Staged Z-pinch Target for Fusion

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arpa·e
CHANGING WHAT'S POSSIBLE

University of Nevada, Reno

Cornell University

University of California, San Diego

MIFTi
MAGNETO-INERTIAL FUSION TECHNOLOGIES, INC.
Clean, Safe, Low Cost Energy ... Forever

Staged Z-pinch: What is it and Why?

STAGED Z-PINCH:

Rahman, Wessel, Rostoker, Staged Z-pinch, PRL 74, 714, 1995

- Magnetized, high-Z liner -> fusion target, e.g.,

  Kr, or Ag -> dt

- Axial, B_z magnetic field is compressed and amplified
- Target is preheated by fast shocks
- The plasma is stable until peak compression

BENEFITS:

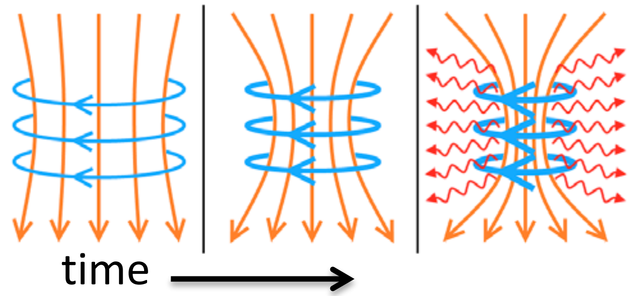
- Efficient, staged-energy transfer
- Magneto-inertial confinement
- Fusion gain, G ~ 1, (may be) possible today, based on:

  Established scalings vs. discharge current

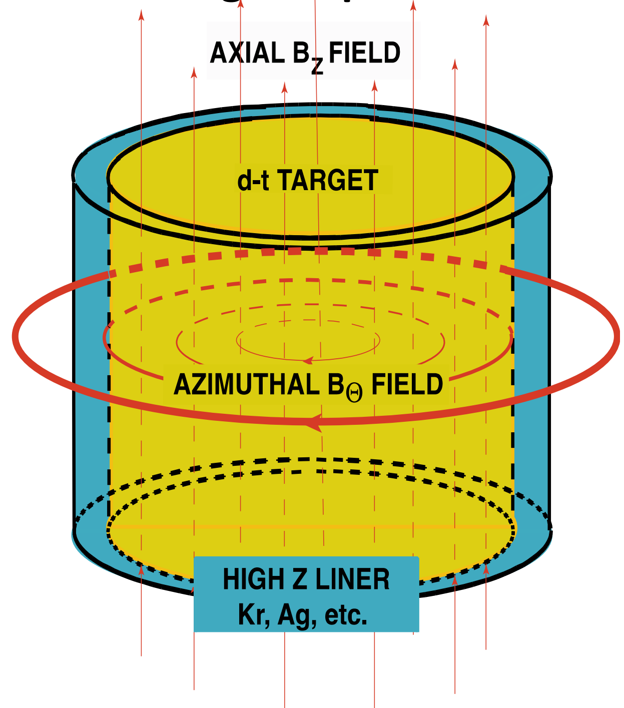
  MHD simulations

  Scalable, rep-rate driver systems (may) exist

Implosion of a Z-pinch



Staged Z-pinch

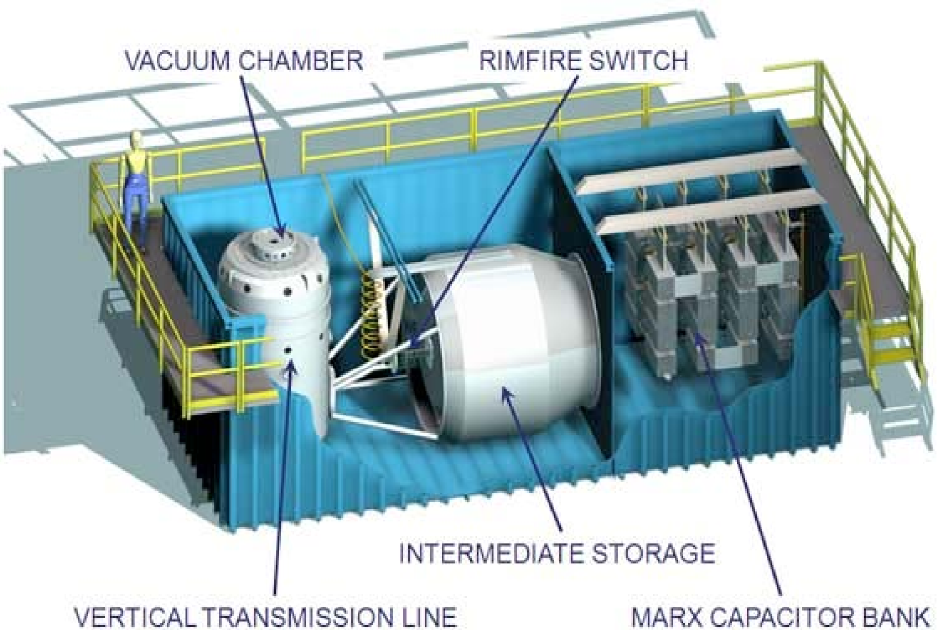


Facilities &Teams at 3 Research Universities

Location & Resource	Z (Ω)	τ (ns)	I (MA)	Diagnostics
Univ.Nev.Reno Zebra Facility	1.9	110	0.95	photo-preionization; neutron time-of-flight; Schlieren & shadow laser imaging; streak, XUV (framing) imaging; XR pinhole imaging; XR spectroscopy
Mass injector is anode mounted, **mass flows toward the high-voltage electrode** Neutron studies possible for, **$Y < 10^{12}$/shot**				
Cornell Univ. - Cobra Facility	0.3	125	0.9	Discharge preionization; Schlieren imaging; shadow & shearing interferometry; XUV imaging; Thomson scattering; XR pinhole imaging; XR spectroscopy
Mass injector is cathode mounted, **mass flows toward the grounded electrode** Neutron studies possible for, **$Y < 10^{8}$/shot**				
UC SanDiego – Test Stand				Gas-flow interferometry; ICCD framing camera; pulsed-power electronics; computational-fluid dynamics
Design, development, and characterization of coaxial, fast-pulsed, gas-puff and plasma-jet injectors, power supply development				

Facilities

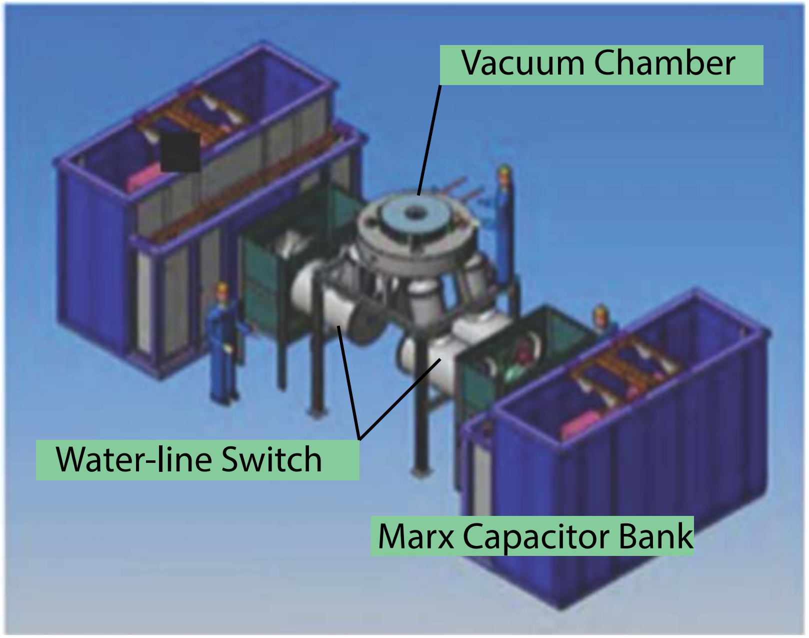
University of Nevada, Reno
Zebra Facility



1 MA, 0.1 μs, 150 kJ, 2.9 Ω

neutron experiments **are** allowed

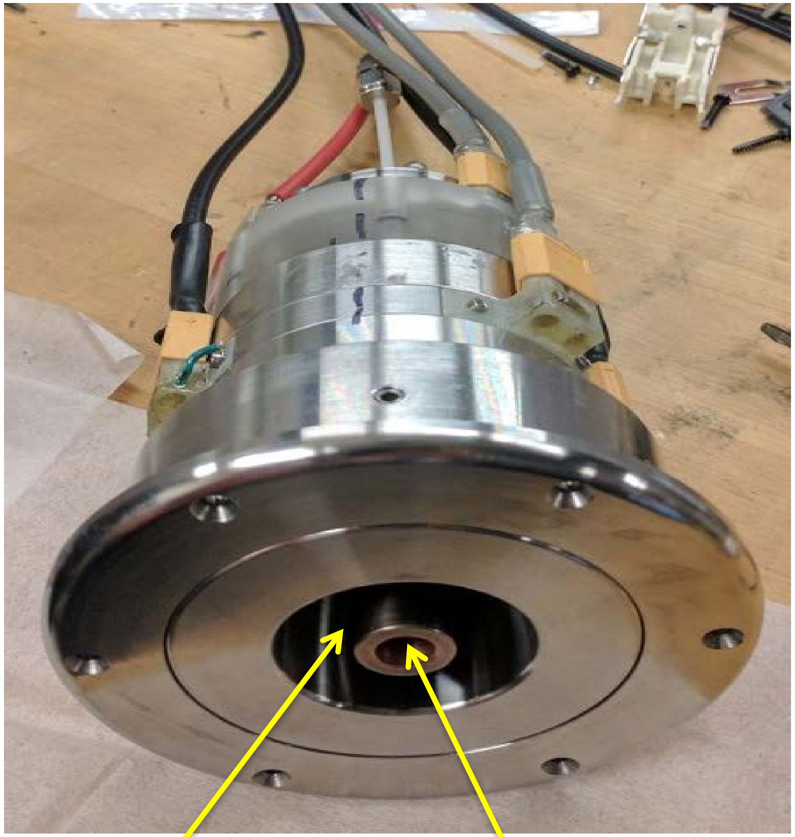
Cornell University
Cobra Facility



1 MA, 0.1-0.25 μs, 150 kJ, 0.3 Ω

neutron experiments **are not** allowed

Injector (UCSD)



Liner Injector

Target Injector

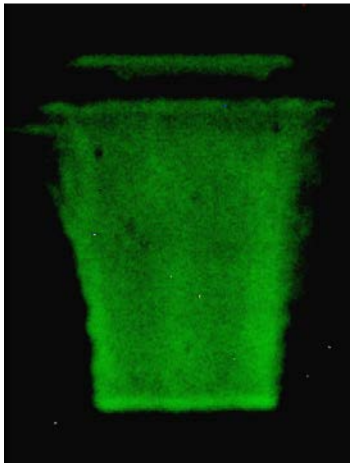
- Originally developed at UCI (1993)
- Updated, refined, & fabricated at UCSD
- 2 coaxial valves + on-axis plasma gun
- Battery operated & optically trigger
- Liner with a 1.2-cm radius
- Target with a 0.5-cm radius
- Injection profiles characterized by:
  - CFD Simulations
  - Interferometry
  - Spectroscopy

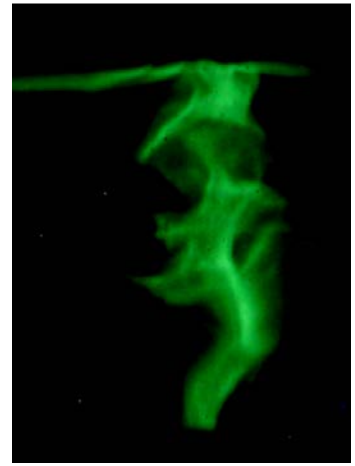
Stability (Cornell)

Extreme Ultraviolet, Fast Framing Camera Images

Run-in phase

Peak compression





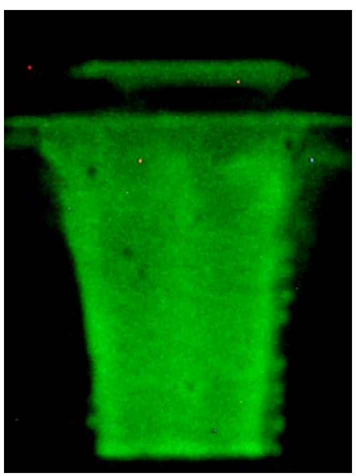
Ar liner

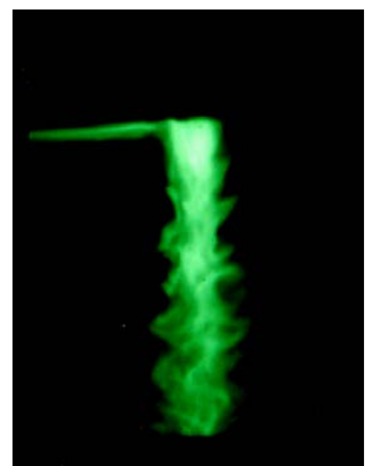
Shot 4422

$n_{Ar} \approx 3.0 \times 10^{16}\ cm^{-3}$

$B_z = 2.4$ kG

Unstable





Ar -> H^+

(Staged Z-pinch)

Shot 4415

$n_{Ar} \approx 3.0 \times 10^{16}\ cm^{-3}$

$n_{H2} \approx 5.0 \times 10^{17}\ cm^{-3}$

$B_{z0} = 2.4$ kG

Stable

$V_{radial} \sim 35 \times 10^6$ cm/s

$T_{ion} \approx 3\text{-}7$ keV

$n_{plasma} \approx 1 \times 10^{20}\ cm^{-3}$

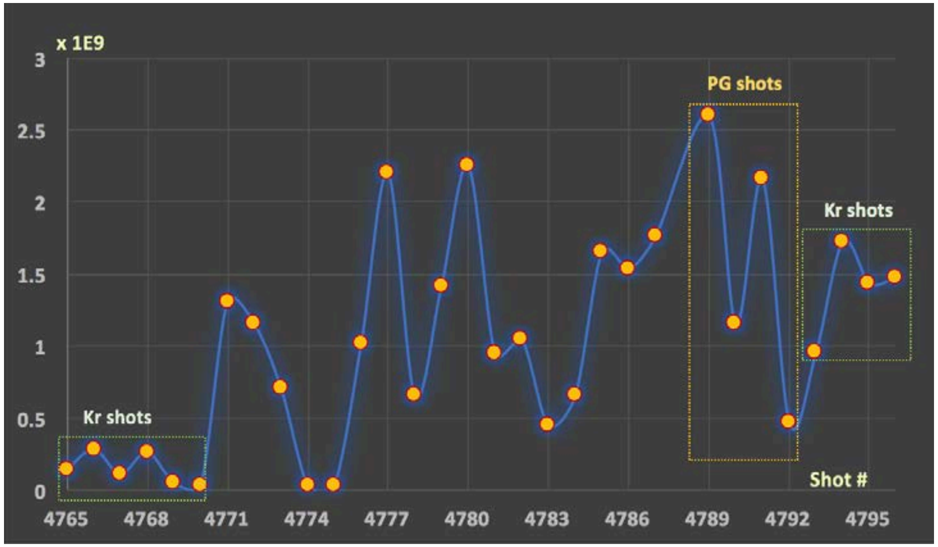
$\tau \approx 5$ ns

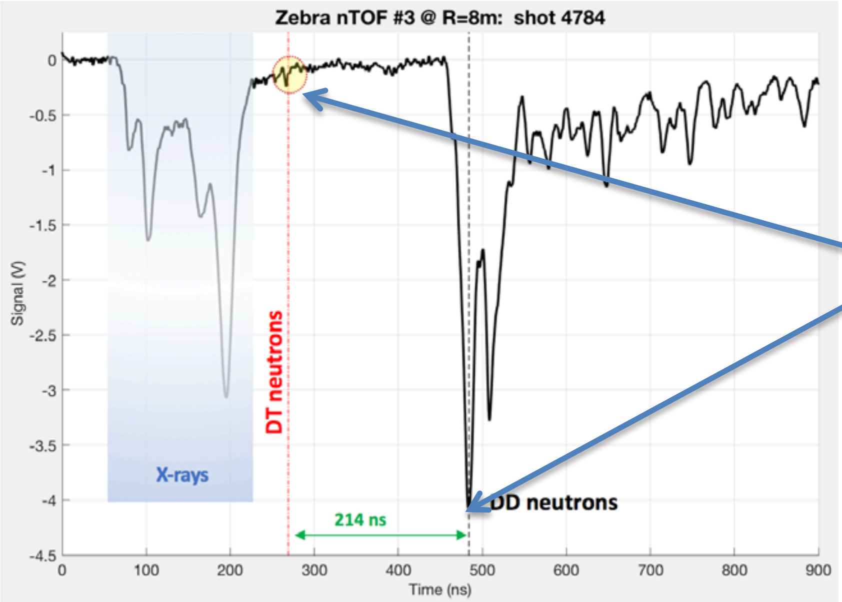
Fusion Neutrons (Zebra)

- SZP at UN Reno
  $d + d \rightarrow t + p$ (50%)
  $\rightarrow He^3 + n$(2.45 MeV) (50%)

- Highest yield $Y_{dd} = 2.6 \times 10^9$
- Consistent high yields: $Y_{dd} > 10^9$

- **Isotropic emission => Thermonuclear**





- Secondary neutrons were also detected
  $t + d \rightarrow He^4 + n$ (14.1 MeV)

- The ratio of secondary to primary yield
  $Y_{dt} / Y_{dd} \sim 10^{-3}$

- **Tritions are confined in a high B_z field**

Summary

- We are testing high Z liners of Ar & Kr -> D target
  - gas liners (scalable to high-repetition rate)
  - scalable to solid liners and much higher current
- The SZP is observed to be stable
  - Implosion velocity, V_{radial} ~ 30-60 cm/μs
  - $V_{radial} \geq$ laser ICF
  - ion temperature, T_{ion} ~ 3 – 8 keV
- Measured dd neutron yields are
  - isotropic => thermonuclear
  - reproducible, peak yields of, Y ~ 3 x 10^9
- dt neutrons are detected
  - magneto-inertial confinement
  - magnetic field, $B_z \geq$ 100's of Tesla

Path Forward

1 Scientific Feasibility

continue to add improvements that increase yield

SZP concept validated when, $Y_{dd} \sim 10^{10} - 10^{11}$ per shot

2 Engineering Feasibility

electrical engineering - define the best driver

mechanical engineering – refine for Hz operation

build & test a prototype system

3 Commercial Feasibility

build & test a demo unit

etc.