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# Φ-meson nuclear transparency in proton-nucleus collisions

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for the ANKE collaboration

STORI'11, Frascati, Octorber 11th 2011

# Scope of the talk

- Physics motivation
- Experiment at ANKE
- Data analysis
- Results and discussion

# Φ in free space

- Meson spectral function:

$$S(m) = \frac{1}{\pi} \frac{\Gamma_0/2}{(m - m_0)^2 + (\Gamma_0/2)^2},$$

$m_0$ – pole mass, $\Gamma_0$ – meson width

$m_0$ = 1.0195 GeV

$\Gamma_0$ = 4.26 MeV

(PDG 2008)

- Φ is a long-lived meson:

$$\lambda_{dec} = \hbar c/\Gamma_0 = 44 \text{ fm} >> \text{R(Au)}$$

# Φ in nuclear matter

- Meson spectral function:

$$S^*(m) = \frac{1}{\pi} \frac{\overbrace{(\Gamma_0 - 2\mathrm{Im}\,U_{opt})/2}^{\Gamma^*}}{(m - (m_0 + Re U_{opt}))^2 + (\underbrace{(\Gamma_0 - 2\mathrm{Im}U_{opt})/2}_{\Gamma^*})^2},$$

- A general picture of numerous studies in different approaches, e.g. effective Lagrangians and QCD sum rules:

  - mass modification is small

  - main medium effect on the Φ is significant increase of its width up to an order of magnitude

# Methods of Φ in-medium width measurement I

- Study of the meson spectral function – measurement of low momentum Φ's:

  - $\Phi \rightarrow e^+e^-$ (BR = $3 \cdot 10^{-4}$)
  - $\Phi \rightarrow K^+K^-$ (BR = 0.49, $K^-$ FSI, hadronic potential)

- Experiments:

**KEK-PS-E325:**

Reaction: $pA \rightarrow \Phi X$, $\Phi \rightarrow e^+e^-$

p-Energy: 12 GeV

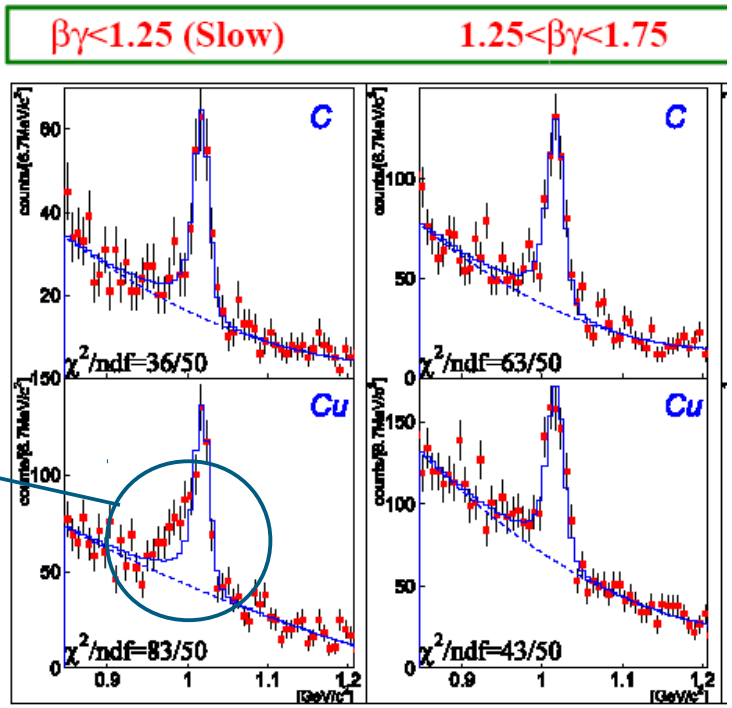
Targets: C, Cu

Result: $\Gamma^*/\Gamma_0 = 3.6$,

$\Gamma^* \approx 11$ MeV for $\langle p_\Phi \rangle = 1$ GeV/c

$\Delta m/m_0 = -3.4\%$

at $\rho = \rho_0$




R.Muto *et al.*,
PRL 98 (2007) 042501

# Methods of Φ in-medium width measurement II

- Attenuation measurement of the Φ flux – analysis of the target mass dependence for the Φ production cross section

The Φ survival probability *D* in the nucleus matter rest frame:

$$D = \exp\left(-\int_z^{\infty} dl \, \frac{\Gamma^*\left(p_\Phi, \rho(r)\right) m_0}{p_\Phi}\right), \qquad \rho(r) \text{ – local nuclear density.}$$

- Experiments:

**Spring-8/LEPS:**
Reaction: $\gamma A \to \Phi X$, $\Phi \to K^+K^-$
γ-Energy: 1.5 - 2.4 GeV
Targets: Li, C, Al, Cu
Result: $\sigma^*_{\Phi N} = 35^{+17}_{-11}$ mb
$\Gamma^* \approx 100$ MeV
for $\langle p_\Phi \rangle = 1.8$ GeV/c

T. Ishikawa *et al.*,
PLB 608 (2005) 215

**JLab/CLAS:**
Reaction: $\gamma A \to \Phi X$, $\Phi \to e^+e^-$
γ-Energy: up to 4 GeV
Targets: $^2$H, C, Ti-Fe, Pb
Result: $\sigma^*_{\Phi N}$ = 16-70 mb

M.H. Wood *et al.*,
PRL 105 (2010) 112301

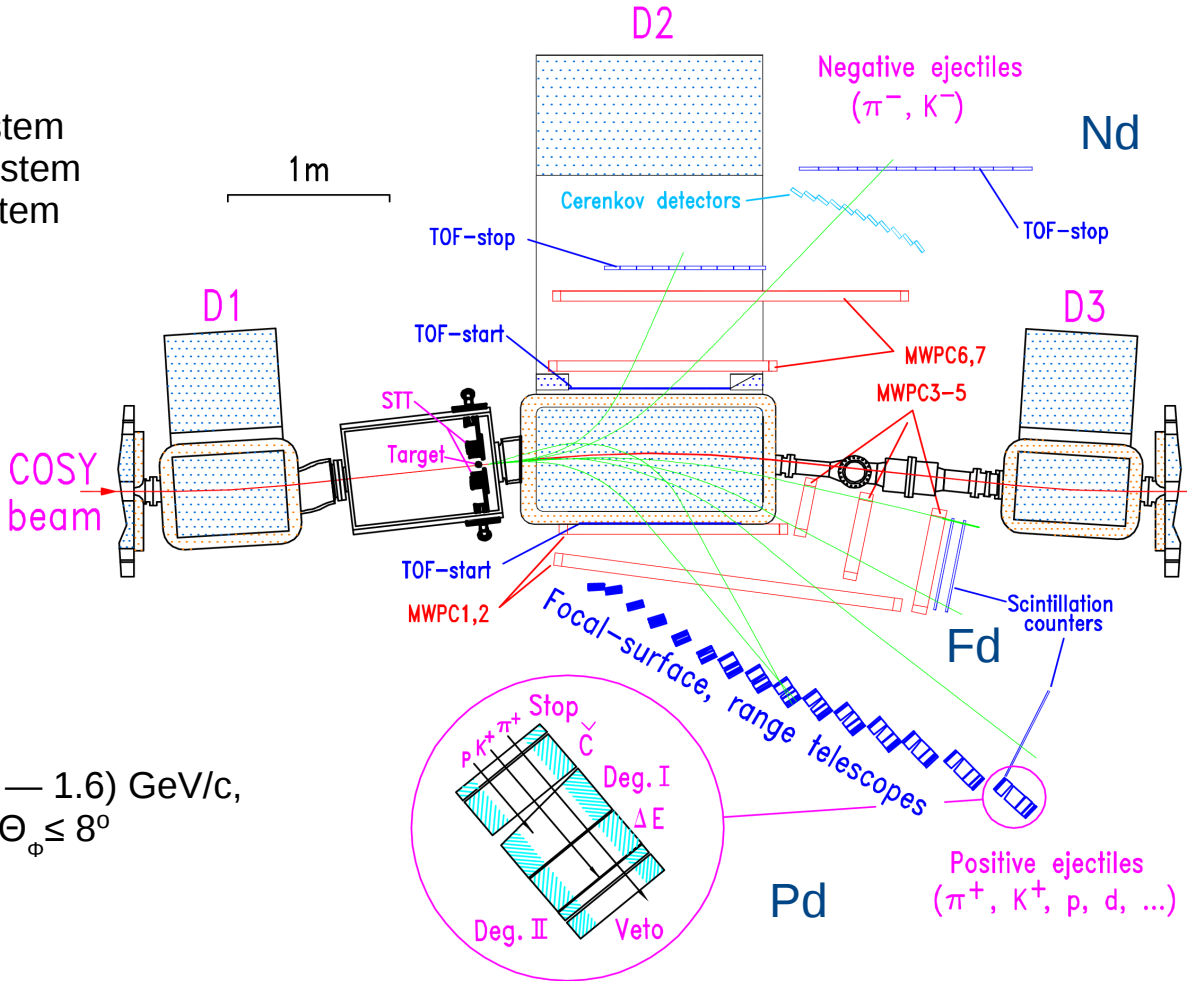
**COSY/ANKE:**
Reaction: $pA \to \Phi X$, $\Phi \to K^+K^-$
p-Energy: 2.83 GeV ($\varepsilon_{NN} \approx 76$MeV)
Targets: C, Cu, Ag, Au
Result: $\Gamma^* = 33$-$50$ MeV
for $\langle p_\Phi \rangle = 1.1$ GeV/c

A.Polyanskiy *et al.*,
PLB 695 (2011) 74

In the low density approximation: $\Gamma^*_{lab}(\rho_0) = \frac{p_\Phi}{E}\sigma^*_{\Phi N}\rho_0$

# ANKE – forward angle magnetic spectrometer at internal target position of COSY

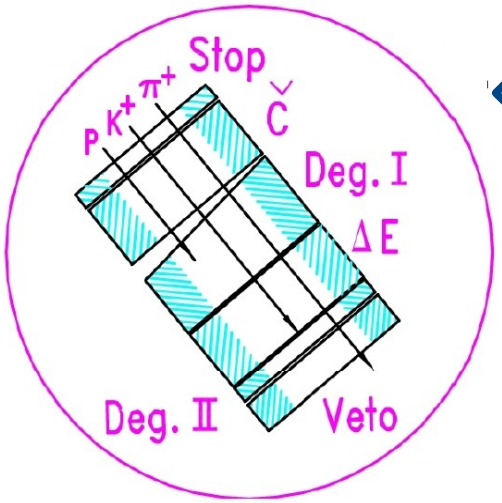
Pd – positive detector system
Nd – negative detector system
Fd – forward detector system

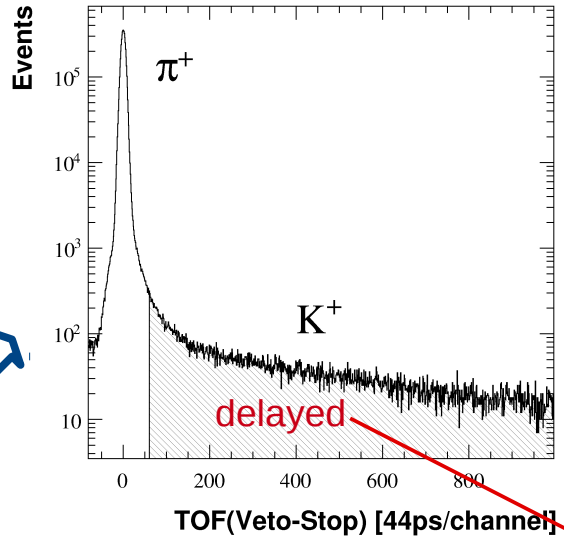


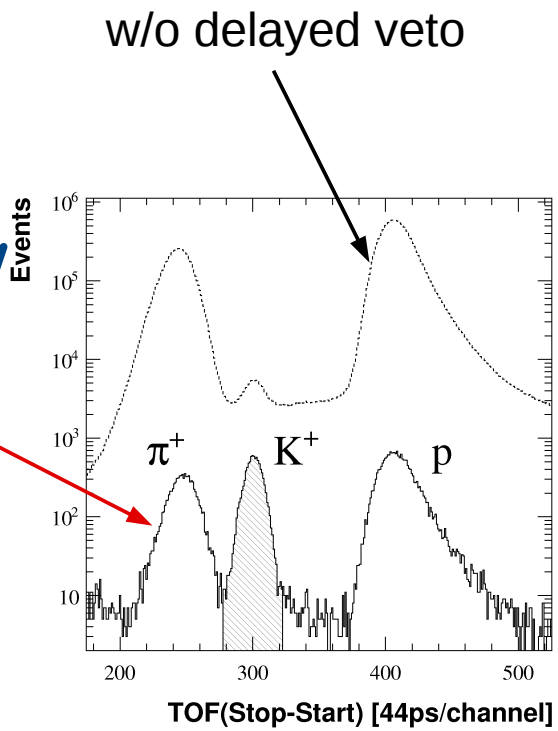

Φ momentum (0.6 — 1.6) GeV/c,
and angular range: $0^o \leq \Theta_\phi \leq 8^o$

# Analysis: $K^+$ selection

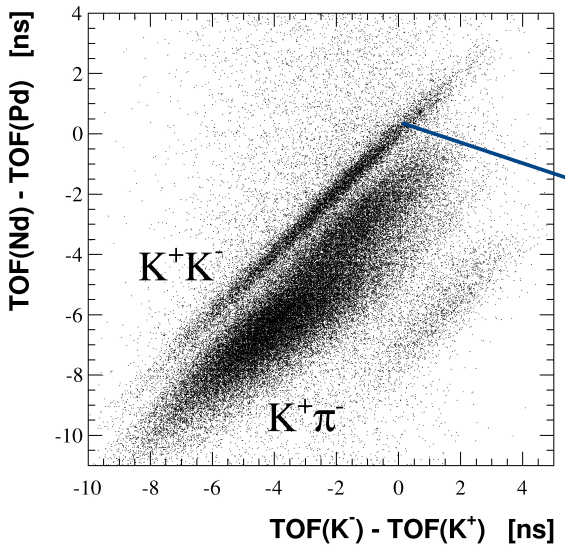
- Delayed Veto Technique
- TOF Stop-Start

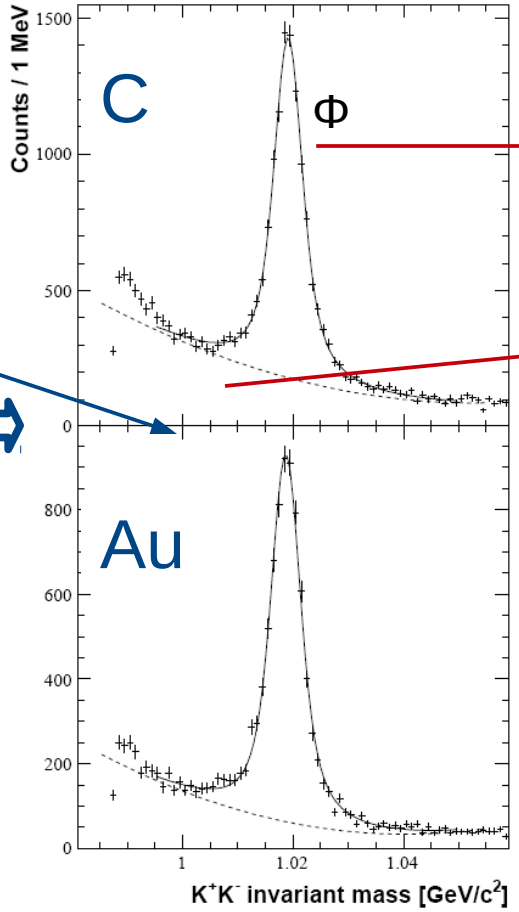


# Analysis: Φ/$K^+K^-$ pairs identification




$pA \rightarrow \Phi X$

$pA \rightarrow K^+K^-X$
"+"
background

7000-10000 Φ's
for each target
(C, Cu, Ag Au)

# A-dependence of Φ production cross section

- A-dependence in the form:

$$R = \frac{T_A}{T_C} = \frac{12}{A}\frac{\sigma_\phi^A}{\sigma_\phi^C} \qquad T_A = \frac{\sigma_\phi^A}{A\,\sigma_\phi^N}$$

$T_A$ – nuclear transparency ratio

- Absolute and relative normalization of the Φ production cross section – use of the know pion data:

relative normalization:

$$\frac{\sigma_\phi^A}{\sigma_\phi^C} = \frac{N_\phi^A}{N_\phi^C}\frac{N_\pi^C}{N_\pi^A}\frac{\sigma_\pi^A}{\sigma_\pi^C} \qquad \frac{\sigma_\pi^A}{\sigma_\pi^C} = \left(\frac{A}{12}\right)^{\alpha_\pi}$$

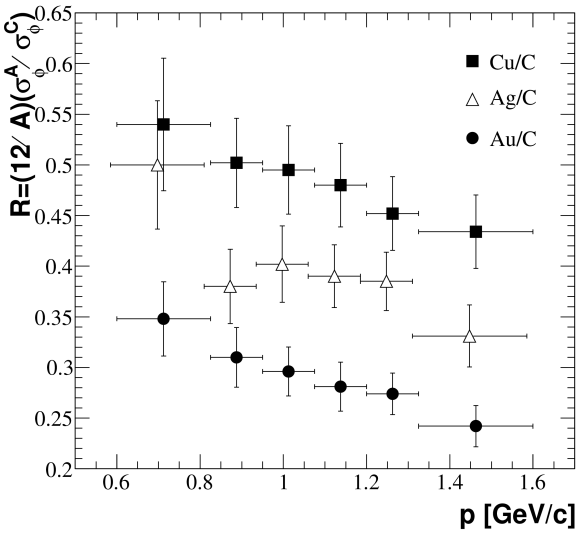
$\pi^+$: p = 0.5 GeV/c, θ ~ $0^0$

$\alpha_\pi$ = 0.38 +/- 0.02

J. Papp et al., Phys. Rev. Lett. 34 (1975) 601;
V. V. Abaev et al., J. Phys. G 14 (1988) 903;
Yu. T. Kiselev et al., Preprint ITEP 56-96, Moscow (1996).

# Transparency ratio: experiment

ANKE(preliminary)



# Transparency ratio: experiment and models

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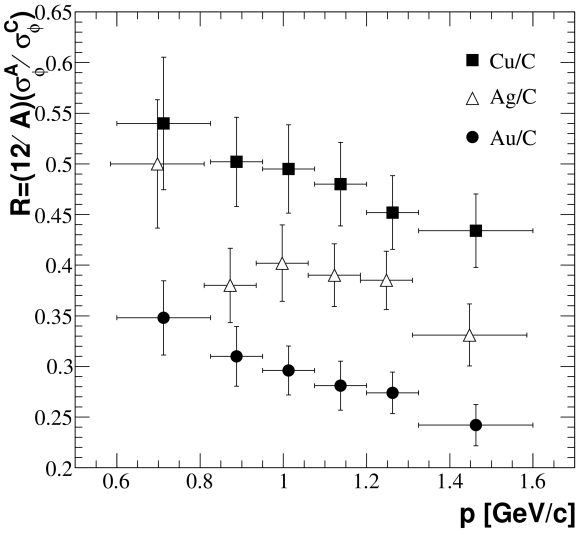
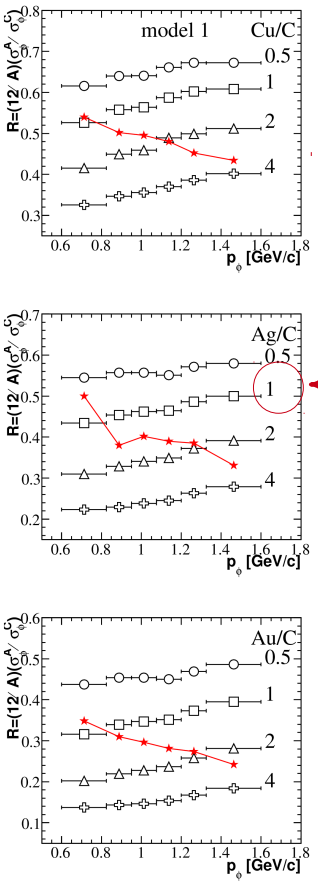
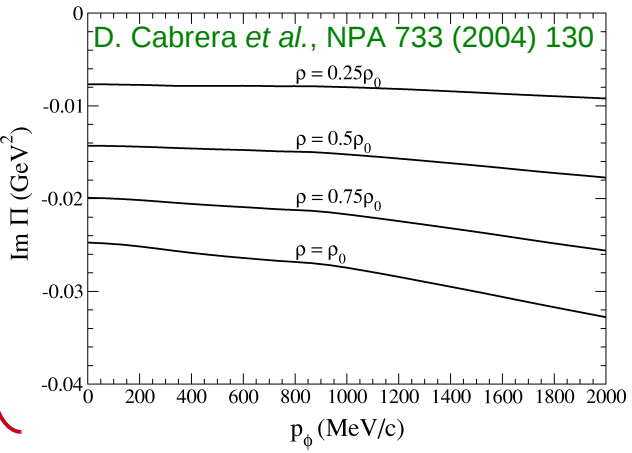



Valencia/E.Oset et al.
MC & Chiral Unitary Approach




V.Magas *et al.*, PRC 71 (2005) 065202; L.Roca (private communication)




Prediction: 28 MeV for Φ at rest for $\rho=\rho_0$

# Transparency ratio: experiment and models

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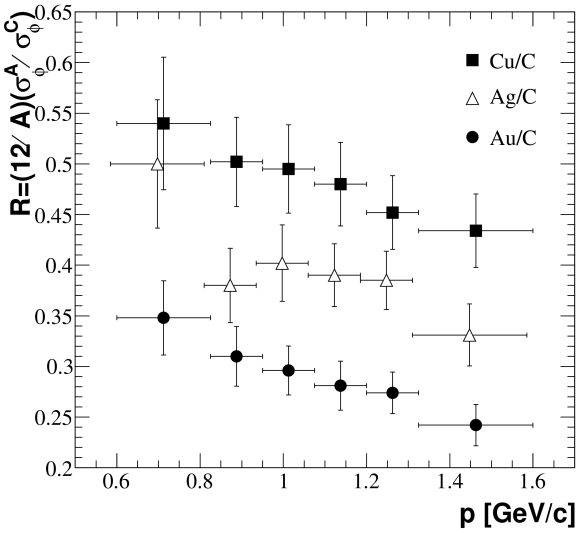


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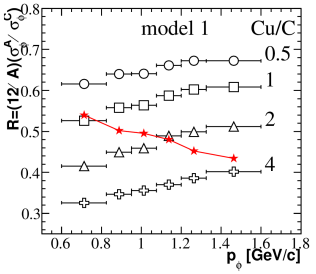


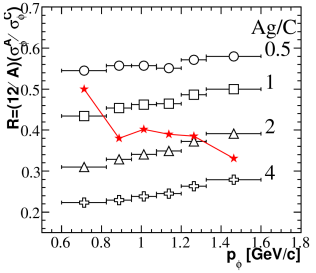


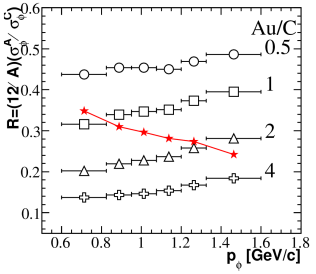


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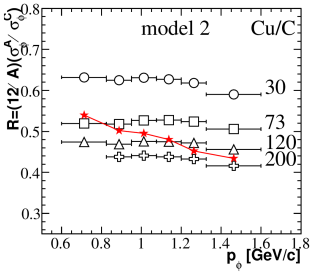
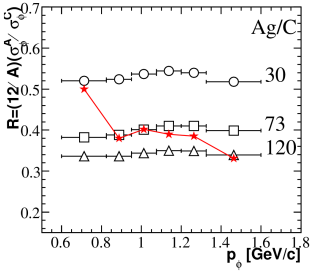
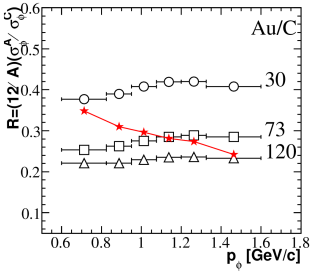
## Moscow/E.Paryev

Nuclear Spectral Function Approach




E.Paryev, J.Phys. G 36 (2009) 015103

# Transparency ratio: experiment and models

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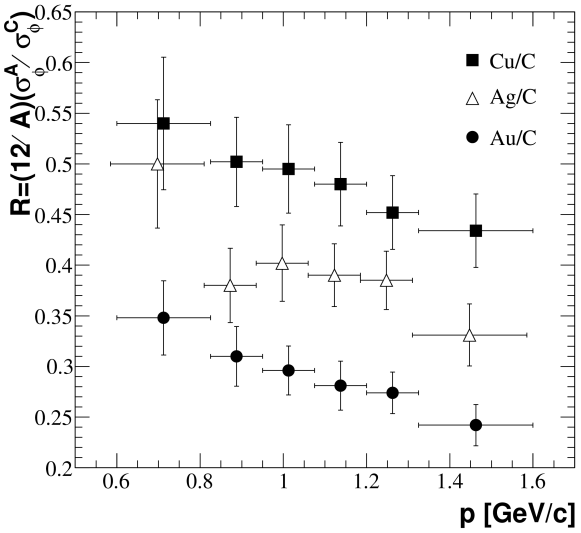


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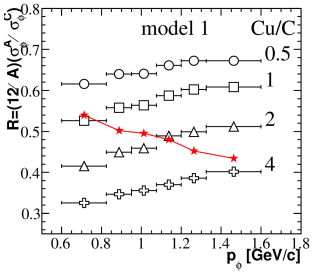


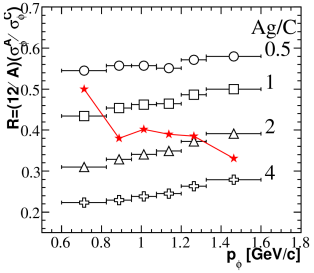


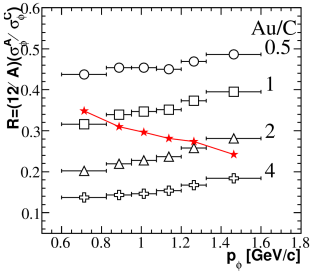


V.Magas *et al.*, PRC 71 (2005) 065202; L.Roca (private communication)

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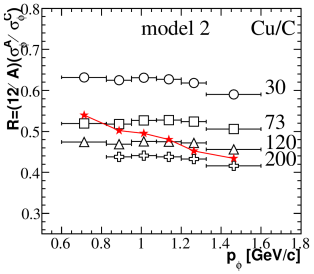
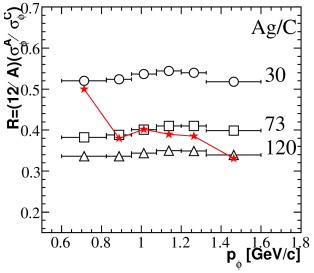
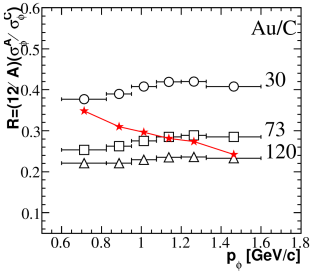


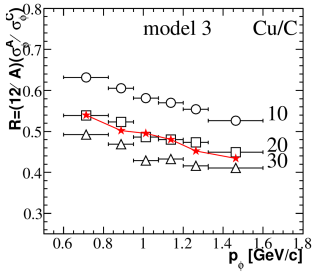



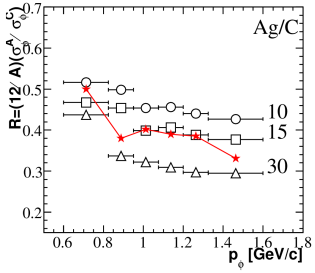



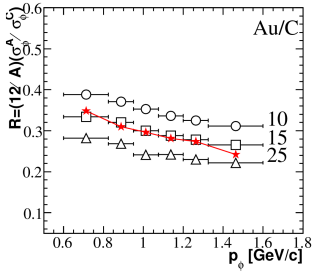

E.Paryev, J.Phys. G 36 (2009) 015103

## Rossendorf/ B.Kämpfer et al.

BUU




H.Schade, B.Kämpfer (private communication); cf. PRC 81 (2010) 034902:

# Transparency ratio: experiment and models

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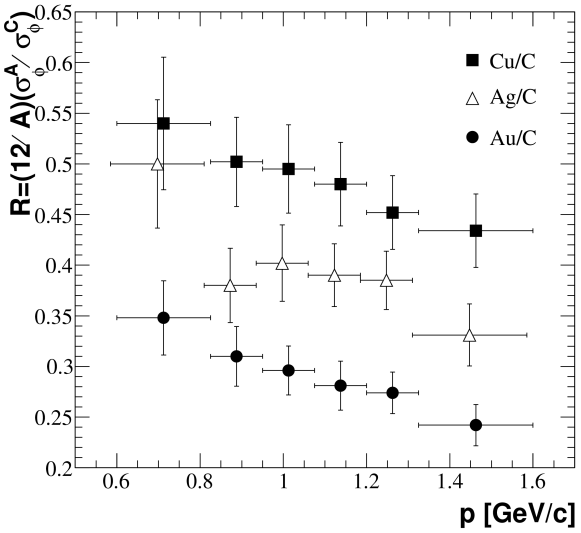


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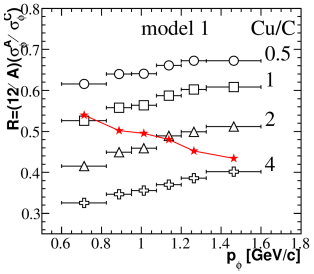


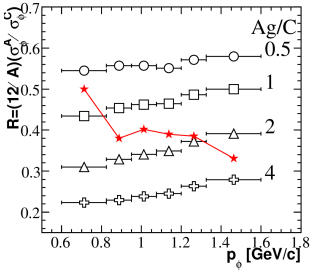


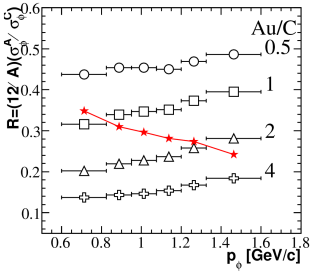


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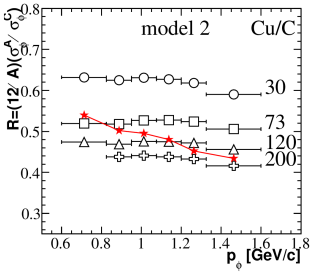


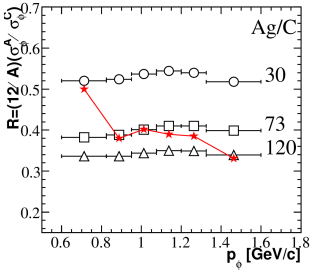


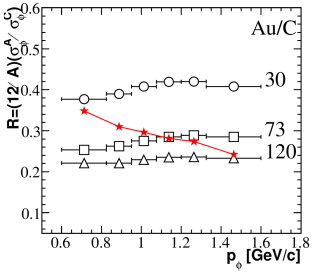


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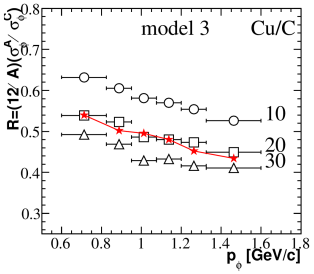
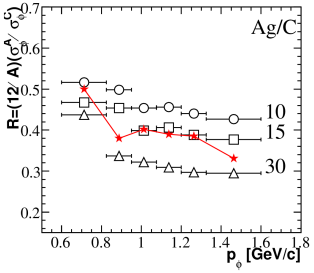
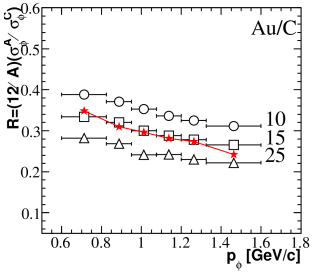
BUU



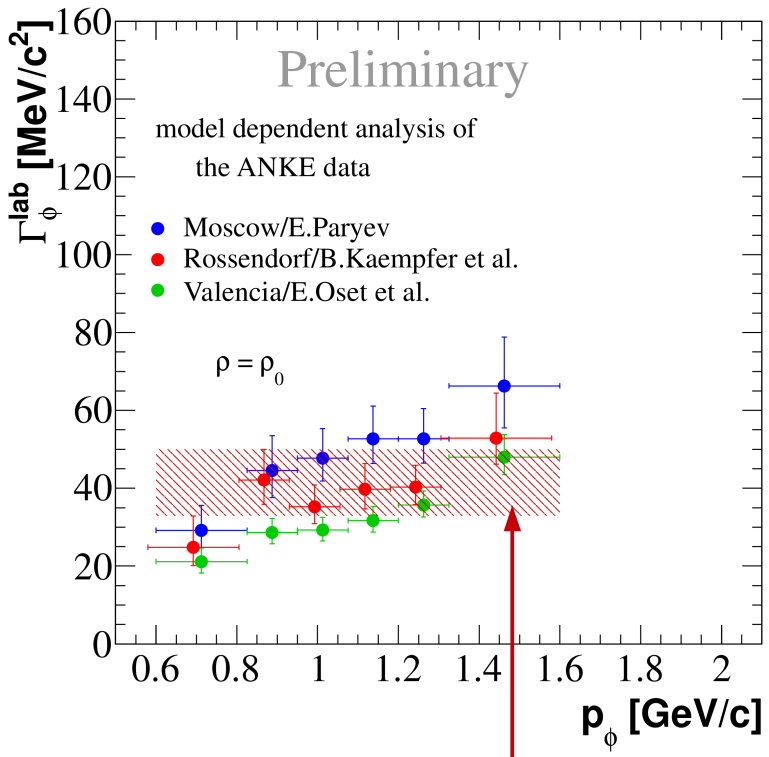

H.Schade, B.Kämpfer (private communication); cf. PRC 81 (2010) 034902:

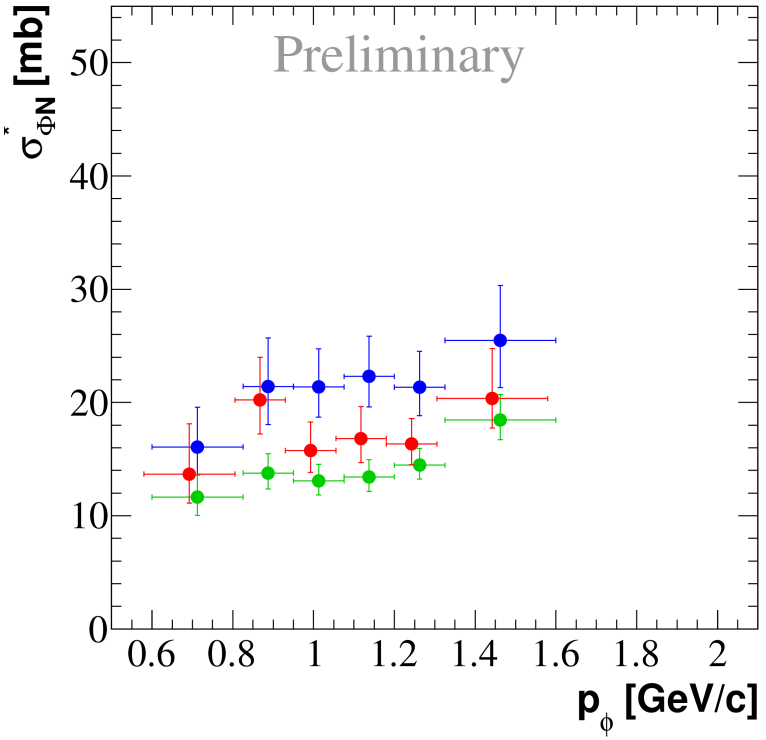
## Relevant features for models:

- forward acceptance
- two-step production processes
- $\sigma_{pn \to pn\Phi}/\sigma_{pp \to pp\Phi} \approx 4$

# In-medium width $\Gamma_\Phi$ and $\sigma^*_{\Phi N}$ cross section (preliminary)

$$\Gamma_\Phi^{lab}(\rho_0) = \frac{p_\Phi}{E}\sigma^*_{\Phi N}\rho_0$$




$\Gamma_\Phi^{lab} \approx$ 33-50 MeV ( $\langle p_\Phi \rangle$ = 1.1 GeV/c, $\rho_0$ = 0.16 fm$^{-3}$ )

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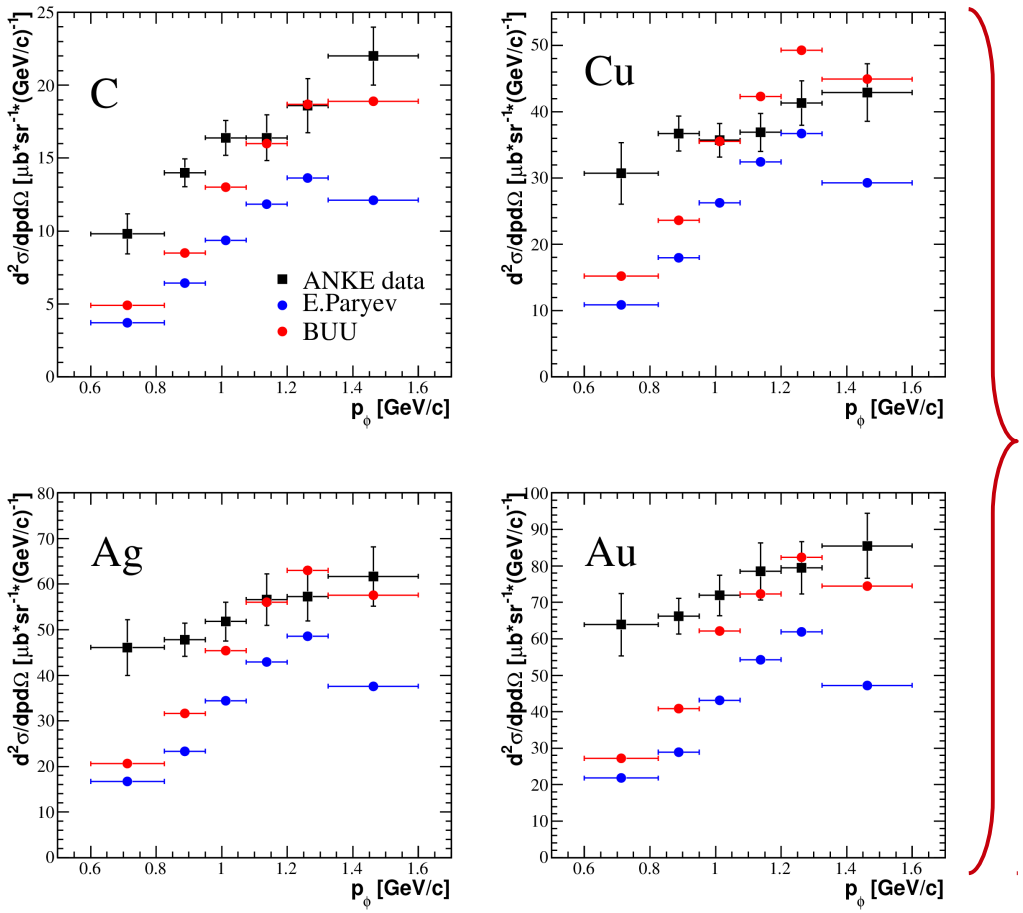
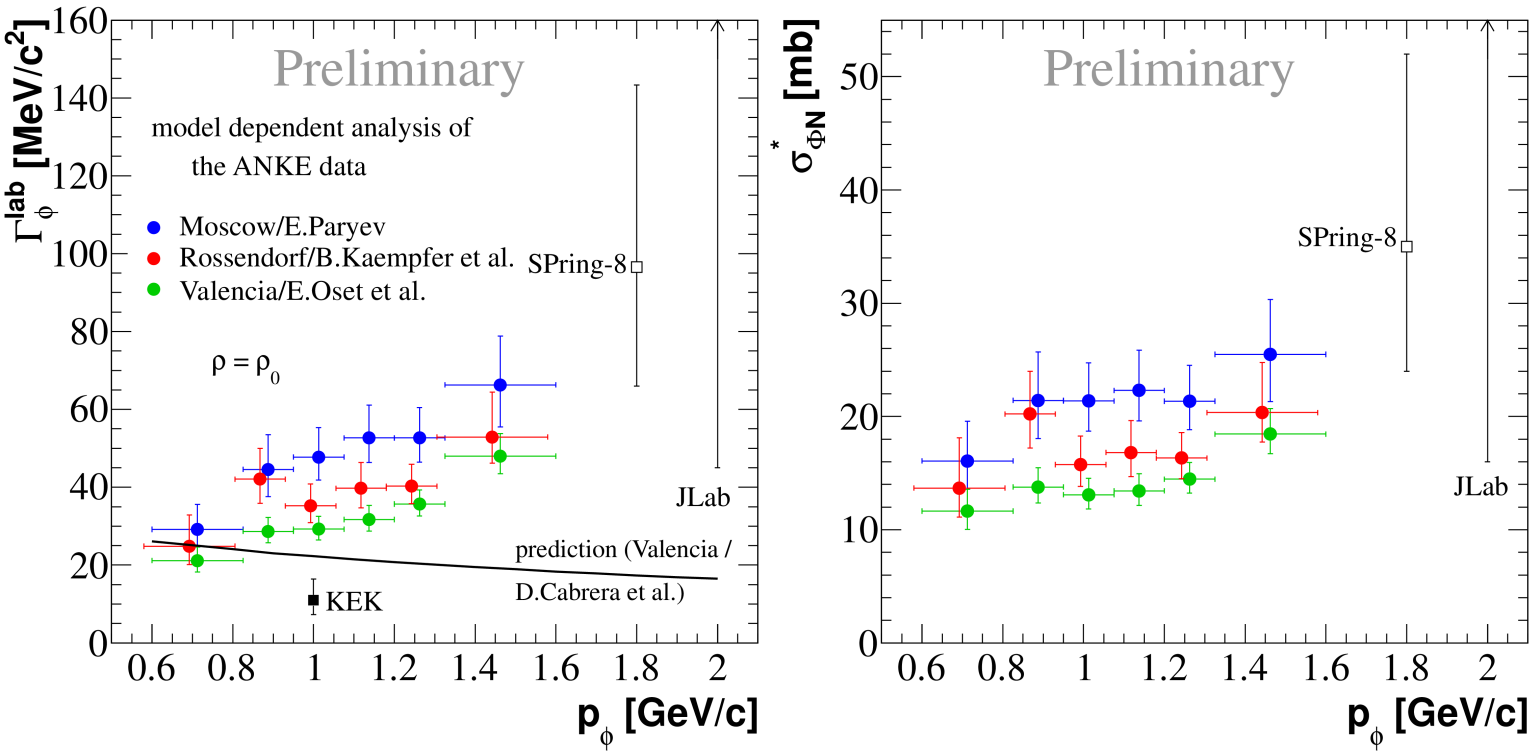
# Double differential cross section of Φ production (preliminary)




Excess in low momentum part

+ common systematics ~ 20 %

# In-medium width $\Gamma_\Phi$ and $\sigma^*_{\Phi N}$ cross section (preliminary)




Model analysis evidences for the increase of the Φ absorption in nuclei

# Summary

Momentum dependence of the Φ-meson production under the forward angles has been studied at ANKE:

- Model analysis evidences for the increase of the Φ absorption in nuclei

- Preliminary differential cross sections are not completely reproduced by current model calculations in the low momentum part

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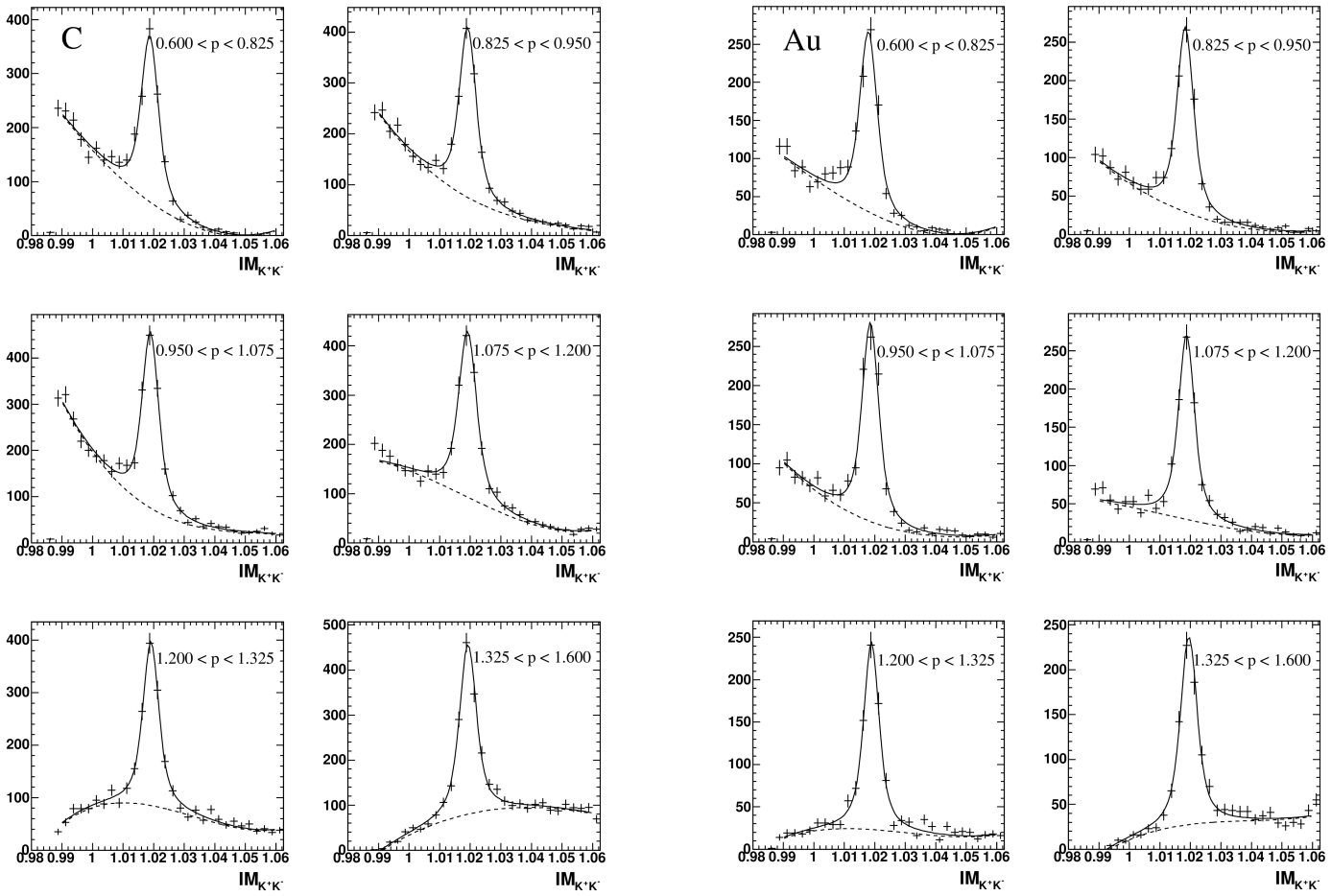
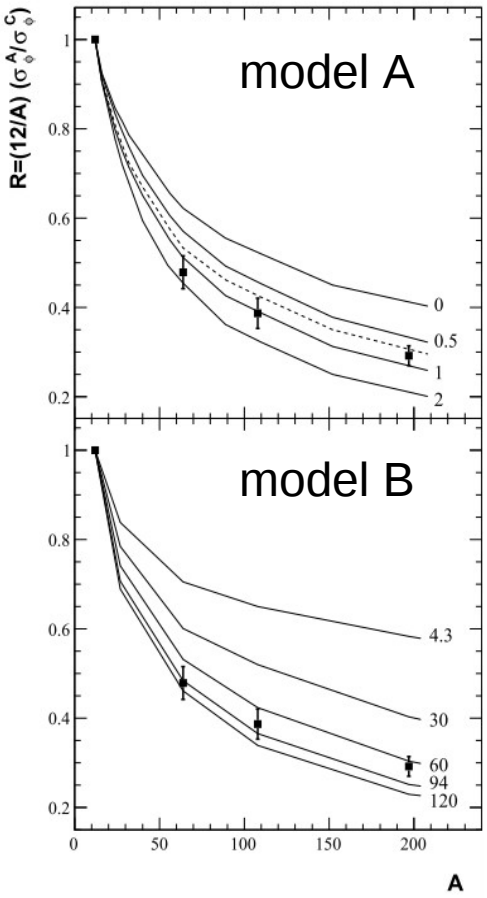
# Thank You!

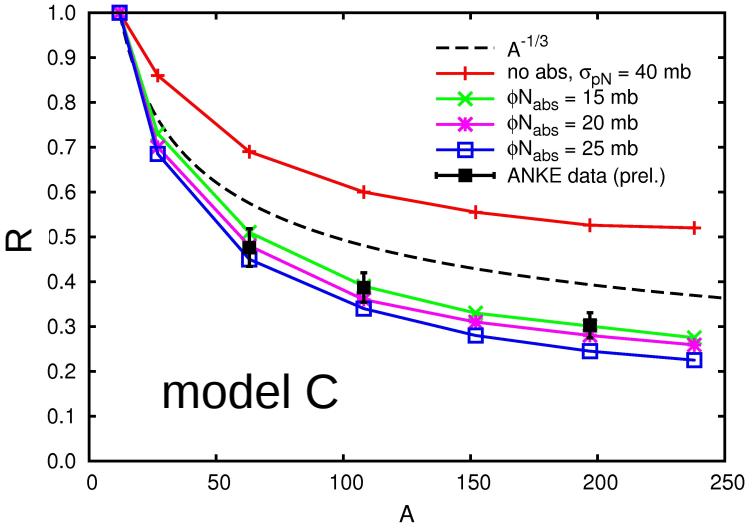
# Extra Slides

# Invariant mass spectra for six momentum bins



# Comparison with three model calculations → Φ in-medium width, and …




Relevant features:

- two-step production
- $\sigma_{pn\to pn\Phi}/\sigma_{pp\to pp\Phi} \approx 4$
- forward acceptance

**A) V.Magas et al., PRC 71, 065202 (2005): MC & Chiral unitary approach**

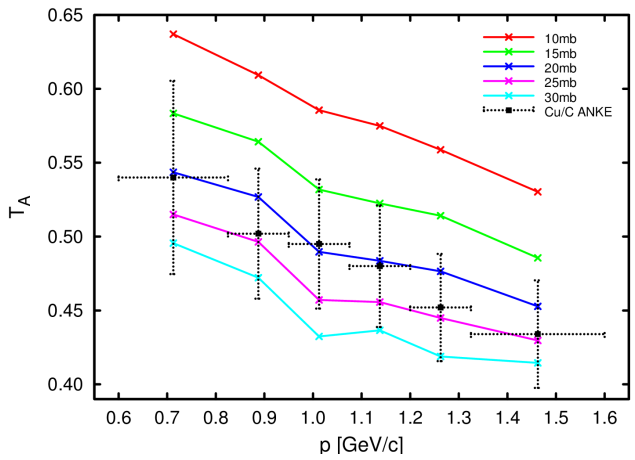
**B) E.Paryev, J.Phys.G. 36 (2009) 015103: Nuclear spectral function**

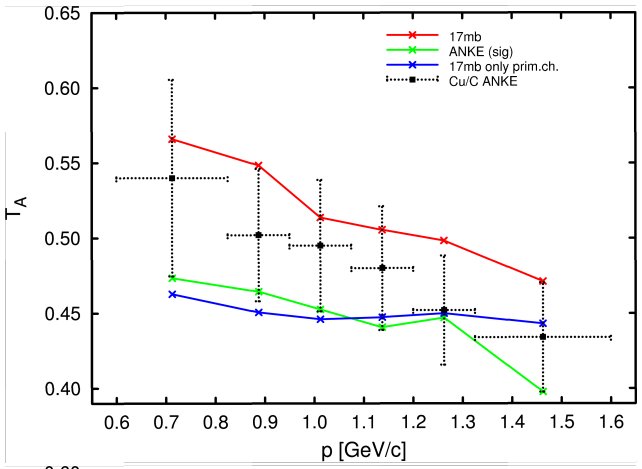
**C) H. Schade, B. Kaempfer (private communication)**

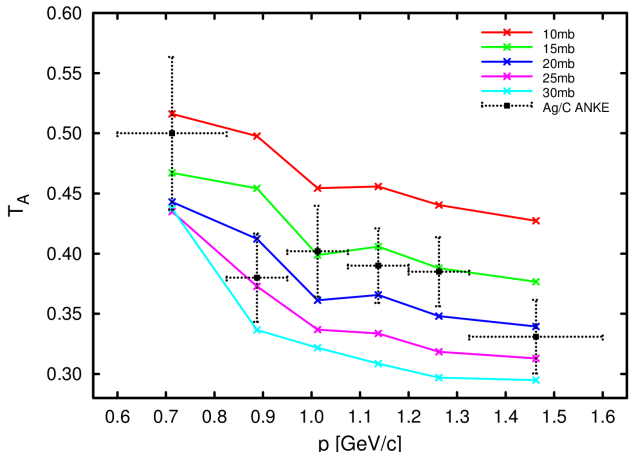
**(cf. PRC 81 (2010) 034902): BUU-Rossendorf**

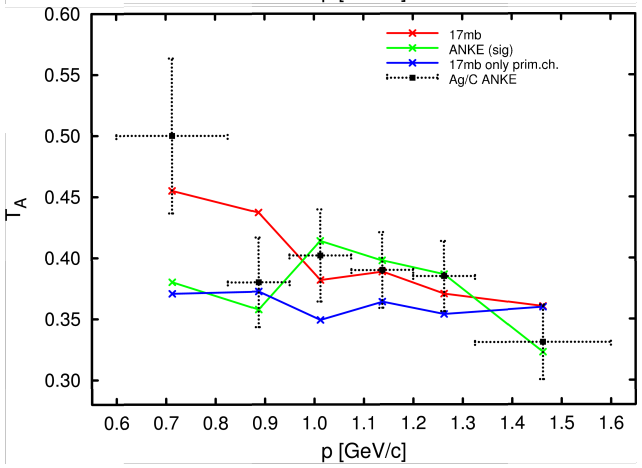
$\Gamma_\Phi^{lab} \approx$ 33-50 MeV ( $<p_\Phi>$ = 1.1 GeV/c, $\rho_0$ = 0.16 fm$^{-3}$ )

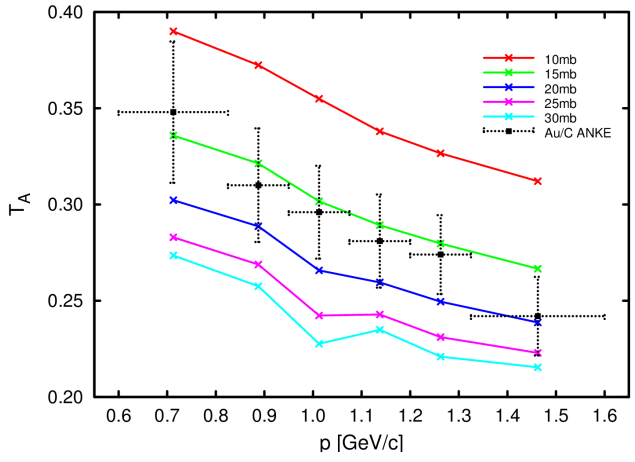
A.Polyanskiy *et al.*, **PLB 695 (2011) 74**

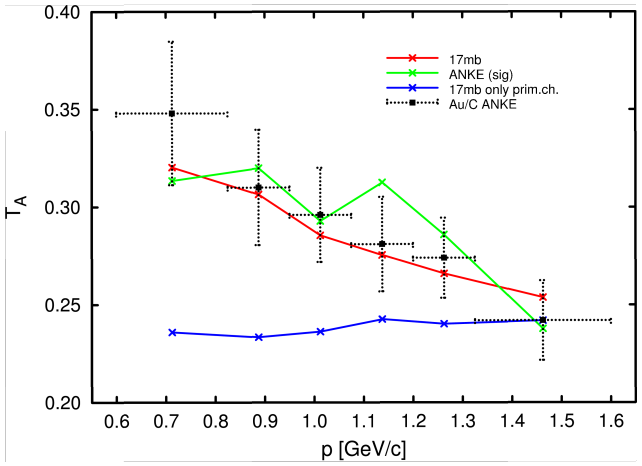


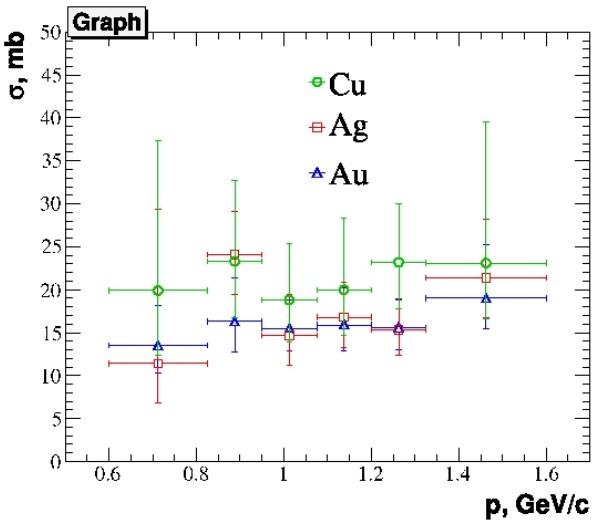



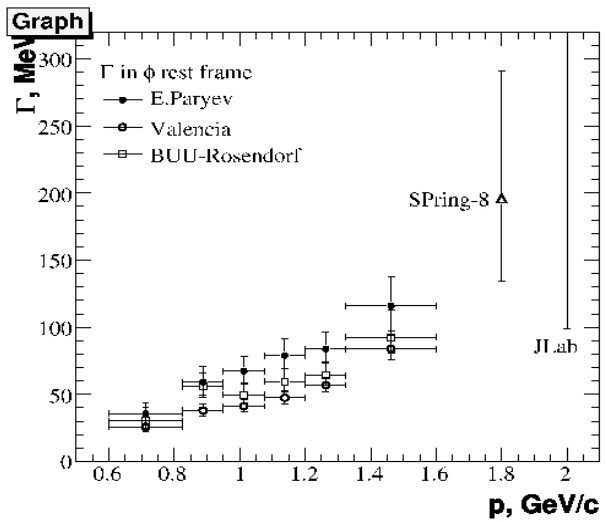



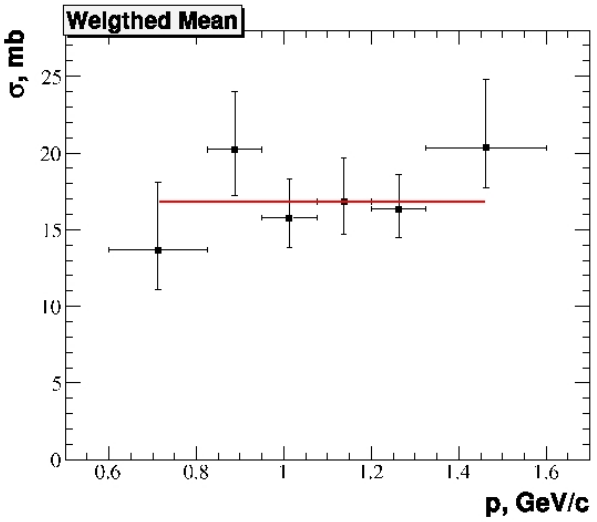

# BUU-Rossendorf (preliminary)

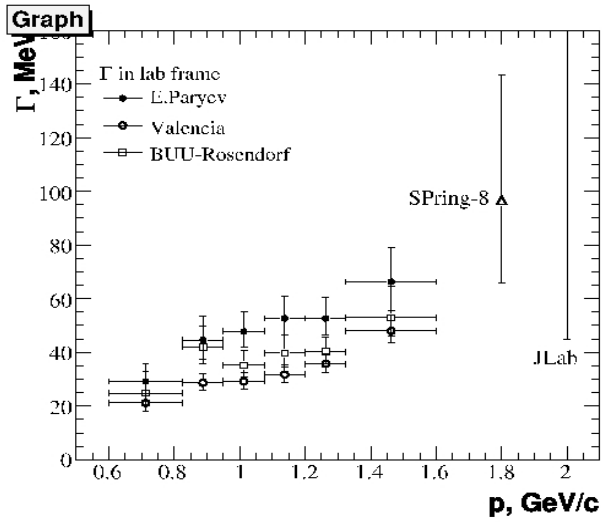
B. Kaempfer &
H. Schade

# BUU-Rossendorf (preliminary)

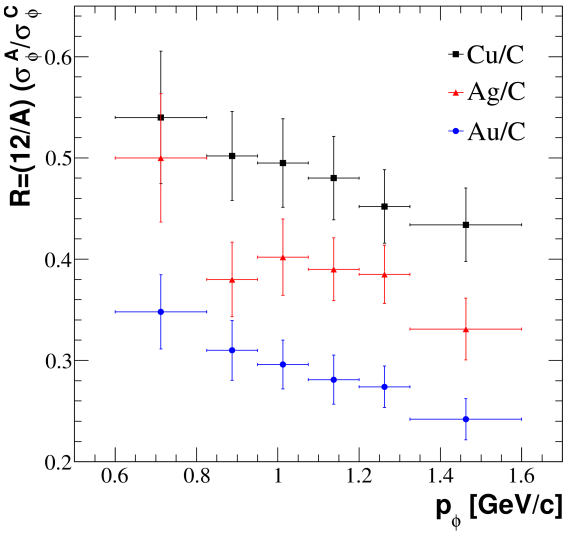


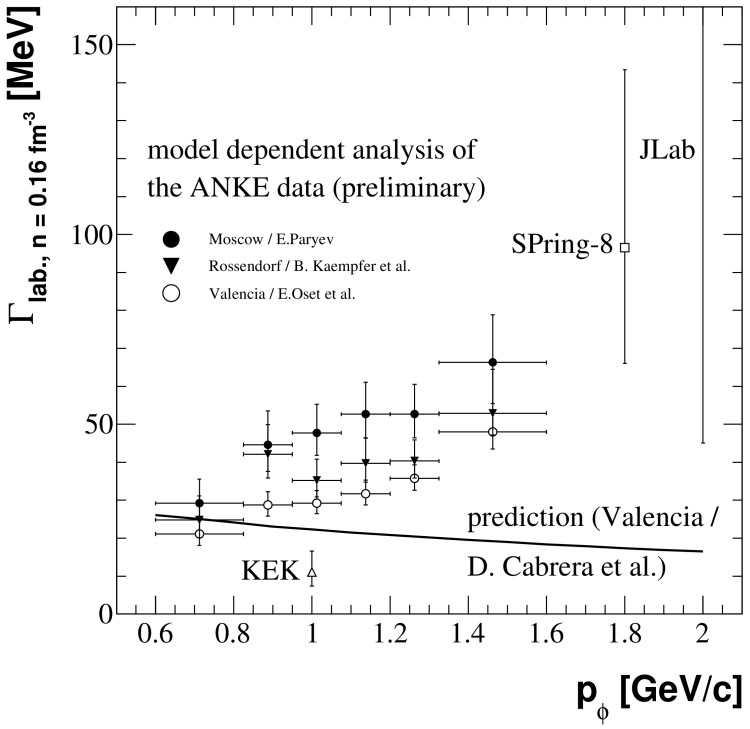



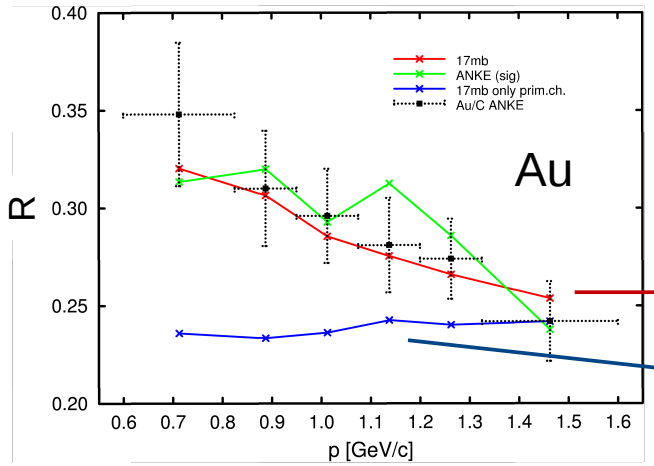



# … its momentum dependence (preliminary)




BUU/Rossendorf(preliminary):

including secondary production processes

only primary production