原子核中の vector meson 測定実験 at (KEK-PS and) J-PARC

Satoshi Yokkaichi
(RIKEN Nishina Center)

- Experiment : J-PARC E16
- Production cross section of ω/ϕ measured by KEK-PS E325

J-PARC E16

Measurements of spectral change of vector mesons in nuclei

- experiment
- detectors
- schedule
- summary

Collaboration
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KEK K.Aoki, K.Ozawa, R. Muto, Y.Morino
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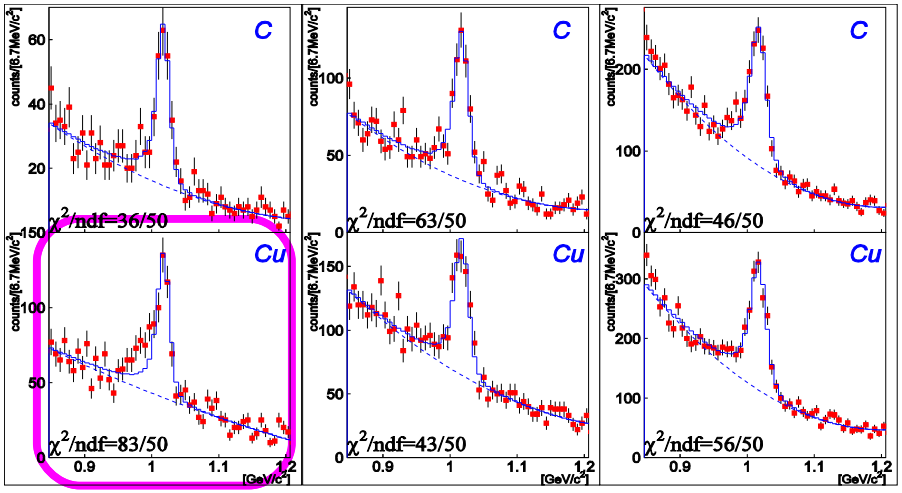
J-PARC E16 experiment

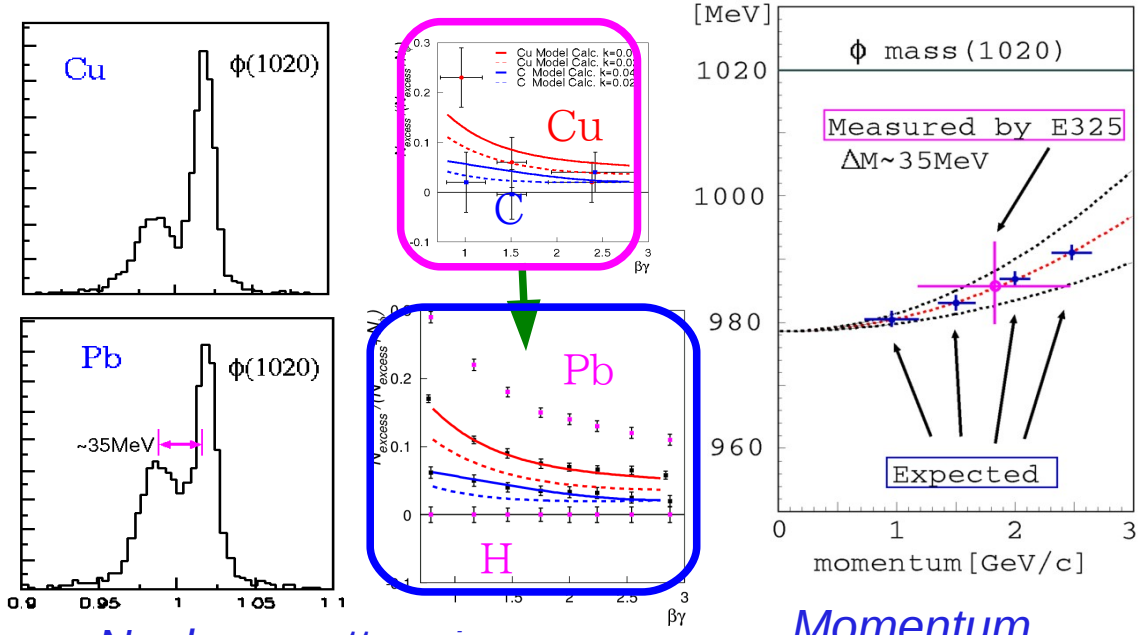
- Measure the vector-meson spectral change in nuclei systematically with the e^+e^- invariant mass spectrum : ϕ and ρ/ω as the KEK-PS E325 experiment
- A 30 GeV primary proton beam (10^{10}/spill) is used at the High-momentum beamline
- ~10^5 $\phi \rightarrow e^+e^-$ for each target with an improved mass resolution, 5MeV.
- confirm the E325 results, and provide new information as the matter size/momentum dependence of the spectral change

Precedent exp.(KEK-PS E325)



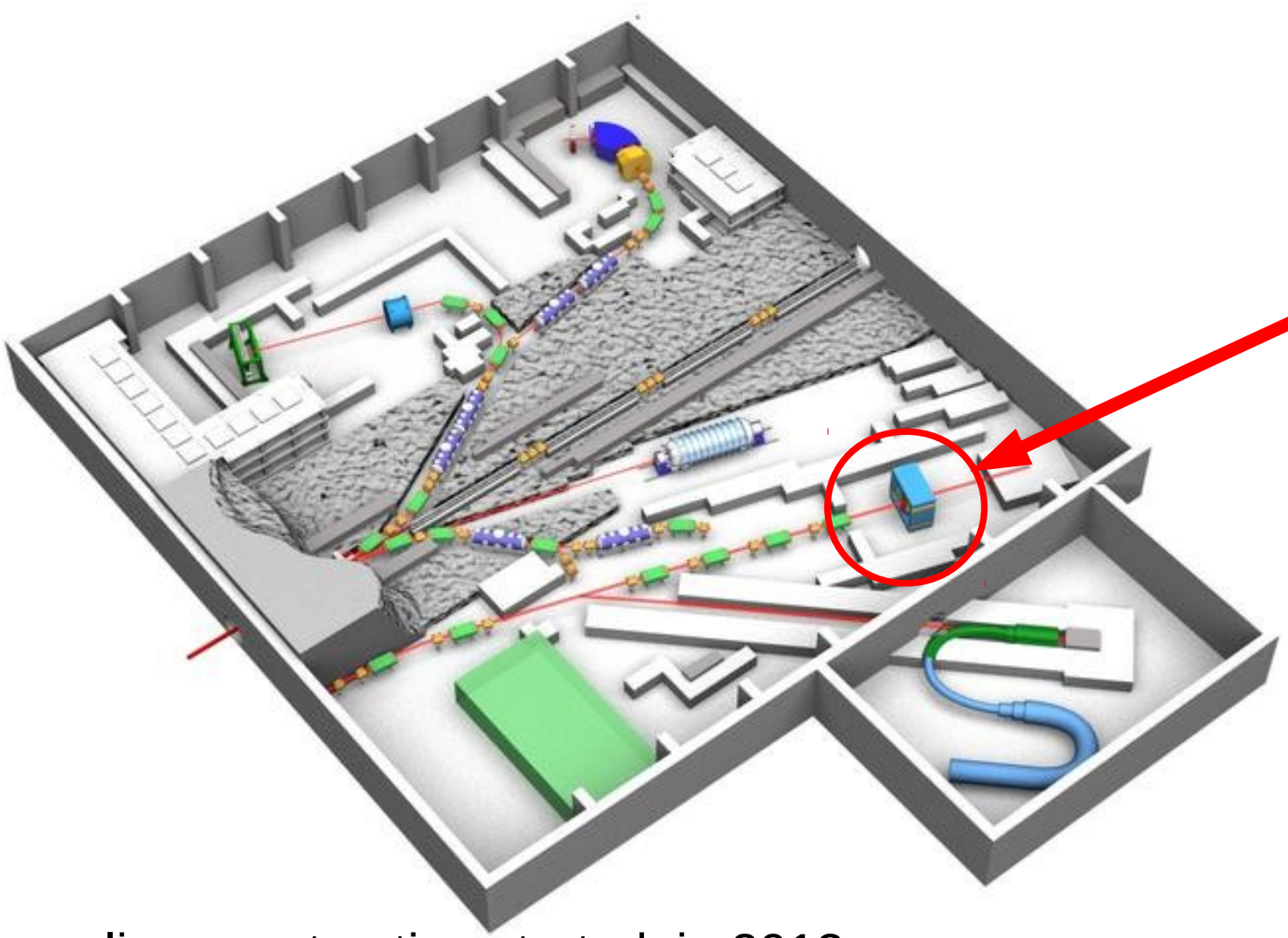
ϕ–mass is modified in large nuclei for slowly moving mesons... consistent with the prediction based on the QCD sum rule

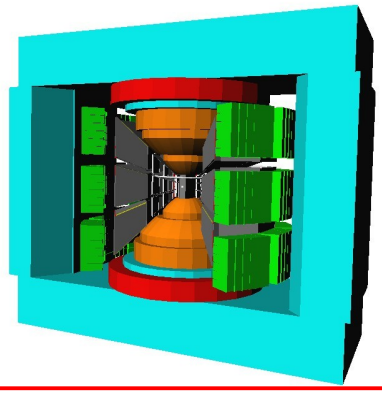
Proposed exp. E16



Nuclear matter size dependence & *Momentum dependence* of spectral modification are measured

High-p beamline in the Hadron hall

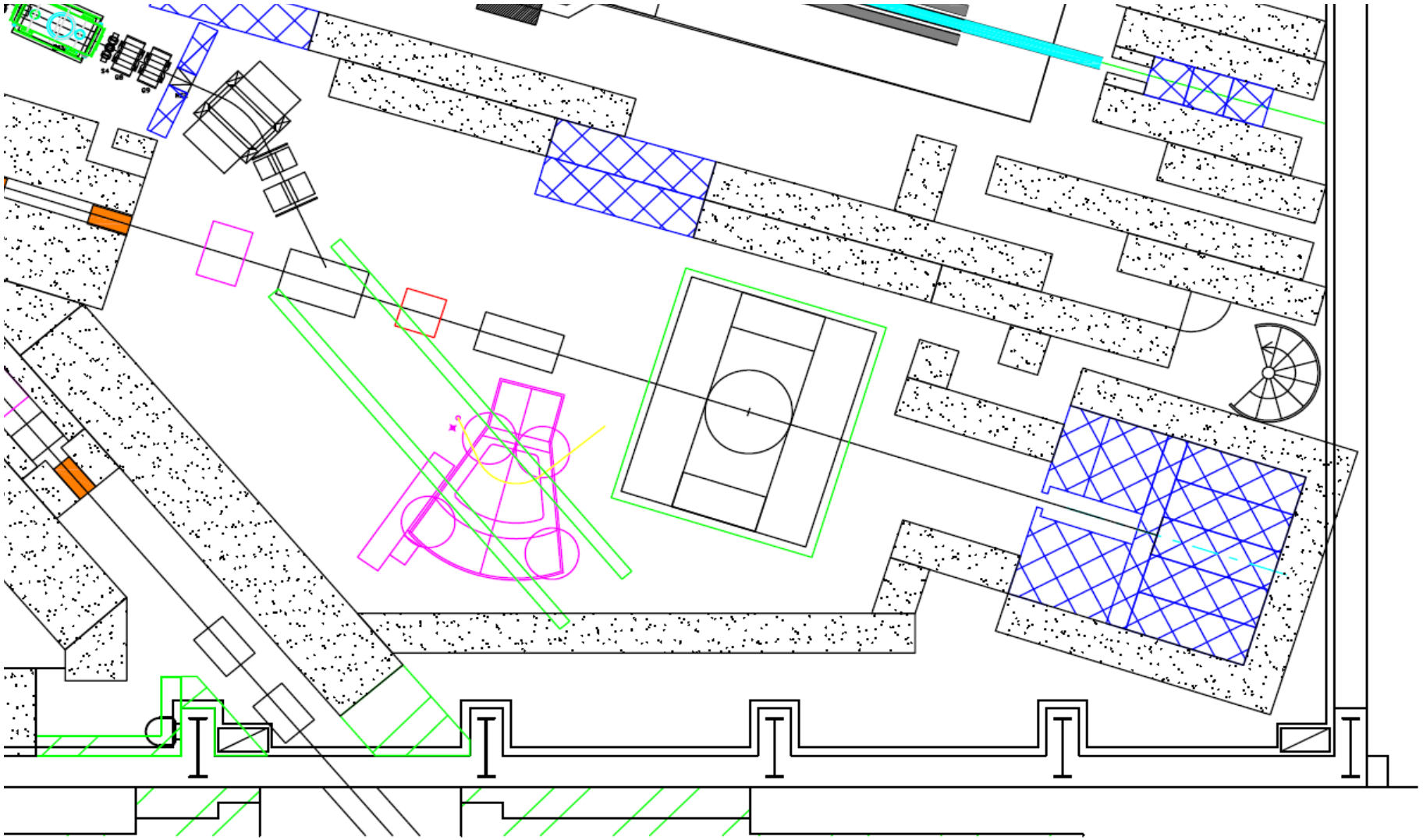




E16 spectrometer

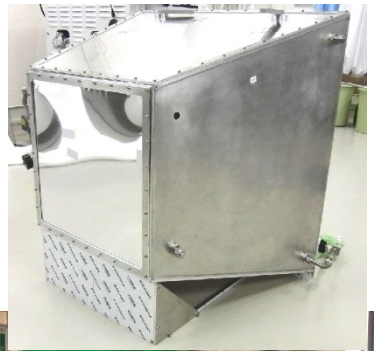
- Beamline construction started in 2013
  - comissioning will be perfomed in 2017

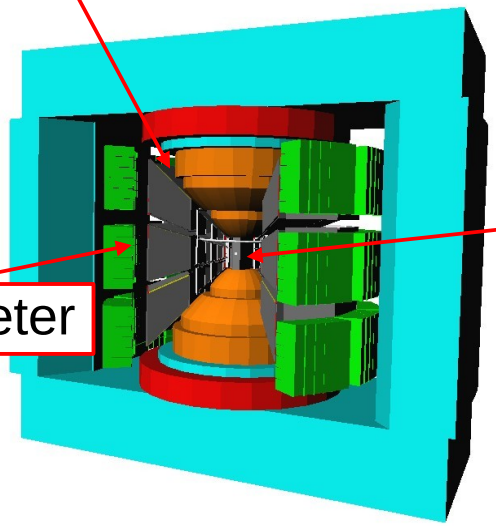
experimental area

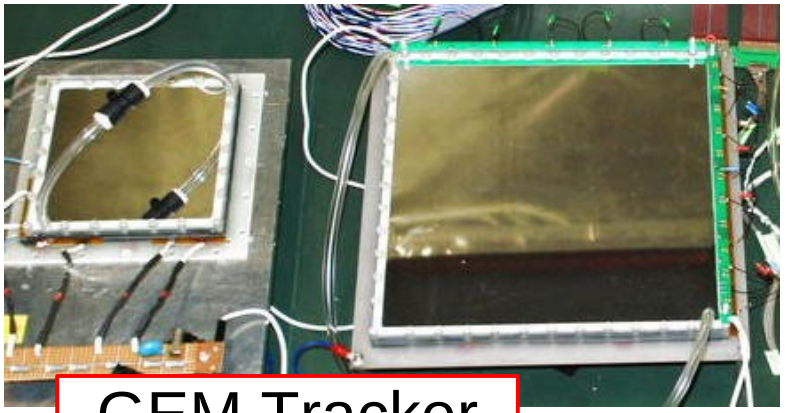


Detector development

Hadron Blind Cherenkov Detector(HBD)

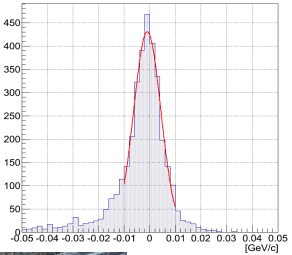






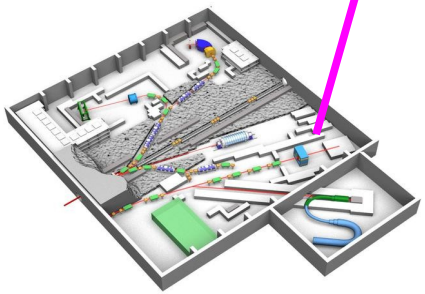
GEM Tracker

position resolution 100 μm is achieved to keep the ~5 MeV mass resolution for the ϕ mesons.



Lead-Glass EM Calorimeter

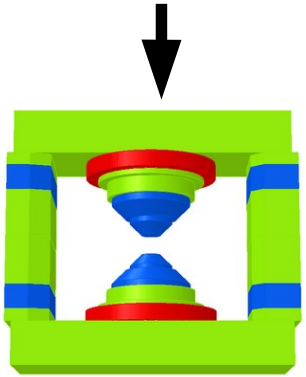
pions are suppresed down to ~0.1% with the combination of the two stage of electron-ID counters

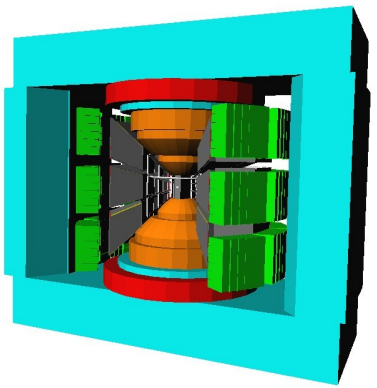


The spectromter magnet reconstruction is completed at the new High-momentum beam line, which is under construction and completed in 2017

Schedule

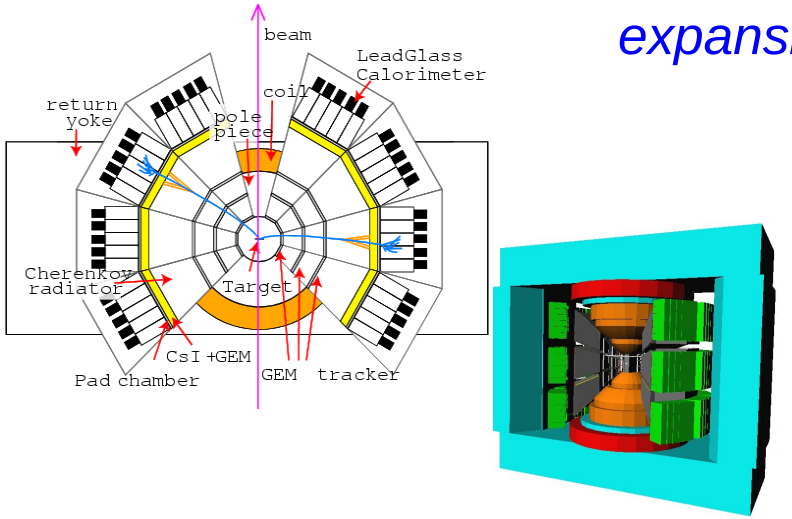
- 2007: stage1 approval
- 2008-2013 : detector R&D
- 2013 Jan : High-p construction budget is approved
- JFY 2015: *toward the stage-2 approval*
  - production of detectors
  - remaining tests of R/O circuits
- In the Hadron hall,
  - 2015 July : spectrometer magnet re-assemble completed
- JFY2017 : 1st physics run with 8 modules
  - 80 shifts of physics run : 4000 ϕ for C/Cu
  - measure the distribution of vector mesons and BKGs
    - effective trigger logic and additional modules



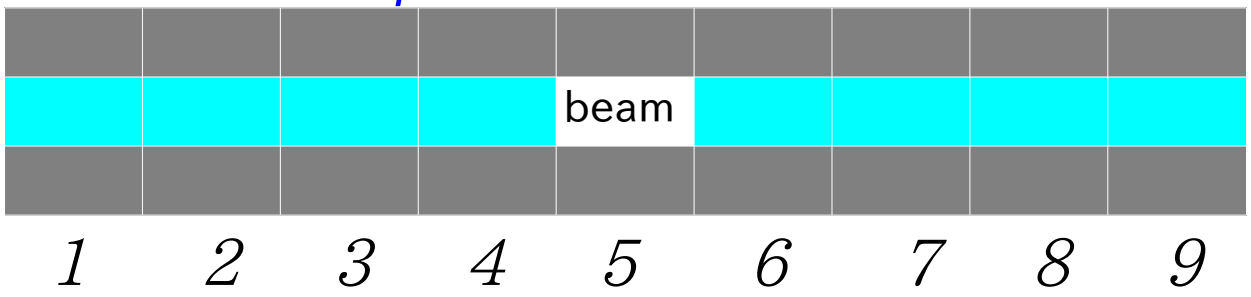


At first : 8 modules-run

- 4000 ϕ mesons in 80 shifts, after the shakedown in 20 shifts
  - slow 400 ϕ ($\beta\gamma$<1.25)
  - using HBD/LG performance : < 1kHz trigger request.
  - target: 80μm Cu x 2 + 400μm C x1: 0.2% interaction in total
  - 1x10^{10} proton/spill (2sec) : 10MHz interactions at targets
- confirm E325 results (2000 ϕ including slow 400 for C/Cu targerts also)
- measure the particle distribution and bkg status: for the effective upgrade



expansion of the barrel shape



Summary(1)

- J-PARC E16 will measure the vector meson spectral modification in nuclei with the ee decay channel, using 30GeV primary proton beam.
  - confirm the observation by E325 and provide more precise information of the modification of mass spectra to clarify the chiral symmetry in the finite density matter.
  - preparation is underway with the Grant-in-Aid. Detector mass-production is just started.
  - Staged Goal of construction : 8 modules out of 26
    - detector and beamline commissioning will be perfomred 2017
    - In JFY 2017, 1st physics run will collect 4000 phi mesons for C and Cu targets, as two times as that collected by E325, with 100 shifts of beam time (20 shifts for shakedown, 80 shifts for the data taking).
- Now requiring the stage-2 approval by PAC.

Experiment KEK-PS E325

- 12GeV p+A $\rightarrow$ $\rho/\omega/\phi$ +X ($\rho/\omega/\phi \rightarrow e^+e^-$, $\phi \rightarrow K^+K^-$)
- Experimental key issues:
  - Very thin target to suppress the conversion electron background (typ. 0.1% interaction/0.2% radiation length of C)
  - To compensate the thin target, high intensity proton beam to collect high statistics (typ. 10^9 ppp $\rightarrow$ 10^6Hz interaction)
  - Large acceptance spectrometer to detect slowly moving mesons, which have larger probability decaying inside nuclei ($1<\beta\gamma<3$)

Collaboration

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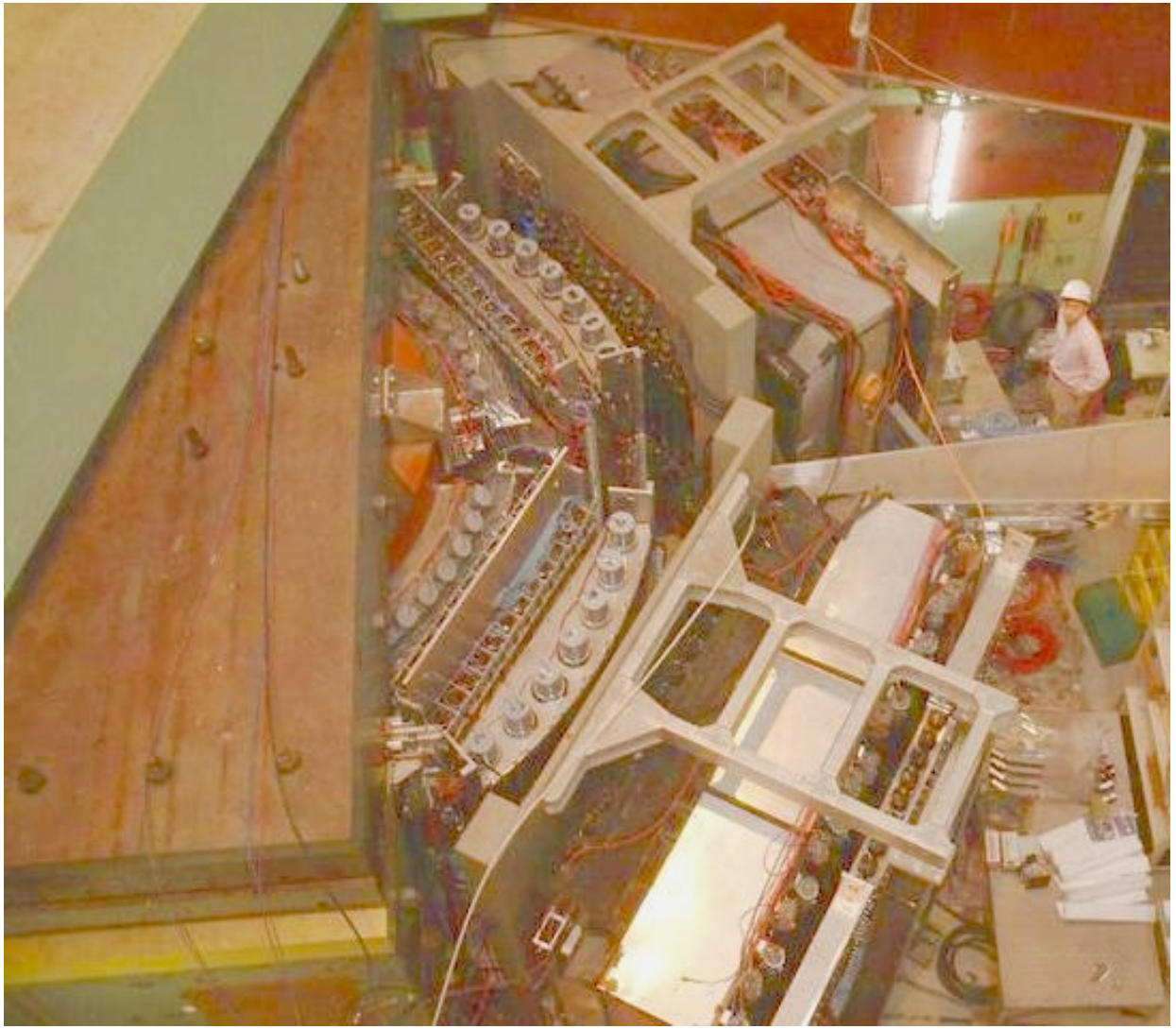
(Kyoto Univ. , RIKEN, KEK, CNS-U.Tokyo, ICEPP-U.Tokyo, Tohoku-Univ.)

(KEK-PS E325)

E325 spectrometer
located at KEK-PS EP1-B primary beam line

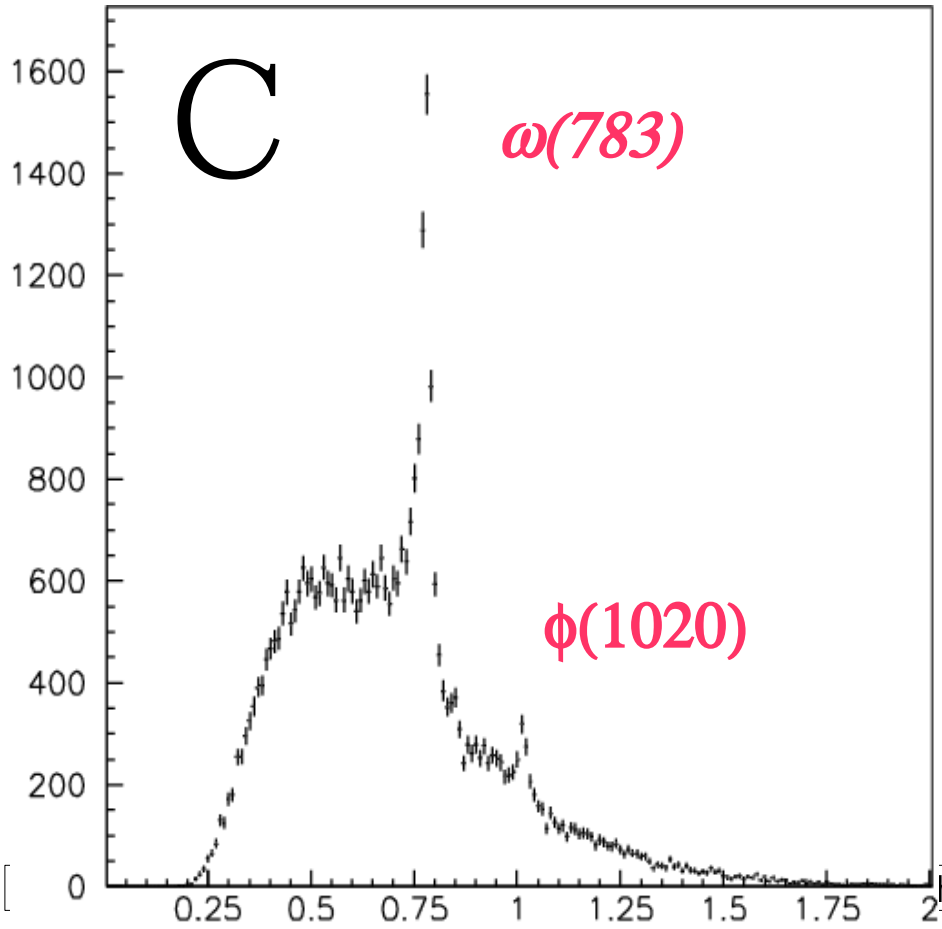
- History of E325
  - 1993 proposed
  - 1996 const. start
  - '97 data taking start
  - '98 first ee data
    - PRL86(01)5019
  - 99,00,01,02....
    - x100 statistics
      - PRL96(06)092301
      - PRL98(07)042501
      - PRC74(06)025201
      - PRL98(07)152302
  - '02 completed
    - NIM A516(04)390



E325 Results (1)

ee invariant mass spectra

M. Naruki et al.,
PRL 96 (2006) 092301
R.Muto et al.,
PRL 98 (2007) 042501

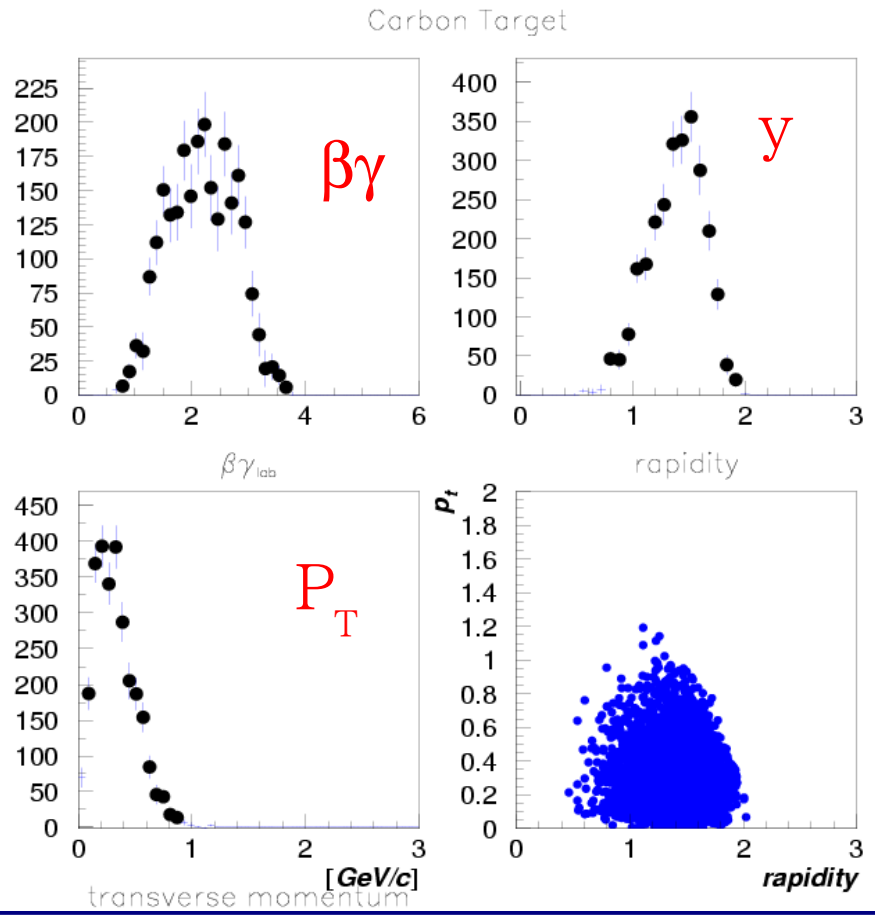


measured kinematic distribution of ω/ϕ → ee

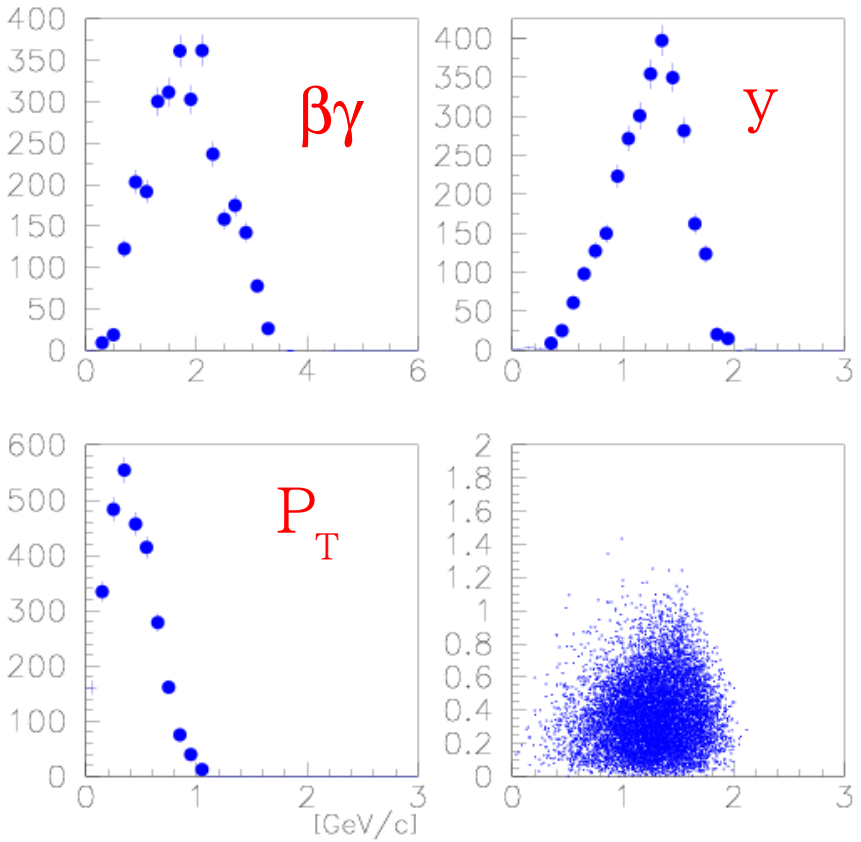
$0 < P_T < 1$ GeV/c, $0.5 < y < 2$ $(y_{CM}=1.66)$

$1 < \beta\gamma\,(=p/m) < 3$ (0.8<p<2.4GeV/c for ω, 1<p<3 GeV/c for ϕ)

ω

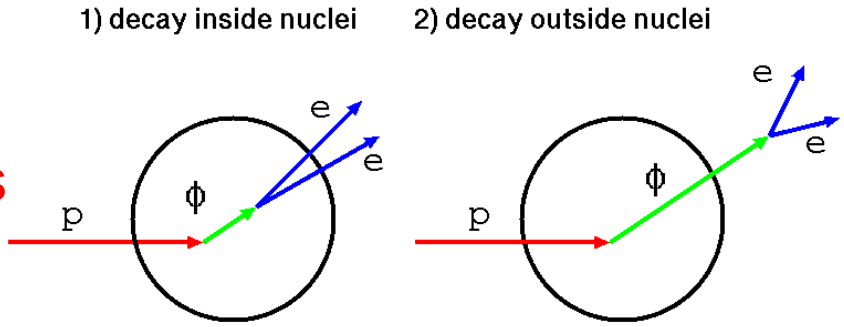


ϕ

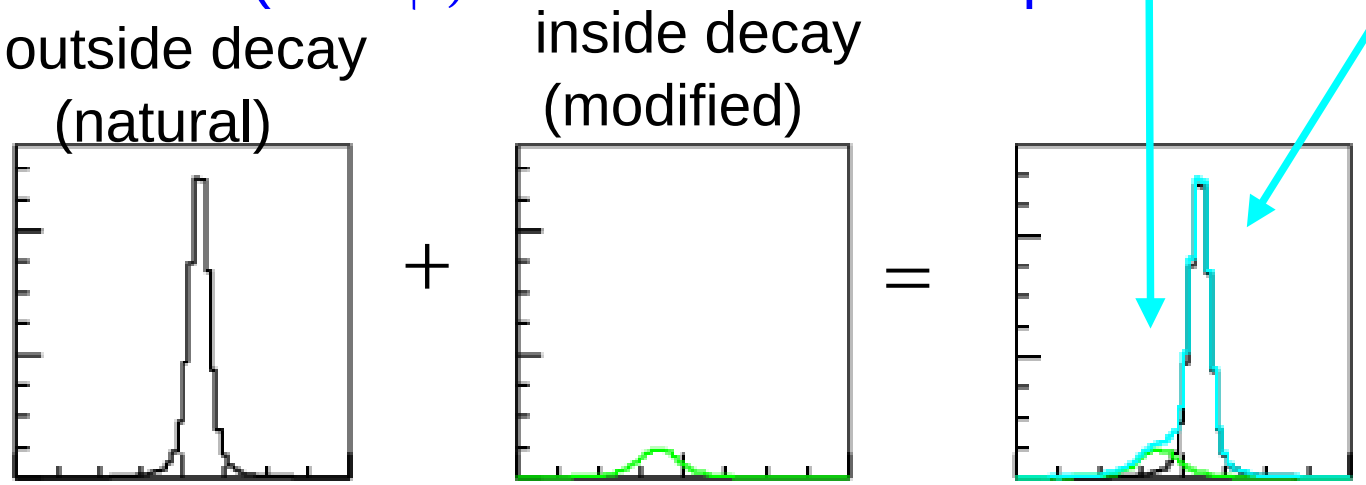


Expected Invariant mass spectra in ee

- smaller FSI in e^+e^- decay channel
- double peak (or tail-like) structure :
  - second peak is made by inside-nucleus decay (modified meson) : amount depend on the nuclear size and meson velocity
    - could be enhanced for slower mesons & larger nuclei



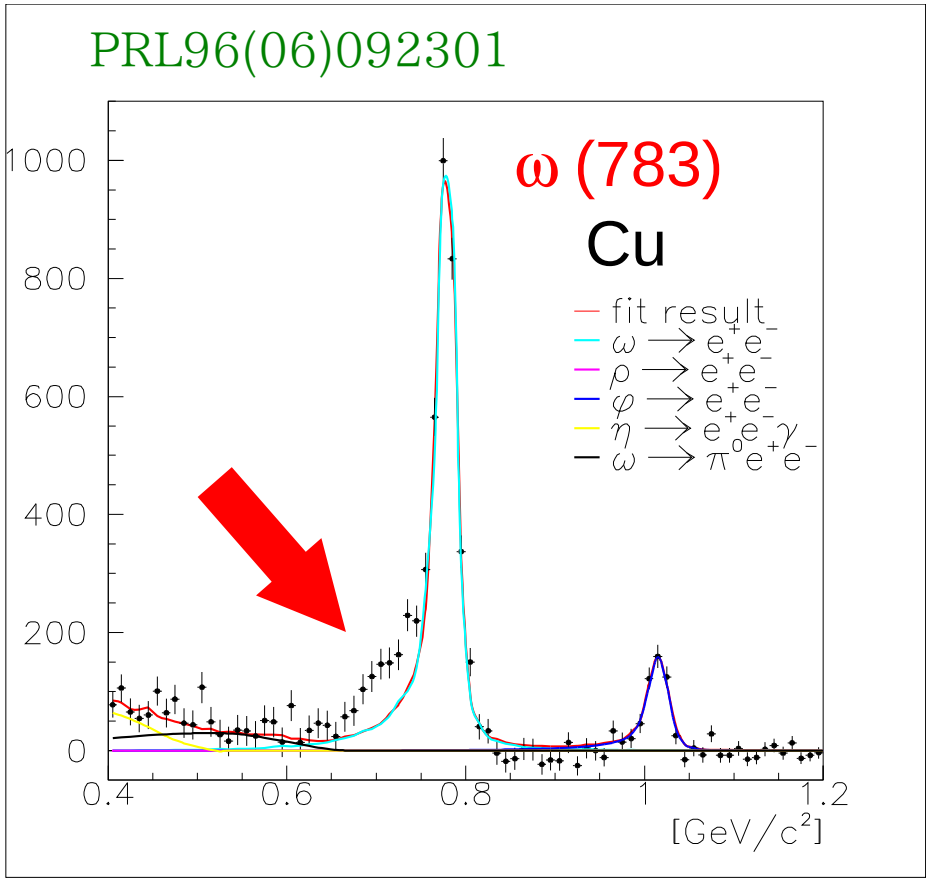
longer-life meson(ω & ϕ)cases : Schematic picture

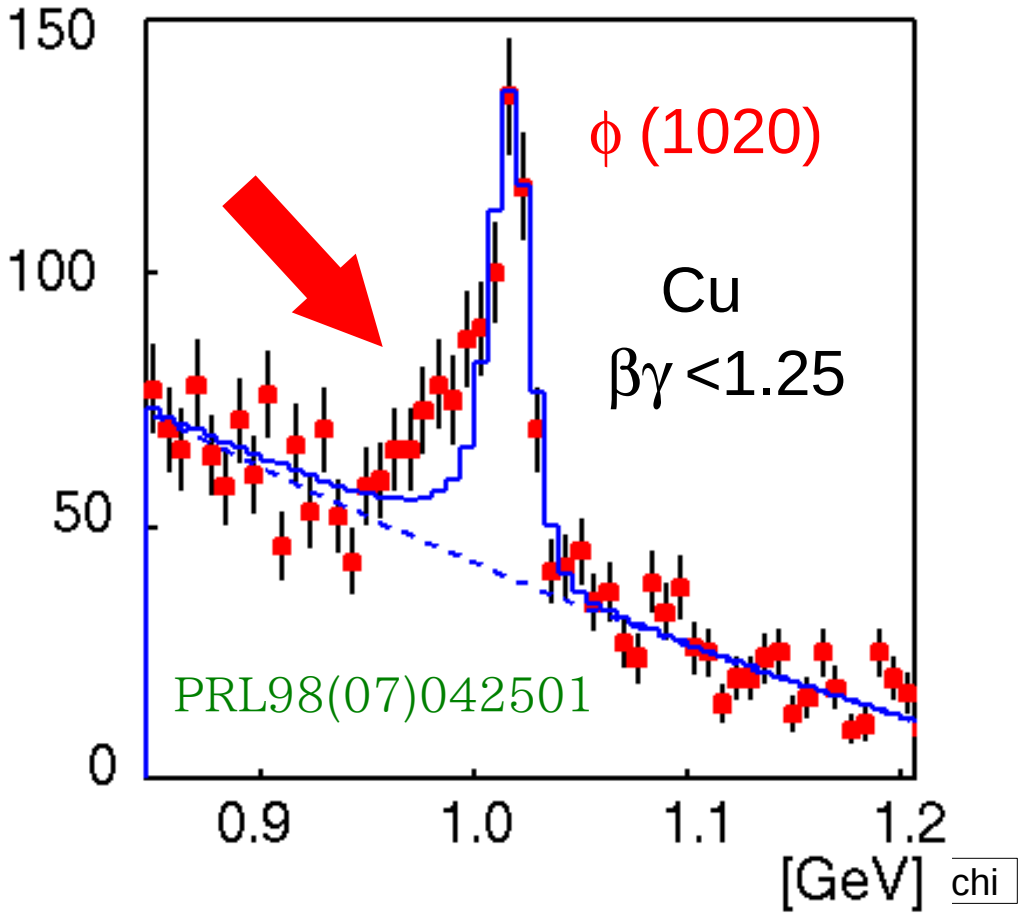


expected
to be observed

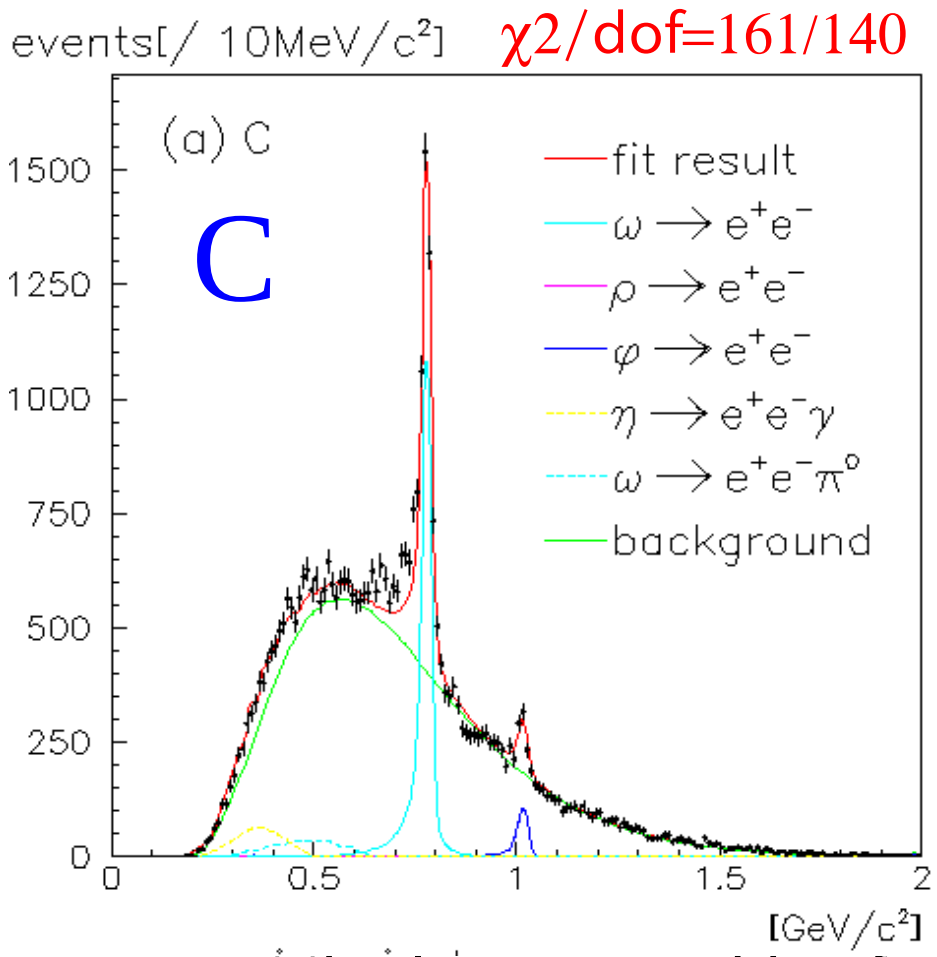
E325 observed the meson modifications

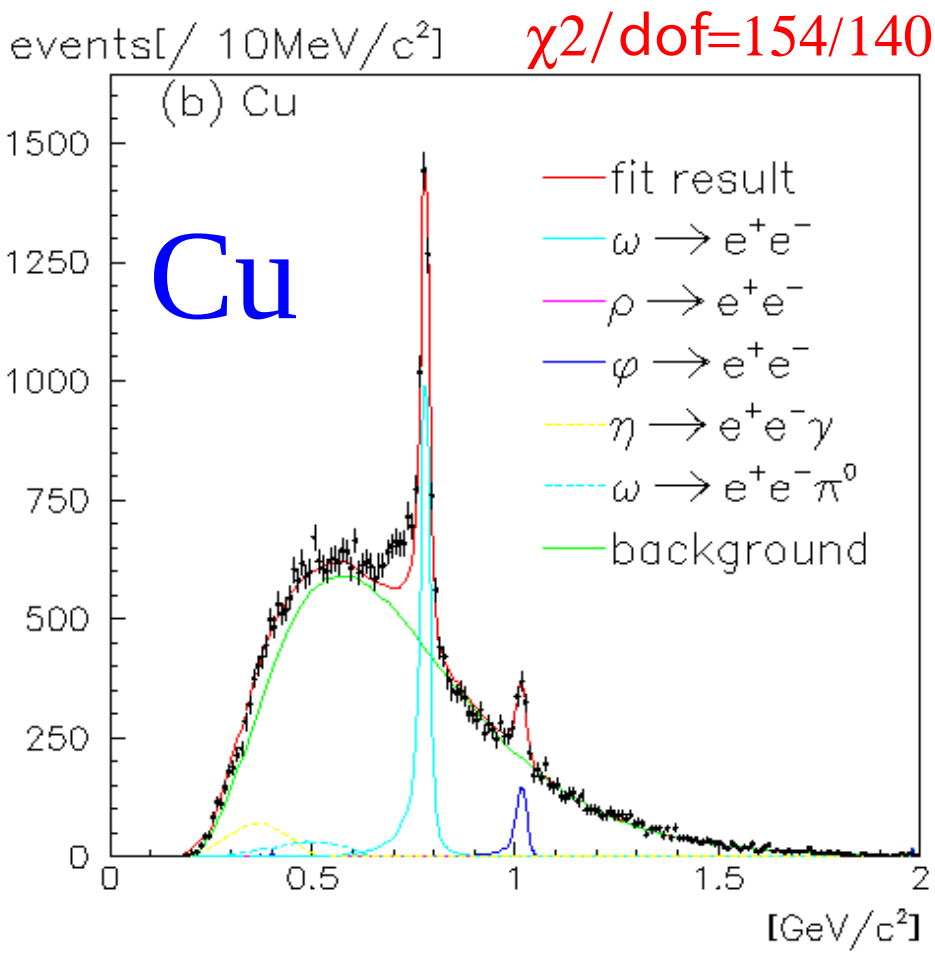
- in the e^+e^- channel
- below the ω and ϕ, statistically significant excesses over the known hadronic sources including experimental effects





Fitting results (ρ/ω)





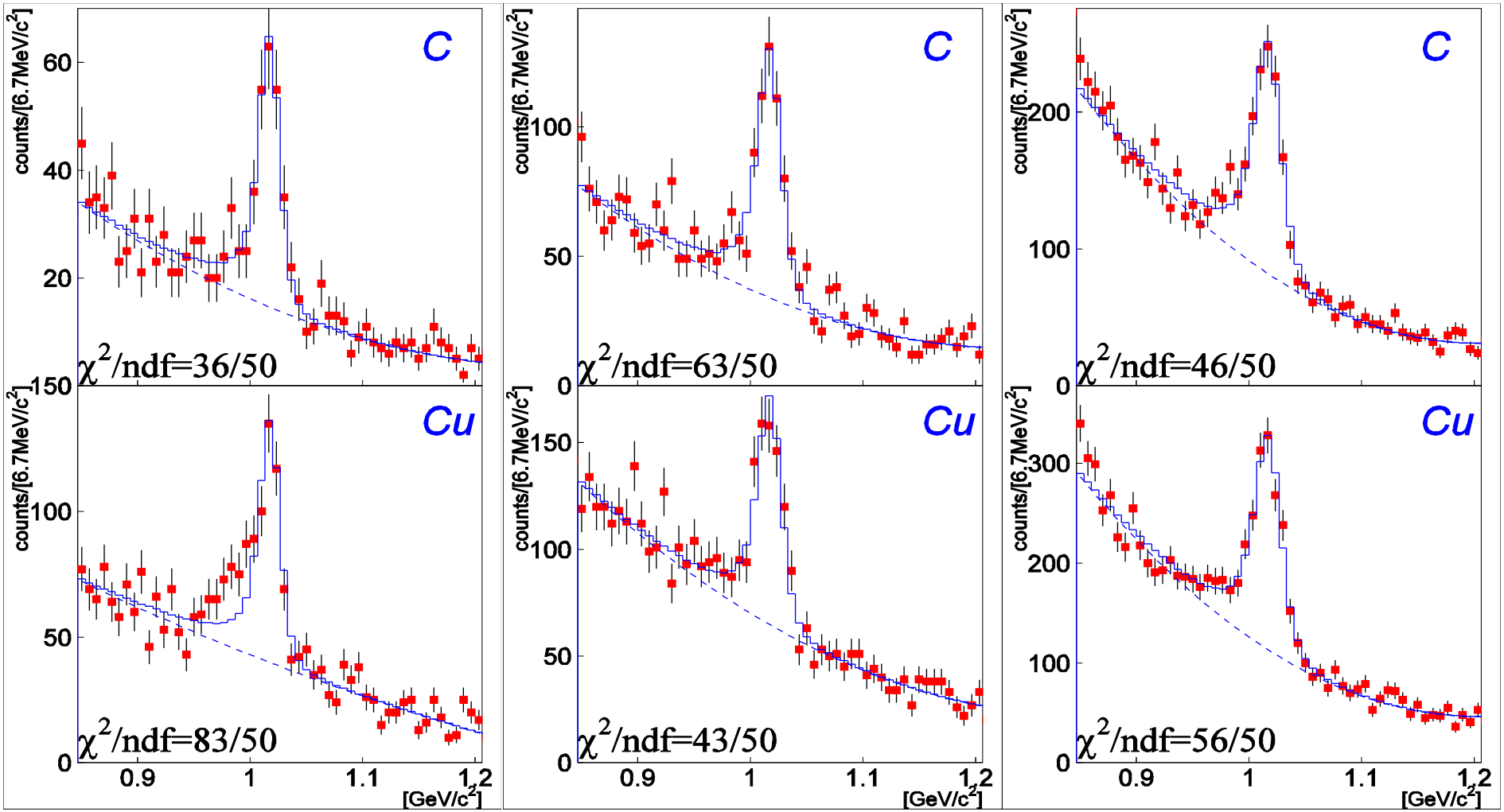
1) excess at the low-mass side of ω

To reproduce the data by the fitting, we have to exclude the excess region : 0.60-0.76 GeV

2) ρ meson component seems to be vanished. (ρ/ω =1.0±0.2 in a former experiment)

e^+e^- spectra of ϕ meson (divided by $\beta\gamma$)

$\beta\gamma<1.25$ (Slow) $1.25<\beta\gamma<1.75$ $1.75<\beta\gamma$ (Fast)



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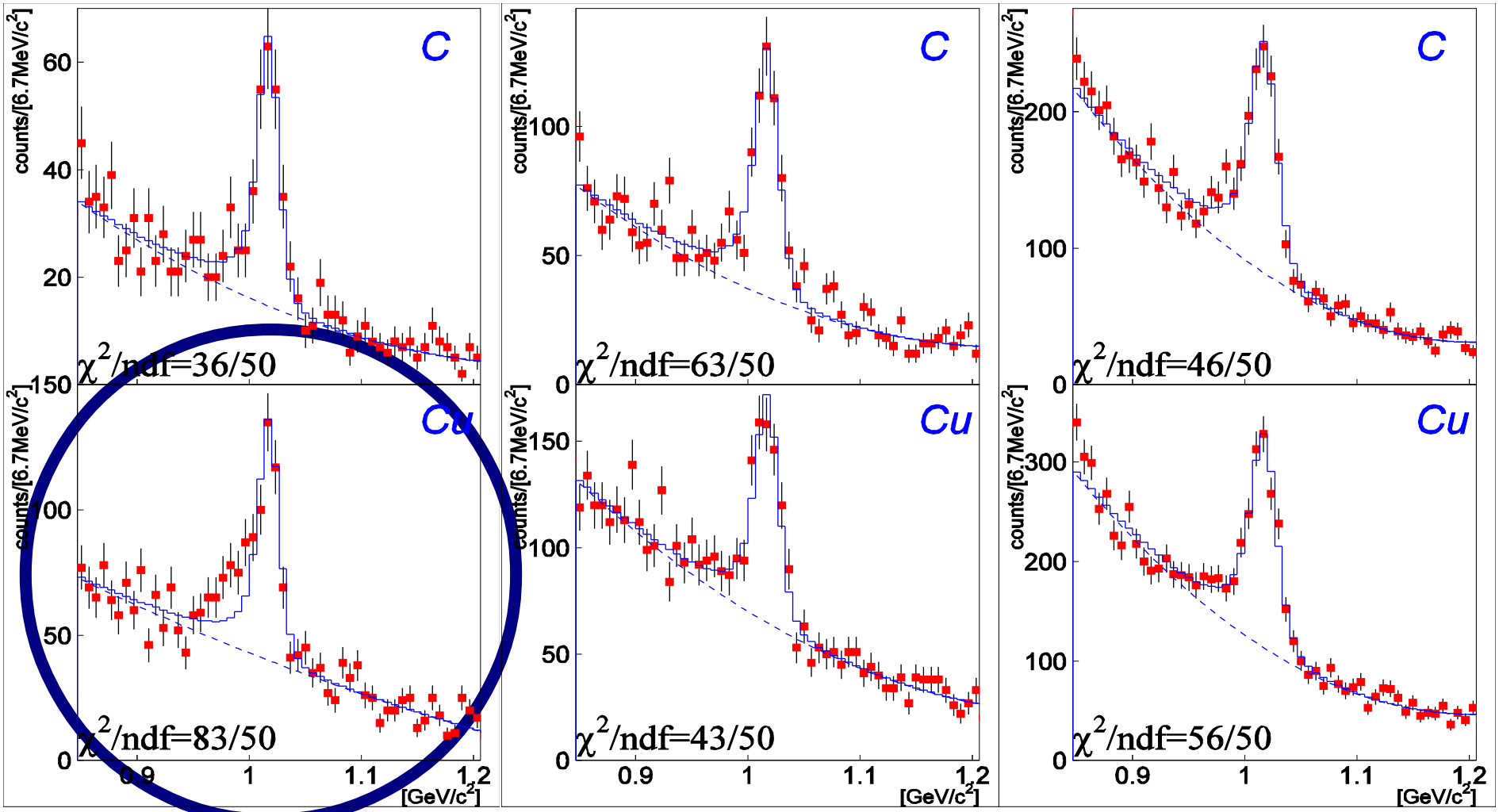

only slow/Cu is not reproduced in 99% C.L.

Dilepton spectrum measurements in the world

Mosel, Leupold, Metag (arXiv:1006.5822)

experiment	momentum acceptance	ρ	ω	ϕ
KEK-E325 pA 12 GeV	$p > 0.6$ GeV/c	$\frac{\Delta m}{m} = -9\%$ $\Delta\Gamma \approx 0$	$\frac{\Delta m}{m} = -9\%$ $\Delta\Gamma \approx 0$	$\frac{\Delta m}{m} = -3.4\%$ $\frac{\Gamma_\phi(\rho_0)}{\Gamma_\phi} = 3.6$
CLAS γA 0.6-3.8 GeV	$p > 0.8$ GeV/c	$\Delta m \approx 0$ $\Delta\Gamma \approx 70$ MeV $(\rho \approx \rho_0/2)$		
CBELSA /TAPS γA 0.9-2.2 GeV	$p > 0$ MeV/c		$\Delta m \approx 0$ $p_\omega < 0.5$ GeV/c $\Delta\Gamma(\rho_0) \approx 130$ MeV $\langle p_\omega \rangle = 1.1$ GeV/c	
SPring8 γA 1.5-2.4 GeV	$p > 1.0$ GeV/c			$\Delta\Gamma(\rho_0) \approx 70$ MeV $\langle p_\phi \rangle = 1.8$ GeV/c
CERES Pb+Au 158 AGeV	$p_t > 0$ GeV/c	broadening favored over mass shift		
NA60 In+In 158 AGeV	$p_t > 0$ GeV/c	$\Delta m \approx 0$ strong broadening		

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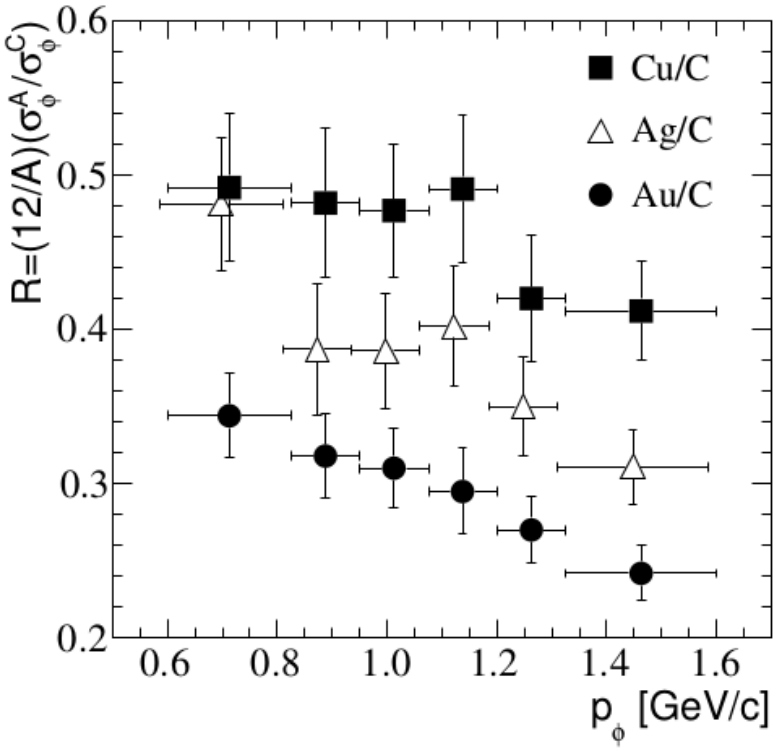
not from the spectra
but CS from the A-dep.

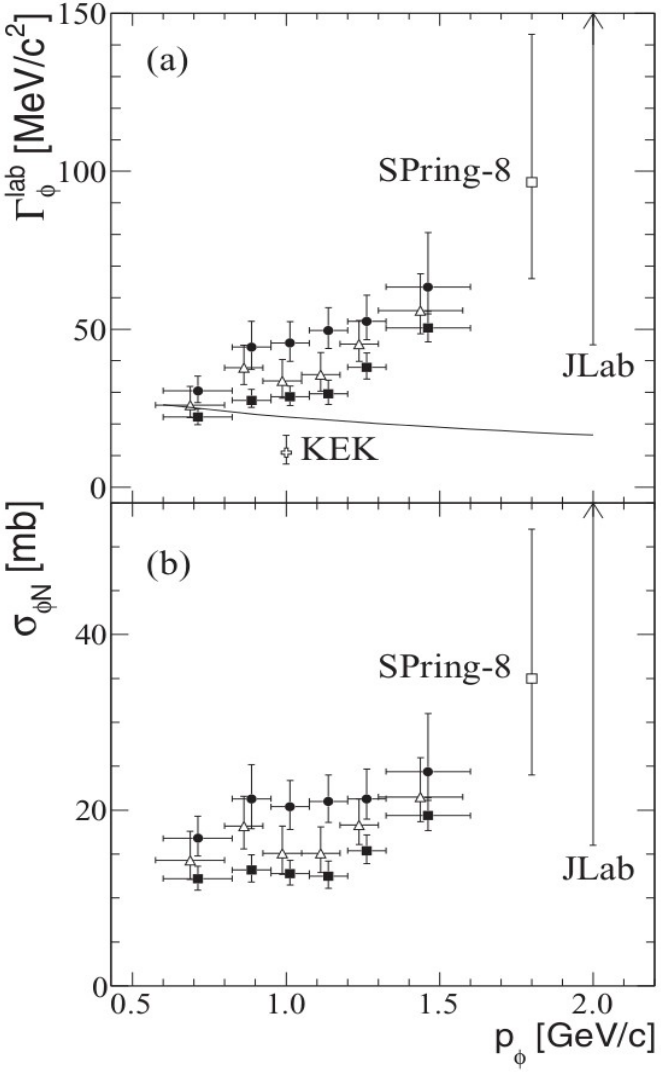
width from A-dependence of cross section

ANKE (PRC85 (2012) 035206) : 2.83 GeV p+A → ϕ → KK

A-dependence of production
σ(Cu)/σ(C) , etc.



models



E325 Results (2)

Production Cross sections

T.Tabaru et al., PRC74(2006)025201

nuclear dependence of CS : $\sigma(A)=\sigma_0 * A^{\alpha}$

$\alpha_\omega = 0.710 \pm 0.021(\text{stat.}) \pm 0.037(\text{syst.})$

$\alpha_\phi = 0.937 \pm 0.049(\text{stat.}) \pm 0.018(\text{syst.})$

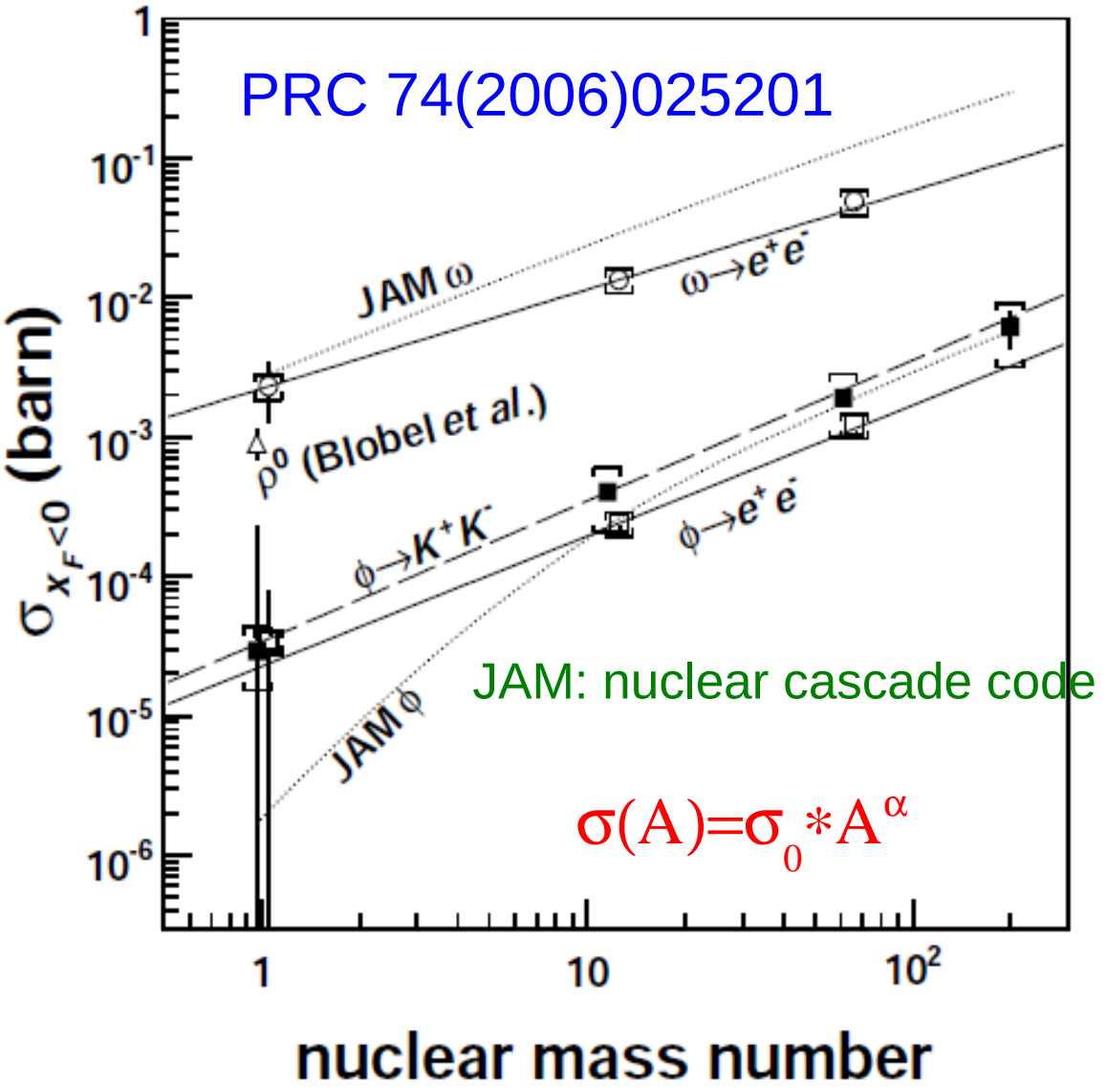
Note:

α ~2/3 : production on the surface of nucleus

α ~1 : production in the whole nucleus

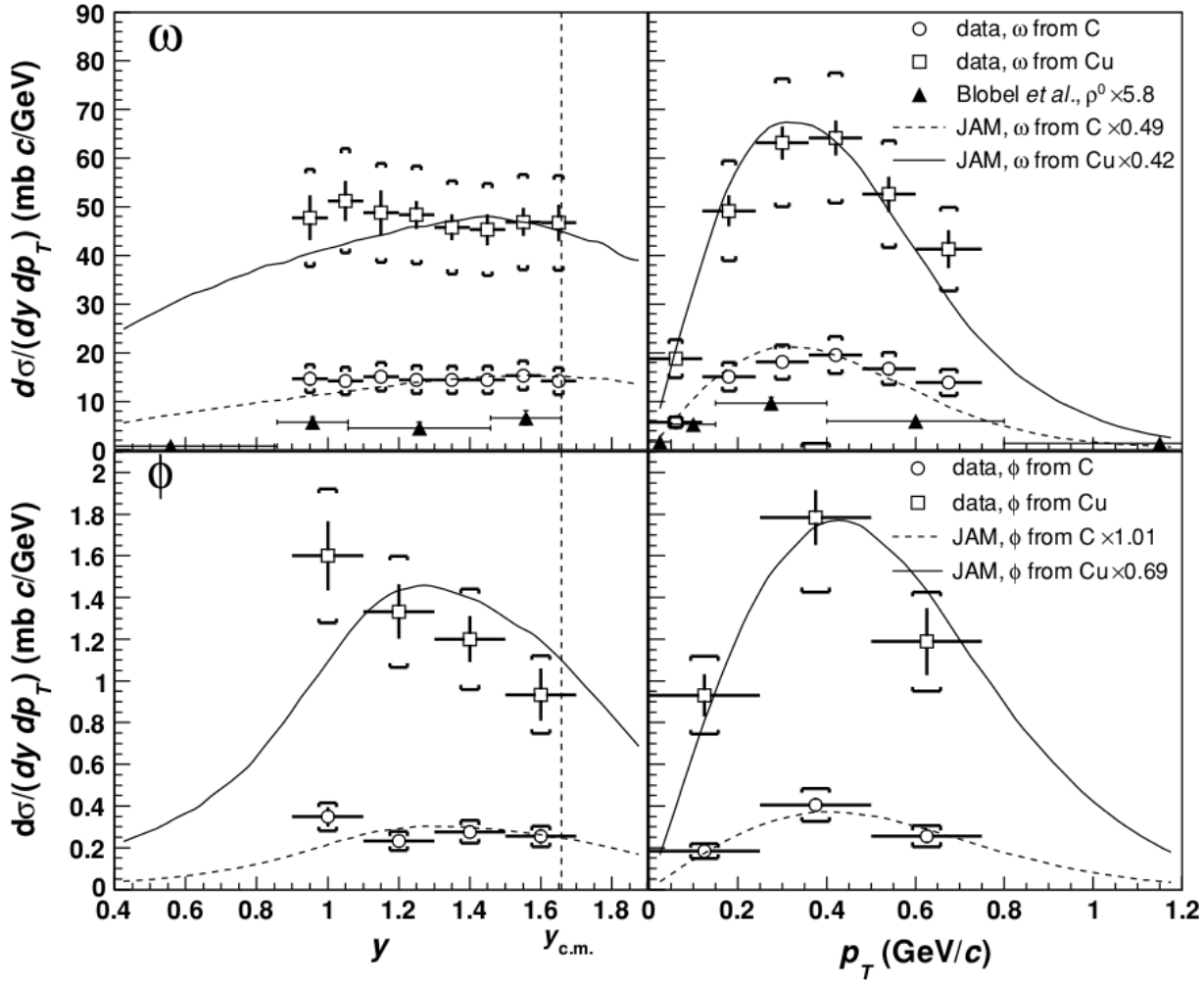
measured production CS of ω & ϕ by E325

- values for the CM backward
- consistent w/ the former measurement for ρ meson by Blobel (PLB48(1974)73)
- Nuclear dependence α_ϕ = 0.937
  corresponds to about $\sigma_{\phi N}$=3.7mb
  (Sibirtsev et.al. EPJA 37(2008)287)
- additional Γ=12 MeV for 2 GeV/c
  ϕ (β=0.9) : consistent with
  $\Gamma=15^{+8}_{-5}$ MeV (i.e. $k_2=2.6^{+1.8}_{-1.2}$)
- Remark:
  Γ_ϕ=15MeV at m_ϕ=985MeV is
  consistent with Oset & Ramos
  (NPA679(2001)616)



production mechanism of ω & ϕ ?

PRC 74(2006)025201 (E325)



different y-dependence

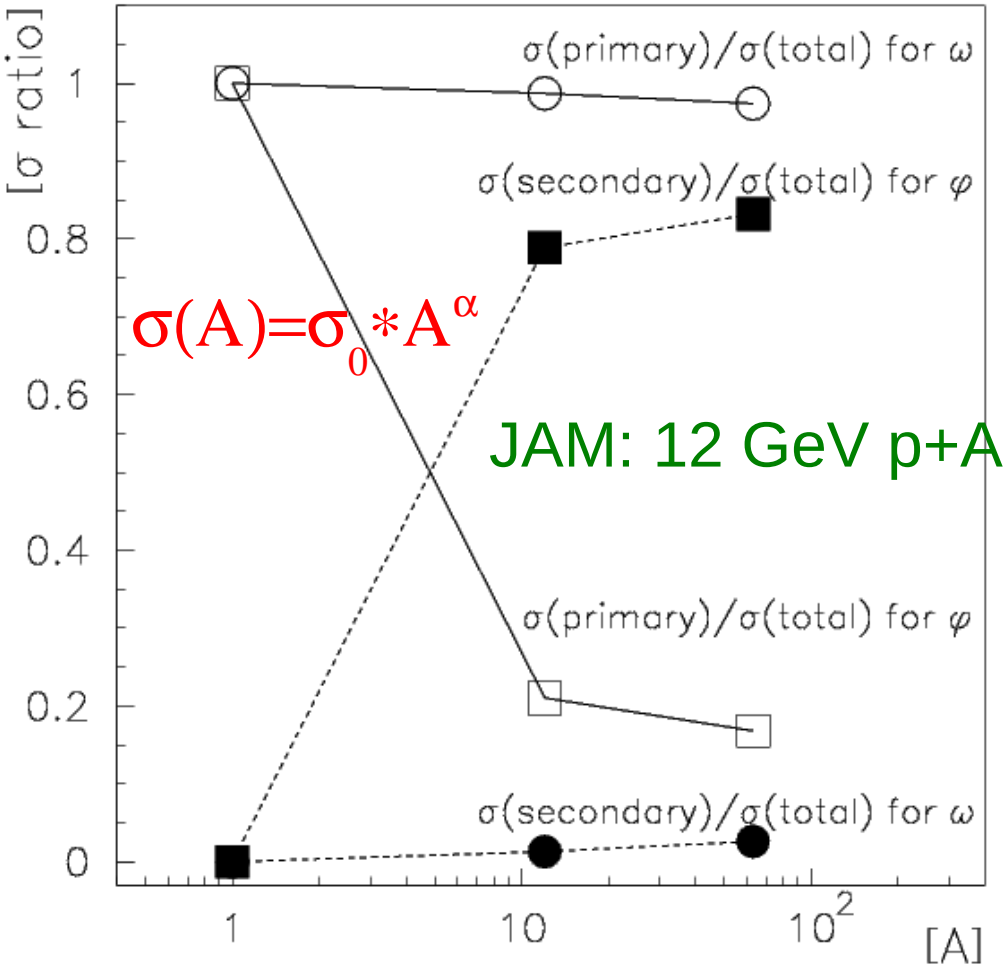
means

different production

mechanism?

G. 7. Differential cross sections of ω (top) and ϕ (bottom) mesons as functions of y (left) or p_T (right). The statistical errors are represented rtical bars, and the systematic errors are represented by brackets. The previous $p + p \rightarrow \rho^0 X$ measurement [29] is indicated by triangles peing scaled up with the nuclear mass number dependence obtained in the present analysis. The dashed and solid curves represent scaled sections of JAM in p + C and p + Cu collisions, respectively. The rapidity of the center of mass system is 1.66, as indicated by $y_{\mathrm{c.m.}}$. The oints are listed in Table VI.

production mechanism of ω & ϕ ?



Two-step production?

p+N->π +X

π+N-> ϕ +X'

why not ω?

hadronic production CS of ϕ

Sibirtsev et.al. EPJA 37(2008)287

$\sigma(A)=\sigma_0 * A^{\alpha}$

	Experiment		Ref.	α	σ_ϕ (mb)
920 GeV	HERA-B		[19]	0.96±0.02	2.1±1.2
30-70GeV	BIS-2		[20]	0.81±0.06	12±4
100 GeV	ACCMOR		[21]	0.96±0.04	2.1±2
120 GeV	NA 11		[22]	0.86±0.02	9±2
12GeV	KEK-PS E325		[23]	0.937±0.049±0.018	3.7
	y	0.9-1.1		0.916±0.101±0.022	4.9±4
	y	1.1-1.3		1.050±0.101±0.02	0±2.8
	y	1.3-1.5		0.881±0.084±0.02	7.2±5.8
	y	1.5-1.7		0.780±0.119±0.019	14±8.3
	p_t	0-0.25		0.971±0.101±0.019	1.7±7
	p_t	0.25-0.50		0.890±0.066±0.019	6.7±4.9
	p_t	0.50-0.75		0.924±0.111±0.021	4.4±4

$\alpha \sim 1$ in high energy hadronic production : 2-step production?

Summary (2)

- KEK-PS E325 measured the vector meson decays in nuclei using 12 GeV proton beam and observed spectral modification of mesons in the ee decay channel.
  - Simply-parametrized model calculation is used to analyze the data, to include the meson velocity and finite nuclear size.
    - Mass 'dropping' (9.2% for ρ/ω and 3.4% for ϕ)is required to reproduce the data.
    - ρ/ω data are reproduced without any width braodening, but ϕ.
  - Spectral shape evaluation in the real world is required for further study.
- Nuclear dependence of production cross section of ω & ϕ are also measured.
  - ϕ–N cross section is evaluated by a theory group, but possibly model-dependence is larger than that of the photoproduction case.
  - production mechanism can be determined?
- J-PARC E16 also measures the nuclear dependence at 30 GeV