Open charm photo-production near threshold

Egle Tomasi-Gustafsson

DAPNIA/SPhN, CEA/Saclay, 91191 Gif-sur-Yvette Cedex, France

Michail P. Rekalo *

Middle East Technical University, Physics Department, Ankara 06531, Turkey

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Abstract

We calculate cross section and beam asymmetry for photoproduction of charmed particles near threshold, in framework of an Effective Lagrangian model. We discuss the sensitivity of the magnetic moments and coupling constants on different reactions.

I. FORMALISM

The spin structure for the amplitude of the photoproduction processes $\gamma+N\to\Lambda_C(\Sigma_C)+D$ can be written in a general form:

$$\mathcal{F}=i\vec{\sigma}\cdot\vec{e}f_1+\vec{\sigma}\cdot\hat{\vec{q}}\vec{\sigma}\cdot\hat{\vec{k}}\times\vec{e}f_2+i\vec{e}\cdot\hat{\vec{q}}\vec{\sigma}\cdot\hat{\vec{k}}f_3+i\vec{\sigma}\cdot\hat{\vec{q}}\vec{e}\cdot\hat{\vec{q}}f_4$$

The differential cross section can be calculated as a function of two structure functions $\mathcal{A}$ and $\mathcal{B}$:

$$\frac{d\sigma}{d\Omega}=\frac{q}{k}(E_1+m)(E_2+M)\frac{\mathcal{B}+\mathcal{A}\sin^2\theta}{128\pi^2 s}$$

*Permanent address: *National Science Center KFTI, 310108 Kharkov, Ukraine*

with

$$\mathcal{A} = |f_3|^2 + |f_4|^2 + 2\mathcal{R}ef_2 f_3^* + 2\mathcal{R}e(f_1 + \cos\theta f_2)f_4^*$$

$$\mathcal{B} = 2\left(|f_1|^2 + |f_2|^2 - 2\cos\theta\mathcal{R}ef_1 f_2^*\right).$$

In case of longitudinally polarized photon beam, the beam asymmetry Σ can be calculated as:

$$\Sigma = \frac{d\sigma_\perp/d\Omega - d\sigma_{||}/d\Omega}{d\sigma_\perp/d\Omega + d\sigma_{||}/d\Omega} = \frac{-\mathcal{A}\sin^2\theta}{\mathcal{B} + \mathcal{A}\sin^2\theta}$$

The formulas derived up to this point have a general validity.

However to go further, the amplitudes f_i, $i = 1-4$ have to be calculated in the framework of a model. We consider here the exchange in $s-$, $t-$ and $u-$ channels (Fig. 1). We can then write each amplitude f_i as the sum of the contributions of the different diagrams:

$$f_i = f_{i,s} + f_{i,t} + f_{i,u}.$$

Let's write explicitely the formulas for these contributions.

For the s-channel:

$$f_{1,s} = g_{NCD}\frac{1}{W+m}\left[Q_N - (W-m)\frac{\kappa_N}{2m}\right]$$

$$f_{2,s} = g_{NCD}\frac{1}{W+m}\left[-Q_N - (W+m)\frac{\kappa_N}{2m}\right]\frac{|\vec{q}|}{E_2+M}$$

$$f_{3,s} = f_{4,s} = 0$$

where Q_N is the electric charge of the nucleon (Q_N=+1 (0) for γp- (γn) -collisions), κ_N is the nucleon anomalous magnetic moment ($\kappa_N = 1.79$ (-1.91) for γp- (γn) -collisions), M is the mass of the charmed baryon (Λ or Σ), and g_{NCD} is the coupling constant for the vertex *Nucleon-Charmed Baryon-D Meson.*

For the u-channel:

$$f_{1,u} = \frac{g_{NCD}}{u-M^2}\left\{Q_C(W-M) - \frac{\kappa_\Lambda}{2M}\left[t - M_D^2 + (W-m)(W-M)\right]\right\}$$

$$f_{2,u} = -\frac{g_{NCD}}{u-M^2}\frac{|\vec{q}|}{E_2+M}\left\{Q_C(W+M) + \frac{\kappa_\Lambda}{2M}\left[t - M_D^2 + (W+m)(W+M)\right]\right\}\frac{W-m}{W+m}$$

$$f_{3,u} = \frac{g_{NCD}}{u - M^2}|\vec{q}|\frac{W-m}{W+m}\left[2Q_C + \kappa_C\frac{W+m}{M}\right],$$

$$f_{4,u} = \frac{g_{NCD}}{u - M^2}(E_2 - M)\left[-2Q_C + \kappa_C\frac{W-m}{M}\right].$$

where Q_C and κ_C are respectively the electric charge and the anomalous magnetic moment of the charmed baryon (Λ or Σ).

For the t-channel:

$$f_{1,t} = f_{2,t} = 0$$

$$f_{3,t} = -2Q_D\frac{g_{NCD}}{t - M_D^2}|\vec{q}|\frac{W-m}{W+m}$$

$$f_{4,u} = 2Q_D\frac{g_{NCD}}{t - M_D^2}(E_2 - M)$$

where M_D and Q_D and κ_C are respectively the mass and the electric charge of the D-meson.

The energies E_1 and E_2 of the initial and final baryons, in the CMS, are determined by the following formulae:

$$E_1 = \frac{s+m^2}{2\sqrt{s}}, \quad E_2 = \frac{s+M^2-m_D^2}{2\sqrt{s}},$$

where s is the total energy, determined by the γ-energy in the Laboratory system: $s = m^2 + 2E_\gamma m$. $\vec{k}$ and $\vec{q}$ are the CMS three-momentum of the target nucleon and of the charmed baryon, respectively:

$$|\vec{k}| = \frac{s-m^2}{2\sqrt{s}}, \quad \vec{q}^2 = E_2^2 - M^2.$$

The Madelstam variables t and u are defined as:

$$t = (p_2 - p_4)^2 = m_D^2 - 2|\vec{k}|(E_D - |\vec{q}|\cos\theta)$$

$$u = (p_3 - p_2)^2 = M^2 - 2|\vec{k}|(E_2 + |\vec{q}|\cos\theta)$$

and the CMS energy of the D-meson is $E_D = W - E_2$, with $W = \sqrt{s}$.

II. THE RESULTS

We have performed different sets of calculations, for different particles. We summarize in Table 1 the set of constants for the different reactions. The values of the magnetic moments given in the table follow a prescription of U(4)-symmetry [3].

In Fig. 2 we report the results for the reaction $\gamma + p \to \Lambda_C^+ + D^0$, at E_γ=11 GeV. The structure functions $\mathcal{A}$ and $\mathcal{B}$ as well as the differential angular distribution and the beam asymmetry are reported as a function of the θ_{cm}, which is the center of mass angle of the D_0 meson (with respect to the direction of the incident photon). The full line represents the sum of all contributions, the Born s-channel is given by the dashed line and the Born u-channel by the dotted line. The Born $t-$ channel does not play any role for this reaction in the present model. The differential cross section is divided by the coupling constant $g^2_{ND\Lambda}$, for which we do not have theoretical or experimental indications ('guessed' range: from 1 to 10).

In order to illustrate the large sensitivity of this reaction to the magnetic moments we show in Fig. 3 the results of the calculation where the magnetic moment of the Λ_C^+ is taken as $\mu(\Lambda_C) = 0.37\ \mu_N$, according to ref. [4]. The asymmetry changes sign and the cross section changes a factor two in magnitude.

In Fig. 4 we report a compilation of 'low energy' results on charm photoproduction. We used the lowest point, for E_γ=20 GeV, as a normalization for a threshold (q/k) or $(q/k)^3$ behavior of the cross section (solid or dashed line), in order to have a guess of magnitude of the cross section in the threshold region. A linear combination is shown by the dotted line.

TABLES

Reaction	Threshold [GeV]	$\mu_{\Lambda,\Sigma}$	$\kappa_{\Lambda,\Sigma}$ $[\mu_N]$	$M_{\Lambda,\Sigma}$ $[GeV]$	M_D $[GeV]$
$\gamma + p \rightarrow \Lambda_C^+ + D^0$	8.7064	1.860	0.860	2.28490	1.86460
$\gamma + p \rightarrow \Sigma_C^{++} + D^-$	9.4856	1.860	-0.140	2.45280	1.86930
$\gamma + p \rightarrow \Sigma_C^+ + D^0$	9.4677	0	0.860	2.45360	1.86460
$\gamma + n \rightarrow \Lambda_C^+ + D^-$	8.7139	1.860	0.860	2.28490	1.86930
$\gamma + n \rightarrow \Sigma_C^+ + D^-$	9.4750	0	0.860	2.45360	1.86930
$\gamma + n \rightarrow \Sigma_C^0 + D^0$	8.5187	-1.860	-1.860	2.24520	1.86460

TABLE I. Table of reactions and constants.

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FIGURES

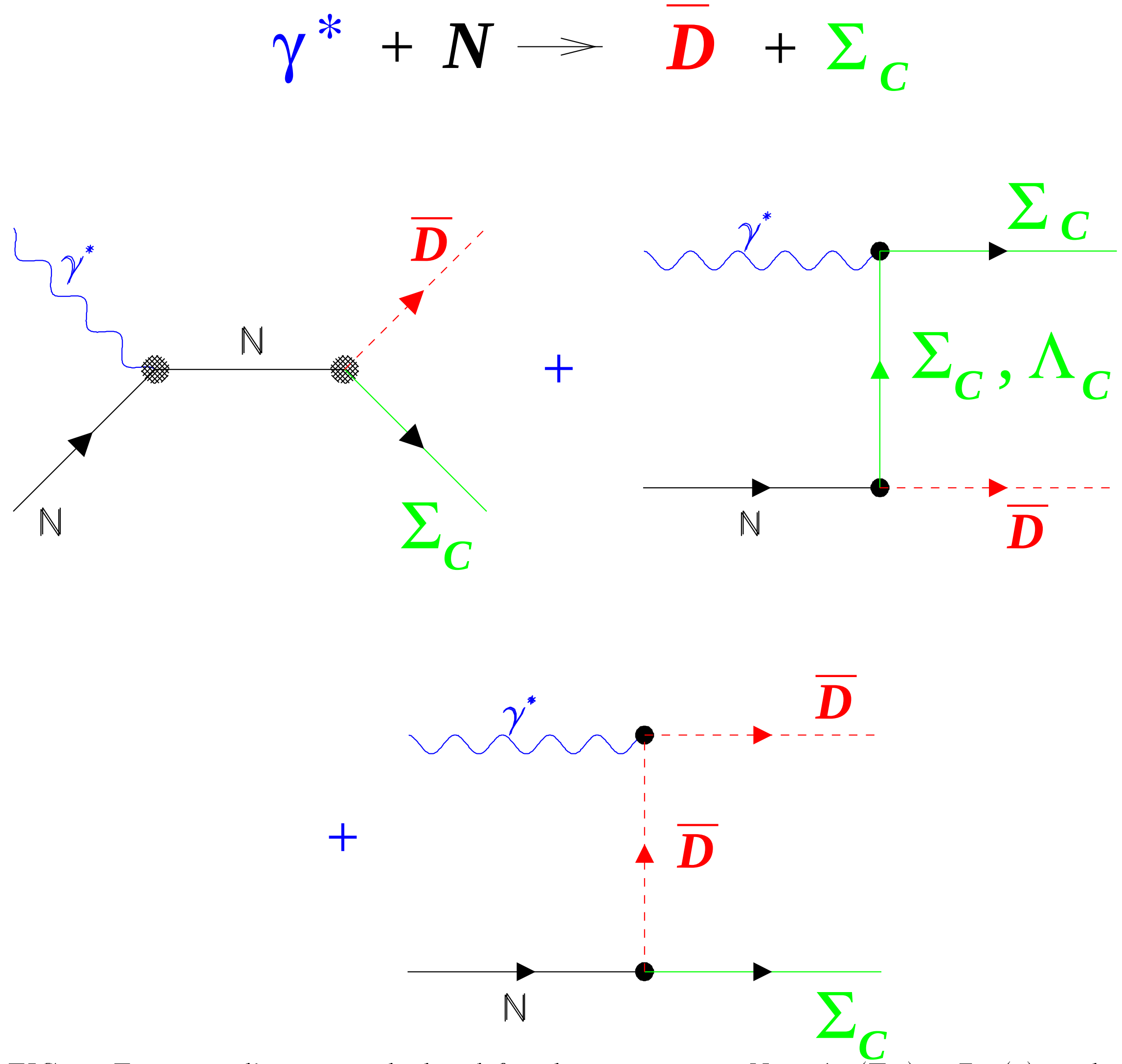

FIG. 1. Feynman diagrams calculated for the process $\gamma + N \rightarrow \Lambda_C(\Sigma_C) + D$: (a)- s-channel, (b)- t-channel, (c)- u-channel)

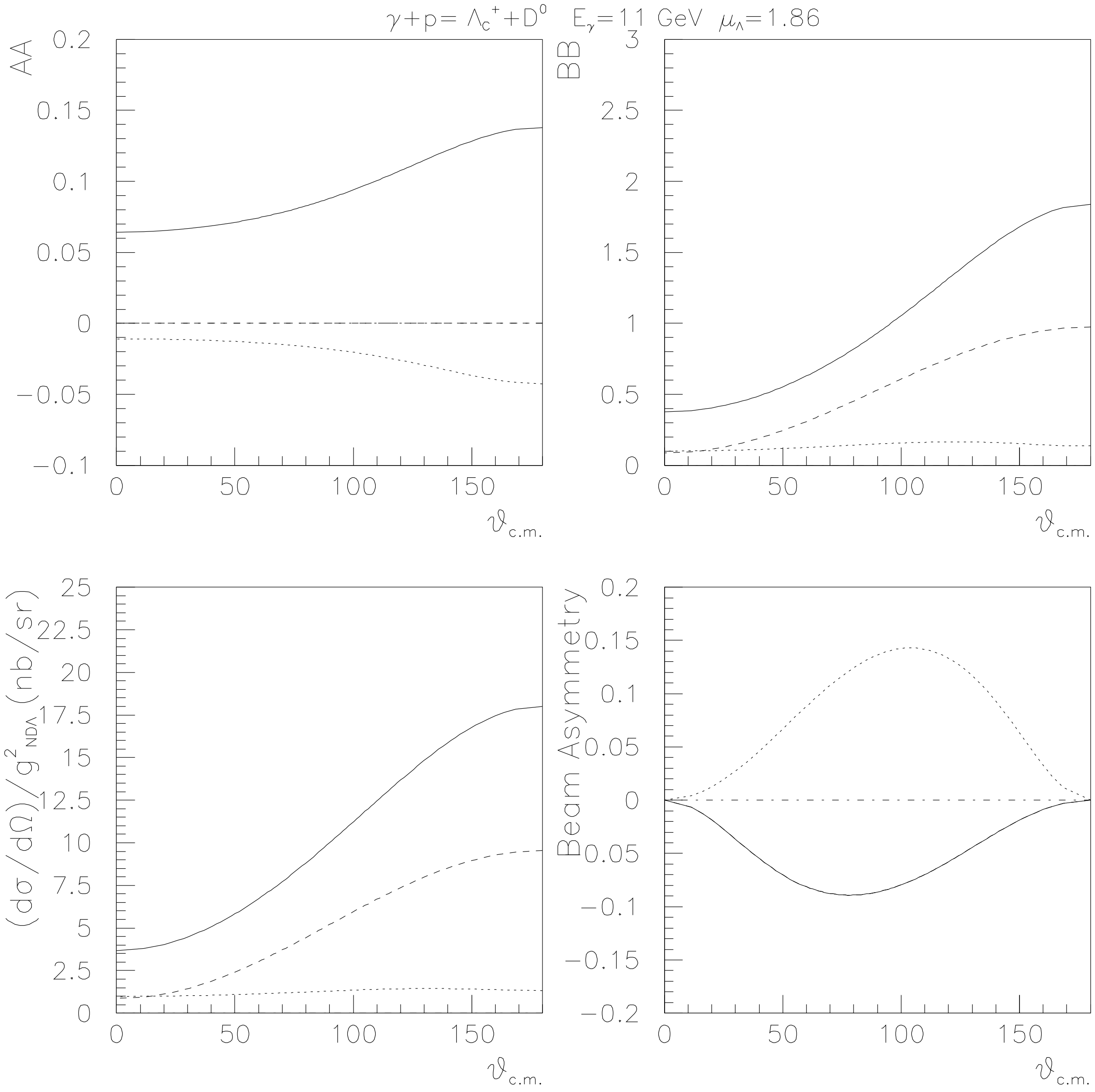

FIG. 2. Structure functions $\mathcal{A}$ and $\mathcal{B}$, differential cross section and beam asymmetry as a function of the D-meson cms angle: full calculation (solid line) Born s-channel (dashed line) and Born u-channel (dotted line).

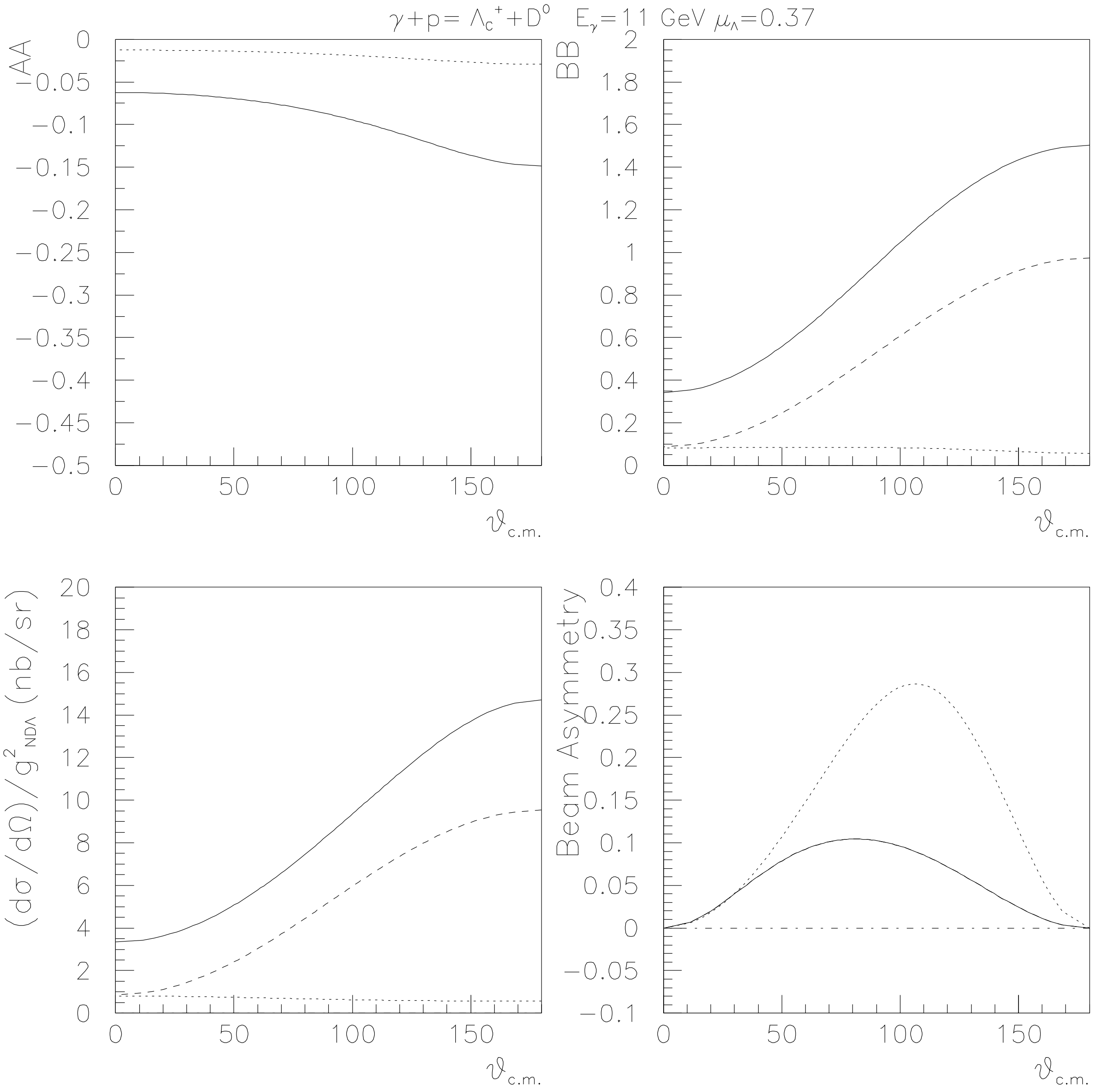

FIG. 3. Same notations as Fig.2 for the Λ_C magnetic moment from [4]

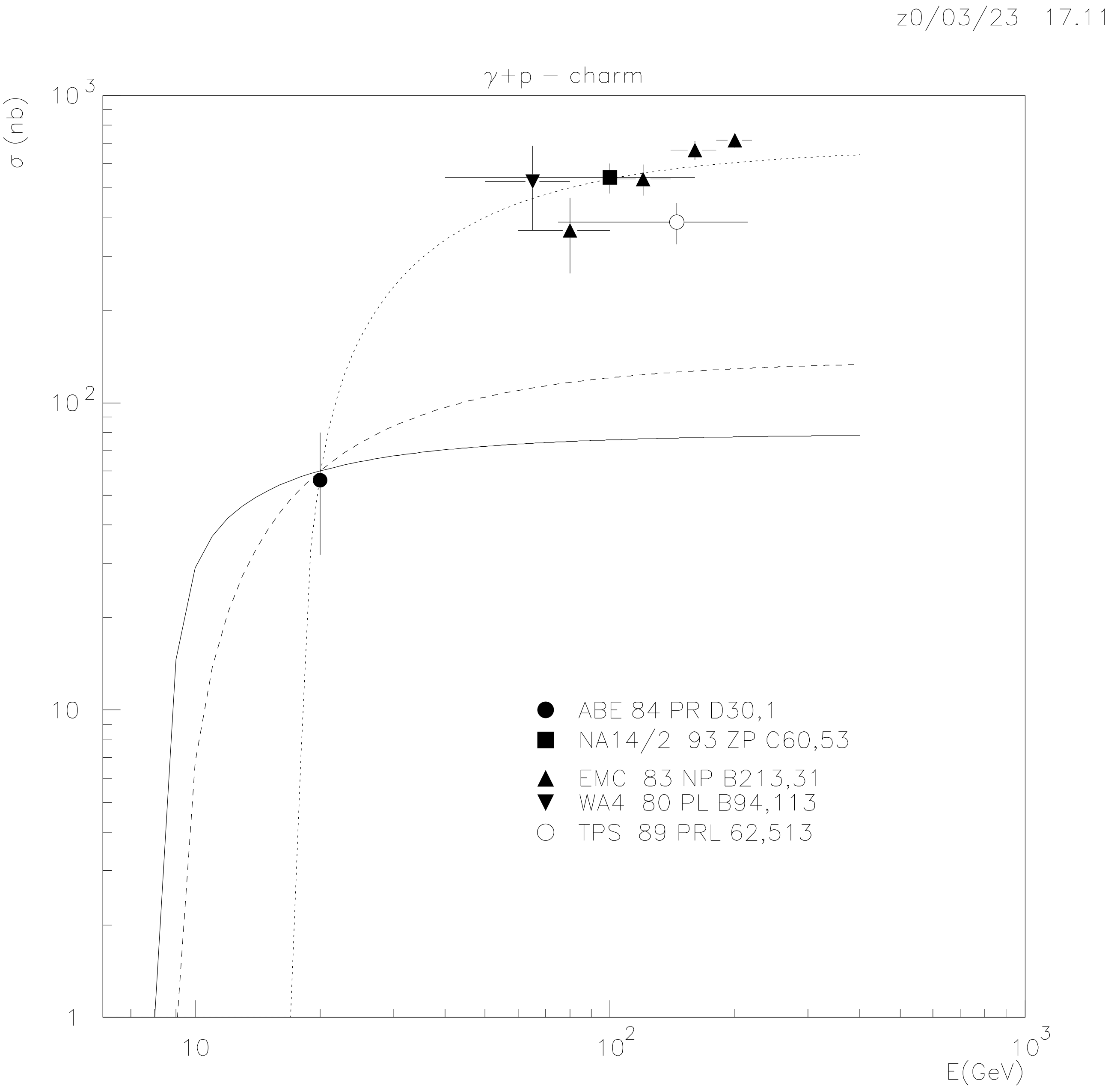

FIG. 4. Existing experimental low energy data from; [5] (circle), [6] (square), [7] (triangles), [8] (reversed triangle), [9] (open circle) The full (dashed) line shows a linear (cubic) behavior in q/k, normalized to the existing point. (The dotted line shows a linear combination)