Development of an Aerogel Cherenkov Counter for the J-PARC E16 Upgrade

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Motivation

Aerogel Cherenkov Counter

Present Status

Summary
Motivation

- J-PARC E16 experiment measures in-medium \( \phi \)-meson modification in di-electron spectrum
  - Topics of the \( \phi \)-meson
    - Di-lepton spectrum
    - \( \Gamma_{\ell\ell} \) vs \( \Gamma_{KK} \) (\( \phi \)-puzzle)

- K\(^+\)K\(^-\) measurement in the E16 experiment is very important
  - Installation of Kaon detectors in the E16 spectrometer is desired

Do decay widths of \( \phi \rightarrow \ell\ell / KK \) change in nuclear matter caused by \( \phi / K \) spectral modification?

- \( \text{Br}^*(\phi \rightarrow \ell\ell) / \text{Br}_0(\phi \rightarrow \ell\ell) \)
- \( \rho_{CR} / \rho_0 \)

Theory

- NPA830,753c(2009).
Forward Kaon Spectrometer

AC(n=1.034) + TOF counter

segmented STC

--- Requirements ---
1. threshold type AC for kaon trigger (veto counter)
2. work in magnetic field
3. small & compact
$\phi \rightarrow e^+e^-/K^+K^-$ acceptance

- e-accepted (double-arm)
- e-accepted (single-arm)
- $K^+$-accepted (opposite-module pair)
- $K^+$-accepted (same-module pair)
- $K^+$-accepted (neighbor-module pair)

E325 acceptance

Improvement of the acceptance overlap between $e^+e^-$ and $K^+K^-$
AC design

- Use $n=1.034$, as same as KEK-PS E325
- 60x60cm$^2$ divided by 6 (or 10) sectors

**Goal:** construct a prototype of $\frac{1}{4}$ size module

**Readout:**
WLS + fiber + (FM)PMT

**Integration range:**
300-800nm
Some Hints in detector development in Russia?

Candidate for PEP-N detector @ SLAC

Aerogel: t74mm, n=1.05
WLS: BBQ

~8 p.e.
Minimum Goal: KEK-PS E325 AC

- $n = 1.034$
- 12.5 cm Aerogel
- 5 inch PMT (H6527)

M. Ishino et al., NIM A457, 581

π Rejection: $1 \times 10^{-2}$ @ 1.4 GeV/c

8 p.e.

1.1 p.e.
We have checked 3-types of the aerogel (n~1.034):
- Panasonic-denko
- KEK-PS E325
- Chiba-U
WLS

- Aerogel (t2cm)
- clear fiber x100 (φ1mm, single clad)
- WLS (ELJEN EJ-299-27, t1mm)

Expected # of photon @ 1GeV/c \( \pi \) & \( n = 1.034 \)

Transmission length \( n = 1.034 \) (KEK)

Cosmic Ray

PMT

H6410 (2”)
WLS (Cont’d)

2cm 2cm

1mm 1mm 1mm

w/ Aerogel

\begin{tabular}{|c|c|}
\hline
\textbf{Entries} & 8381 \\
\textbf{Mean} & 125.2 \\
\textbf{RMS} & 49.73 \\
\textbf{Underflow} & 0 \\
\textbf{Overflow} & 5 \\
\hline
\end{tabular}

$\chi^2 / \text{ndf} = 249.2 / 242$

$\text{Prob} = 0.3614$

$p0 = 4901 \pm 74.0$

$p1 = 2.721 \pm 0.035$

w/o Aerogel

\begin{tabular}{|c|c|}
\hline
\textbf{Entries} & 10140 \\
\textbf{Mean} & 143.7 \\
\textbf{RMS} & 83.37 \\
\textbf{Underflow} & 0 \\
\textbf{Overflow} & 244 \\
\hline
\end{tabular}

$\chi^2 / \text{ndf} = 1600 / 397$

$\text{Prob} = 0$

$p0 = 4498 \pm 73.5$

$p1 = 2.651 \pm 0.060$

failing is failed...
--- What we have learned ---
\* WLS (blue, t1mm) emits several photons with charged particles

→ We cannot install a large amount of WLS in detector acceptance

\* present method of WLS+fiber readout cannot collect Cherenkov light from the Aerogel

--- What we have to do ---
\* reconsider the configuration of the Aerogel and WLS
  ➢ increase the fibers?
  ➢ usage of blue and green WLS?
Other Ways ...

● development of a “normal type” Aerogel Cherenkov Counter with finemesh-PMTs such as BELLE AC.

● development of a “reflection type” Aerogel Cherenkov Counter with optical mirrors such as E325 AC.

E325 AC
NIM A457, 581

BELLE AC
NIM A453, 321
We have been developing an Aerogel Cherenkov Counter for the E16 upgrade in order to measure \(K^+K^-\) pair.

Development of WLS+fiber readout has been started, but we have to adjust the configuration of AC+WLS+fiber. Further study is required…
Expected Photon Spectra

- Expected # of photon @ 1 GeV/c: $\pi$ & $n = 1.034$
- Transmission length: $n = 1.034$ (E325)

Aerogel Detection

$\pi$ 1 GeV/c

N.P. vs wavelength [nm]
WLS (Cont’d)

H6410 (2”)

Aerogel 6cm

WLS 1mm

Aerogel 6cm
WLS (Cont’d)

\[ \pi \ 1\text{GeV/c} \]

Aerogel Detection

PMT

300~600nm

WLS

300~400nm

WLS(blue)

PMT
WLS (Cont’d)

H6410 (2")

Aerogel 9.4cm

WLS 1mm

adc0

his00

Entries 7667
Mean 154.8
RMS 77.03
Underflow 0
Overflow 81
\(\chi^2 / \text{ndf} \) 503.1 / 341
Prob 9.353e-09
p0 4261 ± 65.9
p1 4.617 ± 0.050

adc0

his00

Entries 5370
Mean 93.58
RMS 21.69
Underflow 0
Overflow 4
\(\chi^2 / \text{ndf} \) 117 / 122
Prob 0.6111
p0 2479 ± 144.2
p1 0.6311 ± 0.0442
Photon Fitting

\[
f(x) = C \sum_{n} \frac{\lambda^n \exp(-\lambda)}{n!} \times \frac{1}{\sqrt{2\pi n\sigma_1}} \exp\left(-\frac{(x-(p_0+n p_1))^2}{2n\sigma_1^2}\right)
\]

**Poisson**

\[C: \text{normalized factor}\]
\[\lambda: \text{mean value of photoelectron}\]
\[p_0: \text{pedestal peak}\]
\[p_1: \text{distance of pedestal to single-photon}\]
\[\sigma_1: \text{PMT resolution for single-photon}\]

**Gaussian**

\[\leftarrow \text{parameter}\]
\[\leftarrow \text{parameter}\]
\[\leftarrow \text{constant}\]
\[\leftarrow \text{constant}\]
\[\leftarrow \text{constant}\]
We purchased and tested SiAPDs.

But we **CANNOT** see the signal of a few photons on SiAPD, because of read-out electronics noise!

what we have learned is ... “using low-gain devices for Cherenkov detection is awful difficult!”
We purchased and tested MPPCs.

The dark count signals of ~Mcps were confirmed as written in the product specification.

It seems that usage of the MPPCs for a single-photon detector is too hard! Several tens of photons are required.
Vector Meson, φ


$m_\phi$が変化

\[
\frac{\Gamma^*}{\Gamma_0} = \left(\frac{q}{q_0}\right)^3 \left(\frac{m_0}{m^*}\right)
\]

\[
q = \sqrt{m^{*^2}/4 - m^2_K}
\]

\[
q_0 = \sqrt{m_0^2/4 - m^2_K}
\]

$m_K$が変化

\[
\frac{\Gamma^*}{\Gamma_0} = \left(\frac{q}{q_0}\right)^3
\]

\[
q = \sqrt{m_0^2/4 - m^{*^2}_K}
\]

\[
q_0 = \sqrt{m_0^2/4 - m^2_K}
\]
**φ Puzzle**

核物質中でのφまたはKのスペクトル関数の変化によって、φ→ll/KKの崩壊幅が変化するのではないか？

● theoretical predictions
  \[ \Gamma^*(\phi \rightarrow KK)/\Gamma^*(\phi \rightarrow ll) \] の増加
  \[ \Gamma^*(\phi \rightarrow KK)/\Gamma^*(\phi \rightarrow ll) \] の増加
  \[ \Gamma^*(\phi \rightarrow KK)/\Gamma^*(\phi \rightarrow ll) \] の減少
- etc.

● NA49/NA50@CERN-SPS
- \[ \phi \rightarrow K^+K^-/\mu^+\mu^- \], 158AGeV Pb+Pb
- production CS's are **inconsistent**
**φ Meson Measurements**

**Hot Matter**

- **CERES (NA45)@CERN-SPS**
  - $\phi \rightarrow e^+e^-/K^+K^-$, 158AGeV Pb+Au
  - Production CS’s are **consistent**

- **PHENIX@BNL-RHIC**
  - $\phi \rightarrow e^+e^-/K^+K^-$, $\sqrt{s_{NN}}$=200GeV Au+Au
  - Production CS’s are **consistent**

- **NA60@CERN-SPS**
  - NPA830, 753c (2009).
  - $\phi \rightarrow \mu^+\mu^-/K^+K^-$, 158AGeV In+In
  - Production CS’s are **consistent**

**Cold Matter**

- **E325@KEK-PS**
  - $\phi \rightarrow e^+e^-/K^+K^-$, 12GeV p+C/Cu