A new approach to study the in-medium ϕ(1020)-meson mass

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Letter of Intent for J-PARC

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Abstract

A feasibility study to detect the in-medium mass modification of the ϕ-meson is discussed. We demonstrate that a completely background-free missing-mass spectrum can be obtained efficiently by $(\overline{p},\phi)$ spectroscopy together with the $K^+\Lambda$ tagging. From both missing mass and invariant mass study of the sub-threshold energy region, one can independently deduce the mass shift information. A systematic study over several nuclear targets will yield a unique, definitive and precise determination of the in-medium mass modification of the vector meson $\phi(s\overline{s})$.

1 Introduction

Because in-medium meson properties are fundamentally related to chiral symmetry breaking and its restoration in the nuclear medium, there is currently great experimental interest. It is widely accepted that the vacuum expectation value of $\langle\overline{q}q\rangle$ is none zero due to the spontaneous chiral symmetry braking of the vacuum, and this $\langle\overline{q}q\rangle$-condensation is the major source of masses of low lying hadrons such as protons, neutrons, pions, *etc.* The $\langle\overline{q}q\rangle$ expectation value (chiral order parameter) is a function of temperature and chemical potential (density), so that various experimental studies have been performed to detect the restoration of the chiral symmetry.

One of the milestone of the study using meson is the observation of deeply-bound pionic atom states in nuclei [1]. In the pionic atom case, the Bohr radii of the heavy nuclei locates inside of the nuclear radii, but the s-wave strong interaction of pion is repulsive so the major part of the wave function pushed away from the nuclei, and the pions are bound by the Coulomb force sticking to the nuclear surface. Through the study of the energy shift and width of the state, there is an indication of chiral symmetry restoration through the in-medium modification of the pion decay constant, f_π, leading to a proposed systematic study at RIBF (RIKEN Nishina Center).

Kaonic nuclear bound states provide another channel for study of chiral symmetry. A recent hot topic concerns the possible existence of a deeply bound kaonic nuclear state. In this case, the $\overline{K}N$ interaction is expected to be strongly attractive, so the

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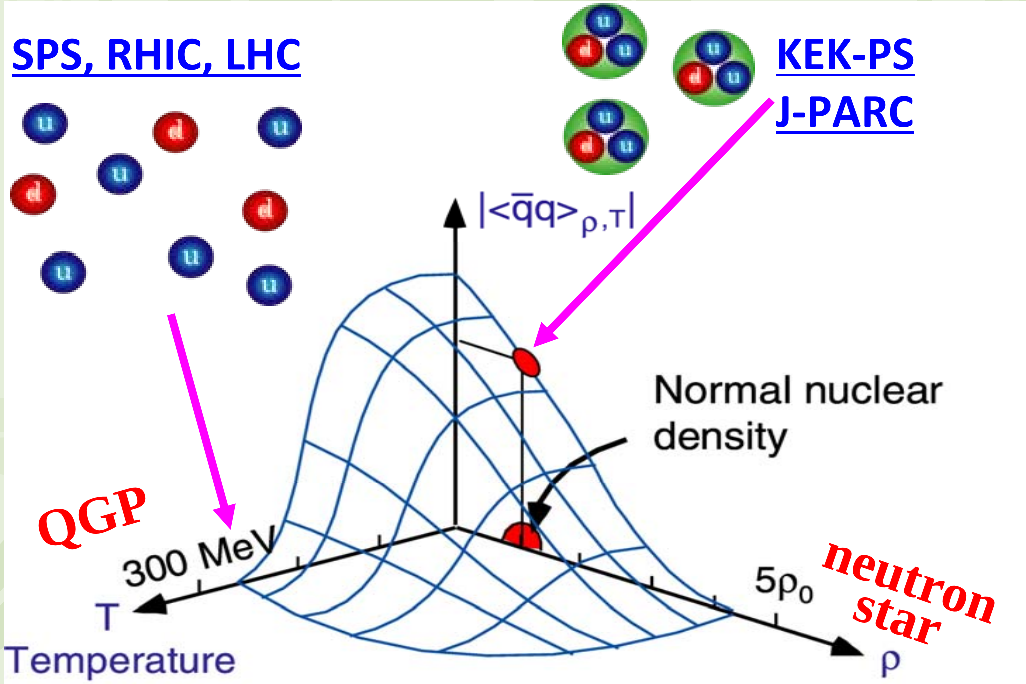
Introduction

- Origin of hadron mass
  → Spontaneous breaking of chiral symmetry !
- Under the extreme condition such as high temperature and/or density, restoration of its broken chiral symmetry has been expected



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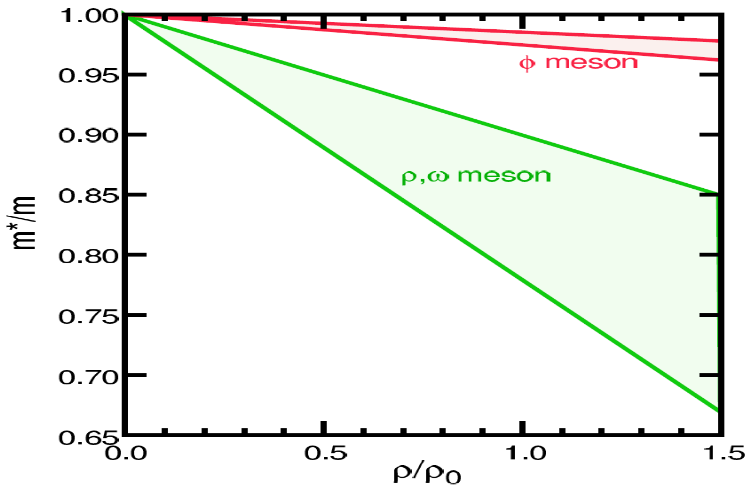


T. Hatsuda, H. Shiomi and H. Kuwabara
Prog. Theor. Phys. 95(1996)1009

Prediction from theory tells us,
Mass of vector meson in medium
will be decreasing
when density increasing

Introduction

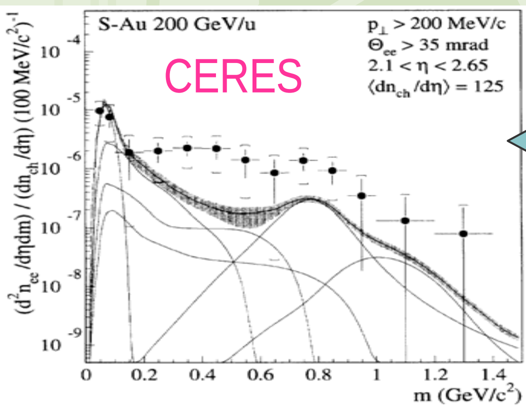
- Experiments have been done to study property of the vector meson in medium, so far

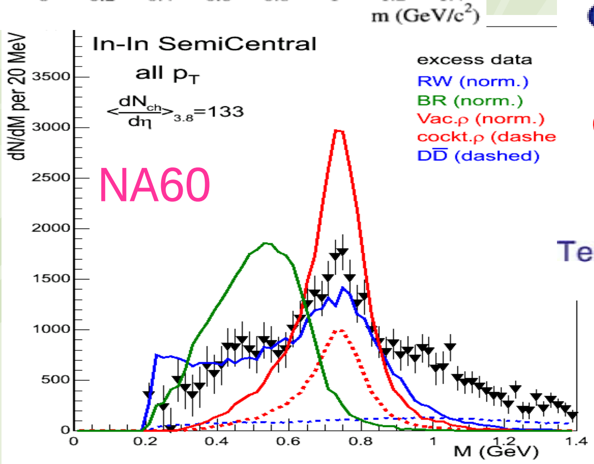
High energy heavy ion collisons
→creating high temperature/density medium and vector meson dynamically

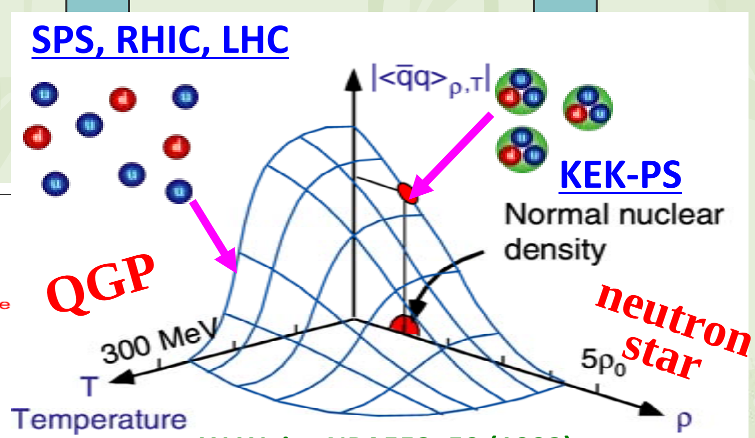
Vector meson production in p-A or γ-A
→ vector mesons are creating dynamically

Width boarding of ρ meson?

Mass shift of Φ/ω mesons in normal nuclear mater







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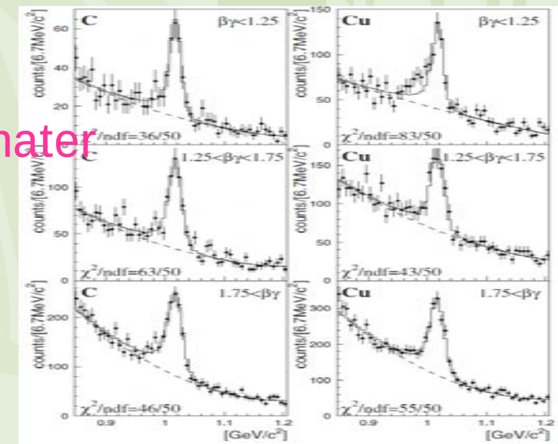
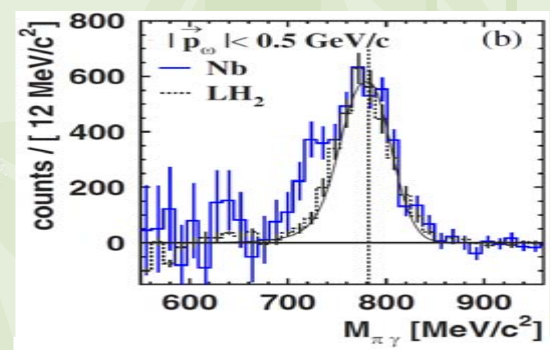


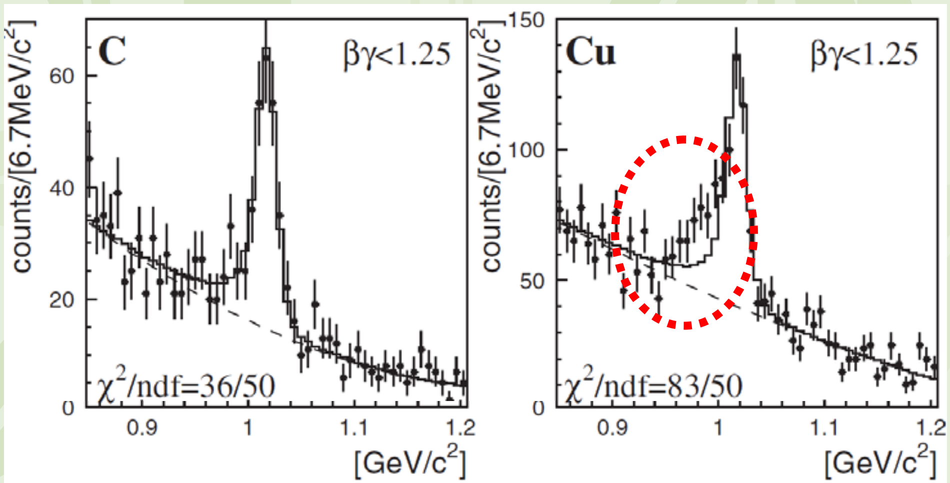
KEK-PS E325 PRL98(2007)042501

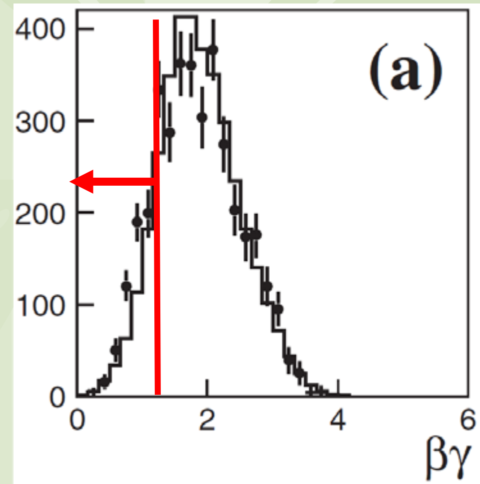


CBELSA-TAPS PRL94(2005)192303

ϕ-Nucleus interaction？

- What we learn from KEK-PS E325 results （PRL98(2007)042501）

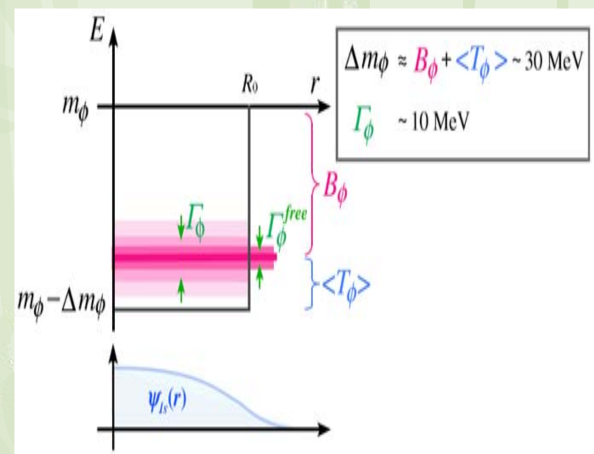




Reduction of the ϕ meson mass observed ! (about 3%), when we selected slowly moving ϕ mesons

ϕ meson in nucleus can be modeled as

ϕ meson is in the energy pocket created by nuclear potential *i.e.* Mass reduced due to binding energy of the system



ϕ-mesic nucleus formation?

3% mass reduction on ϕ meson,
expected depth of the potential must be about 30 MeV

Is it possible to create ϕ mesic nucleus with such a small potential depth?

ϕ meson bound state exist？

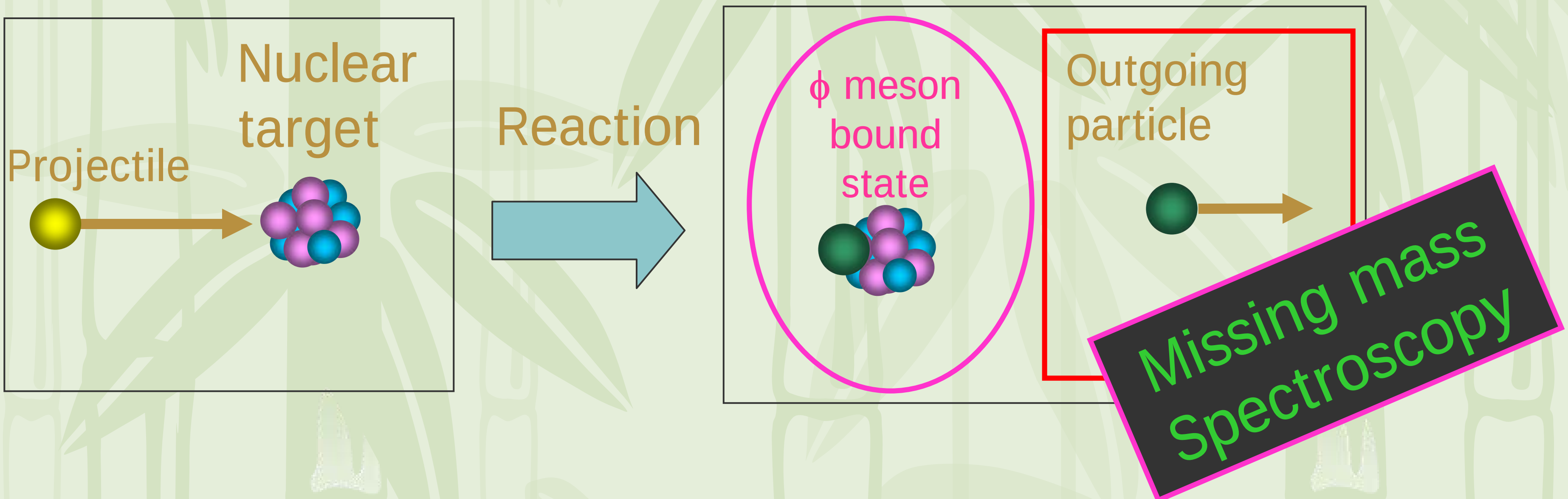
- There are many hints in Λ hypernucleus production
  - Potential depth of Λ-Nucleus ～30MeV
  - Mass of Λ＝1116 MeV/c^2

Those conditions are very similar with the case for ϕ meson

- In the case of Λ hypernucleus production via (π,K) reaction, momentum transfer for the reaction is about 400 MeV/c. This is far away from recoilless condition.

Analogy from Λ hyper nucleus production,
ϕ meson bound state will be produced
even if we selecting elementary process
which has large momentum transfer

Concept for the experiment

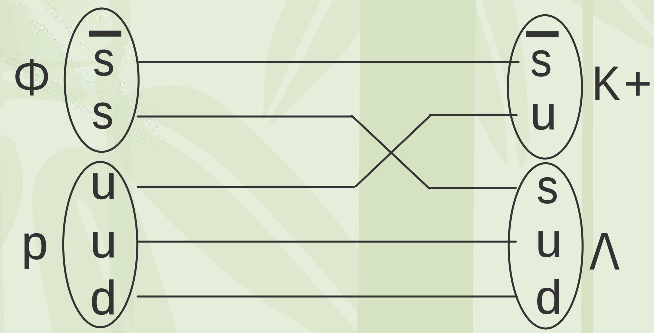


- Question
  - What kind of elementary process to produce ϕ meson can be used for this measurement?
  - Is there any way to identify ϕ meson in nucleus efficiently?

How to identify ϕ meson bound state（1）

- Let's focusing on decay mode
  - Mass of the ϕ meson will be decreasing about 30 MeV.
  - *i.e.* 1019 MeV – 30 MeV = 989 MeV ~ 2 x M_{Kaon}
    Main decay mode for Φ meson, Φ→K+K-, will be suppress.
  - However, Φ meson is in nucleus.
    There are many nucleon surrounding them.
    1019 MeV – 30 MeV + 938 MeV(proton)
    ＝ 1927 MeV > $M_{Kaon}+M_{\Lambda}$
    i.e. $\Phi p \rightarrow K^{+}\Lambda$ will be a dominant decay mode,
    if ϕ meson is in nucleus. (This mode is not suppressed by OZI role)

i.e. $K^{+}\Lambda$ in final state will be a good signal to ensure ϕ meson in medium



ϕ meson production channel

- Ho… …ntly?
  - F… …ction

…oduction

Advan… …y bigger
ϕ meso…
Howev…
(quasi…

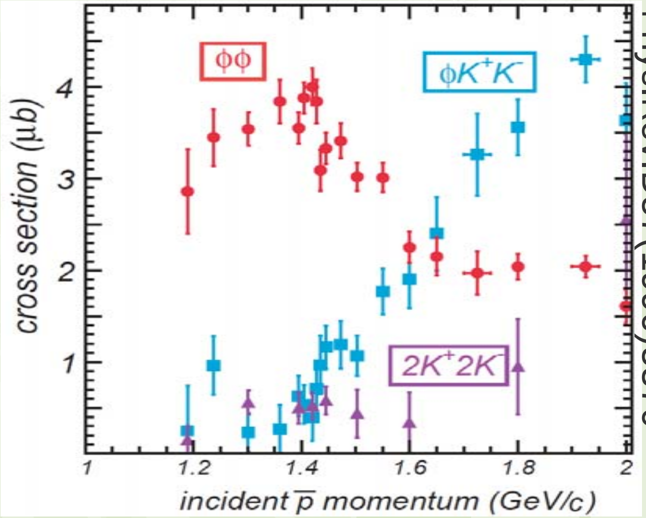
process (@ GeV/c)	channel	cross section	channel	cross section
$\pi^- p$ (2.0)	$\Sigma^- K^+$	87 μb	$\Sigma^-\pi^0 K^+$	52 μb
			$\Sigma^-\pi^+\pi^- K^+$	2.6 μb
			$\Sigma^+\pi^-\pi^- K^+$	3.2 μb
			$\Sigma^0\pi^- K^+$	67 μb
			$\Lambda\pi^- K^+$	152 μb
$\pi^- n$ (5.0)			$(\Lambda/\Sigma^0)\pi^-\pi^- K^+$	51 μb
$\pi^- n$ (2.3)			$\Sigma^-\pi^- K^+$	70 μb
$\pi^+ p$ (2.0)	$\Sigma^+ K^+$	290 μb	$\Sigma^+\pi^0 K^+$	170 μb
			$\Sigma^0\pi^+ K^+$	40 μb
			$\Lambda\pi^+ K^+$	120 μb
			$\Lambda\pi^+\pi^0 K^+$	15 μb
$\pi^+ n$ (2.5)	$\Sigma^0 K^+$	57 μb	$\Sigma^0\pi + \pi^- K^+$	140 μb
			$\Sigma^+\pi^- K^+$	96 μb
			$\Sigma^+\pi^0\pi^- K^+$	7 μb
			$\Sigma^-\pi^+ K^+$	34 μb
			$\Sigma^-\pi^0\pi^+ K^+$	10 μb
	ΛK^+	140 μb	$\Lambda\pi^0 K^+$	107 μb
			[illegible]	61 μb
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$\pi^+ n$ (5.4)	pK^+K^-	137 μb		

This is of course one of the candidate channel, however it is will known that the ϕ meson produced via this channel has large momentum transfer (much bigger than hyper nucleus production in (π.K) reaction)

Are there any promising production channel?

ϕ meson production via $\bar{p}$ beam

- Very interesting production channel for us $\bar{p}+p \rightarrow \phi\phi$ has been measured at CERN/LEAR intensively. (momentum range measured : 1.2-2.0GeV/c)
- Results have been published in 1996
  - Total cross section for $\bar{p}+p \rightarrow \phi\phi$ ～4 μb@1.3 GeV/c
  - $\bar{p}+p \rightarrow \Phi\Phi$ will be a dominant prduction process. （ $\bar{p}+p \rightarrow$ KKKK or KKϕ is much less than production of $\phi\phi$）
- What is the meaning for this???
  - If we select $\bar{p}$ beam momentum = 1.3 GeV/c
  - one ϕ meson in final state means another f must be produced (more than 90% probability)



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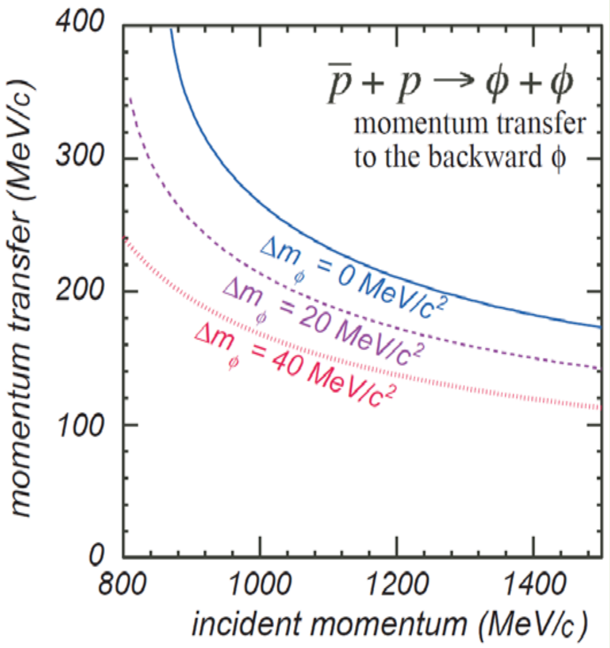
Is it possible to use this channel?

Possible experimental strategy

- In the case of $\bar{p}+p\rightarrow\Phi\,\Phi$ reaction momentum transfer for the reaction is
  ～ 200 MeV/c
- What kind of Experimental setup do we need to propose?
  - Need to identify and catch Φ meson emitted to forward direction (Missing mass via forward going ϕ meson)
  - Placing detector around the target to identify interaction between ϕ meson with nucleus. (identify K Λ in final state,)



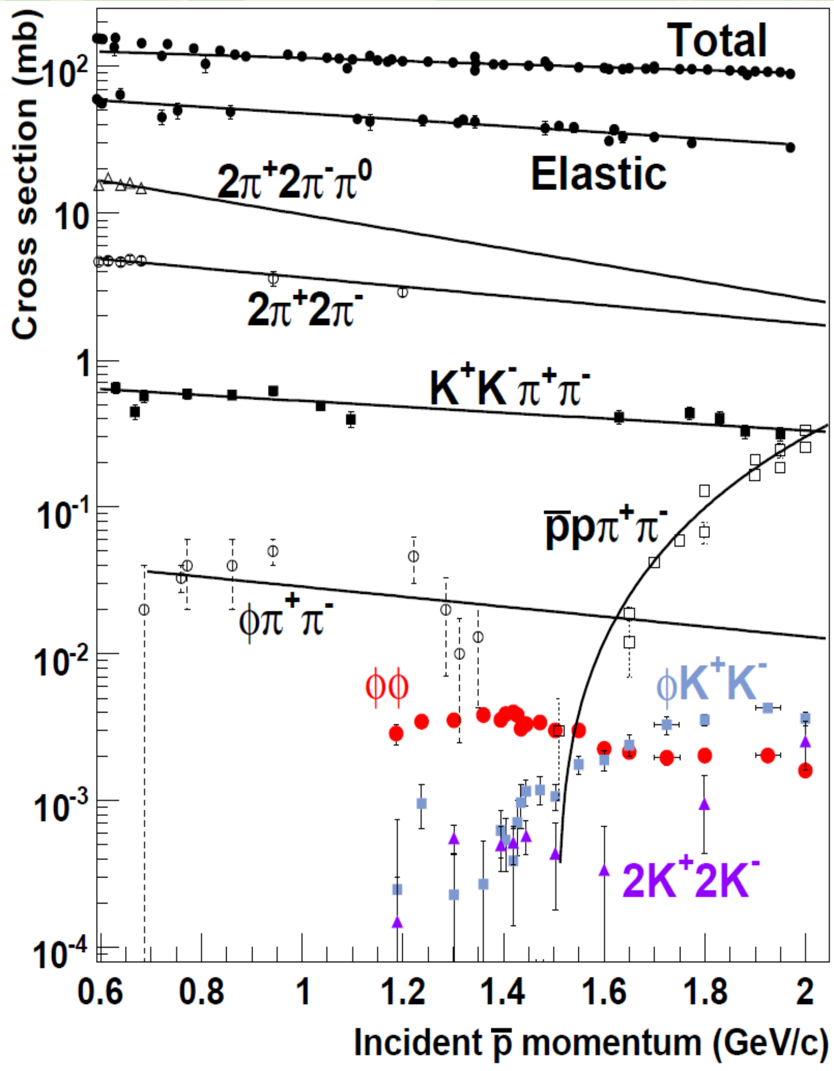
Big advantage for the measurement is

a) Forward going ϕ meson need to be identify. (2 out of 4 strangeness.)
b) K Λ from target region will ensure the f is in nuclear medium
   (2 out of 4 strangeness)

4 strangeness dag can be performed !

Background process

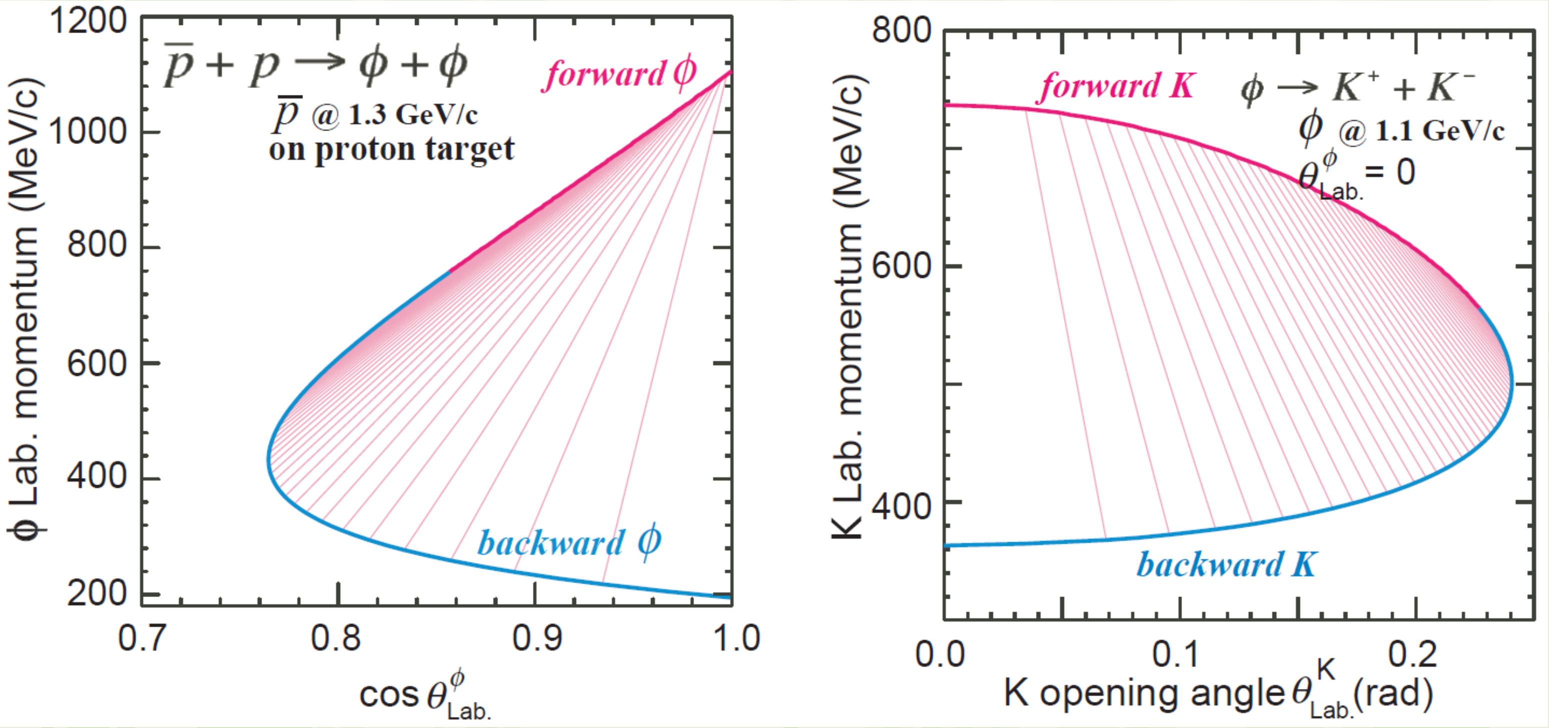
- Once we perform 4 strangeness tag in offline analysis, background free experiment can be performed
- problems are still in trigger level.
  - Summary of low energy p interaction
    - Φ Φ production cross section is 4 order of magnitude smaller compared with total cross section
    - However, once we select event withK+K-, background will be reduce
      2 order of magnitude.
    - If we will be able to require additiona
      Kaon, i.e. Three Kaon trigger, then w
      will performed background free experiment even in trigger level



Kaon identification is key for this experiment

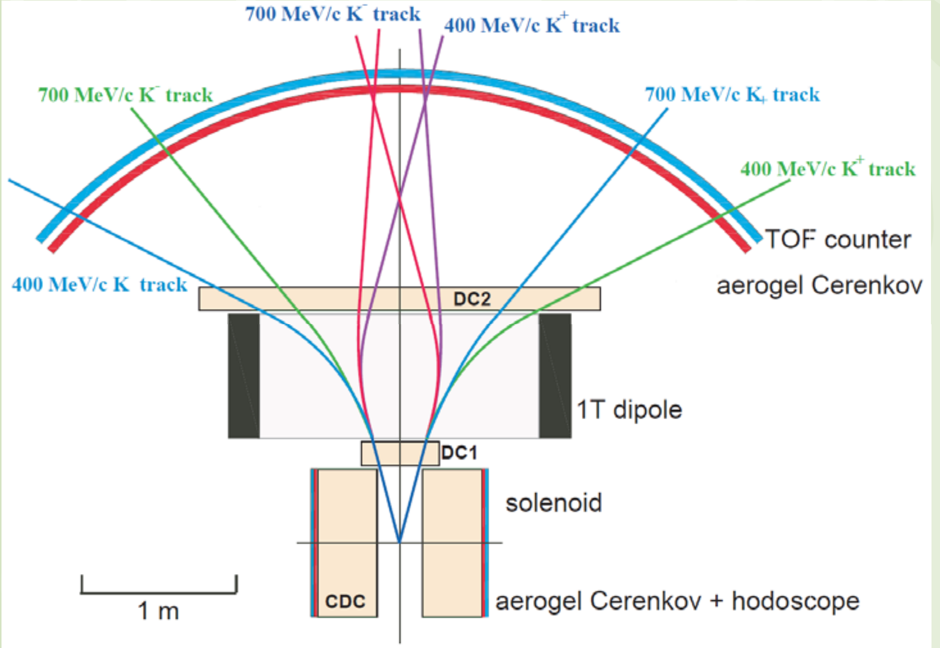
Experimental setup

- Good tracking chamber and PID detector around target
  - Cylindrical Drift Chamber ＋ Kaon ID detector
- ϕ meson emitted to forward direction must be detect efficiently.

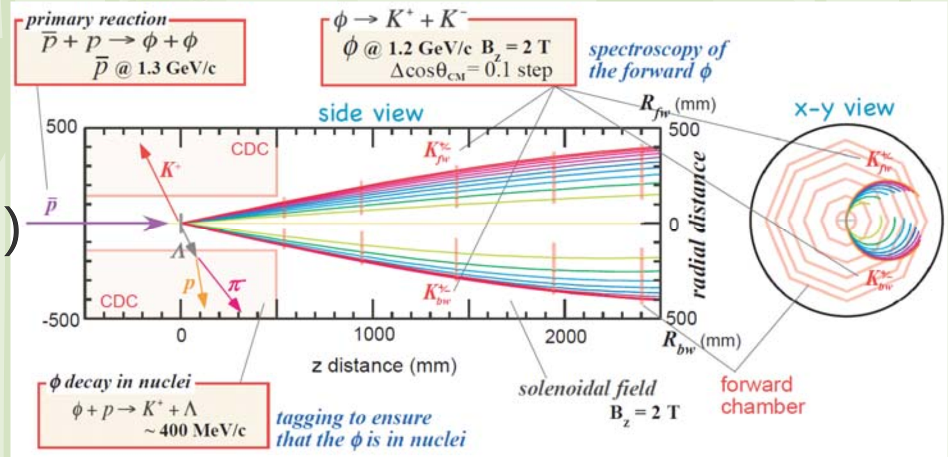


Experimental setup(2)

- **Conventional**
  - LEPS like setup
  - But large dipole magnet behind solenoid magnet to maintain large forward angle acceptance



- **Challenging setup**
  - Everything inside large solenoid magnet(~3m long, 1m diameter)



Event rate estimation

- Event rate for ϕ meson bound state formation are estimated based on the hypernuclear formation rate obtained at KEK-SKS
- Event rate seen in hypernuclear formation via (π^+, K^+) reaction at KEK-PS/K6 with SKS spectrometer
  - 1×10^9 π induced on 1g/cm^2 Carbon target, about 20 grand state $^{12}_{\Lambda}C$ produced
- Basic numbers used for the estimation
  - Beam intensity $I_{\bar{p}}$ = 2.0 x 10^6 / spill
  - Beam momentum used for the experiment = 1.3 GeV/c
  - Momentum transfer = 200 MeV/c
  - $\bar{p}$-p $\rightarrow \Phi\Phi$ cross section = $4/4\pi$ (μb/sr)=0.32(μb/sr)
  - Target thickness 2g/cm^2
  - Acceptance for forward spectrometer (120 msr)
  - $K^+\Lambda$ trigger efficiency
    $(\Omega_{CDC} \times BR(\Phi p \rightarrow K^+\Lambda) \times BR(\Lambda \rightarrow p\pi))$ = 1.7 sr
- Relative capture rate （sticking probability）
  - $R_{capture} = \exp(-q^2/q_F^2)$, q: momentum transfer, q_F: fermi momentum

Event rate estimation (2)

	${}^{12}_{\Lambda}C$	${}^{11}_{\phi}$ B
elementary reaction	$n(\pi^+, K^+)\Lambda$	$p(\overline{p}, \phi)\phi$
beam momentum	1.0 GeV/c	1.3 GeV/c
momentum transfer	500 MeV/c	200 MeV/c
$\overline{p}$ intensity	-	2×10^6 / *spill*
number of incident particle (π^+ or $\overline{p}$)	1×10^9 (*)	$1{,}440\times10^9$/month
target thickness	1.0 g/cm^2 (*)	2.0 g/cm^2
$d\sigma_{CM}/d\Omega$	104 μb/sr	0.3 μb/sr
γ factor	1.17	1.16
relative capture rate ($R_{capture}$)	0.032	0.58
ΛK^+ tagging efficiency ($\Omega_{CDS} R_{K^+\Lambda} R_{\Lambda\rightarrow\pi^- p}$)	12.6 (= 4π) sr (*)	1.7 sr
forward detector efficiency ($\Omega_{FS} R_{\phi\rightarrow K^+K^-}$)	100 msr (*) (SKS)	59 msr
expected yield of the ground state	$\sim$ 20 ev. (*)	$\sim$ 240 ev. / month

- Comparison parameters in hypernuclear formation at KEK-SKS and new experiment for f meson bound state

~ 240 Events are expected for one month of data taking period

Summary

- Based on the results reported by KEK-PS E325 (mass shift of ϕ meson) together with a similarity between Λ hyper nucleus production via (π,K) reaction strongly suggested that the production of ϕ mesic nucleus can be possible.
- The most promising elementary process for the ϕ mesic nucleus production will be $pp \rightarrow \phi\phi$ channel. (Background free experiment can be achieved, in principle)
- Naïve event rate estimation tells us that 240 events candidate for ϕ mesic nucleus will be produce per month, with beam intensity, $2x10^6$/spill, for 1.3 GeV/c anti-proton.
- However, no beamlines exist for pbar with intensity which will provide ~$2x10^6$/spill, at this moment.

New beamline needhed!!

- The Letter of Intent has been submitted to J-PARC center