Study of fusion reactions with MUSIC

Melina Avila

Argonne National Laboratory

Nucleus Nucleus 2015

June 23, 2015

Outline

- Motivation
- The MUSIC detector
- Previous and recent results
- Perspectives and conclusions

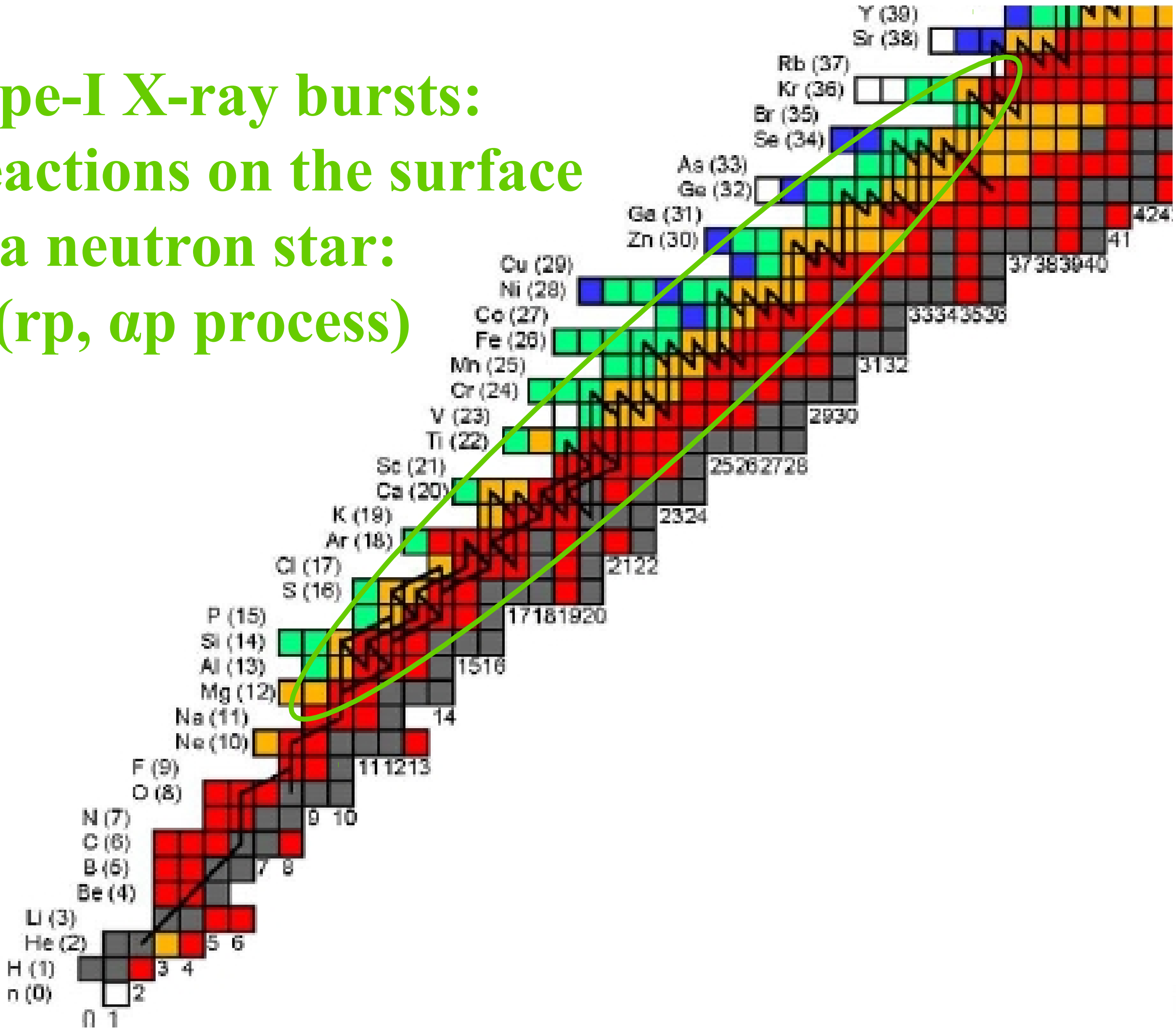
Motivation

Fusion reactions play and important role in nature

- Crucial for the production of heavier elements in stars.
- Play fundamental role to understand X-ray binaries where superbursts have been observed.
- For fundamental nuclear effects.
- Important to have a good understanding of the underlying reaction mechanism.

Nuclear Reactions during X-ray bursts

Type-I X-ray bursts:
Reactions on the surface of a neutron star:
(rp, αp process)



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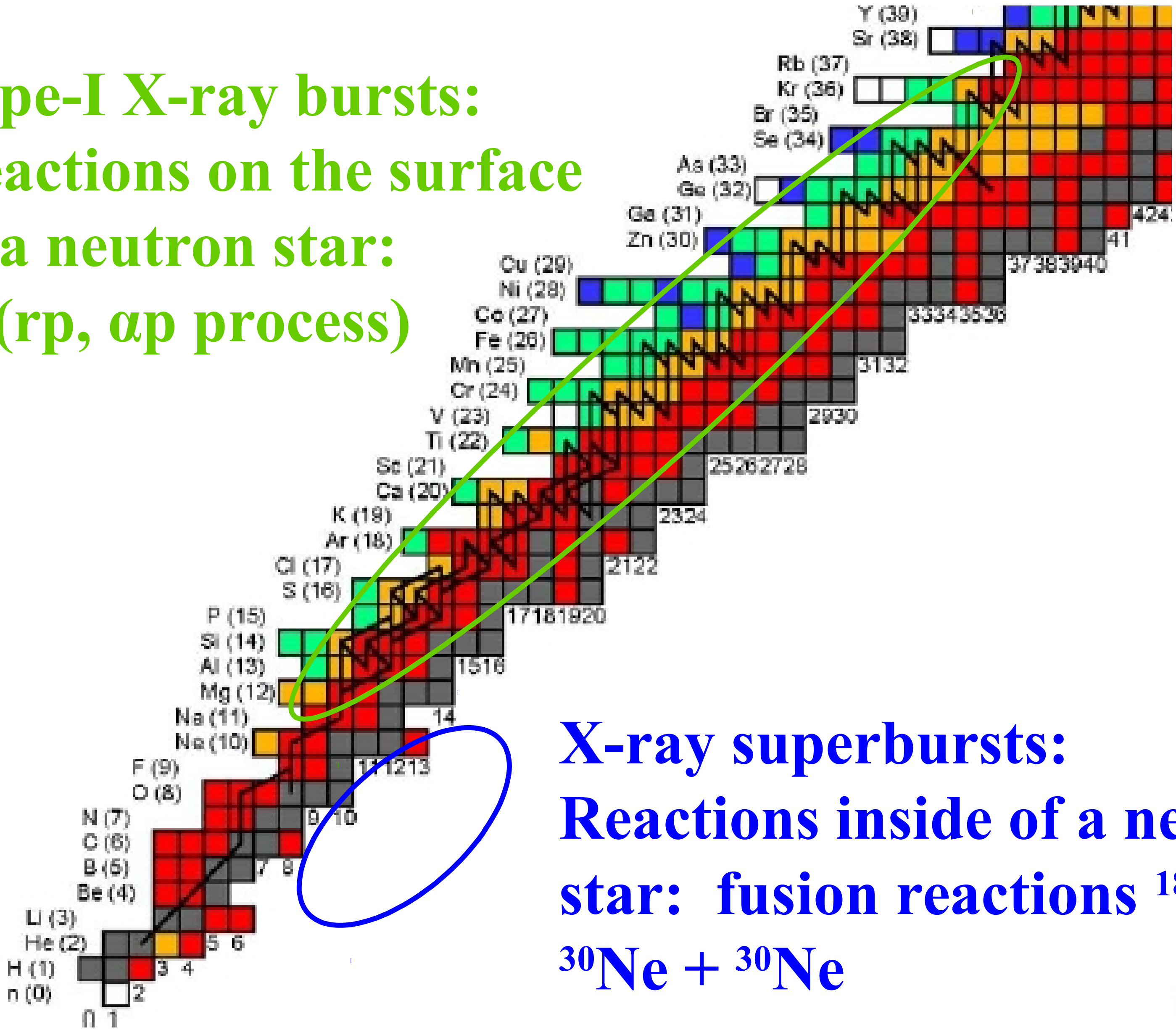
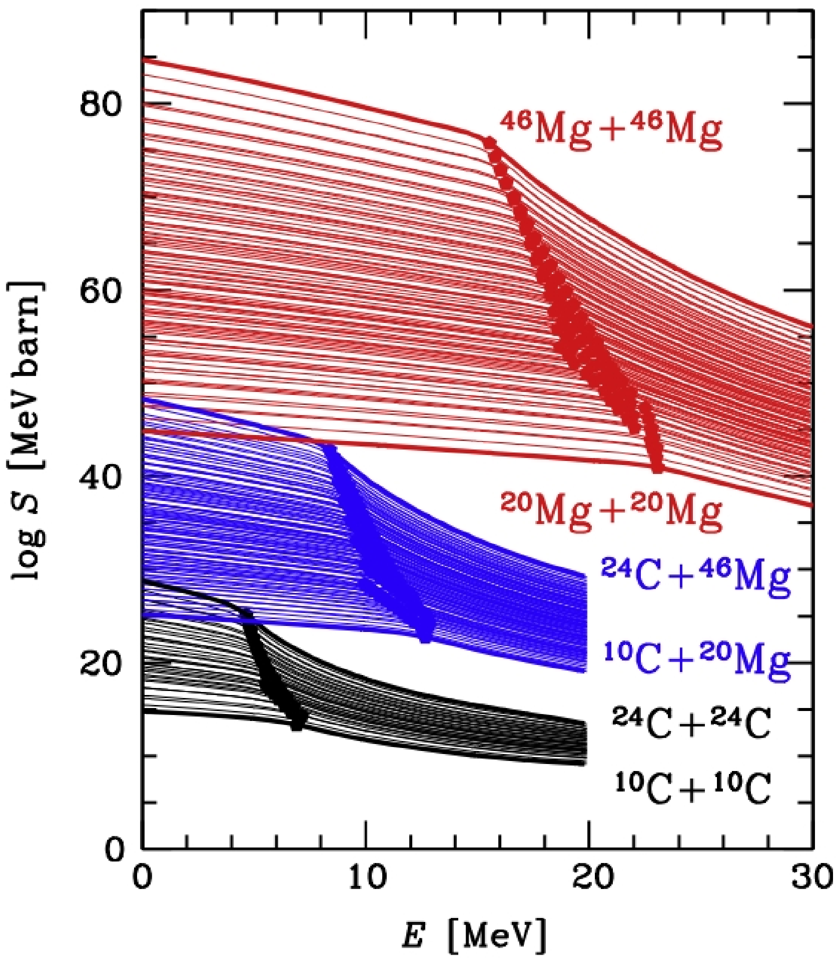
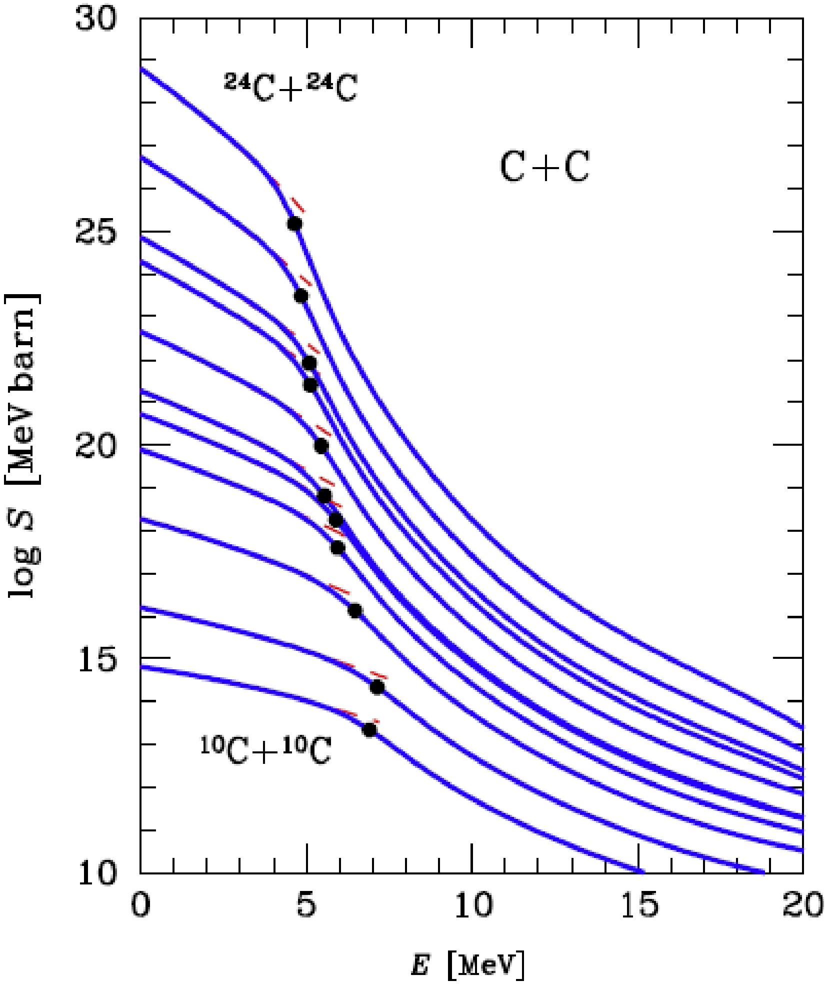


X-ray superbursts: Reactions inside of a neutron star: fusion reactions $^{18}C + ^{18}C$, $^{30}Ne + ^{30}Ne$

X-ray Superbursts

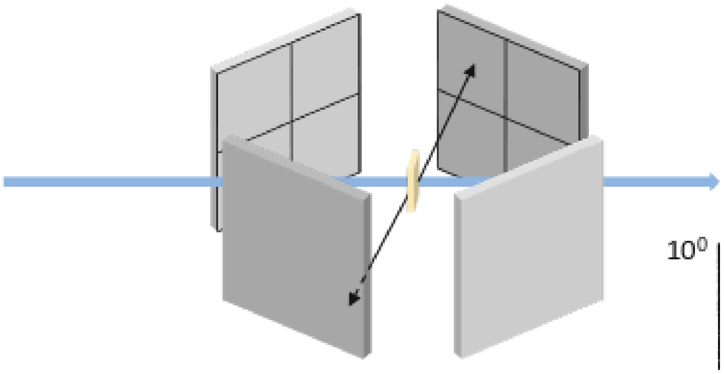


M. Beard et al., ADNDT 96, 541 (2010)

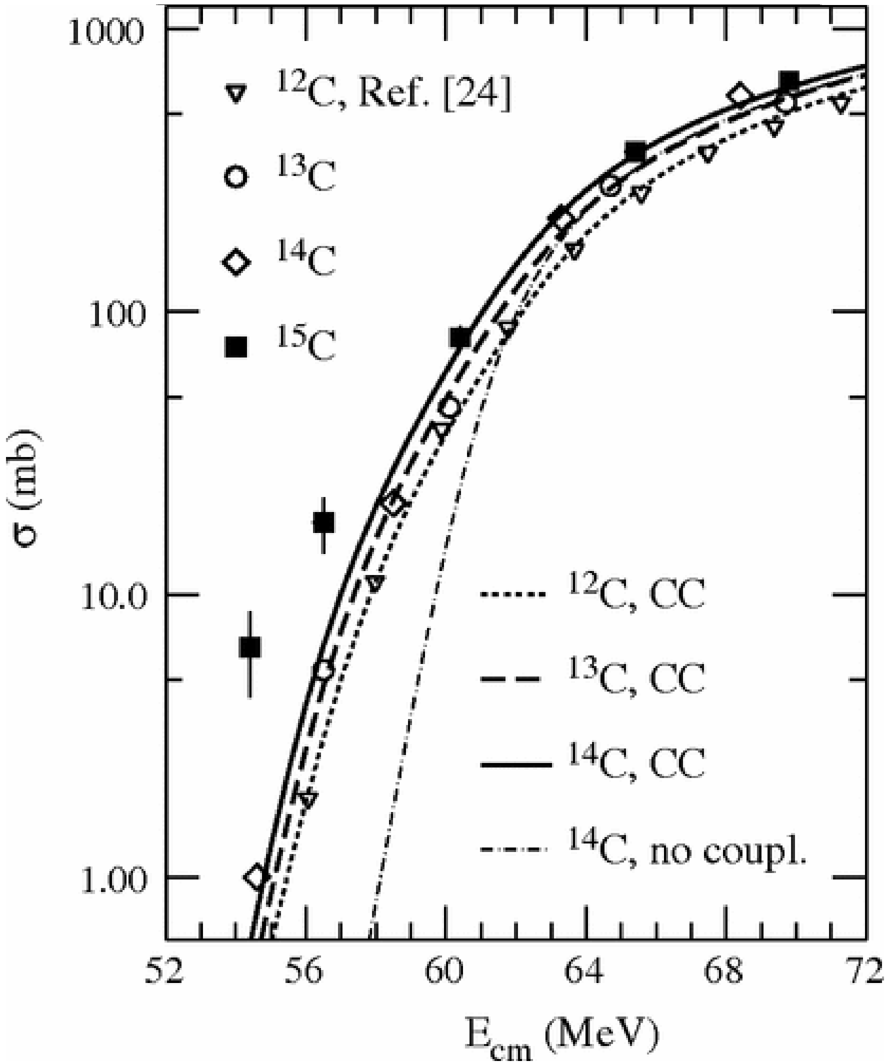


Previous studies of fusion reactions involving Radioactive beams

$^{15}C + ^{232}Th$



Alcorta, M., et al., 2011, PRL106, 172701



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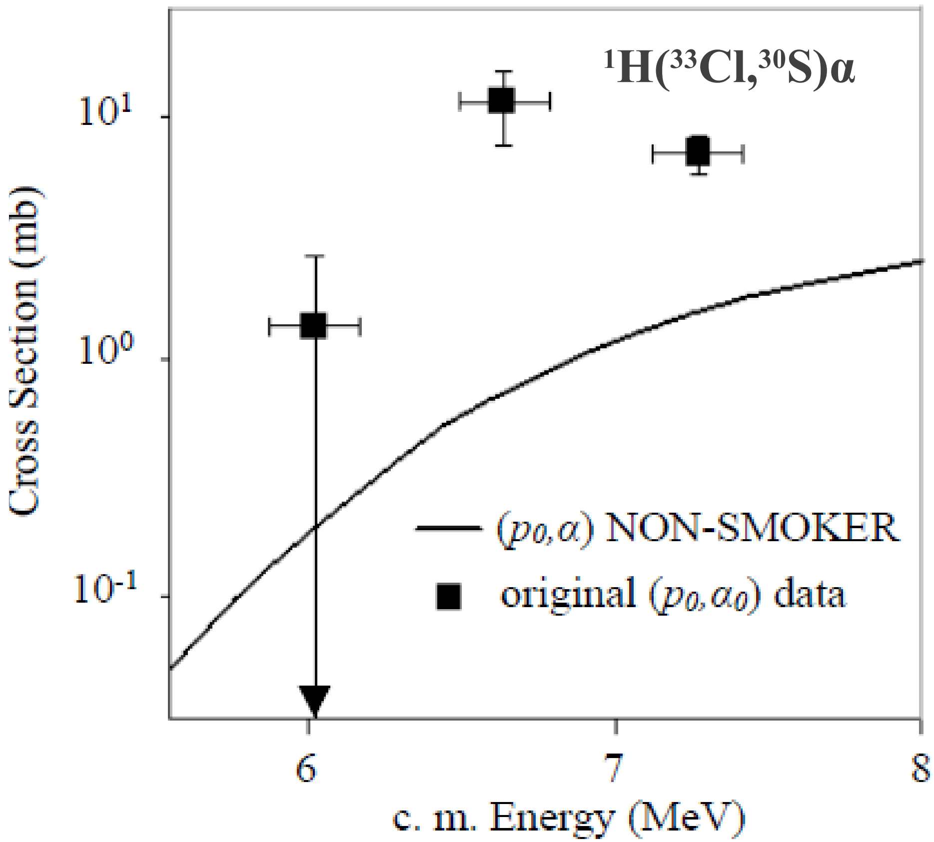

To study the important $^{30}S(\alpha,p)^{33}Cl$ reaction for type I X-ray burst

C.M Deibel et al.,PRC 84, 045802 (2011)

Difficulties associated with previous methods

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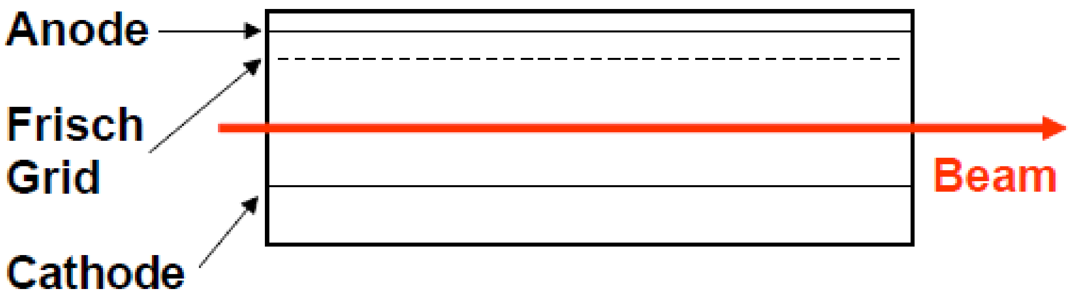
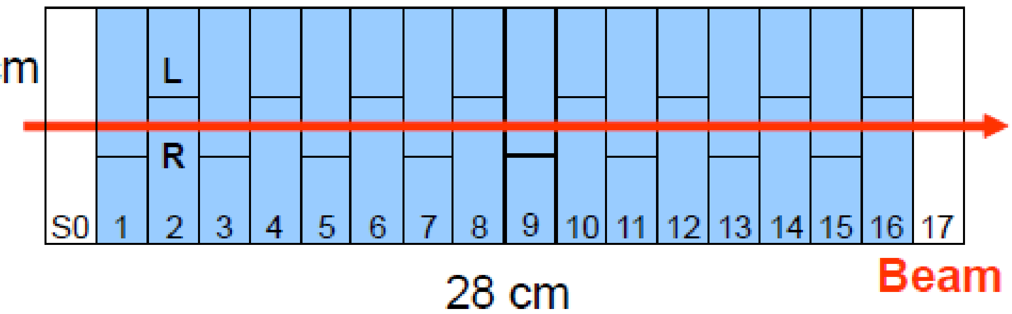
- Low beam intensities.
- Long time to measure a single energy point.
- Difficult to tune the beam and to change energy.

The MUSIC detector

Multi-Sampling Ionization Chamber



Schematic of the anode structure



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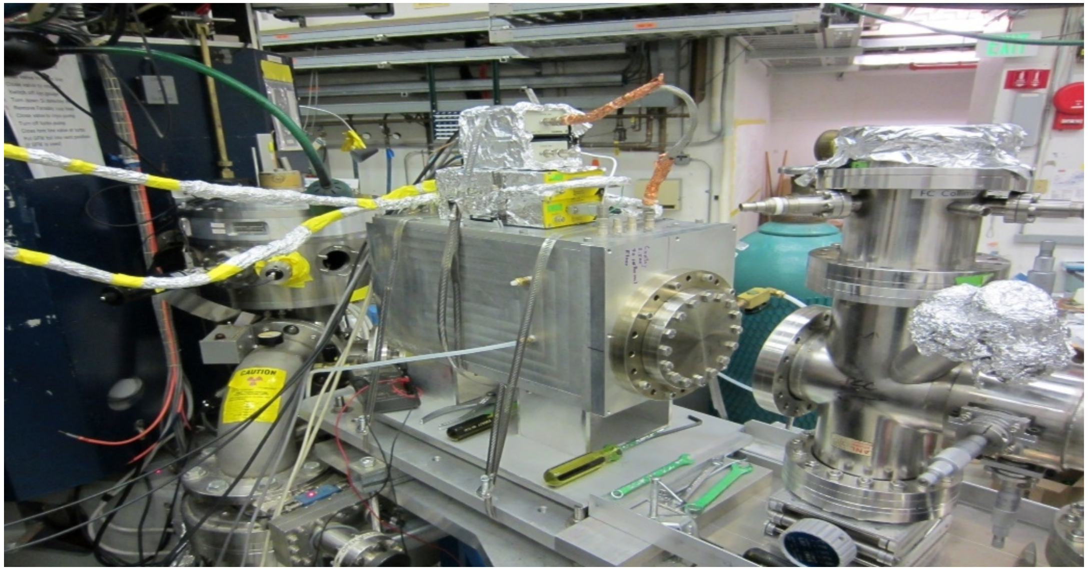
- We measure the energy losses along a particle track.
- No additional monitors for absolute normalization.



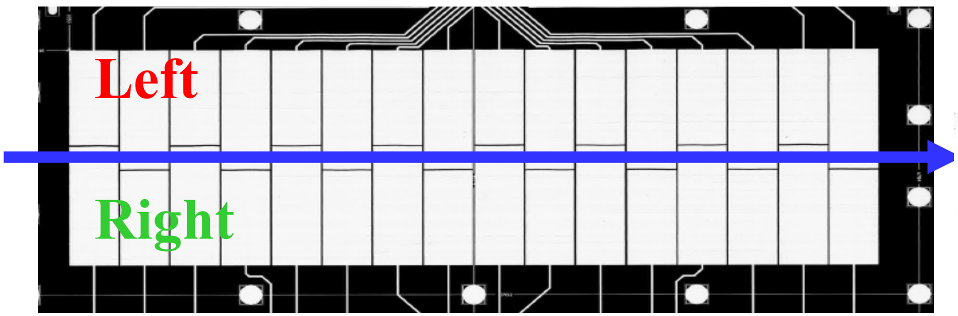
Dimensions:

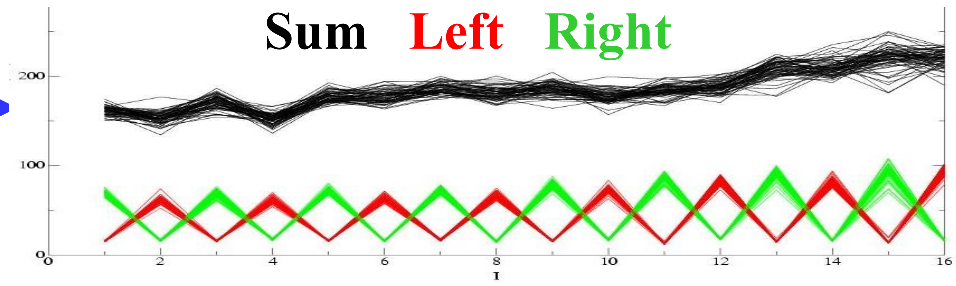
30 cm (L) x 10 cm(w) x 20 cm (H)

Counting gases:

He, CH_4, Ne, Ar

Event-by-event analysis





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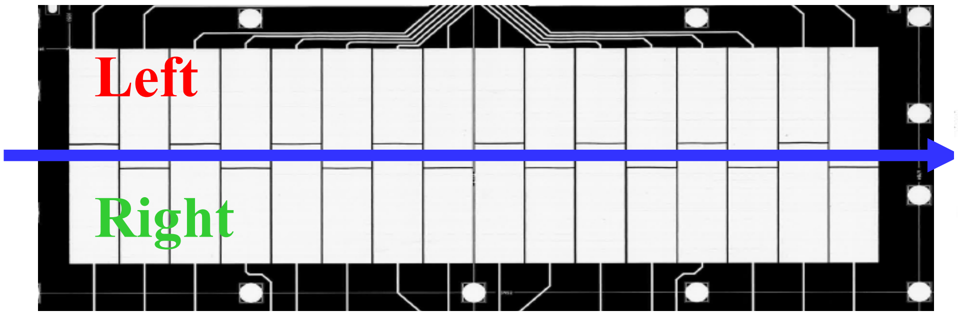
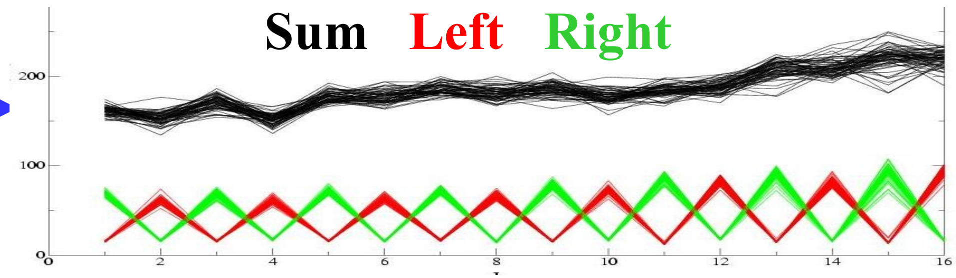
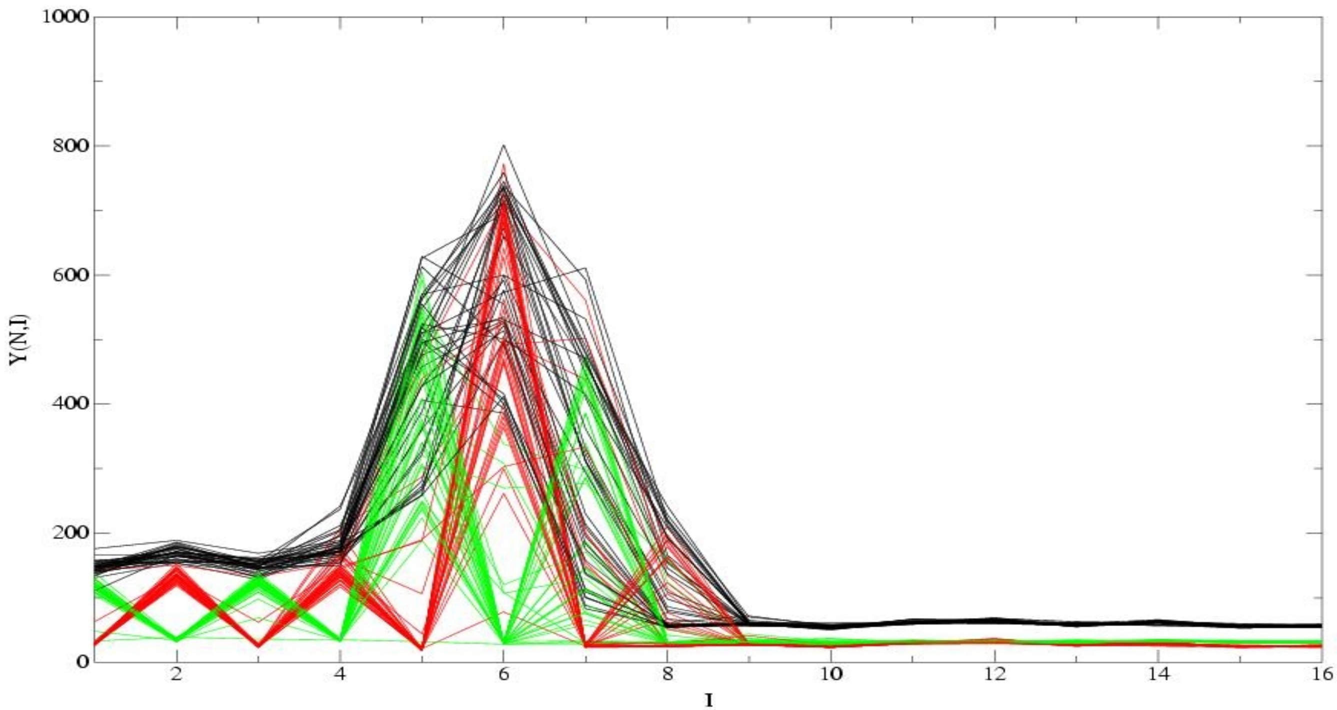




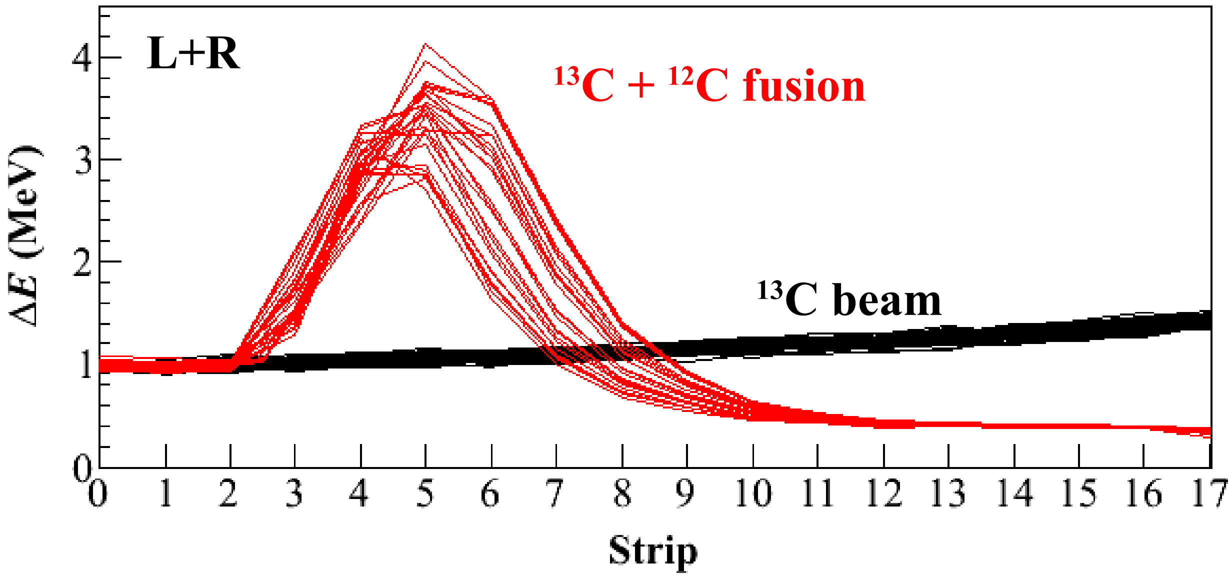


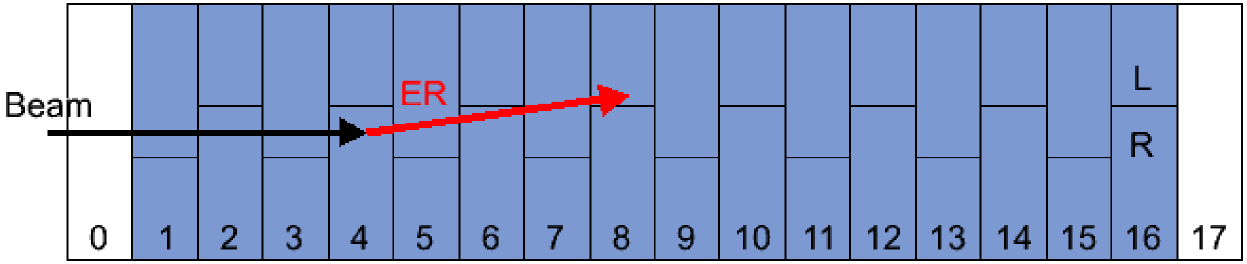
Experimental results

$^{10,12,13,14,15}C + ^{12}C$ experimental campaign

- ^{10}C: $^{1}H(^{10}B,^{10}C)n$ Rate~500/s
- ^{12}C
- ^{13}C
- ^{14}C
- ^{15}C: $^{2}H(^{14}C,^{15}C)p$ Rate ~2000/s

$^{12}C + {}^{13}C$ fusion – test measurement





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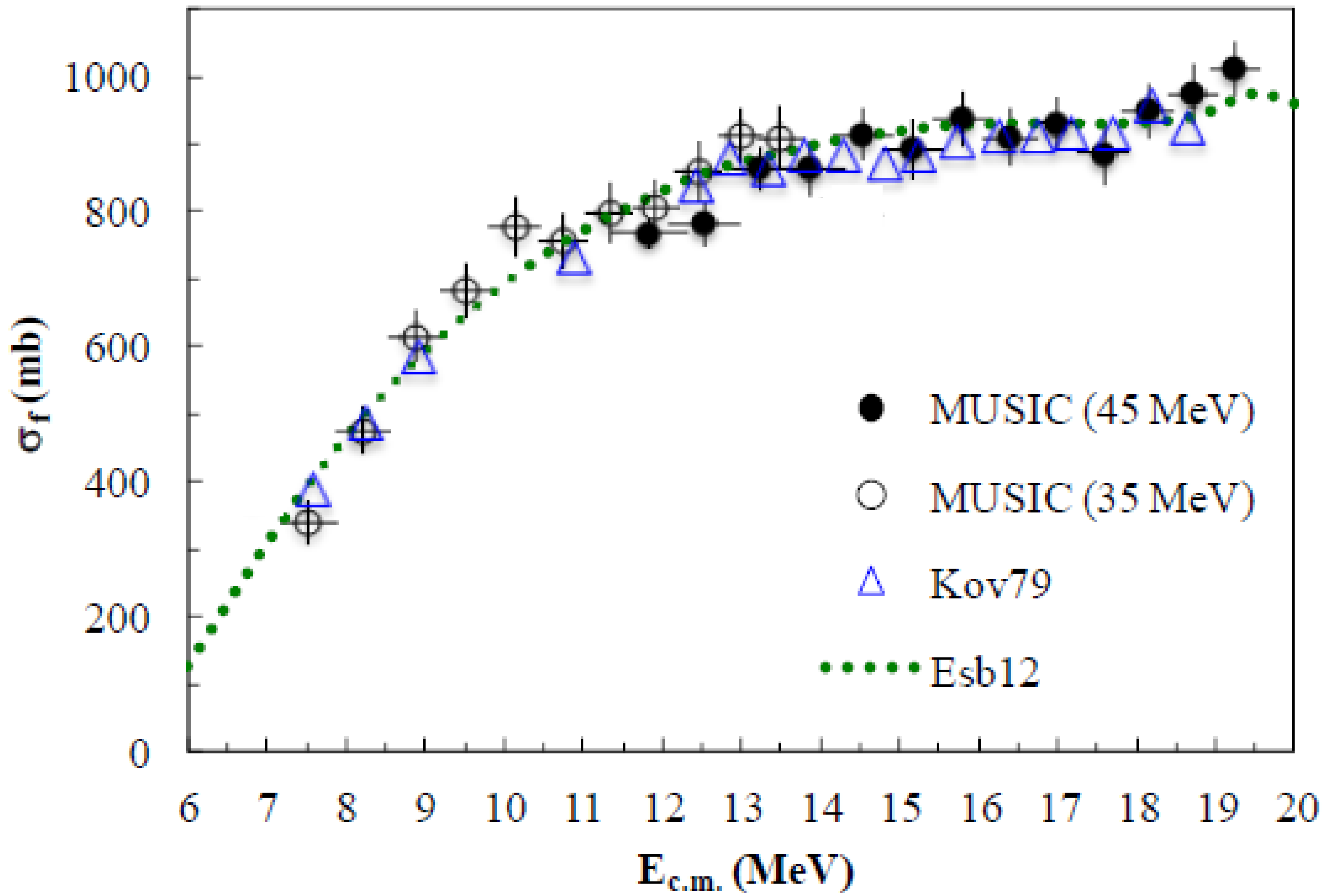
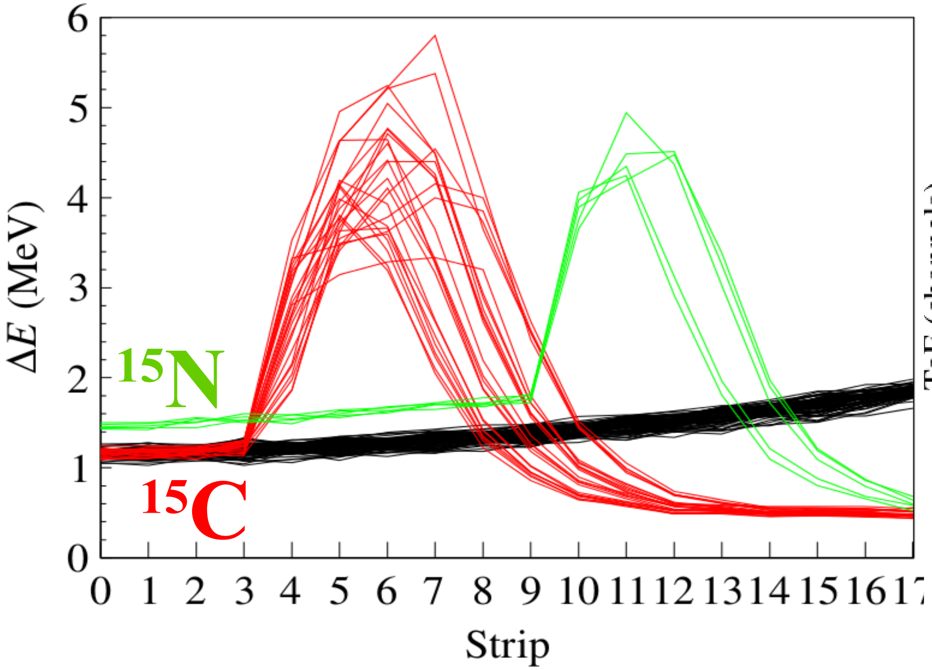
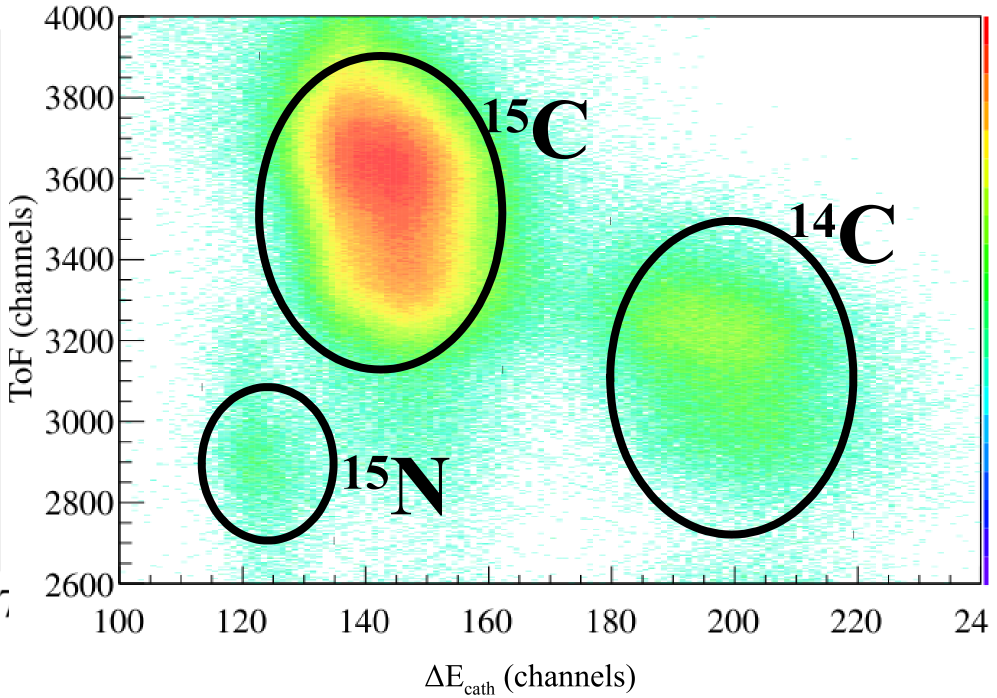
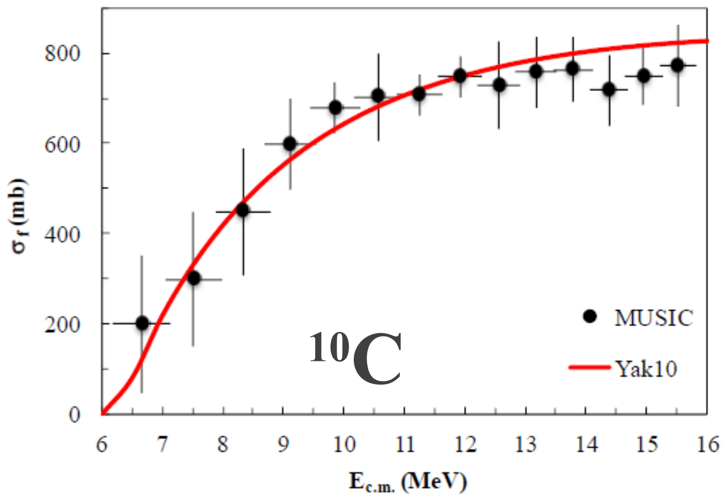


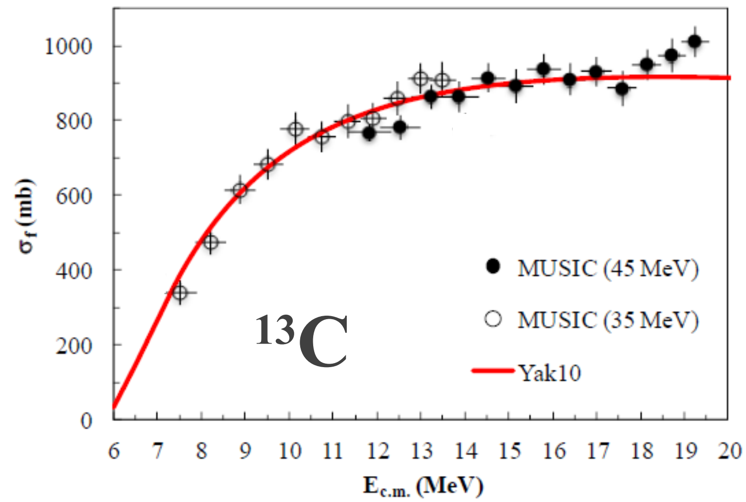
Radioactive beam: $^{12}C + ^{15}C$ fusion

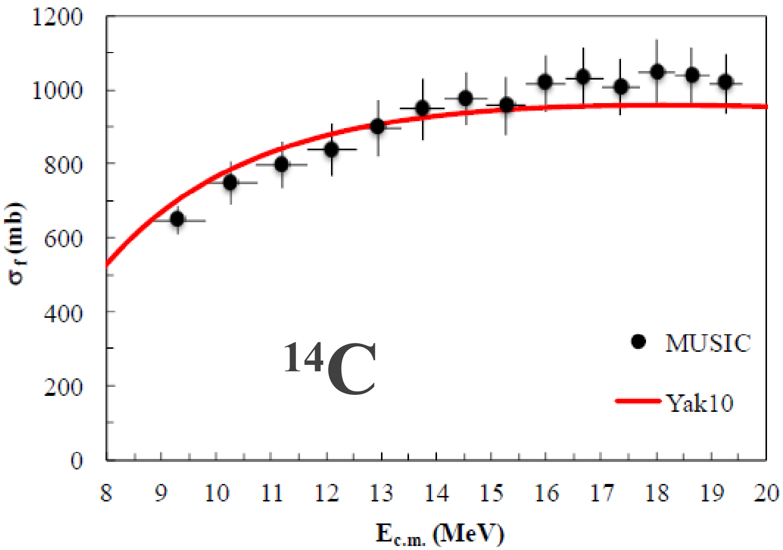


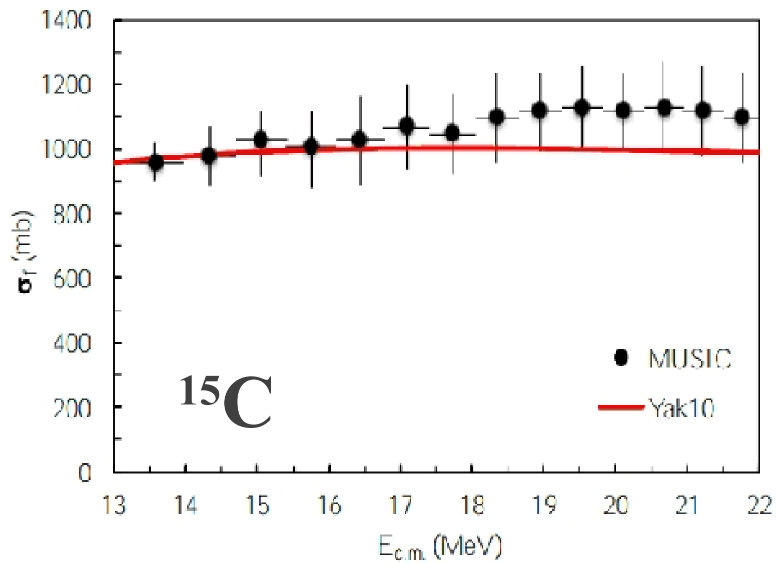


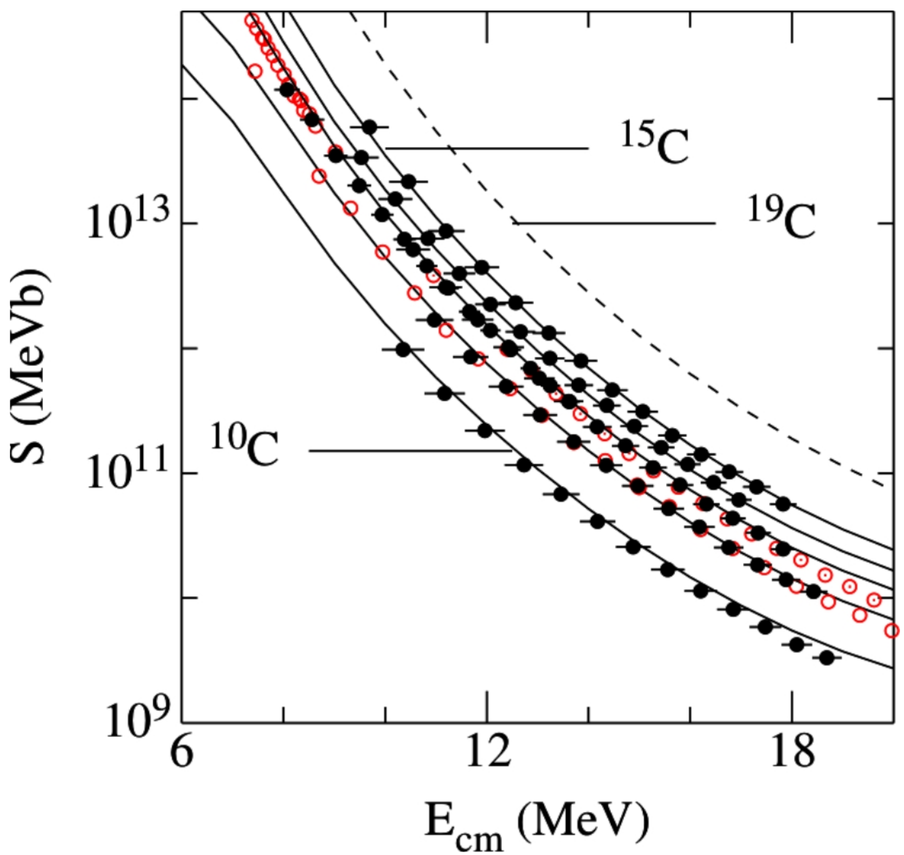
Results: Fusion of ^{12}C +

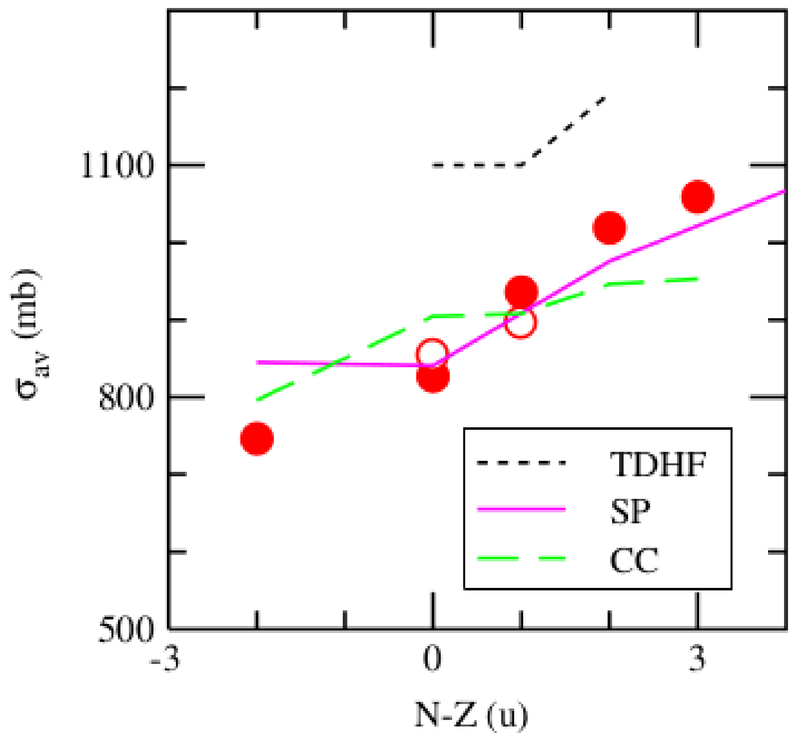








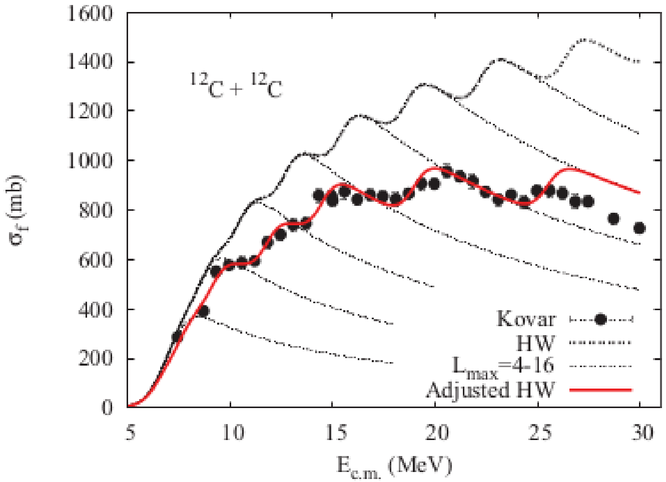


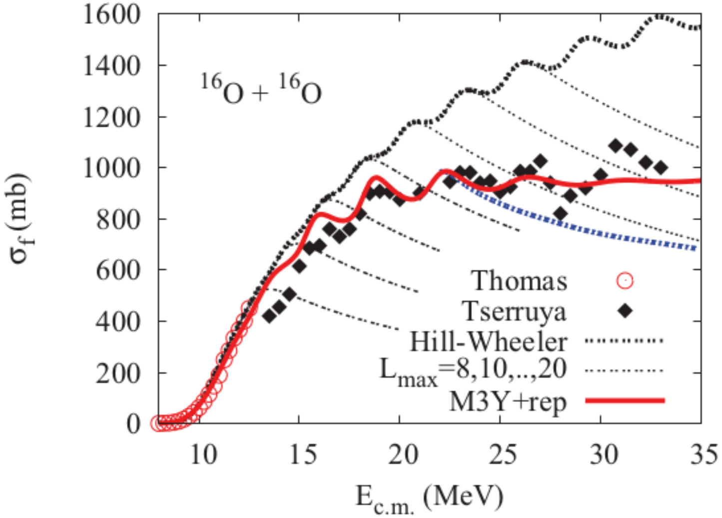


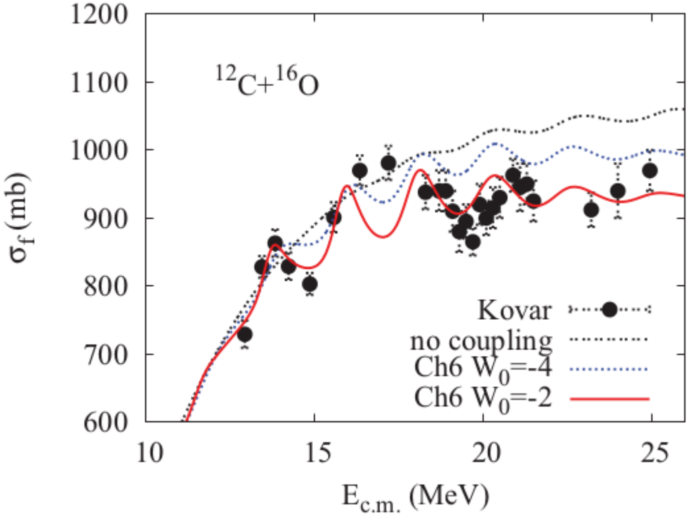
P. F.F Carnelli et al., PRL 112, 192701 (2014)

- Can measure ~12 energies in one experiment.
- Good agreement with theory.

Oscillations above the barrier in fusion data







H. Esbensen PRC 85, 064611 (2012)
N. Rowley et al., PRC 91, 044617 (2015)

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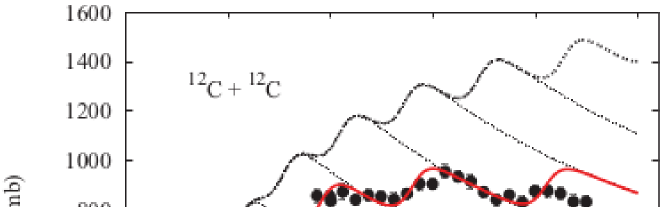

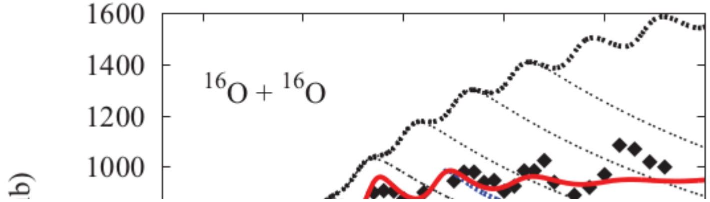

Physics Letters B 746 (2015) 300–304

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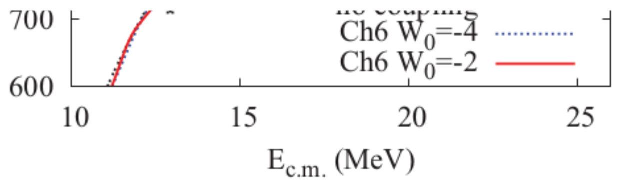
Oscillations above the barrier in the fusion of $^{28}Si + ^{28}Si$

CrossMark

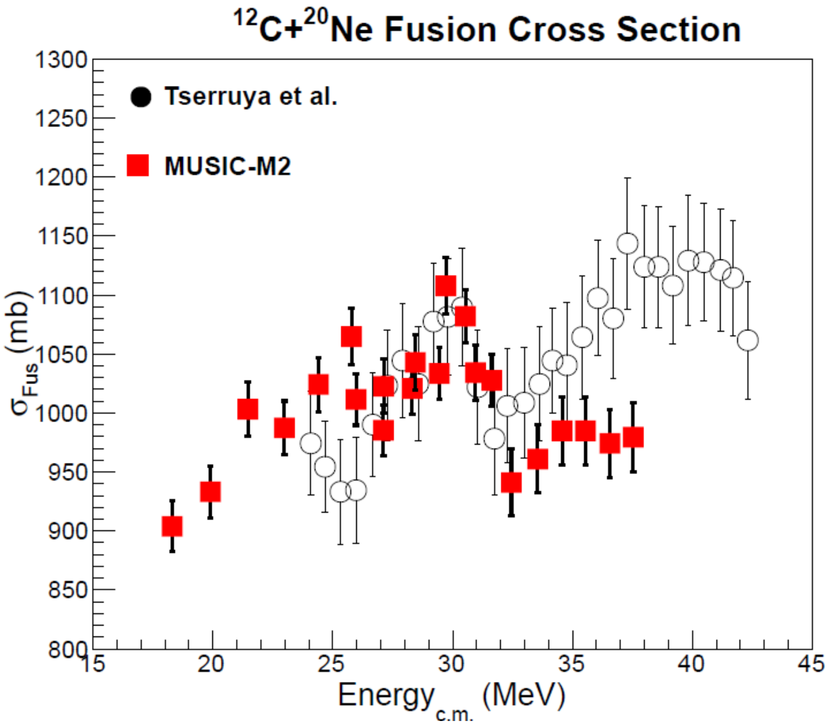
G. Montagnoli [a,*], A.M. Stefanini [b], H. Esbensen [c], L. Corradi [b], S. Courtin [d], E. Fioretto [b], J. Grebosz [e], F. Haas [d], H.M. Jia [b], C.L. Jiang [c], M. Mazzocco [a], C. Michelagnoli [a], T. Mijatović [f], D. Montanari [a], C. Parascandolo [a], F. Scarlassara [a], E. Strano [a], S. Szilner [f], D. Torresi [a]



Ongoing Neon Campaign

- $^{12}C+^{20}Ne$
- $^{20}Ne+^{20}Ne$
- $^{22}Ne+^{20}Ne$
- $^{22}Ne+^{22}Ne$
- $^{22}Ne+^{24}Ne$
- $^{20}Ne+^{24}Ne$

Neon campaign results



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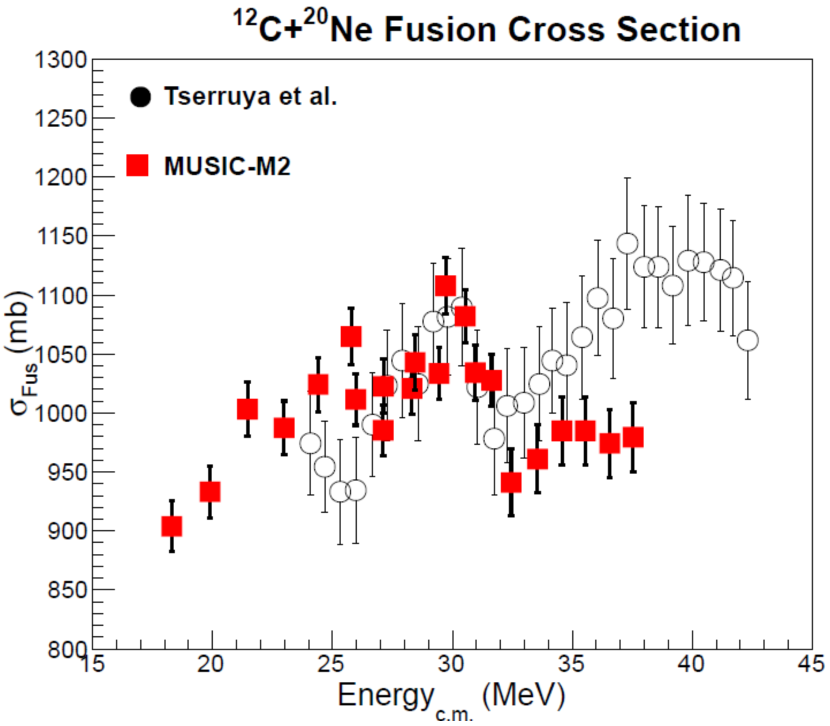

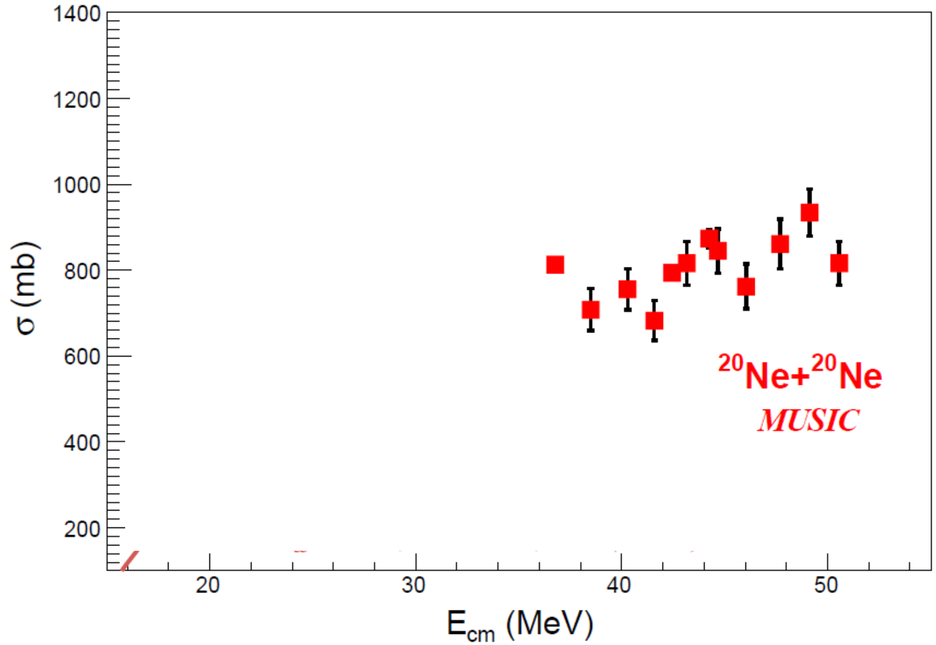

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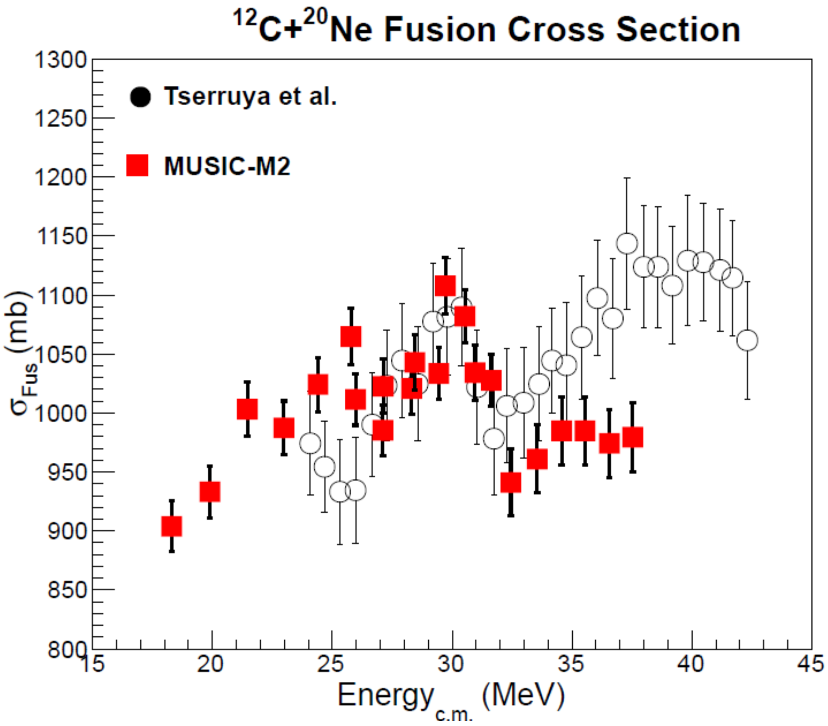
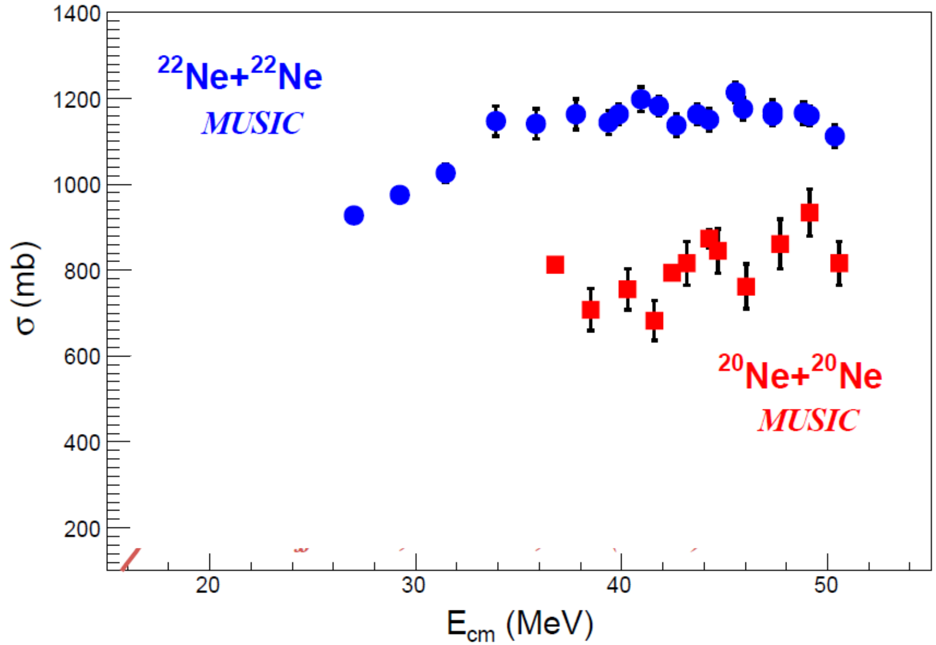
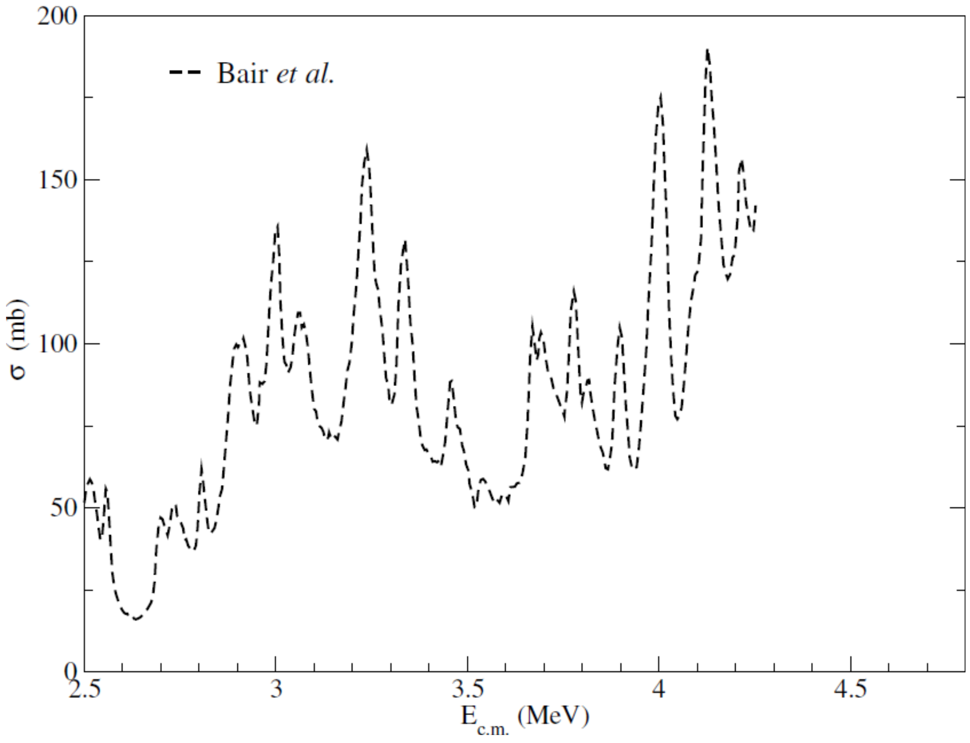




What else can we measure?

The $^{17}O(\alpha,n)^{20}Ne$ reaction with MUSIC



J.K. Bair, et al. Phys. Rev. C **7**, 1356 (1973).

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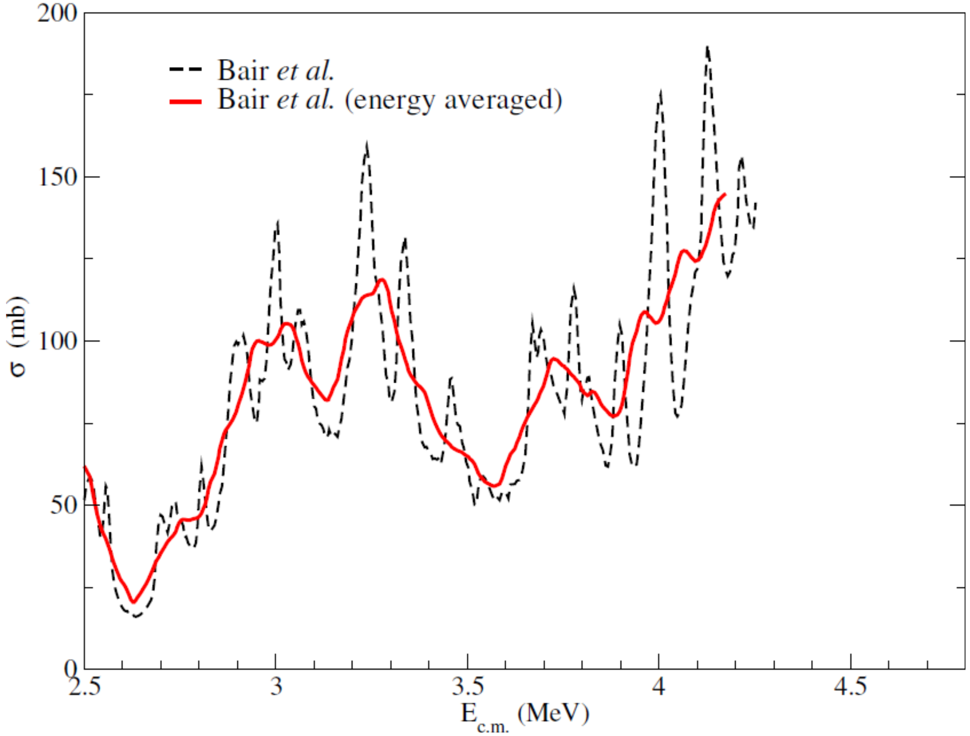

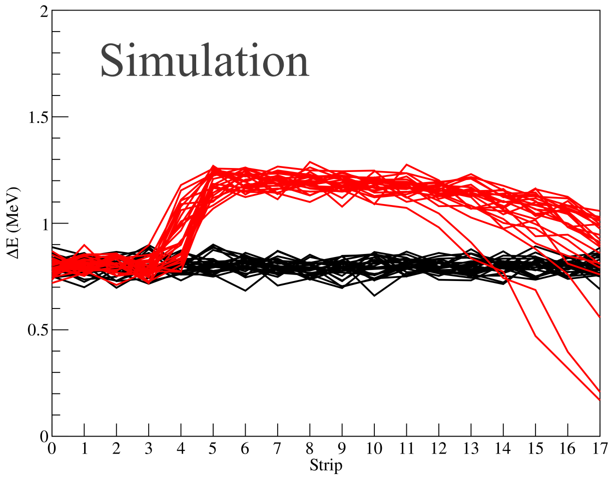

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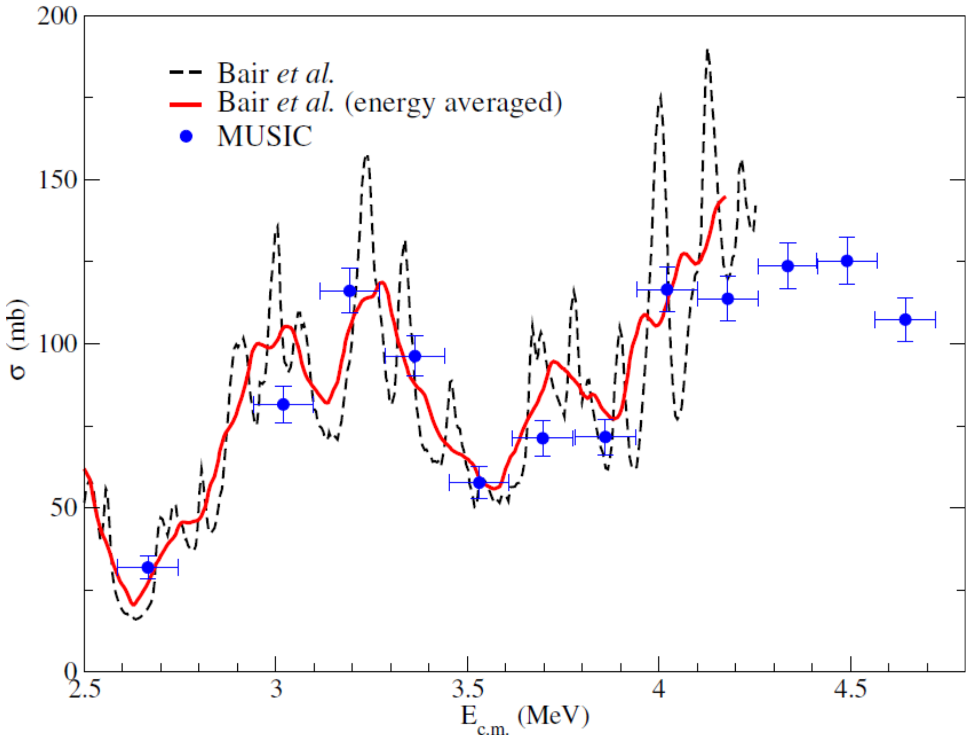

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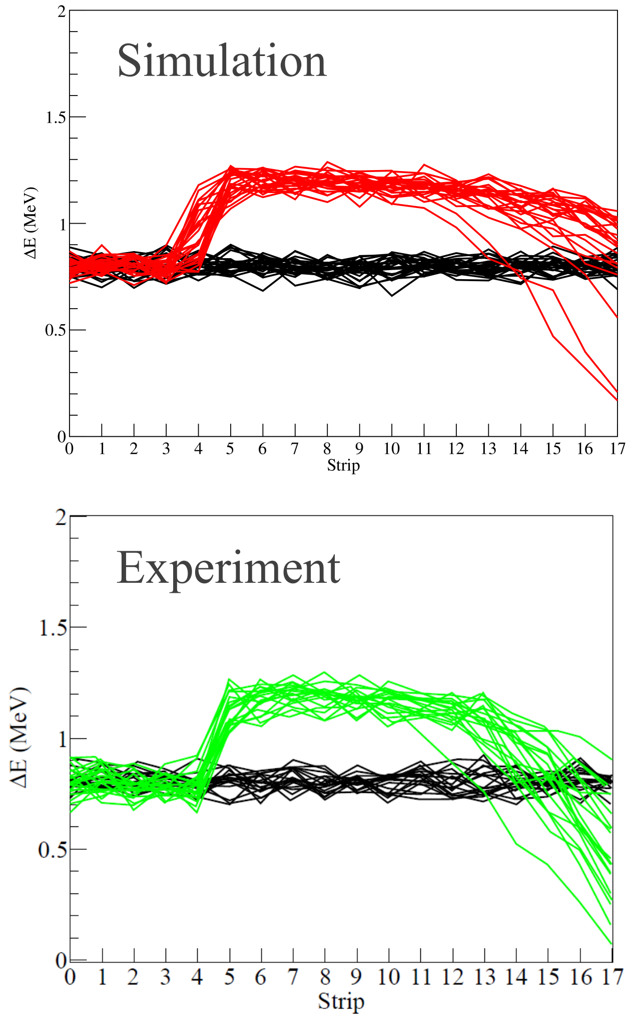
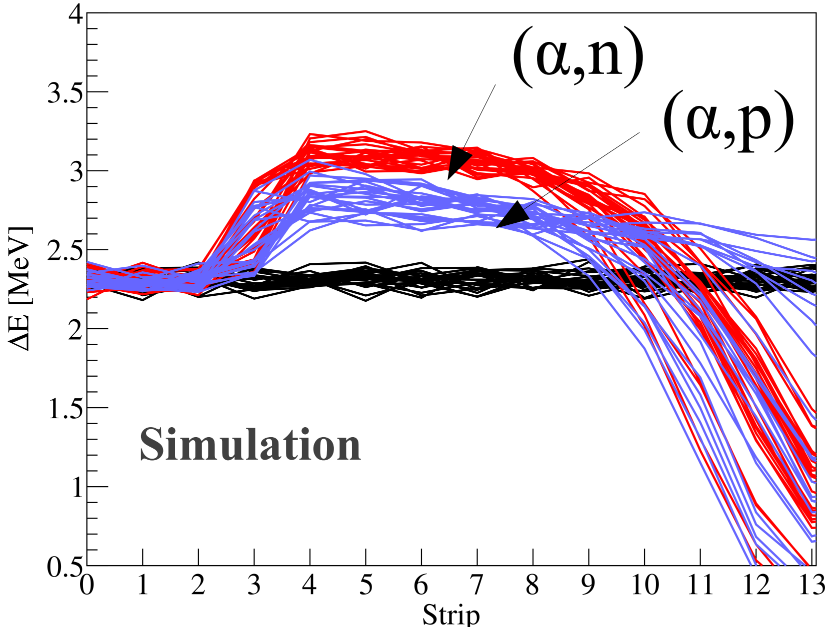


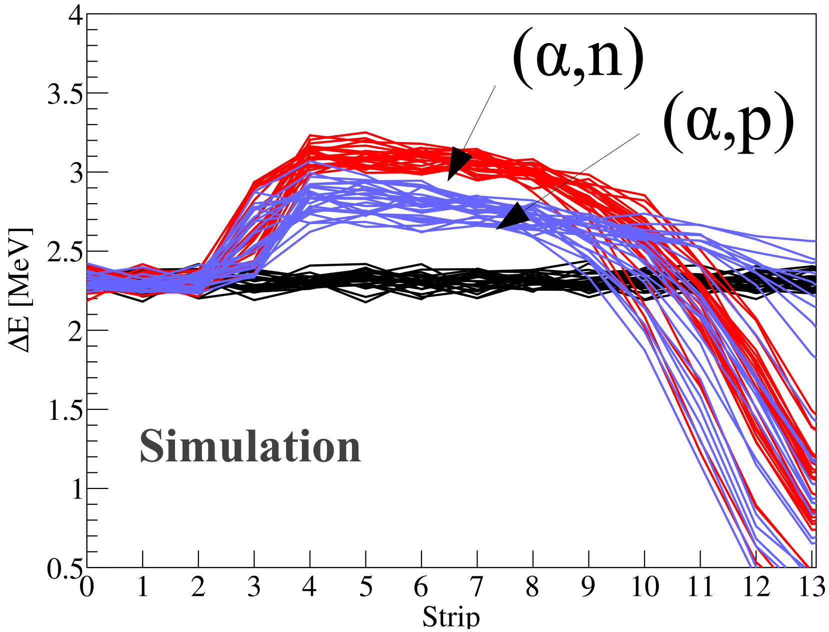
What about (α,p)?

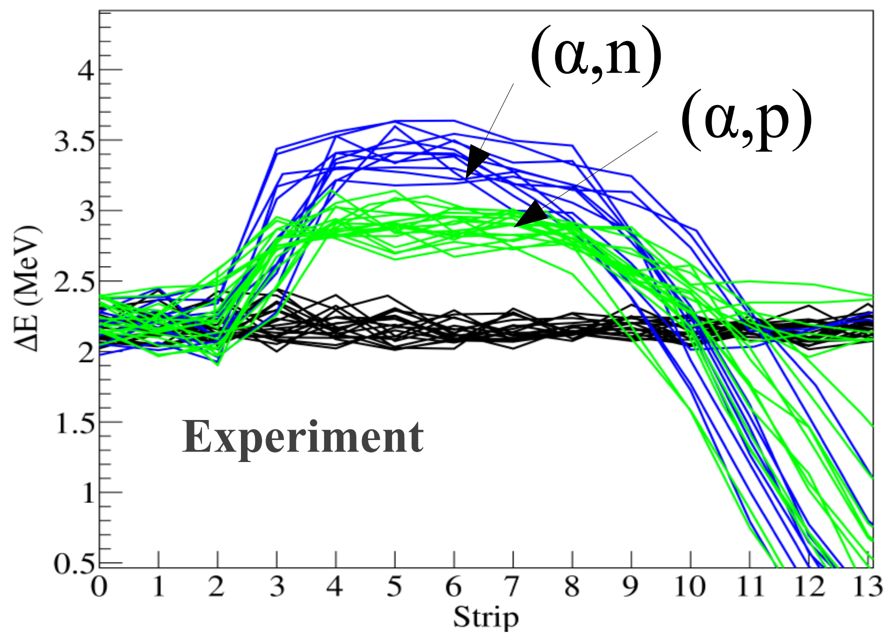
The $^{23}Na(\alpha,p)$ reaction with MUSIC!



The ^{23}Na(α,p) reaction with MUSIC!

$E_{cm} \sim 2.5$ MeV to 6 MeV





Conclusions

- Fusion reactions play an important role. Many of this reactions involve radioactive beams.
- The high efficient detector MUSIC measures excitation functions with a single beam energy.
- Test experiments with $^{12,13}C$ are in very good agreement with previous data.
- Measured for the first time, excitation functions for ^{12}C + $^{10,14,15}C$ with radioactive carbon isotopes which are of interest in nuclear astrophysics.
- Measured $^{20,22}Ne$+$^{20,22}Ne$ excitation functions.
- New possibilities measuring (α,n) and (α,p) reactions.

Collaborators

K.E. Rehm, S. Almaraz-Calderon, P.F.F. Carnelli (TANDAR), B. DiGiovine, H. Esbensen, D. Henderson, C.R. Hoffman, C.L. Jiang, B.P. Kay, J. Lai (LSU), O. Nusair, R.C. Pardo, M. Paul, D. Santiago-Gonzalez (LSU), R. Talwar, C. Ugalde

Thanks for your attention !

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- Crucial for the production of heavier elements in stars.
- Play fundamental role to understand X-ray binaries where superbursts have been observed.
- For fundamental nuclear effects.
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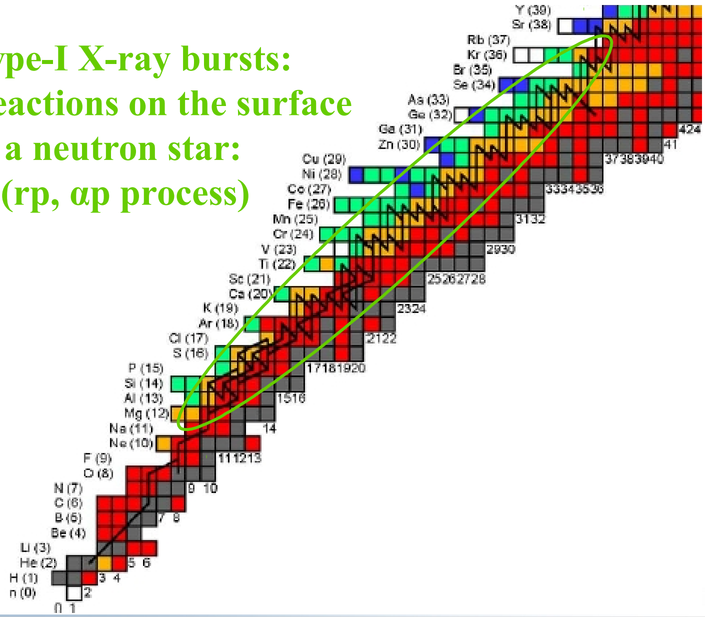

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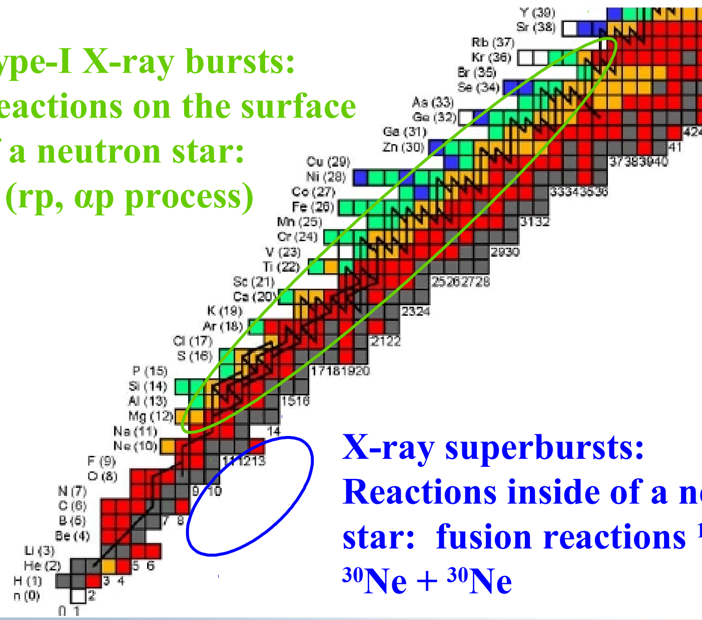

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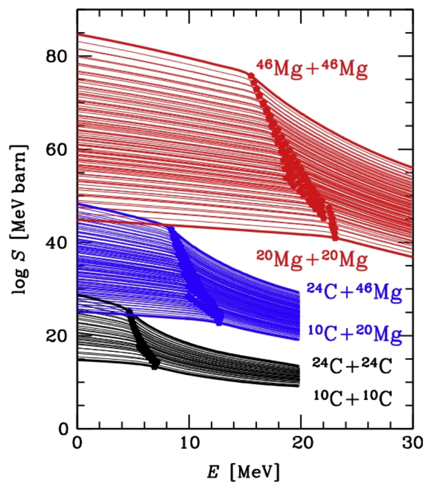
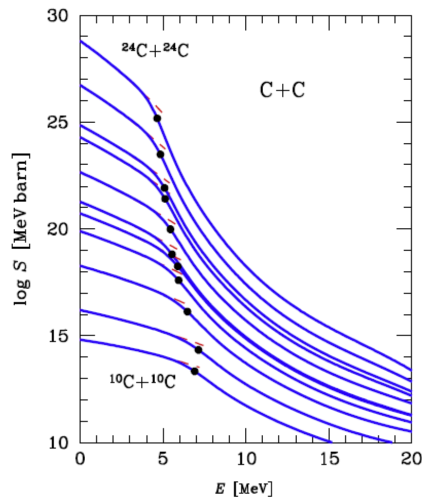
X-ray Superbursts





M. Beard et al., ADNDT 96, 541 (2010)

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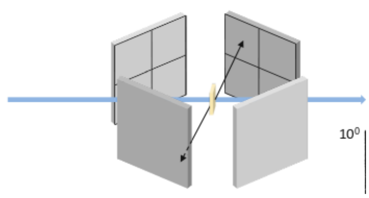
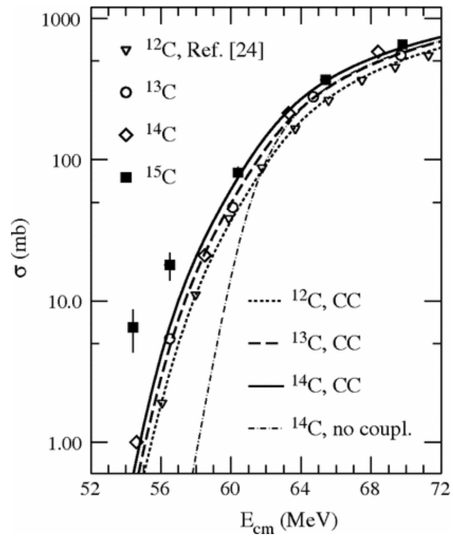


Alcorta, M., et al., 2011, PRL106, 172701



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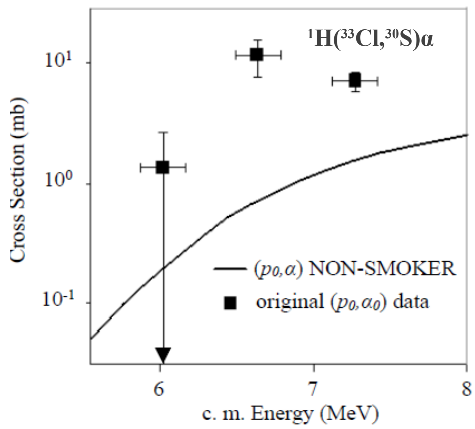

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C.M Deibel et al.,PRC 84, 045802 (2011)

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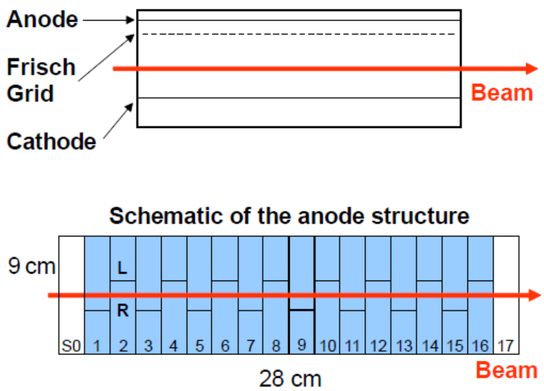

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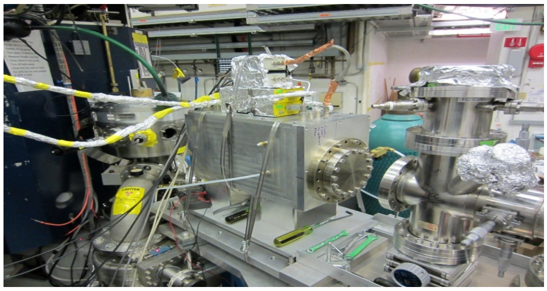

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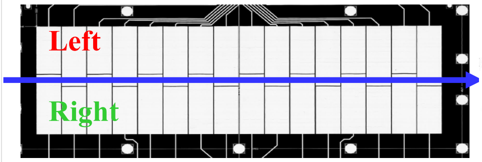

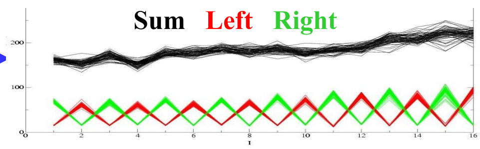

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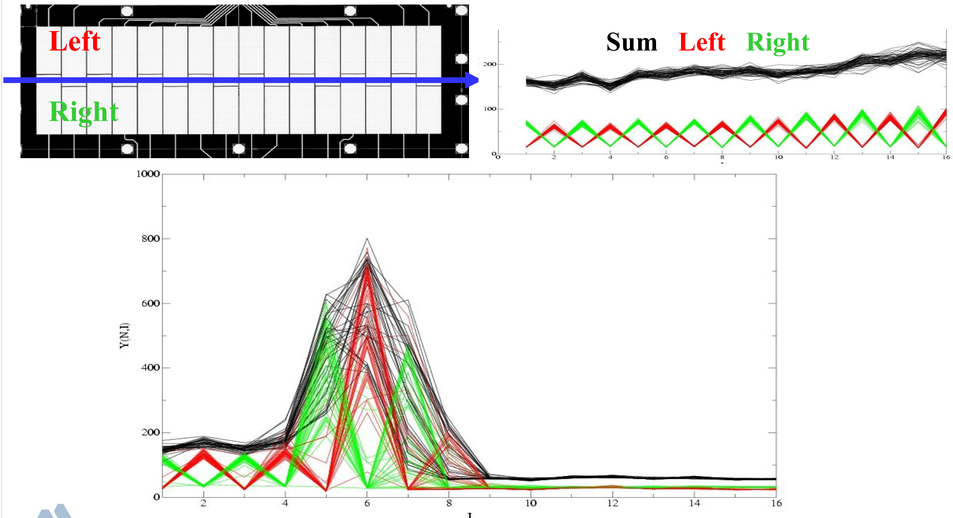

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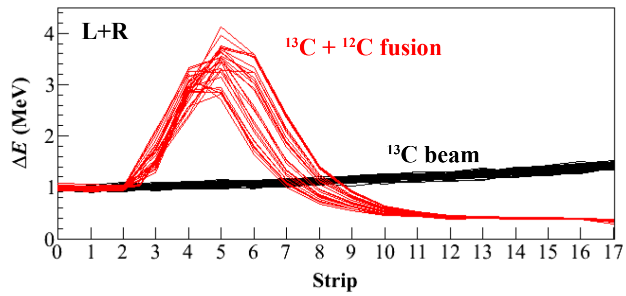
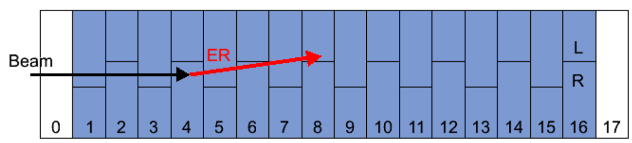
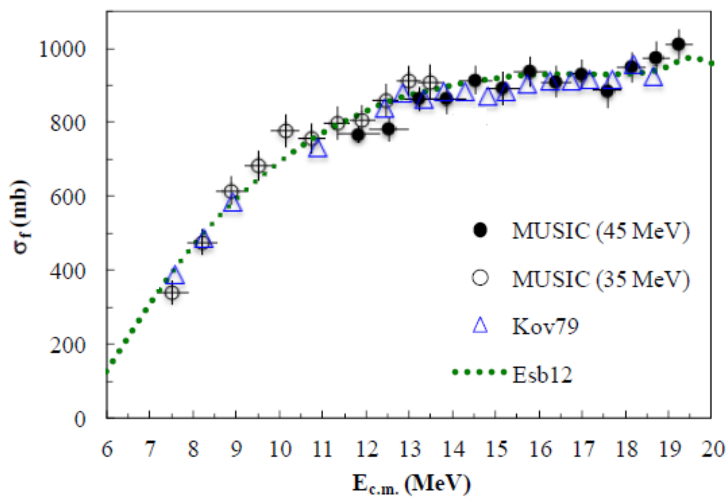
- ^{13}C
- ^{14}C
- ^{15}C: $^{2}H(^{14}C,^{15}C)p$ Rate ~2000/s

^{12}C + ^{13}C fusion – test measurement

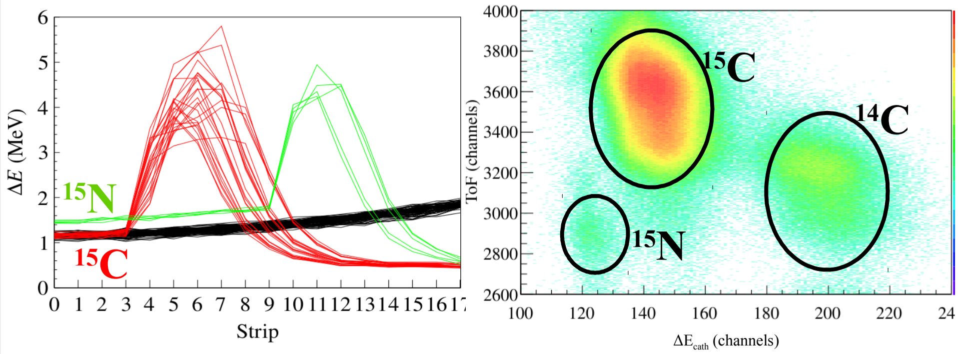




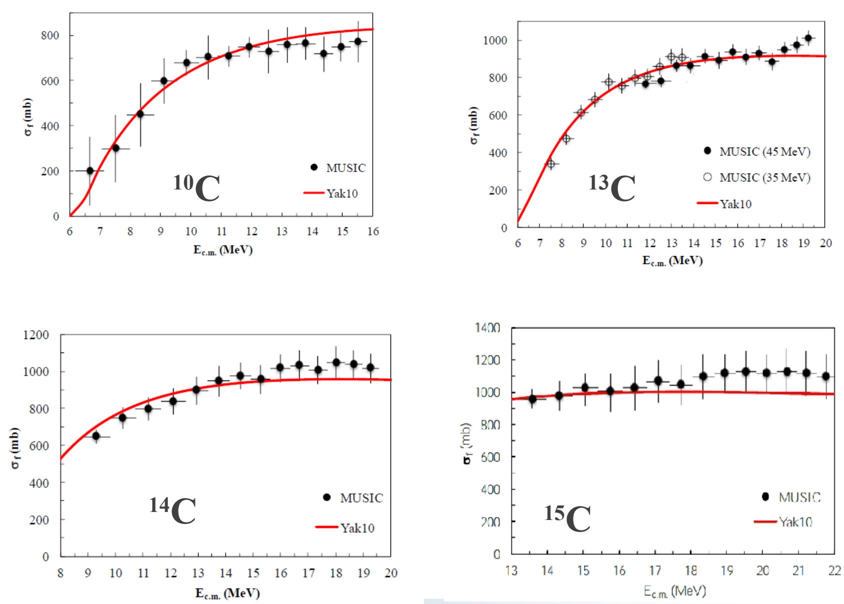
$^{12}C + ^{13}C$ fusion – test measurement



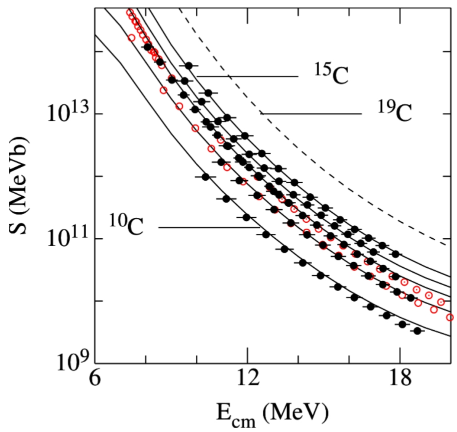
Radioactive beam: $^{12}C + ^{15}C$ fusion

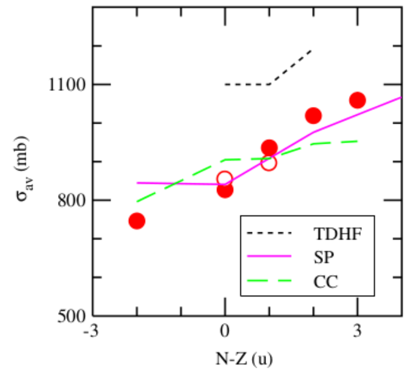


Results: Fusion of ^{12}C +



Go to "View | Header and Footer" to add y

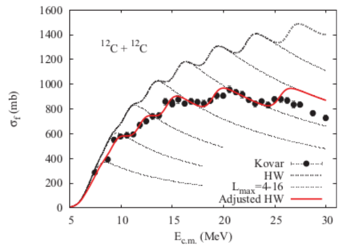


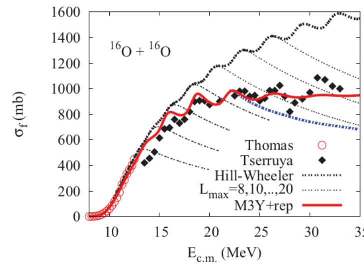


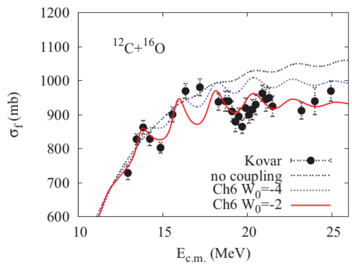
P. F.F Carnelli et al., PRL 112, 192701 (2014)

- Can measure ~12 energies in one experiment.
- Good agreement with theory.

Oscillations above the barrier in fusion data

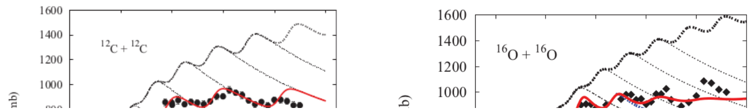






H. Esbensen PRC 85, 064611 (2012)
N. Rowley et al., PRC 91, 044617 (2015)

Oscillations above the barrier in fusion data



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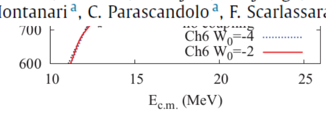
Oscillations above the barrier in the fusion of $^{28}Si + ^{28}Si$

CrossMark

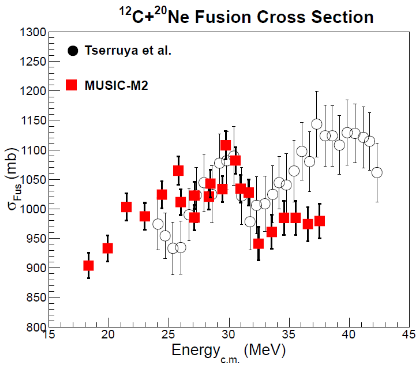
G. Montagnoli [a,*], A.M. Stefanini [b], H. Esbensen [c], L. Corradi [b], S. Courtin [d], E. Fioretto [b], J. Grebosz [e], F. Haas [d], H.M. Jia [b], C.L. Jiang [c], M. Mazzocco [a], C. Michelagnoli [a], T. Mijatović [f], D. Montanari [a], C. Parascandolo [a], F. Scarlassara [a], E. Strano [a], S. Szilner [f], D. Torresi [a]



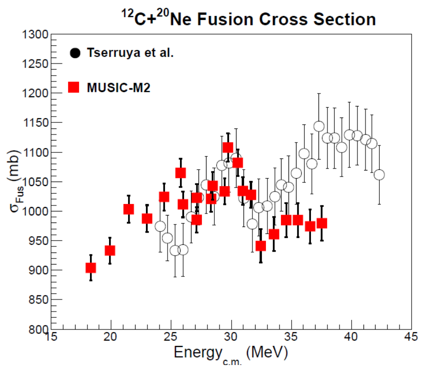
Ongoing Neon Campaign

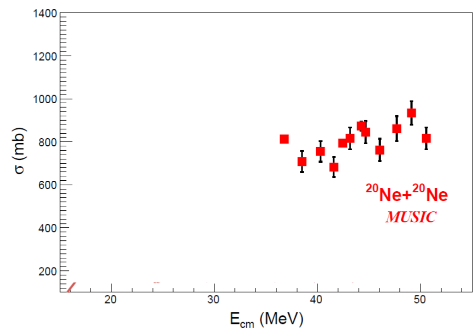
- $^{12}C+^{20}Ne$
- $^{20}Ne+^{20}Ne$
- $^{22}Ne+^{20}Ne$
- $^{22}Ne+^{22}Ne$
- $^{22}Ne+^{24}Ne$
- $^{20}Ne+^{24}Ne$

Neon campaign results

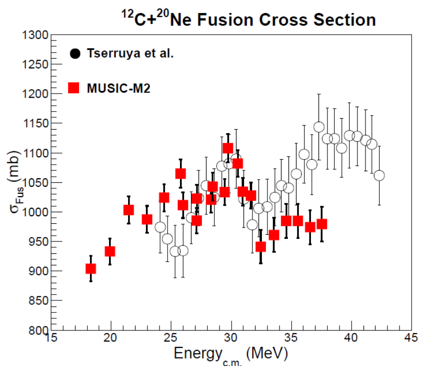


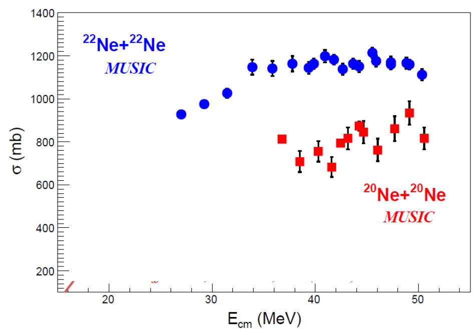
Neon campaign results





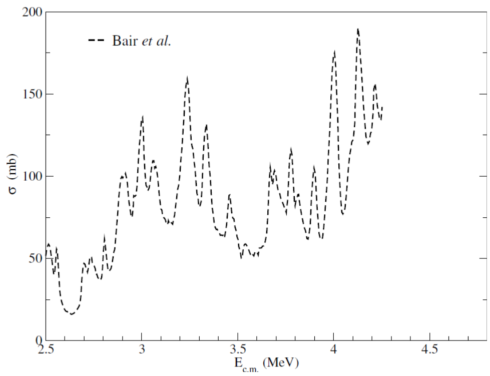
Neon campaign results





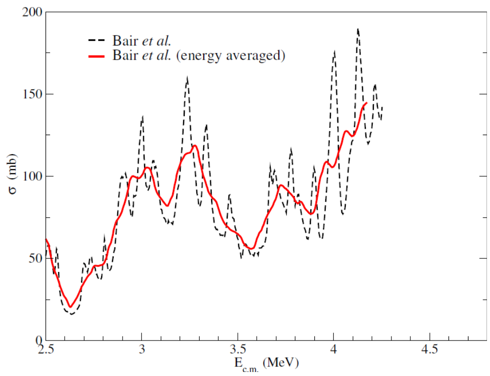
What else can we measure?

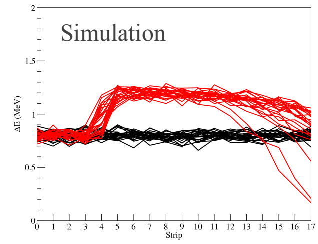
The $^{17}O(\alpha,n)^{20}Ne$ reaction with MUSIC



J.K. Bair, et al. Phys. Rev. C **7**, 1356 (1973).

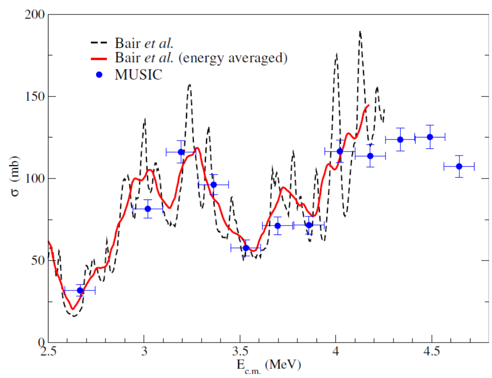
The $^{17}O(\alpha,n)^{20}Ne$ reaction with MUSIC



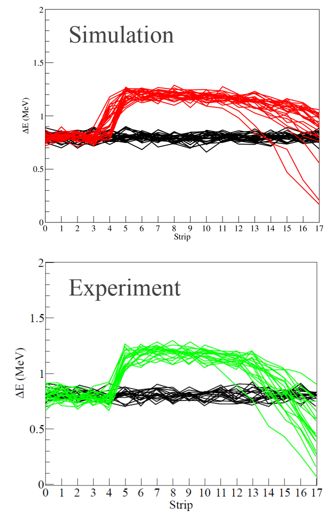


J.K. Bair, et al. Phys. Rev. C **7**, 1356 (1973).

The $^{17}O(\alpha,n)^{20}Ne$ reaction with MUSIC

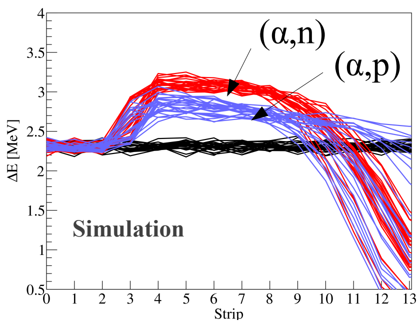


J.K. Bair, et al. Phys. Rev. C **7**, 1356 (1973).



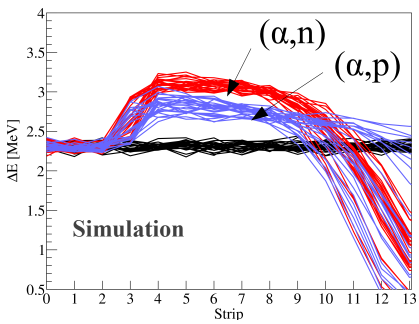
What about (α,p)?

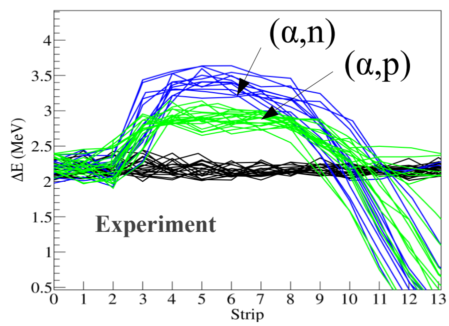
The ^{23}Na(α,p) reaction with MUSIC!



The ^{23}Na(α,p) reaction with MUSIC!

E_{cm} ~ 2.5 MeV to 6 MeV





Conclusions

- Fusion reactions play an important role. Many of this reactions involve radioactive beams.
- The high efficient detector MUSIC measures excitation functions with a single beam energy.
- Test experiments with $^{12,13}C$ are in very good agreement with previous data.
- Measured for the first time, excitation functions for ^{12}C + $^{10,14,15}C$ with radioactive carbon isotopes which are of interest in nuclear astrophysics.
- Measured $^{20,22}Ne$+$^{20,22}Ne$ excitation functions.
- New possibilities measuring (α,n) and (α,p) reactions.

Collaborators

K.E. Rehm, S. Almaraz-Calderon, P.F.F. Carnelli (TANDAR), B. DiGiovine, H. Esbensen, D. Henderson, C.R. Hoffman, C.L. Jiang, B.P. Kay, J. Lai (LSU), O. Nusair, R.C. Pardo, M. Paul, D. Santiago-Gonzalez (LSU), R. Talwar, C. Ugalde

Thanks for your attention !