At all of $\pi^0$ and Direct Photon Cross Section Measurements at PHENIX

Hisayuki Torii, RIKEN
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$A_{LL}$ of $\pi^0$
Outlines

• Experiment
  – PHENIX
  – Electro Magnetic Calorimeter
• Analysis and Results
  – $A_{LL}$ of $\pi^0$
  – Direct photon cross section
• Conclusion
RHIC spin @ BNL

- polarized proton collider
  - energy 200 GeV (and 500 GeV in the future)
  - polarization 40% (70% in the future)

- BRAHMS & PP2PP
- STAR
- PHENIX
- AGS
- LINAC
- BOOSTER
- Pol. H- Source
- Spin Rotators
- (longitudinal polarization)
- Solenoid Partial Siberian Snake
- 200 MeV Polarimeter AGS Internal Polarimeter
- Rf Dipole
- RHIC pC Polarimeters
- Absolute Polarimeter (H↑ jet)
- AGS pC Polarimeters
- Strong AGS Snake
- Helical Partial Siberian Snake
- PHOBOS
- Spin Rotators
- (longitudinal polarization)
- Spin flipper
- Siberian Snakes
PHENIX

- 3.8km with 2 rings
- 120 bunch/ring
- 106ns crossing time
- Maximum energy
  - 250GeV for p(polarized)
  - 100GeV/nucleon for Au
- Luminosity
  - Au-Au : 2 x 10^{26}cm^{-2}s^{-2}
  - p-p : 2 x 10^{32}cm^{-2}s^{-2}
- 6 Crossing points

To measure the collision point, the luminosity, and the multiplicity, and transverse polarization.
- Beam Beam Counter(BBC)
- Zero Degree Calorimeter(ZDC)
- Multiplicity and Vertex Detector(MVD)
Electro-Magnetic Calorimeter

**Lead Scintillator (PbSc)**
- Sandwich type calorimeter
  - Lead and scintillation plate
  - Shish-kebab type readout

**Lead Glass (PbGl)**
- Total reflection calorimeter

PHENIX Detector

Coverage $|\eta|<0.38 \phi = 180^\circ$

24768 Channels

Fine segmented calorimeter.
distinguish two photons from $\pi^0$ photons $pT \sim 25$ GeV/c
<table>
<thead>
<tr>
<th>Run</th>
<th>Year</th>
<th>Species</th>
<th>$s^{1/2}$ [GeV]</th>
<th>$\int L dt$</th>
<th>$N_{tot}$</th>
<th>p-p Equivalent</th>
<th>Data Size</th>
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<tbody>
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<td>01</td>
<td>2000</td>
<td>Au+Au</td>
<td>130</td>
<td>1 $\mu$b$^{-1}$</td>
<td>10M</td>
<td>0.04 pb$^{-1}$</td>
<td>3 TB</td>
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<td>200</td>
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<td>170M</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>p+p</td>
<td>200</td>
<td>0.15 pb$^{-1}$</td>
<td>3.7G</td>
<td>0.15 pb$^{-1}$</td>
<td>20 TB</td>
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<tr>
<td>03</td>
<td>2002/2003</td>
<td>d+Au</td>
<td>200</td>
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<td>5.5G</td>
<td>1.1 pb$^{-1}$</td>
<td>46 TB</td>
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<tr>
<td></td>
<td></td>
<td>p+p</td>
<td>200</td>
<td>0.35 pb$^{-1}$</td>
<td>6.6G</td>
<td>0.35 pb$^{-1}$</td>
<td>35 TB</td>
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<tr>
<td>04</td>
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<td>Au+Au</td>
<td>200</td>
<td>241 $\mu$b$^{-1}$</td>
<td>1.5G</td>
<td>10.0 pb$^{-1}$</td>
<td>270 TB</td>
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<tr>
<td></td>
<td></td>
<td>Au+Au</td>
<td>62</td>
<td>9 $\mu$b$^{-1}$</td>
<td>58M</td>
<td>0.36 pb$^{-1}$</td>
<td>10 TB</td>
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<tr>
<td></td>
<td></td>
<td>p+p</td>
<td>200</td>
<td>0.075 pb$^{-1}$</td>
<td>G</td>
<td>0.075 pb$^{-1}$</td>
<td>10 TB</td>
</tr>
<tr>
<td>05</td>
<td>2004/2005</td>
<td>Cu+Cu</td>
<td>200</td>
<td>? pb$^{-1}$</td>
<td>G</td>
<td>pb$^{-1}$</td>
<td>TB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>p+p</td>
<td>200</td>
<td>3.8 pb$^{-1}$</td>
<td>G</td>
<td>3.8 pb$^{-1}$</td>
<td>260 TB</td>
</tr>
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</table>
Introduction: $A_{LL}$ of $\pi^0$

$A_{LL}$ in $\pi^0$ production

\[
\sigma_{1+2}^3 = \sum_{i,j,k} \int dx_i dx_j dx_k \times f_1^k(x_k, \mu) \cdot f_2^j(x_j, \mu)
\]

parton distribution function (PDF)

\[
\times \sigma_{i,j}^k(p_i, p_j, p_k, \alpha_s(\mu_R), Q^2 / \mu_F, Q^2 / \mu_F)
\]

\[
\times D_k^3(z_k, \mu_F)
\]

fragmentation function (FF)

mid-rapidity $|\eta| < 0.35$, $\sqrt{s} = 200$ GeV

$\pi^0$ production mid-rapidity $|\eta| < 0.35$, $\sqrt{s} = 200$ GeV

gg + qg dominant at low pT

Sensitive to the gluon reaction
Cross section

- Result from run2 result
  - PRL91 (2003) 241803
- Comparison of $\pi^0$ cross section
  - Next-to-leading order (NLO) pQCD
    - CTEQ6M + KKP
    - Matrix calculation by Aversa, et. al.
    - Renormalization and factorization scales are set to be equal and set to $1/2p_T, p_T, 2p_T$
- Calculated by W. Vogelsang

NLO-pQCD described very well down even to $p_T \sim 1$ GeV/$c$
Results obtained for four pT bins from 1 to 5 GeV/c
- $\pi^0$ peak width is 9.5-12 MeV/c$^2$
- Background contribution under $\pi^0$ peak varies from 27% to 8%
- $\pi^0$ reconstruction efficiency varies from 84% to 93%

Background contribution at higher pT is small.
- Still need estimate the effect
$\pi^0$ counting & background

$N_{\pi^0}$: $\pm 25$ MeV/c$^2$ around $\pi^0$ signal

$N_{\text{bck1}}$: Two 50 MeV/c$^2$ wide areas adjacent to $\pi^0$ peak

$N_{\pi^0}$ and $N_{\text{bck}}$ accumulated statistics

<table>
<thead>
<tr>
<th>pt</th>
<th>$N_{\pi^0}$</th>
<th>$N_{\text{bck1}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GeV/c</td>
<td>25 MeV/c$^2$</td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>1777k</td>
<td>1470k</td>
</tr>
<tr>
<td>2-3</td>
<td>1059k</td>
<td>335k</td>
</tr>
<tr>
<td>3-4</td>
<td>201k</td>
<td>27k</td>
</tr>
<tr>
<td>4-5</td>
<td>38k</td>
<td>3.9k</td>
</tr>
</tbody>
</table>

$r = \text{normalized counts of background } [(\text{red})/(\text{blue})]$
**A_{LL} & Systematic Studies**

\[ A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++}/L_{++} - N_{+-}/L_{+-}}{N_{++}/L_{++} + N_{+-}/L_{+-}} \]

++ same helicity
+- opposite helicity

\[ \delta_{A_{LL}} = \frac{1}{P_B P_Y} \frac{1}{\sqrt{N_{++} + N_{+-}}} \]

= Randomly assigns helicity for each crossing

4-5 GeV/c

\[ A_{LL} \]

\[ \chi^2/NDF \]

4-5 GeV/c

Widths are consistent with obtained errors \( \delta(A_{LL}) \)

All \( \chi^2/NDF \) from beam bunchs are \( \sim 1 \)
Comparison with theory

- GRSV-std:
  - best fit to DIS data
  \[ \int_0^1 \Delta G(x) dx \sim 0.7 \text{ at } Q^2 = 1 \text{ GeV}^2 \]

- GRSV-max

\[ \Delta G(x) = G(x) \text{ at } Q^2_{\text{input}} = 0.40 \text{ GeV}^2 \]


PHENIX Preliminary

Confidence Levels

<table>
<thead>
<tr>
<th></th>
<th>GRSV-std</th>
<th>GRSV-max</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 points (1-5 GeV/c)</td>
<td>21-24%</td>
<td>0.00-6%</td>
</tr>
<tr>
<td>3 points (2-5 GeV/c)</td>
<td>27-29%</td>
<td>0.01-13%</td>
</tr>
</tbody>
</table>

Data prefers the GRSV-std curve
Run05 will distinguish between GRSV-std and $\Delta G = 0$ (or GRSV-min).
Direct Photon Production
Prompt Photon Production

Prompt photon production consists of two processes:

\[ \sigma = \sigma_{\text{dir}} + \sigma_{\text{frag}} = \sum_{i,j,k} \int dx_i dx_j \times f_1^i(x_i, \mu) \cdot f_2^j(x_j, \mu) \times \left\{ \sigma(i + j \rightarrow \gamma) + \int dz \sigma(i + j \rightarrow k) \times D_k^3(z_k, \mu_F) \right\} \]

- **Direct Process**
- **Bremsstrahlung Process**

Compton
- Annihilation
- Higher Order

Gluon Compton process dominant \( \sim 75\% \)
→ Sensitive to the gluon polarization.
How to Measure?

Direct Process
Bremsstrahlung Process

No one know which photon from what.

Background
Non-vertex Photon
Neutral hadron contribution
Noise in the detector
Hadron($\pi^0, \eta, \omega..$) decay

Estimate all backgrounds

After subtracting all backgrounds,
the remained photons are the signals.
By taking all combination between the target photon and the surrounding photons, we can know the photon from π⁰ decay.

⇒ 70% of π⁰ decay can be identified from the mass distribution
Background Subtraction

- **Background photon from Identified $\pi^0$**
  - $\pi^0$ mass distribution
    - The mass position and width is well described by the Monte Carlo.
    - All channels (as defined as healthy) are working properly.
      - No $\pi^0$ is miss-identified.
  - Systematic error in estimate of combinatorial background is small (3%)

- **Background photon from $\pi^0$ going to out of our fiducial area.**
  - Estimated by Monte Carlo simulation
    - Systematic error due to lack of knowledge in Monte Carlo is taken into account. The largest contribution is due to the edge of sector.

- **Photon from other hadrons**
  - Measurement of $\eta/\pi^0$ ratio at PHENIX is used.
  - Assumption of mT scaling for other hadron

- **Neutral hadron and photons from non-vertex.**
  - Estimated from GEANT simulation
Result

- PHENIX preliminary result.
- NLO-pQCD calculation
  - Private communication with W. Vogelsang
  - CTEQ6M PDF.
  - Sum of direct photon bremsstrahlung photon
  - 3 scales (1/2pT, 1pT, 2pT)
  - For renormalization scale factorization scale

pQCD calculation can describe our result very well.
Comparison with Other Exp.


Talk by Monique Werlen at RHIC&AGS users meeting

Phenix data clarifies the data/theory puzzle
Strategy of Isolation Method

(1) Signal (direct)
- Compton + annihilation
- About 30% @ 10 GeV

(2) Signal (fragmentation)
- Background (hadron decay)
- About 10% @ 10 GeV
- About 60% @ 10 GeV

(3) Background (hadron decay)

Isolation cut to reduce background:

\[ R = \sqrt{\Delta \eta^2 + \Delta \phi^2} < 0.5 \]

\[ E_{\text{sum}}(R < 0.5) < E_\gamma \times 0.1 \]

What is the efficiency by this cut for signal 1) & 2) ➔ Next slide
S/N Ratio with Isolation Cut

- S/N ratio
  - S = Direct photon
  - N = Remained Bg. Photon
- Isolation cut help to reduce S/N ratio
  - 5 times better than the subtraction method
  - $p_T = 5-17\text{GeV/c}$

Isolation cut is useful for the future measurement of ALL in direct photon
Two methods
  - Subtraction method
  - isolation method
    • To be smaller by 20-40%

They are not different as we expected from pQCD calculation

Rejection for fragmentation photon
  Is not perfect

or

Most of measured photon are
  From direct process
  (compton, annihilation, or NLO)
Prospect of Photon $A_{LL}$ from Run5

- Direct photon
  - Based on 10pb$^{-1}$ 50% pol.
  - The error will be larger by factor $\sim$2.
- Need more statistics.
PHENIX run5 Status

- 5+kHz DAQ rate
- 3.78pb-1

April/17 – May/25

New result will be available this fall!!!

260TB transferred to RIKEN
(50MB/sec on average)

Large Computing Power at RIKEN (RSCC ranked No. 7 in the Top500 most powerful supercomputers in the world at 2004/06)

DST production will finish in the end of August
Summary

\( \pi^0 \)  \hspace{1cm} \text{Direct Photon}

Inclusive Cross Section

\( A_{LL} \) in RUN3&4

\( A_{LL} \) in RUN5

Consistent with NLO-pQCD

Favor GRSV-std than GRSV-max

Will distinguish\( \Delta G = 0 \)

Need more statistics