Geometry of heavy ion collisions during lepton pair production

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IFJ PAN PPSS

July 30, 2021

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- We study the geometry of di-lepton pair production due to fusion.
- These photons are emitted in heavy ions collisions due to strong electromagnetic field.
- Where do di-lepton pairs like to be produced? Inside or outside the nucleus?

Note

For this project we have restricted ourselves to the study of $e^{+}e$ pair production.

Kinematic Variables. Transverse momentum p_T

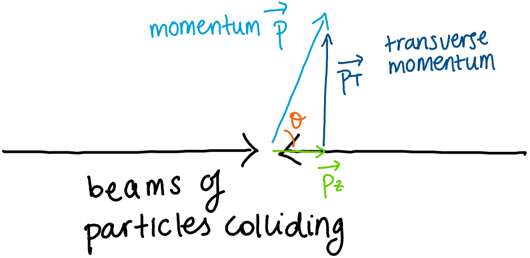


Figure: A graphic representation of transverse momentum.

Note

In high energy physics, we use natural units for the speed of light, i.e. $c = 1$.

Difference between p_t and P_t

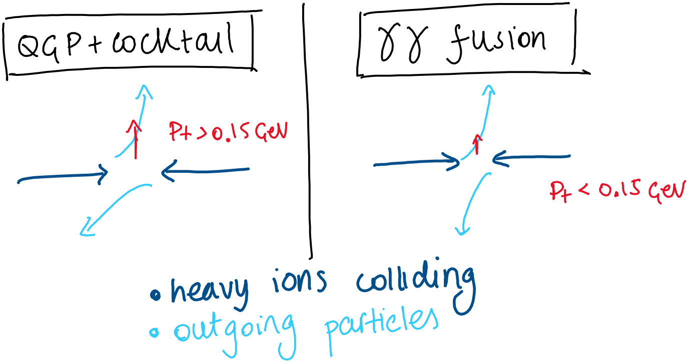


Figure: Graphical representation of the P_t, where $P_t = p_{t,1} + p_{t,2}$

P_t for QGP and cocktail is much larger than P_t for -fusion, because for -fusion: $p_{t;1}$ $p_{t;2}$

Why is low P_T interesting?

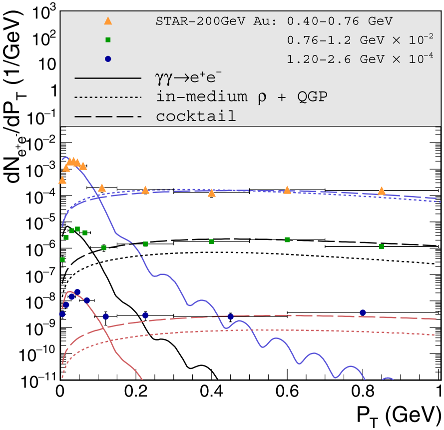


Figure: P_T spectra of the individual contributions in 3 different $M_{+\;-}$ for $c = 60$ 80% Au+Au collisions ($\sqrt{s_{NN}} = 200$ GeV), compared to STAR data

First verification

fusion processes dominate and can explain the low-P_T field for peripheral collisions.

Next steps

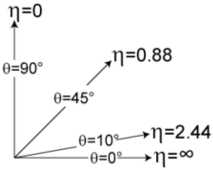
We use the same approach to the electron-positron production @ LHC energy

Rapidity

- Rapidity is usually used as a measure of relativistic velocity.
- The velocity is not an additive quantity, i.e. non-linear in successive transformation. Here comes the need of "Rapidity" to circumvent this drawback, by defining:

$$= \tanh y \text{ or } \frac{1}{2} ln \; \frac{1 + \quad}{1 \quad}$$

- Note: rapidity is approximately the same as pseudo-rapidity when we work with very small masses (e.g. electrons or muons)



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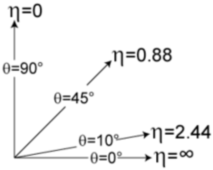


Rapidity y

Rapidity y is given by

$$\begin{aligned} y &= \frac{1}{2} ln \left(\frac{1+}{1-} \right) \\ &= \frac{1}{2} ln \left(\frac{E+p_z}{E-p_z} \right) \eqsim - ln \left(tan \, \frac{}{2} \right) : \end{aligned}$$

Where

- refers to $\frac{v}{c}$.
- p_z refers to the component of momentum relative to the beam axis.
- E is the energy of the particle.

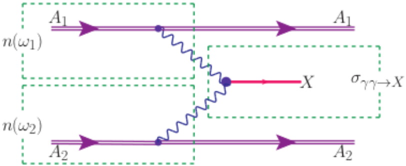
Relationship of y with p_t

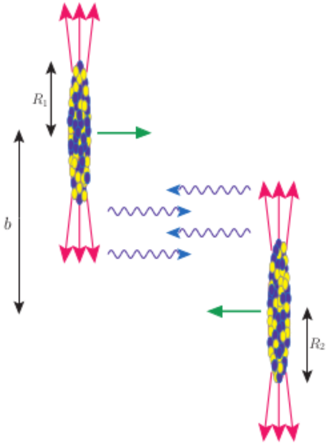
$$y = ln \left(\frac{E + p_z c}{\sqrt{m^2 c^4 + p_T^2 c^2}} \right) :$$

Where p_t is transverse momentum.

Equivalent photon approximation (EPA)

- The time-dependent electromagnetic field can be replaced by a spectrum of photons where photons can be considered as real or quasi-real.





Impact parameter space

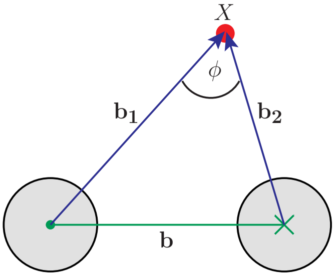
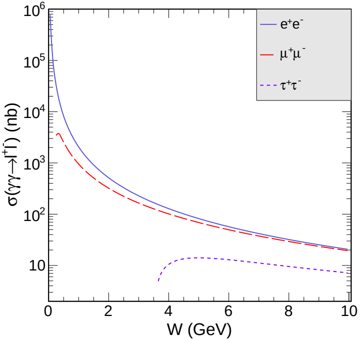


Figure: Graphical representation of b_1 and b_2 vectors. X refers to the place where photons collide and di-lepton pairs are produced.

$$
{}_{A_1A_2\,!\,A_1A_2X} = \mathrm{Z}\; n(!_1)n(!_2)\;\; {}_{!\,X}(!_1;!_2)d!_1d!_2 = :::
$$

$$
= \mathrm{Z}\; N(!_1;b_1)N(!_2;b_2)\;\; {}_{!\,X}({}^{p}\overline{s_{A_1A_2}})2\; b\,\mathrm{d}b\,\mathrm{d}\bar{b}_x\,\mathrm{d}\bar{b}_y\,\frac{W}{2}\mathrm{d}W\;\;\mathrm{d}Y_X
$$

Elementary Cross-Section



- Not getting any value for W $< 2m_l$;
- The cross-section of e^+e is much larger than for di-muon or di-taon production respectively.

$$!_{l^+l^-}(W\quad) = \frac{4\quad {}^{2}_{em}}{W^2}\ (\ "\ 2ln\ \frac{W}{2m_l}\quad 1+\ s\,\overline{\ 1\quad\frac{4m_l^2}{W^2}\ }\ !\ \#$$

$$1+\frac{4m_l^2W^2\qquad 8m_l^4}{W^4}\ !\quad s\,\overline{\ 1\quad\frac{4m_l^2}{W^2}\ }\quad 1+\frac{4m_l^2}{W^2}\ !\ )$$

Impact parameter vs. centrality

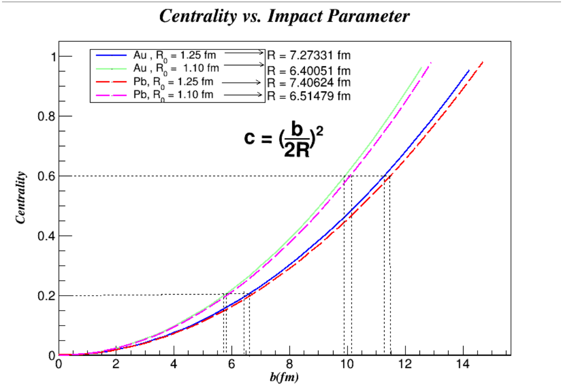
Heavy-ion experiments:

- RHIC - ^{197}Au-^{197}Au
- LHC - ^{208}**Pb**-^{208}**Pb**

centrality

$$c = \frac{b}{2R}^{2}$$

- $R_A = R_0 A^{1=3}$
- $R_0 = (1{:}1 \quad 1{:}25)$ fm



Type of collisions:

- central ($b \quad 0$)
- semi-central
- semi-peripheral
- peripheral
- ultra-peripheral ($b > 2R_A$)

Comparison with ALICE experimental data

Excellent agreement with ALICE experimental data for $M_{e^+e} < 2.5$ GeV.

The ratio of e^+e production inside and outside of the nuclei 1:

Predictions for more central collisions

(a) (b)

Figure: The differential cross sections as a function of invariant mass for 70-90% (a) & 50-70% (b) centrality ranges (for the same kinematical limitations & R_0 parameter)

Note : The orange region has a bigger cross section for the c=(50-70)%

Conclusions

Total cross section (mb)				
	Centrality : 70-90%		**Centrality : 50-70%**	
	$R_0 = 1{:}10$ fm	$R_0 = 1{:}25$ fm	$R_0 = 1{:}10$ fm	$R_0 = 1{:}25$ fm
Inside nucleus	0.07842	0.11090	0.08568	0.12528
Outside Nucleus	0.08876	0.08852	0.09245	0.09231
Full b space	0.16717	0.19942	0.17813	0.21760

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- Errors of the cross sections are smaller than 1%: really precise calculations.

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- The rate at which e^+e pairs are produced depends on the centrality and the radius of the nuclei. We have found that when R_0 is small, they are rather produced outside. However, when we look at larger values of radius, they are more likely to be produced inside of the nuclei.
- **Future Applications:** The same approach can be used to find the differential and total cross-sections for different outgoing particles at numerous energies, e.g. $^+$ pairs @STAR.

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Thank you!