Angular Momentum in HICs via SMASH

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

CRC-TR 211 Strong-interaction matter under extreme conditions

Motivation

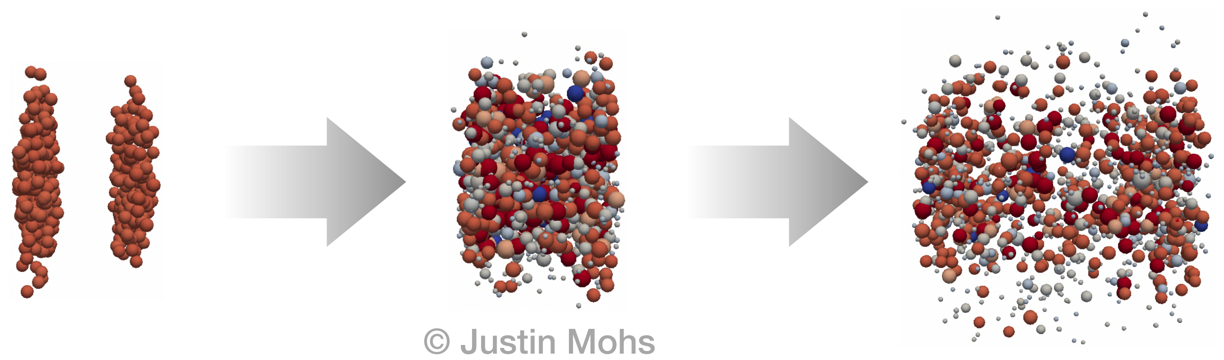
- Large orbital angular momentum $L \sim \mathcal{O}(10^6\hbar)$ in non-central HICs create global polarization of Λ hyperons at mid-rapidity
- Angular momentum of the fireball directly related to vorticity (spin-orbit coupling) as fundamental property of the QGP
- Dynamical description of L within a transport approach yields predictions where the biggest transfer of OAM to the QGP is expected

Our Approach

smash

- Hadronic transport approach for a dynamical non-equilibrium description of HICs at low beam energies
- Including all hadrons up to $m \sim 2.35\, GeV$
- Effective solution of the relativistic Boltzmann equation

$$p^\mu \partial_\mu f_i(x,p) + m_i F^\alpha \partial^p_\alpha f_i(x,p) = C^i_{coll}$$



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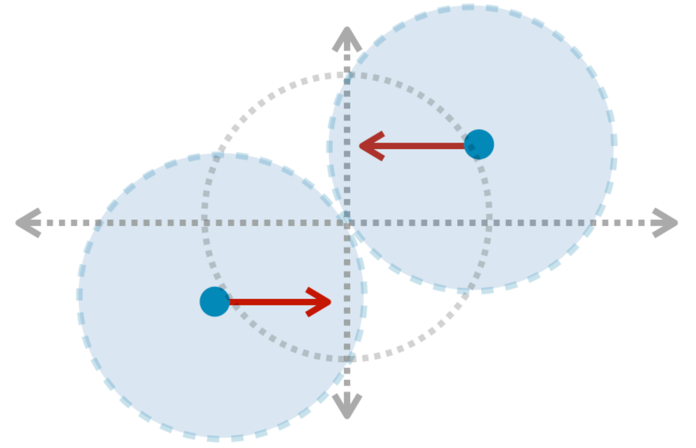
Collisions



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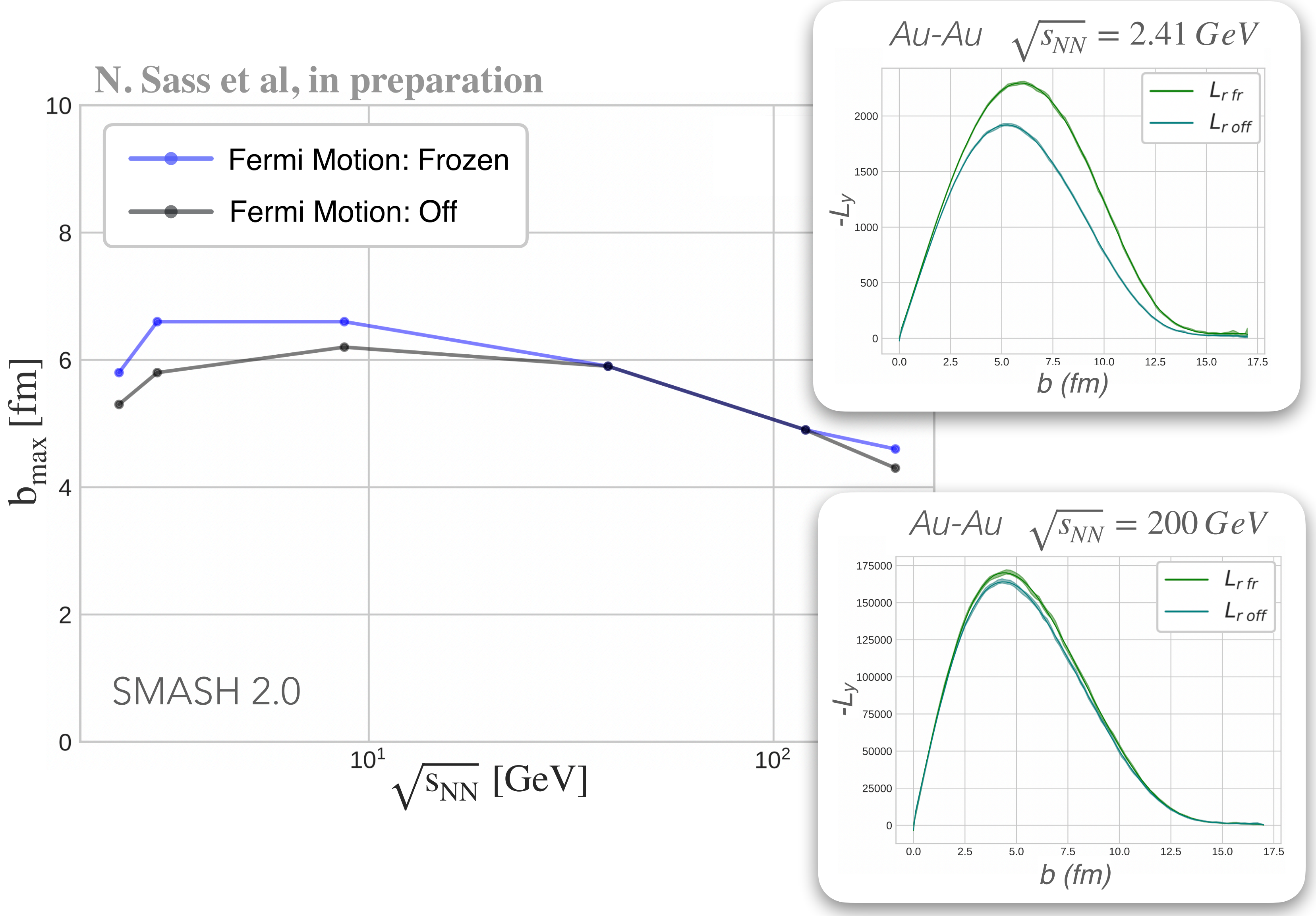
Collisions are performed at a finite distance according to the geometrical interpretation of the cross section

Maximal *L* Transfer

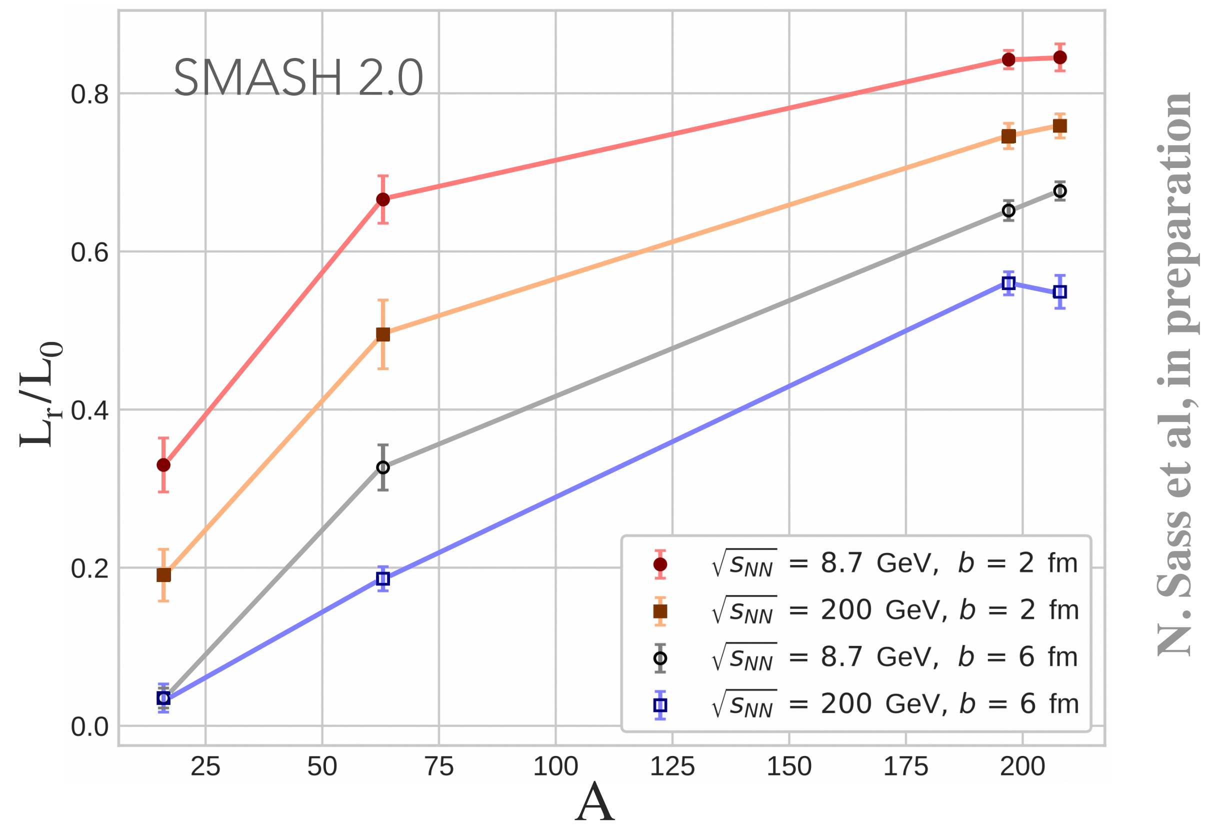
- ***Energy dependence*** of impact parameter b_{max} for which The remaining angular momentum L_r becomes maximal



- ***Fermi motion*** induces additional L into the system

System Size

- ***System size dependence*** of the ratio of the fireball's angular momentum over the initial angular momentum L_r / L_0



- More angular momentum is deposited at mid rapidity in more central collisions and at lower beam energies

Conclusion

- We find a maximum L_r impact parameter b_{max} which is nearly energy independent for a broad energy range, $b_{max} \in [4.5\,\mathrm{fm}, 6.6\,\mathrm{fm}]$
- We observe a higher transfer of initial angular momentum to the fireball at lower beam energies and in more central collisions.
- Future: Implementation of **spin** DoF to describe polarization in nuclear collisions

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Insight into SMASH

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General Setup

- Geometric collision criterion

$$d_{trans} < d_{int} = \sqrt{\frac{\sigma_{tot}}{\pi}} \qquad d^2_{trans} = (\vec{r}_a - \vec{r}_b)^2 - \frac{((\vec{r}_a - \vec{r}_b)\cdot(\vec{p}_a - \vec{p}_b))^2}{(\vec{p}_a - \vec{p}_b)^2}$$

- Test particle method: $\sigma \rightarrow \sigma \cdot N_{test}^{-1}$, $N \rightarrow N \cdot N_{test}$

Initial Conditions

- Sampling of the initial nuclei in coordinate space according to the Woods-Saxon distribution

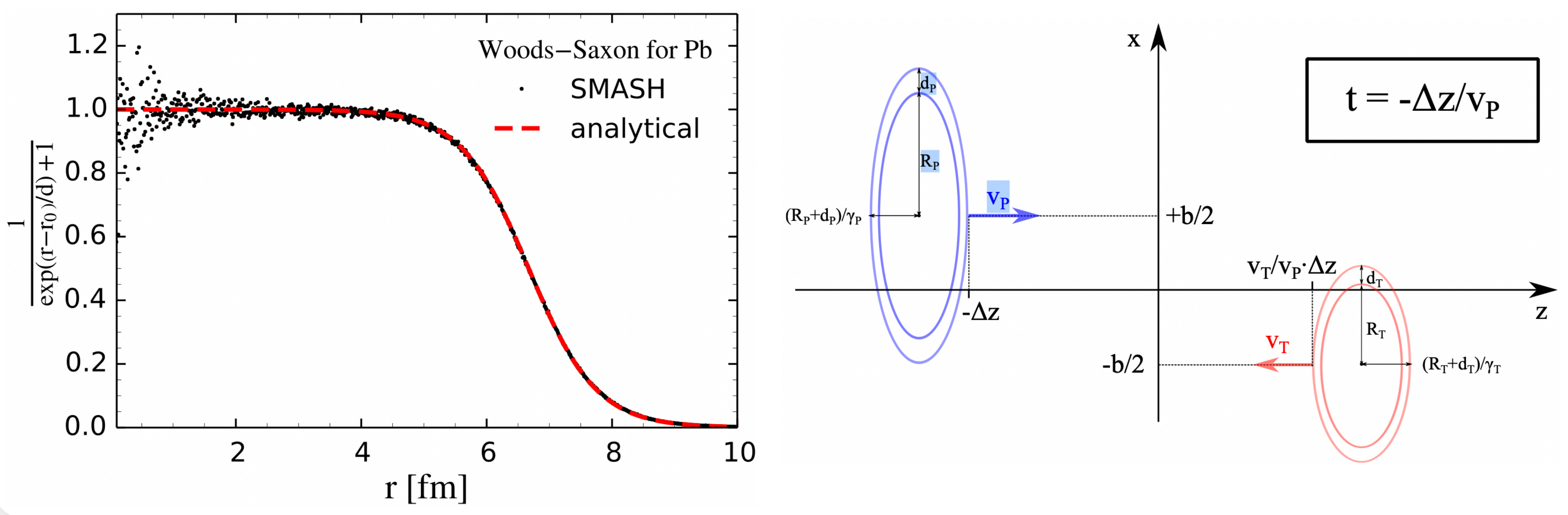
$$\frac{dN}{d^3r} = \frac{\rho_0}{\exp\left(\frac{r-r_0}{d}+1\right)}$$

d: diffusiveness of the nucleus

ρ_0: nuclear ground state density

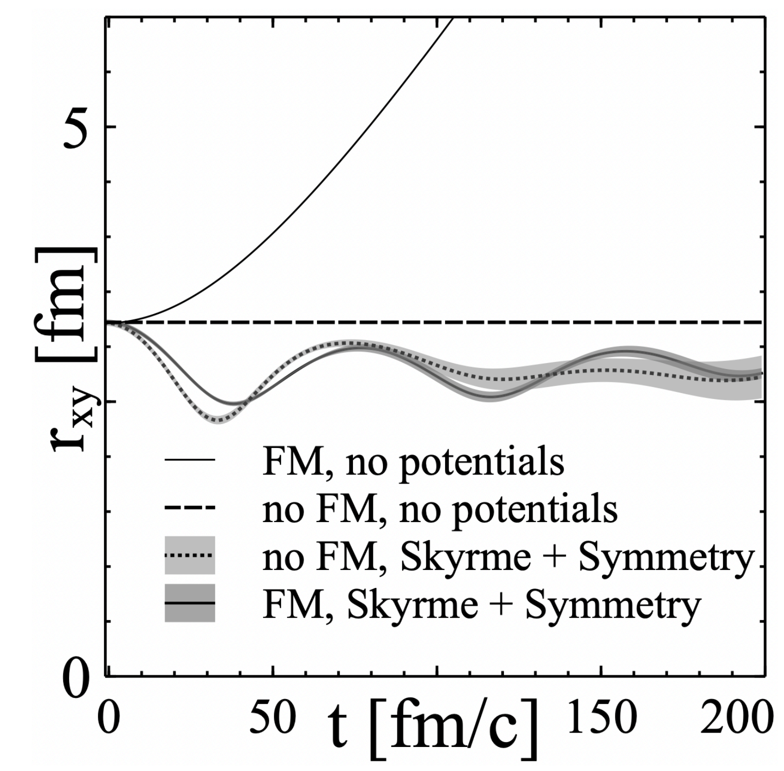
$d \rightarrow 0$: Hard sphere limit

J. Weil *et al.*, Phys.Rev.C 94 (2016) 5, 054905



Fermi Motion

- Nuclei get additional momenta
- Nuclei are „stable“ if additional potentials are turned on
- “Frozen“ Fermi motion only considered for collision and turned off for propagation



Weil *et al.*, Phys.Rev.C 94 (2016) 5, 054905

Resonances

- Particles with widths < 10 keV treated as stable
- Unstable particles assigned a relativistic Breit-Wigner spectral function

$$\mathcal{A}(m) = \frac{2\mathcal{N}}{\pi}\frac{m^2\Gamma(m)}{(m^2 - M_0^2)^2 + m^2\Gamma(m)^2}$$

m: resonance mass

M_0: pole mass

$\Gamma(m)$: width function

$\mathcal{N}$: normalization

- Decay width of two body decay $R \rightarrow ab$ by treatment of Manley et al.

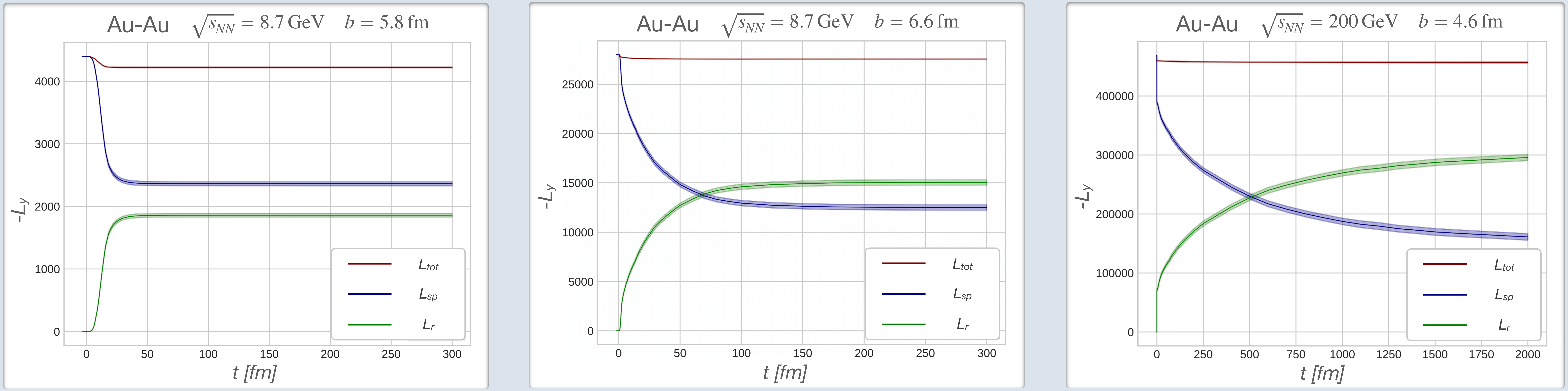
$$\Gamma_{R\rightarrow ab} = \Gamma^0_{R\rightarrow ab}\frac{\rho_{ab}(m)}{\rho_{ab(M_0)}}$$

$\rho_{ab}(m)$: mass integrals over resonance spectral functions

$\Gamma^0_{R\rightarrow ab} = \Gamma_{R\rightarrow ab}(M_0)$

http://smash-transport.github.io

Angular Momentum Evolution



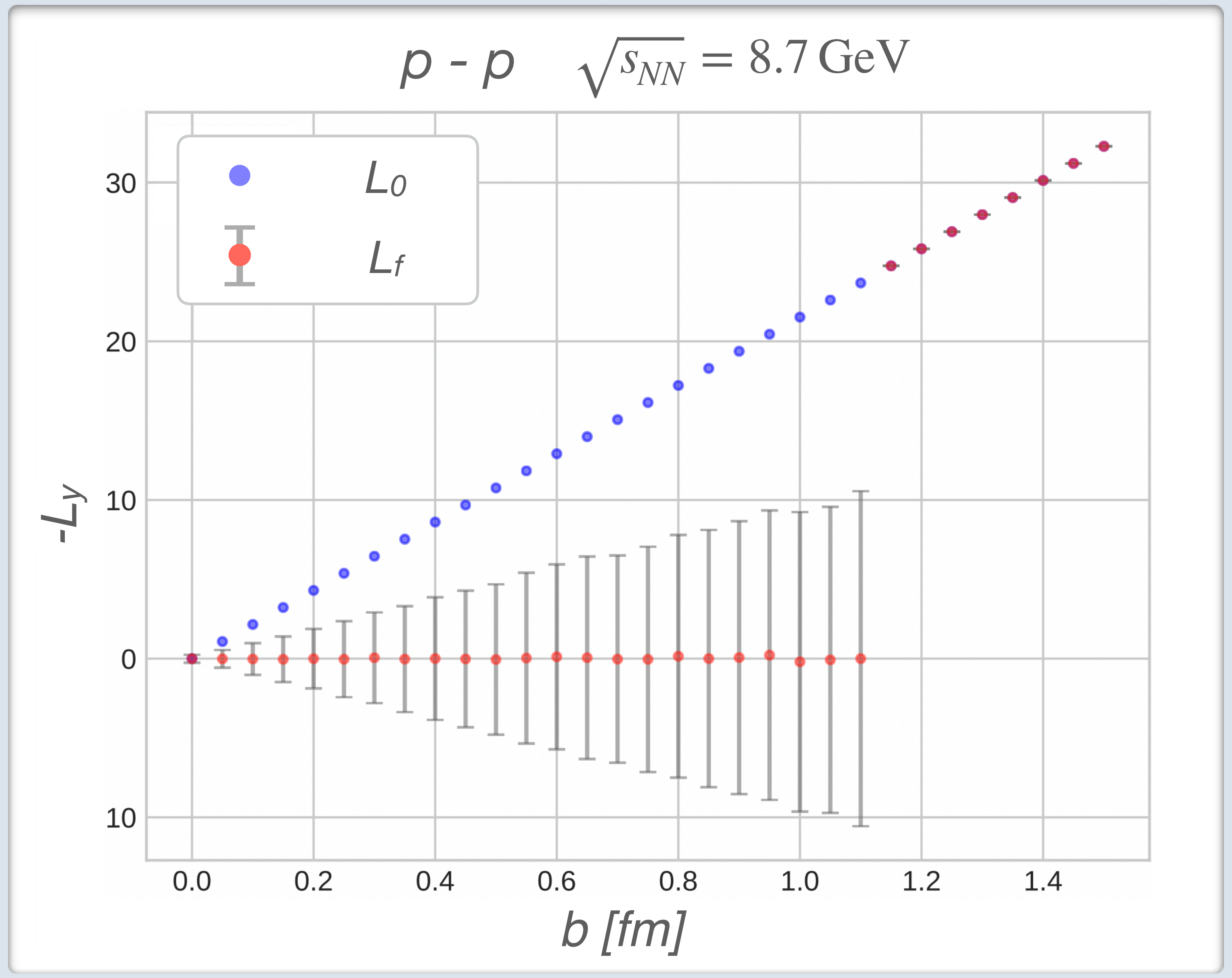
N. Sass et al, in preparation

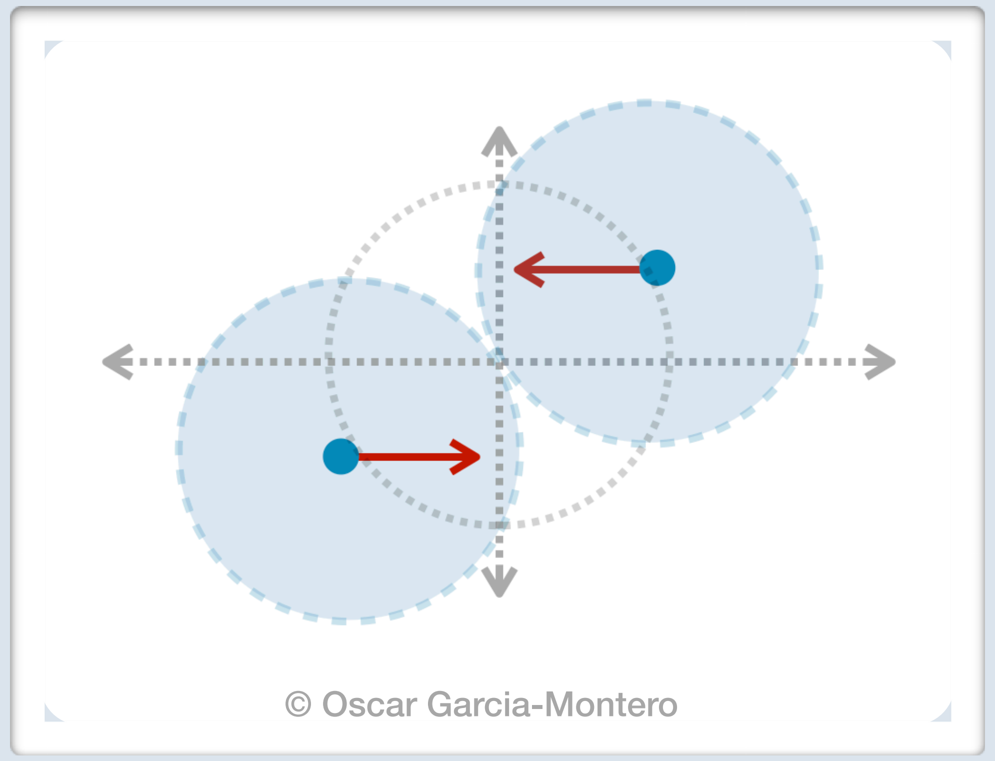
- We observe a kink in the total angular momentum at the time when both nuclei collide

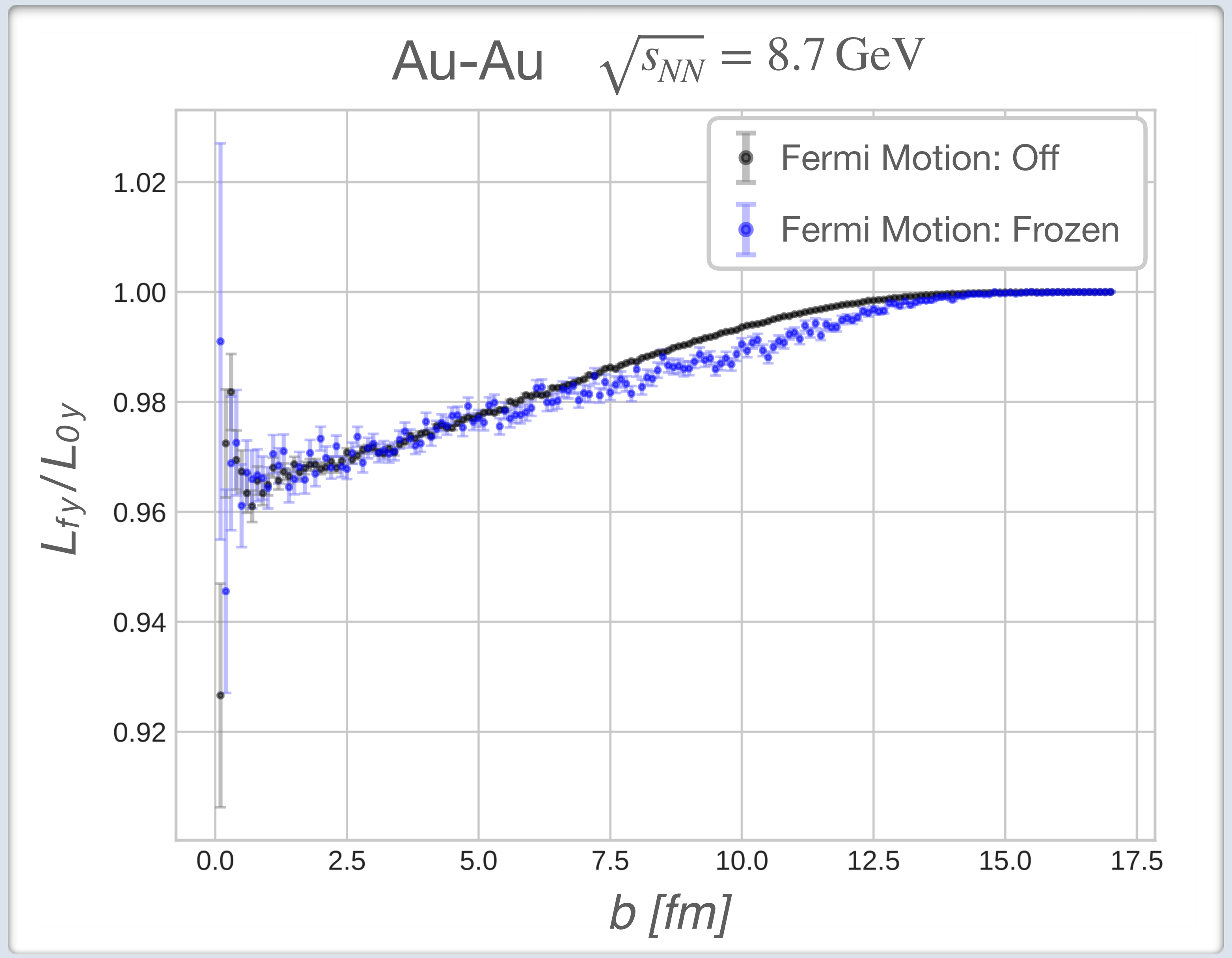
  → Broken angular momentum conservation

- For higher beam energies the kink occurs at smaller times due to higher nuclei rapidities
- Secondary collisions at higher beam energies shift the flattening of L_{sp} and L_r to later times

Angular Momentum Conservation





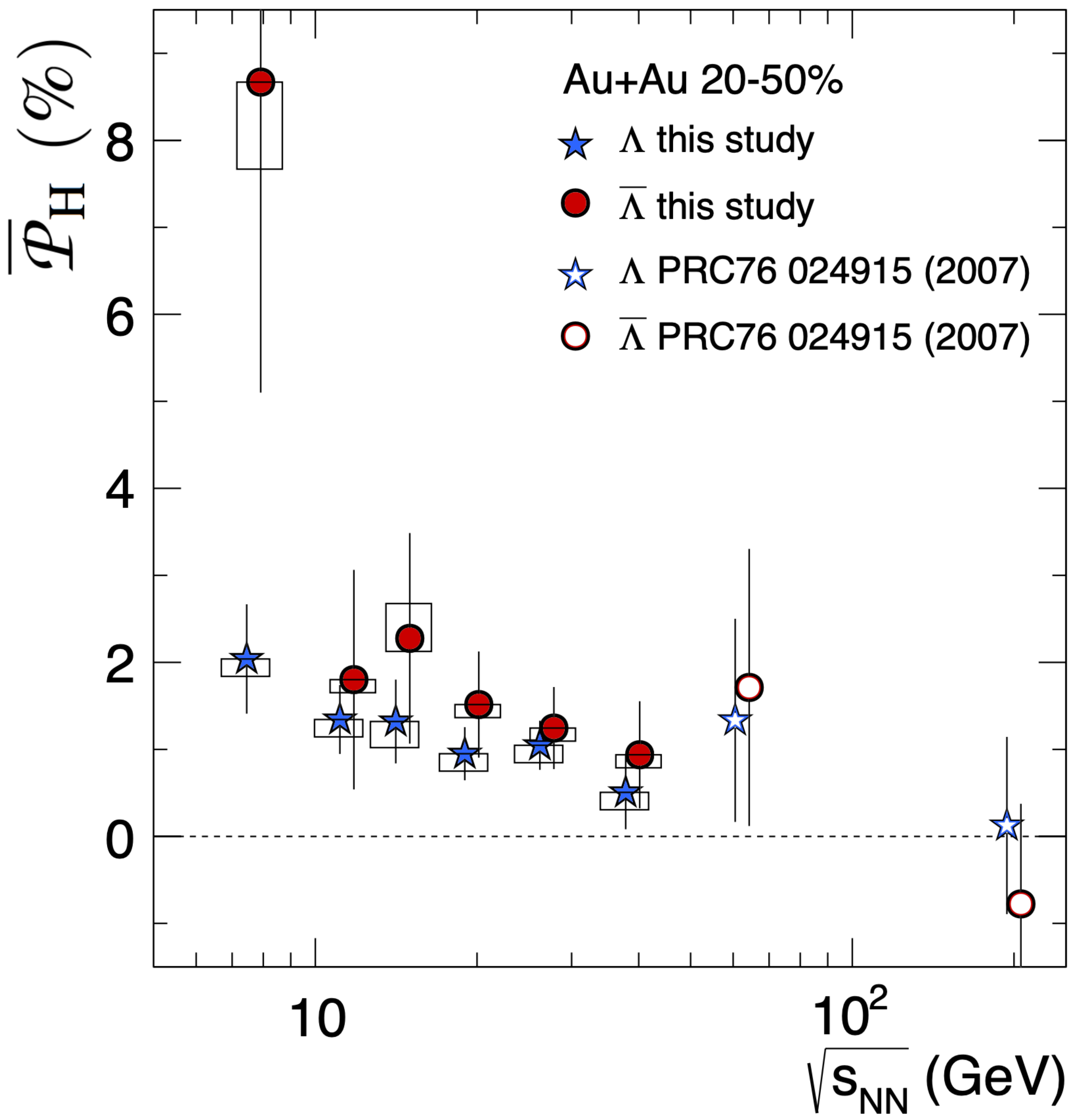


N. Sass et al, in preparation

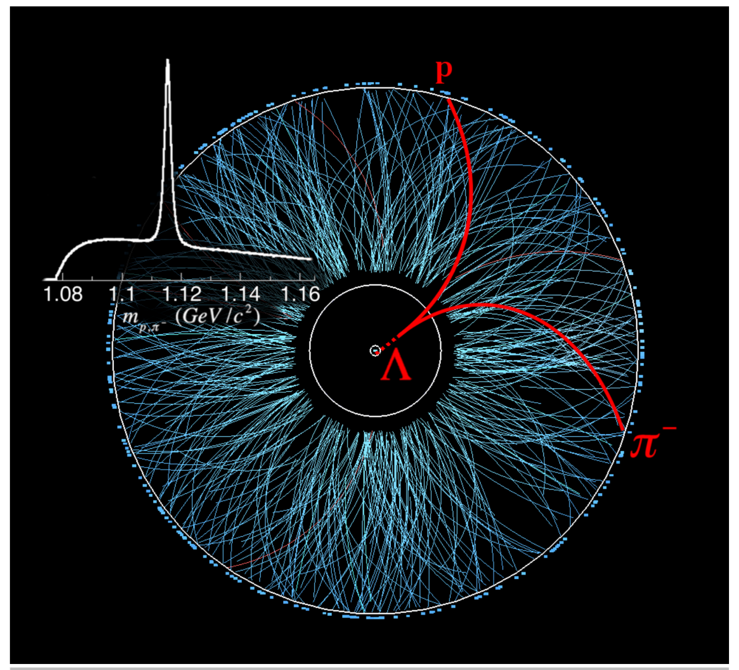
- At $\sqrt{s_{NN}} = 8.7\,\mathrm{GeV}$ protons collide elastically (~1/3) and inelastically (~2/3)
- Geometrical Interpretation of the cross section breaks angular momentum conservation in binary in/elastic collisions
- Collective „loss“ of angular momentum in Au-Au collisions amounts to 3.5% for small impact parameters
- Additional momenta by Fermi motion potentially increase non-conservation of angular momentum

STAR Measurement

- Weak decay $\Lambda \to p + \pi^-$ emits proton predominantly in spin direction of Λ



- The (phase-space) **averaged polarization** is determined by the azimuthal angle distribution of the proton's momentum



- Λ is identified by extrapolation of the measured daughter particles (p, π^-)
- Summation over many events yields a distinct peak in the invariant-mass distribution at the Λ mass

L. Adamczyk *et al.* [STAR], Nature 548 (2017), 62-65