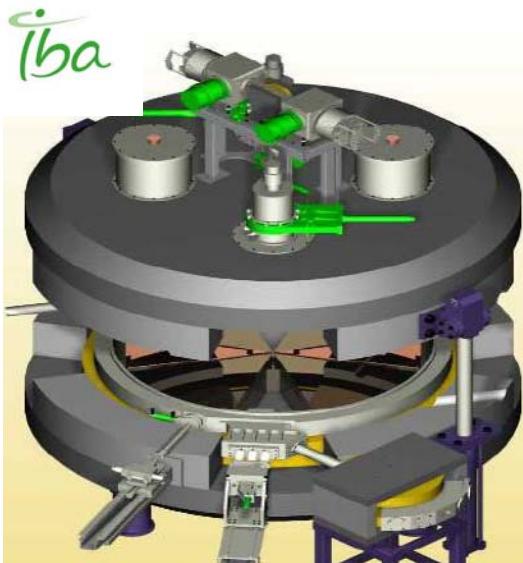


# The C70 ARRONAX Hands-on phase

Freddy Poirier (IN2P3/Subatech)

ECPM May 2012

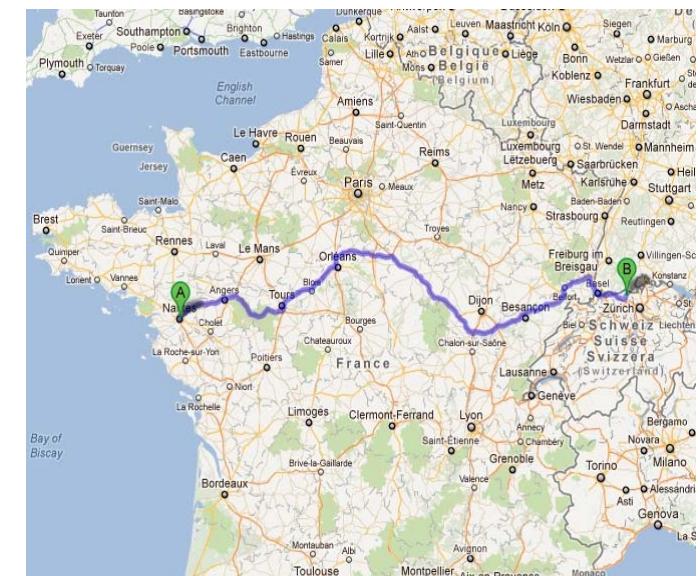
IPAC 2011: "C70  
and beamlines  
status", WEPS69



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

Operation and Maintenance team:  
S.Girault, F.Gomez-Serito,  
C.Huet, L.Lamouric, E.Mace,  
F.Poirier

Cyclotron ARRONAX

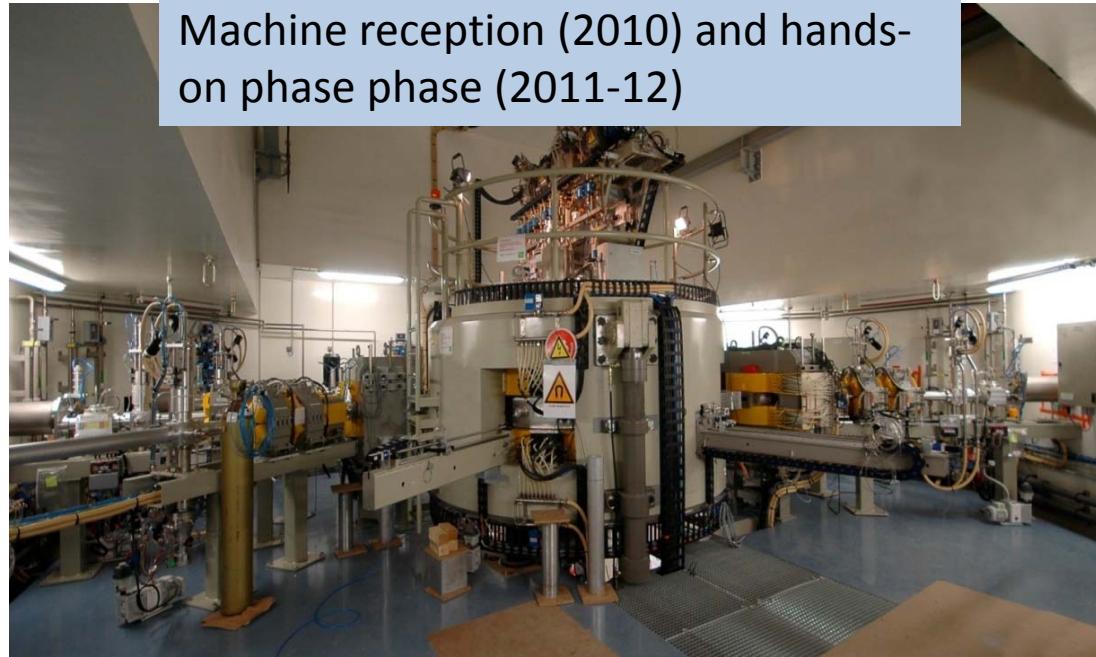


# Historical Background

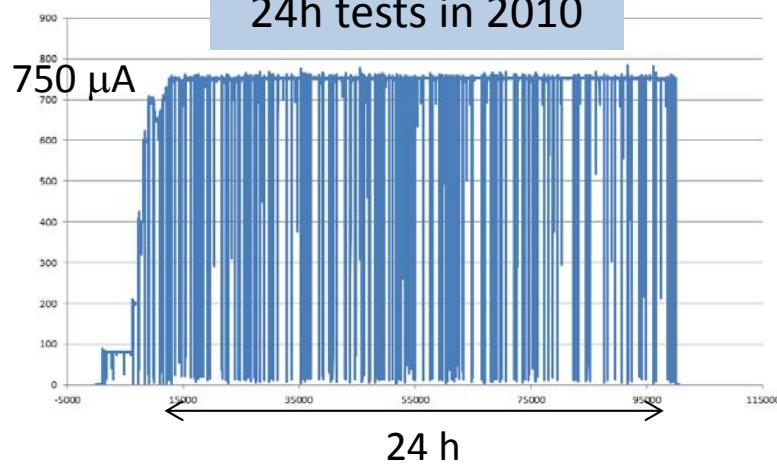
Inauguration in 2008



Machine reception (2010) and hands-on phase (2011-12)



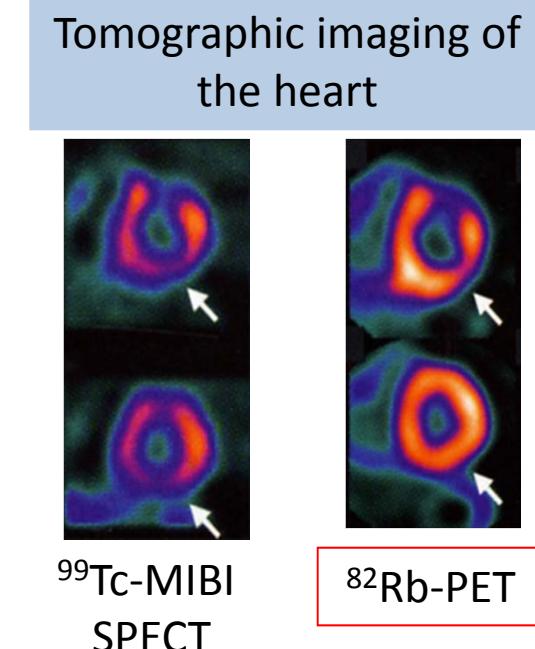
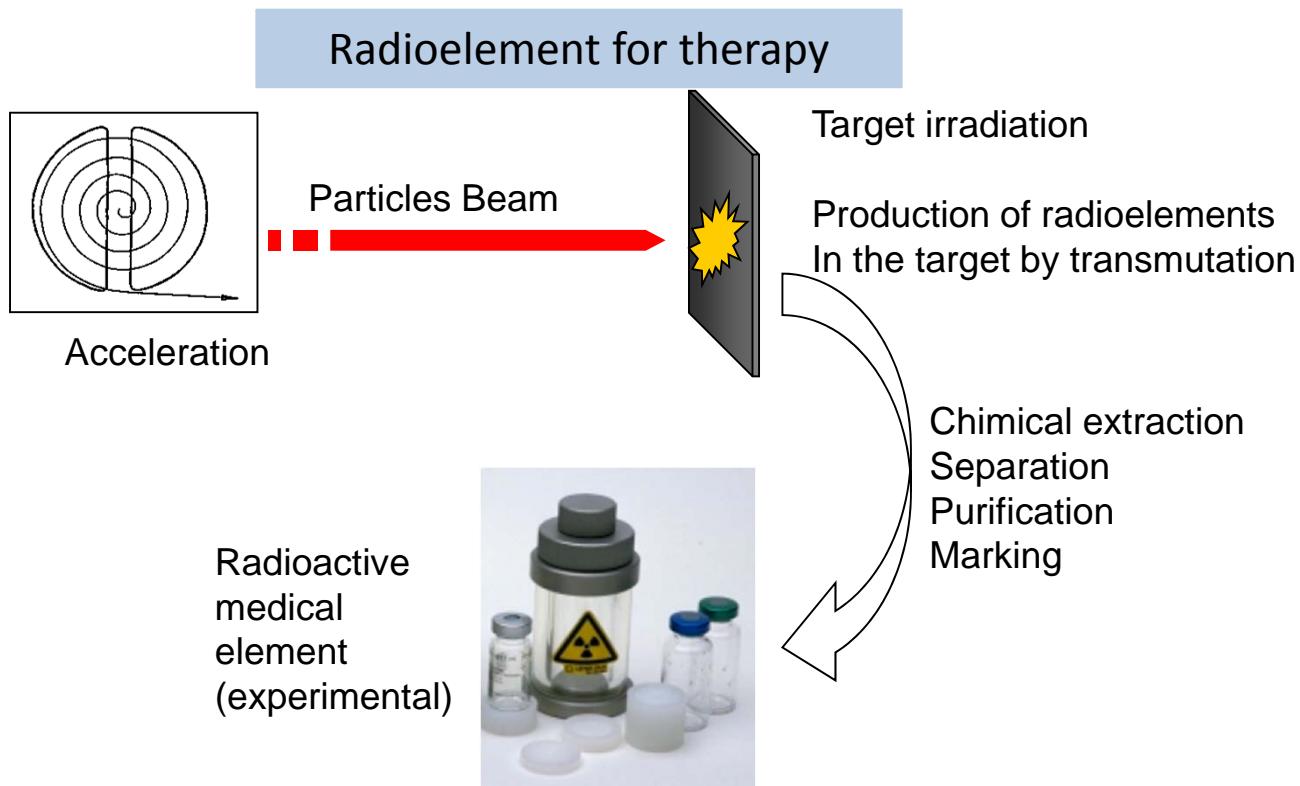
24h tests in 2010



- October 2008 : Inauguration
- March 2010: Low intensity Irradiation
- October 2010: 24h at 750 pμA by IBA
- Dec. 2010: Final machine reception
- 2011-12: Hands-on phase with an extended program on tuning and exploration of beam parameters for users.

# ARRONAX goal

- A tool to produce radionuclides for research in nuclear medicine
  - Imaging:  $\beta^+$  radioelements for PET (ex:  $^{82}\text{Sr}/^{82}\text{Rb}$ ,  $^{44\text{m}}/^{44}\text{Sc}$ ,  $^{52}\text{Fe}$ ,  $^{64}\text{Cu}$  ...)
  - Therapy:  $\alpha$  immunotherapy ( $^{211}\text{At}$ ),  $\beta^-$  radioelements :  $^{67}\text{Cu}$ ,  $^{47}\text{Sc}$



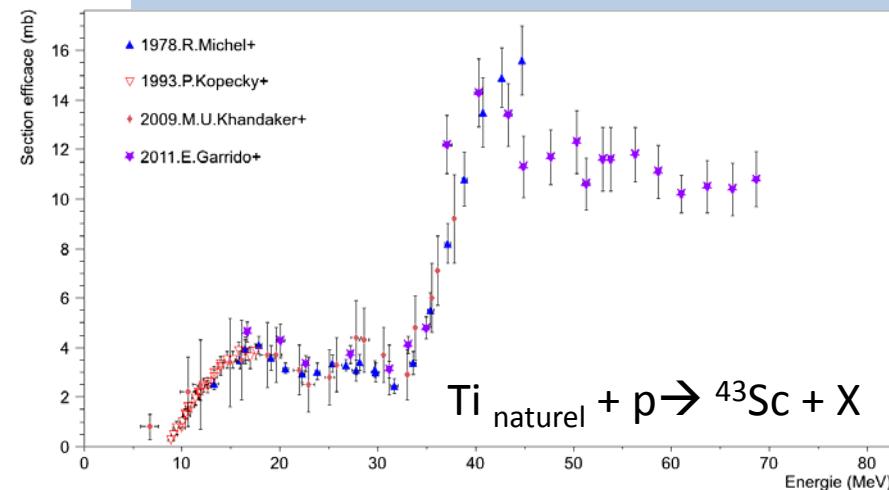
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  - notably alpha radiolyse of water (eg nuclear waste storage)
- A tool for physics research
  - Particularly studies of material under irradiation
  - Development of detection system
  - Measurements of nuclear data

Experience « Stacked Foils »  
 Cross section measurements:  
 exemple from 17 to 69 MeV- (100 nA)



## PIXE - Particle Induced X-ray Emission

- Non destructive Characterisation Method of multielements material, quantitative
- Dvt of mesuring bench
- (~nA)

# ARRONAX goal

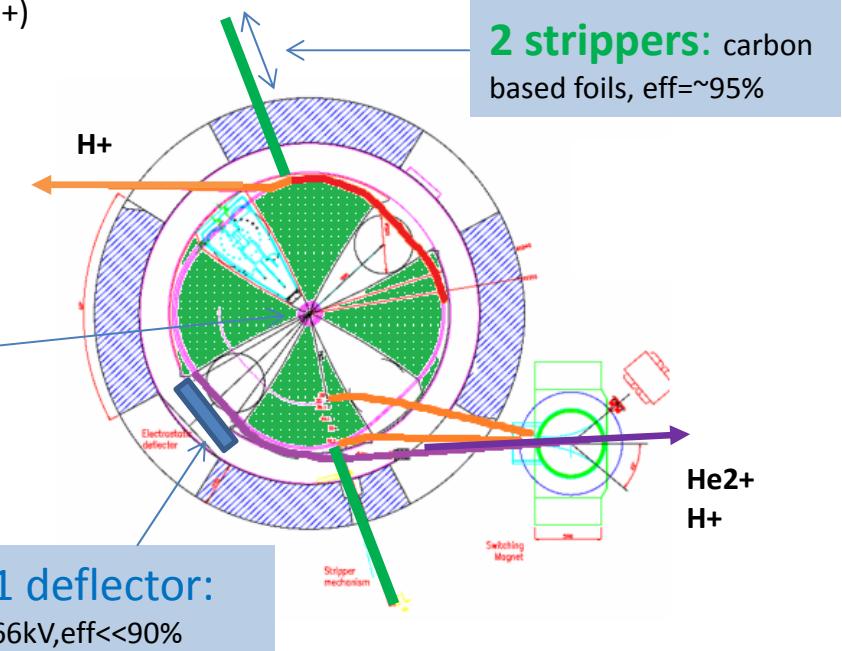
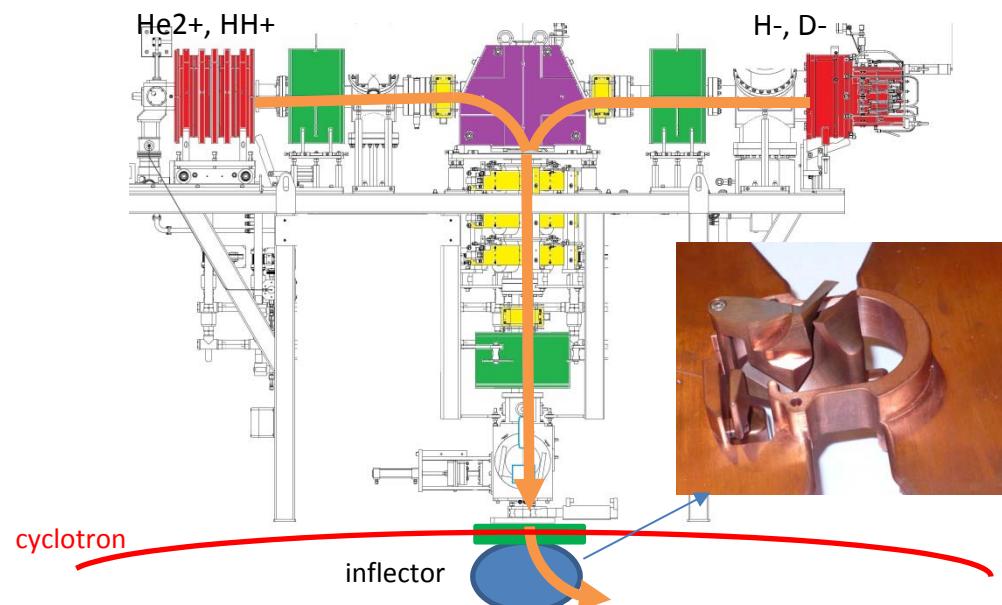
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- A tool for physics research
  - Particularly studies of material under irradiation
  - Development of detection system
  - Measurements of nuclear data
- A tool for training and education
  - University of Nantes
  - École des mines of Nantes
  - CHU (academic hospital) of Nantes
  - Permanent and dedicated trainings
- An industrial production site for medical needs

# Characteristics

- C70 Cyclotron build by IBA:
  - Isochron cyclotron with 4 sectors
    - RF: 30.45 MHz
    - Acceleration Voltage: 65 kV
    - Max magn. field : 1.6T
  - ~4m of diameter
  - Max kinetic energy/n: 30-70 MeV
  - Normalised emittance before extraction:  $\gamma\varepsilon_x = \sim 4\pi \text{ mm mrad}$  (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 (+)

Extracted Particles	Energy range (MeV)	Highest possible current ( $\mu\text{Ae}$ )	most common current range ( $\mu\text{Ae}$ )	Nb of particles / bunch at 1 $\mu\text{Ae}$
H+	30 - 70	375 x 2	0.05 – 80 x 2	205 10 <sup>3</sup>
He2+	70	70	0.07 – 0.1	102 10 <sup>3</sup>
HH+	35	50	0.1 – 1	410 10 <sup>3</sup>
D+	15 - 35	50	0.05 – 1.2	205 10 <sup>3</sup>



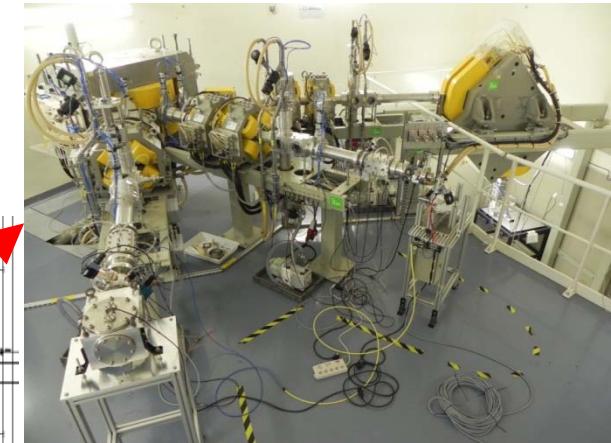
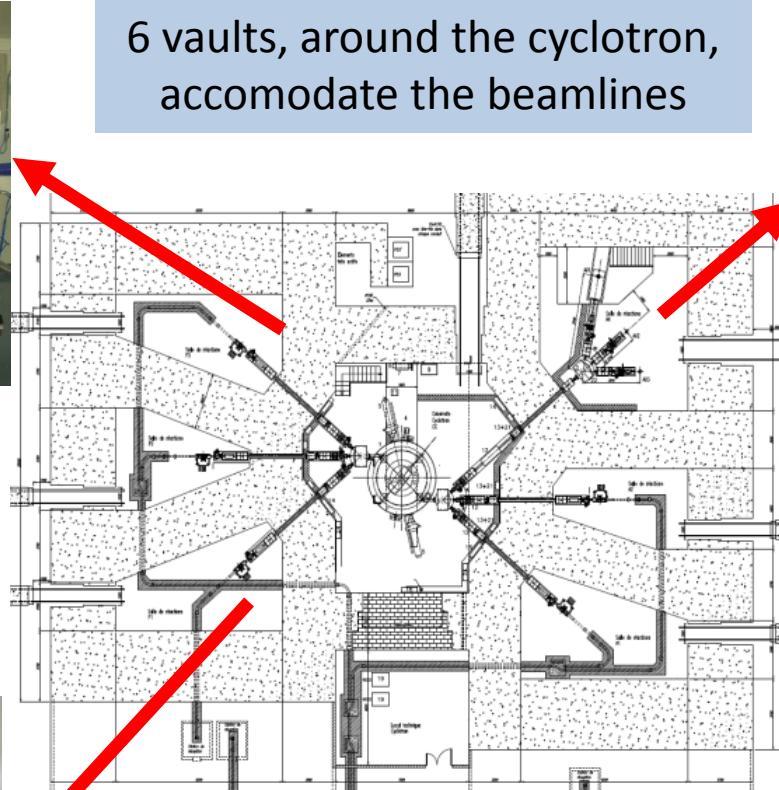
# Beamlines Today



Beamline with irradiation station accomodating rabbits with samples



Beamline for neutronic activator



3 beamlines are dedicated to low current ( $<1.2\mu\text{A}$ ) in the same vault  
1 of these is a top-bottom line with a vertical dipole

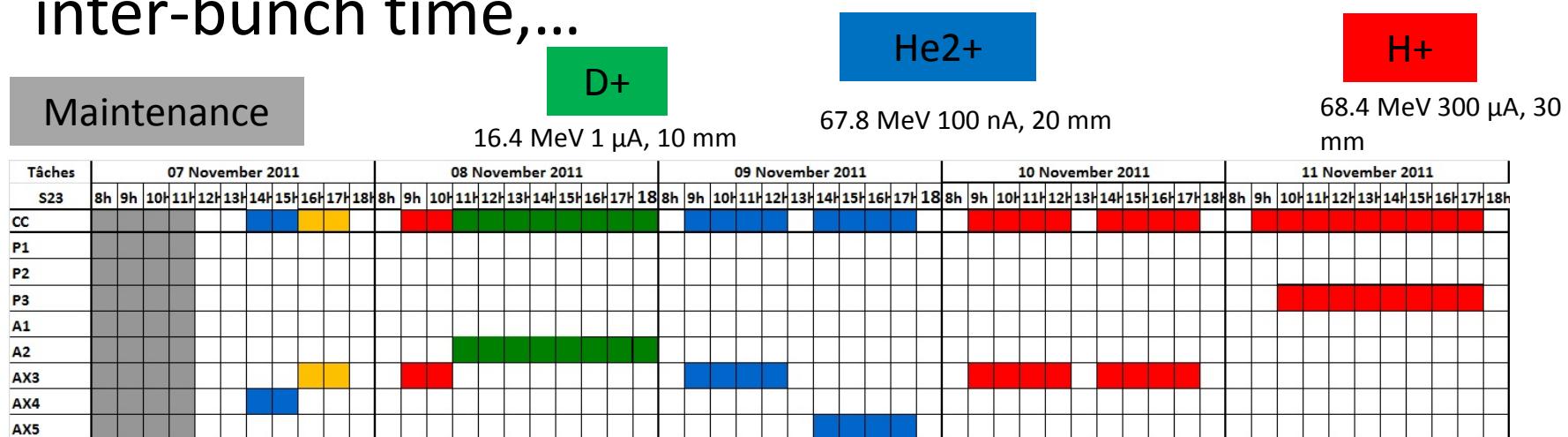
## Beamlines:

- 8 in total
  - 5 dedicated to average and high current
  - 3 dedicated to low (or very low) current

# Operations

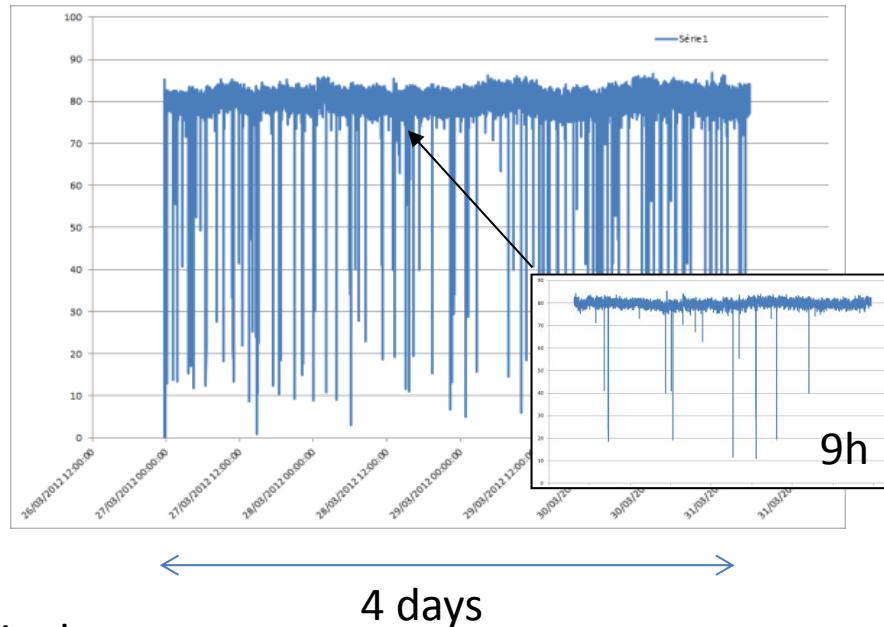
<b>Extracted Particles</b>	<b>Energy range (MeV)</b>	<b>Highest possible current (eμA)</b>	<b>most common current range (eμA)</b>	<b>Nb of particles / bunch at 1 eμA</b>
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Very diverse weeks in terms of beam parameters and beamlines: particles types, energies, beam size, inter-bunch time,...



# Operations

Single 80  $\mu\text{A}$  runs on target at irradiation station



Single run:

- 80.23  $\mu\text{A}$ ,  $\sigma_{\langle i \rangle} = 1.35 \mu\text{A}$
- 1.6% intensity losses (of overall time)

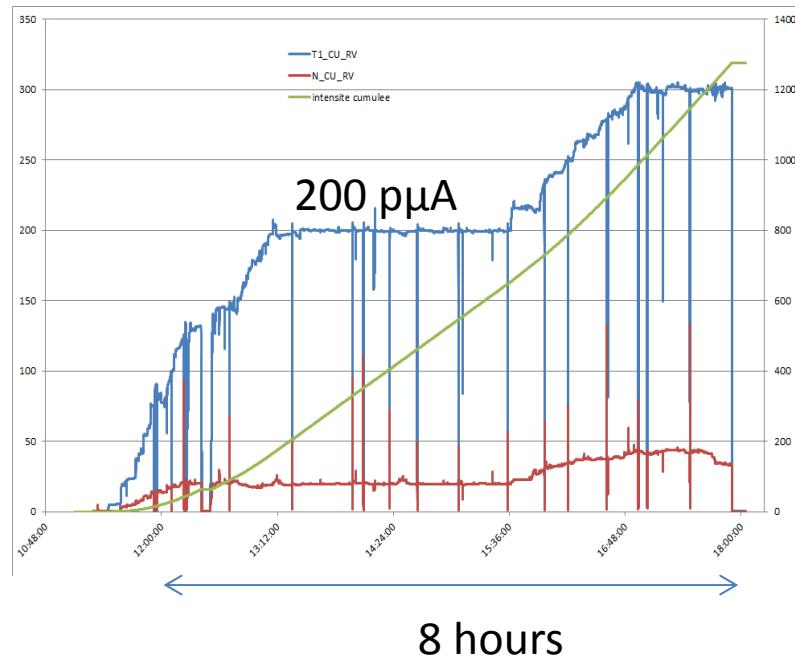
Dual run:

- $\sigma_{\langle i \rangle} = 2.2 \mu\text{A}$  (average over both beams)

Stability studies: in view of general procedure studies of machine, beamlines, and targets before intensity ramp-ups

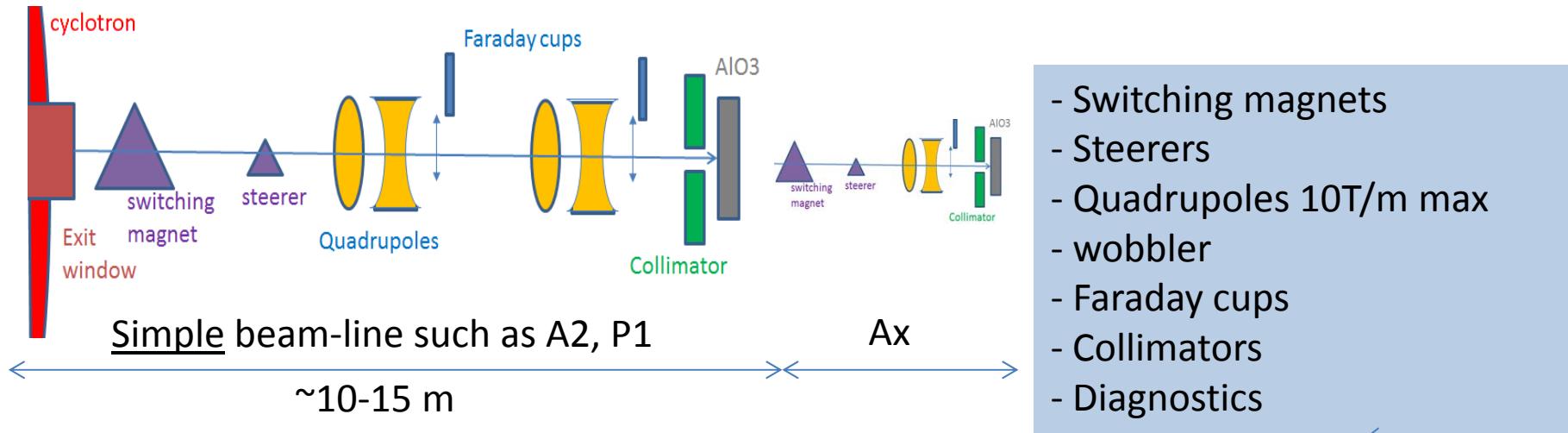
Cyclotron ARRONAX

On neutronic activator 300  $\mu\text{A}$



Test of strategy for current ramp-ups up to 200  $\mu\text{A}$  and to 300  $\mu\text{A}$   
(Constrain from the user are in addition)

# Beam Transport and lines



## Need for Beam Transport Strategy

- It is primarily dependent on what is behind the collimators i.e. if the experimental target is far downstream and which intensity is used.

- 1) current optimisation, using inserted faraday cups, and/or beam dumps at end of line if there is one
- 2) Beam transverse size optimisation

At high current and on an irradiation station with a rabbit, the beam is centred on the collimators upstream the station. The electrical deposit is the measurements

At low current, and for specific needs, optimisation is slightly more complex and relies on dipoles and quadrupoles modifications to get the right beam.

→ diagnostics

# 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:

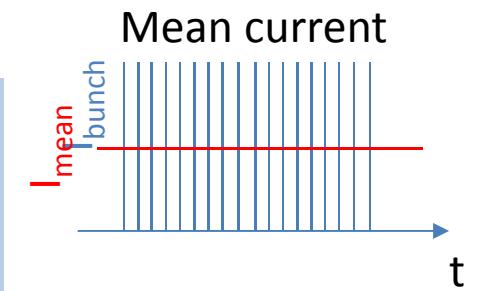
Water cooled layers of titanium /aluminium

15kW max (i.e  $\sim 210\mu A$  at 70MeV)

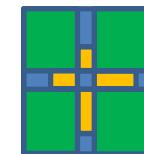
- Beam dumps combined or not with a current integrator (at very low current)

- Profilers: measures the beam density

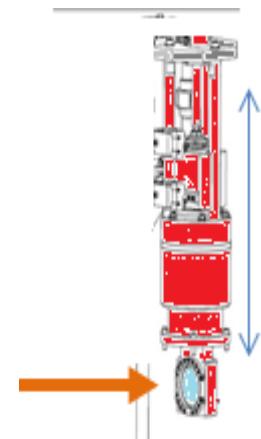
- Alumina foils: or thin film foils for location and size measurements at end of line



Collimator readings



Faraday cup



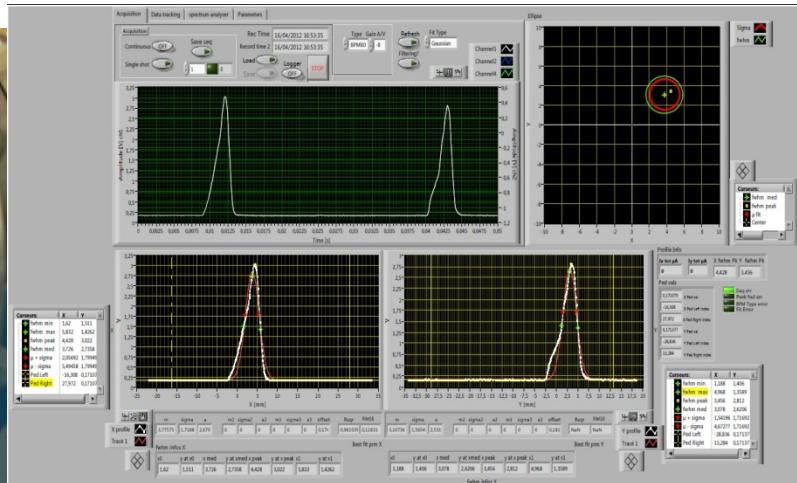
# Diagnostics II

## 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  $\mu$ A for a 10 mm beam

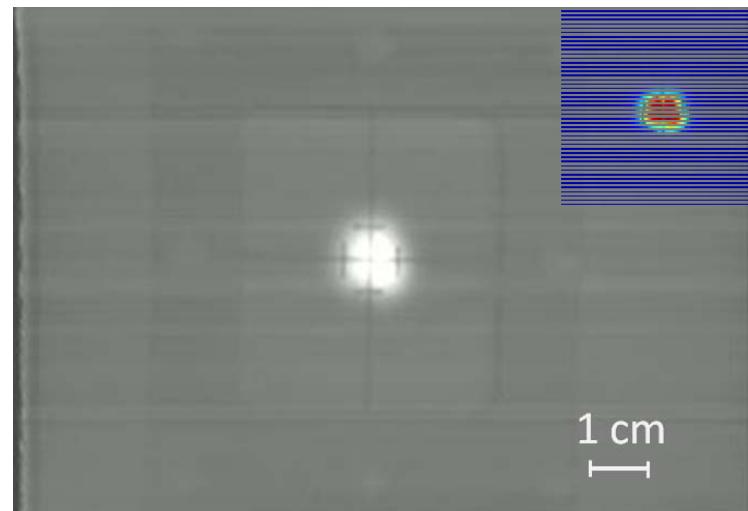


On-line analysis of beam x-y density



## Alumina foil (AlO3) - thickness 1 mm:

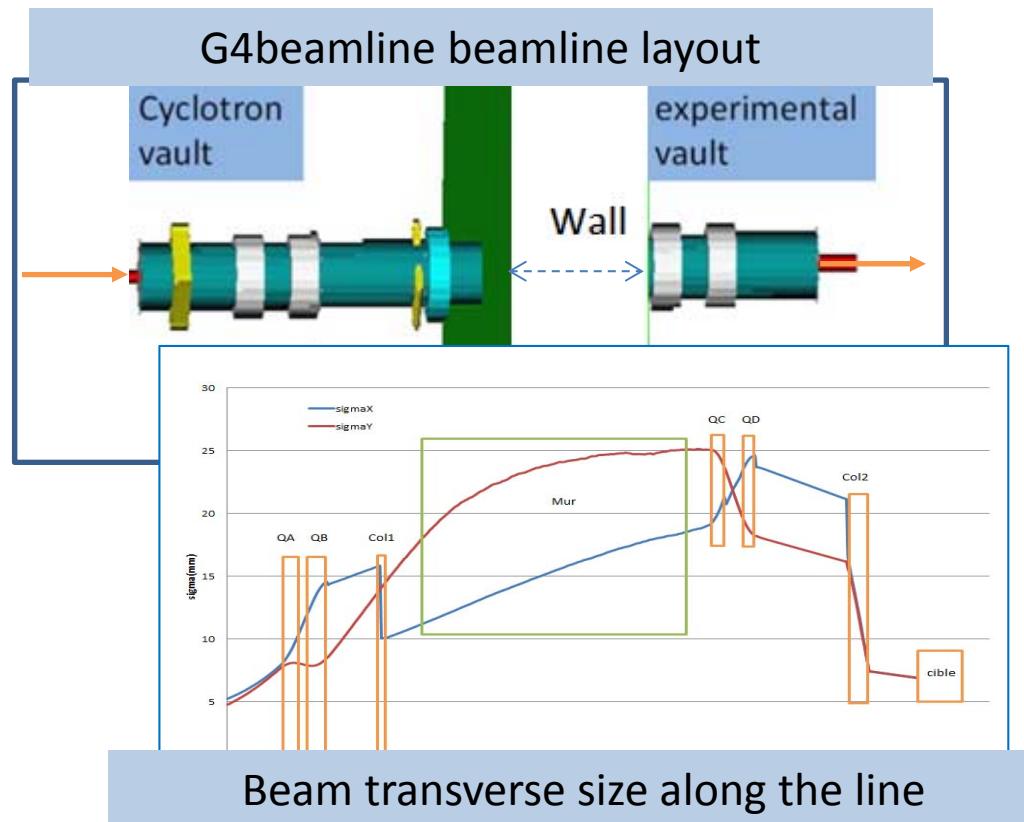
- Installed outside the line, downstream the exit thin kapton (75  $\mu$ m) window
- Check of the center and beam size
- $\sim 1\text{nA} < I_{\text{moy}} < \sim 150 \text{nA}$  for protons and alpha
- Vidikon Camera (radiation hard)
- → Off-line analysis code is developed in GMO, based a Matlab tool from LAL.



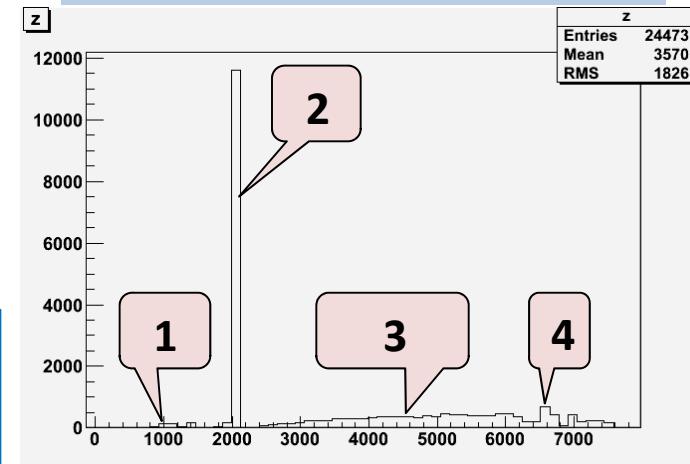
# Simulation

- 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?

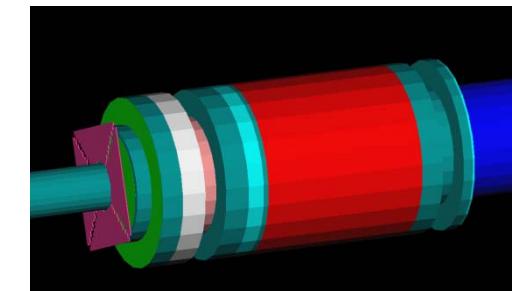
Exemples with G4beamline:



particles losses along the beamline



Details close to beamline end



# Maintenance

- The maintenance knowledge is mainly based on existing C30: Preventive + adaptation to C70 specificities.
- The strategy used here is get-to-know the machine:
  - 4 weeks/year: Main maintenance (IBA)
  - Weekly (Mondays) beamline-cyclotron round watch:
    - List of check-ups done by maintenance group.
    - + whenever problems
  - Building up a “memory” of the machine problems via an electronic logbook (see later)
  - Keeping the information flow between IBA and ARRONAX (both ways):
    - Tasks/Information exchange charts in use at each IBA/Arronax technical meeting since beg. 2011. (very helpful to recall problems and keep tracks, and make sure there is a resolution in view)
  - Training of the GMO team with radio protection group

# Electronic log book (elog)

- Multi-parameters table filled in by the GMO (Operation & Maintenance Group) → from PSI

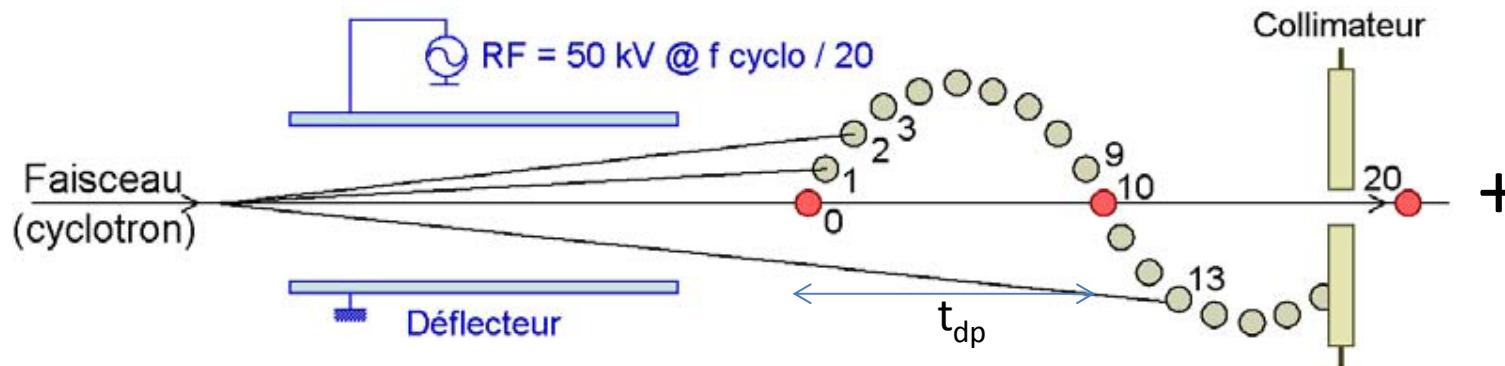
Logbook GMO maintenance, Toutes les entrées												Connecté sous "freddy poirier"	GMO GROUPE MAINTENANCE & OPERATION							
Créer   Chercher   Sélectionner   Importation   Changer le mot de passe   Se déconnecter   Aide																				
Détail   Résumé   Arborescence													-- Toutes les entrées --	-- Intervenant --	-- Structure --	-- Equipement --	-- Etat apres intervention --	-- Localisation --	-- Action --	108 Entrées
Aller à la page <a href="#">1</a> , <a href="#">2</a> , <a href="#">3</a> , <a href="#">4</a> , <a href="#">5</a> , <a href="#">6</a>																				
ID	Date	Date d'intervention	Motif Intervention	Intervenant	Structure	Localisation	Equipement	Statut Cyclo	Etat apres intervention	Action	Texte									
63	vendredi, 01 avril 2011 -- 17:03	vendredi, 01 avril 2011	Surveillance	POIRIER F.	Cyclo	Ax3	Circuits de refroidissement	Intervention sans consequence	OK	Declaration/Diagnostique	- En AX3, toutes les leds sont dans le rouge (sauf A) sur le boitier de la herse eau-air, a gauche de AX3. JBO									
88	mardi, 16 août 2011 -- 16:28	mardi, 16 août 2011	Panne	MACE E.	Cyclo	salle alimentation	Magnetisme	Intervention sans consequence	OK	Termine	La pompe d'eau de la salle d'alimentation (pour l'armoire des aimants de compensation CCI, CCM et CCE) était OFF									
78	vendredi, 08 juillet 2011 -- 13:56	vendredi, 08 juillet 2011	Preventif	GIRAULT S.	Cyclo	Ax4	Lignes transport faisceau	Intervention sans consequence	OK	Declaration/Diagnostique	La feuille kapton montée sur la bride fin de ligne AX4 est marquée ( Brûlissemment d'une partie).									
54	mercredi, 16 mars 2011 -- 10:27	mercredi, 16 mars 2011	Panne	MACE E.	Cyclo	salle alimentation	RF [amplis; Dees; Accord; Gene]	Arrêt TOTAL	OK	Termine	Problème sur RF: Sur FPA (Chaine d'Ampli Final), l'Anode et l'Ecran ne passe pas en jaune.									
81	vendredi, 22 juillet 2011 -- 13:53	vendredi, 22 juillet 2011	Panne	HUET C.	Cyclo	salle alimentation	Stations d'irradiation	possibles	OK	Termine	constaté inversion des câbles des détecteurs de présence d'eau entre p2 et P3 dans l'armoire PS4 à l'arrière									

- Maintenance (12 global parameters):
  - ID number
  - Message Date
  - Intervention date
  - Intervention reason (failure, surveillance, preparation)
  - Person in charge
  - Structure (cyclo, environment)
  - Location (beamlines, cyclo, technical rooms,...)
  - Equipment (beam dump, irradiation stations, strippers, sources, water cooling, cryo pump,...)
  - Status of the cyclotron
  - Action (finished, ongoing,...)
  - Comments + attached files
- Beam on (25 parameters):
  - Pilots, particles, beamlines, targets, energy, current, comments, attached files,...

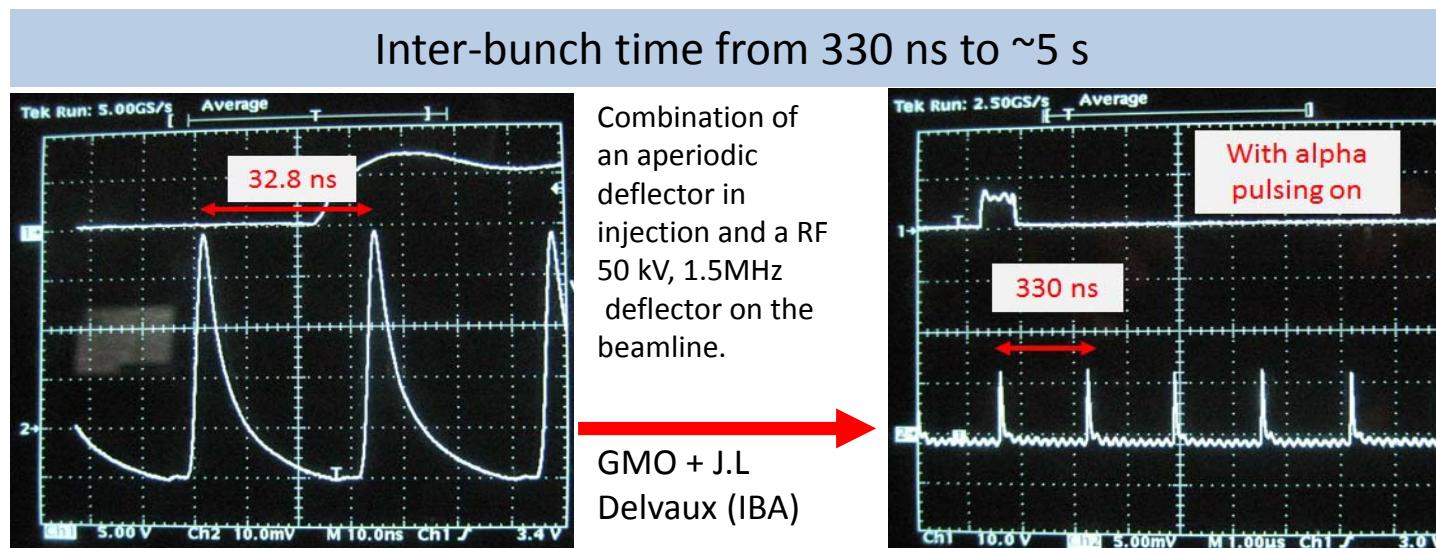
This is not a tracking tool  
but it will help to define  
later the data base  
required

# Cyclotron Adaptations

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



Aperiod. Def.:  
increases the  
inter-bunch  
time by  $n \times t_{dp}$ .



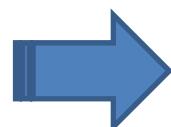
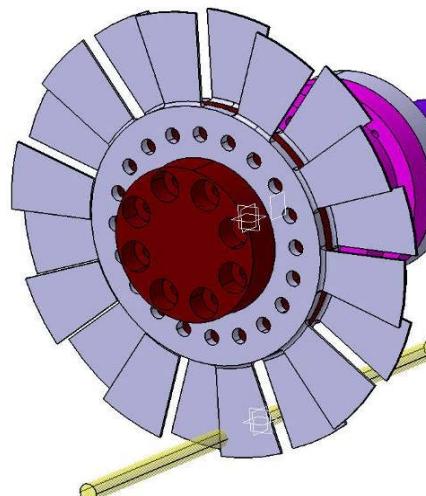
More work on transverse optimisation has to be done

To get towards more user friendly setup

# Beamline Adaptations

- Energy degrader for proton and alpha (Subatech/ARRONAX)
  - In order to get a larger range of available energies (10 to 30 MeV)
    - Protons: Aluminum window of diameter= 10 mm, water thickness = 0.7 mm
    - Alpha: Rotating wheel with 20 aluminium plates (1.25 mm thick)
  - Degrader Installation has been done and the water cooling system has been tested

Alpha degrader:



Proton degrader:



# Present and Future

- The C70 ARRONAX cyclotron is in the hands-on phase:
  - Operations et Maintenances have lead to a high beam uptime (>85%)
    - Injection solenoid has been changed
  - The maintenance and operation group in charge of the cyclotron and its beamlines are gathering the know-how, important for the future of the machine:
    - Time constrain from future users will tighten
    - Towards 3x8 hours and more industrial standards
- For the long term use:
  - Some key points to consolidate:
    - Beam strategy optimisation
    - Studies on beam repeatability
    - Beam characterisation: off-line & on-line codes to check beams
  - Some necessary work: Extension of diagnostics
    - Energy measurements after degradation
    - Studies for Beam Loss monitor , Beam position monitor, ....
    - Development of Data acquisition system for beamlines, cyclotron
  - Continuous development of lines and cyclotron:
    - Installation of energy degrader
    - Neutronic activator (several beam tests done → on-going analysis and validation)
    - Increase of current sent to the sample carriers (rabbits) -long term



• Thank you!