Strangeness in GiBUU

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FIAS

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Outline

- the GiBUU model
- particle production at SIS energies
- strange & non-strange, resonances
- Kaon potential
- comparison to HADES pp / pNb at 3.5 GeV
- current & future developments

The GiBUU model

- hadronic transport model (microscopic, non-equilibrium), based on the BUU equation
- developed for 20+ years in Giessen (in the group of U. Mosel)
- current contributors: T. Gaitanos, K. Gallmeister, A. Larionov, J. Weil, U. Mosel
- unified framework for electroweak (γA, eA, νA) and hadronic (pA, πA, AA) nuclear reactions
- rather modern Fortran95 code base ($\sim$ 200.000 LOC)
- publicly available releases (open source)
- O. Buss et al., Phys. Rep. 512 (2012), http://gibuu.hepforge.org

GiBUU
The Giessen Boltzmann-Uehling-Uhlenbeck Project

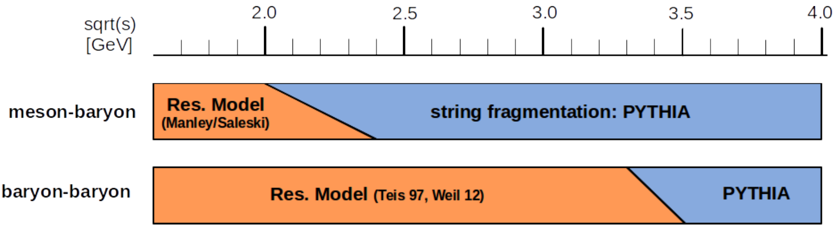
The BUU equation

- BUU equ.: space-time evolution of phase-space density F (via gradient expansion from Kadanoff-Baym)

$$\frac{\partial(p_0-H)}{\partial p_\mu}\frac{\partial F(x,p)}{\partial x^\mu} - \frac{\partial(p_0-H)}{\partial x_\mu}\frac{\partial F(x,p)}{\partial p^\mu} = C(x,p)$$

- degrees of freedom: hadrons (61 baryons and 22 mesons included)
- Hamiltonian H:
  - hadronic mean fields (Skyrme or RMF), Coulomb, ...
- collision term $C(x,p)$: decays and collisions
  - low energy: resonance-model approach
  - high energy: string fragment. (Pythia)
- solve numerically via test-particle method:
  $F = \sum_i \delta(\vec{r} - \vec{r}_i)\delta(p - p_i)$

Particle Production at SIS: Resonances vs Strings



- string theshold for mB: $\sqrt{s} = 2.2 \pm 0.2\,\mathrm{GeV} \approx m_R^{max}$ (rougly corresponds to heaviest resonances)
- for BB: $\sqrt{s} = 3.4 \pm 0.1\,\mathrm{GeV}$, between $m_N + m_R^{max} \approx 3.1\,\mathrm{GeV}$ and $2m_R^{max} \approx 4.4\,\mathrm{GeV}$

STRANGE VS. NON-STRANGE SECTOR

non-strange:

1. resonance production: $NN \to NR, \Delta R$
2. subsequent resonance decay: $R \to \pi N, \eta N, \rho N, \sigma N, \pi \Delta,\ \pi N^*$ (no strange decays here)
3. possibly: dilepton decays

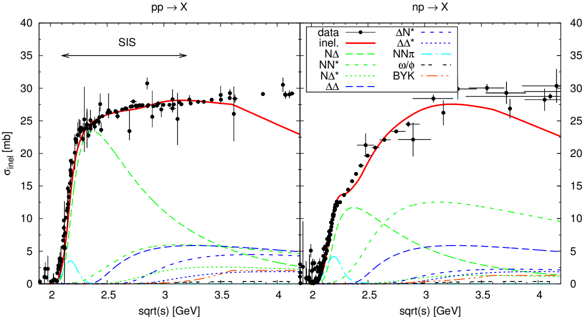
strangeness:

1. direct 3-body production: $NN \to BYK$ ($B = N, \Delta,\ Y = \Lambda, \Sigma,\ K = K^+, K^0$)
2. cross sections parametrized by Tsushima et al.
3. based on R prod. and decay, but in the end: just a parametrization

- somewhat inconsistent (explicit two-step production for non-strange mesons, but direct 3-body production for Kaons)
- but: no 'overlap', both sectors are completely separated

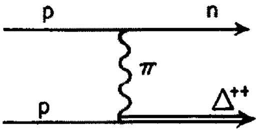
non-strange Resonance Model

- assumption: inel. NN cross section is dominated by production and decay of baryonic resonances
- $NN \to NR, \Delta R$ (R : Δ, 7 N^* and 6 Δ^* states)
- based on Teis RM [Z. Phys. A 356, 1997] with several extensions
- all π, η and ρ mesons produced via R decays (ω, ϕ: non-res.)
- good descr. of total NN cross sections up to $\sqrt{s} \approx 3.5 GeV$



Resonance Production

- $NN \to N\Delta$: OBE model [Dmitriev et al, NPA 459 (1986)]



- other resonances produced via phase-space approach (constant matrix elements):

$$\sigma_{NN\to NR} = \frac{C_I}{p_i s} \frac{|\mathcal{M}_{NR}|^2}{16\pi} \int \mathrm{d}\mu \mathcal{A}_R(\mu) p_F(\mu)$$

$$\sigma_{NN\to \Delta R} = \frac{C_I}{p_i s} \frac{|\mathcal{M}_{\Delta R}|^2}{16\pi} \int \mathrm{d}\mu_1 \mathrm{d}\mu_2 \mathcal{A}_\Delta(\mu_1) \mathcal{A}_R(\mu_2) p_F(\mu_1, \mu_2)$$

- lately: introduced angular distributions $d\sigma/dt = b/t^a$, $a \approx 1$ (Eur.Phys.J. A502014)

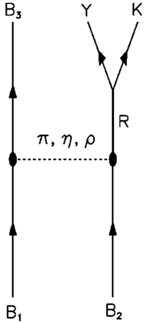
Resonance parameters

- all resonance parameters & decays modes taken from: Manley/Saleski, Phys. Rev. D 45 (1992)
- Manley: PWA including $\pi N \to \pi N$ and $\pi N \to 2\pi N$ data
- no strangeness data included

	rating	M_0 [MeV]	Γ_0 [MeV]	$\|\mathcal{M}^2\|/16\pi$ [mb GeV^2] NR	ΔR	branching ratio in % πN	ηN	$\pi\Delta$	ρN	σN	$\pi N^*(1440)$	$\sigma\Delta$
$P_{11}(1440)$	****	1462	391	70	—	69	—	22_P	—	9	—	—
$S_{11}(1535)$	***	1534	151	8	60	51	43	—	2_S+1_D	1	2	—
$S_{11}(1650)$	****	1659	173	4	12	89	3	2_D	3_D	2	1	—
$D_{13}(1520)$	****	1524	124	4	12	59	—	5_S+15_D	21_S	—	—	—
$D_{15}(1675)$	****	1676	159	17	—	47	—	53_D	—	—	—	—
$P_{13}(1720)$	*	1717	383	4	12	13	—	—	87_P	—	—	—
$F_{15}(1680)$	****	1684	139	4	12	70	—	10_P+1_F	5_P+2_F	12	—	—
$P_{33}(1232)$	****	1232	118	OBE	210	100	—	—	—	—	—	—
$S_{31}(1620)$	**	1672	154	7	21	9	—	62_D	25_S+4_D	—	—	—
$D_{33}(1700)$	*	1762	599	7	21	14	—	74_S+4_D	8_S	—	—	—
$P_{31}(1910)$	****	1882	239	14	—	23	—	—	—	—	67	10_P
$P_{33}(1600)$	***	1706	430	14	—	12	—	68_P	—	—	20	—
$F_{35}(1905)$	***	1881	327	7	21	12	—	1_P	87_P	—	—	—
$F_{37}(1950)$	****	1945	300	14	—	38	—	18_F	—	—	—	44_F

- no strangeness via explicit resonance production
- Manley assigns some ΛK decay channels, but those resonances are not produced in NN collisions

Strangeness: Tsushima model

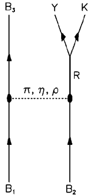


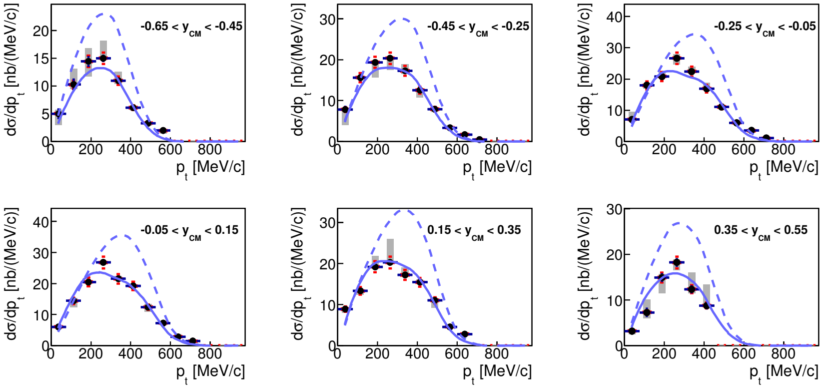
Resonance (J^P)		Width (MeV)	Decay channel	Branching ratio	Adopted value	GiBUU
$N(1650)(\frac{1}{2}^-)$	NN, piN	150	$N\pi$	0.60 – 0.80	0.700	0.89
			$N\eta$	0.03 – 0.10	0.065	0.03
			$\Delta\pi$	0.03 – 0.07	0.050	0.02
			ΛK	0.03 – 0.11	0.070	---
$N(1710)(\frac{1}{2}^+)$	piN	100	$N\pi$	0.10 – 0.20	0.150	0.09
			$N\eta$	0.20 – 0.40	0.300	---
			$N\rho$	0.05 – 0.25	0.150	0.03
			$\Delta\pi$	0.10 – 0.25	0.175	0.49
			ΛK	0.05 – 0.25	0.150	0.37
			ΣK	0.02 – 0.10	0.060	---
$N(1720)(\frac{3}{2}^+)$	NN, piN	150	$N\pi$	0.10 – 0.20	0.150	0.13
			$N\eta$	0.02 – 0.06	0.040	---
			$N\rho$	0.70 – 0.85	0.775	0.87
			$\Delta\pi$	0.05 – 0.15	0.100	---
			ΛK	0.03 – 0.10	0.065	---
			ΣK	0.02 – 0.05	0.035	---
$\Delta(1920)(\frac{3}{2}^+)$	piN	200	$N\pi$	0.05 – 0.20	0.125	0.02
			ΣK	0.01 – 0.03	0.020	---

- Tsushima et al. calculated Kaon production via intermediate resonances in eff. Lagr. model (OBE), Phys. Rev. C59 (1999)
- $BB \to BYK$ ($B = N, \Delta,\ Y = \Lambda, \Sigma,\ K = K^+, K^0$)
- final results are parametrized as $\sigma = a(s/s_0 - 1)^b (s/s_0)^c$
- we just use the parametrization!

HADES: $pp \to K^0_S X$ @ 3.5 GeV

- original model: Tsushima et al. (dashed)
- modified to fit elem. HADES Kaon data (solid lines):
  - parameters had to be adjusted for some channels
  - 5-body channels added ($pp \to \Delta Y^* K \to \pi\pi NYK$)
- arXiv:1404.7011

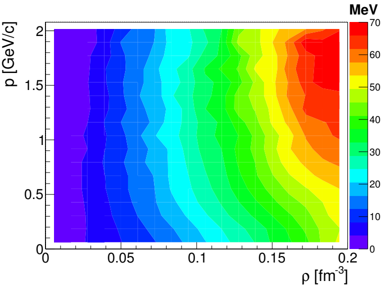




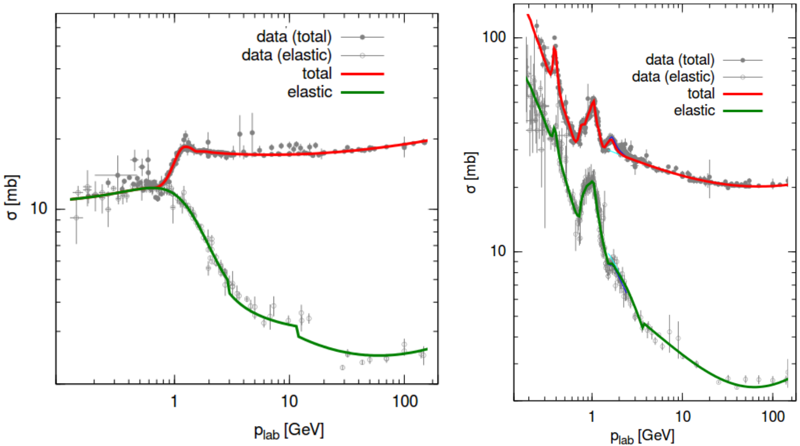
Kaon Potential

- ChPT kaon potential:
  $m_K^* = \sqrt{m_K^2 - \frac{\Sigma_{KN}}{f_\pi^2}\rho_s + V_\mu V^\mu}$
  Brown/Rho, NPA596, 1996
  Schaffner-Bielich, NPA625, 1997

- includes density and momentum dependence (non-linear)
- repulsive for K^+,K^0
- attractive for K^-,$\overline{K}^0$
- $U = E^* - E \approx 35$ MeV for K^+,K^0 at $\rho = \rho_0$, $\vec{p} = 0$



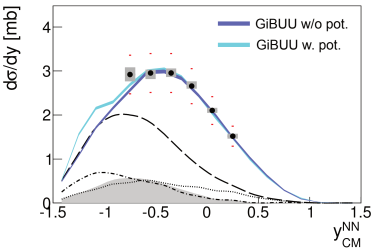
SECONDARY KN COLLISIONS

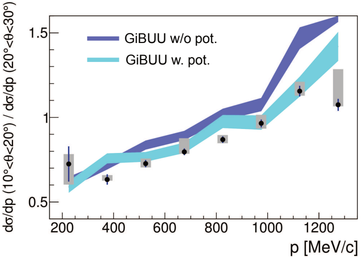


- left: K^+p; right: K^-p
- good agreement with data, many channels contributing

HADES: $pNb \to K_s^0 X$ @ 3.5 GeV

- rap. spectrum mostly insensitive to potential in measured region (left)
- momentum spectra most sensitive in forward region (right)
- take ratio of two polar-angle bins to get rid of systematic uncertainties in abs. norm. (arXiv:1404.7011)





- systematics well under control
- good baseline from pp at same energy
- limited density ($\rho \leq \rho_0$)

Conclusions

- HADES *pNb* data show indications of repulsive K^0 potential
- consistent with ChPT potential of $U(\rho_0) = 35$ MeV
- cold nuclear matter setup has less systematic uncertainties than heavy-ion collisions
- (but: effects not quite as large)

ANNOUNCEMENT: GiBUU IS OPEN SOURCE!

- GiBUU had 'public releases' for some time, but they were only available after registration
- since last week: GiBUU release 1.6 is fully public, can be downloaded via anonymous svn checkout (w/o registr.)
- https://gibuu.hepforge.org/trac/wiki/svn
- development version continues to be private
- next open release 1.7 later this year

The future: SMASH

- next-generation transport code, currently being developed in the group of Hannah Petersen at FIAS
- core tream: H. Petersen, J. Auvinen, M. Kretz, J. Weil (+students)
- aim: clean, modern and future-proof code, which takes advantage of modern computing arch. (multicore, heterogenous), written from scratch in C++
- current status: preparing internal version 0.4, ~20.000 lines of C++ code
- first public release by next year?

The End

Thanks for your attention!