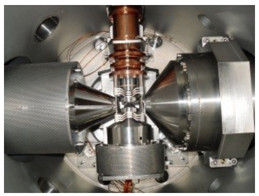
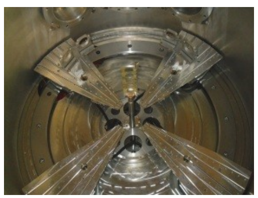


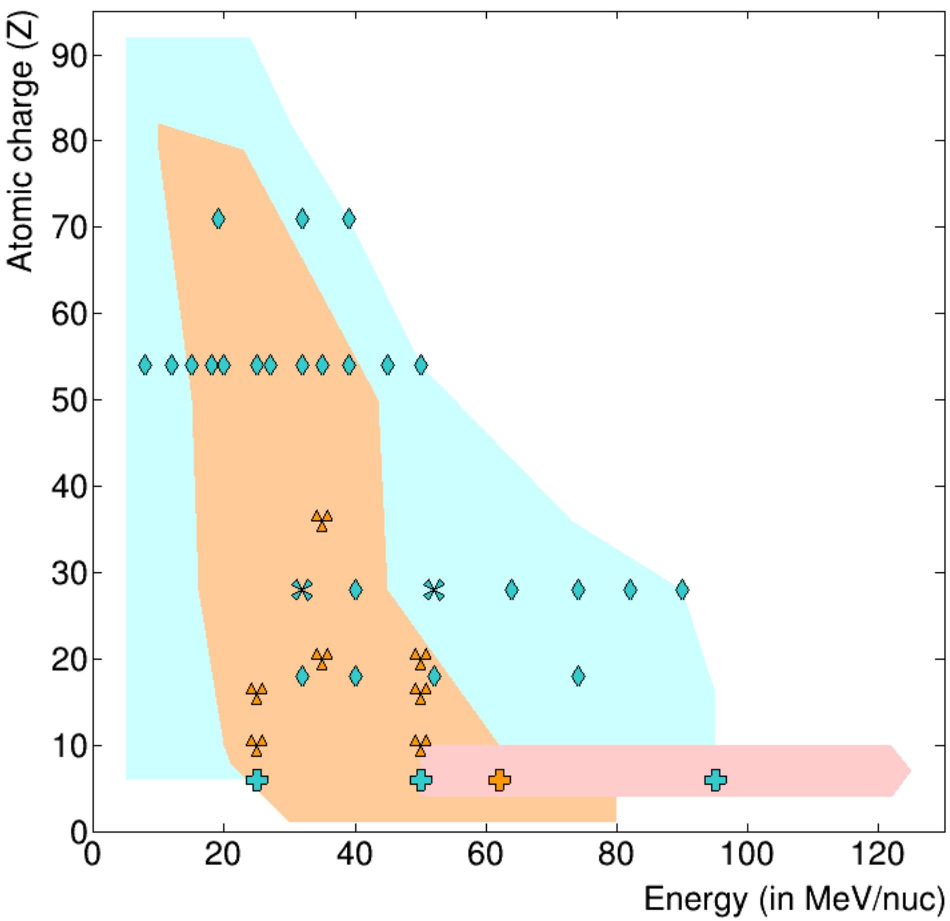
Fragmentation cross section measurements: possible synergies with nuclear physics studies

Diego Gruyer

Normanie Université, ENSICAEN, UNICAEN, CNRS/IN2P3, LPC Caen, France
diego.gruyer@lpccaen.in2p3.fr

On behalf of :
Nuclear dynamics and thermodynamics group
Medical and industrial applications group

Few orders of magnitude



	beam	energy (MeV/A)
GANIL	C – U	5 – 95
LNS	H – Au	25 – 80
ARCHADE	He – Ne	50 – 400

		capabilities
INDRA	1993	charge
FAZIA	2015	charge/mass
INDRA-FAZIA	2019	charge/mass
Telescopes	2010	charge/mass

Introduction
Light/heavy ion collisions from 20 to 100 (400) MeV/u

Medical application group

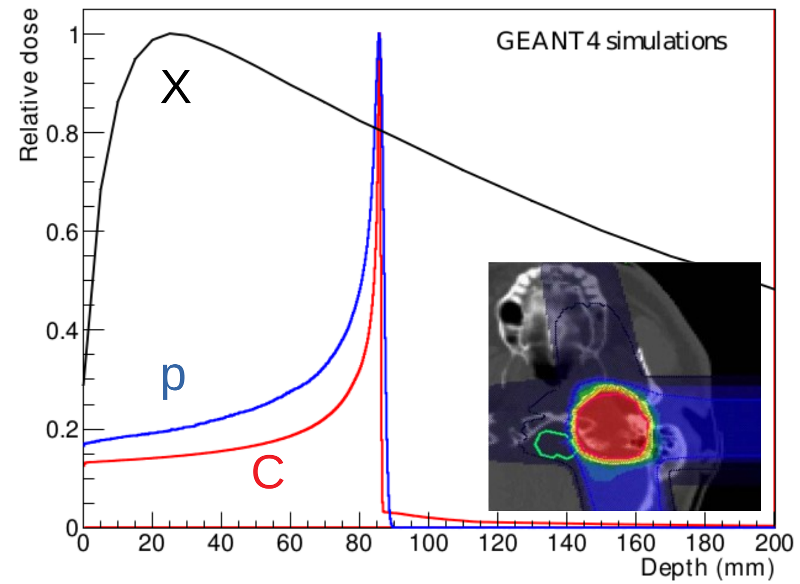
Nuclear dynamics group

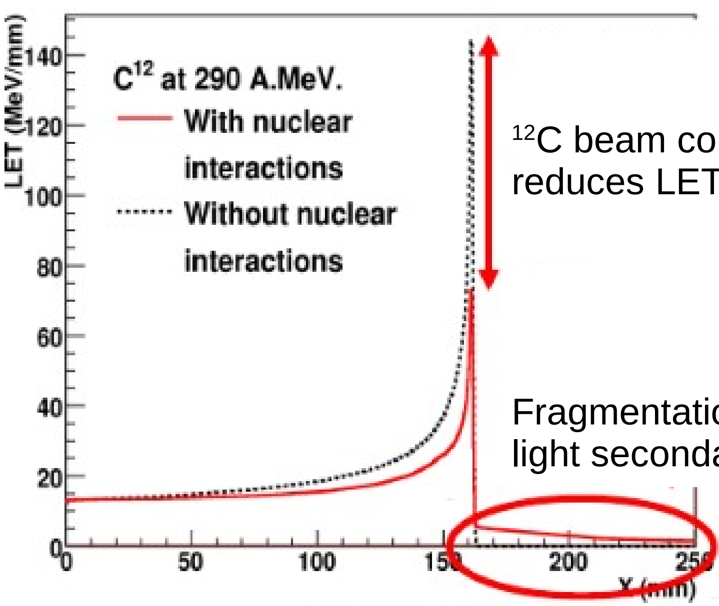
Experimental strategy

Medical applications : treating cancer with ^{12}C beams

Hadrontherapy
Irradiate tumors with ions instead of X-rays
Maximum dose at the end of the path (Bragg)
Small lateral broadening (for Carbon)
Better target the tumor / biological effects

Hadron indication
Treatment of tumor close to organs at risk
Treatment of radioresistent tumors
Carbon beam promising but still experimental





^{12}C beam consumption reduces LET at Bragg peak

Fragmentation tail made of light secondary particles

(courtesy: D. Cussol)

Nuclear fragmentation
Non-negligible modification of the physical dose delivery

Reaction models
GEANT4 not accurate enough
Strong impact on dose prediction
Experimental data up to 400MeV/u

GEANT4 benchmark on fragmentation data
Dudouet et al., PRC **89**(2014)054616

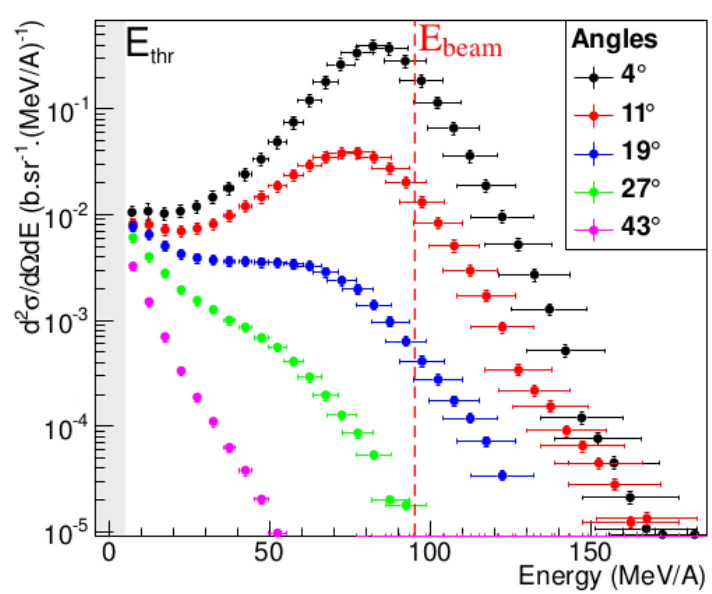
Fragmentation measurements for hadrontherapy

Fragmentation cross section
Energy and angular double differential cross section C + C, CH_2, Al, Al_2O_3, Ti at 50,95MeV/u:

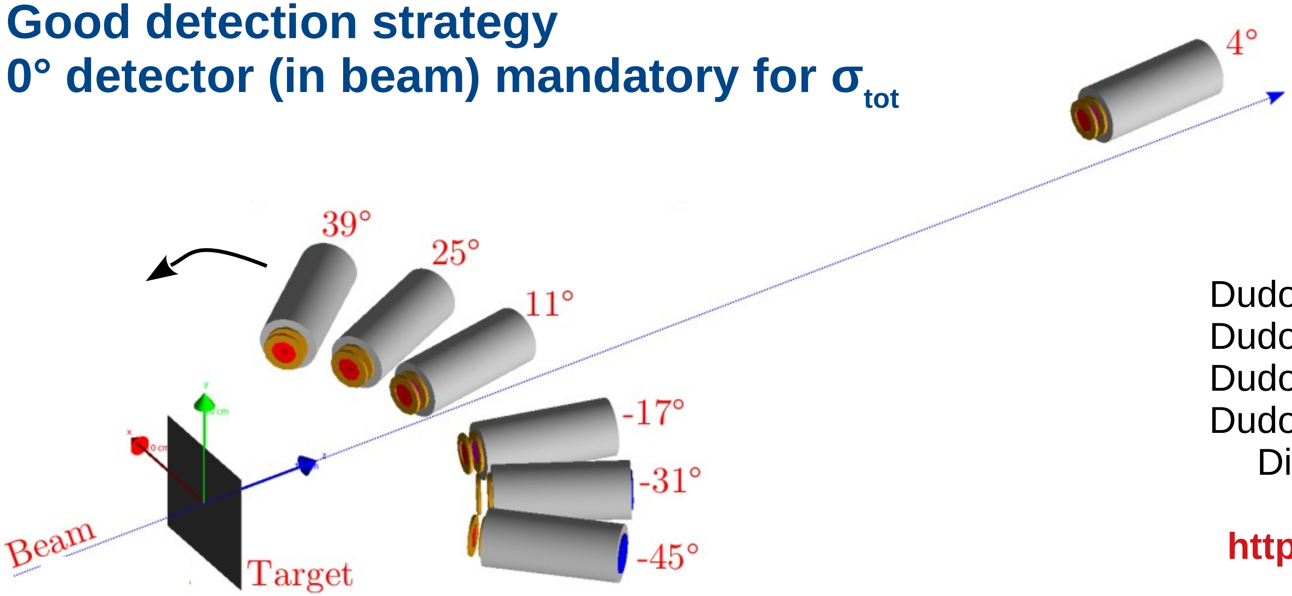
$$\left(\frac{\partial^2 \sigma}{\partial E \partial \Omega}\right)_{Z,A}$$

Simple detection setup
Si-Si-CsI moving telescopes to cover polar angles from 0° to 45°. Charged particle identification by ΔE-E method (Z, A, E, θ).

α in $^{12}C+^{12}C$ at 95MeV/u



Good detection strategy
0° detector (in beam) mandatory for σ_{tot}



Dudouet et al., PRC **88**(2013)024606
Dudouet et al., PRC **89**(2014)054616
Dudouet et al., PRC **89**(2014)064615
Dudouet et al., PRC **94**(2016)014616
Divay et al., PRC **95**(2017)044602

http://hadrontherapy-data.in2p3.fr

Target combination method

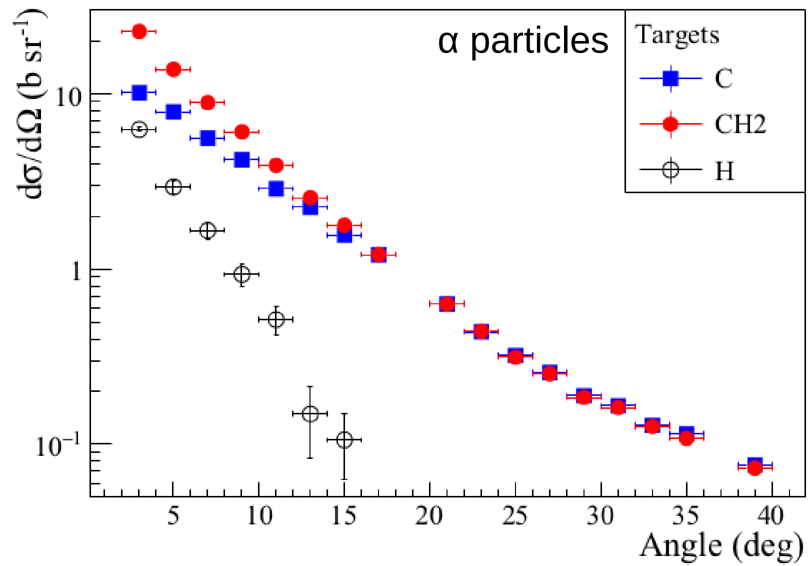
Hydrogen target cross section

C and CH_2 target cross section measured

Remove C contribution to CH_2

Divide by the number of H in CH_2 (2)

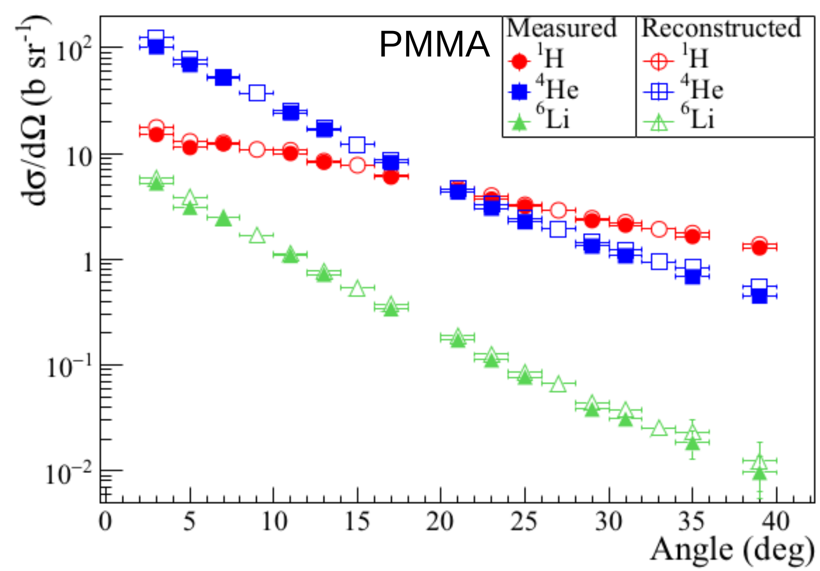
$$\frac{d\sigma}{d\Omega}(\mathrm{H}) = \frac{1}{2}\left(\frac{d\sigma}{d\Omega}(\mathrm{CH_2}) - \frac{d\sigma}{d\Omega}(\mathrm{C})\right)$$



Validation of the method

Compare measured and reconstructed cross section for PMMA ($C_5H_8O_2$) :

$$\frac{d\sigma}{d\Omega}(\mathrm{C_5H_8O_2}) = 5\frac{d\sigma}{d\Omega}(\mathrm{C}) + 8\frac{d\sigma}{d\Omega}(\mathrm{H}) + 2\frac{d\sigma}{d\Omega}(\mathrm{O})$$



Accurate and easy method to emulate Hydrogen target but needs statistics.

Dudouet et al., PRC **88**(2013)024606

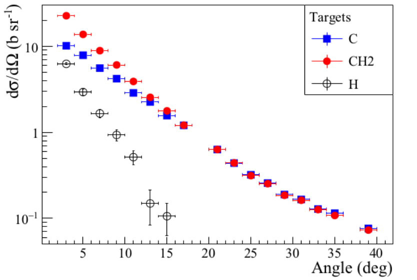
Divay et al., PRC **95**(2017)044602

Introduction

Light/heavy ion collisions from 20 to 100 (400) MeV/u

Medical application group

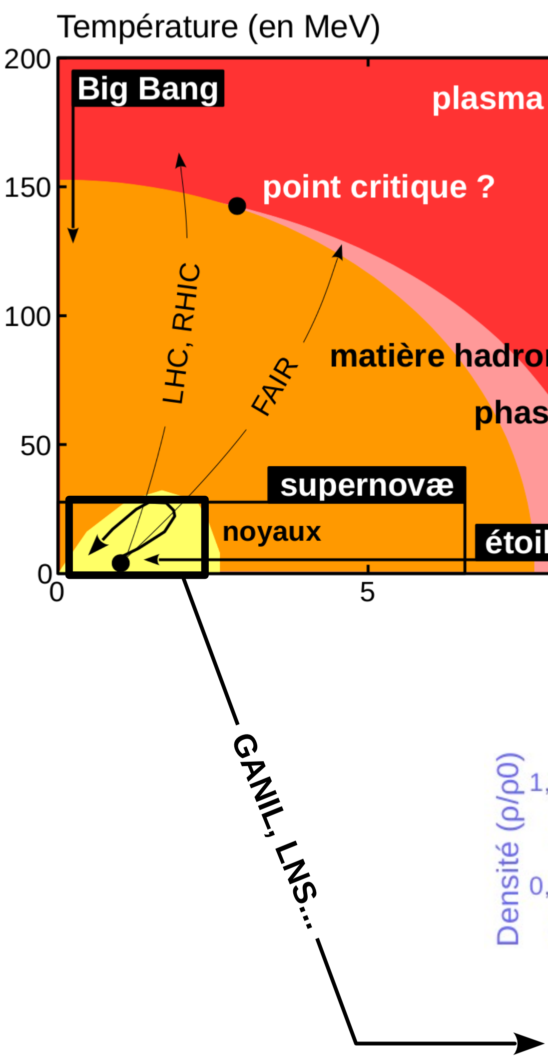
Fixed target reaction with telescope detectors below 100 MeV/u
0° detection mandatory for total cross section
CH_2 – C target combination method can emulate H target



Nuclear dynamics group

Experimental strategy

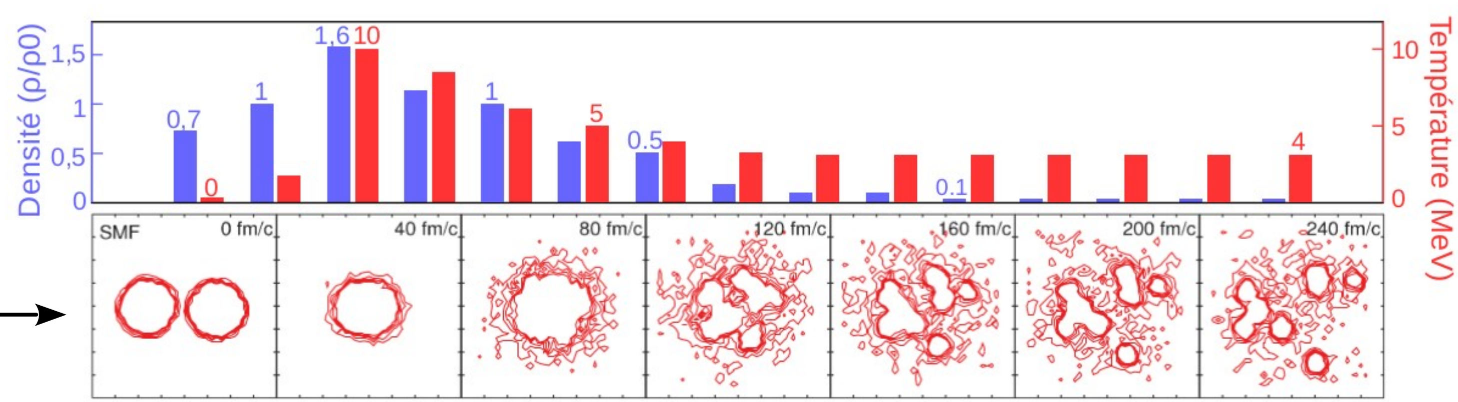
Nuclear dynamics and thermodynamics



Dense matter phase diagram
Composition of different phases
Phase transitions and critical points
Equation of state → $e(\rho, T, \boldsymbol{\delta(\rho_{np})})$

Fermi energy regime
Nuclear degrees of freedom (proton, neutron)
Heavy ion collisions at 10 – 100 MeV/u
Densities ~0.1-1.6 ρ_0, temperature <10 MeV

Reasearch topics
Isovectorial part of the equation of state
Transport properties (in-medium σ_{NN})
Phase transition in finite systems

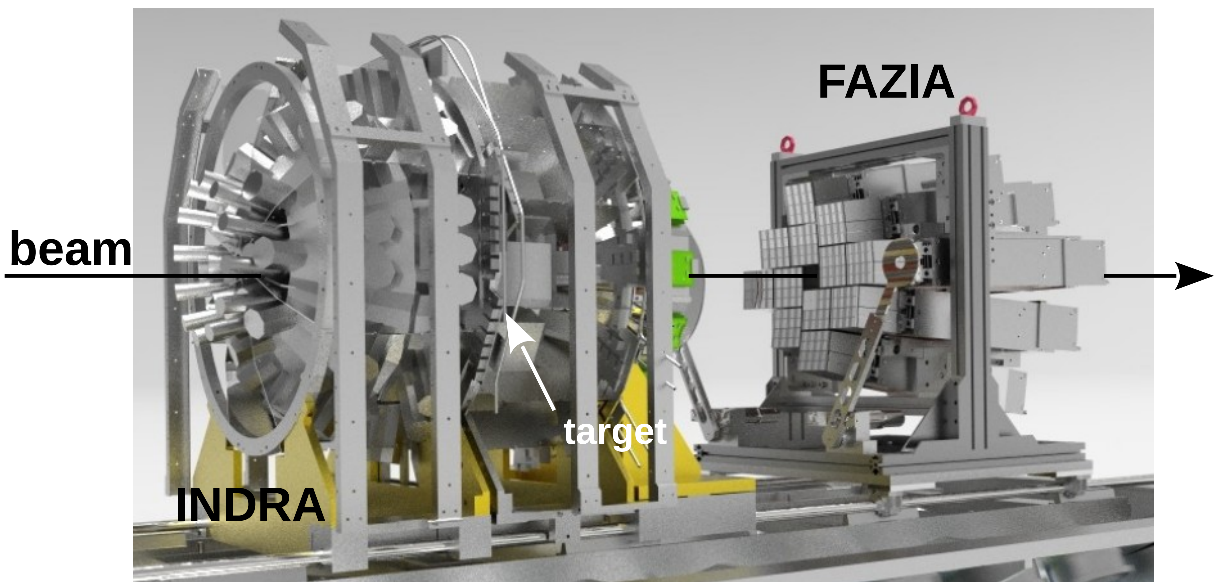


Sn + Sn at 50MeV/A, adapted from Colonna PRC10 et Liu PRC17

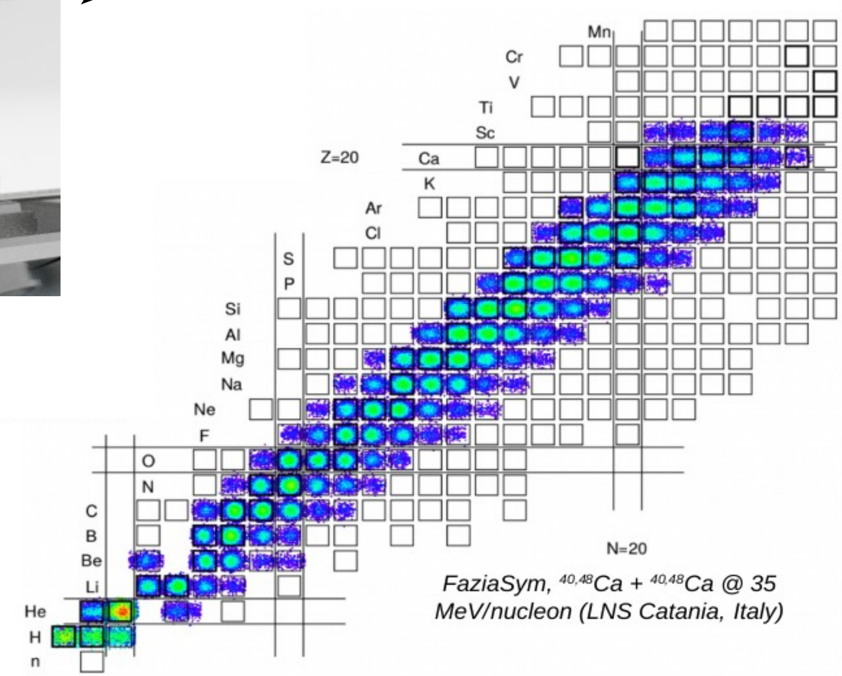
INDRA-FAZIA coupling in GANIL

INDRA (1993)
Old GANIL charged particle detector
Covers polar angles from 14° to 180°
Charge identification
Centrality selection

FAZIA (2015)
New generation charged particle detector
12 Blocks : 192 modules (1.5° to 13°)
Si-Si-CsI(Tl) telescopes (2x2 cm^2)
Reaction products N/Z content



Performances
ΔE-E, Pulse Shape Analysis, ToF
Isotopic identification (Z, A)
Good angular/energy resolution
Very modular and plug-and-play



FAZIA detectors are perfectly adapted for fragmentation cross section measurements at 20 – 100 MeV/u

Introduction

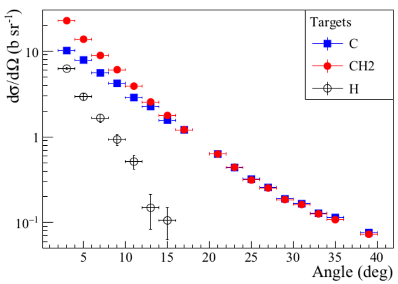
Light/heavy ion collisions from 20 to 100 (400) MeV/u

Medical application group

Fixed target reaction with telescope detectors below 100 MeV/u

0° detection mandatory for total cross section

CH_2 – C target combination method can emulate H target

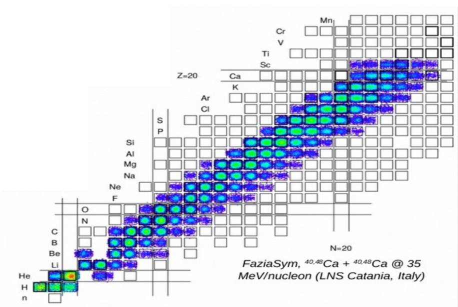


Nuclear dynamics group

FAZIA telescopes measure charge and mass of reaction products

4-5 FAZIA blocks would allow to cover all angles : fast measurement

Very modular blocks : easy to build the suitable geometry



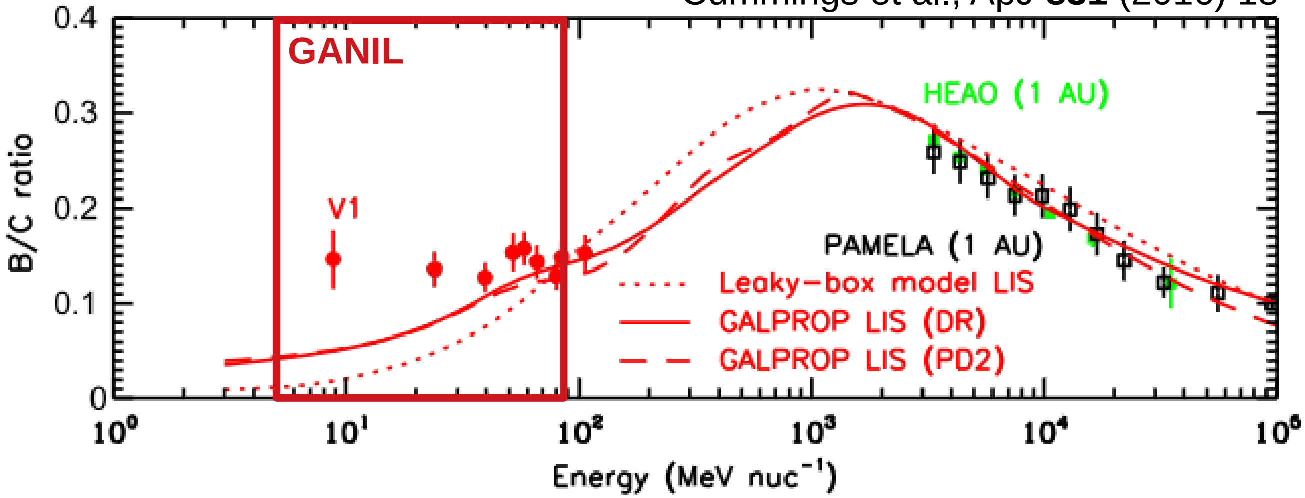
Experimental strategy

Possible short term experimental program at GANIL

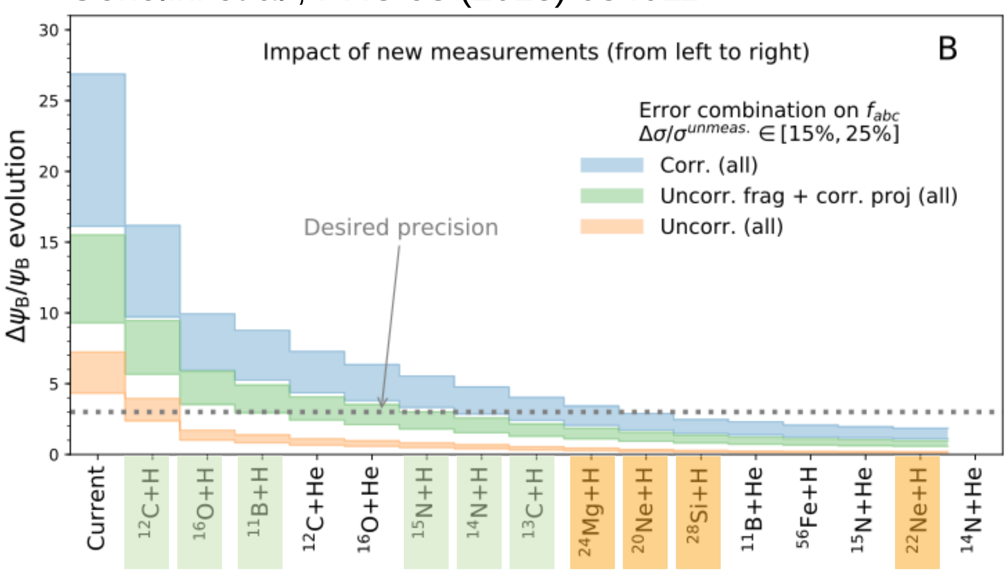
What do we need ?
Clear physics case (easy to explain to nuclear physicists)
High impact on flux predictions
Little technical development

Physics case
Low energy V1 B/C ratio
Models don't fit data
GANIL energies
Huge number of channels
Few key reactions

Cummings et al., ApJ **831** (2016) 18



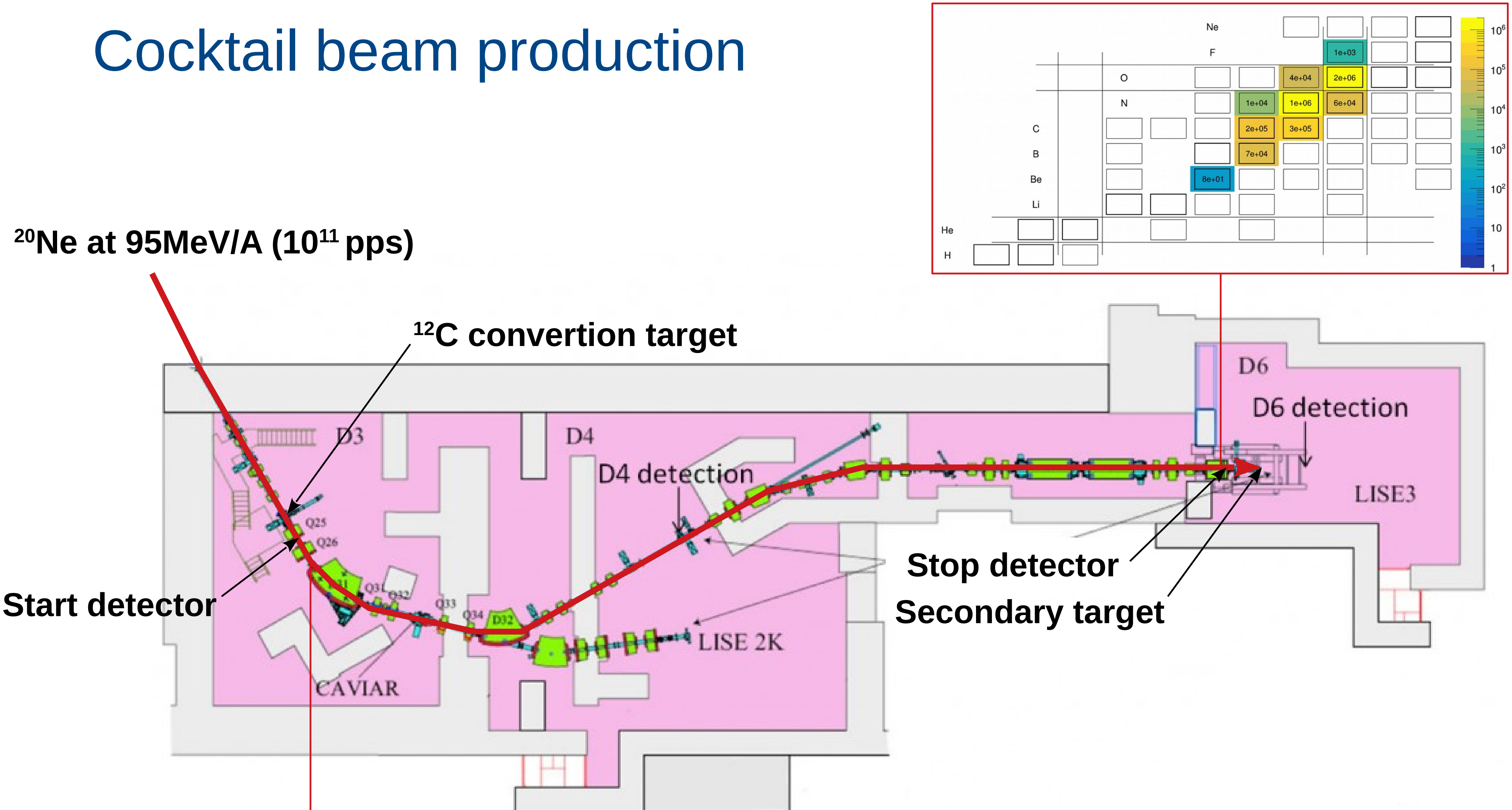
Génolini et al., PRC **98** (2018) 034611

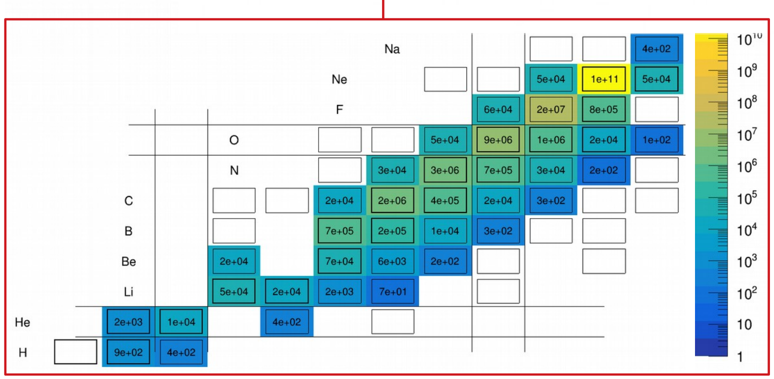


Multi-beam experiment
Fragmentation cocktail beam (O,N,C,B...)
CH_2 – C cross-section combination
Few spare FAZIA blocks available soon

Impact
Desired precision in one experiment
Impact on other fluxes for free
Some reaction also interesting for us

Cocktail beam production





LISE beams at GANIL

Primary Ne beam at 95MeV/A (10^{11} pps)

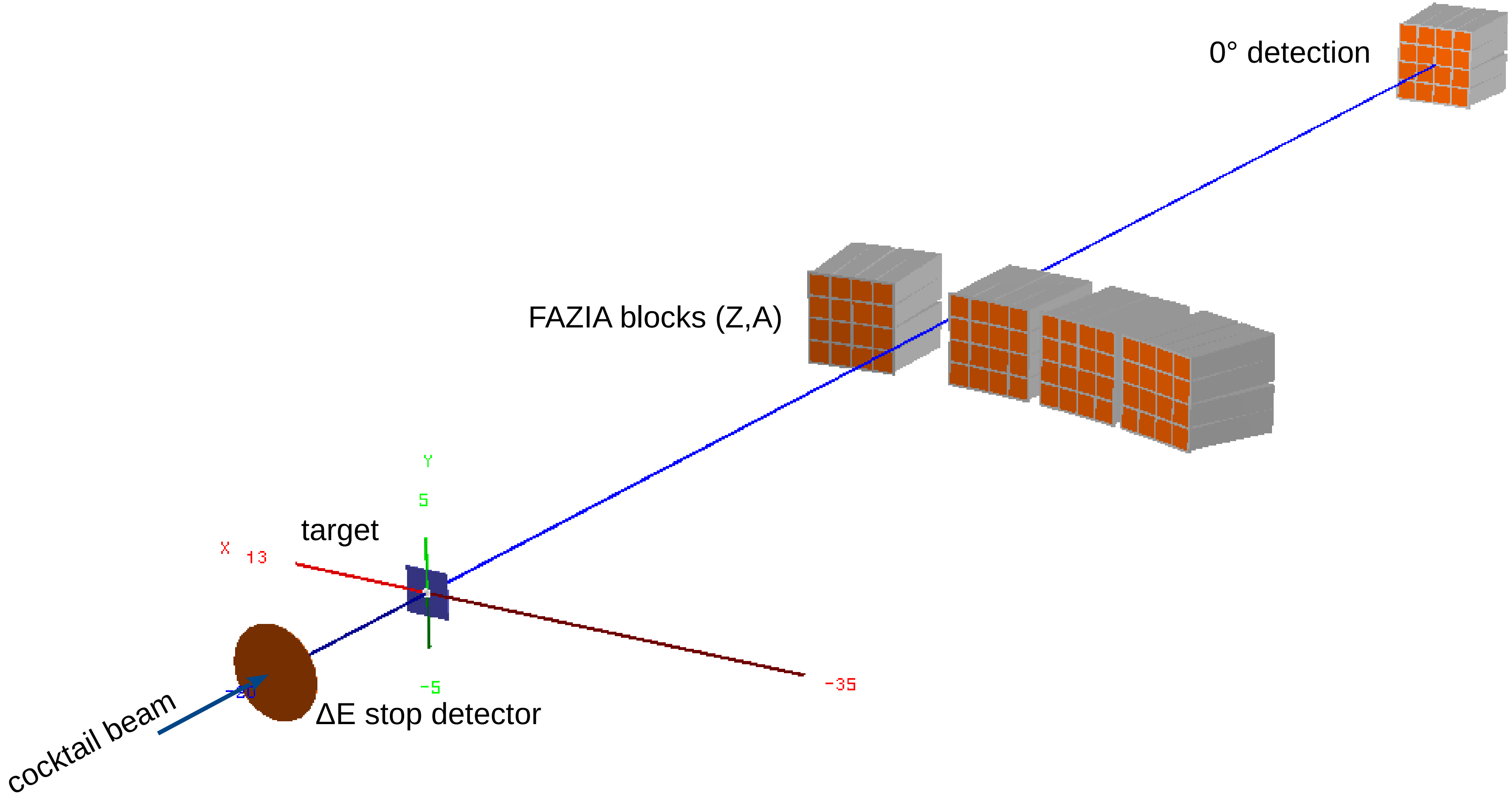
Fragmentation on ^{12}C or ^{9}Be target

Isotope selection with LISE3 separator

~10^5 pps for 7 nuclei of interest

Projectile identification by ΔE-ToF

Possible detection setup



Introduction

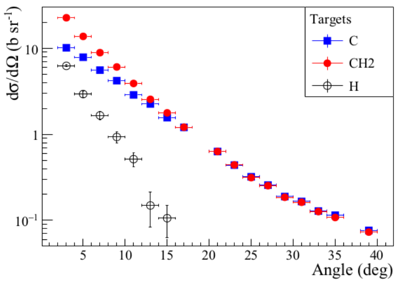
Light/heavy ion collisions from 20 to 100 (400) MeV/u

Medical application group

Fixed target reaction with telescope detectors below 100 MeV/u

0° detection mandatory for total cross section

CH_2 – C target combination method can emulate H target

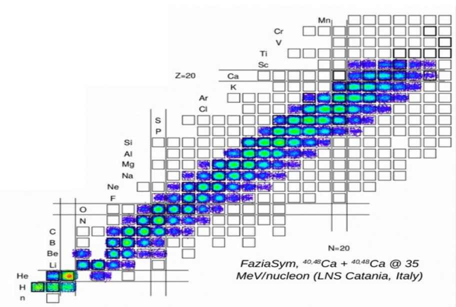


Nuclear dynamics group

FAZIA telescopes measure charge and mass of reaction products

4-5 FAZIA blocks would allow to cover all angles : fast measurement

Very modular blocks : easy to build the suitable geometry



Experimental strategy

Possible experiment at GANIL with FAZIA detectors

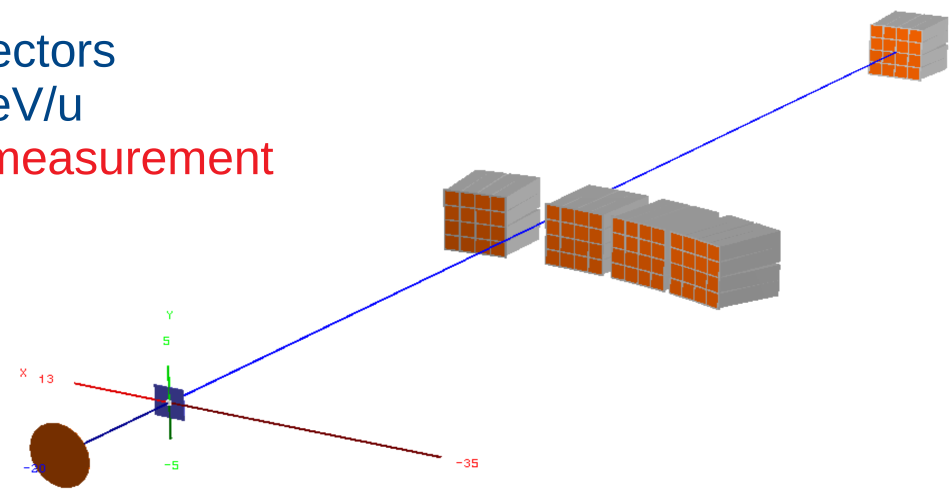
Cocktail beams (C, N, O, Ne…) at 30 to 90 MeV/u

We need tools to quantify the impact of each measurement

We need clear support from GCR community

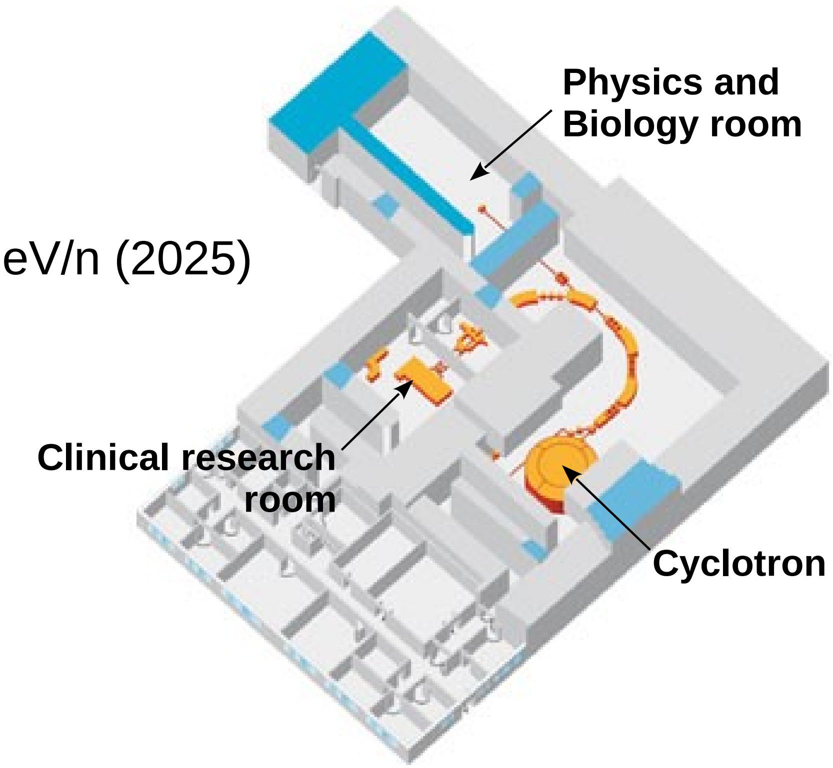
Next step : LoI to the GANIL PAC (SC) ?

Other ideas could emmerge...



Futur opportunities at ARCHADE

ARCHADE
New resource center for hadrontherapy in Caen
First patient treated with proton in july 2018
α, ^{12}C, ^{16}O, ^{20}Ne research beams from 50 to 400 MeV/n (2025)
~300h/year of beam time dedicated to physics



FRACAS detection system
Trackers under development
ΔE-ToF wall of thin scintillator (1/3 built)
Powerfull magnet (ALADIN-like : 1M€)

FRACAS performances
Good charge identification (ΔE-ToF)
Good isotopic identification (trajectory)
Perfect to work with ARCHADE beams

Possible issues
Beam availability at ARCHADE ?
Technical staff for physics ?
Magnet to be build and installed