The OSCAR correlator for low energy nuclear reactions and heavy-ion collisions

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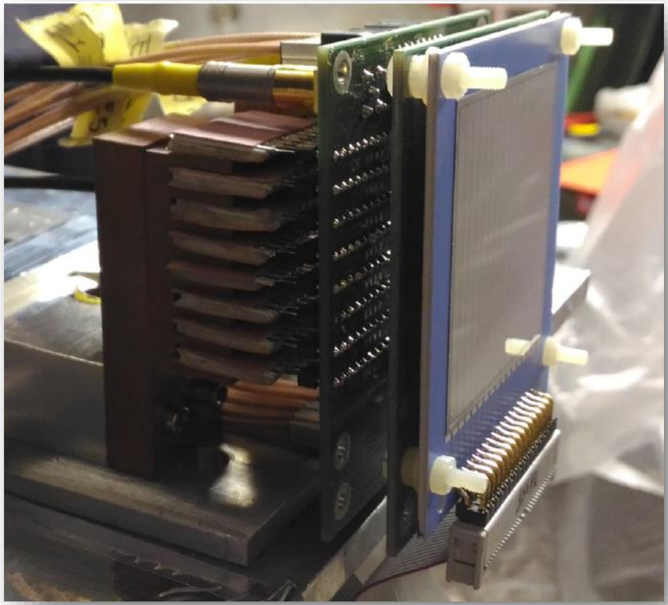
Talk Outline

- OSCAR working principles
- Performance features
- Example of the resonance decay of the ^{12}C Hoyle state
- Applications for low energy HIC and femtoscopy
- Present and future facilities to exploit OSCAR



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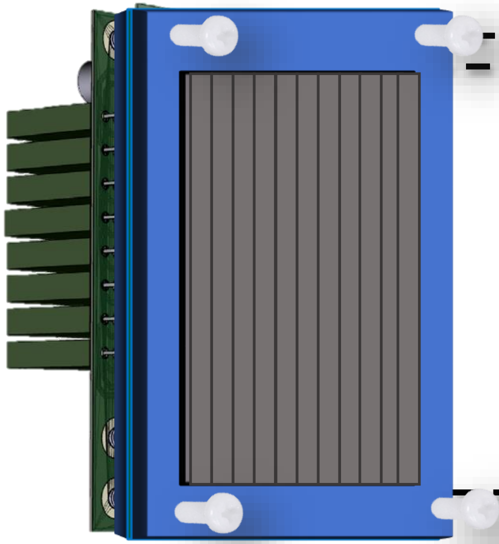
OSCAR as low energy detector

High angular resolution (1° at 55°)

Low energy threshold (~ 0.5 MeV/A)

High granularity and modularity



hOdoscope of Silicons for Correlations and Analysis of Reactions

2nd stage

16 independent ceramic-framed silicon pad detectors. Thickness: 300 µm. Active area: 1 cm^2 each.

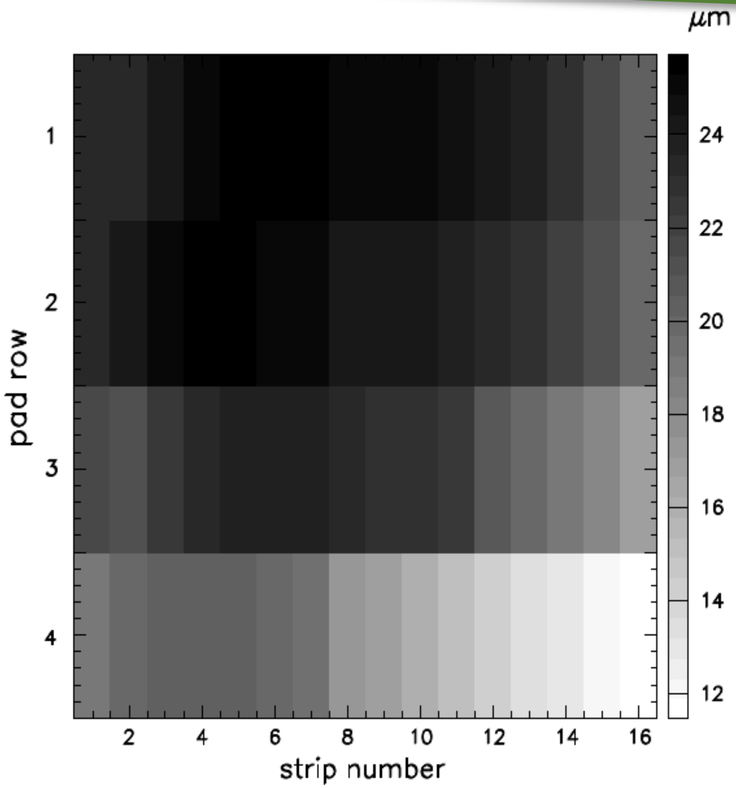
1st stage

Single Sided Silicon Strip Detector (SSSSD): 16 strips
20 µm thickness: low detection threshold, to identify slowest particles

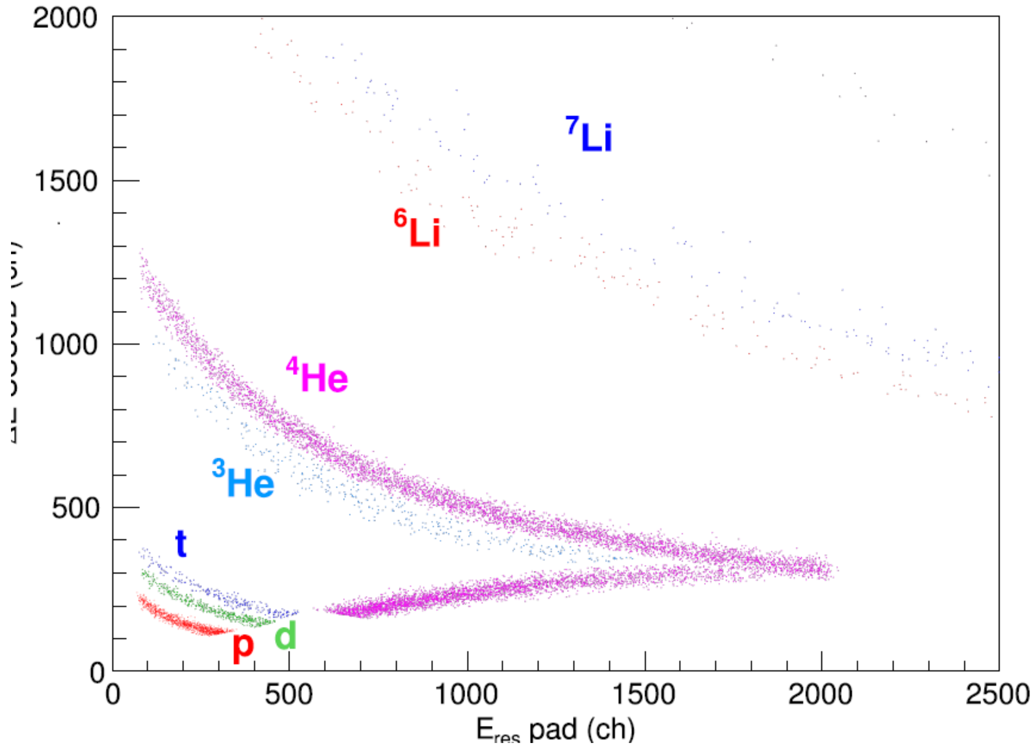
Overlap between the two stages:
64 ΔE-E pseudo-telescopes

Further reading → D. Dell'Aquila, NIM A 877 227-237 (2018).

Performances



Thickness profile of the SSSSD surface



ΔE-E spectrum for one pseudo-telescope: Z = 1, 2, 3 isotopes are clearly separated. Particles are identified in charge and mass with energies as low as 1.2 MeV.

OSCAR is a modular detector!

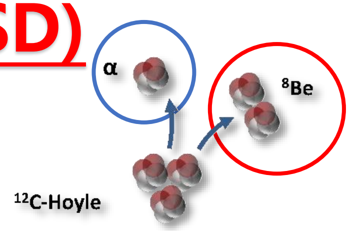
One can combine different OSCAR units in order to obtain more advanced set-ups.

^{12}C Hoyle decay – how has OSCAR helped?

Sequential decay (SD)

$$^{12}C_H \rightarrow {}^{8}Be + \alpha$$

$$\hookrightarrow \alpha + \alpha$$



3-α process (DD)

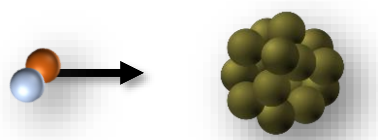
$$^{12}C_H \rightarrow \alpha + \alpha + \alpha$$

***α* particles angular correlation** to discriminate the two mechanisms → Need of a **high granularity** and **high-resolution** correlator

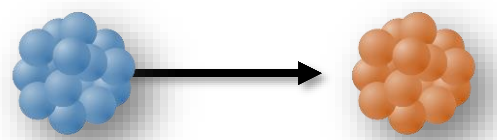
Contradictory results

Direct Reactions

Small number of degrees of freedom



Heavy-ion collisions

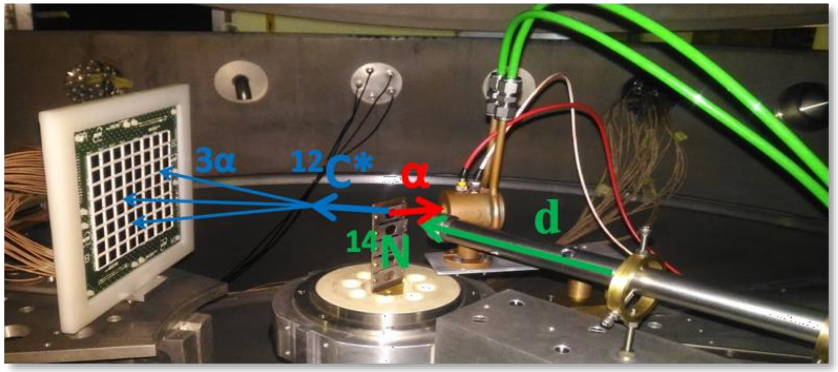


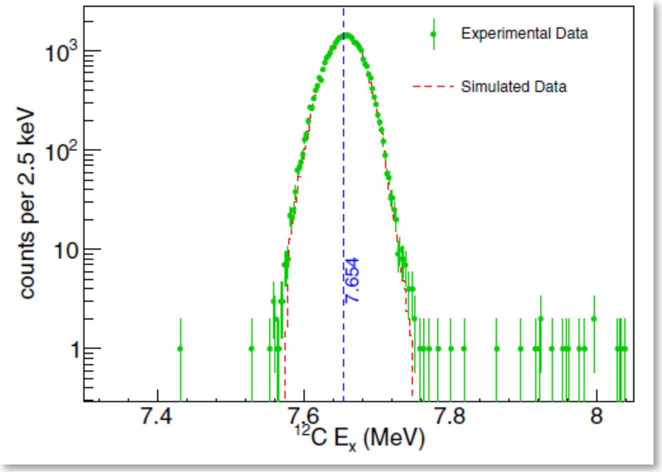
$\sim 0.043\%$ ← **DD to SD Br. Ratio** → $\sim 17\%$

In-medium or reaction mechanism effects?

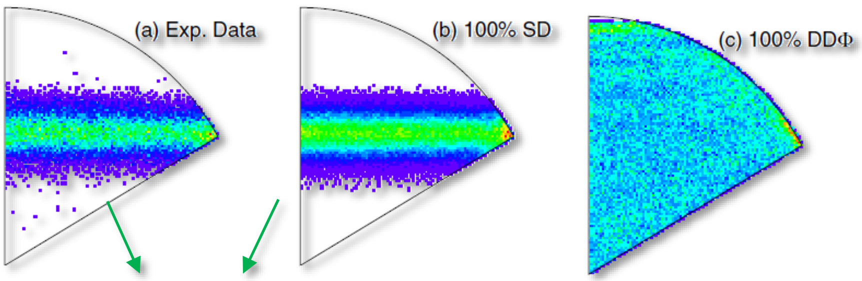
Discrimination between the two processes

$^{14}N(d,\alpha)^{12}C_{Hoyle}$ → **Direct reaction with E_{beam} = 10,5 MeV**



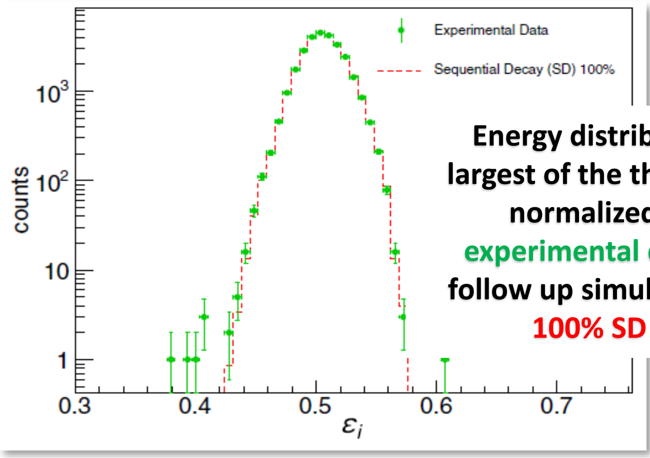


Reconstructed ^{12}C ex. Energy spectrum: very high signal-to-noise ratio for the Hoyle peak → 3.6 x 10^{-4}



Overlap

Dalitz plots clearly show how the experimental data are better justified with the assumption of the SD process as the main decay pathway.

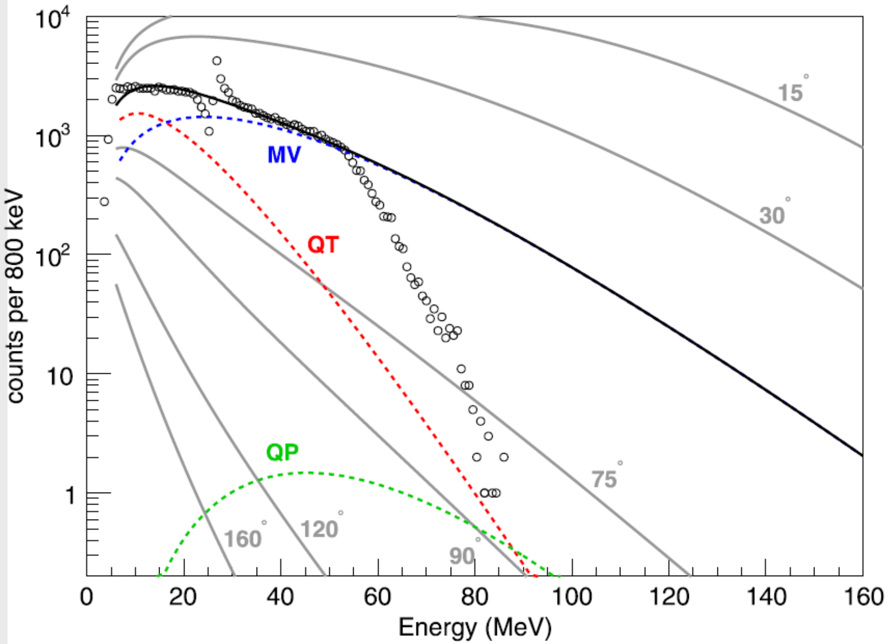


Energy distribution for the largest of the three α particles normalized energies: experimental data perfectly follow up simulated data for a 100% SD process.

DDΦ upper limit: 0.043% (C.L. 95%)

Further reading → D. Dell'Aquila, Phys. Rev. Lett. 119 (2017) 132501.

αs from moving sources and isotopic/isobaric yields

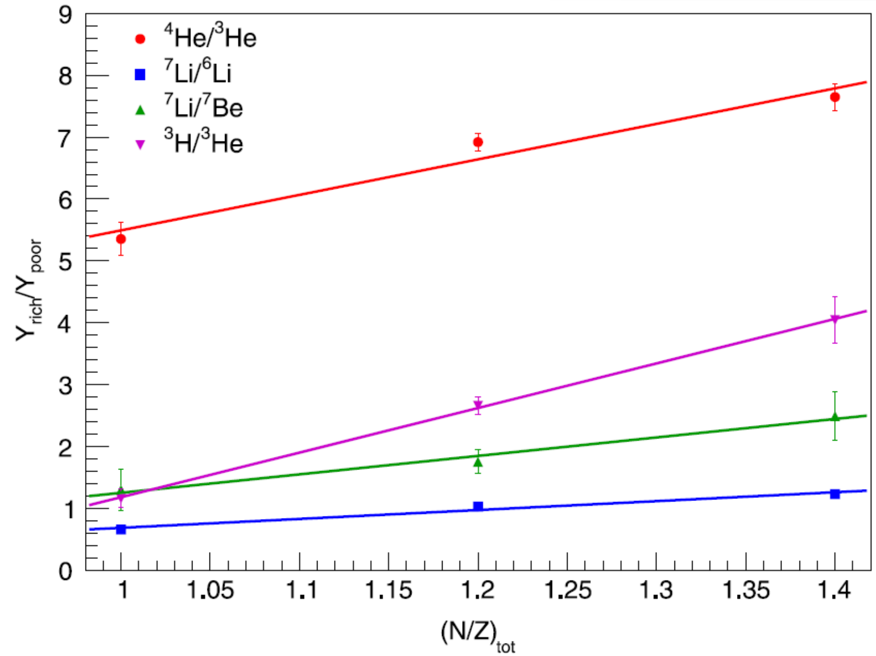


α particles spectrum for the ^{48}Ca + ^{48}Ca reaction at 35 AMeV

Very low energy threshold in HIC

Possibility of identifying the slowest α particles, from the QT moving source

—— Cumulative Maxwellian moving sources fit of the three contributions (QP, QT, MV)

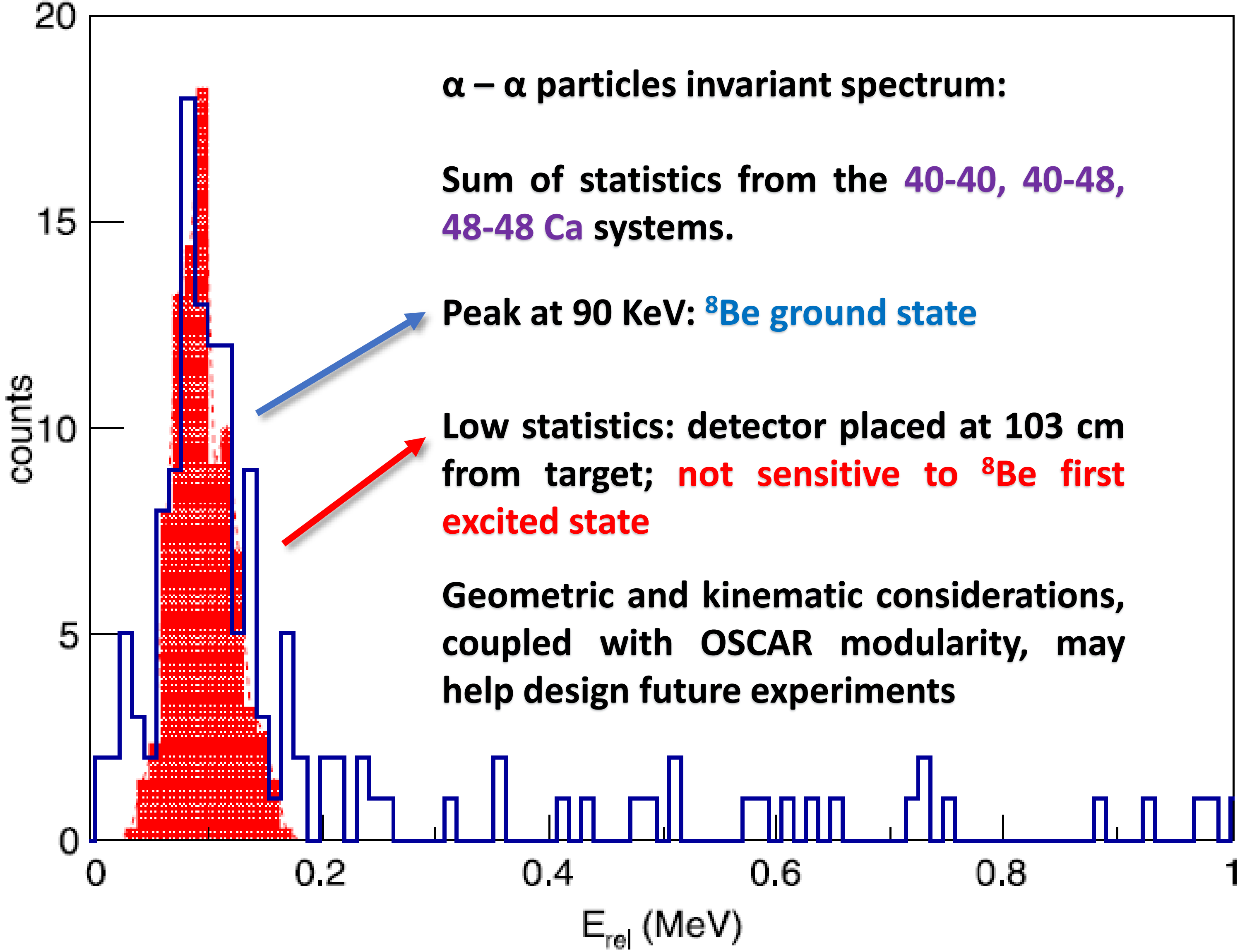


Isotopic and isobaric yields are proportional to the $\left(\frac{N}{Z}\right)_{tot}$, for the following systems

$$^{40}Ca + \ ^{40}Ca \qquad ^{48}Ca + \ ^{40}Ca$$
$$^{48}Ca + \ ^{48}Ca$$

Neutron-richer isotopes or isobars are produced (and detected) with higher yield from neutron-rich collision (especially for tritium and helium-3).

Further reading → D. Dell'Aquila, Phys. Rev. Lett. 119 (2017) 132501.



α – α particles invariant spectrum:

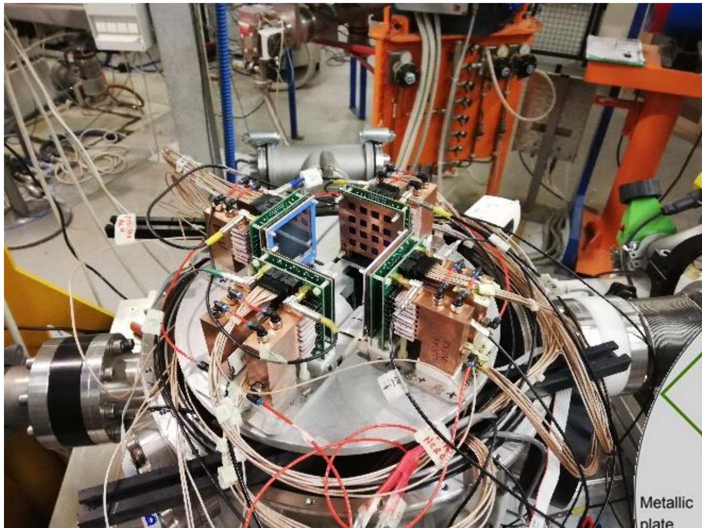
Sum of statistics from the 40-40, 40-48, 48-48 Ca systems.

Peak at 90 KeV: ^{8}Be ground state

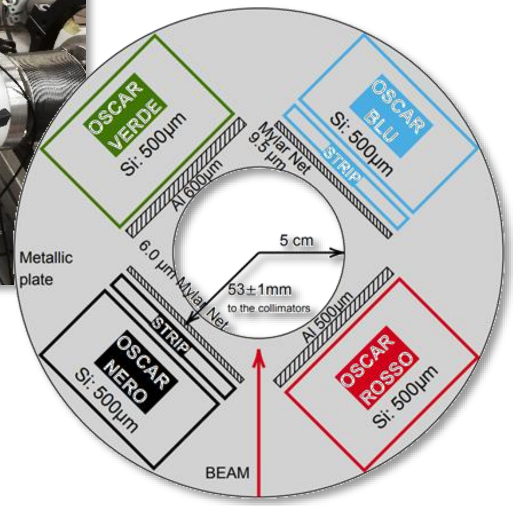
Low statistics: detector placed at 103 cm from target; not sensitive to ^{8}Be first excited state

Geometric and kinematic considerations, coupled with OSCAR modularity, may help design future experiments

Another example of OSCAR(s) application



Four OSCAR modules in the HELICA configuration for the study of the $^3He + {}^{13}C \rightarrow {}^{12}C + {}^4He$ reaction at LNL (Italy)



Every module had a different position, number of stages, and cover layer (Mylar Net or Aluminum, with different thickness)

$$E(^3He) = 1.4 - 2.2\ MeV$$

$$20\ KeV\ energy\ steps$$

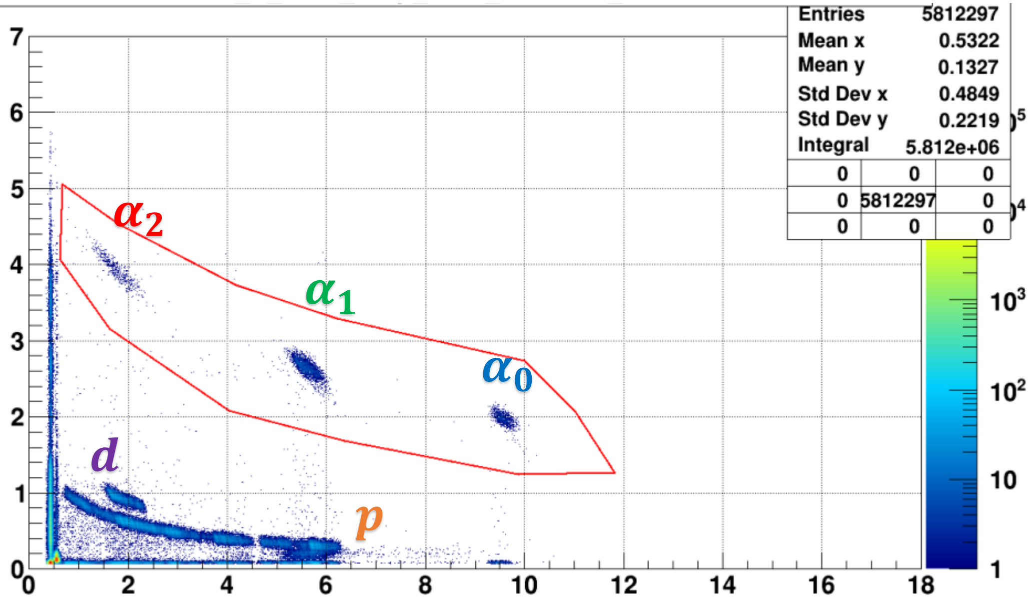
Provided new data for ^{3}He(^{13}C) reaction at under-barrier energies (very few available)

Very low energy threshold → identification of each reaction channel.

$$^3He + {}^{13}C \rightarrow {}^{14}N + {}^2H$$

Including the deuteron channel, *never* seen before!

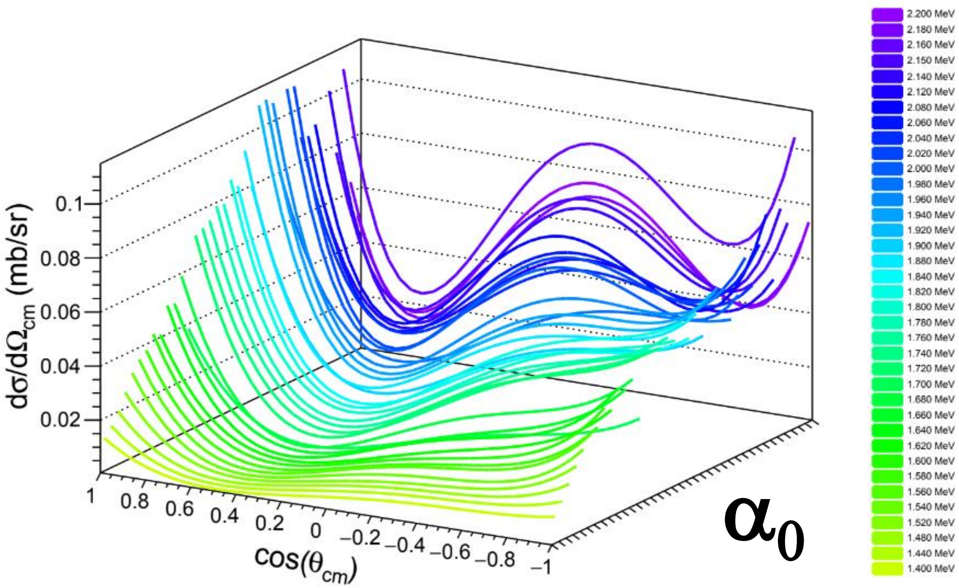
High granularity, E resolution, full coverage of polar angles, low energy threshold, in a compressed geometry



ΔE-E identification of the following channels

$$^{3}He + {}^{13}C \rightarrow \begin{cases} \alpha_0 + {}^{12}C_{gs} \\ \alpha_1 + {}^{12}C_{4,44} \\ \alpha_2 + {}^{12}C^{Hoyle}_{7,65} \\ d + {}^{14}N \\ p + {}^{15}N \end{cases}$$

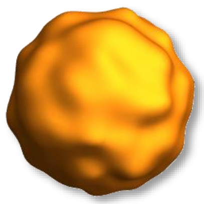
Sizeable evolution **of the *shape* of the angular distributions with *energy* → contributions from *resonances* on a direct *background***



Studied for the α_0, α_1 and α_2 channels

Less pronounced **variations for the α_2 channel!**

Femtoscopy imaging



Emission source

10^{-15} m (fm)

10^{-23} s

Impossible to have a direct measurement!

↓

Relative momenta and correlation function

↓

Koonin-Pratt equation

INPUT

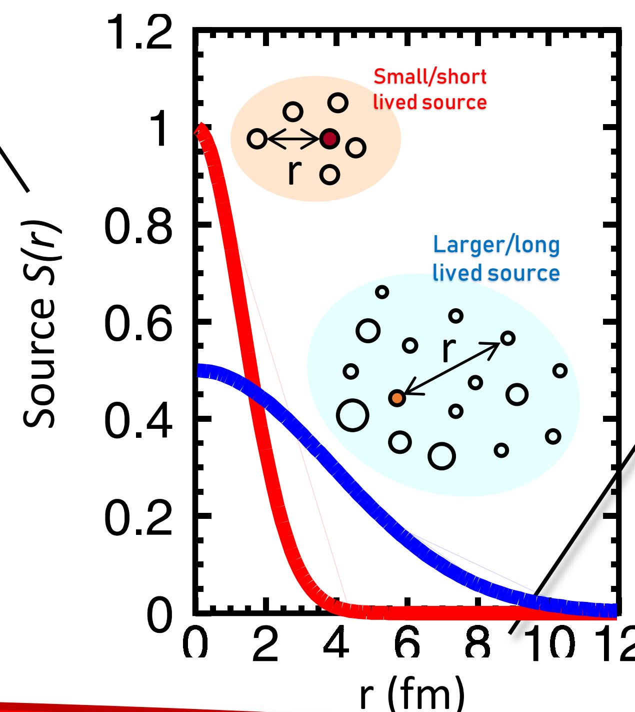
$$R(\vec{q},\vec{P}) = \int d\vec{r} \cdot S_{\vec{P}}(\vec{r}) \cdot K(\vec{r},\vec{q})$$

Source size

OUTPUT

Probability of emission of two particles, separated by a distance $r\ (fm)$ when the second one is emitted

Info on spectroscopy, statics and evolution of nuclear systems



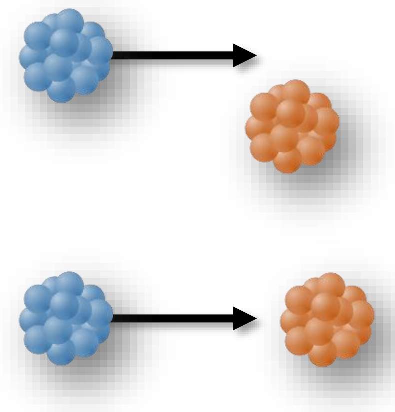
Particles' relative distance

S.E. Koonin, PLB70 (1977) 43; S.Pratt et al., PRC42 (1990) 2646

How can OSCAR be exploited in the femtoscopy field?

Low energy (E/A < 20 MeV)
Femtoscopy

Deeper understanding of systems lifetime, emission of resonances and FSI

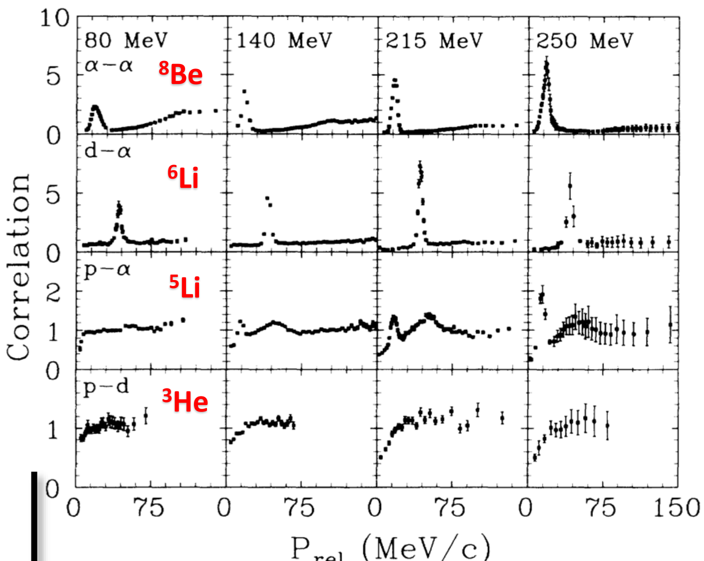


Peripheral collisions — **Production of evaporating QP/QT**

Central collisions — **Fusion/evaporation processes**

Plan to perform new measurements, not explored in the last 30 years

$^{16}O + ^{27}Al$ @ E/A=5, 8.8, 13.5, 15.6 MeV



M.S. Gordon et al., PRC46, R1 (1992)

Pre-formed clusters decay
Or
Independent emission and FSI?

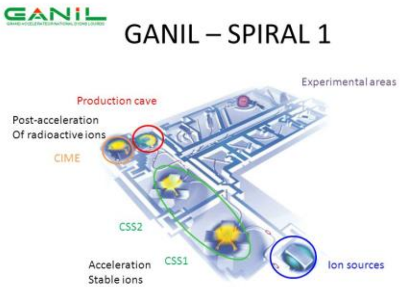
It is possible to see states from different nuclei, but difficult to extract information.

An improvement in data and modeling of statistical decays is very much needed (RIBs, exp. at higher energies, for Target-spectator emissions…)

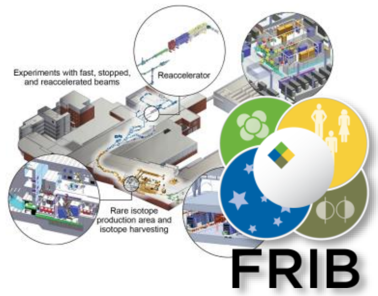
Old measurement: Si-CsI(Tl) telescope, Δθ ≈ 4 deg

Radioactive and stable beams facilities suitable for OSCAR

Available RIBs facilities

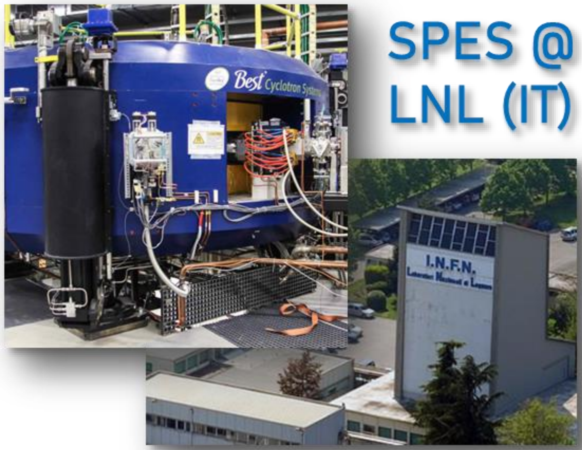


SPIRAL1 @ GANIL (FR)



FRIB @ MSU (USA)

Future RIBs facilities



SPES @ LNL (IT)

SPIRAL2 @ GANIL (FR)

Need of a particle correlator

OSCAR can grant very low threshold, high angular and energy resolution, high modularity and adaptability to complex geometries and coupling with other detectors

Thanks for your kind attention!