Multi-particle interactions within UrQMD

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Thanks to Gunnar Gräf, Hannah Petersen, Marcus Bleicher

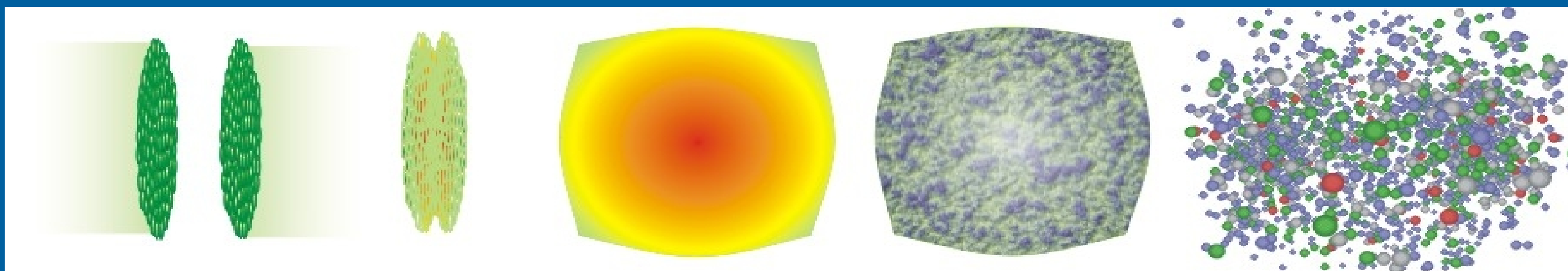
Outline

- *UrQMD in a nutshell*
- *Why multi-particle interactions?*
- *Realization via parton rearrangement*
  concept + criterions + processes + checks
- *Consequences for the reaction dynamics (preliminary results)*
- *Summary & Outlook*

UrQMD in a nutshell

***U**ltra**r**elativistic **Q**uantum **M**olecular **D**ynamics*

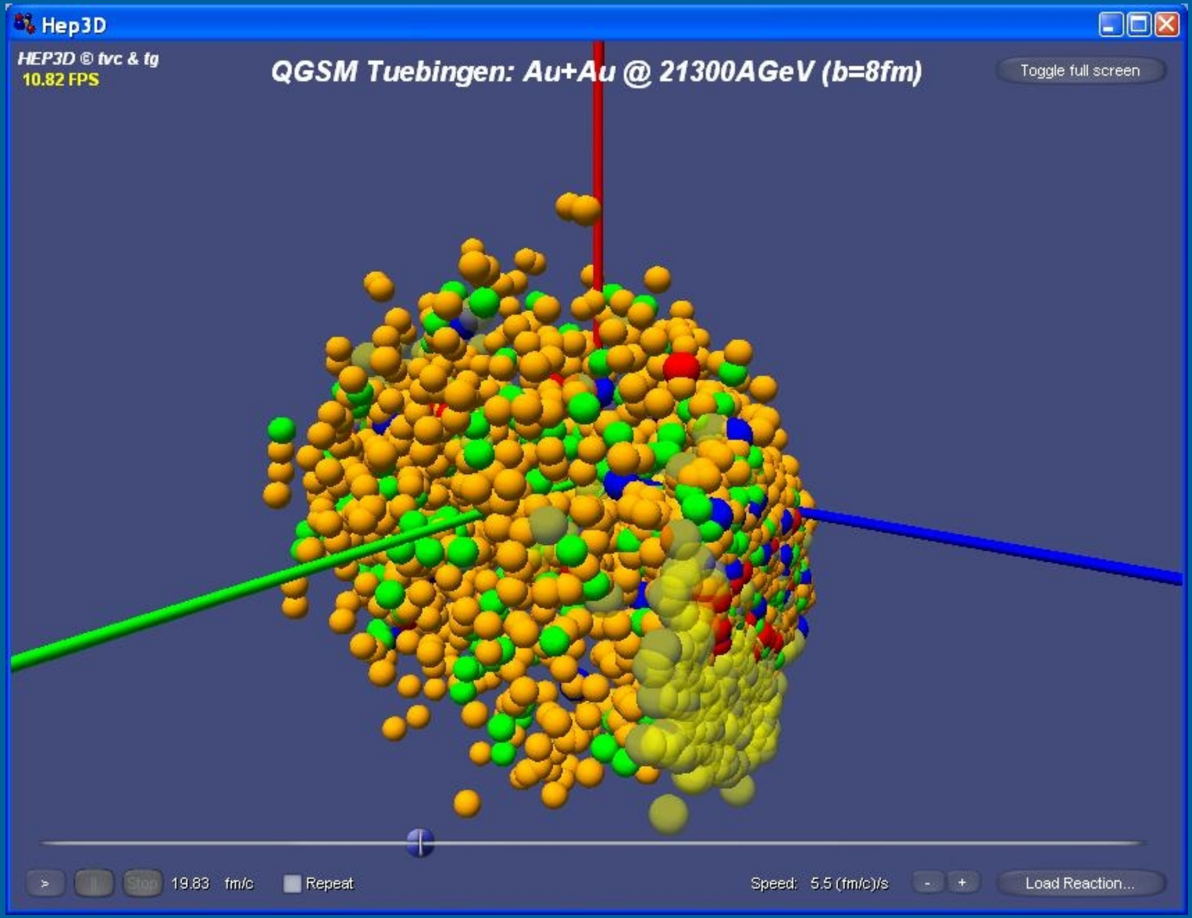
[H. Petersen et al., arXiv:0805.0567v1 (2008)]



- *Non-equilibrium transport approach*
- *All hadrons & resonances up to 2.2 GeV*
- *String excitation & fragmentation*
- *Cross sections fitted to available data, parametrized via AQM or calculated by detailed balance*
- *Generates full space-time dynamics of hadrons & strings*
- *Interactions via 2 ➜ n and 1 ➜ n processes (!!)*

Why multi-particle interactions ?

High particle densities !



Why multi-particle interactions ?

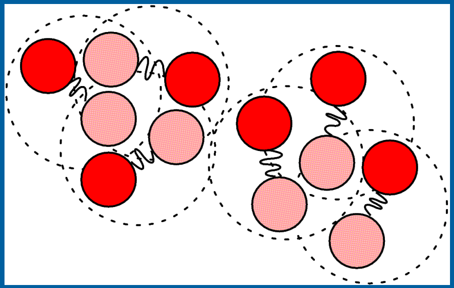
- *Three-particle interactions gain importance in the high density region of collisions*
- *3 ➜ n processes work towards detailed balance*
- *Faster thermal & chemical equilibration due to additional interactions ?*
- *Elliptic flow, anti-hyperon enhancement, ...*

[P. Danielewicz, PRC 42, 1564 (1990)]
[H.W. Barz, B. Kämpfer, NPA 683, 594 (2001)]
[C. Greiner, S. Leupold, JPG 27, L95 (2001)]
[W. Cassing, NPA 700, 618 (2002)]
[Z. Xu, C. Greiner, PRC 71, 064901 (2005)]
[A.B. Larionov et al., PRC 76, 044909 (2007)]

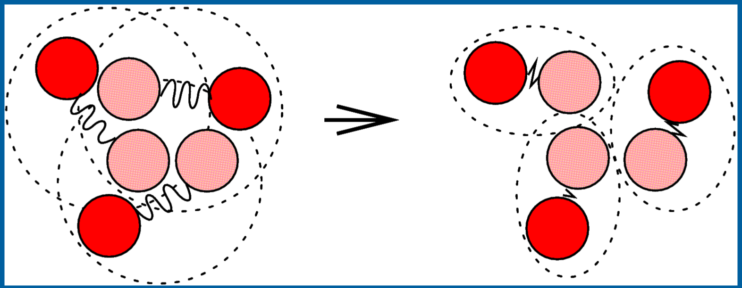
- *3 ➜ n processes (n ≤ 3) introduced via parton rearrangement*

Realization via quark rearrangement

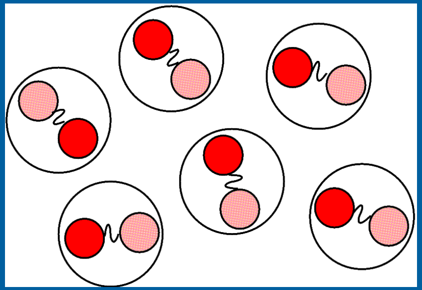
high density



quark rearrangement



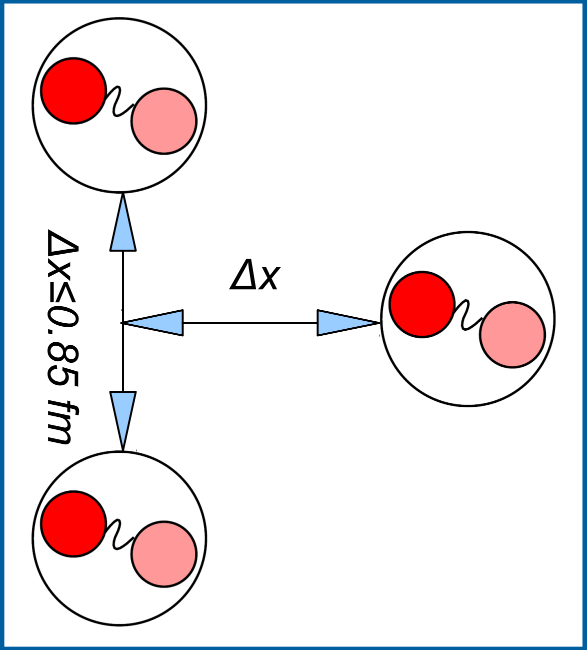
low density

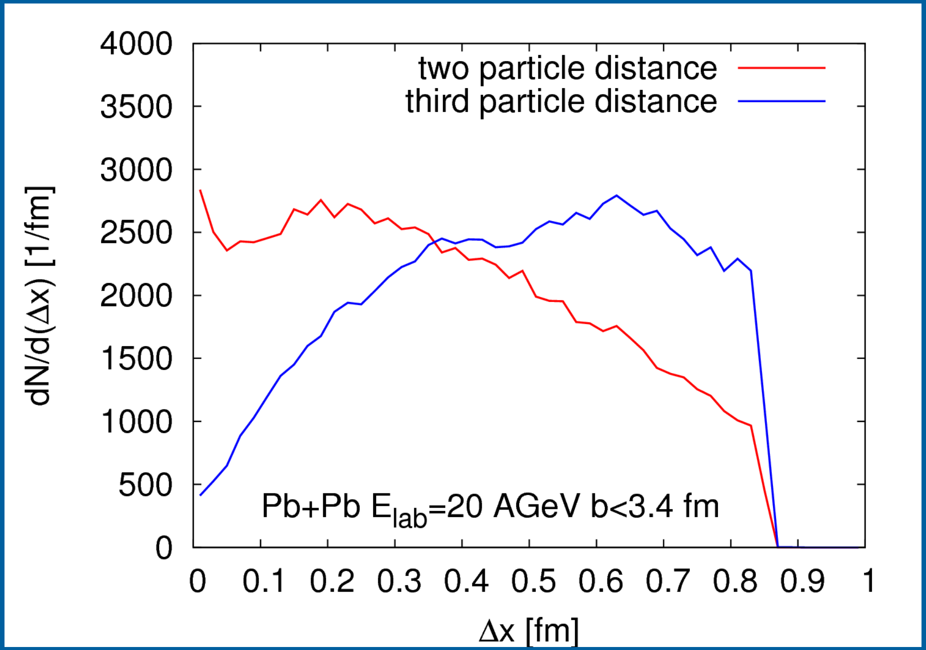


- *Three nearby hadrons can exchange their quarks*
- *Pre-formed hadrons participate in this process*

[J. Bleibel, GB, A. Fässler, C. Fuchs, PRC 76, 024912 (2007)]
[J. Bleibel, GB, C. Fuchs, PLB 659, 520 (2008)]

Criterion for quark rearrangement





- Rearrangement distance $\Delta x \leq 0.85$ fm
- Momentum criterion via uncertainty principle $\Delta x\ \Delta p \geq 1$

Rearrangement processes

- *All processes conserving the quantum numbers are allowed (electric charge, baryon number, ...)*
- *One of the allowed quark configurations is randomly chosen*

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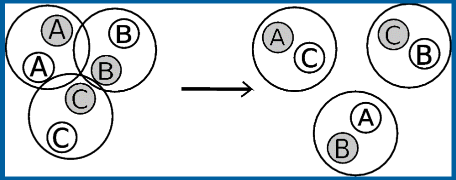
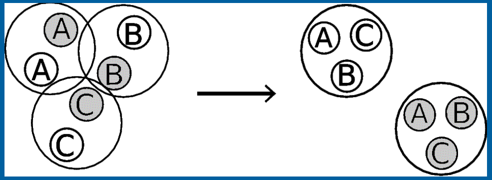
⟶ ***Additional 3-particle reactions at high density:***

3 ➜ 3



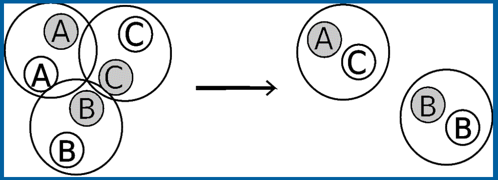
recombination

3 ➜ 2



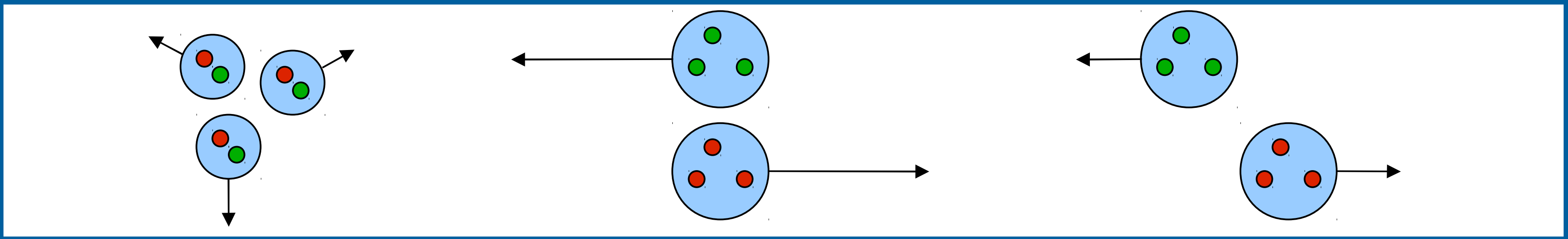
meson fusion

3 ➜ 2



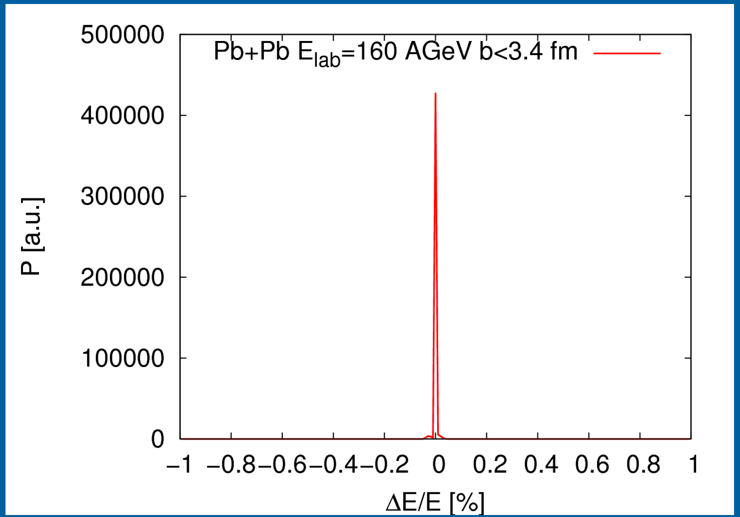
quark annihilation

Rescaling of momenta



- *Energy and momentum conservation due to momentum rescaling*

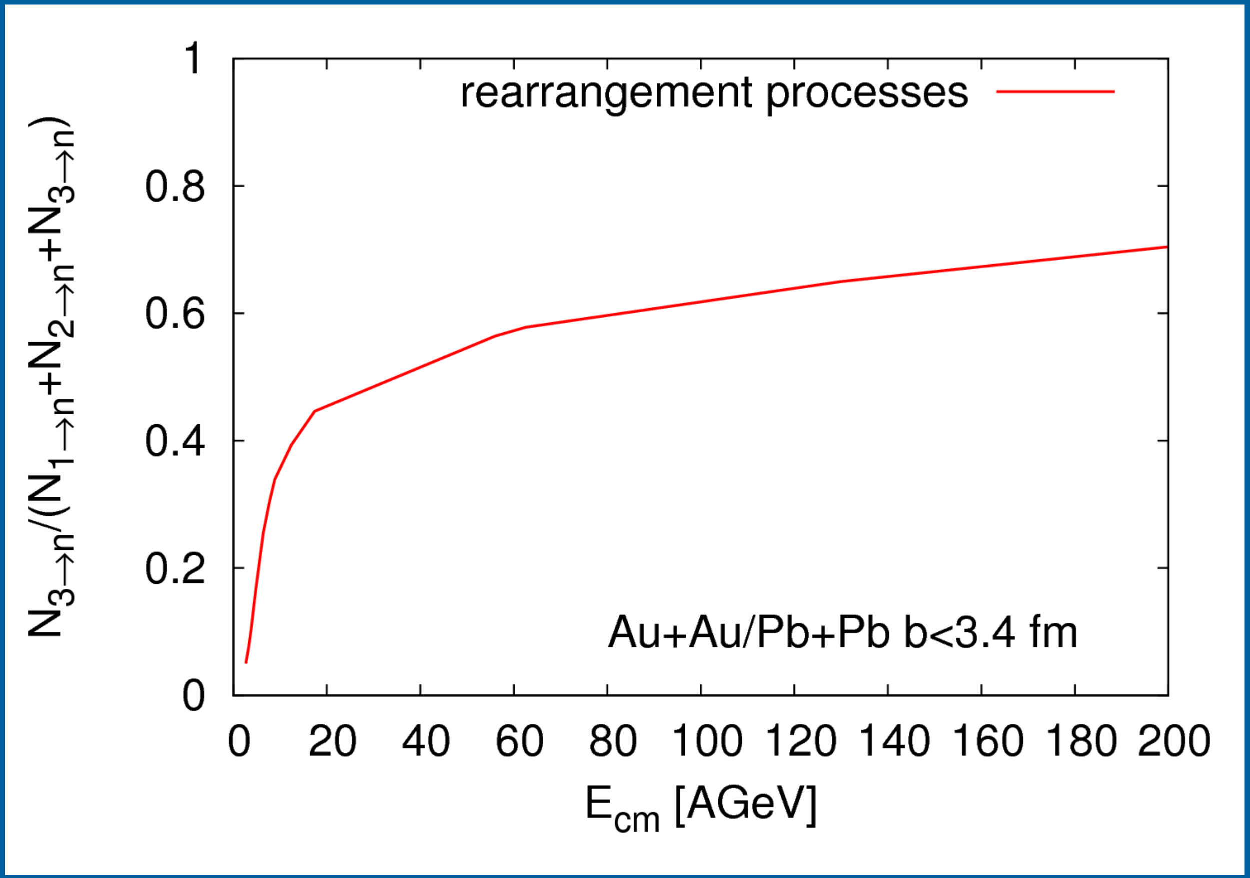
- *Rescaling with one overall factor for all momenta in the process*



$$C_{scale} = \frac{\sqrt{s^2 + \left(m_1^2 + m_2^2\right)^2 - 4\mathrm{m}_1^2 m_2^2 - 2\mathrm{s}\left(m_1^2 + m_2^2\right)}}{2\sqrt{s}\, p_{1,2}}$$

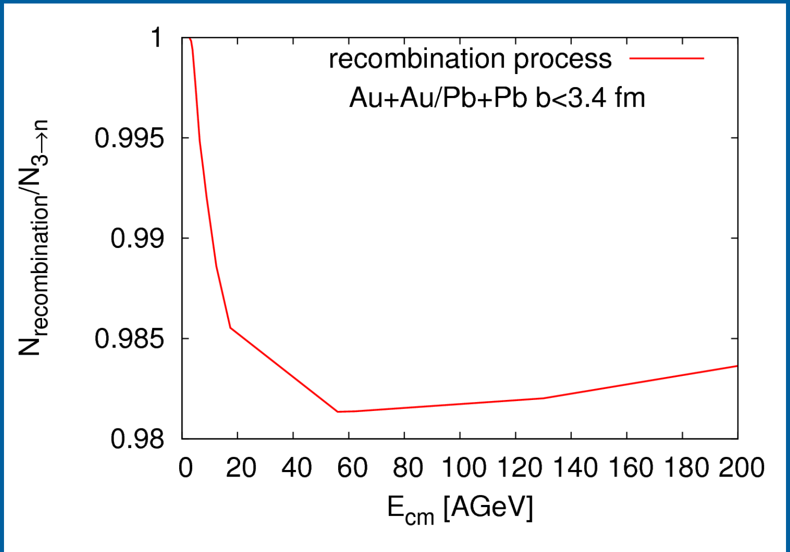
(for two outgoing particles)

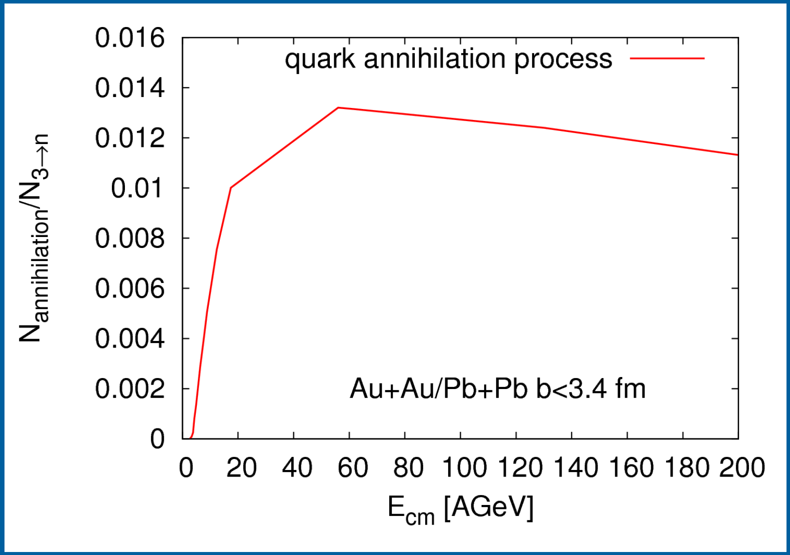
Check: Energy dependence I

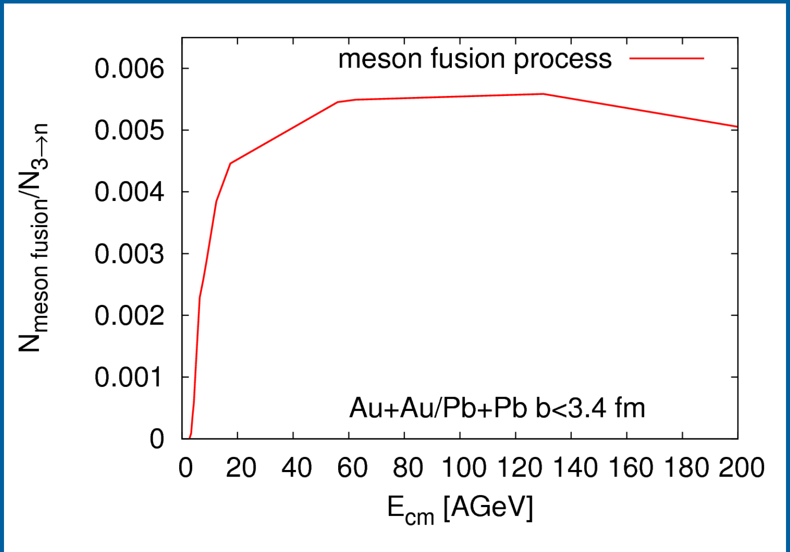


- *Rearrangement becomes dominant for higher energies*

Check: Energy dependence II

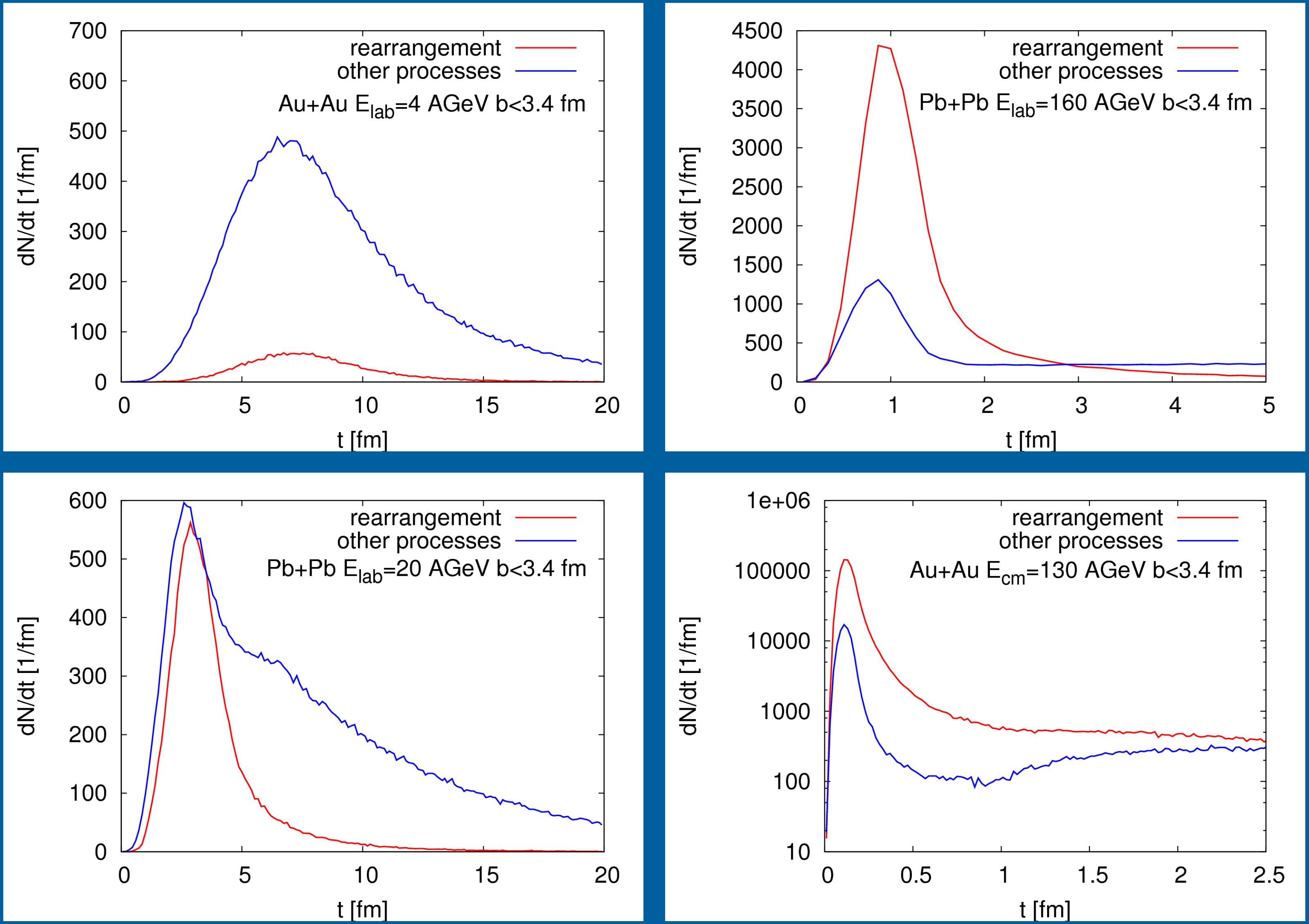




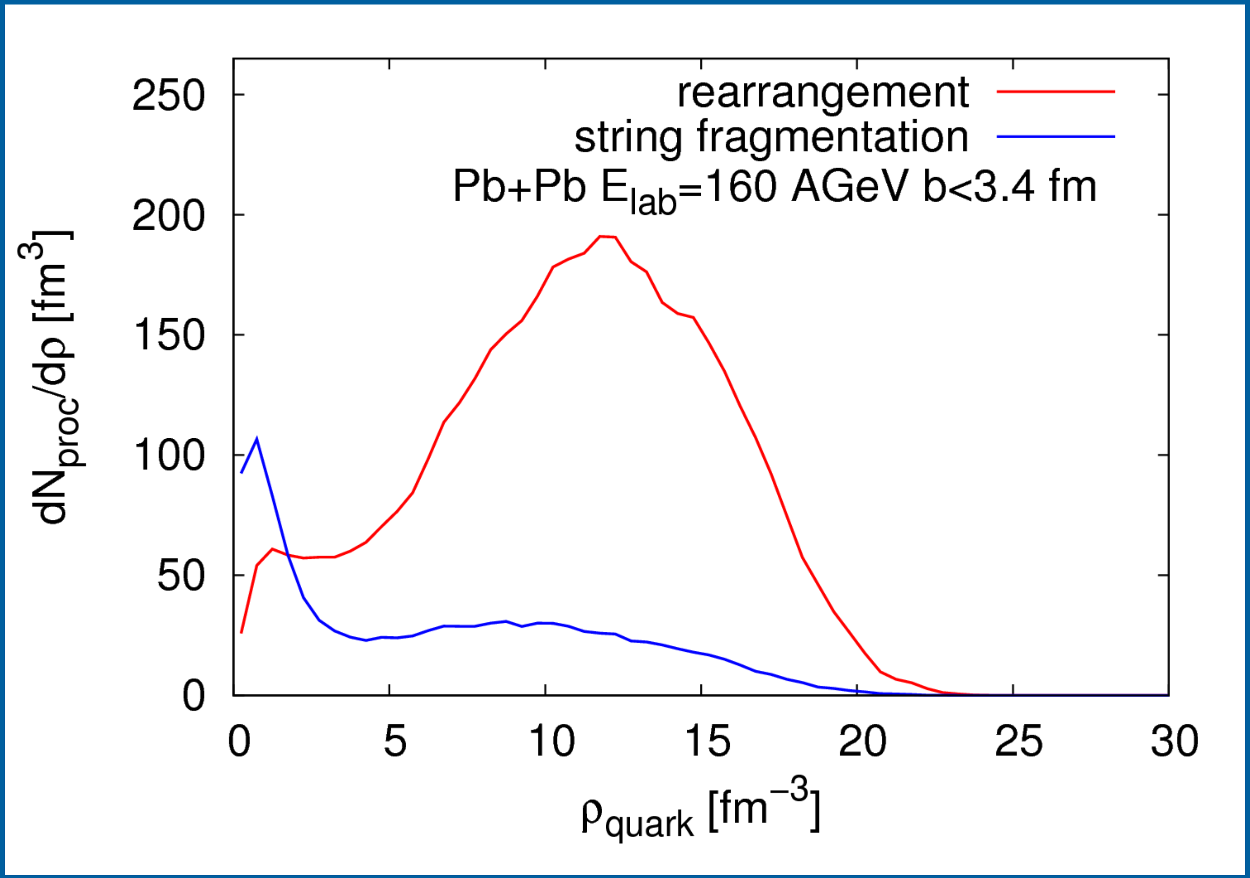


- *Recombination is dominant for all energies*
- *Meson fusion is still important although it is only a tiny fraction*

Check: Temporal development



Check: Density dependence

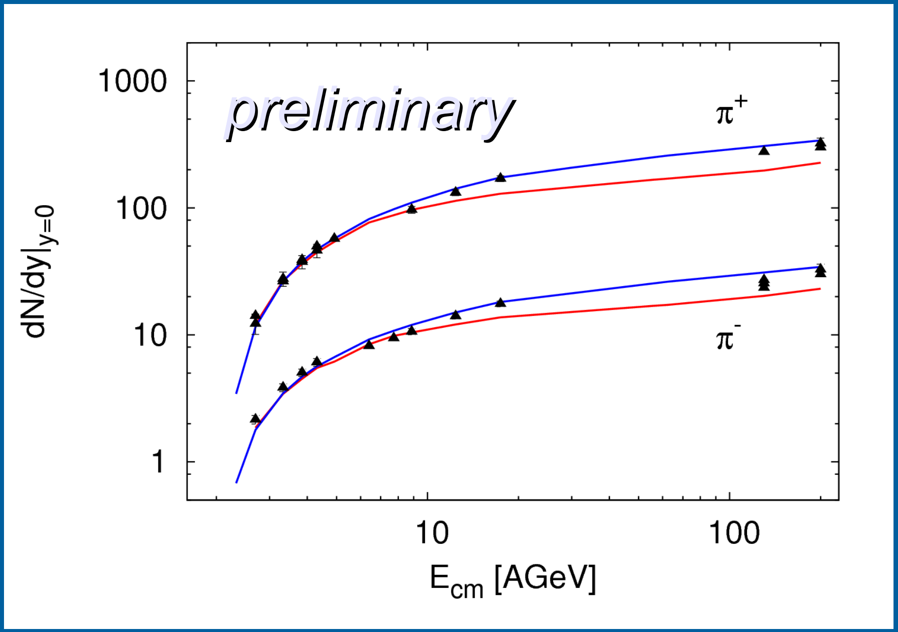


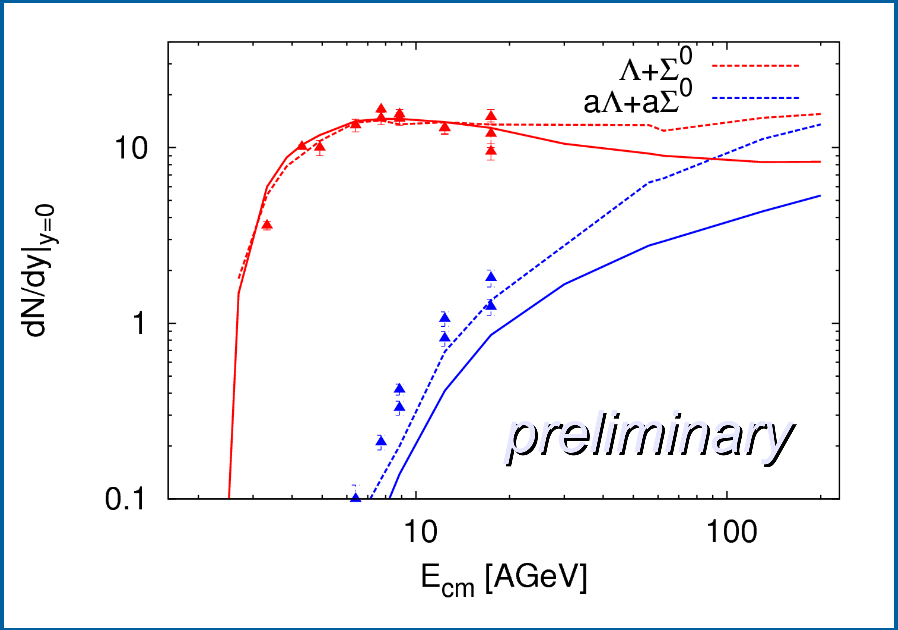
- *Rearrangement happens mostly in regions of high densities*

Consequences for .....

- **Pion production**
  slightly decreasing

↓





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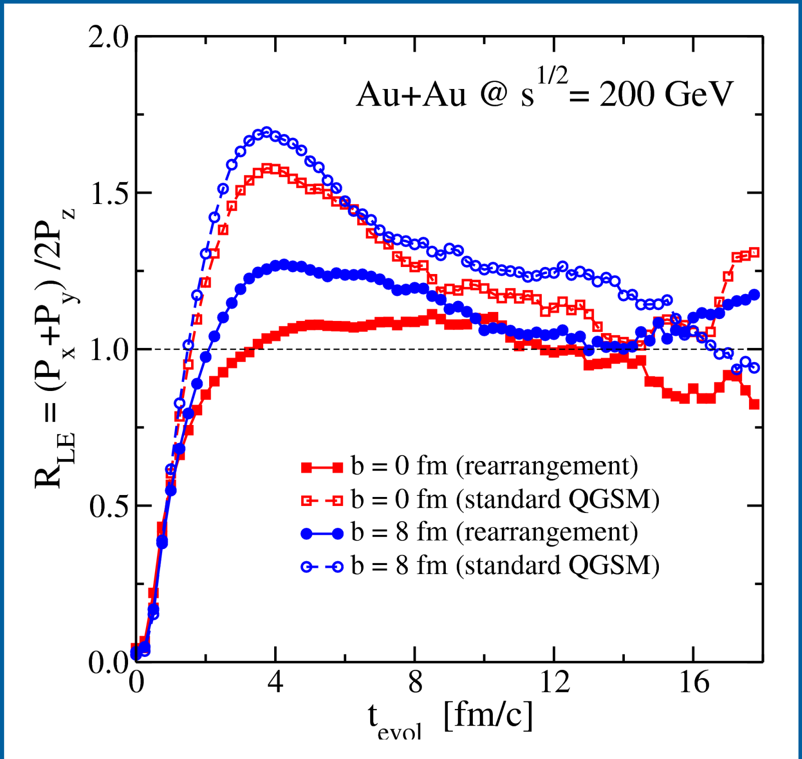
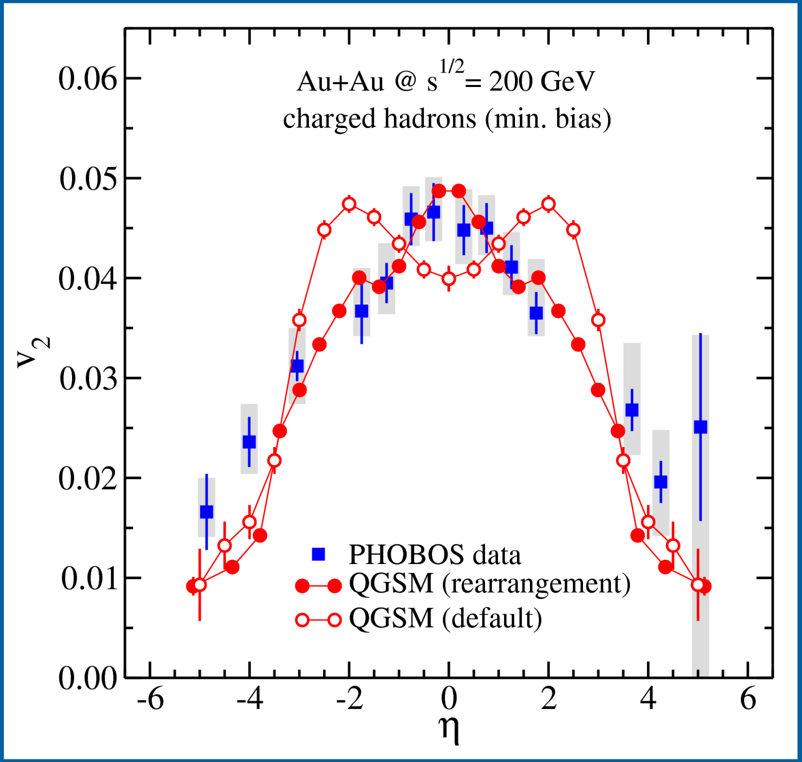
- **Hyperon production**
  enhancement due to meson fusion

Consequences (outlook) for .....

- ***Kinetic equilibration***
  faster with rearrangement

↓





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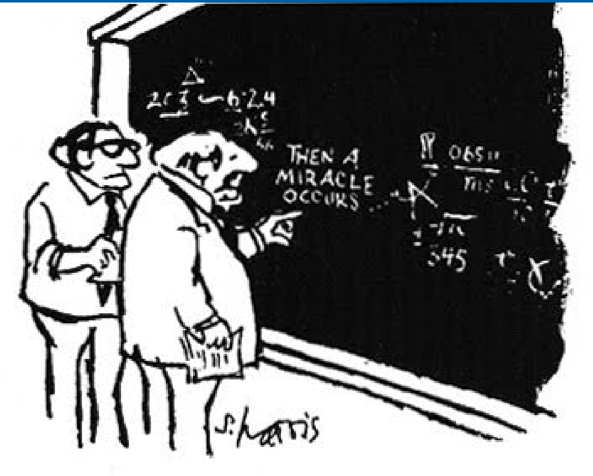
- ***Elliptic flow $v_2(\eta)$***
  improved with rearrangement

[J. Bleibel et al., PRC 76, 024912 (2007)]

Summary & Outlook

- *Dynamic 3-particle interactions are implemented into UrQMD*
- *Energy and momentum are conserved*
- *Rearrangement is dominant in high density regions*
- *Backward reaction for 2 ➜ 3 now added into UrQMD*



"I think you should be more explicit here in step two."

Summary & Outlook

- *Dynamic 3-particle interactions are implemented into UrQMD*
- *Energy and momentum are conserved*
- *Rearrangement is dominant in high density regions*
- *Backward reaction for 2 ➜ 3 now added into UrQMD*

- *Allow only unformed particles to rearrange*
- *Study detailed balance via box calculation*
- *Investigation of particle spectra, elliptic flow and thermalization*

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Anisotropic flow .....

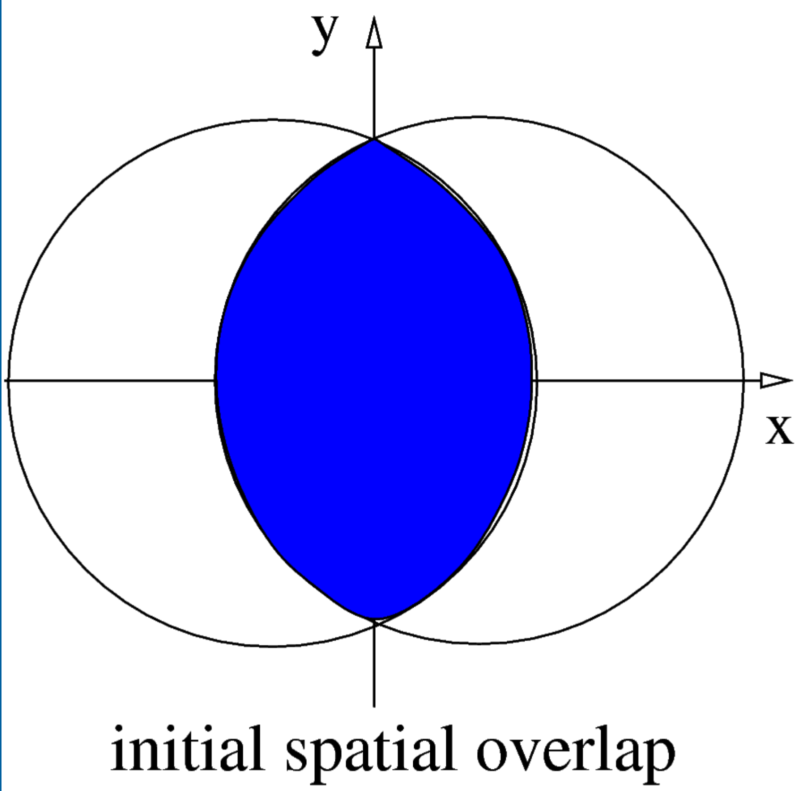
Fourier decomposition of particle distribution

$$E\frac{d^3N}{d^3p}=\frac{d^2N}{d^2p_T\,dy}\left[1+2\sum_{n=1}^{\infty}v_n(p_T,y)\cos(n\wp)\right]$$

2nd harmonic coefficient = elliptic flow

$$v_2(p_T,y)\equiv\langle\cos(2\wp)\rangle=\langle(p_x/p_T)^2-(p_y/p_T)^2\rangle$$

Anisotropic flow .....



$$v_2(p_T, y) = \langle (p_x / p_T)^2 - (p_y / p_T)^2 \rangle$$