Partial decay widths of the φ into e⁺e⁻ and K⁺K⁻ pairs in 12 GeV p+A reactions at KEK-PS E325

Fuminori Sakuma, RIKEN, Japan

KEK$_A$, RIKEN$_B$, Kyoto Univ.$_C$, CNS, Univ. of Tokyo$_D$, Univ. of Tokyo$_E$

J.Chiba$_A$, H.En'yo$_B$, Y.Fukao$_C$, H.Funahashi$_C$, H.Hamagaki$_D$, M.Ieiri$_A$, M.Ishino$_C$, H.Kanda$_C$, M.Kitaguchi$_C$, S.Mihara$_C$, K.Miwa$_C$, T.Miyashita$_C$, T.Murakami$_C$, R.Muto$_A$, M.Nakura$_C$, M.Naruki$_A$, K.Ozawa$_E$, O.Sasaki$_A$, M.Sekimoto$_A$, T.Tabaru$_B$, K.H.Tanaka$_A$, M.Togawa$_C$, S.Yamada$_C$, S.Yokkaichi$_B$, Y.Yoshimura$_C$

(KEK-PS E325 collaboration)

- **Introduction**

- **Results of data analysis**

  - φ → e⁺e⁻ / K⁺K⁻ spectra

  - nuclear mass-number dependences of φ→e⁺e⁻ & φ→K⁺K⁻
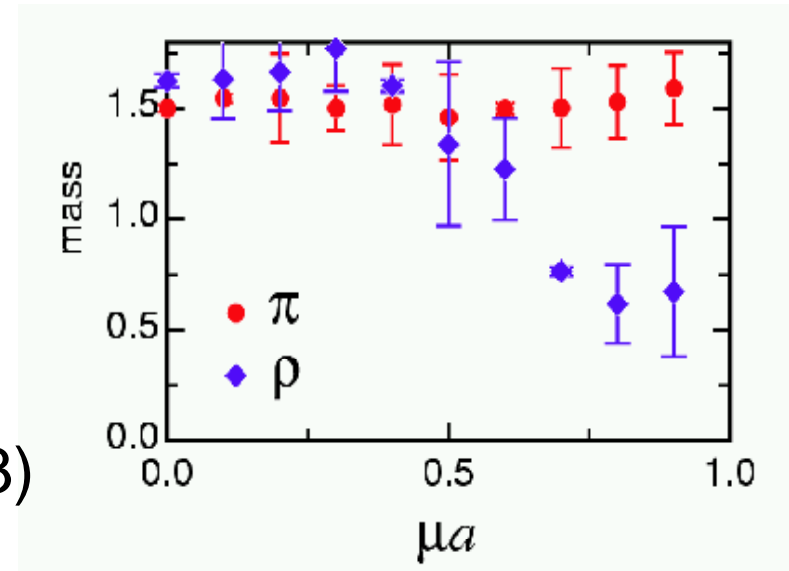
- **Summary**

chiral07
Nov.13-16,2007
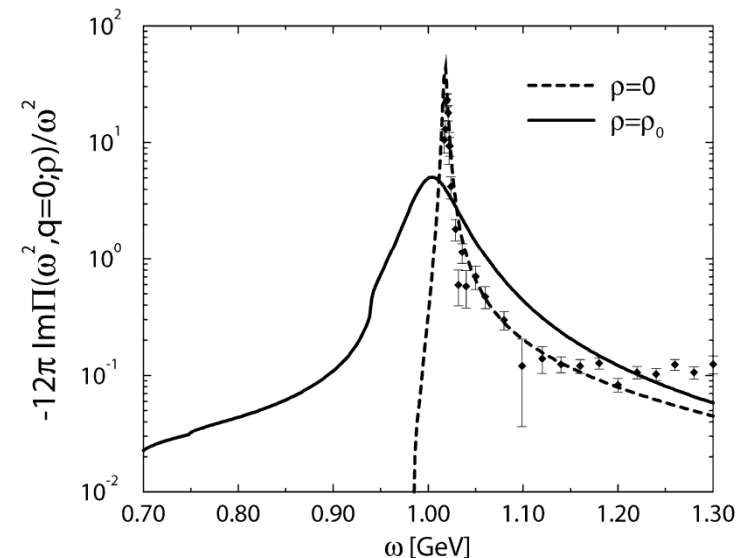
Vector Meson Modification

dropping mass

- Brown & Rho ('91)
  $m*/m=0.8$ $(\rho=\rho_0)$
- Hatsuda & Lee ('92)
  $m*/m=1-0.16\rho/\rho_0$ for ρ/ω
  $m*/m=1-0.03\rho/\rho_0$ for ϕ
- Muroya, Nakamura & Nonaka ('03)
  Lattice Calc.

width broadening

- Klingl, Kaiser & Weise ('97&98)
  1GeV> for ρ, 45MeV for ϕ $(\rho=\rho_0)$
- Oset & Ramos ('01)
  22MeV for ϕ $(\rho=\rho_0)$
- Cabrera & Vicente ('03)
  33MeV for ϕ $(\rho=\rho_0)$

KEK-PS E325 Experiment

Measurements

Invariant Mass of e⁺e⁻, K⁺K⁻

in 12GeV p+A→ρ,ω,φ+X reactions

slowly moving vector mesons
(p_{lab}~2GeV/c)
*large probability
to decay inside a nucleus*

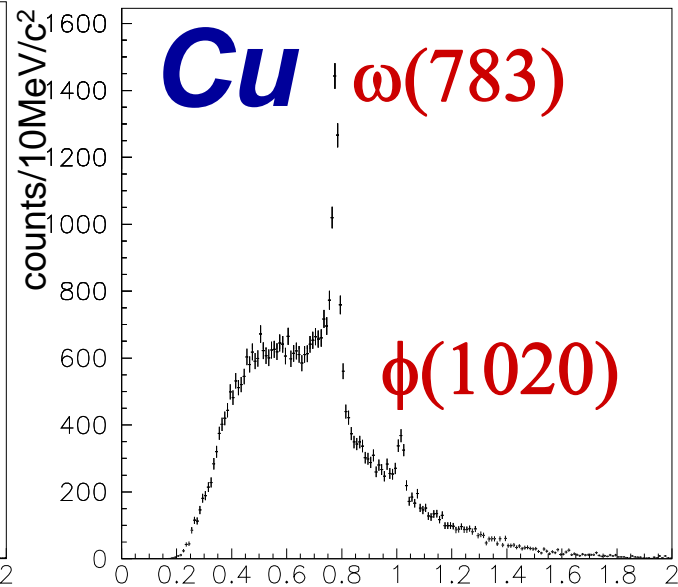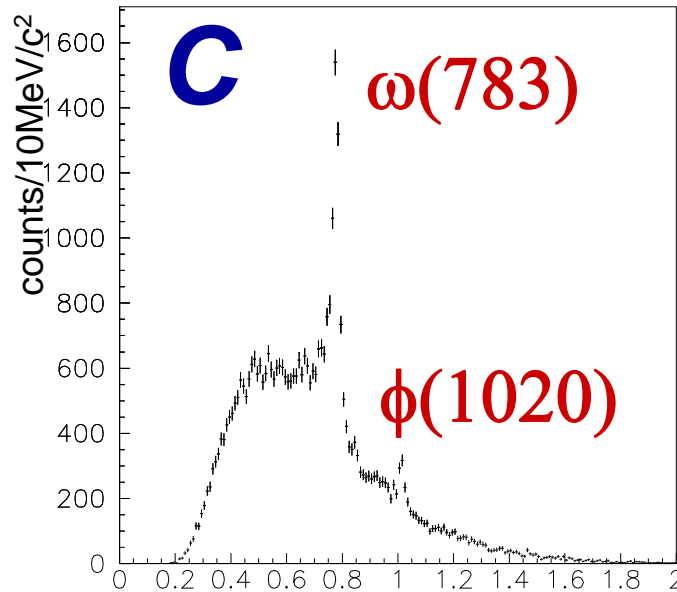## Beam

Primary proton beam
(~10^9/spill/1.8s)

Target

Very thin targets
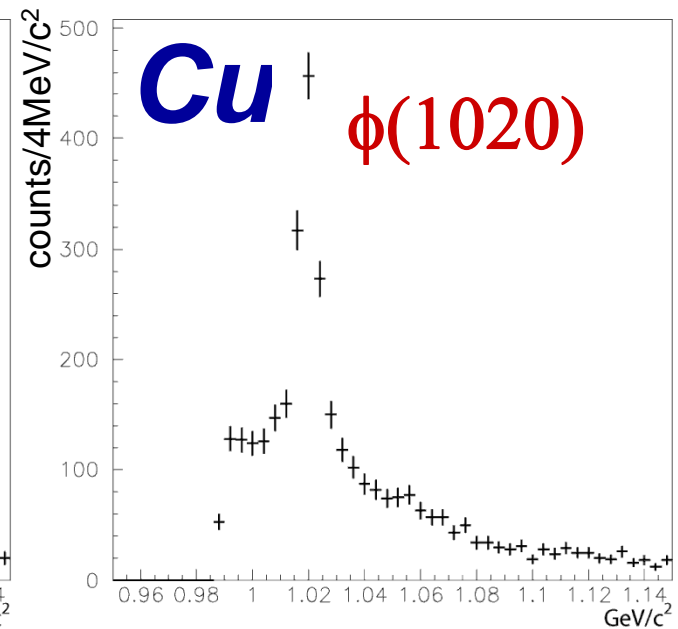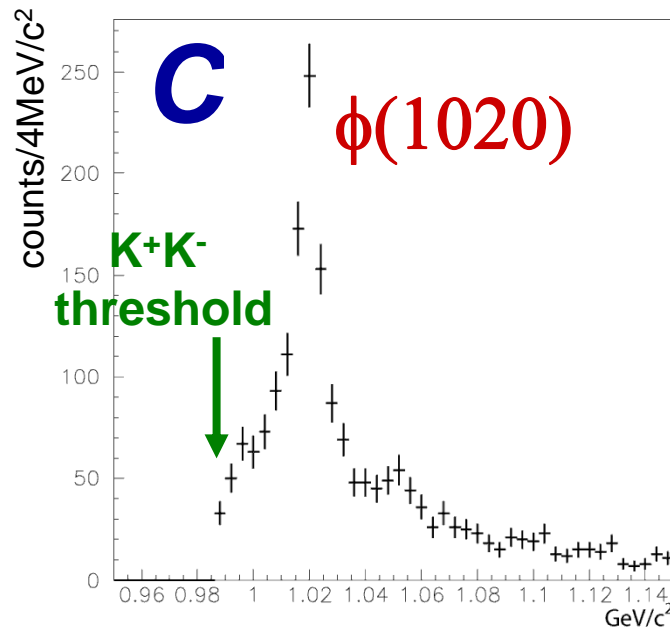(X/λ_I=0.2/0.05%,
X/X_0=0.4/0.5%   for C/Cu)

History of E325

'93 proposed

'96 construction start
- ✓ *NIM,A457,581('01).*
- ✓ *NIM,A516,390('04).*

'97 first K⁺K⁻ data

'98 first e⁺e⁻ data
- ✓ *ρ/ω: PRL,86,5019('01).*

'99~'02

x100 statistics in e⁺e⁻
- ✓ *ρ/ω: PRL,96,092301('06).*
- ✓ **φ→ee: PRL,98,042501('07).**
- ✓ *α: PR,C75,025201('06).*

x6 statistics in K⁺K⁻
- ✓ **φ→KK: PRL,98,152302('07).**

'02 completed

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Observed Invariant Mass Spectra

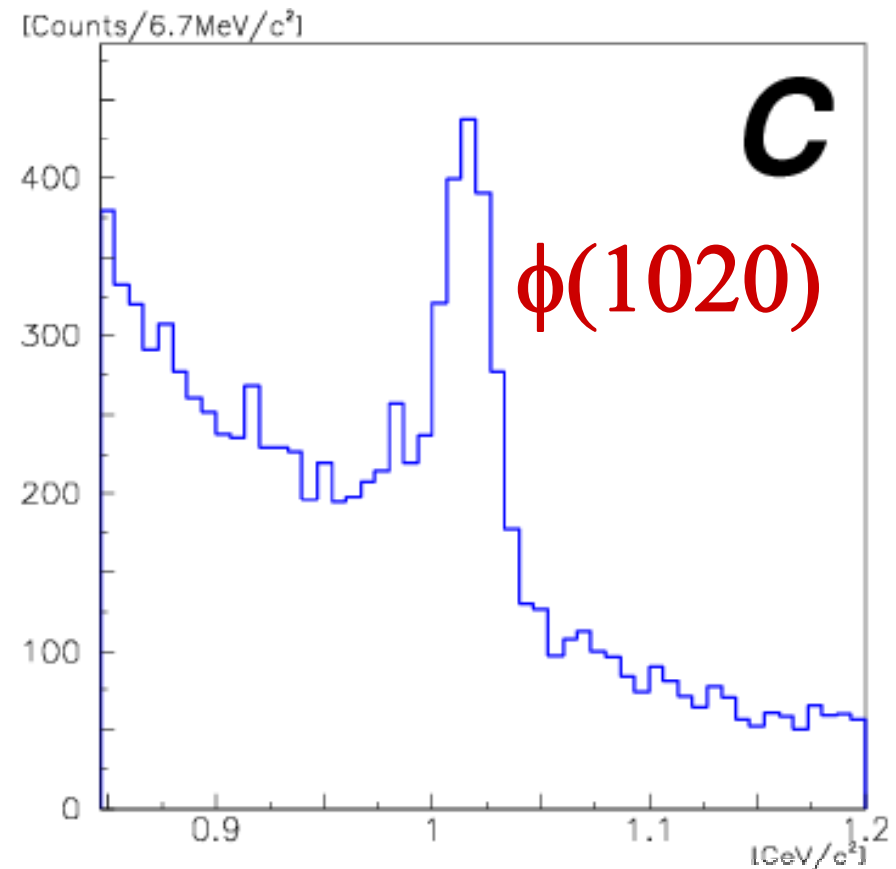# φ→e⁺e⁻ Invariant Mass Spectra

- from 2001 & 2002 run data

- C & Cu targets

- acceptance uncorrected

- fit with
  - simulated mass shape of φ
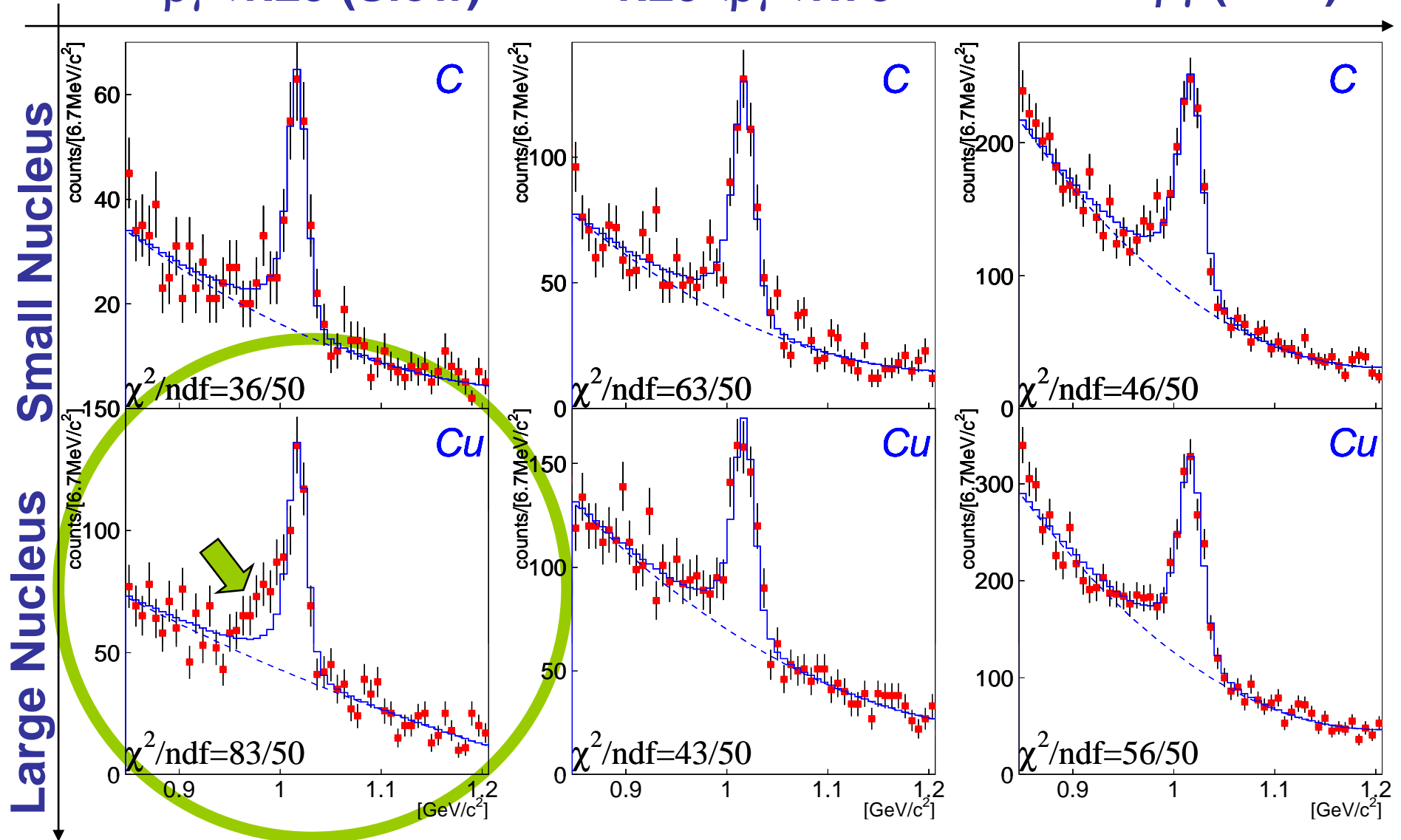 - polynomial background curve

→ **examine the mass shape as a function of βγ (=p/m)**
(anomaly could be enhanced for slowly moving mesons)

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Fitting Results

Model Calculation

- pole mass: $m^*/m = 1 - k_1\rho/\rho_0$ (Hatsuda-Lee formula)

- width broadening: $\Gamma^*/\Gamma = 1 + k_2\rho/\rho_0$

  to increase the decay probability in a nucleus

  – e+e- branching ratio is not changed

    $$\Gamma^*_{e+e-}/\Gamma^*_{tot} = \Gamma_{e+e-}/\Gamma_{tot}$$

- uniformly generated in target nucleus

  – $\alpha_\phi \sim 1$ [*PR, C75, 025201 (2006).*]
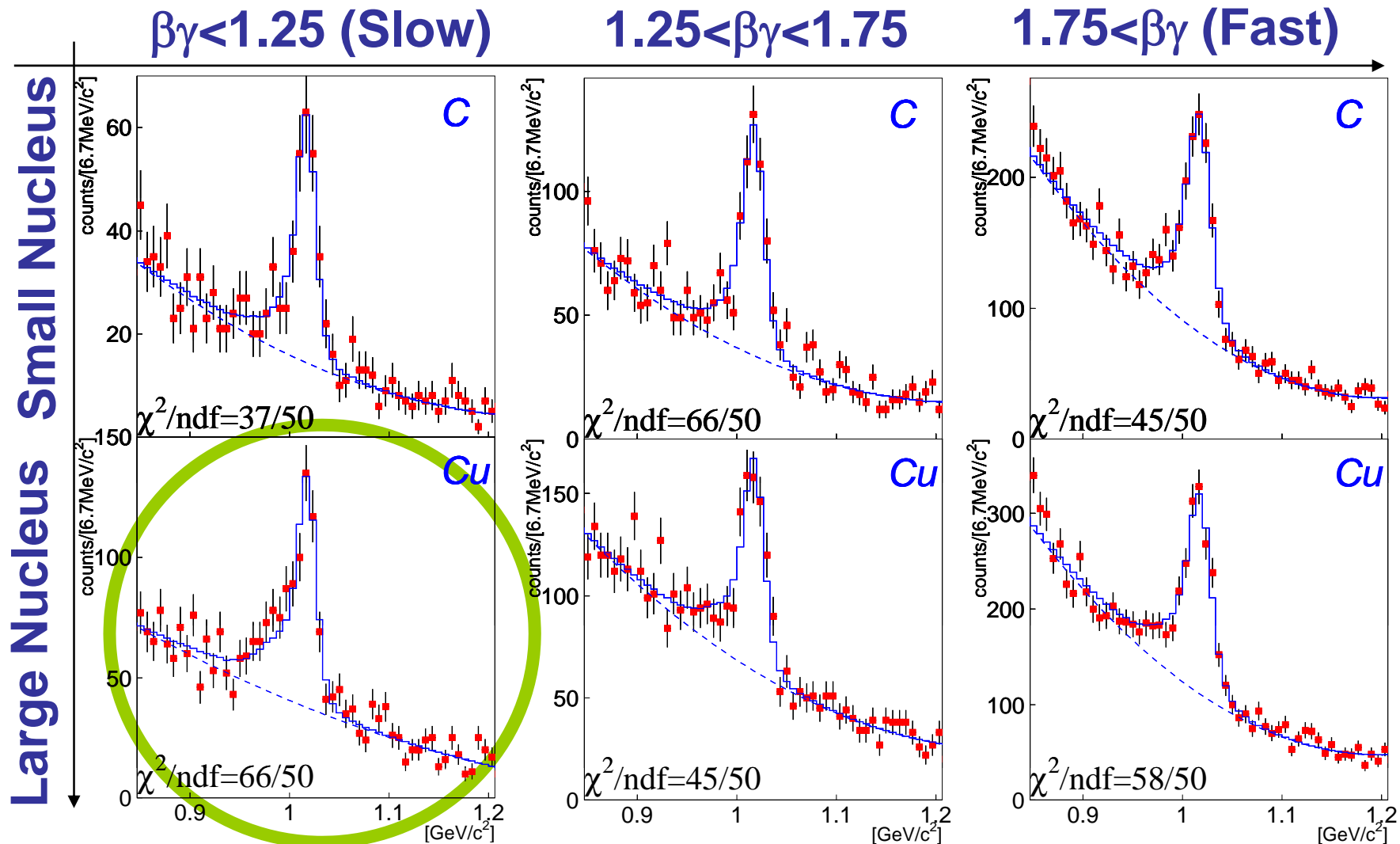
  – decay inside a nucleus (for $\beta\gamma < 1.25$):

	C	Cu
ϕ	3%	6%

p → ϕ

- nuclear density distribution : Woods-Saxon

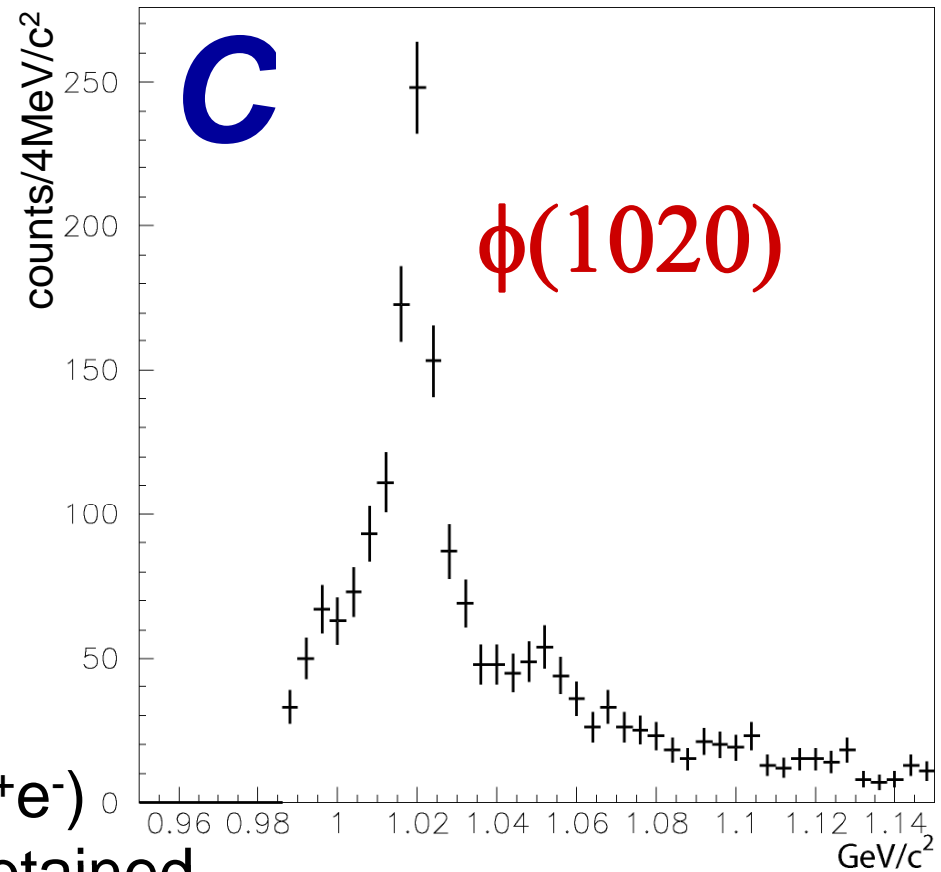# Fitting Results by the Model

$$m^*/m = 1 - 0.034\ \rho/\rho_0, \quad \Gamma^*/\Gamma = 1 + 2.6\ \rho/\rho_0$$

well reproduce the data, even slow/Cu

$\phi \rightarrow K^+K^-$ Invariant Mass Spectra

- from 2001 run data

- C & Cu targets

- acceptance uncorrected

- fit with
  - simulated mass shape of ϕ
    (evaluated as same as $\phi \rightarrow e^+e^-$)
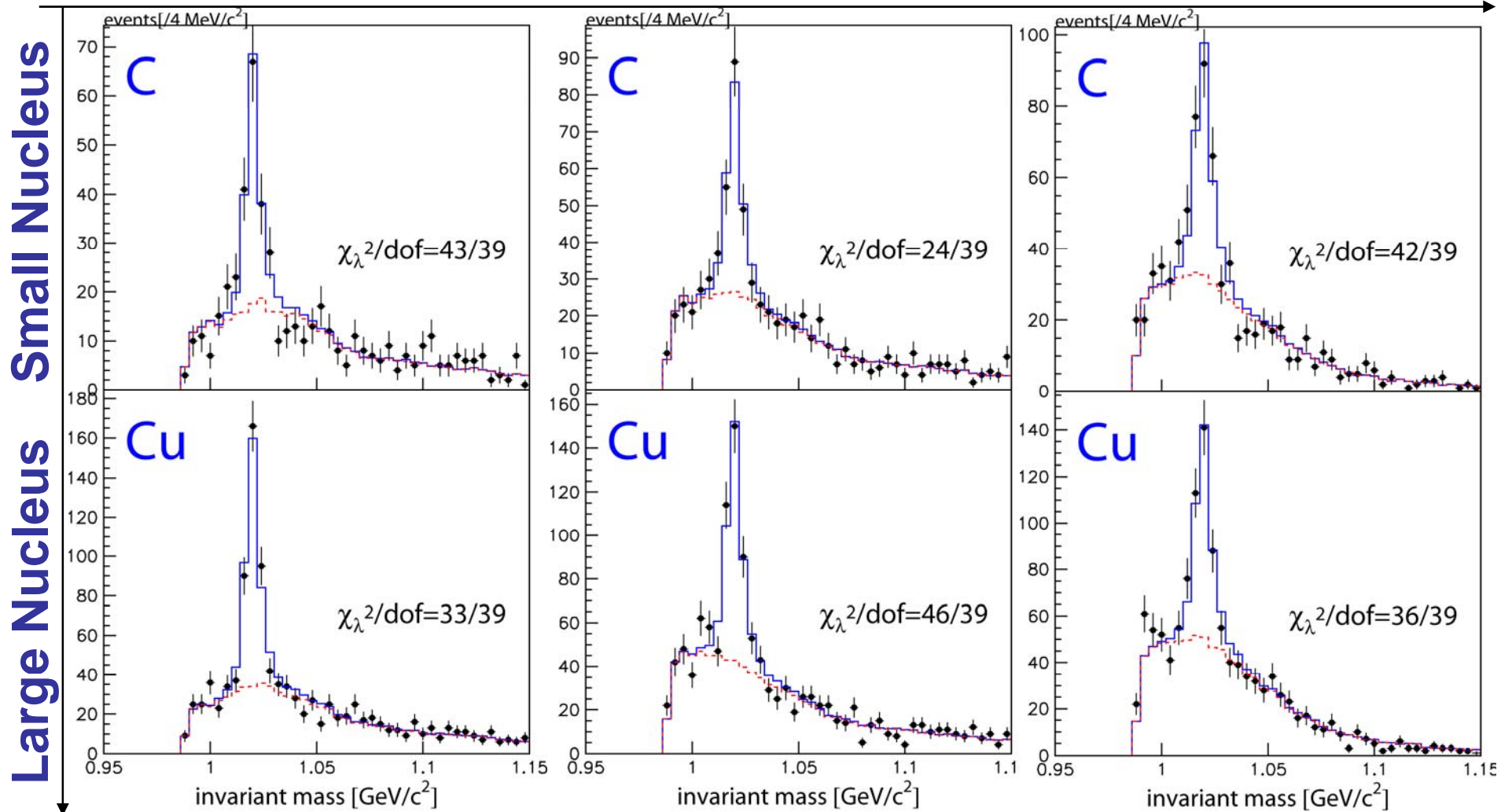 - combinatorial background obtained
    by the event mixing method

→ examine the mass shape as a function of $\beta\gamma$

Fitting Results
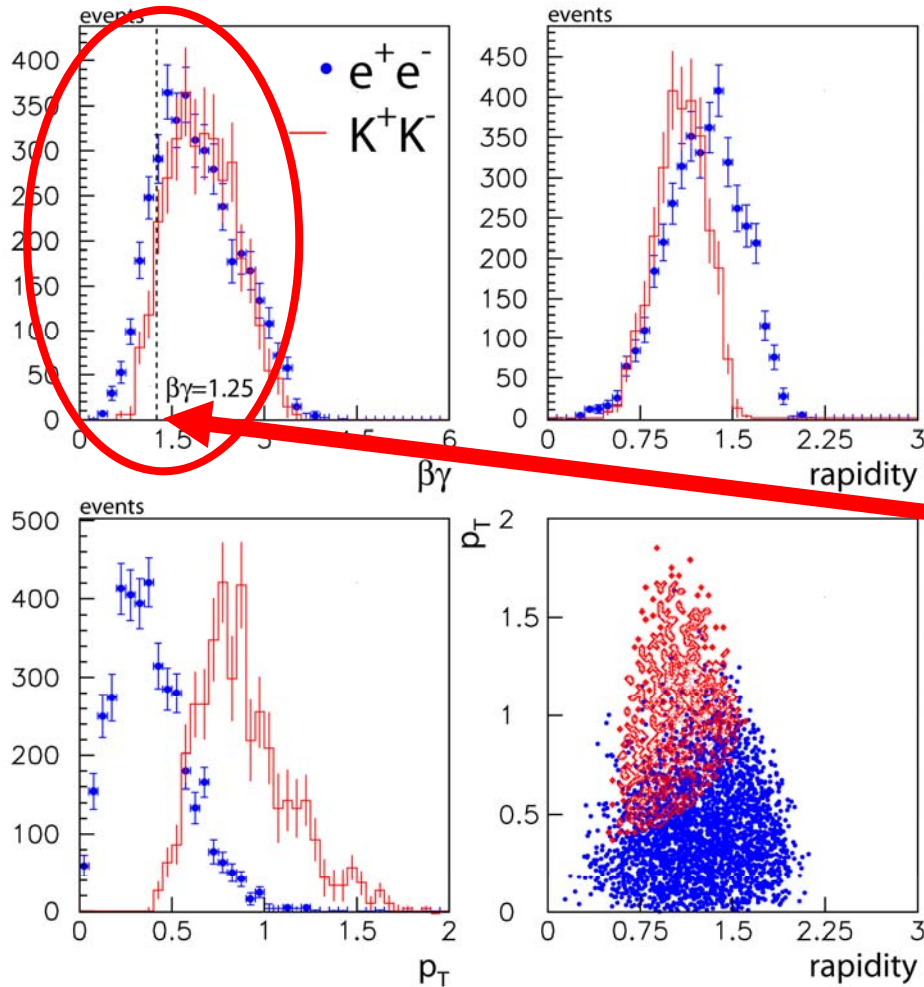
Mass-spectrum changes are NOT statistically significant

However, impossible to compare $\phi \rightarrow e^+e^-$ with $\phi \rightarrow K^+K^-$, directly

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Kinematical Distributions of observed ϕ

●the detector acceptance is different between e^+e^- and K^+K^-

●very limited statistics for $\phi \to K^+K^-$ in $\beta\gamma < 1.25$ where the modification is observed in $\phi \to e^+e^-$

the histograms for $\phi \to K^+K^-$ are scaled by a factor ~3

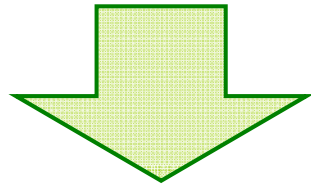*K+K- results are not inconsistent with e+e- results*

Partial Decay Widths of ϕ Meson

small decay Q value
($Q_{K+K-} = 32 \text{MeV}/c^2$)

⇒ **the decay width $\Gamma_{\phi \to K+K-}$ is sensitive to ϕ or K modification**
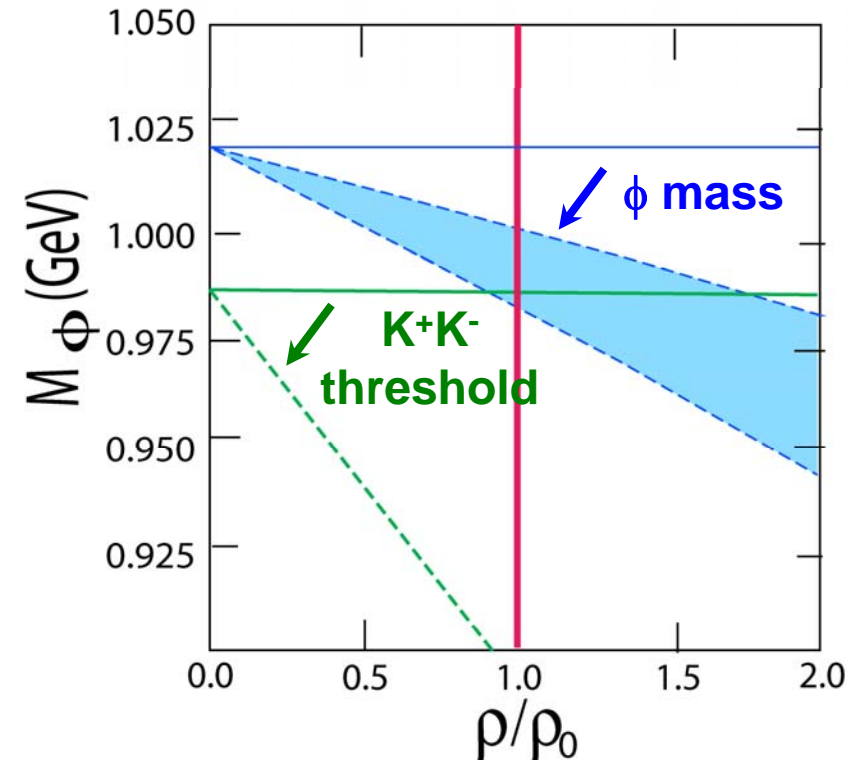
■ **ϕ mass decreases**
→ Q value becomes small
→ $\Gamma_{\phi \to K+K-}$ becomes small

■ **K mass decreases**
→ Q value becomes large
→ $\Gamma_{\phi \to K+K-}$ becomes large

ρ_0:normal nuclear density

ϕ : *T.Hatsuda, S.H.Lee, Phys. Rev. **C46**(1992)R34.*

K : *H.Fujii, T.Tatsumi, PTPS **120**(1995)289.*

$\Gamma_{\phi \to K+K^-}/\Gamma_{\phi \to e+e^-}$ and Nuclear Mass-Number Dependence α

- $\Gamma_{\phi \to K+K^-}/\Gamma_{\phi \to e+e^-}$ changes in a nucleus
  - $\to$ $N_{\phi \to K+K^-}/N_{\phi \to e+e^-}$ also changes
- The lager modification is expected in the larger nucleus
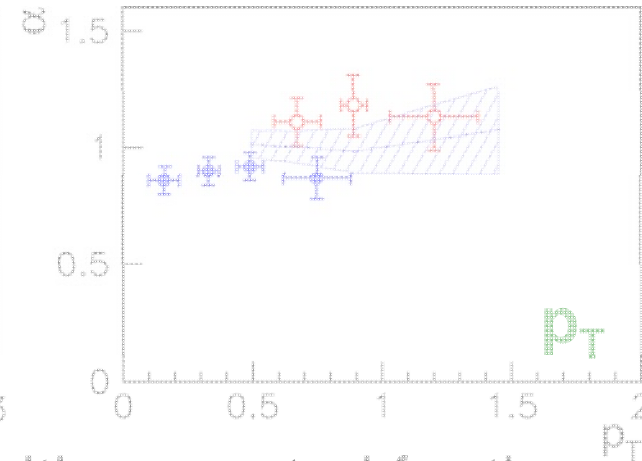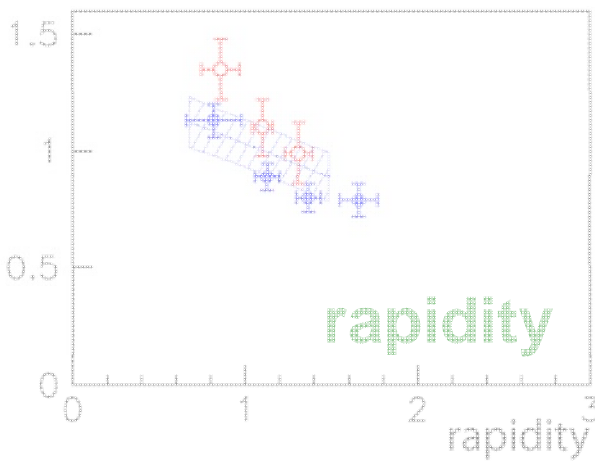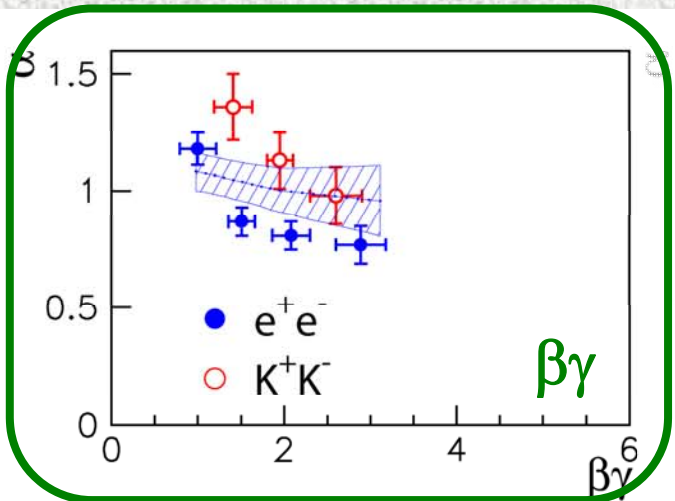
$$\sigma(A) = \sigma(A=1) \times A^{\alpha}$$

$$\Delta\alpha = \alpha_{\phi \to K^+K^-} - \alpha_{\phi \to e^+e^-} \propto \ln\left\{ \frac{\Gamma_{\phi \to K^+K^-}(A_2)}{\Gamma_{\phi \to e^+e^-}(A_2)} \middle/ \frac{\Gamma_{\phi \to K^+K^-}(A_1)}{\Gamma_{\phi \to e^+e^-}(A_1)} \right\}$$

$\Delta\alpha$ shifts from 0
(to be enhanced in slowly moving ϕ mesons)

Results of Nuclear Mass-Number Dependence α

$$\Delta\alpha = \underset{\text{K+K-}}{\bigcirc} - \underset{\text{e+e-}}{\blacksquare}$$

α_{e+e-} with corrected for the K+K- acceptance

←averaged (0.14+/-0.12)

possible **modification** of the **decay widths** is *discussed*

$\alpha_{\phi \to K+K-}$ **and** $\alpha_{\phi \to e+e-}$ **are consistent**

Discussion on broadening of $\Gamma_{\phi \to K^+ K^-}$ and $\Gamma_{\phi \to e^+ e^-}$

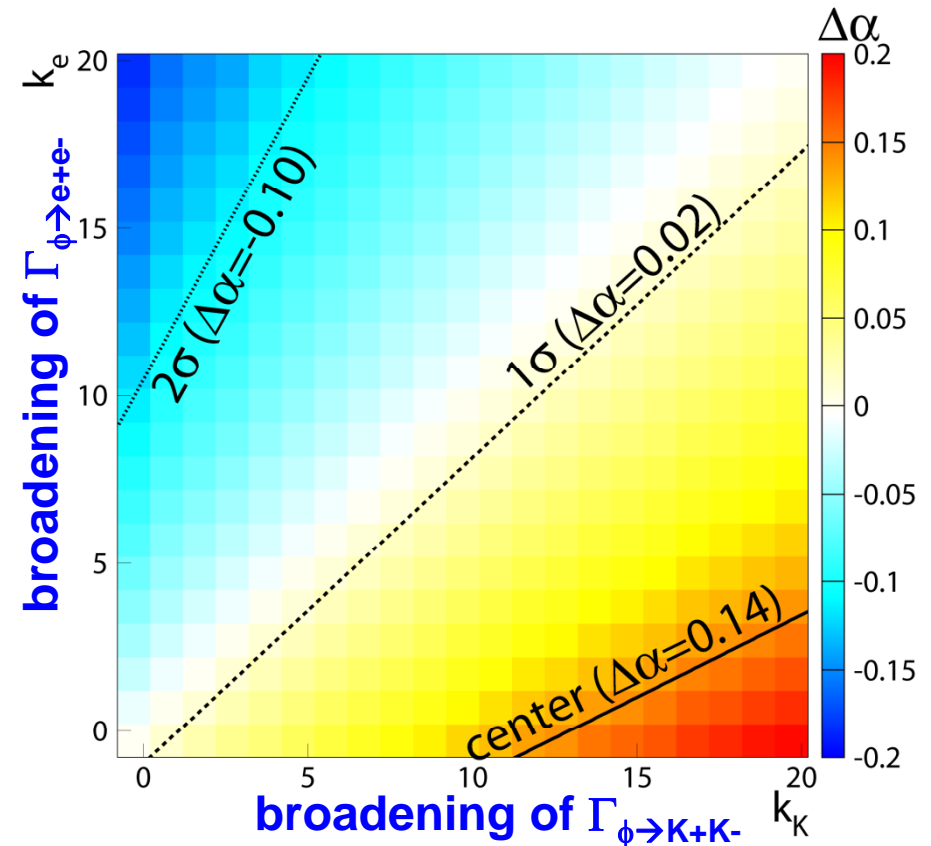$$\Gamma_\phi^* / \Gamma_\phi^0 = 1 + k_{tot}\left(\rho/\rho_0\right),$$

$$\Gamma_{\phi \to K^+ K^-}^* / \Gamma_{\phi \to K^+ K^-}^0 = 1 + k_K\left(\rho/\rho_0\right),$$

$$\Gamma_{\phi \to e^+ e^-}^* / \Gamma_{\phi \to e^+ e^-}^0 = 1 + k_e\left(\rho/\rho_0\right)$$

$$k_{tot} \simeq k_K$$

ϕ meson mainly decays into KK as long as such decays are kinematically allowed

① **The values of expected $\Delta\alpha$ are obtained by the MC.**
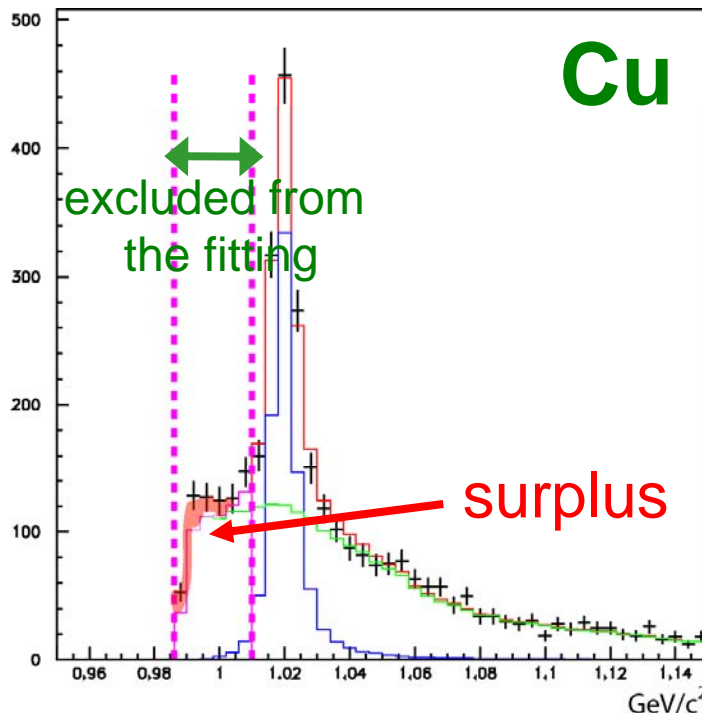
  – ϕ mesons are uniformly produced in a nucleus and decayed according to the values of k_K and k_e.

② **The measured $\Delta\alpha$ provides constraints on k_K and k_e.**

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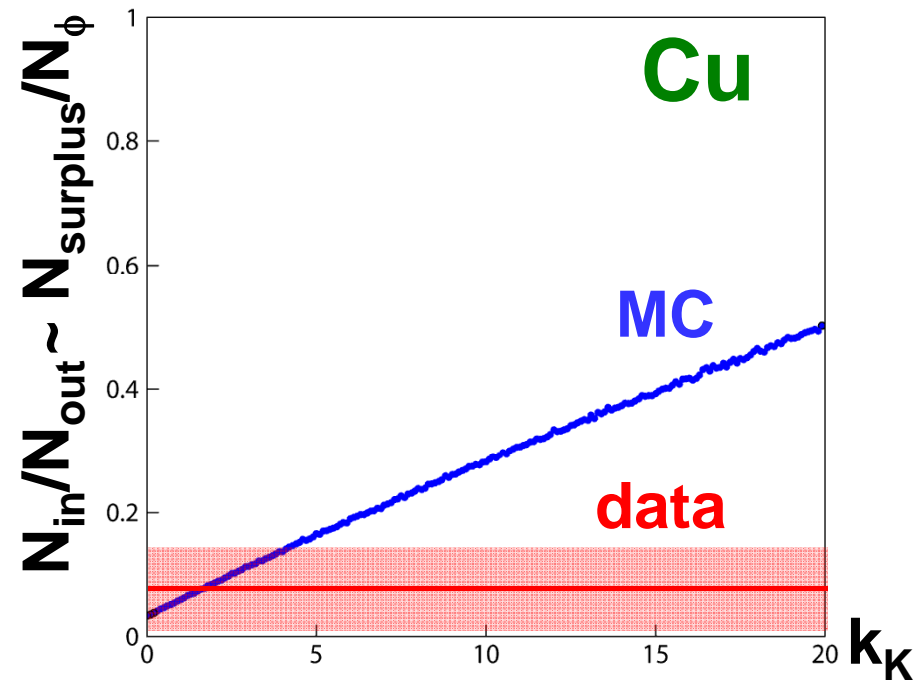# Discussion on broadening of $\Gamma_{\phi \to K+K-}$ and $\Gamma_{\phi \to e+e-}$

③ The constraint on k_K is obtained from the K^+K^- spectra.

– In the K^+K^- spectra, we fit again excluding the region $0.987(=2m_k) \sim 1.01 GeV/c^2$.

– We obtain a surplus over the ϕ peak and BG.

– From the MC, we estimate the ratio of the number of ϕ mesons decayed inside to outside N_{in}/N_{out} (inside = the half-density radius of the Woods-Saxon dist.).

– When the surpluses are assumed as the ϕ-meson decayed inside a nucleus, we obtain the constraint on k_K by comparing DATA with MC

$N_{surplus}/N_{\phi} = 0.044+/-0.037+/-0.058$ (C)
$0.076+/-0.025+/-0.043$ (Cu)

$k_K = 2.1+/-1.2+/-2.1$ (C&Cu)

$$\Gamma_\phi^* / \Gamma_\phi^0 = 1 + k_{tot}(\rho/\rho_0),$$

$$\Gamma_{\phi \to K^+ K^-}^* / \Gamma_{\phi \to K^+ K^-}^0 = 1 + k_K(\rho/\rho_0),$$

$$\Gamma_{\phi \to e^+ e^-}^* / \Gamma_{\phi \to e^+ e^-}^0 = 1 + k_e(\rho/\rho_0)$$

$$k_{tot} \simeq k_K$$

④**Limits on the in-medium decay widths are obtained.**

– We renormalize the PDF eliminating an unphysical region corresponding to $\Gamma^*/\Gamma < 0$, and obtain the 90% confidence limits.

the first experimental limits assigned to the in-medium broadening of the partial decay widths

Summary

- **KEK PS-E325** measured e^+e^- and K^+K^- invariant mass distributions in 12GeV p+A reactions.

- The **significant excesses at the low-mass side of ϕ-meson peak** have been observed in very low $\beta\gamma$ region of Cu target.

- In higher $\beta\gamma$ region or C target, the observed ϕ-meson are consistent with the expected shape in vacuum.

- The observed **nuclear mass-number dependences of $\phi \rightarrow e^+e^-$ and $\phi \rightarrow K^+K^-$** are consistent.