Energy Dependence of $\frac{\text{K}}{\text{K}^+}$ Ratio in In+${}^{28}\text{Si}$ Reaction

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Introduction
Symmetry Energy at high density

- **sub-saturation density**
  - some constraints

- **supra-saturation density**
  - The trend is not fixed.

**Experiment at supra-saturation density**
- Heavy Ion Collision at a few hundred MeV/nucleon
- probe: $\pi^- / \pi^+$ ratio
- Pion: created by decay of $\bar{K} K^- / K^+ K^0 (N/Z)^2$

Comparison between theory and experiment

**IBUU04**

![Graph showing comparison between Au+Au and IQMD](image1)

**Comparison between theory and experiment**


**Im IQMD**

![Graph showing comparison between Im IQMD and other models](image2)

The results of two calculations

Motivation

- **Long Term Plan**
  - N/Z ratio using isotope (unstable nuclei)
  - Beam Energy: a few hundred MeV/nucleon
  - We plan Sn isotope experiments at RIBF using SAMURAI-TPC.

- **Short Term Plan**
  - Experiments using stable beam
  - Beam Energy & N/Z Ratio Dependence
    - Measurement with various conditions
  - Experiments @ Medical Accelerator HIMAC
Experiment and Analysis
Experimental Setup

- **Beam**: ²⁸Si
- **Intensity**: ~ 10⁷ ppp
- **Energy**: 400, 600, 800 AMeV
- **Target**: In ~ 390 mg/cm²
- **Range Counter**: 14 layers (+2) of Sci.
- **measured angle (θ_lab)**: 30, 45, 60, 75, 90, 120 degree
- **solid angle**: 10 msr

**Diagram**:
- Beam
- Target
- Vacuum
- Multiplicity Array
- Ion Chamber
- Air
- Range Counter

**NOT YET Analyzed**
Identification principles of $\pi^+$ (and $\pi^-$)

**<In flight>**
- $\mathrm{d}E/\mathrm{d}x$ is identical for both $\pi^+$ and $\pi^-$

**<After STOP>**

- **$\pi^+$**
  - $\pi^+$ decay to $\pi^+$
  - $\pi^+$
    - Energy $\sim 4$ MeV
    - Range $\sim 1$ mm

- **$\pi^-$**
  - create a pionic atom and captured by a nucleus
  - decay to various particles
  - Unable to use the same identification method as $\pi^+$

- **$\pi^+$** : Double Hits in one counter

**<identification step>**
- $\pi^+$ ID using Double Hit Condition
- $\pi^-$ ID using $E$ conditions of well defined $\pi^+$
- $\pi^-$ = $\pi^- - \pi^+$

$\pi^-, \pi^+$ by Simulation (Geant4)

- Red : $\pi^+$
- Blue : $\pi^-$
Histogram of Range Counter

Example counter: #8

STOP CONDITION

counter #0~8 Hit + counter #9~13 No Hit

E8 (MeV) All Events

counter #8 stop events

stop P through P
**\( \Xi^+ \) Identification**

**< \( \Xi^+ \) events >**

Counter #8 STOP Condition

+ #8 Double Hit Condition

Fit the Histogram

“2\(^{\text{nd}}\) Hit Time - 1\(^{\text{st}}\) Hit Time”

by \( Cexp(-t/\tau) \)

\( \tau = 26.0 \pm 0.6 \text{ nsec} \)

We could clearly select \( \Xi^+ \)

#8 stop events (black) & stop \( \Xi^+ \) (red)

We got \( \Xi^+ \) counts by extrapolation
□ E cut from #0 to 7 in 1 D

□ + (red) : STOP + Double Hits Conditions

 Diagram showing distribution of E cut from #0 to 7 in 1 D.
E cut from #0 to 7 in 1 D

□ + (red) : STOP + □ E CUT + Double Hit Conditions

□ (black) : STOP + □ E CUT Conditions
In order to check background, we rejected counter 6 & 7 E conditions.

There are background in black histogram.
We look n stop events in “n-2 vs n-1” distribution

We call these background as “Through Background” still remain by using E gate.
$E$ cut on 2D

CHECK 6 vs 7 Histogram of 8 stop events

\{ • Red : $\Box^+$  
  • Black : Other Particles (Background etc) \}

< Background Check >
$E$ gates from #0 to 5
"Through Background" still exits.

Cut the “Through Background” using the straight line
Definition of $\pi^-/\pi^+$ ratio

- $\pi^-: \text{STOP} + \pi^- \text{ E cut} + \text{cut line}
- $\pi^+: \text{STOP} + \pi^+ \text{ E cut} + \text{cut line} + \text{Double Hit (extrapolation)}$

$$\pi^- / \pi^+ \text{ ratio} = \frac{\pi^\pm - \pi^+}{\pi^+}$$
Discussion
We discuss the data in Target and Mid Rapidity frames.
\( \square^-/\square^+ \) ratio in Lab frame

For each angle (45deg, 60deg, 90deg, 120deg), there are data points for different energies (400 MeV, 600 MeV, 800 MeV). The x-axis represents \( E_\perp (\text{MeV}) \) and the y-axis represents the \( \square^-/\square^+ \) ratio.
Slopes depend on Beam Energy:

- 400 MeV: $2.9 \times 10^{-3}$
- 600 MeV: $4.8 \times 10^{-3}$
- 800 MeV: $8.5 \times 10^{-3}$
Summary and Next Step

< Summary >

- There are energy dependence in pion ratio.
  - Especially for low energy pion in the mid rapidity frame.

< Next Step >

- We are planning next experiments
  - Good sensitivity to low energy pion
  - N/Z dependence using Xe isotope beam