A new method for the determination of very small Γ_γ partial widths

G.Cardella
for the
NEWCHIM collaboration

Outline

Status of the art

- What is known on ^{12}C formation
- Measured and evaluated decay widths
- Old and New experimental methods adopted

The new method

- Description of the method
- The CHIMERA detector status and ongoing upgrading
- Kinematic coincidences
- Gamma-ray detection

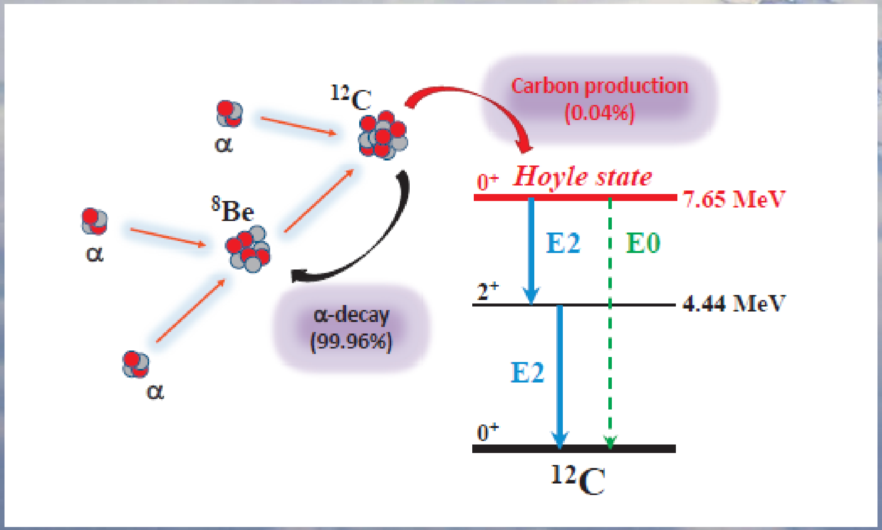
obtained results & future

- ^{68}Ni PYGMY resonance
- Future perspectives

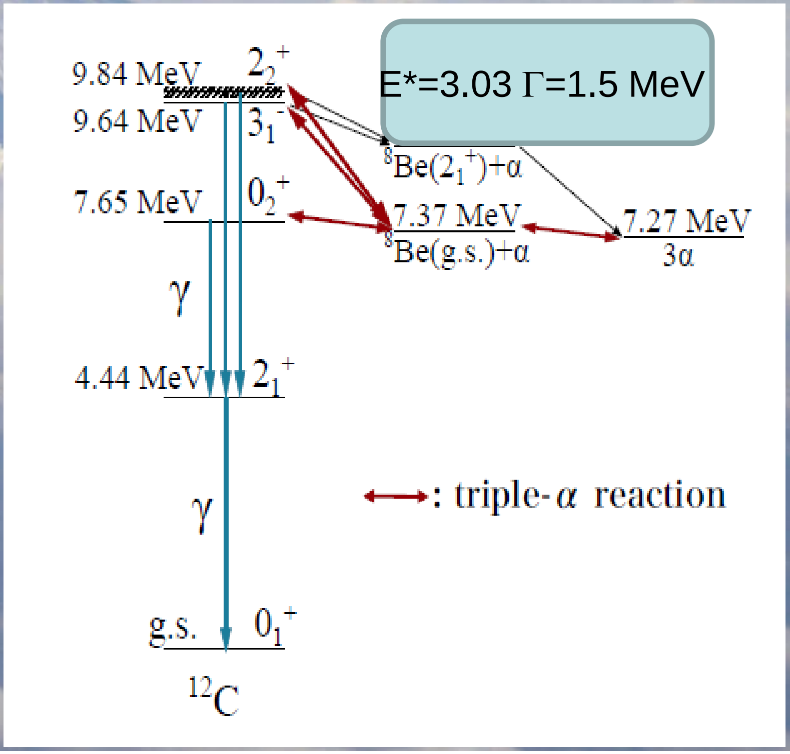
Status of the art: ^{12}C production in the Universe

The 3-α process is the main responsible of formation of ^{12}C in stars
see for instance AGB stars F.Hervig et al PRC **73**, 025802 (2006)

At higher temperature, 10^9k or larger, (core collapse supernova) also the ^{12}C 3^- level at 9.64 MeV give some contribution C.Angulo et al NPA 656 (1999) 3 (NACRE compilation)



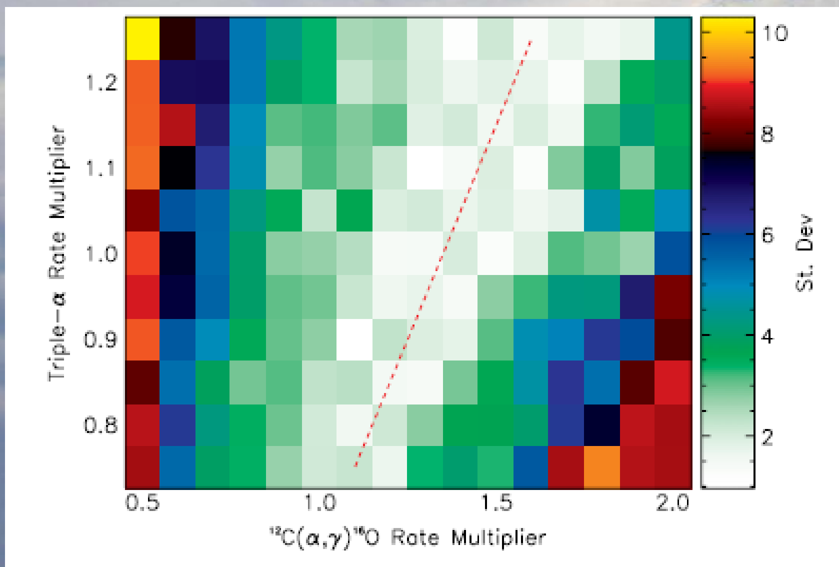
B Alshahrani et al EPJ Web 63,01022(2013)



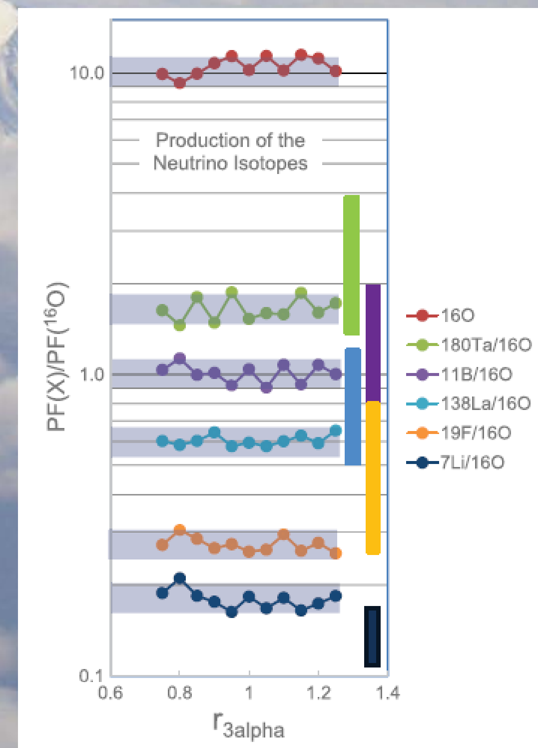
M.Tsumura et al Jou. of phys. Conf.S. 569(2014)012051

Status of the art: Effective values for the 3α and $^{12}C(\alpha,\gamma)^{16}O$ processes

Recent calculations Sam Austin et al PRL 112(2014)111101 show that a very important parameter is the ration between the 3α process and the $^{12}C(\alpha,\gamma)^{16}O$ one. This is also due to various unknown processes as in convection not fully governed by simulations



With this Effective values it was possible to describe the production of neutrino emitter in Supernova explosions with rather good precision

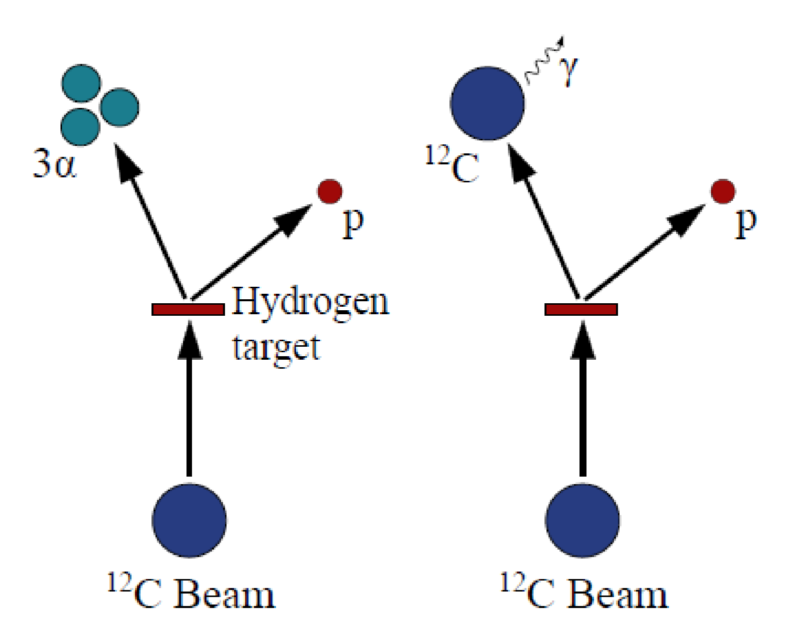


Similar results were obtained this year by the same author on gamma emitting nuclei Al-26 / Ti44 / Fe60 AJL 839(2017)

Status of the art: measurements performed

Hoyle state Γ_{rad}/Γ of $4.12 \pm 0.11\ 10^{-4}$

Most of the measurements done looking for coincidence events p+^{12}C following the methods of D.Chamberlin et al Phys.Rev.C 9(1974)69



(a) α-decay events (b) γ-decay events

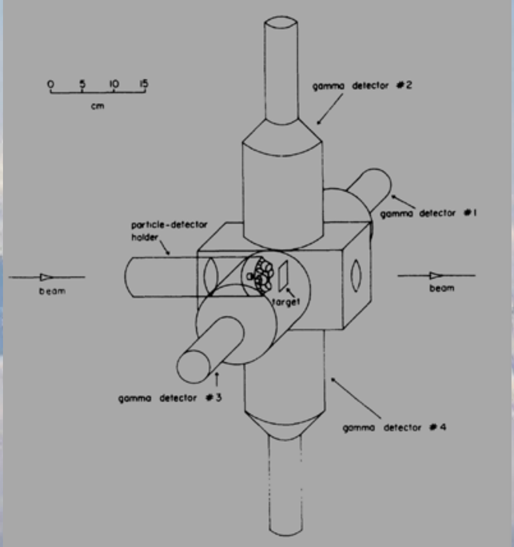
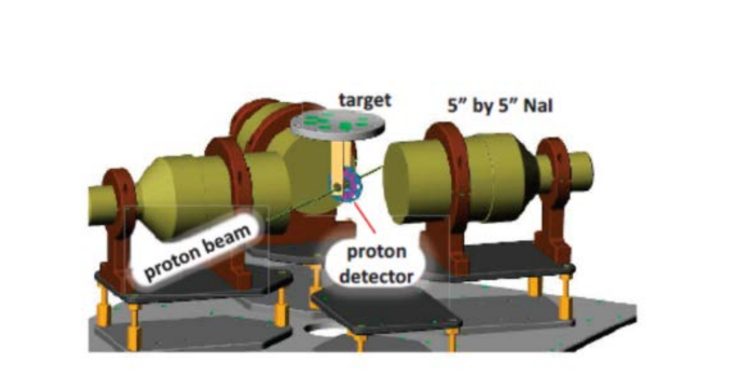


FIG. 3. Schematic of detector geometry.

But also search of γ–γ coincidences A. W. Obstt and W. J. Braithwaite phys.Rev.C 13(1976)2033



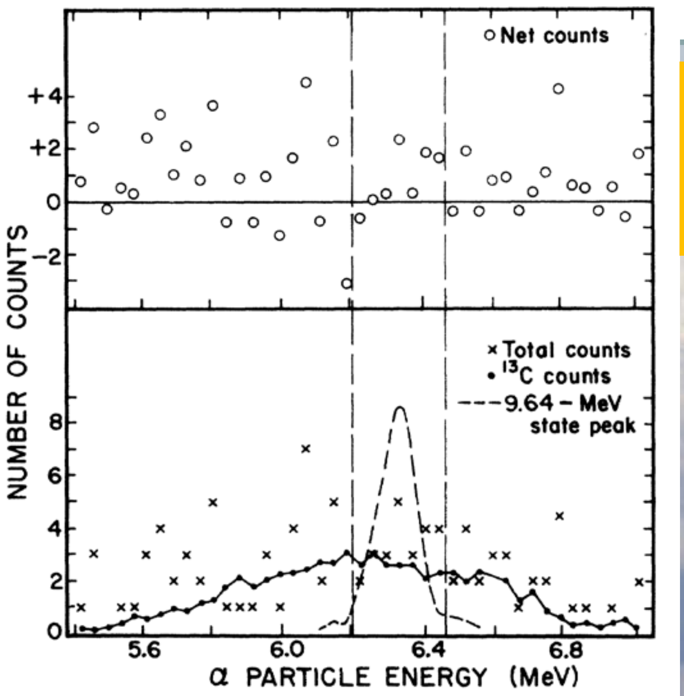
B Alshahrani et al

EPJ Web of Conferences 63, 01022 (2013)

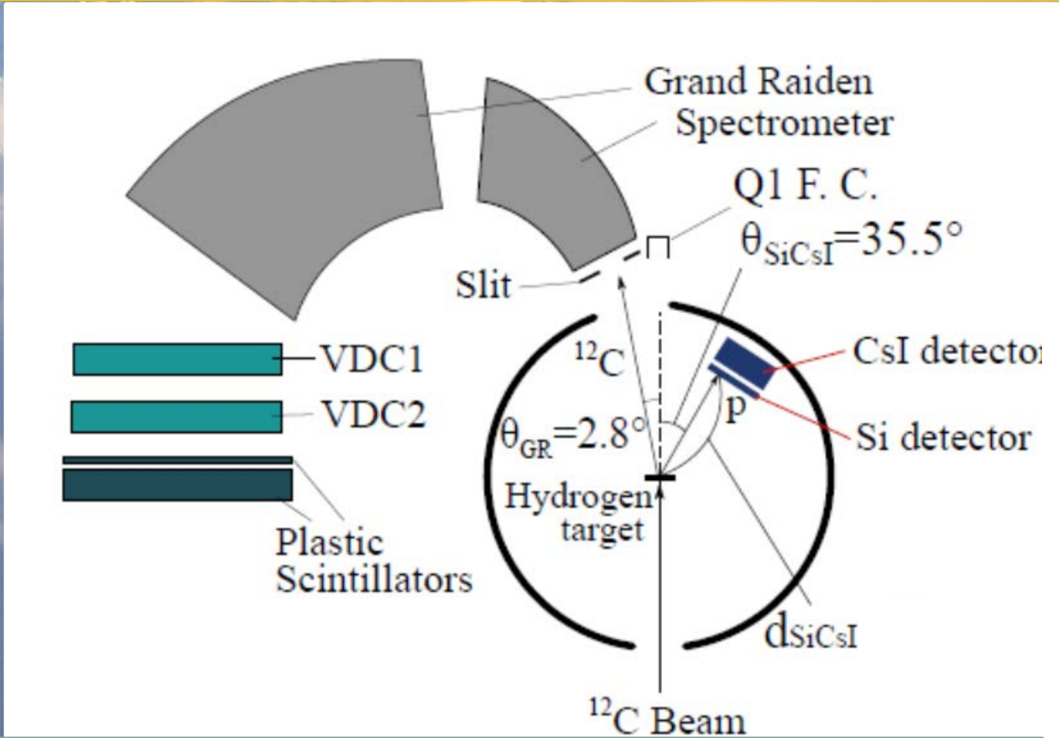
Status of the art: measurements performed

9.64 (3^-)

Γ	Γ_γ	Γ_γ/Γ
34(5) keV	$> 0.31(4)$ meV < 14 meV(1σ C.L.)	$> 9.1\times10^{-9}$ $< 4.1\times10^{-7}$



Upper limits given by Chamberlin et al due to ^{13}C contaminants in the target in experiment based on the recoil measurement α induced reactions at 24 MeV

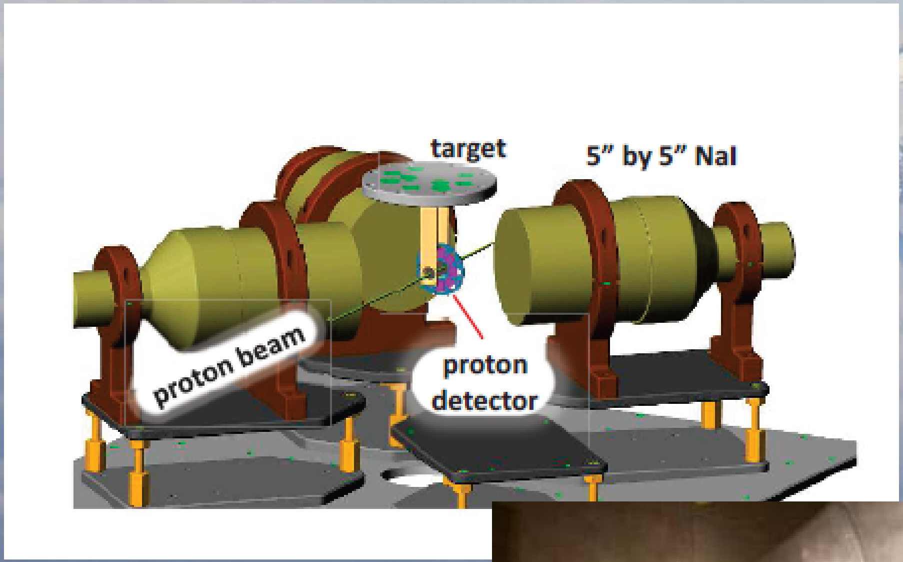


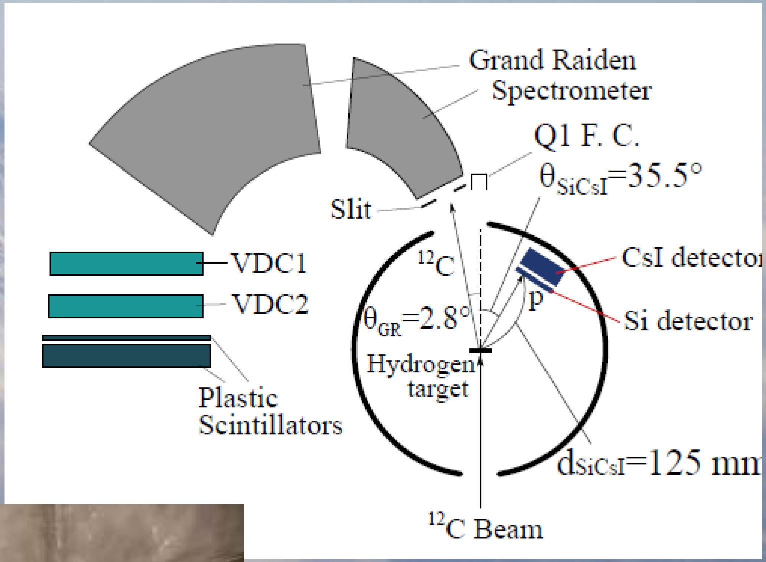
To improve such result a new experiment is in preparation in Japan using ^{12}C beam detected by the Grand Raiden Spectrometer

M.Tsumura et al Journal of Physics: Conference Series **569** (2014) 012051

The new method: description

The Basic idea is to join both detection methods using the CHIMERA detector in order to improve the sensitivity of the measurement : **4 fold coincidence measurement**





γ-ray detection

Kinematic coincidence with ^{12}C recoil

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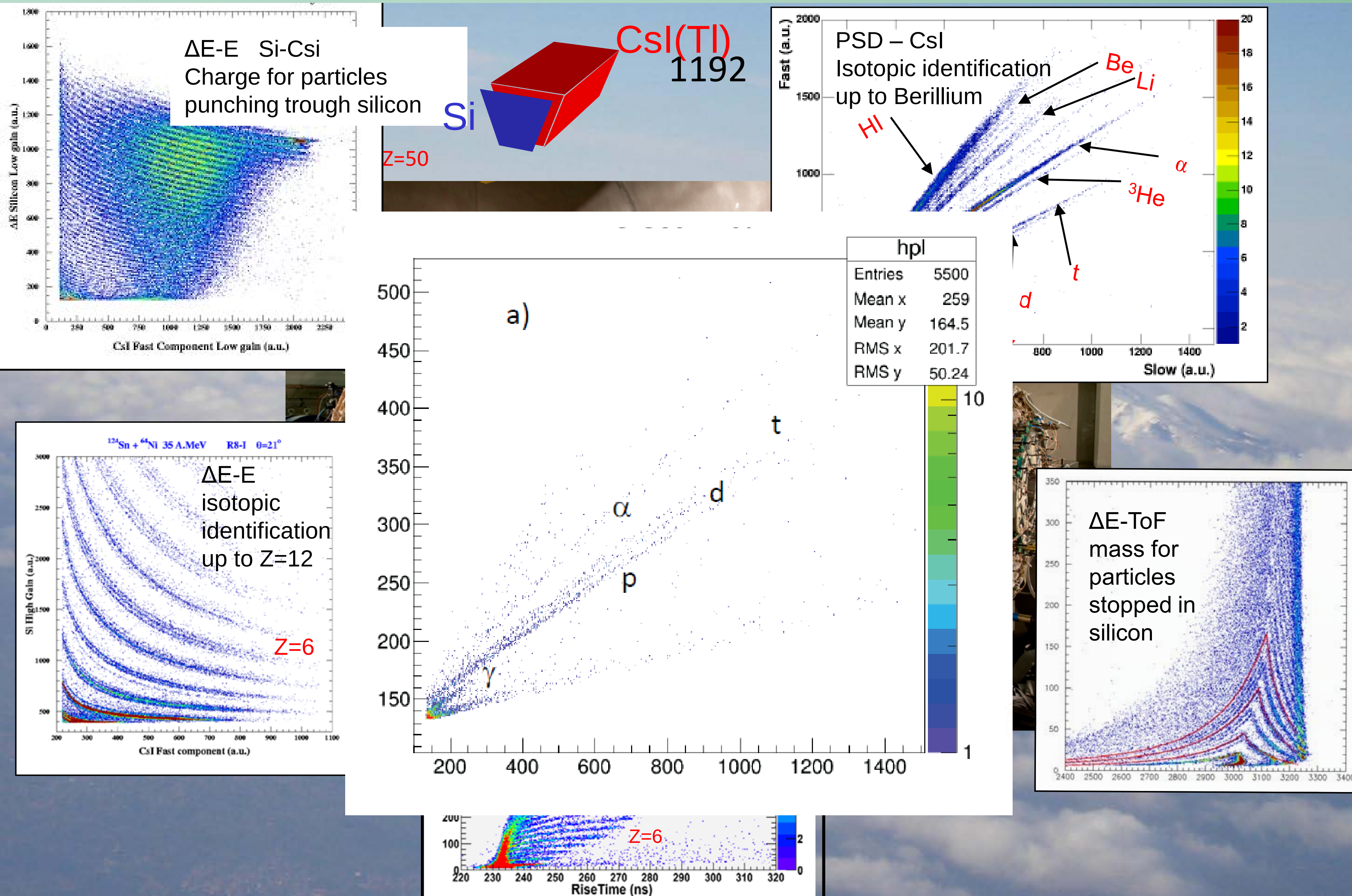
The new method: Characteristics of the CHIMERA detector



The new method I: kinematic coincidences with CHIMERA

Nuclear Instruments and Methods in Physics Research A 715 (2013) 56–61

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Kinematical coincidence method in transfer reactions

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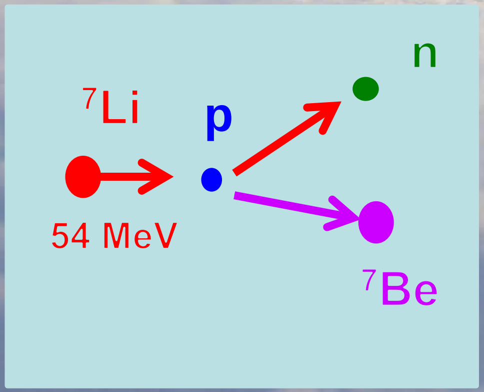
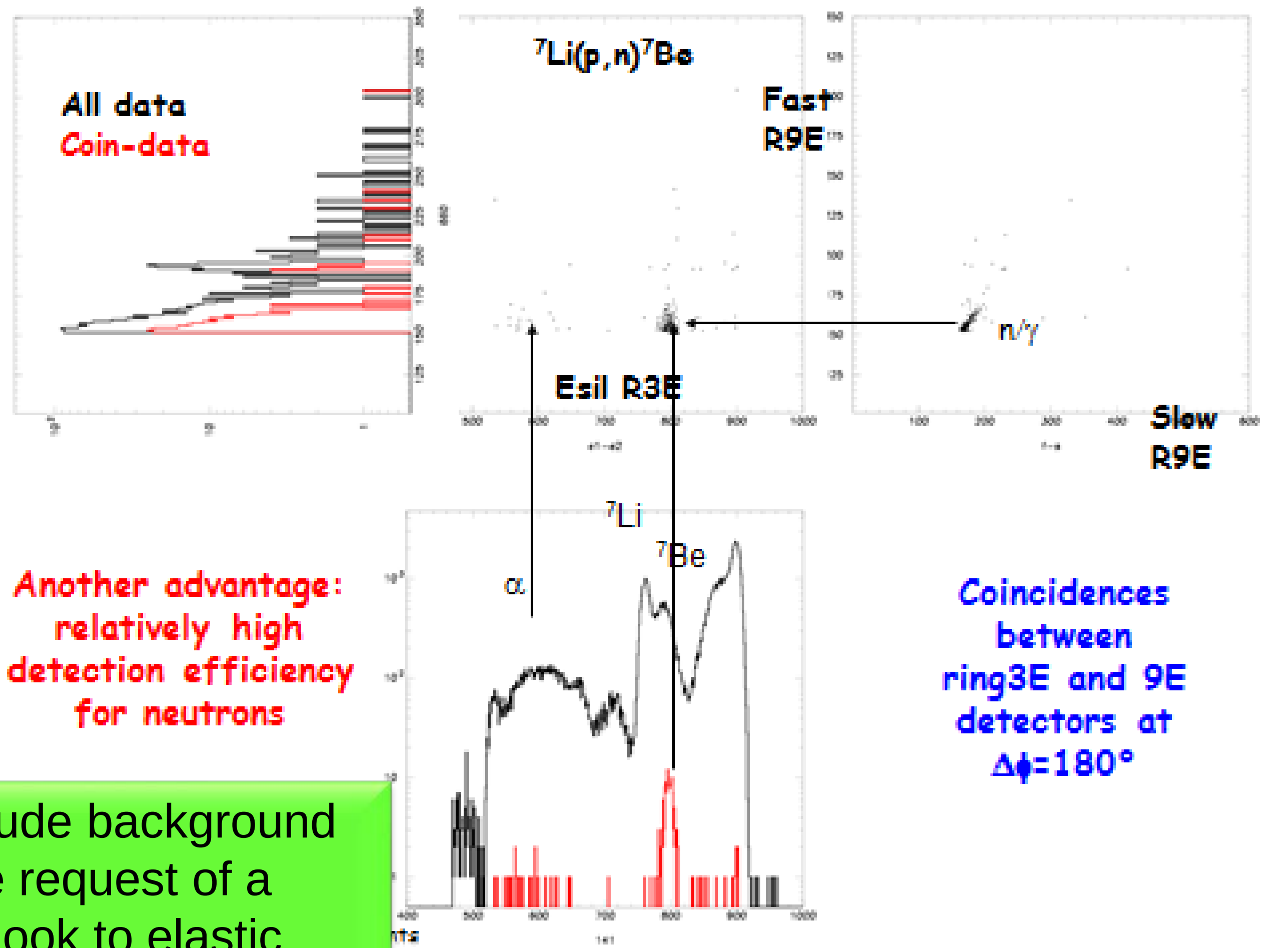
D. Loria[d], T. Minniti[d], E.V. Pagano[b,c], M. Papa[a], S. Pirrone[a], G. P
E. Rosato[f], P. Russotto[b,c], S. Santoro[d], A. Trifirò[d], M. Trimarchi[d],

$\alpha + ^{12}C \rightarrow ^{12}C^{*} + \alpha'$

Detection efficiency around 100%



$\Delta\phi$ (n-^{7}Be) =180°



More than 3 order of magnitude background suppression only with the request of a kinematical coincidence (look to elastic scattering) (no time window no identification)

The new method II: γ-detection with CsI(Tl)

Nuclear Instruments and Methods in Physics Research A 799 (2015) 64–69

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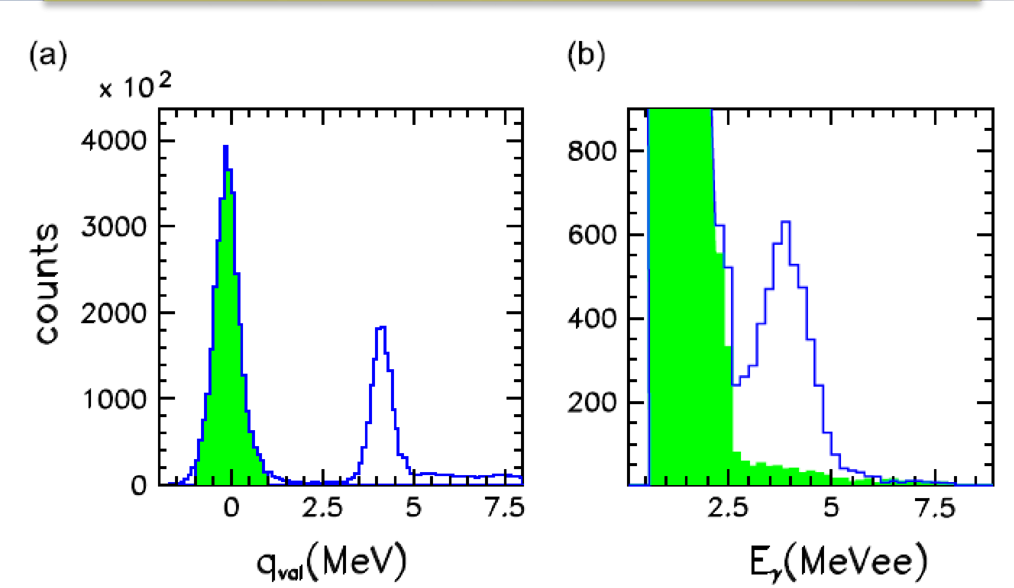
Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Particle gamma correlations in ^{12}C measured with the CsI(Tl) based detector array CHIMERA

Using proton beams on C target we excite the 4.44 MeV level – this level decay emitting a γ-ray that we can see in our CsI(Tl)

The CsI(Tl) of the CHIMERA sphere have a relatively good detection efficiency for γ-rays that we computed with GEANTIV and we have experimentally verified



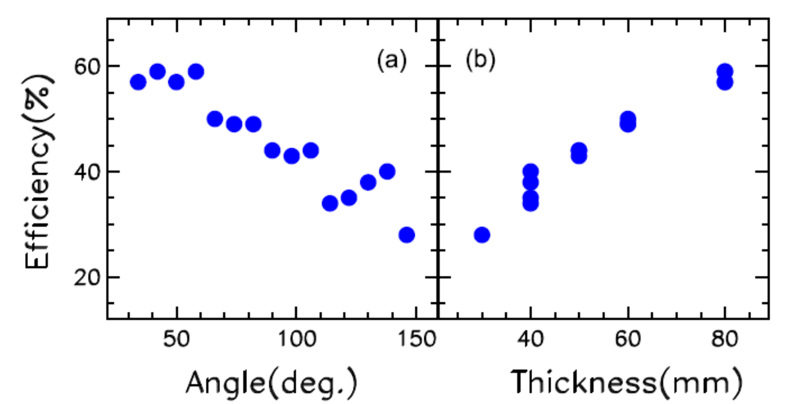
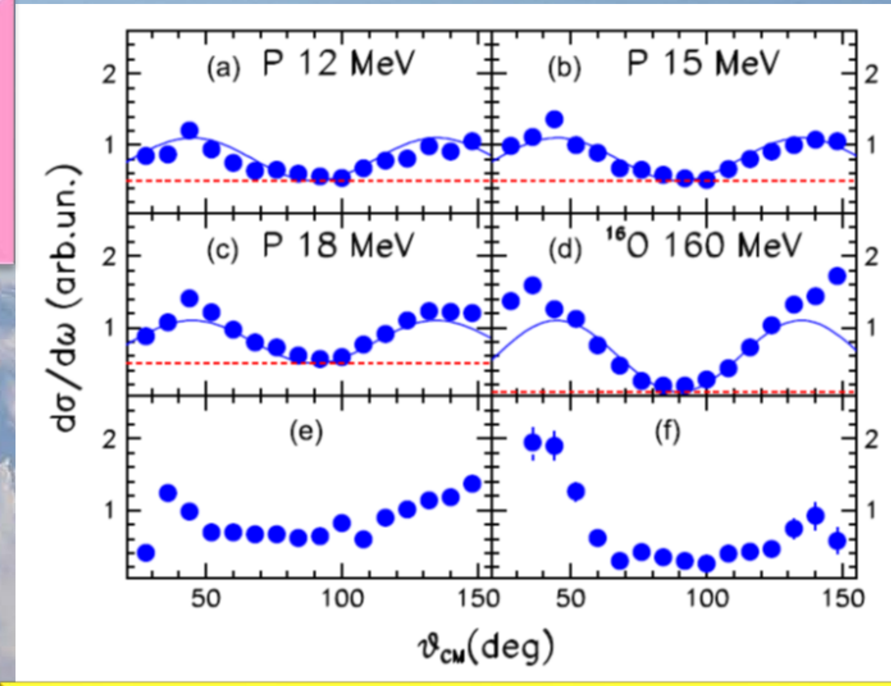
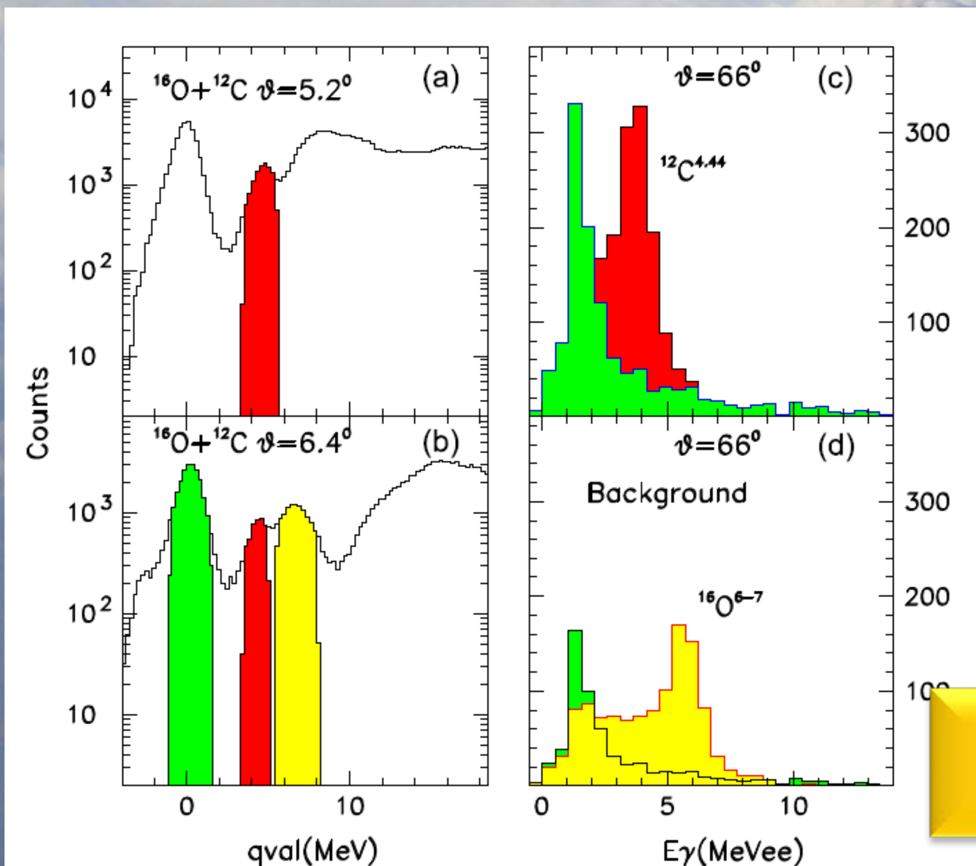


Fig. 1. CsI(Tl) efficiency to γ-rays of 4.44 MeV computed with Geant4 as a function (a) of detection angle, (b) of the thickness of scintillator.

The new method: γ-detection with CsI(Tl)

To verify the E2 character of the transition we can see the angular distribution in the reference frame of emitting recoil nucleus ^{12}C



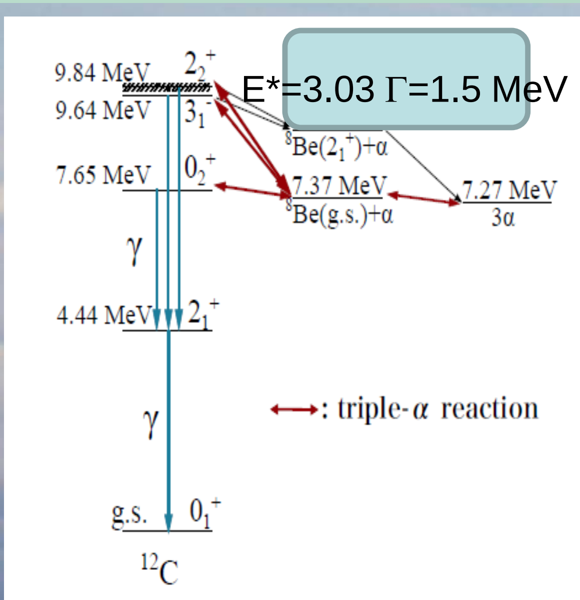


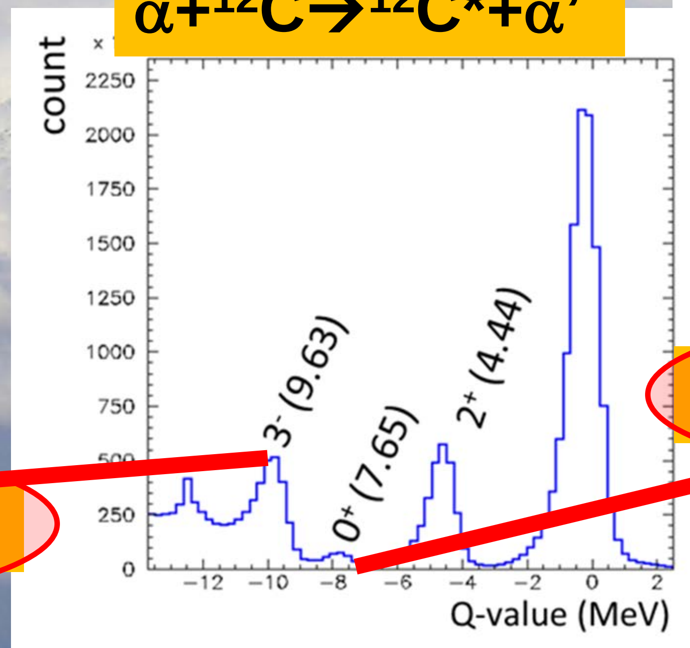
E2 behavior is verified by the minimum at 90° and maxima at 45° and 135° - the minimum is not zero because of the proton spin ½

using zero spin beam (^{16}O) we get more deep minimum

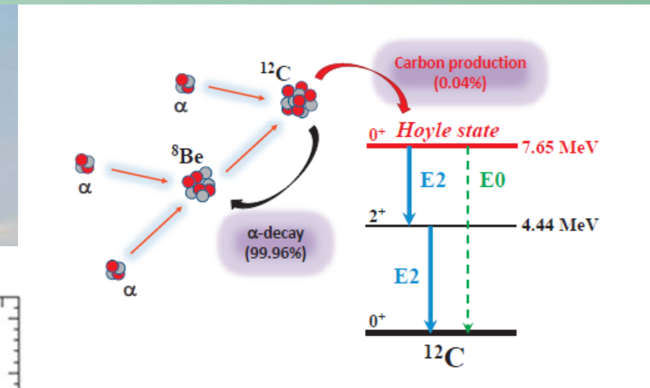
Note that with ^{16}O beam we can also see γ-rays around 6-7 MeV

The method: CHIMERA is able to see the 4 fold coincidence with good efficiency





$\alpha + {}^{12}C \rightarrow {}^{12}C^* + \alpha'$



${}^{12}C + \alpha_3 + \gamma_{5.2} + \gamma_{4.44}$

E1 E2

${}^{12}C + \alpha_2 + \gamma_{3.21} + \gamma_{4.44}$

E2 E2

Around 9-10 MeV it was localized also a 2^+ state interpreted as excited 2^+ Hoyle status. If excited this could decay with a γ-ray of about 2 MeV E2 to the 0^+ Hoyle status we will also look for this channel

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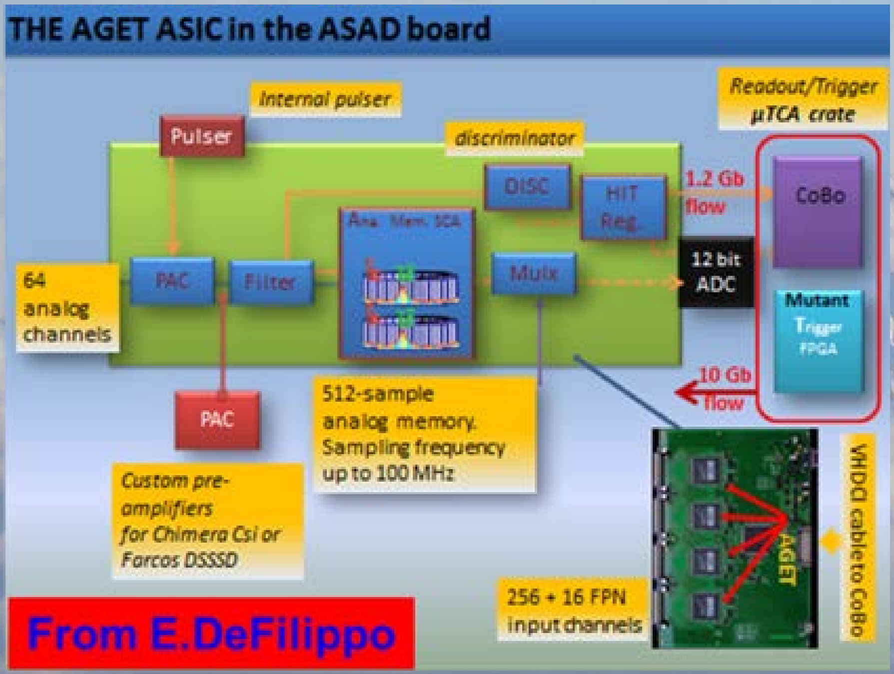
The method: rejection factor

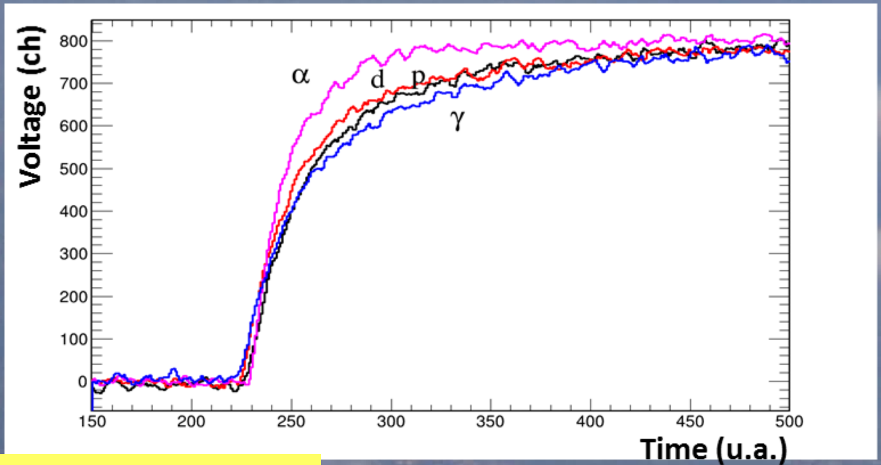
condition	Spurious coincidence suppression factor
4-fold coincidence	from time resolution Si and CsI 10^{-13}
particle and γ identification	from count rate at different angles ≈ 3-100
kinematic coincidence	from $\Delta\theta-\Delta\phi$ ≈ 30
Qvalue - measurement	from Energy resolution ≈ 10-20
total γ-ray energy	from Energy resolution ≈ 5-10

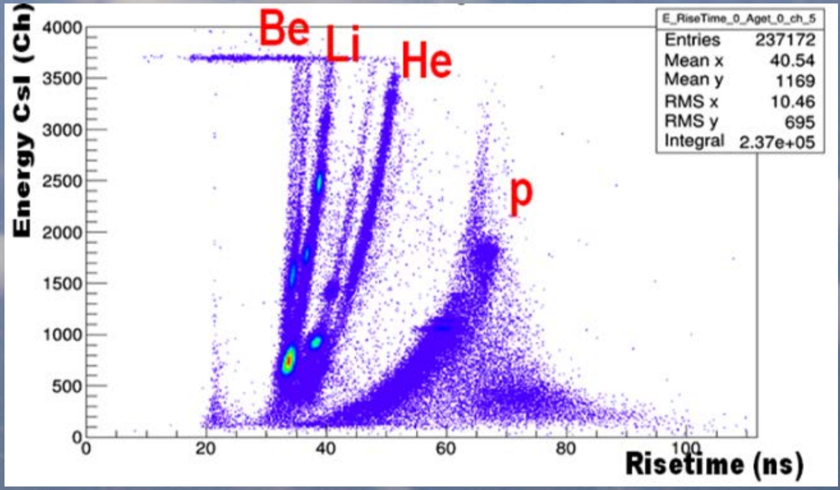
10^{-18} should be enough to well detect 10^{-9} decay probability of the 9.64 3^- level

Recent upgradings : γ-detection with CsI(Tl) NEW GET electronics



We are upgrading the CHIMERA electronics with GET – Using GET we can have the full digitalization of CsI(Tl) signals therefore we can perform a simple identification of γ-rays. Moreover we have also a trigger information from CsI(Tl) missing in the old CHIMERA electronics





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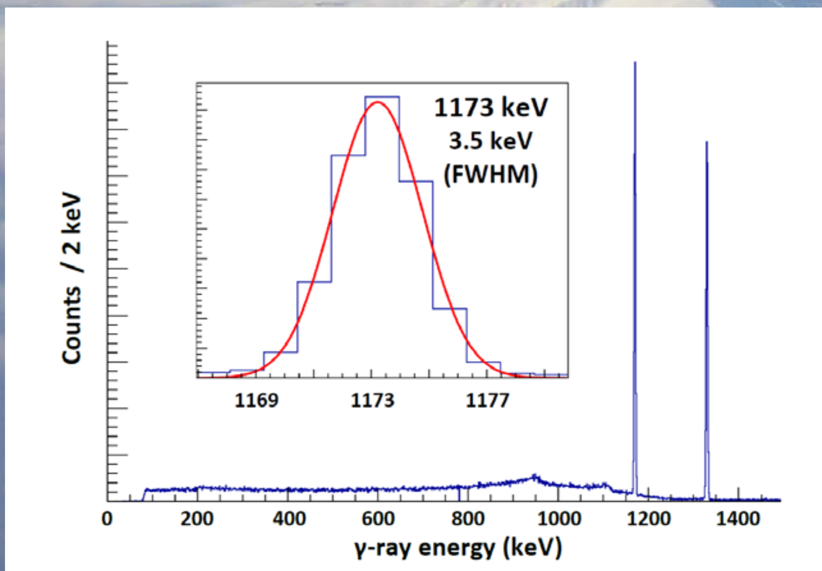
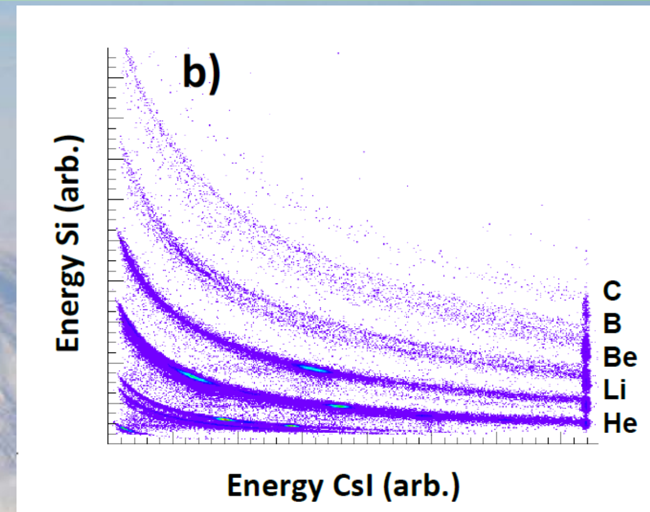
Recent upgradings : γ-detection with CsI(Tl) NEW GET electronics

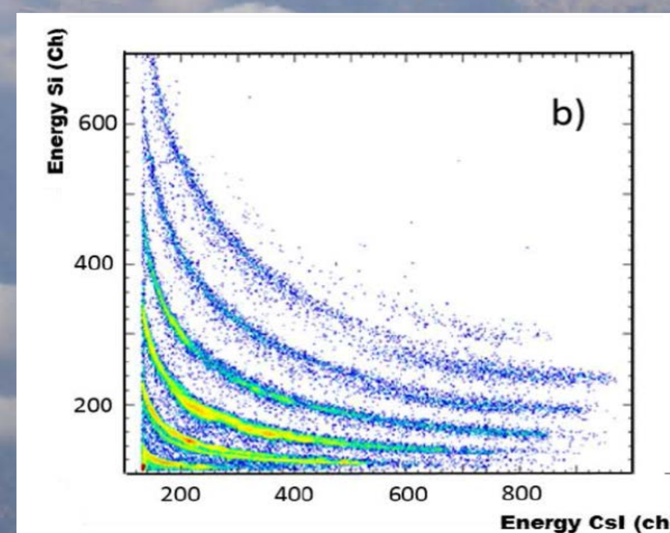
The quality of the new electronics was checked by using signals from a Germanium detector



only 1 keV worse than standard 14 bit Adc with Ortec amplifier

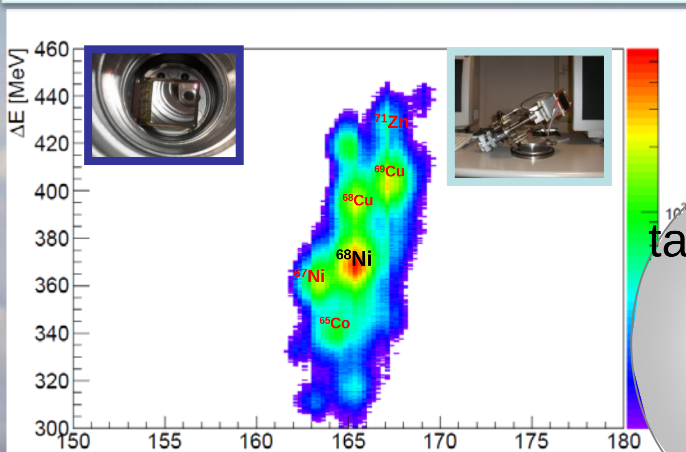


better mass identification in ΔE-E scatter plots (same telescope same reaction)

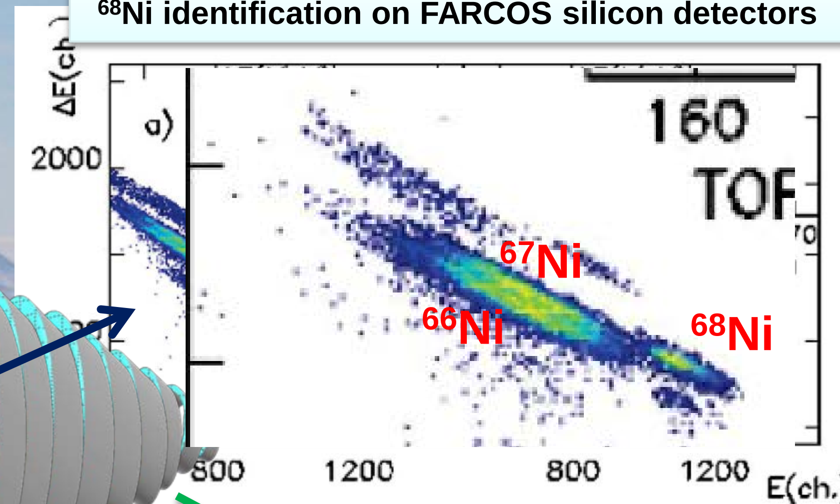


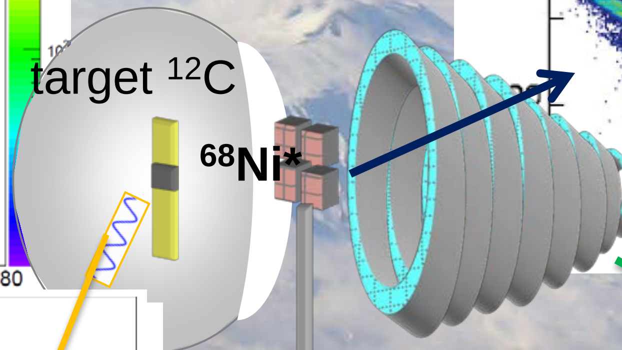
γ-detection with CsI(Tl) : Observation of isoscalar excitation of PYGMY resonance in ^{68}Ni

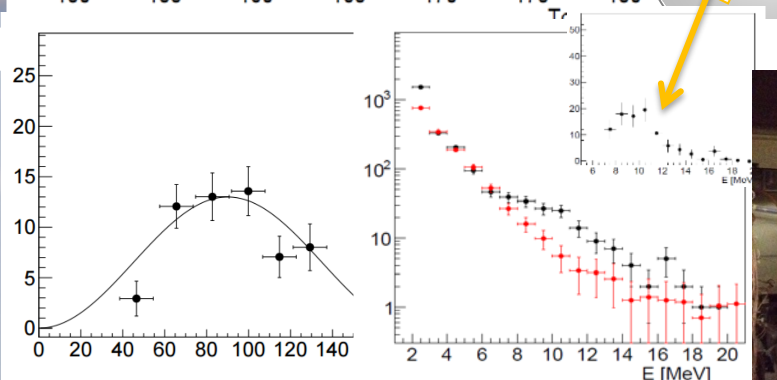
^{68}Ni fragmentation beam produced at LNS and event by event identified

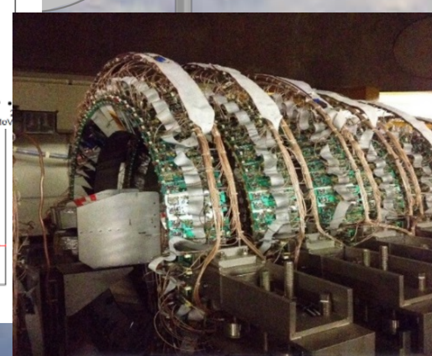


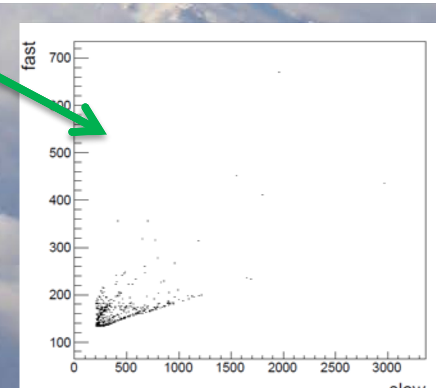
^{68}Ni identification on FARCOS silicon detectors





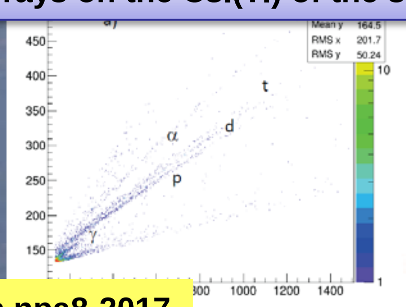


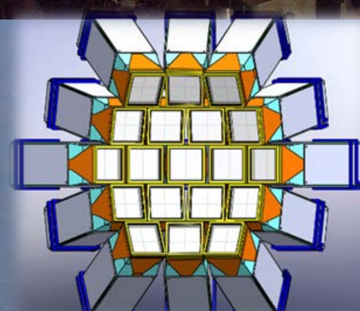




γ-rays on the CsI(Tl) of the sphere

neutrons on the CsI(Tl) of CHIMERA rings covered by FARCOS





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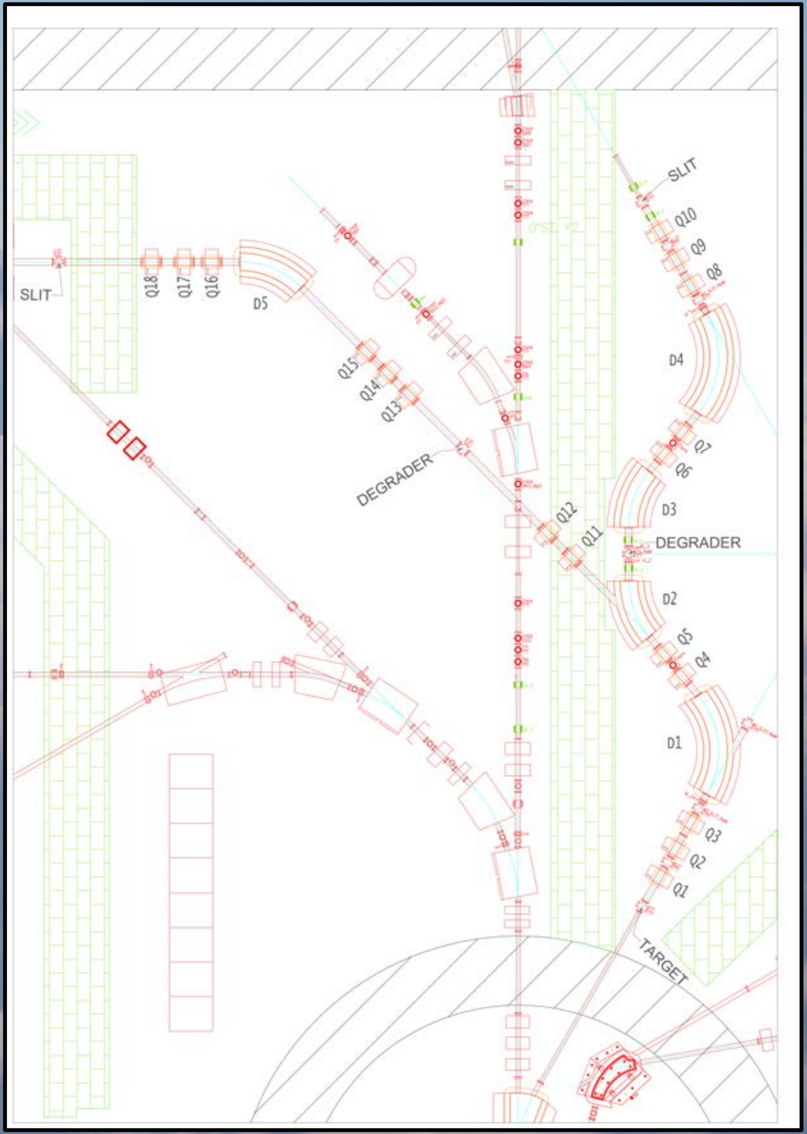
N.Martorana et al ARIS-2017

Future perspectives: upgraded Cyclotron at LNS

An upgrading of the cyclotron is going at LNS – high power beam will be available up to 10 MW

A new fragment separator is going to be implemented in order to use this high intensity beam – we will produce in few years very intense exotic radioactive beams in the range of 10^5-10^6 particle/s

With such beautiful beam and CHIMERA upgraded we hope to perform exciting experiments you are invited to join us with your smart ideas



Summary and outlook

Use of CHIMERA detector

- Chimera show its versatility
- With the new upgrading improved resolution
- Beautiful perspectives for γ-particle coincidences with radioactive and stable beams

The Hoyle measurement

- We hope to have beautiful data at the end of this year
- we should be able to improve the lower limit for the Γ_γ/Γ for the 9.64 3^- level
- We will also search for signals from the decay of the 2^+ excited Hoyle state

Future opportunities

- The new fragment separator at LNS will provide high intensity radioactive beams to perform beautiful experiments

The collaboration

L.Acosta[1,8], L.Auditore[4], G.C.[1], E. De Filippo[1], D.Dell'Aquila[6], S. De Luca[4], N.Gelli[9], B.Gnoffo[1], B.Fornal[10], G.Lanzalone[2,7], S.Leoni[5], I.Lombardo[6], C.Maiolino[2], N.Martorana[2], A.Nannini[9], S.Norella[4], A.Pagano[1], E.V.Pagano[2,3], M.Papa[1], S.Pirrone[1], G.Politi[1,3], L.Quattrocchi[4], F.Rizzo[2,3], P.Russotto[1], D.Santonocito[2], A.Trifirò[4], M.Trimarchì[4], M.Vigilante[6]

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