Cross-sections measurements for hadrontherapy: conception of a large acceptance mass spectrometer

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Hadrontherapy

Use of heavy ions (^{12}C for example) to treat non-operable and radio-resistant tumors

Advantages

- Localized dose
- Small diffusion in the body
- Biological efficiency

Drawbacks

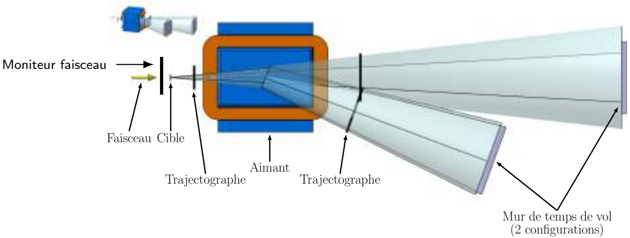
- Fragmentation of heavy ions
- Loss of the ions of the beam
- Production of lighter elements

Aim: Control the dose deposited in the tumor and in the healthy tissues

Know the fragmentation cross-sections of the heavy ions (^{12}C) ► FRACAS

FRACAS (FRAgmentation des ions CArbone et Sections efficaces)

Large acceptance mass spectrometer ▶ measure of fragmentation cross-sections of ^{12}C ions from 100 to 400 MeV/n on targets of medical interest (C, H, N, O)



Study and validation of the system

- Monte-Carlo simulations of FRACAS
- Development of reconstruction algorithms (charges, masses, trajectories)

Conception of 2 detectors

- Beam monitor: position of the beam and time reference
- Downstream trackers: trajectories of the fragments after the magnet

Systematic study of FRACAS

Systematic study of FRACAS

Identify the more precisely possible the charge and the mass of most of the fragments

- Reconstruction algorithms (charges, trajectories, masses)
- Resolution of the detectors (spatial and time)
- Position of the detectors

Find an optimal configuration

Reconstruction of the charges

ΔE - ToF method

Loss of energy in a material by a charged particle

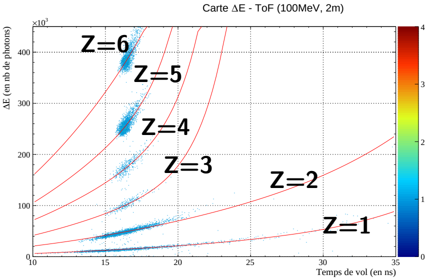
- material (crystal scintillator: YAP)
- reduced velocity of the impinging particle
- charge of the impinging particle

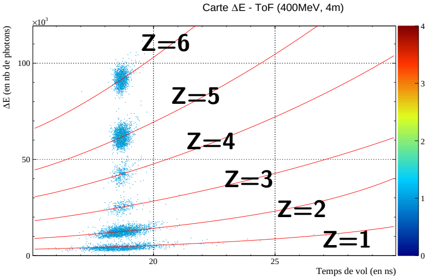
- Fit with the Bethe-Bloch formula

Efficiency :

100 MeV: 99.4±0.9 %

400 MeV: 98.9±0.9 %





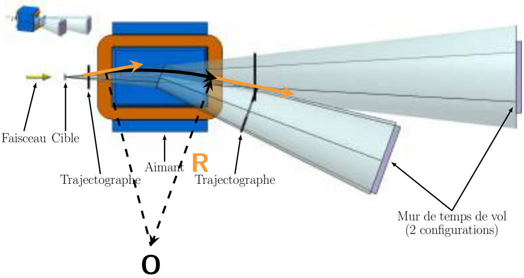
Reconstruction of the masses

Trajectory in a magnetic field B of a charged particle

arc of radius R given by Lorentz force:

$$sin(\theta)BR \propto \frac{A}{Z}\beta\gamma$$

- In and out trajectories of the fragments: R
- Charge: Z
- Time of Flight: β and γ



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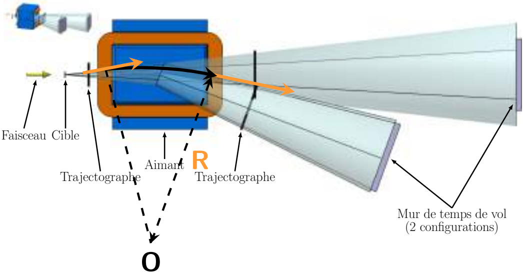
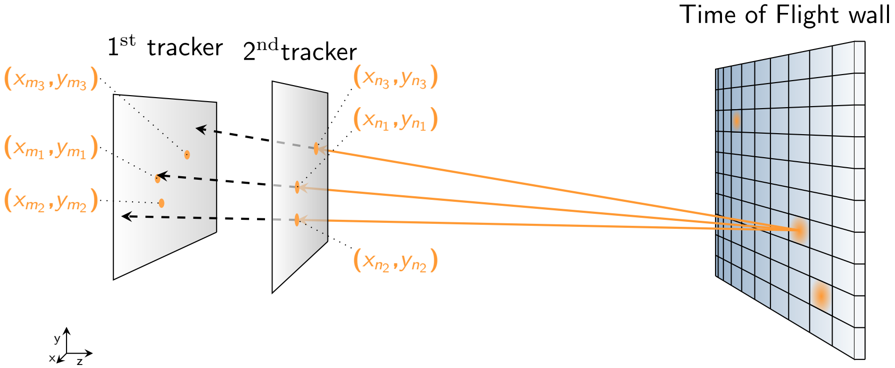
Reconstruct the trajectories



Reconstruction of the trajectories

The algorithm tests all the possible combinations and select the ones that are most likely to come from a trajectory



Performances of the reconstruction of the trajectories

Depends on:

- position of the trackers
- spatial resolution of the trackers

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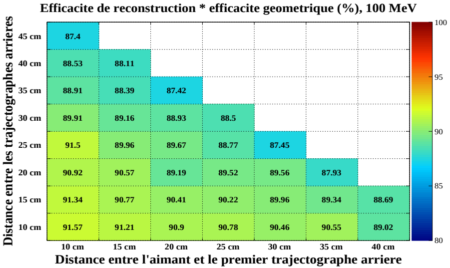
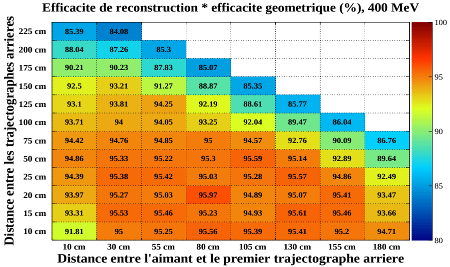
Distance	100 MeV/n	400 MeV/n
magnet /trackers	10 cm ∼ 15 cm	30 cm ∼ 130 cm
between trackers	10 cm ∼ 20 cm	15 cm ∼ 50 cm


Efficacite de reconstruction * efficacite geometrique (%), 100 MeV

	10 cm	15 cm	20 cm	25 cm	30 cm	35 cm	40 cm
45 cm	87.4						
40 cm	88.53	88.11					
35 cm	88.91	88.39	87.42				
30 cm	89.91	89.16	88.93	88.5			
25 cm	91.5	89.96	89.67	88.77	87.45		
20 cm	90.92	90.57	89.19	89.52	89.56	87.93	
15 cm	91.34	90.77	90.41	90.22	89.96	89.34	88.69
10 cm	91.57	91.21	90.9	90.78	90.46	90.55	89.02

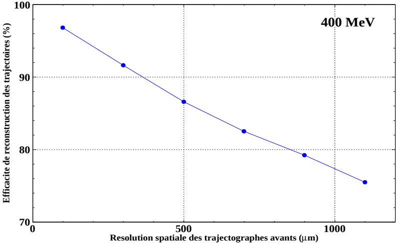

Efficacite de reconstruction * efficacite geometrique (%), 400 MeV

	10 cm	30 cm	55 cm	80 cm	105 cm	130 cm	155 cm	180 cm
225 cm	85.39	84.08						
200 cm	88.04	87.26	85.3					
175 cm	90.21	90.23	87.83	85.07				
150 cm	92.5	93.21	91.27	88.87	85.35			
125 cm	93.1	93.81	94.25	92.19	88.61	85.77		
100 cm	93.71	94	94.05	93.25	92.04	89.47	86.04	
75 cm	94.42	94.76	94.85	95	94.57	92.76	90.09	86.76
50 cm	94.86	95.33	95.22	95.3	95.59	95.14	92.89	89.64
25 cm	94.39	95.38	95.42	95.03	95.28	95.57	94.86	92.49
20 cm	93.97	95.27	95.03	95.97	94.89	95.07	95.41	93.47
15 cm	93.31	95.53	95.46	95.23	94.93	95.61	95.46	93.66
10 cm	91.81	95	95.25	95.56	95.39	95.41	95.2	94.71

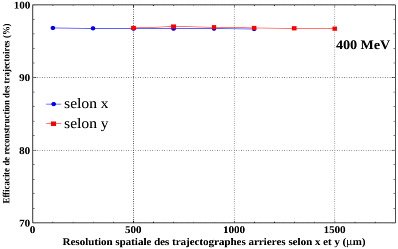
Performances of the reconstruction of the trajectories

Depends on:

- position of the trackers
- spatial resolution of the trackers



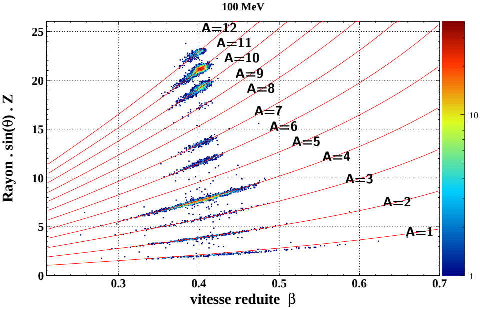
- Upstream: the best possible (ideally 100 μm)
- Downstream: no visible influence

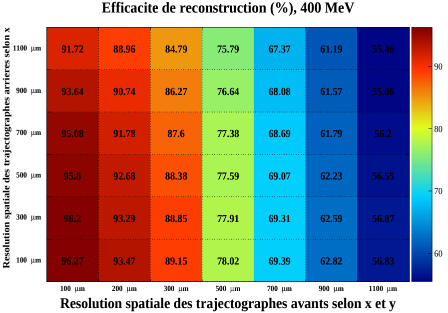


Performances of the reconstruction of the masses

Lorentz force:

$$R sin(\theta) Z \propto A \frac{\beta\gamma}{B}$$




Efficacite de reconstruction (%), 400 MeV

Resolution spatiale des trajectographes arrieres selon x	100 µm	200 µm	300 µm	500 µm	700 µm	900 µm	1100 µm
1100 µm	91.72	88.96	84.79	75.79	67.37	61.19	55.46
900 µm	93.64	90.74	86.27	76.64	68.08	61.57	55.86
700 µm	95.08	91.78	87.6	77.38	68.69	61.79	56.2
500 µm	95.8	92.68	88.38	77.59	69.07	62.23	56.55
300 µm	96.2	93.29	88.85	77.91	69.31	62.59	56.87
100 µm	96.27	93.47	89.15	78.02	69.39	62.82	56.83

Resolution spatiale des trajectographes avants selon x et y

Spatial resolution of the upstream trackers: below 100 μm

Spatial resolution of the downstream trackers on x axis: below 500 μm

Prospects for 2019: study of the system

Actual performances

- Charges: > 98 % at 100 MeV and 400 MeV
- Trajectories: > 90 % at 100 MeV and > 95 % at 400 MeV
- Masses: > 95 % at 400 MeV

Improvement of the performances ▶ developement of new reconstruction algorithms

Trajectories

Algorithm using the trajectory inside the magnetic field

- More complex
- More efficient

Charges and masses

MLE (Maximum Likehood Estimation) for the masses

- Identify the most relevant parameters
- Overcome the need of the reconstruction of the trajectories

Developement of the beam monitor and the downstream trackers

Characteristics and constraints

Moniteur faisceau

- Position of the beam
- Time reference
- Transparent to the beam
- Spatial resolution: below 100 μm

multiple stages PPAC
(Parallel Plate Avalanche Counter)

Downtsream trackers

- Trajectories of the fragments
- Large active area: $\sim$50 × 50 cm^2
- Spatial resolution on one axis: below 500 μm
- Spatial resolution on the other axis: below 1 mm

MWPC
(Multi Wire Proportionnal Counter)

Conception of gaseous detectors ▶ simulation and tests

Simulation: beam monitor (PPAC)

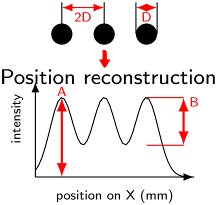
Optimal geometry obtained

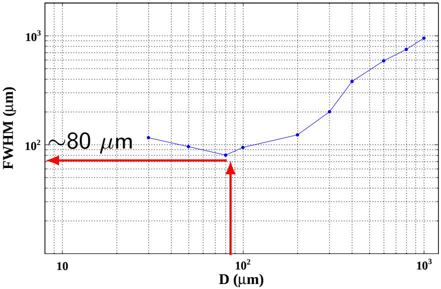
- Gap: 4.75 mm
- Strips: 500 μm spaced by 50 μm

- Gas: iC_4H_{10} at 20 mbar

Evaluation of the spatial resolution

- Derenzo phantoms





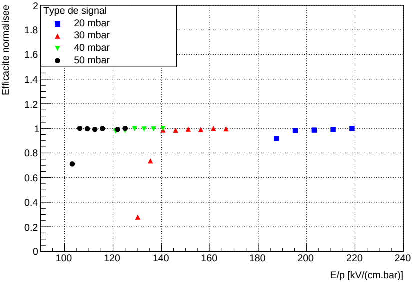
Spataial theoretical resolution ▶ around 80 μm

Tests: beam monitor (PPAC)

Operating range

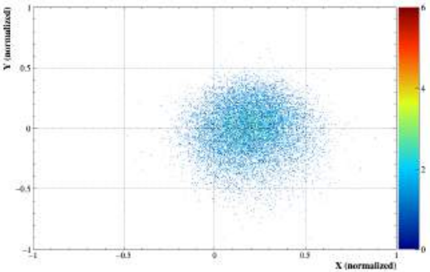
Efficiency plateau (counting rate)

- Tension
- Pressure



Position reconstruction

- 5,5 MeV α particles (source ^{241}Am)
- gap: 4,75 mm, strips: 1,3 mm
- charge division method



Tests: downstream trackers (MWPC)

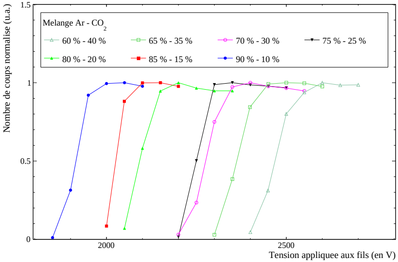
Operating range

- Tension
- Gaseous mixture

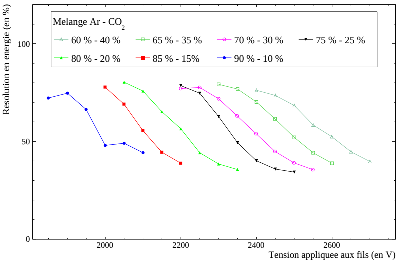
Characteristics

- Wires: 20 μm spaced by 2 mm
- Gap: 8 mm
- Pressure: 1 bar

Efficiency plateau



Energy resolution



Optimal mixture: Ar 75 % CO_2 25 %

Prospects for 2019: conception of detectors

Already done

- Beam monitor: optimal geometry and preliminary tests (plage de fonctionnement)
- Downstream trackers: preliminary tests (plage de fonctionnement and gaseous mixture)

To be done

Beam monitor

- Test of the prototype with the newly designed geometry: evaluate its spatial resolution
- Test of the complete beam monitor under beam with a part of the ToF wall

Downstream trackers

- Find an optimal geometry: evaluate its spatial resolution
- Test of a prototype with this new geometry

Conclusion

Systematic study

Done

- Development of reconstruction algorithm: dichotomy for both charges and masses, test of all the possibilities for the trajectories
- Evaluation of the performances by varying the spatial resolution and the position of the detectors

Prospects for 2019

- Developement of other types of algorithms: MLE for the charges and the masses, use of the trajectories in the magnetic field for the reconstruction of the trajectories

Conception of the detectors

Done

- Beam monitor: Optimal geomatry with simulation and tests
- Downstream trackers: Tests

Prospects for 2019

- Beam monitor: Tests with the optimal geometry
- Downstream trackers: Find an optimal geometry with simulation and do tests with it
- Time of Flight wall: Test of some elements of the wall under beam

Thank you for your attention