Exclusive Pair Production in ultra-relativistic Heavy Ion Collisions

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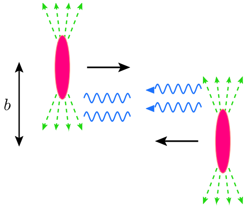
Outline

Equivalent Photon Approximation

Introduction

- E. Fermi (1924), Weizsäcker-Williams (1934)
- Idea: replace the electromagnetic field of a moving particle with an equivalent flux of photons.

$$\omega_L^{\max} = \frac{\hbar}{\Delta t} \sim \frac{\hbar c \gamma_L}{b} \xrightarrow[b_{\min}=R_A]{} \frac{\hbar c \gamma_L}{R_A}$$



E_{CM} (GeV)	$\omega_L^{\max,\gamma\gamma}$ (GeV)
7000	200
3500	100
200	6

- C. Bertulani, S. Klein, J. Nystrand, Ann. Rev. Nucl. Part. Sci. 55, 271 (2005).
- S. Klein, E. Scannapieco, STAR Note 243 (1996).

Equivalent Photon Method

Nuclear Form Factor

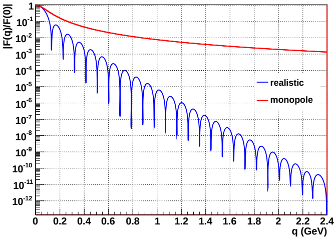
Nuclear charge density (Pb: $R_A = 6.62$ fm, $a = 0.546$ fm):

$$\rho(r) = \rho_0 \left[1 + \exp\left(\frac{r - R_A}{a}\right)\right]^{-1}$$

Nuclear form factors (Pb: $\Lambda = 0.088$ GeV):

$$F(q) = \int_0^\infty \frac{4\pi}{q} \rho(r) \sin(qr) r \mathrm{d}r$$

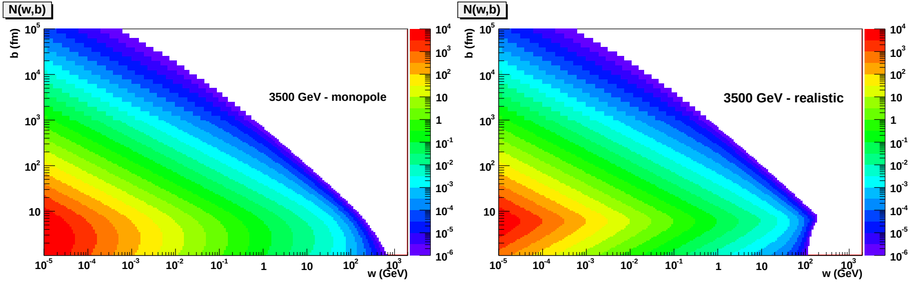
$$F^{\mathrm{mon.}}(q^2) = \frac{\Lambda^2}{\Lambda^2 + q^2}$$



- S.R. Klein, J.Nystrand PRC 60(1999)014903, NPA 752(2005)470.
- M. Klusek-Gawenda and A. Szczurek et al. Phys. Rev. C 82 (2010) 014904, Int.J.Mod.Phys. A 26(2011) 741–743

Photon density

Dependence on photon energy and on impact parameter



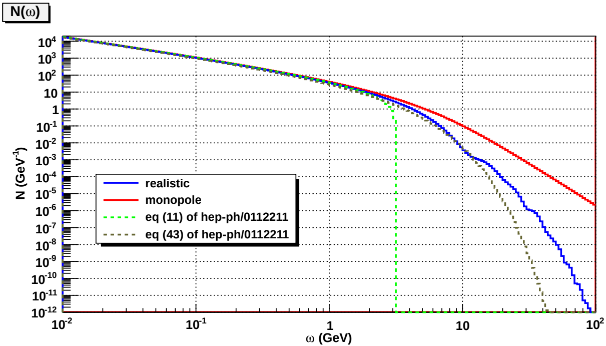
$$N_\gamma(w,b) = \frac{\alpha Z^2}{\pi^2 w b^2}\left[\int_0^\infty \mathrm{d}u\, \frac{J_1(u)}{(bw/u\gamma)^2+1}\, F\left(\sqrt{\frac{u^2}{b^2}+\frac{w^2}{\gamma^2}}\right)\right]^2$$

- For $F^{\text{mon.}}$ the integral is numerically unstable $\rightarrow$ use analytic result.
- For $F^{\text{real.}}$: $u_{max} = b\sqrt{q_{max}^2 - (w/\gamma)^2}$, $q_{max} = 2.4$

Photon density

Dependence on impact paramter

$$N_\gamma(w) = \int d^2\vec{b}\, N_\gamma(w,b) \underset{w\ \text{small}}{\sim} 2\frac{\alpha Z^2}{\pi}\ \ln\left(\frac{\gamma}{wR_A}\right)$$

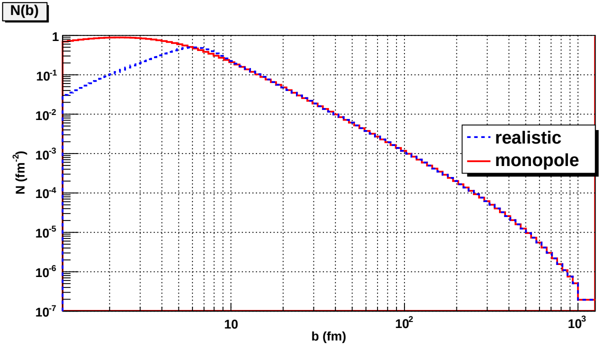


- For small w all four approaches agree

Photon density

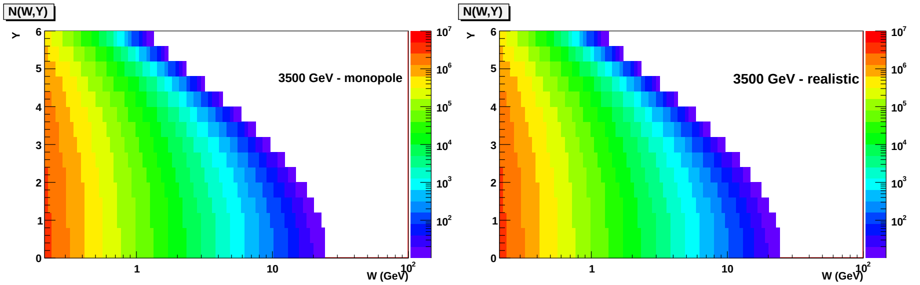
Dependence on photon energy

$$N_\gamma(b) = \int_0^\infty \mathrm{d}w \; N_\gamma(w, b)$$



- at small impact parameters the realistic form factor drops off
- agreement at large *b*

$\gamma\gamma$ Density



W, Y – $\gamma\gamma$ CM energy and rapidity:

$$N_{\gamma\gamma}(W,Y) = \int \mathrm{d}^2\vec{b}_1 \mathrm{d}^2\vec{b}_2\, \theta\left(|\vec{b}_1 - \vec{b}_2| - 2R_A\right) N_\gamma\left(\frac{W}{2}e^{Y}, b_1\right) N_\gamma\left(\frac{W}{2}e^{-Y}, b_2\right)$$

- θ-function can be replaced by a smooth step function
- N_γ can be computed using monopole or realistic form factors

Cross Section Calculation

- $\gamma\gamma$ process $AA \to AA\, X^+X^-$: (e.g. $X = \pi,\ e,\ \mu$)

$$\sigma(AA \to AA\, X^+X^-) = \int \mathrm{d}W\, \frac{d\sigma(\gamma\gamma \to X^+X^-)}{dW} \int \mathrm{d}Y\, \frac{W}{2} N_{\gamma\gamma}(W, Y)$$

- γ-pomeron process $AA \to AA\ V$ ($V = \rho^0, J/\Psi, \Upsilon$)

$$\sigma(AA \to AA\ V) = \int \mathrm{d}w\, \frac{\mathrm{d}N_\gamma}{\mathrm{d}w}\, \sigma(\gamma A \to VA)$$

- Including nuclear breakup[1]

$$\sigma(AA \to A^\star A^\star\, V) = \int \mathrm{d}^2b\, P^{\mathrm{br}}(b) \int \mathrm{d}w\, \frac{\mathrm{d}^3 N_\gamma}{\mathrm{d}w\mathrm{d}^2 b}\, \sigma(\gamma A \to VA)\, \theta(|\vec{b}| - R_A)$$

  - P^{br}: probability of nuclear breakup
  - $\theta(|\vec{b}| - R_A)$ can be replaced by more realistic function

[1] A. Baltz, S.R. Klein and J. Nystrand, Phys.Rev.Lett. 89 (2002) 012301

Coherent ρ^0 Production

Coherent ρ^0 Production

Introduction

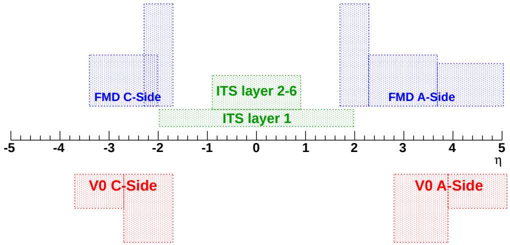
- $AA \rightarrow AA\,\pi^+\pi^-$
- Branching ratio $\rho^0 \rightarrow \pi^+\pi^- \sim 100\%$
- Has been measured at RHIC[2]
- ALICE measurement, analysis is ongoing

- Event characterization:
  - two charged opposite-sign tracks at mid-raidity
  - no tracks outside central rapidity
  - enhancement at low sum-P_T (but track P_T can be big)
  - nuclear breakup: neutrons can be detected in zero-degree calorimeters

[2] C. Adler et al. PRL 89(2002)272302

Coherent ρ^0 Production

Event- and Track Selection



$$AA \longrightarrow AA\,X^+X^-$$

- Ideal event: two charged tracks in an otherwise empty detector.
- Pseudo-rapidity gap, e.g. in ALICE veto on $|\eta| > 0.9$.
- Coherent production: low pair-P_T
- Event emptiness definition: detector noise, dependence on beam background
- Background estimation: like-sign events, analysis of minimum-bias MC.

Coherent ρ^0 Production

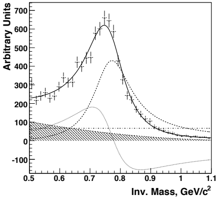
Shape of Invariant mass distribution

The minv distribution is described by the Söding interference formula:

$$\frac{d\sigma}{dm_{\pi\pi}} = \left| A \frac{\sqrt{m_{\pi\pi} m_{\rho^0} \Gamma(m_{\pi\pi})}}{m_{\pi\pi}^2 - m_{\rho^0}^2 + i m_{\rho^0} \Gamma(m_{\pi\pi})} + B \right|^2$$

with minv-dependent width:

$$\Gamma(m_{\pi\pi}) = \Gamma_{\rho^0} \frac{m_{\rho^0}}{m_{\pi\pi}} \left(\frac{m_{\pi\pi}^2 - 4m_\pi^2}{m_{\rho^0}^2 - 4m_\pi^2} \right)^{3/2}$$



- B is the non-coherent *amplitude*
- $(A,\ B,\ \Gamma_{\rho^0},\ m_{\rho^0})$ are determined by a fit.
- The ratio $|B/A|$ ratio has been measured before, cf. e.g. by STAR[3]

[3] PRC 77 (2008) 034910

Coherent ρ^0 Production

Efficiency Corrections

- A real detector is not perfect: need to correct for efficiency
  $\Longrightarrow$ MC simulations.
- Goal: computing a corrected invariant mass histogram
- No unfolding is necessary ($\Gamma_{\rho^0} \sim 150 MeV$)
- We use $(1, N_Y, N_M)$ bins in P_T, rapidity and in invariant mass.
- The correction is applied for each bin in (Y, M):

$$\left(\frac{\mathrm{d}^2\sigma}{\mathrm{d}M\mathrm{d}Y}\right)^{\mathrm{abs}} = \frac{1}{\epsilon(M, Y)}\left(\frac{\mathrm{d}^2\sigma}{\mathrm{d}M\mathrm{d}Y}\right)^{\mathrm{raw}}$$

- Used MC generators:
  - STARlight
  - Phase-space generator, see next slide

Coherent ρ^0 Production

Phase-space MC Generator

- Physics input:
  - kinematics 1$\rightarrow$2
  - θ-distribution of decaying particle$\sim \sin^3\theta \quad (\rho^0 \to \pi^+\pi^-)$
- All remaining free variables are drawn from flat distributions
- Method is based on STARlight

1. Generate the 4-vector of ρ^0 with given M, Y, P_T: $\qquad (\alpha \in [0, 2\pi])$

$$v = (P_T \cos\alpha, P_T \sin\alpha, M_T \sinh Y, M_T \cosh Y)\ , \quad M_T = \sqrt{M^2 + P_T^2}$$

2. Generate two pion-tracks in the rest frame of ρ^0

$$v_\pm = (\pm\vec{p}, M/2) \qquad \text{with} \quad p^2 = M^2/4 - m_\pi^2 \quad \text{and} \quad \theta(\vec{p}) \sim \sin^3\theta$$

3. Then boost $v_\pm$ from the $\gamma\gamma$ CM frame into the laboratory frame using v.

Summary and Outlook

- Equivalent Photon Approximatio:
  - tool to compute UPC cross sections
  - different options for the nuclear form factor, shadowing
  - can be applied to nuclear breakup
- Ultra-peripheral collisions are characterized by
  - two charged opposite-sign tracks at mid-raidity
  - low sum-P_T (coherent production)
- ALICE is working on UPC processes *PbPb*
  - $\rho^0 \rightarrow \pi^+\pi^-$
  - J/Ψ $\rightarrow e^+e^-$, $\mu^+\mu^-$
- Absolute cross sections at mid-rapidity (work is ongoing)
- Nuclear breakup can be studied using zero-degree calorimeters
- Outlook: pPb collsions in 2012.

Thank you for your attention