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An Optical Streak Diagnostic for Observing Anode-Cathode Plasmas for Radiographic Source Development*

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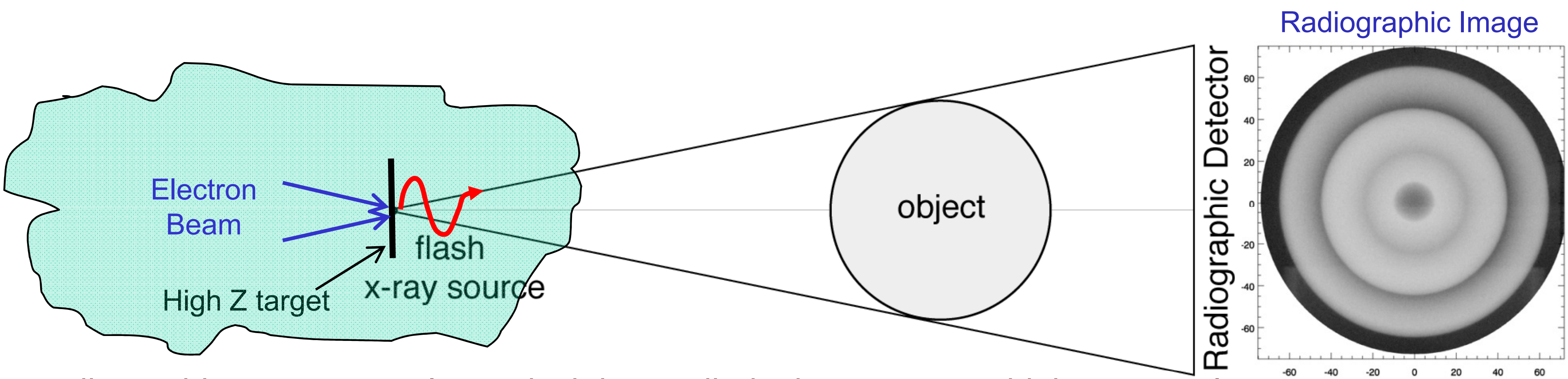
The Development of Compact High Brightness Pulsed Power Driven Radiographic Sources on the RITS 6 Accelerator

NSTec and Sandia National Laboratories are collaborating in the research and development of pulsed power driven electron beam x-ray sources. These sources will be used for flash x-ray radiography on dynamic experiments where material is undergoing rapid change.



These radiographic sources employ a pinch beam diode that extracts a high current electron beam from the cathode and focuses the beam onto a high Z target such as tantalum to create a Bremsstrahlung X-ray source.

The quality of a radiograph depends on:

•Voltage (end point energy)	→	Penetration Power and Contrast
•Dose	→	Signal Level
•Spot size	→	Spatial Resolution
•Pulse width	→	Motion Blur

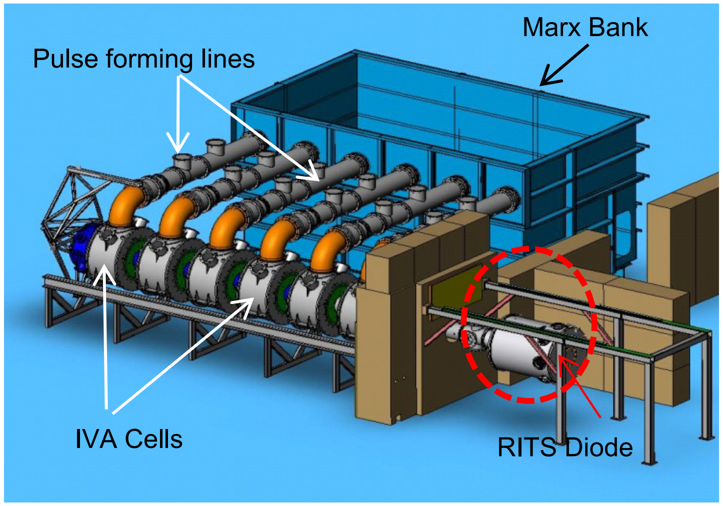
Radiographic Source Development on the RITS 6 Accelerator

The RITS 6 Accelerator at Sandia National Laboratories is six cell inductive voltage adder flash radiography test platform. RITS is used to develop radiographic sources in the 4-7 MeV range for a variety of potential applications.

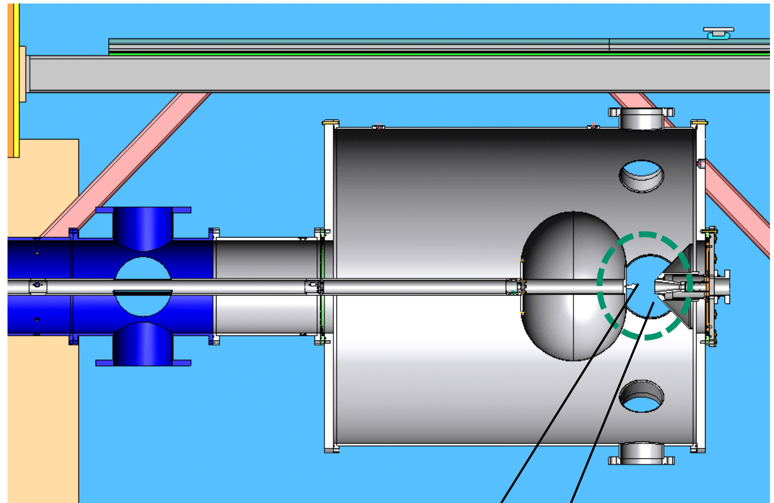
RITS currently operates a pinch beam type diode known as the Self Magnetic Pinch (SMP) which has been studied because of its' radiographic attributes. NSTec and Sandia are developing the SMP diode for potential future applications at the Nevada National Security Site. NSTec provides diagnostic support to Sandia by developing and fielding one-of-a-kind sensors and detectors to measure transient phenomena. This paper describes an addition to an optical streak camera based system for studying plasmas in the SMP diode.

The RITS 6 Accelerator at Sandia National Laboratories

The Effect of Plasmas on Radiographic Source Performance of the Self Magnetic Pinch (SMP) Diode

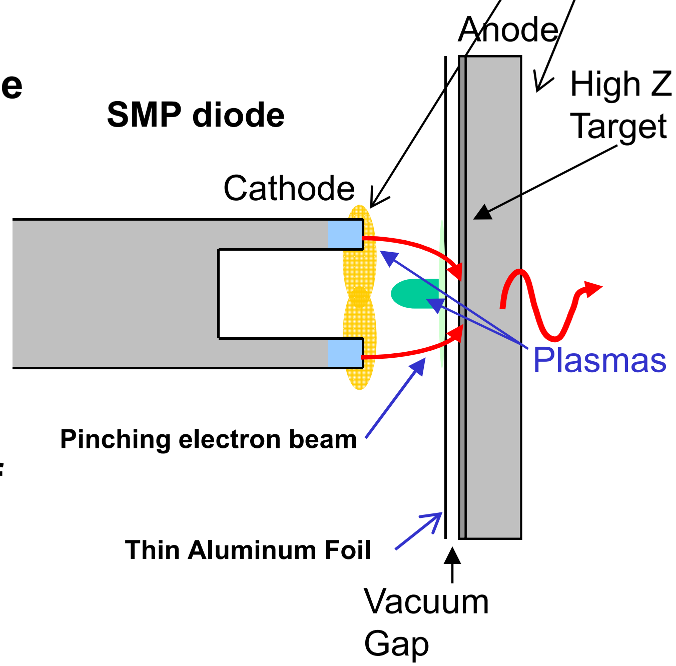


The RITS 6 Accelerator



Pinch beam diodes extract electrons from a small cathode and transport the beam a short distance (~ 1cm) to the anode converter.

Plasmas are created at the anode and cathode surfaces. Some plasma is necessary to allow the electron beam from the cathode to pinch or converge on the anode target via charge neutralization. The pinched beam provides a small spot or x-ray source required for high resolution radiography. Excess plasmas perturb the beam and eventually lead to increased spot size or impedance collapse of the diode which drags the voltage down lowering both the electron/photon energy and dose.



Diode Parameters

- 4-7 MV
- *80 -150 kA*
- 70ns Electrical Pulse
- 45ns Radiation Pulse
- 90 - 350 R@ 1m
- ≤ 2.7 mm spot size

The Need to Characterize Plasma Interactions in the Diode

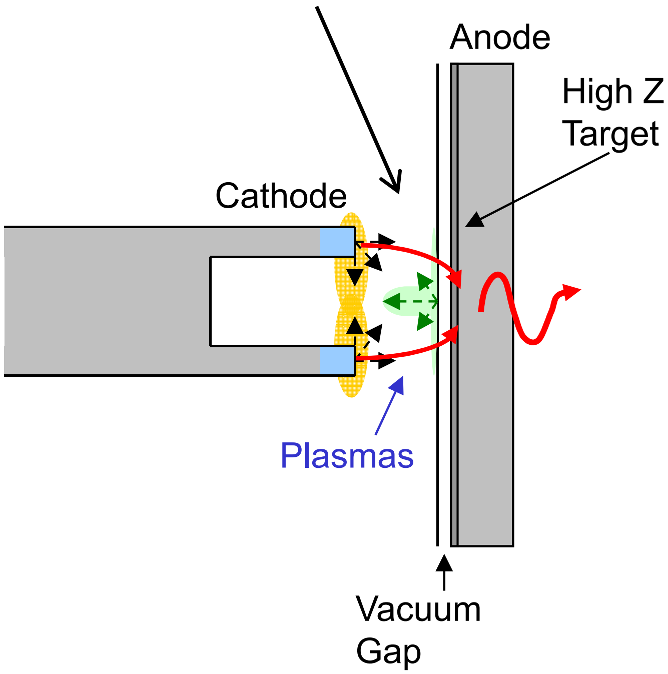
In typical pinch beam diodes, very high electric fields and current densities create plasmas at the target surface which stream toward the cathode. These high E-fields also create plasmas at the cathode surface. The plasmas, while necessary for pinching the beam, can perturb the diode operation in ways that affect the radiographic performance:

•Spot size → affects resolution
•Beam motion → larger average spot size (resolution)
•Diode Impedance → end point energy (penetration)
•Diode Impedance → shortened pulse width (dose)

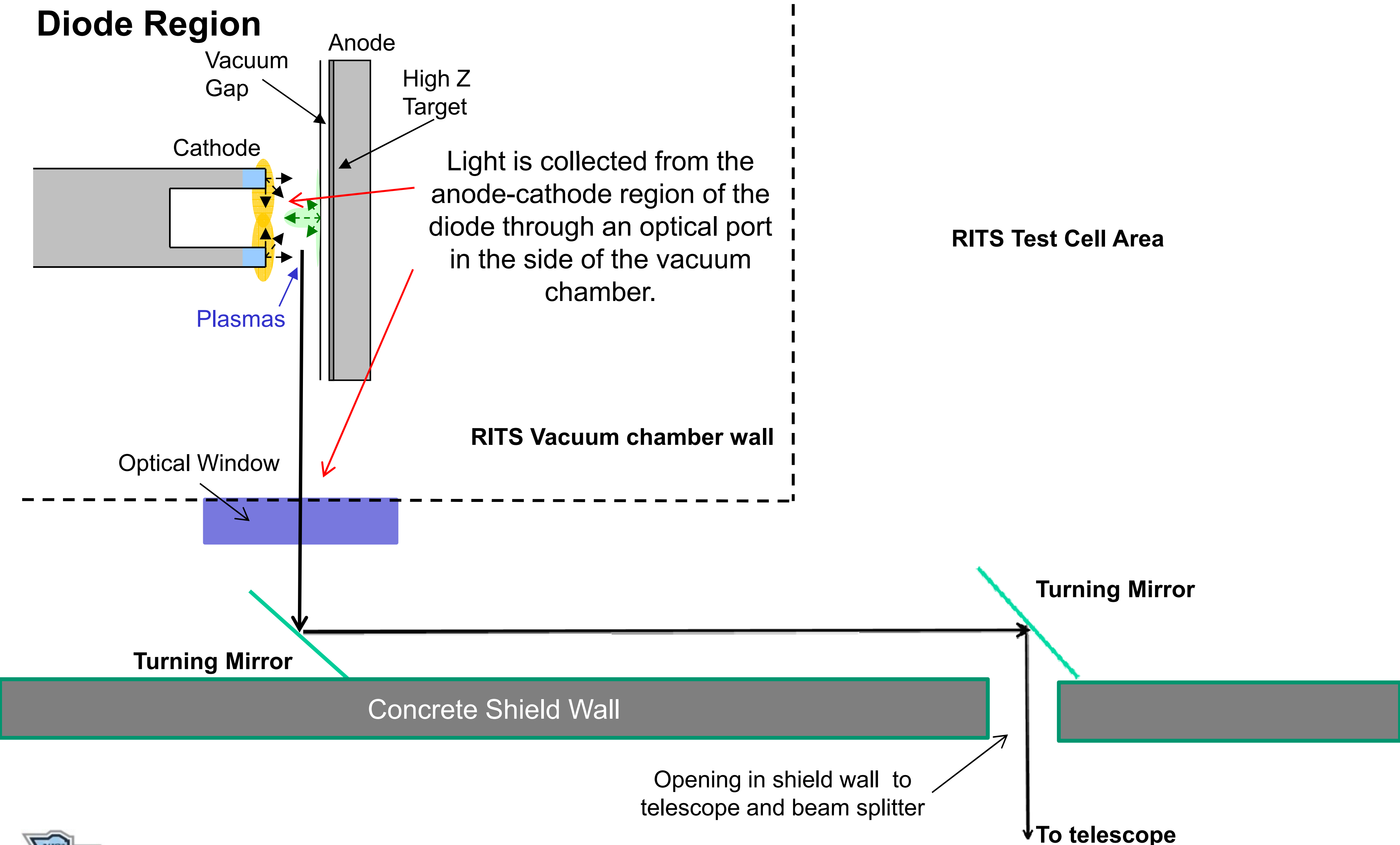
In order to improve diode design, modeling codes need to incorporate these plasma features, and thus drive the need to measure the source, composition, density, temperature and expansion rates of these plasmas.

Two years ago we developed a streak camera based system to observe and measure plasma evolution and closure rates. We improved this diagnostic by adding a beam splitter and gated camera to provide an image of the plasma. This extra dimension provides "snapshots" of the diode plasmas at various times revealing new insight into plasma structure and evolution. The data compliments the streaked images and spectroscopic work already done to characterize the plasma.

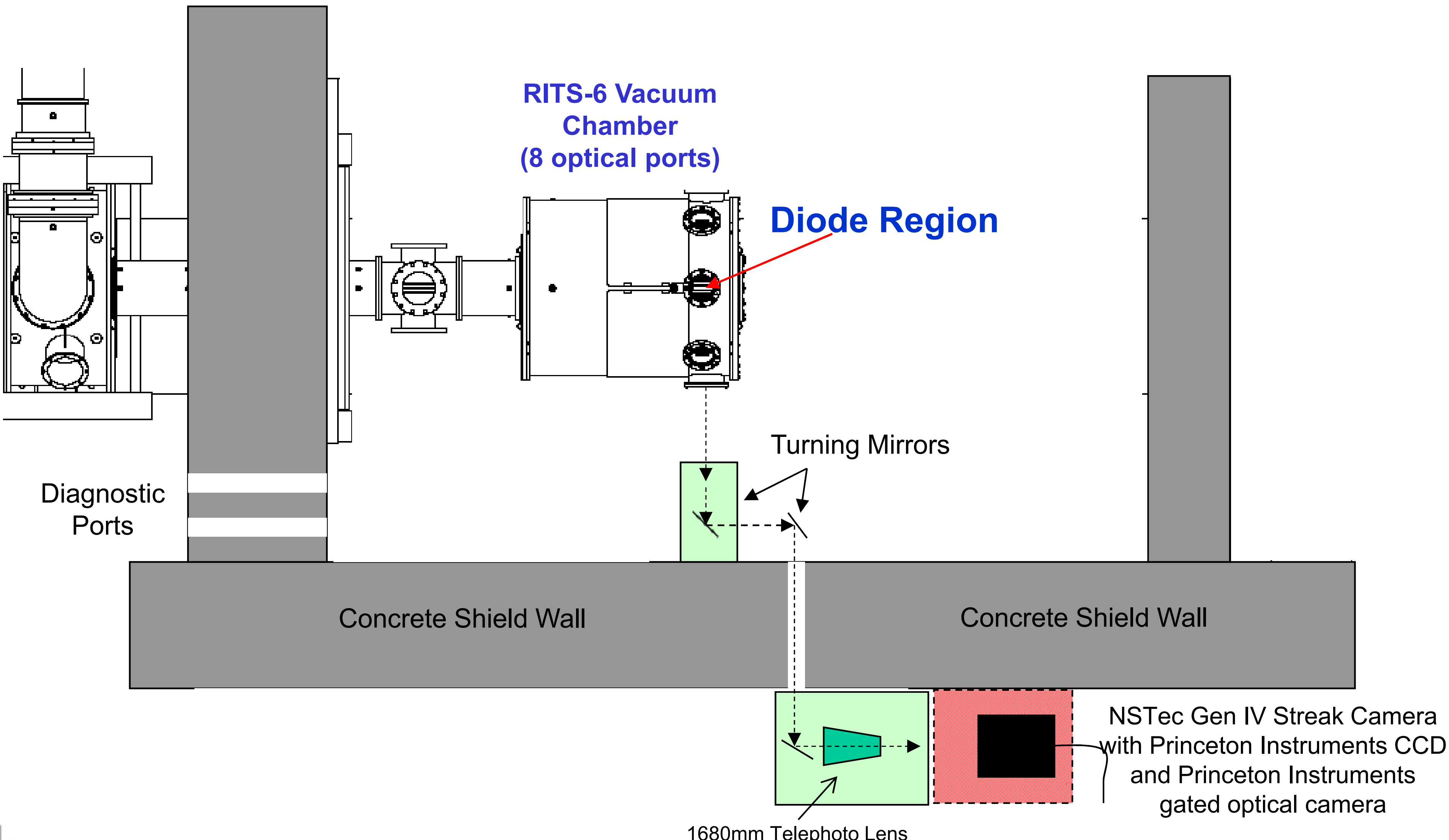
Goal: Develop a diagnostic capable of measuring expansion velocities within the A-K gap of the SMP diode and provide a snapshot image of the plasma



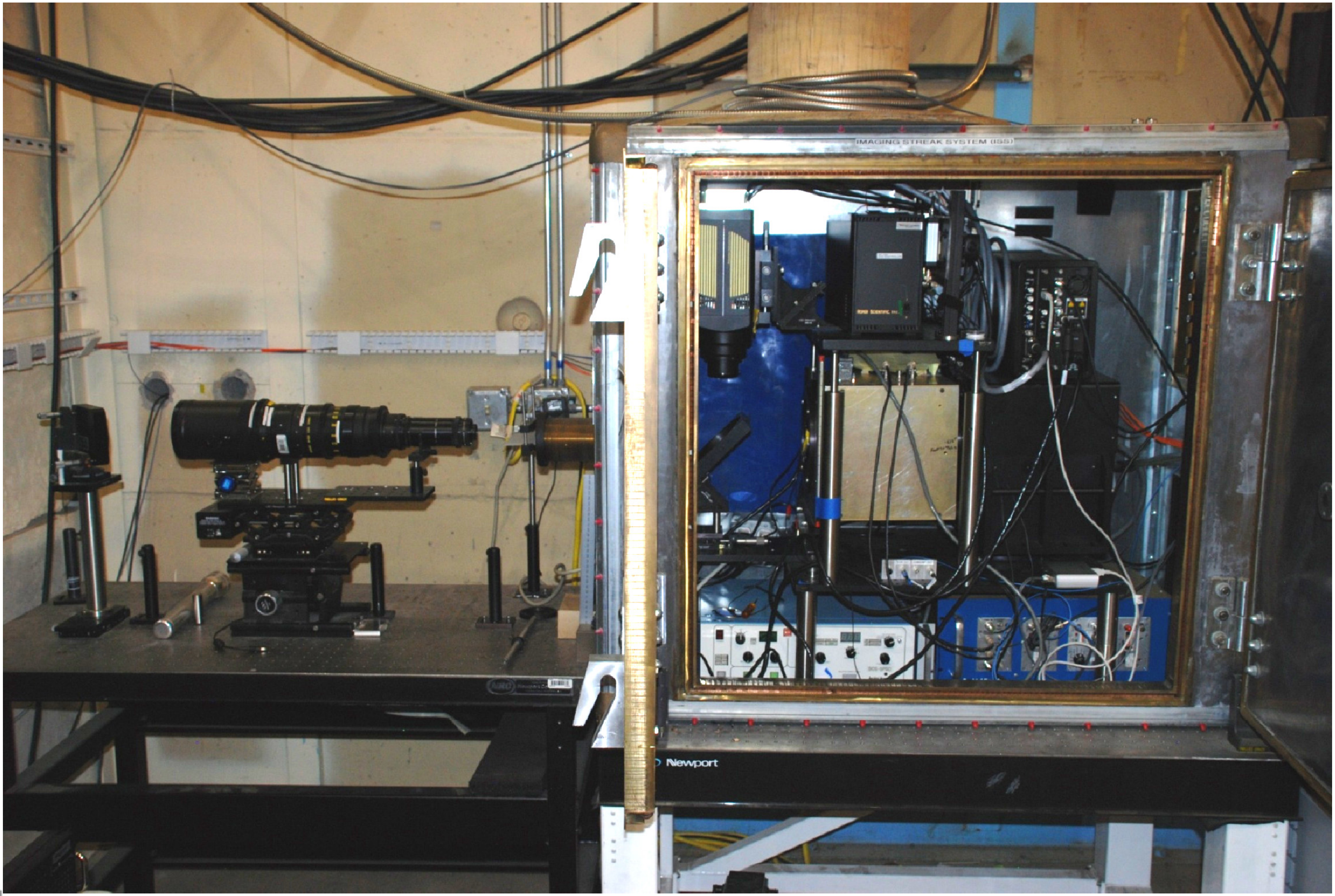
Capturing plasma light from the Diode Region



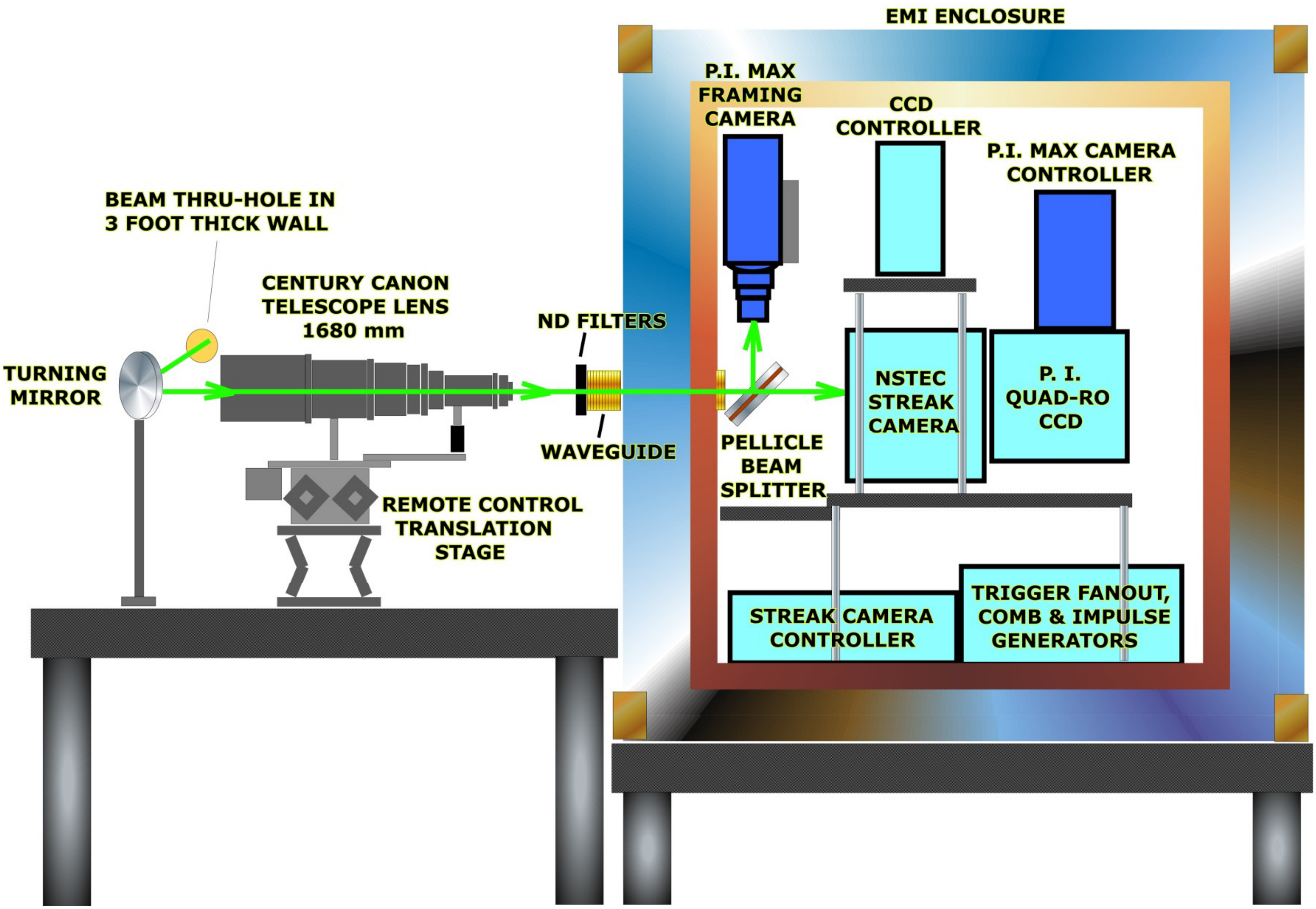
Imaging Streak and Gated ICCD Camera Setup on RITS-6



Imaging Streak Camera Setup on RITS-6



Imaging Streak Camera Setup on RITS-6

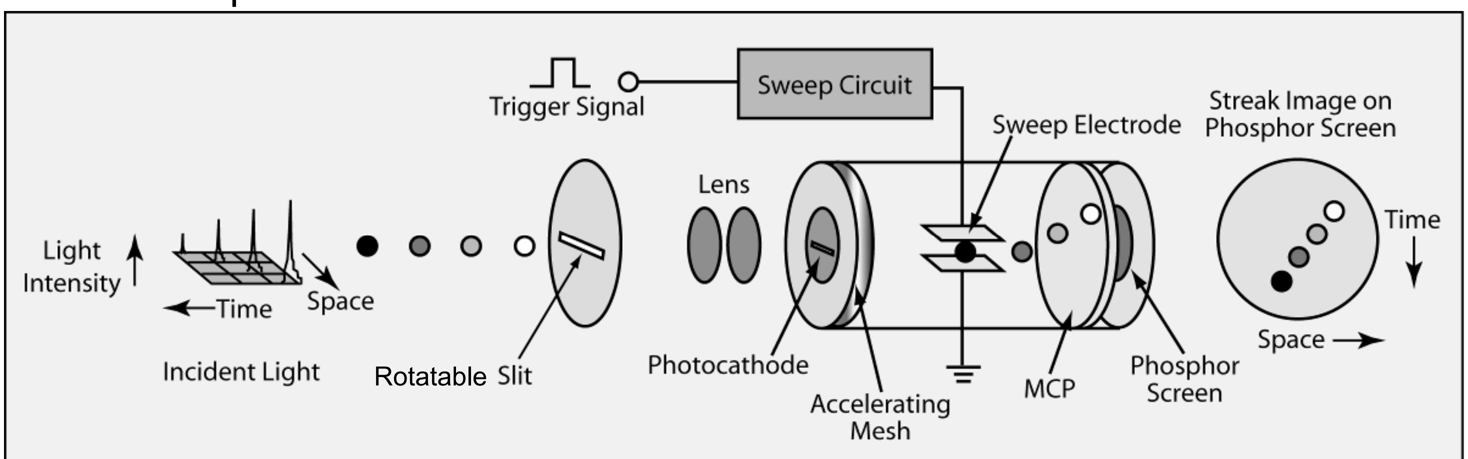


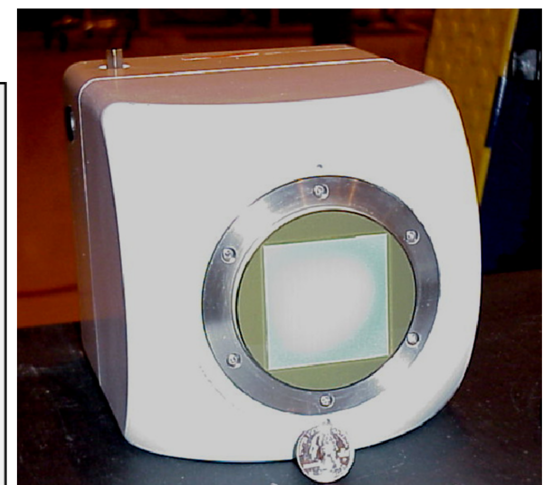
The Development of an Optical Streak Camera Based Plasma Imaging Diagnostic

The optical streak imaging system was designed around the NSTec Gen IV Streak Camera.

NSTec Gen IV Streak Camera
- Continuously Selectable Sweep Rates from 20ns to 500µs
- Photonis P510 Streak Tube
- 6µm Fiber Faceplate (Input/Output)
- 35mm x 4mm Active Area Multi-alkali S-20 Photocathode
- 60mm Aluminized P-22 Phosphor Screen
- Selectable/rotatable input slit sizes
- Full remote control capability from external work station

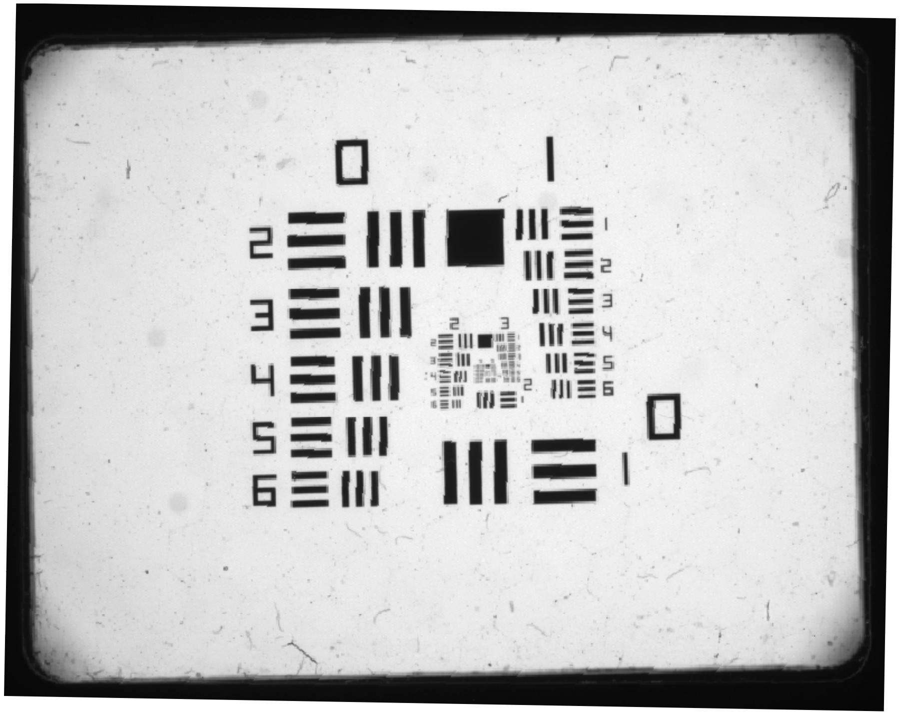
Princeton Instruments Quad-Ro CCD
- 24 µm pixels
- 50mm chip



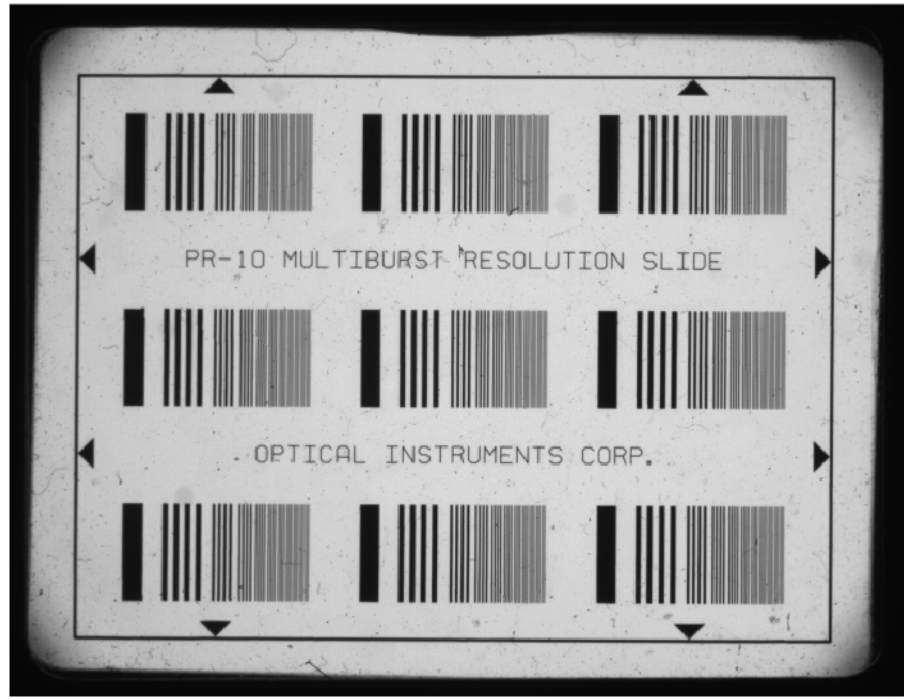


Princeton Instruments Quad-Ro CCD
(Steak camera detector)

Streak Camera and System Characterization

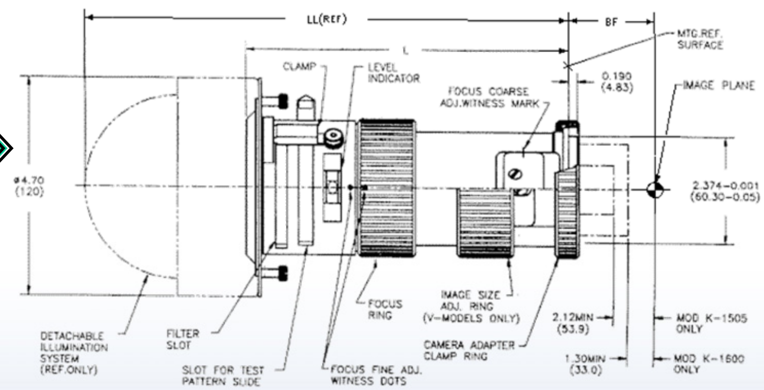


Air Force Resolution Target



PR-10 Multi-bar Resolution Pattern

Davidson Optronics Optoliner with
K-1001V Projector (S/N 3117)
2:1 Demagnification (Actual 0.487)
Pulsed Xe Flashlamp



Air Force Definition of Resolution *

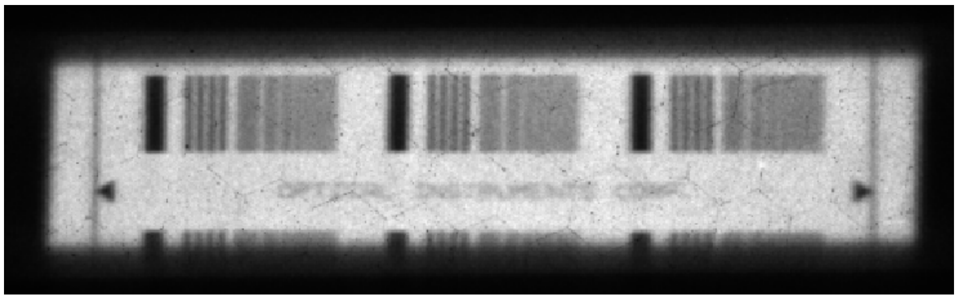
High Contrast: Factor of 100x
Medium Contrast: Factor of 6.5x
Low Contrast: Factor of 1.6x

*For these calibrations, linepairs are not considered distinct and resolvable below a factor of 2.0x (0.3 ND)

Full Streak Camera System: Static Resolution

Peak Intensity: 2320
Background: 450

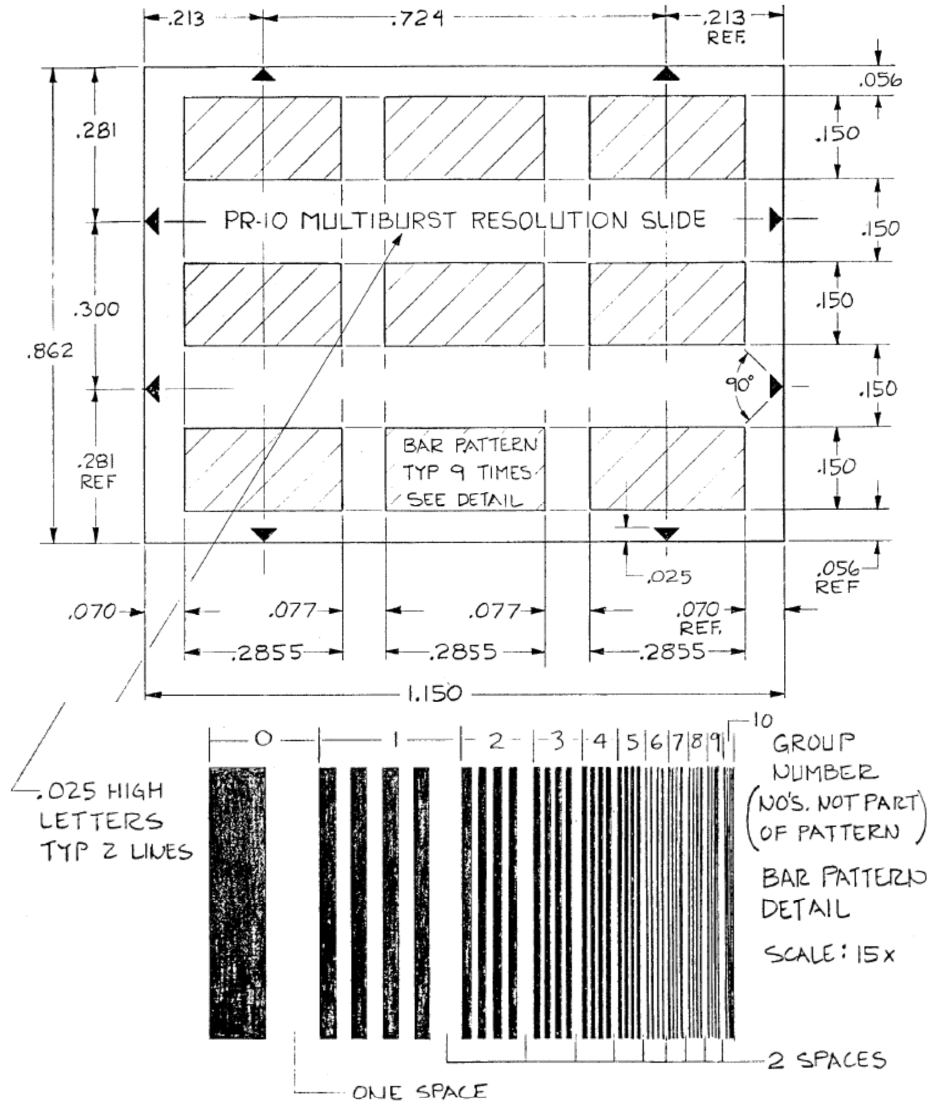
PR-10 Target imaged on active area of streak camera photocathode



Group 0: 3.0 lp/mm; 64x
Group 1: 10.5 lp/mm; 1.9x (just under resolution)
Group 2: 21.0 lp/mm (not resolvable)

Davidson Optronics Optoliner with
K-1001V Projector (S/N 3117)
2:1 Demagnification (Actual 0.435)
Pulsed Xe Flashlamp

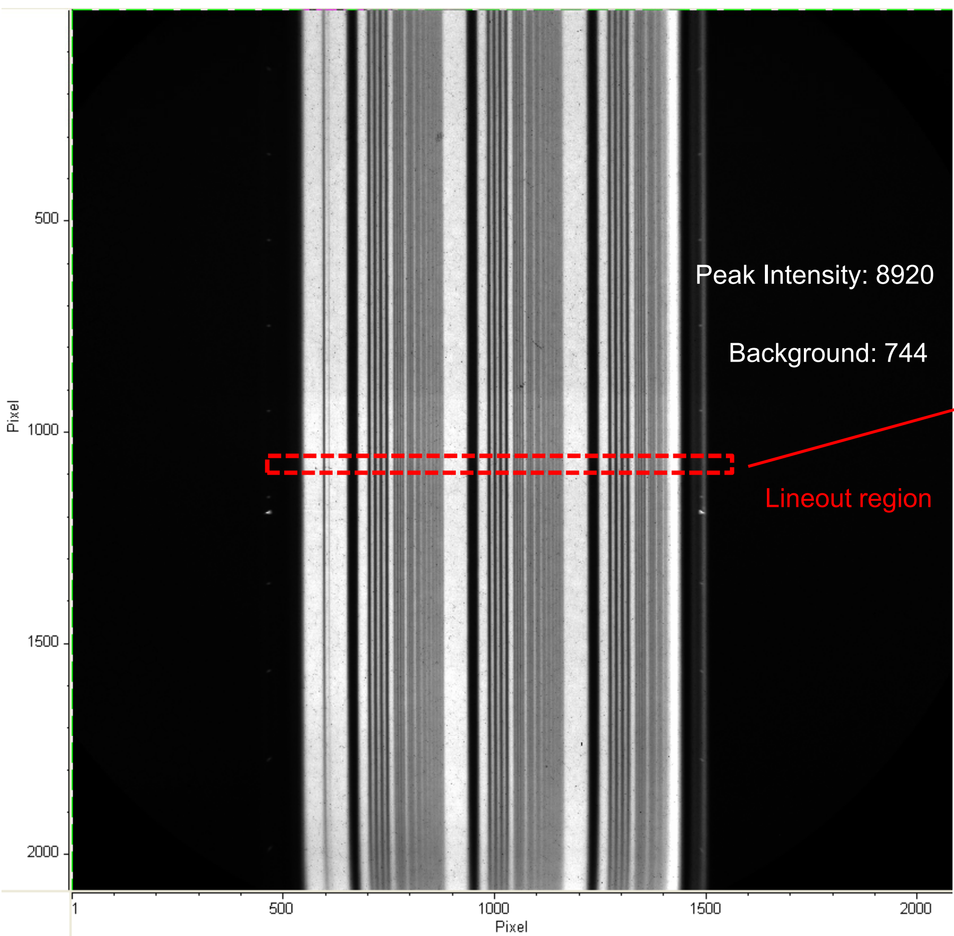
Active area of photocathode:
35mm x 4mm



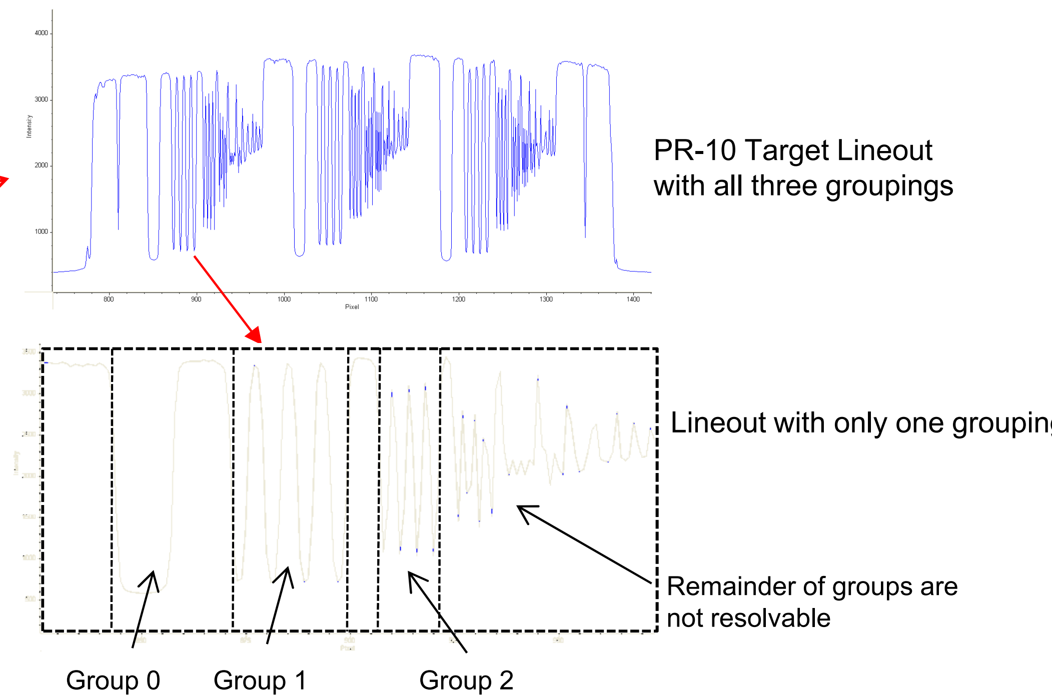
Detail of PR-10 Multiburst Resolution Target

Full Streak Camera System: Dynamic Resolution

PR-10 Target



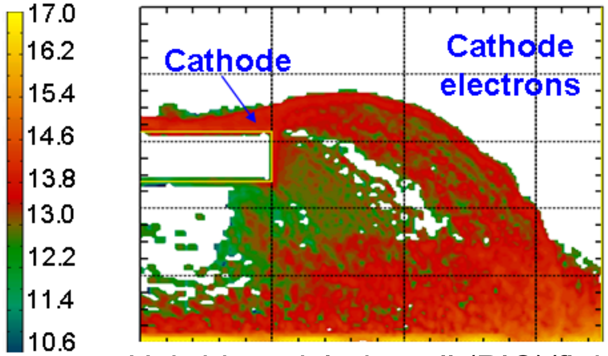
Group 0: 1.3 lp/mm
Group 1: 4.6 lp/mm; 6.2x
Group 2: 9.1 lp/mm; 1.6x (nearly resolved)
Group 3: 13.7 lp/mm (not resolvable)



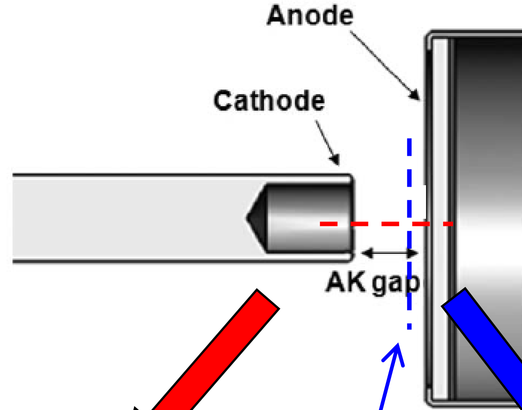
Davidson Optronics Optoliner with
K-2000V Projector (S/N 3039)
1:1 Magnification (Actual 1.113)
Pulsed Xe Flashlamp

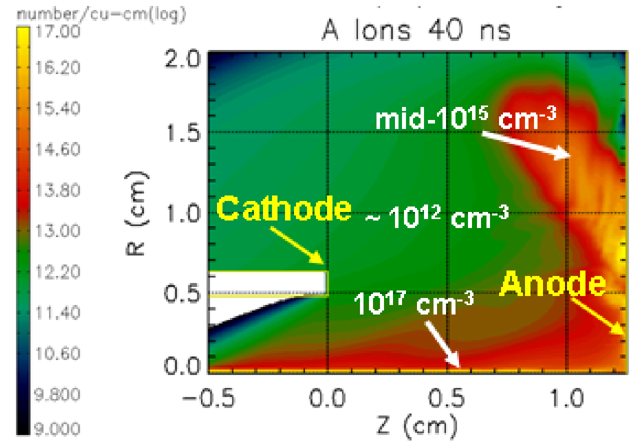
No noticeable degradation in resolution between the static and dynamic images for same location!

Typical Streaked Images of A-K Gap Plasmas

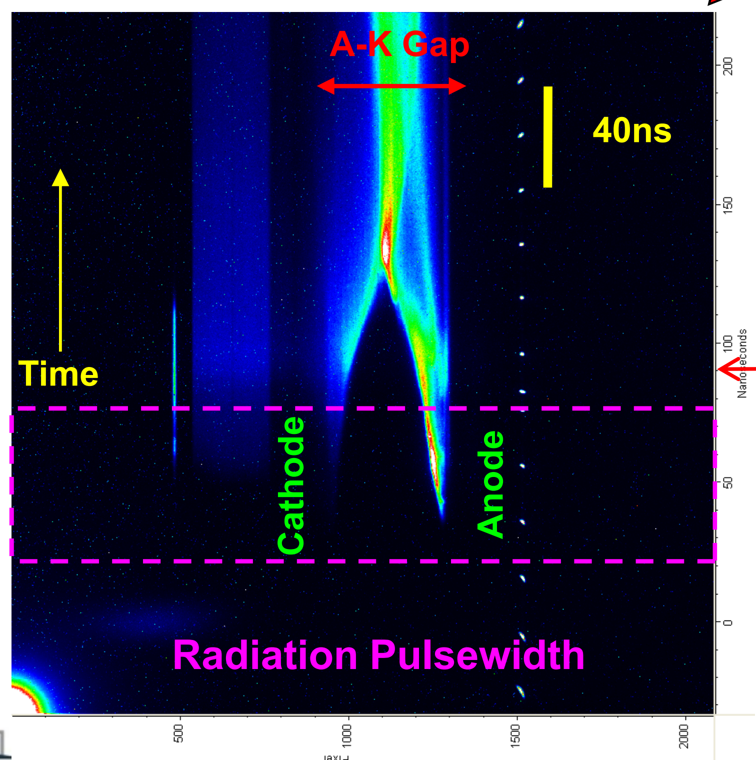


Hybrid particle-in-cell (PIC)/fluid simulations using LSP code





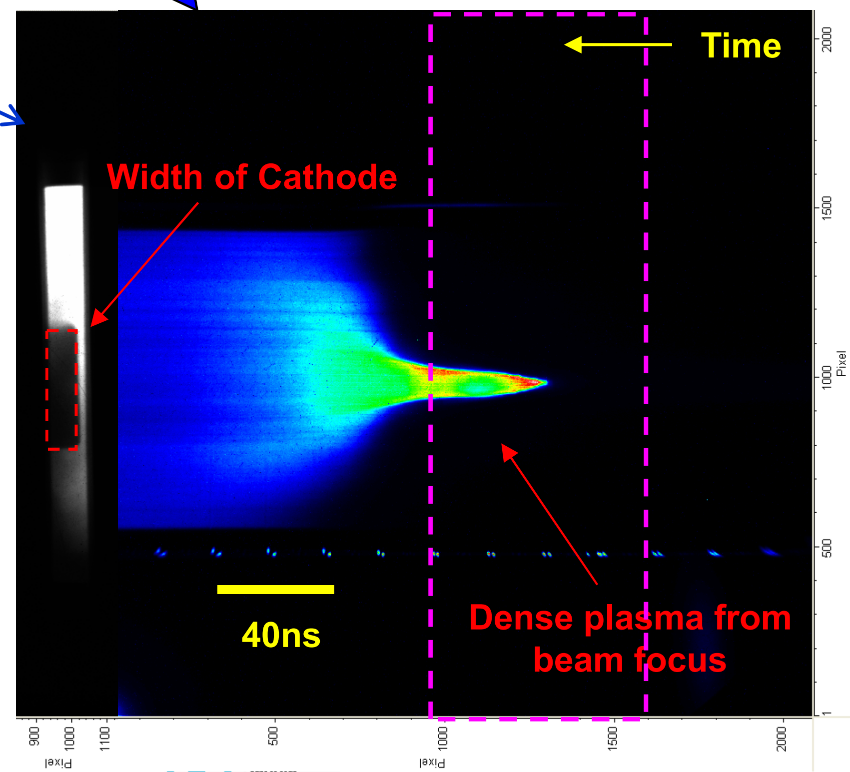
Axial Plasma Evolution



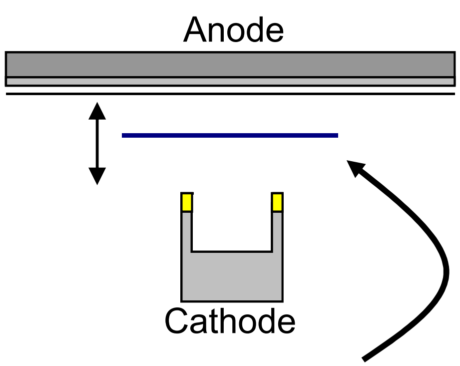
Vertical slit orientation across gap

Horizontal slit orientation spanning gap

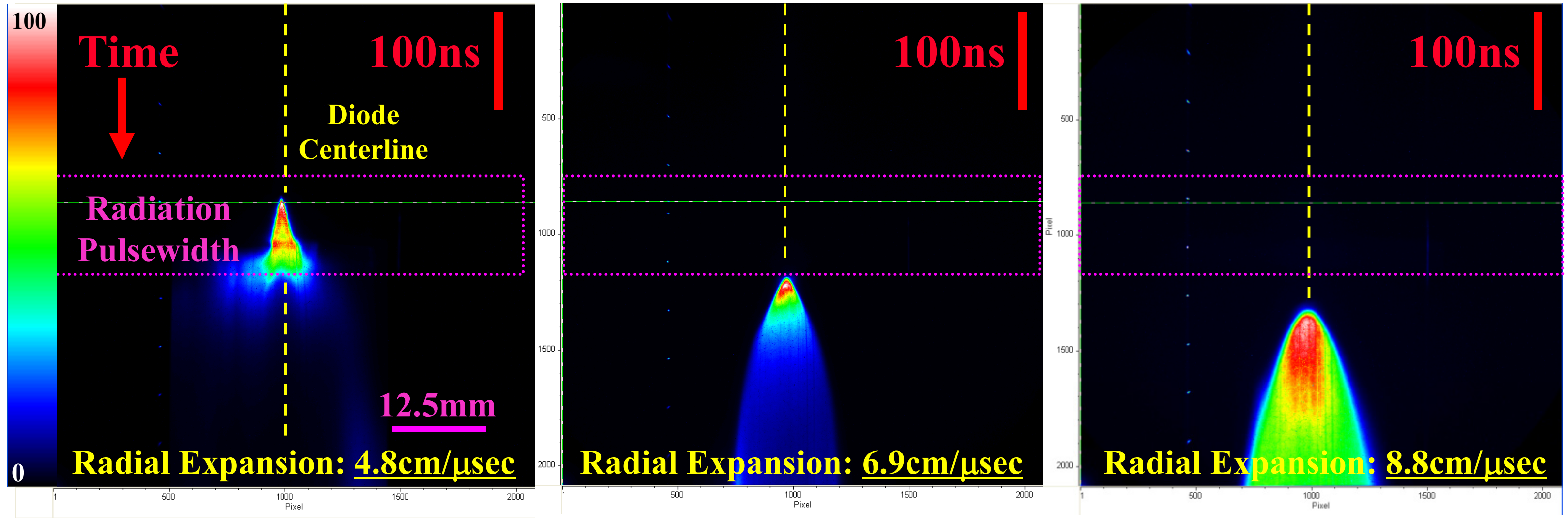
Radial Plasma Evolution



Radial Streaked Images of A-K Gap Plasmas



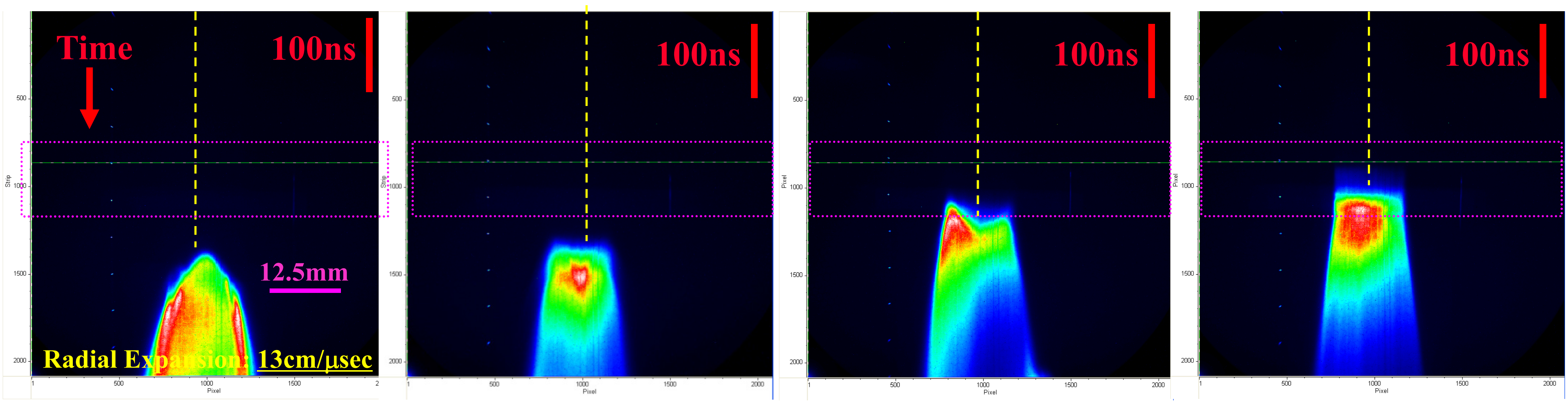
Streak Camera Slit (position varied across A-K gap)



Anode Surface

1/6 Gap

1/3 Gap



Mid-Gap

2/3 Gap

5/6 Gap

Cathode Surface

*Data taken on different shots

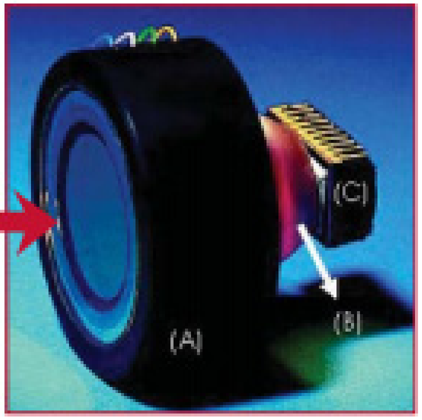
Addition of an ICCD Single Frame Imaging System

The ICCD Framing camera is a commercially available Princeton Instruments model PI-Max.

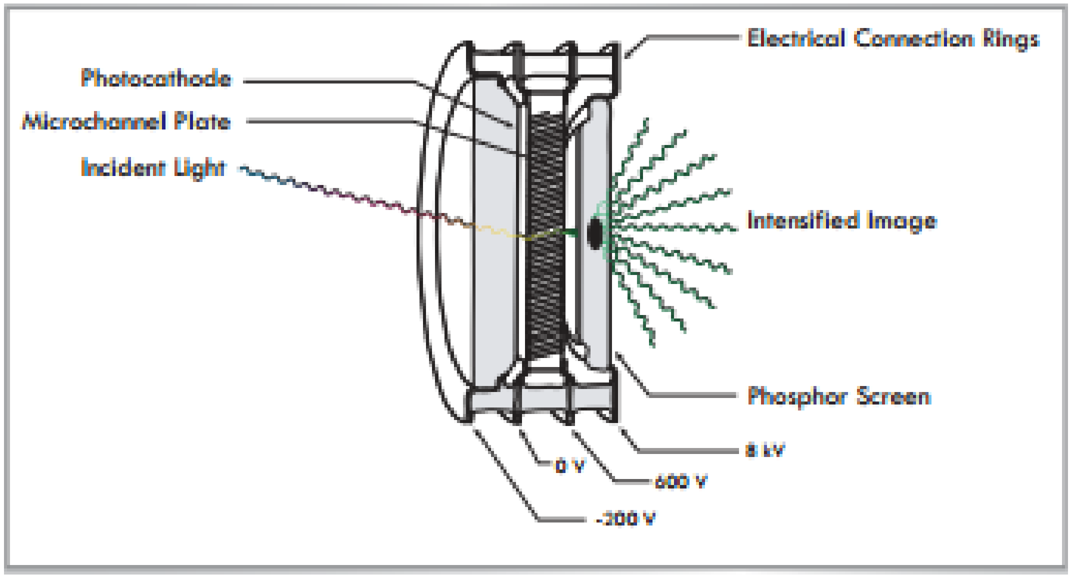
Princeton Instruments PI-Max ICCD Camera

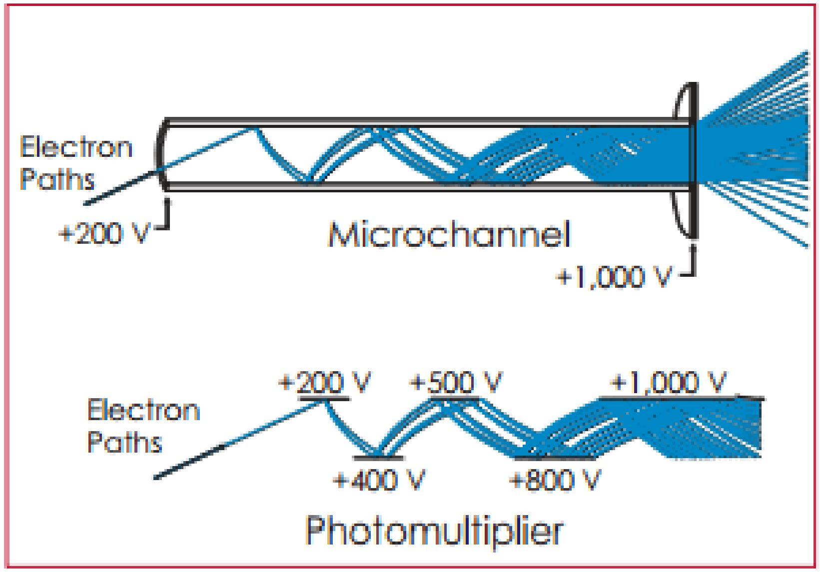
- Gen III filmless GaAsP photocathode (HBf)
- 25mm fiber-optic bonded 1:1 image intensifier
- P43 phosphor screen
- Front-Illuminated CCD
- 1340x1300 pixel array
- 20 micron pixel size
- < 7ns gating
- > 50% peak QE

Princeton Instruments PI-Max Camera

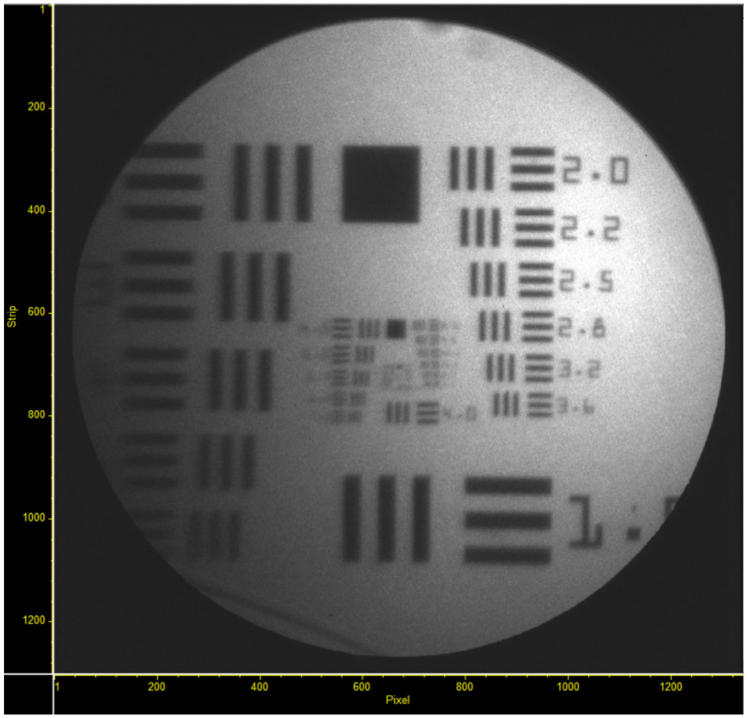


(A) Microchannel Plate, (B) Fiber –optic faceplate, and (C) CCD

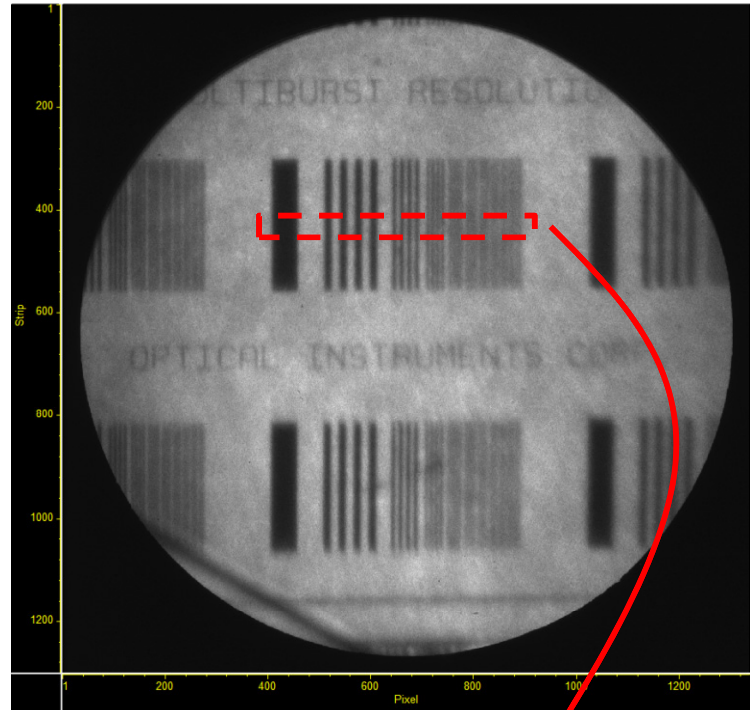




ICCD Framing Camera Full System Characterization

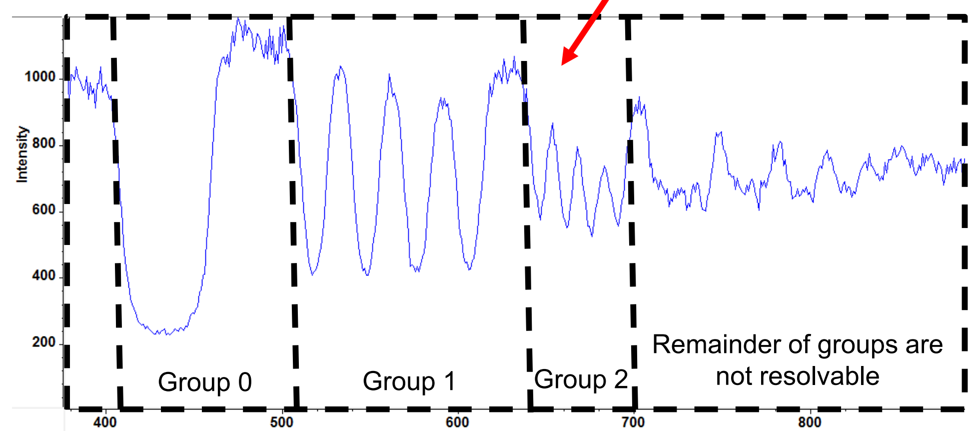


Air Force Resolution Target



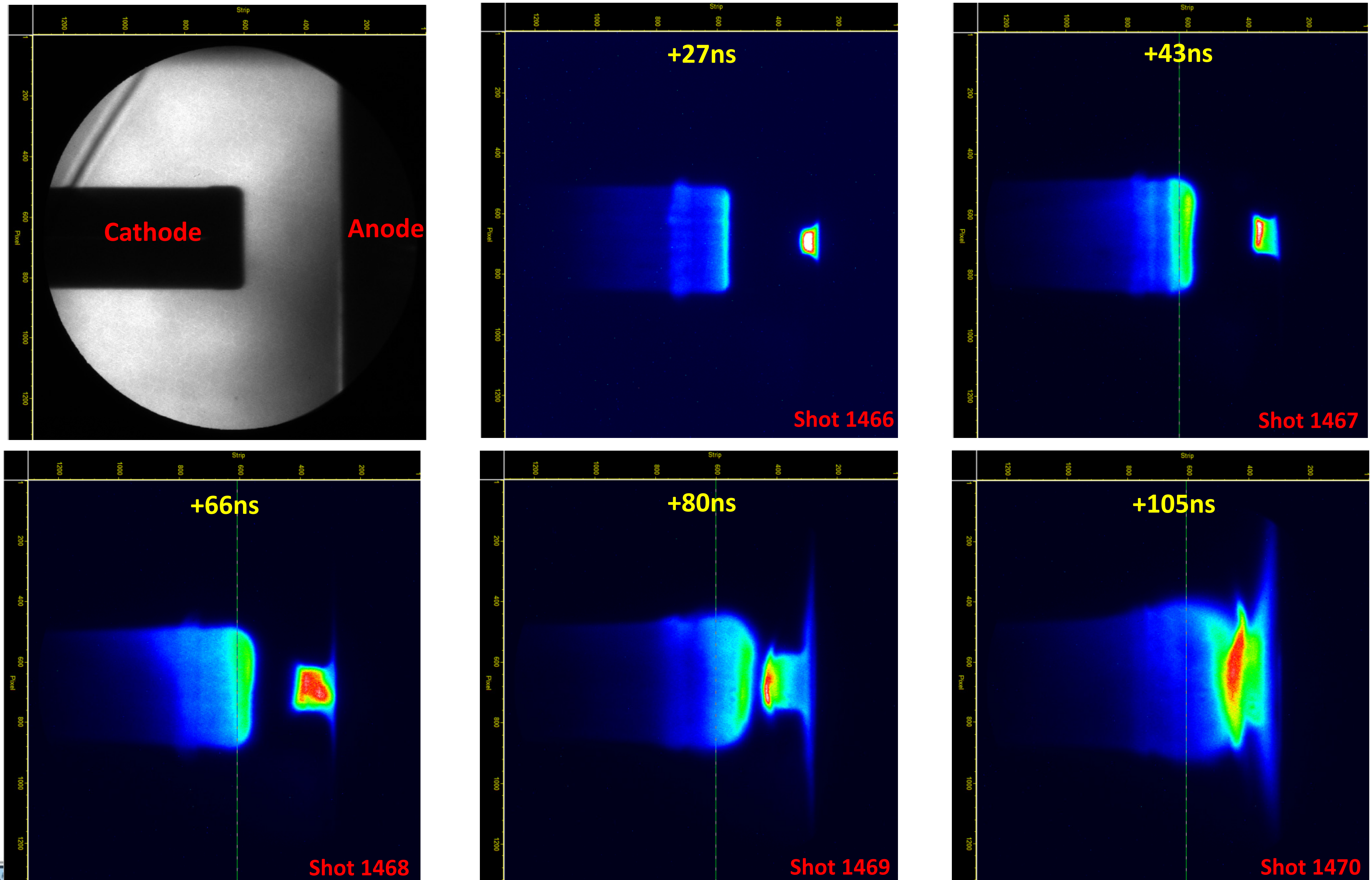
PR-10 Multi-bar Resolution Pattern

Group 0: 1.3 lp/mm; 7.6x
Group 1: 4.6 lp/mm; 2.9x
Group 2: 9.1 lp/mm; 1.6x (nearly resolved)
Group 3: 13.7 lp/mm (not resolvable)



This system can resolve <u>100µm</u> sized features at the source!

Framing Camera Images of Electrode Plasma Expansion



*Green line represents original cathode position

*10ns images taken at ~20ns increments

Summary of Characterization Measurements

Streak Camera

•Total system resolution is limited by the streak camera and CCD detector to 9 lp/mm.

•Resolution does not change significantly between static and dynamic images.

•Sweep speed and slit width changes do not significantly affect streak camera resolution.

•The Air Force resolution target (preferred resolution target) gives more precise resolution measurements than the PR-10 Multiburst target due to a larger number of groupings.

•The PR-10 Multiburst target is more convenient for dynamic (swept) measurements and is the preferred resolution target for streak camera calibrations.

PI-Max ICCD Camera

- Total system resolution is limited to 54 lp/mm due to the 20x20 μm pixel size of the camera.
- Measured full system resolution, including optics, is 9 lp/mm at the source.
- Measurements using both the Air Force resolution target and the PR-10 Multiburst target have been completed.

Conclusions

•An optical streak imaging system using an NSTec developed Gen IV Streak Camera has been successfully implemented on the RITS-6 accelerator at SNL to investigate plasma formation and propagation in radiographic diodes used for flash x-ray radiography.

•The fast sweep rates (20ns – 500μs) and high resolution (up to 9 lp/mm) make this camera system ideal for imaging dynamic plasma species, while its rugged design is well suited for the high EMP/EMI and x-ray environments present around these diodes.

•A second gated optical camera has been added to the system which is capable of recording simultaneous high resolution gated images of both the cathode and anode plasmas. Previously unseen structures observed in the cathode plasmas are providing new insights into cathode surface physics.

•New information on the intensity and spatial extent of early time plasmas from both surfaces allows for comparisons of high dose shots to “identical” low dose shots. This data is providing new insight into the “early time” differences between a “good” and a “bad” shot.

•These diagnostics combined with other spectroscopic and imaging techniques are expected to greatly enhance our physics understanding of the role of plasmas in e-beam diodes.

•Data such as expansion velocities, intensity/density profiles, and tomographic information obtained from these diagnostics are being incorporated into high level LSP, hybrid particle-in-cell / fluid dynamic simulations to help design the next generation enhanced radiographic sources.