PHENIX Low-mass Dileptons and Photons

Itzhak Tserruya
Weizmann Institute of Science
for the PHENIX Collaboration

QM2012, Washington, August 16, 2012
Outline

- Introduction
- Direct Photons
  - $R_{AA}$ up to $p_T = 20$ GeV/c
  - d+Au
  - $v_2$ with conversion photons
- Dileptons - first results with the HBD (Hadron Blind Detector):
  - p+p collisions at $\sqrt{s} = 200$ GeV
  - Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV
  - Comparison to previous results w/o HBD
- Summary
Photons
Long standing issue of direct photons $R_{AA}$ at high $p_T$
Direct $\gamma$ measured to high $p_T$

**p+p**

arXiv:1205.5533

**Au+Au**

arXiv:1205.5759

Statistically improved 2006 pp data

Reanalyze Au+Au data combining PbGl and PbSc calorimeters
\( R_{AA} \) consistent with 1:

- up to \( p_T \sim 20 \) GeV/c
- for all centralities
Thermal radiation from the QGP at RHIC

NLO pQCD consistent with p+p down to $p_T = 1$ GeV/c

Excess of photons (with $1 < p_T < 3$ GeV/c) in Au+Au beyond the $N_{coll}$ scaled p+p yield.

Interpreted as thermal radiation emitted by the medium

First information about the temperature of the system averaged over the space-time evolution of the collision

$T_{ave} = 221 \pm 19^{\text{stat}} \pm 19^{\text{syst}}$ MeV corresponds to $T_{ini} = 300$ to 600 MeV $\tau_0 = 0.15$ to 0.6 fm/c
Direct photons in \( d+Au \) measured via 3 independent methods:

- virtual photons
- \( \pi^0 \) tagging
- statistical subtraction

The NLO pQCD fit to the \( p+p \) data, scaled by \( N_{\text{coll}} \), reproduces well the \( d+Au \) data

No excess of photons.
Direct photons in $d+Au$ and $Au+Au$

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arXiv:1208.1234
B. Sahlmueler Parallel 3C

$R_{dA}$ is consistent with unity

- Large excess of $\gamma$ observed in $Au+Au$ is not due to initial state effects
- Reinforce interpretation of the $Au+Au$ excess as thermal radiation from the QGP
Direct photon $v_2$

- Large $v_2$ at $p_T < 4 \text{ GeV/c}$ where thermal photons dominate
- $v_2$ consistent with 0 at high $p_T$ where prompt photons dominate

- Very surprising result: large $v_2$ implies late emission whereas thermal radiation implies early emission
- Models have difficulties in reproducing simultaneously yield and $v_2$ of photons

Poster 282 M. Csanad
Direct photon $v_2$ via external conversion

Two independent and consistent results

Important confirmation of previous $v_2$ results

Poster 64, R. Petti
First dilepton results with the HBD
Dileptons in PHENIX: Au+Au collisions

- Strong enhancement of $e^+e^-$ pairs at low masses: $m = 0.2 - 0.7 \text{ GeV}/c^2$, concentrated in central collisions
- Challenge for theoretical models

- Result limited by large uncertainty due to the huge combinatorial background of uncorrelated pairs from partially reconstructed $\pi^0$ Dalitz decays and $\gamma$-conversions
- To improve the dilepton measurement PHENIX developed a Hadron Blind Detector (HBD)

PRC 81, 034911 (2010)
HBD performance

NIM A646, 35 (2011)

Windowless CF4 Cherenkov detector

GEM/CSI photo-cathode readout

Operated in B-field free region

Goal: improve S/B by rejecting conversions and π⁰ Dalitz decays

- Successfully operated:
  - 2009 p+p data
  - 2010 Au+Au data

- Figure of merit: $N_0 = 322 \text{ cm}^{-1}$

- 20 p.e. for a single electron

- Preliminary results:
  - S/B improvement of ~5 wrt previous results w/o HBD

Hadron blindness
e-h separation

Close pairs
$m < 0.15 \text{ GeV/c}^2$

Cluster charge

Double electron

Charge (p.e.)

Yield

Charge (p.e.)

Yield

Open pairs

Charge (p.e.)

Yield

Double electron

Close pairs
$m < 0.15 \text{ GeV/c}^2$

Cluster charge
**Au+Au analysis details**

- Strong run QA and strong fiducial cuts to homogenize response of the central arm detectors over time
  - Large price in statistics and pair efficiency
- Two parallel and independent analysis streams: provide crucial consistency check

<table>
<thead>
<tr>
<th>Stream A</th>
<th>Stream B</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBD: underlying event subtraction using average charge per pad</td>
<td>HBD: underlying event subtraction using average charge in track projection neighborhood</td>
</tr>
<tr>
<td>Neural network for eid and for single/double electron separation</td>
<td>Standard 1d cuts for both eid and for single/double electron separation</td>
</tr>
<tr>
<td>Correlated background (cross pairs and jets) subtracted using acceptance corrected like-sign spectra</td>
<td>Correlated background subtracted using MC for the cross pairs and jet pairs</td>
</tr>
</tbody>
</table>

Results shown here are from stream A

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• $\pi^0$ and charged $\pi$ data fit to a modified Hagedorn function:

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

• Use $m_T$ scaling for shape of other hadrons, normalize to measured data

• Fits are done independently for each particle and each centrality

• Open heavy flavor (c,b) contributions determined using MC@NLO

• $J/\psi$ shape from pp, yield from pp scaled by $N_{coll\cdot R_{AA}}$
Run-9 p+p dileptons with the HBD

- Fully consistent with published result PR C81, 034911 (2010)
- Provide crucial proof of principle and testing ground for understanding the HBD
Au+Au dileptons at $\sqrt{s_{NN}}=200$ GeV with the HBD

Peripheral

Semi-peripheral

Semi-central
Run-10: Data/Cocktail

LMR $ (m = 0.15 - 0.75 \text{ GeV/c}^2)$

- Hint of enhancement for more central collisions
- Not conclusive given the present level of uncertainties

IMR $ (m = 1.2 - 2.8 \text{ GeV/c}^2)$

- Similar conclusions for the IMR
Dileptons with and without HBD

Data:

- Different magnetic field configuration:
  - Run-9 (p+p) and Run-10(Au+Au) with HBD: +- field configuration
  - All other runs: ++ field configuration
  - Larger acceptance of low $p_T$ tracks in +- field

- More material due to HBD
  - more $J/\Psi$ radiative tail

- Compare results in three centrality bins:
  - 20-40%, 40-60% and 60-92%

Cocktail:

MC@NLO for open heavy flavor (c,b) contribution instead of PYTHIA

MC@NLO(1.2-2.8) = PYTHIA(1.2-2.8) * 1.16

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Comparison of run-10 to published run-4 results

LMR \((m = 0.15 - 0.75 \text{ GeV}/c^2)\)

**Run 10 – Data/ cocktail**

<table>
<thead>
<tr>
<th>Centrality</th>
<th>Value</th>
<th>Stat</th>
<th>Syst(up)</th>
<th>Syst(dwn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-40%</td>
<td>1.98</td>
<td>0.3</td>
<td>0.9</td>
<td>1.1</td>
</tr>
<tr>
<td>40-60%</td>
<td>1.63</td>
<td>0.2</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>60-92%</td>
<td>0.86</td>
<td>0.1</td>
<td>0.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Run 4 – Data/ cocktail**

<table>
<thead>
<tr>
<th>Centrality</th>
<th>Value</th>
<th>Stat</th>
<th>Syst</th>
<th>model</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-40%</td>
<td>1.4</td>
<td>0.3</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>40-60%</td>
<td>0.8</td>
<td>0.3</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>60-92%</td>
<td>1.5</td>
<td>0.3</td>
<td>0.5</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Consistent results
Comparison of run-10 to published run-4 results

**IMR (m = 1.2 – 2.8 GeV/c²)**

**Run 10 – Data/ cocktail**

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<tr>
<th>Centrality</th>
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<th>Syst(dwn)</th>
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</thead>
<tbody>
<tr>
<td>20-40%</td>
<td>2.56</td>
<td>0.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>40-60%</td>
<td>1.32</td>
<td>0.4</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>60-92%</td>
<td>0.70</td>
<td>0.2</td>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

**Run 4 – Data/ cocktail**

c,b yields based on MC@NLO
MC@NLO = PYTHIA * 1.16

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<tbody>
<tr>
<td>20-40%</td>
<td>1.3</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>40-60%</td>
<td>2.0</td>
<td>0.5</td>
<td>1.1</td>
</tr>
<tr>
<td>60-92%</td>
<td>2.6</td>
<td>0.6</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**Consistent results**
Summary

- $R_{AA}$ of direct photons consistent with 1 from 5 GeV/c up to ~20 GeV/c

- No excess of direct photons in d+Au. Reinforce the interpretation of the excess observed in Au+Au at $p_T = 1-4$ GeV/c as thermal radiation

- Confirmation of the large $v_2$ of thermal photons by an independent analysis based on external conversions

- First results on dileptons using the HBD on p+p and Au+Au collisions in 20-40%, 40-60% and 60-92% centrality bins

- Preliminary results in Au+Au with very strong QA cuts and conservative error estimates consistent with previously published results

- Next: relax QA and fiducial cuts, better assessment of systematics and complete analysis