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DEVELOPMENT OF AN 85KJ STAINLESS STEEL K-SHELL X-RAY SOURCE ON THE Z GENERATOR

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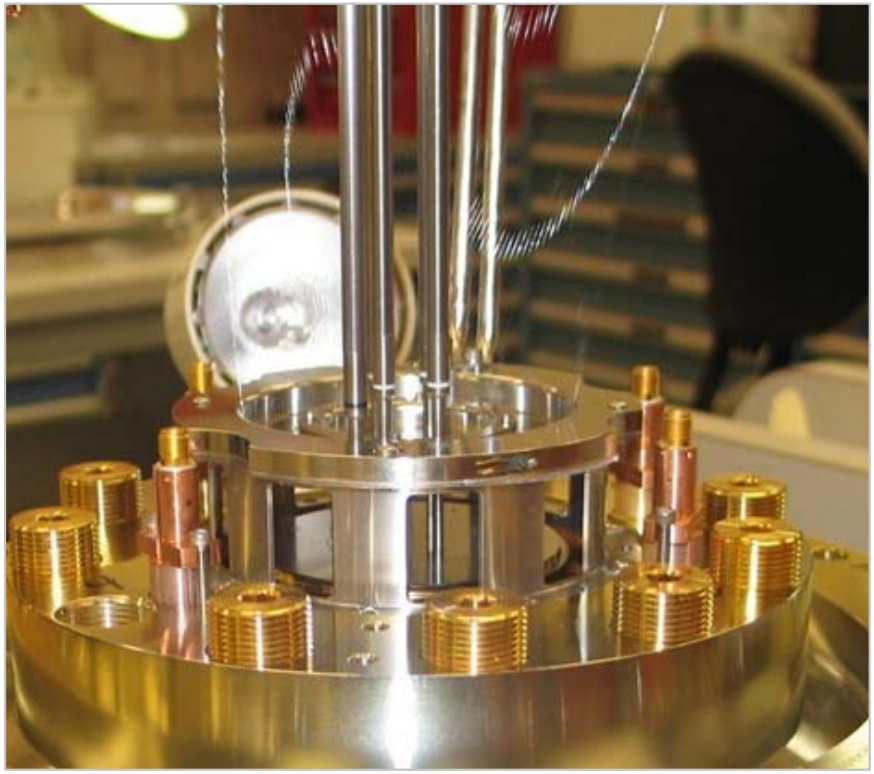
Overview

- First K-shell arrays to be re-established after Z refurbishment were 65mm Stainless Steel (SS) arrays
  - High peak powers (250TW) produced, with good reproducibility
  - 60kJ of Fe/Cr/Ni K-shell produced, with K-shell powers up to 15TW
    - Similar to achieved on old Z
- Here will discuss higher velocity implosions leading to hotter, higher K-shell yields

Shot setup

- All shots discussed use
  - Nested wire arrays
  - Stainless steel wires
  - 2:1 mass and diameter ratio
- Variations are performed in
  - Array Diameters:
    - 65mm, 70mm, 75mm
  - Masses
    - 1.01mg to 2.5mg
  - Implosion time
    - 90ns to 105ns



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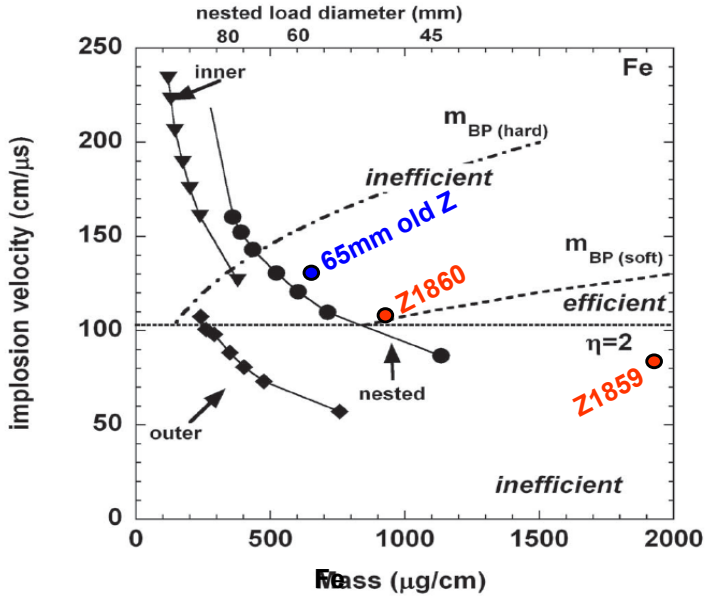
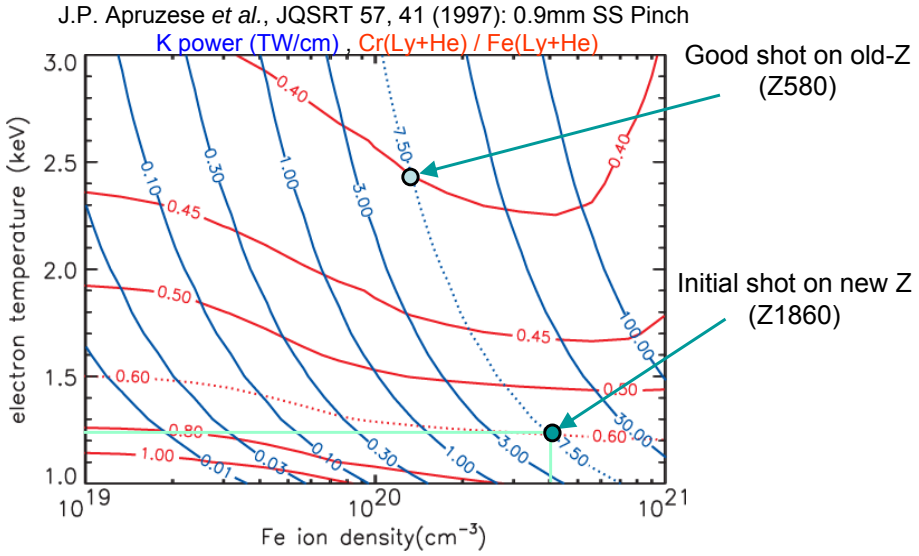
Motivation: 65mm diameter nested arrays on refurbished Z showed low electron temperature at stagnation





From D.J. Ampleford et al., ICOPS 2009

- **Initial SS shots on ZR used 65mm diameter**
  - B-dots: Higher coupled energy than pre-refurbishment Z
  - Spectroscopy: T_e lower than optimum on old Z
- **Need higher KE/ion therefore higher velocity**
  - Larger diameter and earlier implosion time arrays explored with SS

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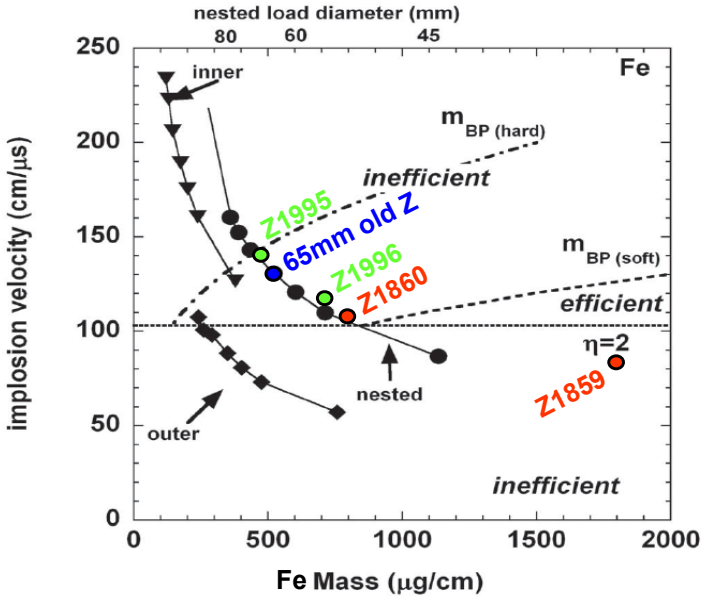
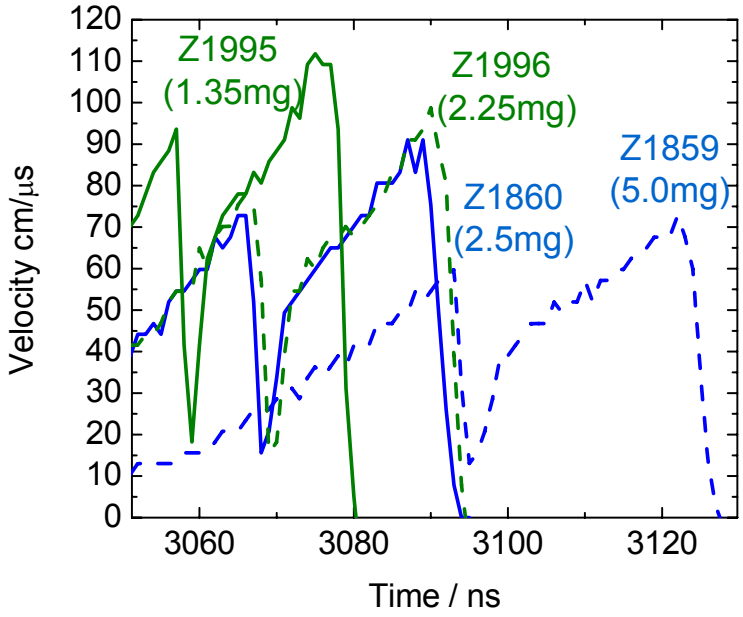
Larger array diameter and lower masses will lead to higher implosions velocities





- **Higher velocities are achievable by**
  - **Using larger array diameters**
  - **Using earlier implosion times**
- **Both also lead to lower masses**
- **Initial higher velocities designed to**
  - **Z1996: match Z1860 implosion time with higher velocity**
  - **Z1995: Push to even higher velocity**

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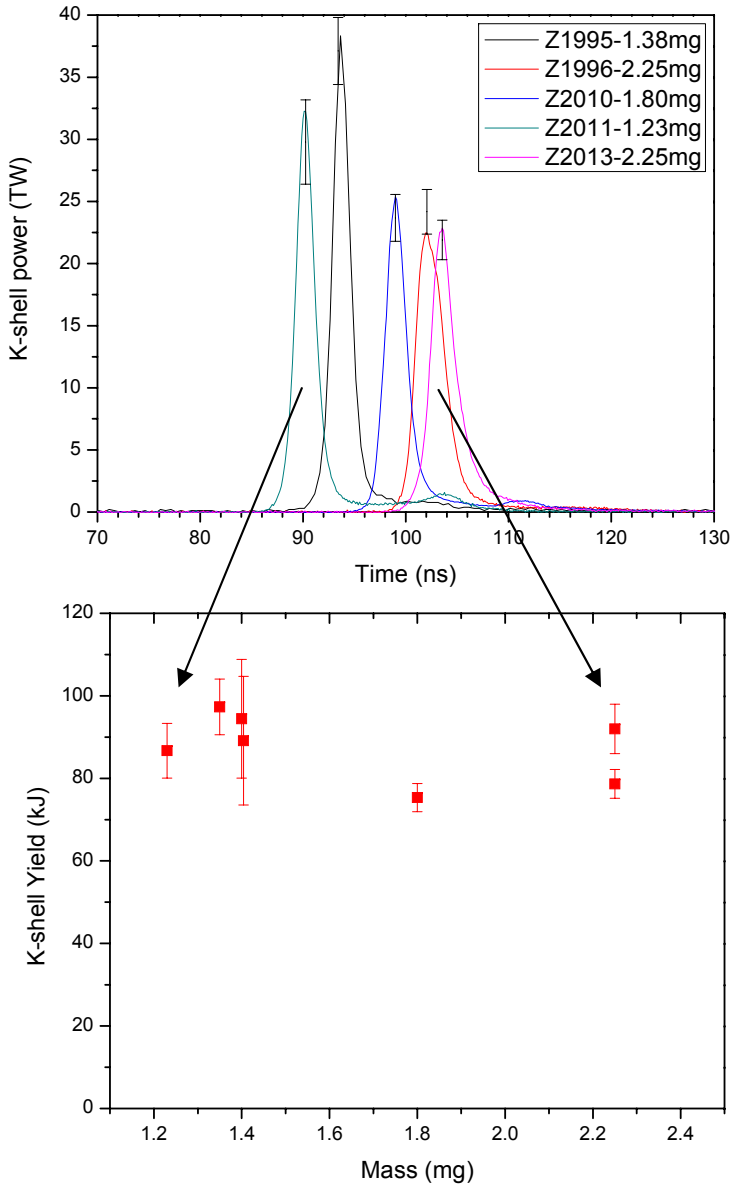
SS mass scan at 70mm has demonstrated ~1.38mg is optimum mass, imploding at ~95ns



- **Optimal K-shell power achieved with**
  - **95ns implosion time**
  - **1.4mg total array mass**
- **K-shell yield reasonably independent of implosion time**

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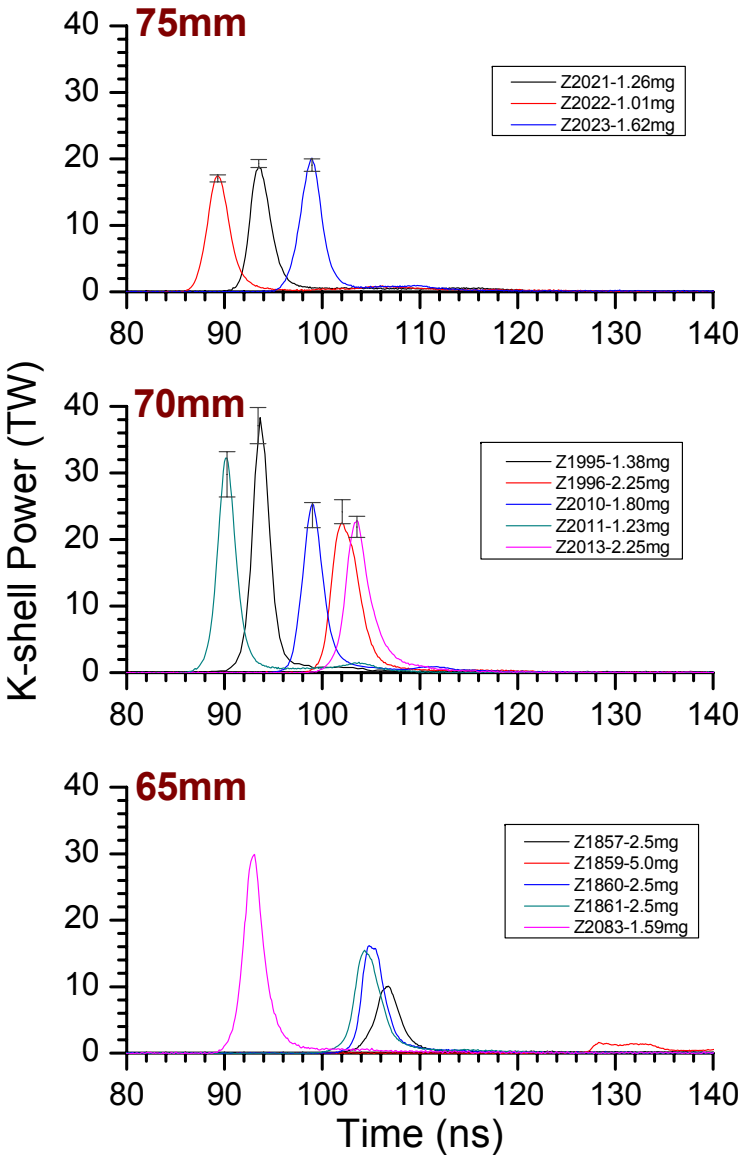
70mm diameter Stainless Steel wire arrays have achieved 85kJ of K-shell emission



- **Stainless steel optimization began in FY08 with initial C7 shots on refurbished generator**
- **Data from initial shots indicated low electron temperature**
  - **Spectroscopy showed T_e lower than pre-refurbishment shots**
  - **Motivated exploring larger array diameters and earlier implosion times**
- **Shots in Sept-Nov 2009 achieved 85kJ of SS K-shell emission**
- **Initial studies indicate output is reproducible**
- **For lighter loads K-shell rise-time is 1.8ns**

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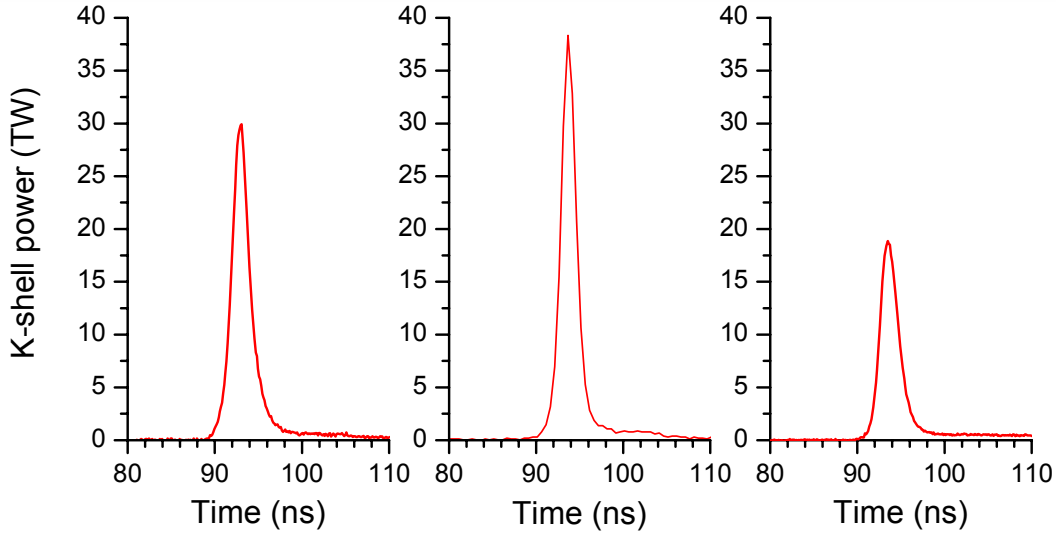
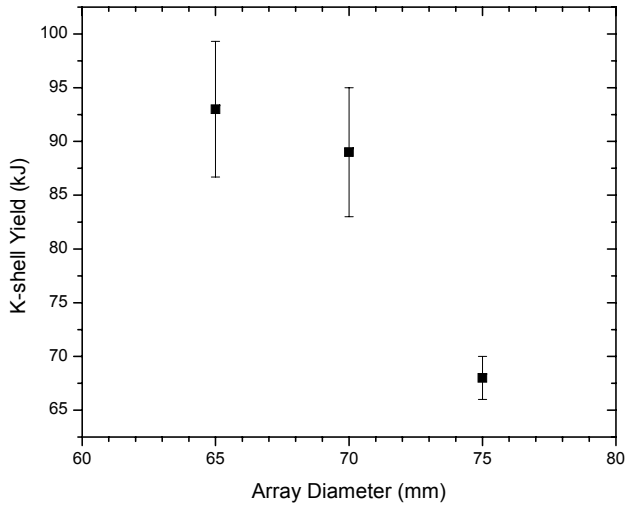
70mm is has highest K-shell power

- For diameter variation at ~95ns implosion time
  - 70mm diameter shows highest power
  - 70 has shortest FWHM
- Marginally better K-shell yield at 65mm diameter, but within error bar





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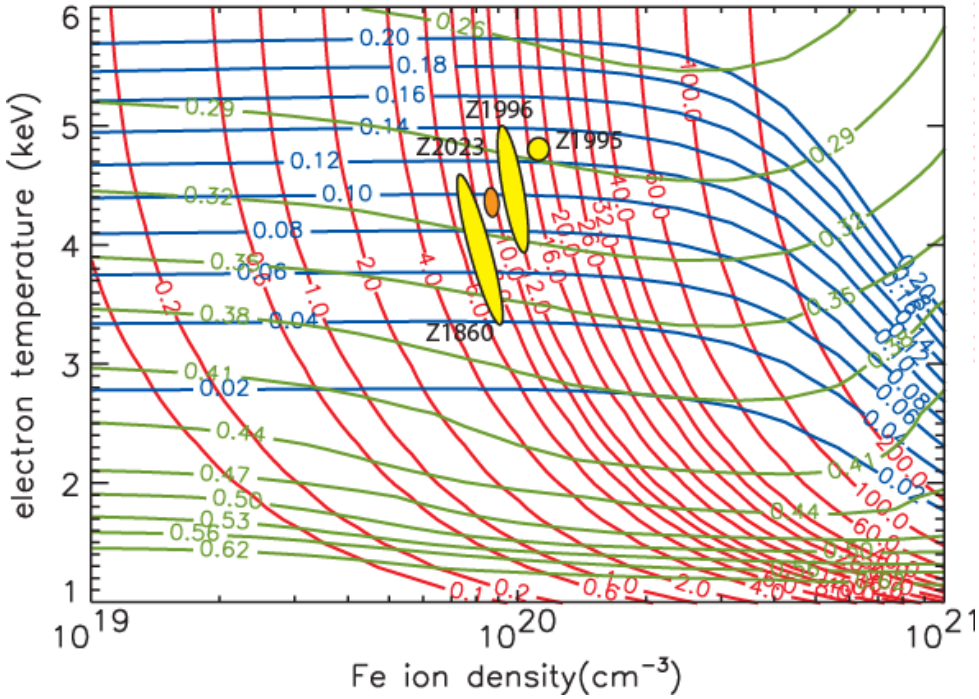
Spectroscopy indicates 1.4mg, 70mm configuration reaching T_e ~ 5keV, N_i ~ 10^{20} cm^{-3}



- J. Apruzese et al. have developed model for determining plasma parameters from line ratios
- Plot shows contours for
  - Cr (Ly+He) / Fe (Ly+He)
  - Fe Lyα / (Heα+IC)
  - K-shell power /length
- Earlier implosion time shots (Z1995, Z2023) have well defined location in phase space
  - Can be represented by single T, N
- Z1995 achieved higher temperature and density despite smaller diameter than Z2023
- Mass participation on Z1995 was ~14%

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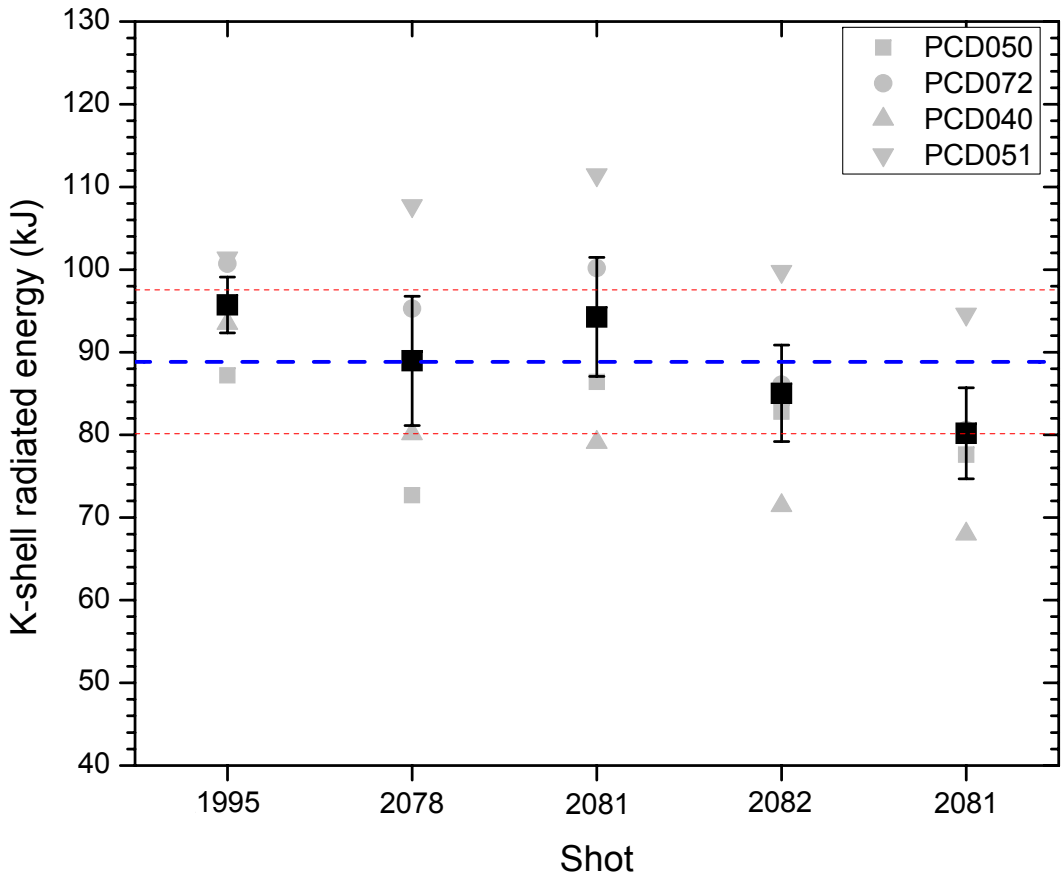
Reproducibility of Z1995 looks reasonable



- Good shot chosen to investigate reproducibility
- On all shots Standard Error in measured PCD yields <10%
- Z2077 had significantly lower yield
  - All others ≥80kJ
  - Number of diagnostic issues on Z2077 led to inconsistent diagnostics from other shots
- Neglecting Z2077
  - Mean = 88kJ
  - St. Dev = 6kJ
- Au bolometer data is lower
  - Not realized during shots due to analysis error
  - Will investigate possible causes

    thicker filter?

    Wrong aperture on bolo head?

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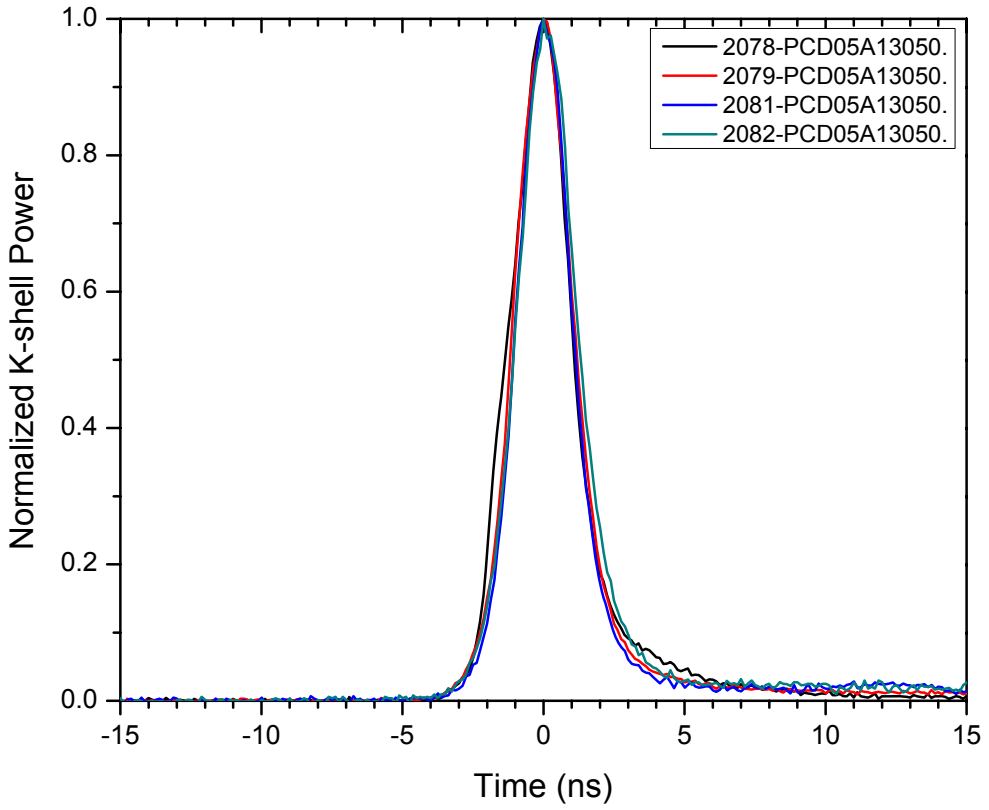
Pulse shape for 1.4mg 70mm load is highly reproducible

- **FWHM is 2.42 ± 0.15ns**
- **Rise time is 1.90ns ± 0.14ns**
- **Heavier masses have longer rise and FWHM**



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Summary

- Higher K-shell powers and yields have been achieved with recent SS arrays on Z
- 70mm wire arrays have demonstrated reasonable reproducibility
- Electron temperatures achieved are ~5 keV
- Cu and Al K-shell wire arrays are also presently being explored on Z

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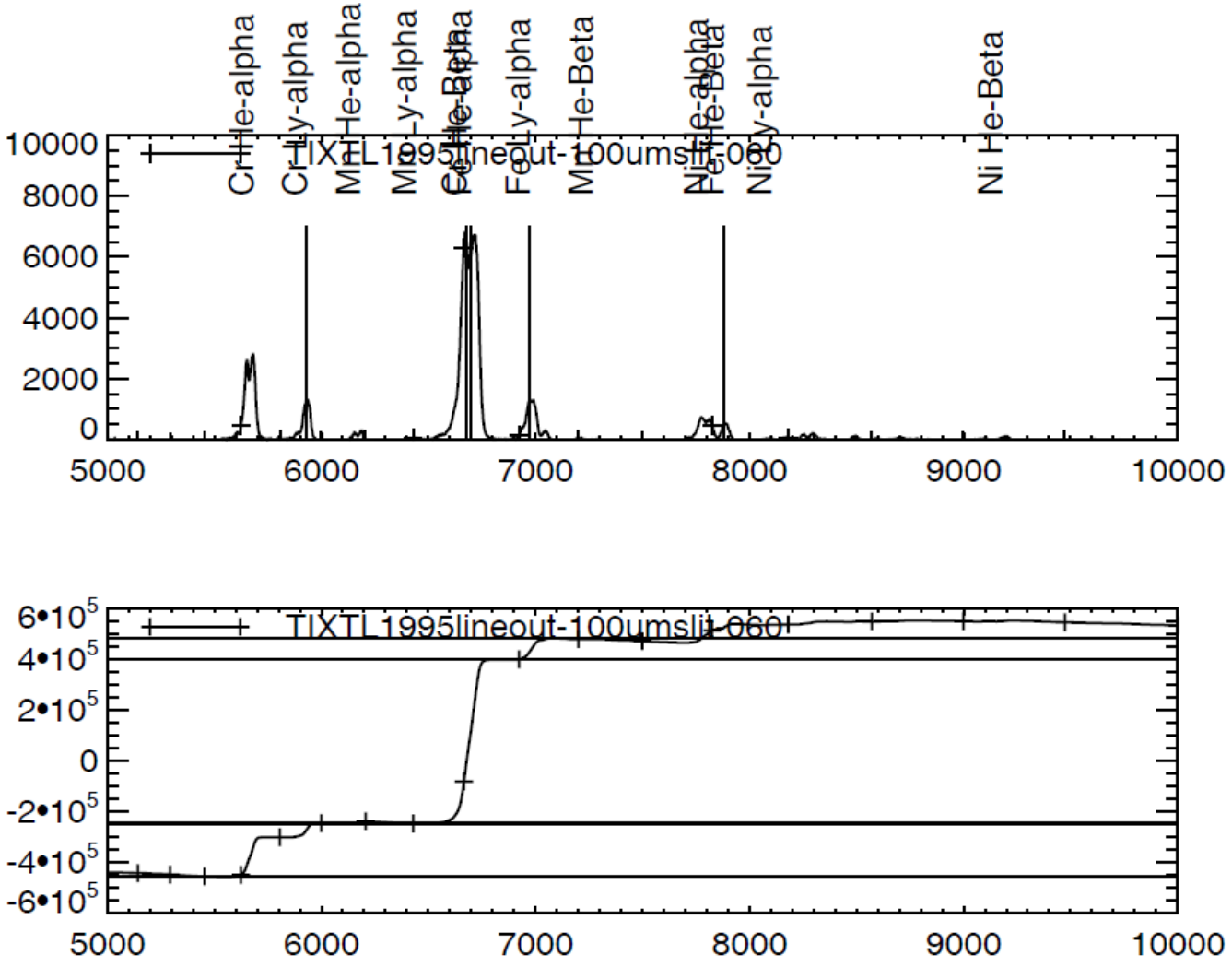
Backup



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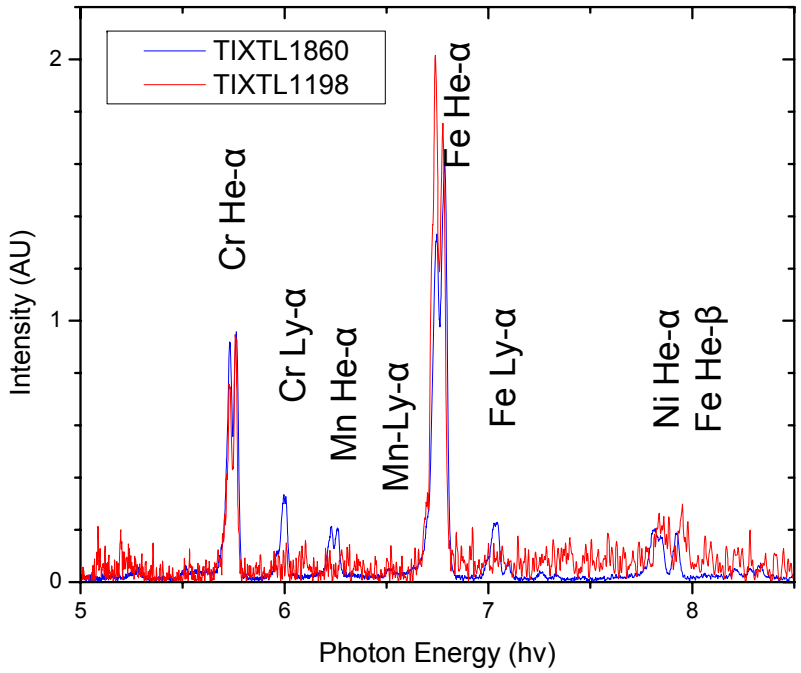
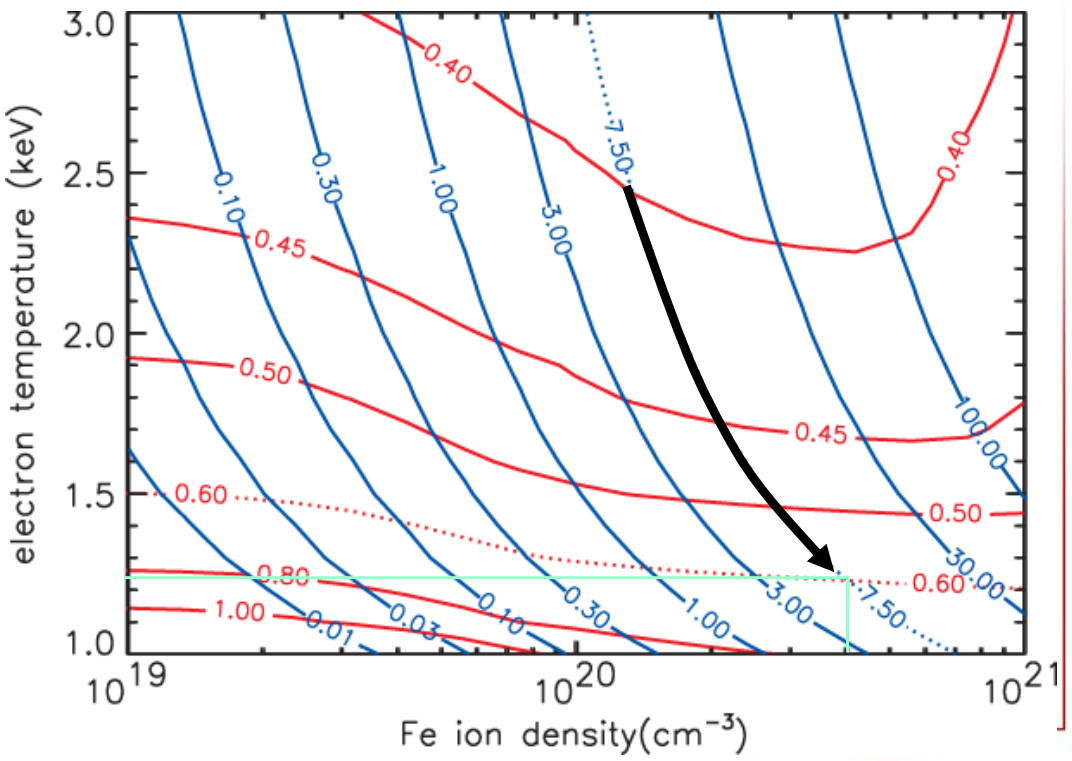
Longer current risetime and hence implosion time on ZR leads to higher pinch density and lower temperature



	Z580	Z1860
Pinch size	~1.2mm	0.9mm
Cr/Fe	~0.4	0.6
K-shell P	7.5TW/cm	7.5TW/cm
N_i (cm^{-3})	$1.2x10^{20}$	$4x10^{20}$
T_e (keV)	2.6	1.25

J.P. Apruzese *et al.*, JQSRT 57, 41 (1997): 0.9mm SS Pinch

K power (TW/cm) , Cr(Ly+He) / Fe(Ly+He)



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Abstract

- We will discuss experiments on the Z generator using large diameter stainless steel wire arrays to produce K-shell emission (hv~6.7keV). Large array diameters and fast implosion times are needed to obtain high velocities and high temperatures in order to excite Fe K-shell emission.

- Since the refurbishment of the Z generator, nested stainless steel wire arrays have been fielded at 65mm, 70mm and 75 diameters, with multiple masses at each diameter. Experiments have achieved ~85 kJ of K-shell yield, with a fast rise (<2ns) to a peak K-shell power of 35TW. These data demonstrate a 40% increase in K-shell yield relative to pre-refurbishment experiments. K-shell spectroscopy is used to infer plasma densities and temperatures for these array configurations. The trends in K-shell output and plasma parameters from these mass and diameter variations will be presented. We will also discuss differences in pre- and post-refurbishment Z that are potentially responsible for this improvement.

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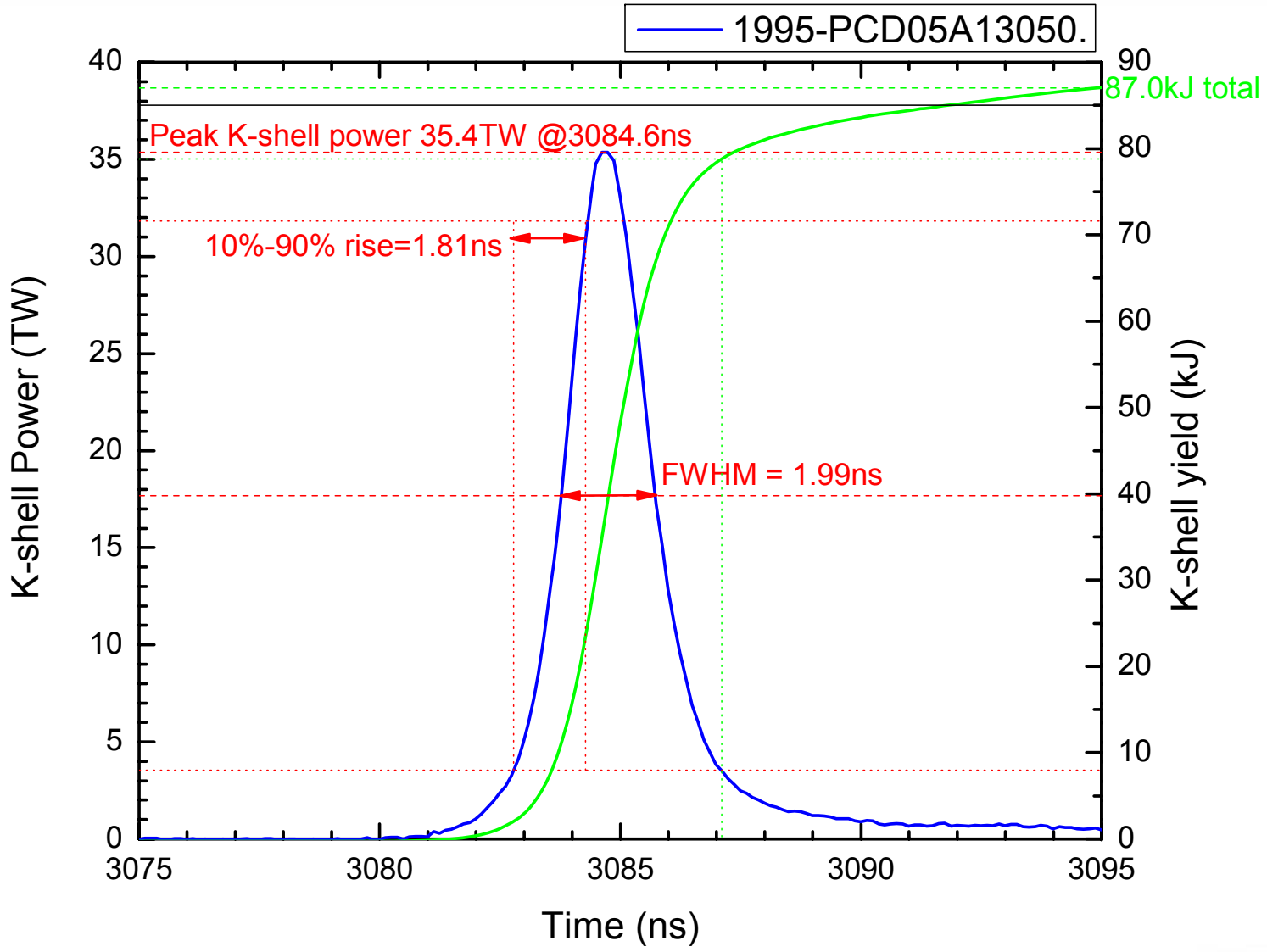
Z1995 rise-time



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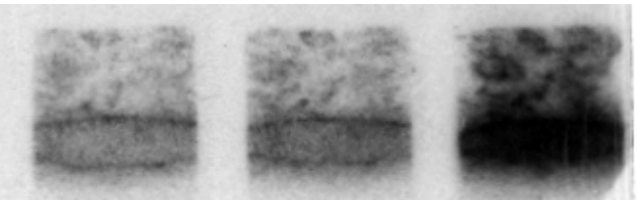
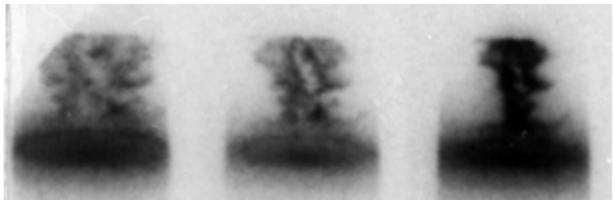
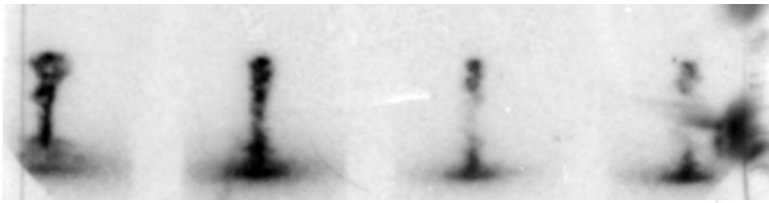
MLM: Still good pinch quality for 75mm arrays (1.26mg shown)



Z2021 -5.8ns



-2.9ns



+0.1ns

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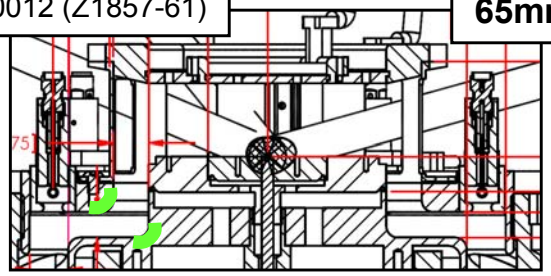
70mm hardware has modified feed geometry

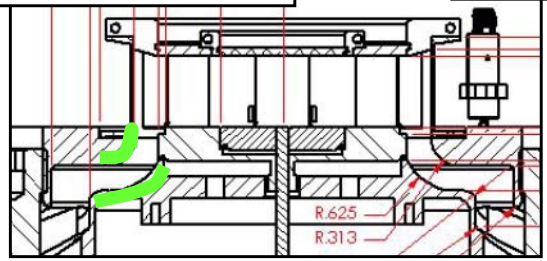
A0012 (Z1857-61)

65mm



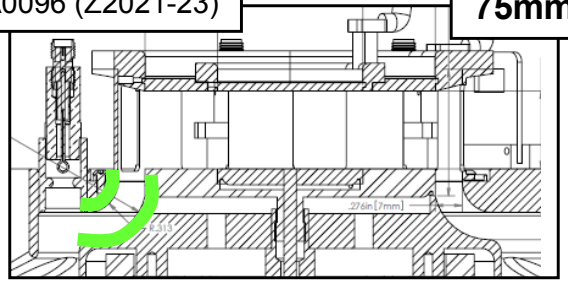
A0083/95 (Z1995-2013)

70mm



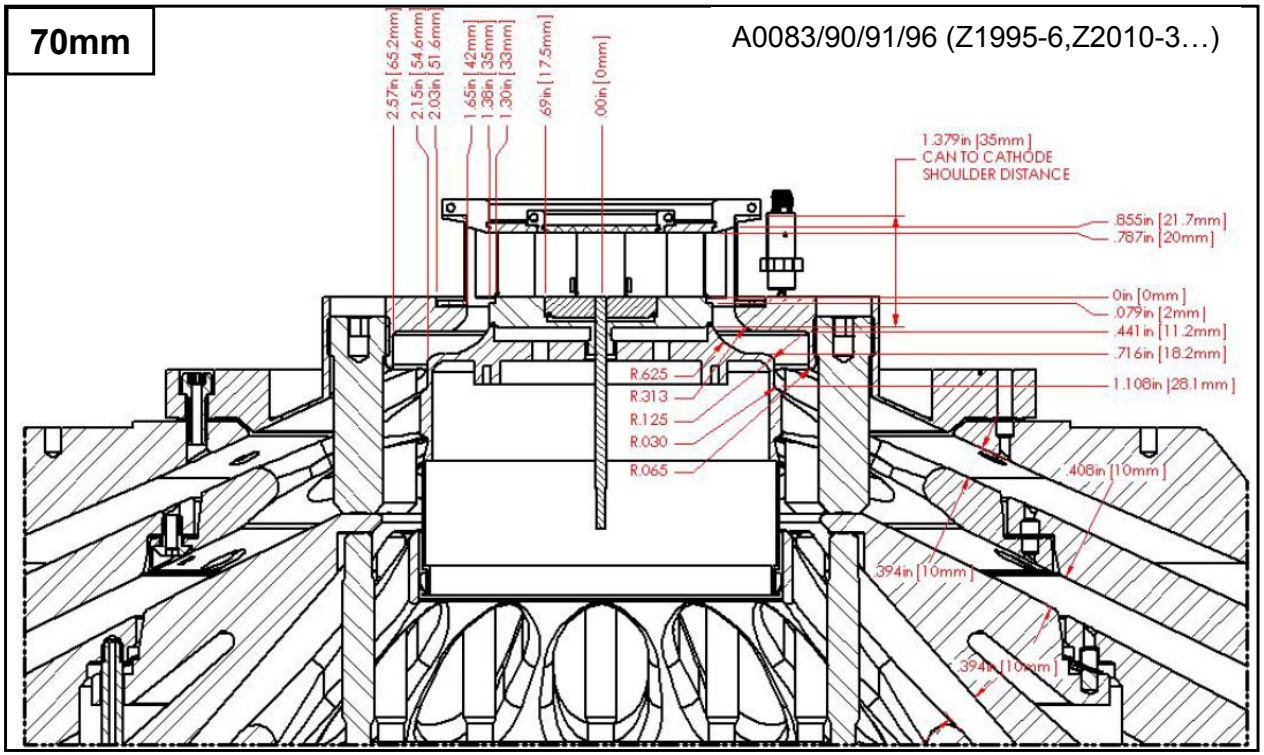
A0096 (Z2021-23)

75mm



70mm

A0083/90/91/96 (Z1995-6,Z2010-3…)



Reconstruction demonstrates better power feed on curved feed (C. Jennings later)

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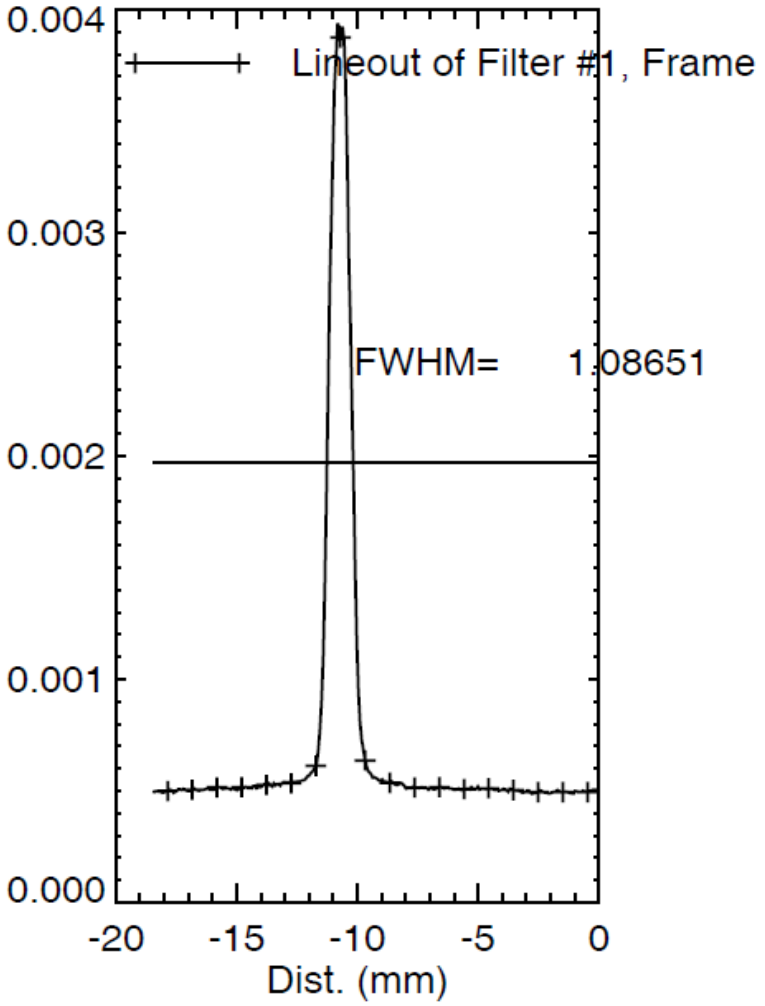
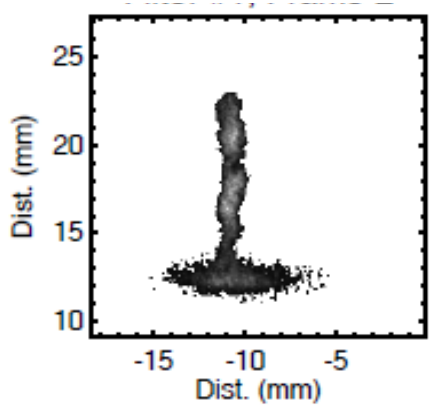
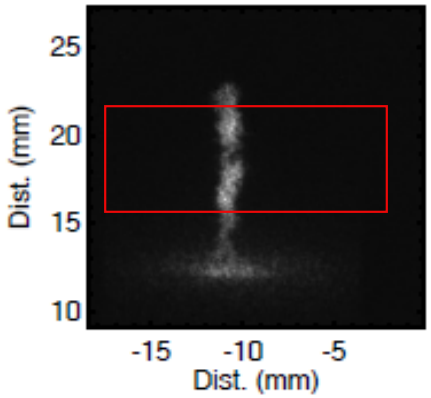
Pinhole imaging shows good pinch for Z1995 (nominal 70mm load)

Frame 6 of MLMR
Max X-rays + 0.06ns







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