Workshop on Low Current, Low Energy Beam Diagnostics
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Experiences from CRYRING diagnostics

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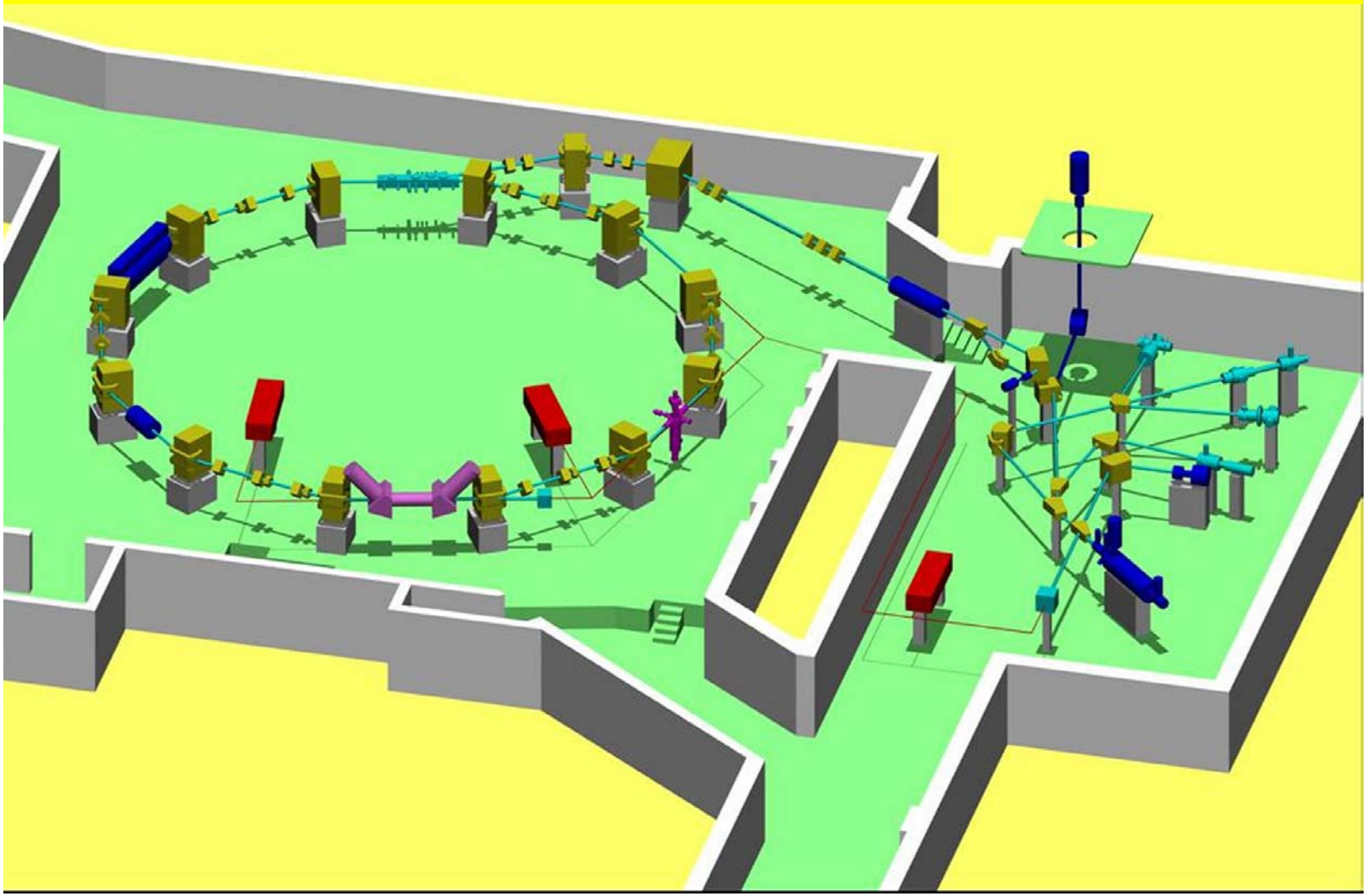
The CRYRING facility



Ions That Have Been Stored in the Ring

The following ions have been stored in the ring, most of them have also been accelerated, and some decelerated. All but a few have been used for physics experiments.

Singly charged positive atomic ions:
H^+, D^+, $^3He^+$, $^4He^+$, $^7Li^+$, $^9Be^+$, $^{11}B^+$, $^{12}C^+$, $^{14}N^+$, $^{16}O^+$, $^{40}Ar^+$, $^{40}Ca^+$, $^{45}Sc^+$, $^{48}Ti^+$, $^{56}Fe^+$, $^{83}Kr^+$, $^{84}Kr^+$, $^{86}Kr^+$, $^{88}Sr^+$, $^{129}Xe^+$, $^{131}Xe^+$, $^{132}Xe^+$, $^{138}Ba^+$, $^{139}La^+$, $^{142}Nd^+$, $^{151}Eu^+$, $^{197}Au^+$, $^{208}Pb^+$

Multiply charged atomic ions:
$^4He^{2+}$, $^{11}B^{2+}$, $^{12}C^{2+}$, $^{12}C^{3+}$, $^{12}C^{4+}$, $^{12}C^{6+}$, $^{14}N^{2+}$, $^{14}N^{3+}$, $^{14}N^{4+}$, $^{14}N^{7+}$, $^{16}O^{2+}$, $^{16}O^{3+}$, $^{16}O^{4+}$, $^{16}O^{5+}$, $^{16}O^{8+}$, $^{19}F^{6+}$, $^{19}F^{9+}$, $^{20}Ne^{2+}$, $^{20}Ne^{5+}$, $^{20}Ne^{6+}$, $^{20}Ne^{7+}$, $^{20}Ne^{10+}$, $^{28}Si^{3+}$, $^{28}Si^{11+}$, $^{28}Si^{14+}$, $^{32}S^{5+}$, $^{36}Ar^{9+}$, $^{36}Ar^{10+}$, $^{36}Ar^{12+}$, $^{36}Ar^{13+}$, $^{40}Ar^{7+}$, $^{40}Ar^{9+}$, $^{40}Ar^{11+}$, $^{40}Ar^{13+}$, $^{40}Ar^{15+}$, $^{48}Ti^{11+}$, $^{58}Ni^{17+}$, $^{58}Ni^{18+}$, $^{84}Kr^{33+}$, $^{126}Xe^{36+}$, $^{129}Xe^{36+}$, $^{129}Xe^{37+}$, $^{136}Xe^{39+}$, $^{136}Xe^{44+}$, $^{207}Pb^{53+}$, $^{208}Pb^{53+}$, $^{208}Pb^{54+}$, $^{208}Pb^{55+}$

Positive molecular ions:
H_2^+, HD^+, H_3^+, D_2^+, H_2D^+, $^3HeH^+$, $^3HeD^+$, $^4HeH^+$, D_3^+, He_2^+, LiH_2^+, D_5^+, BH_2^+, CH_2^+, NH_2^+, OH^+, CH_5^+, NH_4^+, H_2O^+, H_3O^+, HF^+, ND_3H^+, CD_5^+, ND_4^+, D_3O^+, C_2H^+, CN^+, $C_2H_2^+$, HCN^+, $C_2H_3^+$, $HCNH^+$, $C_2H_4^+$, CO^+, N_2^+, N_2^{2+}, $^{13}CO^+$, N_2H^+, $C_2H_5^+$, $H^{13}CO^+$, NO^+, $D^{13}CO^+$, CH_3O^+, CF^+, O_2^+, $CH_3NH_3^+$, CH_3OH^+, $CH_3OH_2^+$, H_2S^+, CD_3O^+, PD_2^+, $N_2H_7^+$, $D_2{}^{32}S^+$, $CD_3OH_2^+$, CD_3OD^+, $H_5O_2^+$, $D_2{}^{34}S^+$, $D_3{}^{32}S^+$, $CD_3OD_2^+$, $^{13}CD_3OD_2^+$, $D_3{}^{34}S^+$, $C_3H_4^+$, $D_2{}^{37}Cl^+$, $D_5O_2^+$, CH_3CNH^+, $C_3D_3^+$, $N_2D_7^+$, N_3^+, $C_3H_7^+$, NaD_2O^+, CO_2^+, HCS^+, $C_2H_5O^+$, DN_2O^+, $C_2H_5OH^+$, CO_2D^+, CD_3CDO^+, $NO^+{\cdot}H_2O$, O_3^+, $DCOOD_2^+$, $CD_3OCD_2^+$, $C_3D_7^+$, CF_2^+, $NO^+{\cdot}D_2O$, DC_3N^+, $CD_3OCD_3^+$, $N_3H_{10}^+$, DC_3ND^+, $CD_3ODCD_3^+$, $H_7O_3^+$, COS^+, $N_2O_2^+$, $CH_3OCOH_2^+$, $D_7O_3^+$, $N_3D_{10}^+$, $C_4D_9^+$, $S^{18}O_2^+$, ArN_2^+, $H_9O_4^+$, $CD_3COHNHCH_3^+$, $CD_3CONHDCH_3^+$, $C_6D_6^+$, $PO^{37}Cl^+$, $H_{11}O_5^+$, $C_2S_2H_6^+$, $C_2S_2H_7^+$, $H_{13}O_6^+$, $PO^{35}Cl_2^+$

Negative atomic ions:
H^-, Li^-, F^-, Si^-, S^-, Cl^-, Se^-, Te^-

Negative molecular ions:
CN^-, C_4^-, Si_2^- Cl_2^-

Range of energies per nucleon: 38 eV/u – 92 MeV/u

Range of total energies: 5 keV – 1.4 GeV

CRYRING diagnostics

- Beamlines:
  - Fluorescent screens
  - Faraday cups
  - Strip detectors
- Storage ring:
  - Faraday cups (one with fluorescent screen)
  - Electrostatic pickups
  - Schottky detector
  - DCCT (Bergoz)
  - ACCT (ICT, Bergoz)
  - Residual gas ionization beam profile monitor
  - Neutral particle detectors

Fluorescent screens

- CHROMOX ($Al_2O_3(Cr)$)
  - Sensitivity varies a lot depending on ion species, energy and pulse length but normally pulses of a few tens of nA can be seen with a standard CCD camera. Pulse lenghts can be made longer to increase intensity. Darken with exposure.
- CsI(Tl)
  - Higher sensitivity, especially for low energy ions, but (probably) not UHV compatible

Not used for intensity measurements

Faraday cups

- Gain up to 10^8 V/A. Higher gains (up to 10^{12} V/A) available, but rise times become unpractical for pulsed beams.

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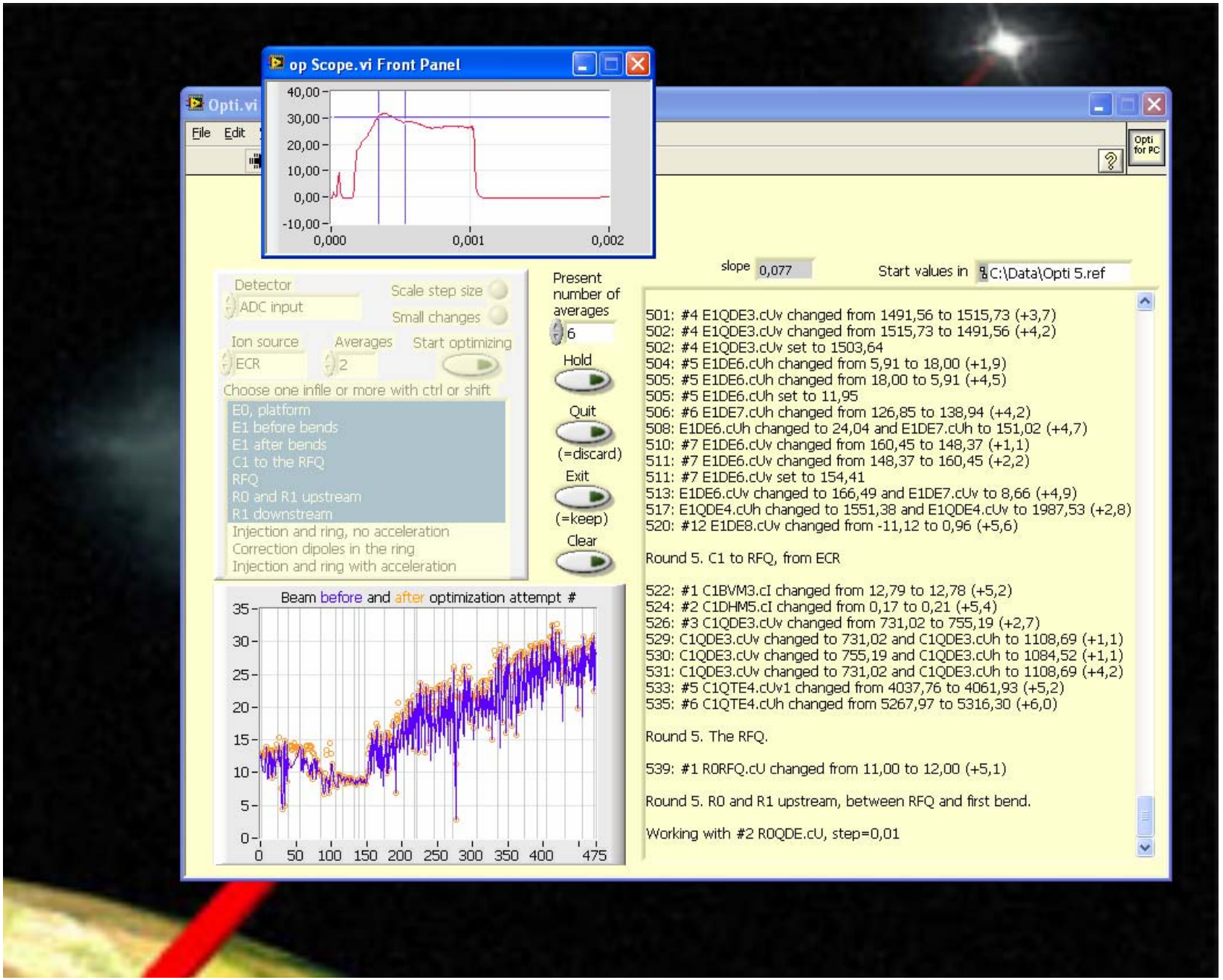
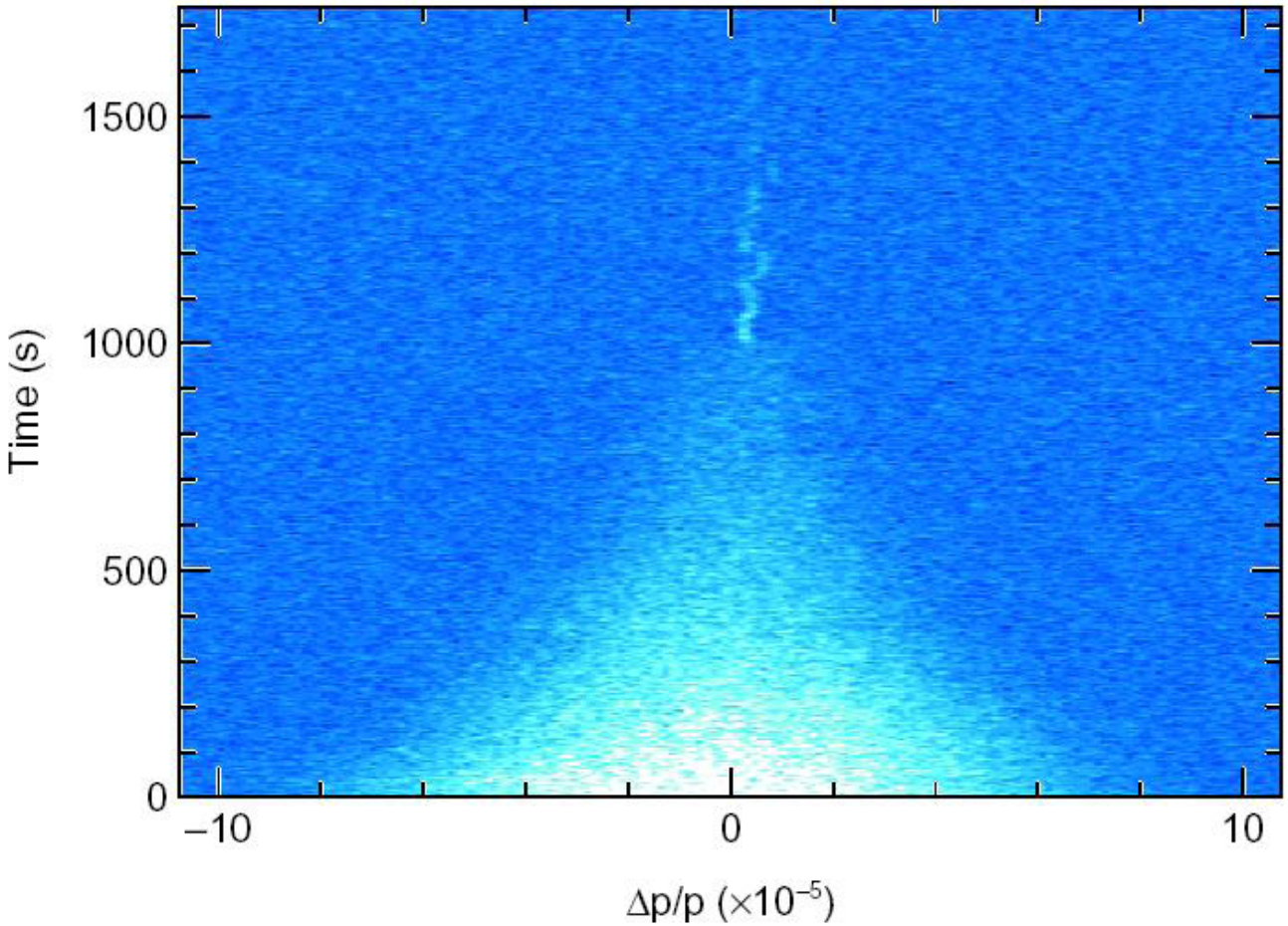
Electrostatic pickups

- Cylindrical, diagonal cut
- Preamplifier input circuit with two FETs, type 2SK300, connected in parallel. The equivalent input noise is 5 μVrms @ 10 MHz BW (G=52 dB).
- Sum signal mainly used with spectrum analyzer for intensity monitoring and optimization

Automatic optimization



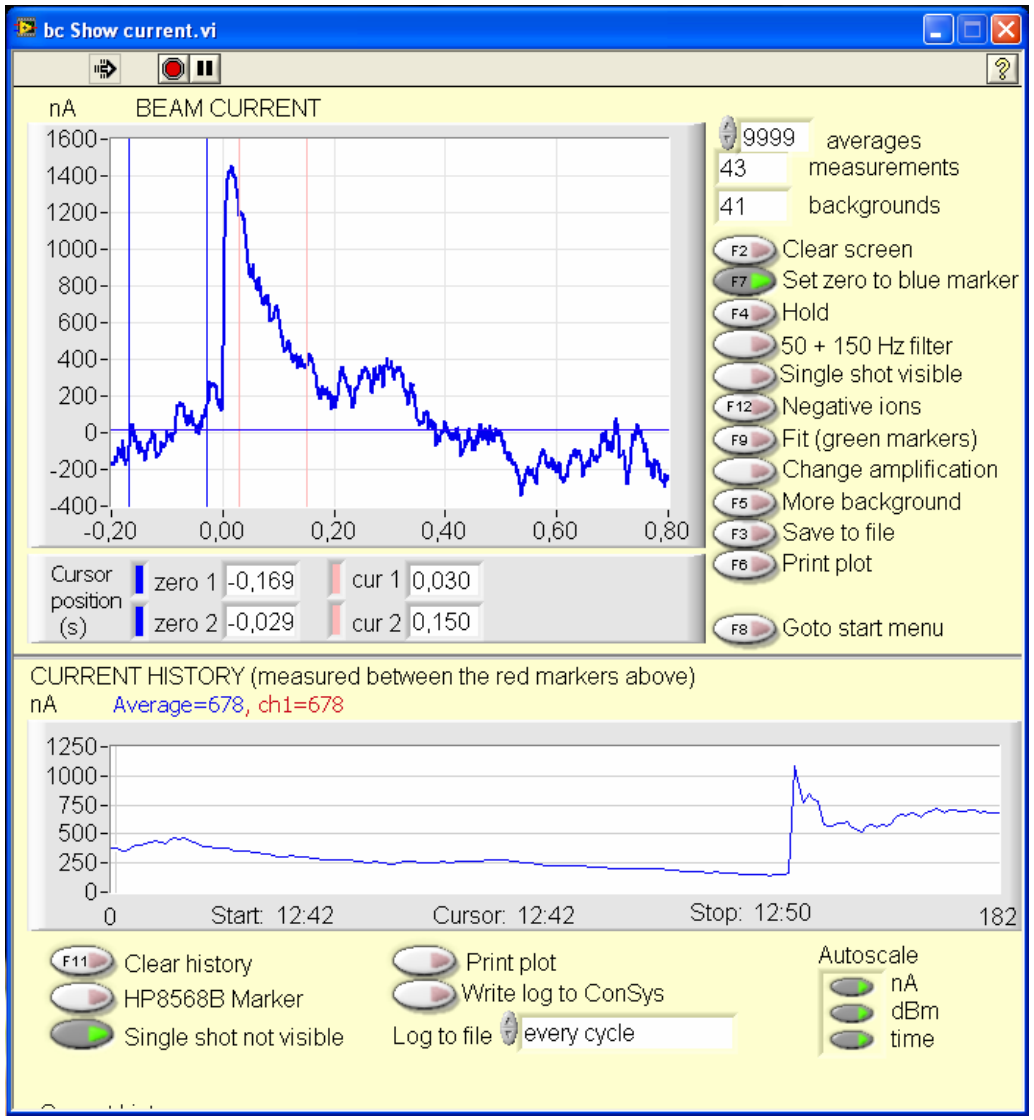
Schottky detector



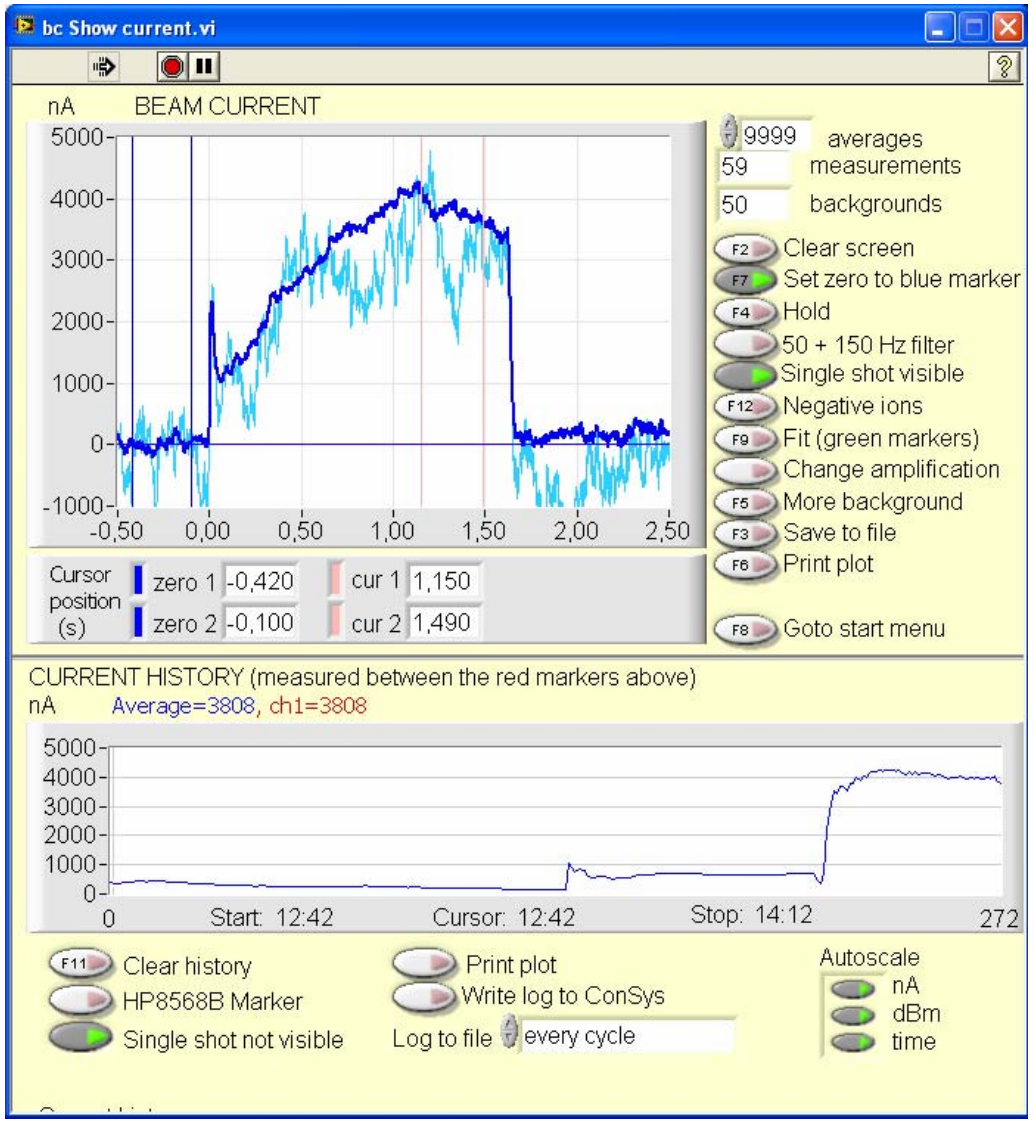
Schottky signal from a beam of Xe^{36+} ions showing the transition of the beam to an ordered state at around 1000 particles

Current measurements
DCCT
Bergoz, about 1 μA noise p-p

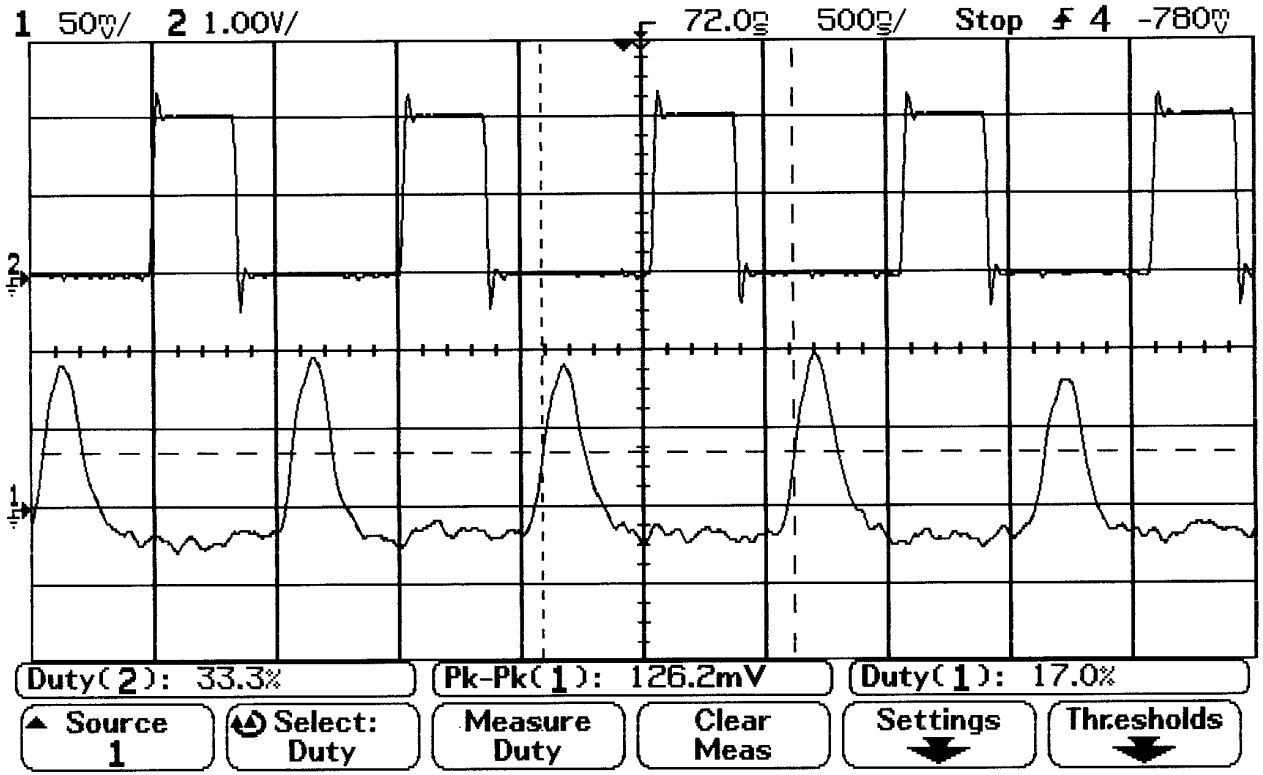
Current measurements
DCCT



Current measurements
DCCT

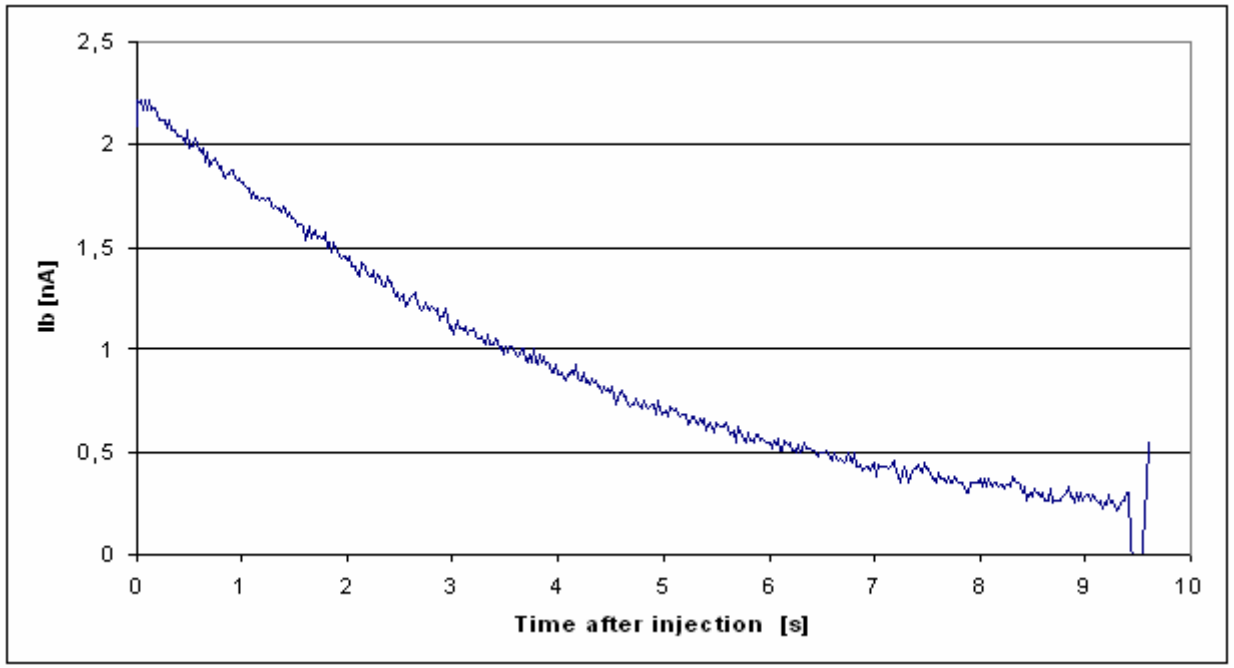


Current measurements
ICT (Integrating Current Transformer)



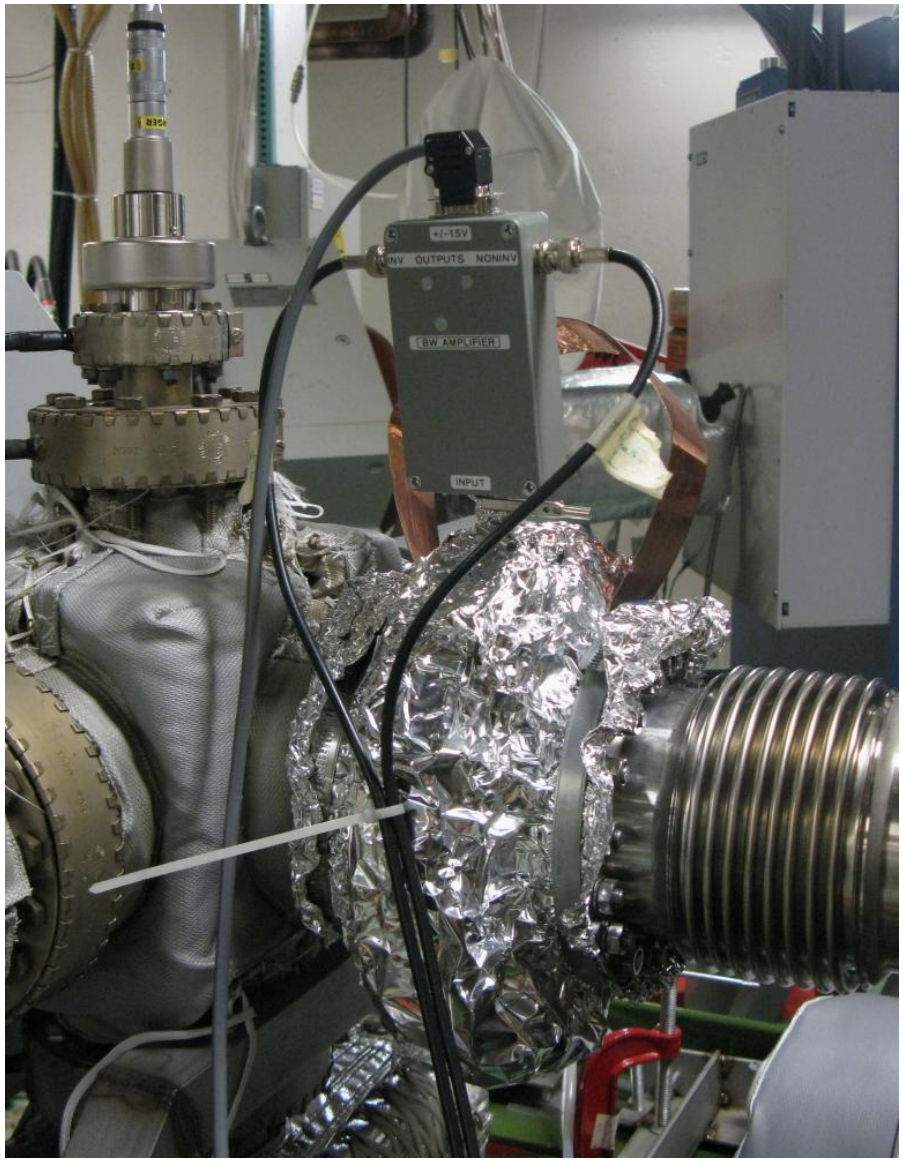
LabView program to normalize pickup signal and ICT signal to extend the measurement range

Current measurements
ICT



H^2S^+ bunched beam current during 10 s, averaged over 66 cycles (BW=20 Hz)

Current measurements
ICT

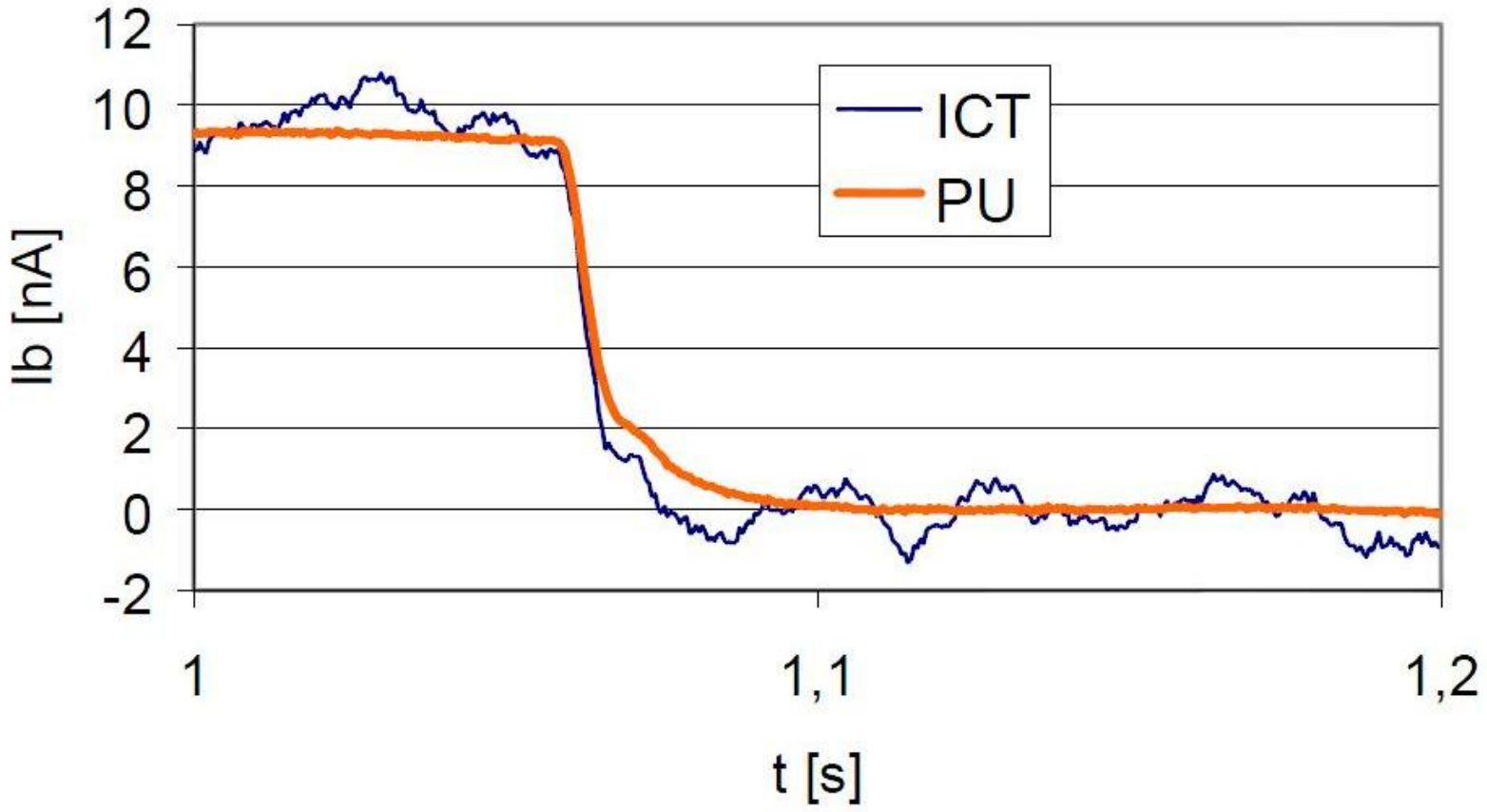


Current measurements
ICT

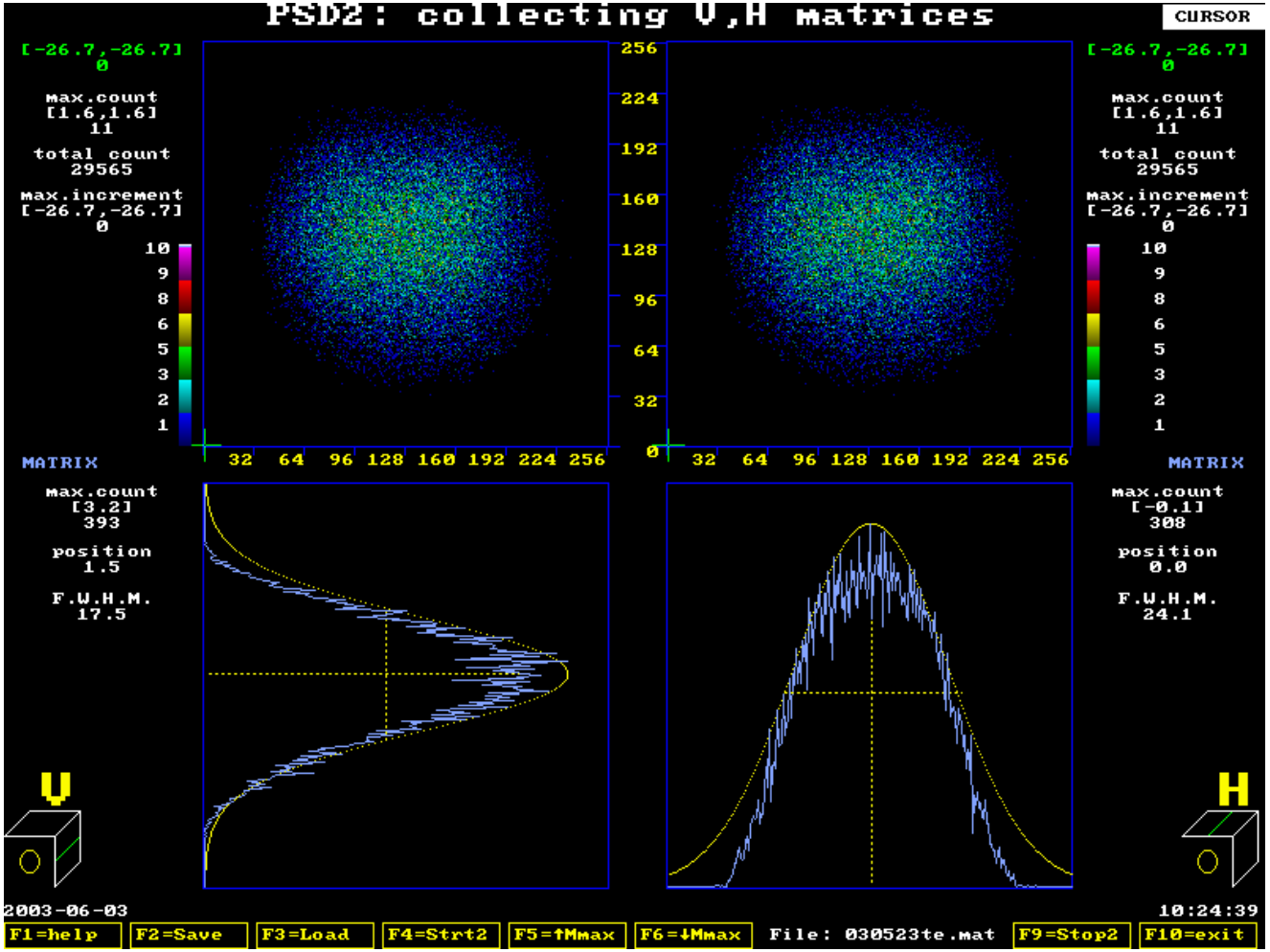
Developments:

- A low noise Wideband Amplifier has been designed and placed close to the Integrating Current Transformer to give 4 V/A sensitivity.
  - Gain 80dB
  - Noise 1 nVrms/√Hz
  - Bandwidth 1 kHz-10 MHz
- A Differential Input Double Integrator with 33.3% duty cycle
- Low Pass Filter
  - Bandwidth 20/100 Hz (20 dB/decade)
- A Programmable Phase Shifter

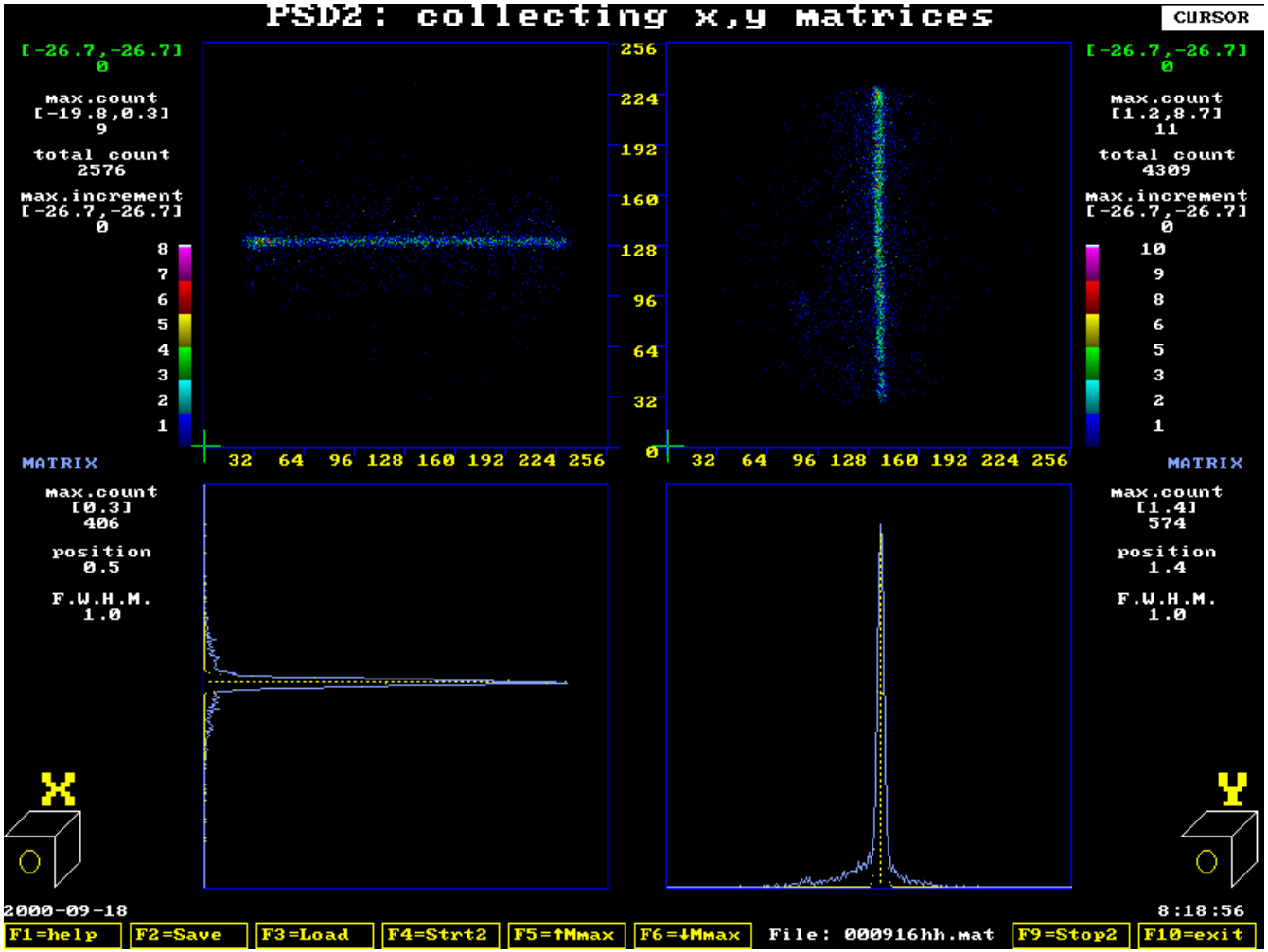
Current measurements
ICT+PU



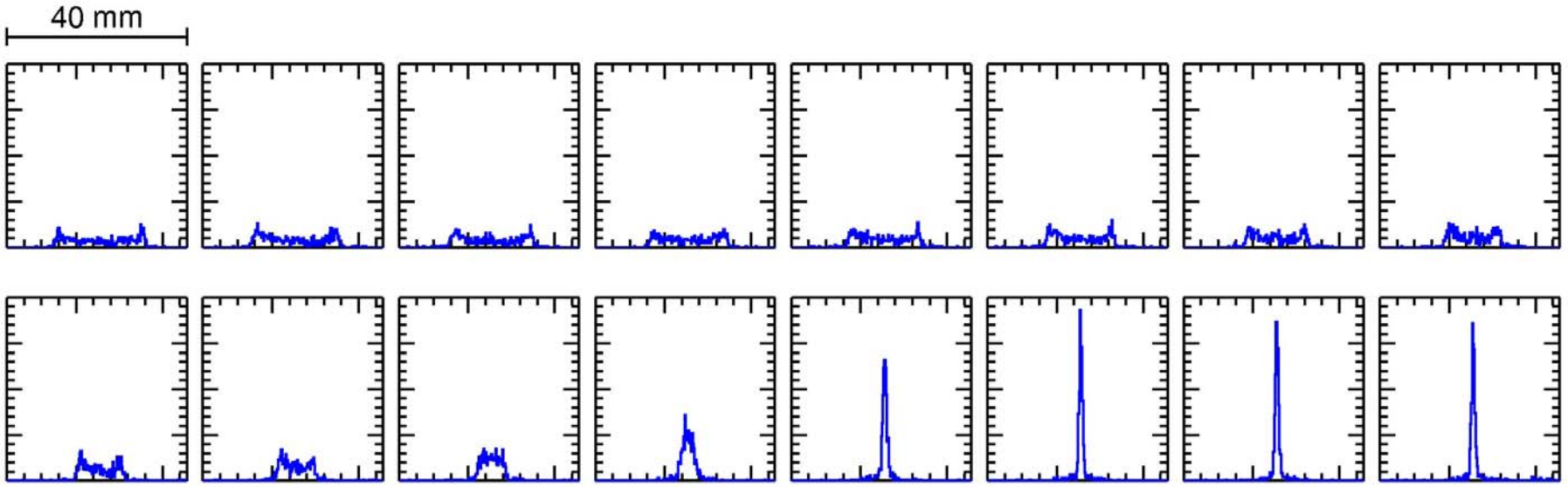
MCP neutral particle monitor



Beam profile monitor



Beam profile monitor, time resolved measurement of transverse cooling



Vertical profiles of an F^{6+} beam during successive 61-ms intervals, starting 61 ms before the electron beam is realigned with the ion beam and cooling begins.

From Danared et al., EPAC 2000, "Studies of Transverse Electron Cooling", http://cern.ch/AccelConf/e00/PAPERS/WEOAF101.pdf

Thank you for your attention!