Dielectron Measurements by PHENIX using the HBD

Quark Matter 2012

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Outline

- Physics Motivation
- HBD detector
- Hadronic Cocktail
- p+p Result
- Au+Au Results
Dielectron Mass Spectrum

- Dileptons spectra carry abundant information about the *evolution* of the medium: They are created at all stages and do not interact strongly.

- **Low Mass Region**
  - Modification of light vector mesons
    → Chiral Symmetry Restoration
  - Thermal photons
    → Temperature of the medium

- **Intermediate and High Mass Region**
  - Open heavy flavor
    → Heavy quark energy loss
  - Quarkonia
    → Quarkonium suppression

- Most striking observation is the $\times 10$ enhancement seen in the $\approx 150$ MeV to $750$ MeV compared to expectation from purely hadronic decays.

**Figure**: 
- Min. bias Au+Au, $\sqrt{s_{NN}} = 200$ GeV
- Data with various decay channels shown.
- Comparison against theoretical predictions (PYTHIA).
- Plot includes data with $|y| < 0.35$ and $p_T > 0.2$ GeV/c.
Challenges of the measurement

- Signal to background in PHENIX published measurement lowest in most interesting region
- Dominant source of background is combinatoric electron pairs from $\pi^0$ decays
  \[ \pi^0 \rightarrow \gamma e^+ e^- \]
  \[ \pi^0 \rightarrow \gamma \gamma \rightarrow e^+ e^- e^+ e^- \]
  that get separated by the magnetic field and only one leg is reconstructed
- Only way to identify such pairs is to tag them before they get separated by the magnetic field
Motivation for a Hadron Blind Detector

- Identification of partially reconstructed Dalitz and early conversion:
  - Measure charge before $e^+e^-$ pair is separated by the magnetic field (Hence the requirement of field free region and change in magnetic field configuration from previous measurements)
  - Background electrons produce twice the signal of signal electrons
  - Hadron Blind Detector (HBD)

![Diagram showing closed and open pairs with data distribution](image-url)
The Hadron Blind Detector

**HBD hardware**
- Windowless Čerenkov Detector
- CF$_4$ - Radiator and Active gas
- Triple GEM signal multiplication
- CsI photo cathode, hexagonal pad readout
- 2.4% total radiation length

**Hadron Blindness**
- Čerenkov threshold for $\pi^\pm \approx 4$ GeV
- Reverse bias operation to repel ionization from charged hadrons

**Double rejection**
- Near zero B-field up to GEMs
- Low mass pairs keep small opening angle and leave twice as much signal as single electrons
Fit $\pi^0$ and $\pi^\pm$ spectra using Hagedorn function

$$E \frac{d^3N}{dp^3} = \frac{A}{(e^{-(ap_T+bp_T^2)} + p_T/p_0)^n}$$

For other hadrons: Use $m_T$ scaling for shape

$$p_T \rightarrow \sqrt{p_T^2 + (m_n^2 - m_{\pi^0}^2)}$$

fit to measured spectra for normalization

The fits are done independently for each species and collision centrality

Changes from published cocktail (Phys. Rev. C 81, 034911 (2010))

- Change in magnetic field configuration $\rightarrow$ change in acceptance
- Open heavy flavor shape from MC@NLO as event generation
  - For p+p, charm and beauty spectra from MC@NLO are adjusted to fit data.
  - For Au+Au, an additional $N_{\text{coll}}$ scaling is applied for each centrality bin
- $J/\psi$ line shape extracted from full detector MC
Effect of changes in cocktail simulation

Finite difference in pair acceptance between full field (++) and partial field (+-) configurations (HBD data was taken with (+-) field configuration).

This difference in acceptance (shown in the mass projection above) should be accounted for in comparisons between HBD results and published phenix results.
Finite difference in total cocktail when using PYTHIA and MC@NLO as open heavy flavor event generator.

Difference (on total cocktail) at IMR (1.2 GeV to 2.8 GeV) \( \approx 16\% \) and even lower at LMR.
Fully reconstructed $\pi^0$ Dalitz pairs ($m < 150$ MeV) are split into two samples:

- Large opening angle ($> 100$ mrad) - single signal amplitude ($\approx 20$ pe)
- Small opening angle ($< 30$ mrad) - double signal amplitude ($\approx 40$ pe)
**p+p Analysis: signal/background improvement**

- **Factor \(\approx x5 - x10\) improvement in S/B in p+p**
  - This improvement is achieved using the HBD just as another EID detector
  - More should be possible in p+p by using double rejection cut, but this is not the limiting systematic uncertainty in p+p results
p+p Result

Excellent agreement between data and cocktail.
Excellent agreement between data and cocktail.

Baseline for Au+Au analysis, as well as simpler environment to test understanding of the HBD detector subsystem.
HBD in Au+Au collisions

Event By Event BG Subtr.
- **Stream A**: Mean charge per pad calculated module by module in each event
- **Stream B**: Median charge per pad calculated for each track near the projection point

High Occupancy ≈100% in central events mostly due to scintillation in CF₄
- Mean single signal ≈20pe over 3 pads
- Mean background ≈10pe per pad highly fluctuating response to scintillation and curlers
  - → High fake id rate

Both Stream A and Stream B use track projection based cluster charge reconstruction and achieve compatible efficiency and rejection

Au+Au Results
- The results shown now for Au+Au are only for 20-40%, 40-60% and 60-92%
Two independent analyses were performed to increase confidence in results. The methods were substantially different in how they handled the HBD reconstruction, electron identification, single/double rejection and correlated background subtraction. In both analyses, the combinatorial background is subtracted using mixed events. The difference is in how the correlated yield is handled.

\[ \text{sig} = \text{UnlikeFG} - \text{Norm} \times \text{MixedUnlikeBG} - \text{CorrelatedUnlike} \]

### Stream A
- **HBD reco:** Background subtracted using average charge per pad
- **EID:** Neural network for both Single/Double and electron identification
- **Correlated dielectron background subtraction using acceptance corrected like sign**

### Stream B
- **HBD reco:** Background subtracted using track projection neighborhood
- **EID:** Standard 1D cut for both Single/Double and electron identification
- **Correlated dielectron background subtraction using MC of cross pairs and jet pairs**

Stream A is used for comparison to cocktail because the PID procedure was superior. Stream B is used as a cross check.
Au+Au Results, Centrality 20-40%

Plenary IVA, I. Tserruya
Au+Au Results, Centrality 40-60%

Plenary IVA, I. Tserruya

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Au+Au Results, Centrality 60-92%

Plenary IVA, I. Tserruya

HBD data

cocktail

\( \pi^0 \rightarrow e^+e^- \)

\( \eta \rightarrow e^+e^- \)

\( \rho \rightarrow e^+e^- \)

\( \omega \rightarrow e^+e^- \) & \( \pi^0 e^+e^- \)

\( \eta' \rightarrow e^+e^- \)

\( \phi \rightarrow e^+e^- \) & \( \eta e^+e^- \)

\( J/\psi \rightarrow e^+e^- \)

\( c\bar{c} \rightarrow e^+e^- \) (MC@NLO)

\( b\bar{b} \rightarrow e^+e^- \) (MC@NLO)

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Au+Au Comparison of two analysis streams

AuAu \sqrt{s_{NN}} = 200 \text{ GeV}
Centrality 20-40%

Stream A
Stream B

PHENIX preliminary
Au+Au Comparison of two analysis streams

Au+Au

Centrality 40-60%

\[ \sqrt{s_{NN}} = 200 \text{ GeV} \]

Stream A

Stream B

\[ \frac{dN}{dm_{ee}} \text{ in PHENIX acc.} \quad [c^{2}/\text{GeV}] \]

\[ 10^{-1} \quad 10^{-2} \quad 10^{-3} \quad 10^{-4} \quad 10^{-5} \quad 10^{-6} \quad 10^{-7} \quad 10^{-8} \]

\[ m_{ee}[\text{GeV/c}^{2}] \]

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QM1012, PHENIX HBD Dielectrons

August 15, 2012
Au+Au Comparison of two analysis streams

Poster 72, J. Sun

Centrality 60-92%

$\sqrt{s_{NN}} = 200$ GeV

Stream A
Stream B
Compatibility with published results

The data/cocktail ratios comparison
- The HBD analysis data/cocktail ratios are in agreement with the published result
- Systematic uncertainties are dominated by conservatively estimated background subtraction errors
Compatibility with published results

Opportunities for improvement

- Extremely tight cuts and run QA used in the interest of uniformity that can be relaxed in future analyses
- The dominant contribution to the systematics comes from the background subtraction method chosen. We expect improvement in systematic uncertainties from alternate subtraction methods
The first dielectron spectrum results using the HBD are shown

$p+p$ results agree very well with the hadronic cocktail expectation

The more peripheral $Au+Au$ results also agree to within systematics with run 4 $Au+Au$ analysis results

In most central $Au+Au$, we are still refining the background subtraction method, stay tuned
Change in magnetic field configuration $\rightarrow$ change in acceptance

\[
\phi_{\text{min}} \leq \left( \phi - \frac{q \times k_{\text{DC}}}{p_T} \right) \leq \phi_{\text{max}}
\]

\[
\phi_{\text{min}} \leq \left( \phi - \frac{q \times k_{\text{RICH}}}{p_T} \right) \leq \phi_{\text{max}}
\]

where $k_{\text{DC}} = 0.058$ and $k_{\text{RICH}} = 0.127$, with $\phi_{\text{min}} = -0.55$ and $\phi_{\text{max}} = 0.957$ for one arm and $\phi_{\text{min}} = 2.185$ and $\phi_{\text{max}} = 3.686$
Performance in Au+Au collisions (Stream A)

1. Subtract the average charge per pad on event-by-event basis for each module
2. Decide which pad to use according to projection point
3. Calculate the total charge in the cluster

Plots to the right: efficiency for singles and rejection for back-plane conversions for all centralities in Au+Au events.
1. Subtract the average charge per pad on event-by-event basis for each module

2. Decide which pad to use according to projection point

3. Calculate the total charge in the cluster

Plots to the right: efficiency for singles and rejection for double hits for centralities 0-10% (top) and 80-90% (bottom)
The SB reconstruction subtracts local background on triplets around track projections and merges all triplets with CG close to the track projection.
Star also has a measurement in a somewhat different acceptance.

Star also observes low mass excess compared to expectation.

However there is disagreement in the amount of the excess seen by STAR and PHENIX.

Although some of it can be attributed to acceptance difference and systematic errors, it is very desirable to have another measurement with very different systematics.