LNL accelerator facilities

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on the behalf of INFN-LNL

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Accelerators

AMICI — ACCELERATOR AND MAGNET INFRASTRUCTURE FOR COOPERATION AND INNOVATION

iFAST

European Commission

The LNL accelerators for users supply **light and heavy stable ions in the order of 10 MeV/u**.

for users

- Electrostatic type accelerators
- RF (superconductive) type linac accelerators

under development

- High intensity linac (RFQ IFMIF, DTL ESS, Anthem)
- Irradiation lines for material tests for industries and users.
- Cyclotron and new normal conductive RFQ
- SPES: Radioactive Ion Beams

- Nuclear Physics experiments
- Applied Physics: neutron experiments, medical and industrial applications, accelerator developments

Light ions facilities

Electrostatic type

CN

Accelerator Configuration&	Beam	E [MeV]#	E/A [MeV/A]	I_{target} (nA)@$	Time structure
CN	$^{1}H^{+}$	6,0	6,0	up to 4000	continuous or pulsed*
	$^{2}H^{+}$	6,0	3,0	up to 1000**	continuous
	$^{3}He^{+}$	6,0	2,0	up to 30	continuous
	$^{4}He^{+}$	6,0	1,5	up to 1000	continuous or pulsed*
	$^{4}He^{++}$	12,0	3,0	up to 10	continuous

Van der Graaf accelerator type. Light ions up to 6 MV terminal voltage.

- Used for applied physics and nuclear physics experiment
- Neutron irradiation experiments.
- Pulsing system at 3 MHz is available

Neutron flux irradiation

- MUNES line
  - The line is equipped with a graphite heavy water **thermal neutron** moderator that generates **a neutron flux of 4.5 × 10^{5} n/(s·cm2), 96% fraction** [0,1]
  - Test of the composite target material: blistering, resistance to power deposition (up to **3 kW/cm^{2}**, beam spot 1 mm radius)
- 0 Line: can be equipped with Li target or Be target.
  - In the latter case, we can reach a neutron flux (5 MeV protons, 3 uA) of 4.5 × 10^{9} s peaked at 1.2 MeV, with maximum 3.2 MeV.
  - Can be equipped with different moderators.

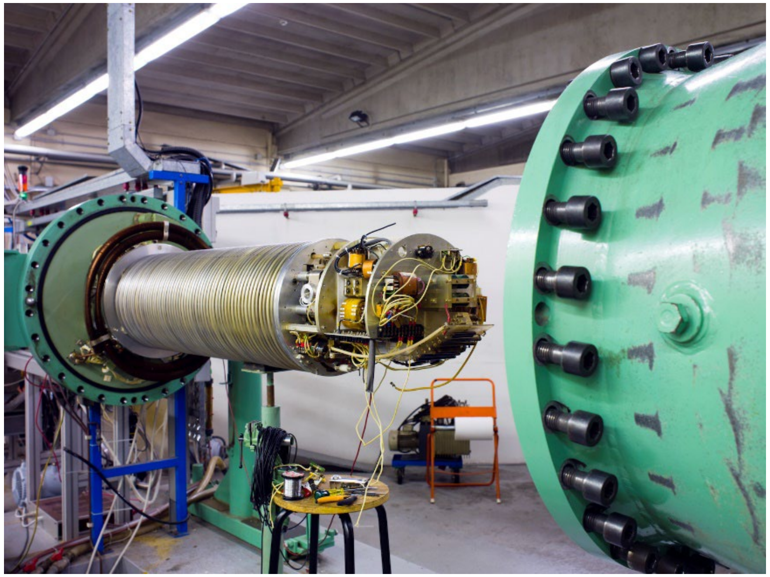
Test of neutron converter for accelerators, materials

Courtesy of Anna Selva. anna.selva@lnl.infn.it

[0] Selva et al, 2022, “Microdosimetry of an accelerator based thermal neutron field for Boron Neutron Capture Therapy” Appl. Radiat. Isot. 182, 110144”

[1] Agosteo et al, 2011, “Characterization of the energy distribution of neutrons generated by 5 MeV protons on a thick beryllium target at different emission angles.”, Appl. Radiat. Isot. 69, 1664”

AN2000



Van der Graaf accelerator type. Light ions with 2 MV terminal voltage

Accelerator Configuration	Beam	E [MeV][£]	E/A [MeV/A]	I_{target} (nA)[§]	Time structure
AN2000	$^{1}H^{+}$	2,0	2,0	up to 1000	continuous
	$^{3}He^{+}$	2,0	0,7	up to 30	continuous
	$^{4}He^{+}$	2,0	0,5	up to 1000	continuous

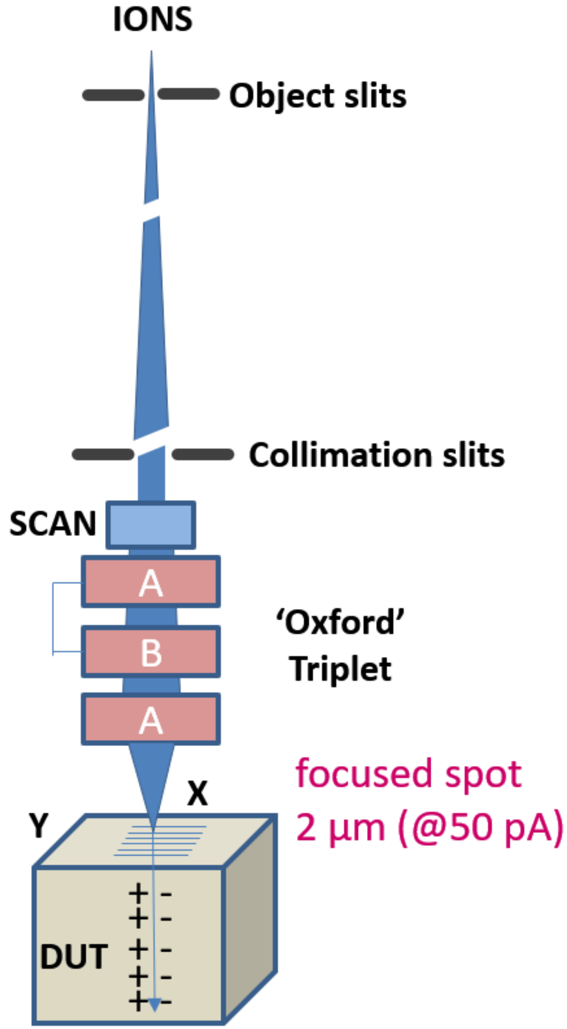
- Used for applied physics and nuclear physics experiment
- Microbeam experiments

AN2000 - microbeam

Ultra low intensity (100-1000 p/s) ion beams rastered on the DUT

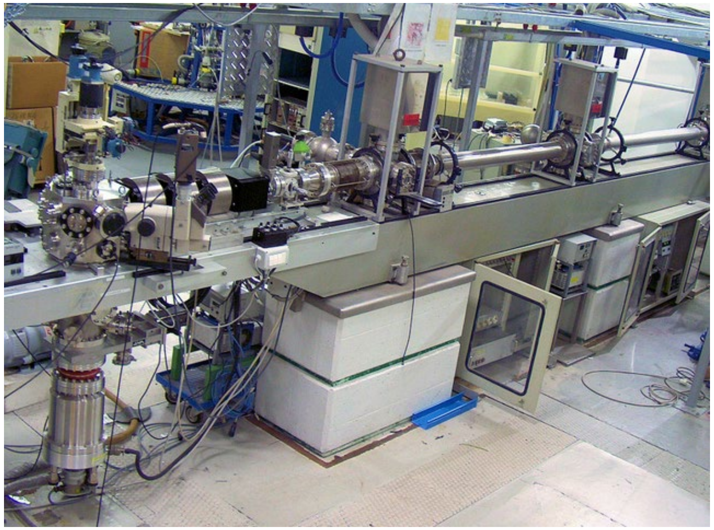
APPLICATIONS

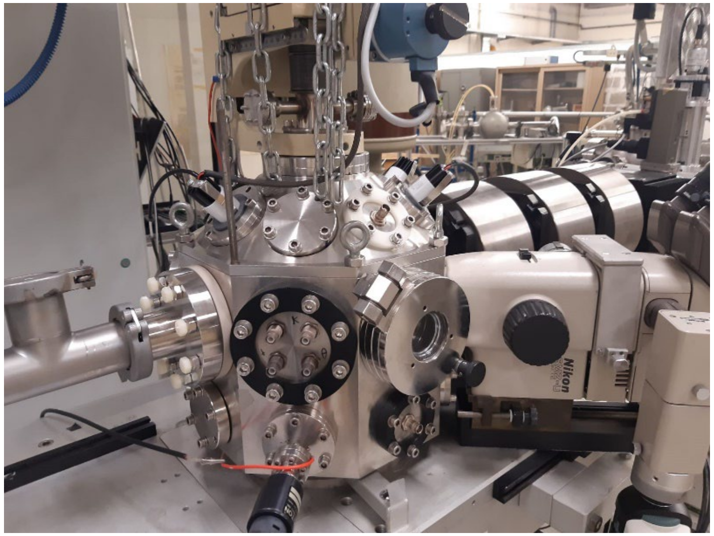
- 2D detectors efficiency maps
- localised irradiations



- Iron yoke cut from single piece, accuracy <2µm
- Accurate hyperbolic pole tips
- Undetectable 6-pole field contamination

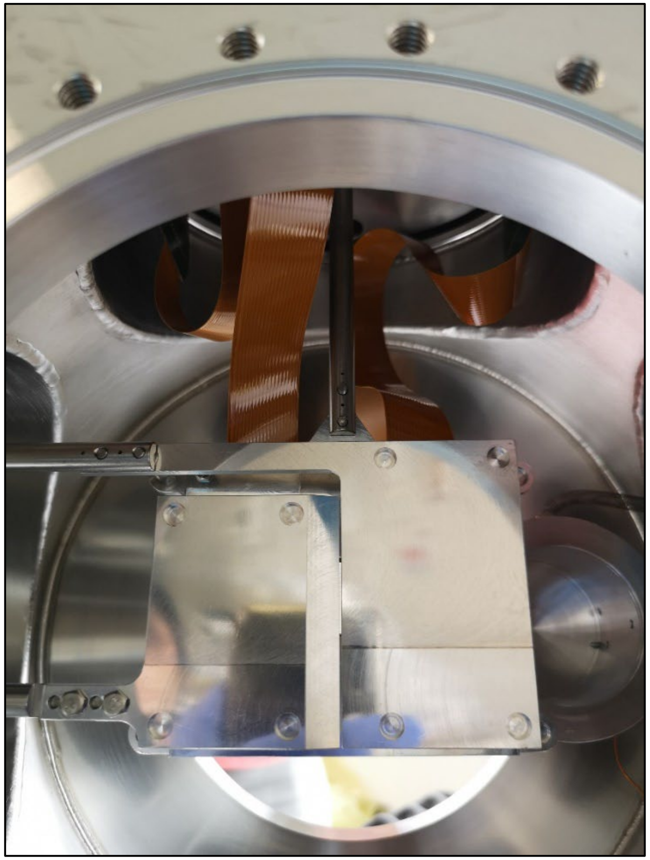
Nucl. Instrum. Meth. B54 (1991) 52-63

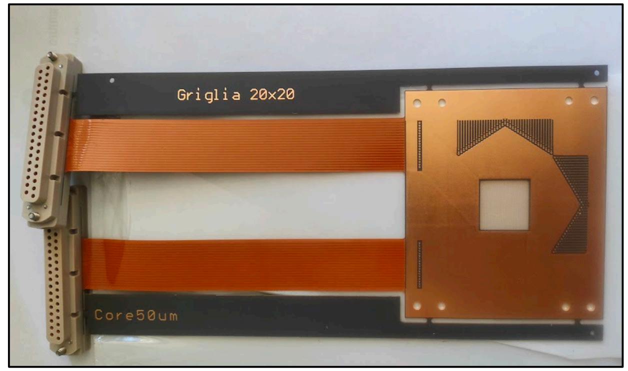




Courtesy of Valentino Rigato and Matteo Campostrini – valentino.rigato@lnl.infn.it

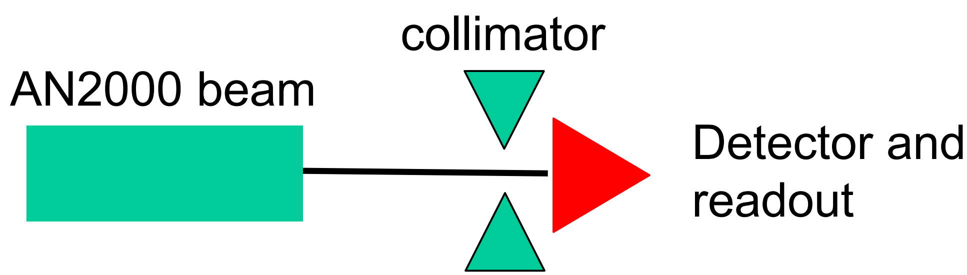
Accelerator components tests AN2000





Courtesy of Pierfrancesco Mastinu

- Beam based alignment of the new SPES diagnostics
- Relation between the centre of the wire and the actual position of the beam

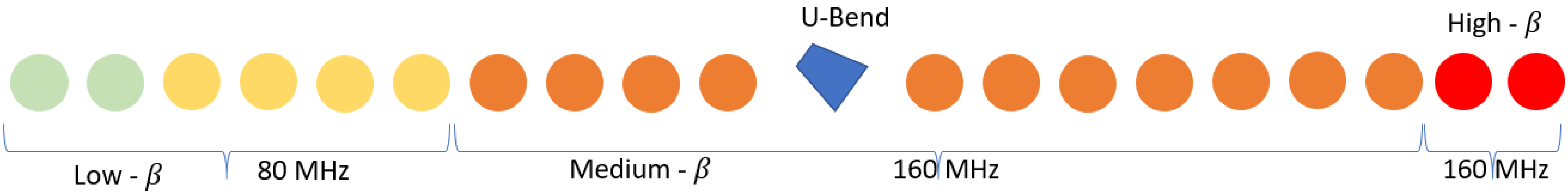


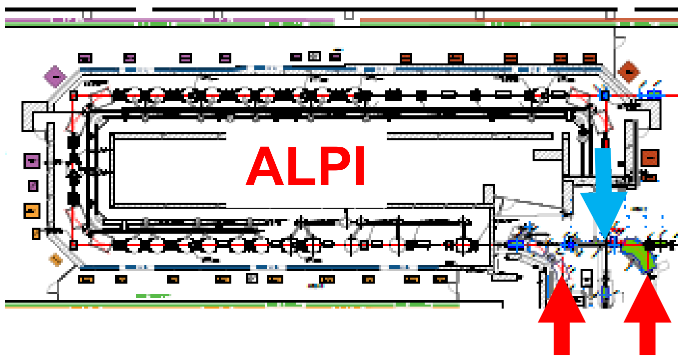
Heavy ion facility

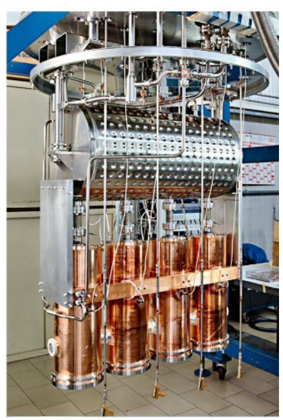
RF type*

*Tandem type accelerator also

Tandem-ALPI-PIAVE facility

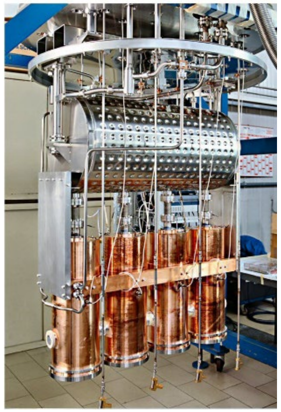




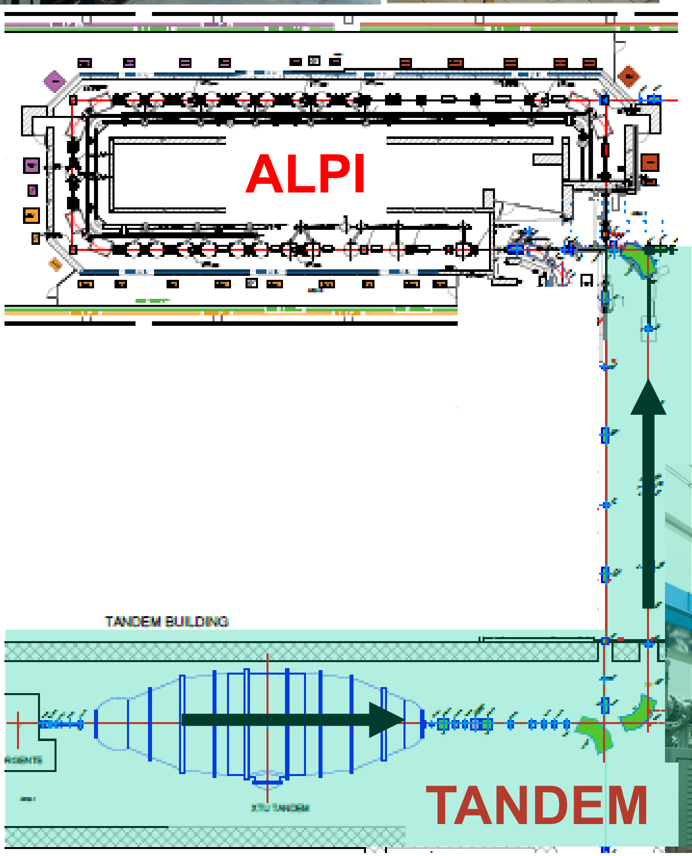


- CW Folded independent cavity linac
- Design and built 80’-90’
- One of the first prototypes in Europe.
- 82 QW cavities at 4 K
  - 80 MHz low beta (0.047, 0.055)
  - 160 MHz medium beta (0.11)
  - 160 MHz high beta (0.13)
- Output energy ions of about 10 MeV/amu

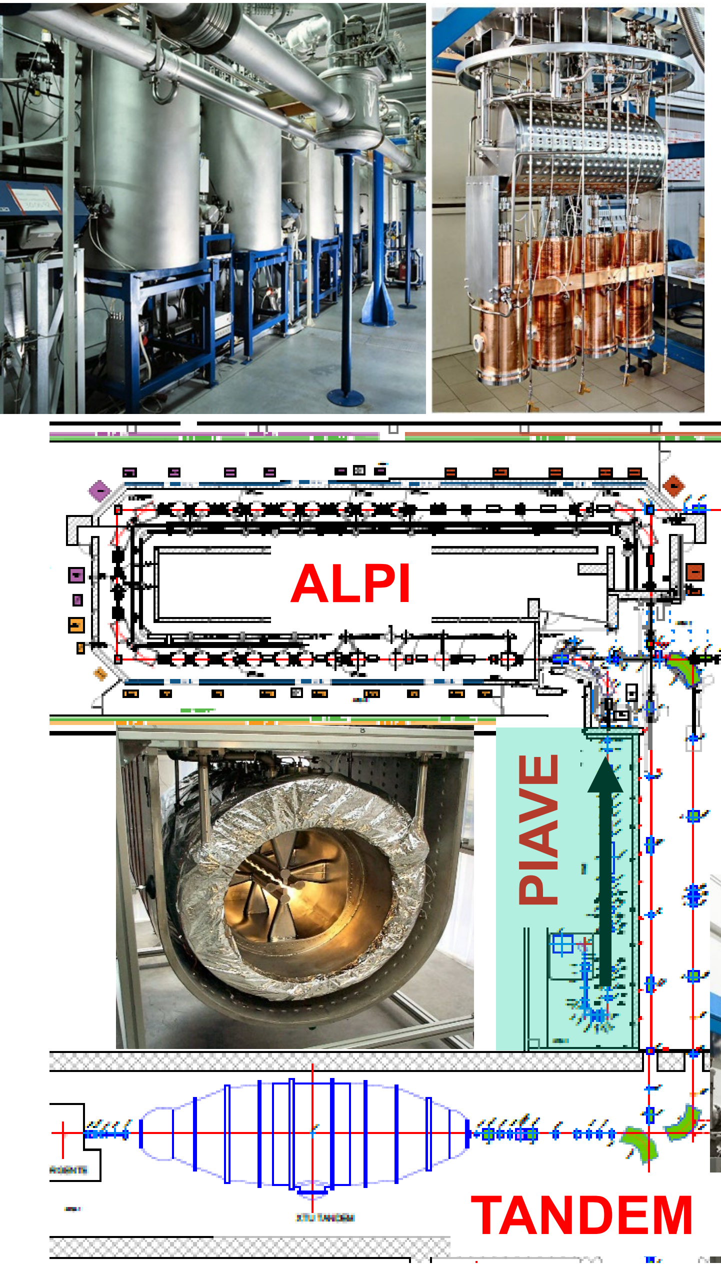
Tandem-ALPI-PIAVE facility



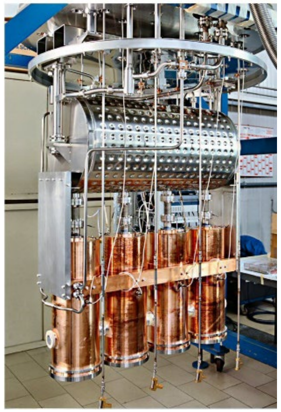
- Tandem XTU accelerator
- 14 MV terminal voltage
- Negative ion source
- Up to light-medium A (around 50) for ALPI injection
- Highest energies output for light ions, 22 MeV/u



Tandem-ALPI-PIAVE facility

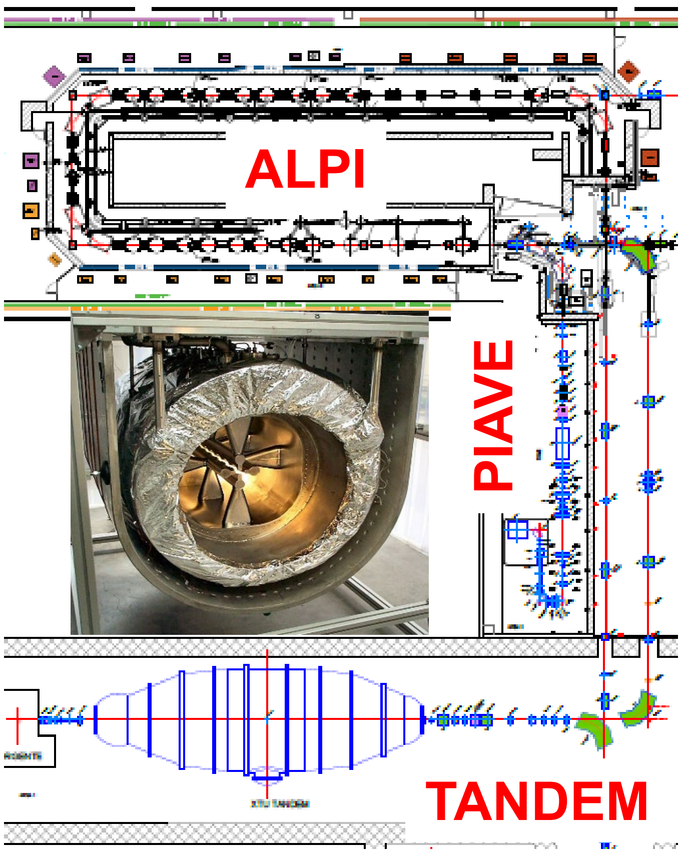


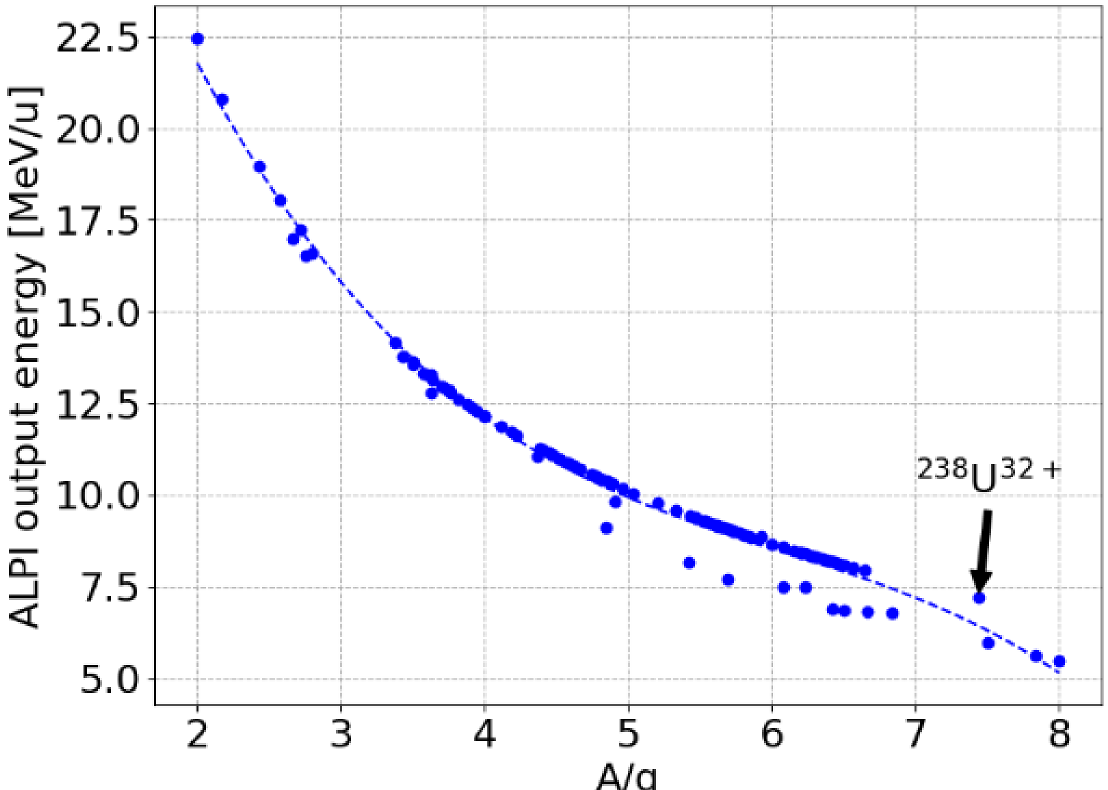
- PIAVE superconductive RFQ
- Medium –heavy mass, $50 < A < 208$
- External buncher three harmonics , two RFQ cavities (80 MHz) with $\lambda\beta/4$ inter-tank distance
- ECR nanogan ion source



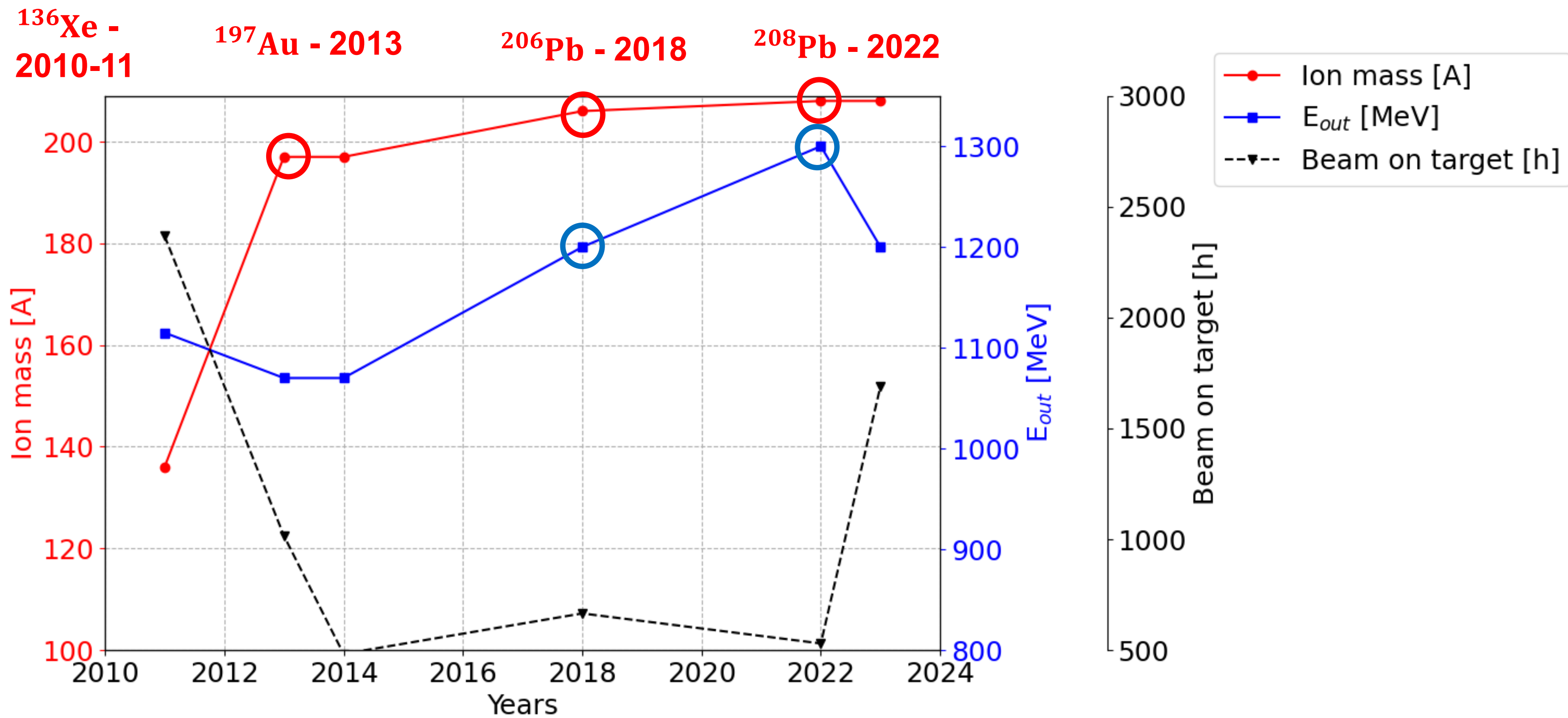
Tandem-ALPI-PIAVE facility

- Up to hundreds nA, max A/q = 8 (NO SC issue whatsoever, problem on the applied fields)
- From C to Pb (to U) and stable isotopes.



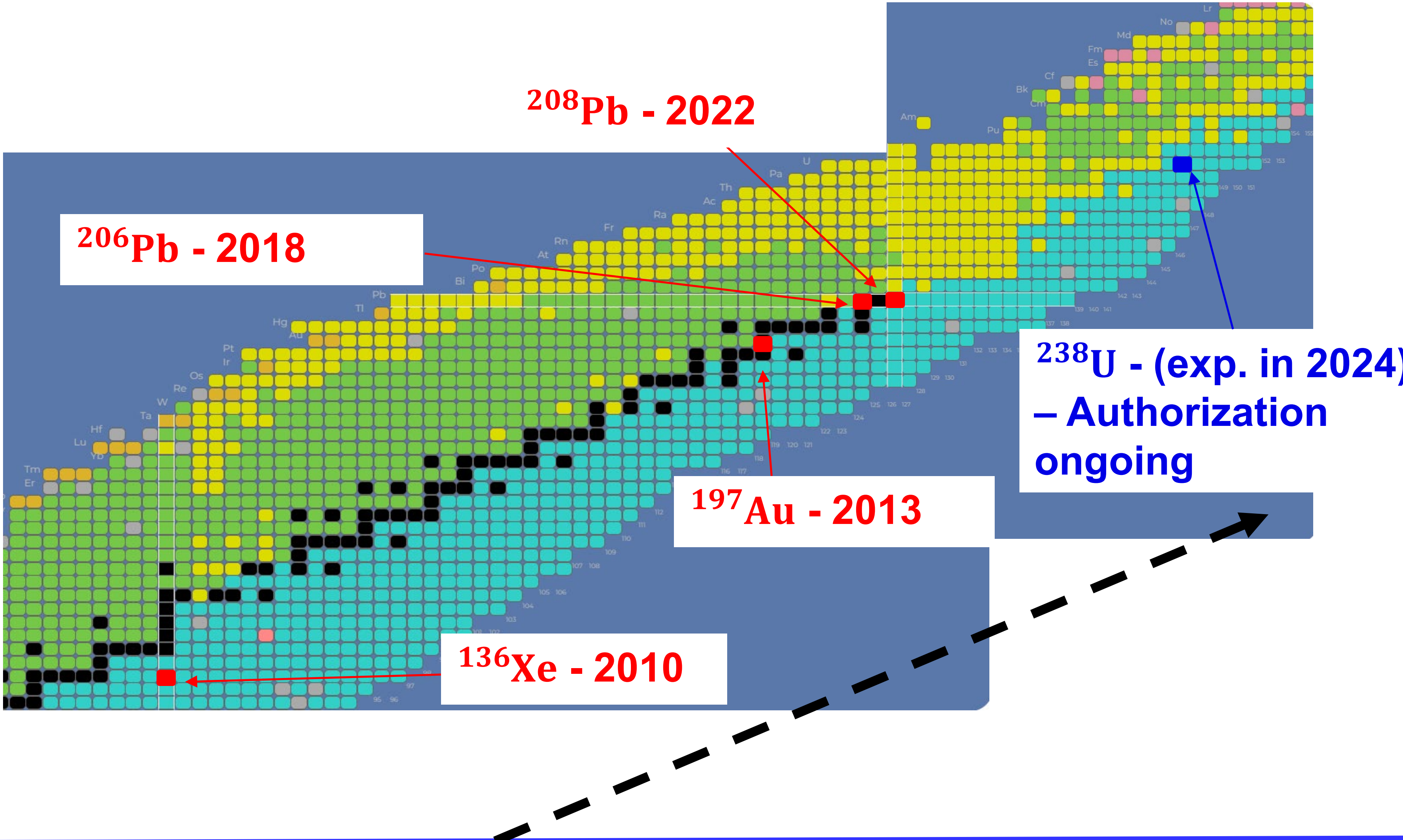


A decades of upgrades to accelerate heavy ions at higher energies



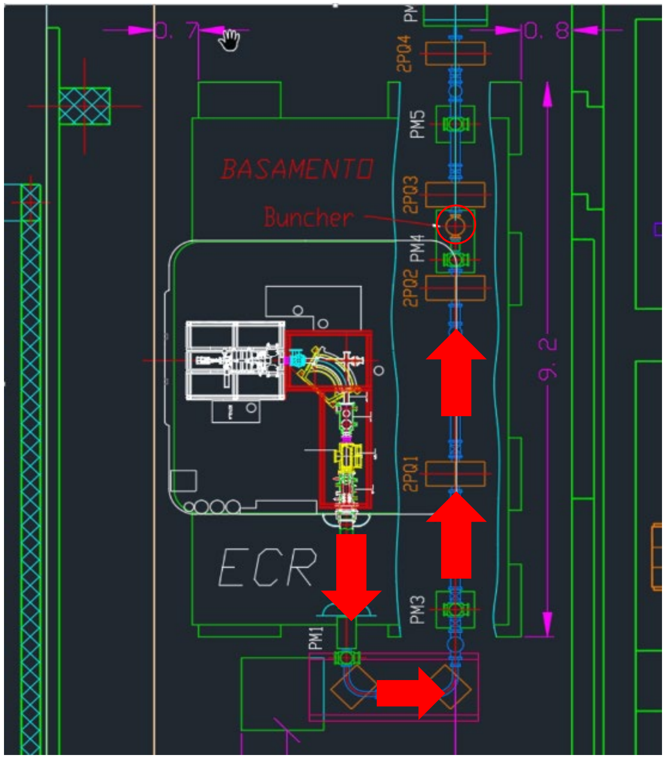
- ALPI beams, from TANDEM and PIAVE
- Drop in energy output in 2023 is due to no experiments requested at 1300 MeV.
- ^{238}U under authorization procedure.

Towards heavy ions



Accelerator components tests TAP - 2

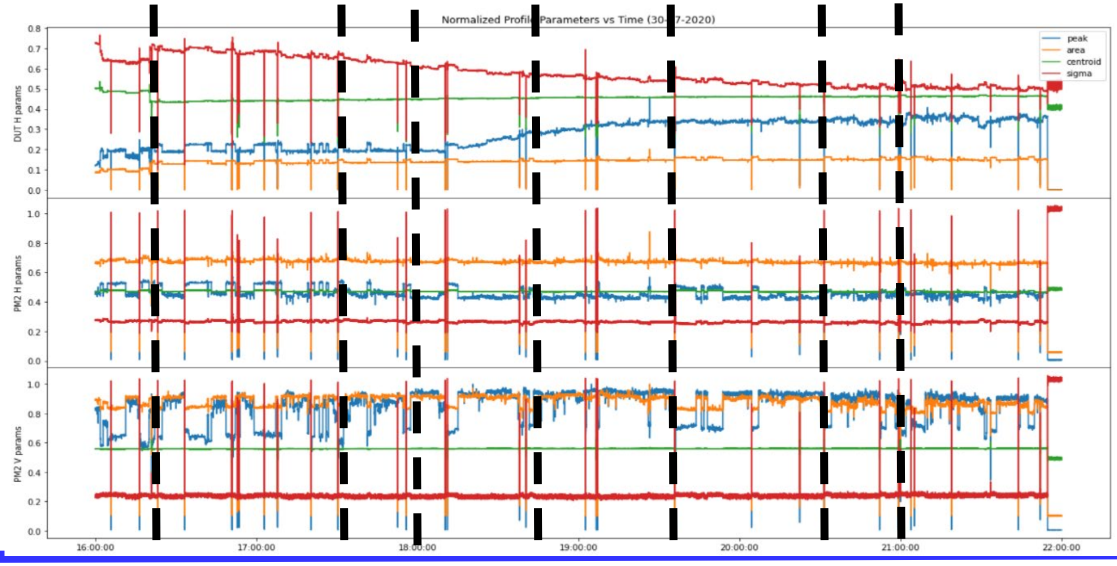
- Test on PIAVE LEBT of new beam profiler



Test of RIB profiler signal and RIB robustness

- $^{136}Xe^{18+}$ @ 2.23 MeV, I = 1.3 uA, 3 W
- Possible to ramp up to 8 MeV, 2 uA, 16 W.

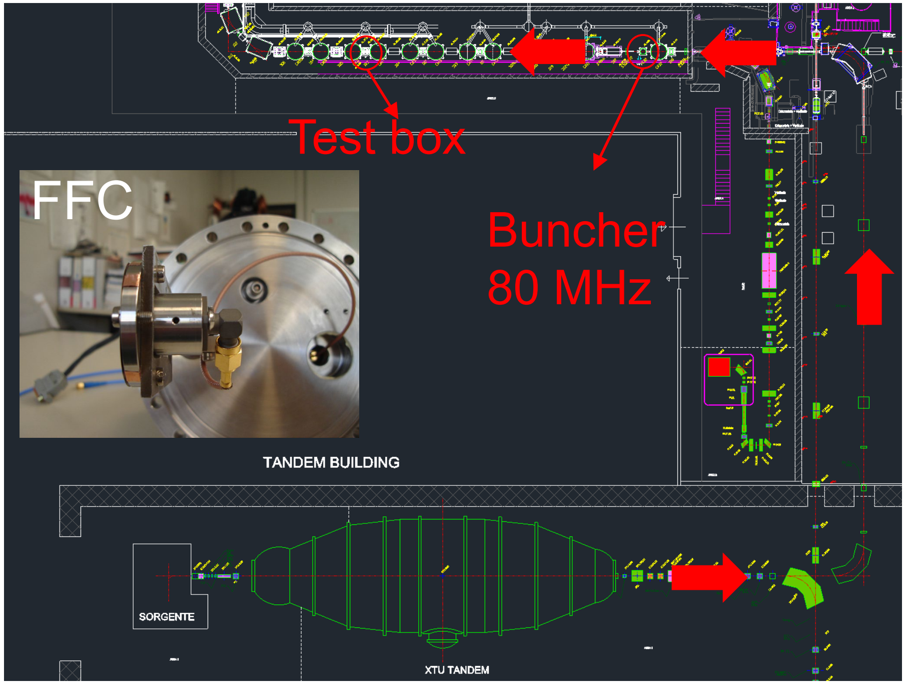
0.98-1.1 mW (interceped power on the central wire)



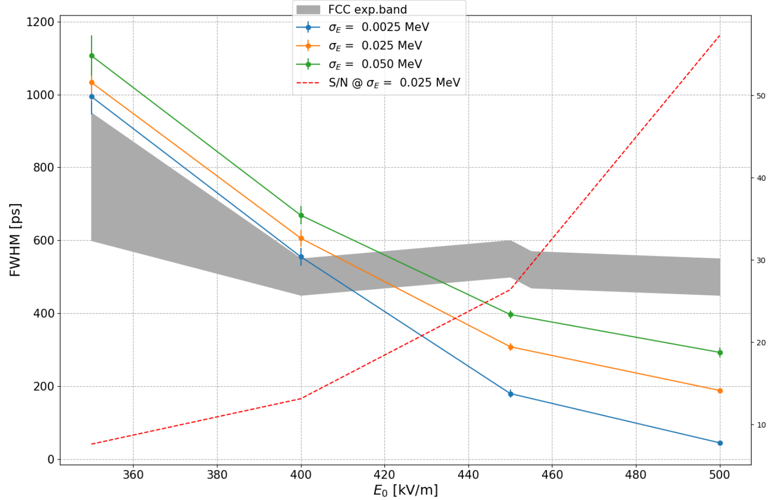
Installed new diagnostic box for testing accelerator components:

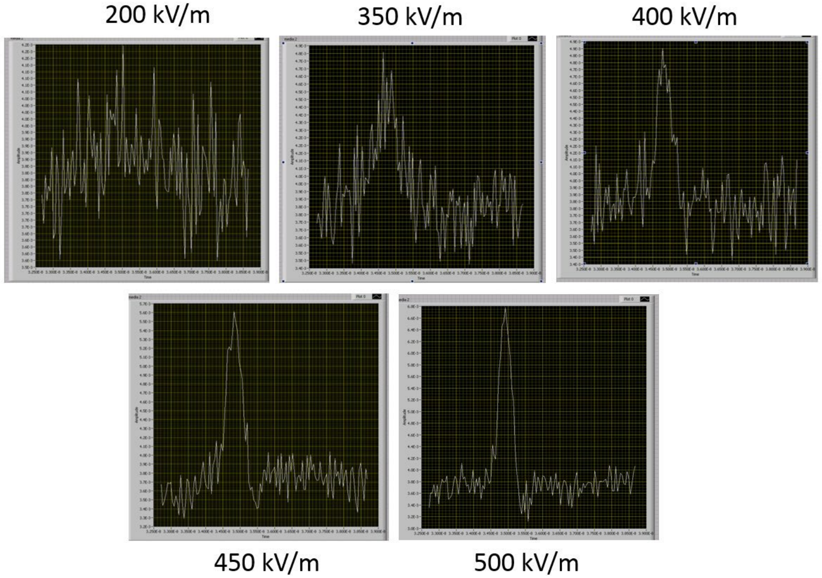
Accelerator components tests TAP - 3

- Test on ALPI of FFC for longitudinal beam measurements



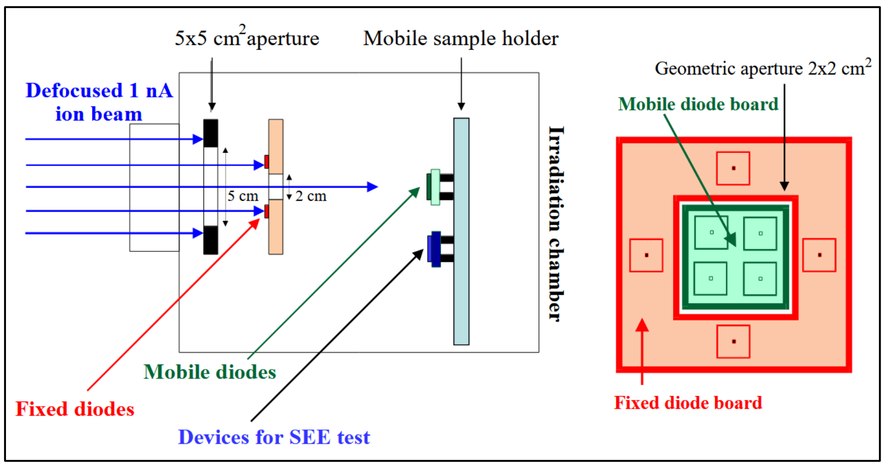
- The beam was $^{18}O^{6+}$ at 100.26 MeV, 100 nA from TANDEM.
- The 80 MHz **buncher** AL.HEB.01 was used in order to focus the beam longitudinally at test BOX diagnostics (which contains the FFC)

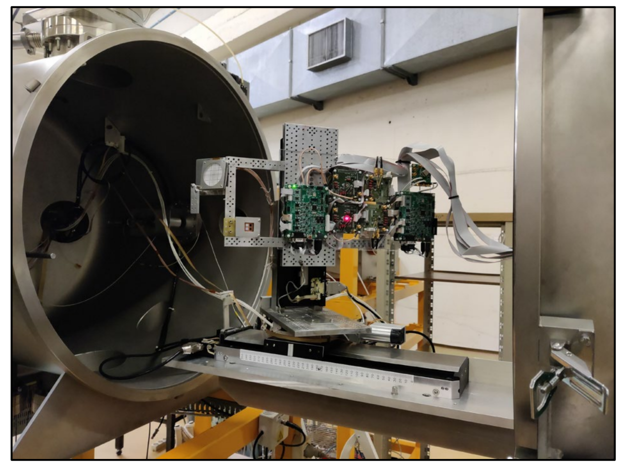




Irradiation for industries

- First irradiation service for private company successfully tested before summer 2023.
- A ^{136}**Xe** beam was accelerated with PIAVE-ALPI complex up to **1 GeV** energy and sent to SIRAD irradiation chamber.
- Flux dosimeter and uniformity calibration was performed by 2 boards hosting 4 silicon diodes each.



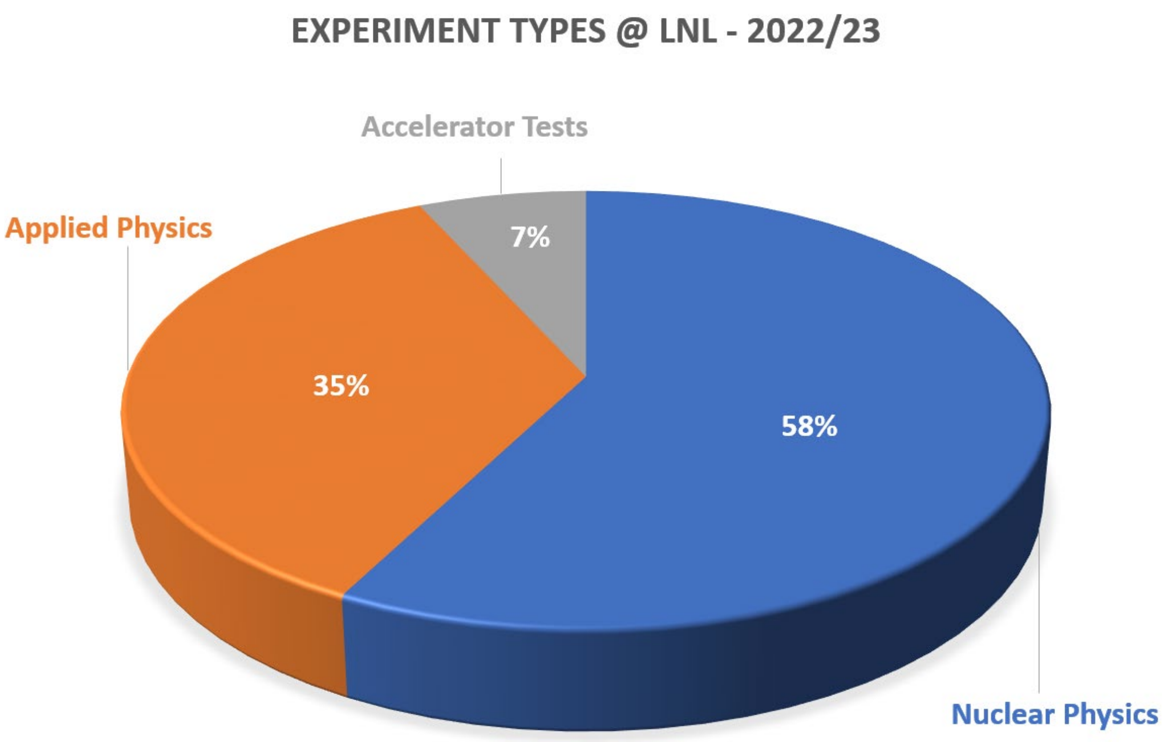


- Average beam flux was about 2 x 10^3 ions/cm^2/sec and total accumulated flux was 1 x 10^7 ions/cm^2 in 8.3 min exposure.
- LET = 89.5 MeV cm^2/mg

Courtesy of Jeff Wyss, wyss@unicas.it

General overview

Experiments - overview



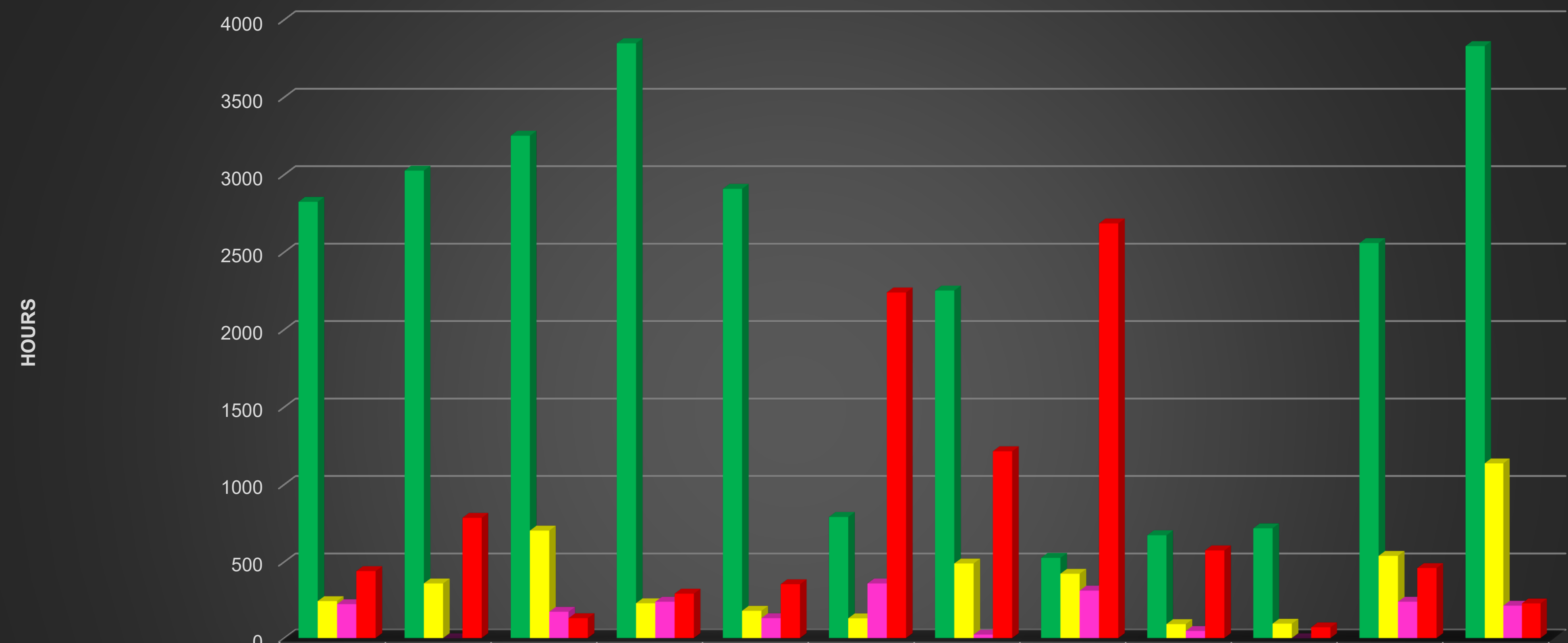
Applied physics:

- Surface studies (sputtering characteristics)
- Irradiation for material/components testing
- Medical physics
- Radiological studies

Accelerator tests:

- Accelerator improvement studies
- Experimental run feasibility studies
- Diagnostics and accelerators components tests
- High level application tests.

Accelerators overview

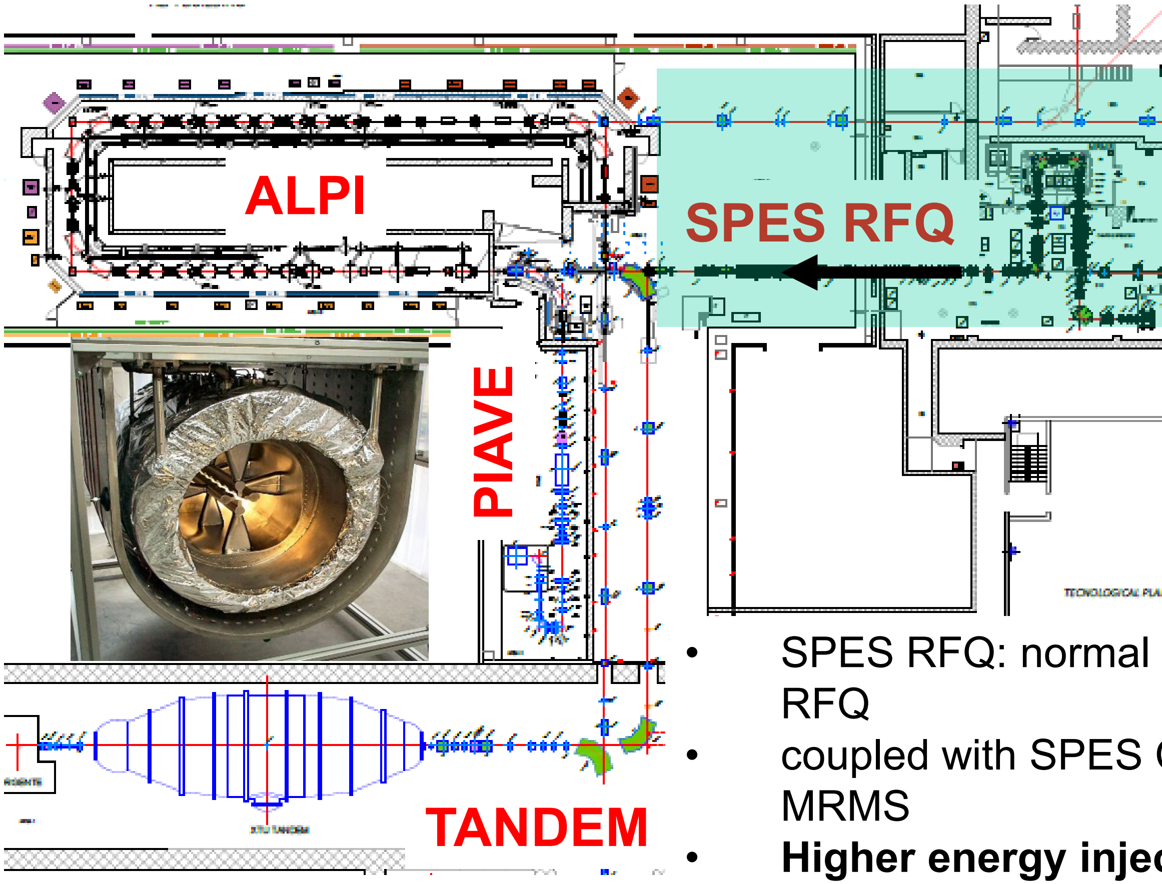


	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023(dec)
Beam on Target	2826,5	3027,5	3253	3849,5	2910	792	2253,5	528	674	719	2560	3831,5
Beam Preparation	244	360	704	230	180,5	131	491	423,5	93	96	541	1138
Accelerator Division Tests	224	0	174	240	132	360	24	313	48	0	240	214
Unscheduled Maintenance	441	786,5	132	293	355	2241	1216	2686,5	576	72	461	229

YEAR

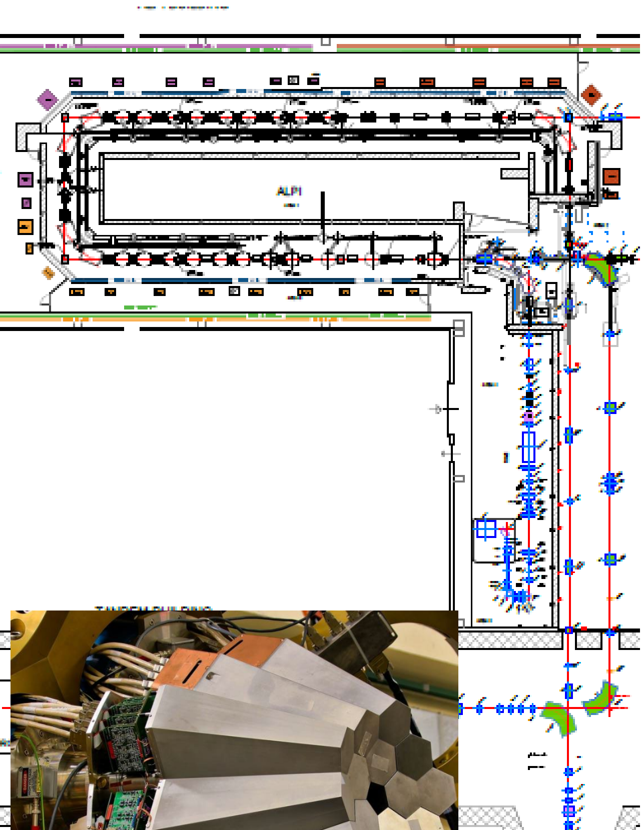
Upgrades

Tandem-ALPI-PIAVE – Normal conductive RFQ



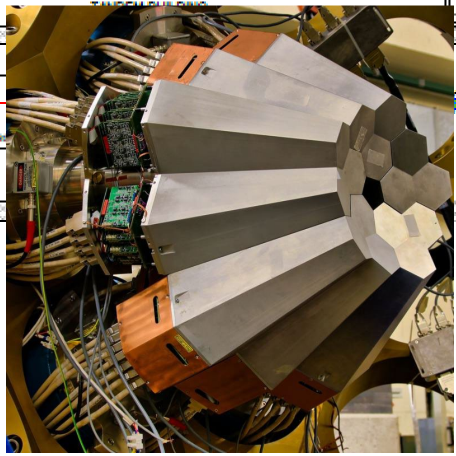
- SPES RFQ: normal conductive 4-vane internal bunching RFQ
- coupled with SPES Charge-Breeder (ECRIS type) and MRMS
- **Higher energy injection to ALPI, 727 keV/u VS 587.5 keV/u (PIAVE)**
- **Optimized longitudinal emittance output**
- **Higher RFQ transmission: 93% SPES vs 55% PIAVE**

SPES upgrade



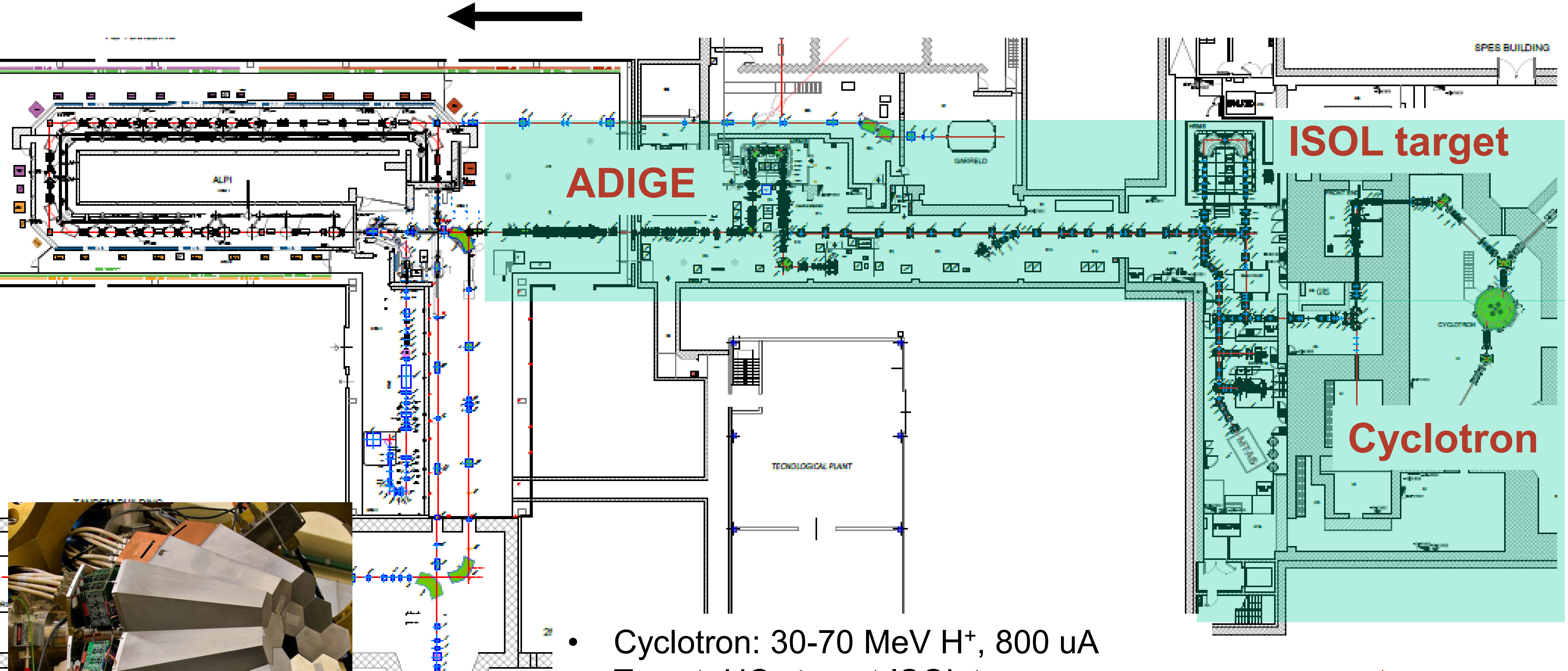
Radioactive ion beams input through the SPES RFQ

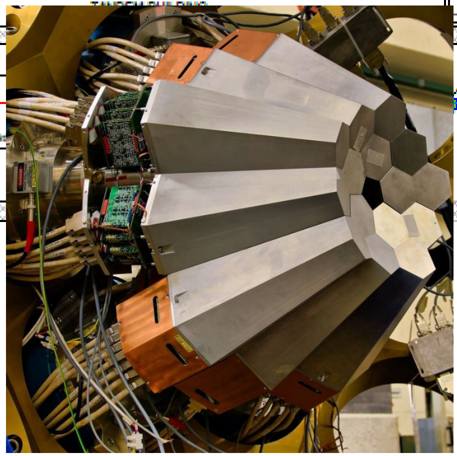
Use of existing superconductive linac ALPI to post accelerate the RIBs



AGATA AGATA: HPGe detector array

SPES upgrade

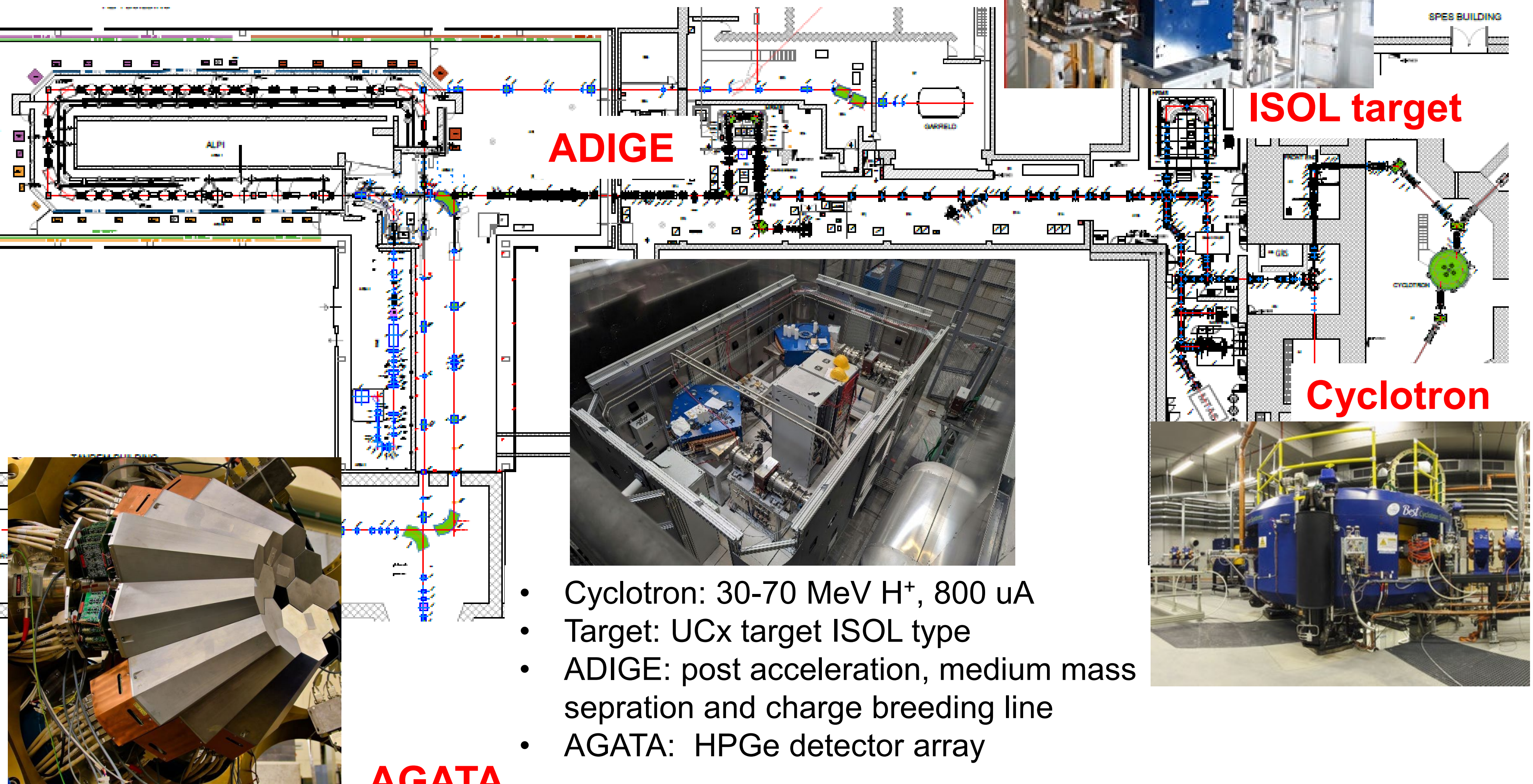




AGATA

- Cyclotron: 30-70 MeV H^+, 800 uA
- Target: UCx target ISOL type
- ADIGE: post acceleration and charge breeding line
- AGATA: HPGe detector array

SPES upgrade



ISOL target

ADIGE

Cyclotron

AGATA

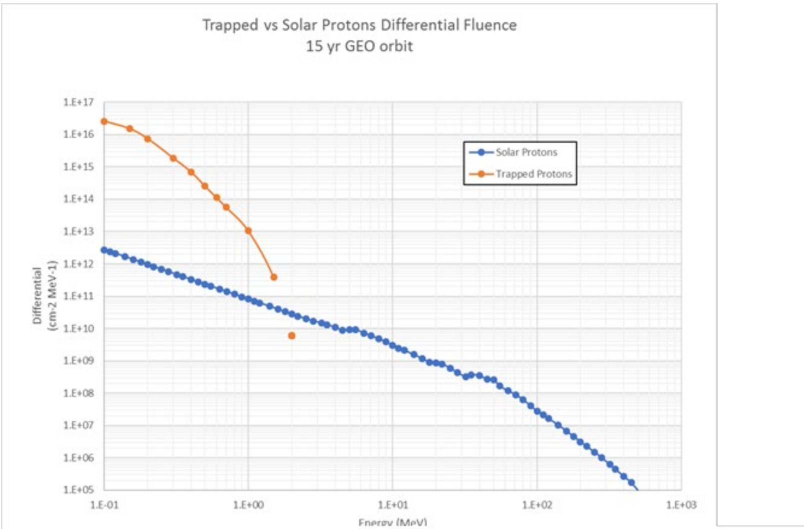
- Cyclotron: 30-70 MeV H^+, 800 uA
- Target: UCx target ISOL type
- ADIGE: post acceleration, medium mass sepration and charge breeding line
- AGATA: HPGe detector array

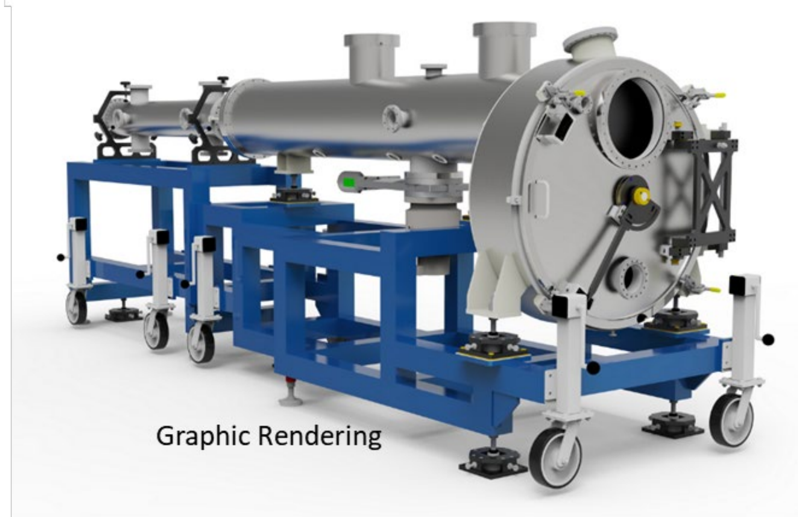
Cyclotron

Normal conductive cyclotron with double extraction lines (70 MeV protons at 800 uA). It is under commissioning, and it will be equipped with eight target stations. Main stations here

- LARAMED: research on medical radionucleotides
- ISOL 1 & 2 : SPES and other activities

CN – irradiation upgrade





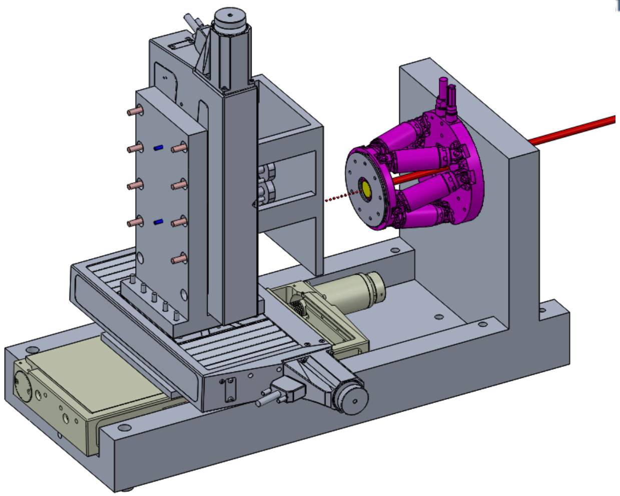
- BEAM FEATURES:
  - Monochromatic Beams: $^{1}H+$, $^{4}He+$
  - Energy: 0.2÷5.5 MeV
  - Standard Beam Size: 2÷8 mm (FWHM)
  - Beam Current: 1-400nA (typical)- (400nA - 2μA energy dependent)
- IRRADIATION SPECIFICATIONS OF THE NEW FACILITY
  - Large area uniform irradiation of spacecraft materials and components in a wide range of energies and fluences
    - Fluence: $1x10^{9} \div 10^{16}$ cm^{-2}
    - Energy: 0.2÷5.5 MeV
  - Large area
    - $\Delta X \cdot \Delta Y = 20x20cm^2$ @ 2 MeV, $\Delta X \cdot \Delta Y = 8 \cdot 8cm^2$ a 5.5 MeV
    - XY beam scanning
  - Uniformity
    - Spatial uniformity: target ≤ ±1%
  - Accuracy
    - Accuracy: base ≤ ±5% - target to ≤ ±3% (multiple Faraday cups)
  - No Carbon build-up (cryogenic LN2 trap)
  - Time for full irradiation
    - From 30s to several hours
  - Certification of irradiation: ESA/ASI ongoing

Courtesy of Valentino Rigato and Matteo Campostrini – valentino.rigato@lnl.infn.it

AN2000 – line upgrades

DUT holder
ΔY travel: 100mm, bi-direct. repeatability ±50 nm
ΔZ travel: 50mm, bi-direct. repeatability ±50 nm
ΔX travel: 150mm, bi-direct. repeatability ±2 μm

Collimator holder
Parallel-kinematic design for six degrees of freedom (X, Y, Z, θ_X, θ_Y, θ_Z) for collimator precise alignment with ion beams



beam

APPLICATIONS

- Shoot single ions in precise position (Z_i,Y_i) in ΔZ, ΔY steps
  - 2D array of individual defects
  - Single photon sources (eg.: QUANTEP)
- Vary the energy keeping the DUT-collimator relative position fixed
  - Individual centers in 3D (Z_i, Y_i, X_i)
- Vary ion specie at same (Z_i,Y_i) position: creation of totally new color centers / defects with multiple single ion implantation in semi and super conductors
- Localized irradiation of nano-wires and band engineered low-D materials(IV, III-V) (QUANTUM SENSING and METROLOGY, PHOTONICS)

Chamber at 0° beam-line at AN2000

- Low divergence ion beams
- Vibration free pumping system
- Water with temperature control (±0.5° C)
- Vacuum: ≤1x10^{-7} mbar

Courtesy of Valentino Rigato and Matteo Campostrini – valentino.rigato@lnl.infn.it

Contact information:

Accelerator Division (beam requests and questions)

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- giovanni.bisoffi@lnl.infn.it
- luca.bellan@lnl.infn.it
- PACbeams@lnl.infn.it (information about beams, species energies)