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The 3rd Light Ion Nuclear Collision workshop

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Subthreshold and near threshold kaon photo-production on nuclei

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- **Abstract.**
- The inclusive meson production in photon-induced reactions in the near threshold and subthreshold energy regimes is analyzed,
  - with respect to the one-step incoherent production processes
  - on the basis of an appropriate folding model,
  - which takes properly into account the struck target nucleon removal energy and internal momentum distribution (nucleon spectral function), extracted from many-body calculations with realistic models of the NN interaction.
- \- Simple parameterizations for the total cross sections of the production in photon-nucleon collisions are presented.
- Comparison of the model calculations of the total cross sections for the reaction in the threshold region with the existing experimental data is given.

1- Introduction

- An unambiguous interpretation of specific phenomena in nucleus-nucleus collisions requires a good knowledge of effects arising from:
- - $\gamma + N$
- - N-N
- - proton-nucleus
- - Nucleus-Nucleus

interactions.

- An extensive investigation of the production of K+ -mesons in proton-nucleus reactions [1-12] at incident energies lower than the free nucleon-nucleon threshold have been carried out over the last years.

$$P + A \rightarrow A^{/} + (\Lambda / \Sigma) + N$$

- $$N + N \rightarrow N + (\Lambda / \Sigma) + K$$

- one hopes to extract from these studies information about:
- - Fermi motion,
- - high-momentum components of the nuclear wave function,
- - clusters of nucleons or quarks,
- - reaction mechanism,
- - in-medium properties of hadrons.

- Finally, the electromagnetic production of mesons on nuclei in the threshold region has up to now received very little consideration [13], probably, because of a lack of suitable facilities and associated detectors.

$$1) \quad \gamma + p \rightarrow k^{+} + \Lambda$$

$$2) \quad \gamma + p \rightarrow k^{+} + \Sigma^{0}$$

$$3) \quad \gamma + n \rightarrow k^{+} + \Sigma^{-}$$

The main goal of the present work is:

- In this work, we present the detailed predictions for:
- the total cross sections,
- - obtained, in the threshold energy region,
- -in the framework of the first collision model [10]
- -based on nucleon spectral function,
- -and compare part of them with the available data.

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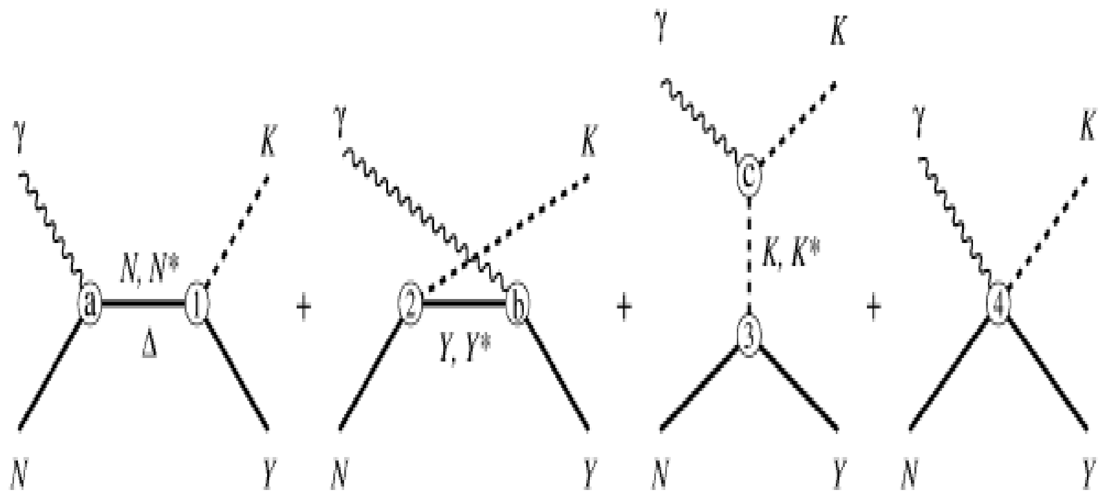
2-First Collision model

- An incident photon can produce a directly in the first inelastic, γN collision due to nucleon Fermi motion. Since we are interested in the bombarding energy region up to approximately 1.3 *GeV*, we have taken into account the following elementary processes which have the lowest free production thresholds:



Feynman diagrams for photo-kaon productions

photo-kaon productions:

1) $\gamma + p \rightarrow k^{+} + \Lambda$

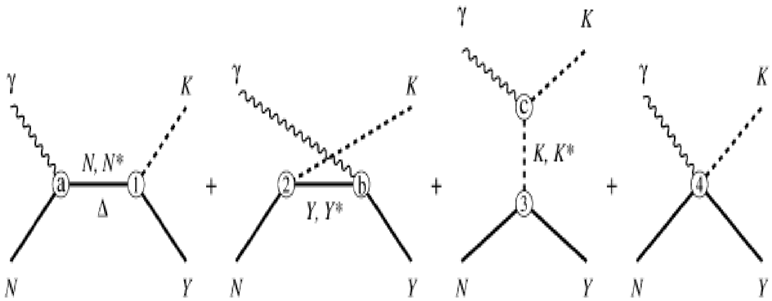
2) $\gamma + p \rightarrow k^{+} + \Sigma^{0}$

3) $\gamma + n \rightarrow k^{+} + \Sigma^{-}$

$$T_{Th}^{1} = 0.91108\,(GeV / c)$$

$$T_{Th}^{2} = 1.0462\,(GeV / c)$$

$$T_{Th}^{3} = 1.0522\,(GeV / c)$$



The invariant inclusive cross section of K^+ production on nuclei by the initial photon with energy E,[10]:

$$E_{k^+}\frac{d\sigma^{(prim)}_{\gamma A\to K^+X}(\mathrm{P}_\gamma)}{dp_{k^+}}$$

$$= Z\left[\left\langle E_{k^+}\frac{d\sigma_{\gamma p\to k^+\Lambda}(\mathrm{P}_\gamma,\mathrm{P}_{k^+})}{dp_{k^+}}\right\rangle+\left\langle E_{k^+}\frac{d\sigma_{\gamma p\to k^+\Sigma^0}(p_\gamma,p_{k^+})}{dp_{k^+}}\right\rangle\right]$$

$$+N\left\langle E_{k^+}\frac{d\sigma_{\gamma n\to k^+\Sigma^-}(p_\gamma,p_{k^+})}{dp_{k^+}}\right\rangle$$

Where: one can write free invariant inclusive cross sections like:

$$\left\langle E_{k^+} \frac{d\sigma_{\gamma N \to k^+ y}(p_\gamma, p_{k^+})}{dp_{k^+}} \right\rangle = \int\int p(p_t, E)\,dp_t\,dE$$

$$\times \left[E_{k^+} \frac{d\sigma_{\gamma N \to K^+ y}(\sqrt{s}, p_{k^+})}{dp_{k^+}} \right]$$

The Lorentz invariant inclusive cross sections for these processes:

$$E_{k^+}\frac{d\sigma_{\gamma N\to K^+Y}(\sqrt{s},p_{K^+})}{dp_{K^+}}=\frac{\pi}{I_2(s,m_y,m_k)}\frac{d\sigma_{\gamma N\to K^+Y}(s)}{d\Omega^*}$$

$$\times\frac{1}{(\omega+E_t)}\delta\left[\omega+E_t-\sqrt{m_y^2+(Q+p_t)^2}\right],$$

$$I_2(s,m_y,m_k)=\frac{\pi}{2}\frac{\lambda(s,m_y^2,m_k^2)}{s}$$

$$\lambda(x,y,z)=\sqrt{[x-(\sqrt{y}+\sqrt{z})^2]\times[x-(\sqrt{y}-\sqrt{z})^2]}$$

$$\omega=E_\gamma-E_{k^+},Q=p_\gamma-p_{k^+}$$

The existing experimental data on the total cross sections have been fitted by the following simple expressions[16]:

$$\sigma_{\gamma N \to K^+ Y}(\sqrt{s}) = \frac{A_Y(\sqrt{s} - \sqrt{s_o})}{B_Y + (\sqrt{s} - \sqrt{s_o})^2}$$

$$\begin{cases} 8.67\left(\dfrac{\sqrt{s} - \sqrt{s_o}}{Gev}\right)^{0.7907} [\mu b] & for \quad \sqrt{s_o} < \sqrt{s} \le 1.873\, Gev \\ 0.3665\left(\dfrac{Gev}{\sqrt{s} - \sqrt{s_o}}\right)^{1.0956} [\mu b] & for \quad \sqrt{s} > 1.873\, Gev \end{cases}$$

Table :Parameters in the approximation of the partial cross section production of K^+ in collision.

reaction	$A_y, \mu b.GeV$	B_y, GeV^2	$\sqrt{s_o}, GeV$
$\gamma + p \to K^+ + \Lambda$	0.6343	0.0151	1.6093
$\gamma + n \to K^+ + \Sigma^-$	0.456	0.1236	1.6909

we will also use in our calculations the following parameterization

$$\sigma_{\gamma p \to K^+ \Lambda}(\sqrt{s}) = \begin{cases} 3.65 \left(\dfrac{\sqrt{s} - \sqrt{s_o}}{Gev} \right)^{0.2275} [\mu b] \; for & \sqrt{s_0} < \sqrt{s} \le 1.6204 GeV \\ 1.29 \, [\mu b] \quad for \;\; \sqrt{s} > 1.6204 GeV \end{cases}$$

3-Nucleon spectral function

- The nucleon spectral function, which represents the probability to find in the nucleus a nucleon with momentum **p***t* and removal (binding) energy *E*, is a crucial point in the evaluation of the subthreshold production of any particles on a nuclear target.

$$P(\vec{P}_t, E) = P_0(\vec{P}_t, E) + P_1(\vec{P}_t, E)$$

Where *P*0 includes the ground and one-hole states of the residual (*A* - 1) nucleon system and *P*1 more complex configurations (mainly 1p-2h states) that arise from the 2p-2h excited states generated in the ground state of the target nucleus by *NN* correlations.

The internal nucleon momentum distribution:

$$
\begin{aligned}
n(\mathbf{p}_t) &= \int P(\mathbf{p}_t, E)dE \\
&= \int P_0(\mathbf{p}_t, E)dE + \int P_1(\mathbf{p}_t, E)dE \\
&= n_0(\mathbf{p}_t) + n_1(\mathbf{p}_t),
\end{aligned}
$$

$$n(\vec{P}_t) = n_0(\vec{P}_t) + n_1(\vec{P}_t)$$

$$n_0(k) = \sum_1^{m_0} A_i^{(0)} \frac{e^{-B_i^{(0)} k^2}}{(1 + C_i^{(0)} k^2)^2}$$

For nuclei with A>4 it will be as follow:

$$n_0(k) = A^0 e^{-B^{(0)}K^2}[1 + C^0 k^2 + D^{(0)}K^4 + E^0 k^6 + F^{(0)}k^8]$$

- in C^{12} , $A^{(0)} = 2.61, B^{(0)} = 2.66, C^{(0)} = 3.54$
  and all other parameters equal to zero,
- for Pb^{208} , $A^{(1)} = 0.275, \quad B^{(1)} = 1.01, \quad C^{(1)} = 0.0304, \quad D^{(1)} = 0.22,$
  and other parameters are zero.[20]

The many-body momentum distribution $n1(\mathbf{p}t)$ for $C12$ has been presented in [18]. Taking into account the corresponding normalization of $n1(\mathbf{p}t)$, it can be parameterized as follows [10]:

$$n_1(p_t) = \frac{s_1}{(2\pi)^{\frac{3}{2}}(1+\alpha_1)} \times \left[\frac{1}{\sigma_1^3} \exp\left(\frac{-p_t^2}{2\sigma_1^2}\right) + \frac{\alpha_1}{\sigma_2^3} \exp\left(\frac{-p_t^2}{2\sigma_2^2}\right) \right]$$

$$\sigma_1^2 = 0.162\ fm^{-2} \quad , \quad \sigma_2^2 = 2.50\ fm^{-2} \quad , \quad \alpha_1 = 2/78$$

4-Off shell calculation:

$$\hat{p}_0 + \hat{p} = \hat{p}_k + \hat{p}_\Lambda$$

$$\hat{p}_0 + \hat{p} - \hat{p}_k = \hat{p}_\Lambda$$

$$\left(\hat{p}_0 + \hat{p} - \hat{p}_k\right)^2 = \left(m_\Lambda\right)^2$$

$$\hat{p}_0 = (E_0, \vec{p}_0) \Rightarrow \hat{p}_0^2 = E_0^2 - \vec{p}_0^2 = m_0^2 = 0$$

$$, \hat{p}_\Lambda^2 = E_\Lambda^2 - \vec{p}_\Lambda^2 = m_\Lambda^2$$

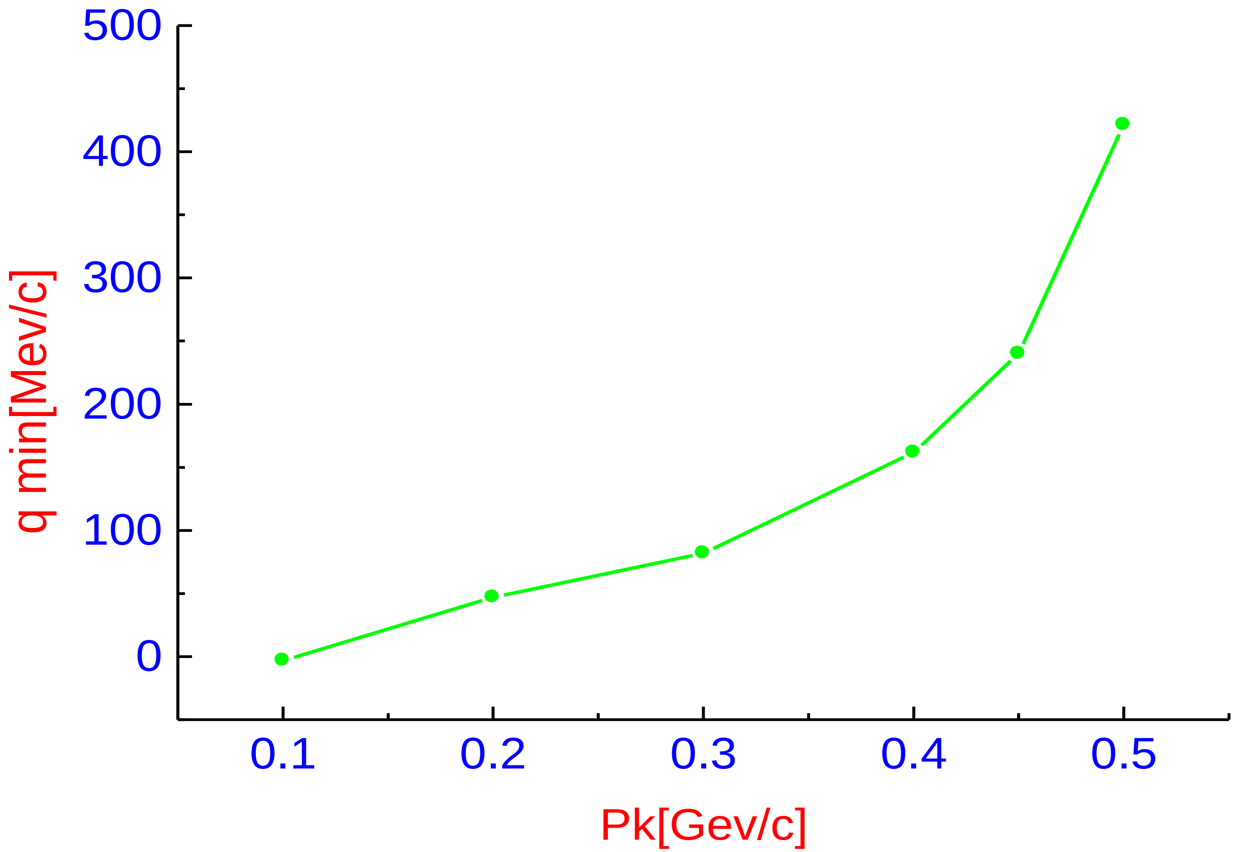
$$M^2 = m^{*2} + m_k^2 - (m_\Lambda)^2$$

$$m_{N'}^2 + m_k^2 + 2\hat{p}_0.\hat{p} - 2\hat{p}_0.\hat{p}_\Lambda - 2\hat{p}.\hat{p}_\Lambda - (m_\Lambda)^2 = 0$$

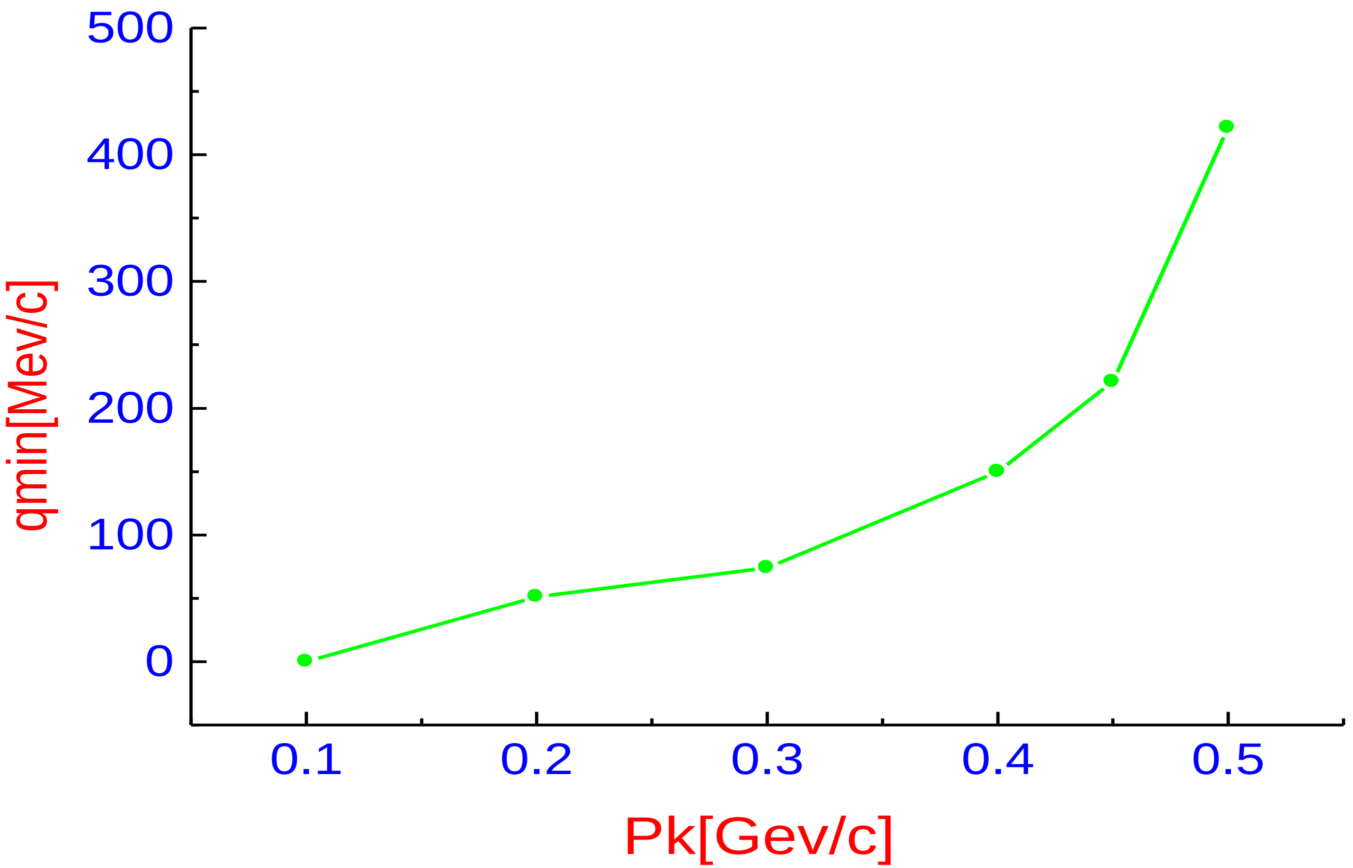
$$q^2\left[1 + \frac{1}{M_B}(m^* + E_0 - E_k)\right] - 2q(p_0 - p_k\cos\theta_k)$$

$$-2\left[-E_0E_k + p_0p_k\cos\theta_k + m^*(E_0 - E_k) + \frac{1}{2}M^2\right] = 0$$

Calculated different q_m related to outgoing kaon with P_K GeV/c from C^{12} in off-shell model.



Calculated different q_m related to outgoing kaon with P_K GeV/c for Pb in off-shell model.



Threshold photon energy for $^{12}_{6}C$ with $\bar{\varepsilon} = 15.5 MeV$ and different p_k.

P_k GeV/c	0.1	0.2	0.3	0.4	0.45	0.5
m_N GeV/c^2	.936	.918	.902	.852	.803	.791
$E_{lab}^{th} GeV$	.924	.93	.958	.99	1.09	1.17

Threshold photon energy for Pb with $\bar{\varepsilon} = 15.5 MeV$ and different p_k.

P_k GeV/c	0.1	0.2	0.3	0.4	0.45	0.5
m_N GeV/c^2	.937	.927	.897	.867	.835	.823
$E_{lab}^{th} GeV$	.93	.95	.97	1.03	1.11	1.2

5- Results

Figure 1. and 2. shows a comparison of the calculated total cross sections for the production of K^{+} mesons from primary channels $\gamma N \rightarrow KY$ with the other work [13] for reaction $\gamma + C^{12} \rightarrow K^{+} + X$ and $\gamma + Pb^{208} \rightarrow K^{+} + X$ The parameterizations for the total cross sections of the sub-processes (1)-(3) were used in the above calculations.

γ

5- Results

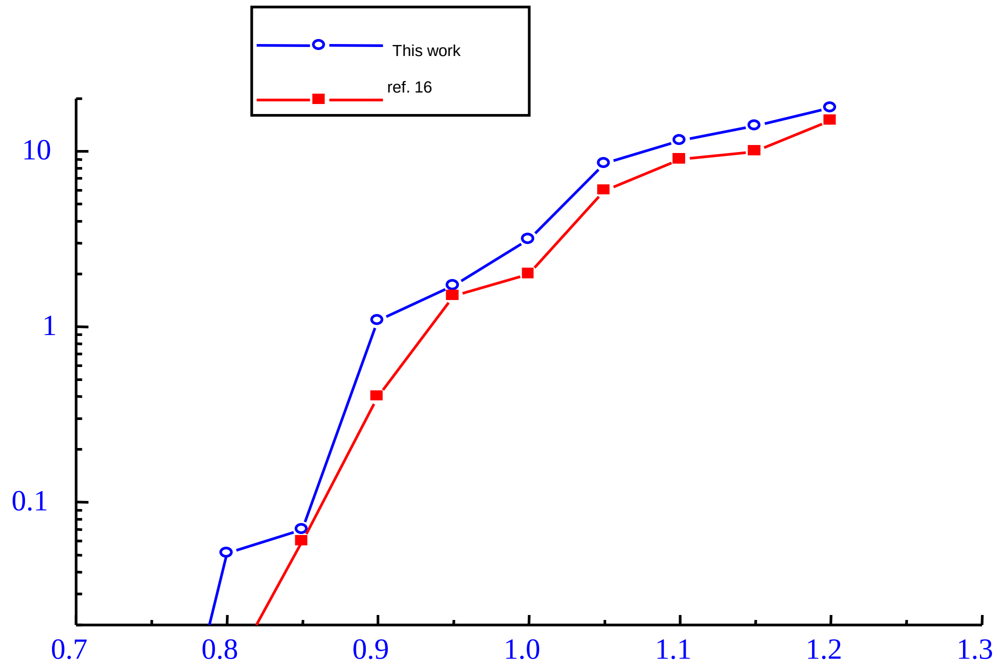


Fig. 1 Total cross section for K^+ production in $\gamma + {}^{12}C$ *from our results with =15.5 MeV and compare to ref.16.*

Results

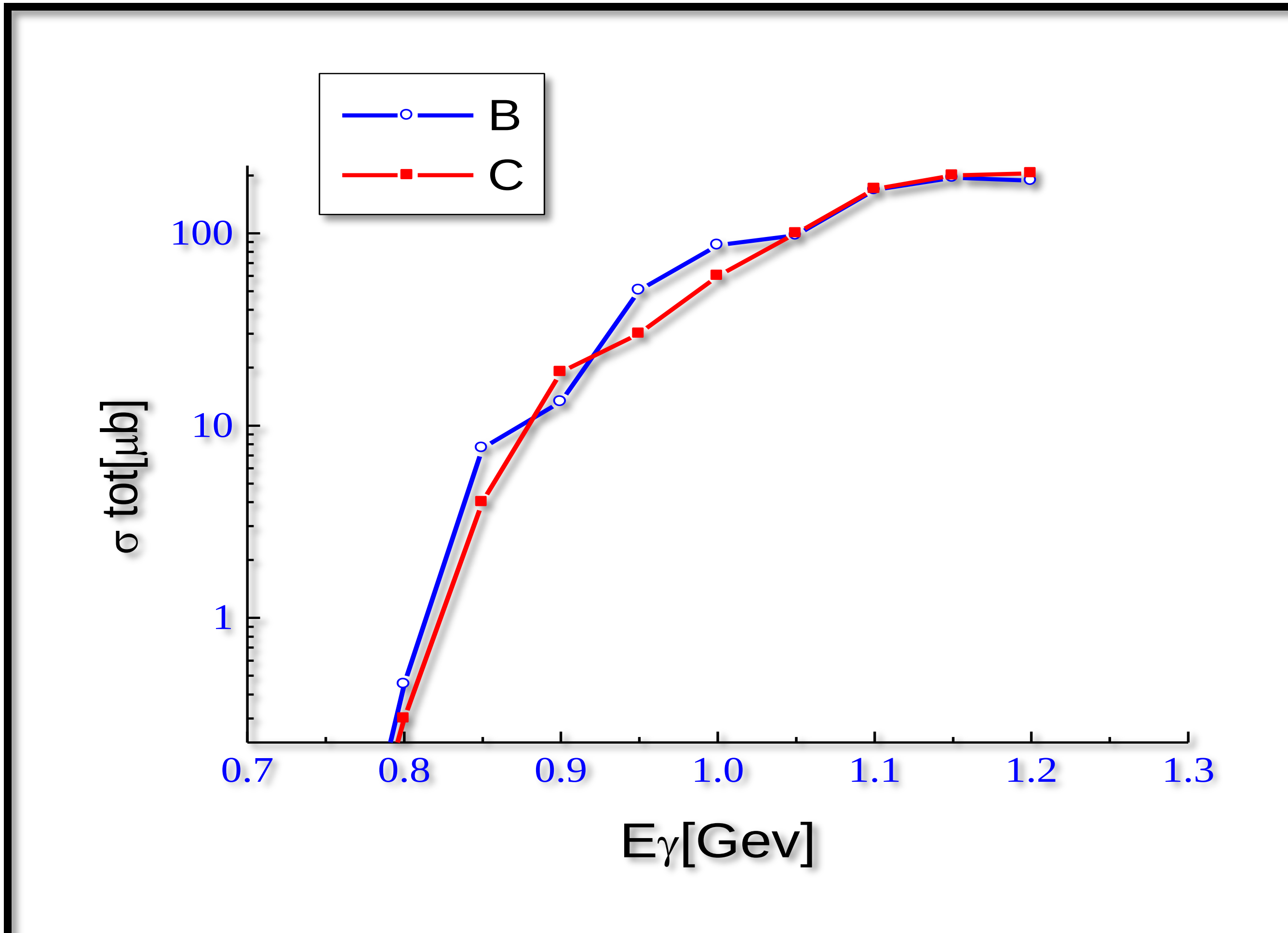


Fig. 2 Total cross section for K+ production in $\gamma + {}^{208}Pb$ *from our results, B, with =12.0 MeV and ,C, compare to ref.16.*

6- Conclusions

- In this work we have calculated the total cross sections for K^+ production from $\gamma + {}^{12}C$ and $\gamma + {}^{208}Pb$ reactions in the near threshold and subthreshold energy regimes by :
  considering incoherent primary photon- nucleon production processes,

  within the framework of the first collision model,

  based on free elementary cross sections for kaon production,

  and on the nucleon spectral function.
  The comparison of the results of our calculations with the existing experimental data [13] was made.

References

- 1. Koptev, V.P., Mikirtyhyants, S.M., Nesterov, M.M.,
- Tarasov, N.A., Shcherbakov, G.V., Abrosimov, N.K.,
- Volchenkov, V.A, Gridnev, A.B., Yeliseyev, V.A., Ivanov,
- E.M., Kruglov, S.P., Malov, Yu.A., Ryabov, G.A.: *ZhETF.*
- **94**, 1 (1988)
- 2. Shor, A., Perez-Mendez, V., Ganezer, K.: *Nucl. Phys.*
- **A514**, 717 (1990)
- 3. Cassing, W., Batko, G., Mosel, U., Niita, K., Schult, O.,
- Wolf, Gy.: *Phys. Lett.* **238B**, 25 (1990)
- 4. Sibirtsev, A.A., BÄuscher, M.: *Z. Phys.* **A347**, 191 (1994)
- 5. Cassing, W., Demski, T., Jarczyk, L., Kamys, B., Rudy,
- Z., Schult, O.W.B., Strzalkowski, A.: *Z. Phys.* **A349**, 77
- (1994)
- 6. Sibirtsev, A.: *Phys. Lett.* **359B**, 29 (1995)
- 7. Muller, H., Sistemich, K.: *Z. Phys.* **A344**, 197 (1992)

- 8. Debowski, M., Barth, R., Boivin, M., Le Bornec, Y.,
- Cieslak, M., Comets, M.P., Courtat, P., Gacougnolle, R.,
- Grosse, E., Kirchner, T., Martin, J.M., Miskowiec, D.,
- MÄuntz, C., Schwab, E., Senger, P., Sturm, C., Tatische®,
- B.,Wagner, A.,Walus, W., Willis, N.,Wurzinger, R., Yonnet,
- J., Zghiche, A.: *Z. Phys.* **A356**, 313 (1996)
- 9. Sibirtsev, A., Cassing, W., Mosel, U.: *Z. Phys.* **A358**, 357
- (1997)
- 10. Efremov, S.V., Paryev, E.Ya.: *Eur. Phys. J.* **A1**, 99 (1998)
- 11. Akindinov, A.V., Chumakov, M.M., Kiselev, Yu.T.,
- Martemyanov, A.N., Mikhailov, K.R., Pozdnyakov, S.A.,
- Sheinkman, V.A., Terekhov, Yu.V.: *APH N.S., Heavy Ion*
- *Physics* **4**, 325 (1996)
- 12. Kiselev, Yu.T., Firozabadi, M.M., Ushakov, V.I.:*Preprint*
- *ITEP* **56{96**, Moscow (1996)

- 13. Yamazaki, H., Maeda, K., Asano, S., Emura, T., Endo,
- S., Ito, S., Itoh, H., Konno, O., Maruyama, K., Niwa, K.,
- Sakaguchi, A., Suda, T., Sumi, Y., Takeya, M., Terasawa,
- T., Yamashita, H.: *Phys. Rev.* **C52**, R1157 (1995)
- 14. Kaplan, D.B., Nelson, A.E.: *Phys. Lett.* **175B**, 57 (1986);
- Nelson, A.E., Kaplan, D.B.: *Phys. Lett.* **192B**, 193 (1987)
- 15. Ciofi degli Atti, C., Simula, S.: *Phys. Lett.* **325B**, 276(1994)

16. E.ya. Paryev,Eur.Phys. J. A 7 127-137(2000) *.* **C43**,

- 17. Bockhorst, M., Burbach, G., Burgwinkel, R., Empt, J., Guse, B., Haas, K.-M., Hannappel, J., Heinloth, K., Hey, T., Hoffmann-Rothe, P., Honscheid, K., Jahnen, T., Jakob, H.P., Jopen, N., Jungst, H., Kirch, U., Klein, F.J., Kostrewa, D., Lindemann, L., Link, J., Manns, J., Menze, D., Merkel, H., Merkel, R., Neuerburg, W.,Paul, E., Plotzke, R., Schenk, U., Schmidt, S., Scholmann,
- J., Schutz, P., Schultz-Coulon, H.-C., Schweitzer, M., Schwille, W.J., Tran, M.Q., Umlauf, G., Vogl, W., Wedemeyer, R., Wehnes, F., Wiskirchen, J., Wolf, A.: *Z. Phys.* **C63**, 37 (1994)
- 18. Ciofe degli Atti, C., Liuti, S.: *Phys. Lett.* **225B**, 215 (1989)
- 19. Ciofe degli Atti, C., Simula, S.: *Phys. Rev.* **C53**, 1689(1996)
- 20. Adeles. R. A, Saghai. S,“ *Phys.Rev*” **C53**, 1689(1996)
- 21. Pace, E., Salme, G.: *Phys. Lett.* **110B**, 411 (1982)
- 22. Ciofi degli Atti, C., Pace, E., Salme, G.: *Phys. Rev* 1155 (1991)

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