Effect of the Two-Close-Frequency Heating to the Extracted Ion Beam and to the X-ray Flux Emitted by the ECR Plasma

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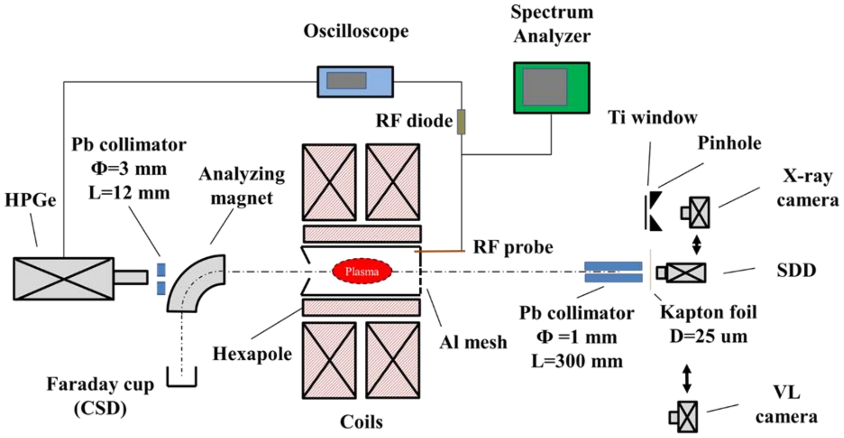
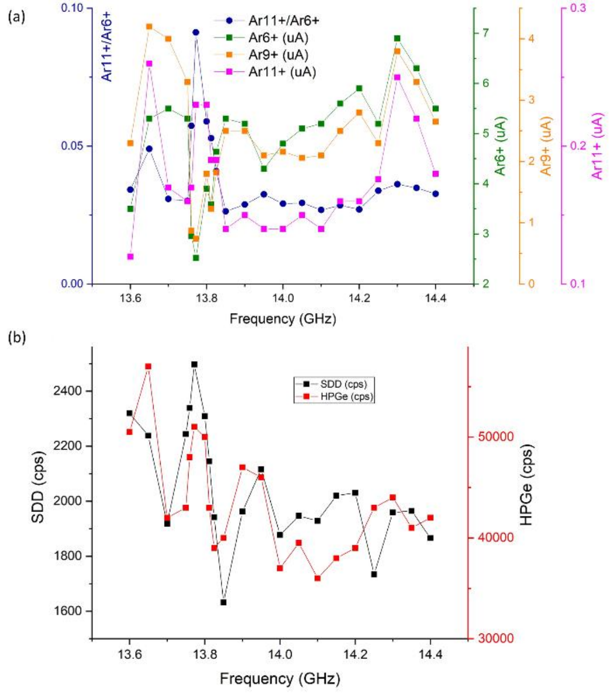
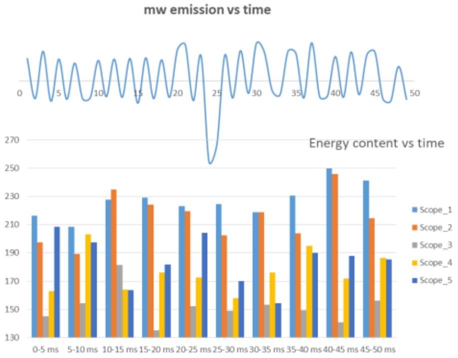
Outline

- Introduction
  - Two frequency plasmas
  - Instabilities
- Motivation
- Multi diagnostics experimental setup
  - Ion source
  - Diagnostic tools
- Results (ion beam, volumetric hard and soft X-ray fluxes)
  - Effect of the single frequency sweep
  - Effect of the microwave power at selected single frequency
  - Effect of the power balance between two close frequencies
  - Effect of the frequency scan at a selected power balance at TCFH mode
  - Effect of the phase shift at TCFH mode.
  - Temporally resolved hard X-ray component







Introduction

Two Far Frequencies (TFF), e.g. 14 GHz + 18 GHz

Z. Q. Xie and C. M. Lyneis, "Improvements on the LBL AECR Source," in Proc. 12th International Workshop on ECRIS, Tokyo, Japan, April 1995, pp. 24-28

IMPROVEMENTS ON THE LBL AECR SOURCE

Z. Q. Xie and C. M. Lyneis

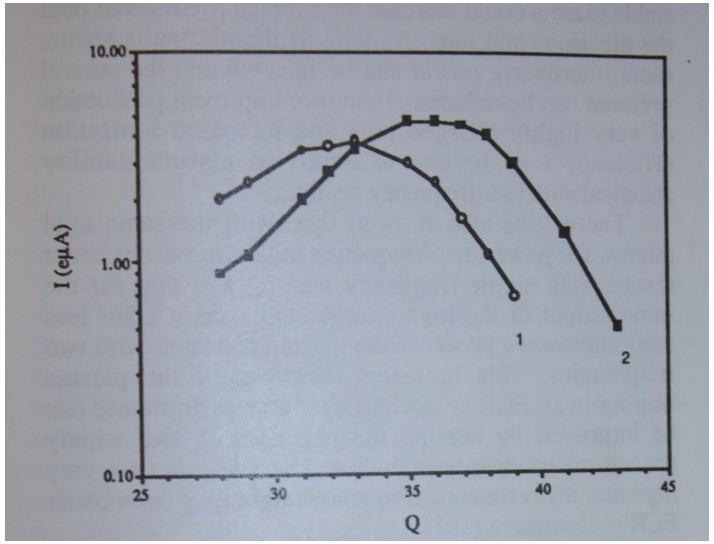
Lawrence Berkeley Laboratory, 1 Cyclotron Road, Berkeley, California, 94720, USA

Abstract

Performance of the LBL AECR source was improved by simultaneously heating the plasma with microwaves of 10 and 14 GHz (two-frequency heating). Plasma stability was improved and the ion charge state distribution shifted to higher charge state. Production of high charge state ions was increased a factor of 2 to 5 or higher for the very heavy ions such as bismuth and uranium, as compared to the case of single-frequency (14 GHz) heating. Fully stripped argon ions at intensity I ≥ 5 enA were directly identified by the AECR charge state analyzing system for the first time. High charge state ion beams of bismuth and uranium produced by the source were injected into the 88-Inch Cyclotron. After acceleration to energies greater than 6 MeV/nucleon, the extracted beam intensities were 1×10^6 pps or higher for $Bi^{50+,51+}$ and $^{238}U^{52+,53+}$. Tests in the AECR source have also shown Al_2O_3 coating is an effective coating and a better method than the electron gun for providing cold electrons to the ECR plasma.

The AECR source will be upgraded to raise its magnetic field strengths to obtain better plasma confinement and

1995



S. Gammino, et. al., "18 GHz upgrading of the superconducting electron cyclotron resonance ion source SERSE," Rev. Sci. Instrum., vol. 70, no. 9, p. 3577, Sep. 1999

ABSTRACT

The superconducting electron cyclotron resonance ion source SERSE of INFN-Laboratori Nazionali del Sud has been recently upgraded with an 18 GHz generator which takes the place of the 14.5 GHz generator, used up to now. In order to further extend the validation of high B mode to higher frequency, some comparative tests have also been carried out, aimed at understanding the role of the magnetic field and frequency on the ion yield at higher levels than were ever done before. The results at the frequencies of 14.5 and 18 GHz are compared and the trend already observed elsewhere is here confirmed. Preliminary observations of the "two frequency heating" have contributed to increase further the currents of the highest charge states.

1999

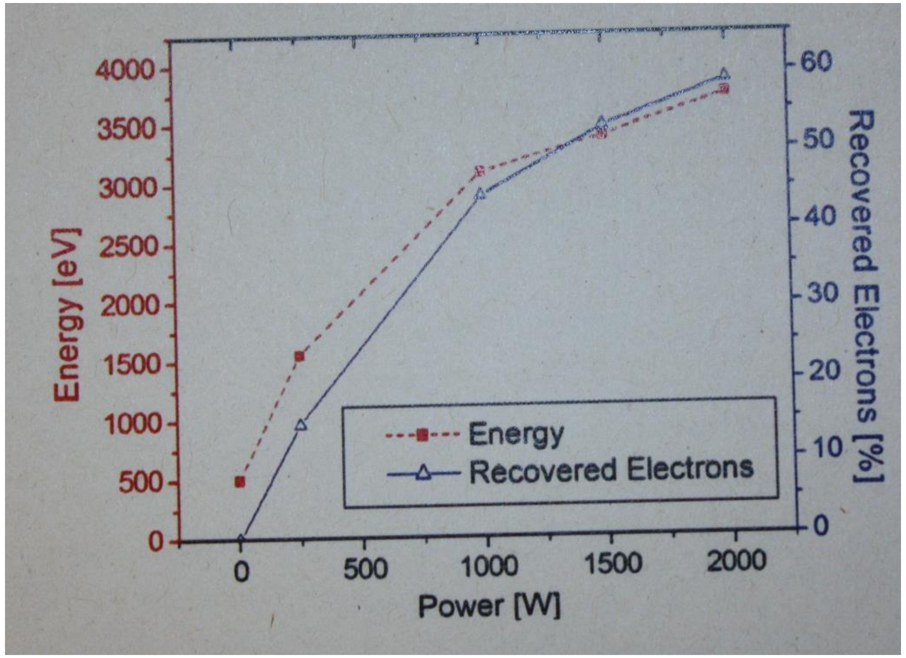
Introduction

Numerical simulation

2008

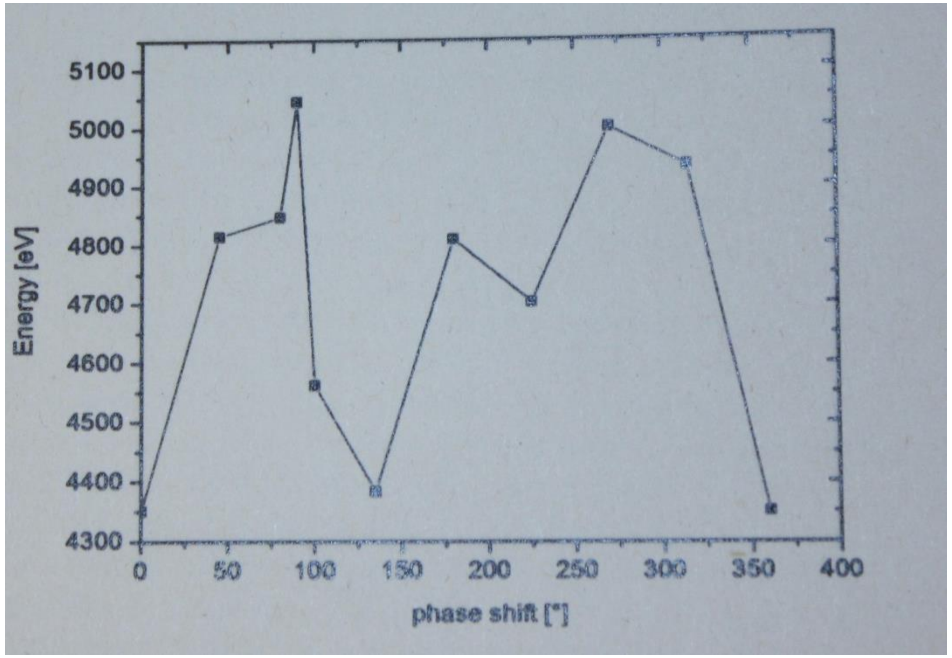
S. Gammino, et al., “Numerical Simulations of the ECR Heating With Waves of Different Frequency in Electron Cyclotron Resonance Ion Sources”, IEEE Transaction on Plasma Science, vol. 36, no. 4, p. 1552

Simulation (14 GHz + 18 GHz)



Two Close Frequencies (TCF), df= several 100 MHz

Significant effect of phase difference is expected



Introduction

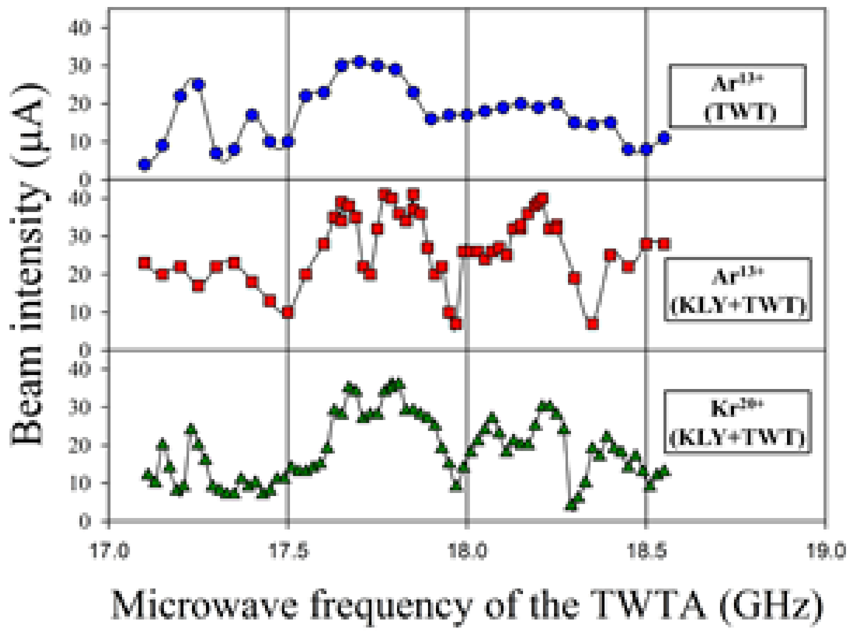
Two close frequencies

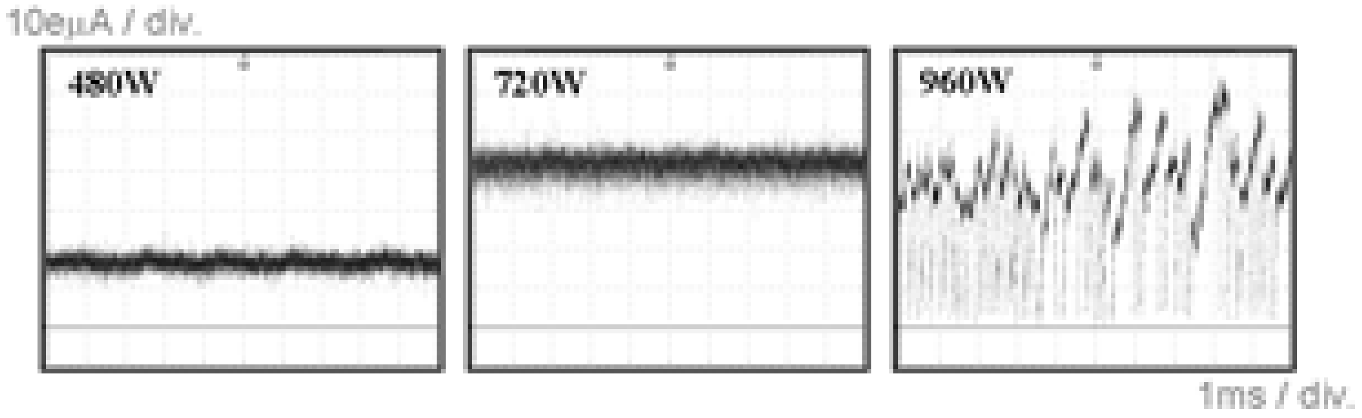
2013

S. Biri, et al., "Two Frequency heating technique at the 18 GHz NIRS-HEC ECR ion source", Rev. Sci. Instrum. vol. 85, p. 02A931, Dec. 2013

A. Kitagawa, et al., "Two-Frequency Heating Technique for Stable ECR Plasma", *in Proc. 20th International Workshop on ECRIS*, Sydney, Australia, Sep. 2012, pp. 10-12

18 GHz + 17.1 – 18.5 GHz





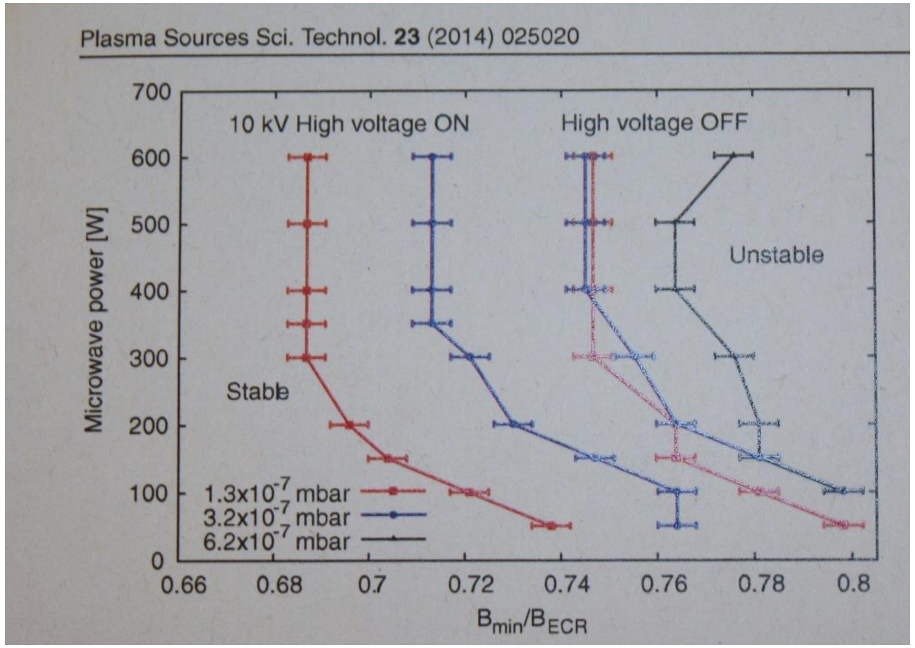
Additional mw can improve the stability even at higher net mw power

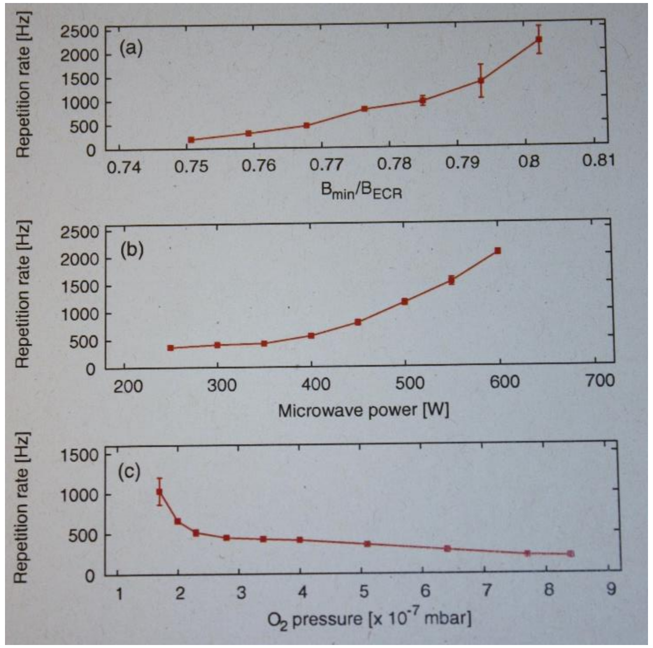
Introduction

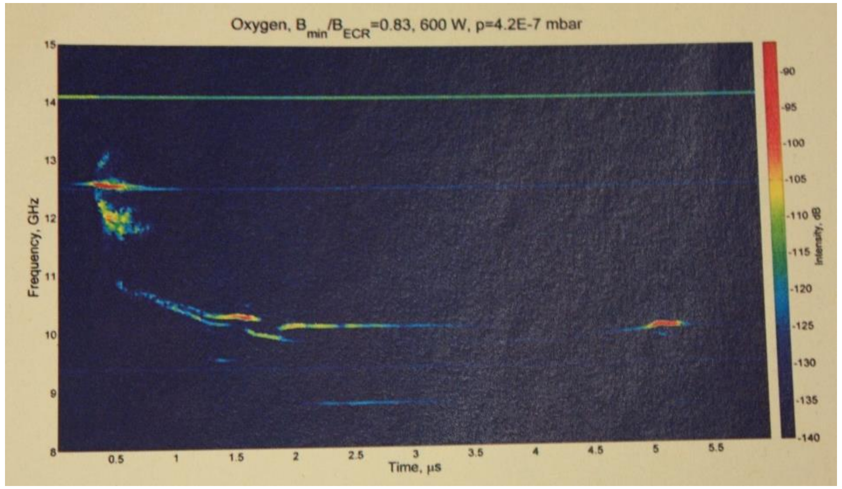
Kinetic instabilities

O. Tarvainen, et al., “Beam current oscillations driven by cy-clotron instabilities in a minimum-B electron cyclotron reso-nance ion source plasma” Plasma Sources Sci. Technol. vol. 23, p. 025020, April 2014

I. Izotov, et al., “Microwave emission related to cyclotron instabilities in a minimum-B electron cyclotron resonance ion source plasma” *Plasma Sources Sci. Technol*. vol. 24, p. 045017, July 2015







Motivation (to understand)

Sándor Biri
Poster: TUP14

Exact mechanism of two-close-frequency heating ?

- Role of 2nd frq. to suppress plasma instabilities
- Structural changes triggered by instabilities
- Structural changes when the turbulences are suppressed
- X-ray spectra in the unstable regimes
- Effect of the relative phase difference at TCFH mode
- Power balance between the two close frequencies

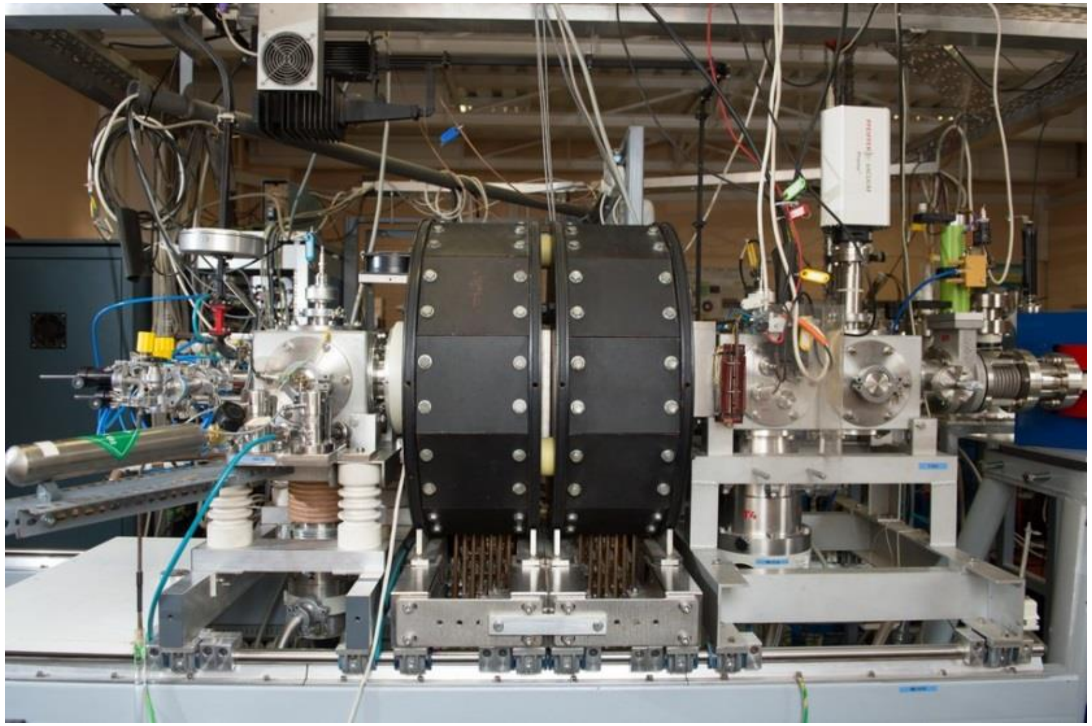
→ Multi-diagnostic setup

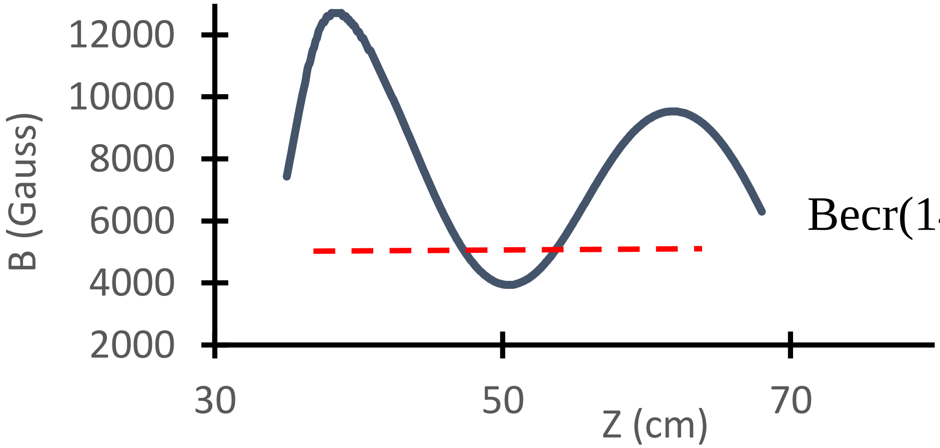
Experimental setup

Atomki ECR laboratory

- Permanent magnet hexapole and room temperate coils
- No post acceleration
- Used for atomic physics, material science, ECR plasma physics

14 GHz ECRIS

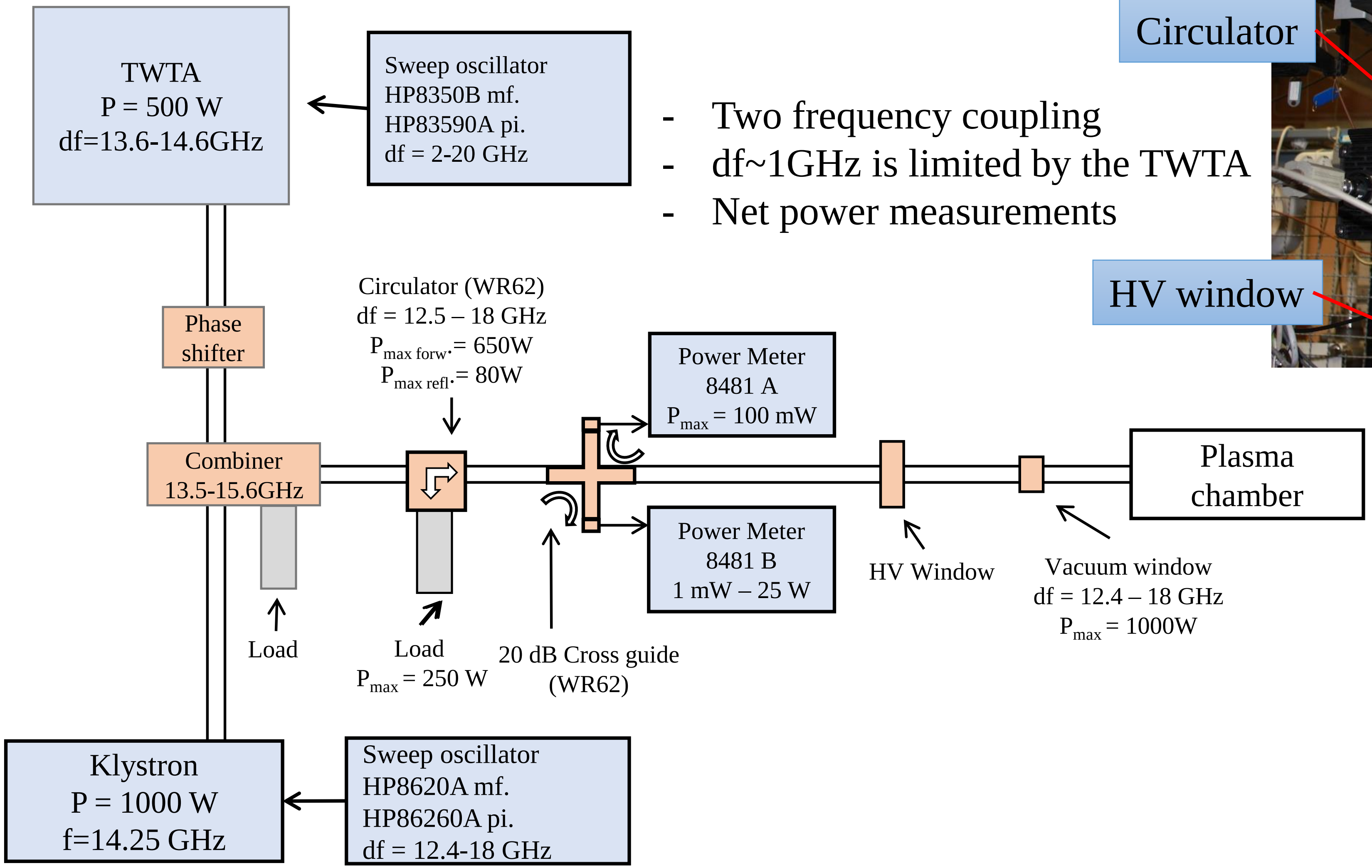




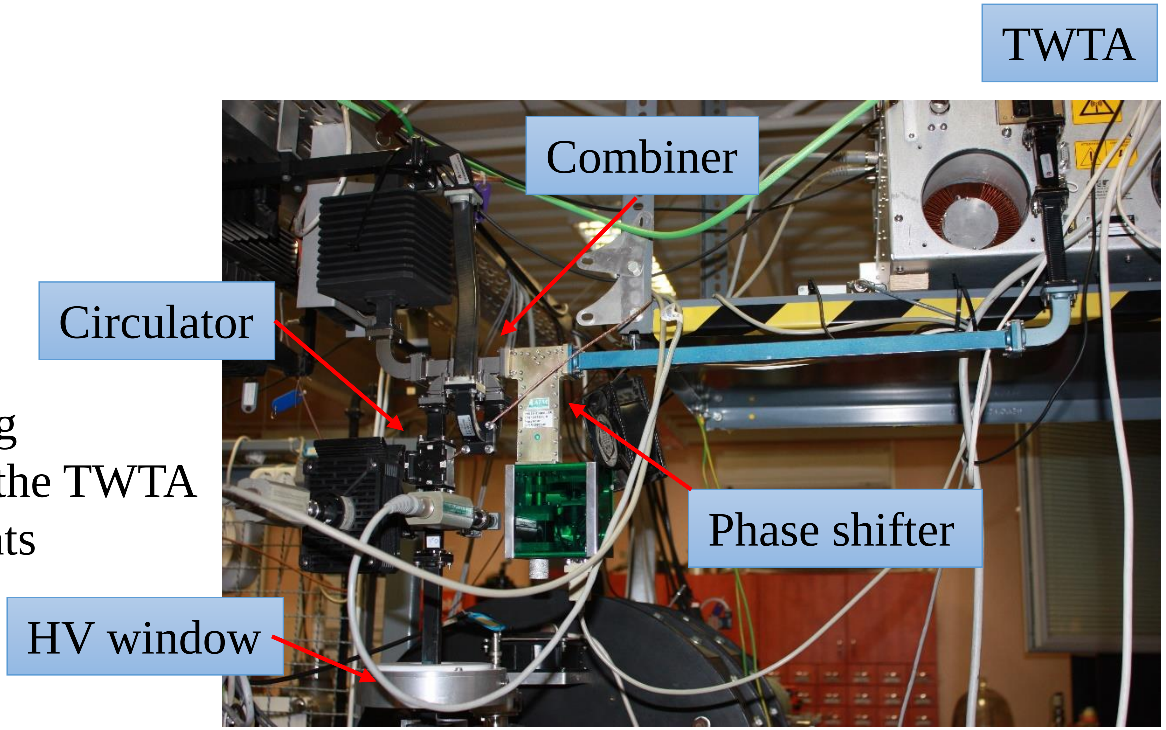
Becr(14.25GHz)=0.51T

$$\frac{B_{min}}{B_{ecr}} \sim 0.76$$

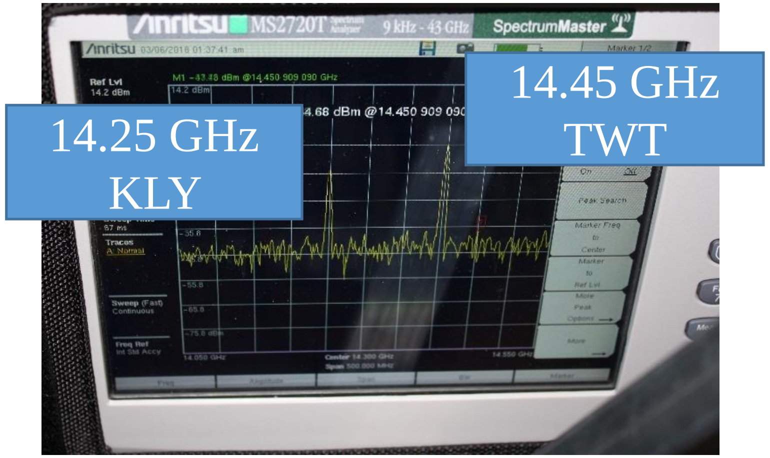
Experimental setup (coupling of TCF)



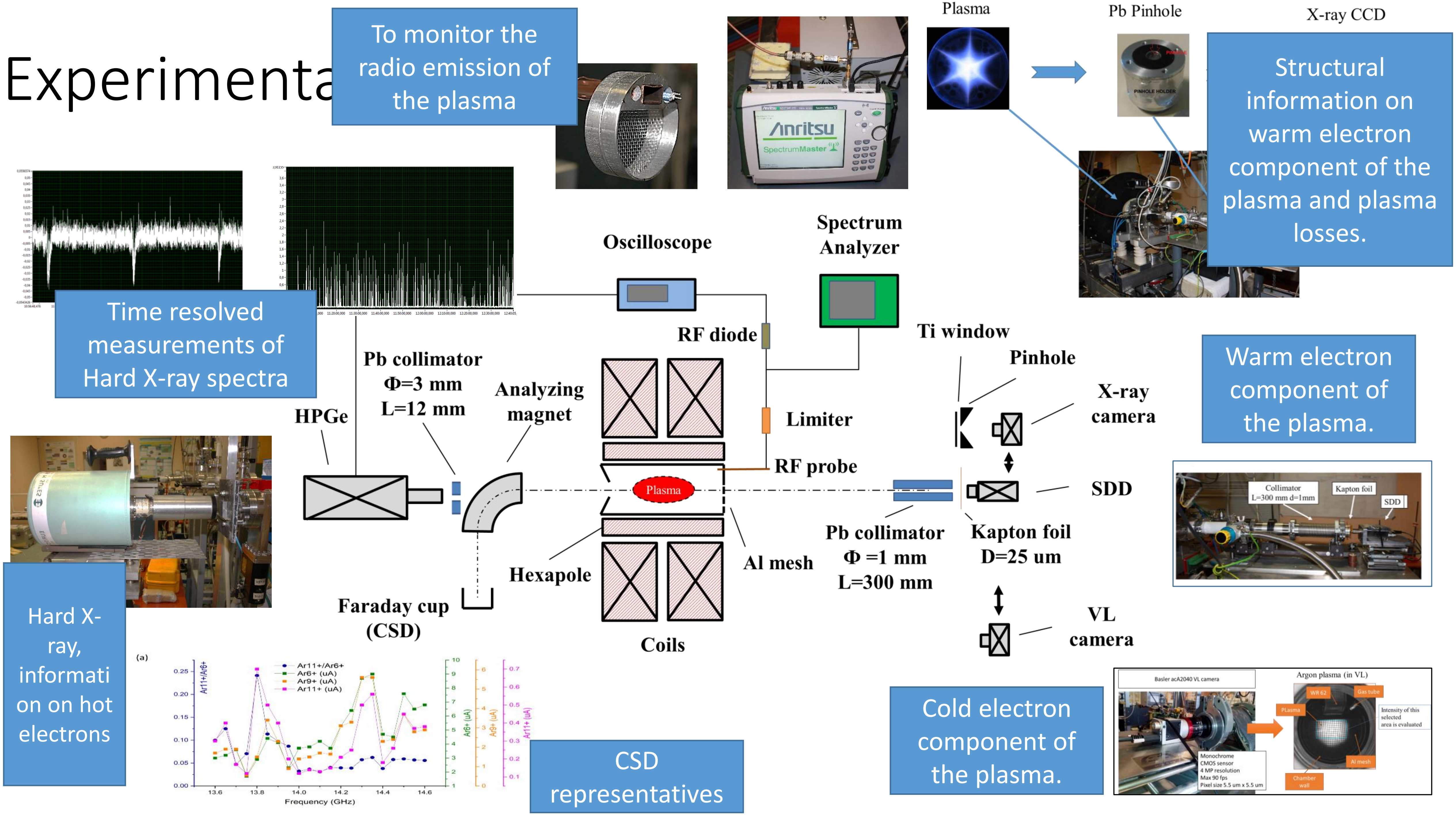
- Two frequency coupling
- df~1GHz is limited by the TWTA
- Net power measurements



Direct frq. measurements by Spectrum Analyzer

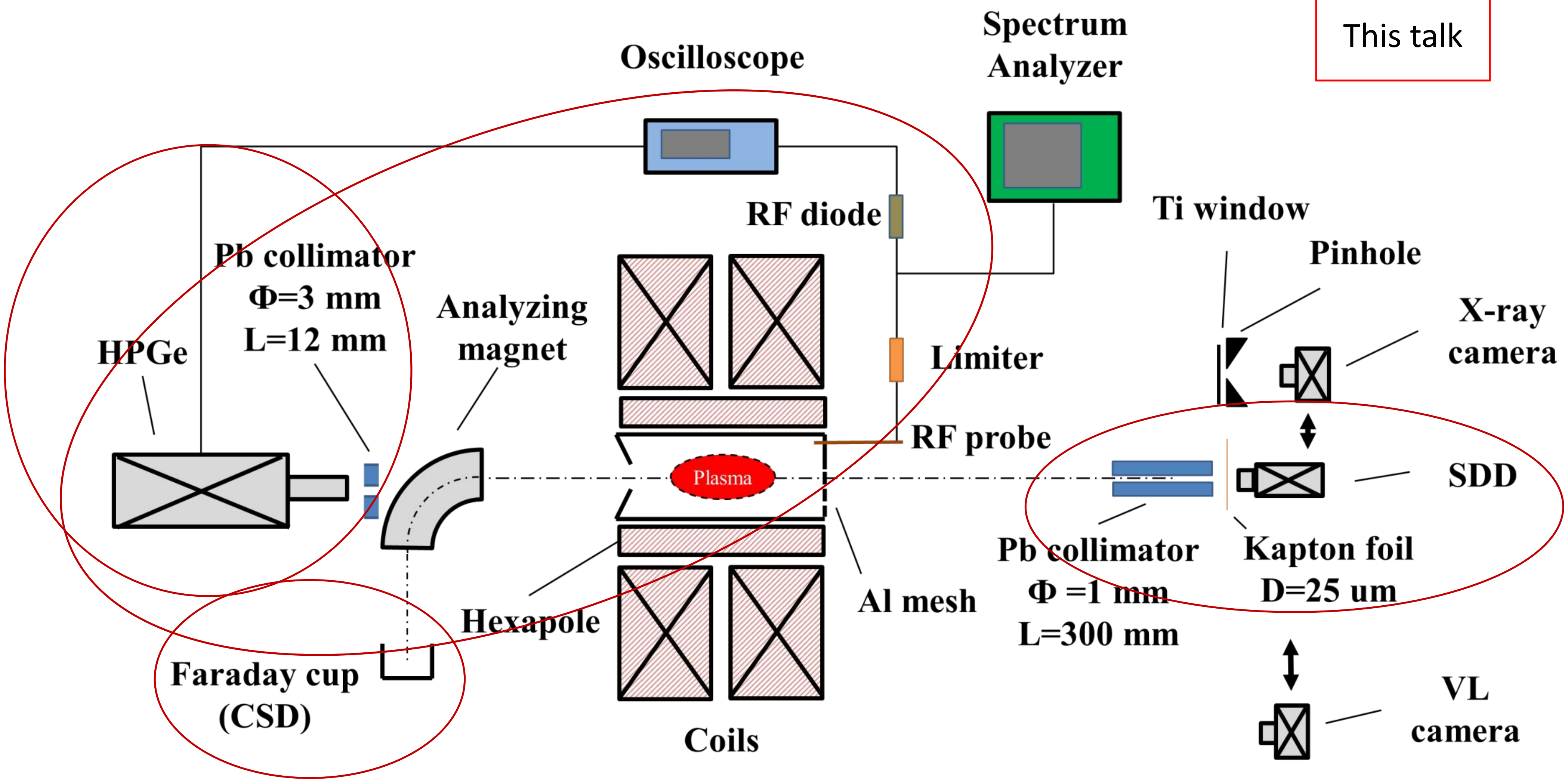


Experimenta



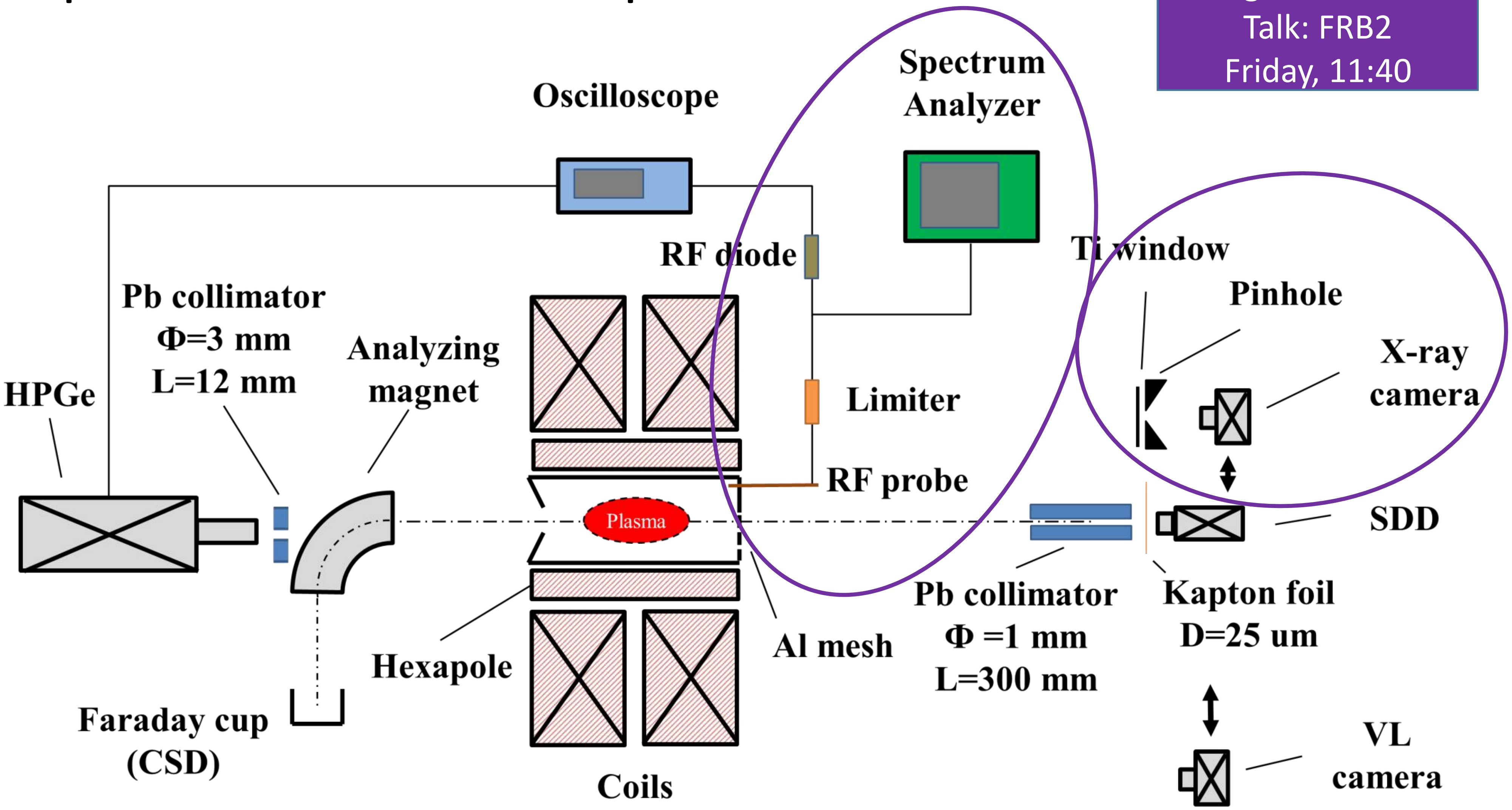
Experimental setup

This talk



Experimental setup

Eugenia Naselli
Talk: FRB2
Friday, 11:40



Systematic investigation

Base: Argon plasma, gas flow opt. at 14.25 GHz (KLY) frequency

Characterization of the source (CSD representatives, Count rates, plasma radio-emission, plasma photos)

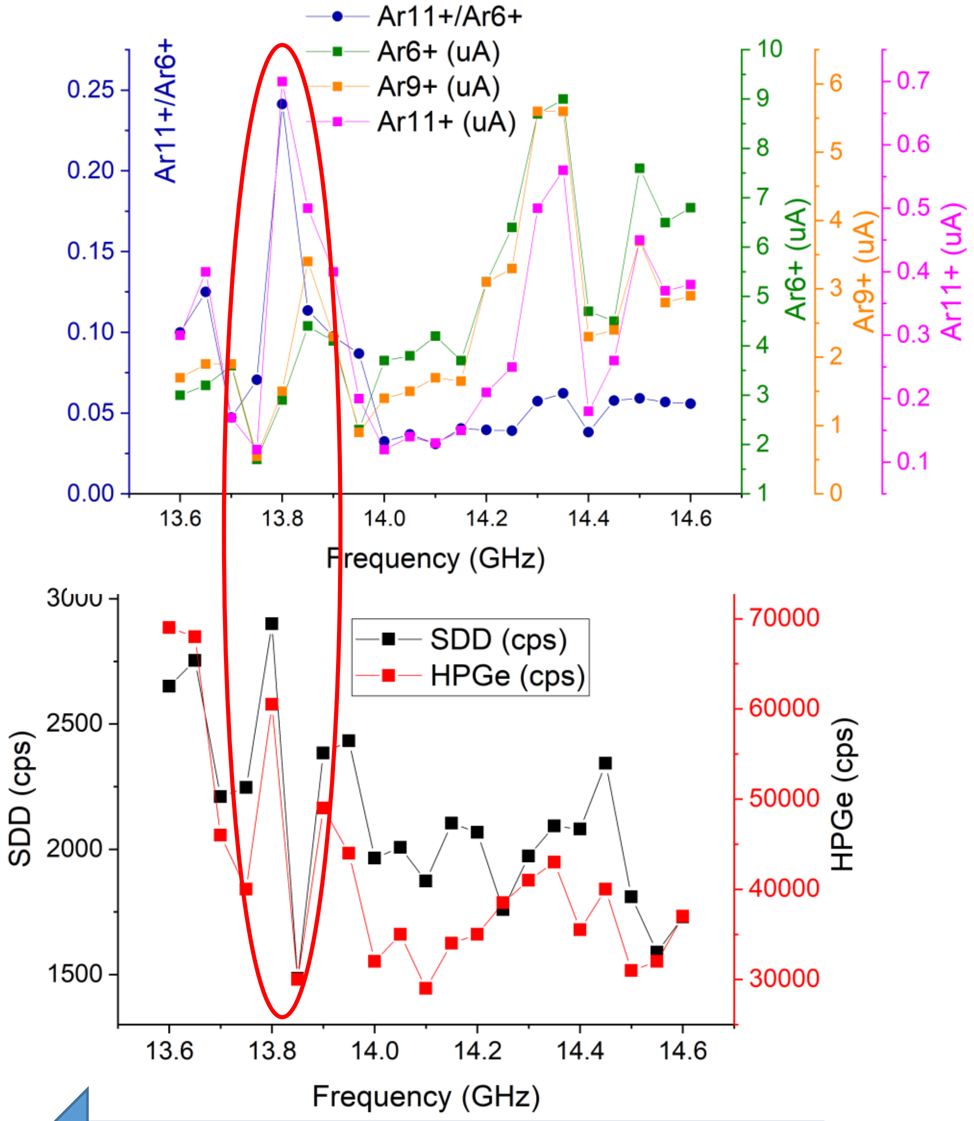
- SFH: frequency scan by TWT; 13.6 GHz – 14.6 GHz, df = 50 MHz, $P_{net} = 200W$
- SFH: TWT power scan at a selected frequency
- TCFH: Power balance scan at a selected frequency
- TCFH: frequency scan by TWT; 13.6 GHz – 14.6 GHz, df = 50 MHz, $P_{net} = 200W$

Time resolved X-ray spectra at 5 representative settings

Spectrally resolved X-ray imaging at 7 representative settings

VL imaging at full frequency scans (single, double)

Results (SFH)



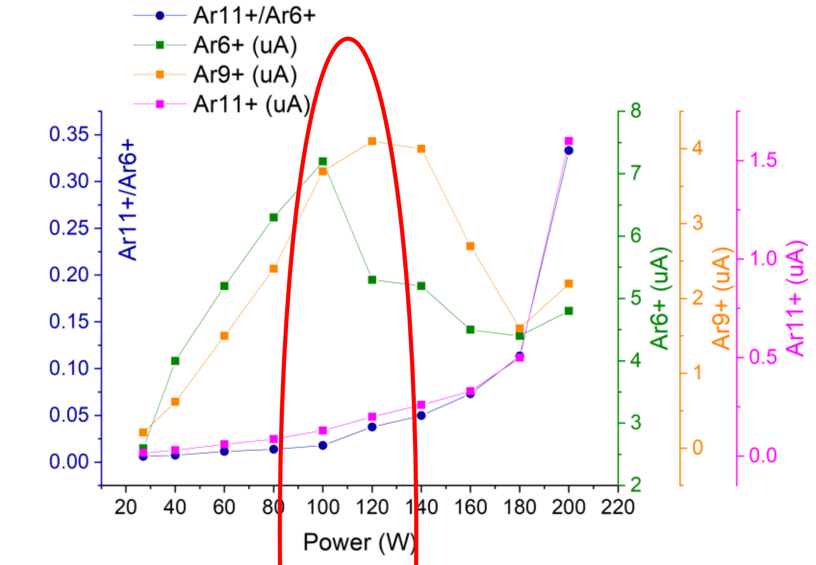
B_{min}/B_{ECR} is increasing from 0.75-0.8

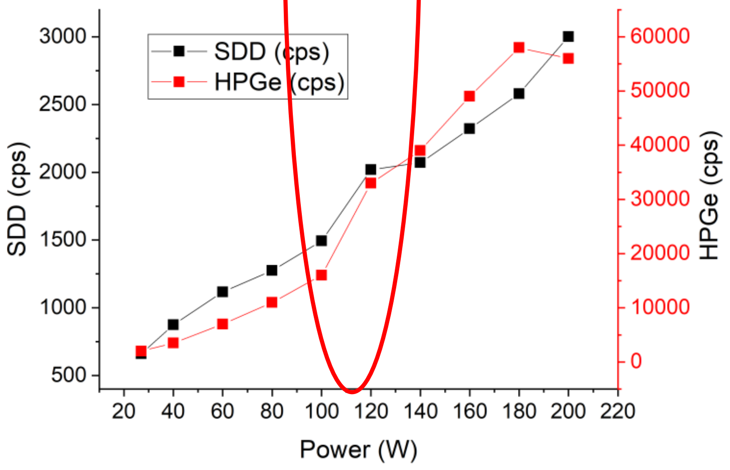
Single frequency scan

P_{TWT} = 200W
f_{TWT} = 13.6 GHz – 14.6 GHz
P_{Kly} = 0 W
f_{Kly} = 14.25 GHz

- Nonlinear fluctuation of the ion beam current as function of frequency (modal density)
- Rising trend of X-ray fluxes and Ar^{11+}/Ar^{6+} ratio toward lower frequencies ← instability caused losses are increasing toward higher B_{min}/B_{ecr}
- Highest Ar11+ current at 13.8 GHz relatively low HPGe rate and high SDD rate. → Dense plasma with moderated losses

Results (SFH)



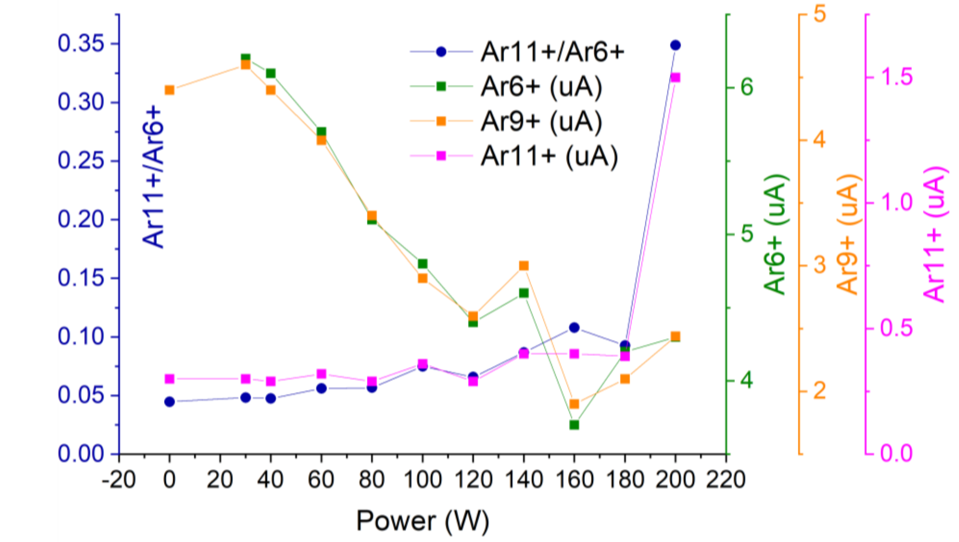


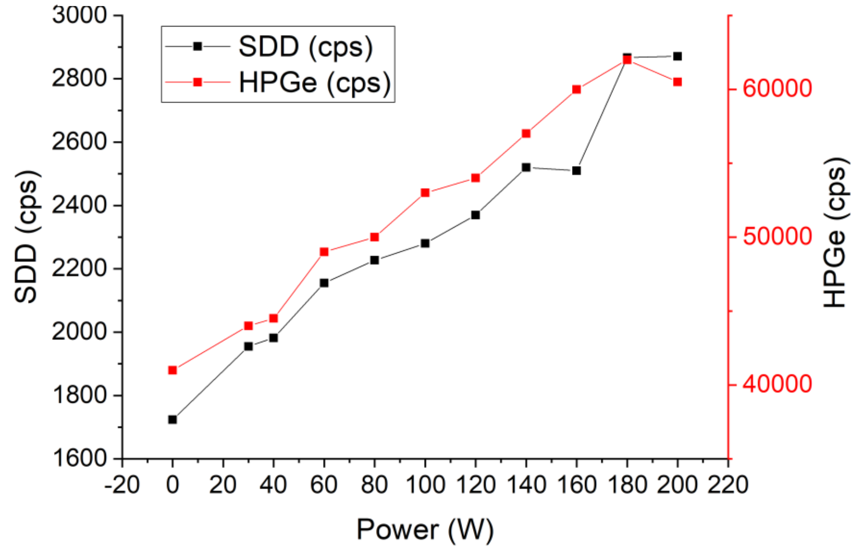
Power dependence at single 13.8 GHz

P_{TWT} = 20 W – 200 W
f_{TWT} = 13.8 GHz
P_{Kly} = 0 W
f_{Kly} = 14.25 GHz

- Linearly increasing trends up to 100 W
- Nonlinear jump on X-ray-s above 100 W
- CSD shift above 100 W

Results (TCFH)



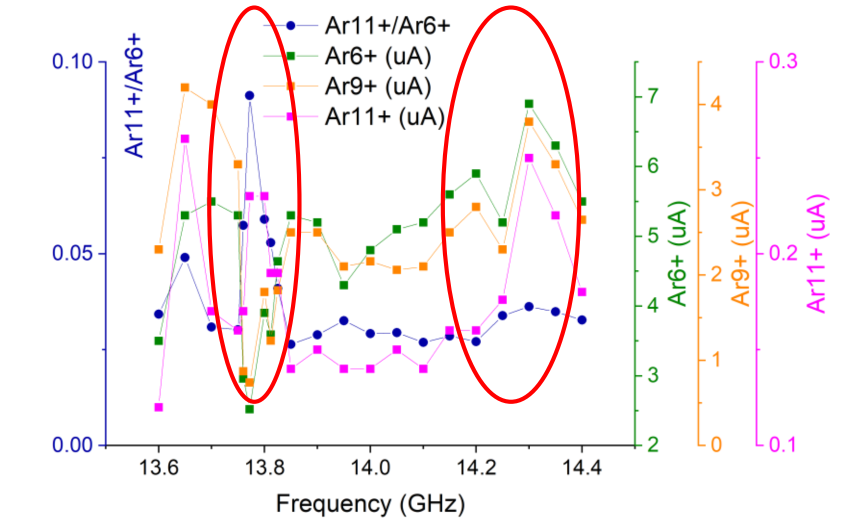


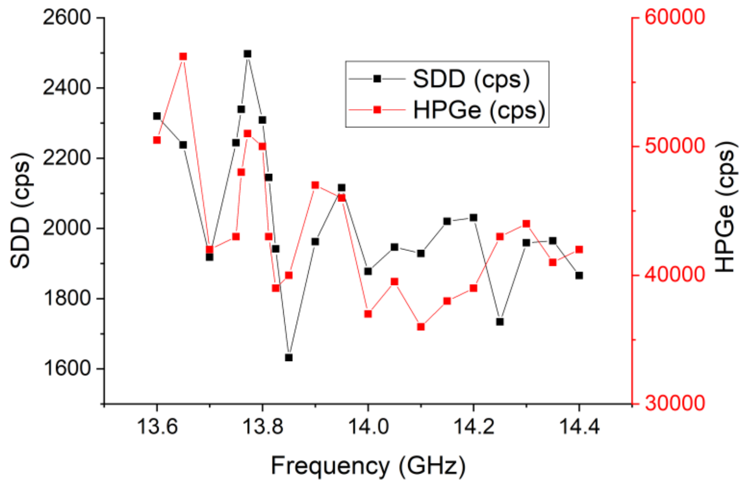
Power balance at 13.8 GHz and 14.25 GHz

P_{TWT} = 0 W – 200 W
f_{TWT} = 13.8 GHz
P_{Kly} = 200 W – 0 W
f_{Kly} = 14.25 GHz

- CSD shift by increasing the TWT power
- The more dominant of the TWT the higher the emitted hard and soft X-ray fluxes
- Instability (see plasma emitted RF signals) was varying significantly with the power ratios. **Power balance is very important.**
- Quite stable plasma conditions at the 120 W klystron and 80W TWT powers

Results (TCFH)





Effect of the frequency scan in TCFH mode

P_{TWT} = 80 W
f_{TWT} = 13.6 GHz – 14.6 GHz
P_{Kly} = 120 W
f_{Kly} = 14.25 GHz

- Currents show rather different trends than the case of single frequency scan
- Optimums at both side of the KLy frq.
- X-ray fluxes are decreasing toward the higher frequencies
- Overall rate was decreased by about 15 % respect to the single frequency operation mode

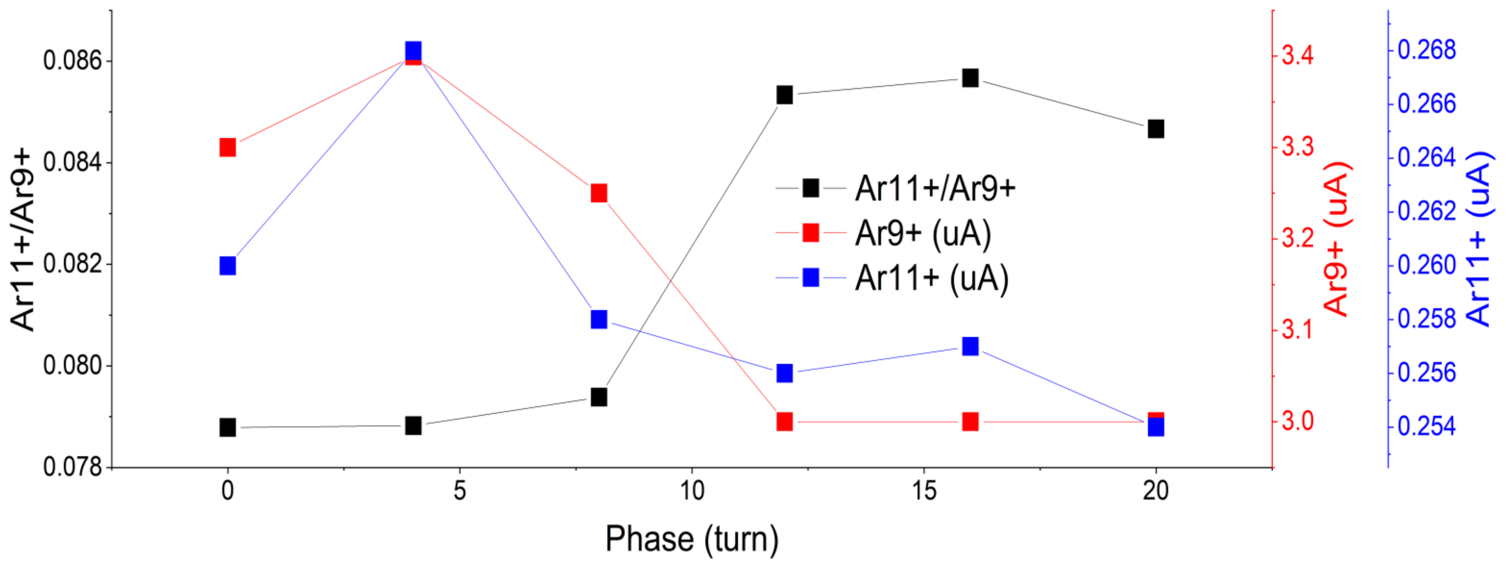
Results (TCFH)

Effect of the relative phase difference (phase shift) at TCFH mode

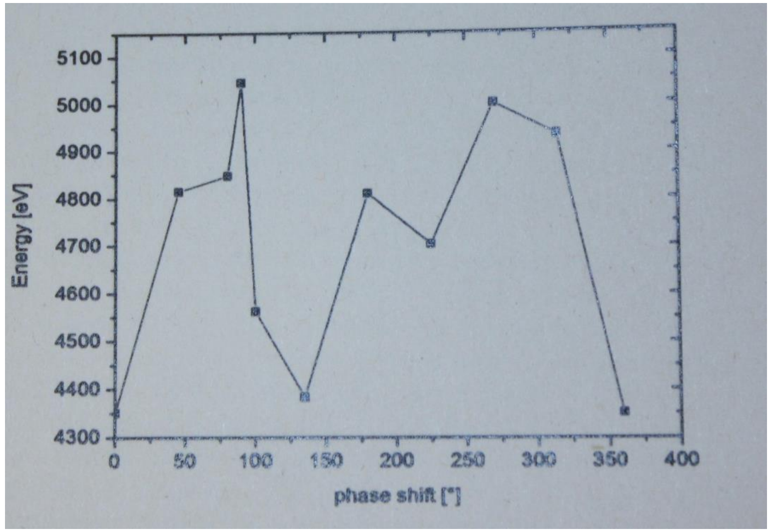
P_{TWT} = 30 W
f_{TWT} = 13.8 GHz
P_{Kly} = 170 W
f_{Kly} = 14.25 GHz

Unstable plasma conditions

Weak but clear (about 10 %) effect at unstable plasma conditions



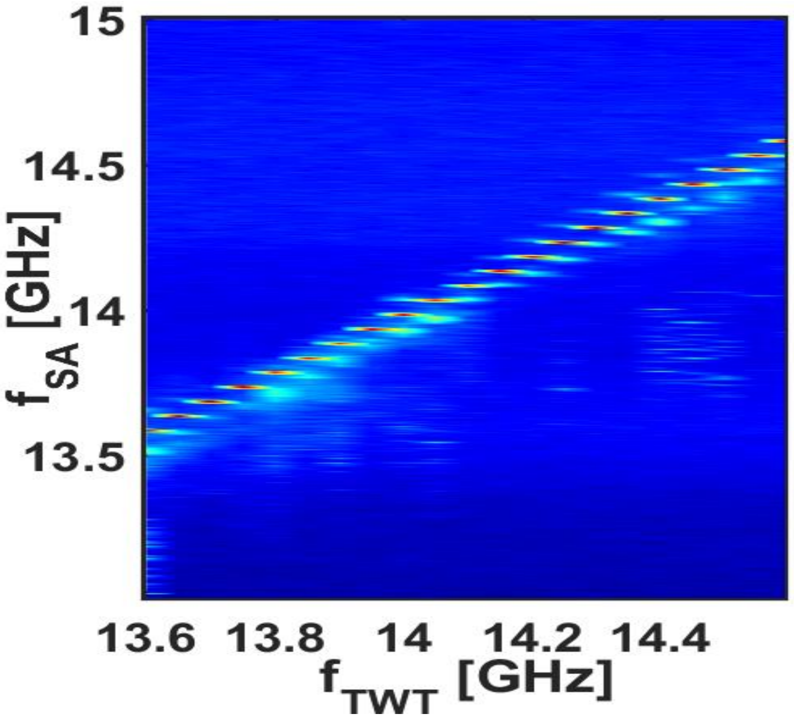
Full range is about π



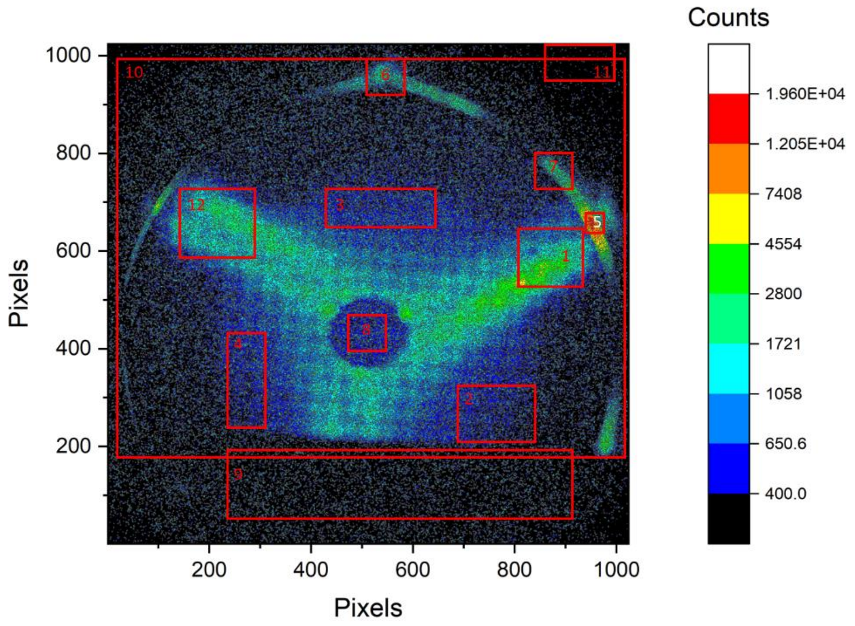
Outlook

Eugenia Naselli
Talk: Friday, 11:40

Radio-emission of the plasma



Spectrally integrated images



Spectrally resolved images

under processing

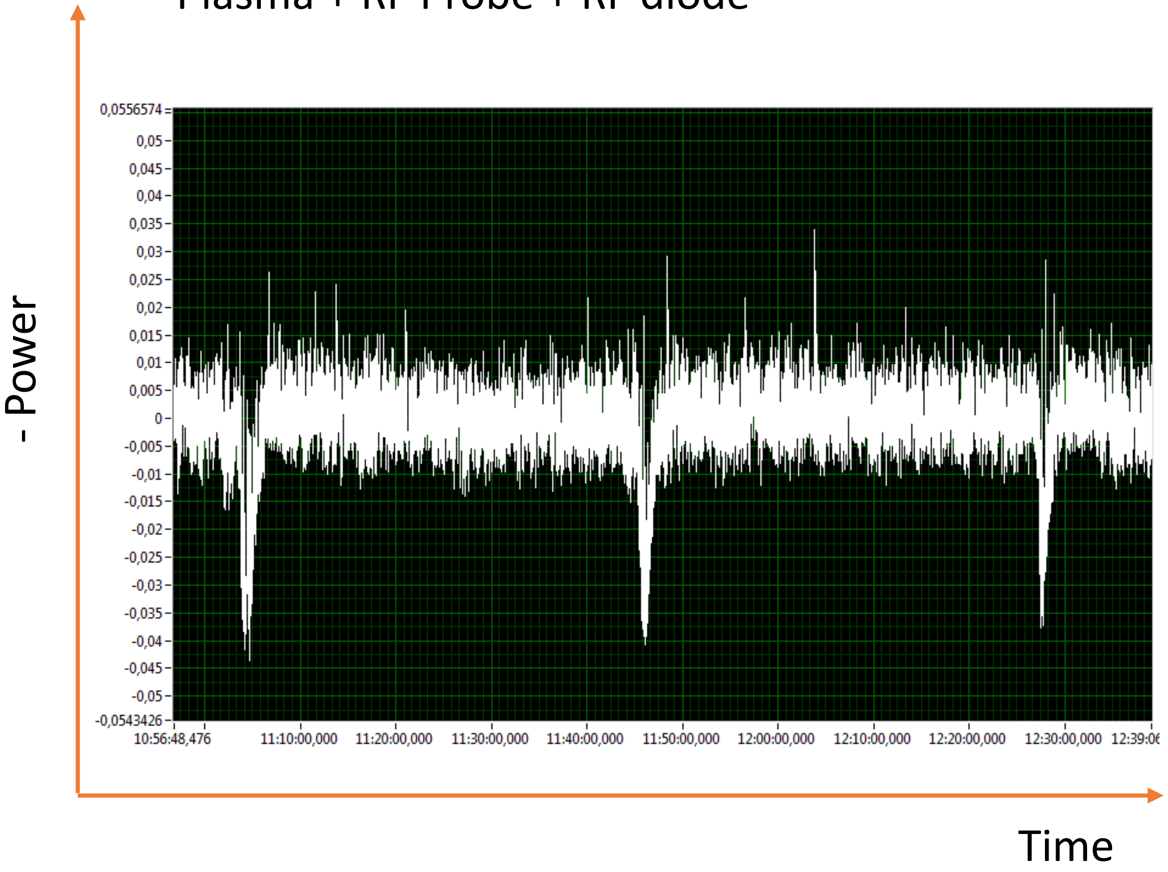
Team

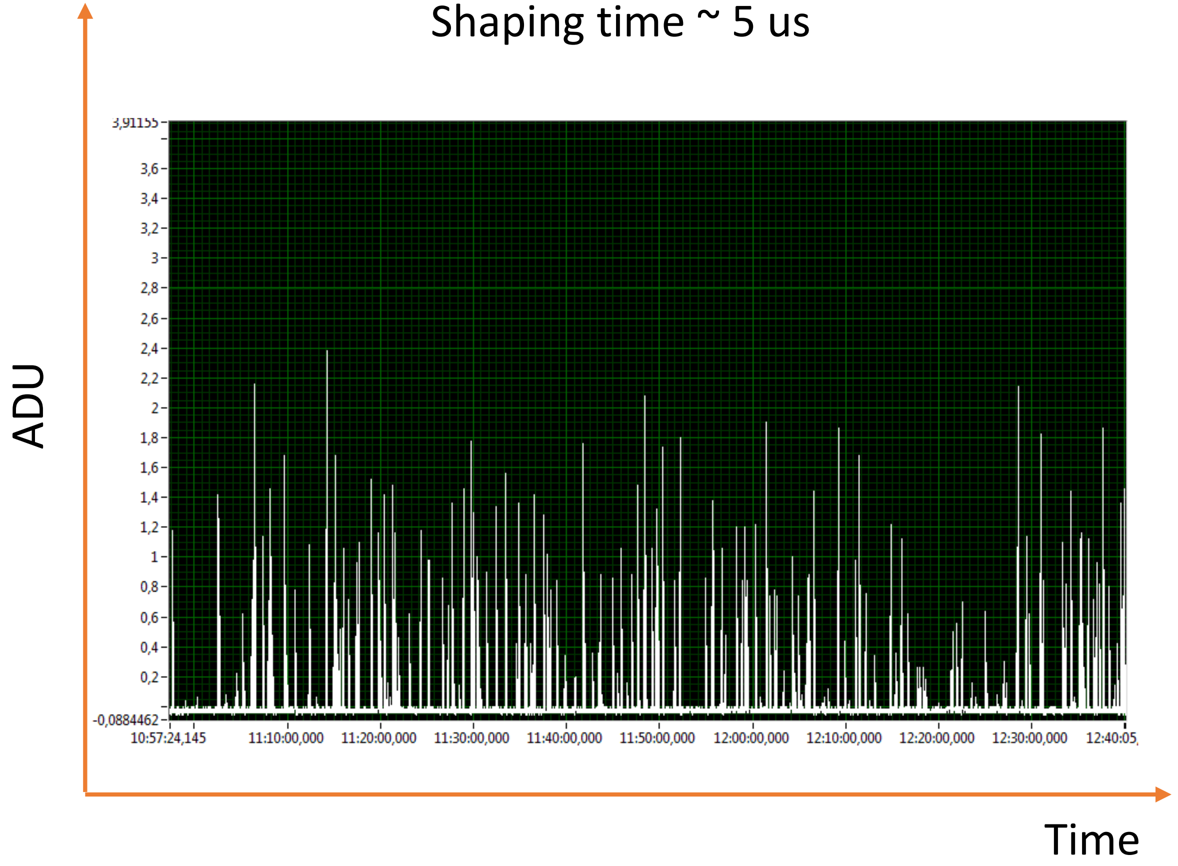
Time resolved hard X-ray component at unstable regime

emission detection conversion

Plasma + RF Probe + RF diode → Oscilloscope ← Data flow from the HPGe detector

Shaping time ~ 5 us





Energy content at different working points