Recent Result on Pentaquark Searches from STAR @RHIC

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The STAR Collaboration

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Outline

• Pentaquark Searches in STAR
• The Puzzle Continues
• RHIC – as an Exotic Particle Factory
Au + Au Collisions at RHIC

Central Event

STAR
(real-time Level 3)
STAR Pentaquark Searches

\[ \Theta^+ \rightarrow p + K_S \]

\[ \Theta^{++} \rightarrow p + K^+ \]

Data Set:

- Au + Au 200 GeV run 2 (~1.7 M, 30-80%)
- p + p data 200 GeV run 2 (~6.5 M)
- d + Au 200 GeV run 3 (18.6 M)
- Au + Au 63 GeV run 4 (5.6 M)
- Cu + Cu 63 GeV run 5 (16.5 M)
- Au + Au 200 GeV Run 4 (10.7 M, 20-80%)
Particle identification

Particle Identification: dE/dx from TPC

![Graph showing dE/dx vs. Rigidity for all tracks with data table]

<table>
<thead>
<tr>
<th>hde1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries: 2.019601e+08</td>
</tr>
<tr>
<td>Mean x: 0.008617</td>
</tr>
<tr>
<td>Mean y: 2.685e-06</td>
</tr>
<tr>
<td>RMS x: 0.7003</td>
</tr>
<tr>
<td>RMS y: 6.607e-07</td>
</tr>
</tbody>
</table>
dAu results

\[ 0.5 \text{GeV}/c < p_t < 1.2 \text{GeV}/c, -0.5 < y < 0.5 \]

\[ pK^+ \text{ and } \bar{p}K^- \text{ from 18.6 M d+Au at 200 GeV} \]

Background – Combinatorial and Correlated Pairs
dAu results

The invariant mass distribution is fitted to a Gaussian plus a linear function. A 3.5-5.0 sigma signal is seen. Measured mass is about 1.53 GeV/c². Full width is about 15 MeV.
Θ^{++} and Λ(1520) Using the Same Analysis Procedure

Same charge Sign (SS) and Opposite Sign (OS) background different
Background Shape Depends on Cuts

\[0.5 \text{GeV/c} < \text{pt} < 1.2 \text{GeV/c}, -0.5 < y < 0.5\]

\[0.4 \text{GeV/c} < \text{pt} < 1.2 \text{GeV/c}, -0.9 < y < 0.9\]

- \(K\) [0.2-0.6] GeV/c
- \(P\) [0.3-1.5] GeV/c
- \(K\) [0.2-0.6] GeV/c
- \(P\) [0.3-1.0] GeV/c
Possible Sources of Background

Double Conversion of $\pi^0$ photons

$\pi^0 \rightarrow \gamma \gamma \rightarrow e^+e^- e^+e^-$

Same-sign e’s within the K and p bands

mostly in the low mass region
opening angle cut $\rightarrow$ very effective

Associated production

$\Lambda K^+ \rightarrow p\pi^- + K^+$

These background sources contribute to the residuals in the event-mixing. But they do not produce a narrow peak!
$\Delta^{++} \rightarrow \pi^+ p$ and using $\pi$ as $K$

- For $0.5 \text{ GeV/c} < p_t < 1.2 \text{ GeV/c}, -0.5 < y < 0.5$
  - Slope depends on the level of pion contamination ($p$ cut)!

- For $0.4 \text{ GeV/c} < p_t < 1.2 \text{ GeV/c}$
Other PID Cuts

Kaon $0.2 < p\&pt < 0.7$, Proton $0.3 < p\&pt < 1.0$, no opening angle cut

$0.5 \text{GeV/c} < \text{pt} < 1.2 \text{GeV/c}$, $-0.5 < y < 0.5$

Invariant Mass (GeV/c$^2$)
Other PID Cuts

Kaon $0.2 < p\&pt < 1.0$, Proton $0.3 < p\&pt < 1.5$, no opening angle cut

![Graph showing a distribution with binomial data]

- $\chi^2$ / ndf: 70.65 / 53
- Raw Yield: $3452 \pm 835.3$
- FWHM/Sigma: $0.006963 \pm 0.001205$
- Mass: $1.531 \pm 0.002$
- $pol0$: $-5.966e+04 \pm 405$
- $pol1$: $1.125e+05 \pm 319$
- $pol2$: $-6.807e+04 \pm 194$
- $pol3$: $1.327e+04 \pm 90$
Can the Peak Be Real??

\[ pK^+ + \bar{p}K^- \]
$\Delta/N^*(1535)$ decay and $\pi \rightarrow K$ does not make the peak

$N^*(1535) \rightarrow p\pi$ wrong charge for $\theta^{++}$. 
$N^*(1535) \rightarrow N\pi\pi$ and $\pi \rightarrow K$ cannot make the peak either

Nstar Mass: 1535 MeV
Nstar FWHM: 150 MeV

Peak at $\sim$1460 MeV
AuAu 62.4 GeV Results

- AuAu 62 GeV data
- 20-80% centrality bin
- 5.6 M events
- Weak Signal (3sigma) if any

Kaon p&pt (0.2, 0.6)
Proton p&pt (0.3, 1.5)
AuAu 200 GeV Run 4 Results

- Year 4 AuAu 200 GeV data
- 20-80% centrality bin
- 10.7 M events
- No Significant Signal (2σ)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi^2 / \text{ndf}$</td>
<td>10.27 / 15</td>
</tr>
<tr>
<td>Raw Yield</td>
<td>$7310 \pm 3627.0$</td>
</tr>
<tr>
<td>FWHM/Sigma</td>
<td>$0.005 \pm 0.002$</td>
</tr>
<tr>
<td>Mass</td>
<td>$1.53 \pm 0.00$</td>
</tr>
<tr>
<td>pol0</td>
<td>$7.02e+05 \pm 4108$</td>
</tr>
<tr>
<td>pol1</td>
<td>$4.31e+05 \pm 2928$</td>
</tr>
<tr>
<td>pol2</td>
<td>$2.948e+05 \pm 1892$</td>
</tr>
<tr>
<td>pol3</td>
<td>$1.757e+05 \pm 1109$</td>
</tr>
</tbody>
</table>

Kaon p&pt (0.2, 0.6)
Proton p&pt (0.3, 1.5)
Cu+Cu 62.4 GeV Run 5 Data

Year 5 CuCu 62 GeV data
0-70% centrality bin
16.5 M events
No signal at all !!
Is There an Obvious Contradiction?

The signal is not significant in Au+Au systems!

d+Au is indeed a favored system:

- signal strength and combinatorial background!!
- RHIC should have another long d+Au run!!
## A Stringent Limit from HERA-B

<table>
<thead>
<tr>
<th>HERA-B</th>
<th>hep-ex/0408048</th>
</tr>
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<tbody>
<tr>
<td>$\sqrt{s}$</td>
<td>42 GeV</td>
</tr>
<tr>
<td>$pA$ (C,Ti,W)</td>
<td>200 M inelastic events</td>
</tr>
<tr>
<td>$\theta^+/\Lambda$</td>
<td>$&lt;0.92%$; 95%CL</td>
</tr>
<tr>
<td>$\theta^+/\Lambda(1520)$</td>
<td>$&lt;2.7%$; 95% CL</td>
</tr>
</tbody>
</table>

Does this imply $\Lambda(1520)/\Lambda \sim 34\%$?

### Our Estimate in STAR

<table>
<thead>
<tr>
<th>d+Au</th>
<th>sqrt(s) 200 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta^{++}/\Lambda$</td>
<td>$\sim 0.35%$</td>
</tr>
</tbody>
</table>

STAR $\Lambda(1520)/\Lambda \sim 10\%$ (corrected for branching ratio)!
The Puzzle Continues

1) If pK\(^+\) peak at 1530 MeV/c\(^2\) is a real pentaquark, then I = 1 likely, there must be a \(\theta^+\). But the recent JLab null result on \(\theta^+\) casts serious doubt on the observation of \(\theta^+\).

2) The STAR observed yield is so small such that many experiments would not have the sensitivity to see it.

3) Within the STAR data we have not seen any significant peak signal in p+p data and Au+Au at 200 GeV and Cu+Cu 62 GeV. What do these null observations mean? Production dynamics or data set bias unknown to us? What is so special about d+Au 200 GeV (18.6 M events)?

4) Can the formation is such that photo-production is not favored?
An Intriguing Production Mechanism

If θ is a real particle, the production is different from normal hadrons which can be described by thermal statistical model.

Coalescence Mechanism --

pK\(^+\) Interaction – Repulsive (not favored)
ΔK\(^+\) Interaction – Attractive !!

ΔK Coalescence → Θ → pK\(^+\)
(NπK = 1575 MeV; ΔK>NπK; but Δ is very wide !)

Δ lifetime ~ 1 fm → not easy for the coalescence process in e+e, photo-production and p+p collisions.

Θ spin 3/2, parity -1; pK d-wave decay → narrow width
(KN formation scattering may not be so sensitive?!)

p+A collisions favored !
Coalescence Production Abundant @RHIC

Many anti-deuteron production!
Combinatorial Background killer for $\theta$ in A+A!
RHIC – Exotic Particle Factory

RHIC – Very Dense Partonic Matter and Rapid Hadronization
-- Hadron Formation Through Parton Clustering (coalescence/recomb.)

→ Unique Collision Environment for Possible Exotic Particles Formation
→ Exotic Mesons, Pentaquarks, Di-baryons $[\Omega\Omega]$ and Strangelets
Clustering and Surface Emission

Volcanic mediate $p_T$ – Spatter (clumps)

Enhancement of Clusters at intermediate $p_T$!
(baryons and hyperons)

Search for Multi-quark (>3) Cluster State at RHIC!
Exotic Particles

Hadrons with internal structure beyond existing QCD qqq and q-qbar framework !!

RHIC –
Dedicated QCD Machine & Beyond

(Deconfinement Phase Transition)

Exotic

(CGC, EMC)
The End
STAR – Exciting Physics Program
A full TOF and Heavy Flavor Tracker upgrade will greatly enhance STAR’s capability!!
$\Theta^+ \rightarrow K_s P$

dAu data, $K_s$ was identified by topological method

- The $\Theta^+$ is probably there, several reasons may be responsible for the less significant signal:
  - Smaller branching ratios
  - Half of the $K_s$ will become $K_L$
  - Efficiency for finding $K_s$ at low $pt$ is low

- This year’s AuAu data may give us an answer?
Other PID Cuts

Kaon $0.2 < p\&pt < 0.8$, Proton $0.3 < p\&pt < 1.5$, no opening angle cut
Other PID Cuts

Kaon $0.2 < p\&pt < 0.8$, Proton $0.3 < p\&pt < 1.0$, no opening angle cut
Is There an Obvious Contradiction?

The signal is not significant in Au+Au systems!
\( \Lambda(1520) \rightarrow pK^- \) branching ratio ~ 22%, corrected for the ratio.
d+Au is indeed a favored system:
signal strength and combinatorial background!!
RHIC should have another long d+Au run!!