Photons @ RHIC: Results from STAR

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STAR Experiment At RHIC
Introduction

Photons in A+A collisions

- Mainly, from $\pi^0$, $\eta$ decays
  - Important probe in many aspects
  - In STAR, allow better statistics to higher $p_T$ than charged pions

- Direct photons
  - Main advantage – large mean free path in the created matter
  - Produced in all stages of the collision
    - thermal photons – access to temperature (initial, hadronization)
    - High $p_T$ photons to investigate hadron supression in A+A collisions

- Extraction of direct photon production is harder due to large hadronic decay background $\rightarrow \pi^0 (\eta)$ measurements very important
Inclusive $\gamma$ and $\pi^0$ from the STAR TPC

Measurement obtained from $\gamma$ conversion in TPC

Material used as $\gamma$ converter:
- Beampipe
- SVT
- SSD
- Inner field cage
- TPC gas

Efficiency
- $\gamma \sim 2\%$
- $\pi^0 \sim 0.04\%$
γ reconstruction

- $e^+$ and $e^-$ are selected through $dE/dx$
  - loose cuts are applied
  - low $p_T$ accepted only if they do not come from collision vertex
- For the pairs, it is required a small opening angle and conversion vertex different from collision vertex
- Trajectory of reconstructed γ points back to collision vertex
Au+Au collisions at \( \sqrt{s_{NN}} = 62.4 \text{ GeV} \) - \( \gamma \) spectra

\( \gamma \) and \( \pi^0 \) – Au+Au at 130 GeV

- Error bars: statistical only
- Systematic uncertainty: 20%
- Combinatorial background has been subtracted
- Other contributions, such as \( \Lambda \) decays, were verified to be negligible

Centrality dependence
- Curves are power law fits

STAR preliminary

\( -1 < y < 1 \)

\( p_t \) (GeV/c)
Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV - $\pi^0$ spectrum

- Each point is the gaussian fit of the $2\gamma$ invariant mass distribution for a given $p_T$
- ~10 MeV width, depending on $p_T$
- Systematic uncertainty of 30%

Comparison of $\pi^0$ to $\pi^+$ and $\pi^-$ from STAR TPC $dE/dx$ and TOFr shows good agreement.
Correlation of large $E_T$ photons with charged particles

- Jet studies allow further investigation of parton energy loss mechanism
- 2 particle correlations
  - probe of intra-jet (same side) and back-to-back jet (away side)
- Previous studies
  - charged particle correlations for $p_T < 6 \text{ GeV/c}$
- This Analysis
  - $\gamma$ (mostly from $\pi^0$) – $h^\pm$ correlations
  - Extends correlation energy range, due to EMC measurement of photons
d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

Data set

- 3.9 M High Tower triggered events
  - EMC patch - 4 x 4 towers
  - High tower trigger - tower in a patch with the highest energy above threshold

Selections and Cuts

- Highest tower energy selected
- Isolation cut
  - No track pointing in a 3 x 3 tower patch around main tower
- Associated track – basic selection criterion used in many STAR analysis
d+Au correlations

$\rho_T$ associated dependence

$E_{\text{trig}}$ dependence

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Jet properties – $< j_T >$ and $\sqrt{< k_T^{rms} >}$

- $j_T$ - transverse momentum component of jet from jet axis
- $k_T$ - transverse momentum component of initial parton

Correlation (Gaussian) widths

- $\sigma_N \rightarrow$ near side
- $\sigma_F \rightarrow$ far side

$$\sigma_N^2 \approx \frac{\left< E_T^2 \right> + \left< p_T^2 \right>}{2 \left< E_T^2 \right> \left< p_T^2 \right>} \left< j_T^2 \right>$$

$$\left< j_T \right> = \frac{\sqrt{\pi}}{2} \left< j_T^2 \right>$$

$$\sqrt{\left< k_T^2 \right>} \approx \frac{\left< E_T \right>}{\left< z \right>} \sqrt{\sigma_F^2 + \sigma_N^2}$$

$E_T \rightarrow E_{\text{trig}}$,

$p_T \rightarrow p_T^{\text{associated}}$

$< z > \rightarrow$ fragmentation function of trigger photon (0.6~0.8)
Centrality dependence of $\sigma_N$ and $\sigma_F$

No strong centrality dependence of either near and far side widths within errors
$<j_T>$ and $\sqrt{<k_T^{rms}>}$ dependences

Increase of $j_T$ with $p_T^{associated}$

$k_T$ is smaller for larger $p_T^{associated}$

$k_T$ is larger for larger $E_T$

$k_T$ almost constant with $E_T$

Preliminary
First Results from Photon Multiplicity Detector

- Two planes CPV+Pre-shower
- Gas (Ar+CO₂) detector of 82944 hexagonal cells
- Detector area: 4.2 m²
- Distance from vertex: 5.4 m
- -3.8 < \( \eta \) < -2.3 and full azimuthal coverage

The CPV plane was not in present analysis
Photon Multiplicity Distribution

Minimum Bias Au+Au @ 62.4 GeV

- $N_\gamma$ at forward rapidities scales with $N_{\text{part}}$
- Better agreement to data of AMPT model than HIJING

$N_\gamma$ vs. $N_{\text{part}}$

$N_\gamma/0.5N_{\text{part}}$ vs. $N_{\text{part}}$

$N_\gamma$ vs. $\eta$

2.3 < $\eta$ < 3.7

Better agreement to data of AMPT model than HIJING
# Limiting Fragmentation trend

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<tr>
<th>Energy dependence</th>
<th>Centrality dependence</th>
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- **Photons undergo limiting fragmentation**
- **No centrality dependence of limiting fragmentation for photons, unlike for charged particles**

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Limiting Fragmentation Scenario for $\pi$ and $\gamma$

- $\pi$ production follows the LF scenario
- Photon production is scaled down by about 7% to reflect the contribution from $\pi^0$
Direct Photon measurements for p+p and d+Au

- EMC measurements
  - Tower + SMD + pre-shower
- p+p and d+Au, towards Au+Au
- Direct photon spectra
  - Subtraction of background and contamination from inclusive spectra
    - $\pi^0$, $\eta$ photon decays
    - other neutral contribution ($\text{n,K}^0$)
    - Contamination from charged hadrons
  - Acceptance/Efficiency corrections
Direct Photon Analysis Status

- Systematic studies of BEMC/BSMD
- Shower properties studies on BSMD
  - Cluster size, energy
  - Development of cluster algorithm
- Acceptance/efficiency
  - d+Au $\pi^0$ embedded data

- EMC module
  - Tower
    - $(\Delta \eta, \Delta \phi) = (0.05, 0.05)$
    - $\delta E/E \sim 16%/\sqrt{E(\text{GeV})}$
  - BMSD
    - $(\Delta \eta, \Delta \phi)$ strip $= (0.007, 0.007)$
    - $\sigma_\eta = 2.4 \text{ mm} + 5.6 \text{ mm} / \sqrt{E(\text{GeV})}$
    - $\sigma_\phi = 3.2 \text{ mm} + 5.8 \text{ mm} / \sqrt{E(\text{GeV})}$
\( \pi^0 \) spectrum for d+Au collisions

From EMC measurements

Mass = 135±1 MeV
Width = 28±0.6 MeV

Event mixing

Reasonable agreement with pQCD calculations within errors

More to come...

- **Photon HBT (Jack Sandweiss talk)**
  - Analysis of $q_{\text{invariant}}$ photon pairs distribution
  - HBT peak produced by direct photons
  - Investigation of spatial and temporal dimensions of QGP phase

- **$\gamma$-charged correlations in Au+Au**
  - Potential observation of away-side correlation from direct photons due to hadron ($\pi^0$) suppression
  - Investigation of parton energy loss
Back up slides
Near and Far side widths

Decrease with increasing $E_{\text{trig}}$

Decrease with increasing $p_T^{\text{associated}}$