Light Nucleus Production in p+p and the BES

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Outline:

Quick overview of major directions of this analysis
  Fragment spectra in p+p collisions
    B_2 and source radii (first measurement at RHIC)
  UE vs in-Jet differences, & dependence on Jet Energy (first measurement anywhere)

Fragment production in BES
  antinucleus production cross-sections and B_2 at low root-s (first measurement anywhere)
  source radii from B_2 vs P_T & \sqrt{s_{NN}} (some RHIC results at high-\sqrt{s_{NN}}, but not at BES/SPS energies)
  direct comparison to HBT (existing results from SPS, but not RHIC)
  (anti)baryon density vs \sqrt{s_{NN}} (significant extension in P_T using TOF, and in \sqrt{s_{NN}} in BES data)

Direct comparison to models (urqmd 2.3/3.3p1, AMPT, Pythia)
  millions of events (from SUG@R & davinci) + coalescence

Major effort recently has been on all the corrections
  Absorption
  Feeddown
  Reconstruction Efficiency
  TOF Matching
  PID Efficiency

Datasets Analyzed with the same code:
11 = p+p  62GeV  run-6  no TOF
12 = d+Au,  200GeV  run-8  no TOF
13 = p+p   200 GeV  run-8  no TOF
14 = p+p   500 GeV  run-9  partial TOF
15 = p+p   200 GeV  run-9  partial TOF
16 = Au+Au 200 GeV  run-10 full TOF
17 = Au+Au 62.4 GeV  run-10 full TOF
18 = Au+Au 39 GeV  run-10 full TOF
19 = Au+Au 7.7 GeV  run-10 full TOF
20 = Au+Au 11.5 GeV  run-10 full TOF
23 = Au+Au 19.6 GeV  run-11 full TOF
25 = Au+Au 27 GeV  run-11 full TOF

…an astoundingly rich data set from an awesome detector!
<table>
<thead>
<tr>
<th>Data</th>
<th>Nev</th>
<th>pythia</th>
<th>ampt</th>
<th>ampt(SM)</th>
<th>urqmd2.3</th>
<th>urqmd3.3p1</th>
</tr>
</thead>
<tbody>
<tr>
<td>pp 200 Run9</td>
<td>183M</td>
<td>653M</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>AuAu 200 Run 10</td>
<td>51.4M</td>
<td>84k</td>
<td>73k</td>
<td>663k</td>
<td>136k</td>
<td></td>
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<tr>
<td>AuAu 62.4 Run 10</td>
<td>48.2M</td>
<td>248k</td>
<td>246k</td>
<td>636k</td>
<td>256k</td>
<td></td>
</tr>
<tr>
<td>AuAu 39 Run 10</td>
<td>37.9M</td>
<td>328k</td>
<td>298k</td>
<td>836k</td>
<td>236k</td>
<td></td>
</tr>
<tr>
<td>AuAu 27 Run 11</td>
<td>46.2M</td>
<td>759k</td>
<td>696k</td>
<td>1.74M</td>
<td>390k</td>
<td></td>
</tr>
<tr>
<td>AuAu 19.6 Run 11</td>
<td>27.8M</td>
<td>1.02M</td>
<td>690k</td>
<td>1.73M</td>
<td>410k</td>
<td></td>
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<tr>
<td>AuAu 11.5 Run 10</td>
<td>15.5M</td>
<td>456k</td>
<td>280k</td>
<td>1.84M</td>
<td>492k</td>
<td></td>
</tr>
<tr>
<td>AuAu 7.7 Run 10</td>
<td>4.8M</td>
<td>984k</td>
<td>708k</td>
<td>4.92M</td>
<td>2.74M</td>
<td></td>
</tr>
</tbody>
</table>

**Experimental Goals:**

Cross-sections for p, d, t (³He, α) versus P_T and P_T/A
in p+p, cross-referencing of tracks in jets to jet energy, angles, etc

Coalescence ratios: B_A vs P_T/A
interpretable in terms of source volumes

Spectra ratios: d/p & t/p vs M_T/A
(net baryon density)

**Theory:**

6-D Dynamic Coalescence using various models.... Pythia, AMPT, UrQMD
Source radii directly from B_A vs P_T/A.... several prescriptions & compare to HBT
World’s Data on $B_2$ in various entrance channels

Comparison to world’s data.....

$B_2 \sim 0.02$

but PT lower limit to avoid inefficiency

These are the run-8 points, p+p will be superseded by run-9 (lots of TOF)

<table>
<thead>
<tr>
<th>Summary* so far:</th>
<th>Experiment</th>
<th>Coalescence Picture:</th>
<th>Pythia+$\Delta p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>p+p, 200 GeV, Run-8:</td>
<td>$B_2 = 0.02 \text{ GeV}^2$</td>
<td>$R \sim 3.3 \text{ fm}$, $p_0 \sim 180 \text{ MeV}$</td>
<td>$\Delta p \sim 210 \text{ MeV}$</td>
</tr>
<tr>
<td>d+Au, 200 GeV, Run-8:</td>
<td>$B_2 = 0.01 \text{ GeV}^2$</td>
<td>$R \sim 4.2 \text{ fm}$, $p_0 \sim 150 \text{ MeV}$</td>
<td>$\Delta p \sim 180 \text{ MeV}$</td>
</tr>
</tbody>
</table>
Dependence of $B_2$ for $p,d$ in Jets vs Jet energy

$B_2 \sim 0.2$

$B_2 \sim 0.002$

$B_2 \sim 0.02$

strong increase in $B_2$ (strong decrease in “source volume”) with inc. $E_{jet}$
Dependence of $B_2$ for p,d in Jets vs Jet energy, from Pythia

Pythia also shows strong increase of $B_2 (1/"V")$ with jet energy.
Antinucleus Production at very low (~SPS) root-s

dbar spectra, and dbar/pbar & B_2 ratios at these very low root-s values not reported by any of the SPS experiments
Cuts and PID

Event Cuts:
\[ |Z_{vtx}| < 50, R_{vtx} < 2, |\eta_{asym}| < 5, |\eta_{asymTOF}| < 5, N_{tofmatch} > 5 \]
refmullt centrality
minimum bias trigger in st_physics stream

Track Cuts:
flag=301, \( N_{\text{hitsfit}}/N_{\text{hitsposs}} > 0.52 \)
“cuts set1”: \( N_{\text{hitsfit}} > 15, N_{\text{hitsdedx}} > 10, \text{gldca} < 2 \)
“cuts set2”: \( N_{\text{hitsfit}} > 25, N_{\text{hitsdedx}} > 15, \text{gldca} < 1 \)
TOF: matchflag>0, |ylocal|<1.8, \( \beta > 0 \)

PID:
“dE/dx-TOF”: log-Z cut on POI, p<0.9 (p), p<1.3 (d), p<1.7 (t)
if TOF info exists (~65-70%), require that \( M^2 \) is consistent with POI
full efficiency but mom’n limited, uses TOF to clean up dE/dx where possible

“dE/dx+TOF”: log-Z cut on POI, no momentum upper limit
require TOF info exists, and require that \( M^2 \) is consistent with POI
65-70% as efficient, but much wider mom’n reach
log(Z) = log(dE/dx(track))/dE/dx(Bichsel) vs. momentum…

what’s this junk?

It’s merged tracks!

plot dE/dx for 1/β < 1.03

rate can be large compared to Abar rate! TOF kills these quite effectively…
absorption
  pbar handled by geant/embedding
  Abar cannot be done w/ geant, need to use an empirical approach

feeddown
  simulation/reconstruction of full events from some model

reconstruction efficiency
  embedding

TOF matching

Not done yet:
  PID Efficiency
  Sector 20
geant does not know how to interact antinuclei w/ arbitrary materials
so use prescription described in Christof Struck’s thesis…
same prescription used in recent antialpha paper after scaling the materials
(remove SVT, add half-depth of TOF)
geant does know how to interact pbars, so one can test the absorption prescription using embedding data!
Light nuclei in $p+p$ and the BES

Feeddown

UrQMD 3.3p1
starsim & Y2010c
geom repairs
realistic $\sigma_{Z_{vtx}}$
bfc.C
TpcRS
MiniMcMk

TpcRS is slow
but most realistic…
no dE/dx fudging!

Uncovered problems in trs
unknown species was given a geantID=0, and then no energy loss, and then no rec. tracks
Fix entailed changes to trs and StarClassLibrary to properly include light antinuclei…
see RT Ticket #2157.
Lots of technical problems in many different codes….  
(many thanks to Hiroshi, Xiangli, Geraldo, Xianglei, Gene, Jason, & Victor!)

**Block 1:**
- dbar in p+p, 200 GeV, run-9  
  20101704  
  DONE  
- dbar in Au+Au, 200 GeV, run-10  
  20101706  
  DONE  
- dbar in Au+Au, 11.5 or 39, run-10  
  20101708  
  DONE

**Block 2:**
- tbar in p+p, 200 GeV, run-9  
- dbar in Au+Au, 200 GeV, run-10  
- tbar in Au+Au, 11.5 or 39, run-10  
- pbar in p+p, 200 GeV, run-9  
- pbar in Au+Au, 200 GeV, run-10  
- pbar in Au+Au, 11.5 or 39, run-10

I also found some existing embedding productions laying around….  
- pbar  
  p+p  
  200 GeV  
  20101701  
- pbar  
  Au+Au  
  39 GeV  
  20103206  
- pbar  
  Au+Au  
  7.7 GeV  
  20103604

OOPS! These were done in SL11c.  
Comparison to the newly available SL10k_emb shows different gIDCA distributions & efficiencies  
…..need to repeat the Block 1 requests (underway)
Light nuclei in p+p and the BES

Embedding

hnprimary

pbar, dbar embedding

- dbar pp200 20101704
- pbar pp200 20101701
- pbar pp200 20101704_test
- dbar AuAu200 20101706_test
- dbar AuAu200 20101706
- pbar AuAu39 20103206
- pbar AuAu7.7 20103604
Light nuclei in p+p and the BES

Embedding
1σ cut on dE/dx, then plot probability there is a TOF match for this track vs. \( P_T \)…. 

Different boxes are refmult bins (same as for embedding) 

- plateau efficiency decreases with refmult 
  (single track requirement in BTofMatchMaker) 
- efficiency: Run-11 > Run-10 
- efficiency: antiparticle < particle 
  (absorption in OFC, TPC rail, TOF box) 

Results in \( 3\times2\times3 \) functions vs \( P_T \)… 

\((p,d,t) (+,-) (\text{run}9,10,11)\)
If TOF match efficiencies are correct, then \( \frac{dE}{dx}-\text{TOF} \) results and \( \frac{dE}{dx}+\text{TOF} \) results should lie on top of each other in the overlapping \( P_T \) range.
Comparison to Lokesh’s protons

Lokesh’s xsecs are not feeddown corrected, mine are.
My FD-uncorrected protons are dead on top of lokesh’s p’s, my pbar’s ~20% less…
Comparison to published d’s and dbar’s
Light nuclei in p+p and the BES

Ratio checks motivated by coalescence arguments

![Graphs showing data and spallation](Image)

STAR Regional Meeting, Kolkata, India January 9-11, 2012
Light nuclei in p+p and the BES

B2 vs $P_T/A$ by $\sqrt{s_{NN}}$ and centrality
Light nuclei in $p+p$ and the BES

$R_g$ vs $\sqrt{s_{NN}}$, $P_T/A > 0.4 \text{GeV/c}$

closed: particle
open: antiparticle
Light nuclei in p+p and the BES

dbar/pbar vs. $P_T$, comparison to Pythia+coalescence

**Graph:**
- **Graph Title:** dbar/pbar vs $P_T$, p+p 200 Run-9
- **Legend:**
  - pythia $\Delta P=400\text{MeV}$
  - pythia $\Delta P=300\text{MeV}$
  - pythia $\Delta P=200\text{MeV}$
  - pythia $\Delta P=100\text{MeV}$
- **Labels:**
  - Open: TPC-TOF, Closed: TPC+TOF

**Axes:**
- X-axis: $P_T$ (in units of GeV/c)
- Y-axis: $\frac{dN}{dP_T}$ (in units of $10^{-7}$ to $10^{6}$)

**Data Points:**
- Open data points for TPC-TOF
- Closed data points for TPC+TOF

**Note:**
- The graph compares the dbar/pbar distributions for different values of $\Delta P$ in Pythia simulations, with the STAR experimental data for TPC-TOF and TPC+TOF compared.
Summary

Trying to produce $p(\bar{p})$ and $A(\bar{A})$ cross-sections with all corrections for all Au+Au data sets plus p+p

Lots of corrections, and not all are easy to get.
…Getting close though…

Must be careful with PID, merged tracks, TOF-matching, etc.

The corrected cross-sections lead to
- $B_A$ ratios and source radii, comparison to HBT ($\Phi_{RP}$-dependence?)…
- d/p ratios and baryon densities…
- source density profiles, degree of equilibration, & other inferences…
  etc…

widest & most detailed root-s measurement in a single & wide acceptance
first measurement of spectra & $B_A$ for antinuclei at low end of SPS range
first observation of dependence of $B_2$ on jet energy
backup
Light nuclei in p+p and the BES

B_2 from Data and from Dynamic Coalescence on Pythia events

dbar/pbar vs P_T, p+p 200 Run-9
Open: TPC-TOF, Closed: TOF+TOF
B₂ vs Pₜ/A vs centrality

B₂ increases ("V" decreases) as collisions get more peripheral
Source Radius at freezeout from $B_2$ values

conversion of $B_A$ into $R_G$ done via WJL et al., PRC 52, 2004 (1995).

hard-sphere $R = 2.2R_G$
hard-sphere $R = 2.2R_G$

conversion of $B_A$ into $R_G$ done via WJL et al., PRC 52, 2004 (1995).

☆HBT
nucl-ex/0411036v2

compare:
$R_G$ and $(R_S^2 R_L)^{1/3}$

Nice agreement at SPS (NA44)
Light nuclei in p+p and the BES

Baryonic Phase Space Density (d/p with a simple prefactor)
then scale the sim x-secs to measured x-secs

then scale the sim FD ratios…

FD ~ 50%
(minbias AuAu200)

no measured $\Sigma^\pm$
…scale by $\Sigma/\Lambda$…

extremely CPU intensive…

will need to pick a few root-s values
and then interpolate…

also “embedding” dbar,tbar
…just for fun – no cost…
Light nuclei in p+p and the BES

Embedding, dbar in p+p 200GeV Run-9 20101704

\[ f(P_T) = p_0 \times \exp\left(\left(\frac{P}{P_T}\right)^{p_1}\right) + p_3 \times P_T \]

\begin{align*}
p_0 &= 0.766 \pm 0.00032 \\
p_1 &= 0.354 \pm 0.00001 \\
p_2 &= 4.235 \pm 0.00002 \\
p_3 &= 0.014 \pm 0.00000
\end{align*}

\[ f(P_T) = p_0 \times \exp\left(\left(\frac{P}{P_T}\right)^{p_1}\right) + p_3 \times P_T \]

\begin{align*}
p_0 &= 0.802 \pm 0.00000 \\
p_1 &= 0.389 \pm 0.00018 \\
p_2 &= 3.164 \pm 0.00000 \\
p_3 &= 0.006 \pm 0.00000
\end{align*}
Embedding (weird shape of dbar eff in p+p 200GeV Run-9 20101704)

dbar efficiency follows pbar efficiency up to ~0.5GeV/c  (?!?)