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Magnetic Field Measurements on the Self Magnetic Pinch Diode At RITS-6 Using Zeeman Splitting

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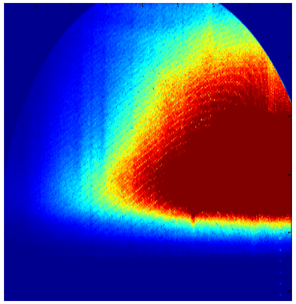
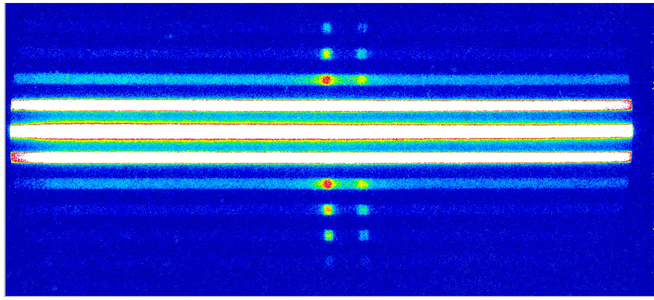
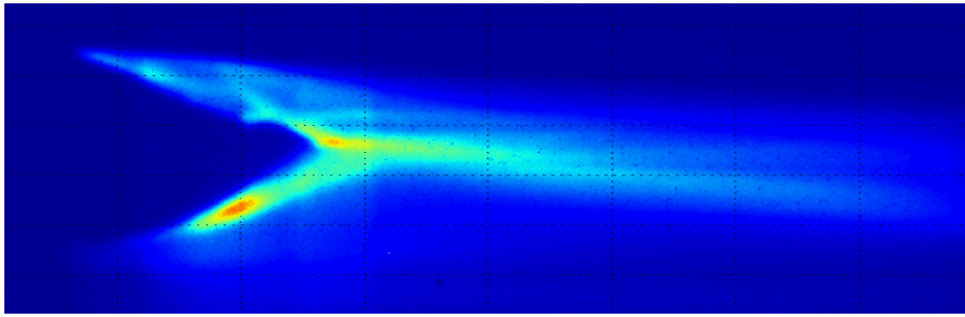
ICOPS 2015, Antalya Turkey







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Outline

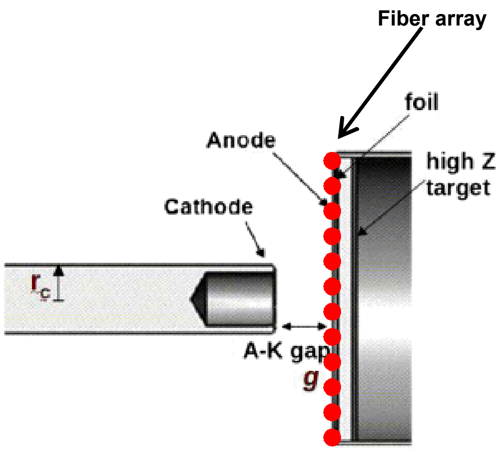
- Motivation
- RITS-6 SMP diode
- Zeeman Splitting Theory
- Experimental Setup
- Measurements
- Results
- Summary and Future Work

Motivation

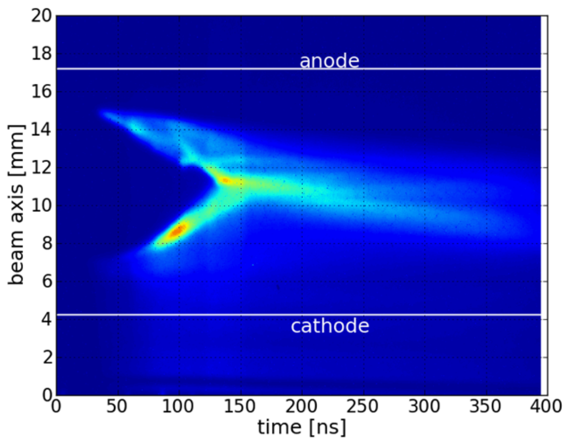
- Determine the current distribution in the SMP Diode using Zeeman splitting to measure local magnetic fields.
- Provide a proof of principle measurement on RITS for future Z convolute B-field measurements
- Compare experimental data with LSP simulations
- Improve diode designs

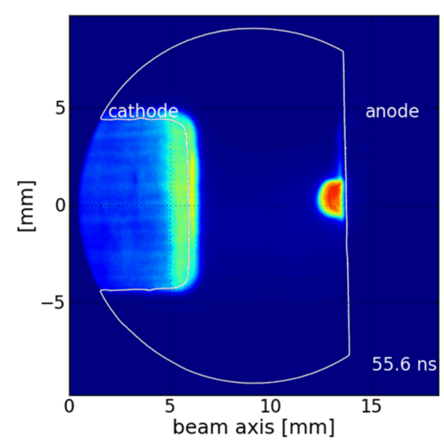
RITS-6 Accelerator

- SMP diode produces an electron beam for x-ray radiography.
- The beam pinches from its self B-field as it crosses the A-K gap
- Plasmas form on the electrode surfaces and expand into the AK gap, decreasing the diode impedance over time[2]
- Diode Parameters
  - ~8.5 MV
  - 130-160 kA
  - Few mm spot size
  - 40-50ns Radiation Pulse with Foil
  - 30-40ns Radiation pulse with bare converter
- Fibers are focused to a 1mm spot across the surface of the foil or converter where the B-fields are the largest.



Diode Configuration[1]

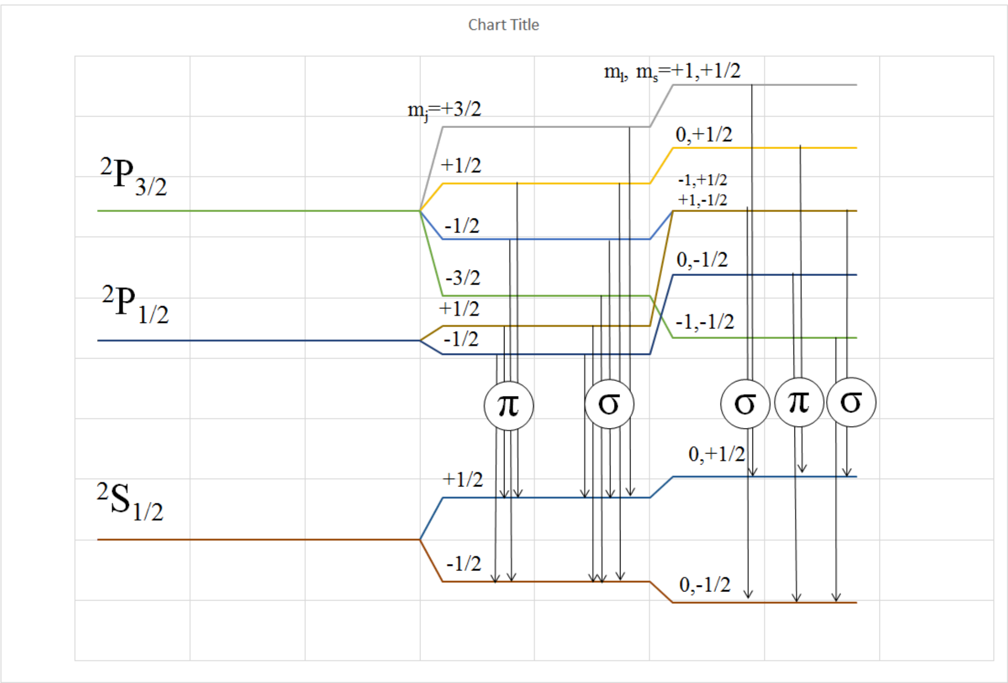




1. N. Bruner et al. 2011
2. N. Bennet et al. 2014

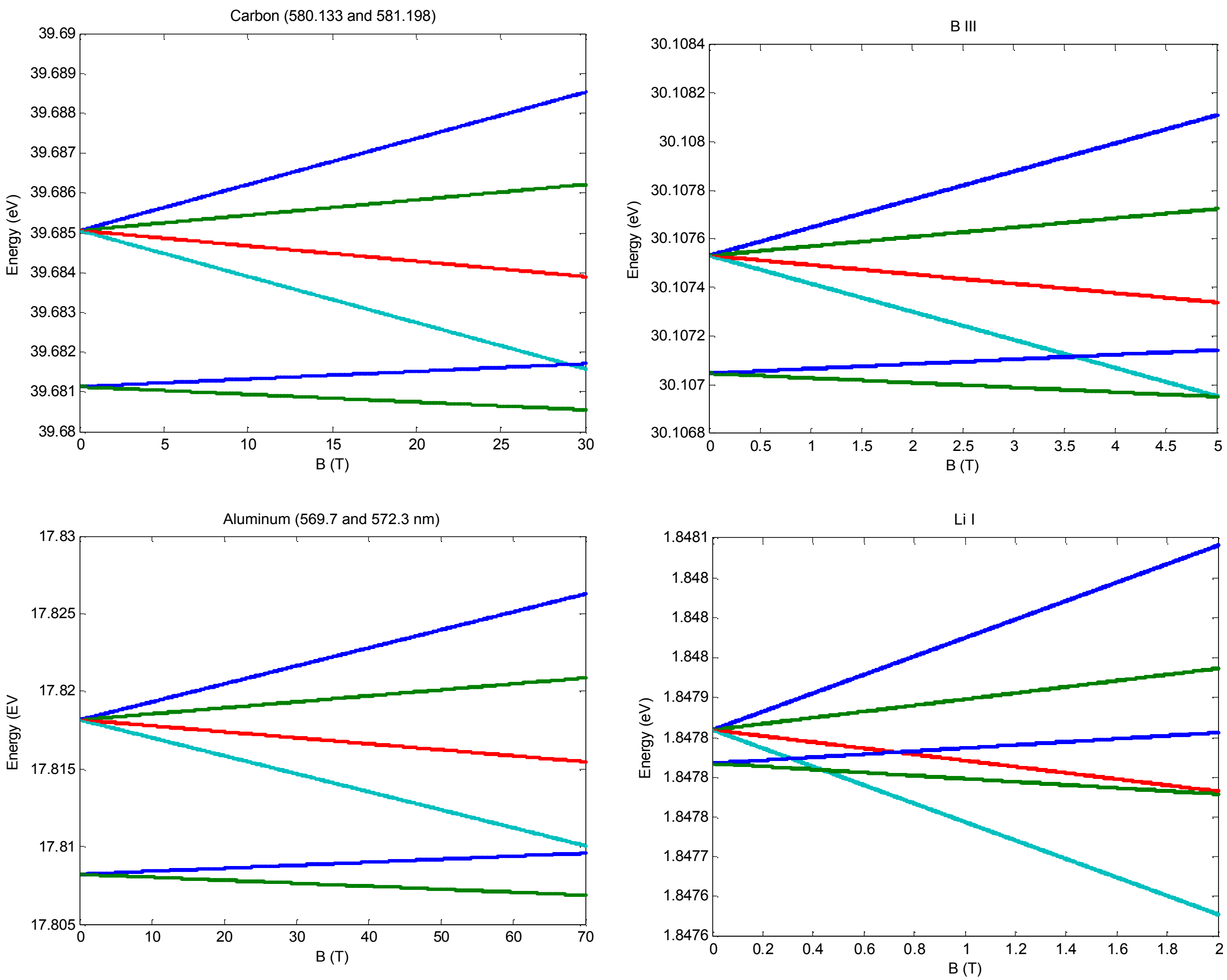
Zeeman Splitting

CIV 580/581nm energy diagram



- Zeeman splitting can be used to infer local B-fields at the plasma location.
- Other B-field measurement techniques such as Faraday rotation and B-dot measurements are limited to measuring fields "outside" the plasma region.
- For small B-fields it is advantageous to look parallel to the field lines, as pi components are not visible.

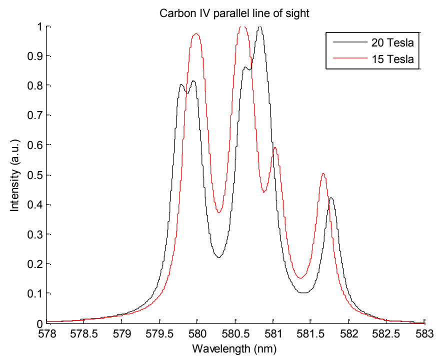
Potential Emission Lines

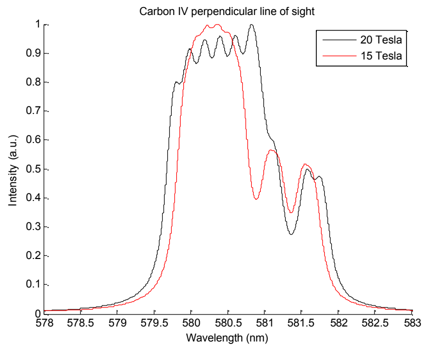


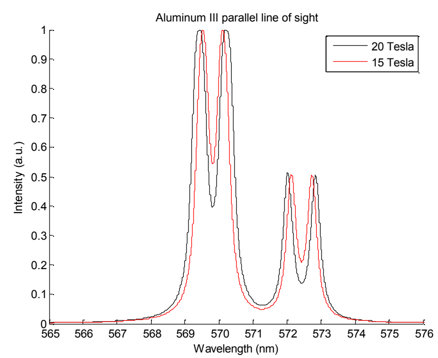
- Lines that transition to the Paschen-Back regime at low fields may be useful.
- Potential dopants include B III, Si IV, Li I, Na I
- C is a contaminant possibly from the oil used on the knob to prevent emission
- Al is usually the foil and anode material.
- Dopants would help isolate the fiber position.

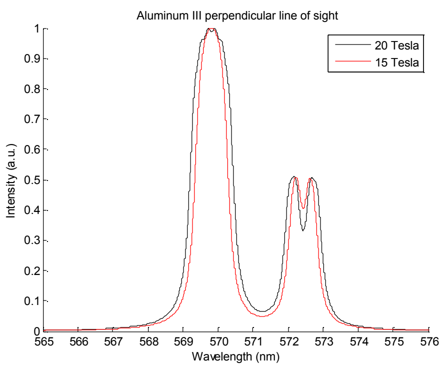
Zeeman Splitting

- Convolution of a .2 nm spectral resolution and stark width.
- 10^{18} cm^{-3} density is at the high end of SMP diode densities.
- Relative intensities based on oscillator strengths
- C IV lines
  - Stark width: 4.3 A at ~10^{18} cm^{-3}
  - Doublet begins to merge at low fields
- Al III lines
  - Stark width: 6 A at ~10^{18} cm^{-3}
  - Large stark width at higher densities may make the line difficult to measure, without high resolution and fields greater than 20 T.









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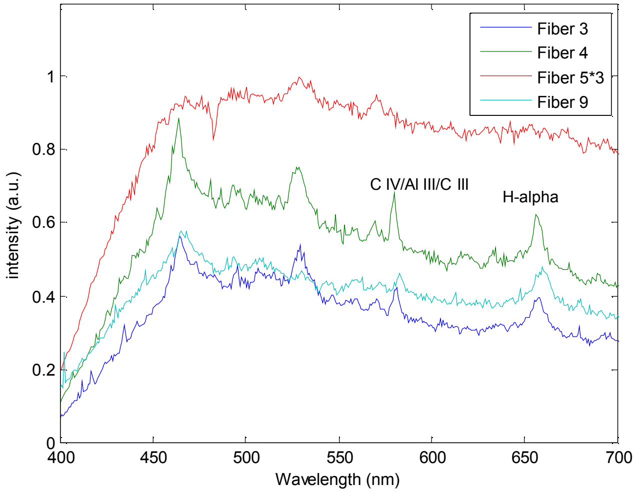
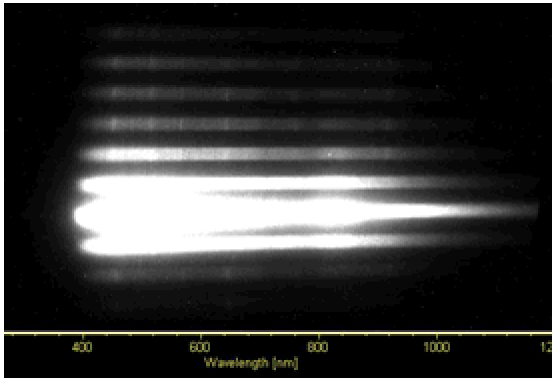
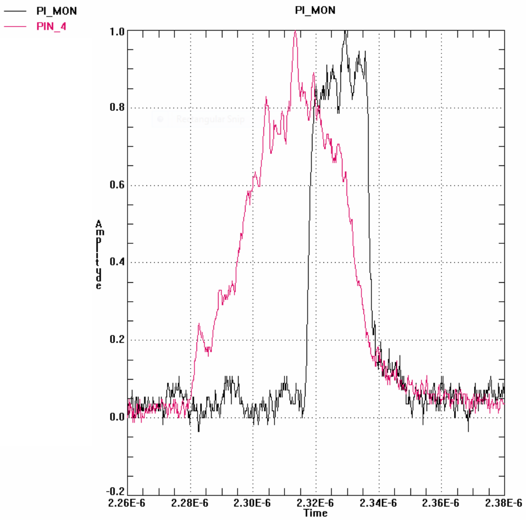
Diode Plasma

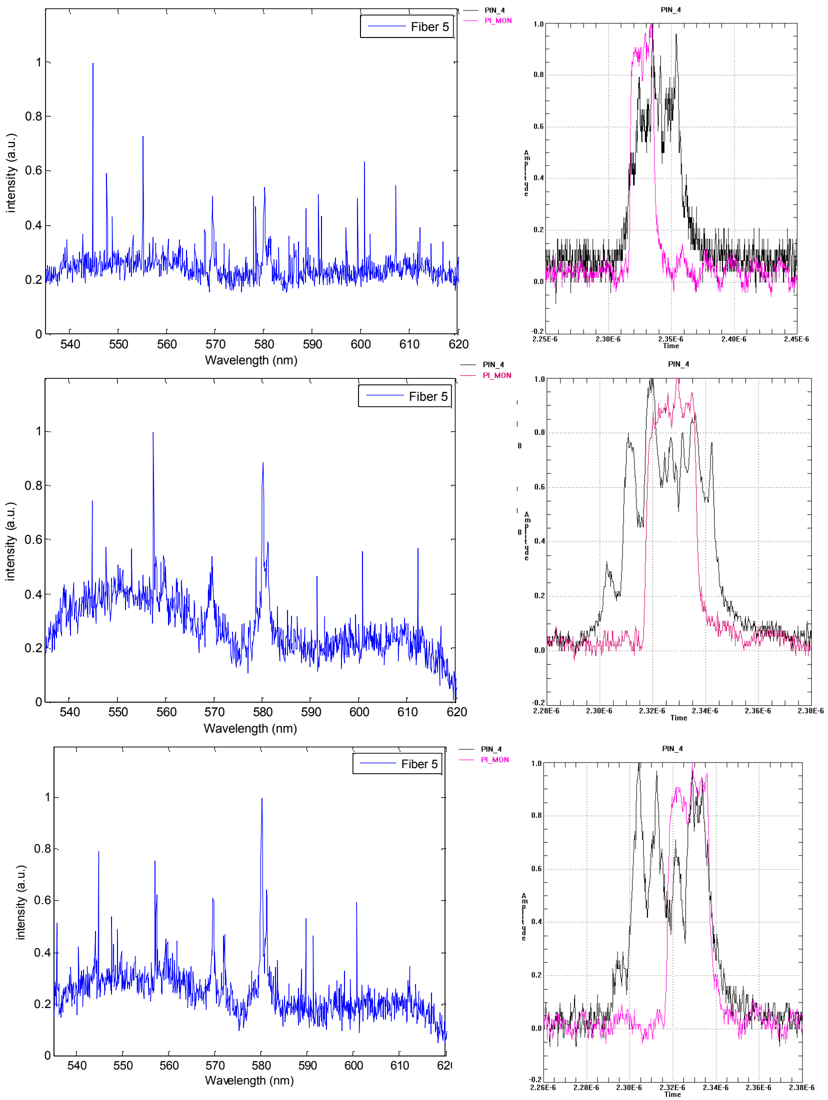






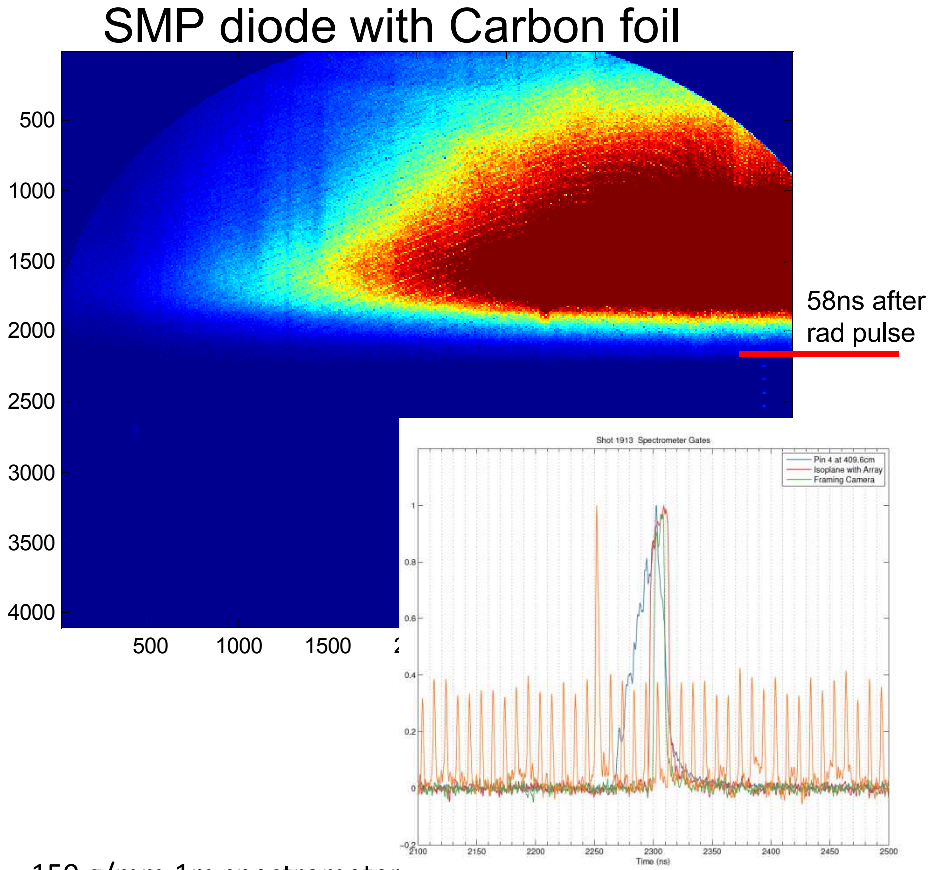
- 150 g/mm, .15m spectrometer, across the surface of the foil. Fiber 7 is on electron beam axis.
- Spectral resolution averaged across all fibers: ~4.9 nm.
- Al, C, H emission lines visible at the end of the radiation pulse.

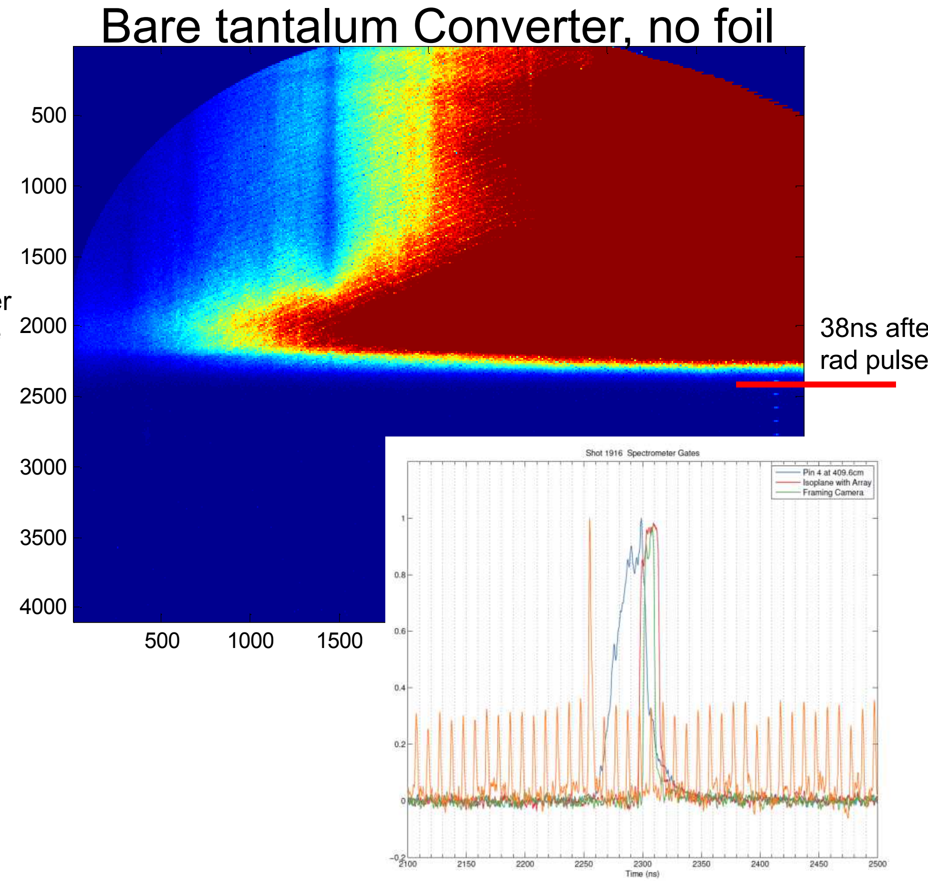
Spectral Time Evolution



- 1200 g/mm, .15m spectrometer, ~3.5 A resolution.
- Fiber 5 is focused ~4mm off axis and across the surface of the Al anode foil.
- Carbon IV doublet resolved throughout the radiation pulse.
- Ratio of CIV/CIII increases with temperature along the radiation pulse
- Late in the pulse the 572 Al III doublet line is visible, as it takes some time for the Al foil to begin to ionize.

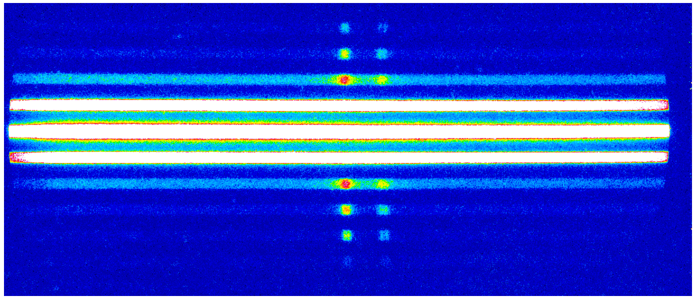
Streaked Spectra

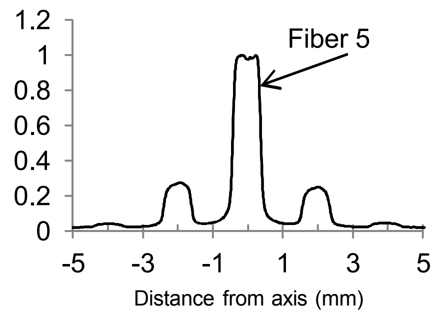


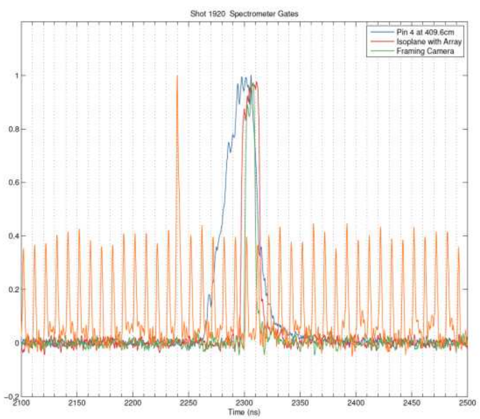


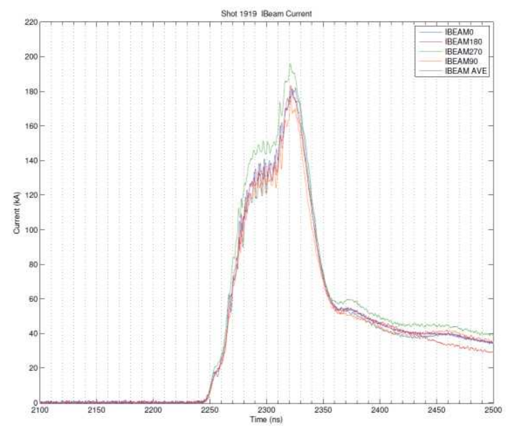
- 150 g/mm,1m spectrometer
- 1-2mm off axis, skimming the surface of the anode
- The foil takes time to ionize, as a result the spectrometer collects less light during the radiation pulse when compared to a bare convertor.
- The foil prevents plasma from expanding into the gap and shorting the ak gap
- In order to achieve reasonable SNR a bare or coated converter plate was used in the Zeeman splitting measurements, which resulted in slightly shorter pulse widths (30-40ns instead of 40-50ns)

Shot 1919





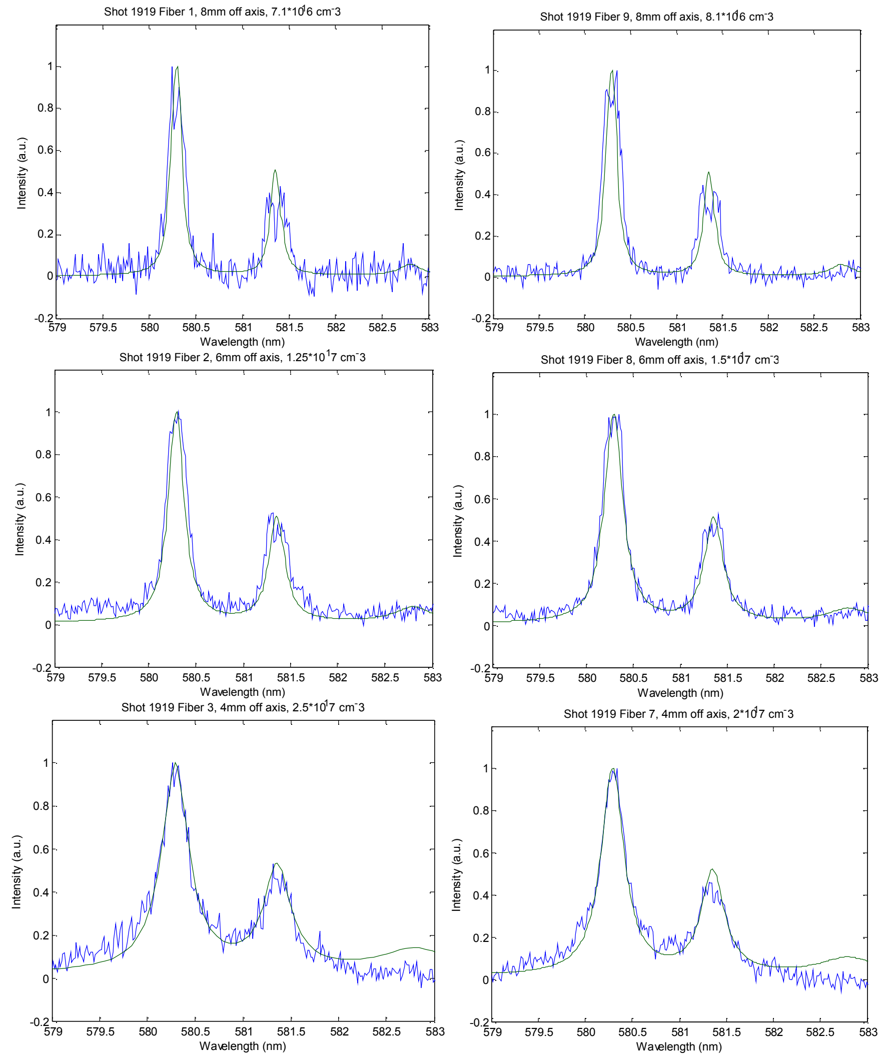




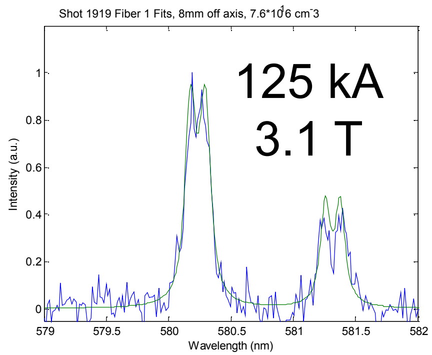
- Carbon coated Tantalum converter plate
- Strong Ca IV emission lines are visible
- Fiber 5 is assumed to be the axis of the e-beam
- Spectra taken at around 140 kA according to b-dots
- 10ns gate

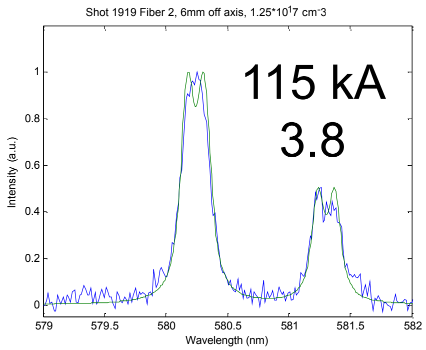
Shot 1919

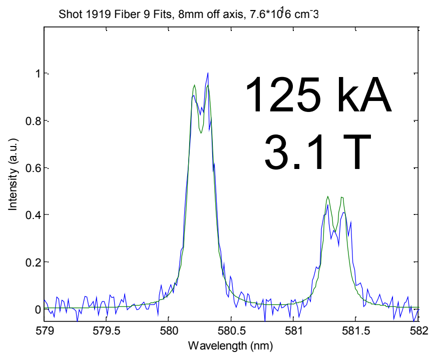
- PrismSpect is initially used to fit the Lorentzian part of the line to obtain a density estimate
- An instrument resolution of 0.6 A was used
- Outer fibers broadened symmetrically around the fiber on axis
- Inner fibers show no splitting or broadening due to magnetic fields (require >4 T at these densities to accurately resolve splitting)

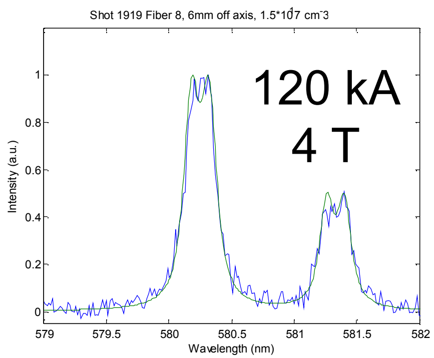


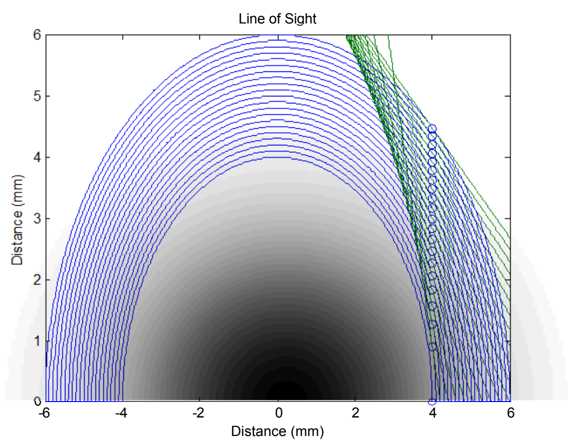
Shot 1919 Splitting Fits







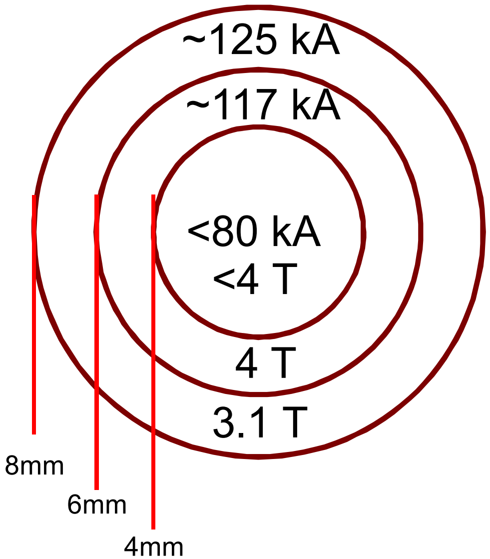




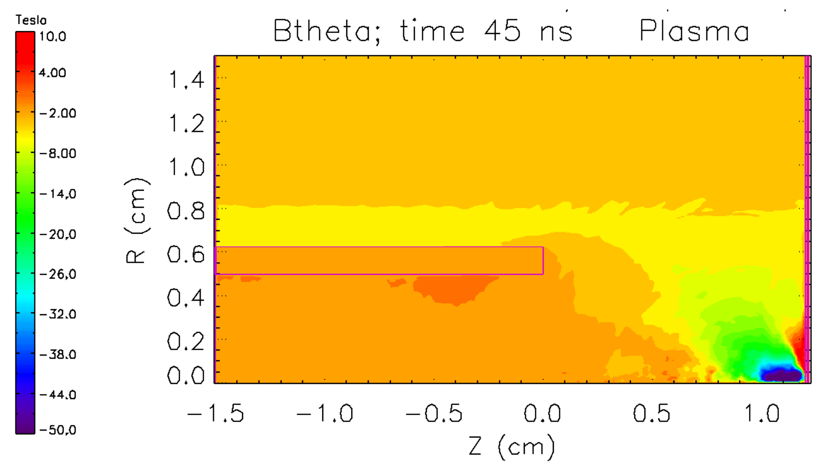
Parallel and perpendicular components change the line profiles.
L.O.S. closer to the center contain more pi components

- Lines are fit using densities and temperatures from PrismSpect, and convolved with the instruments resolution
- Zeeman splitting is fit assuming:
  - Gaussian spot intensity
  - Fiber is well focused for a 1cm chord
    - Sigma and pi line components are factored into the fit
  - Cylindrical symmetry of e-beam

LSP Comparison



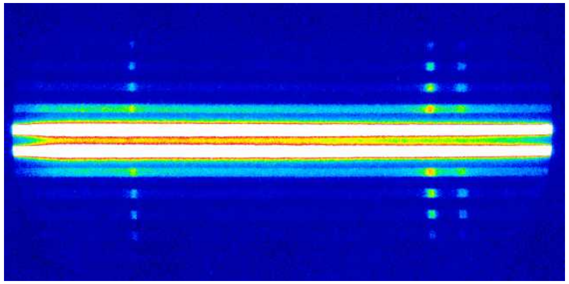
1919 I distribution based on Zeeman Splitting

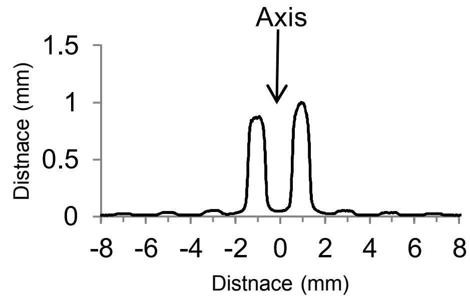


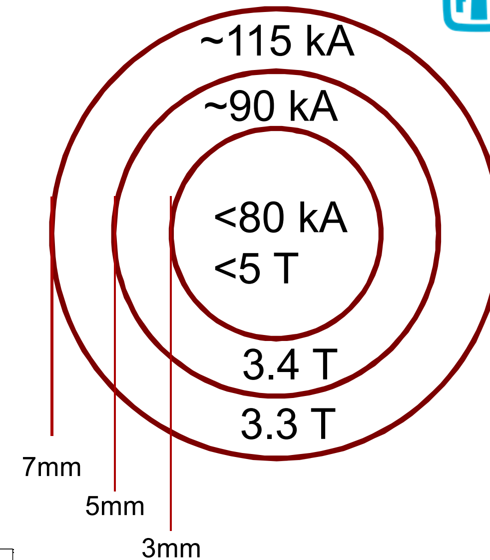
LSP Simulation

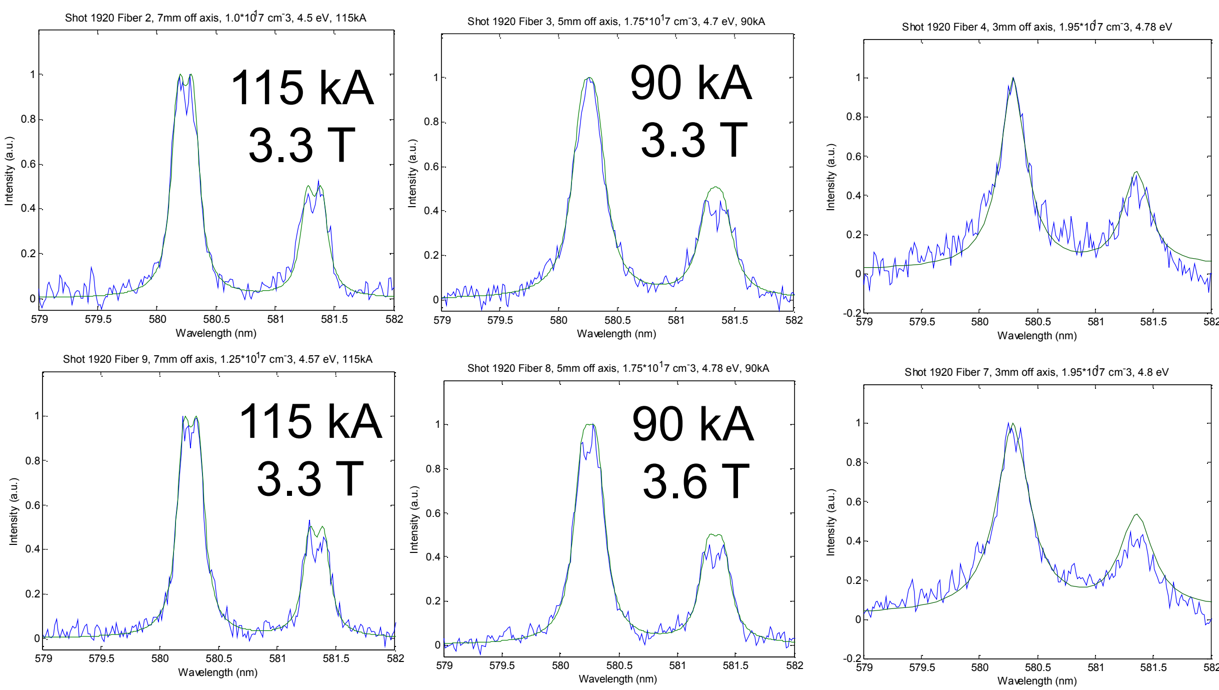
- The LSP simulation suggests that while most of the current is located within a 4mm radius, a fraction of the current is outside this region.
- The high densities and gradients may make B-field measurements difficult to resolve close to the axis.
- However at 90 kA and 0.6 A resolution the B-field splitting/broadening should be resolved on the inner fibers.
  - A large fraction of the total current may be outside a 4mm spot

Shot 1920



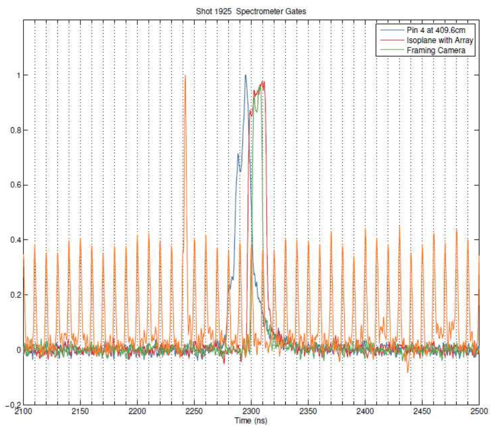


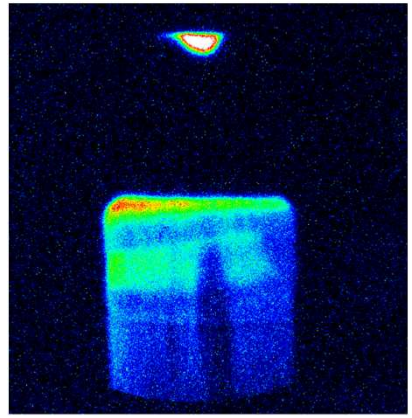


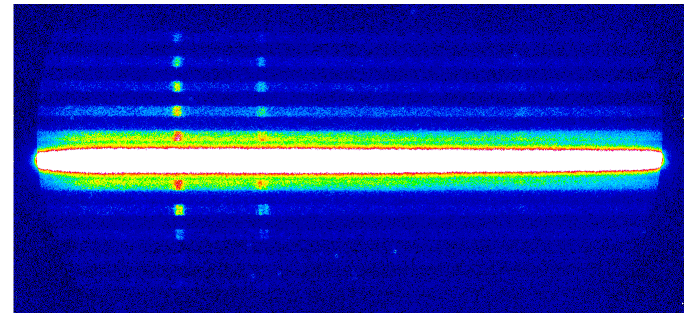


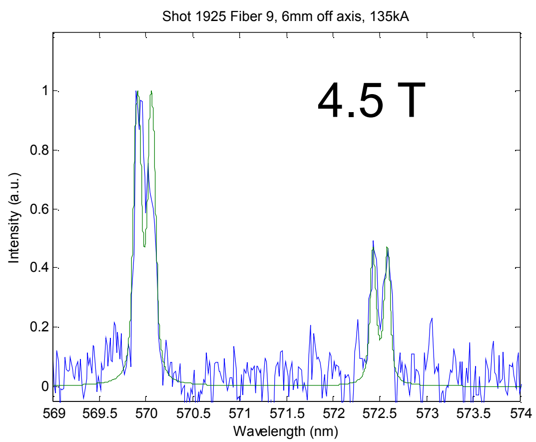
- Si dopant on Tungsten target, with thin film deposition
- Strong C IV and CIII lines are visible
- Splitting is very symmetrical around axis, as in Shot 1919.
- Enclosed current increases with radius.

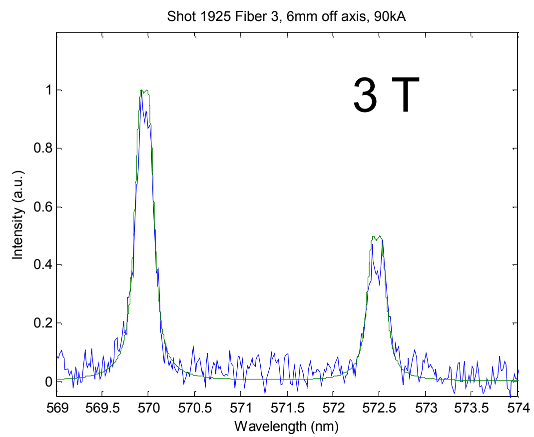
Shot 1925











- Al thermal spray coated Tantalum target with small diameter cathode.
- Spectra taken along the current rise (160-180kA)
- Smaller cathode results in higher current densities.
- Splitting on Al III lines
- Asymmetric profile visible in the framing camera is quantified by the stark width and splitting of the spectra.

Future Work

- Increase signal to noise to better resolve Zeeman splitting
- Try dopants to more accurately spatially resolve the field distribution and increase SNR
- Map the current distribution across the diode for the length of the radiation pulse.
- Further compare experimental data with LSP simulations
- Use the 1m streak spectrometer at higher resolutions to measure the time evolution of the B-field

Conclusions

- Proof of principle B-field measurements have been made on RITS-6
- C IV and Al III line splitting has been measured
- Density and temperature have been calculated using PrismSpec to fit CIV/CIII line ratios and Stark broadened lines
- The data suggests a large fraction of the total current may be outside a few mm radius

References

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- N. Bennett, M.D. Crain, D.W. Droemer, et al. Phys. Rev. ST Accel. Beams 17, (2014)
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