The BGO Calorimeter of BGO-OD Experiment

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Physics Motivations

- Understanding the structure of the proton and its excited states (the resonances) is one of the key questions in hadron physics.

- The dominant decay channel of nucleon resonances is the hadronic decay via meson emission.
Physics Motivations

- Understanding the structure of the proton and its excited states (the resonances) is one of the key questions in hadron physics.

- The dominant decay channel of nucleon resonances is the hadronic decay via meson emission.

- **The photoproduction of mesons provides a very valuable tool for the study of resonances.**
The BGO-OD experiment at ELSA facility

**Experimental program:**
- Pseudoscalar meson photoproduction - $\eta, \eta'$
- Vector meson photoproduction - $\omega, \phi, \rho$
- $K^+\Lambda, K^+\Sigma^0, K^0\Sigma^+$ photoproduction
- $\eta'$ mesic nuclei photoproduction

**Bremsstrahlung photon beam of:**
- energies between $0.2 \div 3.2\text{GeV}$
- intensity $\simeq 10^7\gamma/\text{sec}$
BGO-OD Experimental Apparatus

**ToF**
- 4 layers: 3x3 m²
- 5x20x300 cm³

**Drift chambers**
- 8 double layers
- 2.46 x 1.23 m³
- δ < 300 μm

**Dipole magnet**
- 2.2 x 3.9 x 1.5 m³
- 94 t, B_m = 0.5 T

**MOMO**
- 672 ch. x 2.5 mm, Ø 44 cm

**SciFi2**
- 640 ch. x 3 mm, 66 x 51 cm²

**Open Dipole** - forward spectrometer

**MRPC**
- 480 ch. x 1 cm²
- Ø 14-43 cm

**BGO calorimeter**
- 480 ch., 0.9 x 4π

**MWPC** - inner tracking

**Si strips** - fw tracking (B8)

**Target system** - LHe, LD₂

**Tagging system**
- 120 ch. scint. bars
- 480 ch. scint. fibers

**e⁻ beam**
Main characteristics of a BGO crystal ($Bi_4(\text{GeO}_4)_3$)

- High density ($\rho = 7.3 g/cm^3$)
- High atomic number ($Z = 83$)
- Short radiation length ($X_0 = 1.12 cm$)
- Not hygroscopic
- The wavelength range of the emitted light can be matched with the standard PMs
- BGO time decay $\tau \simeq 300 ns$
The BGO Crystals of the BGO-OD e.m. calorimeter

- Truncated pyramidal sectors with trapezoidal bases;
- 24 cm length ($\approx 21 r./l.$);
- Eight different dimensions;
- Wrapped up in an aluminized mylar reflector ($30\mu m$).
The BGO Rugby Ball

480 BGO crystals ($\Delta \Omega = 0.9 \times 4\pi$)
- 15 sectors in $\theta$, $\theta = 25^\circ \div 155^\circ$; $\Delta \theta = 6^\circ \div 10^\circ$
- 32 sectors in $\phi$, $\phi = 0^\circ \div 360^\circ$; $\Delta \phi = 11.25^\circ$
The BGO Rugby Ball

Mechanical support:
- 24 baskets of Carbon fiber divided into 20 cells
  (0.38 mm for the inner; 0.54 mm for the outer walls)
- Internal diameter of 200 mm
The BGO Calorimeter

BGO Readout System

Main characteristics of the ADC Modules:

- 16 channels (sampling frequency of 160 MHz)
- extraction of the main features of the signal:
  - amplitude and time distribution of the first relative max of the signal and of all other maxima;
  - start time of the signal;
  - total integral;
- trigger: internal or external.
BGO equalization/calibration procedure

- Three $^{22}\text{Na}$ sources ($E_{\text{source}}=1.275\text{ MeV}$)
- Set of the PM’s gain varying their high voltage

$$c_i = \frac{E_{\text{source}}}{ch_{\text{cal}}(i)} = \frac{1.275\text{MeV}}{ch_{\text{cal}}(i)} \quad (i=1,\ldots,480)$$

- $c_i$ fixed with a tolerance of 3%
The Frascati Φ Factory - BTF

- Electron beam with energy of 510 MeV
- Variable length Cu target
- Dipole magnet and system of slits
Experimental Set-up at the BTF

Matrix of the seven BGO crystals.

Plastic scintillator plate used for the trigger of the acquisition
Electronics read-out

The signal from the PM was split and:

- attenuated and sent to ADC
- sent to a FIFO with the $\Sigma$ of the signals.
  - The $\Sigma$ was amplified, sent to a DISCR and to the UNIT COINC (with the signal of the scintillator).
  - A veto to the UNIT COINC is given by the DUAL TIMER.
  - The reset is provided by the I/O Register.
Energy settings

1. ~ 100 MeV → $E_{\text{nom}} = 94.3$ MeV
2. ~ 150 MeV → $E_{\text{nom}} = 140.9$ MeV
3. ~ 200 MeV → $E_{\text{nom}} = 187.8$ MeV
4. ~ 300 MeV → $E_{\text{nom}} = 281.3$ MeV
5. ~ 400 MeV → $E_{\text{nom}} = 374.5$ MeV
6. ~ 500 MeV → $E_{\text{nom}} = 467.3$ MeV

$$E_{\text{nom}}(\text{GeV}) = 0.3 \cdot B(\text{Tesla}) \cdot \rho(\text{m})$$

$$\rho(\text{nom}) = 1.723 \text{ m}$$
Energy Spectrum - 100, 150, 200 MeV
Energy Spectrum - 300, 400, 500 MeV
Linearity curve

Total linearity at constant energy

\[ E_{\text{meas}} = p_0 + p_1 \cdot E_{\text{nom}} \]

\[ \chi^2_{\text{red}} = 0.4 \]
\[ p_0 = (-7.233 \pm 3.971)\text{MeV} \]
\[ p_1 = (0.977 \pm 0.0055) \]

Total linearity at constant multiplicity

\[ \chi^2_{\text{red}} = 0.25 \]
\[ p_0 = (-1.868 \pm 4.845)\text{MeV} \]
\[ p_1 = (0.9628 \pm 0.01027) \]
Energy Resolution

**Measured resolution:**

\[
\sigma_{\text{meas}}^2 = \sigma_{BGO}^2 + \sigma_{BTF}^2
\]

where: \( \frac{\sigma_{BTF}}{E} \approx 1\% \)

**BGO resolution parametrized as:**

\[
\frac{\sigma_{BGO}}{E} (\%) = \sqrt{(a_{\text{CONST}})^2 + \left( \frac{a_{\text{STAT}}}{\sqrt{E_{\text{NOM}}}} \right)^2 + \left( \frac{a_{\text{NOISE}}}{E_{\text{NOM}}} \right)^2}
\]
Energy Resolution

Points with the same colour represent data obtained at the same energy settings.
Energy Resolution

BGO resolution at constant multiplicity

\[
\chi^2/\text{ndf}=50.8/21
\]

- \(a_{\text{CONST}}=1.843\times10^{-8}\pm0.02\)
- \(a_{\text{NOISE}}=0.5658\pm0.08956\)
- \(a_{\text{STAT}}=2.138\pm0.05007\)

Points with the same colour represent data obtained at the same multiplicity.
Energy Resolution

BGO resolution (at the same energy settings)

\[ a_{\text{CONST}} = 2.421^{-9} \pm 7.562 \]
\[ a_{\text{NOISE}} = 0.6099 \pm 0.07656 \]
\[ a_{\text{STAT}} = 2.11 \pm 0.03858 \]

BGO resolution (at the same multiplicity).

\[ a_{\text{CONST}} = 1.843^{-8} \pm 5.02 \]
\[ a_{\text{NOISE}} = 0.5658 \pm 0.08956 \]
\[ a_{\text{STAT}} = 2.138 \pm 0.05007 \]

\[ \downarrow \]

\[ a_{\text{CONST}} \approx 0 \]
Beam Spot vs energy settings
Start time distributions
Start time distributions

Central crystal
Temporal resolution $\simeq 3\text{ns}$

Lateral crystal
Temporal resolution $\simeq 6\text{ns}$
Start time distributions

PM/small crystal
Mean value $\approx -224$ns

PM/Large crystal
Mean value $\approx -234$ns
Invariant mass of $2\gamma$ and missing mass from $2\gamma$

$Lorenzo Magnisi, Bachelor Thesis$

\[ m_{\pi^0} = 136.6 \pm 0.1 \text{ MeV} \]
\[ \sigma = 12.9 \pm 0.1 \text{ MeV} \]

- Particle identification by using the geometric coincidence between the BGO calorimeter and the barrel scintillator.
- 3 signals in the BGO + 1 signal in the barrel ($2\gamma + 1$ proton in the central region)
Invariant mass of $2\gamma$ reconstruction

- Particle identification by using the cluster multiplicity in the BGO calorimeter
- 3 signals in the BGO and no signal in the barrel ($2\gamma$ in the central region + 1 proton in the forward region)
Conclusions

- The new BGO-OD experiment at the ELSA facility has been described;
- The characteristics of the BGO calorimeter have been presented;
- The BGO energy resolution measured at the BTF resulted $\simeq 3\%$ at 1 GeV;
- The BGO timing resolution measured at the BTF has been found $\simeq 3\text{ns}$;
- The good performance of the calorimeter has allowed the invariant mass reconstruction of the $\pi^0$ and $\eta$ mesons during several test beamtimes at ELSA.
Thank You!!