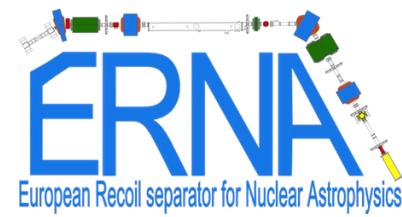


Prospettive in Astrofisica Nucleare

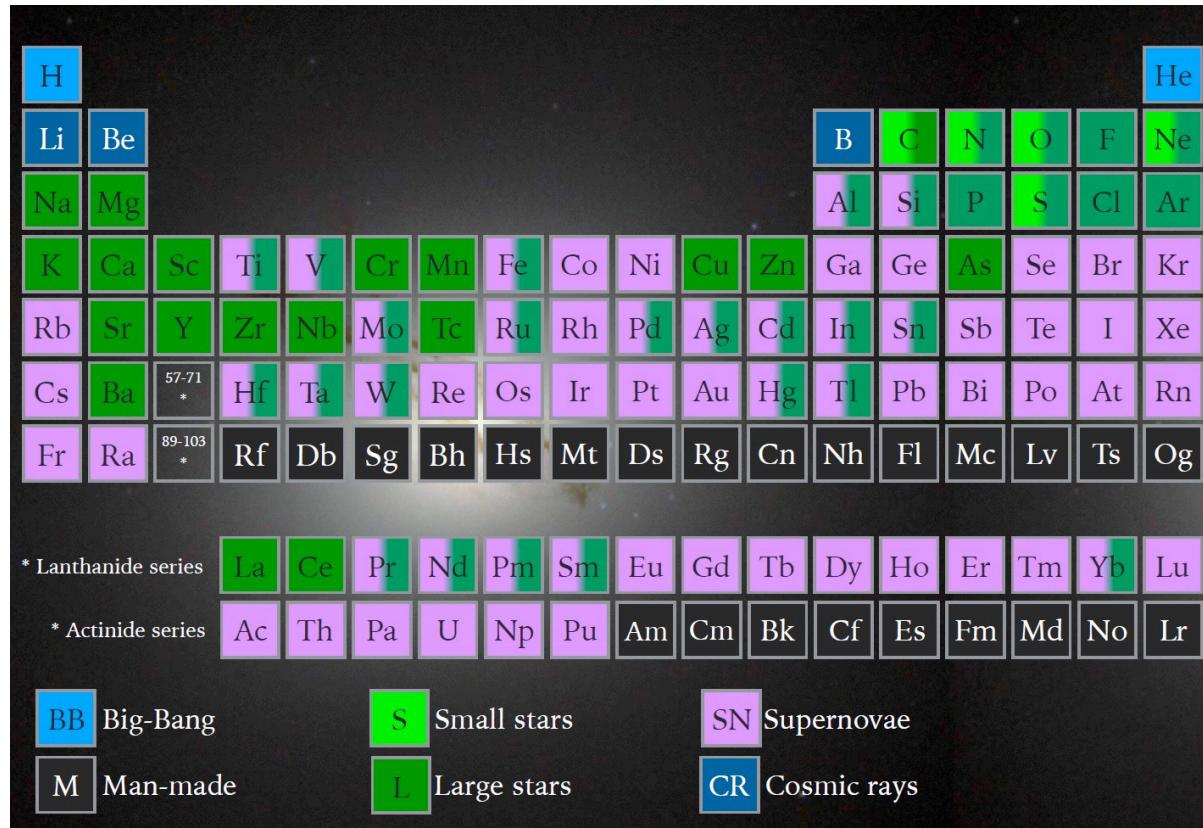


Istituto Nazionale di Fisica Nucleare
Sezione di Roma

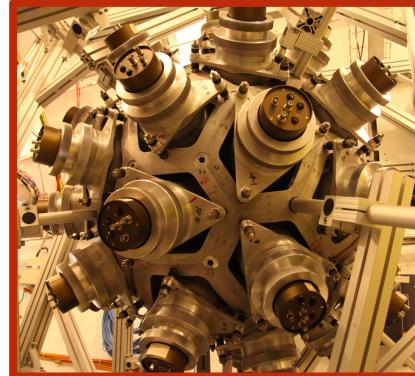
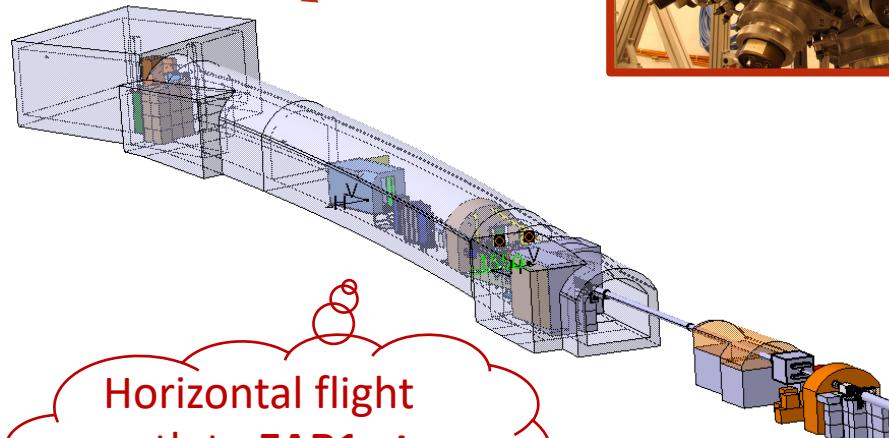


*Alba Formicola, Carlo Gustavino,
Evaristo Cisbani, Salvatore Fiore, Guido Maria Urciuoli*

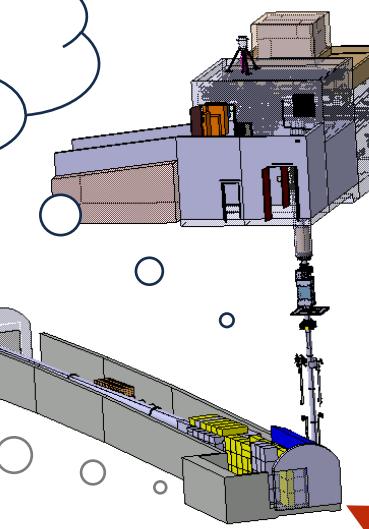
Astrofisica nucleare



time
EAR1: since 2001
EAR2: since 2014
NEAR: Since 2021



vertical flight
path to EAR2 at
18.2 m



NEAR
station

20 Gev/c protons from the PS

Commissioning target di spallazione

Sezioni coinvolte:
Roma 1 + ENEA

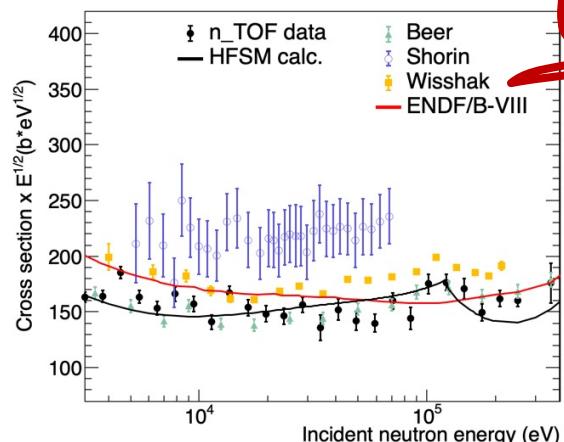


Cristian Massimi, SP n_TOF collaboration

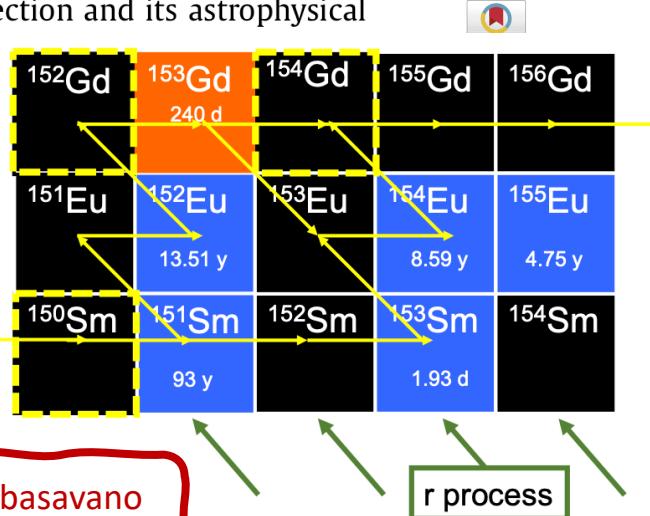


Measurement of the $^{154}\text{Gd}(n,\gamma)$ cross section and its astrophysical implications

La sezione d'urto del ^{154}Gd è stata misurata da 1eV a 300keV a EAR1:
 bersaglio auto supportante di gadolinio metallico arricchito al 66.78% in ^{154}Gd
 Rivelatore C_6D_6
 Caratterizzazione del bersaglio
 a GELINA



Processo s:
 ^{154}Gd s-only

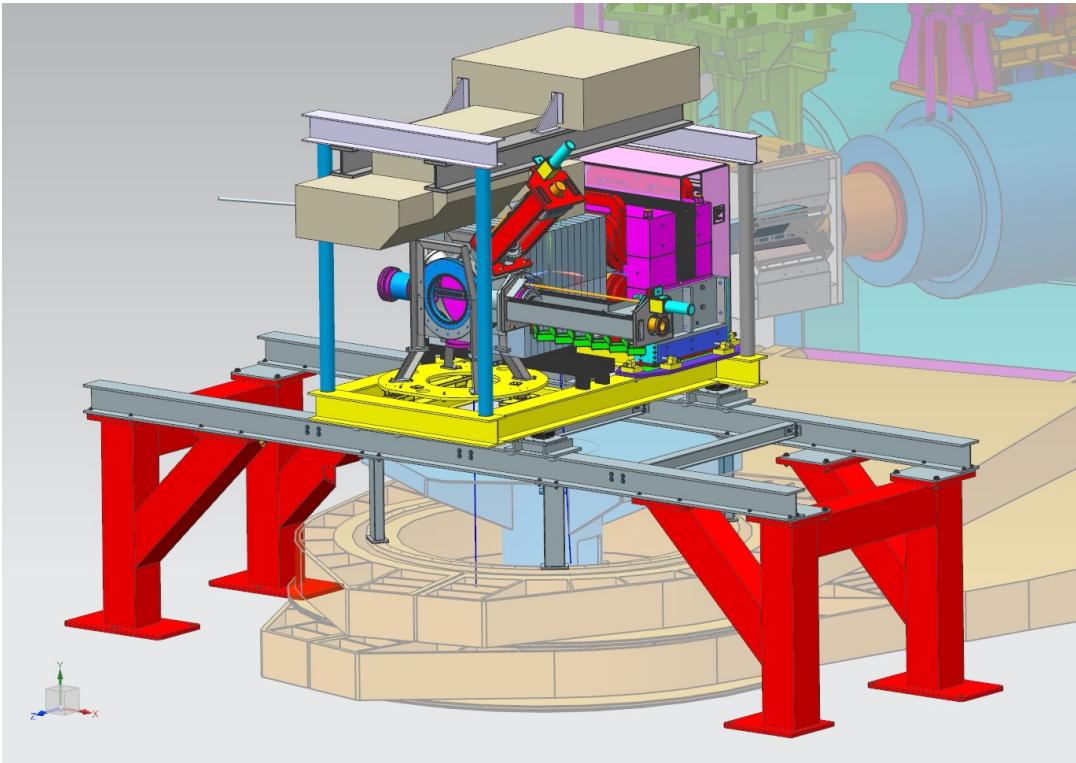


I modelli si basavano sui dati di Wissak
 Il ^{154}Gd può essere formato solo dal processo s. I modelli astrofisici suggerivano una sovrastima della sezione d'urto $^{154}\text{Gd}(n,g)$. La nostra misura ha confermato questa ipotesi, mostrando l'efficacia predittiva e la robustezza dei modelli astrofisici.

^{208}Pb Radius Experiment PREX performed at JLAB

The Lead Radius Experiment ("PREX"), experiment number E12-11-101, uses the parity violating weak neutral interaction to probe the neutron distribution in a heavy nucleus, namely ^{208}Pb , thus measuring the RMS neutron radius to 1% accuracy,

which has an important impact on nuclear theory and especially in the determination of neutron star features.



PHYSICAL REVIEW LETTERS 126, 172502 (2021)

Editors' Suggestion Featured in Physics

Accurate Determination of the Neutron Skin Thickness of ^{208}Pb through Parity-Violation in Electron Scattering

D. Adhikari,¹ H. Albataineh,² D. Androic,³ K. Aniol,⁴ D. S. Armstrong,⁵ T. Averett,⁵ C. Ayerbe Gayoso,⁵ S. Barcus,⁶ V. Bellini,⁷ R. S. Beminiwattha,⁸ J. F. Benesch,⁶ H. Bhatt,⁹ D. Bhatta Pathak,⁸ D. Bhetuwal,⁹ B. Blaikie,¹⁰ Q. Campagna,⁵ A. Camsonne,⁶ G. D. Cates,¹¹ Y. Chen,⁸ C. Clarke,¹² J. C. Cornejo,¹³ S. Covrig Dusa,⁶ P. Datta,¹⁴ A. Deshpande,^{12,15} D. Dutta,⁹ C. Feldman,¹² E. Fuchey,¹⁴ C. Gal,^{12,11,15} D. Gaskell,⁶ T. Gautam,¹⁶ M. Gericke,¹⁰ C. Ghosh,^{17,12} I. Halilovic,¹⁰ J.-O. Hansen,⁶ F. Hauenstein,¹⁸ W. Henry,¹⁹ C. J. Horowitz,²⁰ C. Jantzi,¹¹ S. Jian,¹¹ S. Johnston,¹⁷ D. C. Jones,¹⁹ B. Karki,²¹ S. Katugampola,¹¹ C. Keppel,⁶ P. M. King,²¹ D. E. King,²² M. Knauss,²³ K. S. Kumar,¹⁷ T. Kutz,¹² N. Lashley-Colthirst,¹⁶ G. Leverick,¹⁰ H. Liu,¹⁷ N. Liyange,¹¹ S. Malace,⁶ R. Mammei,²⁴ J. Mammei,¹⁰ M. McCaughan,⁶ D. McNulty,¹ D. Meekins,⁶ C. Metts,⁵ R. Michaels,⁶ M. M. Mondal,^{12,15} J. Napolitano,¹⁹ A. Narayan,²⁵ D. Nikolaev,¹⁹ M. N. H. Rashad,¹⁸ V. Owen,⁵ C. Palatchi,^{11,15} J. Pan,¹⁰ B. Pandey,¹⁶ S. Park,¹² K. D. Paschke,^{11,*} M. Petrusky,¹² M. L. Pitt,²⁶ S. Premathilake,¹¹ A. J. R. Puckett,¹⁴ B. Quinn,¹³ R. Radloff,²¹ S. Rahman,¹⁰ A. Rathnayake,¹¹ B. T. Reed,²⁰ P. E. Reimer,²⁷ R. Richards,¹² S. Riordan,²⁷ Y. Roblin,⁶ S. Seeds,¹⁴ A. Shahinyan,²⁸ P. Souder,²² L. Tang,^{6,16} M. Thiel,²⁹ Y. Tian,²² G. M. Urciuoli,³⁰ E. W. Wertz,⁵ B. Wojtsekhowski,⁶ B. Yale,⁵ T. Ye,¹² A. Yoon,³¹ A. Zec,¹¹ W. Zhang,¹² J. Zhang,^{12,15,32} and X. Zheng¹¹

(PREX Collaboration)

Recent past: experiments PREX and PREX-II at JLab

Electron - Nucleus Potential

$$\hat{V}(r) = V(r) + \gamma_5 A(r)$$

electromagnetic axial

$$V(r) = \int d^3 r' Z \rho(r') / |\vec{r} - \vec{r}'|$$

$$A(r) = \frac{G_F}{2\sqrt{2}} [(1 - 4\sin^2 \theta_W) Z \rho_p(r) - N \rho_N(r)]$$

Pb is spin 0

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_{Mott}} |F_p(Q^2)|^2$$

1 - 4 sin² θ_W ≪ 1 neutron weak charge >> proton weak charge

Proton form factor Neutron form factor

$$F_p(Q^2) = \frac{1}{4\pi} \int d^3 r j_0(qr) \rho_p(r)$$

$$F_N(Q^2) = \frac{1}{4\pi} \int d^3 r j_0(qr) \rho_N(r)$$

Parity Violating Asymmetry

$$A = \frac{\left(\frac{d\sigma_{PV}}{d\Omega} \right)_R - \left(\frac{d\sigma}{d\Omega} \right)_L}{\left(\frac{d\sigma}{d\Omega} \right)_R + \left(\frac{d\sigma}{d\Omega} \right)_L} = \frac{G_F Q^2}{2\pi\alpha\sqrt{2}} \left[\underbrace{1 - 4\sin^2 \theta_W}_{\approx 0} - \frac{F_N(Q^2)}{F_p(Q^2)} \right]$$

Through elastic electron scattering off a nucleus it is possible to determine the neutron form factor and hence the radius of the neutron distribution inside the nucleus. This is performed measuring the **Parity Violating Asymmetry (A_{PV})**, i. e. the fractional difference between the cross sections of right- and left-handed electron elastically scattered off the nucleus. **Measuring A_{PV}** one emphasize the contribution of the Axial part of the electron – nucleus potential, **the axial part of the electroweak potential is mostly sensitive to the neutron distribution**

Measuring A_{PV}, to determine the nucleus neutron skin Δr_{np}, , that is the difference between the radius of the neutron distribution and the radius of the proton distribution inside the nucleus .

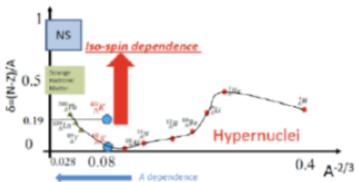


Future

Experiment E12-15-008

Study of the isospin dependence of the ΛN interaction through the high precision spectroscopy of Λ -hypernuclei obtained through the $^{40}Ca(e, e'K^+)^{40}\Lambda K$ and the $^{48}Ca(e, e'K^+)^{48}\Lambda K$ reactions

- Heavy asymmetric hypernuclei are the most sensitive to the strength and the sign of the isospin triplet component of the ΛNN potential.
- $^{48}\Lambda K$ has a large dependence on the ΛNN triplet, while $^{40}\Lambda K$ has not (for symmetric hypernuclei the Pauli principle suppresses any strong contribution from the Λnn or Λpp channels). A comparison of $^{48}\Lambda K$ and $^{40}\Lambda K$ Λ separation energies will clarify the role of the isospin asymmetry in the 3-body hyperon-nucleon interaction.



Behavior of the asymmetry parameter δ as a function of $A^{2/3}$. The blue closed circles represent the case for $^{40}\Lambda K$ ($\delta=0.025$) and $^{48}\Lambda K$ ($\delta=0.188$).

Two complementary experiments already approved by Jlab PAC aim at solving the “hyperon puzzle”:

1) Experiment E12-15-008

An isospin dependence study of the ΛN interaction through the high precision spectroscopy of Λ -hypernuclei with electron beam
(it will investigate the isospin dependence of the $N\Lambda$ interaction)

2) Experiment 12-20-013

Studying Λ interactions in nuclear matter with the $^{208}Pb(e, e'K^+)^{208}\Lambda Tl$ reaction
(it will investigate the A dependence of $NN\Lambda$ and Λ interactions in an uniform nuclear medium)

Studying Λ interactions in nuclear matter with the $^{208}Pb(e, e'K^+)^{208}\Lambda Tl$ reaction

Spokespersons

O. Benhar¹, F. Garibaldi^{1*}, P.E.C. Markowitz², S.N. Nakamura³, J.Reinhold², L. Tang⁴, G..M. Urciuoli¹
* Contact person

- INFN Roma1
- Florida International University
- Graduate School of Science, Tohoku University
- Department of Physics, Hampton University

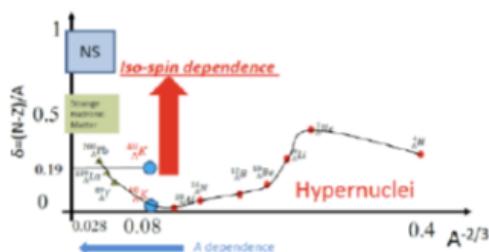
Thomas Jefferson National Accelerator Facility (JLab)

Omar.benhar@roma1.infn.it, franco.garibaldi7@gmail.com, markovit@fiu.edu, nue@lambda.phys.tohoku.ac.jp, reinhold@fiu.edu, tangl@jlab.org, guido.marla.urciuoli@roma1.infn.it

Experiment E12-15-008

Study of the isospin dependence of the ΛN interaction through the high precision spectroscopy of Λ -hypernuclei obtained through the $^{40}Ca(e, e'K^+)^{40}\Lambda K$ and the $^{48}Ca(e, e'K^+)^{48}\Lambda K$ reactions

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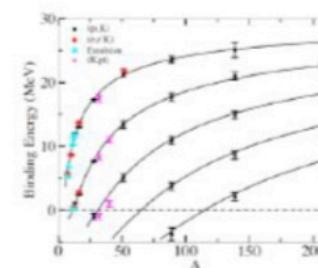
Behavior of the asymmetry parameter δ as a function of $A^{-2/3}$. The blue closed circles represent the case for $^{40}\Lambda K$ ($\delta=0.025$) and $^{48}\Lambda K$ ($\delta=0.188$).

G.M.Urciuoli SP E12- 15-008
E12-20-013

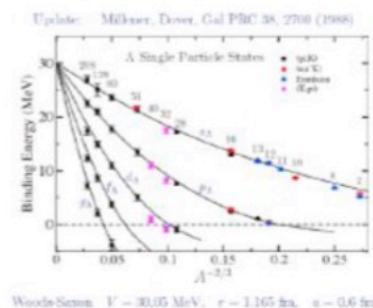
Experiment E12-20-013

Study of $^{208}\Lambda Tl$ spectroscopy through the $^{208}Pb(e, e'K^+)^{208}\Lambda Tl$ reaction

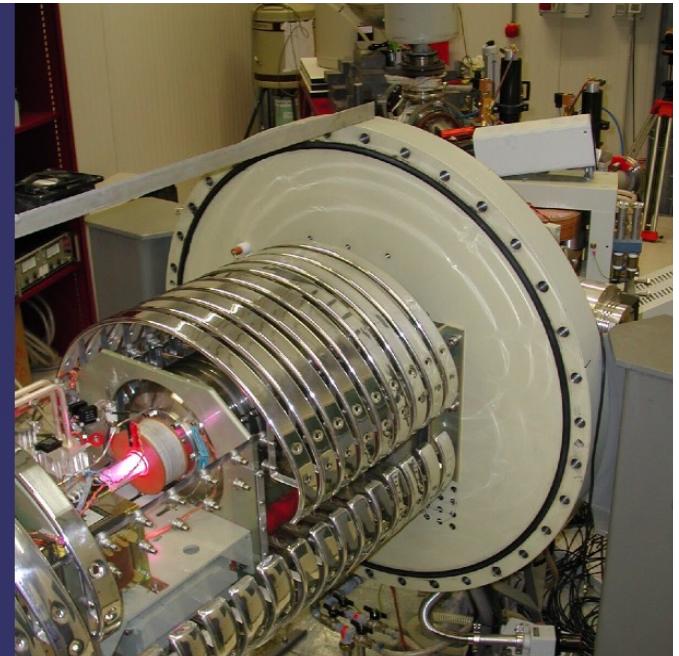
Together with experiment E12-15-008, experiment E12-20-013 will investigate the A dependence of the binding energies of single-particle levels of hypernuclei



The spacings of the single-particle energies as a function of A put more constraints on the theoretical fits.



Update: Millener, Dover, Gal PRC 38, 2700 (1988)
Woods-Saxon: $V = 30.05$ MeV, $r = 1.165$ fm, $a = 0.6$ fm
To understand Hyperon puzzle we need the binding energies and spacings of Lambda single-particle levels for a number of hypernuclei widely spaced in A .



LUNA 400kV accelerator

- $U_{\text{terminal}} = 50 - 400 \text{kV}$
- $I_{\text{max}} = 500 \mu\text{A}$ (on target)
- Allowed beams: H^+ , ${}^4\text{He}$, (${}^3\text{He}$)



LUNA MV accelerator



${}^1\text{H}^+$ (TV: 0.3 – 0.5 MV): 500 μA
 ${}^1\text{H}^+$ (TV: 0.5 – 3.5 MV): 1000 μA



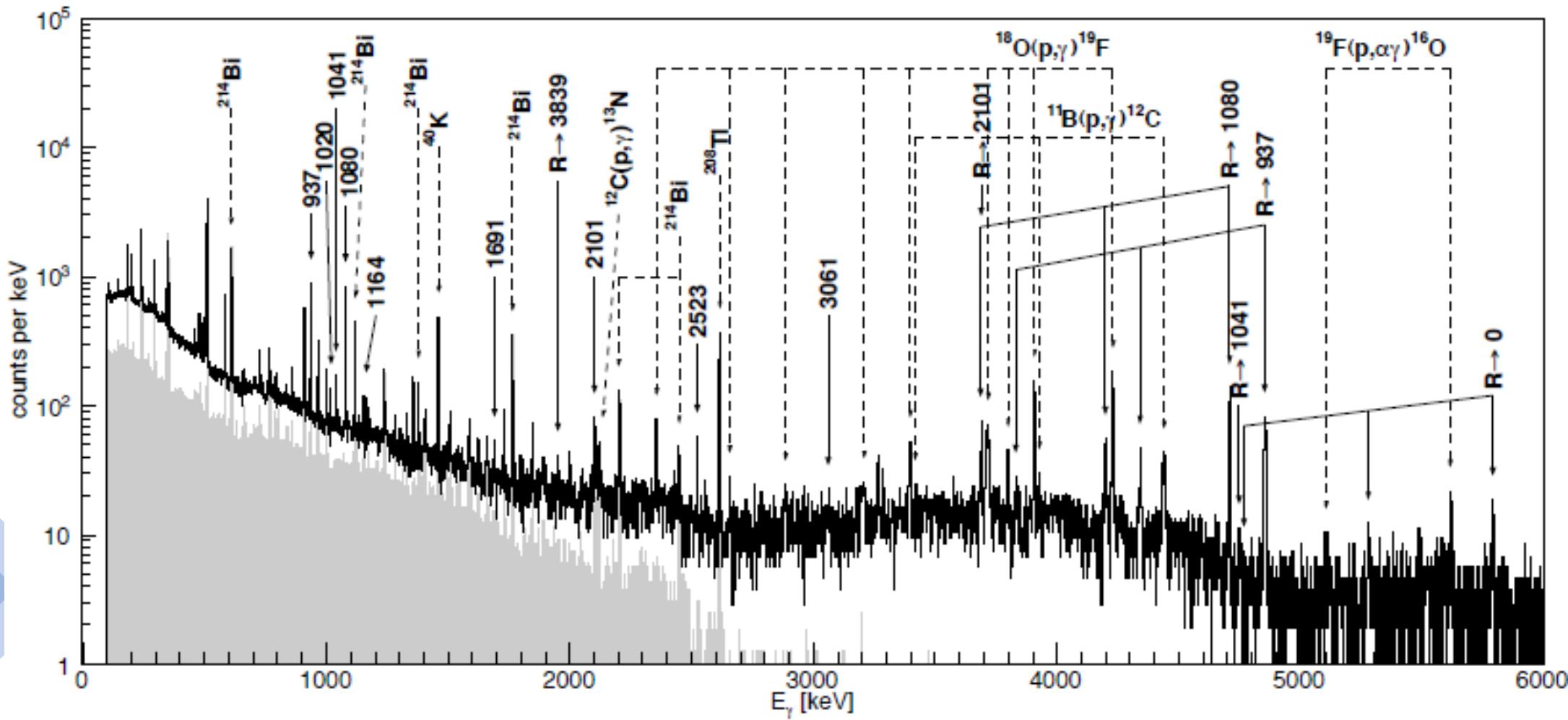
${}^4\text{He}^+$ (TV: 0.3 – 0.5 MV): 300 μA
 ${}^4\text{He}^+$ (TV: 0.5 – 3.5 MV): 500 μA

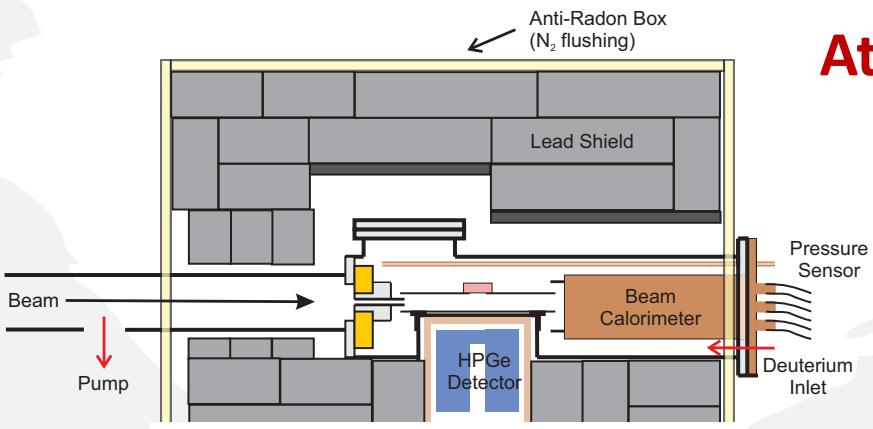


${}^{12}\text{C}^+$ (TV: 0.3 – 0.5 MV): 100 μA
 ${}^{12}\text{C}^+$ (TV: 0.5 – 3.5 MV): 150 μA
 ${}^{12}\text{C}^{++}$ (TV: 0.5 – 3.5 MV): 100 μA

poor signal-to-noise ratio

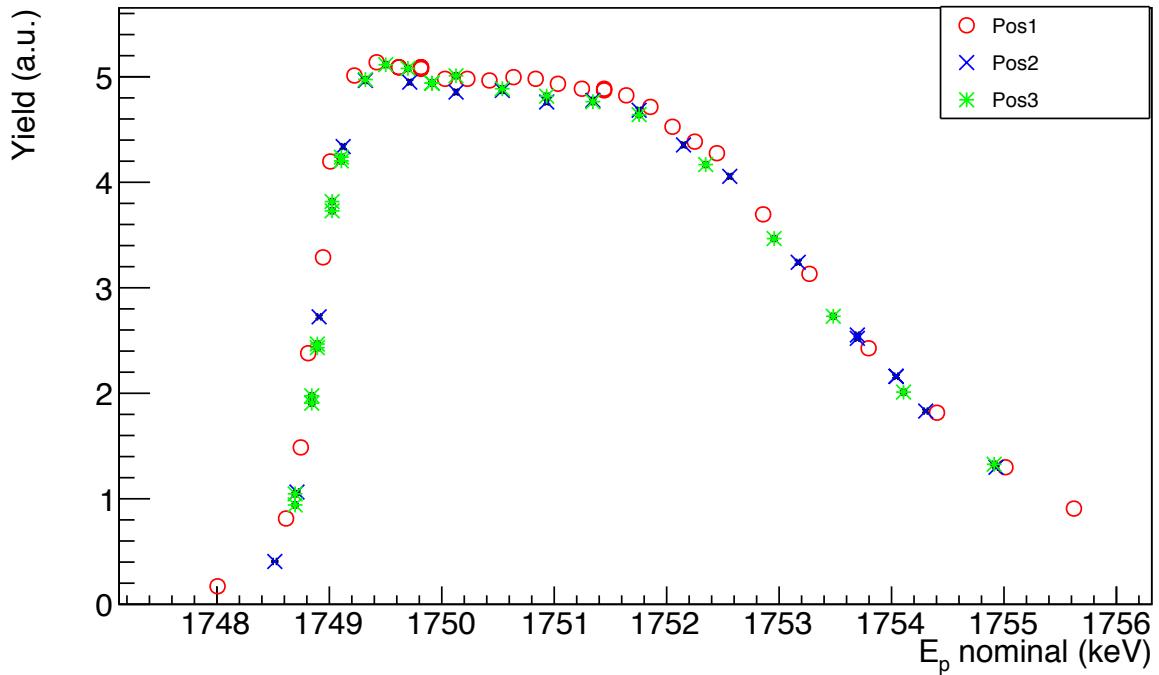
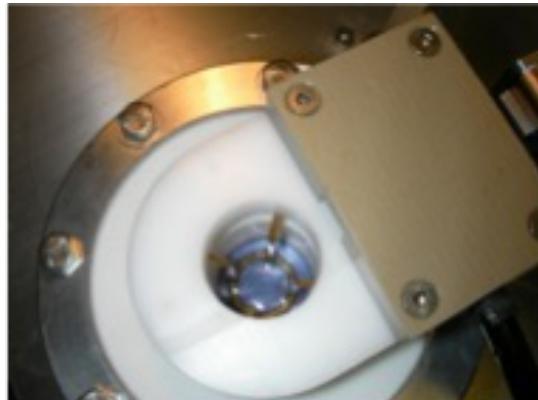
- ⇒ long measurements
- ⇒ ultra pure targets
- ⇒ high beam intensities
- ⇒ high detection efficiency





Attività del gruppo

Bersagli gassosi estesi (10cm) mediante pompaggio differenziale senza l'utilizzo di finestre



Carterizzazione di
bersagli solidi e gassosi :
 N_2O , Mg, Al, D ($10^{18} \text{ atom/cm}^2$)
mediante reazioni nucleari

Attività del gruppo

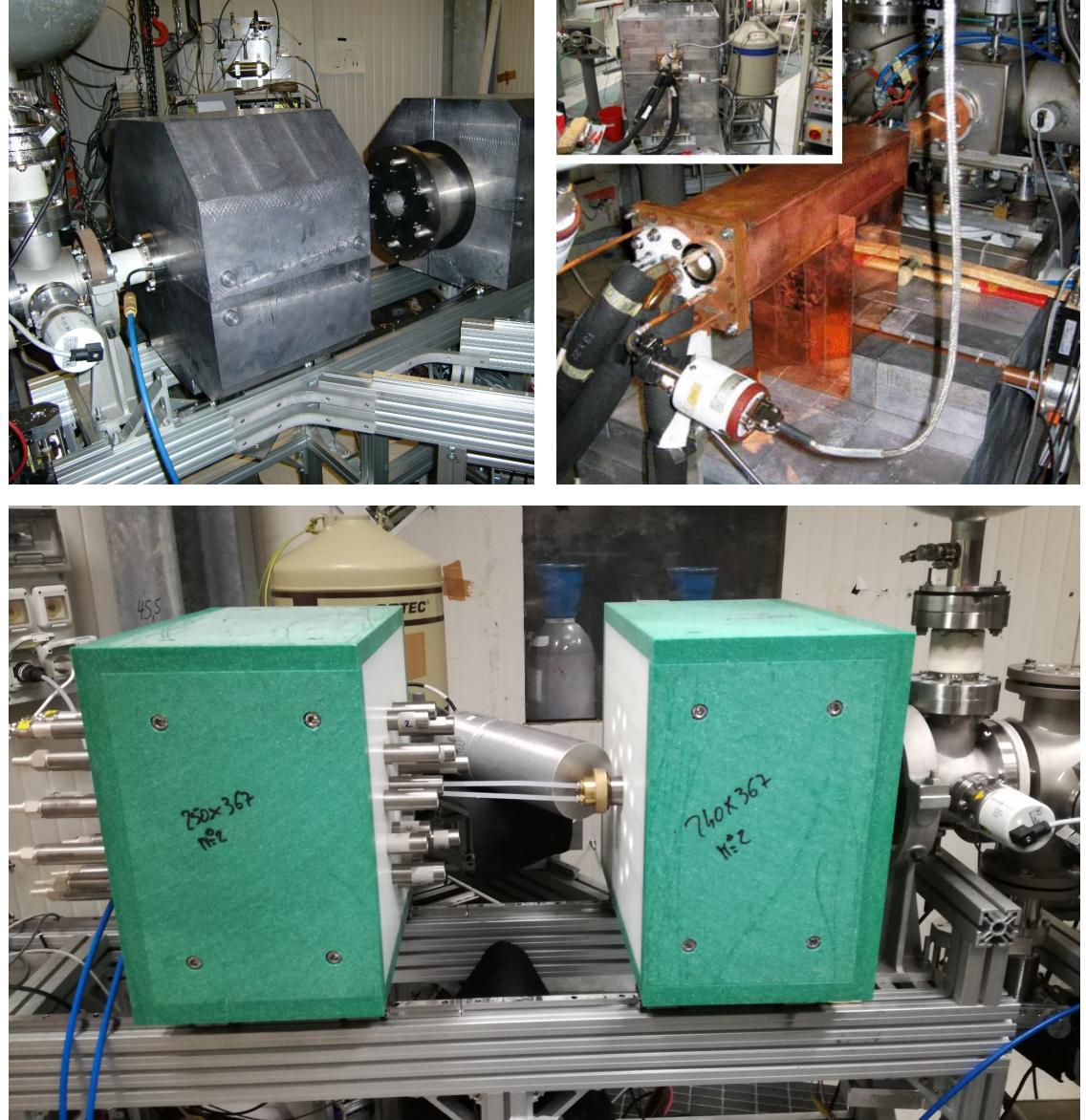


Misure di spettroscopia γ e
rivelazione di neutroni in
condizioni di ultra low background

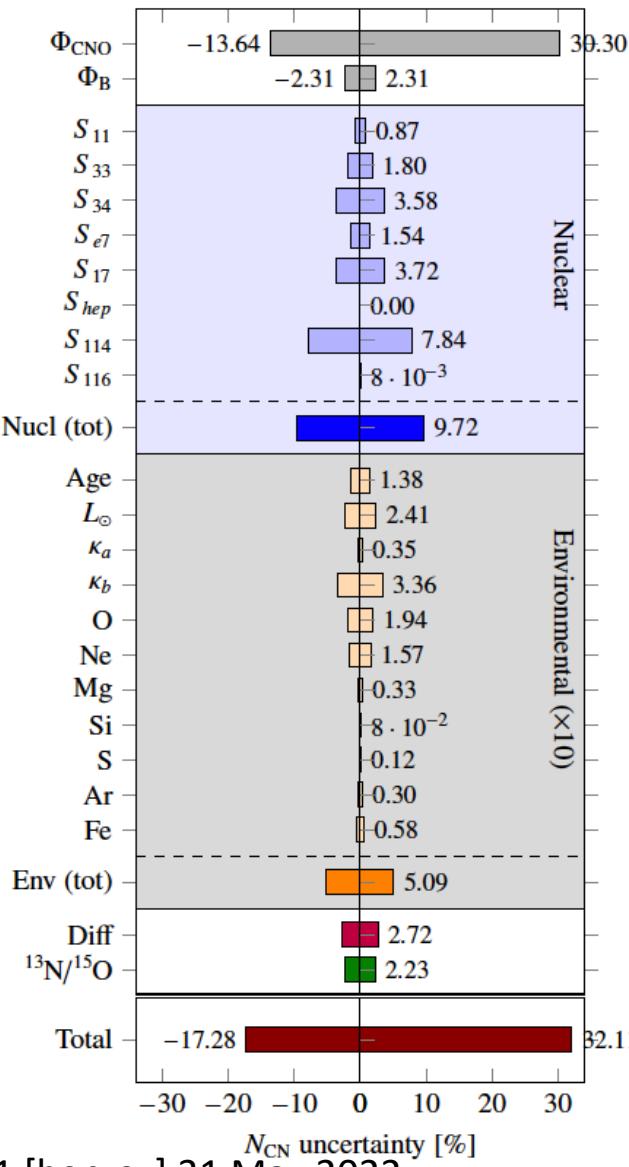
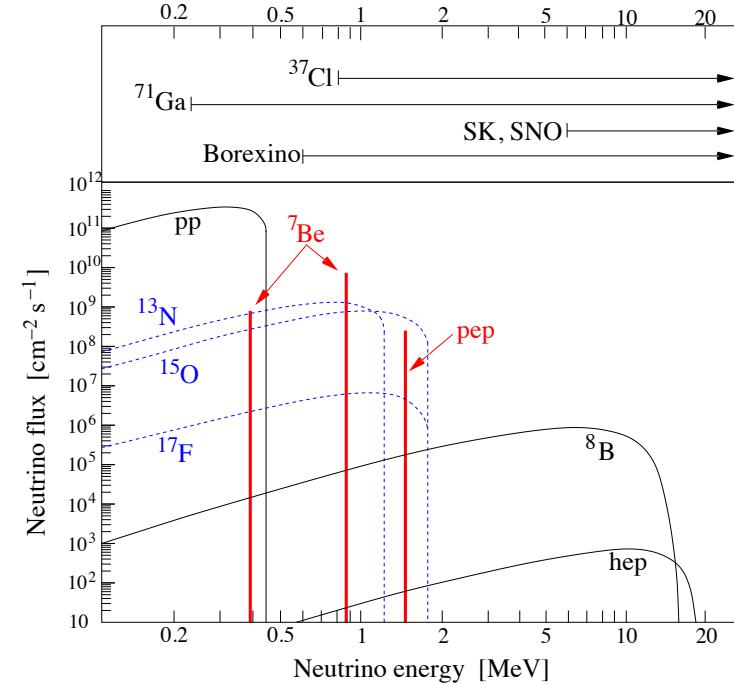
Problemi aperti:

curve di efficienze assolute al di
sopra dei 3MeV per gli spettri- γ

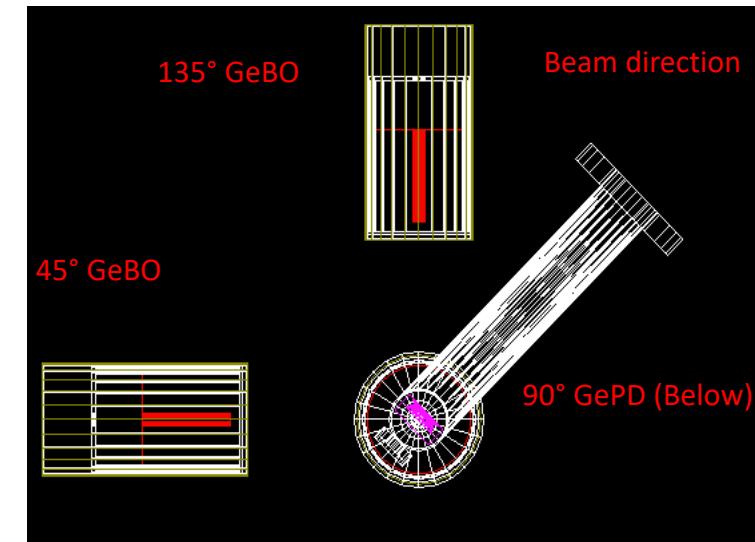
contaminazioni dei supporti di Ta.



$^{14}\text{N}(\text{p},\gamma)^{15}\text{O}$ Bottleneck reaction in CNO cycle

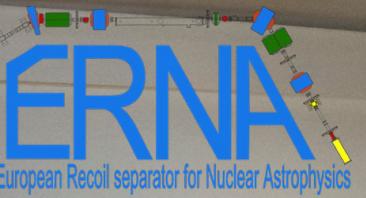


Prossima campagna di misure
2023 @LUNA MV



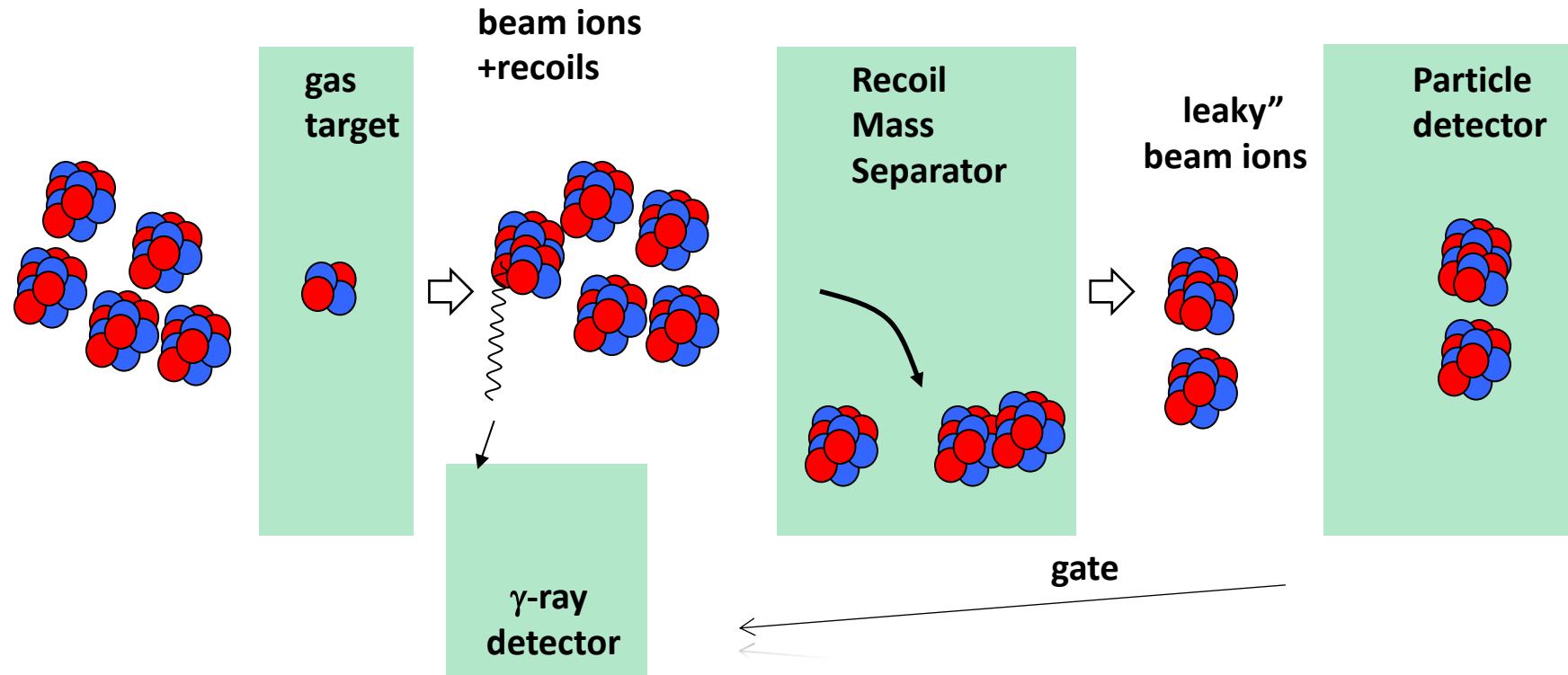
(A.Compagnucci-PhD@GSSI)

Misura di sezione d'urto differenziale
in un ampio intervallo di energie 300keV-1.6MeV



Recoil Mass Separator

reaction yield by means of the direct detection of the recoil ions



$$N_{\text{recoils}} = N_{\text{projectiles}} \times n_{\text{target}} \times \sigma \times T_{\text{ERNA}} \times \Phi_q \times \epsilon_{\text{part}}$$

$$N_{\text{gamma}} = N_{\text{recoils}} \times \epsilon_{\gamma}$$

$^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$ – The Holy Grail of Nuclear Astrophysics

Prossima campagna di misura prevista in luglio 2022 @ERNA

Main Uncertainties in the Presupernova Massive Star Models

$$T \sim 1.5 - 3.5 \cdot 10^8 \text{ K} \quad \rho \sim 0.2 - 4 \cdot 10^3 \text{ g cm}^{-3}$$

Central Abundances

$^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$ is crucial since it determines the $^{12}\text{C}/^{16}\text{O}$ ratio
at core He depletion that in turn drives all the
subsequent nuclear burning stages

Implications on the Initial Mass-Remnant Mass relation → BH/NS forming
CCSNe → GW Progenitors

Criticità del Gruppo

Assenza di laureandi

Assenza di Dottorandi

Difficoltà nel reclutamento di Post-PhD posizioni disponibili (standard e senior)

