using STAR Data

\[
\frac{1}{2\pi p_T} \frac{d^2N}{dy dp_T} \rightarrow \frac{dE_T}{d\eta}
\]
Motivation

\[ \epsilon = \frac{1}{V} \frac{dE_T}{dy} = \frac{J}{A_T \tau c} \frac{dE_T}{d\eta} \]

- Cross check data
- Study PID distribution of energy
- Understand \( E_T/N_{ch} \) better
Calculating $E_T$ from spectra

\[ E_T = \sum_{j=1}^{M} E_{T_{\text{particle } j}} \]

5-10% $\pi^-$ Au+Au $\sqrt{s_{NN}}=39$ GeV

- Strange hadron production in Au+Au collisions at $\sqrt{s_{NN}} = 7.7, 11.5, 19.6, 27,$ and $39$ GeV
  - Phys. Rev. C 102, 034909 (2020)

- Bulk Properties of the Medium Produced in Relativistic Heavy-Ion Collisions from the Beam Energy Scan Program
  - $\pi^\pm, K^\pm, p,$
  - Distance of closest approach to primary vertex $< 3$ cm
  - Includes most but not all daughters

Data

\[ E_T^{\text{PID}} = \int_0^{p_T^{\text{min}}} f(p_T) E_T dp_T + \sum_{i=1}^{N} \int_{p_T^{i}}^{p_T^{\text{max}}} \frac{d^2 N_i}{dy dp_T} E_T(p_T^i, m) + \int_{p_T^{\text{max}}}^{\infty} f(p_T) E_T dp_T \]

Fit

Christine Nattrass, APS April Meeting, 19 April 2021
Calculating $E_T$ from published spectra

$$E_T = f_\pi E_T^{\pi \pm} + f_K E_T^{K \pm} + f_p E_T^{p, \bar{p}} + f_\Lambda E_T^{\Lambda, \bar{\Lambda}}$$
Pion correction $f_\pi$

- Pion ratios influenced by short-lived resonances, dominated by $\eta$ & $\omega$
- Measured ratio of $\pi^0/\pi^\pm$ roughly consistent with PYTHIA*

*Yuri Kharlov, internal ALICE presentation
Pion correction $f_\pi$

$$\eta, \omega, X \rightarrow \pi^0, \pi^\pm$$

$$f_\pi = 1.56 \pm 0.02$$

- $m_T$ scaling
- match to $\eta/\pi^0$ & $\omega/\pi^0$ data
- 100% uncertainties
Kaon correction \( f_K \)

- Also potentially impacted by resonances
- Used ratios of the (preliminary) yields from BES data

\[ f_K = 1.8 \pm 0.2 \]
Proton correction $f_p$

- Lower limit: $f_p = 2$
- Upper limit:

  Yield=Primordial+Generated
  Antibaryons=Generated
  Baryons=Primordial+Generated

  Primordial $n/p = N/Z$

\[
\frac{N_n + N_{\bar{n}}}{N_p + N_{\bar{p}}} = \frac{N / Z + (2 - N / Z) N_{\bar{p}} / N_p}{1 + N_{\bar{p}} / N_p}
\]

<table>
<thead>
<tr>
<th>$\sqrt{s_{\text{NN}}}$</th>
<th>$\frac{N_p}{N_p}$</th>
<th>Ref.</th>
<th>$f_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.7</td>
<td>0.0073 ± 0.0002 ± 0.0006</td>
<td>3</td>
<td>2.49 ± 0.49</td>
</tr>
<tr>
<td>11.5</td>
<td>0.0331 ± 0.0002 ± 0.0028</td>
<td>3</td>
<td>2.46 ± 0.46</td>
</tr>
<tr>
<td>14.5</td>
<td>0.0641 ± 0.0005 ± 0.0109</td>
<td>2</td>
<td>2.43 ± 0.43</td>
</tr>
<tr>
<td>19.6</td>
<td>0.1216 ± 0.0003 ± 0.0104</td>
<td>3</td>
<td>2.39 ± 0.39</td>
</tr>
<tr>
<td>27</td>
<td>0.1892 ± 0.0003 ± 0.0162</td>
<td>3</td>
<td>2.34 ± 0.34</td>
</tr>
<tr>
<td>39</td>
<td>0.3204 ± 0.0003 ± 0.0274</td>
<td>3</td>
<td>2.25 ± 0.25</td>
</tr>
<tr>
<td>62.4</td>
<td>0.469 ± 0.026</td>
<td>5</td>
<td>2.18 ± 0.18</td>
</tr>
<tr>
<td>130</td>
<td>0.708 ± 0.036</td>
<td>5</td>
<td>2.08 ± 0.08</td>
</tr>
<tr>
<td>200</td>
<td>0.769 ± 0.055</td>
<td>5</td>
<td>2.06 ± 0.06</td>
</tr>
</tbody>
</table>

Lambda correction $f_\Lambda$

- **Sigma:** Yield ratios
  - Isospin scaling: 1.5
  - PYTHIA: 1.67
  - HIJING: 1.532

- **Feeddown:** STAR published spectra at $\sqrt{s_{NN}}=200$ GeV (Phys.Rev.Lett.97:152301,2006) with and without feeddown*
  - Does not provide a lot of constraint
  - Use branching ratio
    → $0.68 \pm 0.32$

  \[ f_\Lambda = 1.08 \pm 0.51 \]

*Thanks to Ron Belmont for pointing this out to us

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Christine Nattrass, APS April Meeting, 19 April 2021
Calculating $E_T$ from published spectra

$$E_T = f_\pi E_T^{\pi\pm} + f_K E_T^{K\pm} + f_p E_T^{p,\bar{p}} + f_\Lambda E_T^{\Lambda,\bar{\Lambda}}$$

$f_\pi = 1.56 \pm 0.02 + (E_\eta^\pi + E_\omega^\pi) / (E_\pi^\pi)$

$f_K = 1.8 \pm 0.2$

$2 < f_p < 3$

$f_\Lambda = 1.08 \pm 0.51$
Results & conclusions

- Tracking detectors can measure $E_T$ well
- $E_T$ calculated from STAR spectra do not agree with PHENIX $E_T$
What we need to do

- Double check fits
- Separate uncertainties from extrapolation to $p_T=0$
- Finalize corrections and uncertainties
- Write the paper
- Calculations in small systems?

Suggestions

- STAR: BES $E_T$ measurement
- PHENIX: BES spectra measurements
- sPHENIX $E_T$ measurement
Q&A

Q: Why not do this for PHENIX spectra as well?
A: PHENIX spectra only for $p_T > 0.5$ GeV/c, large extrapolation uncertainty

Q: Why not look at energy distribution by particle type?
Q: Why not look at $E_T / N_{ch}$?
A: We are. To be continued...

Q: Why not look at small systems?
A: We will. To be continued...
How can we estimate the energy density?

- Transverse energy ($E_T$)
  - sum of particle energies in transverse direction
- Volume $V = A_T \tau c$
- $\tau =$ formation time
- Energy density $\varepsilon$

$$\varepsilon = \frac{1}{V} \frac{dE_T}{dy} = \frac{J}{A_T \tau c} \frac{dE_T}{d \eta}$$

- QGP formation for $\varepsilon > 0.5$ GeV/fm$^3$
Methods for measuring $E_T$

- CMS: Tracking + electromagnetic calorimeter + hadronic calorimeter
- PHENIX: Electromagnetic calorimeter
- STAR: Tracking + Electromagnetic calorimeter
- ALICE: Tracking*

*Other methods used as cross checks
Where is the energy?

Scale: diameter in inches = $\sqrt{\text{fraction} \times 5}$
Numbers from 2.76 TeV Phys. Rev. C 94 (2016) 034903

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How does it hit your detector?

π^0 \rightarrow γ γ

K_S^0 \rightarrow \pi^0 \pi^0 \approx 31\% \quad \pi^+ \pi^- \approx 69\%

γ γ γ

Λ \rightarrow n π^0 \approx 36\% \quad p \rightarrow π^+ \approx 64\% \quad n \rightarrow γ γ \approx 35\% \quad \bar{p} \rightarrow π^- \approx 64\% \quad \bar{Λ} \rightarrow n π^0 \approx 36\% \quad \bar{p} \rightarrow π^+ \approx 64\%

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How does it hit your detector?

35% neutral

11% in neutral hadrons

65% charged

7% in secondaries
24% as a $\gamma$
Measure in electromagnetic calorimeter

11% as a neutral hadron
Measure in hadronic calorimeter

58% in primary hadrons
Measure in tracking detectors and hadronic calorimeter

7% in secondary hadrons
Tracks: $p_\mathrm{T} > 900$ MeV/c
Clusters: limited by $B$
→ $\sim 62\%$ of energy measured

$<p_T> \sim 700$ MeV/c

STAR

24% as a $\gamma$ Backgrounds

11% as a neutral hadron
Measure in electromagnetic calorimeter

58% in primary hadrons
Measure in tracking detector

7% in secondary hadrons

Background
Deposit 100% of energy

35% of energy in event

PHENIX

Electromagnetic calorimeter

→ Measure ~57% of energy

Deposit about 1/3 of energy

65% of energy in event
24% as a γ
11% as a neutral hadron

Measure ~56%

58% in primary hadrons

Measure in tracking detector

7% in secondary hadrons
Cut out using tight DCA cut
\[ E_T = \frac{1}{f_{pTcut}} \frac{1}{f_{total}} \sum_{i=0}^{n} f^i_{bg}(p_T) \frac{1}{f_{notID}^{eff}(p_T)} \frac{1}{E_i \sin(\theta^i)} \]

But known well!

What we measure directly

Corrections
ALICE: \( f_{\text{total}} = 0.567 \pm 0.009 \)
ALICE $E_T$

\[ \langle \frac{dE_T}{d\eta} \rangle / \langle dN_{ch} / d\eta \rangle \quad (\text{GeV}) \]

\[ |s_{NN}| \quad (\text{GeV}) \]

- ALICE
- CMS
- STAR
- PHENIX
- NA49
- E802/E917
- WA98
- FOPI estimate
Lambda correction $f_\Lambda$

- STAR BES DCA to PV<3 cm
  Feeddown due to $K^0_S$ done
  Feeddown to p due to $\Lambda$ not done

- STAR published spectra at $\sqrt{s_{NN}}=200$ GeV
  (Phys.Rev.Lett.97:152301,2006) with and without feeddown*

  → Calculate $E_T^{\Lambda}$ feeddown

- Does not provide a lot of constraint

  → Use branching ratio

    $\rightarrow 0.68 \pm 0.32$

    $f_\Lambda = 1.08 \pm 0.51$

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