



Prediction for the isospin asymmetry in Kaon production at SIS energy

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- Simulation in this work

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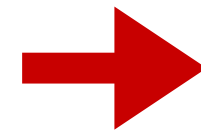
INTRODUCTION

Isospin



In 1932, Werner Heisenberg proposed ;

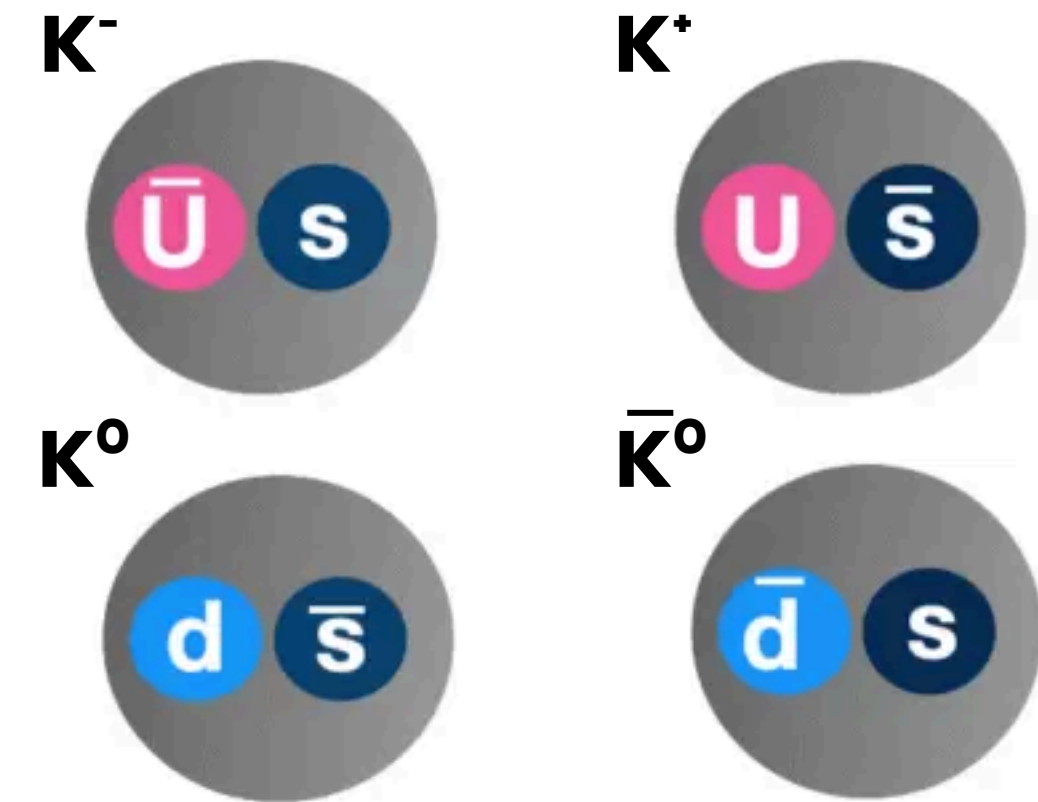
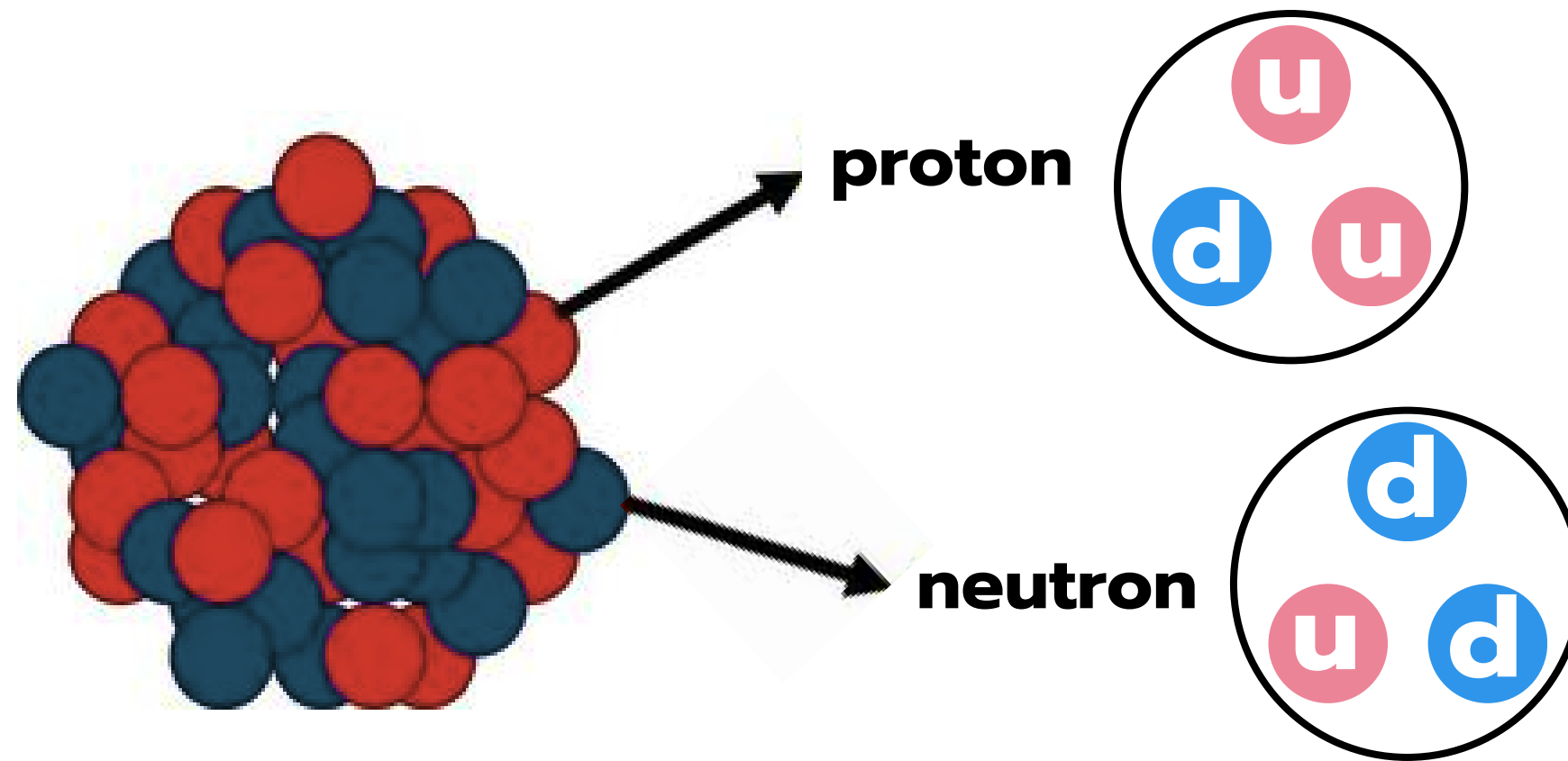
- strong force is charge independent
- $m_{\text{proton}} \sim m_{\text{neutron}}$
- the different is charge



“Switch off charge” → We cannot distinguish them

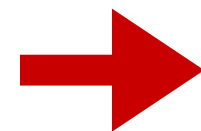
- The neutron and proton form an isospin doublet with total isospin $I = 1/2$ and third component $I_3 = \pm 1/2$.

Nucleus and kaon



Initial source before collisions:

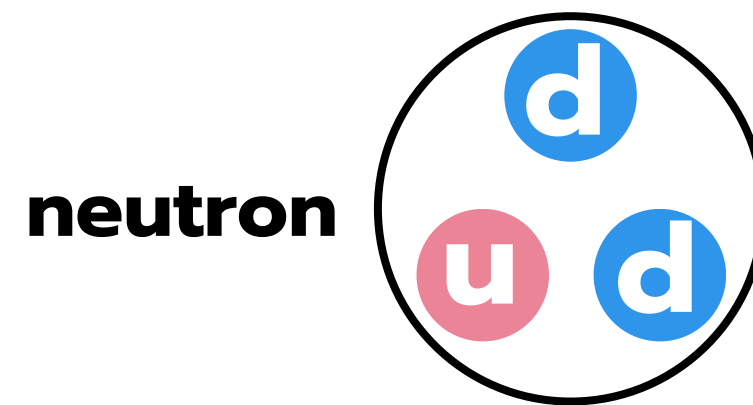
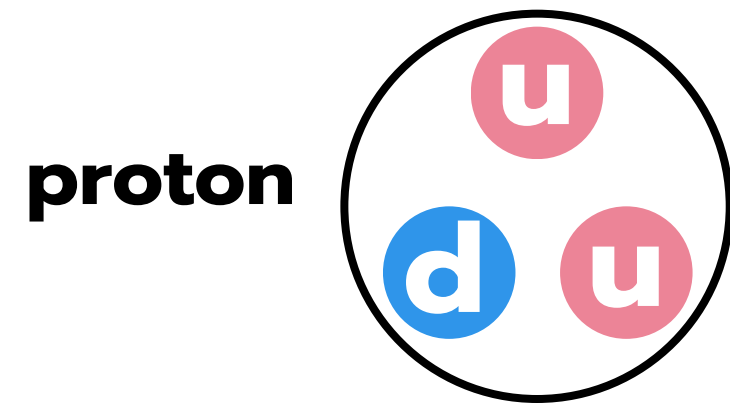
- neutrons > protons
- down-quark > up-quark



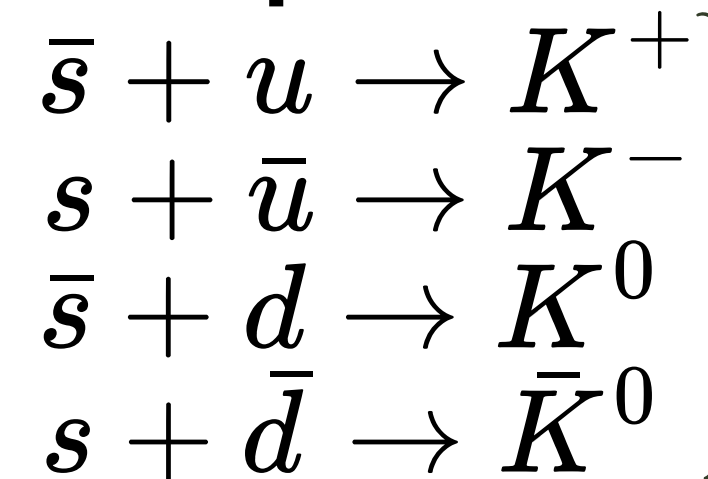
After collisions :

- Does this produce more particles containing down quarks?

Why expect more neutral kaon



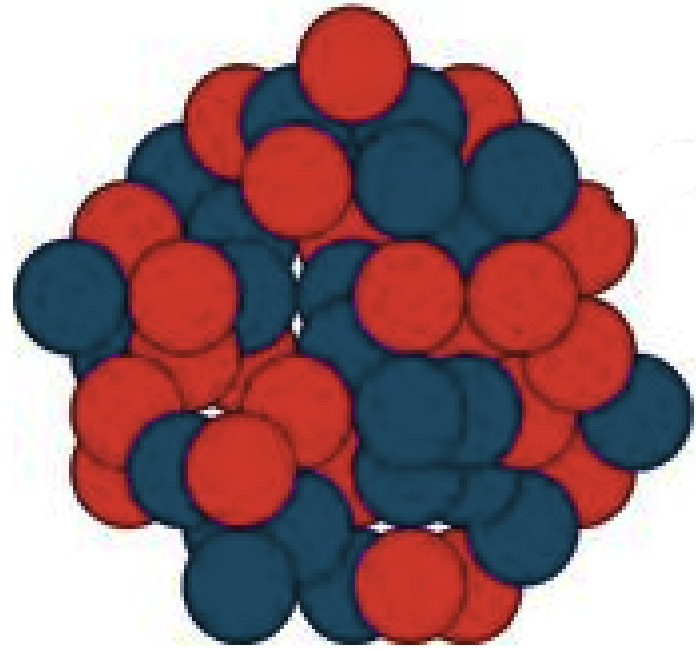
Kaon production via quark combination :



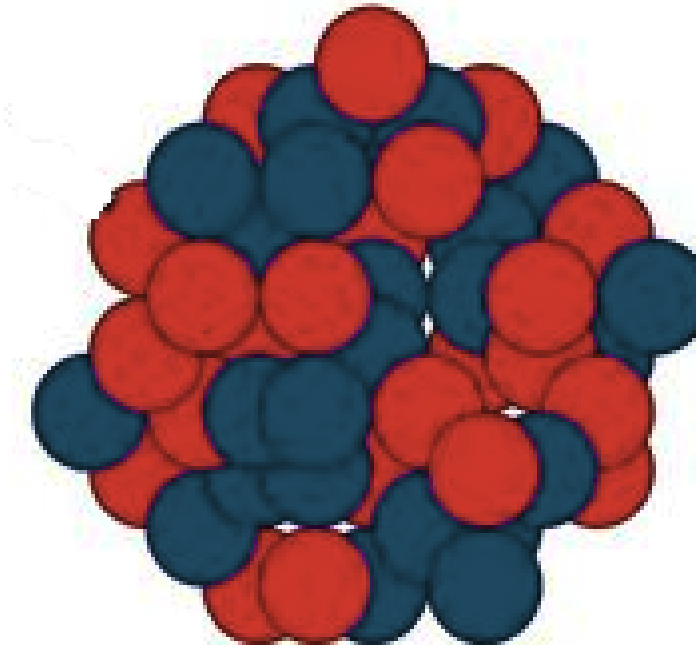
An excess of down-quark naturally favors neutral kaon production via recombination

- Strong interactions preserve an approximate isospin symmetry between up- and down-quark
- Strong interaction is charge independent

Isospin symmetric system



$$Q/A=1/2$$



$$Q/A<1/2$$

- Strong interactions preserve an approximate isospin symmetry between up-quark and down-quark

If isospin symmetry were exact ($Q/A = 1/2$) : **If $Q/A < 1/2$:**

- Charge and neutral kaon yields are equal
- down-quark > up-quark
- Charge kaon yields are smaller than neutral kaon yields

NA61/SHINE evidence

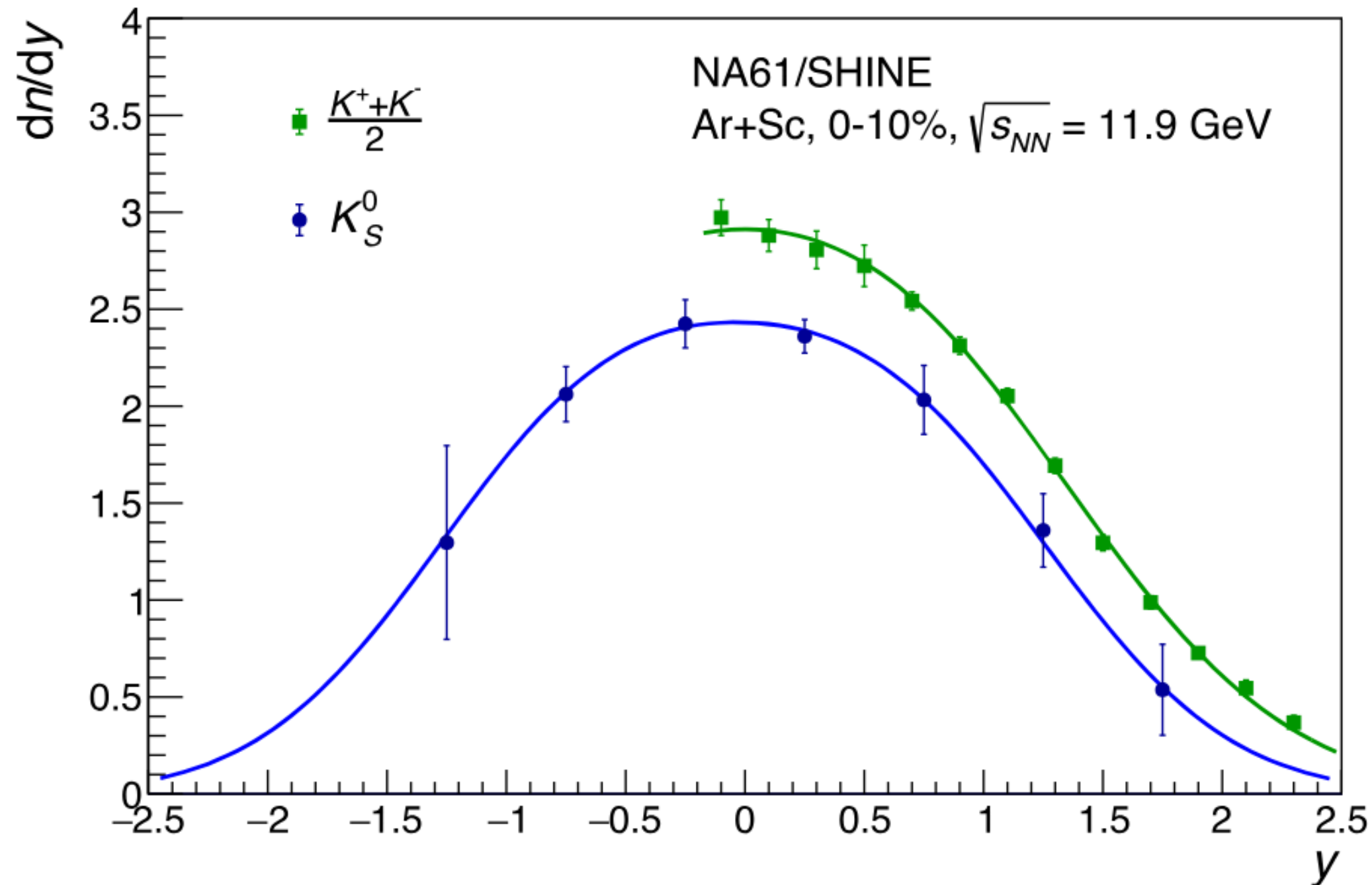


Figure 1. Charge and neutral kaon production

Ar + Sc collisions ($Q/A < 1/2$) :

- Charge kaon yield exceeds neutral kaon yield ($\sim 18.4 \pm 6.1\%$ at mid-rapidity)
- Resonance Decays (such as ϕ , a_0 , f_0)
- Electromagnetic & Weak Decays
- Initial state asymmetry ($Q/A < 1/2$)

World data

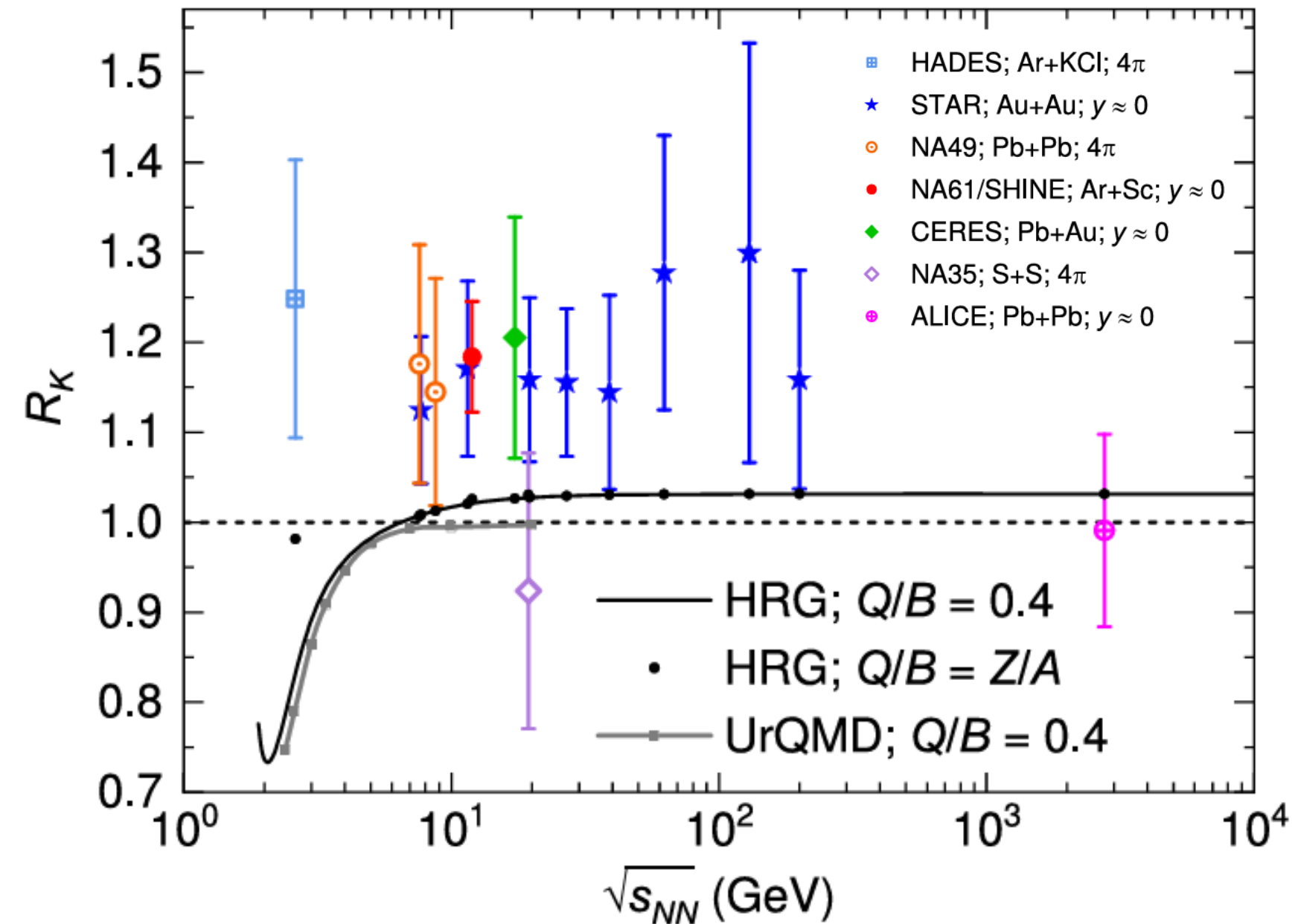


Figure 2. World data charge to neutral kaon ratio

$$R_K = \frac{K^+ + K^-}{2K_s^0} = \frac{K^+ + K^-}{K_0 + \bar{K}_0}$$

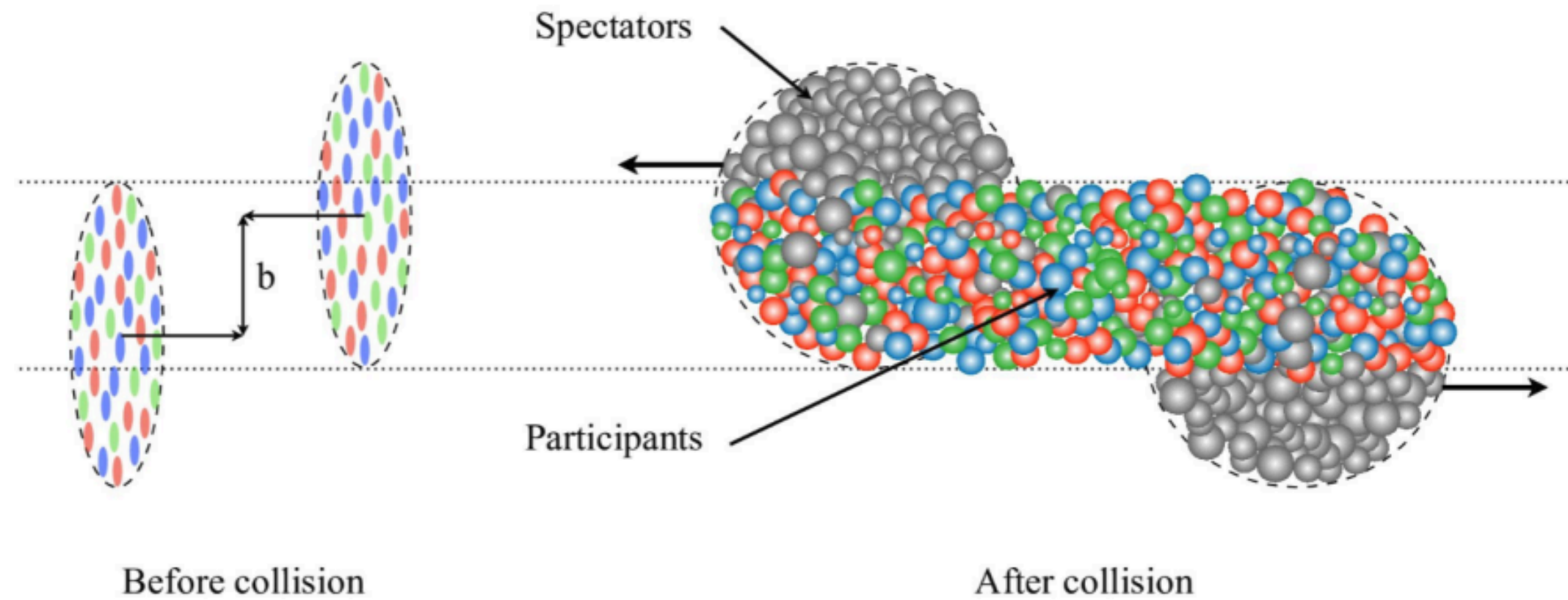
Effect on R_K :

- Initial state asymmetry ($Q/A < 1/2$)
 - $R_K \leq 1$
- Kaon Mass Difference ($m_{\text{charge-kaon}} \neq m_{\text{neutral-kaon}}$)
 - $R_K + 2\%$
- Resonance Decays (such as ϕ , a_0 , f_0)
 - $R_K + 3\%$
- Electromagnetic & Weak Decays
 - uncertainty of R_K observation $< 0.2\%$ from reconstruction

** Measured $R_K = 1.184 \pm 0.061$ (18.4% excess)

SIMULATION

The UrQMD model



The Ultra-relativistic quantum molecular dynamics model :

- Tracking every hadron propagation, every decay, and every collisions
- Enable for big range of energy (SIS to LHC energy)
- Includes elastic and inelastic scattering, resonance and string dynamics

The UrQMD modification

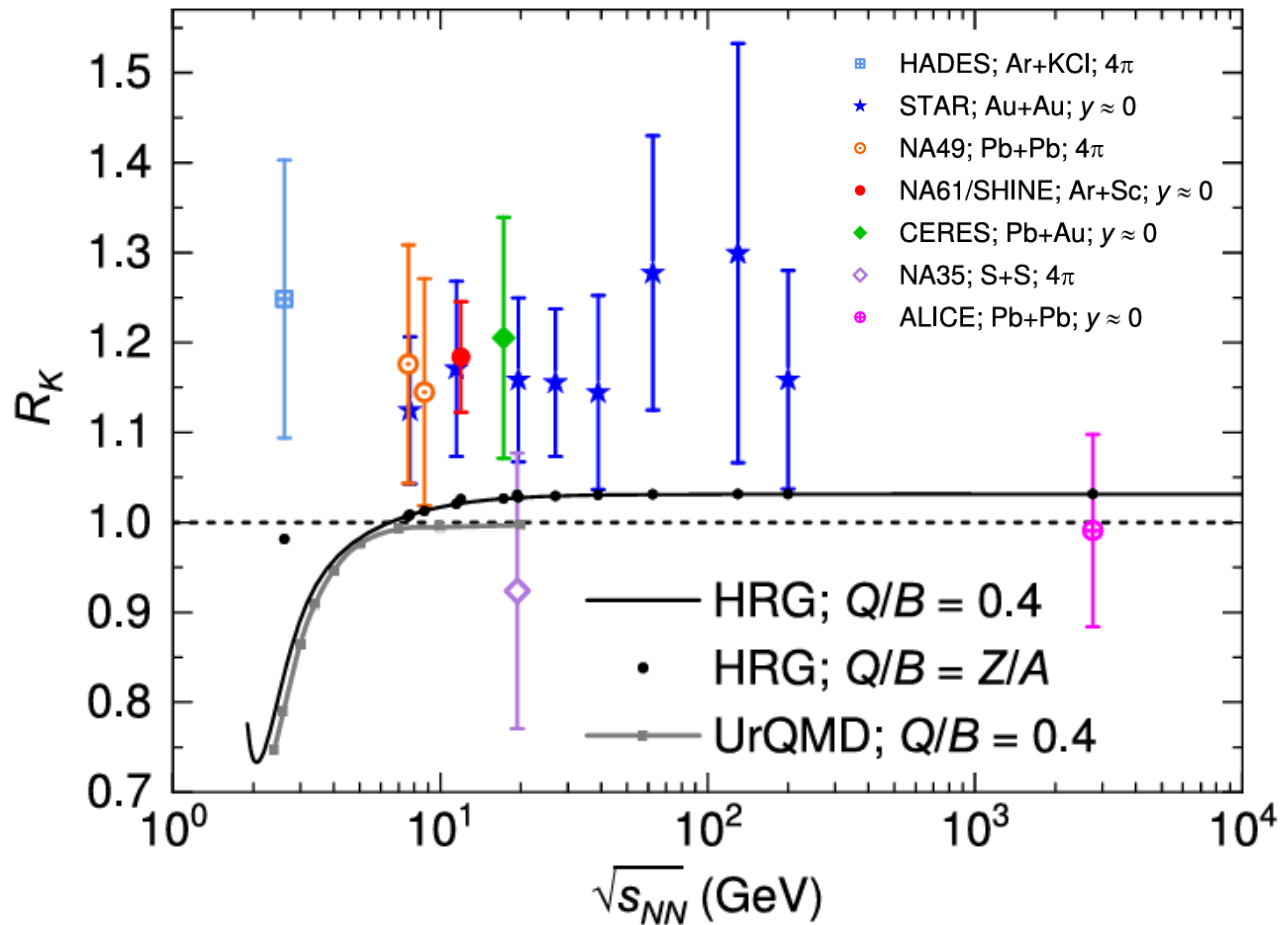


Figure 2. World data charge to neutral kaon ratio

Standard Model Baselines (HRG & UrQMD) :

- Neutron rich ($Q/A < 1/2$) pushes $R_K < 1$
- Maximum theoretical prediction ($R_K \sim 1.03$)

UrQMD relative probability of up- and down-quark production in color-string fragmentation :

Symmetry :

$$P(u) : P(d) = 1 : 1$$

$$P(u) = 42\%$$

$$P(d) = 42\%$$

$$P(s) = 16\%$$



Asymmetry :

$$P(u) : P(d) = 3 : 1$$

$P(u) = 62\%$
 $P(d) = 22\%$

probability shifted

$$P(s) = 16\%$$

UrQMD validation in e^+e^- and $p+p$

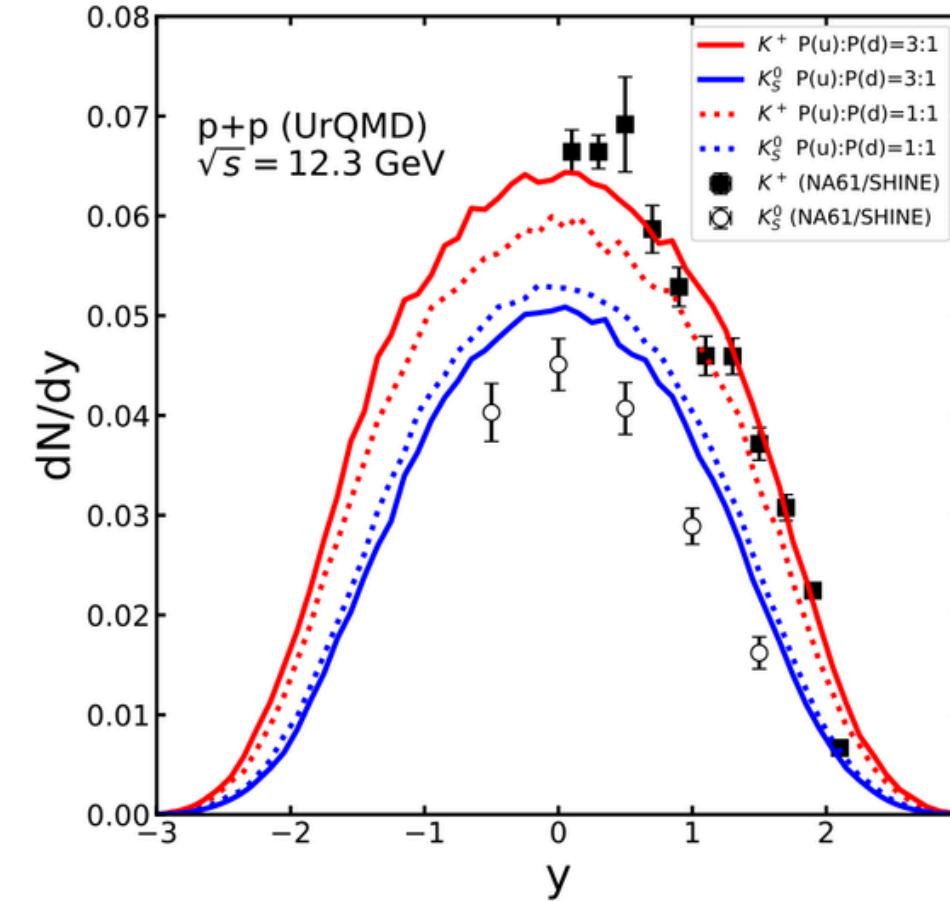
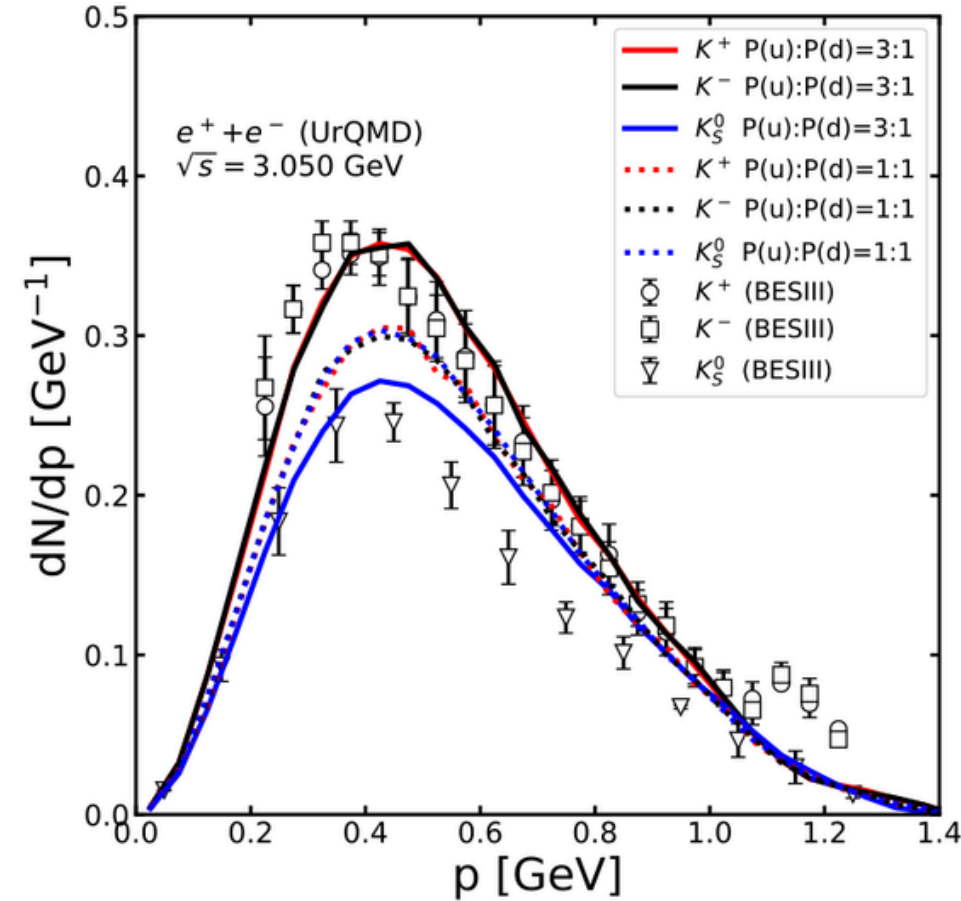


Figure 3. UrQMD momentum distribution in e^+e^- annihilation **Figure 4.** UrQMD momentum distribution in $p + p$ reactions

Asymmetry implemanting in UrQMD :

- $P(u):P(d) = 1:1$ cannot describe these reactions
- $P(u):P(d) = 3:1$ consistent with BESIII and NA61/SHINE
- $R_K > 1$ seems already present in elementary reactions

Simulation in this work

$\pi^- + \text{C}$ collisions :

- $p_{\text{lab}} = 1.0, 1.5, 2.5 \text{ GeV}$ ($b < 2.5 \text{ fm}$)
- Test a $\pi^-(d\bar{u})$ beam on an isospin-symmetric target (Carbon, $Q/A = 1/2$)

$\text{Au} + \text{Au}$ collisions :

- $\sqrt{s_{NN}} = 3.0, 3.2, 3.5, 3.9, 4.5 \text{ GeV}$ ($b < 4.7 \text{ fm}$)
- Covers the transition threshold from SIS18 to low energy RHIC

RESULTS

$\pi^- + \text{C}$ collisions

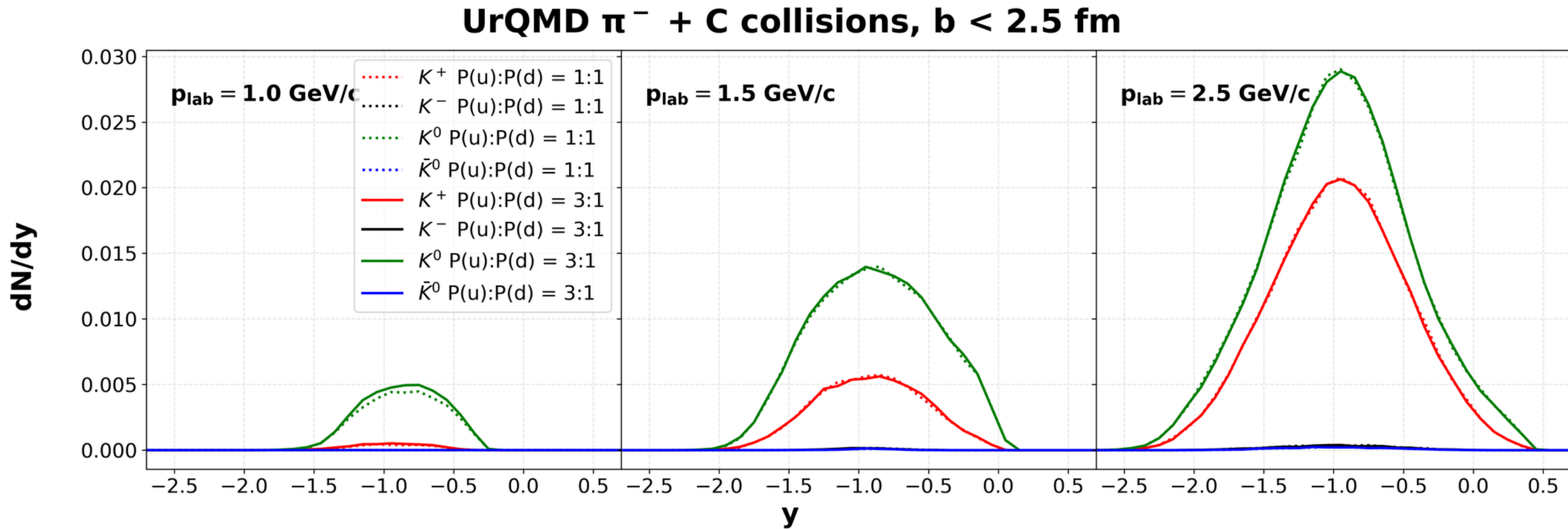


Figure 5. UrQMD charge and neutral kaon rapidity distribution in $\pi^- + \text{C}$ collisions

- Neutral kaon exceed charge kaon across all rapidity and beam momenta
- Neutral kaon production is favored by the down-quark excess of the incoming π^- beam
- Symmetric and asymmetric scenarios demonstrated the same distribution

$\pi^- + \text{C}$ collisions

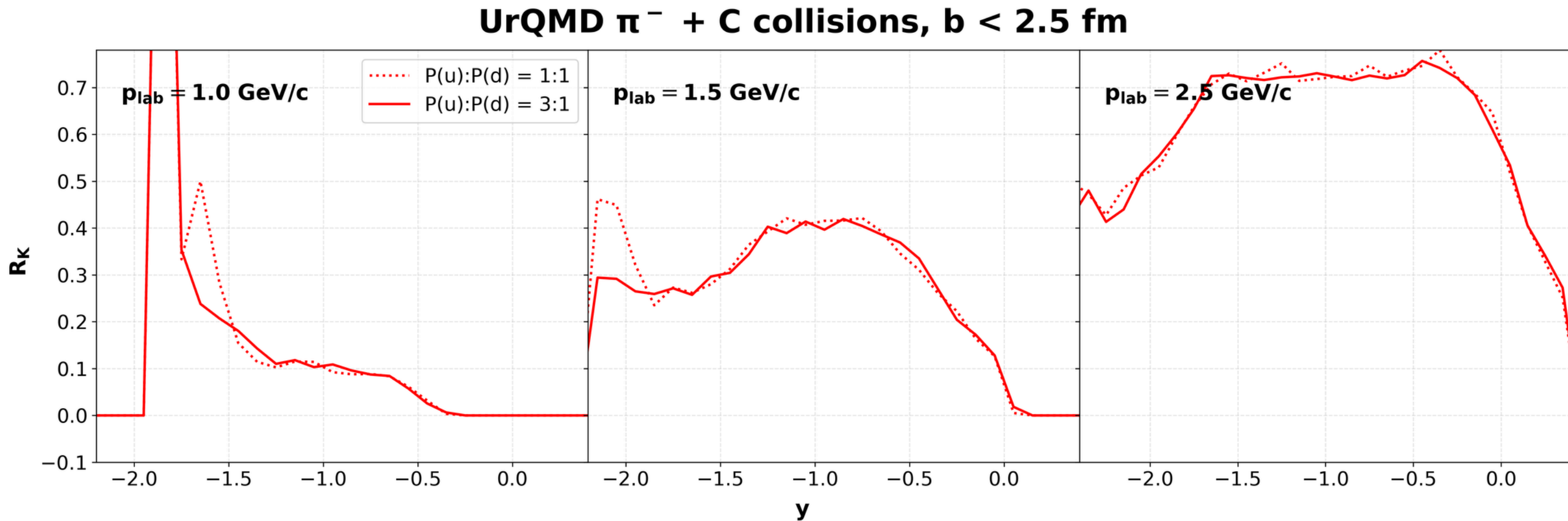


Figure 6. UrQMD charge to neutral kaon ratio in $\pi^- + \text{C}$ collisions

- As beam momentum increases, R_K rises up
- Asymmetry scenario give no change in R_K
- Kaon production in both scenarios is dominated by resonance decays

Au + Au collisions

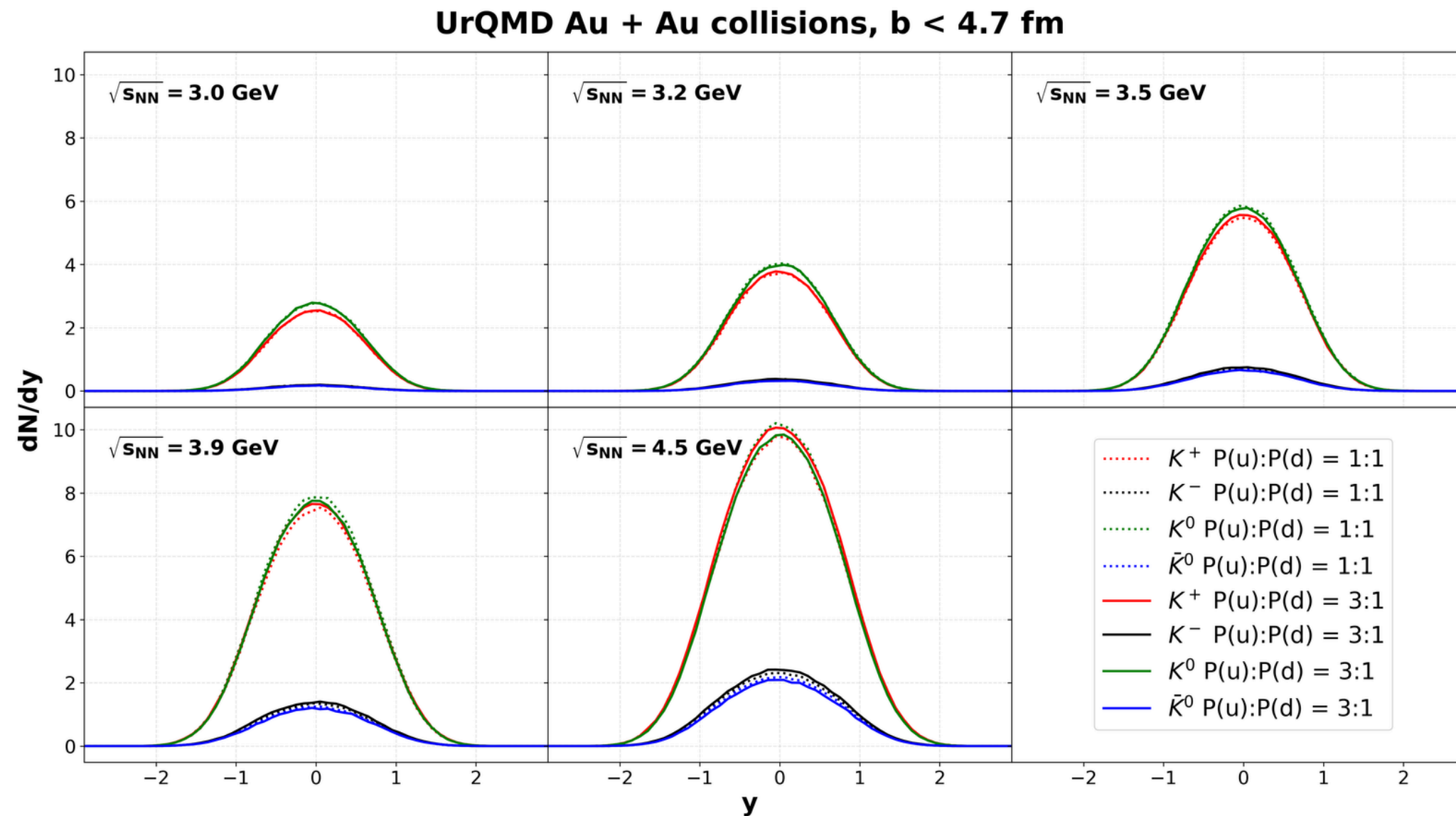


Figure 7. UrQMD charge and neutral kaon rapidity distribution in Au + Au collisions

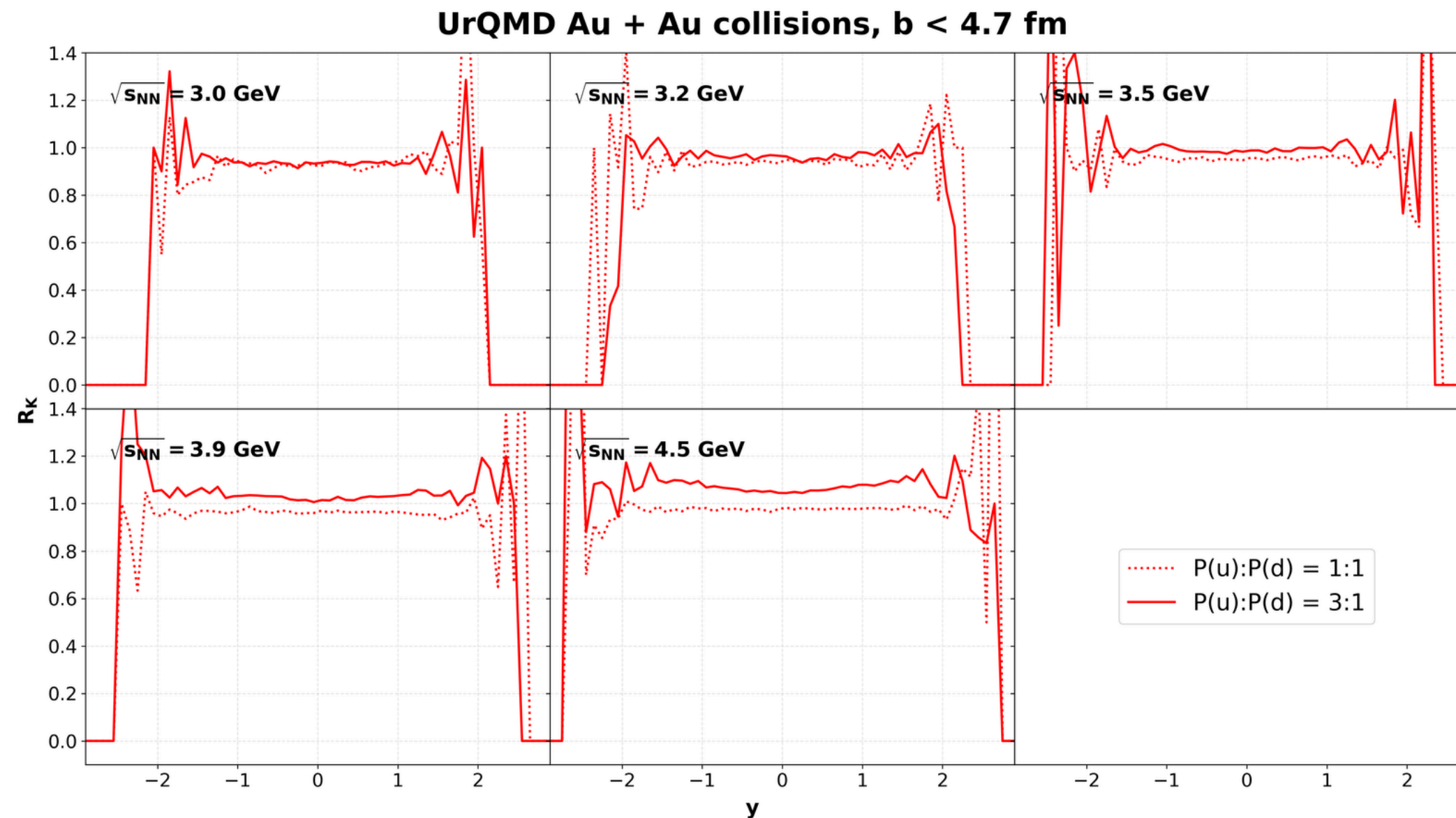
At 3.0 and 3.2 GeV :

- Both scenarios give the same distribution
- Kaon production mainly from resonance decay

At 3.5, 3.9 and 4.5 GeV :

- String excitation open up
- Charge kaon increase while neutral kaon are suppressed

Au + Au collisions



At 3.0 and 3.2 GeV :

- Governed by initial rich neutron and resonance decays makes R_K sits below unity

At 3.5, 3.9 and 4.5 GeV :

- Asymmetry shift R_K up
- String excitation become active and populate the yield

CONCLUSION

Conclusion

- **π^- + C collisions :**

1. $R_K < 1$ across all rapidities due to the π^- down-quark excess.
2. String modification has no effect because kaons originate predominantly from baryonic resonance decays.

- **Au + Au collisions :**

1. Exhibits a clear that below 3.2 GeV, string contributions are negligible
2. Resonance dominance keeps $R_K \leq 1$ below 3.2 GeV
3. String fragmentation activates above 3.5 GeV, driving $R_K > 1$ under asymmetric breakup

- Highlights the need for beam-energy and system-size scans ($N=Z$ vs. $N>Z$) to isolate the effect from resonance to string dominated iso-spin breaking



Thank you for your attention

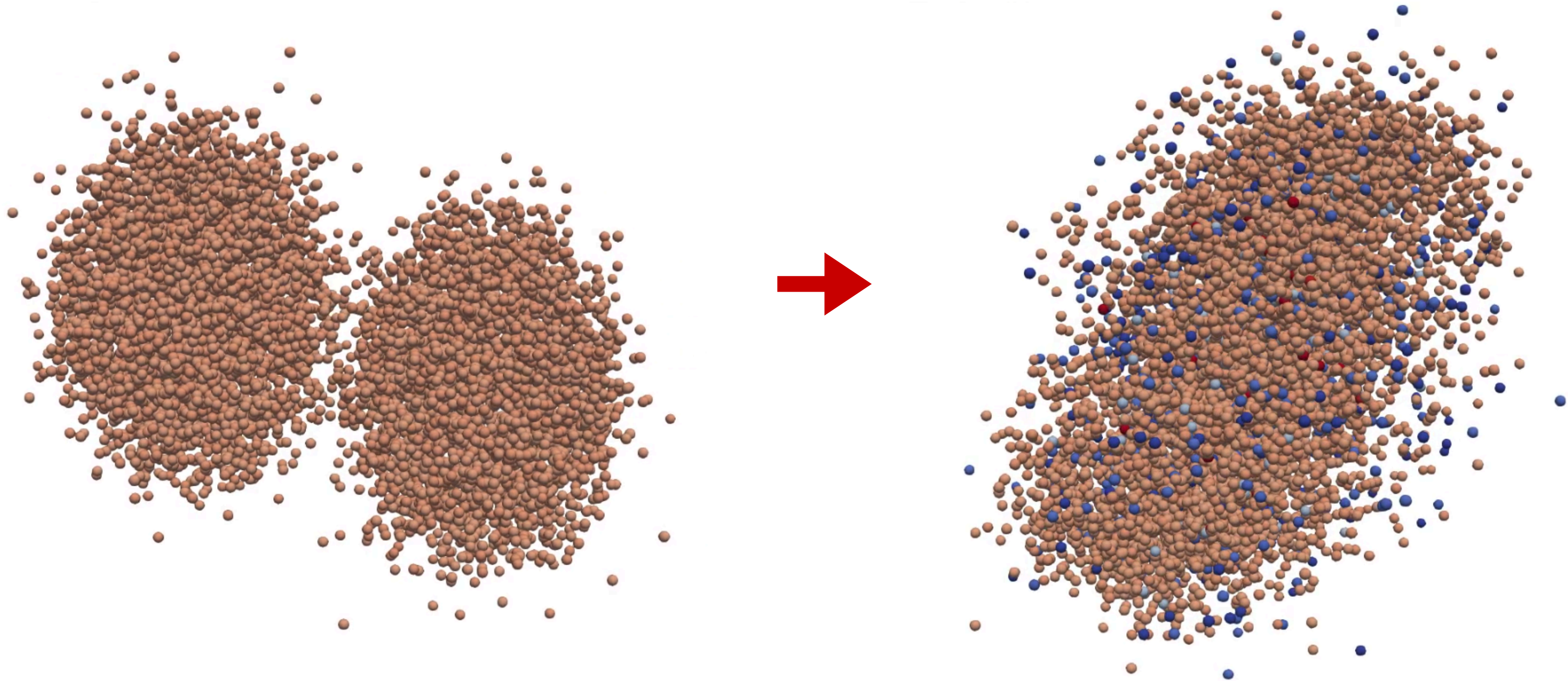
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BACK UP

Au + Au collision



Ref Fig. : smash-transport.github.io

Last work by T. Reichert

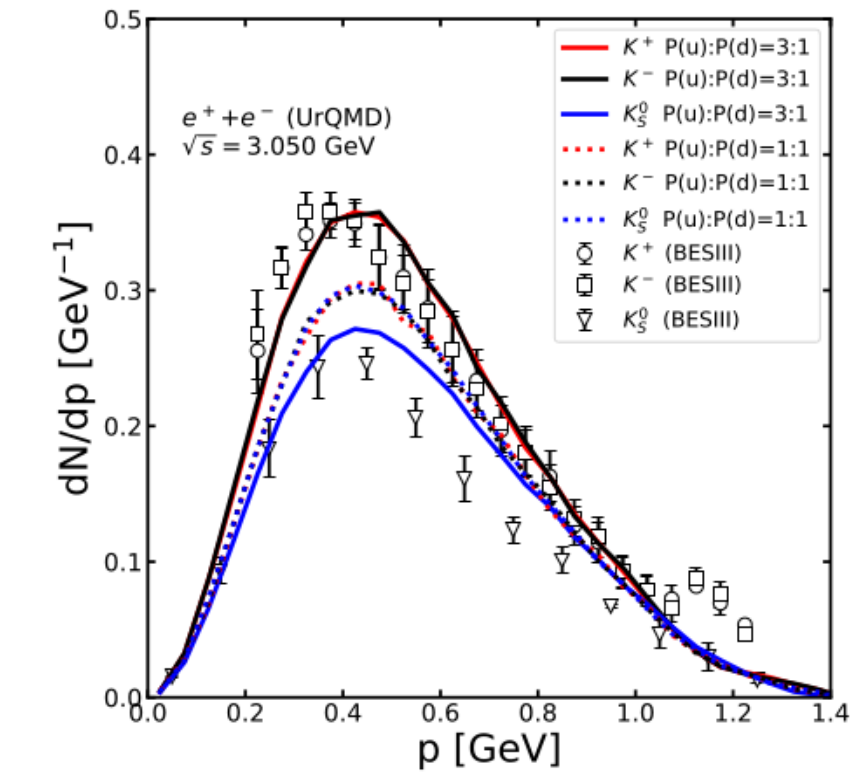


Fig. 1. [Color online] Momentum distributions of K^+ (red) K^- (black) and $K_S^0 = (K^0 + \bar{K}^0)/2$ (blue) in e^+e^- annihilations at $\sqrt{s} = 3.050$ GeV. The dotted lines show the standard parametrization of the color field fragmentation parameters, the full lines show the refitted parameters which allow for an asymmetry between up- and down-quark production in the color field. The symbols show the experimental data by BESIII [9,10].

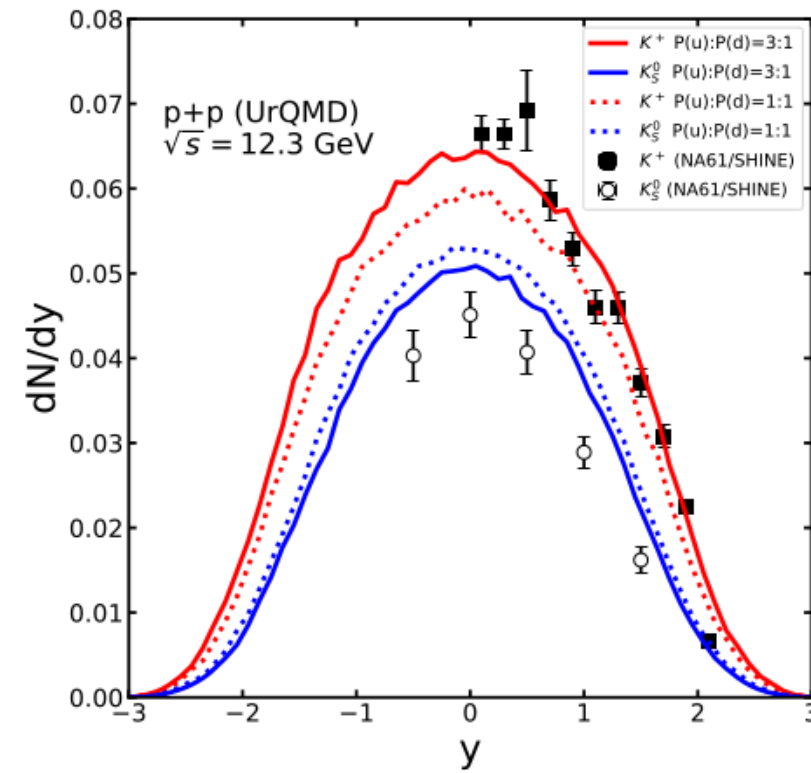


Fig. 2. [Color online] Rapidity distributions of K^+ (red) and $K_S^0 = (K^0 + \bar{K}^0)/2$ (blue) in proton+proton collisions at $\sqrt{s} = 12.3$ GeV. The dotted lines show the standard parametrization of the color field fragmentation parameters, the full lines show the refitted string fragmentation parameters. The symbols show the experimental data by the NA61/SHINE experiment [11,12].

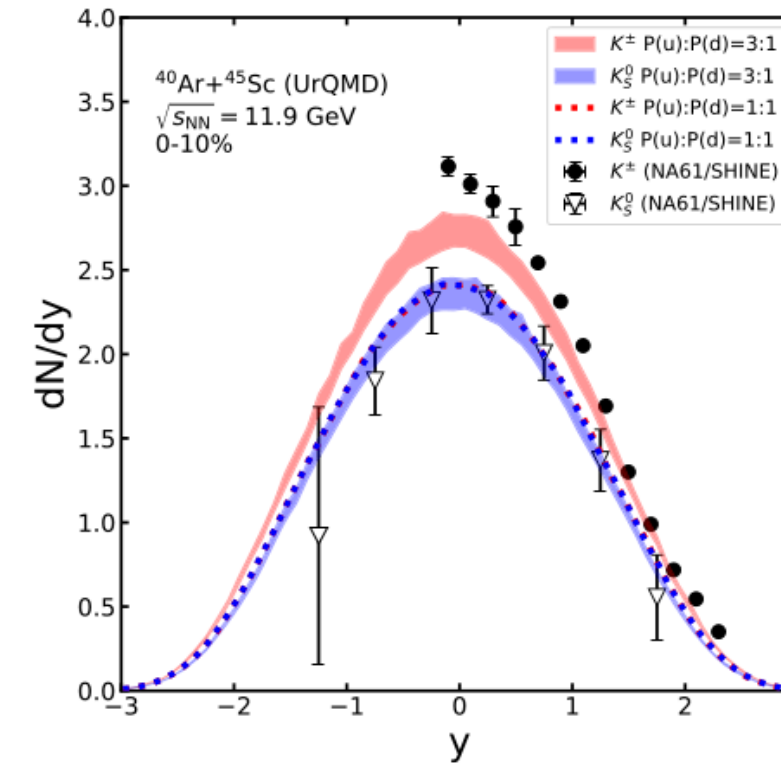


Fig. 3. [Color online] Rapidity distributions of $K^\pm = (K^+ + K^-)/2$ (red) and $K_S^0 = (K^0 + \bar{K}^0)/2$ (blue) in 0–10% central Ar+Sc collisions at $\sqrt{s_{NN}} = 11.9$ GeV. The dotted lines show UrQMD calculations with the standard parametrization of the color field fragmentation parameters, the full lines show the UrQMD results using the refitted string parameters. The error band in the calculation is due to the estimation of the centrality ($\langle N_{wounded} \rangle = 60 - 64$ representing 10% central collisions). The symbols show the experimental data by the NA61/SHINE experiment [1,16].

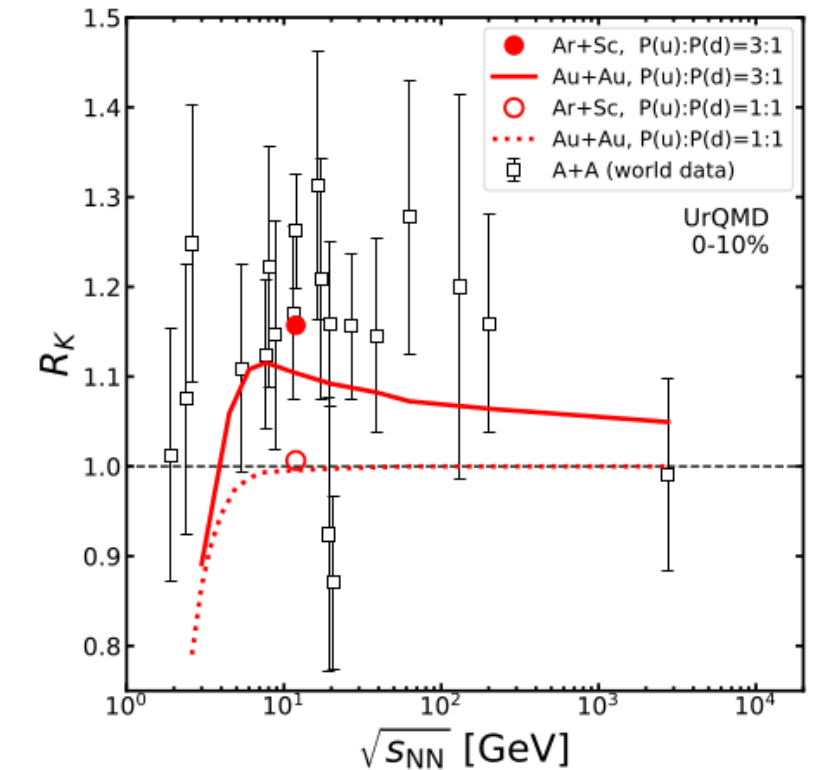


Fig. 4. [Color online] Comparison of the refitted simulations with the world data on the ratio $R_K = (K^+ + K^-)/(K^0 + \bar{K}^0)$. The dotted lines shows UrQMD calculations for central Au+Au reactions with the standard parametrization of the color field fragmentation parameters, the full lines show UrQMD results using the refitted string fragmentation parameters. We further show the UrQMD results for Ar+Sc collisions (circles) because Ar+Sc has a larger protons/neutron ratio than Au+Au. The black squares show the experimental data in nucleus-nucleus collisions (taken from the compilation in Adhikary [16]).

Isospin and their third component

$I_3^{initial} \approx I_3^{final}$ (Not exactly the same just approximately because we know that isospin **is not** conserved)

$$I_3^{initial} = \frac{Z - N}{2} = B \left(\frac{Q}{B} - \frac{1}{2} \right)$$

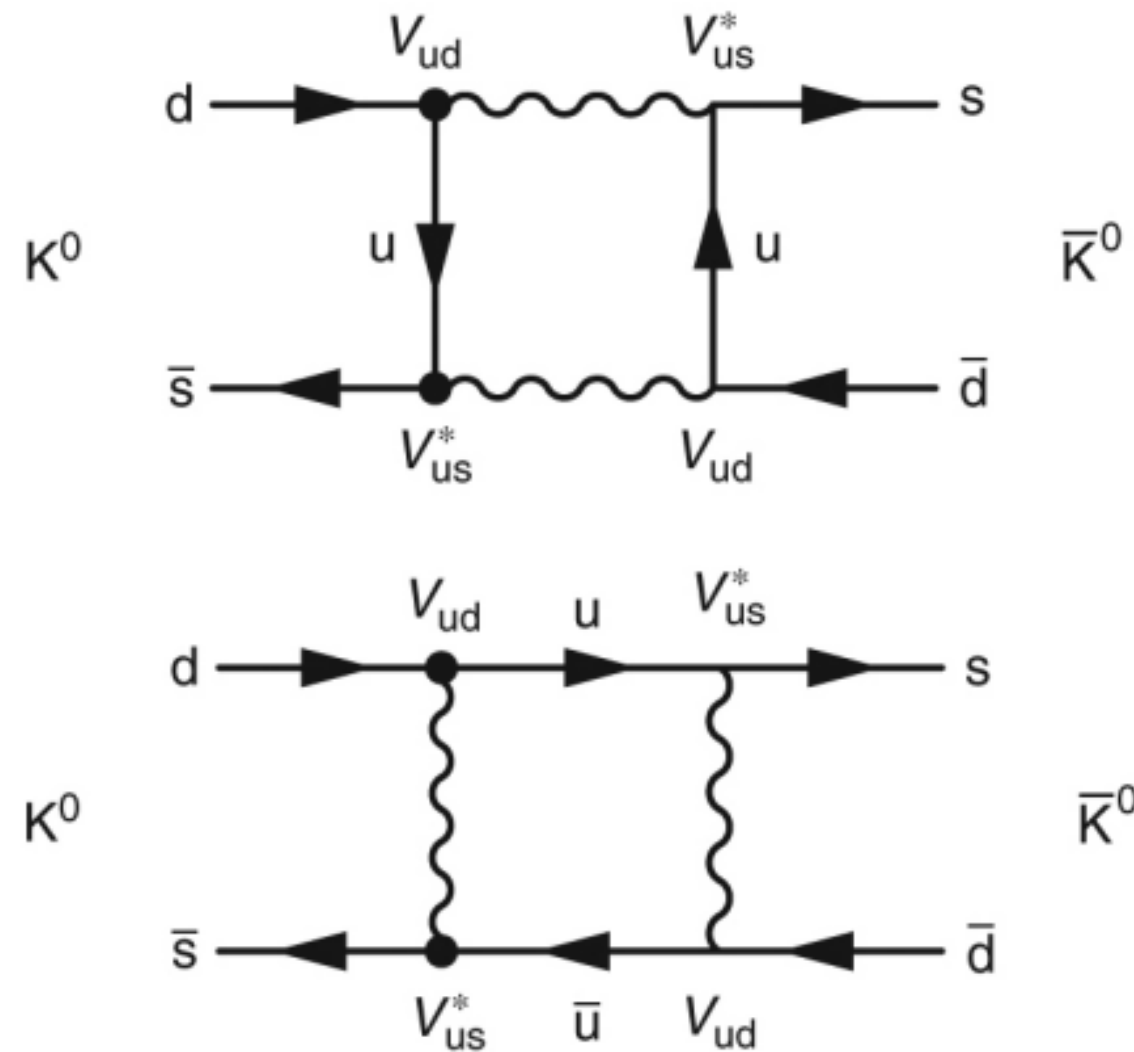
- In strong interaction, isospin are approximate symmetry

Isospin symmetry system : $Q/A=1/2 \rightarrow A(\text{or } B) = Z(\text{or } Q) \rightarrow I_3 = 0$

$$I_3^{initial} = 0 \implies \langle K^+ \rangle = \langle K^0 \rangle \quad \text{and} \quad \langle K^- \rangle = \langle \bar{K}^0 \rangle \implies R_K = 1$$

Isospin asymmetry system : $Q/A < 1/2 \rightarrow A(\text{or } B) > Z(\text{or } Q) \rightarrow I_3 < 0$

$$I_3^{initial} < 0 \implies \text{Favors } I_3 = -1/2 \text{ states } (K^0, K^-) \implies R_K \leq 1$$



- Both are coupling to each other

$$|K_1\rangle = \frac{1}{\sqrt{2}}(|K^0\rangle + |\bar{K}^0\rangle), \quad |K_2\rangle = \frac{1}{\sqrt{2}}(|K^0\rangle - |\bar{K}^0\rangle)$$

$$|K_S\rangle = \frac{1}{\sqrt{1+|\epsilon|^2}}(|K_1\rangle + \epsilon|K_2\rangle)$$

- In experiment this neutral kaon measure by reconstruction

$$K_S^0 \rightarrow \pi\pi$$

, where both K^0 and $\bar{K}^0$ also decay into this channel

cannot distinguish K^0 and $\bar{K}^0$

- In UrQMD all hadron are tracked all the time

$\rightarrow K^0$ and $\bar{K}^0$ is measurable

Kaon production in UrQMD

High Energy :

- mediated primarily by color-string excitation and fragmentation

Low Energy (SIS18 / Threshold) :

- color strings are suppressed or kinematically forbidden
- baryon resonance excitations and decays(e.g. N^* , $\Delta^* \rightarrow K\Lambda$, $K\Sigma$ or $\pi^-N \rightarrow K\Lambda$, $K\Sigma$)

Known ϕ -meson decay :

- charged kaons are slightly lighter ($m_{\text{charge-kaon}} < m_{\text{neutral-kaon}}$), the decay phase space is larger
- $\text{BR}(\phi \rightarrow K^+K^-) \sim 1.45 \times \text{BR}(\phi \rightarrow K^0\bar{K}^0)$

Resonance decays :

- Decay branchings into specific isospin charge states strictly to Clebsch–Gordan coefficients
- Branching ratios for isospin-partner channels are treated as symmetric, without breaking parameters.

Hadronic Resonance

ityp	nucleon	ityp	Δ	ityp	Λ	ityp	Σ	ityp	Ξ	ityp	Ω	ityp	Λ_c
1	N_{938}	24	Δ_{1232}	41	Λ_{1116}	54	Σ_{1192}	63	Ξ_{1317}	69	Ω_{1672}	70	Λ_c
2	N_{1440}	25	Δ_{1600}	42	Λ_{1405}	55	Σ_{1385}	64	Ξ_{1530}				
3	N_{1520}	26	Δ_{1620}	43	Λ_{1520}	56	Σ_{1660}	65	Ξ_{1690}				
4	N_{1535}	27	Δ_{1700}	44	Λ_{1600}	57	Σ_{1670}	66	Ξ_{1820}				
5	N_{1650}	28	Δ_{1900}	45	Λ_{1670}	58	Σ_{1750}	67	Ξ_{1950}				
6	N_{1675}	29	Δ_{1905}	46	Λ_{1690}	59	Σ_{1775}	68	Ξ_{2025}				
7	N_{1680}	30	Δ_{1910}	47	Λ_{1800}	60	Σ_{1915}						
8	N_{1700}	31	Δ_{1920}	48	Λ_{1810}	61	Σ_{1940}						
9	N_{1710}	32	Δ_{1930}	49	Λ_{1820}	62	Σ_{2030}						
10	N_{1720}	33	Δ_{1950}	50	Λ_{1830}								
11	N_{1900}	34	Δ_{2420}	51	Λ_{1890}								
12	N_{1990}	35	Δ_{2750}	52	Λ_{2100}								
13	N_{2080}	36	Δ_{2950}	53	Λ_{2110}								
14	N_{2190}	37	Δ_{3300}										
15	N_{2200}	38	Δ_{3500}										
16	N_{2250}	39	Δ_{3700}										
17	N_{2600}	40	Δ_{4200}										
18	N_{1875}												
19	N_{2700}												
20	N_{3100}												
21	N_{3500}												
22	N_{3800}												
23	N_{4200}												

Table 1: Baryon-itypes used in **UrQMD**. Antibaryons carry a negative sign. **Note the new numbering scheme since version 3.5!**

ityp	0^{-+}	ityp	1^{--}	ityp	0^{++}	ityp	1^{++}	ityp	charmed
101	π	104	ρ	111	a_0	114	a_1	133	D
106	K	108	K^*	110	K_0^*	113	K_1^*	134	D^*
102	η	103	ω	105	f_0	115	f_1	135	J/Ψ
107	η'	109	ϕ	112	f_0^*	116	f_1'	136	χ_c
ityp	1^{+-}	ityp	2^{++}	ityp	$(1^{--})^*$	ityp	$(1^{--})^{**}$	137	Ψ'
122	b_1	118	a_2	126	ρ_{1450}	130	ρ_{1700}	138	D_s
121	K_1	117	K_2^*	125	K_{1410}^*	129	K_{1680}^*	139	D_s^*
123	h_1	119	f_2	127	ω_{1420}	131	ω_{1662}		
124	h_1'	120	f_2'	128	ϕ_{1680}	132	ϕ_{1900}		

Table 2: Meson-itypes in **UrQMD**, sorted with respect to spin and parity, included into the **UrQMD** model. Mesons with strangeness -1 (or charm -1 for itypes > 132) carry a negative sign. See Table 9 for a list ordered by Meson itypes.

Resonance :

- proton or neutron absorb collisions energy → **excited nucleon**

(baryon resonance)
- extreamly short life time
- SIS energy is high but not all energy is enough to pull apart of color-string
- This makes resonance production the dominant gateway for creating strange mesons near collision thresholds

String fragmentation

