STRANEX ECT* Workshop
Torent, 2019/10/21-25

ϕ meson in nucleus

Hiroaki Ohnishi
ELPH
Tohoku University

ϕ meson

- ϕ meson :
  - Vector meson, $J^{PC} = 1^{--}$
  - bound state of hidden strangeness ($\bar{s}s$)
  - 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 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

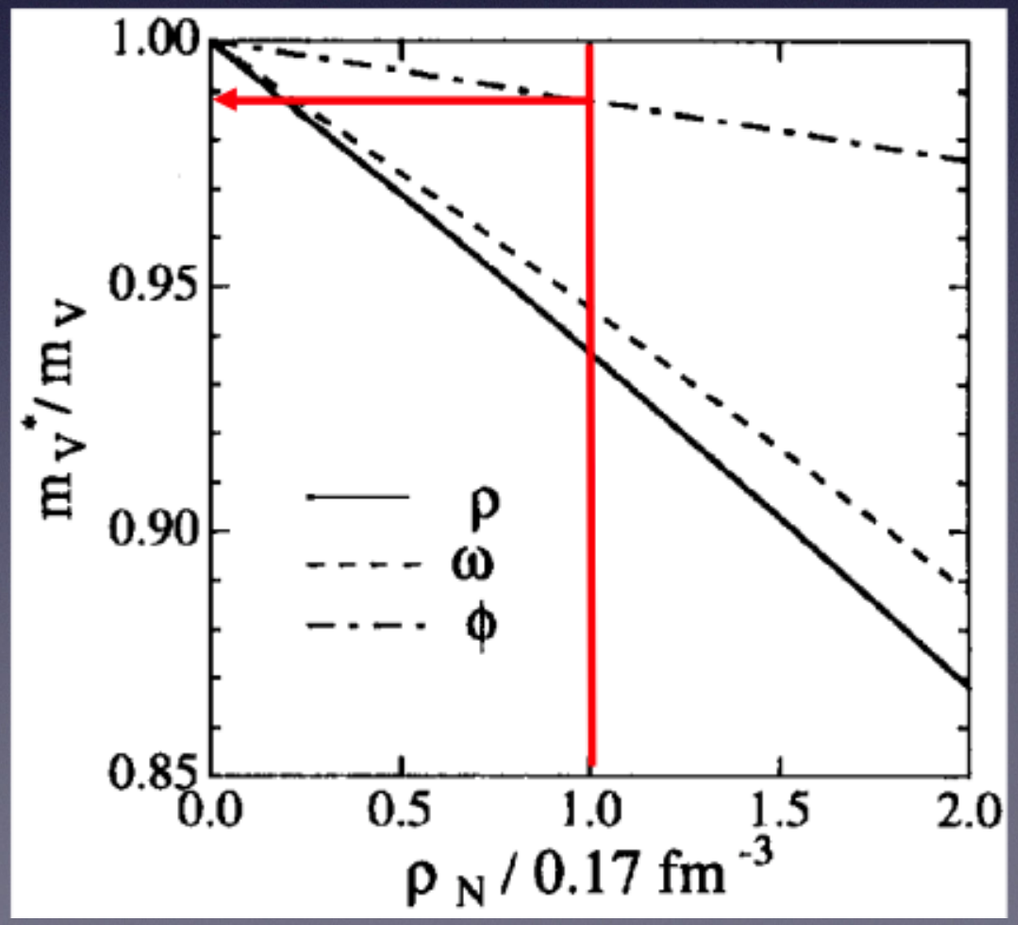
Yuji KOIKE and Arata HAYASHIGAKI

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

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



Theoretical prediction for ϕ mesic nucleus

Theoretical prediction for ϕ mesic nucleus

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Nuclear Physics A 835 (2010) 406–409

NUCLEAR PHYSICS A

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Formation of Slow Heavy Mesons in Nuclei

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

[a] *Department of Physics, Nara Women's University, Nara 630-8506, Japan.*
[b] *Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia-CSIC, Institutos de Investigación de Paterna, Apartado 22085, 46071 Valencia, Spain*

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Formation of Slow He

Satoru Hirenzaki[a], Jun

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Paterna, Apartado 2208

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]

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

Formation of ϕ Mesic Nuclei

. Vicente Vacas[3]

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

Search for the ϕ-N bound state from ϕ meson subthreshold production

S. Liska, H. Gao, W. Chen, and X. Qian
Department of Physics and the Triangle Universities Nuclear Laboratory, Duke University, Durham, North Carolina 27708-0305, USA
(Received 16 March 2007; published 30 May 2007)

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 Carlo studies to demonstrate the feasibility of this technique. Further, we show that proton-induced subthreshold production of ϕ meson from heavy nuclear targets is also suitable for such a search.

DOI: 10.1103/PhysRevC.75.058201 PACS number(s): 13.60.Le, 24.85.+p, 25.10.+s, 25.20.−x

Theoretical prediction for ϕ mesic nucleus

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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

Theoretical prediction for ϕ mesic nucleus

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RAPID COMMUNICATIONS

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.

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Formation of Slow He

Satoru Hirenzaki[a], Jun
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P1

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

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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,†]
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[1]*Department of Physics, Duke University, Durham, North Carolina 27708, U.S.A.*
[2]*Duke Kunshan University, Kunshan, Jiangsu 215316, China*
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CLE PHYSICS

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RAPID COMMUNICATIONS

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

Interaction between ϕN will be attractive, but no evidence for bound state so far

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.

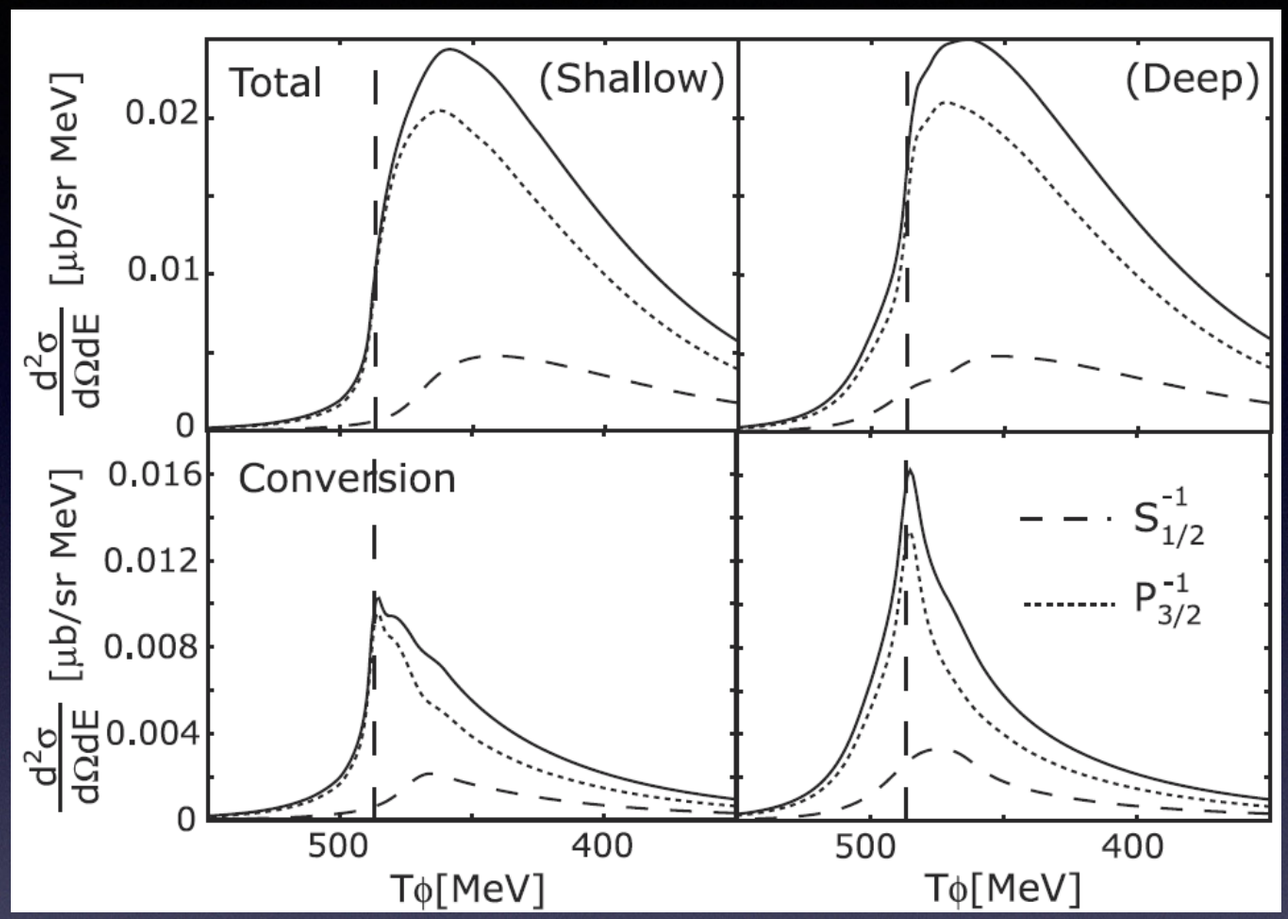

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Table 3. Bound state results (in MeV) for the ϕNN and $\phi\phi$NN systems. The number in parentheses corresponds to the root mean square radius (in fm).

	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

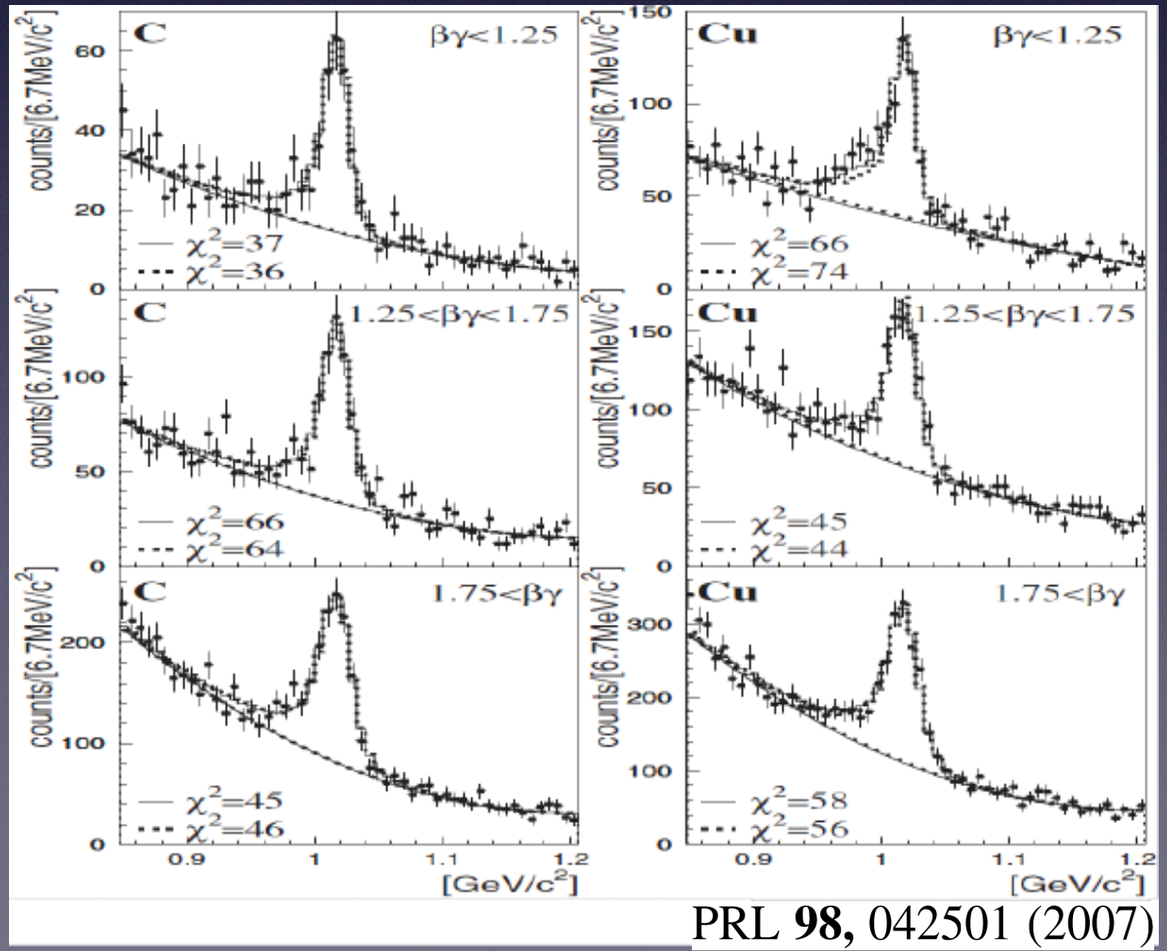
Experimental knowlege about ϕ meson in nucleus

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)

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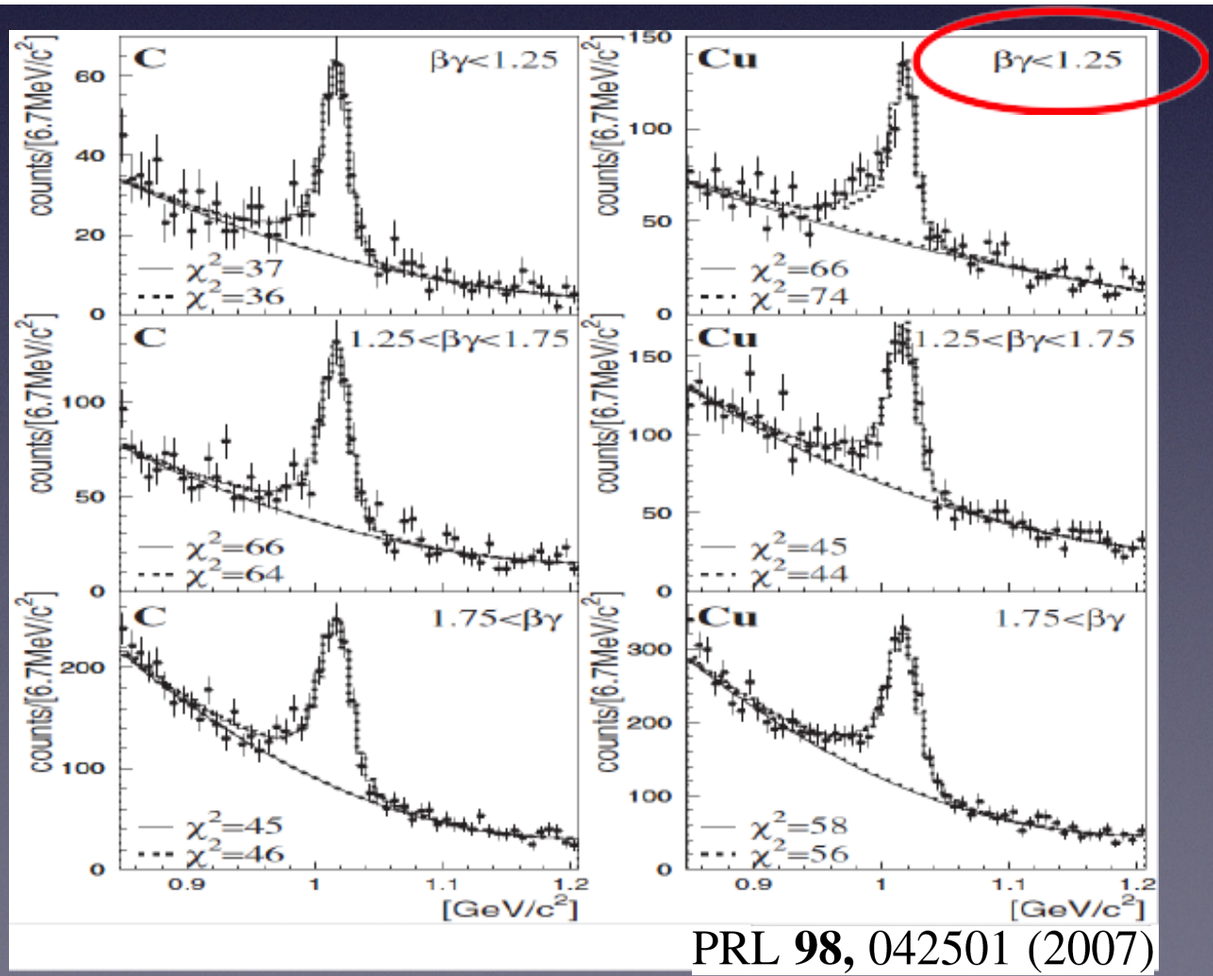
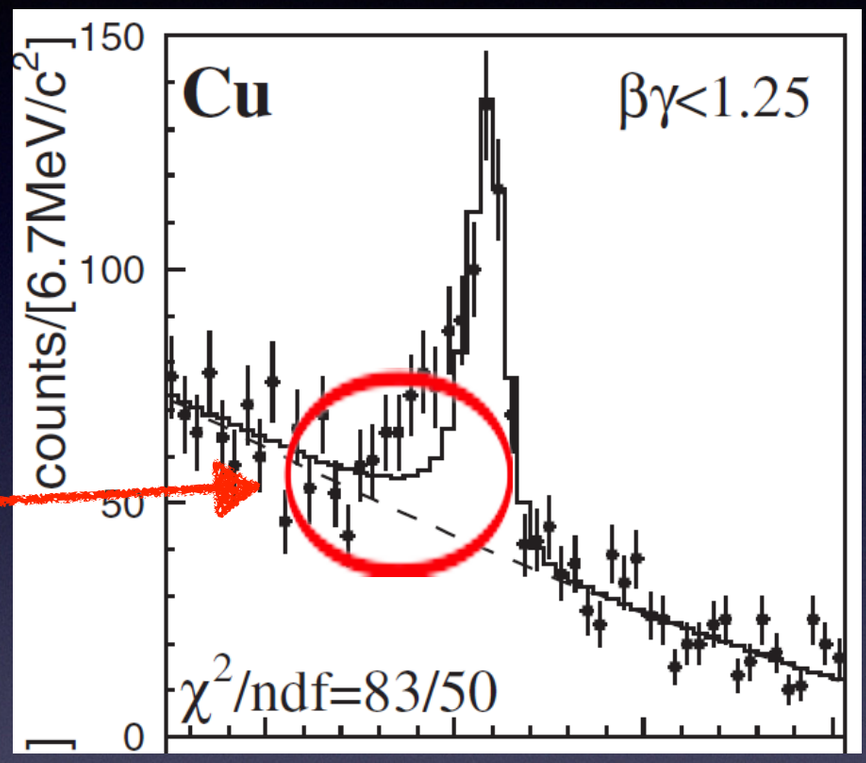


PRL **98,** 042501 (2007)



mass decreasing ~3.4 %

decay width broaden ~x3.6

Experimental knowlege about ϕ meson in nucleus

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

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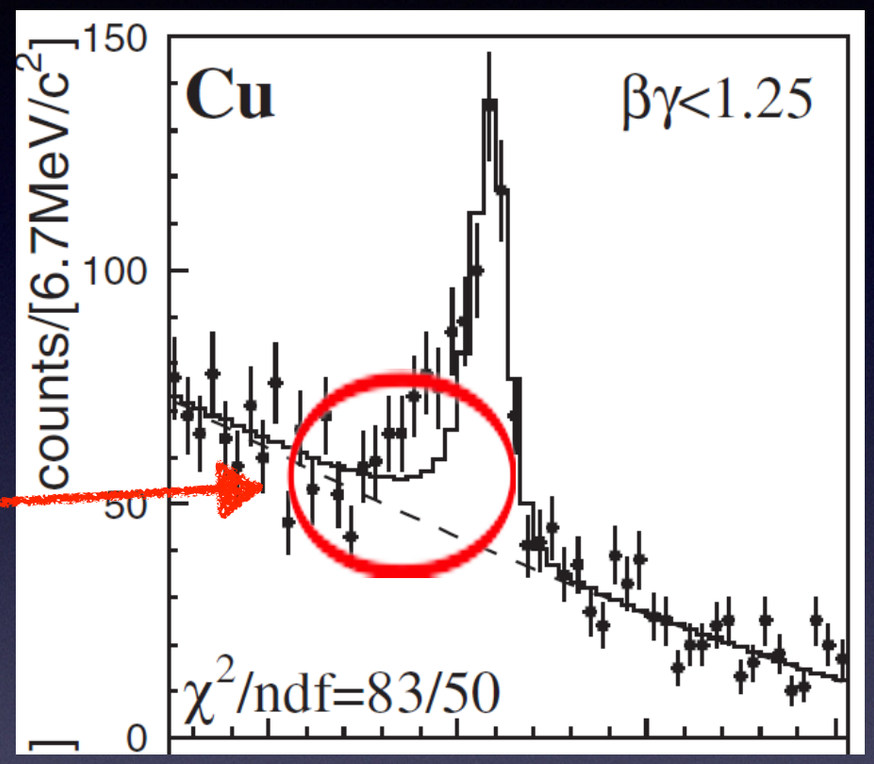
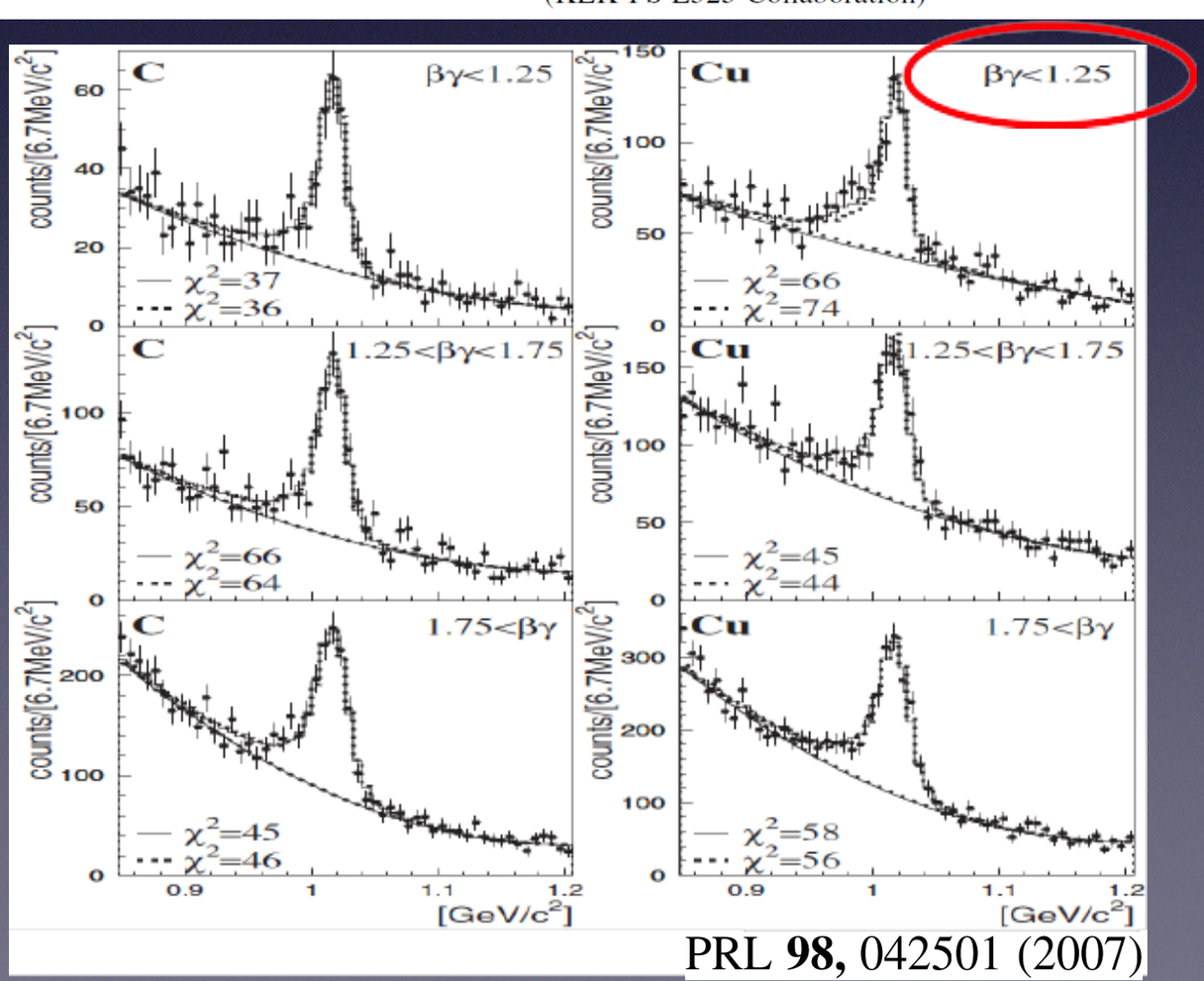




PRL **98,** 042501 (2007)

mass decreasing ~3.4 %

decay width broaden ~x3.6

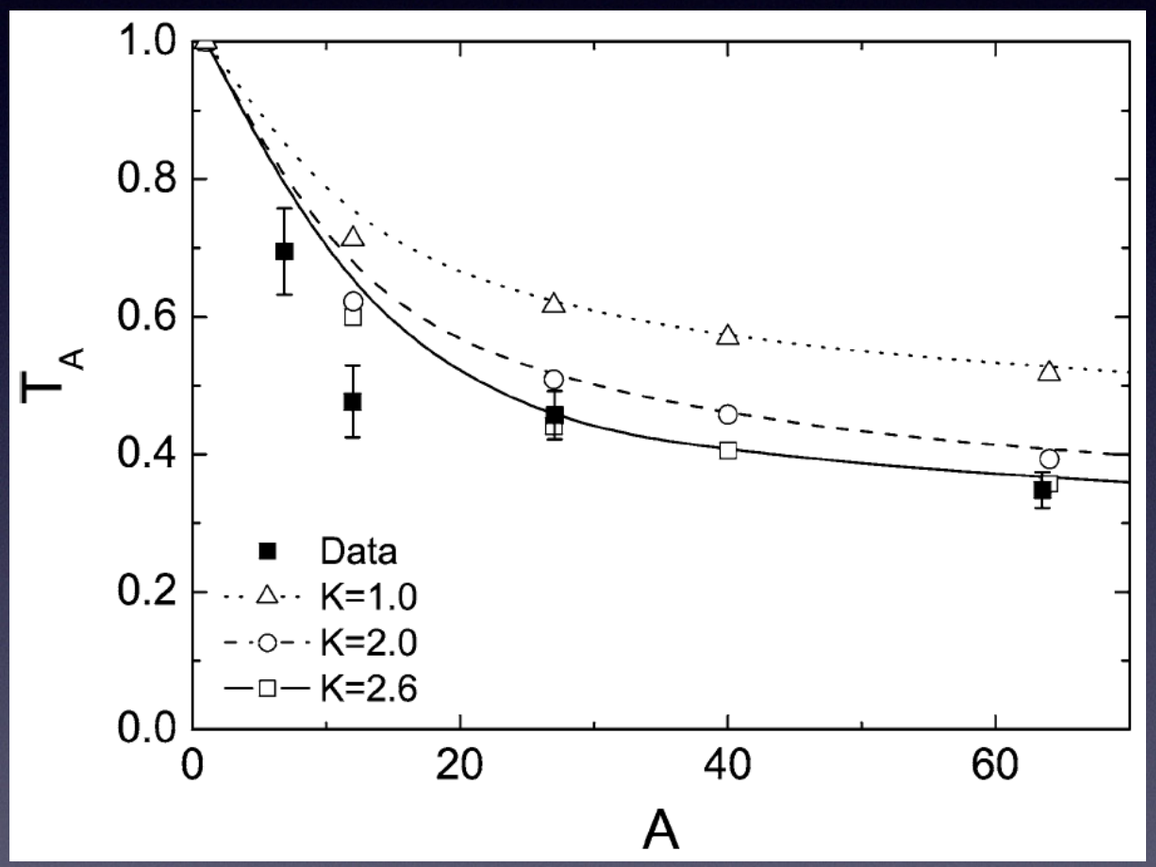
ϕ mass reduction

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 [h], T. Nakano [r], D.S. Ahn [r,d], J.K. Ahn [d], H. Akimune [e], Y. Asano [r], S. Daté [g], H. Ejiri [r], H. Fujimura [h], M. Fujiwara [r,i], S. Fukui [j], S. Hasegawa [r], K. Hicks [k], K. Horie [r], T. Hotta [r], K. Imai [h], 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 [n], N. Matsuoka [r], T. Mibe [r], M. Miyachi [q], N. Muramatsu [r,i], M. Niiyama [h], 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 [r], Y. Shiino [m], H. Shimizu [h], Y. Sugaya [r], M. Sumihama [c], Y. Toi [p], H. Toyokawa [g], M. Uchida [u], A. Wakai [v], C.W. Wang [a], S.C. Wang [a], K. Yonehara [e], T. Yorita [r,g], M. Yoshimura [w], M. Yosoi [r], R.G.T. Zegers [x]

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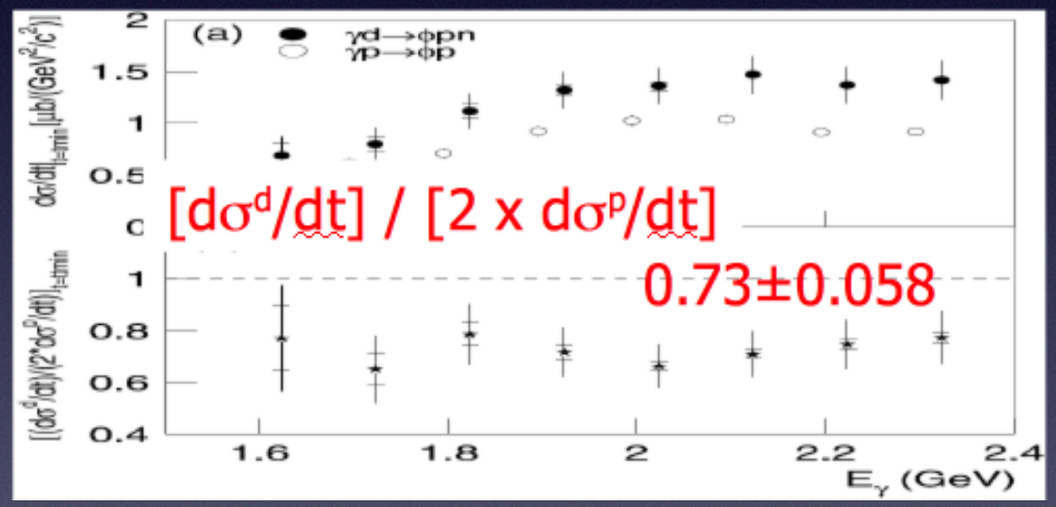
Physics Letters B

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 [t], 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$\to \phi$ X

ϕN cross section

measured: $\sigma_{\phi N}$ = 20 mb

expected: $\sigma_{\phi N}$ = 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 nuclear transparency

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. Chiladze[1,4], S. Dymov[5,6], A. Dzyuba[7], R. Gebel[1], V. Hejny[1], B. Kämpfer[8], I. Keshelashvili[9], V. Koptev[7,‡], B. Lorentz[1], Y. Maeda[10], V. K. Magas[11], S. Merzliakov[1,6], S. Mikirtytchiants[1,7], M. Nekipelov[1], H. Ohm[1], L. Roca[12], H. Schade[8,13], V. 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. Wilkin[17], P. Wüstner[18], and Q. J. Ye[19]

[1]*Institut für Kernphysik and Jülich Centre for Hadron Physics, Forschungszentrum Jülich, D-52425 Jülich, Germany*

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Serdyuk[1,6], A. Sibirtsev[5], V. Y. Sinitsyna[14], H. J. Stein[1], H. Ströher[1], S. Trusov[8,15], Yu. Valda

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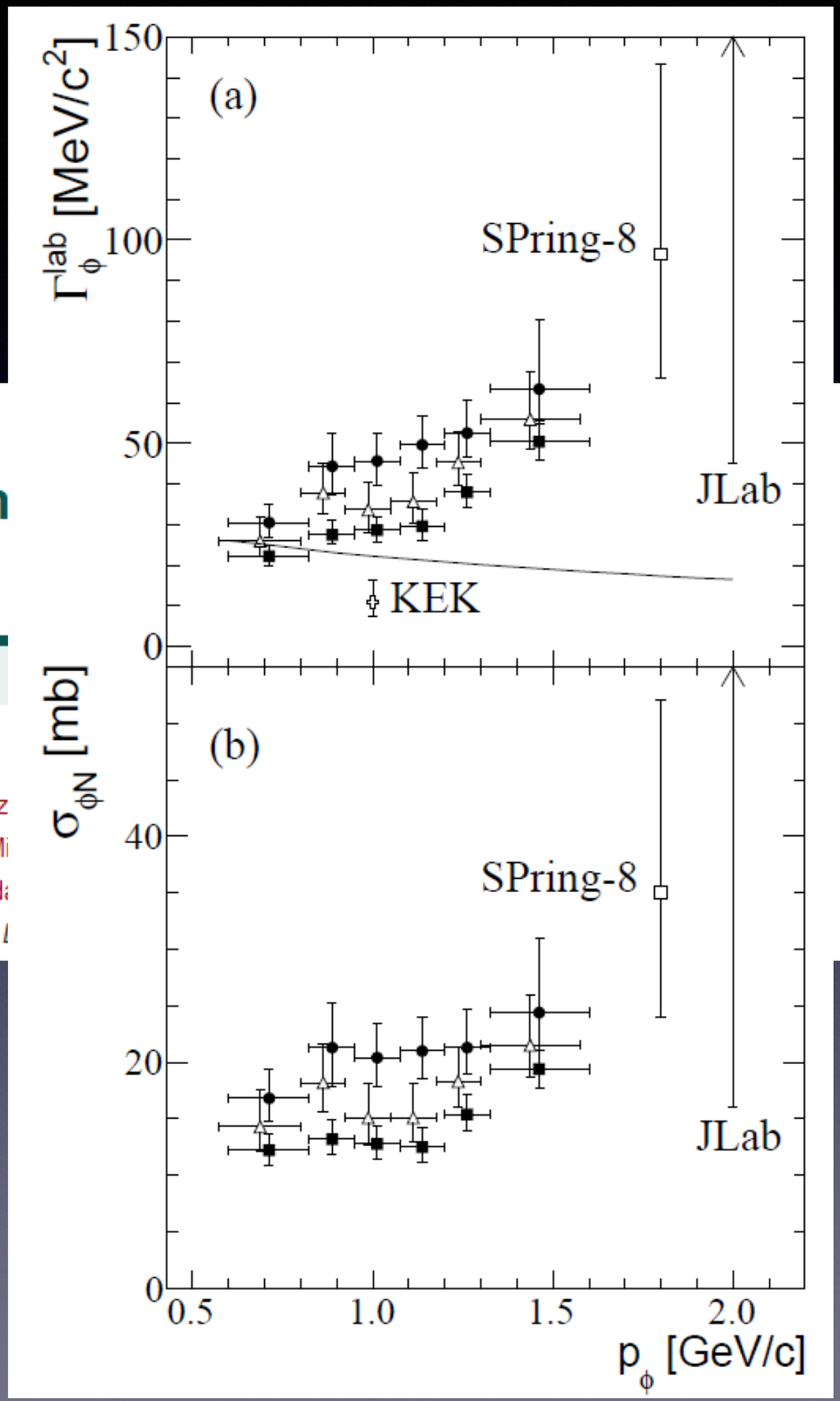

Momentum dependence of transparency ratio by COSY-ANKE

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

Momentum dependence of the φ-meson n

Abstract | References | Citing Articles (1)

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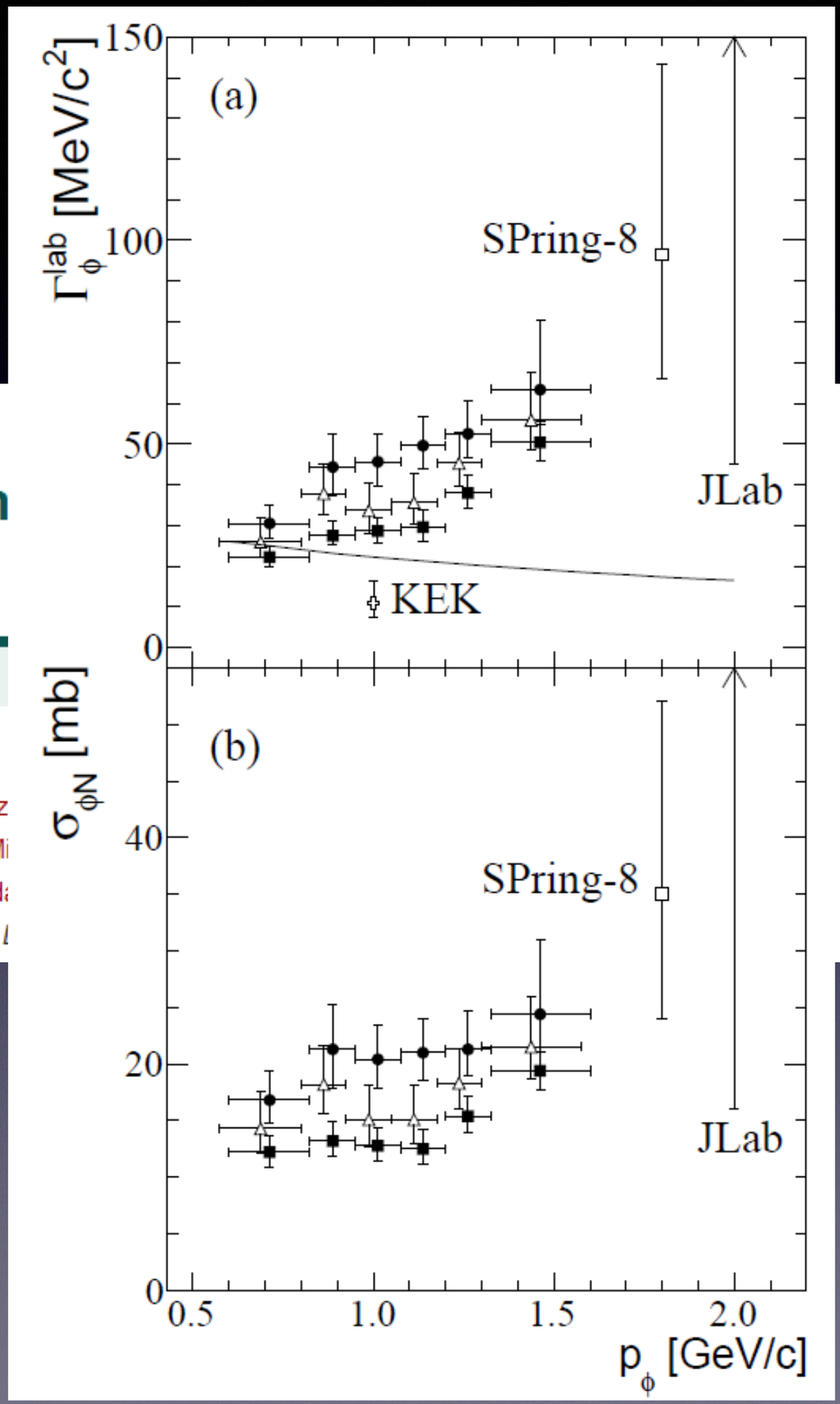
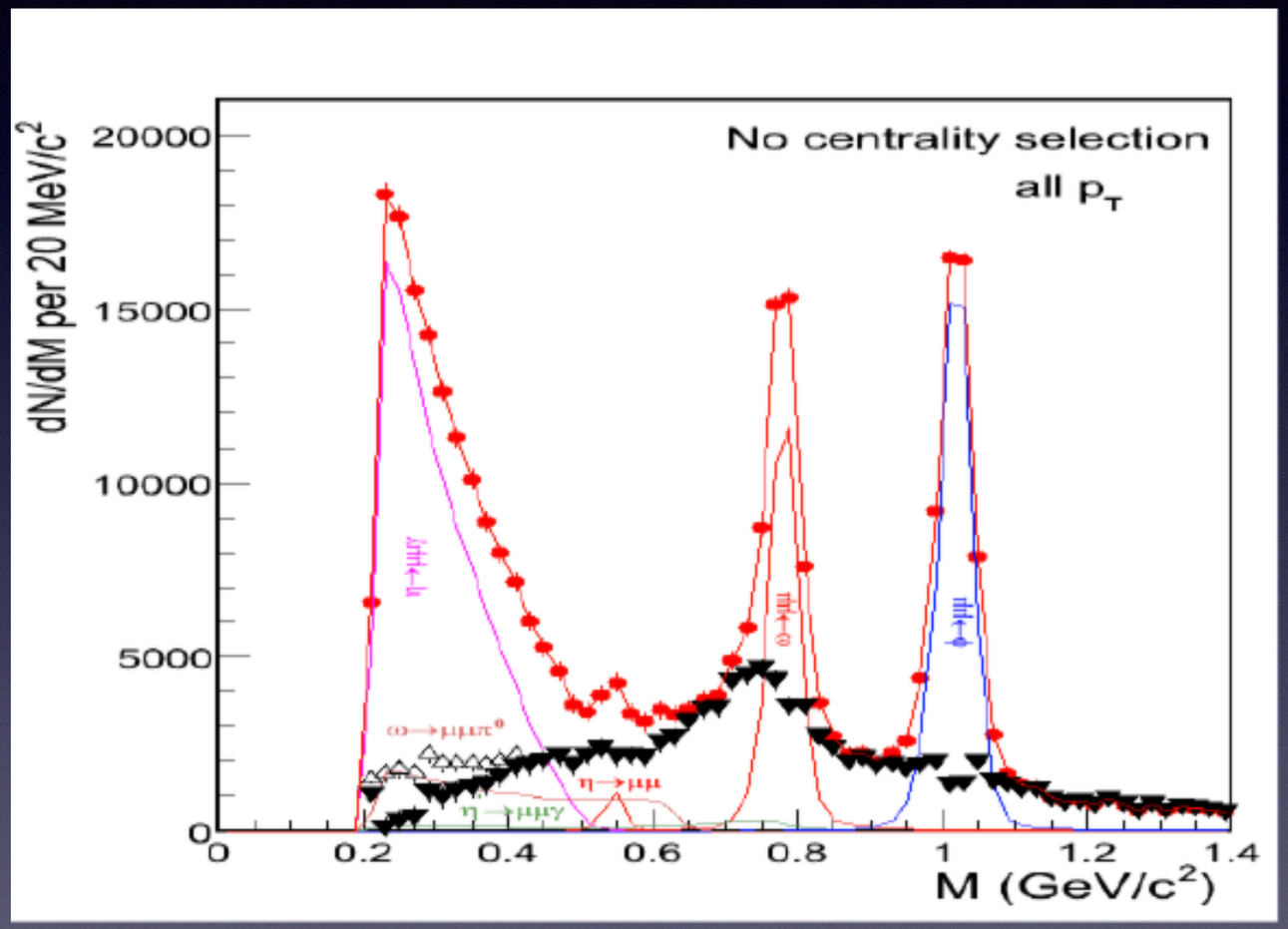
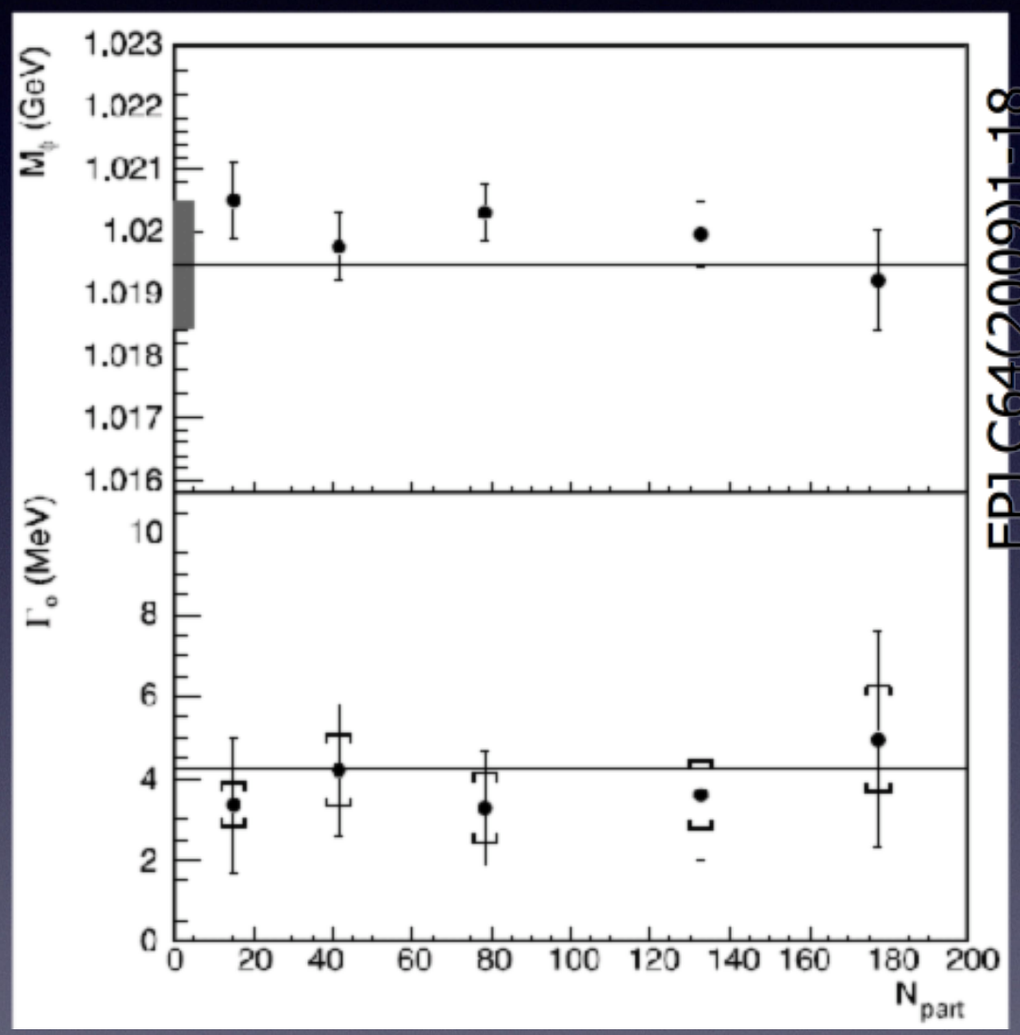


Width increasing ?
as a function of momentum
Less absorption with
low momentum ϕ meson ?

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)

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- 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)

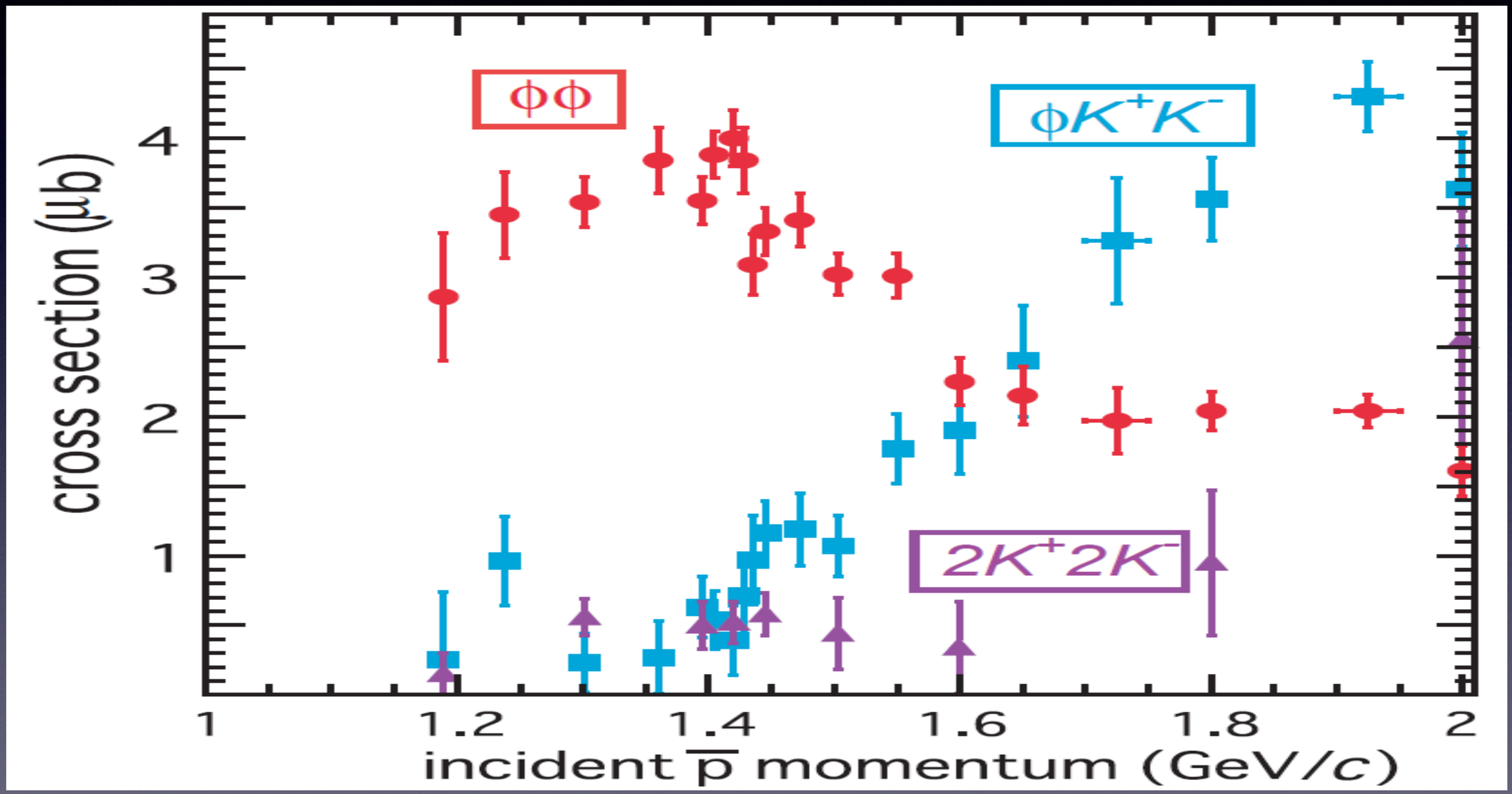
2) Search for ϕ meson bound state

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

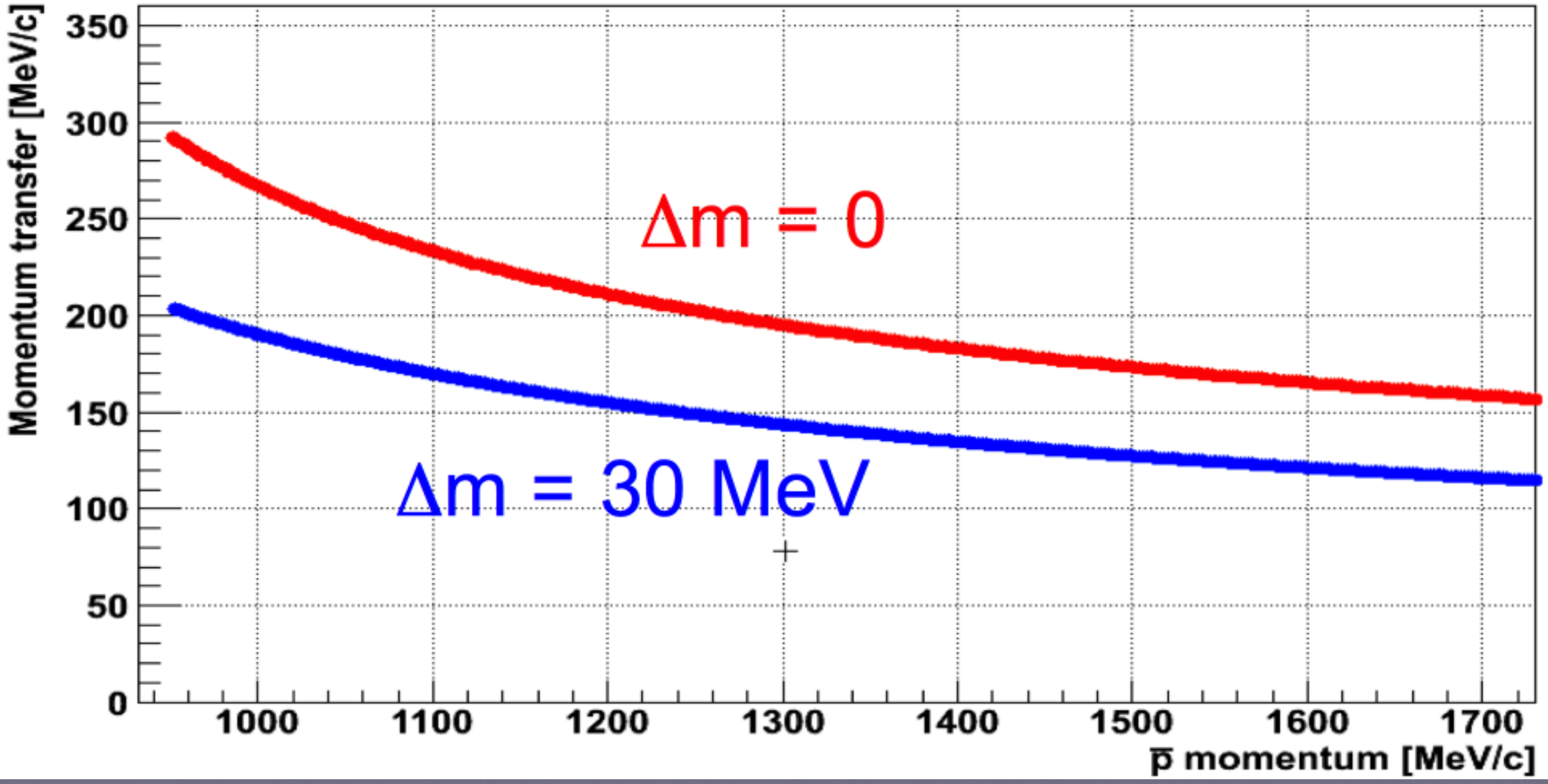


Phys. Rev. D 57 (1998) 5370-5381

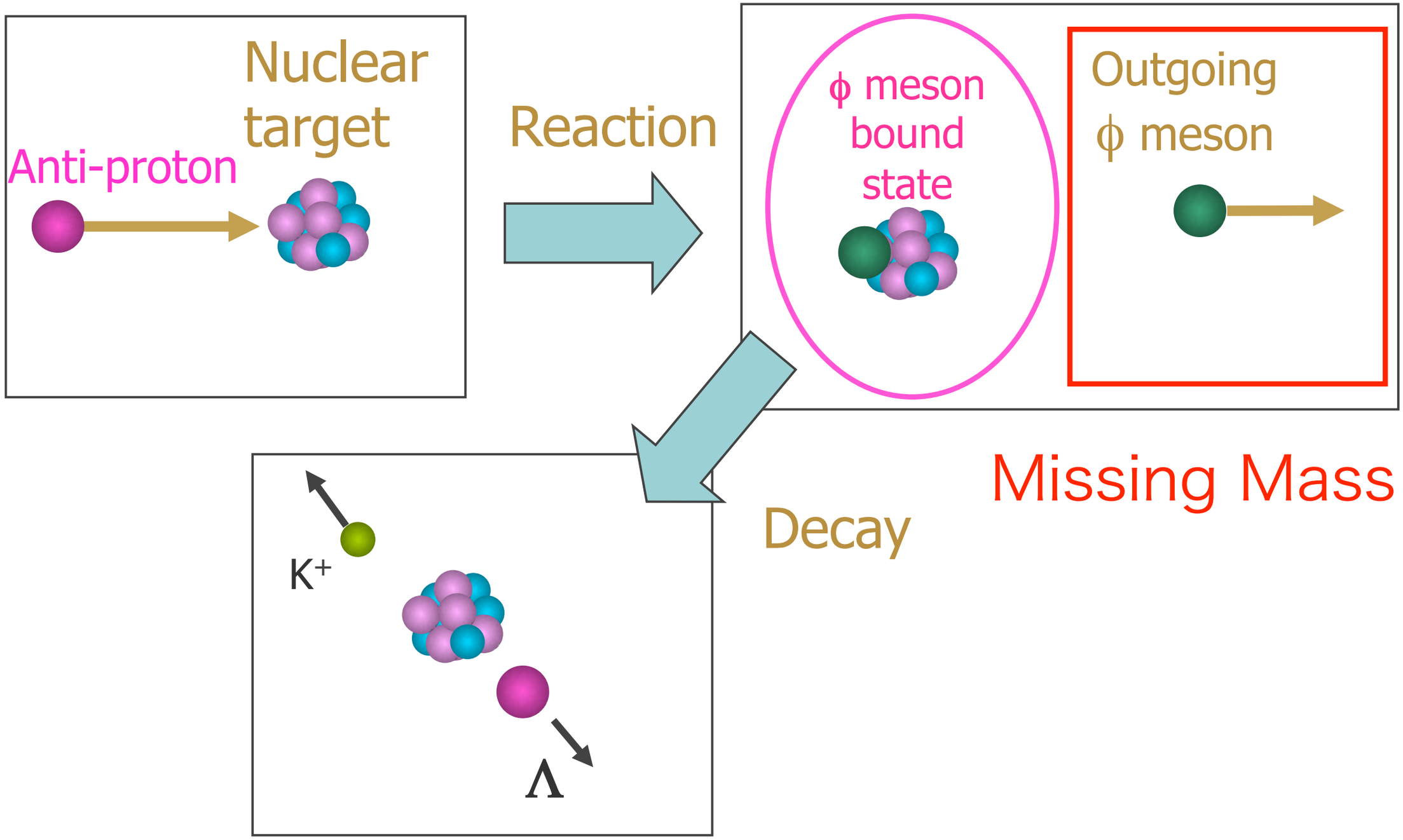
Double ϕ meson production in pp reaction

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

Missing mass by forward going ϕ meson

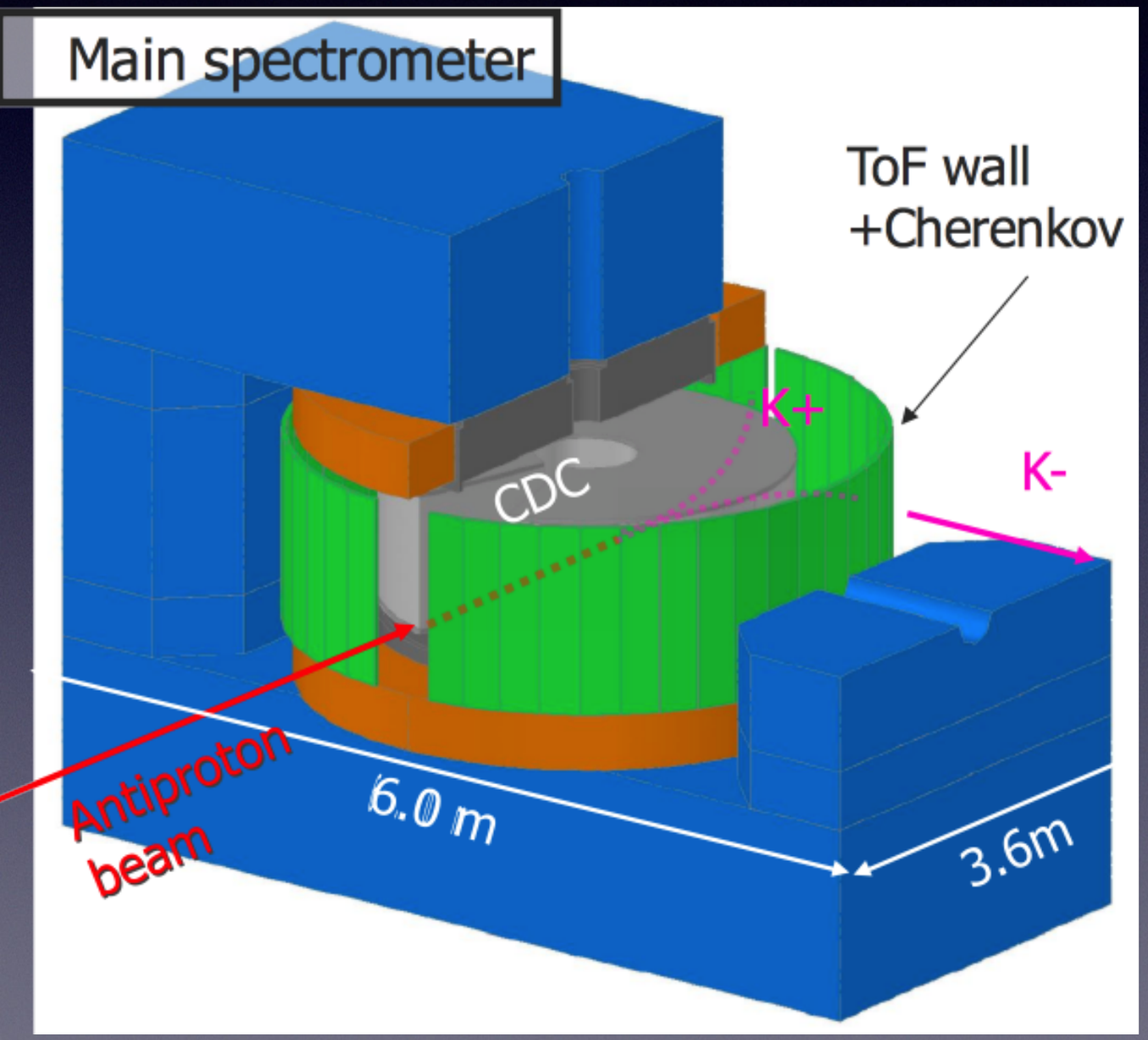


How to produce ϕ mesic nucleus?



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

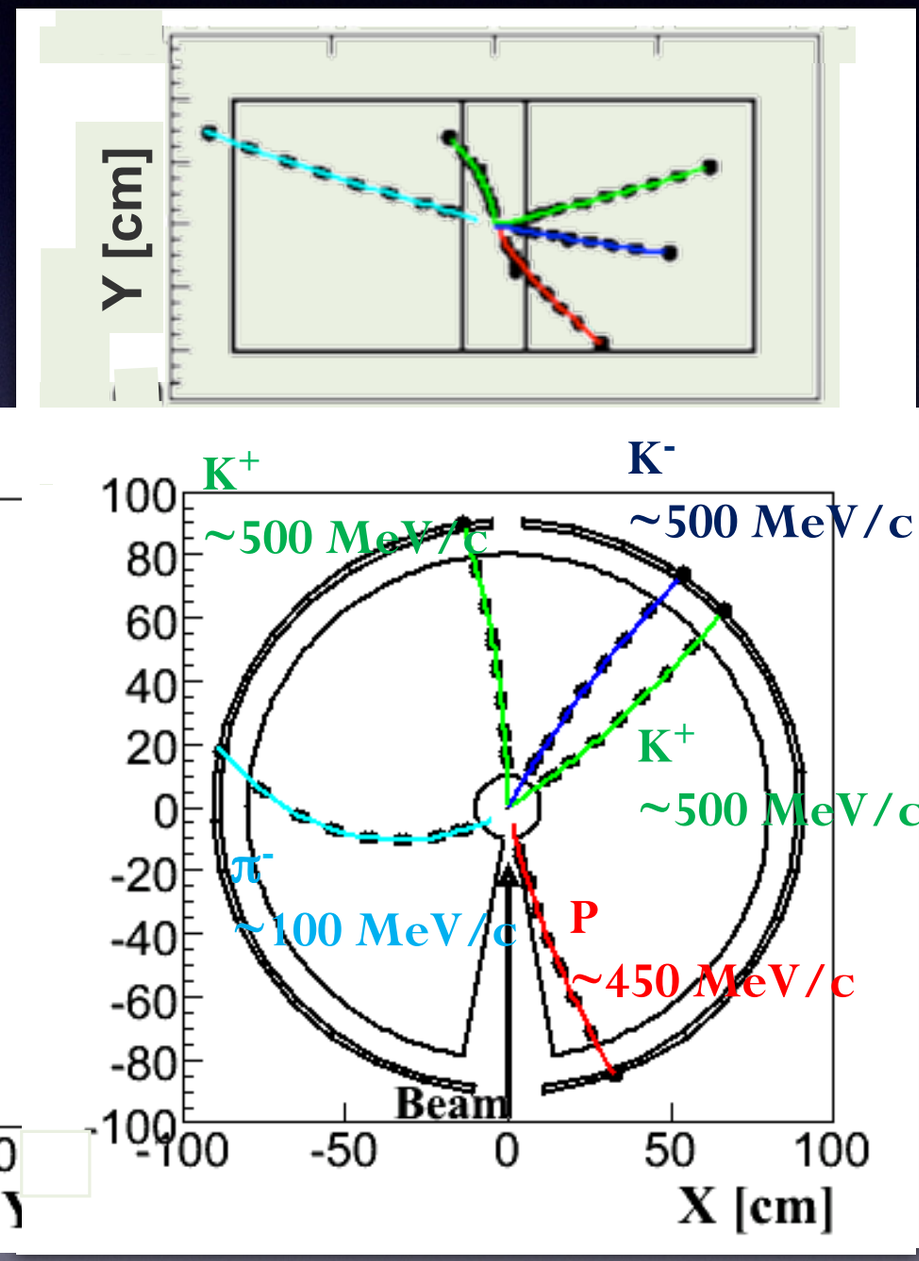
$p + Cu \rightarrow \phi + {}_{\phi}Ni$ ($B_{\phi} = 30$ MeV)

"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



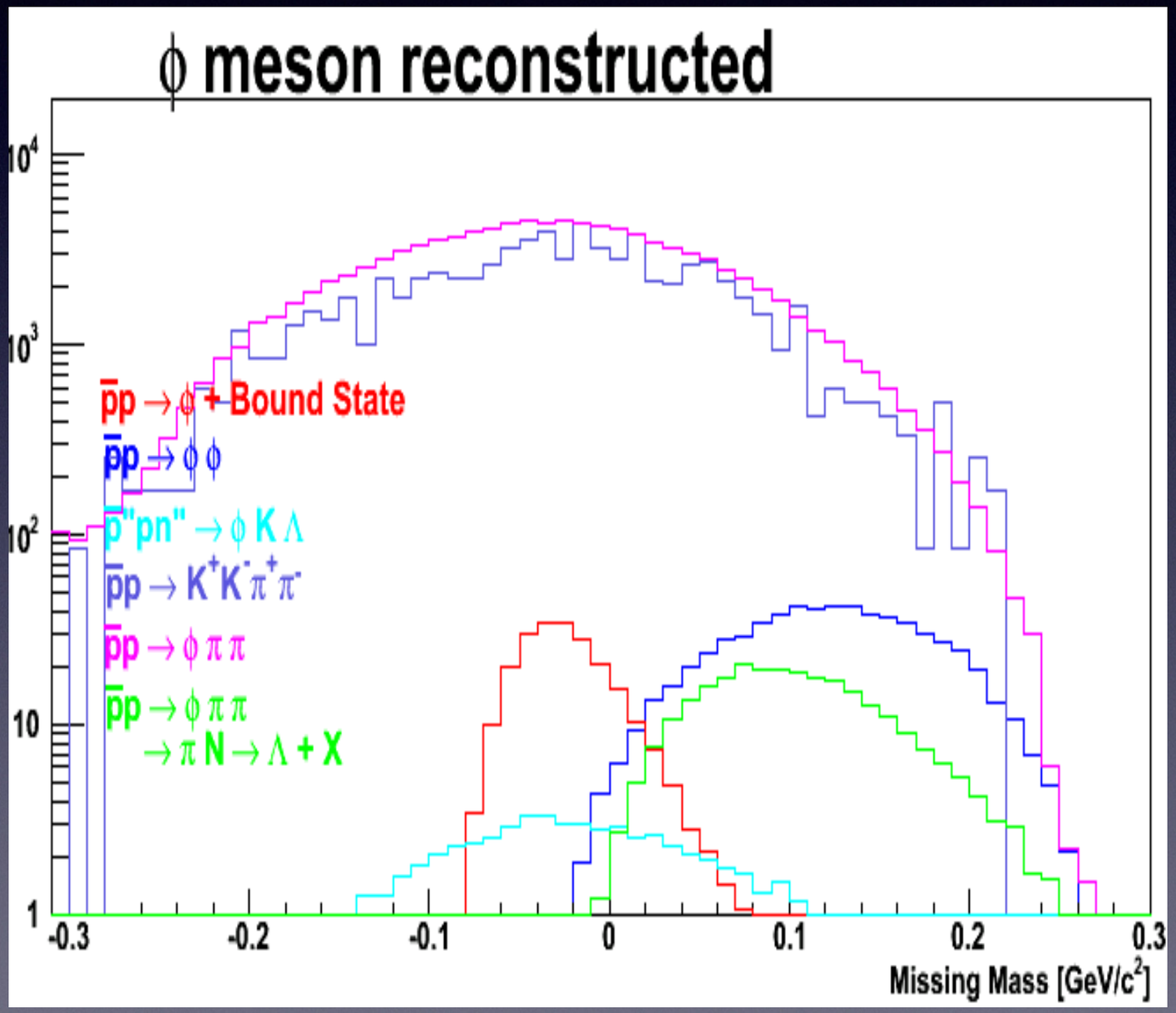
Expected Signal+background

- 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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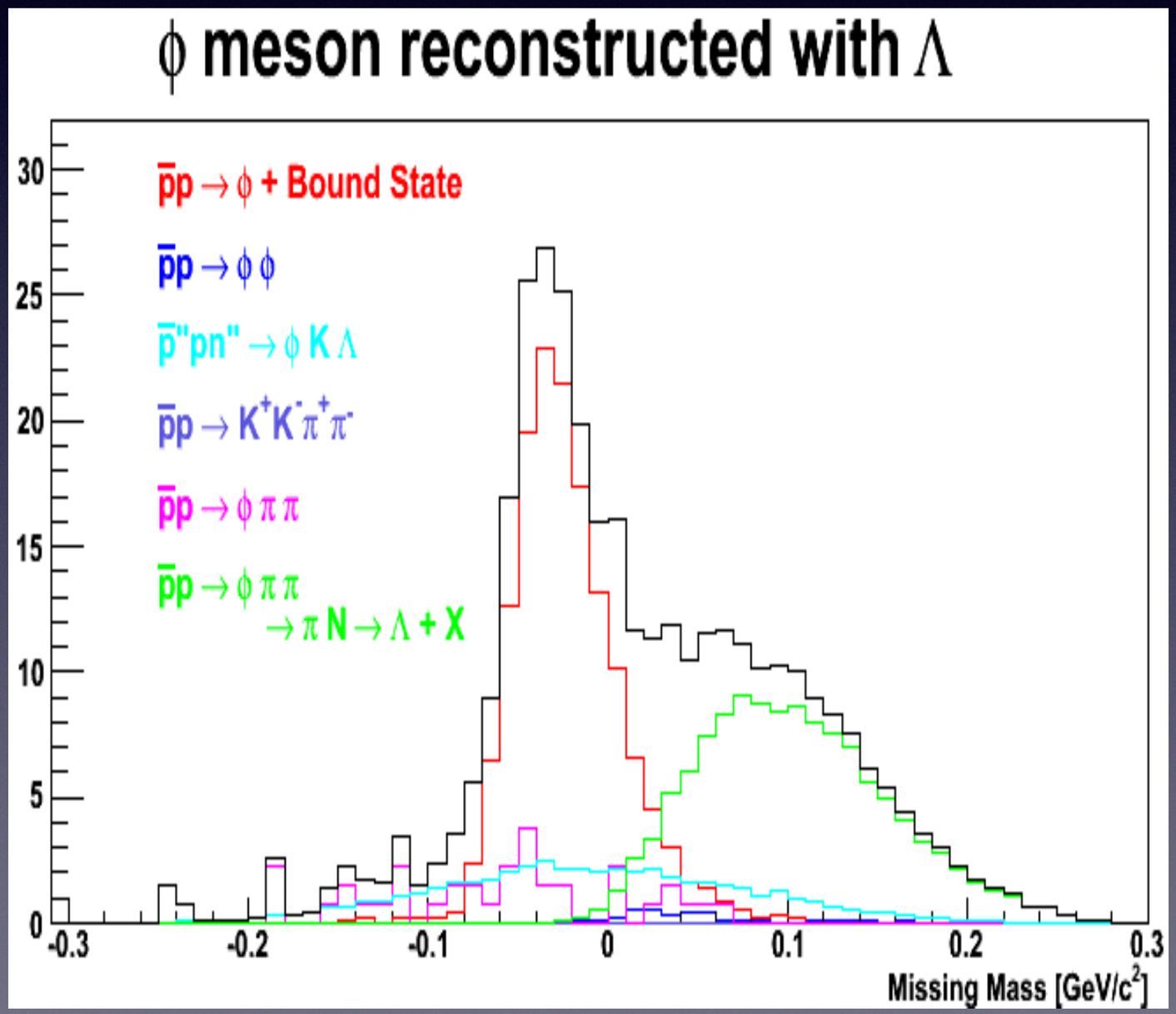

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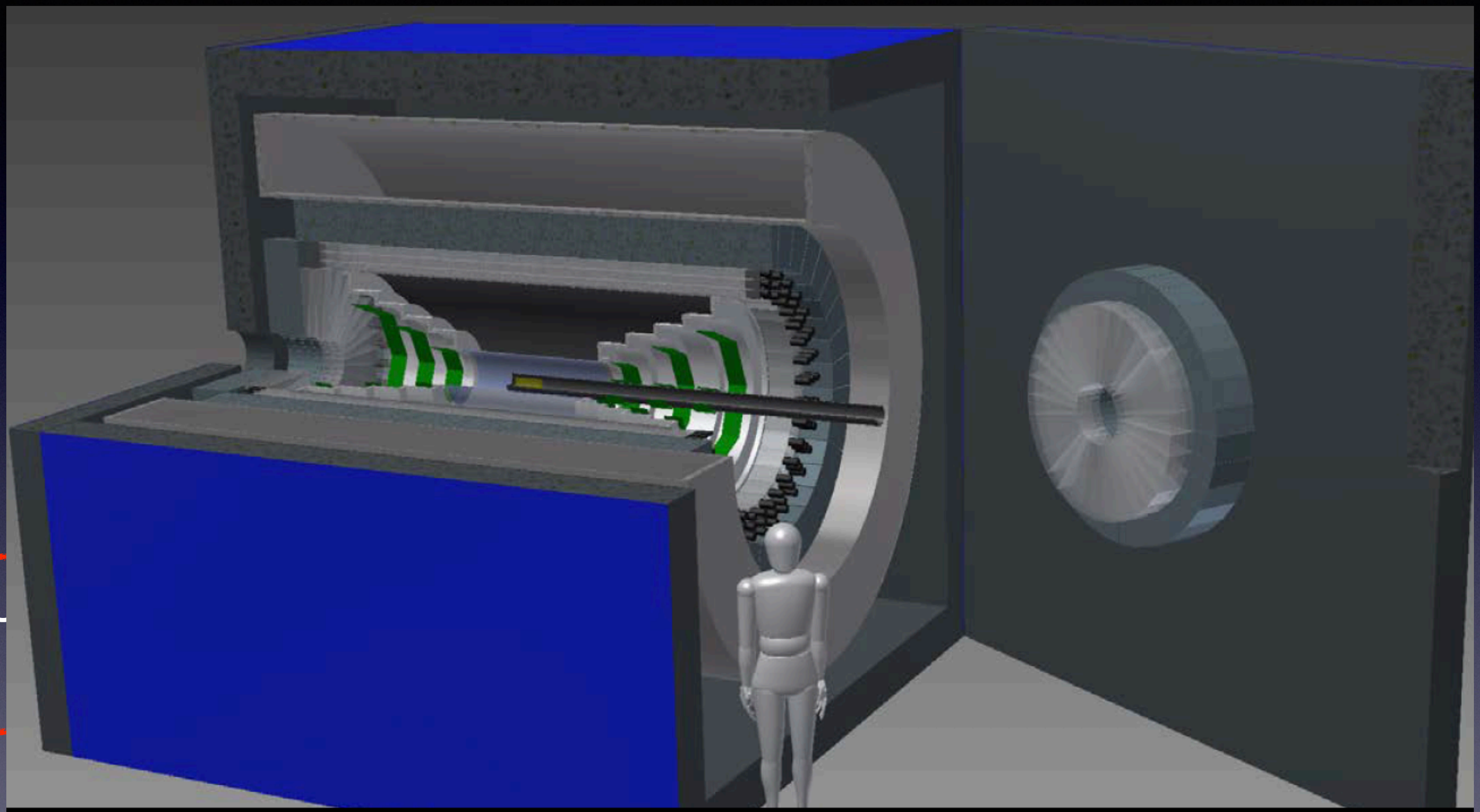
Using Spectrometer which Masa and Fuminori presented yesterday?

Where we could perform



A new 4π detector with γ/n sensitive detectors

Where we could perform this experiment?

- Well at J-PARC K1.8BR ? But we need to construct new spectrometer which has large acceptance in forward direction

Using Spectrometer which Masa and Fuminori presented yesterday?

- J-PARC E50 Spectrometer now under construction at J-PARC High-p beamline?

E50 spectrometer for charmed baryon spectroscopy

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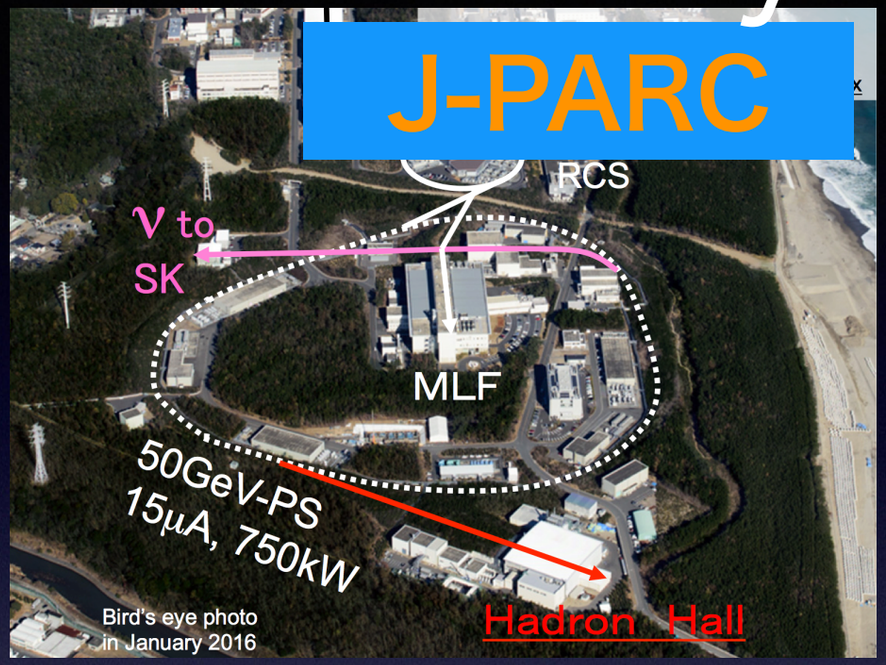
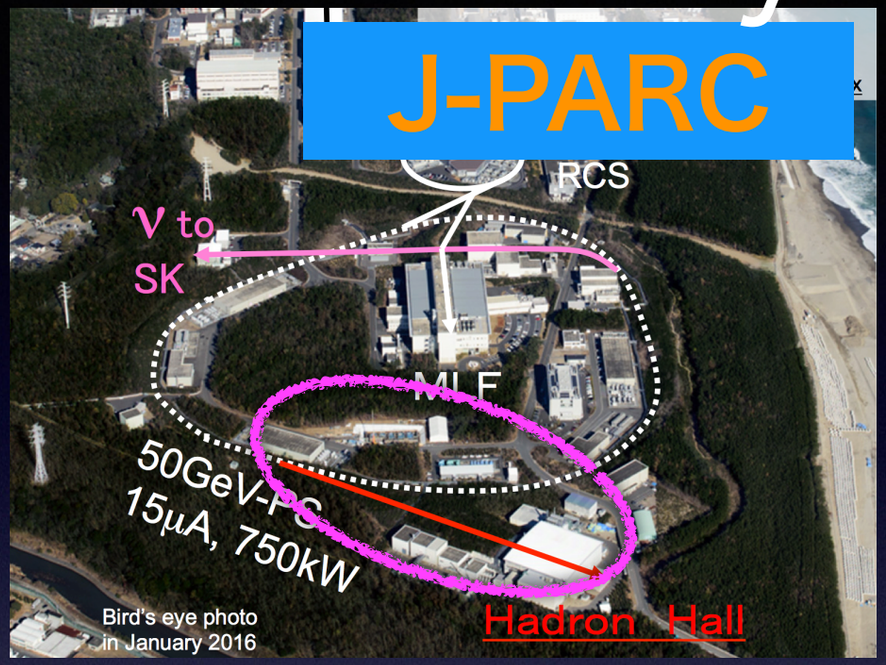


E50 spectrometer for charmed baryon spectroscopy



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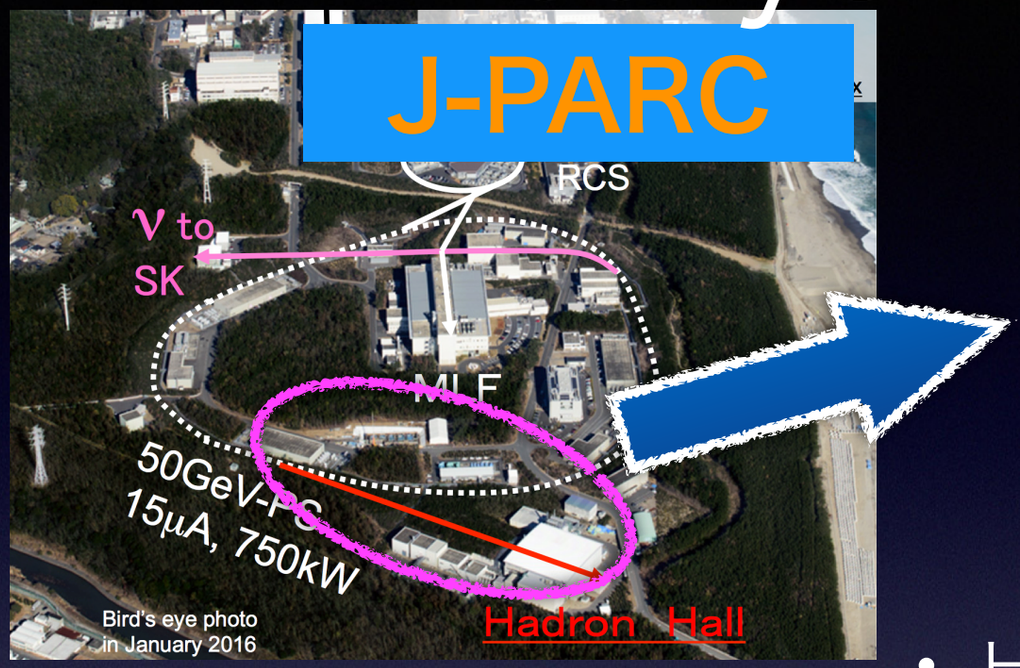
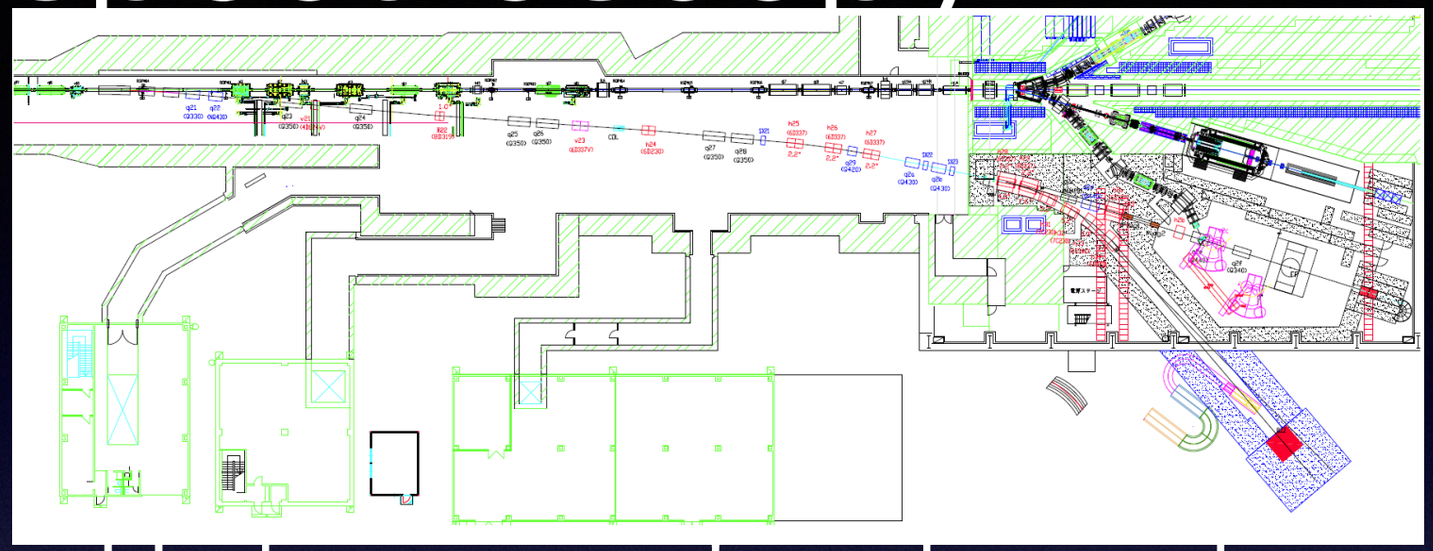
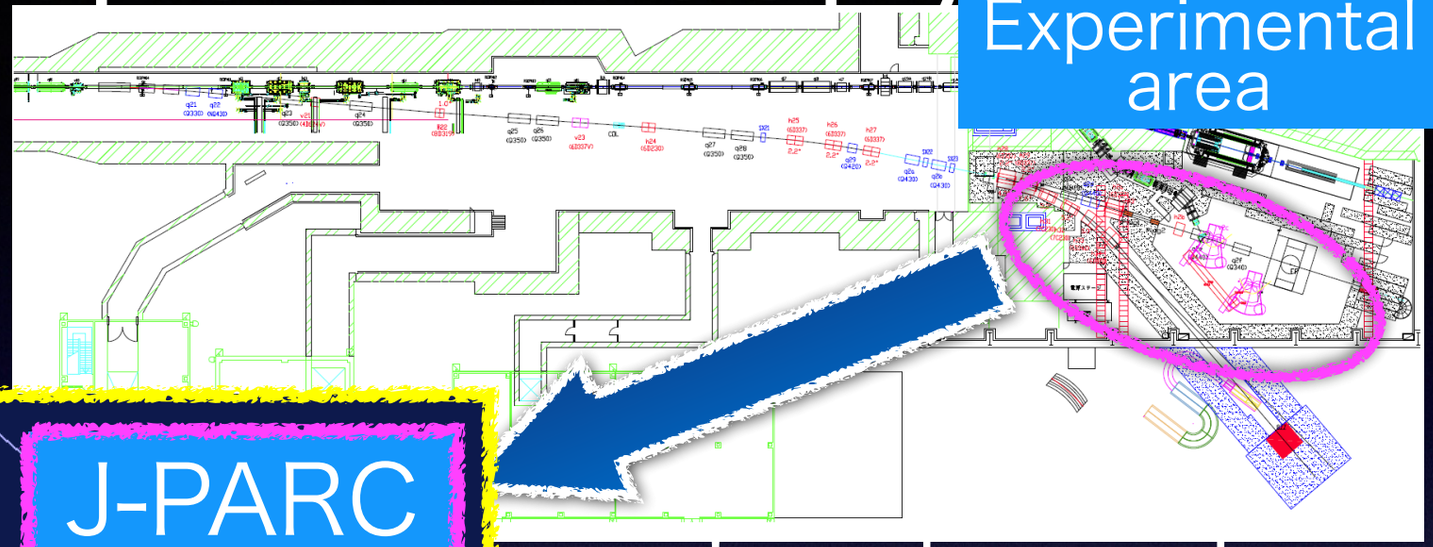




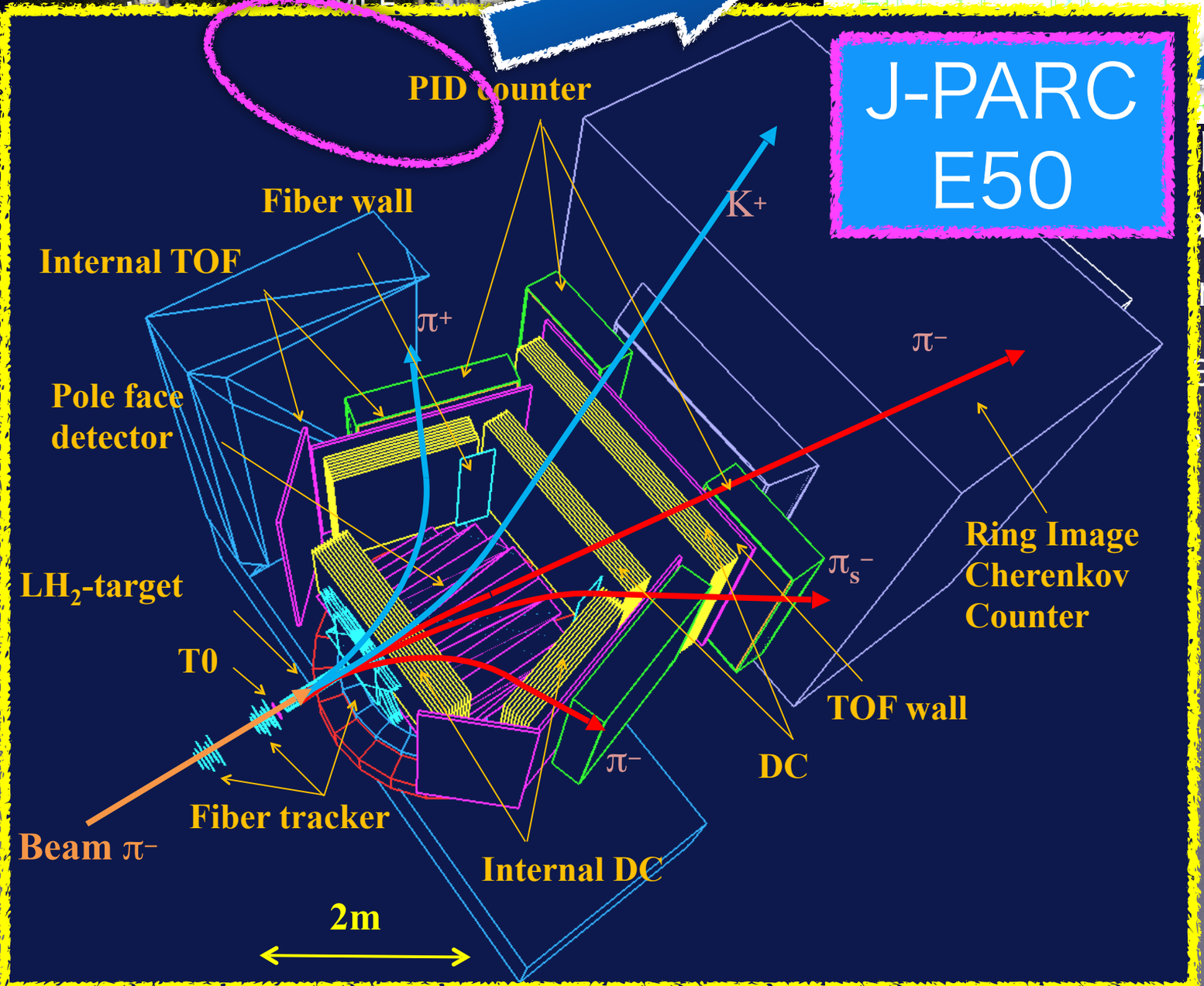
High momentum beam line

- High-intensity beam: > 1.0×10^7 Hz π (< 20 GeV/c)
  - Unseparated beam: π/K/p_{bar}
- High-resolution beam: $\Delta p/p$ ~ 0.1%(rms)
  - Momentum dispersive optics method

E50 spectrometer for charmed baryon spectroscopy



J-PARC E50



mentum beam line

m: > 1.0×10⁷ Hz π (< 20 GeV/c)

m: π/K/p_{bar}

eam: $\Delta p/p$ ~ 0.1%(rms)

rsive optics method

Charmed baryon Spectrometer

- Large acceptance spectrometer
- Data taking by Trigger-less DAQ system

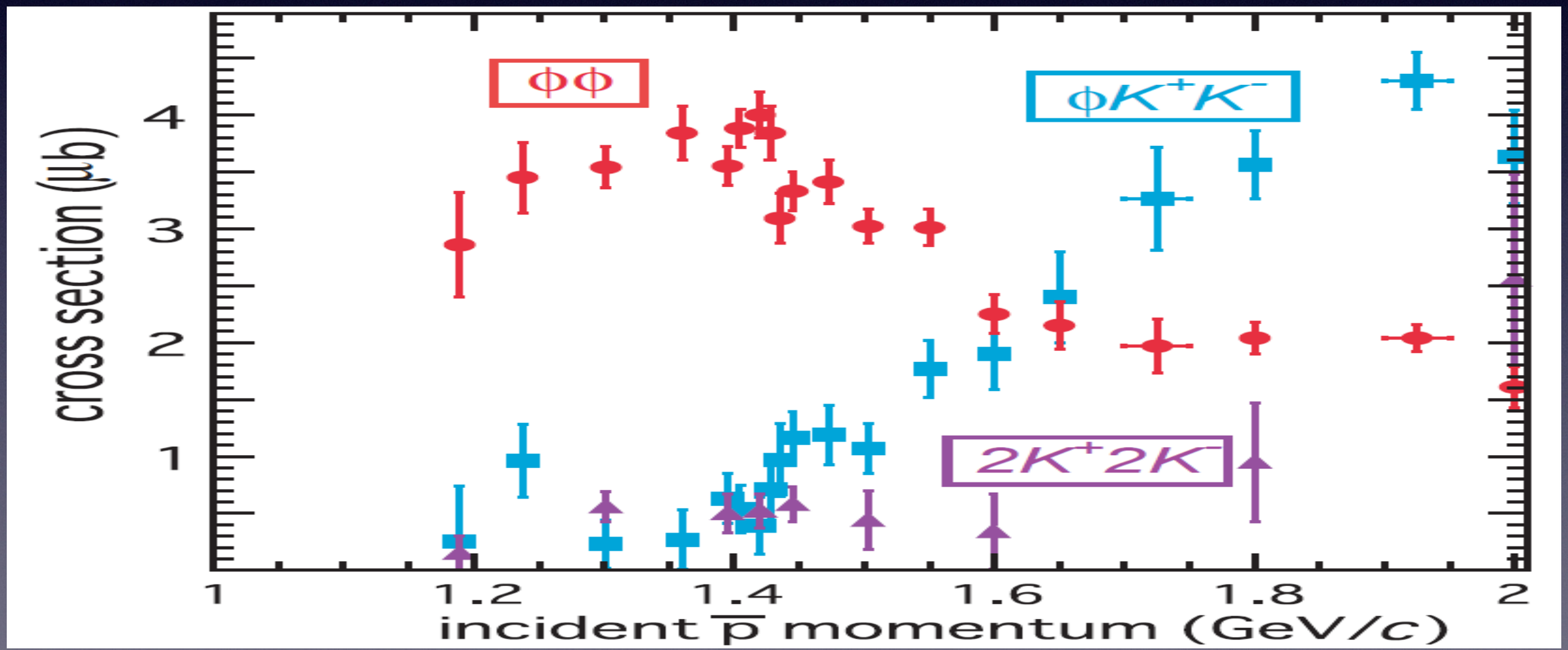
Plan for near future?

Double ϕ meson production

Strong OZI violated process

It is very hard to understand

the reason of large cross section at threshold



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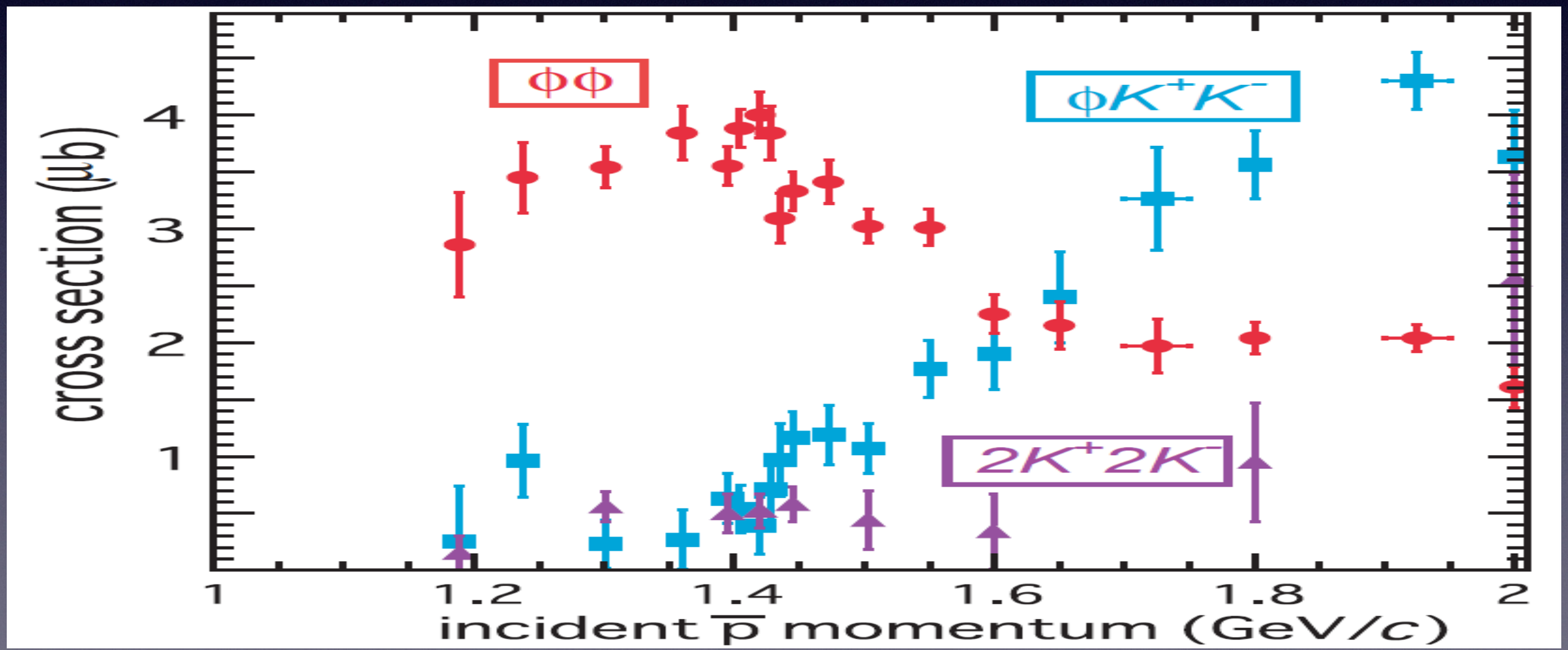

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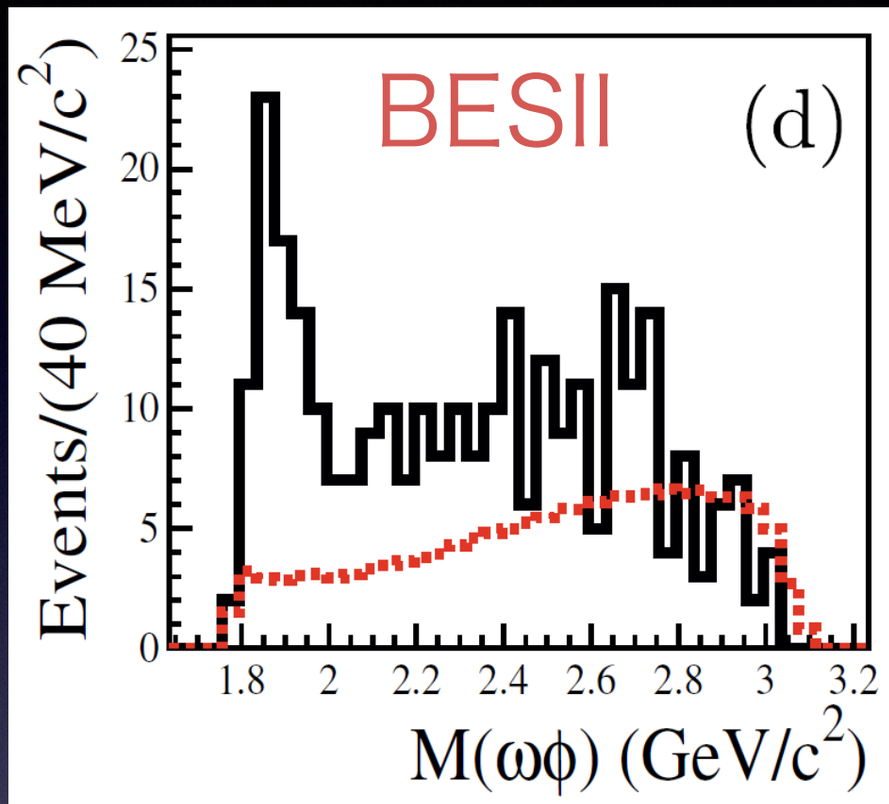
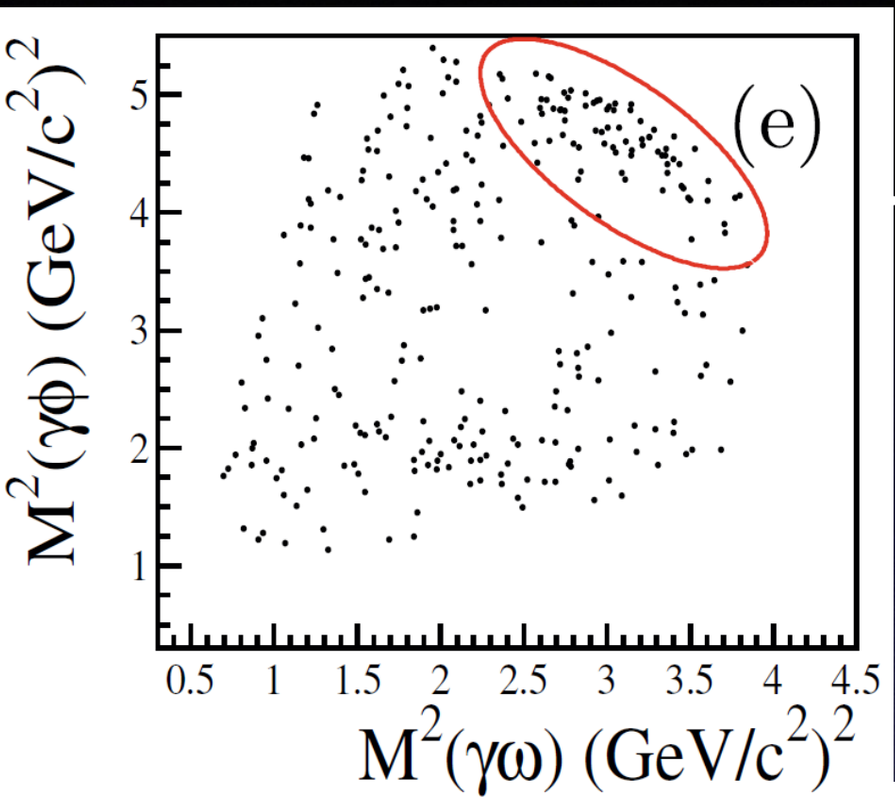
Meson-Meson bound state?



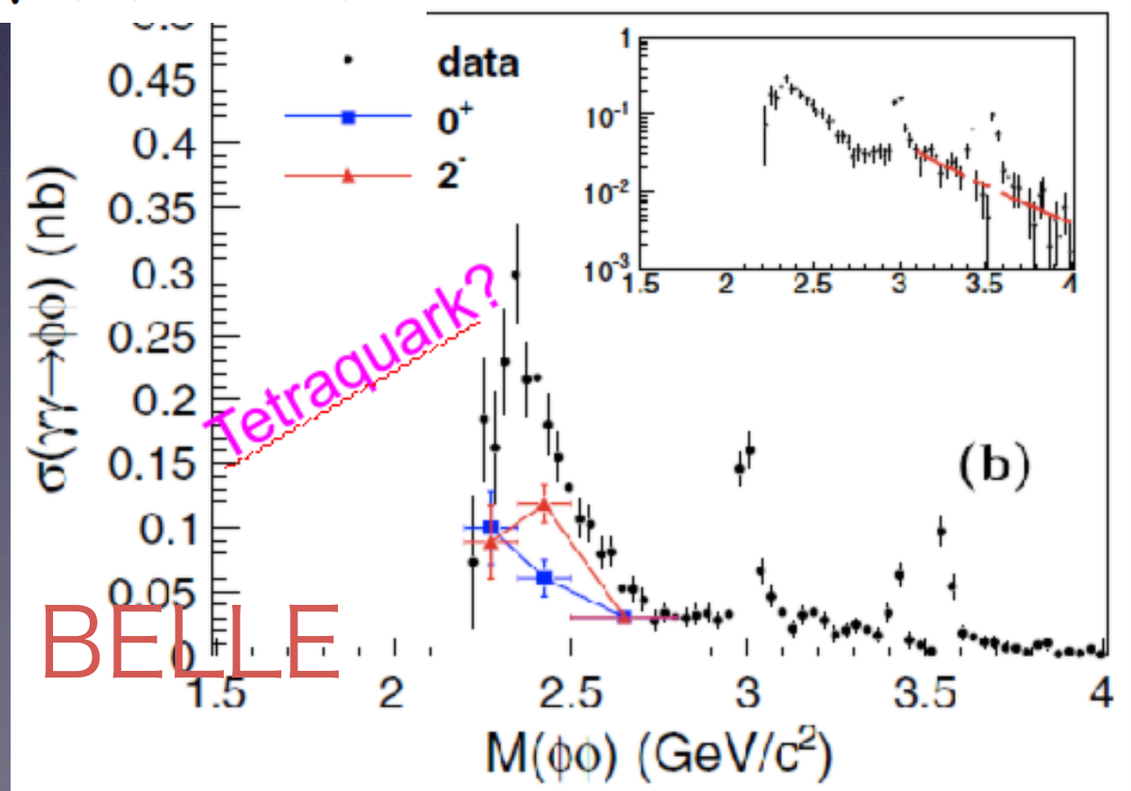
PRL96(2006)162002



PRL108(2012)232001

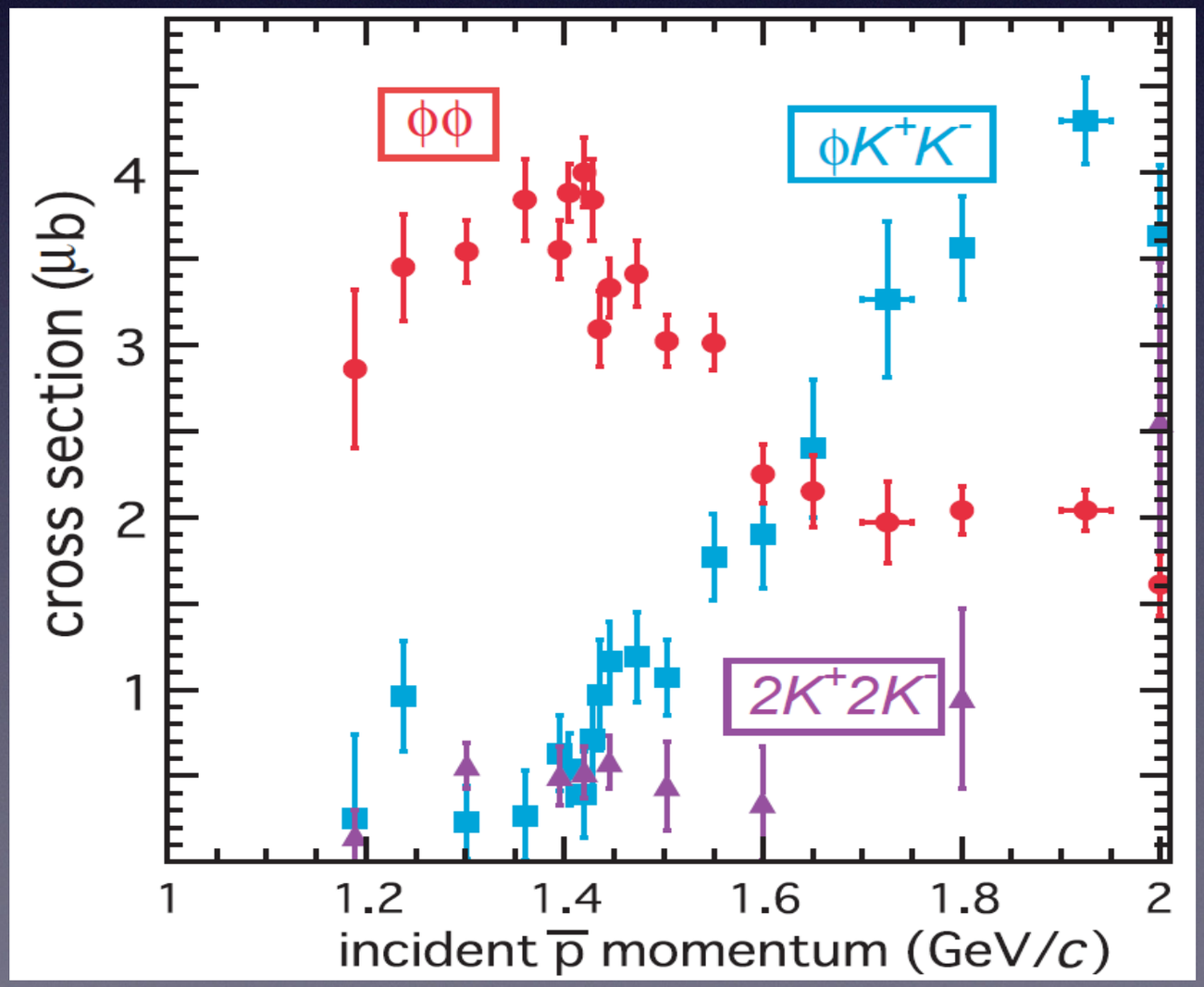
Tetra quark?

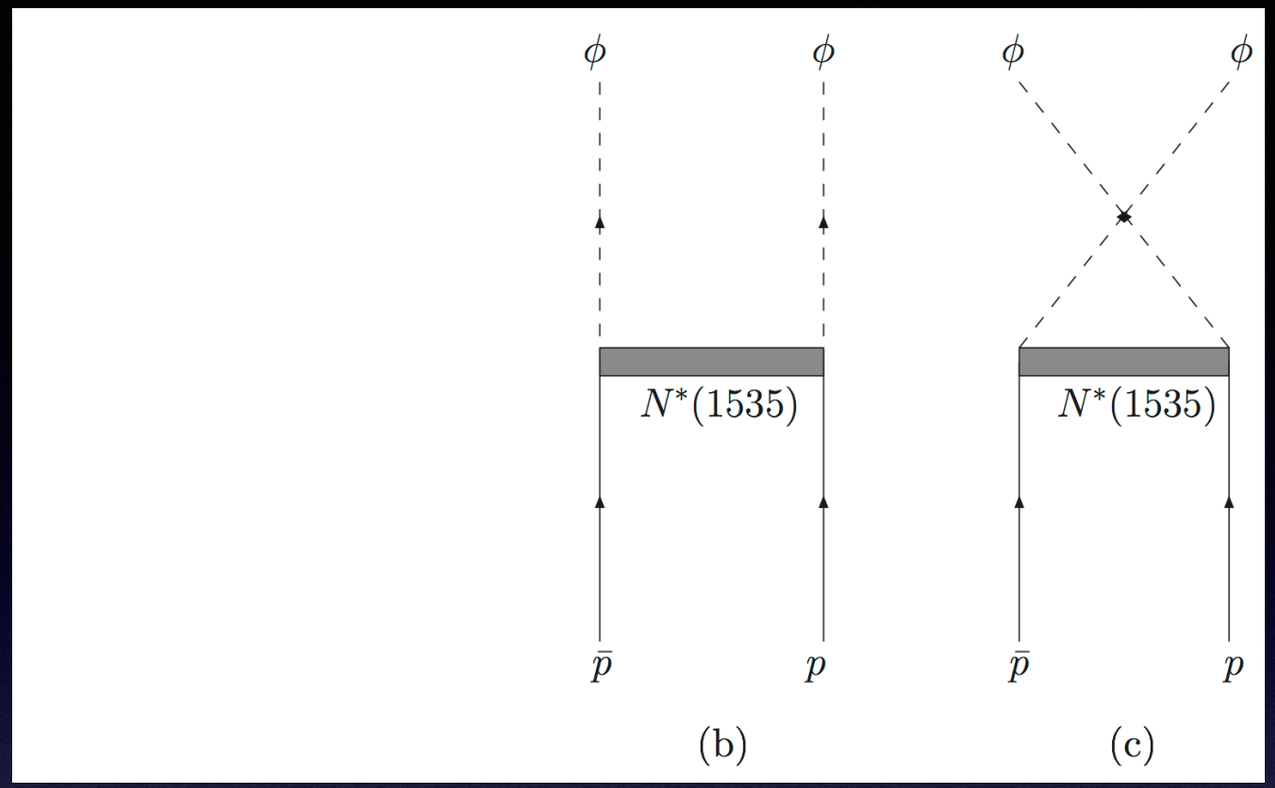
$\omega\,\phi$ bound?



$\phi\,\phi$ 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 !

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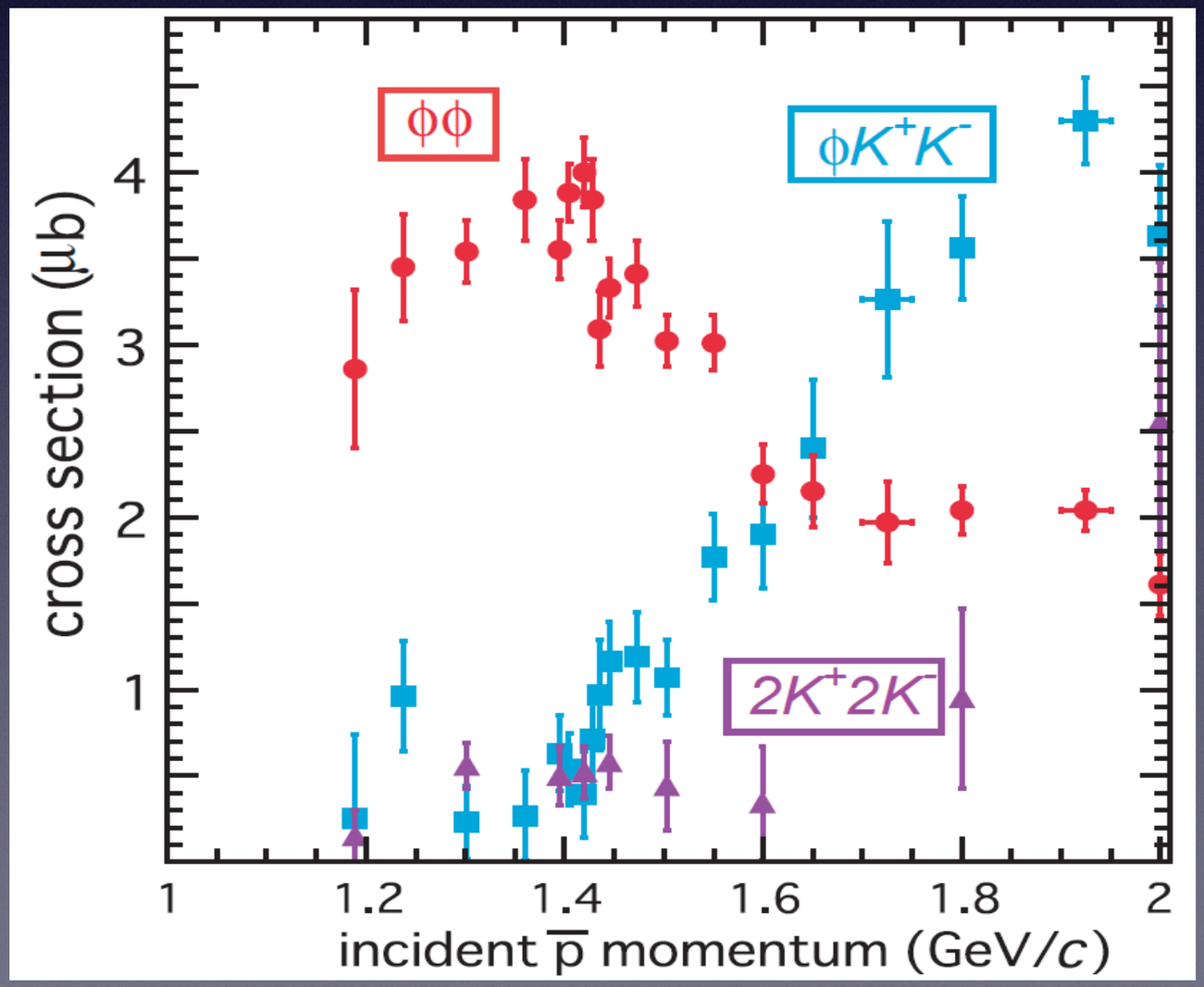

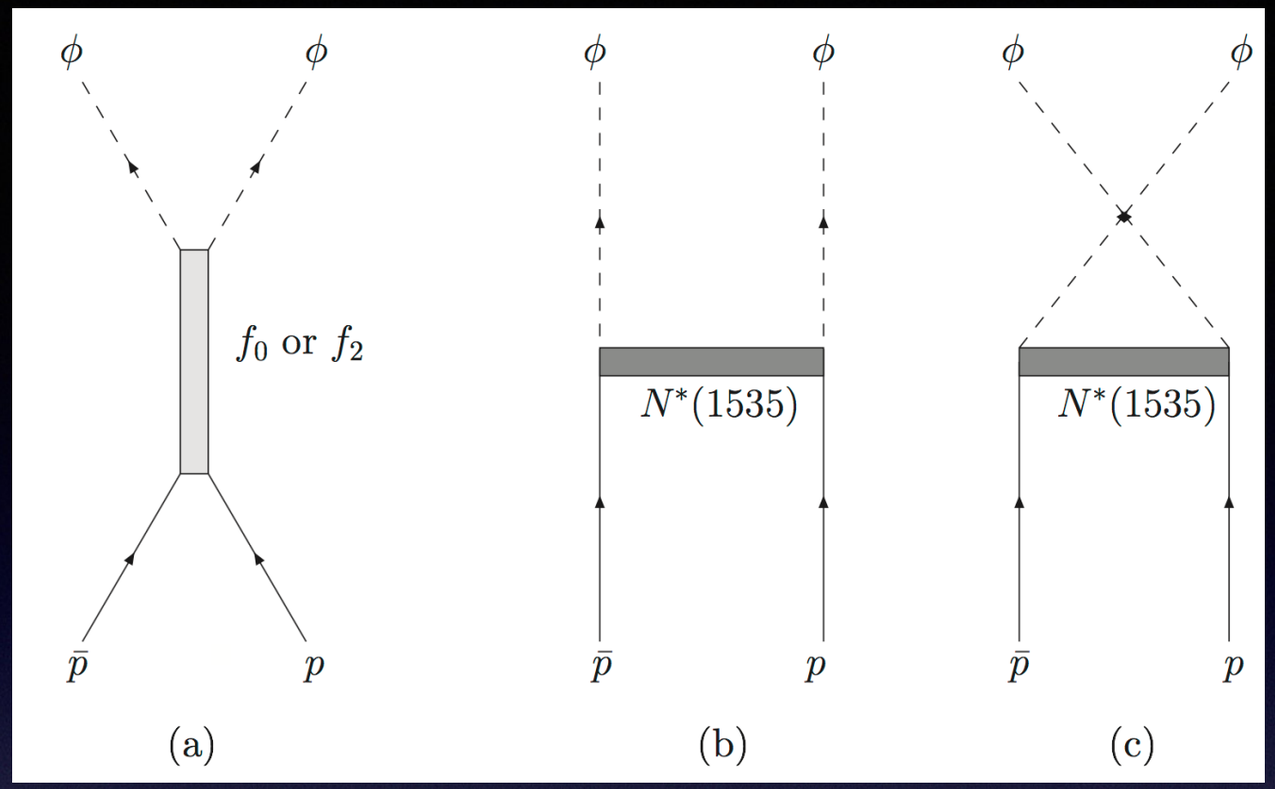

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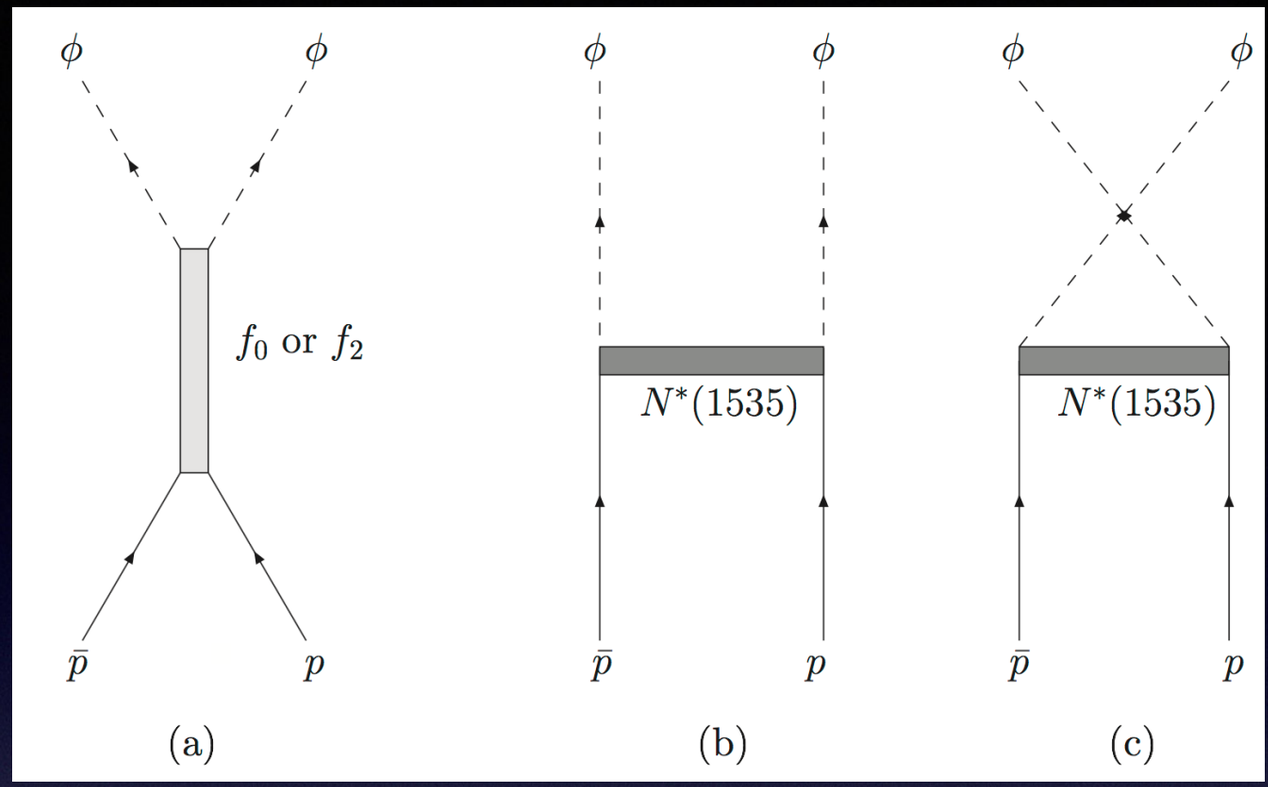
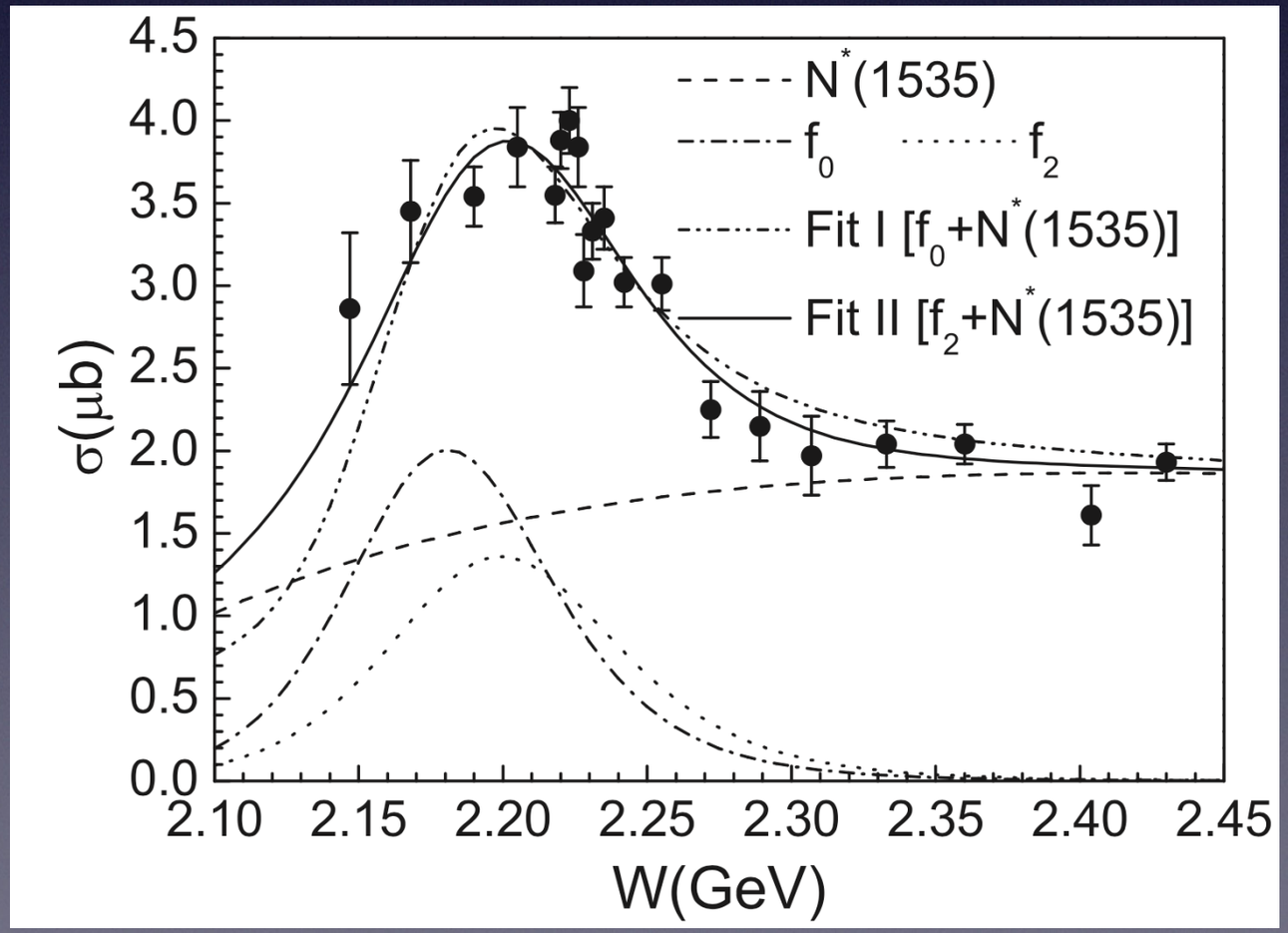




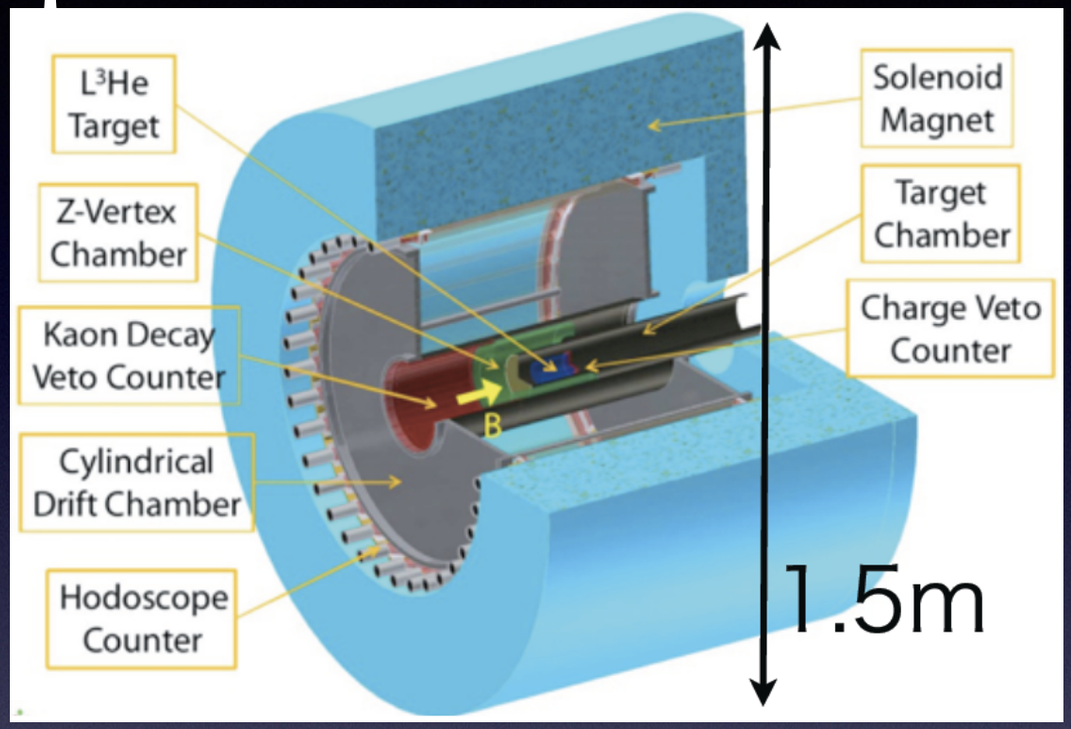
PHYSICAL REVIEW C 90, 048201 (2014)

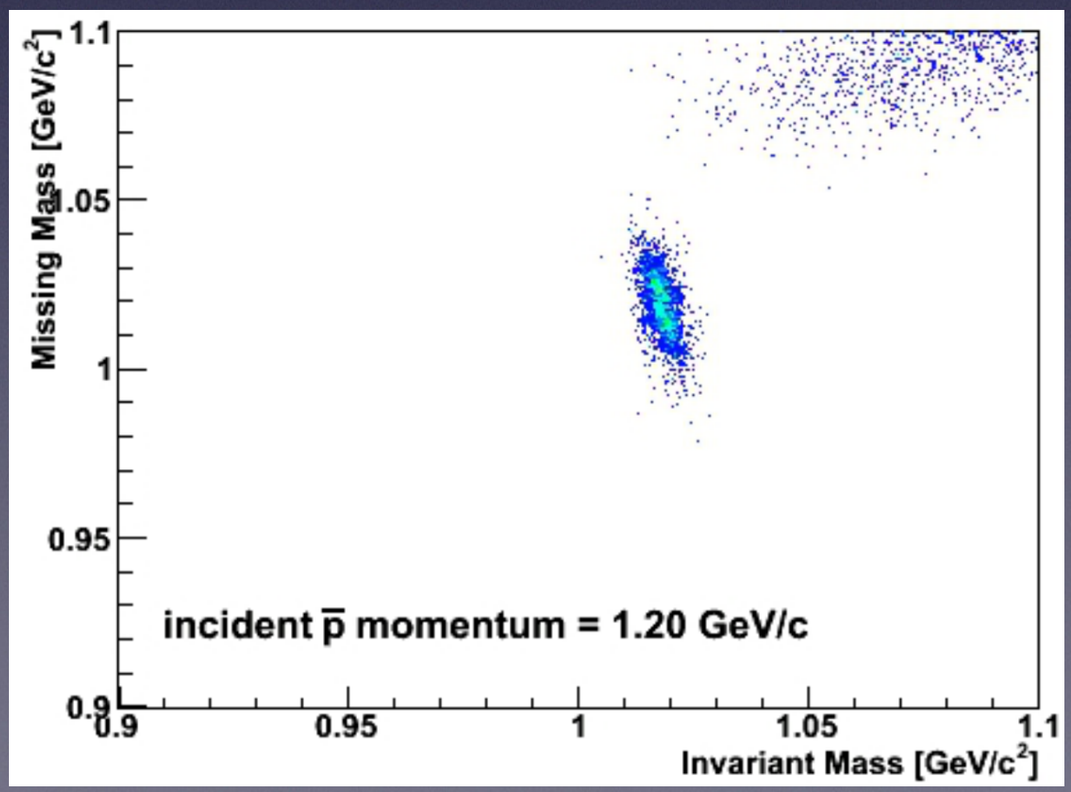
contribution of f0 or f1 ?

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

double ϕ measurement w/ J-PARC E15 spectrometer

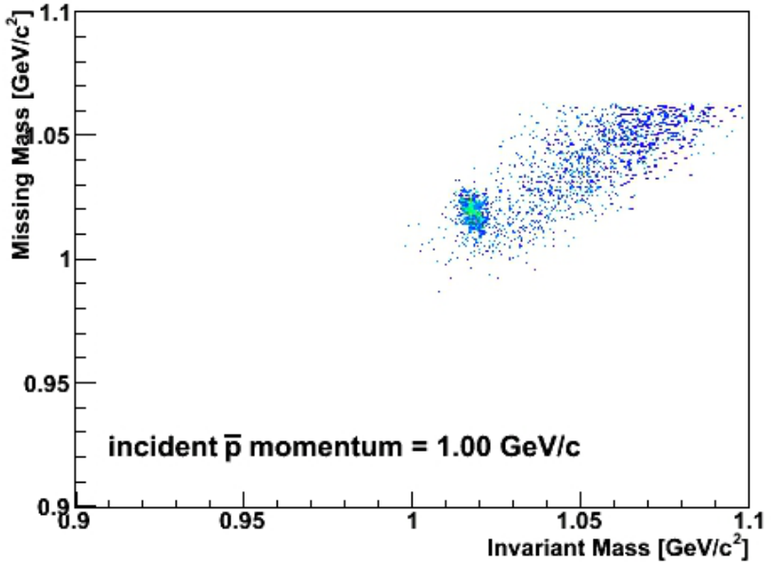
- Using E15 spectrometer
- Large acceptance charged particle spectrometer surrounding target (CDS).
- Detecting K+K- pairs from ϕ decay in CDS
- Calculate invariant mass of K+K- and missing mass, then we can identify double ϕ production

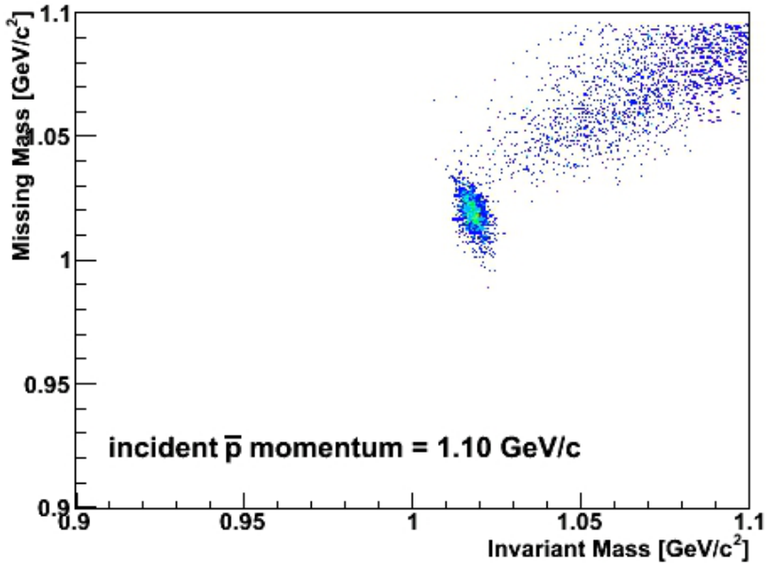


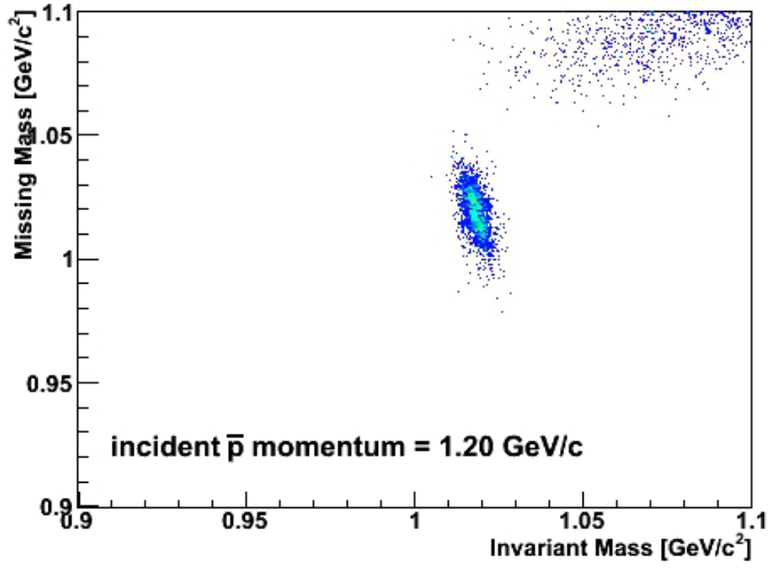


How to identify double ϕ

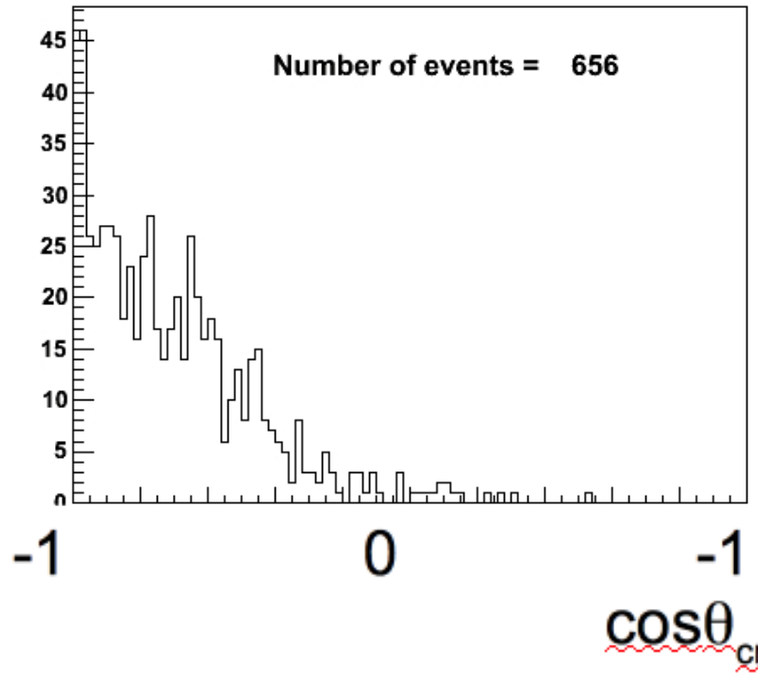
signal

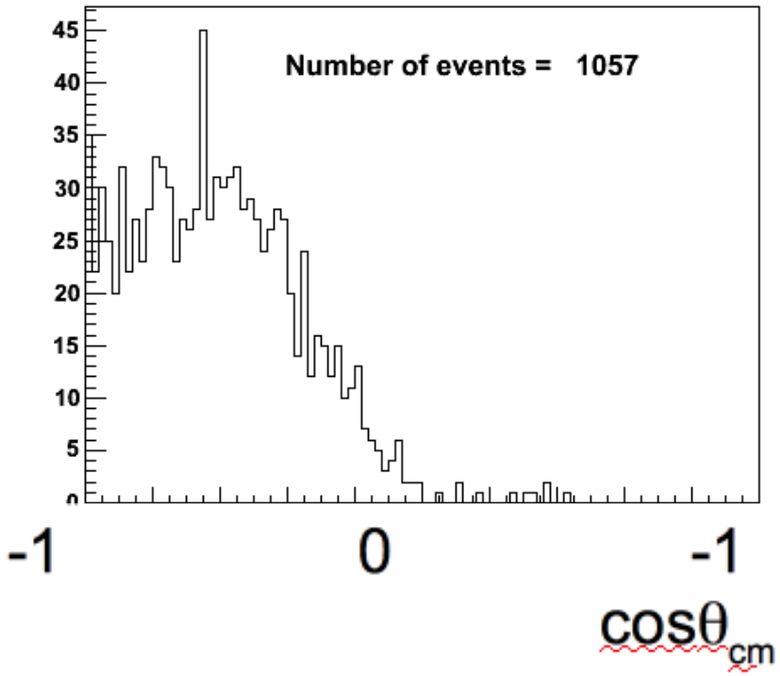


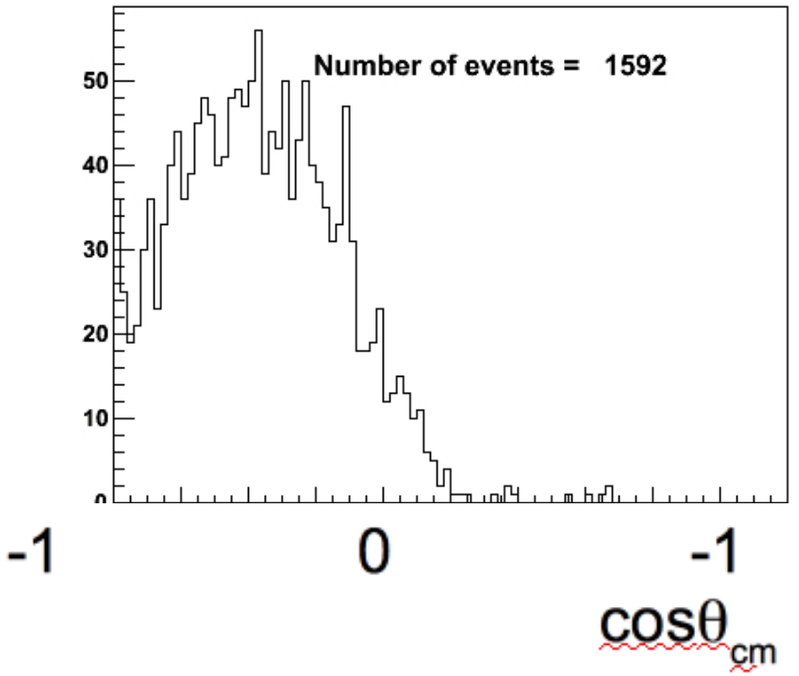




angle acceptance







Summary

- The project to searching for 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 $pp \rightarrow \phi\,\phi$ channel
- The preparation of the document for the beam time request is under the way.
  (Dr. Y. Sada is working on it)