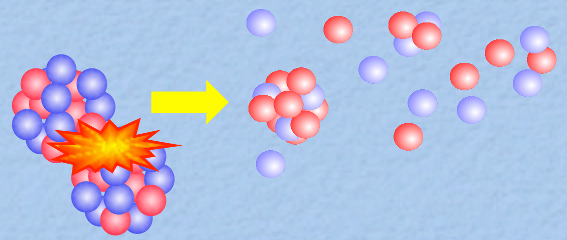
DITANET

Topical Workshop on Detection Techniques
7-8 November 2011 Centro Nacional de Aceleradores – CNA Seville

The FIRST experiment : fragmentation of Ions Relevant for Space and Therapy



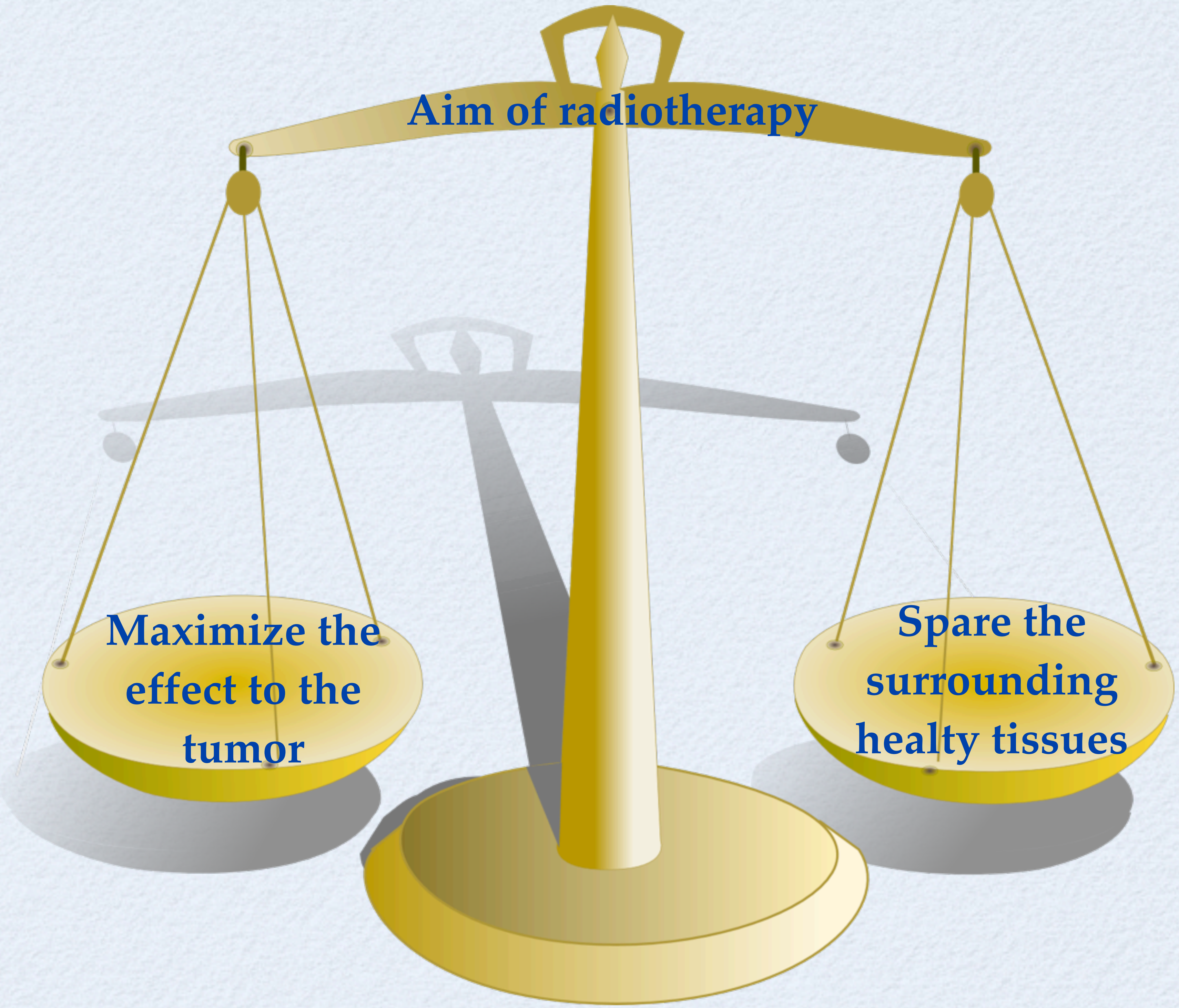
Marzio De Napoli
INFN-LNS Catania
on the behalf of the FIRST collaboration

INFN Istituto Nazionale di Fisica Nucleare

- The role of nuclear fragmentation in medical and space applications
- Why are fragmentation measurements really important ?
- What do we need to measure ?
- How to measure it: the FIRST experiment

The role of Nuclear Fragmentaion in Tumor Therapy

Ionizing Radiation for Tumor Treatment



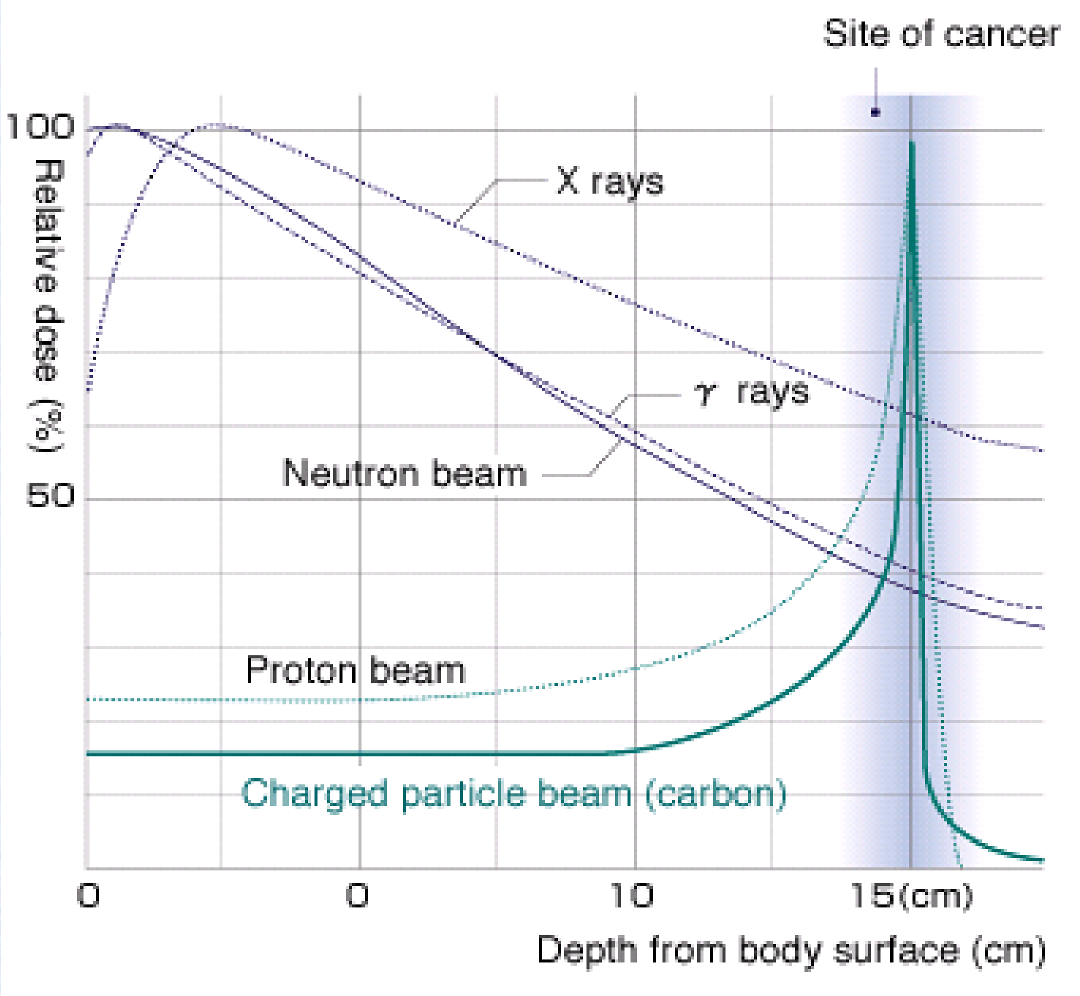
Light ion beams present many advantages in radiation treatments of tumor

Advantages of Carbon beams

Spare the surrounding healty tissues

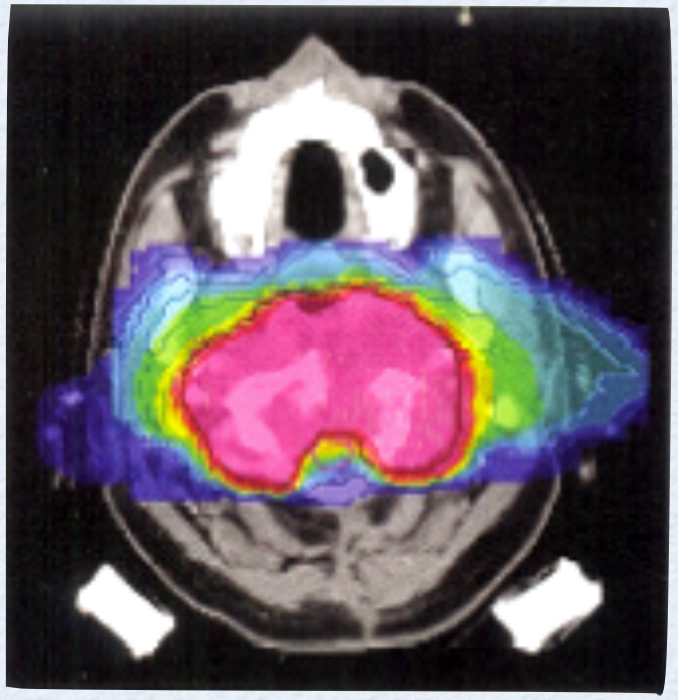
<u>High dose conformation</u>

Better spatial selectivity in dose deposition

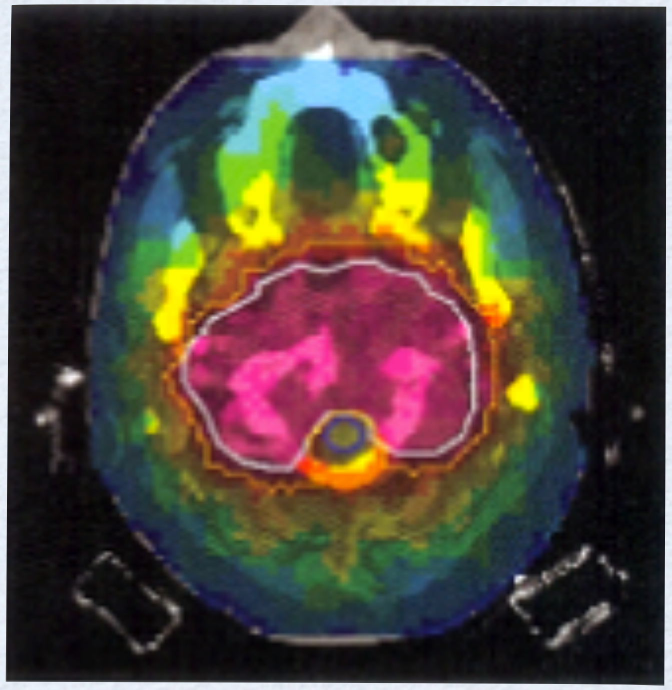


<u>Enhanced ballistic selectivity</u>

Reduced lateral and longitudinal diffusion



Carbon irradiation

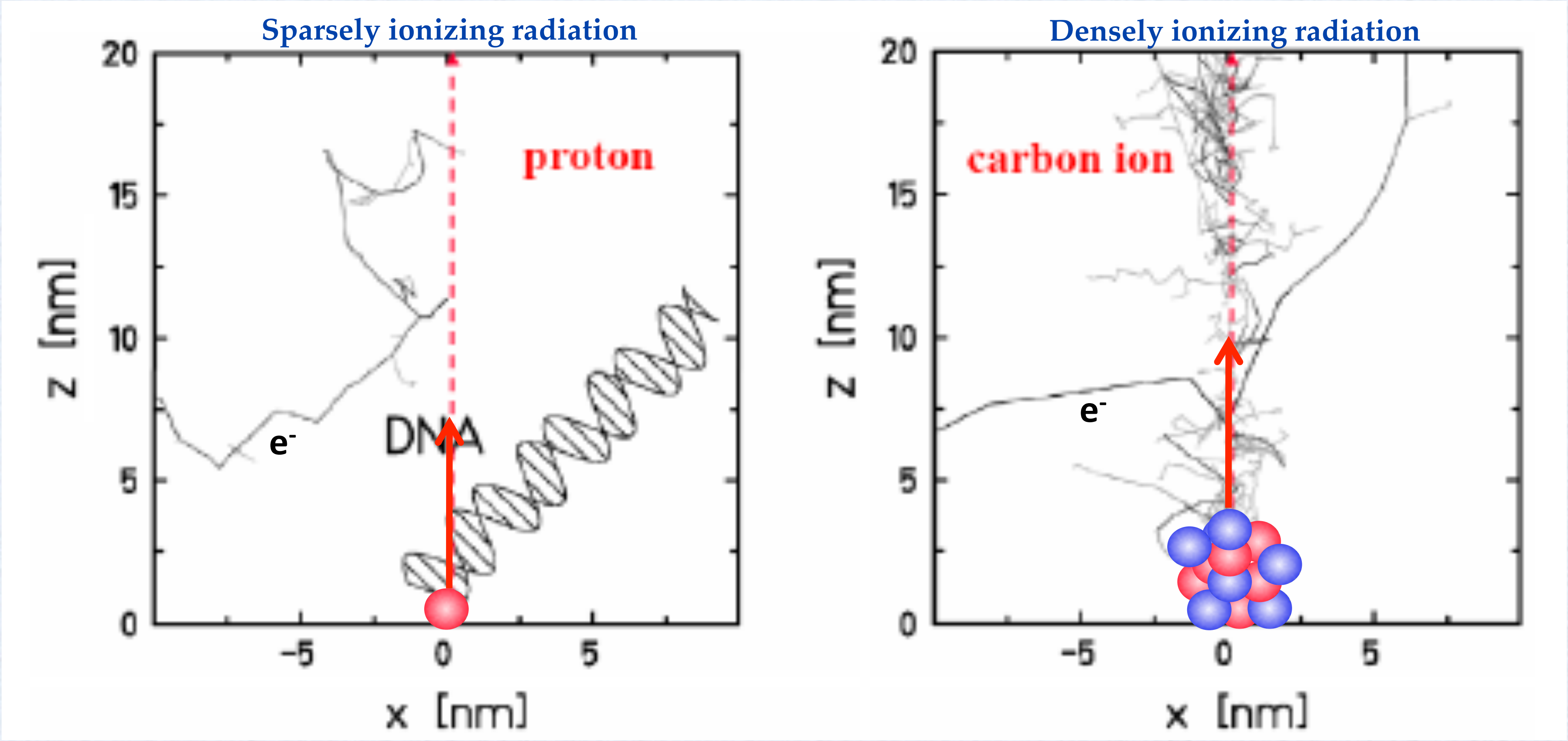


Photons irradiation

Advantages of Carbon beams

Maximize the effect to the tumor

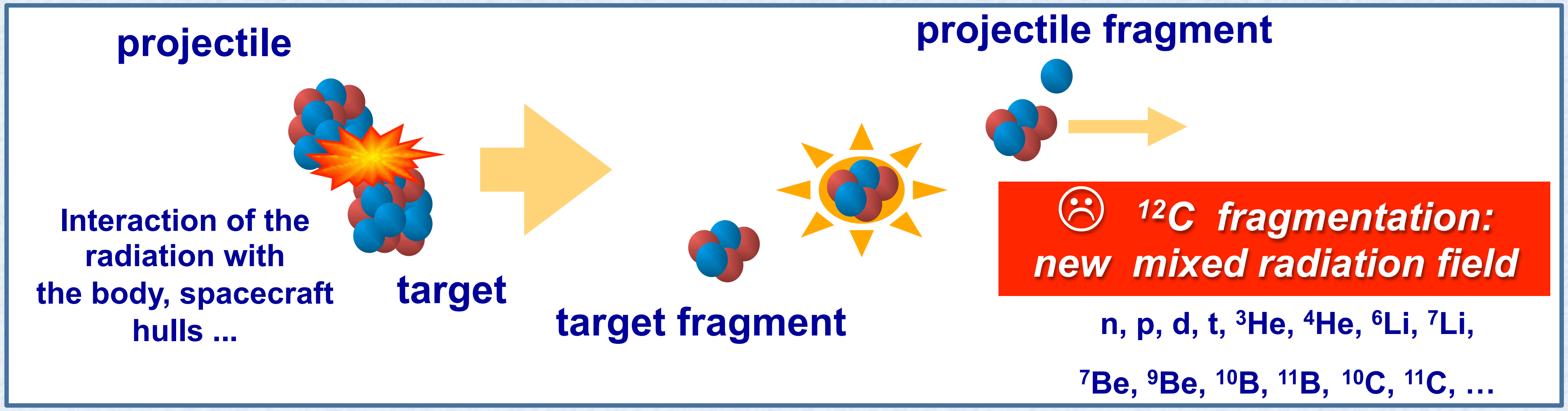
<u>Enhanced biological effectiveness</u>

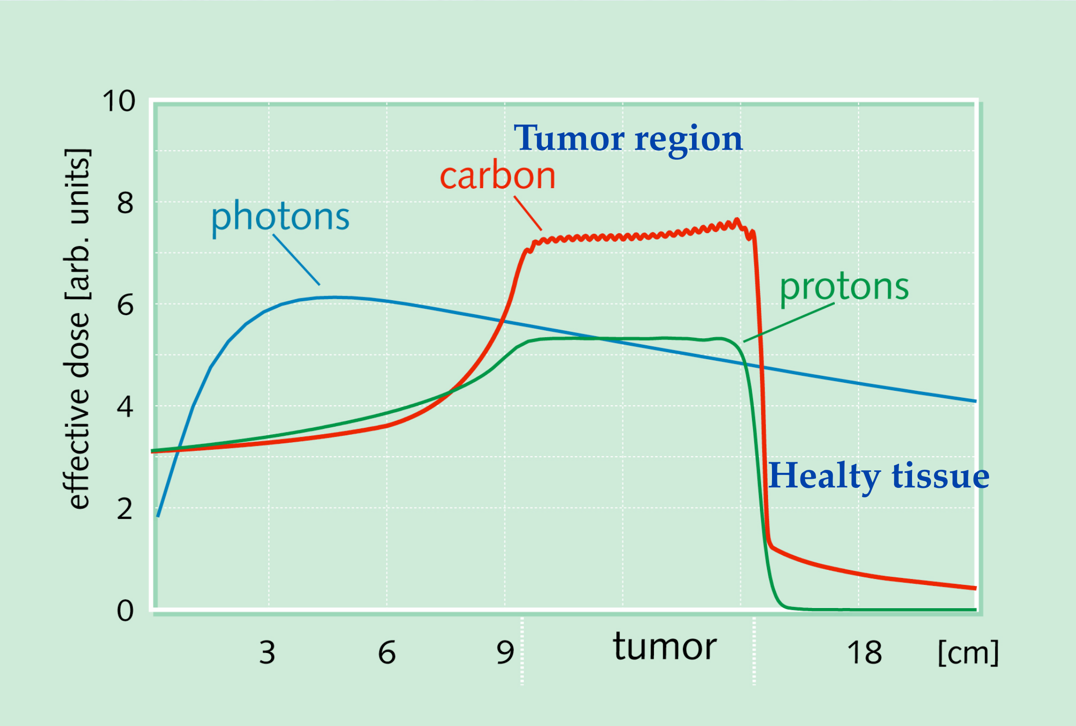


Higher ionization density → Higher biological effectiveness

Disadvantage of Carbon beams

Nuclear Fragmentation





Attenuation of primary beam

Different biological effectiveness of the fragments wrt ^{12}C

Extra-dose in healty tissues

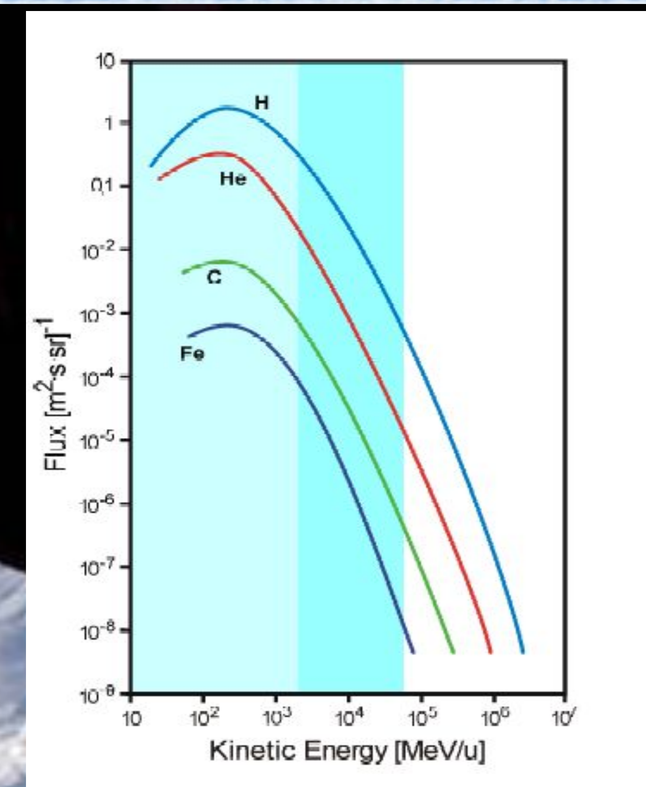
Dose release in healthy tissues with possible long term side effects, in particular in treatment of young patients must be carefully taken into account in the Treatment Planning System

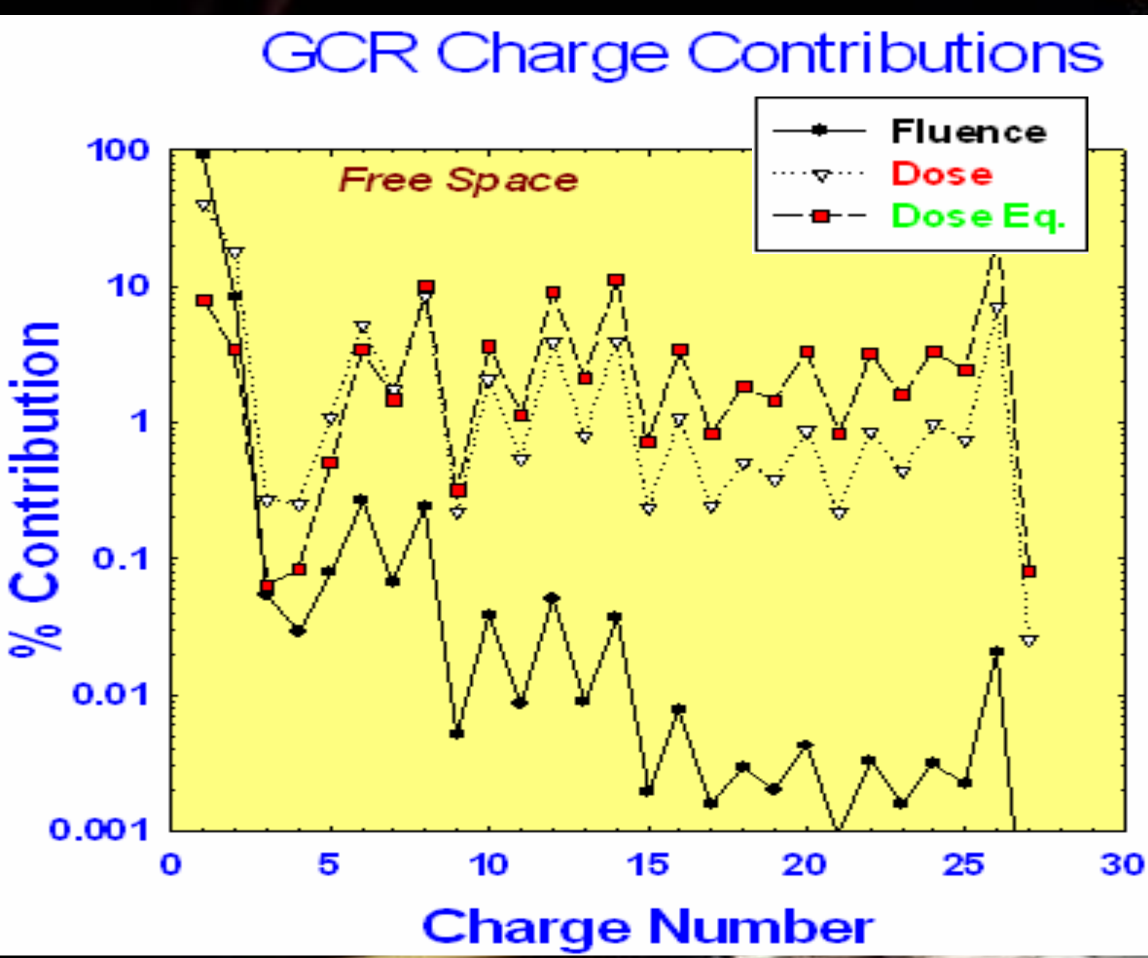
The role of Nuclear Fragmentaion in Space Application

Radiation Field in Space

Galactic Cosmic Radiation (GCR):

- 2% electrons and positrons
- 98% particles :
  - 87% protons
  - 12% α particles
  - 1% heavier ions (HZE particles)

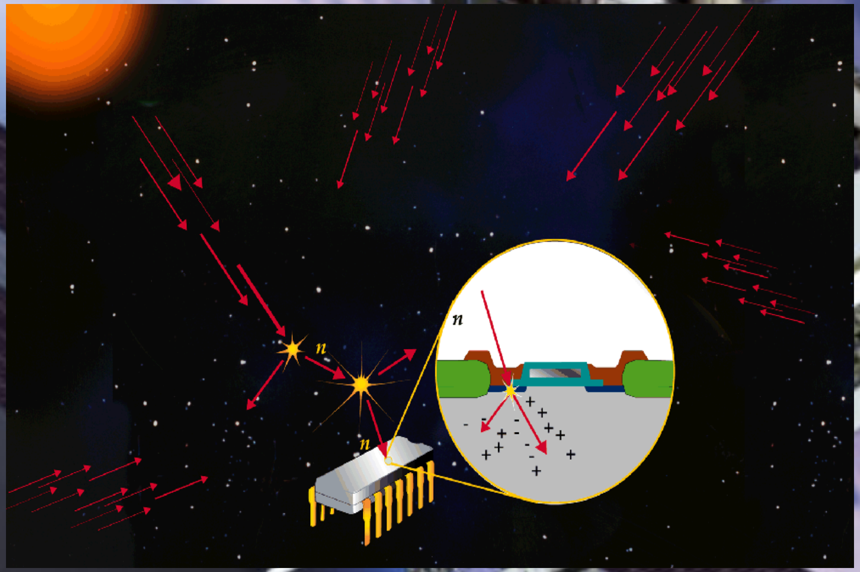




Problems related to GCR

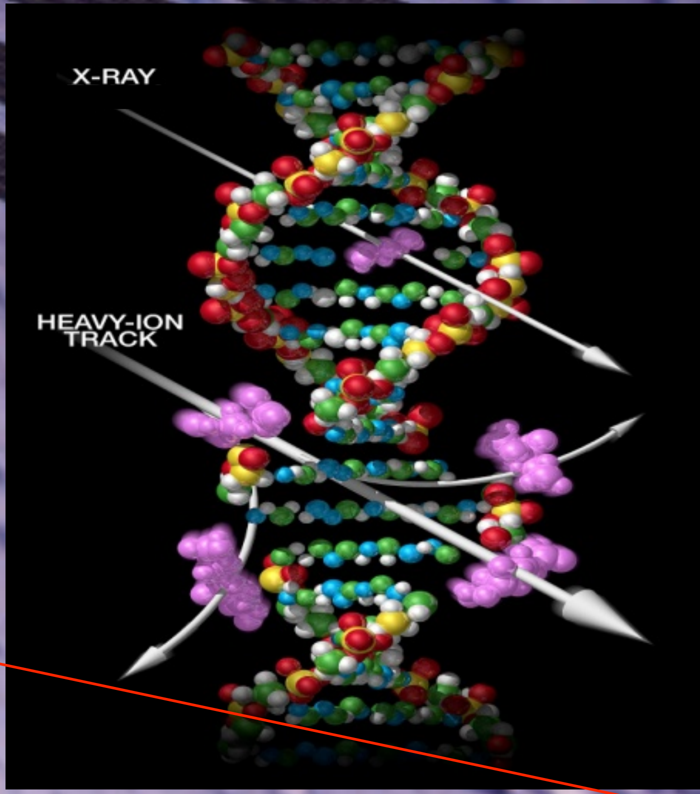
Radiation effects on non-biological material

- Shielding
- Radiation hardening
- Single even upsets in electronic devices
- …



Risk estimation for humans in space

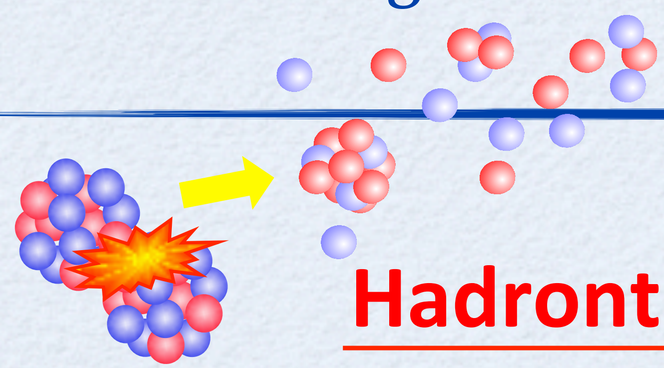
- Acute effect
- Late effects
  - CNS damage
  - cataracts
  - cancer
  - …



Estimate how fragmentation modifies the radiation field for getting safer interplanetary spaceflight

What is in common in HT and Space Exploration

Nuclear fragmentation complicates both spacecraft shielding design and treatment planning for hadrontherapy.



Hadrontherapy

Space Radiation

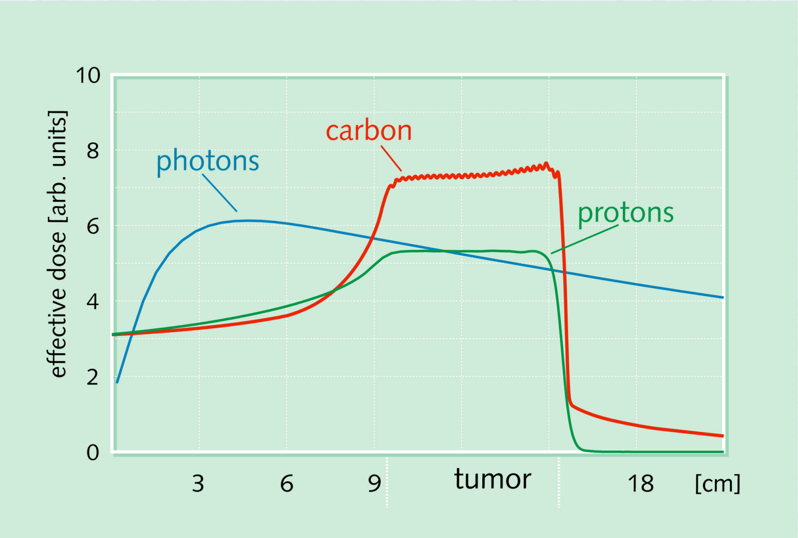
Similar Nuclear Physics processes involved: mixed fields of charged particles are present in astronauts environment and patients treated with carbon ions

Energy and mass range are very close

A precise estimation of the mixed fileds of charged particles is required in both fields for having a better radiation treatments and for getting safer interplanetary spaceflight.

How to do that ?

Why fragmentation measurements ?



Hadrontherapy

Fragmentation inside the patient cannot be avoied and we can anyway not measure inside the human body

Space Radiation

Too many projectile-target-fragment-energy combinations to make it possible to measure all interactions needed for a correct risk assessment ...

We need to perform computer calculations with "reliable" particle transport codes

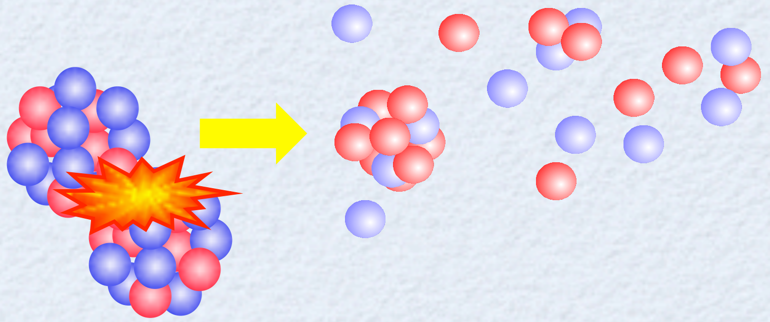
but...

Physical models must be validated by experimental measurements

What do we need to measure ?

To train a nuclear interaction model we need to measure:

- Production yelds of Z=0,1,2,3,4,5 fragments
- $d^2\sigma/d\theta dE$ (angle and energy) with large angular acceptance
- Detect the correlation between emitted fragments



Different combinations of projectile-incident energy-target

<u>Thick target</u> Many thick target measurements have been already done

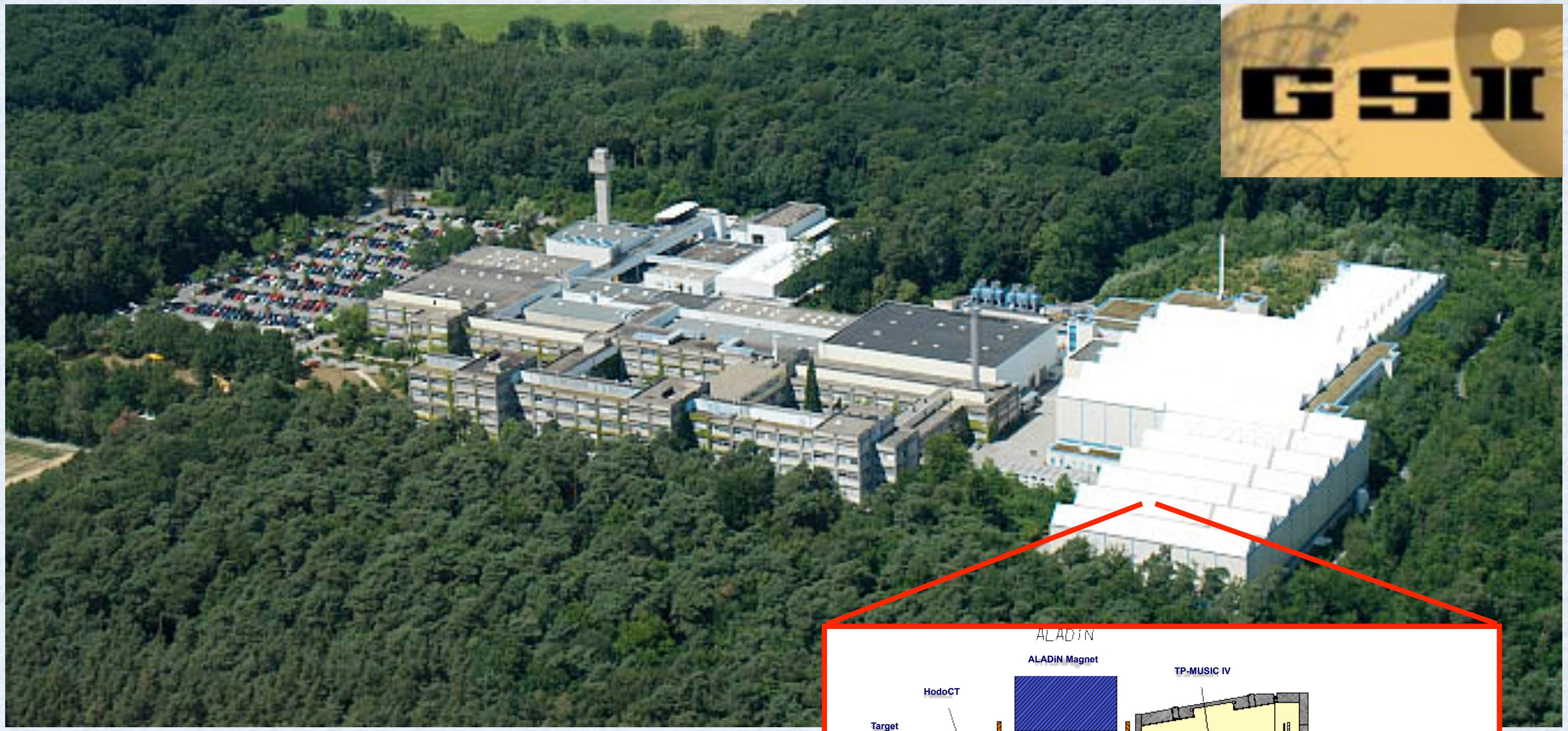
<u>Thin target</u> Many measurements on thin target are already around.. but not wrt production angle and energy

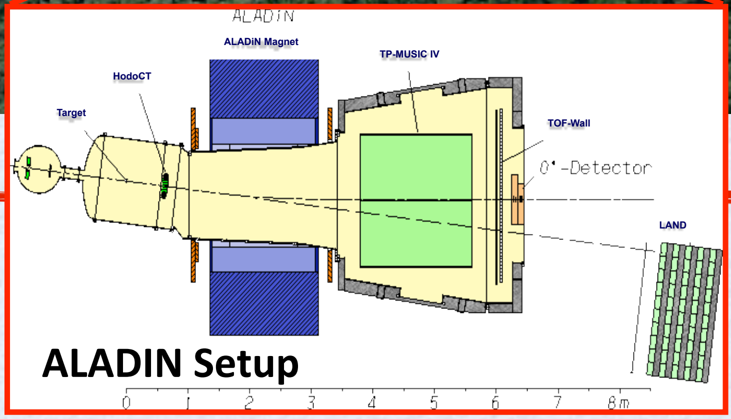
FIRST (Fragmentation of Ions Relevants for Space and Therapy)

The FIRST Experiment

"Terapeutical" beam of ^{12}C @ 200-400 MeV/u available

Existing setup designed for higher E and Z fragments: Dipole magnet, Large Volume TPC, TOF Wall, Neutron detector.



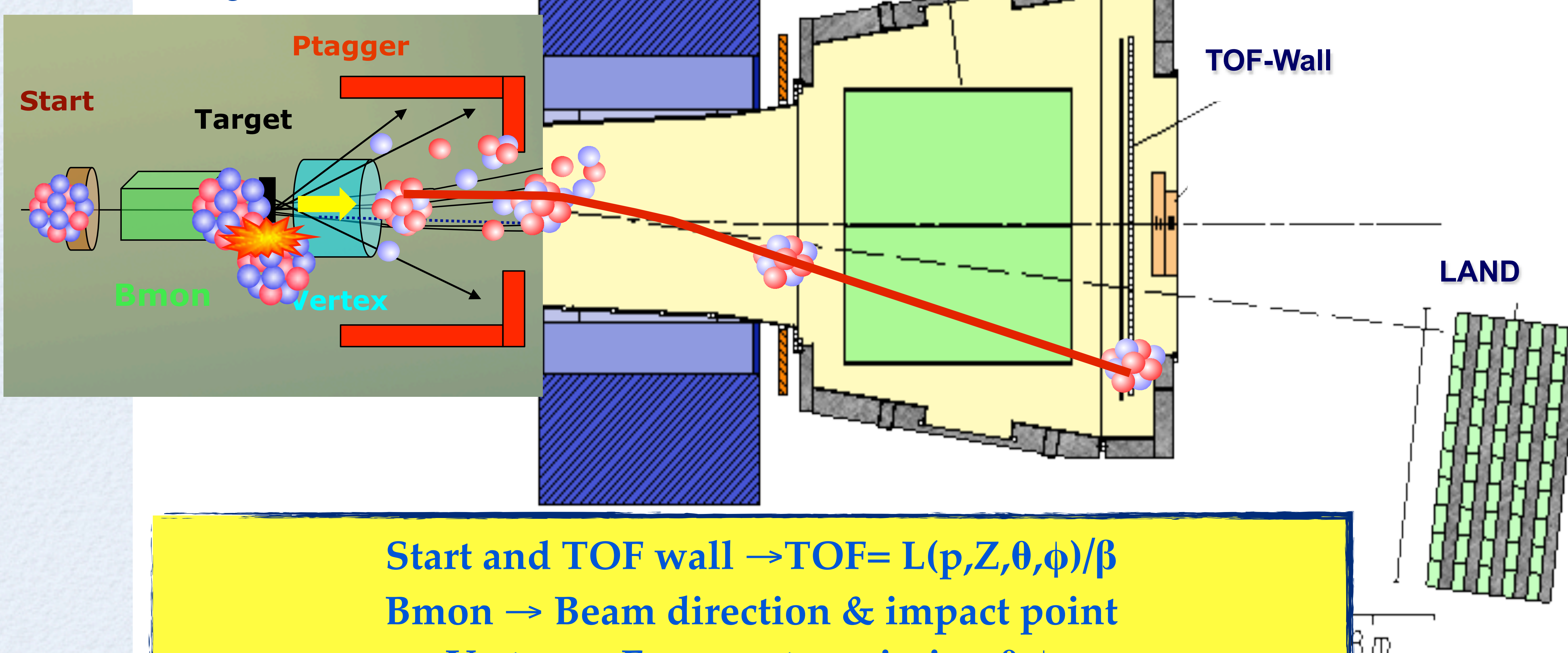


<u>Coincidence experiments</u>

- Decomposition of the total reaction cross-section into the different decay channels
- Understanding of the mechanisms and constraints on the models
- Differences between the models (and mechanisms) when looking at the evolution of the de-excitation channels with excitation energy estimated from particle multiplicities

Experimental Setup

New detectors added to optimize the Interaction Region for this measure



Start and TOF wall →TOF= L(p,Z,θ,ϕ)/β

Bmon → Beam direction & impact point

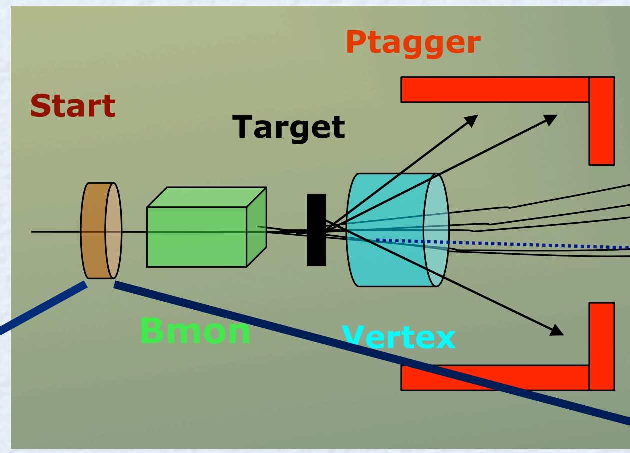
Vertex → Fragments emission θ,ϕ

Ptagger →Large angle p (He): position, TOF, DE/DX

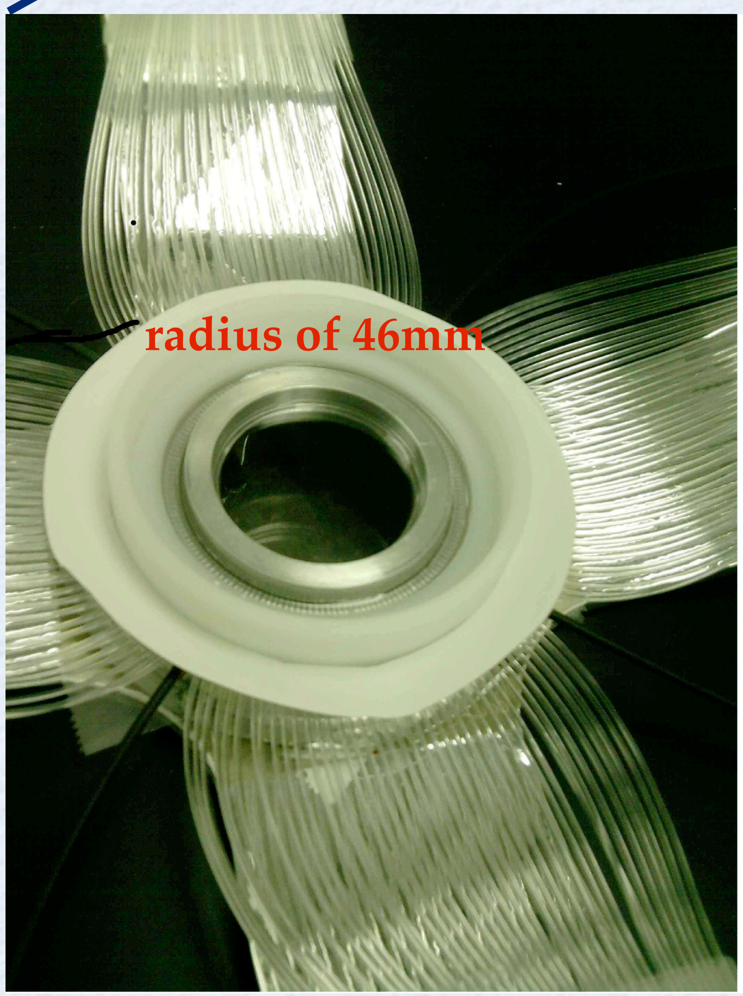
TPC&ToF → R=p/(ZeB), θ,ϕ after bending, Energy loss ∝ (Z/β)²

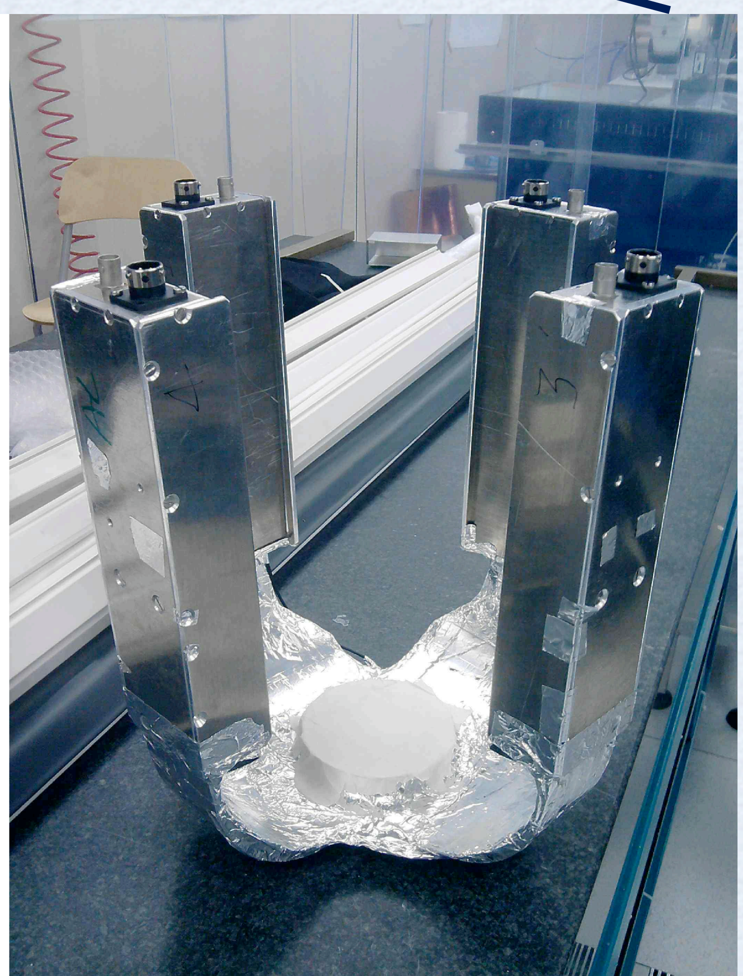
LAND → neutrons

New Target Region: Start Counter



Measure the arrival time of a beam projectile



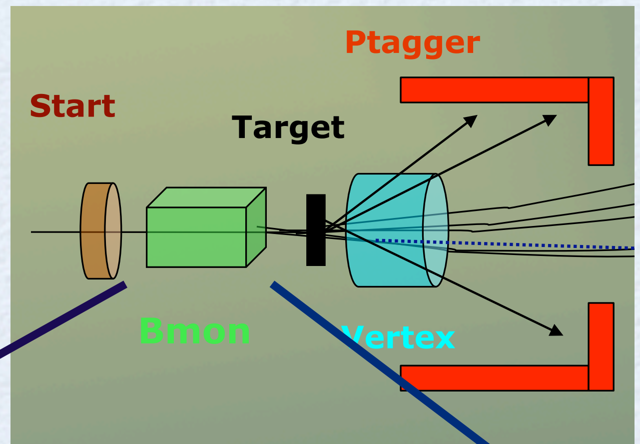


Thin (150μm) scintillator (EJ228) to avoid beam interaction before the target.

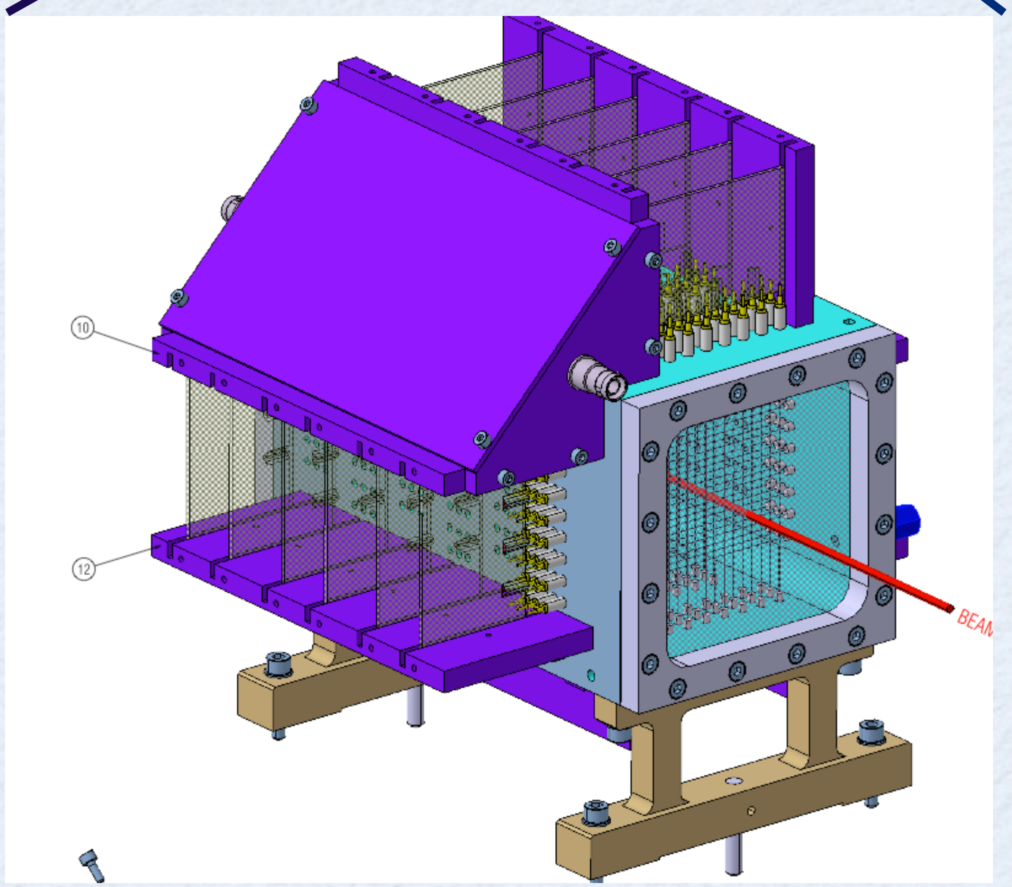
360 optical fibers, 1 mm diameter each, grouped in four bundles that are read by fast PMT Hamamatsu (40% q.e.)

Efficiency >99%, time resolution about 130 ps

New Target Region: Beam Monitor



Tracking the incoming carbon and measure the impact point on the target



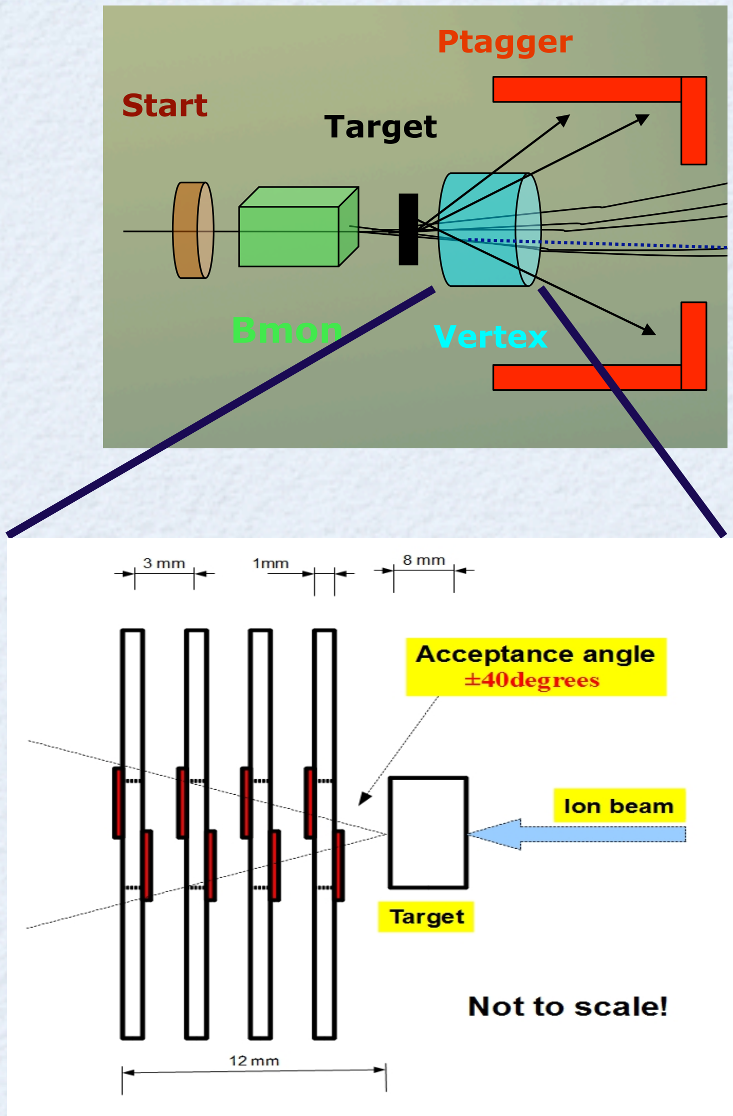
Active volume of the chamber is 2.4 × 2.4 × 14 cm^3

Drift chamber providing two orthogonal profiles of the beam, each view detected by six planes of 3 cells, for a total of 36 sense wires.

The chamber is operated at a working point of 2.1 kV in Argon/CO_2 gas mixture with 80/20 % percentage.

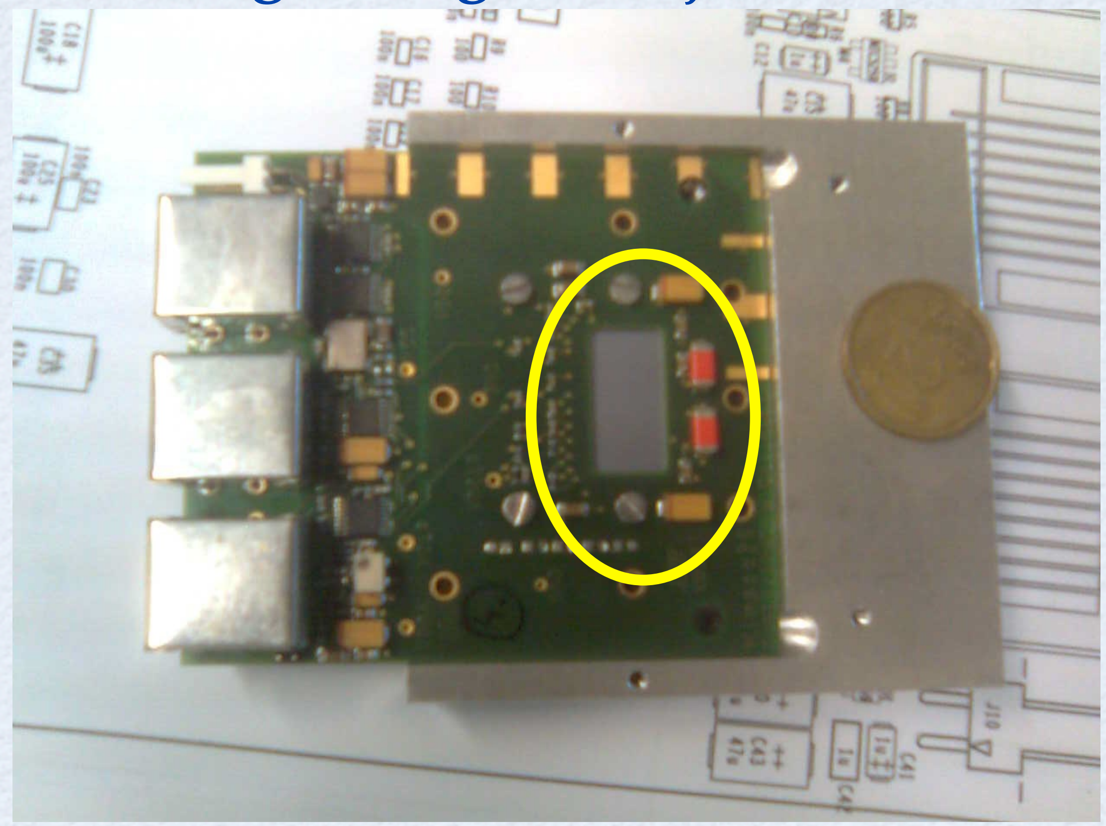
Single hit space resolution: ≈ 80 μm

New Target Region: Vertex



Based on 4 planes of 2x2 cm^2 active area, made of two MIMOSA26 silicon pixel detectors (50µm thin), 2mm spaced (angular coverage +-40°).

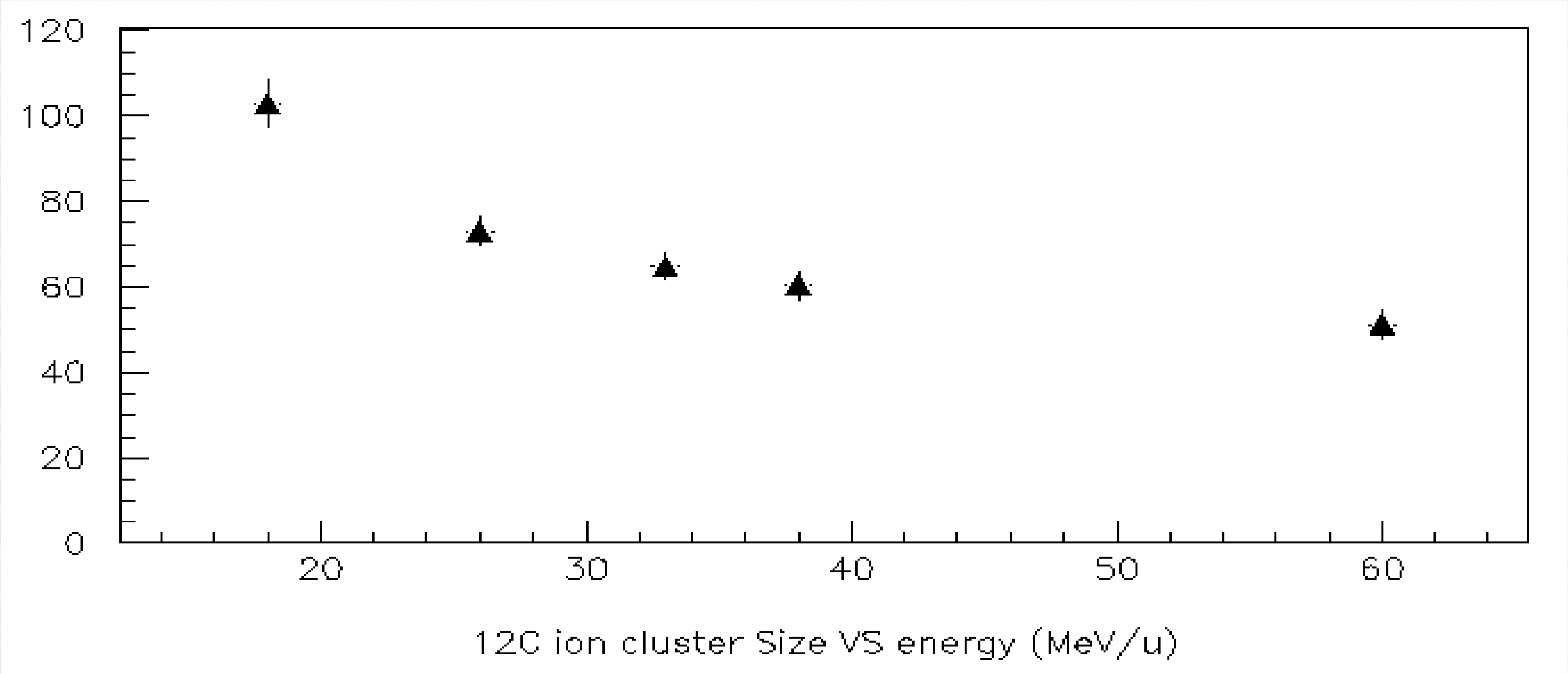
Track all the charged fragments just downstream the target



- Active surface :1152 columns of 576 pixels (21.2x10.6mm^2)
- The sensor provides only digital information on fired pixels
- Digital readout at 10 Khz rate
- Wide dynamic range to detect both minimum ionizing particles and carbon ions of the beam
- On chip electronic to process the signal in few µm layer
- Zero suppression on board to provide only the fired pixel address to reduce the DAQ bandwidth.
- Angular resolution better than 0.2°
- Separation of clusters of pixels ≈50 µm

New Target Region: Vertex

MIMOSA26 Test @ Laboratori Nazionali del Sud in Catania

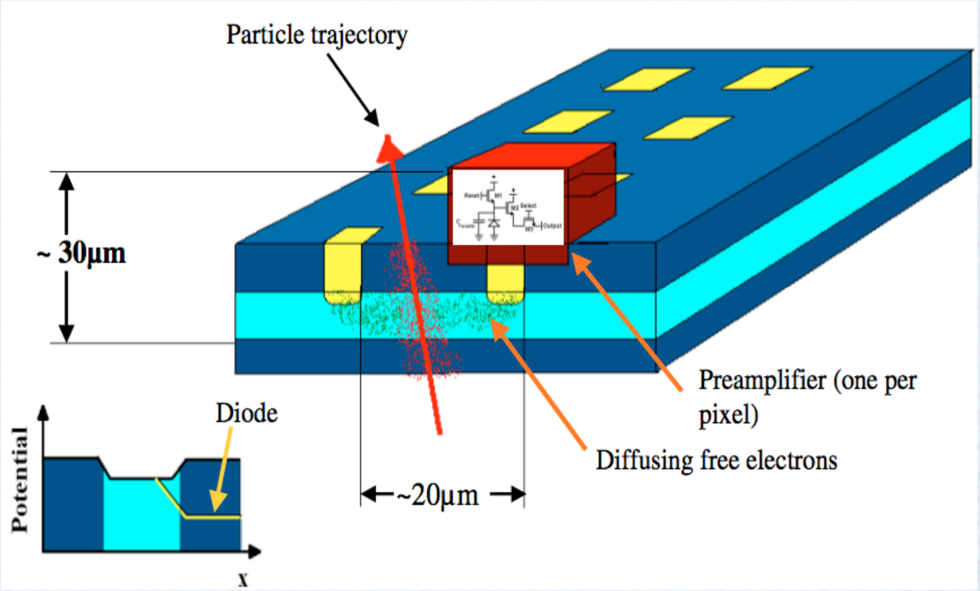


E. Spiriti, M. De Napoli and F. Romano, Nuclear Physics B - PS 215 (2011) pp. 157-161

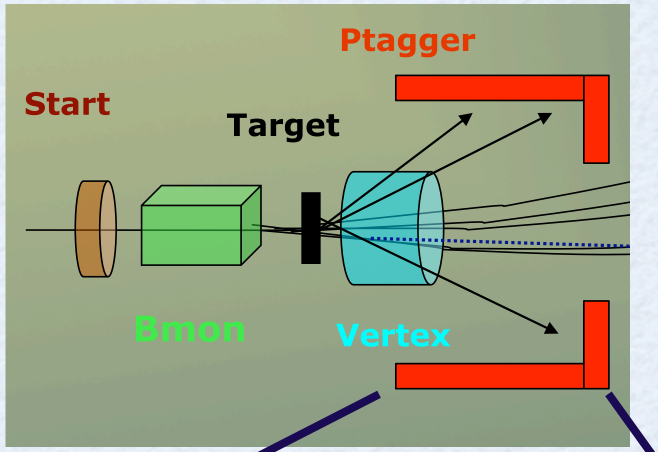
Carbon beams of five different energies: 18, 27, 33, 38, 60 MeV/nucleon

Smaller cluster size -> higher tracks separation capability

Double track separation of 99% for the fragments expected, with maximum diameter of ≈ 6-7 pixels

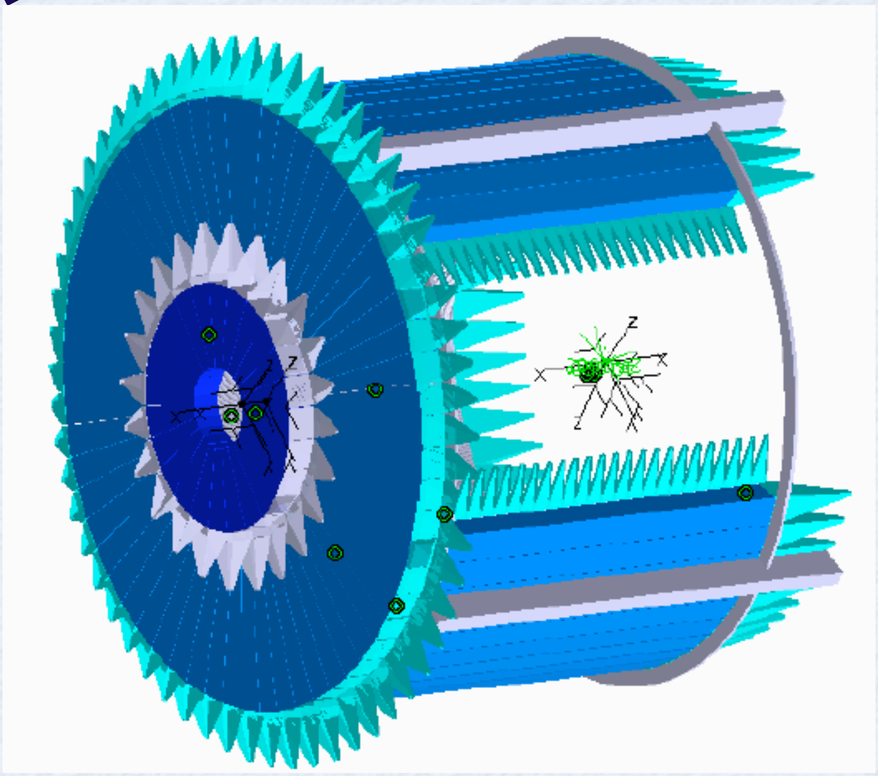


New Target Region: Proton tagger



Detect large angle (5°-60°) slow protons BEAM (He) with $\beta<0.5$.
Measures TOF, ΔE (-> kinetic energy) and impact position.

Organic scintillator modules (EJ-200) (3.5 cm thick) : decay time of 2.1 ns, 10000 photons/MeV light yield, 425 nm wavelength of maximum emission, 4 meters attenuation length.

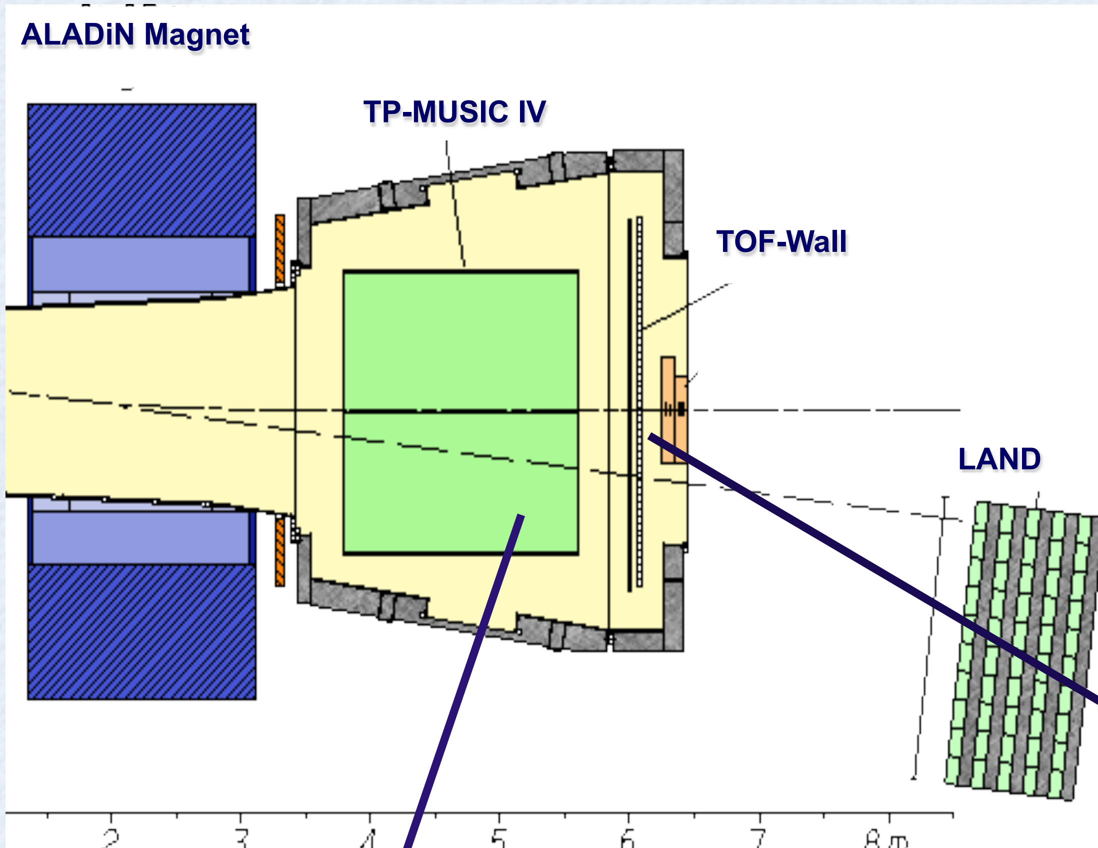


The scintillators are read by silicon photomultipliers SiPM:
4x4 mm^2 active area
Peak sensitivity wav 480 nm
Photon Detection Eff 22%
time resolution ≃ 200 ps

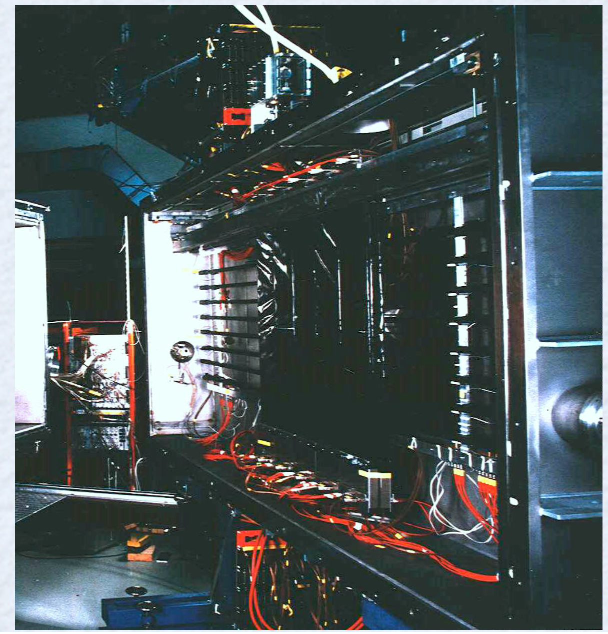
ToF resolution around 270 ps (protons 200MeV)

The SIPM output is processed by a custom electronics that amplifies, reshapes, splits and discriminates the signals so to properly feed them in TDC, ADC and to provide a discriminated OR signal for triggering purpose.
Individual control of SiPM Supply Voltage

Forward Region : ALADIN + TPC + ToF

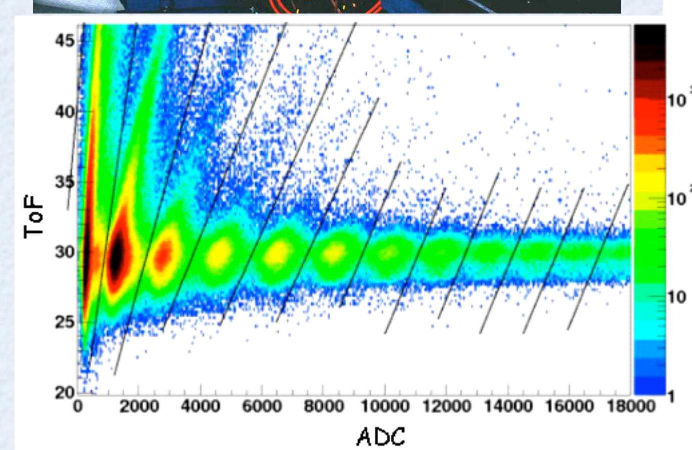


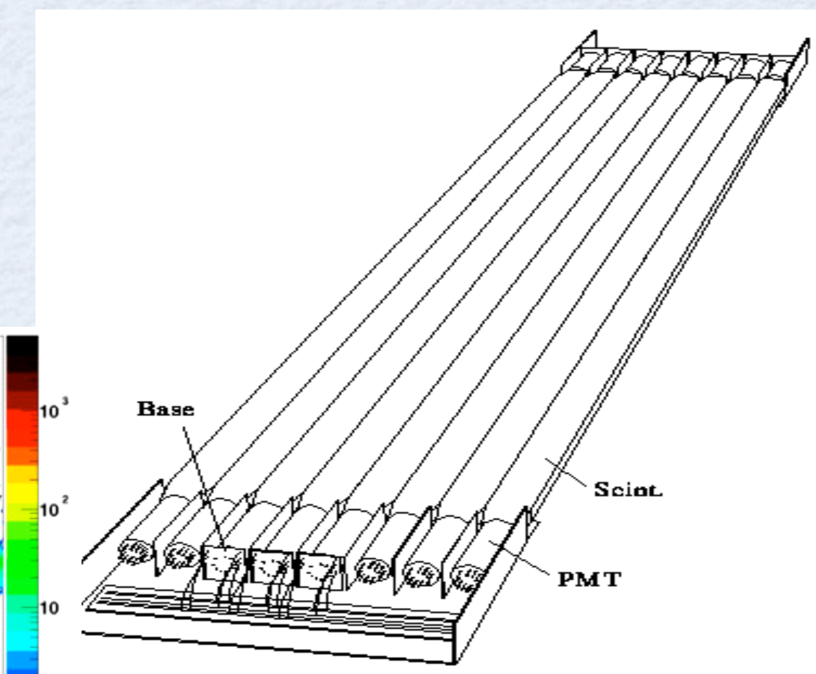
Fragments bending → R=p/(ZeB)



Fragment DE/Dx → $(Z/\beta)^2$

ToF -> mass

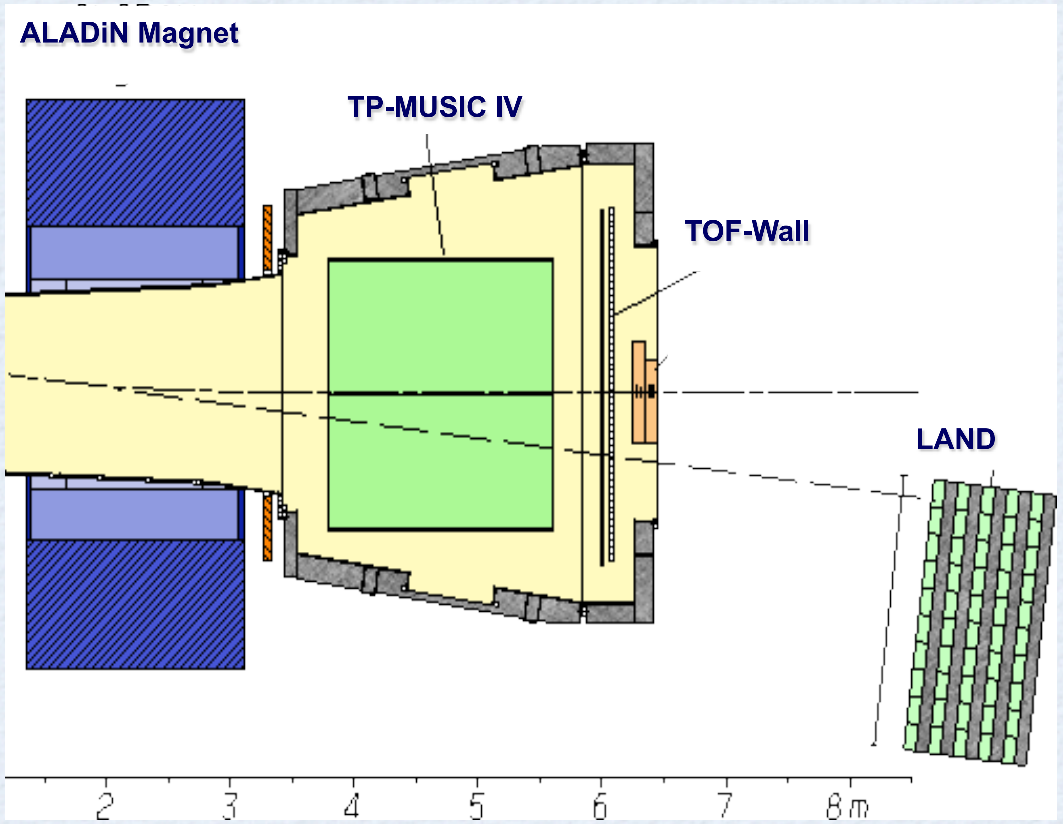


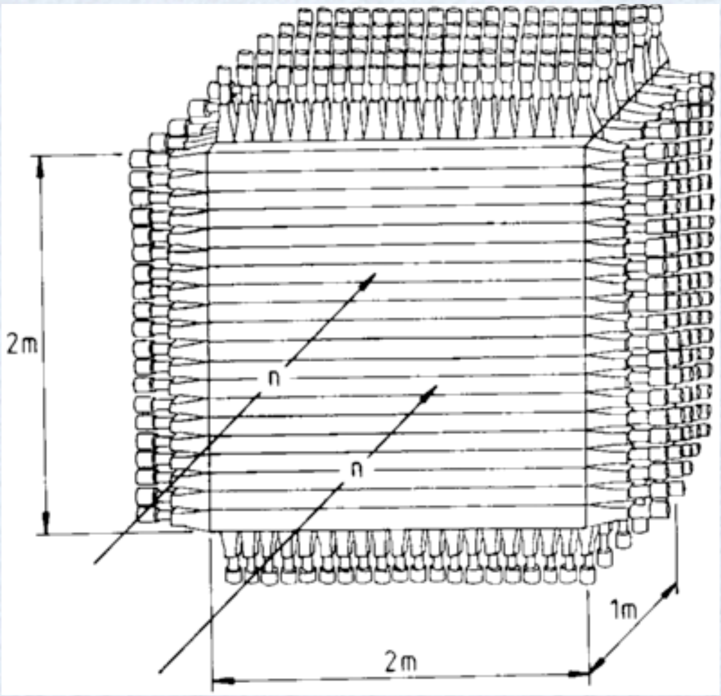


Time Projection Multiple Sampling Ionization Chamber 2.1 m large, 1 m long and 1.8 m high. A cathode plane in the middle separates the active volume of the detector into two distinct drift regions with ionization chamber sections and proportional counters on each side

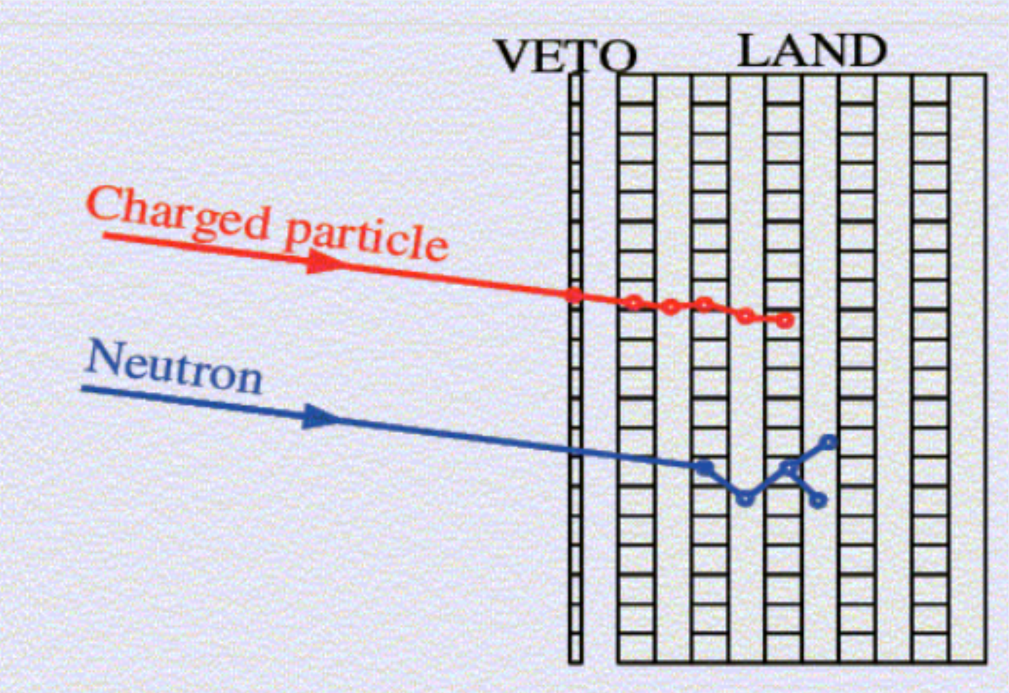
The ToF-Wall is composed by two detector layers (front and back), each made of 12 modules, each built up of 8 plastic scintillators (BC408), 1.10 m long, 2.5 cm wide and 1 cm thick,

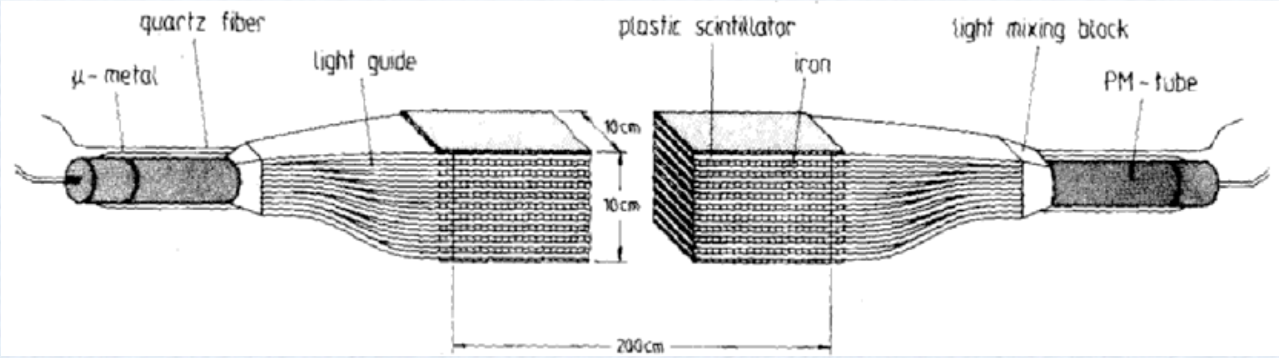
Forward Region: LAND





Efficiency about 90% for neutrons with an energy higher than 300 MeV.
Time resolution is about 500 psec.
Position information with a resolution of 5 cm.





- Active volume: 2x2x1 m^3, $-4.1° < \phi < 4.1°$ vertically and $-2.2° < \theta < 2.2°$ horizontally
- Divided in 200 paddles 200x10x10 cm3.
- Each paddle made of 11 sheet of iron (2.5/5 mm thick) ad 10 sheet of scintillator (5 mm thick)
- Veto in front of the detector for charged particle

Summary & Conclusions

- An international collaboration (Germany, France, Italy, Spain) has started an experimental campain at GSI to measure fragmentation cross sections

- The detector is an evolution of a pre-existing setup, optimized for the detection of the Z<6 fragment with large angular acceptance and accuracy at the few % level

- The scientific program of the FIRST experiment has started this summer with the study of the $^{12}C+^{12}C$ @ 400 MeV/nucleon fragmentation. Data analysis is in progress

- In future (2013) the experimental setup can be seen as a facility to measure the fragmentation of light ions (He, Li, O projectiles on different target of interest) and for fragmentation measurement of interest for space radioprotection (mainly Fe projectiles)

The FIRST Collaboration

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SPARE SLIDES

DAQ & Trigger

The readout is handled by Multi Branch System (MBS), a general DAQ framework developed at GSI.

MBS can handle easily the different Front End Electronics standards used by the different subdetectors: FASTBUS, CAMAC and VME.

All the trigger modules, one in each readout crate, are connected via a trigger bus to distribute the trigger and dead-time signals and to ensure event synchronisation.

Data collected by single controllers are broadcast via Ethernet to an event-builder where they are merged and saved in the standard GSI format.

The final trigger decision is based on the coincidence of trigger from the Start Counter with trigger of any of TOFWALL, LAND2, KENTROS and downscaled Veto Counter.

Efficiency about 95%

MUSIC