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
OSCAR as low energy detector

High angular resolution (1° at 55°)

Low energy threshold (~ 0.5 MeV/A)

High granularity and modularity

16 independent ceramic-framed silicon pad detectors. **Thickness**: 300 μm. **Active area**: 1 cm² each.

**1st stage**

Single Sided Silicon Strip Detector (SSSSD): 16 strips

20 μm thickness: low detection threshold, to identify slowest particles

**2nd stage**

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

OSCAR as low energy detector

**OSCAR features and characteristics**

- **High angular resolution** (1° at 55°)
- **Low energy threshold** (~ 0.5 MeV/A)
- **High granularity and modularity**

**1st stage**

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

**2nd stage**

- 16 independent ceramic-framed silicon pad detectors. **Thickness**: 300 μm.
- **Active area**: 1 cm² each.

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

Each pad is overlapped with 4 strips:
Schematic of the 64 telescopes

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.
Thickness profile of the SSSSD surface

$\Delta E - E$ 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.
Sequential decay (SD)

\[ ^{12}\text{C}_\text{H} \rightarrow ^{8}\text{Be} + \alpha \]

\[ \alpha + \alpha \]

\[ ^{12}\text{C}_\text{H} \rightarrow \alpha + \alpha + \alpha \]

3- \( \alpha \) process (DD)

\( \alpha \) particles angular correlation to discriminate the two mechanisms

Need of a high granularity and high-resolution correlator

Contradictory results

Direct Reactions

Heavy-ion collisions

Small number of degrees of freedom

\(~0.043\%\)

DD to SD Br. Ratio

\(~17\%\)

In-medium or reaction mechanism effects?
$^{14}N(d,\alpha)^{12}C_{Hoyle} \rightarrow$ Direct reaction with $E_{\text{beam}} = 10.5$ MeV

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

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 $\alpha$ particles normalized energies: experimental data perfectly follow up simulated data for a 100% SD process.

DDΦ upper limit: 0.043% (C.L. 95%)

αs from moving sources and isotopic/isobaric yields

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

Very low energy threshold in HIC

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

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

$^{40}\text{Ca} + ^{40}\text{Ca}$, $^{48}\text{Ca} + ^{48}\text{Ca}$

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

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 $^3\text{He} + ^{13}\text{C} \rightarrow ^{12}\text{C} + ^4\text{He}$ reaction at LNL (Italy)

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

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

20 KeV energy steps

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

Very low energy threshold $\rightarrow$ identification of each reaction channel.

Including the deuteron channel, never seen before!

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

High granularity, $E$ resolution, full coverage of polar angles, low energy threshold, in a compressed geometry
Preliminary results from the HELICA experiment

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

**Sizeable evolution of the shape**

of the angular distributions

with energy \( \rightarrow \) contributions

from resonances on a direct background

Studied for the \( \alpha_0 \), \( \alpha_1 \) and \( \alpha_2 \) channels

**Less pronounced** variations for the \( \alpha_2 \) channel!
Femtoscopy imaging

Impossible to have a direct measurement!

Relative momenta and correlation function

Koonin-Pratt equation

INPUT

Source size

OUTPUT

\[ R(\bar{q}, \bar{P}) = d\bar{r} \times S_{\bar{P}}(\bar{r}) \times K(\bar{r}, \bar{q}) \]

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

Small/short lived source

Larger/long lived source

Source size

Particles’ relative distance

\[ R(q, P) = \int d\bar{r} \times S_P(r) \times K(r, q) \]

Info on spectroscopy, statics and evolution of nuclear systems

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**
- **Peripheral collisions**
  - Production of evaporating QP/QT
- **Central collisions**
  - Fusion/evaporation processes

**Deeper understanding of systems lifetime, emission of resonances and FSI**

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

- 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-Csl(Tl) telescope, Δθ ≈ 4 deg**
Available RIBs facilities

- GANIL – SPIRAL 1
  - SPIRAL1 @ GANIL (FR)

Future RIBs facilities

- SPIRAL2 @ GANIL (FR)
- SPES @ LNL (IT)
- FRIB @ MSU (USA)

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!