

Interferometric Signatures of Collectivity in Small Systems

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Where does it come from?

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Possible explanations include:

- ▶ Initial-state correlations (e.g., CGC)
- ▶ Escape mechanisms
- ▶ *String hadronization models* (e.g., Lund string/Pythia)
- ▶ *Hydrodynamics*

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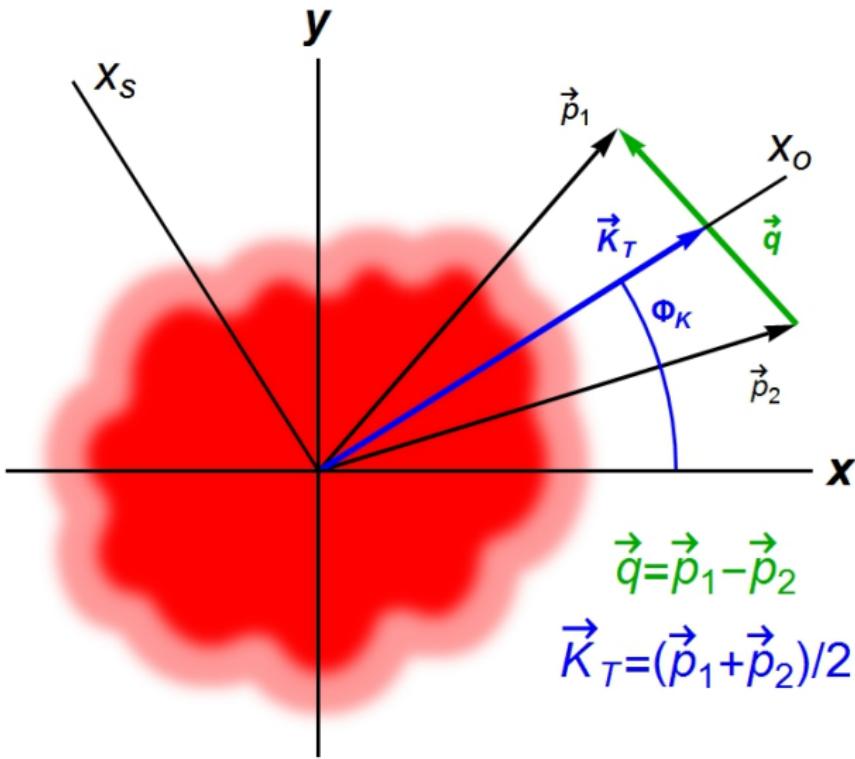
- ▶ Initial-state correlations (e.g., CGC)
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How can we discriminate between models?

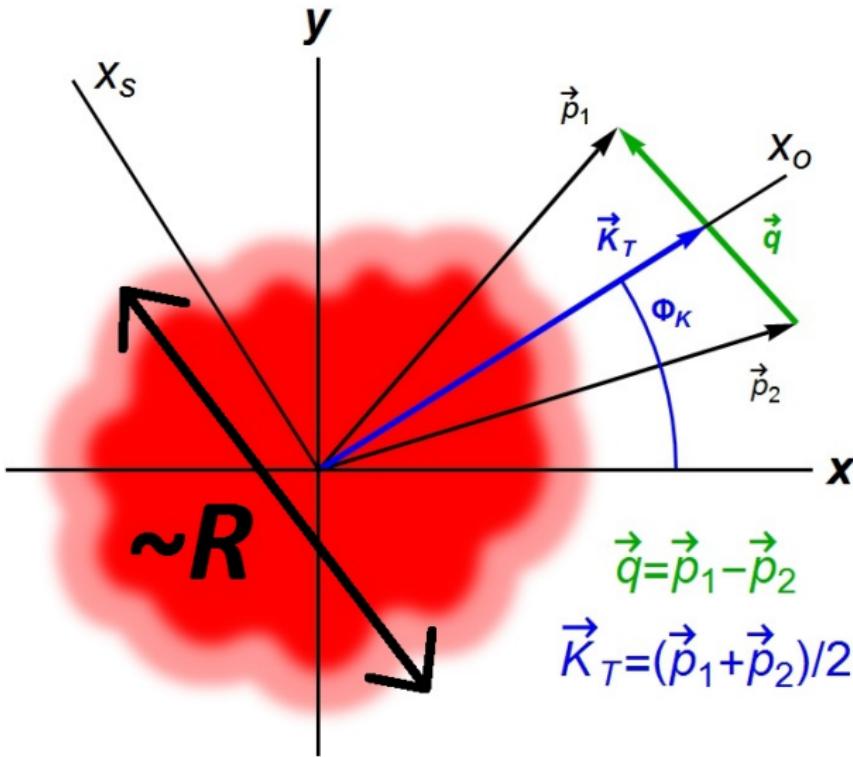
Various observables:

- ▶ Anisotropic flow, strangeness enhancement, etc.
- ▶ **This talk:** Hanbury Brown–Twiss (HBT) interferometry
 - *Scaling of radii with $dN_{\text{ch}}/d\eta$ in hydrodynamics and Pythia*
 - **N.B.** – work in progress!

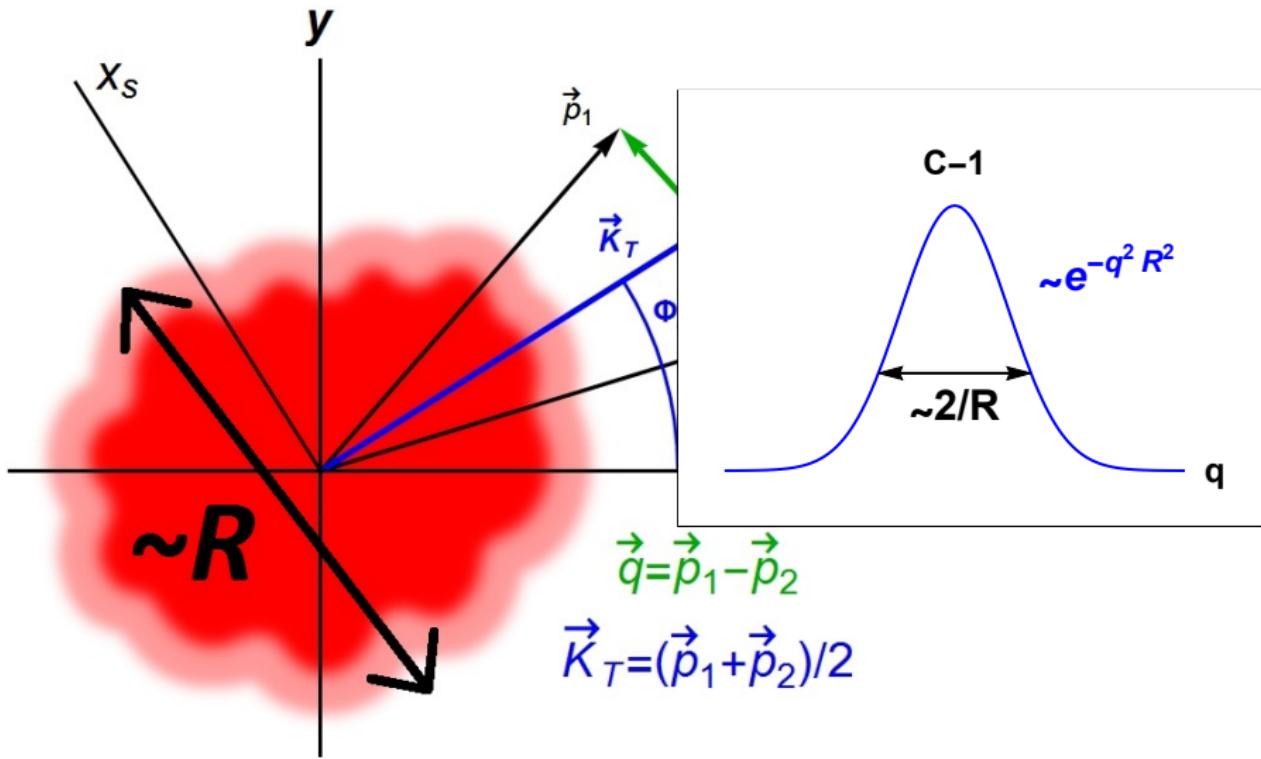
HBT in a nutshell



HBT in a nutshell



HBT in a nutshell



HBT formalism

$$C(\vec{p}_1, \vec{p}_2) \equiv E_{p_1} E_{p_2} \frac{d^6 N}{d^3 p_1 d^3 p_2} / \left(E_{p_1} \frac{d^3 N}{d^3 p_1} E_{p_2} \frac{d^3 N}{d^3 p_2} \right)$$

HBT formalism

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$$\text{Hydrodynamics: } S(x, p) = \frac{1}{(2\pi)^3} \int_{\Sigma(x_f)} \frac{p \cdot d^3 \sigma(x_f) \delta^4(x - x_f)}{e^{(p \cdot u(x_f) - \mu)/T} \pm 1}$$

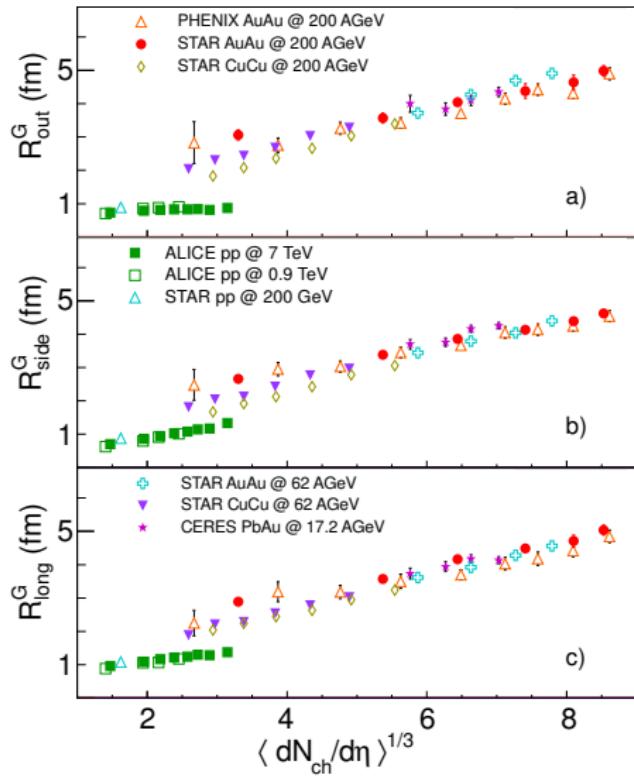
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 \text{Pythia: } S(x, p) &= \sum_{j=1}^N \delta^{(4)}(x - x_i) \delta^{(4)}(p - p_i)
 \end{aligned}$$

Ref. *U. W. Heinz, [arXiv:hep-ph/0407360 [hep-ph]].*

Ref. *S. Ferrerres-Solé and T. Sjöstrand, Eur. Phys. J. C **78**, 983 (2018).*

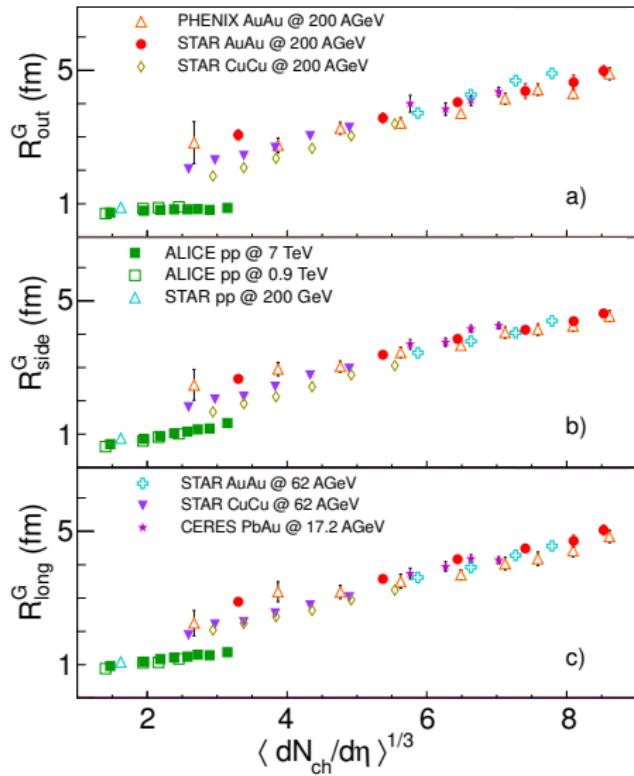


Expectations:

$$V \sim R_{\text{out}} R_{\text{side}} R_{\text{long}} \propto dN_{\text{ch}}/d\eta$$

Suggests:

$$R_i \propto (dN_{\text{ch}}/d\eta)^{1/3}$$



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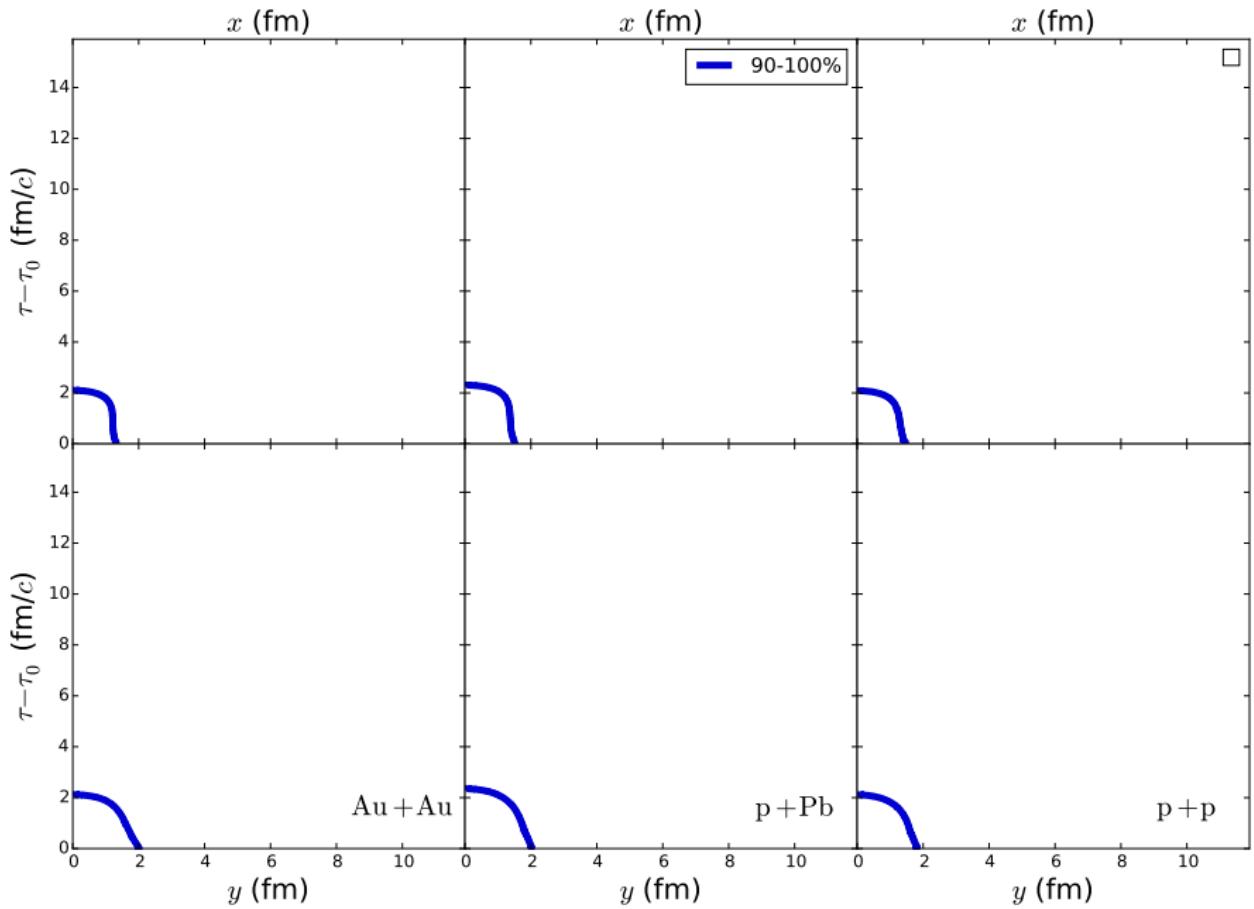
Suggests:

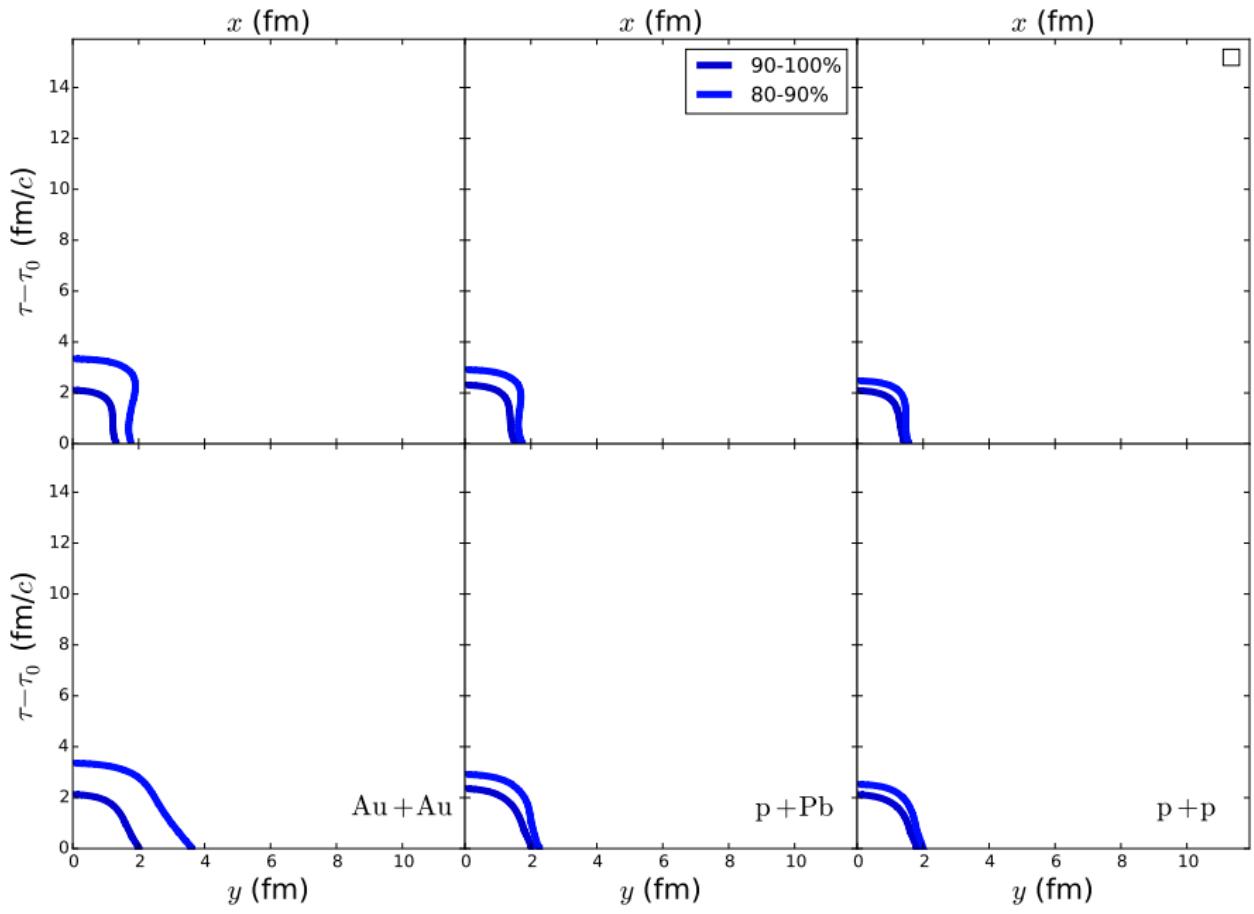
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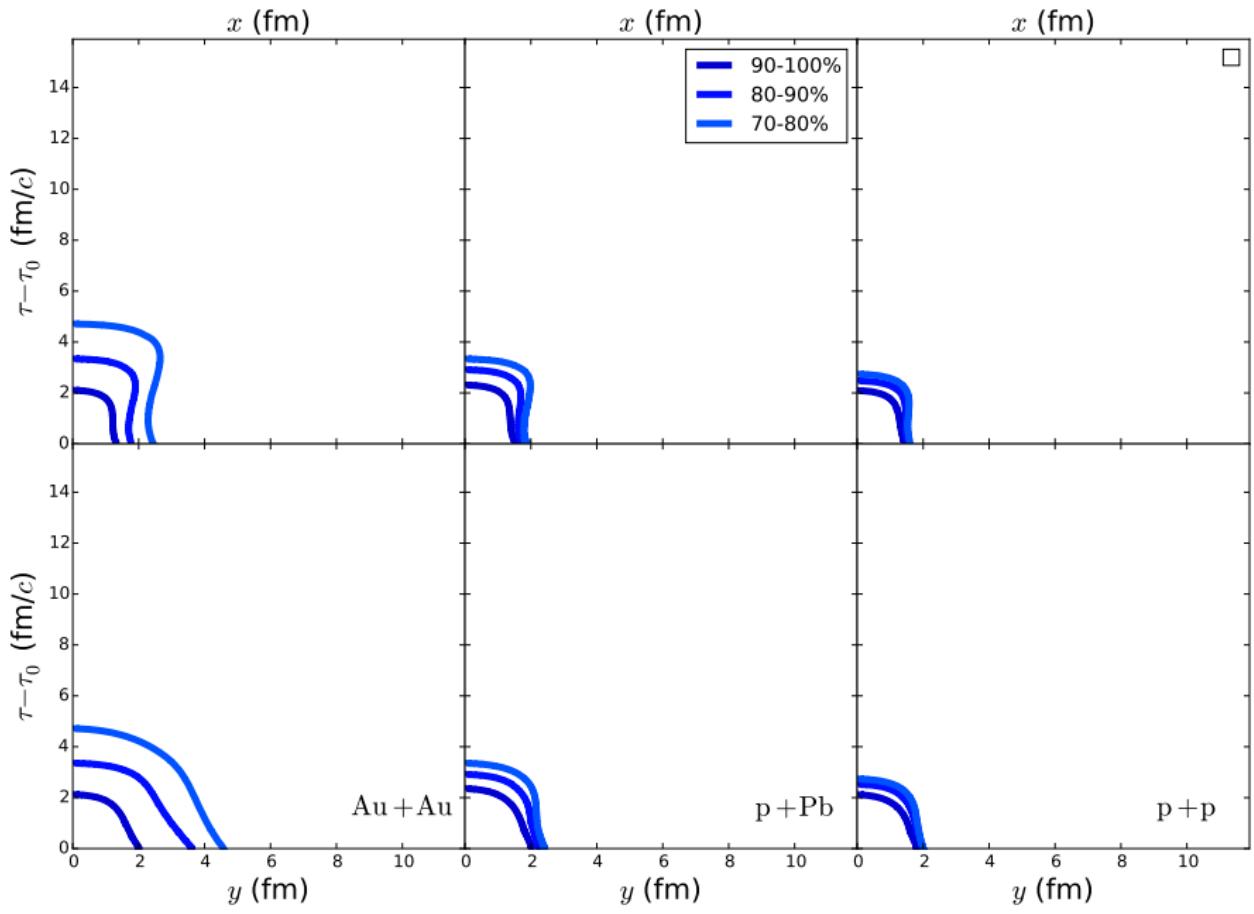
Observations:

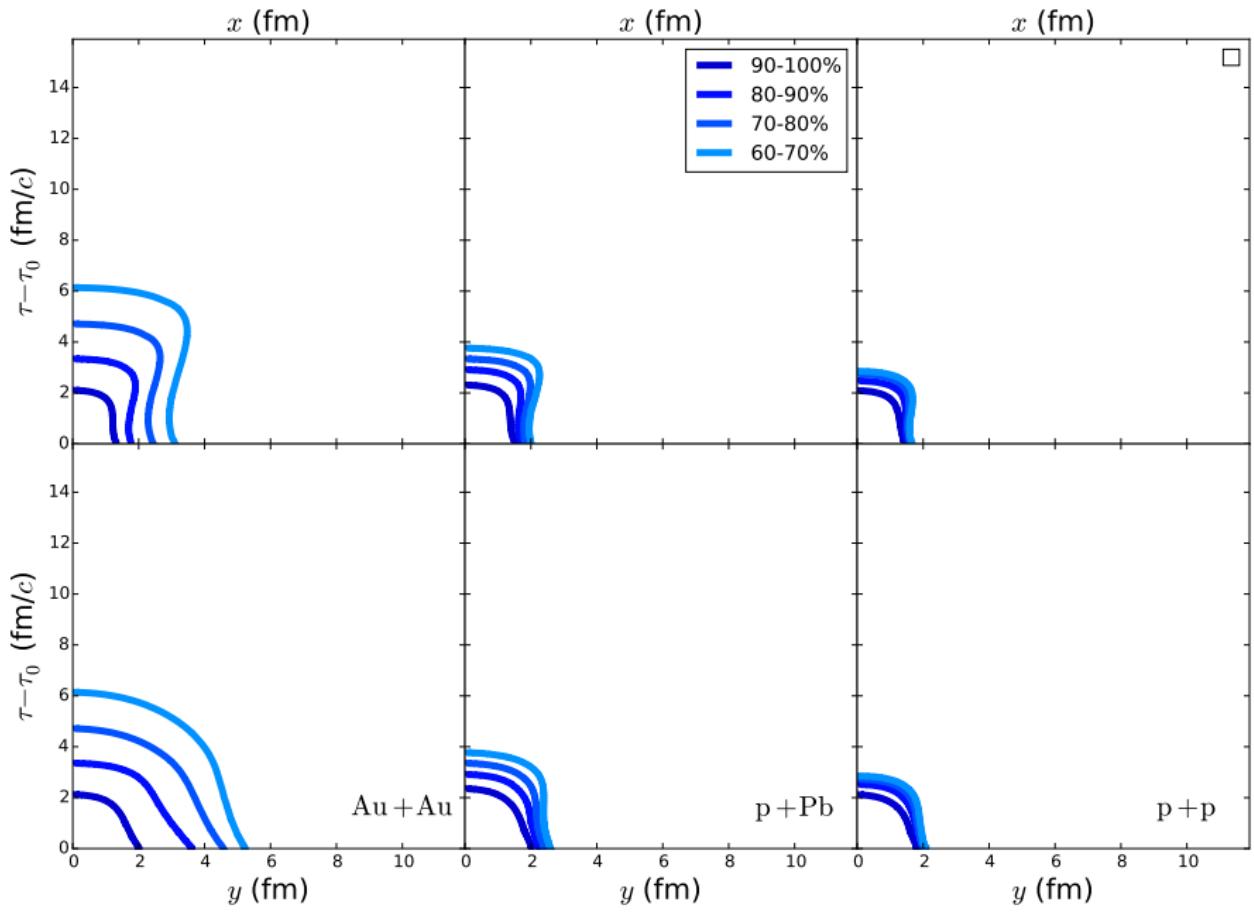
- ▶ Radii different in pp vs. AA
- ▶ Slopes different in pp vs. AA
- ▶ Slope for pp R_{out} less than for R_{side} , R_{long}

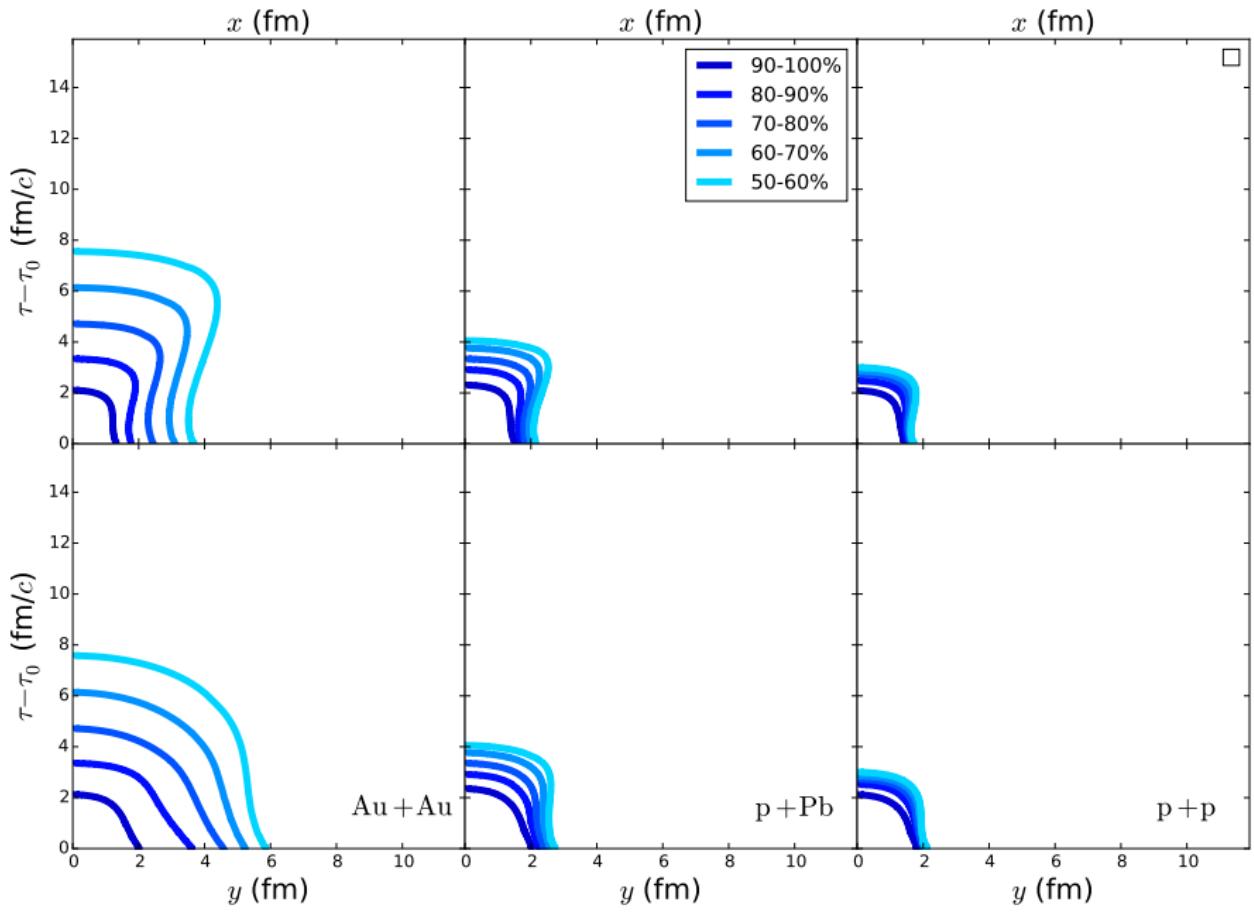
First: what kinds of geometries does hydrodynamics predict?

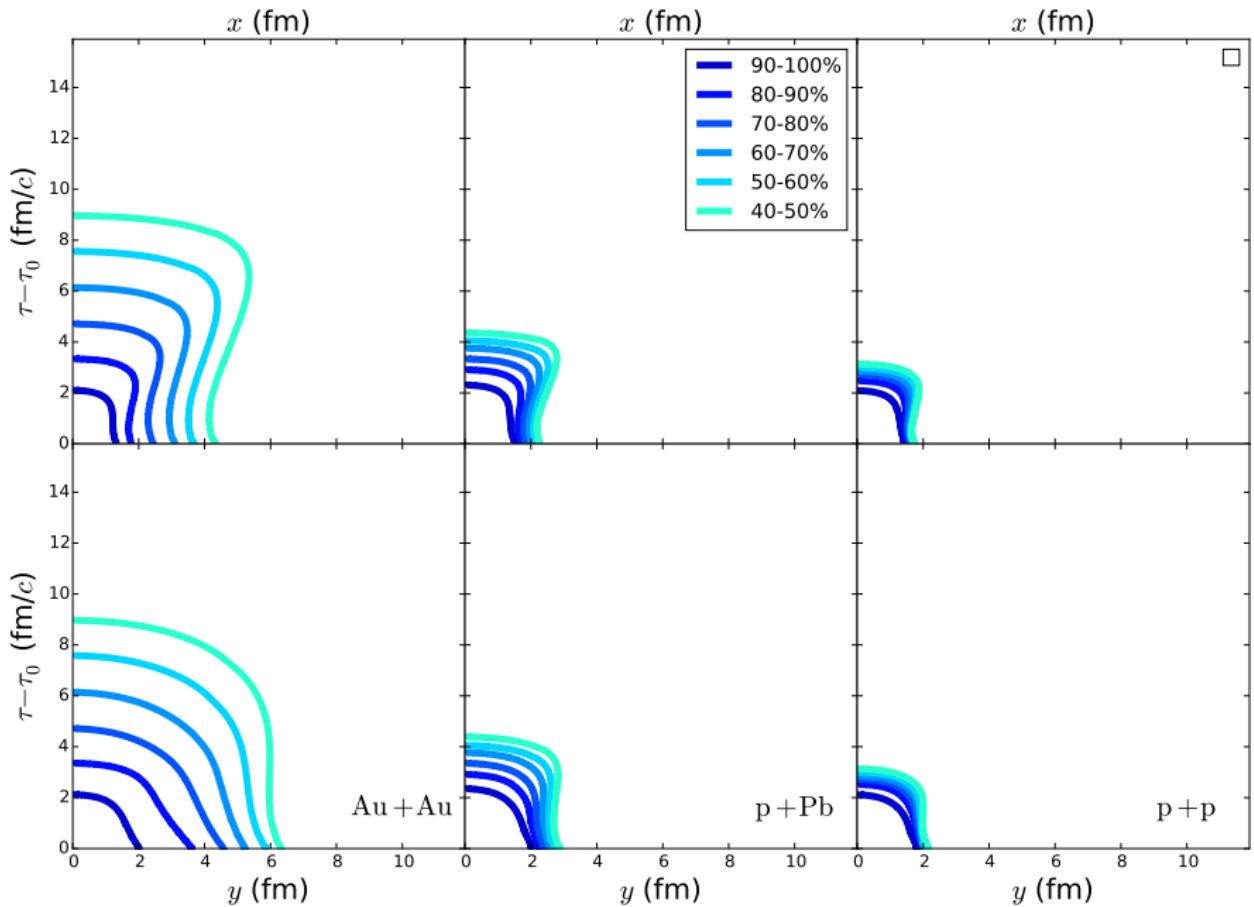


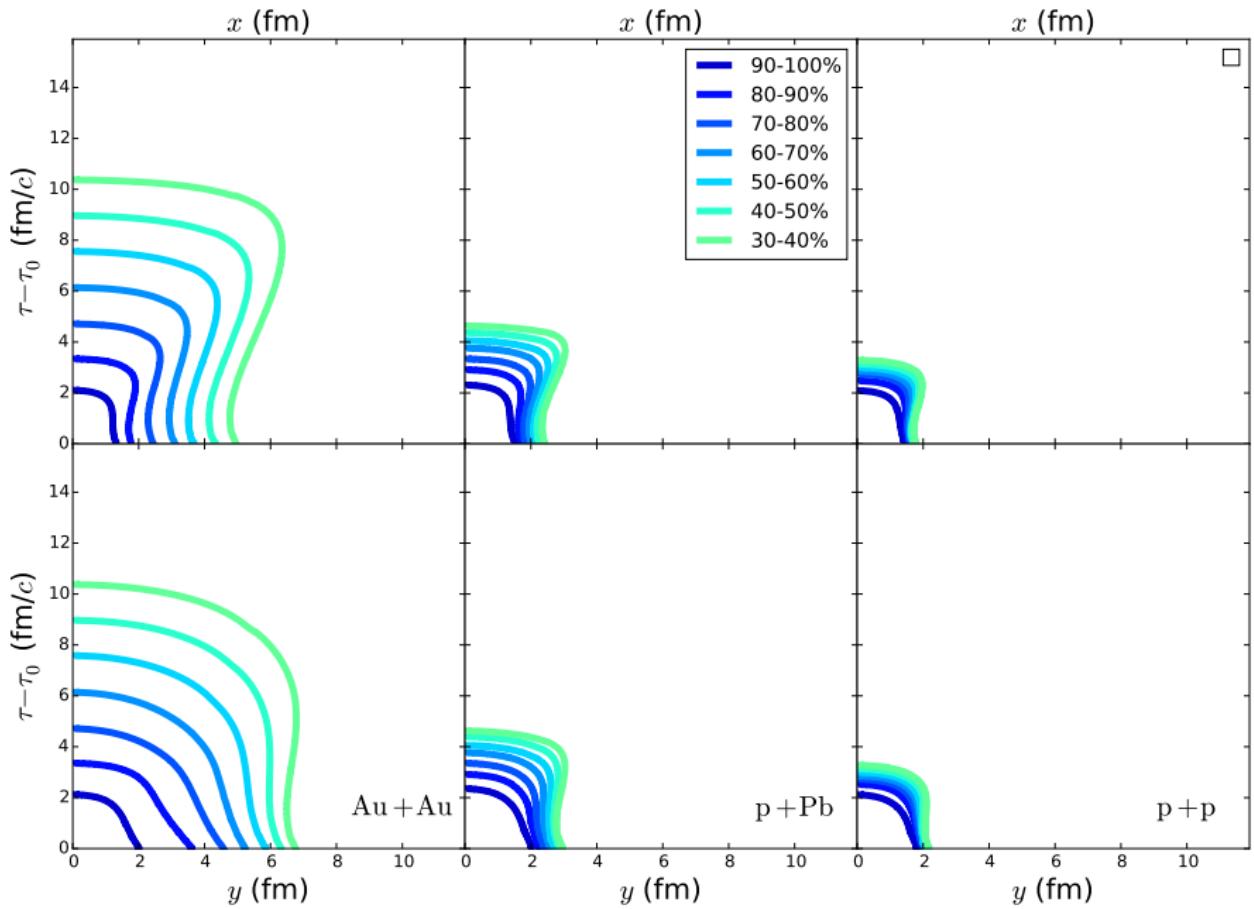


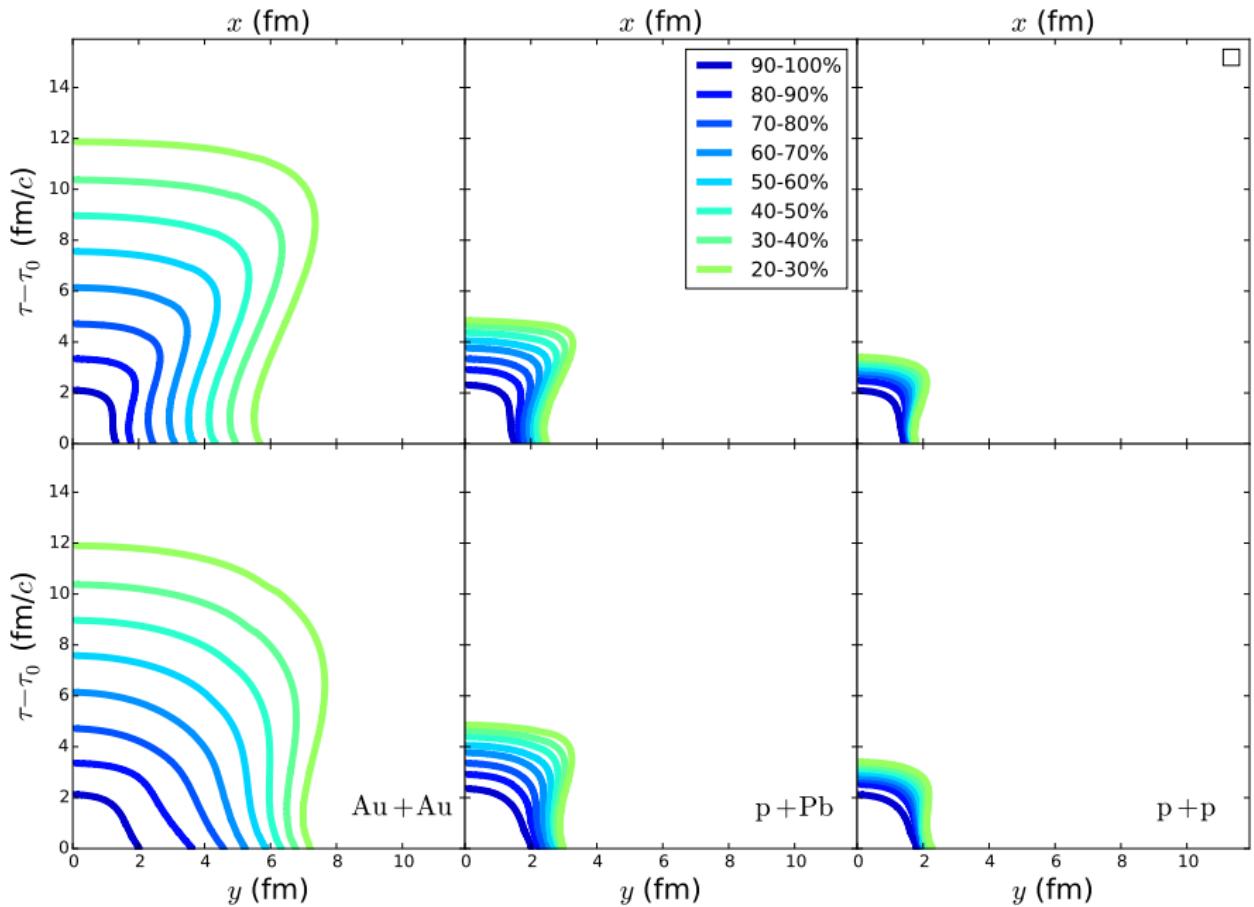


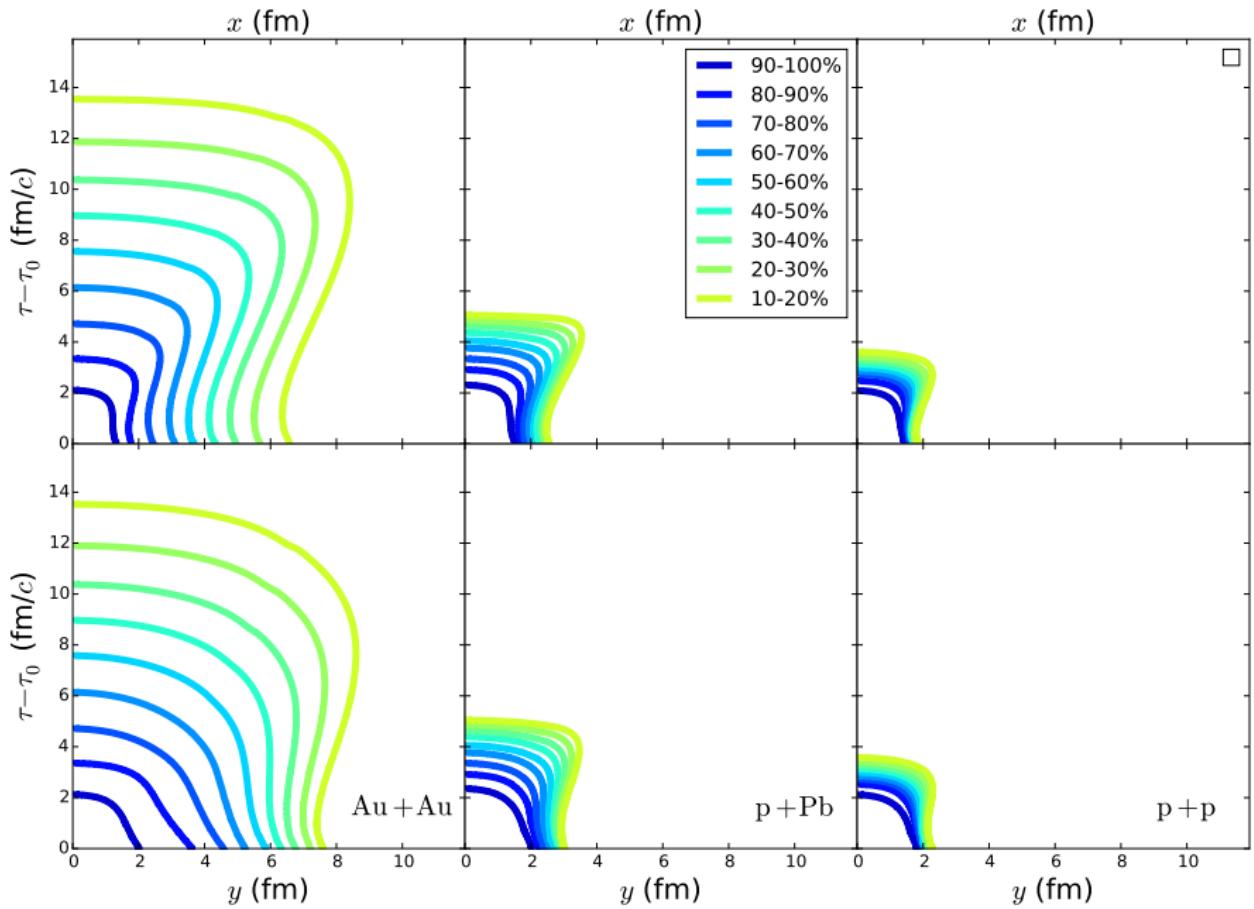


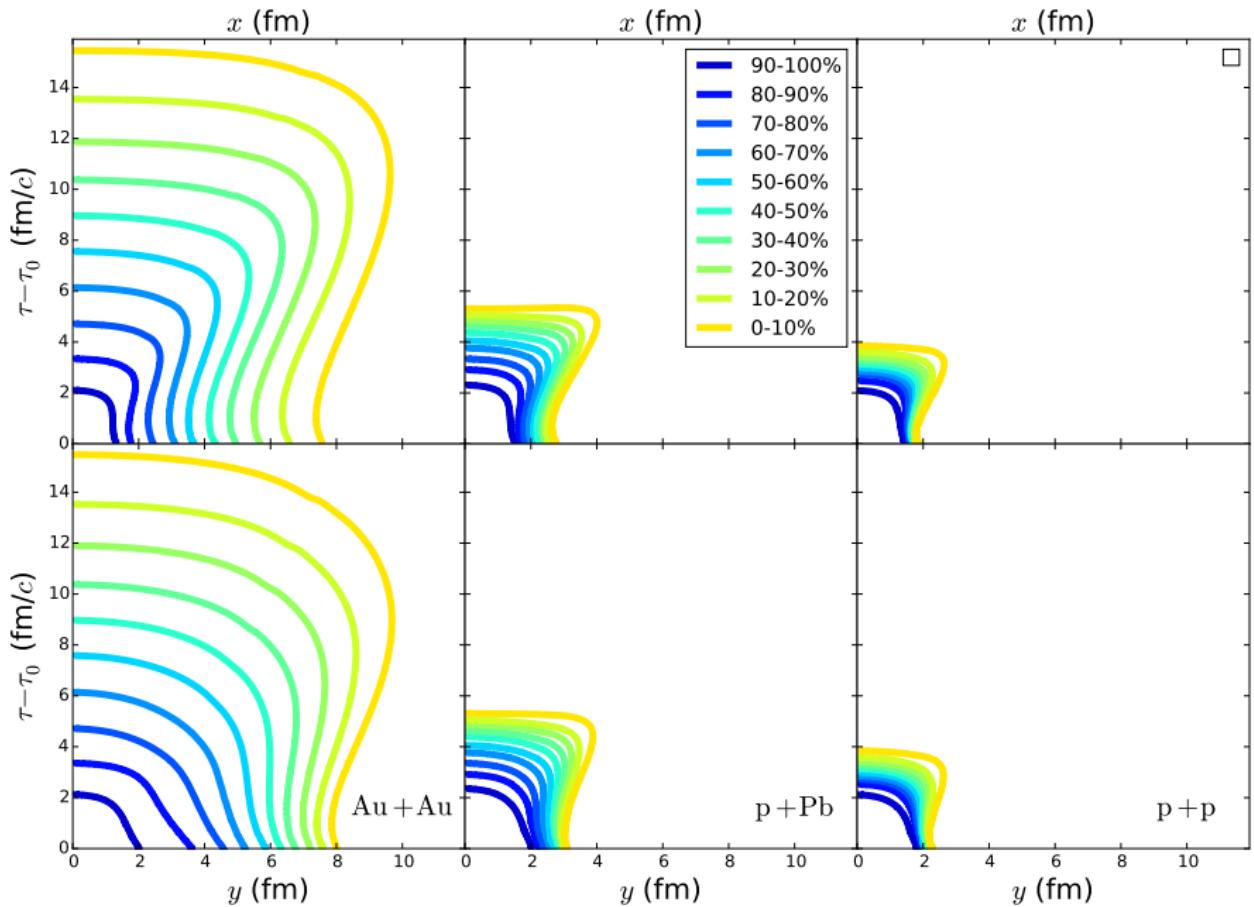


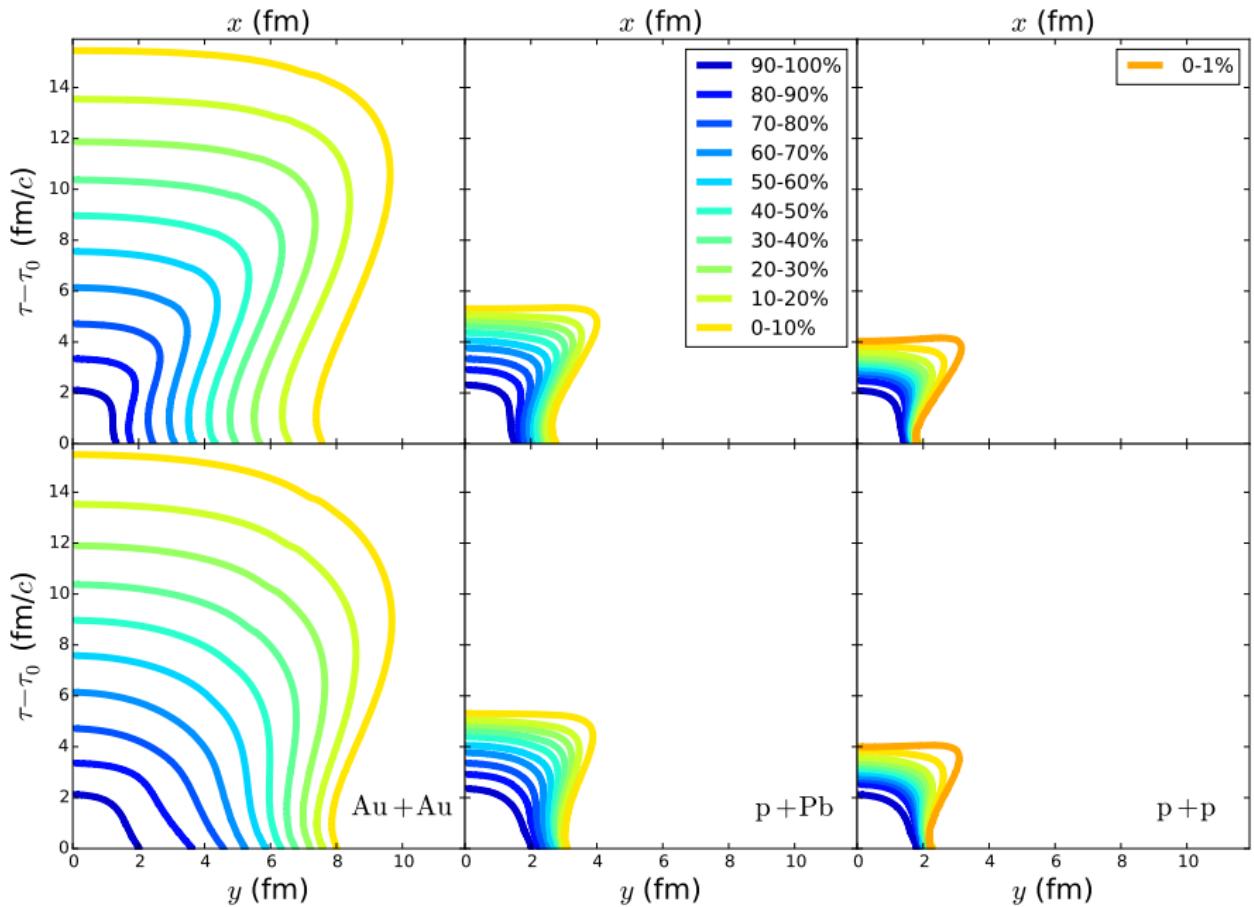


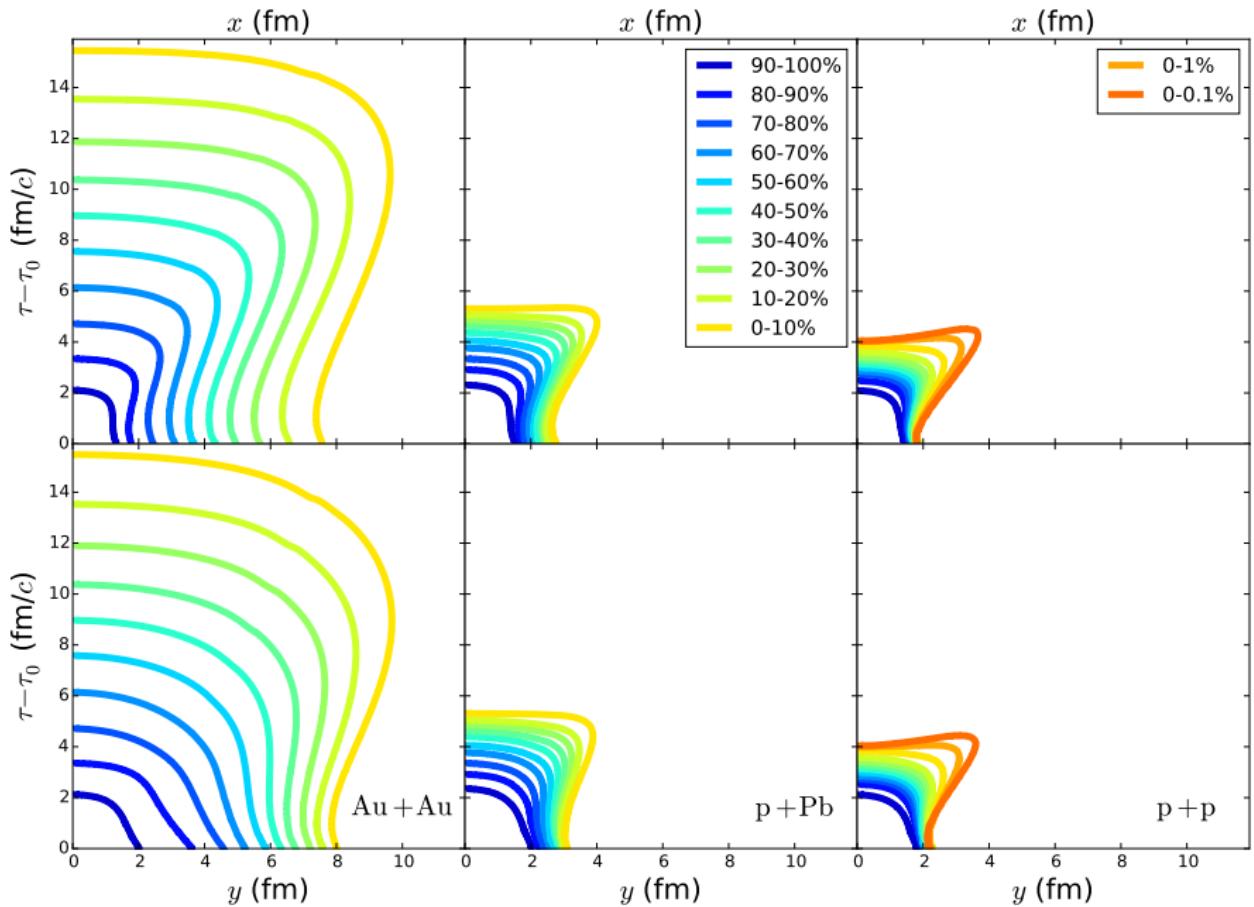


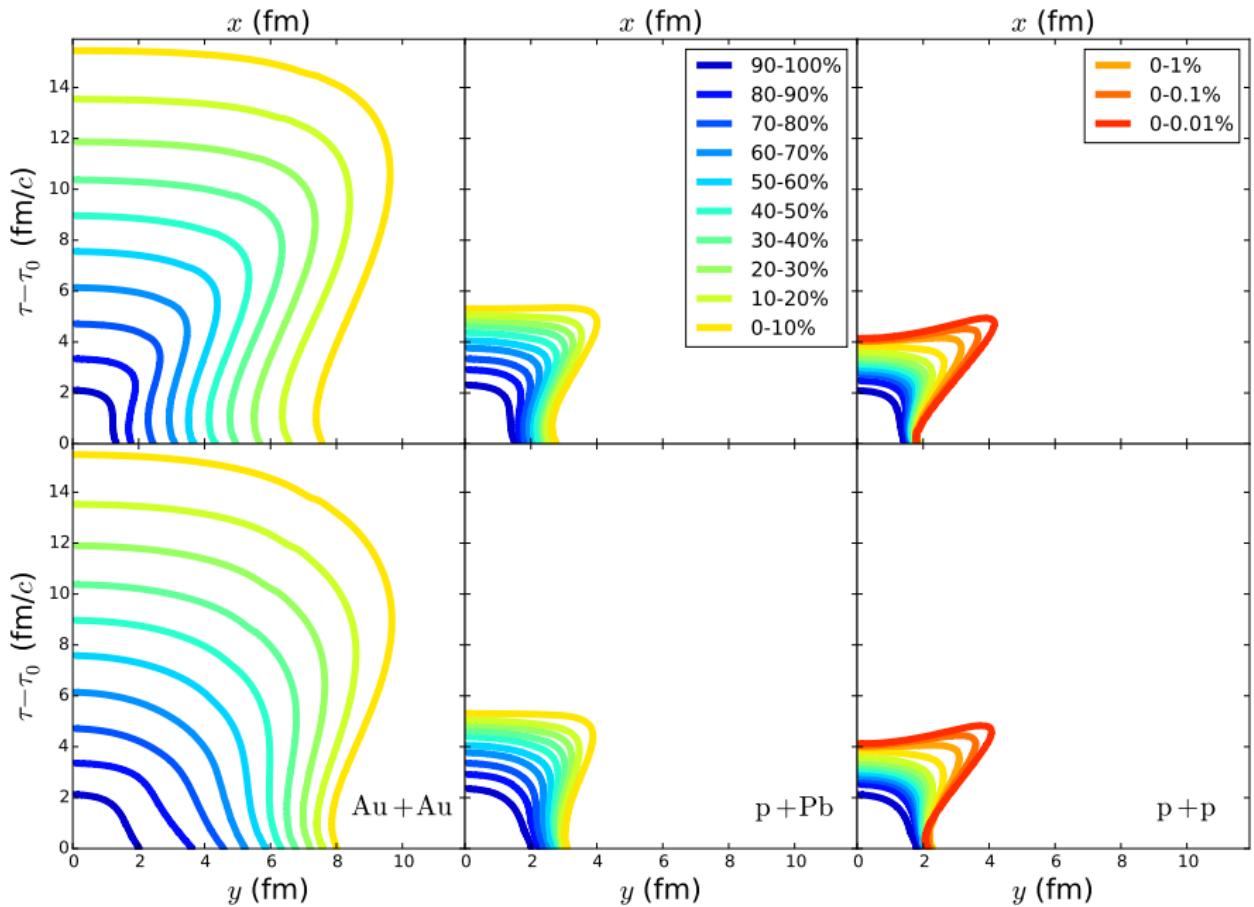


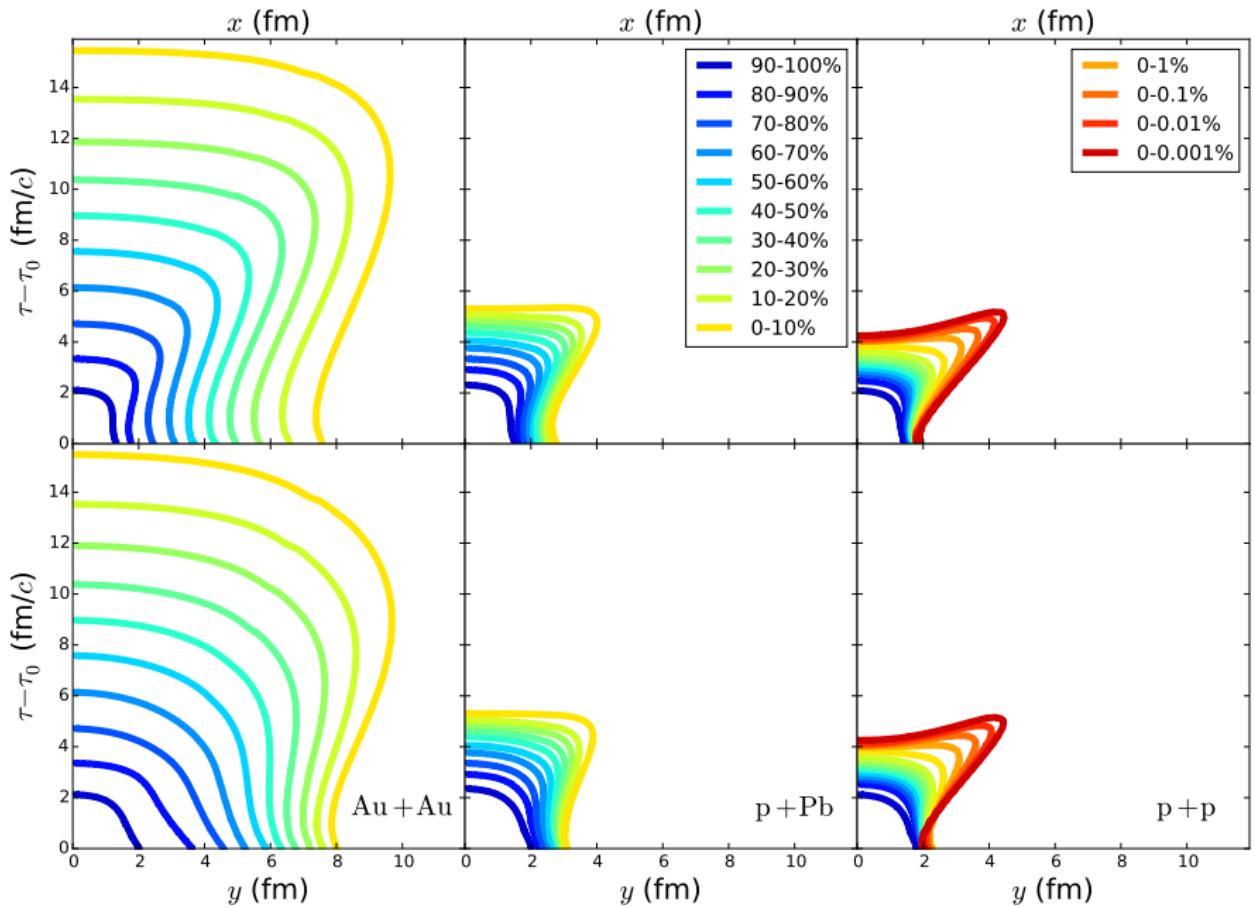


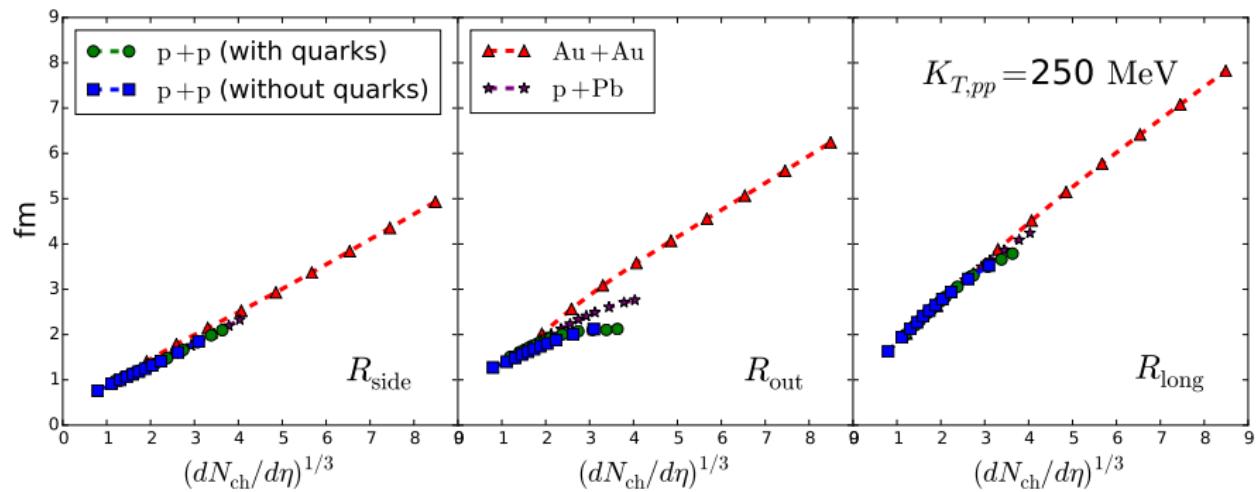


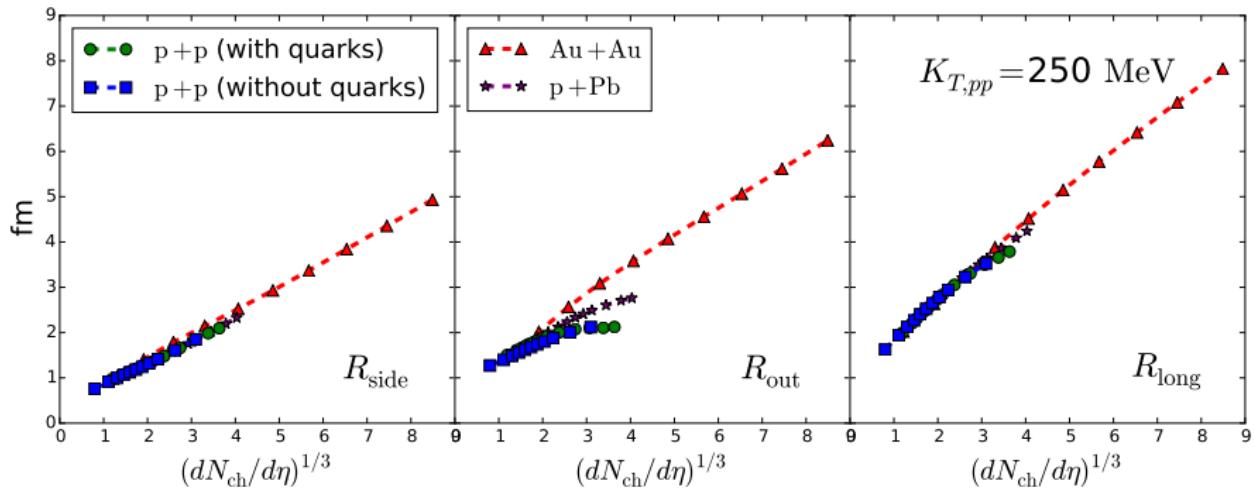










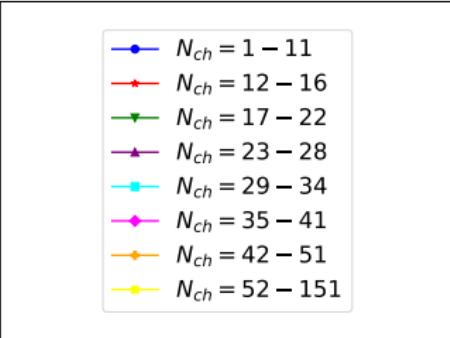
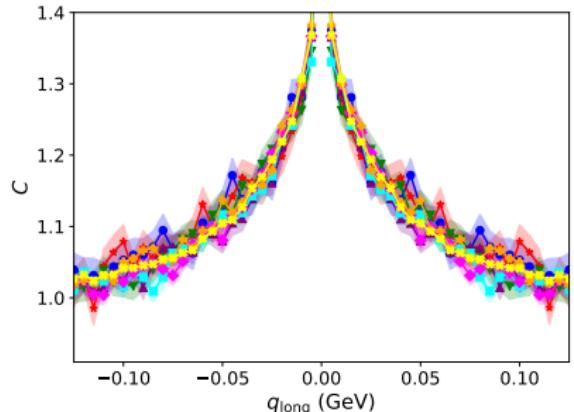
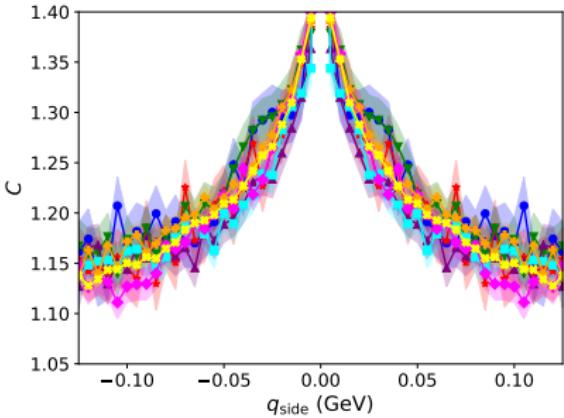
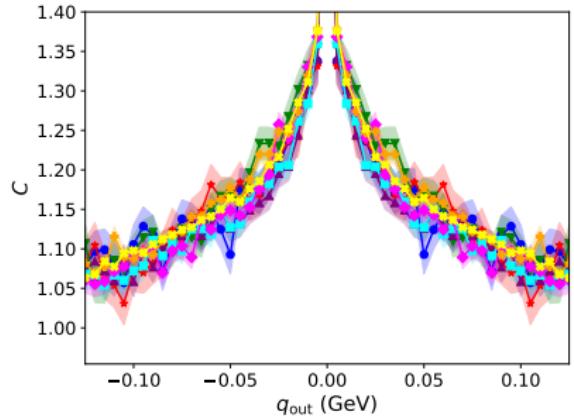


Overall, hydrodynamics compares fairly well:

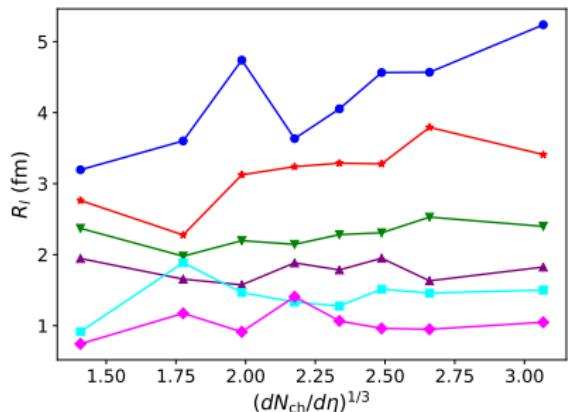
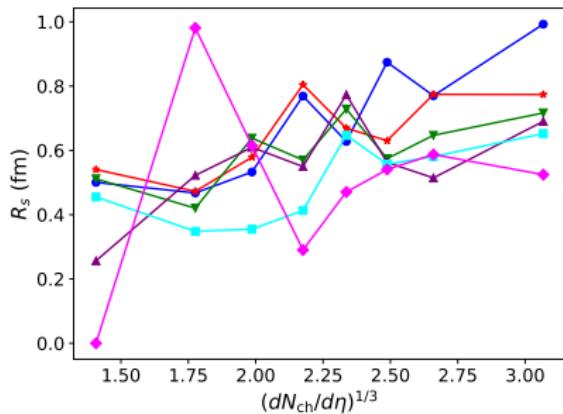
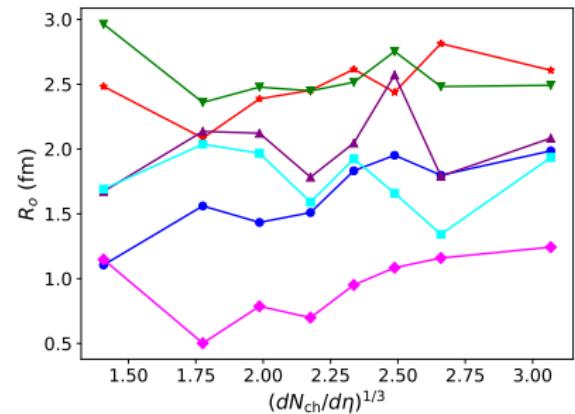
	System radii	System slopes	Slope hierarchy
R_{out}	✓	✓	✓
R_{side}	✗(?)	✓	✓(?)
R_{long}	✗(?)	✗(?)	✓(?)

Next: what does Pythia give?

Correlation functions vs. N_{ch} ($K_T = 0 - 100$ MeV)

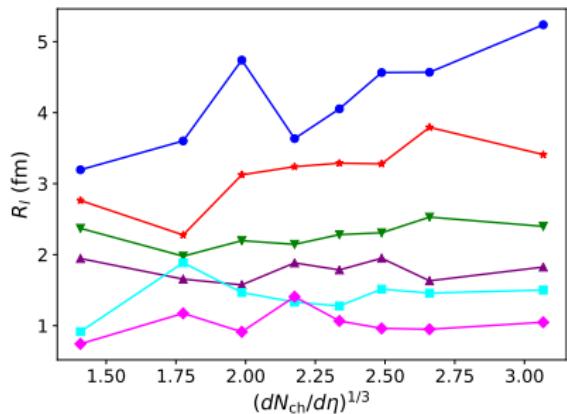
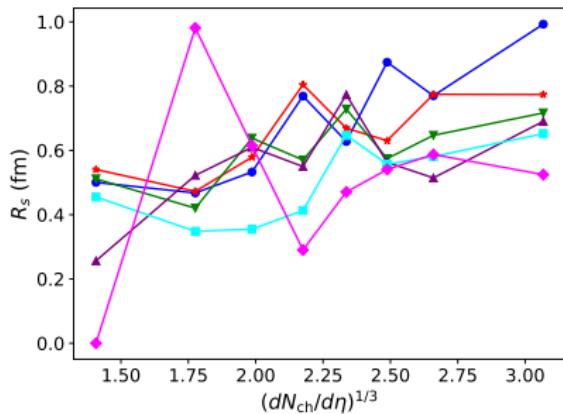
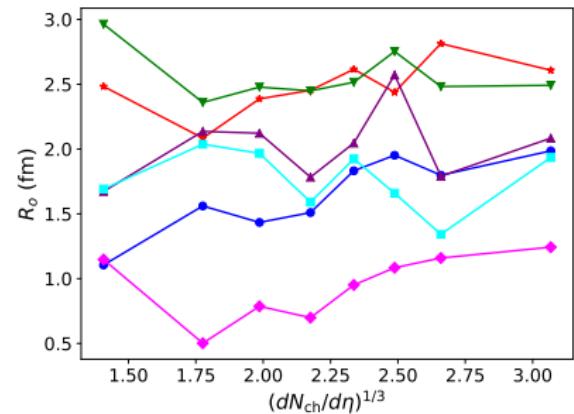


$R_i((dN_{\text{ch}}/d\eta)^{1/3})$ vs. K_T



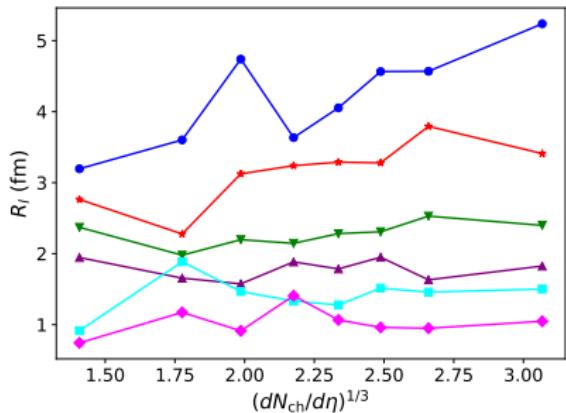
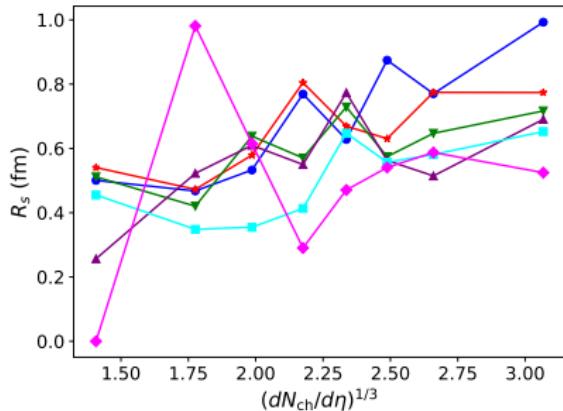
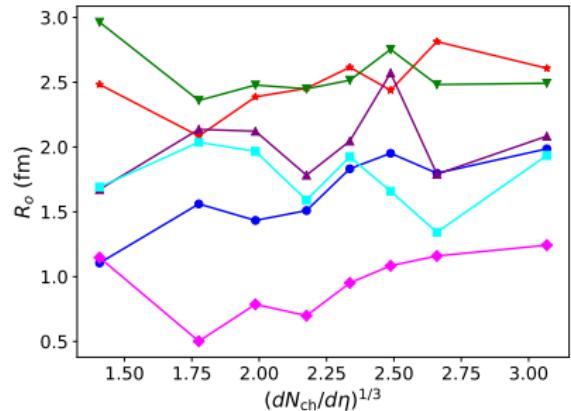
- $K_T = 0 - 100$ MeV
- $K_T = 100 - 200$ MeV
- $K_T = 200 - 300$ MeV
- $K_T = 300 - 400$ MeV
- $K_T = 400 - 500$ MeV
- $K_T = 500 - 600$ MeV

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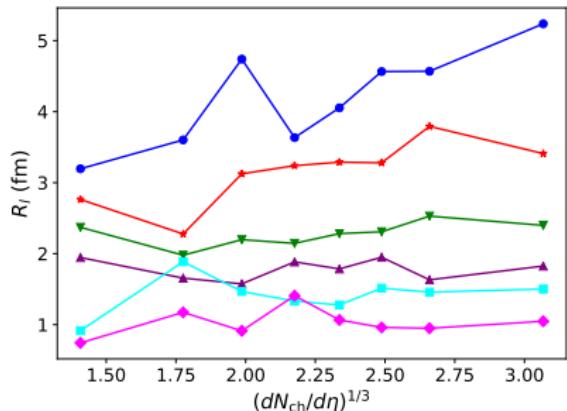
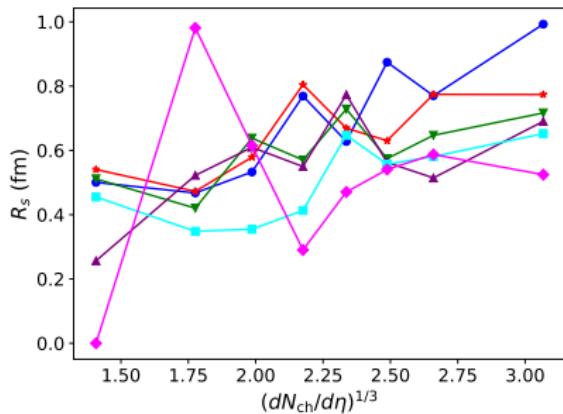
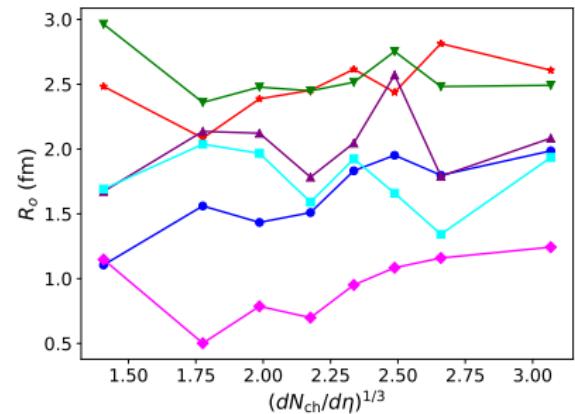
- ▶ R_o, R_l show mild K_T dependence

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$R_i((dN_{\text{ch}}/d\eta)^{1/3})$ vs. K_T



- ▶ R_o, R_l show mild K_T dependence
- ▶ R_s mostly independent of K_T
- ▶ Slopes generally close to zero

Conclusions (I)

- ▶ Data show non-trivial hierarchy of $dN_{\text{ch}}/d\eta$ -scaling in p+p R_o^2 as compared with R_s^2 , R_l^2
- ▶ Same feature is *not* present in Au+Au

Conclusions (I)

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- ▶ Hydrodynamics generates this hierarchy automatically:
 - Small systems have much stronger collective flow than large systems
 - Flow generates *very* different geometries for different systems at same multiplicity

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- ▶ Same feature is *not* present in Au+Au
- ▶ Hydrodynamics generates this hierarchy automatically:
 - Small systems have much stronger collective flow than large systems
 - Flow generates *very* different geometries for different systems at same multiplicity
- ▶ Pythia may also reproduce observed hierarchy
 - Better statistics needed
 - Agreement likely to improve with inclusion of collective dynamics

Conclusions (II)

Ongoing work:

- ▶ Hydrodynamics
 - Add initial-state fluctuations
 - Include viscosities
 - Incorporate hadronic rescattering
- ▶ Pythia
 - Complete similar analyses for p+Pb and Pb+Pb systems
 - Improve pair statistics
 - Explore effects of string shoving, hadronic rescattering, etc.



Conclusions (II)

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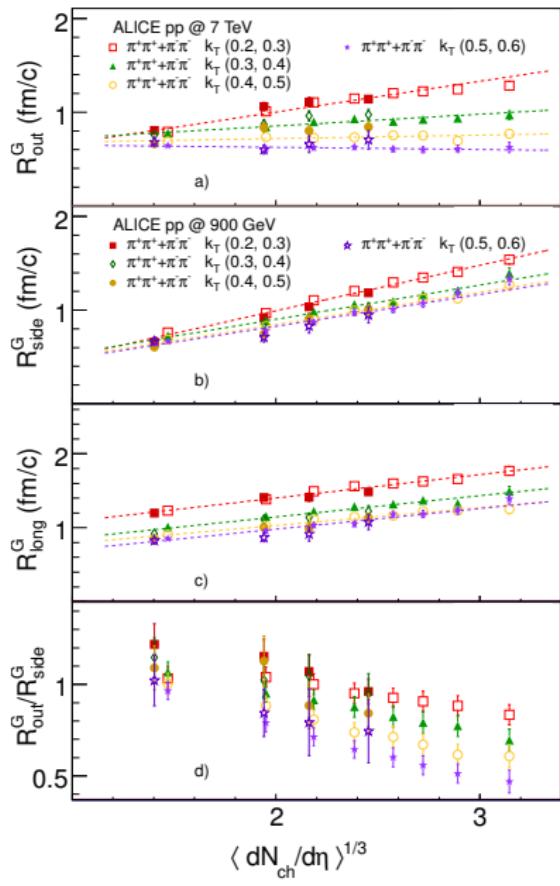
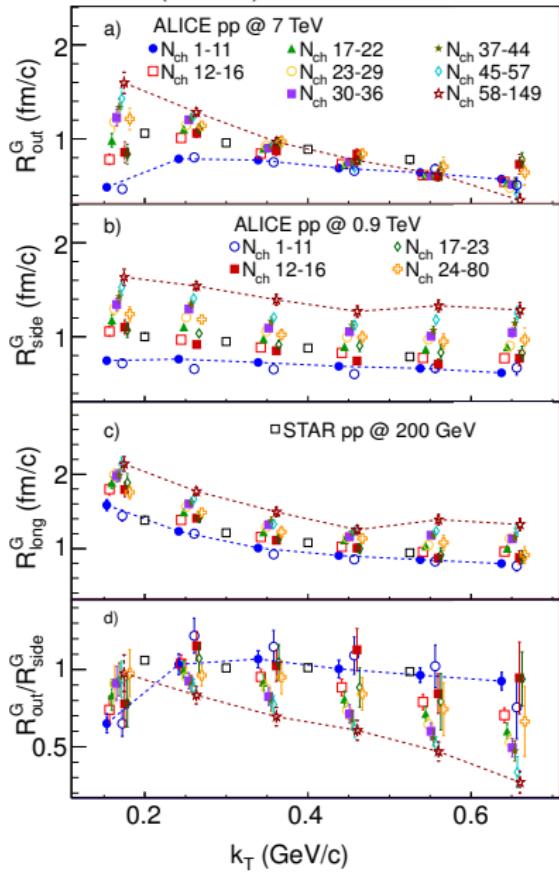
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Thanks!

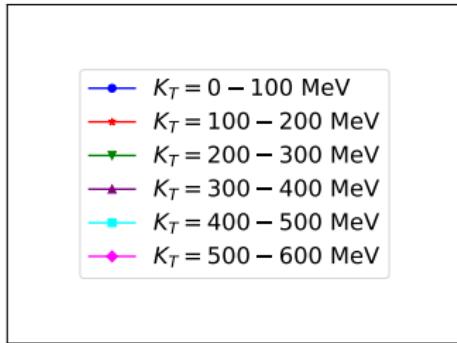
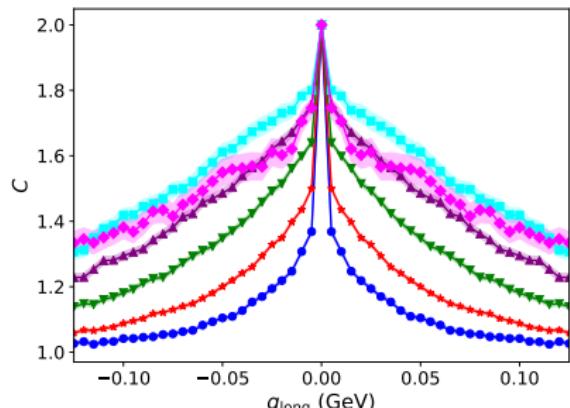
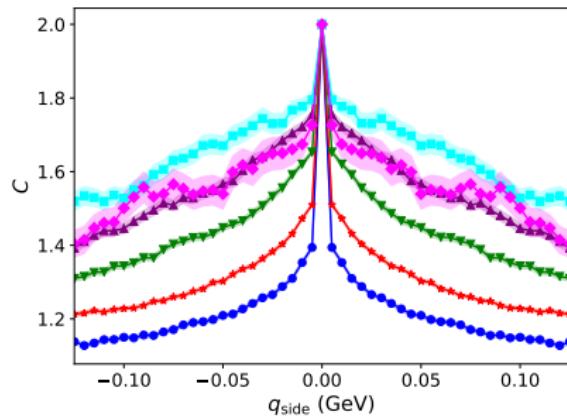
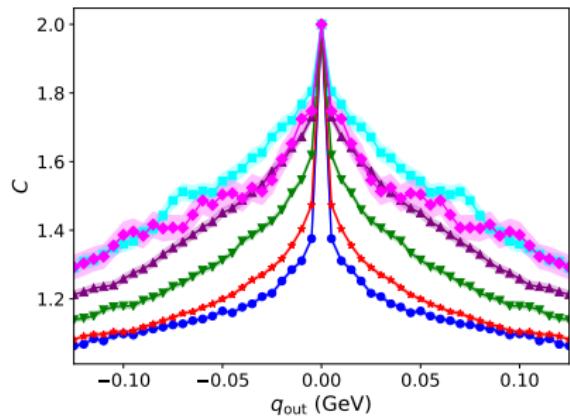


Backup slides

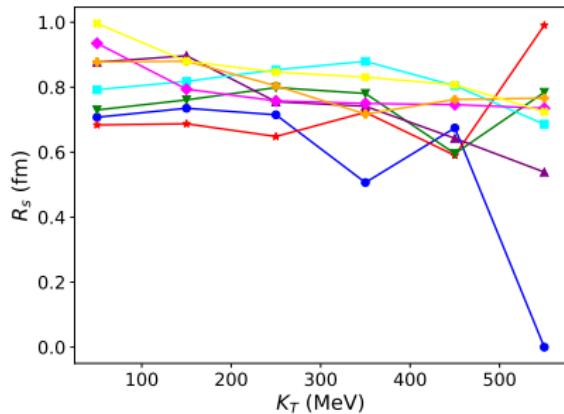
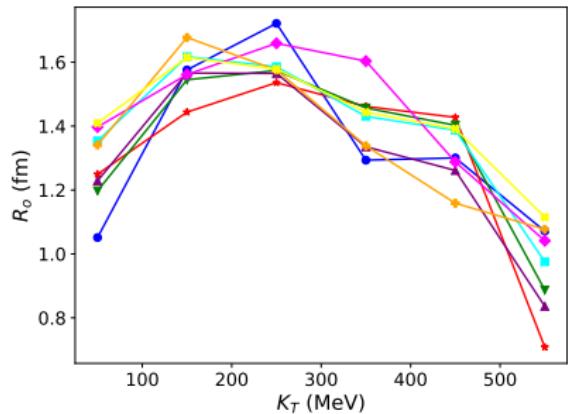
ALICE (2011)



Pythia: Correlation functions vs. K_T



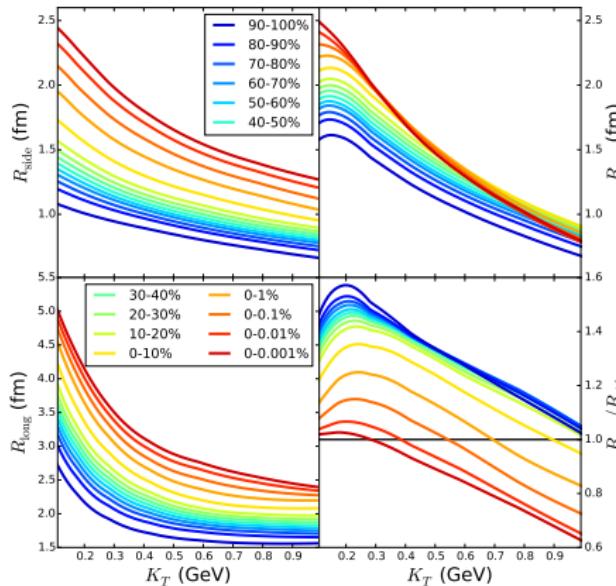
Pythia: $R_i(K_T)$ vs. N_{ch}



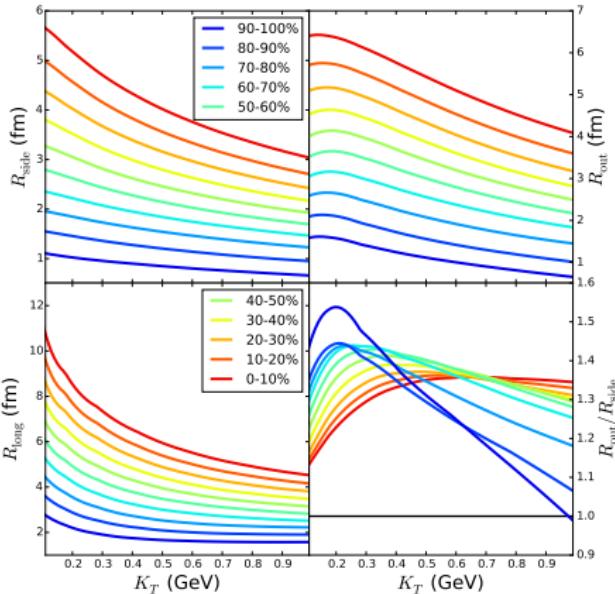
\bullet	$N_{ch} = 1 - 11$
\bullet	$N_{ch} = 12 - 16$
\blacktriangleleft	$N_{ch} = 17 - 22$
\blacktriangleright	$N_{ch} = 23 - 28$
\square	$N_{ch} = 29 - 34$
\blacktriangledown	$N_{ch} = 35 - 41$
\blacktriangle	$N_{ch} = 42 - 51$
\blacktriangleright	$N_{ch} = 52 - 151$

Hydrodynamics

p+p



Au+Au



Generic consequences of strong collective flow:

- ▶ K_T -scaling
- ▶ Possibility of $R_o^2/R_s^2 < 1$

Hydrodynamics

p + p (with quarks)

