AntiNucleus Production at RHIC

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- AntiNucleosynthesis
- Preliminary STAR results for $\bar{d}$ and $^3\overline{He}$
- Future prospects in STAR
- Conclusions

AntiNucleosynthesis via Coalescence

- Composite particles formed via final-state coalescence:

Probe of spatial and momentum correlations among (produced) AntiNucleons

$$E\frac{d^3N_A}{dp^3} = B_A(E\frac{d^3N_p}{d(p/A)^3})^A$$

- Coalescence parameters related to source size:

$$B_A \propto (1/V)^{A-1}$$

V is effective volume.

- Expect,

$$V \propto (dN_{ch}/dy)^{\alpha}$$

$\alpha \leq 1$ (freeze-out at constant density)

AntiNucleus rates reflect competition between AntiNucleon production rate and increasing effective volume.

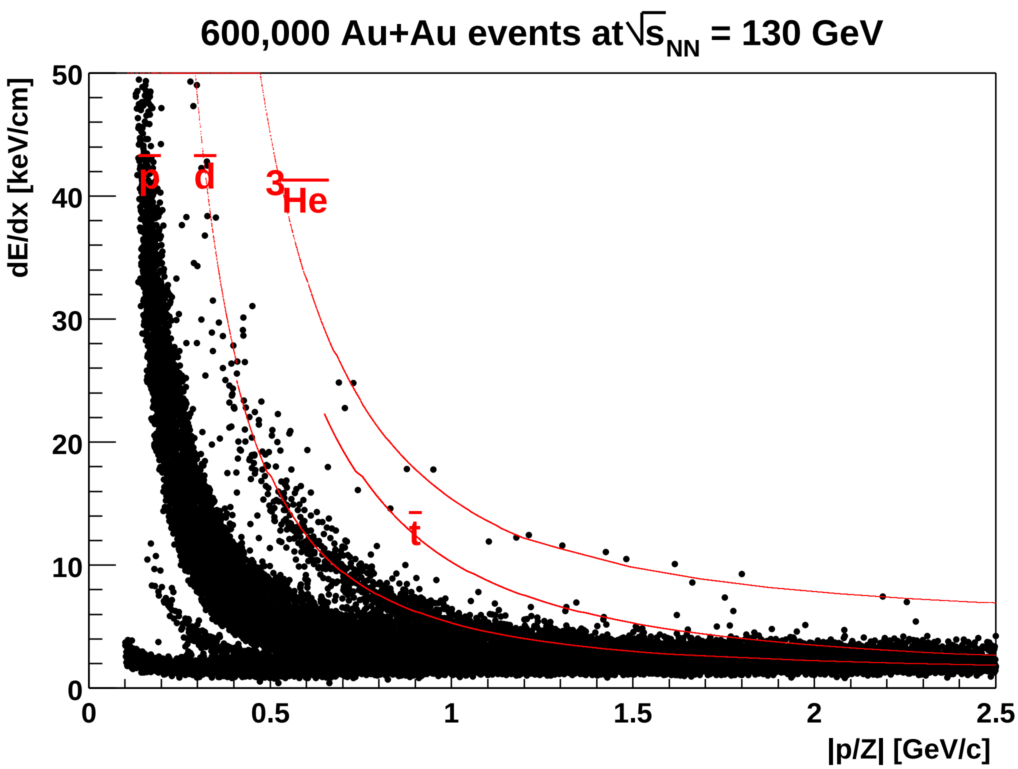
AntiNucleus Measurements in STAR

Identify AntiNuclei via ionization in TPC (dE/dx):

$$\frac{dE}{dx} = A * \frac{Z^2}{\beta^2}(B + ln(1 + \beta^2\gamma^2) - \beta^2)$$

- up to 45 dE/dx samples
- path-length L $\approx$ 1.4 meters
- Use 70% truncated mean to avoid Landau tails
- Optimum dE/dx resolution around 7%

Eliminate most π, K, track quality cuts, negative tracks ...

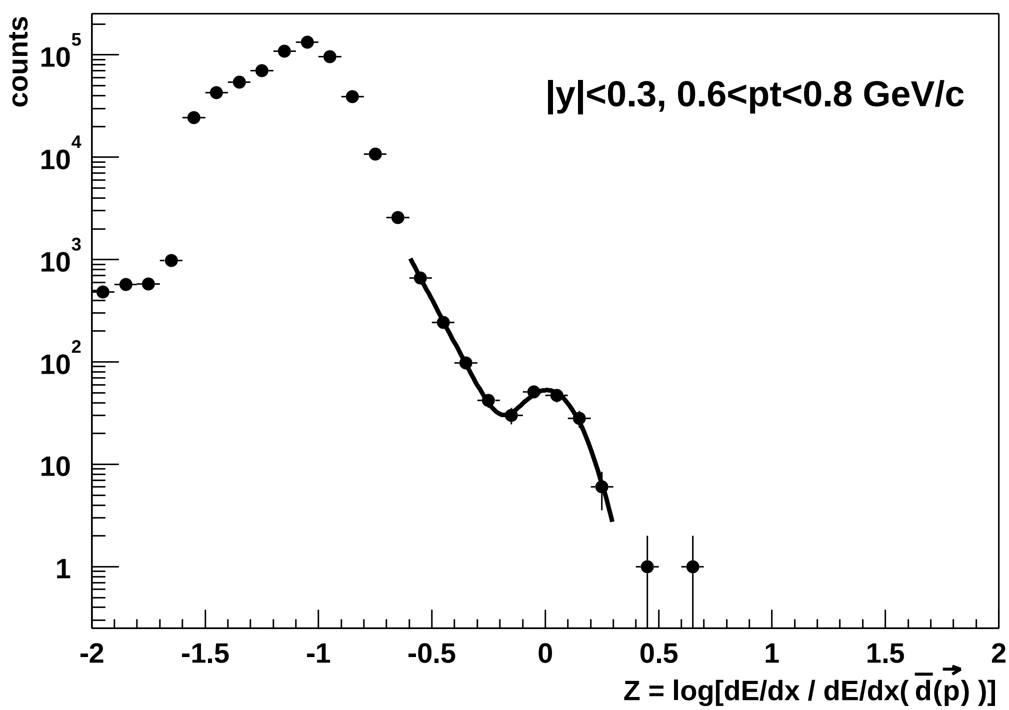


Extracting $\bar{d}$ yield

Define:

$$Z_i = log(\frac{dE/dx_{measured}}{dE/dx_{expected}(i, \vec{p})})$$

i = particle assumption



$$f(Z) = e^{A+B*Z} + D * e^{(Z-\mu)^2/\sigma^2}$$

- For this p_T bin, $\bar{d}$ yield = 145, $S/B(3\sigma) \approx 2.5$.
- At $0.4 < p_T < 0.6$ GeV/c, $\bar{d}$ yield = 94, $S/B(3\sigma) \approx 30$.

$\bar{d}$ yield

- Evaluate efficiency by embedding tracks into real events (Efficiency $\approx$ 30-40% due to tight PID cuts).
- Correct for absorption in detector ($\sigma_{inel}(\bar{d}) = \sqrt{2}\sigma_{inel}(\bar{p})$)

$\bar{d}$ Invariant Yields (top 10% σ_{geom}, $|y| < 0.3$):

$$\begin{aligned} \frac{1}{2\pi p_t}\frac{d^2N}{dydp_t} &= 2.54 \pm 0.26(stat.) \pm 0.64(sys.) \times 10^{-3} GeV^{-2} [p_T = 0.5 GeV/c] \\ & \quad 1.89 \pm 0.19(stat.) \pm 0.47(sys.) \times 10^{-3} GeV^{-2} [p_T = 0.7 GeV/c] \end{aligned}$$

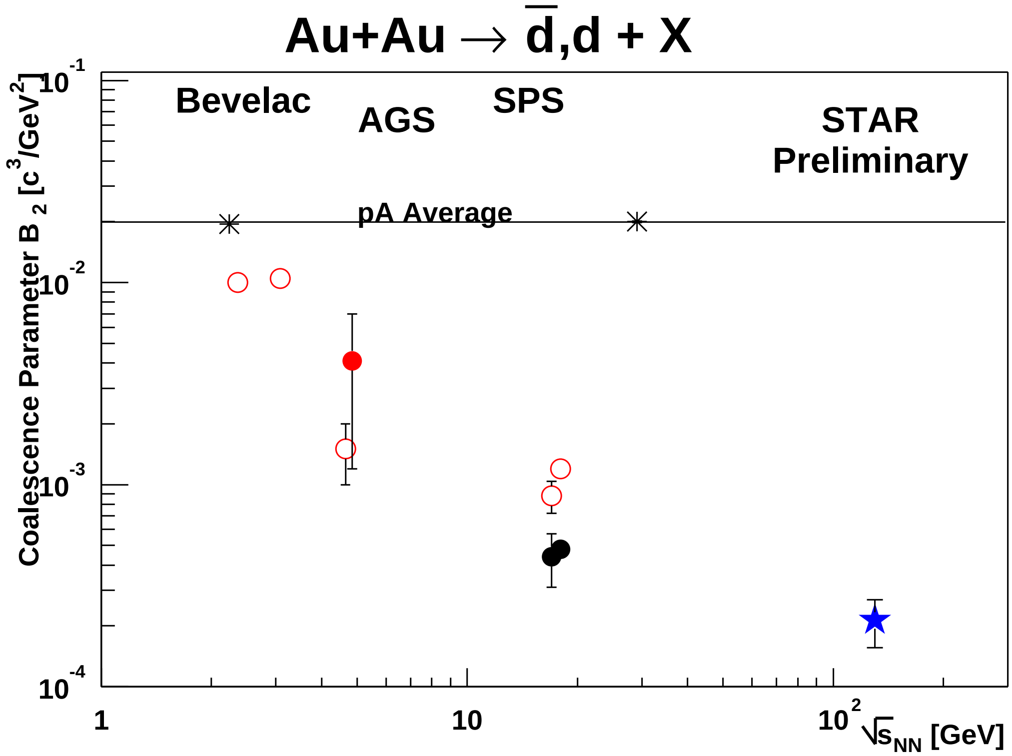
Factor of 50 increase from SPS

$\bar{p}$ Invariant Yields at same velocity (top 11% central):

$$\begin{aligned} \frac{1}{2\pi p_t}\frac{d^2N}{dydp_t} &= 3.29 \pm 0.18(stat.) GeV^{-2} [p_T = 0.275 GeV/c] \\ & \quad 3.05 \pm 0.10(stat.) GeV^{-2} [p_T = 0.35 GeV/c] \end{aligned}$$

$$B_2 = 2.13 \pm 0.20(stat.) \pm 0.53(sys.) \times 10^{-4} \frac{GeV^2}{c^4}$$

$d,\bar{d}$ Coalescence excitation function



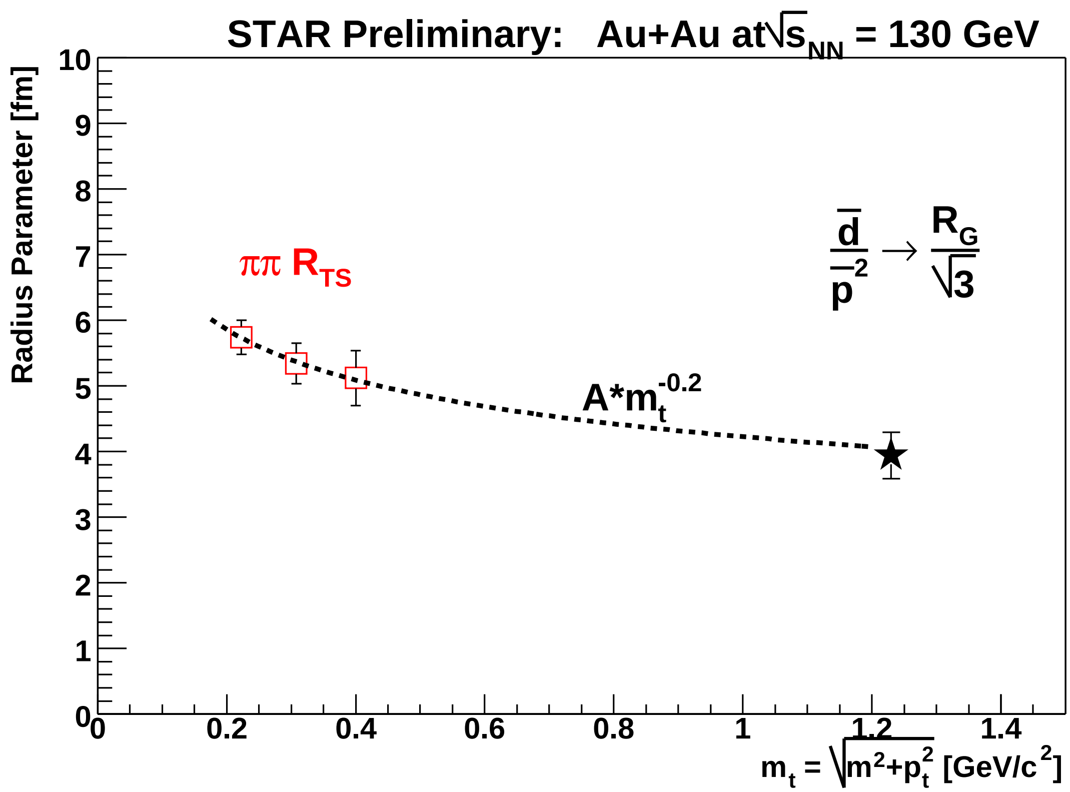
- Decrease in B_2 between SPS and RHIC.
- Assuming $B_2 \propto 1/V$, $123 \pm 77\%$ increase in volume relative to SPS.

Source Size Comparison to HBT

Using static Gaussian model (W. Llope et al.):

$$R_G^3 = \frac{3}{4}(\pi)^{3/2}(\hbar c)^3 \frac{m_d}{m_p^2}\frac{1}{B_2}$$

$$R_G = 6.83 \pm 0.21(stat.) \pm 0.57(sys.) fm$$



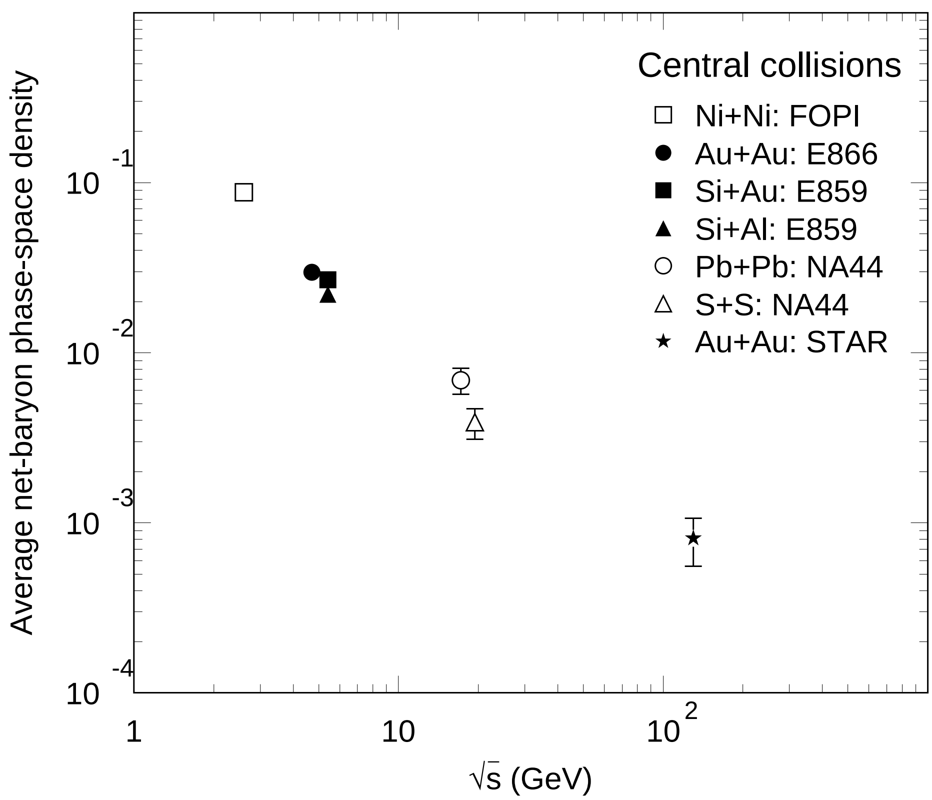
Net-Baryon phase space density

$$\langle f \rangle_{\overline{N}} = \frac{4}{3} \frac{\frac{1}{2\pi p_t} \frac{d^2 N_{(\bar{d})}}{dy dp_t}}{\frac{1}{2\pi p_t} \frac{d^2 N_{(\bar{p})}}{dy d(p_t/2)}}$$

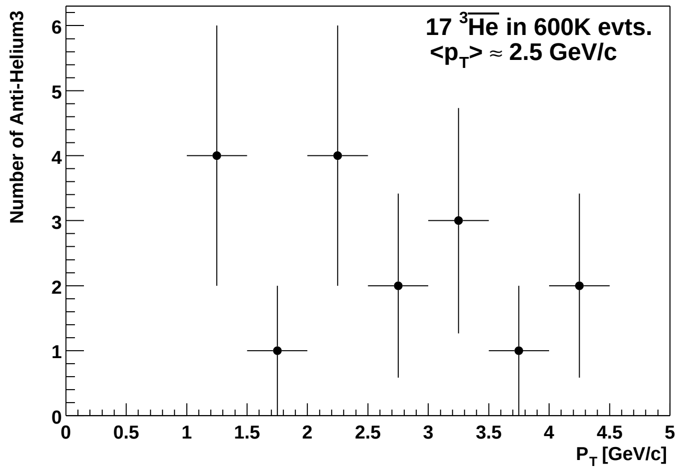
$$\bar{p}/p \approx 0.6 \rightarrow \langle f \rangle_{N-\bar{N}} \approx \frac{2}{3} \langle f \rangle_{\bar{N}}$$

To get net-baryon density, correct for Hyperons using Hijing:

$$\langle f \rangle_{B-\bar{B}} = 1.23 * \langle f \rangle_{N-\bar{N}}$$



Extracting ${}^{3}\overline{He}$ yield



- To extract invariant yield, calculate cross-section weighted average efficiency in STAR acceptance. Assume Boltzmann distribution with T=1.4 GeV.
- Correct for absorption using $\sigma_{inel}({}^{3}\overline{He}) = 2\sigma_{inel}(\bar{p})$.

${}^{3}\overline{He}$ Invariant Yield (top 20% σ_{geom},$|y| < 1$):

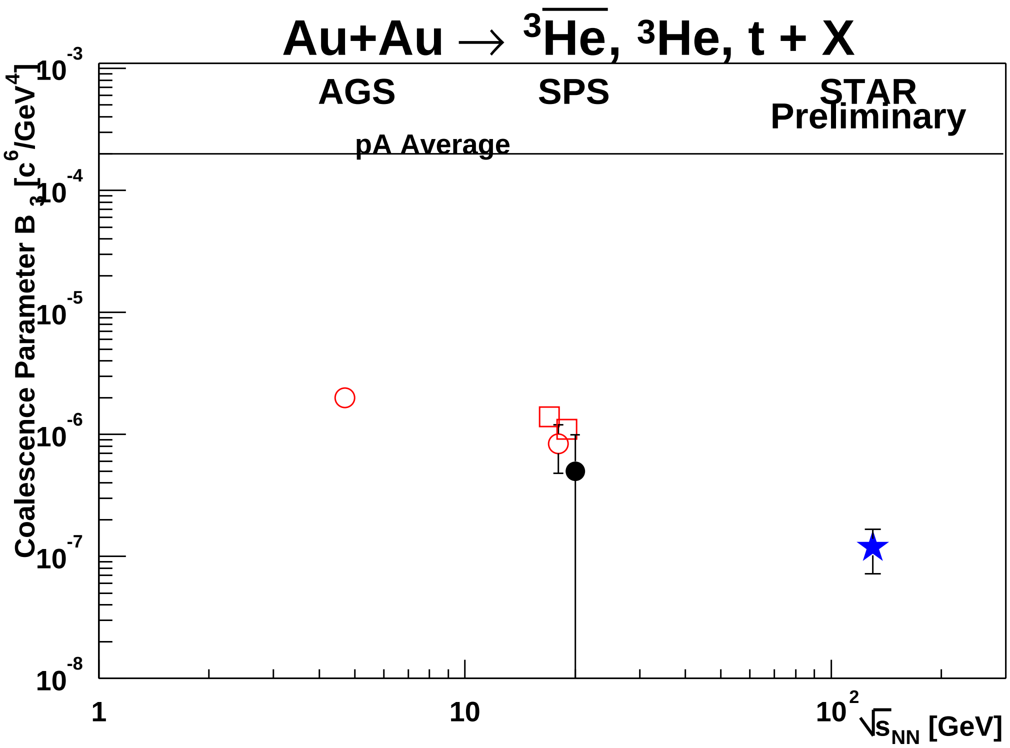
$$\frac{1}{2\pi p_t}\frac{d^2N}{dydp_t} = 9.4 \pm 2.2(stat.) \pm 2.3(sys.) \times 10^{-7} GeV^{-2} [p_T = 2.5 GeV/c]$$

$\bar{p}$ Invariant Yield at same velocity (top 18% central):

$$\frac{1}{2\pi p_t}\frac{d^2N}{dydp_t} = 1.99 \pm 0.09(stat.) GeV^{-2} [p_T = 0.825 GeV/c]$$

$$B_3 = 1.19 \pm 0.33(stat.) \pm 0.33(sys.) \times 10^{-7} \frac{GeV^4}{c^6}$$

t, ^3He, $\overline{^3He}$ excitation function



Assuming $B_3 \propto (1/V)^2$, $147 \pm 97\%$ increase in volume relative to SPS (average of ^3He and $^3\overline{He}$).

$^3\overline{He}$ dN/dy

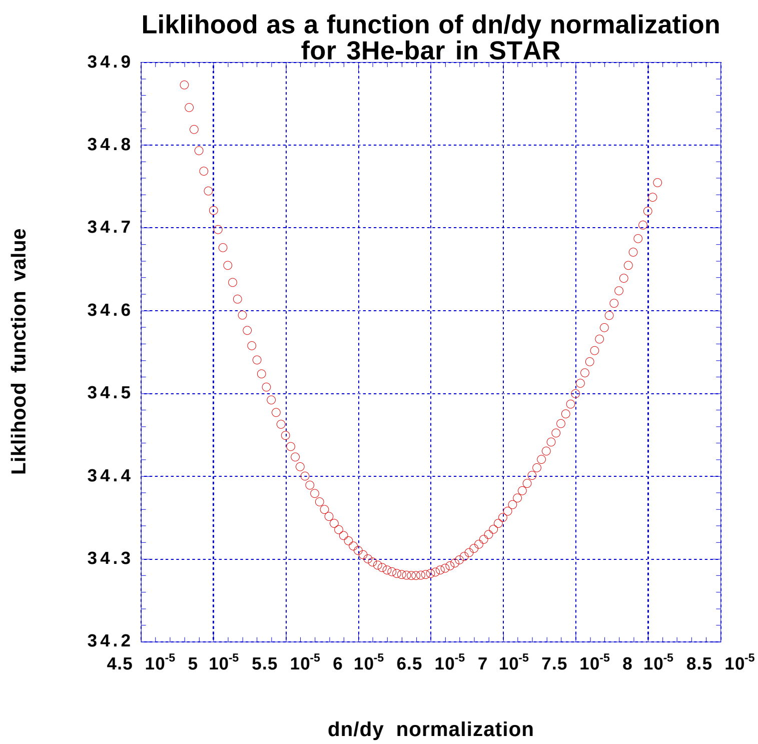
Extract dN/dy by assuming flat rapidity and Boltzmann p_T distribution:

$$\frac{d^2N}{dydp_T} = \frac{dN}{dy}\frac{p_T}{T(m+T)}e^{-(m_T-m)/T}$$

Calculate expectation for each y, p_T bin:

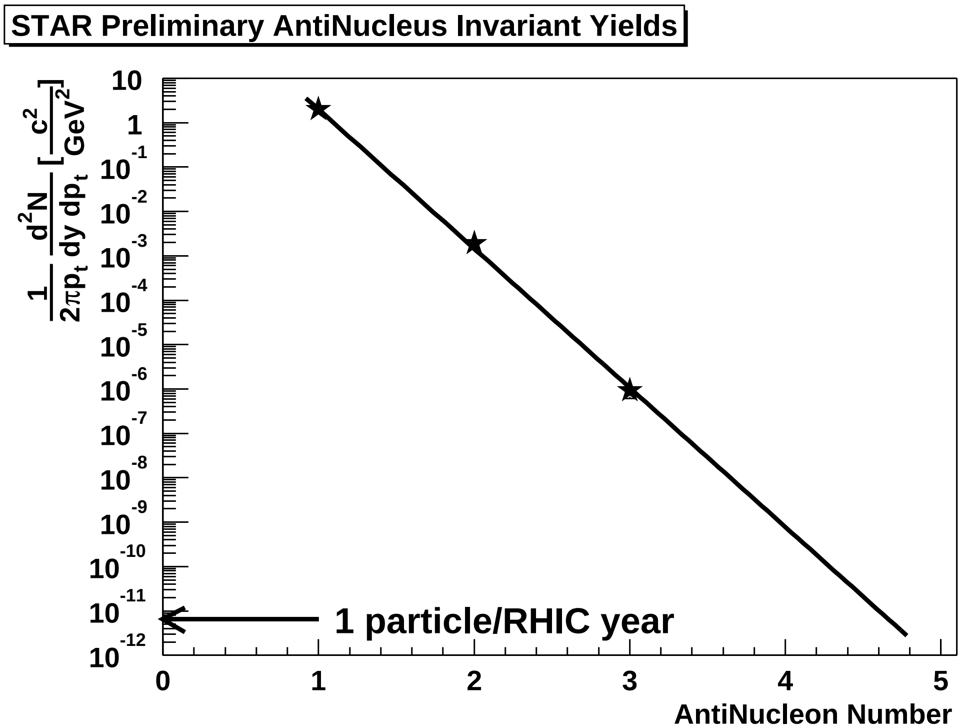
$$f(y, p_T) = \mathrm{efficiency(y, p_T)} * \frac{\mathrm{d^2N}}{\mathrm{dydp_T}}$$

Assuming a temperature of 1.05 GeV, minimize the log-likelihood over all measured (p_T, y) bins (including zeros):



$$\frac{dN}{dy} = 6.4 \pm 1.3(stat.) \pm 1.6(sys.) \times 10^{-5}$$

The Future – New AntiNucleus States



Above data at $\sqrt{s}_{NN} = 130$ GeV. Top RHIC energy at $\sqrt{s}_{NN} = 200$ GeV. Should have higher $\bar{A}$ yields.

Level-3 trigger – Online event reconstruction can identify Z=-2 candidates.

$\overline{^4He}$ possible

Conclusions

- Copious AntiNucleus Production at RHIC measured by STAR:
  - First measurements of $\bar{d}$ and $^3\overline{He}$ production show large increase in yields compared to lower energies.
  - Future possibilities for first observation of $\bar{\alpha}$ and beyond.
- Initial Coalescence parameters from $\bar{d}$ and $^3\overline{He}$ suggest roughly factor of 2 increase in AntiNucleon freeze-out volume relative to SPS.