Some Applications of Diamond Detectors in the Atomic Physics Division of GSI

Christophor Kozhuharov

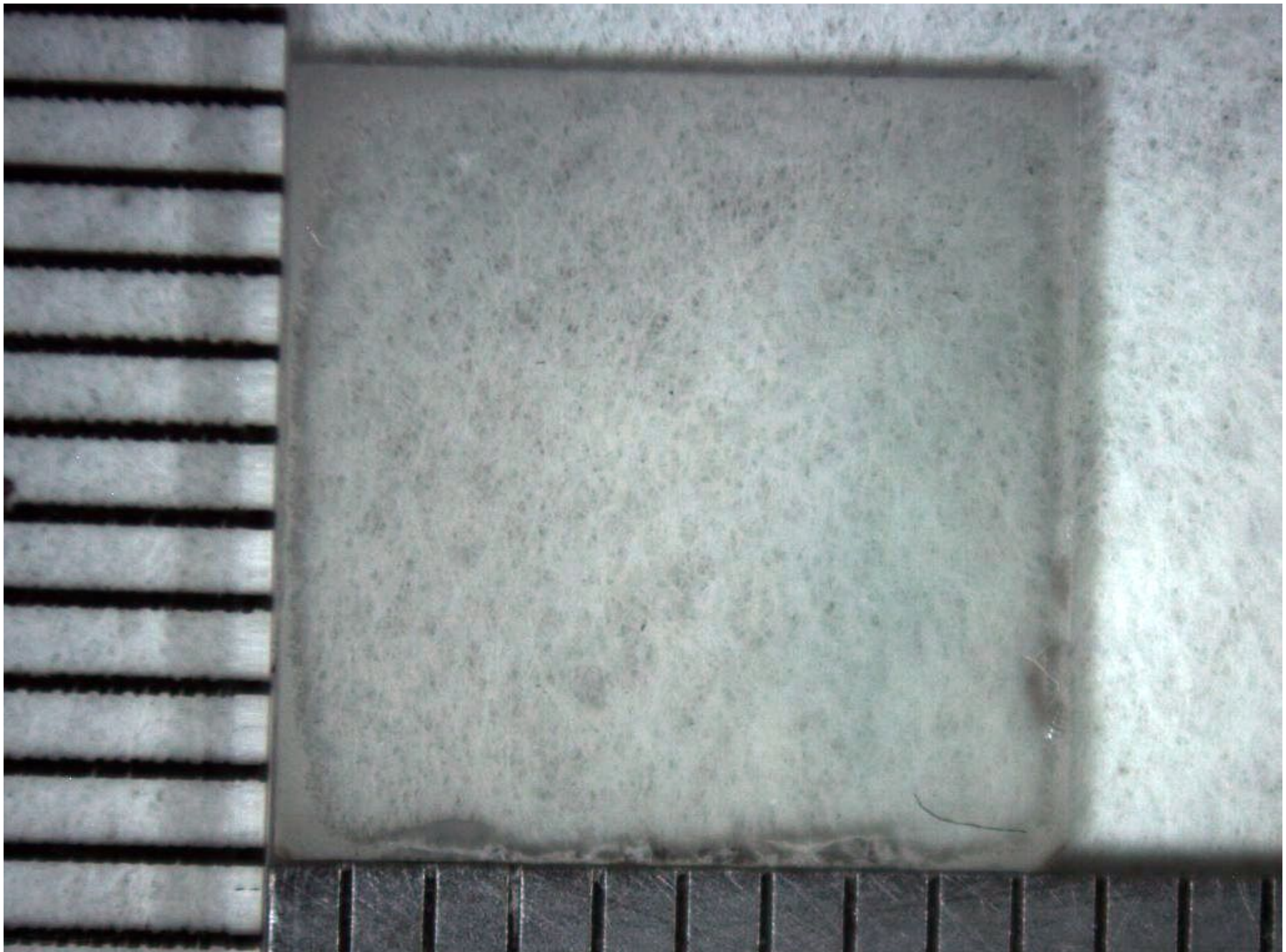
1st CARAT Workshop at GSI

15-Dec-2009

Ordered SC Diamonds

as of December 2009

photograph courtesy of Kevin Oliver



Rückschau: Diamantentest – Falsches Funkeln?
Sendedatum: Sonntag, 13. Dezember 2009

Erst seit wenigen Jahren haben es russische und amerikanische Firmen geschafft, die Herstellungsmethoden der synthetischen Diamanten so zu verfeinern, dass sie konkurrenzfähige Schmuckdiamanten züchten können. Lupenrein und zu einem Drittel des Preises. Und die Entwicklung steckt noch in den Kinderschuhen.

Neue Verfahren lassen immer bessere Qualitäten und höhere Karatzahlen zu. Im CVD Verfahren werden die Diamanten nicht mehr, wie traditionell üblich, unter hohem Druck und hohen Temperaturen gepresst, sondern wachsen in einem Kohlen-Wasserstoff Gasgemisch Schicht für Schicht heran. Kleinste Verunreinigungen und Einschlüsse, ein Nachteil der Hochdruck-Methoden, können so verhindert werden. In Europa noch ziemlich unbekannt, werden diese Labor-Steine in Amerika bereits offensiv vermarktet.

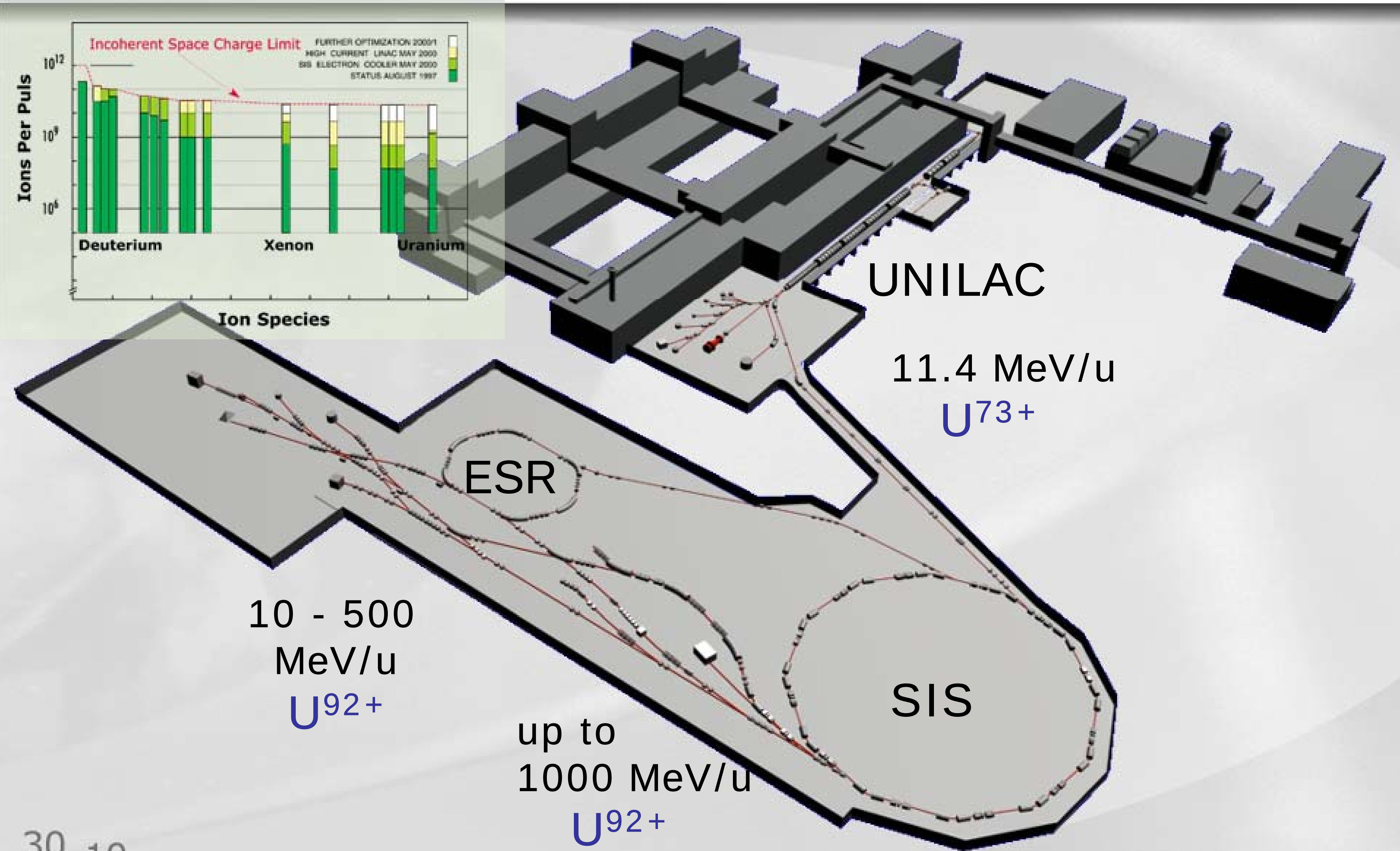
Adressen & Links
Die Goethe-Universität in Frankfurt am Main forscht zu Diamanten:
www.hochdrucklabor.uni-frankfurt.de
In Österreich beschäftigen sich Mineralogen mit der Gemmologie, der Edelsteinkunde:
www.gemmologie.at
Autor: Krischan Dietmaier (WDR)
Dieser Text gibt den Fernsehbeitrag vom 13.12.2009 wieder. Eventuelle spätere Veränderungen des Sachverhaltes sind nicht berücksichtigt

Outline

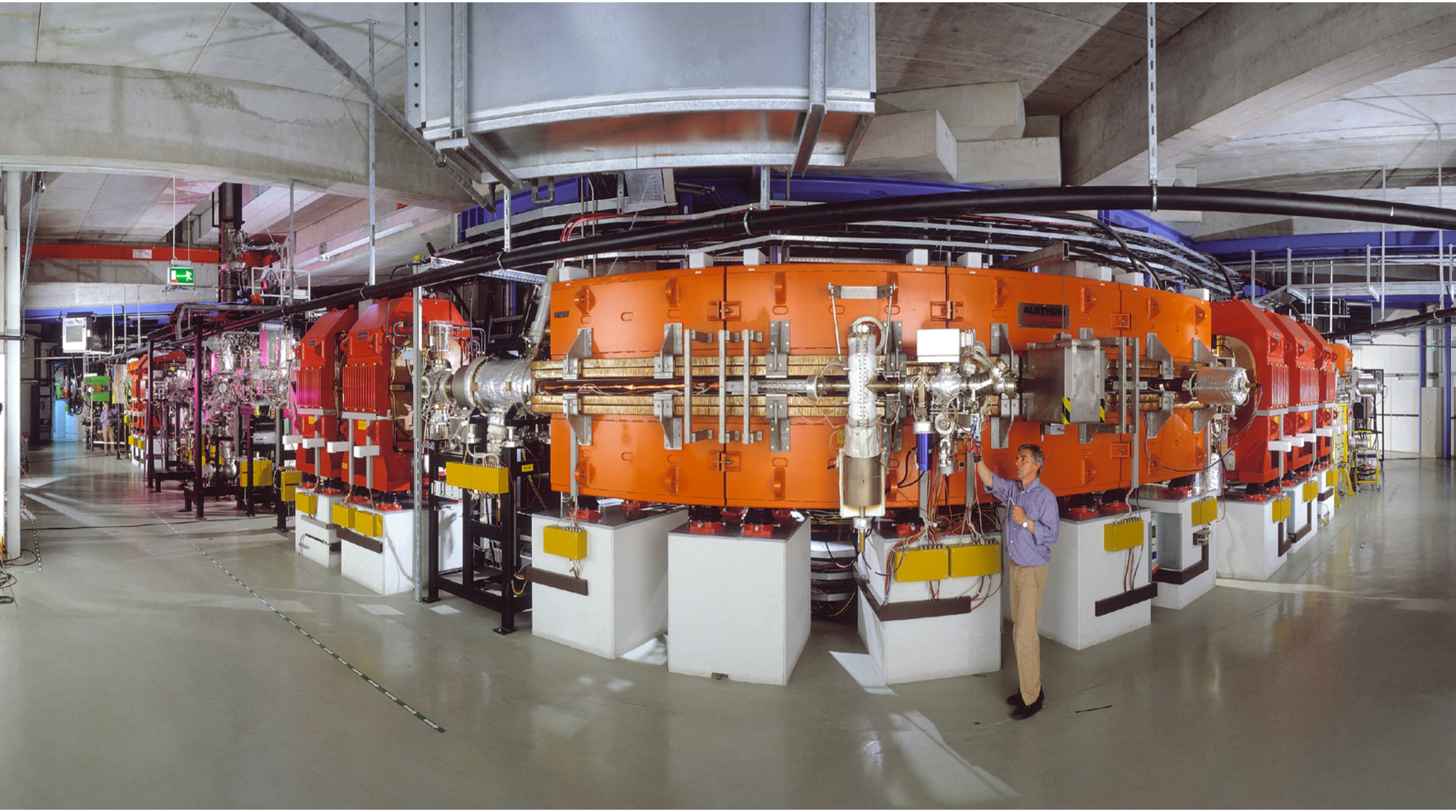
- Atomic Physics Division at GSI:
  - Experimental Areas
    - ESR incl. HITRAP, UNILAC (Cave A)
- Diamonds at HIITRAP:
  - Bunch length Measurement
  - Energy measurements
- Diamonds at ESR:
  - Necessity (cold beams, 'gas'-jet droplets...)
  - Future plans (ultra high vacuum 10^{-11})
- Diamonds at the UNILAC
  - Low-energy electrons (sub keV)
- Summary and Outlook

The Atomic Physics Division at GSI

GSI Accelerators

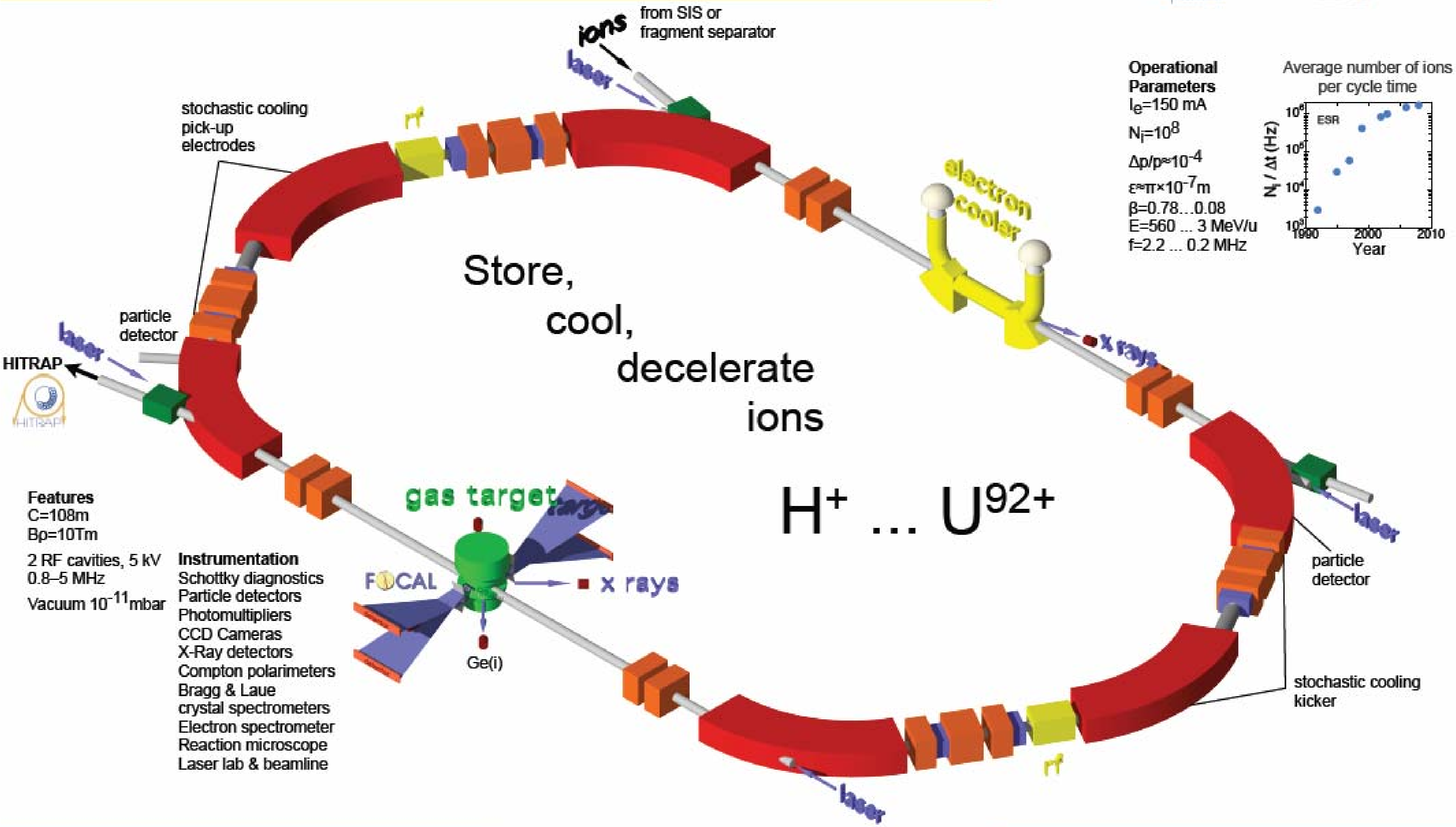


The Experimental Storage Ring, ESR



Atomic Physics

Experimental Storage Ring

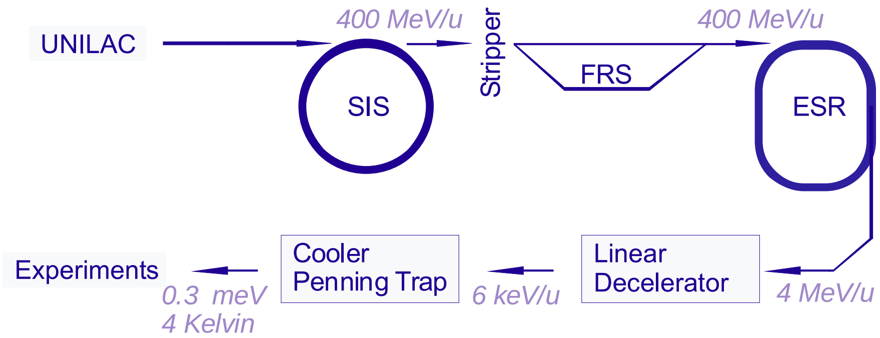


Operational Parameters
I_e=150 mA
$N_i=10^8$
$\Delta p/p \approx 10^{-4}$
$\varepsilon \approx \pi \times 10^{-7}$ m
β=0.78…0.08
E=560 … 3 MeV/u
f=2.2 … 0.2 MHz

Features
C=108m
Bρ=10Tm
2 RF cavities, 5 kV
0.8–5 MHz
Vacuum 10^{-11} mbar

Instrumentation
Schottky diagnostics
Particle detectors
Photomultipliers
CCD Cameras
X-Ray detectors
Compton polarimeters
Bragg & Laue
crystal spectrometers
Electron spectrometer
Reaction microscope
Laser lab & beamline

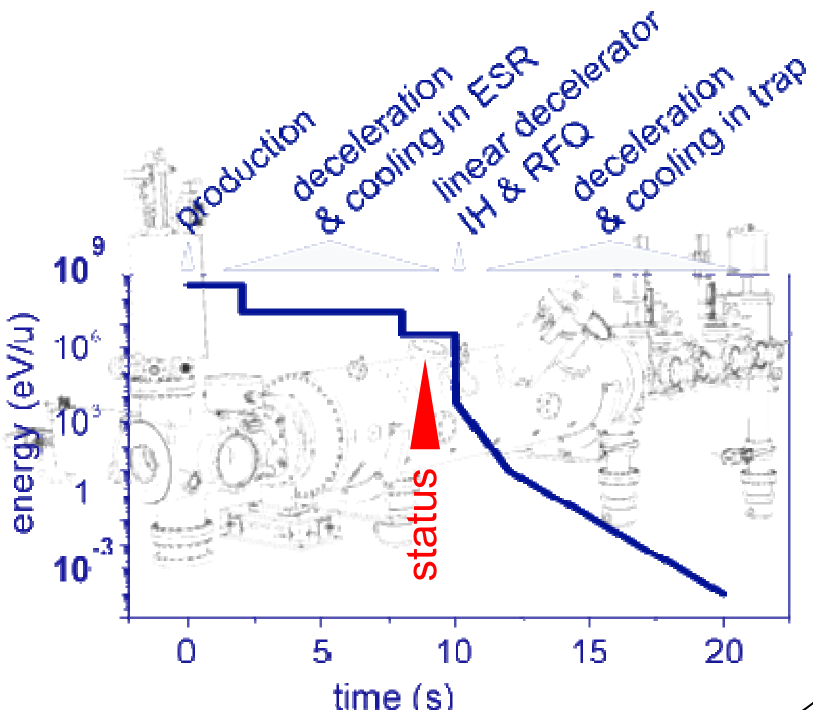
The HITRAP Facility



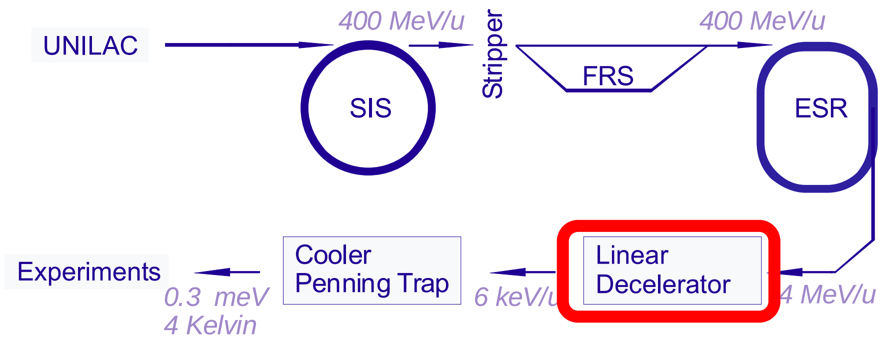
Beam available to users – intense source of HCI

type	A/q < 3 (U^{92+} ...)
ions/sec	10^4
ions/pulse	10^5
energy	keV/q ... meV/q
energy spread	≥ 0.3 meV

Deceleration cycle – 13 orders of magnitude reduction in energy



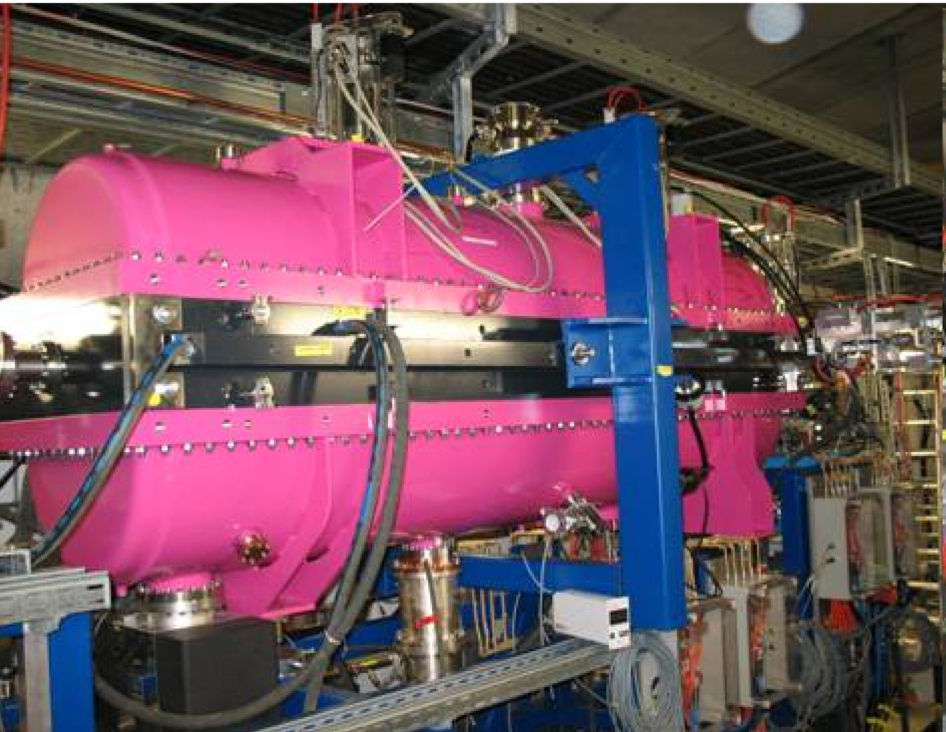
The Linear Decelerator



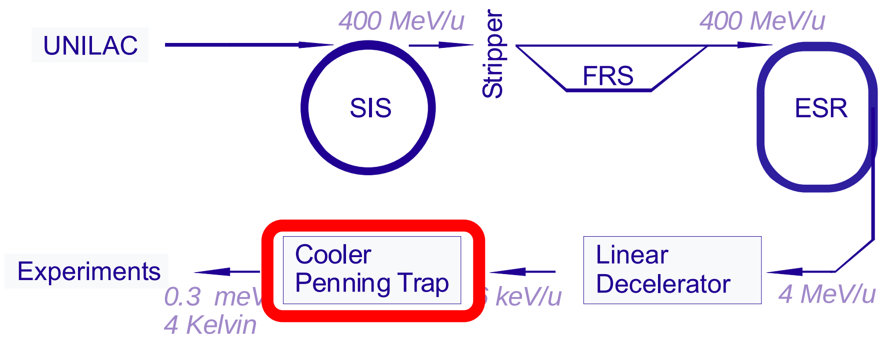
Two-step linear decelerator

- interdigital H-type structure (IH)
4 MeV/u to 500 keV/u

- radio-frequency quadrupole (RFQ)
500 keV/u to 6 keV/u

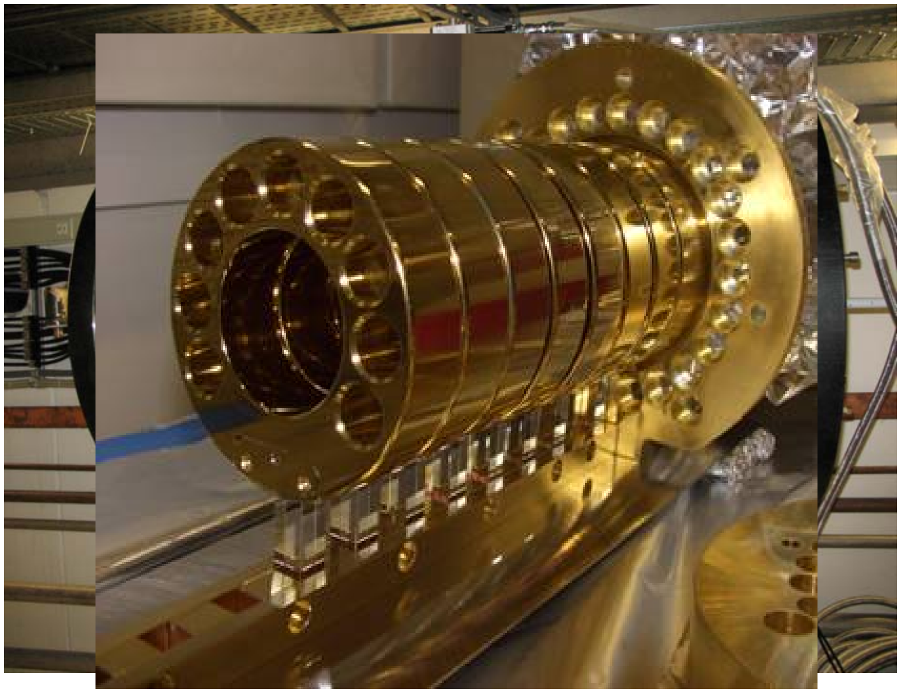


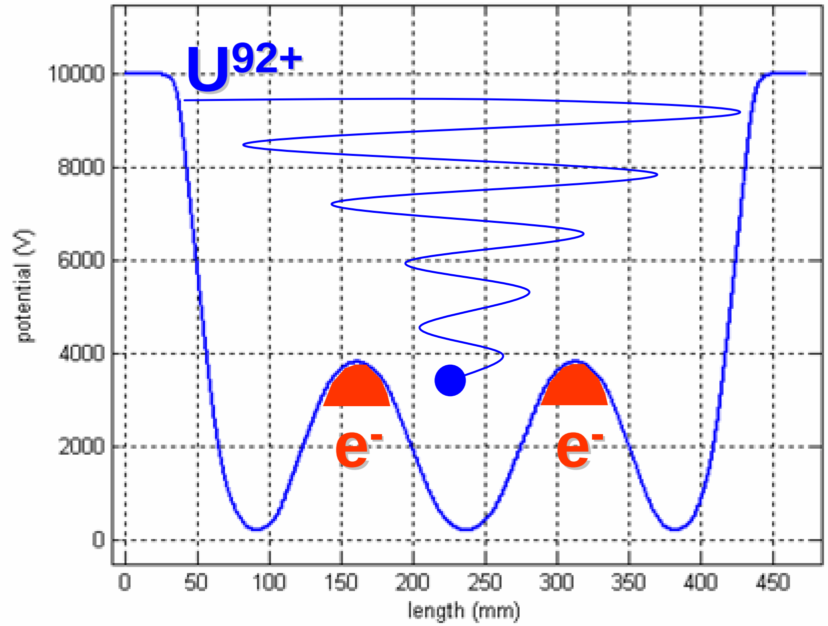
Cooler Penning Trap



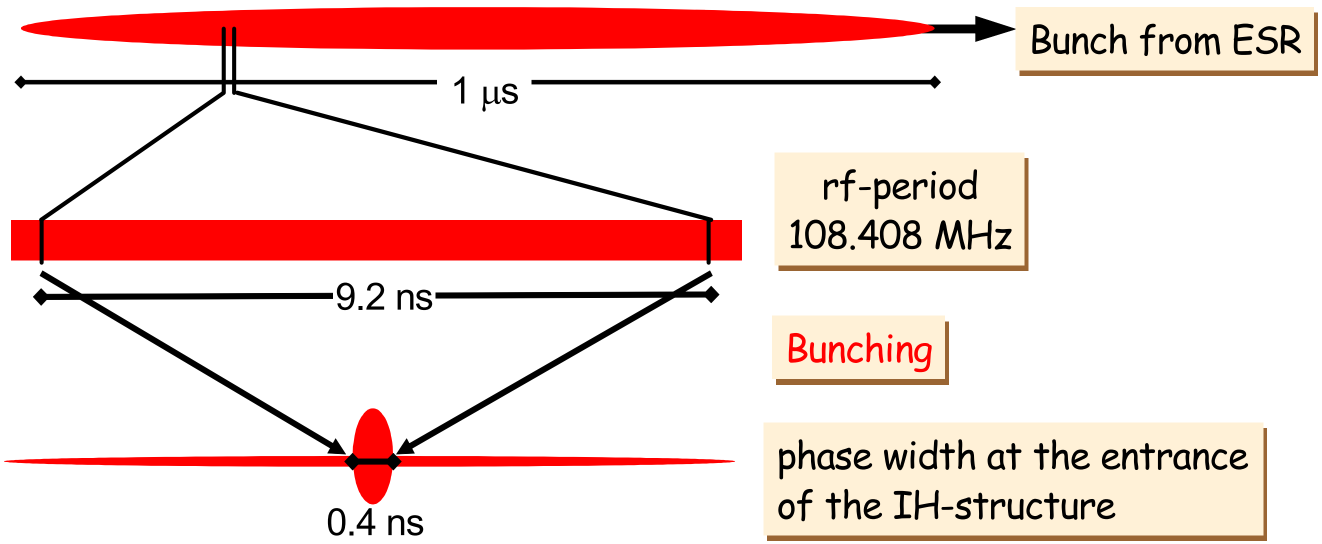
Combination of electron and resistive cooling

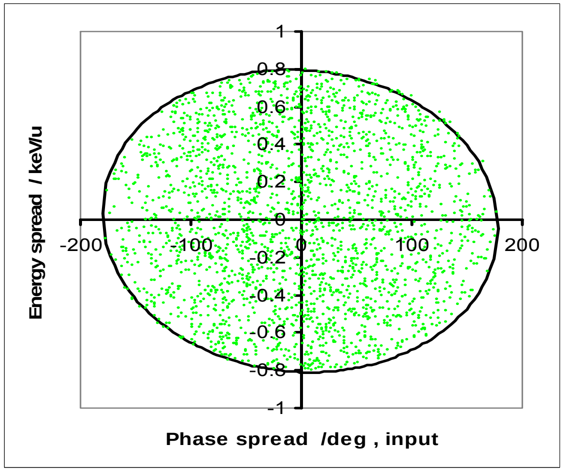
final temperature	4K
charges to store	10^7



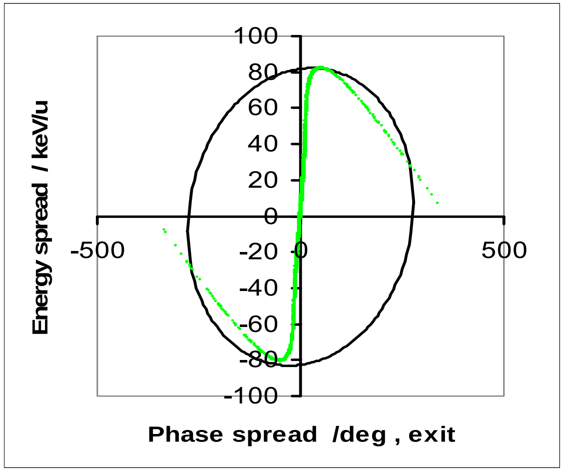


Beam dynamics design: Bunching of the ESR beam

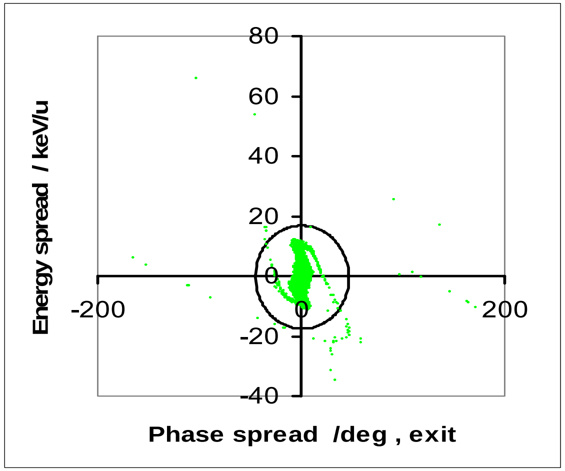




entrance DDB

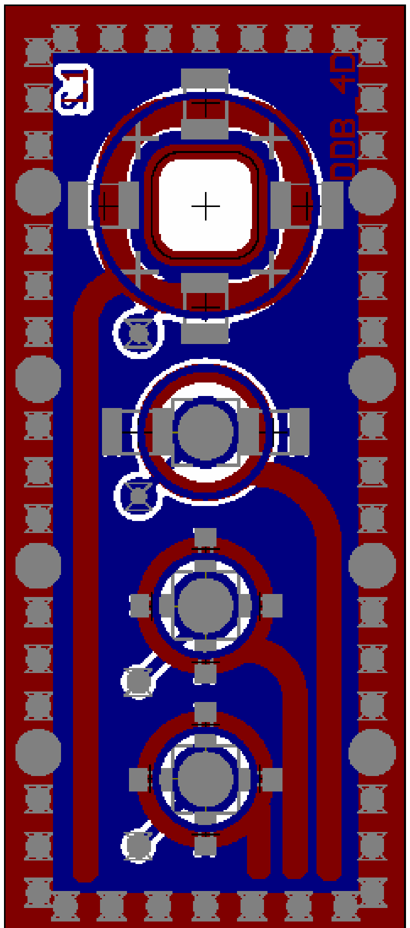


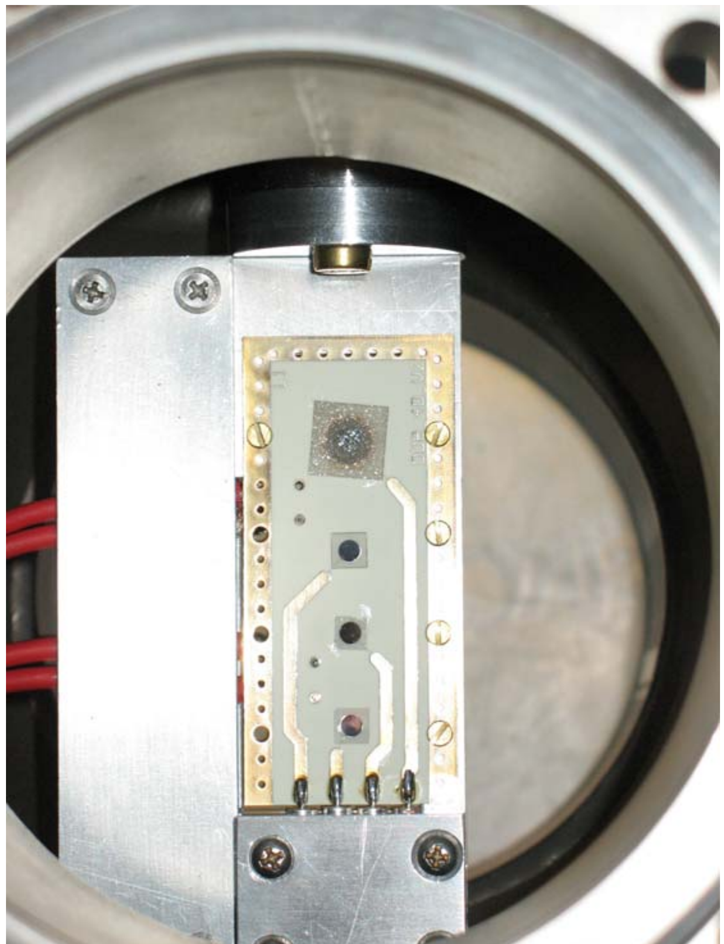
entrance IH-structure



entrance RFQ

HITRAP Commissioning Detectors





^{20}Ne, E/A = 4MeV/u

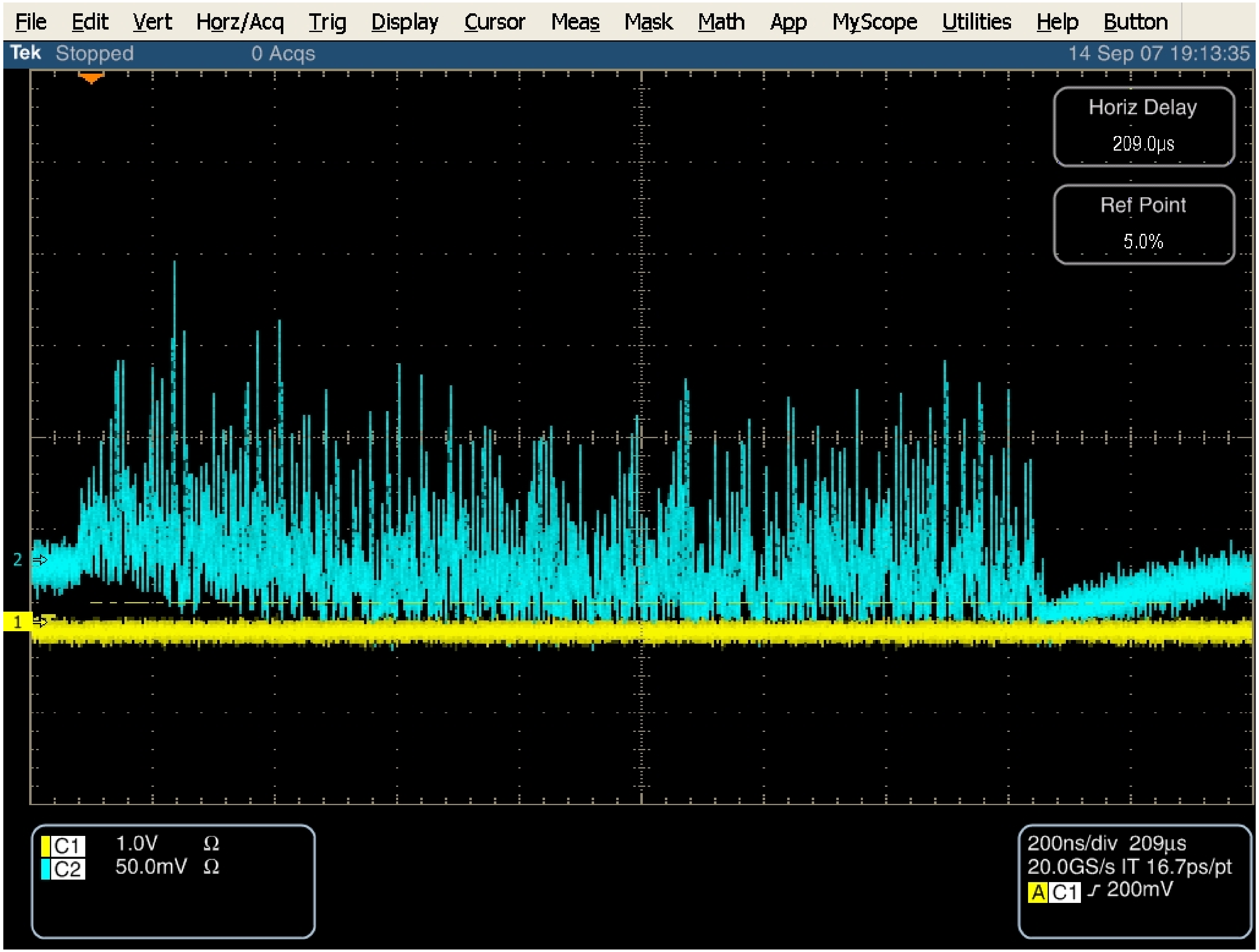
Detectors:

- Poly-crystalline CVD
  600 μm
- Single crystal CVD
  480 μm
- Poly-crystalline CVD
  15 μm thick
- Poly-crystalline CVD
  10 μm thick

Diameter of the active areas
for all detectors = 3 mm
(smaller capacitance)

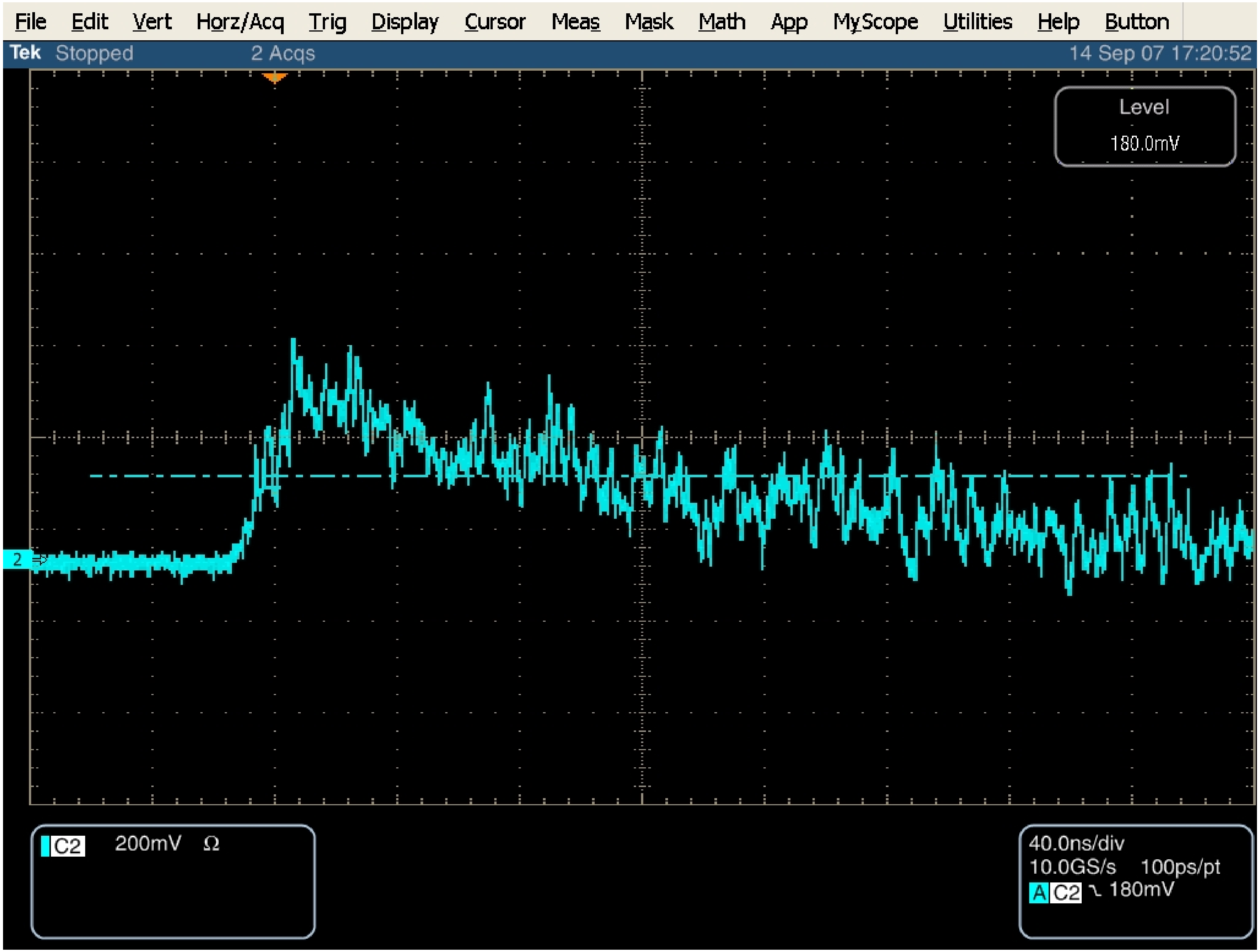
Fast amp for the pc-CVDs.

Extraction pulse from ESR

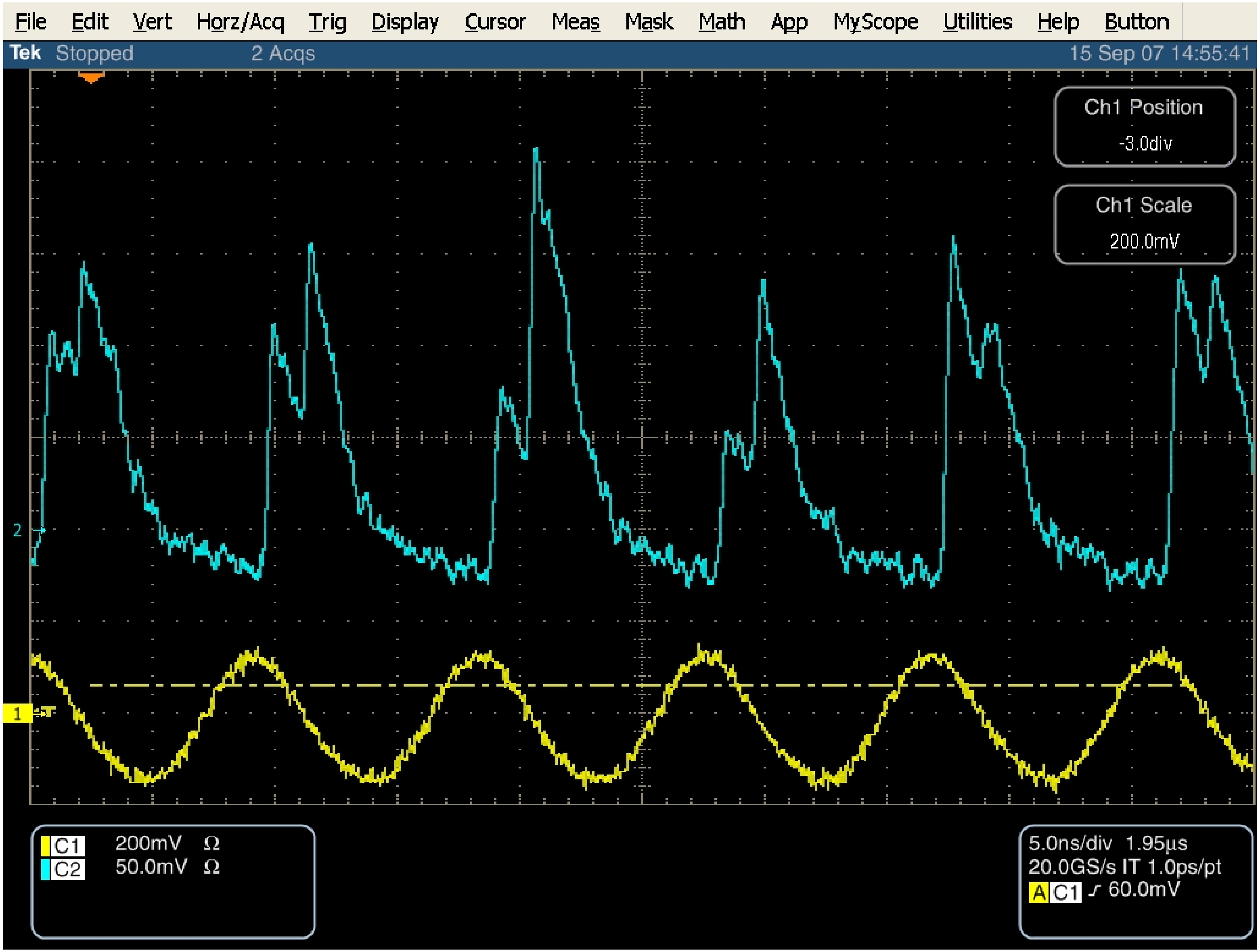


15 µm PC with DBA amplifier (x100)

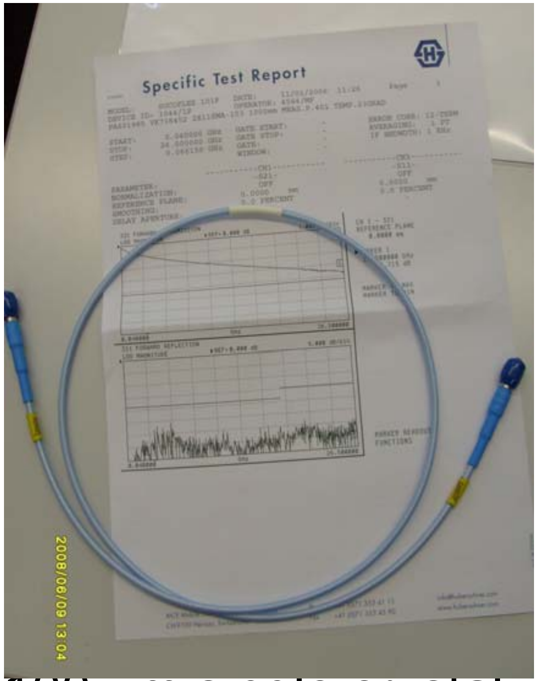
Extraction pulse without applying bunching RF.

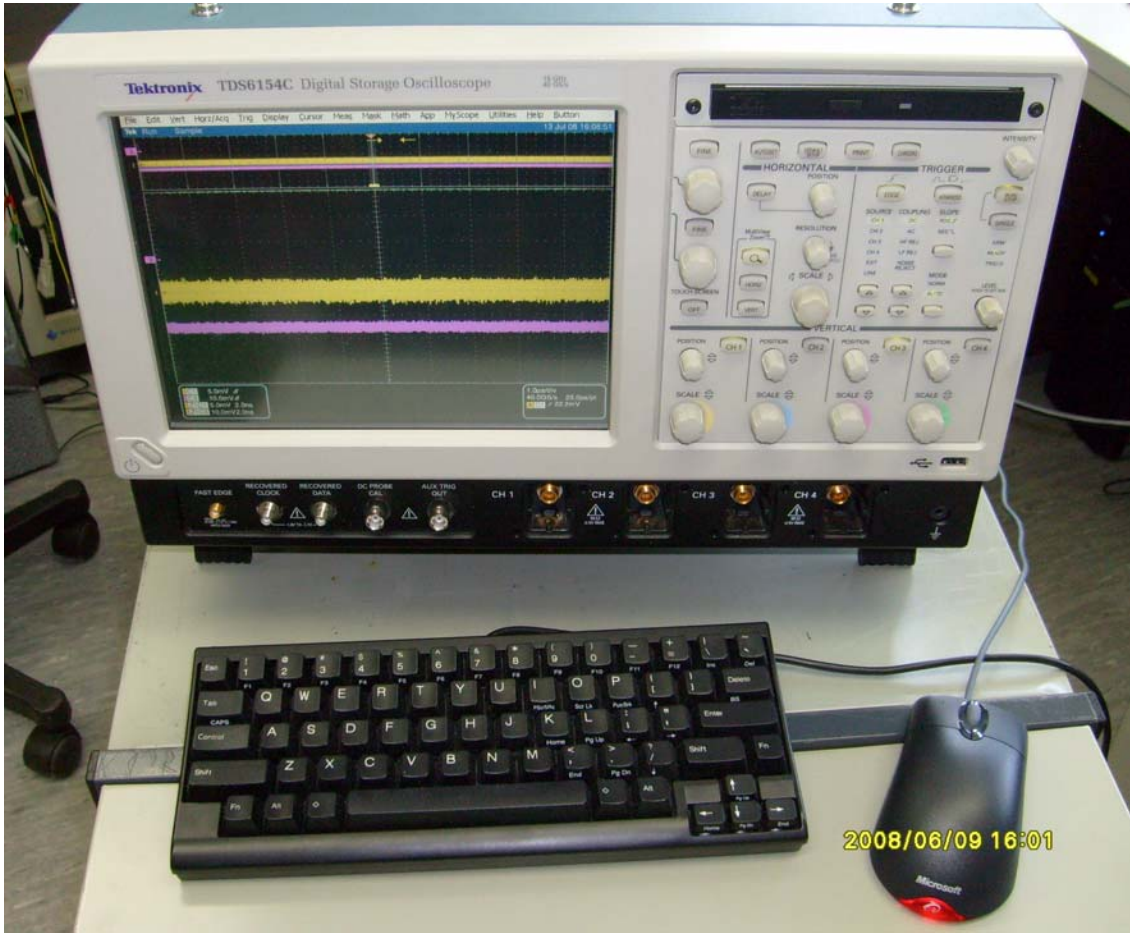


Bunching RF applied



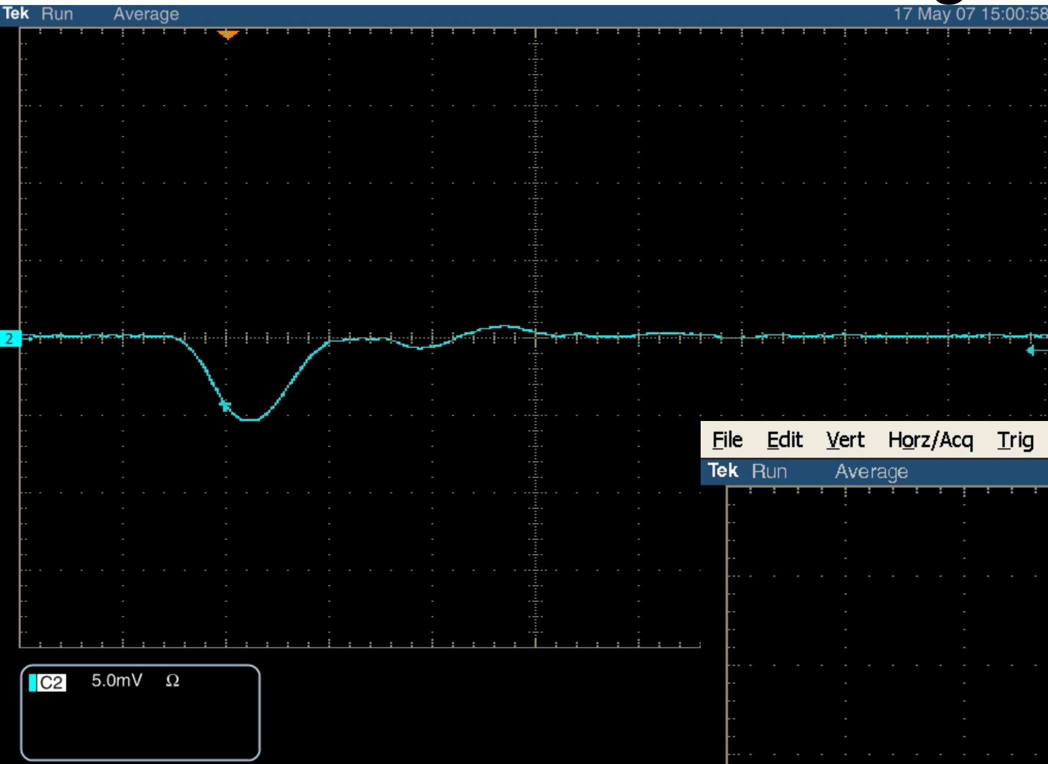
Test of a single crystal diamond detector with α-particles





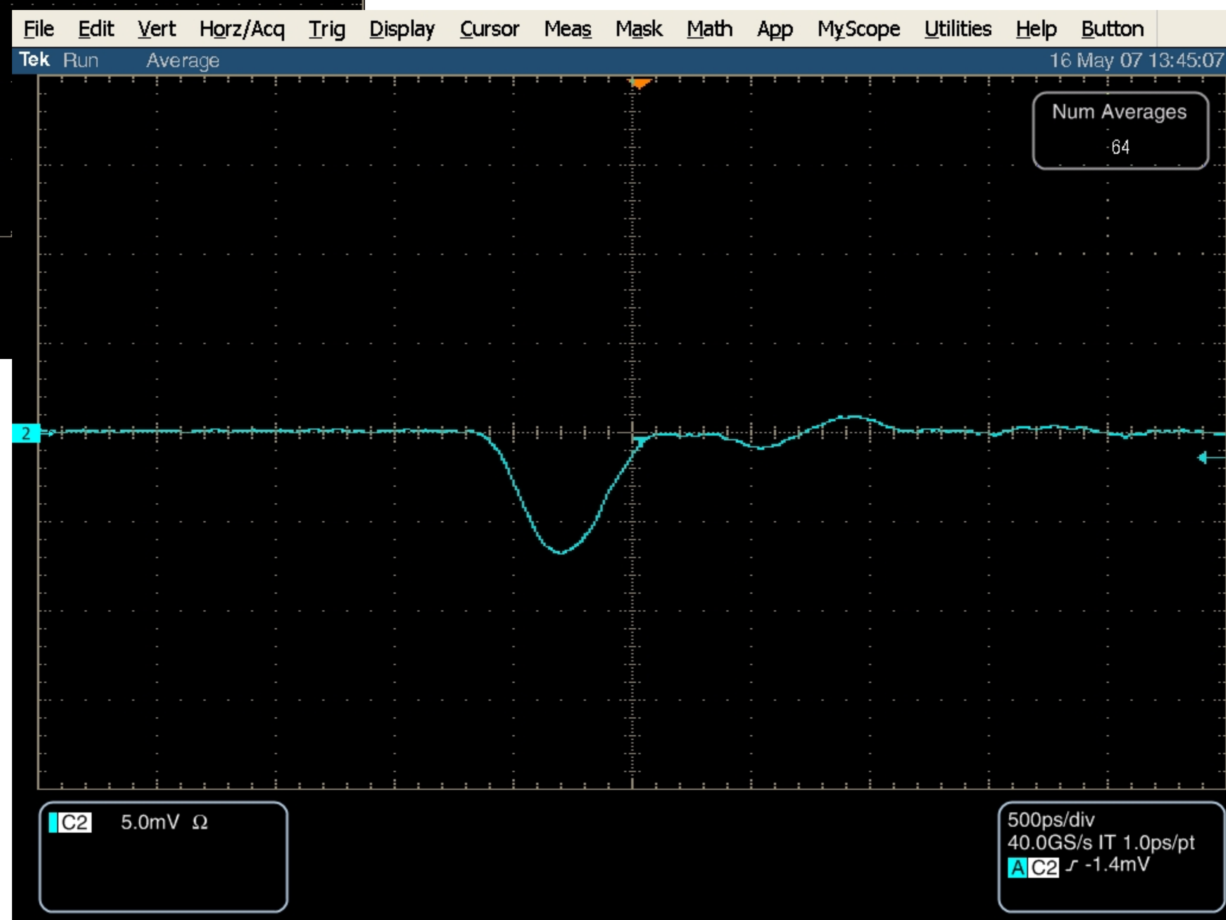
- 100 µm single crystal active area 3 mm diameter,
- Tektronix TDS 6154C, 15 GHz band width, 40 GS/s, 64 MB memory
- Suhner Sucoflex 101P

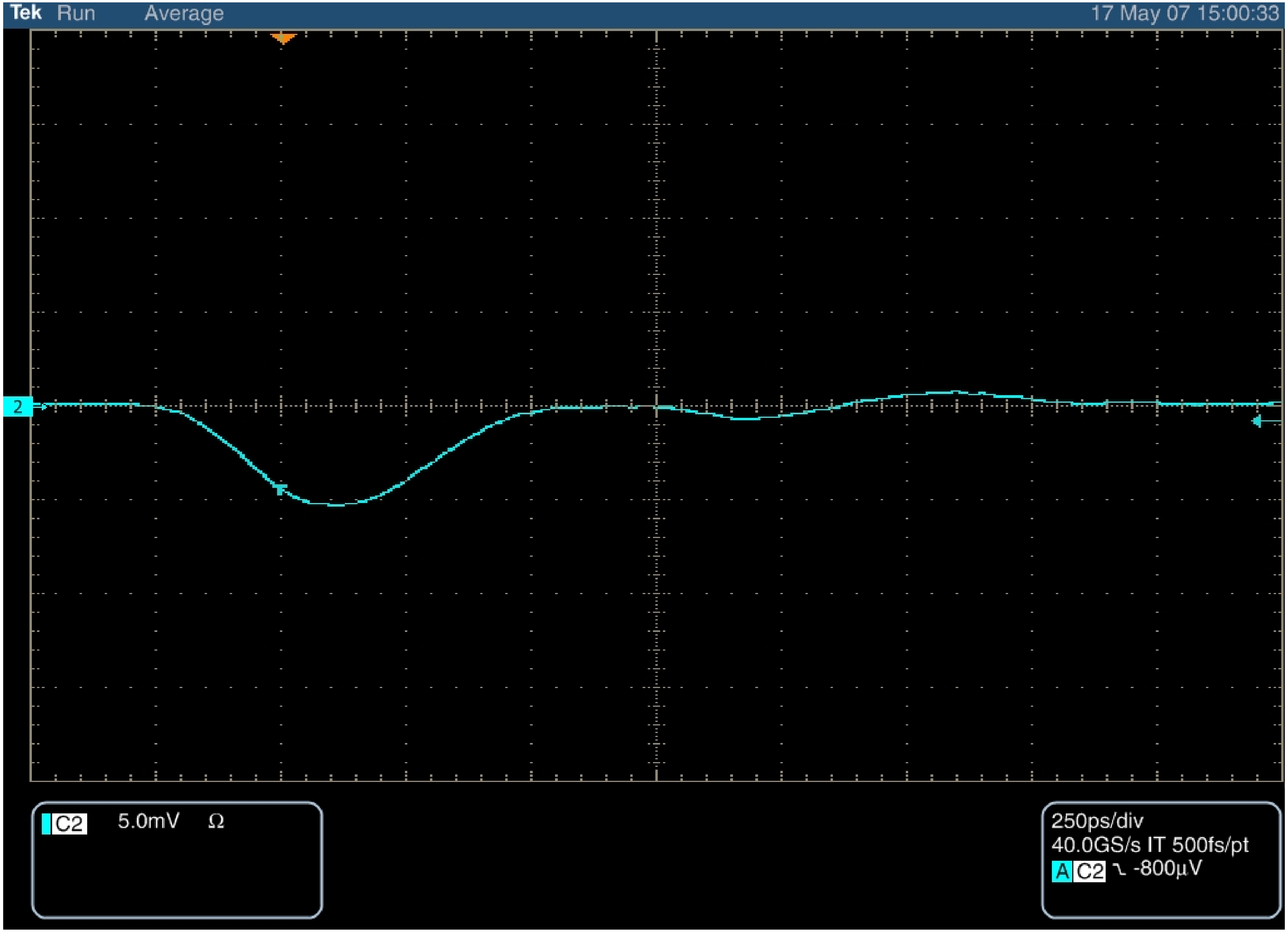
Direct α-signal from SC



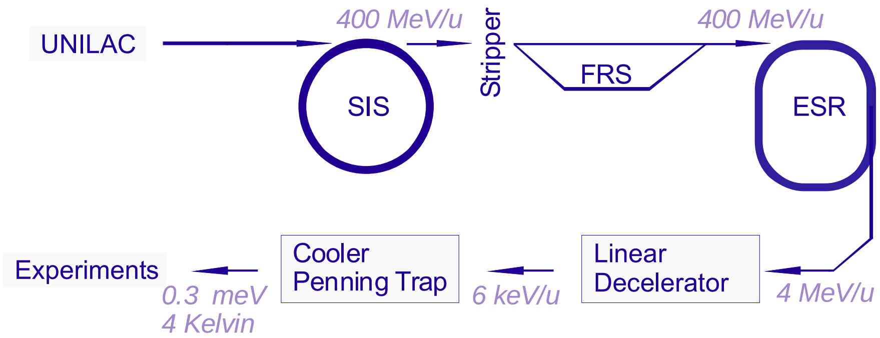
← ^{239}Pu

^{241}Am →




Tek Run Average
17 May 07 15:00:33
2
C2 5.0mV Ω
250ps/div
40.0GS/s IT 500fs/pt
A C2 ⌐ -800µV

The HITRAP Facility



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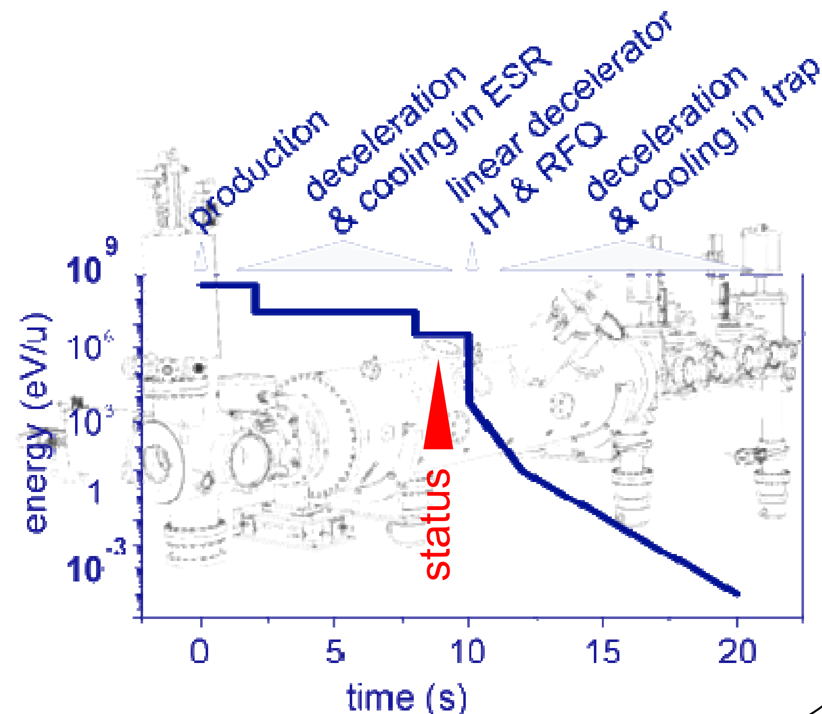
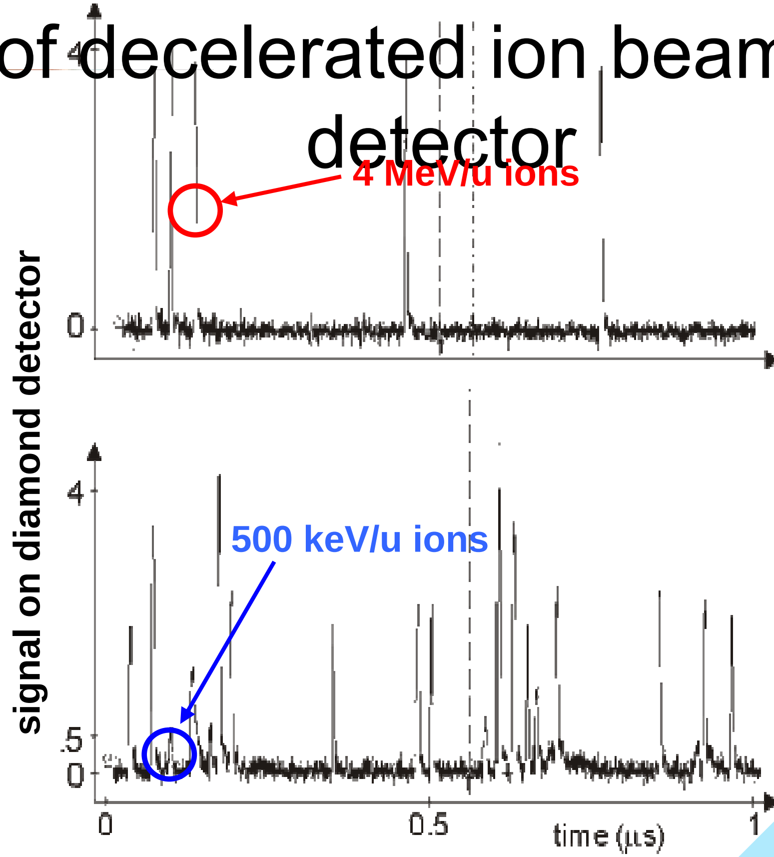
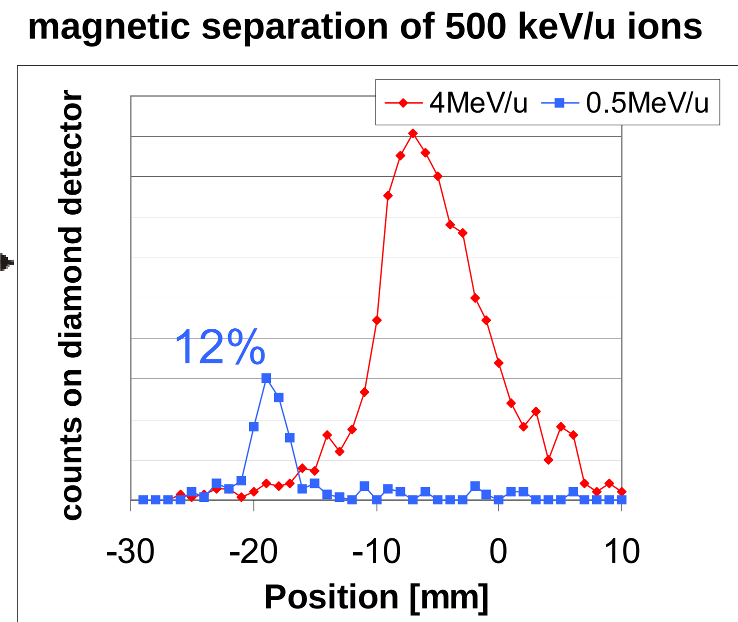
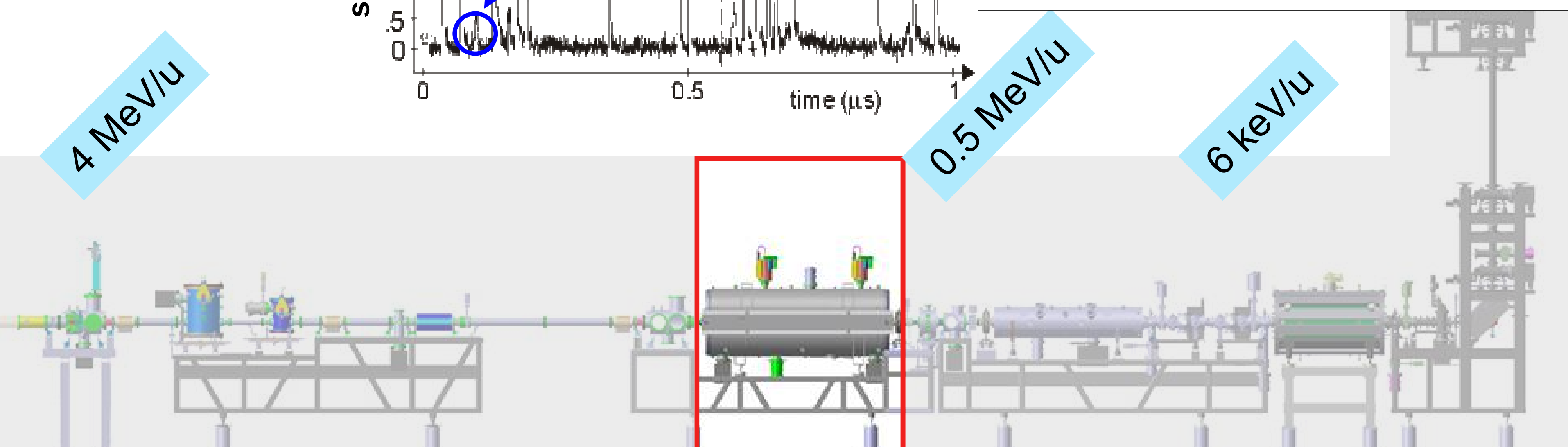
Deceleration cycle – 13 orders of magnitude reduction in energy

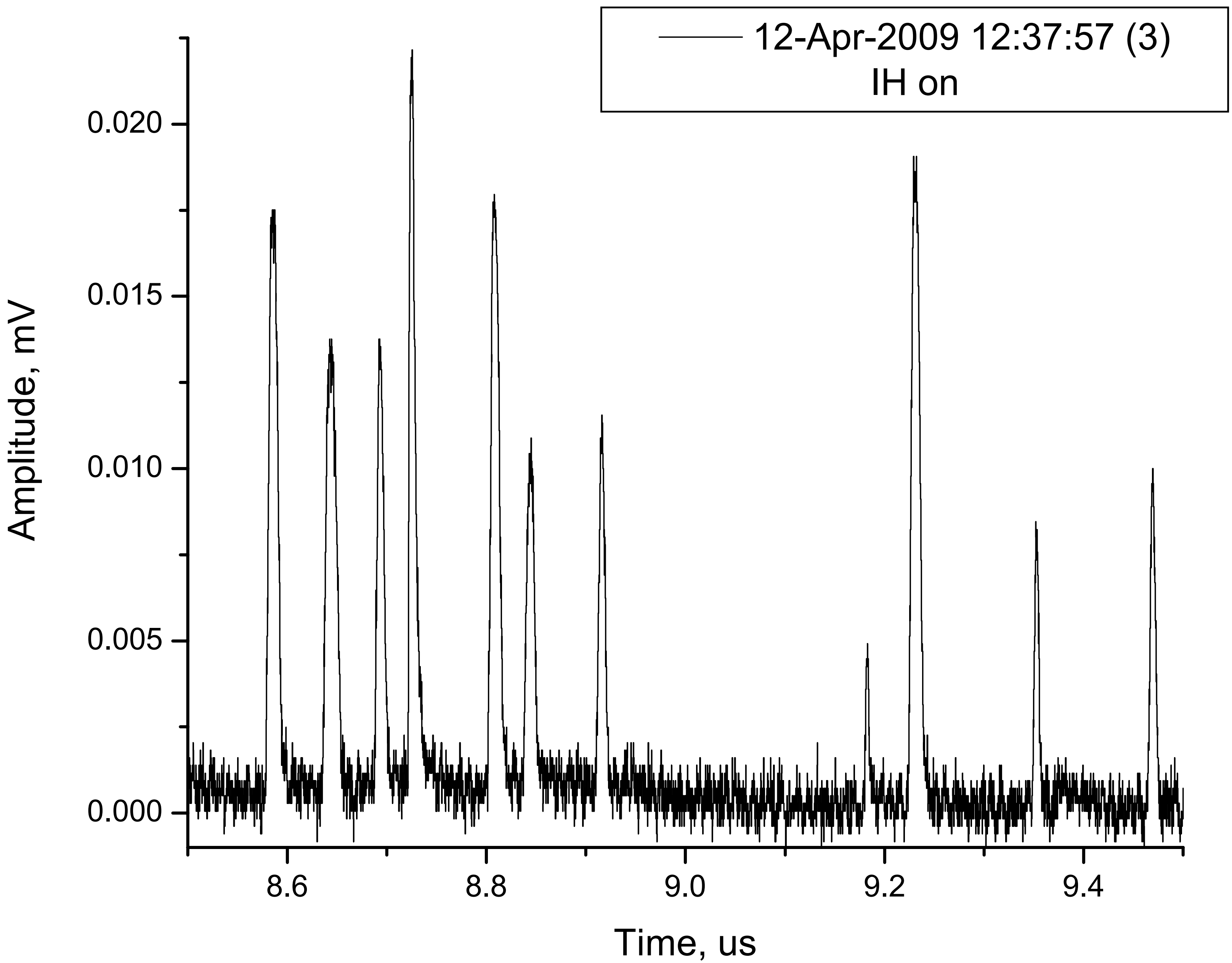


- deceleration of bunched ion beam from 4 MeV/u to 0.5 MeV/u
- detection of decelerated ion beam with diamond detector

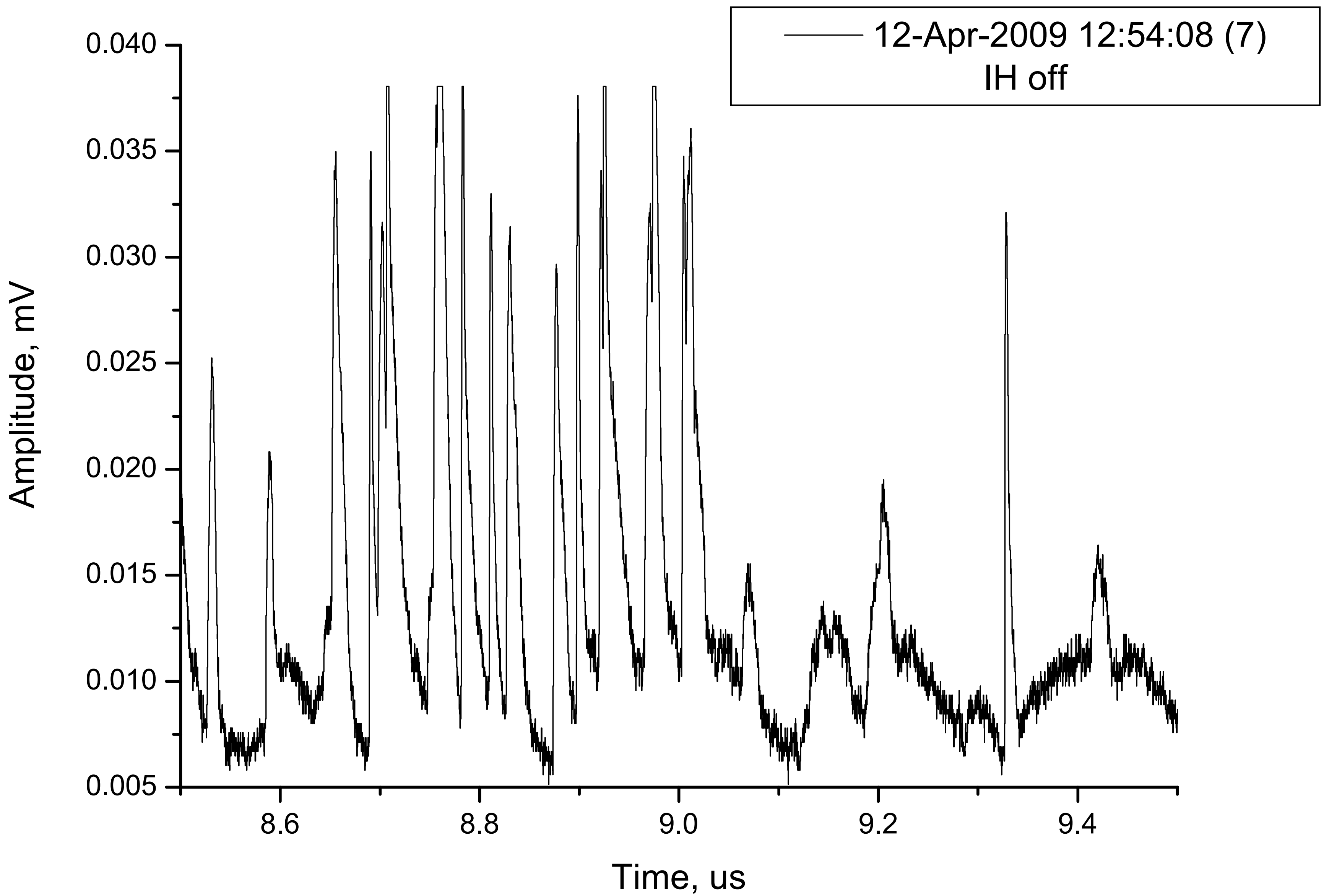






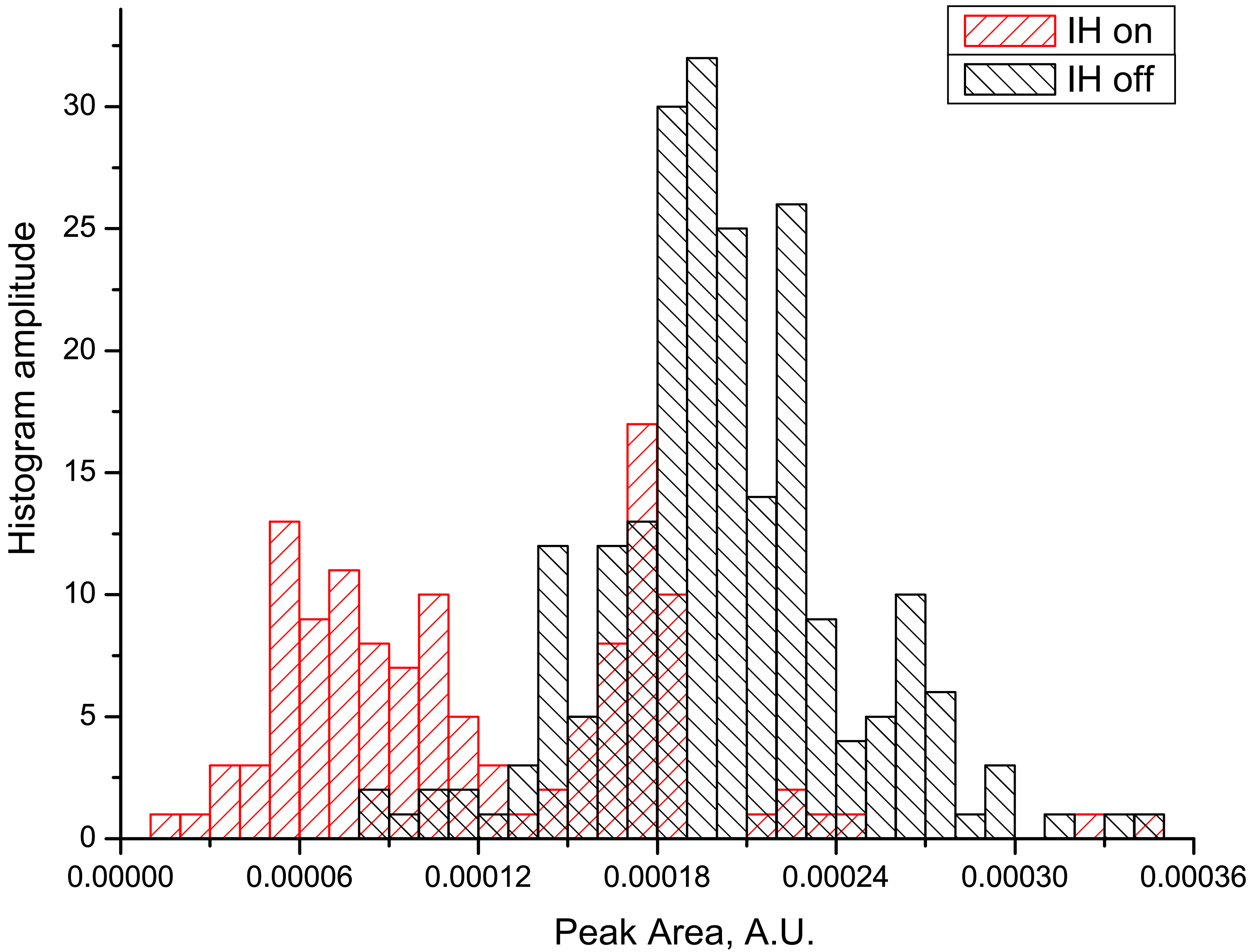


12-Apr-2009 12:37:57 (3)
IH on
Amplitude, mV
0.000
0.005
0.010
0.015
0.020
8.6
8.8
9.0
9.2
9.4
Time, us



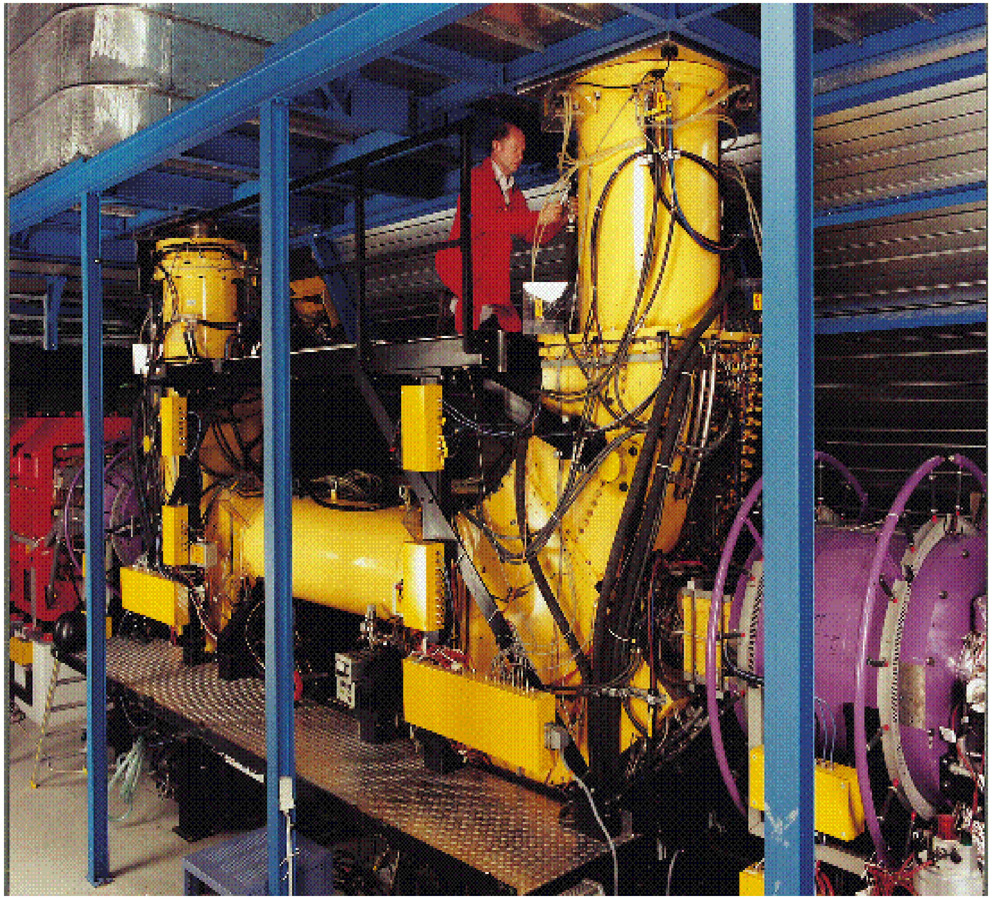
12-Apr-2009 12:54:08 (7)
IH off
Amplitude, mV
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
8.6
8.8
9.0
9.2
9.4
Time, us

Area distribution of the particles detected by SCD

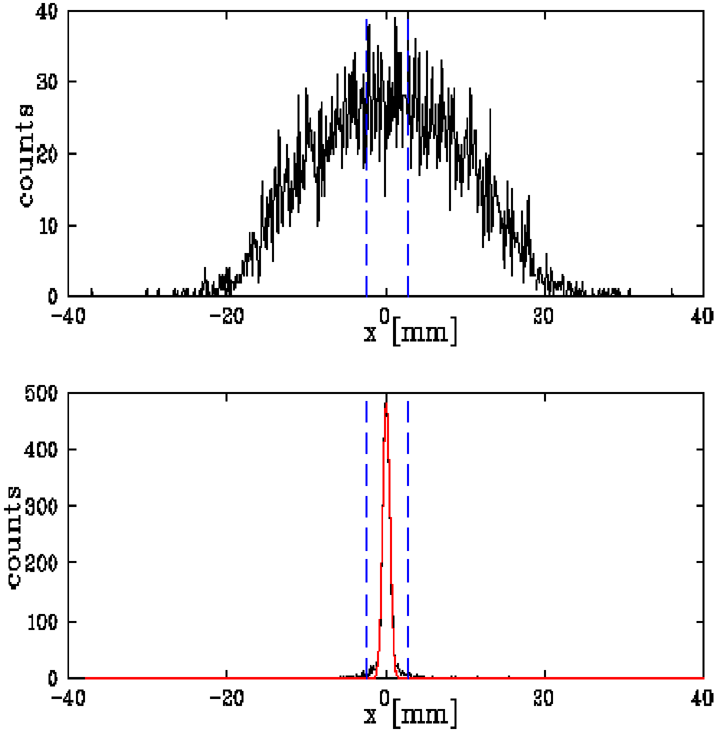


Cooling, i.e. enhancing the phase space density at constant beam velocities

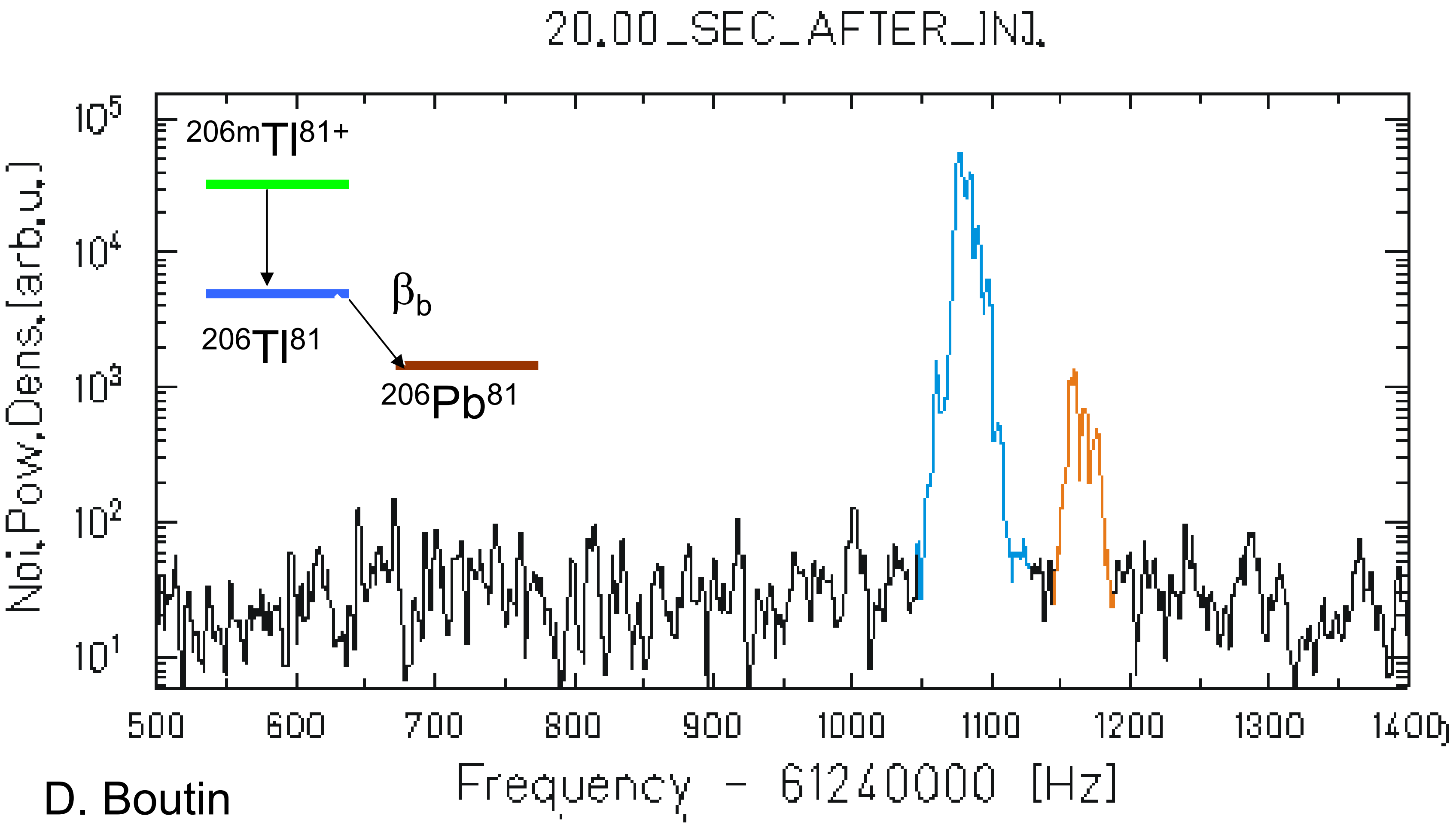
Electron cooling: G. Budker, 1967 Novosibirsk



The momentum exchange of the ions with the cold collinear e^- beam leads to an excellent emittance

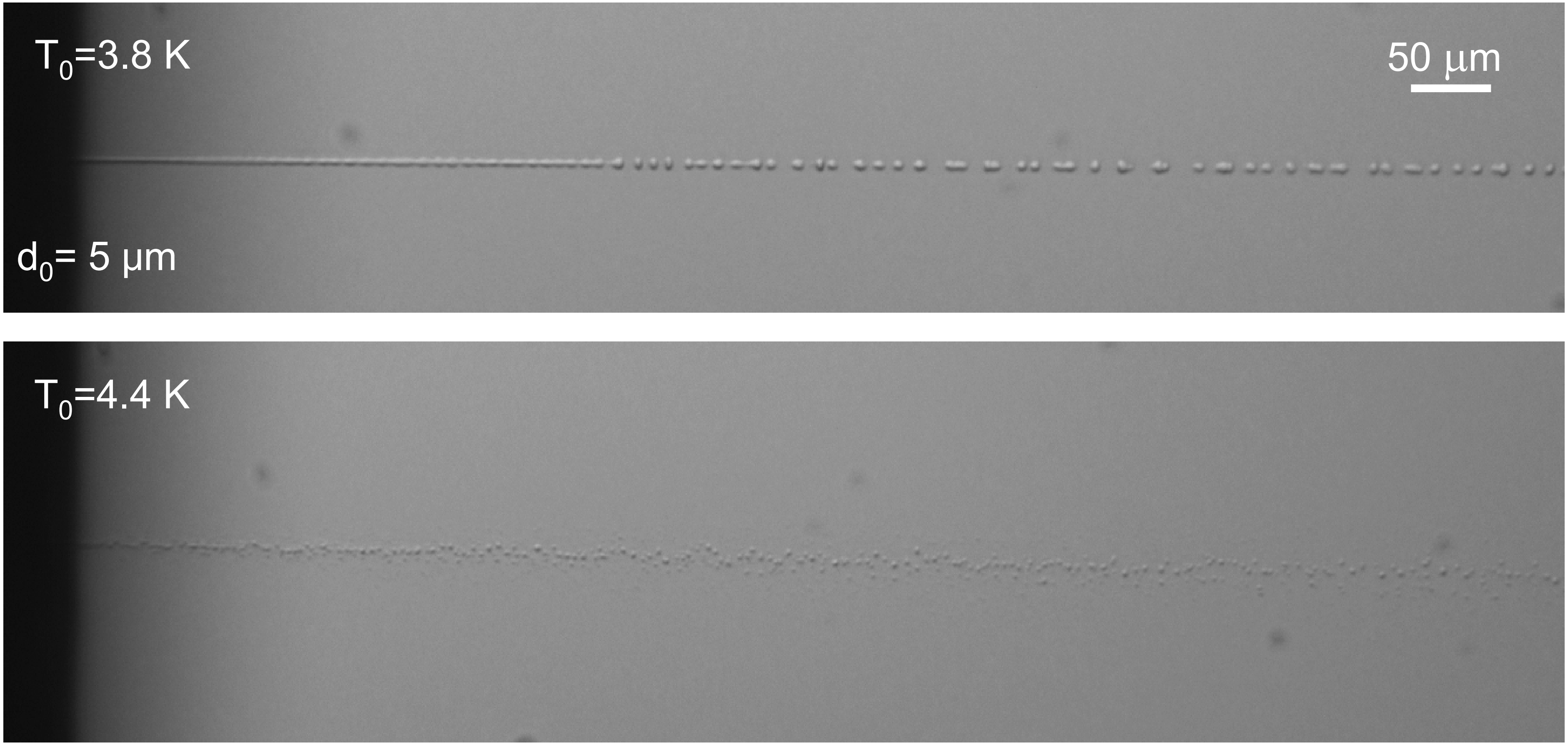


Cooling, Isomer Decay, Bound-β-Decay

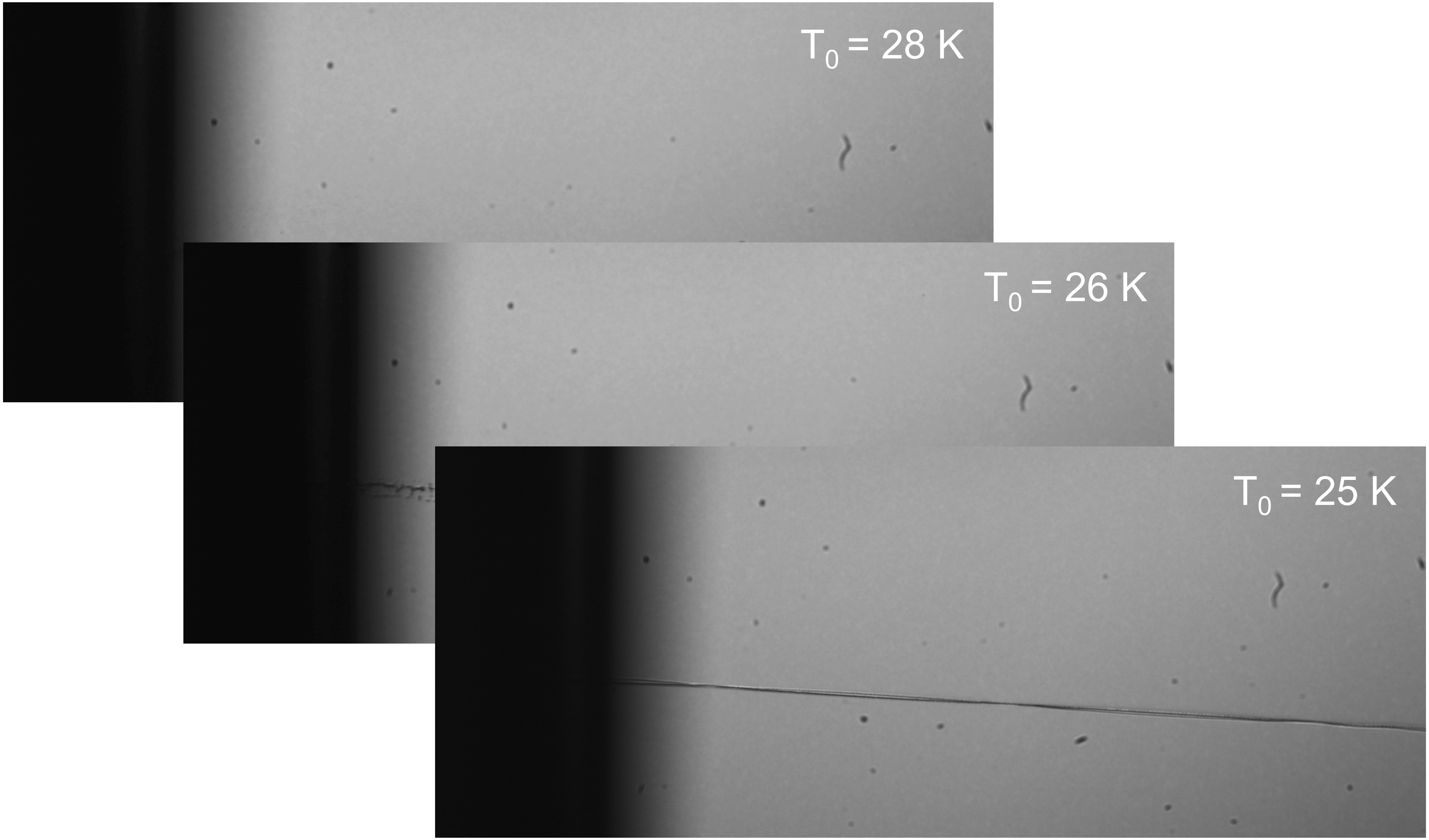


D. Boutin

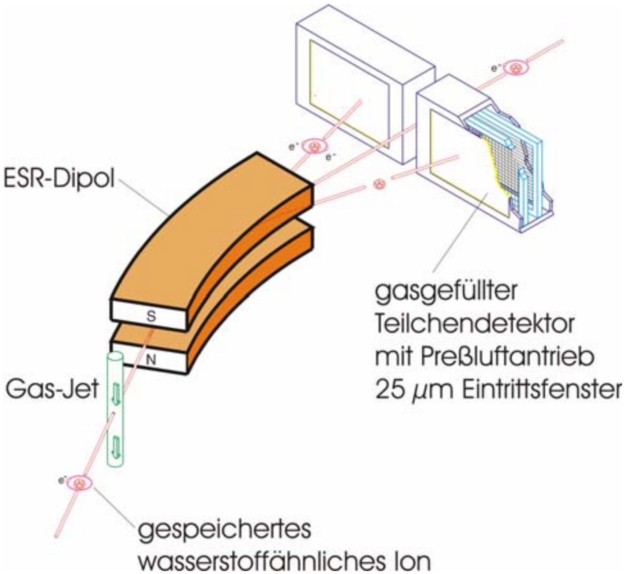
He droplet beam

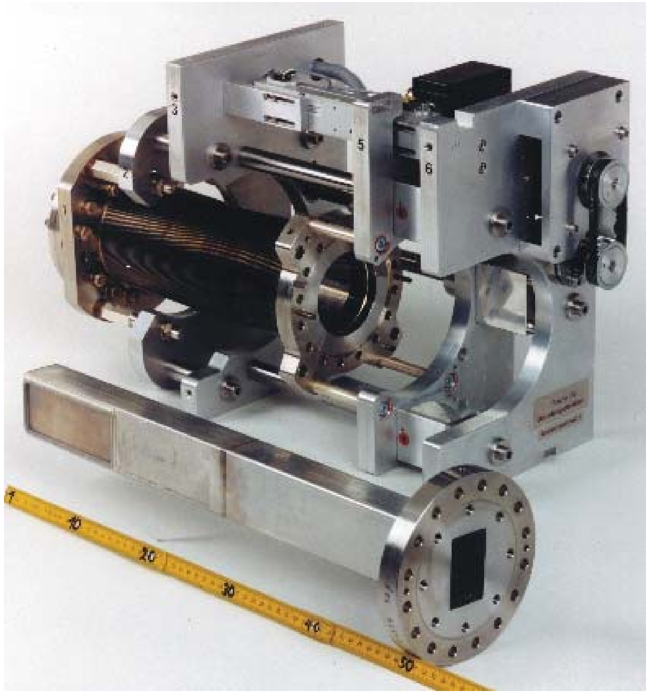


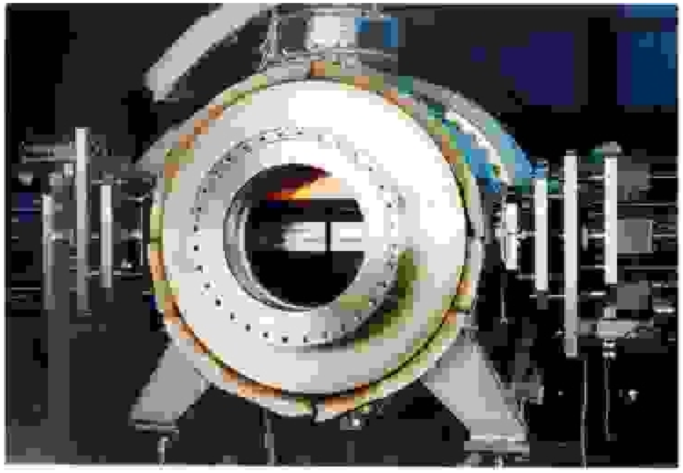
Production of a liquid H_2 droplet beam

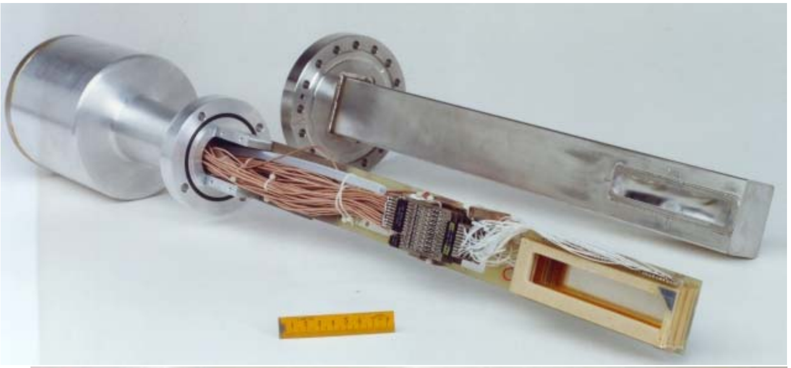


ESR Detectors



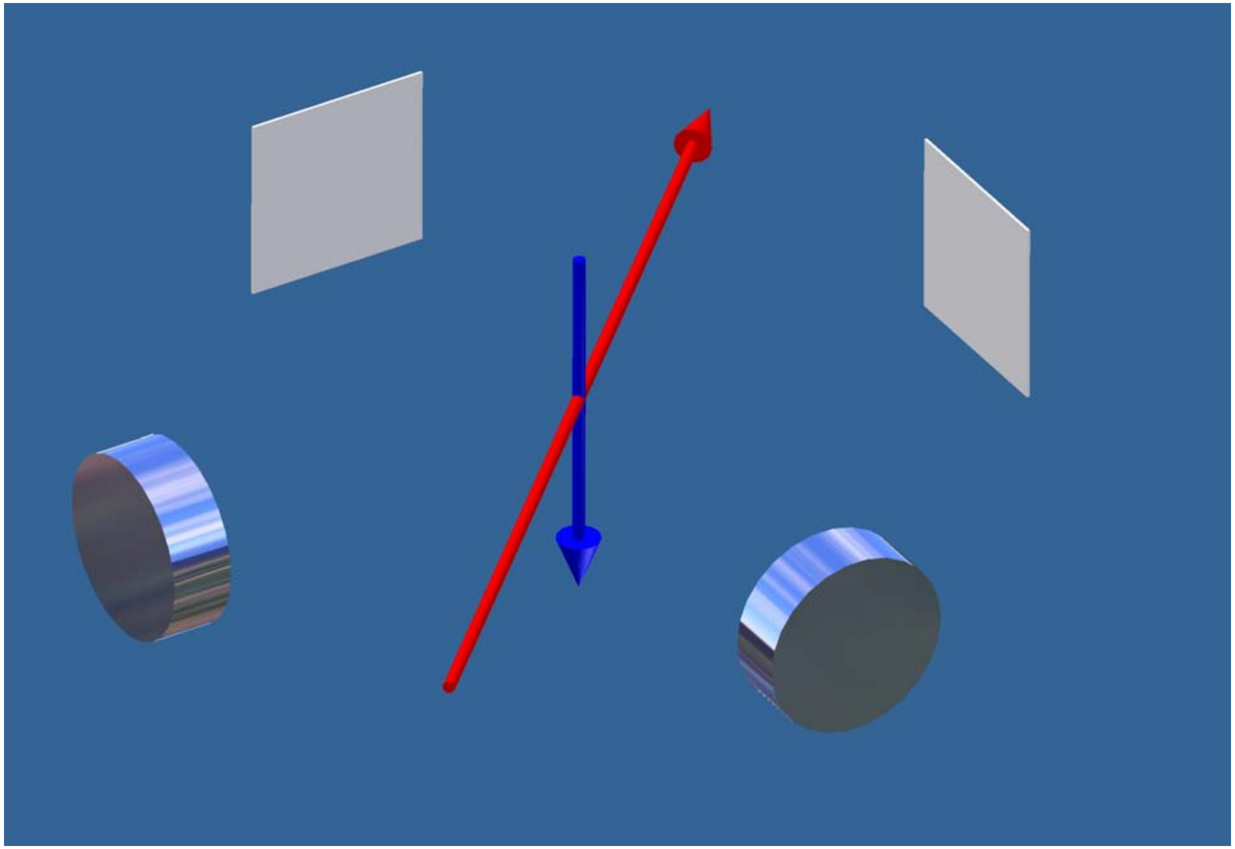






New Project: In Ring Studies of Quasi-Atoms at Bombarding Energies below the Coulomb Barrier

Objective: MO-X-ray Observation for Fixed Impact Parameters

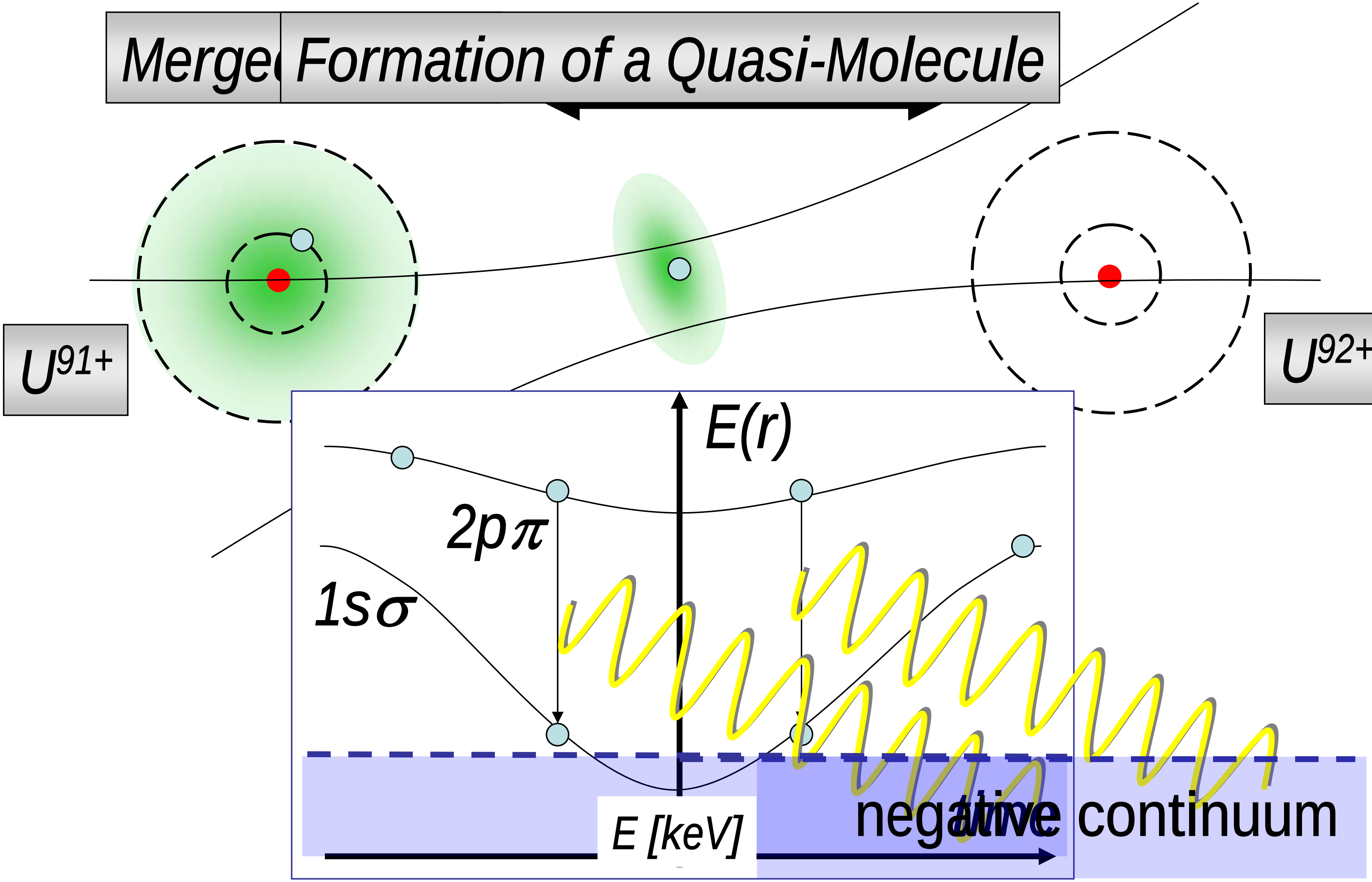


4.7 AMeV Xe-Beam ➔ Xe Gas Jet (v/c = 0.10, 2a = 28 fm)
Particle scattering angles $\vartheta \approx 90°$ c.m. (45° lab.)

Challenges:

- Polar-angle (ϑ) sensitive diamond detector wafers (6x6cm^2) suited for the ultra-high vacuum of the storage ring, with broad bandwidth read-out of kinematic coincidences.
- Position-sensitive Ge-Detectors with very good detection efficiency, energy resolution and timing capabilities.
- Fast Doppler-shift correction. The MO-X-ray quanta are emitted from the combined system moving in beam direction (red arrow), whereas the background γ-quanta are emitted from the scattered particles moving towards the particle detectors, away from the X-ray detectors and can be reconstructed as sharp lines

Supercritical fields

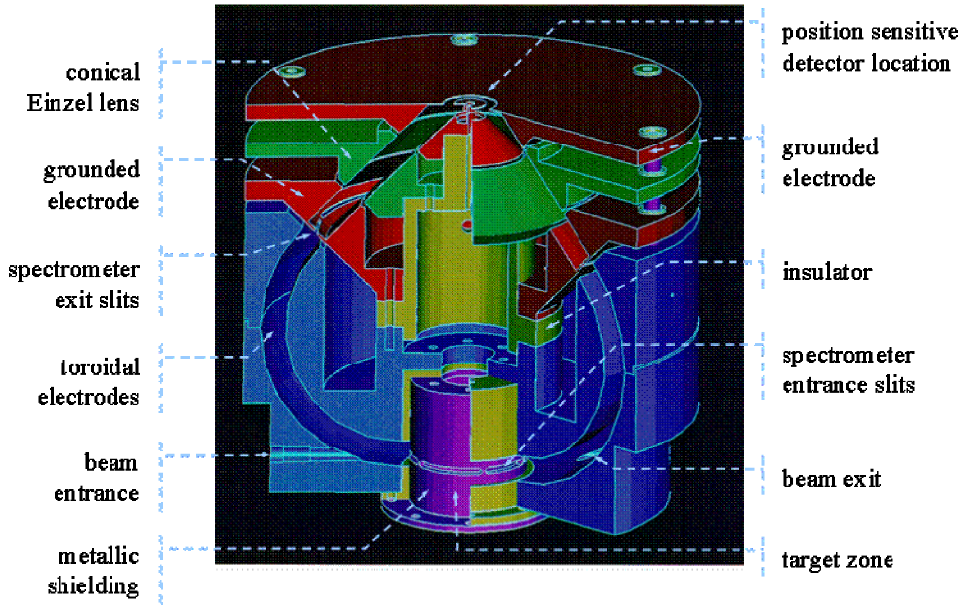


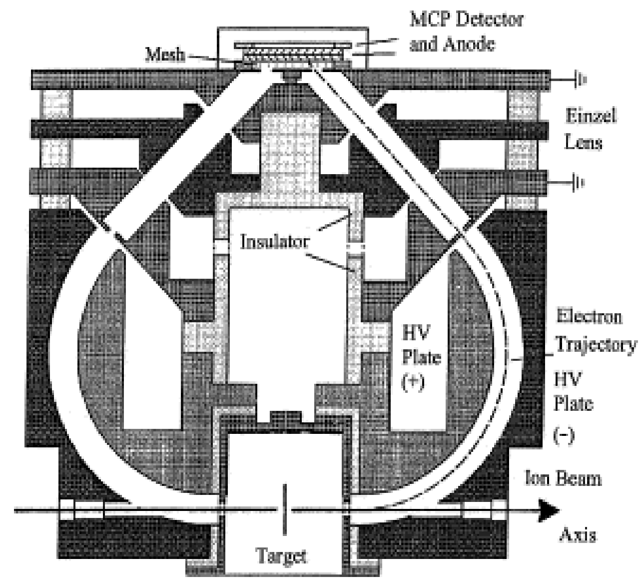
Diamonds as Future Targets

- Energy Spectra and Angular Distribution of Low-Energy Electrons (ESA-Project)

- Detailed knowledge of low-energy electron emission in collisions of ions with solids and gases is of utmost importance for the modeling of dose distributions and track structures needed for the prediction of ion radiation effects in radiotherapy and related fields.
- The used data originate predominantly from measurements with gaseous targets, scaled up to the density of liquids and solids.
- Methods are needed to identify, study and analyze problems that mask the complex and interdependent processes of electron emission and transport

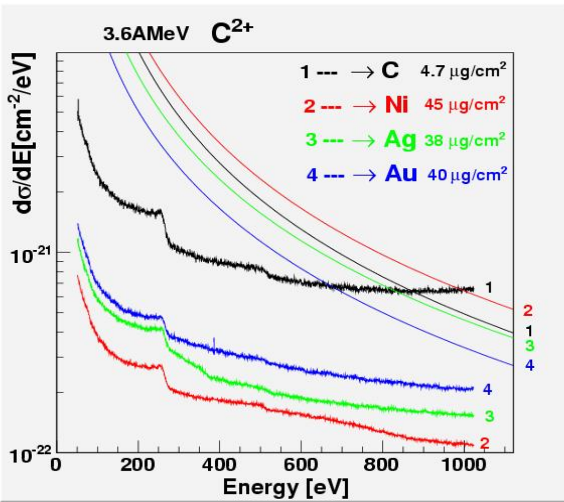
Toroid Electron Spectrometer

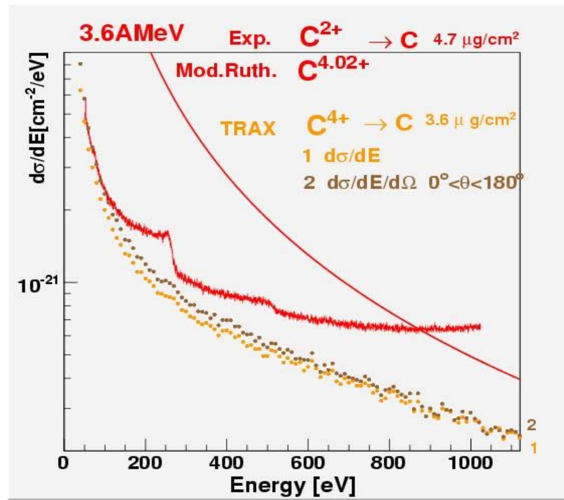


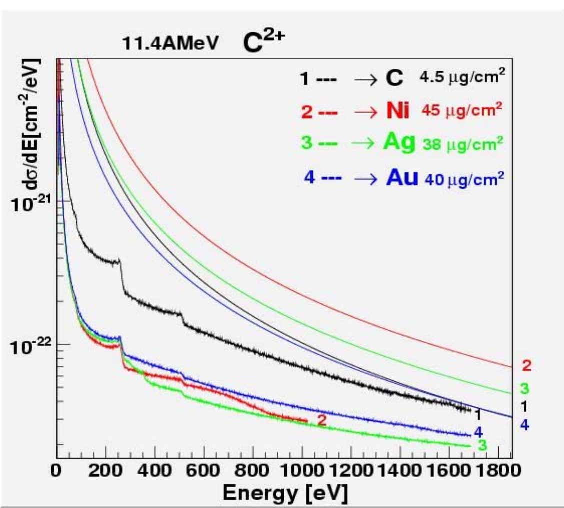


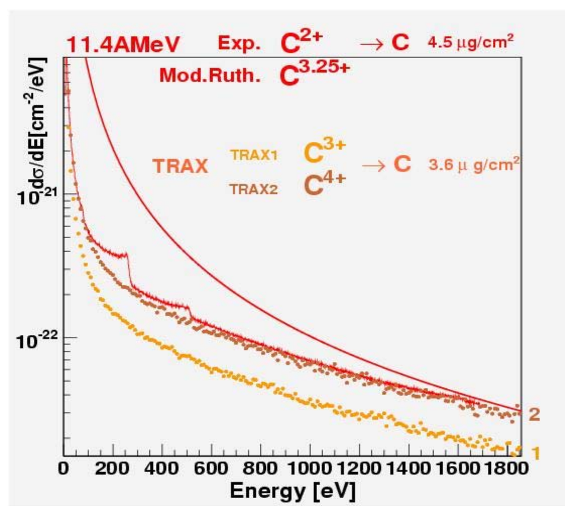
The spectrometer is rotationally symmetric. Electrons emitted in the plane perpendicular to the symmetry axis are energy and angle analyzed.

Measurements with Carbon Beam







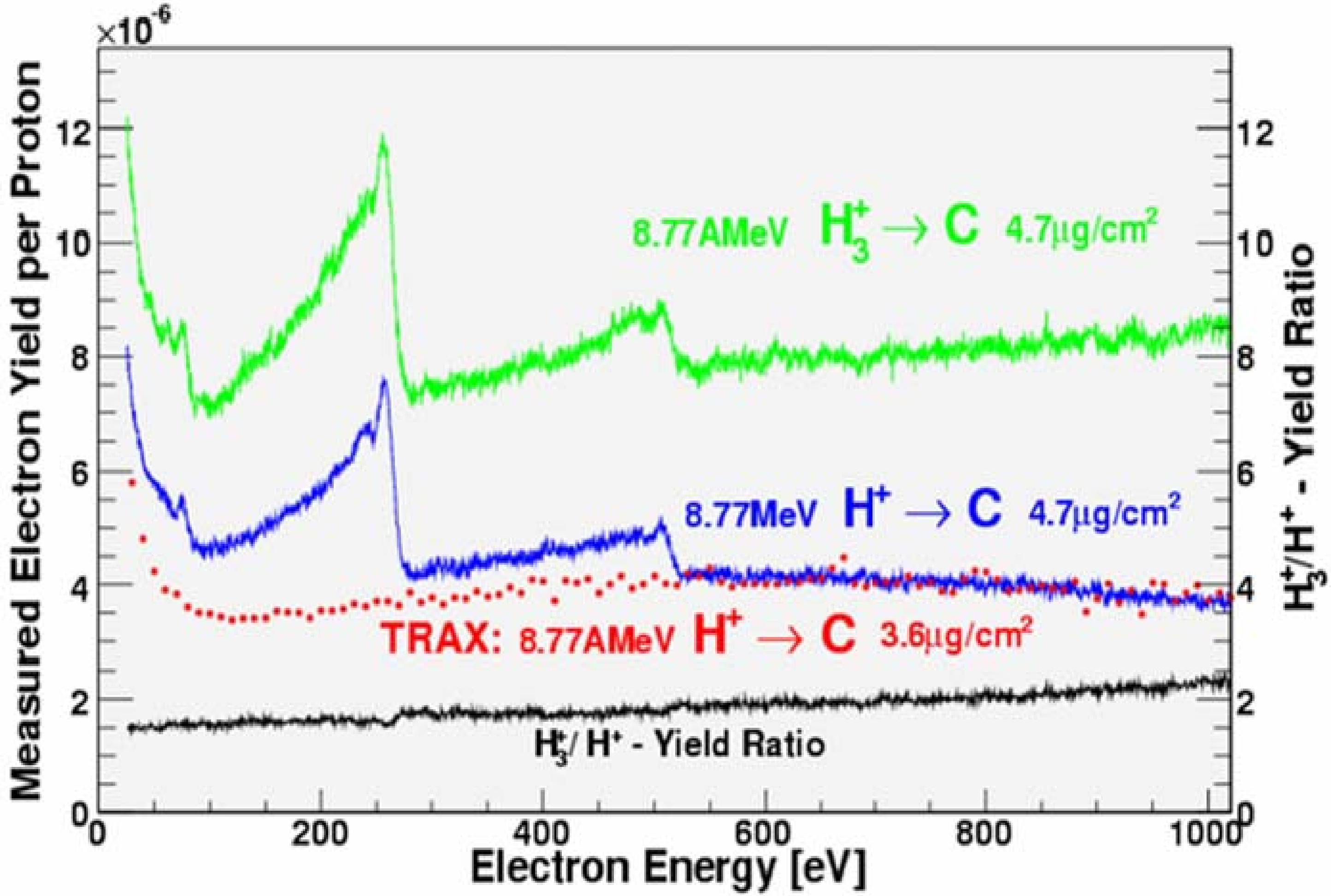


Electrons emitted in collisions of C^{2+} projectiles with C, Ni, Ag, and Au targets.

Bombarding energy E/A = 3.6 and 11.4 MeV/u

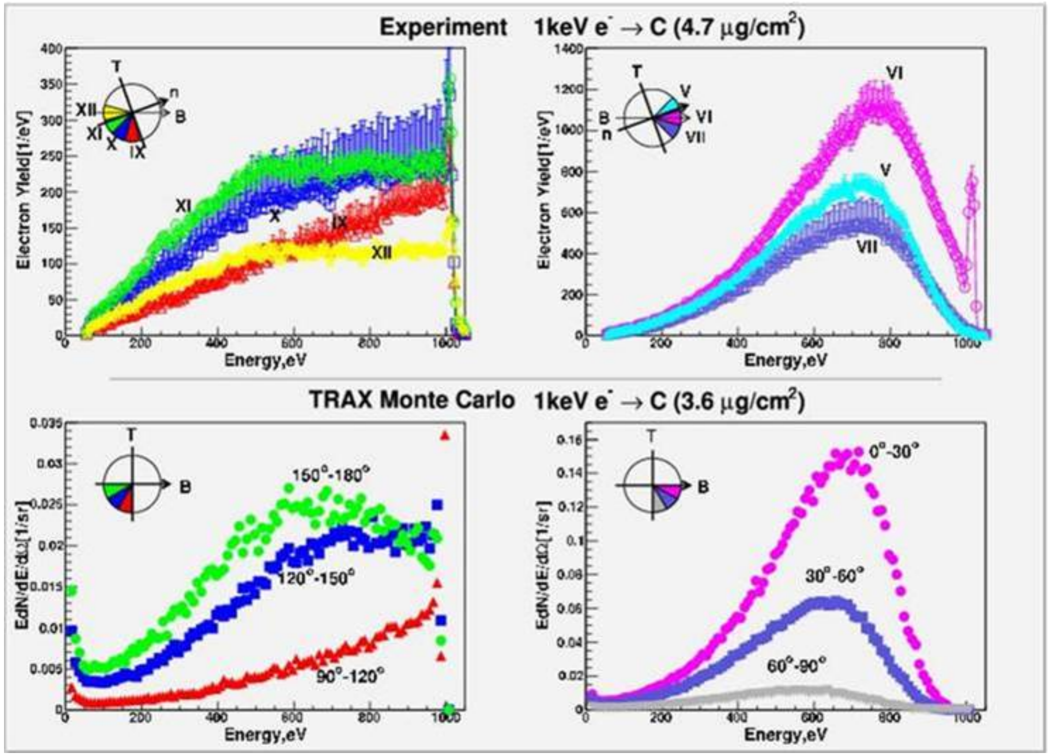
Solid lines - measured and/or calculated spectra for all projectile-target combinations

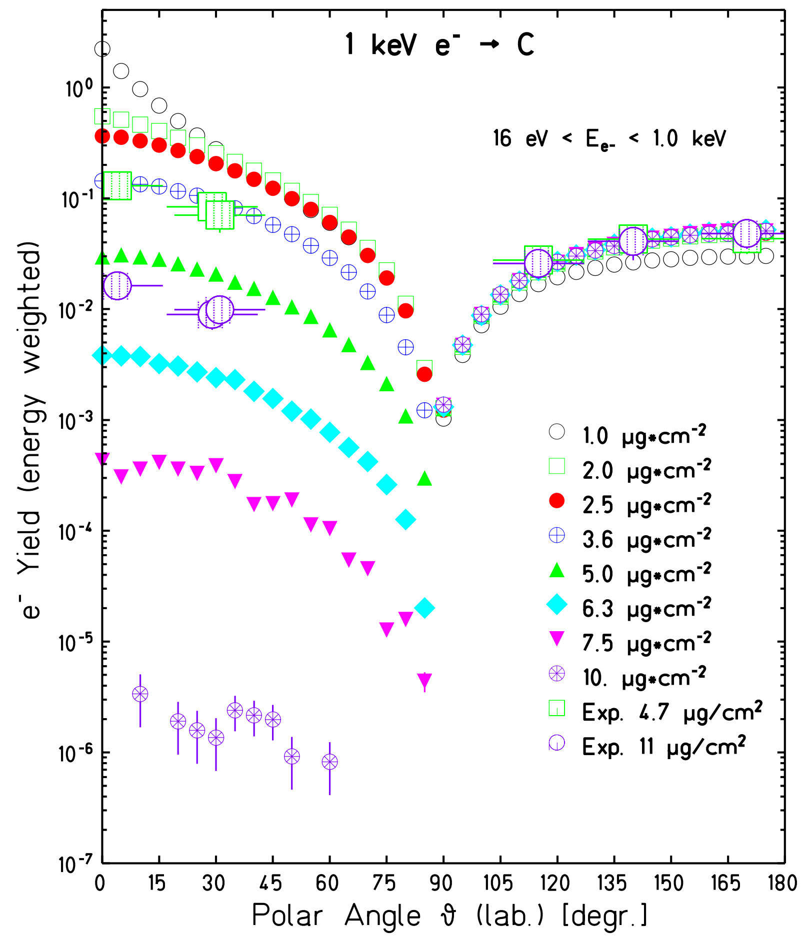
Dotted line - simulated spectra for the carbon target.



×10^-6
Measured Electron Yield per Proton
8.77AMeV $H_3^+ \rightarrow C$ 4.7μg/cm²
8.77MeV $H^+ \rightarrow C$ 4.7μg/cm²
TRAX: 8.77AMeV $H^+ \rightarrow C$ 3.6μg/cm²
H_3^+/ H^+ - Yield Ratio
H_3^+/H^+ - Yield Ratio
Electron Energy [eV]
0
200
400
600
800
1000
2
4
6
8
10
12

Measurements with an electron beam





Measured and simulated spectra of electrons from a carbon target bombarded with 1 keV electrons

Conclusions and Outlook

I. **At the HITRAP facility, we have utilized thin diamond detectors (15 μm) as a bunch length monitor for 4 AMeV heavy ions.**

II. **Also at the HITRAP facility, we used single crystal diamond detectors to determine the efficiency of the deceleration procedure by measuring very high instantaneous rates of 4 AMeV, 2.3 AMeV, and 0.5 AMeV heavy ions.**

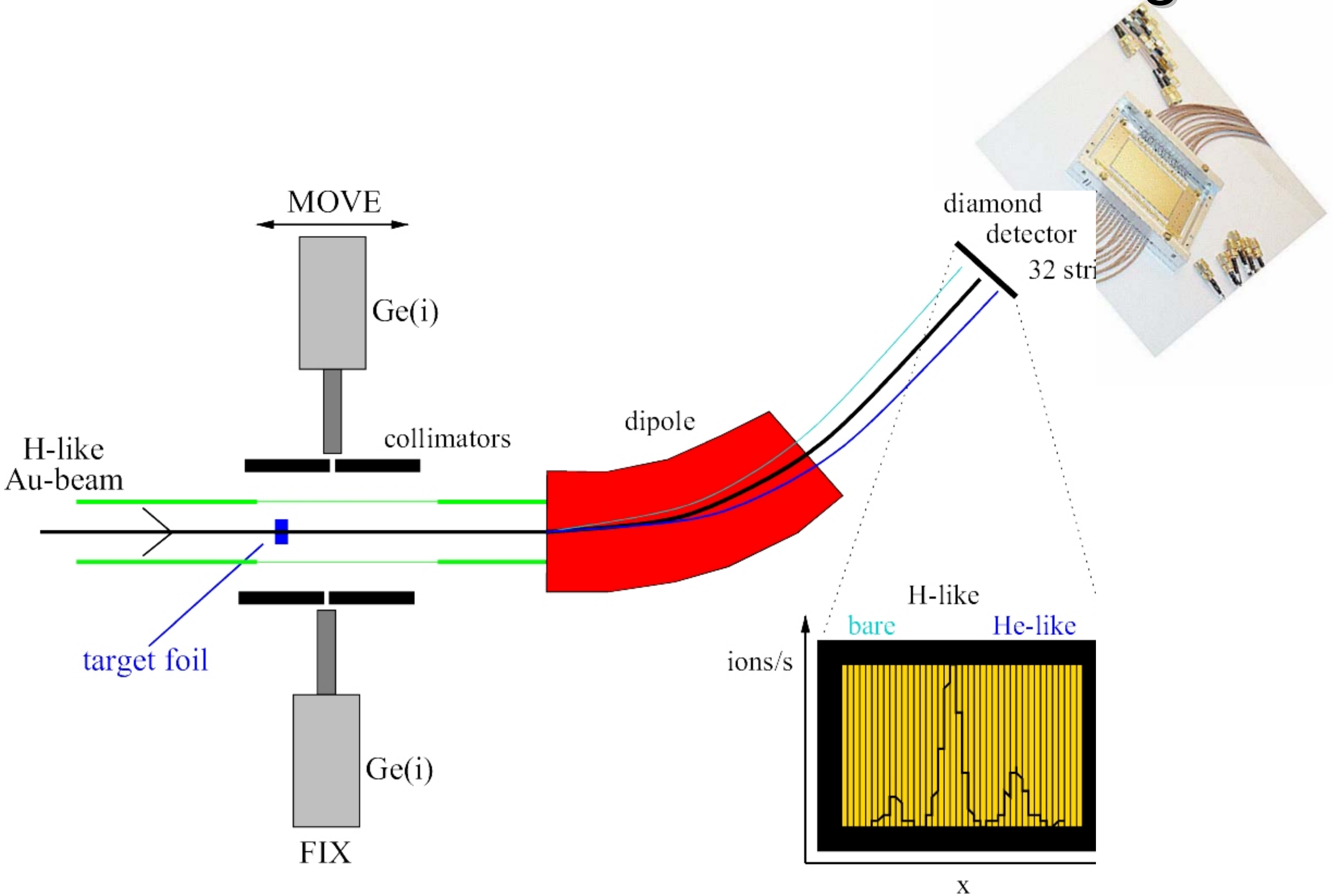
III. **At the ESR, cold beams and fluid droplet targets lead to extremely high fluencies—certainly a challenge for every type of detector.**

IV. **In a future project, we would like to employ large area position-sensitive diamond detectors in ultra high vacuum for kinematic coincidences.**

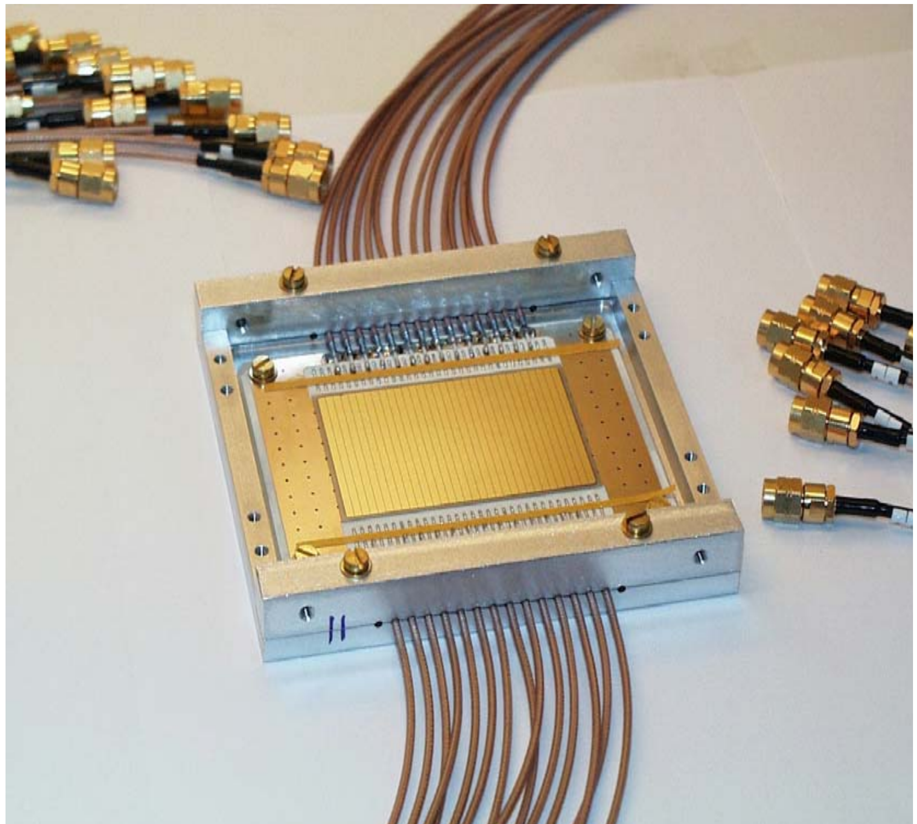
V. **At the UNILAC, within an ESA-project, we plan to study low-energy electron emission, by using a single crystal CVD-diamond detector both as a target as well as a projectile detector. The low energy electron spectra can also reveal details about the electron temperature, contact potentials, etc.**

Atomic Physics Application

Focal Plane Detector for different charge states



The world-wide largest CVD-DD in Use (?)



d_D = 200 μm

C_{str} = 16.3 pF

A = 60 x 40 mm^2 $\Rightarrow$ 32 stripes, 1.8 mm pitch