Search for ϕ meson-nuclear bound state

Hiroaki Ohnishi
RIKEN

Introduction

ϕ meson

- ϕ meson :
  - Vector meson, $J^{PC} = 1^{--}$
  - the lightest bound state of hidden strangeness ($s\bar{s}$)
  - narrow width = 4.43 MeV/c^2, Long life time = 45 fm/c
- Interaction between ϕ-nucleon
  - ϕ-N interaction could be attractive.

    → QCD van der waals interaction

    (multi-gluon exchange)

ϕ meson in nucleus

Progress of Theoretical Physics, Vol. 98, No. 3, September 1997

QCD Sum Rules for ρ, ω, ϕ Meson-Nucleon Scattering Lengths and the Mass Shifts in Nuclear Medium

Yuji KOIKE and Arata HAYASHIGAKI

Graduate School of Science and Technology, Niigata University Niigata 950-21

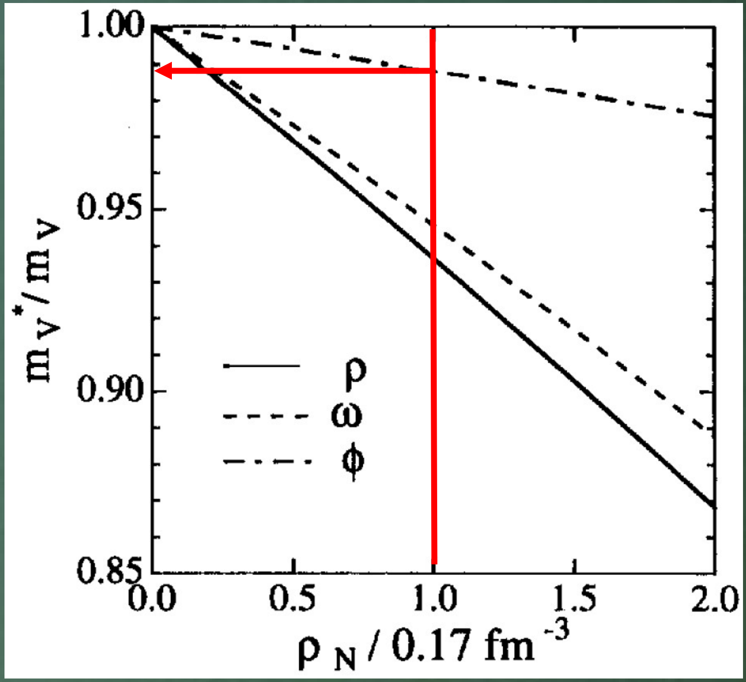
(Received April 14, 1997)

results

$$a_\rho = -0.47 \pm 0.05 \text{ fm},$$
$$a_\omega = -0.41 \pm 0.05 \text{ fm},$$
$$a_\phi = -0.15 \pm 0.02 \text{ fm},$$

Attraction!

- Expected mass shift of ϕ ~ 1-2% (@ $\rho=\rho_0$) = 10 MeV to 20 MeV



Theoretical prediction?

a

Search for th

Department of Physics and the Tria

The subthreshold photoproduction of ϕ mesons from heavy nuclear targets has been suggested as a candidate to search for the ϕ-N bound state, a quantum chromodynamics molecular state. In this Brief Report, we present detailed Monte
subthreshold p

DOI: 10.1103/

Progress of Theoretical Physics, Vol. 124, No. 1, July 2010

Formation of ϕ Mesic Nuclei

Junko Yamagata-Sekihara,[1,*] Daniel Cabrera,[2] Manuel J. Vicente Vacas[3] and Satoru Hirenzaki[4]

[1]*Laboratory for Nuclear Science and*
[2]*Physi*

We show that the QC
inside a nucleus to form
in the case of subthresh
and such an experiment

DOI: 10.1103/PhysRevC.63.022201

IOP Publishing — Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. **37** (2010) 085109 (10pp) doi:10.1088/0954-3899/37/8/085109

The ϕ–NN and $\phi\phi$–NN mesic nuclear systems

Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Nuclear Physics A 835 (2010) 406–409
NUCLEAR PHYSICS A
www.elsevier.com/locate/nuclphysa

Formation of Slow Heavy Mesons in Nuclei

Satoru Hirenzaki[a], Junko Yamagata-Sekihara[b]

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[b]*Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia-CSIC, Institutos de Investigación de Paterna, Apartado 22085, 46071 Valencia, Spain*

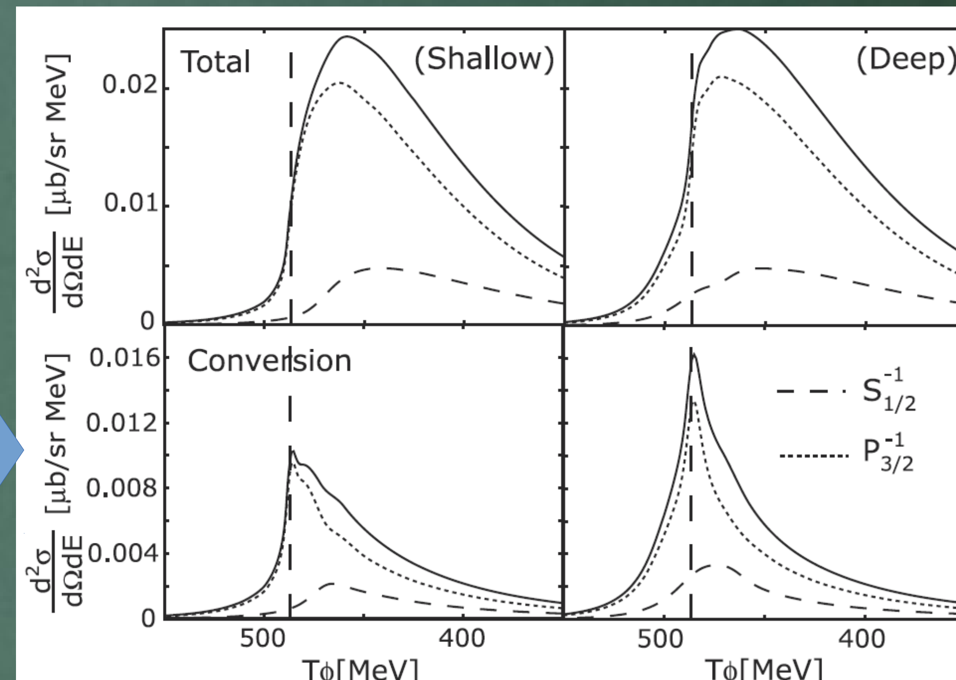
Theoretical prediction?

Progress of Theoretical Physics, Vol. 124, No. 1, July 2010

Formation of ϕ Mesic Nuclei

Junko YAMAGATA-SEKIHARA,[1,*)] Daniel CABRERA,[2] Manuel J. VICENTE VACAS[3] and Satoru HIRENZAKI[4]

No clear structure.



IOP PUBLISHING — JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS
J. Phys. G: Nucl. Part. Phys. **37** (2010) 085109 (10pp) doi:10.1088/0954-3899/37/8/085109

The ϕ–NN and $\phi\phi$–NN mesic nuclear systems

S A Sofianos[1], G J Rampho[1], M Braun[1,3] and R M Adam[2]

[1] Department of Physics, University of South Africa, PO Box 392, Pretoria 0003, South Africa
[2] South African Nuclear Energy Corporation, PO Box 582, Pretoria 0001, South Africa

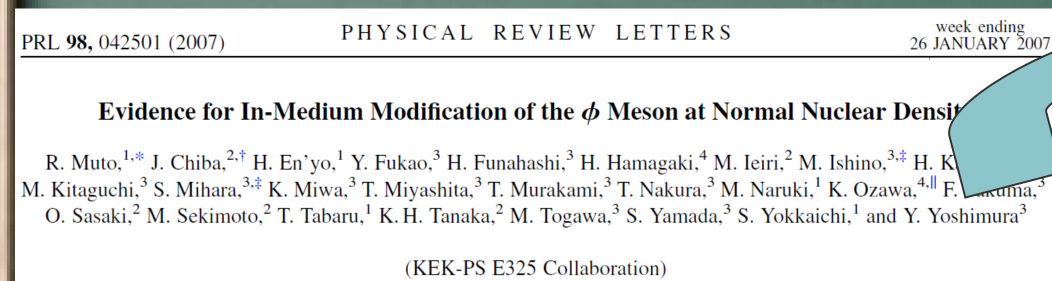
Table 3. Bound state results (in MeV) for the ϕNN and $\phi\phi$NN systems. The number in parentheses corresponds to the root mean square radius (in fm).

	Singlet			Triplet		
System	EAA	SEM	Other	EAA	SEM	Other
ϕNN	22.88 (1.0844)	23.609	21.8 [5]	39.364 (0.8345)	39.842	37.93 [5]
$\phi\phi$NN	75.473 (0.4671)			124.590 (0.4239)		

ϕNN bound state are expected : BE~20-30 MeV

ϕ meson in nucleus
- experiment -

ϕ meson in nucleus

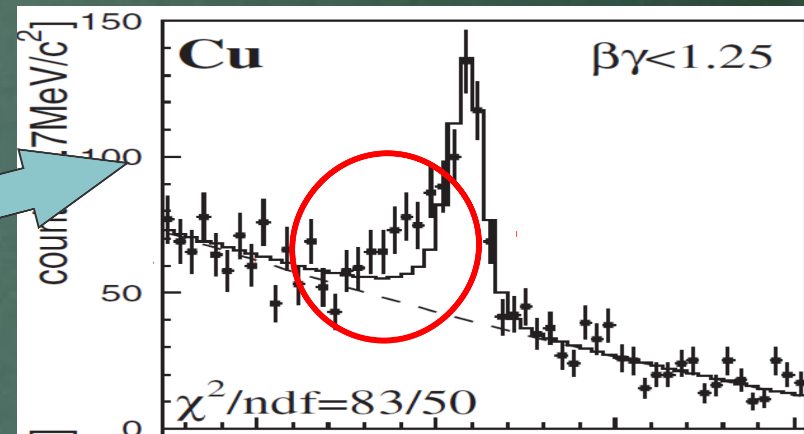


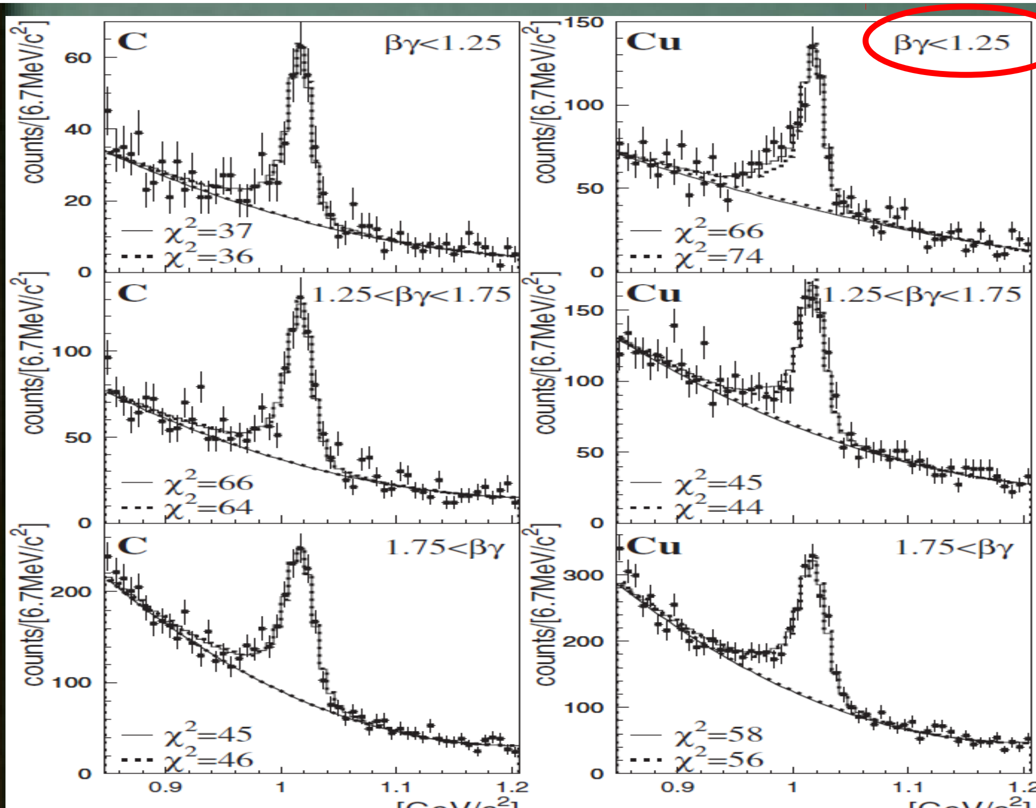
PRL **98,** 042501 (2007) PHYSICAL REVIEW LETTERS week ending 26 JANUARY 2007

Evidence for In-Medium Modification of the ϕ Meson at Normal Nuclear Densit

R. Muto,[1,*] J. Chiba,[2,†] H. En'yo,[1] Y. Fukao,[3] H. Funahashi,[3] H. Hamagaki,[4] M. Ieiri,[2] M. Ishino,[3,‡] H. K M. Kitaguchi,[3] S. Mihara,[3,‡] K. Miwa,[3] T. Miyashita,[3] T. Murakami,[3] T. Nakura,[3] M. Naruki,[1] K. Ozawa,[4,||] F. ...kuma,[3] O. Sasaki,[2] M. Sekimoto,[2] T. Tabaru,[1] K. H. Tanaka,[2] M. Togawa,[3] S. Yamada,[3] S. Yokkaichi,[1] and Y. Yoshimura[3]

(KEK-PS E325 Collaboration)





PRL **98,** 042501 (2007)

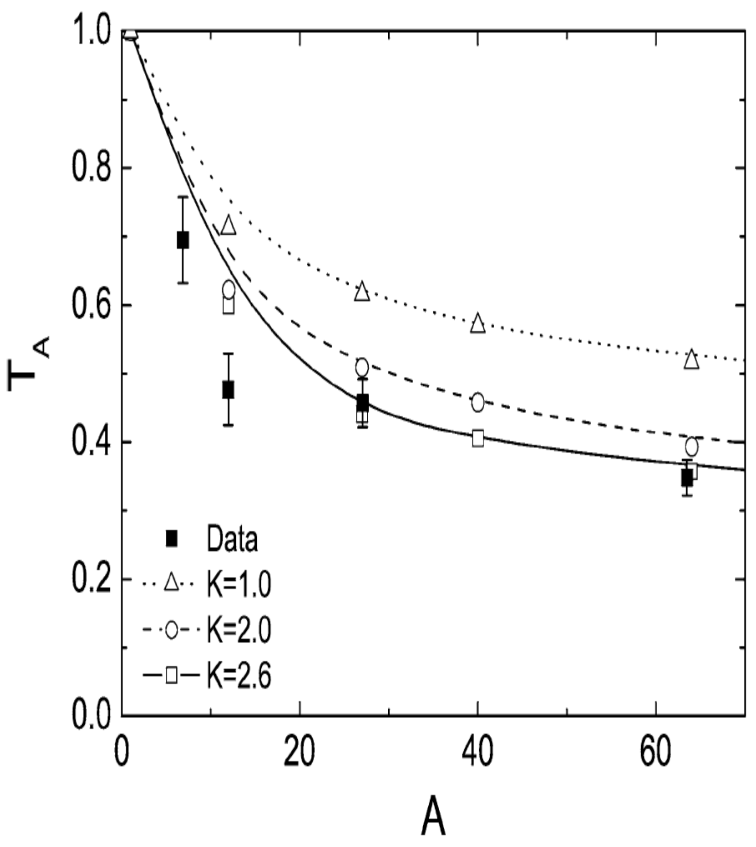
3.4% mass shift
x 3.6 width broadening

Existence of attractive interaction between ϕ-N

About Decay Width

ϕ meson in normal nuclear media

- Transparency ratio, $T_A=\sigma_{\gamma A\text{-}\phi X}/A(\sigma_{\gamma p\text{-}\phi X})$,



NPA765(2006)188-196

- Data : PLB 608(2005)215
  $\gamma A \rightarrow \phi X$: Extracted $\sigma_{\phi N}$ =30 mb
- Analysis : NPA 765(2006)188
  $\sigma_{\phi N}$ expected (Theo.) ~10 mb
- discrepancy between $\sigma_{\phi N}$
  measured and expected
  is explained by width broadening of ϕ in nuclear media by factor 16! ($\Gamma_{\text{in nucleus}}$ ~70 MeV)

$\sigma_{\phi N}$ ~10 mb : $\lambda_{\text{interaction}}$ = 7.0 fm

$\sigma_{\phi N}$ ~20 mb : $\lambda_{\text{interaction}}$ = 3.5 fm

ϕ meson with deuteron

Contents lists available at ScienceDirect
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Measurement of the incoherent $\gamma d \to \phi pn$ photoproduction near threshold

LEPS Collaboration

W.C. Chang[a,*], M. Miyabe[b], T. Nakano[c], D.S. Ahn[c,d], J.K. Ahn[d], H. Akimune[e], Y. Asano[f], S. Daté[g], H. Ejiri[c], H. Fujimura[h], M. Fujiwara[c,i], S. Fukui[j], S. Hasegawa[c], K. Hicks[k], K. Horie[c], T. Hotta[c], K. Imai[b], T. Ishikawa[h], T. Iwata[l], Y. Kato[c], H. Kawai[m], K. Kino[c], H. Kohri[c], N. Kumagai[g], S. Makino[n], T. Matsuda[o], T. Matsumura[p], N. Matsuoka[c], T. Mibe[c], M. Miyachi[q], N. Muramatsu[c,i], M. Niiyama[b], M. Nomachi[r], Y. Ohashi[g], H. Ohkuma[g], T. Ooba[m], D.S. Oshuev[a], C. Rangacharyulu[s], A. Sakaguchi[r], P.M. Shagin[t], Y. Shiino[m], H. Shimizu[h], Y. Sugaya[r], M. Sumihama[c], Y. Toi[o], H. Toyokawa[g], M. Uchida[u], A. Wakai[v], C.W. Wang[a], S.C. Wang[a], K. Yonehara[e], T. Yorita[c,g], M. Yoshimura[w], M. Yosoi[c], R.G.T. Zegers[x]

Contents lists available at ScienceDirect
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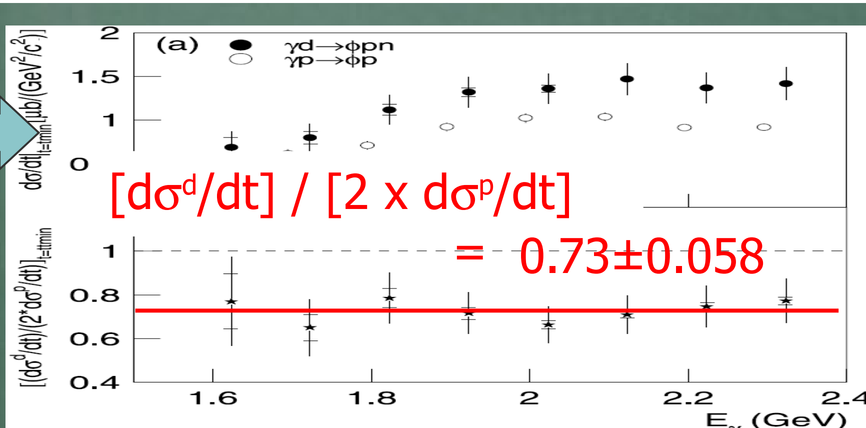
www.elsevier.com/locate/physletb

The extraction of ϕ–N total cross section from $d(\gamma, pK^+K^-)n$

CLAS Collaboration

X. Qian[a,*], W. Chen[a], H. Gao[a], K. Hicks[b], K. Kramer[a], J.M. Laget[c,d], T. Mibe[b], S. Stepanyan[d], D.J. Tedeschi[e], W. Xu[f], K.P. Adhikari[af], M. Amaryan[af], M. Anghinolfi[w], H. Baghdasaryan[am], J. Ball[c], M. Battaglieri[w], V. Batourine[d], I. Bedlinskiy[z], M. Bellis[k], A.S. Biselli[p,ag], C. Bookwalter[r], D. Branford[o], W.J. Briscoe[s], W.K. Brooks[al,d], V.D. Burkert[d], S.L. Careccia[af], D.S. Carman[d], P.L. Cole[u,d], P. Collins[h], V. Crede[r], A. D'Angelo[x,ai], A. Daniel[b], N. Dashyan[ao], R. De Vita[w], E. De Sanctis[v], A. Deur[d], B. Dey[k], S. Dhamija[q], R. Dickson[k], C. Djalali[e], G.E. Dodge[af], D. Doughty[m,d], R. Dupre[g], P. Eugenio[r], G. Fedotov[aj], …



$[d\sigma^d/dt] / [2 \times d\sigma^p/dt]$
$= 0.73 \pm 0.058$

ϕ meson absorption? by nuclear matter?
even with deuteron (single nucleon??)

Experiment : $\gamma d \to \phi X$
Extracted ϕN cross section
$\sigma_{\phi N}$ = 20 mb
Again $\sigma_{\phi N}$ Expected,
$\sigma_{\phi N}$ = 11 mb (upper limit)
How to explain this discrepancy?
Again width broadening of ϕ meson in nuclear matter even on deuteron?

Why absorption of ϕ takes place on deuteron?
Is this only a case with gamma induced experiment?

One more

- Momentum dependence of transparency ratio by COSY-ANKE

Phys. Rev. C 85, 035206 (2012) [8 pages]

Momentum dependence of the φ-meson nuclea

Abstract | References | Citing Articles (1)

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Hide All Authors/Affiliations

M. Hartmann[1,*], Yu. T. Kiselev[2,†], A. Polyanskiy[1,2], E. Ya. Paryev[3], M. Büscher[1], D. Chiladze[1,4], S. Dyr
Keshelashvili[9], V. Koptev[7,‡], B. Lorentz[1], Y. Maeda[10], V. K. Magas[11], S. Merzliakov[1,6], S. Mikirtytchiants
Serdyuk[1,6], A. Sibirtsev[5], V. Y. Sinitsyna[14], H. J. Stein[1], H. Ströher[1], S. Trusov[8,15], Yu. Valdau[1,16], C. W
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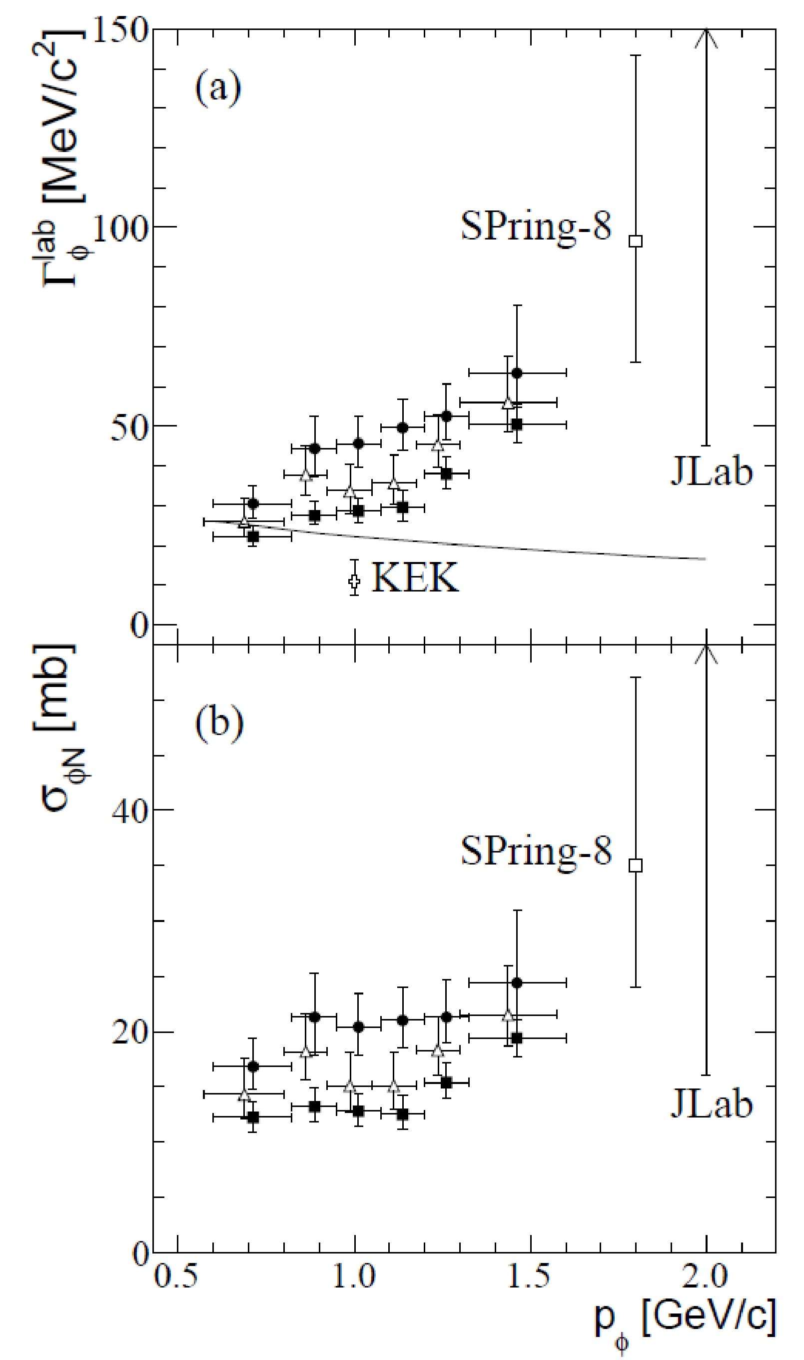
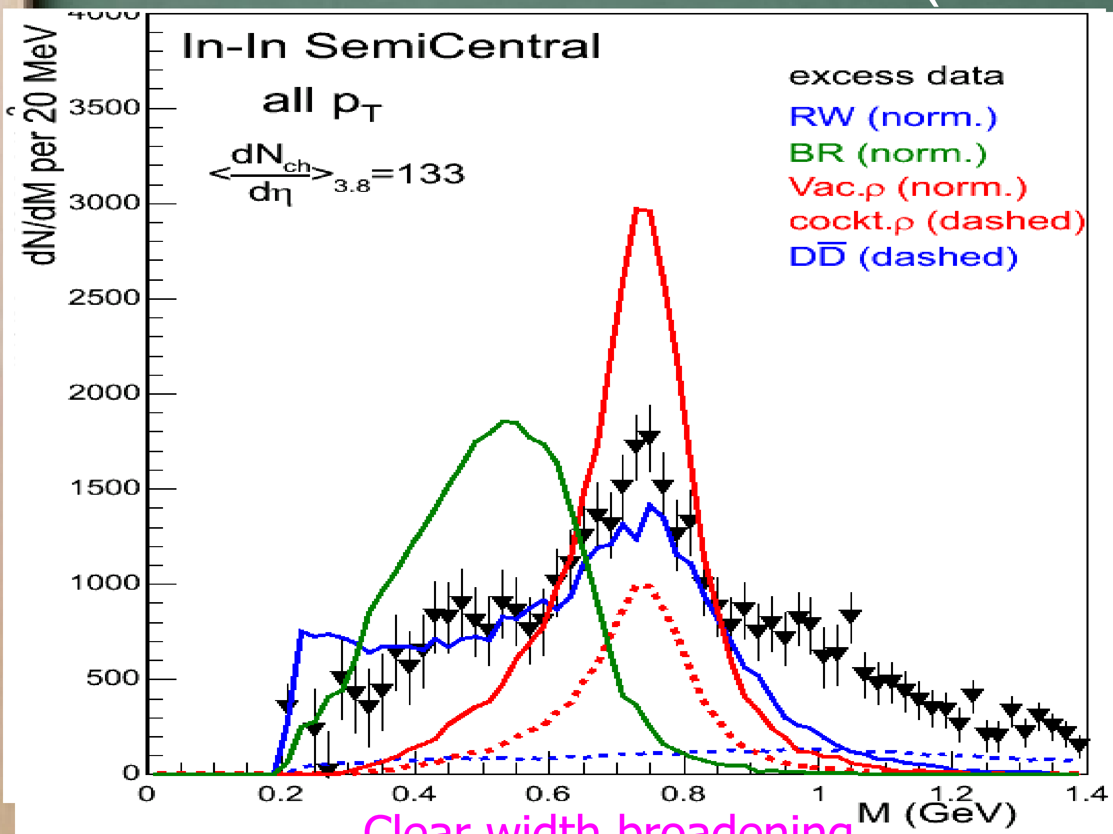


Width increasing ?
as a function of momentum
less absorption with
low momentum ϕ meson ?

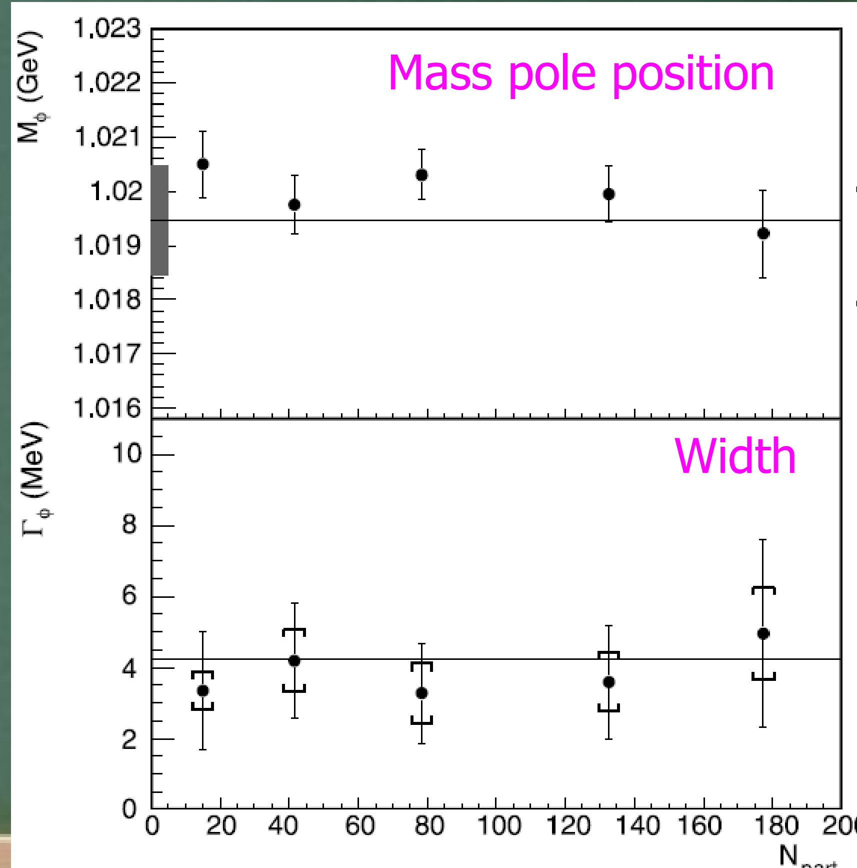
At High Temperature

ϕ meson in hot nuclear media

- ϕ meson production in 158 GeV/c In-In collisions at CERN/SPS (NA60)
  - mass shift and width broadening are not identified in hot nuclear matter (within detector resolution)



Clear width broadening have observed in ρ meson spectra



EPJ C64(2009)1-18

New experiment needed to answer the question about ϕ meson in nucleus

Two experiments are proposed at J-PARC

1) Study on meson mass modification in nuclei using primary proton beam at J-PARC

→ detail study of ϕ->e+e- in nucleus (J-PARC E16 experiment)

2) Search for ϕ meson bound state

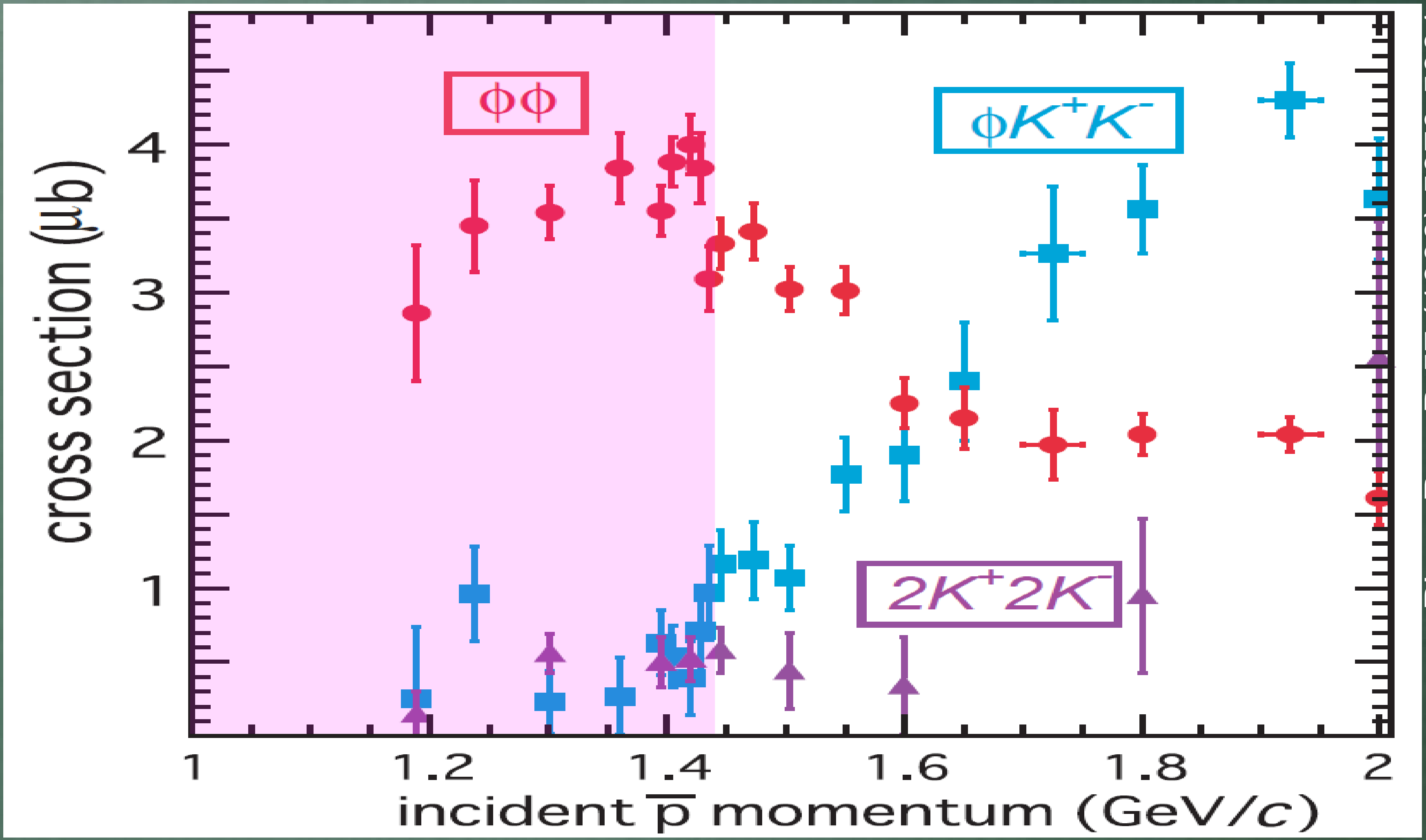
→ This taik!

Key point to produce ϕ meson bound state

- We want to embedding ϕ meson in nucleus
- What we need ?
  - Low momentum ϕ meson beam
    → which is not available
  - Then, can we producing ϕ meson in nucleus ?

LEAR / JETSET

- Double ϕ meson production in $\bar{p}p$ reaction



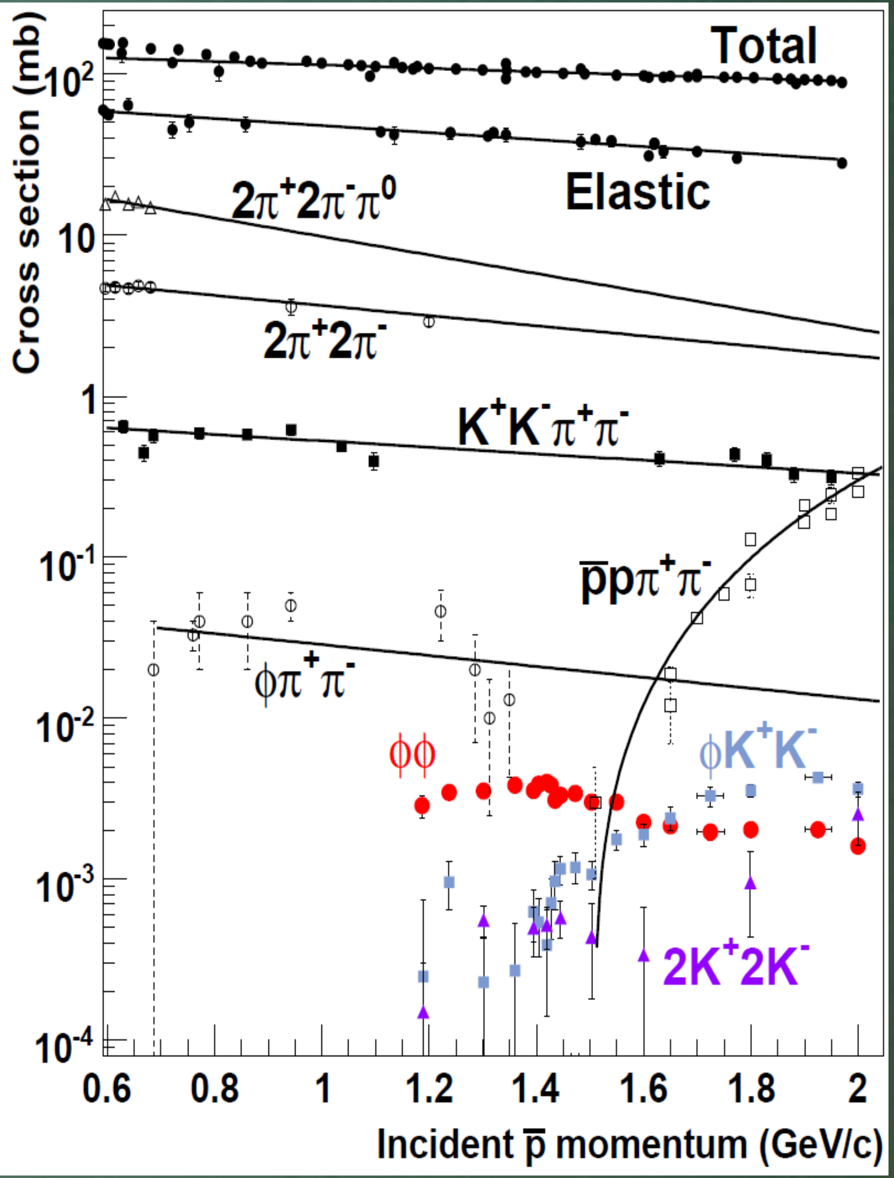
Phys. Rev. D 57 (1998) 5370-5381

$\phi\phi$ production dominated around production threshold

Background processes

List of background

Process	σ_{Total} (mb)
signal	$23. \times 10^{-3}$
$\pi^+\pi^0\pi^-$	33.
$2\pi^+2\pi^-$	47.
$\pi^+2\pi^0\pi^-$	14.
$2\pi^+\pi^02\pi^-$	224.
$2\pi^+2\pi^02\pi^-$	125.
$3\pi^+3\pi^-$	18.
$2\pi^+3\pi^02\pi^-$	86.
$2\pi^+4\pi^02\pi^-$	22.

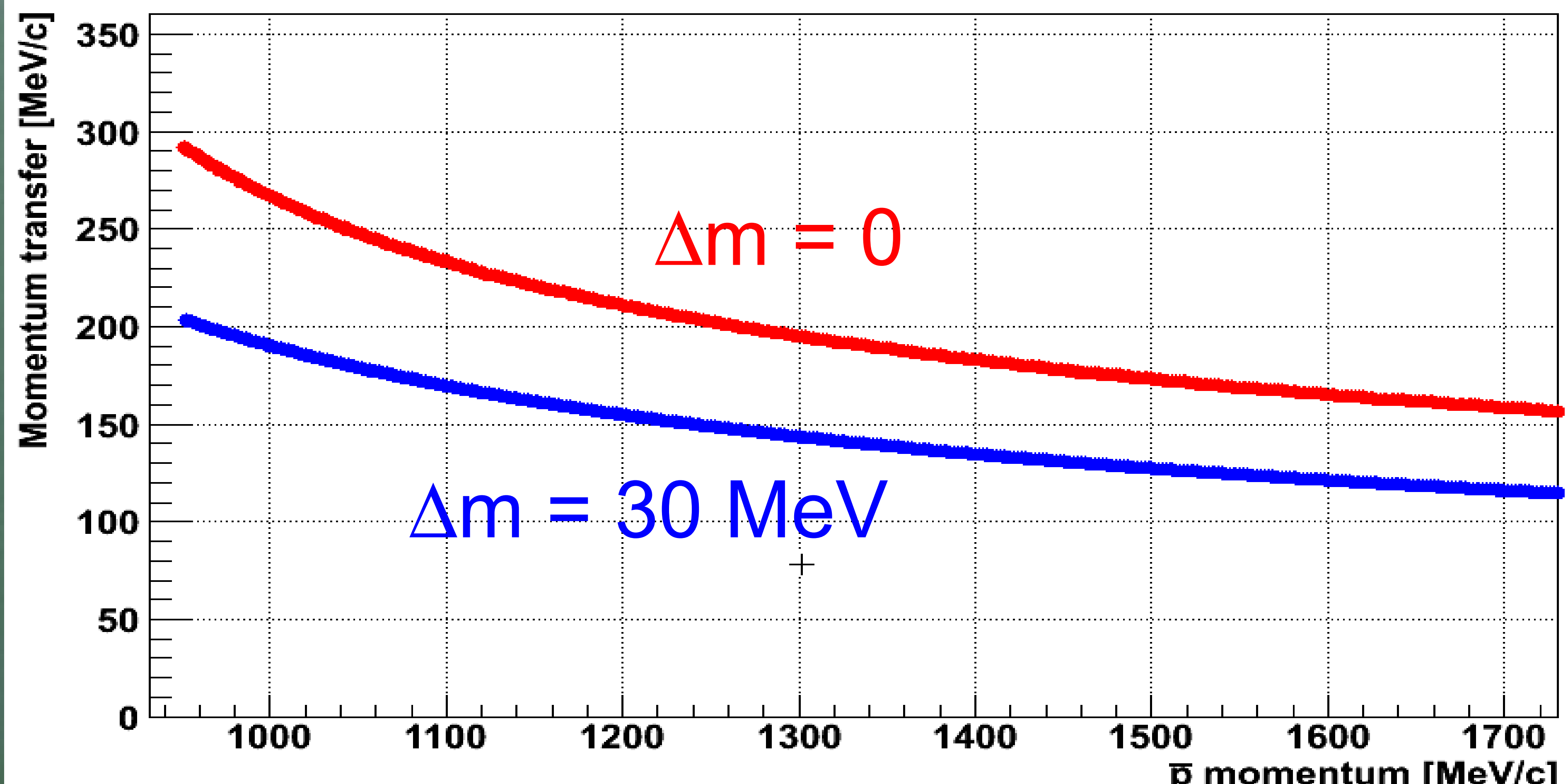


Event selection like 3 strangeness, i.e. 3 Kaons in a events reduce background significantly

Concept for the experiment

$$\overline{p} + {}^{A+1}_{Z+1}\mathrm{X}' \rightarrow \{\phi \; {}^{A}_{Z}\mathrm{X}\} + \phi$$

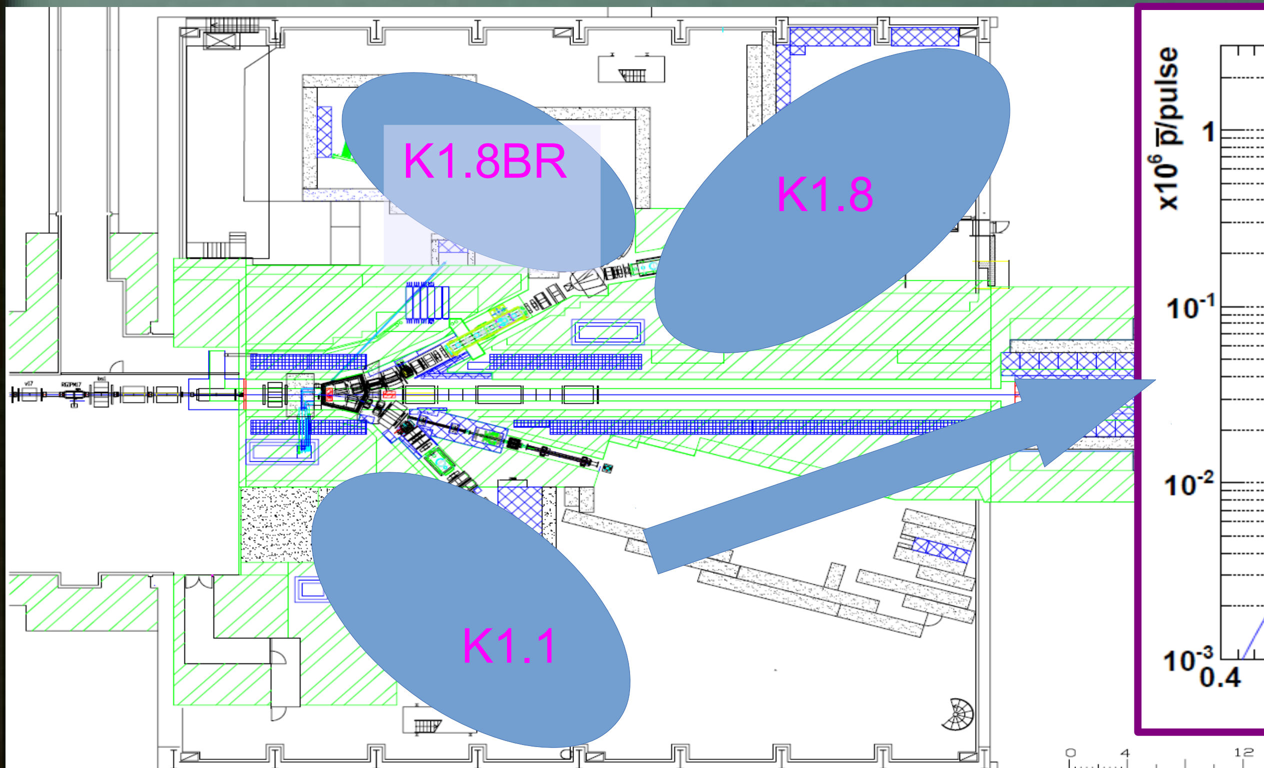
Missing mass
by forward going

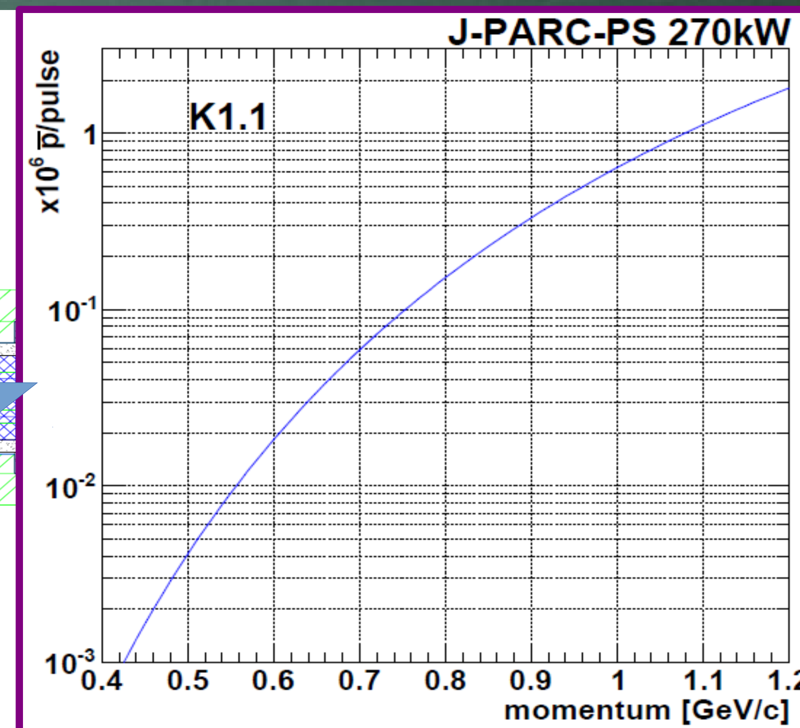


Anti-proton beam at J-PARC

J-PARC secondary beam line

- Low momentum $\bar{p}$ beam available





~ 1 M $\bar{p}$ / pulse (3.5s) @ 1 GeV/c will be able to use for experiments

- One production target for secondary beam ($\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$)
- Three secondary beamlines (max. momentum)
  - K1.8BR : up to 1.1 GeV/c
  - K1.8 : up to 2.0 GeV/c
  - K1.1 : up to 1.1 GeV/c

Study of in medium mass modification for the ϕ meson using ϕ meson bound states in nucleus

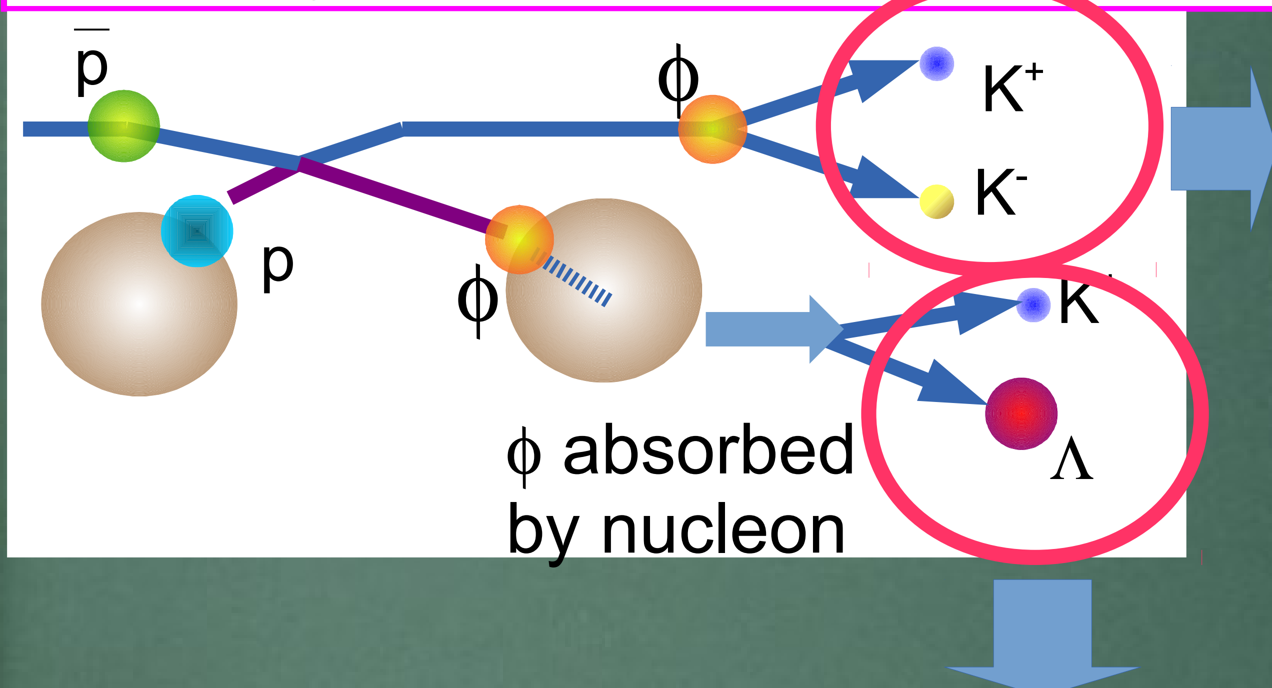
J-PARC E29 experiment

P.B"uhler[1], C. Curceanu[2], C. Guaraldo[2], O.Hartmann[1],
K.Hicks[3], M.Iwasaki[4,5], T.Ishiwatari[1], P.Kienle[6], J.Marton[1],
R.Muto[7], M.Maruki[7], M.Niiyama[4], H.Noumi[8], H.Ohnishi[4],
S.Okada[2], A.Romero Vidal[2], A.Sakaguchi[9], F. Sakuma[4],
S. Sawada[7], D. Sirghi[2], F. Sirghi[2], K. Suzuki[1],D.J. Tedeschi[10],
K.Tsukada[4], O. Vazquez Doce[2], E. Widmann[1],
S. Yokkaichi[4] and J. Zmeskal[1]

29 members from 10 institute

What we need?

$$\overline{p} + {}^{A+1}_{Z+1}\mathrm{X}' \rightarrow \{\phi\ {}^{A}_{Z}\mathrm{X}\} + \phi$$



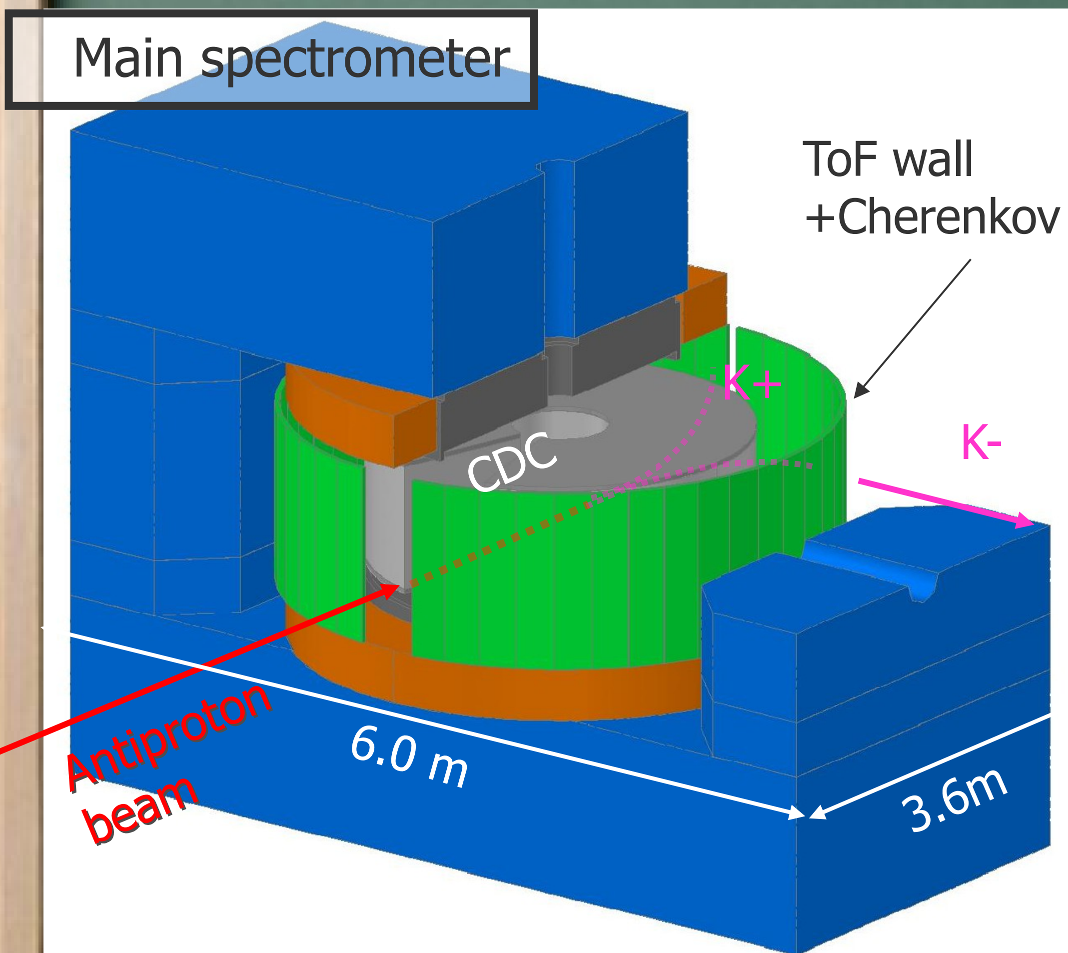
High resolution forward Kaon spectrometer

Large angle charged particle Spectrometer for decay product

$\phi N \rightarrow K\Lambda$, for example.

Conceptual design of the detector

- Large solid angle charged particle spectrometer (with large gap dipole magnet)



Using antiproton beam with 1.0 – 1.1 GeV/c

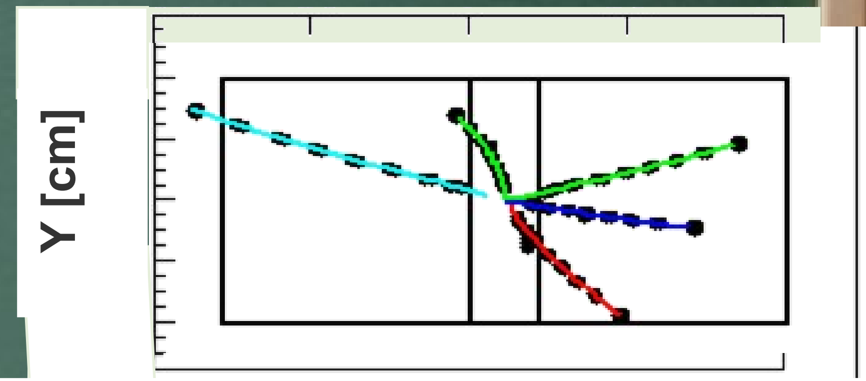
Large acceptance for forward going ϕ meson (for missing mass analysis)

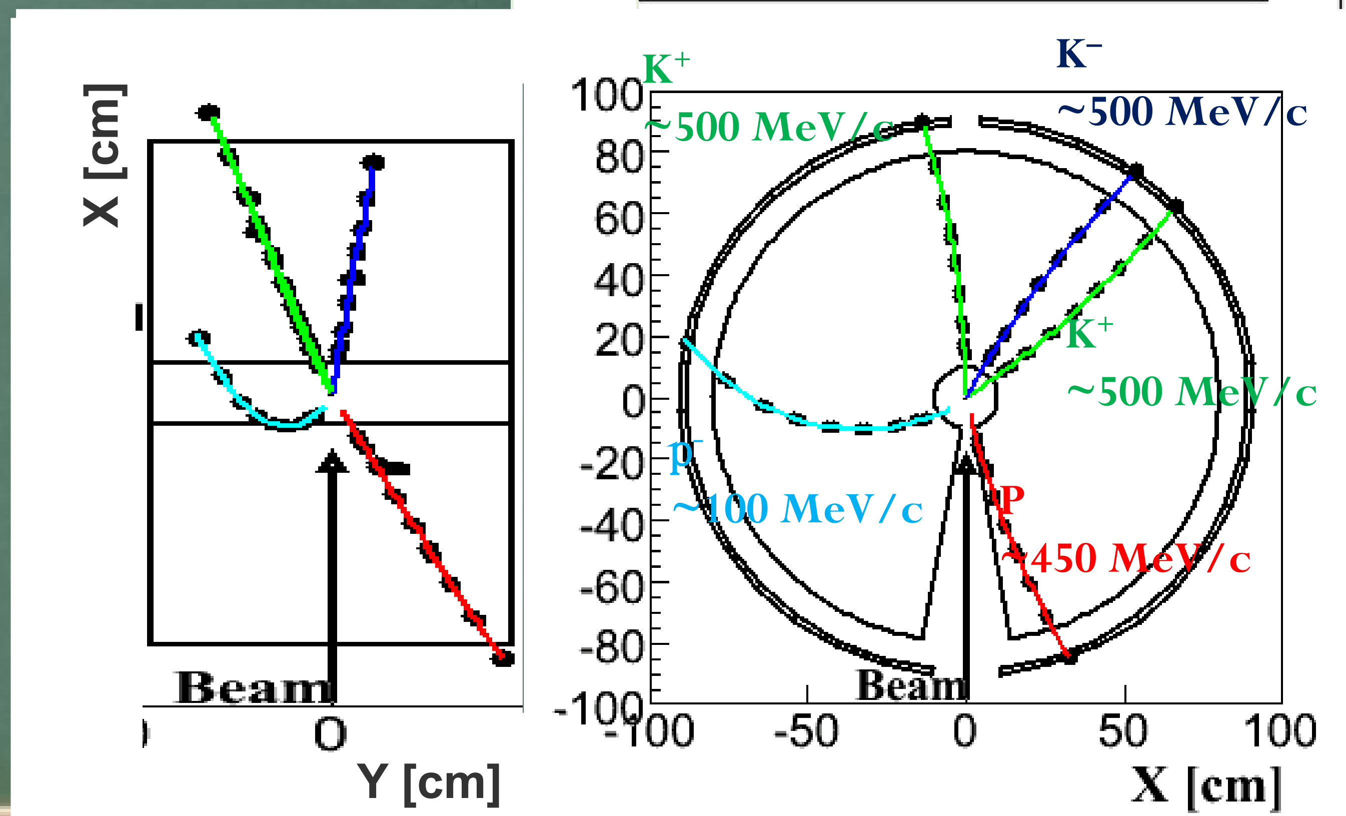
Large solid angle for the decay particles, K^+ / Λ, from ϕ mesic nucleus

Typical event display

- p + Cu → ϕ + $_{f}$Ni (B_f = 30 MeV)
- "ϕ"+"p" → K^+ + Λ

  (proton & f at rest)
- All decay processes are isotropic.





Detector simulation using GEANT4 is in progress

Expected Signal + background

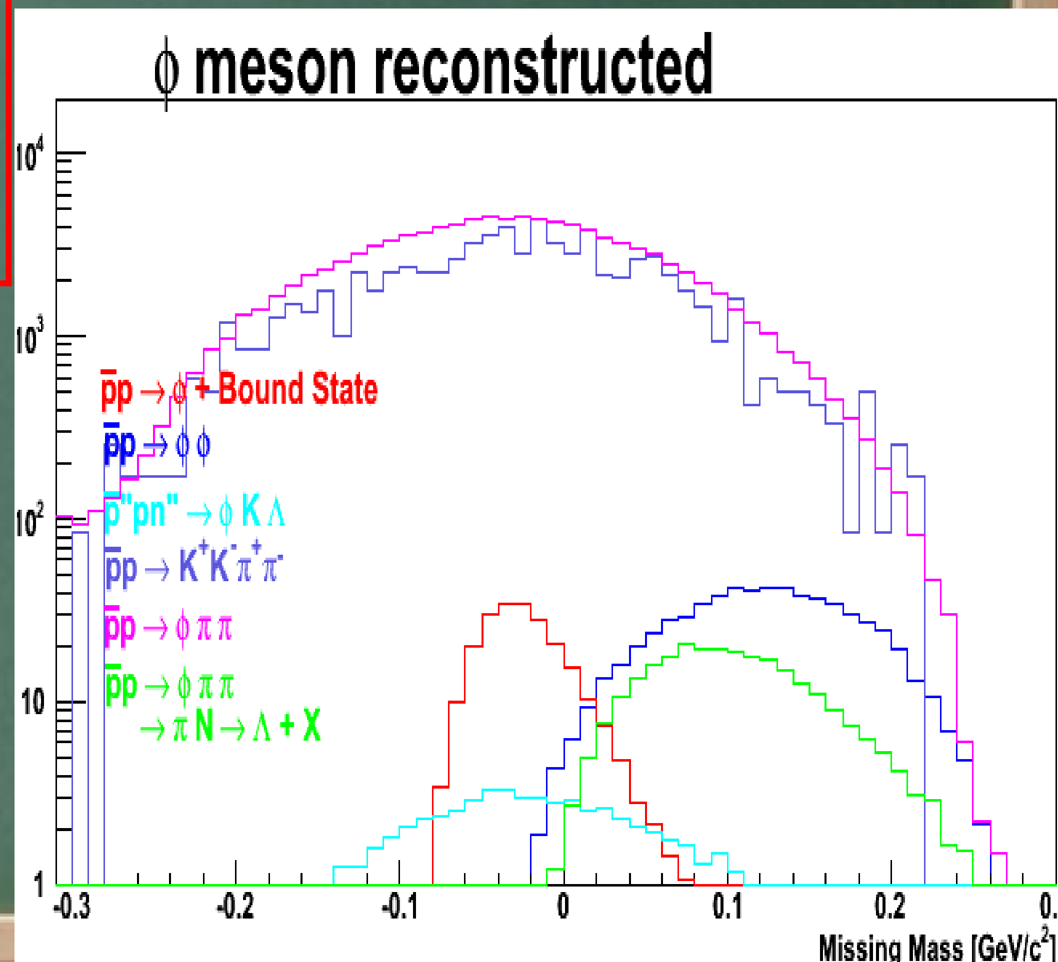
- Expected missing mass distribution with background (On Carbon target) :

270 kW, one month

- Assumption for the signal

Δm_ϕ = 35 MeV

Γ_ϕ = 15 MeV



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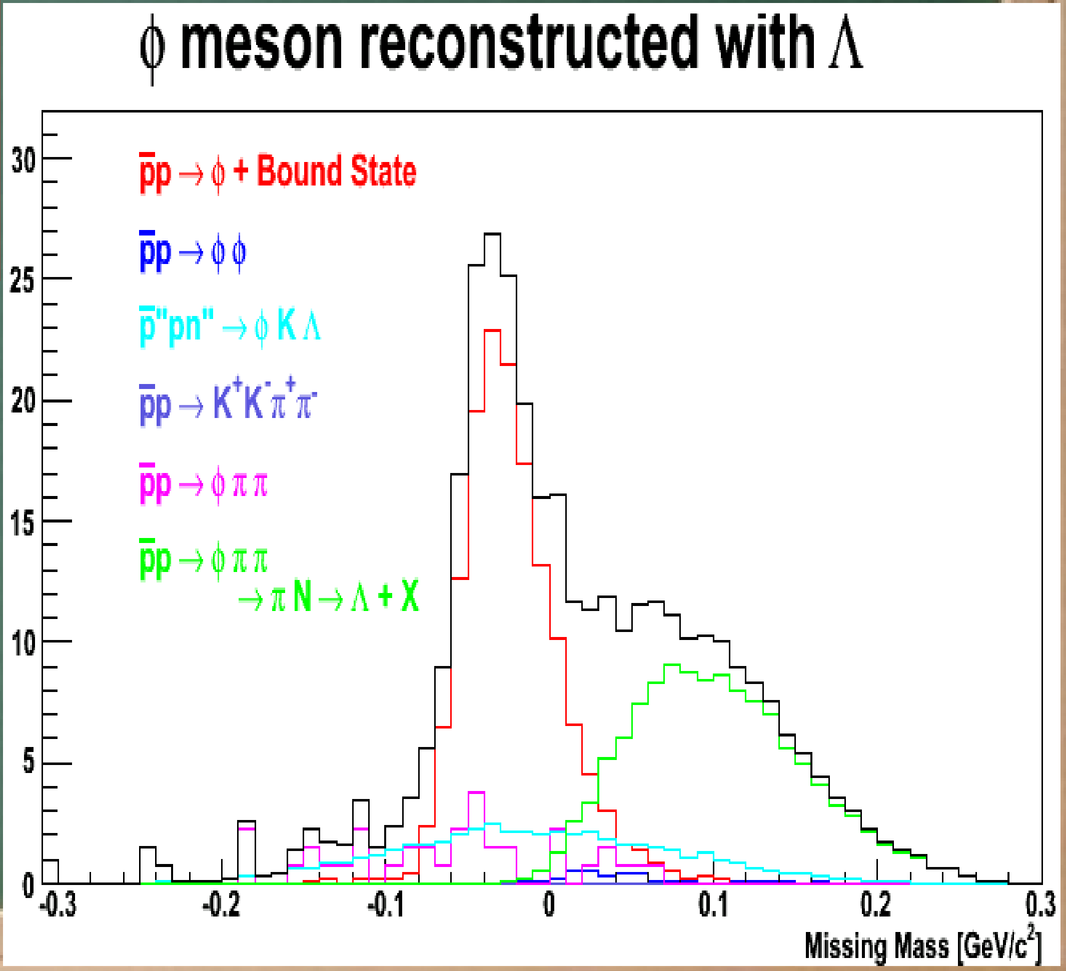
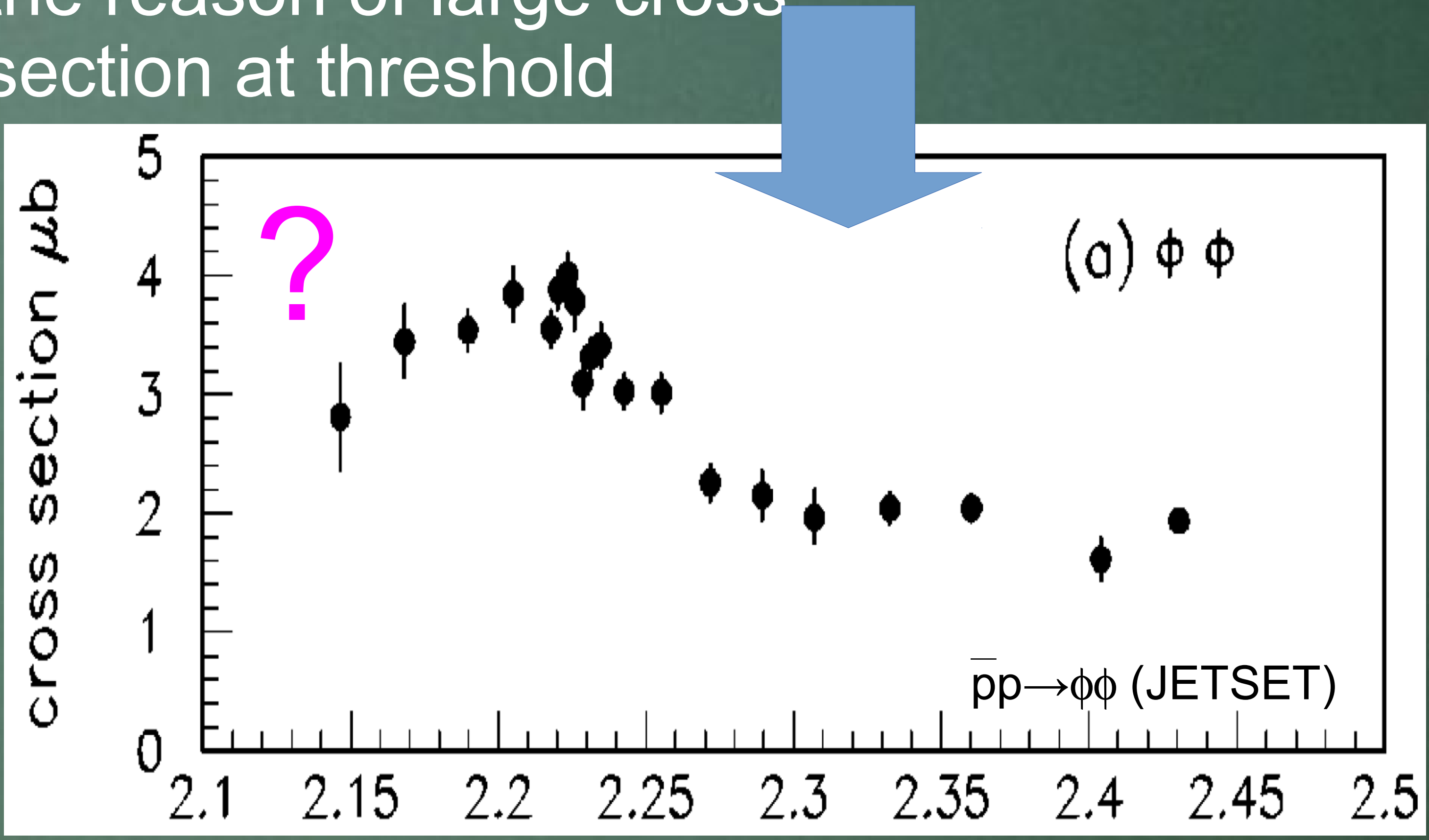


However, problems? on double ϕ meson production

Double ϕ meson production

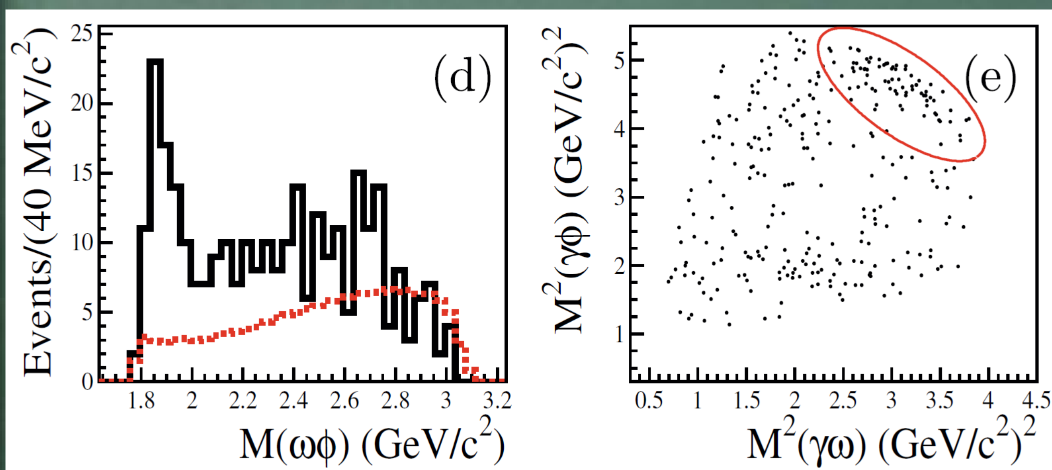
- Strong OZI violated process
  - It is very hard to understand the reason of large cross section at threshold

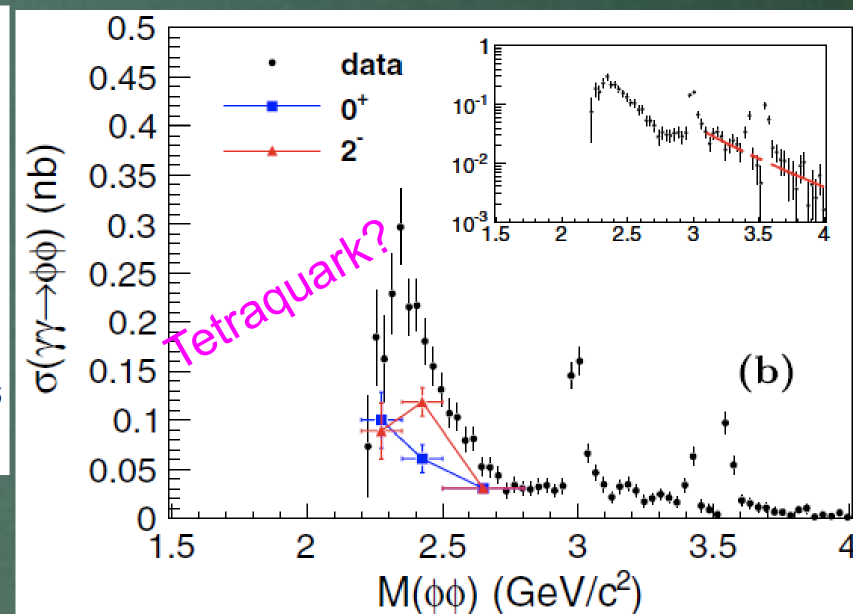


Phys. Rev. D 57 (1998) 5370-5381

Double φ meson production

- Recently, ωφ bound system has been observed? at BESII (PRL96(2006)162002)
- Moreover γγ→φφ has been measured at Belle with high statistics (PRL108(2012)232001).





M=1812^{+19}_{-26}+18 MeV/c2, Γ=105±20±28 MeV/c2

Why not in φφ????

φφ production itself is still interesting very much!

1^{st} phase for E29

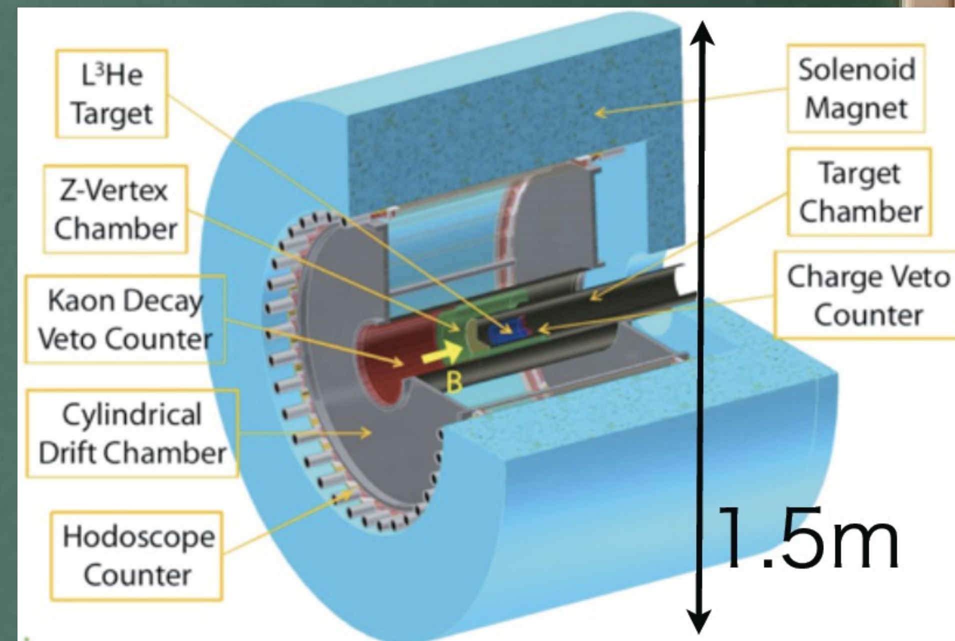
We are now planing to perform 1^{st} phase experiment using spectrometer at K1.8BR beamline

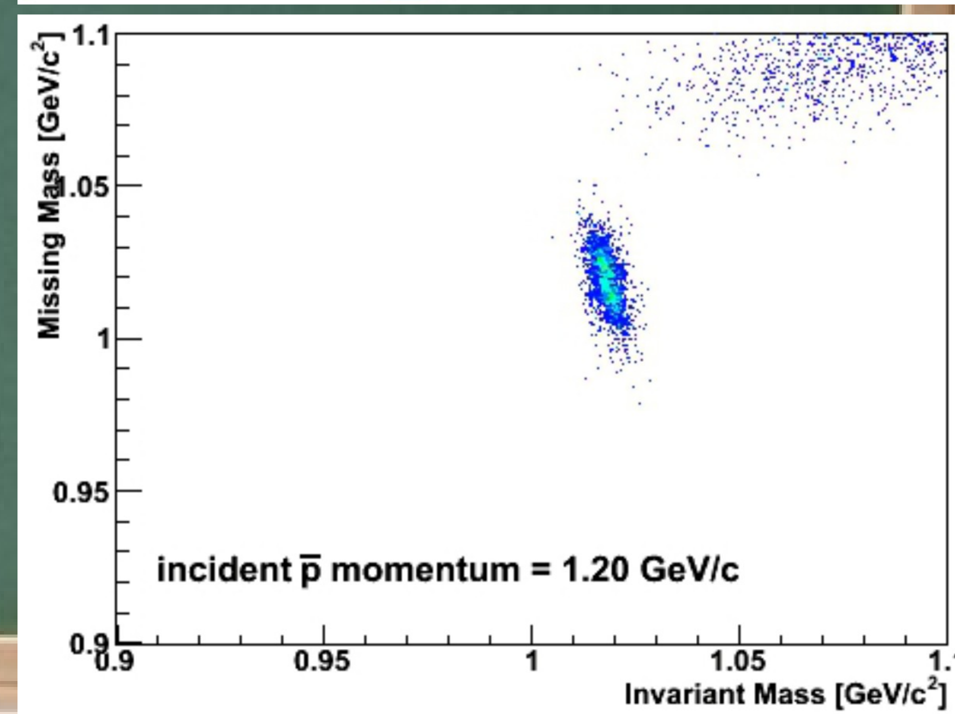
- Maximum momentum for anti-proton at J-PARC/K1.8BR → 1.1 GeV/c
- Unfortunately, cross section of double ϕ meson production only available from $\bar{p}$ monemtum = 1.2 GeV/c and higher
- Thus, we are planed to perform the experiment to confirm the cross section of $\bar{p}p \rightarrow \phi\phi$ with $\bar{p}$ momentum lower than 1.2 GeV/c (no data available) on hydrogen target
- Also planed to take data with deuteron (or light nuclei)

Idea for phase-1 experiment

- Using E15 spectrometer
- Large acceptance charged particle spectrometer surrounding target (CDS).
- Detecting K+K- pairs from ϕ decay in CDS
- Calculate invariant mass of K+K- and missing mass, then we can identify double ϕ production

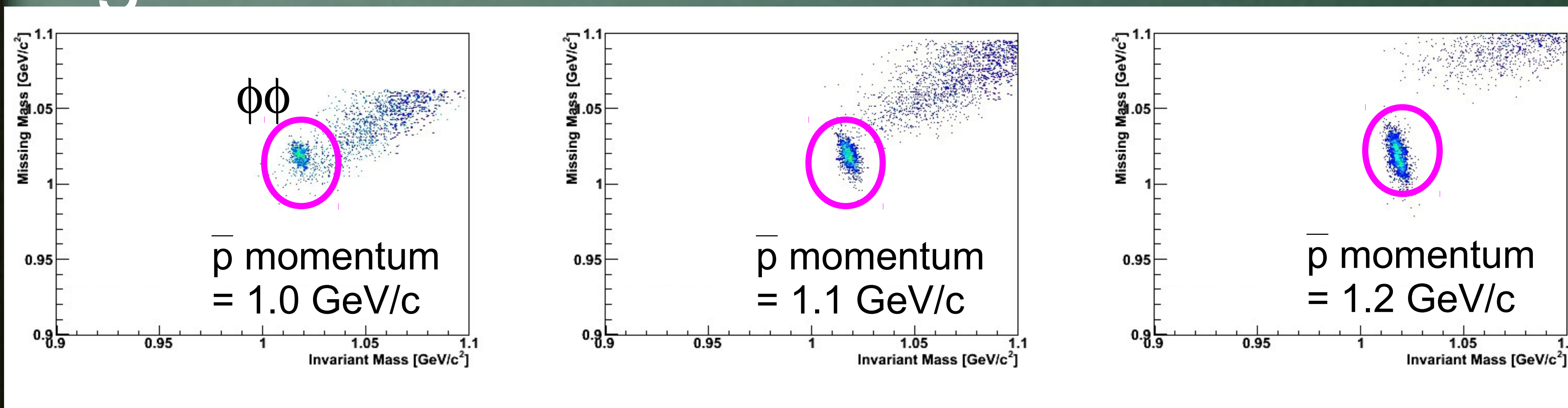
Good enough to investigate elementary process !



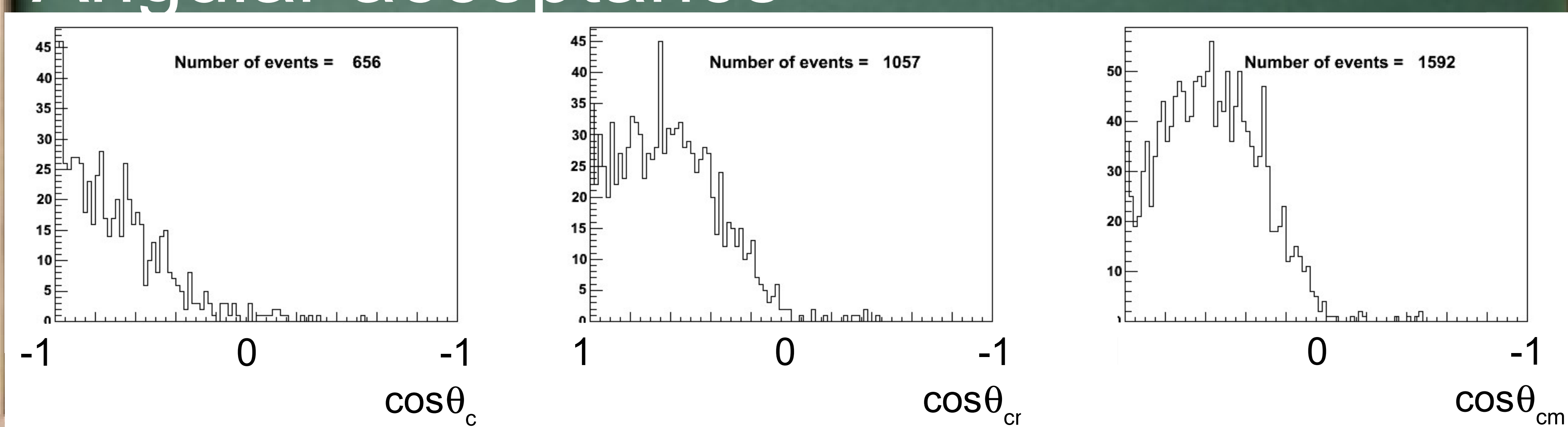


Idea for phase-1 experiment

Signal



Angular acceptance



Plane for next years

- We will ask to J-PARC PAC (probably next January) for approval of E29 1st phase experiment
  - Perform the experiment at K1.8BR
  - Using Detector ready exist
    → Problem might be a beam time availability

- Once we finish to taking data and confirm the cross section of double ϕ production, we will go forward to perform full experiment to search for ϕ meson bound state

Summary

- The project to searching for ϕ meson bound state has been proposed to J-PARC and now we got stage-1 approval (E29)
- The most promising elementary process for the ϕ mesic nucleus production will be $\bar{p}p \rightarrow \phi\phi$ channel
- Preparation for the E29 phase-1 is in progress