A method of $\eta'$ rejection in p+p and Au+Au collisions

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- Mass drop of the $\eta'$ and HBT
- Kinematical cuts to reject $\pi$ from $\eta'$
- Efficiency and loss analysis

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Chiral Symmetry Breaking

- The three-quark model
  - SU(3) flavour-symmetry
  - Spontaneously broken
    => 9 Goldstone bosons
  - Corresponding to light mesons
    • There are only 8! (Meson-octet)

- $U_A(1)$ chiral symmetry explicitly broken
  - Distinct topological vacuum-states
  - Tunneling b/w them – quasiparticles (instantons)!
  - 9th boson gains mass – $\eta'$ (958 MeV)
Restoration of the Symmetry

- High energy densities
  - Asymptotic freedom $\alpha_s \rightarrow 0$
  - Nontrivial topology vanishes
  - $U(1)$ no more broken
  - $SU(3)$ restored

  **Remark:**
  From SSB, One expects massless mesons.
  However, the flavour symmetry is inexact.

- Mass reduction
  Lower bound (Gell-Mann – Okubo):

  $$m_{\eta'} = m_0 + \Delta m$$

  $$m_0^2 = \frac{1}{3} (2m_K^2 + m_\pi^2); m_0 \approx 400\text{MeV}$$

  Upper bound (S,NS isosinglet eigenstates):

  $$m_s^2 = 2m_K^2 + m_\pi^2; \quad m_s \approx 700\text{MeV}$$
Signature: Particle Abundancy

• Hagedorn-model
  - Production of light mesons:

\[ \sigma_i \sim \left( \frac{m}{2\pi} \right)^{3/2} e^{-m/T_H} \]

- \[ T_H \sim 160 \text{ MeV} \] Hagedorn-temperature

• In case of a possible mass drop:
  - Number of \( \eta' \)'s would be small:
  - With a strongly reduced \( \eta' \) mass:
    - An enhancement of a factor of 50 at maximum
    - Increased weight of strange states, rather 3 to 16

• Consequence of the reduced mass:
  An increased abundancy of \( \eta' \) mesons
The $\eta'$ through Phase Transition

- **Hadronization**
  - Reduced-mass $\eta'$ mesons produced with a decreased mass with an increased abundancy

- **Decoupling from non-Goldstonionic matter**
  - Mean free path for annihilation is large
  - Long lived

- **"Condensate" in the medium**
  - Low-$p_T$ $\eta'$ mesons are unable to get on-shell in the vacuum
  - Medium acts as a trap for low- $p_T$ $\eta'$ mesons

- **As medium dissolves, the $\eta'$ mesons regain their original mass**

Channels of Observation

- **Direct leptonic decay** $\eta' \rightarrow \ell^+ \ell^-$
  - Increased $\eta'/\pi$ proportion in the low-$p_T$ range
  - Excess in the $\ell^+ \ell^-$ spectrum under the $\rho$ mass

- **$\eta$ meson (BR=73%)** $\eta' \rightarrow \eta \pi^+ \pi^-$
  - Including decay through $\rho$
  - Decay of $\eta$ meson
    - 23% $\eta \rightarrow \pi^+ \pi^- \pi^0$
    - 5% $\eta \rightarrow \pi^+ \pi^- \gamma$
    - 39% $\eta \rightarrow 2\gamma$
    - 33% $\eta \rightarrow 3\pi^0$
  - Enhanced production of uncorrelated pions
  - BEC of charged pions
    - Sensitive to the sources of the pions

- **Direct measurement** $\eta' \rightarrow \gamma \gamma$
  - Would be convincing, however, poor S/B ratio ($\pi^0 \rightarrow \gamma \gamma$)
Correlations & Core-Halo picture

- Pions from QM freezeout
  - Primordial (from phase transition)
  - Fast decaying resonances
  - Long-life resonances ($\omega$, $\eta$, $\eta'$, $K_S^0$)
  - Core/halo ratio: $\lambda(p_t)$
  - BEC intercept parameter

**Hot and dense matter: $\eta'$ mass reduction**

↓

Enhanced $\eta'$ content

Decay: $\eta' \to \eta + \pi^+ + \pi^- \to (\pi^0 + \pi^+ + \pi^-) + \pi^+ + \pi^-$

Average $p_t$ of $\pi'$s 138 MeV

↓

More non-interacting $\pi'$s at low $p_t$

$\lambda(p_t)$ measures fraction of interacting $\pi'$s

↓

A hole in $\lambda(m_t)$

Kapusta, Kharzeev, McLerran

Z. Huang, X-N. Wang

Vance, Csörgő Kharzeev

T. Hatsuda, T. Kunihiro
Phys. Rept. 247:221,1994
Simulations & experimental results

- Vértesi, Csörgő, Sziklai:
- Mass drop compatible with the data

- Other reasons possible?

Calculations: $m_{\phi}^* = 530$ MeV, $B^* = 55$ MeV

RHIC Datasets ($Au+Au, s_{NN}=200$ GeV)

Resonances: Kaneta et al.
  nucl-th/0405068
  present model
  model, no mass drop
  PHENIX ($Au+Au$ 200 GeV)
  nucl-ex/0401003
  STAR ($Au+Au$ 200 GeV)
  nucl-ex/0903.1296

PHENIX Sinyukov
PHENIX prelim
STAR Edgeworth
STAR Gauss
Detailed analysis

- Mass drop analyzed in detail
  - Csörgő, Vértesi, Sziklai: arXiv:0912.0258, .5526

- Maximal mass with $5\sigma$ contours: 730 MeV
- Best fit between 340-530 MeV
Need for confirmation

- Idea: reject pions from $\eta'$
- Method already tested
  - Kulka and Lörstad
    NIM A295, 443 (1990)
- In electron-positron
- Lund MC
Pion distribution analysis

• Kinematics as expected
• Cut possible
• Optimal cut to be explored
Rejection method

- Analyze $\pi^+\pi^+\pi^-\pi^-$ quadruplets
- Check if they fall within the kinematical cuts
  - $m_{+-}^2$ in 0.075 to 0.171 GeV$^2$/c$^2$ (in both combinations)
  - $m_4^2$ in 0.43 to 0.69 GeV$^2$/c$^2$
- Apply this to pairs:
  - Look for all quadruplets with this pair in it
  - If inside mass interval, it is FOUND
  - Check if from $\eta'$ or not
- Apply this to particles:
  - Look for all quadruplets with this particle in it
  - If inside mass interval, it is FOUND
  - Check if from $\eta'$ or not
- Acceptance cuts make it more complicated
Scenarios

• We checked several scenarios:
  – Pair or particle cuts
  – Acceptance: total, rapidity cut ($\eta<0.35$), angular cut (cut out a PHENIX-like half)
  – Negative or positive pions (essentially the same, will quote only $\pi^+$)

• Two simulations: Pythia and HIJING

• Au+Au and p+p, 200 GeV and 14 TeV

• Important numbers
  – Cut efficiency (% of $\eta'$ descendants tagged)
  – Cut loss (% of non-$\eta'$ descendants NOT tagged)
14 TeV p+p results

• No acceptance cut
  – Pairs: Efficiency 70%, Loss 40%
  – Particles: Efficiency 98%, Loss 5%

• Rapidity cut
  – Pairs: Efficiency 31%, Loss 16%
  – Particles: Efficiency 64%, Loss 14%

• Rapidity & transverse angular cut
  – Pairs: Efficiency 17%, Loss 8%
  – Particles: Efficiency 46%, Loss 11%
200 GeV p+p results

• No acceptance cut
  – Particles: Efficiency 98%, Loss 22%
  – Pairs: Efficiency 96%, Loss 3%

• Rapidity cut
  – Particles: Efficiency 56%, Loss 8%
  – Pairs: Efficiency 67%, Loss 3%

• Rapidity & transverse angular cut
  – Particles: Efficiency 52%, Loss 6%
  – Pairs: Efficiency 85%, Loss 4%
200 GeV Au+Au results

• No acceptance cut
  – Not done due to computing time problems

• Rapidity cut
  – Particles: Efficiency 99%, Loss 99%
  – Pairs: Efficiency 100%, Loss 55%

• Rapidity & transverse angular cut
  – Particles: Efficiency 99%, Loss 99%
  – Pairs: Efficiency 100%, Loss 52%
Results for pairs

- p+p, 200 GeV, angular + transverse cut
- p+p, 200 GeV, angular cut
- p+p, 200 GeV, no cut
- p+p, 14 TeV, no cut
- p+p, 14 TeV, angular cut
- p+p, 14 TeV, angular + transverse cut
- Au+Au, 200 GeV, angular + transverse cut
- Au+Au, 200 GeV, angular cut

Preliminary results

- Efficiency
- Loss
Results for particles

- p+p, 200 GeV, angular + transverse cut
- p+p, 200 GeV, angular cut
- p+p, 200 GeV, no cut
- p+p, 14 TeV, no cut
- p+p, 14 TeV, angular cut
- p+p, 14 TeV, angular + transverse cut
- Au+Au, 200 GeV, angular + transverse cut
- Au+Au, 200 GeV, angular cut

- Efficiency
- Loss
Summary

- Proof of concept, done in Au+Au and p+p
- Needs to be cross-checked
- Cut dependence to be explored
- Pair rejection seems to be doable in Au+Au
- Has to be done on an experimental sample
Thank you for your attention