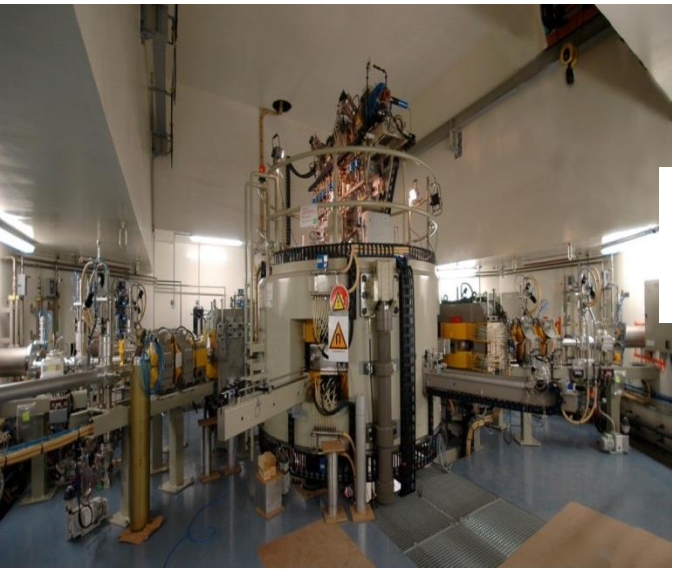
Studies and Upgrades on the cyclotron C70 ARRONAX

Freddy Poirier (Arronax/CNRS)

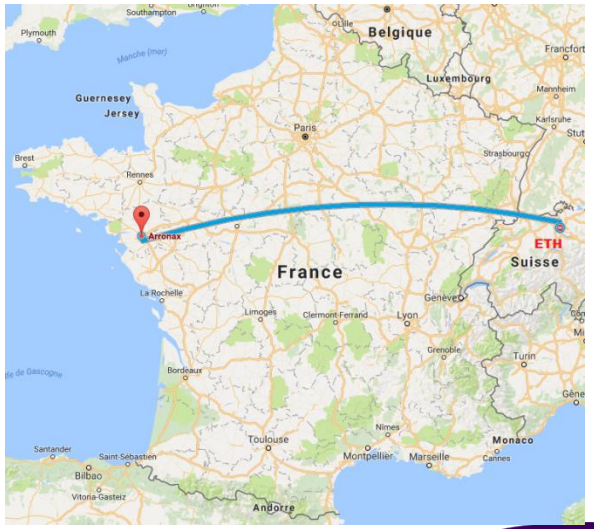
On behalf of the accelerator group

S. Girault, F.Bulteau Harel, J.B. Etienne, X.Goiziou, F. Gomez, A.Herbert, L.Lamouric, D. Poyac, H.Trichet, C.Huet, E.Mace

CYCL13: "On-Going operations with the cyclotron C70", MOPPT010

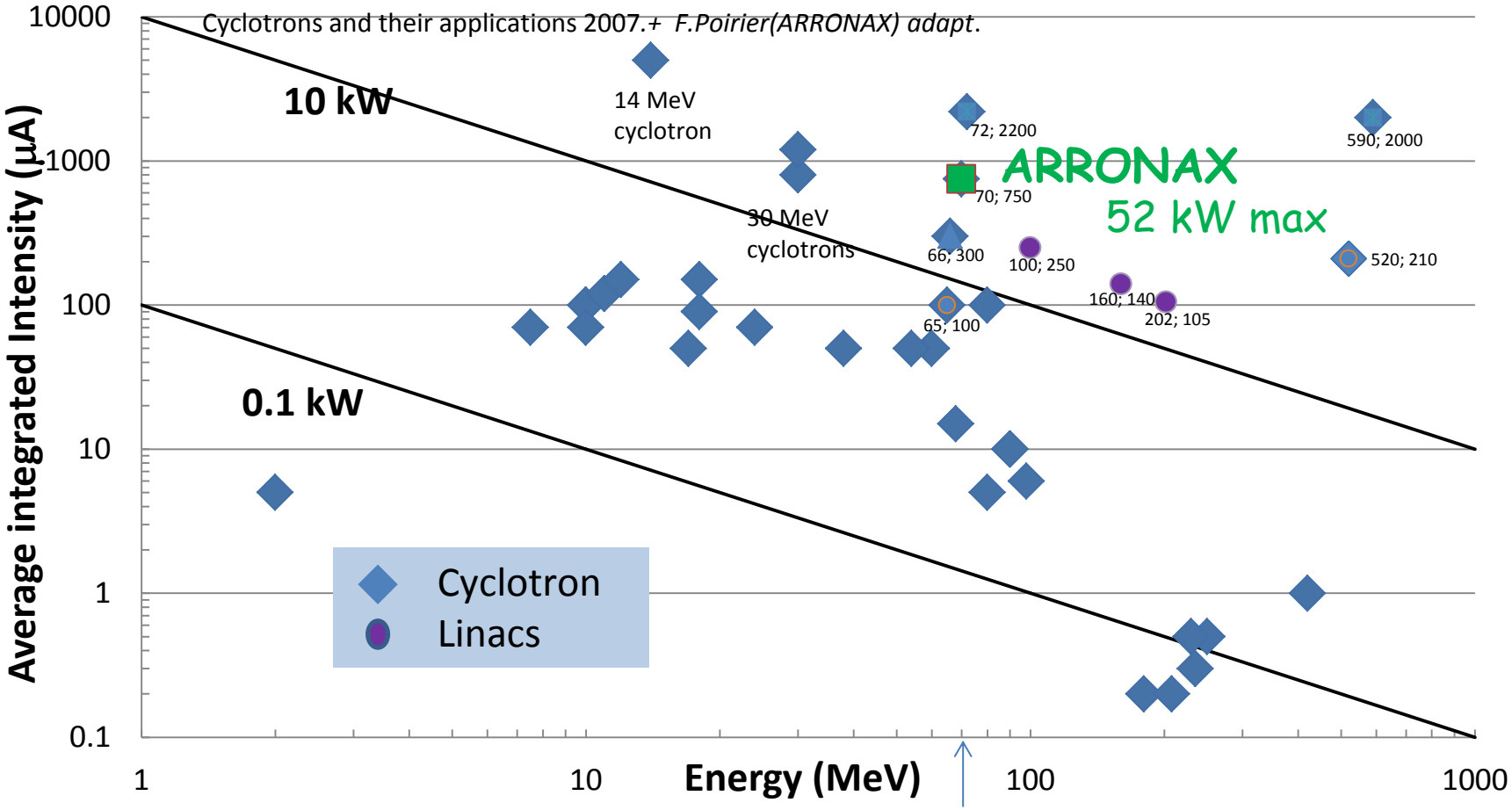


ARRONAX: Accelerator for Research in Radiochemistry and Oncology at Nantes Atlantique.



Proton cyclotrons and linacs for radio-isotopes

(tentative map)



Arronax is positionned among the high power cyclotrons

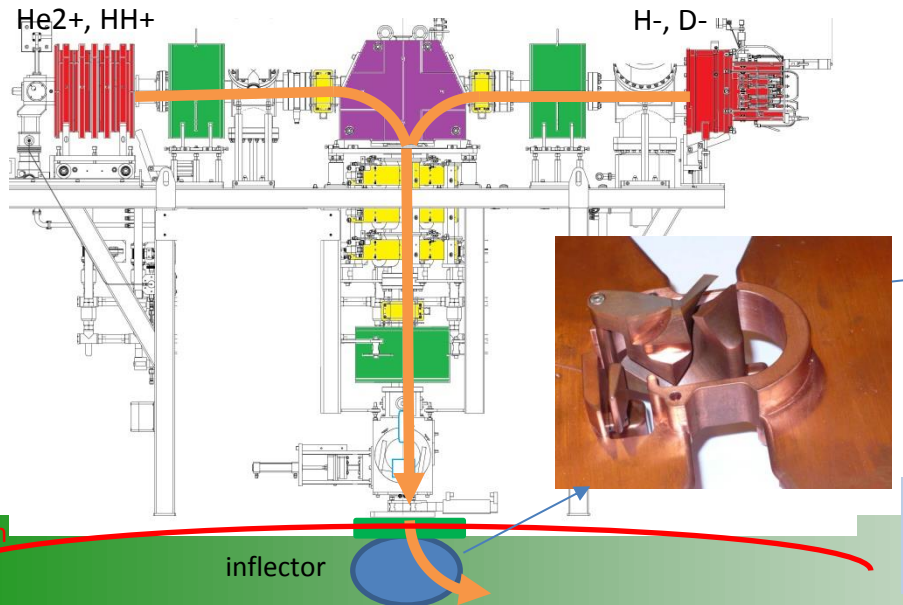
Several new proton machine are being commisionned/built at 70 MeV (IBA/Best)

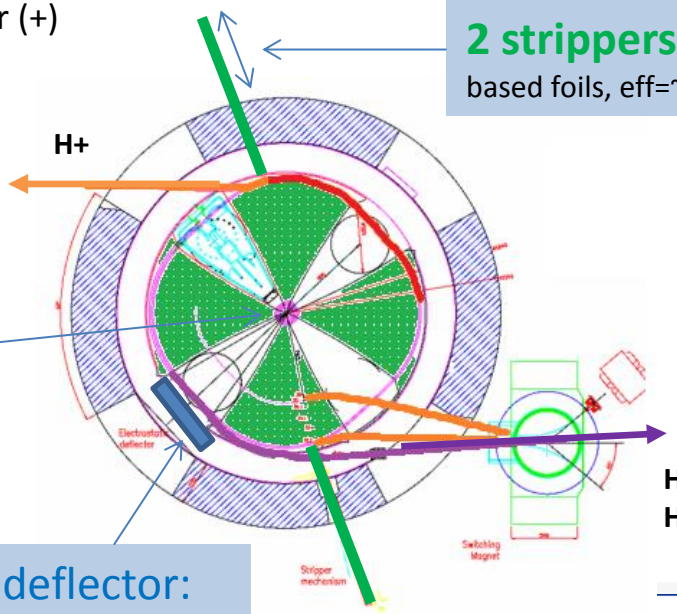
ARRONAX

afaq ISO 9001 Qualité AFNOR CERTIFICATION

Characteristics

- C70 Cyclotron build by IBA:
  - Isochron cyclotron with 4 sectors
    - RF: 30.45 MHz
    - Acceleration Voltage: 65 kV
    - Max magn. field : 1.6T
  - Max kinetic energy/n: 30-70 MeV
  - Normalised emittance before extraction: $\gamma\varepsilon_x$=~4π mm mrad (simulation)
- Main additional elements:
  - 2 Multiparticle sources.
    - Multicusp (H-,D-) with multiple magnets, 5mA max.
    - Supernanogan ECR ion source (He2+,HH+)
  - Injection: Series of magnetic elements (glaser, steerer, quad.) on the top of the cyclotron to adapt the beam to the entrance of the cyclotron, and finally the spiral inflector
  - Extraction: stripper (-) or electrostatic deflector (+)





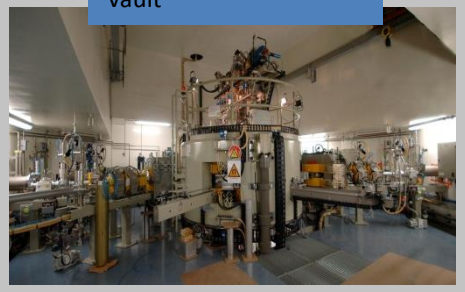
2 strippers: carbon based foils, eff=~95%

1 deflector:
66kV,eff<<90%

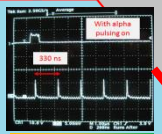
Beamlines

Irradiation station for rabbits at end of line

Cyclotron (30.45 MHz, 65 kV) in the central vault



3 beamlines in 6th vault with a top-bottom capability, used mostly for low current experiments e.g. PIXE, stacked foils, radiolysis, physics, radiobiology. Beam exit from a kapton foil



Alpha pulsing

P3

Irradiation station

Station for RbMetal

P2

Irradiation station

Simplified carbon α Energy Degraders

A2

P1

Water cooling

A1

Proton degrader

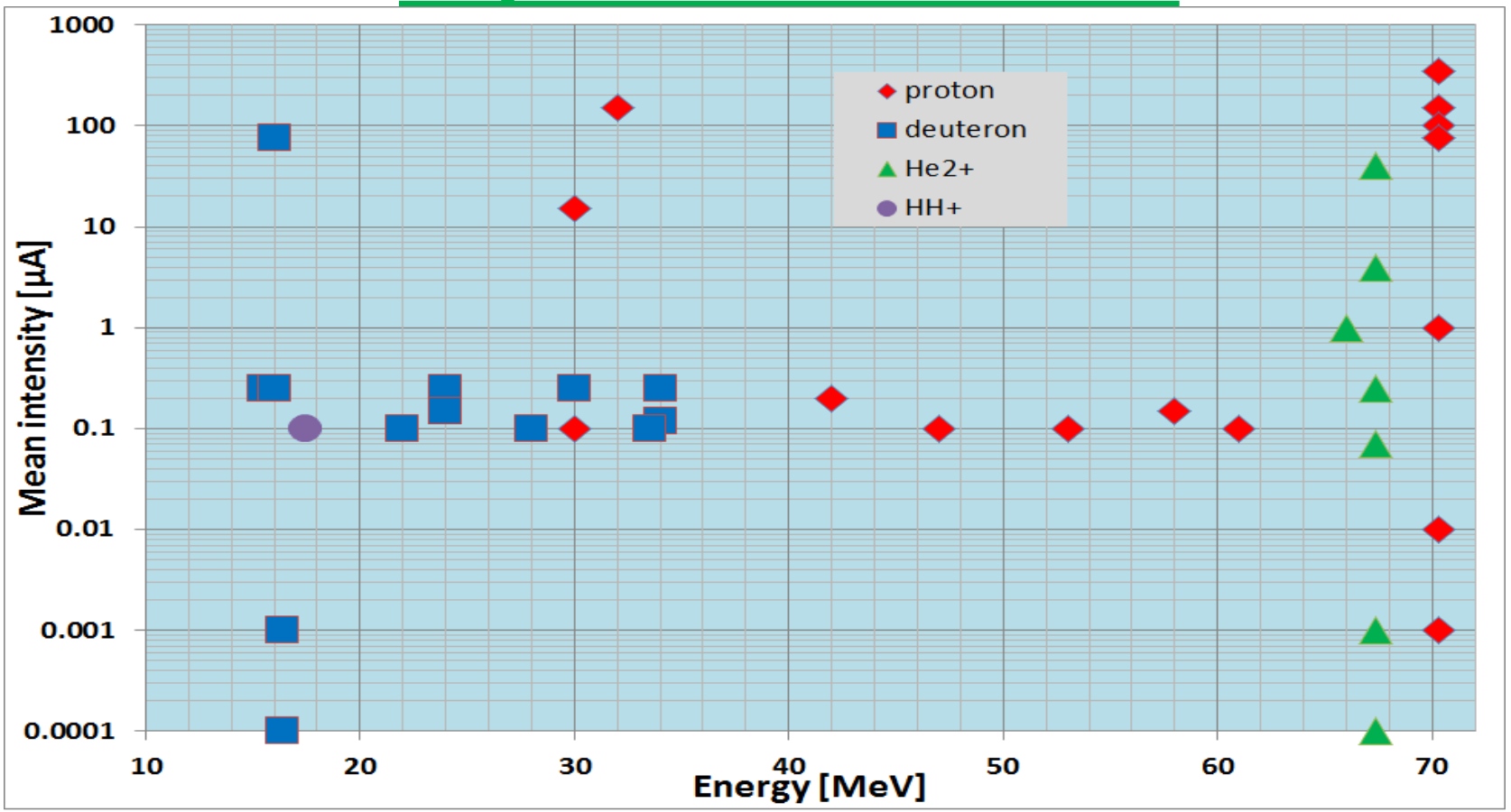
Vault for the neutronic activator

New Neut. Activator

- Running
- Testing/modification

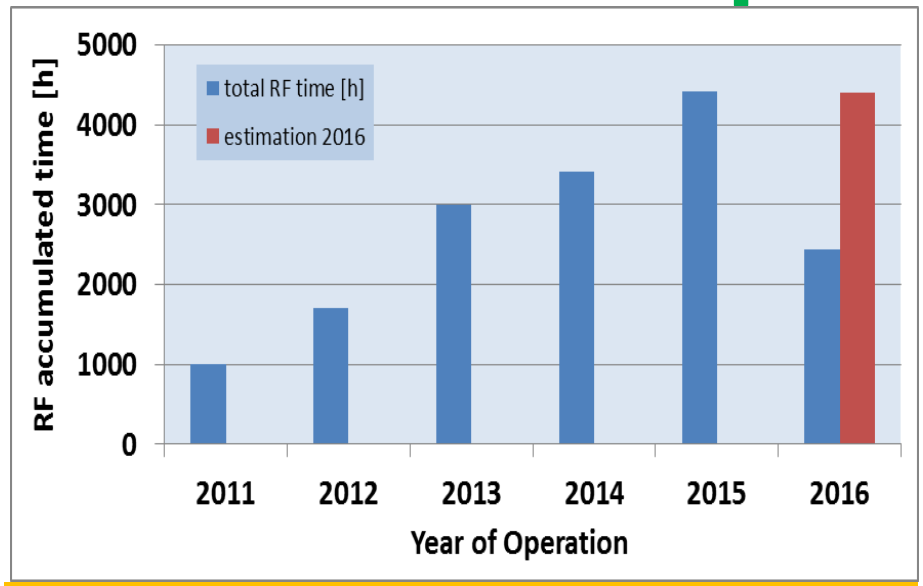
Irradiation station

Operationnal use



- **Large range of intensity and energy:**
  - 7 orders of magnitude of intensity
    - Runs for Radio-isotopes at high intensity and high integrated intensity
    - R&D runs → Precisions in operation
  - Several beamlines in use and bunches frequencies variation not included here

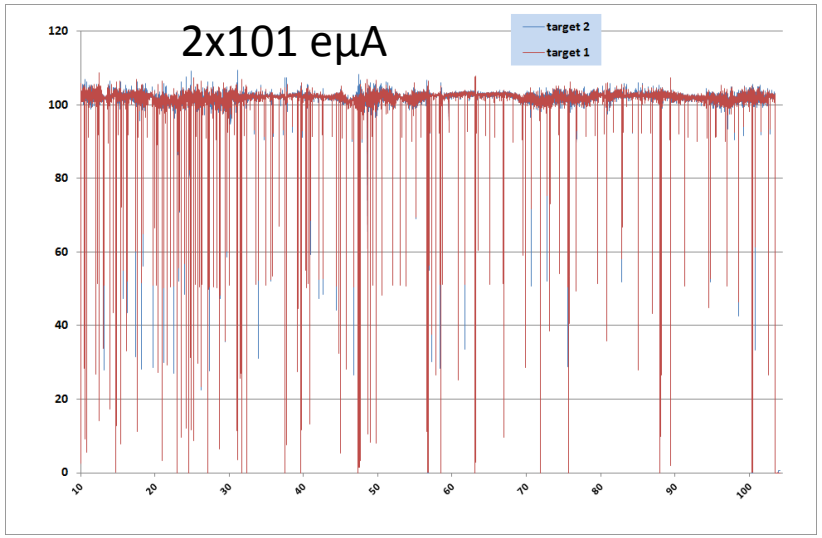
Operations



- RF use:
  - 2015 : 4400 hours
  - 2016 (projected): similar

Transmission rates

Particles	Estimated Intensity in cyclotron [µA]	Transmission rate (End-of_line/injection)
H+	252	43%
D+	64	37%
He2+	26.6	10%



Dual mode operation with protons:

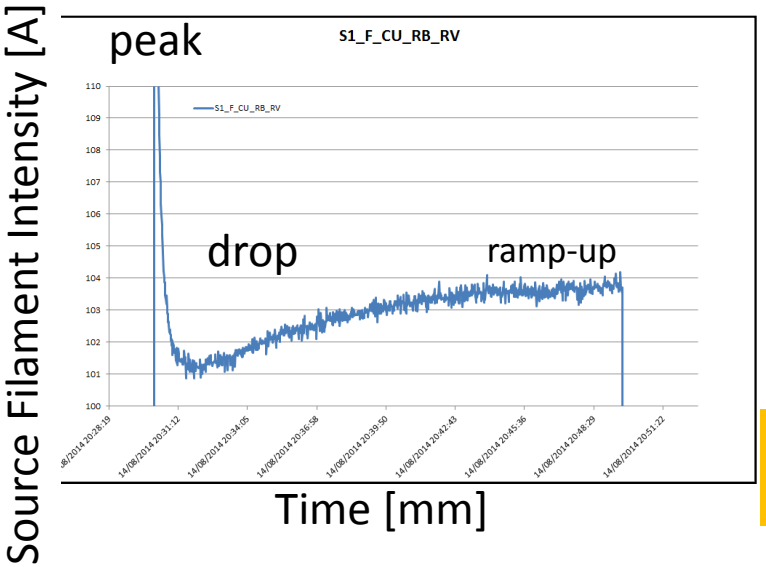
- ✓ Here stable run over 98 hours
- ✓ $\langle I \rangle$=101.5 eµA, $\sigma_{\langle i \rangle}$=5.4 eµA
- ✓ Breakdowns = 1.8% of the overall time
- ✓ Vacuum in the center of the machine =4x10^{7} mbar
- ✓ Neutral current (H^0) = 9eµA in 2014 (18µA in 2012)

Now running at 150uA on target

Machine studies

- Twofolds, mostly driven by users needs
  - Users wants high current,
    - Mitigate potential target damages (beamline also)
  - Users wants to have lower intensity/more precise beam in a short time
- The studies spans over:
  - Source studies
  - End-of-line beam characteristics
  - Mapping of the magnets
  - Beamlines beam dynamics studies including quad-scan (towards emittance measurements)

Studies at low intensity (<1uA)



Here for our multicusp H-/D- source

Intensity from the source follows a specific pattern (peak, drop and ramp-up) before stabilisation which occurs after several tens of minutes:

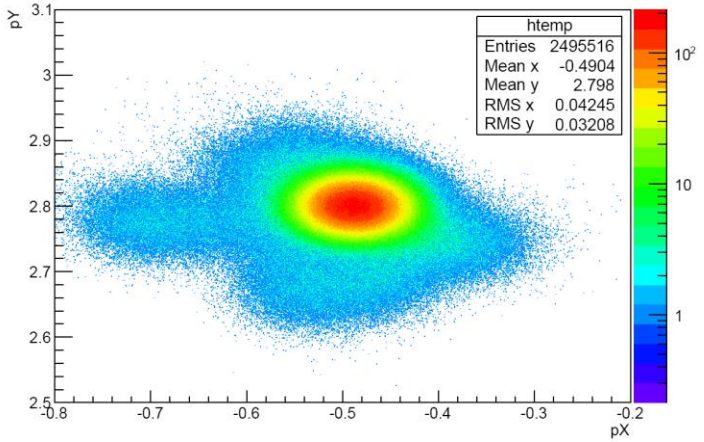
- Impact on how early we can do a stable beam
- Impact on how soon we can perform maintenance (exponential decrease kicks-in)

→Adaptation of source filament use
(confirmed also with end-of-line users measurements)

Beam stability at low current 20 pA

(Dosion – LPC Caen/Arronax team):

- Intensity
- Geometry



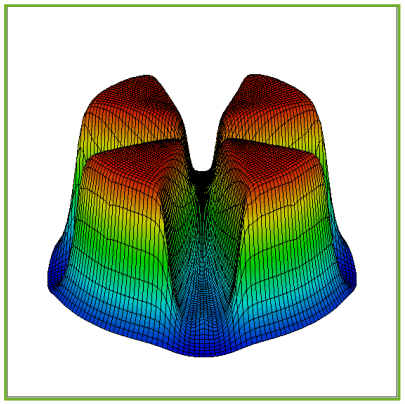
→ 40 μm beam geometric instability: recipe in use validated for this specific use (with strategy of beam blow-up in injection)

Studies at high intensity (>10uA)

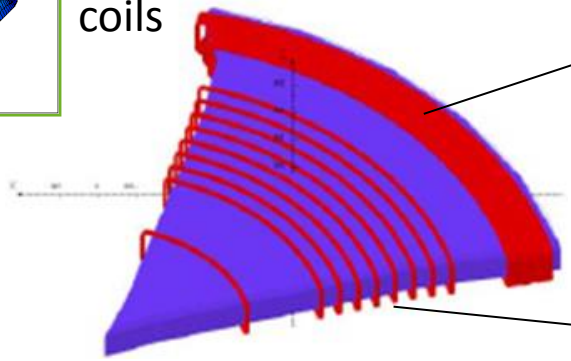
Are the settings in the machine adequate?

- 3 Compensation coils in addition to the main coil
- Mapping of the extracted intensity from the machine has shown several region to use/avoid, for the accelerator magnets setting:
  - Included check of isochronicity
  - On-going work for all magnets, history and pilots technics
  - On operation, setting modification accordingly

Magnetic field in the machine



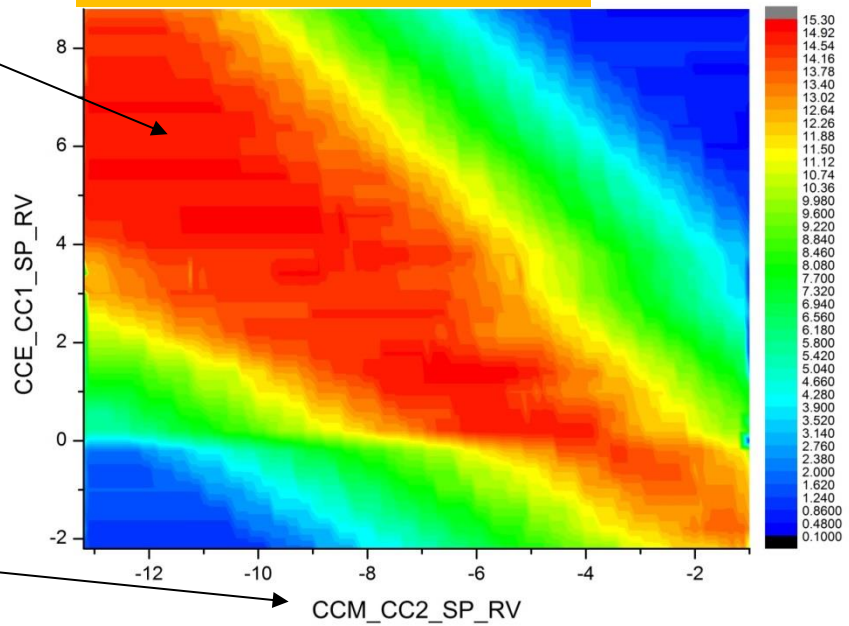
Additional compensation coils



Cyclo magnet mapping

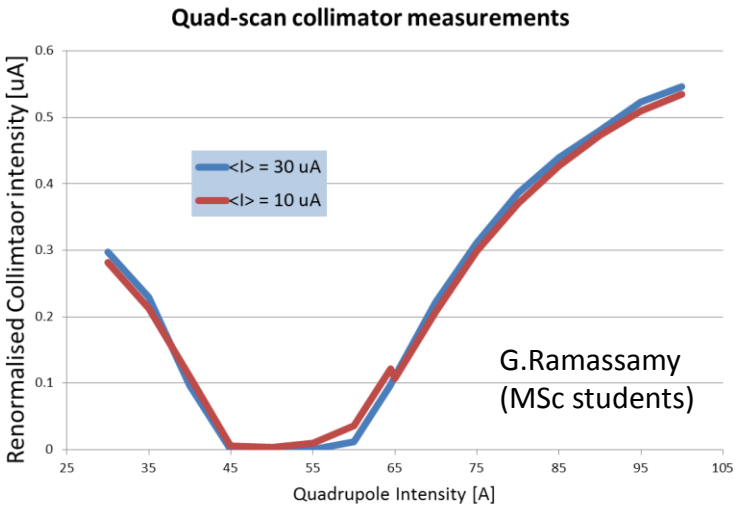
Stable area

Intensity [uA] on faraday cups at extraction

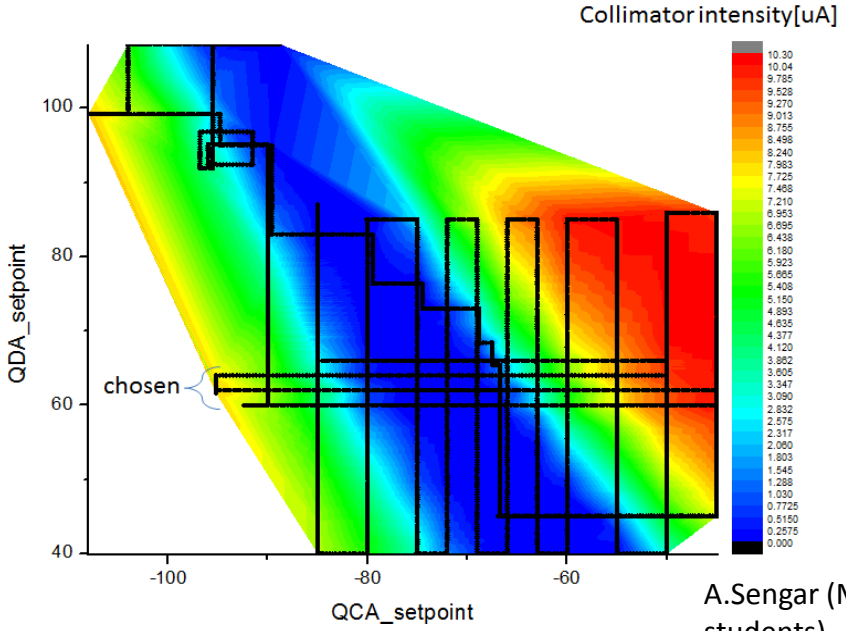


Studies at high intensity(>10uA)

- Are the settings in the beamlines adequate?
  - Quad-scan to check the beam dimension and setting of the quads and losses along the beamlines
- Can the beam characteristics be tackled? Emittance?



Quad-scan results



A.Sengar (MSc students)

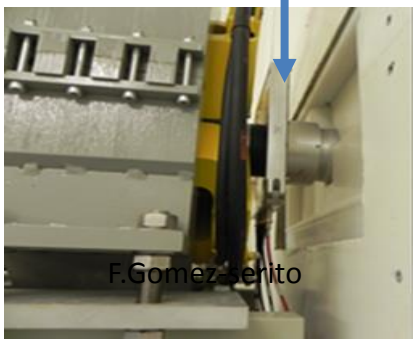
Multi Quad-scan results

Using a simulation model, and a technique close to single wire but with collimators, first measurements of the emittance were performed at Arronax:
Indicated us that we can approach the emittance measurements without new tools:
- It takes time though and needs dedicated scans

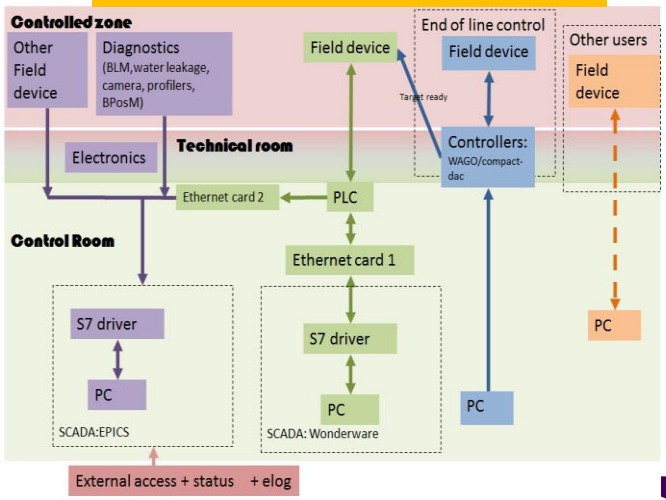
On-going Developments

- New upgrade on the control server → done
- Collaboration with IBA for new collimators
- Beam loss monitors (BLM)
  - 1 running prototype
    - EPICS updated system thanks to Master students and iThemba
- Alpha pulsing: on-going work (next slide)
- Parallel data acquisition system for cyclotron → done
- For the future:
  - extension for several BLM
  - Beamline modification
  - Extension of our EPICS network to support beam and technical diagnostics

BLM

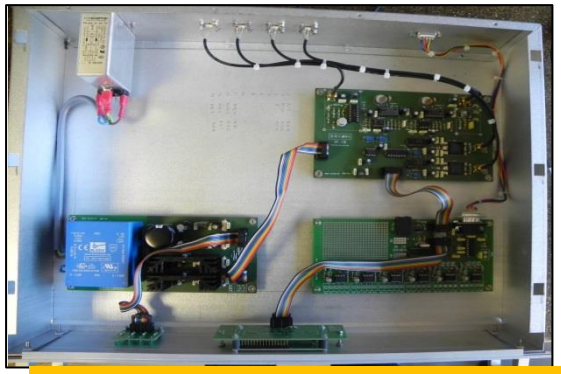


Extension of network



Pulsation

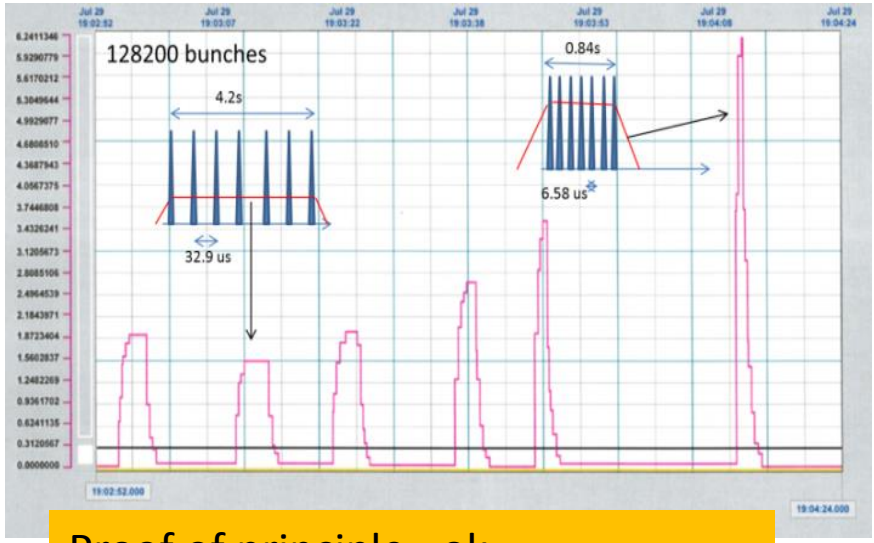
- Goal: modify the inter-bunch space from 32.8 ns to a few millisec
- Initial system built by IBA.
  - Based on a 3kV chopper in the injection and a 50kV deflector in one beamline
- System adapted to new users specification: → bunch train
  - Drive the chopper to allow start/stop modes
  - Modify the electronics/software
  - Adapted for all particles



EPICS

New electronics and EPICS control system

A.Leateron, E. Mace + previous M2 students



Proof of principle= ok
Control system adequate for trains

Users also want to have trains with only 32.8 ns inter-bunch time →
Need to change the power system of the chopper: Solid-state?

Conclusion

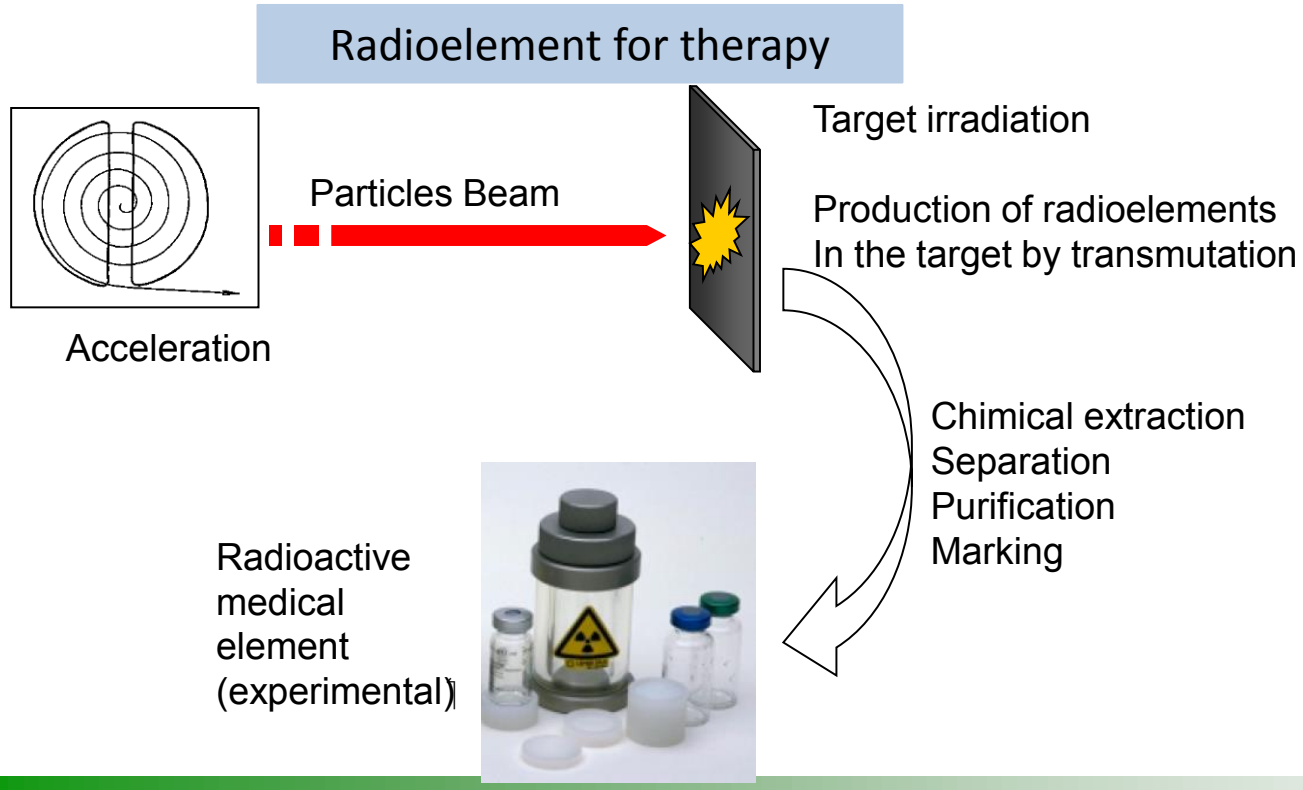
- Arronax C70 is up and running:
  - ~5 years of experience
  - Machine is used for very various and wide range of runs/parameters
  - Success in responding to the users needs (happy?)
- Maintenance and interventions are high:
  - New CMMS (maint. Management software) used → better tracking
  - 150 interventions/year
  - Specific applied maintenance technics due to activation in place
- Several developments are necessary and being done:
  - Tools and techniques for maintenance have to be developped
  - Operation:
    - Implementation of a foundation to support EPICS software based tools
  - Beam diagnostics are highly needed
    - Looking for specialist and collaborations
  - Thorough simulations of accelerator/beamlines are also needed:
    - Help to grasp the impact of the parameters
    - Help to refine the technics (emittance measurements, ballistic beam-based alignment?)

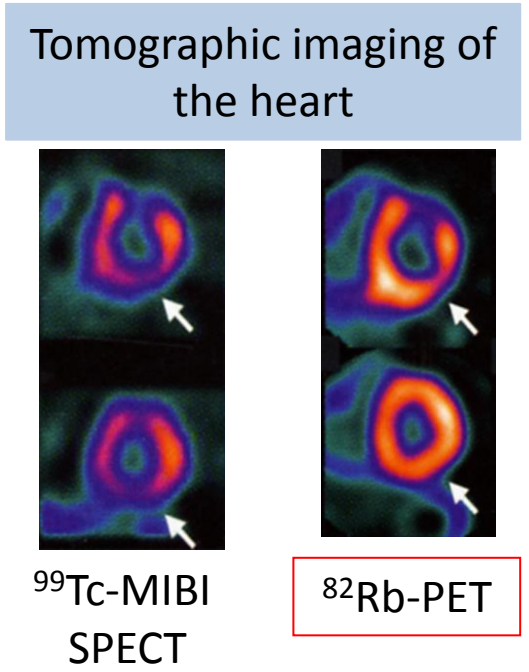
• Thank you!

Several of these projects are supported in part by the “Agence National de la Recherche”, called “Investissements d’Avenir”, Equipex ArronaxPlus n°ANR-11-EQPX-0004

ARRONAX Activities

- A tool to produce radionucleides for research in nuclear medecine
  - Imaging: β+ radioelements for PET (ex: $^{82}Sr/^{82}Rb$, $^{44m/44}Sc$, ^{52}Fe, ^{64}Cu ...)
  - Therapy: α immunotherapy (^{211}At → preclinic phase), β^- radioelements : ^{64}Cu (preclinic phase), ^{47}Sc





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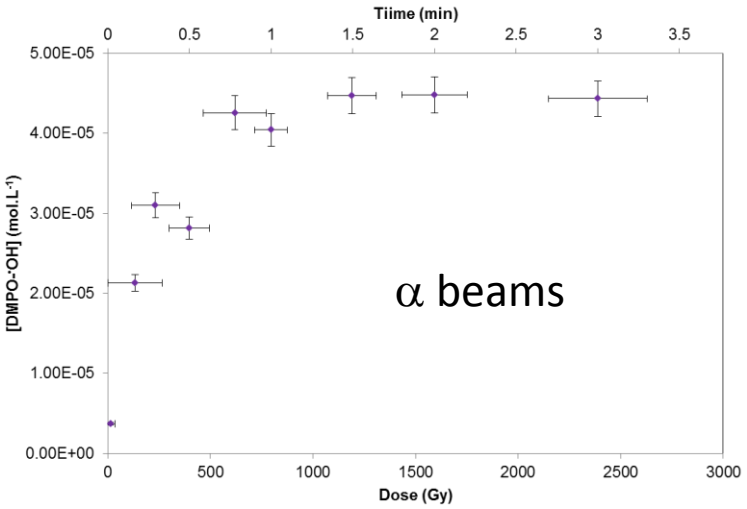
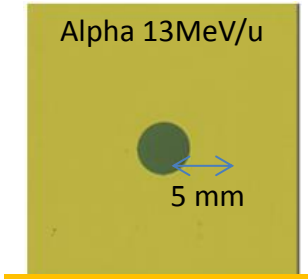
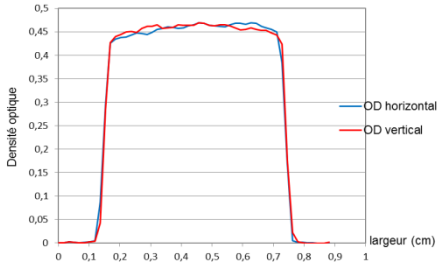
- A tool for radiochimistry & radiobiology research
  - specifically alpha radiolyse of water (eg nuclear waste storage).
  - Radiobiology with characterisation of dosimetry tools and living cells (with GANIL,ICO,INFN)



OH production at 62 MeV

M.Fattahi *et al*. (Subatech)





Radiograf-chromic characterisation after irradiation

C.Koumeir, *et al*.

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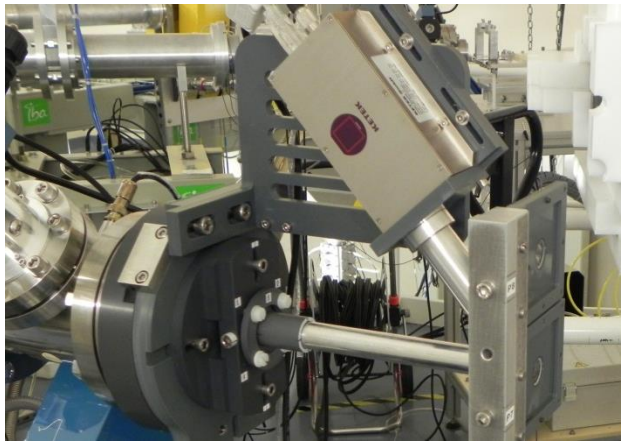
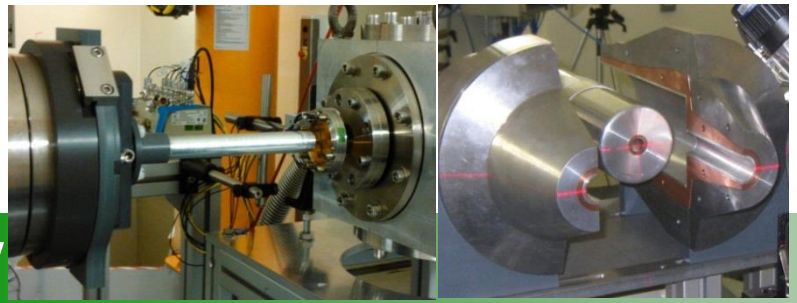
  - radiobiology
- A tool for physics reasearch
  - Particularly studies of material under irradiation
  - Development of detection system
  - Measurements of nuclear data



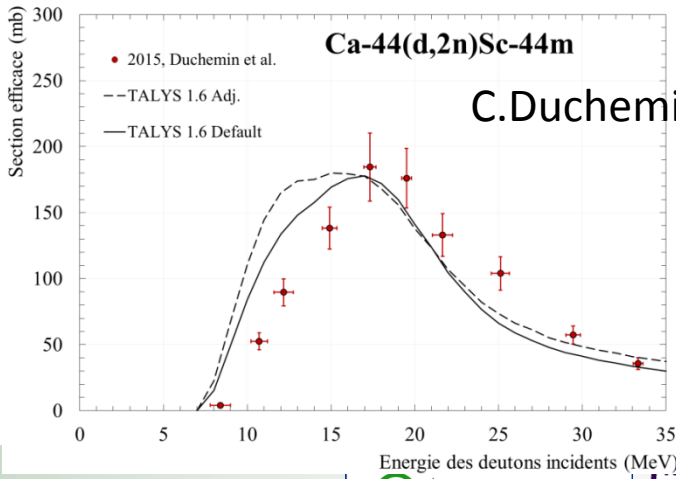
PIXE/PIGE - Particle Induced X-ray Emission

- Non destructive Caracterisation Method of multielements material, quantitative
- Dvt of mesuring benches
- (~nA)



Experiment « Stacked Foils » - Sc44

Cross section measurements:
example from 9 to 35 MeV- (100 nA)



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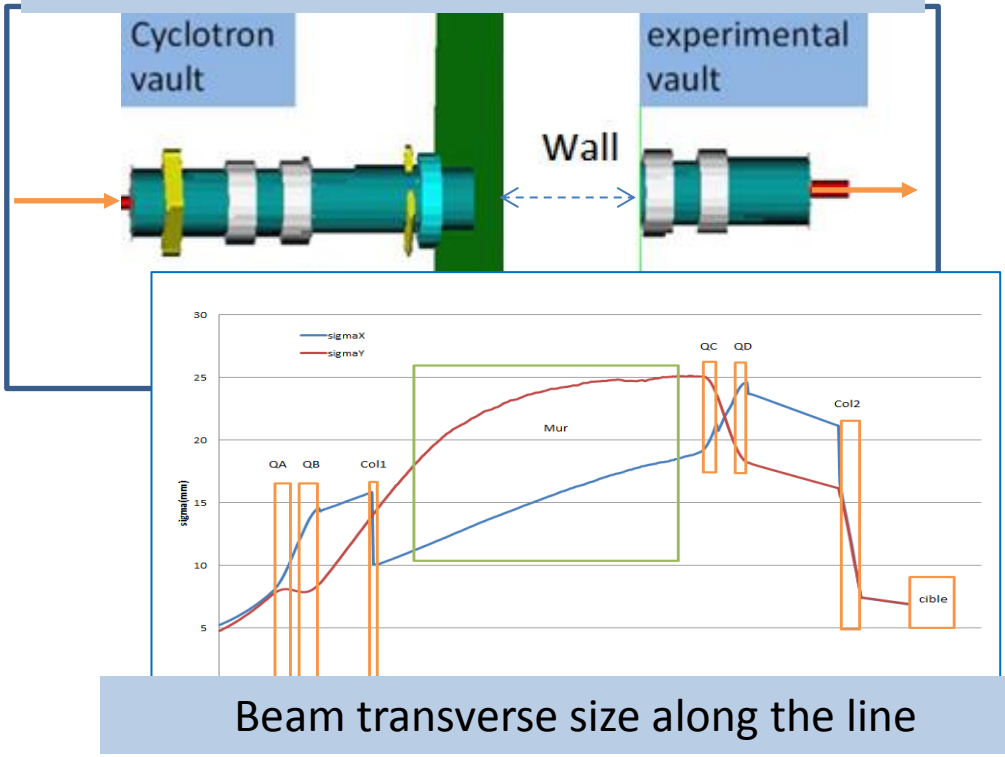
- A tool for training and education
  - University of Nantes
  - École des mines of Nantes
  - CHU (accademic hospital) of Nantes
  - Permanent and dedicated trainings
- An industrial production site for medical needs

Simulation

- Development of simulation with G4beamline, Astra &Transport:
  - General simulation studies
  - Support and confirm Beam transport strategies
  - Benchmark/Confirmation of beam characteristics (beam size, particles losses, emittance,…) + users are in demand of this
  - Extrapolation to high current technique?

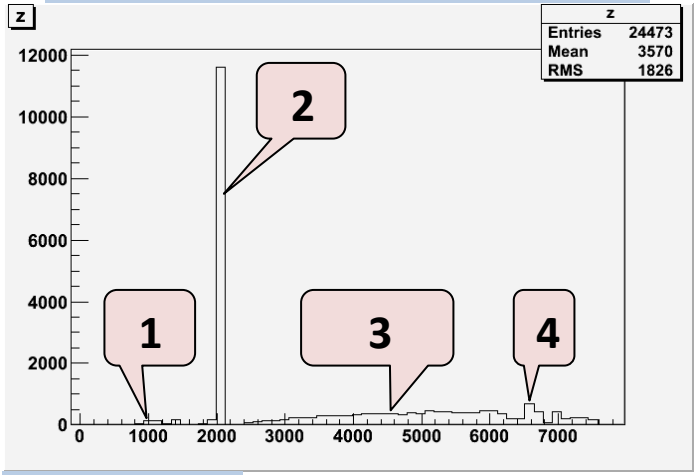
Exemples with G4beamline:

G4beamline beamline layout

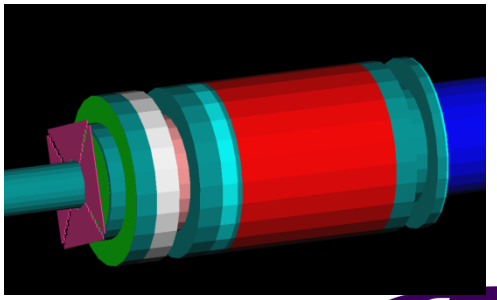


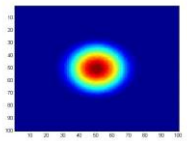
Beam transverse size along the line

particles losses along the beamline



Details close to beamline end

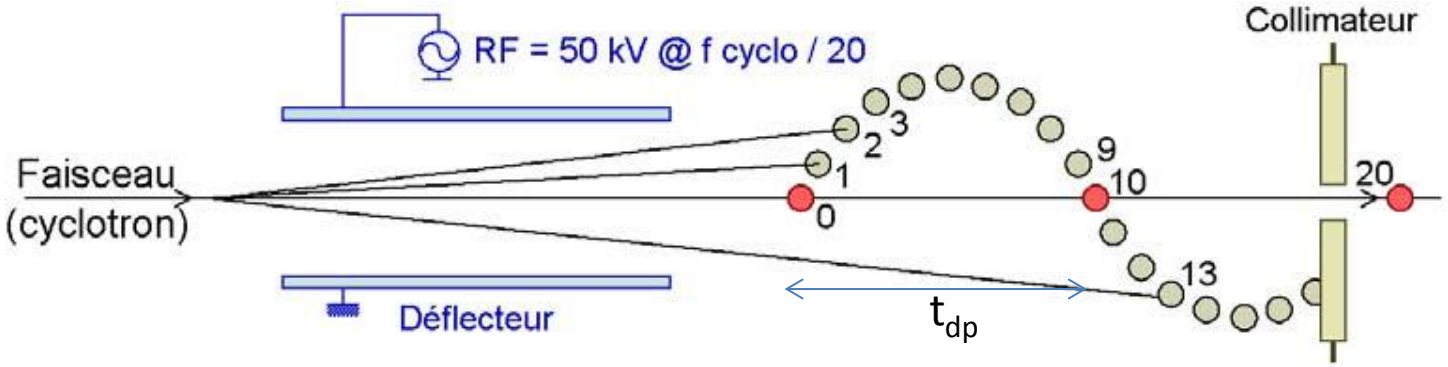




Works from students , Wajan, D.Guiraud, S.Picot

Cyclotron initial alpha pulsing

- Alpha pulsing: Deflectors for inter-bunch time modification (He2+/2011-12):
  - Periodic Deflector on the beamline 50 kV @ $f_{cyclo}/20$
  - Chopper (Deflector) in the injection timed to the period. def.



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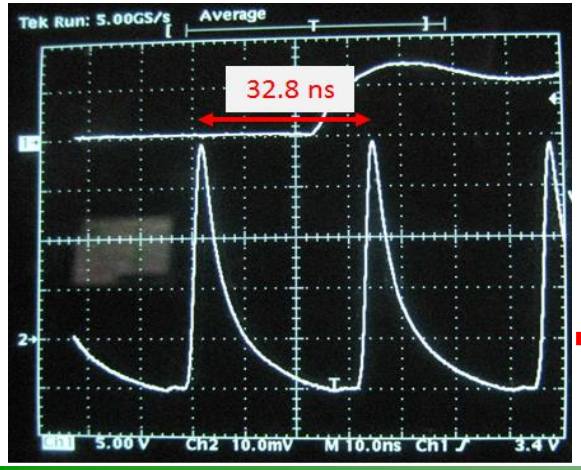
Chopper: increases the inter-bunch time by n *x* t_{dp}.

Inter-bunch time from 330 ns to ~5 s



Combination of an aperiodic deflector in injection and a RF 50 kV, 1.5MHz deflector on the beamline.

GA + J.L Delvaux (IBA)

More work on transverse optimisation has to be done

To get towards more user friendly setup

Diagnostics I

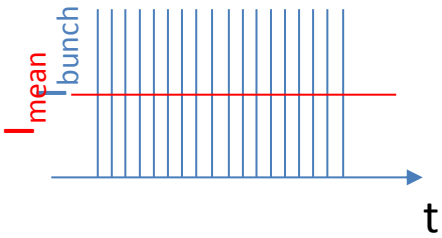
The main diagnostics are:

- **Current measurements (I_{mean}):**
  - On the 4 individual fingers of the collimators
  → aperture from 10 to 30 mm limiting the transverse size right at exit of collimators,
  - Faraday cups:
    Water cooled layers of titanium /aluminium
    15kW max (i.e ~210µA at 70MeV)
  - Beam dumps combined or not with a current integrator (at very low current)

- **Profilers:** measures the beam density

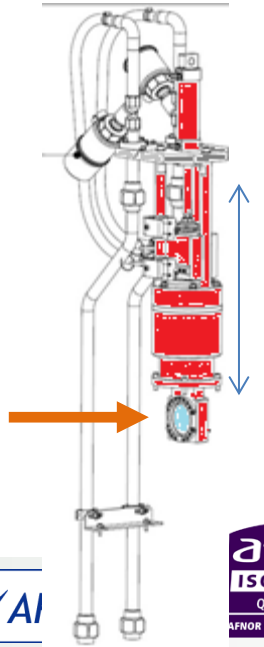
- **Alumina foils:** or thin film foils for location and size measurements at end of line

Mean current



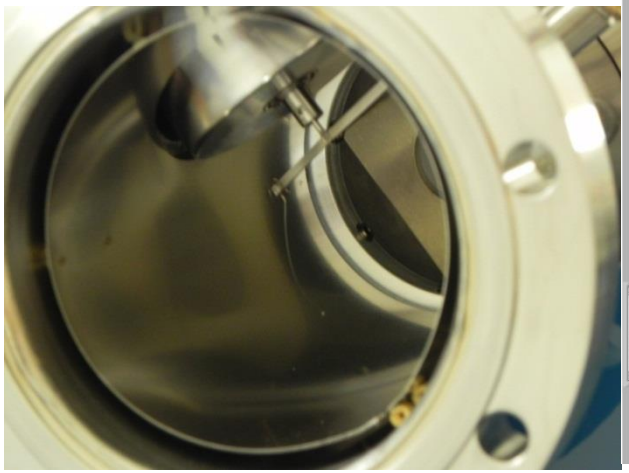
Collimator readings

Faraday cup

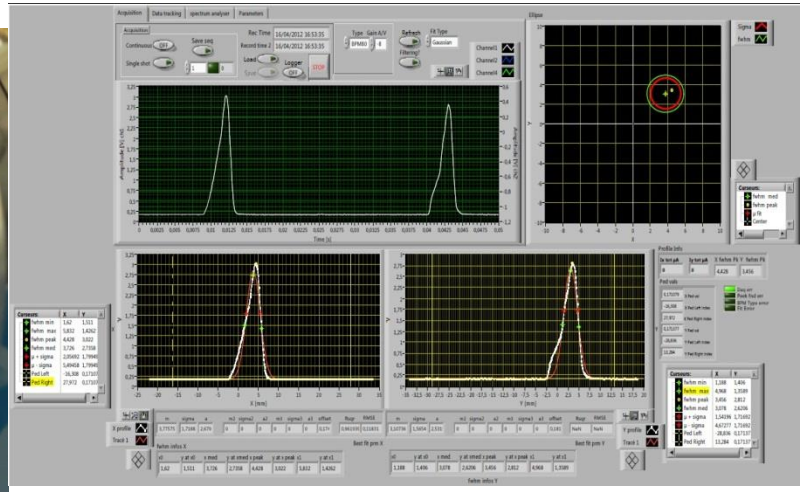


Diagnostics II (low intensity)

Profiler NEC 80 (83):
- Installed downstream a collimator
- A single wire, frequency 18 Hz (19Hz)
- Helicoidal Radius = 2.7 cm (5.31)
- Limit (theo.)=150 µA for a 10 mm beam



On-line analysis of beam *x-y* density



Alumina foil (AlO3) - thickness 1 mm:
- Installed outside the line, downstream the exit thin kapton (75 µm) window
- Check of the center and beam size
- ~1nA <I_{moy}<~150 nA for protons and alpha
- Vidikon Camera (radiation hard)

- → Off-line analysis code is developed in GMO, based a Matlab tool from LAL.