Centrality Dependence of Dilepton Production in Heavy Ion Collisions

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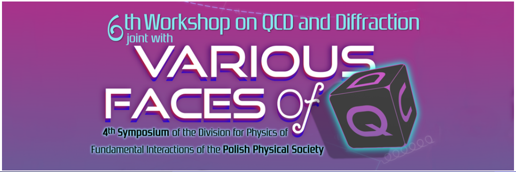
arXiv:1809.07049 / Phys. Lett. B



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INTRODUCTION

- First measurements of e^+e^- production in the mass region $0.4 < M_{e^+e^-} < 2.6$ GeV at low p_T^e in non-central and non-ultraperipheral A-A collisions (STAR)
- Previous dilepton measurements over a wide p_T^{lepton} region and in the mass region below ≈ 0.7 GeV (NA60, STAR)
- Photon-photon process & photoproduction process
- $\gamma\gamma \to l^+l^-$ & coherent $\gamma A \to VA$ - peaked at very low p_T^{lepton} (ALICE)
- UPC - STAR, ALICE, ATLAS, CMS
- This talk - first result including centrality classes

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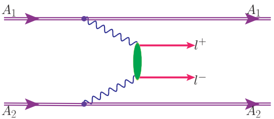
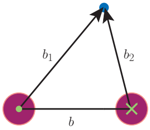
$\gamma\gamma$ FUSION





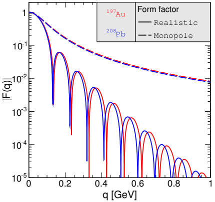
$$\frac{d\sigma\left(AA \to AAl^+l^-\right)}{dy_{l^+}\,dy_{l^-}\,dp_T^2\,d^2\mathbf{b}} = \int d^2\mathbf{b}_1 d^2\mathbf{b}_2\,\delta^{(2)}(\mathbf{b}-\mathbf{b}_1-\mathbf{b}_2)$$

$$\times\; N(\omega_1,b_1)N(\omega_2,b_2)\frac{d\sigma(\gamma\gamma\to l^+l^-;\hat{s})}{d(-\hat{t})}\,,$$

$$N(\omega,b) = \frac{Z^2\alpha_{\rm EM}}{\pi^2}\left|\int_0^\infty dq_T\,\frac{q_T^2 F_{\rm em}(q_T^2+\frac{\omega^2}{\gamma^2})}{q_T^2+\frac{\omega^2}{\gamma^2}}J_1(bq_T)\right|^2$$

$$(!)\,F_{\rm em}^{\rm real}\left(\mathbf{q}^2\right) = \frac{4\pi}{|\mathbf{q}|}\int\rho(r)\sin(|\mathbf{q}|\,r)\,r\,dr$$

$$F_{\rm em}^{\rm mon}\left(\mathbf{q}^2\right) = \frac{\Lambda^2}{\Lambda^2+|\mathbf{q}|^2}$$



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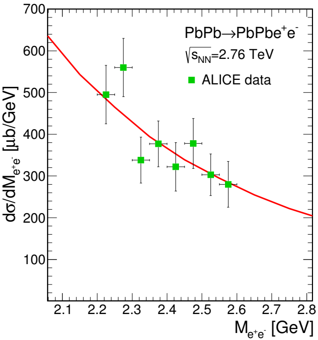
$AA \to AAe^+e^-$ - ULTRAPERIPHERAL COLLISION

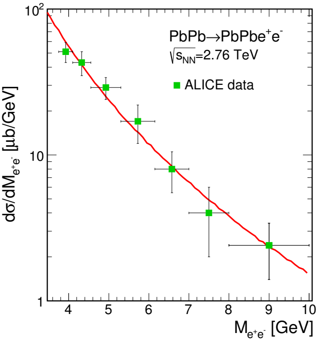
- ALICE Collaboration (Abbas, E. et al.), *Charmonium and e^+e^- pair photoproduction at mid-rapidity in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV*, Eur. Phys. J. **C73** (2013) 2617

2.2 GeV $< M_{ee} <$ 2.6 GeV

$|y_e| < 0.9$

3.7 GeV $< M_{ee} <$ 10 GeV



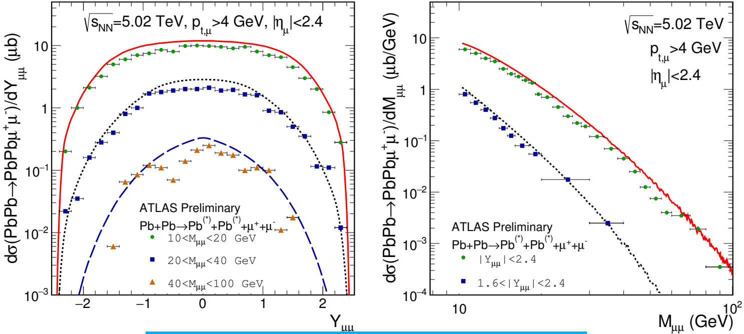


Good description of single pair production $\Rightarrow$ two l^+l^- pair production

$AA \to AA\mu^+\mu^-$ - UltraPeripheral Collision

- ATLAS Collaboration, *Measurement of high-mass dimuon pairs from ultraperipheral lead-lead collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV with the ATLAS detector at the LHC*, ATLAS-CONF-2016-025

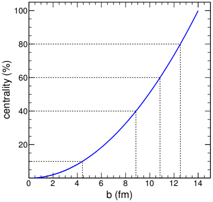
$\frac{d\sigma}{dY_{\mu^+\mu^-}}$ $\quad p_{t,\mu} > 4$ GeV, $|\eta_e| < 0.9$ $\quad \frac{d\sigma}{dM_{\mu^+\mu^-}}$



"Overwriting" of single $\mu^+\mu^-$ pair production

$AA \to AAl^+l^-$

ULTRA-PERIPHERAL → PERIPHERAL →



→ SEMI-PERIPHERAL → SEMI-CENTRAL

- STAR Collaboration (Adam, J. et al.), *Low-p_T e^+e^- pair production in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV at STAR*, Phys. Rev. Lett. **121** (2018) 132301

$$\frac{\mathrm{d}N_{l^+l^-}[\mathcal{C}]}{\mathrm{d}M} = \frac{1}{f_{\mathcal{C}} \cdot \sigma_{\mathrm{AA}}^{\mathrm{in}}} \int_{b_{\min}}^{b_{\max}} \mathrm{d}b \times \int \mathrm{d}y_{l^+}\mathrm{d}y_{l^-}\mathrm{d}p_T^2\, \delta(M - 2\sqrt{\omega_1\omega_2})\, \frac{\mathrm{d}\sigma(AA \to AAl^+l^-)}{\mathrm{d}y_{l^+}\mathrm{d}y_{l^-}\mathrm{d}p_T^2 db},$$

$$f_{\mathcal{C}} = \frac{1}{\sigma_{\mathrm{AA}}^{\mathrm{in}}} \int_{b_{\min}}^{b_{\max}} db \frac{d\sigma_{\mathrm{AA}}^{\mathrm{in}}}{db},$$

$$\frac{d\sigma_{\mathrm{AA}}^{\mathrm{in}}}{db} = 2\pi b\left(1 - e^{-\sigma_{\mathrm{NN}}^{\mathrm{in}} T_{\mathrm{AA}}(b)}\right),$$

$$T_{\mathrm{AA}}(b) = \int d^3\mathbf{r}_1 d^3\mathbf{r}_2\, \delta^{(2)}(\mathbf{b} - \boldsymbol{r}_{1\perp} - \boldsymbol{r}_{2\perp})\, n_{\mathrm{A}}(r_1) n_{\mathrm{A}}(r_2).$$

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THERMAL DILEPTON RADIATION

- R. Rapp and H. van Hees,
  Thermal dileptons as fireball thermometer and chronometer,
  Phys. Lett. **B753** (2016) 586

$$\frac{dN_{l^+l^-}}{dM} = \int d^4x \, \frac{M\, d^3P}{P_0} \, \frac{dN_{l^+l^-}}{d^4x\, d^4P},$$

$$\frac{dN_{l^+l^-}}{d^4x\, d^4P} = -\frac{\alpha_{\mathrm{EM}}^2 L(M)}{\pi^3 M^2} \, f^B(P_0; T) \, \mathrm{Im}\Pi_{\mathrm{EM}}(M, P; \mu_B, T),$$

- $f^B(P_0; T)$ - thermal Bose function
- $L(M)$ - final-state lepton phase space factor
- $\mathrm{Im}\Pi_{\mathrm{EM}}(M, P; \mu_B, T)$ - the EM spectral function is well known in the vacuum, being proportional to the cross section for $e^+e^- \to$ hadrons.
  - $M \leqslant 1$ GeV - saturated by the light vector mesons,
  - $M > 1$ GeV - characterized by a $q\bar{q}$ continuum which hadronizes into multi-meson states

Hadronic Cocktail

When all particles decouple from the system, long-lived hadrons can decay into lepton pairs and are measured by the detector system.

TABLE III. Input yields of various cocktail components for 0-80% minimum-bias Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

Source	B.R.	dN/dy or σ	Uncertainty (%)	Reference
$\pi^0 \to \gamma ee$	1.174×10^{-2}	98.5	8	STAR [33,34]
$\eta \to \gamma ee$	7×10^{-3}	7.86	30	PHENIX [17,35]
$\eta' \to \gamma ee$	4.7×10^{-4}	2.31	100	PHENIX [17], STAR [31]
$\rho \to ee$	4.72×10^{-5}	16.7	42	STAR [42]
$\omega \to ee$	7.28×10^{-5}			
$\omega \to \pi^0 ee$	7.7×10^{-4}	9.87	33	STAR [43]
$\phi \to ee$	2.95×10^{-4}			
$\phi \to \eta ee$	1.15×10^{-4}	2.43	10	STAR [36]
$J/\psi \to ee$	5.94×10^{-2}	2.33×10^{-3}	15	PHENIX [38]
$\psi' \to ee$	7.72×10^{-3}	3.38×10^{-4}	27	PHENIX [44,45]
$c\bar{c} \to ee$	1.03×10^{-1}	$d\sigma^{c\bar{c}}/dy = 171\ \mu$b	15	STAR [41]
$b\bar{b} \to ee$	1.08×10^{-1}	$\sigma_{pp}^{b\bar{b}} = 3.7\ \mu$b	30	PYTHIA[32]
$DY \to ee$	3.36×10^{-2}	$\sigma_{pp}^{DY} = 42$ nb	30	PYTHIA[32]

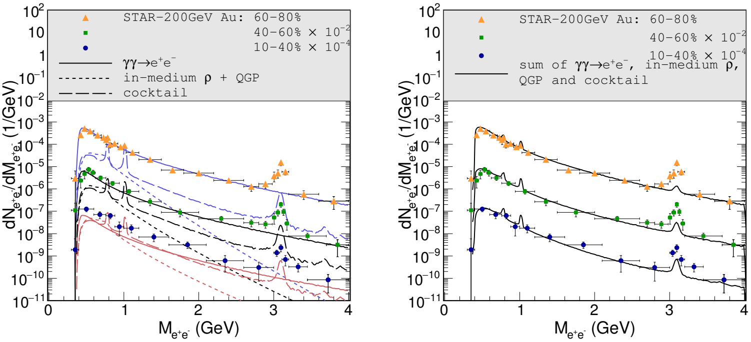
Phys. Rev. **C92** (2015) 024912

Au+Au 200 GeV

Centrality

$p_T^{e^+e^-} < 0.15$ GeV, $p_T^e > 0.2$ GeV, $|\eta| < 1$, $|y^{e^+e^-}| < 1$

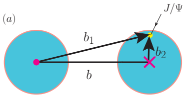
$\frac{dN}{dM_{e^+e^-}}$



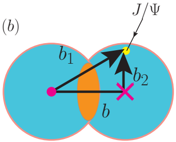
Good agreement with STAR data

$M_{e^+e^-} \approx 3$ GeV $\rightarrow$ coherent J/ψ production ?

J/ψ PHOTOPRODUCTION



$$N^{(0)}(\omega, b) = \frac{Z^2 \alpha_{em}}{\pi^2} \left| \int u^2 J_1(u) \frac{F\left(\frac{\left(\frac{\omega b}{\gamma}\right)^2 + u^2}{b^2}\right)}{\left(\frac{\omega b}{\gamma}\right)^2 + u^2} \right|^2 ,$$



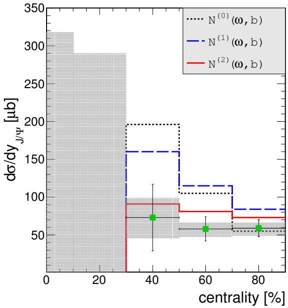
$$N^{(1)}(\omega, b) = \int N^{(0)}(\omega, b_1) \frac{\theta(R_A - \mathbf{b_2})}{\pi R_A^2} d^2 b_1 ,$$

$$N^{(2)}(\omega, b) = \int N^{(0)}(\omega, b_1) \frac{\theta(R_A - \mathbf{b_2}) \times \theta(\mathbf{b_1} - R_A)}{\pi R_A^2} d^2 b_1 .$$

Region of overlapping nuclei
$\rightarrow$ quark-gluon plasma.

$p_T^e > 0.2$ GeV, $2.5 < y < 4$

- ➢ ALICE Collaboration (Adam, J. et al.), *Measurement of an excess in the yield of J/ψ at very low p_{T} in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV*, Phys. Rev. Lett. **116** (2016) 222301
- ➢ Phys. Rev. **C93** (2016) 044912



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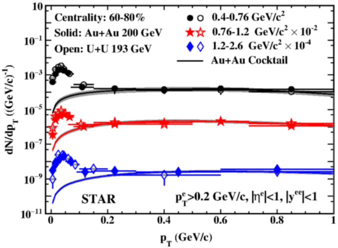
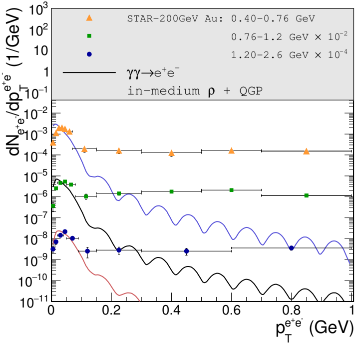
AU+AU 200 GEV

$p_T^e > 0.2$ GeV, $|\eta| < 1$, $|y^{e^+e^-}| < 1$, $c = (60-80)\%$

$$\frac{dN}{dp_T^{e^+e^-}}$$





$p_T^{e^+e^-} < 0.1$ GeV $\to \gamma\gamma$ fusion, $p_T^{e^+e^-} > 0.2$ GeV $\to$ cocktail,

$p_T^{e^+e^-} = (0.1-0.2)$ GeV $\to$ thermal radiation ?

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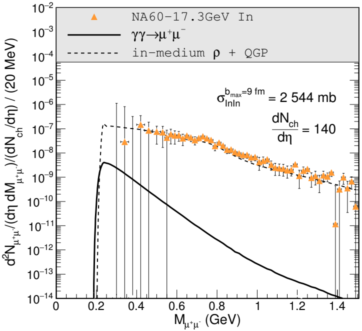
IN+IN 17.3 GEV

$3.3 < Y^{\mu^+\mu^-,LAB} < 4.2$

$$\frac{d^2N}{d\eta dM_{\mu^+\mu^-}} \Big/ \frac{dN_{ch}}{d\eta}$$



- Na60 Collaboration (Arnaldi, R. et al.), *NA60 results on thermal dimuons*, Eur. Phys. J. **C61** (2009) 711

Only Thermal Radiation (!)

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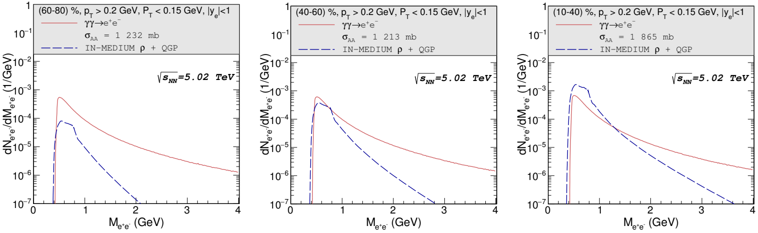
PB-PB 5.02 TEV

$$p_T^{e^+e^-} < 0.15 \text{ GeV}, \ p_T^e > 0.2 \text{ GeV}, \ |y^e| < 1$$

$$\frac{dN}{dM_{e^+e^-}}$$



PERIPHERAL....SEMI-PERIPHERAL....SEMI-CENTRAL

$\gamma\gamma \rightarrow e^+e^- \Leftarrow$ $\Rightarrow$ in-medium ρ+QGP

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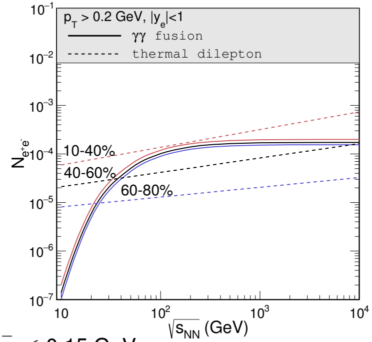
CONCLUSION

$p_T^{e^+e^-} < 0.15$ GeV, $p_T^e > 0.2$ GeV, $|y^e| < 1$

$N_{e^+e^-}(\sqrt{s_{NN}})$

$c = (10-40)\%$
$c = (40-60)\%$
$c = (60-80)\%$



- ✓ Dilepton production at $p_T^{l^+l^-} \leqslant 0.15$ GeV
- ✓ Thermal radiation vs. coherent photon fusion (+ cocktail)
- ✓ Description of the NA60 & STAR data
- ✓ Peripheral collisions → coherent contribution
- ✓ Increasing number of participant nucleons → thermal radiation
- ✓ Ultrarelativistic collisions → $\gamma\gamma$ fusion

THANK YOU

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