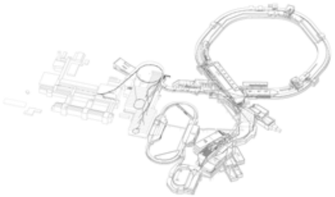


# Beam Instrumentation at CRYRING@ESR

A. Reiter (BEA)
on behalf of Departments of Beam Instrumentation and Decelerator

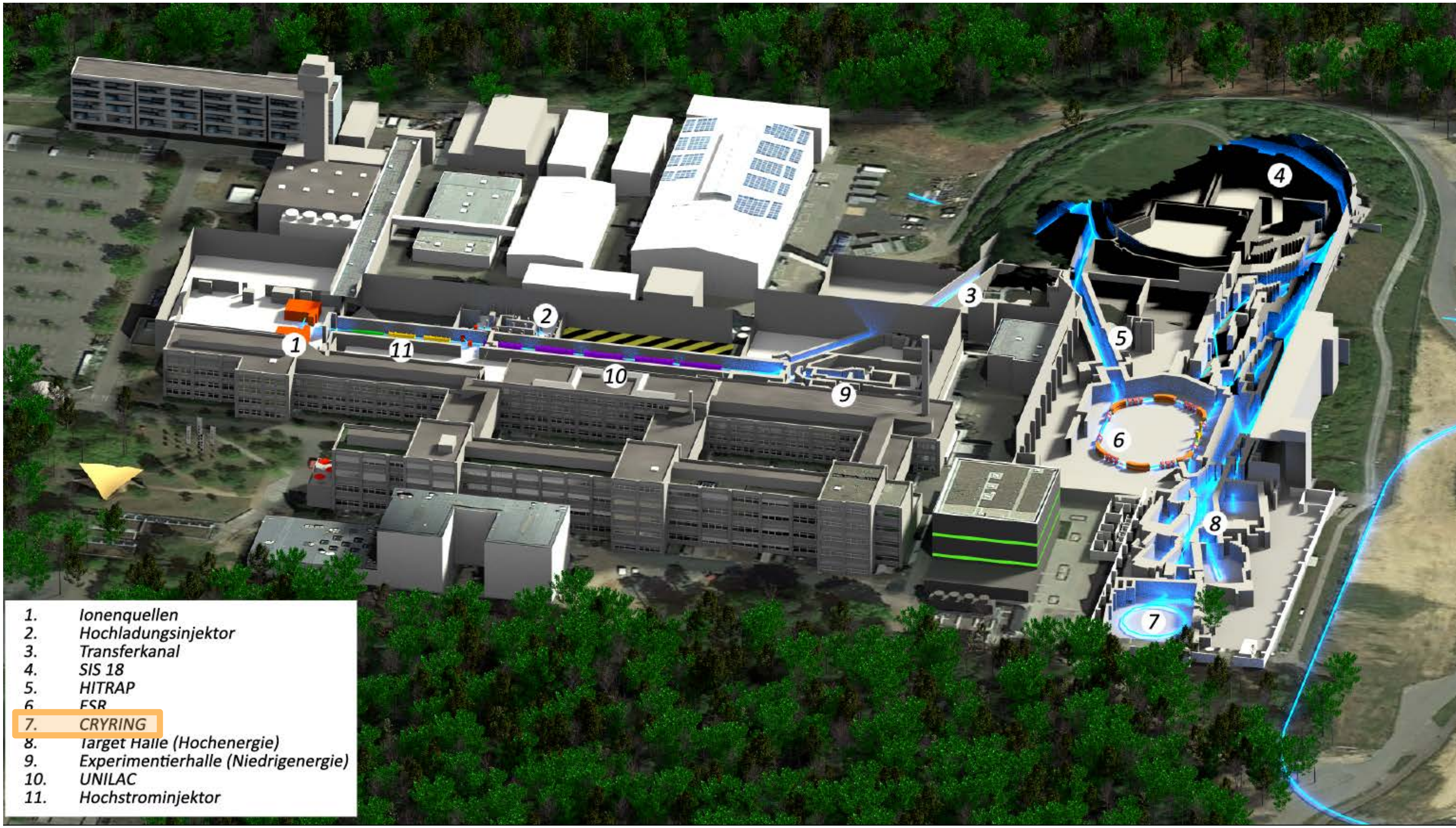
Accelerator Seminar
28th April 2022

# CRYRING@ESR
## Outline of Talk

- **Overview of CRYRING@ESR**
  - Layout of facility
  - Main Parameters of low-energy storage ring
- **Injection Schemes**
  - Local Injector
  - ESR Injection
- **Beam Instrumentation**
  - Local Injector
  - ESR Injection
  - CRYRING
- **Detector signals across a selected machine cycle**
  - Injection
  - Acceleration
  - Rebunching
  - Flattop

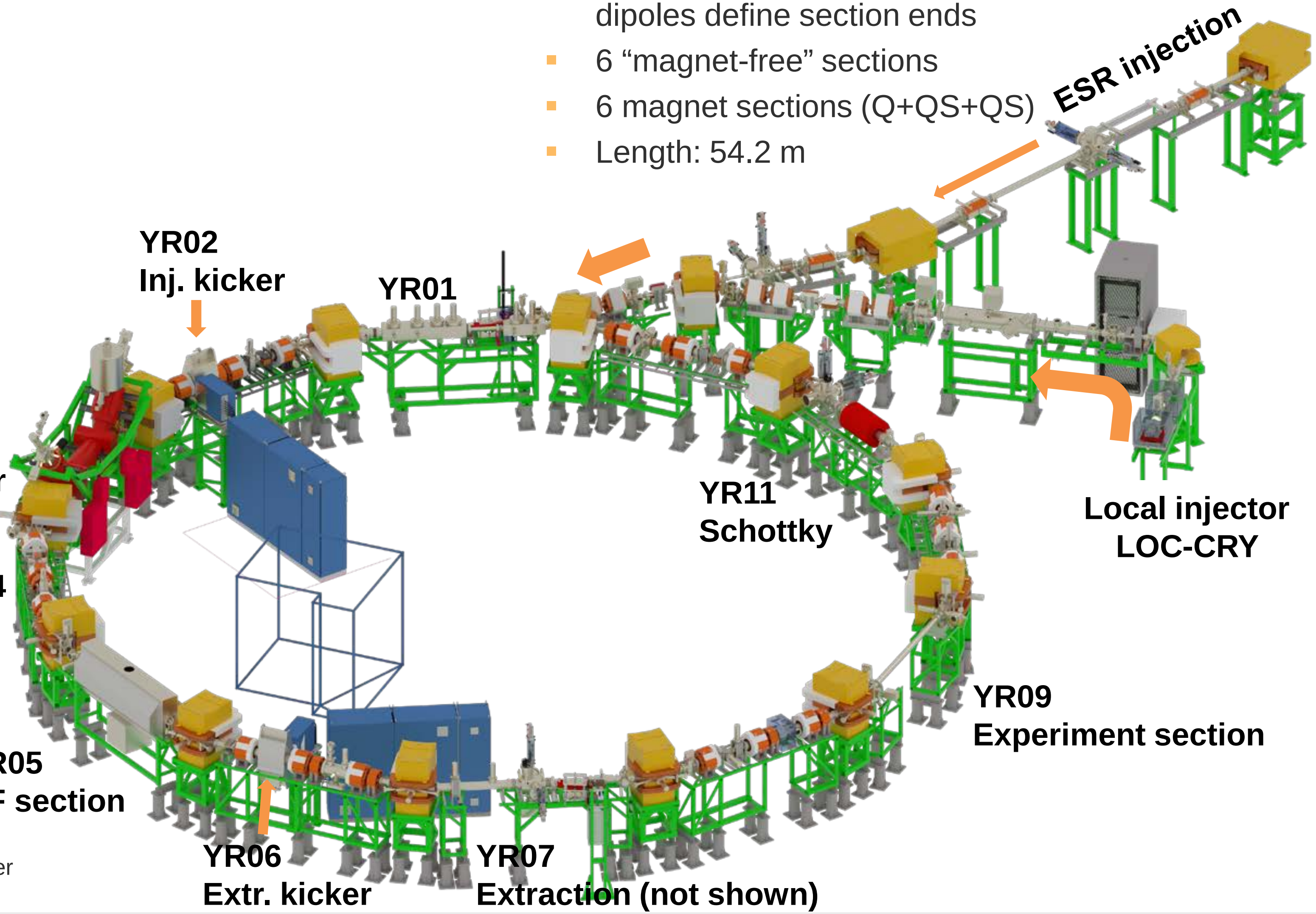
# CRYRING@ESR

## Overview of existing facility



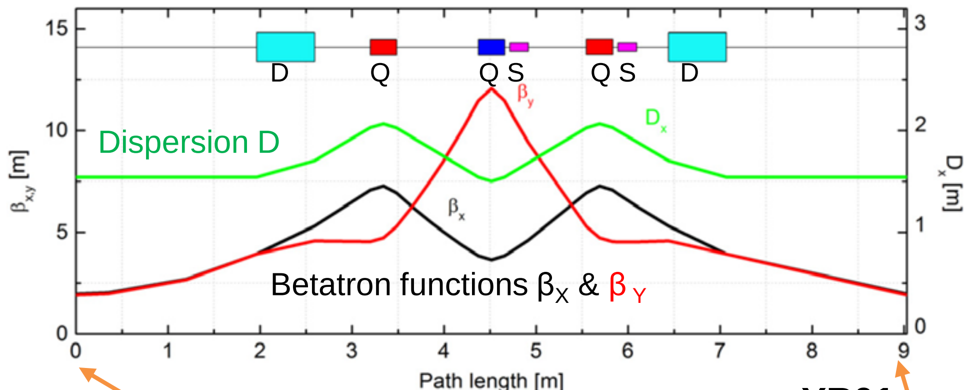
# CRYRING@ESR
## Section Layout & Ion Optics

- CRYRING consists of 12 sections: YR01 – YR12, dipoles define section ends
- 6 “magnet-free” sections
- 6 magnet sections (Q+QS+QS)
- Length: 54.2 m

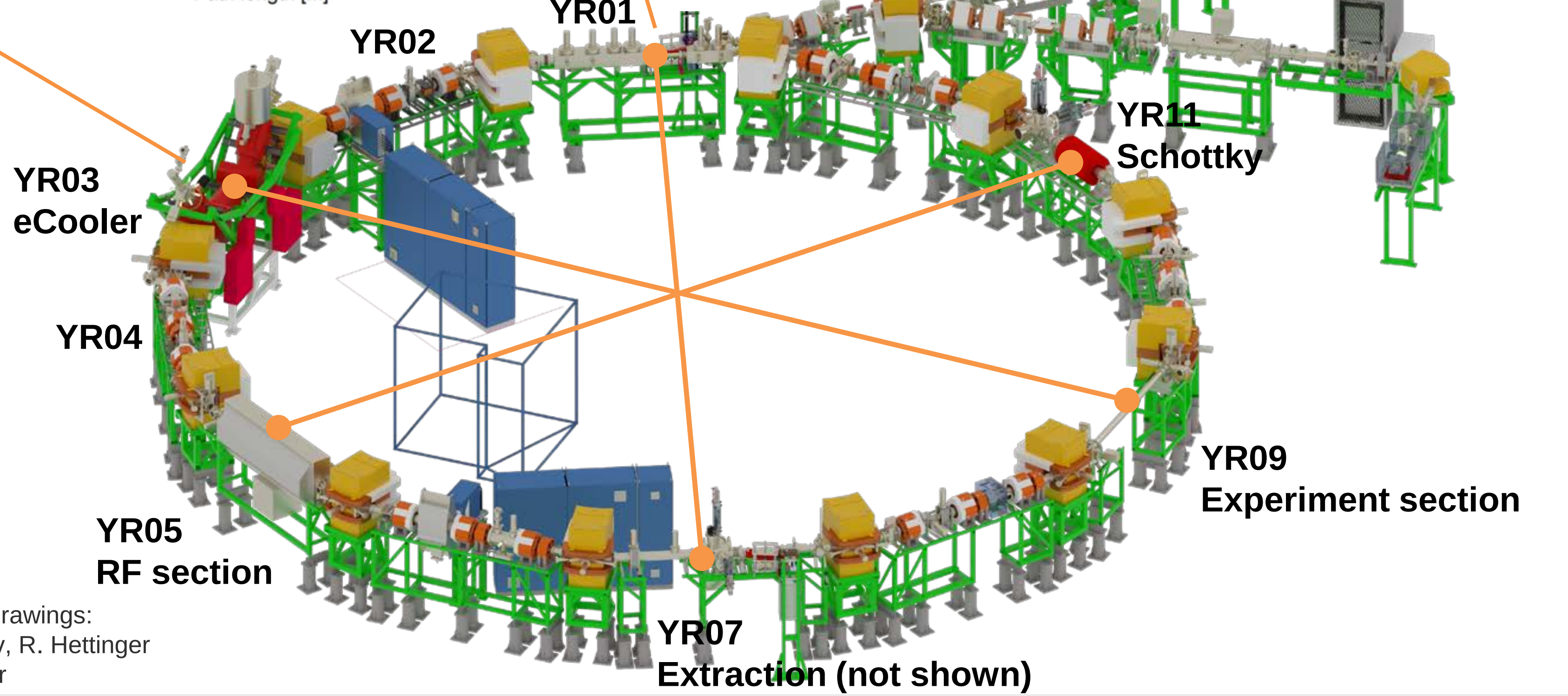



Technical drawings:
G. Vorobjev, R. Hettinger
W. Geithner

# CRYRING@ESR
# Section Layout & Ion Optics




- CRYRING consists of 12 sections: YR01 – YR12, dipoles define section ends
- Ion optics has six super-periods, defined by centres of non-magnetic sections
- Length: 54.2 m




Technical drawings:
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W. Geithner

# CRYRING@ESR
## Main Parameters

Reference paper “Ion-optical design of CRYRING@ESR”, O. Gorda *et al.*, 2015 *Phys. Scr.* 2015 014043

| Parameter | Value | Comments / Examples |
|---|---|---|
| Circumference L(YR) | 54.178 m = L(ESR)/2 | Stretched by 2.55 m wrt. original setup |
| Magnetic rigidity Bρ | (0.054 – 1.44) Tm | < 96 MeV protons (β < 0.42)<br>< 15 MeV/u $U^{91+}$ (β < 0.18)<br>< 0.17 MeV/u $Mg^{+}$ (β < 0.02) |
| Ramp rate | 1 T/s | 4 T/s or 7 T/s technically possible |
| Injection types | Fast injection (few µs) of cooled, highly-charged heavy ions from ESR | 30 MeV protons<br>< 15 MeV/u HCI |
| | Multi-turn injection (~ 50 µs/few turns) of low charge states from local injector: RFQ (q/A ≥ 0.35) or ion source with HV = (30 – 40) kV | 300 keV/u RFQ (108.48 MHz)<br>RFQ acceleration (RF upgrade planned)<br>RFQ transport mode (5 keV/u $Li^{1+}$) |
| Revolution frequency | tens kHz – 2.4 MHz | 5 keV/u: 18 kHz , 300 keV/u: 140 kHz |
| Ring RF frequency | ~135 kHz – 2.4 MHz | 5 keV/u $Li^{1+}$: 145 kHz (h=8), 2.14 MHz (h=6) |
| Harmonic number h | 1 – 18 | 1.6 keV/u Mg+: h = 14, 15, 18<br>3 keV/u C+ or $Ne^{2+}$: h = 8, 10 |
| Momentum acceptance | ± 1 % | |
| Transverse acceptance | 50 π mm mrad | Bumper injection geometry in YR01 |
| Design tune values | Q(h) = Q(v) = 2.42 | |
| Max. beam size | ± 35 mm | |
| Extraction | Fast / slow extraction in YR07 | Short experiment beam line |

More information on: https://www.gsi.de/work/forschung/appamml/atomphysik/anlagen_und_experimente/cryringesr

# CRYRING@ESR
## Rough Timeline

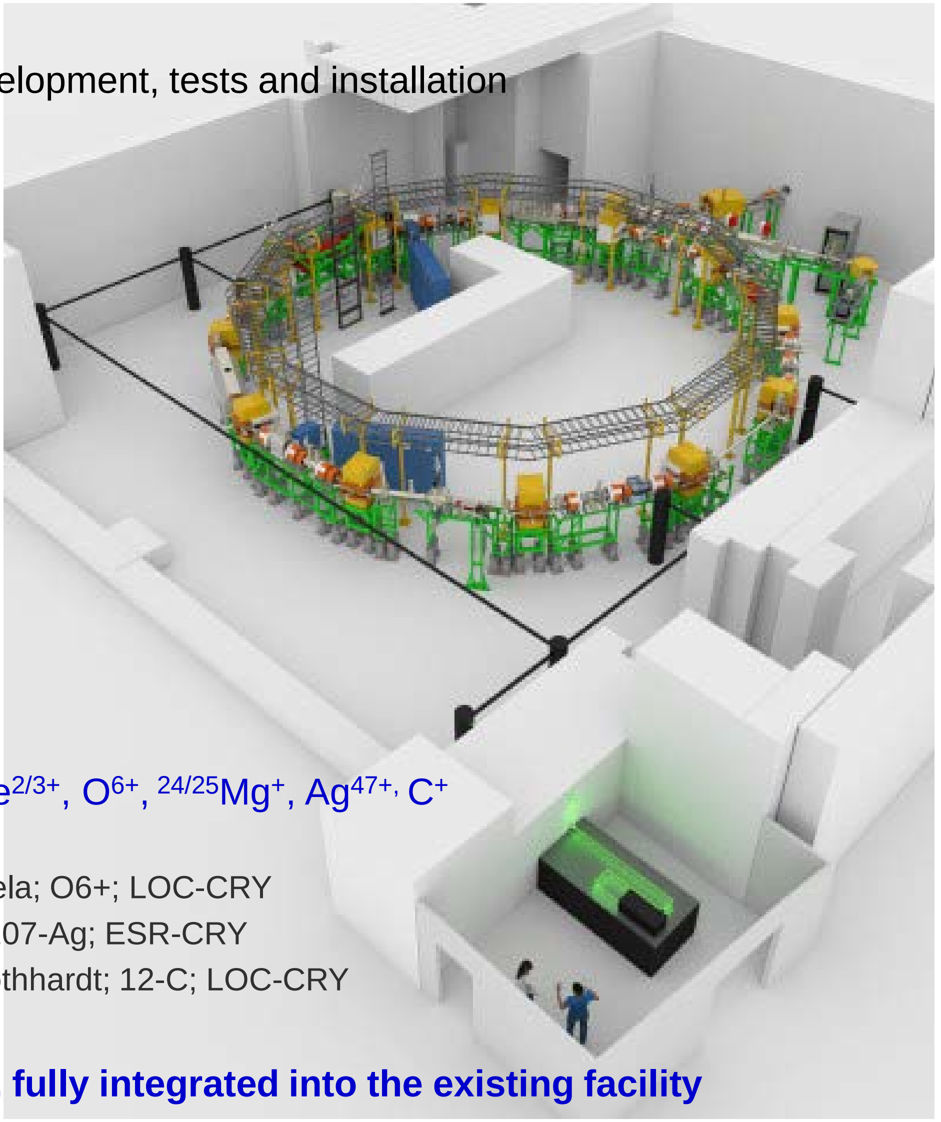
Nov. 2012: KickOff Meeting Controls@GSI
2013 – 2015: Transport & delivery to GSI, system development, tests and installation
Jan. – Aug. 2016: Commissioning of local injector

July 2016: 1$^{st}$ transport ESR to section YR01
Oct. 2016: 1$^{st}$ turn ($H_2^+$ beam from local injector)
May 2017: 1$^{st}$ electron beam in eCooler
Aug. 2017: 1$^{st}$ stored beam ($H_2^+$, local injector)
Nov. 2017: 1$^{st}$ cooled beam ($H_2^+$, local injector)
2018: Commissioning with $H_2^+$, $D^+$, $Mg^+$, $Ar^+$
Setup of laser laboratory

2019: 1$^{st}$ stored ESR beam ($Ar^{18+}$, 13 MeV/u)
Comm. with $Mg^+$, $C^+$, $D^+$ ; 1$^{st}$ experiments
2020: Comm. & Experiments with $Ne^{7+}$, $Pb^{78+}$, $Pb^{82+}$
2021: Comm. & Experiments with $D^+$, $Pb^{67+}$, $U^{91+}$, $Ne^{2/3+}$, $O^{6+}$, $^{24/25}Mg^+$, $Ag^{47+}$, $C^+$

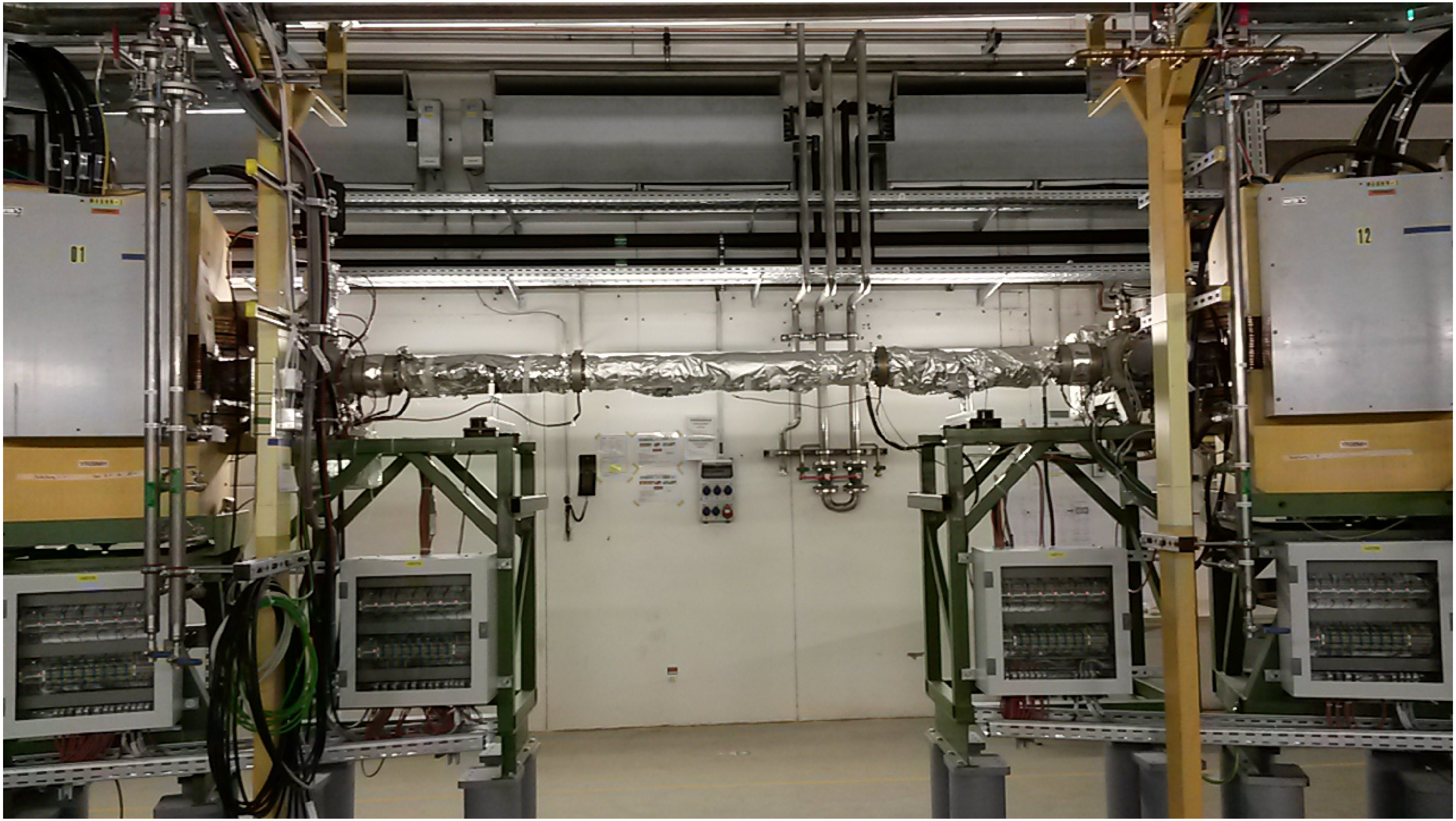
- E131 Schippers; 208-Pb; ESR->CRY
- E148 Sanchez; 24-Mg; LOC-CRY
- E138 Weber; 238-U; ESR-CRY
- E140 Lestinsky; Ne3+; LOC-CRY
- E153 Biela; O6+; LOC-CRY
- CMAT; 107-Ag; ESR-CRY
- E129 Rothhardt; 12-C; LOC-CRY

2022: GSI@WORK: Beam Time Schedule

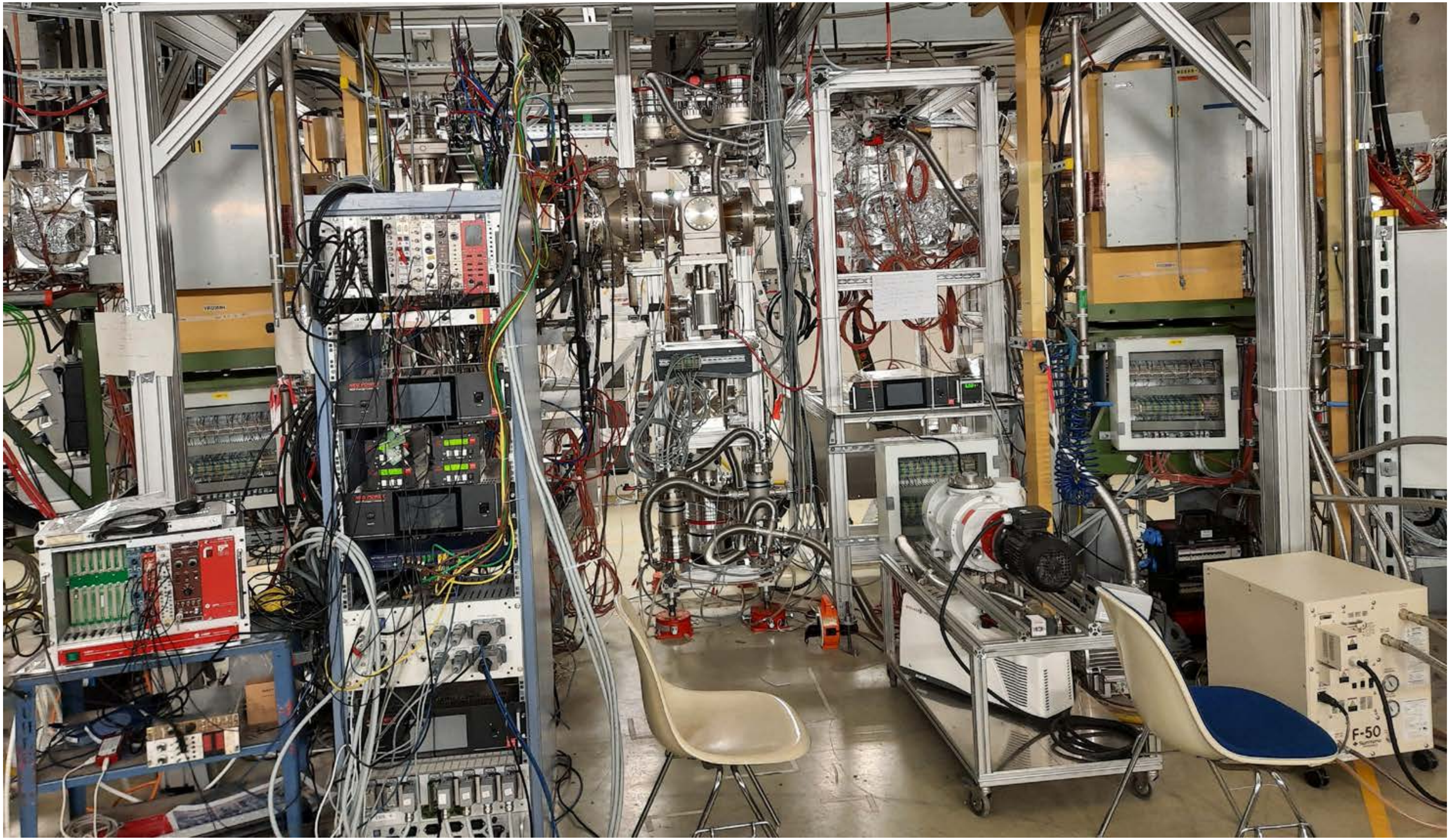


**CRYRING@ESR is a scientific instrument, fully integrated into the existing facility**

# Section YR09 (Jan. 2018) – beam pipe

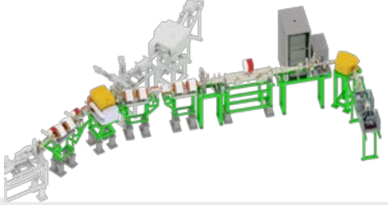


# CRYRING@ESR
## Section YR09 (April 2022) – beam pipe & much more

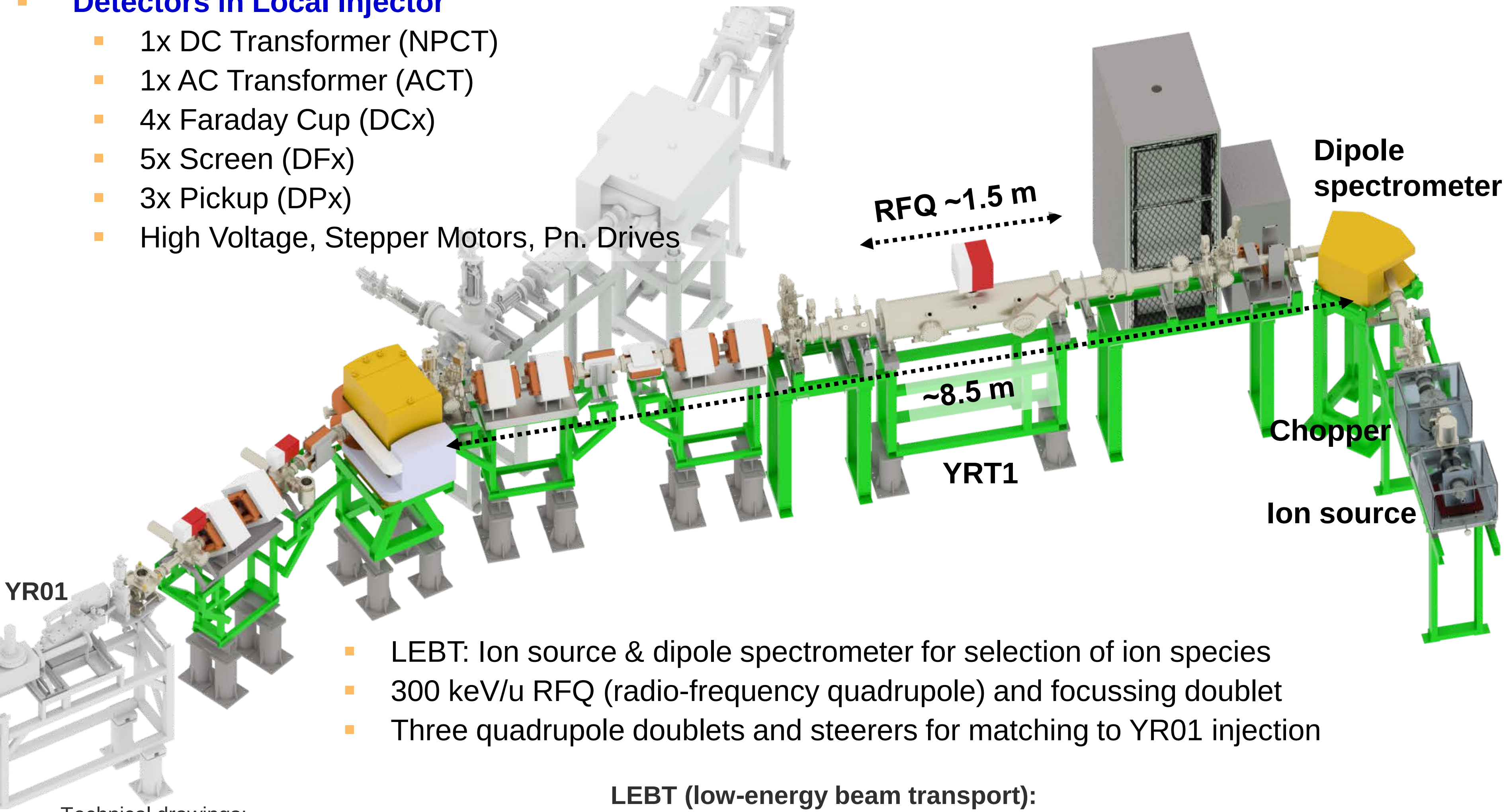


# LOC-CRY: Local Injector
## Light ions of low charge states for CRYRING

# LOC-CRY: Local Injector
# Overview Beam Instrumentation



- **Detectors in Local Injector**
  - 1x DC Transformer (NPCT)
  - 1x AC Transformer (ACT)
  - 4x Faraday Cup (DCx)
  - 5x Screen (DFx)
  - 3x Pickup (DPx)
  - High Voltage, Stepper Motors, Pn. Drives

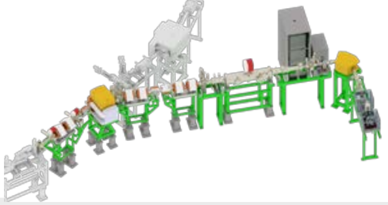



- LEBT: Ion source & dipole spectrometer for selection of ion species
- 300 keV/u RFQ (radio-frequency quadrupole) and focussing doublet
- Three quadrupole doublets and steerers for matching to YR01 injection

Technical drawings:
G. Vorobjev, R. Hettinger
W. Geithner

**LEBT (low-energy beam transport):**
**Source branch up to RFQ is electrostatic, apart from spectrometer dipole**
**Focussing doublet after RFQ is electrostatic**

# LOC-CRY: Local Injector
## Overview Beam Instrumentation



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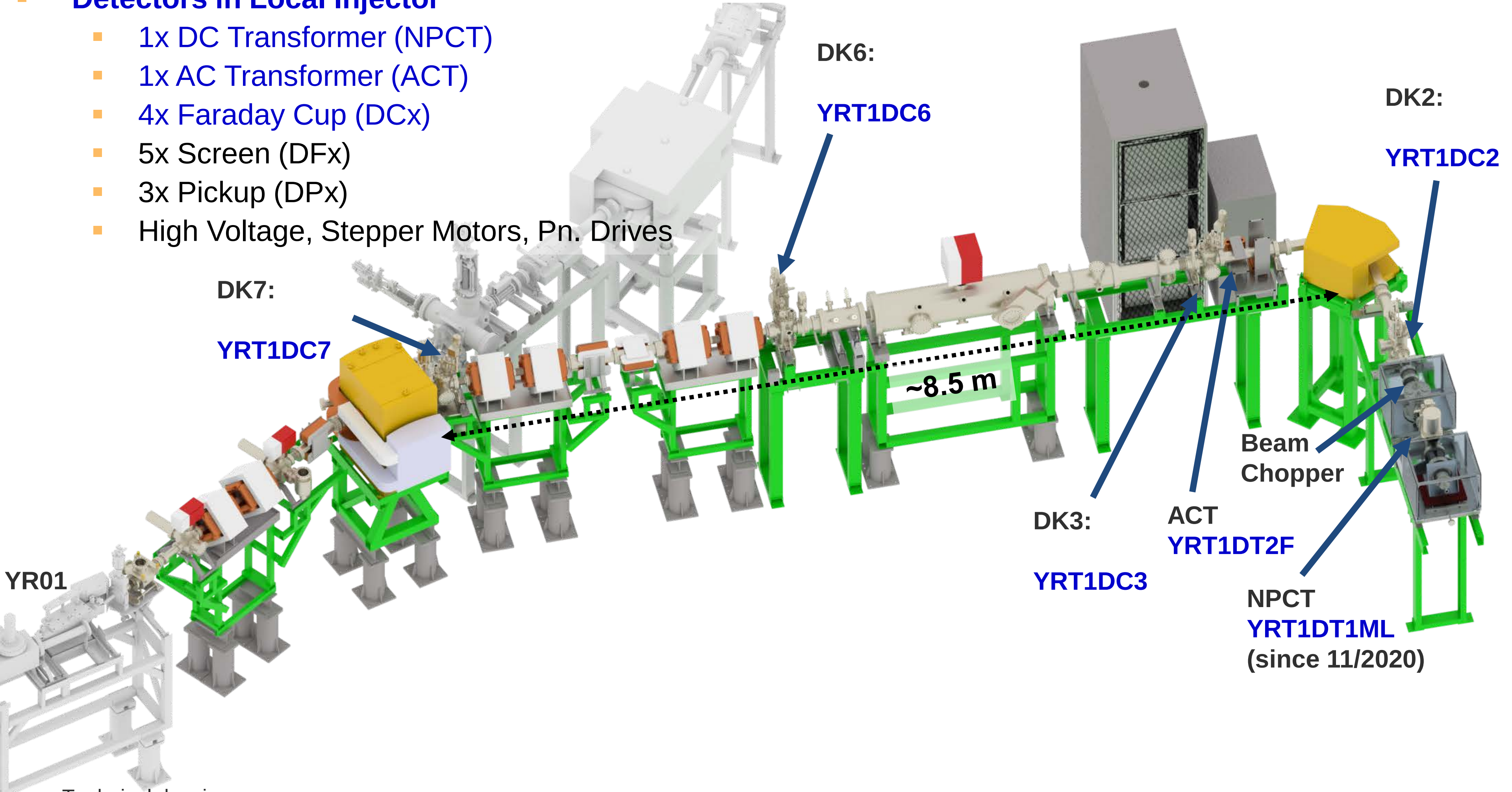
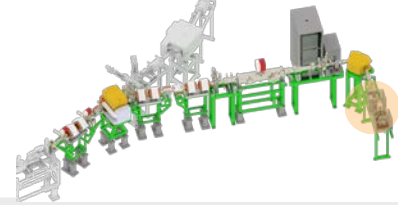
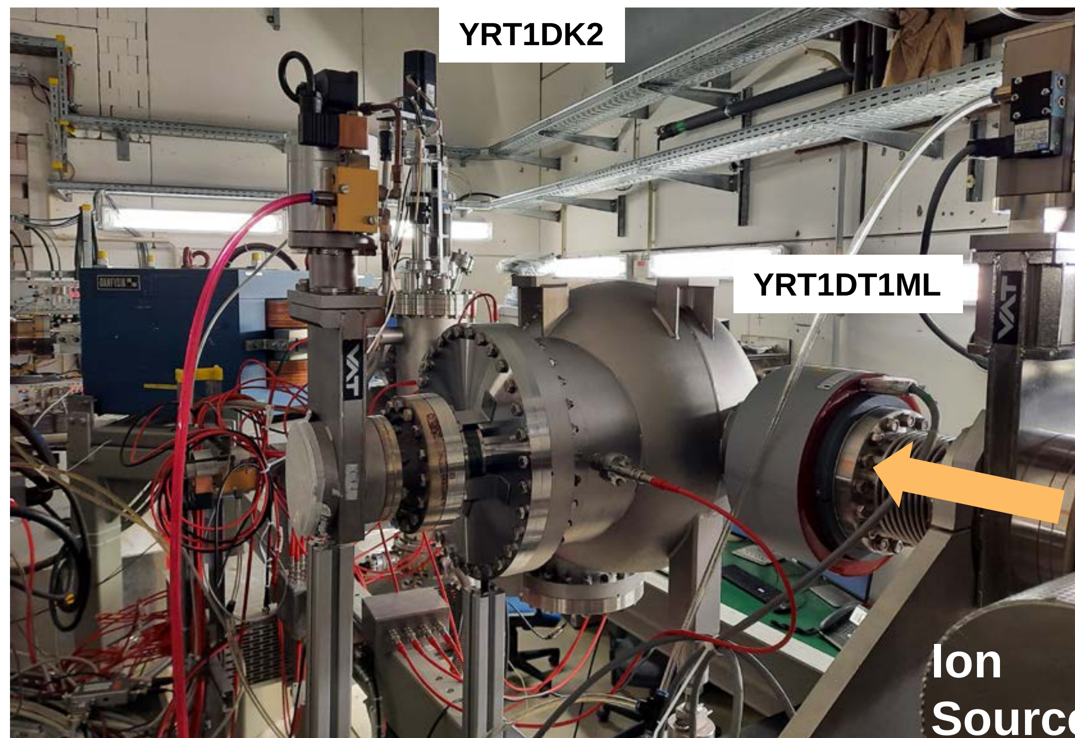



Technical drawing:
G. Vorobjev, R. Hettinger
W. Geithner

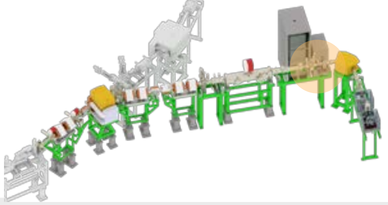
# LOC-CRY: Local Injector
## DC Transformer YRT1DT1ML



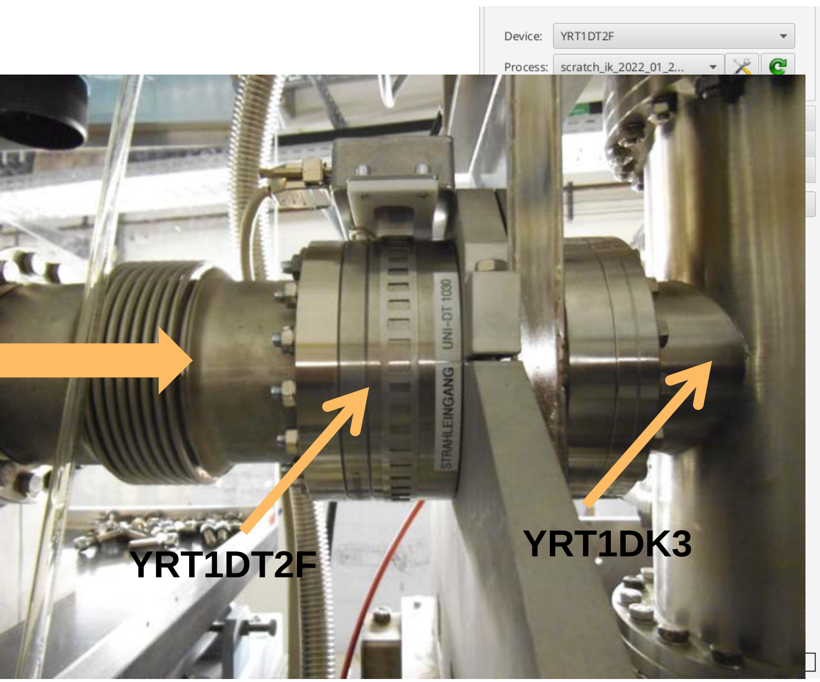
- Bergoz NPCT-175-HR-C040, 175 mm diameter with high resolution option
  - Task: Monitoring of ion source current (DC or pulsed)
  - Ranges: **2 mA**, (20 mA, 200 mA and 2 A, not used!)
  - Bandwidth: **>1 kHz** (2 mA), 7 kHz (20 mA), >10 kHz (200 mA, 2A)
  - Installation: November 2020, at the moment without external housing without adverse effects.
- DAQ:
  - Hardware: VME scaler system
  - Application: Lassie Spill & Monitor

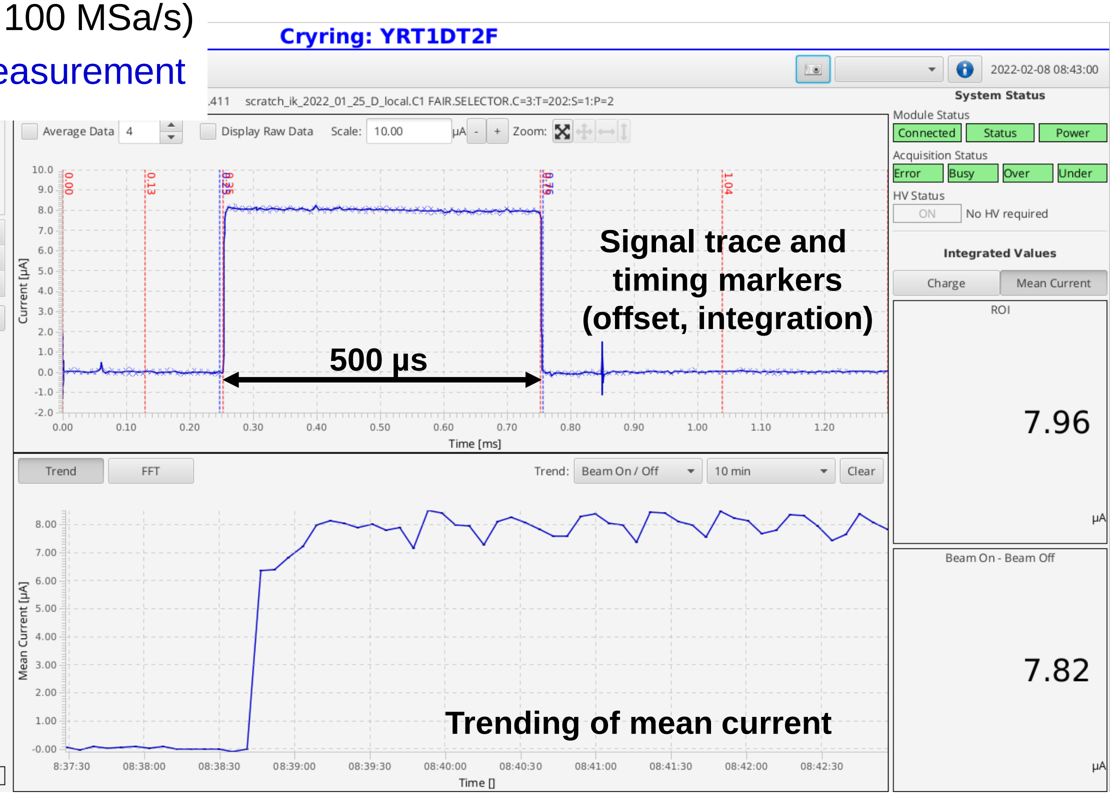



# LOC-CRY: Local Injector
# AC Transformer YRT1DT2F

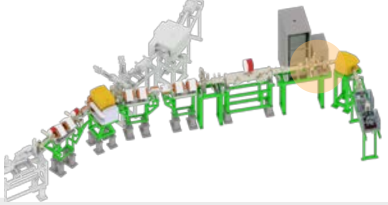


- GSI-type AC current transformer UNI-DT 1030 with amplifier unit
  - Task: Monitoring of chopped, analysed beam, typ. currents (1 – 20) µA, after spectrometer
  - Ranges: **10 µA**, 100 µA, 1 mA, 10 mA
  - Bandwidth: <1 MHz
  - Pulse width: (5 – 500) µs, defined by chopper window
- DAQ:
  - Hardware: VME ADC system (max. 100 MSa/s)
  - Application: Cryring Linac Current Measurement



# LOC-CRY: Local Injector
# AC Transformer YRT1DT2F & Faraday Cup



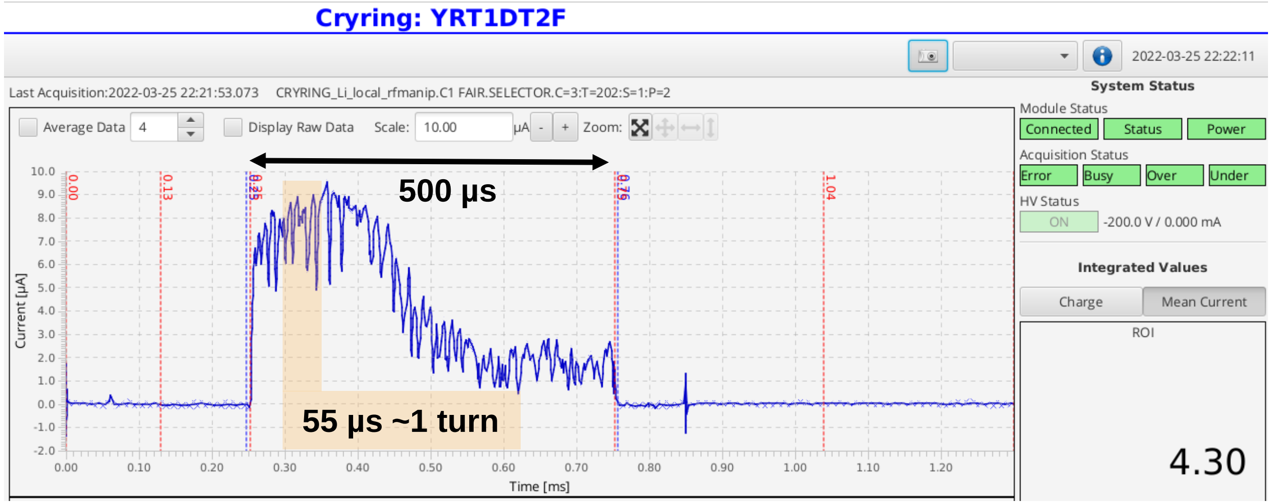
GUI application integrates current measurements of different devices.

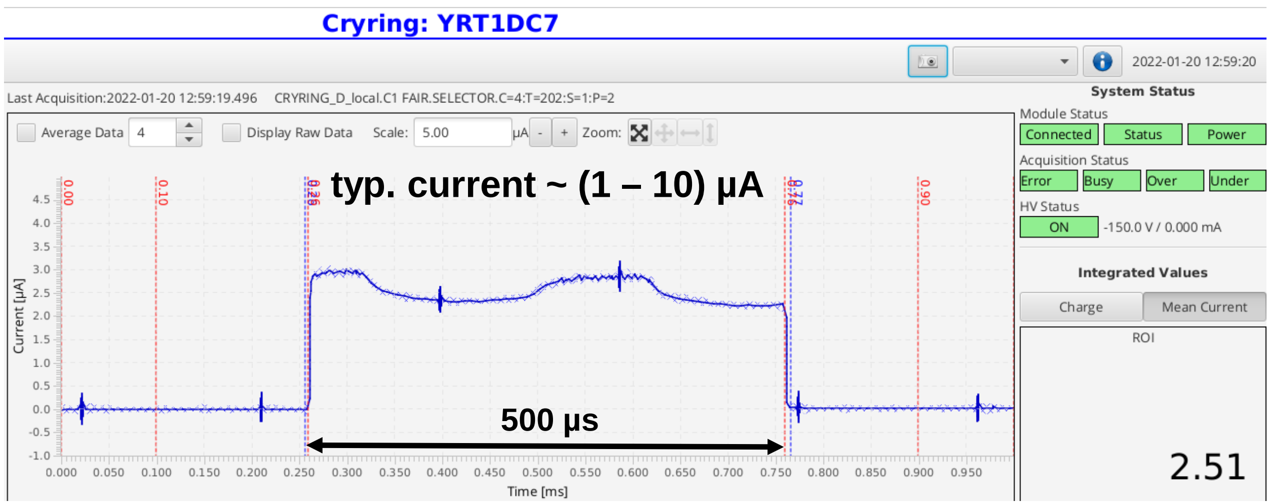
**ACT measurement**

- March 2022: ACT signal of $Li^{1+}$ beam <10 µA at E = 5 keV/u
- Pulses with large variations in shape and intensity depending on operational parameters

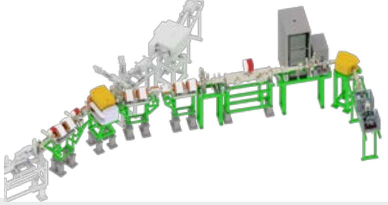
**FC measurement**

- Jan. 2022: Signal of $O^{1+}$ beam in last Faraday Cup in Linac
- Current amplifier:
  - trans-impedance amplifier Femto DHPCA-100
  - Gain: ($10^2$ – $10^8$) V/A
  - AC & DC measurements
  - Bandwidth: full, 10, 1 MHz
- A/D converter
  - VME ADC
  - DAQ rate: up to 100 MHz



# LOC-CRY: Local Injector
## Overview Beam Instrumentation



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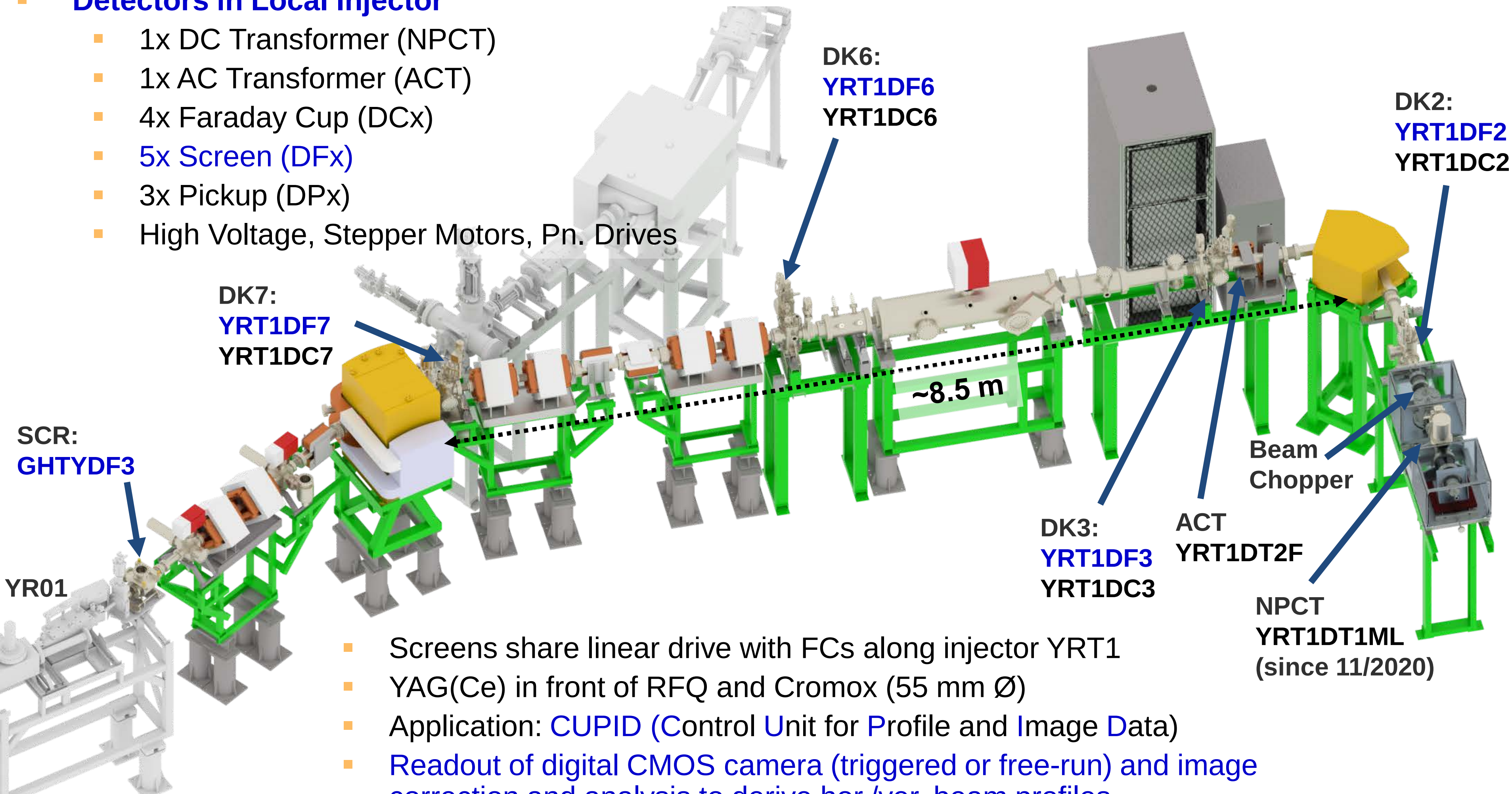
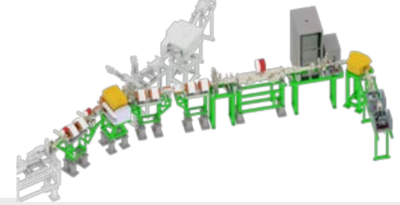
  - High Voltage, Stepper Motors, Pn. Drives




- Screens share linear drive with FCs along injector YRT1
- YAG(Ce) in front of RFQ and Cromox (55 mm Ø)
- Application: CUPID (Control Unit for Profile and Image Data)
- Readout of digital CMOS camera (triggered or free-run) and image correction and analysis to derive hor./ver. beam profiles
- More during discussion of ESR injection

Technical drawing:
G. Vorobjev, R. Hettinger
W. Geithner

# LOC-CRY: Local Injector
## Overview Beam Instrumentation



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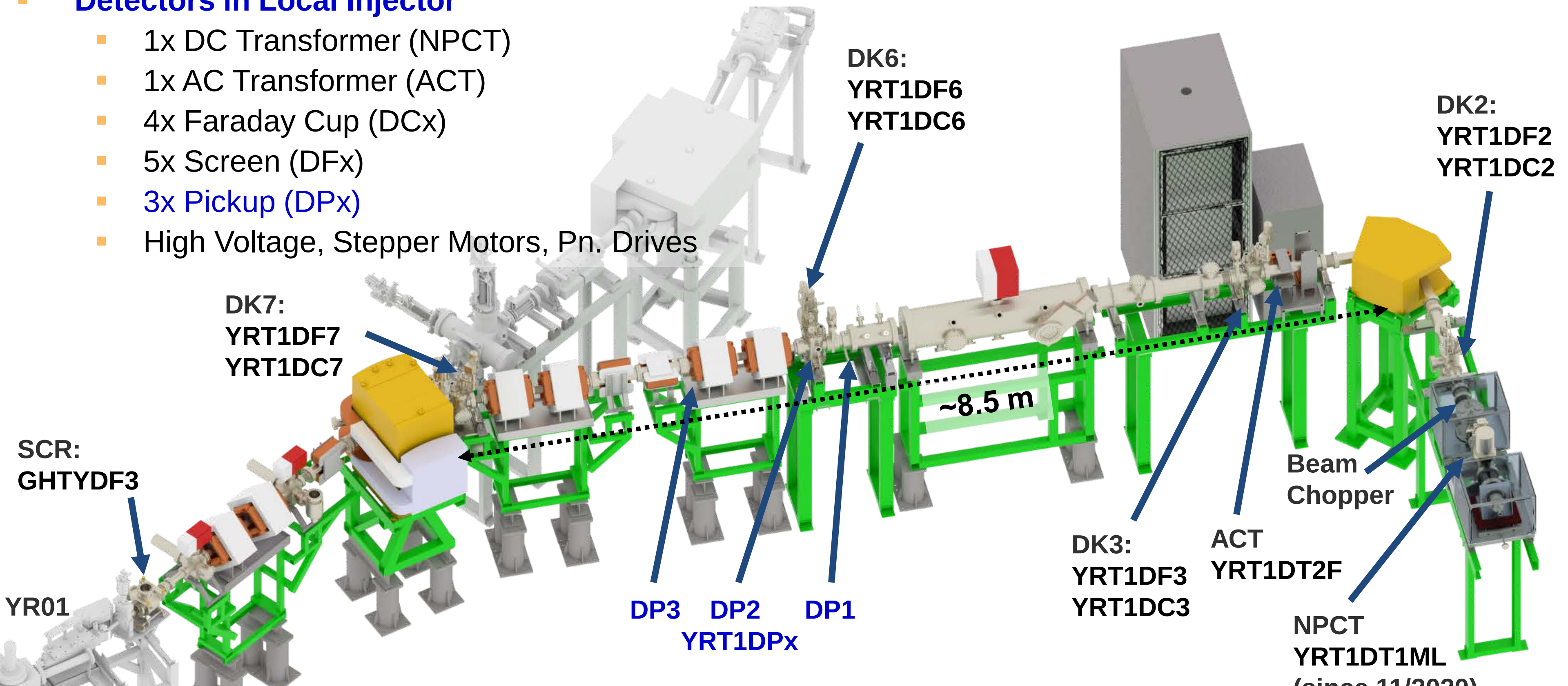
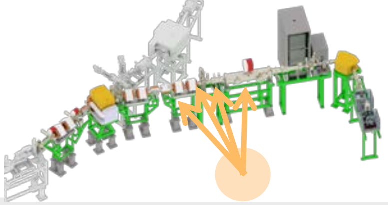



- Energy measurement via time-of-flight
- Focusing doublet: no electrons (generated in RFQ) reach DP1 or DP2
- Pickup distances: (DP1/DP2) = 423 mm and (DP2/DP3) = 1043 mm
- DP3 position ~2 meters after RFQ exit still ok.

Technical drawing:
G. Vorobjev, R. Hettinger
W. Geithner

# LOC-CRY: Local Injector
## RFQ Acceleration: Macropulse at 300 keV/u

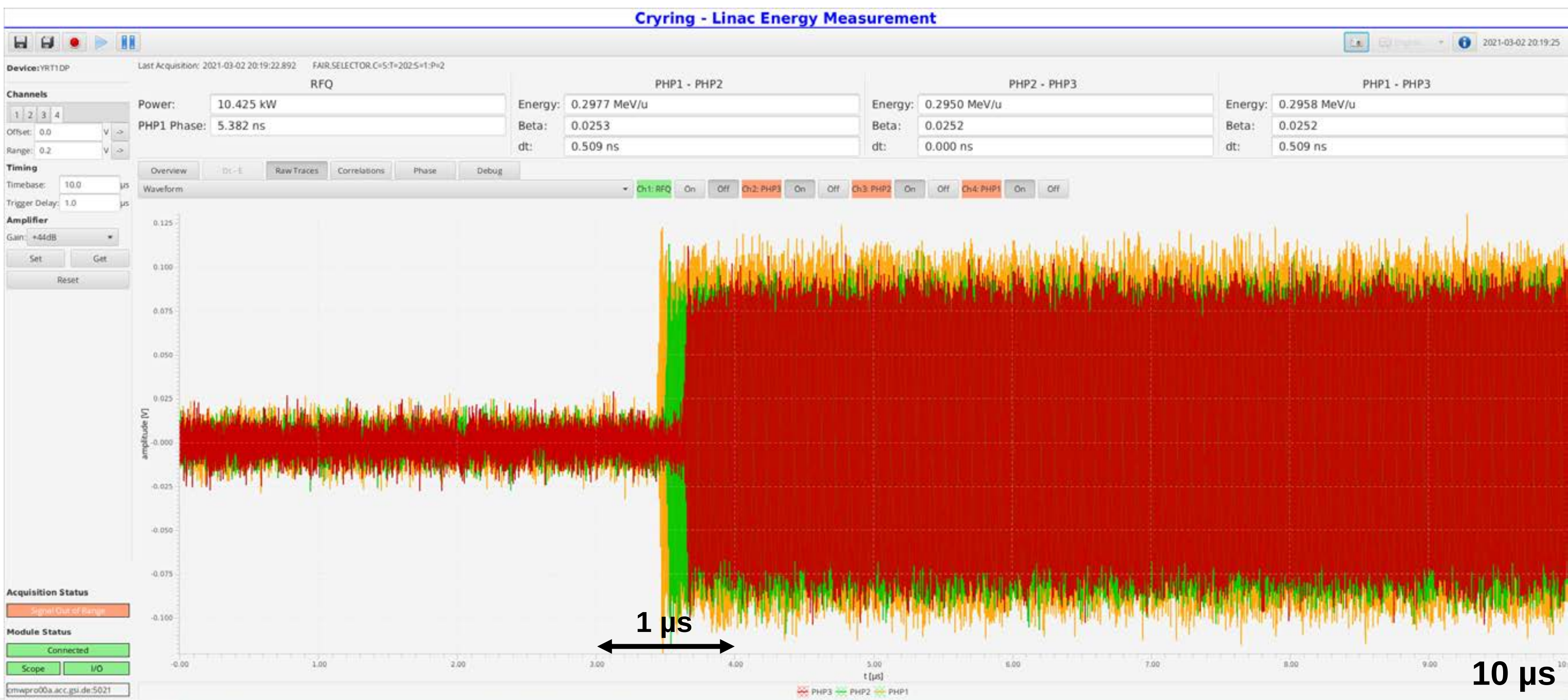


Three capacitive ring pickups DP490 (diam. 50 mm, length 10 mm) and UNILAC DPX amplifiers (38 – 50 dB)

- Task: Energy measurement and monitoring of tank and pickup signals (raw, average, interleaved)
- Trending of RF power, beam energy and pickup voltages (Vpp) as relative current monitor

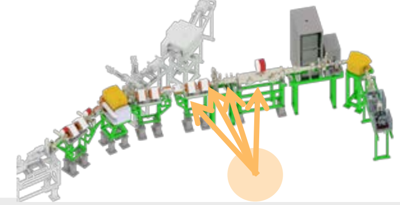
DAQ:

- Hardware: 5 GSa/s digital oscilloscope (BW=1 GHz) and LXI readout via PC
- Application: FESA class and GUI application for automated energy measurement

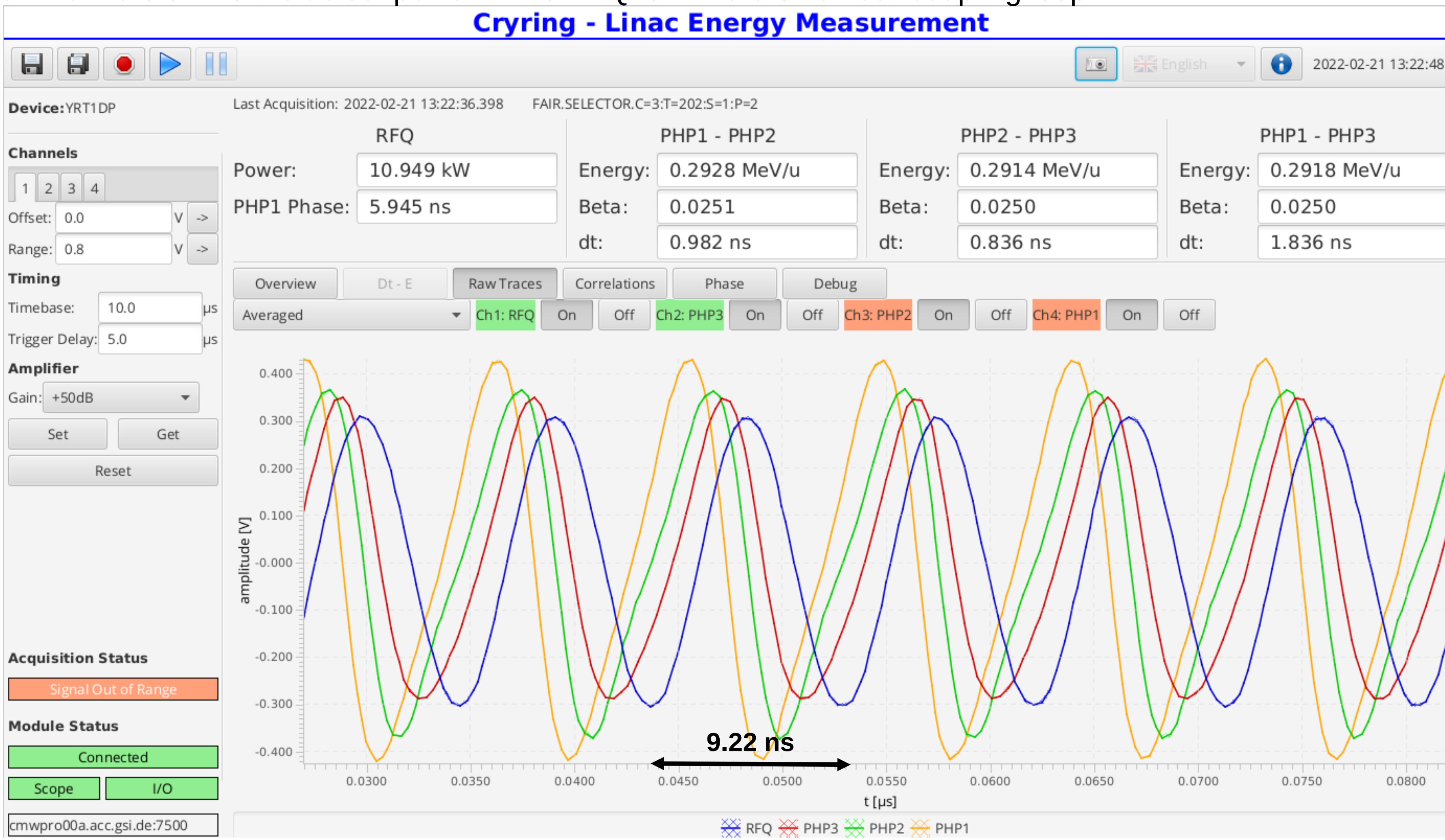


# LOC-CRY: Local Injector

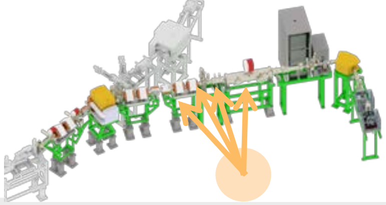
## RFQ Acceleration: Pickup and tank signals



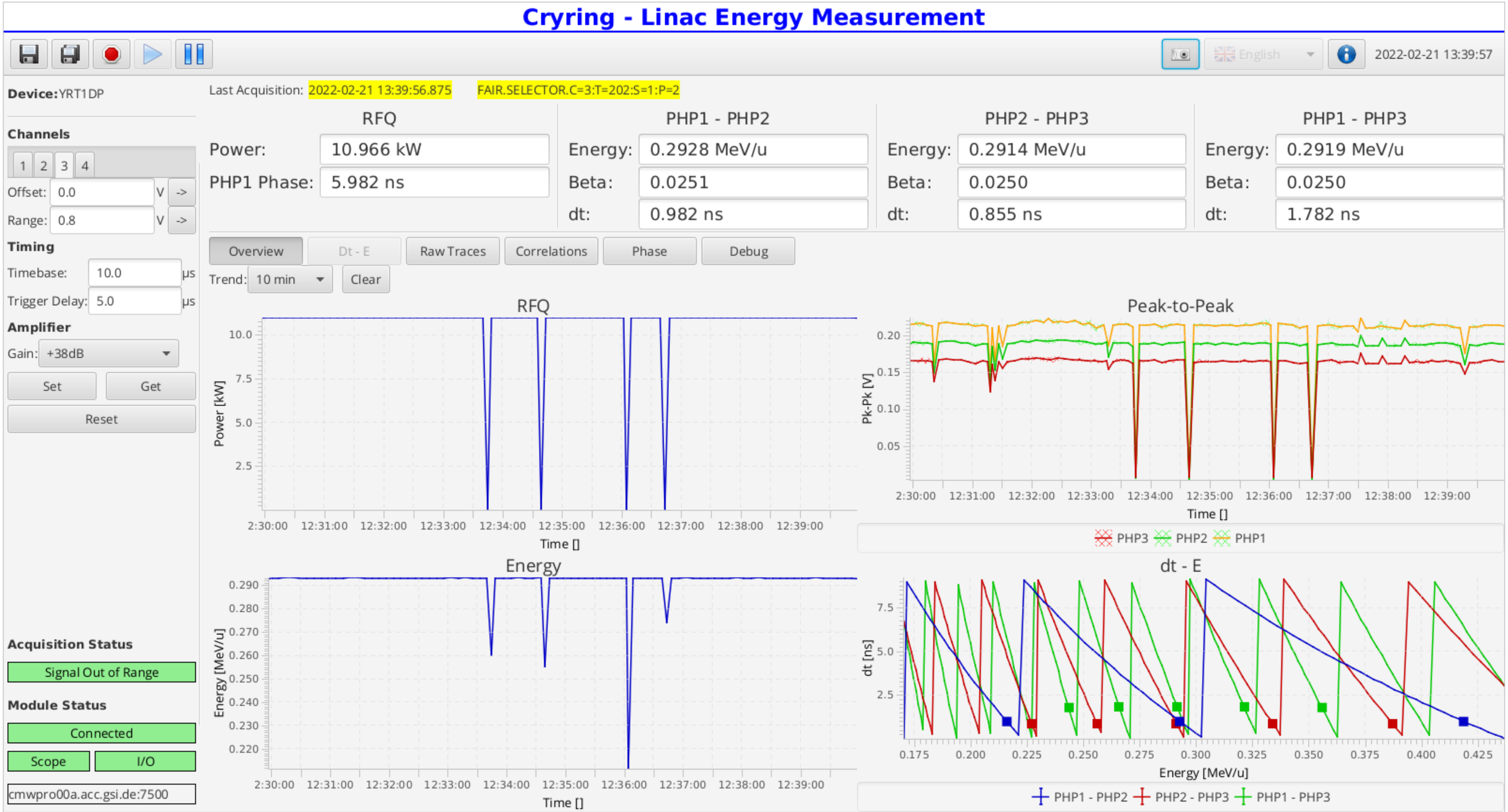
Three averaged signal traces of pickups (PHP1 to PHP 3) and tank signal (108.48 MHz RFQ) which monitors online the actual power in the RFQ tank via a small out-coupling loop.



# LOC-CRY: Local Injector
## RFQ Acceleration: Operational Display

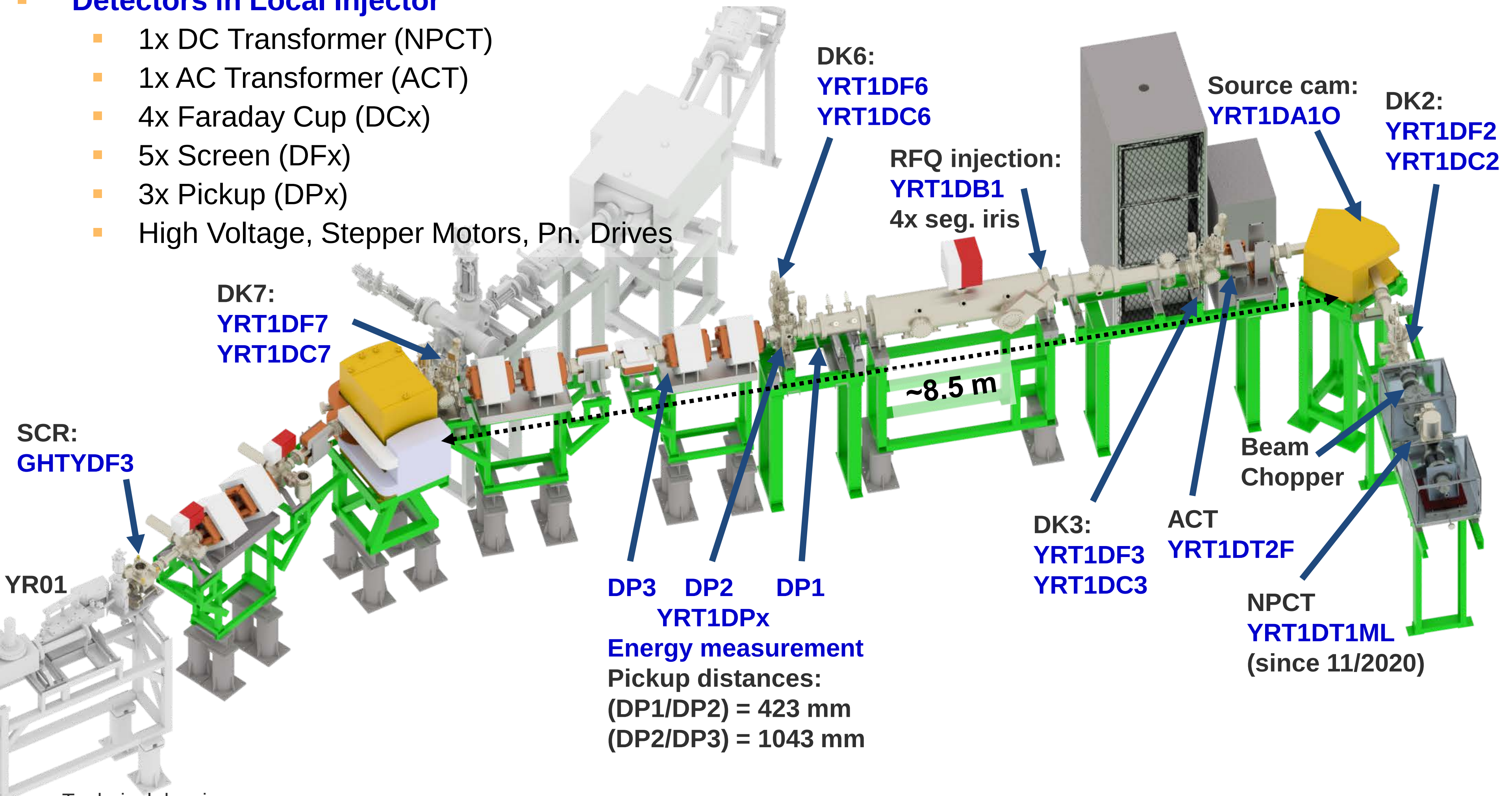


Overview of trend data for RFQ tank power, pickup voltages Vpp and beam energy for online monitoring



# LOC-CRY: Local Injector
## Overview Beam Instrumentation (all)

- **Detectors in Local Injector**
  - 1x DC Transformer (NPCT)
  - 1x AC Transformer (ACT)
  - 4x Faraday Cup (DCx)
  - 5x Screen (DFx)
  - 3x Pickup (DPx)
  - High Voltage, Stepper Motors, Pn. Drives




Technical drawing:
G. Vorobjev, R. Hettinger
W. Geithner

# LOC-CRY: Local Injector

## Summary

- Beam Instrumentation consists mainly of standard detectors and devices.
- RFQ accelerator works very well and provides a stable beam. RF upgrade planned to extend acceleration range for ions.

- Current: OK
  Hardware and software used soon at HITRAP (beam time in May)
- Profile: OK
- Energy: Replace old pickup DP 490 with new GSISD-P010 (HIT type) less prone to external noise.
  Linac energy/TOF application developed for CRYRING is
  in use at UCW Demonstrator, UNILAC, and soon HITRAP.
- Emittance: No space for slit-grid setup; estimates via quadrupole variation

# ESR-CRY: ESR Injection

## Highly-charged heavy ions for CRYRING

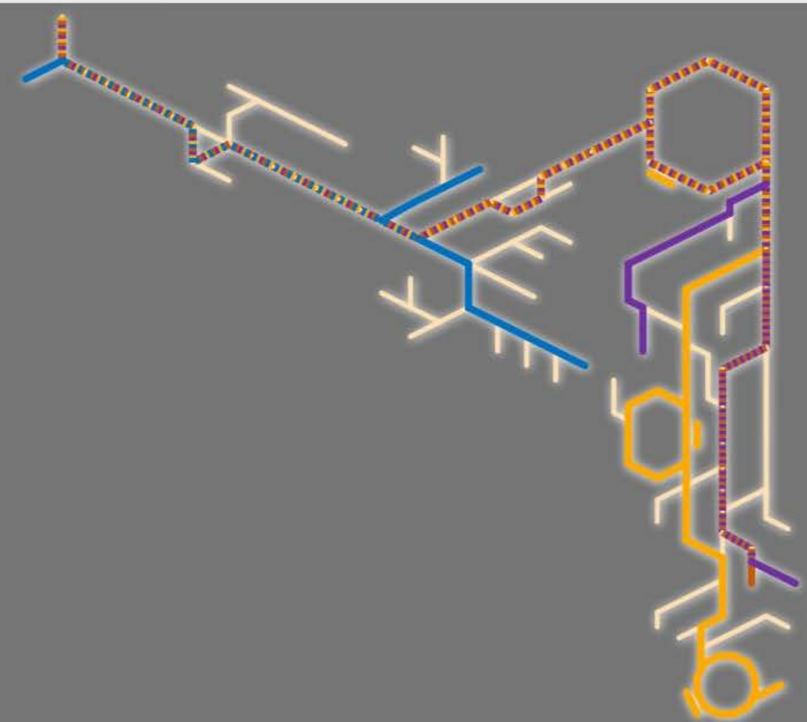
https://facilitystatus.acc.gsi.de/facilitystatus/?viewDark=true

Most Visited | GSI Mail | Acc. Status | UNILAC | CryTools | BI Apps | BI Clipboard | CSCO Apps | BISMARC | OLOG | GSI Tel. | PCT PT100 | CUPID Ctrl | Pneu View | SDAPLC008 | SDAPLC004 | WR Timing

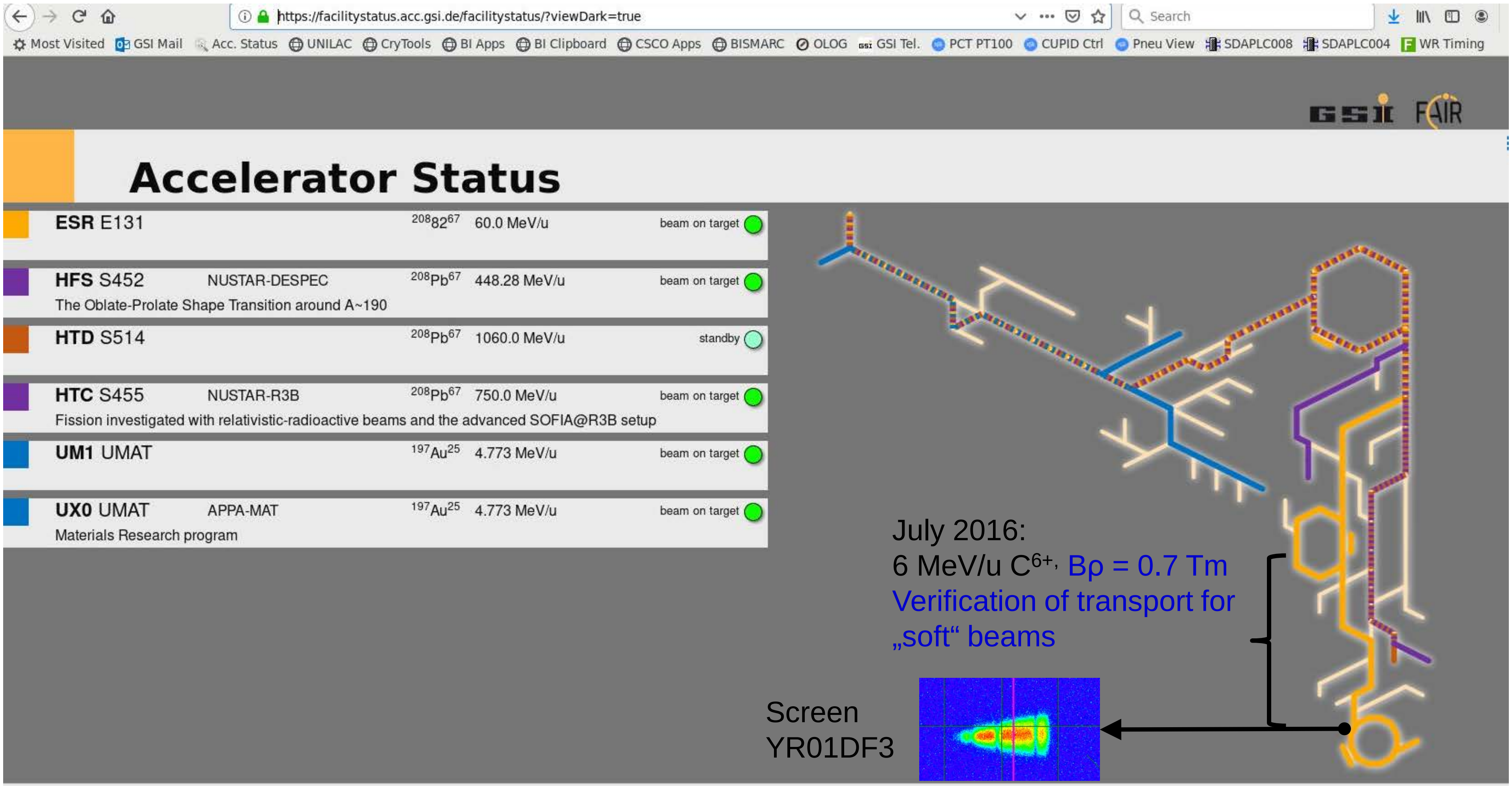
GSI FAIR

## Accelerator Status

| | | | | | |
|---|---|---|---|---|---|
| **ESR** E131 | | $^{208}82^{67}$ | 60.0 MeV/u | beam on target | |
| **HFS** S452 | NUSTAR-DESPEC | $^{208}Pb^{67}$ | 448.28 MeV/u | beam on target | The Oblate-Prolate Shape Transition around A~190 |
| **HTD** S514 | | $^{208}Pb^{67}$ | 1060.0 MeV/u | standby | |
| **HTC** S455 | NUSTAR-R3B | $^{208}Pb^{67}$ | 750.0 MeV/u | beam on target | Fission investigated with relativistic-radioactive beams and the advanced SOFIA@R3B setup |
| **UM1** UMAT | | $^{197}Au^{25}$ | 4.773 MeV/u | beam on target | |
| **UX0** UMAT | APPA-MAT | $^{197}Au^{25}$ | 4.773 MeV/u | beam on target | Materials Research program |



# ESR-CRY: ESR Injection
## Highly-charged heavy ions for CRYRING



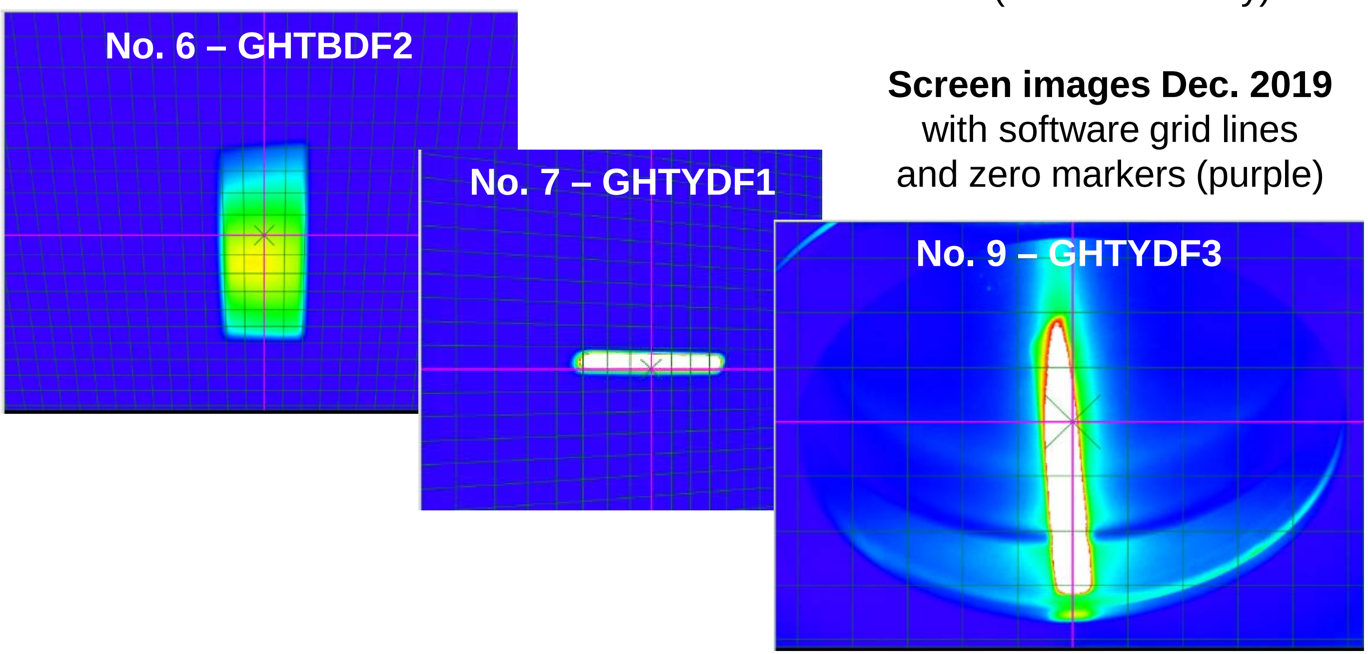

July 2016:
6 MeV/u $C^{6+}$, Bρ = 0.7 Tm
Verification of transport for „soft“ beams

Screen YR01DF3

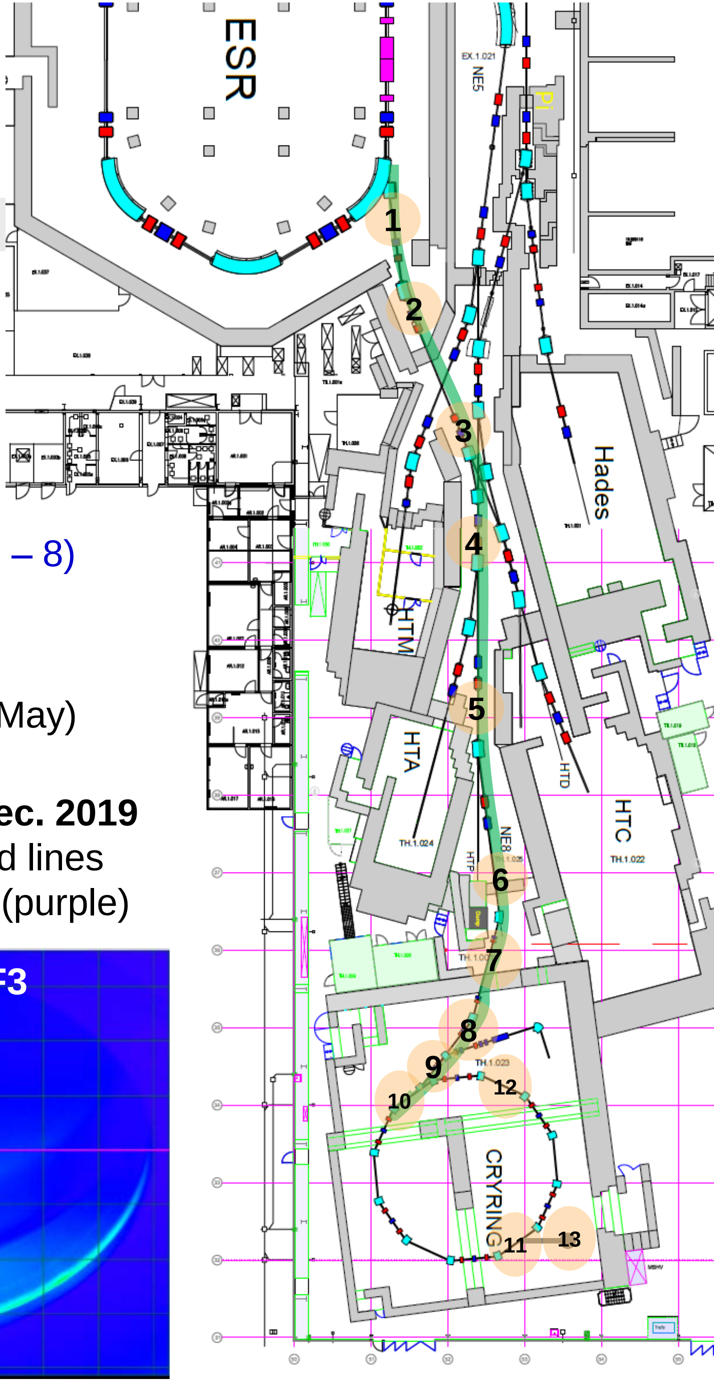
# ESR-CRY: ESR Injection

## Overview Screens & Faraday Cups

- Extraction energy ~(4 – 15) MeV/u makes Faraday Cups possible
- Original upgrade GHTB and GHTY beam lines (pos. 6 – 9)
- 9 Screens, positions roughly indicated in drawing
- 2021 upgrade: 3x FC added after ESR (65 mm diam.) in beam lines GTT1 and GHTT
- Now available: 6x FC for transmission monitoring (pos. 1, 3, 5, 6 – 8)
  9x screen up to YR01
- OPE & SYS teams: Improved ion optics model & emittance measurement (beam time May)

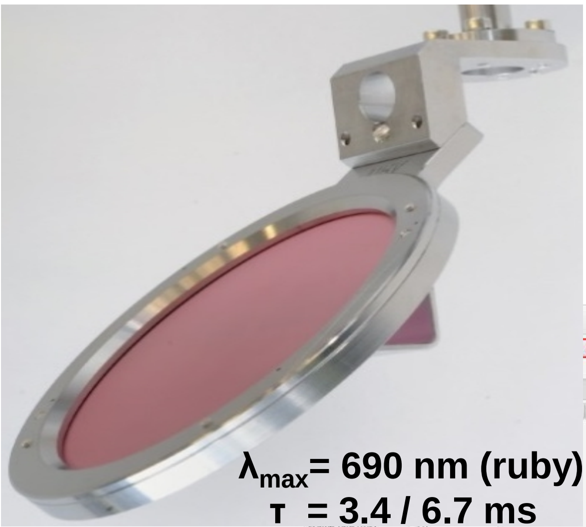



**Screen images Dec. 2019**
with software grid lines
and zero markers (purple)



# ESR-CRY: ESR Injection
## Cromox insulator, P43 phosphor and YAG crystal

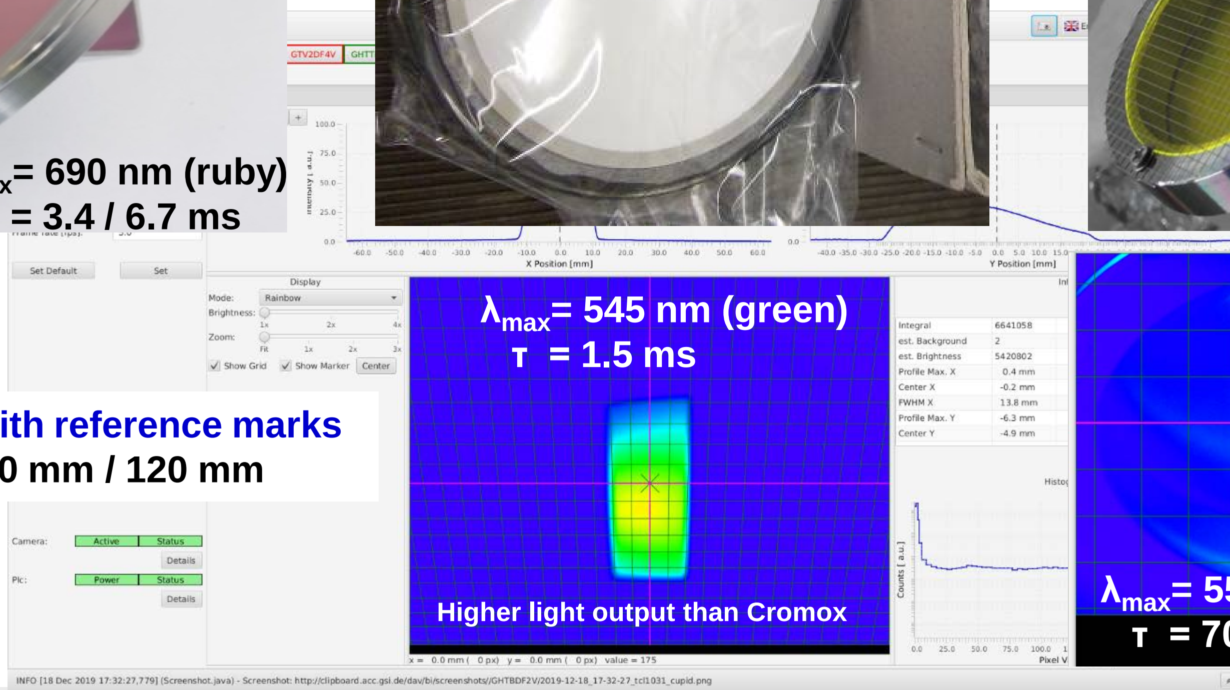
**Robust “Cromox” ($Al_2O_3$:Cr)**
**Aluminium oxid**
**activated by chrome**



**$\lambda_{max}$= 690 nm (ruby)**
**$\tau$ = 3.4 / 6.7 ms**

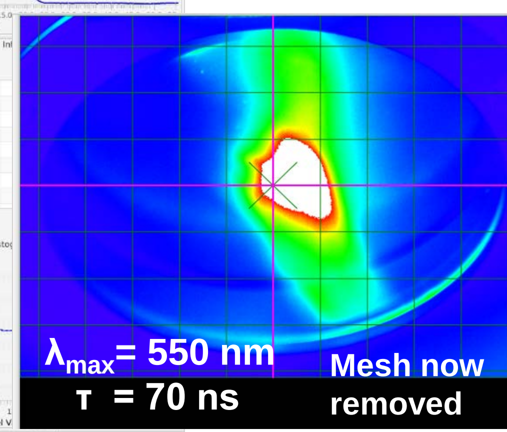
**Sensitive “P43” ($Gd_2O_2S$:Tb)**
**Gadolinium oxysulphide**
**terbium doped**

**“YAG” ($Y_3Al_5O_{12}$:Ce)**
**Yttrium aluminum garnet**
**activated by cerium**




**$\lambda_{max}$= 545 nm (green)**
**$\tau$ = 1.5 ms**

**Higher light output than Cromox**



**$\lambda_{max}$= 550 nm**
**$\tau$ = 70 ns**

**Mesh now removed**

**Target holder with reference marks**
**Active area: 100 mm / 120 mm**

# ESR-CRY: ESR Injection
## Camera system configurations

**Injector Linac YRT1**
**Camera & lens with fixed focus and fixed iris**

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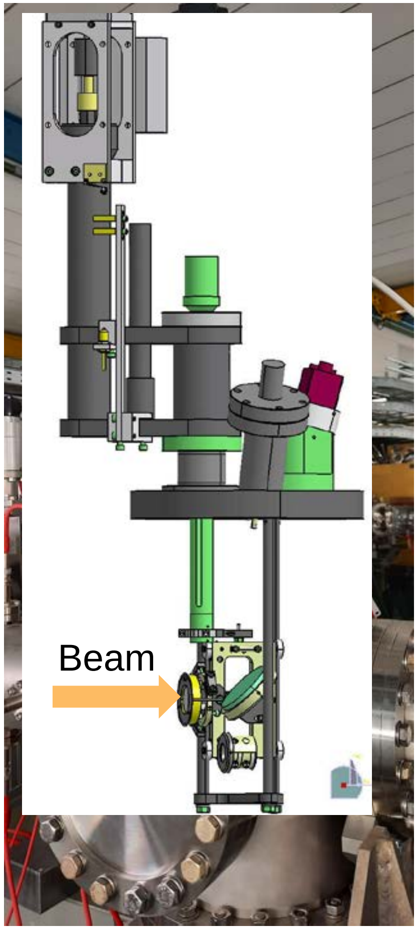
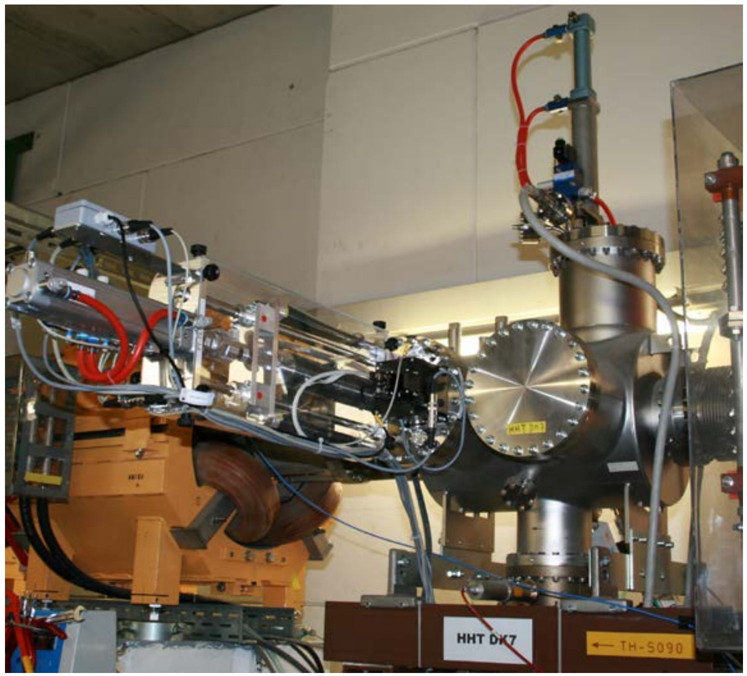


# ESR-CRY: ESR Injection
# Camera system configurations

**Injector Linac YRT1**
**Camera & lens with fixed focus and open iris**

**Standard HEST/HEBT beam line**
**Camera & lens with fixed focus and iris control**



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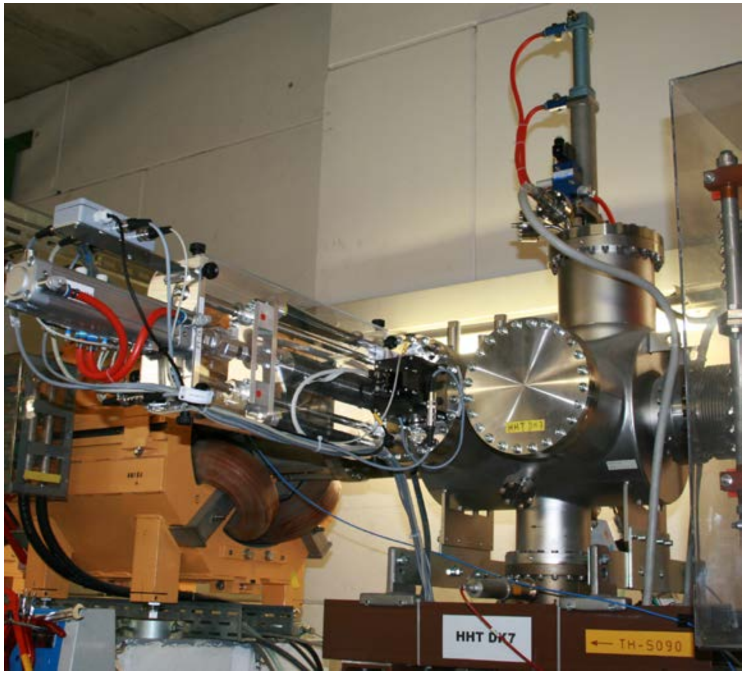
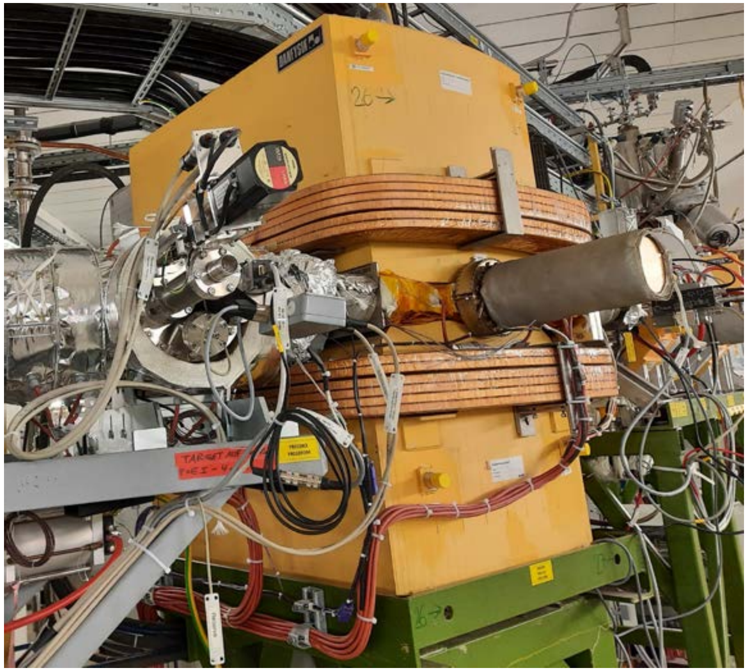


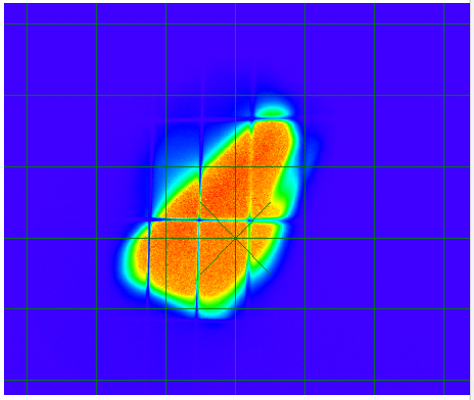

**Injection screen YR01DF3**
**Camera & lens with control of focus and iris**

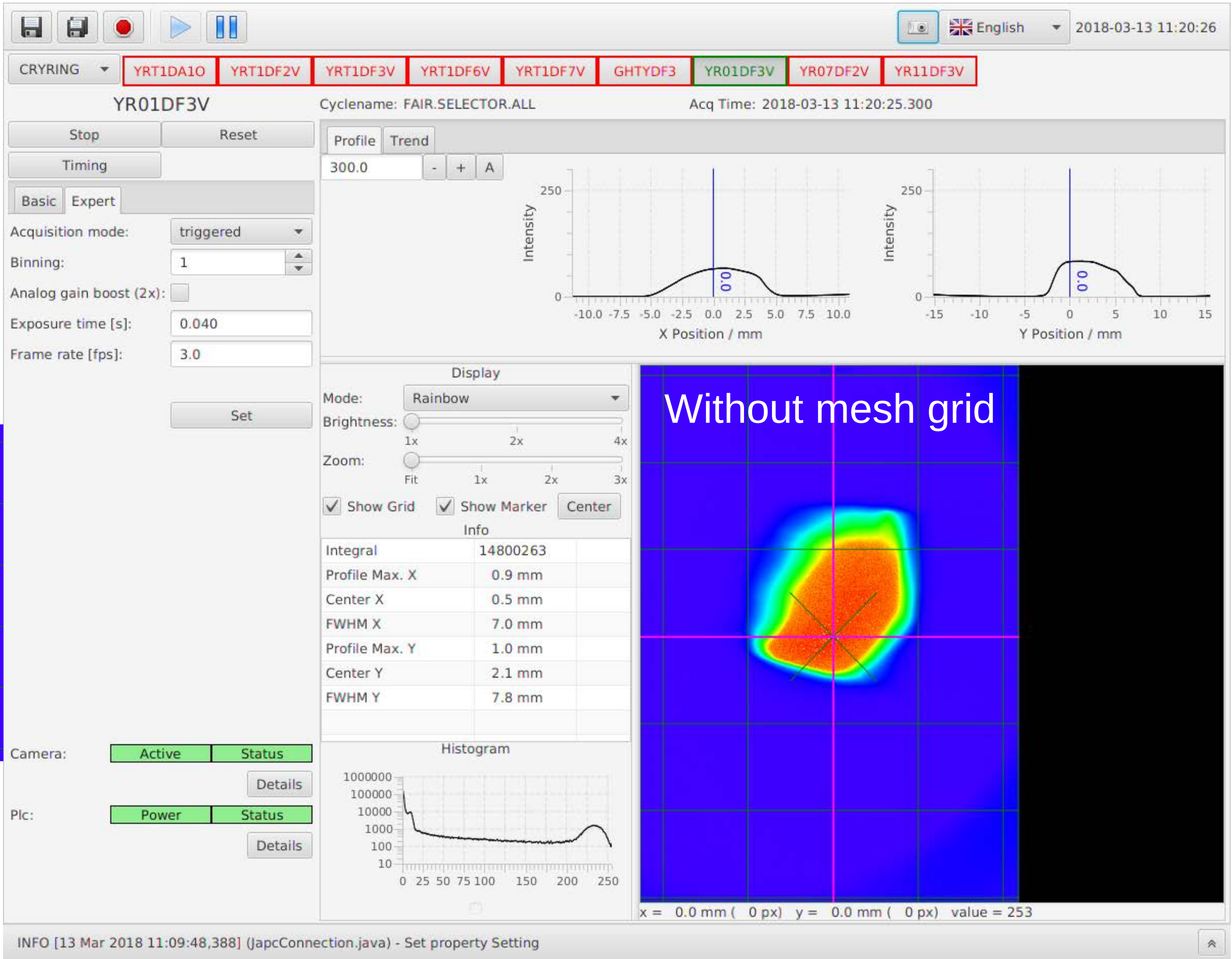


- YR01:
  - Design orbits for RFQ/ESR injection differ by 55 mm.
  - Pneumatic drive replaced by stepper motor drive.
- All systems equipped with LED for tests and calibration images
- Now: All screens without reference marks which moved to mechanical holder.

# ESR-CRY: ESR Injection
# CUPID & screen YR01DF3 (March 2018)

With mesh grid





# ESR-CRY: ESR Injection
## Summary

- Beam Instrumentation consists of Screens and Faraday Cups.
- Current: OK
- Profile: OK

- Operation: Recent upgrade seems to have improved situation.
  Wait for further feedback from this year`s operation and dedicated machine experiment.

# CRYRING@ESR
## Layout of Beam Instrumentation

- **1st turn diagnostics**
  - Screen (SCR)
  - Faraday Cup (FC)
  - BPM
- **Position & Beam Loss**
  - Beam position monitor (BPM)
- **Profile**
  - Ionisation Profile Monitor (IPM)
- **Beam current transformers**
  - DC Transformer (PCT)
  - AC Transformers (ICT)
  - [Cryogenic Current Comparator (CCC)]
- **Beam intensity measurement**
  - Schottky sum (zero-span mode)
  - YR12 BPM sums
    with mixer and integrator hardware
  - IPM count rates
- **Schottky & Tune measurement**
  - Hor. & Vert. Exciter (EXC)
  - Transverse Schottky (SKY)
  - BPMs

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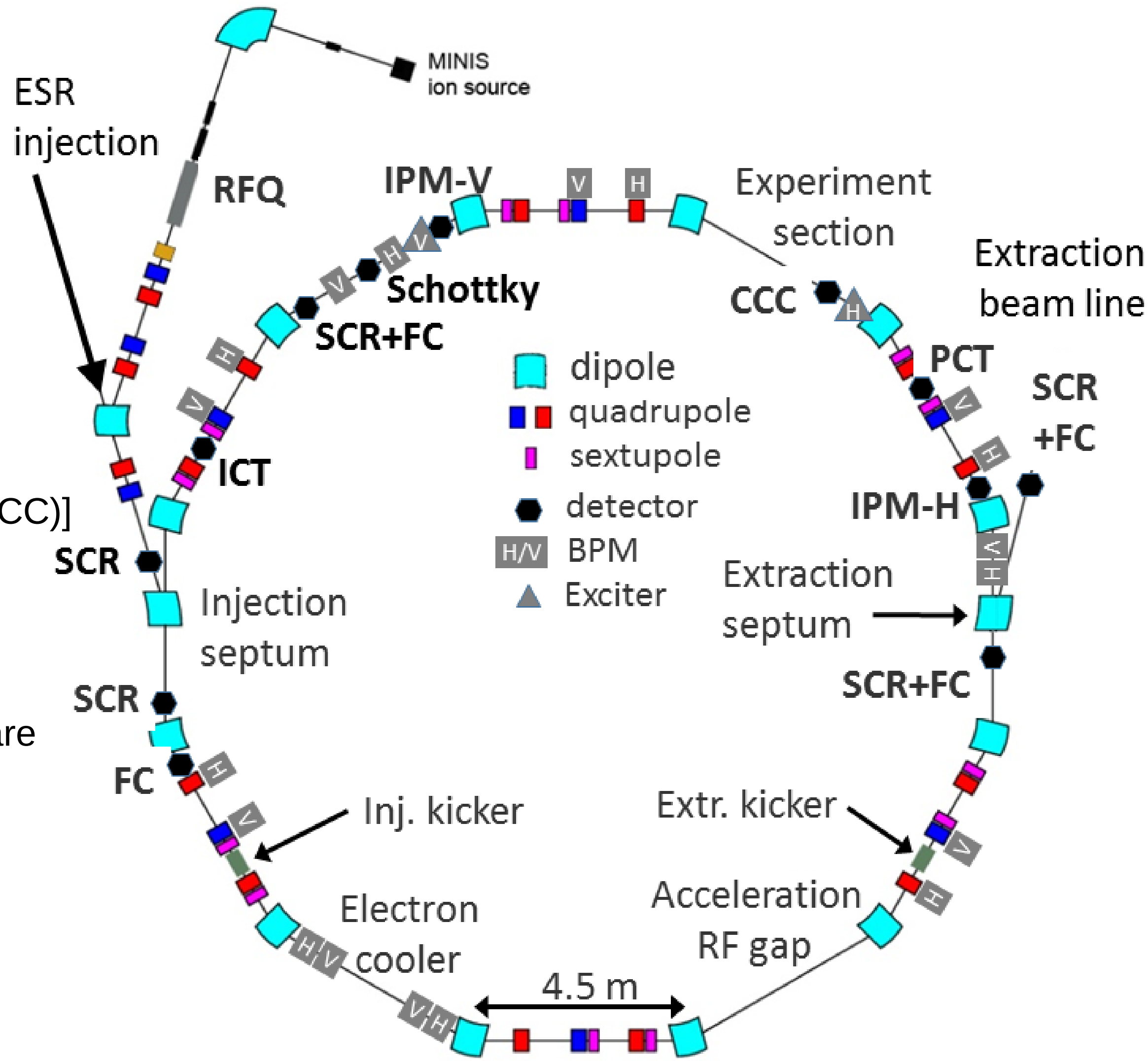

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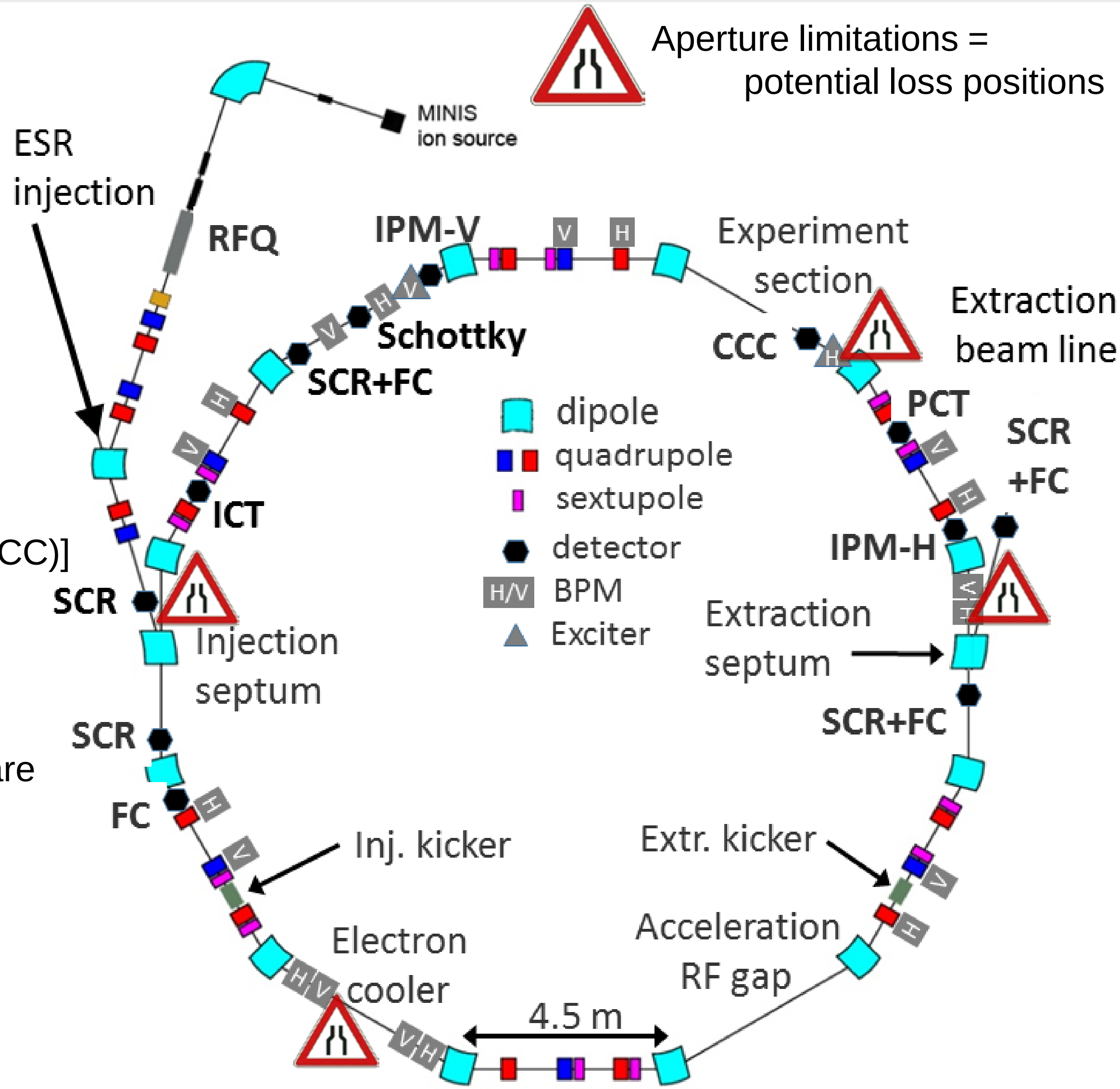


# CRYRING@ESR
## Magnet section YR08

Q Q S Q S

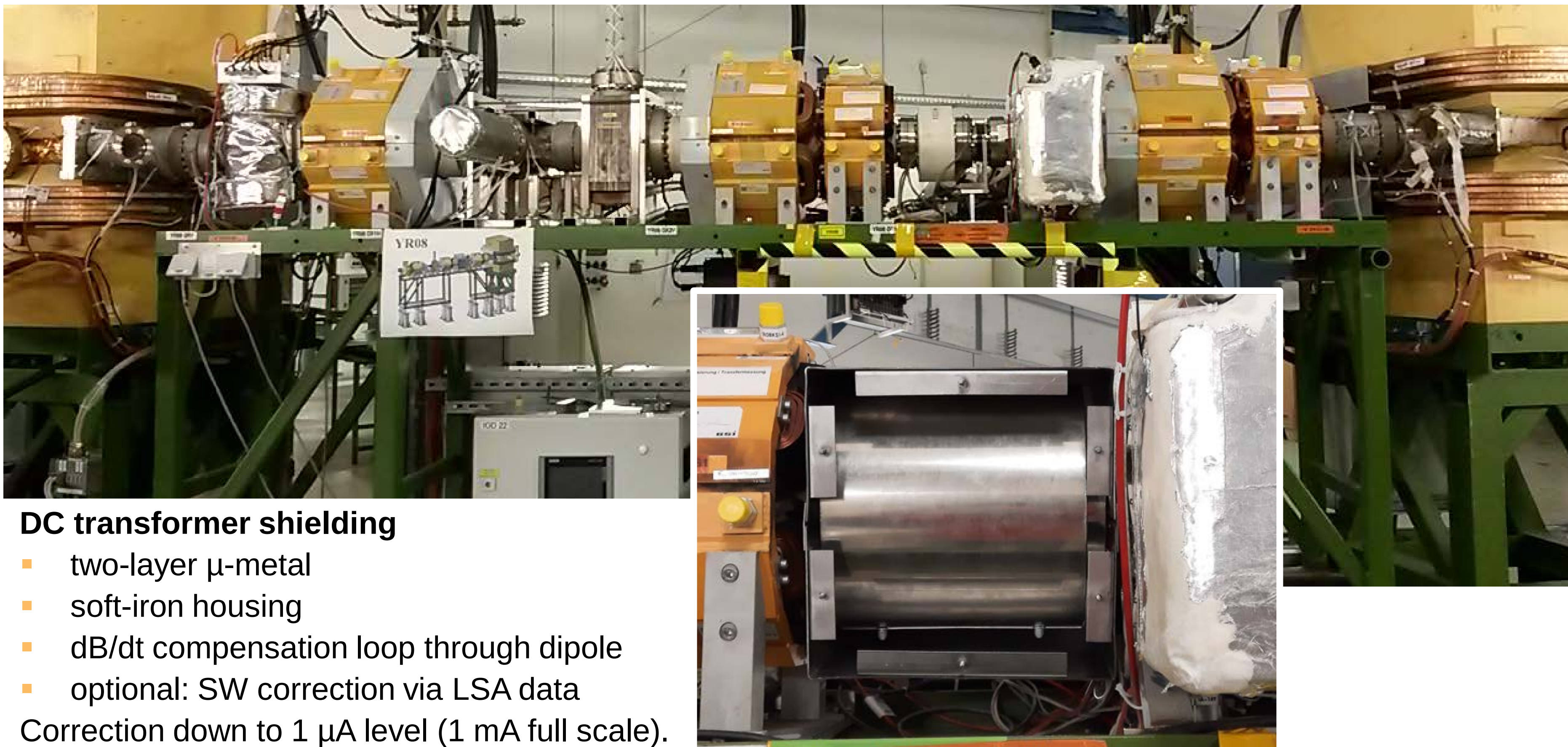
IPM BPM BPM DC Trafo

**Length of IPM chamber ~ 250 mm**

# CRYRING@ESR
## Magnet section YR08

**Q** **Q S** **Q S**

**IPM BPM** **BPM** **DC Trafo**




**DC transformer shielding**

- two-layer µ-metal
- soft-iron housing
- dB/dt compensation loop through dipole
- optional: SW correction via LSA data

Correction down to 1 µA level (1 mA full scale).

# CRYRING@ESR
## “Magnet-free” section YR11

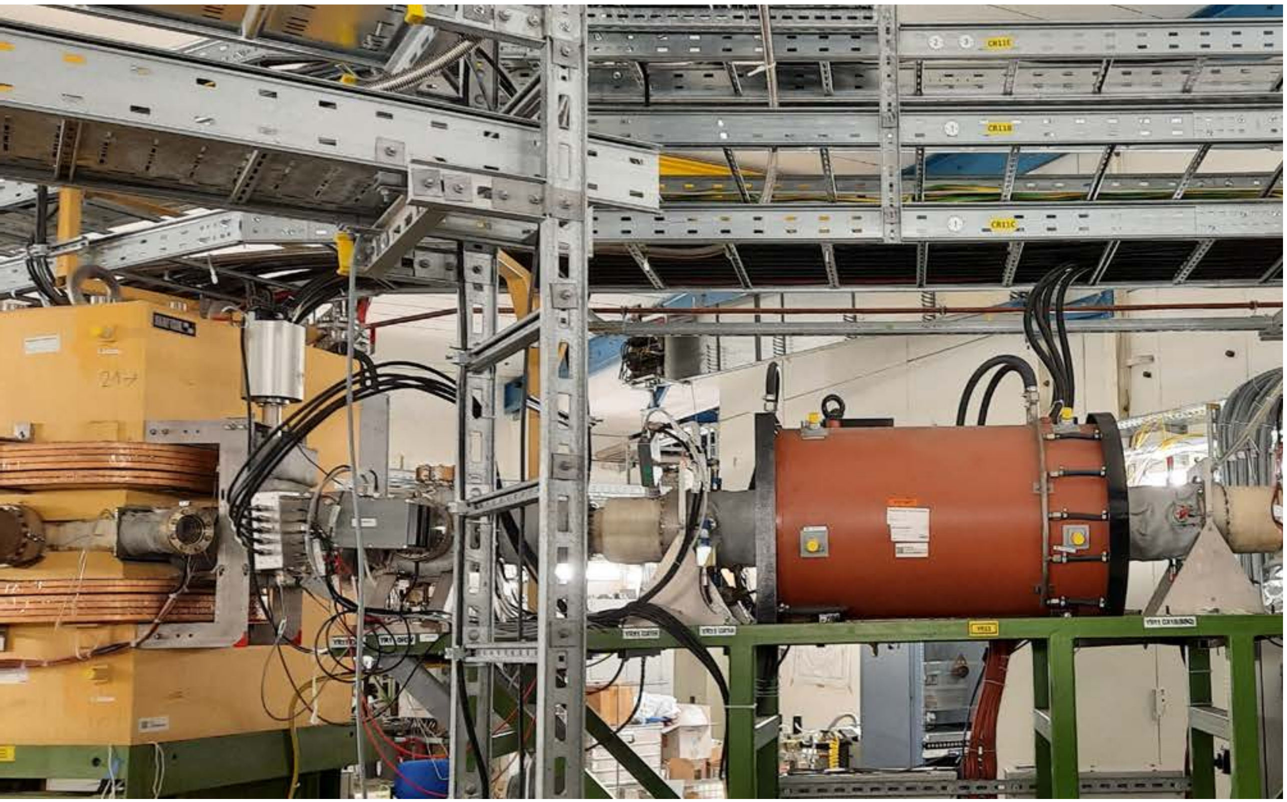
**IPM - Exciter - BPM - Schottky detector - BPM - Screen & FC**

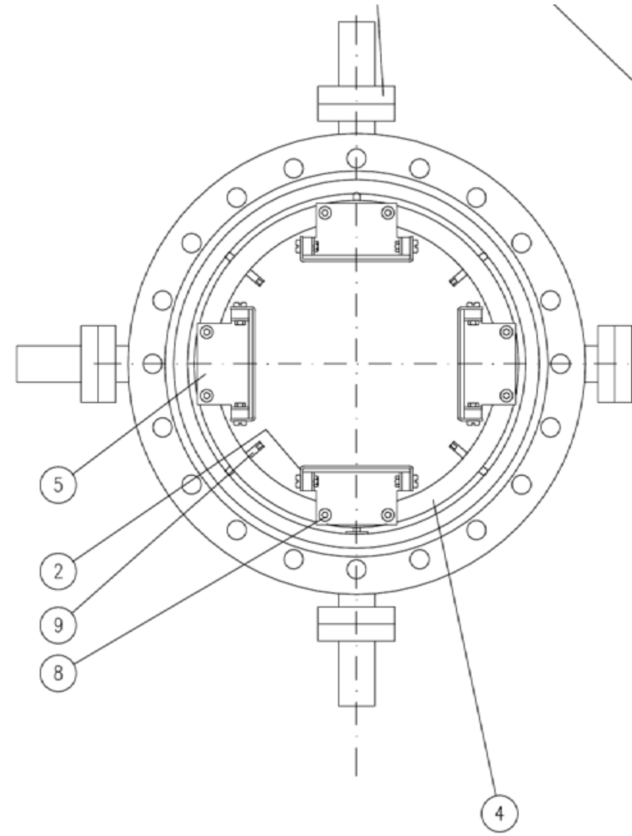
**Dipole vacuum chambers with straight port**

- Glass viewing ports for zero-deg. diagnostics after each dipole

# CRYRING@ESR
## “Magnet-free” section YR11

**IPM - Exciter - BPM - Schottky detector - BPM - Screen & FC**






1.4 m

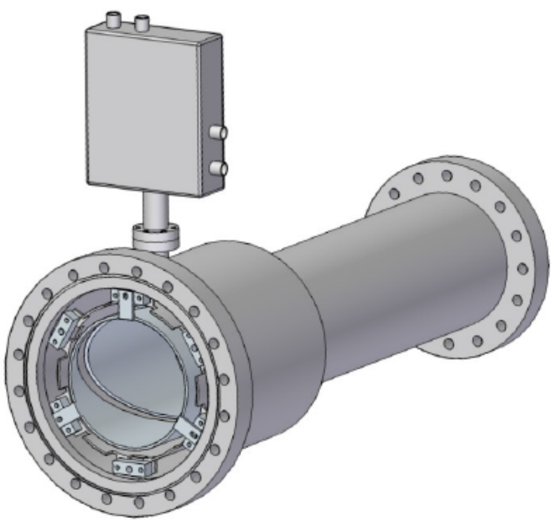
# CRYRING@ESR

## Beam Position, Tune, Beam Loss & Intensity

- 7x hor. & vert. BPM with 100 mm diameter, capacitance C=40 pF
- 2x hor. & vert. BPM with 77 mm diameter and voltage bias in eCooler YR03, capacitance ~ 100 pF
- Pickup parameters 100 mm BPMs:
  - Cylindrical shape, diagonal cut with linear response, 150 mm length
  - Sensitivity S = 1.3%/mm (effective radius $r_{eff} = S^{-1} = 75$ mm)
  - Position calculation via signal asymmetry:

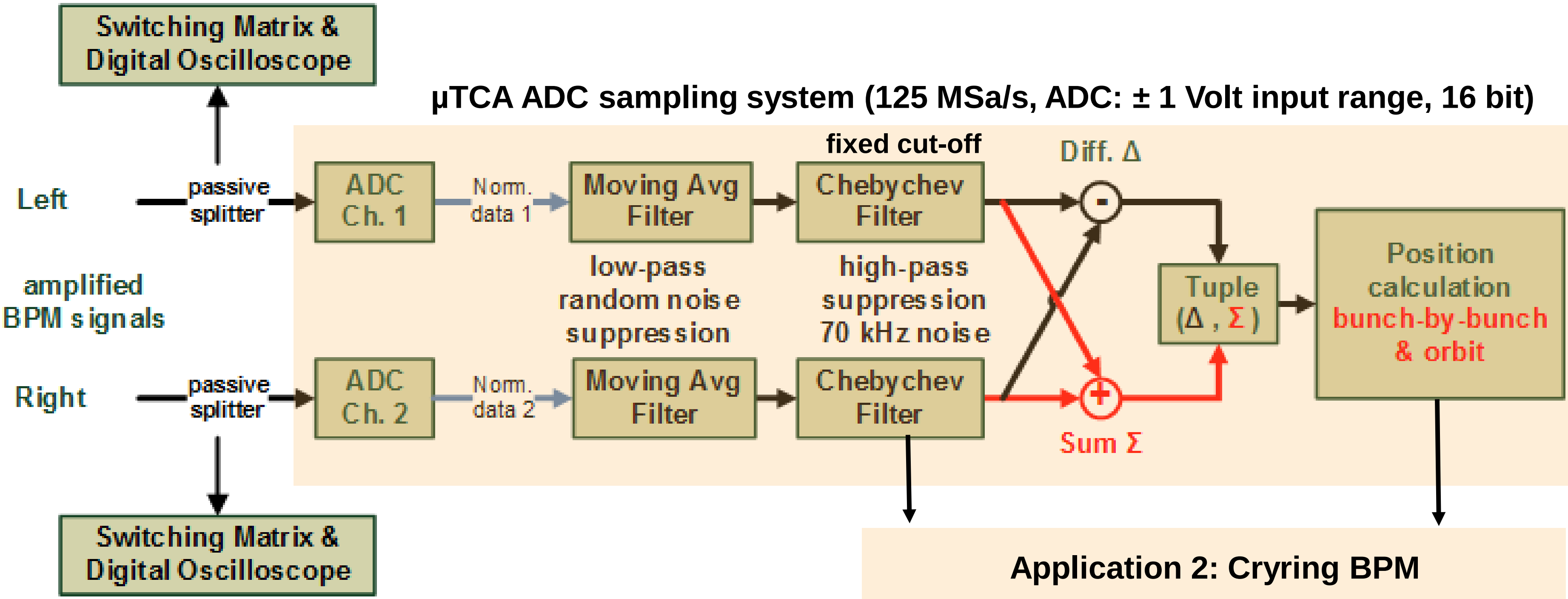
$$\Delta x = r_{eff}\left(\frac{R-L}{R+L}\right)$$ with R/L = right/left electrode signal

- New in-house amplifier “CryAmp”:
  - High-impedance, low-noise, selectable bandwidth 40/4 MHz
  - 40/60 dB gain with input protection



# Sketch of two BPM readouts

µTCA ADC sampling system (125 MSa/s, ADC: ± 1 Volt input range, 16 bit)




**Application 1: BPM Scope**

Signal traces of two user-selected BPMs
(special uses: long. cooling, electron beam measurements, injection monitoring, trouble-shooting)

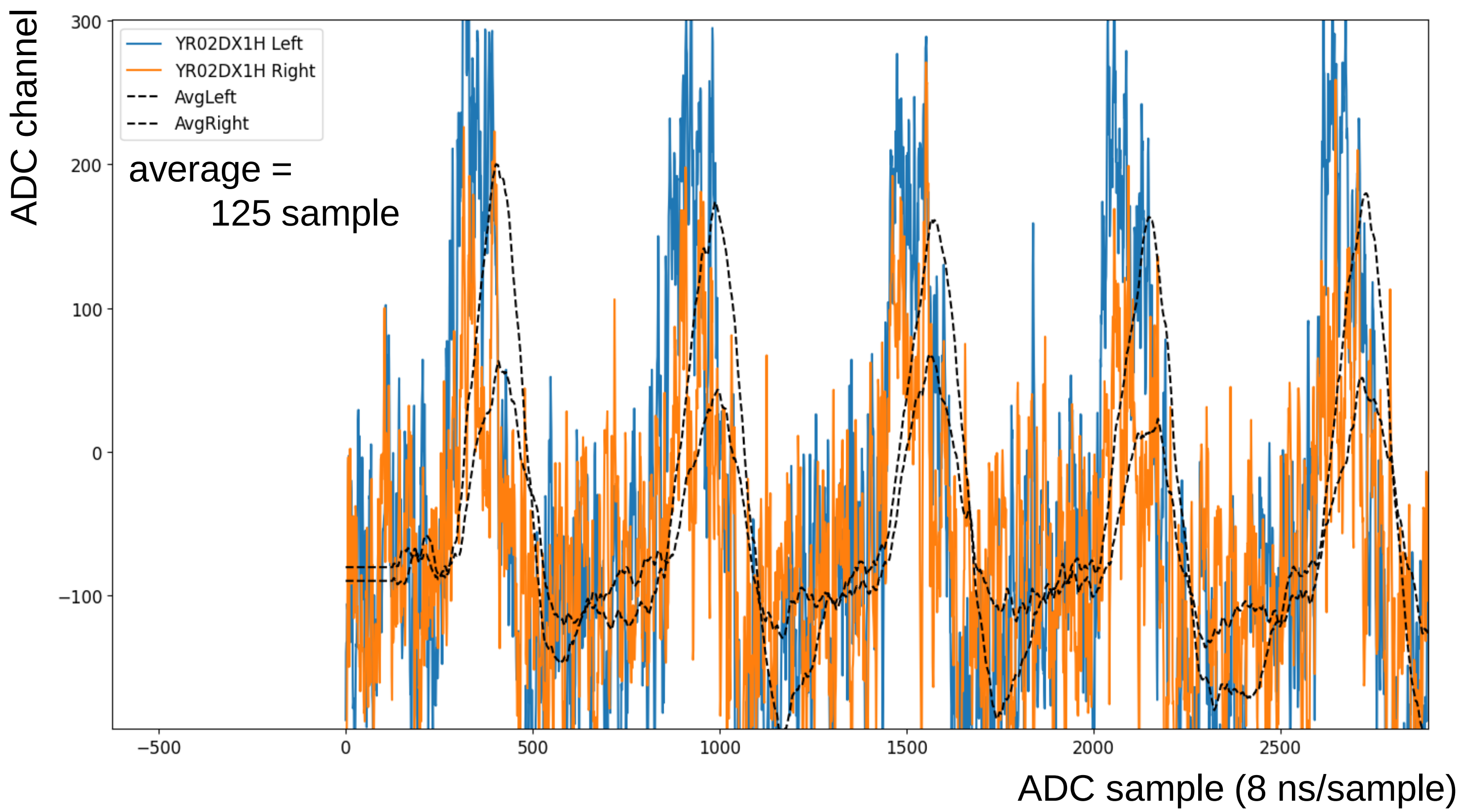
**Application 2: Cryring BPM**

Raw data: Injection monitoring (100 µs)
Bunch-by-bunch positions via RF gate signal
Orbit: Averaged positions (user defined)
Tune: FFT calculation for user-selected BPM

- Filter stages were introduced in autumn 2021
- Chebychev filter active only for eCooler BPMs in YR03 to suppress 70 kHz and (10–15) MHz of ion pump HV

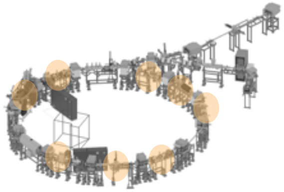
# Minimum signal estimate for position calculation

- Beam: $3\times10^6$ D+, 1 MeV/u ($f_{rev}$ = 250 kHz), h=1, I~125 nA
- Signal amplitude ~ 10 mV ~ 1% full scale (300 ch.) => 10 µV from BPM electrode (60 dB gain)
- Rule of thumb: signal-to-noise S/N > 3 for reasonable measurement (depends e.g. on energy, duty factor)
- Operation at higher harmonics (RFQ transport mode, h = 6 – 18) reduces bunch charge significantly.
- Very rough rule of thumb: Above $1\times10^7$ e stored, measurements start to be meaningful.



# CRYRING@ESR

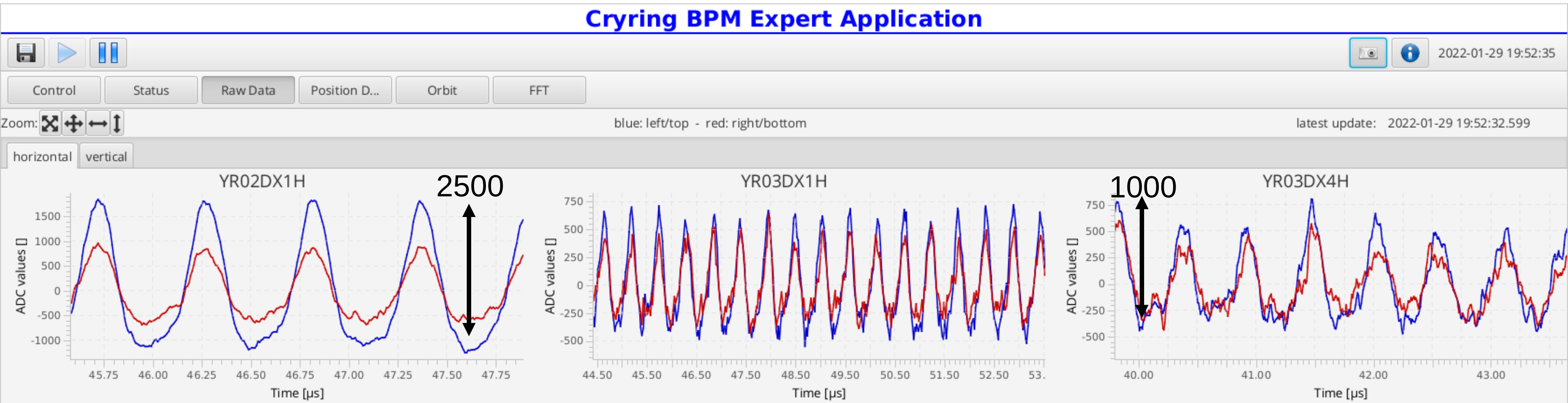
# RFQ injection: transport mode, $O^{2+}$ beam, 5 keV/u



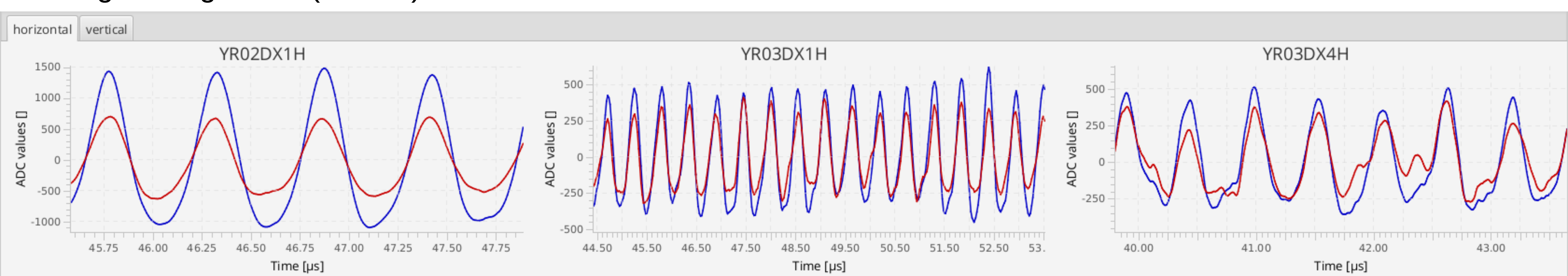
- Beam: ~$4 \times 10^6$ Oxygen $O^{2+}$, 0.5 MeV/u ($f_{rev}$ = 181 kHz), h=10, I~200 nA
- Signal amplitude ~ 40 mV ~ 4% full scale (2500 ch.) => 40 µV from BPM electrode (60 dB gain)
- Bunch quality good enough for 100 mm BPMs, but worse in section YR03 for eCooler BPMs.

Moving Average = 1 (raw data, 8 ns)

ratio BPM amplitudes ~ ratio of capacitances




Moving Average = 16 (128 ns)



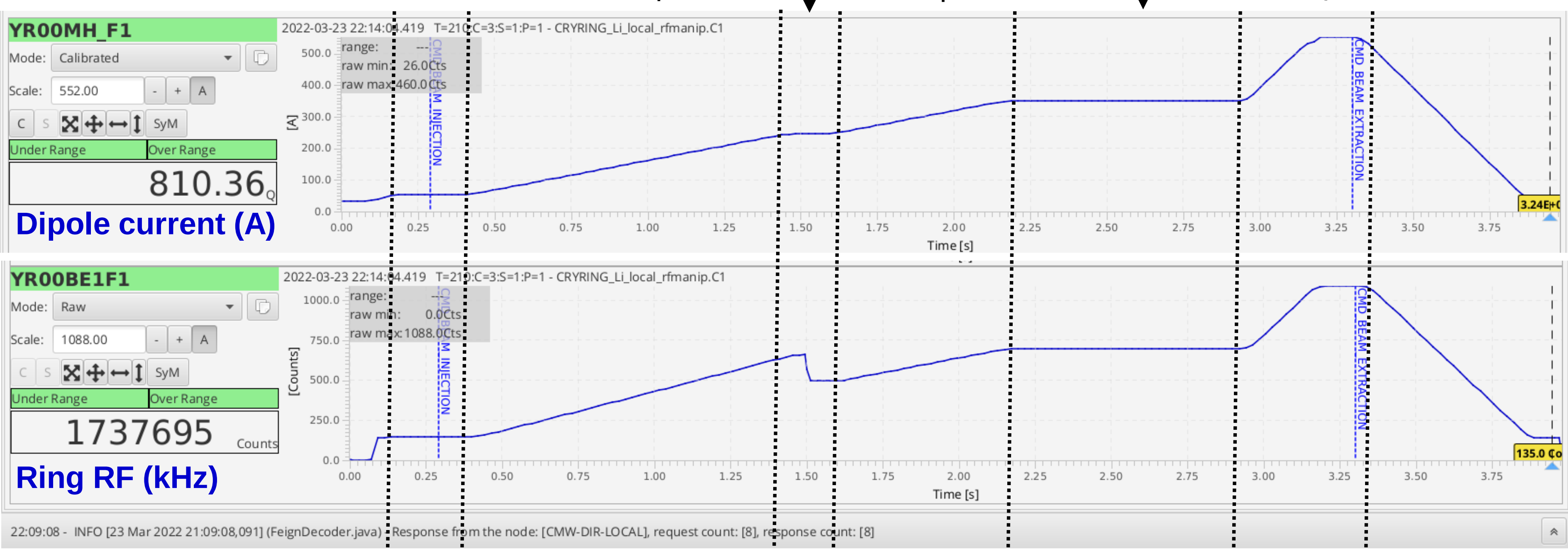
# Machine cycle with rebunching $Li^{1+}$ 5 keV/u (March 2022)

- **Lassie Scaler system: 1 kHz monitoring of reference signals and all 7 intensity signals**
- Typical stored beam currents:
  - RFQ injection: 100 nA to few µA
  - ESR injection: (10 – 50) µA
- Dipole current and Ring RF during machine setup to intermediate energy 150 keV/u

Injection plateau – Ramp 1 – Short re-bunching plateau – Ramp 2 – Experiment flattop – “Hysteresis” ramp 3

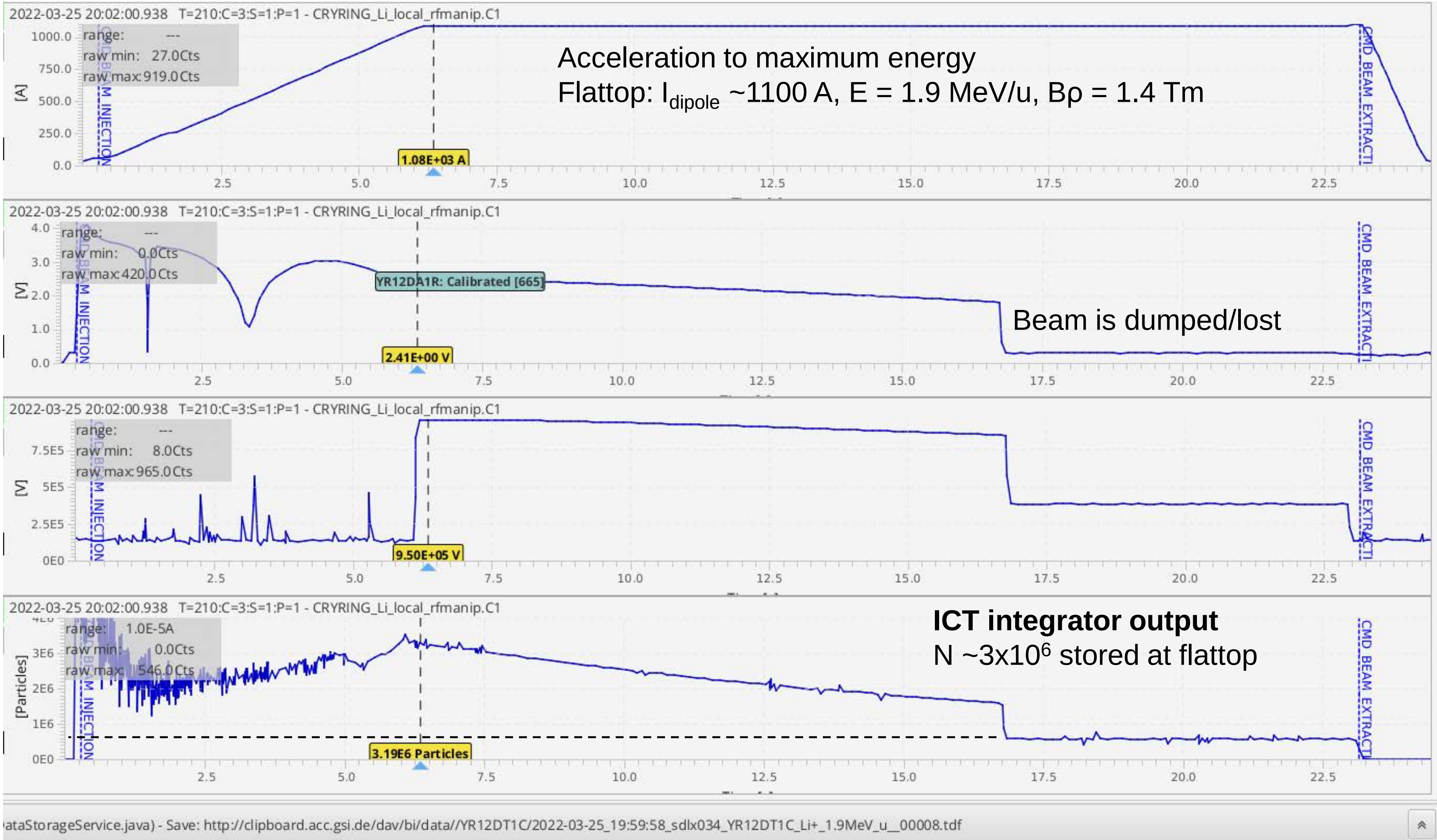
Bρ = 0.07 Tm from h=8 to h=6

Ramp 1 Ramp 2 Ramp 3



CRYRING@ESR

# Machine cycle with rebunching $Li^{1+}$ 5 keV/u (March 2022)




Acceleration to maximum energy

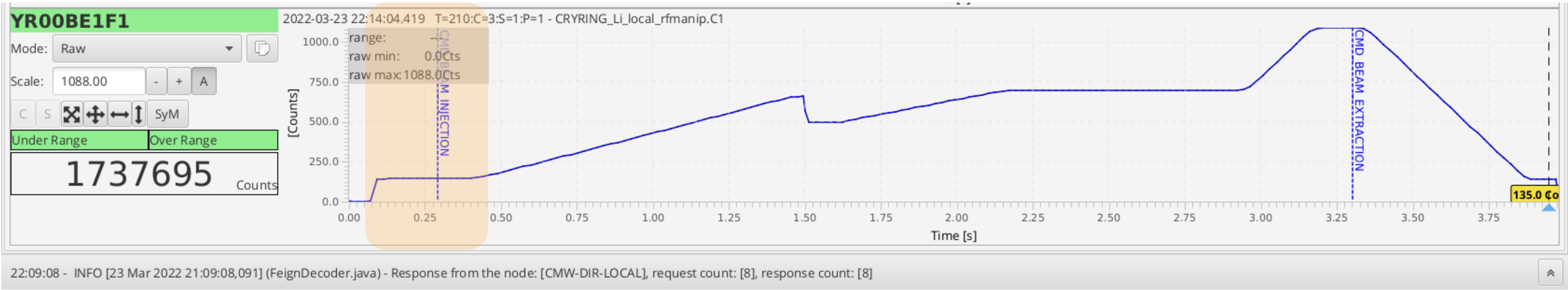
Flattop: $I_{dipole}$ ~1100 A, E = 1.9 MeV/u, Bρ = 1.4 Tm

Beam is dumped/lost

**ICT integrator output**

N ~3x$10^6$ stored at flattop

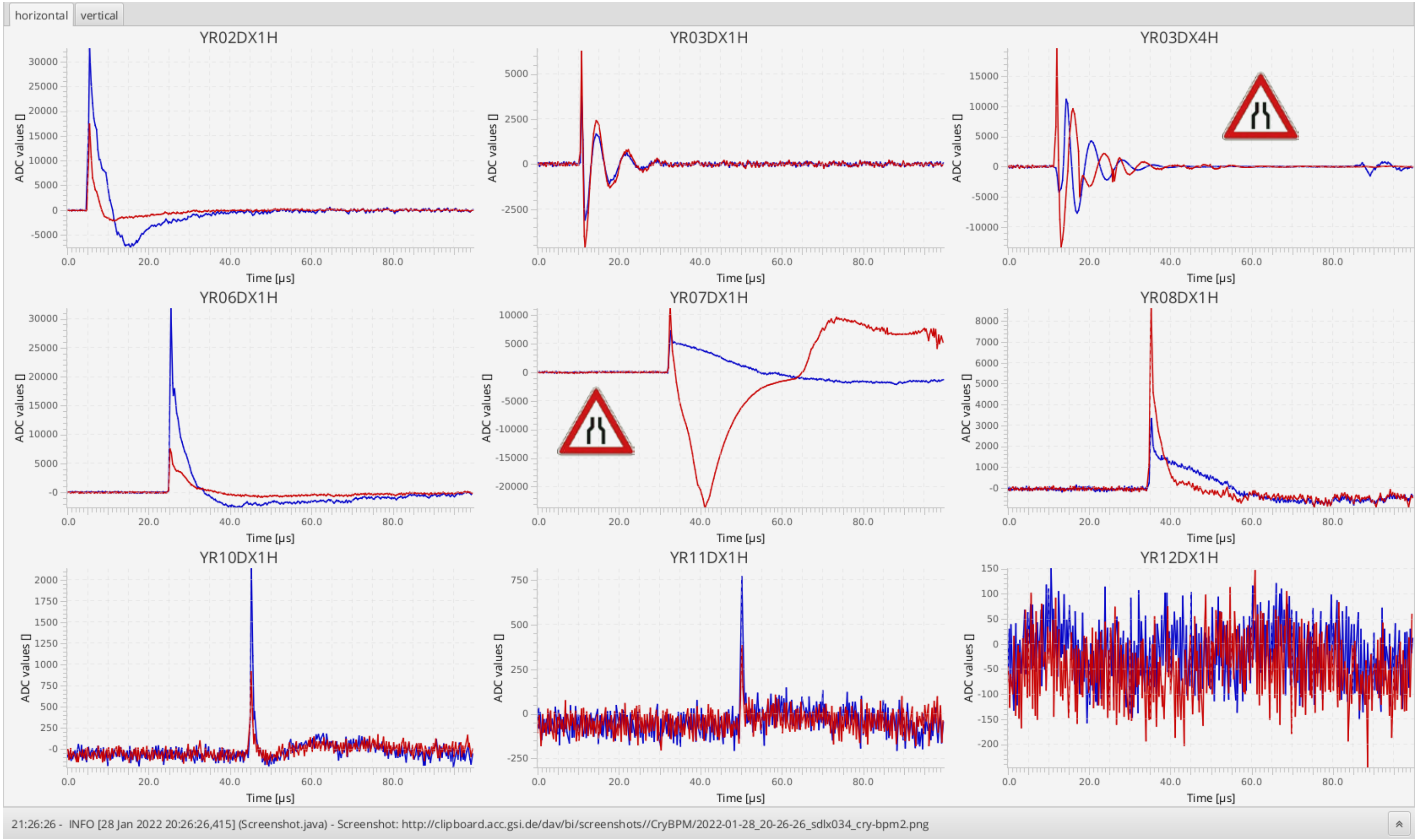
# CRYRING@ESR
# Injection




- Injection at Bρ = 0.07 Tm is not so easy.
- It takes very little to lose the beam.

# RFQ Injection: Transport mode, 5 keV/u $O^{2+}$ (Jan. 2022)

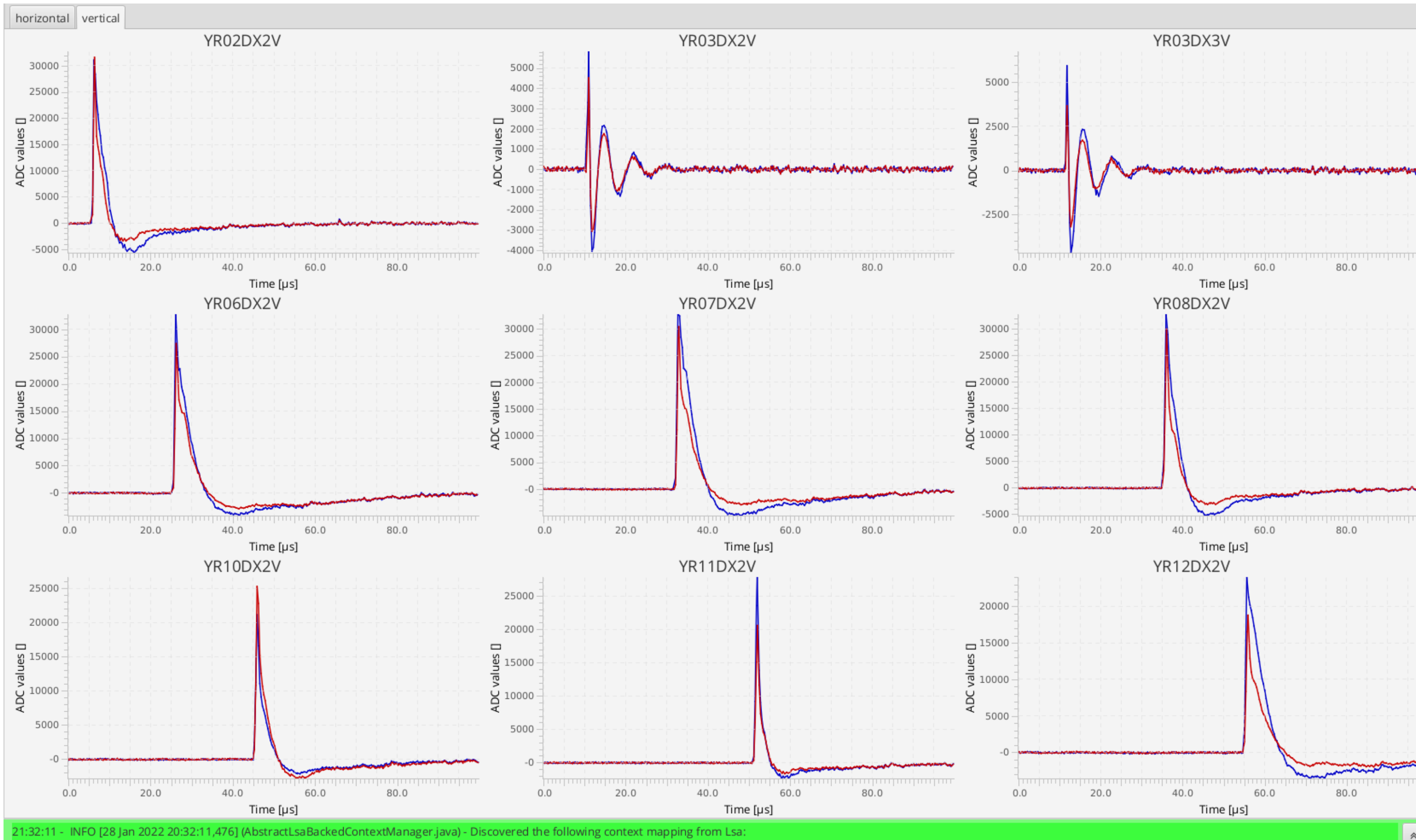
- $1^{st}$ turn diagnostics: Horizontal BPM signal traces in 100 µs window
- "Bad injection": Several loss locations (asym. signals): YR03 exit, YR06 (?), YR07, YR08
- Decreasing signal strength until beam is lost



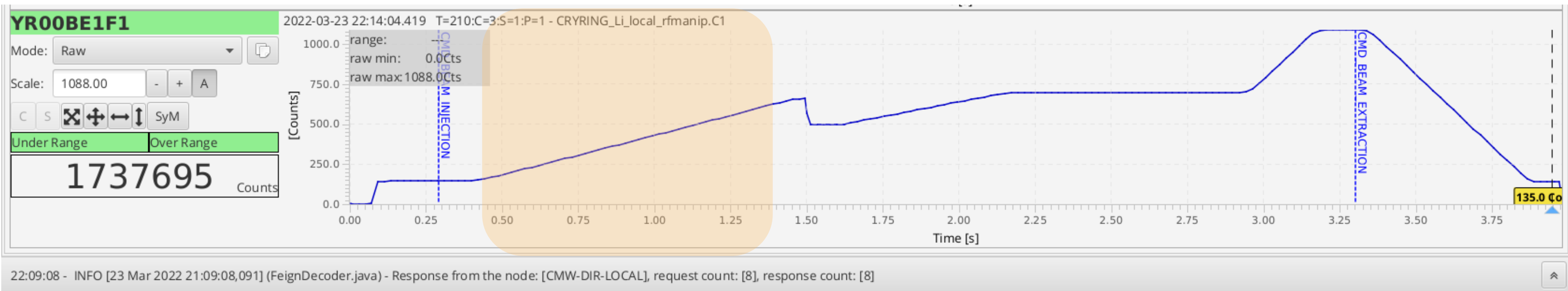
# CRYRING@ESR

# RFQ Injection: Transport mode, 5 keV/u $O^{2+}$ (Jan. 2022)

- $1^{st}$ turn diagnostics: Vertical BPM signal traces after ESR injection in 100 µs window
- “Good injection”: Symmetric signals on both BPM electrodes
- YR03: Ringing in signal trace due to Chebychev filter



# Acceleration ramp

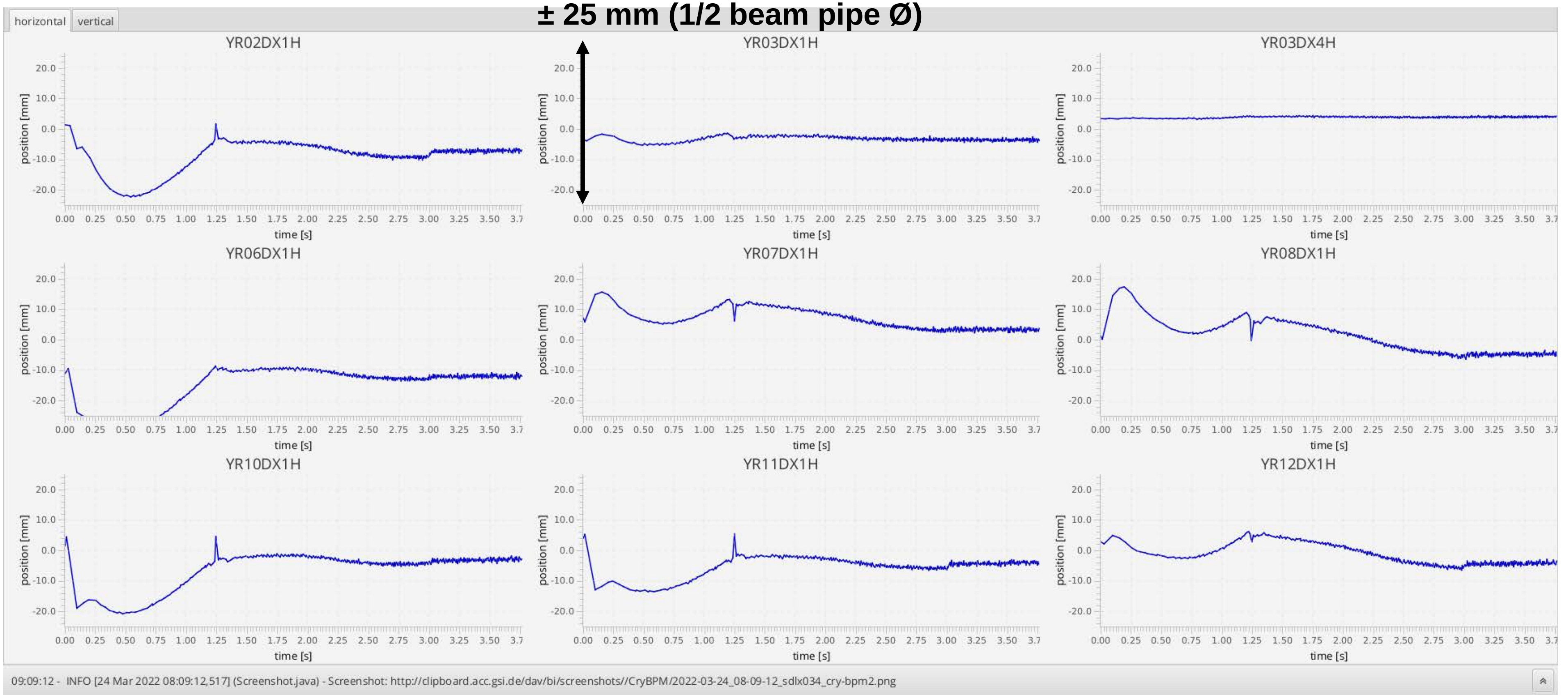



- Acceleration from Bρ = 0.07 Tm is not so easy.
- Iterative procedure using several intermediate energies (increasing length of ramp) often necessary.

# Orbit movement during acceleration

- Horizontal orbit with “typical large bump” during early part of ramp in all 100 mm BPMs
- Short spike during rebunching

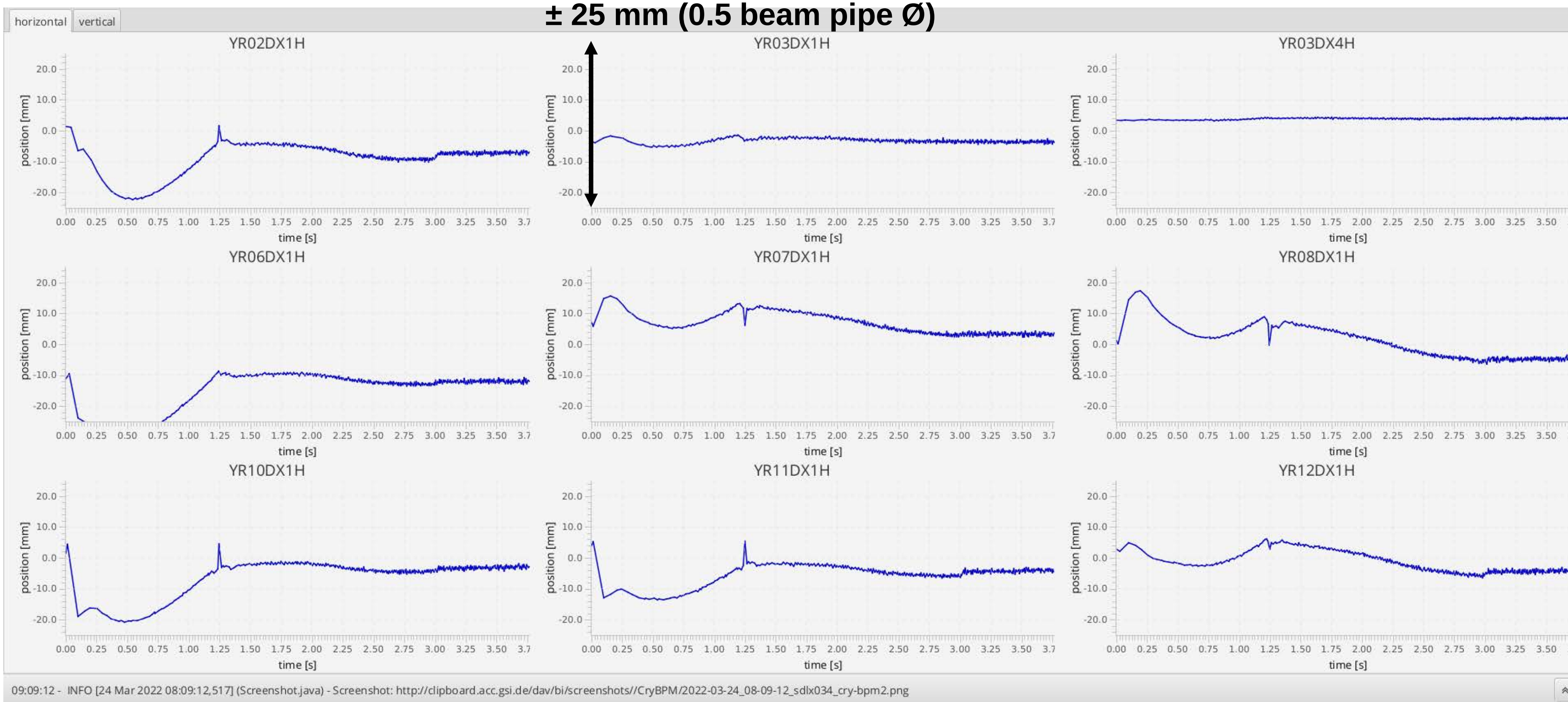
± 25 mm (1/2 beam pipe Ø)



# CRYRING@ESR
## Orbit movement during acceleration

- eCooler BPMs are less sensitive than 100 mm BPMs due to larger capacitance (100 pF vs 40 pF)
- No measurement on sensitivity S available yet. Using theoretical value S=2.7%/mm underestimates positions!
- 70 kHz distortions (and harmonics) not fully removed by simple filter.

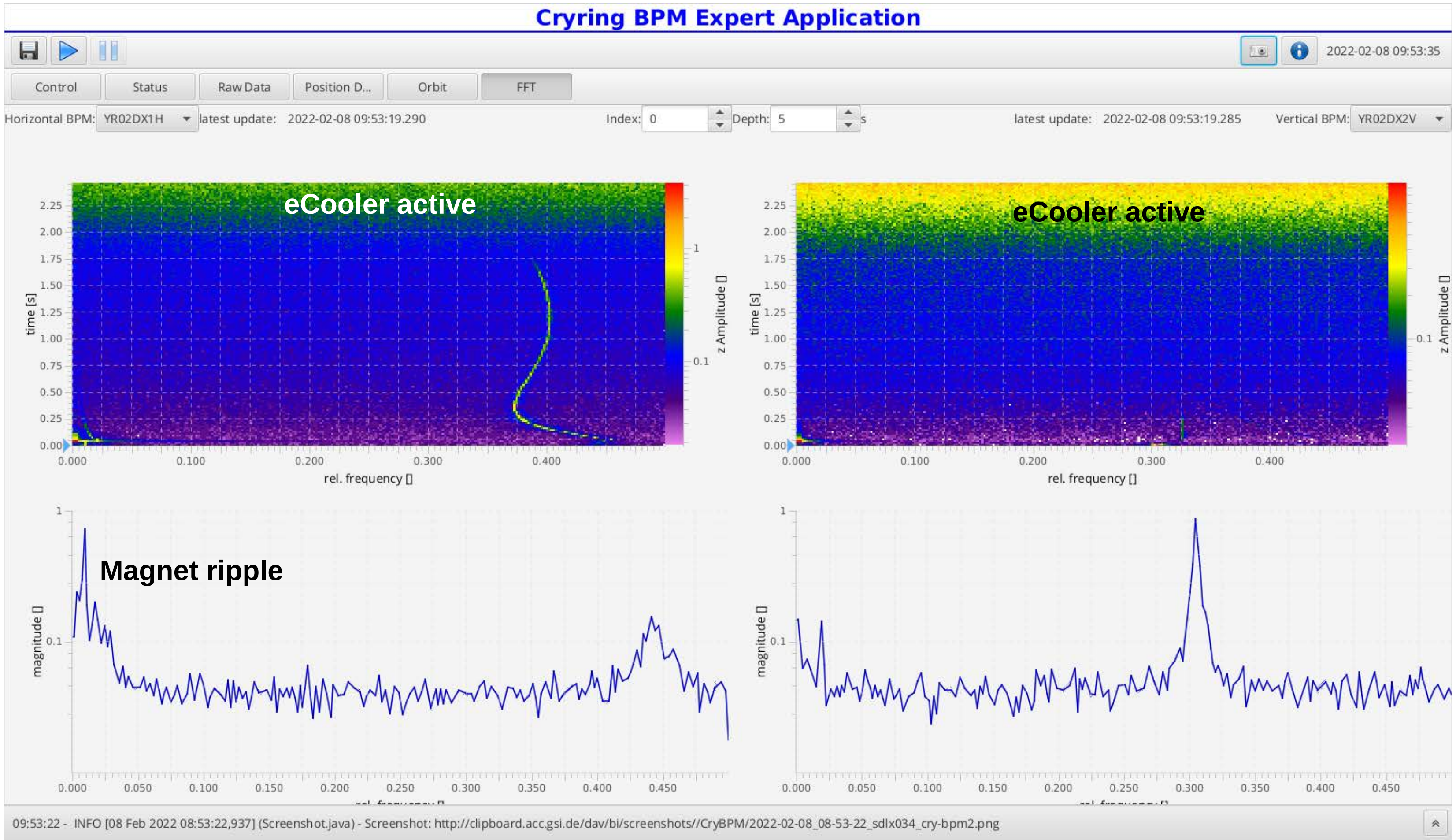
**± 25 mm (0.5 beam pipe Ø)**



# CRYRING@ESR

# Orbit movement during acceleration - tune

- Beam: $O^{2+}$ 5 keV/u, no excitation (Feb. 2022)
- Tune spectra from FFT of beam positions (calculated in software), averaged over all 100 mm BPMs
- Track tune from injection and during ramp



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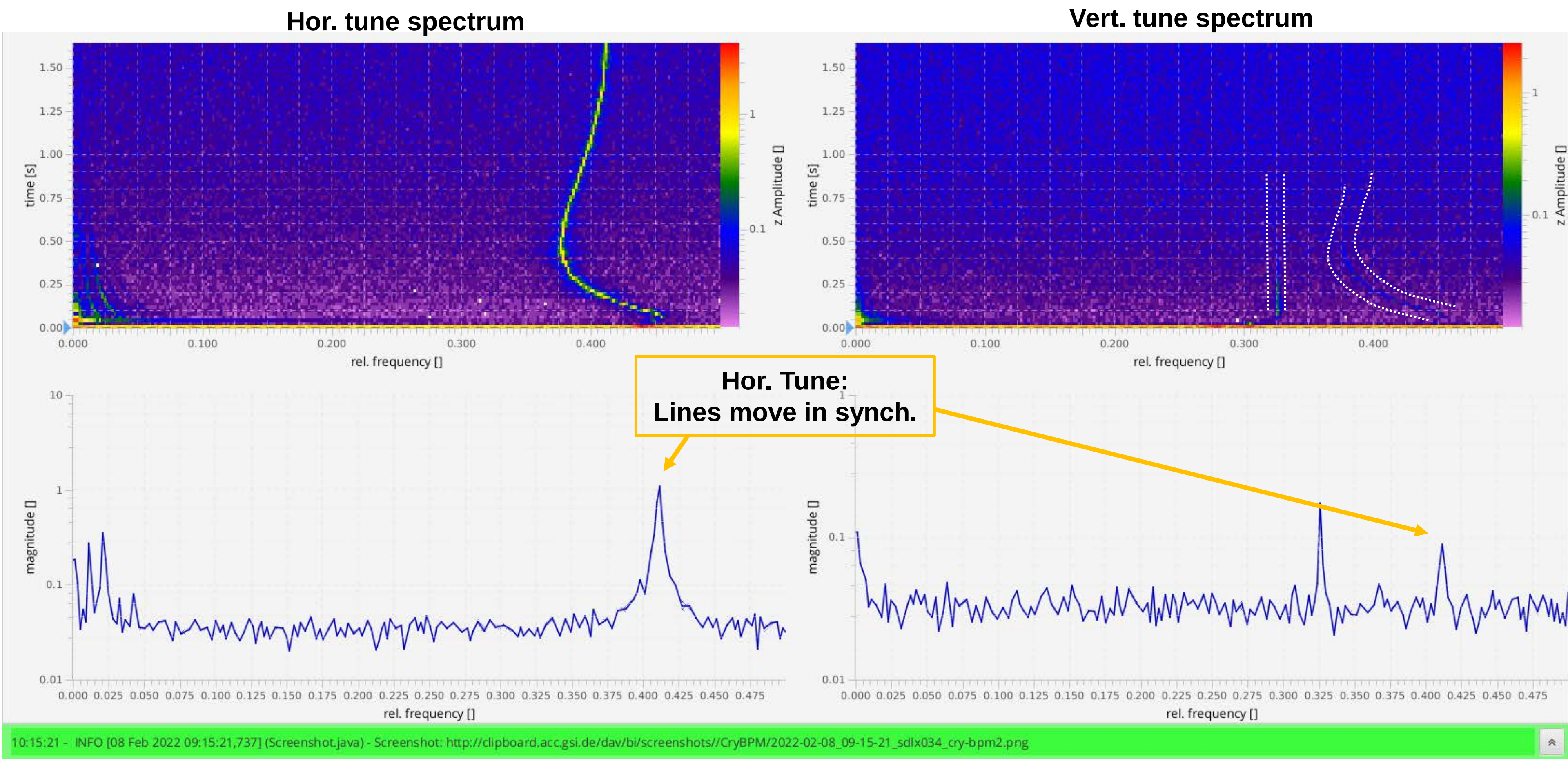
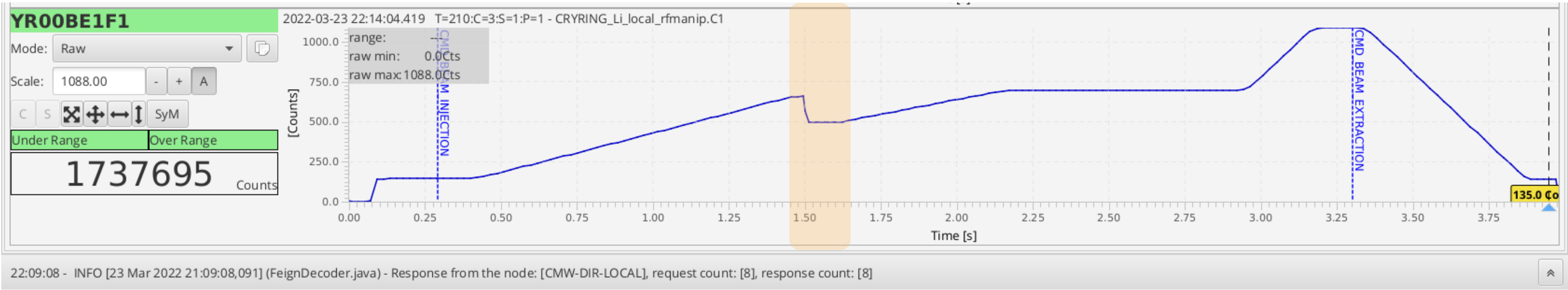
## Orbit movement during acceleration - tune

- Beam: $O^{2+}$ 5 keV/u, no excitation (Feb. 2022)
- Tune spectra from FFT of beam positions (calculated in software), averaged for all 100 mm BPMs
- Coupling between transverse planes



# CRYRING@ESR
## Rebunching

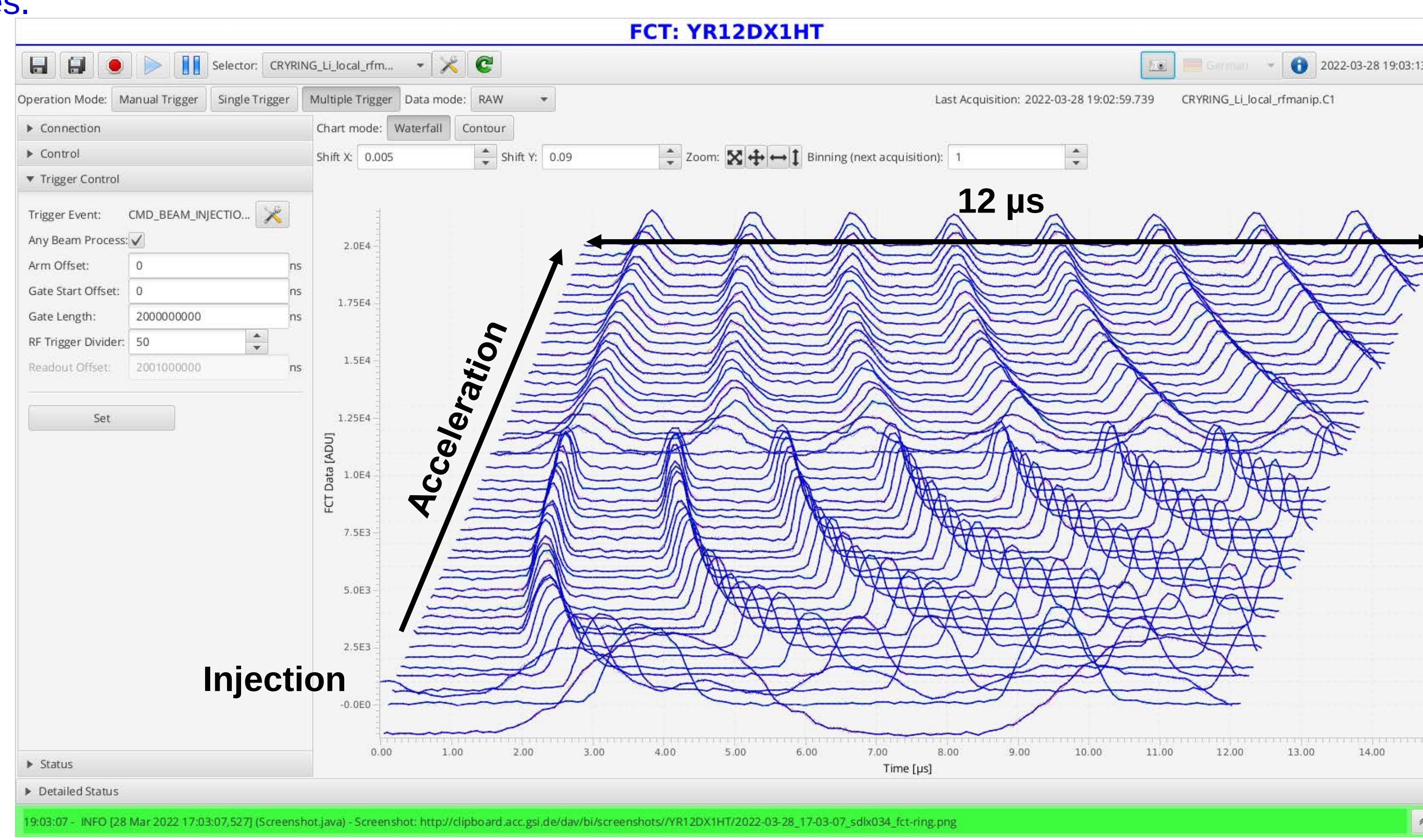



- Rebunching from h=8 to h=6 necessary to avoid exceeding maximum frequency of ring RF system.
- At 2 MeV/u: $f_{rev}$= 2.14 MHz (h=6) for $Li^{1+}$

# CRYRING@ESR

## FCT application with BPM sum signal

- FCT DAQ system was installed in preparation of machine experiment of bunch-to-bucket transfer between ESR and CRYRING (machine beam time D. Beck et al.).
- DAQ system acquires data blocks of user-defined length, synchronised by RF signal & rate divider.
- Same system in use at SIS18 and ESR, but FCT signal replaced by much larger BPM sum signal (~50 mV) at these low energies.



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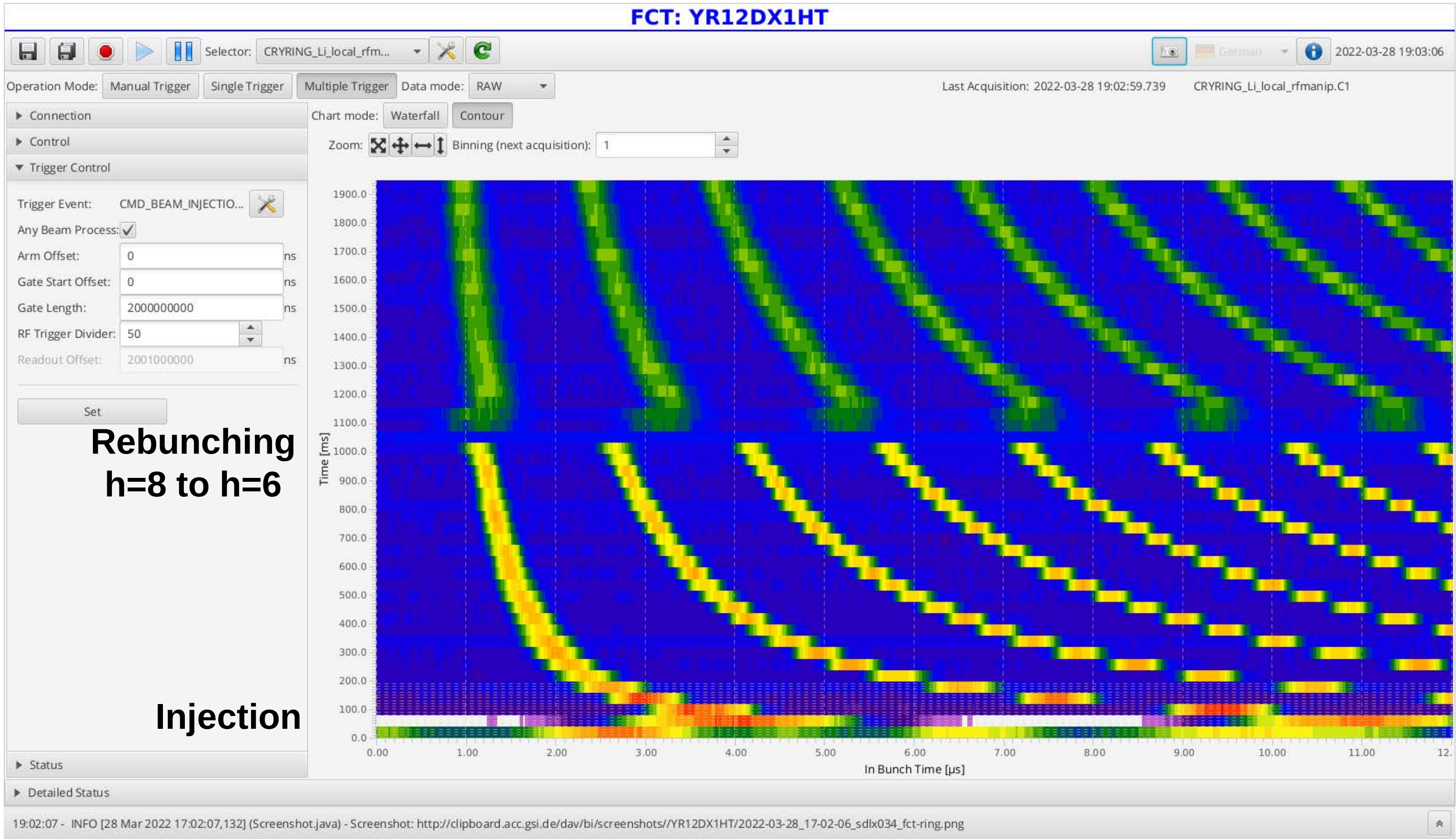
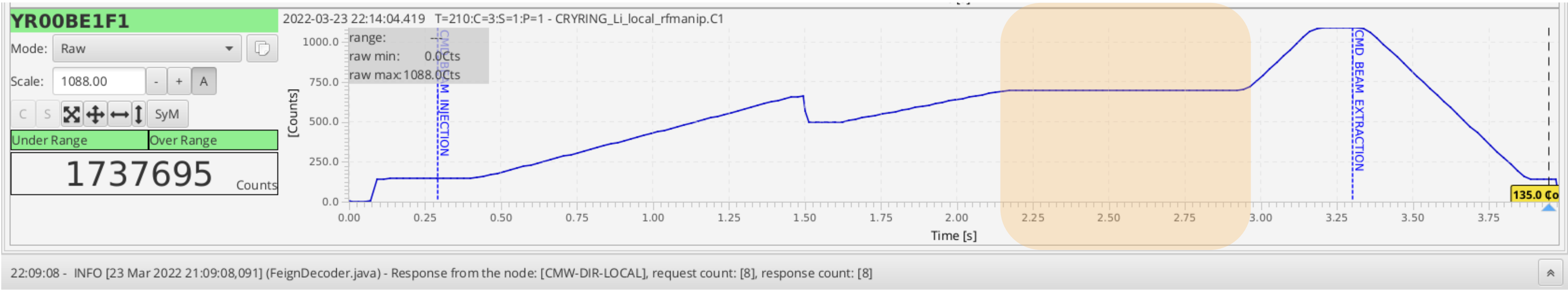


# CRYRING@ESR

# Flattop – Cooling




- At low-energies, a standard IPM can distort beam orbit or be totally destructive!
- Electron capture of singly-charged particles may provide an alternative.

# Electron Cooling
## Zero-degree Diagnostics (Feb. 2021)

- Singly-charged ions (here: $Mg^{1+}$) and electron beam can interact and result in neutral particles that can be detected in forward direction behind the electron cooler in section YR04.
- Detector test setup: MCP stack with screen observed by digital camera and laptop
- “Clean” signal & little background at moderate high voltage
- CUPID integration and online analysis to be discussed

by M. Lestinsky

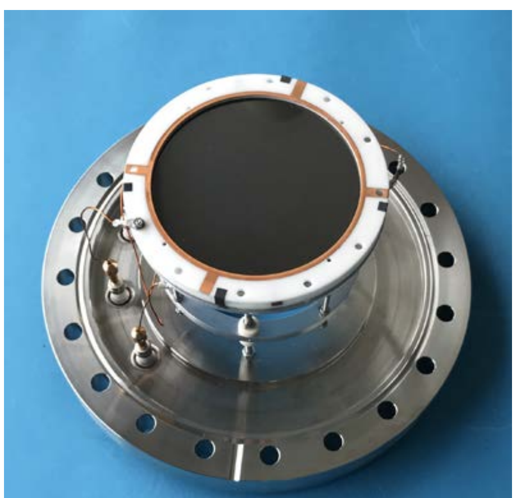
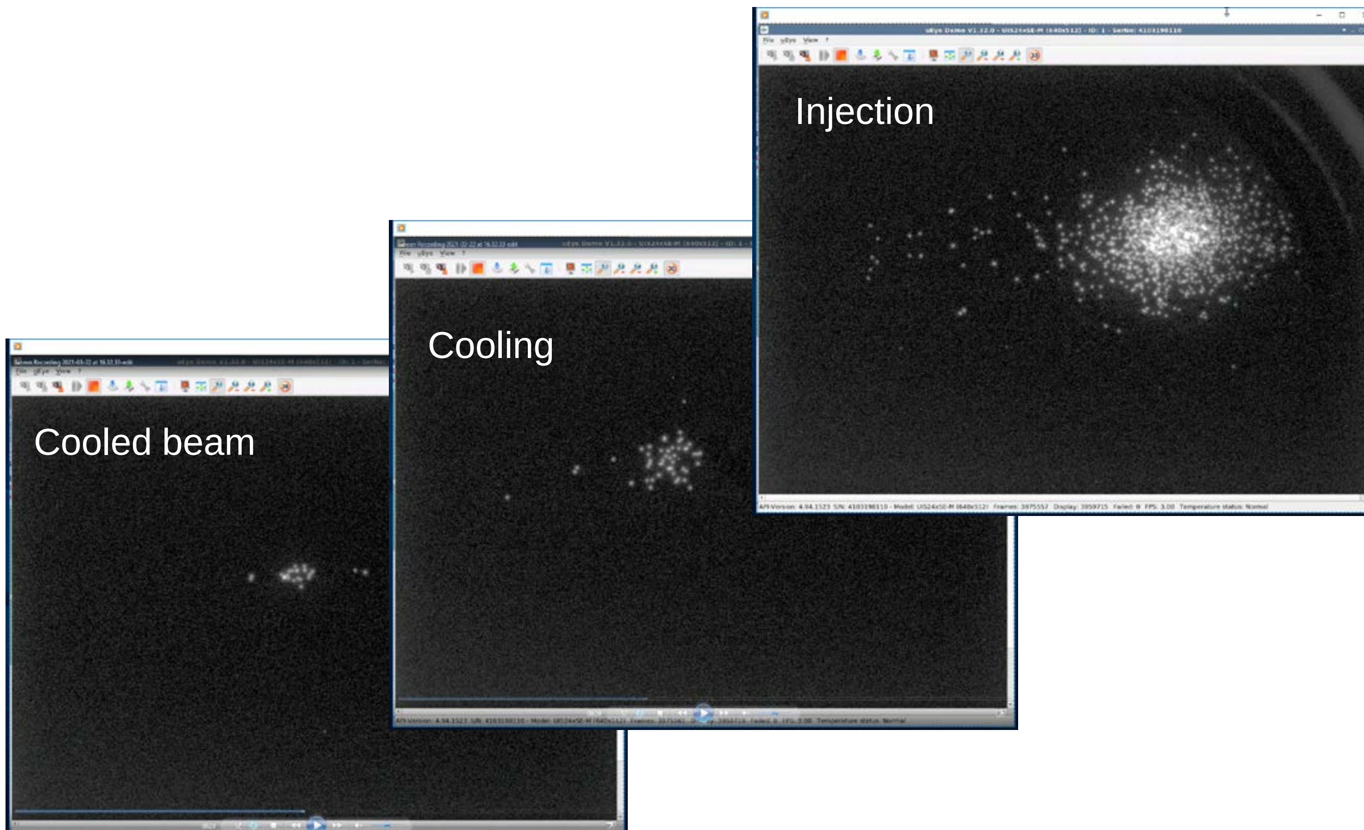


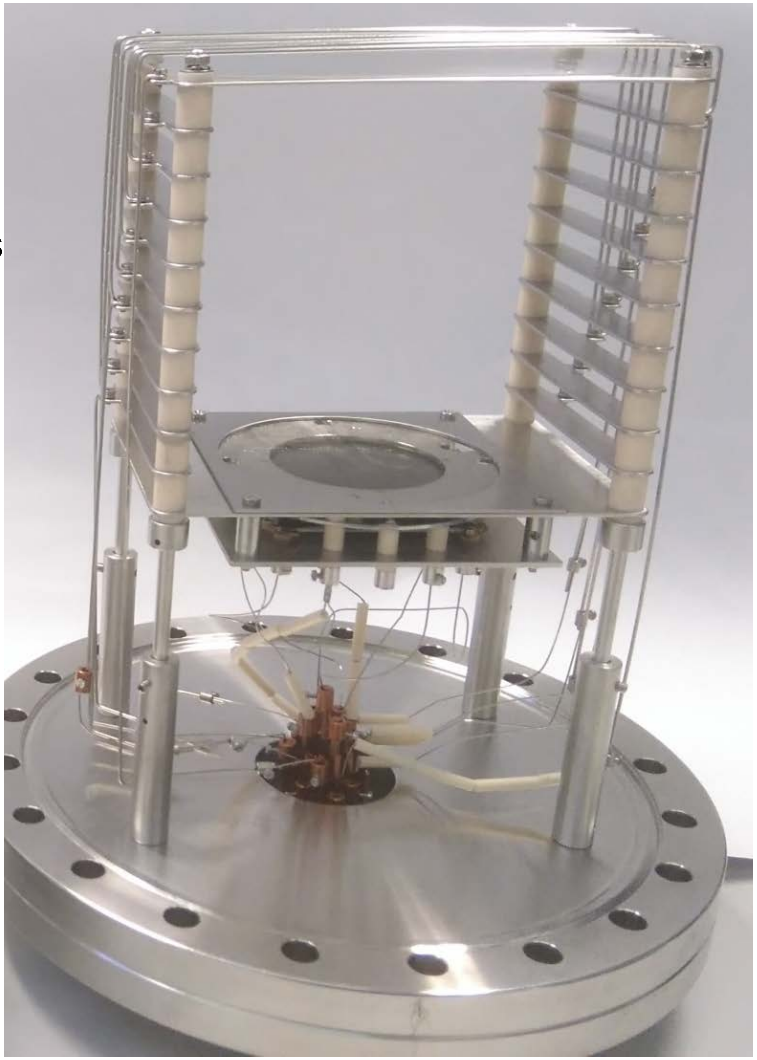
Image: RoentDek Handels GmbH
https://roentdek.com/info/DET40/



# Electron Cooling
# Ionisation Profile Monitor

**IPM with resistive-anode readout**

- Field cage: 100 mm , 80 mm depth
- Chevron type stack of 2 MCPs (40 mm diam., late 90s)
- Circular-arc terminated resistive anode encoder (RAE)
- Charge-sensitive pre-amplifiers and spectroscopy main amplifiers
- Fast amplifier output for ADC gate and count rate
- DAQ: VME peak-sensing ADC, 130 kHz readout
- Position (X, Y) of each event via charge division
- Resolution: 0.3 mm (FWHM)



**Operation**

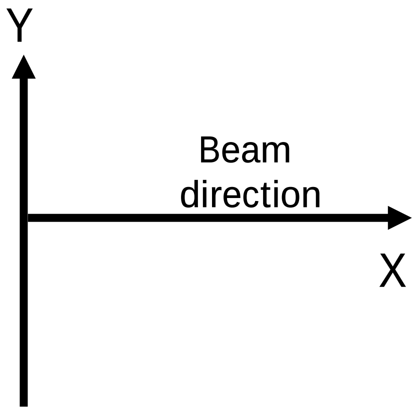
- Monitoring of cooling and beam intensity
- MCPs operated at moderate HV values
- MCP count rates: up to 150 kHz (HCI from ESR)
- Cross check profile/width via scrapers

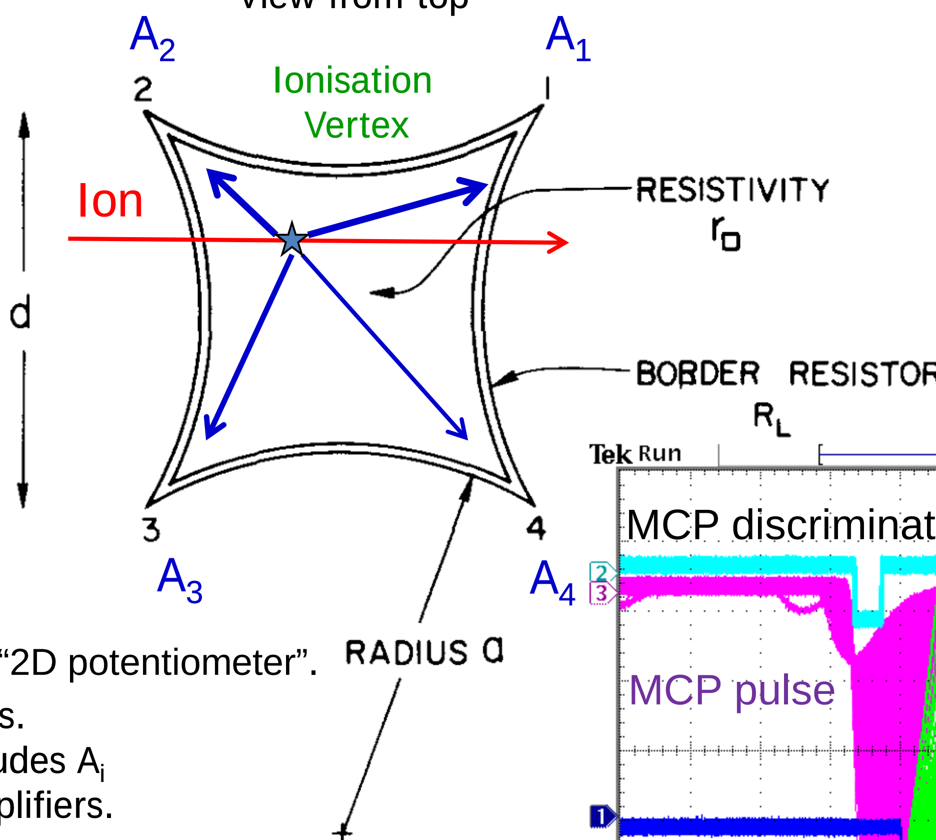
**Limitation**

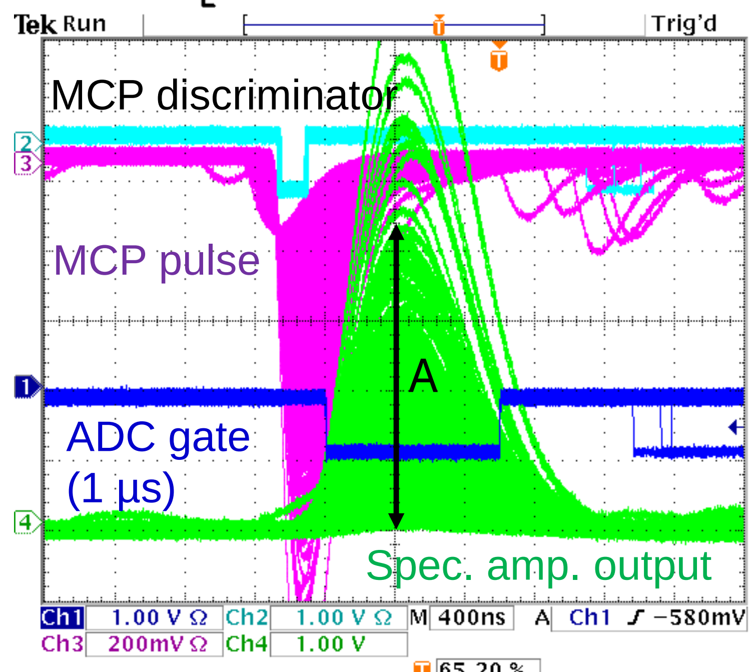
- Not useable for RFQ transport mode injection (few keV/u)
- Different "low-energy IPM" design needed, e.g. fast switching of field cage at flattop, correction elements for kick compensation

# Ionisation Profile Monitor
# Resistive Anode Encoder Readout

M. Lampton, C.W. Carlson
Rev. Sci. Instr. 50, 1093 (1979)



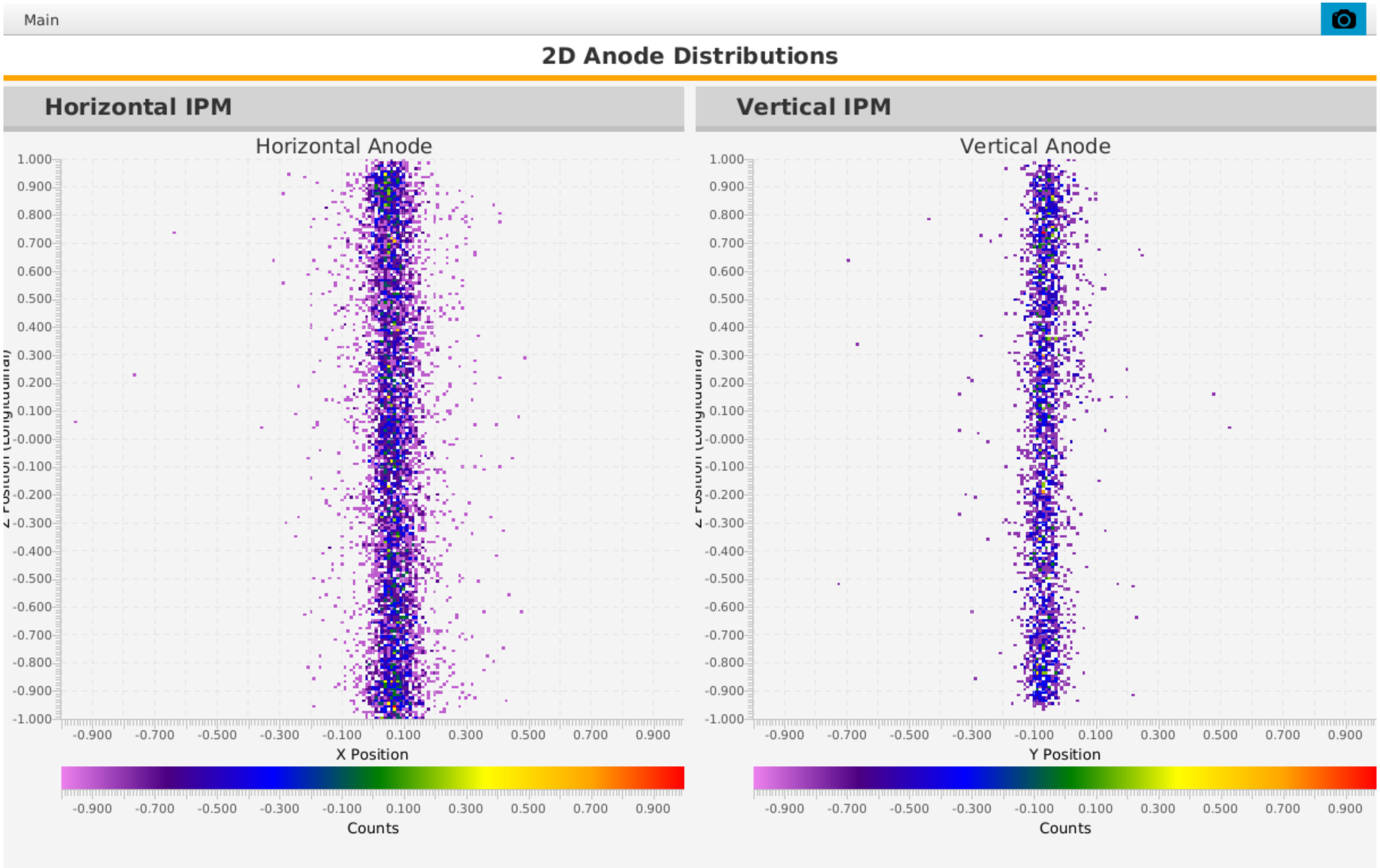

Resistive Anode Encoder acts as "2D potentiometer".
Readout of charges at four corners.
Vertex reconstruction uses amplitudes $A_i$ (peak values) of spectroscopy amplifiers.

$$\frac{y}{d/2} = \frac{(A_1 + A_2) - (A_3 + A_4)}{(A_1 + A_2 + A_3 + A_4)}$$

"Same asymmetry equation"
as for BPM position!

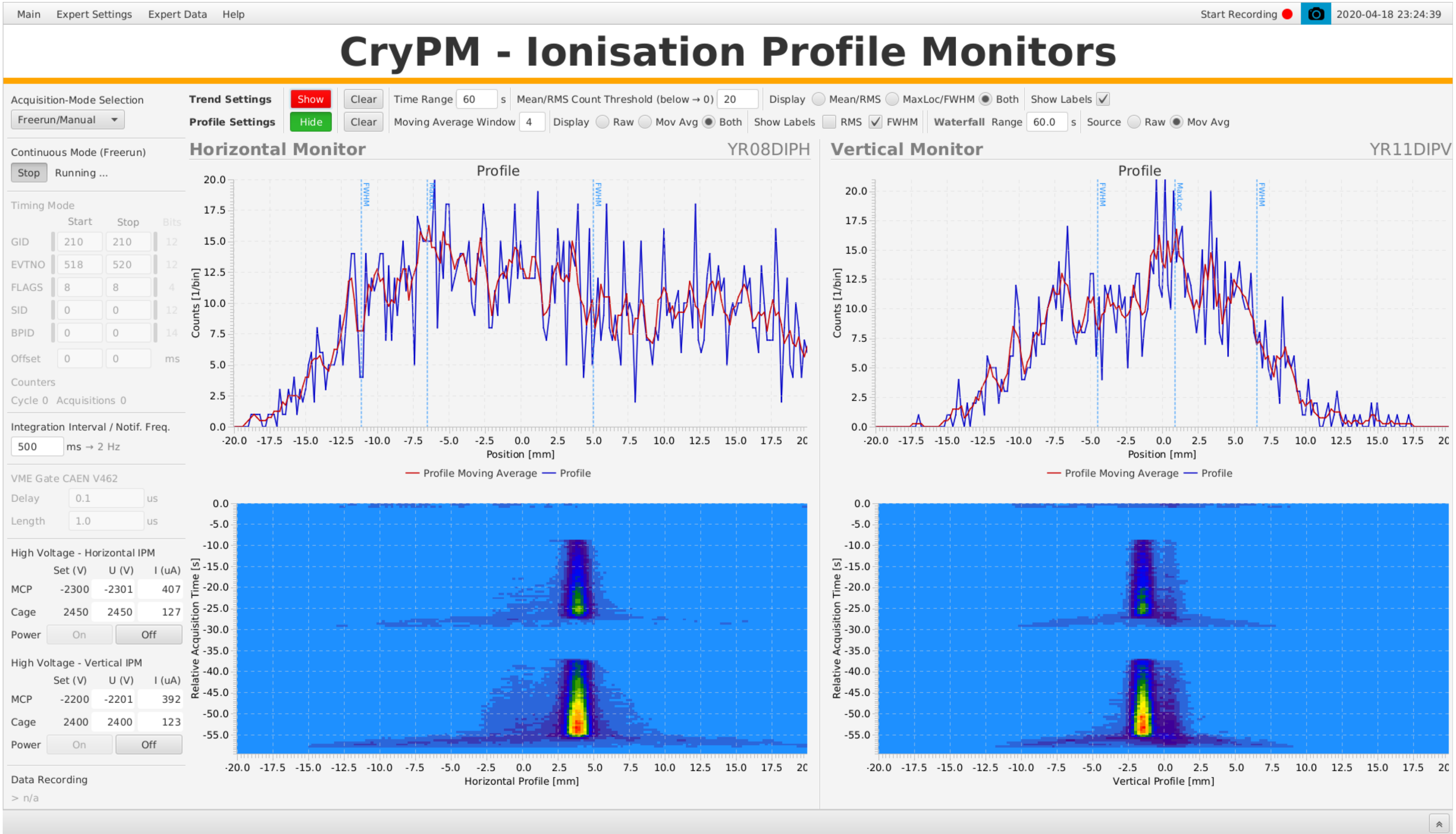
# Ionisation Profile Monitor
## Vertex distributions

- Example of cooled beam show rather uniform distribution across MCP surface.
- Despite their age, the two MCP stacks still seem to be in good condition.

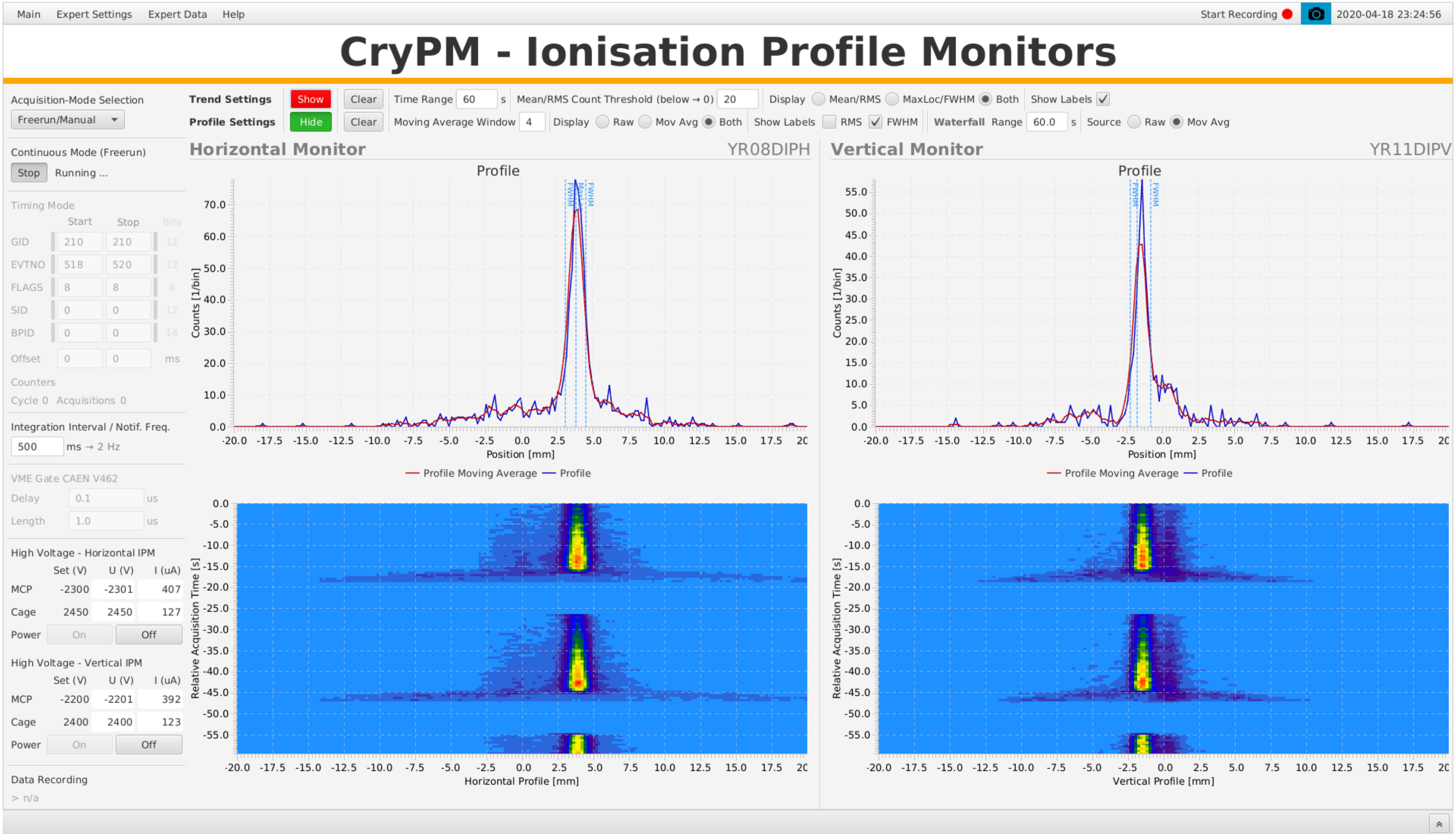


# Ionisation Profile Monitor

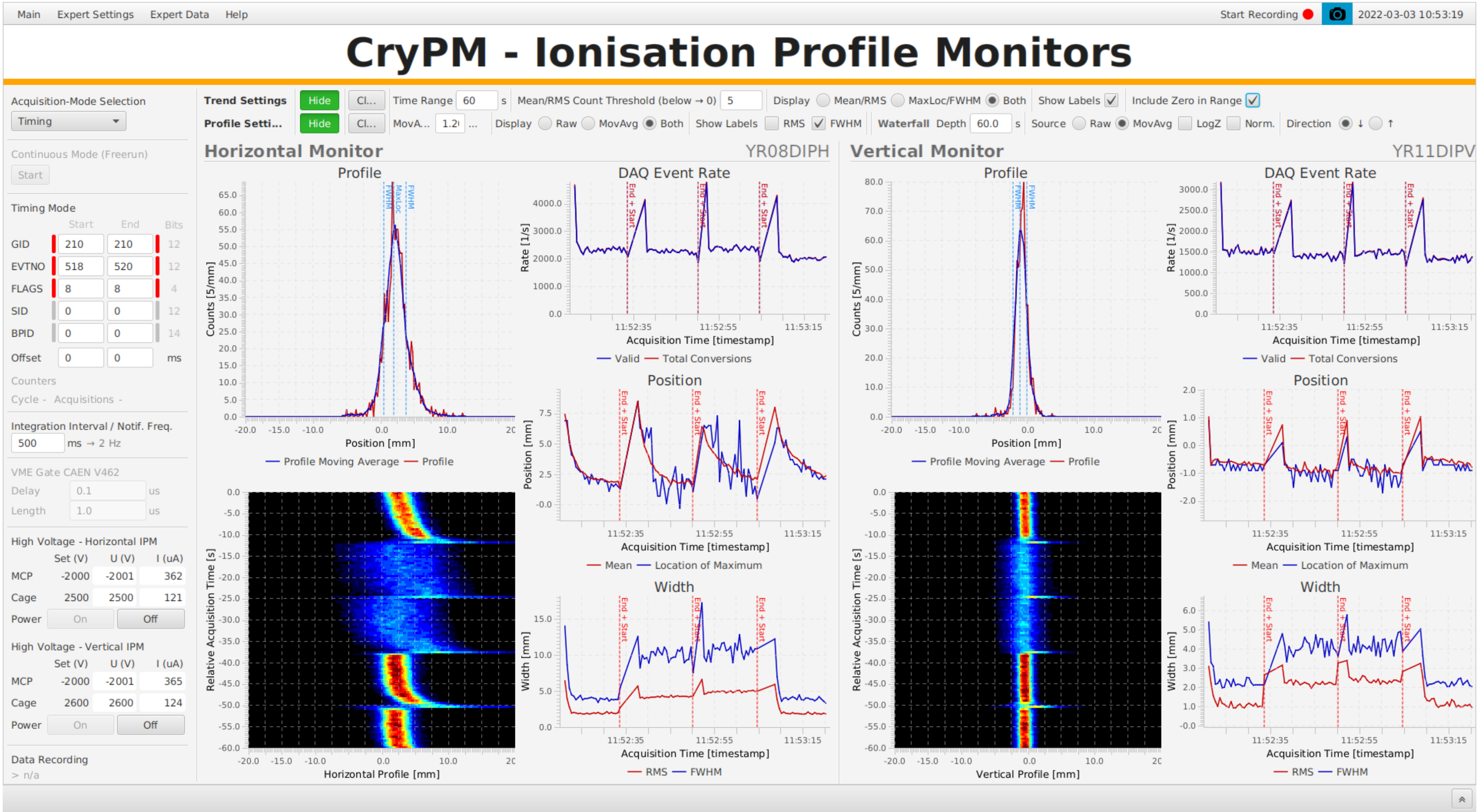
## Profiles of 11.1 MeV/u $Pb^{67+}$ beam at injection



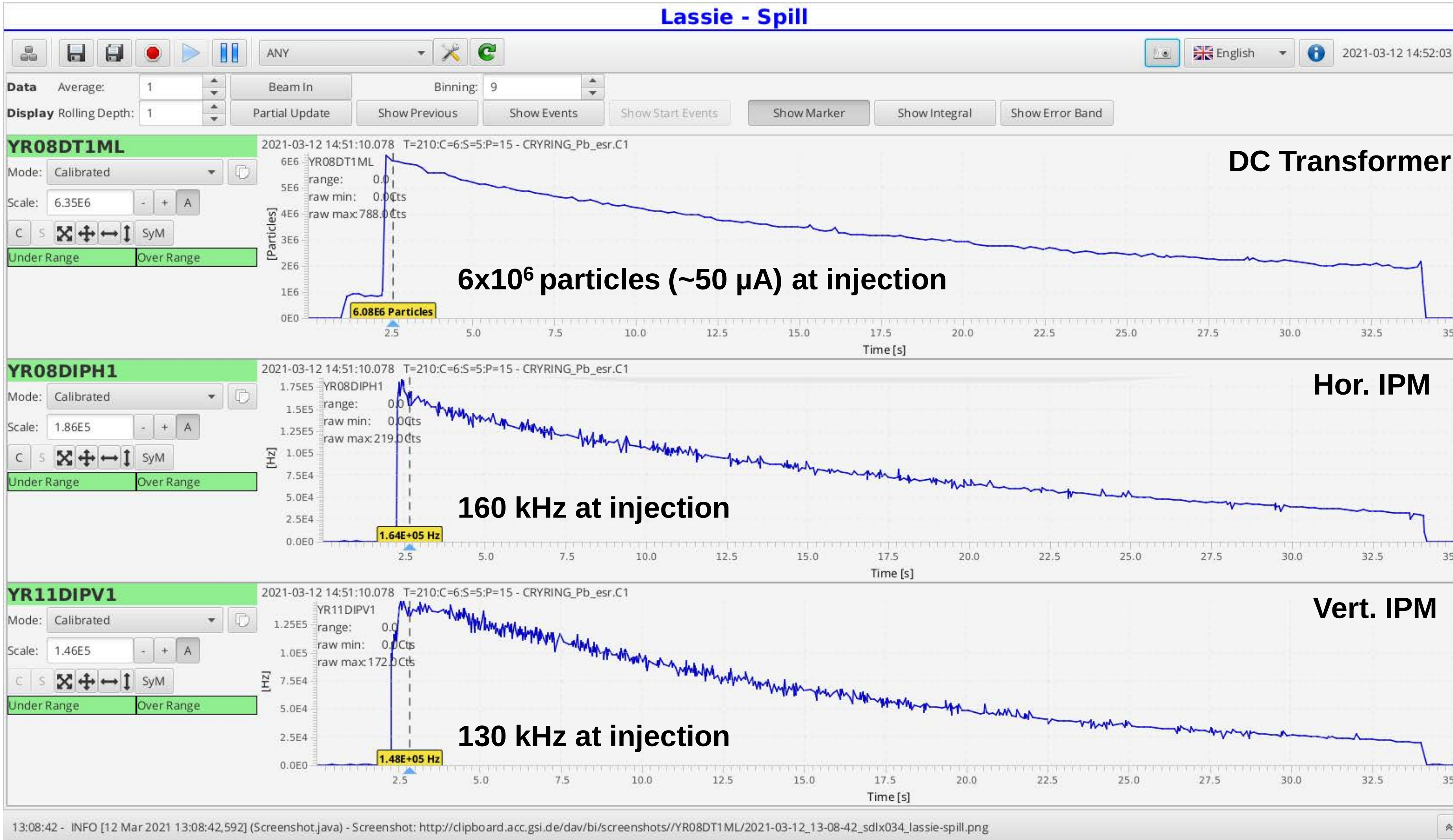
# Ionisation Profile Monitor
## Profiles of of 11.1 MeV/u Pb$^{67+}$ beam after cooling



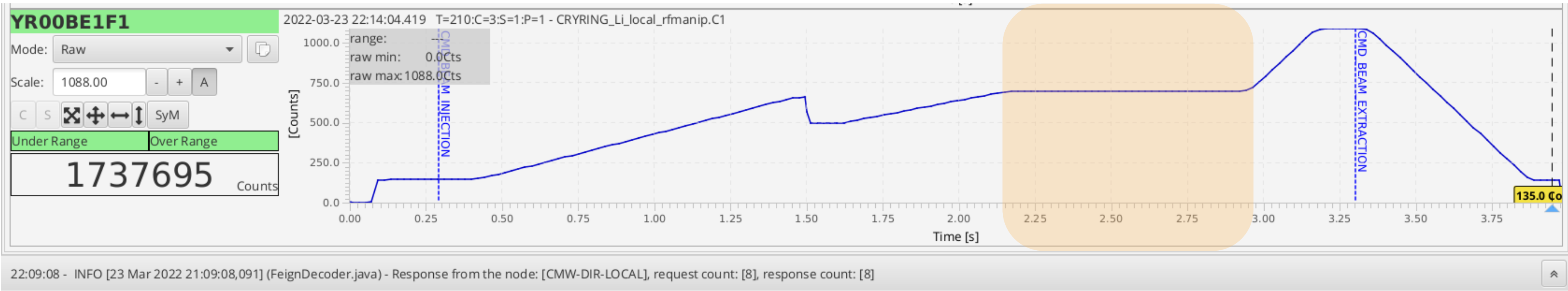
# Ionisation Profile Monitor
## Profiles of D+ beam



# Ionisation Profile Monitor
## IPM count rates of 11.1 MeV/u $Pb^{67+}$ beam



# CRYRING@ESR
## Flattop – Storage



# CRYRING@ESR

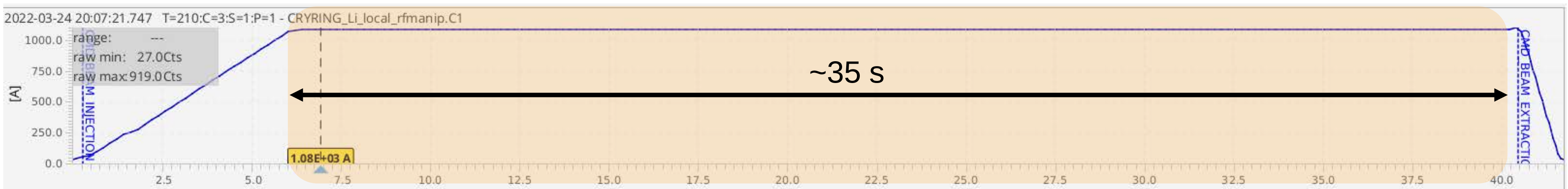
## Flattop – Storage / Current Measurement

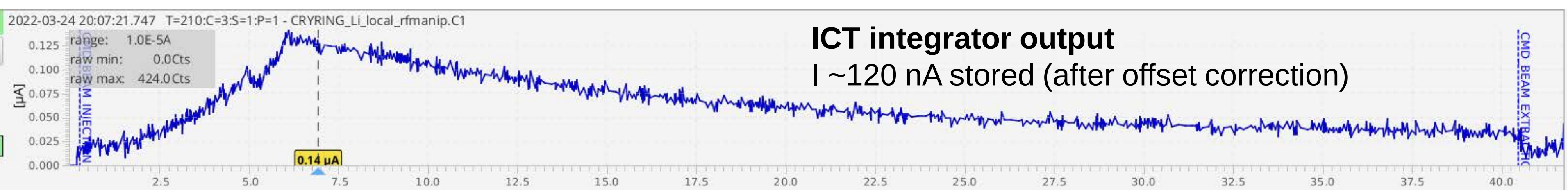
**Absolute intensity**

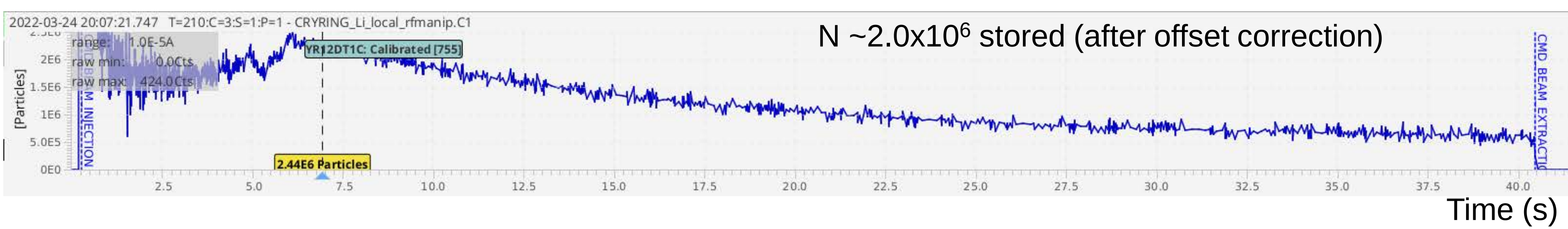
- AC and DC beams can be monitored above 5 µA current with DC transformer (PCT, 1 mA range)
- AC beams can be monitored with ICT transformer & integrator

**Relative intensity**

- AC and DC: IPM count rates
- AC: Schottky sum (zero-span mode), BPM & integrator, CryRadio (heterodyne mixer similar to SIS radio)



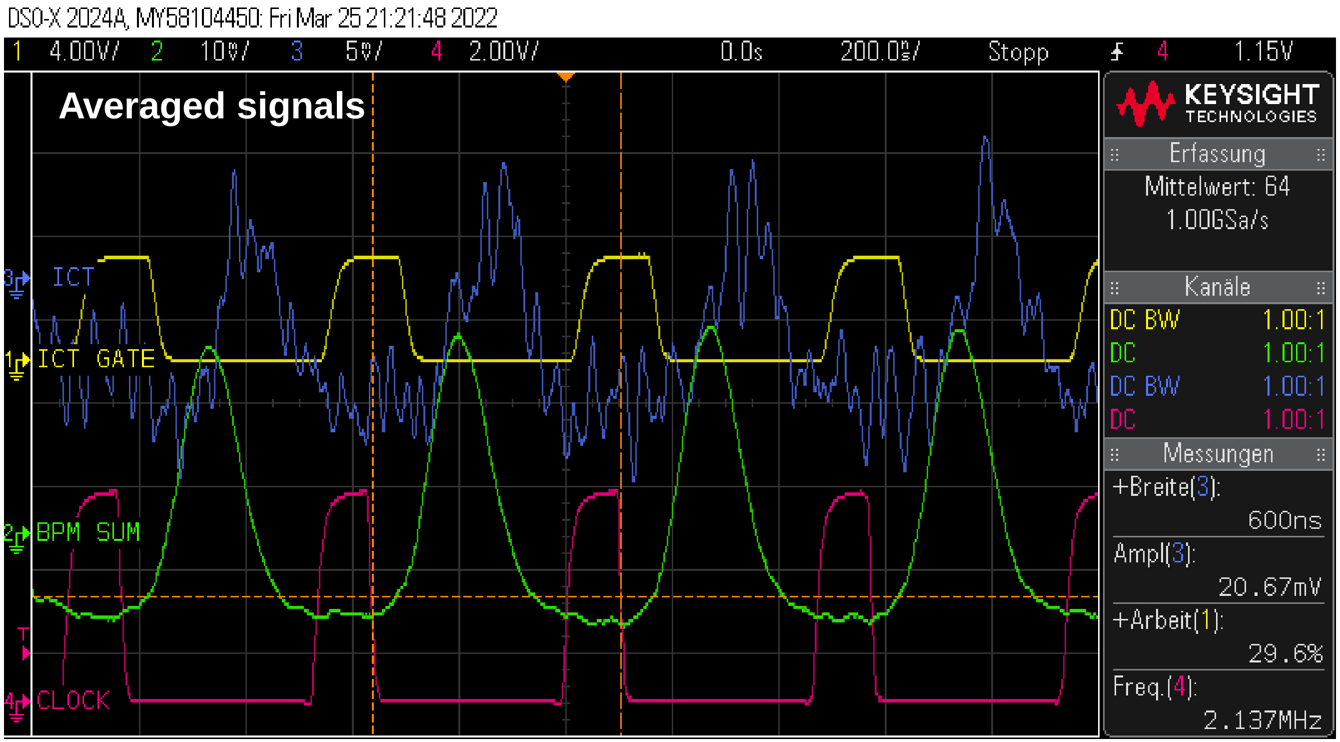



# Flattop: Raw signals of ICT and BPM (2 MeV/u)

- $2 \times 10^6$ $Li^{1+}$ ions correspond to I~120 nA stored current.
- ICT Transformer (50 MHz)
  - Amplitude ~ 10–15 mV after 80 dB amplification => 1 µV from transformer
- BPM sum (4 MHz)
  - Amplitude ~ 30 mV after 60 dB amplification => 30 µV from both electrodes
- Bunch signals are converted to a low-bandwidth voltage outputs in fast-switching, gated integrator cards

  ICT output proportional to beam current I (sensitivity S = 10 V / 10µA).



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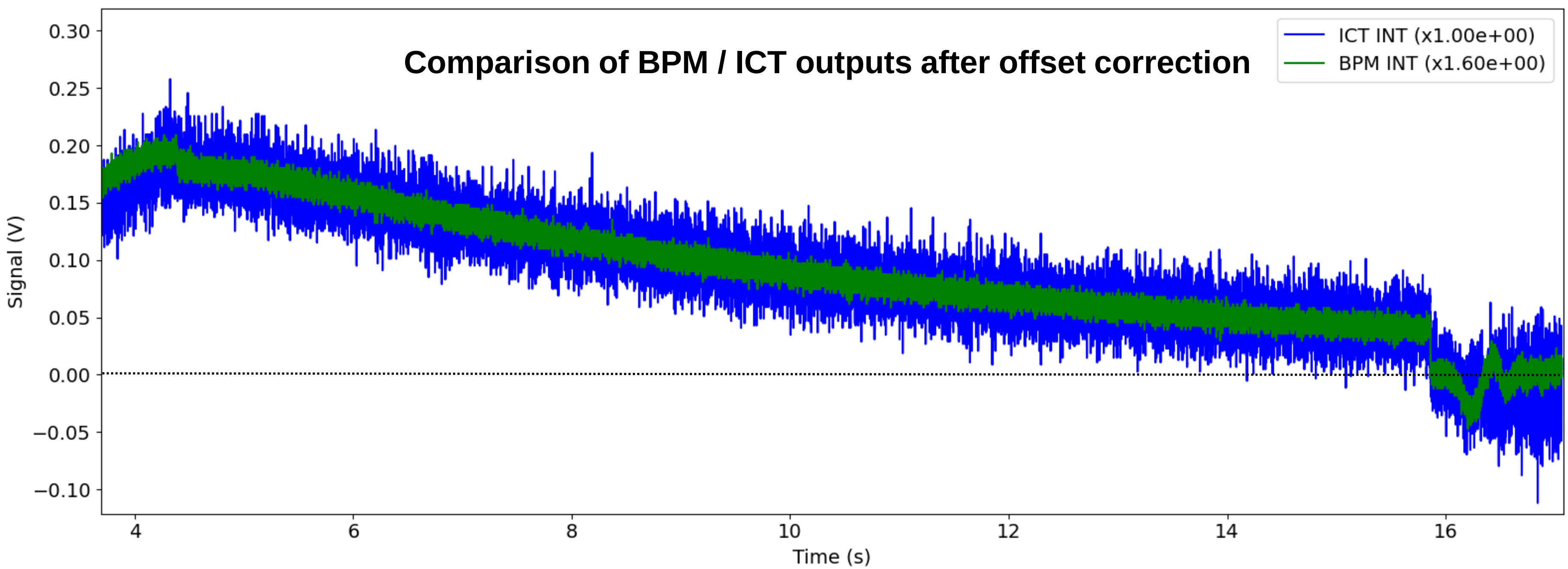
  ICT output proportional to beam current I (sensitivity S = 10 V / 10µA).
- Good common behaviour of both signals (2 cards: 1x MSL & 1x GSI redesign)



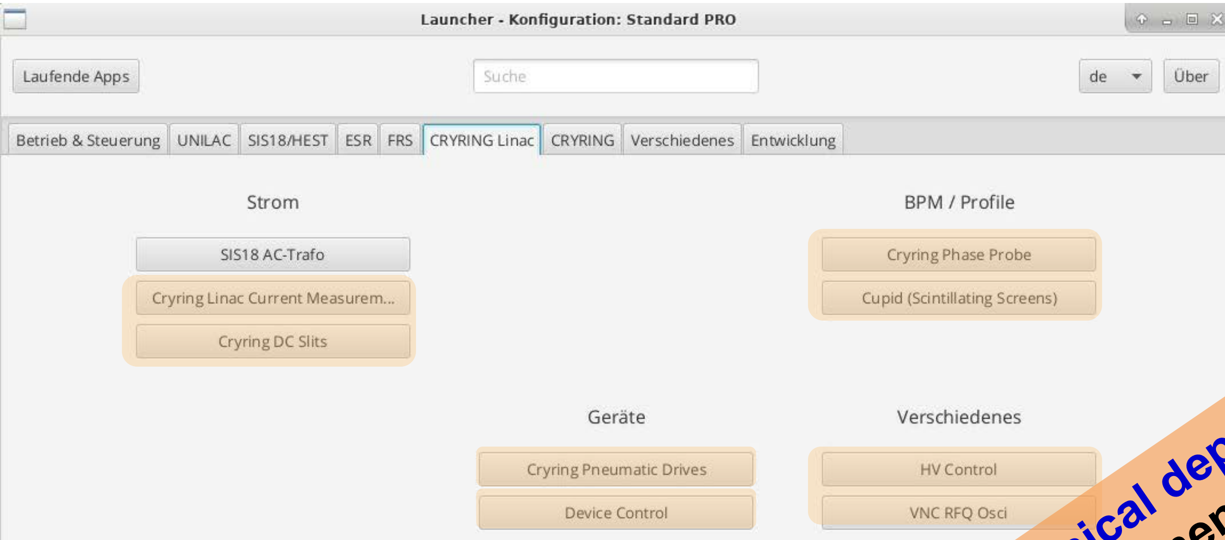
# CRYRING@ESR
## Summary & Outlook

- Standard instrumentation is complete after BPM system upgrade.
- 1$^{st}$ turn diagnostics: OK
- Position & Beam Loss: OK
- Profile: IPMs OK
  ”low-energy IPM” needed
  (for RFQ transport mode)
- Beam current transformers: OK (I >100 nA, bunched)
  but often experiments need coasting beam
  CCC for currents down to ~10 nA

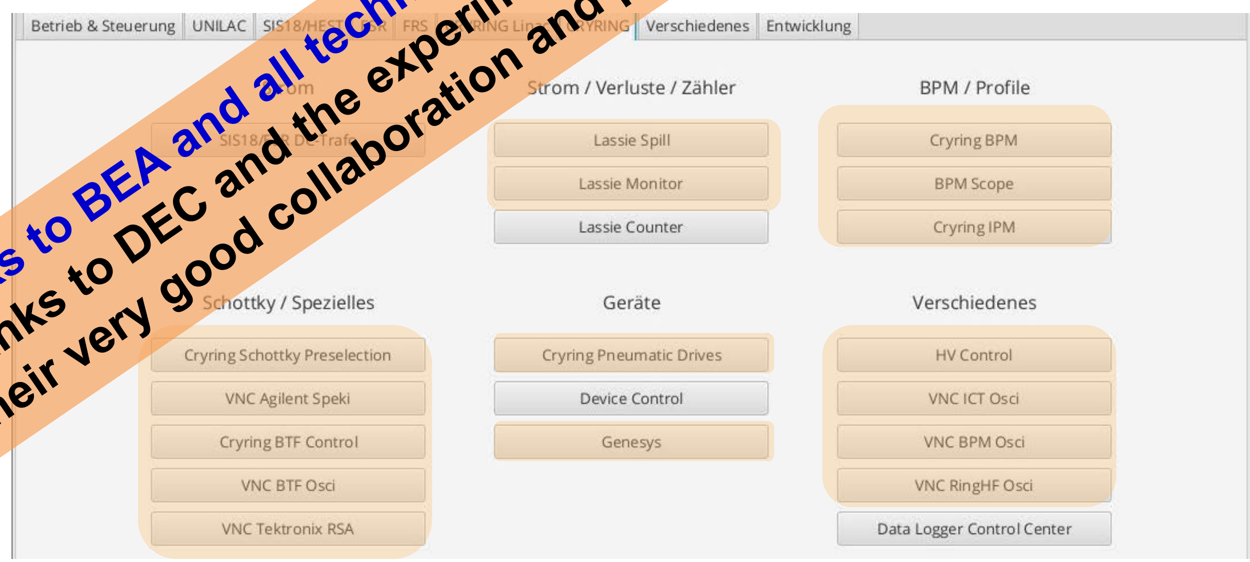
  Dedicated talk by D. Haider on recent
  CCC development and tests measurements
  coming up soon!
- Beam intensity: OK
- Schottky & Tune: OK
- Special diagnostics
  - FCT application: OK
  - 0-degree Diagnostics: integration missing

# ACKNOWLEDGEMENTS

## Behind the GUI buttons? Lots of HW and SW efforts!








**Thanks to BEA and all technical departments!**

**Thanks to DEC and the experiment crews for their very good collaboration and patience!**

# Time`s up, thanks a lot for your attention!


by H. Rödl