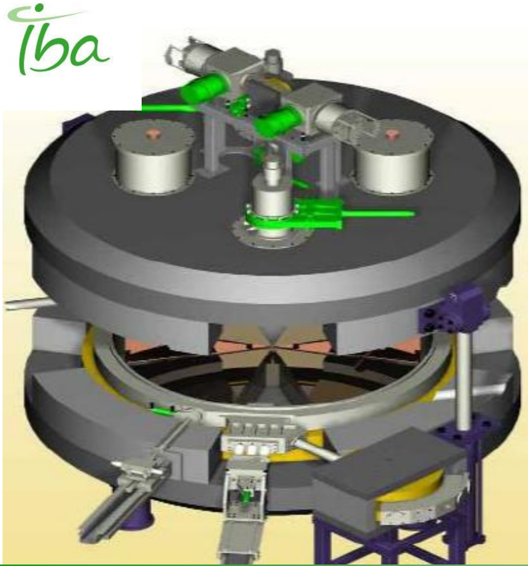
The C70 ARRONAX Hands-on phase and operation

Freddy Poirier (IN2P3/Subatech)

WAO 2012

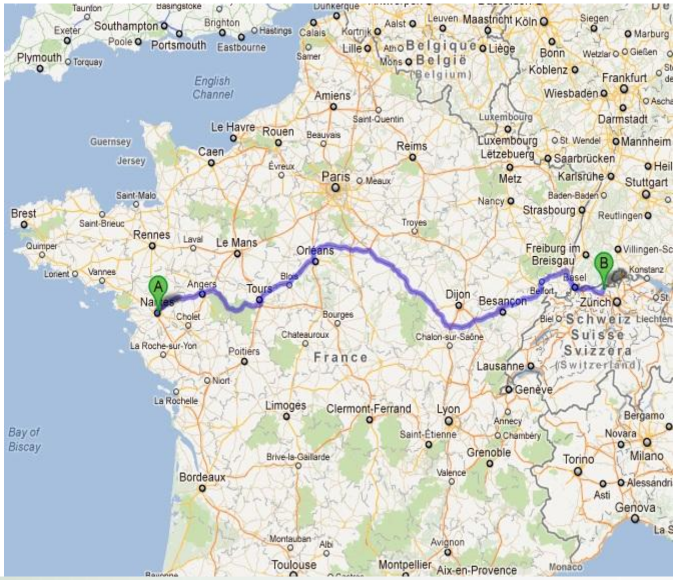
IPAC 2011: "C70 and beamlines status", WEPS69
IPAC 2012: "C70 Hands-on phase", MOPPD024



ARRONAX

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

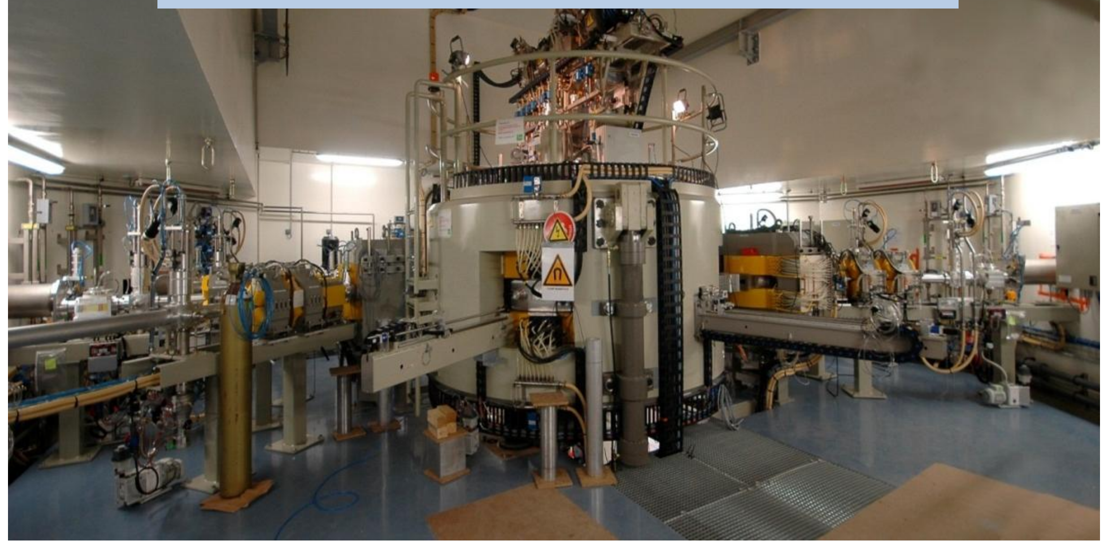
Operation and Maintenance team:
S.Girault, F.Gomez-Serito, C.Huet, L.Lamouric, E.Mace, F.Poirier



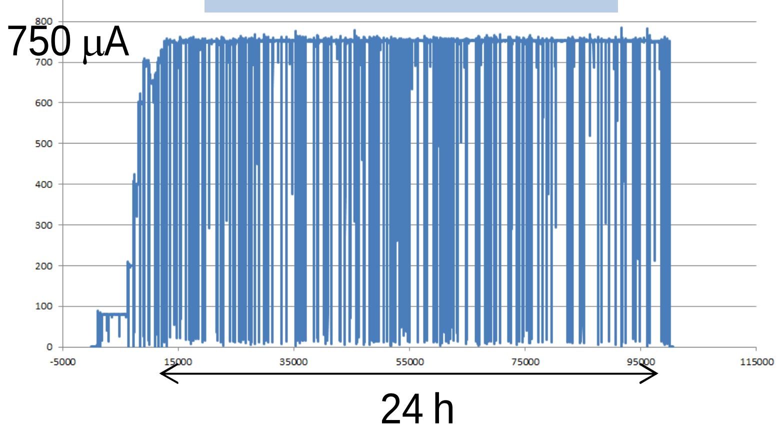
Historical Background

Inauguration in 2008

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



24h tests in 2010

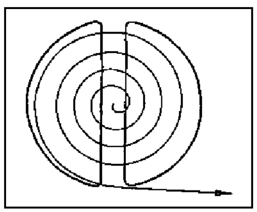


- October 2008 : Inauguration
- March 2010: Low intensity Irradiation
- October 2010: 24h at 750 pµA on beam dumps
- Dec. 2010: Final machine reception
- 2011-12: Hands-on phase with an extended program on tuning and exploration of beam parameters for users.

ARRONAX goal

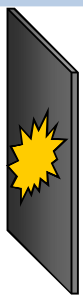
- A tool to produce radionucleides for research in nuclear medecine
  - Imaging: β+ radioelements for PET (ex: ^{82}Sr/^{82}Rb, $^{44m/44}$Sc, ^{52}Fe, ^{64}Cu ...)
  - Therapy: α immunotherapy (^{211}At), β^- radioelements : ^{67}Cu, ^{47}Sc

Radioelement for therapy



Acceleration

Particles Beam



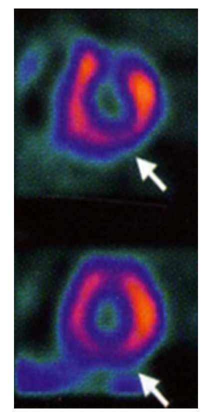
Target irradiation

Production of radioelements
In the target by transmutation

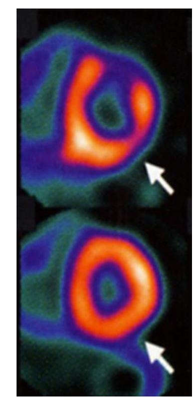
Chemical extraction
Separation
Purification
Marking

Radioactive
medical
element
(experimental)

Tomographic imaging of the heart



^{99}Tc-MIBI
SPECT



^{82}Rb-PET

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  - notably alpha radiolyse of water (eg nuclear waste storage)

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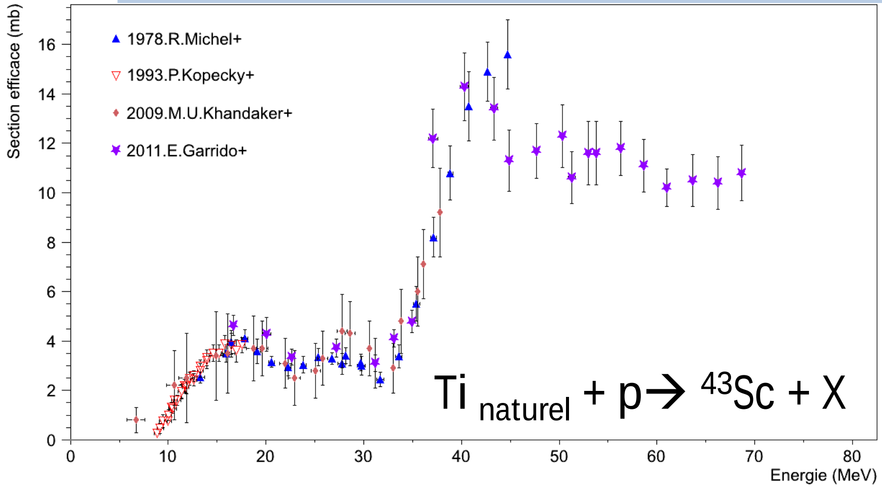
- A tool for physics research
  - Particularly studies of material under irradiation
  - Development of detection system
  - Measurements of nuclear data

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



PIXE - Particle Induced X-ray Emission
- Non destructive Caracterisation Method of multielements material, quantitative
- Dvt of mesuring bench
- (~nA)

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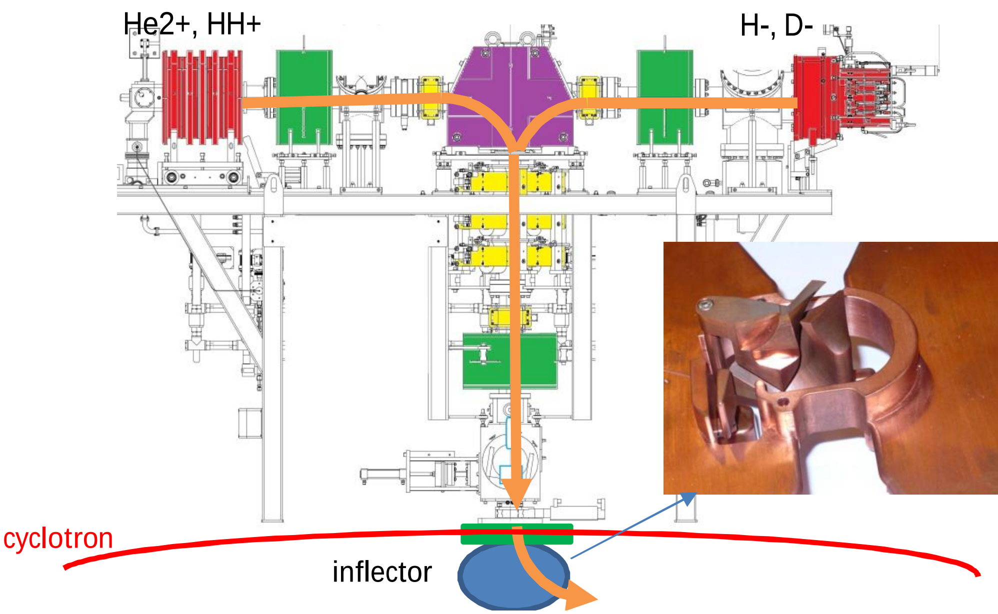
  - Particularly studies of material under irradiation
  - Development of detection system
  - Measurements of nuclear data
- A tool for training and education
  - University of Nantes
  - École des mines of Nantes
  - CHU (accademic hospital) of Nantes
  - Permanent and dedicated trainings
- An industrial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

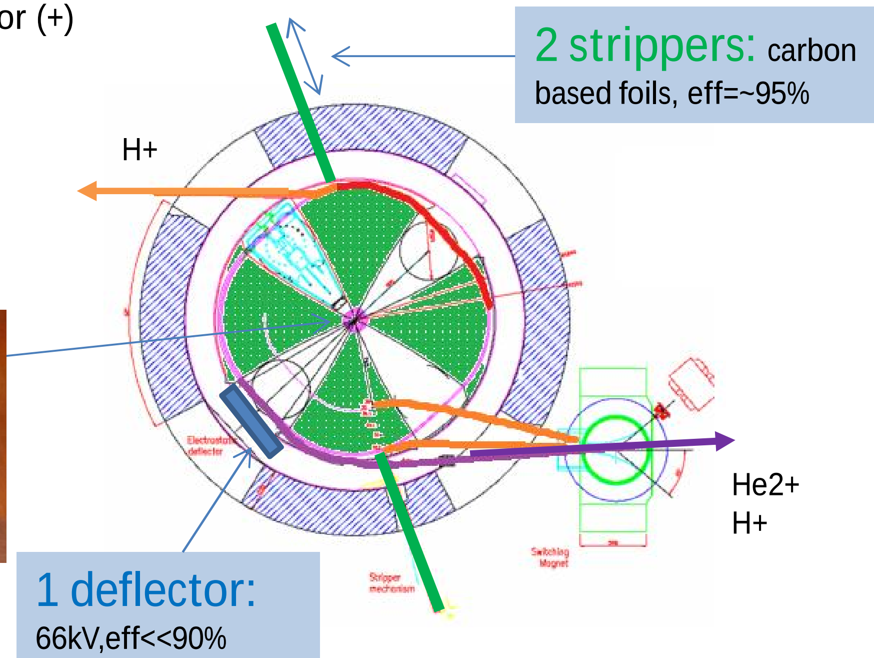
Characteristics

- 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: $\gamma\varepsilon_x$=~4π mm mrad (simulation)

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

- 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 (+)

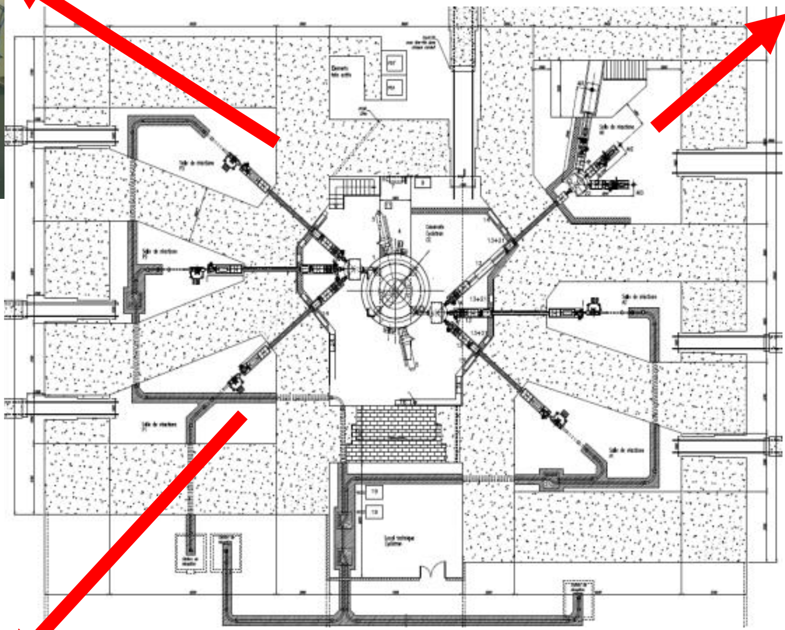


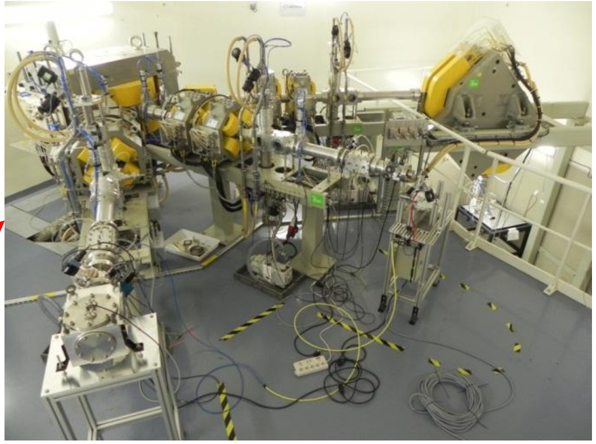


Beamlines Today

Beamline with irradiation station accomodating rabbits with samples

6 vaults, around the cyclotron, accomodate the beamlines





3 beamlines are dedicated to low current (<1.2μA) in the same vault
1 of these is a top-bottom line with a vertical dipole

Beamline for neutronic activator

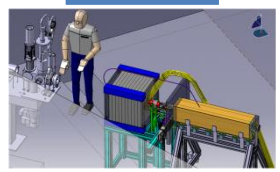
Beamlines:

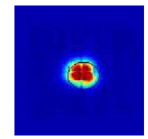
- 8 in total
  - 5 dedicated to average and high current
  - 3 dedicated to low (or very low) current

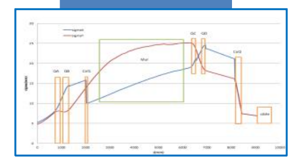
How we do business (1)

GMO: Maintenance and Operation Group Tasks

- Operation
  - Beam follow up, Beam Optimisation, Beam Creation
- Maintenance and beamline adaptation
  - Curative, preventive
- External Projects
- Computing
- Developments
- Beam dynamics







GMO: 6 persons
3 have more than 3 years of experience and are “senior operators”

- Operators deal with basically every aspects of the accelerator: Operation, maintenance, users, developments (beamline, diagnostics), computers, mechanics, beam dynamics.
- To comply with french law on industrial accelerators (yes this cyclotron falls into this class by its use), they have to pass a national certificate: camari
- Each operator is 3 times a week in charge of the operation with/without a senior (that is when every one is on site) for none “heavy weeks”.

Operations

Very diverse weeks in terms of beam parameters and beamlines: particles types, energies, beam size, inter-bunch time,…

“None-heavy” operational weeks:

Maintenance

D+

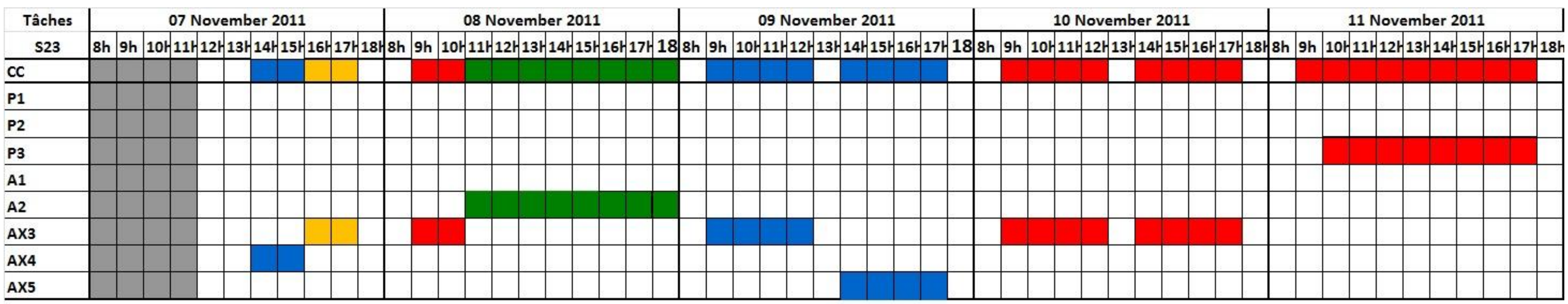
16.4 MeV 1 µA, 10 mm

He2+

67.8 MeV 100 nA, 20 mm

H+

68.4 MeV 300 µA, 30 mm



Tuning of the machine and beamline is performed before sending the beam to the users and can take up to a few hours

+ heavy weeks: so called production week: Approximately, once a month over a week the group is on 24h operation with 38.5 hours/week/ope

Require a minimum of 4 persons for this

Agenda of a scheduled week not a cyclotron/beamline use

How we do business (2)

For these production weeks: e.g. 24 hours/days over 5 days

Mornings	6h30→14h12	x5/week	op1
Evenings	14h00→21h42	x5/week	op2
Nights*	21h15→6h45	x4/week	op3
Days	9h00→17h42	x5/week	op4 (5-6)

With this scheme (tested 3 times so far) each operator keeps the same time slot:
Results:

Worked well but

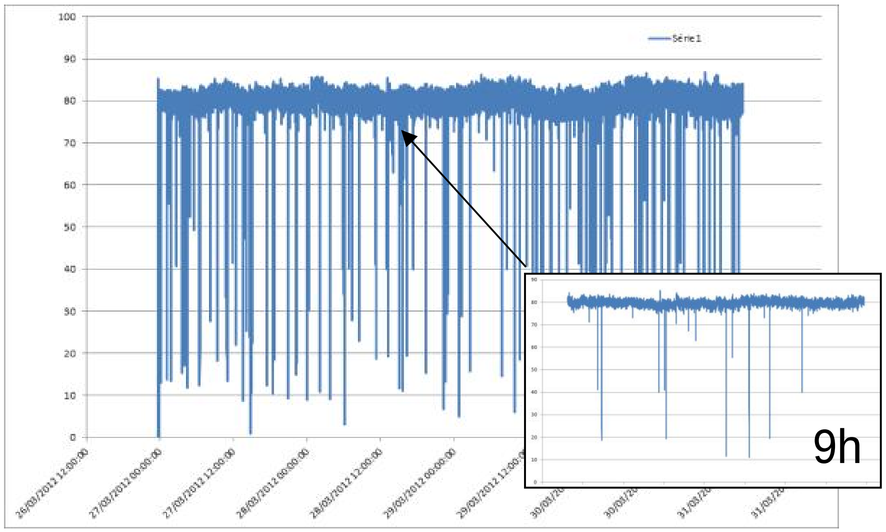
Tiredness

Operation Information is being lost (to some degree), counterbalanced by the use of elog

15 to 30 min of overlay between shifts
+ op during days to help deal with operation + maintenance
*Backed up by the presence of a lab personnel

Operations

Single 80 µA runs on target at irradiation station



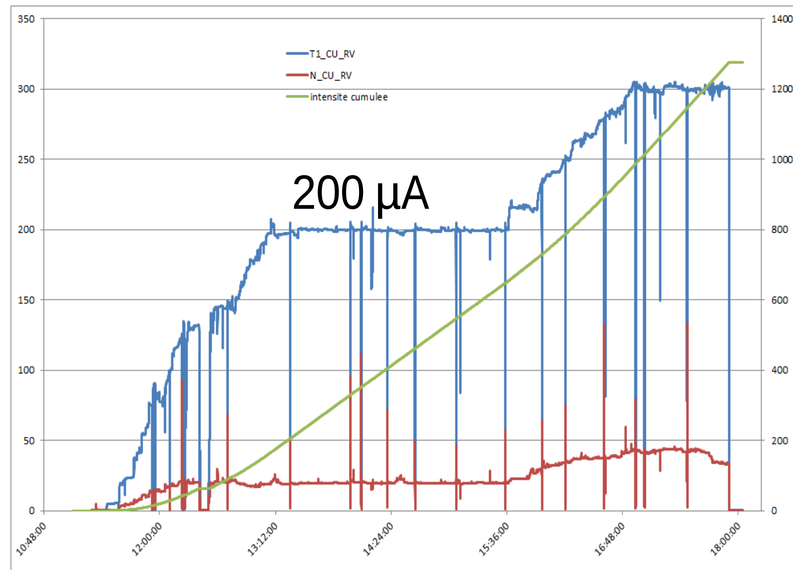
4 days

Single run:
- 80.23 µA, $\sigma_{<i>}$=1.35 µA
- 1.6% intensity losses (of overall time)

Dual run:
- $\sigma_{<i>}$=2.2 µA (average over both beams)

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

On neutronic activator 300 µA

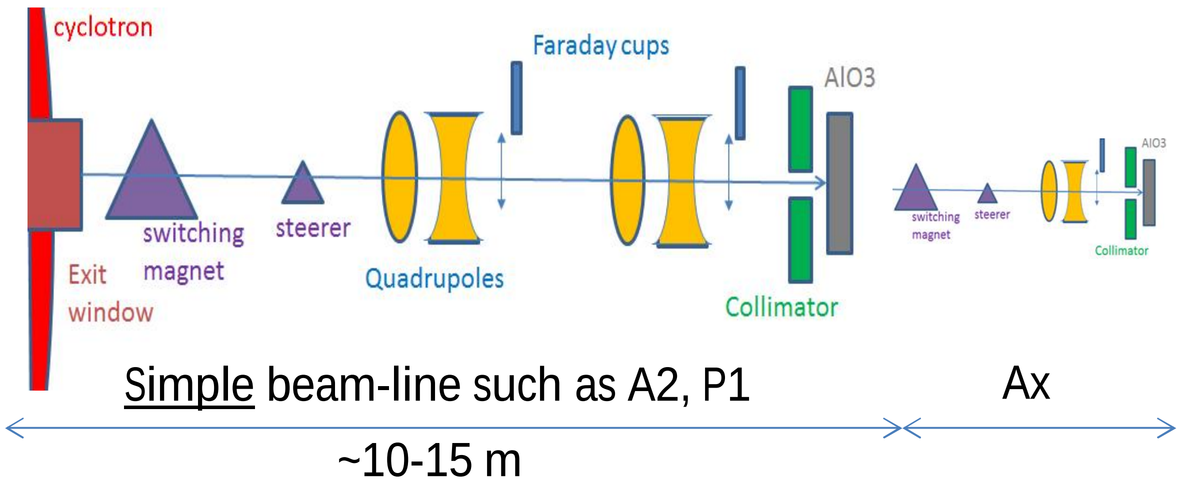


8 hours

Test of strategy for current ramp-ups up to 200 µA and to 300 µA (Constrain from the user are in addition)

Operators are constantly tuning the machine even on steady runs

Beam Transport and lines



- Switching magnets
- Steerers
- Quadrupoles 10T/m max
- wobbler
- Faraday cups
- Collimators
- Diagnostics

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 (Imean):
  - 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:

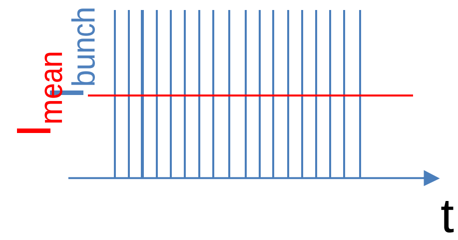
    Water cooled layers of titanium /aluminium

    15kW max (i.e ~210µA at 70MeV)
  - Beam dumps combined or not with a current integrator (at very low current)

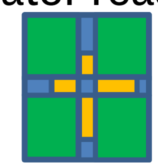
- Profilers: measures the beam density

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

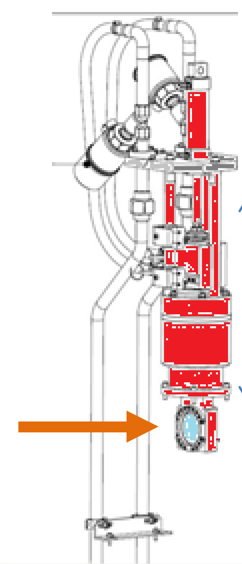
Mean current



Collimator readings

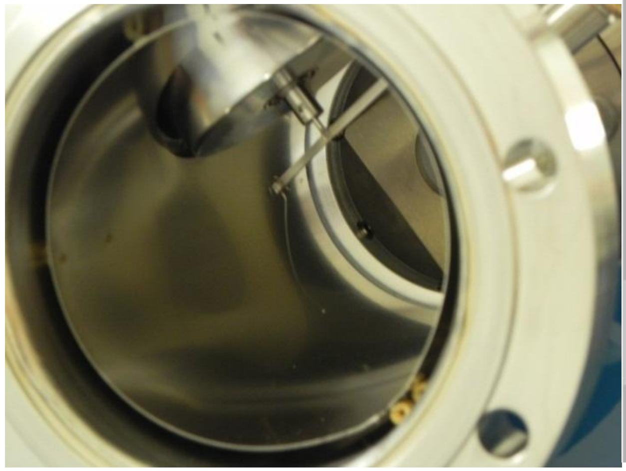


Faraday cup

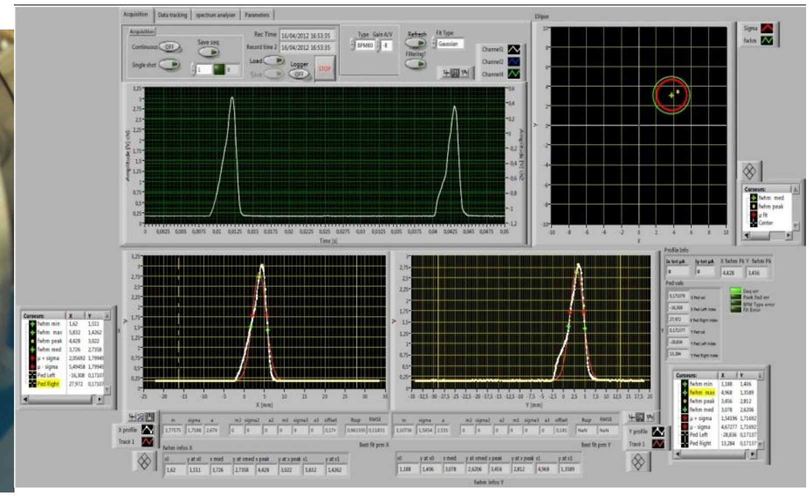


Diagnostics II

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

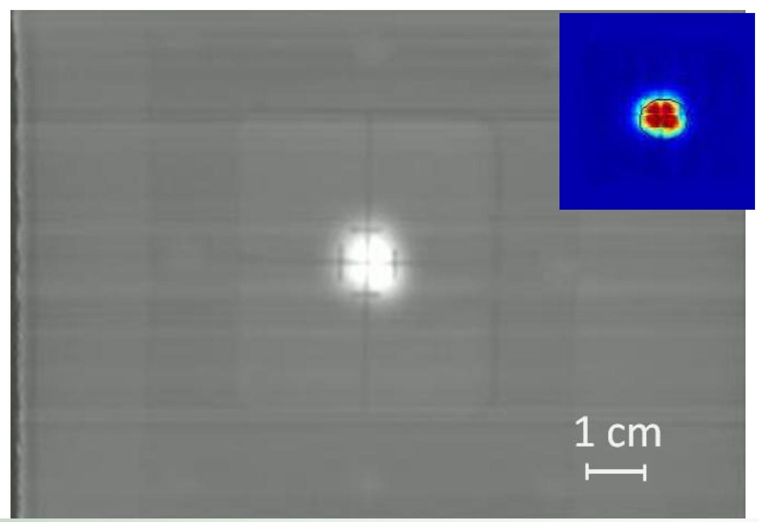


On-line analysis of beam *x-y* density



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.



Maintenance

- The maintenance knowledge is mainly based on existing Cyclotron at lower energies (30 MeV) for Preventive
- Curative: The strategy used here is get-to-know the machine
  - 4 weeks/year: Main maintenance (done with GMO/IBA)
  - Weekly (Mondays) beamline-cyclotron round watch:
    - List of check-ups done by ARRONAX maintenance group.
  - Building up a “memory” of the machine problems via an electronic logbook (see later)
  - Keeping the information flow between cyclotron designer 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

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 1, 2, 3, 4, 5, 6

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 (Brunissement 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]	Arret TOTAL	OK	Termine	Probleme 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 cables des detecteurs de présence d'eau entre p2 et P3 dans l'armoire PS4 a l'arriere	

- 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

Present and Future

- The C70 ARRONAX cyclotron prototype 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 and tuning
    - 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 → ok)
    - Increase of current sent to the sample carriers (rabbits).

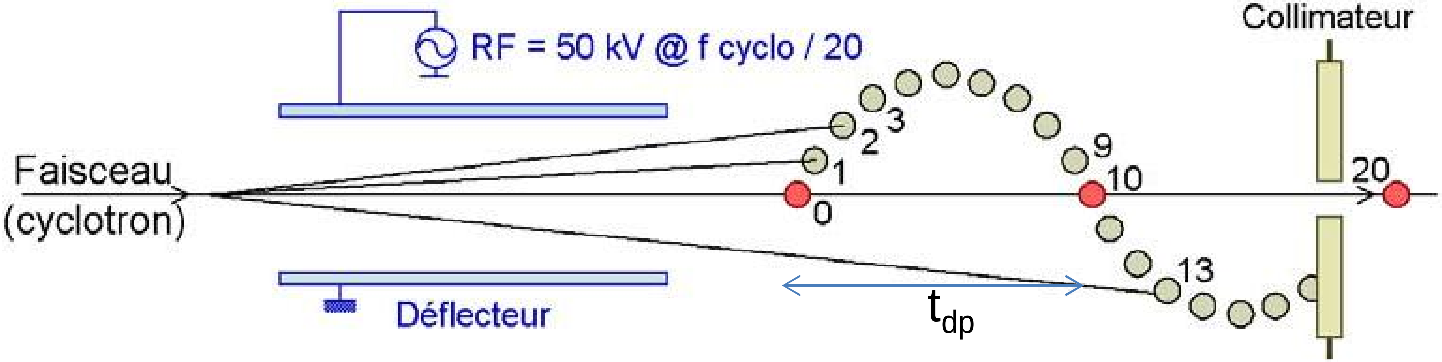
Further

- The group will grow up in numbers
  - Plan is mostly to keep them with operation/maintenance tasks + a specialisation
  - Still relying a lot on flexibility of the operators as we are far from smooth operation
  - Nearly no automation in beam tuning:
    - New possible scheme is being studied based on new diagnostics to be put in: with a Parallel machine/human interface (manpower…gasp!) connected to existing PLC
  - Operators agenda will probably change in view of the latest runs
  - One of the hot topics that we can foresee is communication and tracking information:
    - We'll look at tools (software) that offer this possibilities: CMMS + APS?

- Thank you!

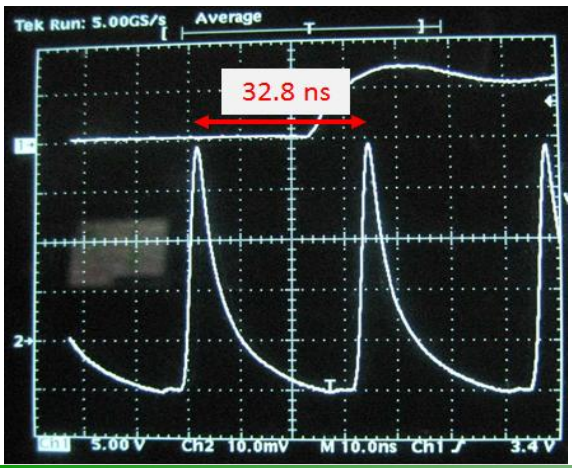
Cyclotron Adaptations

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



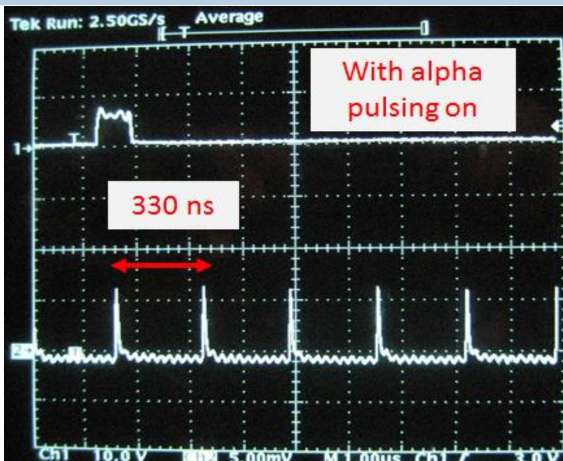
+ Aperiod. Def.: increases the inter-bunch time by n x t_{dp}.

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.

GMO + J.L Delvaux (IBA)



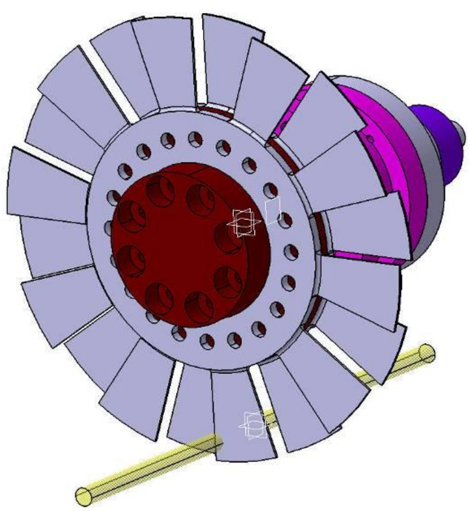
More work on transverse optimisation has to be done

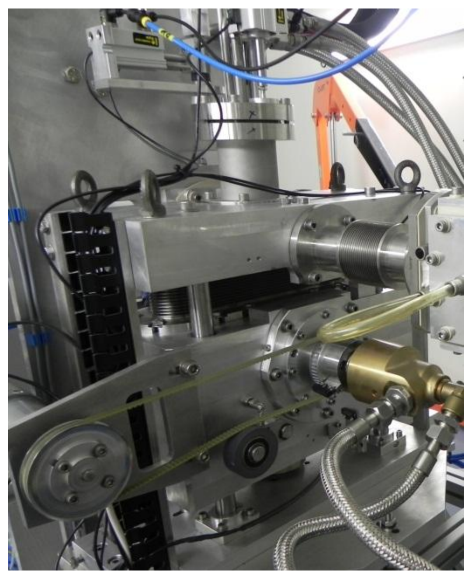
To get towards more user friendly setup

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: Alumium 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:





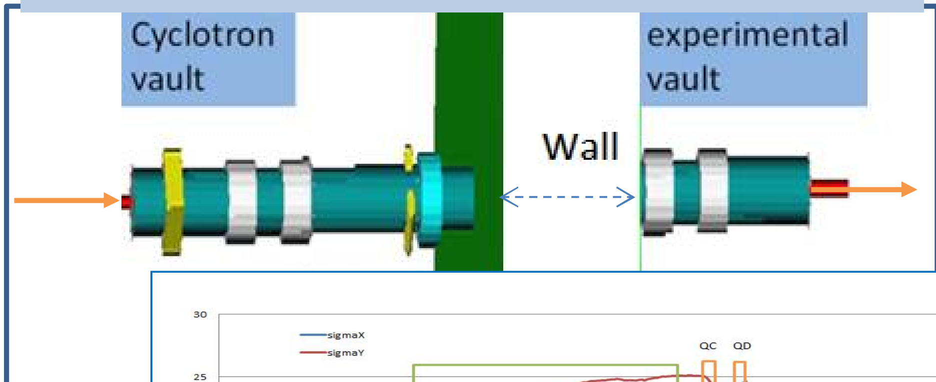
Proton degrader:

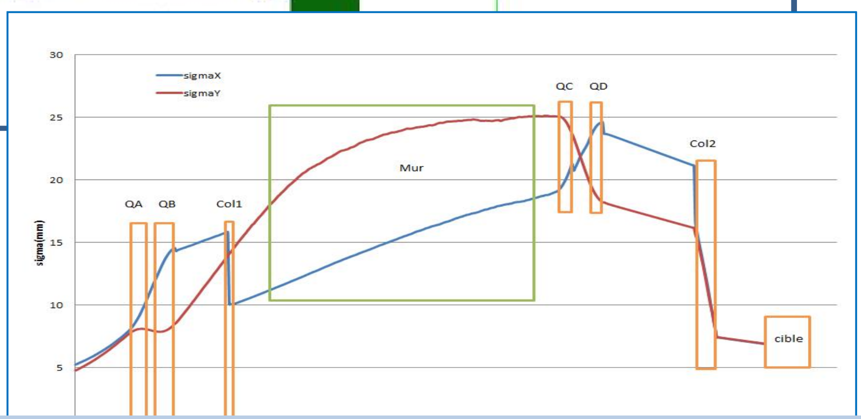
Simulation

- 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?

An exemple with G4beamline:

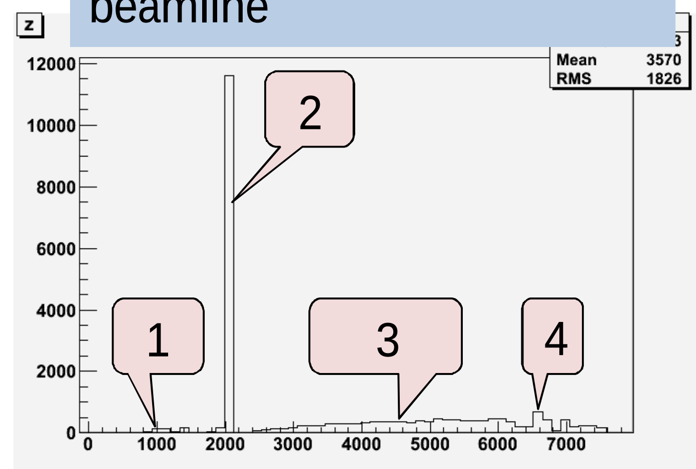
G4beamline beamline layout





Beam transverse size along the line

particles losses along the beamline



Preliminary work from <2 student , W.Tan - EMN