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Positive Ion Current – Hot Coulomb Explosion?

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Outline

First observations

Analytical calculations

Fit of theory to data

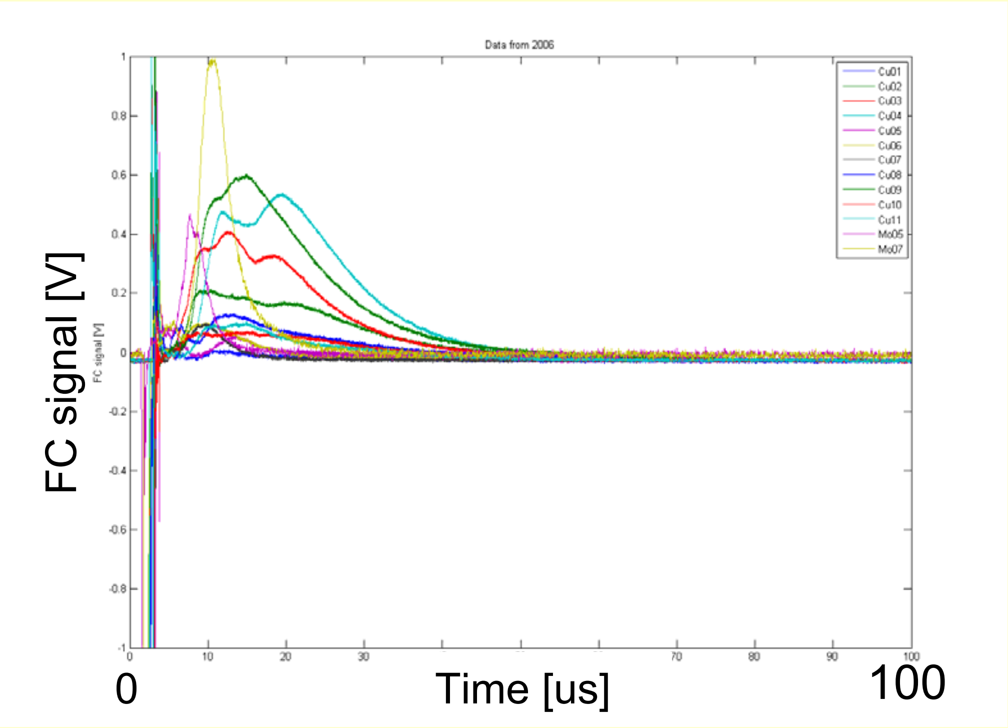
Recent and ongoing measurements

First observations

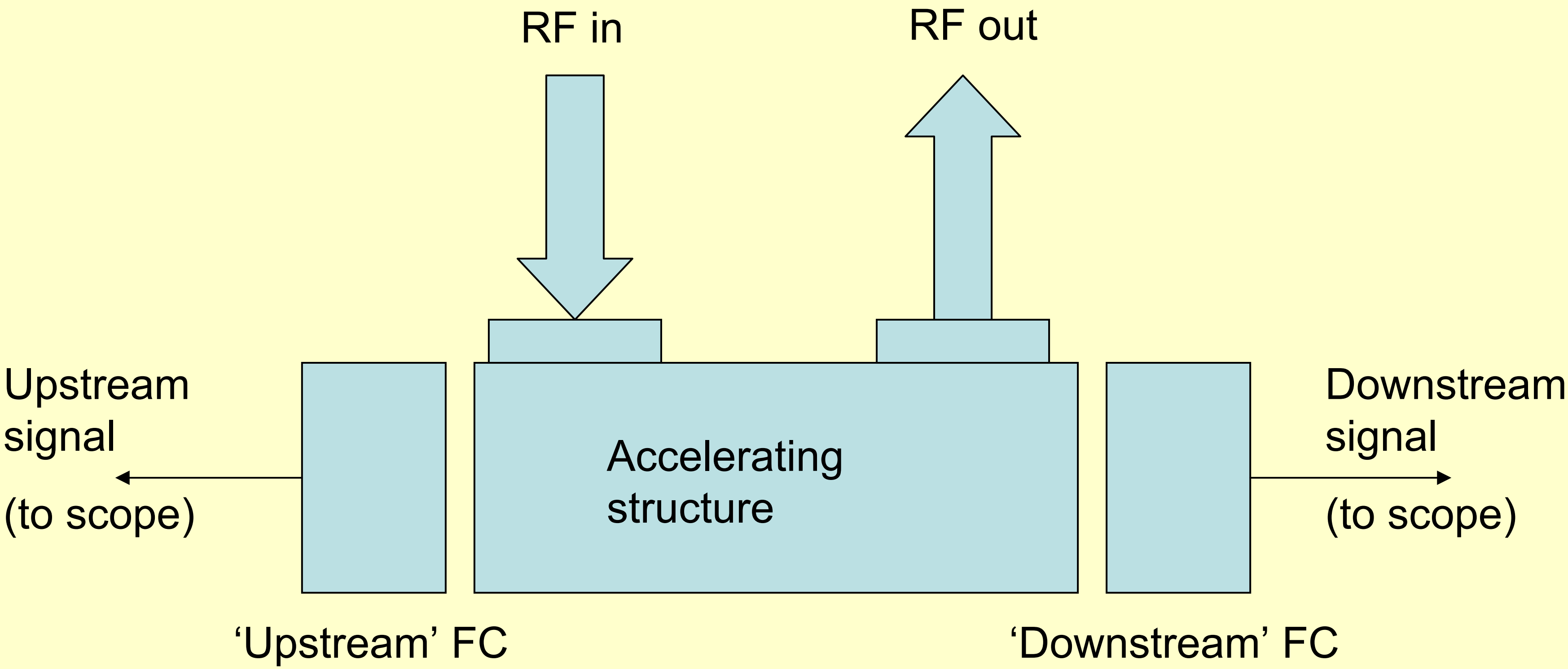
First measurements spring/summer 2006.

FC signal after RF-breakdown viewed by oscilloscope.

Timescale ~ 50 μs.



Set-up


RF in
RF out
Upstream signal
(to scope)
Accelerating structure
Downstream signal
(to scope)
'Upstream' FC
'Downstream' FC

Analytical calculations

- One possibility: Ion originates from **Coulomb explosion** of **spherical**, **homogenous** distribution of ions.

- Last & Jortner, Phys. Rev. A 71 (2005): **dN/dE, not** including motion due to temperature **T**.

- Ziemann, NIM. A 575 (2007): **dN/dt, including** motion due to temperature **T**.

- **dN/dt** = f (N_0, α, t_s)
  - $\mathbf{N_0}$ = number of particles in sphere
  - $\boldsymbol{\alpha}$ = RMS width of velocity distribution due to thermal motion (**T**)
  - $\mathbf{t_s}$ = arrival time of fastest ions from cold distribution.

Theory Fit

Fit to data allows for determining:

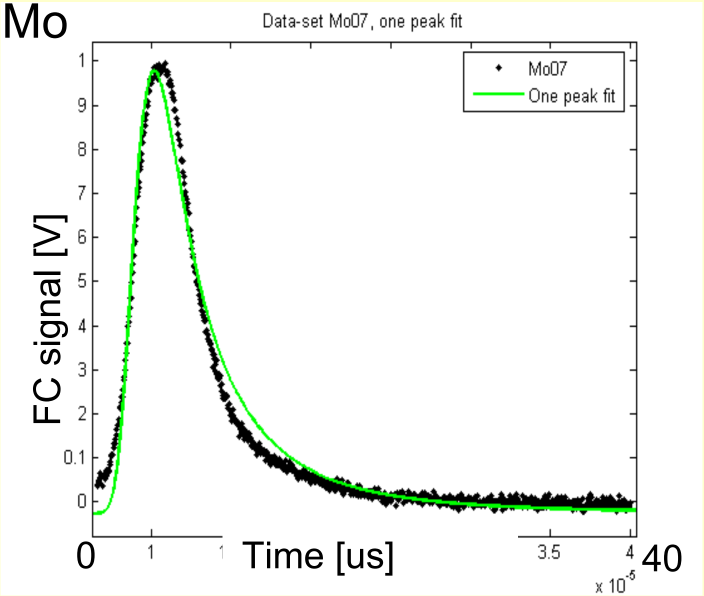
- temperature of ion sphere,
- number of particles in sphere,

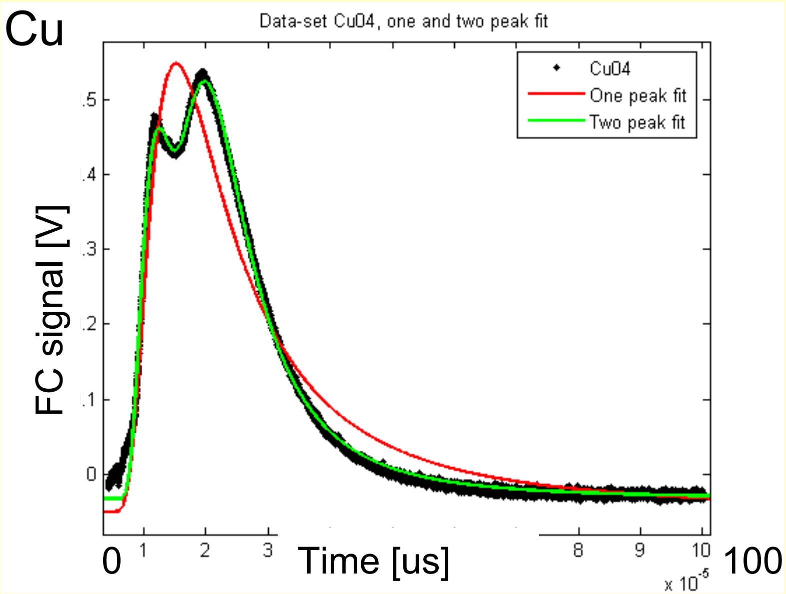
but only if

  - the distance to the detector
  - the mass of the ions
  - the number of ions reaching the detector is well understood
    (solid angle coverage, acceptance of FC etc, etc…)

…are all known!

First fit: 2006 data





Calculated **T**:
Mo: Order of **10 000 [K]**
Cu: Order of **30 000 [K]** resp. **7000 [K]**
(Assuming detector at 0,1 m distance,
Mass of ions = mass of Mo resp. Cu ions)

2006 Data Limitations

- Not many (11 Cu and 2 Mo)
- Set-up not well known
  - Acceptance of FC?
  - Distance to FC?
  - Signal attenuation?

$\longrightarrow$ **New measurements needed!**

Recent Measurements

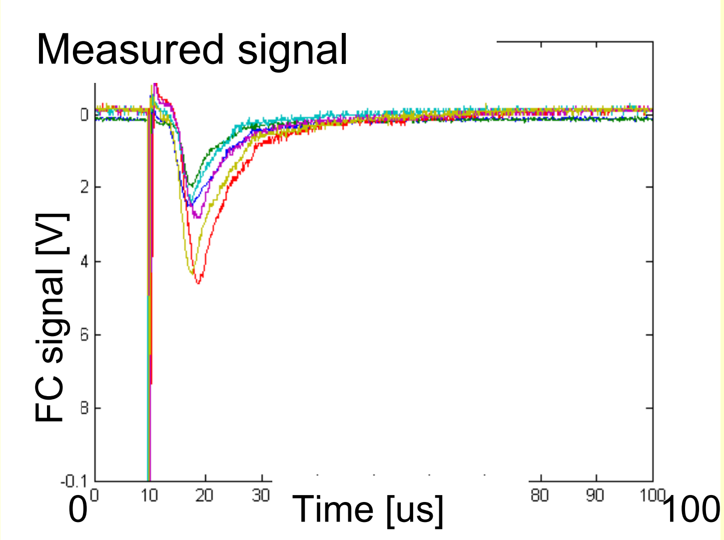
Negative signal!

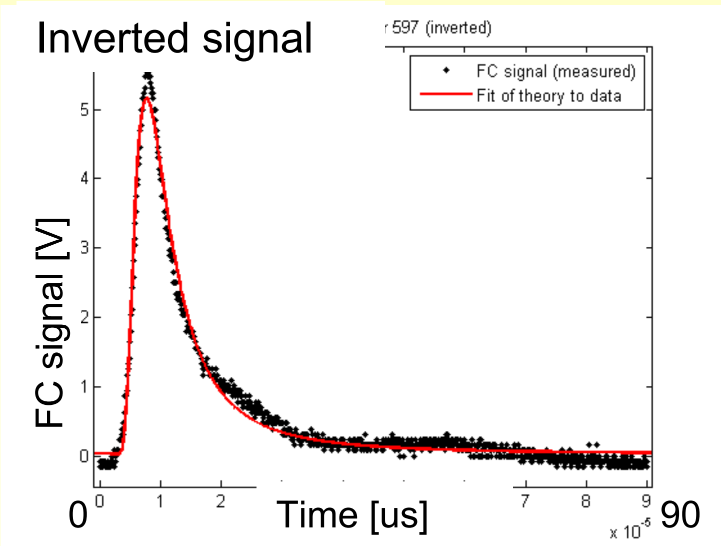
Explanation:
secondary e⁻ emission.
→ signal inverted if ion causes more than 1 electron emission (re-absorbed by FC)

→ Fit the inverted signal

Calculated **T**=order of 100 **[kK]**

Possible solution: put a bias voltage on the FC!





Ongoing Measurements

- Right sign from FC ion part.
- Need to add amplifiers. (Attenuation due to splitting signals several times).
- Need to add resistive power splitters (use BNC-T now → possibly reflections).
- Require calibration
- Need to vary bias voltage, RF pulse energy etc in order to increase understanding.
- Suggestions for future set-up (to use in two-beam test-stand):
  - Dipole magnet (separate ions from electrons, measure energy)
  - Silicon detector instead of FC (accurate measurement of N_0)

The Arrival-time Spectrum of Hot Coulomb Explosions

Arrival time spectrum (due to EM force and thermal motion):

$$\frac{dN}{dt} = \frac{3N_0\alpha^2}{\sqrt{\pi}t_s}\left(\frac{t_s}{t}\right)^2 V_2\left(\frac{1}{\alpha}, \frac{1}{\alpha}\frac{t_s}{t}\right),$$

$$V_2(w_s, s) = \frac{s}{2}e^{-s^2} - \frac{s+w_s}{2}e^{-(s-w_s)^2} + \frac{\sqrt{\pi}}{2}\left(s^2 + \frac{1}{2}\right)(erf(s) - erf(s-w_s)).$$

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3 free parameters in this model:

* $N_0 = \dfrac{4\pi\rho R^3}{3}$

N_0: Number of particles in initial sphere,

ρ: the number density of initial sphere,

R: the radius of initial sphere.

* $\alpha = \sqrt{2}\sigma / v_s,$

$\sigma = \sqrt{kT/m}$

α: RMS width of thermal velocity distribution divided by v_s,

k: Boltzmanns constant,

T: the temperature of the initial charge distribution,

m: the mass of the ions.

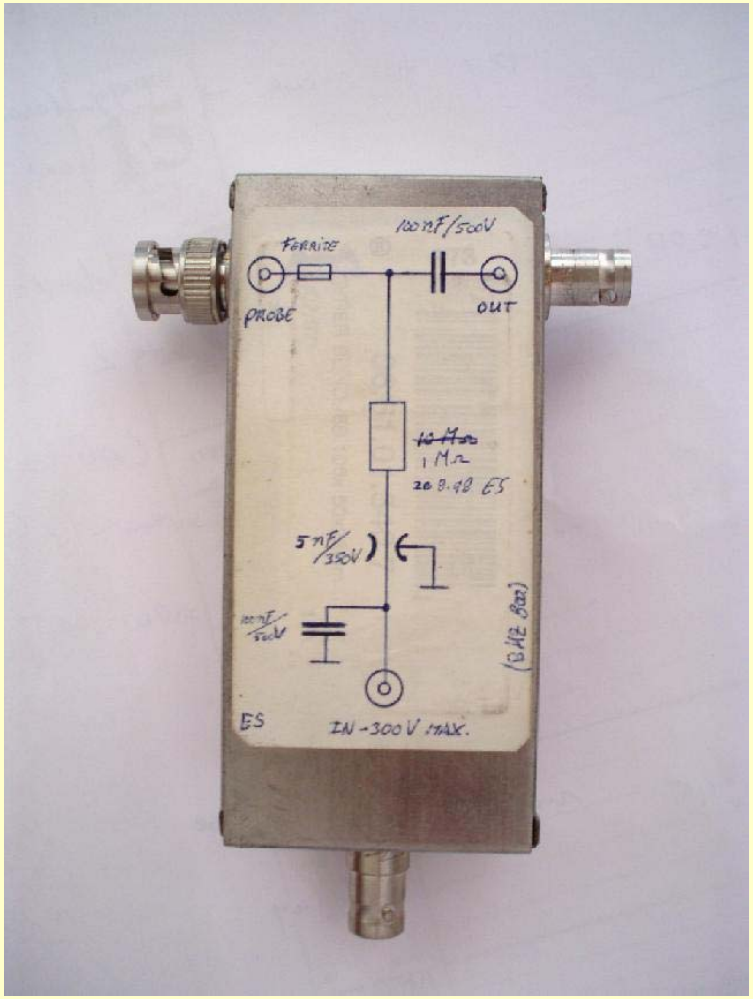
* $t_s = L / v_s$

t_s: arrival time of the fastest ions from cold distribution,

L is the distance from the detector to the Coulomb explosion,

v_s is the velocity of the fastest ions from a cold Coulomb explosion

HV Bias Box

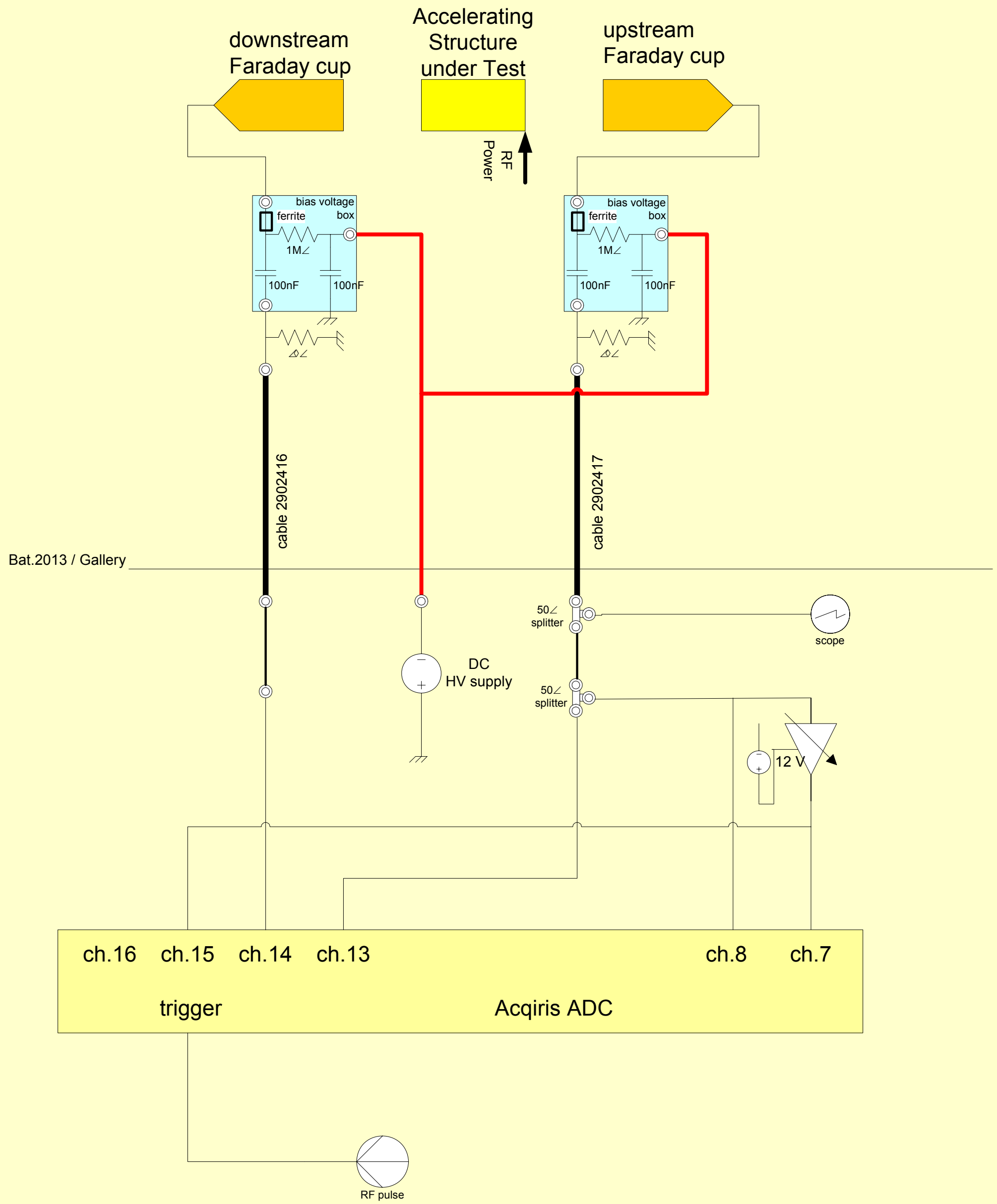


FC (left) sees a high-pass filter with cut-off frequency of 1.5 Hz

HV (bottom) sees a low-pass filter with cut-off frequency of 1.5 Hz

Signal out (right) is decoupled by a capacitance, and has 0 bias voltage.

Signal Schematic



Cu and Mo properties

- Boling point
  - Cu: 2855 **[K]**
  - Mo: 5830 **[K]**
- Heat of vaporization
  - Cu: 4.75 **[MJ/kg]**
  - Mo: 6.83 **[MJ/kg]**
- Energy per RF pulse ~ 1 **[J]**
  - enough to vaporize order of 1 mg material
  - 1 mg copper corresponds to a sphere with radius R=0.3 **[mm]**

- Ionization energy
  - Cu: E_{ion} = 7.478 **[eV]**
  - Mo: E_{ion} = 7.099 **[eV]**

- Temperature needed to ionize Cu: $E_{ion}=(3/2)*k_B*T_{ion}$ $\rightarrow T_{ion} = 2*E_{ion}/(3*k_B)$ ≈ 100 **[kK]**

Abstract

RF-breakdowns in the CTF accelerating structures have been observed to be accompanied by a fast burst of negative particles (electrons, ns scale), and a slower burst of positive particles (possible ions, us scale). One possible source of the slow ion burst is a hot coulomb explosion. A theory which predicts the arrival time spectrum of particles from such an event have been derived. Previously taken data from CTF have been fitted to this theory. Current and future measurements of the ions are discussed.