Si detector for HIE-ISOLDE

Francesca Zocca

CERN - BE/BI/PM

Instituto de Estructura de la Materia – CSIC , Madrid

on behalf of BE/BI/PM section and ISOLDE collaboration

(E.Bravin, M.A.Fraser, M.Pasini, D.Voulot, F.Wenander)

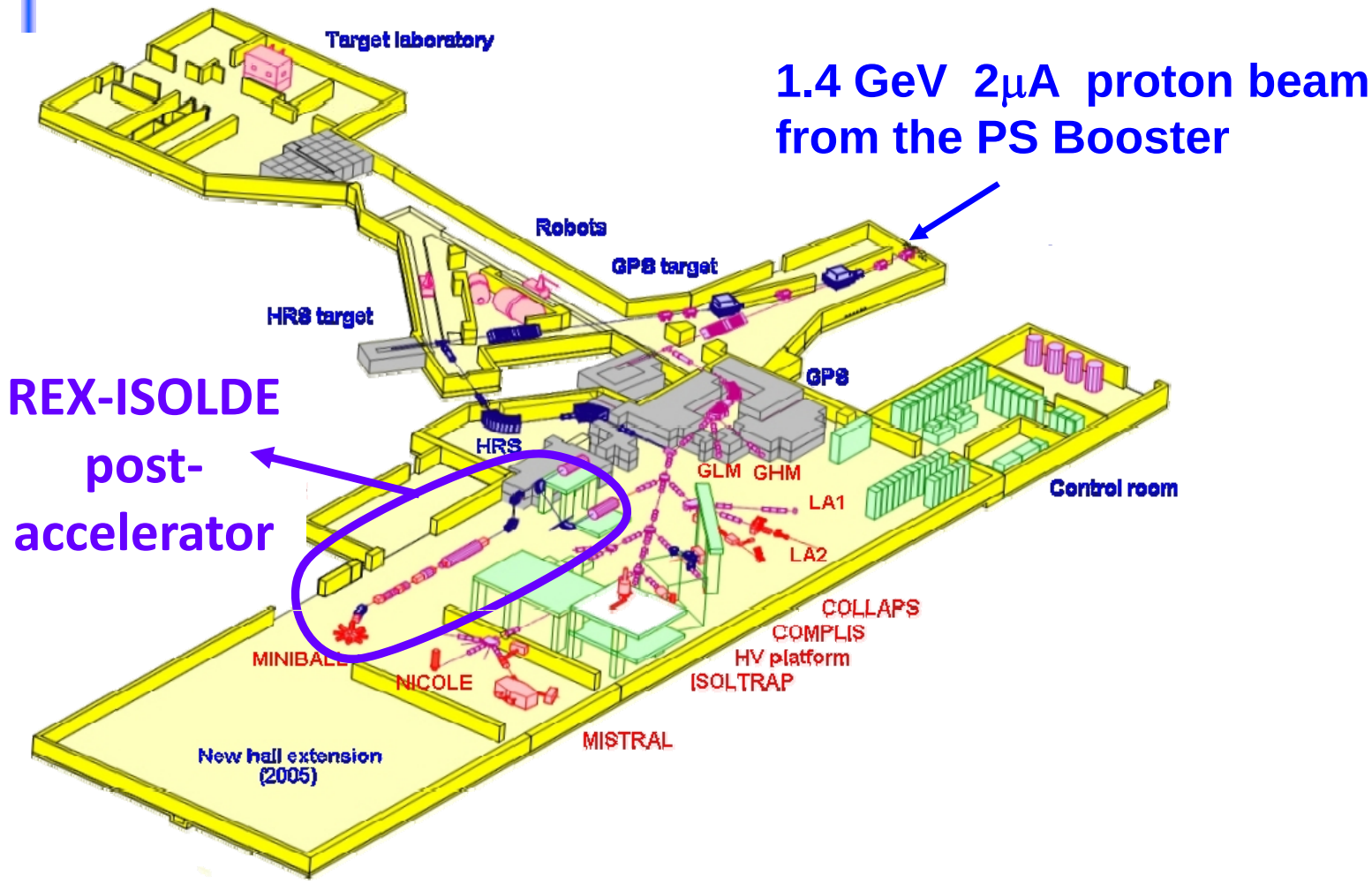
BI-day – Divonne, Nov. 24th 2011

Outline

- High-Intensity and Energy (HIE)-ISOLDE project
- HIE-ISOLDE linac, the superconducting upgrade of REX
- Silicon detector monitor for longitudinal profile measurements: structure and characterization
- Beam energy and time profile measurements
- Cavity phase tuning procedure by means of energy and time-of-flight measurements
- Conclusions and future developments

ISOLDE facility

Isotope **S**eparator **O**n-**L**ine **DE**vice

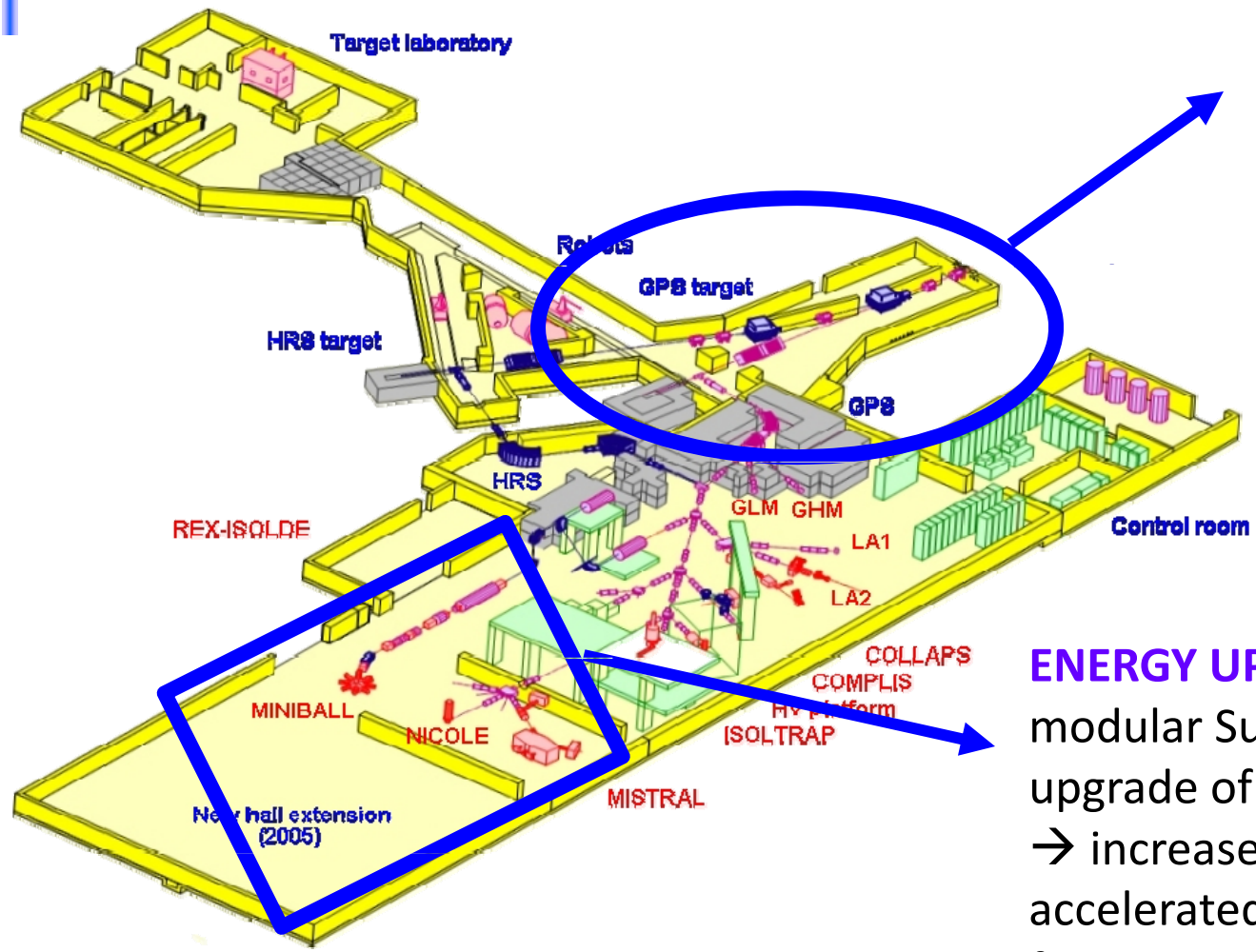


1.4 GeV 2μA proton beam from the PS Booster

REX-ISOLDE post-accelerator

HIE-ISOLDE project

High **I**ntensity and **E**nergy upgrade of the ISOLDE facility



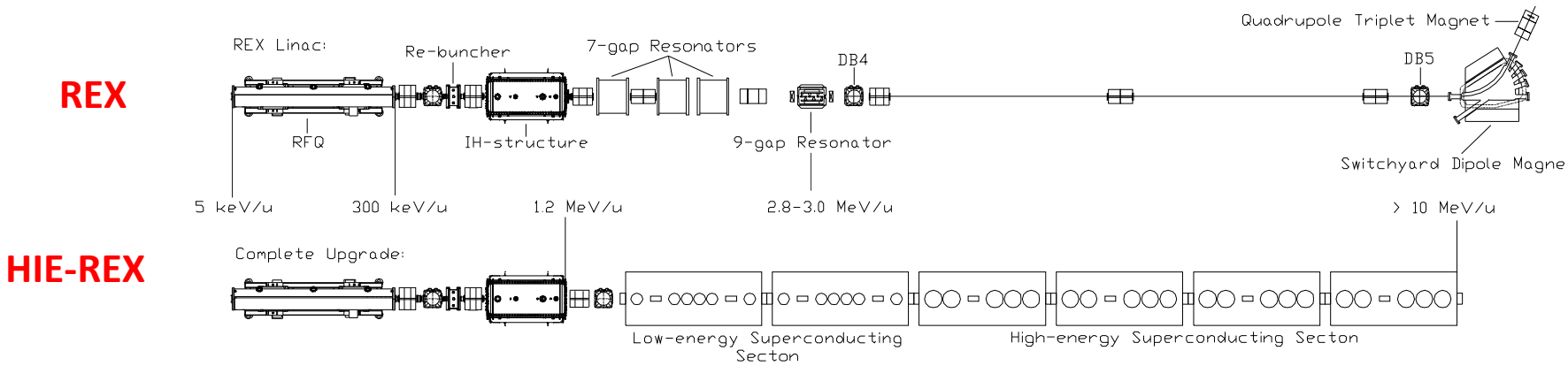
INTENSITY UPGRADE

Upgrade of the proton injectors chain (LINAC 4 + PS Booster) → increased beam power delivered on targets: from 2 kW to 10 kW

ENERGY UPGRADE

modular Super-Conducting (SC) upgrade of REX post-accelerator → increased energy of the post-accelerated radioactive beams: from 3MeV/u to 10 MeV/u

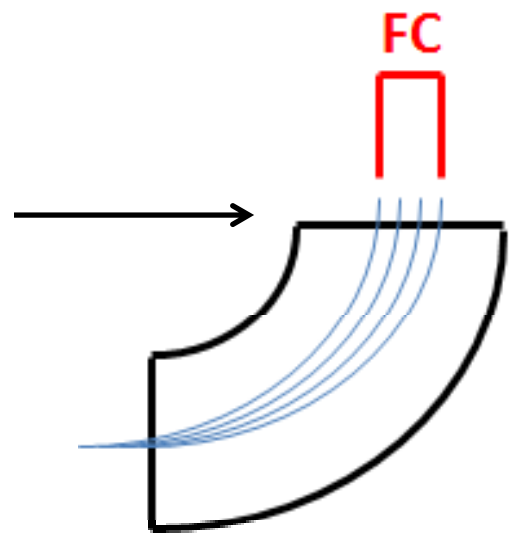
HIE-ISOLDE linac & cavity phase-up



6 cryomodules with 32 superconducting cavities

- Increase in the number of cavities:
  from 5 (REX) → to 34 (HIE-REX)
- REX phase-up procedure: relative measurement of the beam average energy vs. the RF phase downstream the cavity by means of the switchyard dipole magnet

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

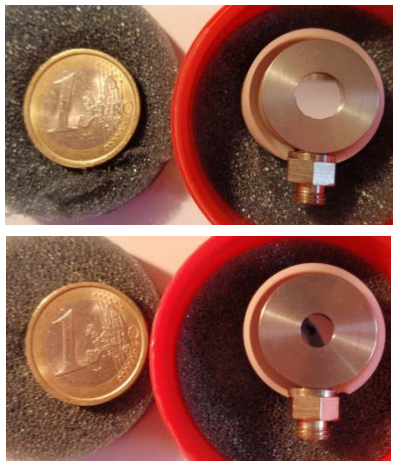


Need for a quick and eventually automated phase-up

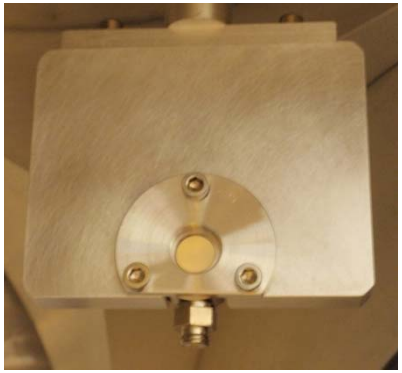
Silicon detector monitor

- Longitudinal profile monitor to be placed downstream the cryomodules aimed at the phase tuning of the superconducting cavities
- High sensitivity required by the low intensity beams at REX (100-500pA pilot beams)
- PIPS (Passivated Implanted Planar Silicon) detector, suited for charged particle spectroscopy → beam particles stopped → measure of energy and time of arrival

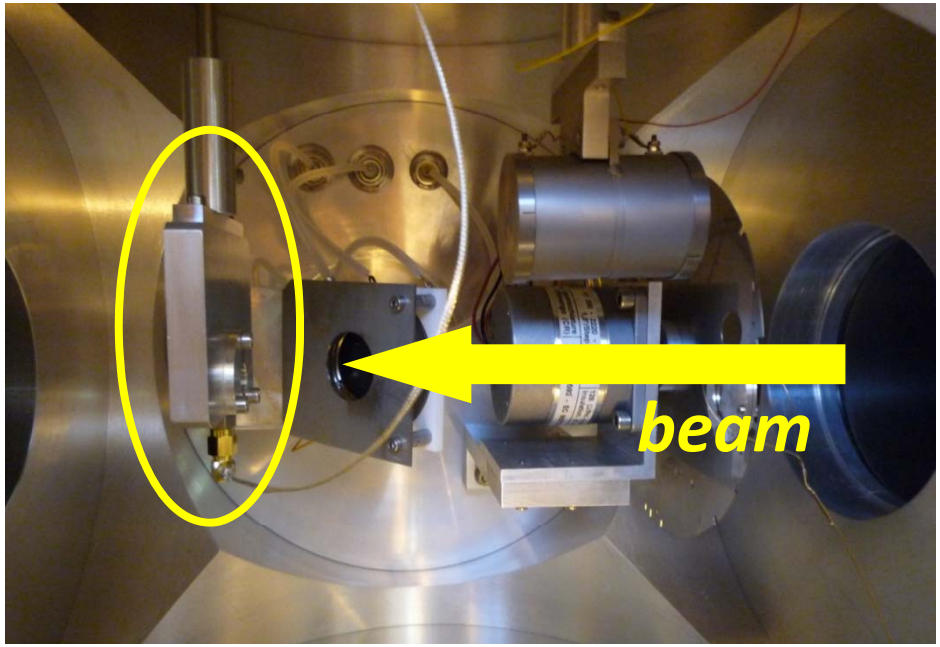
Canberra PIPS det



Mechanical support

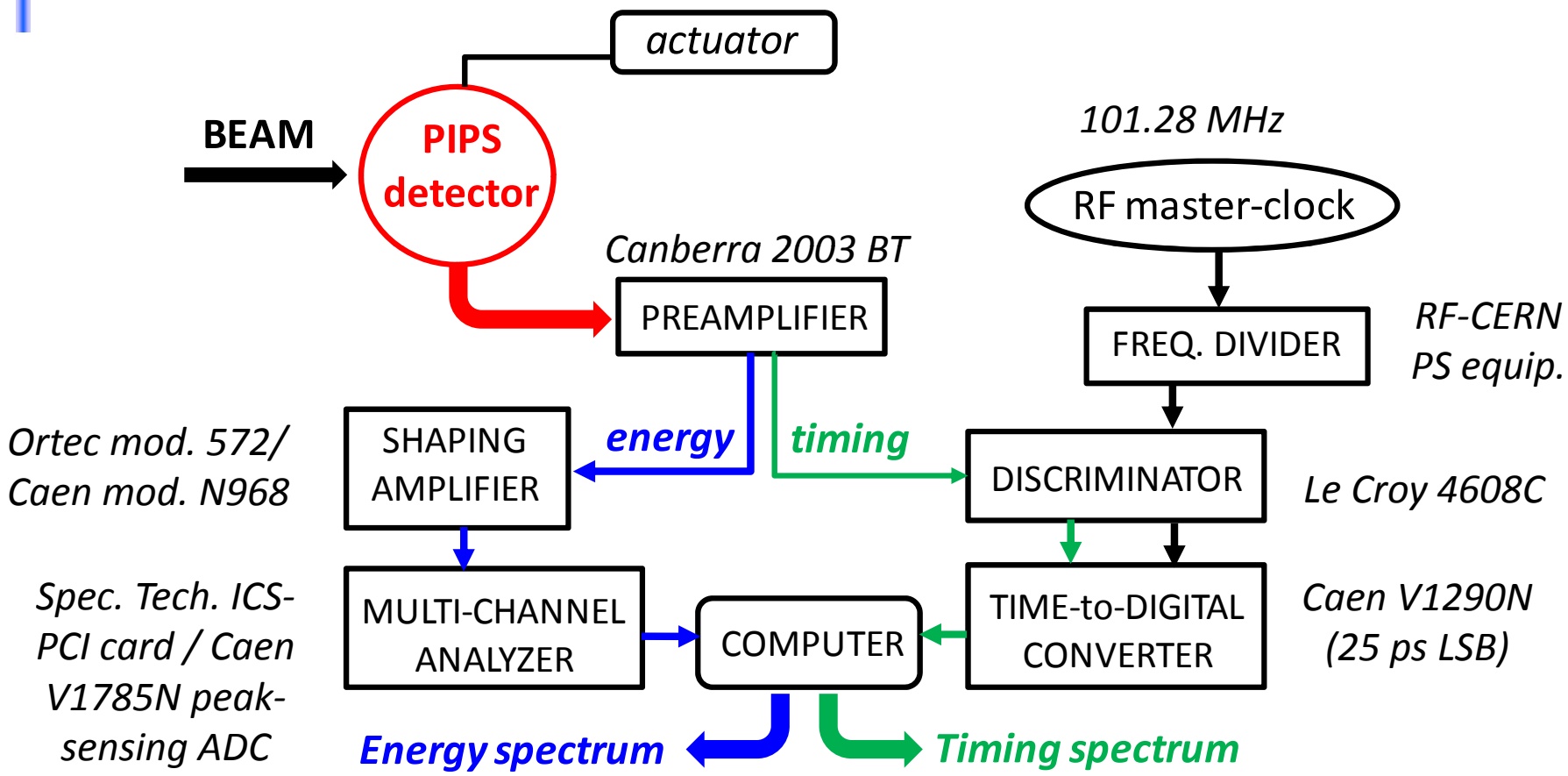


Test setup inside one REX diagnostic box

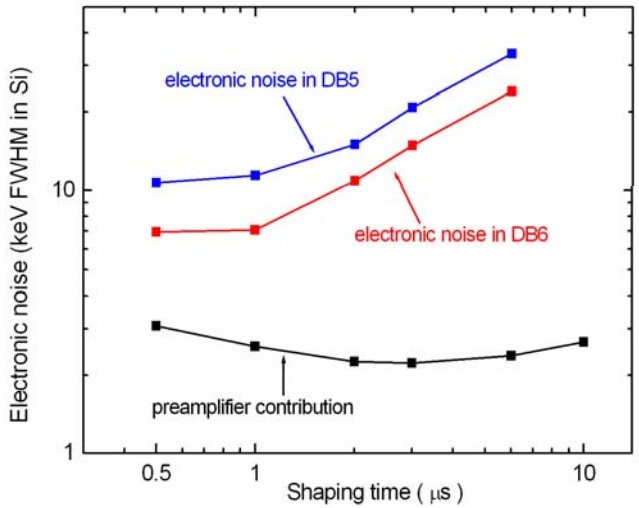


Area= 50mm^2 / 25 mm^2
Thickness = 300 μm / 500 μm
Bias voltage = +60 V / +100 V
Capacitance = 30 pF / 11 pF

Monitor structure and DAQ setup

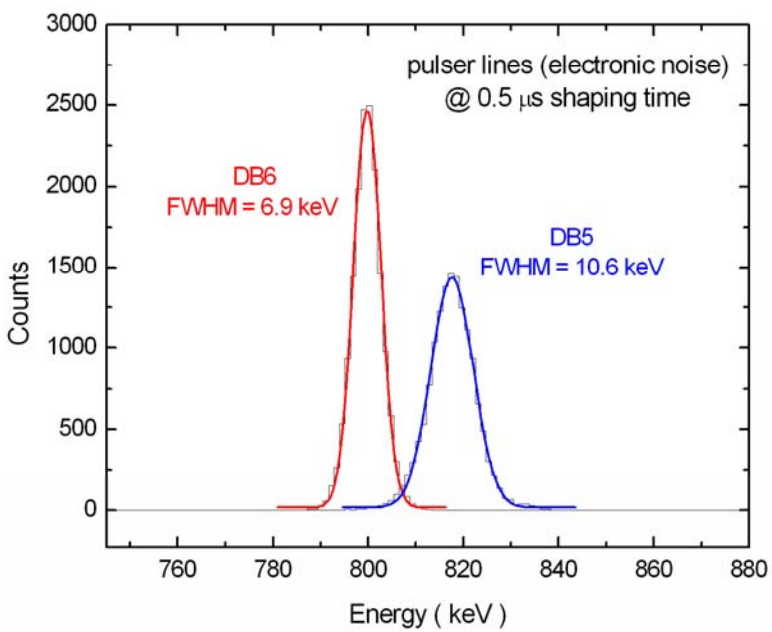


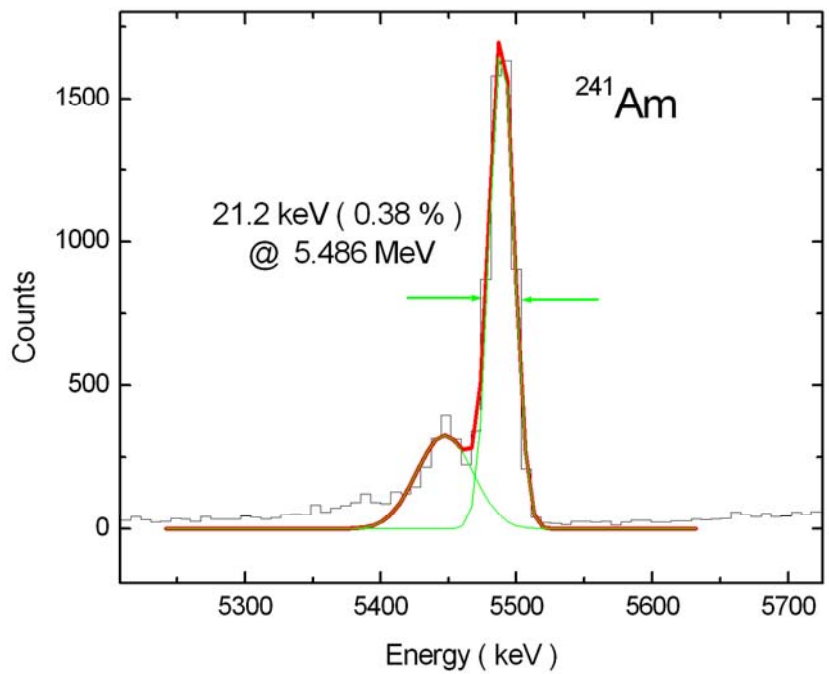
Electronic noise and alpha resolution



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

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





Test beam composition and intensity

- Test beam: buffer-gas beam diffusion from REXTRAP (typical pilot beam used to tune the linac)
- A/Q=4: $^{12}C^{3+}$, $^{16}O^{4+}$, $^{20}Ne^{5+}$ + some $^{36}Ar^{9+}$ …
- Repetition rate = 33 Hz and pulse length = 450 μs
  → machine duty cycle = 1.5%
- Single particle detection regime → a strong attenuation of the beam intensity is required (~ 10^6):

$$R_S = R_P \, T_P \, f_{REP}$$

R_S = average count rate on silicon
R_P = average count rate inside the pulse
T_P = pulse length
f_{REP} = repetition rate

($T_P f_{REP}$ = duty cycle)

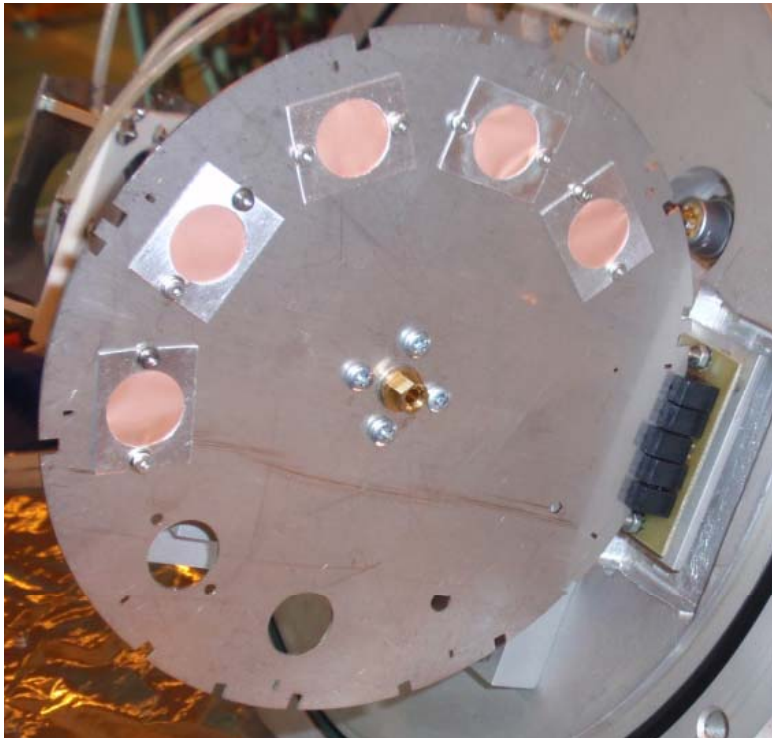
R_P must be kept < 10 kHz → R_S must be kept < 150 Hz
(→ average number of particle per pulse < 4.5)

Beam attenuation methods

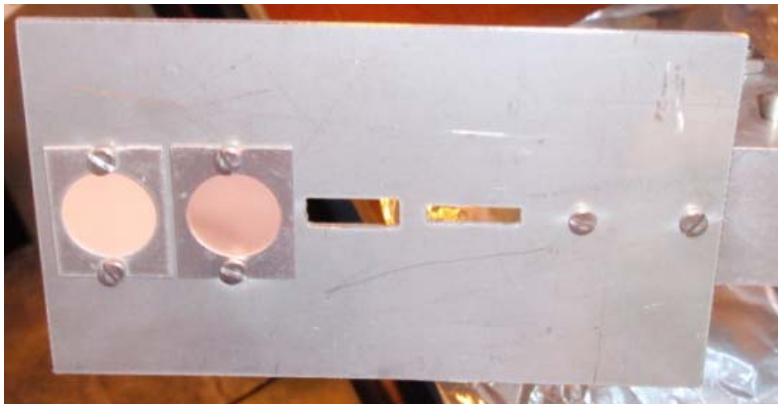
→ manipulation of REXEBIS parameters + collimators along the linac:

removing the time structure of the pulse extracted from the EBIS (Electron Beam Ion Source) resulted in a strongly reduced beam intensity

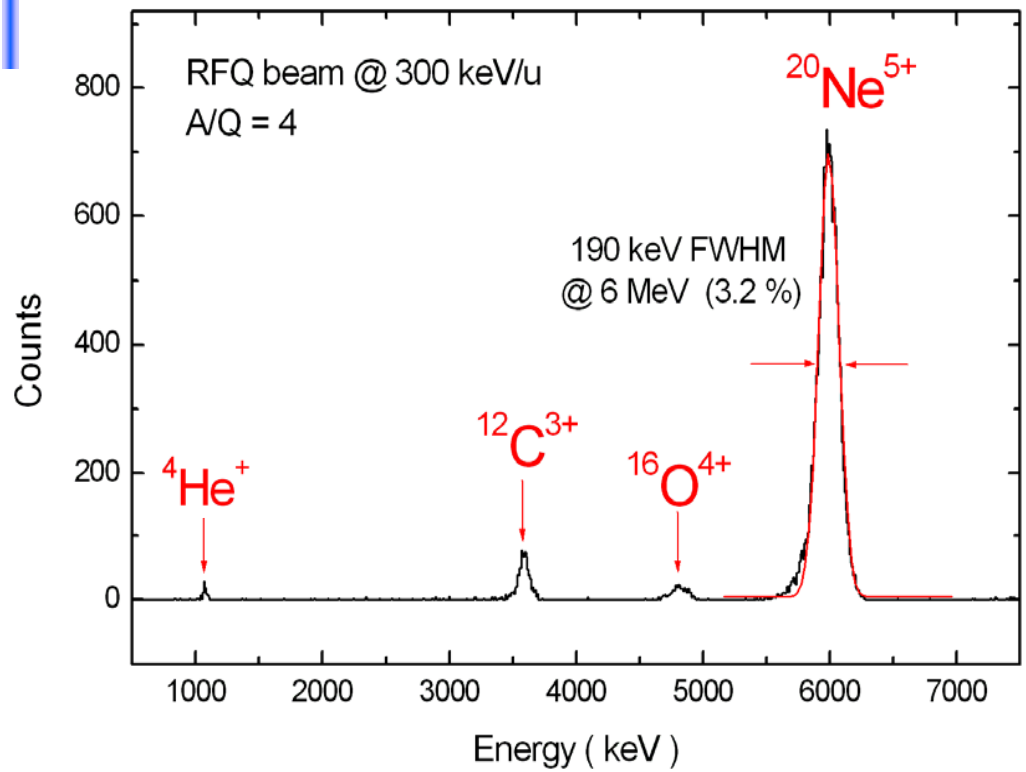
→ perforated copper foils placed upstream and downstream the RFQ:



- thickness=15 μm (particle energy 5keV-300keV)
- holes diameters = 50 μm and 35 μm
- holes spacing = 0.2-5 mm
- transmission factors per foil = 5% - 0.01%



Beam energy spectrum



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)

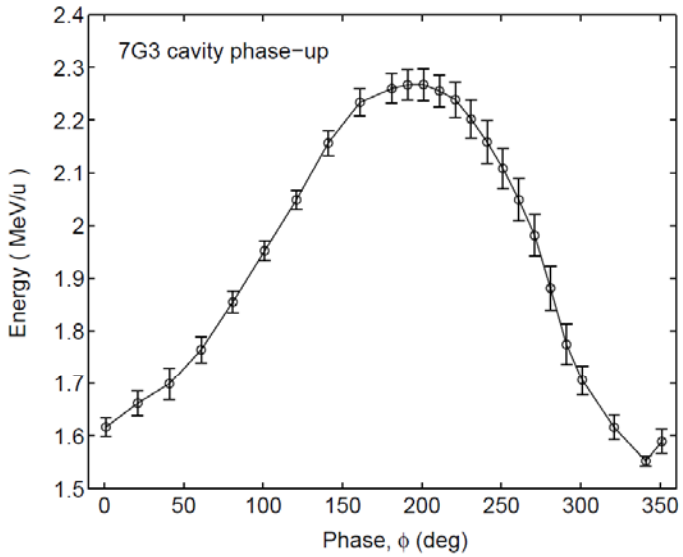
Helium, carbon, oxygen and **neon peaks** well identified

Measured **monitor energy resolution**:

in the range from **1.3 to 0.4 % rms** (3 to 1 % FWHM)

while varying REX beam energy from **300 keV/u to 3 MeV/u**

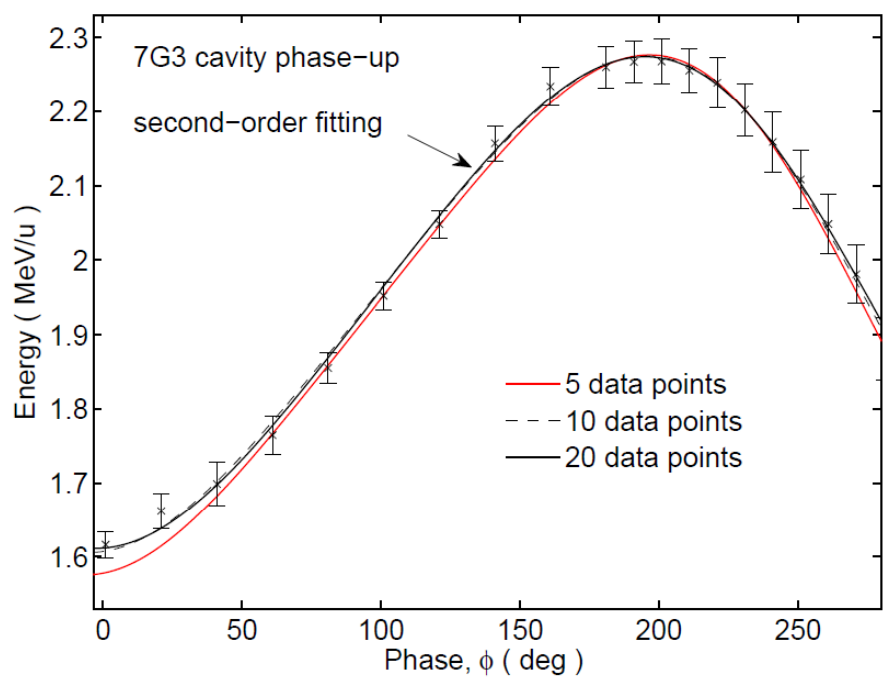
Cavity phase-up demonstration



Fast and accurate phase-up procedure of REX 7-gap resonator @ 1.95 MeV/u

Peak channel number of the energy signal quickly recorded as a function of the RF phase

$$\Delta W_0 = a(\beta)\cos\phi + b(\beta)\sin 2\phi + c(\beta)$$

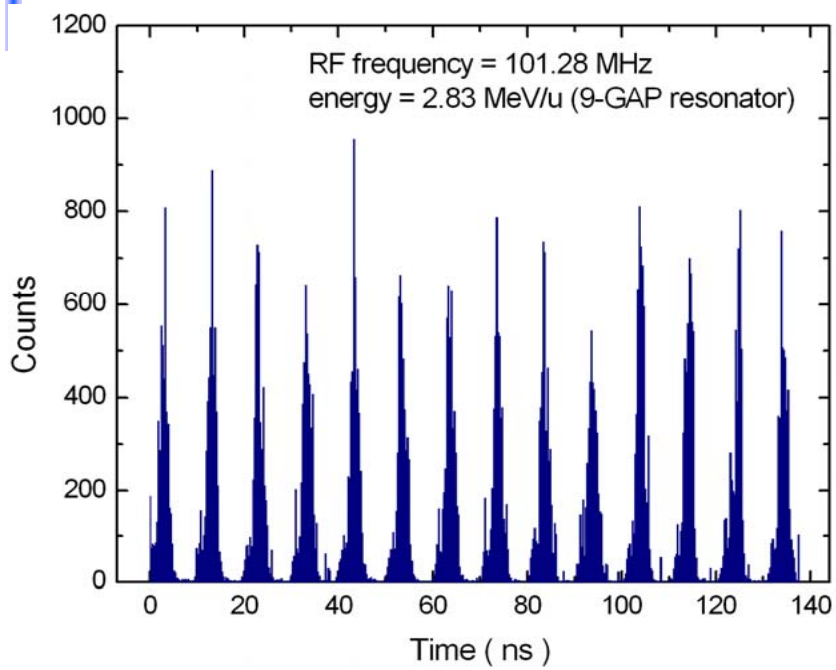


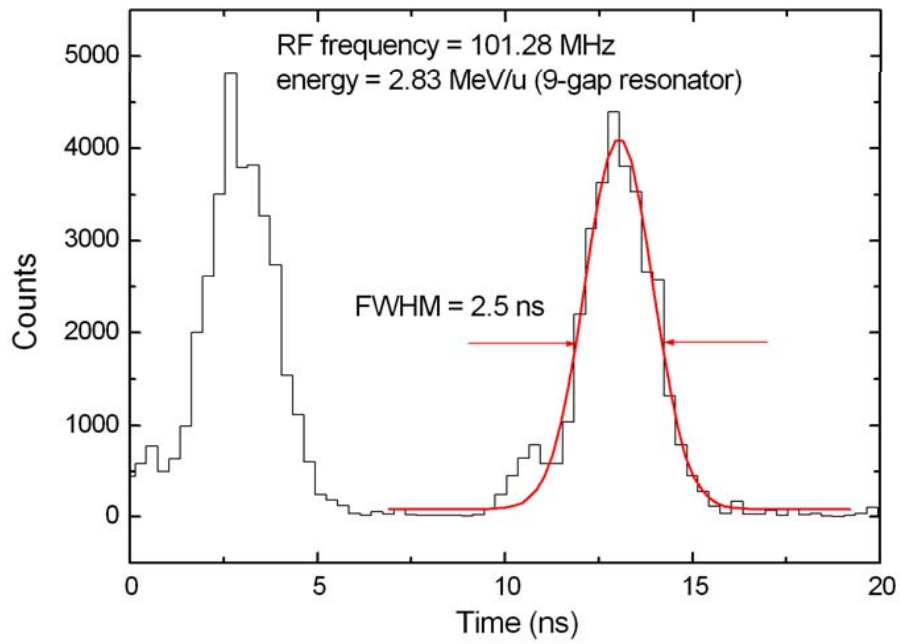
synchronous phase determined with the required accuracy of ± 2.5 degrees even with a minimized number of points in the phase-up curve

reasonable **measurement time** of a few minutes per cavity (@ 100Hz count rate)

Beam time profile

Estimated system timing resolution < 200 ps rms

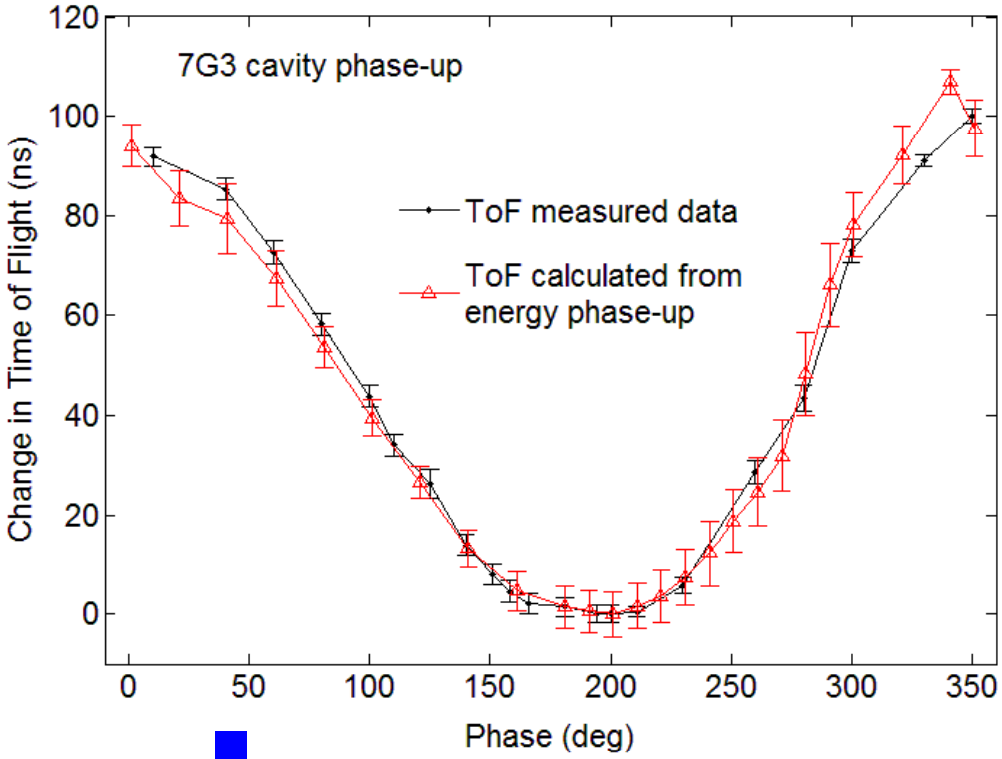




Acquired beam time structure with the **expected bunch period of 9.87 ns (RF=101.28MHz)** @ energy = 2.83 MeV (output energy of the 9-gap resonator)

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

Time-of-Flight cavity phase-up



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

Bunch spacing of 9.87 ns :

→ phase must be varied slowly to be able to identify the bunch

→ 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 & developments

- A prototype Si-detector monitor has been developed and tested for the HIE-ISOLDE superconducting upgrade of the REX-ISOLDE post-accelerator
- The monitor is intended for longitudinal profile measurements aimed at a quick and eventually automated phase-up procedure of the foreseen 32 superconducting cavities
- Beam energy spectrum and ion identification with resolutions of 1.4 % to 0.4 % rms in the energy range 0.3-3 MeV/u
- Beam time profile with resolution of < 200 ps rms
- Cavity phase-up demonstrated with both energy and ToF measurements
- **Future developments**: implementation of the final system in a diagnostic box downstream the HIE-ISOLDE linac, automated system control, optimization of the beam intensity attenuation factors to achieve the fastest possible phase-up procedure

Acknowledgements

MANY THANKS to:

M. Duraffourg	BE/BI/PM
G.J. Focker	BE/BI/PM
W. Andreazza	BE/BI/ML
J. Broere	BE/RF
E. Piselli	BE/OP
M. Lozano	BE/OP