Ion Beam Cocktail Development and ECR Ion Source Plasma Physics Experiments at JYFL

Olli Tarvainen

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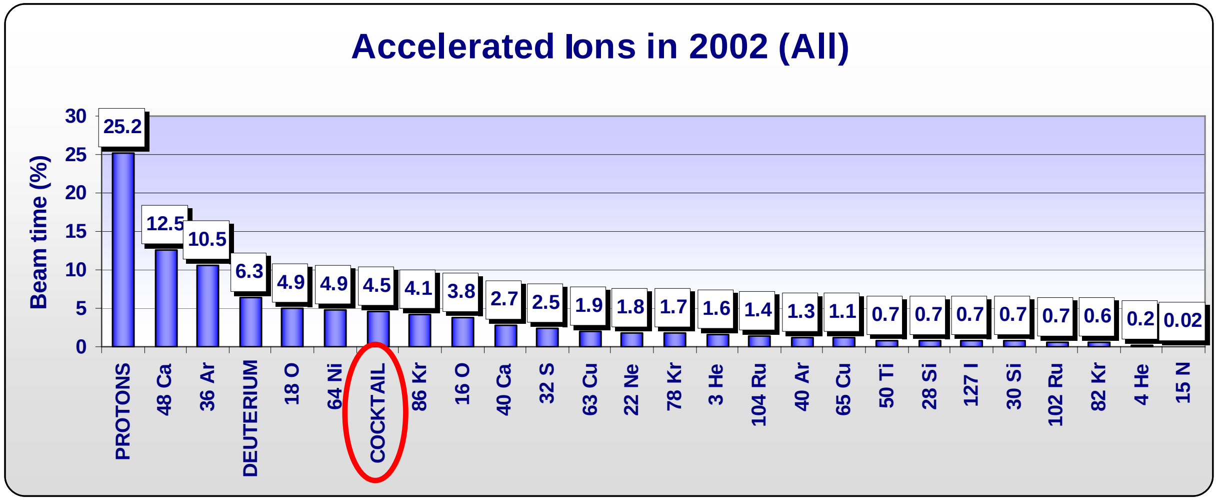
Outline

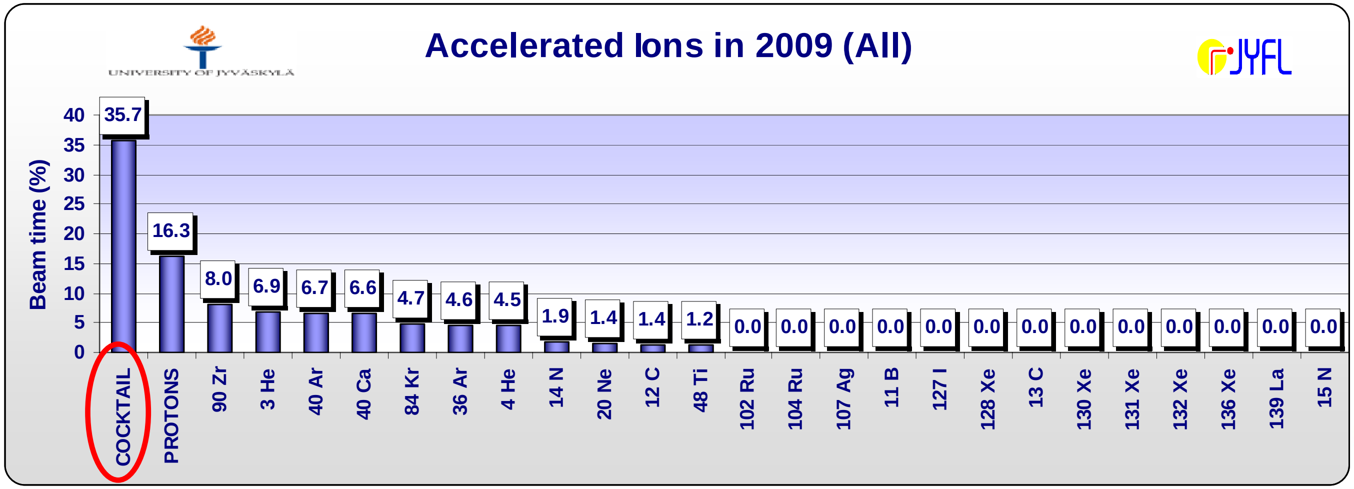
- JYFL accelerator laboratory
- Heavy ion beam cocktails for component irradiation at JYFL
- ECRIS plasma physics experiments

JYFL accelerator laboratory

- K-130 cyclotron
  - Two ECR ion sources
  - Negative light ion source
- Pelletron
  - Injector upgrade in 2009
- MCC-30 cyclotron (2009-2010)

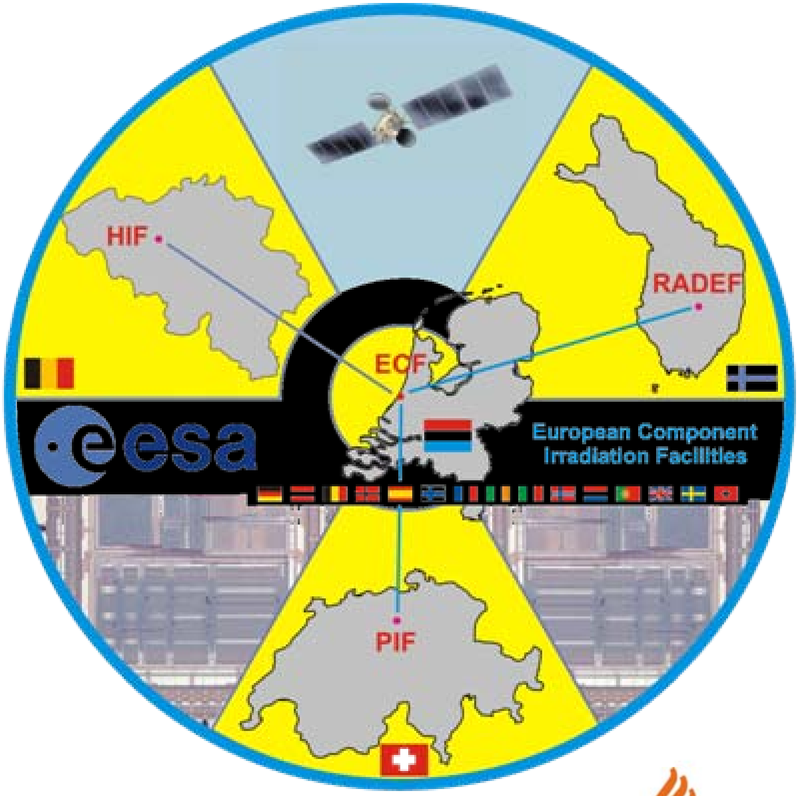
K-130 cyclotron – accelerated ions





Heavy ion beam cocktails at JYFL

- Efficient testing of single event effects:
  - Adequate penetration depth
  - Varying LET-value
  - Fast transition between projectiles



9.3 MeV /u high penetration cocktail at JYFL

Ion	Energy [MeV]	Penetration depth [μm]	LET [MeV/ (mg/cm²)]	$\Delta(m/q)$ [%]
$^{15}N^{4+}$	139	202	1.7	0.0
$^{30}Si^{8+}$	278	130	6.0	-0.09
$^{56}Fe^{15+}$	523	97	18	-0.56
$^{82}Kr^{22+}$	768	94	30	-0.71
$^{131}Xe^{35+}$	1217	89	53	-0.26

Proposed 10.77 MeV/u beam cocktail

Ion	**Energy [MeV]**	**Penetration depth [μm]**	**LET [MeV/(mg/cm^2)]**	**$\Delta(m/q)$ [%]**
$^{14}N^{4+}$	151	242	1.6	0.0
$^{35}Cl^{10+}$	377	138	8.3	-0.11
$^{56}Fe^{16+}$	603	117	18	-0.14
$^{80}Kr^{23+}$	862	108	29	-0.74
$^{132}Xe^{38+}$	1422	106	52	-0.85

How to reach Xe^{38+} routinely?

- Multiple frequency heating
  - Double frequency heating, factor of 2-5 for high charge states
  - Triple frequency heating → 20-40% gain
- Improved hexapole
  - Radial field from 0.93 T to 1.07 T (simulation)
  - Only for ”clean beams”, nuclear physics with old chamber (MIVOC, sputtering)
  - Affects the beam allocation procedure due to ”campaigns”
- Afterglow mode
  - Time structure almost irrelevant for irradiation tests

ECRIS plasma physics at JYFL

The objective is to understand how and why different ion source parameters and techniques affect the production of highly charged ions

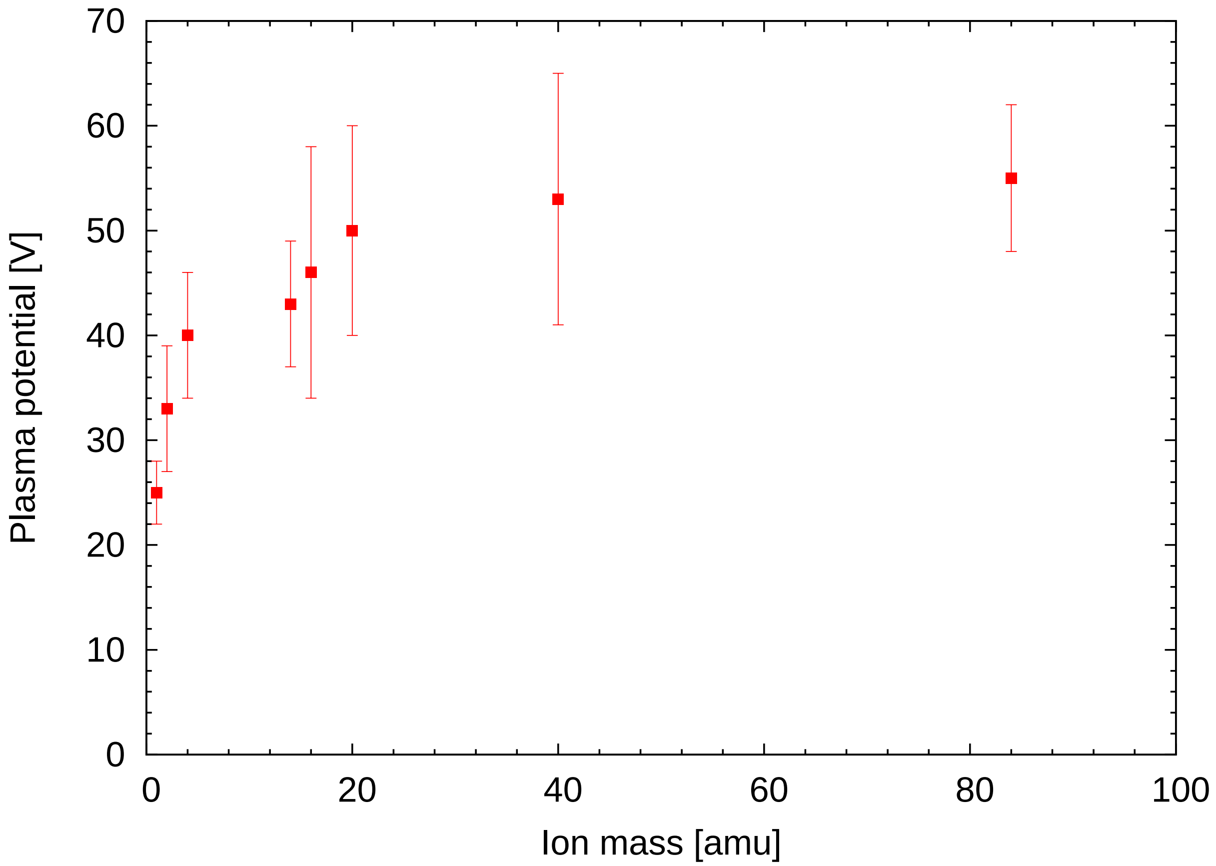
- Plasma potential measurements
- Time-resolved bremsstrahlung measurements (PhD Thesis by T. Ropponen in 2009-2010)
- Plasma breakdown studies

Plasma physics experiments

Source parameters studied:

- Magnetic field
- Microwave power
- Neutral gas pressure
- Bias disc voltage
- Gas species

Plasma potential vs ion mass



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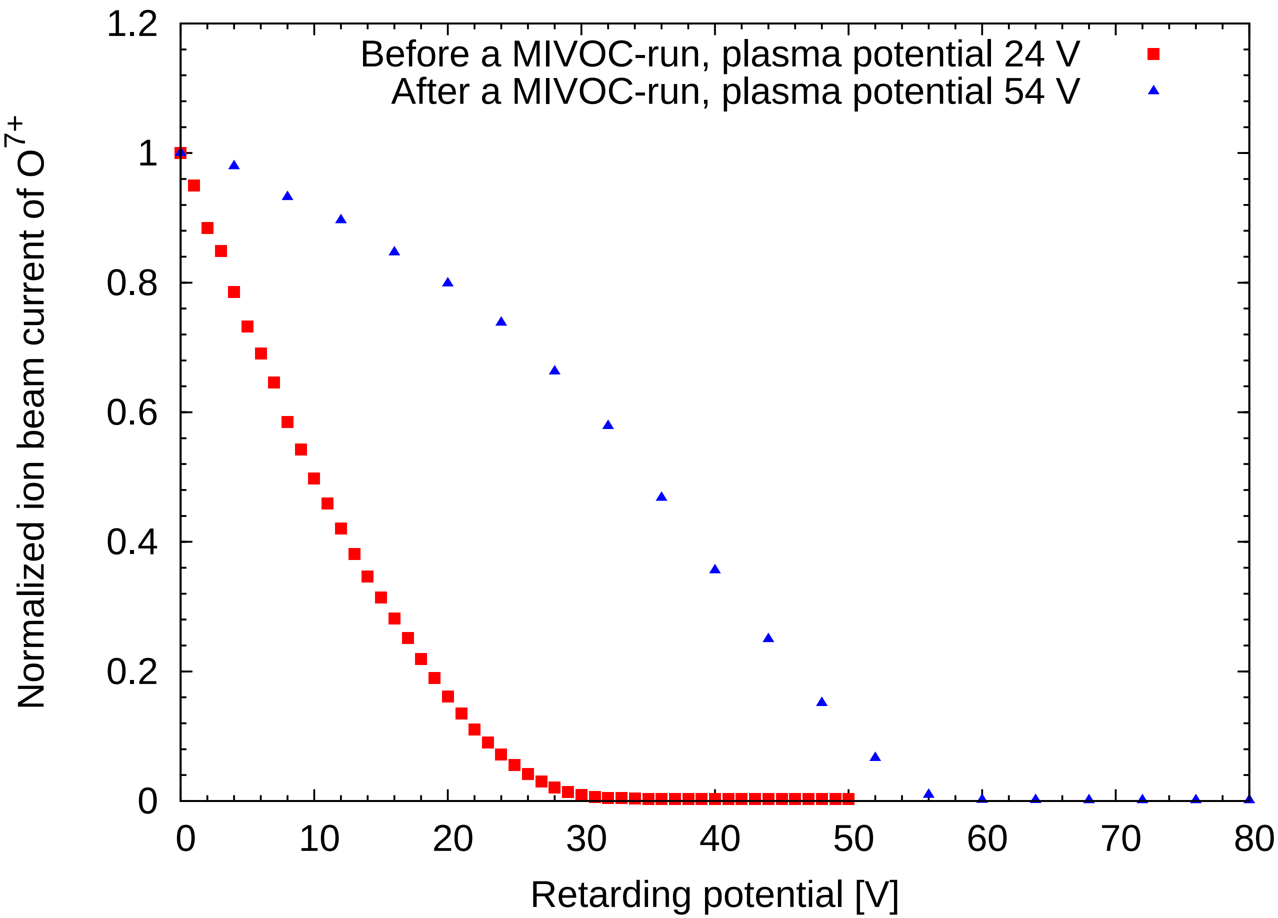
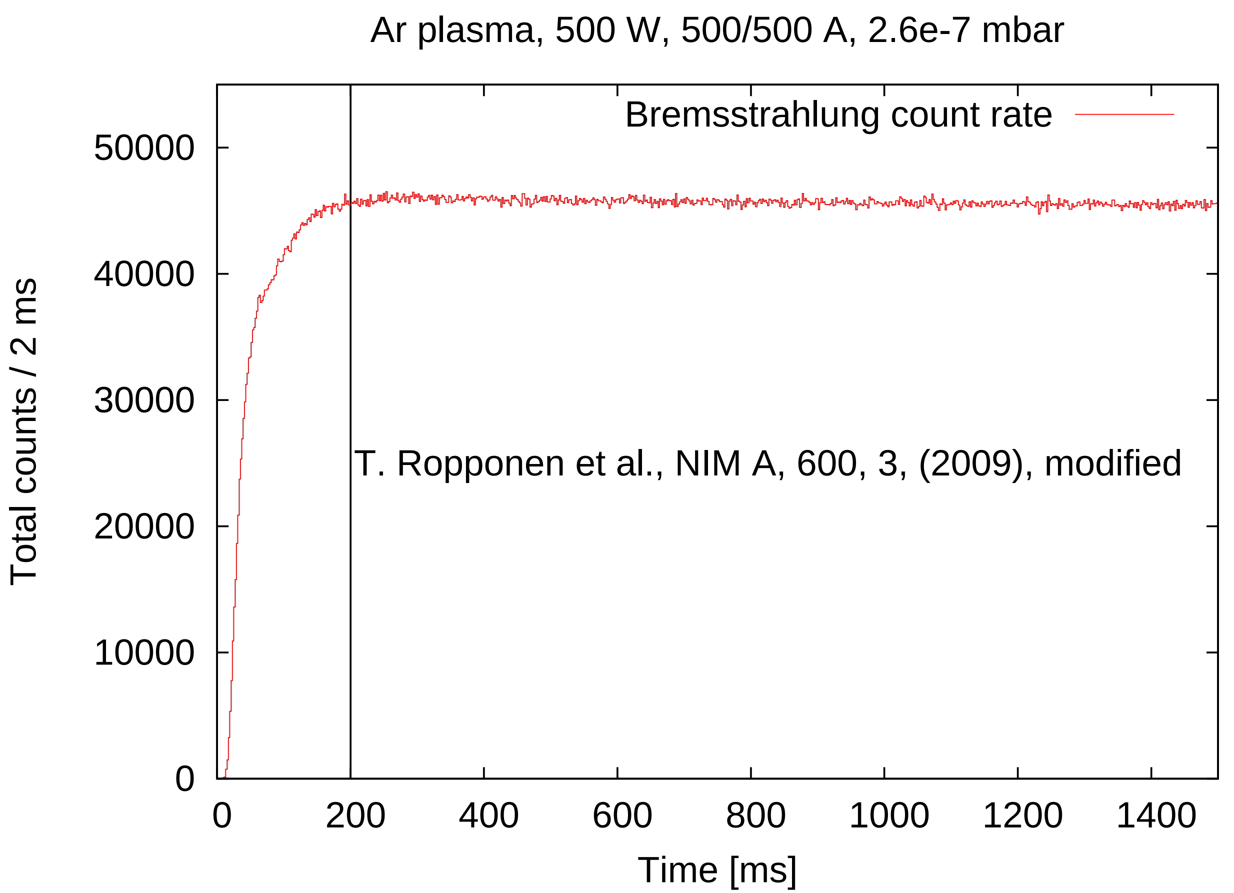
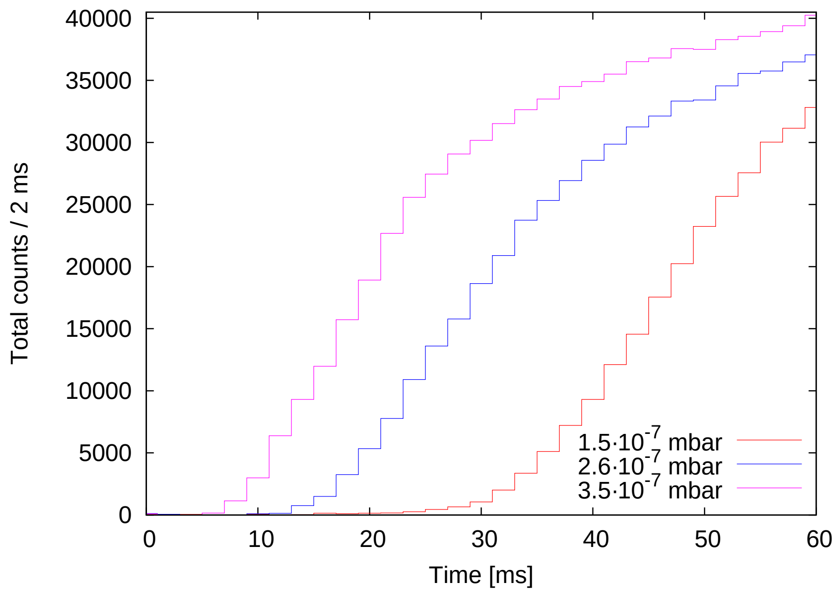
Effect of secondary electrons

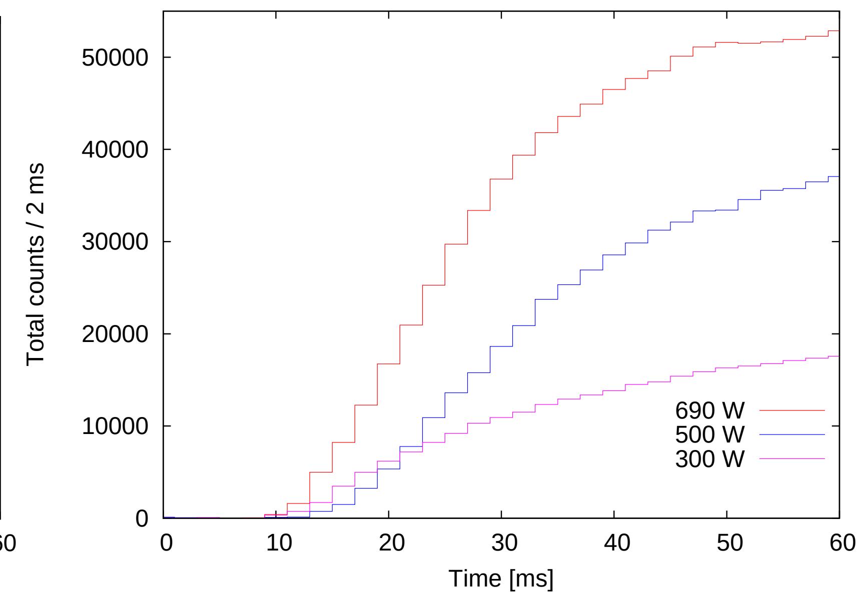


Reaching steady state bremsstrahlung emission



What happens in the beginning of the rf pulse?





T. Ropponen et al. Submitted to
IEEE Transactions on Plasma Science

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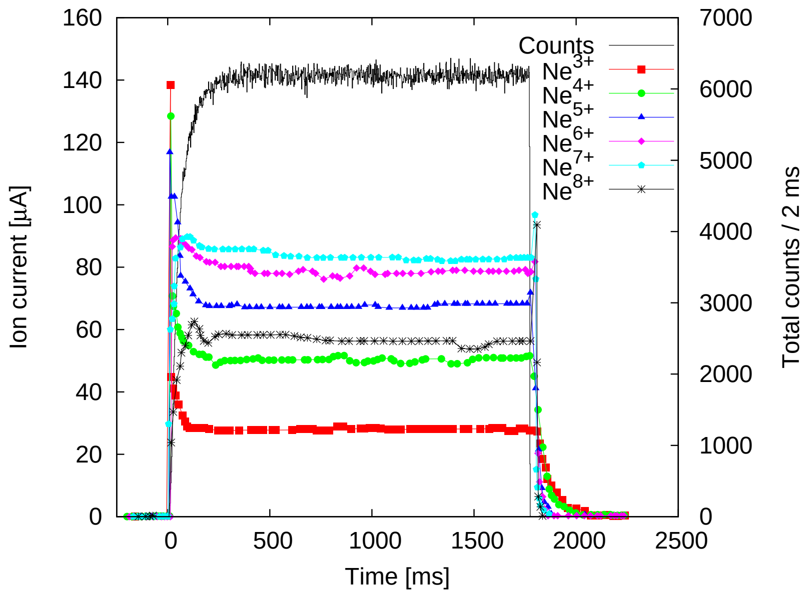
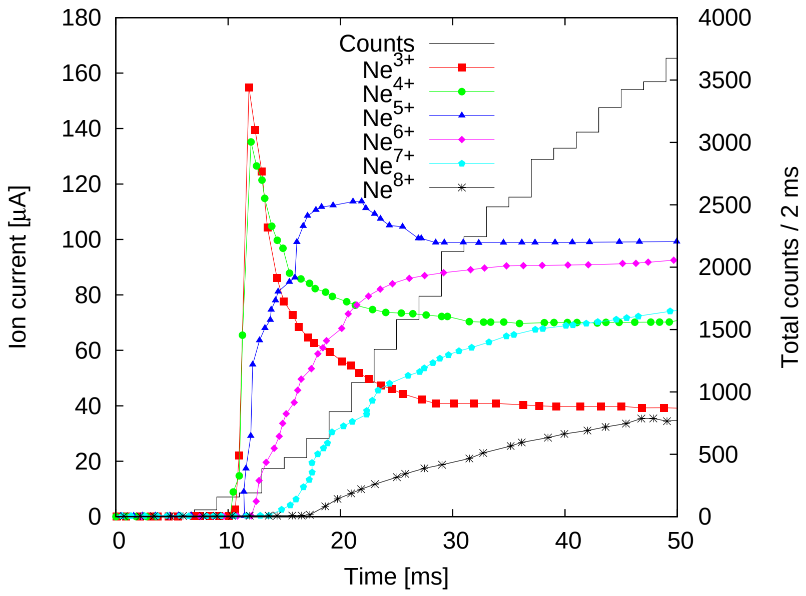
Time-resolved ion current – the preglow effect





Preglow – superadiabatic EEDF

- Theory:

  Microwave pulse is applied

  → All free electrons reach stochastic limit (EEDF is superadiabatic)

  → electron density increases

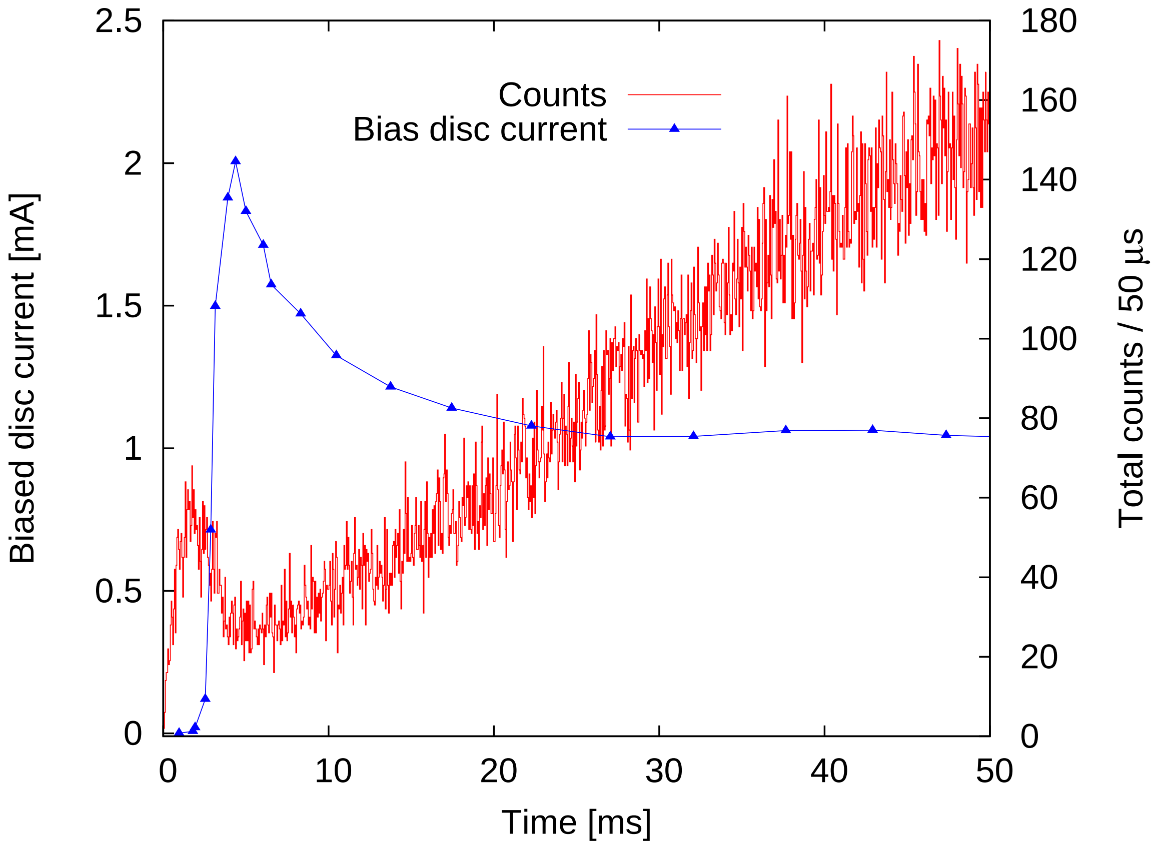
  → power not sufficient to maintain superadiabatic EEDF

  → average energy collapses

  → EEDF becomes the well-known double Maxwellian

I.V. Izotov et al. IEEE Transactions on Plasma Science, 36, 4, Part 2, (2008), p.1494.

Preglow – superadiabatic EEDF?



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Plasma breakdown time - theoretical

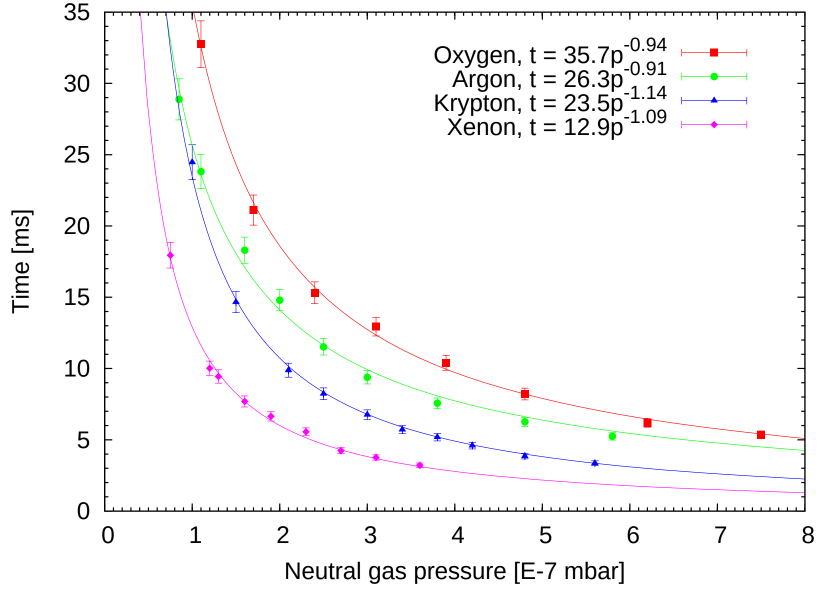
- Simple model based on volumetric rate of ionizing collisions

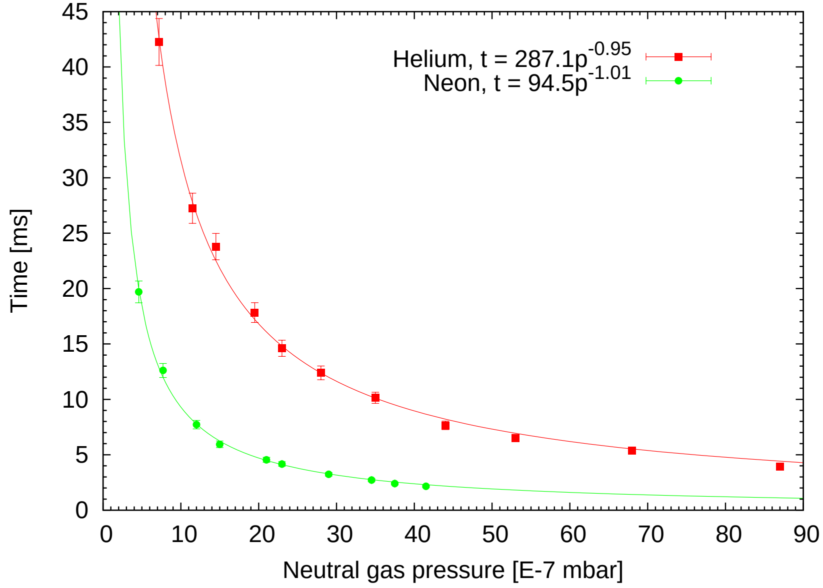
$$f = \frac{dn_e}{dt} = n_e n_n \langle \sigma_{ion} v \rangle$$

$$t_{breakdown} = \frac{\ln\left(\frac{n_{e,critical}}{n_{e,0}}\right)}{n_n \langle \sigma_{ion} v \rangle}$$

- Plasma breakdown time affected by
  - Neutral gas density
  - Neutral gas species (ionization probability)
  - Density of ”seed electrons”

Plasma breakdown time – Neutral gas density & species





O. Tarvainen et al. accepted for publication in Plasma Sources Science and Technology

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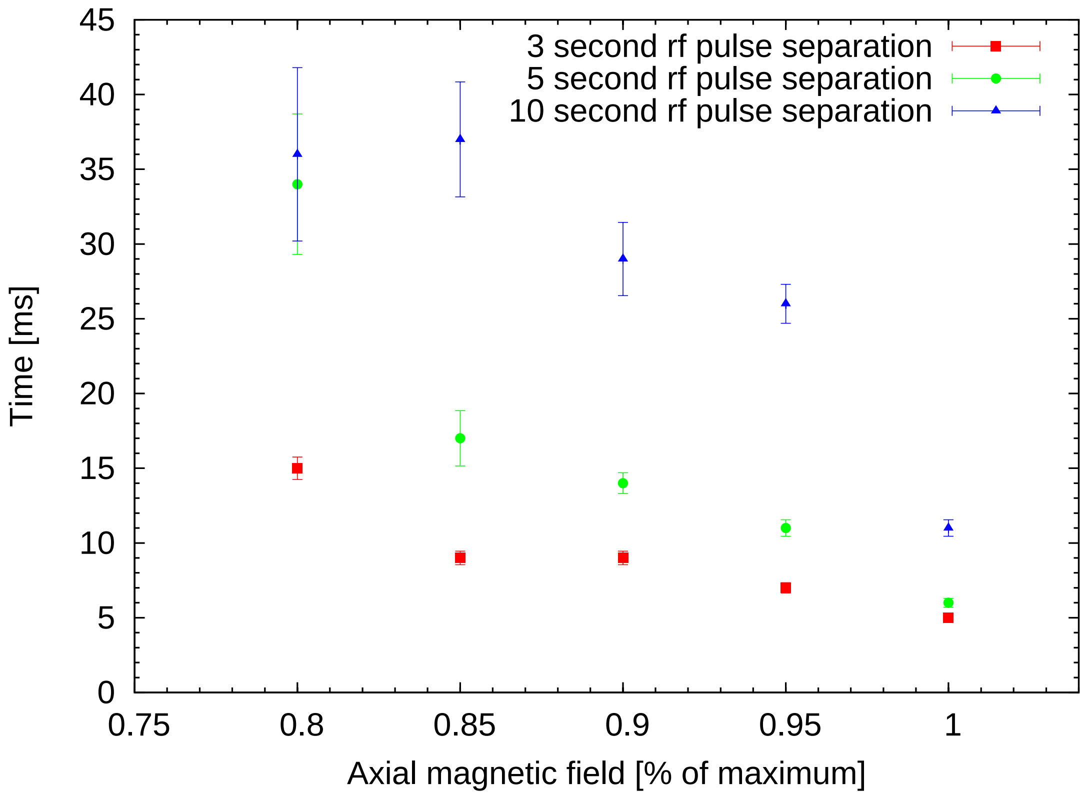
Plasma breakdown time – Seed electrons



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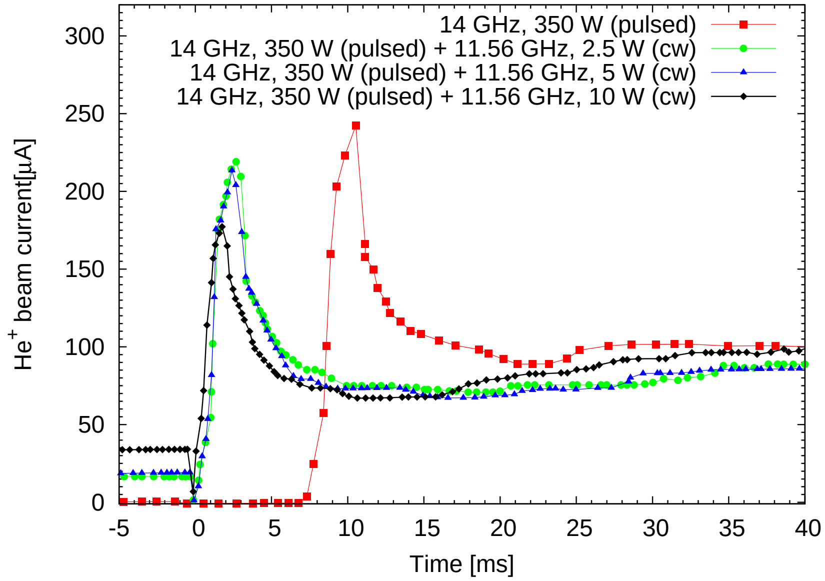

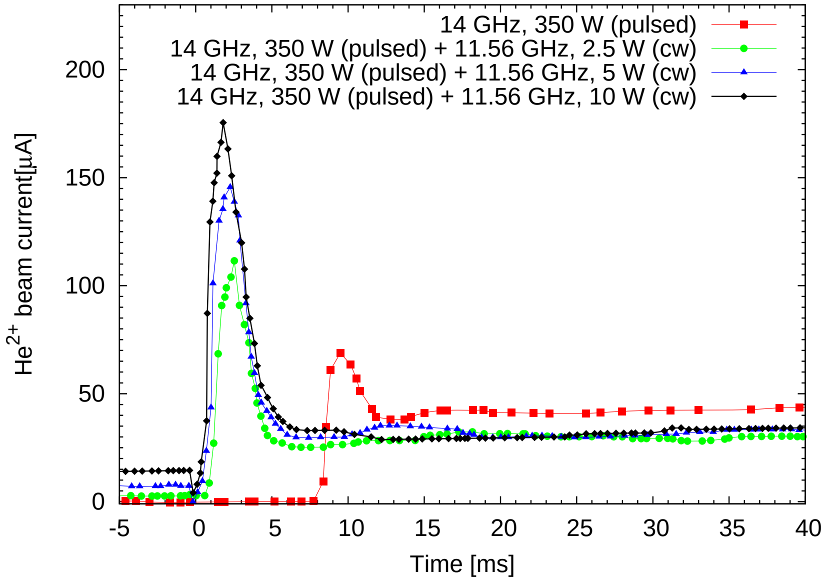

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Plasma breakdown time – Seed electrons

- Seed electrons
  - shift the preglow CSD towards higher charge states (faster ionization of HCI)
  - Optimize the repetition rate for afterglow?
- Beam optics seem to affect the shape of the preglow pulse
  - Plasma potential evolves
  - Degree of space charge compensation evolves

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Future prospects

- ”Upgrading” the ion beam cocktail at JYFL requires higher charge states than presently available
  - Pulsed operation mode could possibly be utilized for beam cocktails
  - More work is needed to understand the time scales related to HCI production in pulsed mode (to optimize repetition rate)