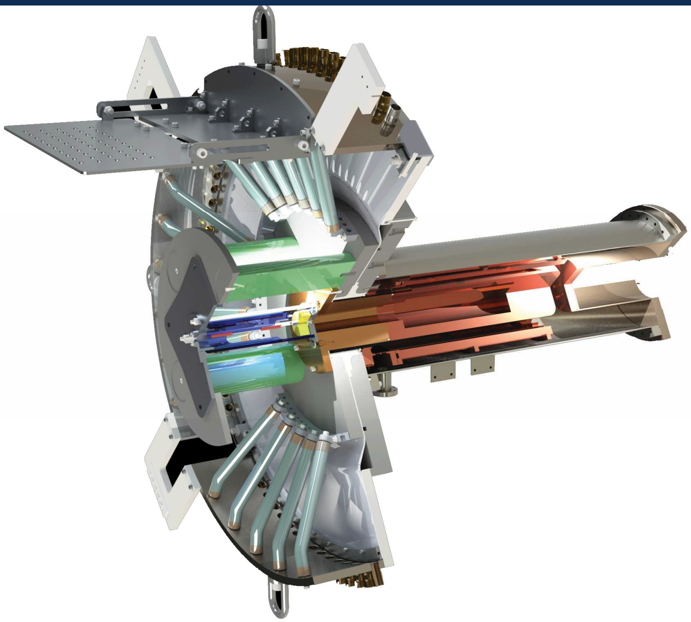
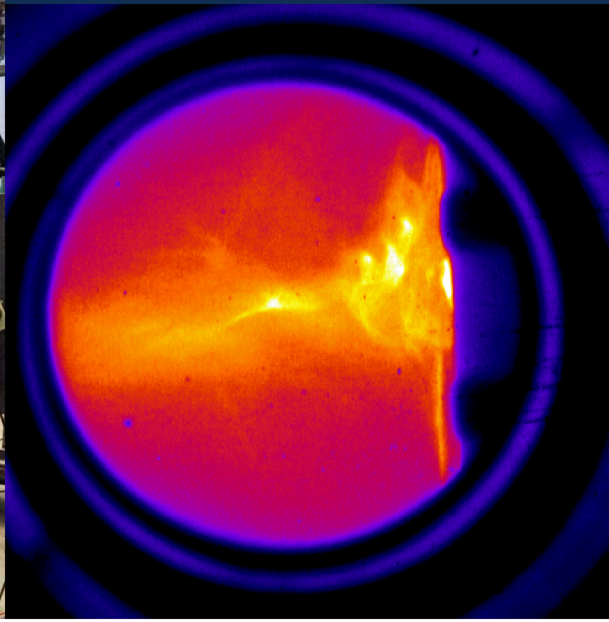
Electrical and X-ray diagnostics on the NSTec 2-MA dense plasma focus system

SAND2017-6145C





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U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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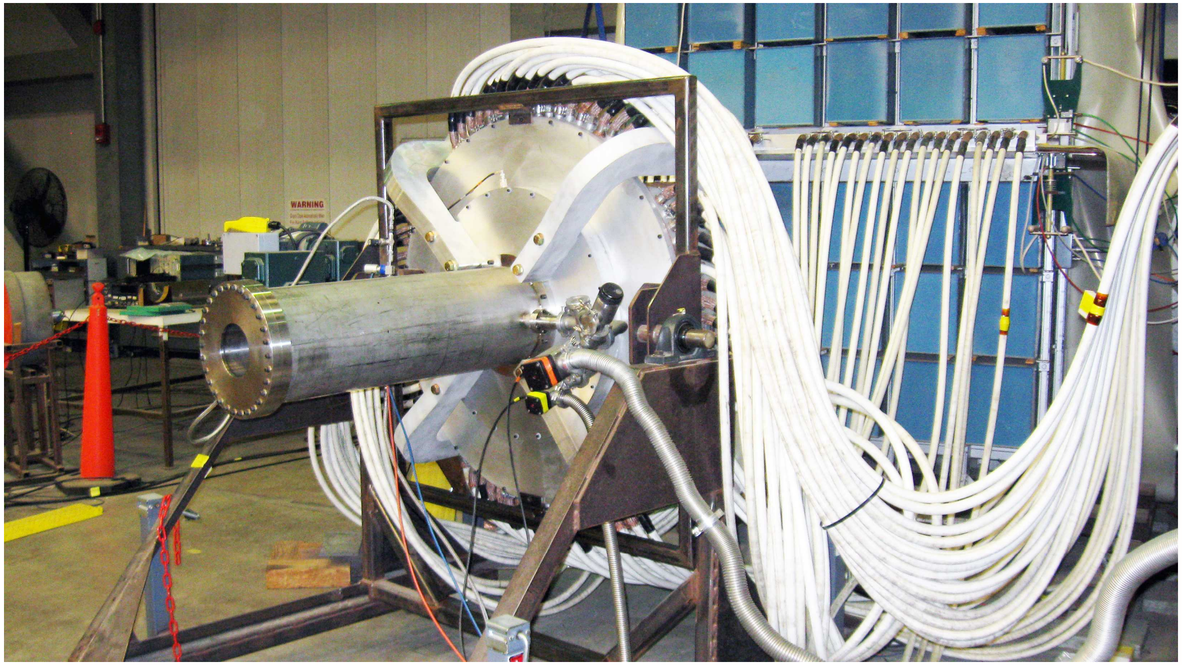
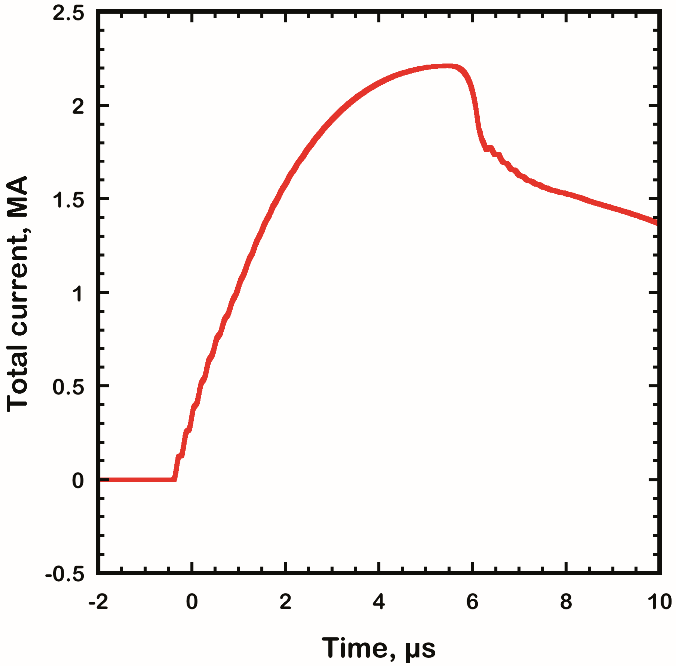
Introduction

- Sandia National Laboratories collaborated with NSTec to field additional diagnostics on their 2-MA dense plasma focus neutron source system
- In a brief experimental series, we added voltage, current, and X-ray diagnostics to the NSTec system
- We will show the electrical measurements, a basic analysis of the data, and the preliminary X-ray results

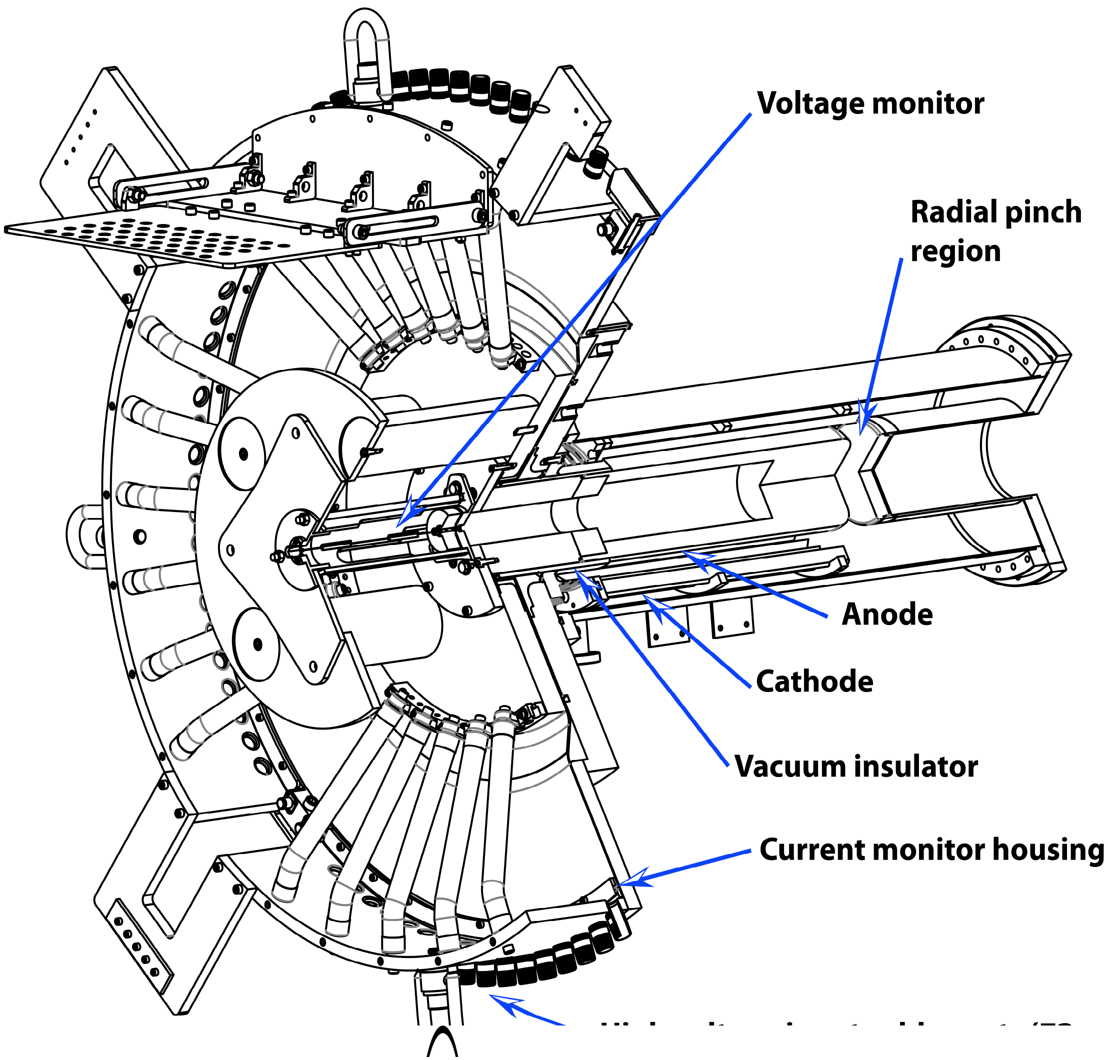
The basics: Current and voltage

- **A large DPF creates challenges for acquiring high-fidelity electrical signals**
  - **Slow rise time makes derivative (I-dot, V-dot) signals small**
  - **Large current and slow rise time makes flux penetration into signal lines significant and pervasive**





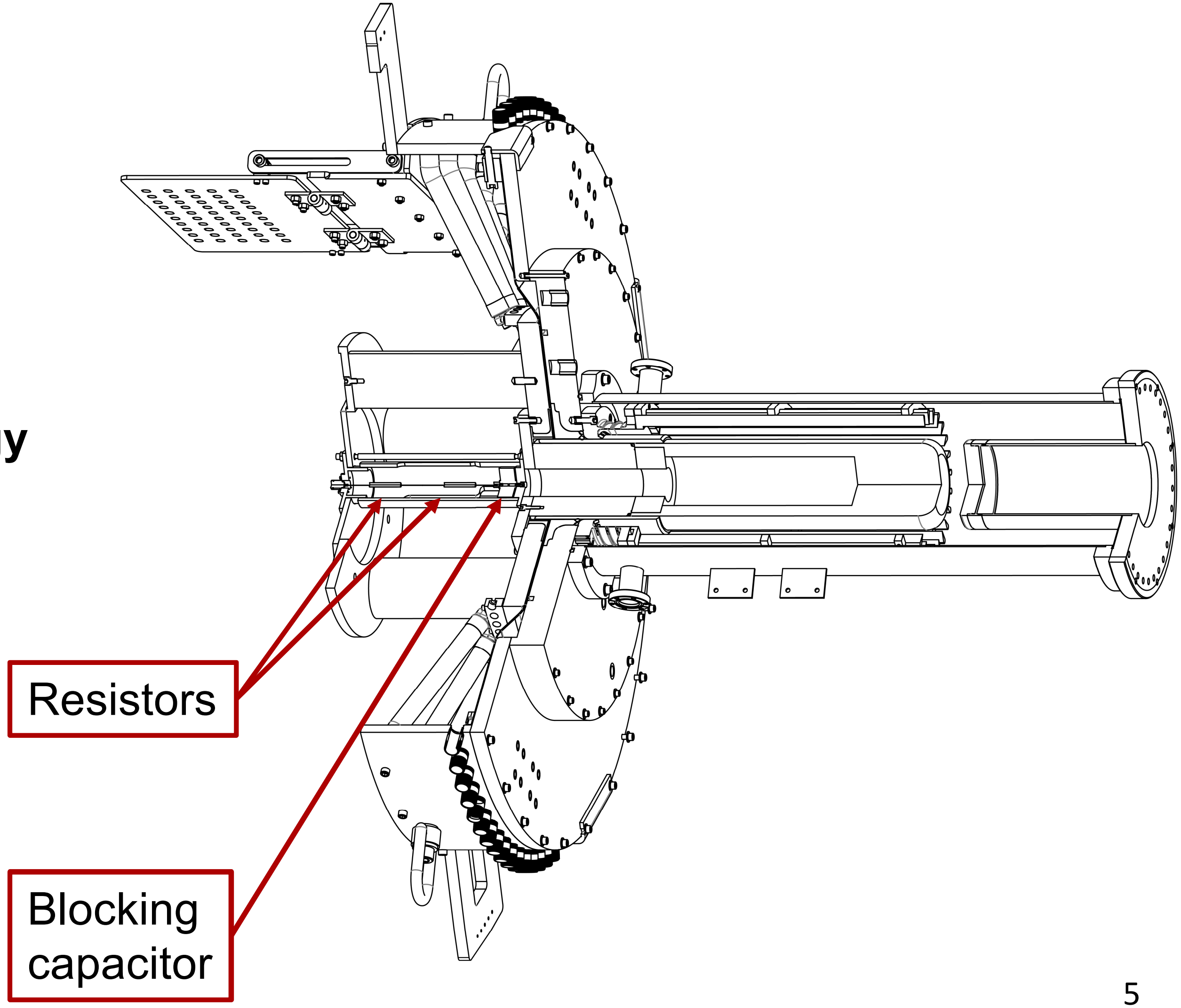
Current measurement with segmented Rogowski coil



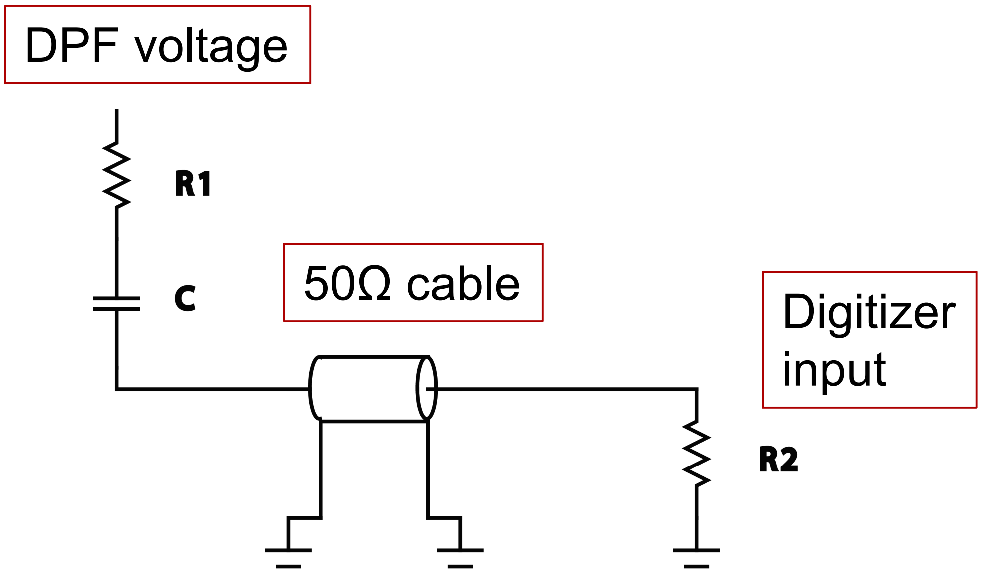
Current monitor is 8-segment Rogowski coil, which allows some spatial resolution and common-mode noise rejection

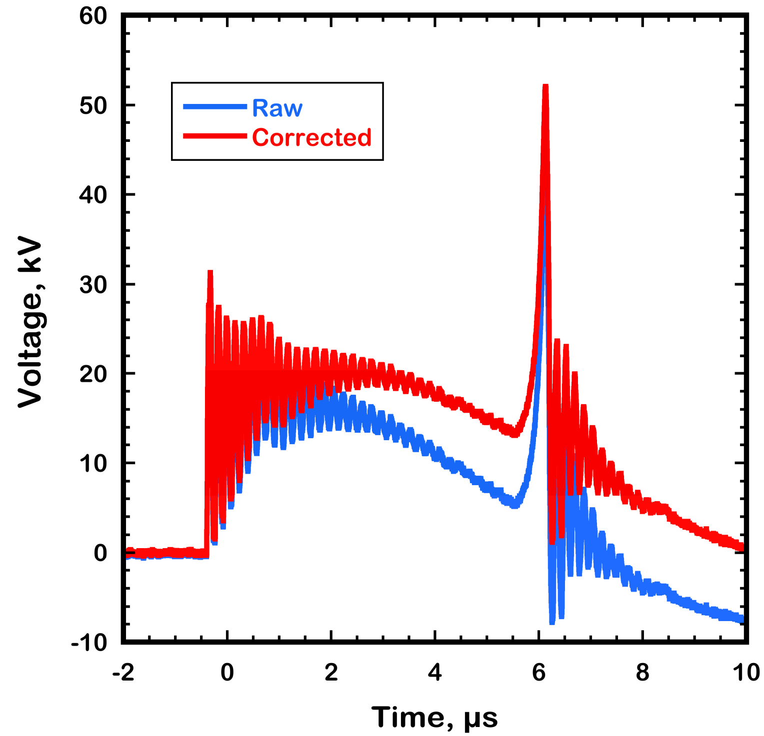
Voltage is measured with a resistive divider

- **The resistors are precision, low voltage-coefficient devices that have limited energy-handling ability**
- **A capacitor limits energy deposition in case of delayed DPF current**



The voltage monitor data are processed

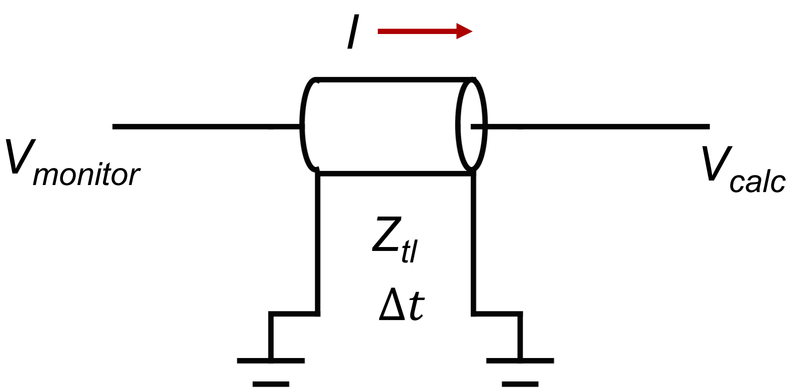


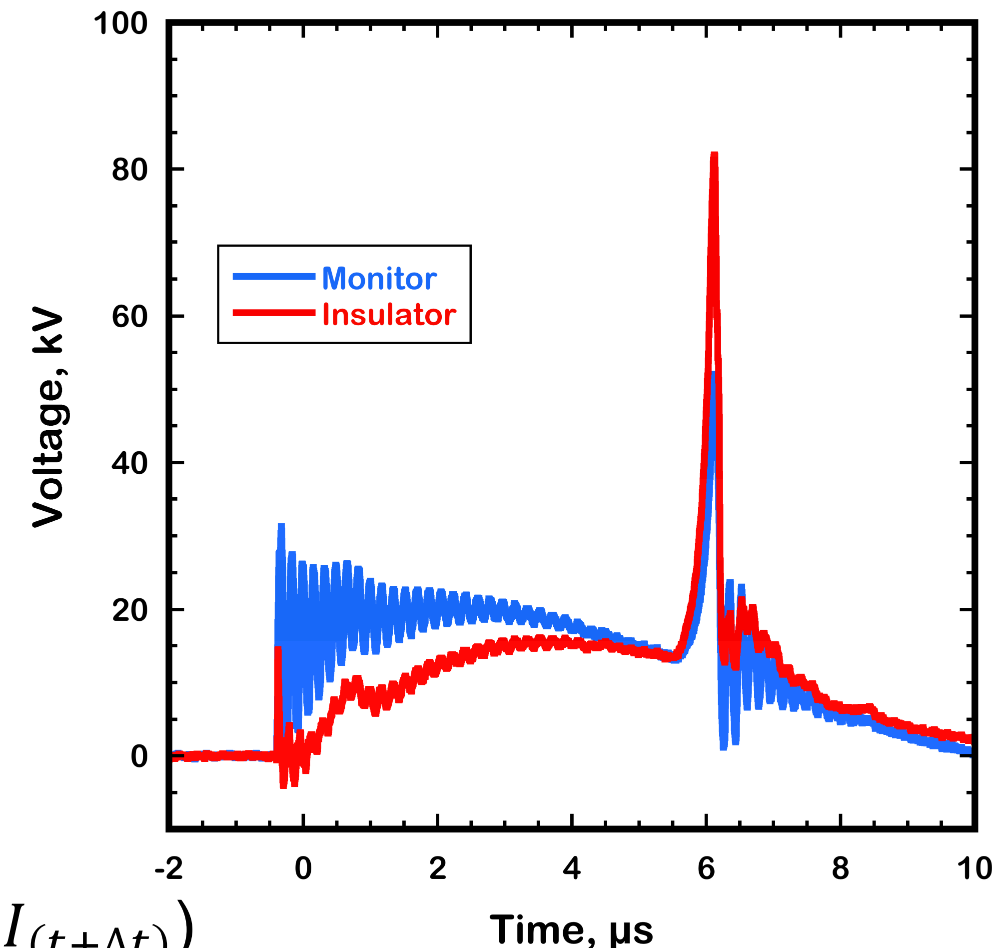


- **Droop correction for the DC-blocking capacitor requires only component values and the waveform data**
  - **Scale factor is:** $\left[\frac{R_1}{R_2} + 1\right]$
  - **Droop corrected scaled data:** $V_{cor} = V_{mon} + \frac{1}{C(R_1+R_2)} \int_{-\infty}^{t} V_{mon}\, d\tau$

The monitor voltage waveform is translated to the insulator position

- A transmission-line model accounts for displacement current and is exact





$$V_{calc} = V_{monitor} + \frac{Z_{tl}}{2}\left(I_{(t+\Delta t)} - I_{(t+\Delta t)}\right)$$

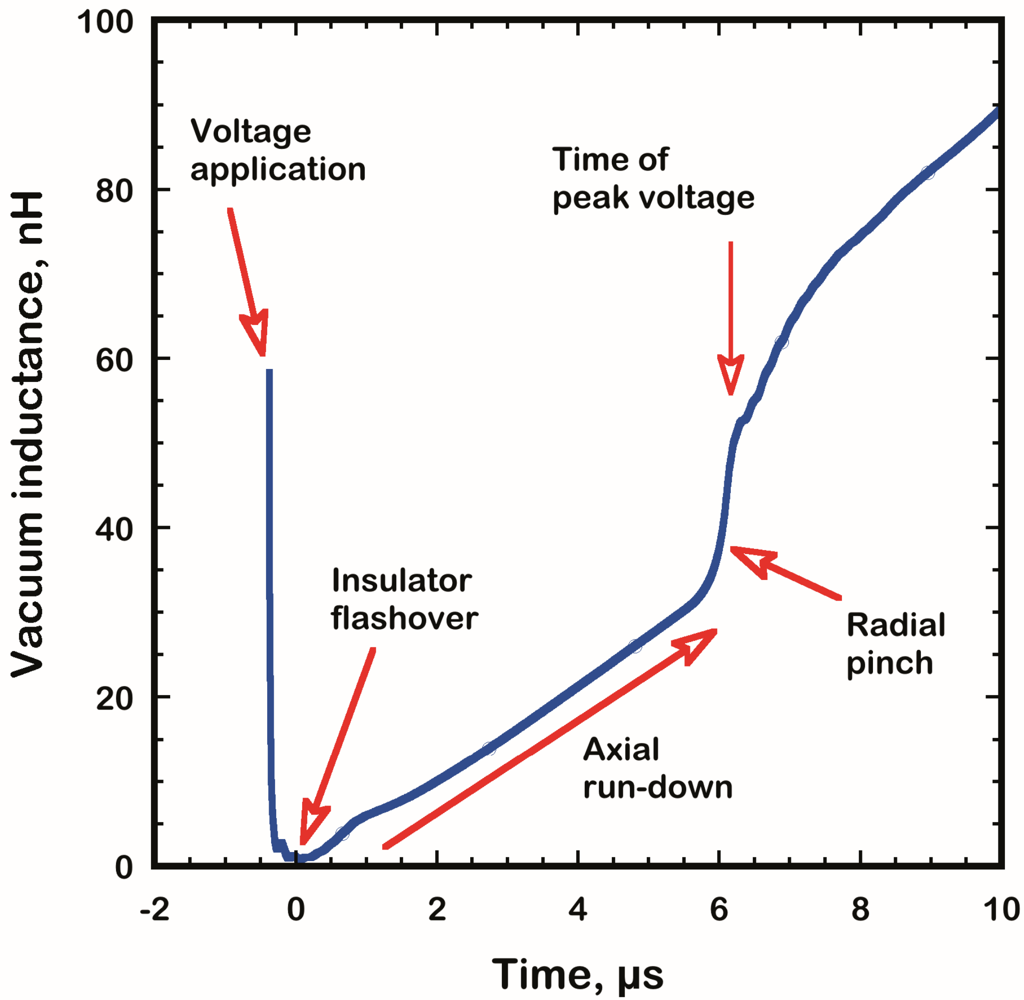
Current and insulator voltage allows inductance calculation

$$L(t) = \frac{1}{I}\int_{-\infty}^{t} V(\tau)d\tau$$

Assumes that sheath resistance is small:

$$R_{sheath} << \frac{inductance}{time}$$

To meet this assumption on this system, the allowable sheath resistance is of order 2mΩ



We can further analyze the current sheath

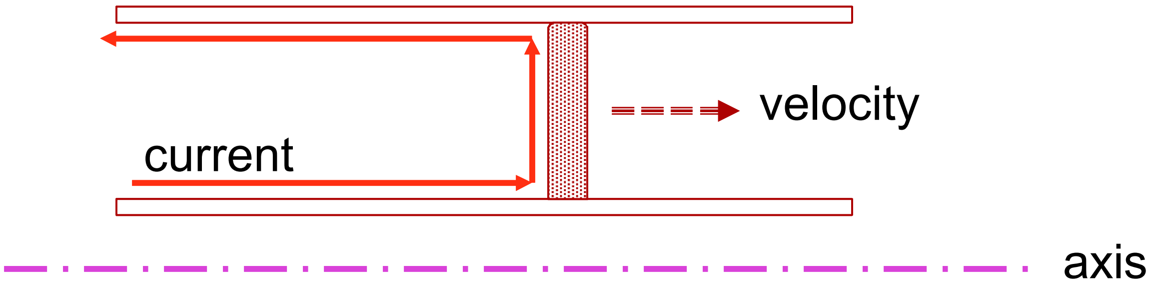
- We assume an effectively two-dimensional current sheath
- We also assume that DPF inductance is proportional to sheath position during axial run-down and velocity is proportional to L'

$$Force = \frac{d}{dt}(momentum)$$

$$= \frac{Z_{vacuum}}{2c} I_{DPF}^2$$

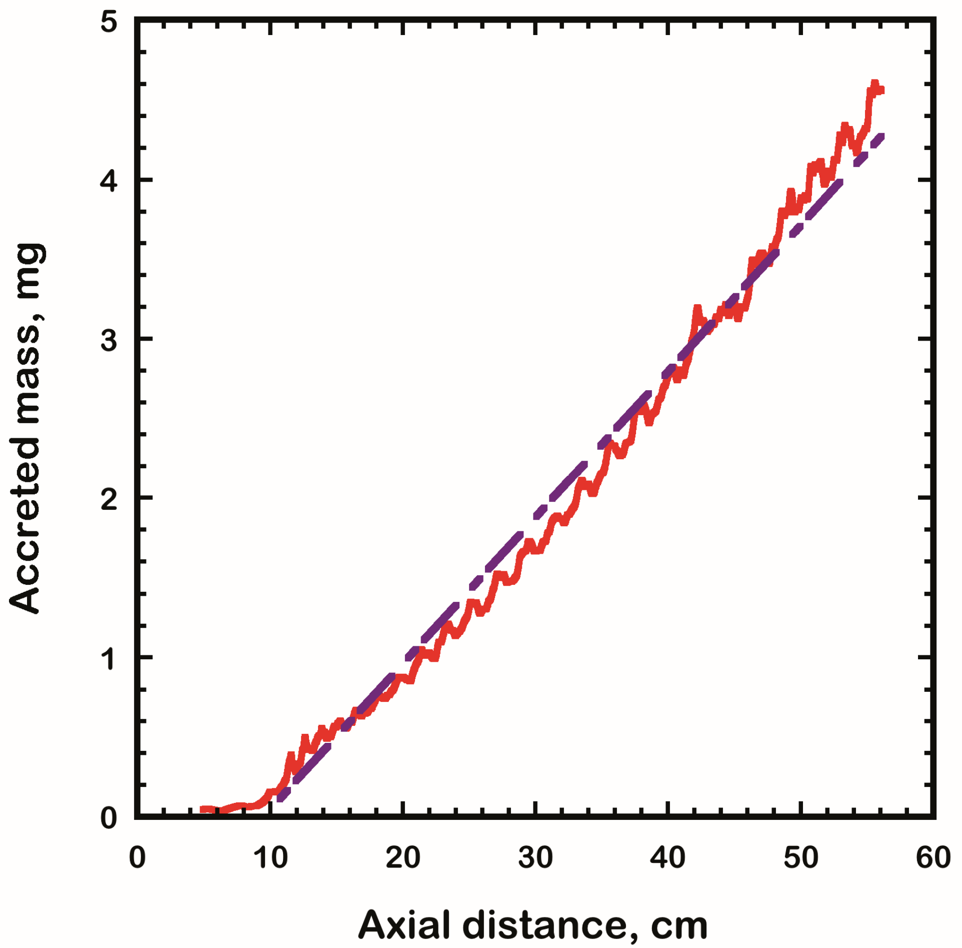
$$\frac{Z_{vacuum}}{2cI_{DPF}^2} = \frac{d}{dt}(mv)$$

$$m = \frac{Z_{vacuum}}{2cv} \int_{-\infty}^{t} I_{DPF}^2 \, d\tau$$



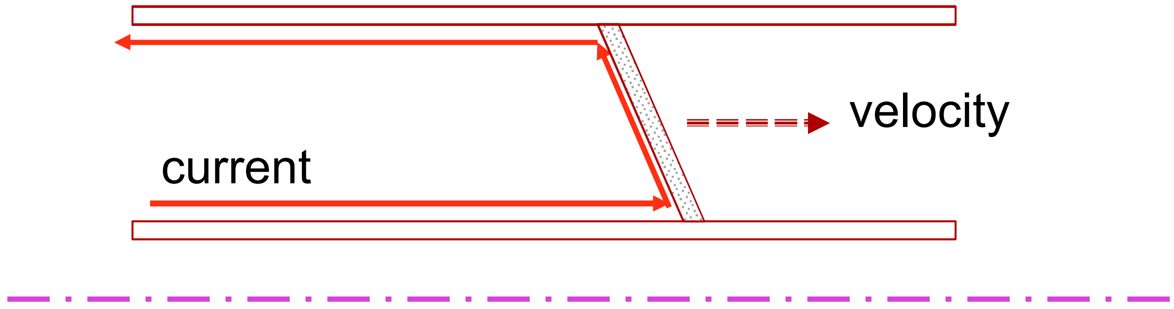
It is possible to calculate the accreted plasma mass on every shot with the voltage and current measurement

- A few lines of high-level IDL routines allow immediate mass results
- This is about half of the neutral gas fill density
- We expect that the sheath is not purely radial and that mass is ejected



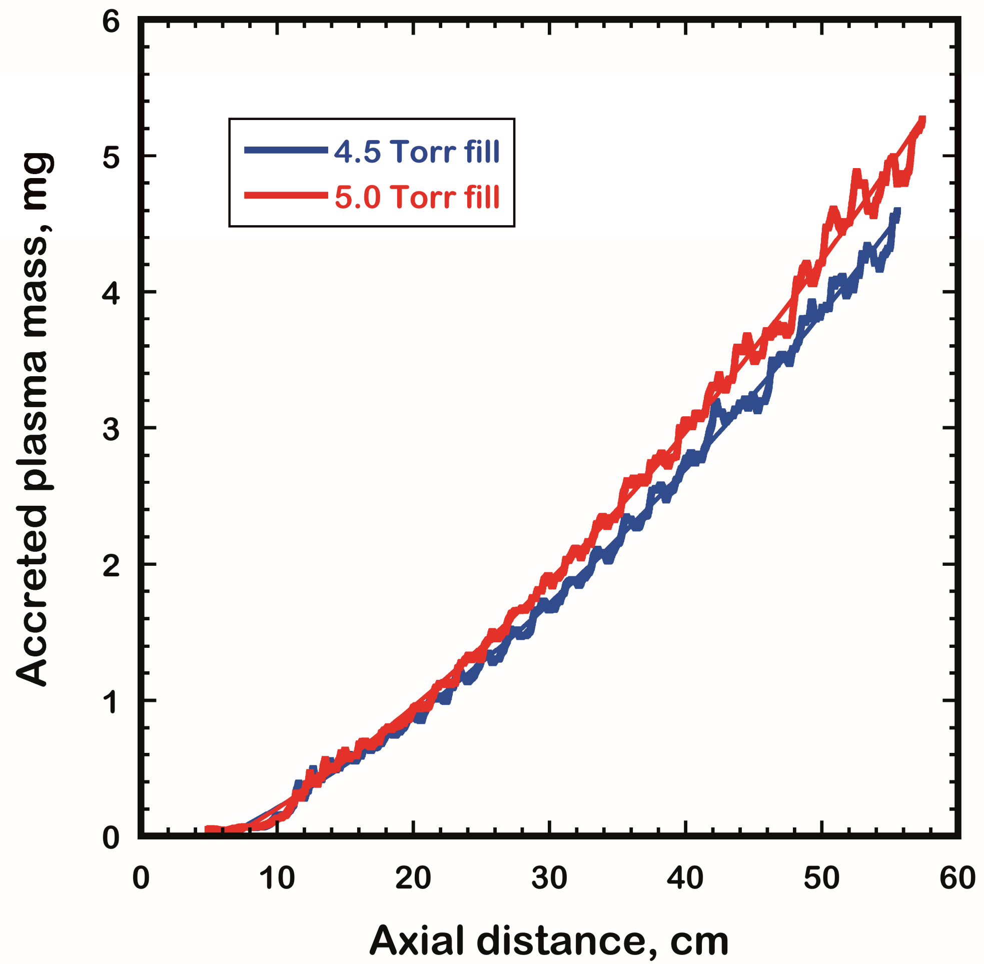
The magnetic pressure at the anode is twice the cathode pressure

- **This will give an axial component to the sheath and radial mass ejection**



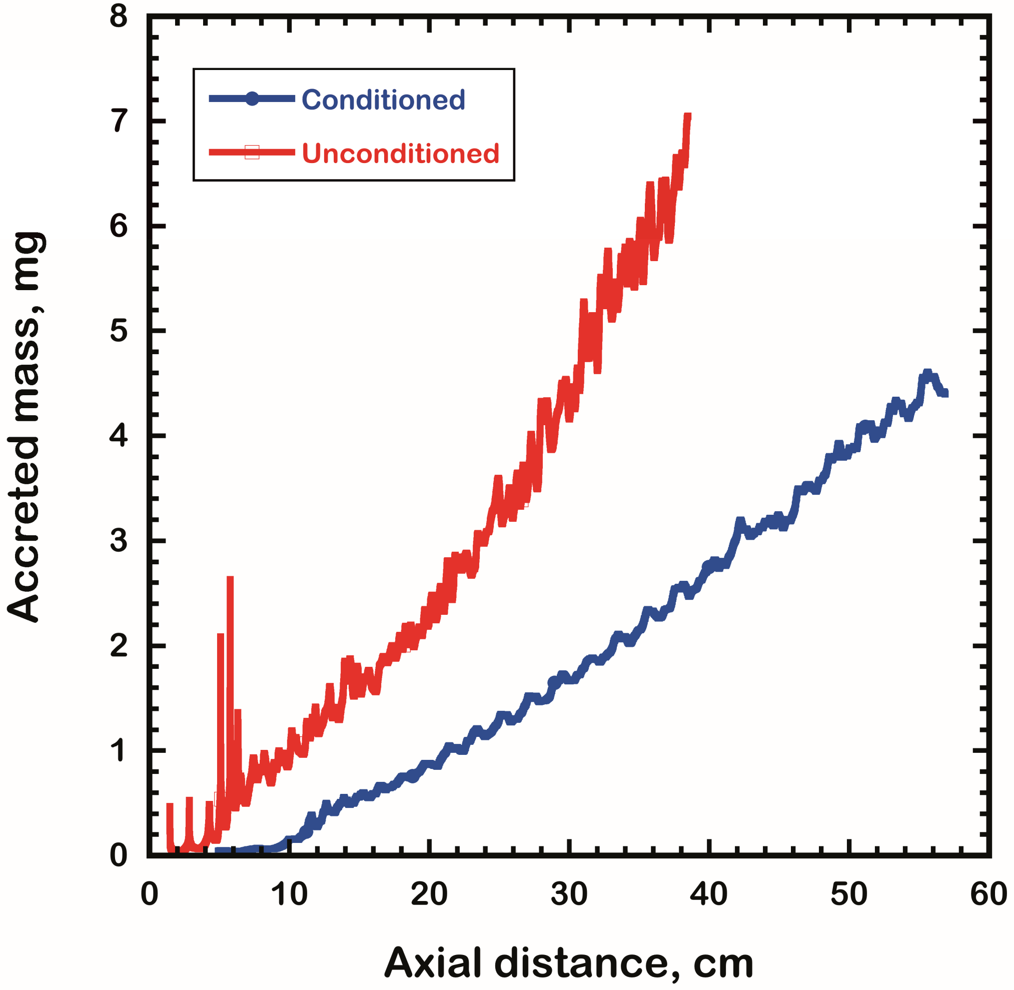
The mass calculation is sensitive to small changes in gas fill

- **We looked at two nominally identical shots, one at 4.5 Torr and the other at 5 Torr**
- **The measured mass difference (ratio 1.12) agrees with the fill pressure difference (ratio 1.11)**

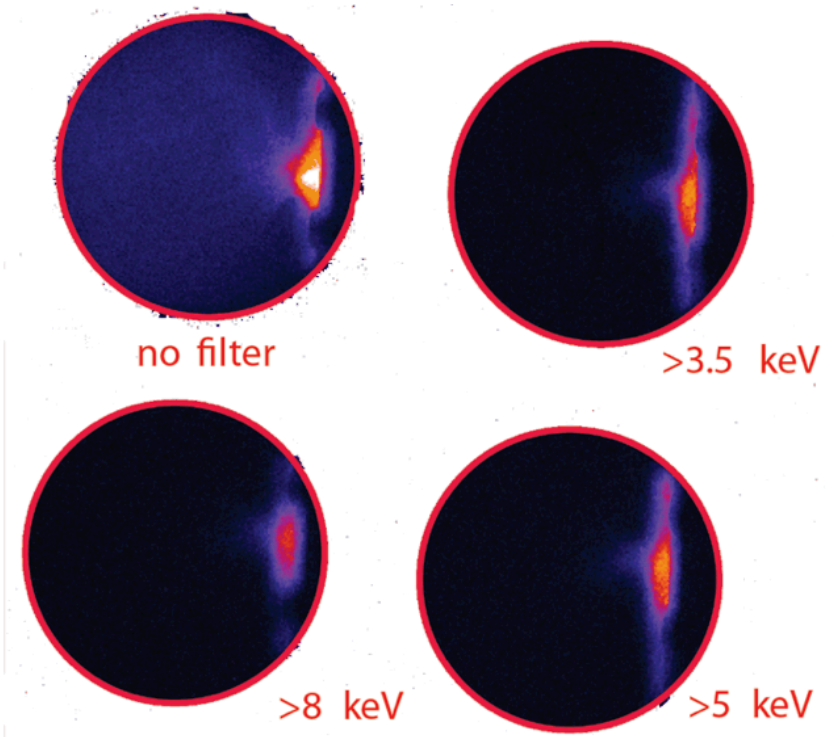


Electrodeconditioning affects the accreted mass

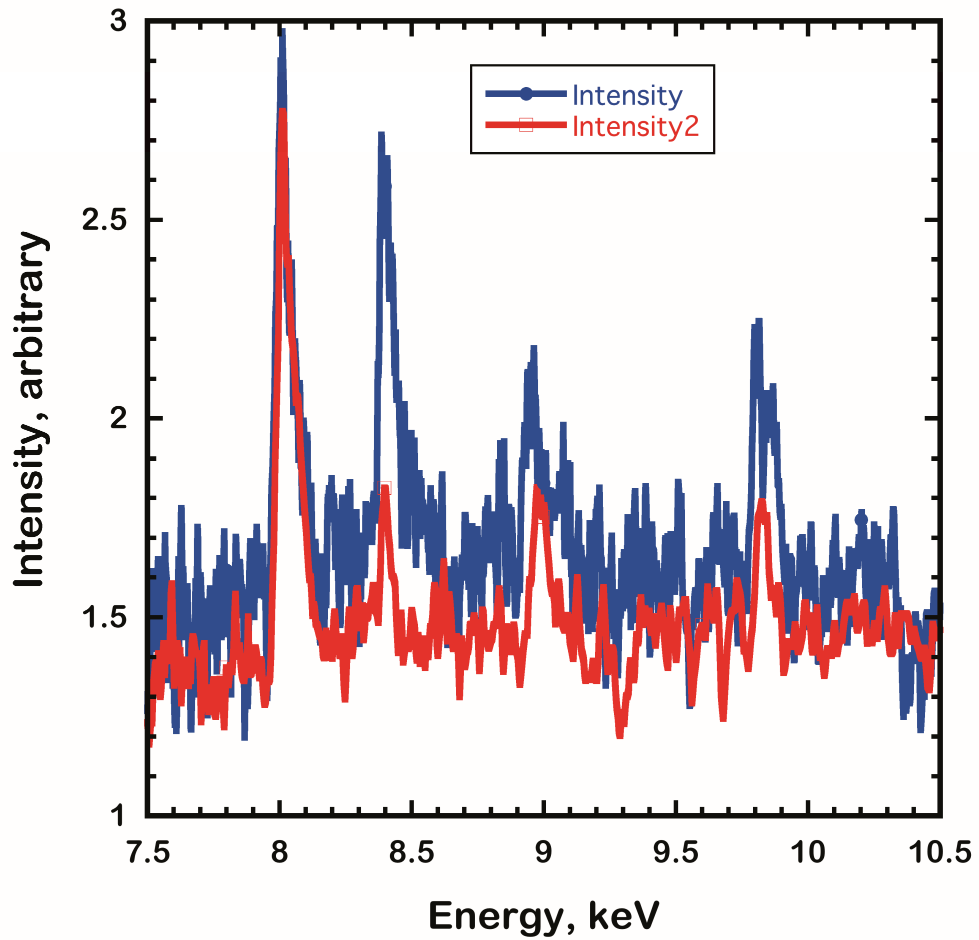
- **Compare two otherwise identical experiments:**
  - **The first discharge after opening the chamber (unconditioned)**
  - **Several discharges later (conditioned)**



Preliminary time-integrated X-ray data



Pinhole camera one shot



Bent-crystal spectrometer two shots

Conclusions

- **We added calibrated diagnostics to the NSTEc dense plasma focus with special attention to electrical noise**
- **We showed simple waveform calculations to yield insulator voltage, inductance in vacuum, and plasma mass**
- **The plasma mass calculation is sensitive to ~10% changes in neutral gas fill**
- **The plasma mass calculation shows large differences with unconditioned electrodes**
- **Preliminary X-ray data shows adequate signals for spectroscopy and pinhole images**