Dedicated Arrays: MEDEA

GDR studies ($E_\gamma = 10-25$ MeV)

Highly excited CN

$E^* \sim 250-350$ MeV, $4 \leq T \leq 8$ MeV

intermediate energy region

$10 \text{ MeV/A} \leq E_{\text{beam}} \leq 100 \text{ MeV/A}$

- large variety of emitted particles
  - $\gamma$-rays, $\pi$'s, n, p, $e^\pm$, $\alpha$, ... heavy fragments
- wide energy range
  - $\sim 1-300$ MeV

The limit of nuclear existence:

limiting temperature of Compound Nucleus

experimental observable:

GDR yield vs. $E^*$

for a precise determination of Compound Nucleus excitation energy

a study of various reaction products is needed
MEDEA
Multi Element Detector Array
(GANIL-LNS)

4π array
180 BaF₂ detectors:
- γ's
- light charged particles

30° ≤ θ ≤ 170°
0° ≤ φ ≤ 360° ⇒ Ω ∼ 3.7 π

R = 22 cm, Δθ ∼ 15°
crystal dimensions: Ø = 62 mm, L = 20 cm, V = 1300 cm³

High granularity:
high multiplicity events & angular resolution

forward wall
120 phoswich detectors:
- light charged particles
- heavier fragments

10° ≤ θ ≤ 30°
0° ≤ φ ≤ 360°

R = 55 cm, Δθ ~15°
(ΔE-E) plastic scintillators
NE102A & NE115(τ ~ 2.4 ns & 230ns)
crystal dimensions: L = 2 mm + 30 cm
same PMT, separation of signals via PSA
ΔE threshold = 14, 19, 23, 54 MeV
for p, d, t and α

Large crystal size:
reduction of shower leakage through crystal surfaces
Monte Carlo Simulations:
determination of optimal thickness of BaF$_2$
for detection of $\gamma$-rays up to 300 MeV

**NOT much improvement is observed from 20 to 22 cm**

**MEDEA crystal size:**

$L = 20 \text{ cm} \sim 10 \times X_0$ (radiation length $X_0 = 2.05 \text{ cm}$)

$\sim$ Range 300 MeV protons

$\sim$ Range 1 GeV $\alpha$

$\Delta E_\gamma/E_\gamma = 12\%$ (@ 662 keV line of $^{137}\text{Cs}$)

Radiation length $X_0$: - typical scale for high-energy electromagnetic cascades:

- high-energy electrons: mean distance to reduce to 1/e energy by bremsstrahlung
- high-energy $\gamma$'s: 7/9 of mean free path for pair production
Scattering chamber

paraffine shield for \( \gamma \) calibration source

\( \frac{1}{2} \) BaF\(_2\) ball

beams

phoswich wall

D type BaF\(_2\) crystals

\( \sim 10^{-5} \) mbar
BaF$_2$ ball:
discrimination of $\gamma$-rays & neutrons: TOF

$^{129}$Xe (@45MeV/A) + $^{197}$Au
forward
backward
$\gamma$-rays & light charged particles

Fast $\gamma$-rays & cosmic $\gamma$
Fast + Slow Z=2

Phoswich wall:
identification of $\gamma$-rays & light charged particles:

$^{129}$Xe (@45MeV/A) + $^{197}$Au

Fast (ΔE) $\Delta E = E - E_{\text{res}}$
Slow (E) Z=1

PSA of anode output:
- fast: $\Delta E$ detector
- slow: $E_{\text{res}} = E - \Delta E$ detector
Investigation of Progressive disappearance of GDR with excitation energy

Evolution of GDR yield with $E^*$

- Evidence for progressive quenching of collective motion (GDR)
- Competition between collective motion & particle decay
- Onset of GDR quenching: $E^* \sim 250$ MeV, $E^*/A \sim 2.5$ MeV
- Statistical decay regime

$LNS$ Catania: MEDEA-MULTICS-MACISTE Setup
**Dedicated Arrays: TAPS**

Low and High energy photons detection

Relativistic Heavy Ions Physics

**Relativistic Heavy Ions:**
study of nuclear matter under extreme conditions

\[ \rho \sim 2-3 \rho_0 \]
\[ T \sim 300 \text{ MeV} \]

\[ \downarrow \]

nucleons are excited into **resonances** which decay via **mesons emissions**

**neutral mesons decay:**

\[ \pi^0 \rightarrow \gamma + \gamma \ (99\%) \]
\[ \eta \rightarrow \gamma + \gamma \ (39\%) \]

\[ m_{\pi^0} = 134.97 \text{ MeV} \]
\[ m_\eta = 547.75 \text{ MeV} \]

- \[ E_{\gamma 1}, E_{\gamma 2} \text{ photons energies (up to 1 GeV)} \]
- \[ \Theta_{12} \text{ opening angle between photons (} \leq 180^0) \]

\[ m_{\text{meson}} c^2 = \sqrt{2E_{\gamma 1}E_{\gamma 2}(1 - \cos \Theta_{12})} \]

reconstruction of **invariant mass** requires:

\[ E_{\gamma 1}, E_{\gamma 2} \text{ photons energies (up to 1 GeV)} \]
\[ \Theta_{12} \text{ opening angle between photons (} \leq 180^0) \]

**High energy \( \gamma \)-rays develop electromagnetic showers**

\[ \Rightarrow \text{ full reconstruction of em shower is needed} \]
TAPS
Two/Three Arm Photon Spectrometers
(GSI-GANIL)

384 individual BaF$_2$ detectors packed in arrays of 64 modules

angular range: $10^0 \leq \theta_{lab} \leq 165^0$

target distance: $0.5 \text{ m} \leq D \leq 3.5 \text{ m}$

precise determination of point of impact of electromagnetic showers

individual detector telescope
$L = 25 \text{ cm} = 12 X_0$, $\varnothing = 54 \text{ mm}$
BaF$_2$ gain monitor by N$_2$-laser

Array of 64 plastic/BaF$_2$ telescopes

$0.01 X_0$

$\gamma$-particle discrimination:
- pulse shape analysis
- TOF
- Veto detectors (particle suppression)
Response to electrons
above critical energy \( E_c \geq 13 \text{ MeV} \)
electrons generate EM Showers
\( \Rightarrow \) cluster of detectors are needed

\[ E_e = 43.5 \text{ MeV} \]

position resolution: \( \Delta x, y \sim 3 \text{ cm} \)
(from center of gravity of deposited energies)

Response to high-energy photons
High-energy photons generate EM Showers
\( \Rightarrow \) cluster of detectors are needed
\[ E_\gamma = 186 \text{ MeV} \]

\[ E_{\text{mean}} = 19 \text{ MeV} \]
\[ E_{\text{mean}} = 5.6 \text{ MeV} \]

position resolution: \( \Delta x, y \sim 2.5 \text{ cm} \)
(from center of gravity of deposited energies)
Response to charged particles $p$ and $\alpha$

- $E_p = 55$ MeV
- $E_\alpha = 100$ MeV

Fast + Slow projection

Fast

Discrimination against neutrons

- high-energy neutrons: 
  (n,p) interactions 
  TOF + response CPV + PSA
- low-energy neutrons ($< 100$ MeV): 
  (n,$\gamma$) interactions 
  TOF only

$\varepsilon \sim 17\%$ for $E_n \geq 5$ MeV

invariant mass spectrum

inelastically scattered $p$ (@55 MeV) on $^{12}$C

$\Delta E/E \sim 2.4\%$

to $^{12}$C excited

$^{20}$Ne + Al 
350 MeV/u

$\pi_0$ production
Dedicated Arrays: TAPS
Low and High energy photons detection (KVI-Groningen)

Proton-proton scattering @ 190 MeV
study of virtual bremsstrahlung below pion-production threshold

\[ p + p \rightarrow p + p + \gamma^* \rightarrow p + p + e^+ + e^- \]

\[ \sigma \sim 3-5 \text{ pb} \]

SALAD
- 2 wire chambers
- 24 plastic scintillators (VETO of elastic channel)

Photon invariant (relativistic) mass:

\[ M_\gamma = \frac{E_\gamma}{c^2} \]

Trigger
2 proton events in SALAD (2 charged particle tracks)
&
2 lepton events in TAPS (2 charged EM showers)
Virtual photons

The electron and nucleon interact by the electromagnetic force, the carrier of this is the *virtual photon* as has different properties to ordinary photons.

Take for example two electrons: These repel each other due to the electromagnetic force, we say that there is a *mediator* or *exchange* particle which is transferred between them, the photon.

If one imagines two ice skaters facing each other and one throws a ball to the other person both skaters will move apart, just as two electrons would repel each other.
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When delving inside the proton (or neutron) it is not the electron which actually 'probes' the nucleon but the photon. An electron gives some of its energy (and so loses some of its momentum) to the photon. The more momentum which is transferred to the photon, the more energy it has and so the shorter the wavelength of the photon. One can imagine that a longer wavelength photon will only 'see' the whole nucleon and so be elastically scattered, but for shorter wavelength photons it can 'see' the constituents of the nucleon, the quarks inside. This is why physicists want to build larger and larger accelerators, so that they can see more and more of the structure of particles.