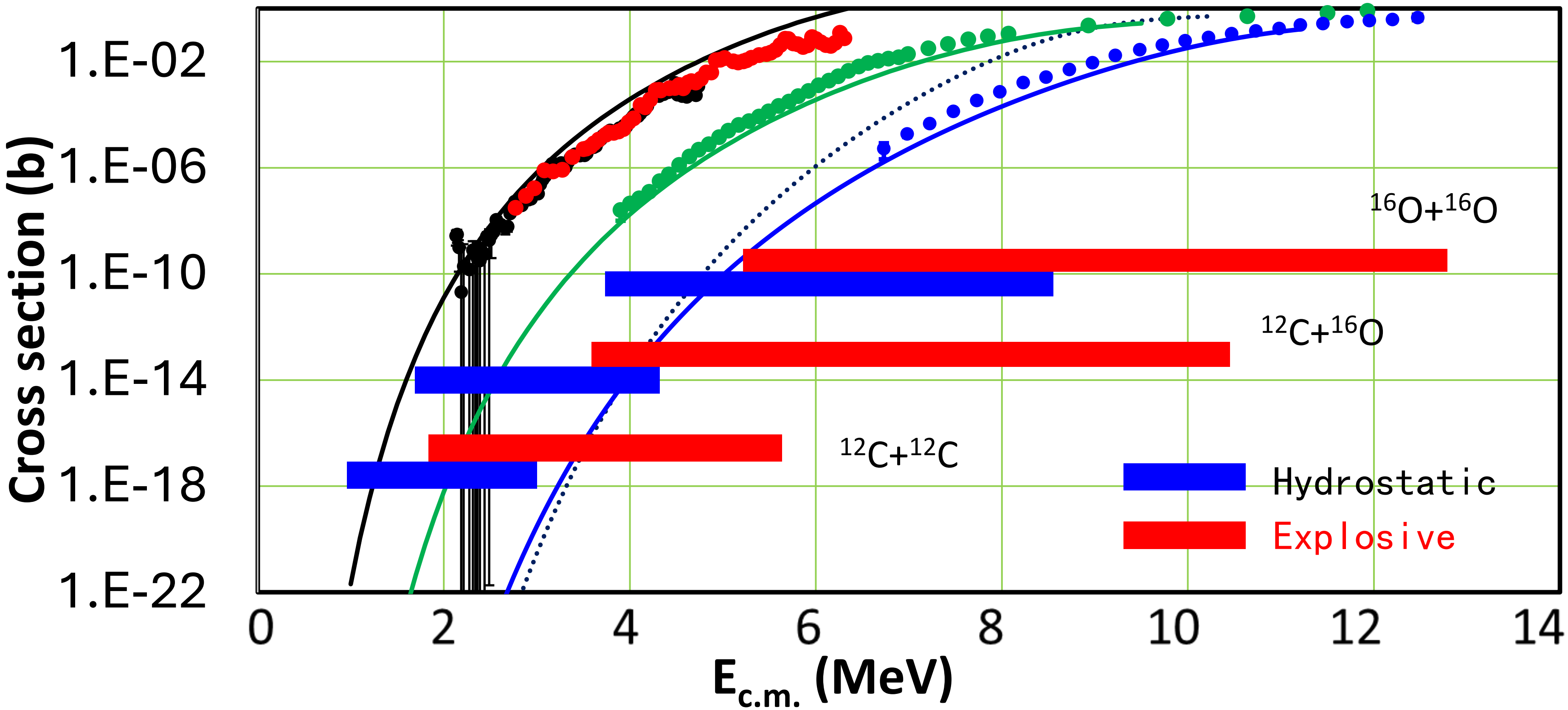
Heavy Ion Fusion Reaction in Stars



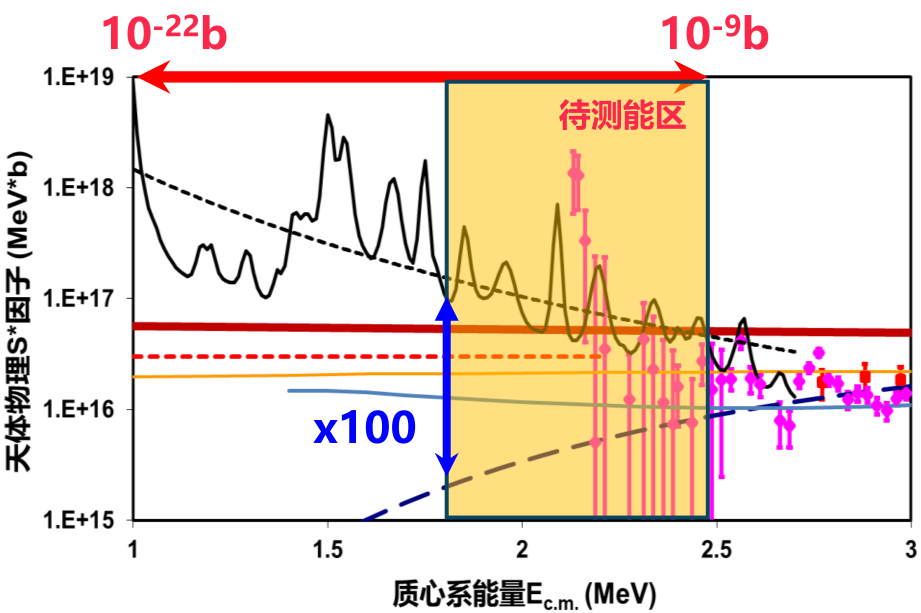
Low Energy High Intensity Heavy ion Accelerators

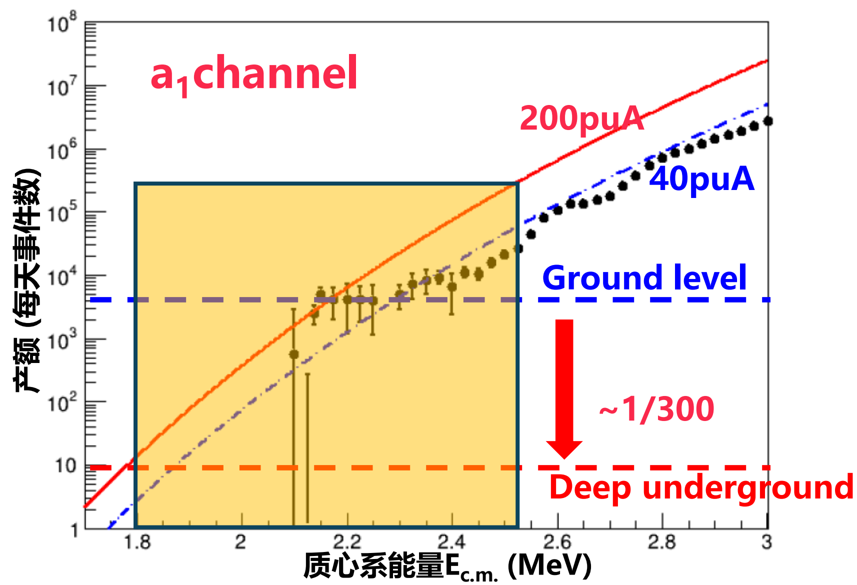
$^{12}C+^{12}C$

Terminal Voltage:
0.2 – 3.5 MV
C+ beam:
$E_{c.m.}$=0.1-1.75 MeV, 100-150 μA
C++ beam:
$E_{c.m.}$=0.2-3.5 MeV, 50 pμA

Energy: 0.3-0.7 MeV/u
C++ beam:
Ec.m.=1.8-4.2 MeV
~200 pμA

Studying $^{12}C+^{12}C$ fusion reaction in underground lab





LUNA-MV: higher yield using high intensity beam; deep underground lab achieves lower gamma-ray background

https://www.jinaweb.org/science-research/scientific-resources/data

SCIENCE RESEARCH

- MA 1: The Origin of the Elements
- MA 2: High Density Matter Probed by Neutron Stars
- Publications
- Scientific Resources
  - Data
  - Codes
  - Jobs
  - Virtual Journal
  - Conference List
  - Diversity
- Scientific Animations

Nuclear Data for Astrophysical Applications

REACLIB: JINA-CEE Reaclib Database

Weak Rates: Weak Interaction Data

KADONIS: Neutron and Proton Capture Rates for s- and p-process

STARLIB: Reaction Rates With Uncertainties

BRUSLIB: Reaction rates including NACRE|| and NetGen tool

NNDC MACS: Neutron induced reaction rates from NNDC

Tools and Data: Nucastrodata.org

NON-SMOKER: Statistical Model Reaction Rates

Astrophysical Data for Nuclear Astrophysics Applications

JINAbase: Observed Stellar Abundance Database

SAGA: Observed Stellar Abundances

NuGRID Yield Set1: Predicted Stellar Abundance Yields: Stellar Evolution and Explosion and Post-Processing Data Package https://www.jinaweb.org/science-research/scientific-resources/codes

SCIENCE RESEARCH

MA 1: The Origin of the Elements

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Publications

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Scientific Animations

Public Codes for Nuclear Astrophysics

JINA-CEE AZURE2: R-matrix code for nuclear reaction rates

JINA-CEE dStar: Neutron star cooling model code

NuGRID WENDI: Web Exploration of NuGRID Data Interactive

NuGRID/JINA-CEE SYGMA and OMEGA: Chemical evolution model modules and stellar yields

NuGridPy: Python package to read, visualize and analyze NuGrid and MESA code output

NucNet: Reaction Network Code (see JINA-CEE/NAVI wiki from network school on how to use the code, exercises, projects, etc)

SkyNet: Reaction Network Code

Xnet: Reaction Network Code

rJAVA: r-process simulation software

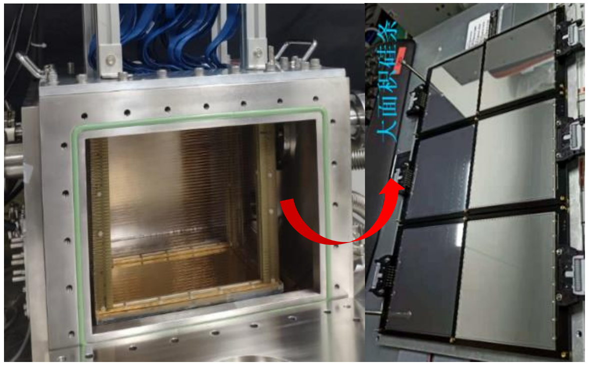
MESA: Stellar Evolution Code

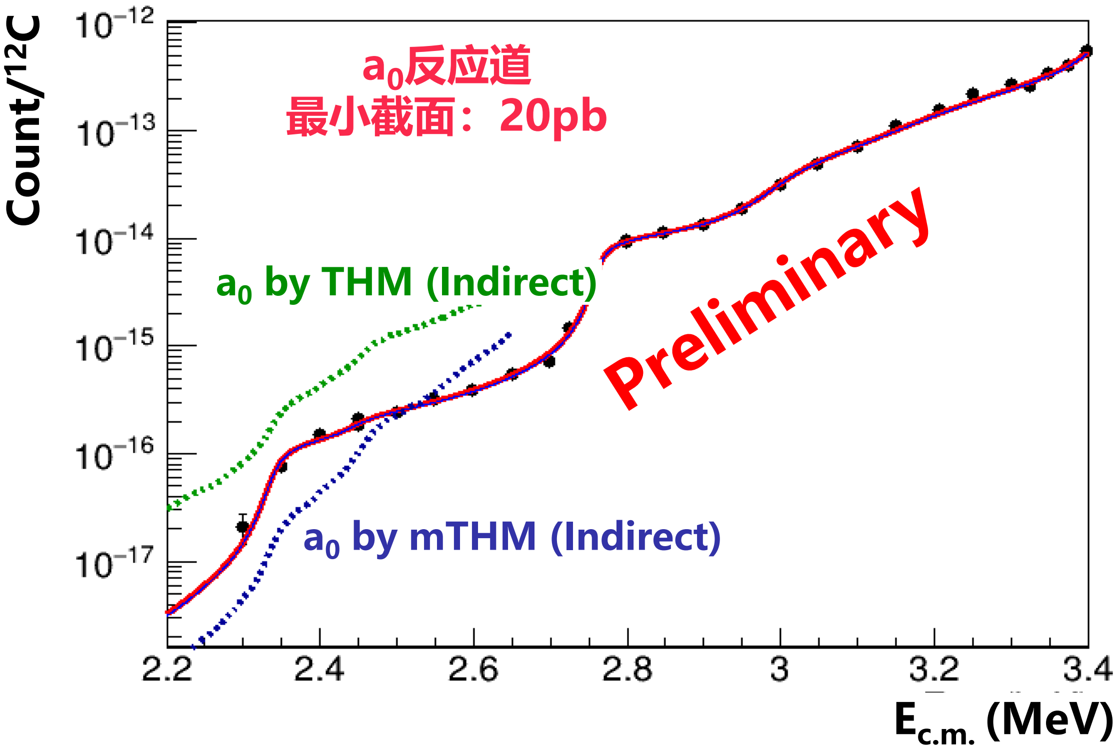
MESA-web: Web version of MESA by JINA-CEE

Timmes Collection: Nuclear astrophysics codes

Nucastrodata.org: Reaction network related online tools at nucastrodata.org

基于LEAF开展$^{12}C+^{12}C$熔合反应





LEAF: 利用时间投影室等先进的带电粒子探测技术，首次将a_0反应道测量推进到E_{cm}<2.6MeV，发现THM等外推模型并不适用

Nuclear physics for Astrophysics - experiment

3. Indirect Methods in Nuclear Astrophysics

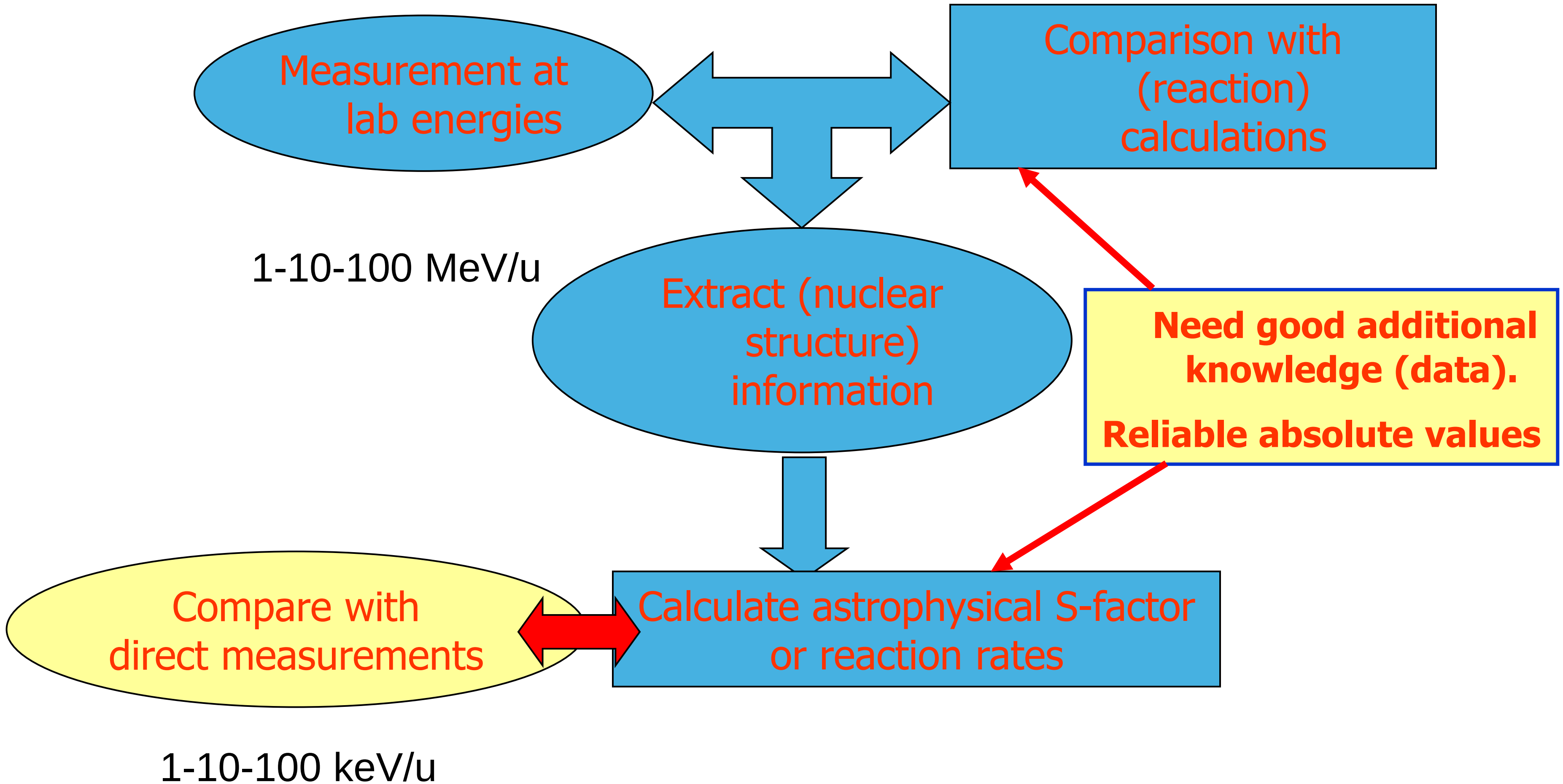
NUSYS, July 27 – Aug. 2, 2024, Zhuhai, China

Indirect Methods in Nuclear Astrophysics

Experiments/reactions at larger energies to be used to evaluate astrophysical S-factors or reaction rates

- Review of existing indirect methods in nuclear astrophysics
  - “the list”
  - Specifics. Assessment of problems with the accuracy of indirect methods, importance of calculated absolute values
  - The need for modern theories and codes; parameters to use in calculations
  - Will illustrate mostly with own experiments, data, results ...
- Review of experimental methods, equipment and specifics
- New facilities, including RIB facilities, and their nuclear astrophysics programs
- Related topics – new directions

Indirect methods in nuclear astrophysics



The incomplete "list"

Dedicated methods:

A. Coulomb dissociation
B. Single-particle transfer reactions – ANC method
C. (Nuclear) breakup reactions
D. Trojan Horse Method
E. Spectroscopy of resonances:
   - transfer reactions
   - Gamma-ray spectroscopy
   - Beta-delayed proton emission
   - TTIK –

   Most involve RIBs (some not!)
F. New?! Contribution of excited states

Reactions in laser induced plasmas

Indirect methods - at international facilities

Experiments at energies x10, 100, 1000 higher → NA

- Nucleon-transfer w. stable or RIBs @ Texas A&M University
  - Obtain data at ~10 MeV/u, used to evaluate radiative proton capture cross sections/reaction rates: (p,γ)
  - Proton transfer (mostly) → determine ANC
  - Neutron transfer + charge symmetry → determine ANC
  - Ion-Ion optical potentials involved – double folding procedure determined
- Coulomb and nuclear breakup, w RIBs @GANIL, @RIKEN
  - ^{23}Al, ^{24}Si nuclear breakup
  - ^{9}C case at RIBF – exp NP1412-SAMURAI29R1
- Beta-delayed proton-decay at TAMU

B. Transfer reactions: the ANC method

Depend on OMP * n Factors !!!

Transfer reaction B+d→A+a peripheral (absorption)

- Transfer matrix element:

$$M = \left\langle \chi_f^{(-)} I_{Bp}^{A} \left| \Delta V \right| I_{ap}^{d} \chi_i^{(+)} \right\rangle$$

$$\frac{d\sigma}{d\Omega} = \sum \left[S\, S \left(\frac{d\sigma}{\quad} \right) \right]$$

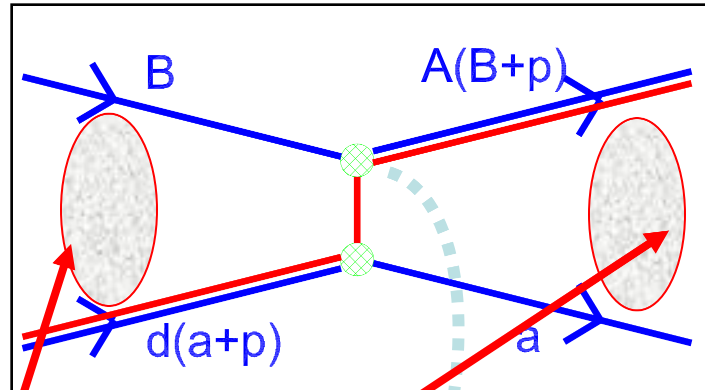
Depend on geom (r_0,a) of proton-binding potential < 20-40%

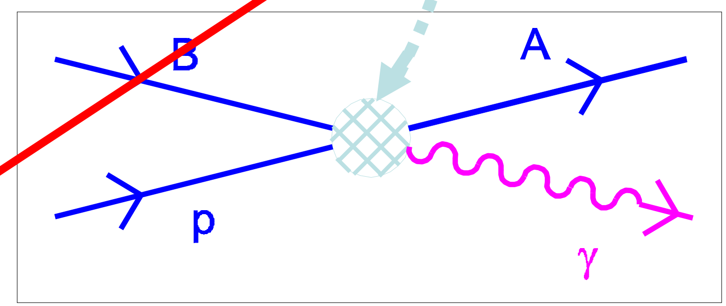
$$\frac{d\sigma}{d\Omega} = \sum (C^{A}_{Bpl_A j_A})^2 (C^{d}_{apl_d j_d})^2 \frac{\sigma_{l_A j_A l_d j_d}}{b^2_{Bpl_A j_A}\, b^2_{apl_d j_d}}$$

ANC - independent on binding potential geometry!

OMP knowledge crucial for reliable absolute values!

Semi-micr proc. JLM interaction (LT ea, PRC, 2000)

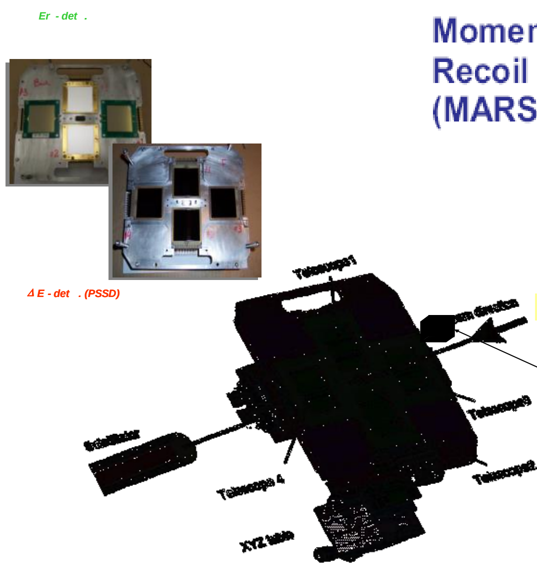


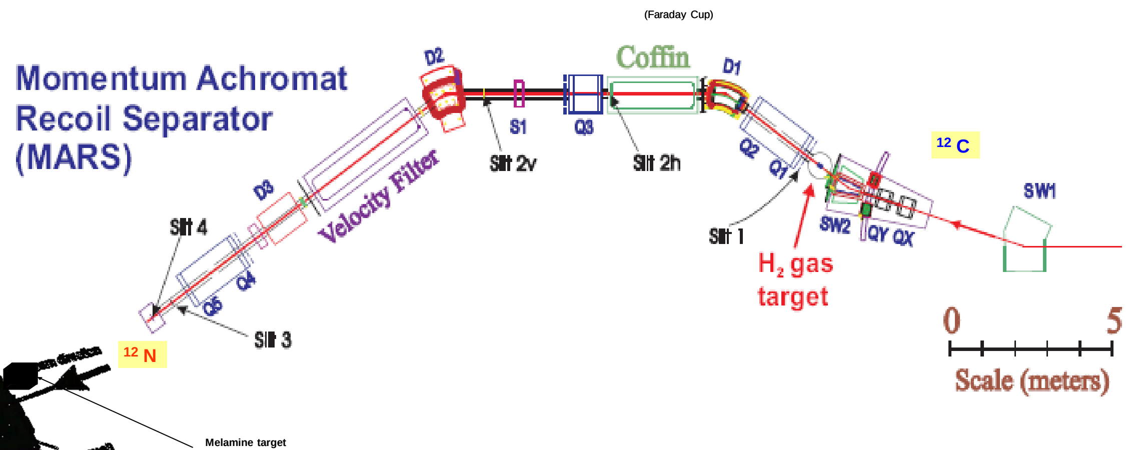


$$\sigma_{(p,\gamma)} \propto (C^{A}_{Bp})^2$$

$$I^{A}_{Bp} \overset{r_{Bp} > R_N}{\approx} C^{A}_{Bp} \frac{W_{-\eta_A, l+\frac{1}{2}}(2\kappa_{Bp} r_{Bp})}{r_{Bp}}$$

Cross sections for (p,γ) from p-transfer reactions with RNB from MARS

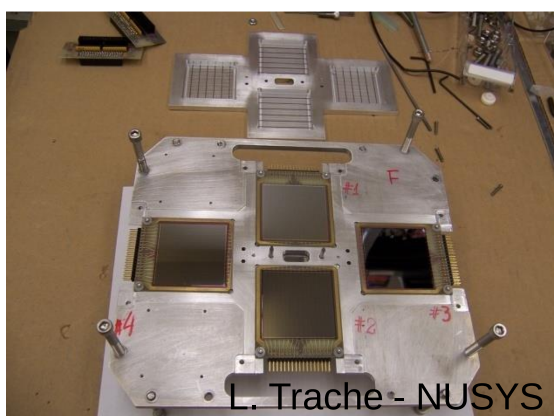


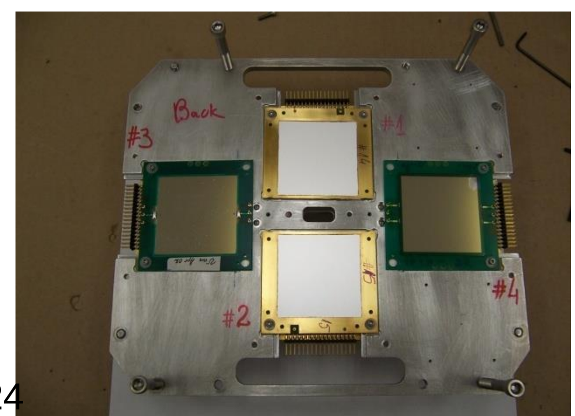


^{12}N @12 MeV/u
99% pure, 4 mm dia
Melamine target

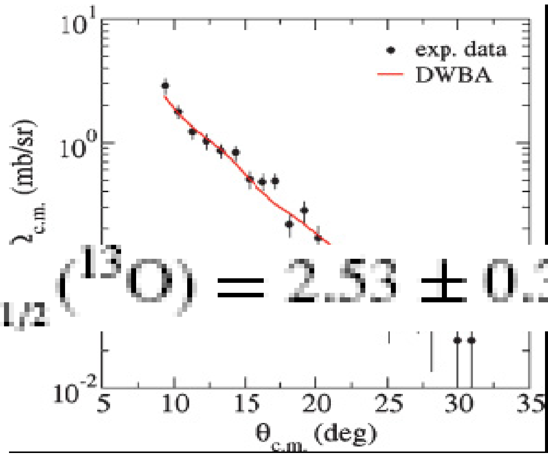
^{12}C @23 MeV/u
H_2 cryotarget

Four telescope system ("the cross"):
ΔE – PSD 65, 110 μm
E – 500 μm



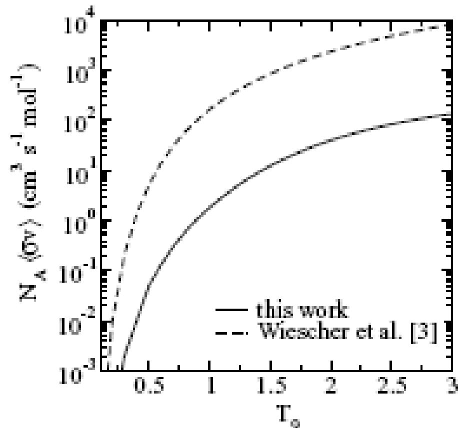


$^{14}N(^{12}N,^{13}O)$ proton-transfer react $\Rightarrow$ $^{12}N(p,\gamma)^{13}O$ (rap I,II proc)

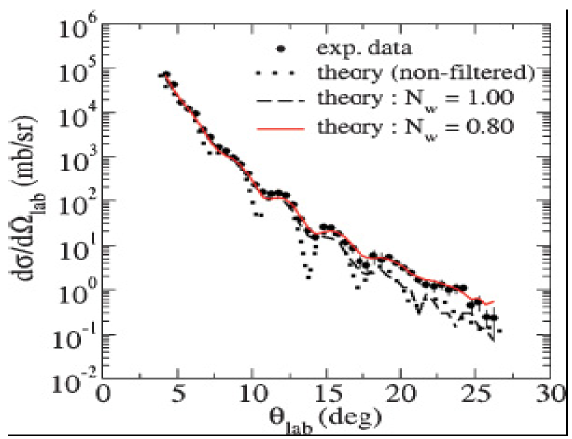


$$C^2_{p_{1/2}}(^{13}O) = 2.53 \pm 0.30\ \text{fm}^{-1}$$

ANC, S-factor 0-2 MeV
Reaction rate



Transfer & elastic @12 MeV/u
TAMU MARS ^{12}N beam $2{\cdot}10^5$ pps



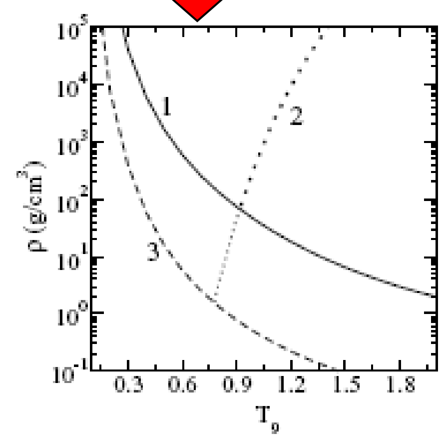


FIG. 10. Temperature and density conditions at which the $^{12}N(p,\gamma)^{13}O$ reaction may play a role. Curve 1 represents the equilibrium line between the rates for ^{12}N proton capture and $^{12}N\ \beta$ decay. Curve 3 illustrates the same result as determined from Ref. [3]. Curve 2 shows the line of equal strength between the rate of the ^{12}N radiative proton capture to ^{13}O and the rate for the inverse process, ^{13}O photodisintegration. See text for details.

A. Banu et al, Phys Rev C 79, 025805 (2009)

Works for RNBs

Optical Model Potentials for Nucleus-Nucleus collisions for RNBs

Essential to make credible DWBA calc needed in transfer studies

Have established semi-microscopic double folding using JLM effective interaction:

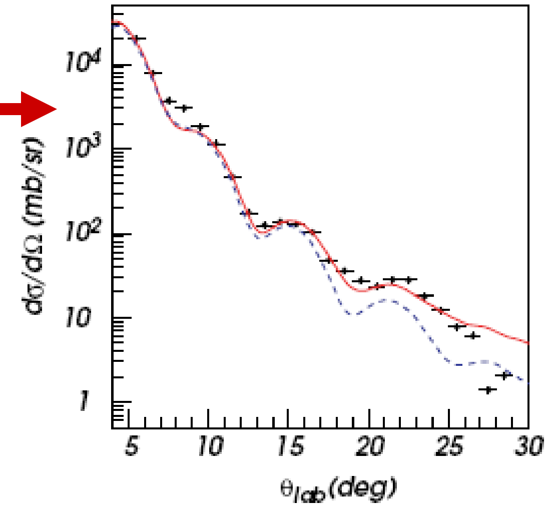
- Established from exps with stable loosely bound p-shell nuclei: ^{6,7}Li, ^{10}B, ^{13}C, ^{14}N … @ 10 MeV/u
- Independent real and imaginary parts, energy and density depend.
- Parameters: renormalization coeff. (Nv~0.4-0.5, Nw=1.0)
- Predicts well elastic scatt for RNBs: ^{7}Be, ^{8}B, ^{11}C, ^{12}N, ^{13}N, ^{17}F, ^{14}C, …
- Good results for transfer reactions (tested where possible)

L. Trache ea, PRC 61 (2000), F Carstoiu ea PRC 70 (2004)

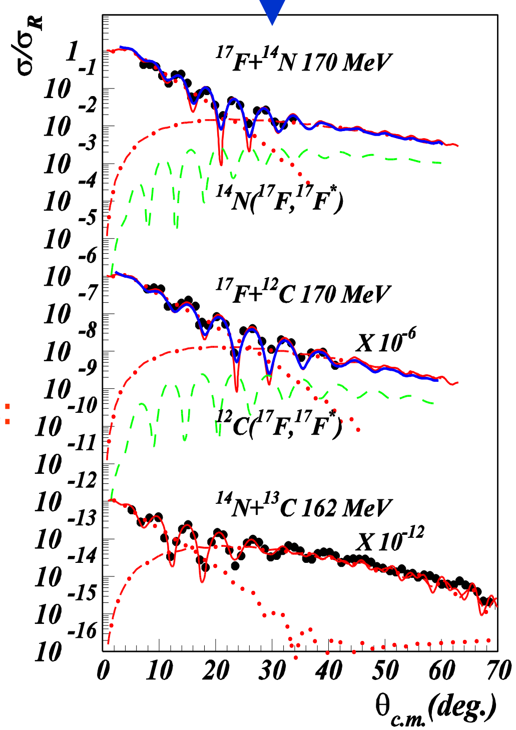
TAMU exps @ 12 MeV/u

G. Tabacaru ea, PRC 73, 025808 (2006)

^{7}Be on melamine

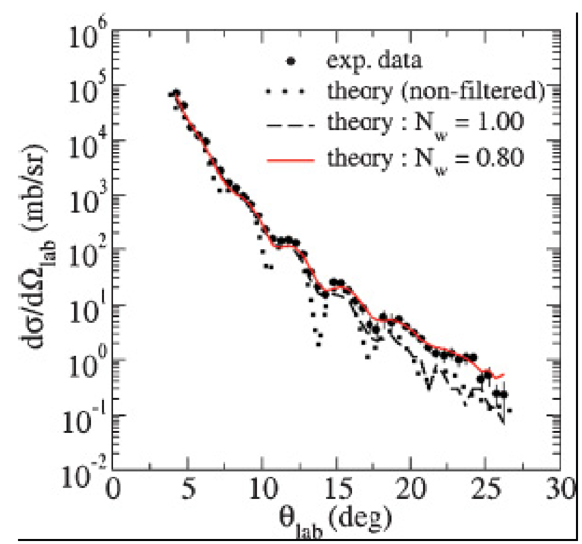


ORNL exps @ 10 MeV/u



J. Blackmon ea, PRC 73, 034606 (2005)

^{12}N on melamine

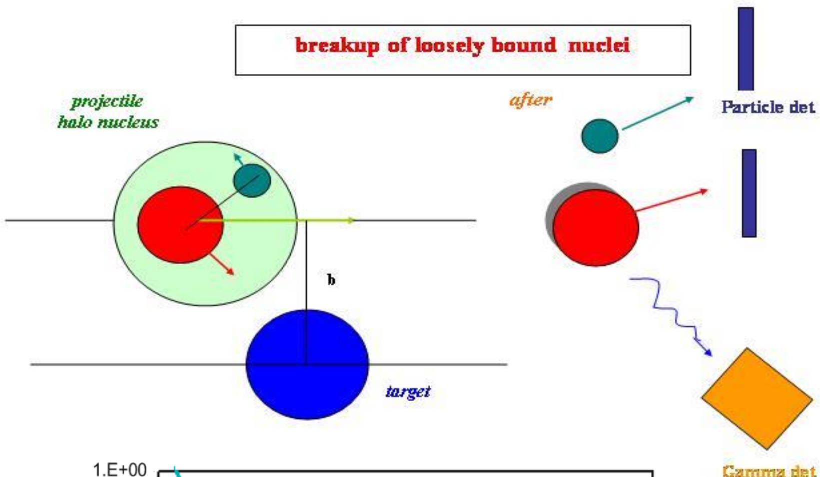


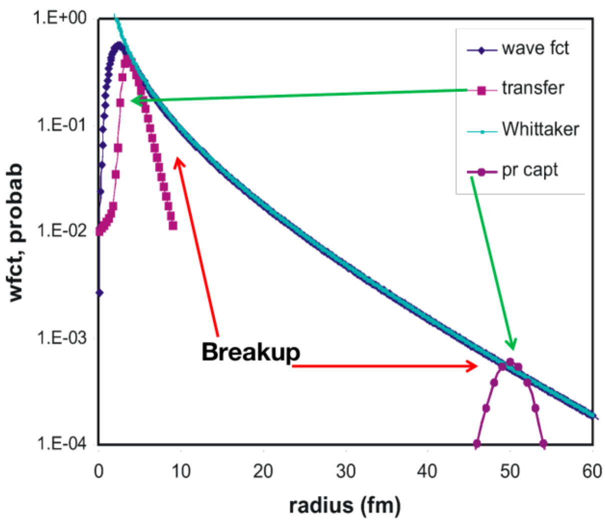
A. Banu ea, PRC 79, 2009.

Theory framework & methods for NA

B.2 Nuclear breakup

Breakup





L. Trache , Rom. Journ. Phys. 52 (2007) 823

radiative capture B(p,γ)A

$$\sigma_{rc}(E_p) = C^{A\;2}_{nlj} \cdot w(E_p)$$

$$\sigma^{th}_{-1p} = \sum SF(c,nlj)\sigma^{th}_{sp}(nlj)$$
$$= \sum SF(c,nlj)[\sigma^{strip.}_{sp}(nlj) + \sigma^{diff.}_{sp}(nlj) + \sigma^{coul.}_{sp}(nlj)]$$

$$SF(c,nlj) = \frac{C^2_{nlj}}{b^2_{nlj}}$$
$$= \frac{\sigma_{exp}}{\sigma^{th}_{sp}}$$

- **^{9}C case: proton in *1p* shell**

$$\sigma_{-1p} = \left[SF(1p_{3/2}) + SF(1p_{1/2})\right] \sigma_{sp}(1p_j)$$
$$= \frac{C^2_{p_{3/2}} + C^2_{p_{1/2}}}{b^2_p} \sigma_{sp}(1p_j)$$
$$\rightarrow \sigma_{^8B(p,\gamma)^9C} = (C^2_{p_{3/2}} + C^2_{p_{1/2}}) \cdot w(E_p)$$
$$= C^2_p \cdot w(E_p)$$

It works: Summary of the ANC extracted from ^{8}B breakup for $^{7}Be(p,\gamma)^{8}B$ with different interactions (2004)

Data from:

F. Negoita et al, Phys Rev C 54, 1787 (1996)

B. Blank et al, Nucl Phys A624, 242 (1997)

D. Cortina-Gil e a, EuroPhys J. 10A, 49 **(**2001).

R. E. Warner et al. – BAPS 47, 59 (2002).

J. Enders e.a., Phys Rev C 67, 064302 (2003)

All available breakup cross sections on targets from C to Pb and energies 27-1000 MeV/u give consistent ANC values!

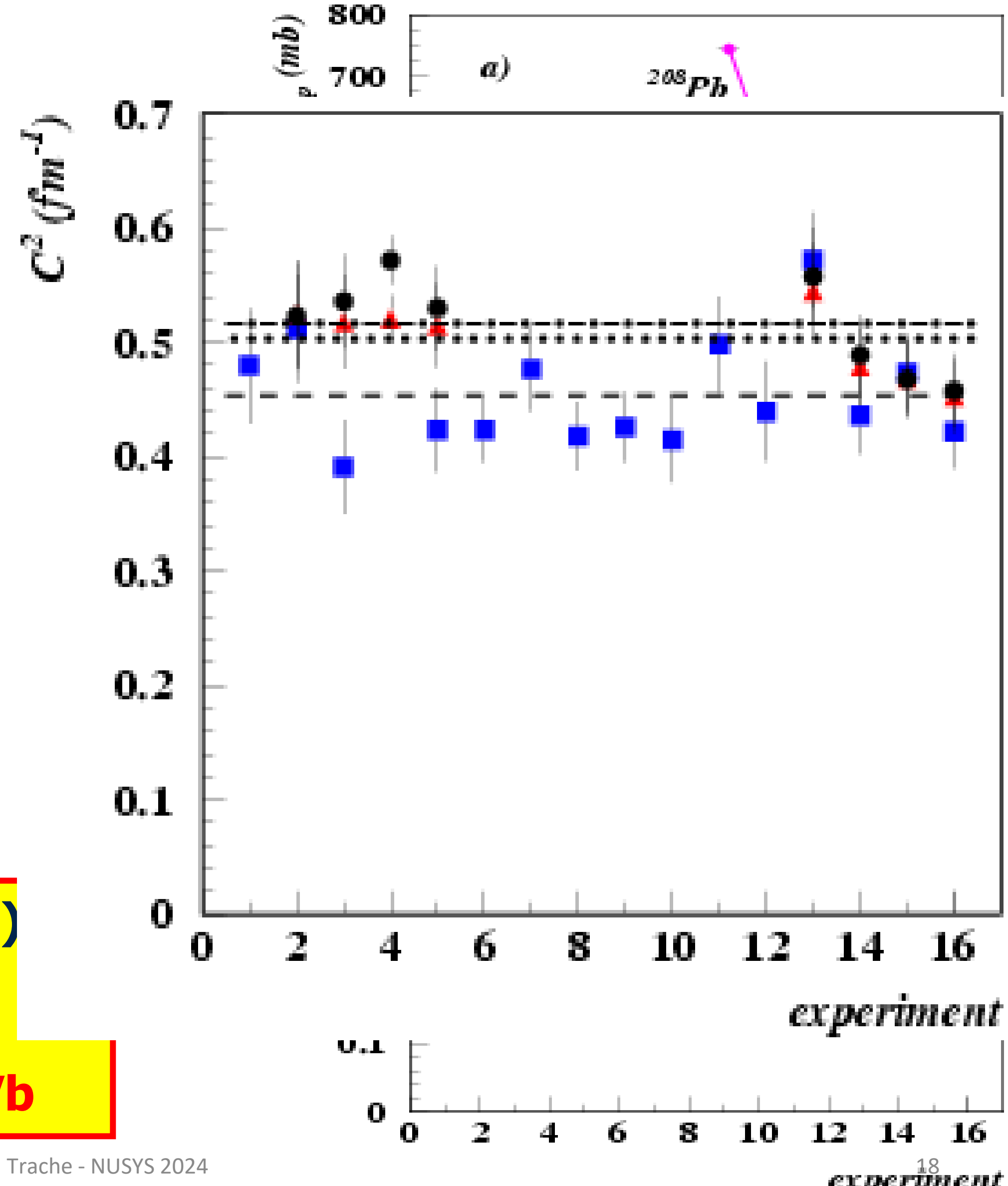
Summary of results:

LT ea, PRL 87, 2001

LT ea, PRC 67, 2004

3 different effective nucleon-nucleon interactions slightly different values & accuracy to about 10% :

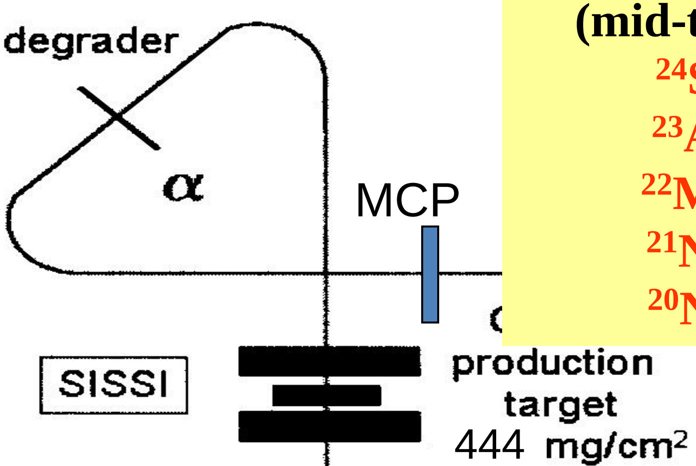
$^{7}Be(p,\gamma)^{8}B$ (solar neutrinos probl.)
p-transfer: $S_{17}(0)$=18.2±1.7 eVb
Breakup: $S_{17}(0)$=18.7±1.9 eVb
Direct meas: $S_{17}(0)$=20.8±1.4 eVb



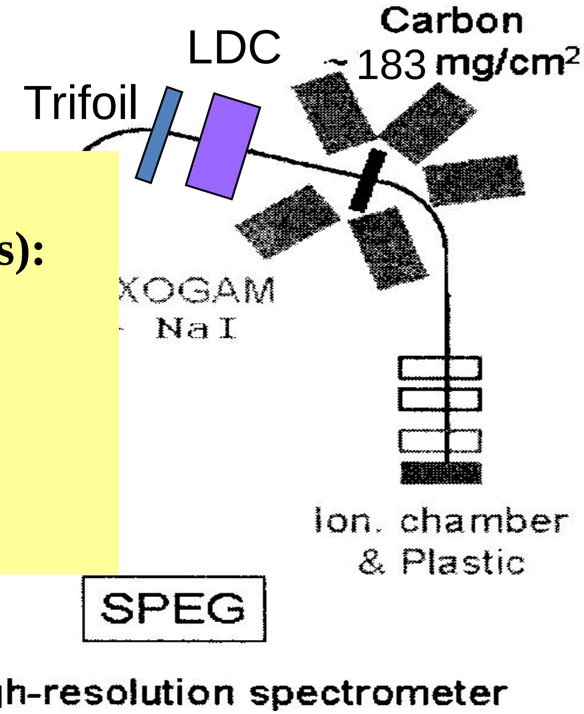
E491 exp. @ GANIL

Gamma-ray detectors:
8 EXOGAM clovers 4% effic.
12 NaI crystals 6% effic.

Experimental details



Cocktail beam
(mid-target energies):
^{24}Si 53 MeV/u
^{23}Al 50 MeV/u
^{22}Mg 47 MeV/u
^{21}Na 43 MeV/u
^{20}Ne 39 MeV/u



^{32}S primary beam
95 MeV/u, ~ 400 W

- large angular acceptances: 4° (horiz. & vertic. planes)
- broad momentum acceptance: $\Delta p/p = 7\%$

A. Banu et al., NIC10 2008 & PRC 84, 015803 (2011)

Complementarities: Coulomb and nuclear dissociation

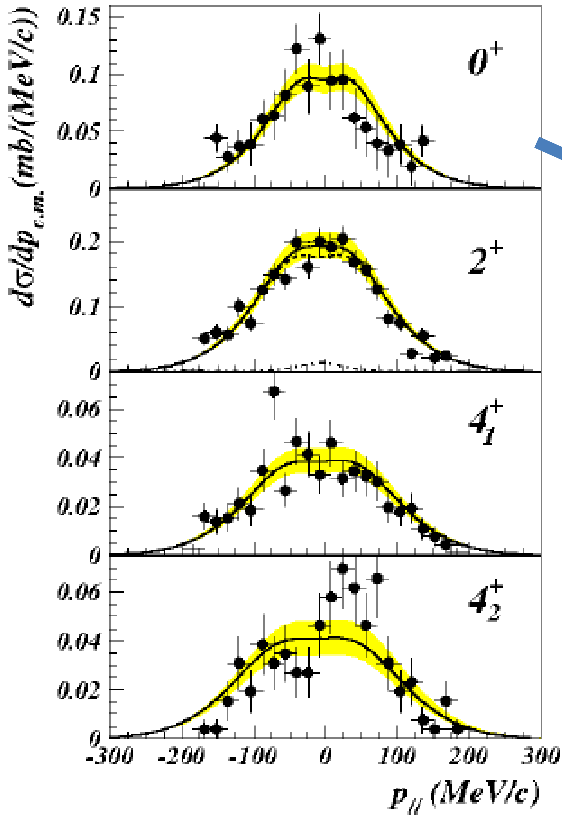
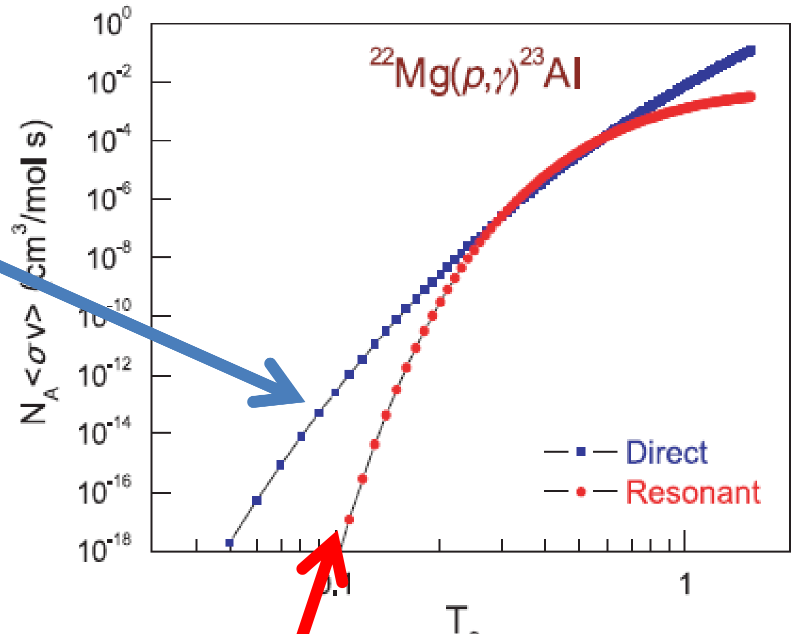


FIG. 3. (Color online) Experimental exclusive momentum distributions determined in the center-of-mass frame for ^{22}Mg



$\Gamma_\gamma = 7.2 \pm 1.4 \times 10^{-7}$ eV, which was obtained from the Coulomb dissociation of ^{23}Al at 50 MeV/u [46], is adopted here to evaluate the resonant reaction rate, which is given by

$$N_A\langle\sigma\upsilon\rangle = 0.12 T_9^{-3/2} \exp\left(-\frac{4.47}{T_9}\right). \qquad (9)$$

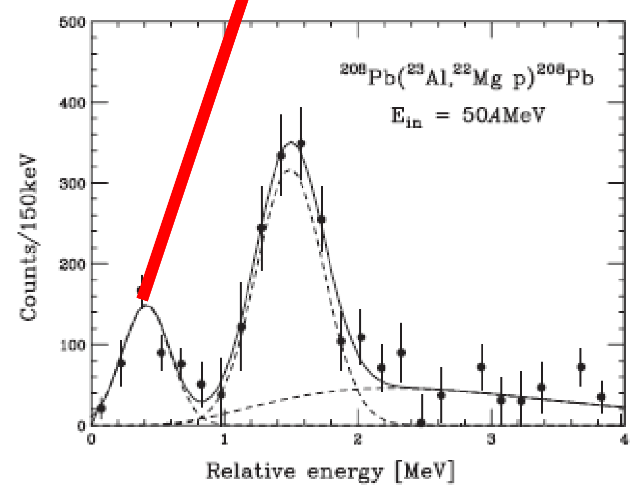


Figure 2. Relative energy spectrum between ^{22}Mg and proton obtained for the ^{23}Al + ^{208}Pb reaction. The solid curve represents the result of a fit with two Gaussian functions and a distribution assuming a non-resonant component. The dashed curves show each component.

[46] T. Gomi, T. Motobayashi et al, JPG 31 (2005)

warnings

Careful!

Measuring “inverse reactions” does not mean we determine cross sections for NA.

- We must determine the transitions at state level, therefore, the matrix elements for the pair direct-inverse transitions and use them appropriately to evaluate the quantities needed.
- Example before was a good one: ^{23}Al g.s. has configuration mixing, each contributing to breakup; p-capture occurs on the Mg(0^+) component only
- Similarly in the next example, where we talk about Coulomb Dissociation vs radiative capture

A. Coulomb dissociation

- Radiative capture - direct process
  - X(p,γ)Y
- Photodissociation - inverse process
  - Y(γ,p)X
    - **Use detailed balance theorem**
- virtual photons – Coulomb Dissociation

$$\frac{d^2\sigma}{dE_\gamma d\Omega}(E_\gamma,\theta) = \frac{1}{E_\gamma}\left[\frac{dN(E1,E_\gamma)}{d\Omega}\sigma_{E1}^{photo}(E_\gamma) + \frac{dN(E2,E_\gamma)}{d\Omega}\sigma_{E2}^{photo}(E_\gamma) + \ldots\right]$$

$^{9}C \rightarrow {}^{8}B+p$ breakup for $^{8}B(p,\gamma)^{9}C$

The reaction is important in the hot pp chains, in explosive H burning, at large temperatures, for creating alternative paths across the A=8 mass gap
(see e.g. M. Wiescher et al., Ap. J. 343 (1989)352.)

pp IV $^{8}B(p,\gamma)^{9}C(\beta^{+}\nu)^{9}B(p)^{8}Be(\alpha)^{4}He$ and
rap I $^{8}B(p,\gamma)^{9}C(\alpha,p)^{12}N(p,\gamma)^{13}O(\beta^{+}\nu)^{13}N(p,\gamma)^{14}O$.

Use breakup of $^{9}C \rightarrow {}^{8}B+p$ at intermediate energies to obtain $^{8}B(p,\gamma)^{9}C$ at astrophysical energies.

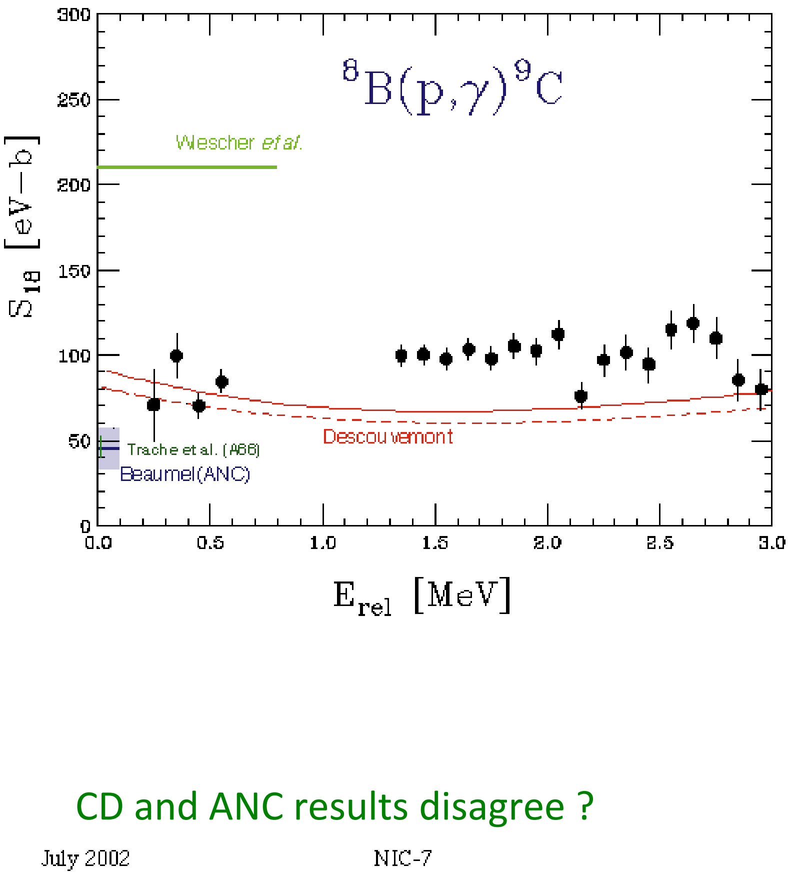
Eexisting data from:

B. Blank et al., Nucl Phys A624 (1997) 242
^{9}C @285 MeV/u on C, Al, Sn and Pb targets
Trache et al. ANC from breakup, 2002

Beaumel (ANC from (d,n) reaction)

Hisanaga, Motobayashi et al. (Coulomb dissociation)

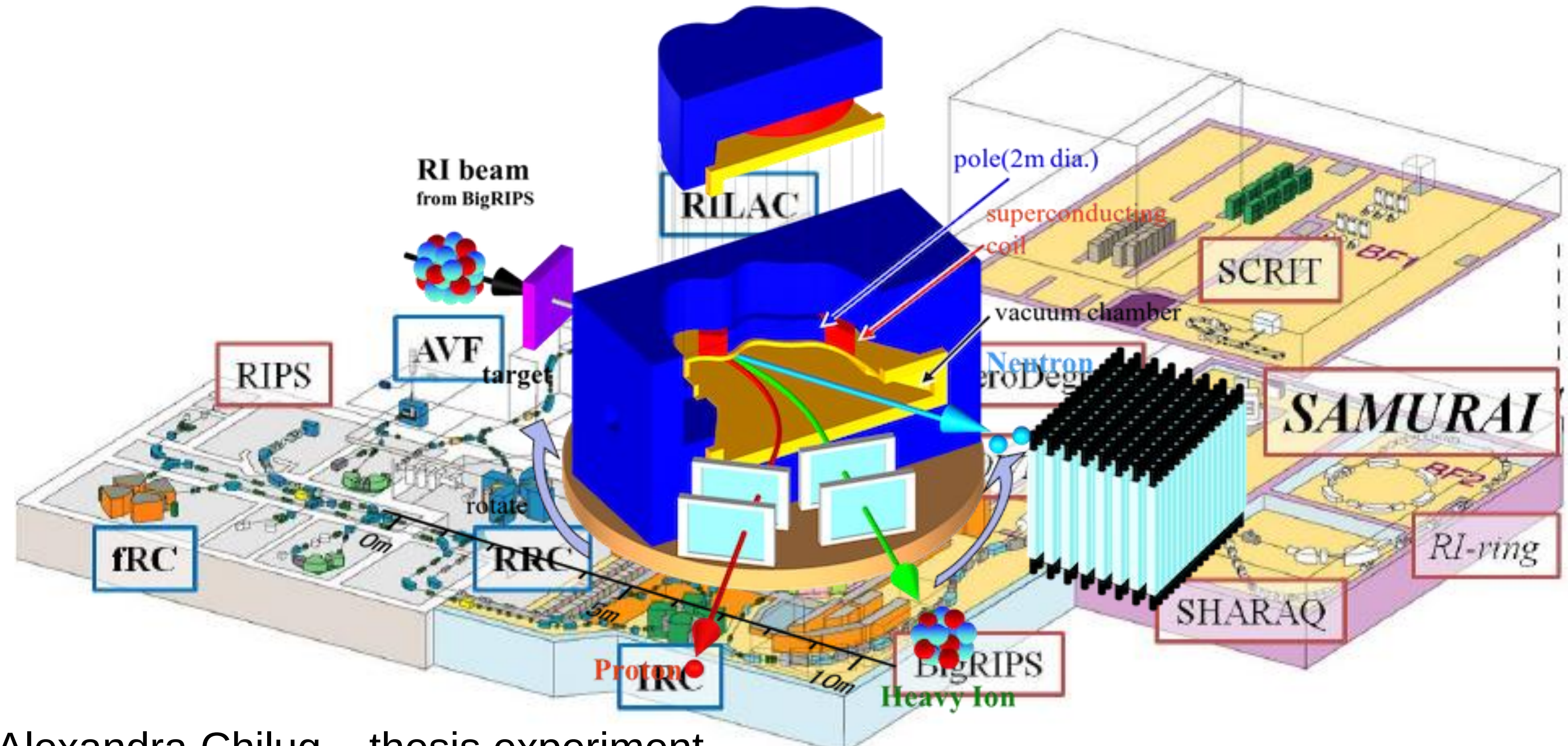
Astrophysical S-factor



CD and ANC results disagree ?

Exp. NP1412SAMURAI29

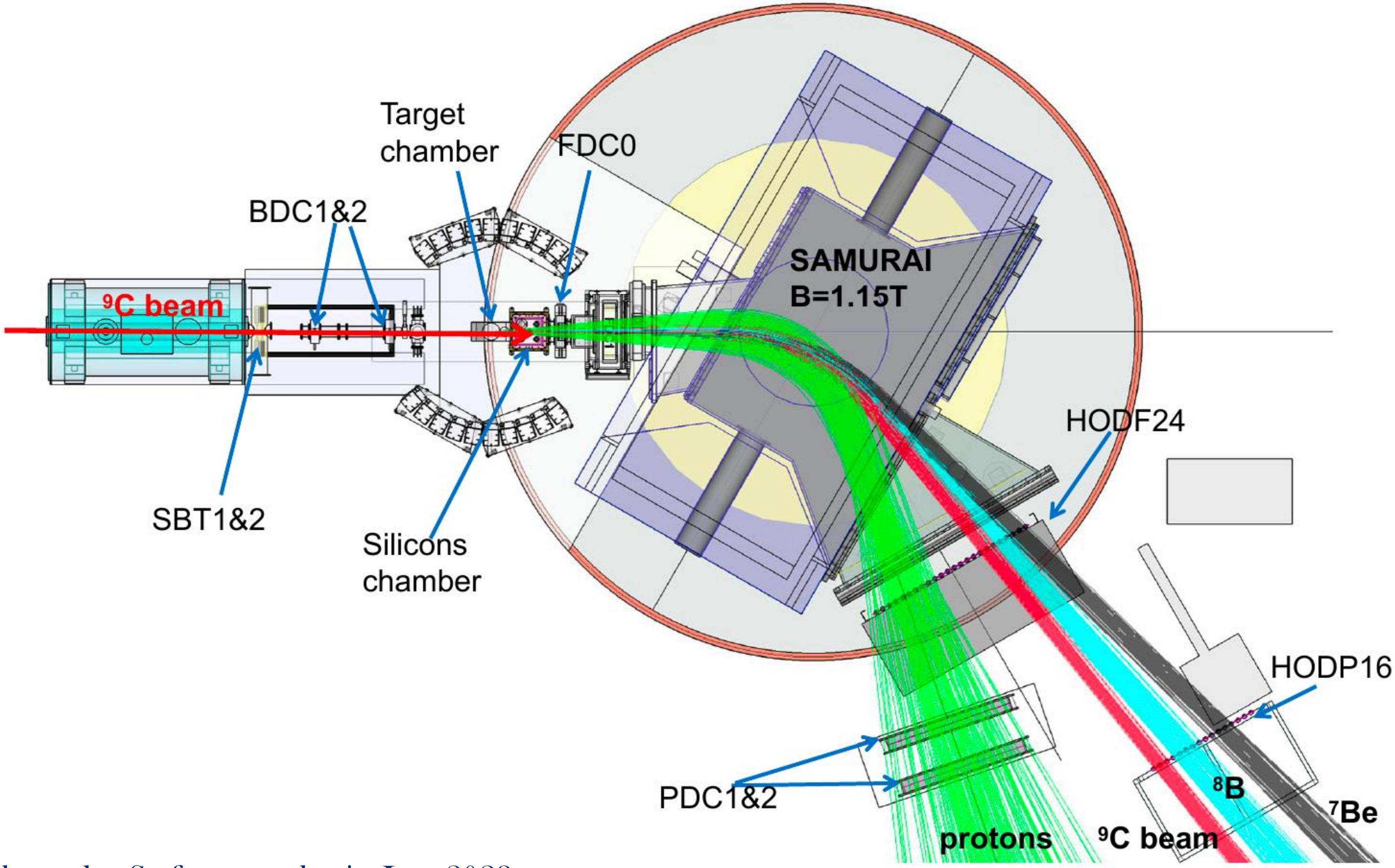
- Primary beam ^{18}O @ 260 MeV/u
- Secundary beam ^{9}C (160 MeV/u) ➔ target ➔ Si detector system ➔ SAMURAI ➔ detectors for p and HI



Alexandra Chilug – thesis experiment

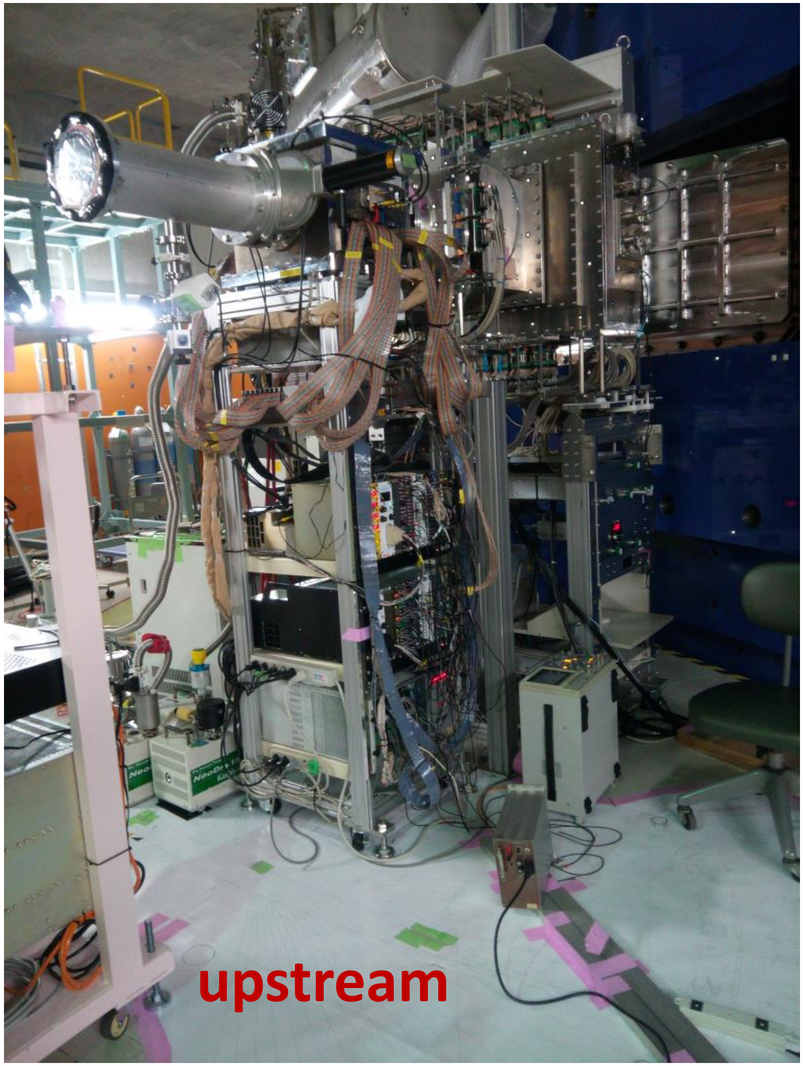
SAMURAI29 experiment

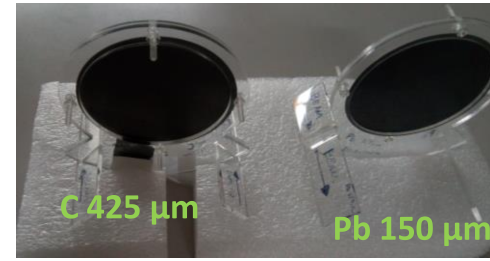
Detection systems at F13 focal plane:



Alexandra Stefanescu, thesis, Jan. 2023

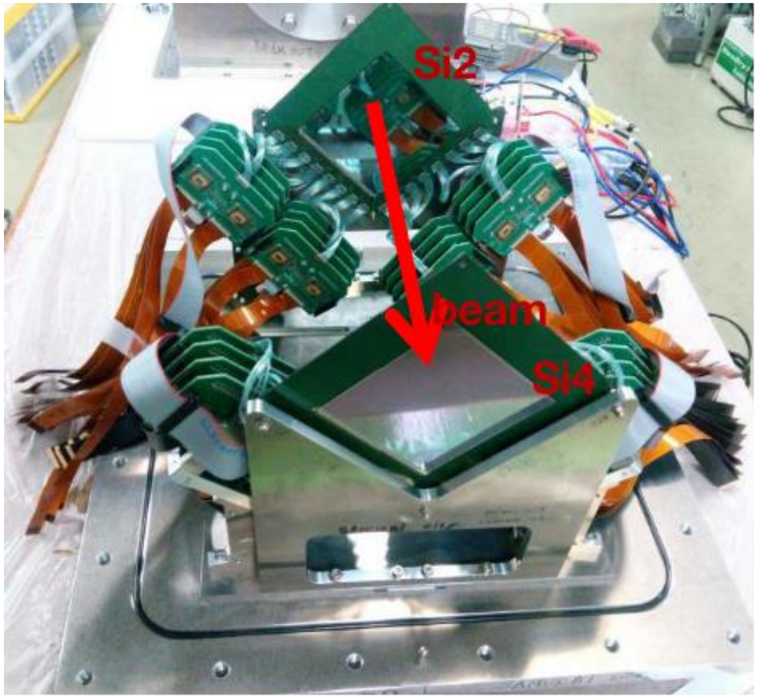
Experimental setup S29



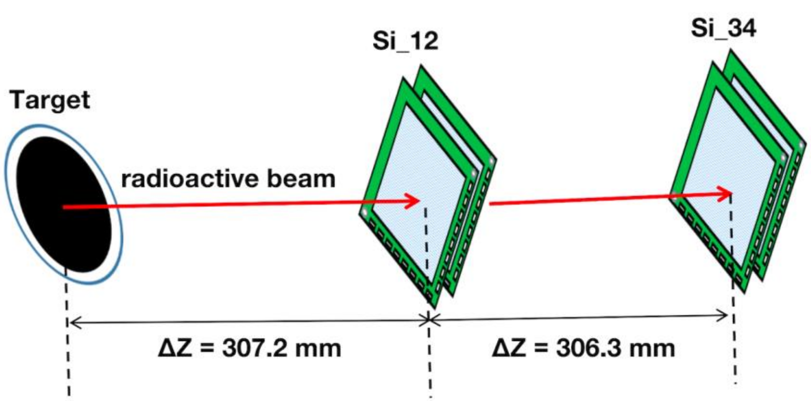


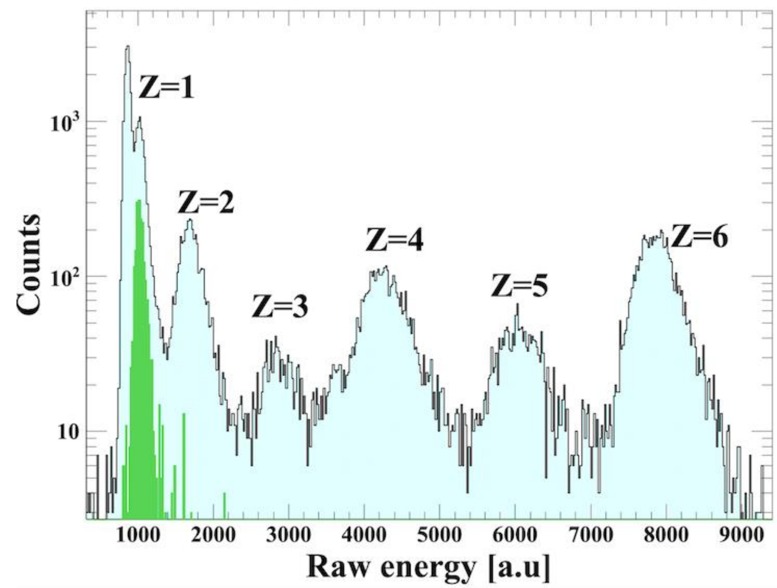
SAMURAI29 experiment

Detection systems at F13 focal plane: Silicon GLAST detectors



- System made up of 4 x position sensitive Si GLAST detectors
- placed between target and SAMURAI
- used for reaction products tracking (simultaneously)
- Active area: 87.552x87.552 mm^2
- Number of strips: 128 / detector (4x128=512 strips)
- Substrate thickness: 325 µm
- Strip pitch: 684 µm
- 2 x MotherBoard with 16 slots/MB: 2x32x16=1024 ch
- High dynamic range: 100 KeV (protons) and ~8-900 MeV (fragments), possible due to the dual gain preamplifiers

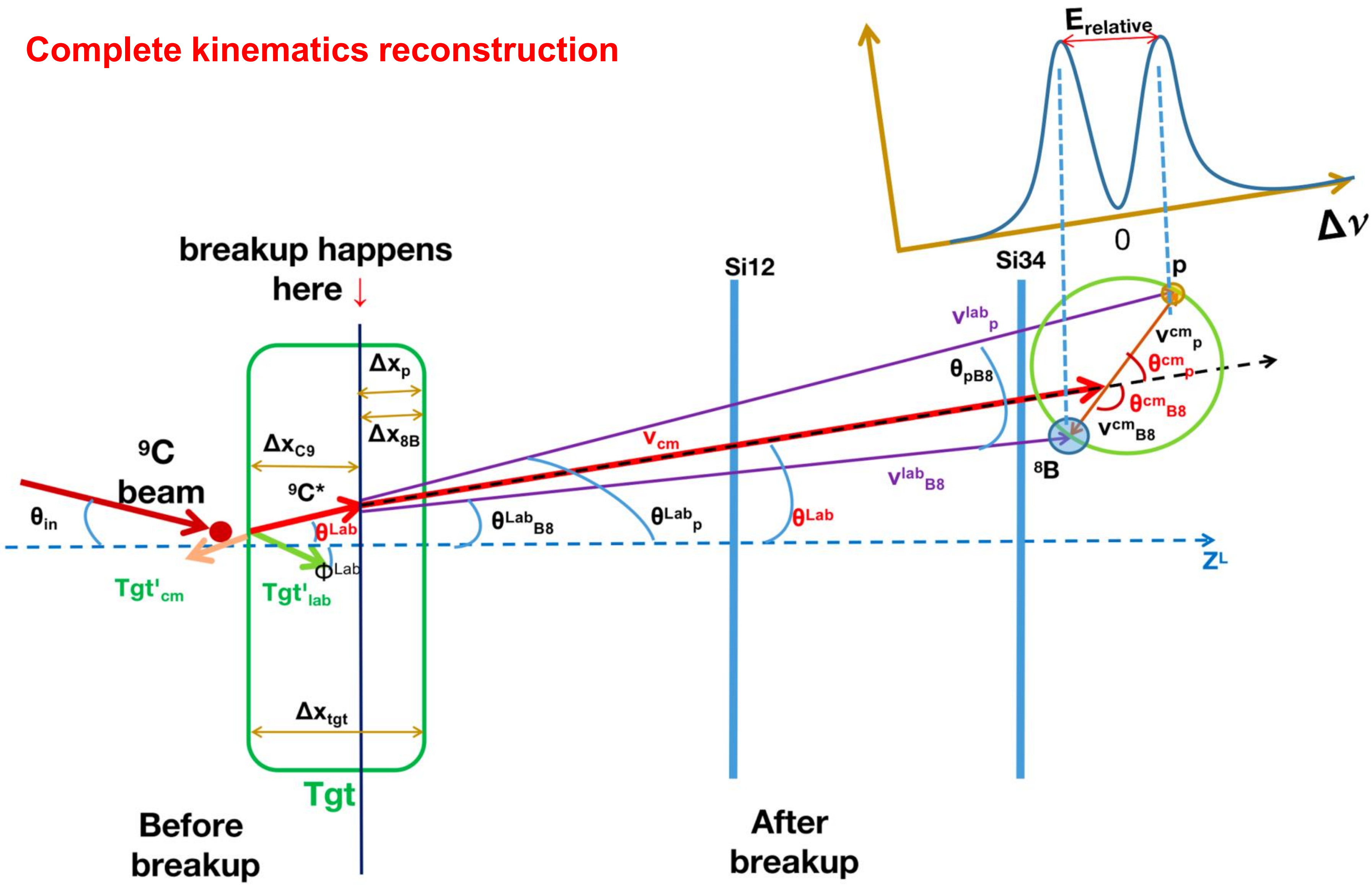




A.I. Stefanescu et al., Eur. Phys. J. A 58 (2022)

SAMURAI29 experiment

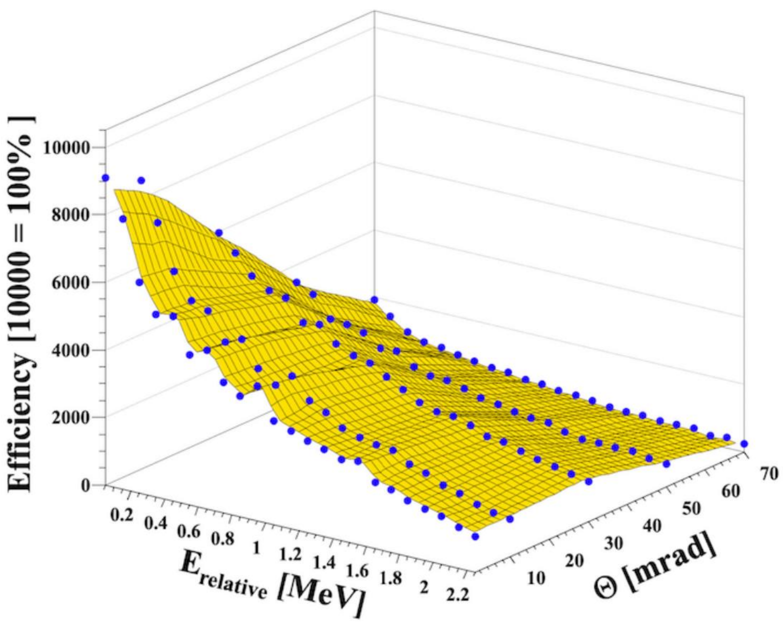
Complete kinematics reconstruction

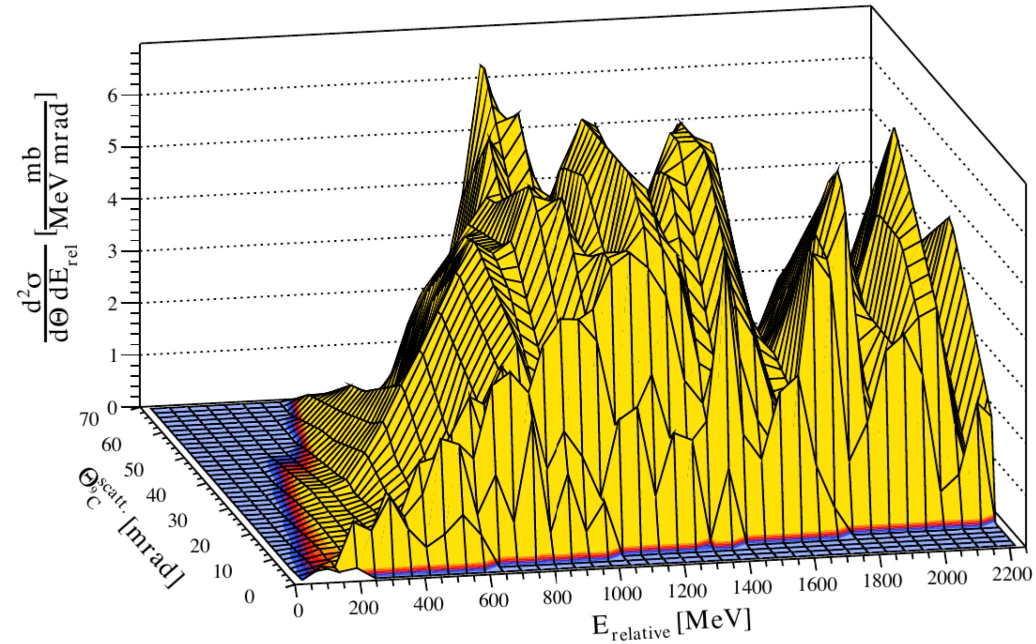


SAMURAI29 experimental results

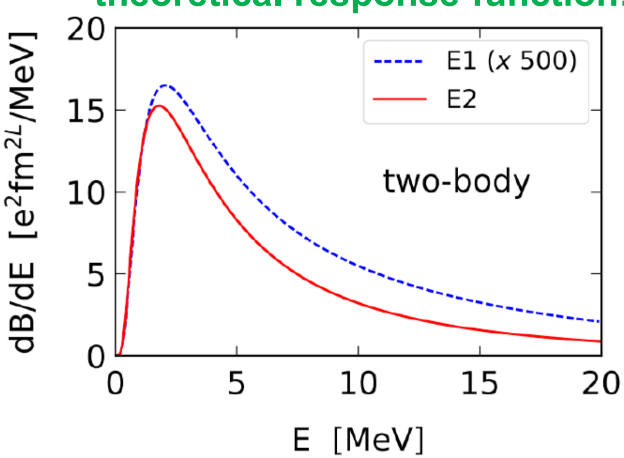
Coulomb breakup on Pb target

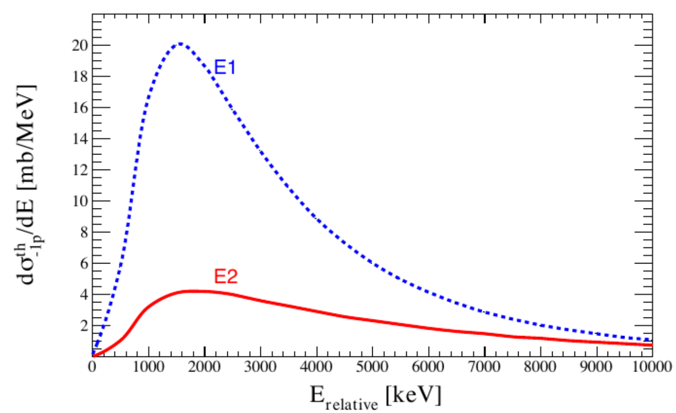
experimental response function (105 points):





theoretical response function:





Collaborators:

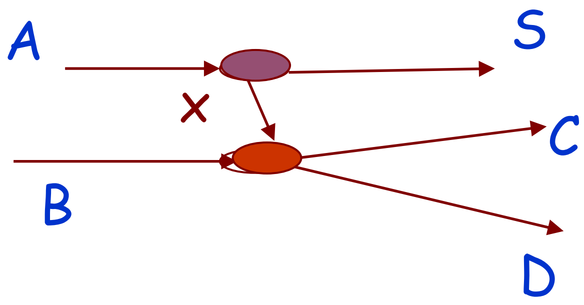
- **IFIN-HH**: L. Trache, **A. Stefanescu,** D.Tudor, I.C.Stefanescu, A.E.Spiridon, F. Carstoiu
- **RIKEN/CNS**: **V.Panin**, T. Motobayashi, K. Yoneda, T. Uesaka, H. Otsu, H. Baba, S. Ota, T. Kobayashi, Y. Togano, L. Stuhl, Y. Kubota, M. Sasano, J. Zenihiro, D. Ahn, Y. Shimizu, N. Iwasa, H. Sato …
- **TAMU**: **A. Saastamoinen**, C. Bertulani.
- **ATOMKI**: Z. Halasz, Z. Elekes, G. Kiss
- **WU**: L. Sobotka, J. Elson
- **INFN**: A. Bonaccorso
- **LPC Caen**: J. Gibelin

Acknowledgement: AS, ICS and DT were supported by RIKEN through IPA fellowships

Trojan Horse Method

Claudio Spitaleri, Aurora Tumino, Marco LaCognata et al., LNS and Univ di Catania

Reaction can be described by a Feynmam diagram



The A nucleus presents a strong cluster structure:
A = x ⊕ S clusters

Three body reactions

A + B → C + D + S

-The upper pole describes the *virtual break up* of the target nucleus A into the cluster x *(participant)* and S

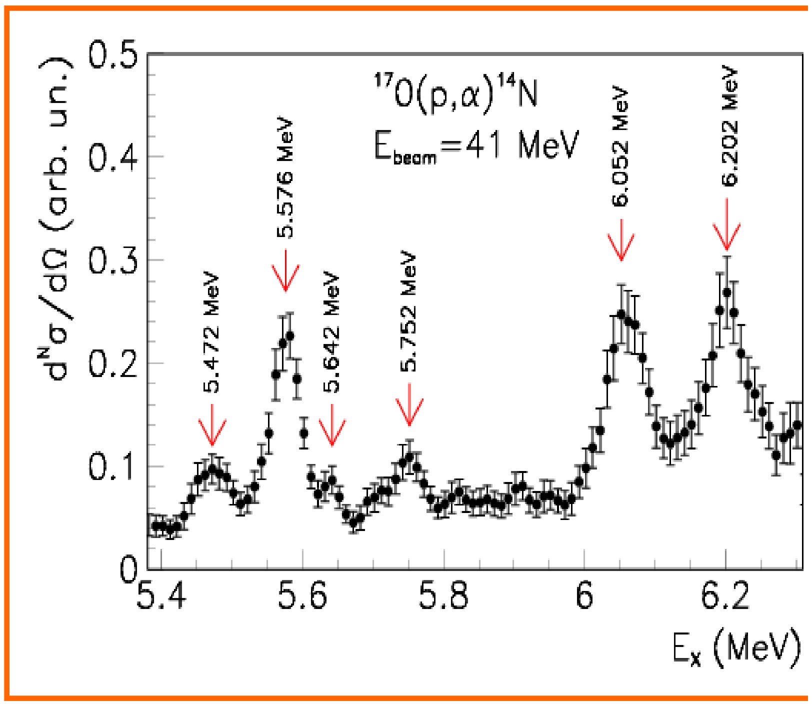
-The S cluster acts as a *spectator* to x+ B → C + D virtual reaction which takes place in the lower pole

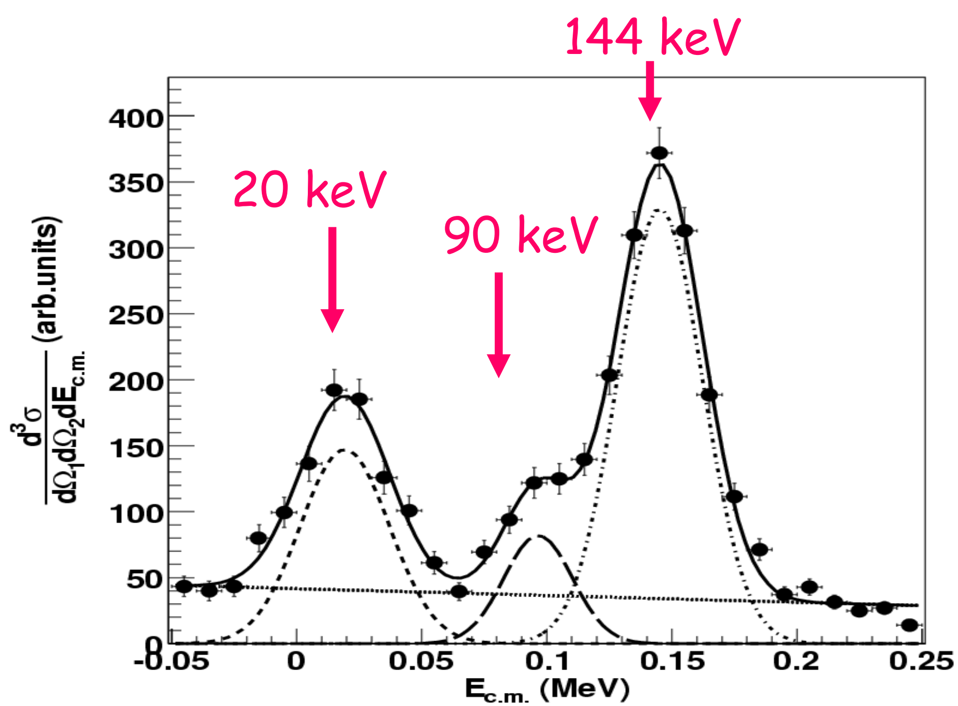
D

Trojan Horse Method

- The most direct from indirect methods!

$^{18}O + p \rightarrow \alpha_o + ^{15}N$





- THM for C+C

- Does it need further confirmation?
- Theory?!
- PWBA or DWBA?!
- THM with RIBs?!

Also expected, desired …

- Assessment of problems with the accuracy of indirect methods, importance of calculated absolute values
- The need for modern theories and codes; parameters to use in calculations
- Review of experimental methods, equipment and specifics
- New facilities, including RIB facilities, and their nuclear astrophysics programs

Spectroscopy of resonances

Locate and characterize resonances (by any means) => sufficient to evaluate the reaction rates

- Low energy resonances are the most important
- Energy of resonances are very important, and easier to determine
- "resonance strengths" … less so

Can do:

- Transfer reactions
- Trojan Horse Method measurements
- Gamma-ray spectroscopy
- Decay studies … like beta-delayed proton-decay βp

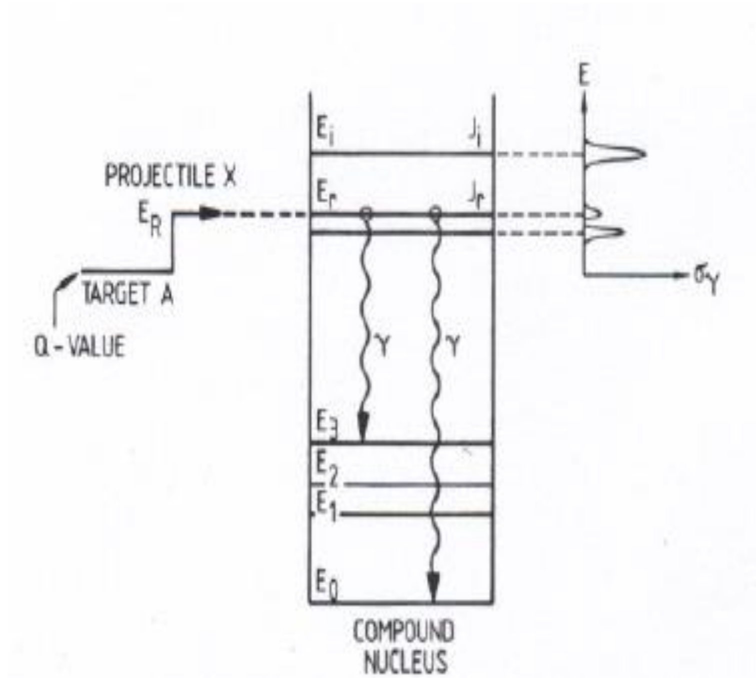
Resonant Reaction Rates

* **Resonant** reaction is a two-step process.

$$\sigma_\gamma \propto \left| \langle E_f | H_\gamma | E_r \rangle \right|^2 \left| \langle E_r | H_f | A + p \rangle \right|^2$$

* The cross section (Breit-Wigner):

$$\sigma(E) = \frac{\lambda}{4\pi} \frac{2J+1}{(2J_1+1)(2J_2+1)} \frac{\Gamma_p \Gamma_\gamma}{(E-E_r)^2 + \left(\frac{\Gamma}{2}\right)^2}$$



* C. Rolfs and W. Rodney, "Cauldrons in the Cosmos".

* The contribution to the reaction rate:

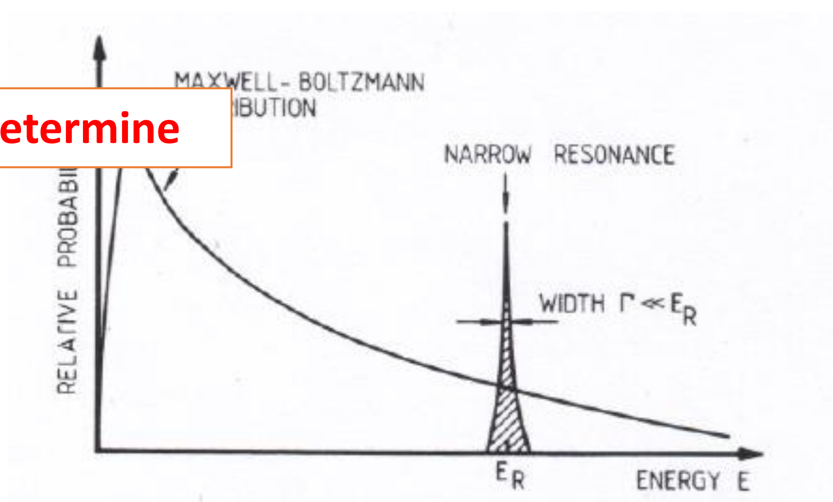
$$\langle \sigma v \rangle_{res} = \left(\frac{2\pi}{\mu k T} \right)^{3/2} \hbar^2 \omega\gamma \exp\left(-\frac{E_r}{kT} \right)$$

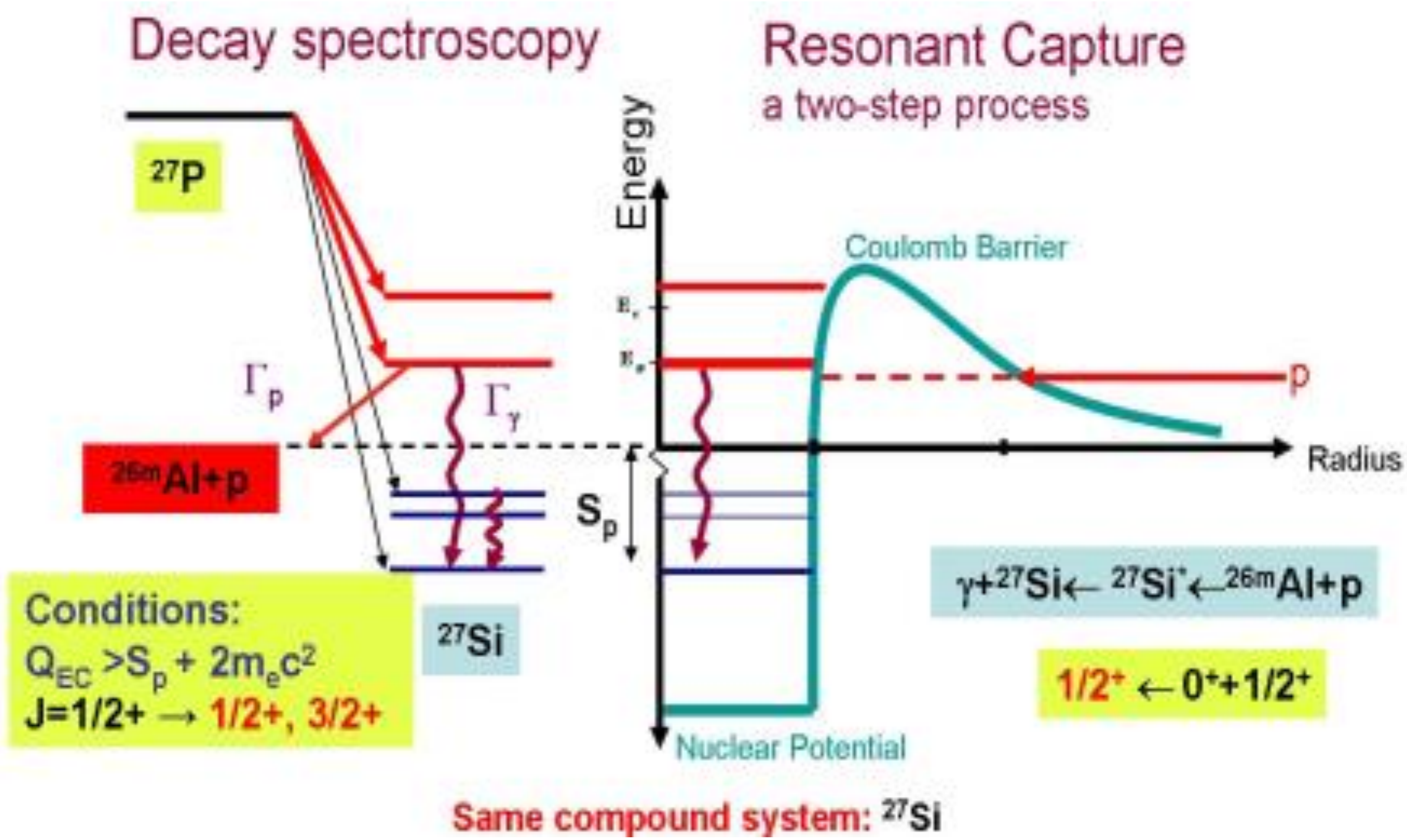
where

$$\omega\gamma = \frac{2J_r + 1}{(2J_p + 1)(2J_t + 1)} \frac{\Gamma_p \Gamma_\gamma}{\Gamma_{tot}}$$

to determine

ωγ= resonance strength





Resonant contributions to reaction rate:

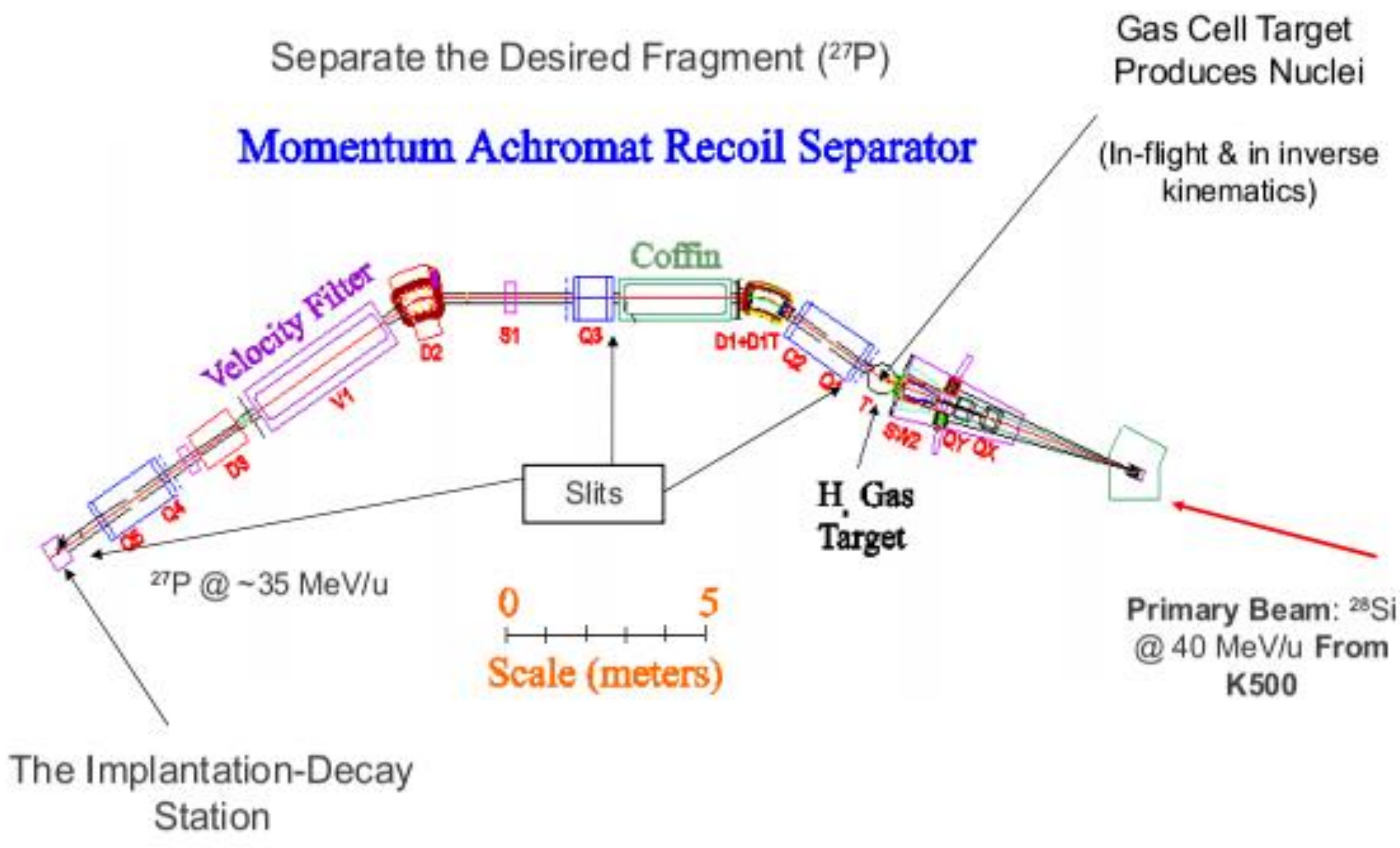
$\langle \sigma \upsilon \rangle_{re}$ … $\frac{\Gamma_p \Gamma_\gamma}{\Gamma_{tot}}$

Lower proton energies most important, but very difficult:

- lower branching
- increased exp difficulties (det windows, background, etc…)

Secondary beam ^{27}P

$^{28}Si^{10+}$ primary beam @40 MeV/u from K500 Cyclotron + LN2 H target
^{27}P in-flight inverse kinematics at Cyclotron Inst, Texas A&M Univerity



Comparison Si detector – gas detector: ^{23}Al βp

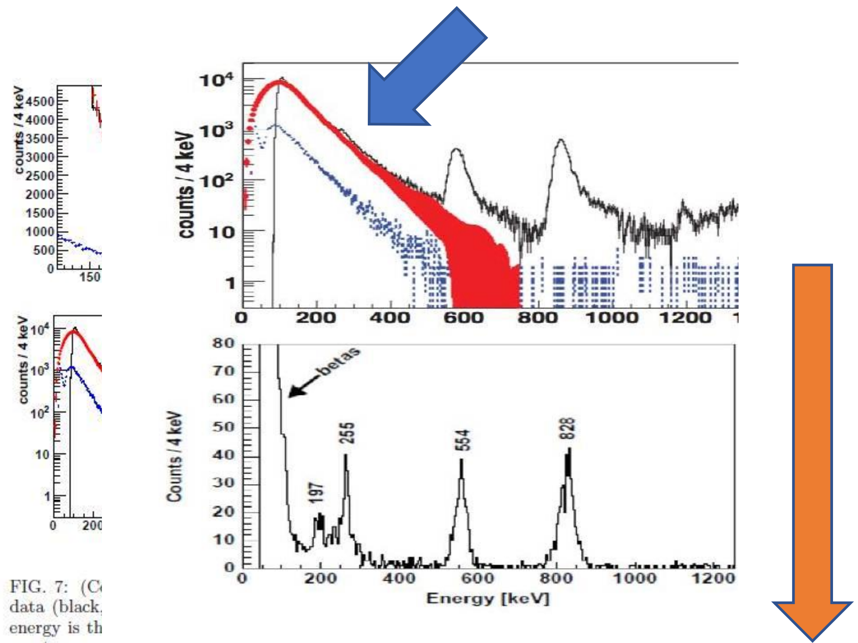
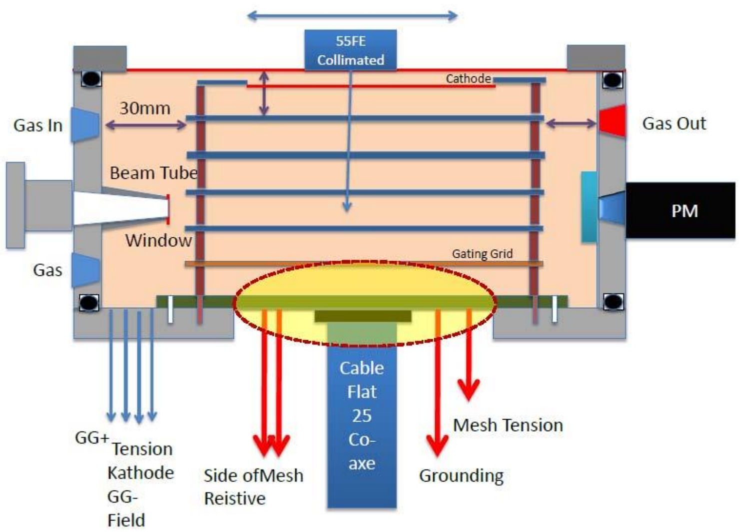
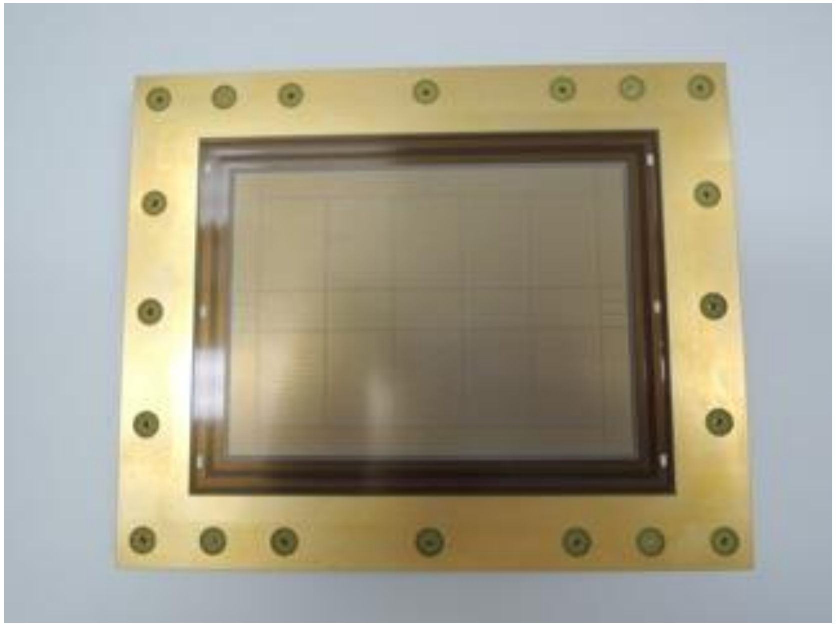


FIG. 7: (C
data (black,
energy is th
spectrum, s
shown with
panel shows only the low energy part where the proton group at ∼ 270 keV is clearly visible on top of the β background, whereas the lower panel shows the total spectra.

A. Saastamoinen, LT et al, PRC 83 (2011)
E. Pollacco, LT et al., NIM 2014

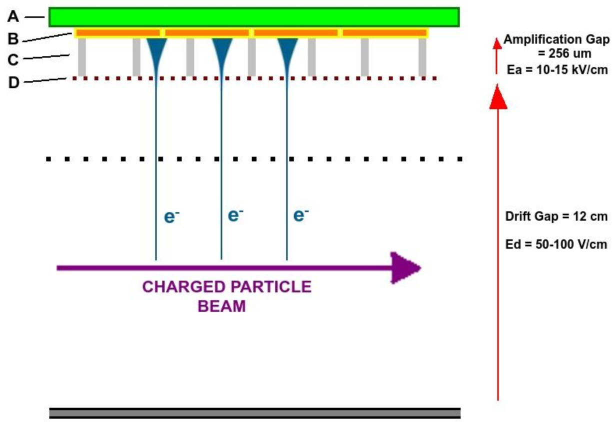
AstroBox2 - the micromegas detector

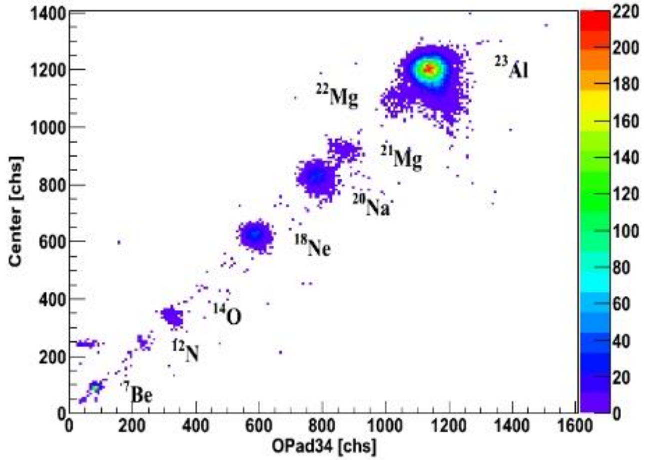




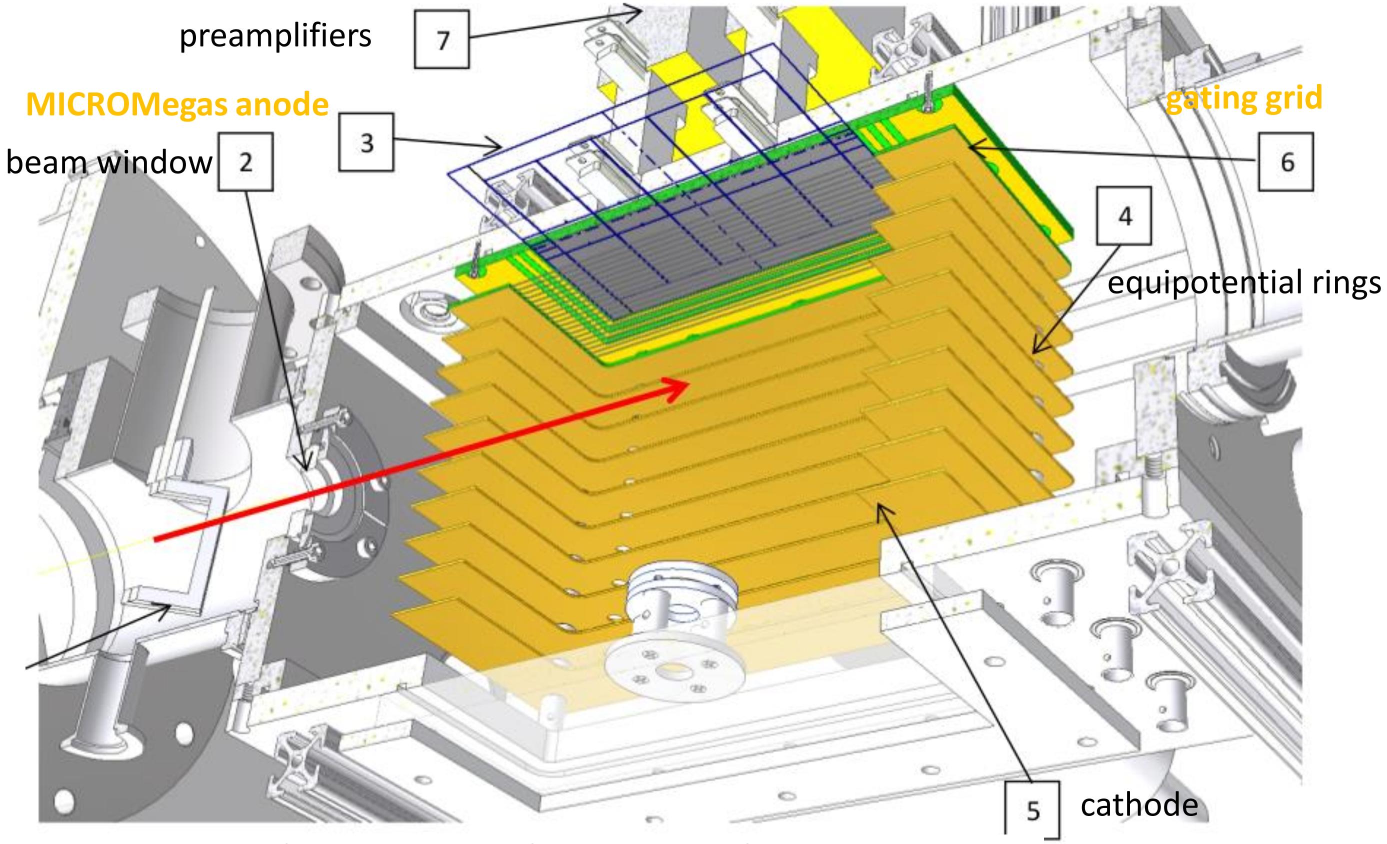
Chamber: design and prod: TAMU
Micromegas: Bucharest, Saclay, CERN
Electronics: Bucharest
Gas (P10) handling: existing at TAMU
Assembly and source tests: Saclay + TAMU

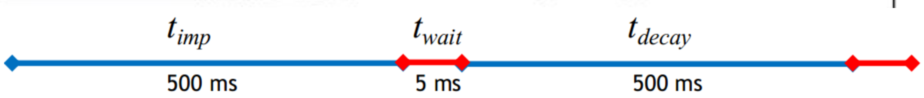
Detectors with micromegas



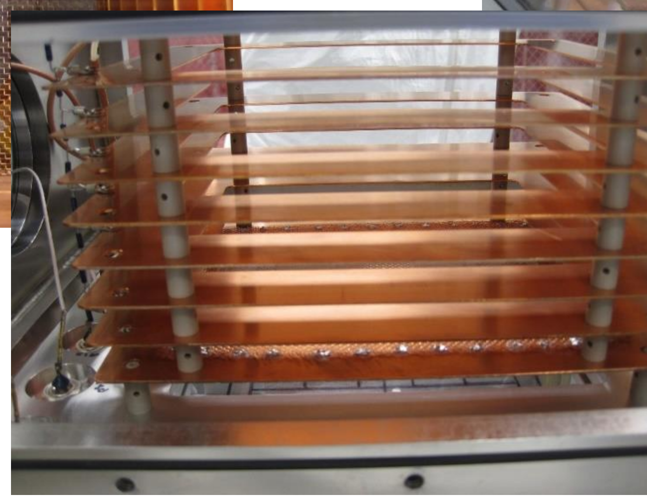


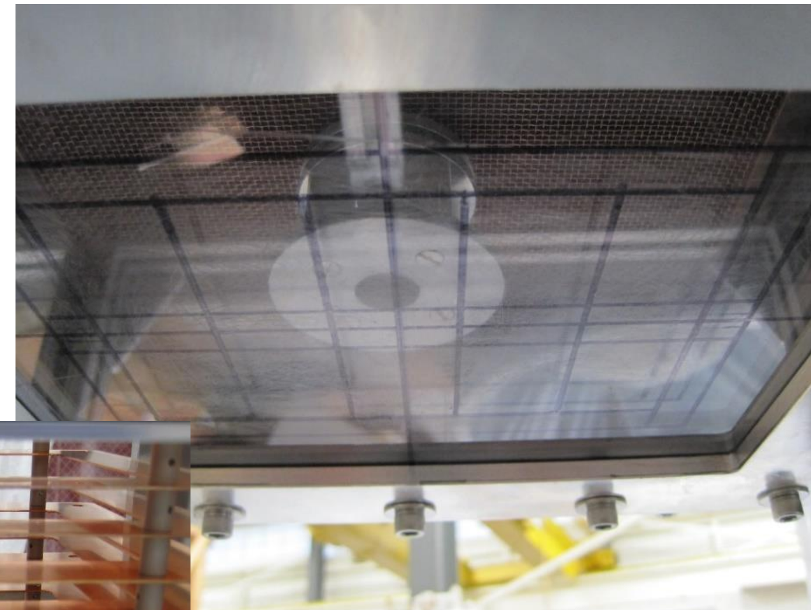
The Detector – AstroBox2



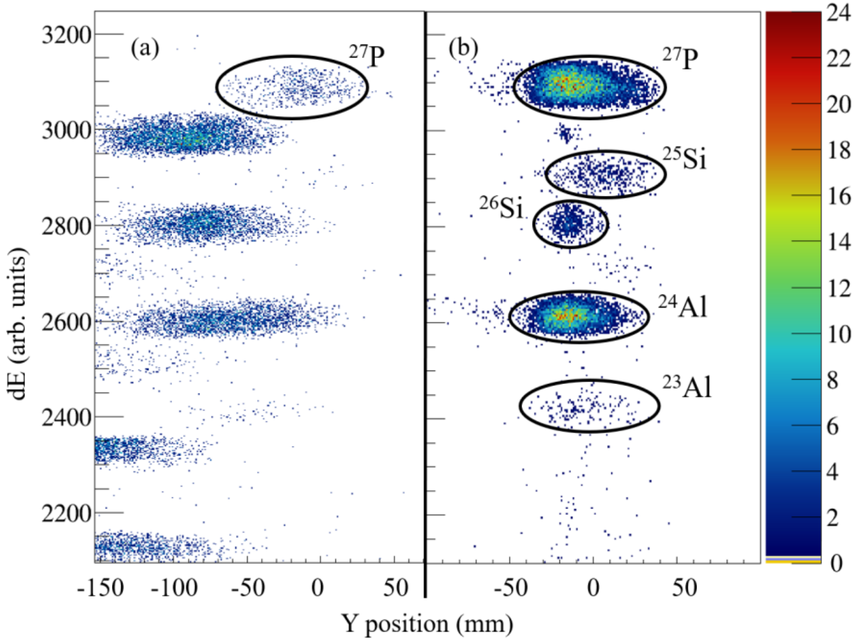


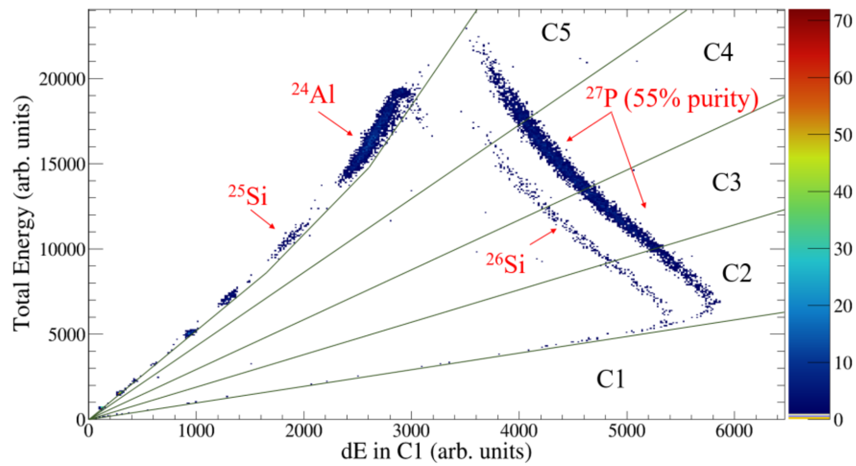
Inside of the detector chamber





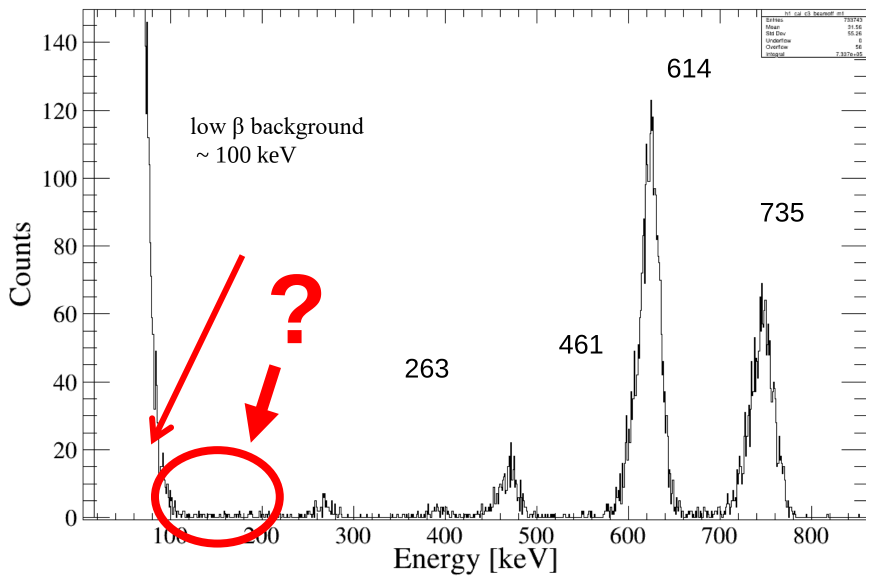
^{27}P separation

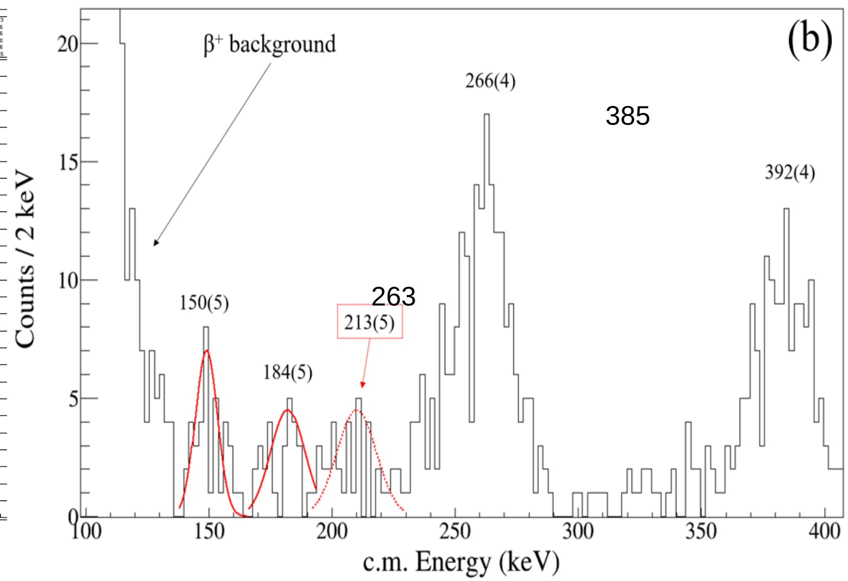




TAMU experiment, Nov. 2019

Ionut Stefanescu – thesis





Resonant contributions to reaction rate:

$$\langle \sigma \upsilon \rangle_{res} = \left(\frac{2\pi}{\mu kT} \right)^{3/2} \hbar^2 \omega\gamma \exp\left(-\frac{E_r}{kT} \right)$$

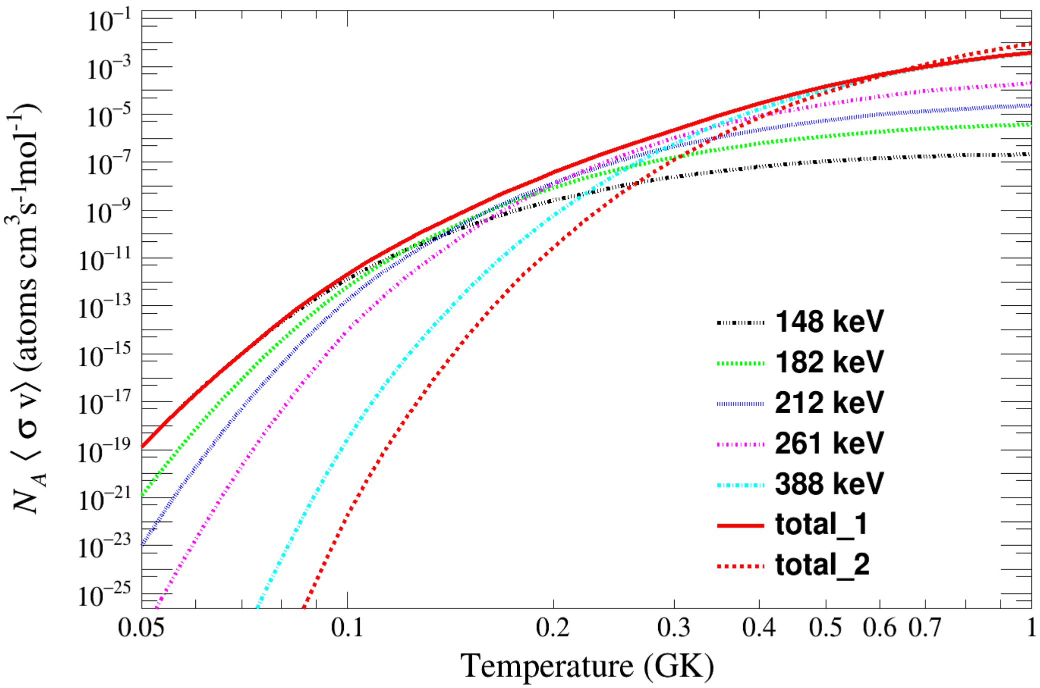
$$\omega\gamma \equiv \frac{2J_r + 1}{(2J_p + 1)(2J_t + 1)} \frac{\Gamma_p \Gamma_\gamma}{\Gamma_{tot}}$$

Need energy, J_r and resonance strength

$^{26m}Al(p,\gamma)$ resonances

E_p [keV]	E_level [keV]	Rel intens [%]	βp ratio [abs values]	ωγ [eV]
150(8)	7842(8)	0.09	5.8(8) $\times 10^{-7}$	2.64 x 10^{-7}
184(8)	7876(8)	0.29	1.78(14) $\times 10^{-6}$	6.34 x 10^{-6}
213(8)	7905(8)	0.18	1.12(12) $\times 10^{-6}$	5.09 x 10^{-5}
266(8)	7958(8)	1.23	8.30(32) $\times 10^{-6}$	9.12 x 10^{-4}
392(8)	8084(8)	1.14	9.98(40) $\times 10^{-6}$	6.26 x 10^{-2}
470(2)	8162(2)	7.94	4.66(8) $\times 10^{-5}$	0.25
619(2)	8311(2)	100	5.88(3) x10^{-4}	0.57
738(2)	8430(2)	96.8	5.64(3) x10^{-4}	0.63

The reaction rate for ^{26m}Al(p,γ) ^{27}Si from ^{27}P βp-decay



IC Stefanescu, thesis March 2024 and

IC Stefanescu et al., Phys. Rev. C, July 2024, in press

Acknowledgements

- Collabor
  - NAG
    - Flo
    - Ale
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    - Da
    - Ion
    - Iul
    - Ma
  - MARS
  - RIKEN
  - **AB2 c**
    (CERN),
- Acknow
  of Resea

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Other nuclear astrophysics activities

We are active in international training and outreach activities

- Carpathian Summer School of Physics, 30 editions so far
- European collaborations: ChETEC-INFRA and EURO-LABS projects offer support for TransNational Access to European facilities: travel, accommodation and subsistence cost covered
- Facilities: accelerators, astronomy telescopes and supercomputers for NA projects
- My institute, IFIN-HH, is active part and has the 9 MV and the 3 MV tandem accelerators in the list
- Had (in 2023) and will organize in 2026 Basic Training Schools: hands-on activities, 12-14 days, costs covered by EURO-LABS. 29 students from 4 continents, 8 countries in 2023.
- See https://www.chetec-infra.eu/ and https://web.infn.it/EURO-LABS/

Carpathian Summer School of Physics 2020

Sinaia, Aug. 18-27, 2021

Carpathian Summer School of Physics 2023 in images

There will be CSSP25
Probably June 22-30, 2025
Keep an eye on it, we may offer
Fellowships for students!

CSSP is part of the European Network of Nucl Astro Schools

From discussions with ENNAS partners

With ChETEC-INFRA support:

- Russbach remains in each winter => March 2025
- Carpathian schools in odd years => in 2025
  - Sinaia again, June 2025
- Next ESSENA school of Catania – in June 2024

https://web.infn.it/EURO-LABS/

PROJECT ACRONYM: EURO-LABS – EUROpean Laboratories for Accelerator Based Science
PROGRAMME: Horizon EU (Research infrastructure services to support health research, accelerate the green and digital transformation, and advance frontier knowledge)
DURATION: September 2022- August 2026 (4 years)
TOTAL BUDGET: 14.5 M€
TOTAL EC CONTRIBUTION: 14.2 M€
CONSORTIUM: 33 participants from 18 countries
PROJECT COORDINATOR: Paolo Giacomelli (INFN)
SCIENTIFIC COORDINATOR: Navin Alahari (GANIL)

- The project brings together, for the first time, the three research communities of nuclear physics, accelerator and detector technologies for high energy physics, in a pioneering super-community of sub-atomic scientists.
- It provides effective access to a network of 45 Research Infrastructures

https://www.chetec-infra.eu/

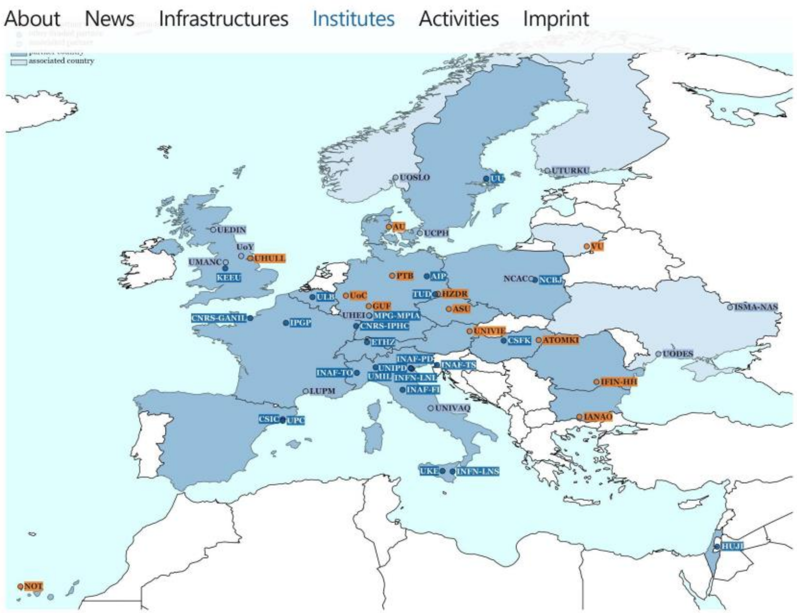
Period: 2021-2025, 5M euro

Research Infrastructure in NA:

- Accelerators
- Astro telescopes
- Computing facilities

Supports use of 13 TransNational Access Facilities by users from all over the world

- Have to pass a PAC – next term for application: Aug. 17, 2024



Thank you!