Beam diagnostics developments for the HIE-ISOLDE linac

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Outline

- Beam instrumentation developments for the HIE-ISOLDE upgrade of the REX linac (HIE-REX)
- Silicon detector monitor for cavities phase-up
- Prototype monitor structure
- Beam test setup
- Measurement results (cavity phasing, energy & timing beam profiles)
- Conclusions & future developments

Beam diagnostics tasks for HIE-REX

Main beam parameters to be measured:

- intensity
- position
- transverse profile
- transverse emittance
- energy - relative (cavity phase-up)

  - absolute
- longitudinal profile and emittance

  (energy and time spread)

Beam diagnostics tasks for HIE-REX

Main beam parameters to be measured:

- intensity
- position
- transverse profile

} *diagnostic box ("short-box") in each inter-cryomodule region → Faraday cup, slit and current-sensitive device (for low intensity beams)*

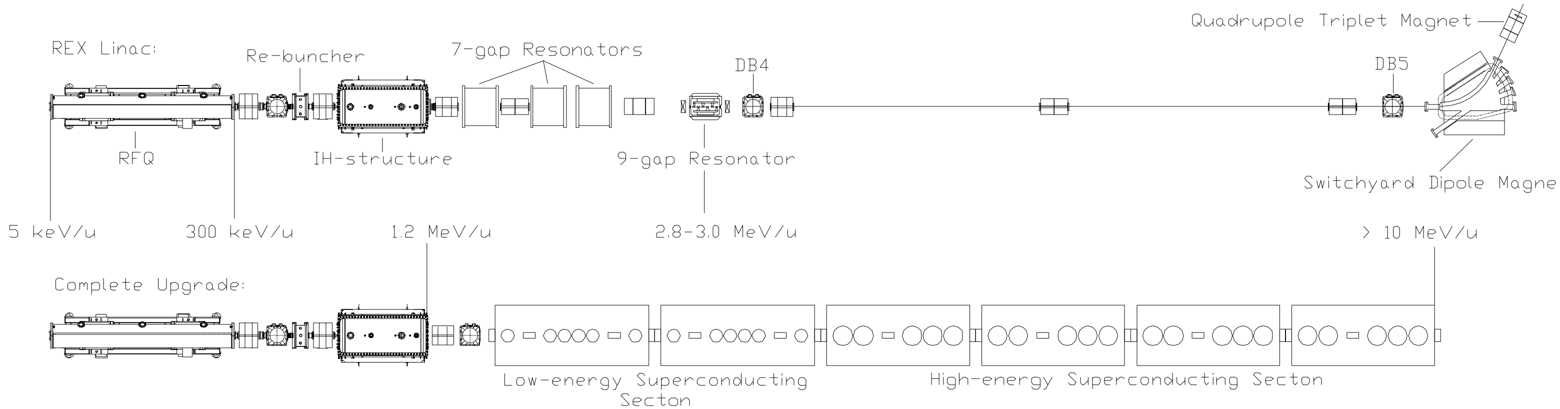
- transverse emittance → *transverse emittance meter*
- energy - relative (cavity phase-up) → *silicon monitor*
  - absolute → *ToF system…*
- longitudinal profile and emittance (energy and time spread)

} *(spectrometer) solid state detectors* (↑ *silicon monitor*)

HIE-REX cavities phase-up

REX

HIE-REX



6 cryomodules with superconducting cavities

- Increase in the number of cavities: from 5 (REX) to 34 (HIE-REX)
- Phase-up standard procedure based on the relative measurement of the beam average energy vs. the RF phase downstream the cavity

→ REX phase-up based on the use of the switchyard dipole magnet

→ robust and reliable procedure but time consuming and difficult to automate

Need for a quick and eventually automated phase-up

Silicon detector monitor

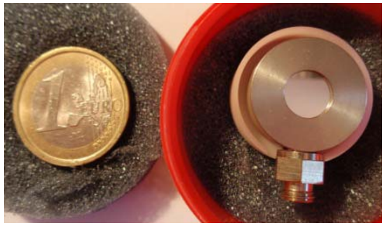
Based on the experience at the ISACII accelerator at TRIUMF

PIPS (Passivated Implanted Planar Silicon) detector, suited for charged particle spectroscopy, placed on the beamline→ beam particle stopped→ measure of energy and time of arrival

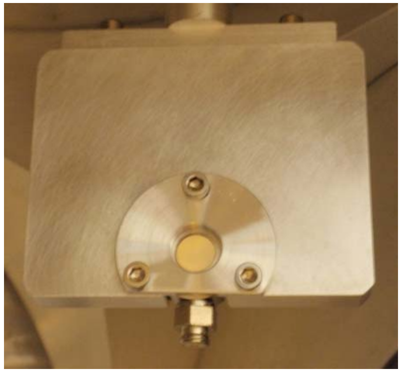
⇓

Test of the performance of a prototype monitor in terms of cavity phase scanning and longitudinal (energy & time) beam profile measurements

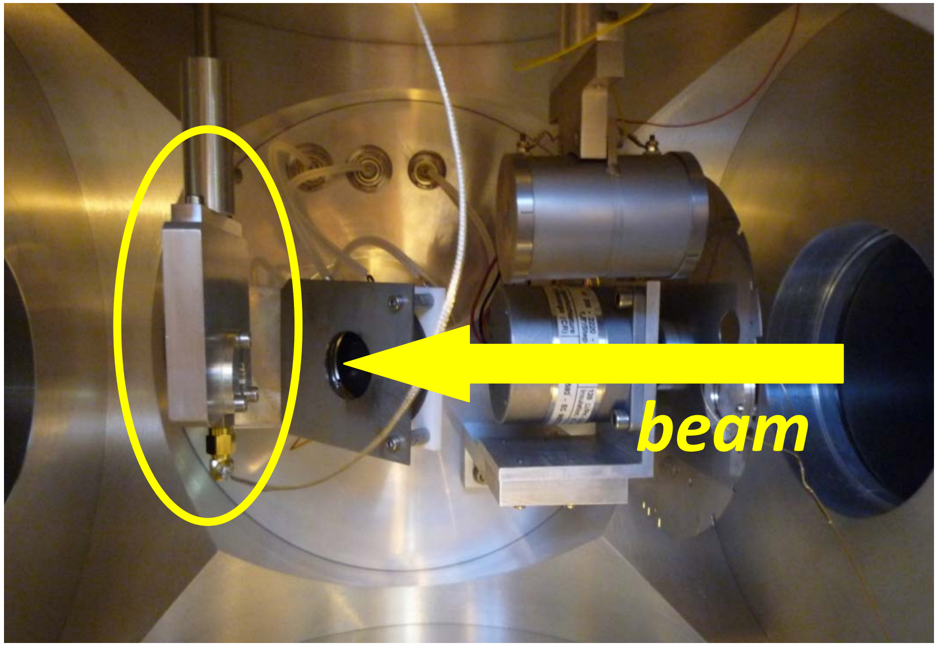
Canberra PIPS det



Mechanical support

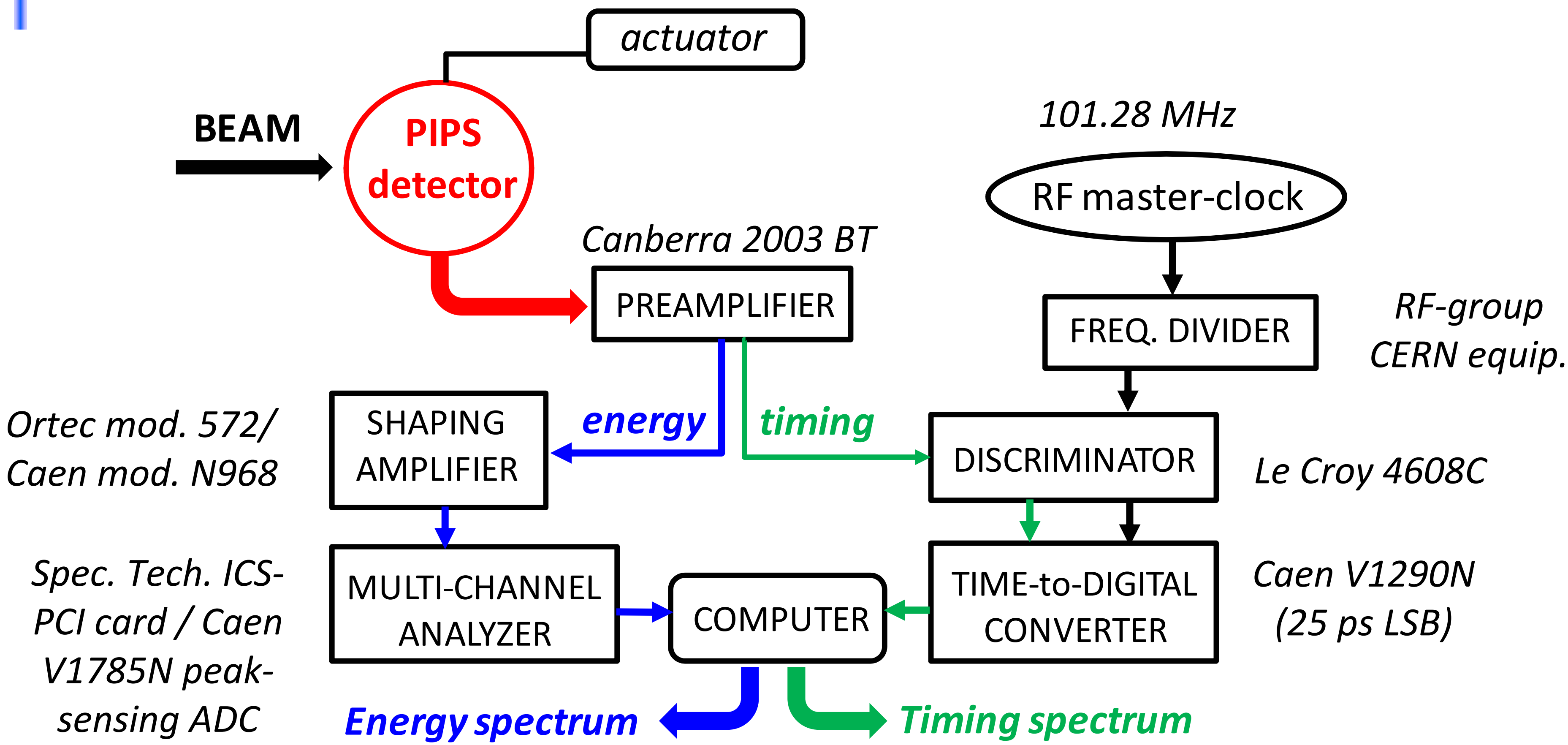


Test setup inside one REX diagnostic box

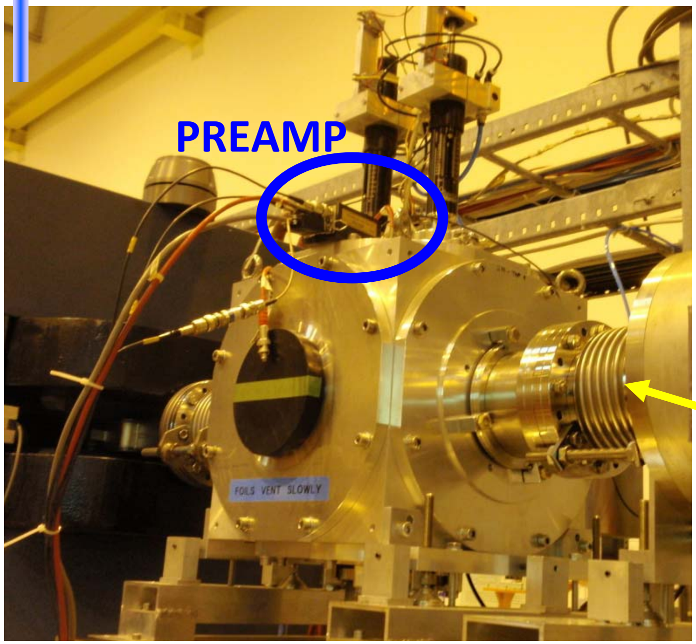


Area= $50 mm^2$
Thickness = 300 μm
Bias voltage = +60 V
Entrance window = 100 nm
Capacitance = 30 pF
Timing resolution < 140 ps

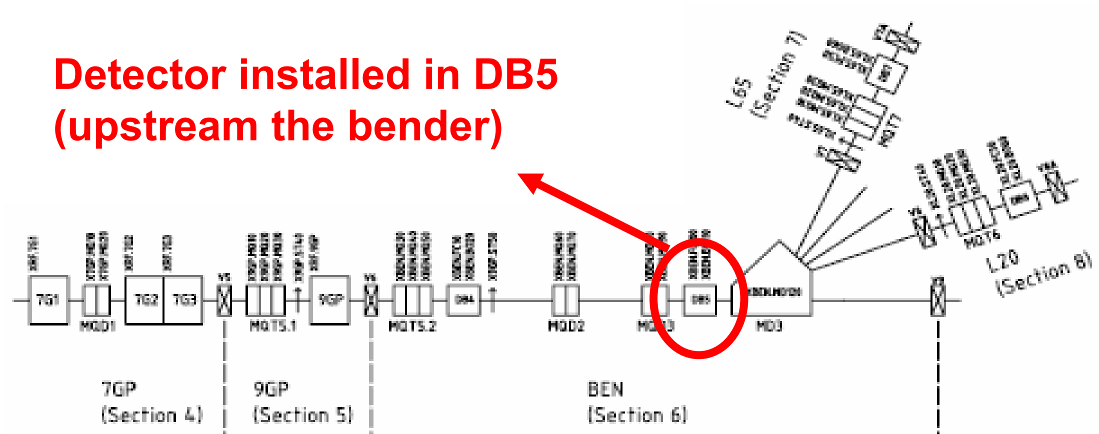
Monitor structure and DAQ setup

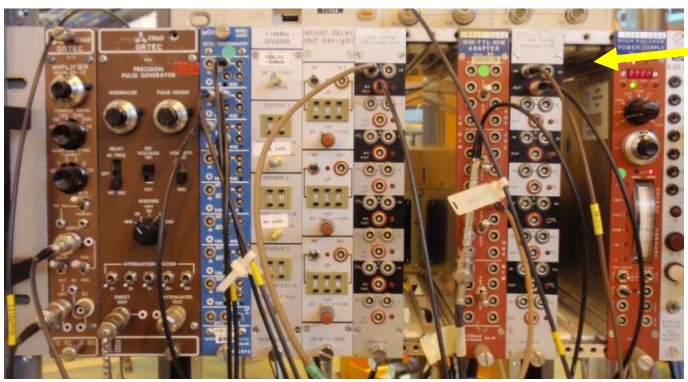


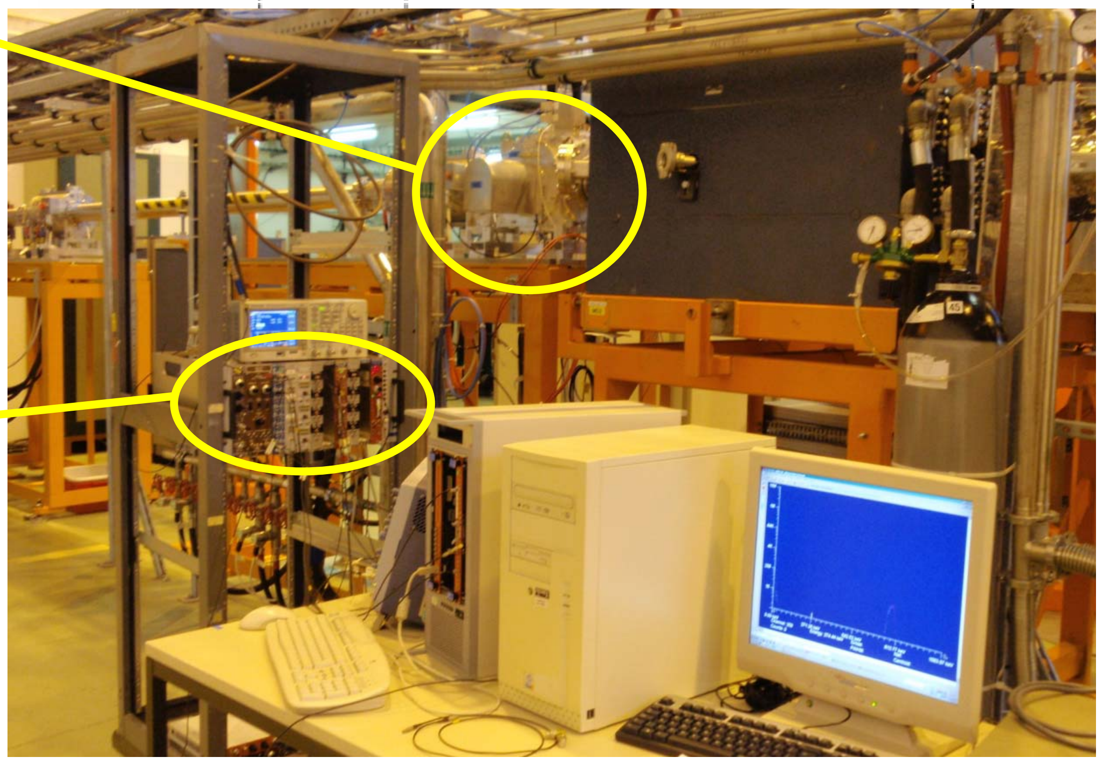
Test setup in the Isolde hall



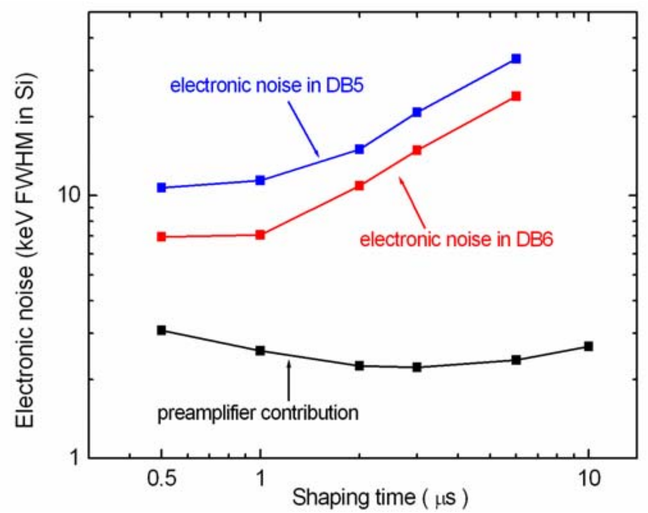
Detector installed in DB5
(upstream the bender)





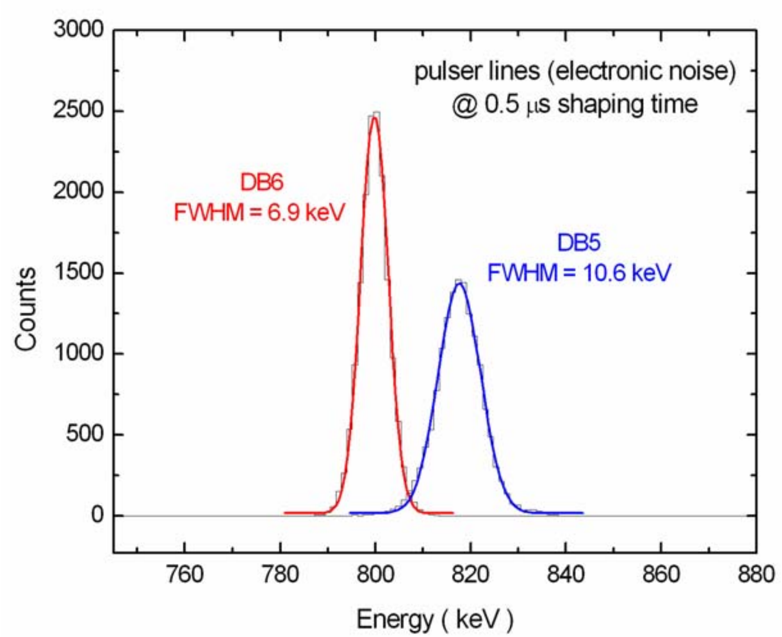


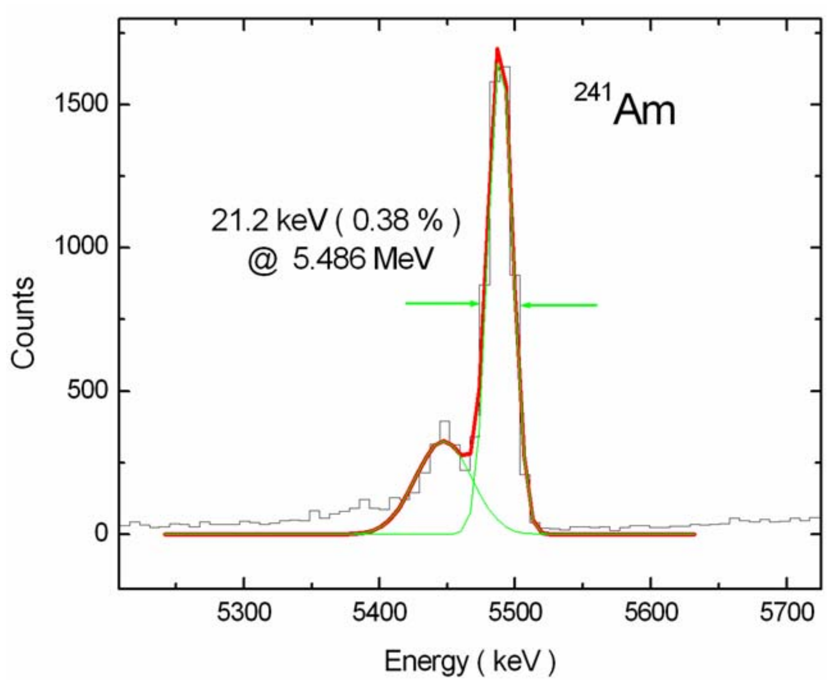
Electronic noise and alpha resolution



<u>Nominal quoted by Canberra</u>:
electronic noise = 5.8 keV (FWHM)
alpha resolution = 14.3 keV (FWHM) (0.26 %)

<u>Measured in diagnostic box DB5</u>:
electronic noise = 10.6 keV (FWHM)
alpha resolution = 21.2 keV (FWHM) (0.38 %)





Beam composition and intensity

- Ionized residual gas from inside the EBIS (typical pilot beam)
- A/Q=4 (typical): $^{12}C^{3+}$, $^{16}O^{4+}$, $^{20}Ne^{5+}$ + some $^{36}Ar^{9+}$ …
- Repetition rate = 33 Hz and pulse length = 450μs
  → machine duty cycle = 1.5%
- Strong attenuation of the beam intensity to reach the kHz level inside the 450 μs pulse window: single particle detection regime

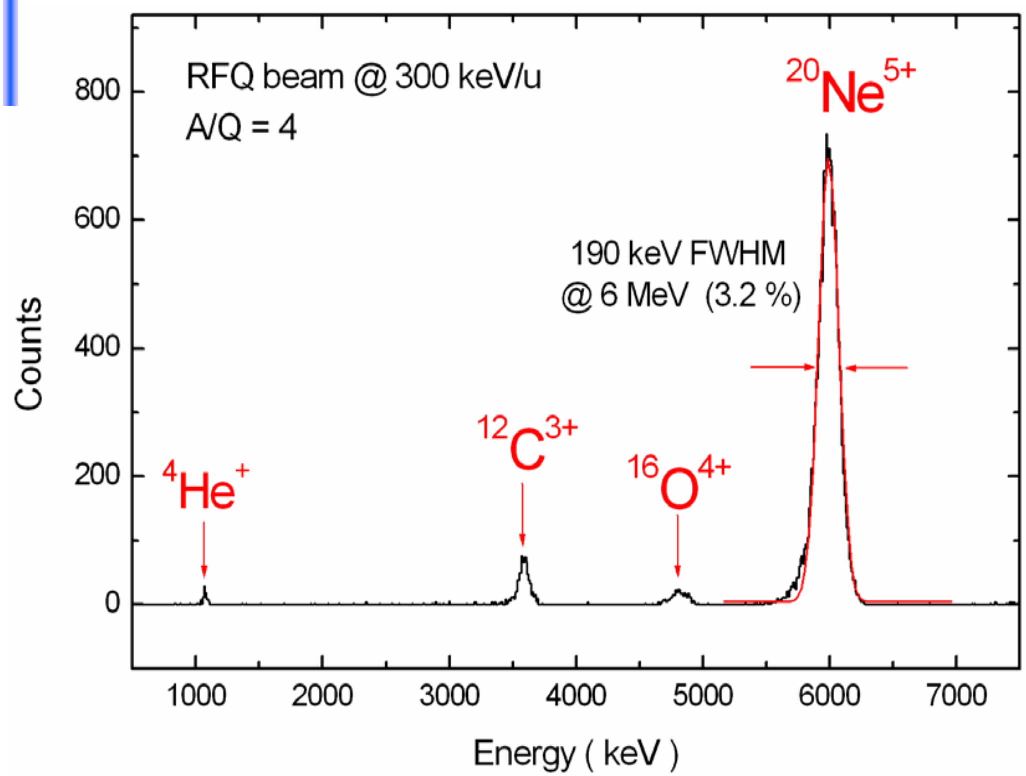
  count rates of 1.5-7 kHz inside the 450μs pulse window
  → 0.9 - 3 particles per pulse
  → average count rate of 23-100 Hz (33 Hz repetition rate)

- Attenuation methods:

  → manipulation of EBIS parameter + collimators along the linac

  → attenuator copper foils placed upstream and downstream the RFQ

Monitor energy resolution



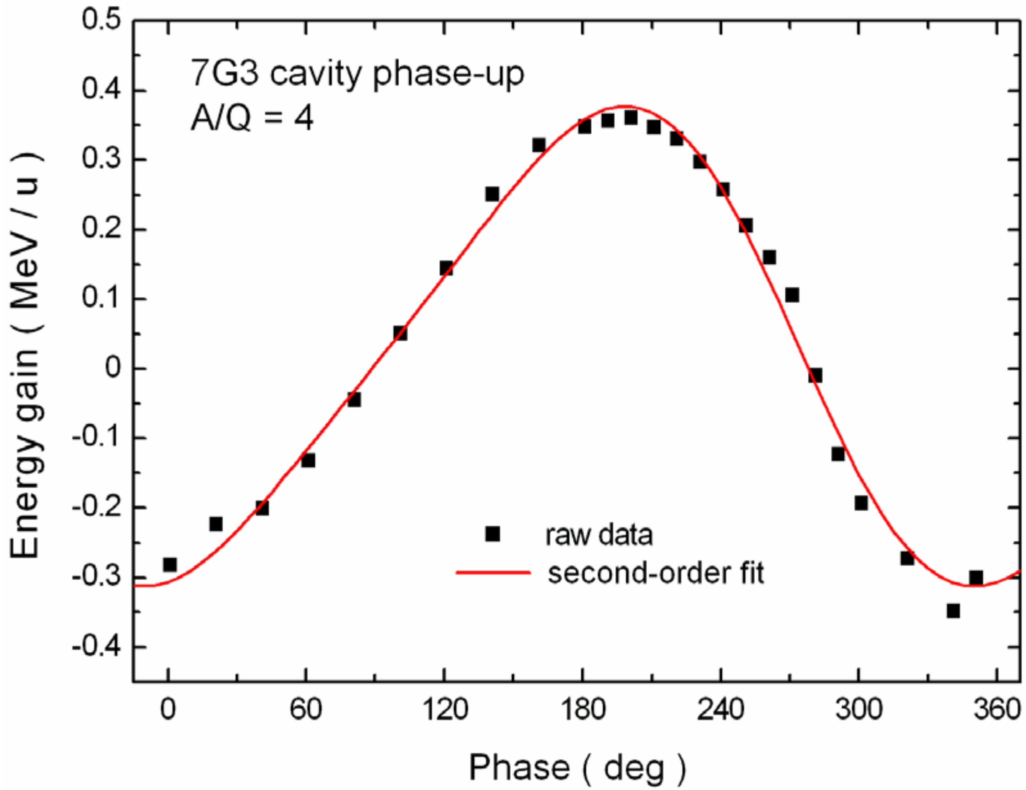
REX BEAM SPECTRUM
at 300 keV/u and A/Q=4

Average particle count rate = 100 Hz (count rate of 6.7 kHz in the RF pulse window)

→ **Helium, carbon, oxygen** and **neon peaks** well identified

While varying REX beam energy from 300 keV/u to 3 MeV/u, the measured monitor energy resolution varies in the range from 3 to 1 % FWHM (or 1.3 to 0.4 % rms).

Cavity phase-up demonstration



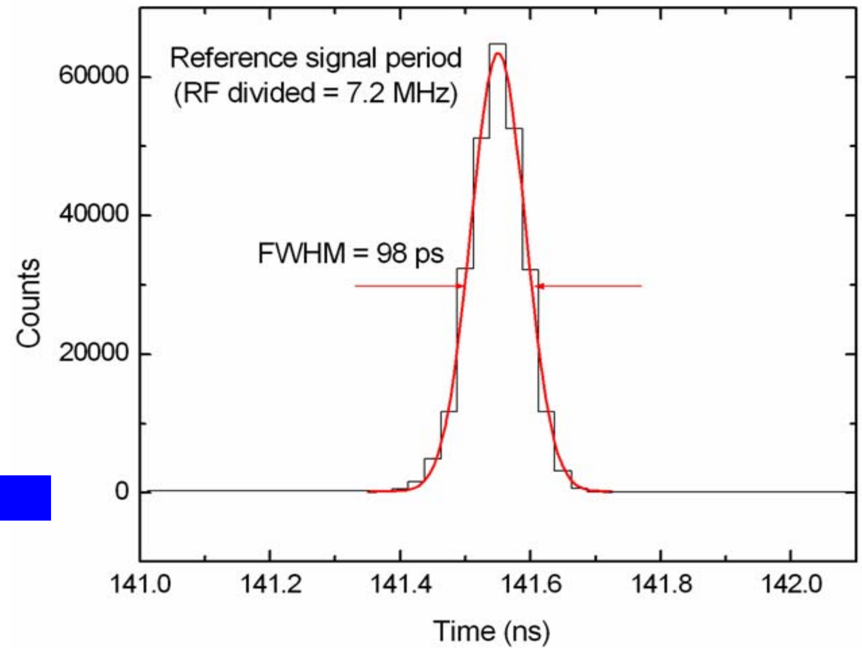
For the 7G3 cavity the maximum change in the average energy was ± 15 % @ 1.92 MeV/u

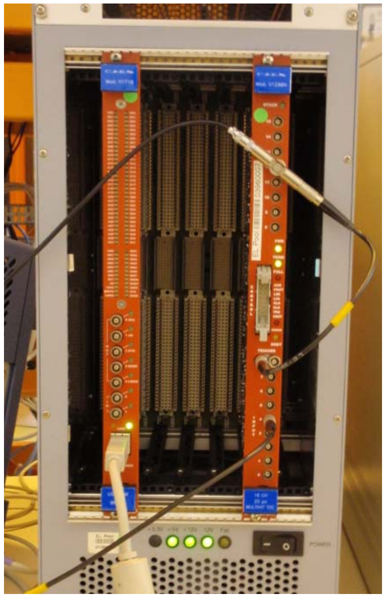
The monitor resolution allowed for accurate peak energy measurement while varying the cavity phase

<u>HIE-REX cavities in standard accelerating mode</u>: the simulated change in average energy ranges from ± 15 % to ± 3.5 % depending on the considered cavity → the monitor energy resolution is compatible with a quick phase-up procedure

Monitor timing resolution

- VME TDC Caen V1290N characterized by a resolution of 25 ps (LSB)
- Reference signal = RF master clock of the cavities divided by a factor 14 → 7.2MHz





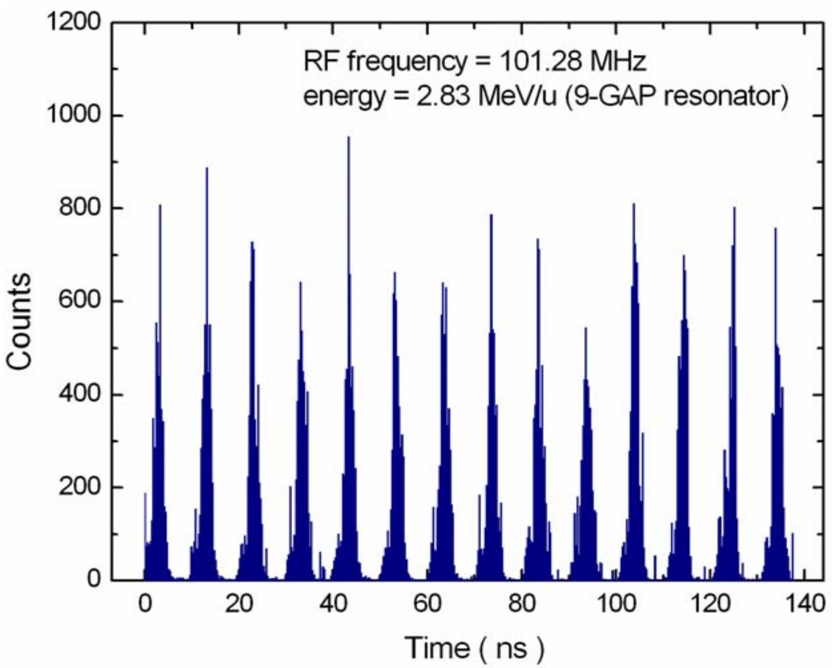
Reference signal resolution = 43 ps rms (98 ps FWHM)

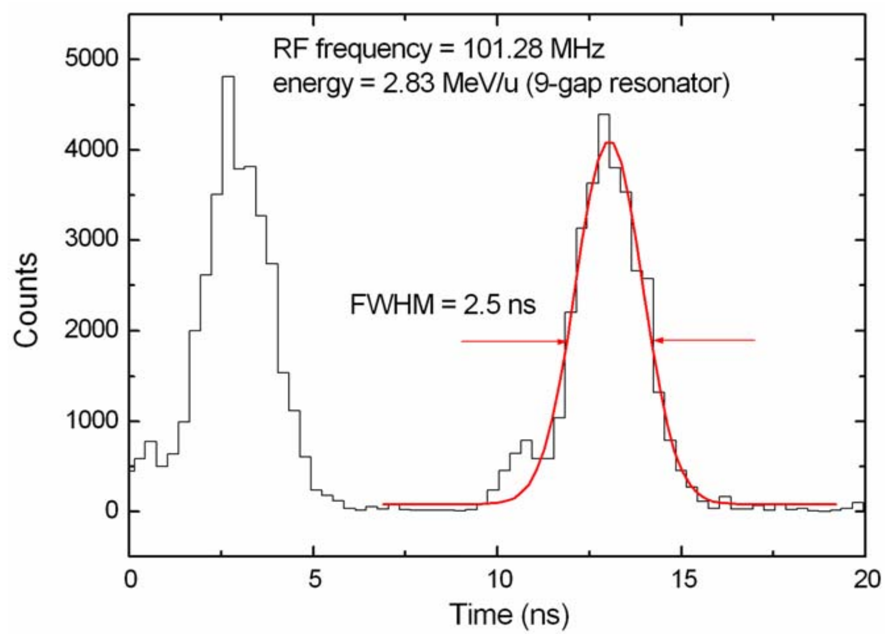
Detector "estimated timing resolution" = 140 ps

The system timing resolution is likely < 200 ps FWHM

Beam time profile

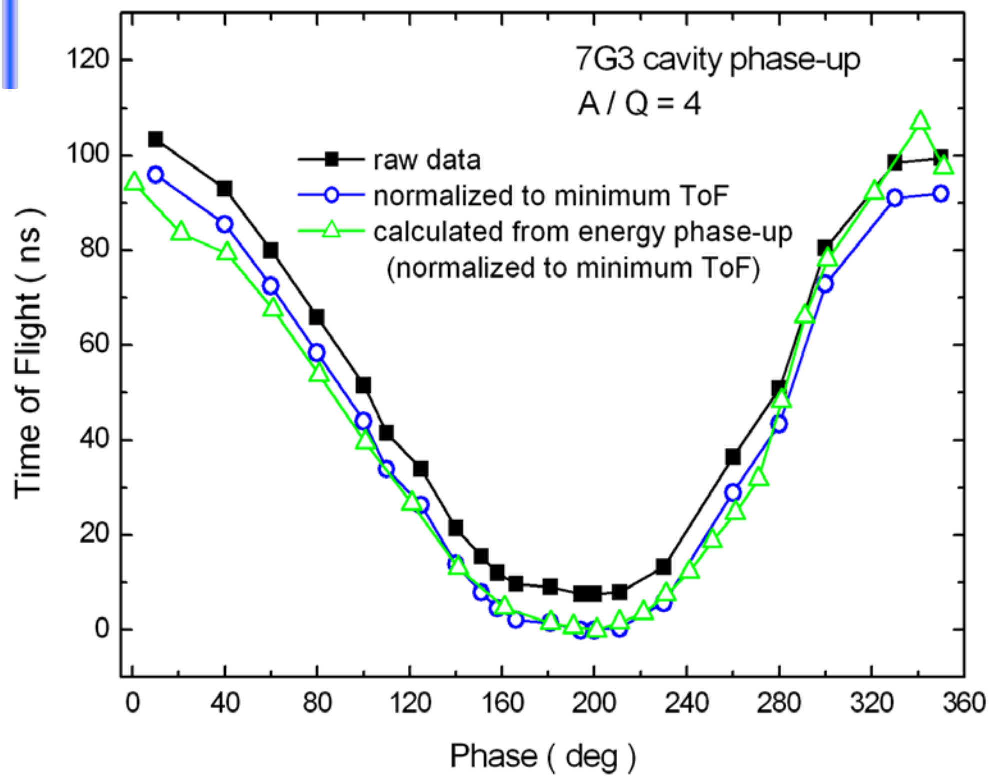
energy = 2.83 MeV (output energy of the 9-gap resonator)
time structure of 14 bunches, with the **expected period of 9.87 ns**





Measured bunch length of 2.5 ns FWHM → compatible with the time spread expected at the output of the 9-gap resonator and after a drift of approximately 9 m to the silicon detector

ToF cavity phase-up



The bunches arrival time (ToF) vary up to 90 ns over the 10.6 m drift distance between the 7GP3 cavity and the silicon detector monitor

Bunch spacing of 9.87 ns → challenging to differentiate between bunches arriving at the monitor → phase must be varied slowly such that the bunch being tracked never moves more than 9.87 ns in arrival time and can always be identified → too much time-consuming

Principle demonstrated → viable option for cavity phasing should a chopper be incorporated in the HIE-ISOLDE upgrade and the bunch spacing increased

Conclusions & future developments

- A silicon detector monitor is being developed for a quick phase-up procedure of the HIE-ISOLDE linac cavities
- A first monitor prototype is now installed at REX and has been successfully tested on beam
- Further developments are foreseen for the final installation downstream the SC linac, for the eventually automated operation and for the integration of the DAQ system
- Next step: complete project of the inter-tank diagnostic boxes (for intensity and transverse profile measurement) and first prototype test

… thanks for your attention !