Detection of $K^+$ Mesons in Segmented Electromagnetic Calorimeters

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Tagged Photon Hall at MAMI

TAPS
384 BaF2 Crystals
Forward 21°
1.5m upstream

CB 672 NaI(Ti) Crystals
Spherically arranged around target
93% phase space

MAMI-C provides 1.5GeV e-
Tag Brem. Photons to 1.4GeV-

$E \approx 2 \text{ MeV}$
$I \approx 10^8 \gamma/s$

Linear or circular pol.
The CrystalBall and TAPS

Calorimeters

CB
Truncated triangular pyramid
40.6cm or 15.7 rad.len.
Energy resolution~2%E
Angular resolution~3°
Time resolution~4ns

TAPS Crystal
Hexagonal Crystal
25cm of 15 rad.len.
Energy Res~2.5%E
Angular Res~1°
Time Res~1ns

See proceedings CALOR04 D.P. Watts

Excellent γ detectors ⇒ neutral mesons
Extra Equipment

- Thin scintillator barrel for particle ID ($\pi^\pm, p, D, e^-$)
  - Comprises 24 detectors 4mm thick
- Cylindrical wire chambers for tracking (Pavia)
- Cryogenic Hydrogen, Deuterium targets
- Polarised Targets (H, D, He)
- Solid Targets (C, O, Pb...)
CB@MAMI Diverse Physics Program

- \(\eta\) and \(\eta'\) decays - Test of fundamental symmetries (C,CP,CPT...)

"Complete measurement" of meson photoproduction → Baryon spectroscopy

- Polarised beam, target and recoil baryon

- \(\omega\) production on nuclei - Medium modifications

- Threshold \(\pi^0, K^+\) production – Test of LET/ChPT

- Radiative resonance decay - Magnetic moment of \(\Delta\) and \(S_{11}\) resonances

- Nucleon Knockout from nuclei – NN interaction

- Meson production on nuclei – Nuclear structure
Coherent $\pi^0$ Photoproduction

$^{208}Pb (\gamma, \pi^0)^{208}Pb$

Analyse $\pi^0$ decay photons from CB

Characteristic Diffraction Pattern
Minima $\rightarrow$ Nuclear Mass radius
$\rightarrow$ Neutron skin thickness
$\rightarrow$ Neutron stars, atomic parity non-conservation

Publication in prep.
Incoherent $\pi^0$ Photoproduction

Tag Inc. reaction with nuclear decay $\gamma$

$^{12}\text{C} \left( \gamma, \pi^0 \right) ^{12}\text{C}^* (4.4 \text{MeV})$

$E_\gamma = (225-245) \text{MeV}$

Measuring transition matter form factors
Sensitive test of $\Delta N$ interaction

C.M. Tarbert et al. (CB@MAMI collab)  
K⁺ Photoproduction

\[ \gamma p \rightarrow K^+ \Lambda \]
\[ K^+ \Sigma^0 \]
\[ K^0 \Sigma^+ \]

\[ \Lambda \rightarrow n\pi^0 \text{ or } p\pi^- \]
\[ \Sigma^0 \rightarrow \gamma \Lambda \]
\[ \Sigma^+ \rightarrow p\pi^0 \text{ or } n\pi^+ \]

We can measure with polarised beam, target and recoil hyperon
Measurements are sensitive to intermediate nucleon resonance
At threshold also an important test of ChPT in SU(3) sector

K⁰ reconstructed from decay to 2π⁰
How to identify K⁺ without a magnetic field…..?
K+ Decays

- Mass $m = 493.667$ MeV
  
  $K^+ \rightarrow \mu^+ \nu_\mu \quad 63.51\%$
  
  $\rightarrow \pi^+ \pi^0 \quad 21.16\%$

- $T_\mu = 152$ MeV  $T_\pi = 109$ MeV

- Mean life $\tau = 12.386$ ns (CB $\sigma_{\text{time}} = 4$ ns)

  $c\tau = 3.713$ m
First cluster from K+ t<1ns

Secondary cluster from decay to $\mu$
Resolve >10ns later
Up to 8 crystals and 150 MeV

Also detect secondary $\pi$ decay cluster
Up to 360 MeV
**K⁺ Tag Algorithm**

- Construct as large a cluster possible from neighbouring hits
- Split cluster using timing coincidences of crystals (~8ns)
- First split cluster is K⁺, second is decay
- Cut on second cluster Energy, Time, Length and Number of crystals
- $\Delta E-E$ of K⁺ cluster
Kaon Tag Cuts

Characteristics of second cluster

![Graph of Energy vs. Time with fitting parameters: $\chi^2/\text{ndf} = 432.5/33$, $\text{const} = 2.875e+04 \pm 189$, and $\tau_{K^+} = 12.4$ ns.]

![Graph of Length of Cluster vs. Number of Crystals in Cluster with fitting parameters: $\chi^2/\text{ndf} = 432.5/33$, $\text{const} = 2.875e+04 \pm 189$, and $\tau_{K^+} = 12.4$ ns.]

- Real Data
- GEANT4 based sim.

- decay $\mu$: 150 MeV
- decay $\pi$: 350 MeV
ΔE-E Cut

Simulation

Real Data

ΔE from PID scintillator, E from CB
K$^+(\Lambda\Sigma)$ Photoproduction

Very Raw Excitation Spectra (no accept. cor.)

Detection efficiency $\sim$10%
Gives $\sim$2000 K$^+$/hour
CB stops K$^+$ up to 330MeV
or else they pass untagged
Background from sim. $\pi^\pm < 10^{-5}$
Polarisation Measurement

!!Preliminary!!

Weak decay of $\Lambda$ sensitive to its polarisation.

$\Lambda \rightarrow N\pi$

For helicity polarised photons:

$$A(\theta_i) = \frac{N^+ - N^-}{N^+ + N^-} = \alpha P^\gamma P^i \cos \theta_i$$

where $\theta_i$ is the angle between decay $N$ and axis $i$.
Summary

- **CB@MAMI** Up and running since 2004
- First paper on Incoherent $\pi^0$ production published
- Upgrade to MAMI-C gives photon beam energy up to 1.4 GeV
- Allows use of $K^+$ decay tag in CB and TAPS to investigate strangeness physics
- Polarisation observables in photoproduction
- $K^+$ production on nuclei (incl. Hypernuclei)