MEMO production at FAIR

Nuclear matter physics at SIS100

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Historical notes

- Exotic forms of bound objects with strangeness have been proposed long ago.[1]
- H di-baron by Jaffe.[2]
- Strangelets (Multistrange Quark bags).
- MEMO's [3]
- Purely Hyperonic states [4]

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[1] A. R. Bodmer, Phys. Rev. D **4** (1971) 1601.

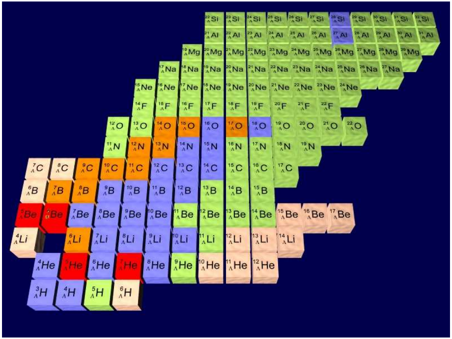
[2] R. L. Jaffe, Phys. Rev. Lett. **38** (1977) 195 [Erratum-ibid. **38** (1977) 617].

[3] J. Schaffner, H. Stoecker and C. Greiner, Phys. Rev. C **46** (1992) 322.

[4] J. Schaffner, C. B. Dover, A. Gal, C. Greiner and H. Stoecker, Phys. Rev. Lett. **71** (1993) 1328.

What's a MEMO?

- Metastable Exotic Multihypernuclear Object.
- Consist of nucleons, Λ's and Ξ's.
- Are stabelized due to pauli blocking.
- Lifetimes: $10^{-10} - 10^{-5}s$



- As an example a chart of possible hypernuclei: (GSI-webpage)

Search for the H-dibaryon

- The H-dibaryon is a 6-quark state was found to decay dominantly by $H \rightarrow \Sigma^- + p$ for moderate binding energies.
- No conclusive results from HI-collisions (AGS)[a]
- Seems to be excluded in pN reactions at Fermilab over a wide range of Masses ($2.194 < M_H < 2.231$ GeV) and lifetimes ($5 \cdot 10^{-10}$ to $1 \cdot 10^{-3}$ sec)[b] (allthough different production mechanism)

[a] H. Caines *et al.* [E896 Collaboration], Nucl. Phys. A **661**, 170 (1999).
[b] A. Alavi-Harati *et al.* [KTeV Collaboration], Phys. Rev. Lett. **84**, 2593 (2000)

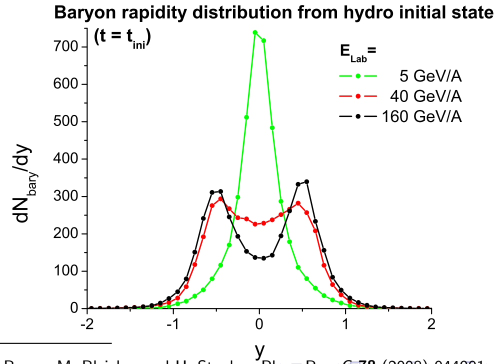
Search for Hypernuclei

- On the conventional hadronic side, hypernuclei are known to exist already for a long time.
- Hypernuclei have been detected in heavy-ion reactions at the AGS by the E864 collaboration [a] (large penalty factor ≈ 50 !?)
- Thermal production overestimated Hypernuclei production.[b]
- Hypernuclei and Anti-Hypernuclei have been detected at RHIC (NO penalty factor !?)[c].

[a] L. E. Finch [E864 Collaboration], Nucl. Phys. A **661**, 395 (1999)
[b] P. Braun-Munzinger and J. Stachel,J. Phys. G **21** (1995) L17
[c] See talk of Dr. CHEN, Jinhui at the 2009 Quark Matter

The hybrid Model

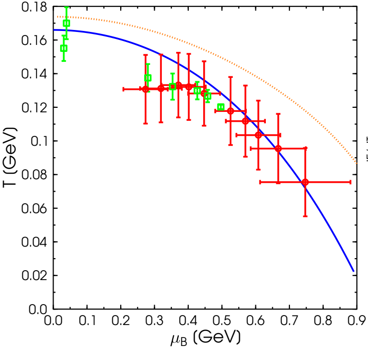
- We investigate production of MEMO's in a micro+macro hybrid approach [1] to heavy ion collisions.
- Initial state from UrQMD mapped on 3+1 d Hydro grid.
- Accounts for fluctuations, baryon density phase-space separation and transparency.

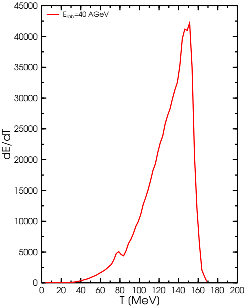


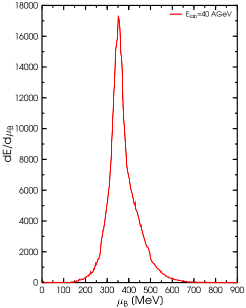
[1] H. Petersen, J. Steinheimer, G. Burau, M. Bleicher and H. Stocker, Phys. Rev. C **78** (2008) 044901.

The hybrid Model

- Isochronous Freezeout when all cells are below $5\epsilon_0 \approx 700\ MeV/fm^3$
- Cooper frye Prescription $E\frac{dN}{d^3p} = \int_\sigma f(x,p)p^\mu d\sigma_\mu$
- For MEMO production the final state interactions are neglected.
- T and μ_B have a distribution at freezeout (still f_s is locally 0):

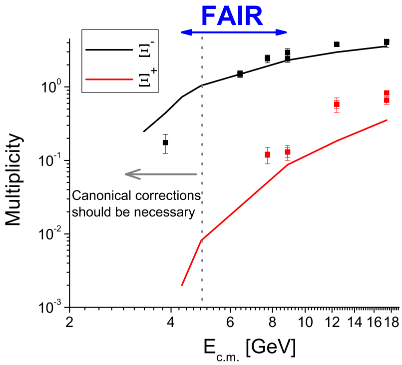


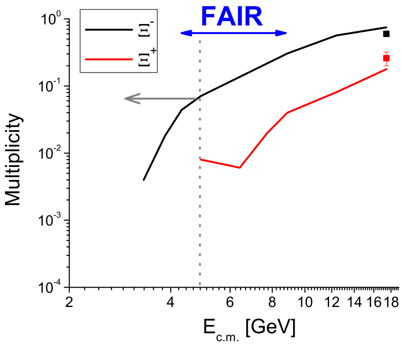




Multiplicities for different beam energies

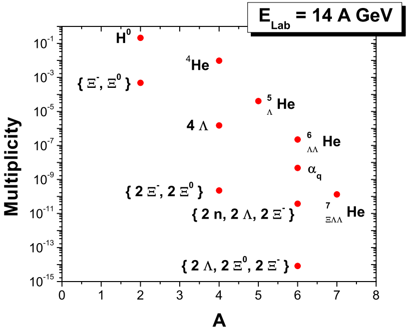
- Multiplicities for Ξ and Ω from the hybrid model in comparison to data.

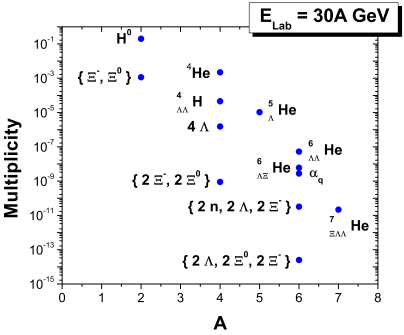




Multiplicities for different beam energies

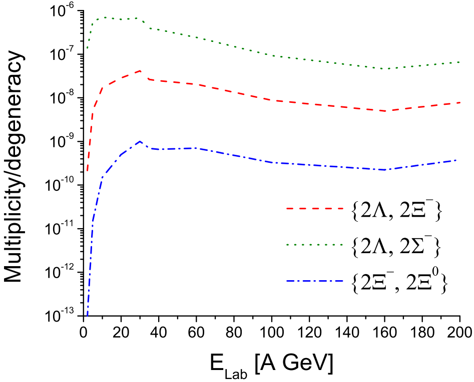
- Multiplicities for various MEMOs (per degeneracy factor) at different beam energies.





Excitation functions

- Excitation functions show a clear maximum for several MEMOs.

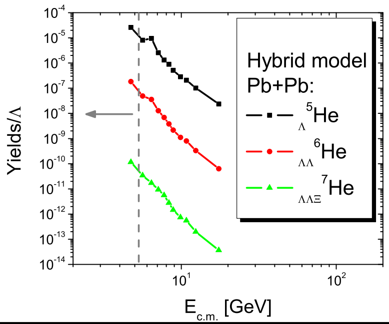


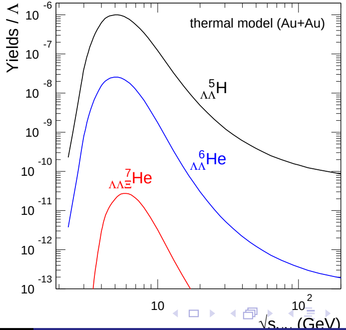
Model comparisons

Comparison to statistical model

- Excitation functions from hybrid model (left) compared to the thermal model[a] including canonical corrections (right).

[a] A. Andronic, P. Braun-Munzinger and J. Stachel, Nucl. Phys. A **772**, 167 (2006) [arXiv:nucl-th/0511071].



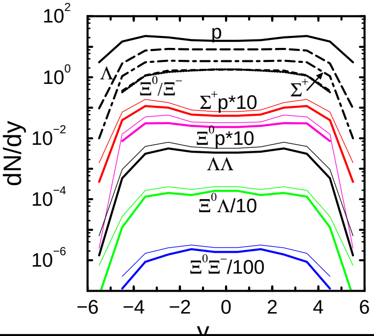


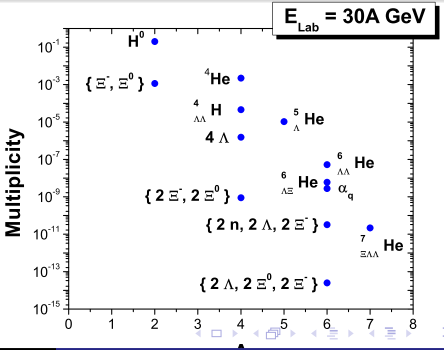
Model Comparisons

Comparison to coalescence calculations

- Coalescence model predictions at RHIC energies $\sqrt{s} = 200A$ GEV (multiplicty of $\Xi^0\Xi^- \approx 10^{-3}$)[a].

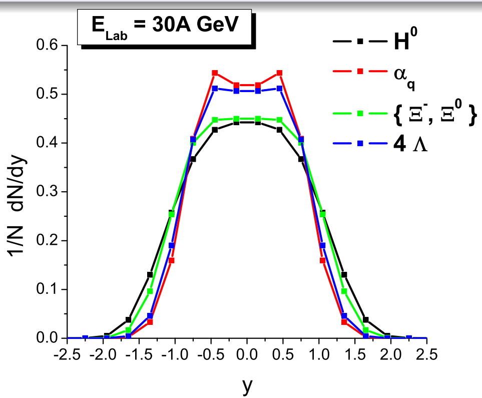
[a] J. Schaffner-Bielich, R. Mattiello and H. Sorge,Phys. Rev. Lett. **84**, 4305 (2000)





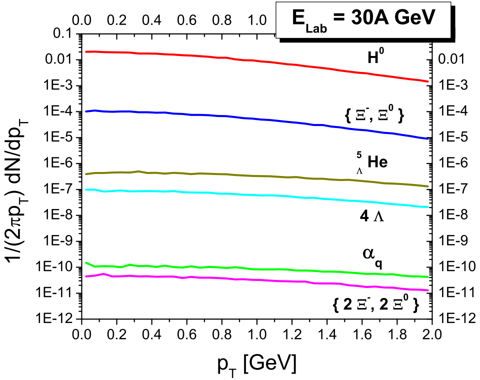
Rapidity Spectra

- Rapidity ditributions for different MEMOs (normalized for visibility).



Momentum distributions

- Transverse momentum ditributions at mid-rapidity $|y| \leq 0.5$.



How to detect them

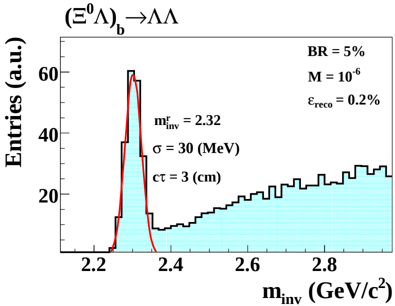
For a detection in heavy-ion experiments one is mainly interested in candidates whose final decay products are charged: as

$$
\begin{aligned}
(\Sigma^+ p)_b &\rightarrow p + p & (1)\\
(\Xi^0 p)_b &\rightarrow p + \Lambda & (2)\\
(\Xi^0 \Lambda)_b &\rightarrow p + \Xi^- \text{ or } \Lambda + \Lambda & (3)\\
(\Xi^0 \Xi^-)_b &\rightarrow \Xi^- + \Lambda \quad . & (4)
\end{aligned}
$$

The dibaryon should show up in the invariant mass spectrum after background subtraction from event-mixing With this method the weak decay of the lightest hypernucleus ${}^3_\Lambda\mathrm{H} \rightarrow {}^3\mathrm{He} + \pi^-$ has been detected in heavy-ion collisions by the E864 collaboration.

How to detect them

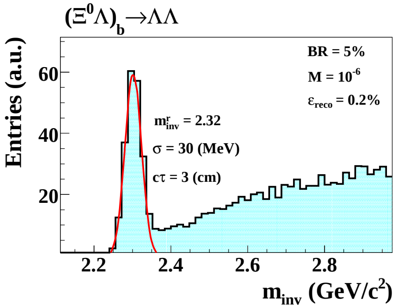
- Simulation of possible signal[a]



[a] Private communication from P. Senger

How to detect them

- Simulation of possible signal[a]
- Another way is by directly observing their decay systematics:
  -charged particle decaying in two equally charged particles
  -strong 'kink' in the track of a charged particle
  -two charged particles created from nowhere



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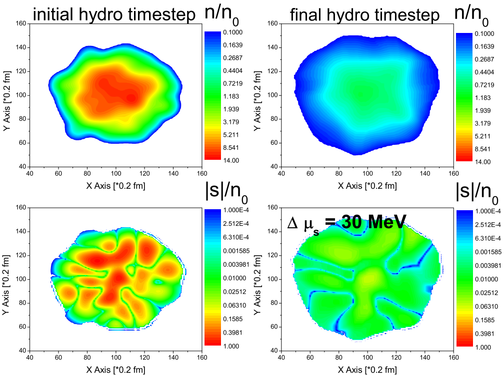
First Summary

- We presented thermal production of MEMO's in AA collisions from a hybrid model.
- Predictions for multiplicities, rapidity and transverse momentum spectra were calculated.
- Fluctuations and non equlibrium initial conditions enhance MEMO production.
- CBM experiment at FAIR is ideally placed for for the search of exotic multihypernuclear Objects.

Strangeness fluctuates

- The net strangeness density fluctuates in coordinate space on an event-by-event basis. $E_{lab} = 40\ A$ GeV



Maybe distillation[1]?

- Total strangeness in an HI collsision globally vanishes.
- In the QGP phase s and $\bar{s}$ are produced as pairs: $\mu_s = 0$.
- In the hadronic phase a variety of strange hadrons: $\mu_B \neq 0 \Rightarrow \mu_s \neq 0$.
- In the mixed phase: associated production of K^+ and s-quark at finite baryon densities.

[1] C. Greiner, P. Koch and H. Stoecker, Phys. Rev. Lett. **58** (1987) 1825.

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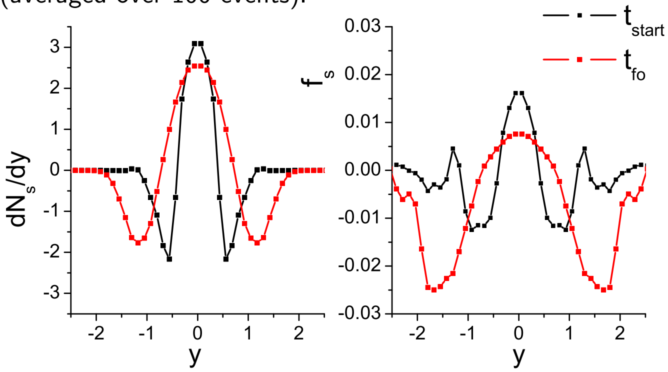
- In the mixed phase: associated production of K^+ and s-quark at finite baryon densities.
- Leads to separation of strangeness in the phases and enriches the QGP phase with strangeness thus enhancing cluster formation.
- Initial fluctuations further enhance the effect of distillation.

[1] C. Greiner, P. Koch and H. Stoecker, Phys. Rev. Lett. **58** (1987) 1825.

Seperation in phase space

- It can be shown that strangeness also separates in Rapidity (averaged over 100 events).



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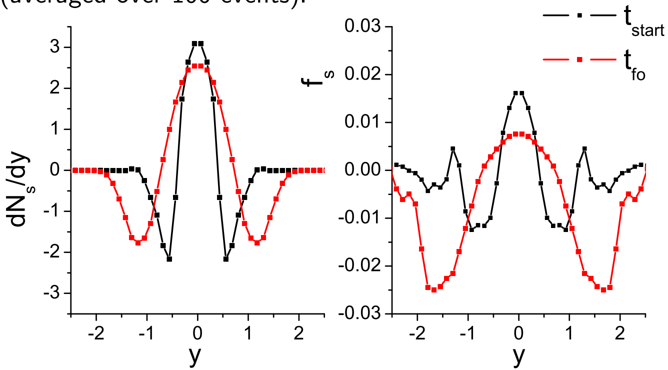

- Effect on thermal production small $\Delta\mu_s \approx 3MeV$

Summary and Outlook

Summary

- Net strangeness fluctuates.
- Both effects should again enhance the production of exotic multihypernuclear Objects
- Assuming strangeness conservation at midrapidity is only justified when averaging over many events.
- Statistical models trying to estimate particle yields should therefore include effects of local non neutrality of strangeness.

Outlook

- Include strangeness fluctuations in the freezeout.
- Make the EoS dependent on net strangeness density (may change the phase diagramm if a phase transition is included!)