Bunch Extension Monitor for LINAC of SPIRAL2 facility

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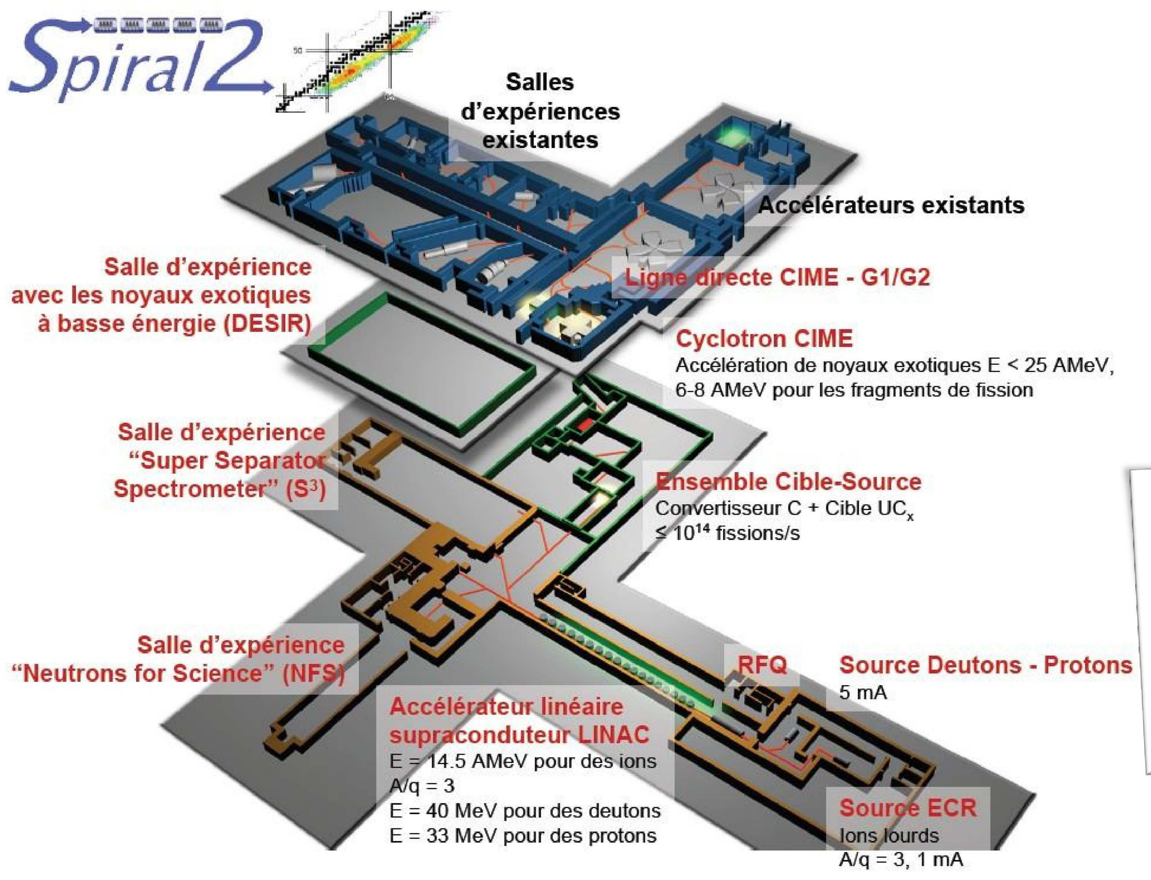
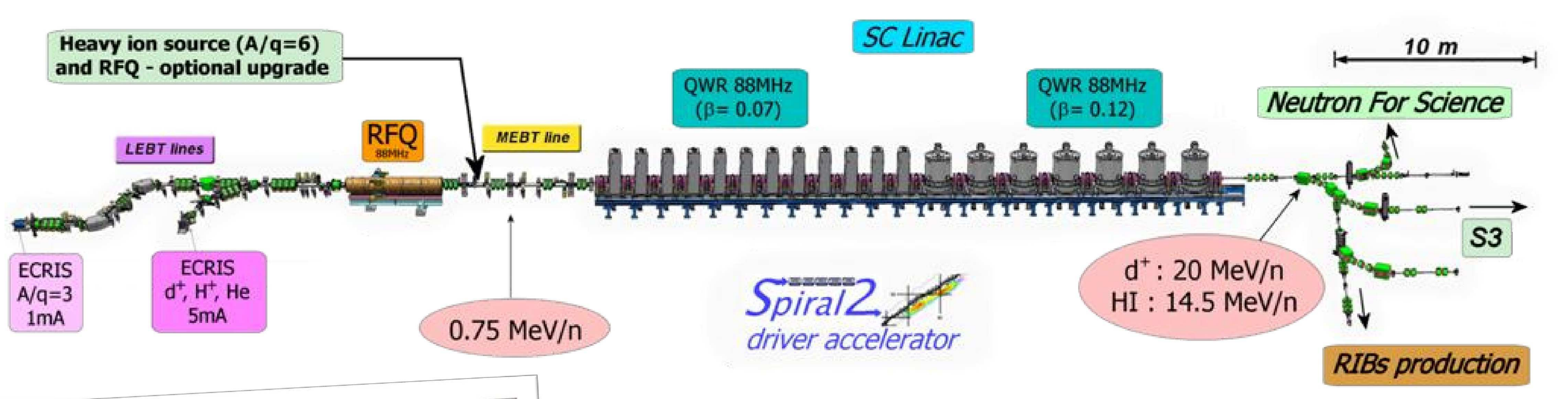
Introduction to SPIRAL2 project

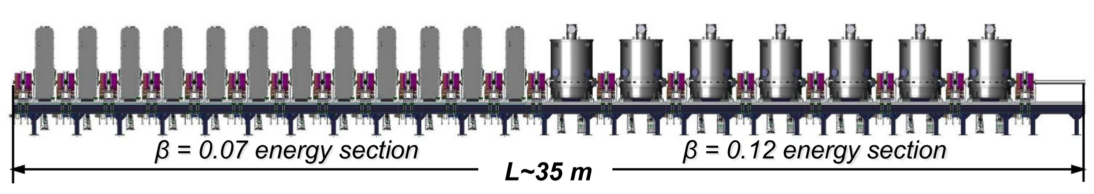


The SPIRAL2 project is based on a multi-beam driver in order to allow both ISOL and low-energy in-flight techniques to produce RIB. A superconducting light/heavy-ion linac with an acceleration potential of about 40 MV capable of accelerating 5 mA deuterons up to 40 MeV and 1 mA heavy ions up to 14.5 MeV/u is used to bombard both thick and thin targets. These beams could be used for the production of intense RIB by several reaction mechanisms (fusion, fission, transfer, etc.) and technical methods (ISOL, IGISOL, recoil spectrometers, etc.). The production of high intensity RIB of neutron-rich nuclei will be based on fission of uranium target induced by neutrons, obtained from a deuteron beam impinging on a graphite converter (up to 10^{14} fissions/s) or by a direct irradiation with a deuteron, 3He or 4He beam.

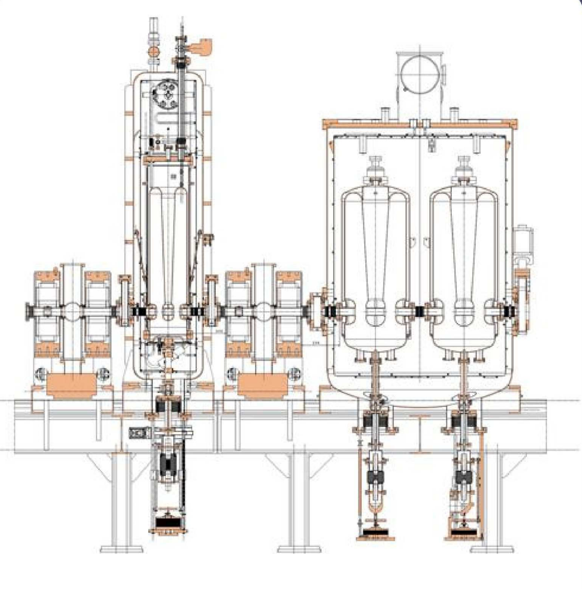
The post acceleration of RIB in the SPIRAL2 project is assured by the existing CIME cyclotron, which is well adapted for separation and acceleration of ions in the energy range from about 3 to 10 MeV/u for masses A~100-150. SPIRAL2 beams, both before and after acceleration, can be used in the present experimental area of GANIL.

The LINAC driver

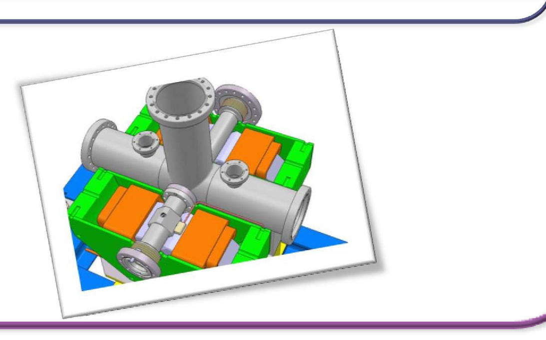




Particles	Protons	Deutons	Ions	
Q/A	1	1/2	1/3	1/6
I (mA) max.	5	5	1	1
W_O min. (Mev/A)	2	2	2	2
W_O max. (Mev/A)	33	20	14.5	8.5
CW max. beam power (KW)	165	200	44	48



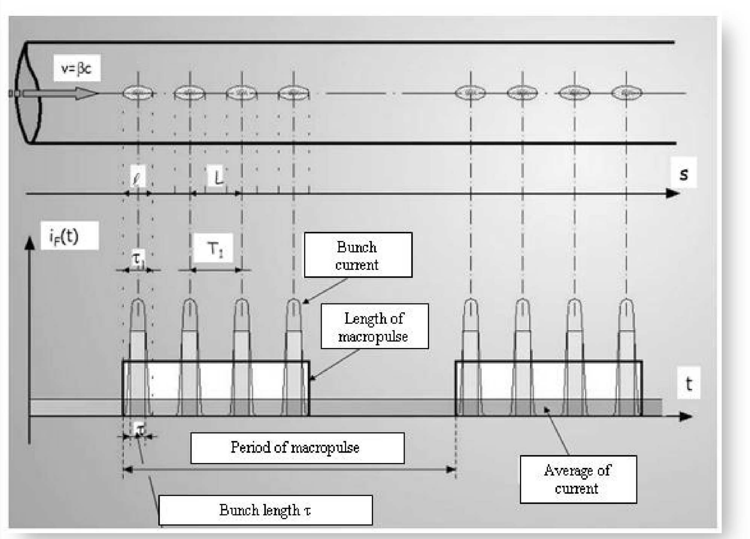
Cryomodule	A	B
Valve-to-valve length [mm]	610	1360
Quantity of cavities	12	14
f [MHz]	88.05	88.05
β_{opt}	0.07	0.12
Epk/Ea	5.36	4.76
Bpk/Ea [mT/MV/m]	8.70	9.35
r/Q [Ω]	599	515
Vacc @ 6.5 MV/m & β_{opt}	1.55	2.66
Lacc [m]	0.24	0.41
Beam tube ∅ [mm]	38	44



Principe of operation

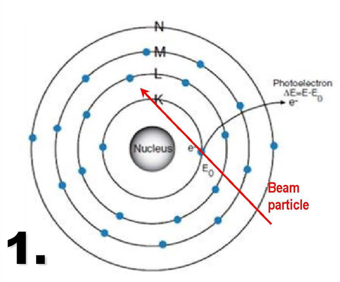
The bunch extension monitor of SPIRAL2 is non-destructive detector with principle of operation based on registration of x-rays induced by the beam particles from thin tungsten wire. The thin tungsten wire with diameter 150 µm doesn't bring in distribution into LINAC's beams. The x-rays emitted from the wire during interaction with beam particles are registered by x-ray detector. Beam ions are interacted with atoms of the matter of wire and produced and their ionization. The atoms become excited and as the way of de-excitation emits its characteristic x-rays. The characteristic x-rays for each matter have the specific energies which are corresponded to the binding energies of electrons at K,L,M… shells. Elements with higher mass have a higher energies.

Beam time structure

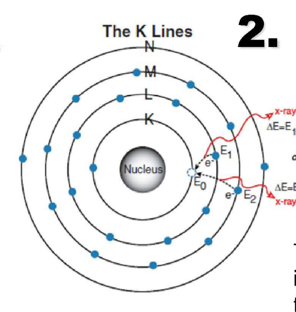


- Frequency of the pulses: 88.0525 MHz (period of bunches: T~11.36 ns)
- Phase extension of the pulse (±2 σ): 60 ° or ~1.9 ns for bunch length τ
- Period of macropulse: can vary between 100 µs and 1s
- The form factor $\eta = \frac{\text{macropulce length}}{\text{period of macropulce}}$ is lay at range $1 < \eta < 10^4$

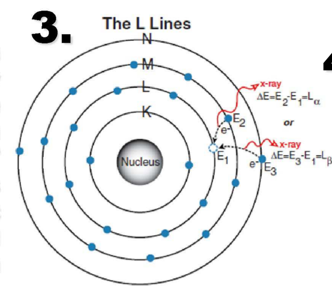
Excitation processes at atom



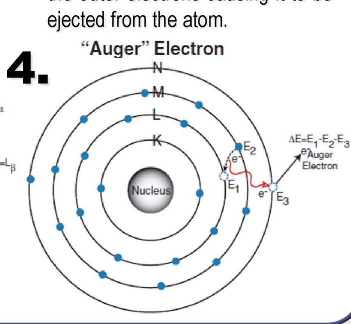
1. An electron in the K shell is ejected from the atom due to hit with beam ion.



2. An electron from the L or M shell "jumps in" to fill the vacancy. In the process, it emits a characteristic x-ray unique to this element and in turn, produces a vacancy in the L or M shell.



3. When a vacancy is created in the L shell by either the primary excitation x-ray or by the previous event, an electron from the M or N shell "jumps in" to occupy the vacancy. In this process, it emits a characteristic x-ray unique to this element and in turn, produces a vacancy in the M or N shell.

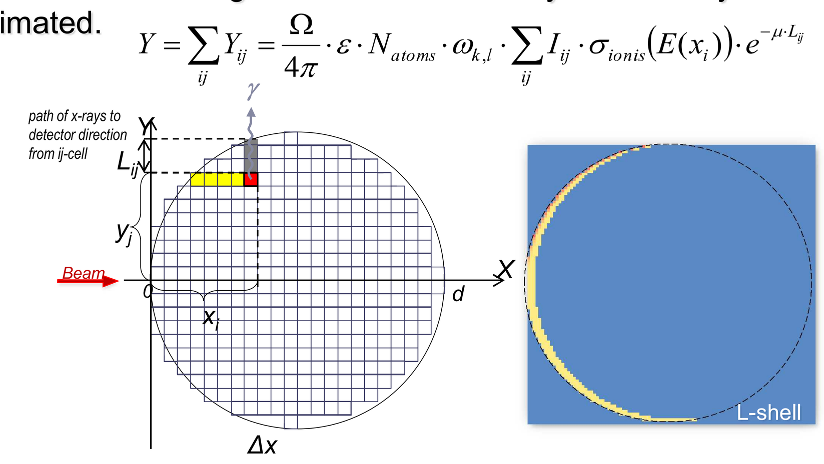


4. The excitation energy from the inner atom is transferred to one of the outer electrons causing it to be ejected from the atom.

Calculations of x-ray production by ions

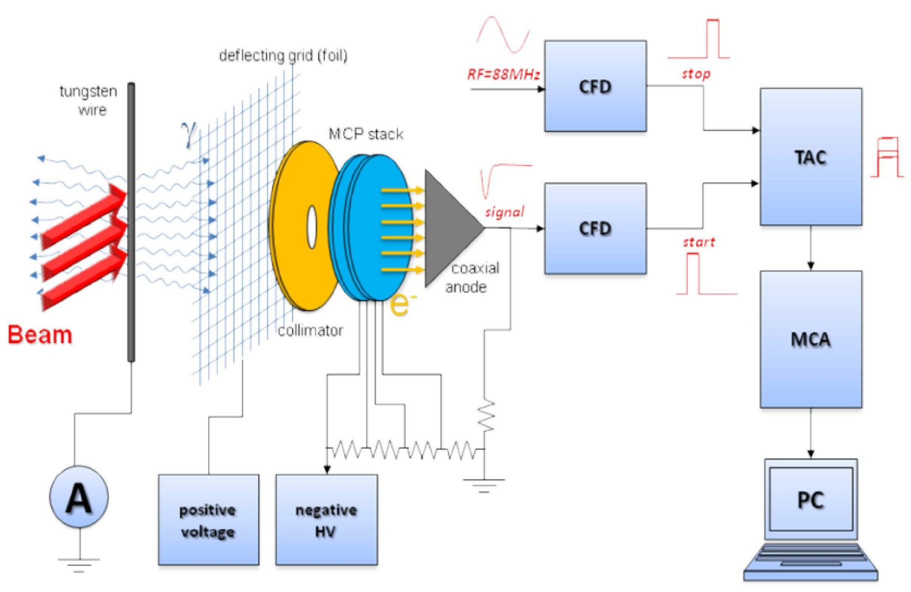
A prediction of x-ray production by ions was done in case of interaction with tungsten wire. A relative yield of x-ray was estimated.

$$Y = \sum_{ij} Y_{ij} = \frac{\Omega}{4\pi} \cdot \varepsilon \cdot N_{atoms} \cdot \omega_{k,l} \cdot \sum_{ij} I_{ij} \cdot \sigma_{ionis}(E(x_i)) \cdot e^{-\mu \cdot L_{ij}}$$

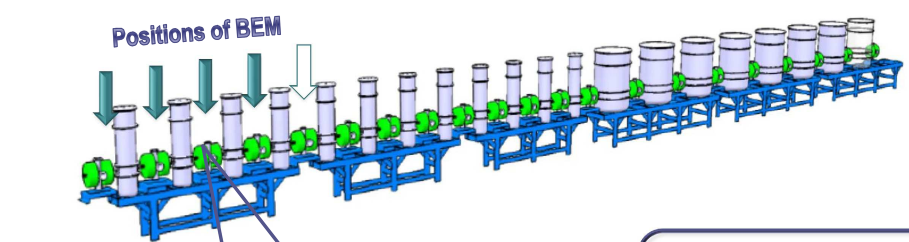


- $\frac{\Omega}{4\pi}$ — solid angle for registration
- ε — registration efficiency of detector for x-rays of these energies
- N_{atoms} — concentration of target atoms per cm²
- $\omega_{k,l}$ — fluorescence yields of photons for K-, L-shell ionizations
- I_{ij} — number of incident ions of the beam at ij-cell (pps)
- $\sigma_{ionis}(E(x_i))$ — ionization cross section for K-,L-shells as function of incident ion energy
- $e^{-\mu \cdot L_{ij}}$ — attenuation of x-ray at material of target

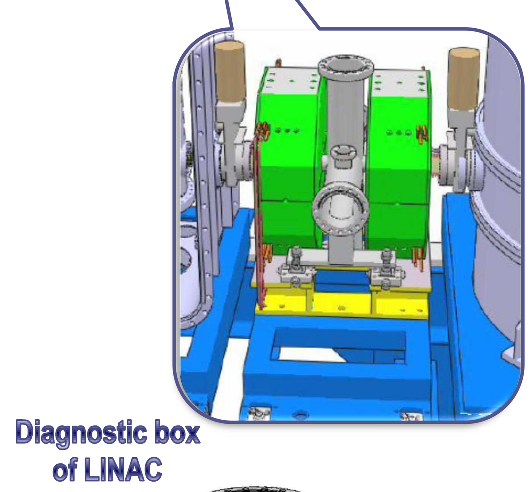
Principal schema of BEM electronics



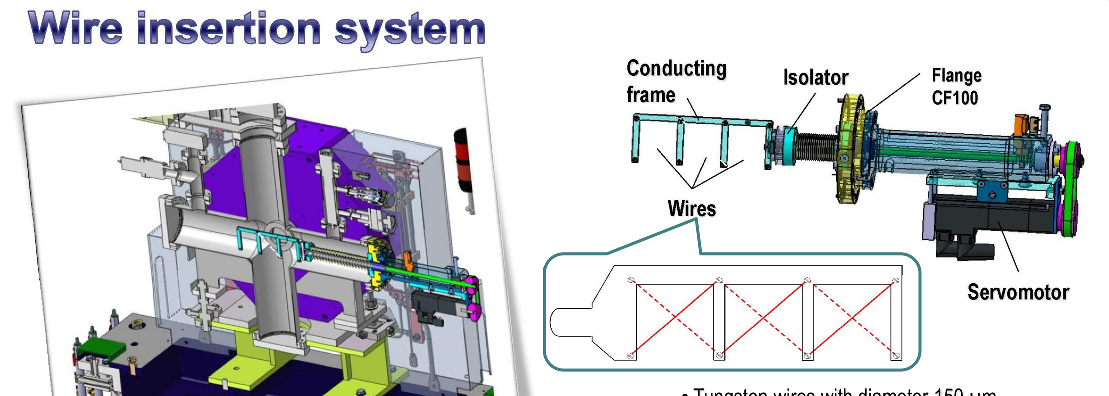
BEM description



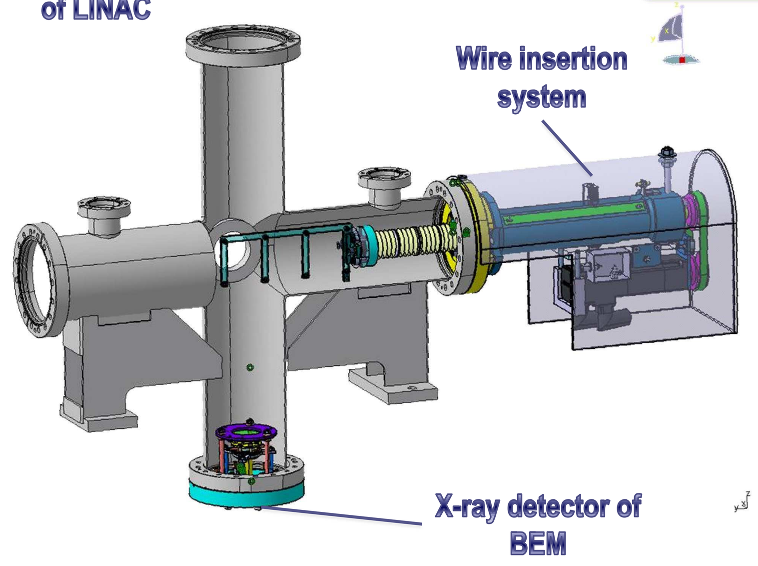
The bunch extension monitor will be installed at first four (five) warm sections of LINAC. The warm section includes two quadrupoles and diagnostic box between them. The BEM is occupied two flange of diagnostic box and mechanically consisted of 2 parts: a x-ray detector and system for wire insertion.



Wire insertion system



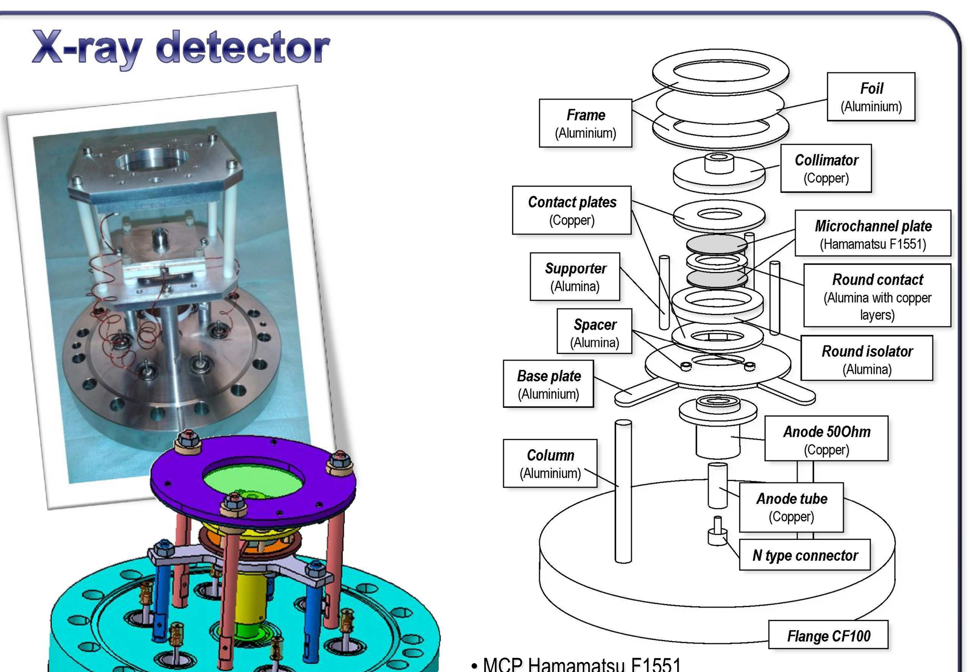
- Tungsten wires with diameter 150 µm
- Three positions
- Positioning precision is better than 100 µm



Insertion of wire into the beam during measurements will be performed with special system. This system allows wire positioning with tolerance better than 100 microns. Wire holder contains 3 tungsten wires in case of damage one of them. Reference measurements of current from the wire inserted into the beam also will be implemented.

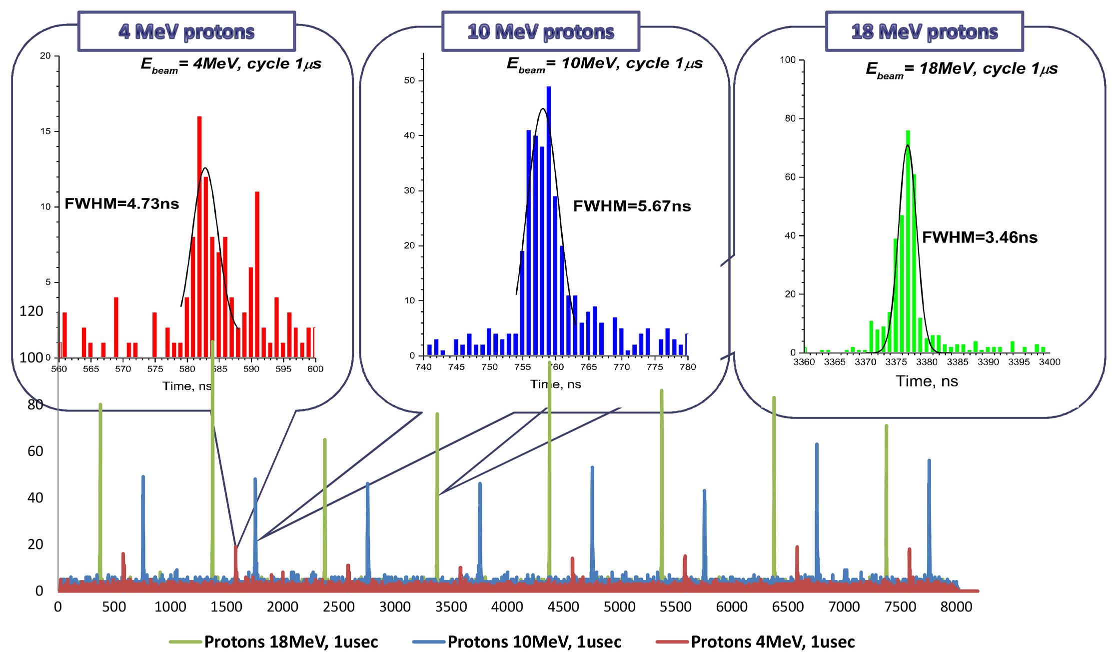
The design of x-ray detector is based on registration of x-rays by micro channel plates. We are using stack of HAMAMATSU's MCP without coating which are placed at chevron configuration. The gain of 2 stages MCP is about 10^7 at applied voltage -2 kV. The output electrons from MCP are collected by coaxial anode matched for 50 Ohms impedance and transmitted thru coaxial cable with small coefficient of losses for signal fronts less 1ns.

X-ray detector



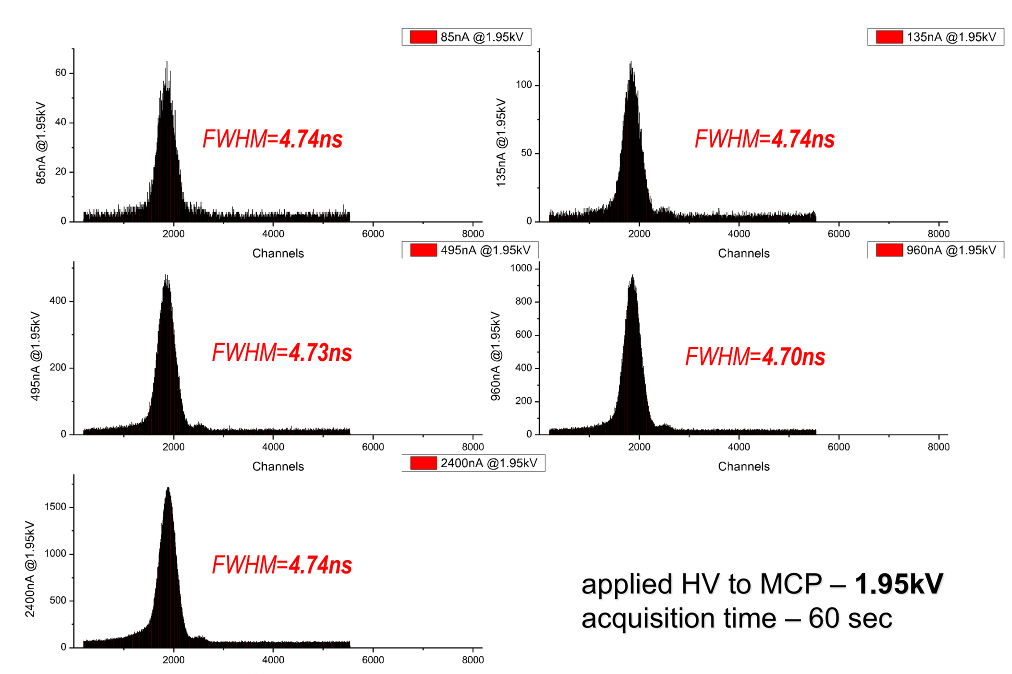
- MCP Hamamatsu F1551
- Diameter 18mm, l/d=40, gain up to 10^7
- Coaxial anode with fast readout
- Efficiency of x-ray registration ~1-10%

Test with proton beam at TANDEM, IPN'O



The first test of prototype was performed at the proton beam IPNO tandem at different energies of the beam. It has shown the prove of principle of operation of detector.

Test with $^{36}Ar^{+10}$ beam at IRRSud line, GANIL



The next test was performed at IRRSud beam line of GANIL with ion beam of $^{36}Ar^{+10}$ at energy 0.98 MeV/n. This test was done at different values of beam intensities.

Results and conclusions

What was done

- Prototype of non-interceptive bunch extension monitor was designed.
- The first tests with proton beam was successfully carried out.
- Design of prototype was optimized. The second test with beam of heavy ions was done. Measurements of bunch length and count rates were performed at different conditions. Results were compared with calculations.
- The time resolution for detector was estimated for two types of electronics. It lays at range 40 – 50 picoseconds.
- Design of multiposition wire insertion system was created.

What is planning to do

- Measurements of x-ray background conditions for BEM at proximity of LINAC cavity
- Verification and final choice of electronics
- Making of command-control software for BEM and its integration into LINAC control
- Performing one more test of BEM prototype with high intensity ion beam
- Fabrication of five (six) units of BEM, adjusting and calibration of each detector
- Installation BEMs into LINAC warm sections

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