Reactions with weakly bound nuclei around the Coulomb barrier

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INCT-FNA
INSTITUTO NACIONAL DE CIÊNCIA E TECNOLOGIA FÍSICA NUCLEAR E APLICAÇÕES

XIV LASNPA 2024

Outline

1. Motivation

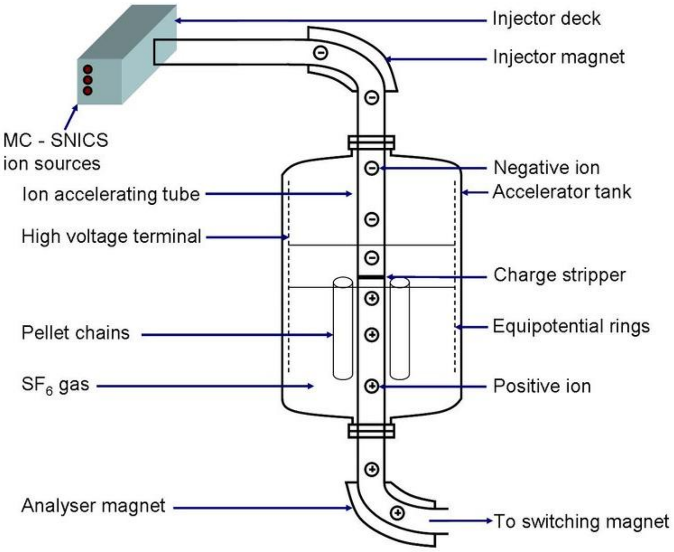
2. LAFNA (Open Laboratory for Nuclear Physics & Applications)

3. Scientific program: Measurements and Results

4. Conclusions

Reactions at energies around the Coulomb barrier

Why are we still doing research with electrostatic accelerators?

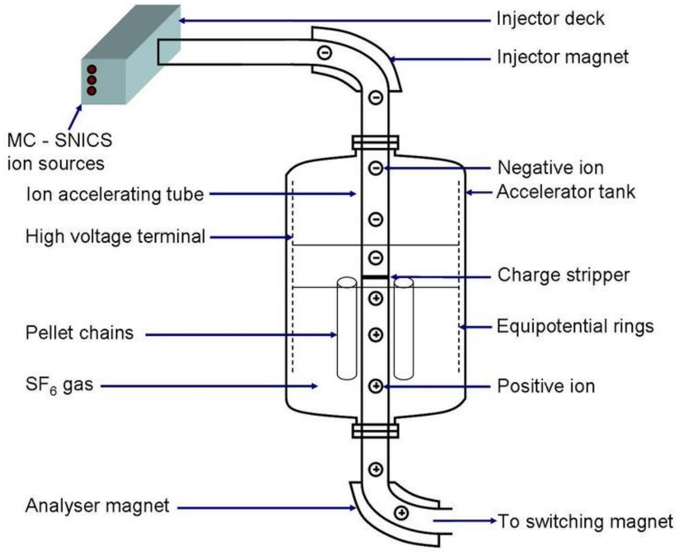


Reactions at energies around the Coulomb barrier

Why are we still doing research with electrostatic accelerators?

... to address important questions in

- nuclear structure
- nuclear reactions
- nuclear astrophysics



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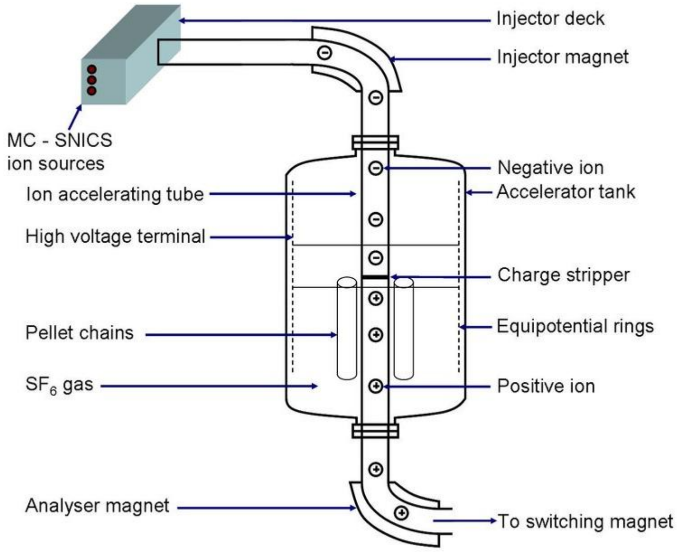
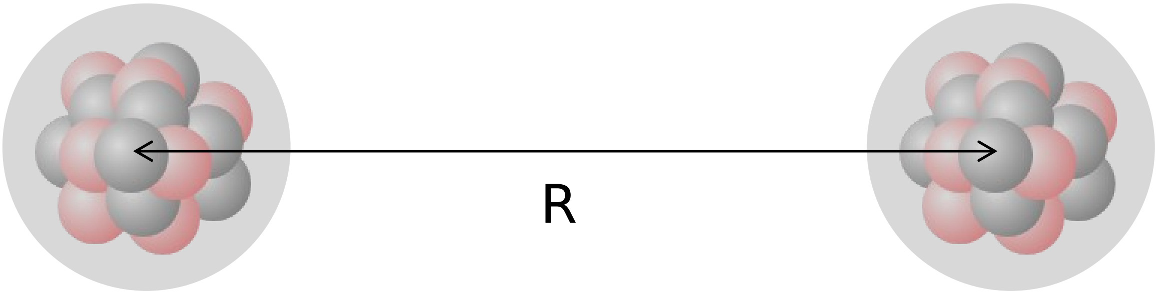
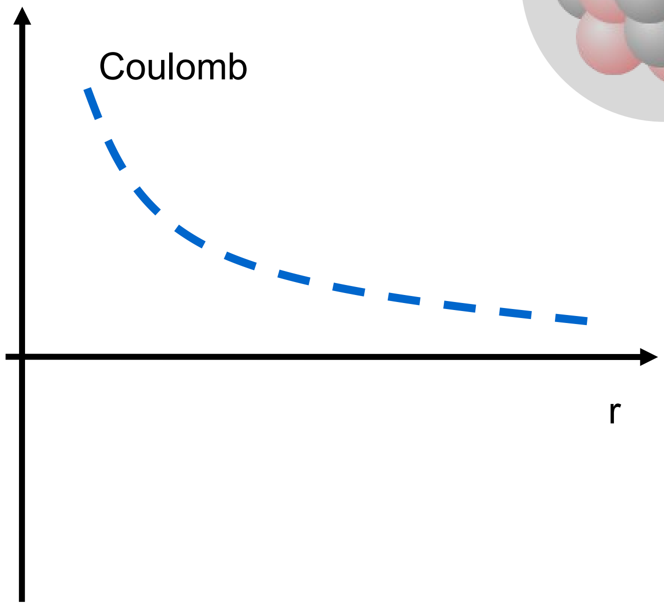


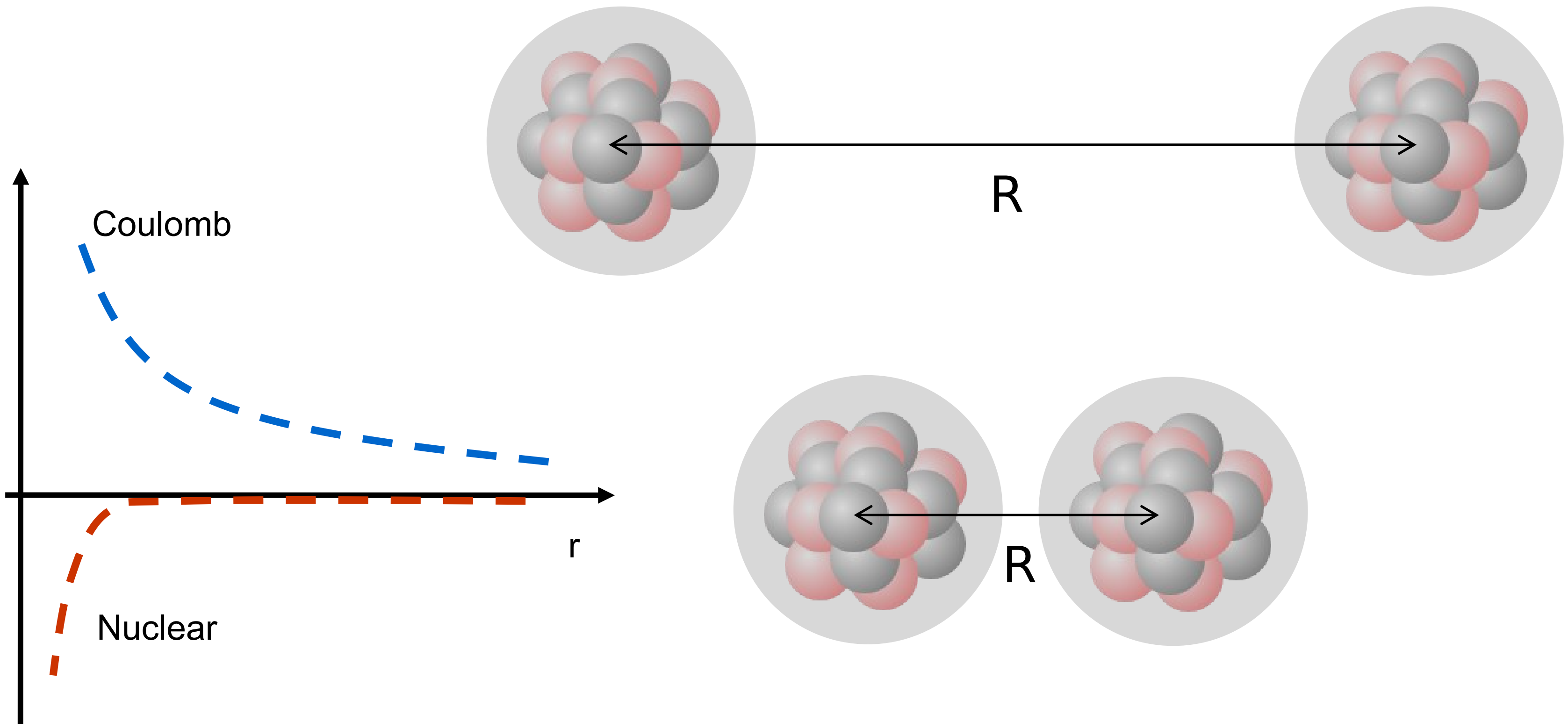
... develop into applications related to health, materials science, biology and medicine, aerospace technologies, and many others ...

Reactions at energies around the Coulomb barrier

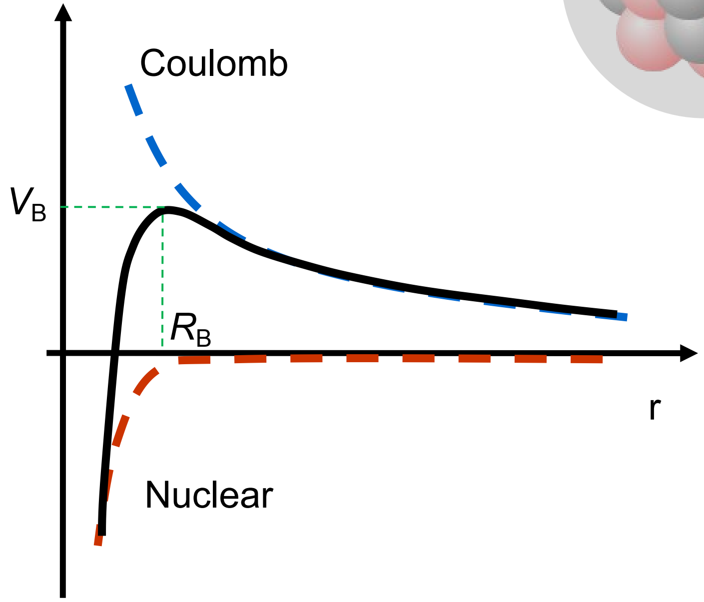


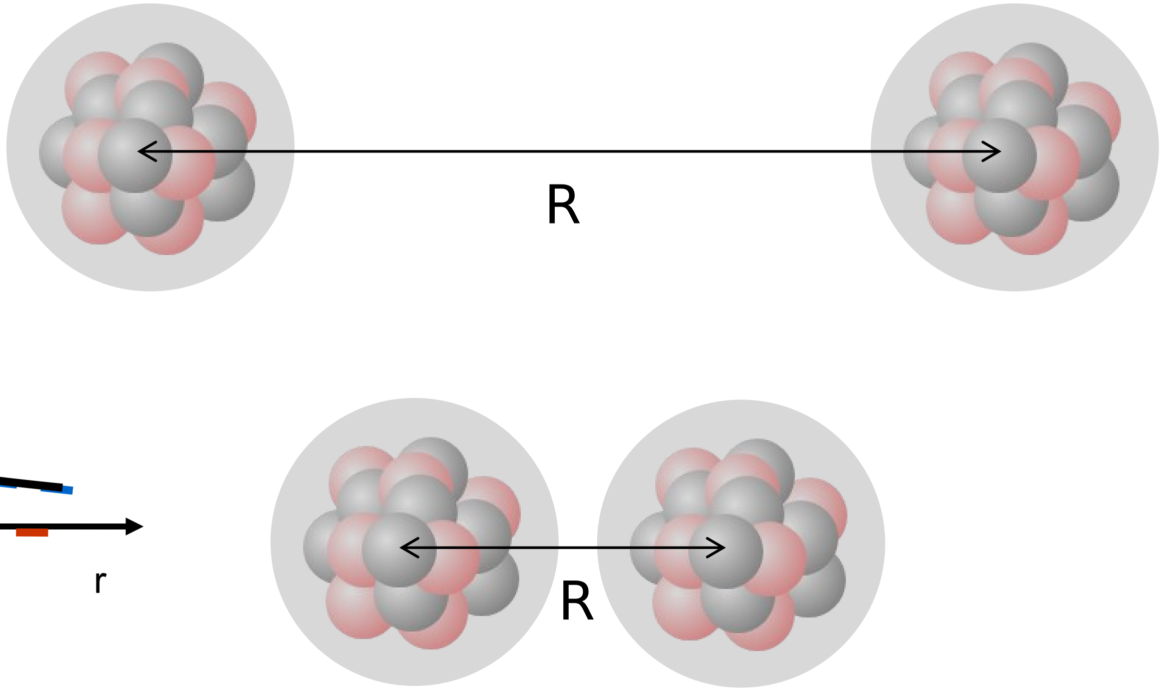


Reactions at energies around the Coulomb barrier



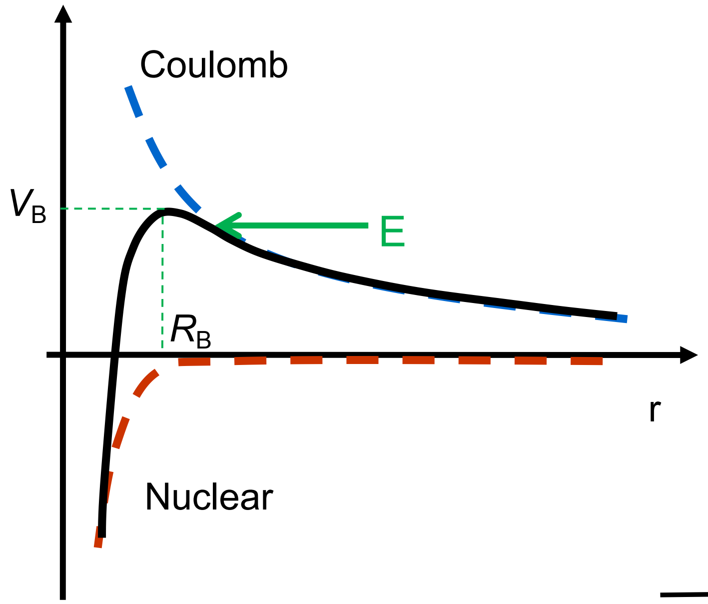
Reactions at energies around the Coulomb barrier

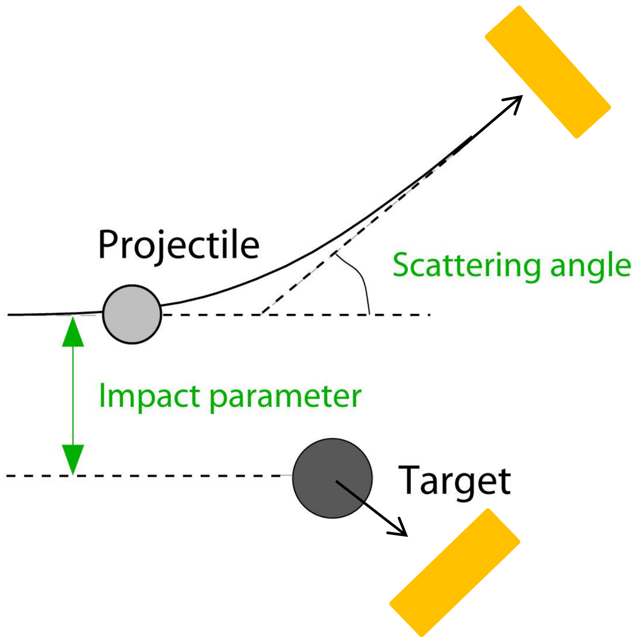




Reactions at energies around the Coulomb barrier

Elastic scattering: overwhelming process





→ very useful for probing the nuclear interaction!!!

Optical model

Complex potential:

$$\boldsymbol{U} = \boldsymbol{V} + i\boldsymbol{W}$$

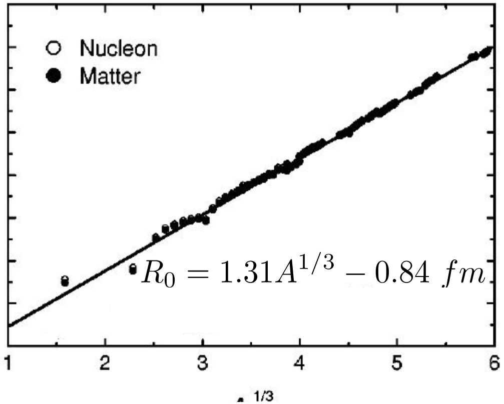
$$\left(-\frac{\hbar^2}{2\mu}\nabla^2 + \boldsymbol{U} - E\right)\Psi = 0$$

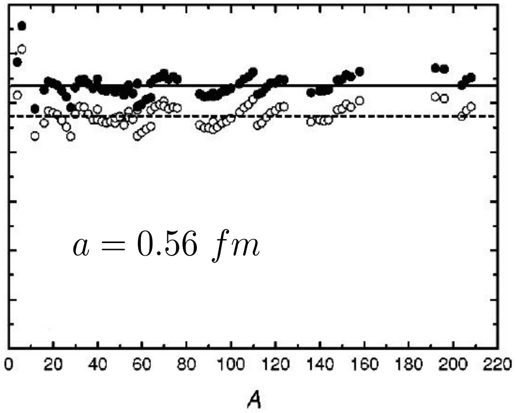
The São Paulo potential:

$$V_{SPP} = \int \rho_1(r_1)\rho_2(r_2)V_0\delta(\vec{R} - \vec{r}_1 + \vec{r}_2)e^{-4v^2/c^2}d\vec{r}_1 d\vec{r}_2$$

$$v^2 = \frac{2}{\mu}E_k(R) = \frac{2}{\mu}[E - V_C(R) - V_{SPP}(R,E)]$$

$$\rho = \rho_0\left[1 + e^{(r-R_0)/a}\right]^{-1}$$





PHYSICAL REVIEW C
covering nuclear physics

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Toward a global description of the nucleus-nucleus interaction

L. C. Chamon, B. V. Carlson, L. R. Gasques, D. Pereira, C. De Conti, M. A. G. Alvarez, M. S. Hussein, M. A. Cândido Ribeiro, E. S. Rossi, Jr., and C. P. Silva

Phys. Rev. C **66**, 014610 – Published 17 July 2002

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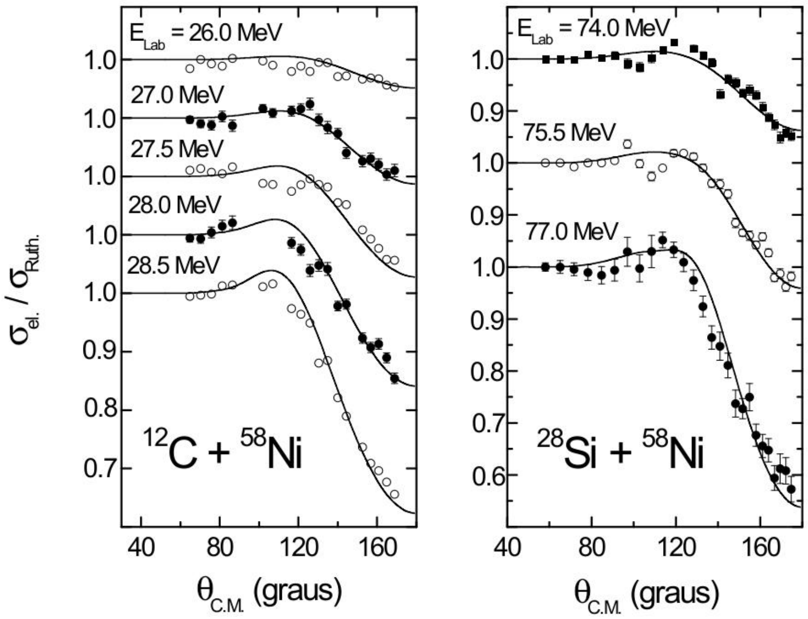
L. R. Gasques - PhD thesis - 2003



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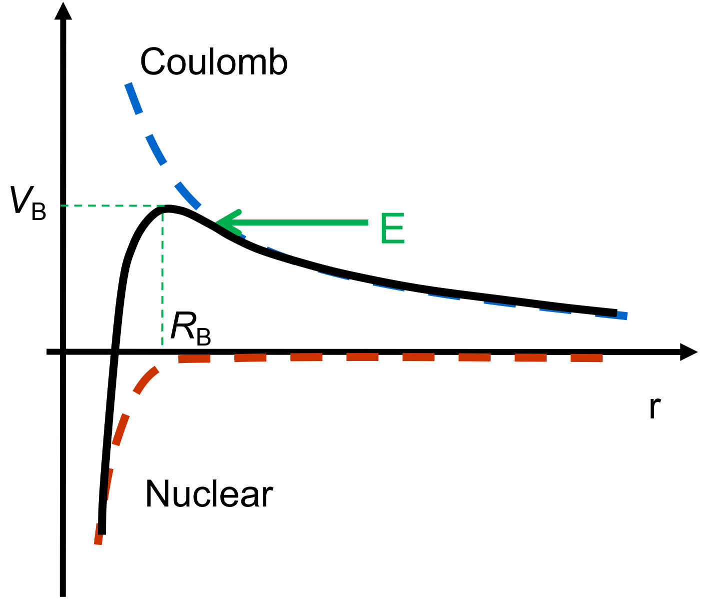
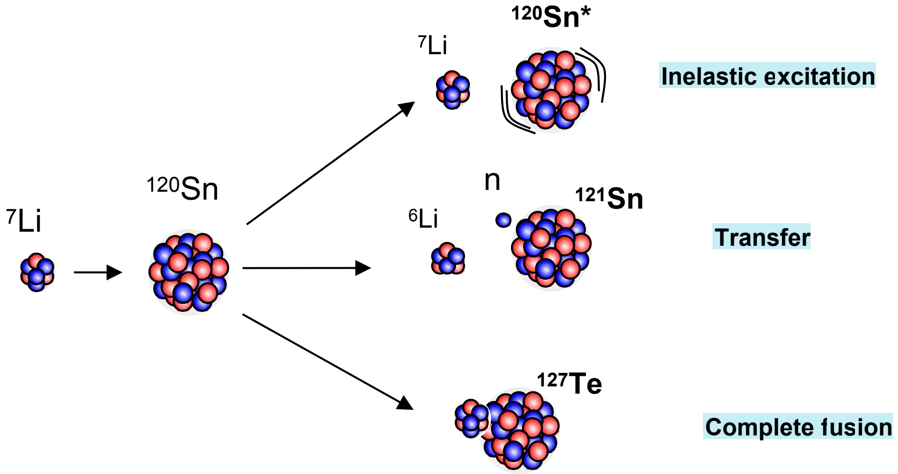
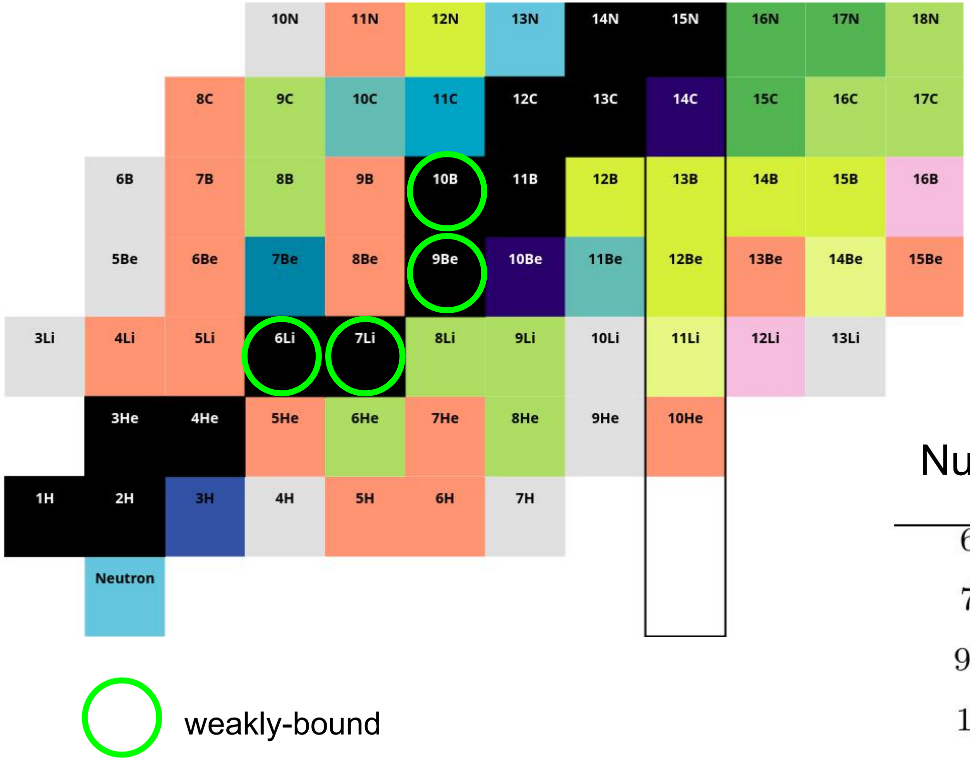
Reactions at energies around the Coulomb barrier

Besides the elastic scattering, other processes may occur ...





Weakly-bound nuclei - Cluster structure



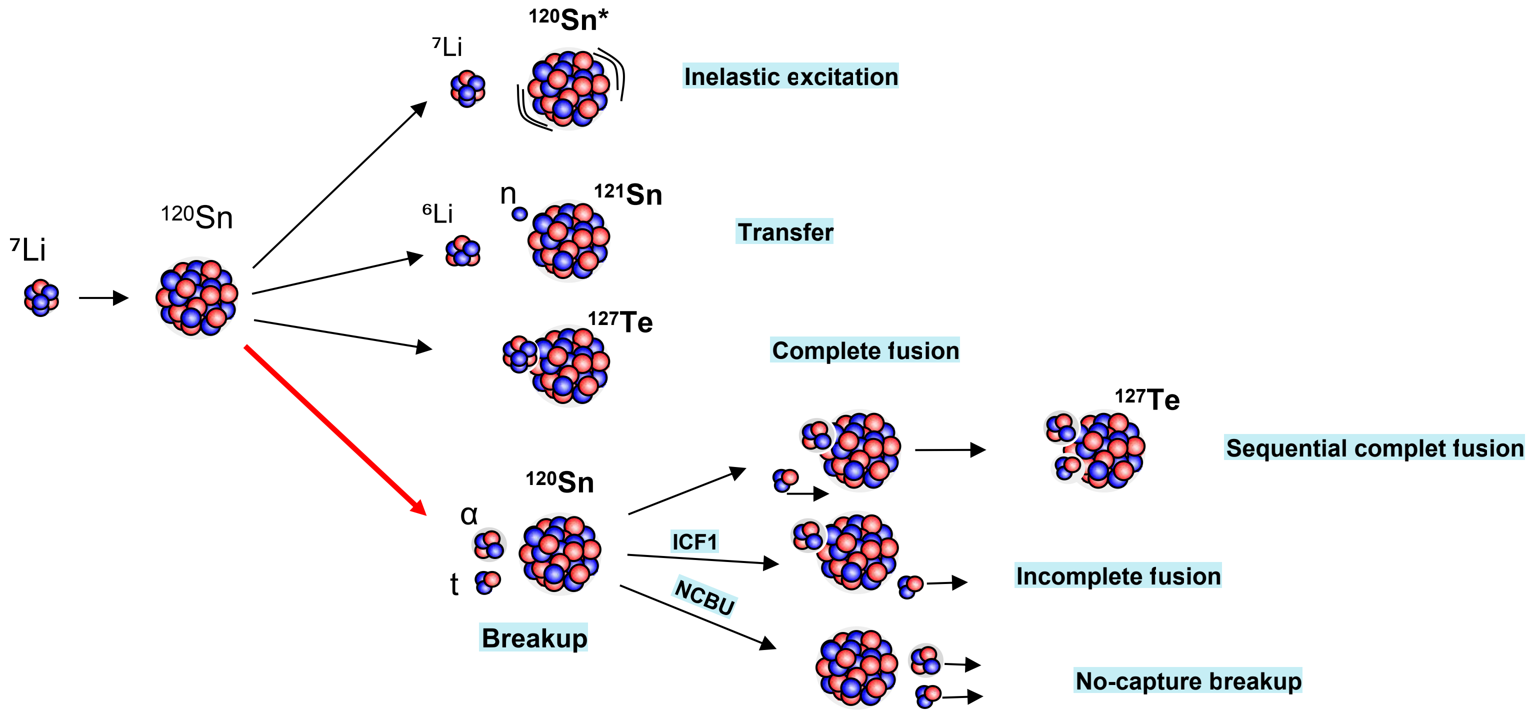
Nucleus	Cluster	B.E. (MeV)
$^{6}\mathrm{Li}$	$\alpha + \mathrm{d}$	1.474
$^{7}\mathrm{Li}$	$\alpha + \mathrm{t}$	2.467
$^{9}\mathrm{Be}$	$\alpha + \alpha + \mathrm{n}$	1.665
$^{10}\mathrm{B}$	$^{6}\mathrm{Li} + \alpha$	4.46

https://www.nndc.bnl.gov/nudat3/

Courtesy of V. Scarduelli

Reactions at energies around the Coulomb barrier

Weakly-bound nucleus = larger probabilty to breakup



Reactions at energies around the Coulomb barrier

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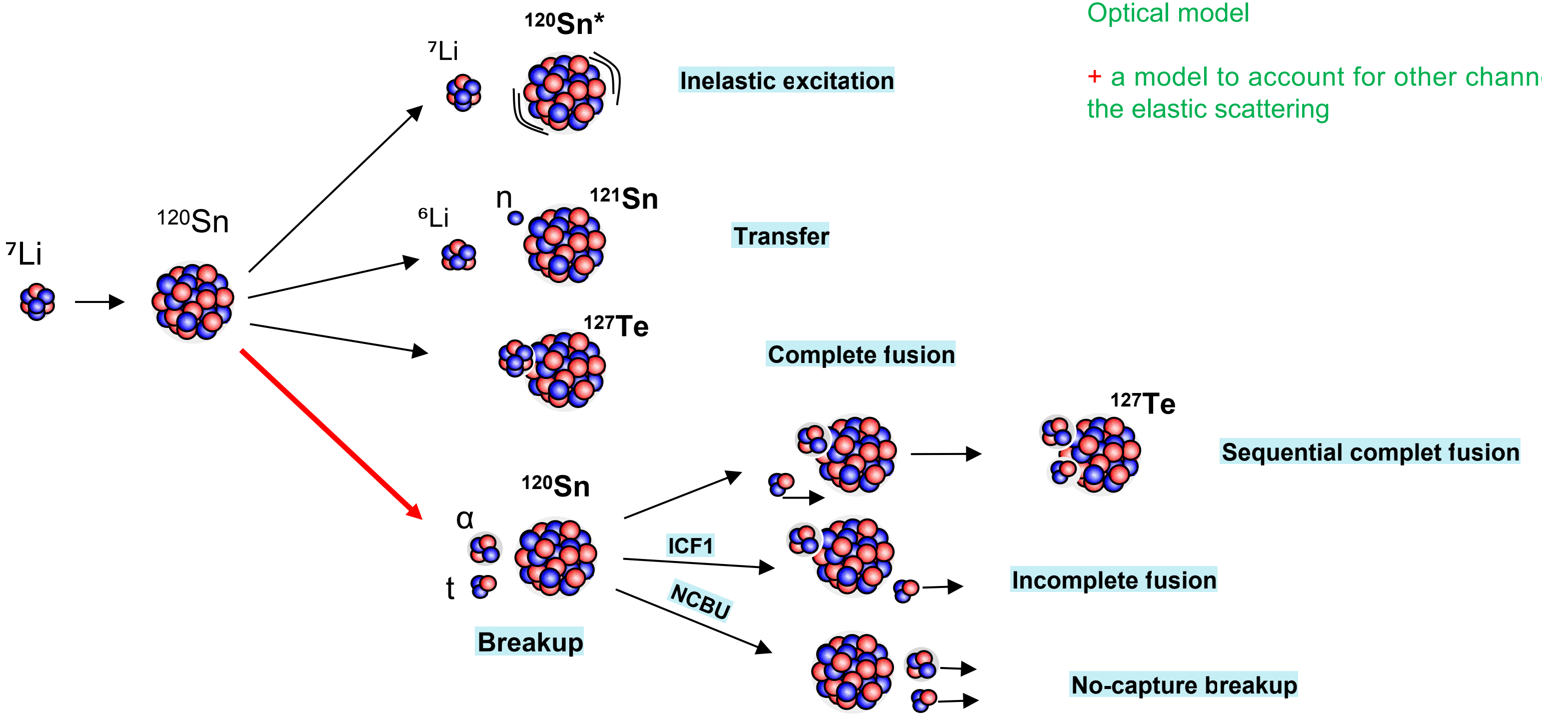
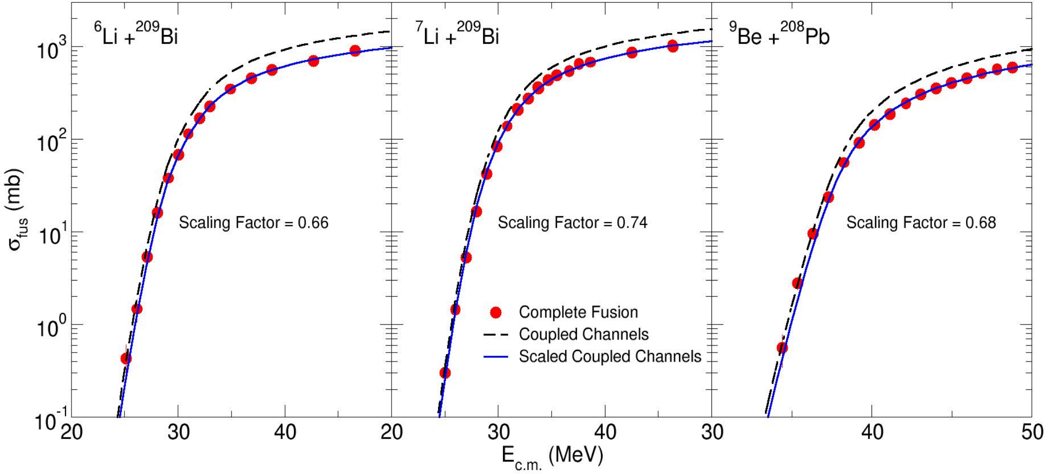
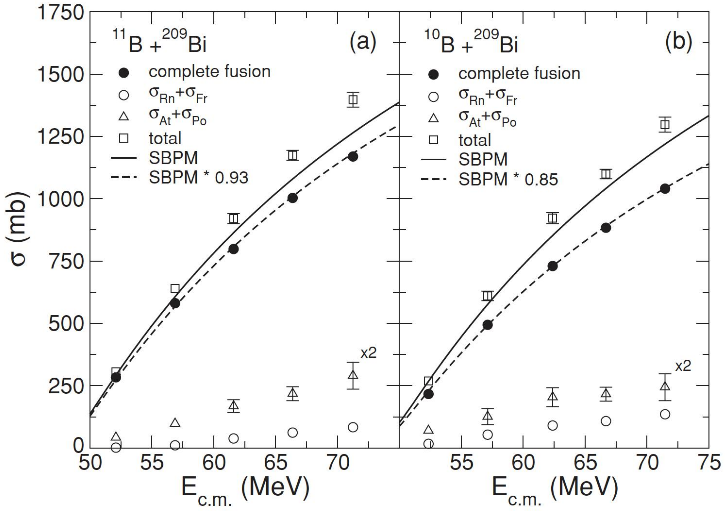


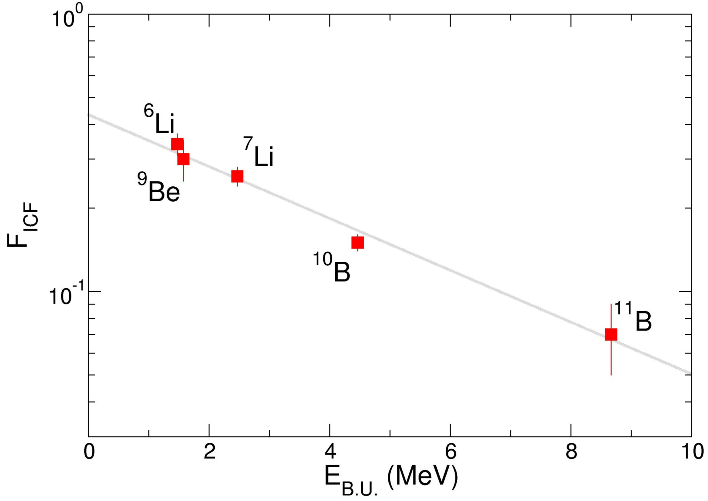
Optical model

+ a model to account for other channels besides the elastic scattering

Reaction dynamics: weakly-bound projectiles

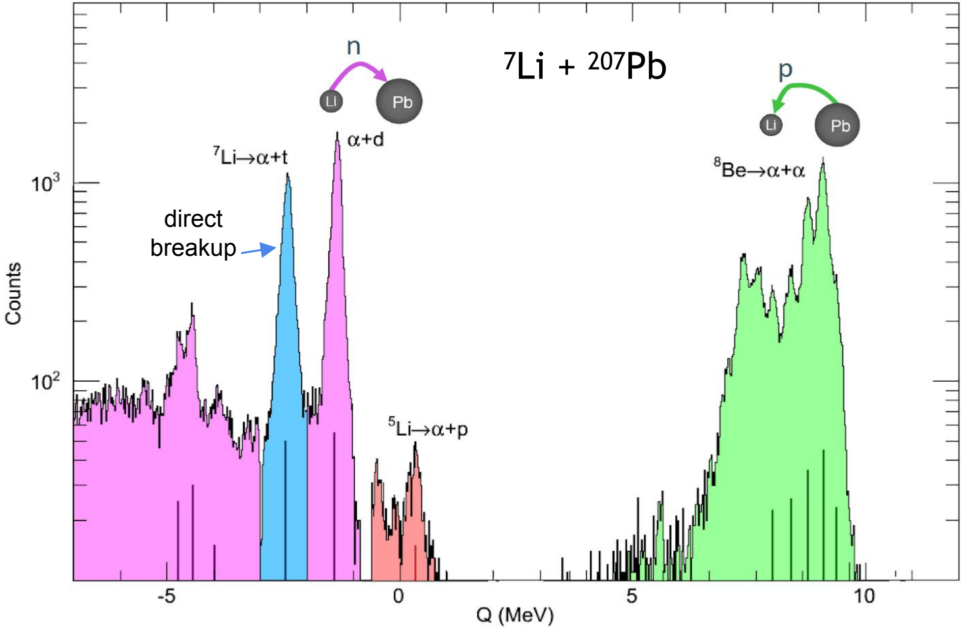






Australian National University

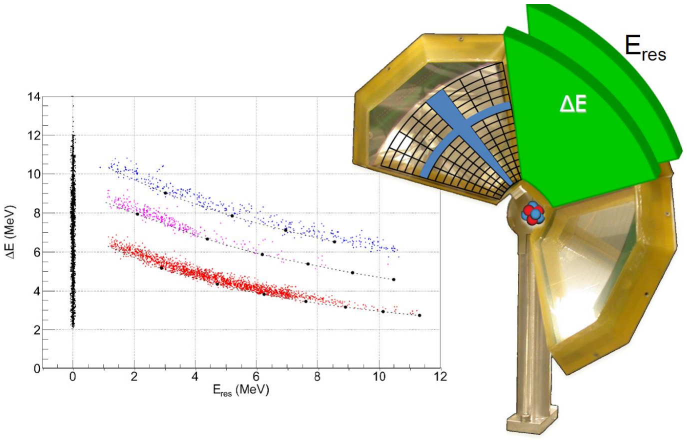
Nature should be simple... but apparently it is not



PHYSICAL REVIEW C **88,** 034609 (2013)

D.H. Luong, et al.

DOI: 10.1103/PhysRevC.88.034609



BALiN (Breakup Array for Light Nuclei)

Breakup followed by transfer

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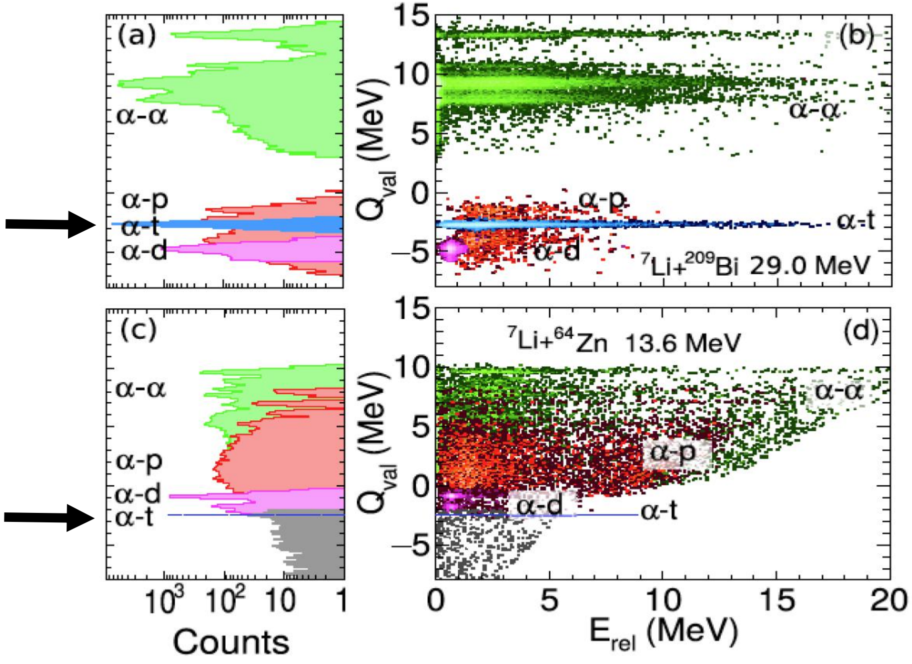

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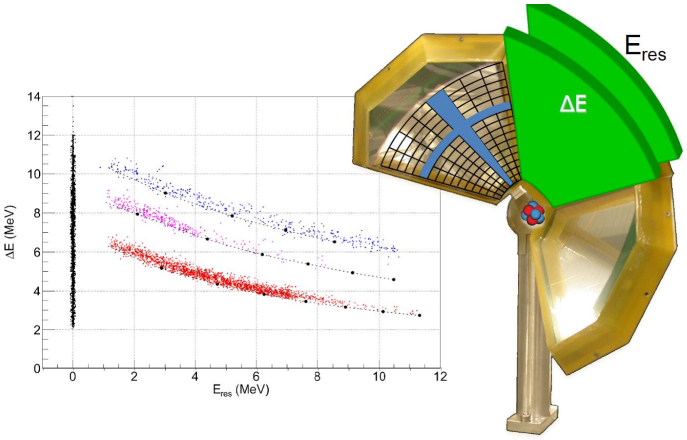
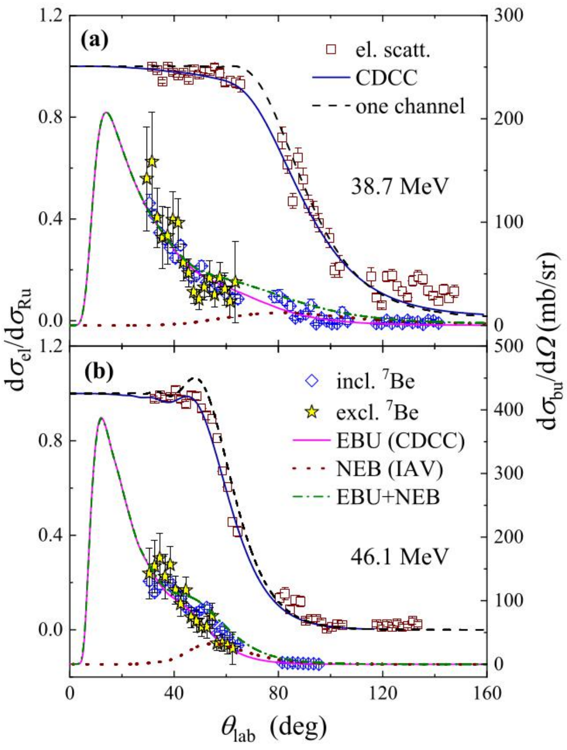


BALiN (Breakup Array for Light Nuclei)

Breakup followed by transfer

^{8}B + ^{120}Sn breakup



nature communications

Article

https://doi.org/10.1038/s41467-022-34767-8

Breakup of the proton halo nucleus ^{8}B near barrier energies

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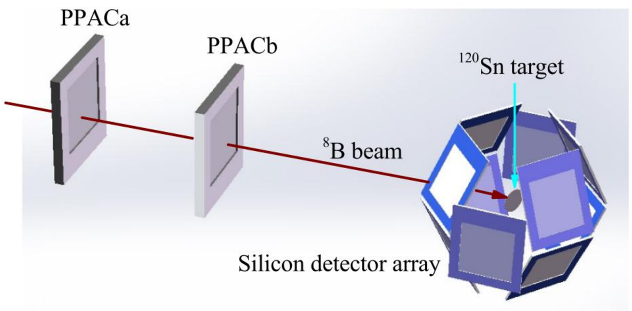
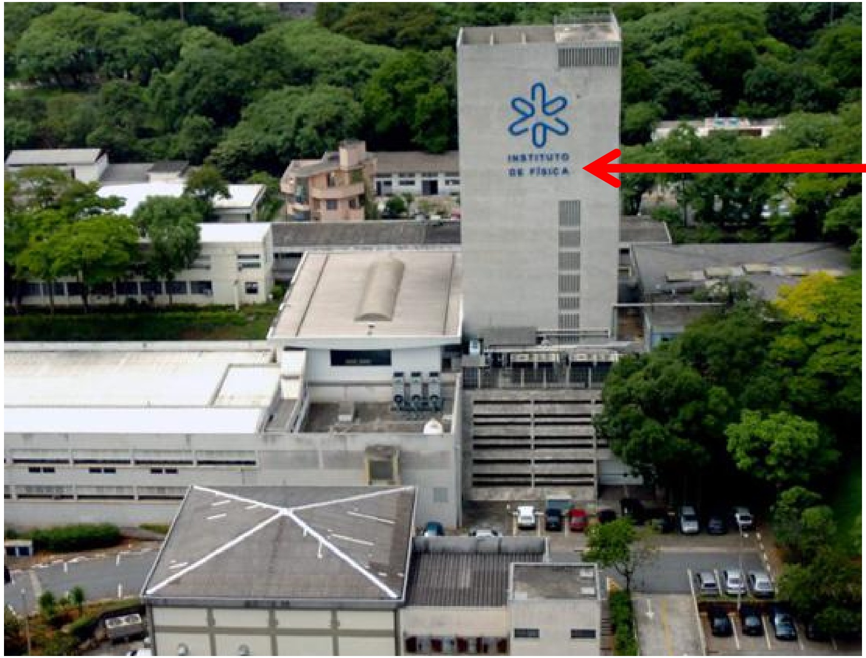
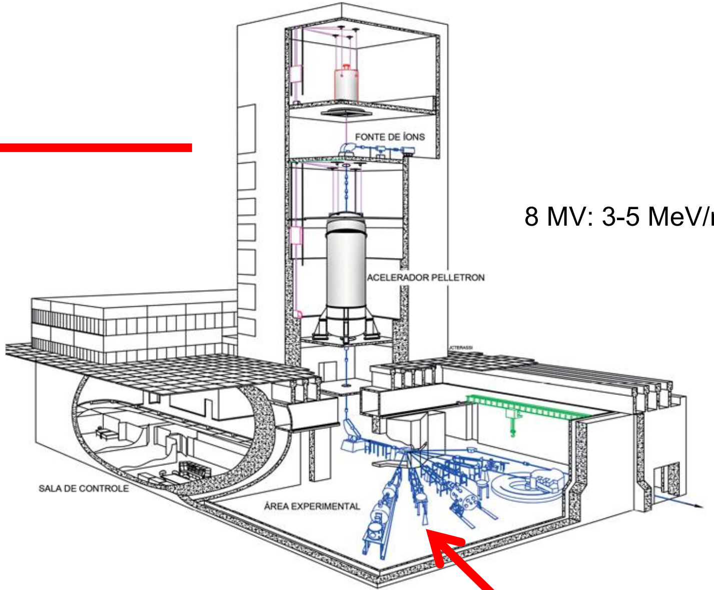
Check for updates

L. Yang[1,2], C. J. Lin[1,3], H. Yamaguchi[2,4], A. M. Moro[5,6], N. R. Ma[1,2], D. X. Wang[1], K. J. Cook[7,8,21], M. Mazzocco[9,10], P. W. Wen[1], S. Hayakawa[2], J. S. Wang[11], Y. Y. Yang[12], G. L. Zhang[13], Z. Huang[13], A. Inoue[14], H. M. Jia[1], D. Kahl[15], A. Kim[16], M. S. Kwag[17], M. La Commara[18], G. M. Gu[17], S. Okamoto[19], C. Parascandolo[20], D. Pierroutsakou[20], H. Shimizu[2], H. H. Sun[1], M. L. Wang[13], F. Yang[1] & F. P. Zhong[1,3]



LAFNA - IF - USP





8 MV: 3-5 MeV/nucleon

30B beamline

30B SETUP - TIMELINE

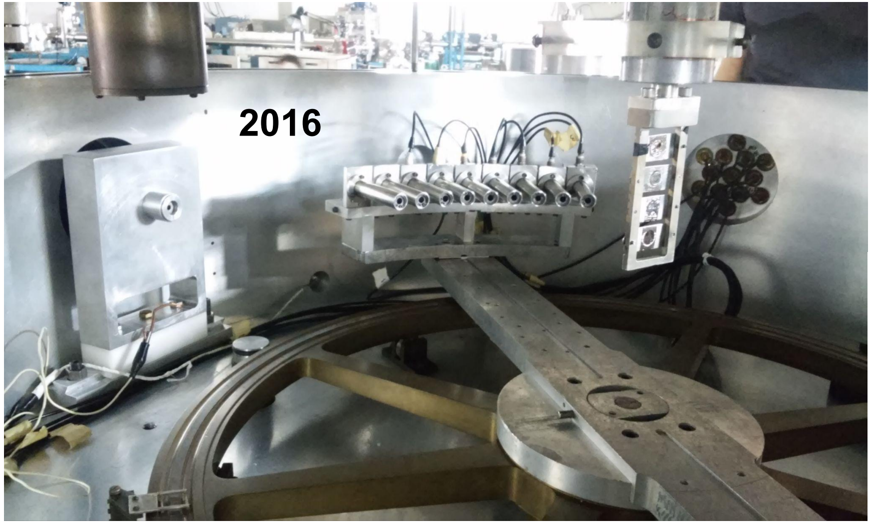
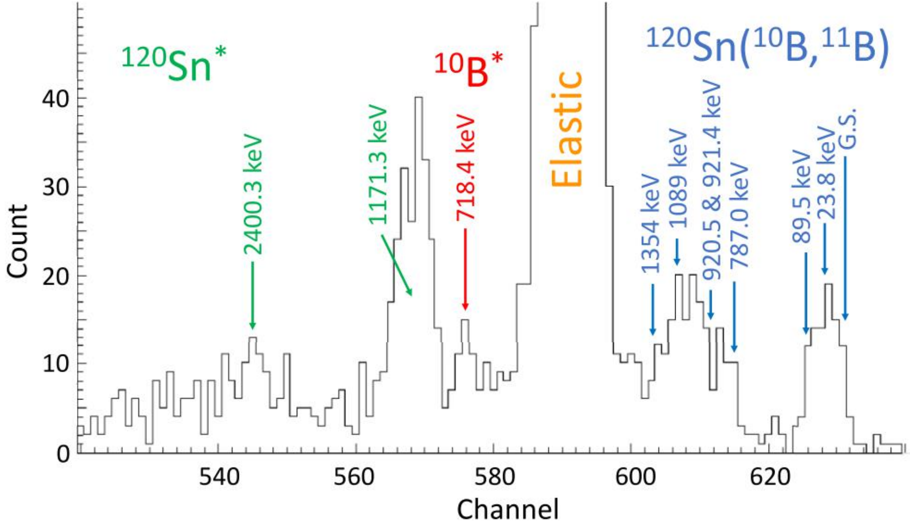


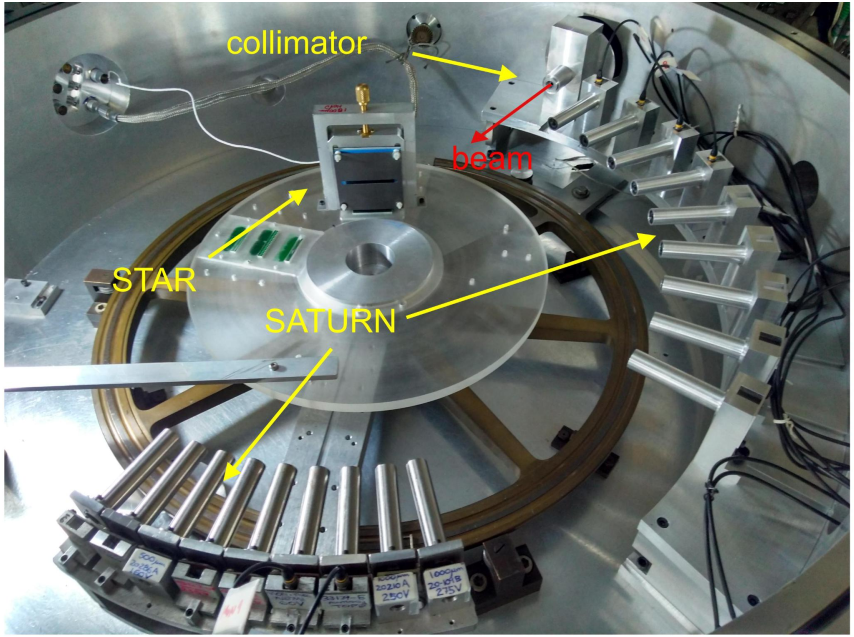
Image from Juicing Vegetables

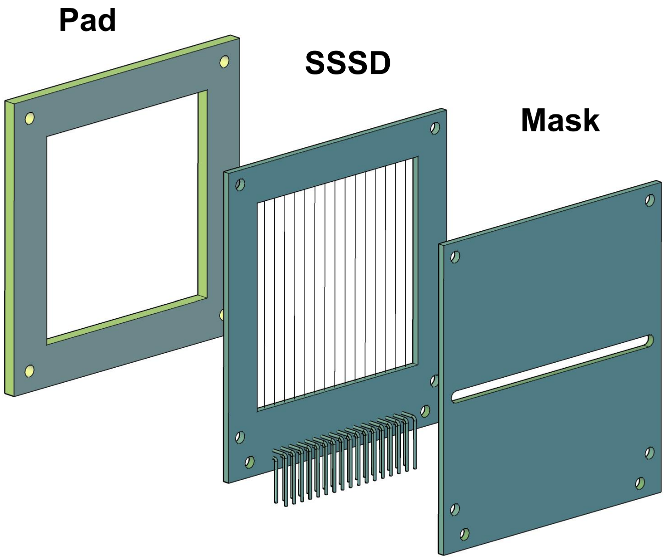
$^{10}B + ^{120}Sn$ @ 40 MeV



30B SETUP - TIMELINE

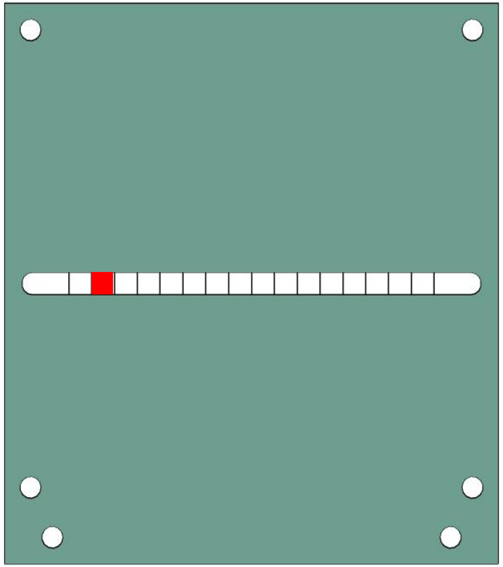
2018





30B SETUP - TIMELINE

16 pseudo-telescopes



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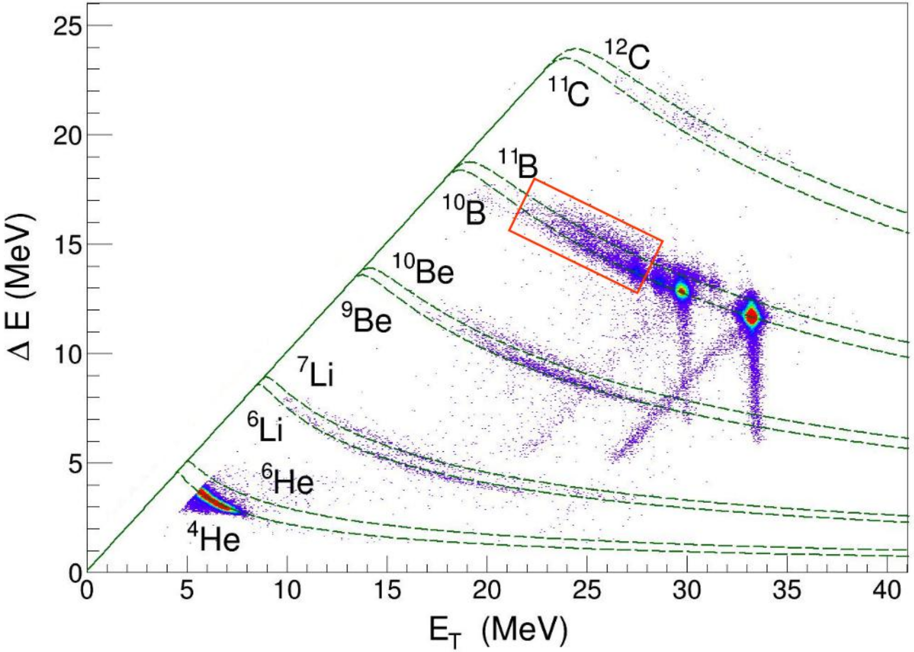

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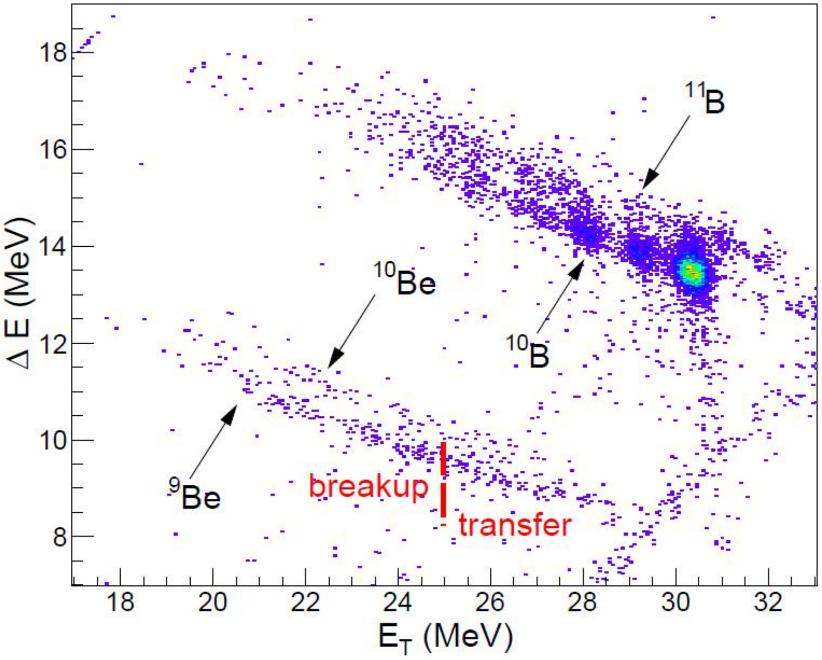
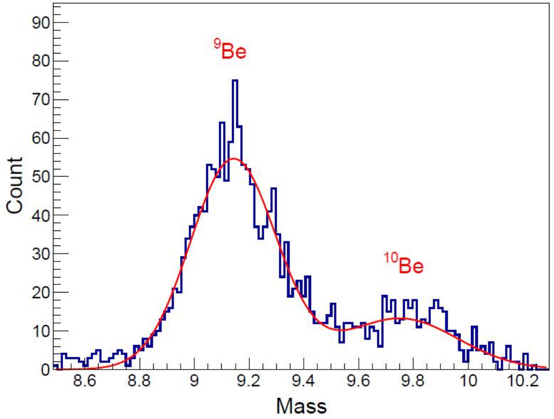
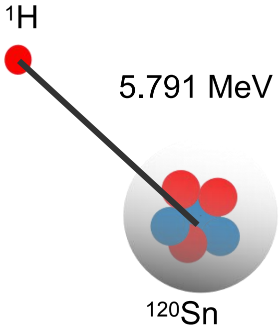
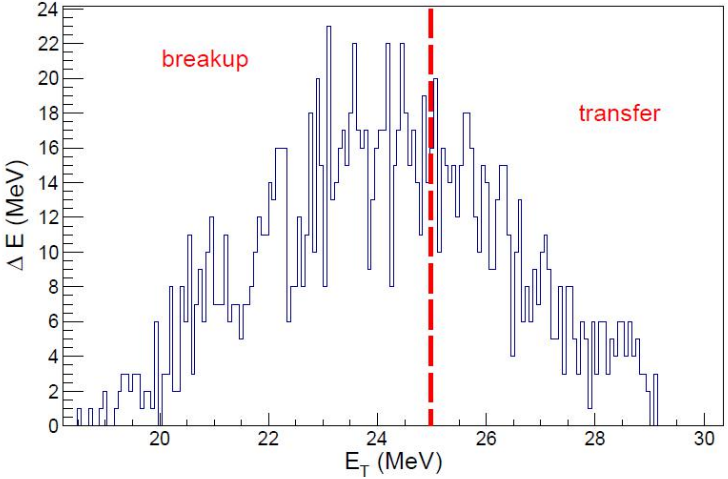
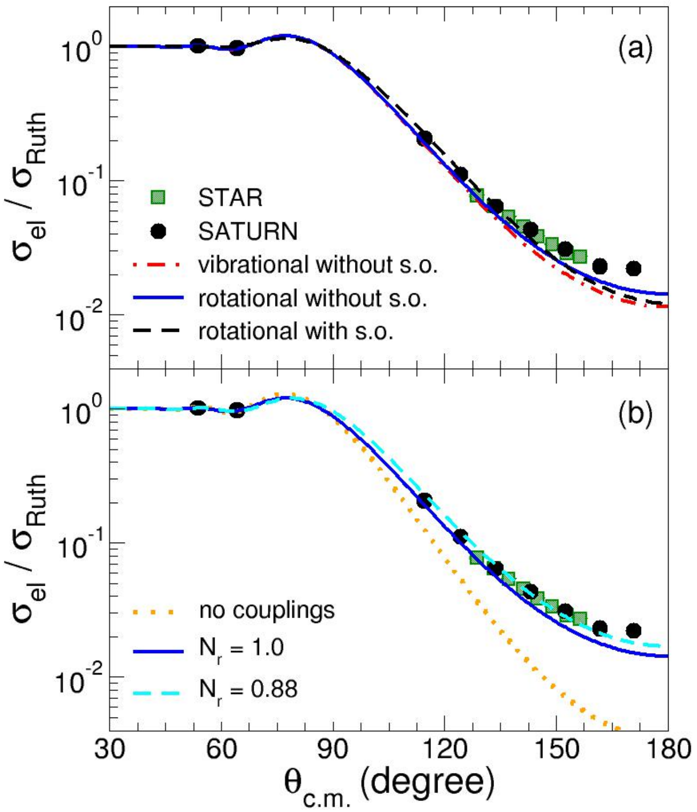


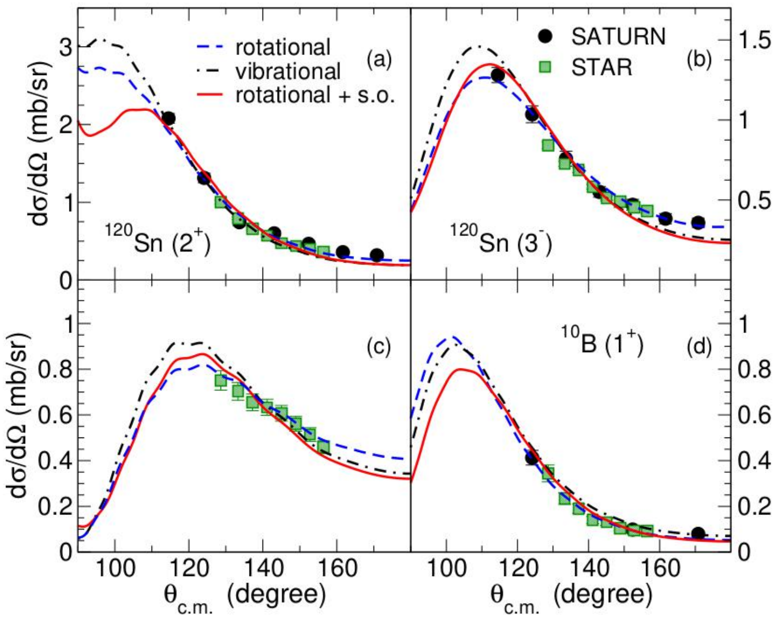






Coupled-channel calculations





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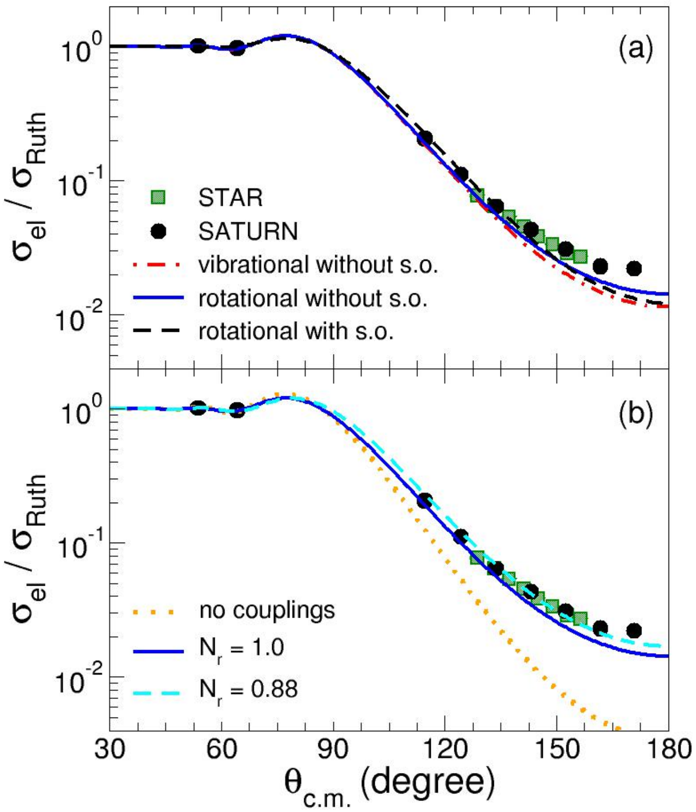
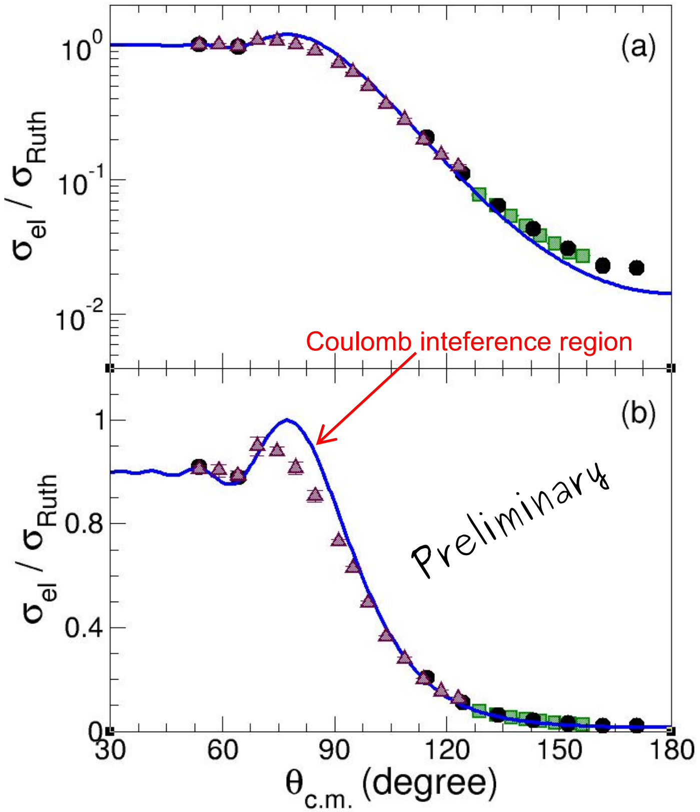
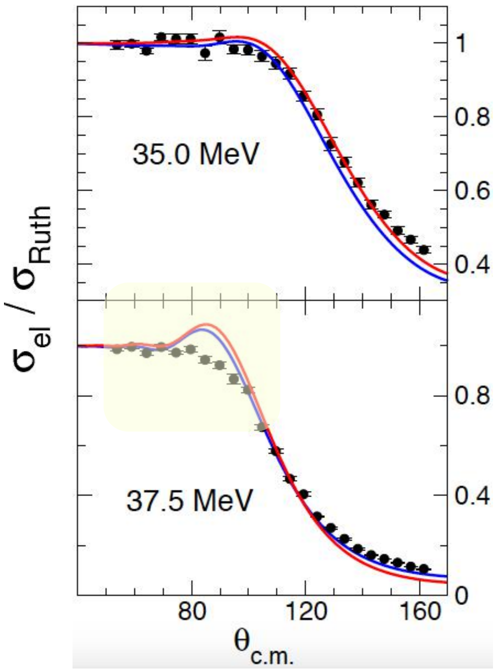




Weakly-bound nuclei - Cluster structure



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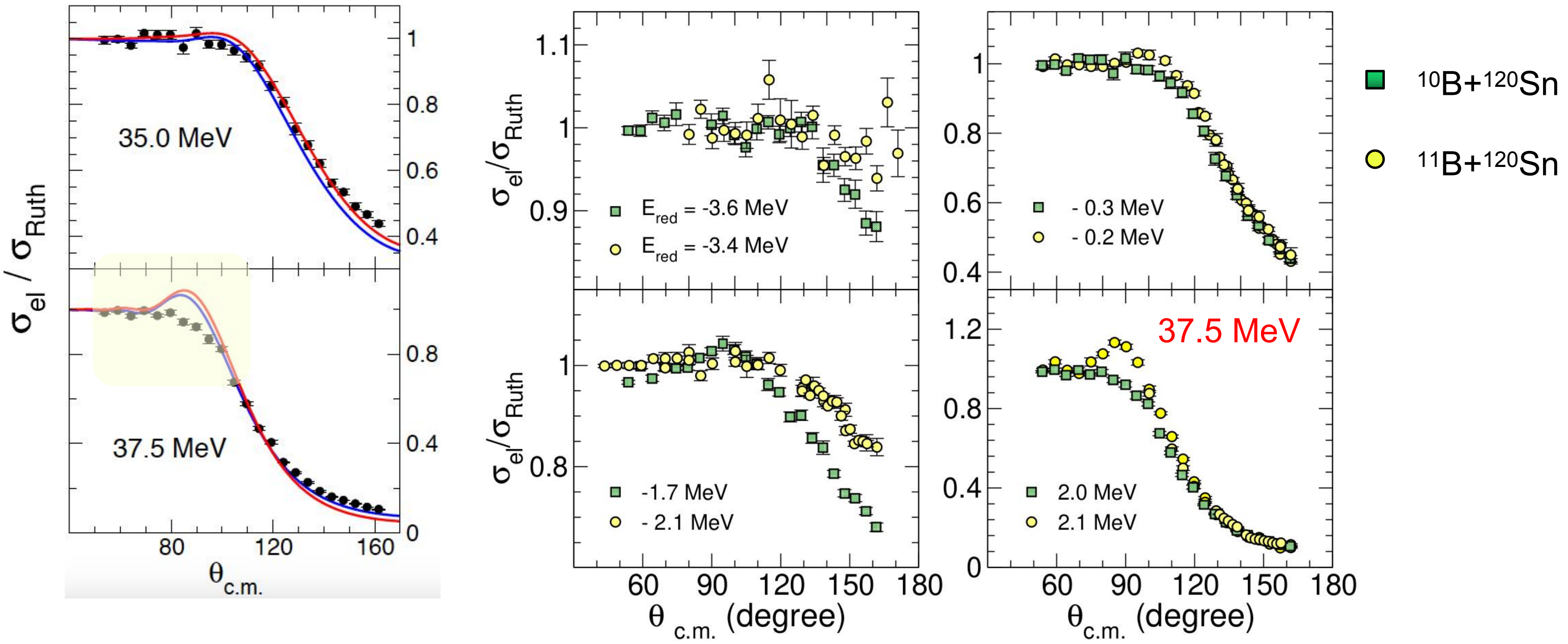


Inclusive measurements

$^{6,7}Li + ^{120}Sn$

$^{6,7}Li + ^{124}Sn$

$^{10,11}B + ^{120}Sn$

$^{10}B + ^{197}Au$

Exclusive measurements

$^{6,7}Li + ^{196}Pt$

$^{6,7}Li + ^{119}Sn$

$^{10,11}B + ^{119}Sn$

$^{12,13}C + ^{64}Zn$

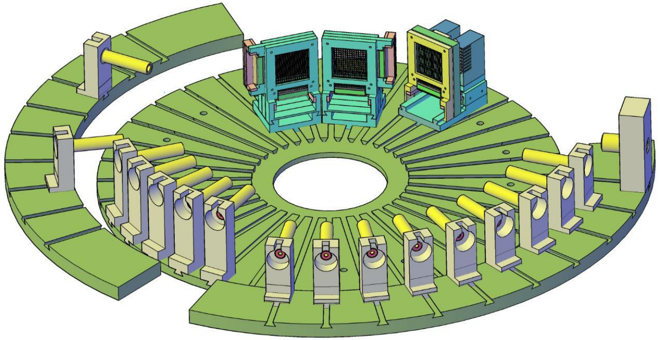
$^{12,13}C + ^{119,120}Sn$

2016

2022

2023

Inclusive measurements



Basic requirements:

- Large granularity
- Large geometric efficiency

Exclusive measurements

$^{6,7}Li + {}^{196}Pt$

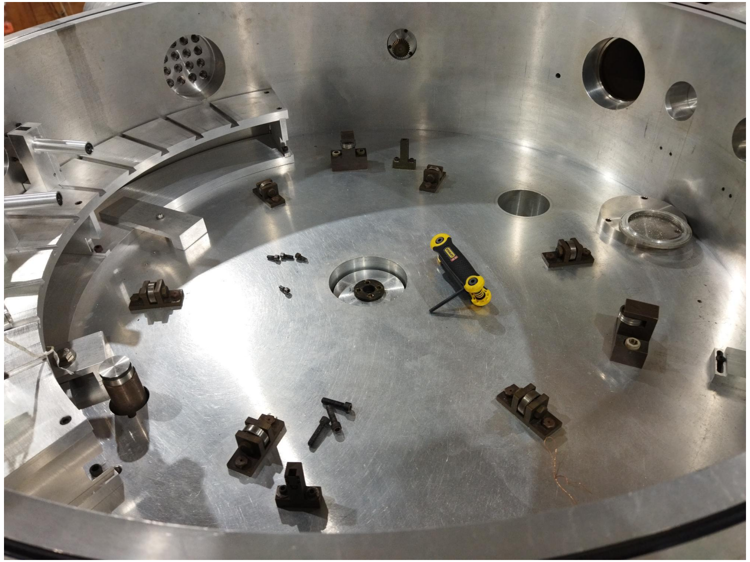
$^{6,7}Li + {}^{119}Sn$

$^{10,11}B + {}^{119}Sn$

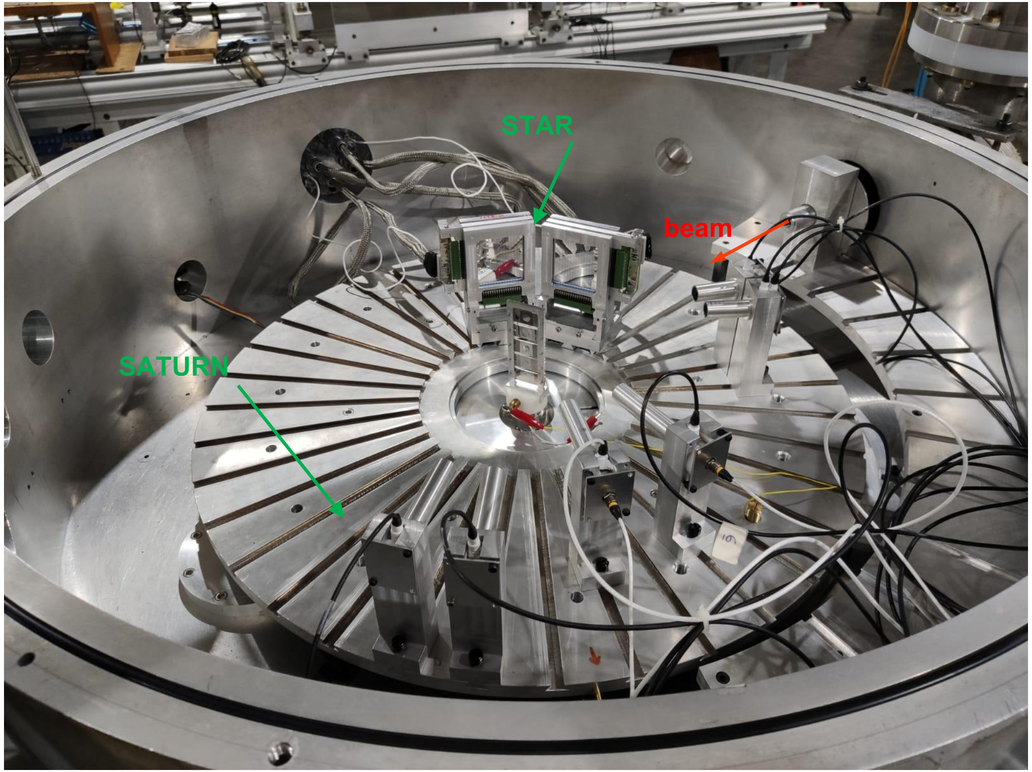
$^{12,13}C + {}^{64}Zn$

$^{12,13}C + {}^{119,120}Sn$

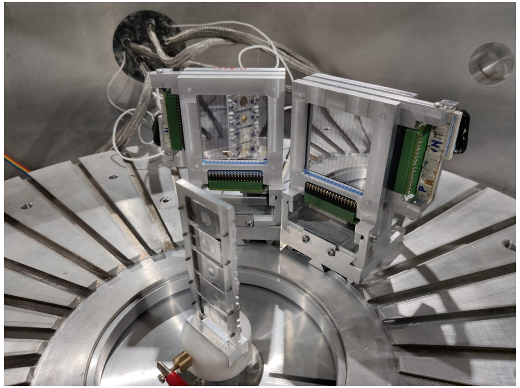
30B SETUP - TIMELINE

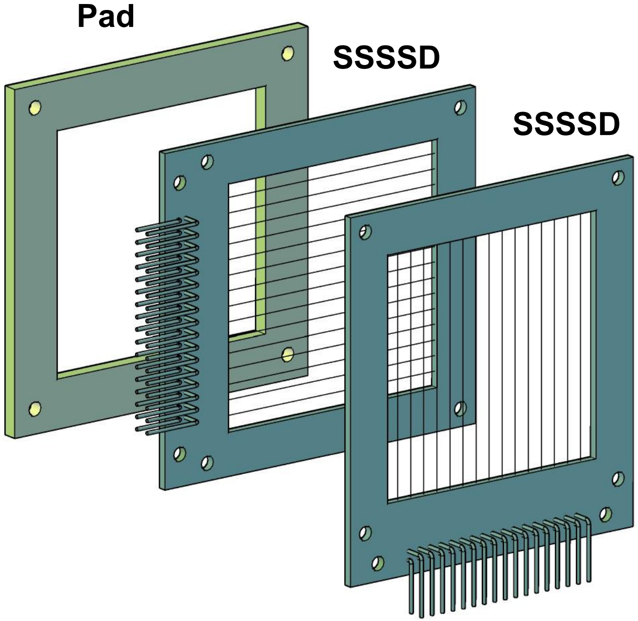


2023

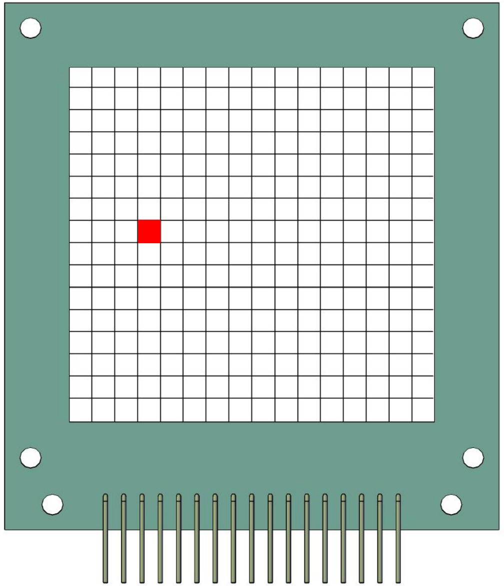


Large area 16 strips telescopes (1000 + 300 + 20 microns)

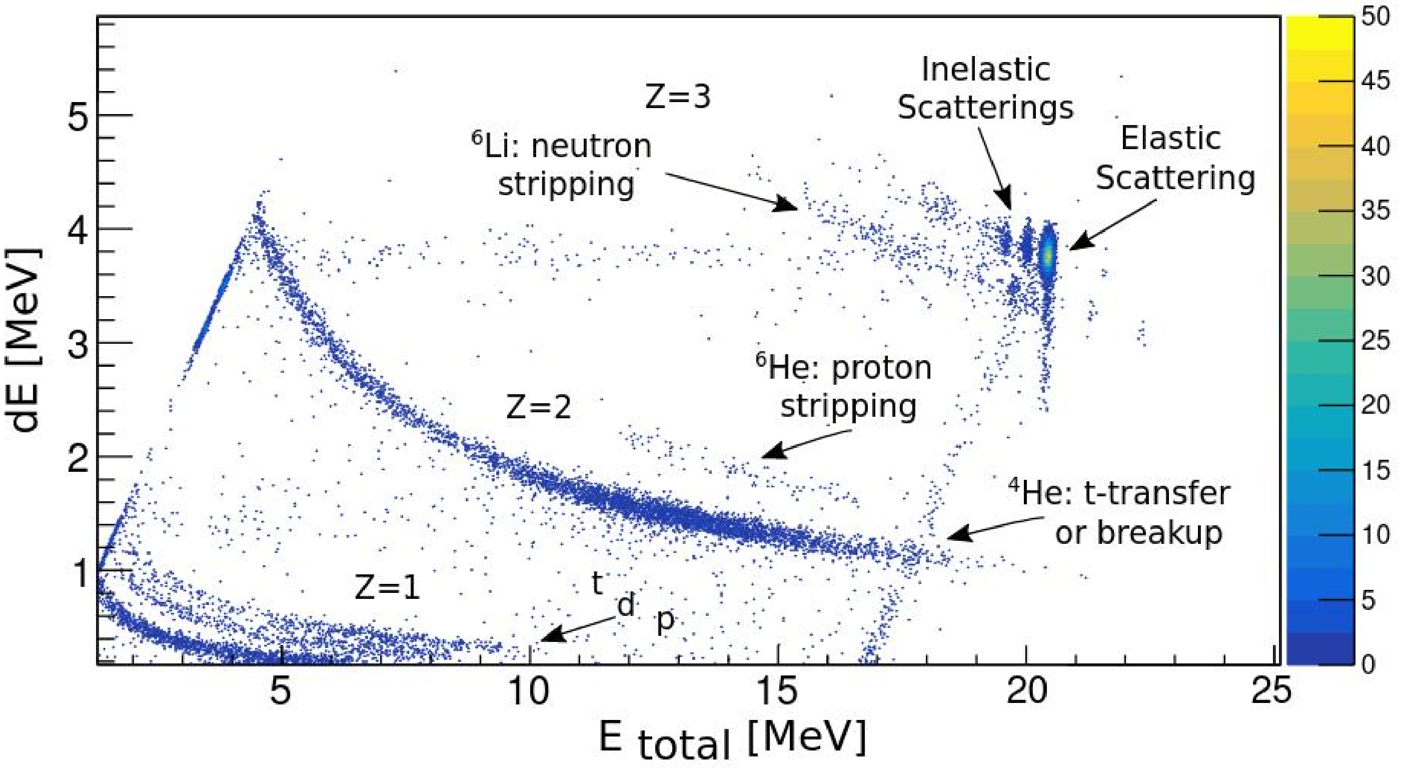


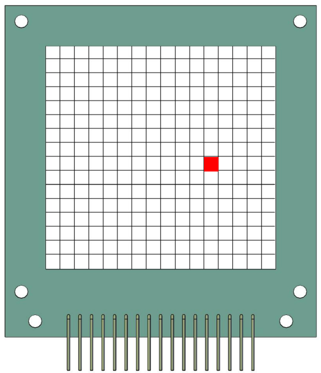


256 pseudo-telescopes



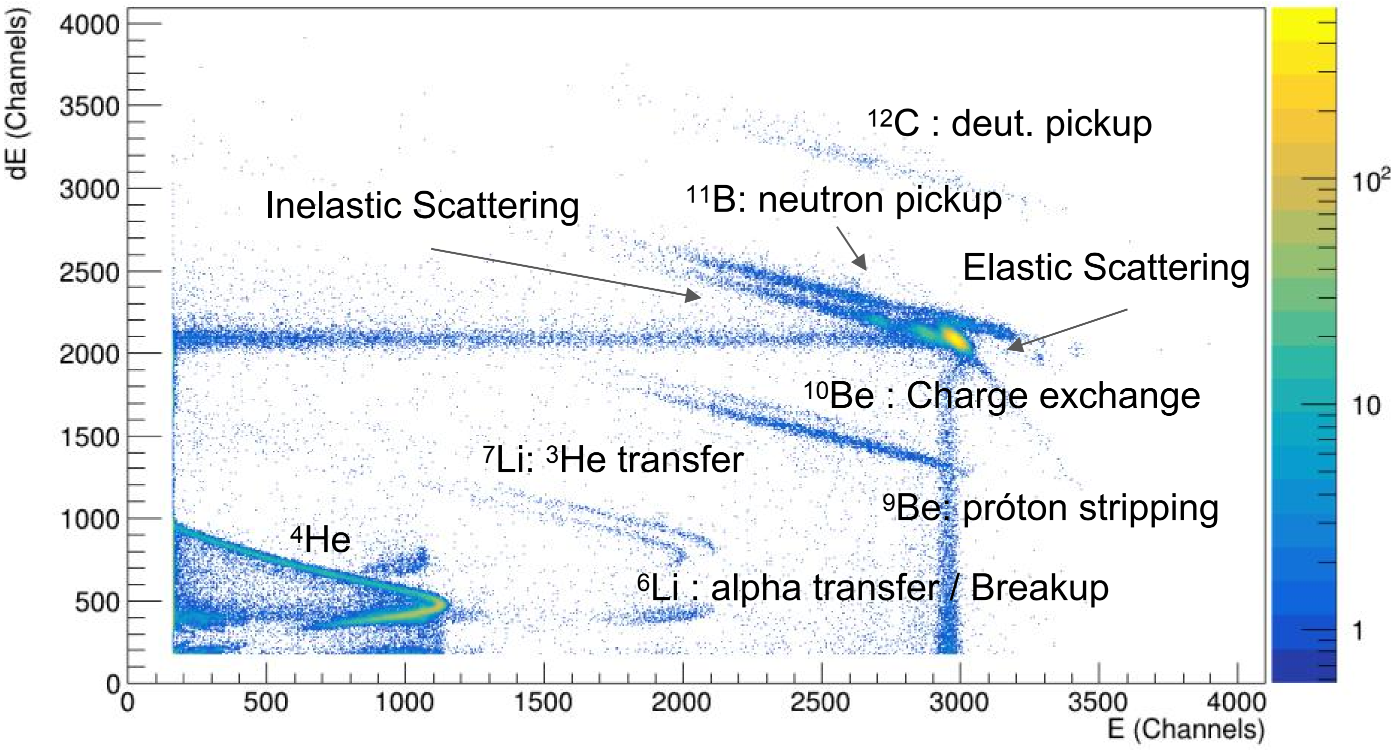
$^{7}Li+^{119}Sn$ @ 24 MeV

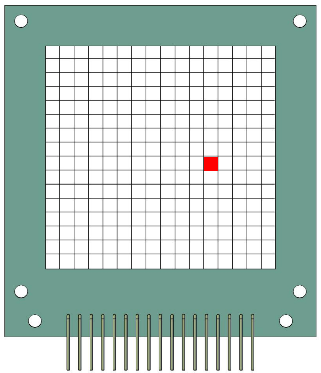




256 pseudo telescopes
area 3 x 3 mm²

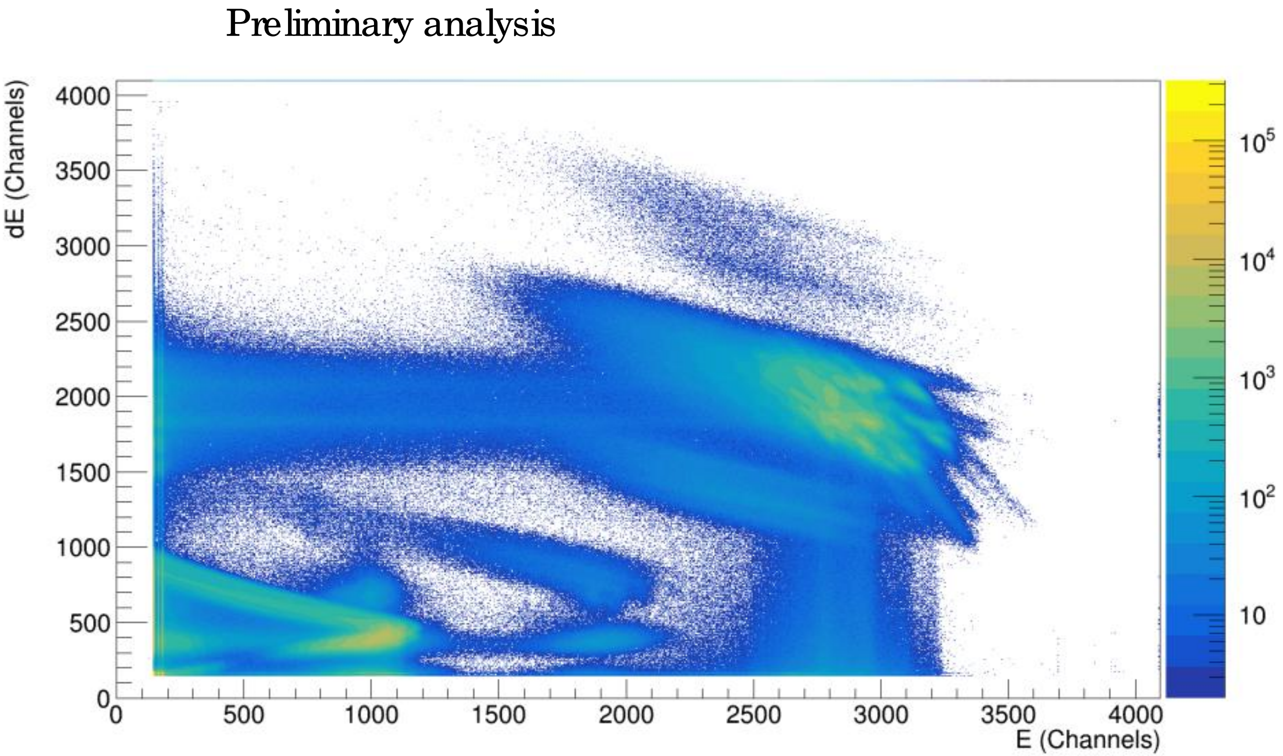
$^{10}B+^{119}Sn$ @ 40 MeV

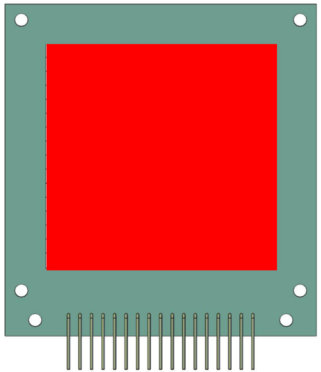




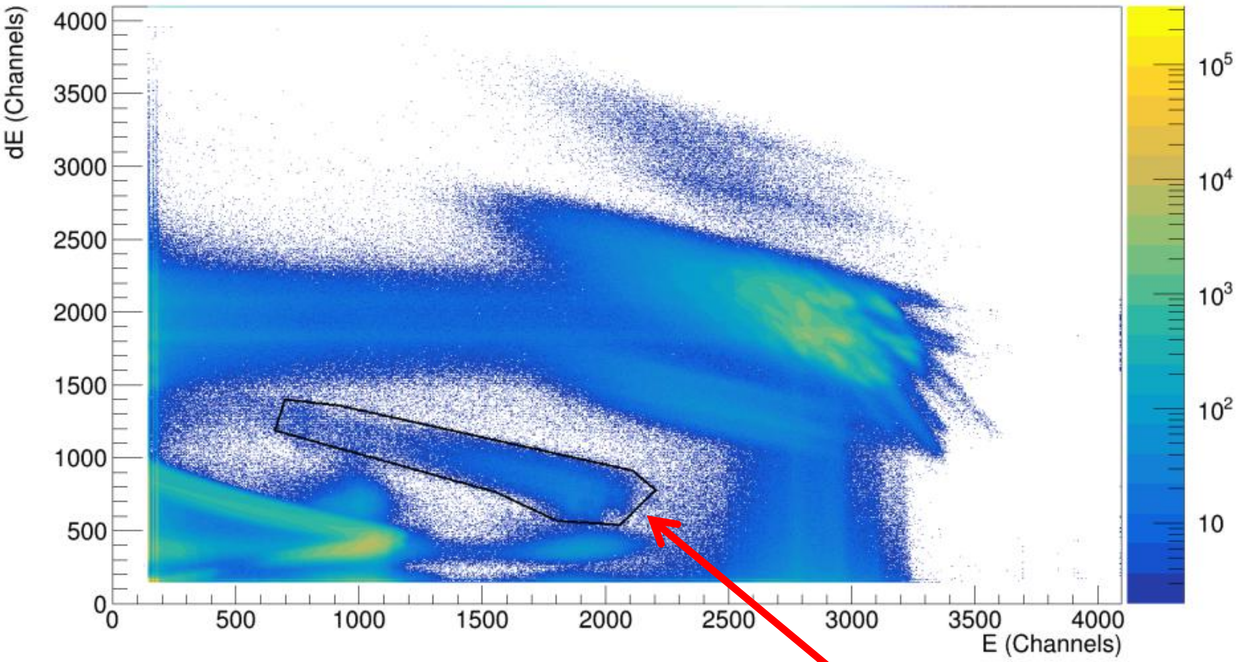
256 pseudo telescopes
area 3 x 3 mm²

Sum of all 256 pixels $^{10}B+^{119}Sn$ @ 40 MeV

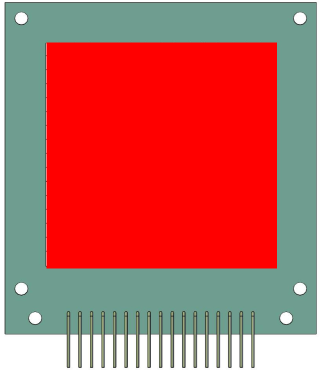




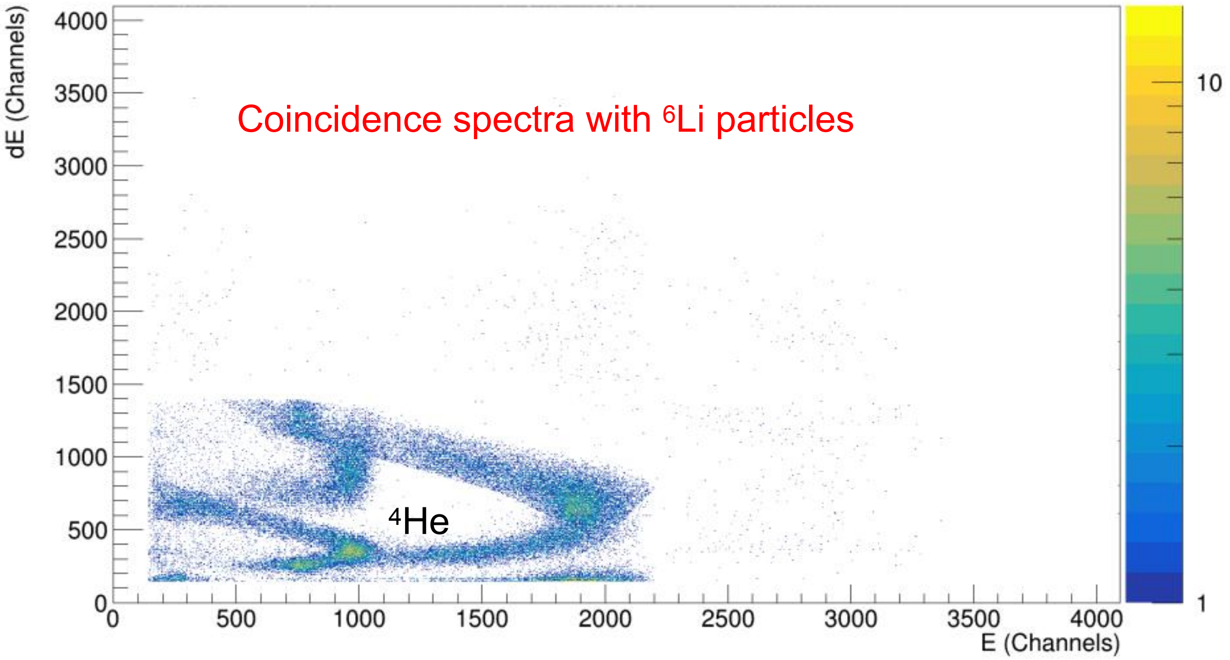
Sum of all pixels $^{10}B+^{119}Sn$ @ 40 MeV

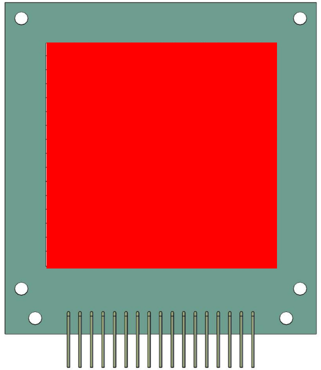


gate on ^{6}Li events



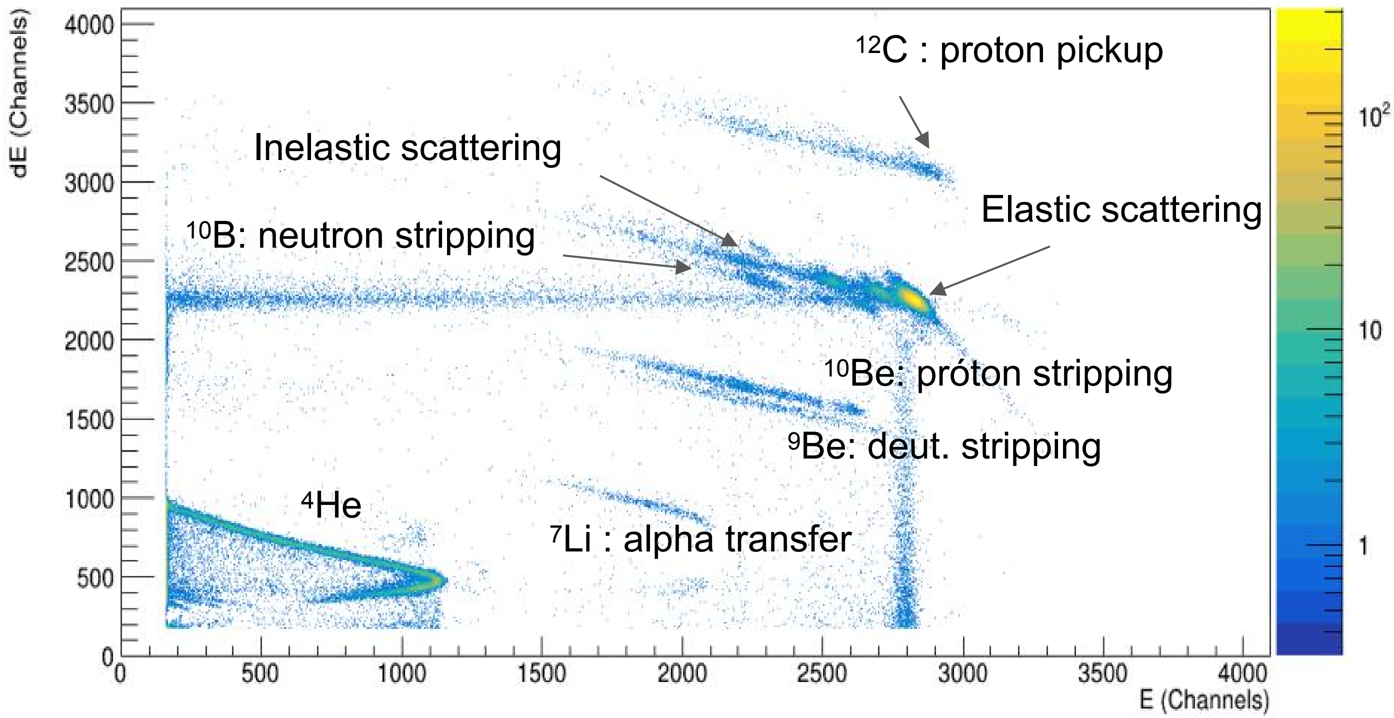
Sum of all 256 pixels $^{10}B+^{119}Sn$ @ 40 MeV

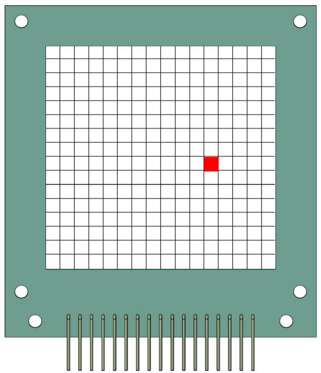




$^{11}B+^{119}Sn$ @ 40 MeV

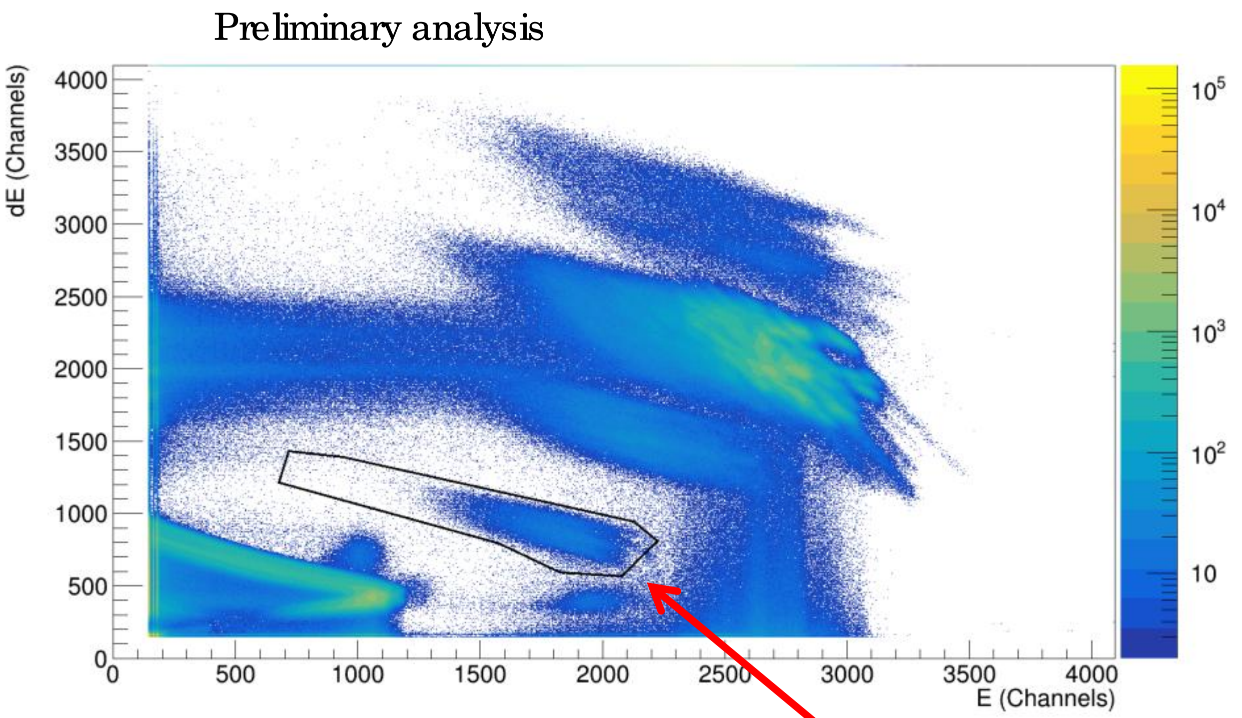
Experimental campaign 17-28 of April 2023



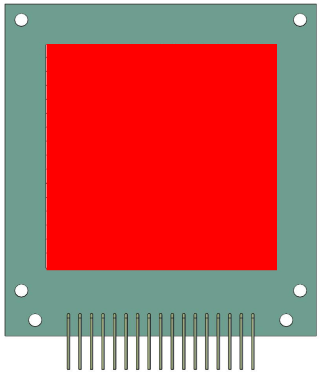


256 pseudo telescopes
area 3 x 3 mm^2

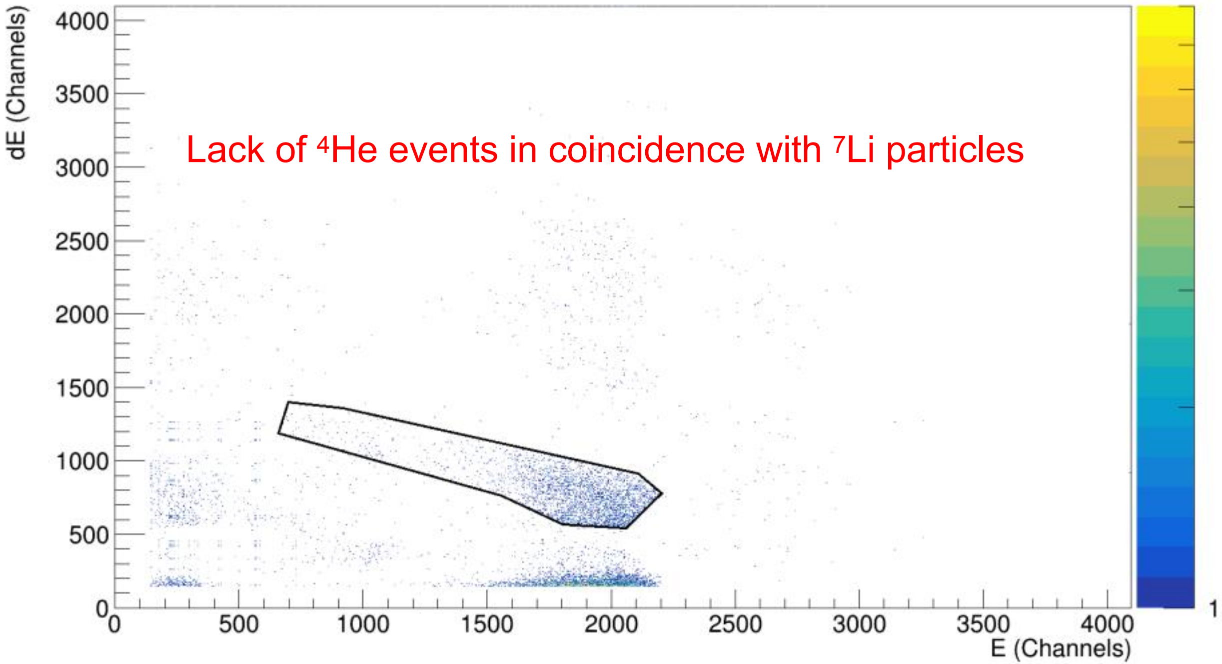
Sum of all 256 pixels $^{11}B+^{119}Sn$ @ 40 MeV

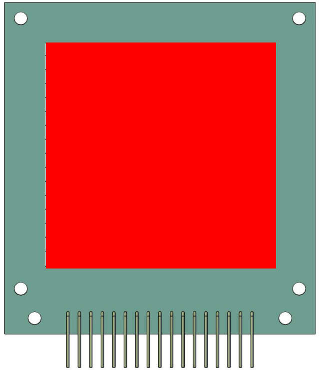


gate on ^7Li events



Sum of all 256 pixels $^{11}B+^{119}Sn$ @ 40 MeV





Summary

- Several reactions have been investigated at LAFNA

- The simultaneous description of many reaction processes are a good benchmark for nuclear potential models

- All in all, coupled-channel calculations provide a reasonable description of the data

Summary

- Several reactions have been investigated at LAFNA

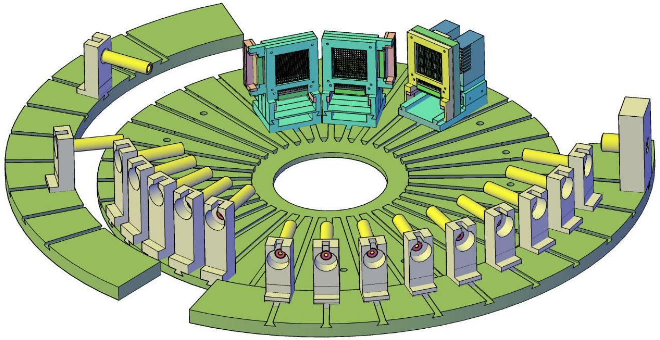
- The simultaneous description of many reaction processes are a good benchmark for nuclear potential models

- All in all, coupled-channel calculations provide a reasonable description of the data

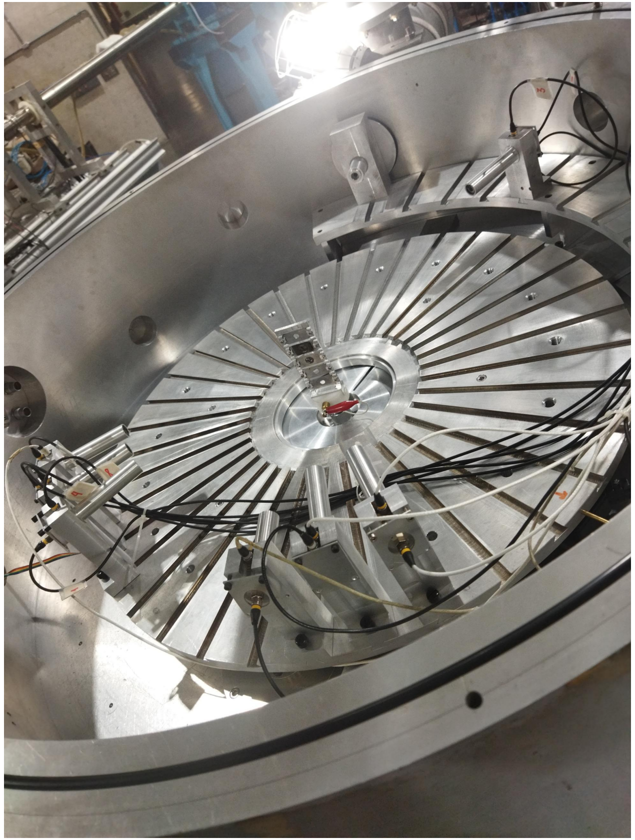
The development of instrumentation is extremely important and must go on ....

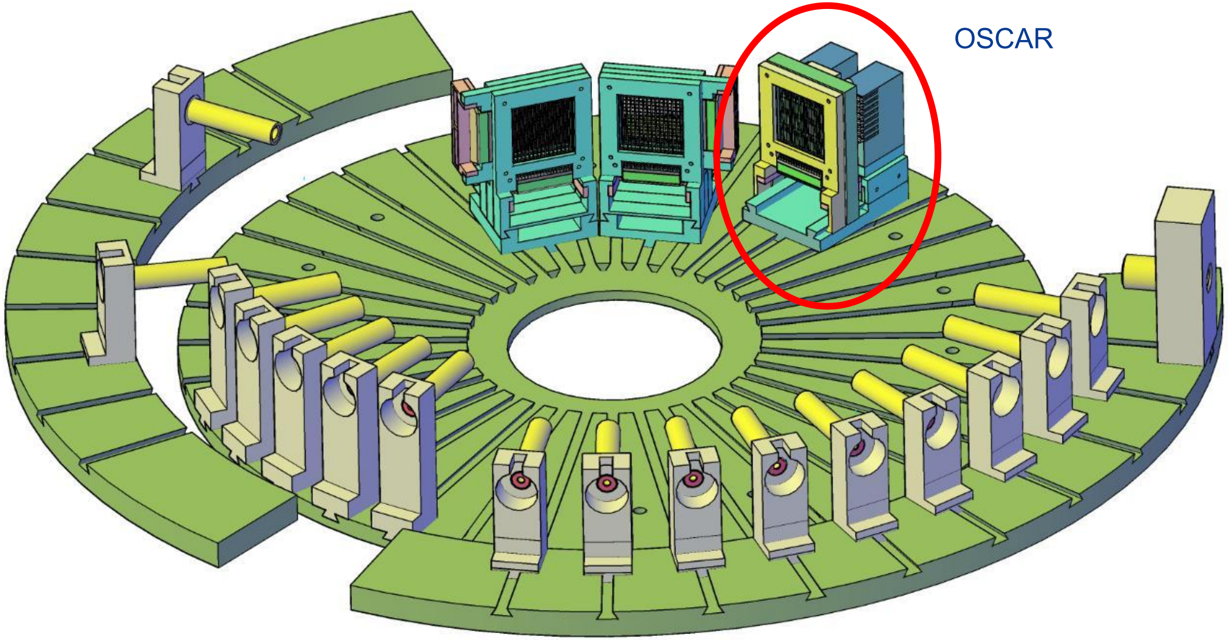
Students are very welcome for joining our research group!

Thank you !



Forthcoming





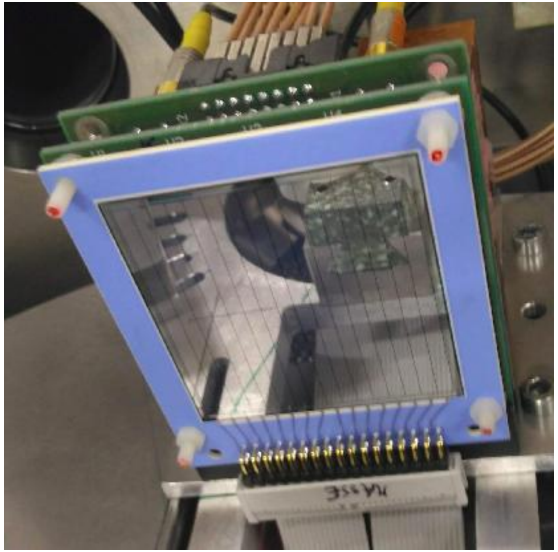
Forthcoming

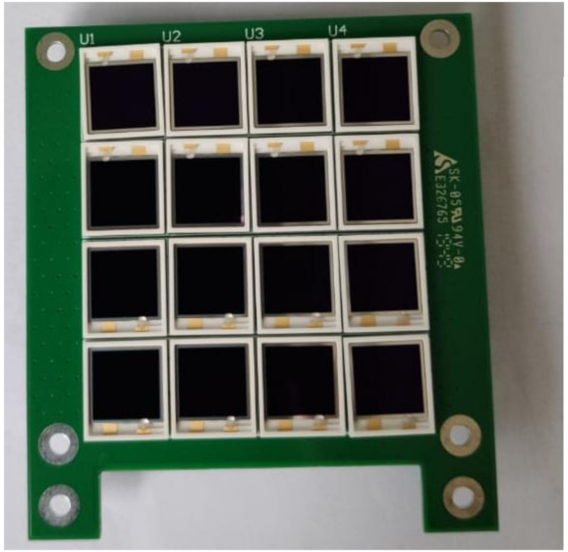
OSCAR (hOdoscope of Silicons for Correlations and Analysis of Reactions)

D. Dell'Aquila et. al., NIM A877, 227 (2018)

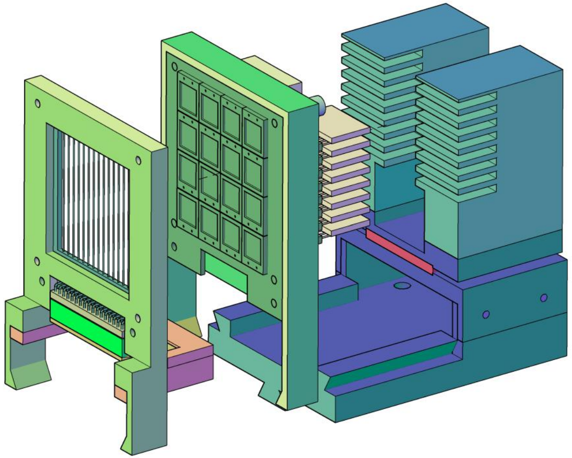
INFN - USP collaboration (MOU)

Si PIN photodiodes

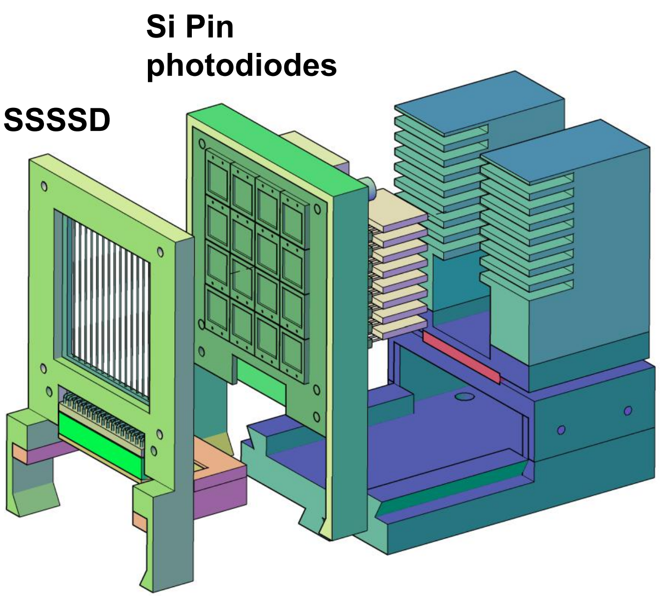


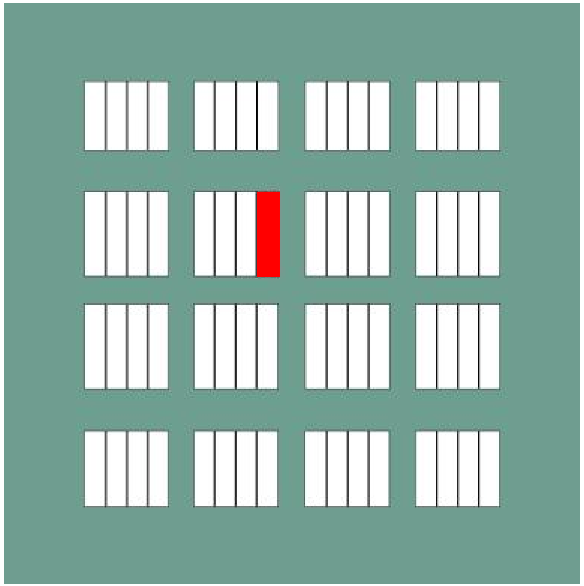


Building 2 pieces



OSCAR - H**O**doscope of **S**ilicons for **C**orrelations and **A**nalysis of **R**eactions

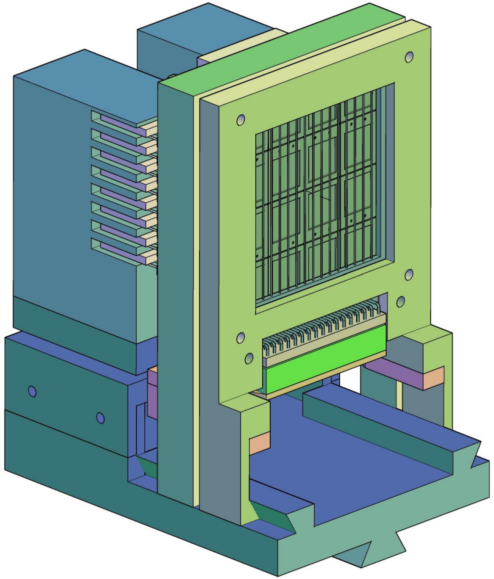


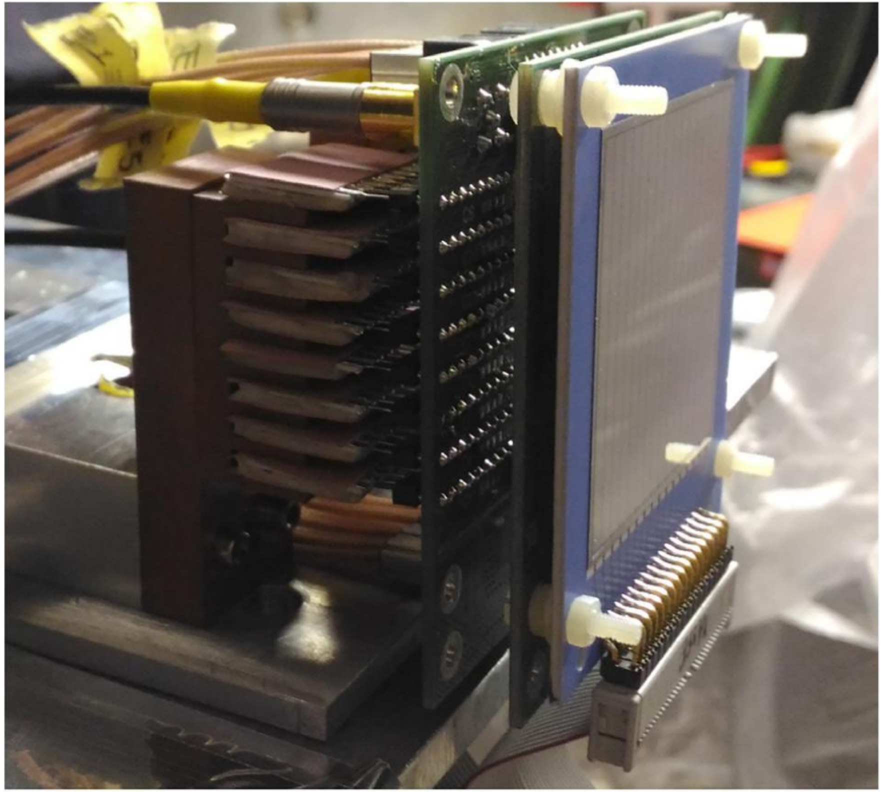


64 pseudo telescopes

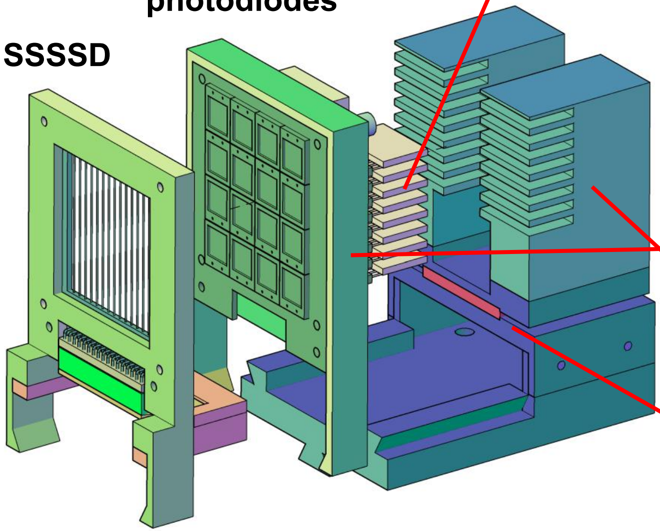
SSSSD (W1-SS): Single Sided Silicon Strip Detector - 16 strips - 20µm
16 - Si Pin diodes 10x10mm

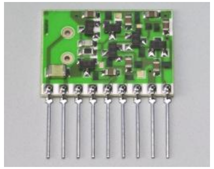
OSCAR - H**O**doscope of **S**ilicons for **C**orrelations and **A**nalysis of **R**eactions

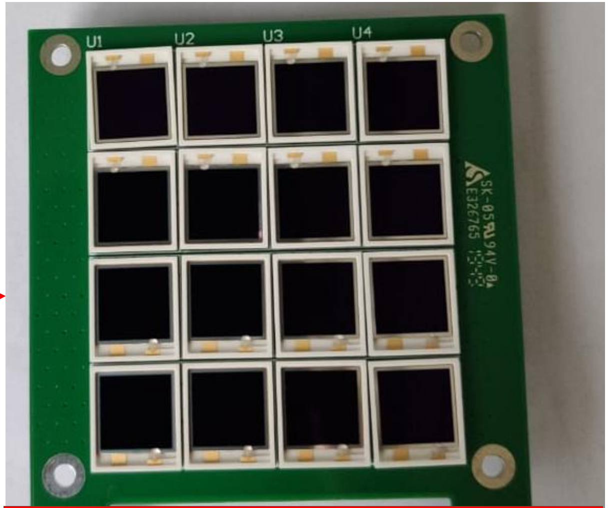




OSCAR - H**O**doscope of **S**ilicons for **C**orrelations and **A**nalysis of **R**eactions







Large area Si PIN photodiodes

SSSSD (W1-SS): Single Sided Silicon Strip Detector - 16 tiras - 20µm
16 - Si Pin diodes 10x10mm

Hamamatsu - S3590 series
Photosensitive area = 10x10mm

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São Paulo potential version 2 (SPP2) and Brazilian nuclear potential (BNP) ☆, ☆☆

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[a] Universidade de Sao Paulo, Instituto de Fisica, Rua do Matao, 1371, 05508-090, Sao Paulo, SP, Brazil
[b] Departamento de Física, Instituto Tecnológico de Aeronáutica, Centro Técnico Aeroespacial, São José dos Campos, SP, Brazil

Code Ocean webpage: https://codeocean.com/capsule/9505815/tree/v1

Code: *Regina.f*

Files: distribution.dat & density.dat