ENERGETIC PROCESSES AROUND REGULAR BLACK HOLES

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INTRODUCTION . The investigation of high-energetic particles collisions in the vicinity of rotating black holes was initiated in [1] where the collisional version of the Penrose process [2] was investigated. The new urge to considering such processes came from an interesting observation made in Ref. [3]. It was found there that two particles which move towards the horizon of the extremal black holes can produce an infinity energy in the centre of mass frame Ec.m.. This effect (called the BSW one after the names of its authors) provoked a large series of works and is under active study currently. The most part of them was restricted to the investigation of the vicinity of the horizon where collision occurs.

The spacetime around a RBH can be obtained using GR coupled to nonlinear electrodynamics (NED) and thecorresponding action for these coupled fields is written

$$S=\frac{1}{16\pi}\int dx^4\sqrt{-g}\,\big(R-L(F)\big) \tag{1}$$

where$F=F^{\mu\nu}F_{\mu\nu}$is the electromagnetic field invariantand $F_{\mu\nu}=A_{\nu,\mu}-A_{\mu,\nu}$is the electromagnetic field tensorand $A_\mu$is the electromagnetic field four potential. The spacetime around the RBH has been found bycoupling Einstein's theory of gravity to NED where theLagrangian is found as a function of the electromagnetic
field invariant.

$$L(F)=\frac{4n}{\alpha}\frac{(\alpha F)^{\frac{k+3}{4}}}{\left[1+(\alpha F)^{\frac{k}{4}}\right]^{1+\frac{n}{k}}} \tag{2}$$

For the case $k=1$and $n\geq 3$, where n is assumed to be an integer [1], the metric tensor is,

$$ds^2=-f dt^2+f^{-1}dr^2+r^2 d\Omega^2 \tag{3}$$

The effective potential for a charged particle a constant plane ($\theta = const$ and $\dot{\theta} = 0$) can be found by solving equation $\mathcal{E} = V_{eff}$(taking $\dot{r} = 0$) and we have and four-velocities of the charged particle

$$\dot{t} = \frac{1}{f}(\mathcal{E} - qA_t)$$

$$\dot{r}^2 = (\mathcal{E} - qA_t)^2 - f[1 + \left(\frac{l}{rsin\theta} - \frac{qB}{2}rsin\theta\right)^2]$$

$$\dot{\phi} = \frac{l}{r^2sin^2\theta} - \frac{qB}{2} \qquad (4)$$

In this section, we will study the centre-of-mass energy of two particles in the case of charged-charged, chargedneutral particles collisions. The expression for the centreof-mass energy for two particle system with mass m_1 and m_2, in a given gravitational field is as a sum of two-momenta

$$\{E_{cm}, 0,0,0\} = m_1 {u_1}^{\mu} + m_2 {u_2}^{\mu} \qquad (5)$$

where, ${u_1}^{\alpha}$ and ${u_2}^{\beta}$ are four-velocity of the two colliding particles and the velocities satisfy the condition $u_\mu u^\mu = -1$. Keeping the condition one can square (5) and we have.

$${E_{cm}}^2 = {m_1}^2 + {m_2}^2 - 2m_1m_2g_{\mu\nu}u^\mu u^\nu \qquad (6)$$

Let us consider simple estimation, assuming that the mass of the particles is different from each other N times, i.e. $m_1 = Nm_2$, N can not be zero, obviously that $N > 1$ corresponds to $m_1 > m_2$, and vice versa $N < 1$ to$m_1 < m_2$ .Thus, the expression for center-of-mass energy (6) takes the following form.

$$\mathcal{E}_{cm}^2 = \frac{E_{cm}^2}{m^2} = 1 + N^2 - 2Ng_{\mu\nu}{u_1}^\mu {u_2}^\nu \qquad (7)$$

Using (4) and (7) conducted an analysis.

Here we will consider the collision of the charged particles with the same mass m_1=$m_2 = m$ (charge might be different, for example, electron and positron) and initial energy $\mathcal{E}_1 = \mathcal{E}_2 = 1$, then the expression for the centerof-mass energy takes the following form Now we will study in detail, center-of-mass energy of two colliding (neutral/charged) particles with different cases, i.e. particles with the same mass (m_1=$m_2 = m$) and different mass $m_2 \neq m_1$ (assuming $m_1 = Nm_2$, here N is some non-zero number) and the angular momentum ($l_1 = -l_2$=l and $l_1 \neq l_2$), and initial energies $\mathcal{E}_1 = \mathcal{E}_2 = 1$ in the equatorial plane using equations of motion charged particles .In figure 1 radial dependence of center-of-mass is plotted in different values of Q and n.

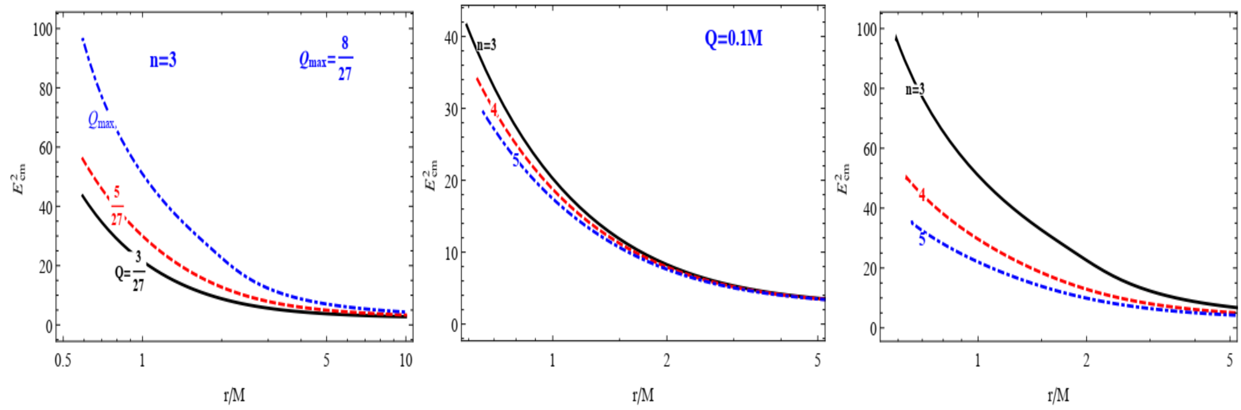

FIG. 1: Radial dependence of center-of-mass energy for charges with value $q = -100$ and $q = 2$

One can see from left panel of this figure that the center-of mass energy increases as the charge of RBH increase, but the increase of n cause to decrease the energy (middle panel), left panel is plotted for extreme charged RBH case for given values of n obviously that the maximum of the energy is at horizon when $r \to r_h$

Let us consider that two charged particle having the same charge and the same angular momentum collision with opposite direction. The question that what is the minimum values of charge q and angular momentum l that the center-of-mass energy $\mathcal{E} > 100$ can be greater than 100.

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