Measurement of Electron Cyclotron Resonance Ion Source Bremsstrahlung and Ion Production Time Evolution

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Overview

1. Radial measurements
2. Data acquisition
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3. The effect of collimation
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3. The effect of collimation
4. Time evolution
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5. Conclusions
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5. Conclusions
Why radial measurement?

1. Main interest: high energy electron population
2. Strong plasma flux follows magnetic field lines
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2. Strong plasma flux follows magnetic field lines
1. Distance between ECRIS chamber and Ge detector about 1 m

2. The effect of opening and shielding around the collimator was studied
   - 0.5 mm² → 4.0 mm²
   - Hole did not change the count rate or the shape of the spectra
   - Shielding changed the count rate and the shape of the spectra

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Measurement geometry

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Why radial measurement?

Radial measurement geometry & setup

- Reference timing signal (TTL, 1.76/5.92 s)
- 14 GHz GUNN-type oscillator

Unpublished figure

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Bremsstrahlung time evolution, ECRIS 2008, ANL
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Measurement setup — schematic

- Germanium detector
- Digital Signal Processing unit (TNT2)
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- Digital Oscilloscope

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Hardware

1. Shaping time 2.0 $\mu$s (rise time + flat top)
2. Energy resolution ($^{152}$Eu): 4.2 keV @ 444 keV
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Software: C++ code on Unix/Linux platform

1. 680 RF pulses taken into account
2. Pile-ups etc. removed

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Change of the shielding

1. Lower part of the spectra relatively unchanged
   - High energy part directly from plasma chamber
   - Lower energy part from scattering, through the coils/shielding

2. Original shielding (Pb plates) around the collimator: “hump”

Steady state Ar plasma 1500 ms, 500 W, 500/500 A, 2.6e-7 mbar

Modified from submission to NIMA

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3. Increased shielding: no “hump”

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Original shielding and collimation
Changed shielding and collimation

Counts / 2 ms
Energy [keV]
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Time scale comparison with different shielding

- Different shielding does not affect the timescales
  - Steady state phase is reached at the same time

Ar plasma, 500 W, 500/500 A, 2.6e-7 mbar

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Ar plasma, 500 W, 500/500 A, 2.6e-7 mbar
Total (integrated) count rate vs. time (argon plasma)

Ar plasma, 500 W, 2.6e-7 mbar

Binj 2.111 T, Bmin 0.388 T, Bext 1.019 T
Binj 2.011 T, Bmin 0.346 T, Bext 0.946 T
Binj 1.945 T, Bmin 0.321 T, Bext 0.901 T

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Bremsstrahlung time evolution, ECRIS 2008, ANL
Total (integrated) count rate versus time

Argon plasma, 500/500 A, 2.6e-7 mbar

Unpublished

690 W
500 W
300 W

Time [ms]

Total counts / 2 ms

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Bremsstrahlung time evolution, ECRIS 2008, ANL
Total (integrated) count rate vs. time (oxygen plasma)

O plasma, 500/500 A, 2.6e-7 mbar

Unpublished

680 W
500 W
300 W
1. Argon plasma, 500 W, 500/500 A, 2.6e-7 mbar
2. Time T=0 corresponds to the leading edge of the RF pulse ("RF on")

"RF on" phase, original shielding
“RF on” phase animation

1. Argon plasma, 500 W, 500/500 A, 2.6e-7 mbar
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“RF on” phase, original shielding
Argon charge states & bremsstrahlung

1. Preglow: from $\text{Ar}^{5+}$ to $\text{Ar}^{8+}$
2. Rise times 5.5–6.5 ms
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1. Steady state at 200 ms
2. Bremsstrahlung count rate saturates after ion currents

![Graph showing argon charge states and bremsstrahlung]

**Ar plasma, the whole RF pulse**

- Ar$^{5+}$
- Ar$^{7+}$
- Ar$^{8+}$
- Ar$^{12+}$
- Counts

submitted to NIMA

Ion current [$\mu$A] vs. Time [ms]

Total counts / 2 ms

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Argon charge states & bremsstrahlung

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![Graph showing ion current and total counts over time for different Ar charge states.](attachment:graph.png)

**Legend:**
- **Time (ms)**: The x-axis represents time in milliseconds.
- **Ion current [µA]**: The y-axis represents the ion current in microamperes.
- **Total counts / 2 ms**: The y-axis indicates the total number of counts every 2 milliseconds.
- **Ar plasma, the whole RF pulse**: The graph shows the behavior of different Ar charge states over time.

**Submissions:**
- Submitted to NIMA

**Tommi Ropponen (tommi.ropponen@phys.jyu.), JYFL**
Stochastic heating theory vs. measurements

1. Modified stochastic heating theory of Sergeichev et al.
2. ECR settings can be used (RF power, B field)

![Graph showing energy vs. time with different lines for different Q values and Argon plasma.]

Sergeichev et al., Q=1
Sergeichev et al., Q=3
Sergeichev et al., Q=5
Argon plasma
Sergeichev et al., Q=44

**Time evolution**

**Spectrum time evolution animations**

**Ion production**

**Theory vs. measurements**
Stochastic heating theory vs. measurements

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3. Demands very high Q value to be accurate, but
   - First 100 ms ok
   - After 100 ms theory overshoots the measured values
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Part I

1. The effect of collimation and shielding has to be studied more
   - Time scales are not affected
   - Shape of the spectra is affected

2. “Hump” ends at around 400 keV
   - Evidence from lower and higher energy electron populations?
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Part II

1. High Bmin — instabilities in bremsstrahlung counts
2. Steady state for argon bremsstrahlung plasma at 200 ms
3. Steady state for oxygen bremsstrahlung plasma at 600 ms or more
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1. High $B_{\text{min}}$ — instabilities in bremsstrahlung counts
2. Steady state for argon bremsstrahlung plasma at 200 ms
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Part III

1. Several preglow peaks observed
   - Rise times of a few milliseconds

2. Ion currents reach steady state before bremsstrahlung emission
   - Intensity could be maintained high with pulsed RF?
   - Needs to be studied
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Stochastic heating theory vs. measurements

- ECR settings as input values
- No friction between particles, no stochastic limit
- Needs relatively high Q values but then overshoots
- Radial resonance limiting the measured energies?
  - 0.85 T at the pole → resonance field for about 360 keV
  - No radial resonance field for electrons with higher energy
  - Saturation of measured endpoint energies
Part IV

Stochastic heating theory vs. measurements

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