Setup for hypernuclear gamma-ray spectroscopy at the J-PARC K1.8 beam line

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for the Hyperball-J collaboration

Contents

- Introduction
- Magnetic spectrometer : SksMinus
- γ-ray detector array : Hyperball-J
- Summary

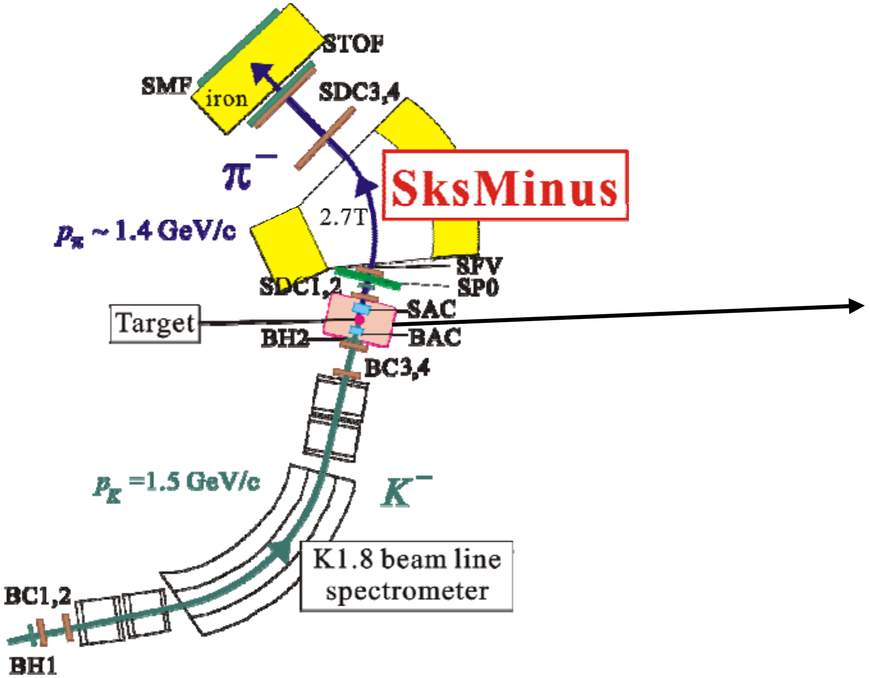
Introduction

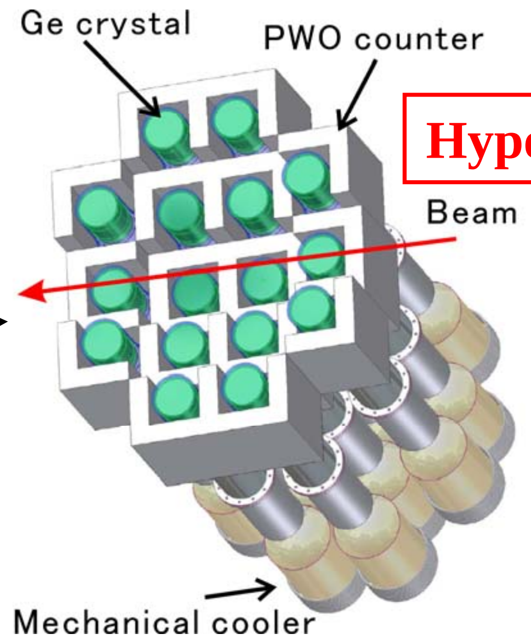
E13 Day-1 experiment at J-PARC

Several light hypernuclear γ-ray spectroscopy experiments are planned.

($^{4}_{\Lambda}$He, $^{7}_{\Lambda}$Li, $^{10}_{\Lambda}$B, $^{11}_{\Lambda}$B, $^{19}_{\Lambda}$F)

(K^-, π^-) reaction @ p_K = 1.5 GeV/c



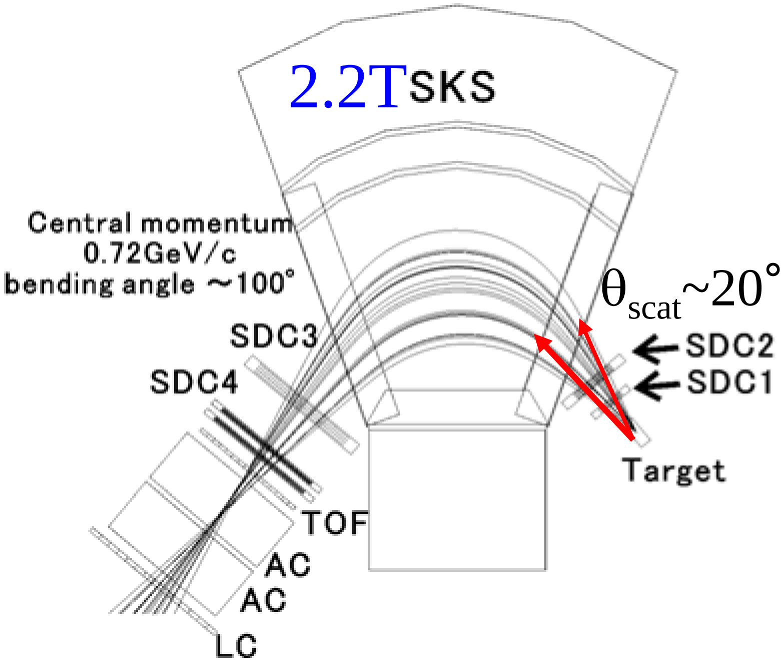


Missing mass analysis ← Particle-γ coincidence → γ-ray measurement

Optimized magnetic spectrometer + Hyperball-J

Magnetic spectrometer
-SksMinus-

Previous SKS setup

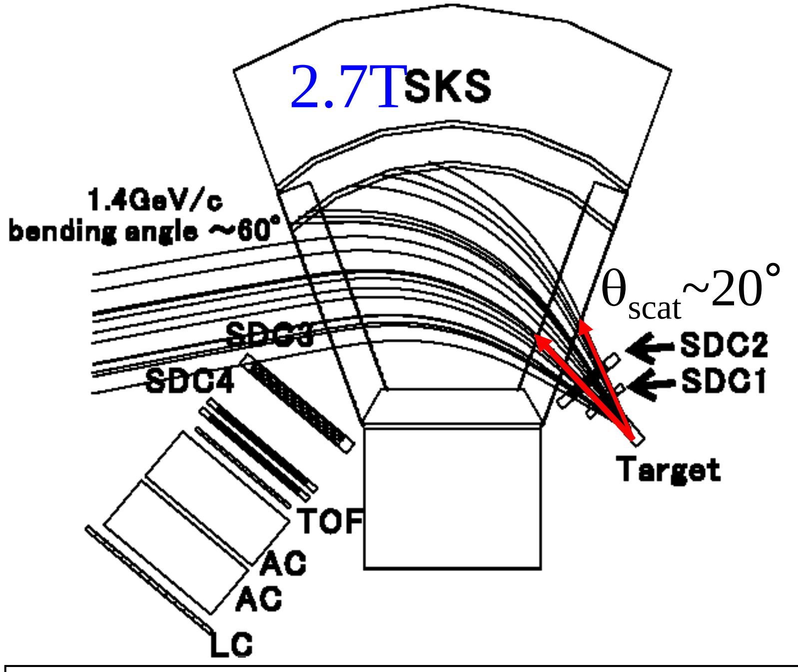


- Incident beam direction
- Size and placement of detectors at the exit of the SKS magnet

1.05 GeV/c (π^+, K^+) reaction (K^+ 0.72 GeV/c)

Momentum resolution	0.1%FWHM (0.72 MeV/c) @ 720 MeV/c, 2.2T
Acceptance	100 msr @ 0.72GeV/c
Maximum central momentum	1.0 GeV/c @ 2.7T

Previous SKS setup



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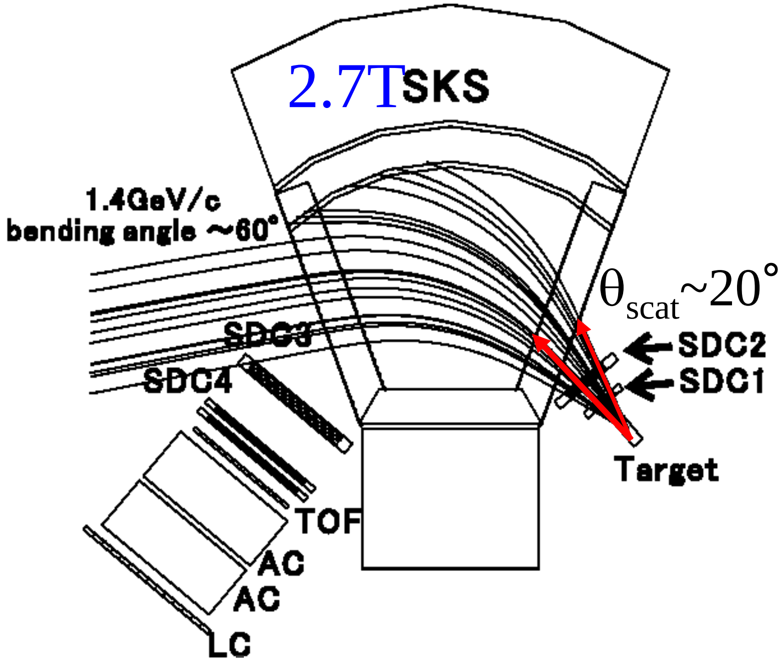
- ~~Size and placement of detectors at the exit of the SKS magnet~~

SksMinus setup



For the beam condition
- Determination of incident beam angle (20 degree)
- Larger drift chamber

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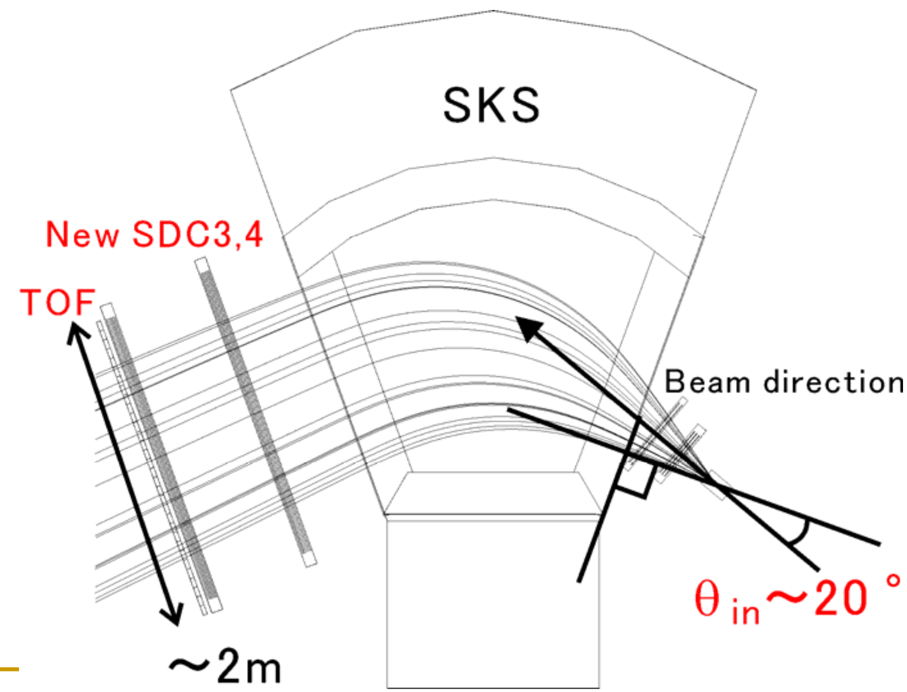


SksMinus setup

(K^-, π^-) reaction @ p_K = 1.5 GeV/c ⇒Analyze 1.4 GeV/c π^-

Requirements

- **Acceptance >100 msr, ~20° scattering angles**
- **Momentum resolution < 4 MeV/c (FWHM)**

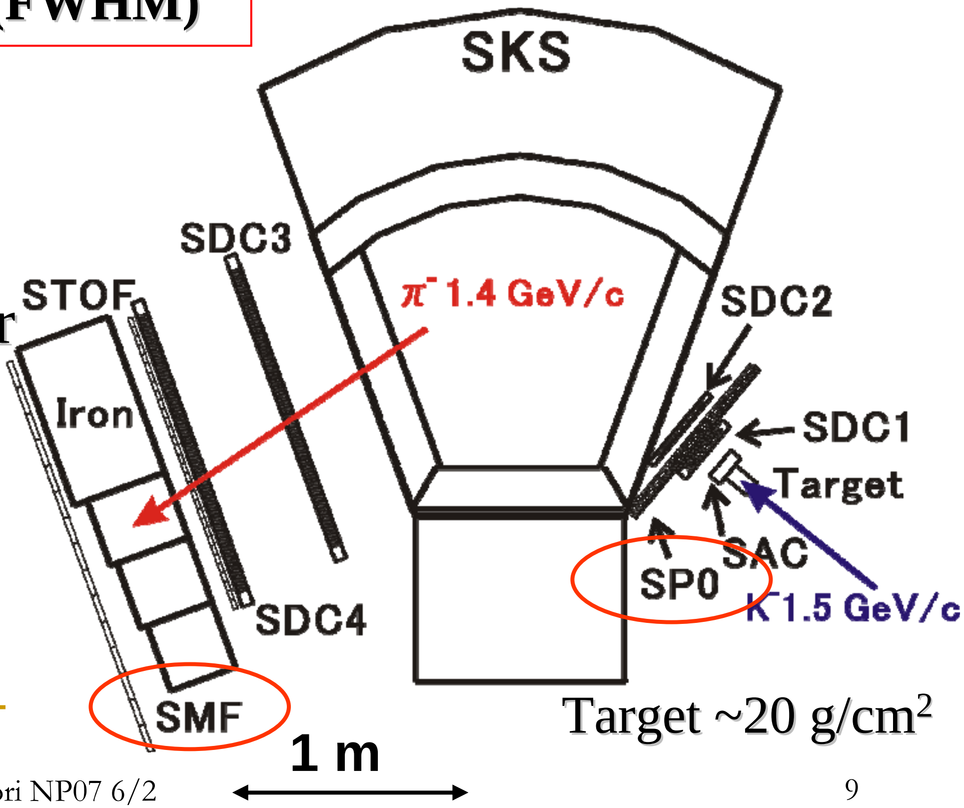
SDC1~4 : Drift chambers

STOF : TOF counter

SAC : Aerogel Cherenkov counter

Beam decay background veto

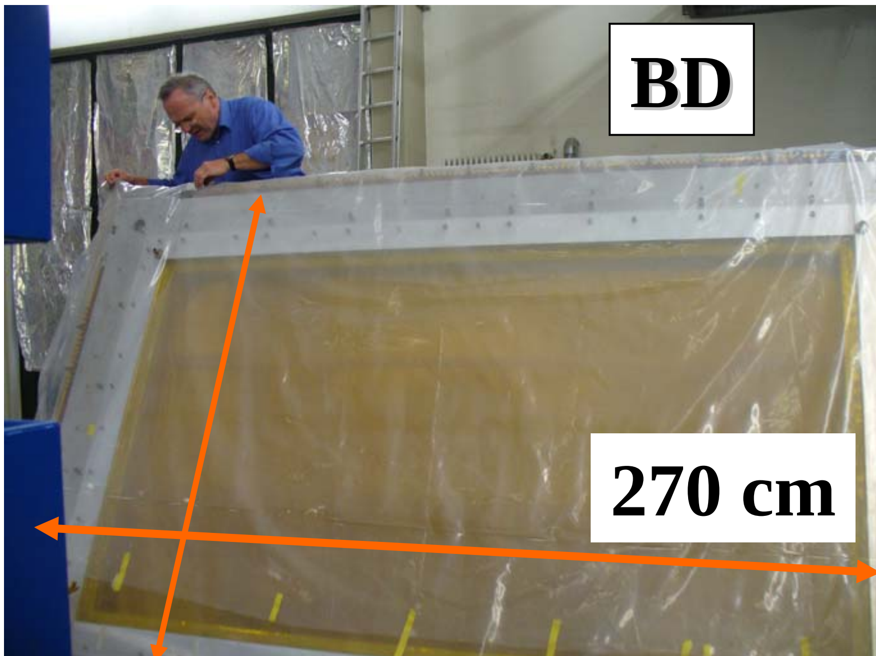
- SMF : μ^- from $K^- \rightarrow \mu^- + \overline{\nu}$
- SP0 : π^- from $K^- \rightarrow \pi^- + \pi^0$



Target ~20 g/cm²

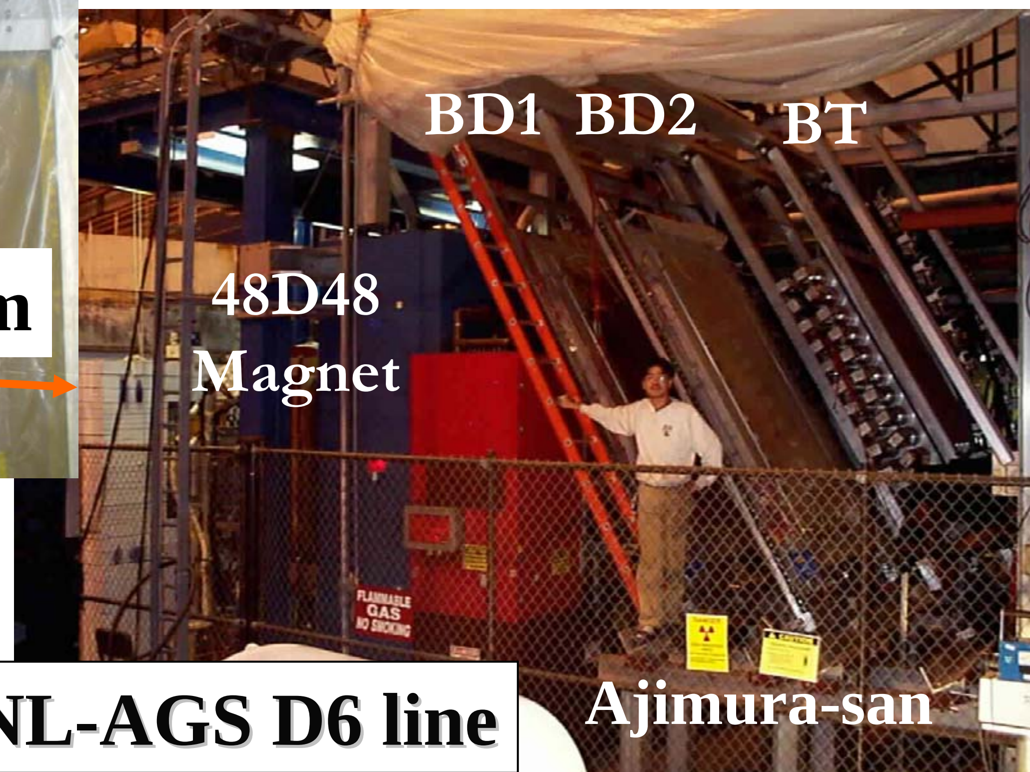
Drift chamber and TOF counter

To keep the large acceptance



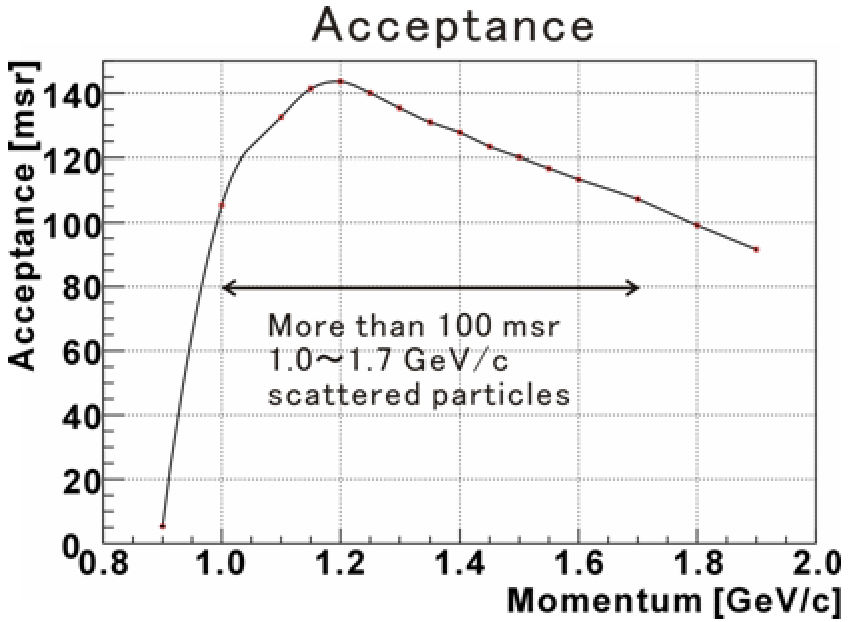
170 cm

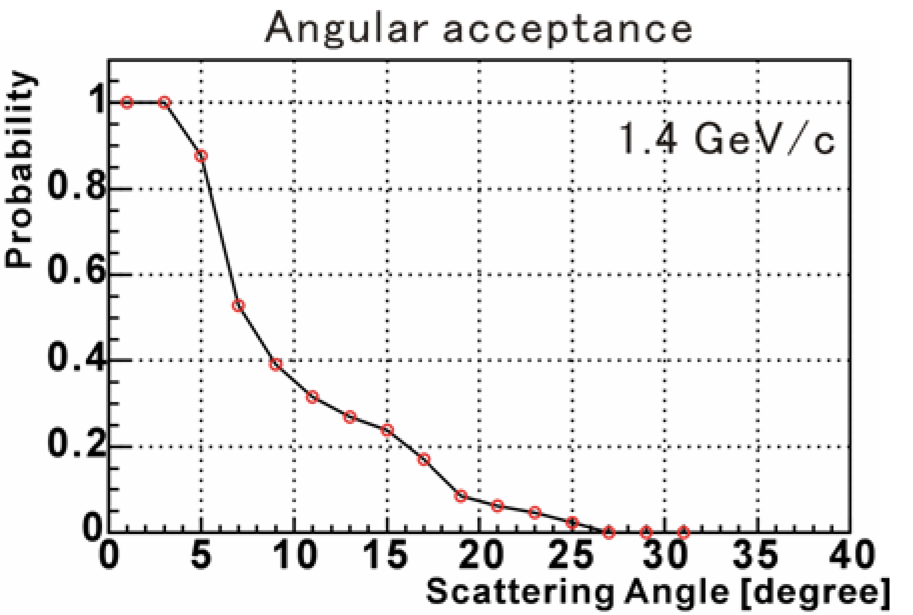
BD and BT from BNL are used as SDC3&4 and STOF, respectively.



BNL-AGS D6 line

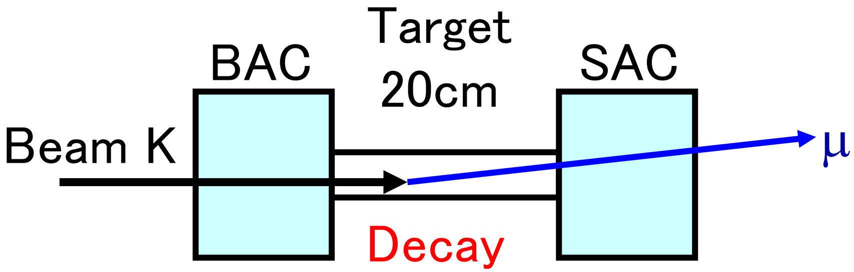
Simulation results of acceptance and momentum resolution

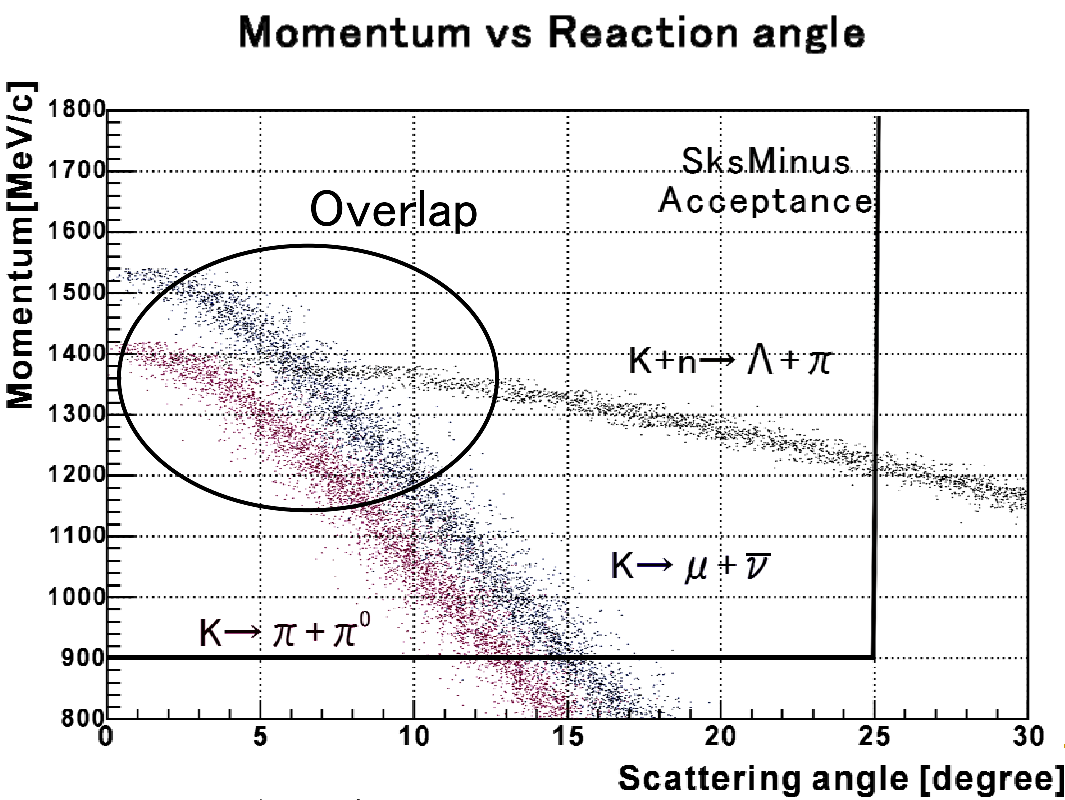




- Acceptance at 1.4 GeV/c,
  ~130 msr
- Enough angular acceptance,
  ~20 degree
- Momentum resolution at 1.4 GeV/c
  ~2.1 MeV/c (FWHM)

Background events : Beam decay





(K, π) Reaction with K Decay

- Trigger rate
- Missing mass

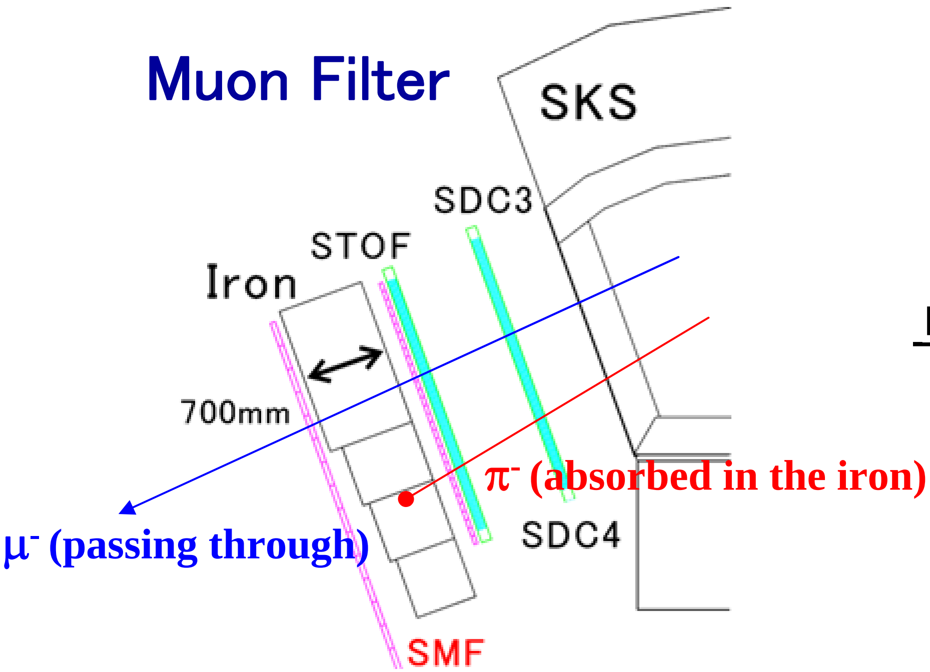
$K^- \rightarrow \mu^- \bar{\nu}$ (63.4%)

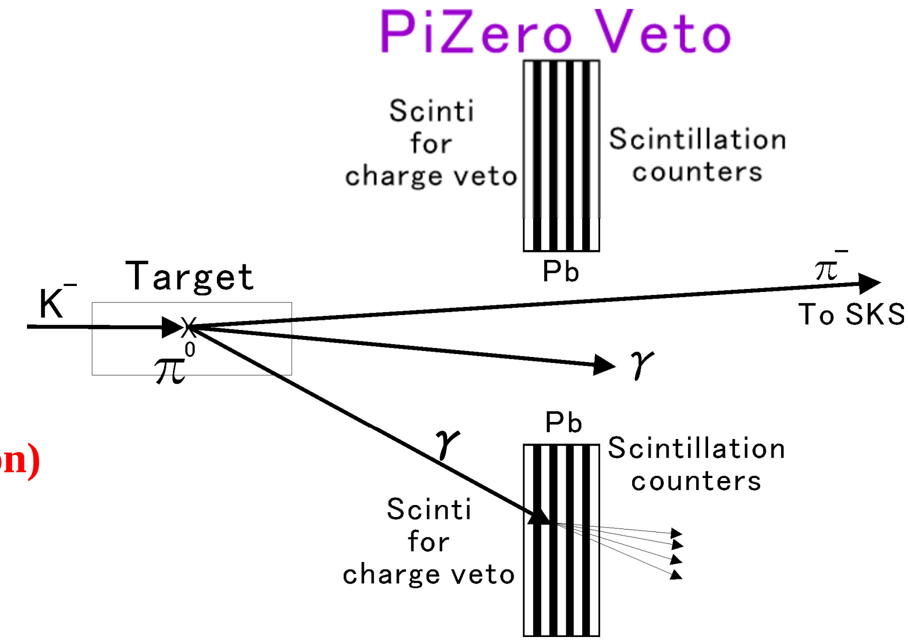
⇒**Muon Filter**

$K^- \rightarrow \pi^- \pi^0$ (21.1%)

⇒**PiZero Veto**

Beam decay veto counters





86% of $\mu^{-}\nu$ events detected
Others rejected (stopped in the iron) by offline analysis
Totally **> 99.9 %**

- Over kill for true π **~2.5%**

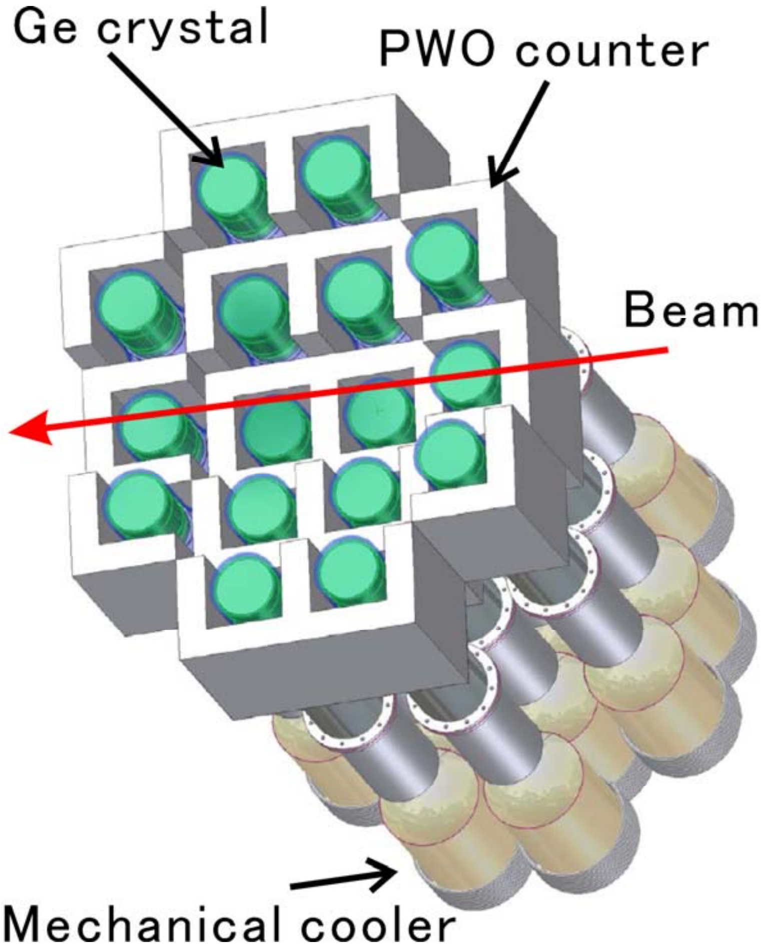
80% of $\pi^{-}\pi^{0}$ events detected

10 sets of 3 mm lead plate and 8 mm scintillation counter layer at 1.5 GeV/c beam.

Sufficient performance to reduce the trigger rate and background

Hyperball-J

Hyperball-J



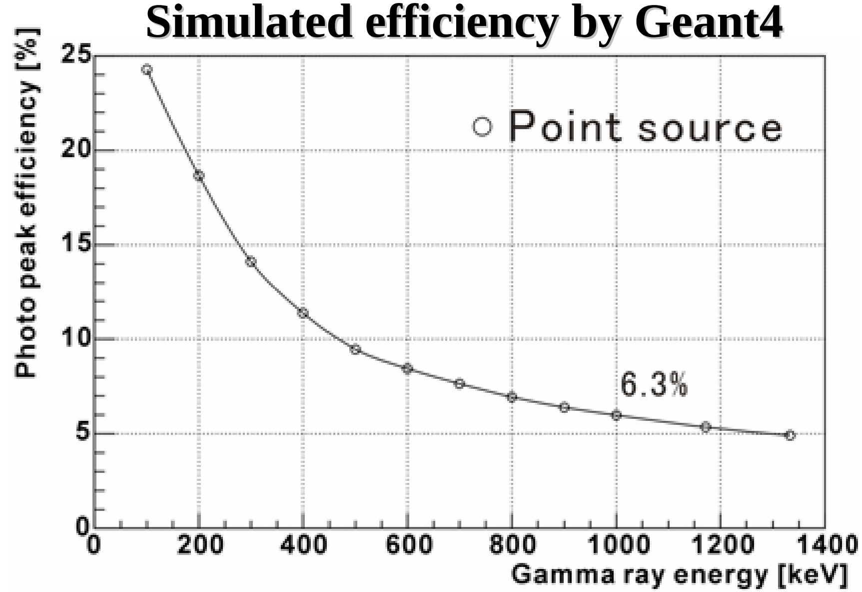
Hyperball-J (half)

Severe radiation damage
High counting rate

at J-PARC

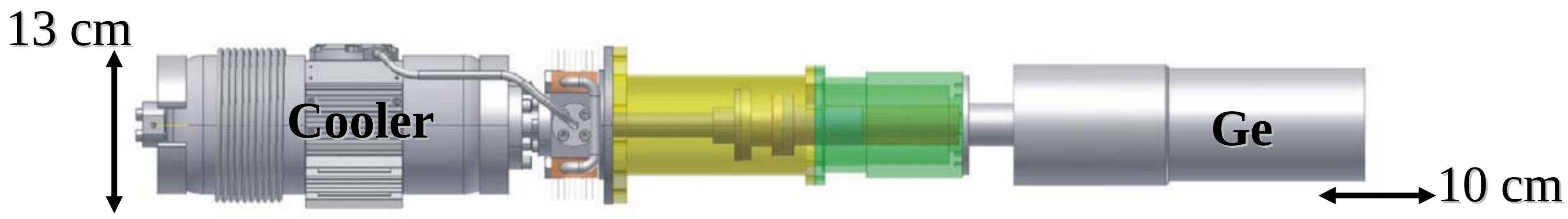
- Mechanical cooler
- ➡ PWO background suppressor
- Waveform readout

Simulated efficiency by Geant4



~6% photo peak efficiency @ 1 MeV

New Ge detector with Mechanical cooling



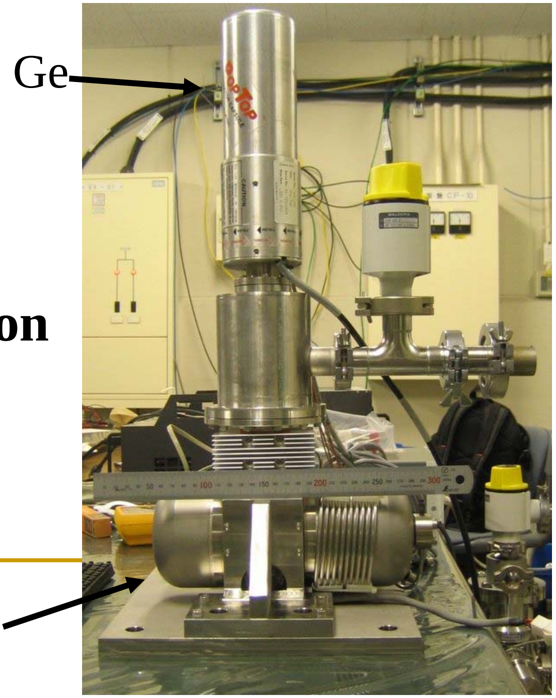
Mechanical cooler

⇒Suppression of the radiation damage effect with Ge crystal below 85 K (Liquid nitrogen cooling ~90 K)

R&D in KEK and Tohoku Univ.

- **Cooling power**
  Ge crystal temperature less than 85K when biased
- **Low mechanical vibration for 2 keV energy resolution**
  Minimization of microphonics noise

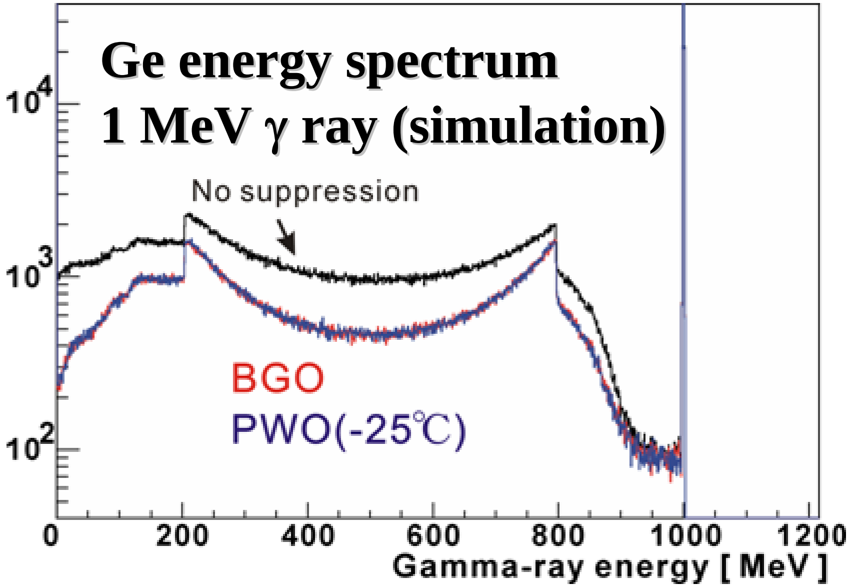
→ **Achieved**

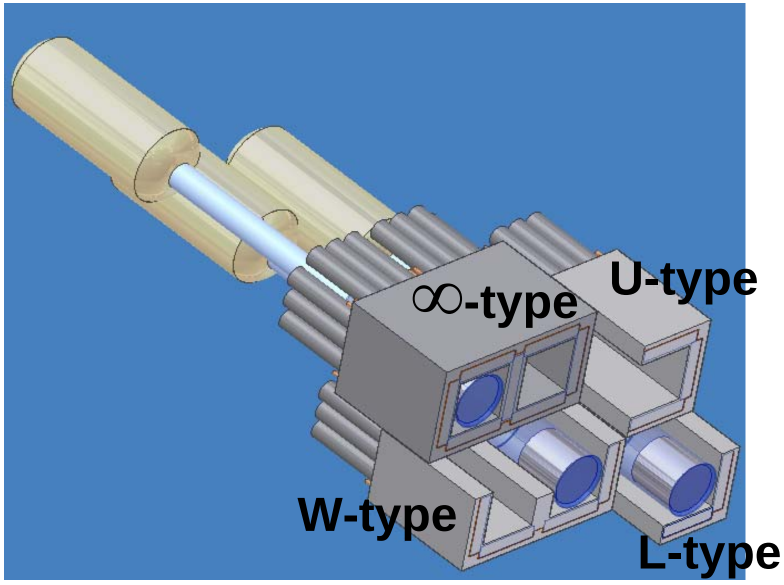


Background suppressor : $PbWO_4$

The PWO crystal has very first decay constant ~6 ns.
(~300 ns for BGO)
But **small light yield** (PWO/BGO=1/10)

- Doped PWO crystal
- Cooling of PWO below 0℃





PWO suppression for γ ray spectroscopy is possible.

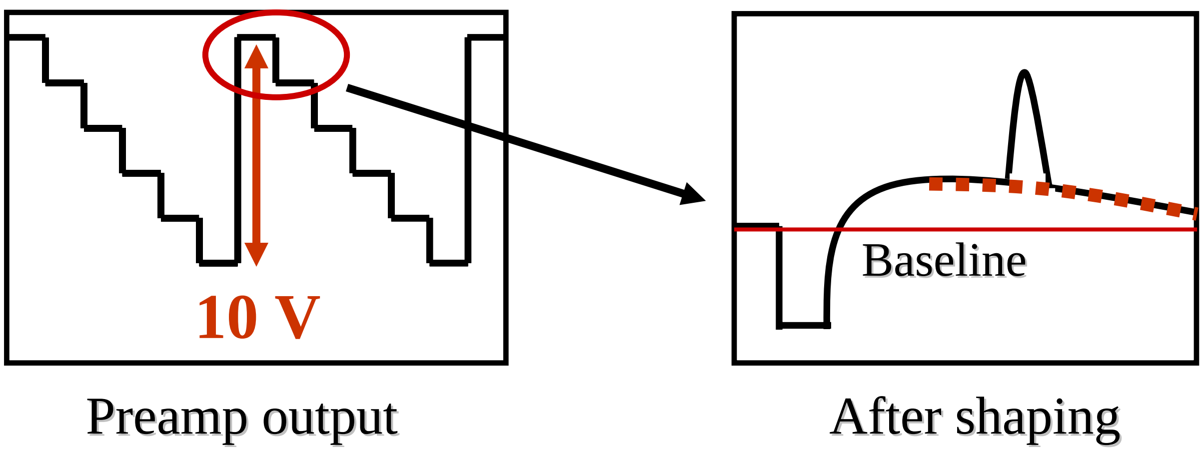
Waveform readout

To improve energy resolution
and recover rejected events
at high counting rates

- Baseline shift restoration
- Pile-up signal decomposition

→

Pulse height ADC
⇒ Sampling ADC
(waveform digitization)
(after shaping)



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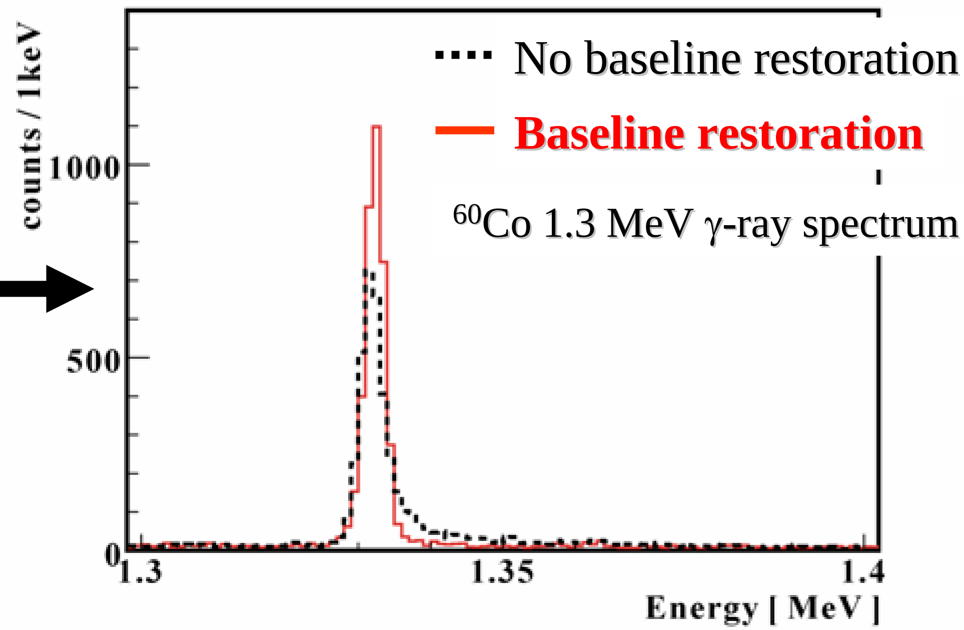
In the LNS test experiment, the positron beam is irradiated to Ge detector to make frequent baseline shits by reset signal.
⇒The restoration of the baseline shits



3.7 keV⇒ 3.1 keV (FWHM)
(2.6 keV w/o beam)

Summary

Summary

- J-PARC E13 experiment by the (K^-, π^-) reaction @ p_K =1.5 GeV/c
  - Optimal magnetic spectrometer
  - New Hyperball system for the high counting rate
- Magnetic spectrometer, SksMinus and newly constructed array, Hyperball-J

SksMinus performance

- More than 100 msr acceptance and 20 degree coverage
- ~2 MeV/c momentum resolution

Hyperball-J

- ~6 % efficiency
- Mechanical cooling system
- PWO counter
- Waveform readout

The experiment will be performed in 2009.

Backup

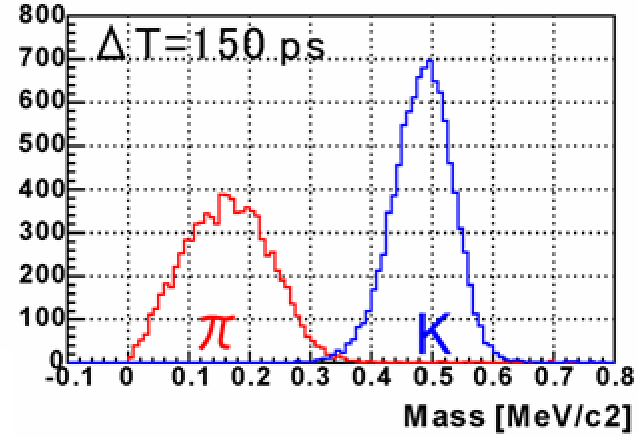
Particle identification

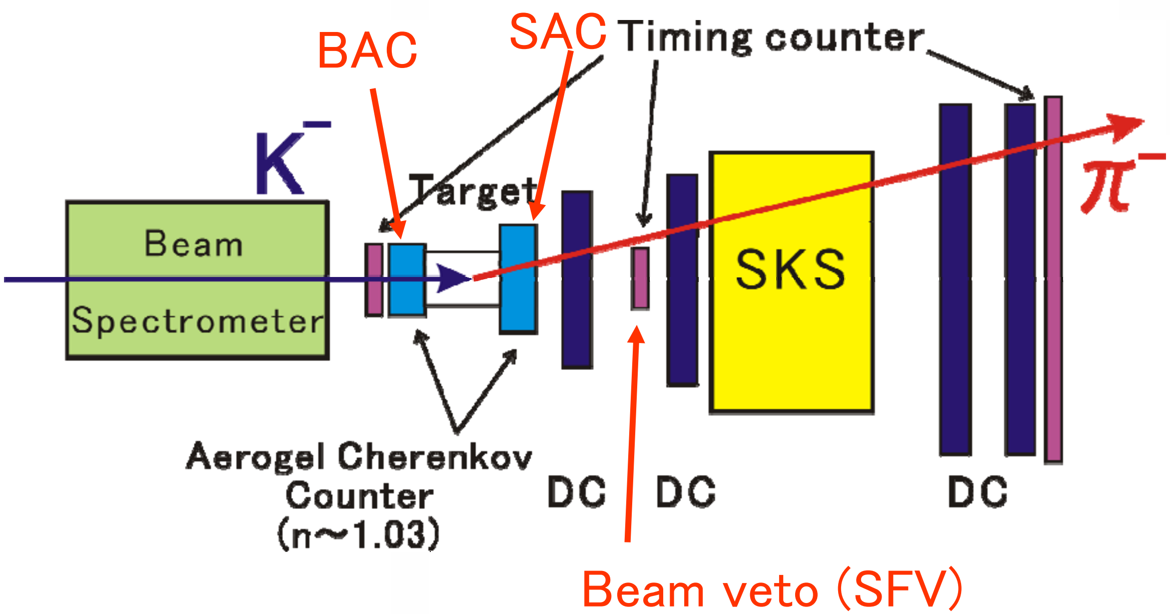
Reaction ID by BAC and SAC (n=1.03) @ trigger

Rejection of K^- beam through background

SAC ~98% + Beam veto (SFV)

STOF : Time resolution ~150 ps (rms)





(K^-, π^-) reaction

Large production rate (/beam)

Large elementary cross section, $n(K^-, \pi^-)\Lambda$: order of mb

> $n(\pi^+, K^+)\Lambda$: $\sim 10^2$ μb, $p(e, e'K^+)\Lambda$: ~1 μb

Large sticking probability

Angular selectivity

Small momentum transfer

$\theta \sim 5°$ ~ 100 MeV/c : $\Delta L = 0$

$\theta \sim 10°$ ~ 200 MeV/c : $\Delta L = 1$ or 2 @ 1.5 GeV/c beam

Spin-flip cross section exists at large angles ($\theta > 10°$).

More advantages in hypernuclear γ-ray spectroscopy experiment