To Be Collective or Not to Be Collective

Jamie Nagle, Darren McGlinchey, Javier Orjuela Koop
University of Colorado

QUARK MATTER 2015
The XXVth International Conference on Ultrarelativistic Nucleus-Nucleus Collisions

Hydrodynamics (SONIC) in Small Systems

Exploiting Intrinsic Triangular Geometry in Relativistic ^{3}He + Au Collisions to Disentangle Medium Properties

J. L. Nagle,[1,*] A. Adare,[1] S. Beckman,[1] T. Koblesky,[1] J. Orjuela Koop,[1] D. McGlinchey,[1] P. Romatschke,[1] J. Carlson,[2] J. E. Lynn,[2] and M. McCumber[2]
[1]*University of Colorado at Boulder, Boulder, Colorado 80309, USA*
[2]*Los Alamos National Laboratory,Los Alamos, New Mexico 87545, USA*
(Received 20 December 2013; revised manuscript received 27 June 2014; published 12 September 2014)

http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.113.112301

Parton Cascade (AMPT) in Small Systems

Azimuthal Anisotropy Relative to the Participant Plane from AMPT in Central p+Au, d+Au, and ^{3}He+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV

J.D. Orjuela Koop, A. Adare, D. McGlinchey, J.L. Nagle[1]
[1]*University of Colorado, Boulder*
(Dated: July 30, 2015)

http://arxiv.org/abs/1501.06880

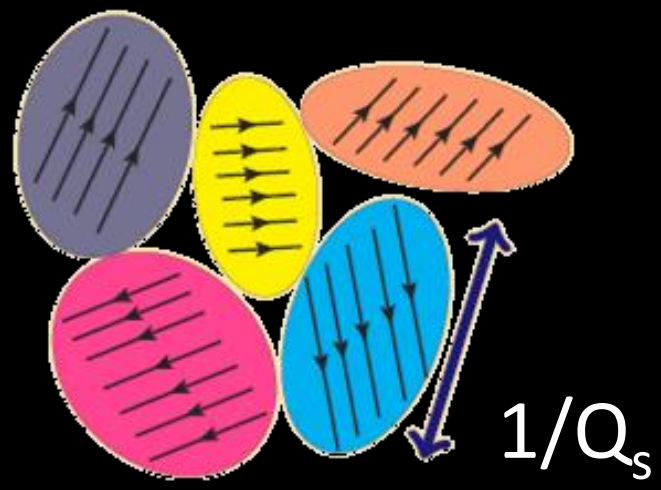
Useful inputs from Zi-Wei Lin and Denes Molnar

AMPT motivation, He *et al.* (arXiv:1502.05572v3)

Initial Momentum or Geometry Correlations

Initial State QCD Physics

Non-Geometry correlations directly in momentum space



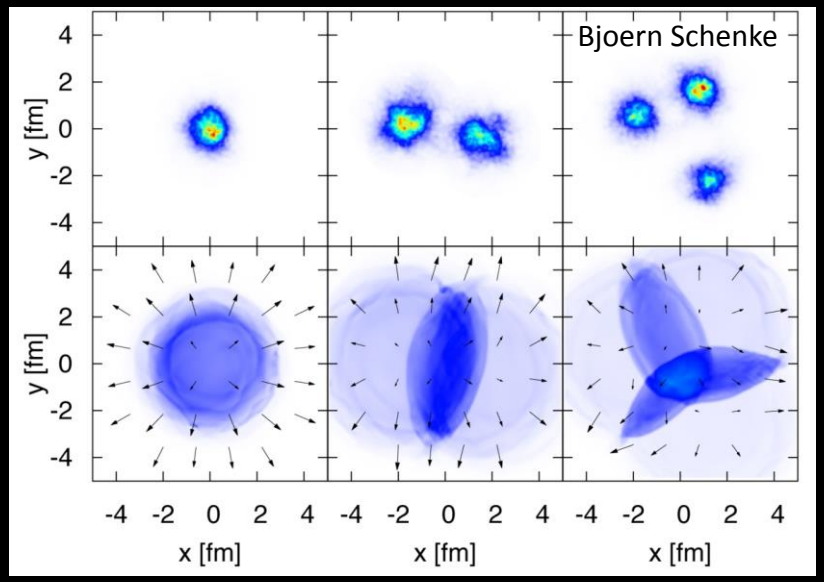
$$\text{Correlation} \sim \frac{1}{N_c^2 Q_s^2 S_\perp}$$

Important in small systems!

Not published…

$v_2(pAu) > v_2(d,{}^3HeAu)$

Initial Geometry rules

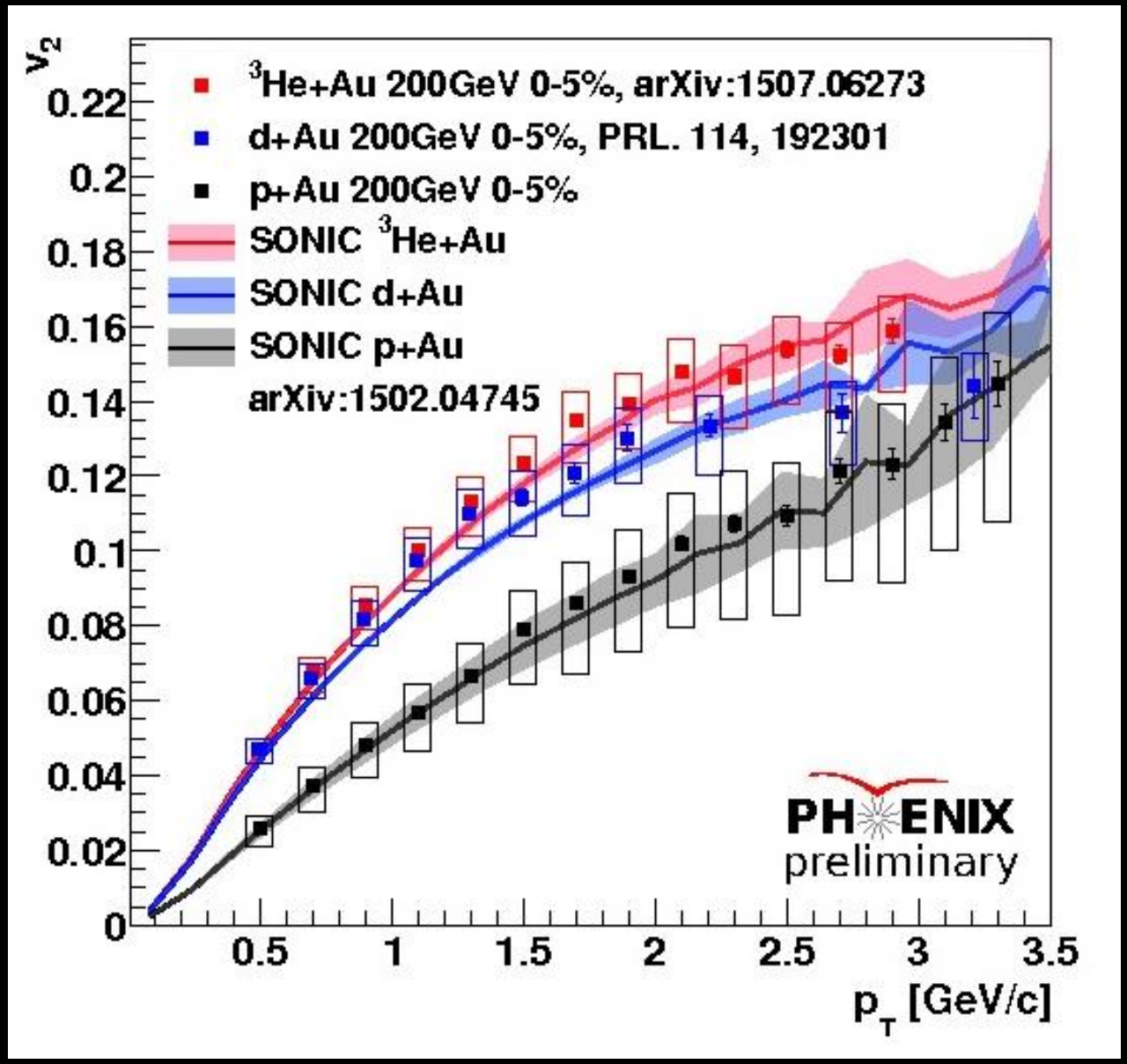


Hydrodynamics is one model for final-state interactions

Published predictions

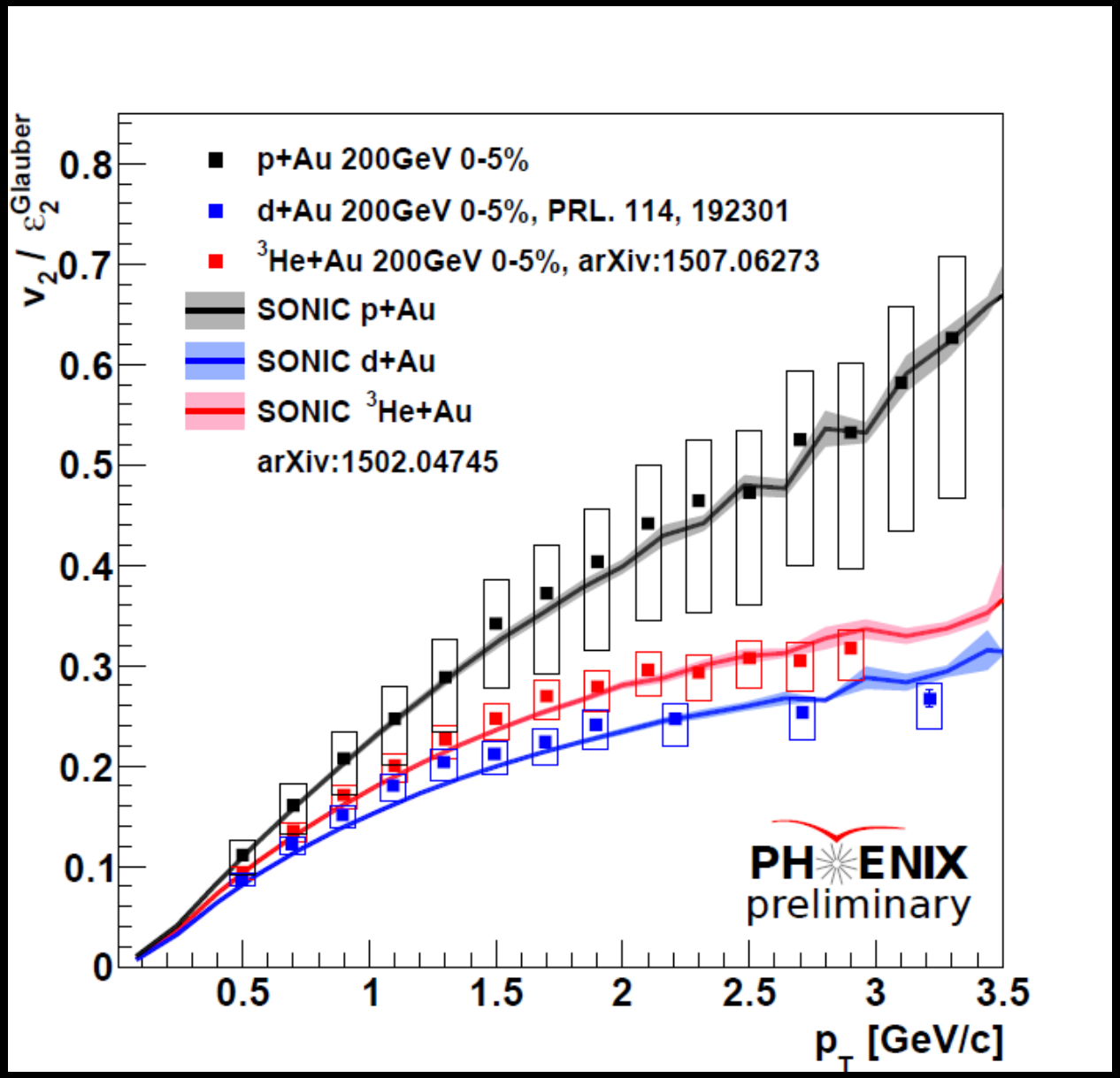
$v_2({}^3HeAu) \sim v_2(dAu) > v_2(pAu)$

Glauber +Hydrodynamics+Cascade Predictions

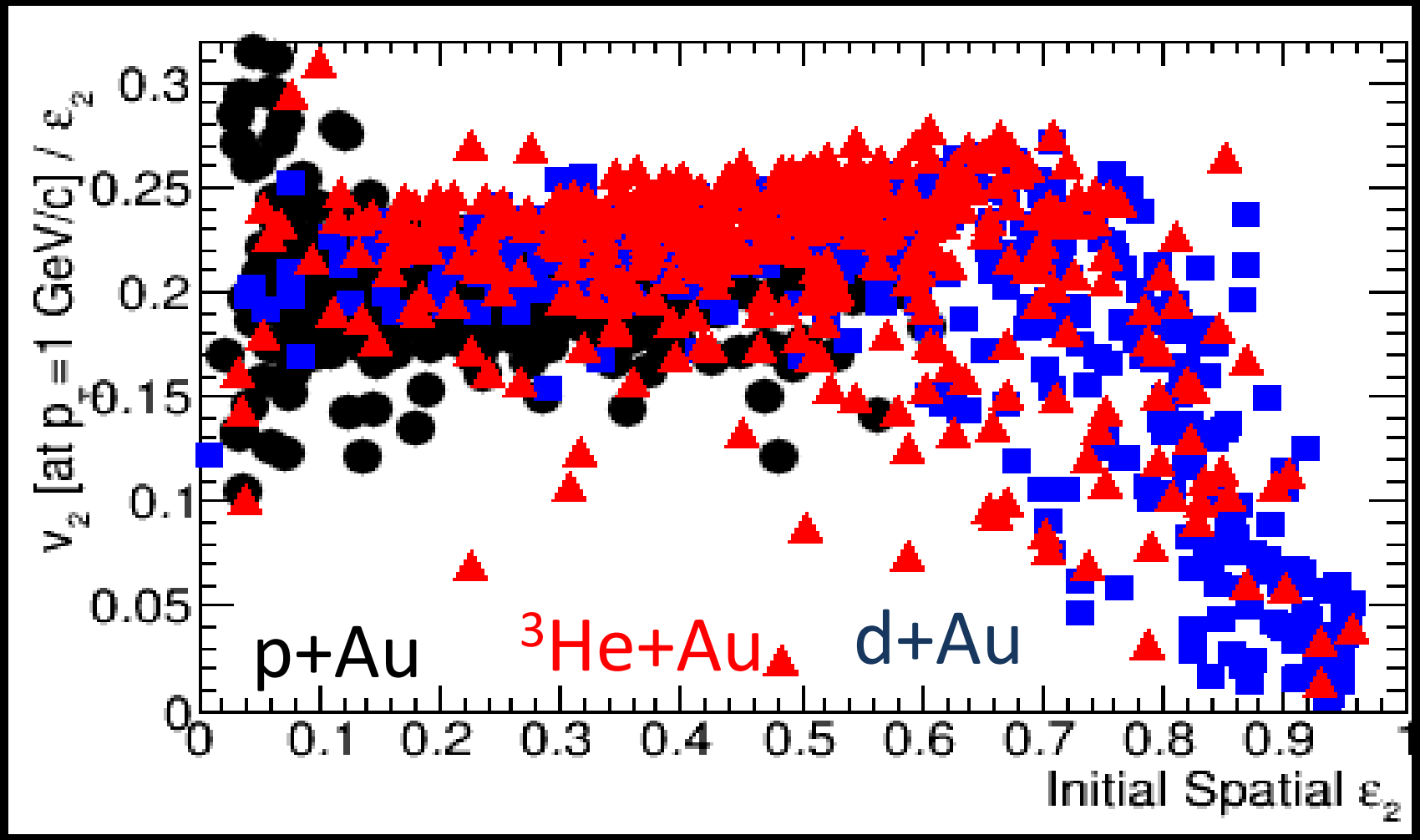


Romatschke, Nagle et al. , http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.113.112301

No Simple Eccentricity Scaling



No Simple Eccentricity Scaling

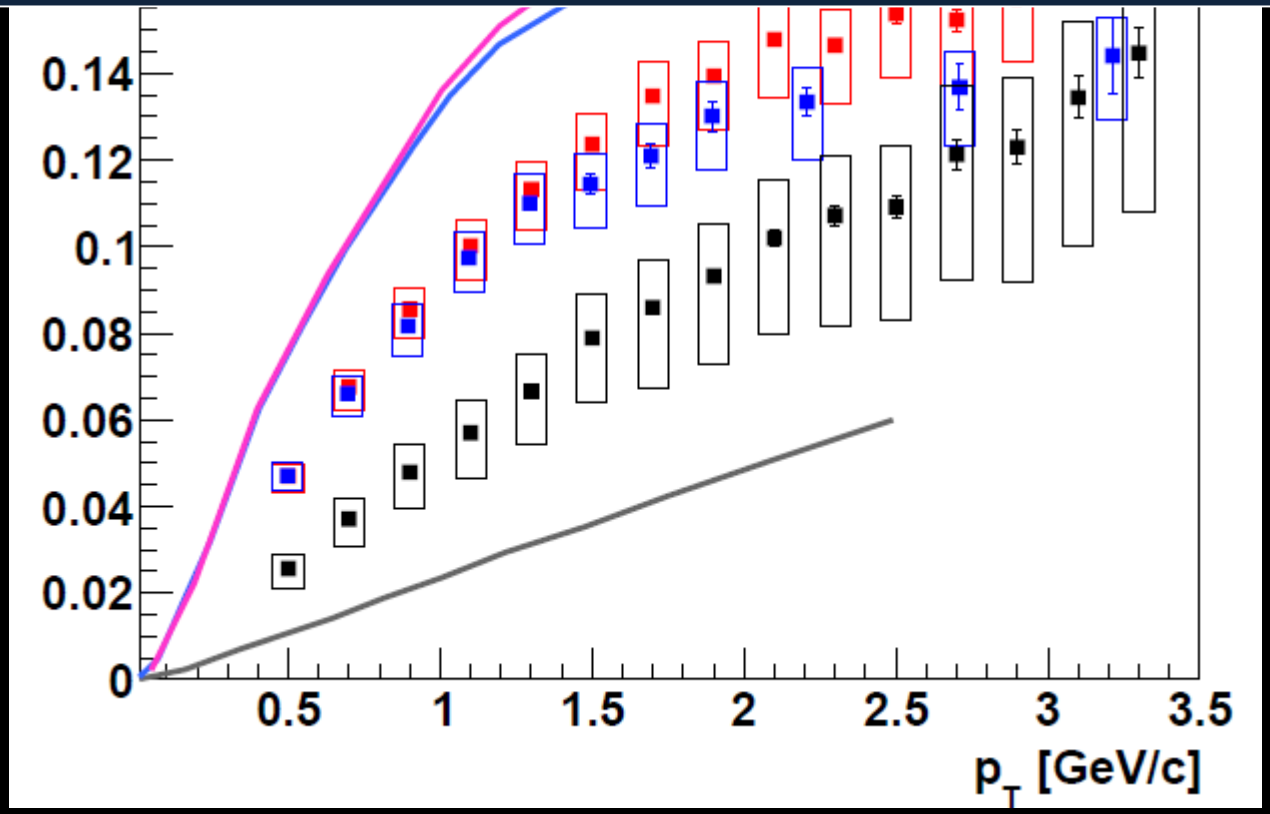


^{3}He/d+Au – some events hot spots never connect and so $\varepsilon_2 \rightarrow v_2$ translation incomplete

IP Glasma+Hydrodynamics Predictions

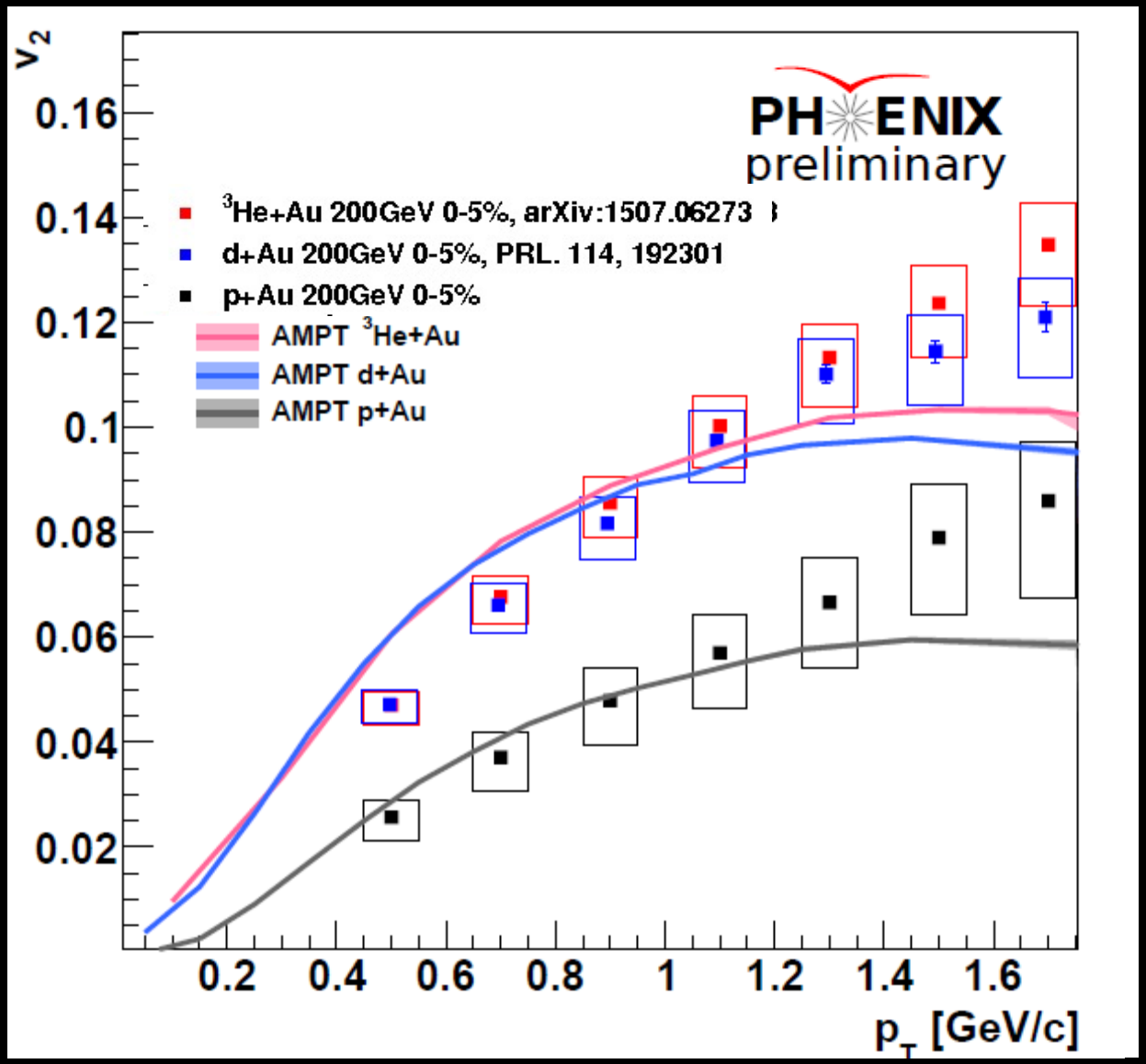
With larger η/s, one can match ^{3}He/d+Au.

p+A is because initial ε_2 is very small.
Possible solution is giving proton more substructure



Schenke, Venugopalan, http://www.sciencedirect.com/science/article/pii/S0375947414003522

AMPT Predictions



Modified Initial Glauber including ^{3}He wavefunction (same I.C. as SONIC)

String melting

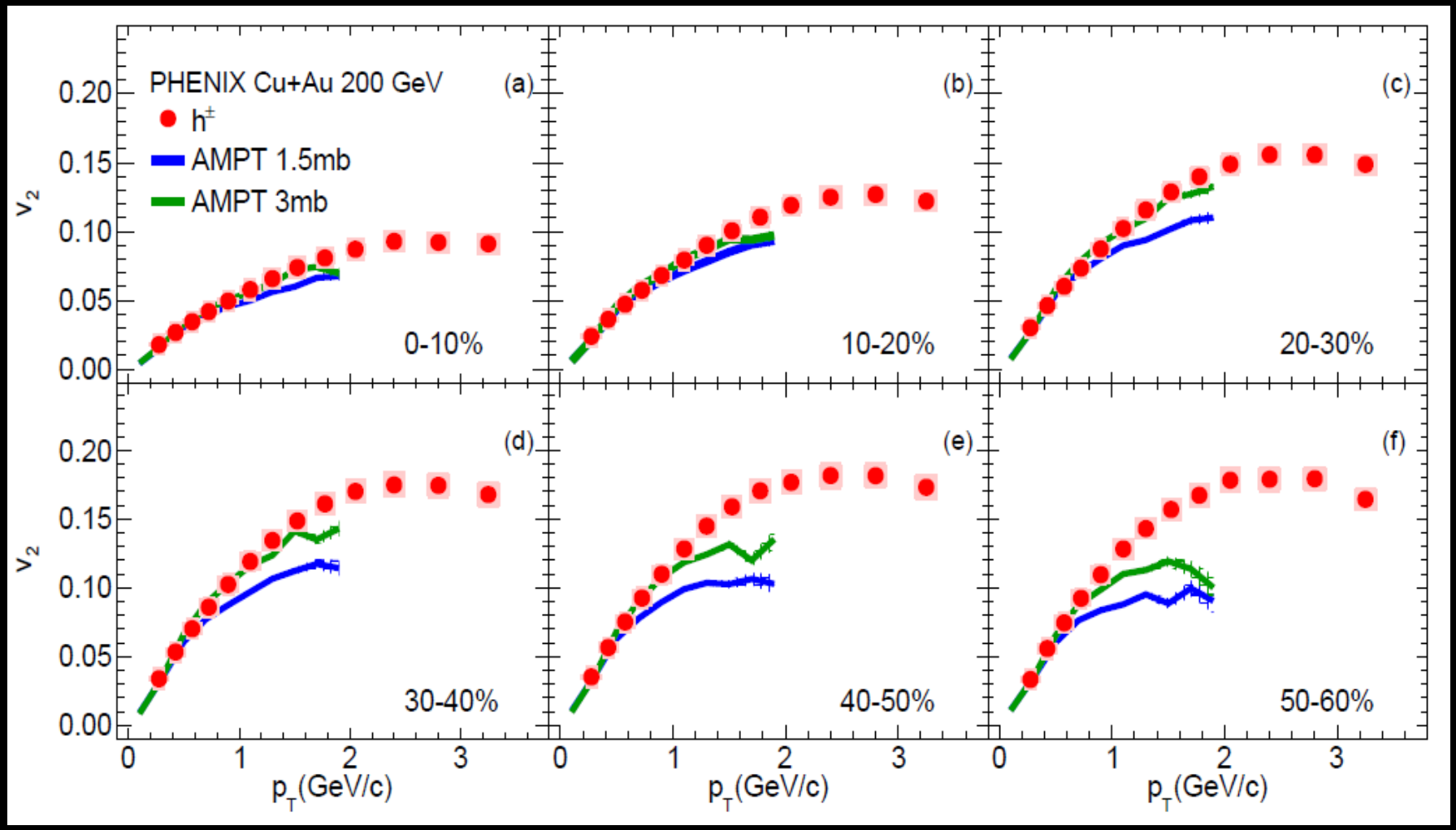
Lots of partons

σ= 1.5 mb

Hadron Cascade

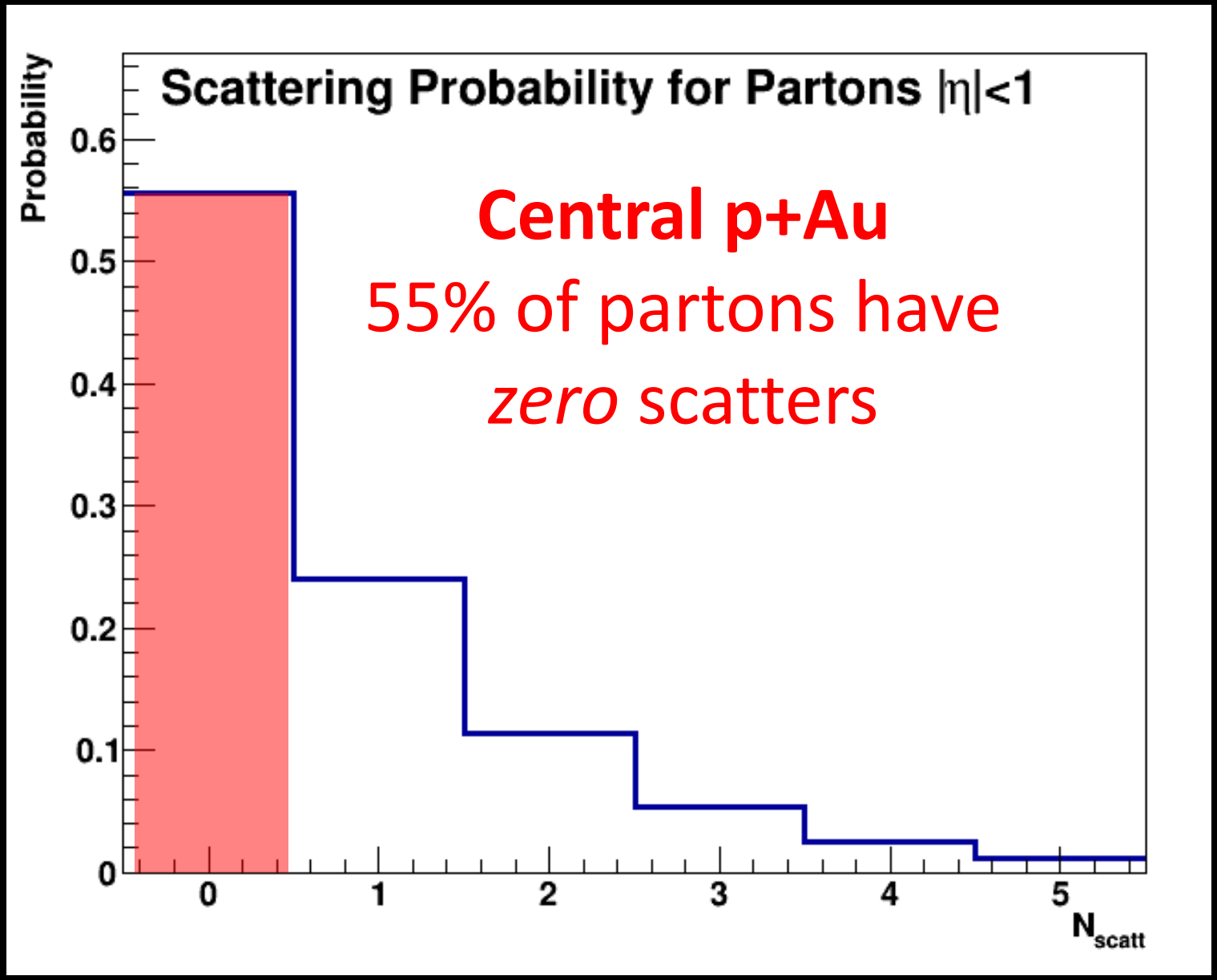
Orjuela Koop *et al*. http://arxiv.org/abs/1501.06880

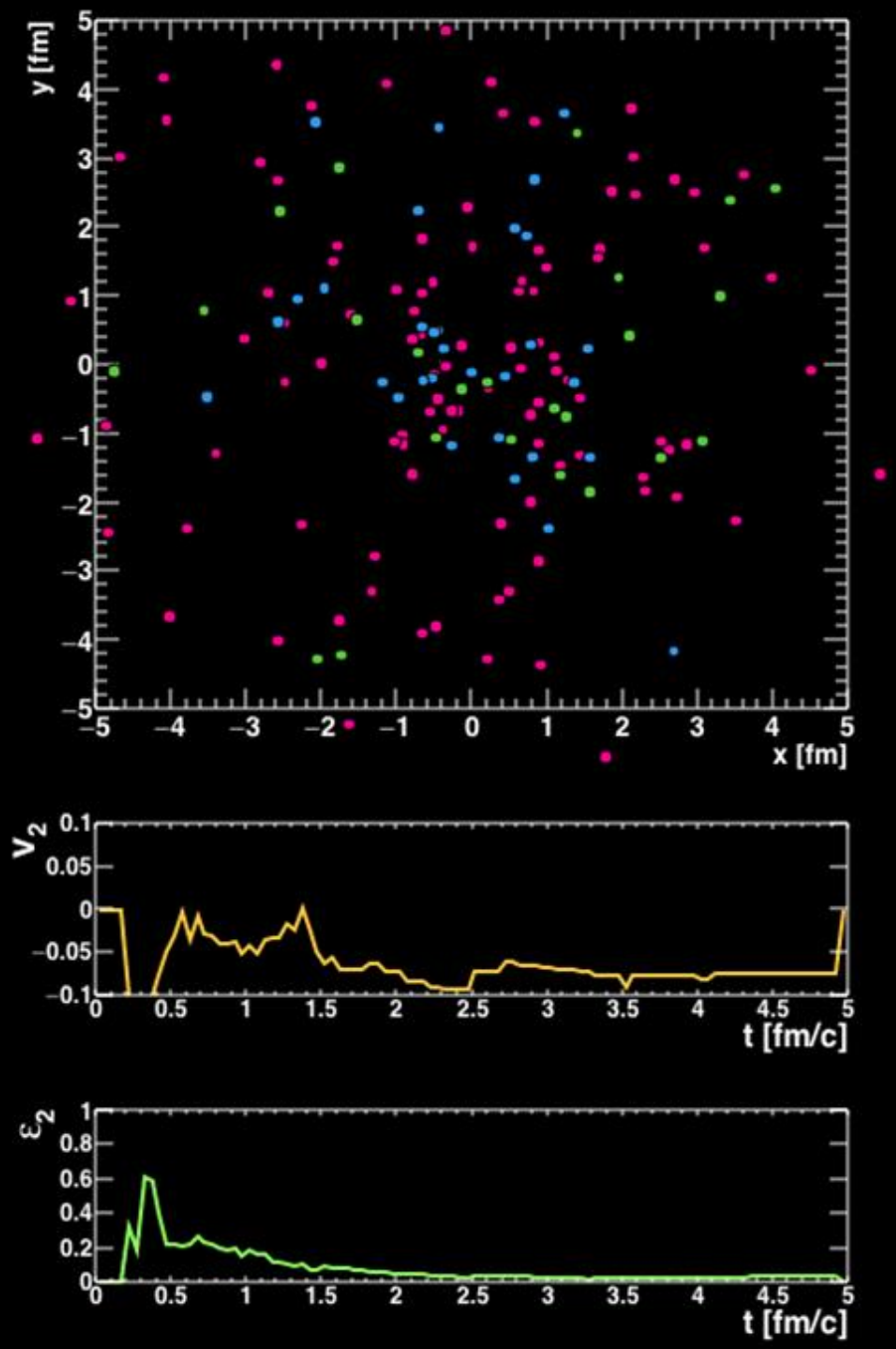
AMPT (same code) Cu+Au @ 200 GeV



PHENIX arXiv:1509.07784

AMPT Details



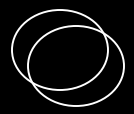


Central p+Au @ 200 GeV

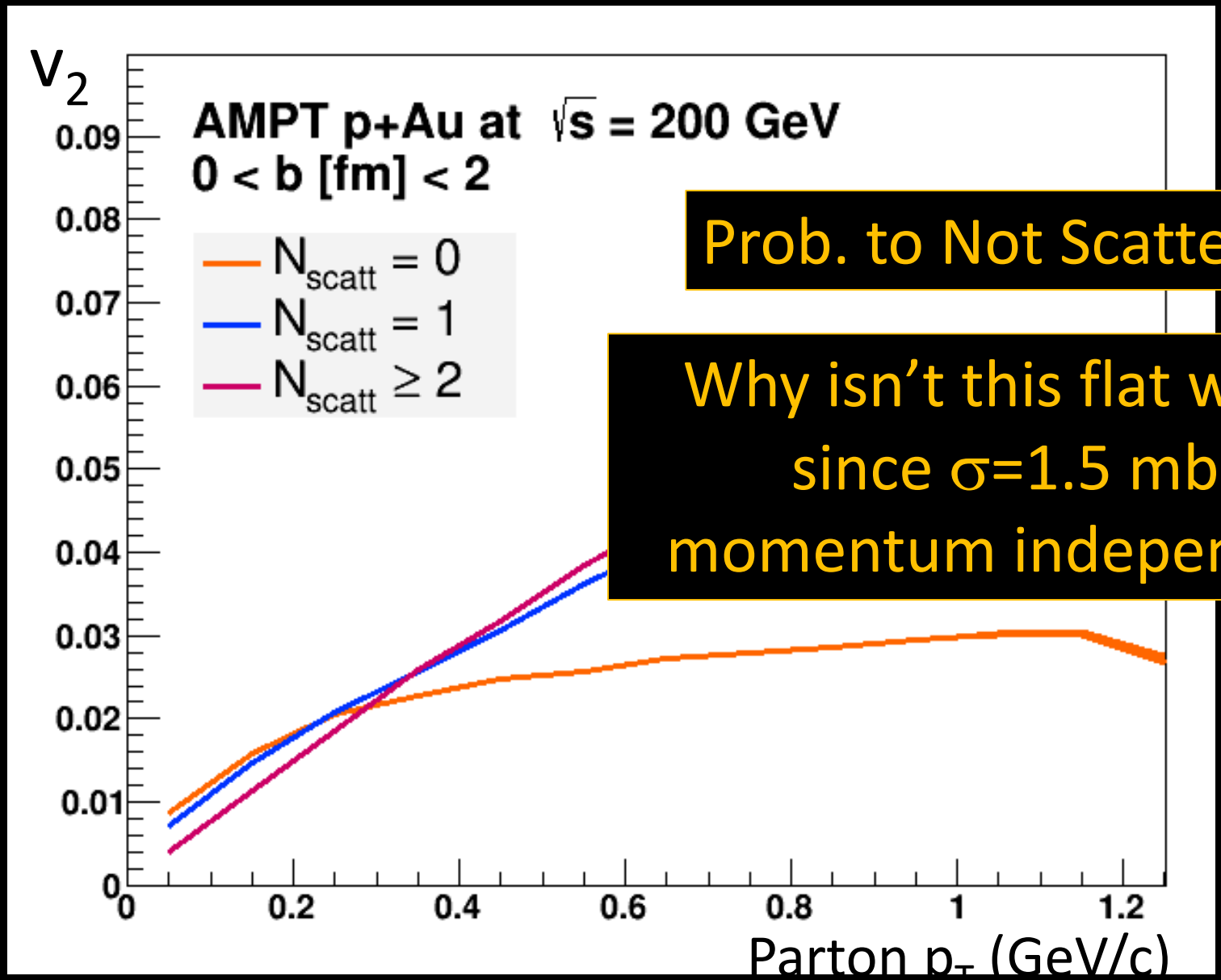
~ 200 partons
AMPT has all (anti)quarks
m < 30 MeV/c^2
<u>and zero gluons</u>!

Scatters = 0
Scatters = 1
Scaters >=2

~ 45 parton-parton scatterings



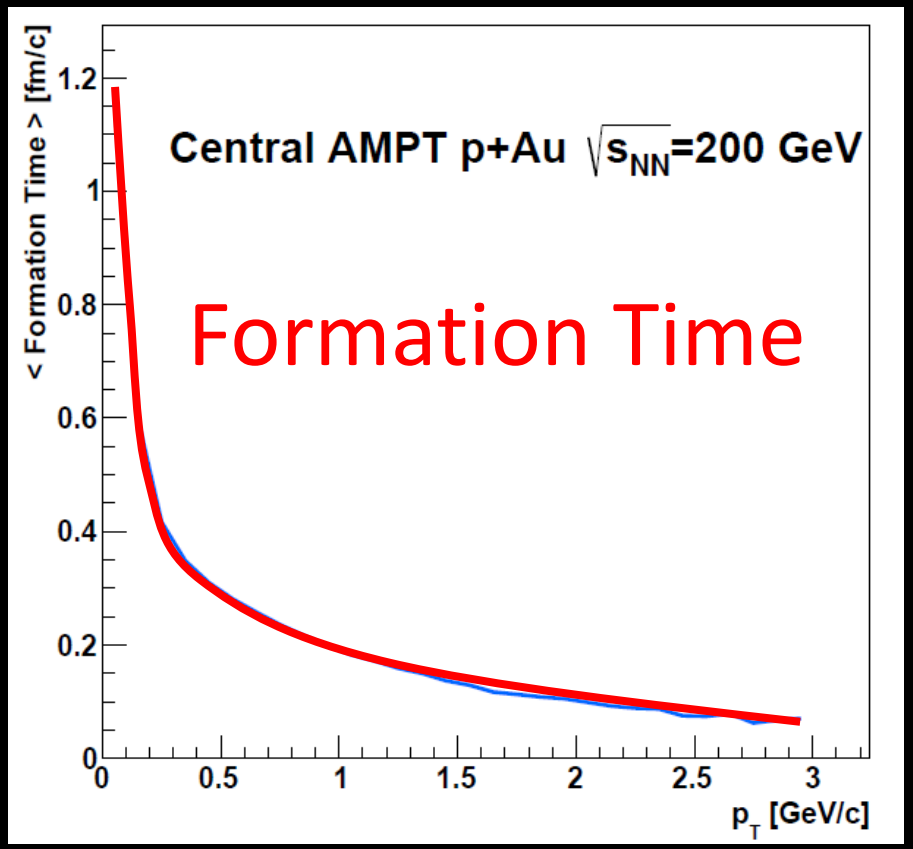
AMPT – Just the Partons (ZPC)

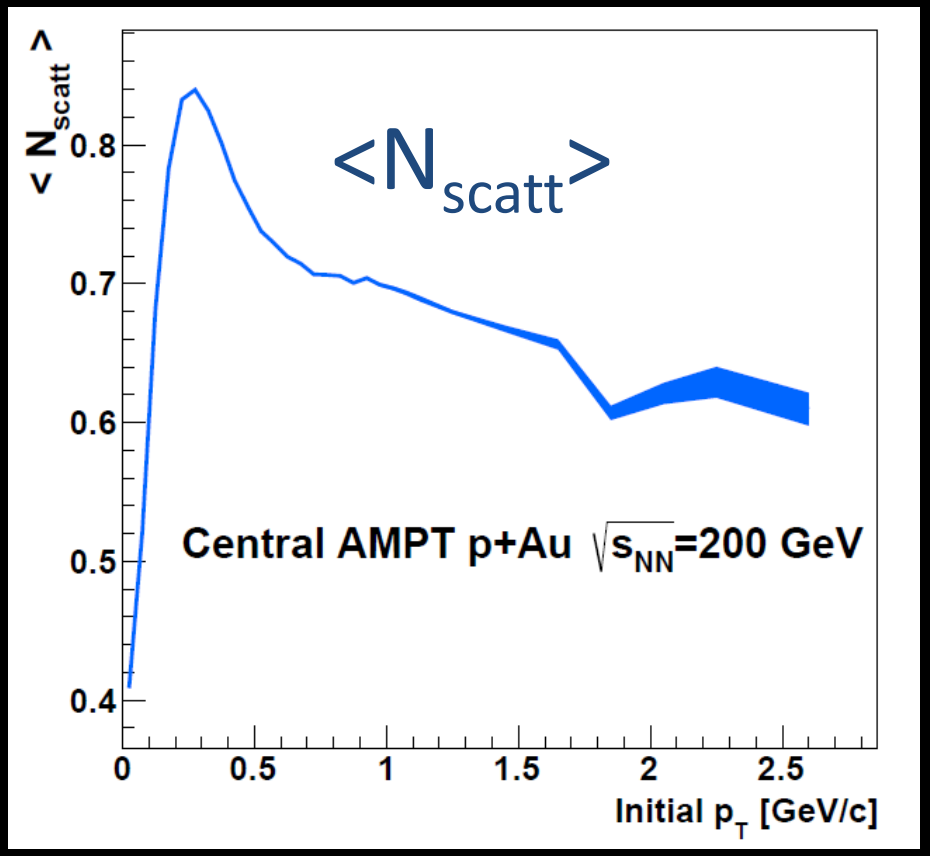


Prob. to Not Scatter (ϕ)

Why isn't this flat with p_T since σ=1.5 mb is momentum independent?

Parton Formation Time





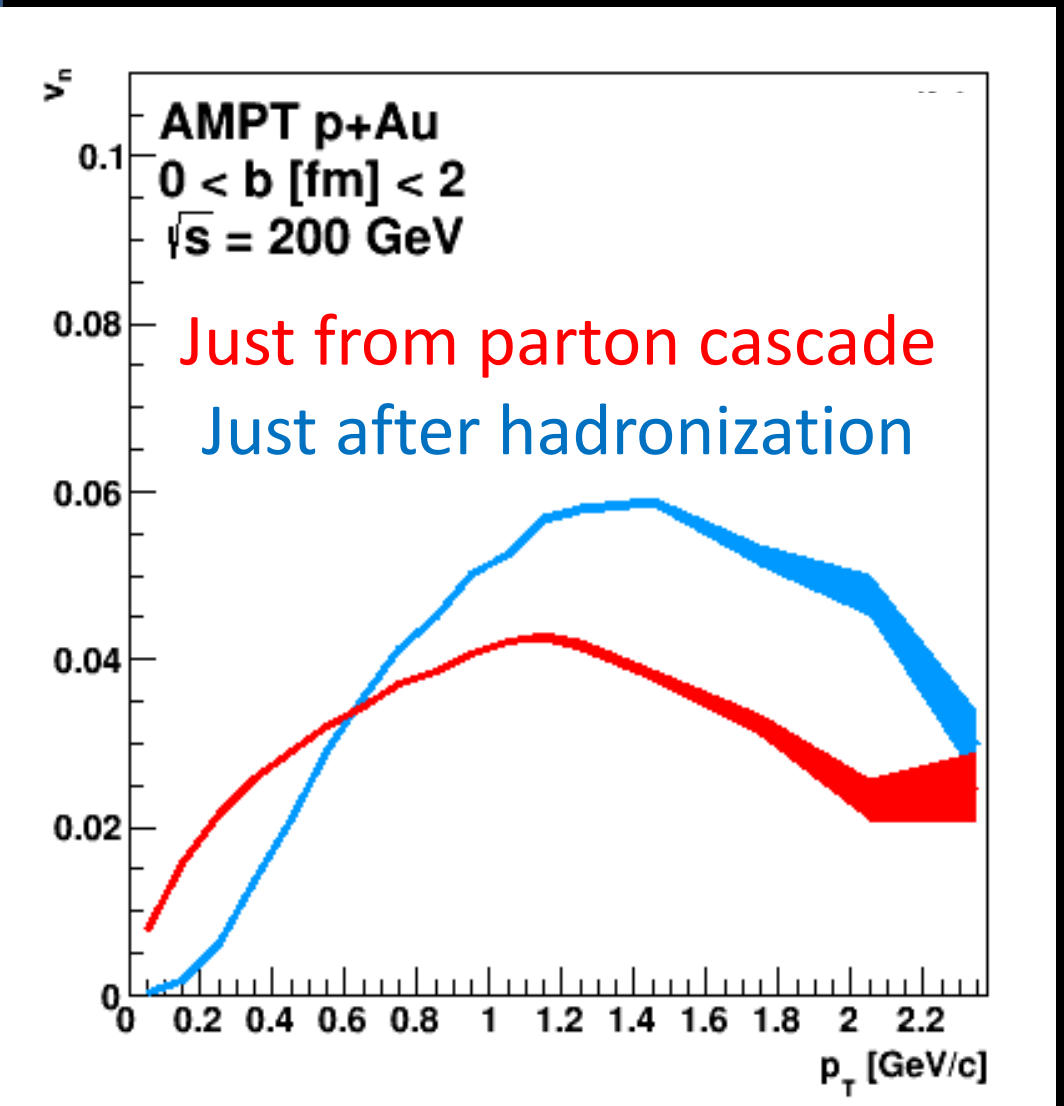
Low p_T partons do not interact for > 1 fm/c

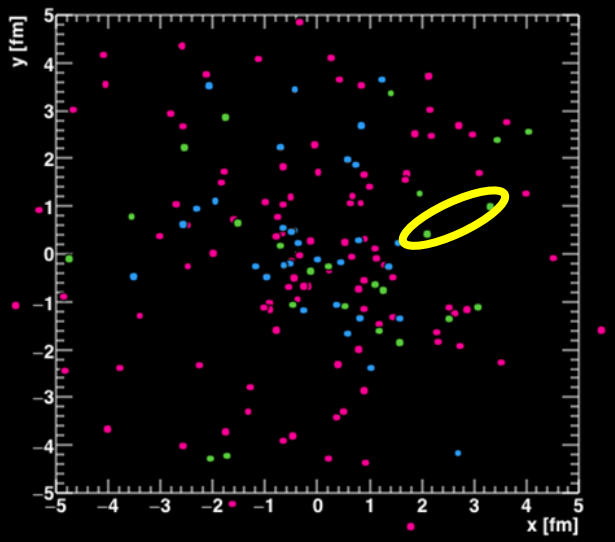
$v_2(p_T)$ depends on formation time

Not yet clear why $<N_{scatt}>$ drops for high p_T partons

Hadronization in AMPT

200 quarks/antiquarks → ~ 100 mesons

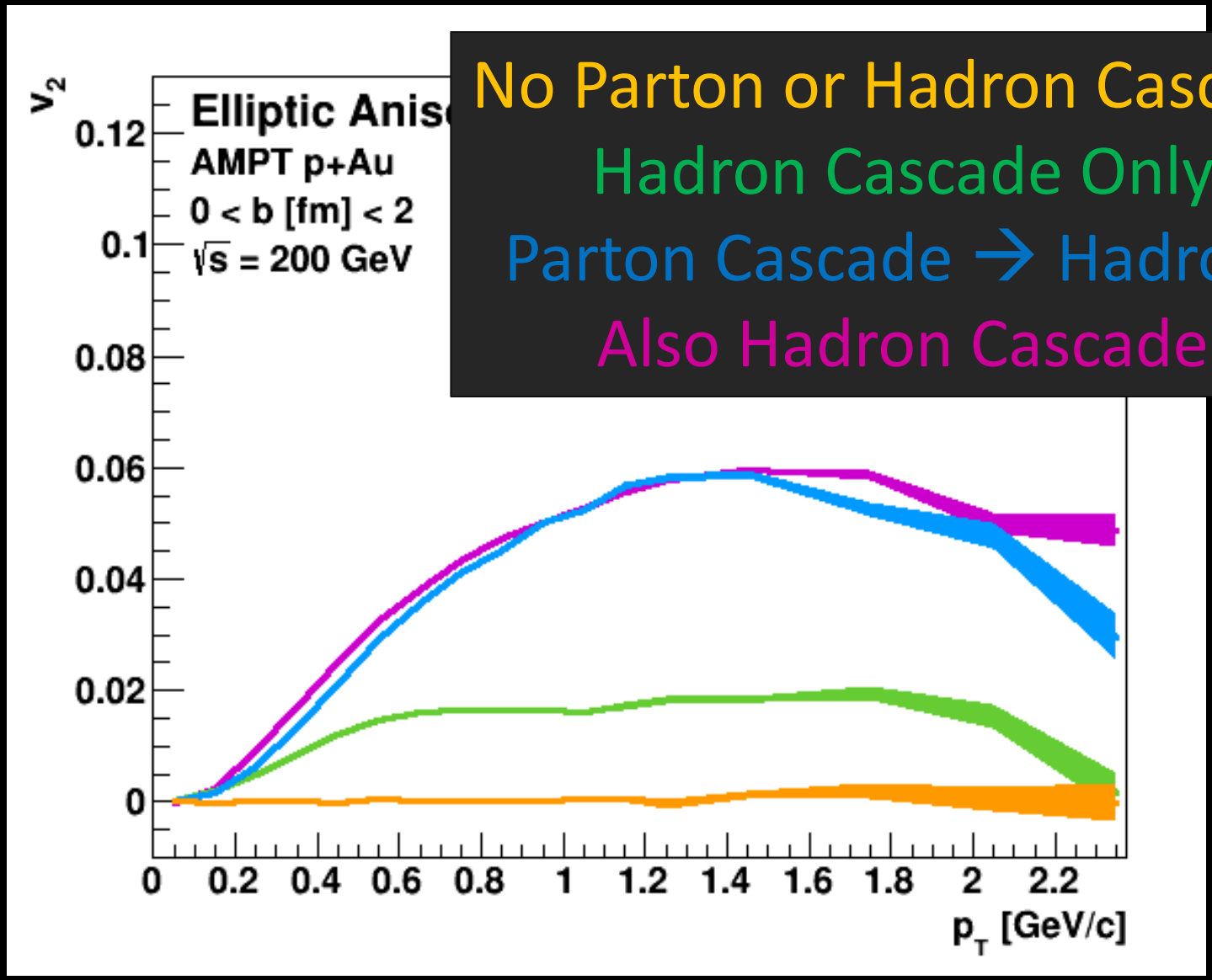




Coalescence just by closest spatial partner (no momentum space)

How to assign a theory uncertainty?

Contributions for Each Stage

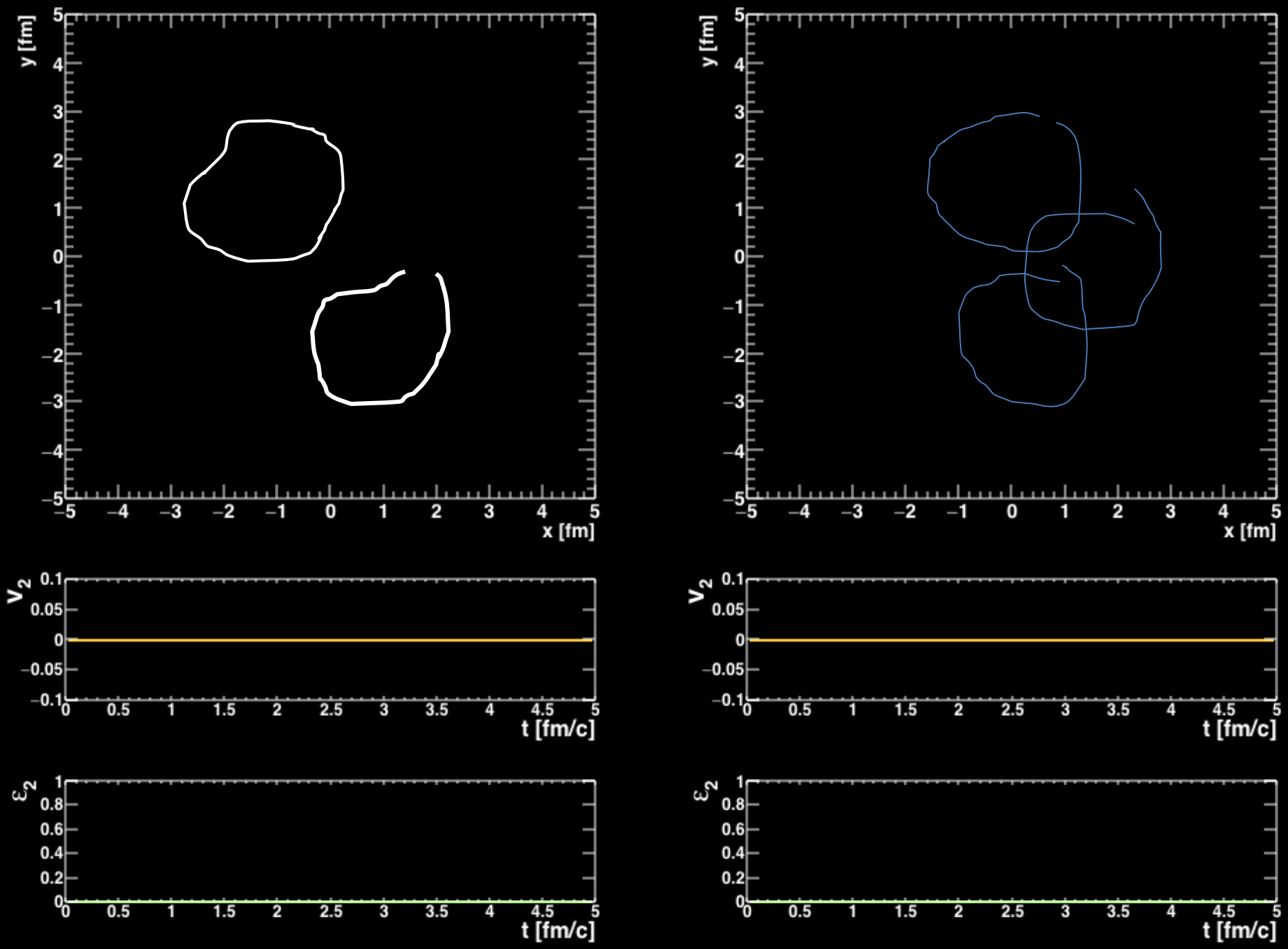


No Parton or Hadron Cascade

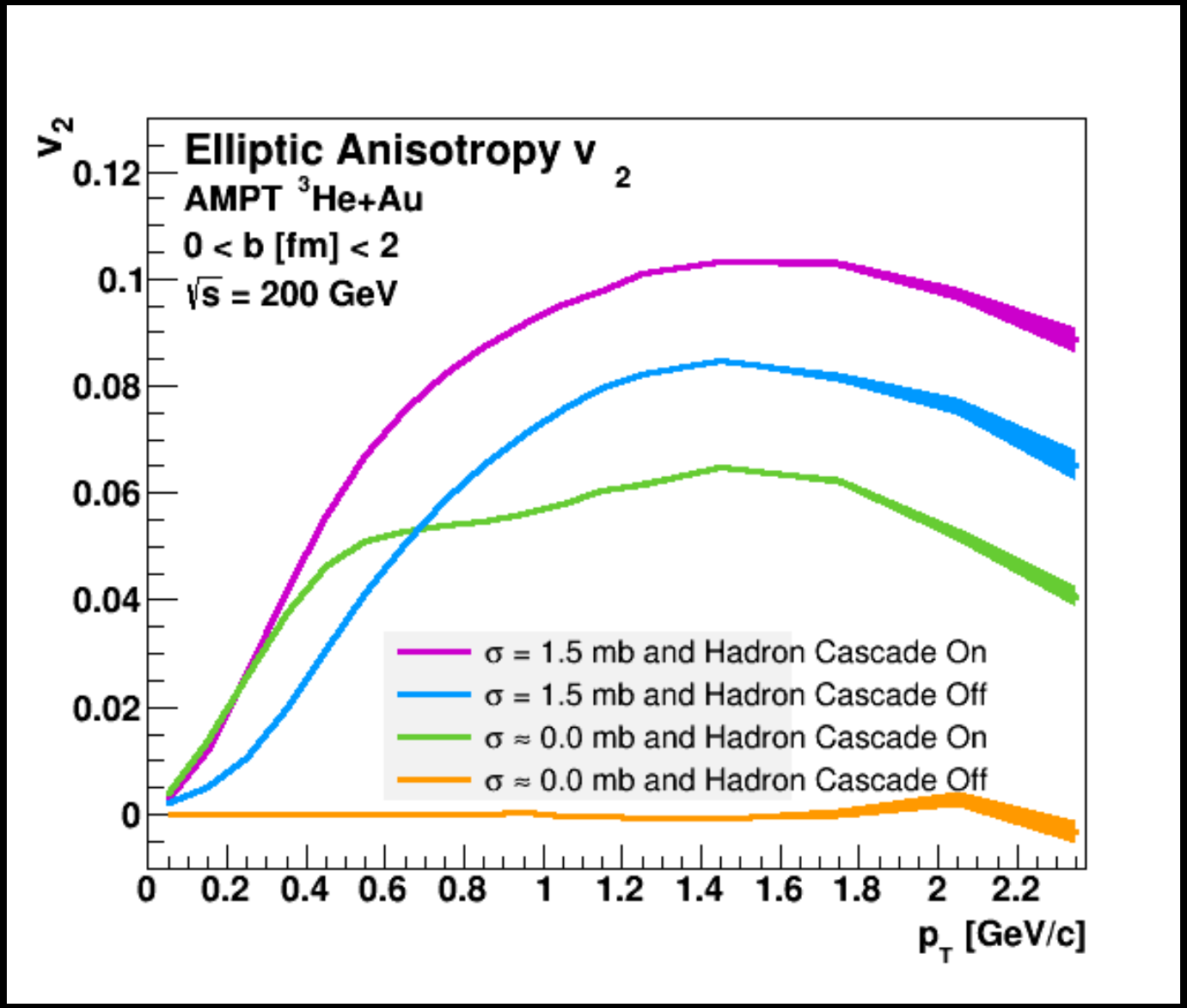
Hadron Cascade Only

Parton Cascade → Hadrons

Also Hadron Cascade

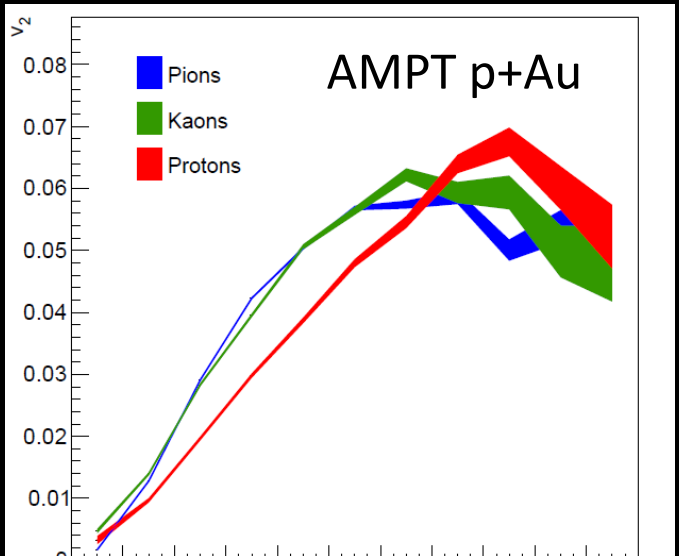

y [fm]
x [fm]
v_2
t [fm/c]
ε_2
t [fm/c]
y [fm]
x [fm]
v_2
t [fm/c]
ε_2
t [fm/c]

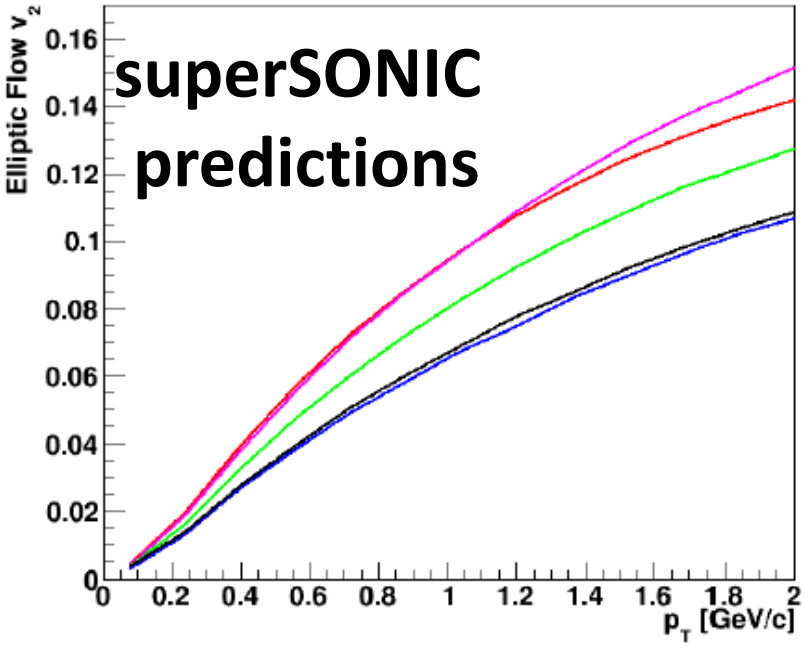
Different Picture in ^{3}He+Au

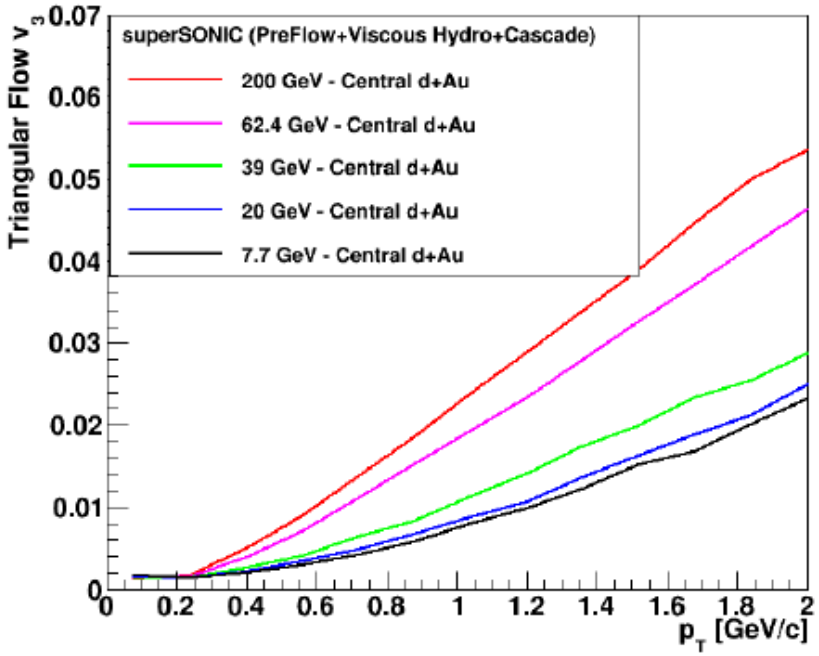


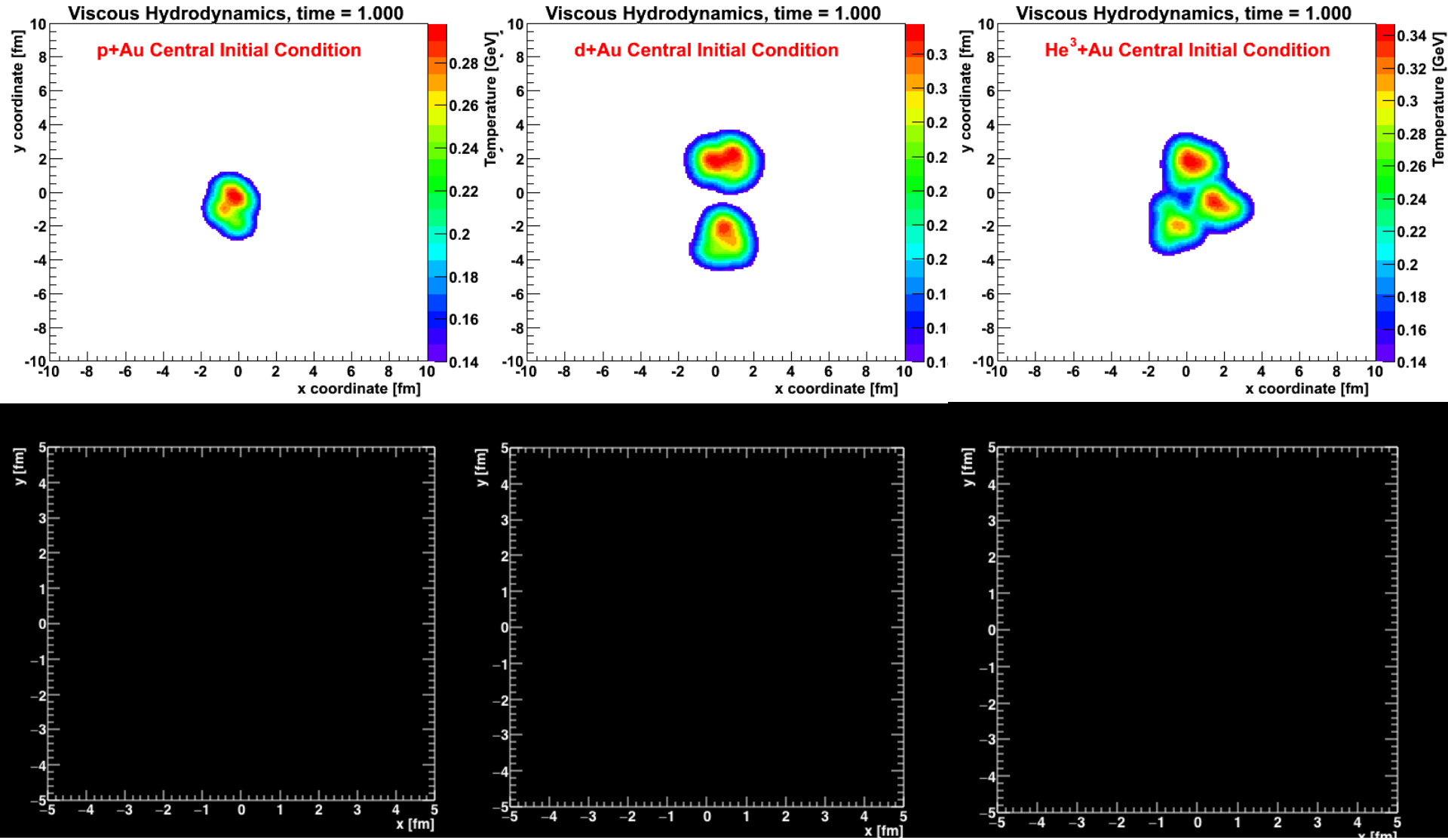
Further Discriminating (?) Tests

Species dependence signature of velocity field, though coalescence can mimic some features (all?)







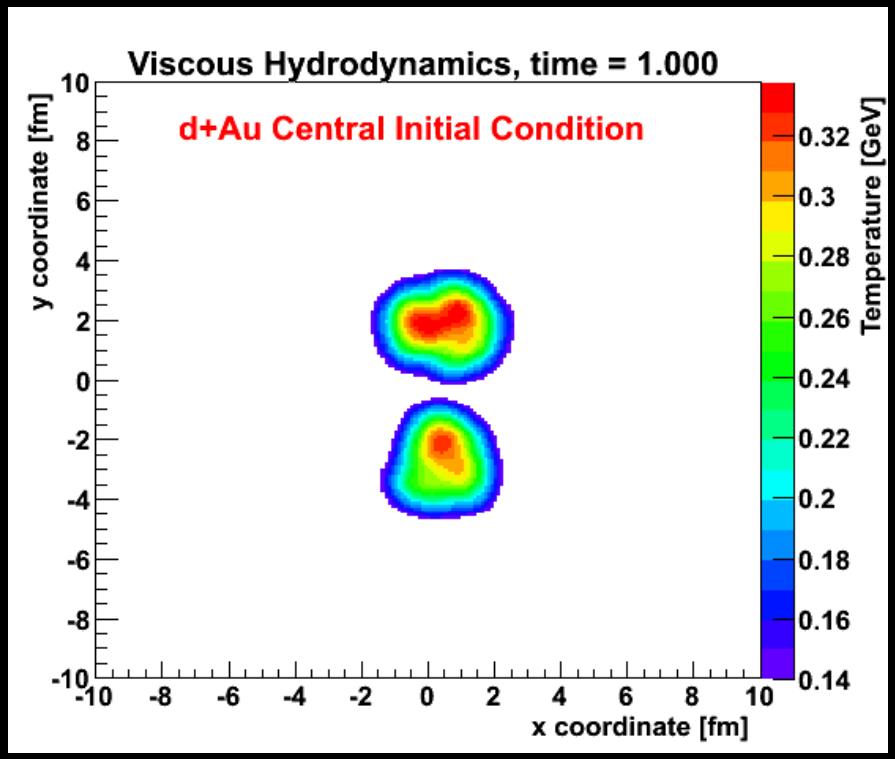


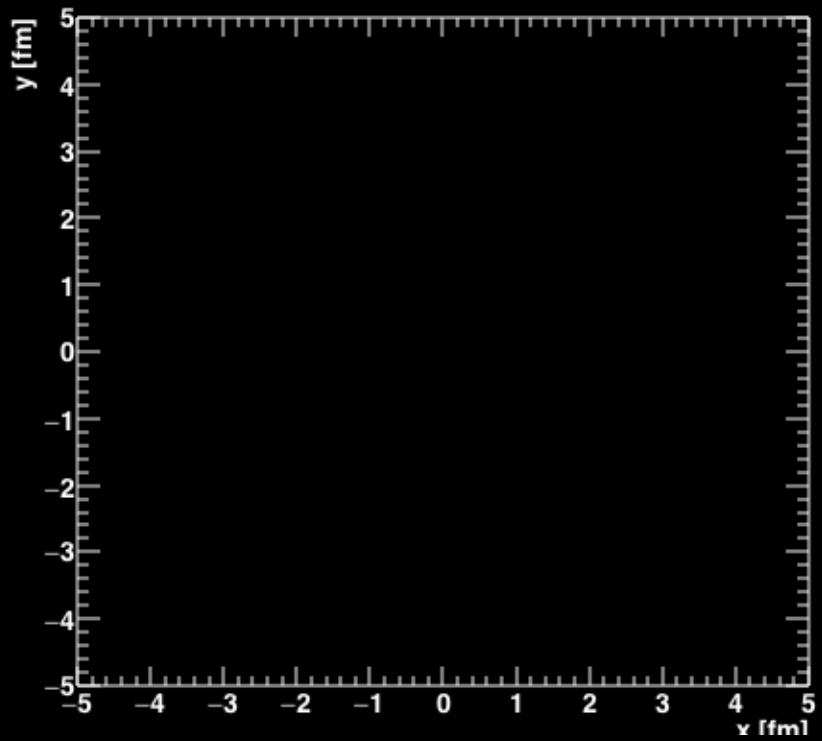
Definitive evidence for geometry, not initial momentum correlations

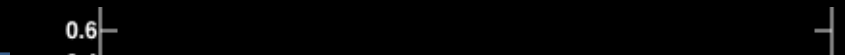
However, competing final state explanations needs work to discriminate.

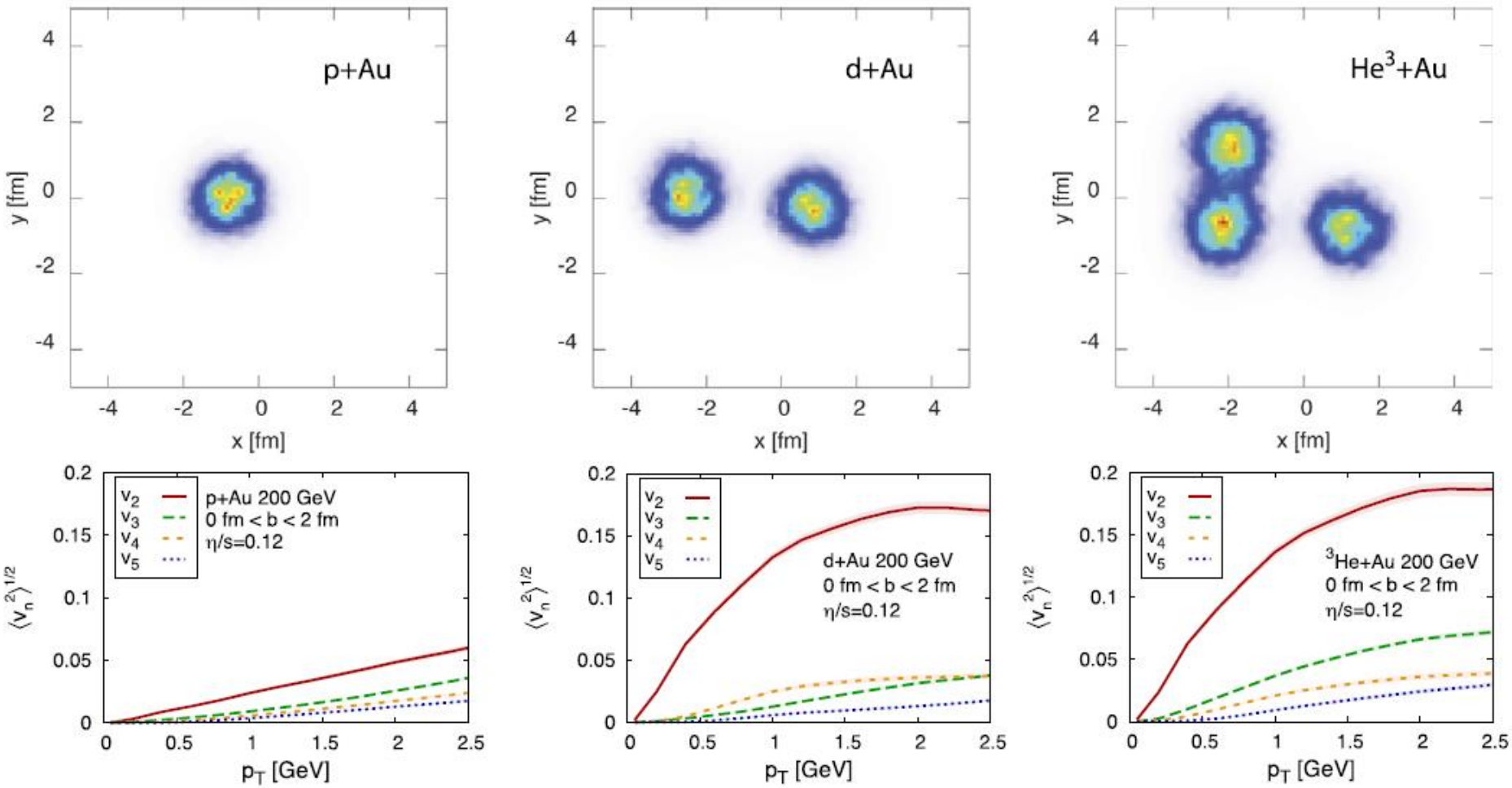
Extras

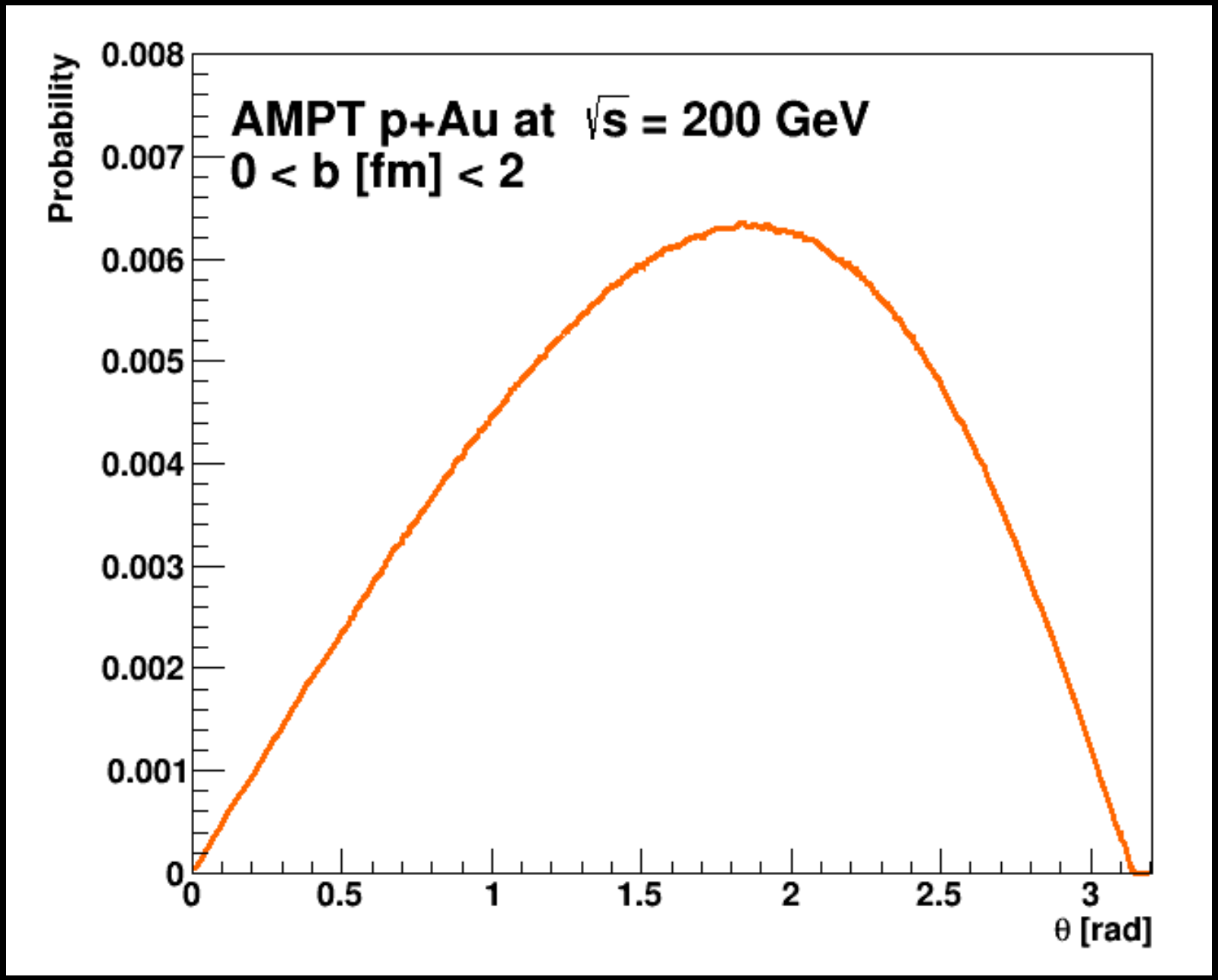
Geometry Rules – but what final-state mechanism

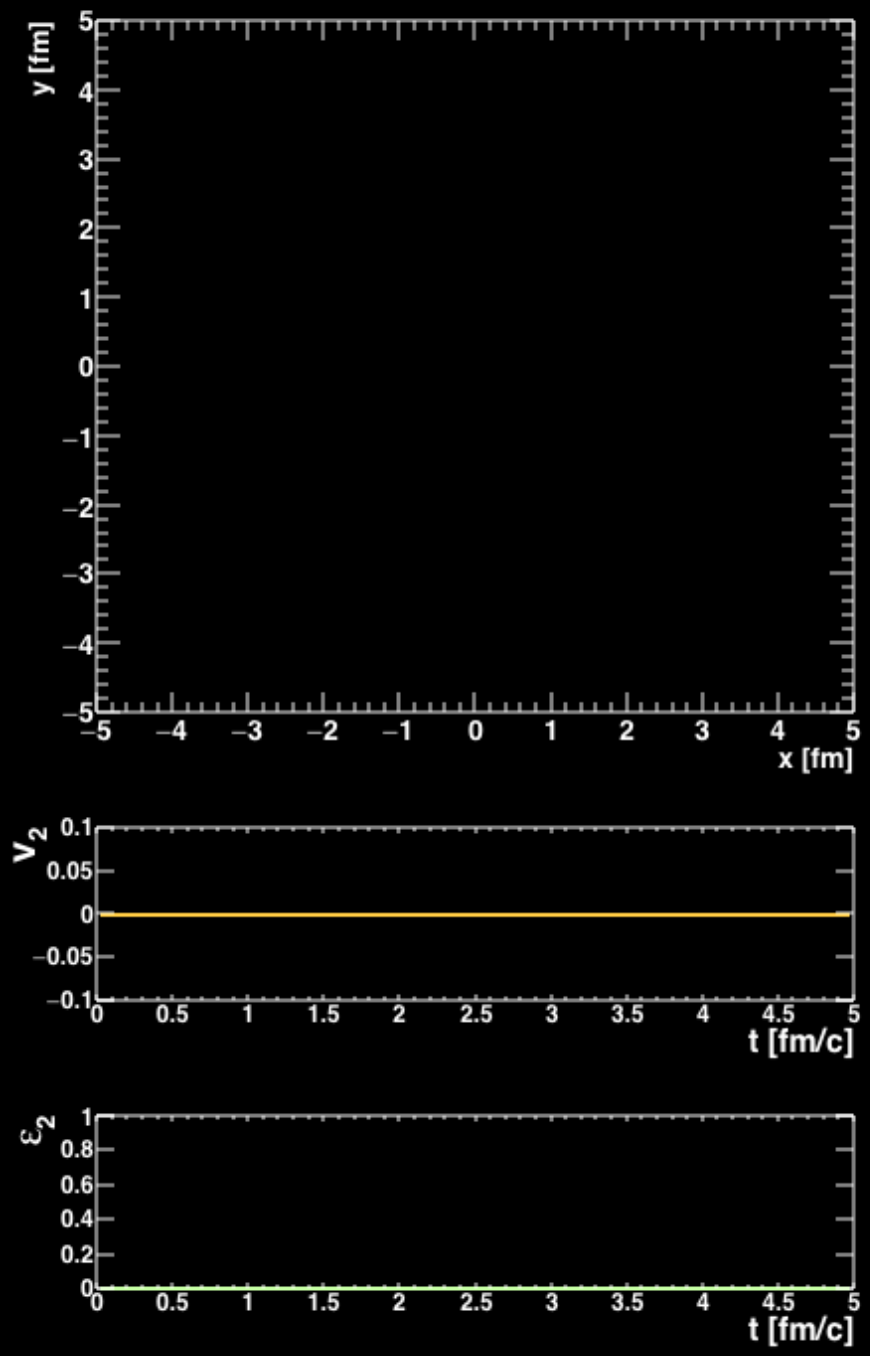


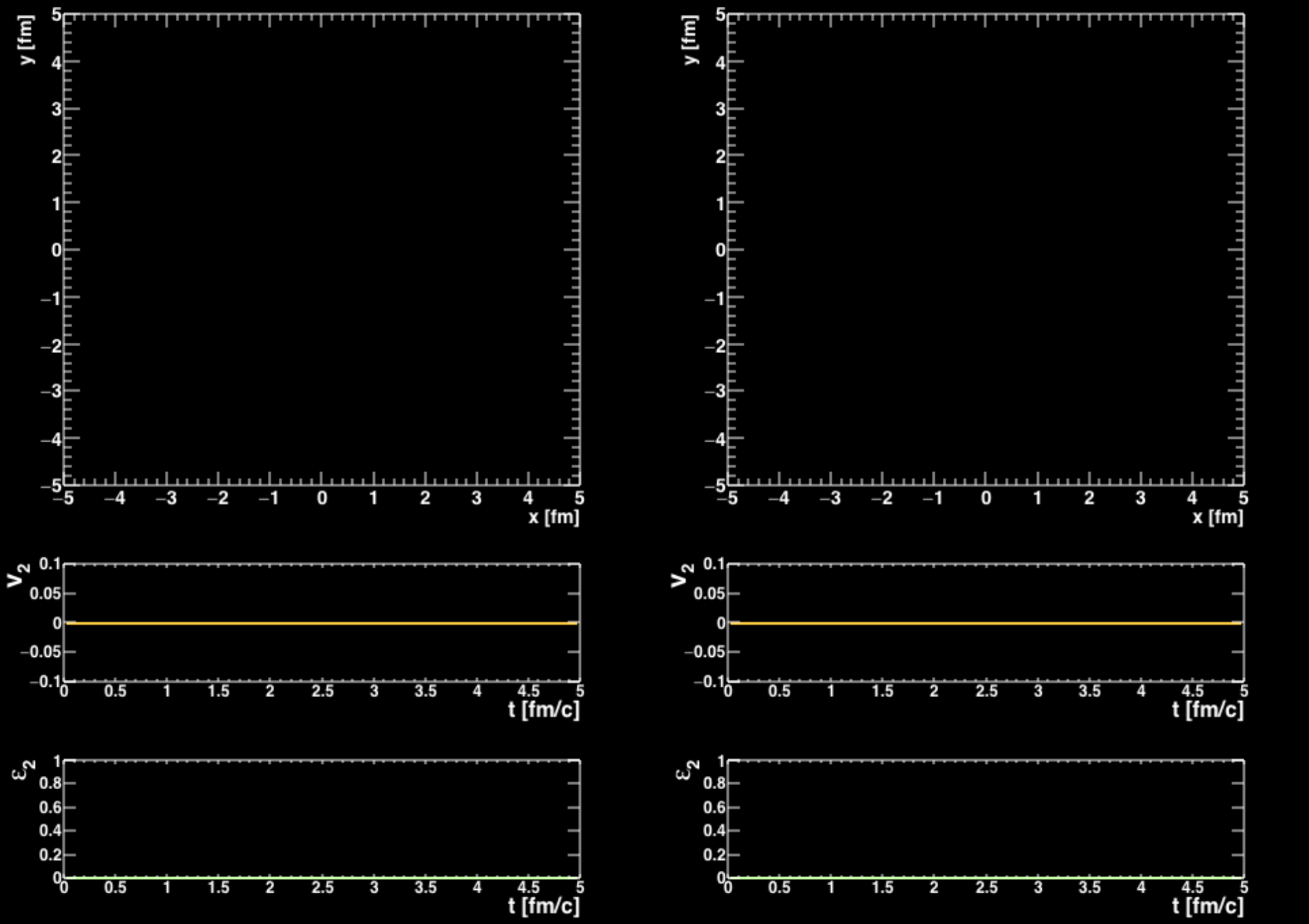


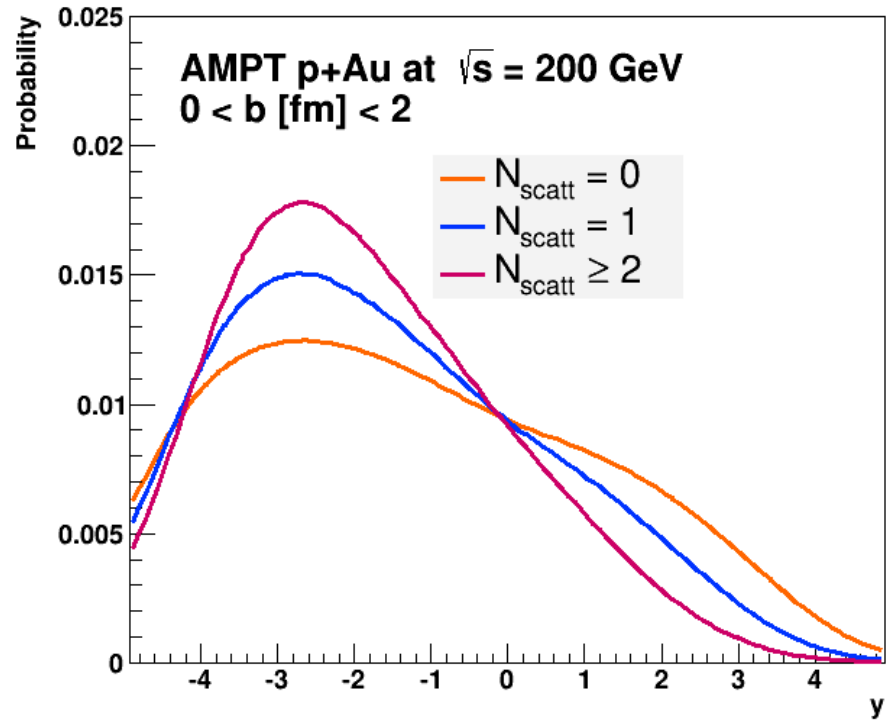


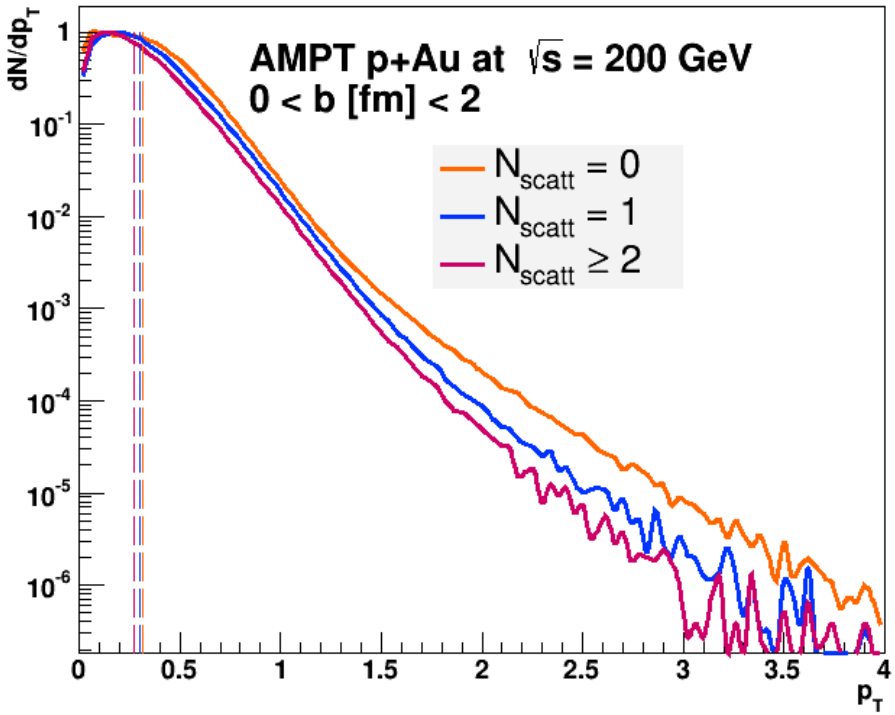

p+Au
d+Au
He^3+Au
y [fm]
x [fm]
$\langle v_n^2 \rangle^{1/2}$
p_T [GeV]
v_2
v_3
v_4
v_5
p+Au 200 GeV
0 fm < b < 2 fm
η/s=0.12
d+Au 200 GeV
0 fm < b < 2 fm
η/s=0.12
^{3}He+Au 200 GeV
0 fm < b < 2 fm
η/s=0.12

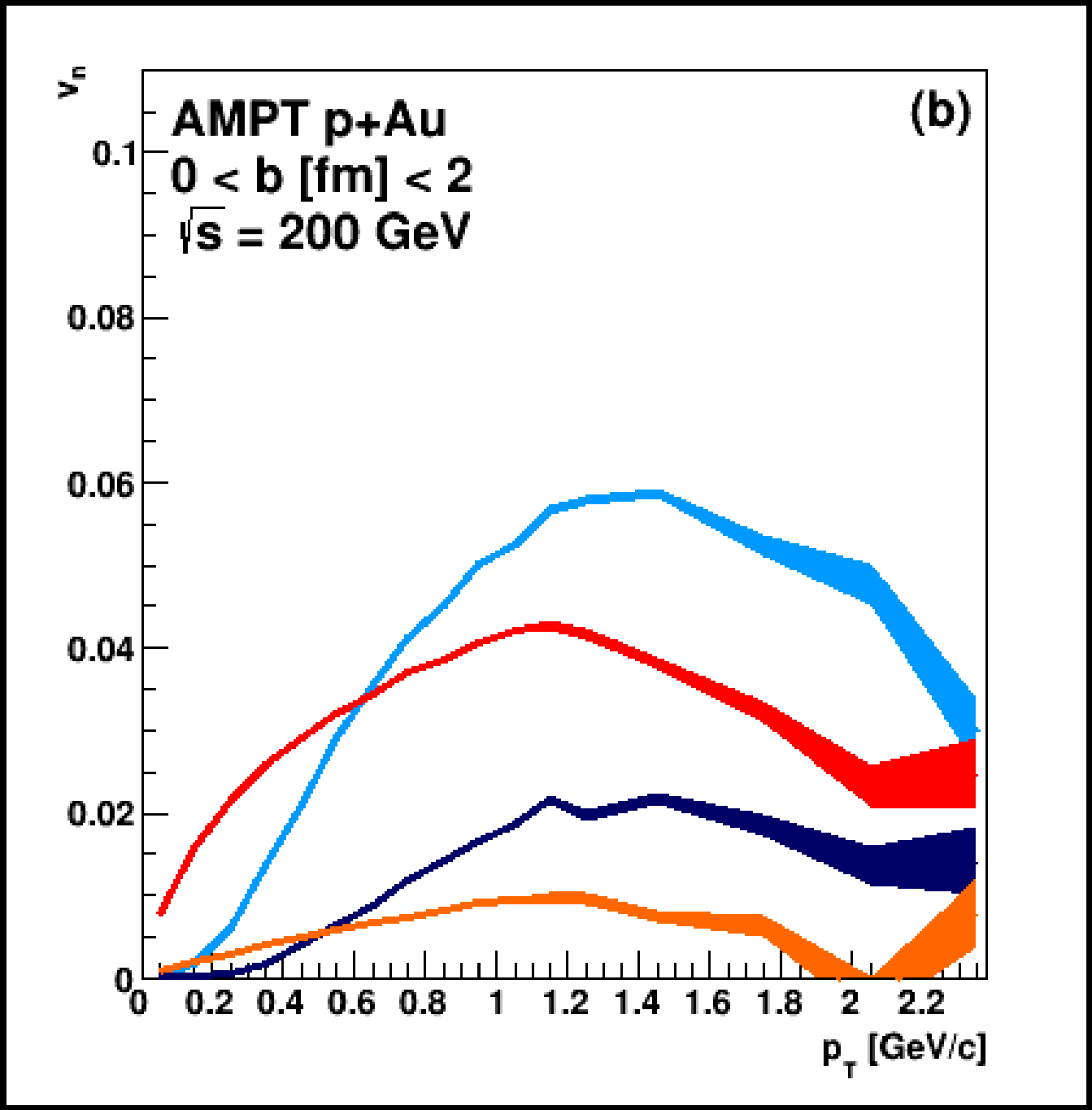

AMPT p+Au at √s = 200 GeV
0 < b [fm] < 2
Probability
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0
0.5
1
1.5
2
2.5
3
θ [rad]


y [fm]
x [fm]
v_2
t [fm/c]
ε_2
t [fm/c]


y [fm]
x [fm]
v_2
t [fm/c]
ε_2
t [fm/c]
y [fm]
x [fm]
v_2
t [fm/c]
ε_2
t [fm/c]


AMPT p+Au at √s = 200 GeV
0 < b [fm] < 2
N_scatt = 0
N_scatt = 1
N_scatt ≥ 2
Probability
y


AMPT p+Au at √s = 200 GeV
0 < b [fm] < 2
N_scatt = 0
N_scatt = 1
N_scatt ≥ 2
dN/dp_T
p_T


AMPT p+Au
0 < b [fm] < 2
√s = 200 GeV
(b)
v_n
0.1
0.08
0.06
0.04
0.02
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
p_T [GeV/c]