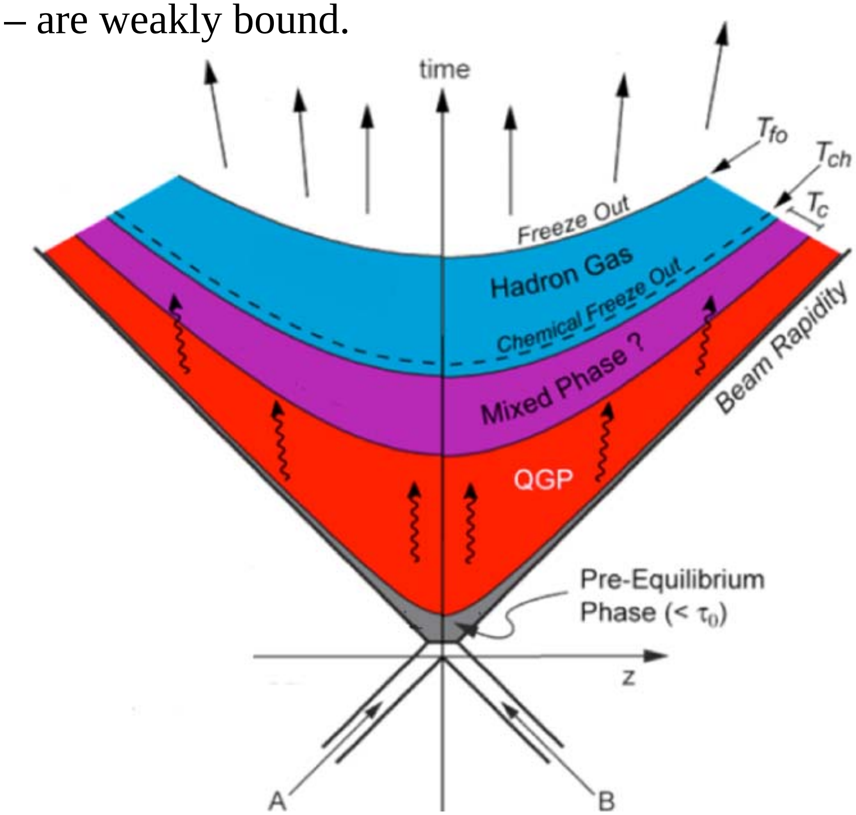
Light (anti)Nucleus Production in $\sqrt{s_{NN}}$ = 7.7 – 200 GeV Au+Au Collisions in the STAR Experiment

W.J. Llope for the STAR Collaboration
Rice University

Introduction

Light (anti)nuclei – *e.g.* (anti)deuterons & (anti)tritons – are weakly bound.
$B_d \sim 2.2$ MeV, $B_t \sim 8$ MeV



Implies that observed (anti)nuclei are formed:
- near thermal freeze-out hypersurface.
- from nucleons close to each other in phase space with rates that are thus sensitive to the local phase space densities and flow.

A complete understanding of the hot and dense partonic and/or nuclear systems formed at RHIC requires an understanding of the latest stages of the collisions.

Light nucleus rates and spectra are a “direct” nucleon correlation observable that is complementary to two-particle correlations obtained, *e.g.*, from intensity interferometry (HBT).

Thermodynamic approaches and the sudden approximation can provide insight on source “homogeneity volumes” and emission profiles, (anti)proton phase space densities, *etc.*

Datasets, Cuts, & Particle Identification

$\sqrt{s_{NN}}$	Run	N_{events}
7.7	2010	5M
11.5	2010	15M
19.6	2011	37M
27	2011	46M*
39	2010	58M*
62.4	2010	59M*
200	2010	51M*
200	2011	47M*

*Not entirety of available data.

Cuts

Outlier run rejection based on multiple global observables.

Event Cuts

$|Z_{vtx}| < 50$cm for $\sqrt{s_{NN}} \leq 39$ GeV, $|Z_{vtx}| < 30$cm otherwise

$R_{vtx} < 2$cm

Pileup event rejection based on multiple global observables.

Primary Track Cuts

$N_{hitsfit} > 15$ (of 45 possible)

$N_{hitsdedx} > 10$ (of ~35 possible)

Global partner D.C.A. to primary vertex < 3 cm

TOF: "good match" criterion ≥ 1

TOF: $Y_{local} < 1.8$ cm

Centrality

Uses primary track multiplicity within $|\eta| < 0.5$

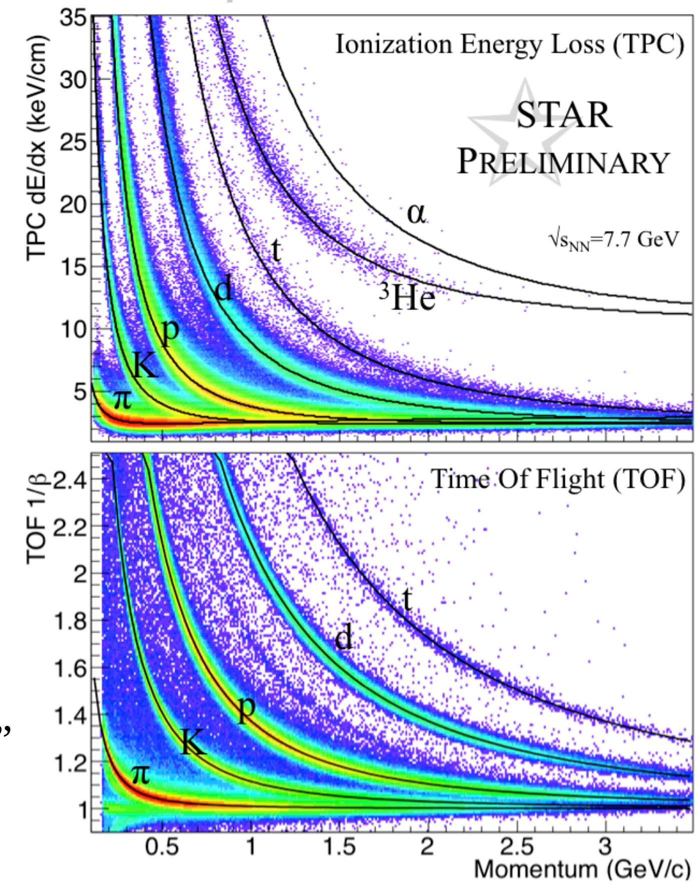
Corrected for Z_{vtx} and beam luminosity dependence

Particle Identification

Uses TPC dE/dx and Time Of Flight (TOF)

…Careful avoidance of dE/dx "merged tracks"

Statistical, in small (P_T,y,centrality) bins



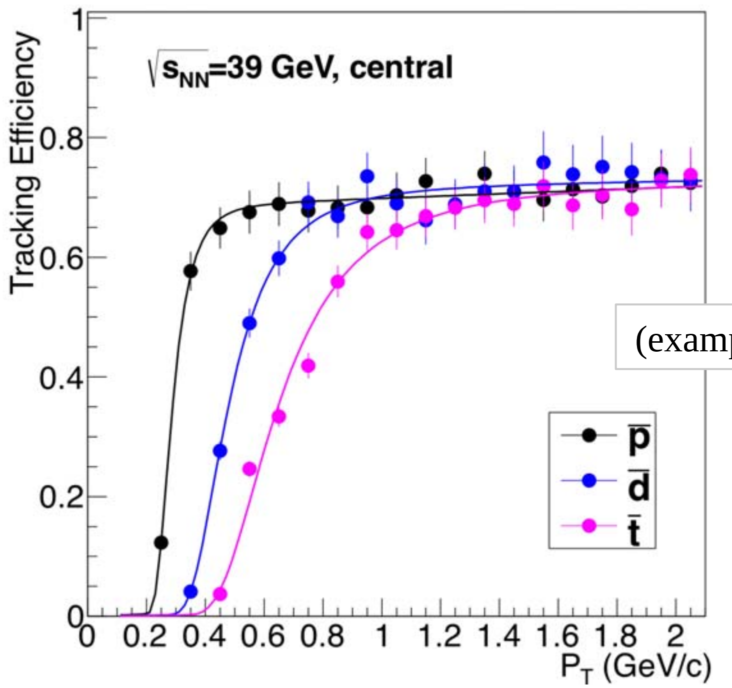
Uncertainties are statistical only.

Corrections

Efficiencies depend on year, $\sqrt{s_{NN}}$, centrality, species, rapidity, P_T

Track Reconstruction Efficiency

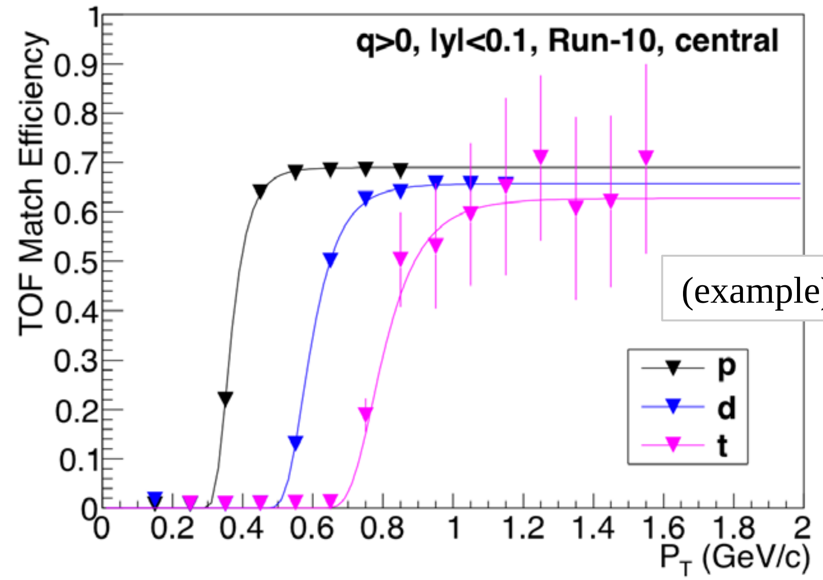
embed simulated tracks into real events
careful sampling by day
done for p,d,t & antiparticles at many $\sqrt{s_{NN}}$ values
interpolation by track multiplicity for other data sets



(example)

TOF Matching Efficiency

determined from data using TPC-identified tracks



(example)

Antinucleus Absorption

Geant**3** does not know nucleus+X cross-sections
Use phenomenological model

T. F. Hoang, *et al.*, Z. Phys. C29, 611 (1985)

Check material budget via p & pbar embedding

(anti)proton Feed-down ($\Lambda,\Sigma \rightarrow p$)

UrQMD 3.3p1 simulations
full reconstruction

Cross-sections vs. M_T-M_0

$M_T^2 = P_T^2 + M_0^2$

p: $M_0 = 0.9383\ GeV/c^2$

d: $M_0 = 1.8756\ GeV/c^2$

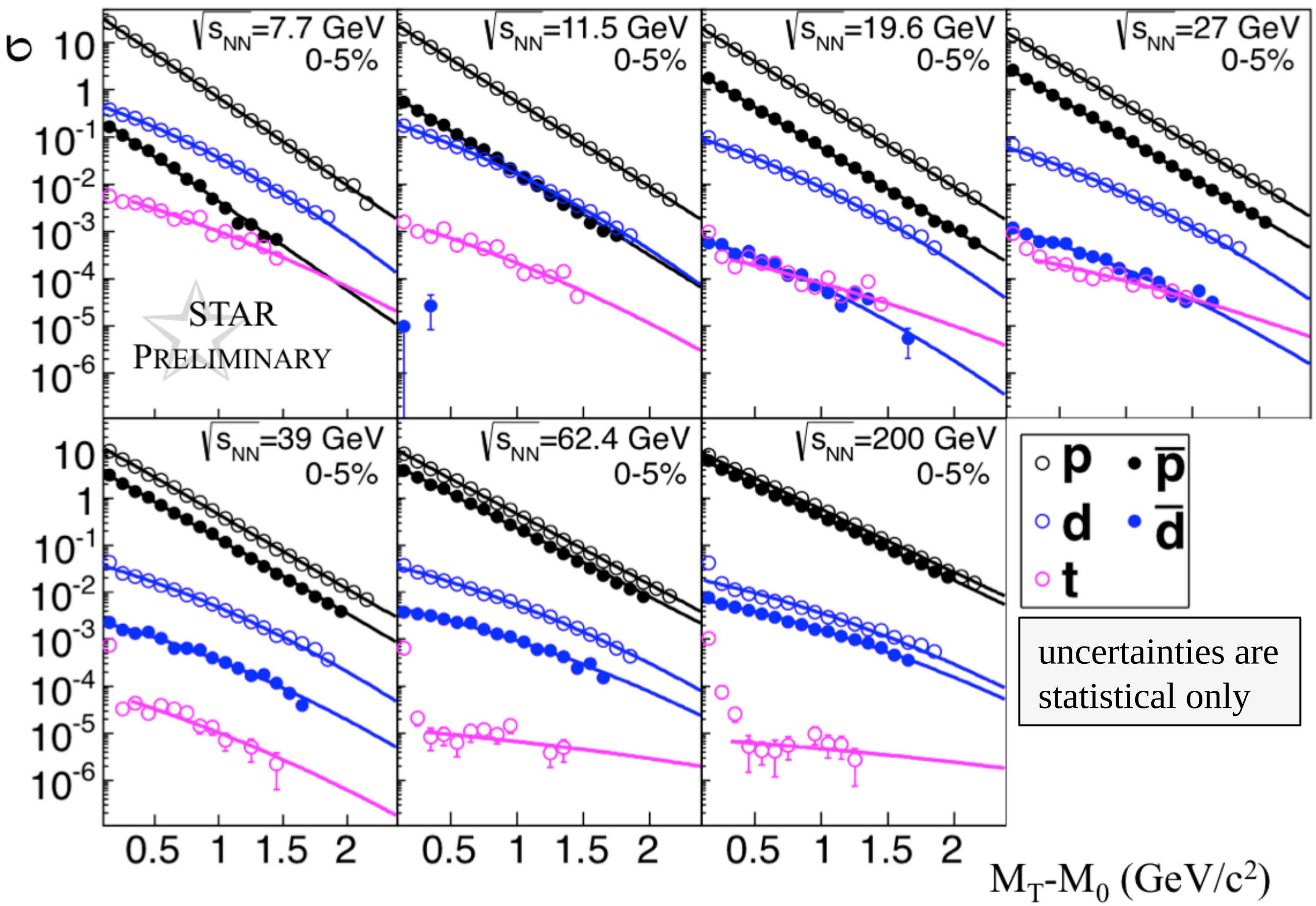
t: $M_0 = 2.8093\ GeV/c^2$

(Anti)protons: ~exp[M_T/T]

(Anti)nuclei: ~exp[$(M_T/T)^2$]

Spectra become harder with mass number, A.

Reflects strong transverse expansion



Sharp increase in nucleus cross-sections at low M_T is due to spallation:

X + Beam Pipe = p,d,t + Y

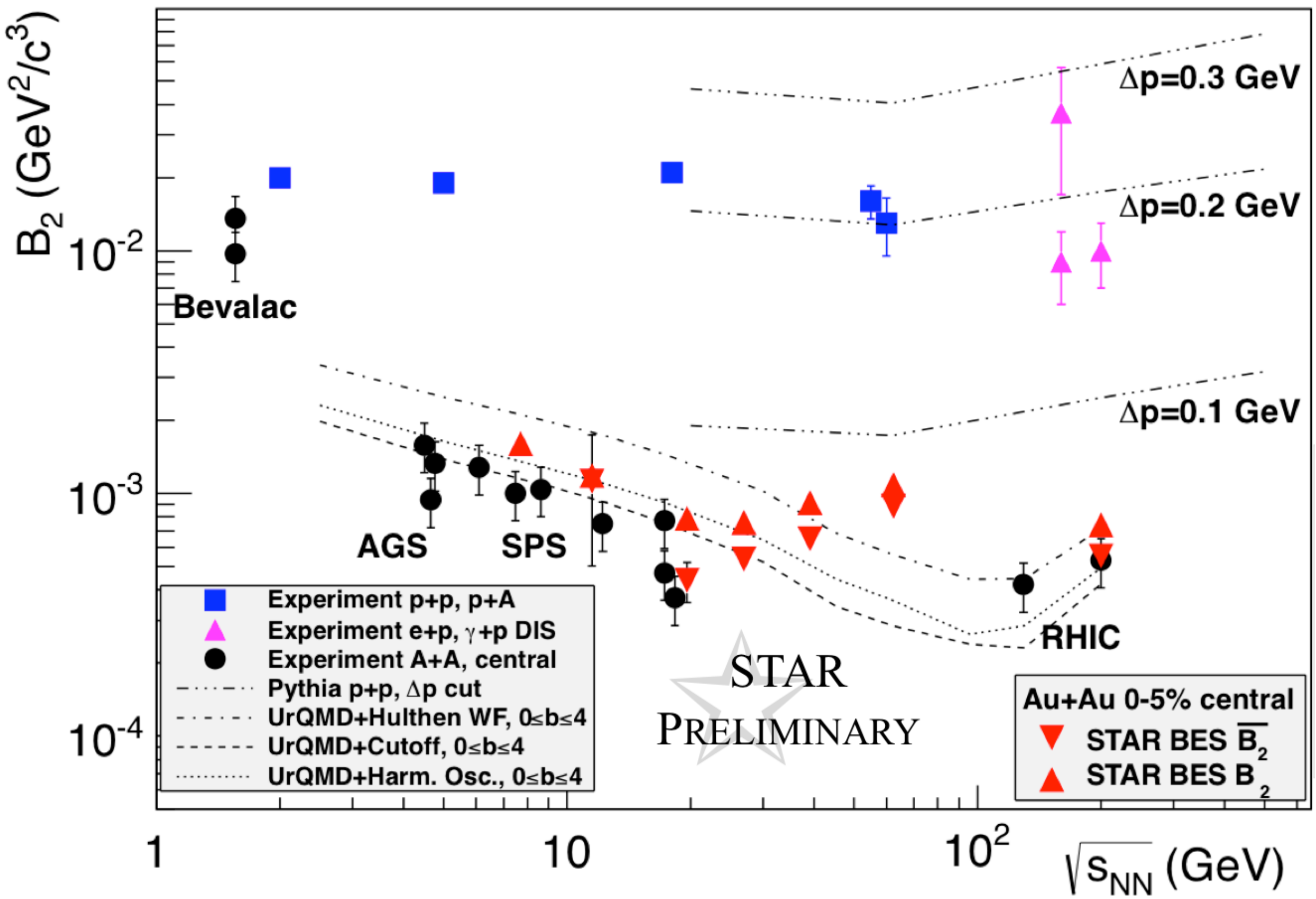
Significant for $P_T < \sim 0.5 * A$, does not produce antinuclei

Coalescence Ratio B_2

$B_2 = \sigma_d/\sigma_p^2$, where the cross-sections are evaluated at the same velocity (P_T/A)

B_2 is a dimensioned ratio that can be related in model-dependent ways to a "homogeneity volume": $\mathbf{B_A \sim 1/V}$

WJL, S. Pratt *et al.*, Phys. Rev. C **52**, 2004 (1995),   R. Scheibl & U. Heinz, Phys. Rev. C **59**, 1585 (1997)



for data points see *e.g.*
N. George, Ph.D, Thesis
Yale University (1999)

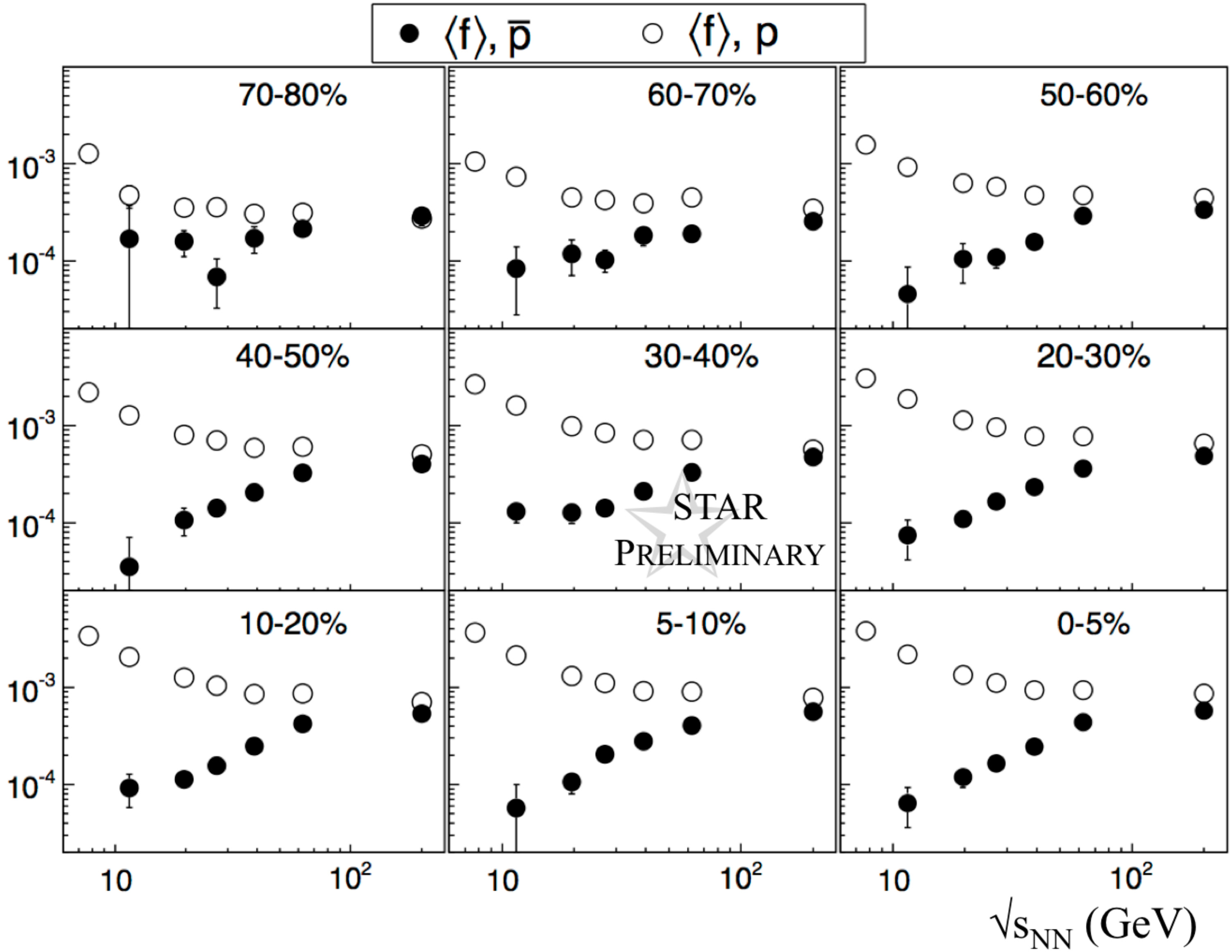
p+X: ZEUS, HERA, H1, E886, NA44
Bevalac: EOS
AGS: E814, E896, E864, E878, E877
SPS: NA44, NA49, NA52
RHIC: STAR, PHENIX, BRAHMS

Lines are UrQMD 3.3p1 or Pythia model calculations plus a "dynamic coalescence afterburner"
uses 6D coalescence with one of three d wave functions for A+A (UrQMD), 3D coalescence for Pythia.

J. L Nagle et al., Phys. Rev. C **53**, 367 (1996), B. Monreal, WJL, *et al.*, Phys. Rev. C **60**, 31901 (1999)

(anti)Proton Phase-Space Density

$$\langle f \rangle = \frac{1}{3}\frac{\sigma_d}{\sigma_p}$$

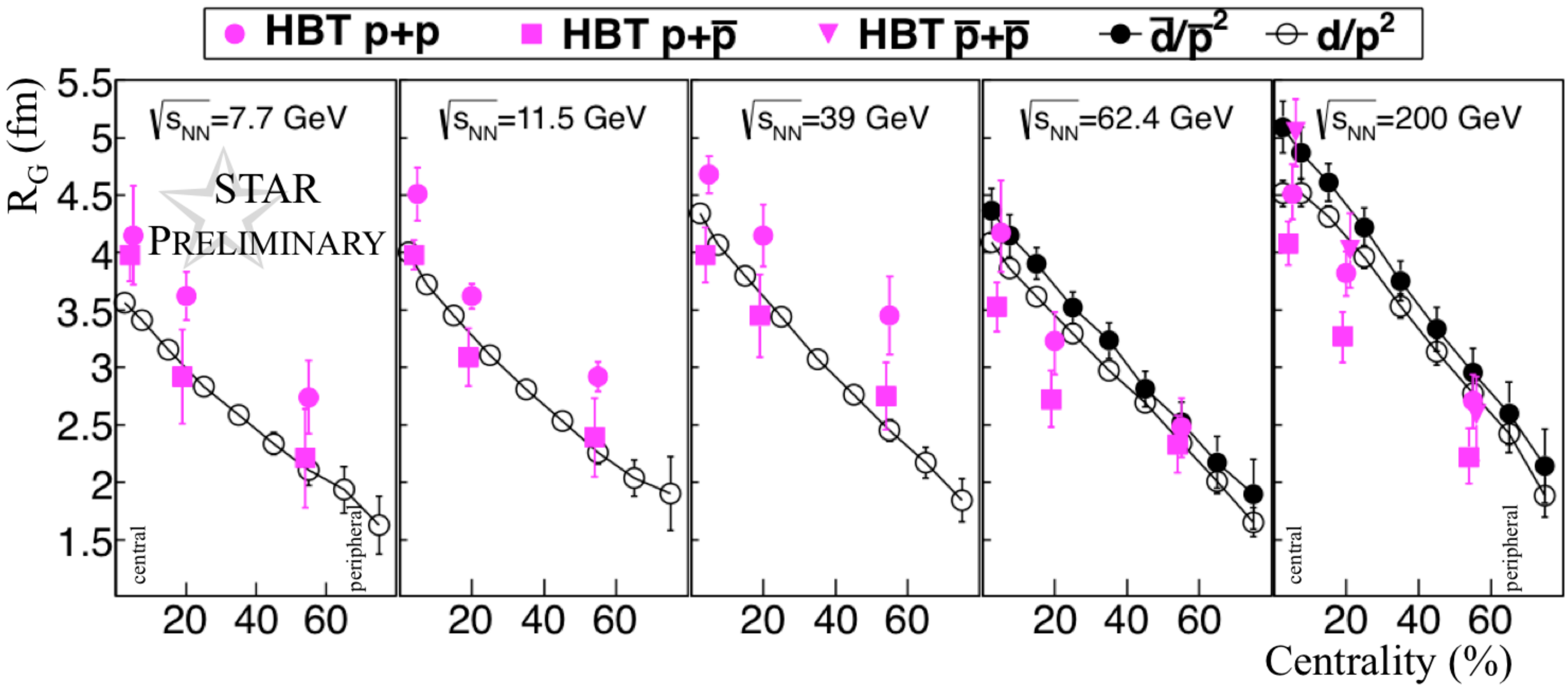


Proton density falls with $\sqrt{s_{NN}}$, Antiproton density rises with $\sqrt{s_{NN}}$
Trends reflect decreasing baryochemical potential, μ_B, with increasing $\sqrt{s_{NN}}$

Source "Homogeneity" Radii

$$B_2 = \frac{\sigma_d}{\sigma_p^2}, \quad (R_G^2 + \frac{\delta^2}{2})^{3/2} = \frac{3}{2}\frac{\pi^{3/2}\hbar^3}{B_2 m_p c^2}$$

(anti)deuteron Gaussian width: δ ~ 2 fm
m_p = proton mass



HBT results from H. Zbroszczyk, 7th WPCF, 2011
http://http://tkynt2.phys.s.u-tokyo.ac.jp/wpcf2011/talks/sept20/Zbroszczyk.pdf

Summary

- Light (anti)nuclei have been measured in Au+Au collisions at seven beam energies by STAR at RHIC.
- Spectra versus P_T, P_T/A, M_T/A, and M_T-M_0 provide information on the nucleon source near freeze-out.
- Hardening of the spectra with the mass number reflects strong transverse flow.
- Qualitative reproduction of B_2 values by UrQMD+dynamic coalescence calculation.
- Gaussian radii from B_2 values similar to that from (anti)proton intensity interferometry (HBT).
- Antiproton and proton phase space densities approach each other as $\sqrt{s_{NN}}$ increases, reflecting decreasing μ_B.