Construction of Scintillation Counters

- Scintillator \( (q (\Delta E) \rightarrow h\nu) \)
- Light guide (collect, direct)
- Photomultiplier \( (h\nu \rightarrow e^-) \)
- Base (power, readout)

Scintillating Materials

\[
\text{Inorganic} \begin{cases} 
\text{gas} \ (\text{Ar, Xe,} \ldots) \\
\text{liquid} \ (\text{He, Xe,} \ldots) \\
\text{solid} \ (\text{NaI, CsI, BGO, BaF}_2, \ldots)
\end{cases}
\]

\[
\text{Organic} \begin{cases} 
\text{liquid} \ (\text{xylene, benzene,} \ldots) \\
\text{solid} \ (\text{polystyrene,} \ldots)
\end{cases}
\]
BGO Detectors

BGO has high density, efficiency for Compton scattered photons

Anti-Compton Shield detectors for high-resolution $\gamma$ spectroscopy
NaI(Tl) and CsI(Tl) Scintillation Detectors

Commercial NaI(Tl) detectors: Integral lines. (Harshaw)

Segmented CsI(Tl) detectors for LASSA array (deSouza)
Light Guides

Liouville Theoreme: constant phase space volume (decrease cross section of guide → loss of intensity)

Bending radius $r$ large enough for total internal reflection

$$n^2 - 1 > (\frac{d}{2r} + 1)^2$$

$n=$ refractive index
d=$diameter of guide
Electronic Photo-Multipliers

Criteria for choice:

- match photo cathode to scintillator light
- quantum efficiency
- rise time
- entrance window (glass, quartz,..)
- gain factor

Philips 56 AVP

- photocathode
- focusing electrode
- accelerating electrode
- first dynode
- multiplier
- anode
- glass envelope
- input optics
- window
- last dynode
- foot
- pumping stem
- base
- key
PM Operation

**Fast PM:** pulse rise time $\sim 2\text{ns}$, gain: $3 \cdot 10^7$

- Philips XP2041
- 5” dia cathode
- 14 dynodes
- + focusing electrodes

- PM Voltage divider (progressive)
  - $U_0 = 2000\text{V}$

- Mu-metal shield tube provides protection from external B field.

- Mu metal soft iron

**PM Schematic**
Channel Electron Amplifiers

Glass fiber tube (straight or curved), few $10\mu m$ dia. etched, inside coating LiF, MgF$_2$, KCl, CsI,..

- Soft core glass
- Lead glass cladding

Stacked tubes

MCP face

Multi-Channel Plate

“Chevron”
Applications of Channel Plate Multipliers

high gain=high efficiency, fast response. Use for timing (TOF-Start/Stop)

HI beam releases δ electrons in C foil, multiplied with multi-stage chevron
Examples of MCP e-Multipliers

Chevron mounted: El-Mul Technologies Ltd.
Environment of $\gamma$ Scintillation Measurement
Photon Response

\[ ^{137}\text{Cs} - \gamma \text{ spectrum with inorganic scintillator (NaI)} \]

\[ ^{22}\text{Na} - \gamma \text{ spectrum with organic scintillator (NE213)} \]
Primary ionization and excitations of $e^-$ or excitons $(e^-, h^+)$ → sequential deexcitation with different time constants.

Advantage: high density, stopping power → good efficiency

Disadvantage: slow response – $\mu$s decay time, “after glow”, some are hygroscopic
Scintillation Mechanism: Organic Scintillators

Excitation of molecular states determined by $\pi$ electrons: singlets ($\uparrow \downarrow$) and triplets ($\uparrow \downarrow$). Form vib. band heads

Trapping of e- in triplet states, slow decay to $S_0$ g.s.

Triplet excited (3:1) via ion recombination.

Decay via collisions

$TT \rightarrow SS + \text{phonons}$ ($\tau \sim 300 \text{ ns}$)

E1 excitation/rad. less transitions depends on ionization density ($A,Z,E$)
Different radiation leads to different mix of fast and slow → ID

Pulse shape discrimination retained electronically →
Pulse Shape Analysis

2 signals of equal total light output

\[ Q_1 = \int_{t_0}^{t_1} I(t) \, dt \]  
\[ Q_2 = \int_{t_1}^{t_2} I(t) \, dt \]  
\[ Q_1 + Q_2 = Q \propto L(Energy) \]
Pulse Shape Discrimination

Organic Scintillator

Inorganic Scintillator CsI(Tl)

Bicron Corp.

INDRA Collaboration

W. Udo Schröder, 2004
Light Charged Particle Identification: CsI(Tl)

A-Z Identification of LCP’s: CsI(Tl) with photodiode read-out and pulse shape discrimination (Chimera 14° (ring 6I)).

PID threshold for $\alpha$ and protons: 4-5 MeV proton equivalent energy. Good p,d,t discrimination $> 20$ MeV proton energy.

Pagano et al., 2001

W. Udo Schröder, 2004
ΔE-E Isotope Identification

Combine CsI with Si ΔE
A-Z identification (up to Z=9) based on a Bethe-Bloch formula, no need for energy calibration

2) L.. Tassan Got, Preprint IPNO-DR—01-008

W. Udo Schröder, 2004
THE CHIMERA DETECTOR

CHIMERA characteristic features

<table>
<thead>
<tr>
<th>Experimental Method</th>
<th>$\Delta E$ - $E$ → Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta E$ - $E$ - TOF → Velocity, Mass</td>
</tr>
<tr>
<td></td>
<td>Pulse shape Method → LCP</td>
</tr>
</tbody>
</table>

| Basic element       | Si (300$\mu$m) + CsI(Tl) telescope |

<table>
<thead>
<tr>
<th>Primary experimental observables</th>
<th>TOF $\delta t \leq 1$ ns</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Kinetic energy, velocity</td>
</tr>
<tr>
<td></td>
<td>$\delta E/E$ Light charged particles $\approx 2%$</td>
</tr>
<tr>
<td></td>
<td>Heavy ions $\leq 1%$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total solid angle $\Delta \Omega/4\pi$</th>
<th>94%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granularity</td>
<td>1192 modules</td>
</tr>
<tr>
<td>Angular range</td>
<td>$1^\circ &lt; \theta &lt; 176^\circ$</td>
</tr>
<tr>
<td>Detection threshold</td>
<td>$&lt;0.5$ MeV/A for H.I.</td>
</tr>
<tr>
<td></td>
<td>$\approx 1$ MeV/A for LCP</td>
</tr>
</tbody>
</table>
CsI(Tl) Light Output Parameterization

Abondanno et al., NIM A488, 604 (2002)

Data fitted $^7$Li, ..., $^{48}$Ti

$$L(E) = \gamma \left[ E + E_0 \left( e^{-E/E_0} - 1 \right) \right]$$

$E_0 = d_1 \cdot Z$

$\gamma = d_2 / Z + d_3 + d_4 \cdot Z$

$d_1 = (5.31 \pm 0.05) \text{ MeV}$

$d_2 = (101.03 \pm 0.49) \text{ MeV}^{-1}$

$d_3 = (7.60 \pm 0.06) \text{ MeV}^{-1}$

$d_4 = (0.00 \pm 0.22 \cdot 10^{-3}) \text{ MeV}^{-1}$

W. Udo Schröder, 2004
Non-Linear Light Output Response

NE213 liquid scintillator: \( e^-\)-equivalent energies \( E_e \leftrightarrow E_p \)

\[
E_e(E_p) = \begin{cases} 
(0.18 \text{MeV}^{-1/2}) E_p^{3/2} & E_p < 5.25 \text{MeV} \\
0.63 E_p - 1.10 \text{MeV} & E_p \geq 5.25 \text{MeV}
\end{cases}
\]

W. Udo Schröder, 2004
Efficiency of p-Recoil Neutron Detectors

ET: Electronic detector threshold

\[ \varepsilon(E_n, E_T) = \frac{F_2}{F_1 + F_2} \approx \sigma(E_n) \left[ 1 - \frac{E_T}{E_n} \right] \]

\[ \sigma(E_n) = \sum_{x,y} \sigma_{x(n,y)}(E_n) \quad \text{all } n\text{-induced} \]

W. Udo Schröder, 2004