FOPI

Softening of the kaon spectra in 1.9A GeV nucleus-nucleus collisions by ϕ(1020) meson production and decay

Krzysztof Piasecki

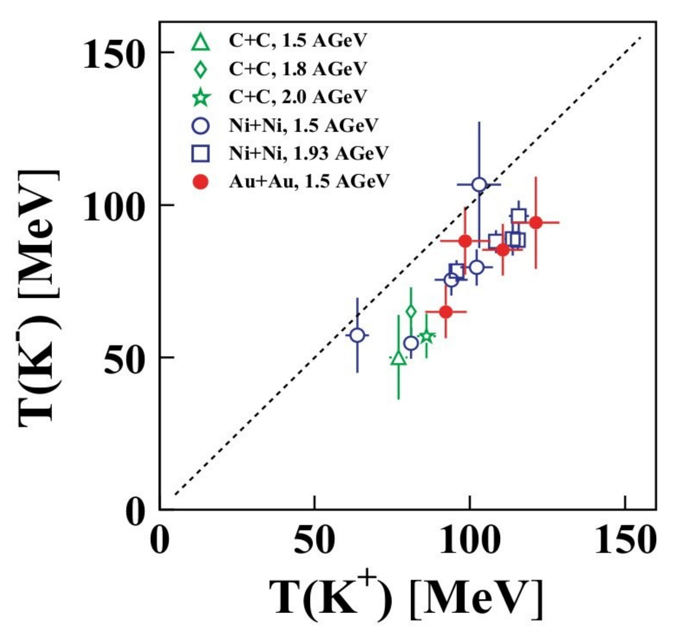
Institute of Experimental Physics, University of Warsaw

- Motivation:
  different *T* (slopes) of K^+ and K^- vs ϕ mesons
- Experimental data on ϕ , K^- production
- 2-source model of K^- emission
- Summary

Faculty of Physics Warsaw University

Kaon dynamics near threshold

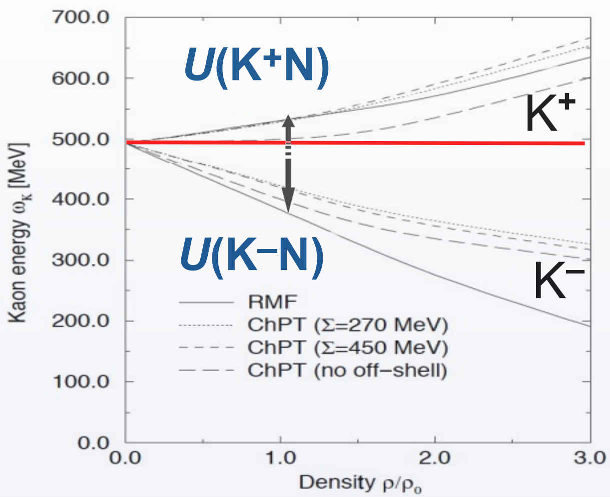
- $K^{+/-}$ production near threshold (1..2A GeV)



A. Foerster et al. (KaoS) PRC 75, 024906 (2007)

- Interplay between:
  - KN scattering
  - K^- absorption
  - In-medium effects

- In-medium modifications of $K^{+/-}$ mass

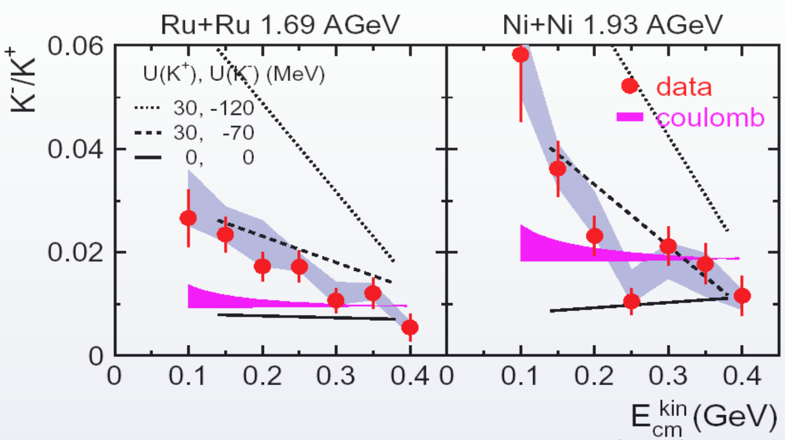


J. Schaffner-Bielich et al. NPA 625, 325 (1997)

- As Kaon escapes the Collision zone,

  $m_{K-} \nearrow m_0 \rightarrow$ K^- reduces E_{kin}

  $m_{K+} \searrow m_0 \rightarrow$ K^+ increases E_{kin}

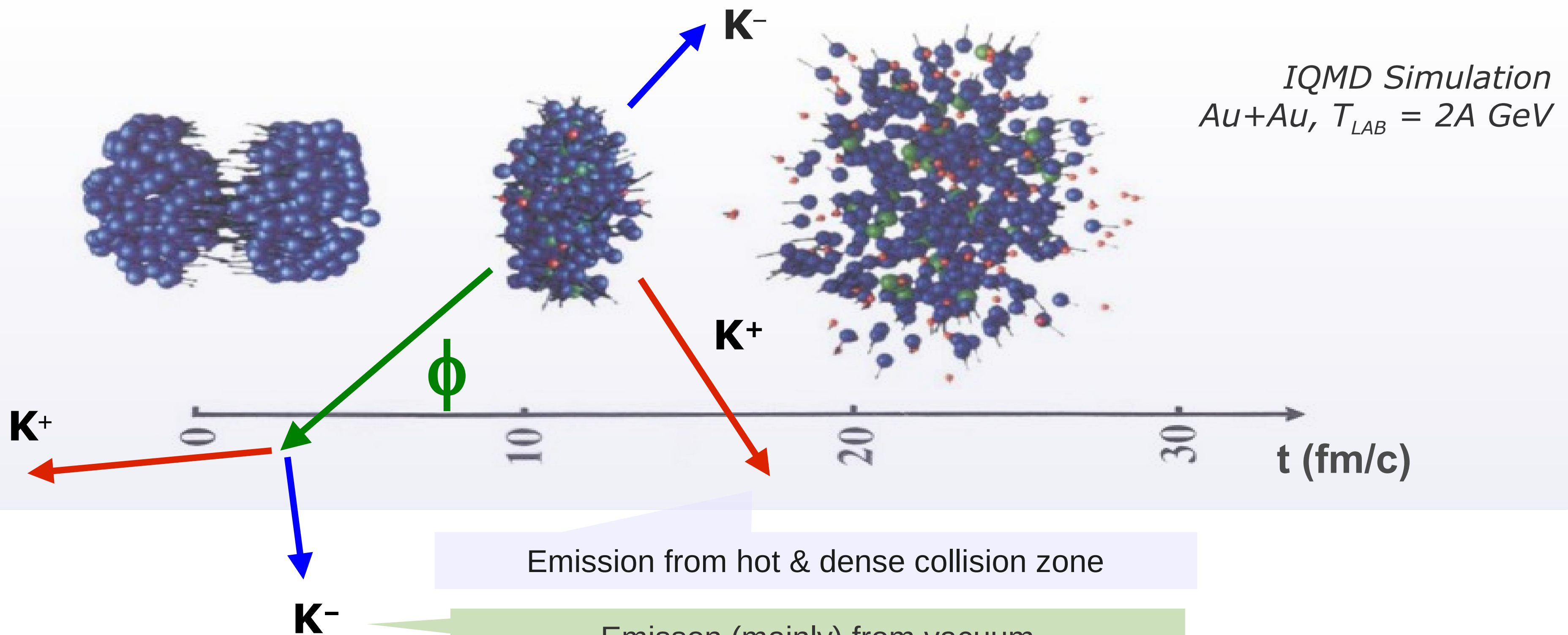


K. Wiśniewski et al., Eur. Phys. J. A 9, 515 (2000)

ϕ meson : a missing player

- ϕ ($s\bar{s}$) : m = 1.02 GeV
- $E_{b,\ threshold}$ = 2.6 GeV (SIS-18: sub-threshold only)

- $c\tau$ = 50 fm
- $\phi \rightarrow K^{+}K^{-}$ (BR ~ 50%)



Emission from hot & dense collision zone

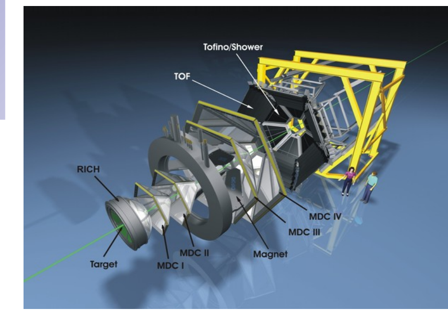
Emisson (mainly) from vacuum

Q1: How strong is the $\phi \rightarrow K^{+}K^{-}$ contribution to K^{-}, K^{+} yields ?

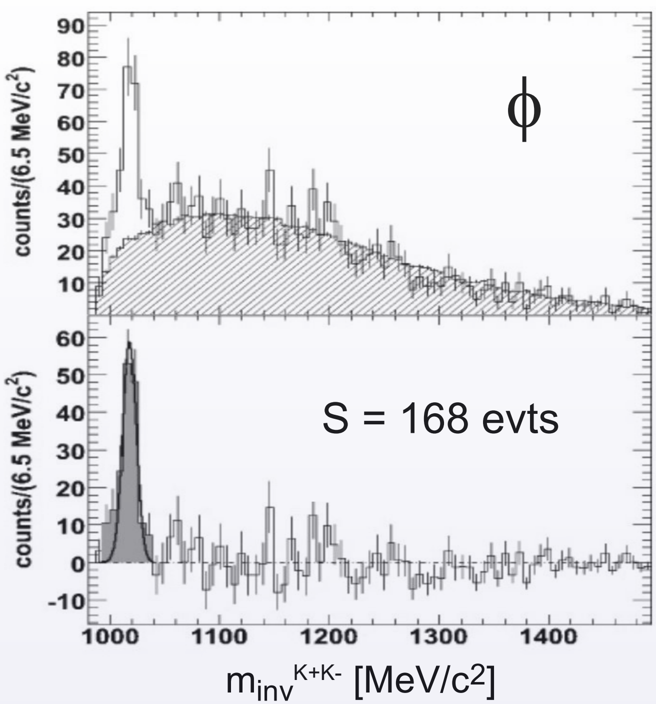
Q2: Can it modify *T* of $K^{+/-}$? Can it disturb the extracted U_{KN} potential?

Experimental data (1)

- Ar+KCl @ 1.756A GeV
- Trigger: 35% central collisions

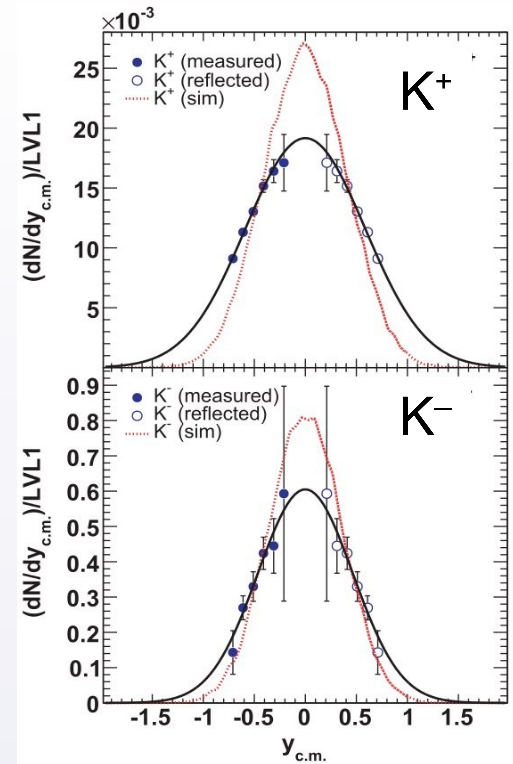


G. Agakishiev et al., PRC 80, 025209 (2009)



- $P(\phi) = (2.6 \pm 0.7 \pm 0.1) \cdot 10^{-4}$

- $P(K^+)$:
  $(2.8 \pm 0.2 \pm 0.1) \cdot 10^{-2}$
- $P(K^-)$:
  $(7.1 \pm 1.5 \pm 0.3) \cdot 10^{-4}$

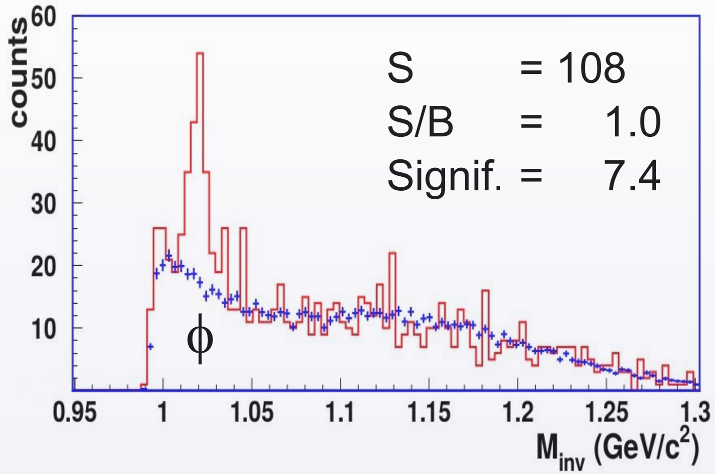


- Connection: $\phi \rightarrow K^+K^-$ (BR = 50%)
  → Impact of ϕ on K^+ : *negligible...*

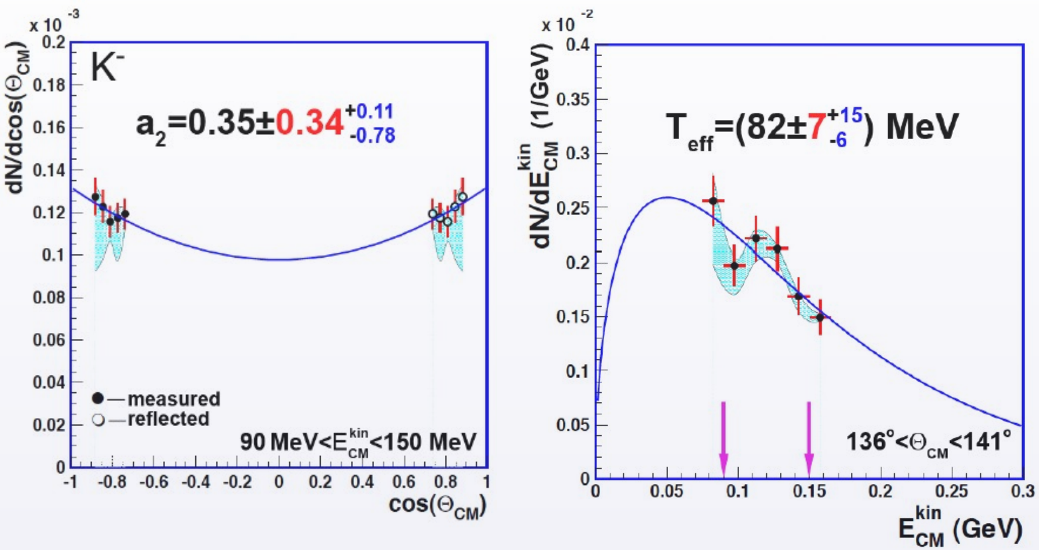
→ $\frac{\phi}{K^-} = 37 \pm 13 \pm 3$ %

→ 18 ± 6 % of K^- comes from ϕ decays

- Al+Al @ 1.91A GeV
- Trigger: 9% most central collisions



- $P(\phi) = (2.6 \pm 0.7 \pm 0.1) \cdot 10^{-4}$



- $P(K^-) = (9.5 \pm 0.8 \pm 0.9) \cdot 10^{-4}$

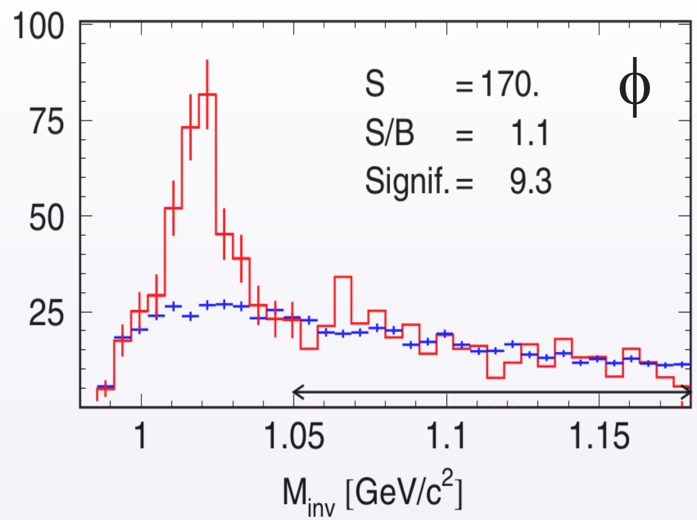
$$\frac{\phi}{K^-} = 35 \pm 6 \,^{+5}_{-12}\ \%$$

18 ± 3 % of K⁻ comes from ϕ decays

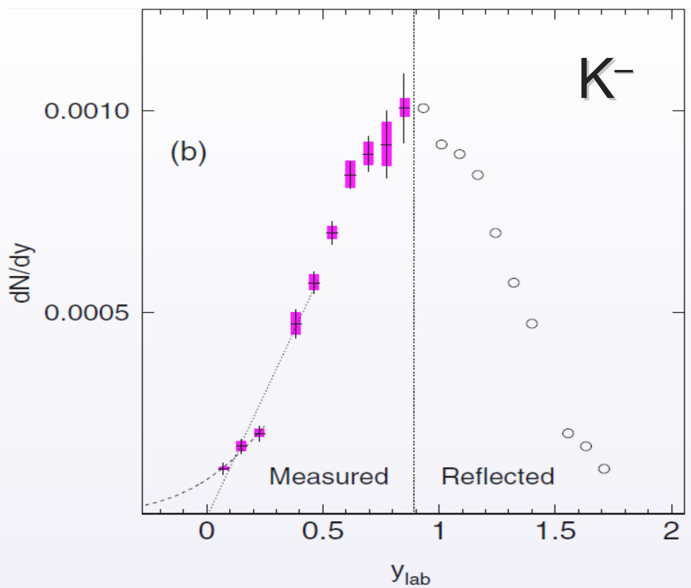
P. Gasik, Ph. D. (IFD UW), draft in preparation

- Ni+Ni @ 1.91A GeV
- Trigger: 52% (semi-)central collisions

KP et al., Phys. Rev. C 91, 054904 (2015)



- $P(\phi) = (4.4 \pm 0.7 \pm 1.4) \cdot 10^{-4}$



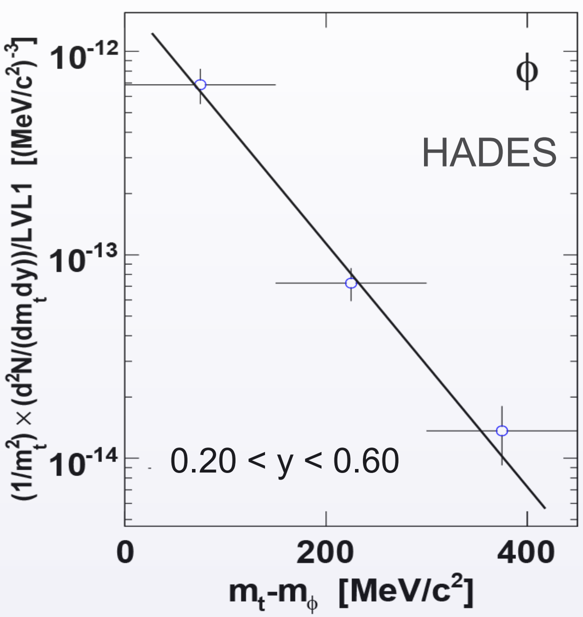
- $P(K^{-}) = (9.8 \pm 0.2 \pm 0.6) \cdot 10^{-4}$

$$\frac{\phi}{K^-} = 44 \pm 7 \,^{+16}_{-10}\ \%$$

22 ± 3 % of K^- comes from ϕ decays

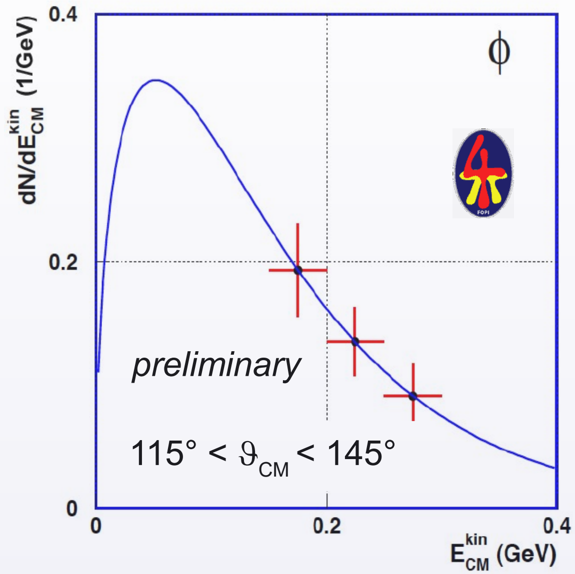
Kinematic distributions of ϕ

- Ar+KCl @ 1.76A GeV



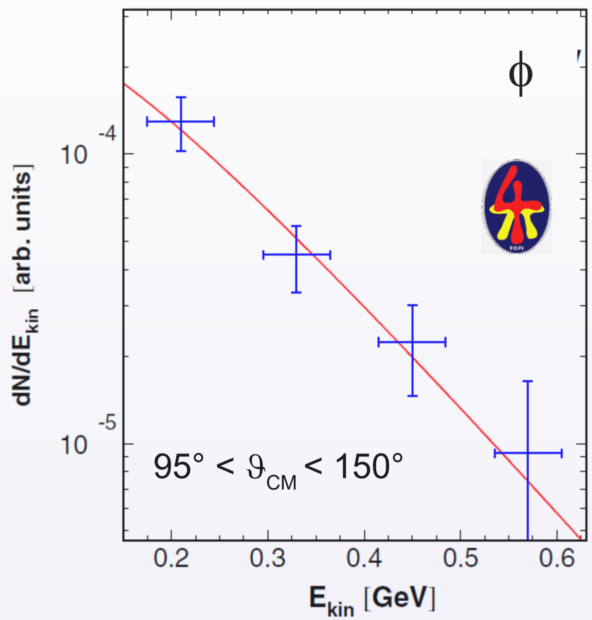
T_{eff} = 84 ± 8 MeV

- Al+Al @ 1.9A GeV



T_{eff} = 93 ± 14 ± 16 MeV

- Ni+Ni @ 1.9A GeV



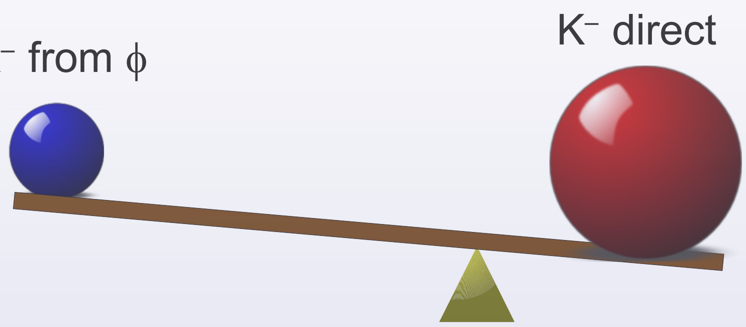
T_{eff} = 106 ± 18 ± 16 MeV

2-source model of ϕ emission

- $\phi \rightarrow K^+K^-$ simulation in PLUTO

ϕ source temperature : T_{IN} (ϕ) ≈ 100 MeV

Slope of daughter K^- : T_{OUT} (K^-) ≈ 60 MeV



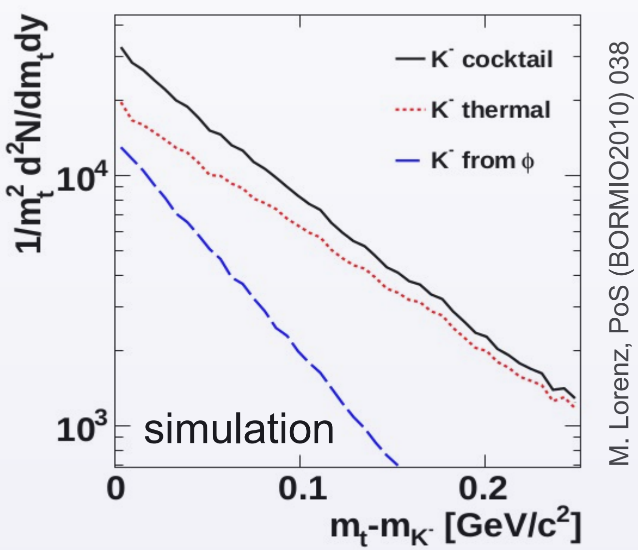
- Ar+KCl @ 1.76A GeV (HADES)

Experiment :

Particle	T_{eff}
K^-	$69 \pm 2 \pm 4$
K^+	$89 \pm 1 \pm 2$
ϕ	84 ± 8

<u>Conjecture</u> :

T (direct K^-) = T (K^+)



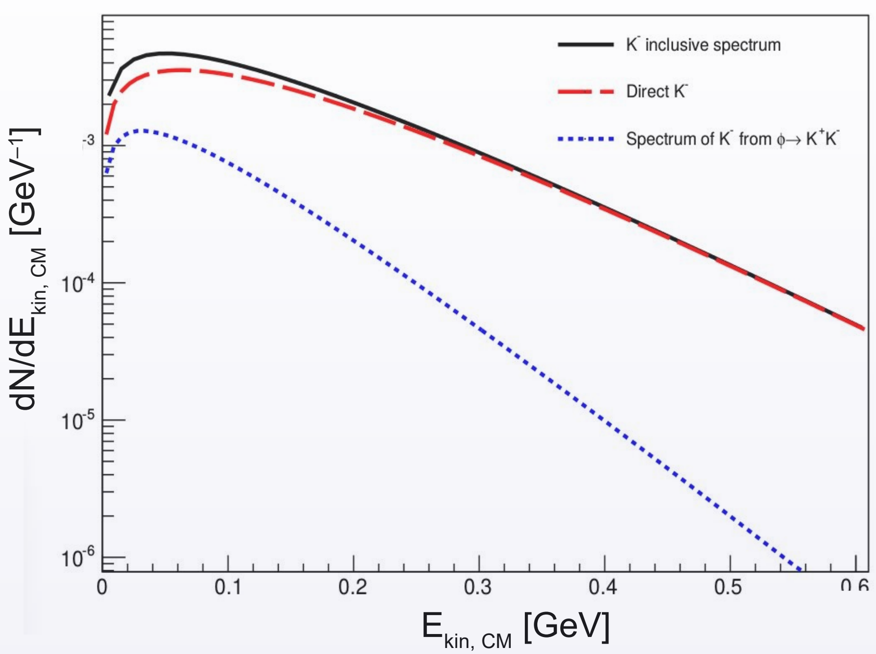
ϕ admixture reduces T(K^-) from 89 MeV to 74 MeV

2-source model of ϕ emission

- Al+Al @ 1.9A GeV (FOPI)

Experiment :

Particle	T_{eff}
K^-	$82 \pm 7 \pm 11$
K^+	$109 \pm 2 \pm 9$
ϕ	$93 \pm 14 \pm 16$



P. Gasik, Ph. D. (IFD UW), draft in preparation

T (K⁻ from ϕ) = 58 MeV

T (K⁻ direct) = 92 ± 16 MeV

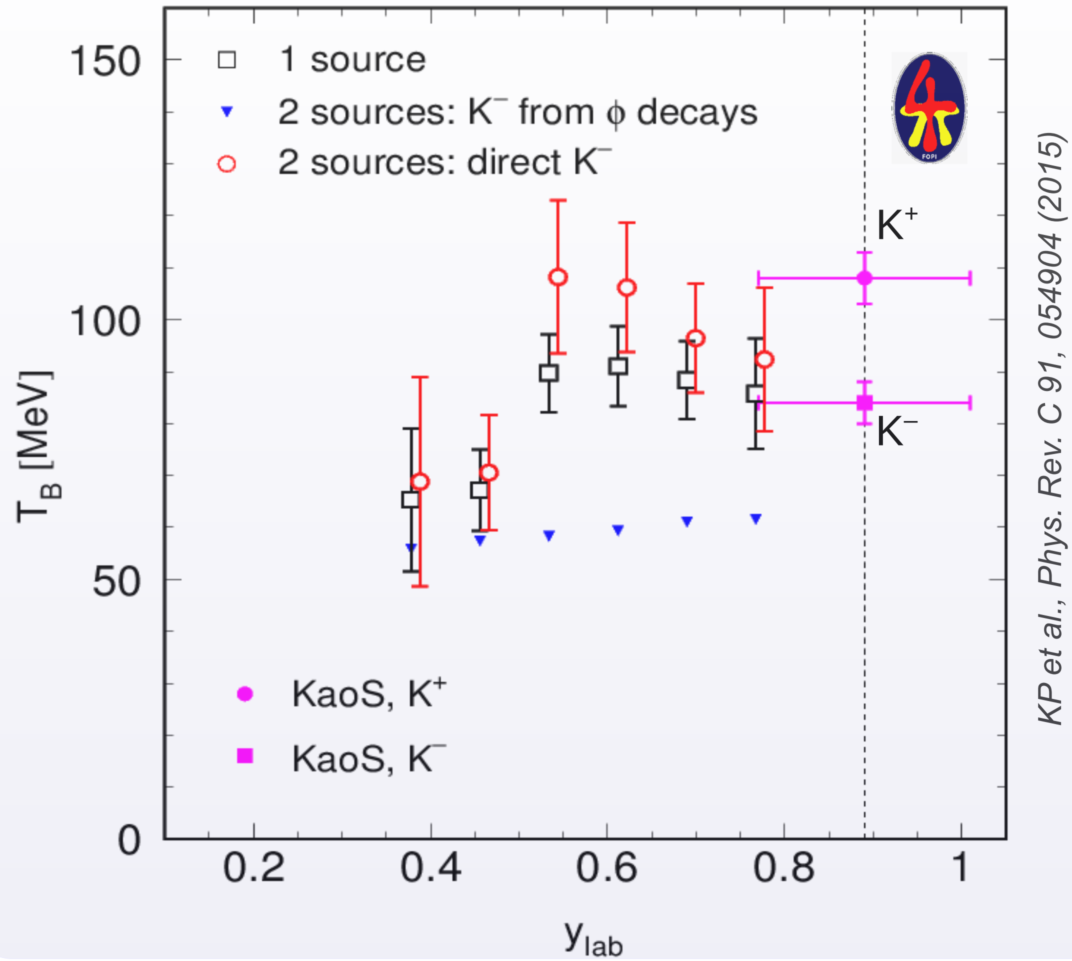
ϕ contribution to K⁻ : indication that T_{direct} @ ~10 MeV above $T_{inclusive}$

2-source model of ϕ emission

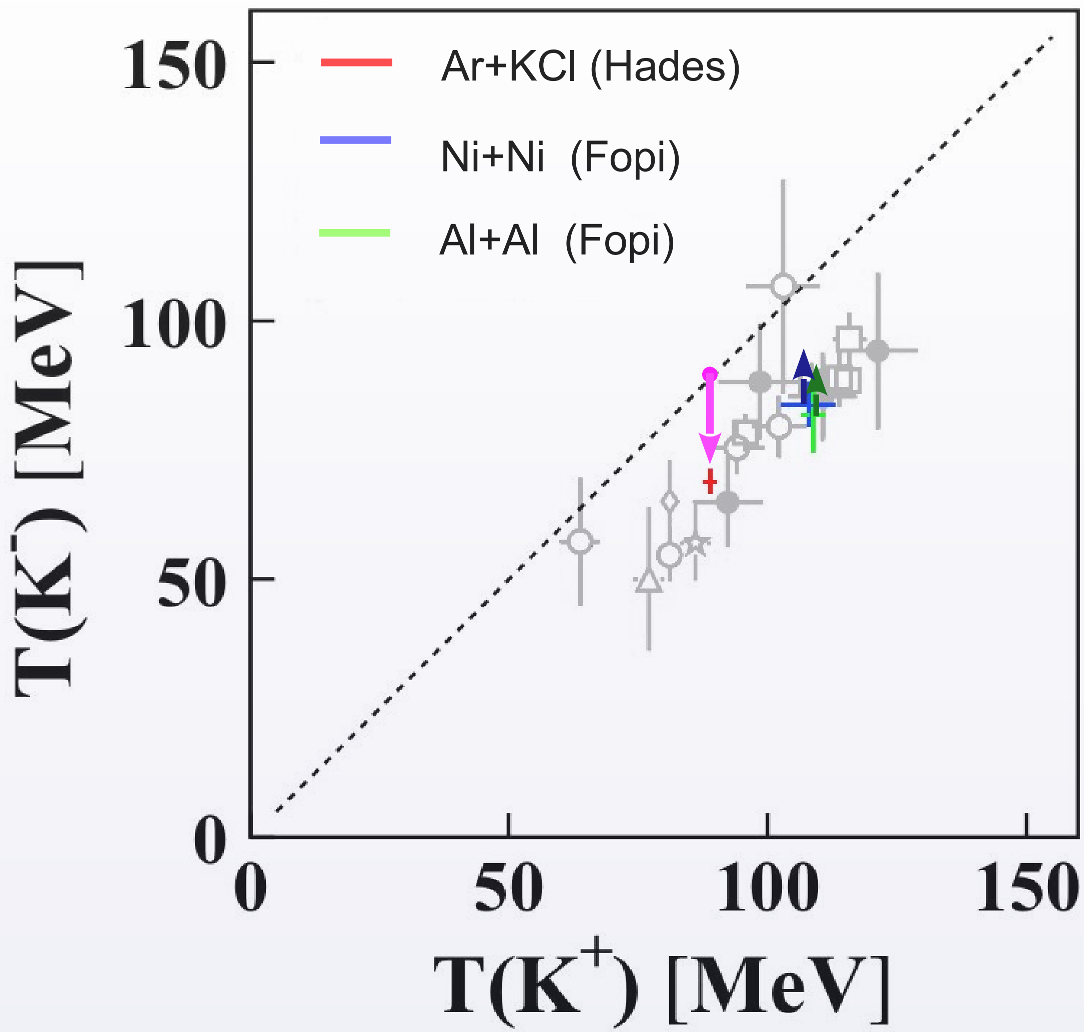
- Ni+Ni @ 1.9A GeV (FOPI, KaoS)

Experiment :

Particle	T_{eff}
K^-	84 ± 4
K^+	108 ± 5
ϕ	$106 \pm 18 \pm 16$



ϕ contribution to K^- : indication that T_{direct} @ ~10 MeV above $T_{inclusive}$



Previously:

Difference of K^+,K^- slopes explained by U_{KN} potentials

Present studies:

About 50% can be explained by $\phi \rightarrow K^+K^-$ decays

Summary

- Total yields of K^+, K^- and ϕ mesons near free NN thresholds, obtained for:

Ar+KCl @ 1.76A GeV
Ni+Ni @ 1.91A GeV
Al+Al @ 1.91A GeV

$\frac{\phi}{K^+}$ *negligible*

$\frac{\phi}{K^-} \approx 0.4$ → **~ 20% of K^- originate from ϕ decays**

- E_{kin} (or m_T) distributions of K^+, K^- : A gap between slopes :
  $T(K^+) = T(K^-)$ + 20..25 MeV

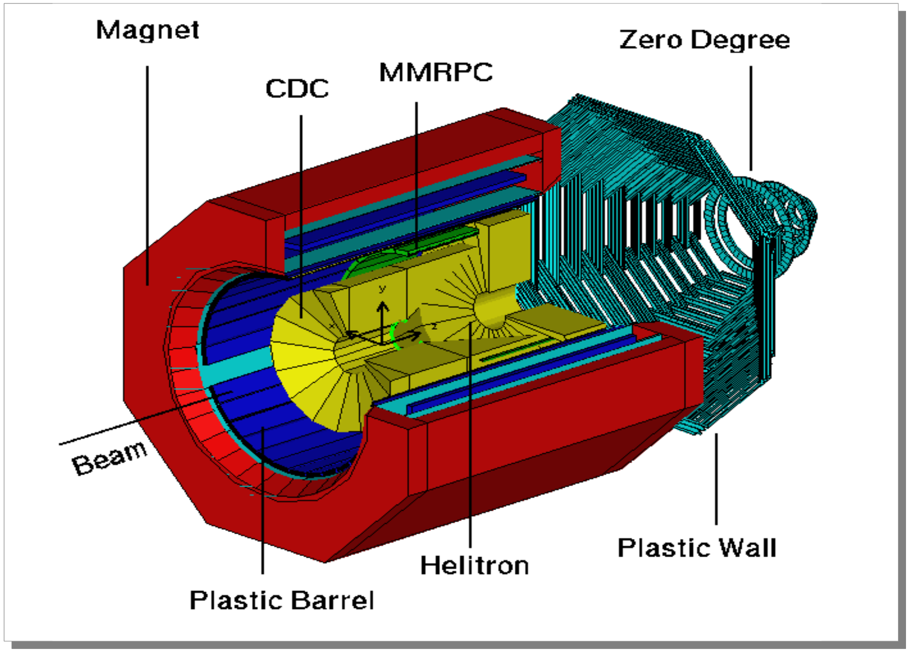
- 2-source model of K^- emission [direct + ϕ-decays] :
  - Ar+KCl : Assuming $T(K^-_{direct}) = T(K^+)$, cocktail nearly explains the gap
  - Ni+Ni, Al+Al : Accounting for ϕ decays indicates that ***$T(K^-_{direct}) \approx T(K^-_{inclusive}) + 10$ MeV***

Extraction of KN potentials via [experiment ↔ transport model] comparison should include the ϕ production data on both sides.

Thank You!

Backup slides

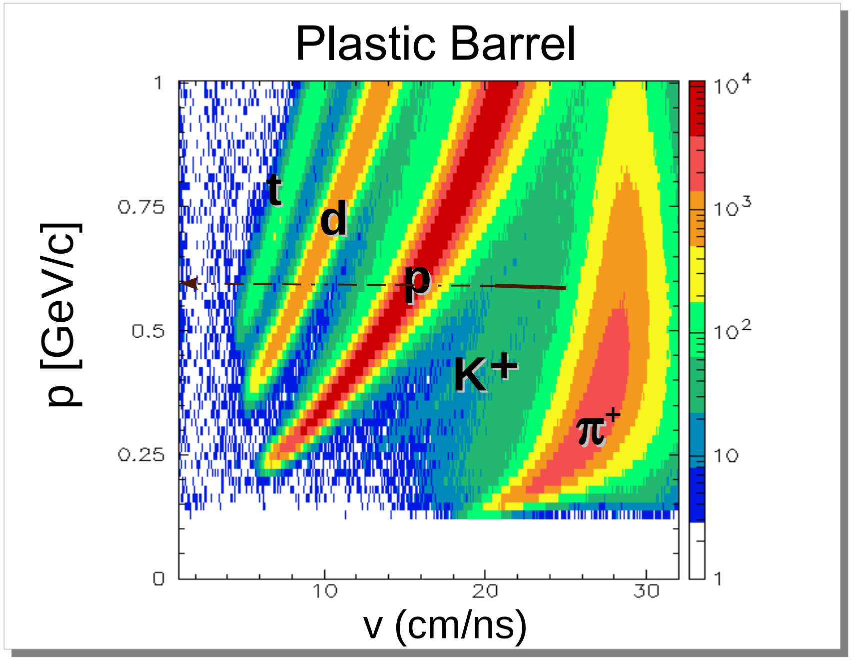
FOPI experimental setup

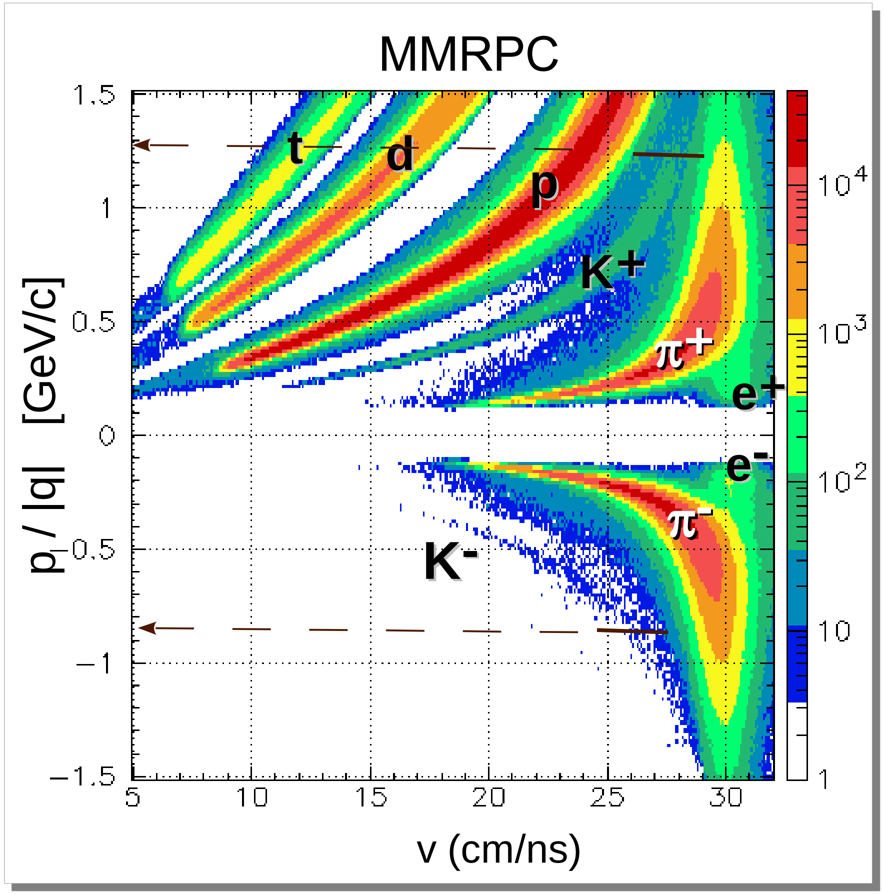


- Nearly 4π coverage
- Drift chambers: CDC, Helitron

  ToF : Plastic Barrel, RPC

  Forward: Plastic Wall, Zero Degree
- Direct PID of $\pi^{\pm}$, $K^{\pm}$, p, d, t, $^{3,4}He$





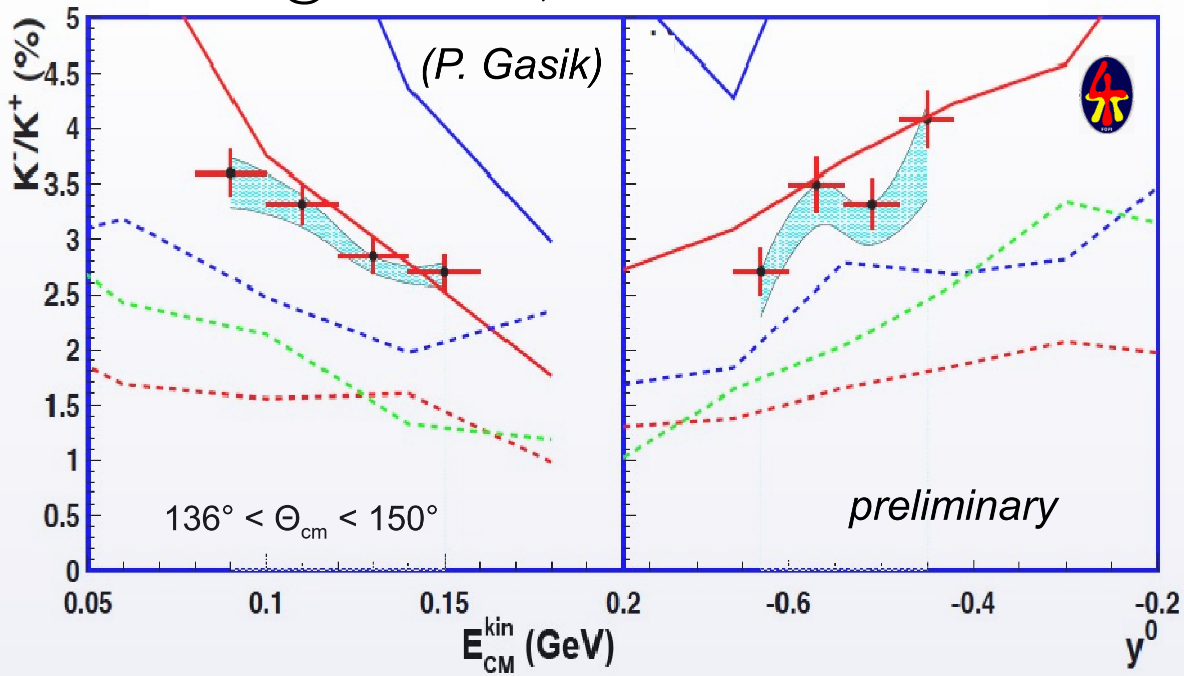
K^-/K^+ : experiment vs transport

- K^+ : U_{KN} repulsive
  K^- : U_{KN} ~attractive
  K^-/K^+ : promising observable

- IQMD transport code
  - $m_{K\pm}(\rho) = m_{K\pm}(\rho_0) \cdot \left(1+\alpha_{\pm}\cdot\frac{\rho}{\rho_0}\right)$
  - at $\rho=\rho_0$
    Δm_{K+} = 40 MeV, Δm_{K-} = −100 MeV

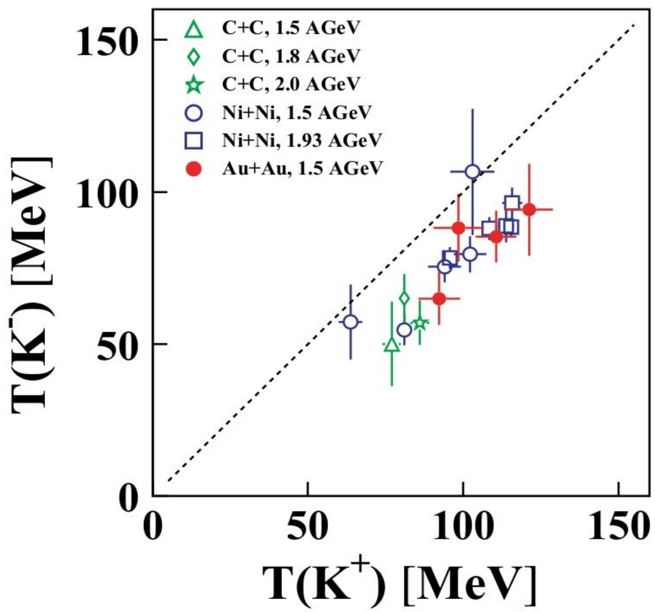
- HSD transport code
  - K^+ as in IQMD
  - K^- : off-shell G-matrix approach

Al+Al @ 1.93A GeV, 9% most central events

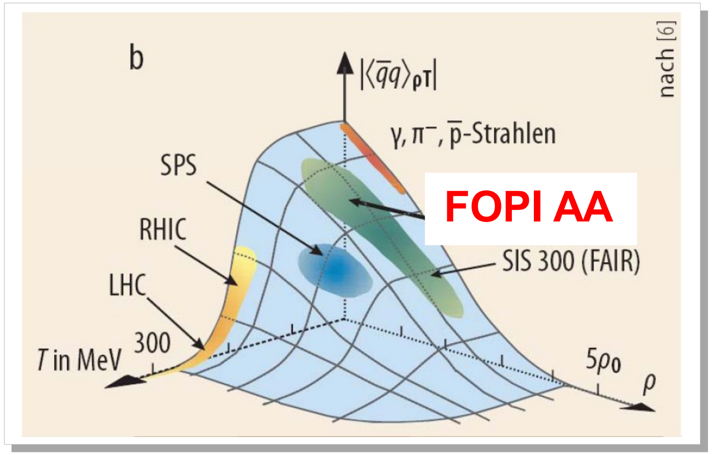


IQMD, NO Pot.
HSD , NO Pot.
HSD, U_{K+}=40 MeV, K- Not Modified
HSD, U_{K+}=40 MeV, U_{K-}= G-Matrix
IQMD, U_{K+}=40 MeV, U_{K-}=-100 MeV

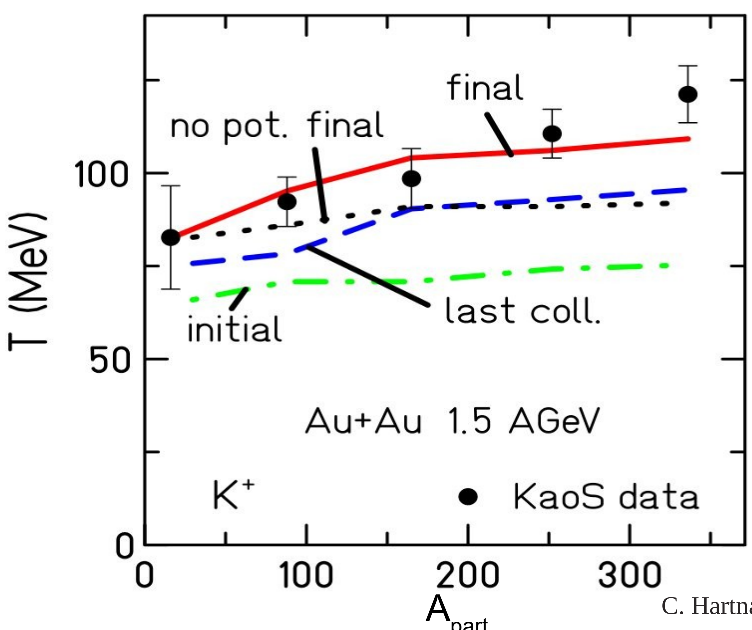
- Clear preference for $U_{KN} \neq 0$ option
- "U_{K+} only" scenario : insufficient
- IQMD: potentials used probably too strong

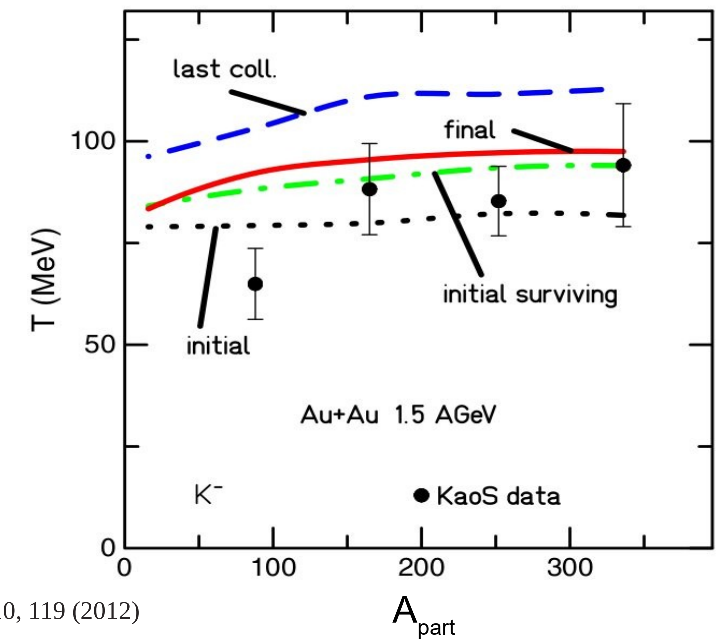


A. Foerster et al. (KaoS) PRC **75**, 024906 (2007)



M. Kotulla et al., Phys. Jour. 8, 3 (2009)

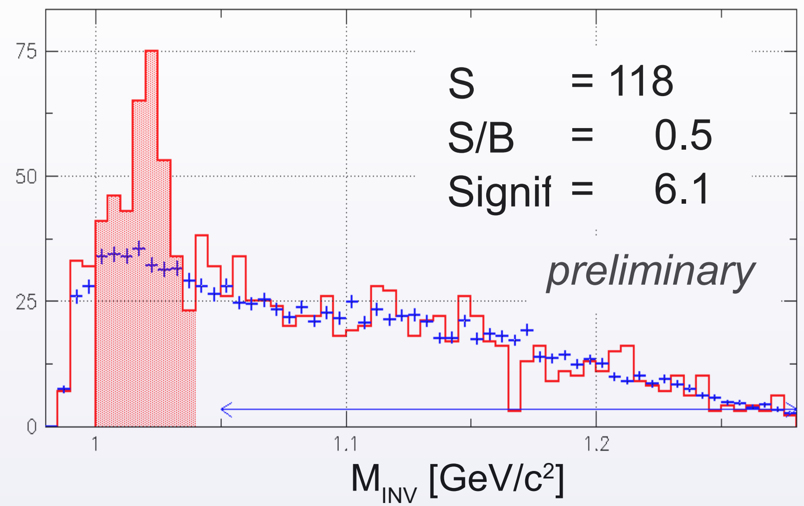


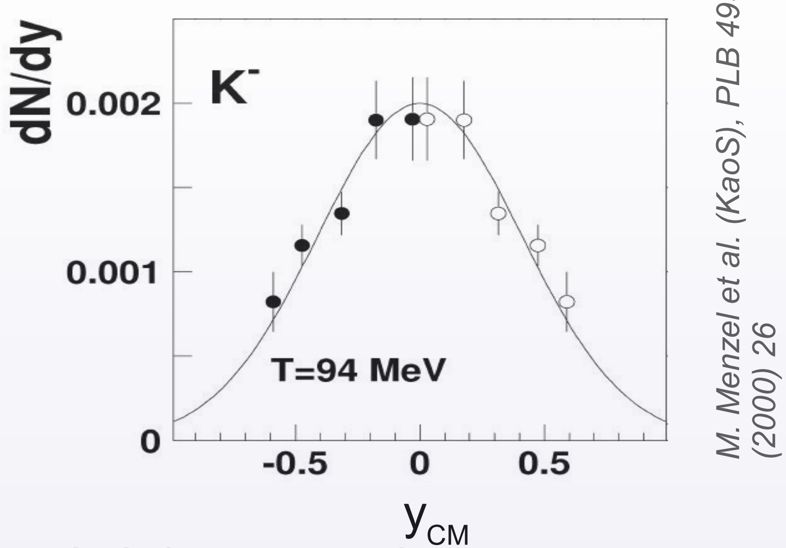


C. Hartnack *et al.* Phys. Rep. 510, 119 (2012)

Subthreshold ϕ – another sample

- Ni+Ni @ 1.93A GeV
- Trigger: 23% most central collisions
- KP (analysis in progress)



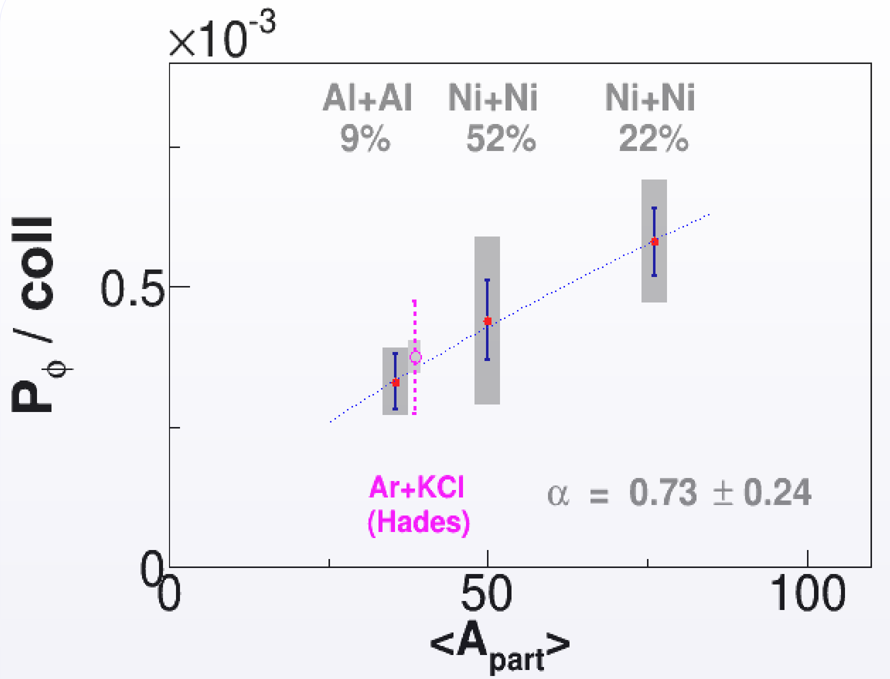


- $P(K^-)$ / 1 triggered event: $(21. \pm 4.) \cdot 10^{-4}$
- Number of identified ϕ : 118
- $P(\phi)$ / 1 triggered event: $(6.2 \pm 1.0) \cdot 10^{-4}$

→ $\frac{\phi}{K^-} = 29 \pm 7 \pm 10\%$

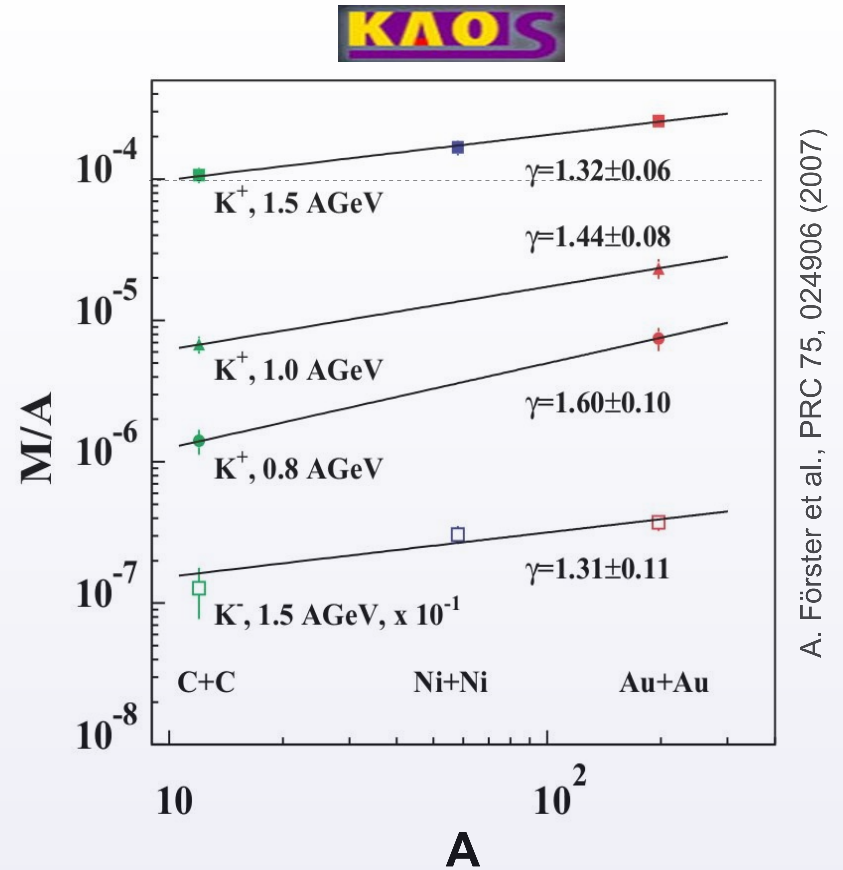
→ 14 ± 3 % K^- comes from ϕ decays

ϕ production – A_{part} dependency



Fit: $P(\phi) = N \cdot \langle A_p \rangle^{\alpha}$

→ $\alpha = 0.73 \pm 0.24$



- Behaviour different than that for K^{+-0} and Λ?
  - BR of different prod. channels is unknown
  - Possible absorption at high $\langle A_{part} \rangle$

Strangeness production and absorption

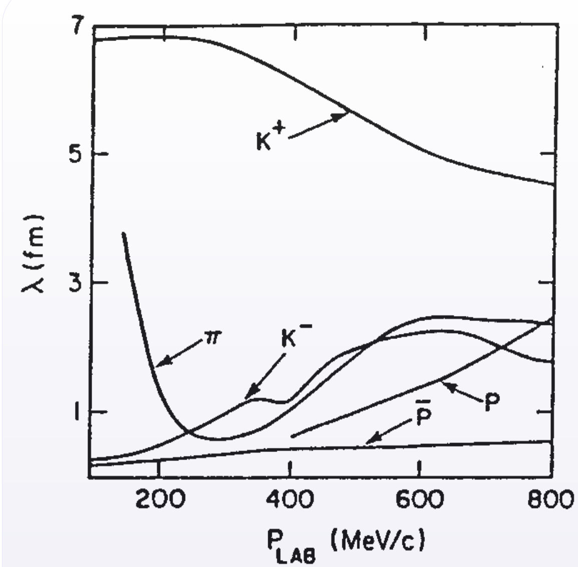
	K^+	K^-	ϕ
Production (primary)	BB → BYK$^+$ $T_{pp \to p\Lambda K+}$ = 1.58 GeV	BB → BBK$^+$K$^-$ $T_{pp \to ppK+K-}$ = 2.5 GeV	BB → BBϕ $T_{pp \to ppK+K-}$ = 2.6 GeV
Production (secondary)	πB → YK$^+$	πY → (Σ^* →) BK$^-$ BY → NK$^-\Lambda$ BY → BBK$^-$ πB → BK$^+$K$^-$ ϕ → K$^+$K$^-$	πB → Bϕ ρB → Bϕ πN* → Nϕ $\rho\pi$ → ϕ *K$^+$K$^-$ → ϕ negligible*
Absorption	K$^+$Y → πB	K$^-$B → πY	ϕN → KΛ
Elastic scat. (char. exch.)	K$^+$B ↔ K$^+$ B K$^+$n ↔ K^0 p	K$^-$B ↔ K$^-$B K$^-$p ↔ $\overline{K}^0$n	ϕN → ϕN

[B] = *p, n, N, N*, Δ*

[Y] = *Λ, Σ*

Yields from	Ni + Ni (1.93 GeV)
B + B	3.5×10^{-4}
π + B	2.9×10^{-4}
ρ + B	8.9×10^{-4}
$\pi + \rho$	1.6×10^{-4}
π + N(1520)	0.5×10^{-4}
Total yield	1.7×10^{-3}

H.W. Barz et al. (BUU) ,
Nucl. Phys. A 705 (2002) 223



C.B. Dover, G.E. Walker
Phys. Rep. **89** (1982) 1

ϕ yield – BUU predictions

- ***BUU*** calculations for Ni+Ni @ 1.93A GeV, 9% most central collisions

- ϕ production channels:

$$BB \rightarrow \phi \;,\quad B = \{N, \Delta\}$$

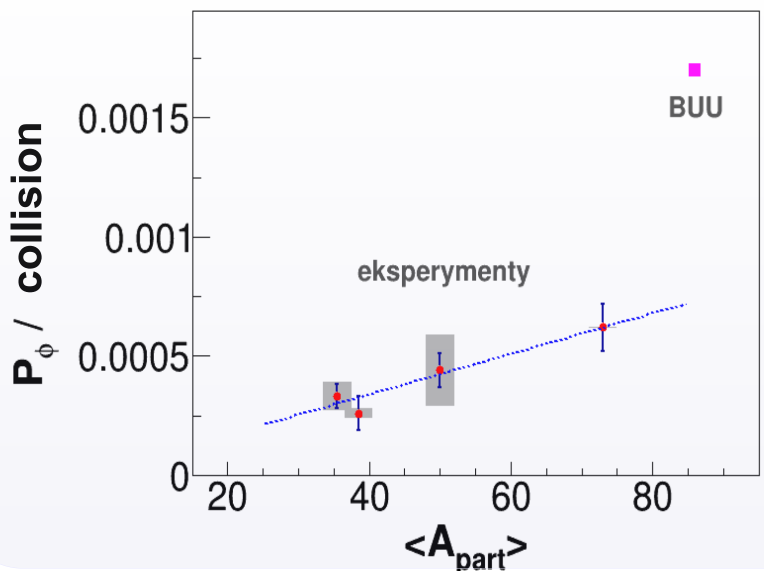
$$\mu B \rightarrow \phi \;,\quad \mu = \{\pi, \rho\}$$

$$\pi\rho \rightarrow \phi$$

$K^+K^- \rightarrow \phi$ negligible

Yields from	Ni + Ni (1.93 GeV)
B + B	3.5×10^{-4}
π + B	2.9×10^{-4}
ρ + B	8.9×10^{-4}
$\pi + \rho$	1.6×10^{-4}
π + N(1520)	0.5×10^{-4}
Total yield	1.7×10^{-3}

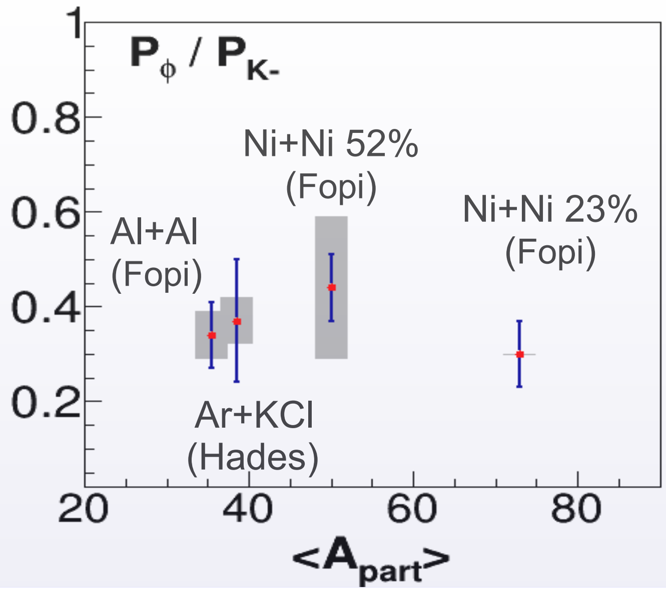
H.W. Barz et al. (BUU) ,
Nucl. Phys. A 705 (2002) 223



BUU:

ϕ yield overestimated

ϕ yield compared to K^-



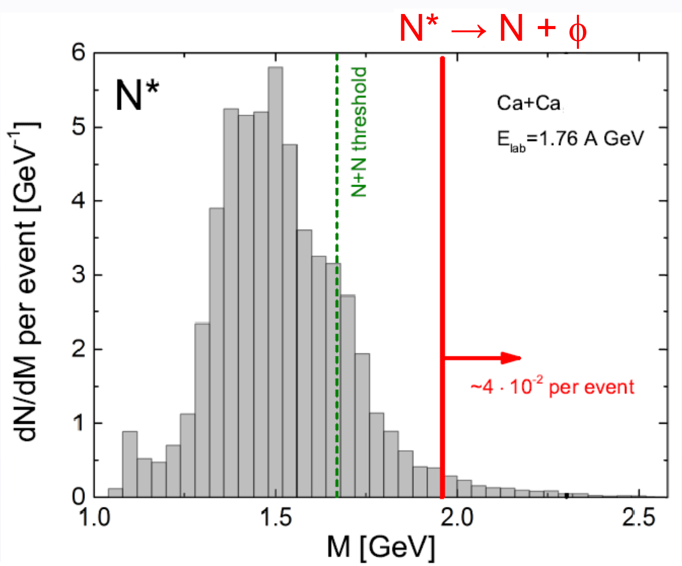
- $c\tau$ = 50 fm

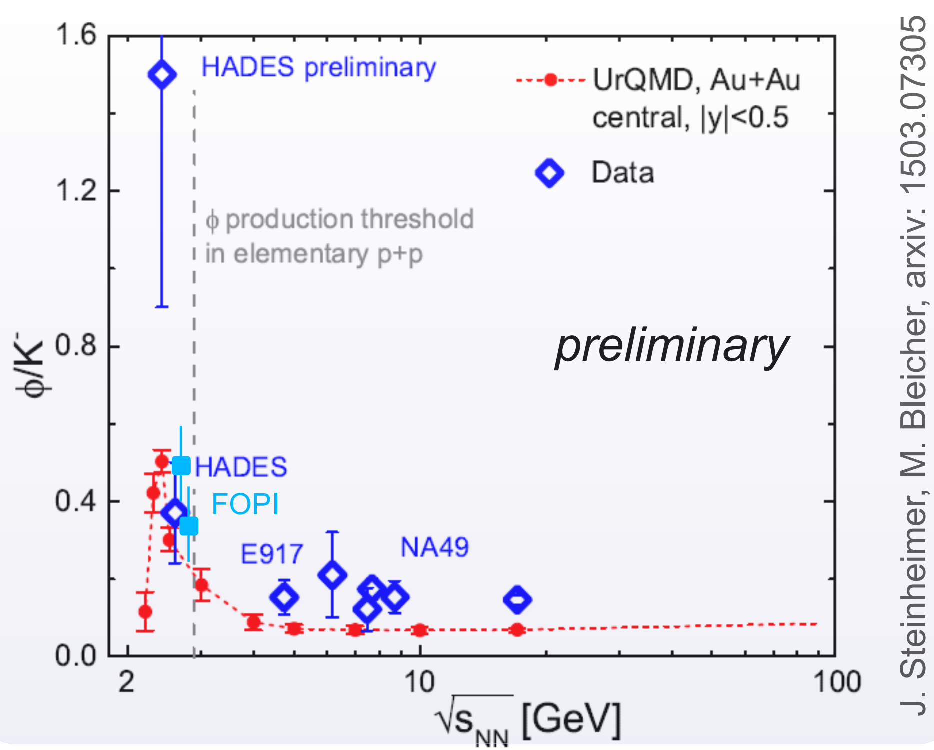
  $\phi \rightarrow K^+K^-$ (BR ~ 50%)

- $\frac{\phi}{K^-} \approx \frac{1}{3}$ → ~ 15 .. 20% K^- originates from ϕ decays

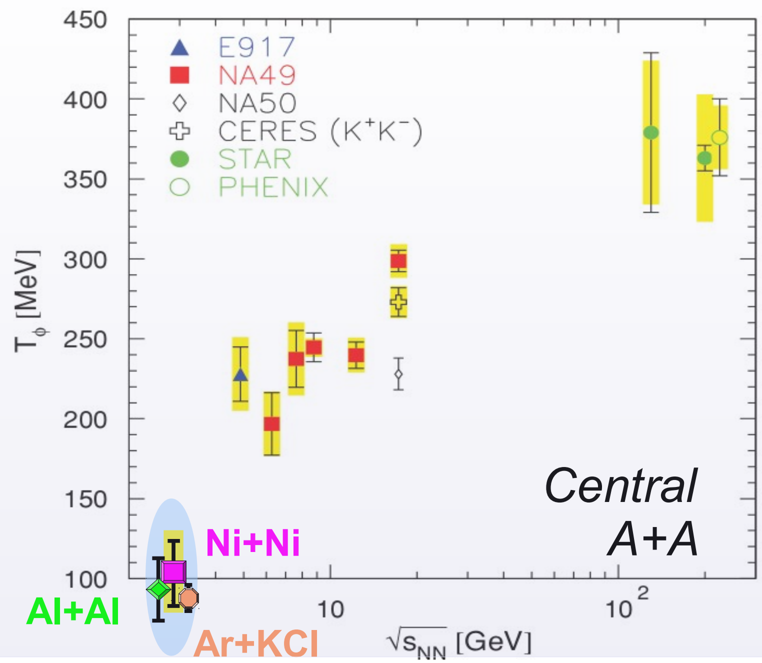
- **UrQMD** model

  Resonance states <u>in medium</u>:





Excitation function of ϕ inverse slopes



C. Alt et al. (NA49), Phys. Rev. C **78**, 044907 (2008)
B. Back et al. (E917), Phys. Rev. C **69**, 054901 (2004)

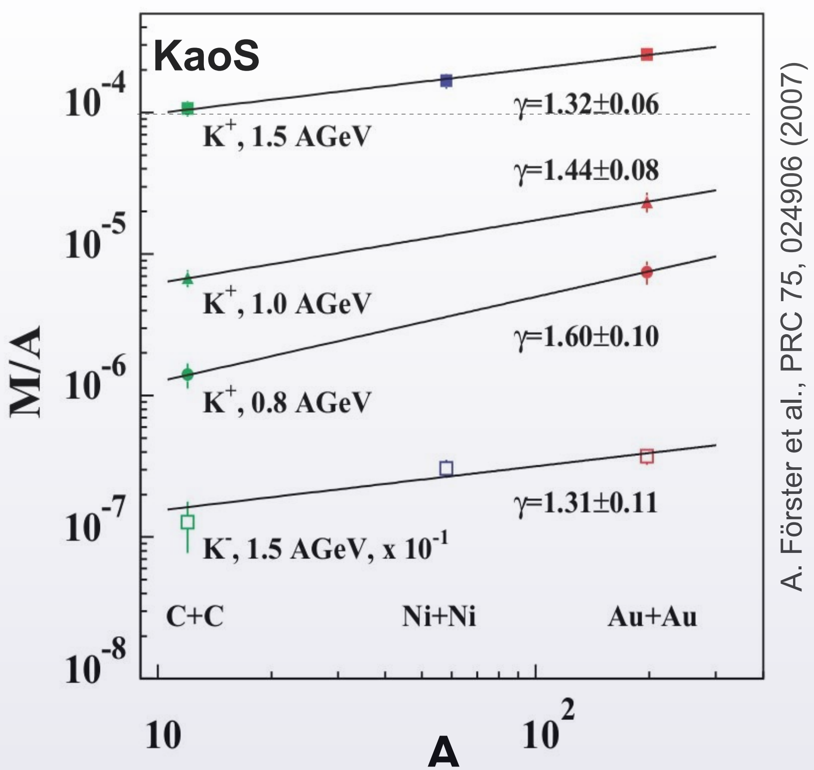
Production of Kaons in AA: Primary or secondary?

If primary:

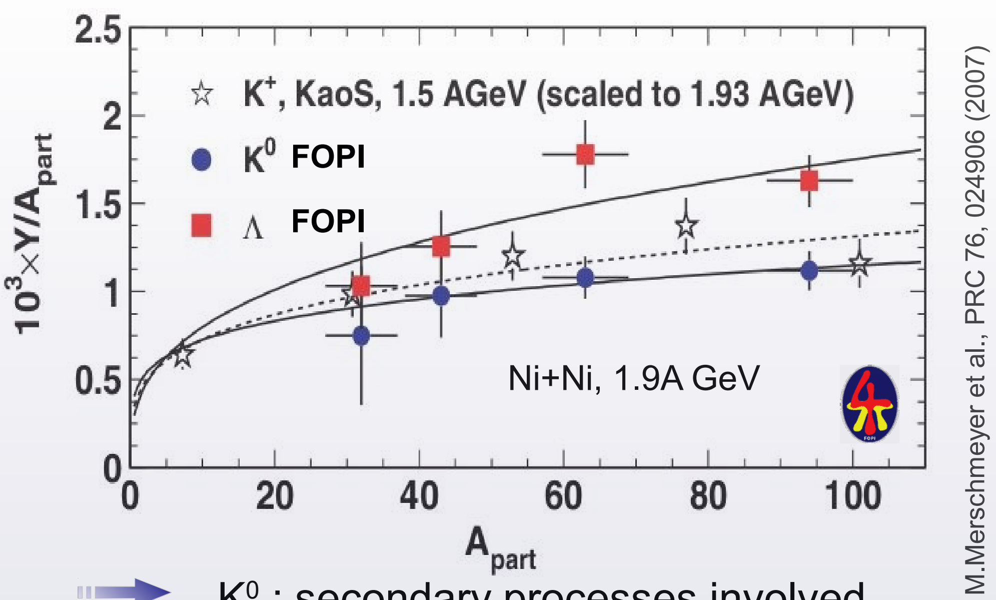
For pA → KX: $MUL_K = \frac{\sigma_K}{\sigma_{inelastic}} = const$

AA→ KX: Glauber: AA = A ⊗ NA

$\Rightarrow \quad MUL_K^{AA} = A \times MUL_K^{pA} \propto A$



→ secondary processes are involved



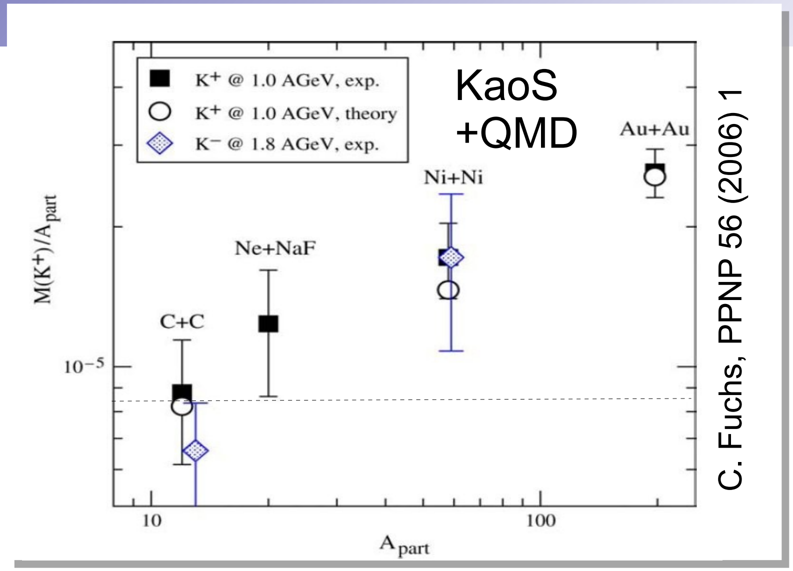
→ K^0 : secondary processes involved

K^{+0} near-threshold production processes:

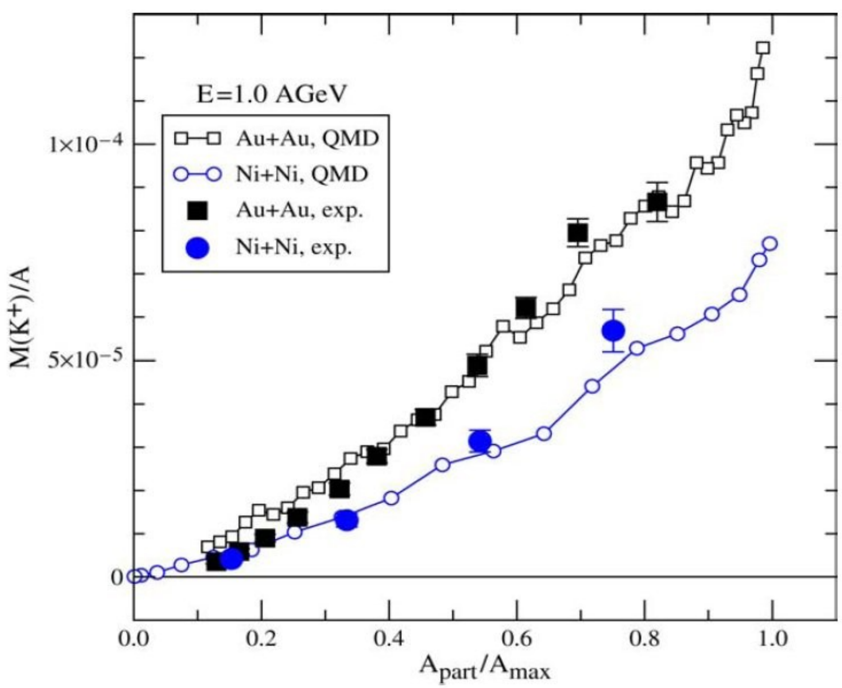
- $N_{beam} + N_{target}$, N_{target} has Fermi motion
- predominantly via ΔN , ΔΔ → $K^{+,0}$ Y B
  πN , πΔ → $K^{+,0}$ Y
  Y = [Λ,Σ]
- U_{KN} involved (increases K mass → lower yields)

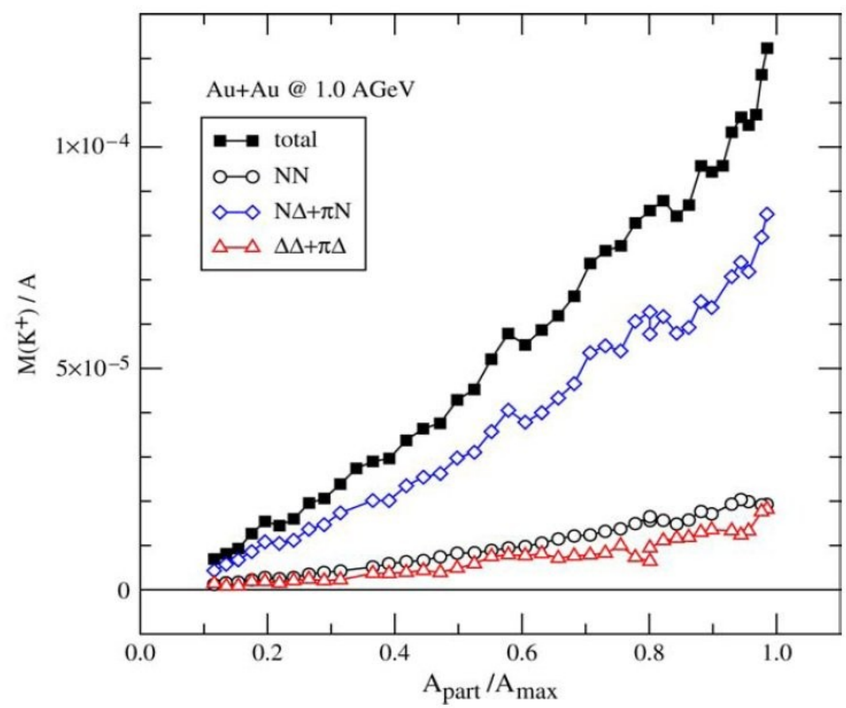
- K^+ Primary: (Fermi momentum)
  NN → N**K**$^+$Y (Y = Λ, Σ)

  K^+ Secondary:
  BB → B**K**$^+$Λ (BB = NΔ, ΔΔ)
  πB → **K**$^+$Y (B = N,Δ)



➡ Secondary processes involved





Sub- and near-threshold Production of K⁻

- in medium: mainly **strangeness exchange**:

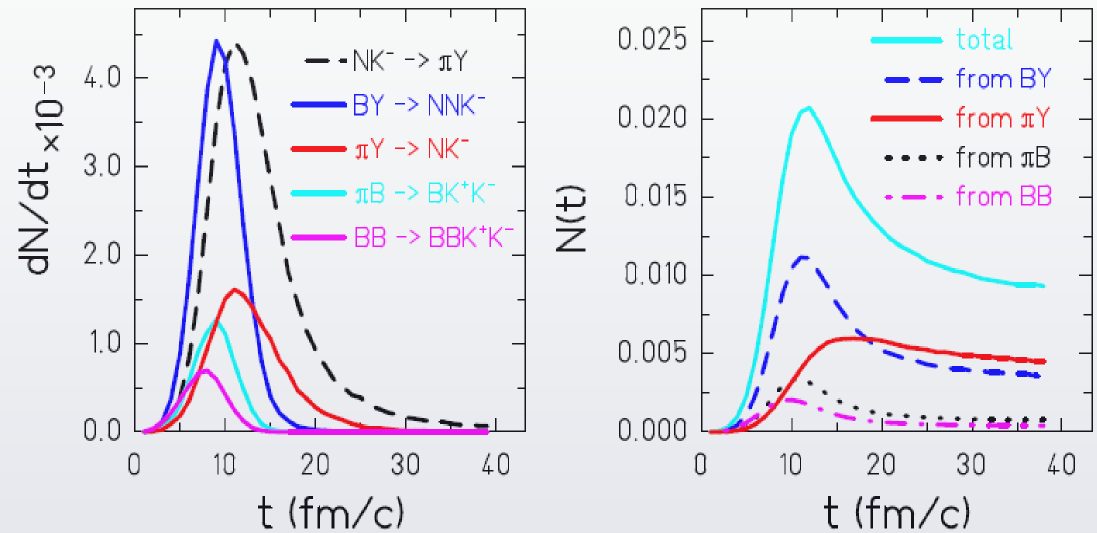
$BY \rightarrow NNK^-$, $\pi Y \rightarrow K^- B$

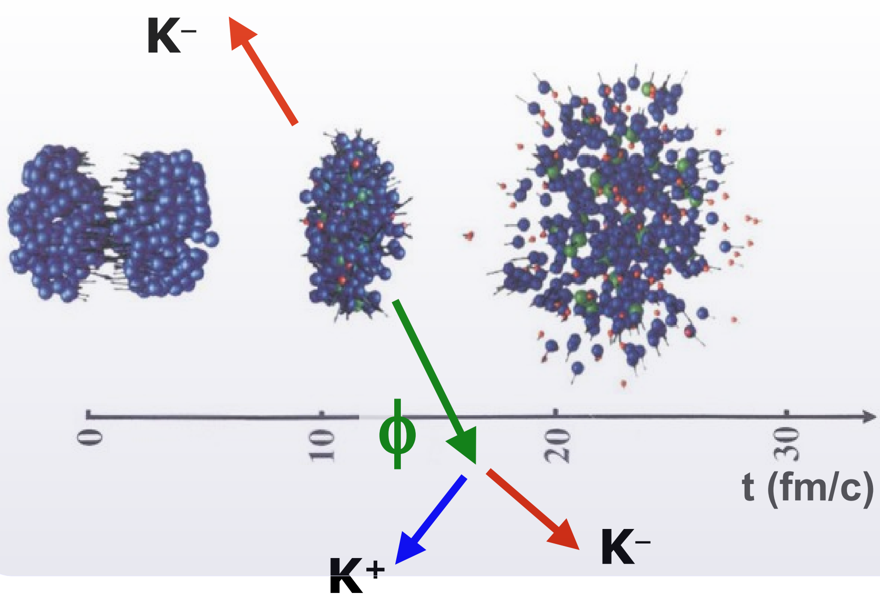
  - strong reabsorption: $K^- B \rightarrow \pi Y$
  - coupled to resonances Σ(1385), Λ(1405)

$\pi + Y \rightarrow \Sigma^* / \Lambda^* \rightarrow K^- + B$

Q: Can we see them?

Au+Au @ 1.5A GeV (IQMD transport code)





- $\phi(1020) \rightarrow$ **K⁻K⁺** decay (mostly outside collision zone)

  Q: How strong is this contribution?

- In-medium effects: "U_{KN} potential" or "spectral density"

  Q: How strong is this influence?

Particle yields vs Statistical Model and UrQMD

- **Al+Al** : 8 independent ratios involving p, d, π^-, K^+, K^-, K^0_s, ϕ, K^{*0}, $\Sigma^{*\pm}$, Λ
- **Ni+Ni** : 8 independent ratios involving p, d, π^+, π^-, K^+, K^-, K^0_s, ϕ, Λ

Statistical Model

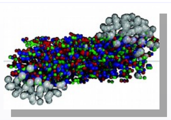
→ Grand Canonical ensemble;

→ For S≠0, Canonical ensemble

→ calc: THERMUS code

S.Wheaton, J.Cleymans , hep-ph/0407175

→ *SM* fitting quite well



UrQMD v 2.3

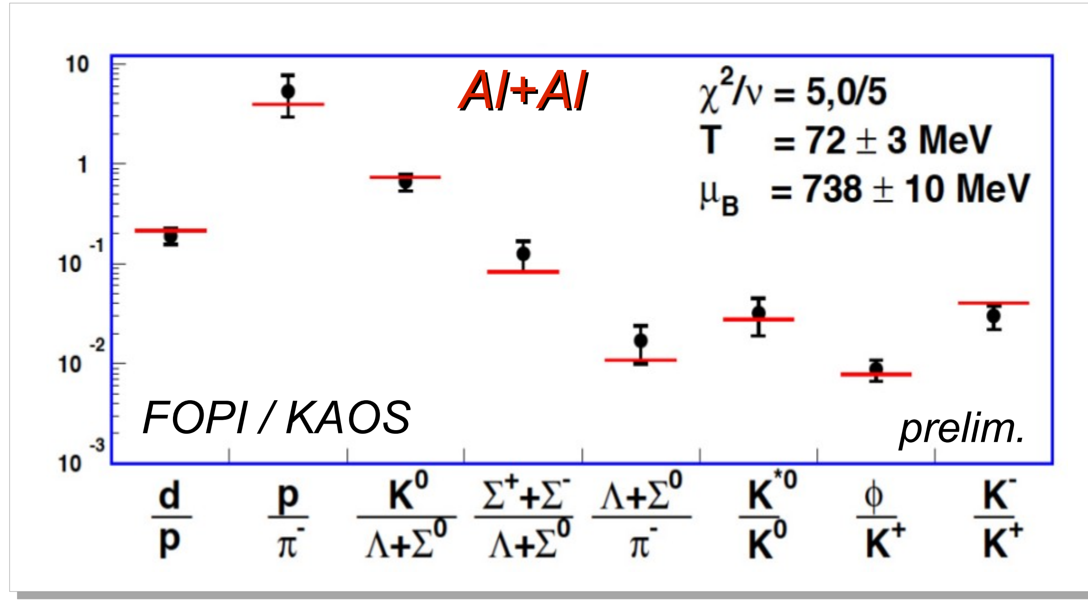
→ No equilibration assumed

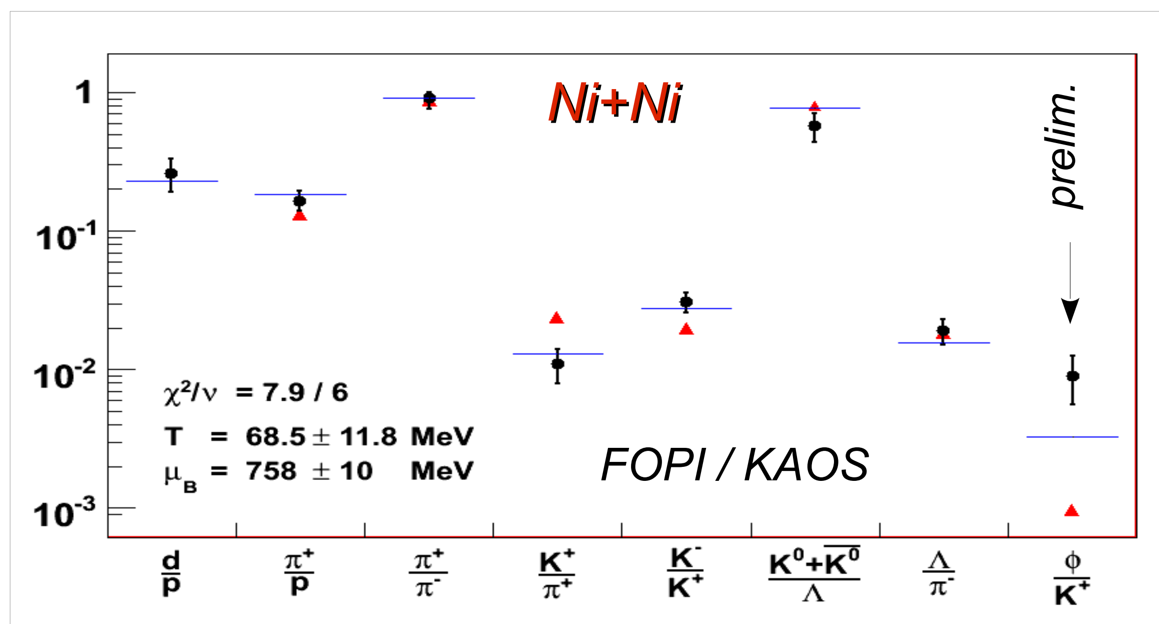
→ Cascade model – no mean field

– no in-medium effects

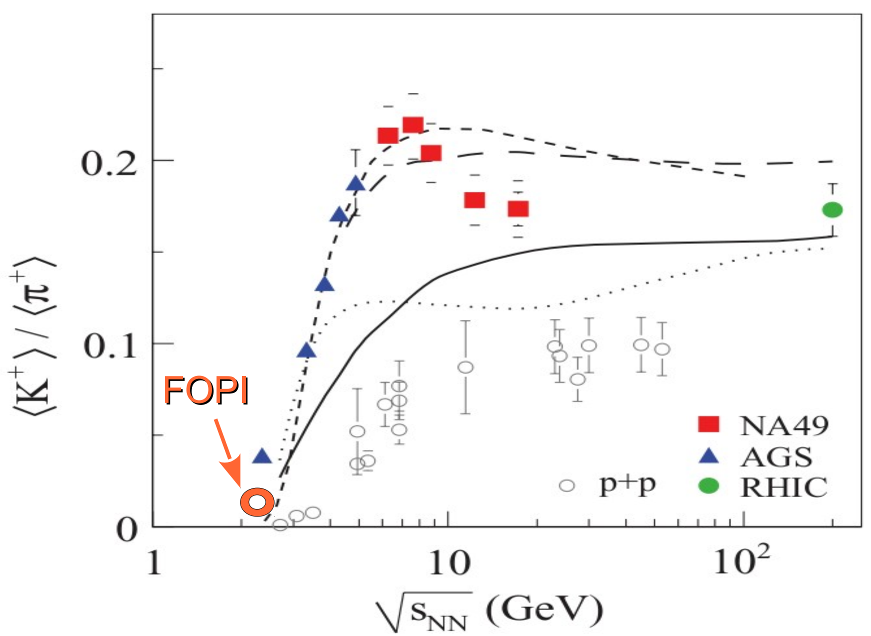
→ *J. Phys. G: Nucl. Part. Phys. 25 (1999) 1859*

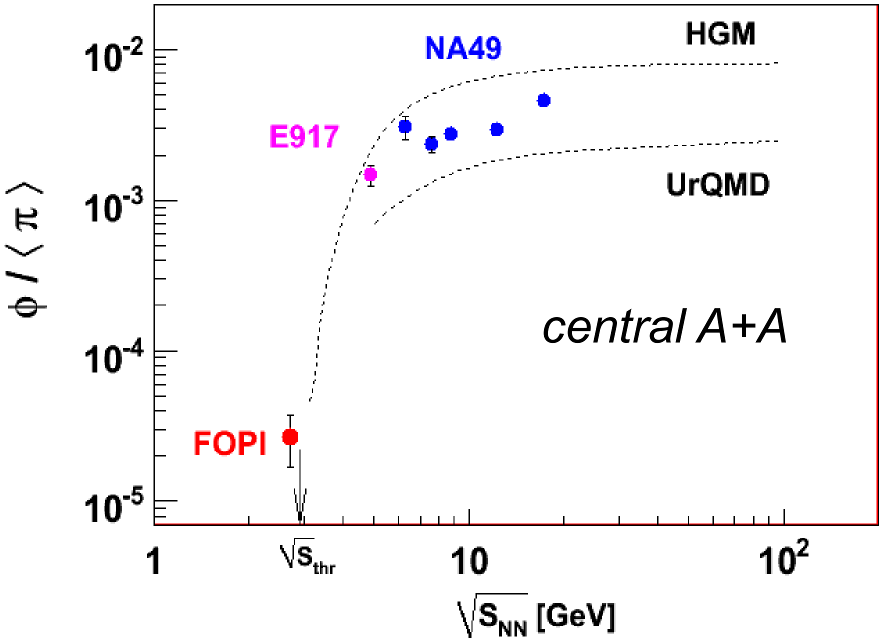
→ *UrQMD* fits quite well too

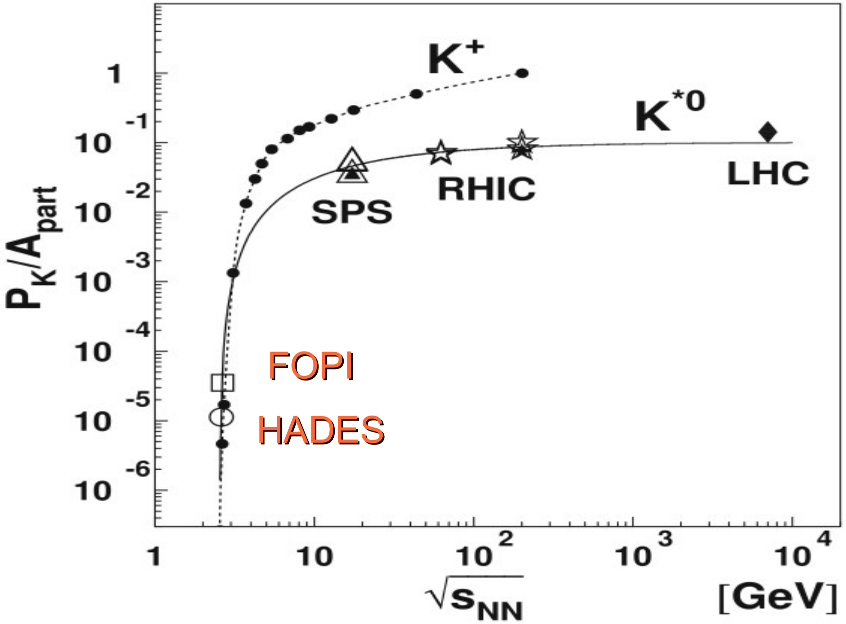




Strange meson excitation functions near threshold



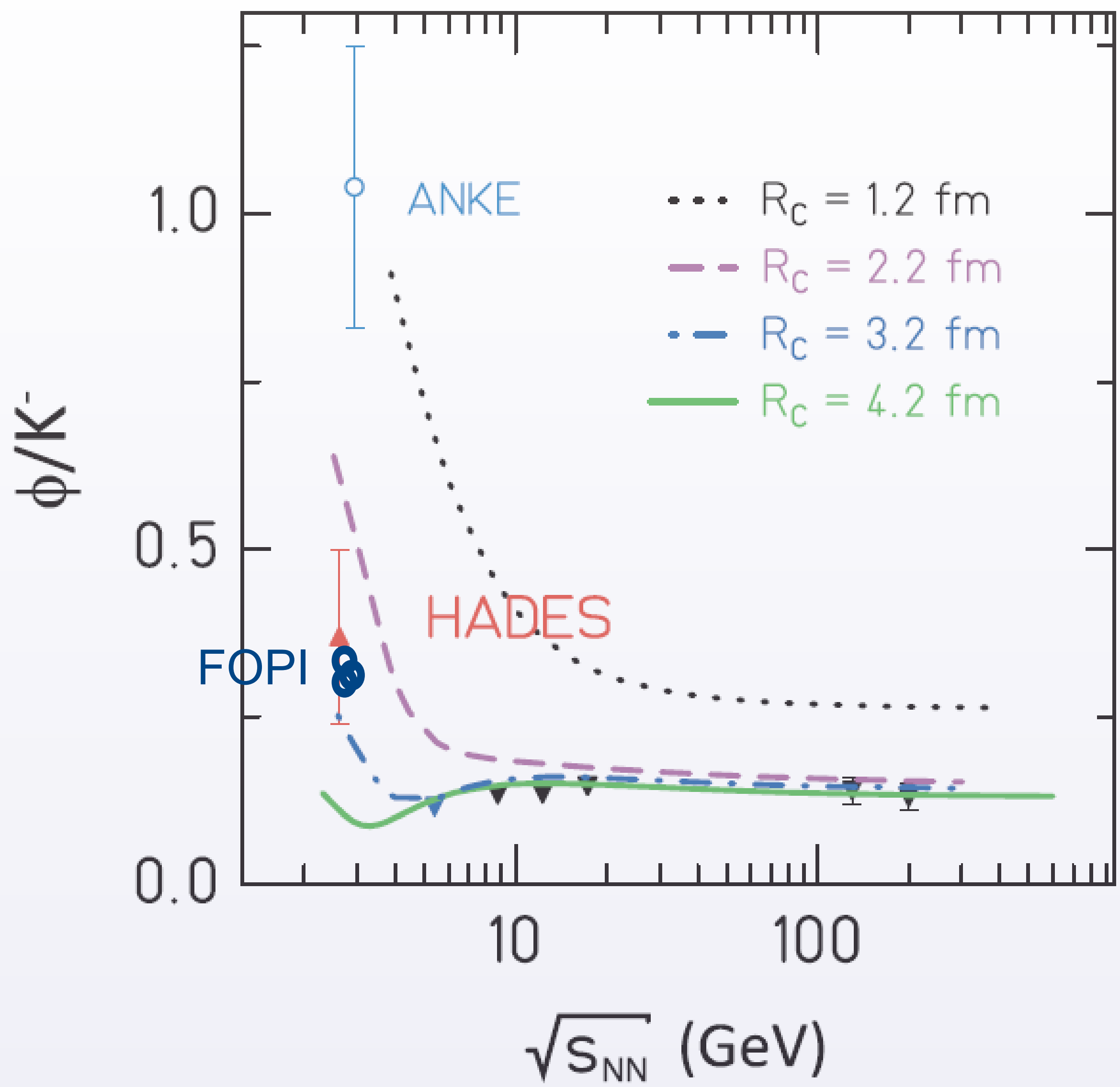




C. Alt et al. (NA49), Phys. Rev. C **78**, 044907 (2008)
B. Back et al. (E917), Phys. Rev. C **69**, 054901 (2004)

G. Agakishiev et al., Eur. Phys. J. A (2013) 49: 34

ϕ/K^- within the statistical model approach



J. Cleymans et al. PLB **603**, 146 (2004)

G. Agakishiev et al., PRC 80, 025209 (2009)