Effects of Conservation Laws on Particle Correlations in Relativistic Nuclear Collisions

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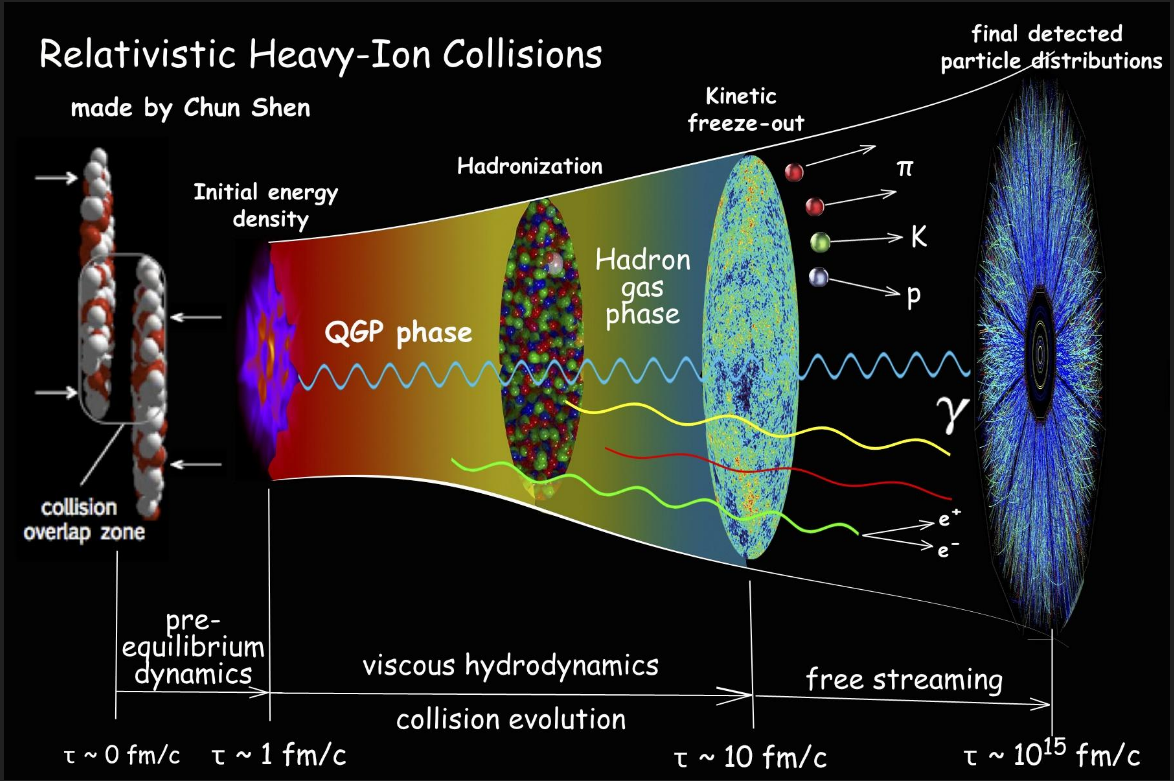
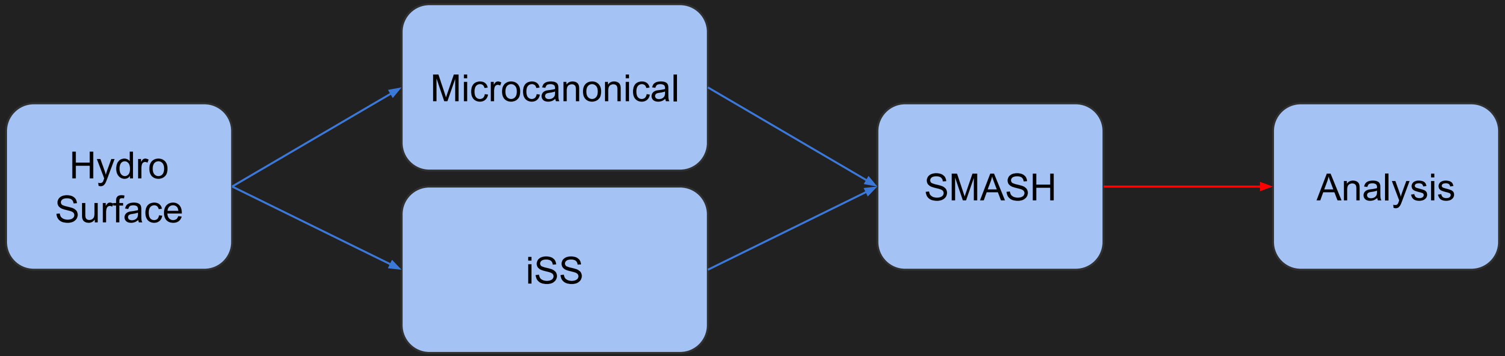
Talk Outline

- Motivation
- Setup
  - Workflow in simulation chain
  - Conventional particle sampling technique
  - Microcanonical particle sampler
- Results
  - Single particle observables
  - Two particle correlations



- Techniques for simulating hadronization include conventional grand-canonical (iSS) sampler and recently developed microcanonical sampler. [D. Oliinychenko and V. Koch, Phys. Rev. Lett. 123, 182302 (2019)]
- Explore sensitivity of correlation observables to local conservation laws of electric charge, strangeness, and baryon number with microcanonical particle sampling.

Workflow



- Grand-canonical (iSS) sampling does not preserve multi-particle correlations from the hydro surface.
- Microcanonical sampling imposes non-trivial correlations to particles from local conservation laws.
  [D. Oliinychenko and V. Koch, Phys. Rev. Lett. 123, 182302 (2019)]
- Particle correlations are further propagated in hadronic transport.

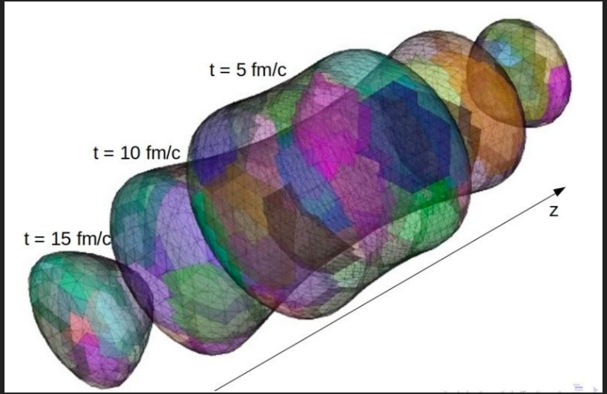
Microcanonical Sampler - The Physics

[D. Oliinychenko and V. Koch, Phys. Rev. Lett. 123, 182302 (2019)]

- The hypersurface is divided into patches, which in turn contain fluid cells.
- Each patch is considered an isolated system, with fixed total energy and momentum.
- Conservation laws apply over individual patches.

$$\begin{pmatrix} P^{\mu}_{tot} \\ B_{tot} \\ S_{tot} \\ Q_{tot} \end{pmatrix} = \sum_i \int \begin{pmatrix} p^{\mu}_i \\ B_i \\ S_i \\ Q_i \end{pmatrix} \frac{p^{\upsilon} d\sigma_{\nu}}{p^0} f_i(p^{\alpha}u_{\alpha}, T, \mu_i) \frac{g_i d^3p}{(2\pi h)^3}$$

$$P\left(N, \{N_S\}^{species}, \{x_i\}_{i=1}^N, \{p_i\}_{i=1}^N\right)$$
$$= N\left(\prod_S \frac{1}{N_S!}\right) \prod_{i=1}^N \frac{g_i}{(2\pi h)^3} \frac{d^3p_i}{p_i^0} p_i^{\mu} d\sigma_{\mu} f_i(p_i^{\nu}u_{\nu}, T, \mu_i)$$
$$\times \delta^{(4)}\left(\sum_i p^{\mu} - P^{\mu}_{tot}\right) \delta^{B_{tot}}_{\sum_i B_i} \delta^{S_{tot}}_{\sum_i S_i} \delta^{Q_{tot}}_{\sum_i Q_i}$$



[D. Oliinychenko, (2020)]

Estimates of Patch Number & Patch Size

- Different patch energies relate to different patch numbers and patch sizes

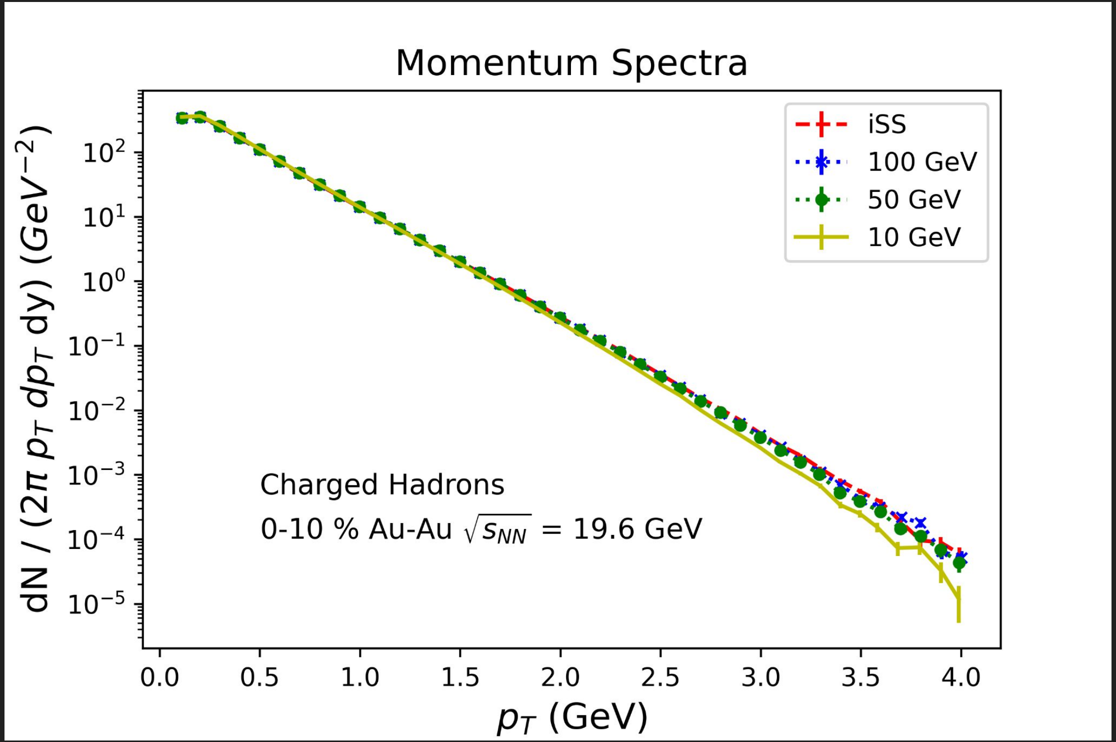
$$patch\ number \propto \frac{E_{total}}{E_{patch}}$$

$$patch\ size \propto \sqrt[3]{\frac{E_{patch}}{e_{sw}}}$$

For 0 - 10 % Au-Au Collisions at 19.6 GeV

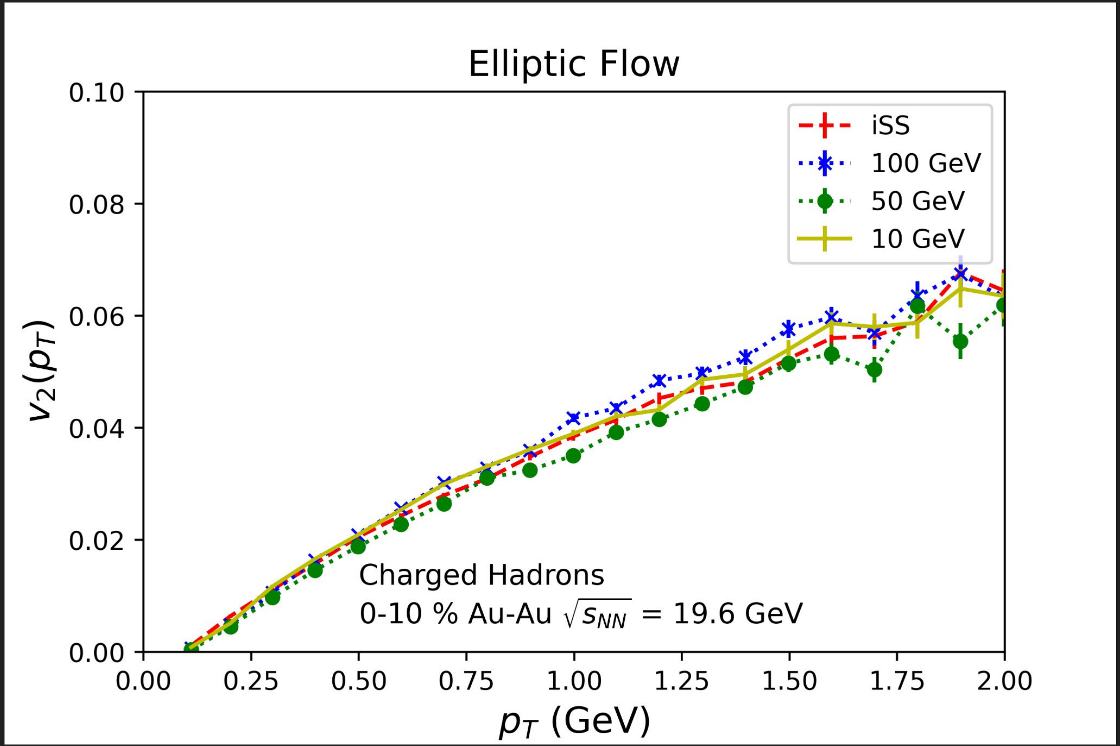
Patch energy (GeV)	Patch number	Patch size (fm)
100	38	7.4
50	77	5.8
10	386	3.4

Single Particle Observables



Particle spectra becomes steeper as we reduce the patch energy, reflecting conservation of energy.

Single Particle Observables

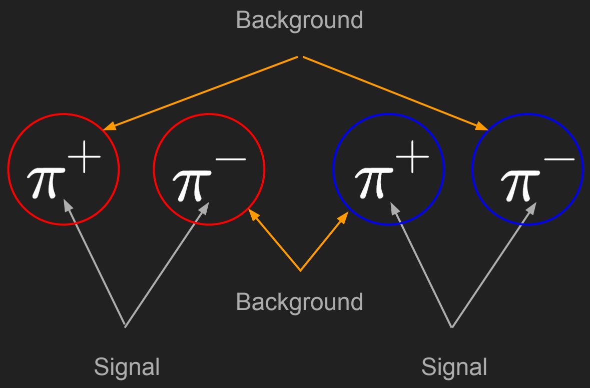


Within statistical fluctuations, no significant difference between grand-canonical and microcanonical sampling treatments.

Two Particle Correlations

- Identified particle pairs are assorted in a 3x3 matrix.

$$\begin{bmatrix} \pi^+\pi^- & \pi^+k^- & \pi^+\overline{p} \\ k^+\pi^- & k^+k^- & k^+\overline{p} \\ p\pi^- & pk^- & p\overline{p} \end{bmatrix}$$



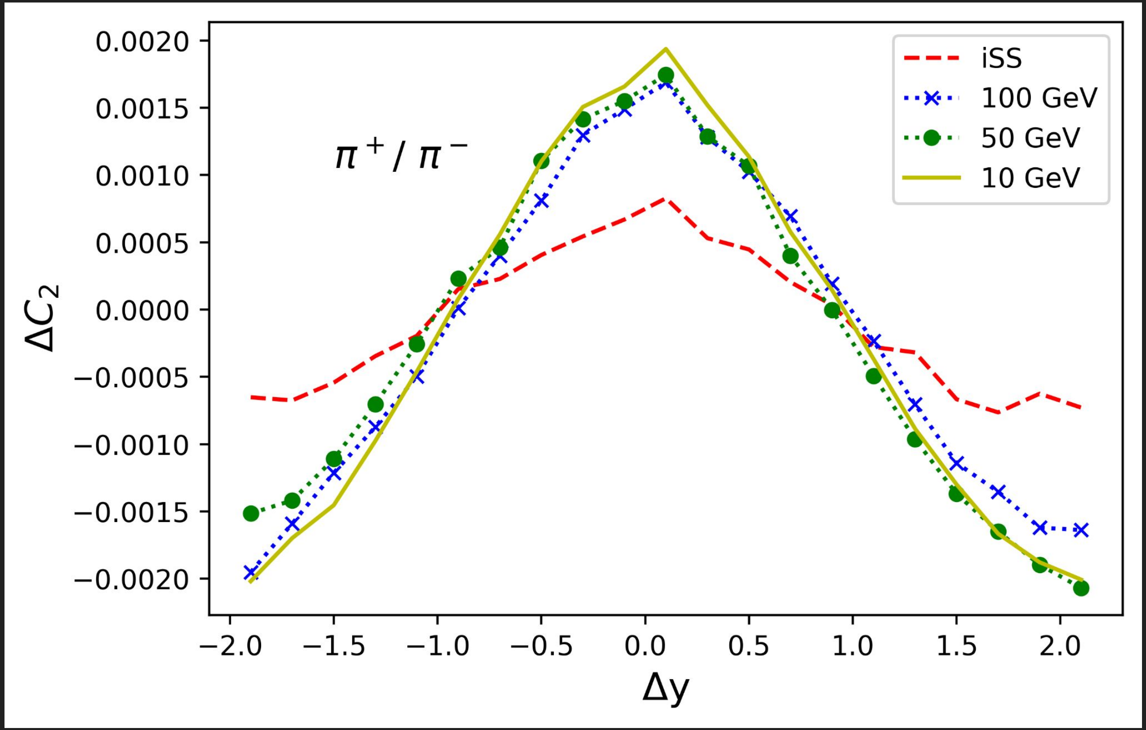
$$\Delta C_2 = C_2(OS) - C_2(SS); C_2 = \frac{\rho^{(2)}(p_1, p_2)}{\rho^{(1)}(p_1)\rho^{(1)}(p_2)}$$

- The “background” correlations are subtracted out by same-sign correlations to leave only the “true” correlations.

- Correlations are studied as functions of rapidity difference between the pairs |Δy|.

Two Particle Correlations

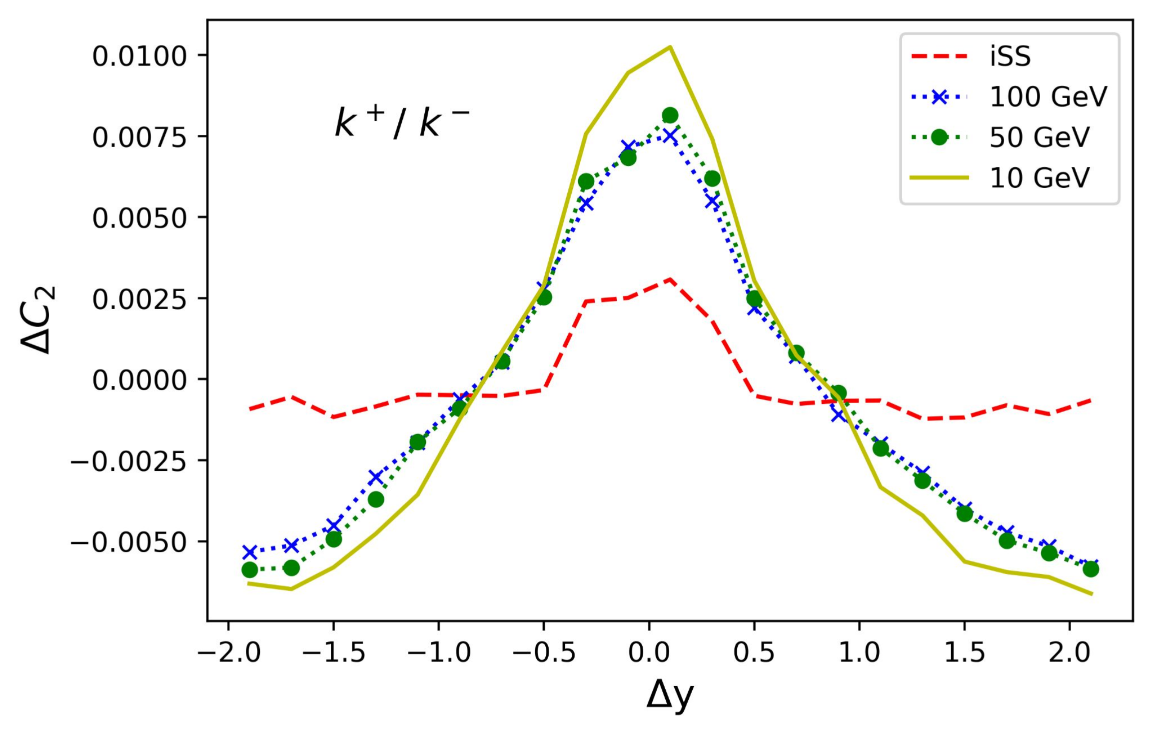
$$\begin{bmatrix} \pi^+\pi^- & \pi^+k^- & \pi^+\overline{p} \\ k^+\pi^- & k^+k^- & k^+\overline{p} \\ p\pi^- & pk^- & p\overline{p} \end{bmatrix}$$



- Correlations in the iSS+SMASH case are from resonance decay + hadronic scattering.
- The local electric charge conservation produces stronger short-range correlations.

Two Particle Correlations

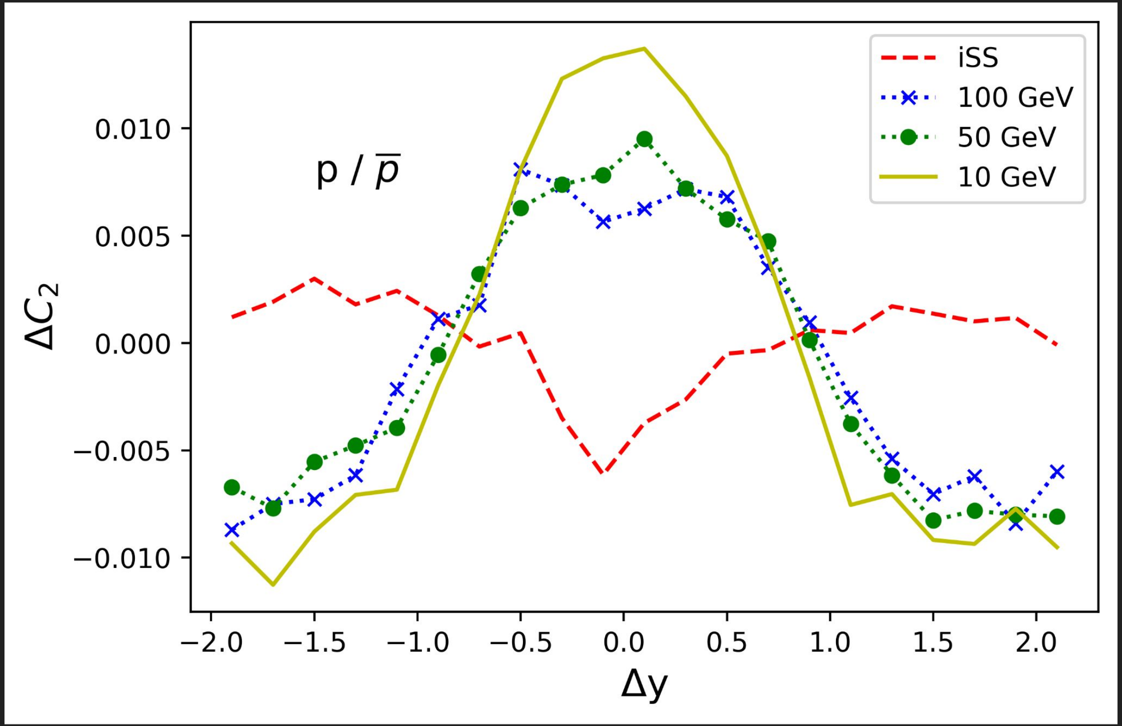
$$\begin{bmatrix} \pi^+\pi^- & \pi^+k^- & \pi^+\bar{p} \\ k^+\pi^- & k^+k^- & k^+\bar{p} \\ p\pi^- & pk^- & p\bar{p} \end{bmatrix}$$



- The local electric charge and strangeness conservation produce stronger short-range correlations.
- Correlation functions are narrower with smaller patch energy (shorter correlation length).

Two Particle Correlations

$$\begin{bmatrix} \pi^+\pi^- & \pi^+k^- & \pi^+\bar{p} \\ k^+\pi^- & k^+k^- & k^+\bar{p} \\ p\pi^- & pk^- & p\bar{p} \end{bmatrix}$$

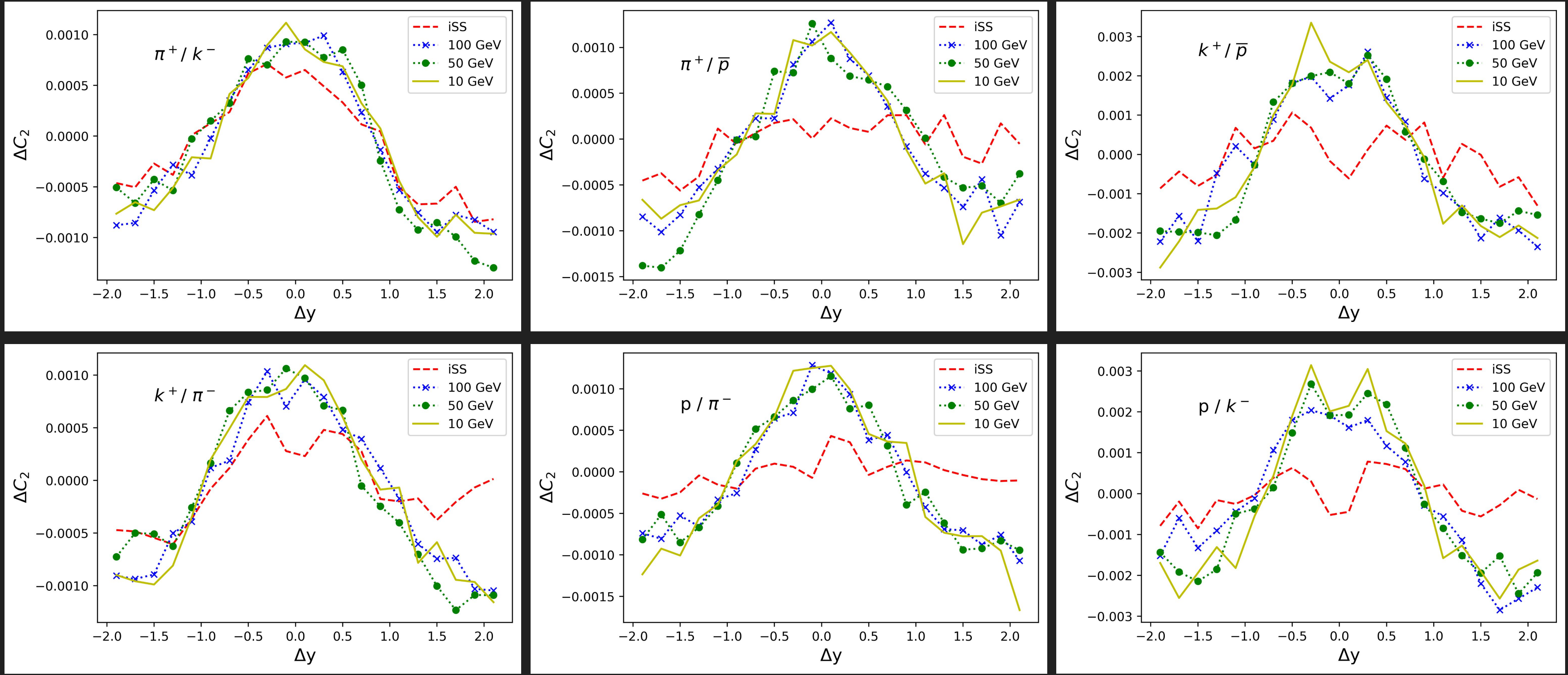


- The local electric charge and baryon number conservation overcomes annihilation in small |Δy|.
- Correlation functions are sensitive to the correlation length for B and Q conservation.

Two Particle Correlations

Mixed Species

$$\begin{bmatrix} \pi^+\pi^- & \pi^+k^- & \pi^+\overline{p} \\ k^+\pi^- & k^+k^- & k^+\overline{p} \\ p\pi^- & pk^- & p\overline{p} \end{bmatrix}$$



Conclusion

- Setup of simulation framework to study local conservation laws on particle correlations.
- Local charge (B, S, Q) conservations enhance the two particle correlations in small $|\Delta y|$ between identified particle pairs.
- Outlook:
    - Study physics of off-diagonal particle correlations with more statistics.
    - Study the effects of local conservation laws on three-particle correlations.
    - Comparison to STAR measurements.

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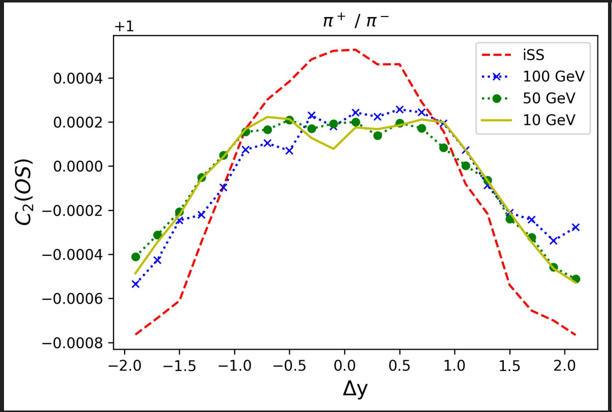
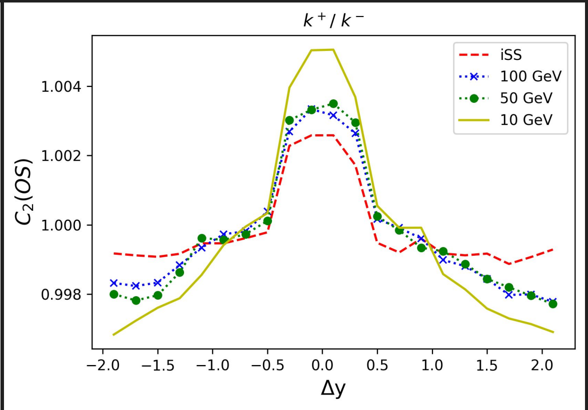
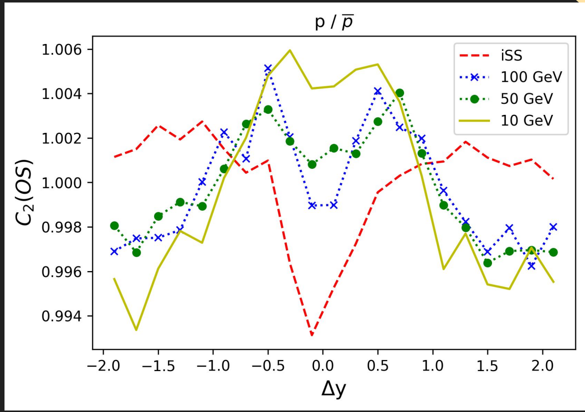
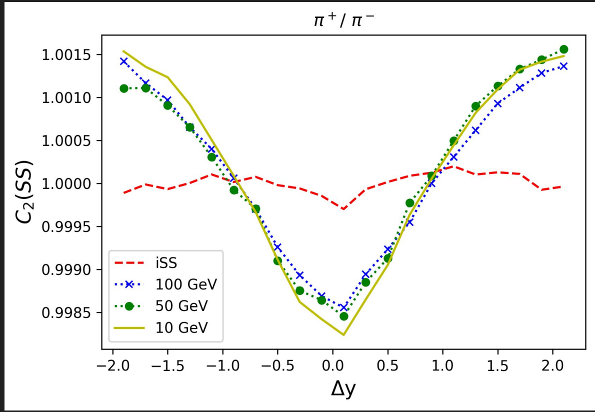
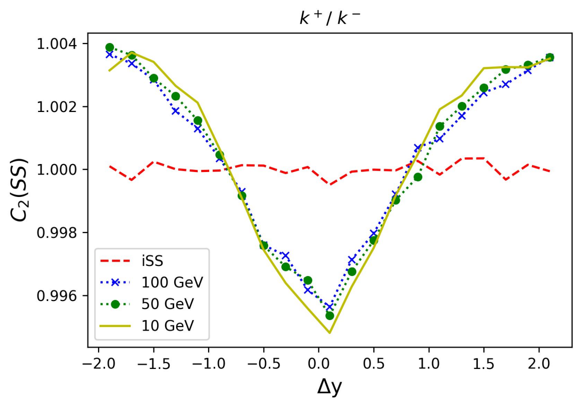
Appendix - C_2(OS) and C_2(SS) Plots

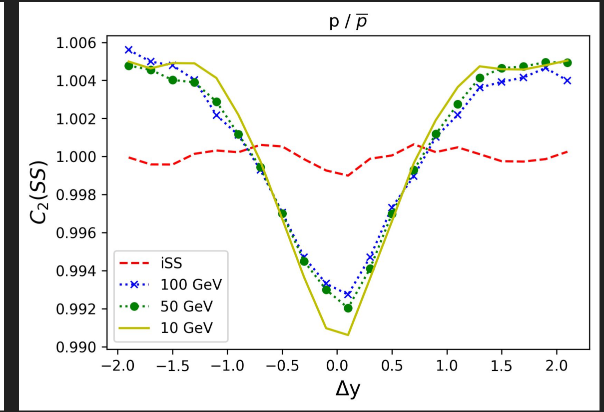












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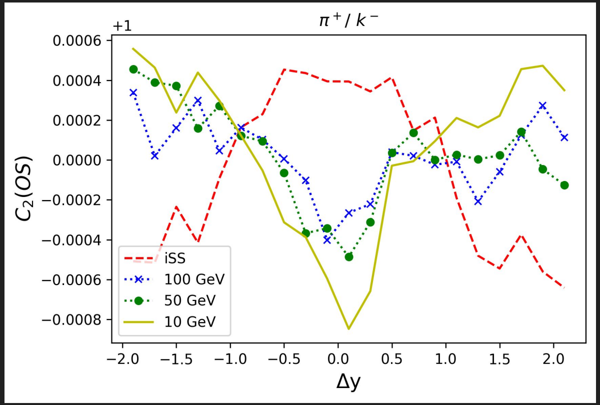

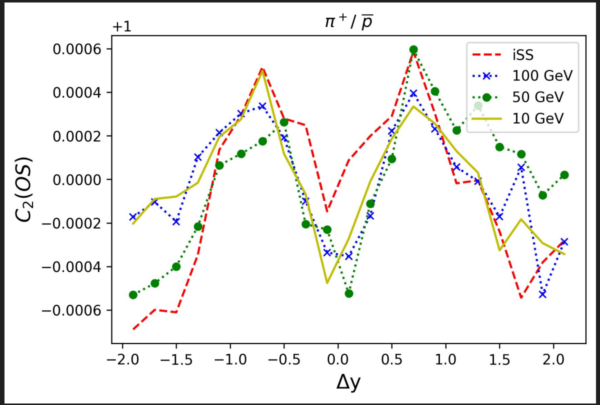

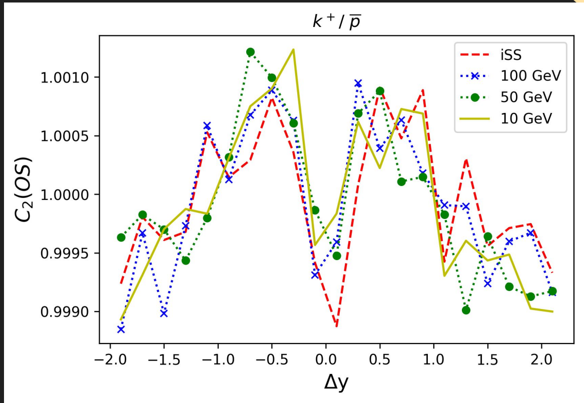

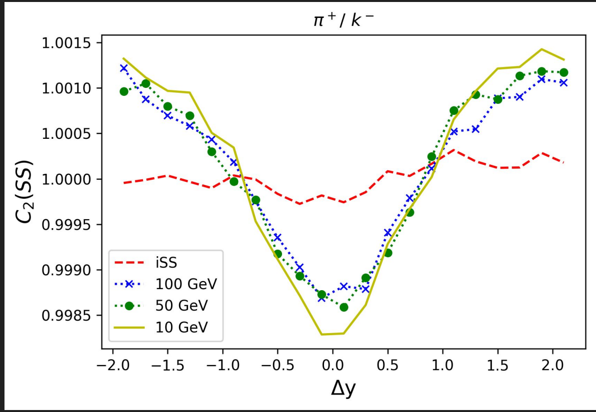

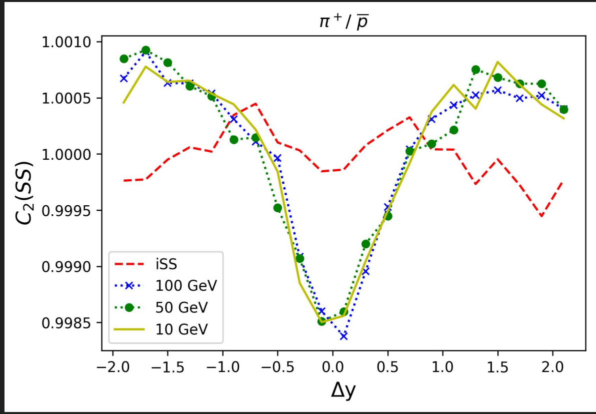

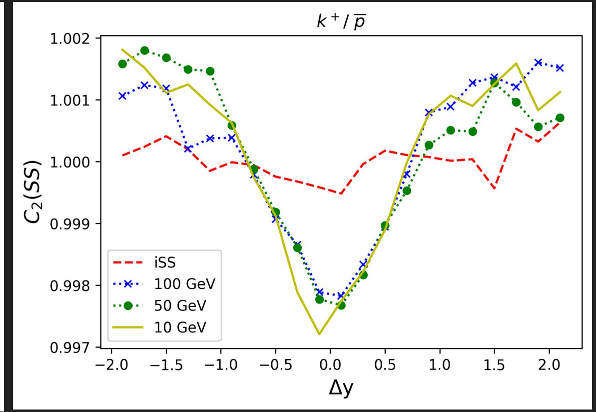

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