Charged particles detectors Arrays (1)

- Basic concepts of particle detection: scintillators & semiconductors
- Light charged particles \((p, \alpha, e)\) Arrays: DIAMANT, ISIS, EUCLIDES, MiniOrange
- Large Arrays: CHIMERA, INDRA (MULTICS, RingCOUNTER (Garfield))
- Heavy fragments detection: RFD (recoil filter detector), Saphir
Charged Particles identifications

Organic scintillators

energy levels

singlet triplet

Stati Vibrazionali (~ 0.15 eV)
Stati Elettronici (~ 3-4 eV)

prompt fluorescence
(from singlet state):

\[ I = I_0 e^{-t/\tau} \quad \tau = \text{lifetime} \quad S_{10} \]

~ few ns

the slow component \((\tau \sim \text{ms})\)
due to delayed phosphorescence
(from triplet state)
is larger for particles with large \(dE/dx\)

\[ \frac{dL}{dx} = \frac{S dE}{1 + kB \frac{dE}{dx}} \]

equazione di Birks

light yield

\( S = \text{scintillator efficiency} \)
\( kB = \text{fitting constant} \)
Inorganic Scintillators: CsI(Tl), BaF$_2$, ...

Light output:

\[ L(t) = \frac{h_f}{\tau_f} \exp\left(-\frac{t}{\tau_f}\right) + \frac{h_s}{\tau_s} \exp\left(-\frac{t}{\tau_s}\right) \]

Sum of two exponential functions:
fast & slow components

1. $\tau_s$ independent of particle nature

2. $R = \frac{h_s}{(h_f+h_s)}$ increases with decreasing ionisation density

3. $\tau_f$ increases with decreasing ionisation density

\[ \Rightarrow \text{it is possible to identify different particles} \]

N.B. CsI have been used at first for particle studies:
- less fragile than NaI
- good particle discrimination
Optimization of particle discrimination:

- **ballistic deficit effect:** amplitude degradation at the output of pulse shaping circuit, due to finite shaping time constant

  [N.B. the preamplifier *rise-time* corresponds to the charge collection time ⇒ full charge collection is obtained only with ∞ shaping time constant]

  \[ B = 1 - F = 1 - \frac{Q_p}{Q_t} \]

  *particle-type information* is carried by preamplifier *rise-time* constant ⇒ ballistic deficit \( B \) depends on type of particle

Very good method for particle discrimination with CsI(Tl) + PIN photodiode detectors instead of PM tube: useful in compact geometry
CsI(Tl) + PIN photodiode detectors
15×15×3 mm³

Pulse generator
simulated α and p signals
measured signals

Figure of merit
quality of particle identification

Particle separation
down to M ~ 0.6

Energy threshold
E_α ~ 4 MeV
d_β ~ 2.5 MeV

J. Gal et al., NIMA366(1995)120
- **zero-crossing method:**
  
  the zero-crossing point of a **bipolar** signal depends on the pulse-shape of the original **unipolar** signal (input rise time)

  particle-type information is carried by the preamplifier **rise-time** constant
  
  ⇒ zero-crossing depends on type of particle

  1. different particles give different unipolar signals (different rise time)

  2. bipolar signal with zero-crossing depending on input rise time

  CR-RC-CR double differentiating circuit

  the time interval measured by **TAC** is proportional to the decay-time of the detector pulse

  Also used for particle discrimination with **CsI(Tl) + PIN** photodiode detectors
DIAMANT: EUROBALL ancillary
84 CsI(Tl) with PIN diode detectors
4π geometry
inner radius R = 32mm to 49mm

Advantages:
- high efficiency: $\varepsilon_{\text{proton}} \approx 70\%$, $\varepsilon_{\alpha} \approx 50\%$
- low energy threshold: 2 MeV for p, 4 MeV for $\alpha$

Limitation:
- large dead time (long decay time of light pulse $\tau \sim 1000$ ns)
  $\Rightarrow$ limitation in count rate
- large absorption & scattering of $\gamma$'s
  $\Rightarrow$ limitation in resolving power of Ge array

Operating mode:
DIAMANT alone: particle-xn channels
DIAMANT + Ge: particle-xn + xn channels
Charged Particles identifications by Solid State Detectors (Si, ...)

- smaller dead time ($\tau \sim$100-200 ns, compare to 1000 ns for CsI)
- good energy resolution ($\sim$ 10-20 keV)
- limited $\gamma$-absorption
- possibility of large solid angle coverage ($\sim 4\pi$)
- large sizes, up to 20 cm$^2$

**Detection method:**

1. $\Delta E$ energy loss
2. $E-\Delta E$ telecopes
3. Pulse Shape Analysis

**Si detectors are preferred to Ge:**

- simplicity of operation (room temperature, ...)
- lower $\gamma$-absorption ($Z_{Si}=14$, $Z_{Ge}=32$, $\rho_{Si}=2.33$ g/cm$^3$ $\rho_{Ge}=5.32$ g/cm$^3$, ...)
- ...
- **Si detectors, \( \Delta E \) method**

\[
\frac{dE}{dx} \propto \frac{mZ^2}{E}
\]

- useful to discriminate between few types of particles: \( p, \alpha \)
- detailed simulation studies of \( dE/dx \) in Si for various particles

\[ \Rightarrow \text{different} \quad dE/dx \quad \text{for different particles} \]
Si-Ball: NORDBALL ancillary

17 $\Delta E$ Si detectors
n-type, pentagon shape

- **thickness** 170 $\mu$m
- **shielding** with absorber foils
to optimize $p$ and $\alpha$ penetration
  (optimum thickness: MonteCarlo simulation)

- $4\pi$ geometry: $\Omega \sim 90\%$ $4\pi$
- Inner radius $R = 5$ cm
- Housing sphere radius $R = 10$ cm
γ-spectra particle gated

analysis of contaminant shows

12% α interpreted as p
0.9% p interpreted as α

as a consequence of the overlapping energy distributions of p and α

T. Kuronyanagi et al., NIMA316(1992)289
Si detectors, \( \Delta E - E \) method

\[
\frac{dE}{dx} \times E \propto \frac{mZ^2}{E} \times E = mZ^2
\]

\( t \sim 100-200 \, \mu m \)

\( t \sim 1000 \, \mu m \)

Very useful method to separate ions up to \( A = 25-30 \)
ISIS/EUCLIDES: GASP/EUROBALL ancillary

40 $E-\Delta E$ Si n-type telescopes
130 $\mu$m + 1000 $\mu$m

- capacitance $C = 850$ pF, 130 pF
- shielding with Al foil (~10-20 $\mu$m) to reduce radiation damage from scattered beam ions (optimum thickness: Monte Carlo simulation)

$4\pi$ geometry: $\Omega_{\Delta E} \sim 72\% 4\pi$, $\Omega_E \sim 65\% 4\pi$
Inner radius $R = 6.7$ cm

$\gamma$-spectra particle gated $\Rightarrow$ increased selectivity Ge array

$\Delta E$ $^{32}$S(140 MeV) + $^{40}$Ca

Operating mode:
- Stand-alone
- InnerBall
- Innerball + Hector
- Neutron-Wall
- Recoil Filter Detector

efficiency: $\varepsilon_{\text{proton}} \approx 50\%$, $\varepsilon_{\alpha} \approx 40\%$
Si-Ball Berlin
(EUROBALL ancillary)

162 Si (p⁺-n-n⁺ structure)
- thickness ~ 500 µm
- Active area ~ 750 mm²

G. Pausch et al., NIMA365(1995)176
Dedicated Arrays: CHIMERA

Multifragmentation, transition liquid-gas

Heavy Ion Reactions 10 MeV/A – 1 GeV/A

E*~ 250-350 MeV, 4 ≤ T ≤ 8 MeV

- large number of particles
- several Z and A
- wide dinamic energy range

Caloric curve of the nucleus

Caloric curve of the water

Multifragmentation: T≈5 MeV, E*≈4-5/A MeV

Vaporization: T>6 MeV, E*>10/A MeV

**CHIMERA**
*(GANIL, LNS, GSI(?)*)

1192 $\Delta E$-$E$ Si-CsI(Tl) telescopes

Si thickness $\sim 300 \, \mu$m
CsI(Tl) thickness $\sim 10 \, $cm

9 rings in forward direction
sphere Inner radius $R = 40 \, $cm

Large scattering chamber

unique device for:
- granularity (1192 mod.)
- low energy threshold ($\sim 250 \, \text{keV/A for H.I.}$)
- efficiency ($\sim 95\%$)

*good event reconstruction even with high multiplicity*

$\Rightarrow$ $\Delta E$-$E$, E-TOF, PSD in CsI(Tl)
Identification method

\[ \Delta E - E \rightarrow Z, E \quad \text{and} \quad \Delta E - \text{TOF} \rightarrow M, E \]

- **Si-\(\Delta E\) (high gain)**
- **Si-\(\Delta E\) (low gain)**

**CSI-Fast**

- **PSD**
- **CsI(Tl)**

**H.F. Cyclotron**

100 ns

**HF Start**

**Si**

300\(\mu\)m

10cm

(Pd)18x18mm\(^2\)

**Ident. method**

- **Cyclotron**
- **CSI(Tl)**
- **Si**
- **Si-\(\Delta E\)**

**4He**

**6He**

**3He**

**Li**

**H.I.**

**PSD**

HF Start

100 ns

**HF Start**

**Si**

300\(\mu\)m

10cm

(Pd)18x18mm\(^2\)

**Cyclotron**
Other Dedicated Arrays for charged particles:
MULTICS (+MEDEA, LNS), Ring Counter (+GARFIELD, LNL)

Heavy Ion Reactions at intermediate energy
10 MeV/A - 100 MeV/A

low energy threshold + high energy resolution

MULTICS
48 modules
3 stages telescope