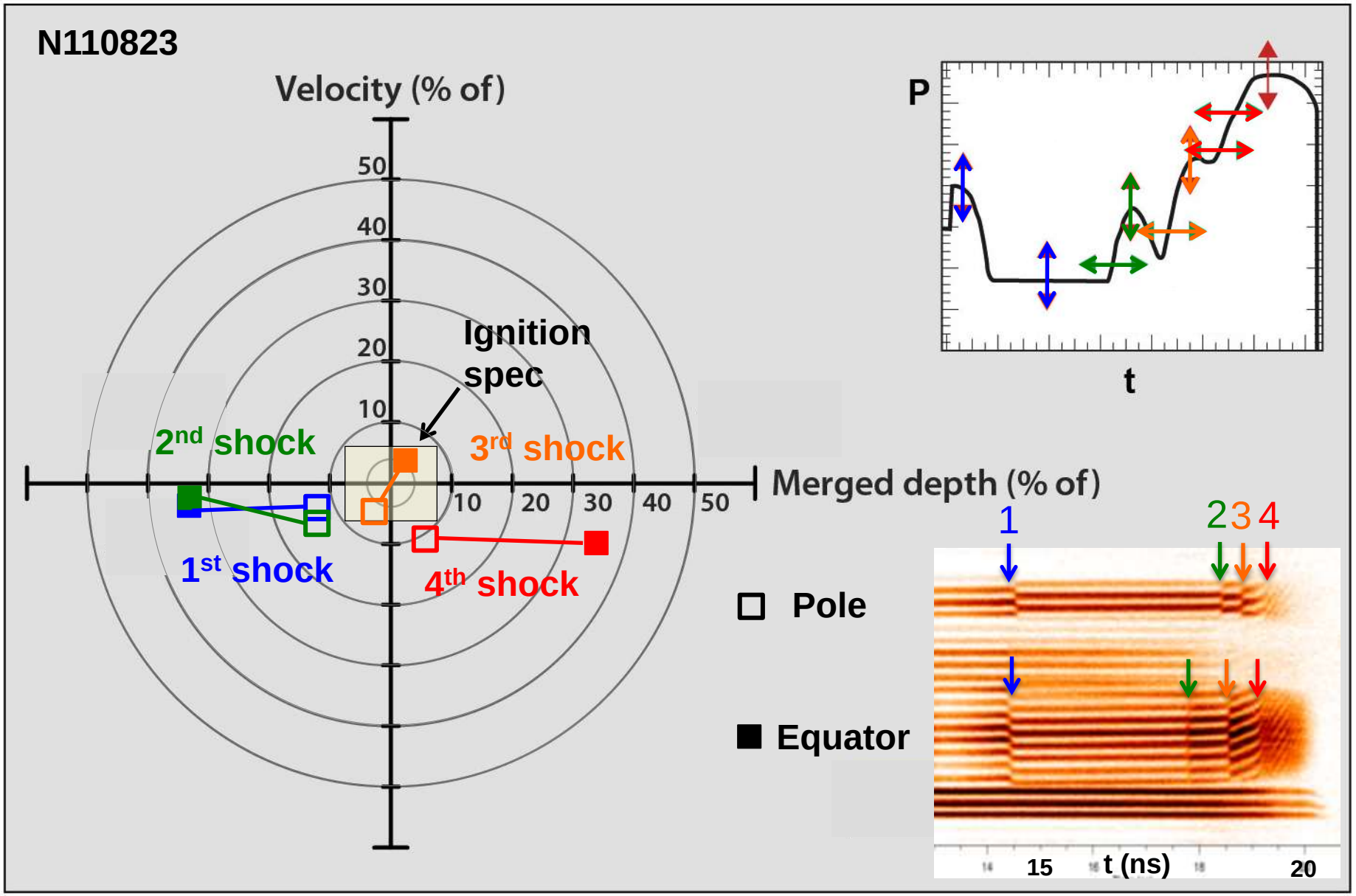


D_2 filled cone

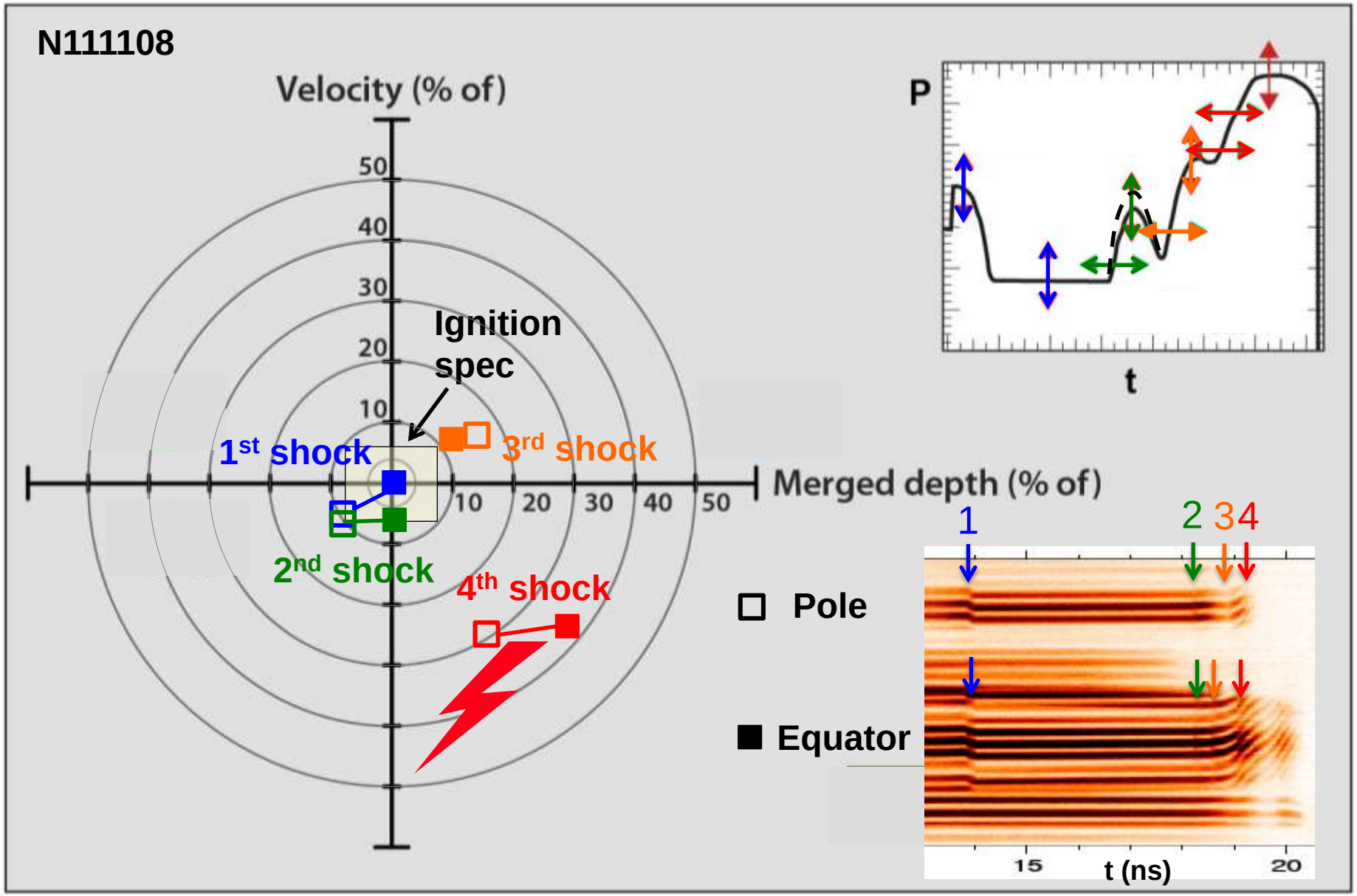


- Velocity was 5-10% low on the pole
- The October 2011 campaign used the mirrored keyhole to correct time dependent asymmetry

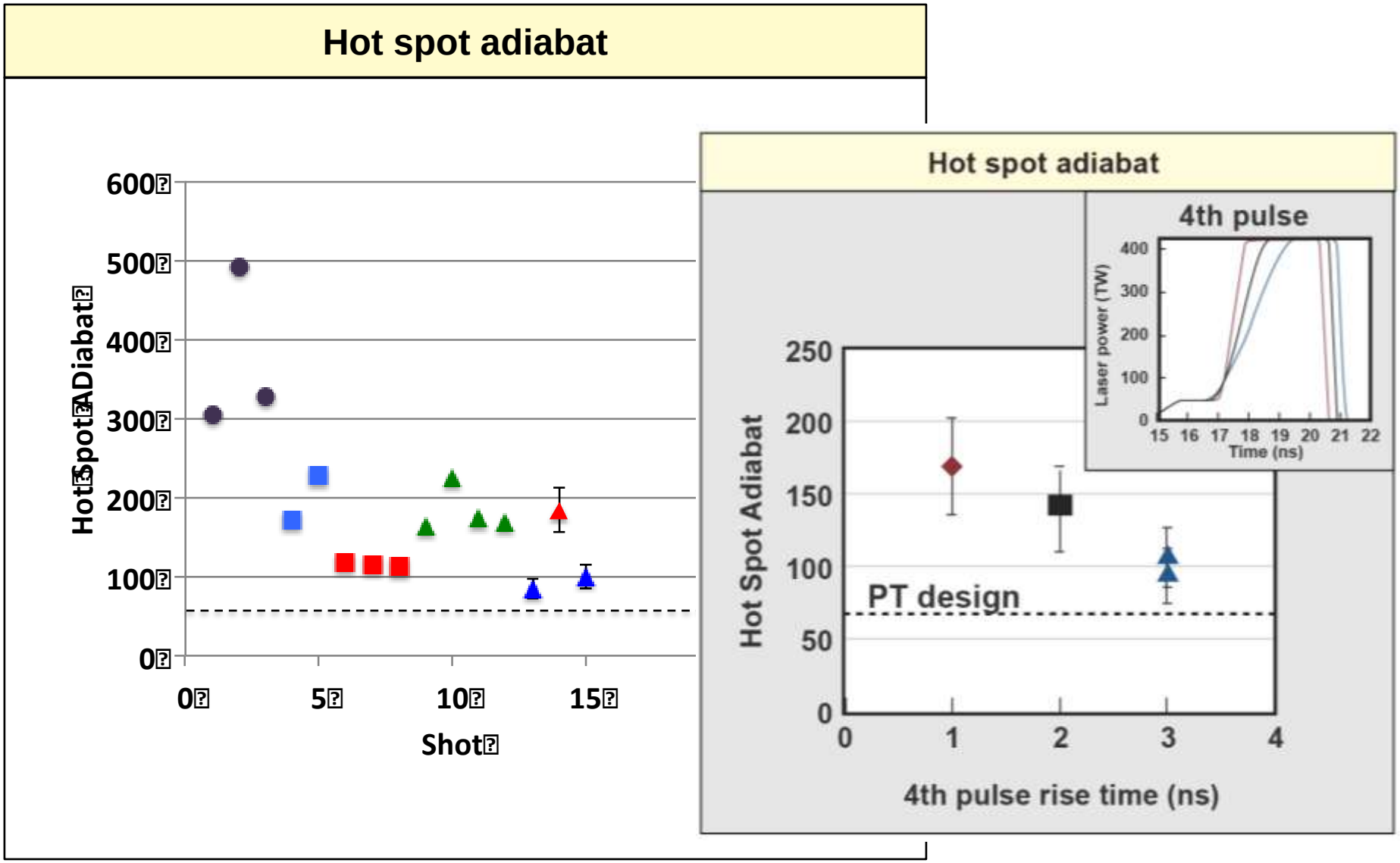
August 2011 - Equator vs. pole asymmetries in shock velocities and merge depths exceeded ignition tolerance



November 2011: Symmetrized shock within ignition tolerance by setting independent inner and outer cone 2nd pulse powers

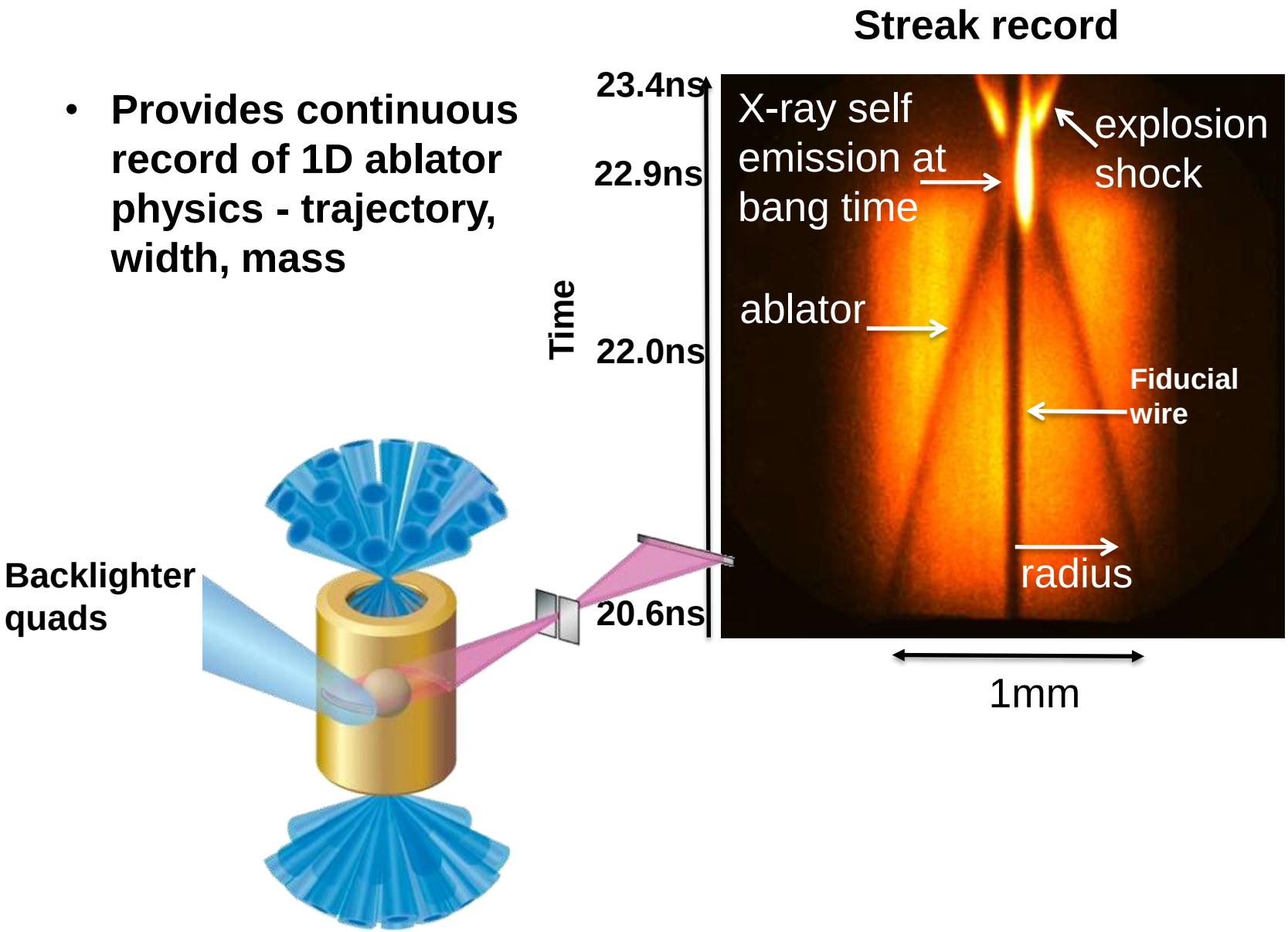


Hot spot adiabat is approaching point design conditions with slow rise 4th pulse



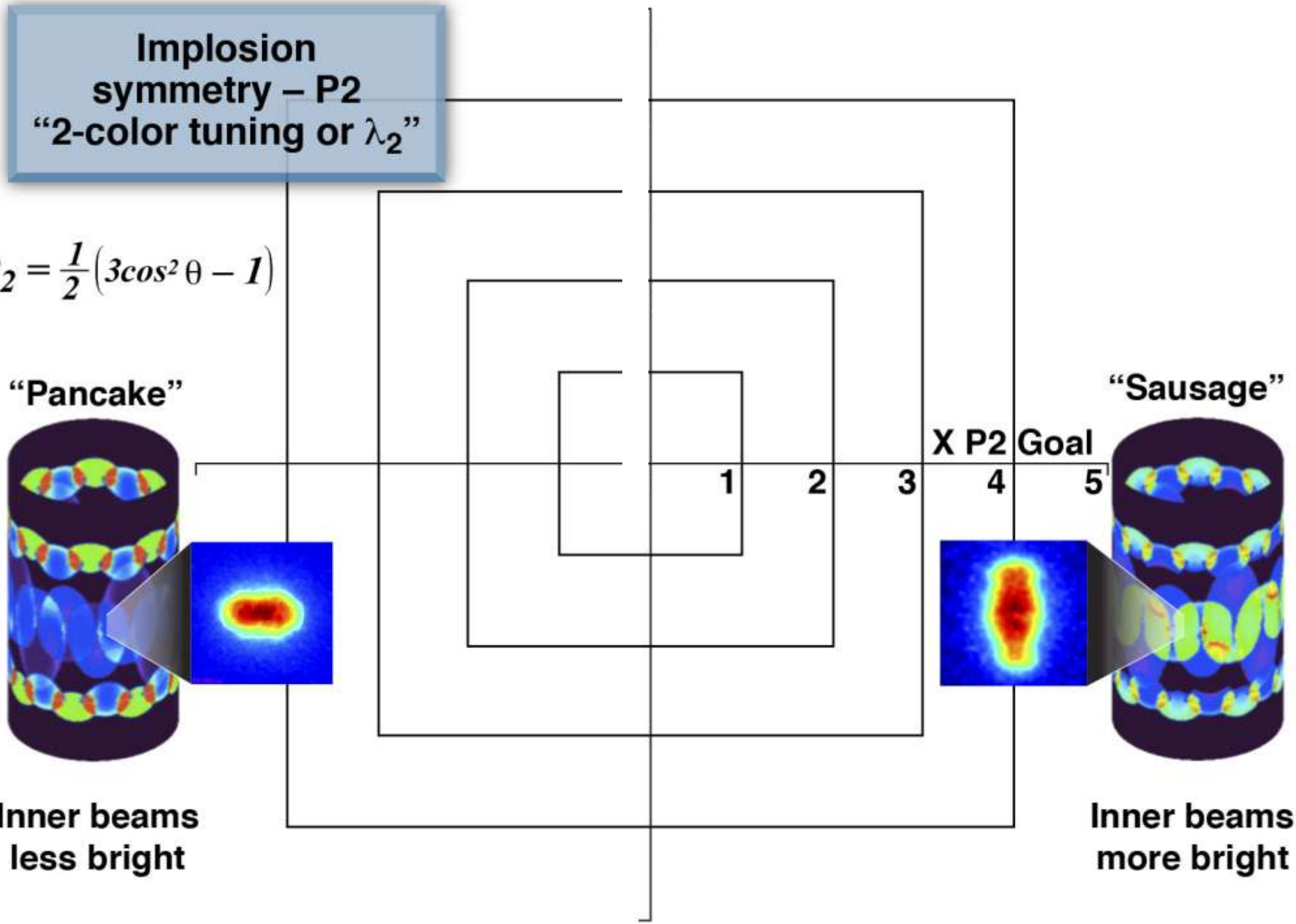
Commissioned streaked backlit diagnosis to further improve implosion performance

- **Provides continuous record of 1D ablator physics - trajectory, width, mass**



Implosion symmetry – P2 "2-color tuning or λ_2"

$$P_2 = \frac{1}{2}\left(3\cos^2\theta - 1\right)$$

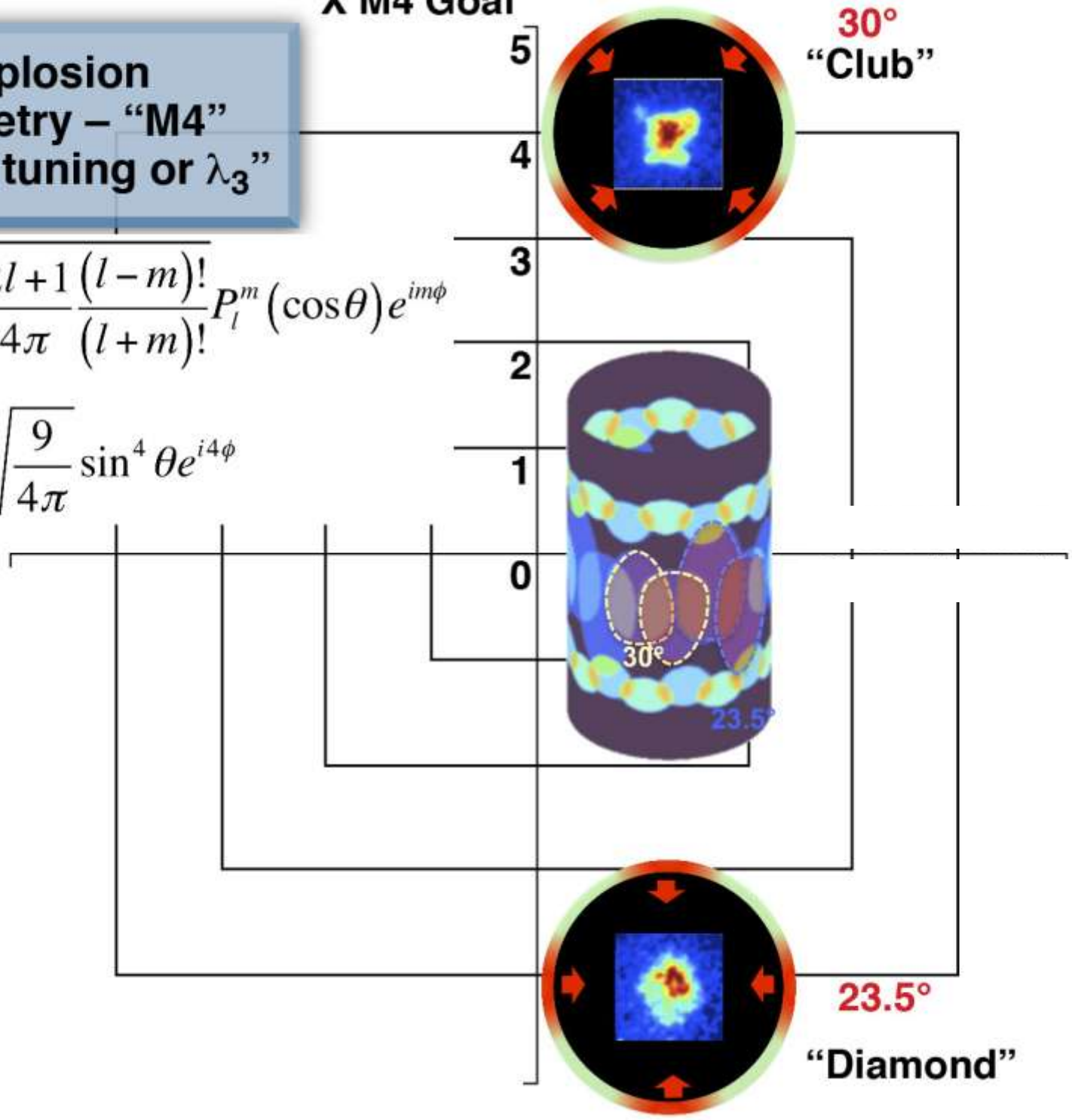


X M4 Goal

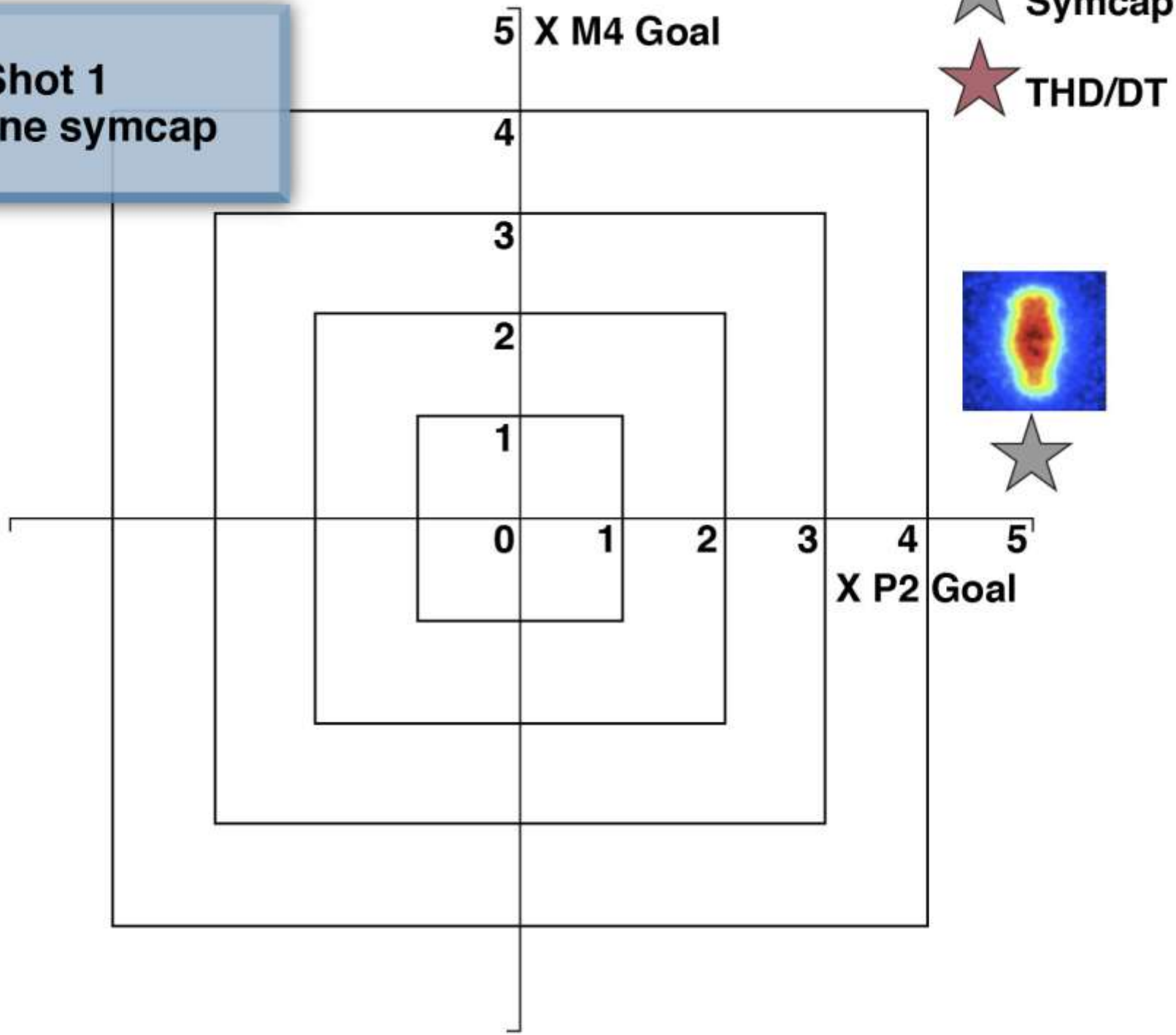
Implosion symmetry – "M4" "3-color tuning or λ_3"

$$Y_l^m(\theta,\phi) = \sqrt{\frac{2l+1}{4\pi}\frac{(l-m)!}{(l+m)!}} P_l^m(\cos\theta) e^{im\phi}$$

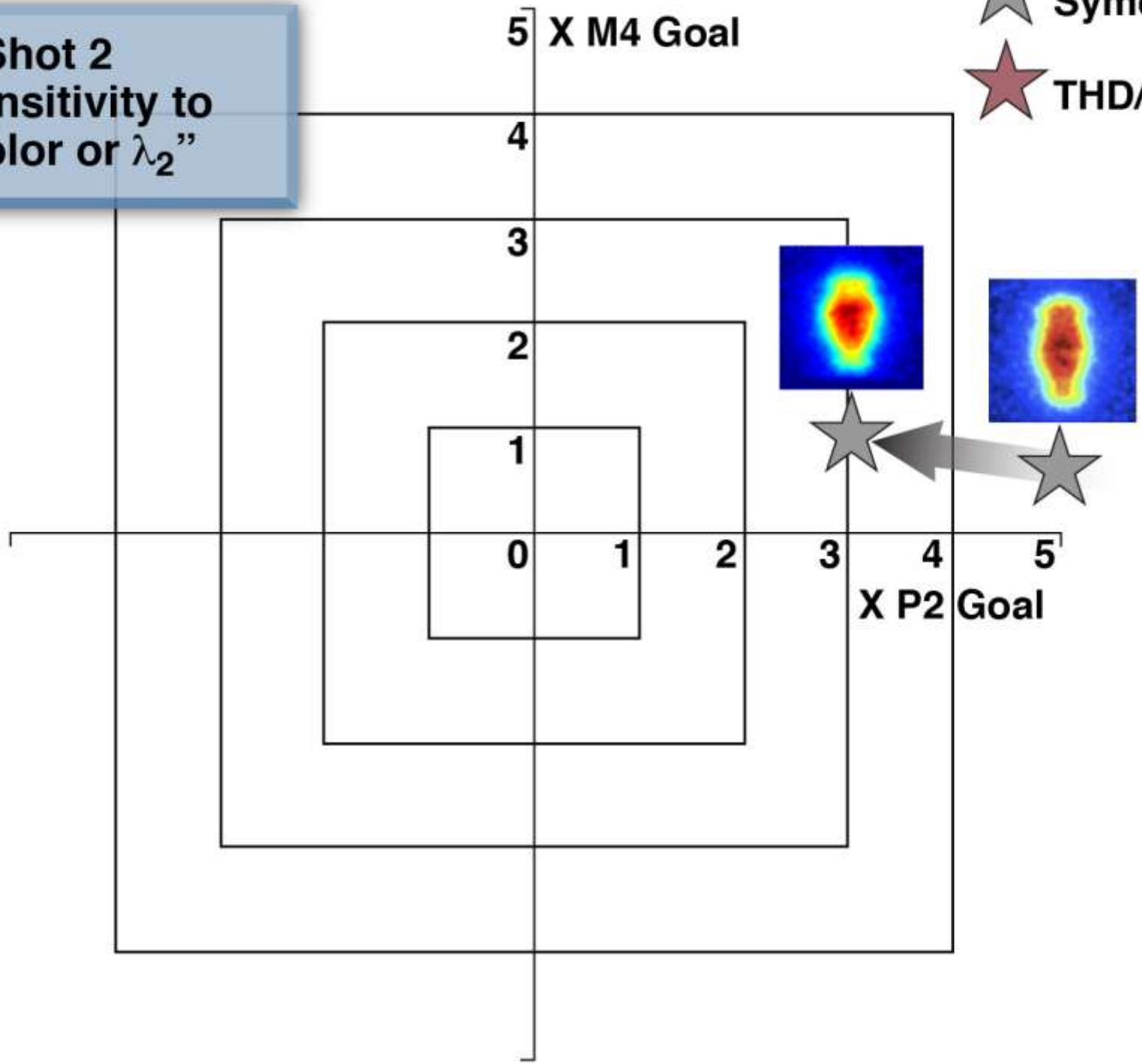
$$Y_4^4(\theta,\phi) = 105\sqrt{\frac{9}{4\pi}}\sin^4\theta e^{i4\phi}$$

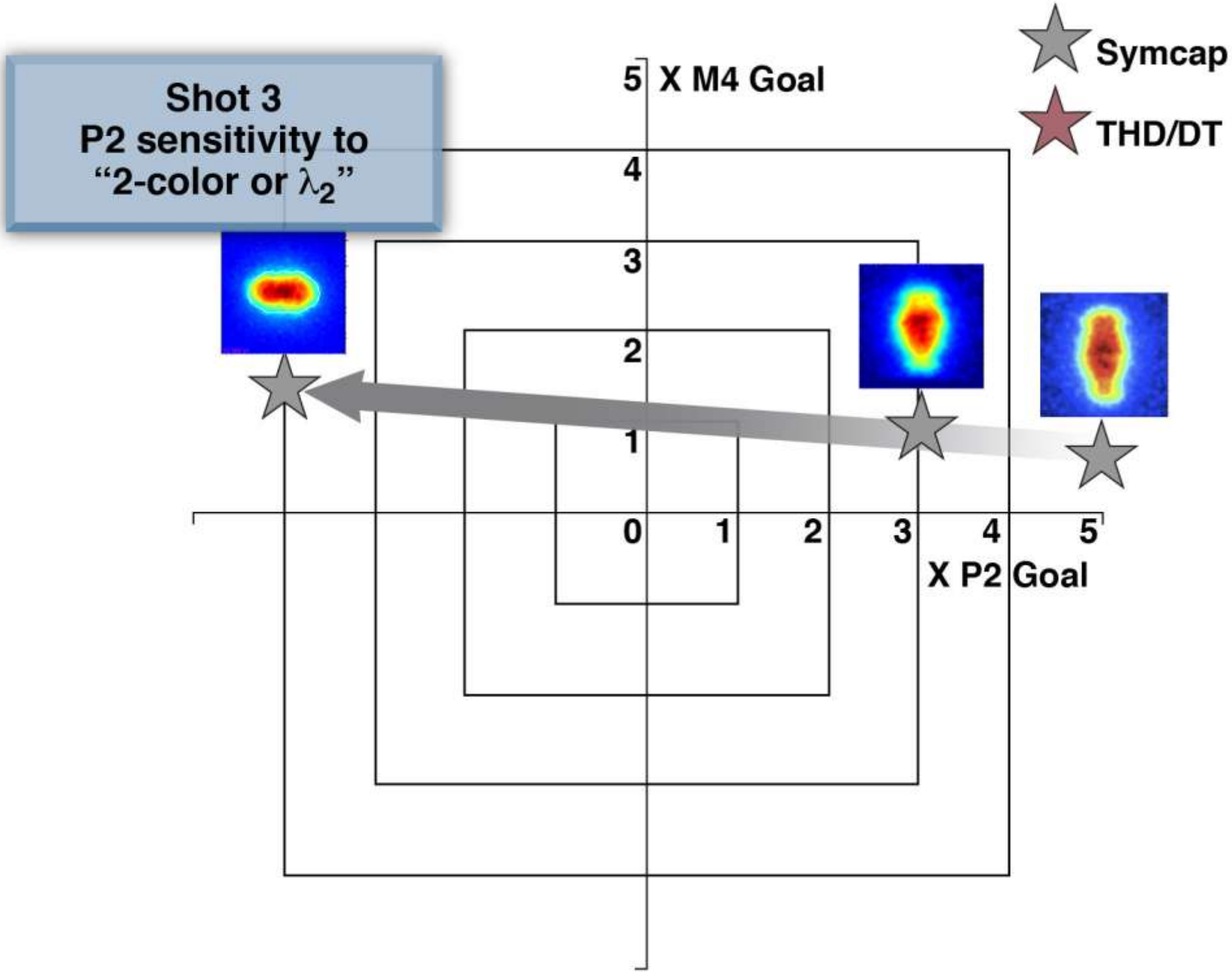


Shot 1
Baseline symcap

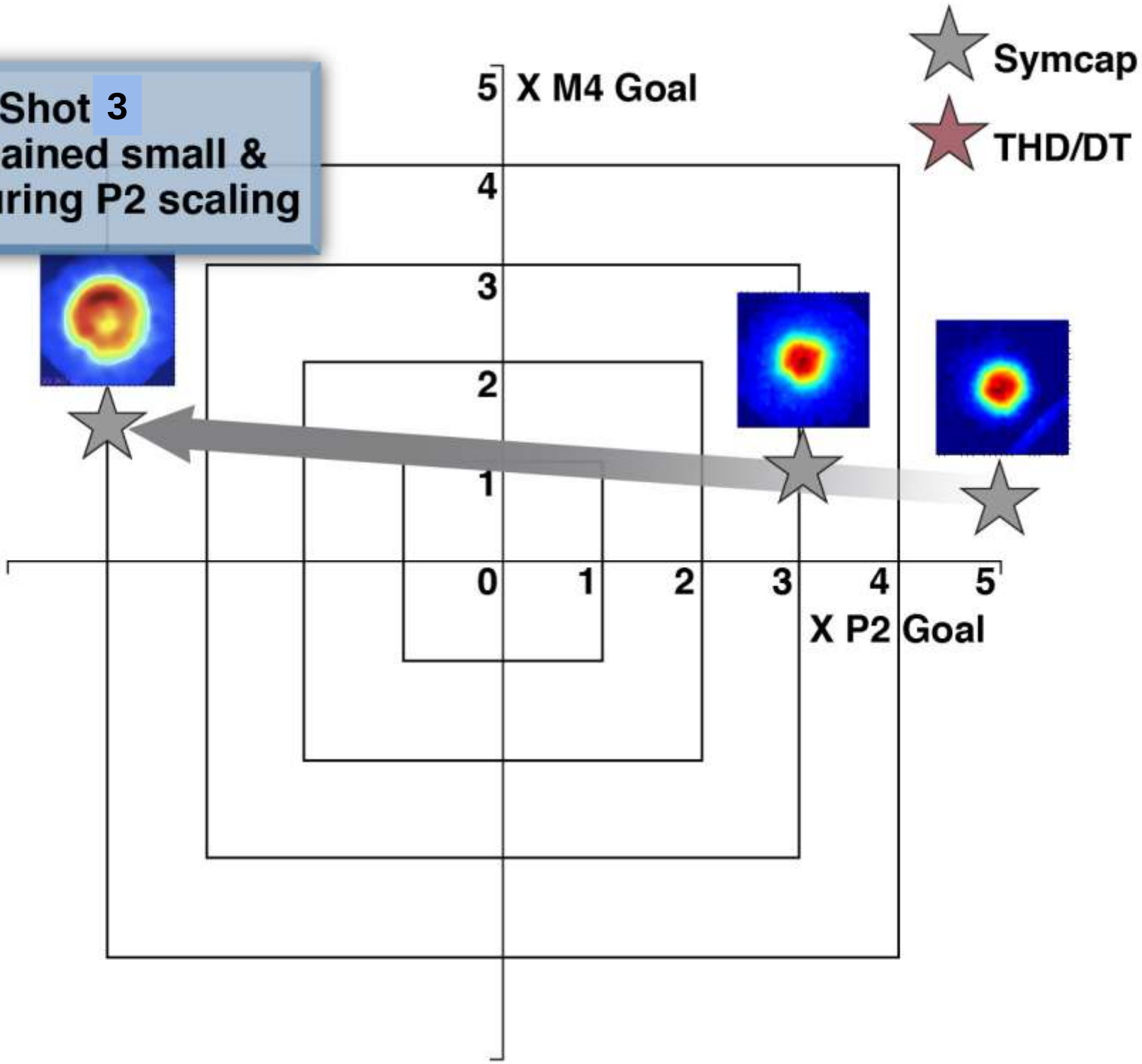


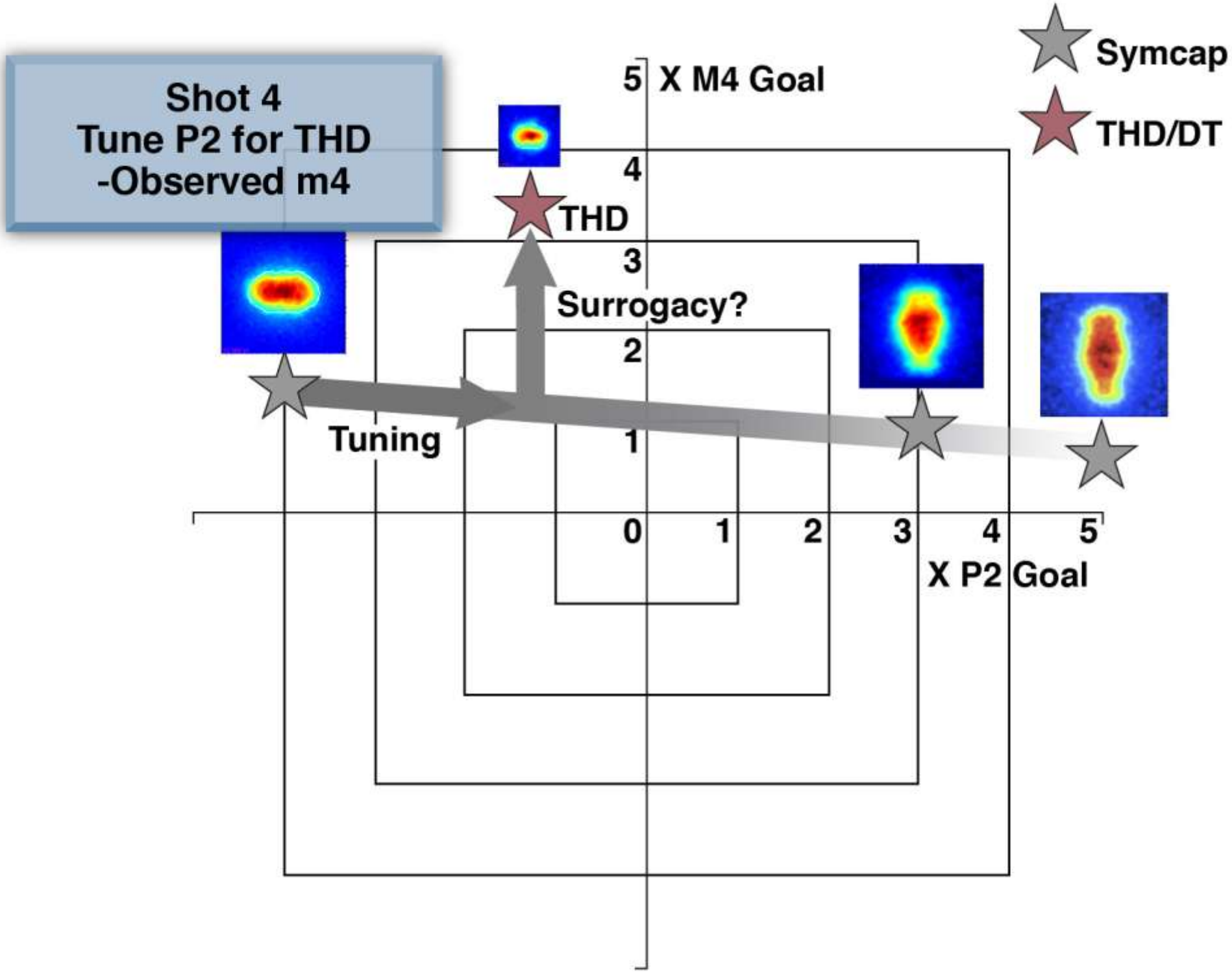
Shot 2
P2 sensitivity to
"2-color or λ_2"

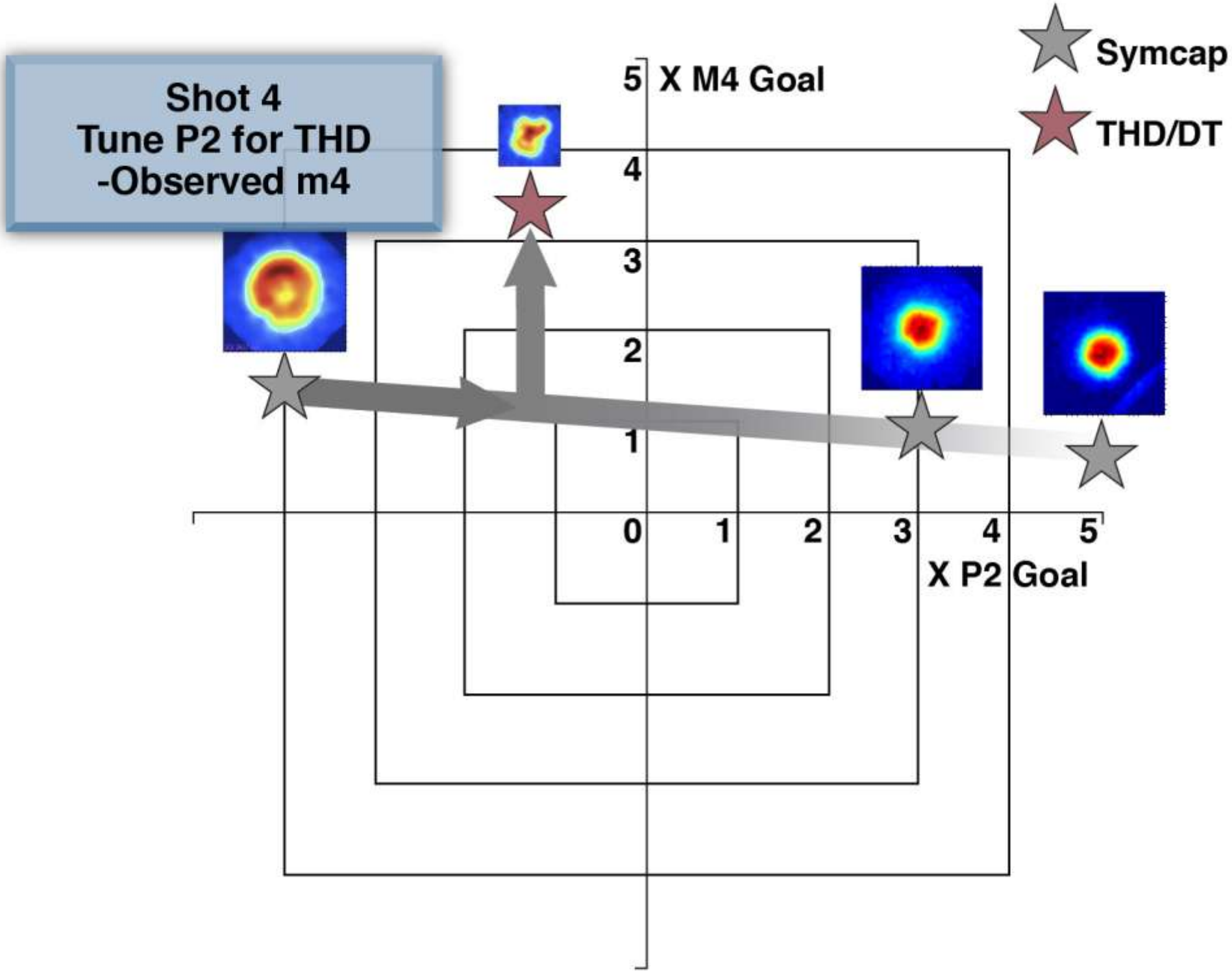


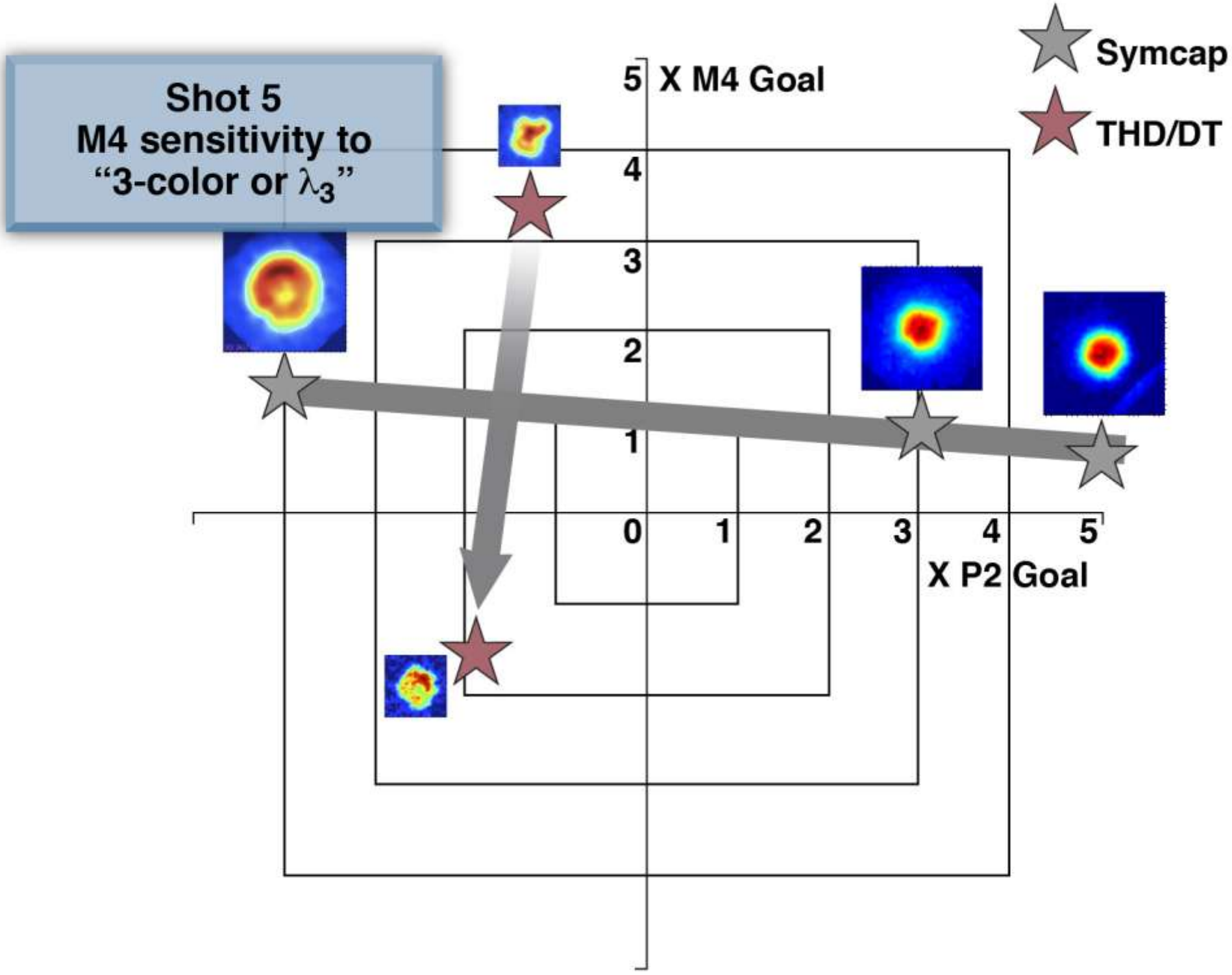

Shot 3
P2 sensitivity to
"2-color or λ_2"
Symcap
THD/DT
5 X M4 Goal
4
3
2
1
0
1
2
3
4
5
X P2 Goal

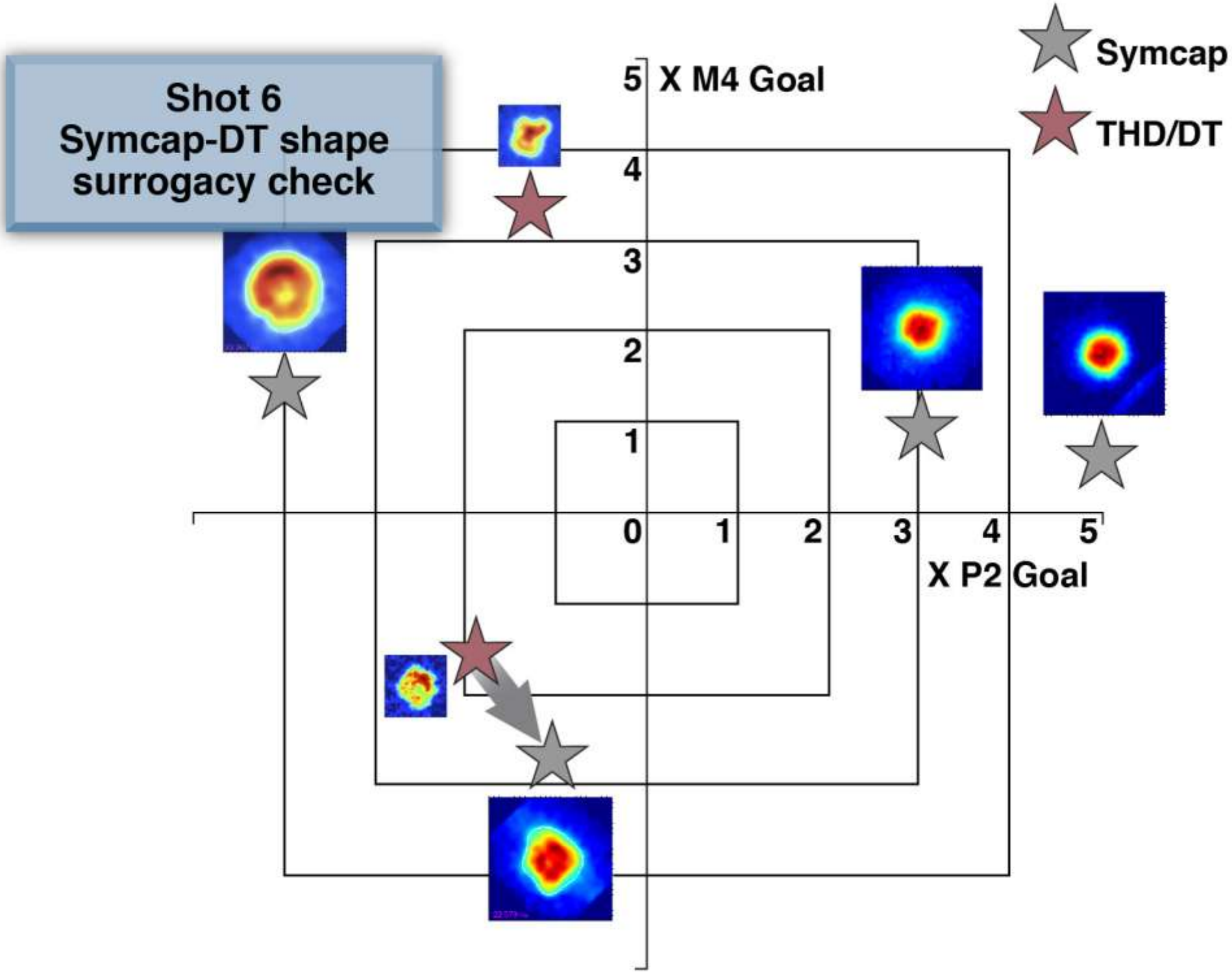
Shot 3
M4 remained small & stable during P2 scaling

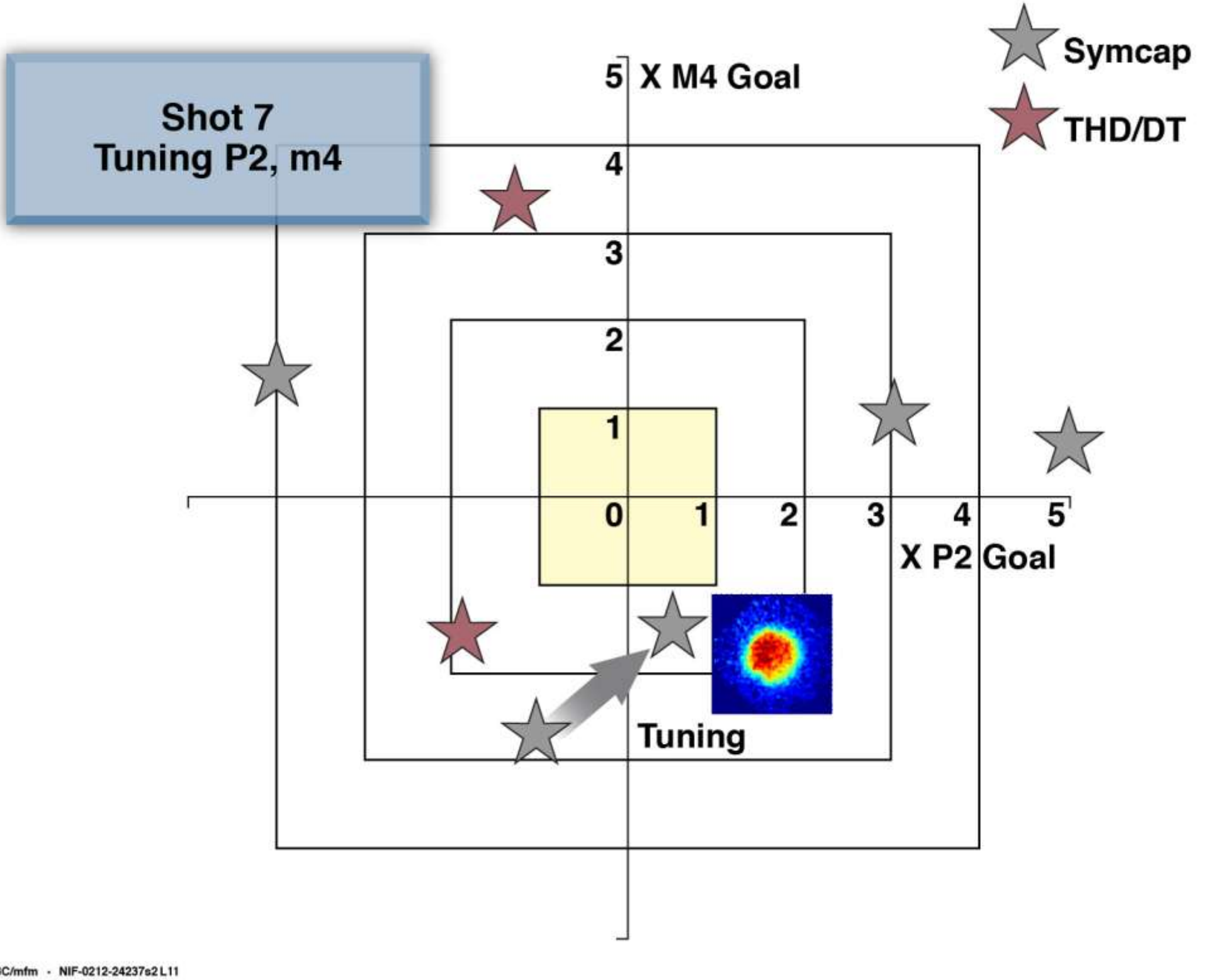



Shot 4
Tune P2 for THD
-Observed m4
Symcap
THD/DT
5 X M4 Goal
4
3
2
1
0
1
2
3
4
5
X P2 Goal
THD
Surrogacy?
Tuning


Shot 4
Tune P2 for THD
-Observed m4
Symcap
THD/DT
5 X M4 Goal
4
3
2
1
0
1
2
3
4
5
X P2 Goal

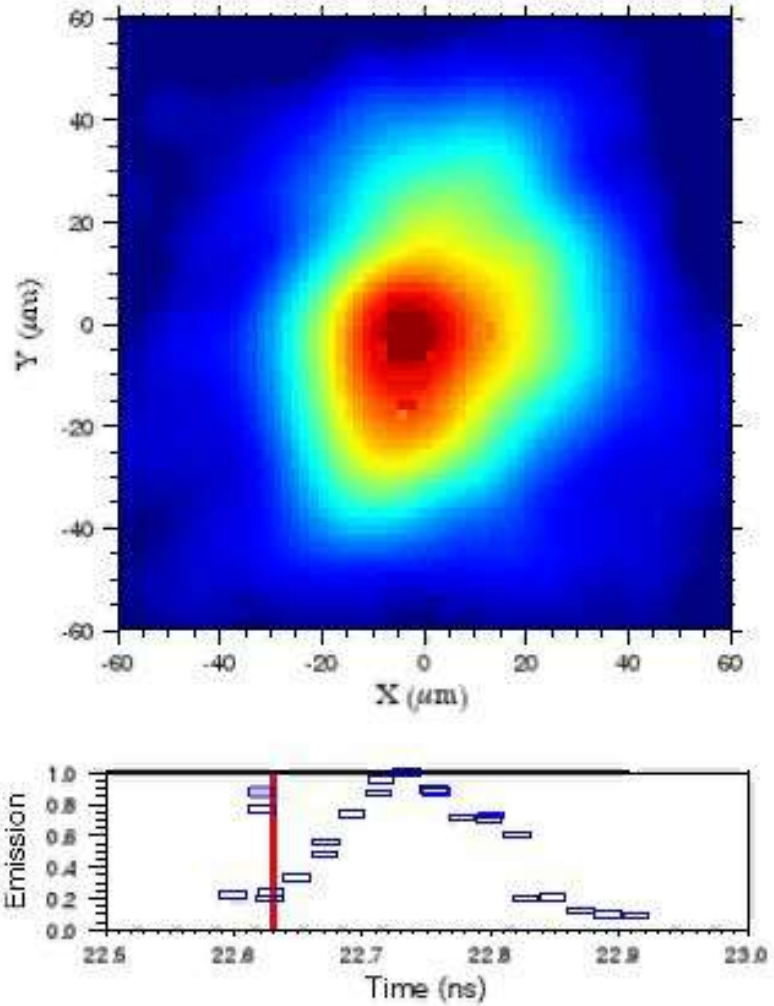

Shot 5
M4 sensitivity to
"3-color or λ_3"
Symcap
THD/DT
5 X M4 Goal
4
3
2
1
0
1
2
3
4
5
X P2 Goal


Shot 6
Symcap-DT shape surrogacy check
Symcap
THD/DT
5 X M4 Goal
4
3
2
1
0
1
2
3
4
5
X P2 Goal

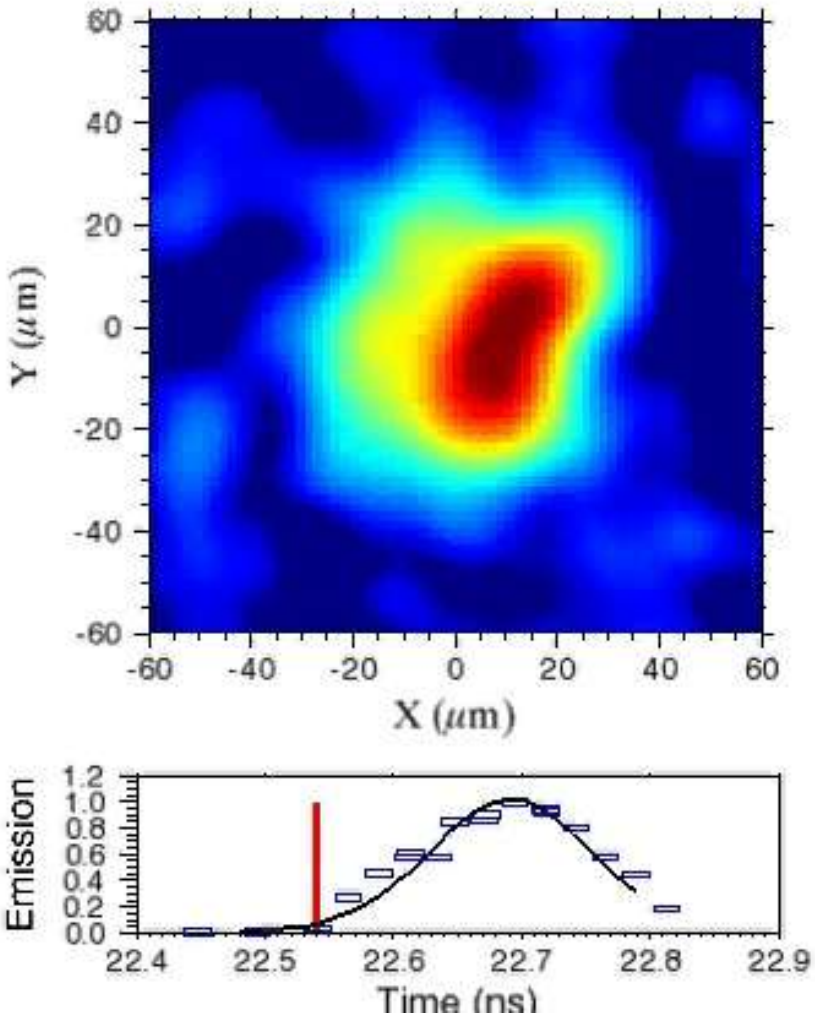

Shot 7
Tuning P2, m4
Symcap
THD/DT
5
X M4 Goal
4
3
2
1
0
1
2
3
4
5
X P2 Goal
Tuning

Most recent DT implosion experiments show efficient compression and a symmetric hot spot

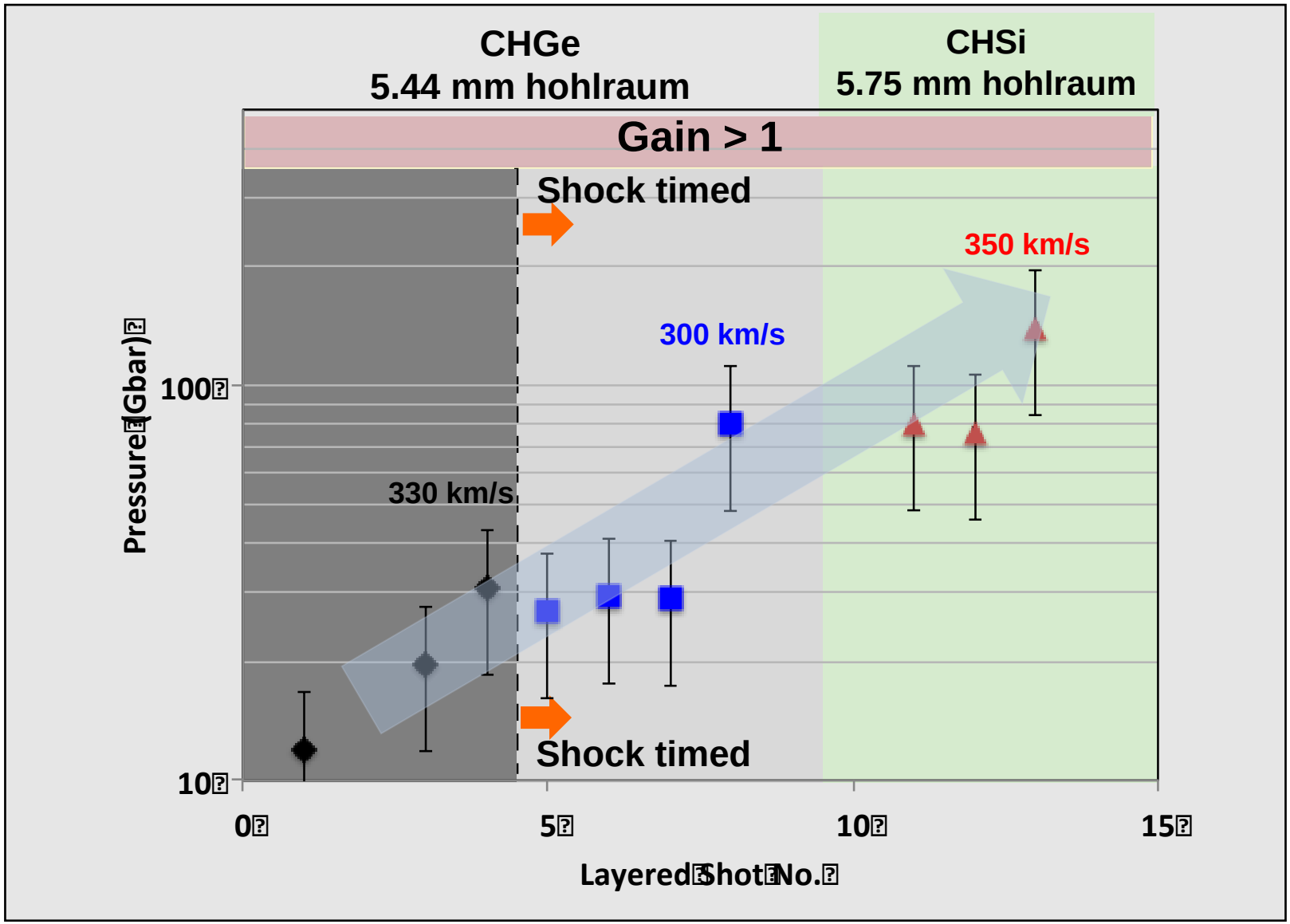
9 keV x-ray emission in the equatorial direction N120205



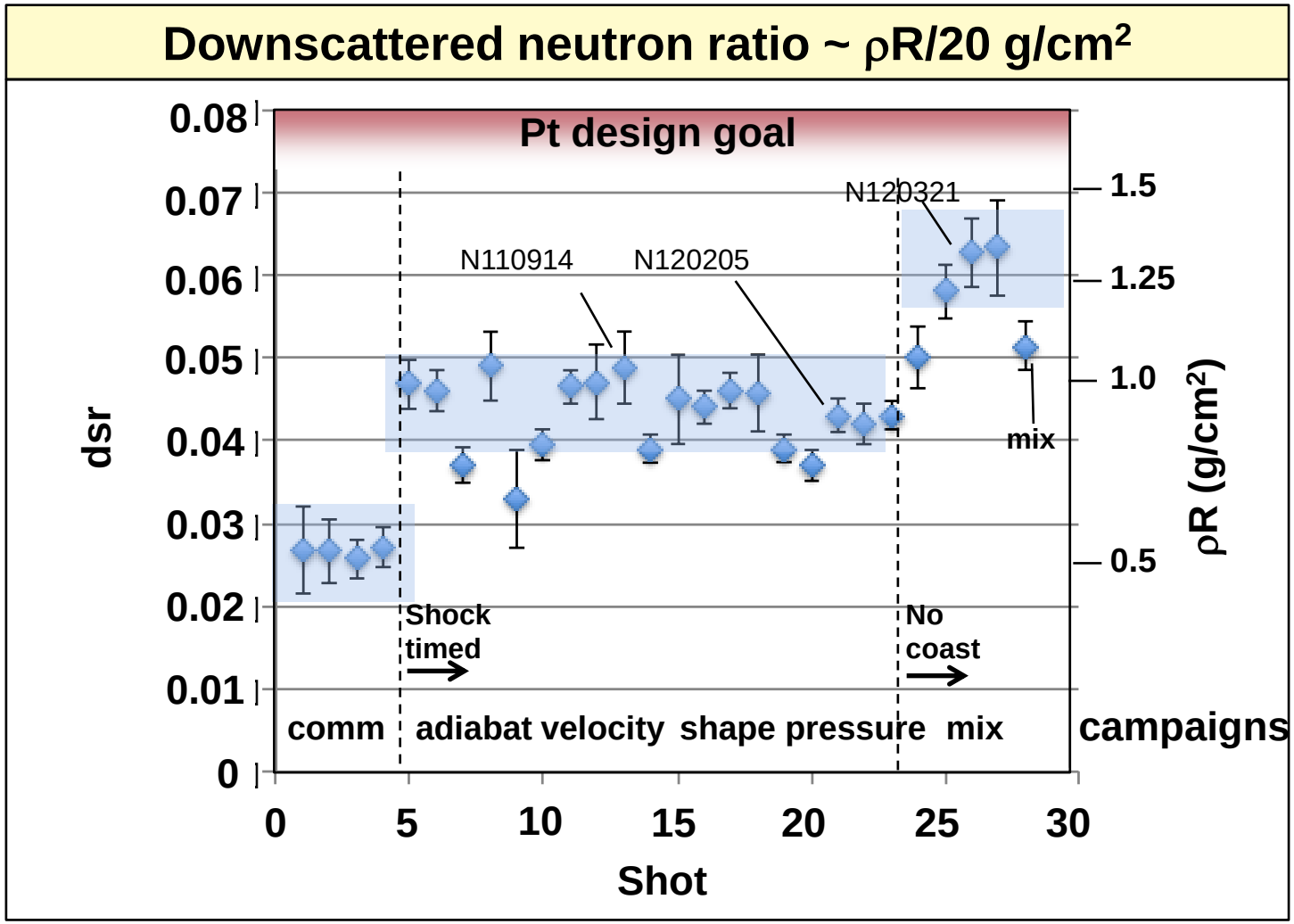
9 keV x-ray emission in the polar direction N120205



Pressures are judged to be within ~ 3X of ignition regime



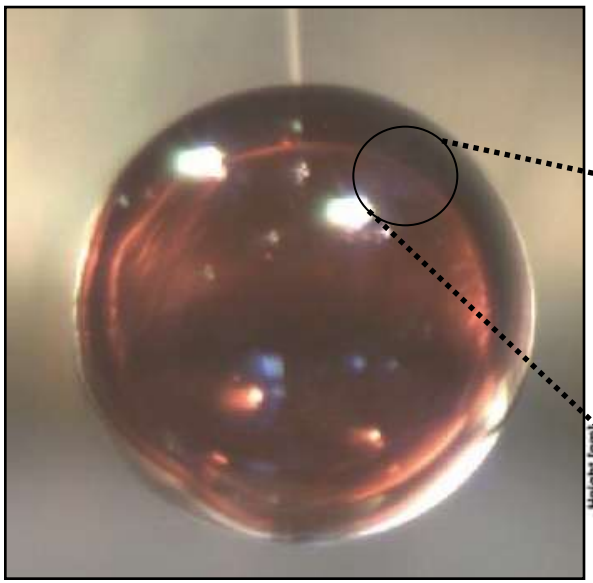
Recent experiments have increased DT fuel $\rho R > 1 g/cm^2$ at stagnation



Recent improvement attributed to reduction in coasting (longer laser pulse)

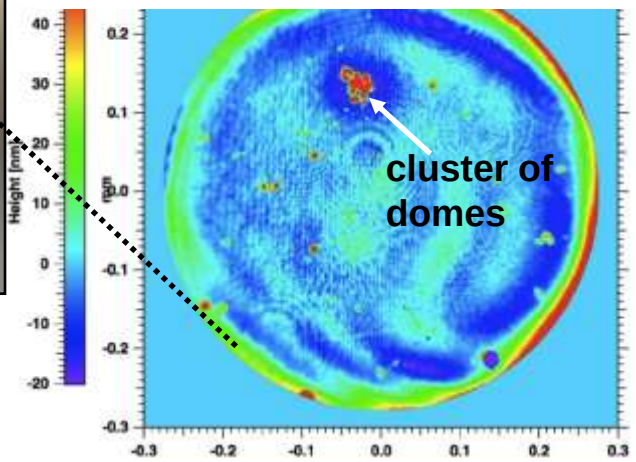
Mix is the focus of the next few months

CH capsule

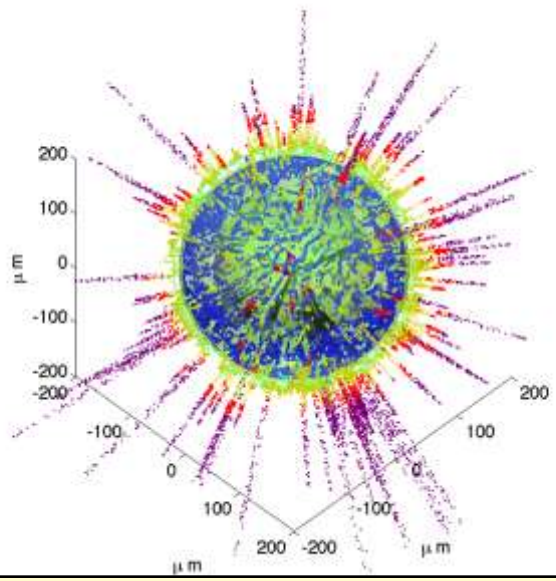


~ 2 mm

PSDI medallion
Surface seeds



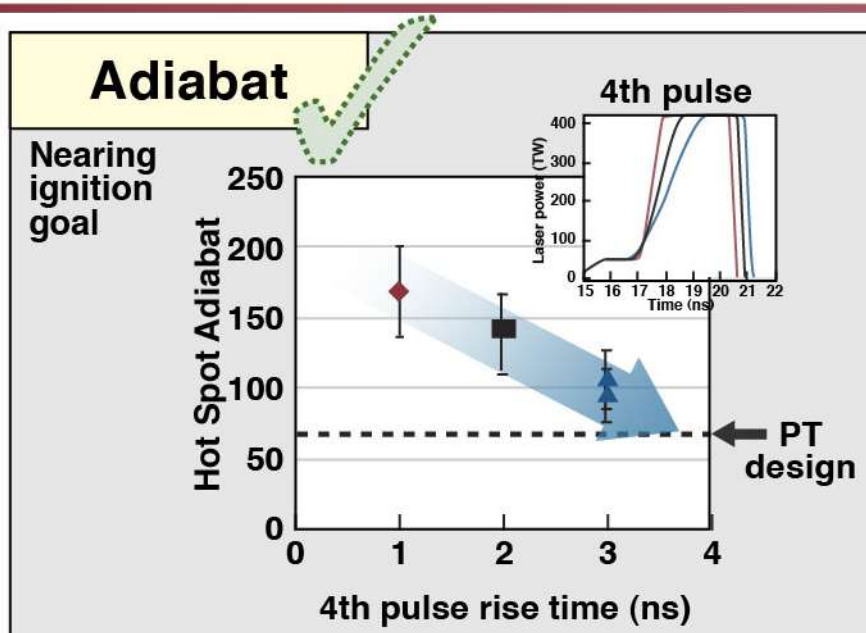
Seeds grow during implosion



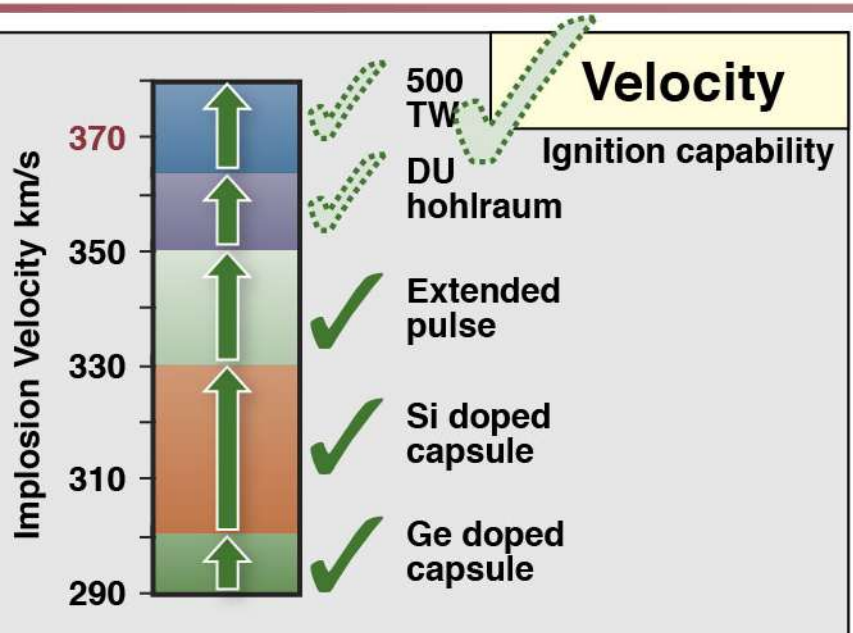
Too much mix causes shell break up and loss of performance

Progress on implosion parameters

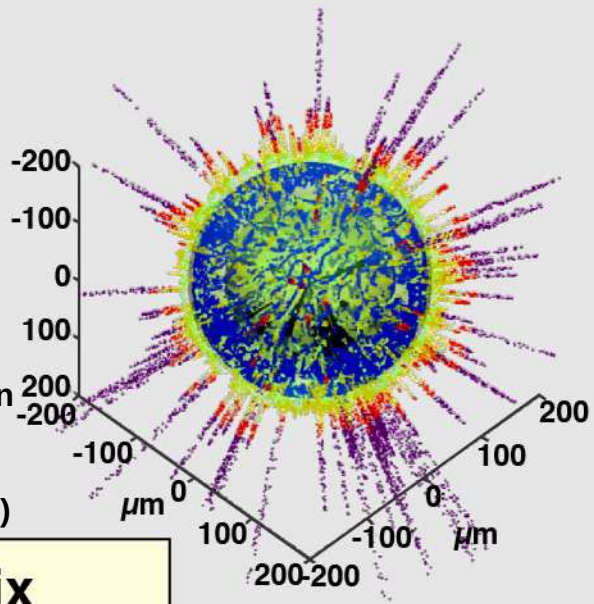
Adiabat



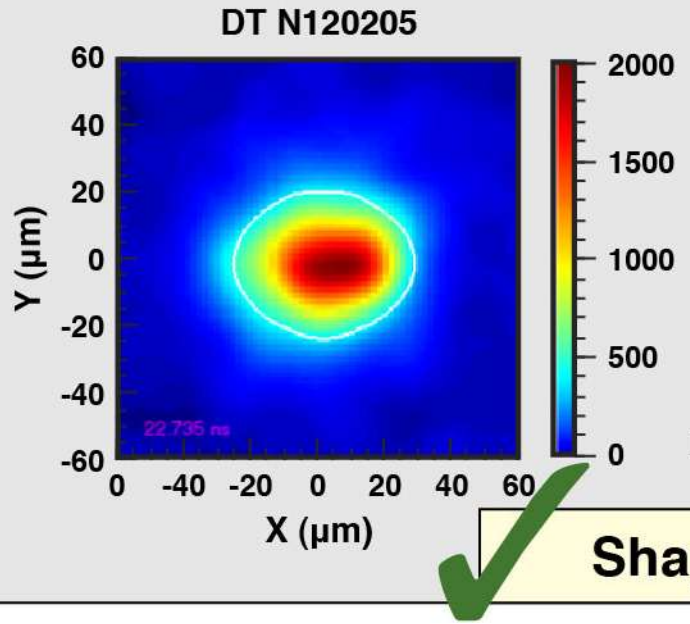
Velocity



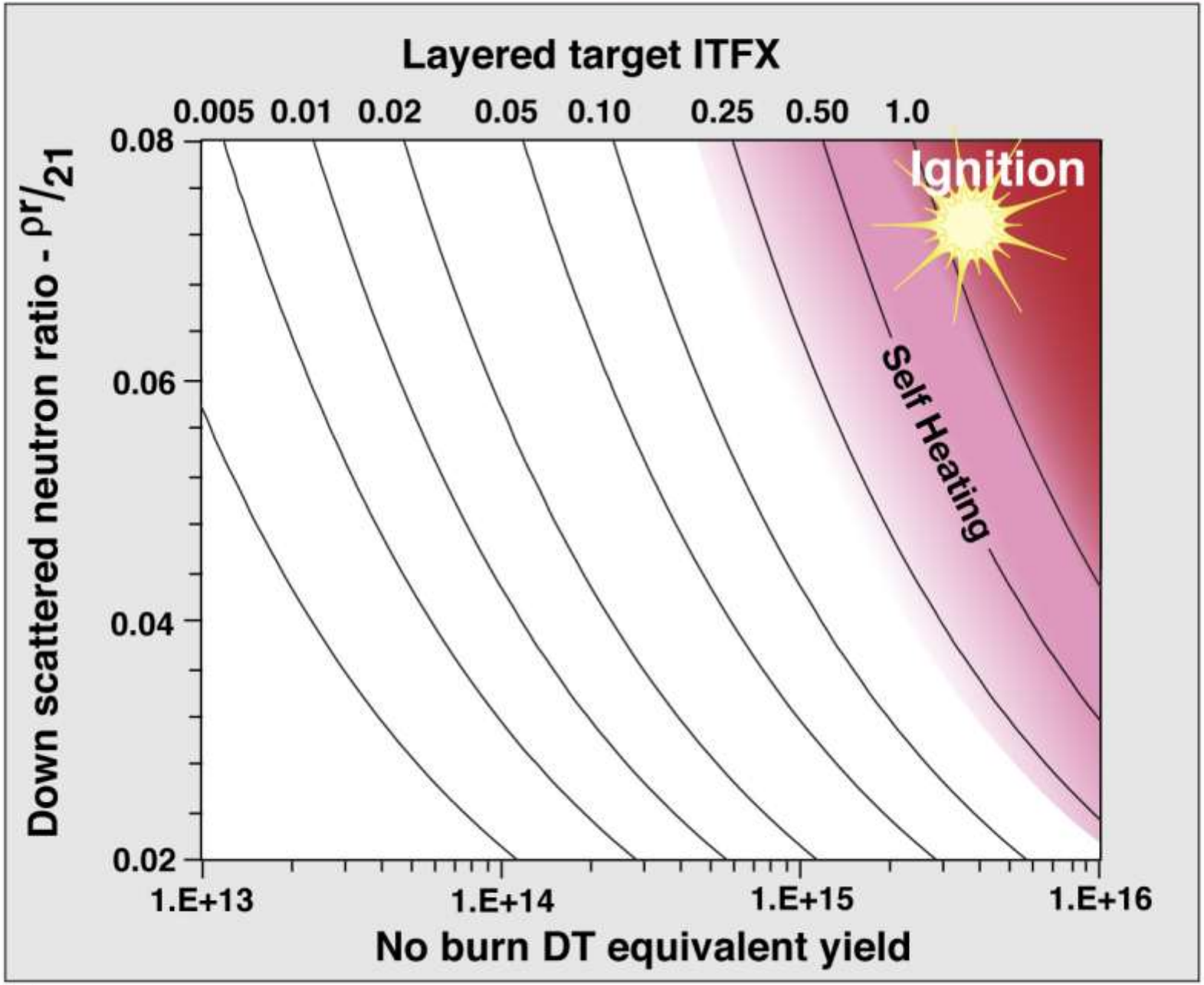
Mix



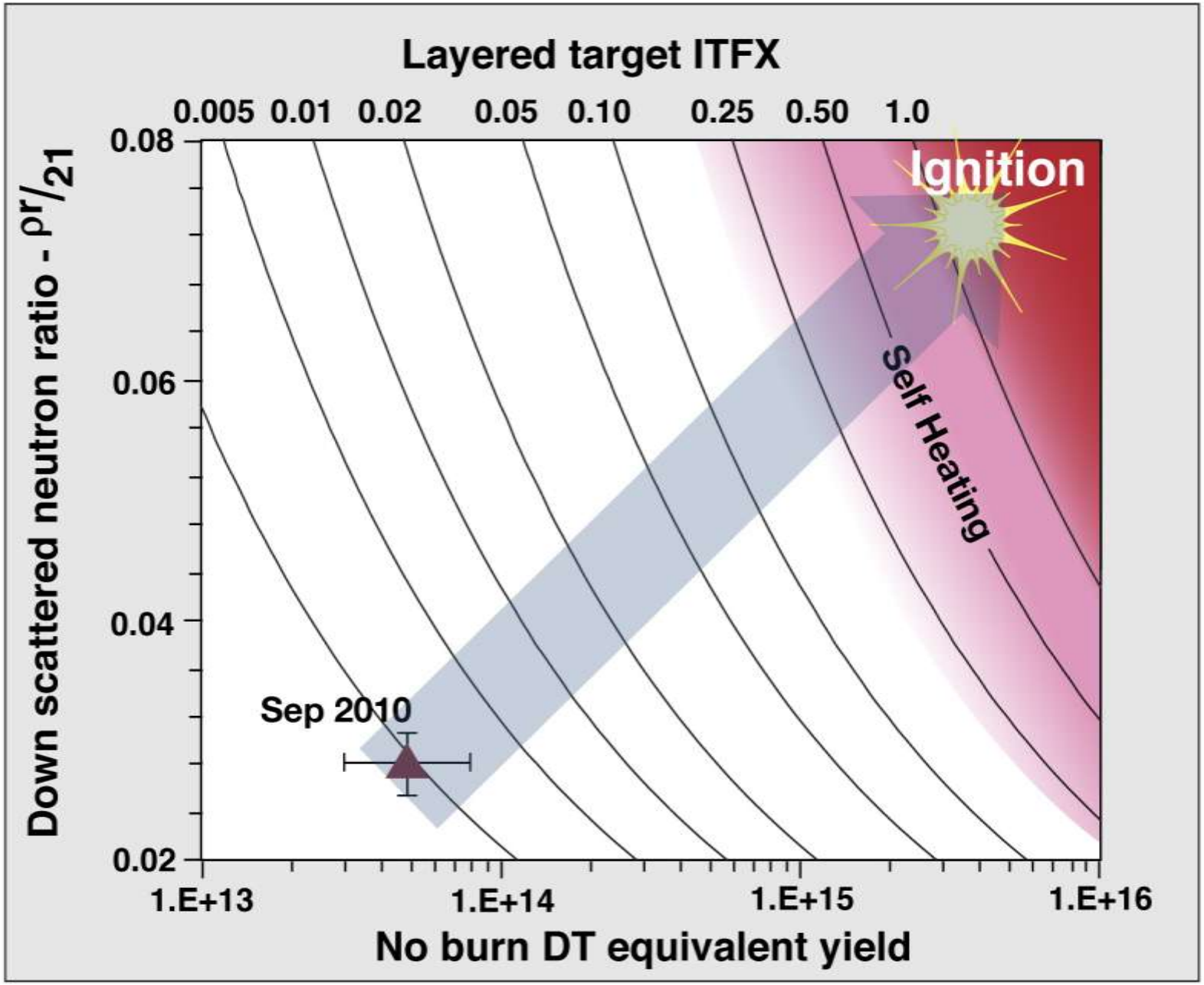
Shape



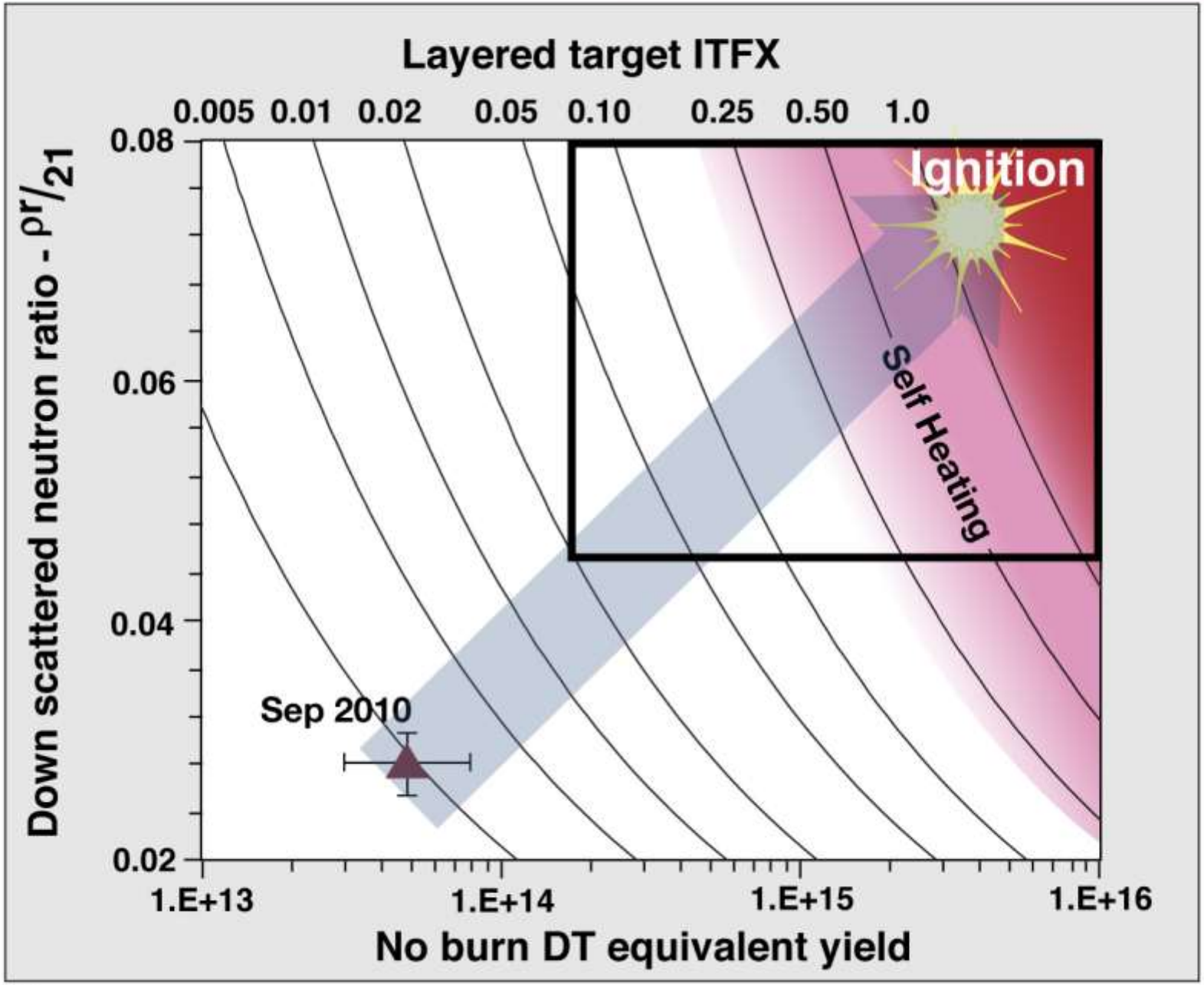
Pathway to Ignition



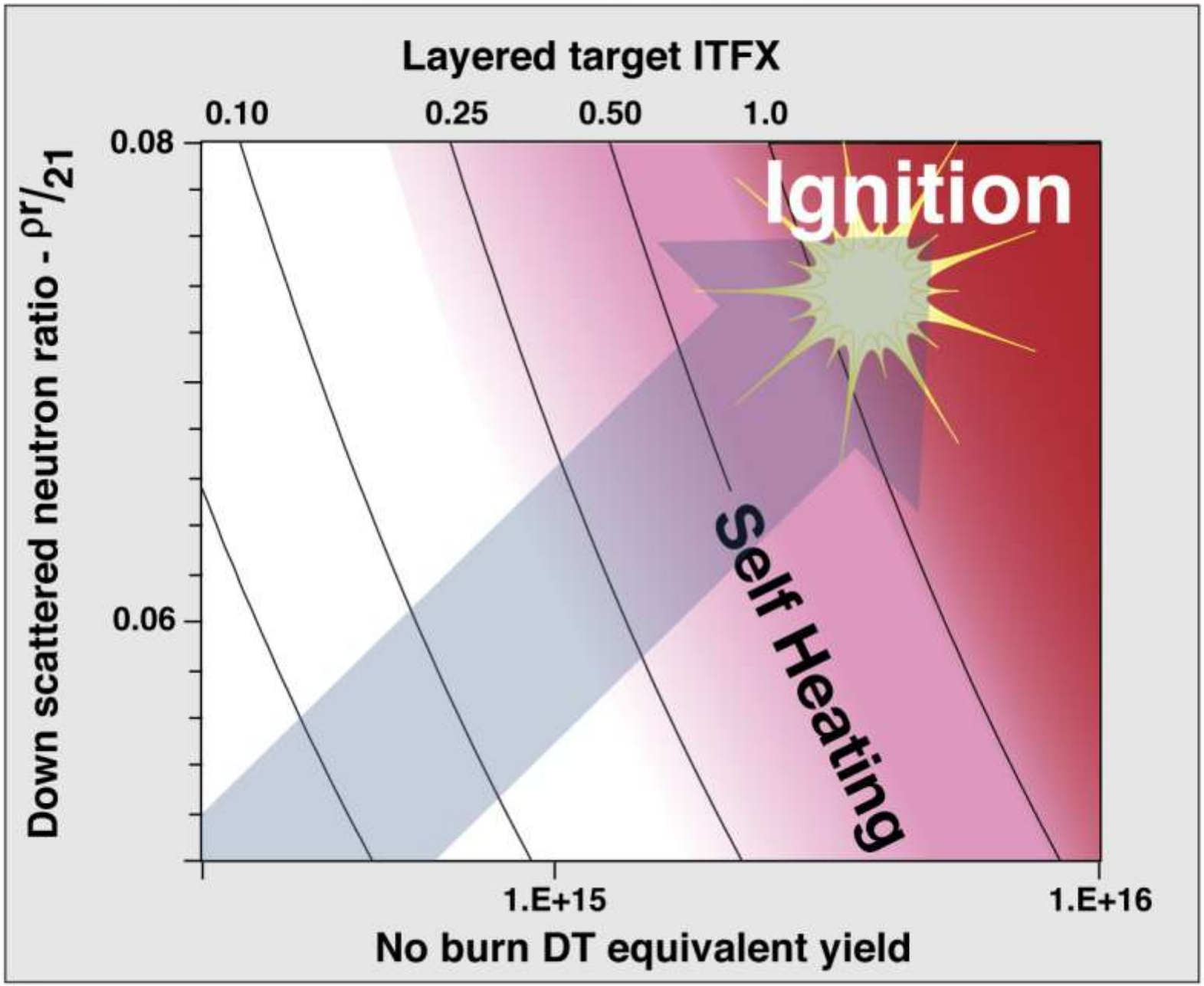
Pathway to Ignition



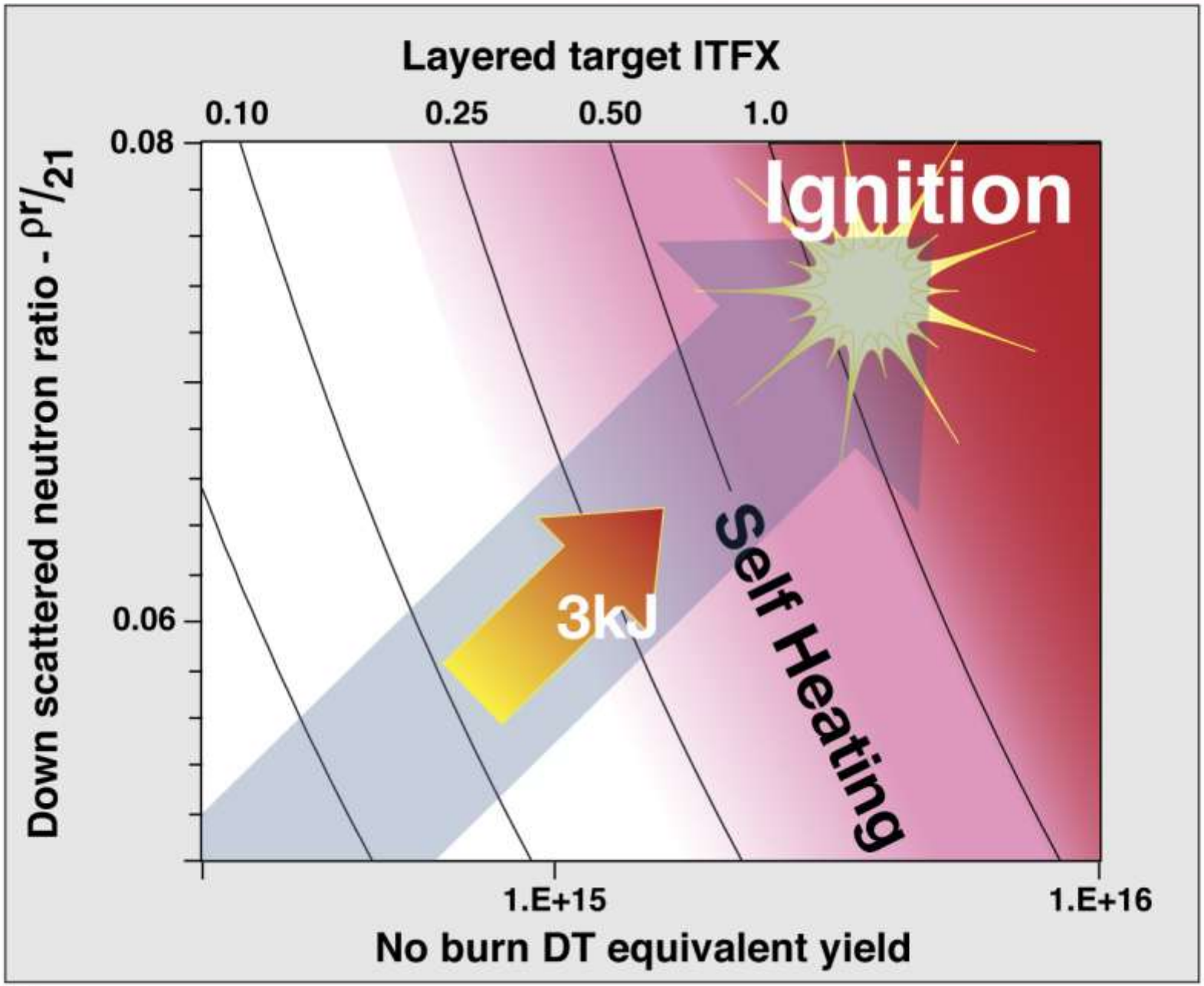
Pathway to Ignition



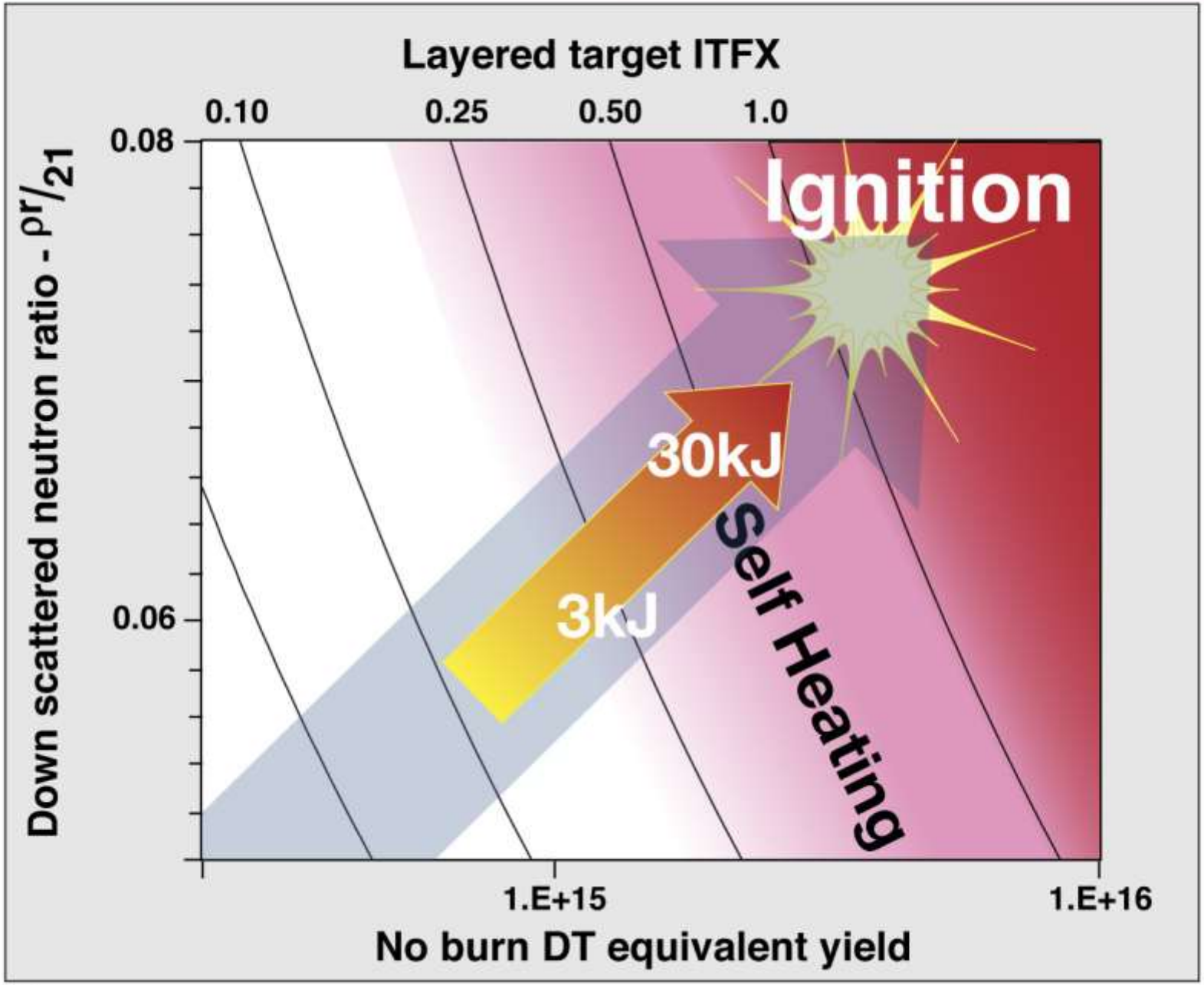
Pathway to Ignition



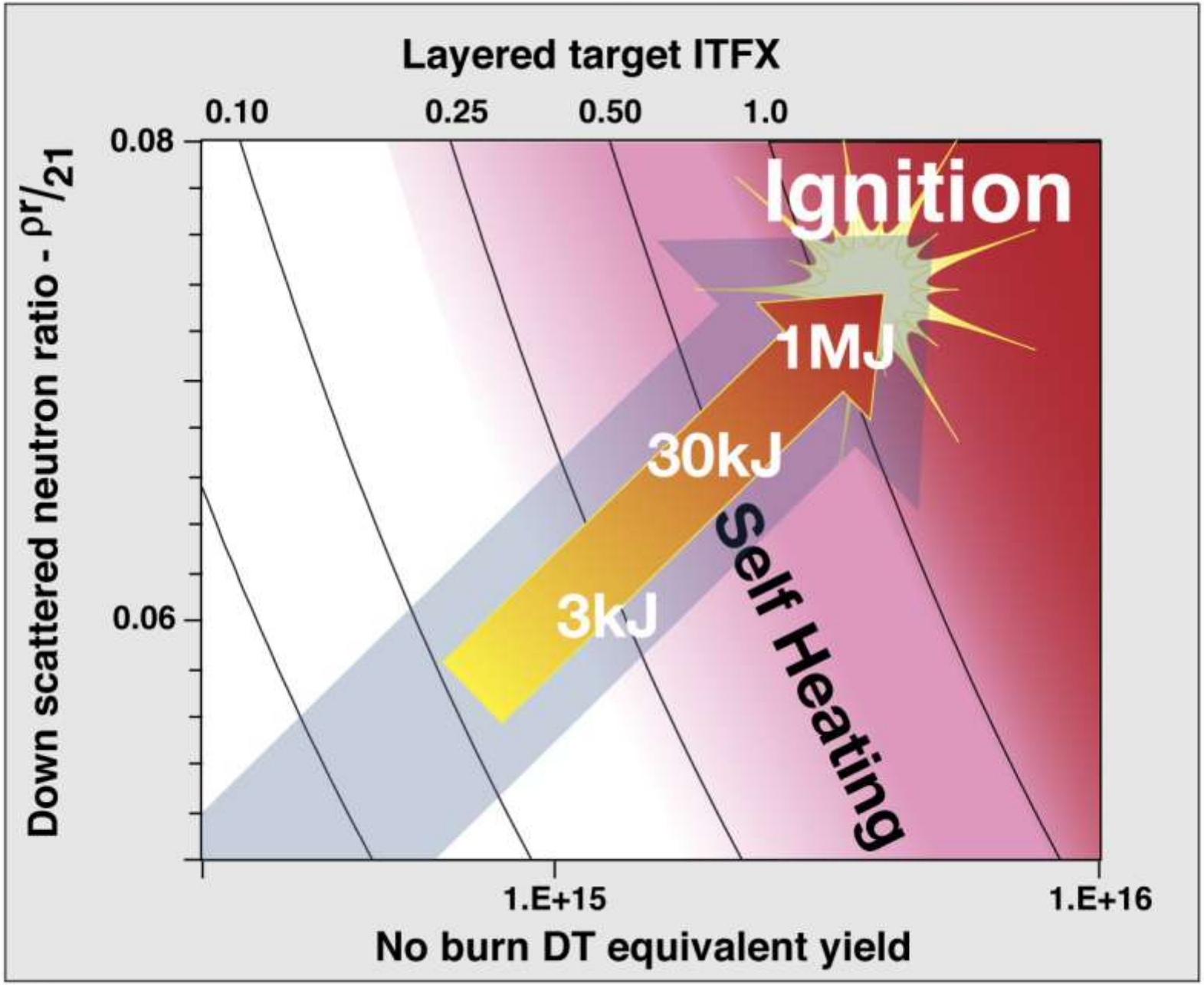
Pathway to Ignition



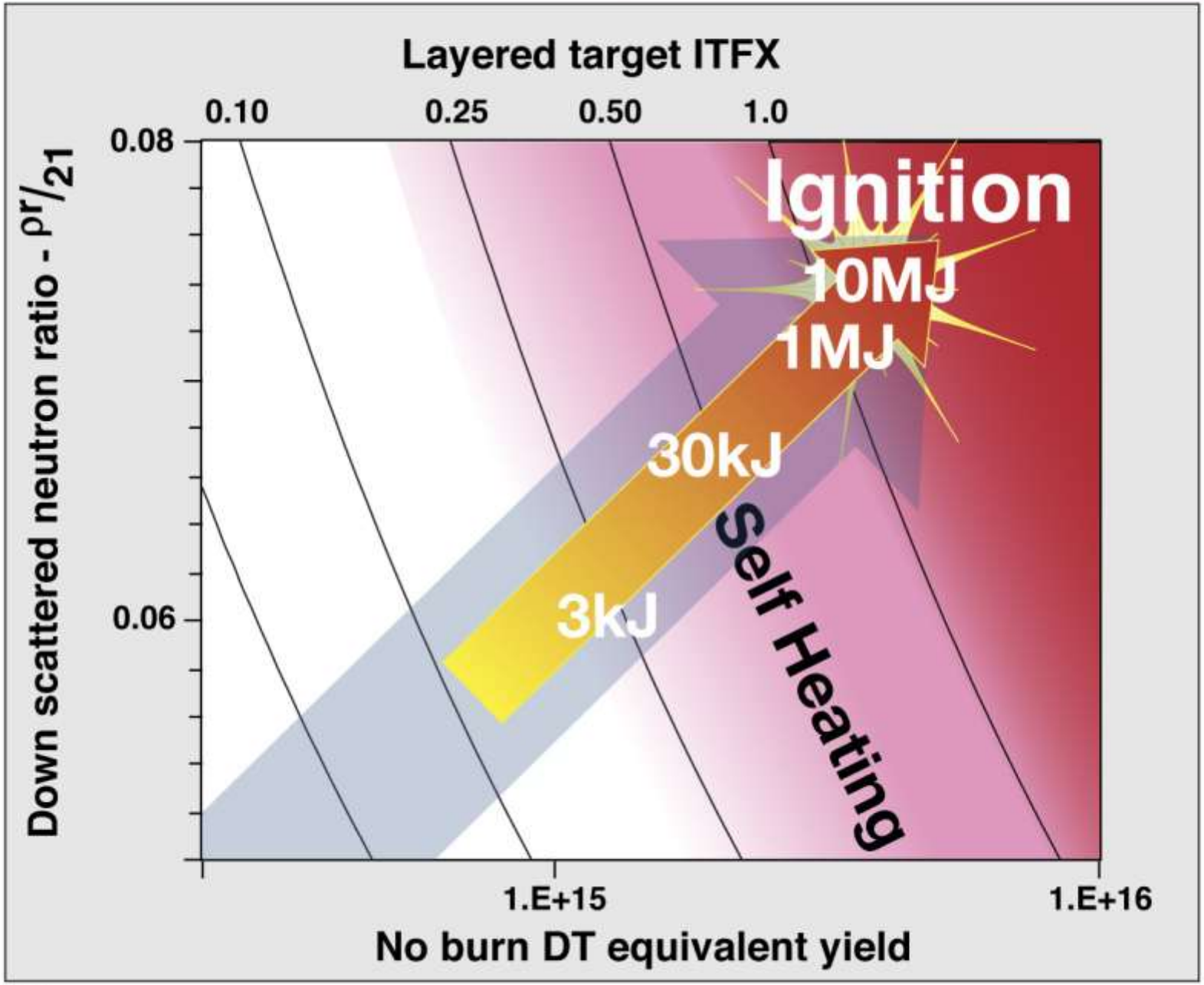
Pathway to Ignition



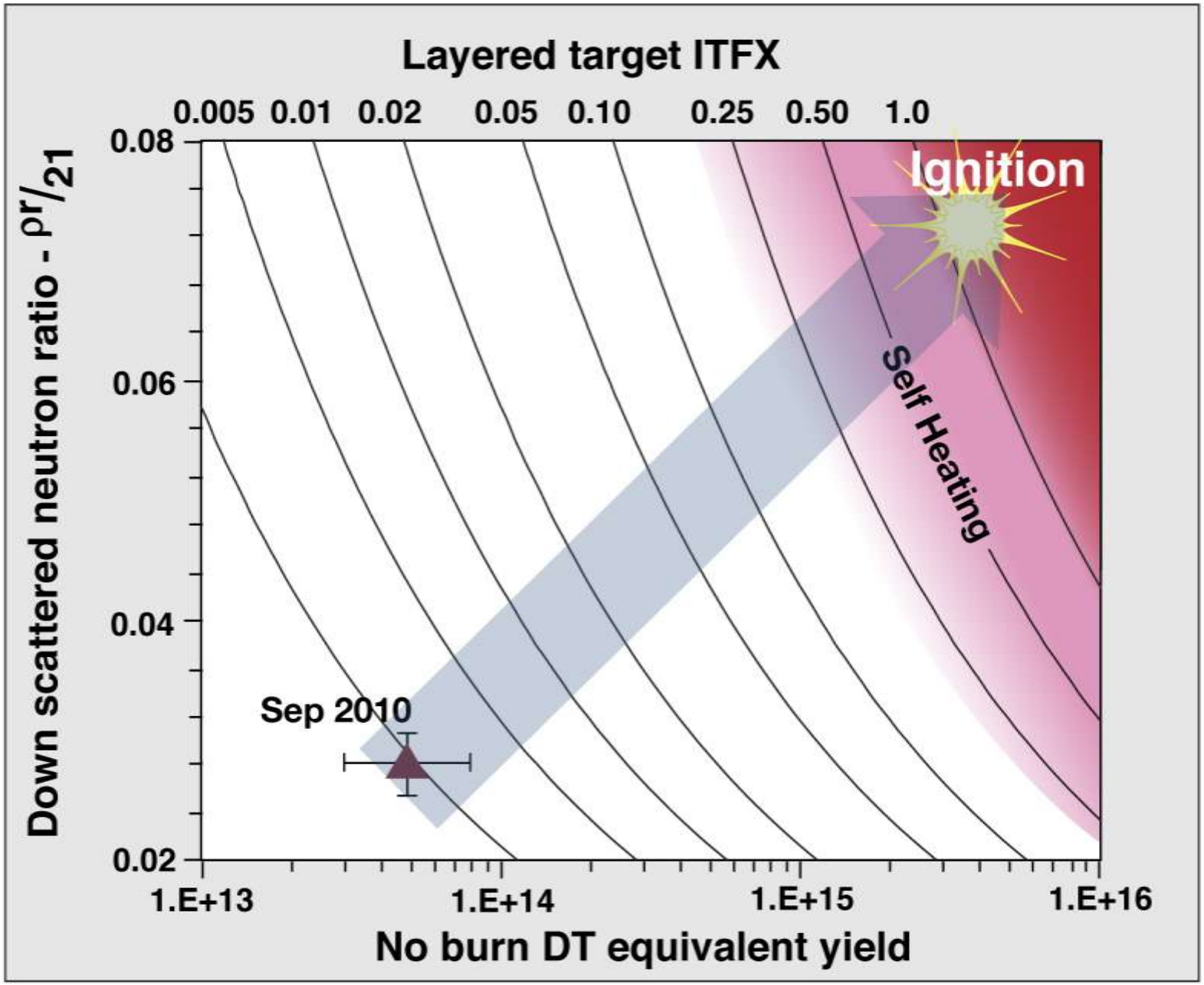
Pathway to Ignition



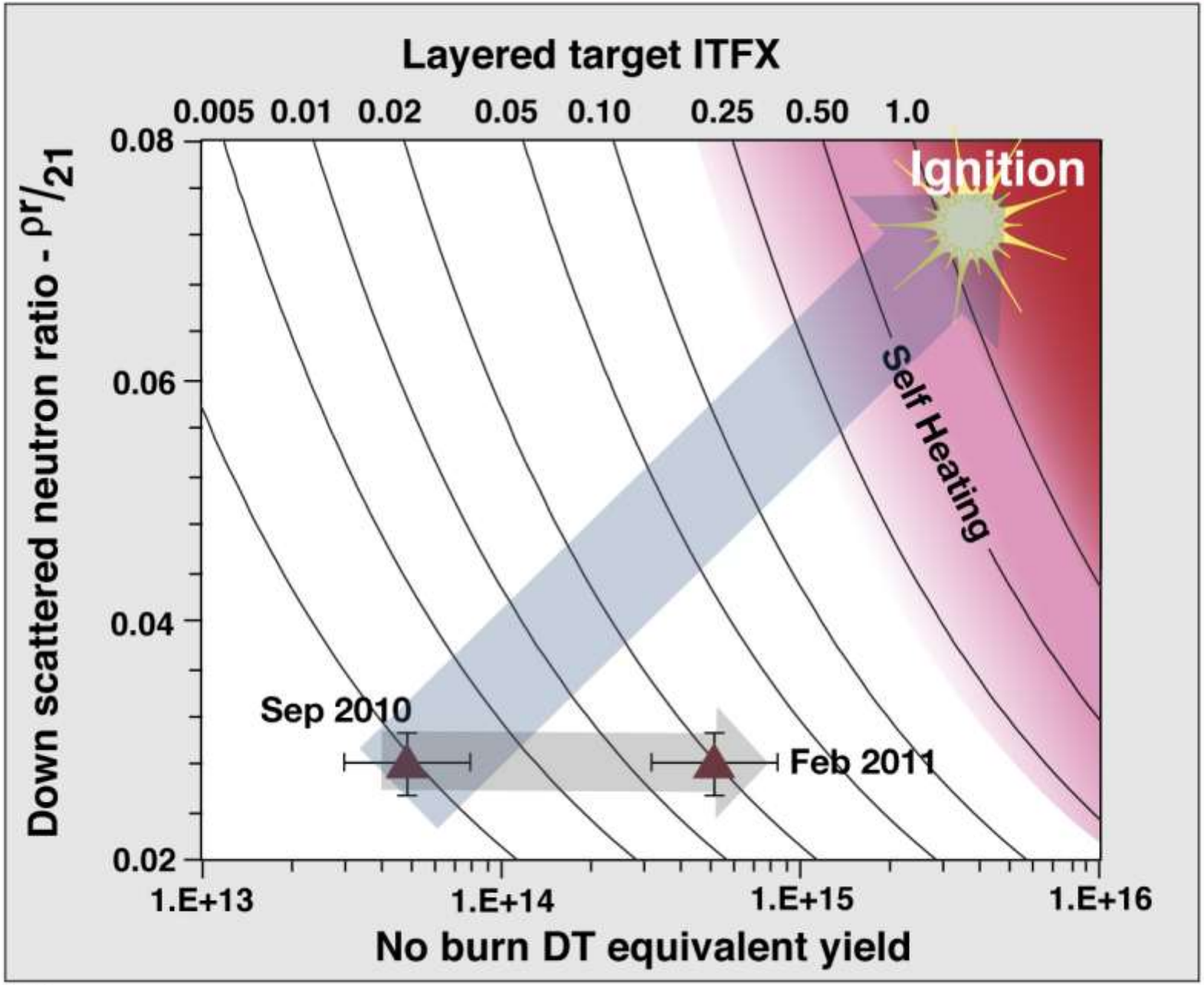
Pathway to Ignition



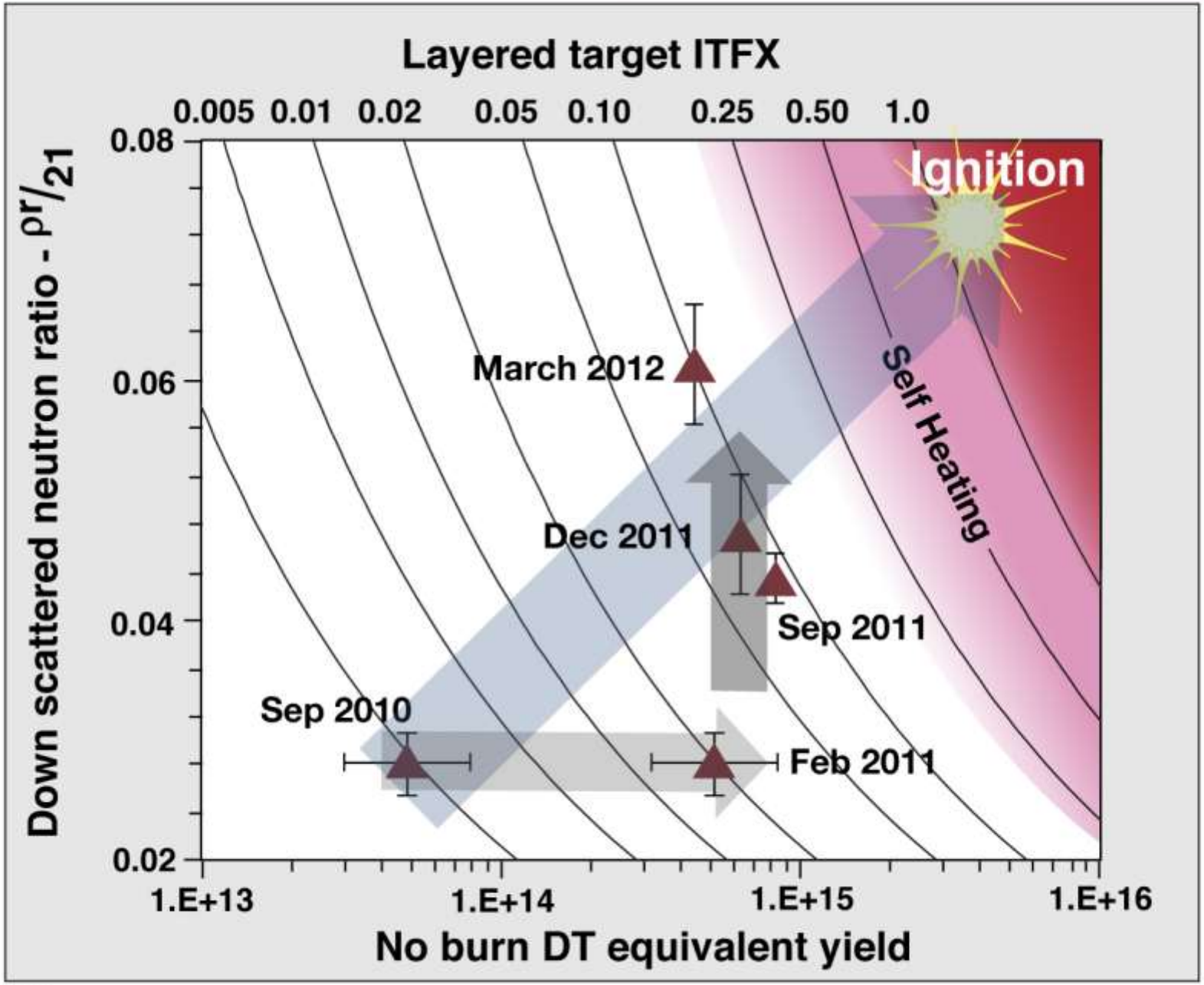
Pathway to Ignition



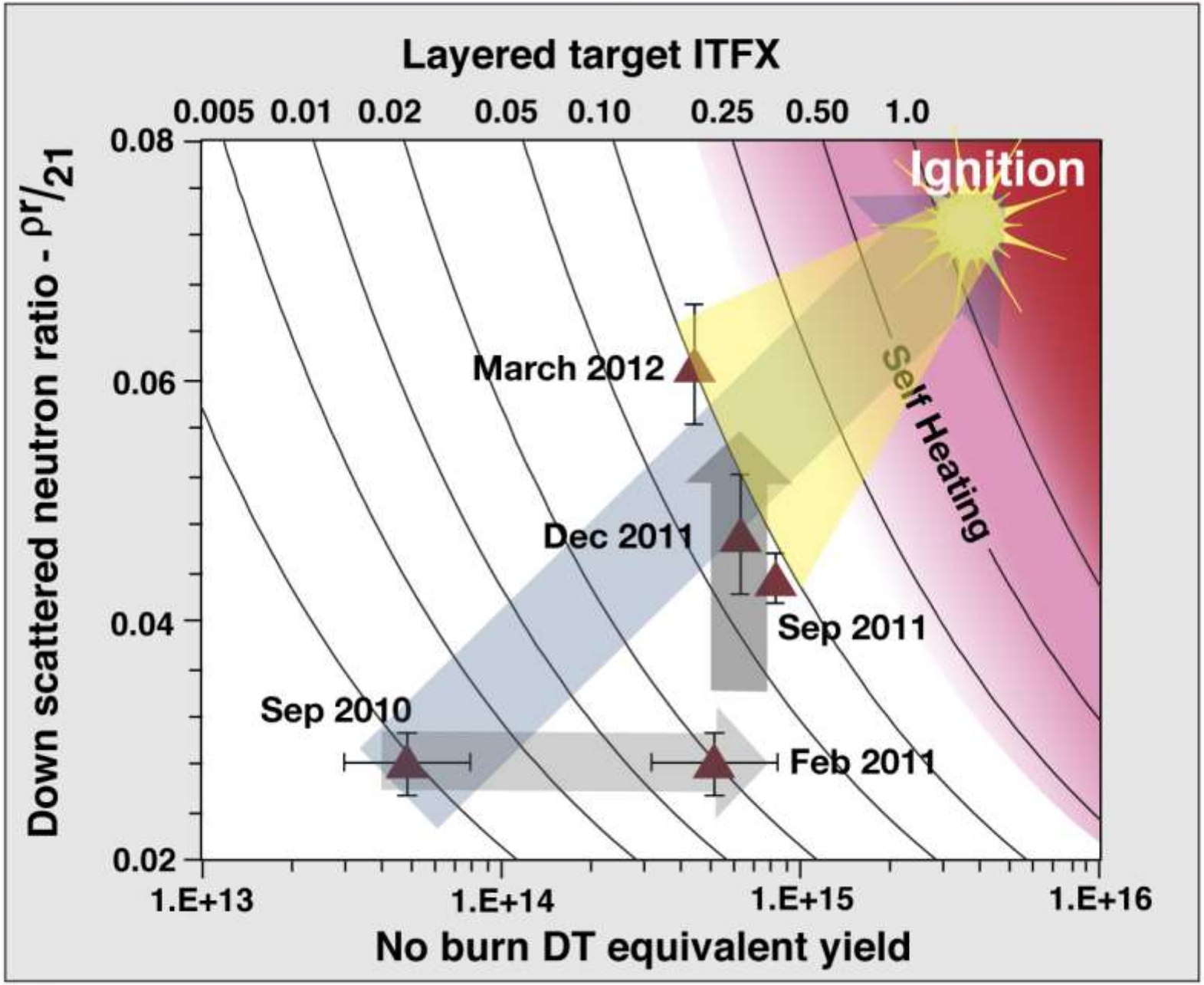
Pathway to Ignition



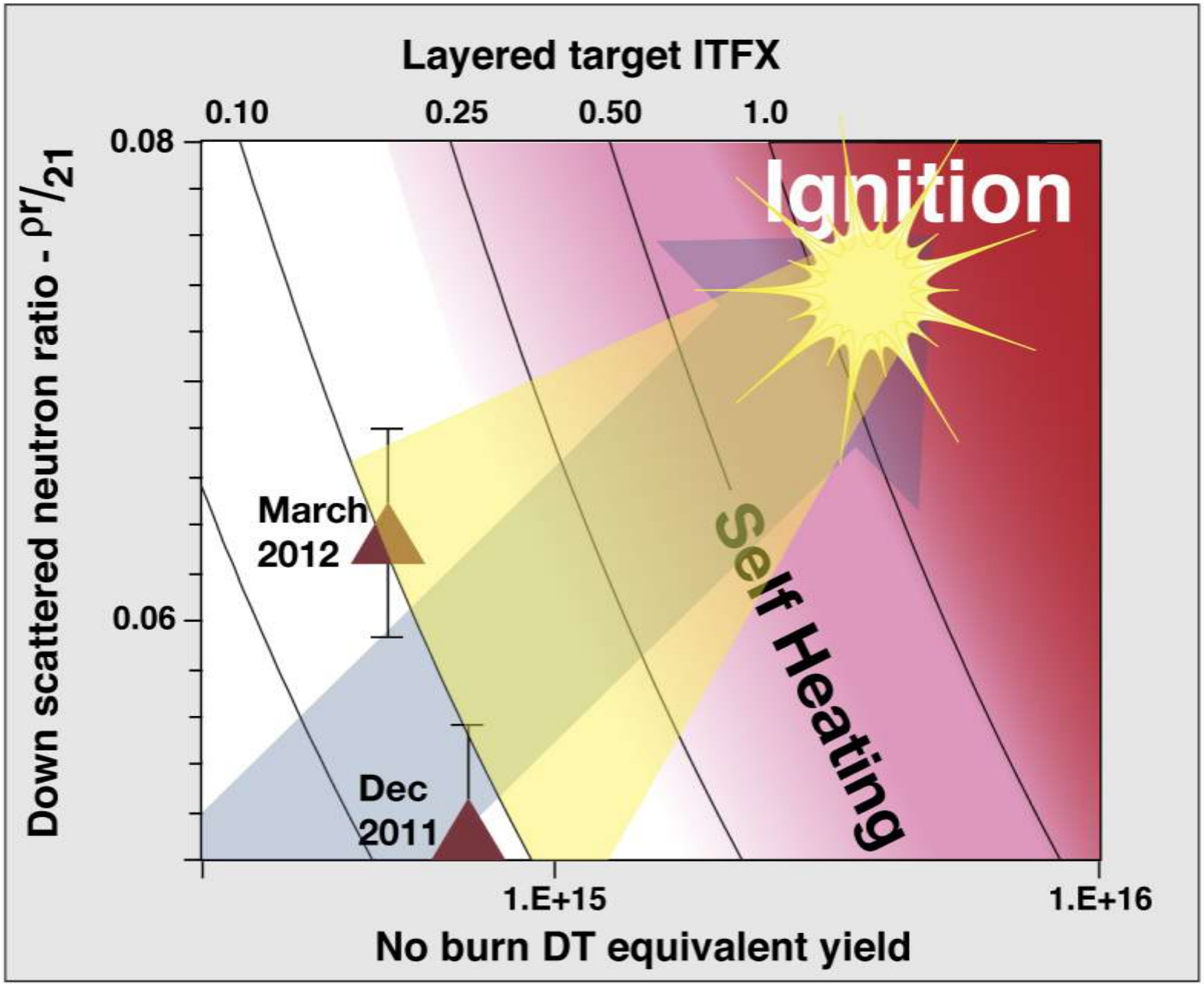
Pathway to Ignition



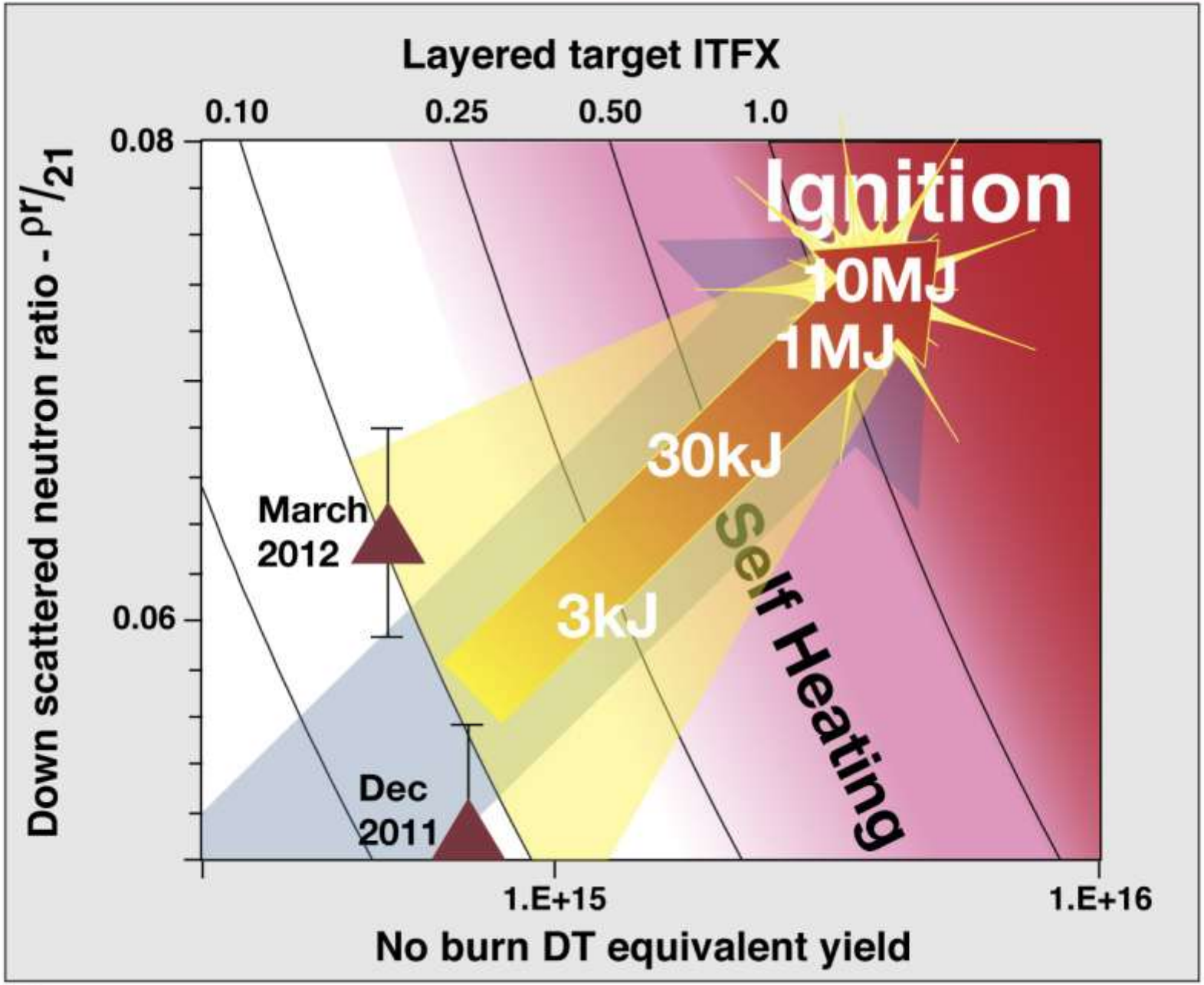
Pathway to Ignition



Pathway to Ignition



Pathway to Ignition



Summary status of the National Ignition Campaign

- NIF laser operating 24/7 with exceptional reproducibility & reliability
- NIF achieved sustainable operations at its design point (1.8 MJ / 500 TW)
- NIF optics quality and laser performance consistent with performance significantly greater than the design spec (1.8MJ)
- Hohlraum energetics campaign started in August 2009
  - Laser-plasma instability losses are acceptable
  - Laser-plasma coupling has provided a robust tuning mechanism
  - Required hohlraum temperature achieved
- Cryogenic layered implosion campaign started in September 2010
- Precision optimization started in May 2011
  - Implosion velocity: path to exceeding required value
  - Implosion shape: controllability of low-order m- and l- modes
  - Shock timing (adiabat): issues with 4th shock pressure
  - Mix: current campaign focus
- Pathway to ignition continues to follow the established NIC methodology
- Plans for progress beyond 2012 will be reported to Congress in November

Thanks to the NIF team

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Frazier,1 G. Frieder,1 T. Fung,1 G. N. Gawinski,1 C. R. Gibson,1 E. Giraldez,1 S. M. Glenn,1 B. P. Golick,1 H. Gonzales,1 S. A. Gonzales,1 M. J. Gonzalez,1 K. L. Griffin,1 J. Grippen,1 S. M. Gross,1 P. H. Gschweng,1 G. Gururangan,1 K. Gu,1 S. W. Haan,1 S. R. Hahn,1 B. J. Haid,1 J. E. Hamblen,1 B. A. Hammel,1 A. V. Hamza,1 D. L. Hardy,1 D. R. Hart,1 R. G. Hartley,1 C. A. Haynam,1 G. M. Heestand,1 M. R. Hermann,1 G. L. Hermes,1 D. S. Hey,1 R. L. Hibbard,1 D. G. Hicks,1 D. E. Hinkel,1 D. L. Hipple,1 J. D. Hitchcock,1 D. L. Hodtwalker,1 J. P. Holder,1 J. D. Hollis,1 G. M. Holtmeier,1 D. M. Holunga,1 J. B. Horner,1 H. Huang,1 S. R. Huber,1 A. W. Huey,1 D. N. Hulsey,1 S. L. Hunter,1 T. R. Huppler,1 M. S. Hutton,1 N. Izumi,1 J. L. Jackson,1 M. A. Jackson,1 K. S. Jancaitis,1 D. R. Jedlovec,1 B. Johnson,1 M. C. Johnson,1 T. Johnson,1 M. P. Johnston,1 O. S. Jones,1 D. H. Kalantar,1 J. H. Kamperschroer,1 R. L. Kauffman,1 G. A. Keating,1 L. M. Kegelmeyer,1 S. L. Kenitzer,1 J. R. Kimbrough,1 K. 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