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Ion-ion validation at low energy

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Nucleus-nucleus models validation (low energy)

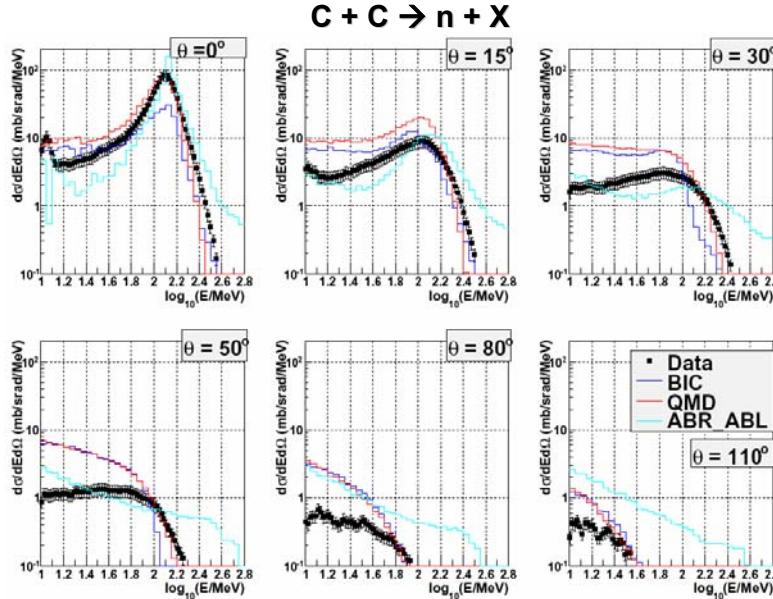
Catania group (LNS-INFN) is involved on nucleus-nucleus models validation at low energy (10-400 MeV/n) → range of interest in hadrontherapy applications.

Nucleus-nucleus interaction models available in Geant4:

- **Binary Light Ion Cascade**
- **Quantum Molecular Dynamics (QMD)**
- **Abrasion Ablation**
- **G4QLowEnergy**
- **INCL_ABLA**

few experimental data published for thin targets at low energy!

(most of them → secondary neutron production)



incident beams:
He, C, Ne, Ar

targets:
C, Al, Cu, Pb

Comparison between experimental neutron double differential cross sections production at different angles and prediction of the different models

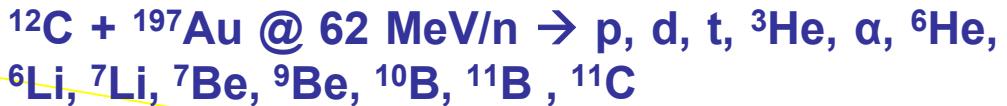
Reference: H.Sato et al., *Measurements of double differential neutron production cross sections by 135 AMeV He, C, Ne, and 95 AMeV Ar ions* Phys. Rev. C, 64, 054607 (2001)

Charged fragments production (LNS experiment)



^{12}C beam accelerated by the LNS Superconducting Cyclotron (SC) of INFN at 62 MeV/n on ^{197}Au and ^{12}C targets .

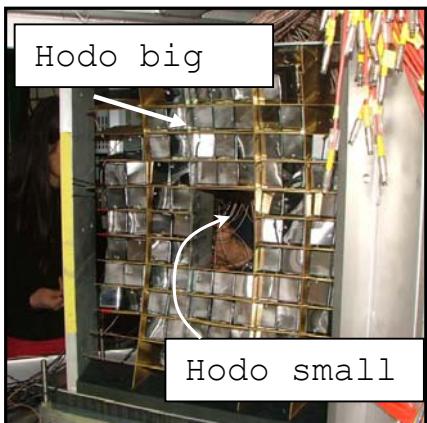
Fragments detected:



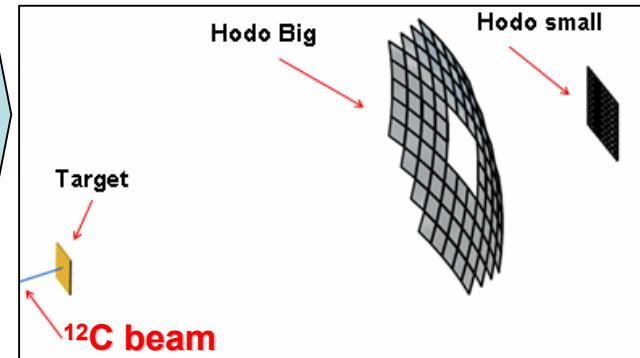
INFN Laboratori
Nazionali del Sud ,
Catania - Sicily - Italy

The **Hodo-small**, set up at a distance of 80 cm from the target consisted of 81 two-fold telescopes: 300 μm Silicon detectors 1x1 cm^2 of active area followed by a 10 cm long CsI(Tl) and covered the angular range $\theta_{\text{lab}} = \pm 4.5^\circ$.

The **Hodo-big**, set up at a distance of 0.6 m from the target, consisted of 89 three-fold telescopes 50 μm + 300 μm Silicon detectors 3x3 cm^2 surface followed by a 6 cm long CsI(Tl). It covered the angular range θ_{lab} between $\pm 4.5^\circ$ and $\pm 16.5^\circ$.



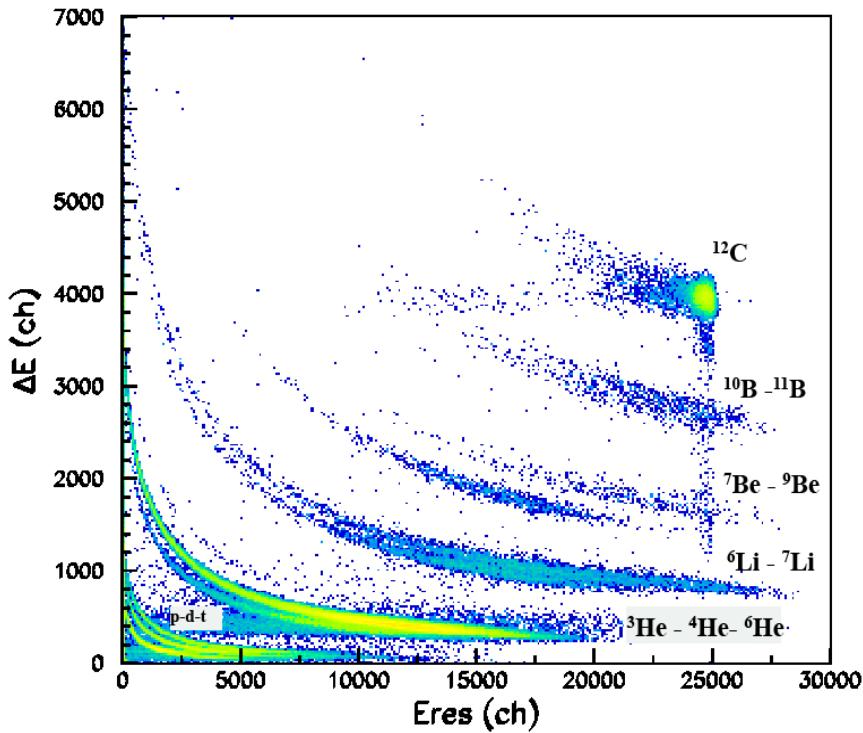
Scheme of the experimental apparatus



Hodo Small	Thickness	Active area	Covered angles
Si- ΔE	300 μm	1x1 cm^2	$\theta_{\text{lab}} = \pm 5^\circ$
CsI(Tl)-E	10 cm	1x1 cm^2	

Hodo Big	Thickness	Active area	Covered angles
Si- ΔE_1	50 μm	3x3 cm^2	$\pm 5^\circ \leq \theta_{\text{lab}} \leq \pm 21.5^\circ$
Si- ΔE_2	300 μm	3x3 cm^2	
CsI(Tl)-E	6 cm	3x3 cm^2	

Charged fragments production (LNS experiment)



A typical inclusive ΔE - E scatter plot of a Hodo-Big telescope. It is possible to distinguish the Carbon elastic scattering and the well resolved reaction products.

Double differential cross sections measured and compared with Geant4 models (`geant4.9.2.ref08`):

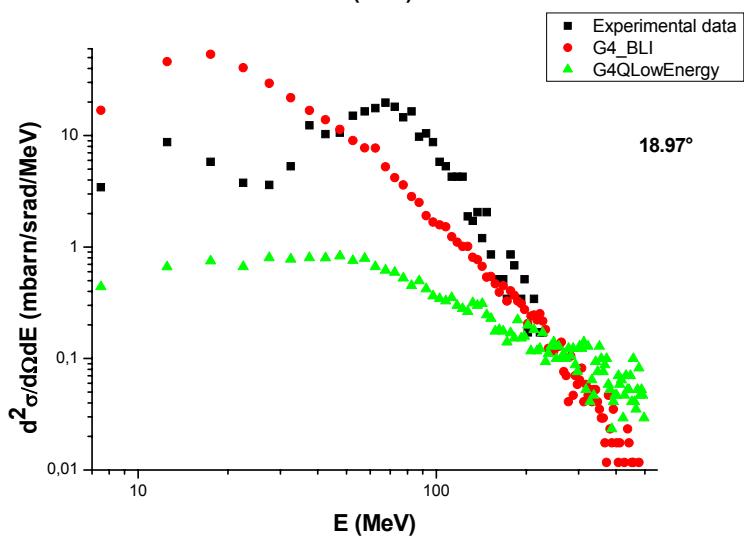
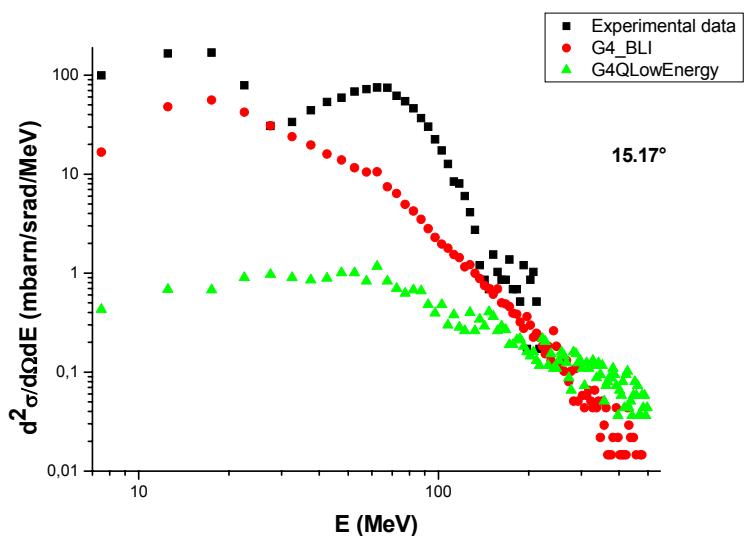
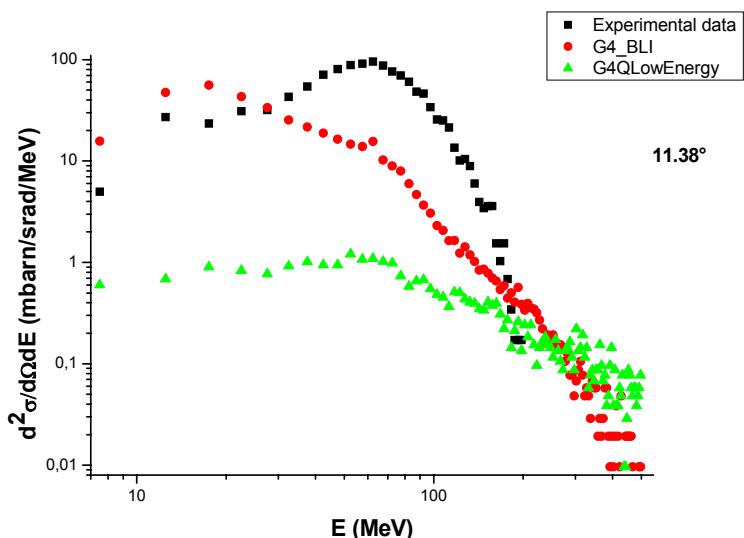
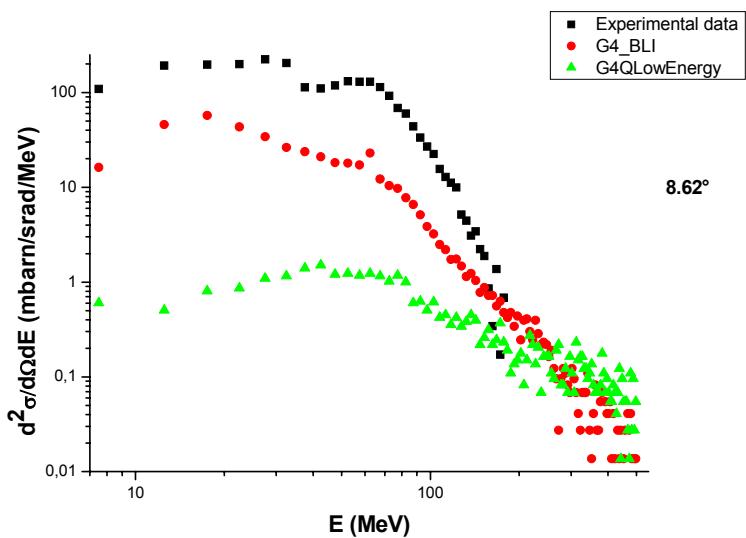
Comparisons:

Angles: $8.62^\circ, 11.38^\circ, 15.17^\circ, 18.97^\circ$; $\Delta\theta = 2.66^\circ$

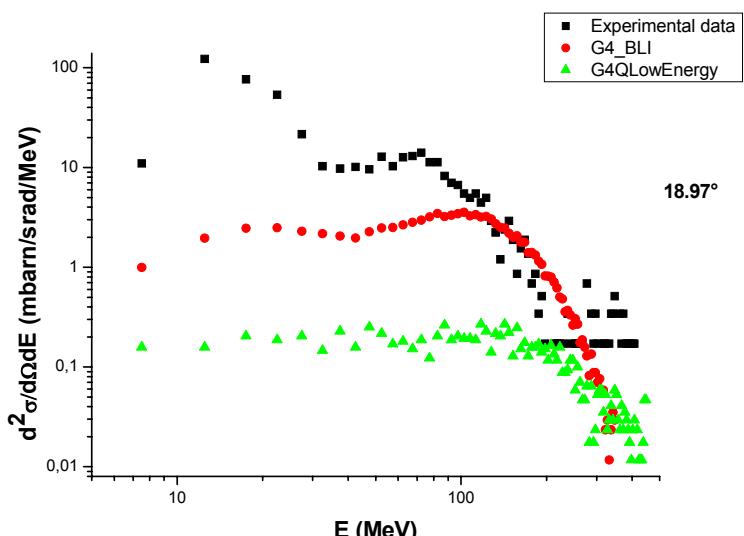
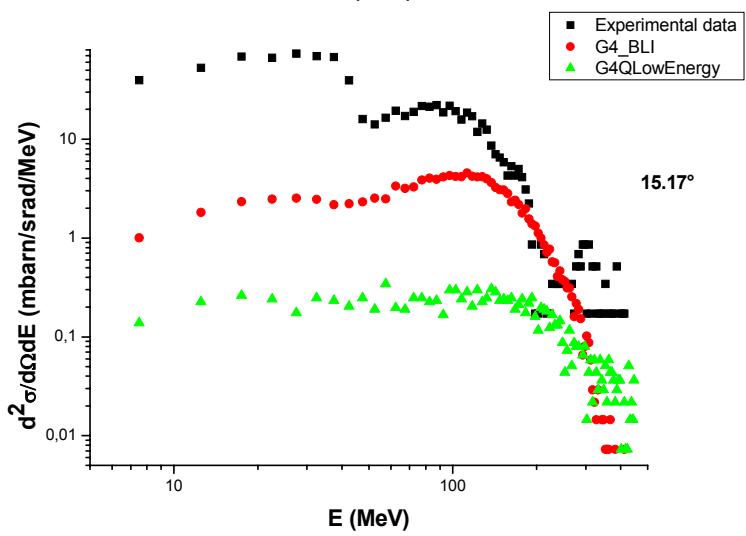
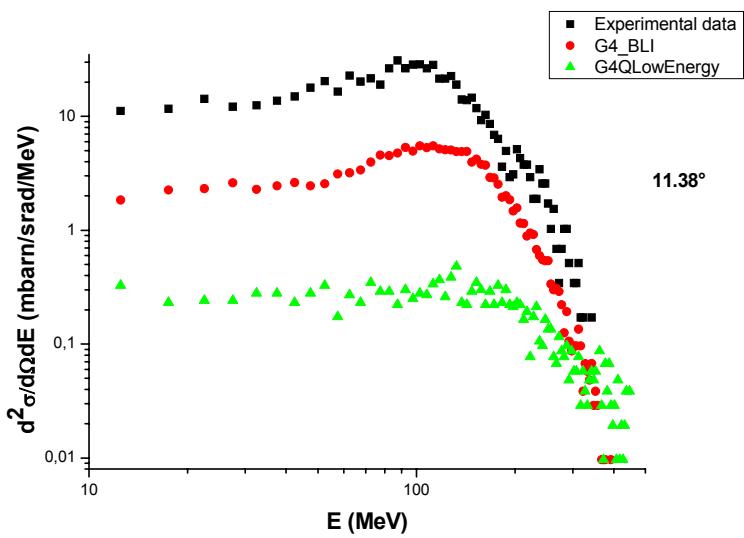
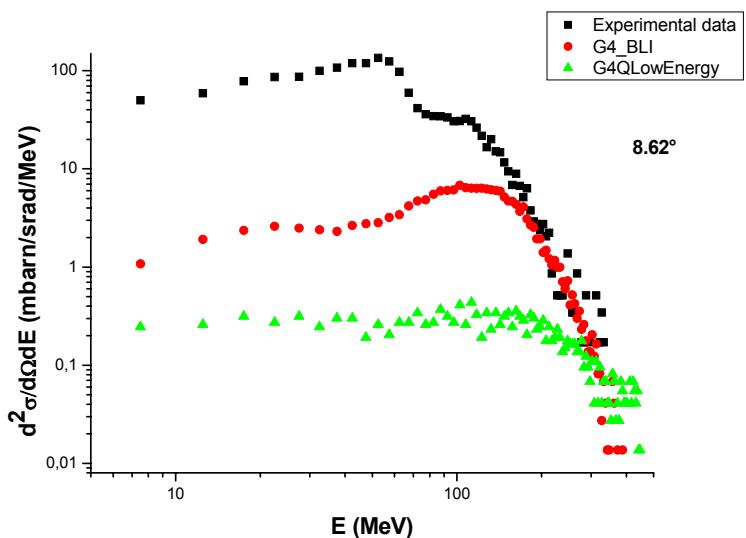
Isotopes compared: p, d, t, α , Li^7

Nucleus-nucleus models compared: **BinaryLightlon (de_excitation fixes included)**
G4QLowEnergy (preliminary version)

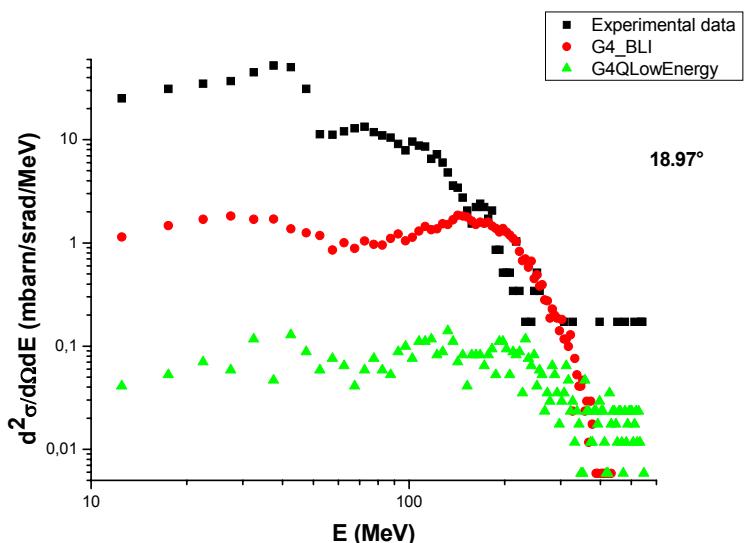
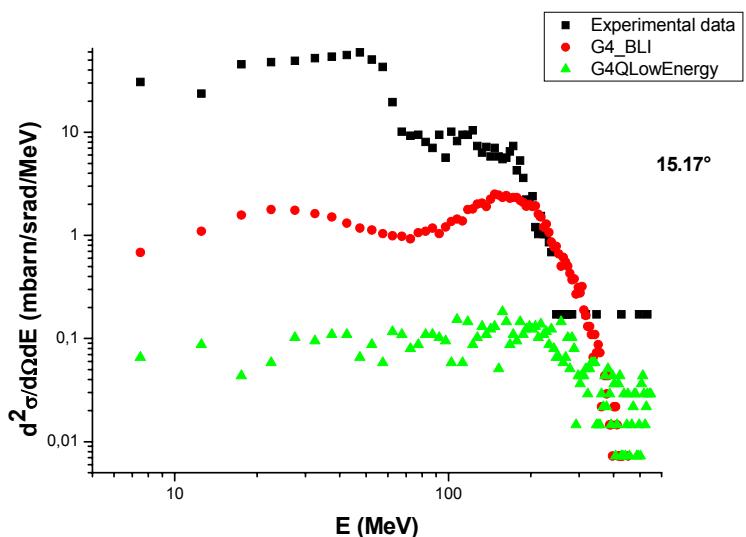
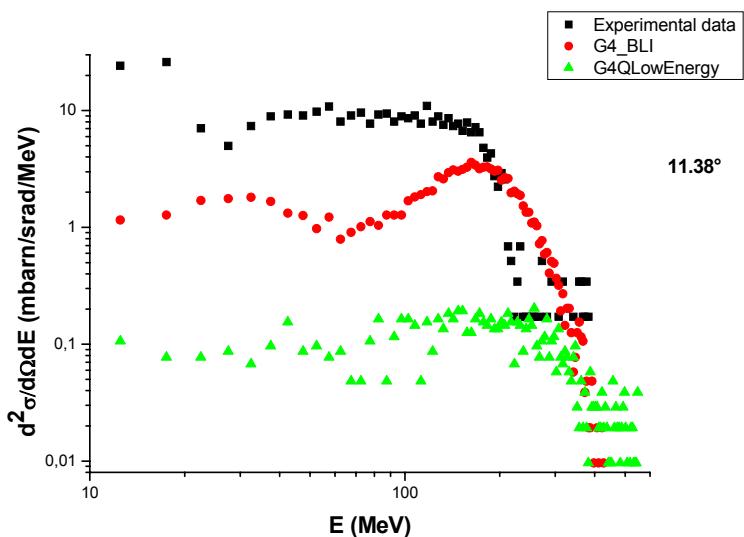
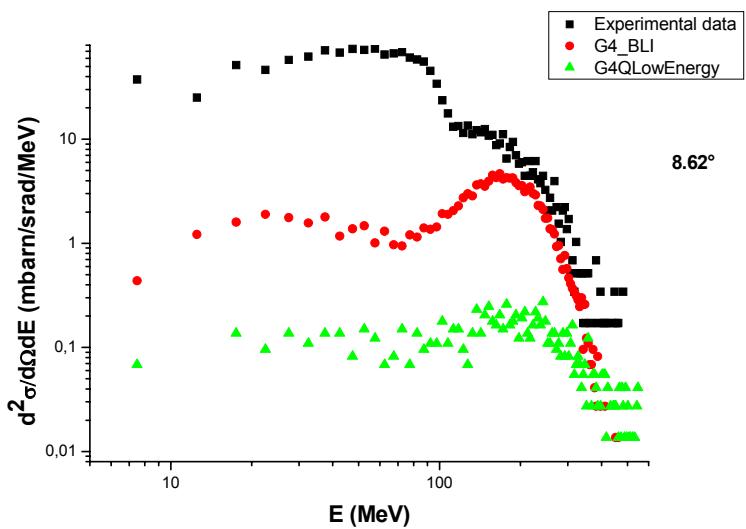
Proton double differential cross sections



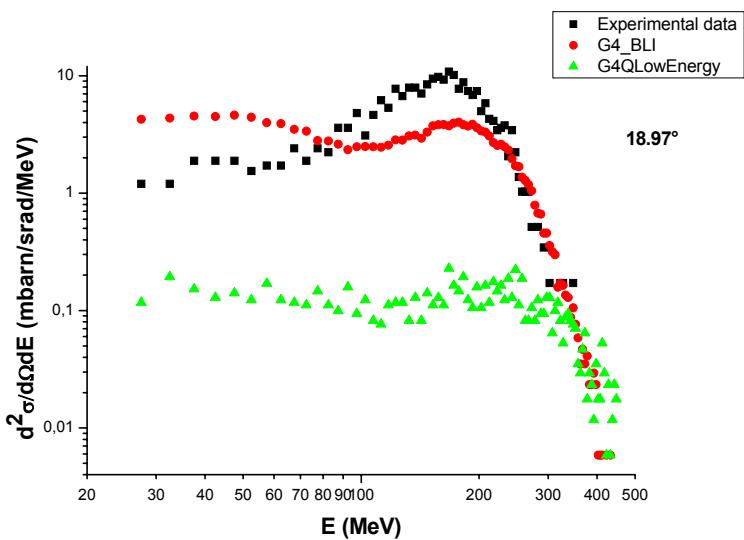
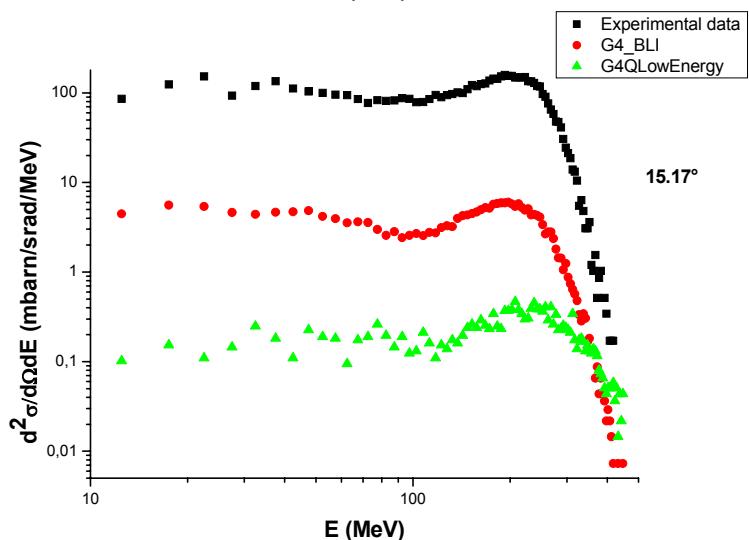
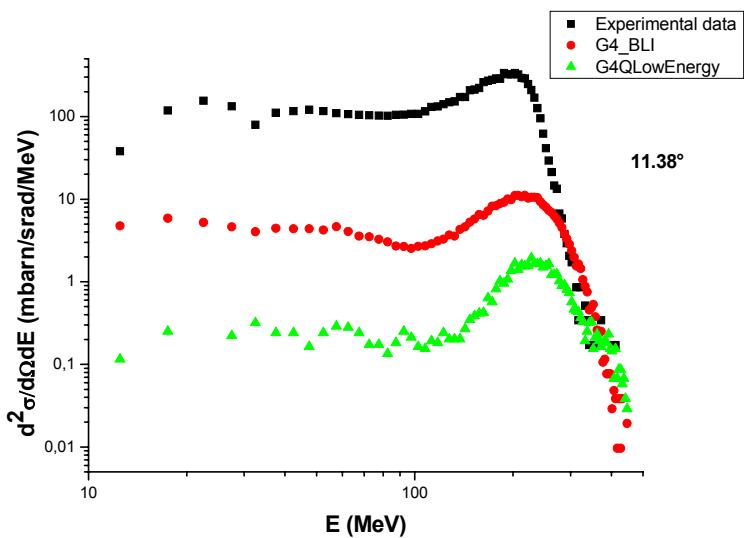
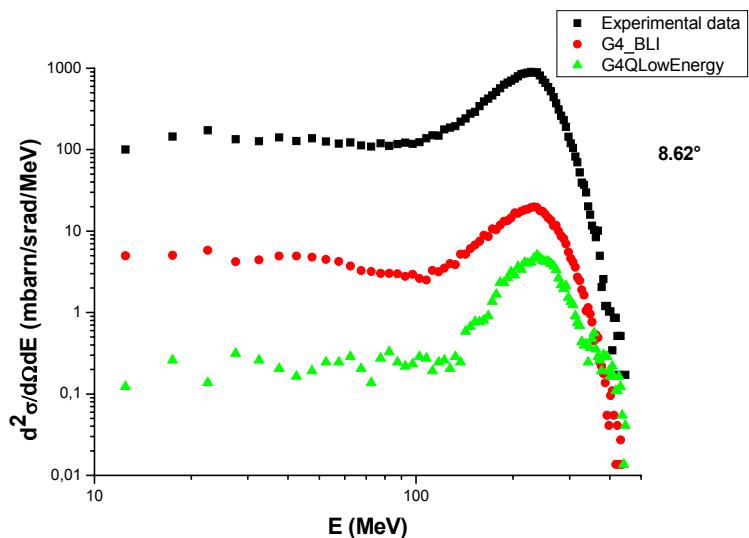
Deuteron double differential cross sections



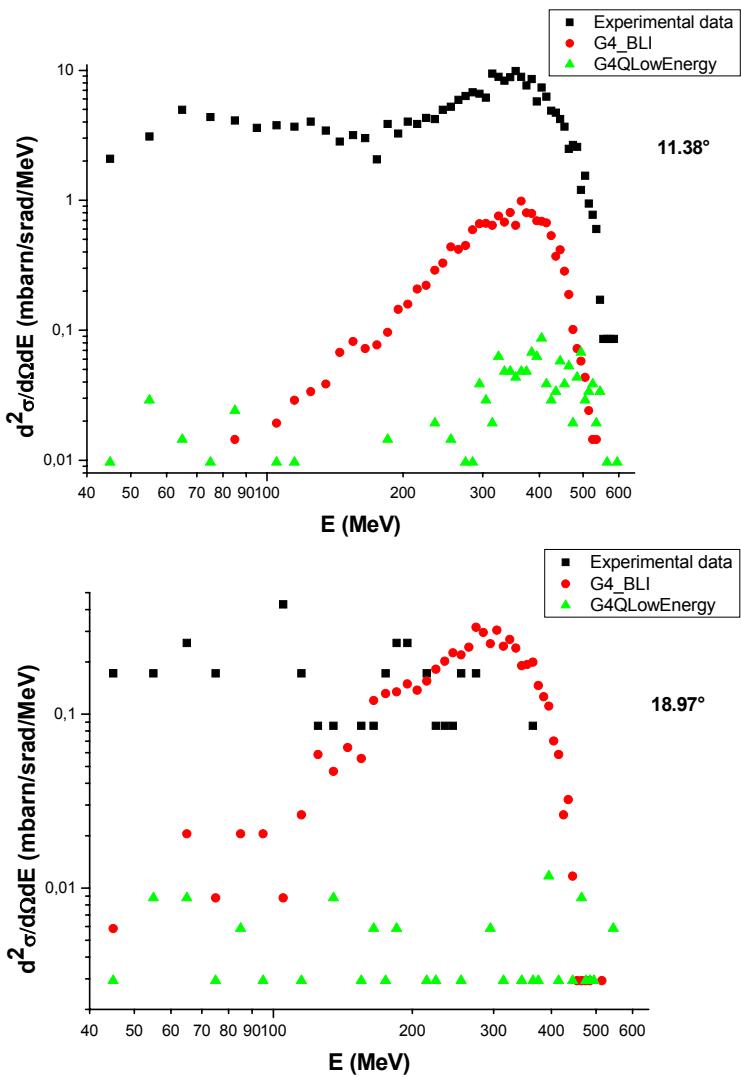
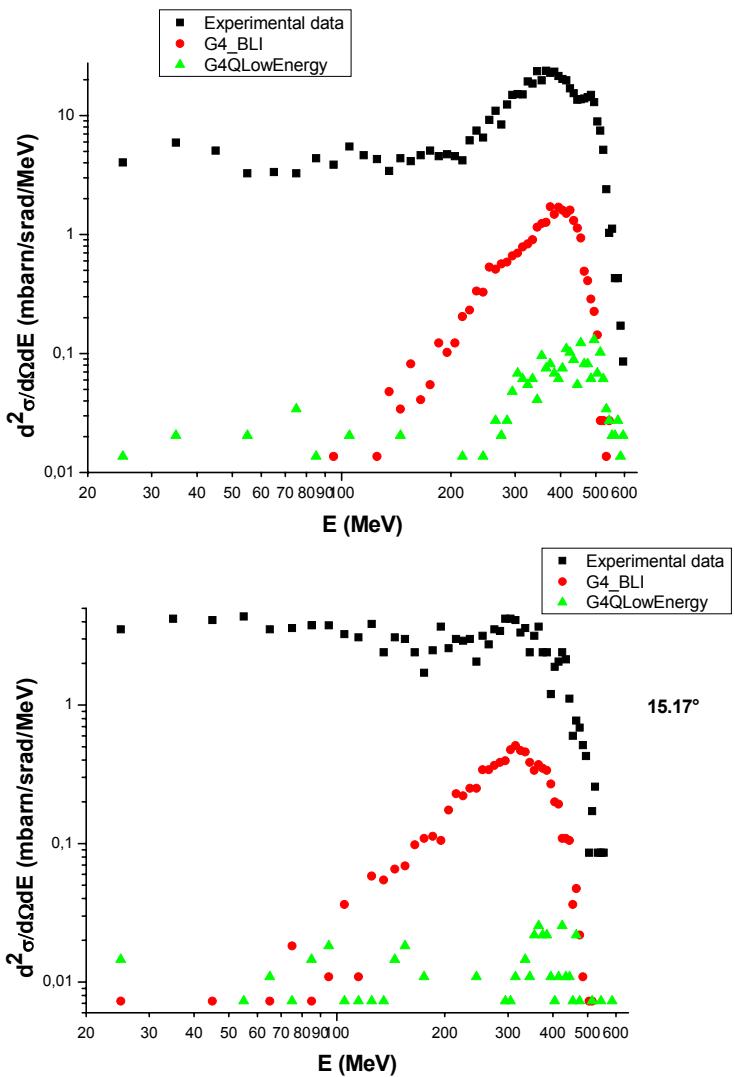
Triton double differential cross sections



Alpha double differential cross sections



Lithium double differential cross sections



Conclusions and future plans

- In general, models seem to underestimate the charged fragments production (especially G4QLowEnergy)
- The experiment has been recently performed again in order to collect much more statistics in fragments production. Also an upgrade in the experimental setup has been carried out for the direct measurement of the total incident particles.
- In April 2009 C + C @ 62 MeV/n has been also performed with the upgraded experimental setup. Analysis is still in progress.
- New measurements at higher energy at GSI approved for 2010-2011

FIRST experiment

FIRST : Fragmentation of Ions Relevant for Space and Therapy

INFN (LNS,LNF,MI,TO,RM2,RM3) :

C.Agodi, G.Battistoni, T.Bohlen, G.A.P.Cirrone, G.Cuttone, M.De Napoli,
E.Iarocci, F.Marchetto, M.C.Morone, V.Patera, E.Rapisarda, F.Romano,
P.Sala, A.Sciubba, C.Sfienti, E.Spiriti

Dsm/IRFU/SPHN CEA,IN2P3: Saclay, Caen, Strasbourg, Lyon

A.Boudard, J.E.Ducret, F.Haas, M.Labalme, S.Leray, M.D.Salsac, C.Ray

GSI

T.Aumann, K.Boretzy, M.Durante, M.Helic, A.Kelic, R.Pleskac, M.V.Ricciardi,
D.Schardt, C.Scheidenberger, H.Simon, M.Winkler

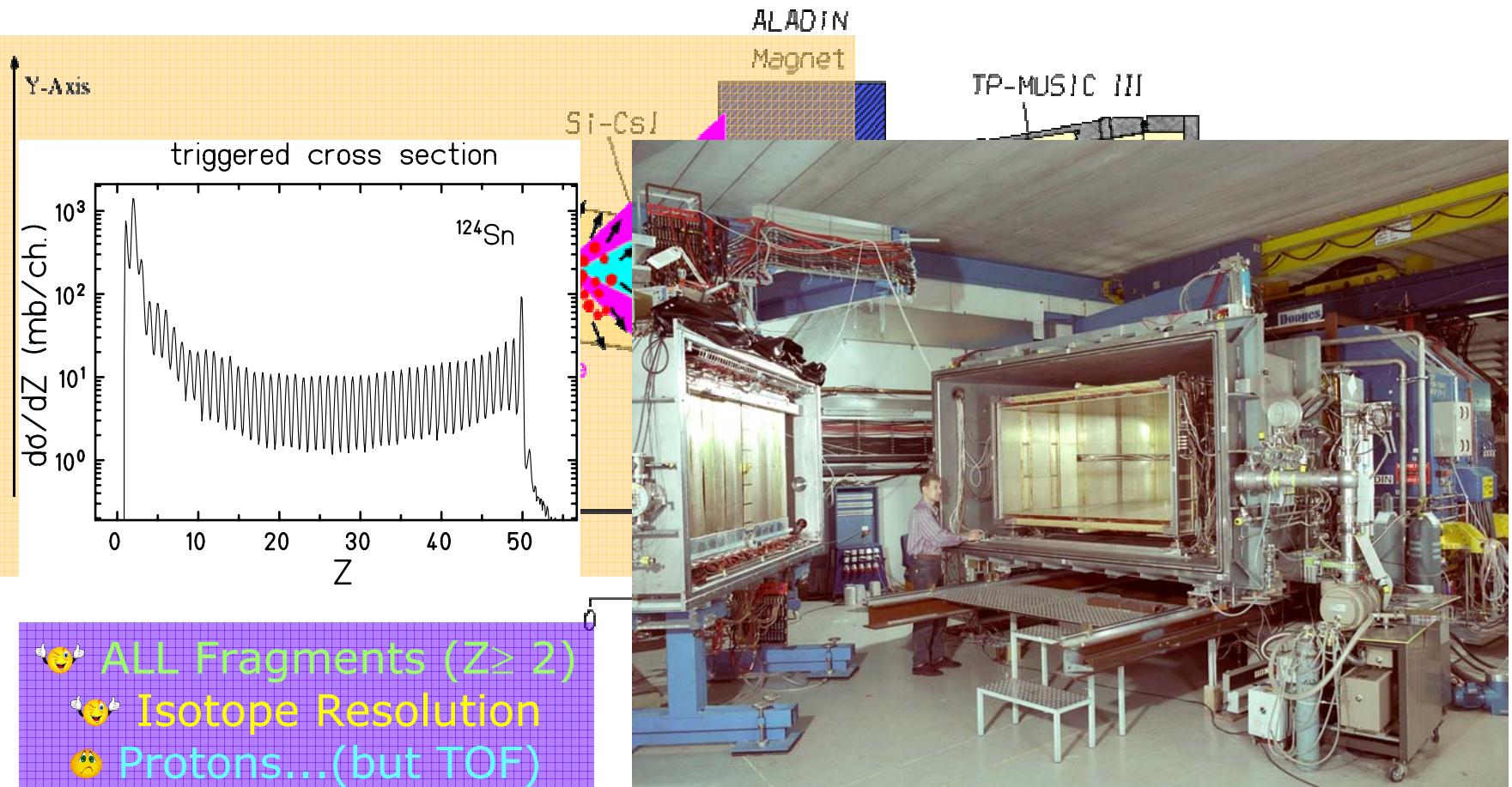
ESA

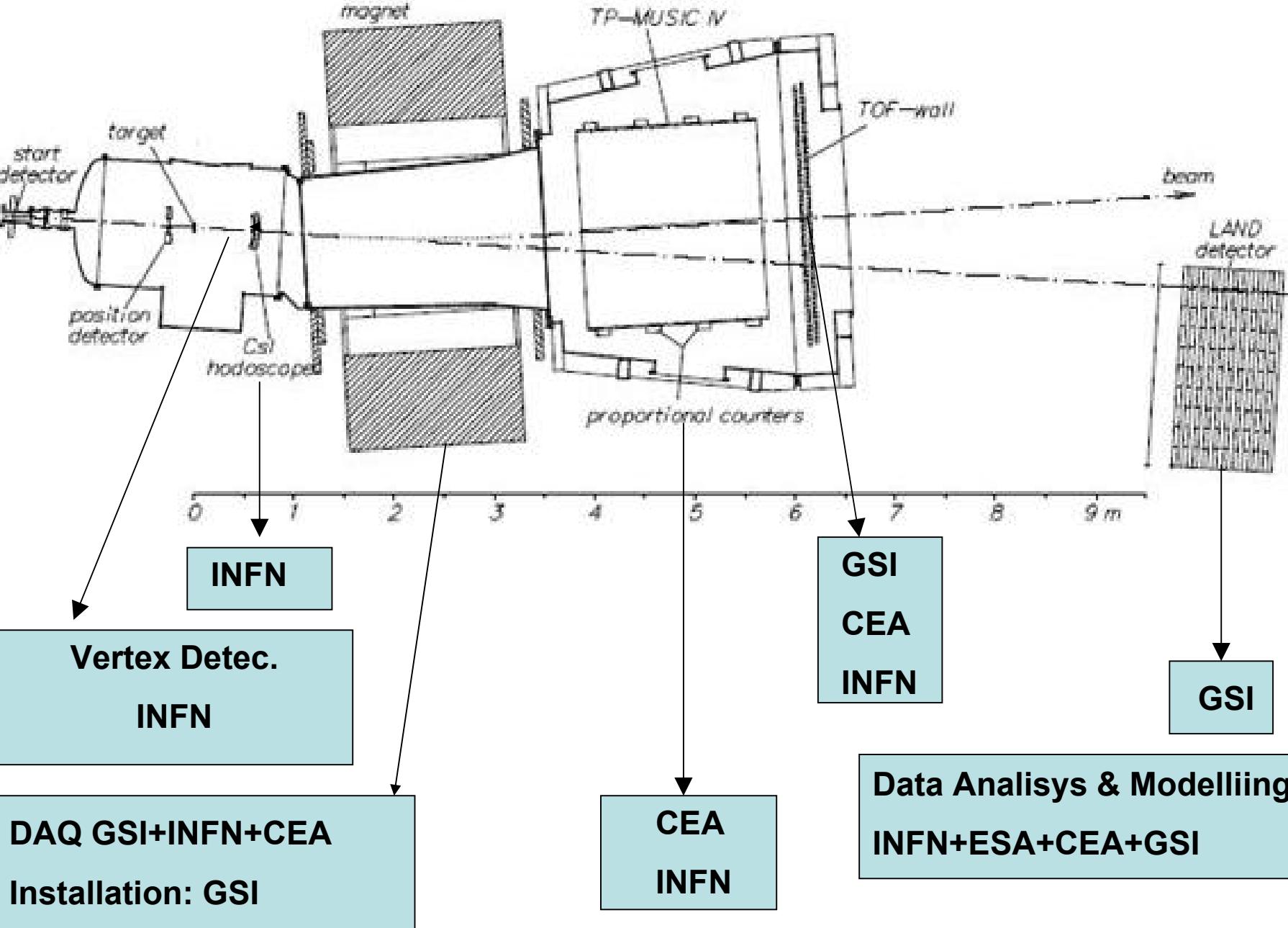
P.Niemenen, G.Santin

The total beam time approved is 33 BTU (11 Days):

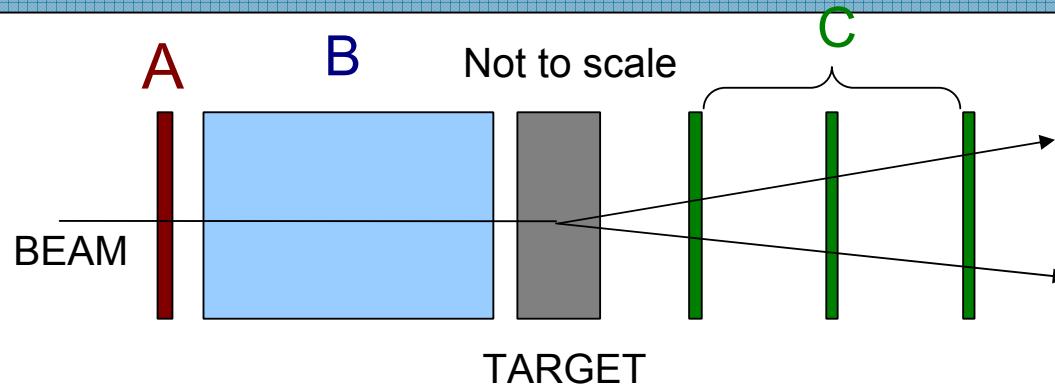
- Calibration
- C + C @ 200, 400 MeV/n
- C + Au @ 200, 400 MeV/n
- O + C @ 200, 400 MeV/n

The ALADiN Spectrometer





Instrumented target region (vertex detector)



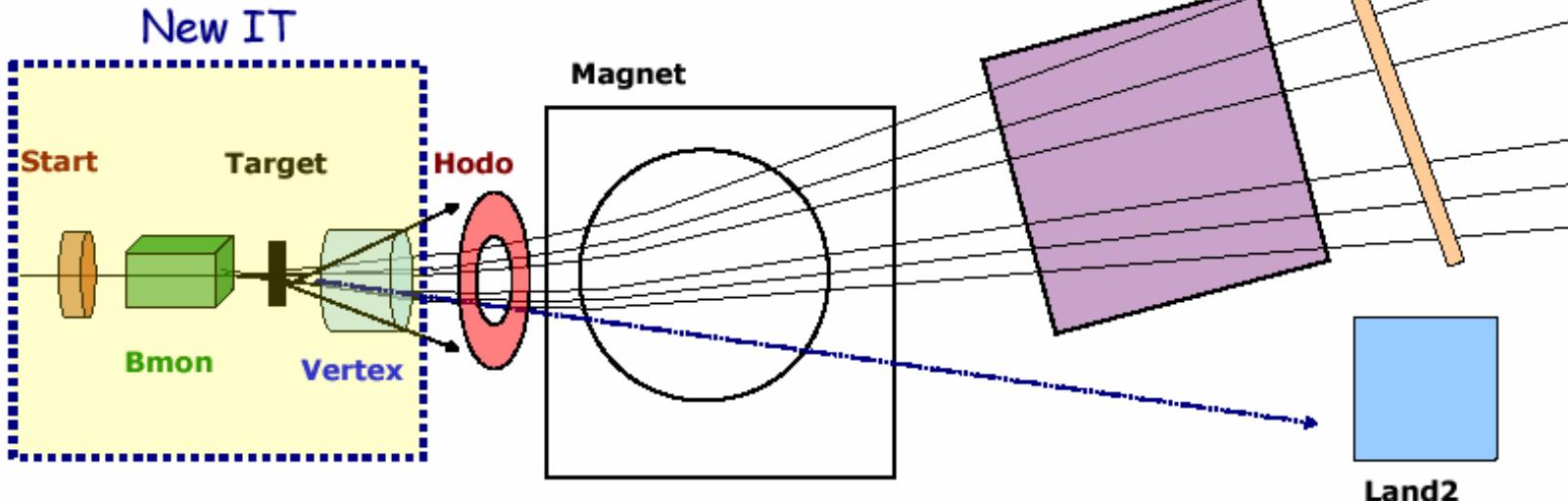
- **A. Start counter. Scintillator:** gives the start to TOF measurement.
- **B. Beam tracker. Gaseus detector:** measures the beam impact point on target event by event ($< 200 \mu\text{m}$ spatial resolution) and detect eventual interaction of the beam in A
- **C. Vertex tracker. Si telescope:** measures ($< 0.1^\circ$) the line of flight of the fragments reaching the MUSIC.

Measuring the Positions and the Angles with Vertex and Music ONLY the momentum absolute value has to be calculated

First test-beam of vertex detector two weeks ago with 62 MeV/n ^{12}C beams at LNS

Setup element features

Which measure what....



MUSIC → $Z/p, \theta, \varphi$ after bending

MUSIC → Energy loss $\propto (Z/\beta)^2$

Hodo → Large angle fragment energy, θ, φ

Vertex → Fragments emission θ, φ

Start and TOF wall → $TOF = L(p, Z, \theta, \varphi)/\beta$

Bmon → Beam impact point

To extract $Z, A, \theta_{emiss}, p_{emiss}$
the reconstruction must
exploit all the setup
information

LAND2 → neutron flux

Thanks for your attention