FOOT test beam at LNS

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On behalf of the proponents

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LNS beam request

Group	Detector type	Measurements
LNF & Perugia	Silicon tracker	test the capability of thinned sensors to detect incoming charged ions
Pisa	Scintillator bar+SiPM	time resolution with the coincidence of the two bars and study the response as a function of the longitudinal positions on the scintillation bar
Napoli	Emulsion films	Test the charge identification capability of the new emulsion batch

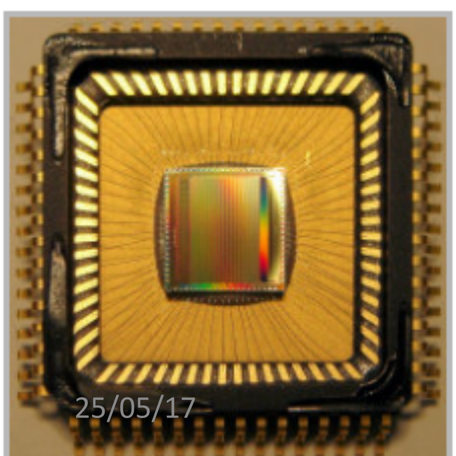
dE/dx - TOF detector structure

- 20 + 20 plastic scintillator bars (400 x 20 x 2.5 mm^3) arranged in two orthogonal layers, with SiPM read-out on both sides
- 80 channels read-out in coincidence each-others and with the start counter
  - Time resolution of 70 ps (standard deviation)
  - High energy resolution
  - Data rate of few kHz/chn
  - synchronization with the start counter and the other detectors of the system

Adoption of a Fast Digitizer

DRS 4

PAUL SCHERRER INSTITUT PSI



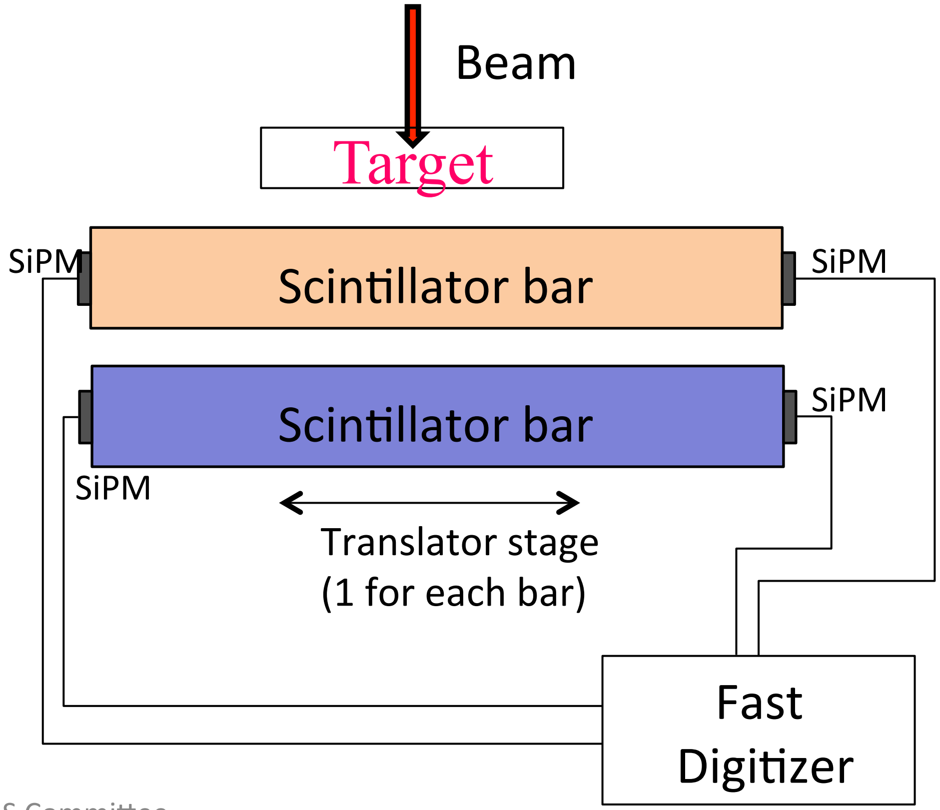
Developed in the MEG collaboration and used in the Fast-Digitizer CAEN modules

https://www.psi.ch/drs/DocumentationEN/DRS4_rev09.pdf

Assessment of the performances of the first two samples of the SiPM + Scintillator detectors

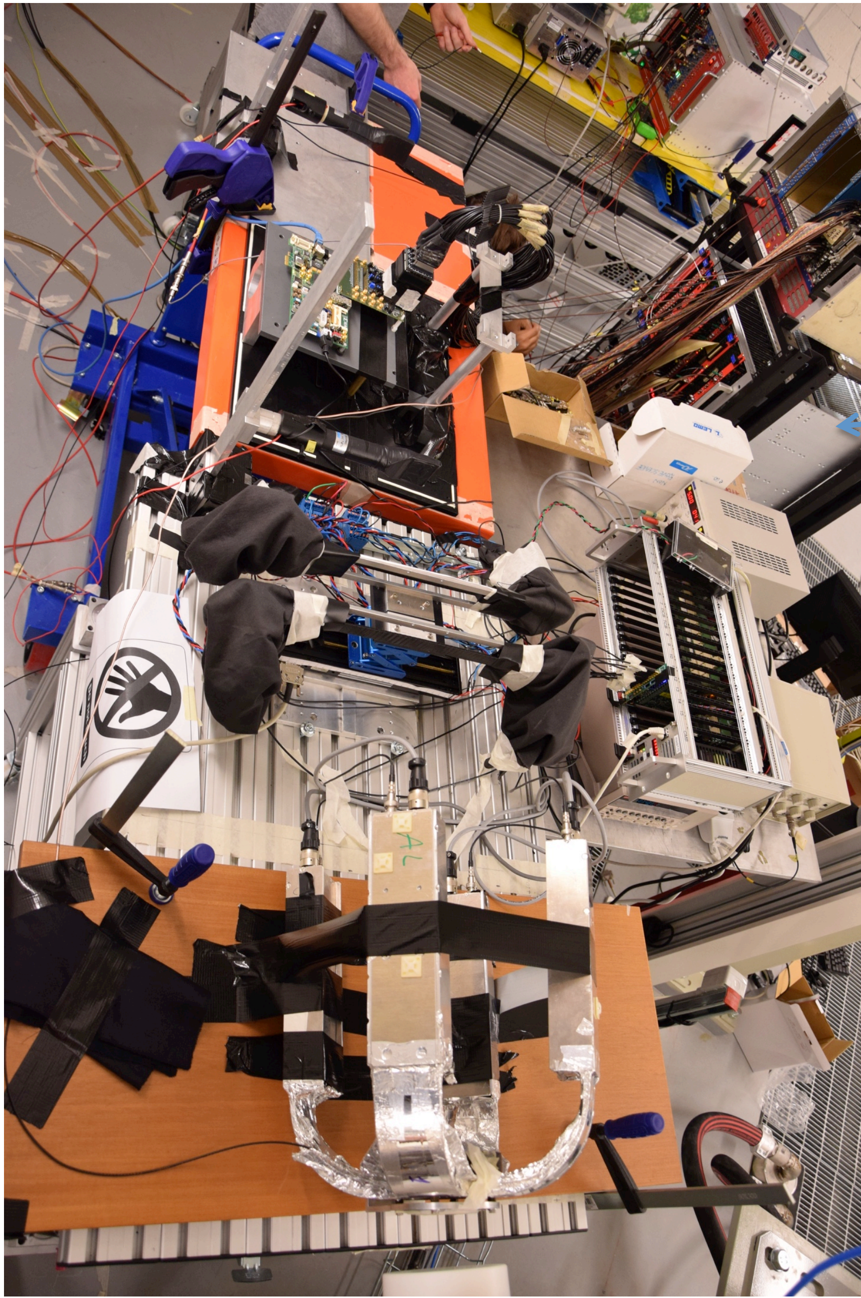
- Measurement of the collected signal and analysis of time resolution
- Study the signal dependence on the position along the bar and model the correction

Experimental set-up



- Test with different energies and ions to check the dynamic range
- Beams: H, He, ^{9}Be, ^{11}B, C ^{13}C, N and O from 62 to 80 MeV.
- For each energy, irradiation repeated several times
- 2 BTU for this study in the second half of 2017

dE/dx detector based on plastic scintillator



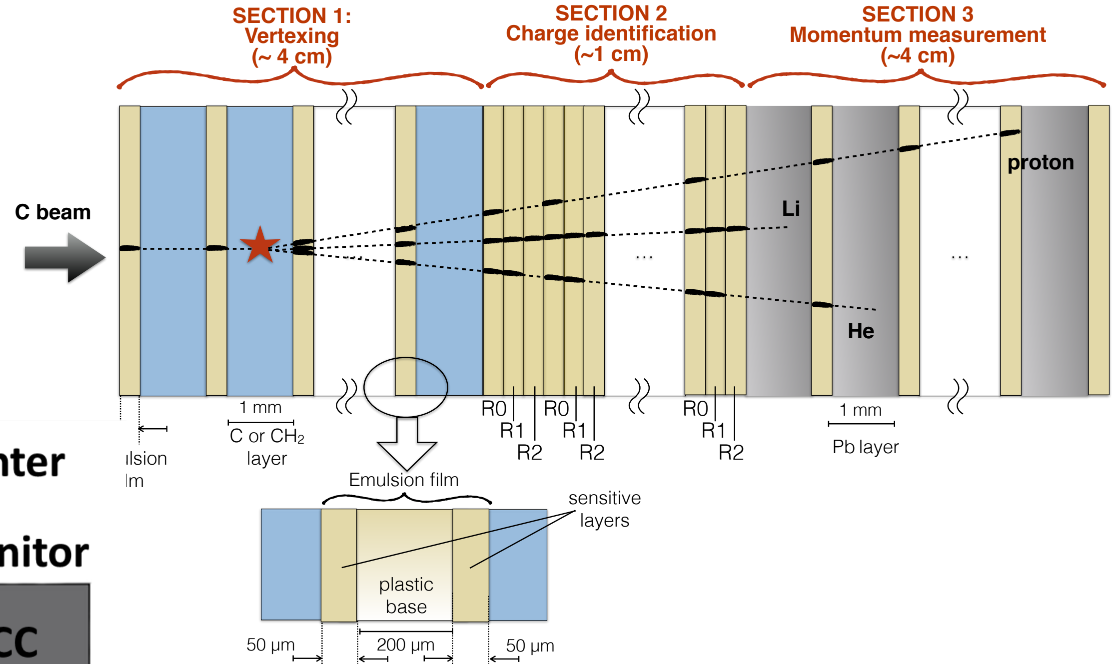
Set-up at Trento

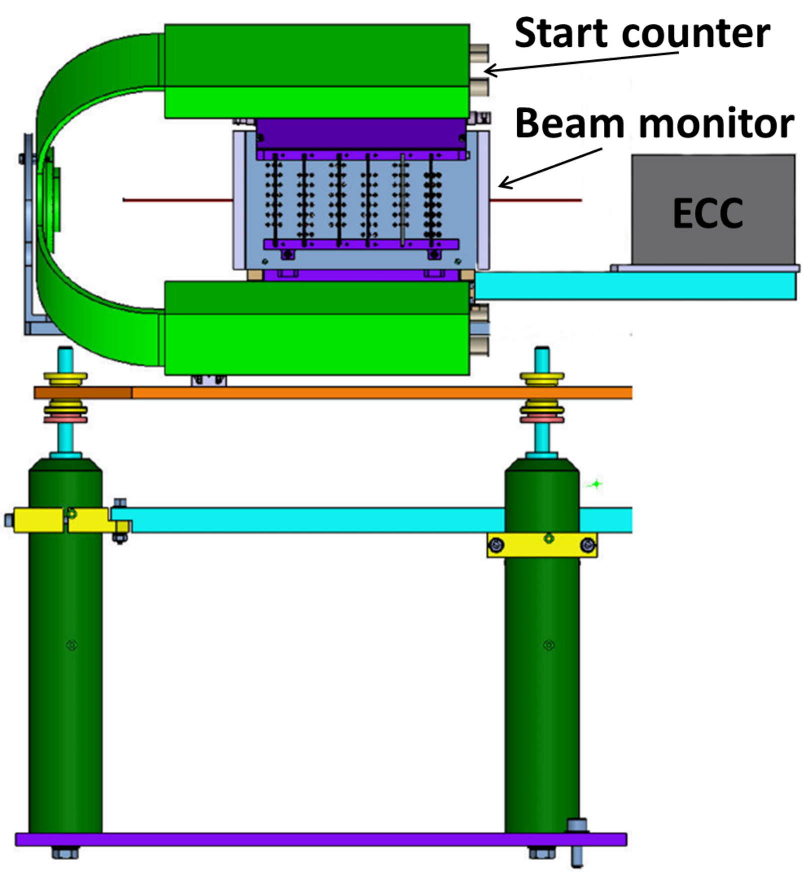
See Giusy's slides

2 bars (400x20x3 mm^3) in coincidence

Single bar 200 x 20 x 2 mm^3

Emulsion measurement



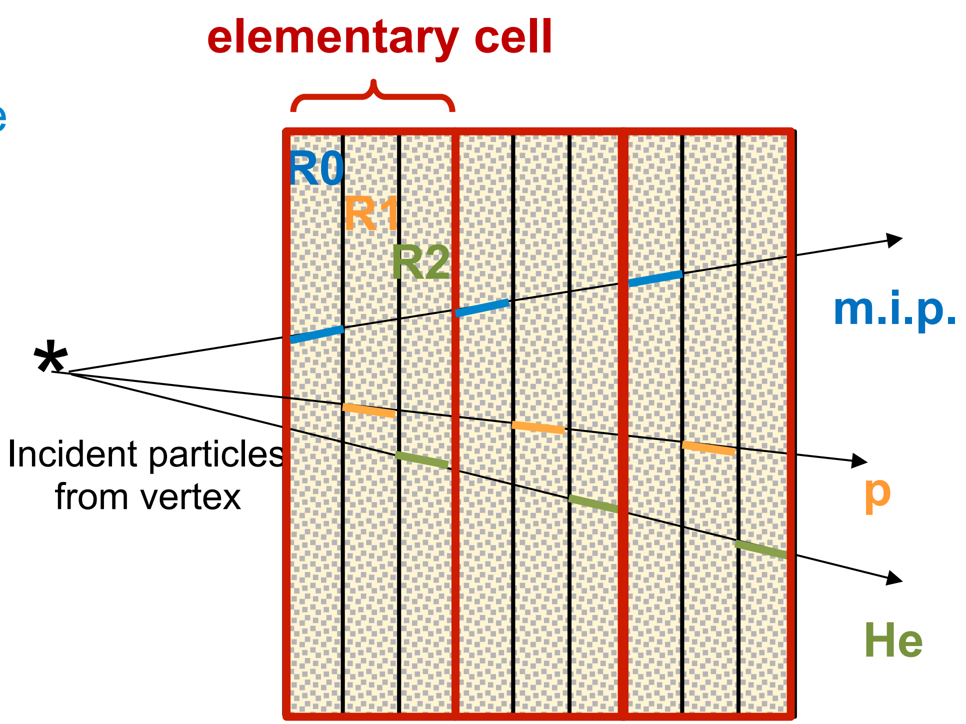


- Section 2: made of emulsion films only
  - charge identification for low Z fragments (H, He, Li)

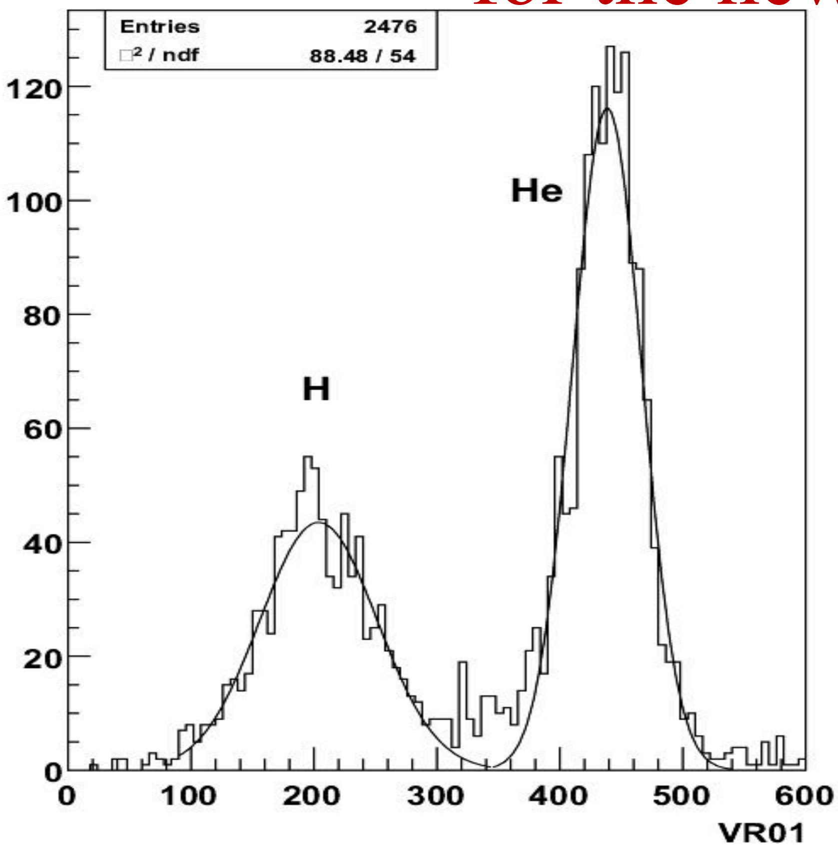
section 2: details

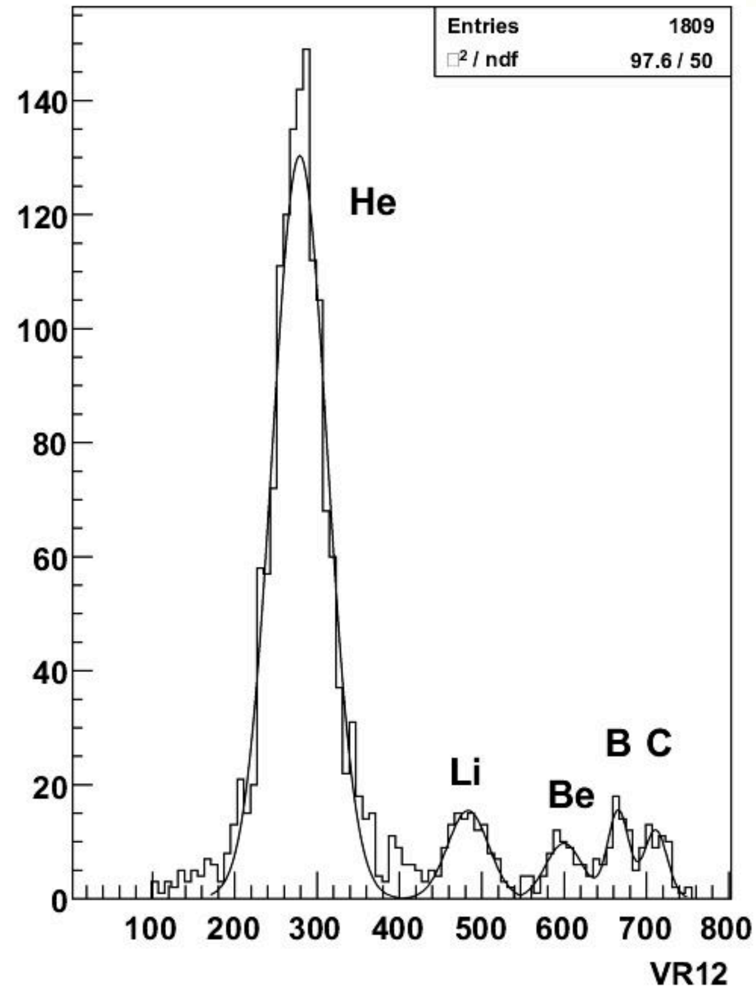
- Charge identification for low Z fragments (H, He, Li)
- Emulsion were differently treated after the exposure and before the chemical treatment according to their position in the elementary cell (0, 1, 2)

- **R0:**
  - Not refreshed
  - Developed soon after the exposure
  - **Sensitive to m.i.p.**
- **R1:**
  - Appropriate refreshing for protons
  - Insensitive to m.i.p.
  - **Sensitive to protons**
- **R2:**
  - Appropriate refreshing for He
  - **Sensitive to He**



Charge separation to be tested for the new emulsion batch





- 1 cell = 0.9 mm length

Cells	3	9	13	20
H-He	3.3	4.5	6.5	
He-Li	2.6	3.9	4.3	5.0
Li-Be	1.7	2.7	3.1	3.5

JINST 2 (2007) P06004

Summary of BTU requests for the 3 sub-detectors

Beam	Energy (MeV)	BTU Emulsion	BTU Tracker	BTU Scintillator
H	80	3	3	
D	80	3		
^{4}He	80	3	3	0.2
^{9}Be	45	3		0.3
^{11}B	55			0.3
^{12}C	80		3	0.3
^{13}C	55			0.3
^{14}N	80			0.3
^{16}O	80			0.3
Total		***12***	***9***	***2***

9 BTU allocated by LNS Committee

- 1 BTU = 8 hours
- Time lost to change the source is not included in the assigned BTU
- Nevertheless, need to keep the overall experimental activity comparable with the BTU time
- Using gas sources makes it easier to change from one source to the other (tank exchange, takes ~ 1h)
- Replacement of the tank is done by technicians (working hours 9-17)
- Changing energy is the most time consuming operation (several hours). For comparison, p → He doable in 30 min
- The machine tuning and the beam delivery is not included in the BTU
- Agreed to take data in the period July 20th – 25th in the “Zero degree” hall (in air)

9 BTU allocated

Beam	Energy (MeV)
H	80
D	80
He	80
C	80
O	80
Total	

Luigi Cosentino: head of the accelerator division
Stefano Romano: head of the research division (user support)
Pablo Cirrone: beam monitoring

Beam properties in the “zero degree” hall:
Continuous beam with ns bunches
Beam size: ~4 cm diameter
Uniformity ~ ±30%
Currents down to pA → ~ 10^7 protons/s
Faraday cup sensitive to pA
Further reduction achievable with slits (~ few 10/s)
Requires beam monitoring

Deuteron important to test the isotopic identification

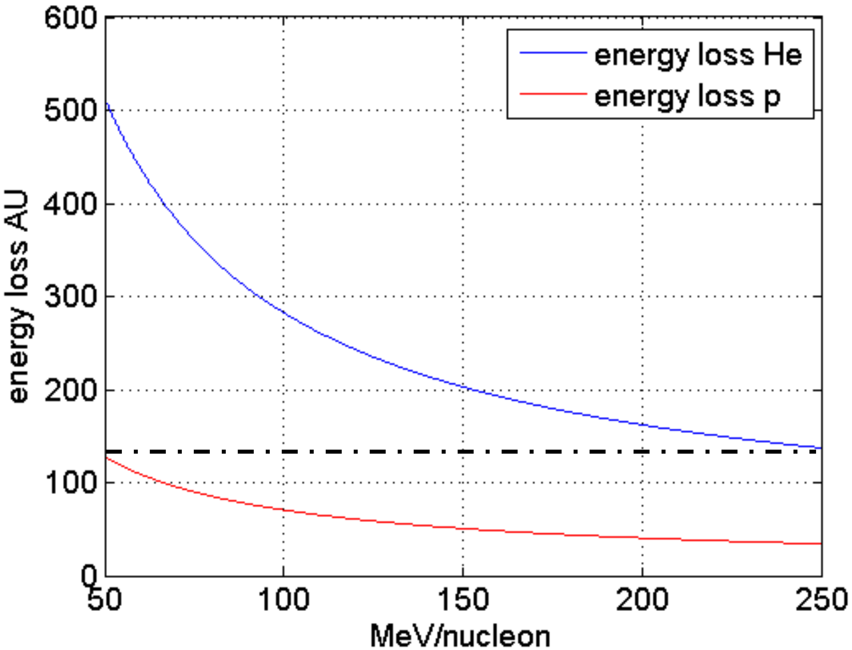
Compare LNS available energies with FOOT specs

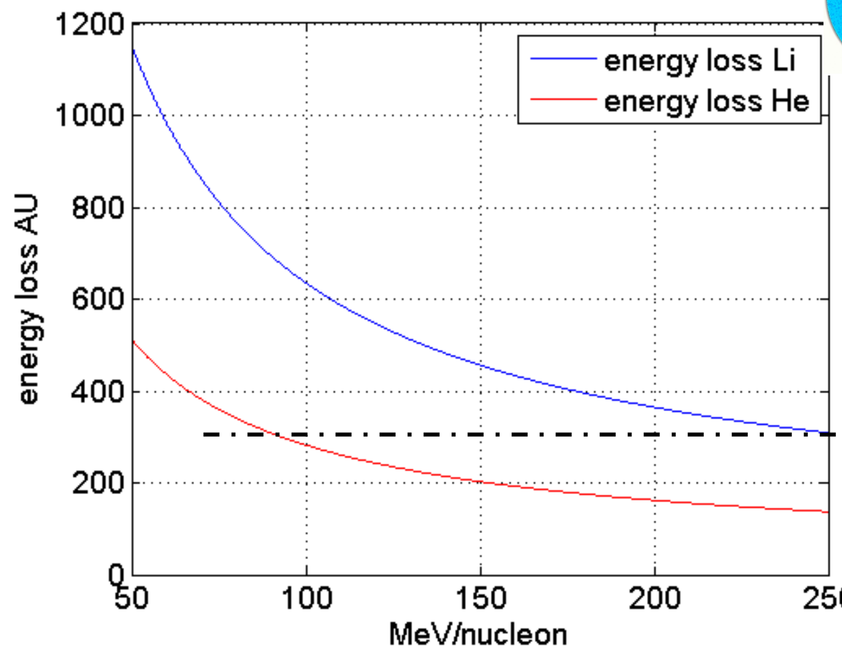
Ionization loss (Bethe-Block formula)

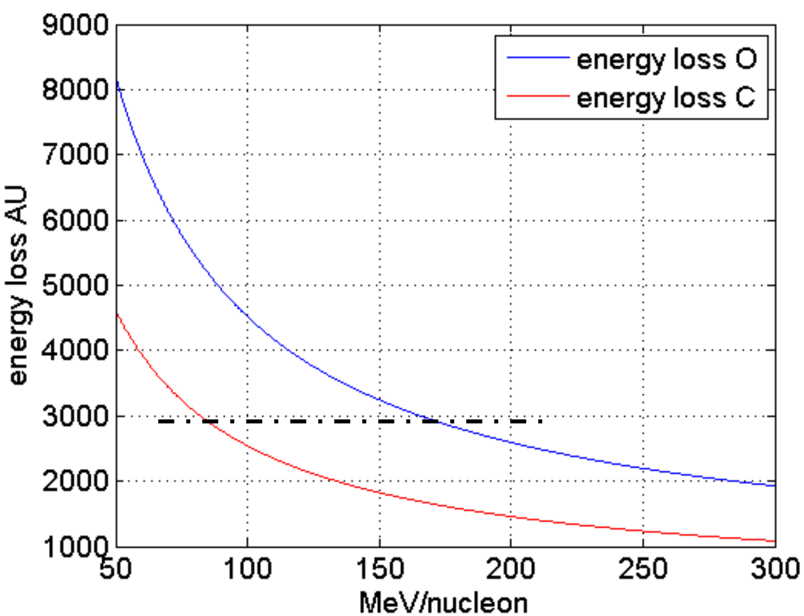
$$-\frac{dE}{dx} = 4\pi N_A m_e r_e^2 \rho \frac{Z}{A}\frac{z^2}{\beta^2}\left(\frac{1}{2} ln \frac{2m_e c^2\beta^2\gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta}{2}\right)$$

$$T_{max} = \frac{2m_e c^2\beta^2\gamma^2}{1 + \frac{2\gamma m_e}{m_0} + \left(\frac{m_e}{m_0}\right)^2}$$

- z: atomic number of incident particle
- I: characteristic ionization constant
- T^{max}: max energy transfer
- $\delta(\beta\gamma)$: density effect correction to ionization energy loss







Beam	H^+ 47 MeV	He 80 MeV	C 80 MeV
^4He	250 MeV		
^6Li		216 MeV	
^{16}O			158 MeV

Refreshing machine

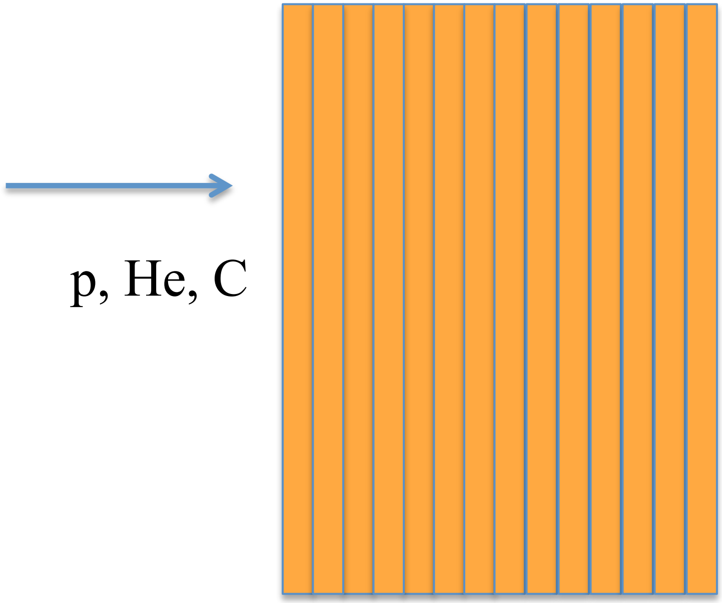
- Climatic chamber: GENVIRO 120C
- Temperature range: [-70, 180]°C
- Temperature uncertainty: ± [0.1, 0.3] °C
- Humidity range: [10, 98]%
- Humidity uncertainty: ± [0.5, 1.5]%
- Inner Volume: 550x400x550 cm^3 (120 L)

Machine bought and delivered at LNGS where a dark room is available
due to the earthquake in January, building still not accessible
Agreed to install it in the dark room underground

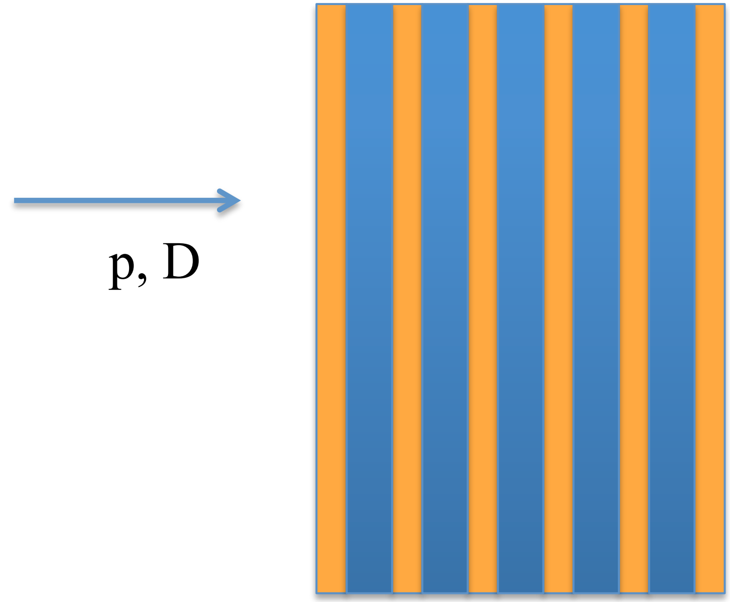
Plan before LNS

- Operate the refreshing chamber underground at LNGS (from June 15th …)
- Commission the machine and use cosmic-rays to study the "erasing" properties of these new films (June 15th – July 10th)
- Nagoya University will provide the emulsion films, first (small) batch to be delivered in June and the second one in July
- The emulsion chamber will be assembled in a dark room at LNGS one day before departure
- Transportation by ferryboat and car

Plan at LNS



Only films to optimise the refreshing procedure and calibrate the detector tor the charge measurement



Films interleaved with passive material (Aluminium, plastic, …) to test the mass Identification with deuteron (and ^{3}He)

Two independent measurements:
range (kinetic energy), multiple scattering ($p\beta$).
at high-energy, the energy loss is negligible, not the case here →
Develop a new algorithm and use LNS beam to validate MC simulations

Conclusive considerations

- Beam-line at LNS shared between scintillator (Pisa) and emulsions (Naples)
- Two set-ups are compatible
- In spite of the early purchase of the climatic chamber (delivered at LNGS early in March), huge delays in the commissioning (earthquake, water accident, …)
- The optimisation of the refreshing procedure delayed, new schedule prepared. Refreshing machine to be commissioned in June
- Main goal at LNS: expose to different Z beams to optimise the emulsion treatment procedure for the new film batches
- Use the opportunity at LNS to test isotope discrimination