Plasma Sources for Drivers and NDCX-II

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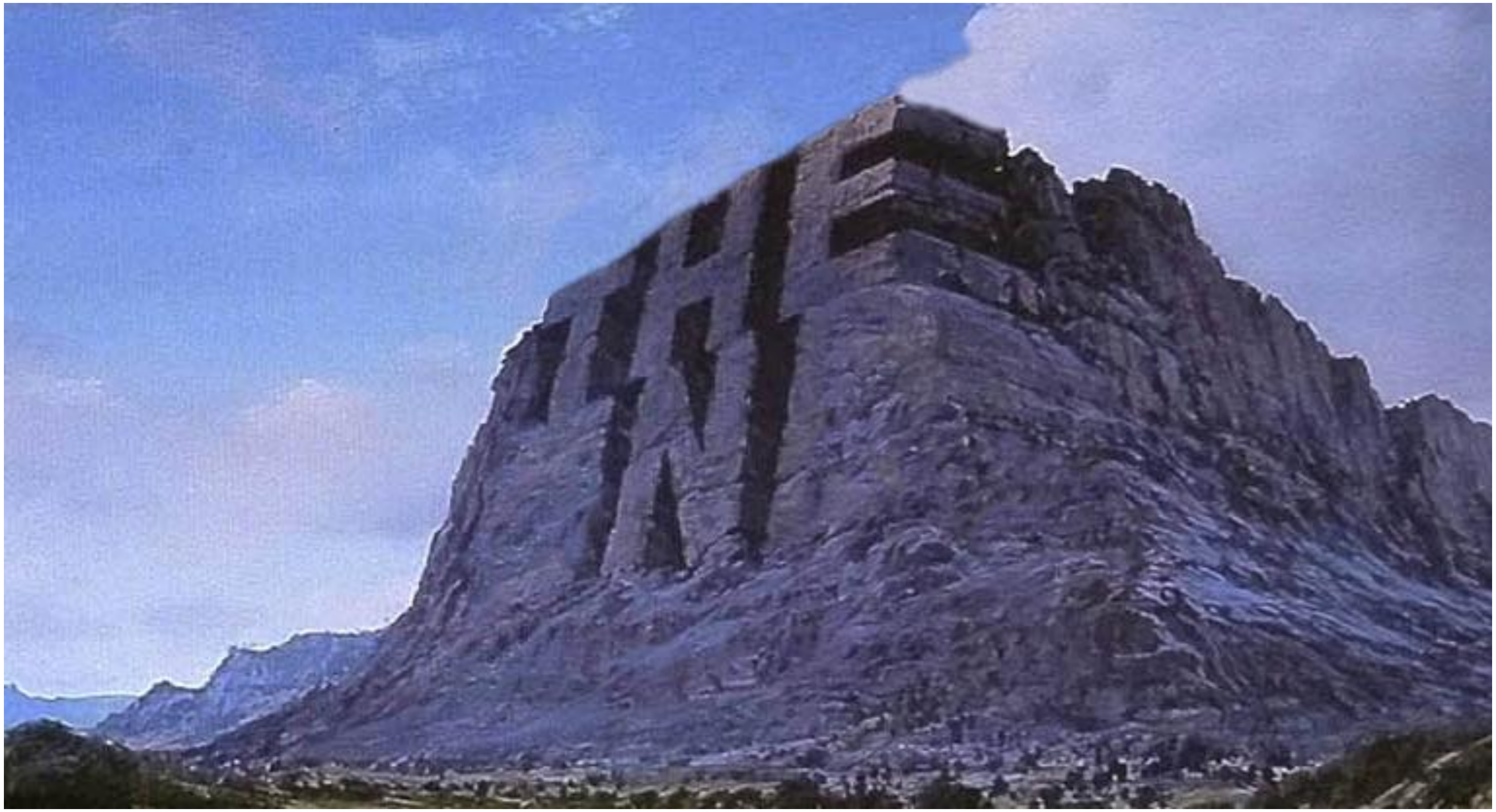
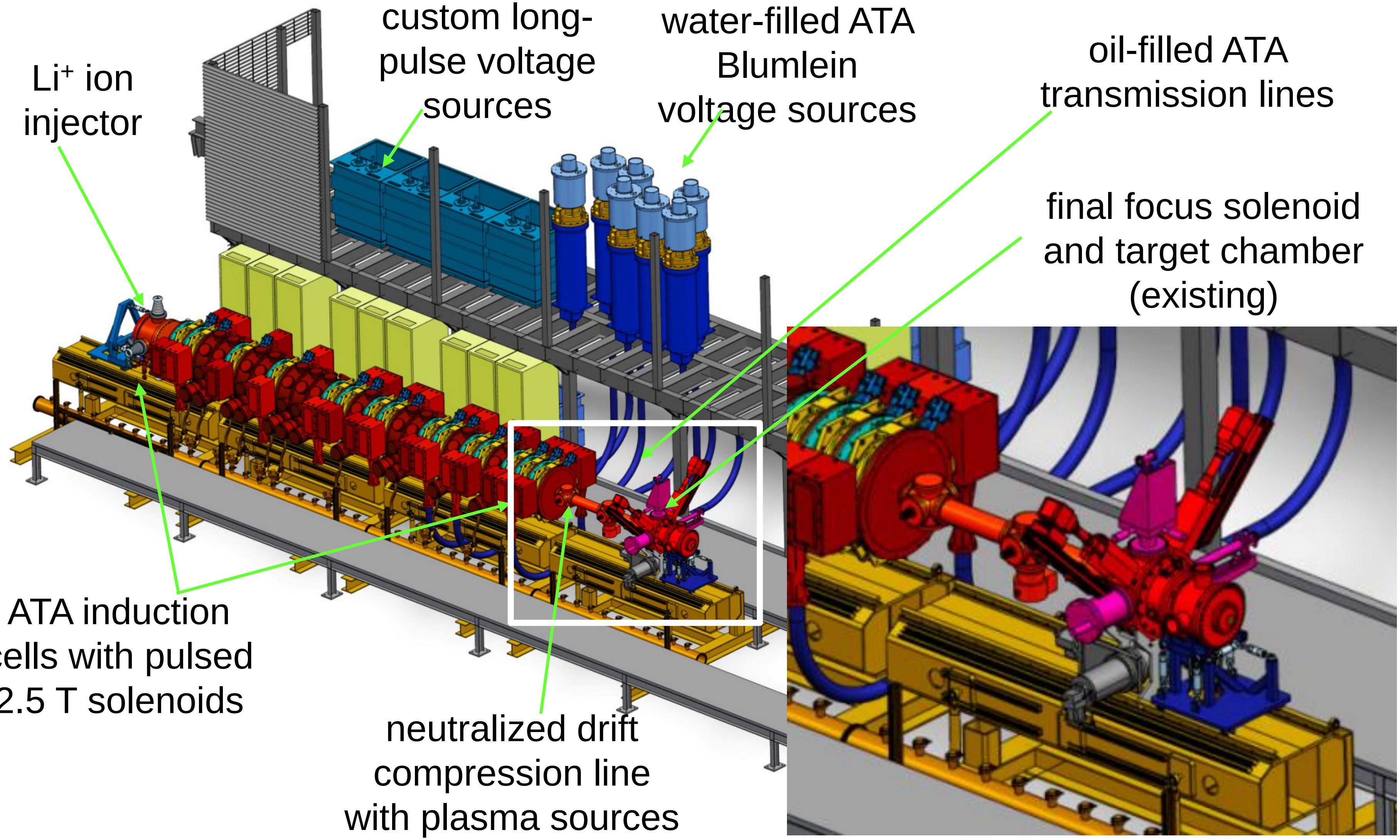
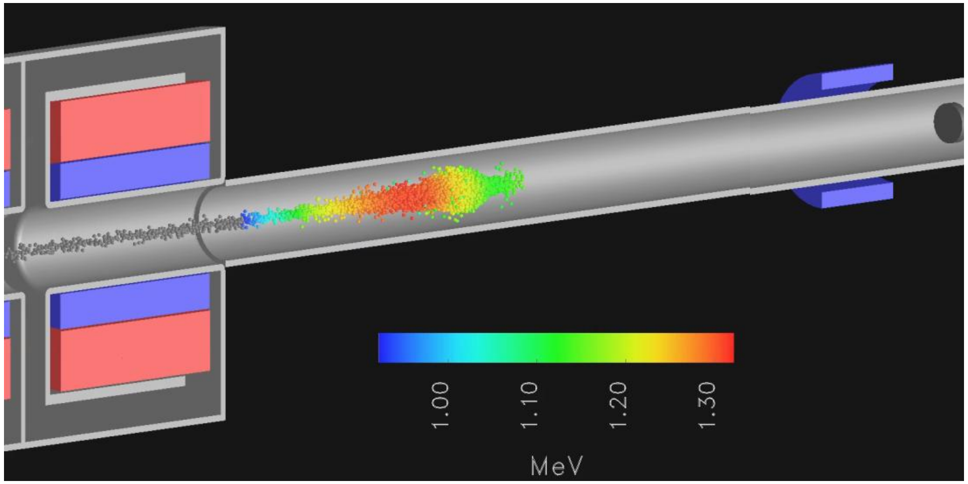
N is for Neutralization



NDCX-II Layout



NDCX-II Plasma Source Requirements



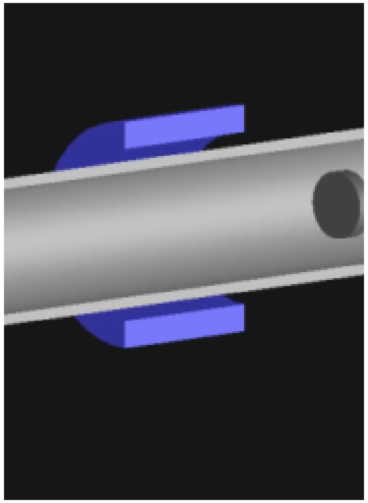
- Local plasma density should exceed the local beam density throughout the drift region – including inside both the final focus solenoid and the target chamber.

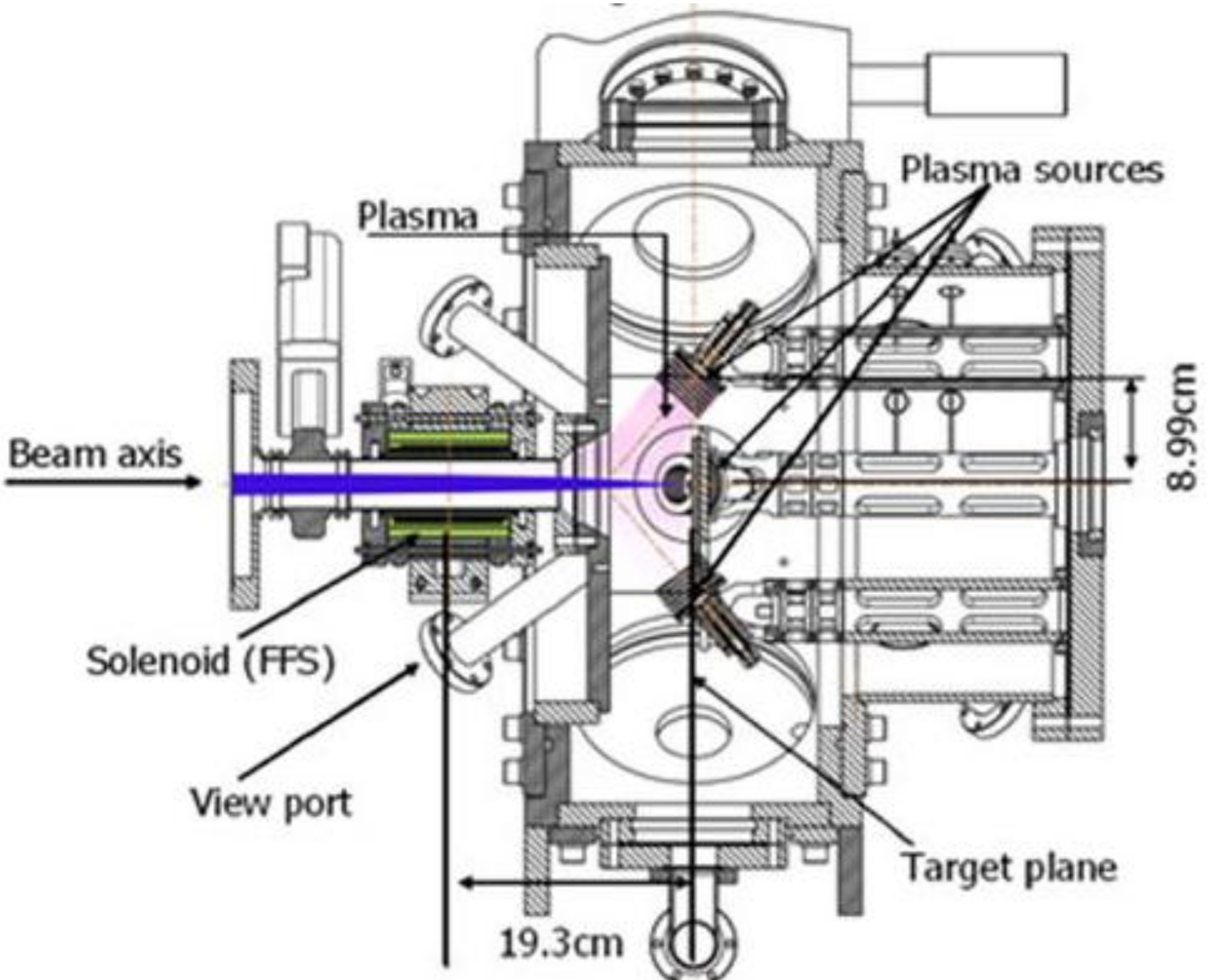
  n_b ~ mid 10^9 cm^{-3} at beginning of neutralized drift section.
  n_b ~ mid 10^{10} cm^{-3} ~30 cm before target spot.
  n_b ~ 10^{13} cm^{-3} at target spot.

- Plasma sources should not employ electric or magnetic fields that would disturb the beam propagation.

- Plasma sources should not introduce so many neutrals as to interfere with the beam propagation by stripping or charge exchange.

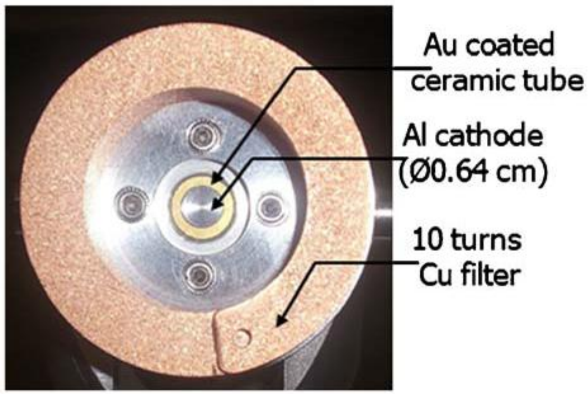
The NDCX-I Final Focus Solenoid and Target Chamber

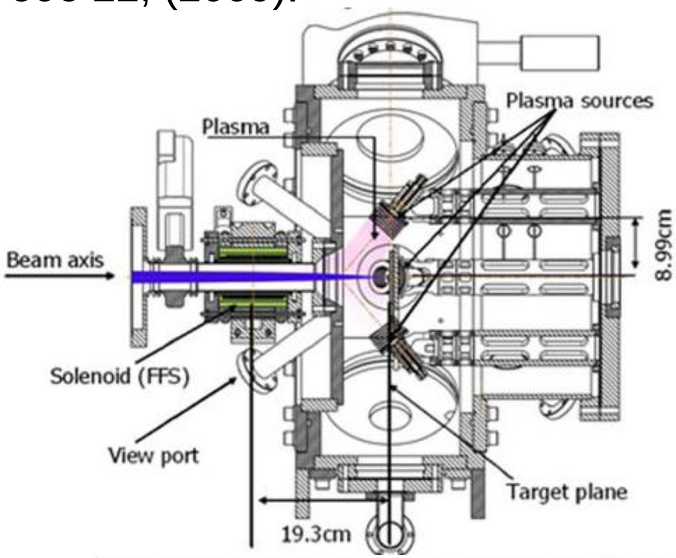




Final Focus Solenoid and Target Chamber – Cathodic Arc Plasma Source (CAPS)

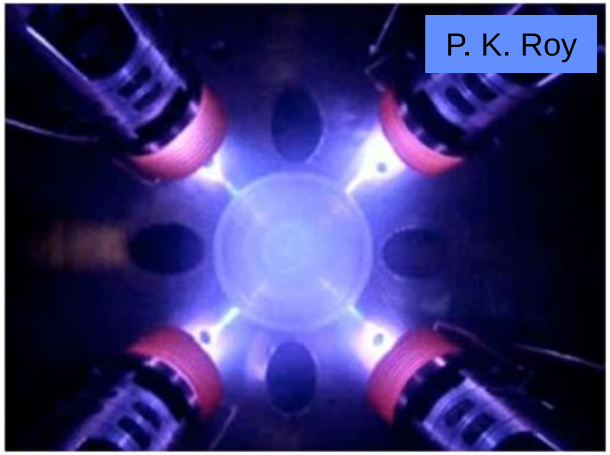
Developed by André Anders and collaborators.
P. K. Roy et al., Nucl. Instr. and Meth. in Phys. Res. **A 606** 22, (2009).



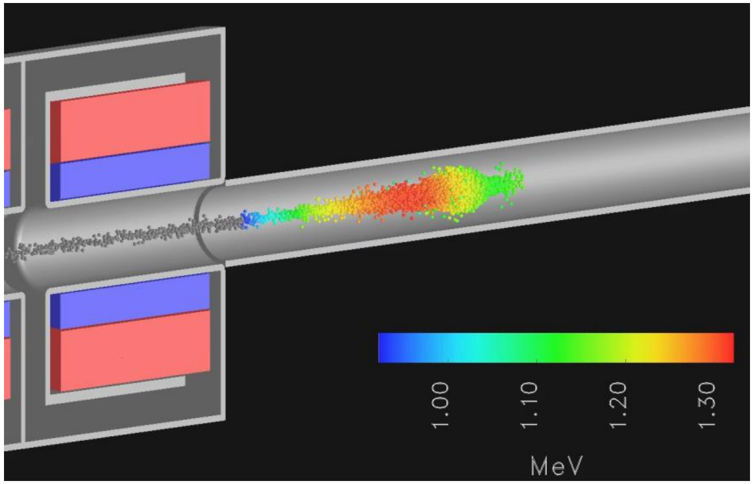


The four CAPS produce a plasma density of 10^{12} cm^{-3} on the beam axis near the target spot and a plasma density of 10^{13} cm^{-3} on the beam axis at the midplane of the 8 T Final Focusing Solenoid (FFS).

A 3 kV pulse drives 800 A peak current through each of the four sources.



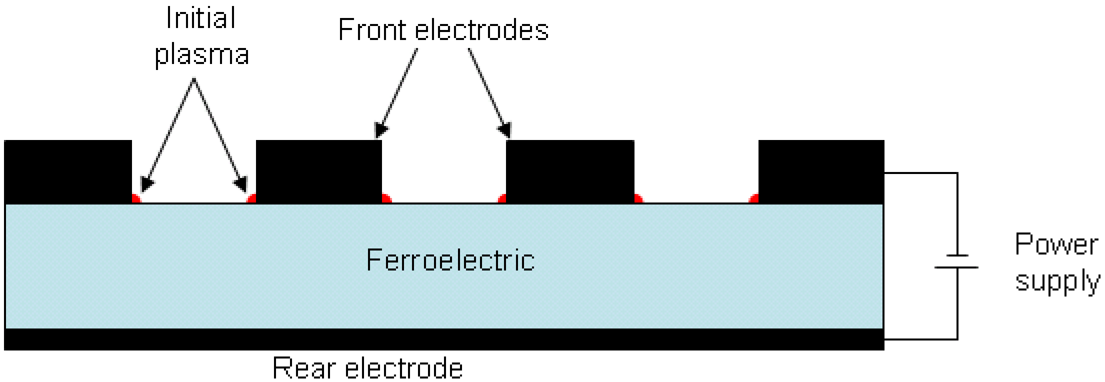
Drift Compression Region Upstream of Final Focusing Solenoid – High Dielectric Ferroelectric Ceramics



Drift Compression Region Upstream of Final Focusing Solenoid – High Dielectric Ferroelectric Ceramics

A high-dielectric ($\varepsilon/\varepsilon_0$ ~ 1000) ceramic produces a large polarization surface charge density when a high voltage is applied. The resulting large electric field creates a plasma on the mesh-lined surface.

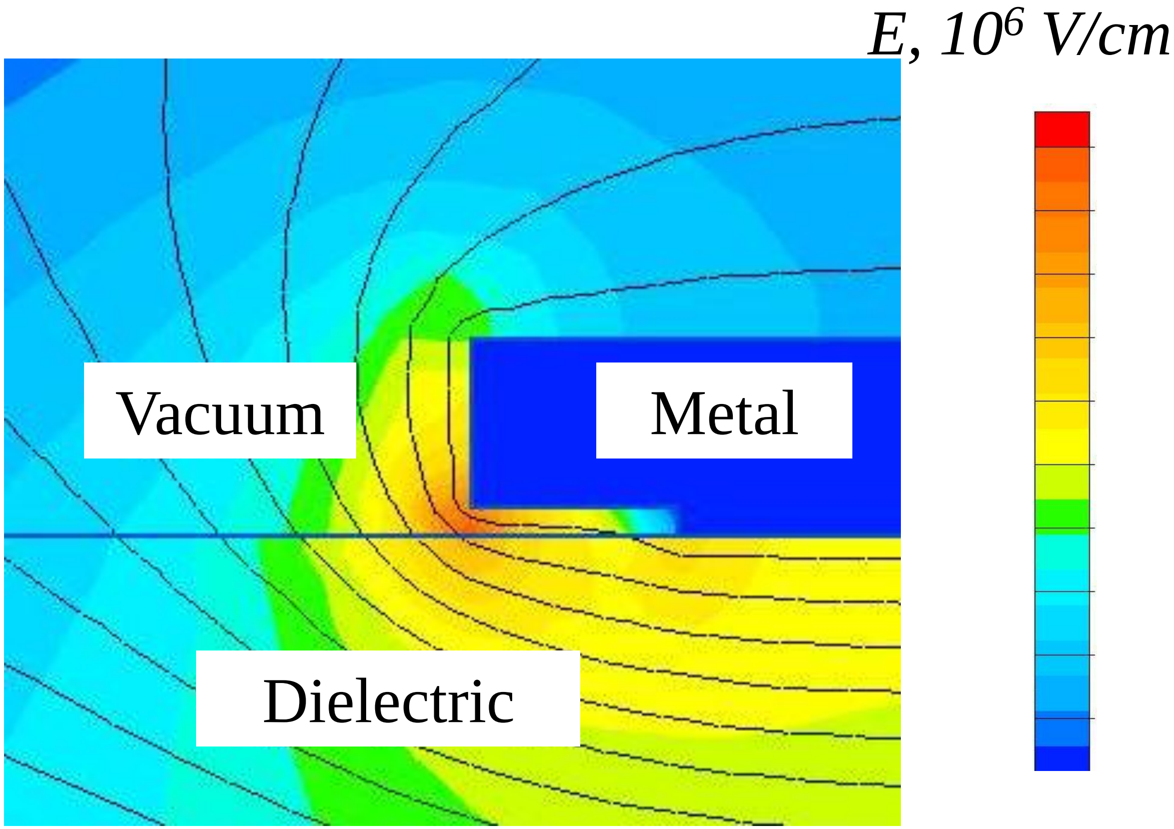
- Ceramics such as Lead Zirconium Titanate (PZT) and Barium Titanate ($BaTiO_3$) have relative dielectric coefficients of several thousand.
- Commonly used in transducers and high-power capacitors.



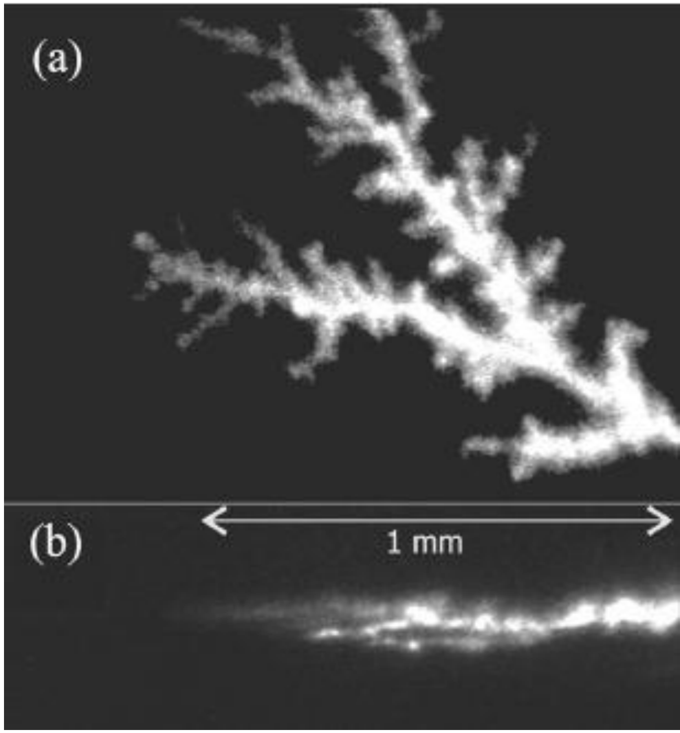
- Explosive plasma formation in triple points
- Avalanche of electrons along the insulator-vacuum interface
- Secondary electron and ion emission
- Gas desorption and ceramic ablation
- Ionization of the neutral cloud

Identified and studied by Krasik, Felsteiner, Haber and Kaganovich.

Strong Tangential Electric Fields Drive Plasma Flow Along the Dielectric Ceramic Surface

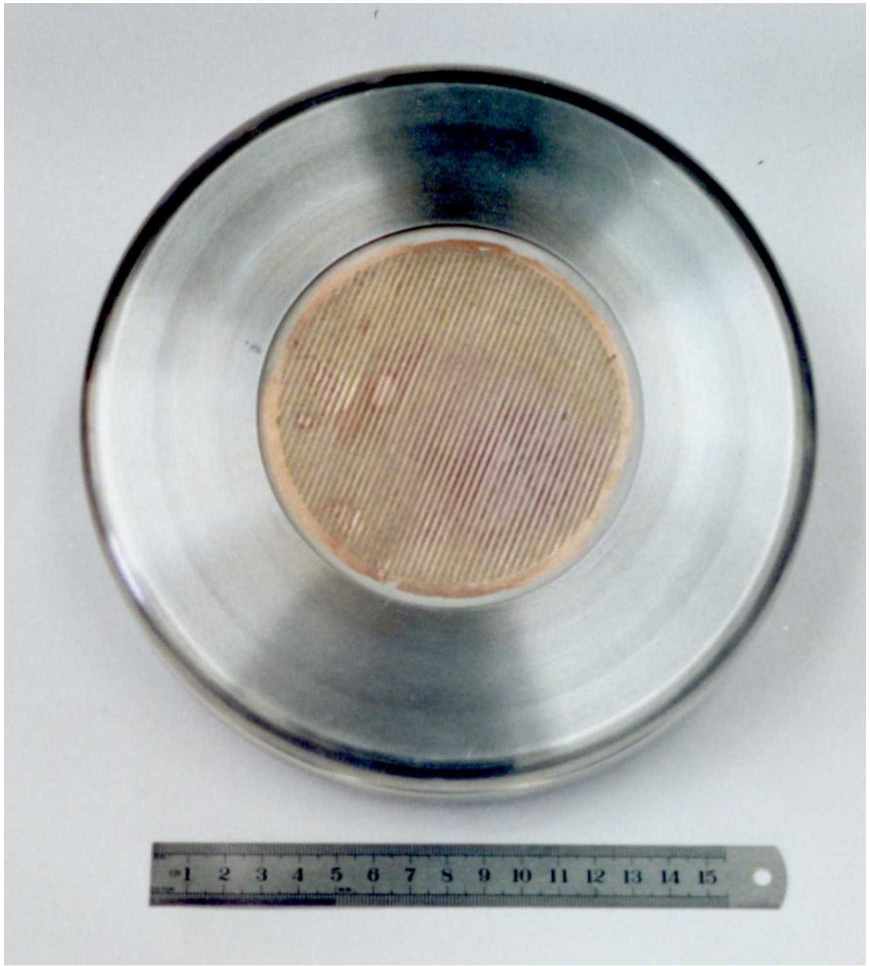


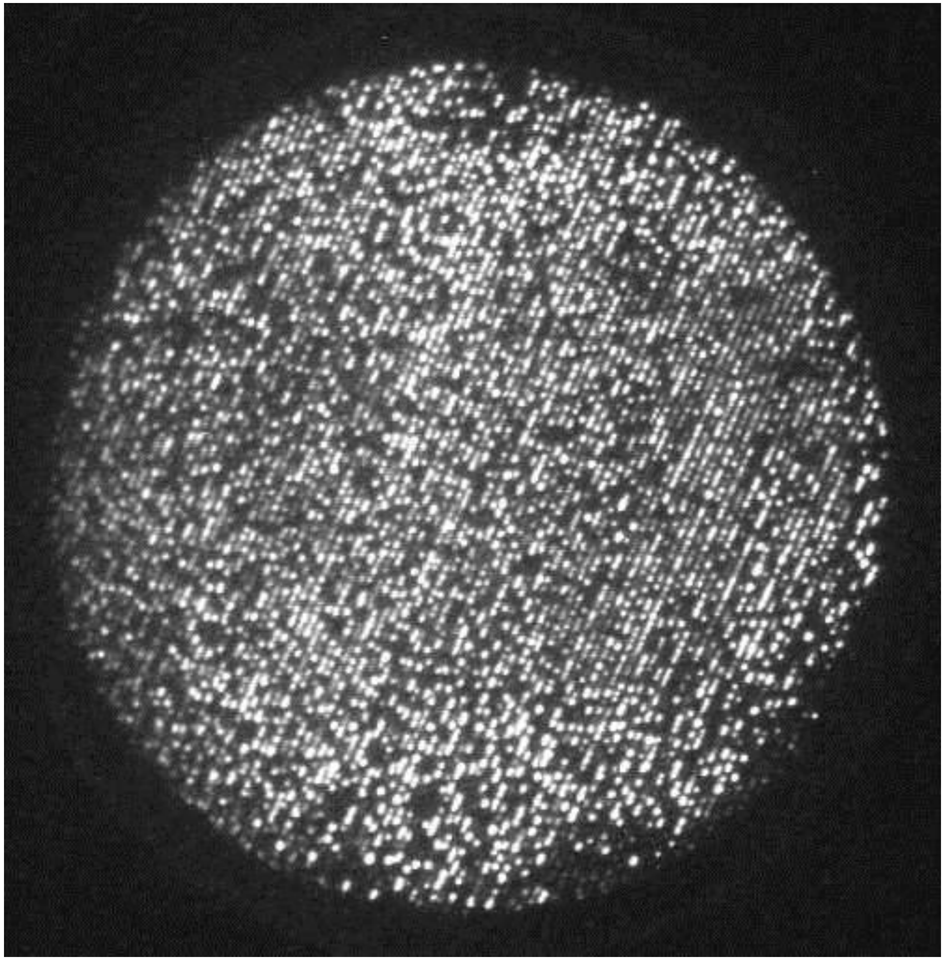
A high-dielectric ($\varepsilon/\varepsilon_0$ ~ 1000) ceramic produces a large polarization surface charge density when a high voltage is applied. The resulting large electric field creates a plasma on surface.



Ya. E. Krasik 20 ns exposure

Example: Planar High Dielectric Ferroelectric Ceramic Plasma Source

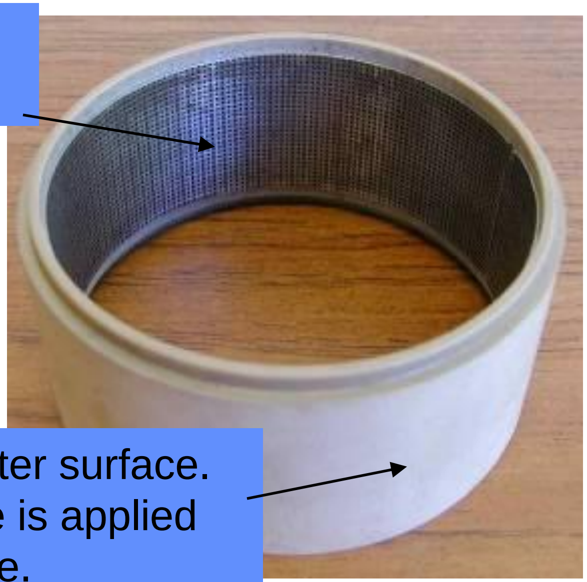




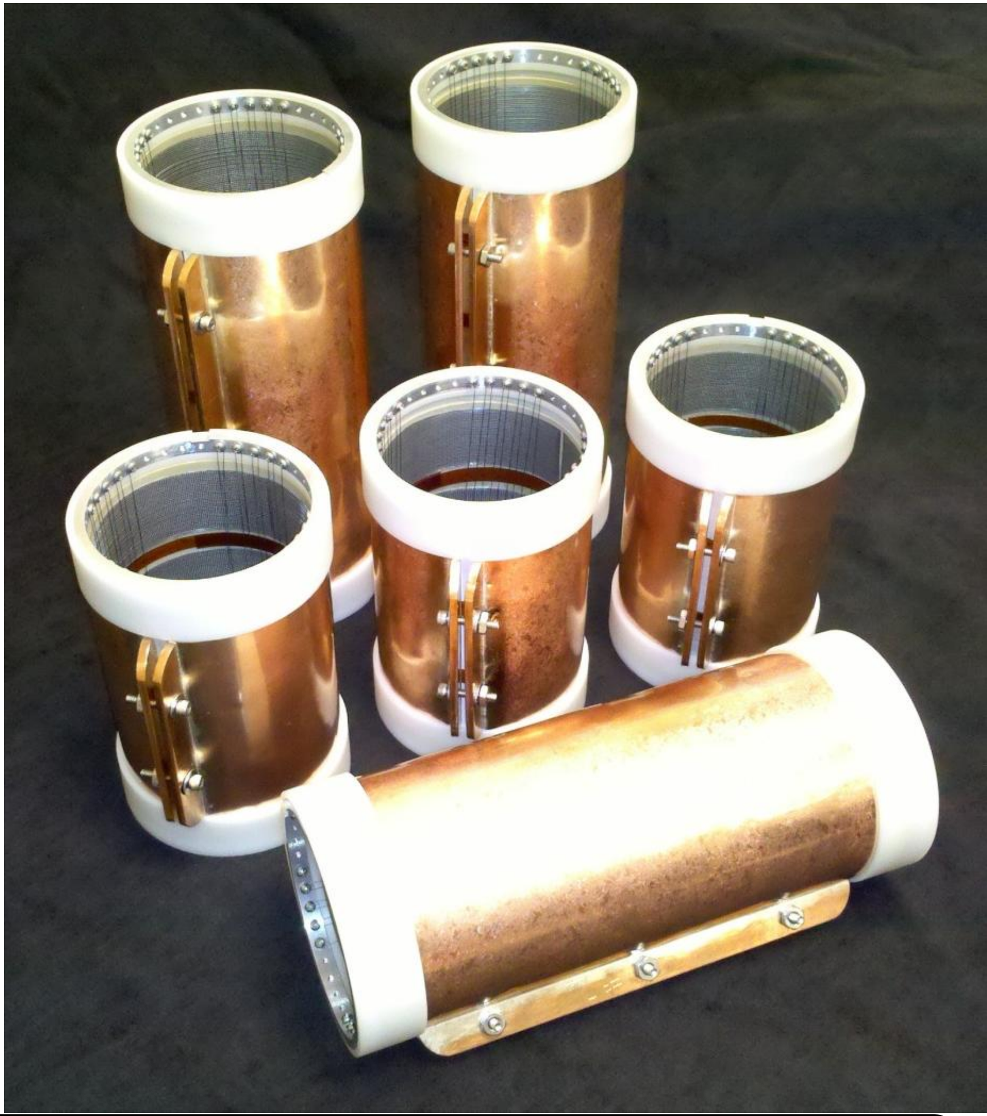
Barium Titanate Plasma Sources for NDCX-II are Made in a Cylindrical Shape to Fill the Beamline

Grounded interior mesh

3.000” ID
3.300” OD
1.600” length



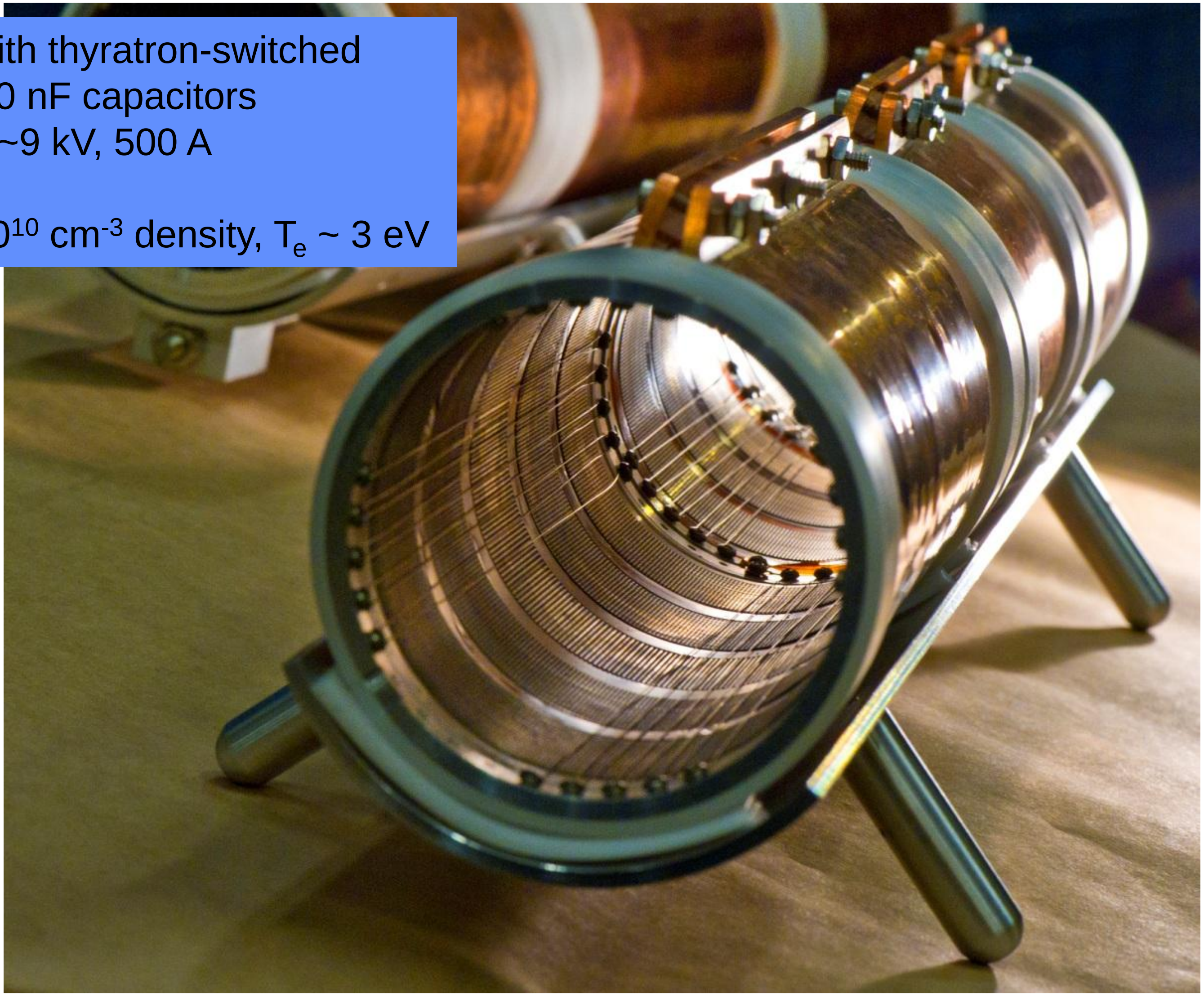
Metalized outer surface. High voltage is applied here.



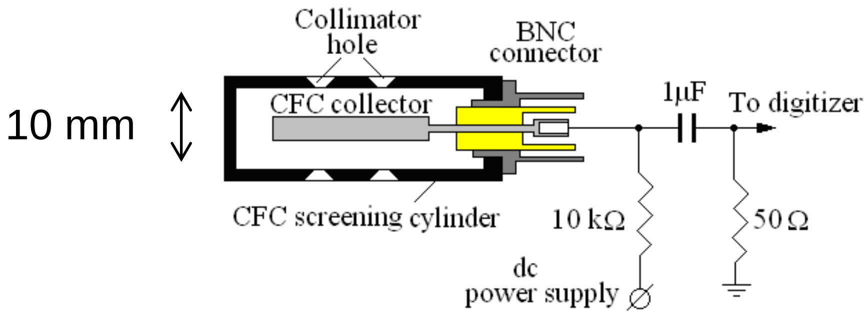
Assembled Ferroelectric Plasma Sources are Placed Together on a Support Cradle

Driven with thyratron-switched
150 nF capacitors
~9 kV, 500 A

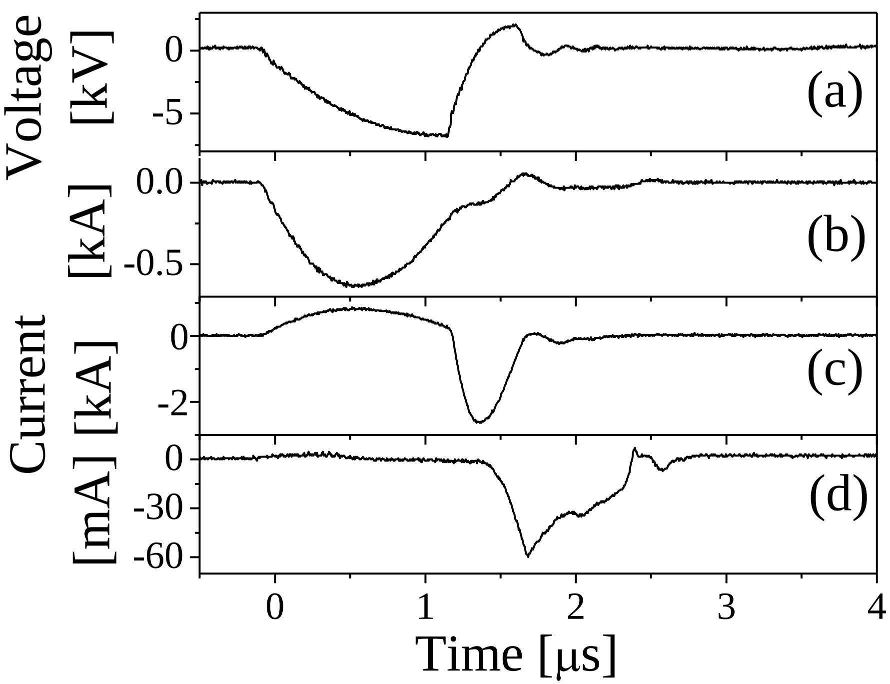
10 μs, mid 10^{10} cm^{-3} density, T_e ~ 3 eV

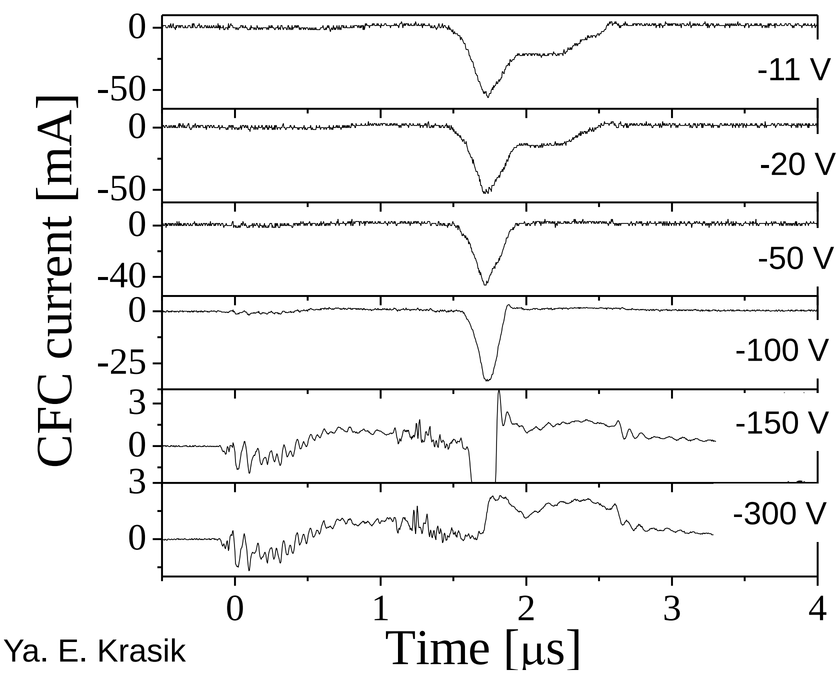


Collimated Faraday Cup Measurements Show On-Axis Densities of 2 x 10^{11} cm^{-3} With Crowbar



n ~ 2 x 10^{11} cm^{-3}

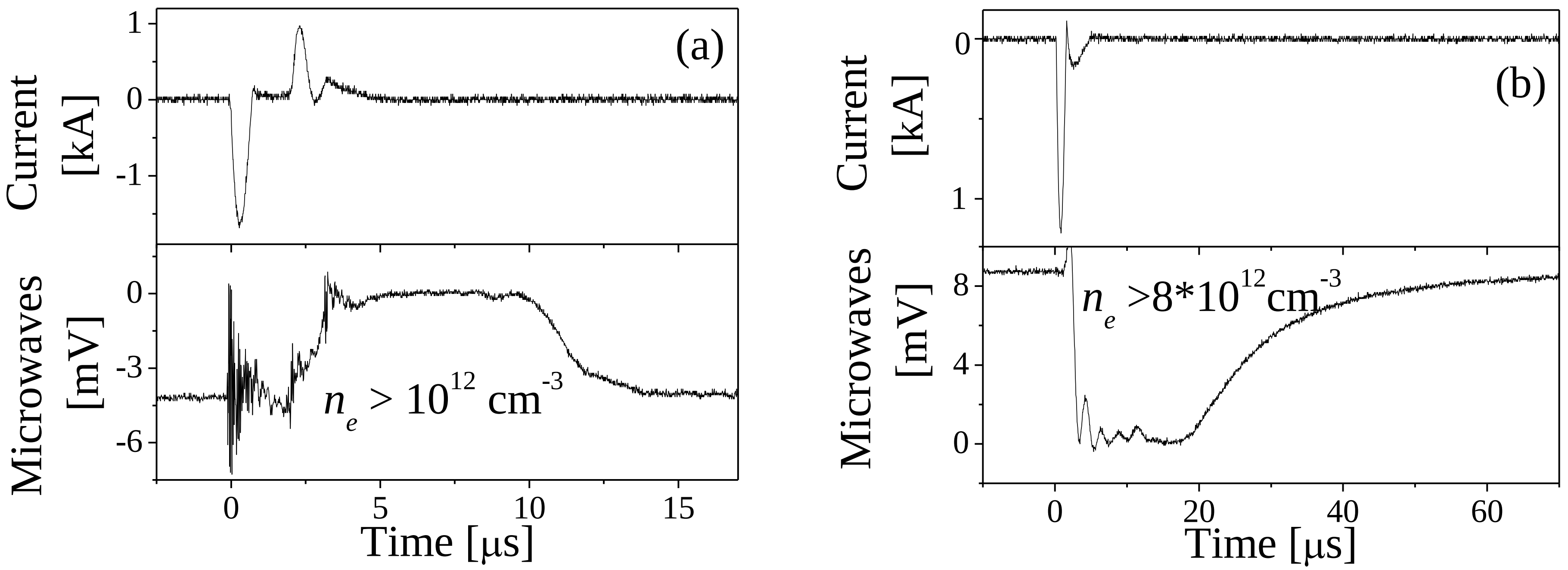




Ya. E. Krasik

Microwave Cutoff Measurements Show Large Plasma Density When Crowbar is Used

Ya. E. Krasik



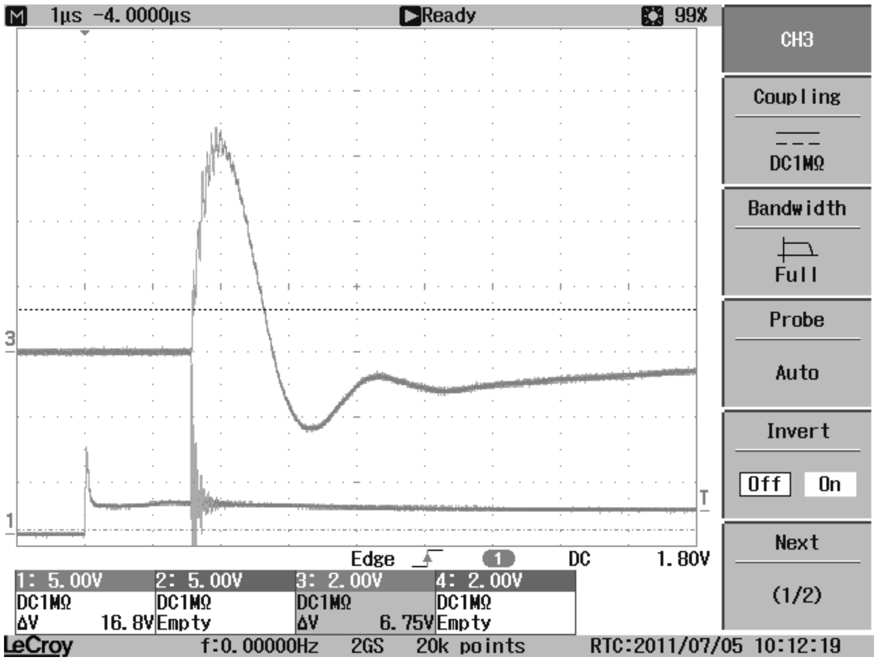
9 kV Charging Voltage
9 GHz (3 cm)

11 kV Charging Voltage
25 GHz (1.2 cm)

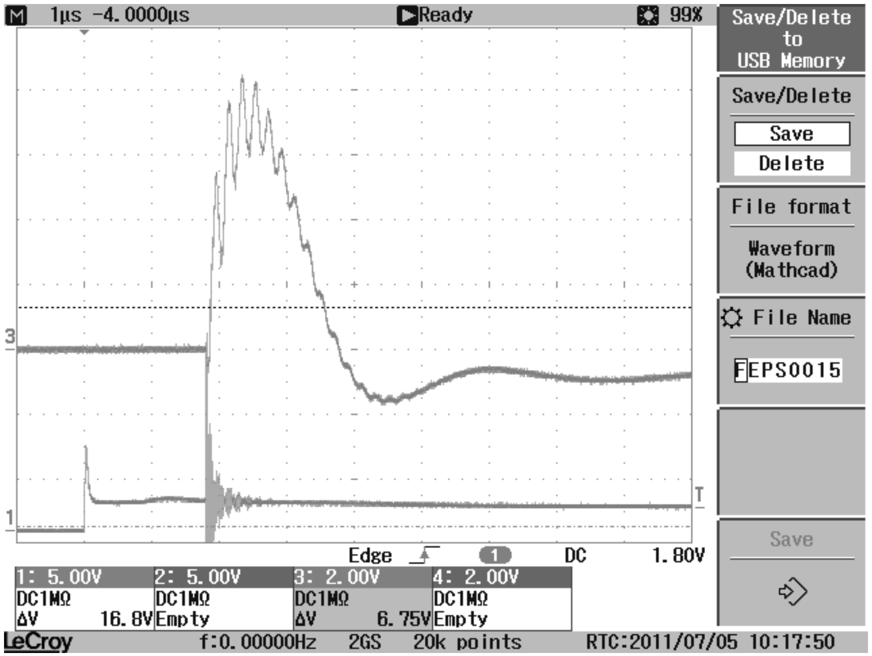
No cutoff with 70 GHz observed

Fast Voltage Waveform Risetime Increases Plasma Formation Rates – Self-Inductance of Cables Is Acceptable for NDCX-II

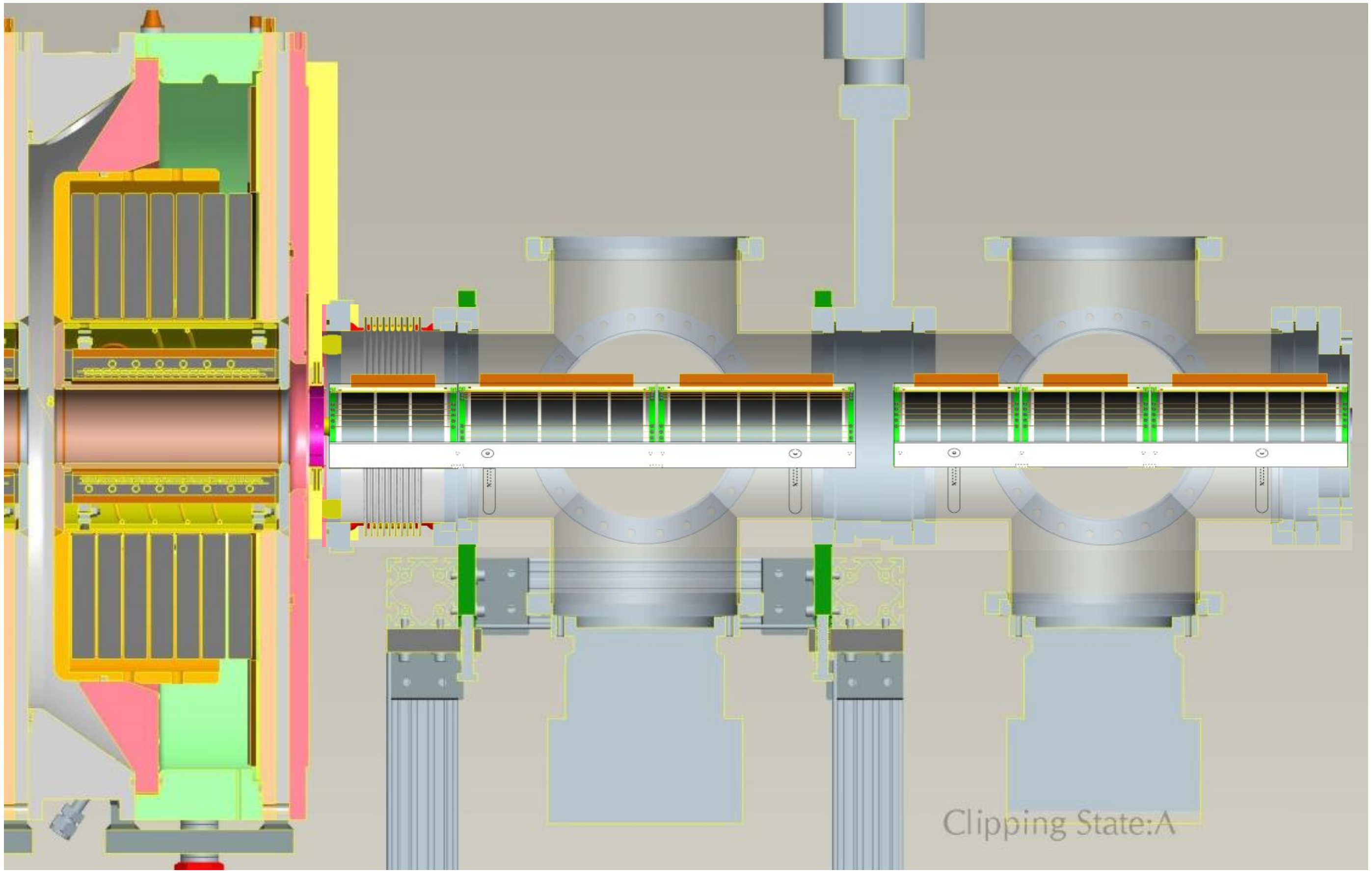
2 m coaxial cable



6 m coaxial cable

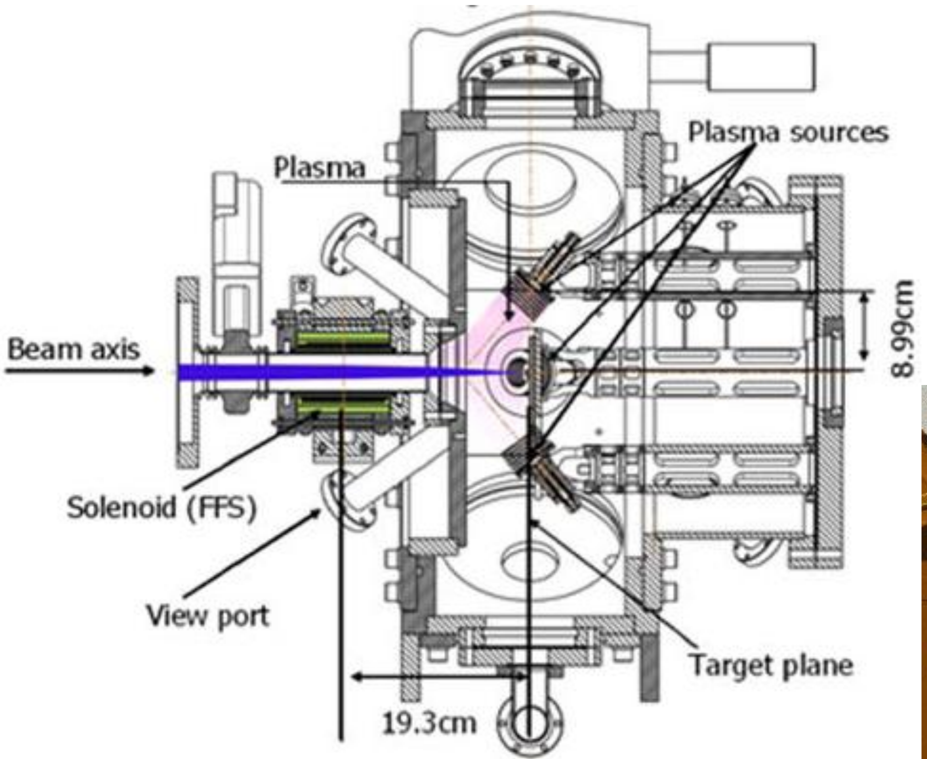


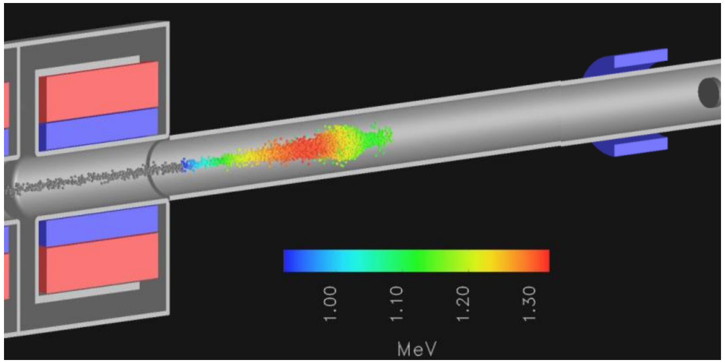
The Plasma Source Provides Plasma from the Exit of the Last Cell to the Entrance of the Final Focus Solenoid

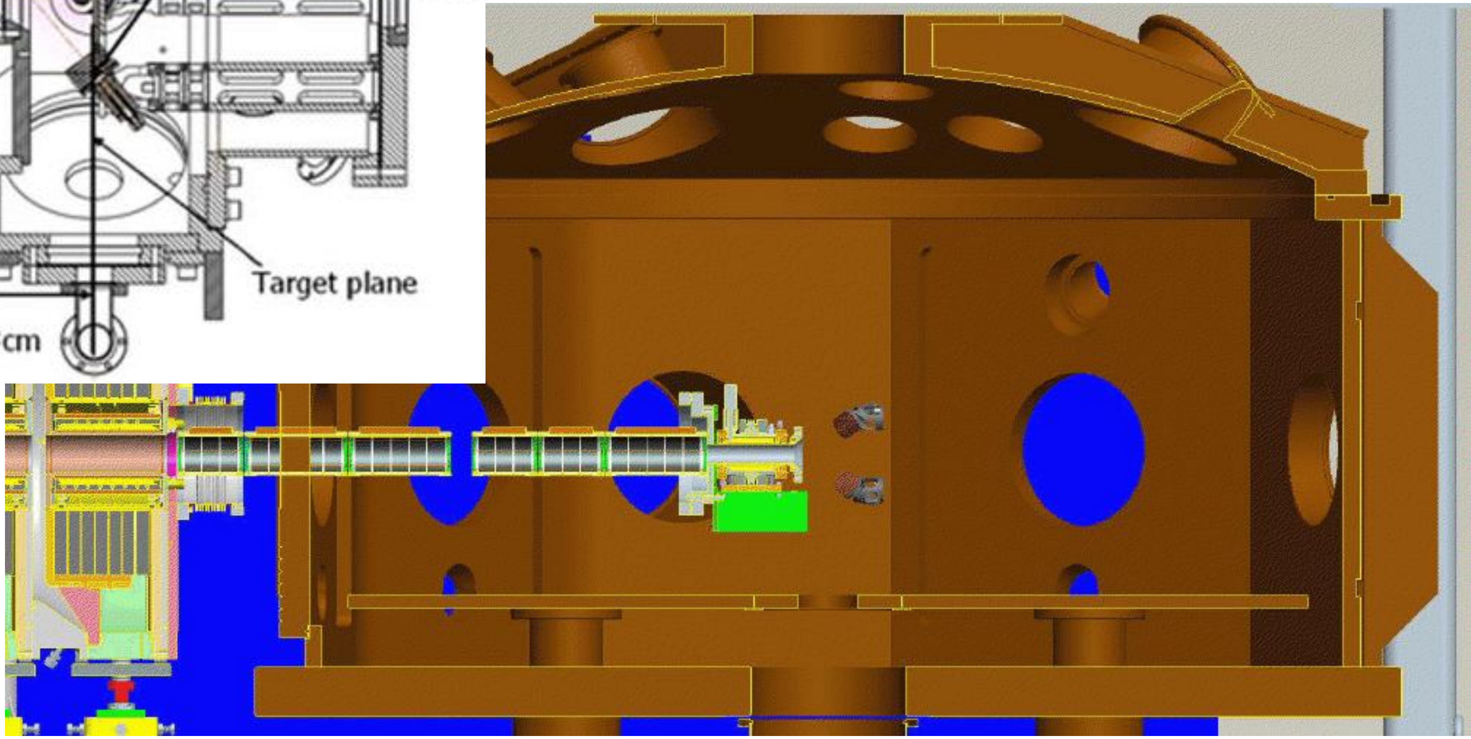


The plasma source is divided into an upstream section and a downstream section separated by a gate valve. The gate valve allows the beamline vacuum to be maintained during target chamber access.

Target Chamber Configurations







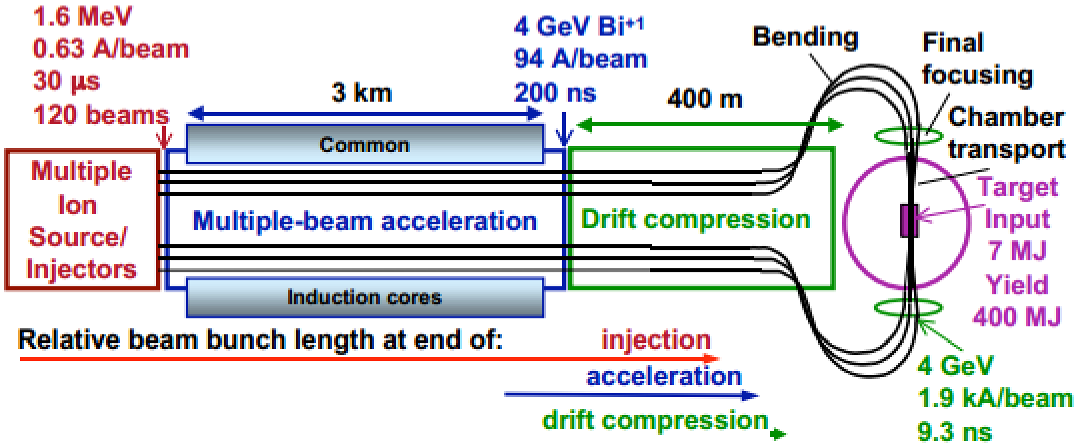
The Ferroelectric Plasma Source Will Soon Be Installed on NDCX-II

Each Module is Driven by an Independent Pulser to Allow Precise Timing and the Plasma Density to be Varied

Driver Requirements

Beam density in driver:	10^{10} cm^{-3} – 10^{14} cm^{-3}
Driver repetition rate:	10 Hz
Plasma source lifetime in driver:	10^{8} Shots
Target Chamber environment	

RPD

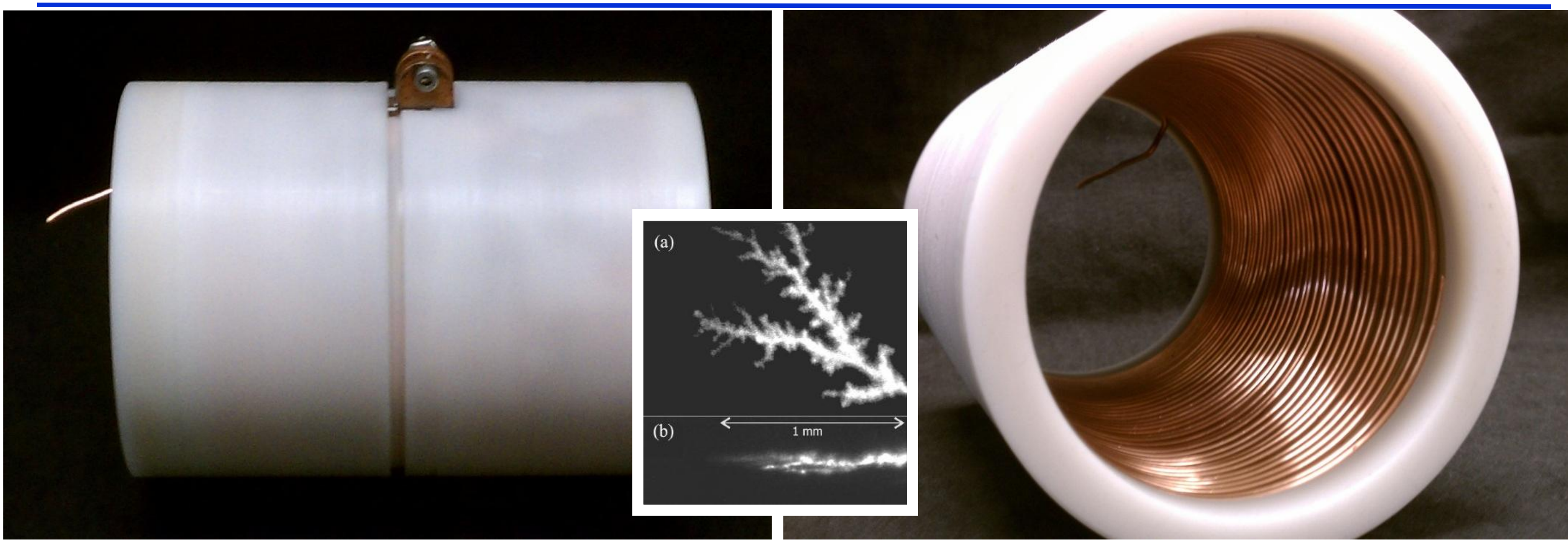


Present Cathodic Arc and Ferroelectric plasma source:

Repetition rate:	0.5 Hz
Ferroelectric source lifetime:	50,000 shots
Cathodic Arc source lifetime:	50,000 shots

The Ferroelectric Plasma Source Is Scalable

Improved Design with Solid Outer Threaded Jacket and Spiral Wound Inner Electrode

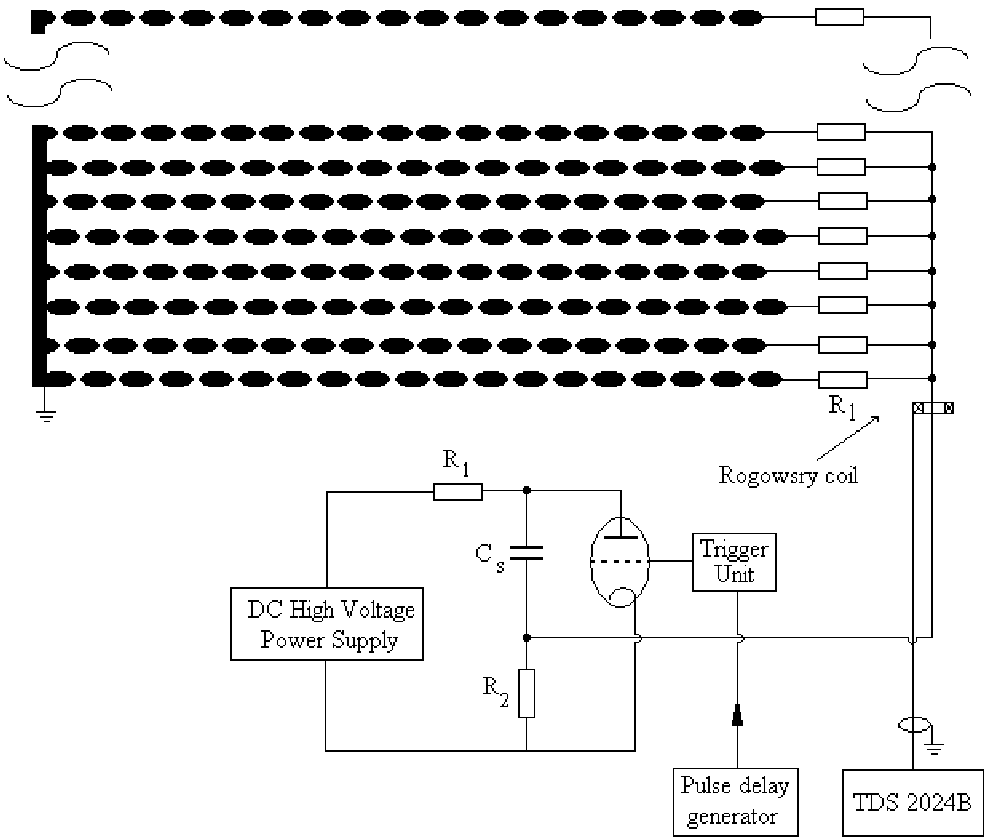


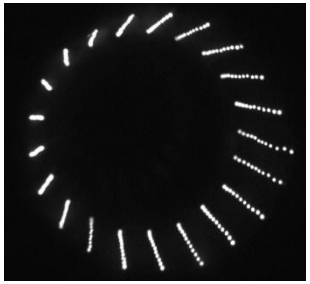
Replacing the perforated steel sheet inserts with a continuous copper "spring" increases the open spaces where ceramic is exposed to mm-size regions.

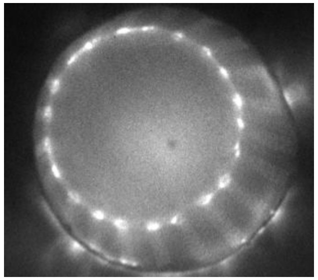
The outwards force of the expanding copper "spring" ensures that it makes good contact with the inner surface of each ceramic ring, despite possible small misalignments.

A threaded outer jacket holds the assembly together axially instead of wires running axially along the perforated steel sheets.

Flashboard Plasma Source is Being Tested







16kV, 4kA

Plasma density in the mid 10^{12} cm^{-3} range

Ya. E. Krasik

Excimer Lasers at PPPL and LBNL Will be Used in Laser-Based Plasma Source Development

- 10 Hz
- XeCl, 308 nm, 4.0 eV 200 mJ, 20 ns
  $n_c = 1.2 \times 10^{22}$ cm^{-3}
- ArF, 193 nm, 6.4 eV
  $n_c = 3.0 \times 10^{22}$ cm^{-3}
- With 1 mm spot size,
  I ~ 1 GW/cm^2
  F ~ 10 J/cm^2

Laser-ionization of vapor
Laser-ablation of solid target

Summary

- Ferroelectric (FEPS) and Cathodic arc (CAPS) plasma sources work well on NDCX-I and will be used on NDCX-II, with modifications, to ensure that the local plasma density exceeds the local beam density in the neutralized drift region.
- Development of high density plasma sources will continue in order to meet the demands of NDCX-II and future HEDLP and IFE projects.

The End