Z-Pinch IFE Program

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2002 Fusion Summer Study
Snowmass, CO
July 8-19, 2002

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

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Related Z-Pinch Research

Russia (next slide)

LANL

LLNL

Cornell University

Imperial College

Weizmann Institute

University of Nevada, Reno

Naval Research Laboratory

University of Michigan

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Russian activity in Z-pinches and beams

- Kurchatov Institute of Atomic Energy (Moscow)
- TRINITY (Troitsk)
- Institute of Nuclear Physics (Novosibirsk)
- Lebedev Institute (Moscow)
- VNIIEPh (Sarov)
- VNIITPh (Snejinsk)
- Efremov Institute (St. Petersburg)
- Institute of High Current Electronics (Tomsk)
- Physical and Technological Institute (Sukhumi)
- Institute of Spectroscopy (Troitsk)
- ITEPh (Moscow)

U.S./Russia Collaboration on Z-Pinch IFE is being initiated

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KURCHATOV INSTITUTE
RUSSIAN RESEARCH CENTRE

“Z-pinch driver looks now so attractive that IFE Power Plant based on kiloterawatt Z-pinch (PPZ) schemes have to be developed.”

V. Smirnov et al.

KURCHATOV INSTITUTE
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IFE Systems (choose one from each category)

Major drivers:

Laser	Heavy ion	Z-pinch
(KrF, DPSSL)	(induction linac)	(pulsed power)
	GeV, kA	MV, MA
		MJ now

Targets:

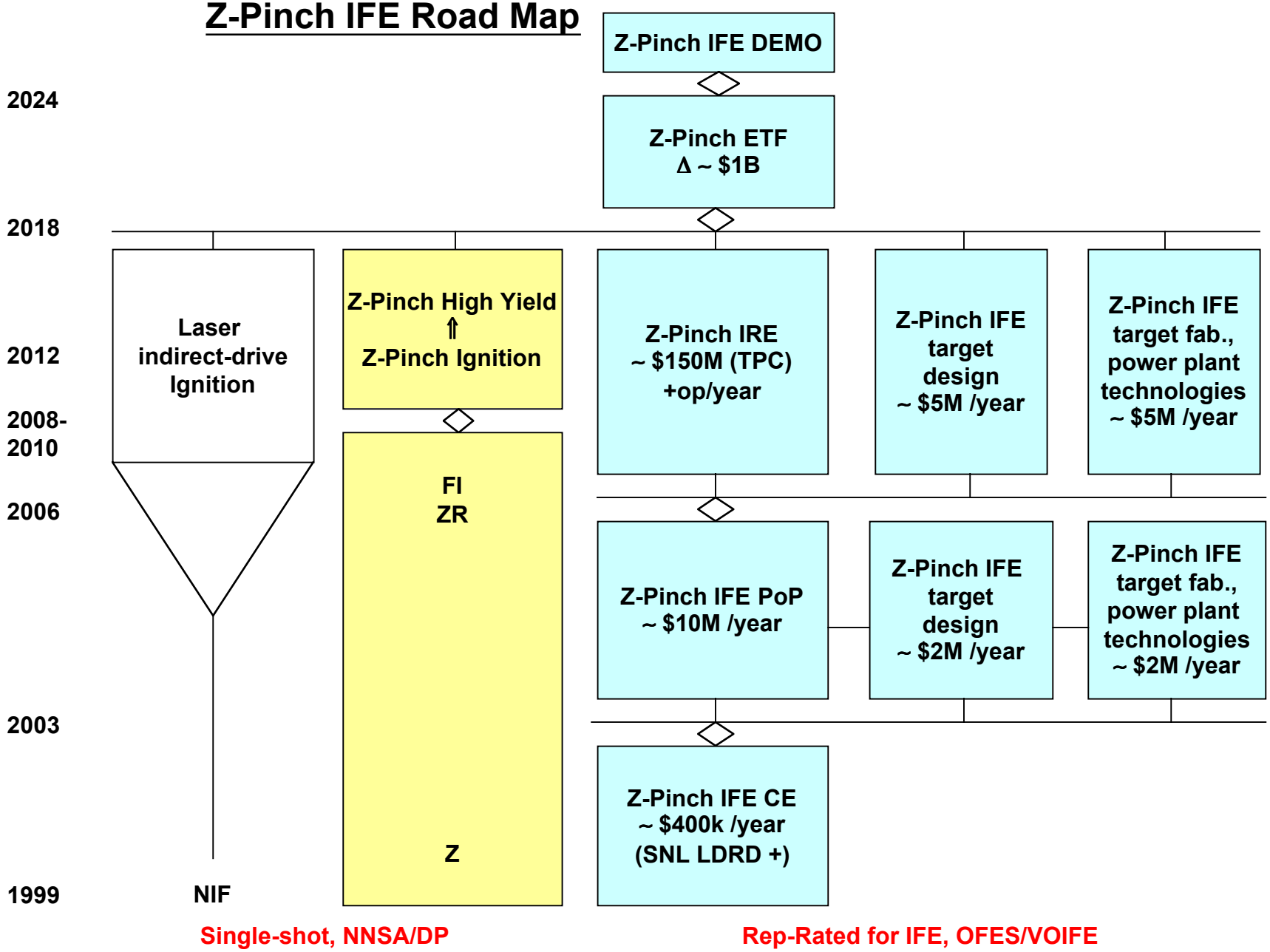
Direct-drive Indirect-drive

Fast Igniter option (major driver + PW laser)

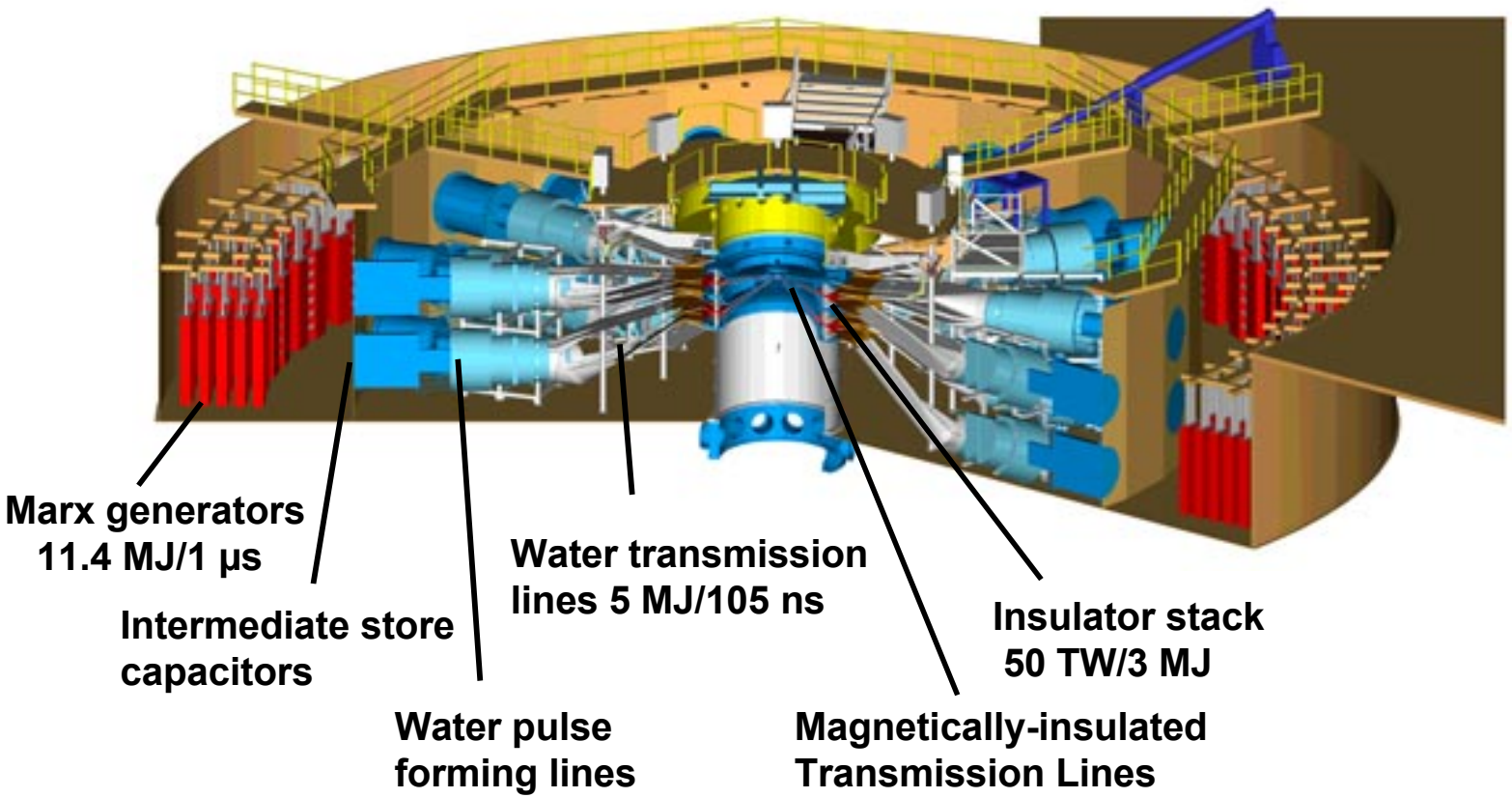
Chambers:

Dry-wall Wetted-wall Thick-liquid wall Solid/voids

Z-Pinch IFE Road Map



Z, the world's most powerful x-ray source for z-pinch-driven targets, is on the pathway to z-pinch IFE



X-rays from z-pinch wire array: ~ 6 ns, ~ 1.6 MJ, ~ 230 TW
High efficiency (wall-plug to x-rays): ~ 15%

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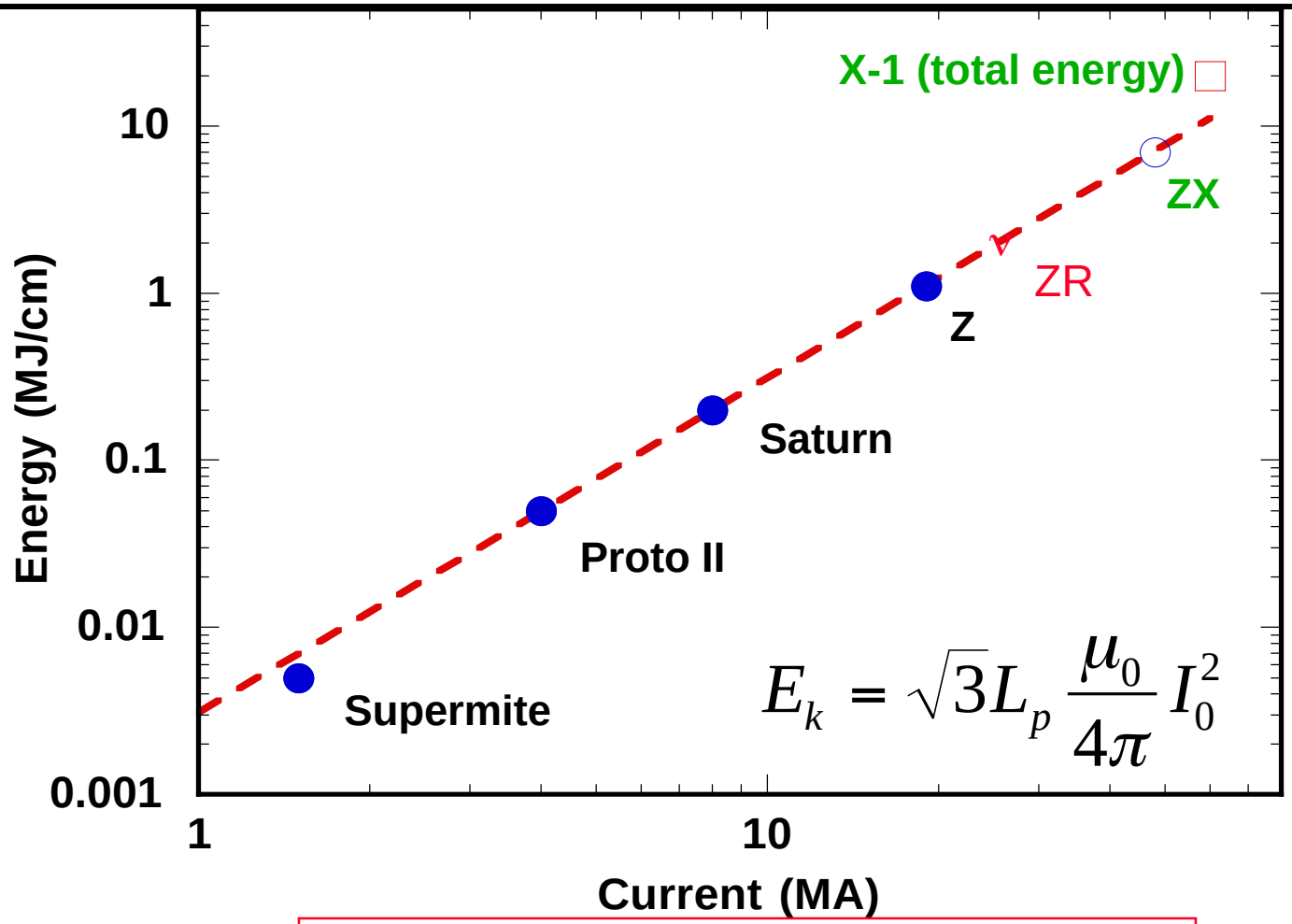
Z-pinches offer the promise of a cost-effective energy-rich source of x-rays for IFE



ZR will be within a factor of 2-3 in current (4-9 in energy) of a High Yield driver.

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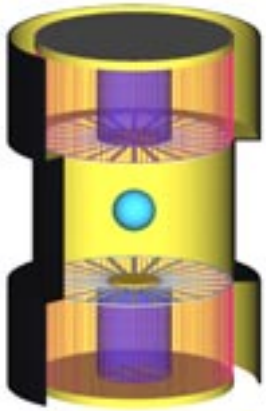
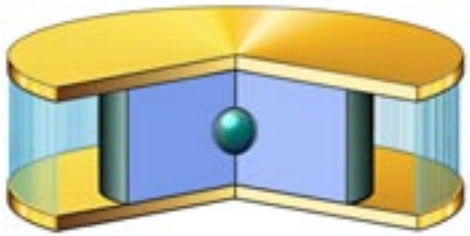
Two complementary Z-pinch indirect drive concepts for high-yield ICF and IFE are being explored

	ICF – IFE Current / E_{abs} / Yield	Features
Double-Pinch Hohlraum 	2 x 62-68 MA 1.3 – 2.6 MJ 400 – 3500 MJ	Dual power feed, double-pinch Capsule isolated from z-pinches Symmetry via hohlraum design demonstrated on Z (2x16 MA) η_{hohl} ~ 8-16 %
Dynamic Hohlraum 	54 – 95 MA 2.4 – 7.2 MJ 530 – 4400 MJ	Capsule inside single pinch and converter Core T_e > 1 keV, dopant x-ray spectra measured on Z (20 MA) η_{hohl} ~ 20 %

J. Hammer, M. Tabak, R. Vesey, S. Slutz

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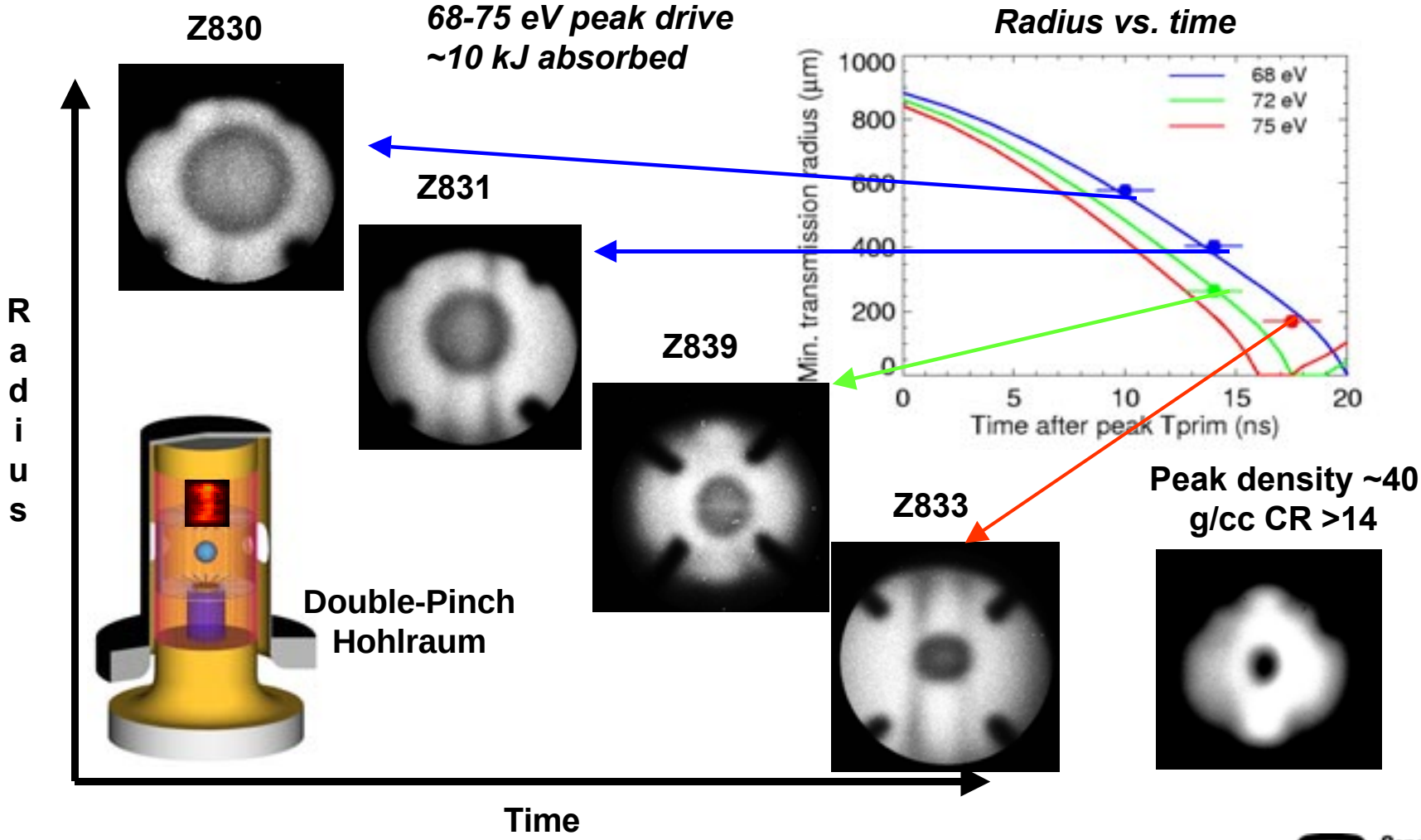
Double-pinch hohlraum capsule implosion experiments on Z demonstrate capsule convergence ratios of 14-20; backlit capsule images agree with simulations



G. Bennett, M. Cuneo, R. Vesey

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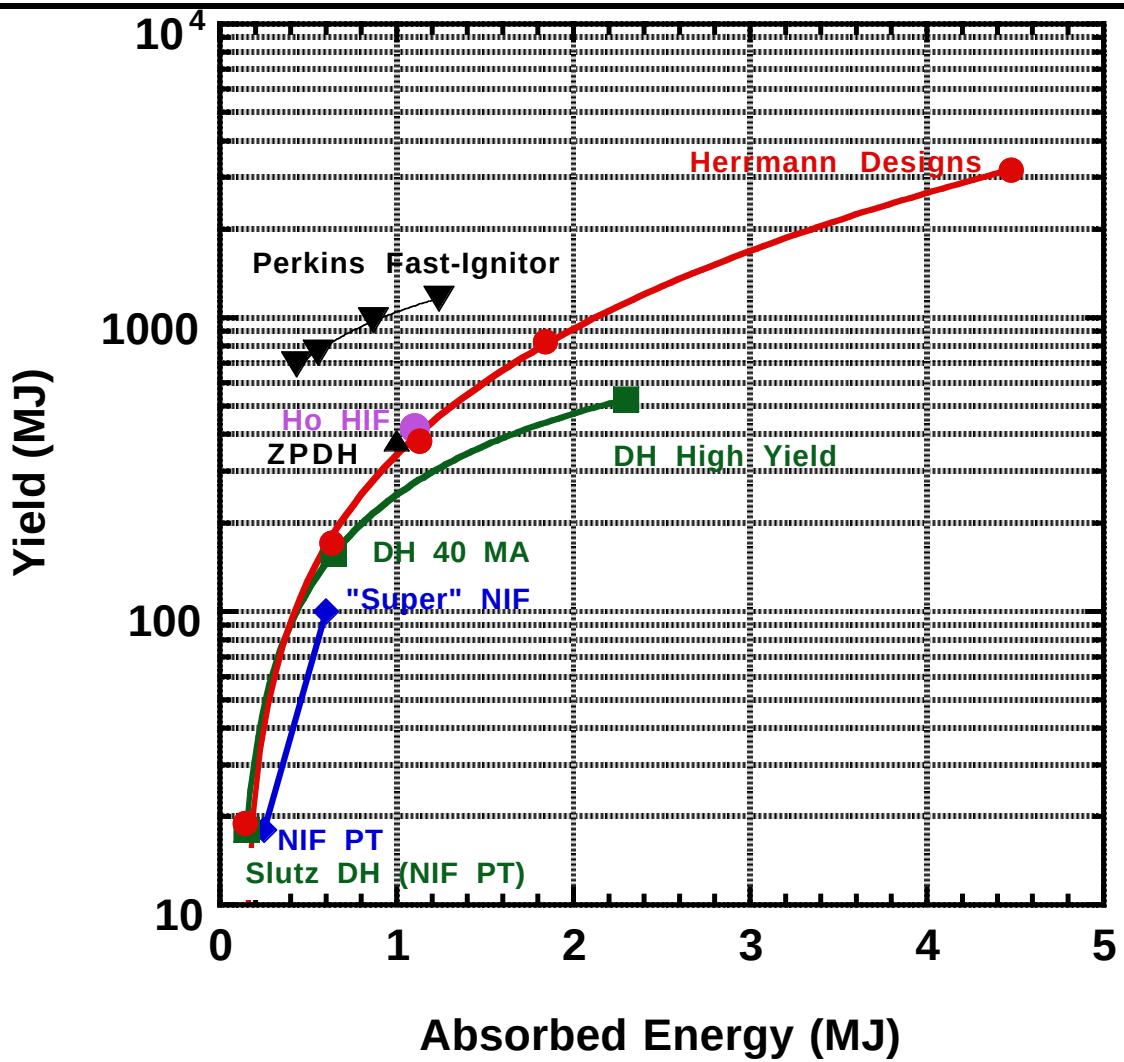
A variety of target concepts (ZPDH, DH, FI) are being investigated for scaling to high yields for Z-Pinch IFE

ICF Capsule Design Scaling



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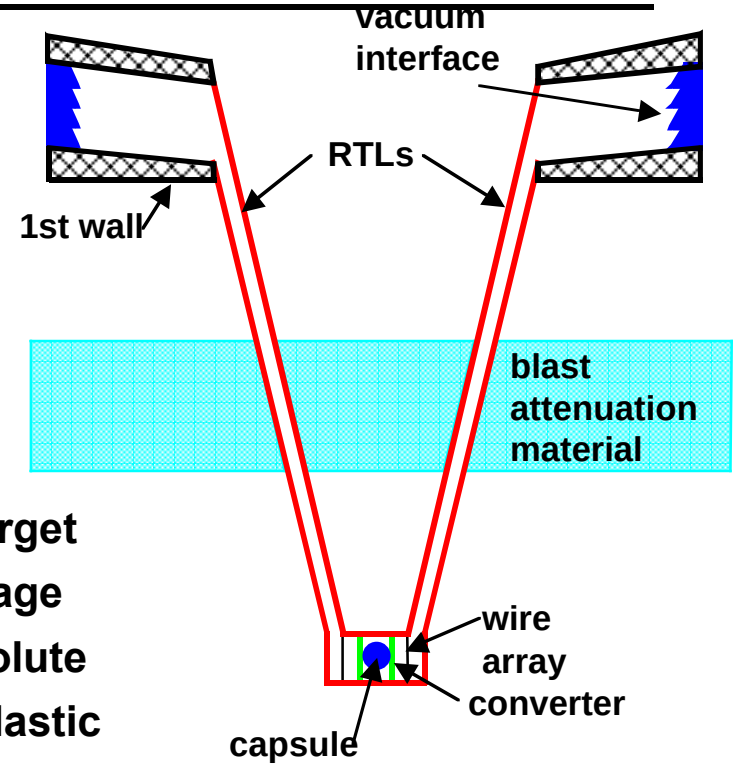
Rep-rated z-pinch power plant concept uses a Recyclable Transmission Line (RTL)

- High yield (~ few GJ), low rep-rate (~0.1 Hz)
- RTL made of solid coolant (e.g., Flibe) or material easily separable from coolant
- RTL's pumped down before loading
- Essentially no chamber vacuum requirement
- Can pack solid or liquid Li or Flibe up next to target
- Wall lifetime limited by shock, not neutron damage
- RTL can bend around corners; can shield convolute
- Works in a robust, dirty environment of metal/plastic



RTL experiments on Saturn at the 10 MA level, with power plant level electrical stresses, have demonstrated uniform electrical turn-on, proper magnetically-insulated transmission line operation, high electrical conductivity, and low mass (results scale to 80 kg RTL with 90% electrical efficiency for power plant).

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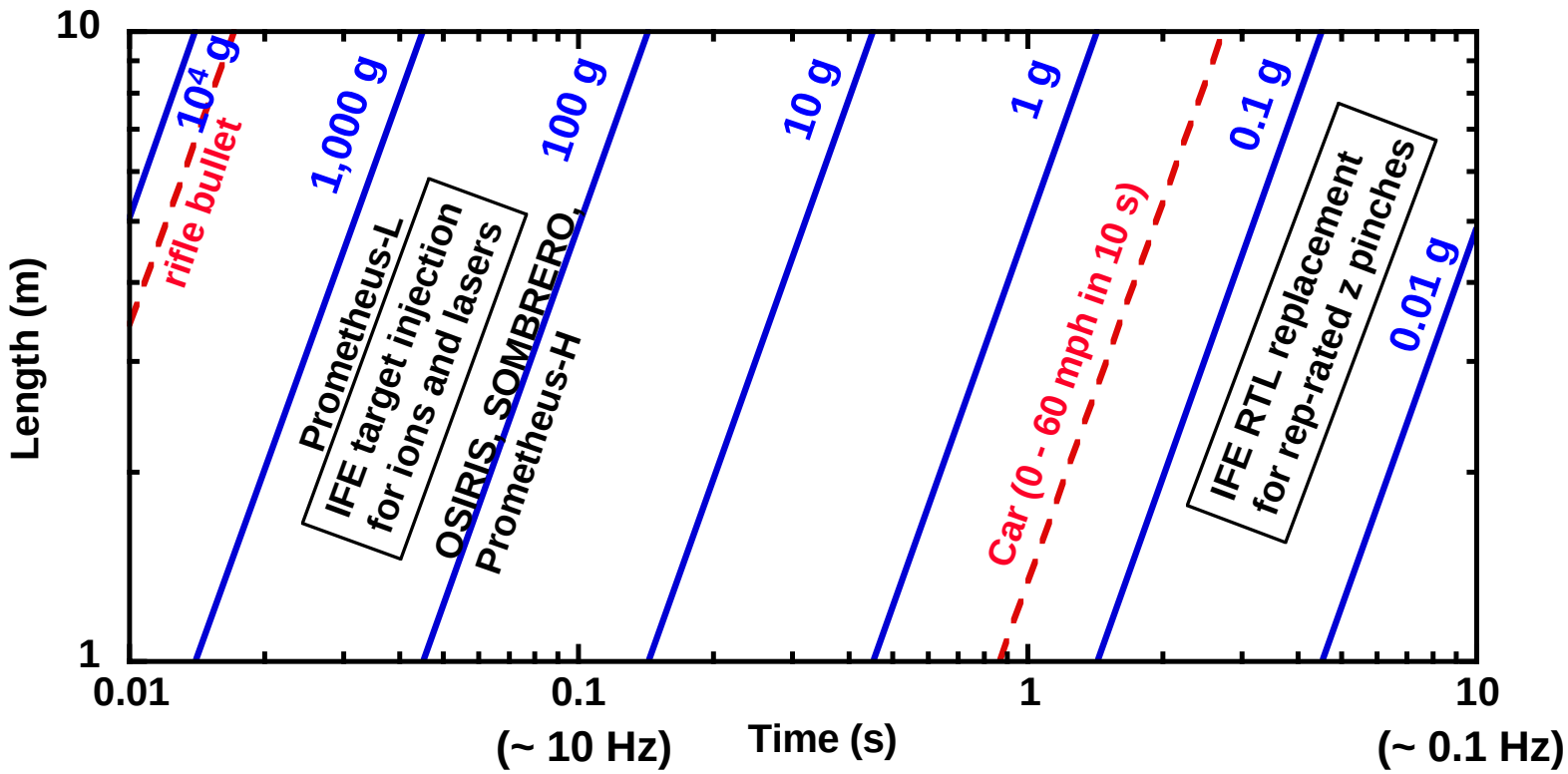
RTL replacement requires only modest acceleration for IFE

$L = 0.5\ a\ t^2$, or $a \sim 1/t^2$

Acceleration is 10^4 less than for IFE target injection for ions or lasers



Z-Pinch RTL approach eliminates problems of final optic, pointing & tracking of N beams, and high speed target injection

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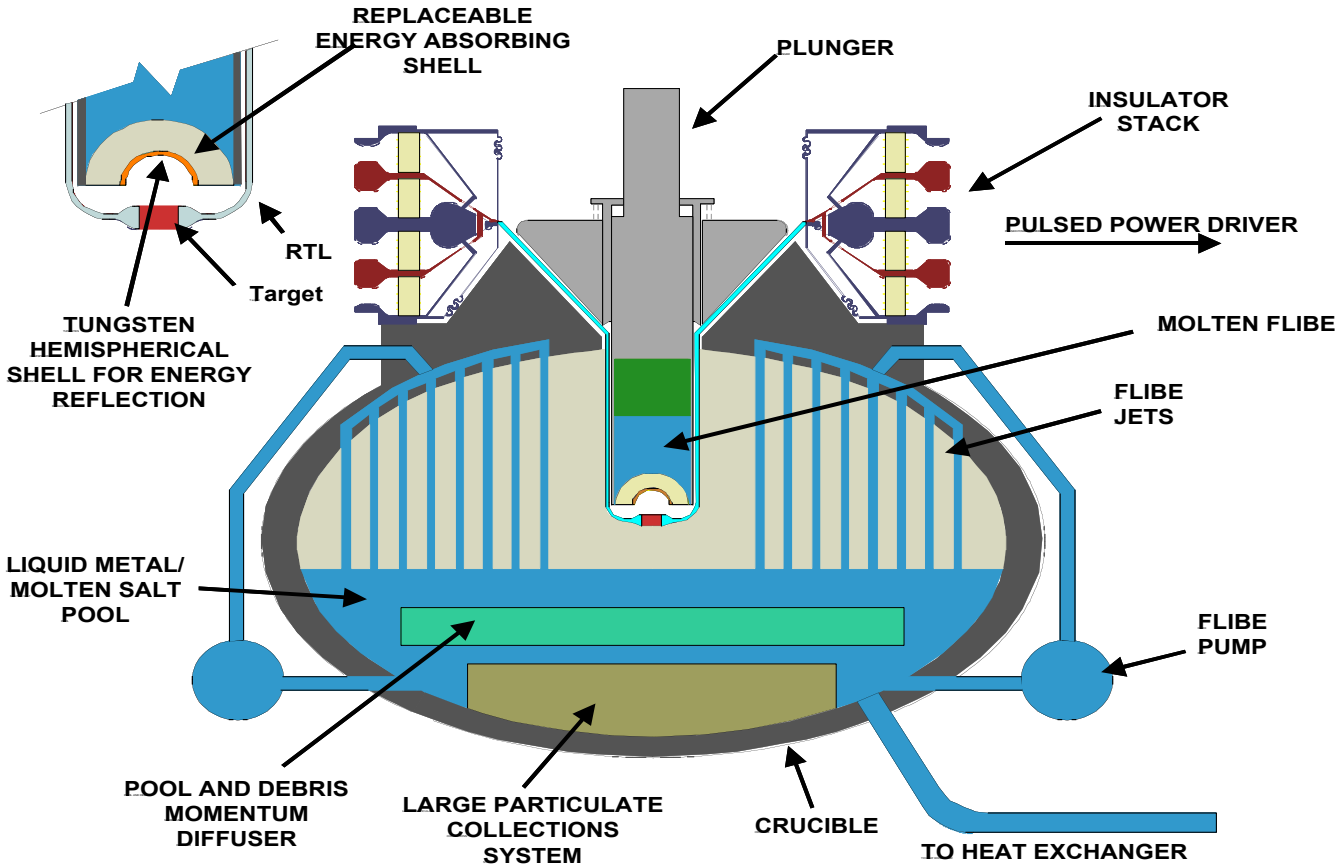
First z-pinch power plant study has produced a plausible scenario for RTL operation, including vacuum and electrical connections



Producing economical recyclable transmission lines remains the most important issue

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Z-Pinch IFE is being developed as an integrated system

	CE	PoP	IRE
Targets (capsule compression, symmetry experiments, etc. on Z,ZR, etc.) (DP) Z-Pinch Driven Target Dynamic Hohlraum Target Fast Ignition, Advanced Targets	(X)	(X)	(X)
Driver (Rep-Rated) Fast cycling Marx/waterPFL/… RHEPP technology LTD technology		X	X
Standoff (Recyclable Transmission Line - RTL) RTL material choice, optimum shape, low inductance, etc. Electrical turn-on, conductivity, low mass, mechanical strength, etc. RTL/Chamber interface issues, etc.	X	X	X
Chamber and Power Plant Thick liquid walls, solid/voids, containment, etc. Power Plant design Manufacturing, target fabrication, costing, etc.	X	X	X
Integrated, Rep-Rated, Scaled RTL Cycle Experiment @ 0.1 Hz Model RTL cycle Couple with z-pinch load Automated, rep-rated, demonstration experiments		X	X

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Rep-rated pulsed power is being studied for the z-pinch power plant concept

Status: Z (20 MA) at ~ 1 shot/day is ~ 10^{-5} Hz
Z-Pinch IFE needs ~ 1 shot/10 seconds is 0.1 Hz
RHEPP has demonstrated 2.5 kJ at 120 Hz (0.3 MW ave. pwr.)

Survey of possible rep-rated pulsed power scenarios for 0.1 Hz :
- fast charging MARX/water PFL/…
- RHEPP (magnetic pulse compression)
- linear transformer driver (LTD)

Tentative choice: LTD
- LTD is very compact, very fast (pioneered in Tomsk, Russia)
- direct charging of compact capacitors
- IVA (inductive voltage adder)
- MITL (magnetically-insulated transmission line)
- modular, scalable, easily rep-rateable

Planned Scaled facilities:
- PoP scale experiment: 1 MA, 1MV, 100 ns, 0.1 Hz
- IRE: 10 MA, 2 MV, 100 ns, 0.1 Hz
- ETF: 60 MA, 5-10 MV, 100 ns, 0.1 Hz

LTD studies for a 1 MA driver (PoP scale) and a 10 MA driver (IRE scale) are in progress

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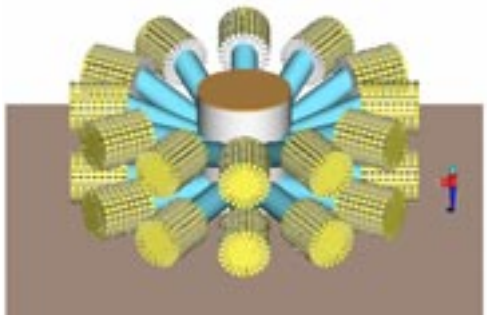
Comparison of Existing Saturn Assembly with the Proposed New LTD (Z-Pinch IRE will be this scale)

Present Device	New Design
30-m diameter.	**14.8-m diameter.**
6 -m height.	**5-m height**
250,000-gallon oil tank.	**None**
250,000-gallon water tank.	**None**
2 m diameter insulating stack.	**None**



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Scaled RTL Cycle Experiments

PoP (Proof of Principle):

1 MA, 1 MV, 100 ns, 0.1 Hz
scaled RTL
integrated experiment for N shots
~ 5 kJ x-ray output per shot

IRE (Integrated Research Experiment):

10 MA, 2 MV, 100 ns, 0.1 Hz (rep-rated Saturn scale)
scaled RTL
integrated experiment for N shots
~ 0.5 MJ x-ray output per shot

ETF (Engineering Test Facility):

Extension of Z-pinch HY Facility
~ 60 MA, 5-10 MV, 100 ns, 0.1 Hz
full-scale RTL
~ 0.5 GJ fusion yield per shot

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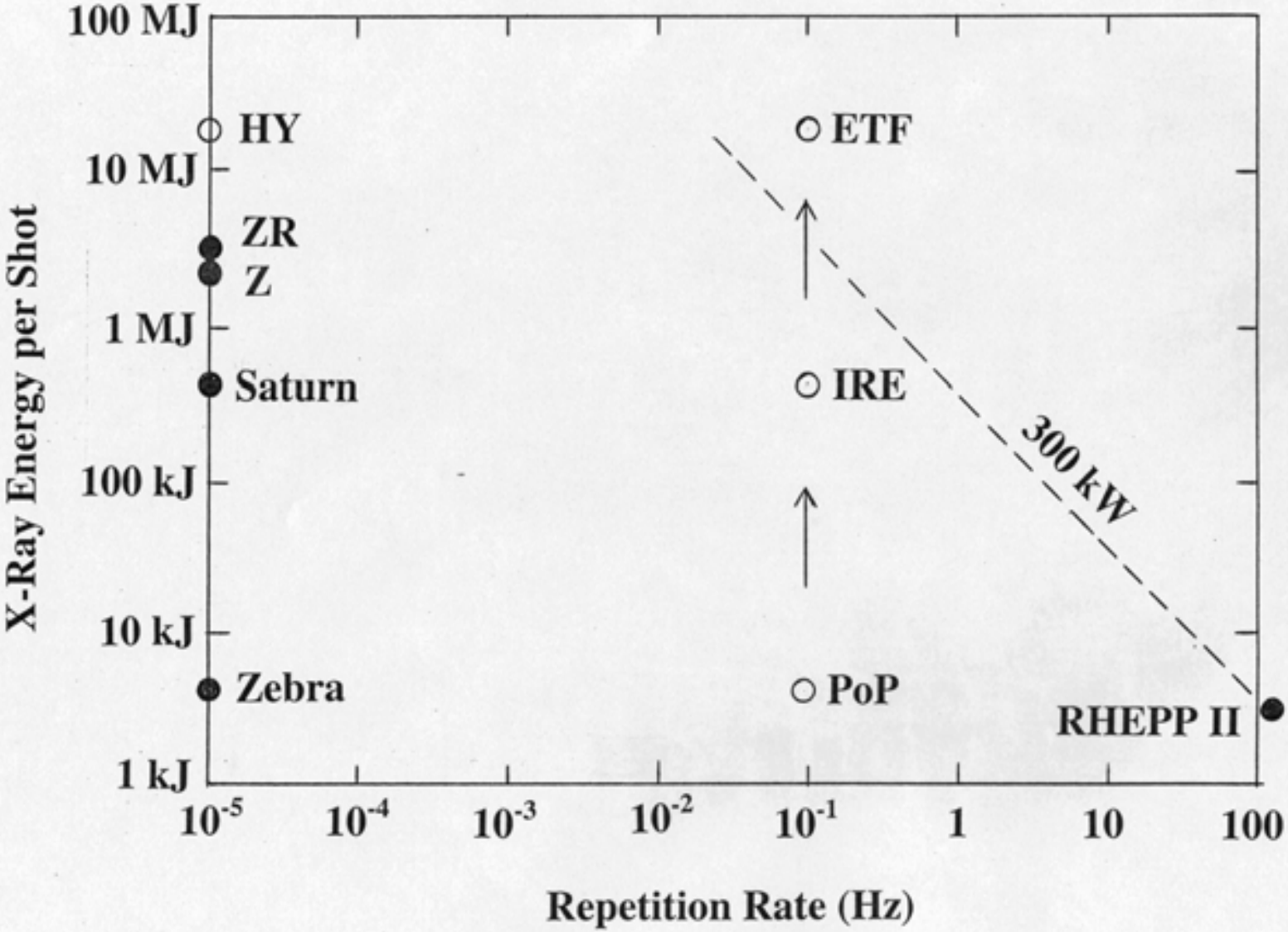
Z-Pinch IFE Development Path



Z-Pinch IFE Program - Conclusions

Z-Pinches have joined lasers in capsule implosion experiments

Z-pinch driven capsule compression experiments on Z

- double-pinch hohlraum (Cr > 14),
- dynamic hohlraum (Cr ~ 10)
- cone compression for fast ignition

High yield target simulations for 0.5 GJ - 3 GJ

- double-pinch hohlraum; dynamic hohlraum; fast ignition

Z-pinch driver development Z ⇨ ZR ⇨ High Yield

- ZR will be within a factor of 2-3 in current (4-9 in energy) of high yield

Recyclable Transmission Line (RTL) concept for rep-rated operation

- Saturn RTL experiments at 10 MA successfully completed

Z-pinch power plant (3 GJ @ 0.1 Hz per chamber)

- First integrated design study completed

Rep-rated Z-Pinch driver

- Linear Transformer Driver (LTD) technology (no oil, no water, no insulator stack)

PoP - IRE - ETF

- 1 MA @ 0.1 Hz; 10 MA @ 0.1 Hz; ~ 60 MA @ 0.1 Hz

Z-Pinch IFE Road Map

- Leverages DP investment in Z-Pinches, Merits home in DOE

Z-Pinch IFE ready for PoP level now
Z-Pinch IFE will be ready for IRE decision in 3-5 years

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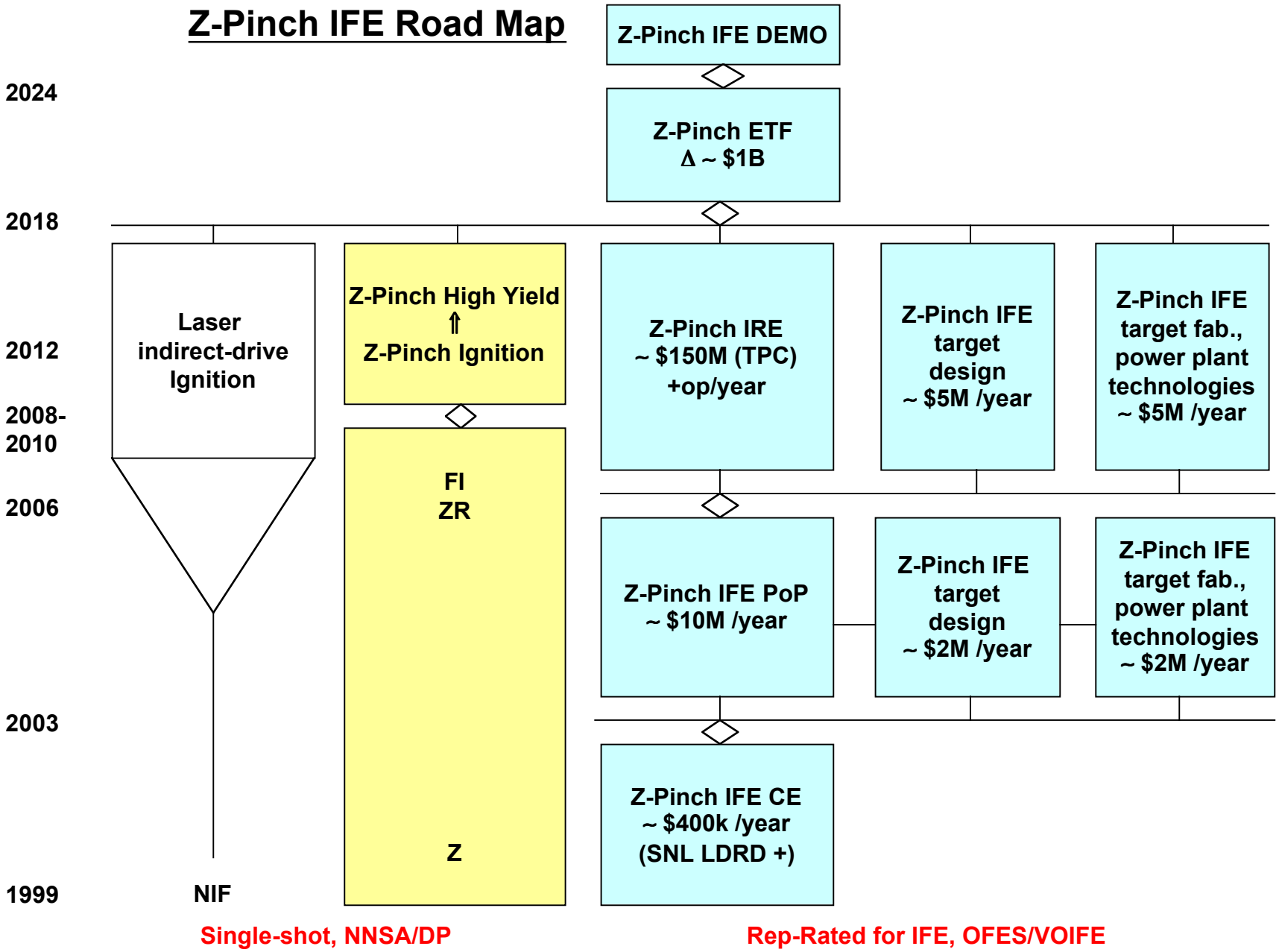
Z-Pinch IFE Road Map