Coherent Electromagnetic Interactions in Ultra-Peripheral Heavy Ion Collisions

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• Ultra Peripheral Collisions
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• Cross Sections
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• Summary
Heavy Ion Collision

(Au Au, 200GeV/nucleon, University of Frankfurt)

RHIC

2000 : AuAu  @ $\sqrt{s_{NN}} = 130$GeV

2001 : AuAu, $\bar{p}p$  @ $\sqrt{s_{NN}} = 200$GeV

2003 : dAu, $\bar{p}p$  @ $\sqrt{s_{NN}} = 200$GeV

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Ultra-Peripheral Collisions

Nuclei ‘miss’ geometrically and interact via long range fields

Coupling strength \( \Rightarrow \) large cross sections

- **Photon-** \( \gamma \propto Z^2 \)
  
  Equivalent Photon Approximation (Weizsaecker-Williams, Fermi)

- **Pomeron-** \( P \propto A^{4/3} \) (surface) to \( A^2 \) (volume)

Coherent coupling to extended charge of both nuclei

- \( \Lambda_{\gamma}, \Lambda_P > R_A \)

  \( \Rightarrow \) **Small transverse momentum:**
  
  \( p_T < h/2R_A \sim 90 \text{ MeV} \)

- Longitudinal component
  
  \( P_L < \gamma h/2R_A \sim 6 \text{ GeV} \)

- Quasi Real Photons

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Exclusive Vector Meson Production $\gamma A \rightarrow VA$

Exclusive $\rho$ production
$AuAu \Rightarrow AuAup^0$

\[ \begin{array}{c}
\text{Au} \\
\gamma^* \rho \\
\pi \\
\text{Au}
\end{array} \quad \begin{array}{c}
\text{Au} \\
\pi \\
\text{Au}
\end{array} \quad \begin{array}{c}
\text{Au} \\
p \\
\pi \\
\text{Au}
\end{array} \]

- Extrapolate $\gamma p \rightarrow Vp$ to $\gamma A \rightarrow VA$ with Glauber calculation

$\Rightarrow$ Large cross sections:
- 350 mb at $s_{NN}^{1/2}=130$ GeV
- 590 mb at $s_{NN}^{1/2}=200$ GeV


$\Rightarrow$ Factorize as function of impact parameter

\[ \sigma = \int d^2 b P_{2GDR}(b) P^0 \rho(b) \]

- Nuclear breakup by single (1n1n) and multiple (xnxn) neutron emission
- Single/multiple neutron emission selects different impact parameters
Experimental Signature of UPC

- Two oppositely charged tracks with vertex
- Low total $p_T$
- Back-to-back in transverse plane

Challenge: Trigger!

Coincident signals from nucl. Breakup in zero degree calorimeters (ZDC)

Topology requirements in central trigger barrel (CTB)

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Transverse Momentum & Invariant Mass Spectra

Topology Trigger
AuAu $\rightarrow$ AuAu$\rho^0$

- **2000**: 130 GeV; 9hrs dedicated, 30k triggers
- **2001**: 200 GeV; trigger mix 1.5M topology triggers

- Peak at low $p_T$ $\Rightarrow$ coherent interaction
- Background model from like-sign pairs normalized to data

No neutron signal in ZDC $\Rightarrow$ gold nuclei remain in ground state

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Meson Production with Nuclear Break-up

Minimum Bias (ZDC) Trigger AuAu ⇒ Au*Au*ρ^0

- 2000: ~400k triggers L~60/mb
- 2001: ~1.7M triggers L~250/mb
- Amplitude ratio ππ/ρ similar to lepton nucleon scattering

ZDC Response

Signal region: $p_T < 0.15$ GeV

200GeV
**Cross Section** $\sigma (\text{AuAu} \rightarrow \text{Au}(\ast)\text{Au}(\ast)\rho)$

130 GeV – PRL $^{89}$, 272303 (2002), 200 GeV Preliminary
Luminosity normalization from 7.2b hadronic AuAu cross section
Systematic uncertainties ~20%

Theory: A. Baltz, S. Klein J. Nystrand

![Graph showing cross section data for different scenarios](attachment:image.png)
Determination of Gold Radius

\[ d\sigma^{\rho A} / dt \propto e^{-bt} \]

\[ R_A = \sqrt{4b} \]

\[ R_A = 7.5 \pm 2 \text{ fm} \]
Coherent Interactions in Deuterium-Gold

2003 dAu-> ρdAu

Golden photon torch on d

- $\sqrt{s} = 200 GeV$
- Trigger on the breakup of the deuterium (ZDC)
- Level0 trigger purity 10%!!
- 0.9M events
- First results: clear signal (5 minute testrun) data is in production

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Two-Photon Interaction \( \text{AuAu} \Rightarrow \text{Au*Au*e^+e^-} \)

Identified e^+e^- via dE/dx only at low momentum \( p < 0.13 \text{ GeV} \)

Small acceptance (\( \sim 10^{-6} \)) for e^+e^- pairs

cross section is peaked in the forward region and at low (non-reconstructable) invariant mass

Magnetic field cuts of very low momentum tracks (\(< 60 \text{MeV}\)) where cross section is large

Coherent e^+e^- Pairs

\( p_T < h/\pi b \sim 20 \text{MeV} \) (\(< b > \sim 40 \text{fm}\))

Physics Topics:

\( \Rightarrow \) Validity of WWA and factorization

\( \Rightarrow \) Strong field QED \( Z\alpha \sim 0.6 \)

\( \Rightarrow \) Large cross section \( \propto Z^4\alpha^4 \)

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Cross-section

Within acceptance 
0.14<$M_{ee}$<0.26 GeV, $|\eta|<1.15$

Total $4\pi$ cross section 33kB!

$\sigma_{measured} = 6.0\text{mb} \pm 17\% \pm 18\%$

$\sigma_{predicted} = 7.8\text{mb}$

Predictions
LO QED
S.Klein V.Morozov

* Normalized to total hadronic cross-section,

$\mathcal{L} = 62 \text{ mbarn}^{-1}$

10% systematic error

Phd. Thesis V. Morozov

$\frac{d\sigma_{ee}}{dW_\gamma}$

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Summary

• First measurements for coherent meson production in ultra-peripheral heavy ion collisions with and without nuclear excitation
  \[ \text{Au} + \text{Au} \rightarrow \text{Au} + \text{Au} + \rho^0 \text{ and } \text{Au} + \text{Au} \rightarrow \text{Au}^* + \text{Au}^* + \rho^0. \]
• Low \( p_T \) = coherent coupling
• Cross Sections agree with predictions
  => Approximate factorization of rho-production and nuclear excitation
  => Weizsaecker-Williams photon flux from large relativistic charges ok.
  => Glauber extrapolation of \( \gamma N \) to \( \gamma \text{Au} \) ok
• Cross section for electron-pair production reproduced by LO calculations
• This is just the beginning; Future analysis topics:
  – Vector meson spectroscopy, excited states (\( \rho^*, \ldots \))
  – Multiple VM production
  – Hard diffraction - higher mass states \( J/\psi \)
  – Interference of decaying particles

RHIC is a good place to study diffractive and electromagnetic processes in heavy ion collisions. Lots of data and physics topics.