φ meson in nucleus

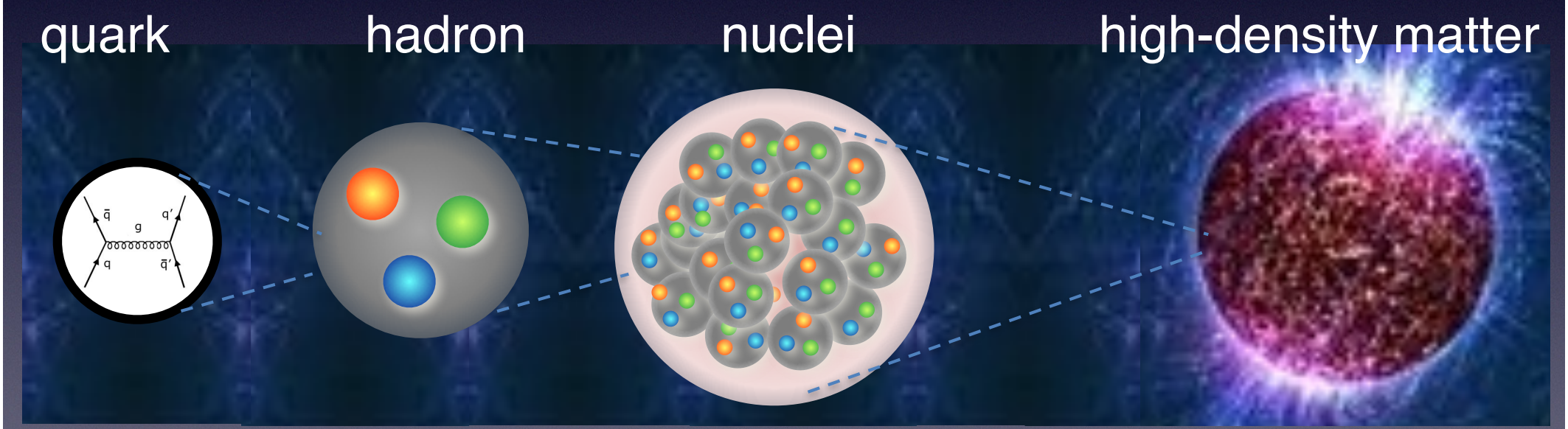
Hiroaki Ohnishi
RIKEN/Nishina Center
Osaka Univ./RCNP

How the matter created by QCD

QCD is the “theory” to describe strong interaction

Final goal is to understand strong interacting matter

quark/hadron/nuclei to high density nuclear matter



However, even the first step

how hadron created from quarks is not clear yet.

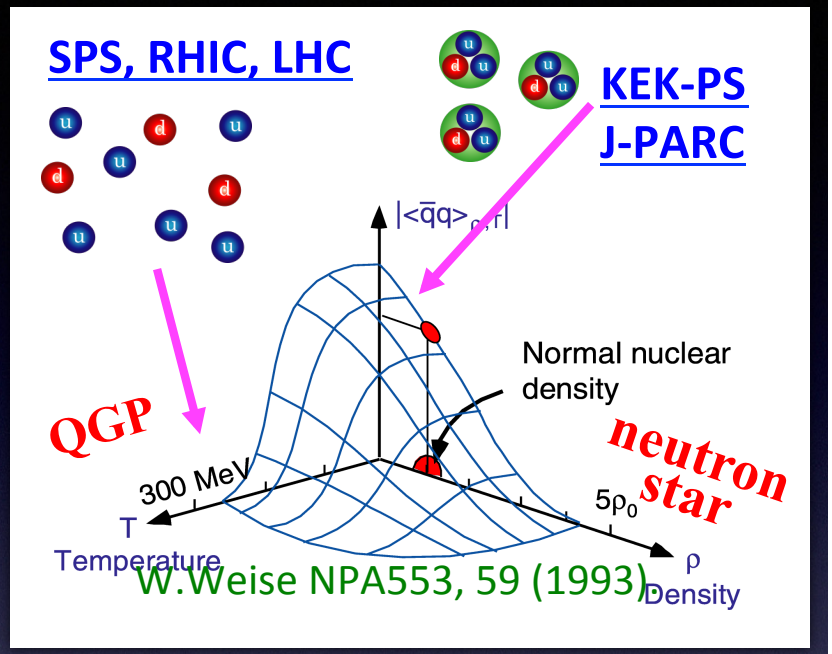
Questions need to be answered

- How hadrons are formed from quarks
  What is the effective DoF to describe hadron?

- How the property of the hadron are changing when the environmental condition is changed, such as high density?

Hadron in nuclear media

- quark condensates $< \bar{q}q >$ will change as a function of T/ρ
- $< \bar{q}q >= 0$ will be realize at high T and ρ
  (restoration of chiral symm.)



- relation exist between $< \bar{q}q >$ and Hadron mass, for example, Gell-Mann-Oakes-Renner relation

$$-4m_q < \bar{q}q >= m_\pi^2 f_\pi^2$$

$$-(m_q + m_s) < \bar{q}q + \bar{s}s >= m_K^2 f_K^2$$

Meson property will change under the extreme condition

The property of the hadron in nucleus

- Meson in nucleus will be a good probe to investigate QCD vacuum structure,
  $c.f. < q\bar{q} >_\rho @ \ \rho \neq 0$
- different meson will probe different condensation parameters

$$
\begin{cases}
\pi & : -4m_q < \bar{q}q >= m_\pi^2 f_\pi^2 \\
\mathrm{K} & : -(m_q + m_s) < \bar{q}q + \bar{s}s >= m_K^2 f_K^2 \\
\rho, \omega \text{(light } q\bar{q}\text{)} & : < \bar{q}q >_\rho^2 + < \bar{u}\gamma_\mu D_\mu u >_\rho \\
\phi \ (\ \bar{s}s\ ) & : m_s < \bar{s}s >_\rho + \cdots \\
\mathrm{D} \text{ (light-heavy)} & : m_Q < \bar{q}q >_\rho + \cdots
\end{cases}
$$

ϕ meson

- ϕ meson :
  - Vector meson, $J^{PC} = 1^{--}$
  - bound state of hidden strangeness (ss)
  - narrow width = 4.43 MeV/c2
    → 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 nuclear matter

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

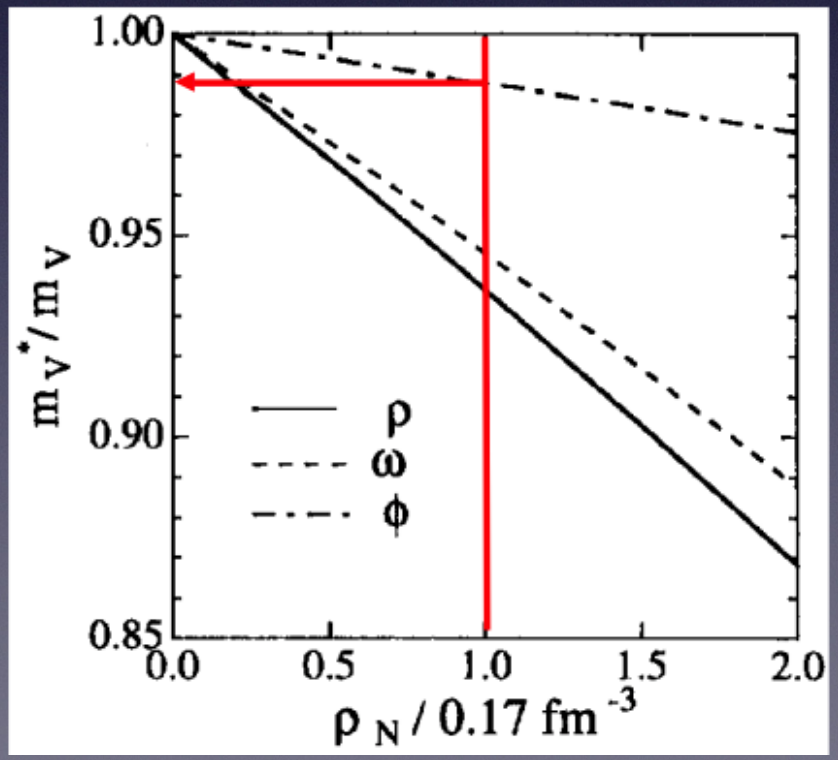
Yuji KOIKE and Arata HAYASHIGAKI

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

(Received April 14, 1997)

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

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



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Nuclear Physics A 835 (2010) 406–409

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Formation of Slow He

Satoru Hirenzaki[a], Jun

[a]Department of Physics, Nara Wome

[b]Departamento de Física Teórica and IFIC, Centro Mixto U

Paterna, Apartado 2208

Search for a hidden strange baryon-meson bound state from ϕ production in a nuclear medium

Haiyan Gao,[1,2] Hongxia Huang,[1,3,*] Tianbo Liu,[1,2,†]

Jialun Ping,[3] Fan Wang,[4] and Zhiwen Zhao[1]

[1]*Department of Physics, Duke University, Durham, North Carolina 27708, U.S.A.*

[2]*Duke Kunshan University, Kunshan, Jiangsu 215316, China*

[3]*Department of Physics, Nanjing Normal University, Nanjing, Jiangsu 210097, China*

[4]*Department of Physics, Nanjing University, Nanjing, Jiangsu 210093, China*

CLE PHYSICS

J. Phys. G: Nucl. Part. Phys. **37** (2010) 085109 (10pp) doi:10.1088/0954-3899/37/8/085109

Junko YAMAGATA-SEKIHARA,[1,*]

and

PHYSICAL REVIEW C **75**, 058201 (2007)

Search for the ϕ-N bound state from ϕ meson subthre

S. Liska, H. Gao, W. Chen, and X. Qian

Department of Physics and the Triangle Universities Nuclear Laboratory, Duke University, D

(Received 16 March 2007; published 30 May 2007)

The subthreshold photoproduction of ϕ mesons from heav
to search for the ϕ-N bound state, a quantum chromodynami
detailed Monte Carlo studies to demonstrate the feasibility of t
subthreshold production of ϕ meson from heavy nuclear targ

DOI: 10.1103/PhysRevC.75.058201 PACS nu

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]

RAPID COMMUNICATIONS

th Africa

ra

PHYSICAL REVIEW C, VOLUME 63, 022201(R)

ϕ-N bound state

H. Gao,[1] T.-S. H. Lee,[2] and V. Marinov[1]

[1]*Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*

[2]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439*

(Received 6 October 2000; published 5 January 2001)

We show that the QCD van der Waals attractive potential is strong enough to bind a ϕ meson onto a nucleon inside a nucleus to form a bound state. The direct experimental signature for such an exotic state is proposed in the case of subthreshold ϕ meson photoproduction from nuclear targets. The production rate is estimated and such an experiment is found to be feasible at the Jefferson Laboratory.

DOI: 10.1103/PhysRevC.63.022201 PACS number(s): 25.20.Lj, 13.75.Gx, 24.85.+p

Not observed yet

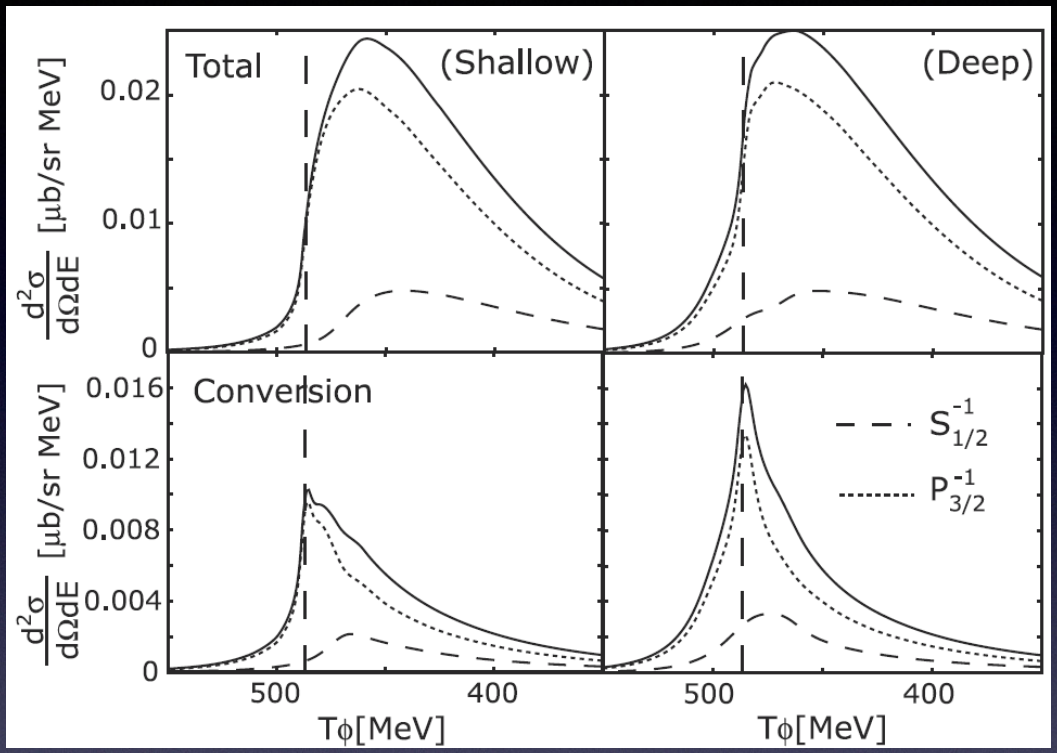
Try to see a little more

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 may exist w/ B.E~20-30 MeV

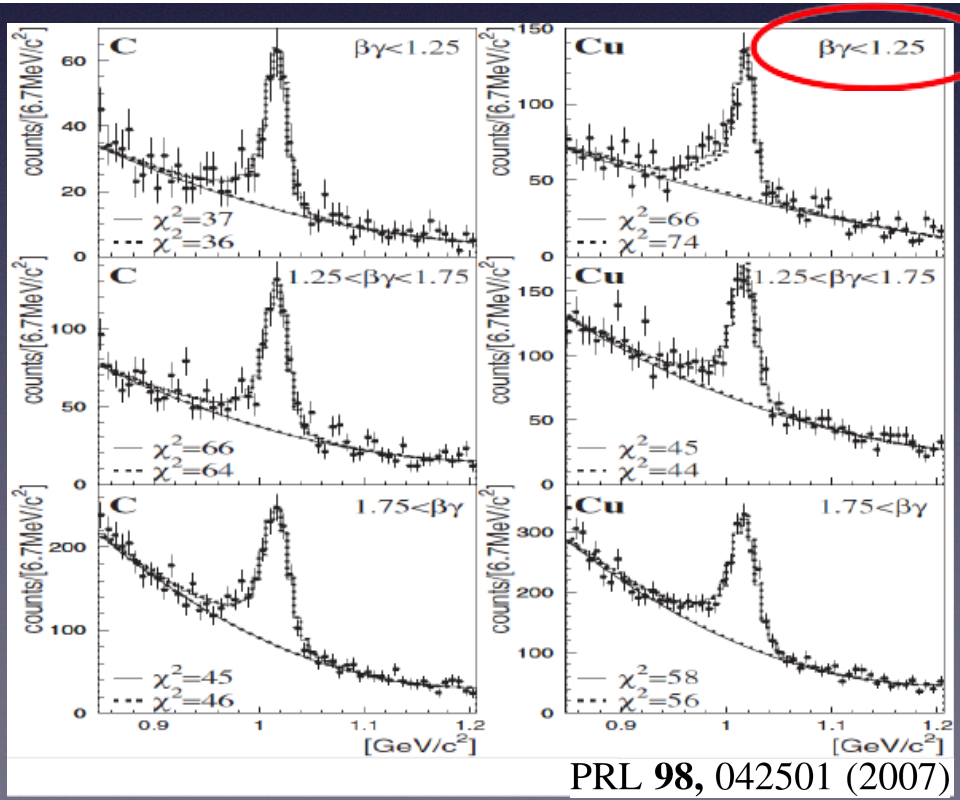
Experimental knowlege about ϕ meson in nucleus

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

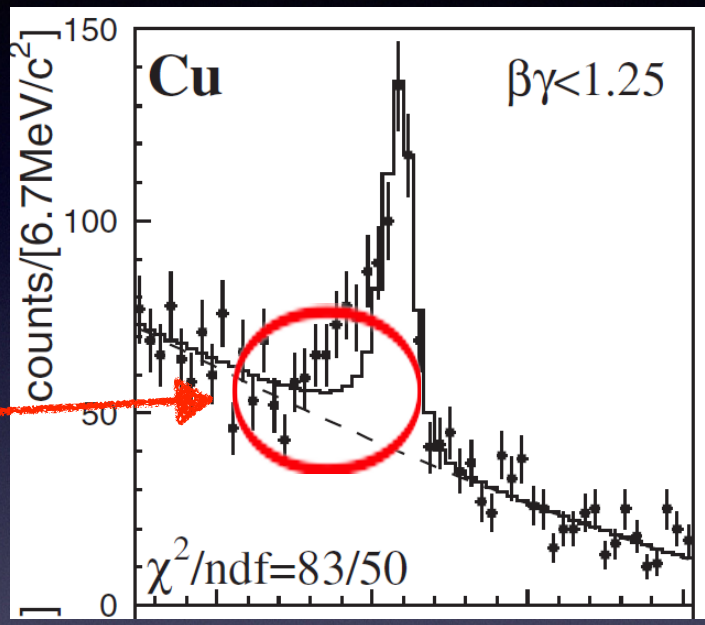
Evidence for In-Medium Modification of the ϕ Meson at Normal Nuclear Density

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. Kanda,[3,§] 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. Sakuma,[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)



mass decreasing ~3.4 %

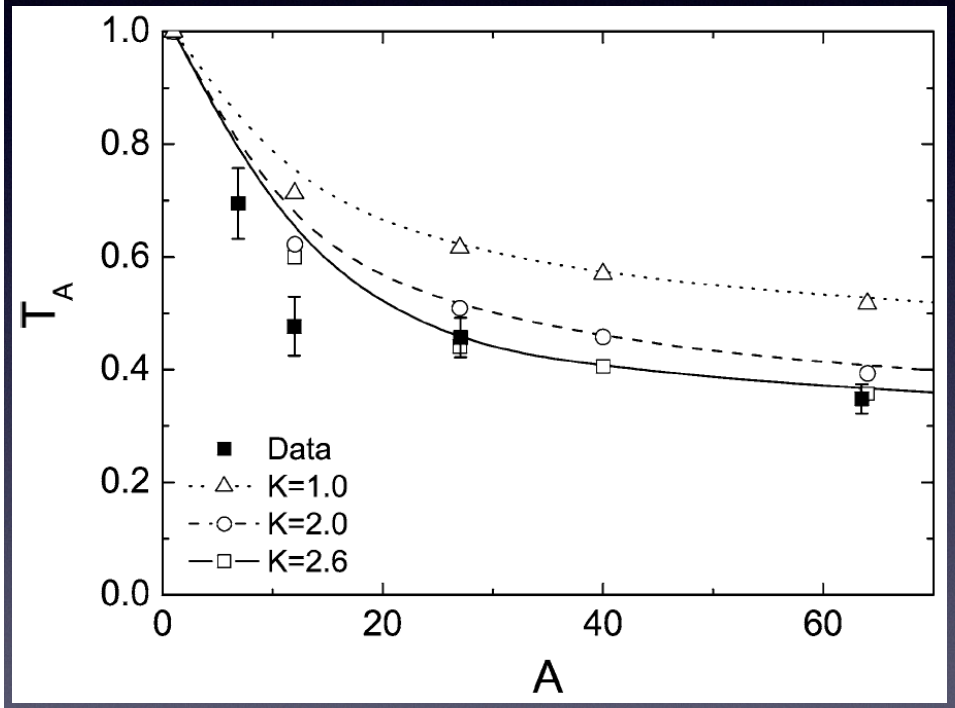
decay width broaden ~x3.6

ϕ mass reduction

might be attraction btw ϕN

Decay width of ϕ in nucleus

Transparency ratio, $T_A = \dfrac{\sigma_{\gamma A \to \phi X}}{A(\sigma_{\gamma p \to \phi X})}$



NPA765(2006)188-196

- γ A→ϕ 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 fm

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

ϕ meson in ? deuteron

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

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[b], 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[b], 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[b], 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

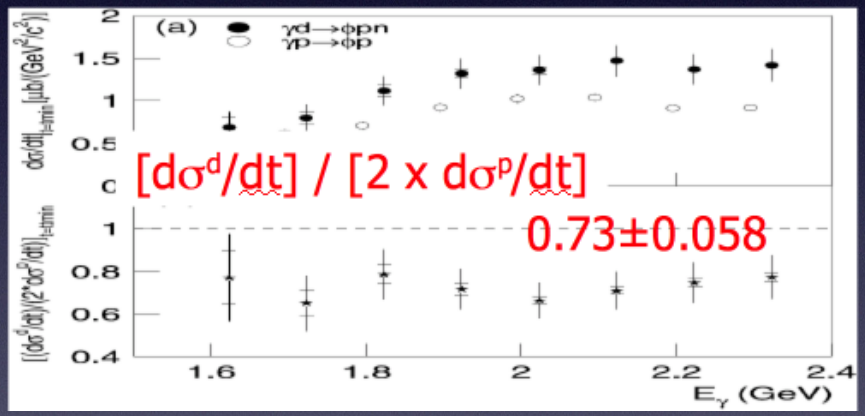
Physics Letters B

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], S. Fegan[l], R. Forsch[an,1], A. Fradi[y], M.Y. Gabrielyan[q], G.P. Gilfoyle[ah], K.L. Giovanetti[aa], F.X. Girod[c,2]



ϕ meson absorption?
even with deuteron
(on single nucleon??)

Experiment : γ d→ϕ X

ϕN cross section

measured: σ ϕN = 20 mb

expected: σ ϕN = 11 mb

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?

Momentum dependence of transparency ratio by COSY-ANKE

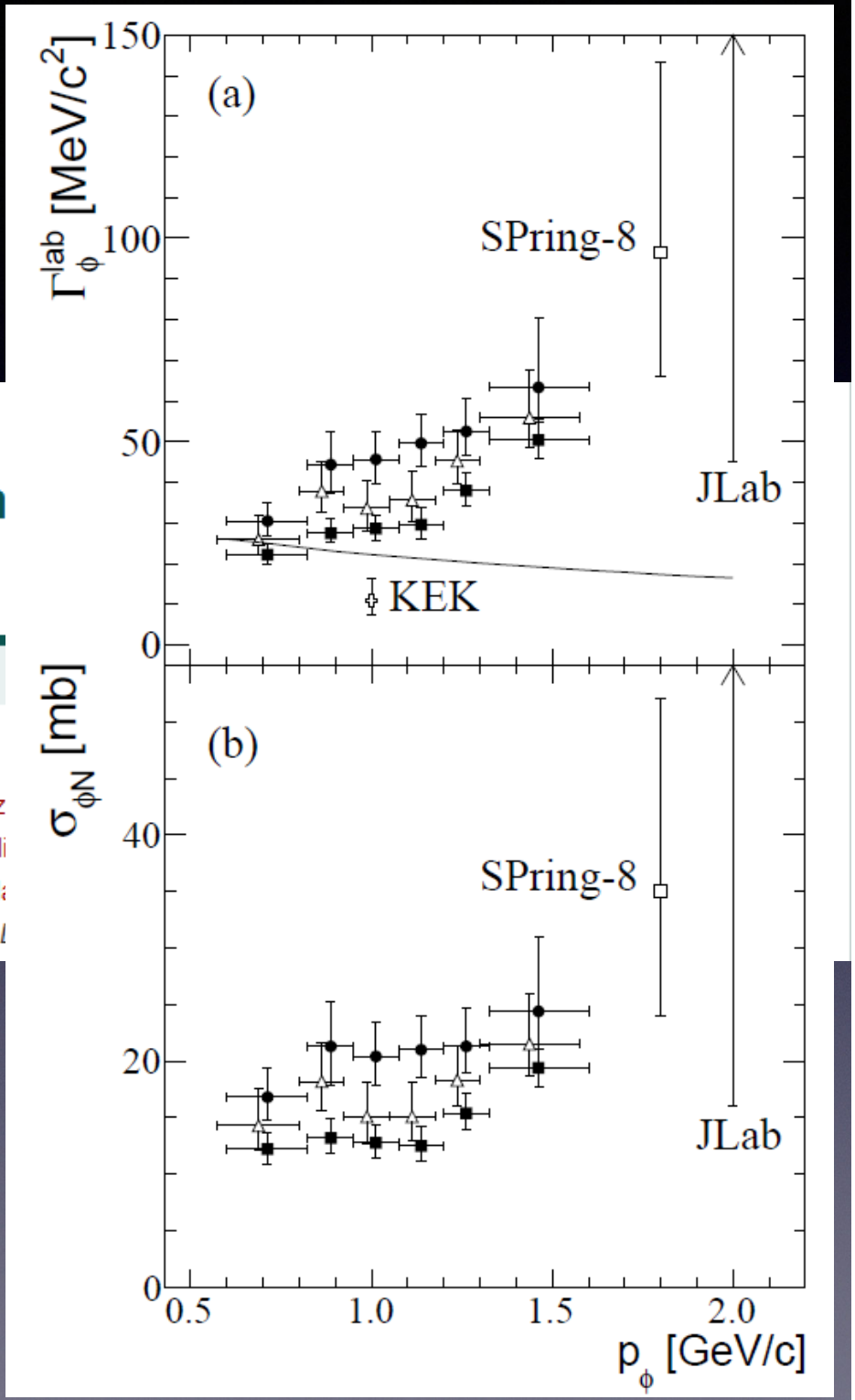
Phys. Rev. C 85, 035206 (2012) [8 pages]

Momentum dependence of the φ-meson n

Abstract | References | Citing Articles (1)

Hide All Authors/Affiliations

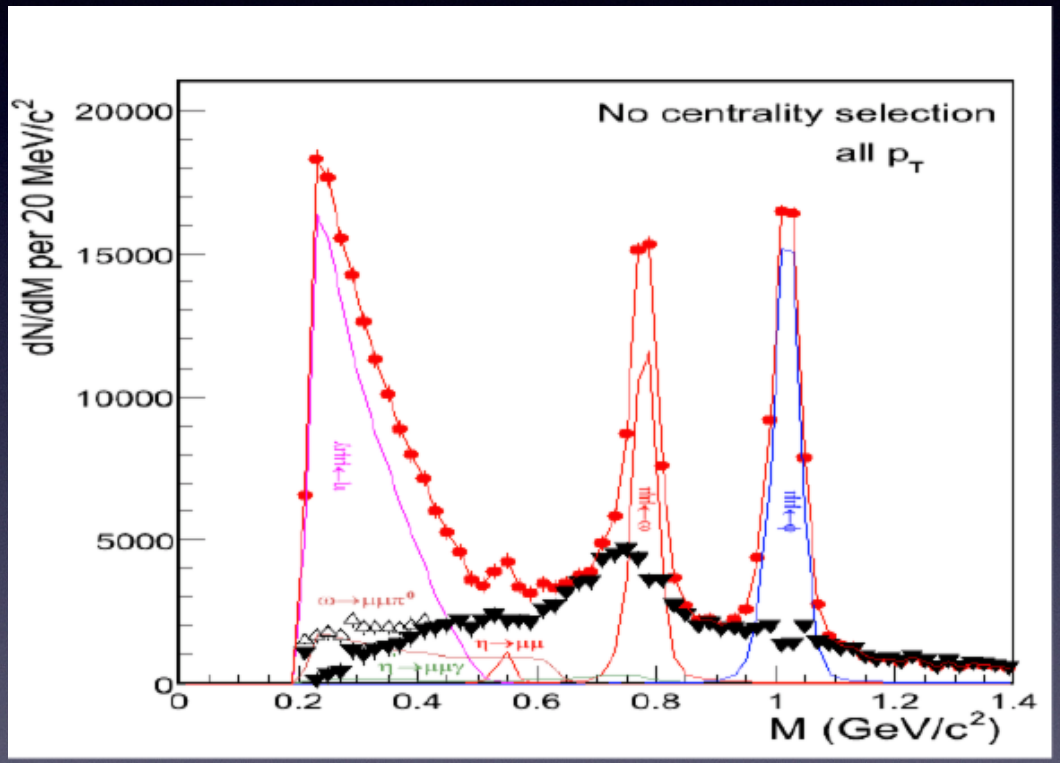
M. Hartmann[1,*], Yu. T. Kiselev[2,†], A. Polyanskiy[1,2], E. Ya. Paryev[3], M. Büscher[1], D. Chiladz
Keshelashvili[9], V. Koptev[7,‡], B. Lorentz[1], Y. Maeda[10], V. K. Magas[11], S. Merzliakov[1,6], S. Mi
Serdyuk[1,6], A. Sibirtsev[5], V. Y. Sinitsyna[14], H. J. Stein[1], H. Ströher[1], S. Trusov[8,15], Yu. Valda
[1]*Institut für Kernphysik and Jülich Centre for Hadron Physics, Forschungszentrum Jülich,*

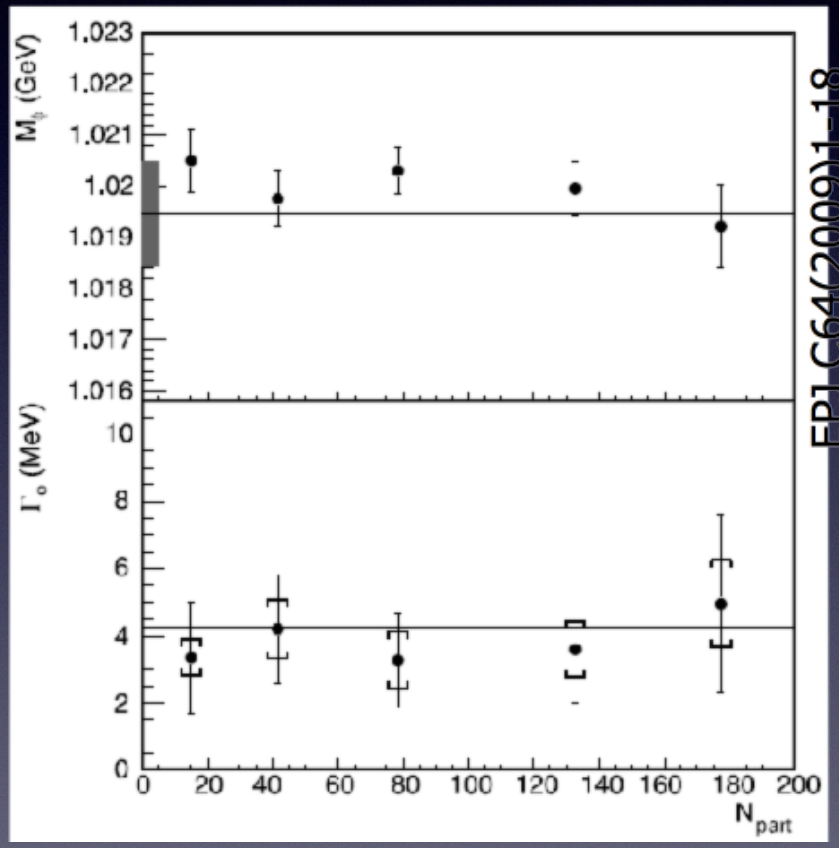


Width increasing ?
as a function of momentum
Less absorption with
low momentum ϕ meson ?

ϕ meson in high temperature?

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)

What do we want to know?

- Property of ϕ meson under high density environment (inside nucleus)

1) Study on meson mass modification in nuclei using primary proton beam at J-PARC
   → detail study of f->e+e- in nucleus
   (J-PARC E16 experiment)

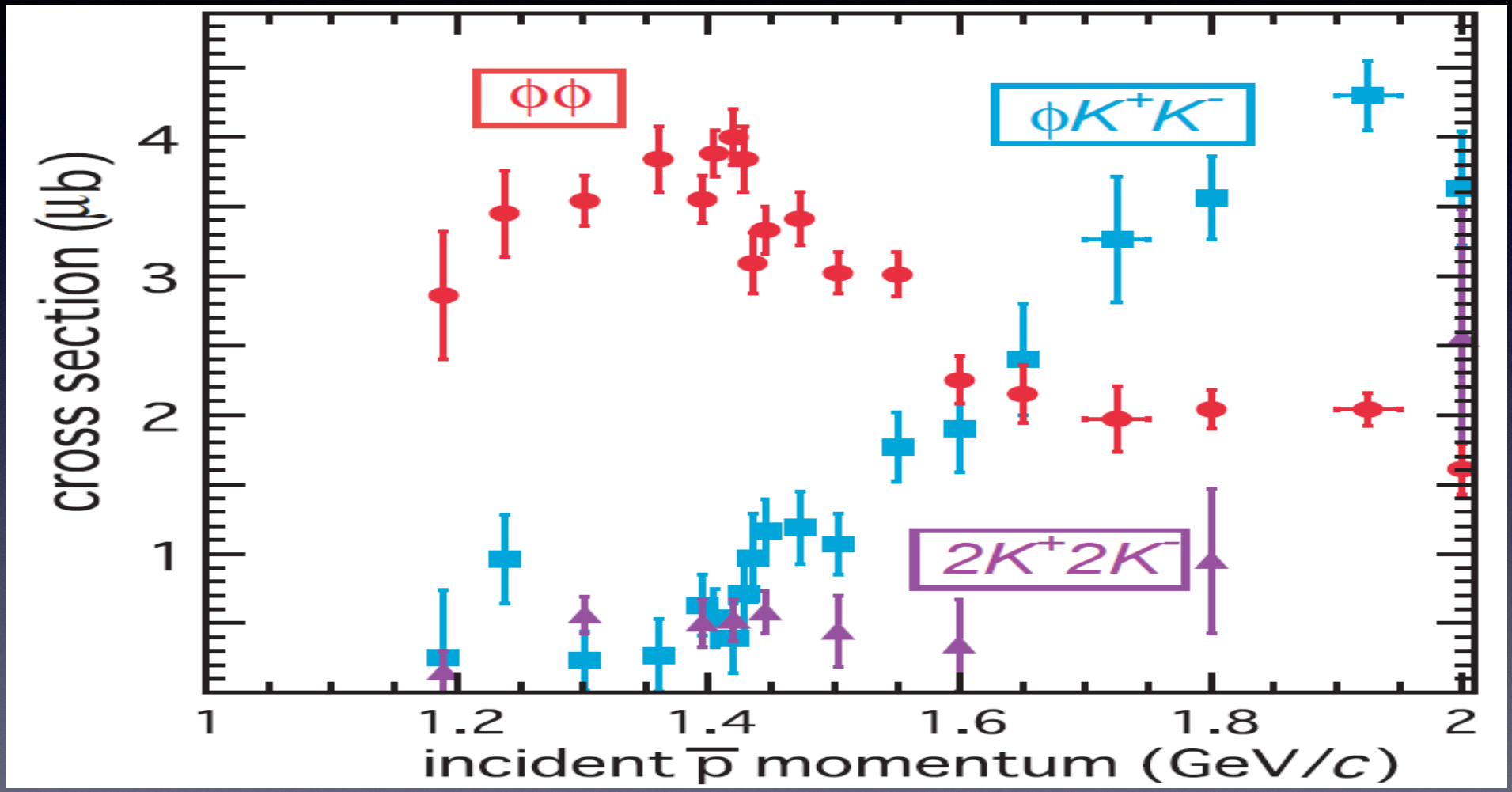
2) Search for ϕ meson bound state

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 slowly moving ϕ meson in nucleus ?
  → Need to find good elementary process

LEAR / JETSET

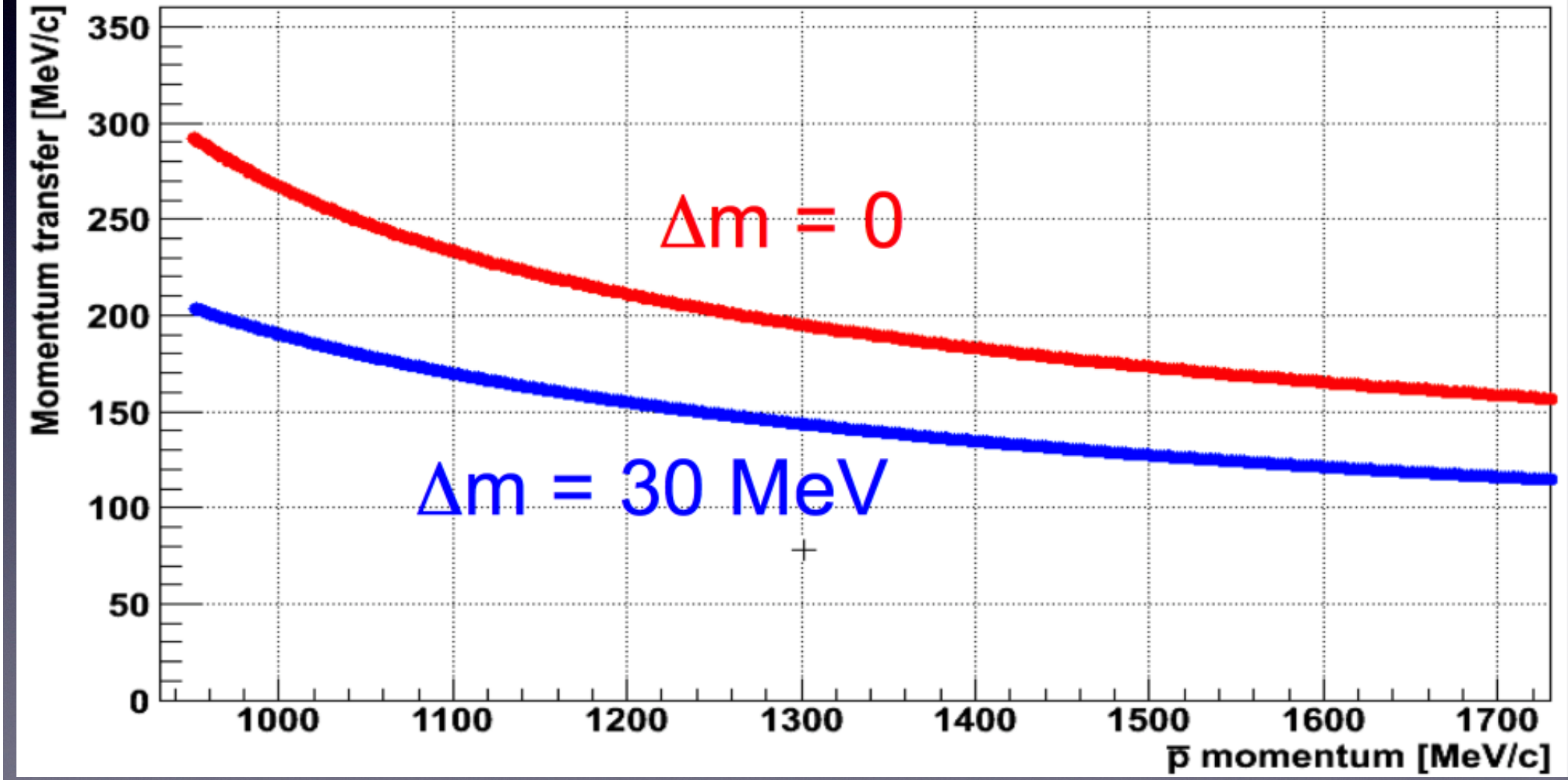


Phys. Rev. D 57 (1998) 5370-5381

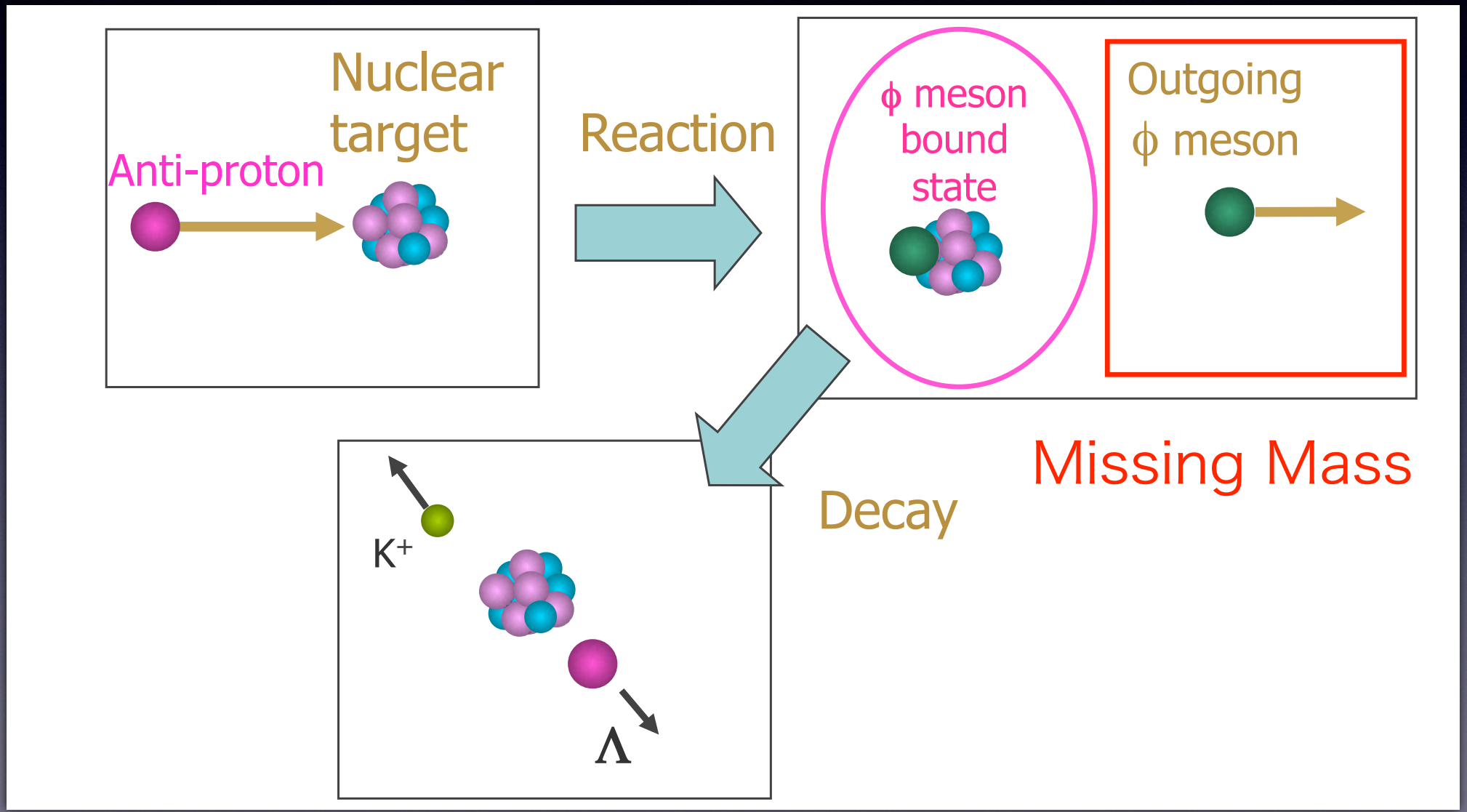
Double ϕ meson production in pp reaction

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

Missing mass by forward going ϕ meson

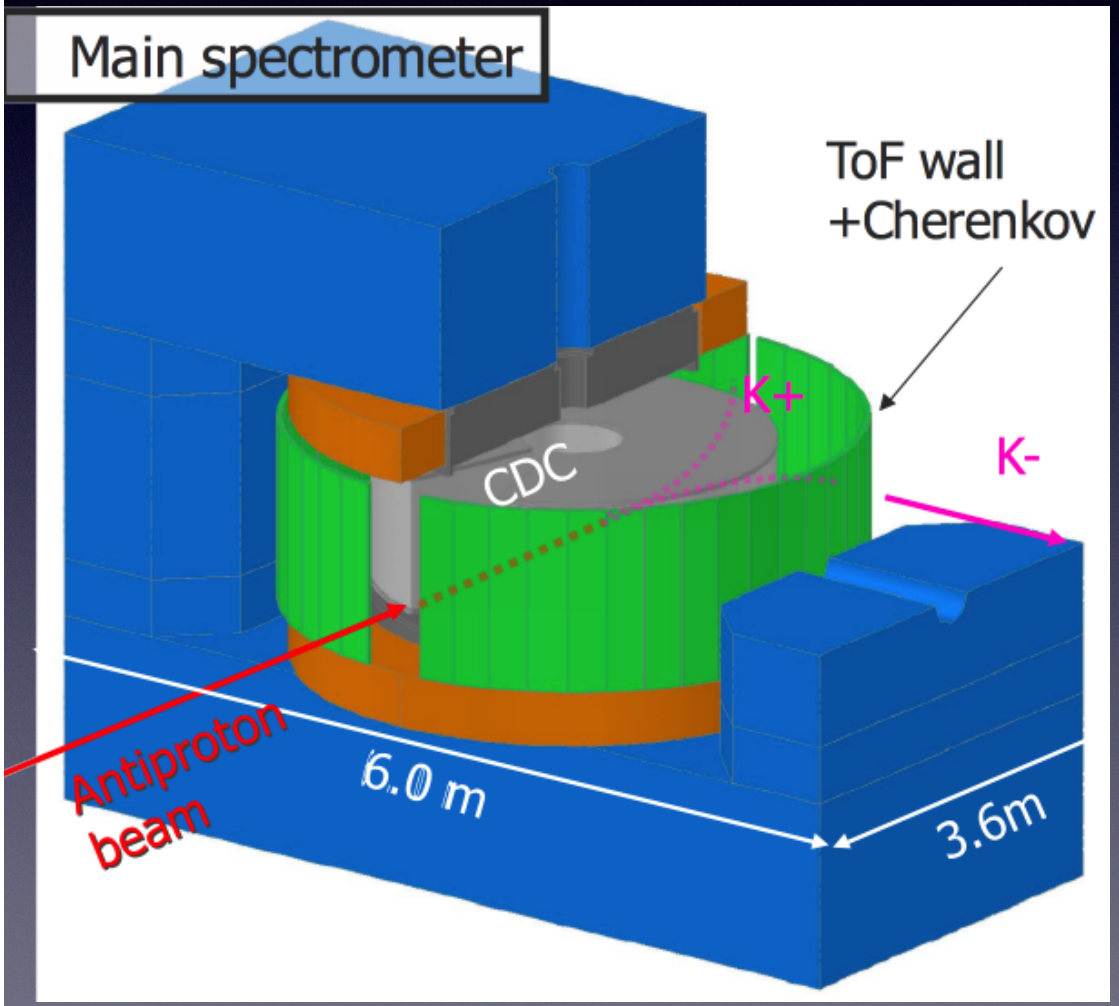


How to produce ϕ mesic nucleus?



Conceptual design

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

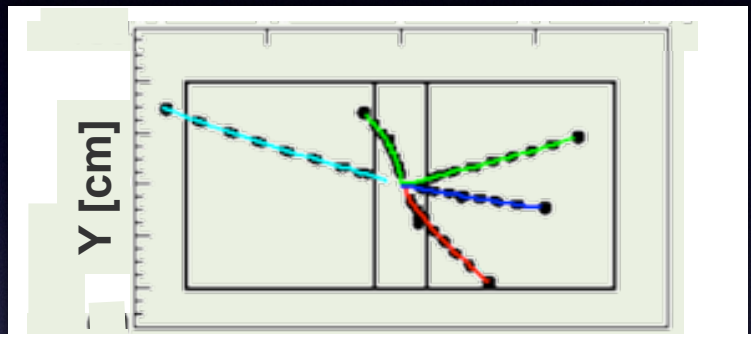
$p + Cu \rightarrow \phi + {}_{\phi}Ni$ ($B_{\phi} = 30$ MeV)

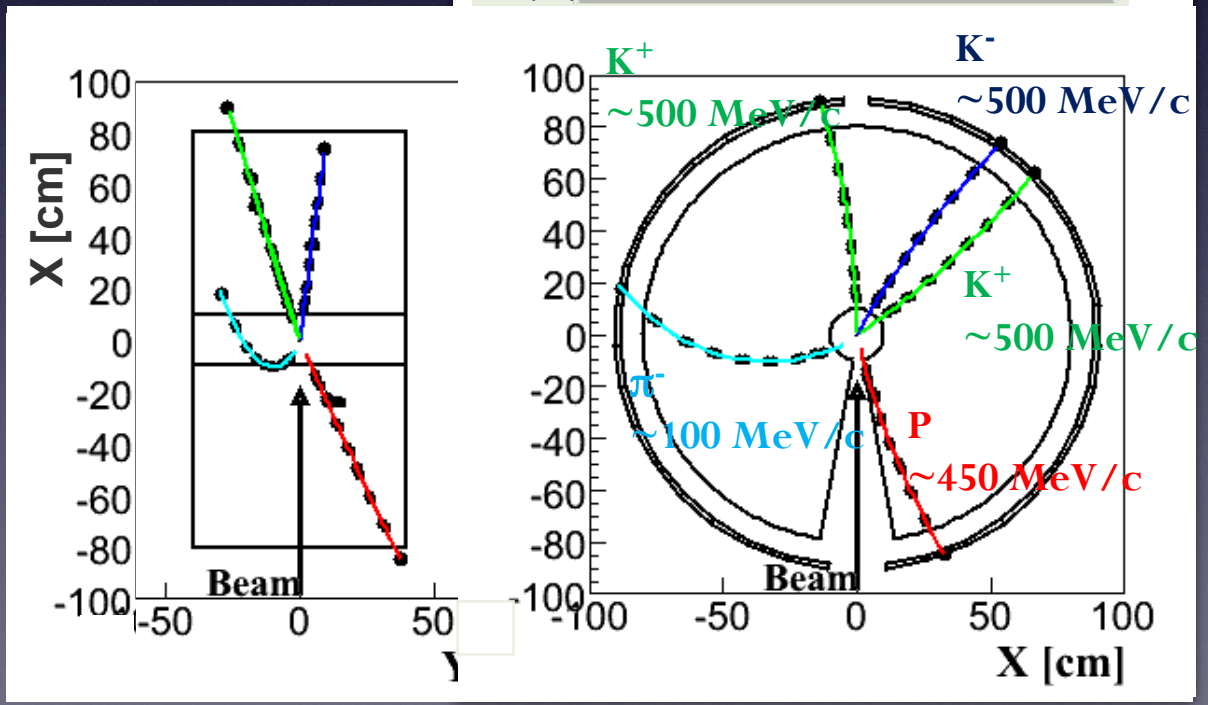
"ϕ"+"p" $\rightarrow K^+ + \Lambda$

(proton & ϕ at rest)

All decay processes are isotopic.

Detector simulation using GEANT4 based on conceptual detector design is in progress





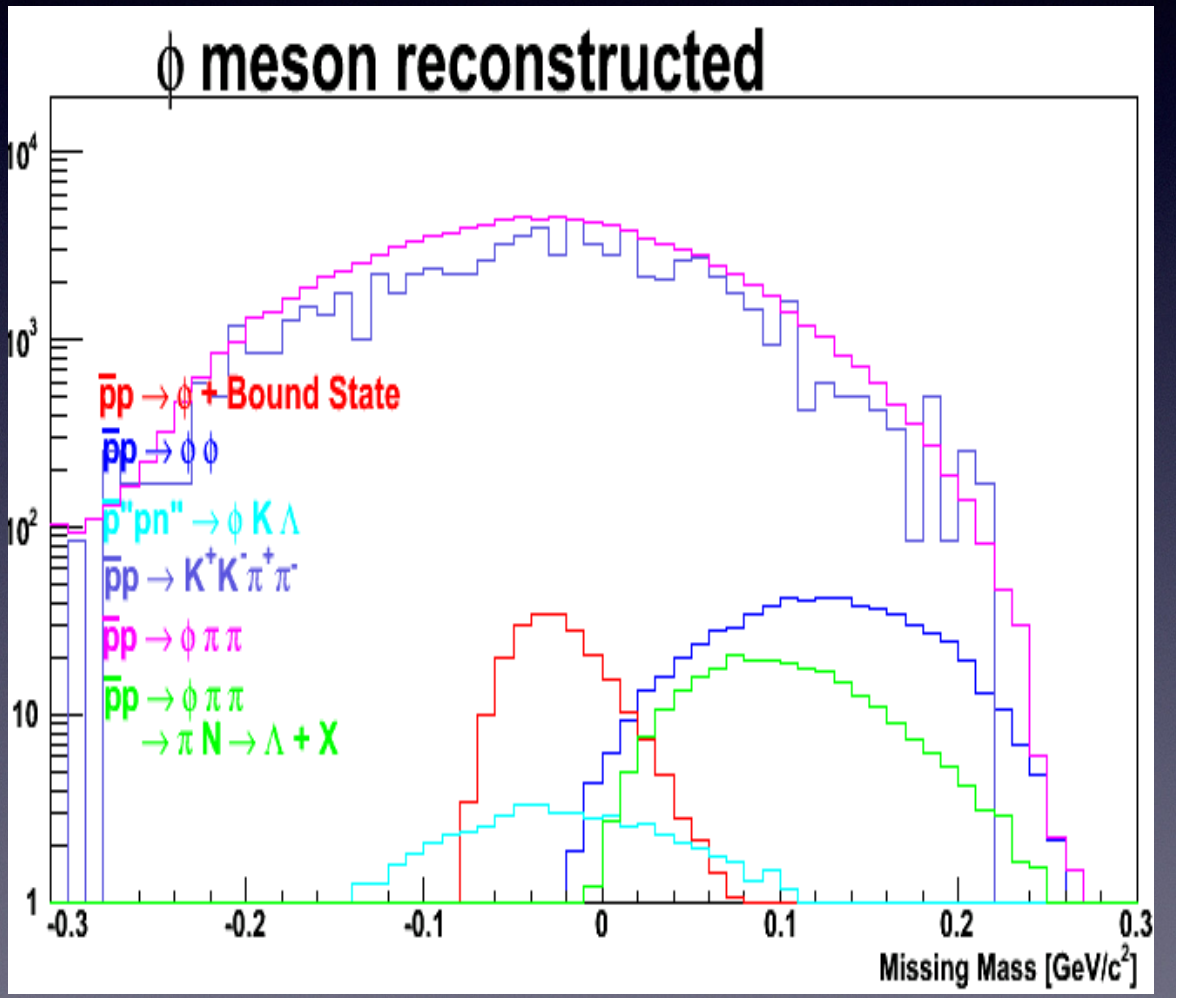
Expected Signal+background

- 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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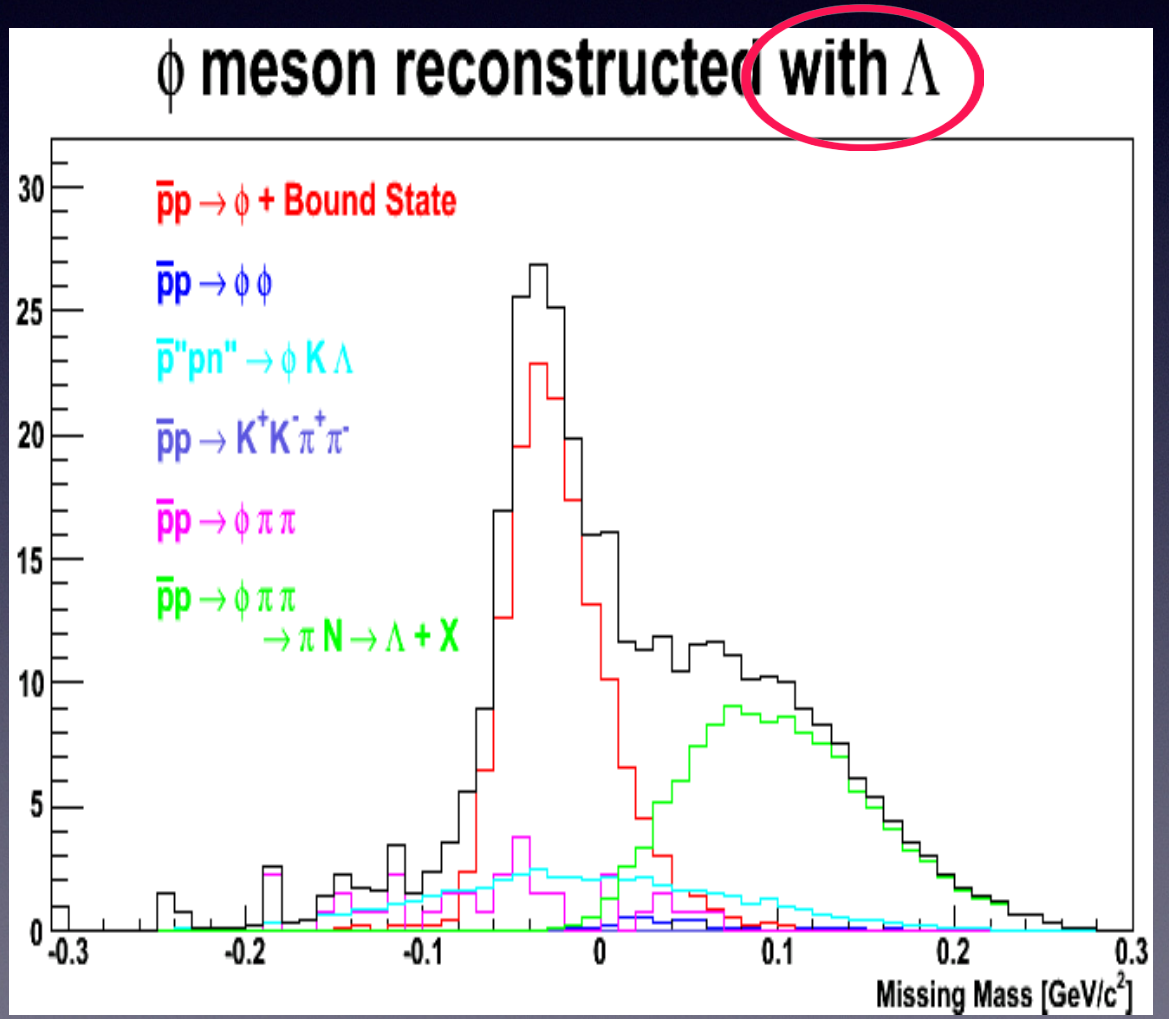
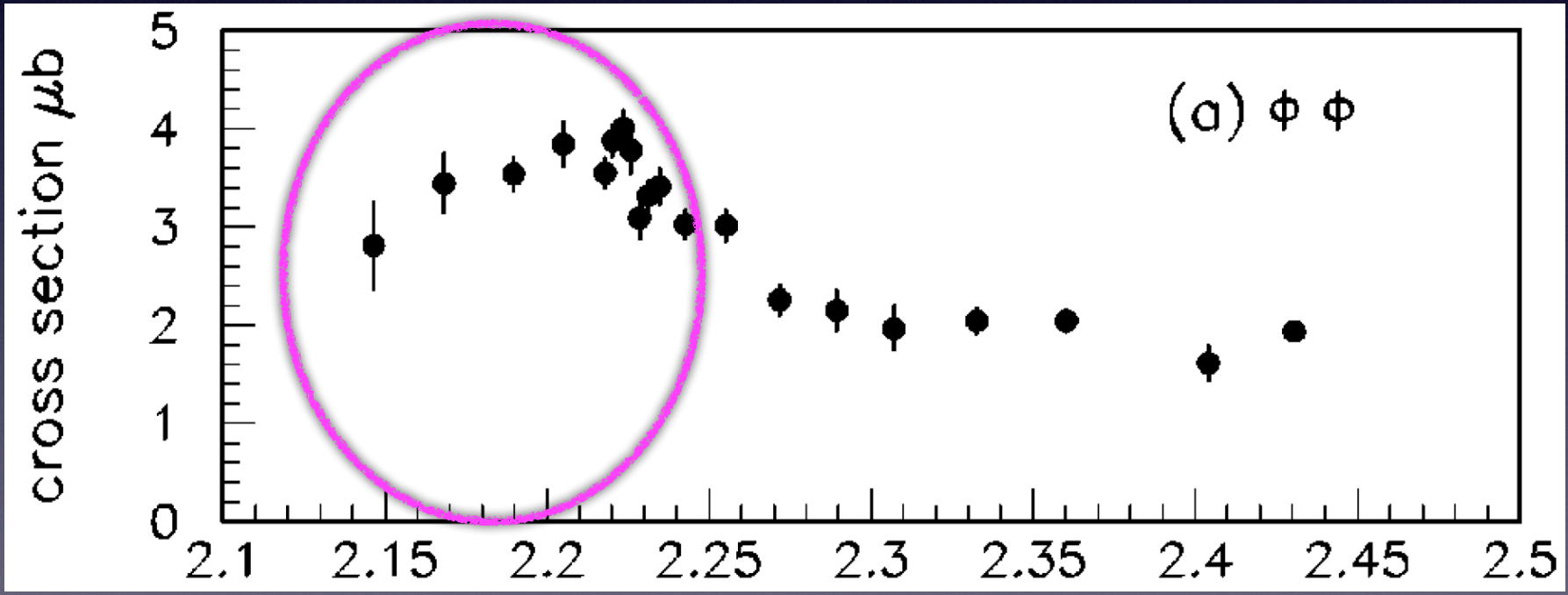


Double ϕ meson production

Strong OZI violated process

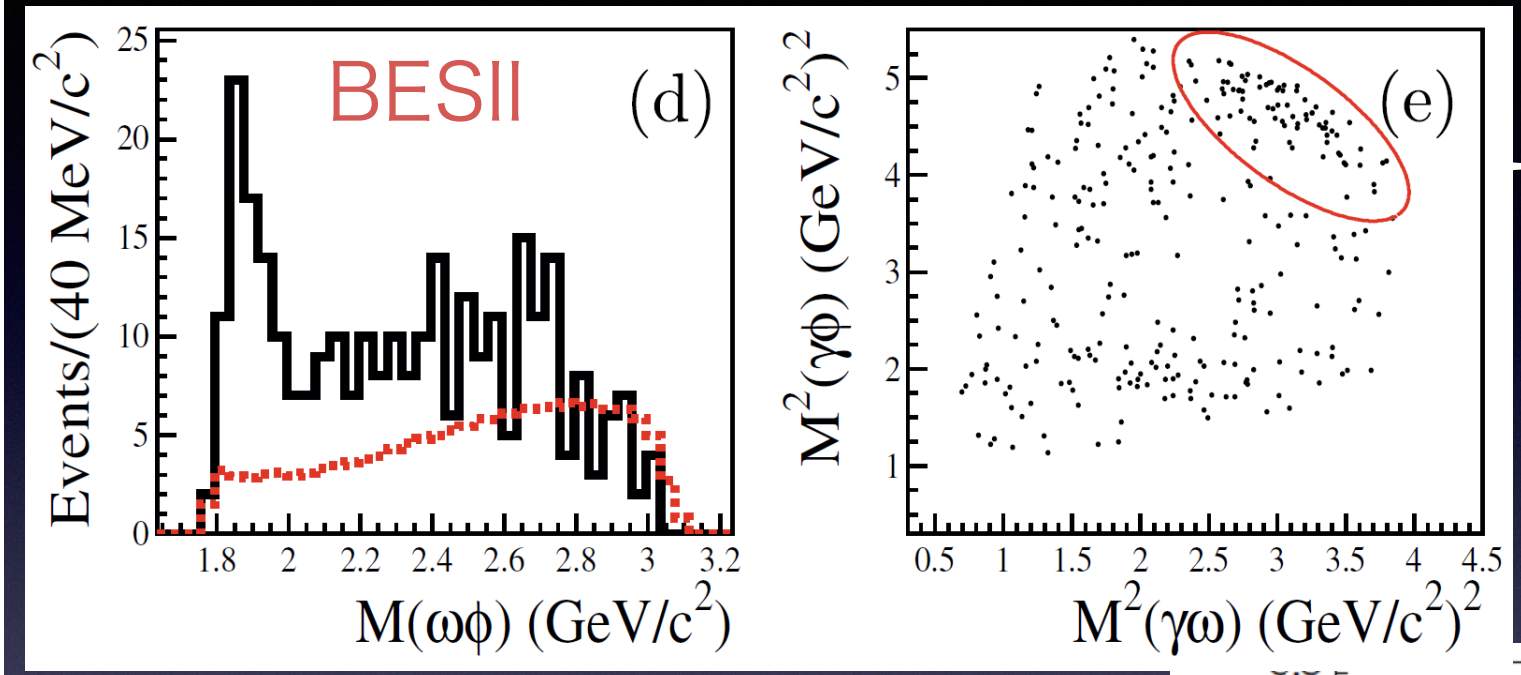
It is very hard to understand

the reason of large cross section at threshold



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

Meson-Meson bound state?

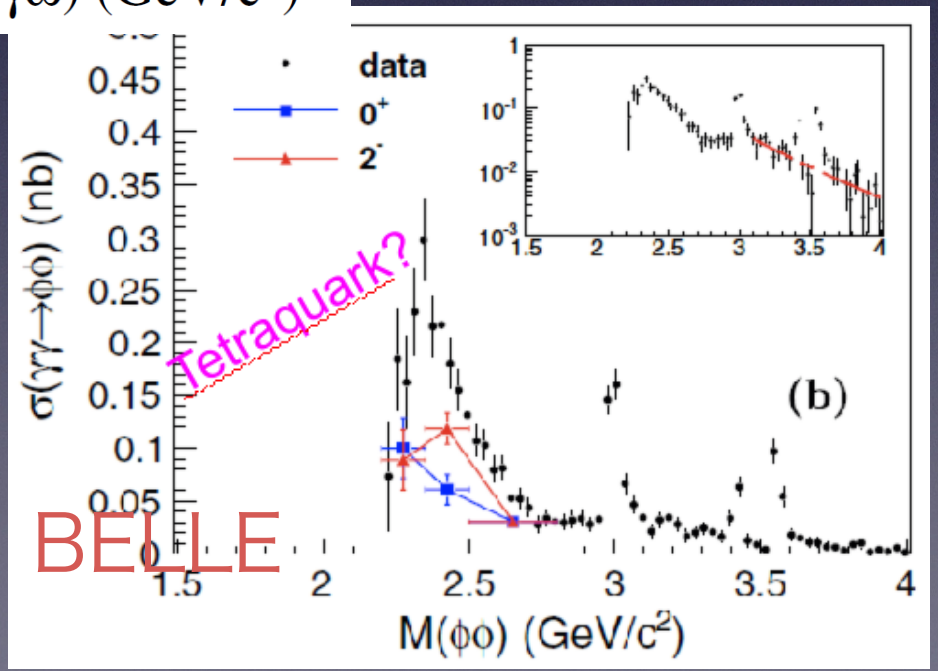


PRL96(2006)162002

$\omega\,\phi$ bound?

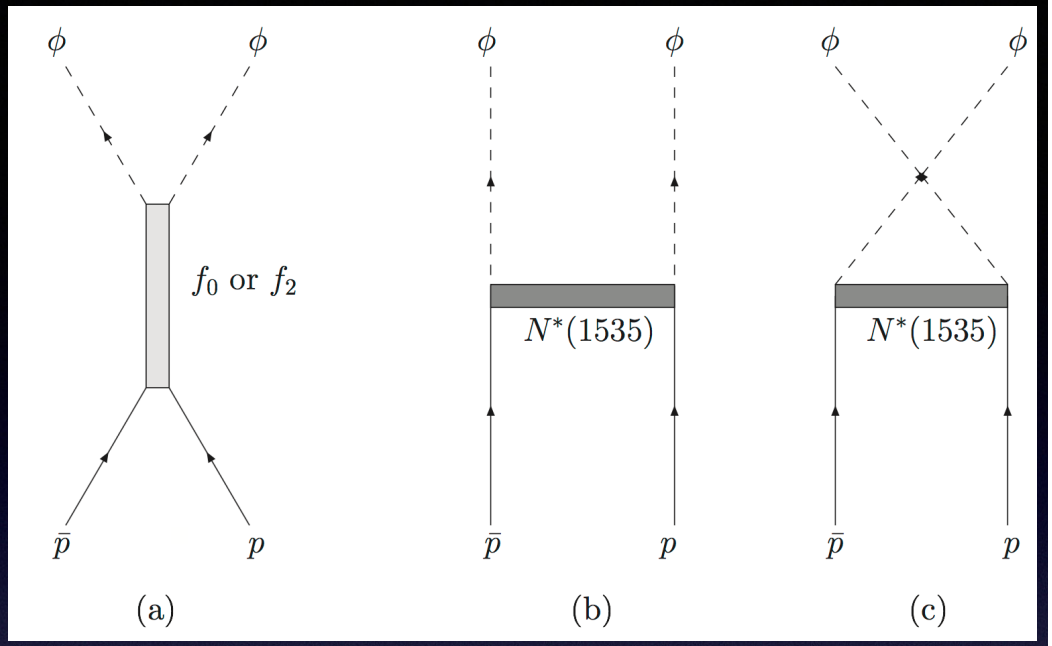
Tetra quark?

PRL108(2012)232001

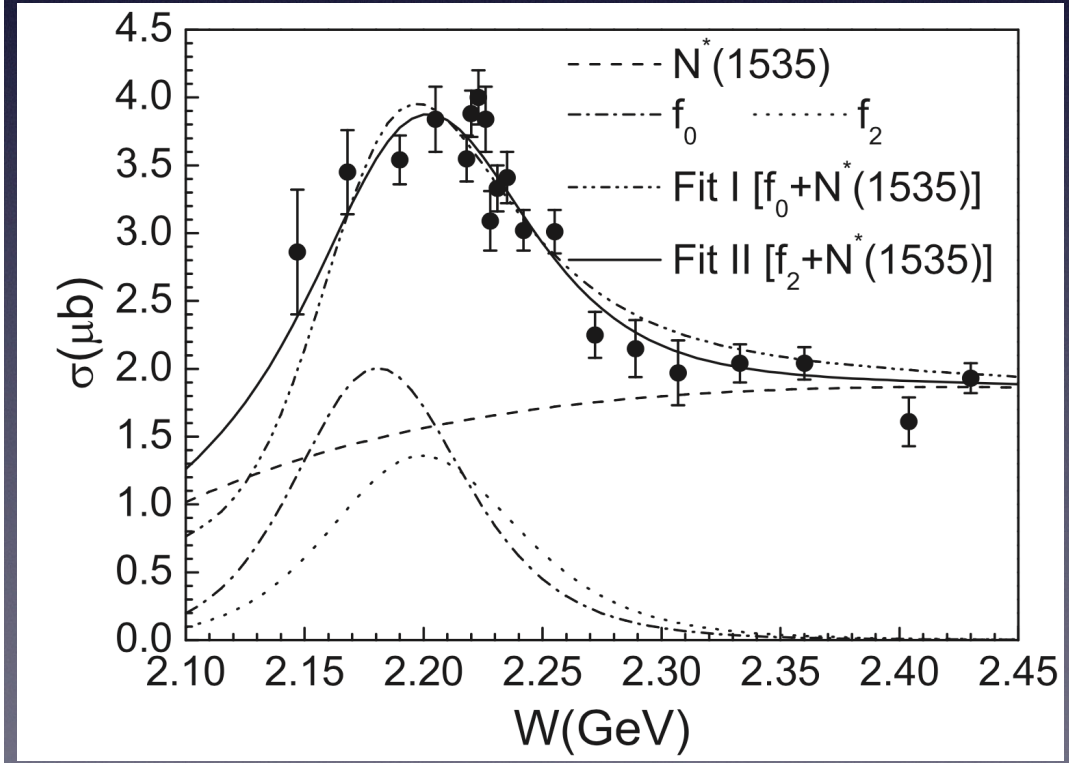


$\phi\,\phi$ bound?

The reason why enhancement of the cross section of double ϕ event on threshold is not known.



PHYSICAL REVIEW C 90, 048201 (2014)

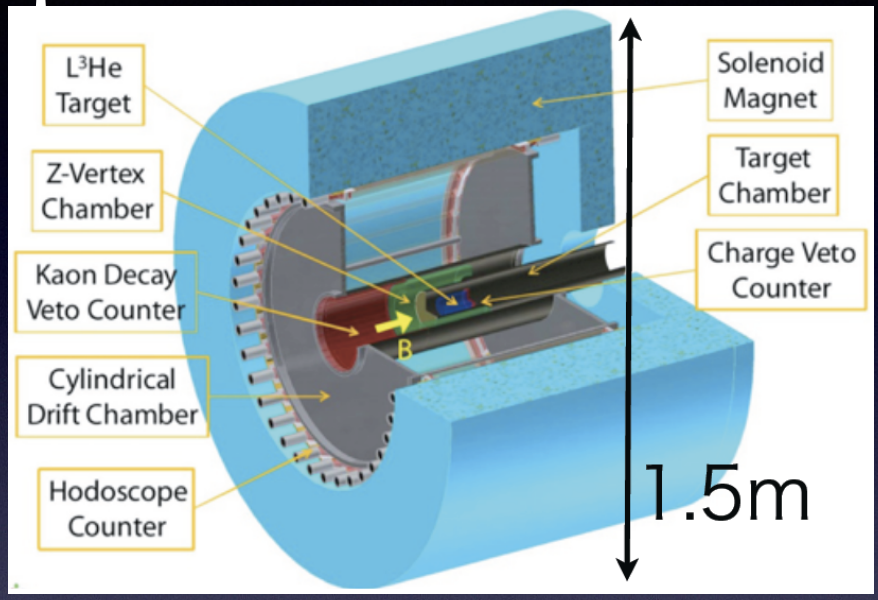


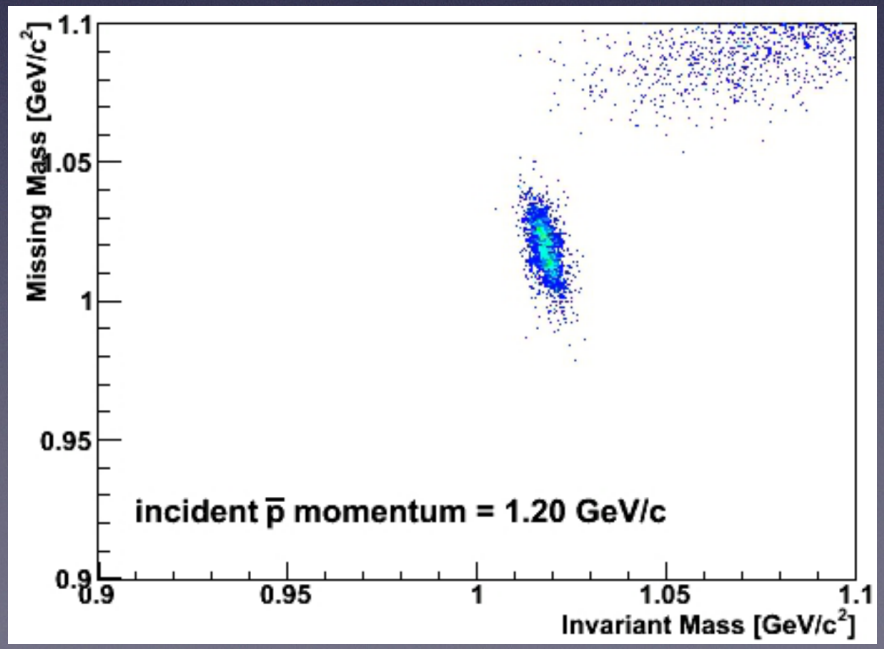
contribution of f0 or f1 ?

It is very important to measure the cross section on threshold !

double ϕ measurement w/ J-PARC E15 spectrometer

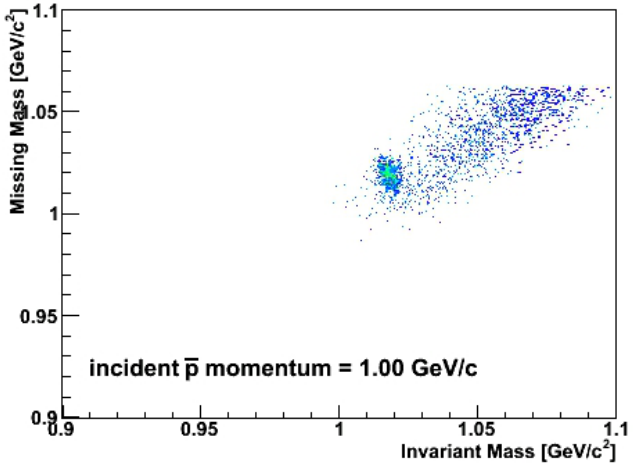
- Using E15 spectrometer
- Large acceptance charged particle spectrometer surrounding target (CDS).
- Detecting K+K- pairs from ϕ decay in CDS
- Calculate invariant mass of K+K- and missing mass, then we can identify double ϕ production

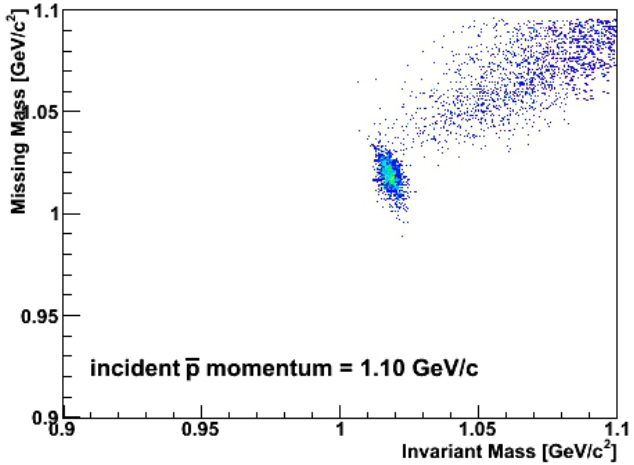


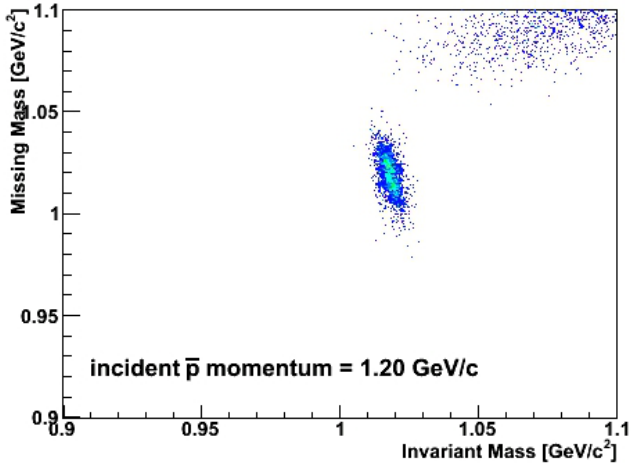


How to identify double ϕ

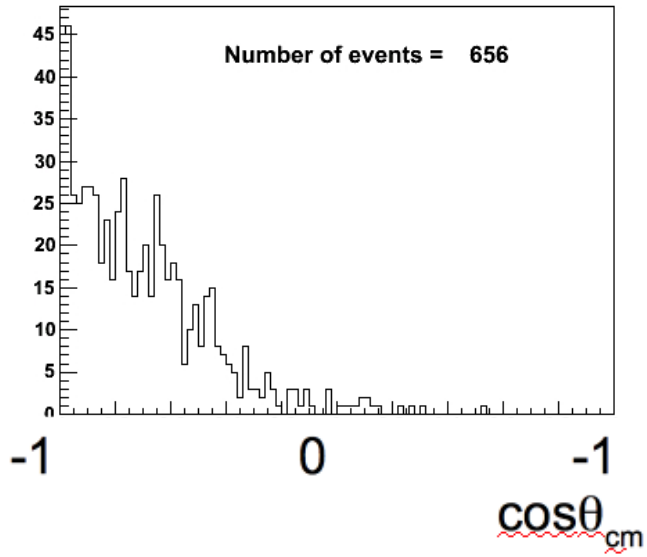
signal

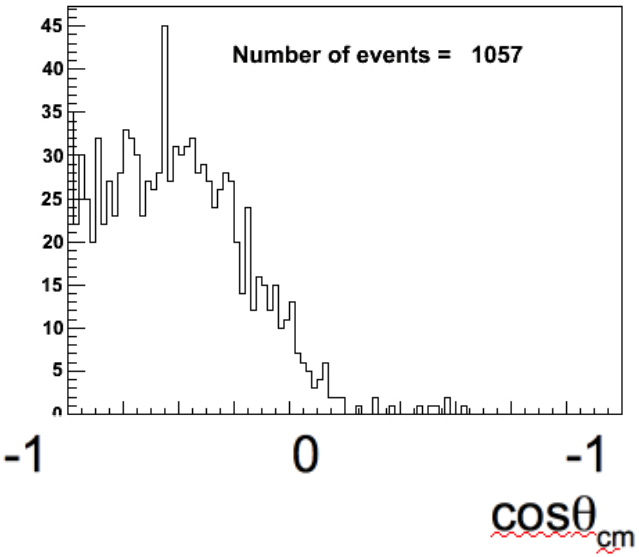


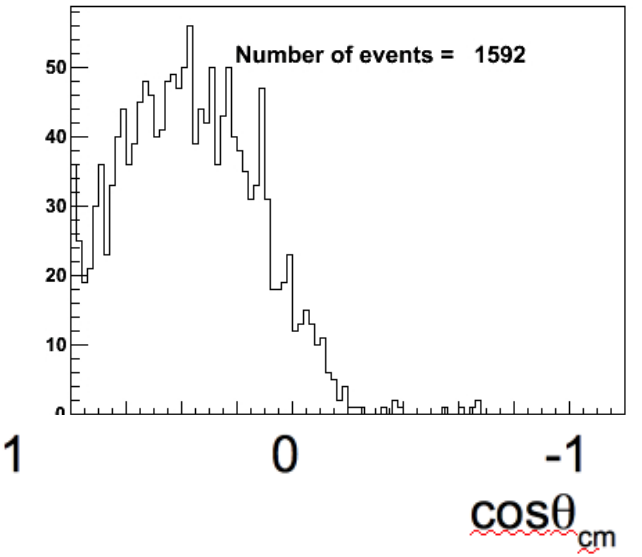




angle acceptance







Summary

- The project to searching for f 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 $pp \rightarrow \phi\,\phi$ channel

- Preparation for the E29 phase-1 is in progress

Plan for next years

- We will ask to J-PARC PAC (probably next July) for approval of E29 1st phase experiment using detector ready exist
  (E15 spectrometer)
  → Problem might be a beam time availability

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