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MAGPIE
Centre of Excellence in High Energy Plasma Physics

Pulse shaping of interaction and stagnation pulses using nested conical wire arrays

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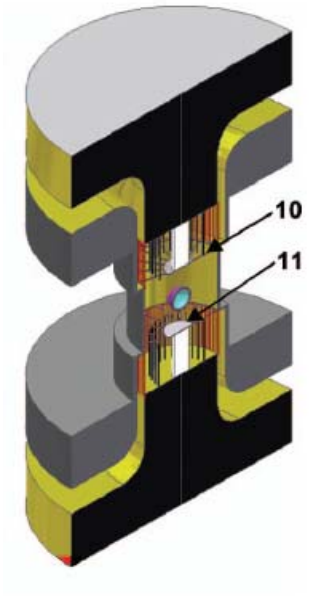
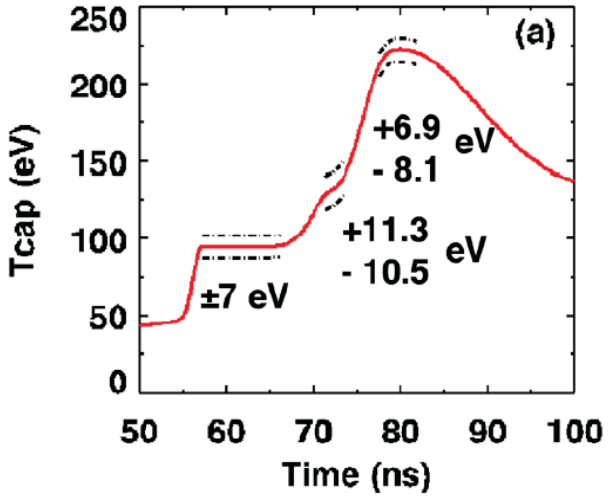
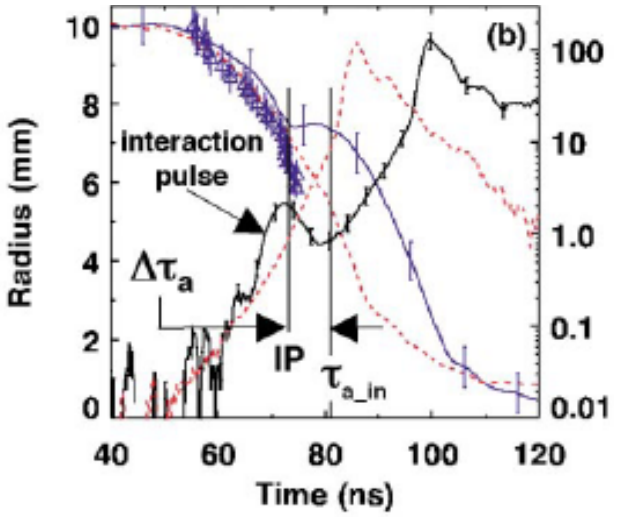
Pulse shaping is vital to z-pinch ICF concepts





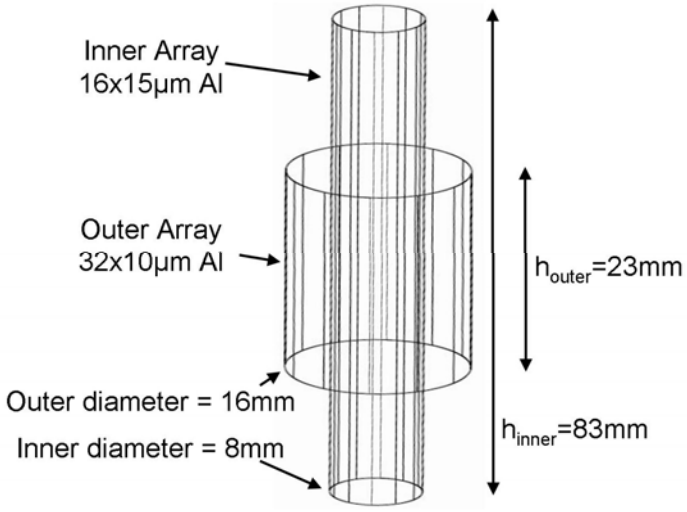


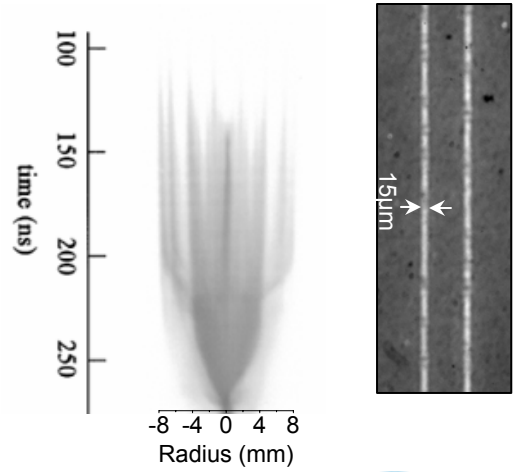
- Three or more controlled x-ray pulses are required in order to heat a fusion capsule
- One suitable pre-pulse is observed as the imploding outer array of two nested arrays interacts with the inner array, however detailed physical mechanism of the interaction pulse is not fully understood
- Necessary to broaden main pulse (and interaction pulse)
  - nested arrays on Z are *too good* at temporal compression

Images reproduced from
M.E. Cuneo et al. Phys Plas 13 056318, 2006

Nested wire arrays on MAGPIE use high inductance inner to suppress current through the inner array to be similar to Z

- High wire number in outer at 20MA leads to Inductive contrast: $L_{outer} \ll L_{inner}$
  e.g. Cuneo et al PRL 94, 225003 (2005)
- High wire number not possible at ~1MA
- Array design can give same inductive contrast (by lengthening inner)
  Lebedev et al. PRL 84, 1708 (2000)
- Negligible inner current confirmed by
  - Radial optical streak
  - X-pinch radiography
  - B-dot probes
- Present experiments use
  - Outer array 16-32 x 10μm Al 5056 at 16mm
  - Inner array 16 wire Al, W or CH at 8mm





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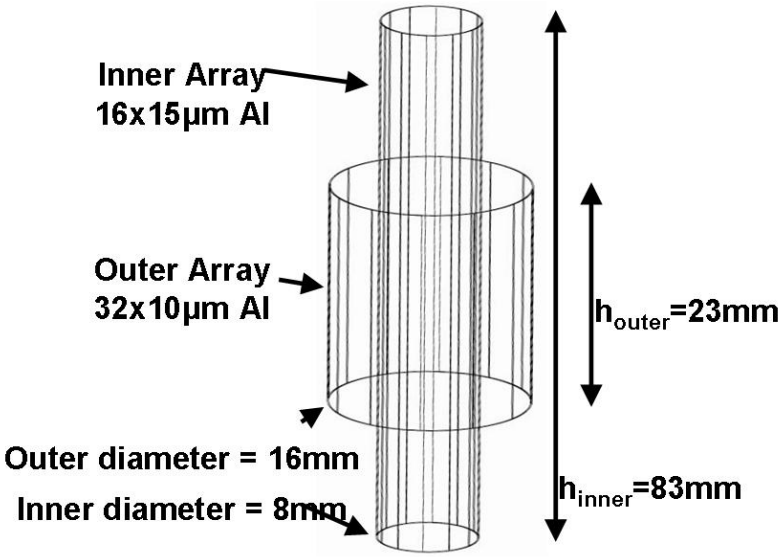
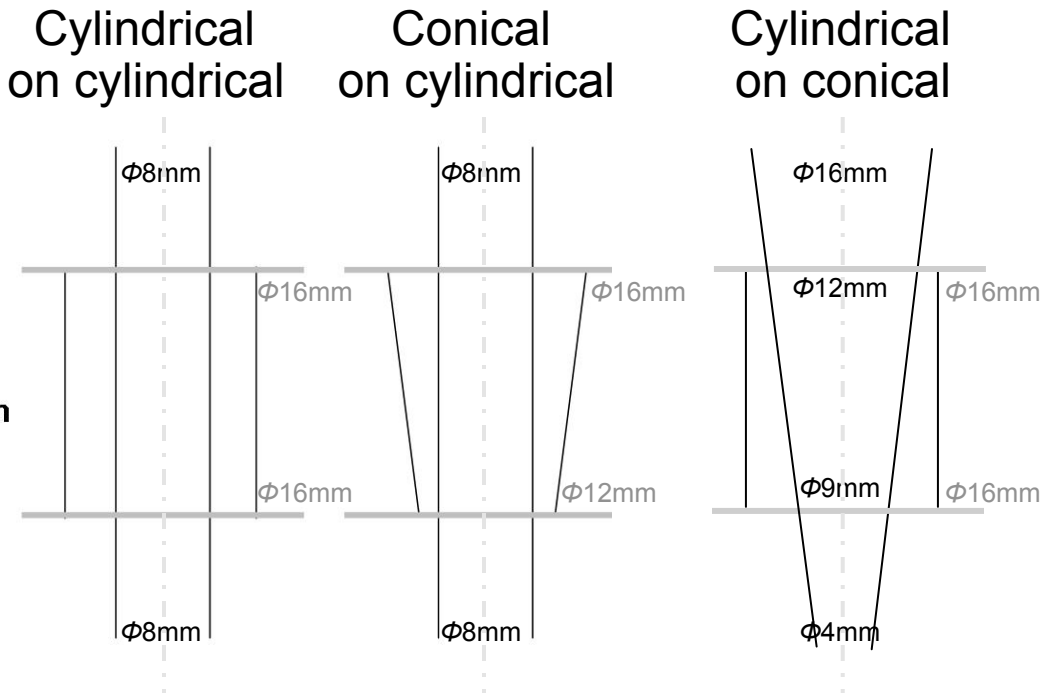
Conical nested setup

- One suggested technique to lengthen the main pulse from nested arrays is to seed a zipper using conical arrays
  c.f. zipper observed in gas puff experiments

- Two modified setups tested on both MAGPIE and Z





Use of a conical outer array will alter mass ablation rate

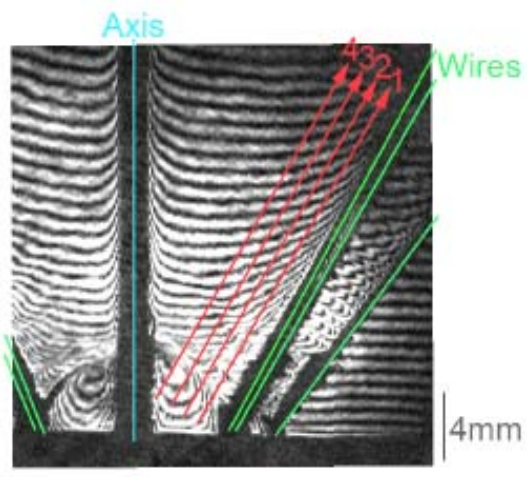
- With conical outer array the global field strength is varied along the length of the wire

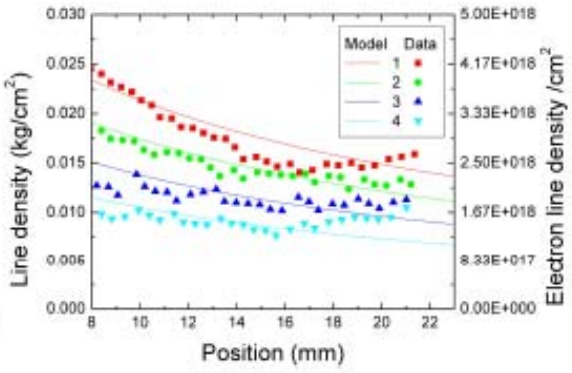
$$B(z,t) = \frac{\mu_0 I(t)}{2\pi R(z)} = \frac{\mu_0 I(t)}{2\pi(R_0 + z\tan(\alpha))}$$

- Variation in global field alters mass ablation (due to fixed v_{abl})

$$\dot{m} = \frac{\mu_0 I(t)}{2\pi V_{abl}(R_0 + z tan(\alpha))}$$

  - Mass density profiles in single conical arrays are consistent (v_{abl}~15cm/μs)

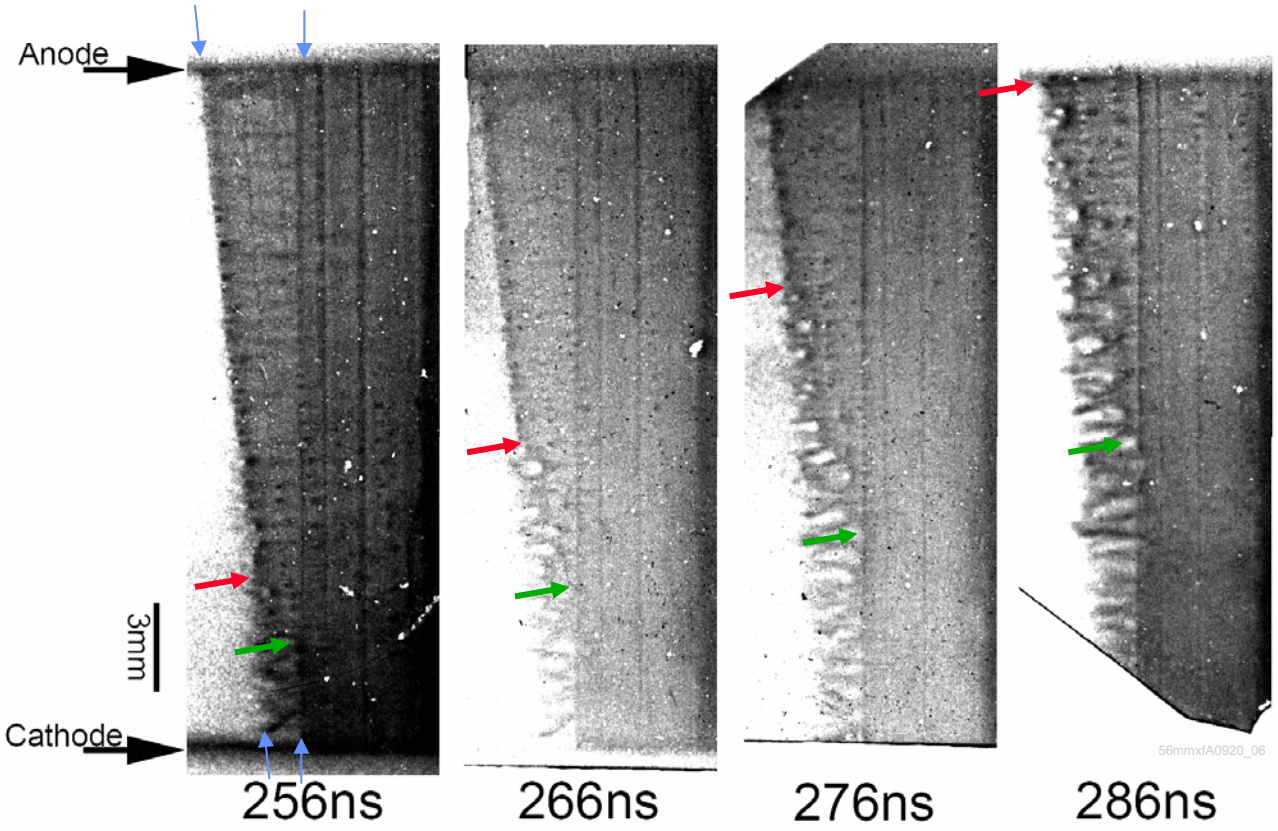




- Time of mass depletion (for single or nested) is expected to be a function of axial position

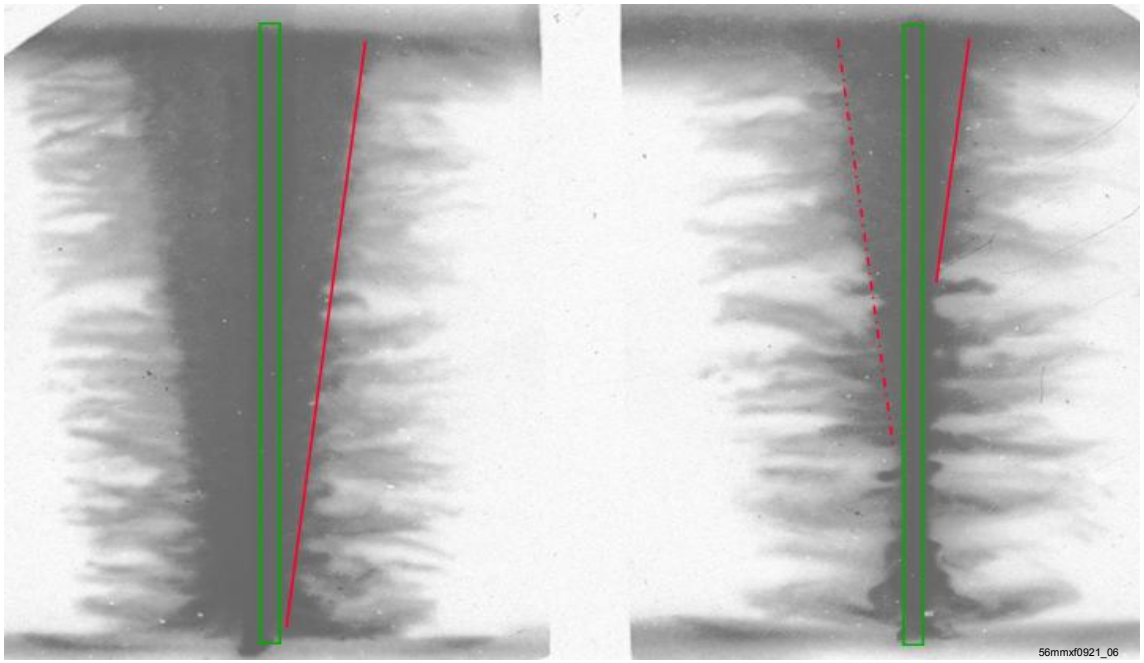
A conical outer array can be used to seed an axial zipper

- Nested conical data agrees with predicted delay in time of wire breakage



- Also see that zipper of implosion gives an axial dependence time of interaction with the inner array

Axial zipper survives through the interaction, leading to a zippered implosion of inner

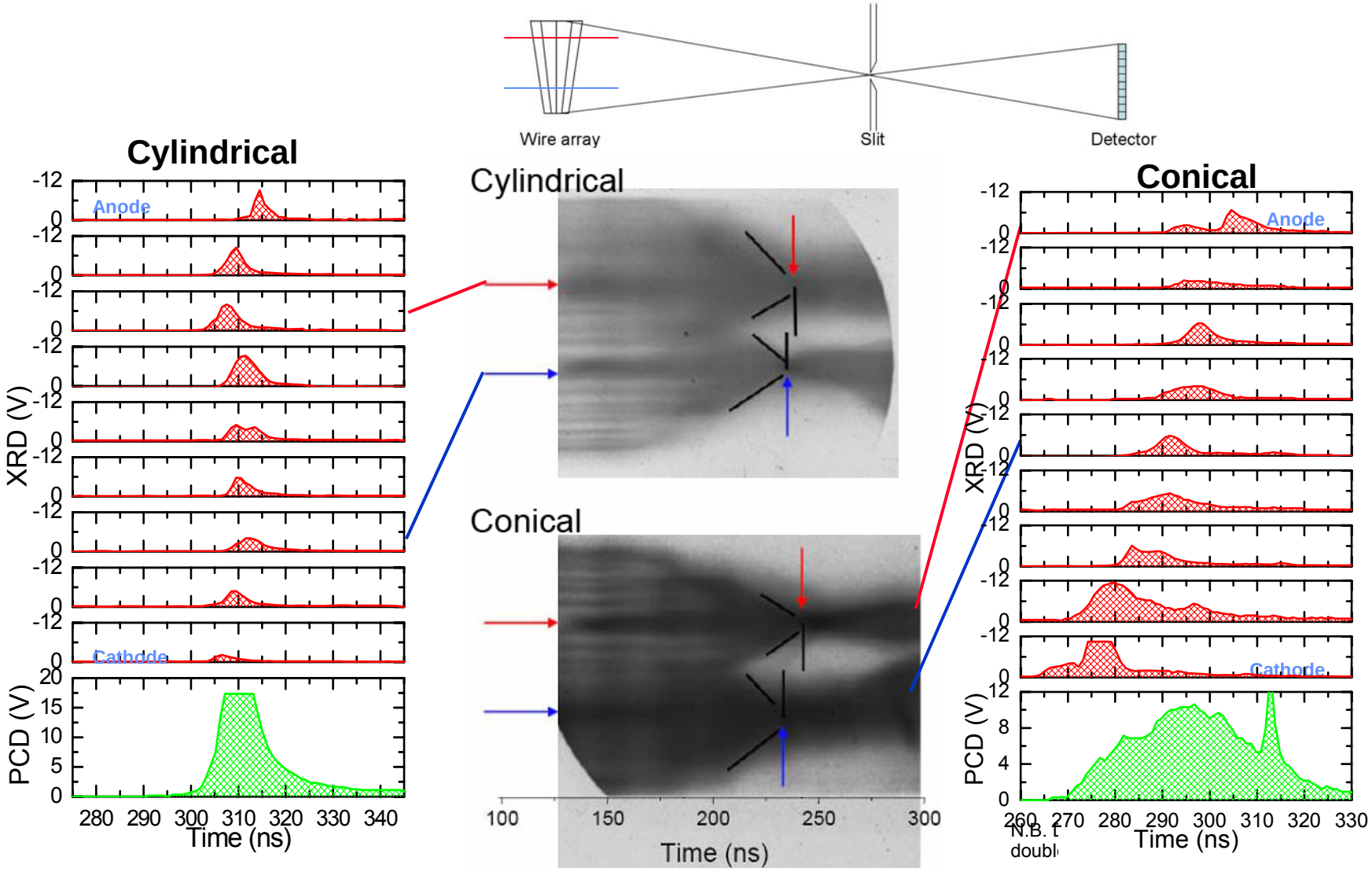


Time: 291ns 301ns

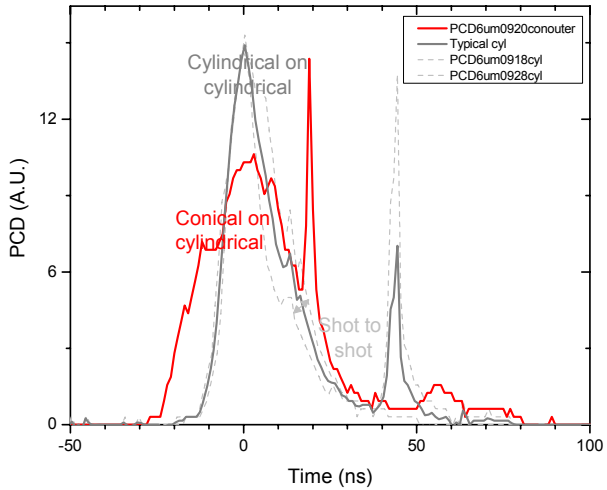
- Data indicates change in implosion position 13.9mm in 10ns
- Implies zipper velocity ~139cm/μs
- Zipper can be extrapolated to estimate zipper along full axis Δt_{zip}~16.5ns
- On MAGPIE, left-right asymmetry also present due to concentricity issue,
  - will effect pulse, but temporal effect is less (Δt_{L-R}~7ns)

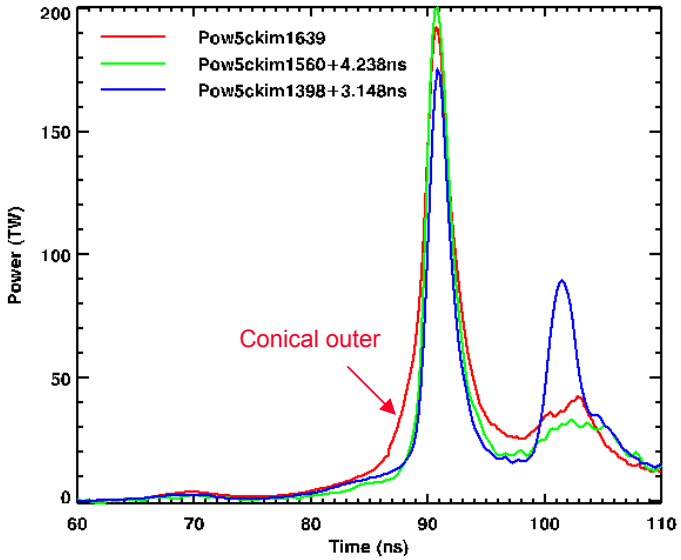
Seeded zipper translates into a zippered stagnation, and elongated x-ray pulse

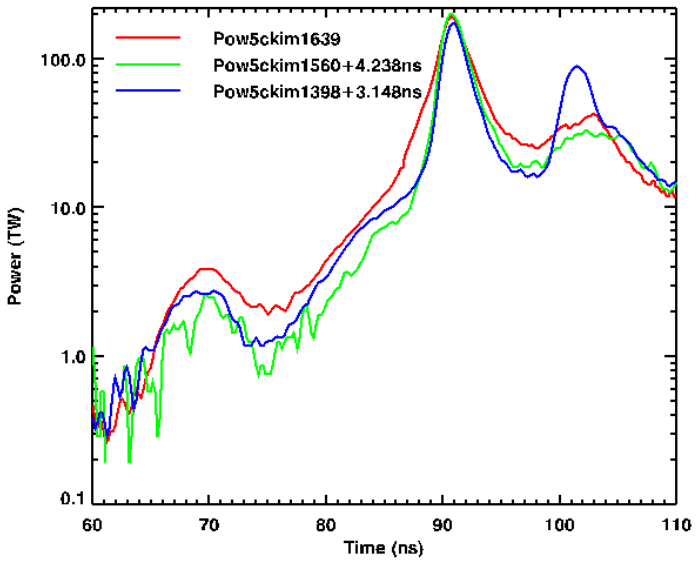
- Twin radial optical steak and zipper array each indicate conical outer zippers stagnation
- Axial dependence of stagnation time leads to pulse lengthening



Comparison of conical and cylindrical outers indicates success at widening main pulse







For conical outer on MAGPIE:

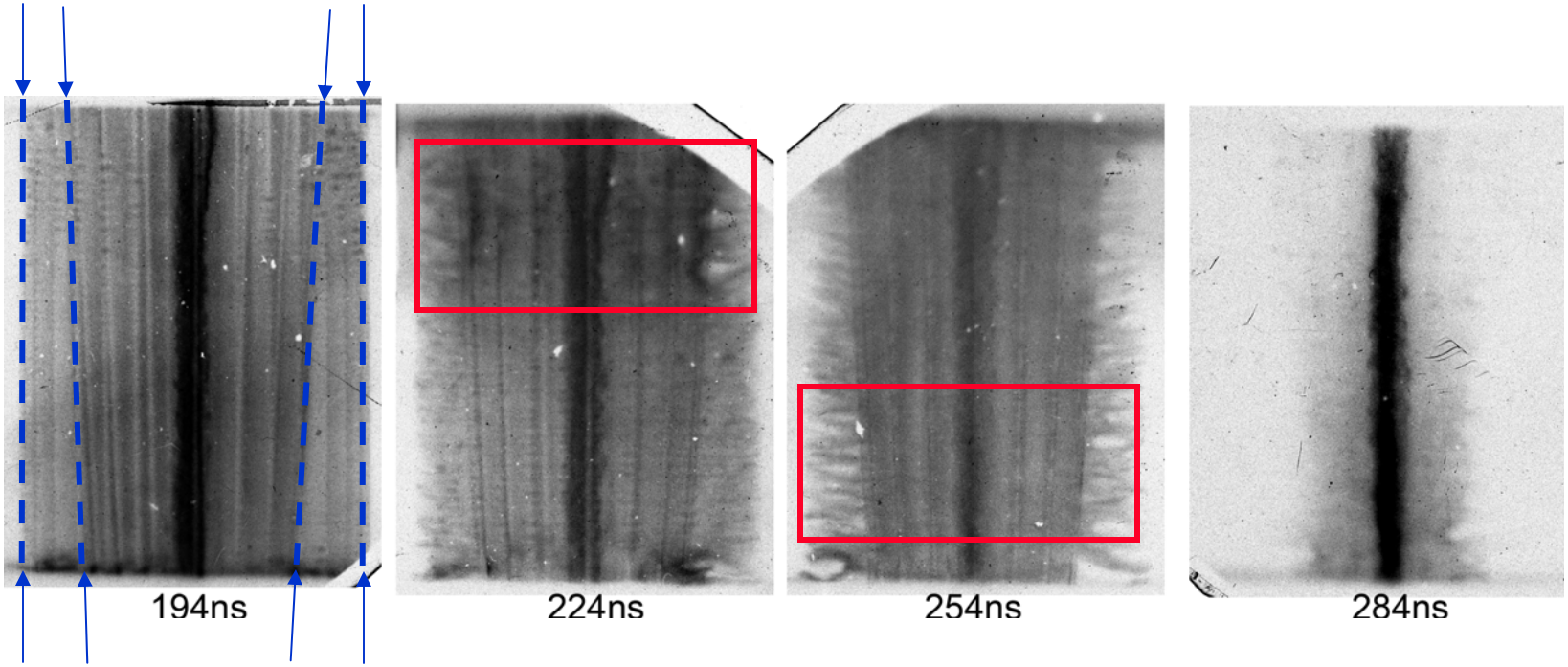
- See a longer rise in x-ray pulse
- Peak power down, but total energy similar
  - (possibly 25% higher for conical outer)

For conical outer on Z:

(Z1639, Cuneo et al., 22mm Cathode, 20m anode, 12mm inner)

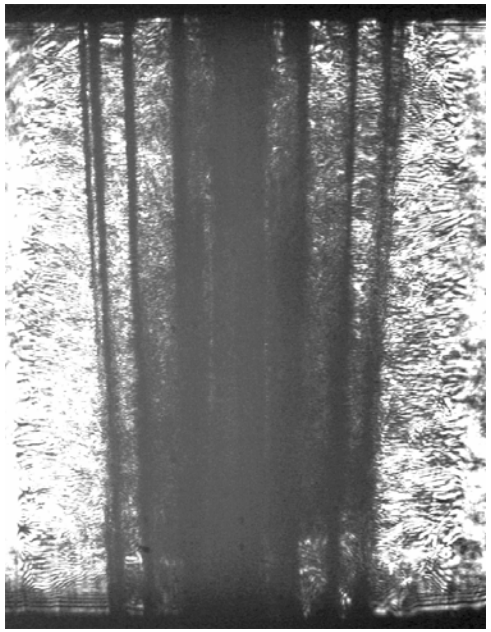
- Increased foot pulse power by 45% because of increase in outer velocity
- Increase first step by zippering implosion onto foam
  - power by a factor of ~4.6
  - energy by ~4.2
- Increase energy in the first step from 25 kJ to 104 kJ
- Energy radiated after the first step is unchanged
- Conical outer increases energy radiated in the main peak 22%

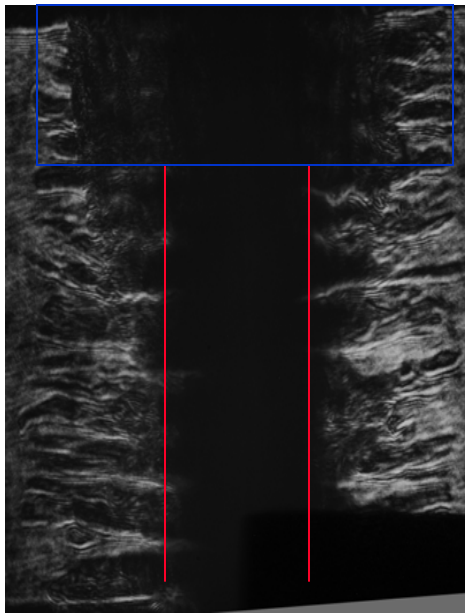
Inclining inner leads to change of time of flight of outer to inner, and alters timing of Interaction

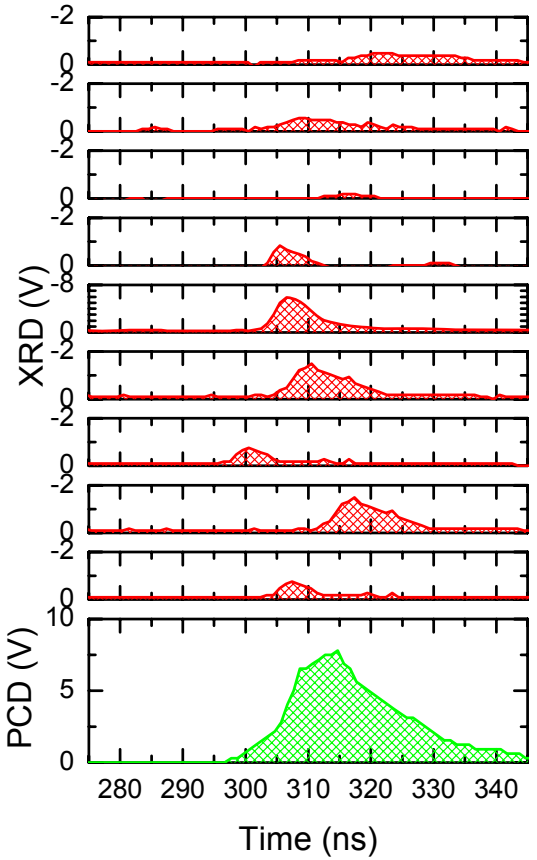


- Cylindrical wire arrays show variation in time of inner collision with inner array diameter
- Conical inner shows that time of interaction varies with z
- Power pulse will be lengthened
- Zipper less significant after inner ablation

Nested array with conical inner does not globally zipper stagnation on MAGPIE, but would alter Interaction Pulse



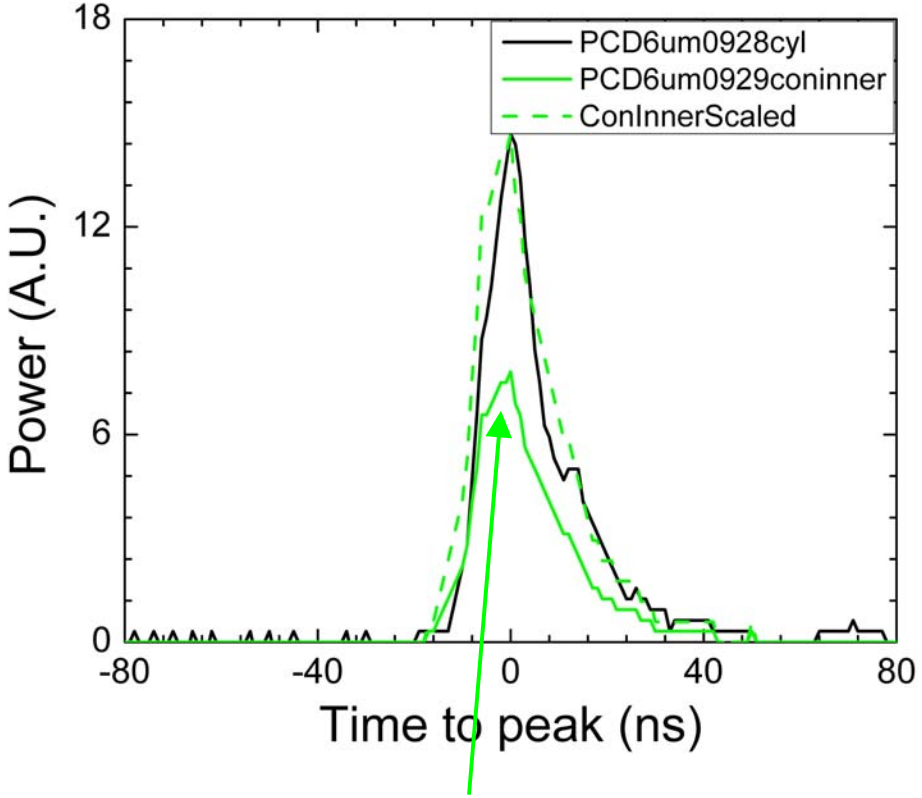




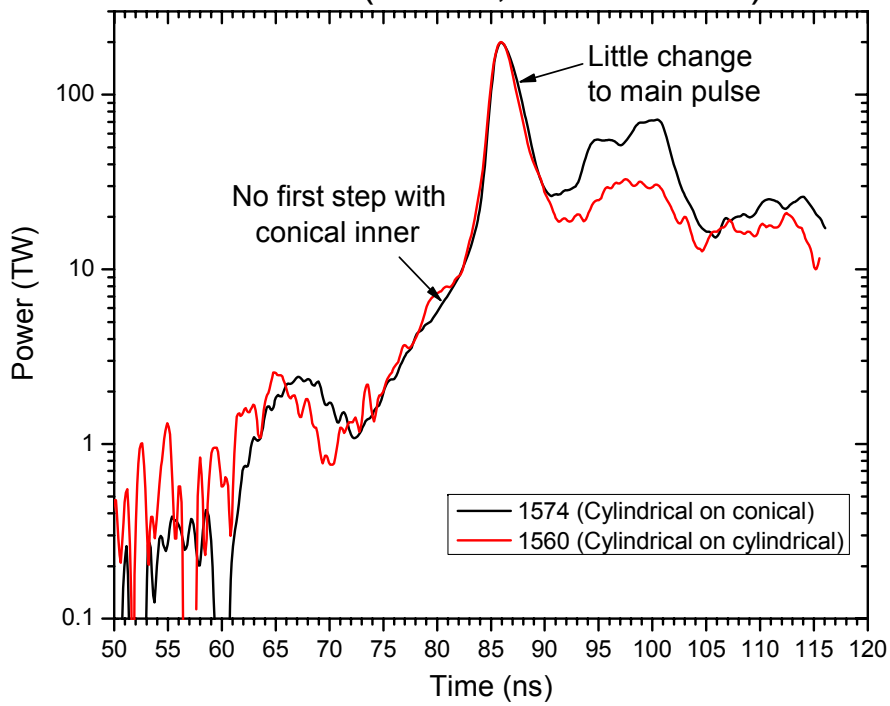
- Laser imaging after interaction indicates no substantial zipper
- Zipper array confirms no zipper in stagnation
- Laser imaging does show top section does not participate in implosion

Conical inner has some effects, but does not alter width of main pulse on MAGPIE or Z

MAGPIE: PCD (hv>200eV)



Z: XRD (Z1574, Cuneo et al.)



MAGPIE power lower than cylindrical
due to part of array not participating in implosion

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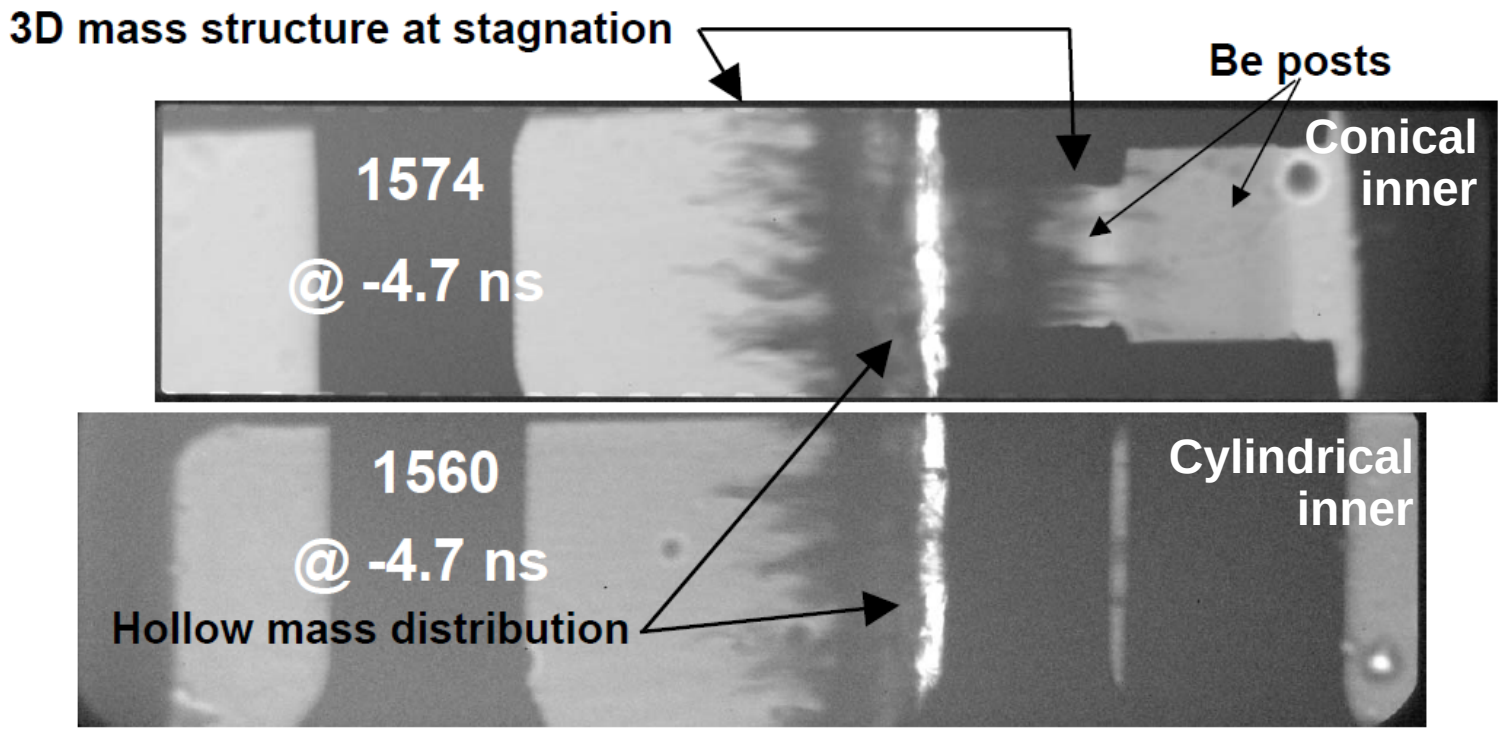
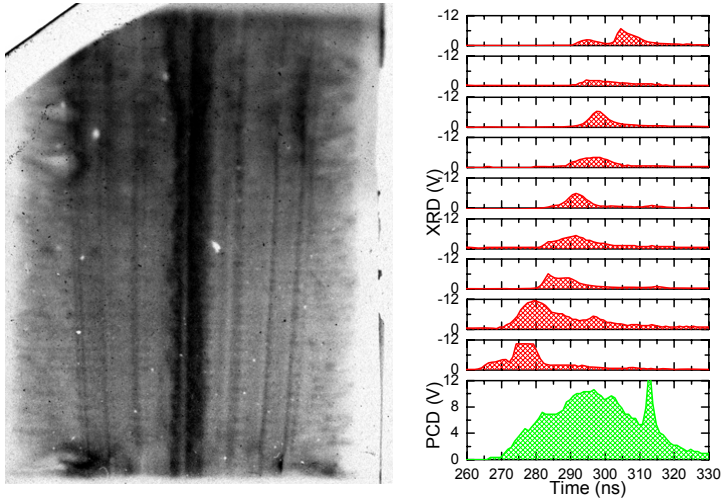
Radiography on Z indicates no zipper present after interaction



- For Z see no evidence of change to the mass distribution post-interaction

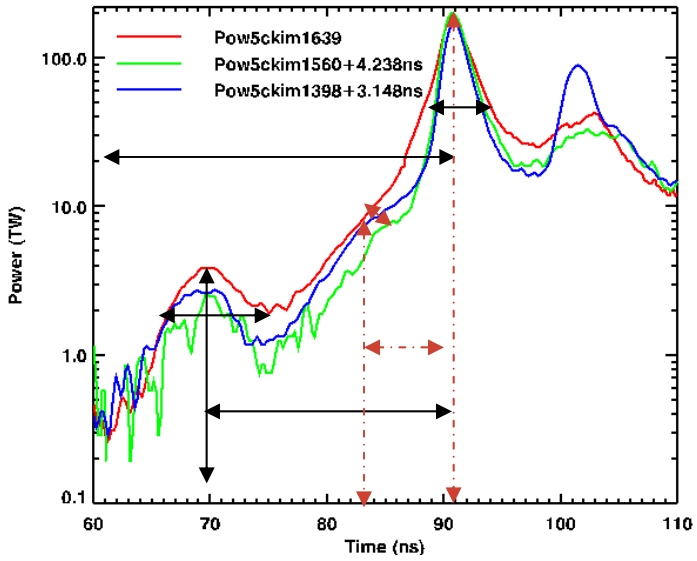
Summary: What can we now control



- Conical inner can control
  - Time scale of interaction
- Conical outer can control
  - Time scale of interaction (MAGPIE)
  - Time scale of main stagnation
- Need a more quantitative comparison

Combine with previous data (Cuneo et al.), now have control of:

- Time of peak (Outer mass, inner mass, outer diameter)
- Interaction to peak (inner diameter and mass)
- Pulse length of stagnation (outer angle)
- Pulse length of interaction (relative angle between outer and inner – needs verification)
- Understanding of interaction may lead to control of amplitude and length (need more experiments)



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