Influence of neutron skin in heavy ion collisions at RHIC energies

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Introduction

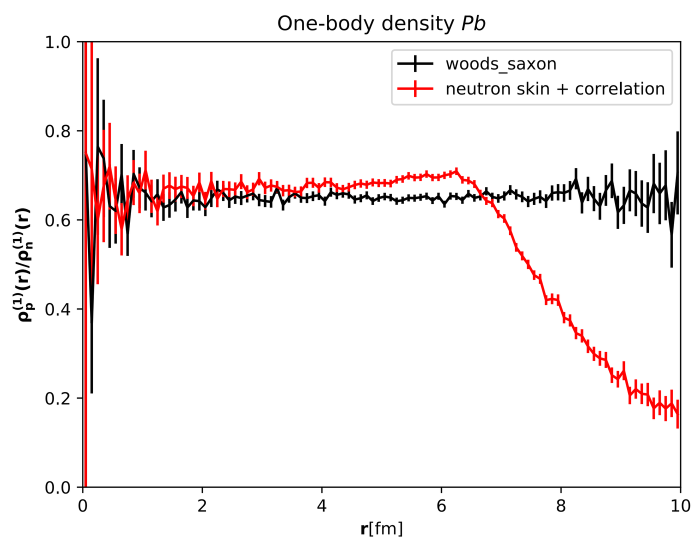
Neutron skin effect

- Classically the density of protons and neutrons inside the nucleus is modeled with the so called Woods-Saxon distribution

$$\rho(r) = \frac{\rho_0}{e^{\frac{r-r_0}{d}}+1} \qquad \begin{cases} r_{0,p} = r_{0,n} \\ d_p = d_n \end{cases}$$

- However experimental measurements in neutron rich nuclei like ^{208}Pb [1]. (#n/#p ~ 1.4) showed that
  $r_{0,p} \neq r_{0,n}$ and $d_p \neq d_n$
  this is known as the neutron skin effect
- Isospin dependent values for d and r_0 result in a nonzero Δr_{np} wich is defined as

$$\Delta r_{np,^{208}Pb} = \sqrt{\langle r_n^2\rangle - \langle r_p^2\rangle} = 0.15 \pm 0.03\,\text{fm}$$



- While the total one-body density is unaffected, the ratio of the proton to neutron density changes.

Isobar run at RHIC

- Recently there has been a measurement of the isobar nuclei ^{96}Zr and ^{96}Ru at RHIC at $\sqrt{s} = 200$ GeV with the goal of studying the chiral magnetic effect
- Underlying idea:
  ➡ Keep the background component (v_2) fixed
  ➡ Handle on the magnetic field strength via the atomic number

Neutron skin for ^{96}Zr

- Since

$$\left.\frac{\#n}{\#p}\right|_{Zr} = \left.\frac{\#n}{\#p}\right|_{Pb} > \left.\frac{\#n}{\#p}\right|_{Ru}$$

  We consider the neutron skin to appear at ^{96}Zr
- Under the condition that the neutron skin is halo like ($r_{0,p}$ ~ $r_{0,n}$), Δr_{np} is the same as for ^{208}Pb and keeping the size of the nucleus fixed we obtain the following Woods-Saxon parameters individually for protons and neutrons

System	r_0 / fm	d / fm	β_2	β_4	$r_{0,p}$ / fm	$r_{0,n}$ / fm	d_p / fm	d_n / fm
^{96}Zr	5,02	0,46	0	0	5,08	5,08	0,34	0,46
^{96}Ru	5,085	0,46	0,158	0	5,085	5,085	0,46	0,46

Model

- We are using the relativistic hadronic transport approach SMASH, see also *smash-transport.github.io* [2]
- SMASH contains all well-established hadrons with masses up to ~ 2 GeV
- It gives an effective solution to the relativistic Boltzmann equation

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

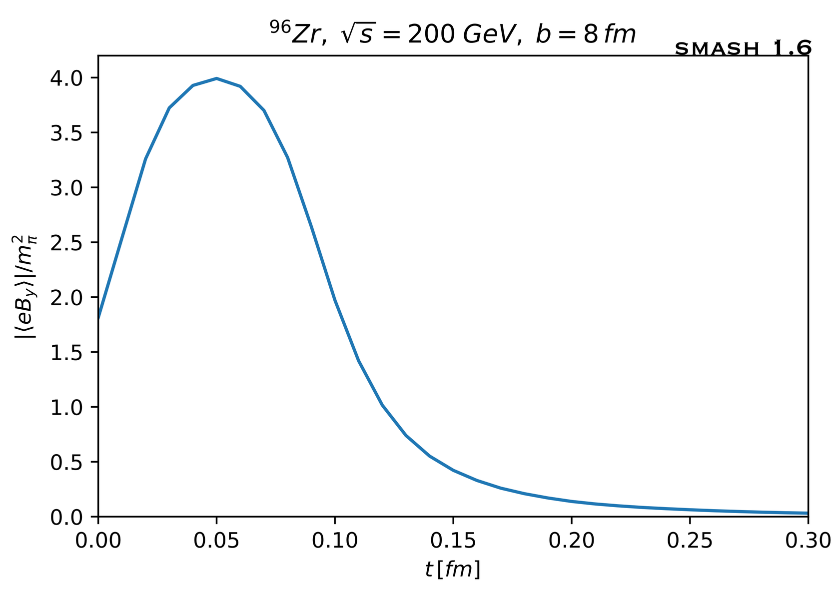
- Nuclei Configurations including nucleon-nucleon correlations plus neutron skin are computed by Alvioli et al. [3]
- Modeling of cross section via resonance formation and decay
- String excitation in high energy regime by PYTHIA for interactions with large $\sqrt{s}$

Magnetic fields in heavy-ion collisions

Magnetic fields can be computed using Lienard-Wiechert potentials

$$e\vec{B}(t,\vec{r}) = \alpha_{EM} \sum_i \frac{(1-v_i^2)(\vec{v}_i \times \vec{R}_i)}{R_i^3[1-(\vec{R}_i \times \vec{v}_i)/R_i]^{3/2}}$$

- Sum runs over all charged particles
- Most central point $\vec{r} = (0,0,0)$ for all calculations
- $\vec{R}_i(t) = \vec{r} - \vec{r}_i(t)$



Acknowledgements

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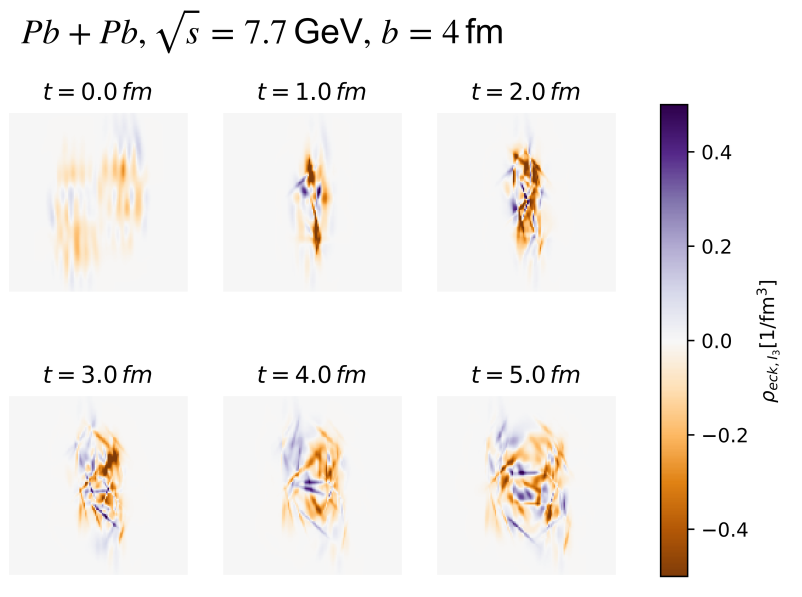
Density calculation

- Initial state isospin 3 distribution could be use as input parameter for a hydrodynamic calculation
- Construct a current with density factor I

$$j^\mu = \int I \frac{p^\mu}{p^0} f(r,p,t) \frac{d^3p}{(2\pi\hbar)^3}$$

- Split positively and negatively charged current

$$\rho_{eck} = \sqrt{j^\mu j_\mu} = \rho_+ - \rho_-$$

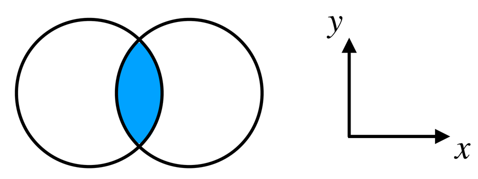


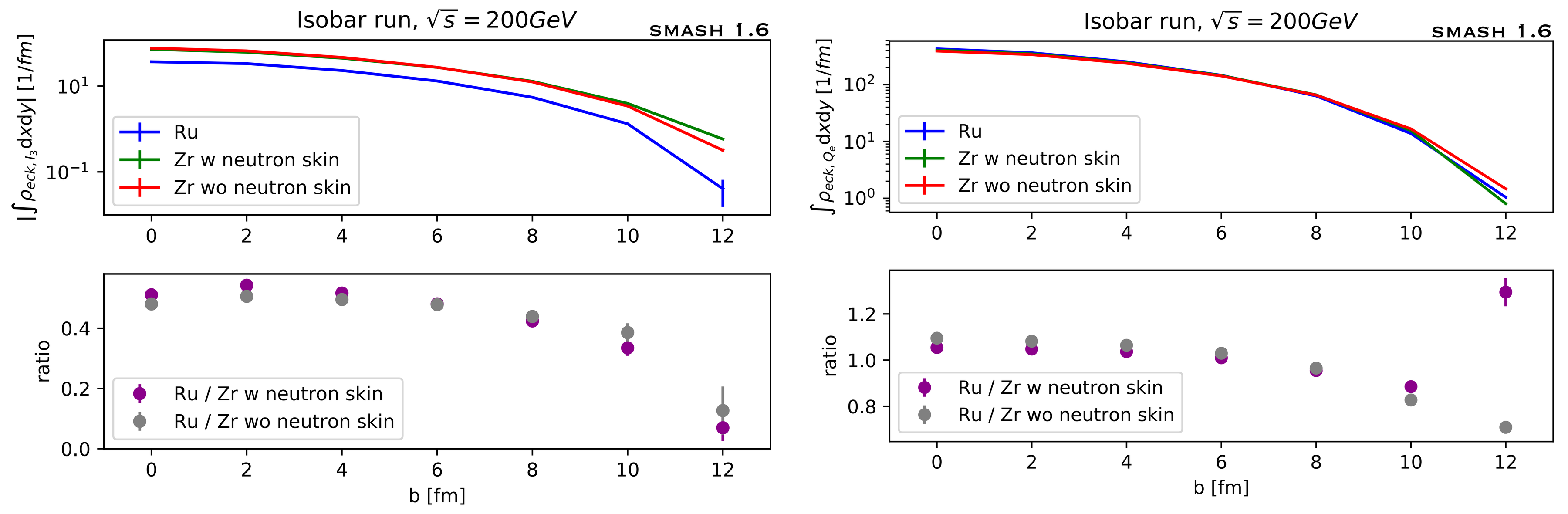
Time evolution of isospin 3 density

Results

Isospin 3 and electric charge densities

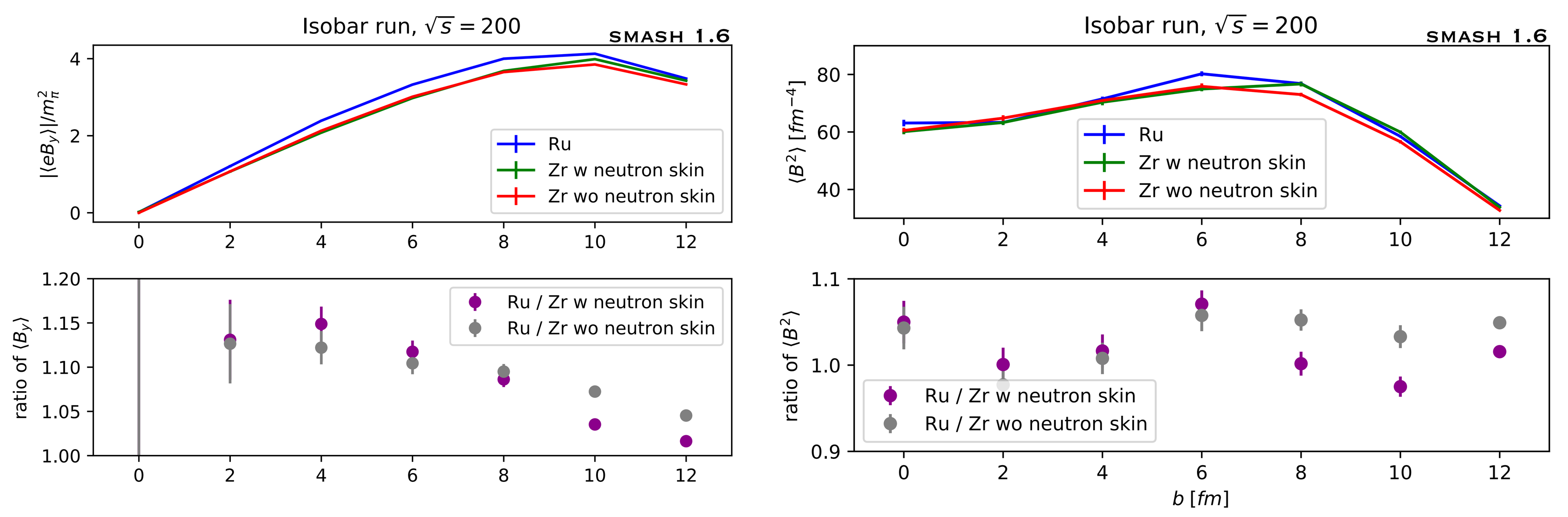
Integrate over the participant density in the transverse plane





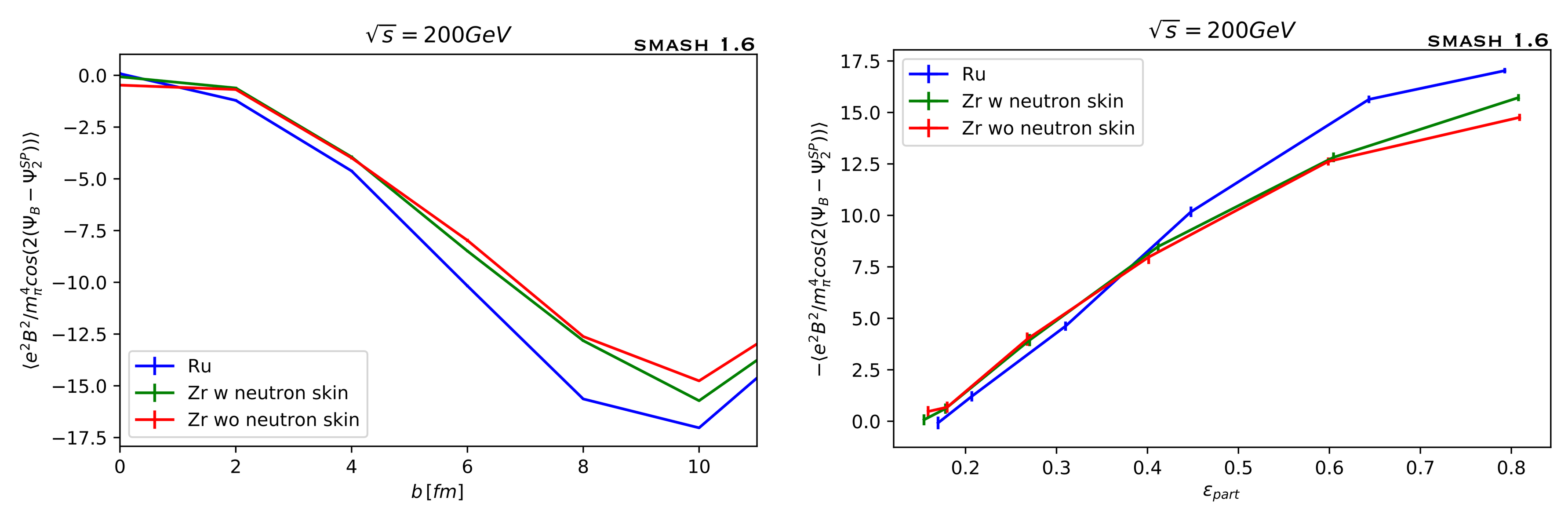
Magnetic fields

Computing the magnetic field at the time both nuclei completely overlap



CME search related observables

Correlation between angle of magnetic field and Ψ_2^{SP} [4]



Conclusions

- We implemented the neutron skin effect for the nuclear density distribution of ^{96}Zr in the hadronic transport approach SMASH
- Neutron skin increases the magnetic field strength for impact parameter > 8 fm
- The ratio of B^2 between Ru and Zr is reduced from ~10% to ~5%
- Our result suggests a smaller CME signal to background ratio than previously expected for peripheral isobar collisions at RHIC

References

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