ANKE-COSY Internal report

DIFFRACTION pd-SCATTERING AT COSY ENERGIES

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Juelich, 2001

1 Glauber-Sitenko theory

Diffraction theory of hadron-nucleus scattering at high energies, developed independently by R. Glauber [1] and A. Sitenko [2], based on (i) the eikonal approximation for one particle Green function describing a propagation of a particle in a potential field, (ii) an approximation of 'frozen scatterring centers' (nucleons) inside the target and (iii) neglects off-shell effects in the amplitude of hadron-nucleus scattering. In contrast to the Born approximation, this approach conserves the unitarity of the amplitudes. The theory uses as input hadron-nucleon amplitudes (usually in spinless approximation) and nucleus densities. In the limit of the full absorption in hN-collisions (imaginary part of the amplitude dominates) the hadron - nucleus scattering is similar to the scattering of the light on the black sphere. In real case with nonzero real part of the hN-amplitudes the theory allows to desribe with an accuracy about 10% the cross sections of hadron-nucleus scattering at low transferred momenta $q \ll k$, here k is the momentum of scattered hadron in c.m.s., q is the transferred momentum.

Here we discuss the pd-scattering at low transferred momenta in view of luminosity determination at the ANKE-COSY facility. The pd- scattering cross section in cms consists of the elastic and inelastic terms:

$$\frac{d\sigma^{sc}}{d\Omega} = \frac{d\sigma^{el}}{d\Omega} + \frac{d\sigma^{inel}}{d\Omega}. \tag{1}$$

The general expression for the cross section (1) was obtained in Ref.[1] in closure approximation, which includes the sum over complete set of the final pn states. It means that the final state pn-interaction (fsi) is taken into account properly in this approach. The formulas in terms of pN-scattering amplitudes, the deuteron elastic formfactor $S(q)$ and the deuteron wave function in coordinate space given in Ref.[1] by Eqs.(3.15) and (3.16):

$$\begin{aligned} \frac{d\sigma^{sc}}{d\Omega} &= |f_n(\mathbf{q})|^2 + |f_p(\mathbf{q})|^2 + 2S(\mathbf{q})Re[f_n(\mathbf{q})f_p^*(\mathbf{q})] - \\ &-\frac{1}{\pi k} Im f_n^*(\mathbf{q}) \int S(\mathbf{q}' - \frac{1}{2}\mathbf{q}) f_n(\frac{1}{2}\mathbf{q} + \mathbf{q}') f_p(\frac{1}{2}\mathbf{q} - \mathbf{q}') d^2\mathbf{q}' - \\ &-\frac{1}{\pi k} Im f_p^*(\mathbf{q}) \int S(\mathbf{q}' + \frac{1}{2}\mathbf{q}) f_n(\frac{1}{2}\mathbf{q} + \mathbf{q}') f_p(\frac{1}{2}\mathbf{q} - \mathbf{q}') d^2\mathbf{q}' + \\ &+\frac{1}{(2\pi k)^2} \int d\mathbf{r} |\phi(\mathbf{r})|^2 \left| \int d^2\mathbf{q}' \exp{(i\mathbf{q}' \cdot \mathbf{s})} f_n(\frac{1}{2}\mathbf{q} + \mathbf{q}') f_p(\frac{1}{2}\mathbf{q} - \mathbf{q}') \right|^2, \end{aligned} \tag{2}$$

$\phi(\mathbf{r})$ is the deuteron wave function, and $S(\mathbf{q})$ is the deuteron elastic formfactor related to $\phi(\mathbf{r})$ by

$$S(\mathbf{q}) = \int \exp{(i\mathbf{q}' \cdot \mathbf{r})} |\phi(\mathbf{r})|^2 d\mathbf{r}; \tag{3}$$

$f_n(\mathbf{q})$ and $f_p(\mathbf{q})$ are the pn and pp elastic scattering amplitudes,respectively,

$$f_N(\mathbf{q}) = \frac{k}{4\pi} \sigma_N (i + \alpha_N) \exp{[-\frac{1}{2}\beta_N q^2]} \tag{4}$$

here σ_N, α_N, β_N are the parameters of the pN-amplitude determined from the experimental data. The elastic cross section is given by Eq. (3.17), (3.18) in the same paper:

$$\frac{d\sigma^{el}}{d\Omega} = S^2(\frac{1}{2}\mathbf{q})\left\{|f_n(\mathbf{q})|^2 + |f_p(\mathbf{q})|^2 + 2\,Re[f_n(\mathbf{q})f_p^*(\mathbf{q})]\right\} - \tag{5}$$
$$-\frac{1}{\pi k}S(\frac{1}{2}\mathbf{q})Im\left\{[f_n^*(\mathbf{q}) + f_p^*(\mathbf{q})]\int S(\mathbf{q}')f_n(\frac{1}{2}\mathbf{q}+\mathbf{q}')f_p(\frac{1}{2}\mathbf{q}-\mathbf{q}')d^2\mathbf{q}'\right\} +$$
$$+\frac{1}{(2\pi k)^2}\left|\int S(\mathbf{q}')f_n(\frac{1}{2}\mathbf{q}+\mathbf{q}')f_p(\frac{1}{2}\mathbf{q}-\mathbf{q}')d^2\mathbf{q}'\right|^2.$$

For the amplitude of pd-elastic scattering, $F_{pd}(q)$, an explicite formula can be derived straightforwardly, which gives the elastic cross section as

$$\frac{d\sigma^{el}}{d\Omega} = |F_{pd}(q)|^2. \tag{6}$$

After that the inelastic cross section can be written as

$$\frac{d\sigma^{inel}}{d\Omega} = \frac{d\sigma^{sc}}{d\Omega} - \frac{d\sigma^{el}}{d\Omega}. \tag{7}$$

An approximate expression for the inelastic scattering is given in Ref.[3] as the following

$$\frac{d\sigma}{dq^2} \approx \frac{1}{2}\left\{|f_{pp}+f_{pn}|^2\left[1+S(q)-2S^2(\frac{1}{2}q)\right] + |f_{pp}-f_{pn}|^2\left[1-S(q)\right]\right\} \tag{8}$$

Starting from Eqs.(1) and (7), we derived here detailed formulas. For the deuteron nuclear density we use (a) one-gaussian approximation (b) the S-component of the Reid-soft-core wave function, renormalized to unity and (c) the three gaussian formfactor from Ref. [3]. The parameters of the pN-scattering amplitudes are taken from Ref.[4].

2 Numerical results

The numerical results are shown below in Figs. 1-15. The elastic cross section is in a good agreement with the data at initial kinetic energy in laboratory system 1.05 GeV, 1.95 GeV [11]. At lower energies $T < 1$ GeV the agreement becomes worse. It is well known that the validity of the Glauber-Sitenko theory for pd-scattering at $T < 1$ GeV is rather questionable.

The inelastic cross sections calculated by Eq. (7) on the one hand and by Eq. (8) from Ref.[3] coincide one which other with high accuracy, excluding the energy of 0.5 GeV, as shown in Figs.6, 14. At zero transferred momentum this cross section vanishes (see, for example, Eq. (8) at S(q=0)=1) due to orthogonality of the deuteron bound state and the pn-scattering wave function in the spin-triplet state.

Note 1 : This feature is not taken into account in the Born approximation (or spectator model). It leads to wrong result in the fsi-region at $E_{pN} = 0 - 10MeV$. On the other hand, in the region of quasi-free pN-collision at high relative energy in pN-system $E_{pN} > 100 - 200 MeV$ the spectator model works rather well [5].

Note 2 : If one takes into account the spin-flip pN-amplitude, then the inelastic cross section will not vanish due to transition to the $^1S_0$ state. The experimental data [3] on the breakup $pd \to pnp$ at 0.95 GeV shows that this spin-flip amplitude in pp-scatering seems negligible in comparison with the non-flip one. For this reason the cross section $pd \to p(fast\,forward) + (np)(^1S_0)$ is negligible. In the charge exchange pn-scattering $pn \to np$ at small angle the spin-flip amplitude is nonvanishing. However, the $pn \to np$ subprocess contributes to the reaction $pd \to n(fast\,forward) + (pp)(^1S_0)$ with the fast neutron at small angle in the final state and not important in the diffraction scattering of the proton under discussion. Information about the spin-flip amplitude of the pp-scattering is rather poore at higher energies.

The available experimental data on the inelastic cross section of the pd-scattering ($pd \to pnp$) at 0.95 GeV [3] are described by our calculation with an accuracy of $\sim 10\%$ (Fig.6).

We demonstrate the relative contribution of the elastic and inelastic scattering 0.6-2.0 GeV to the full cross section given by Eq.(1). These cross sections are comparable one which other in the region of ANKE acceptance $\theta_{lab} \sim 5^\circ - 10^\circ$. The role of single, double pN-scattering and their interference is demonstrated in Fig.16

References

[1] V.Franco, R.J. Glauber. Phys.Rev. **142** (1966) 1195.

[2] A.G. Sitenko. Fiz. Elem. Chast. At. Yadr. **4** (1973) 547.

[3] B.S. Aladashvili, J.F. Germond, V.V. Glagolev et al. J.Phys.G: Nucl.Phys. **3** (1977) 1.

[4] Particle DAta Group Report UCRL 20000 NN, 1979.

[5] V. Punjabi et al. Phys. Rev. **C 38** (1988) 2728.

[6] E.T. Boschitz et al. Phys.Rev. **C 6** (1972) 457.

[7] O.G. Grebenjuk et al. Nucl.Phys. **A500** (1989) 637.

[8] E. Winkelmann et al. Phys. Rev. **C 21** (1980) 2535.

[9] F.Irom, G.J. Igo, et al. Phys. Rev. **C 28** (1983) 2380.

[10] G.W. Bennet et al. Phys.Rev.Lett. **19** (1967) 387.

[11] N. Dalkhazhav et al. Yad.Fiz. 8 (1968) 342

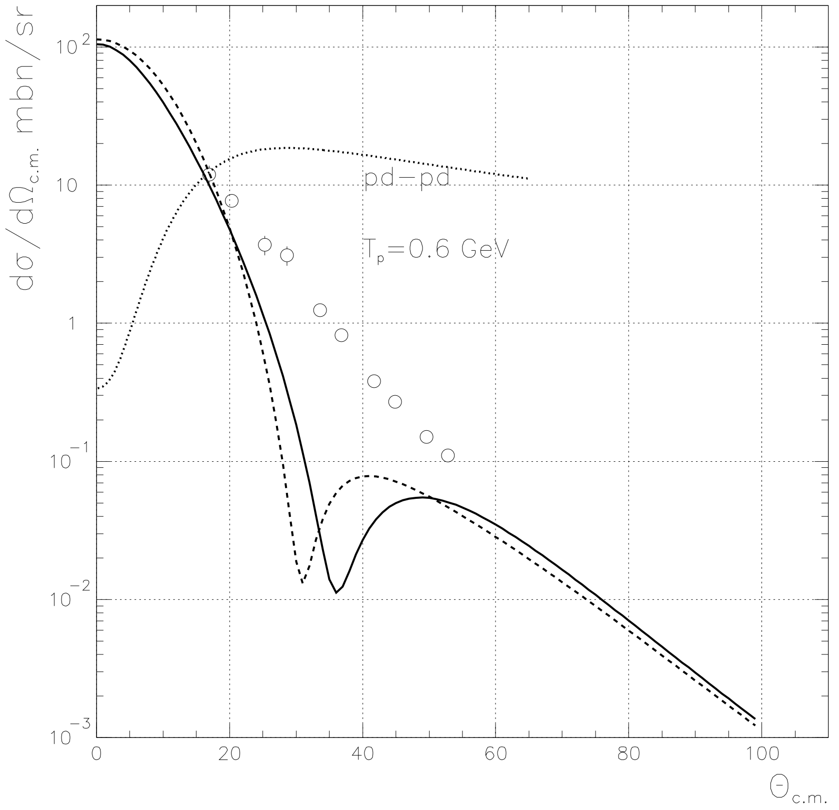

Figure 1: The experimental data [6] on cross section of elastic pd scattering versus the cms scattering angle θ_{cm} at $T_p = 0.6$ GeV in comparison with the calculation within Glauber theory for one gaussian w.f. (dashed line), the renormalized S-wave RSC w.f. (full) and inelastic scattering (dotted).

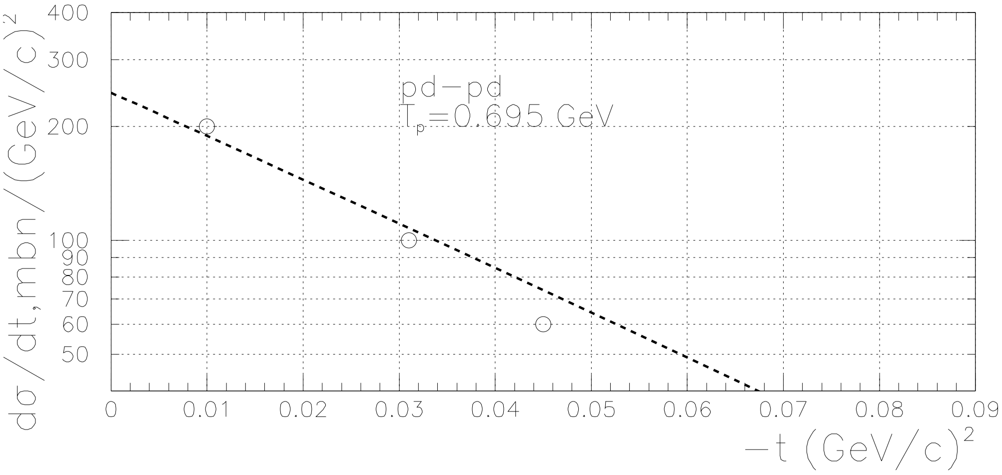

Figure 2: The experimental cross section [7] $d\sigma/dt$ for pd-elastic scattering at 0.695 GeV in comparison with the Glauber calculation with the one-gaussian w.f.

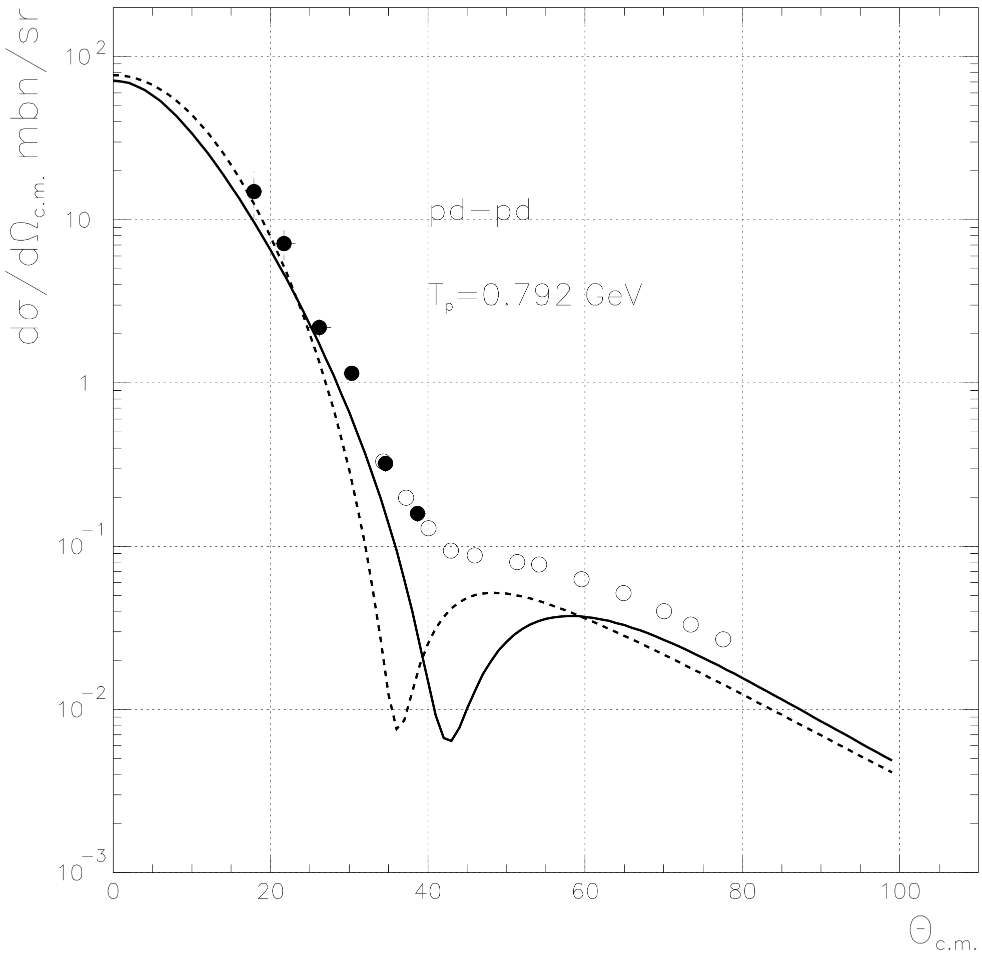

Figure 3: The same as in Fig. 2, but for 0.792 GeV. Experimental data are from Refs.[9] (open circles) and [8] (•)

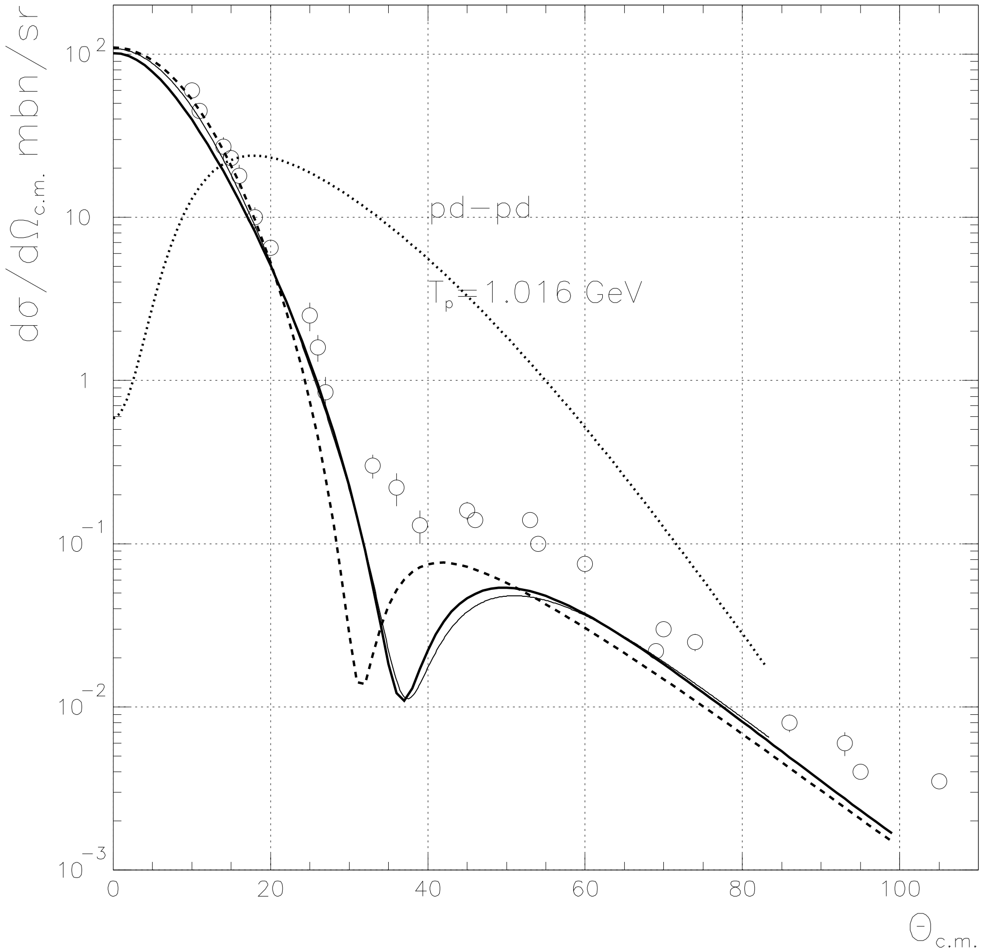

Figure 4: The same as in Fig. 2, but for 1.016 GeV. Exp. data are from [10]. The elastic cross section calculated according to Eq. (5) with the ABB formfactor from [3] is showm by the full thin line.

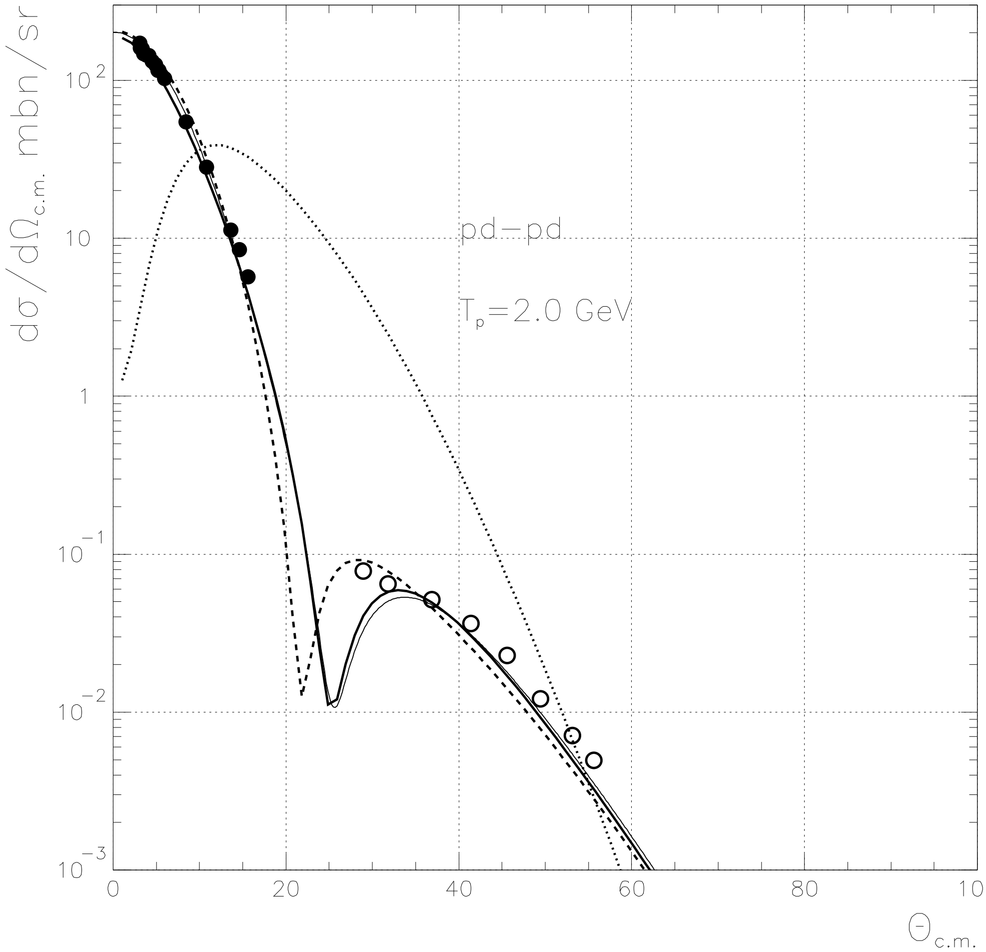

Figure 5: The same as in Fig. 2, but for 1.96 GeV. Exp. data are from Refs. [11] (•) and [10] (open circles). The elastic cross section calculated according to Eq. (5) with the ABB formfactor from [3] is showm by the full thin line.

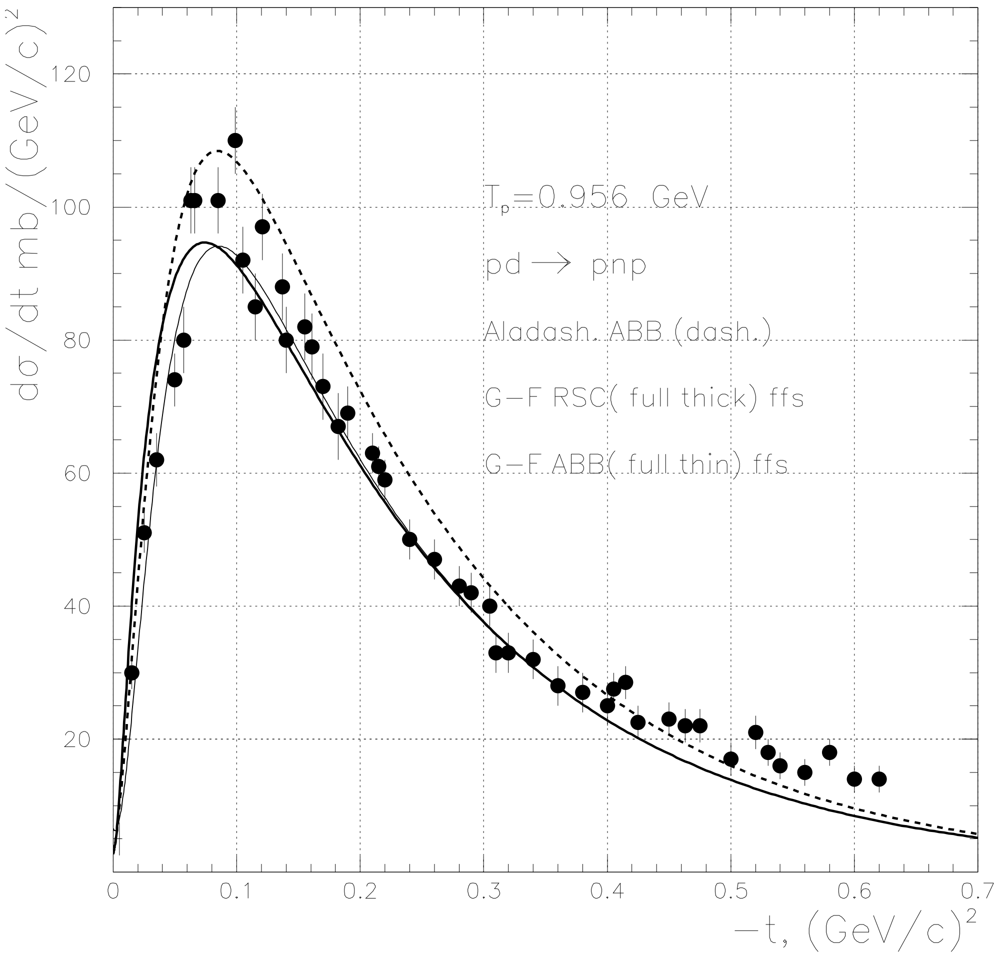

Figure 6: Cross section of the inelastic scattering $pd \to pnp$ at $T_p = 0.956$ GeV according to Eqs.(2,5, 7) with the RSC formfactor (full thick), the ABB formafactor (full thin) and according to Eq.(8) with the ABB formfactor [3] (dashed) in comaprison with exp. data from [3] (points).

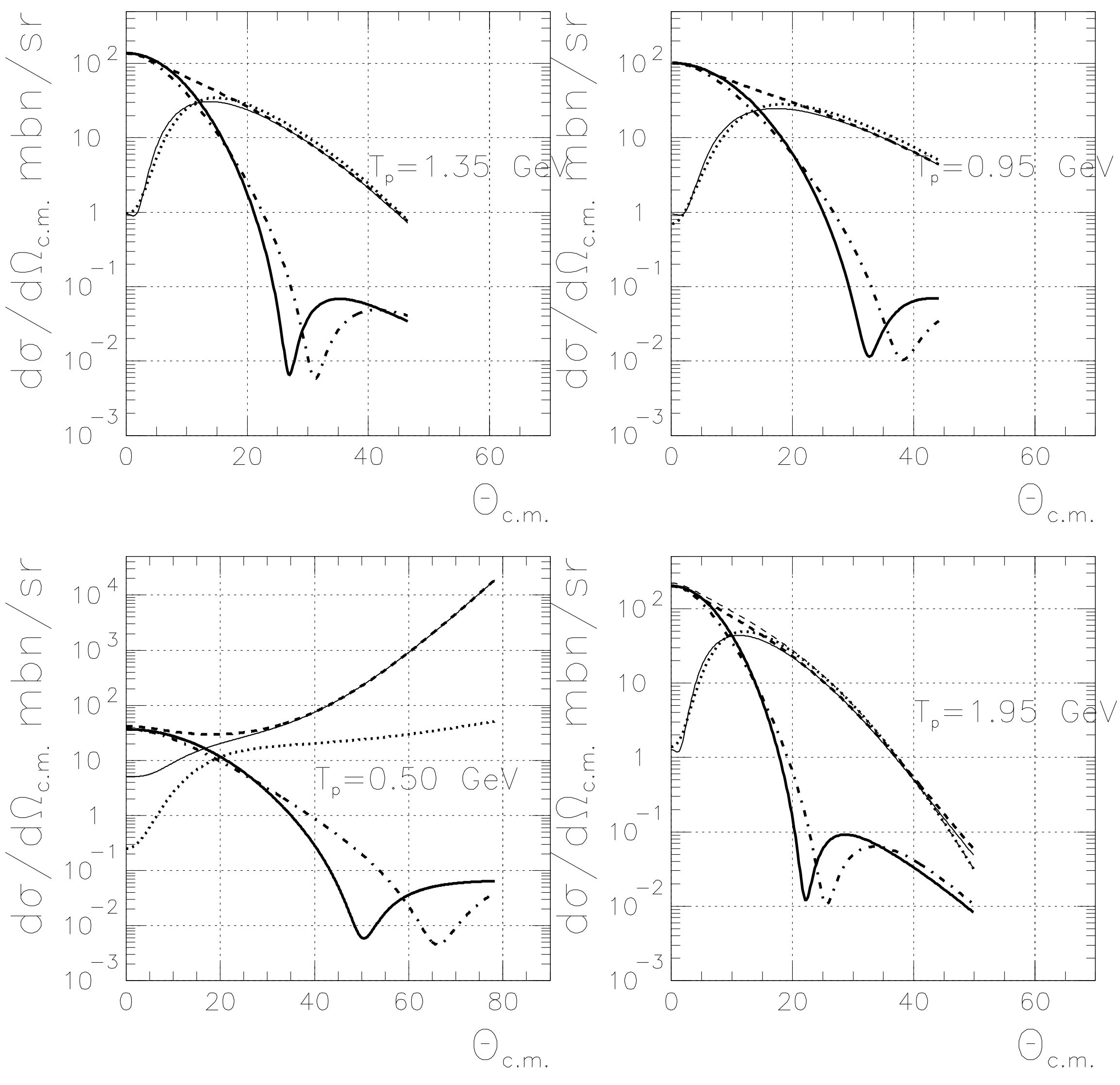

Figure 7: Elastic and inelastic pd-scattering calculated in the Glauber theory at different initial energies. Dotted line — inelastic scattering by Franco-Glauber (1966) from Aladashvili (1977) (and Deuteron form-factor from Aladashvili) with interpolation of NN-parameters like for pure elastic pd-scattering; dashed - elastic plus inelastic by Eq.(3.16) from Glauber-Franco (1966). Full thin – inelastic by original Glauber-Franco (1966) formalism; inelastic (full thin) with the RSC S-wave w.f.; Full thick - elastic 1 gaussian. Dashed-dotted — elastic (RSC 5-gaussian) from Glauber-Franco Eq.(3.18).

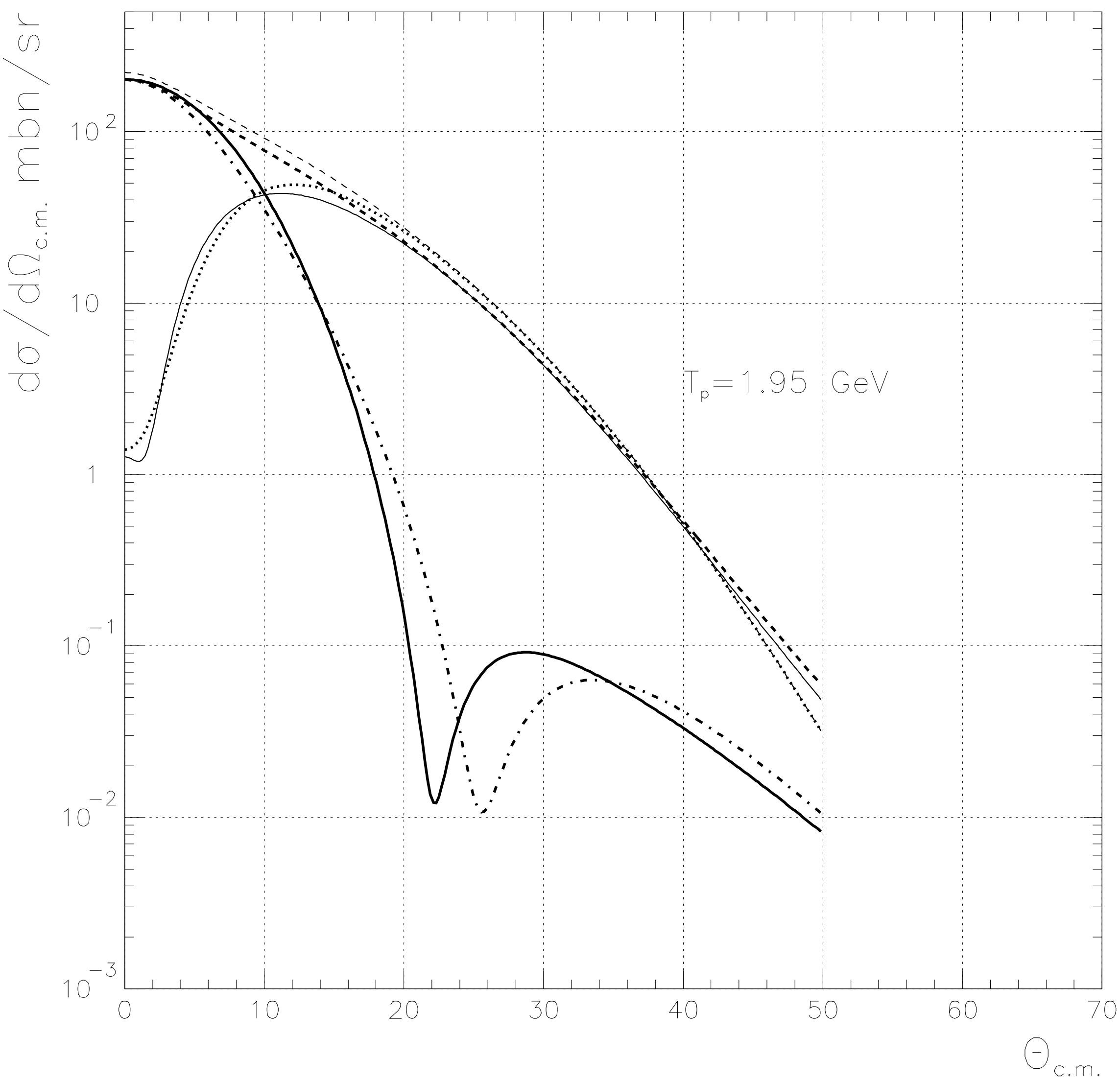

Figure 8: Elastic and inelastic pd-scattering calculated in the Glauber theory at 1.95 GeV. Dotted line — inelastic scattering by Franco-Glauber (1966) from Aladashvili (1977) (and Deuteron form-factor from Aladashvili) with interpolation of NN-parameters like for pure elastic pd-scattering; dashed - elastic plus inelastic by Eq.(3.16) from Glauber-Franco (1966). Full thin – inelastic by the original Glauber-Franco formalism(1996) with RSC d.w.f; full thick — elastic with one gaussian w.f.; dashed-dotted — elastic (RSC 5-gaussian) from Glauber-Franco Eq.(3.18); dashed (thin) — single pN-scattering (including interference pn- and pp-amplitudes) for the elastic+inelastic pd-scattering.

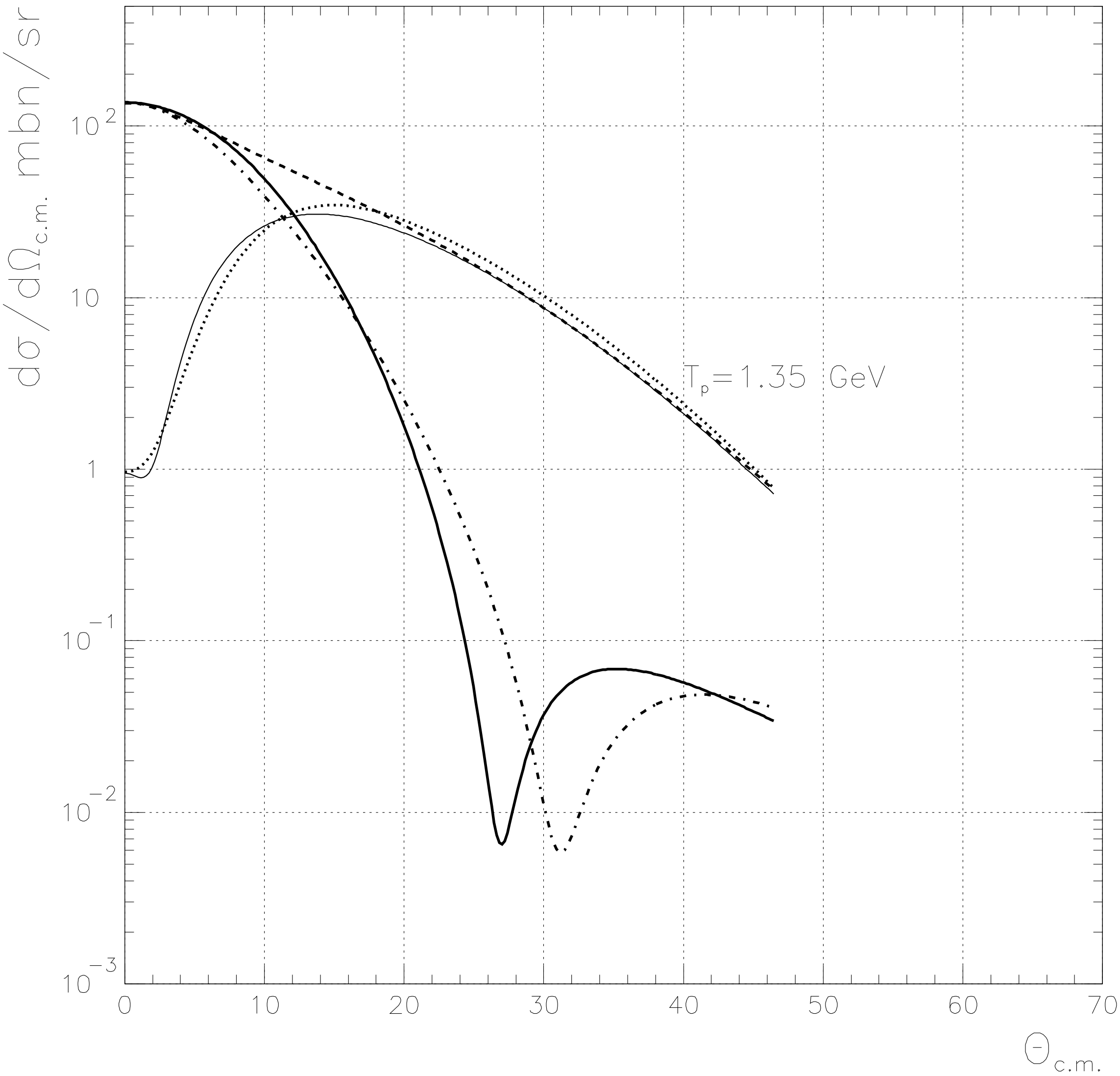

Figure 9: The same as in Fig. 8, but for 1.35 GeV

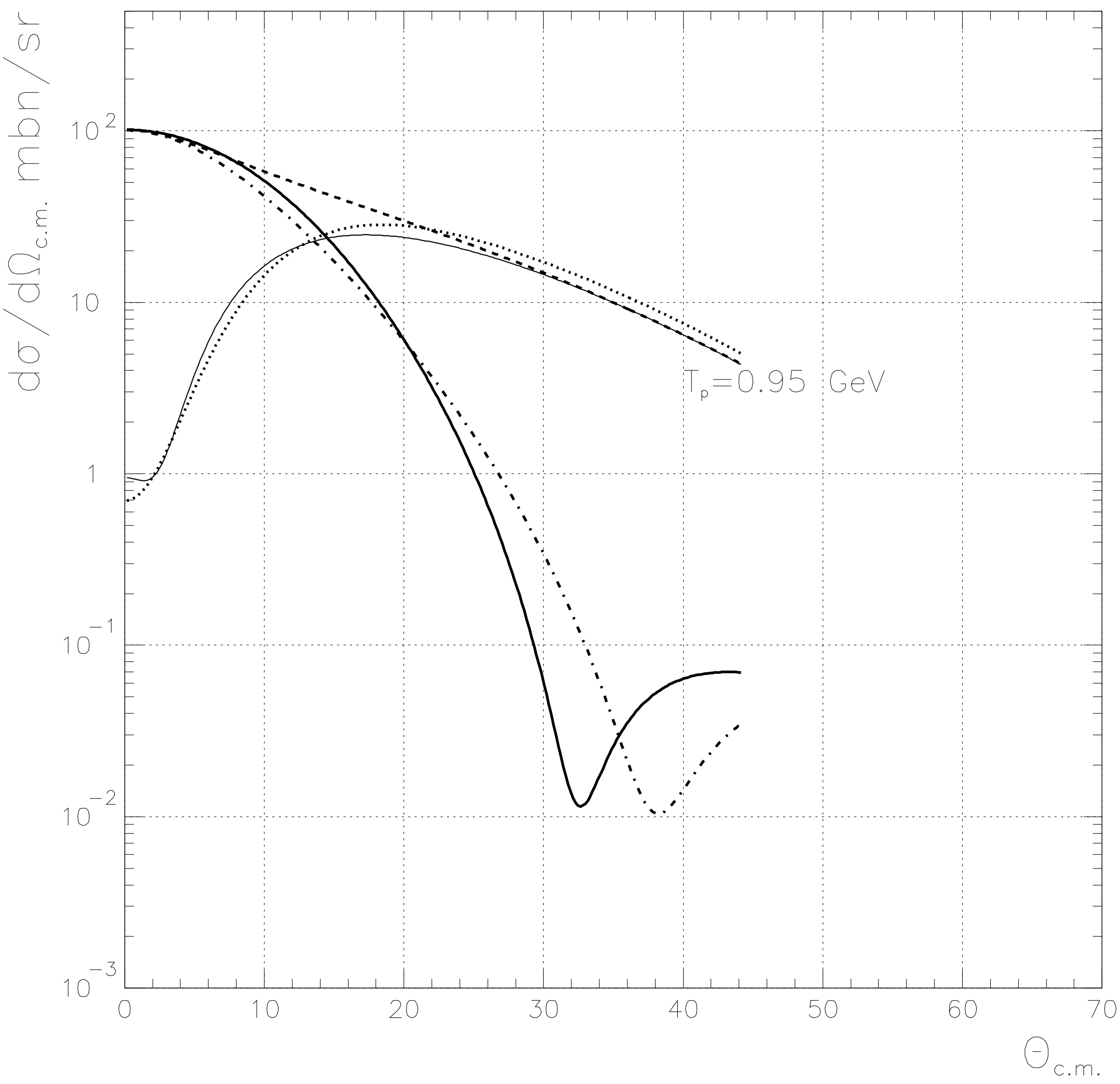

Figure 10: The same as in Fig. 8, but for 0.95 GeV

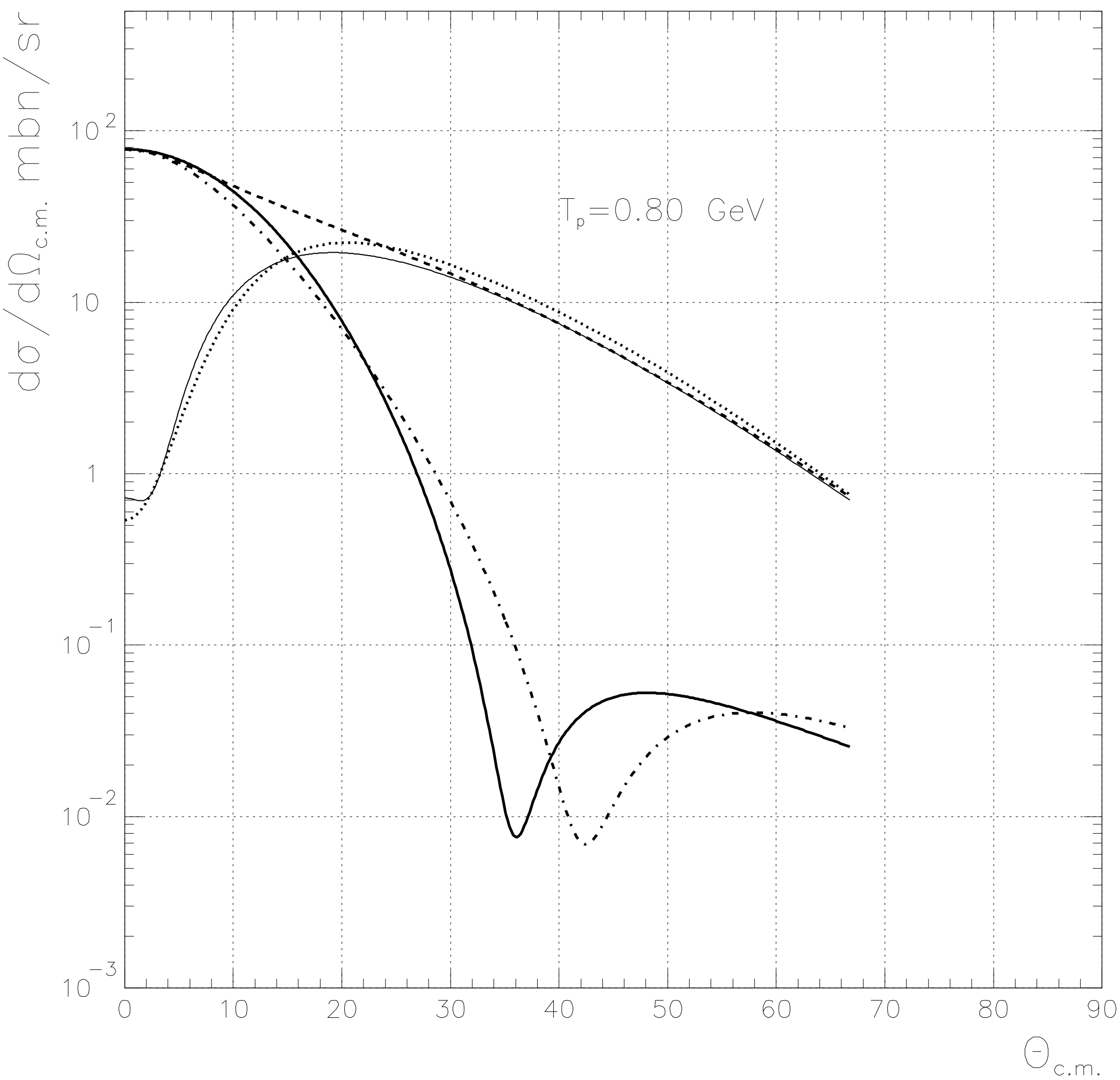

Figure 11: The same as in Fig. 8, but for 0.8 GeV

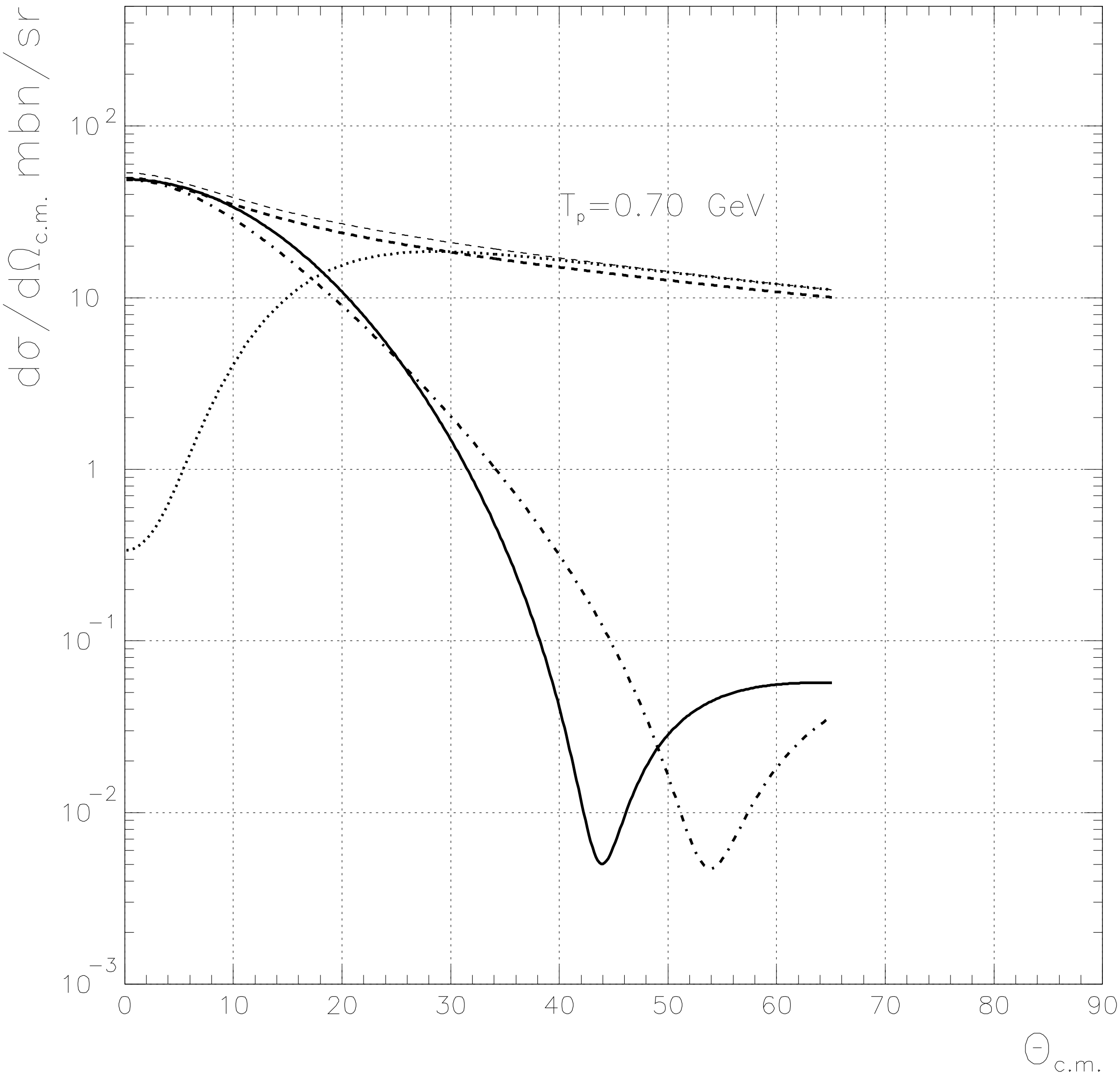

Figure 12: The same as in Fig. 8, but for 0.7 GeV

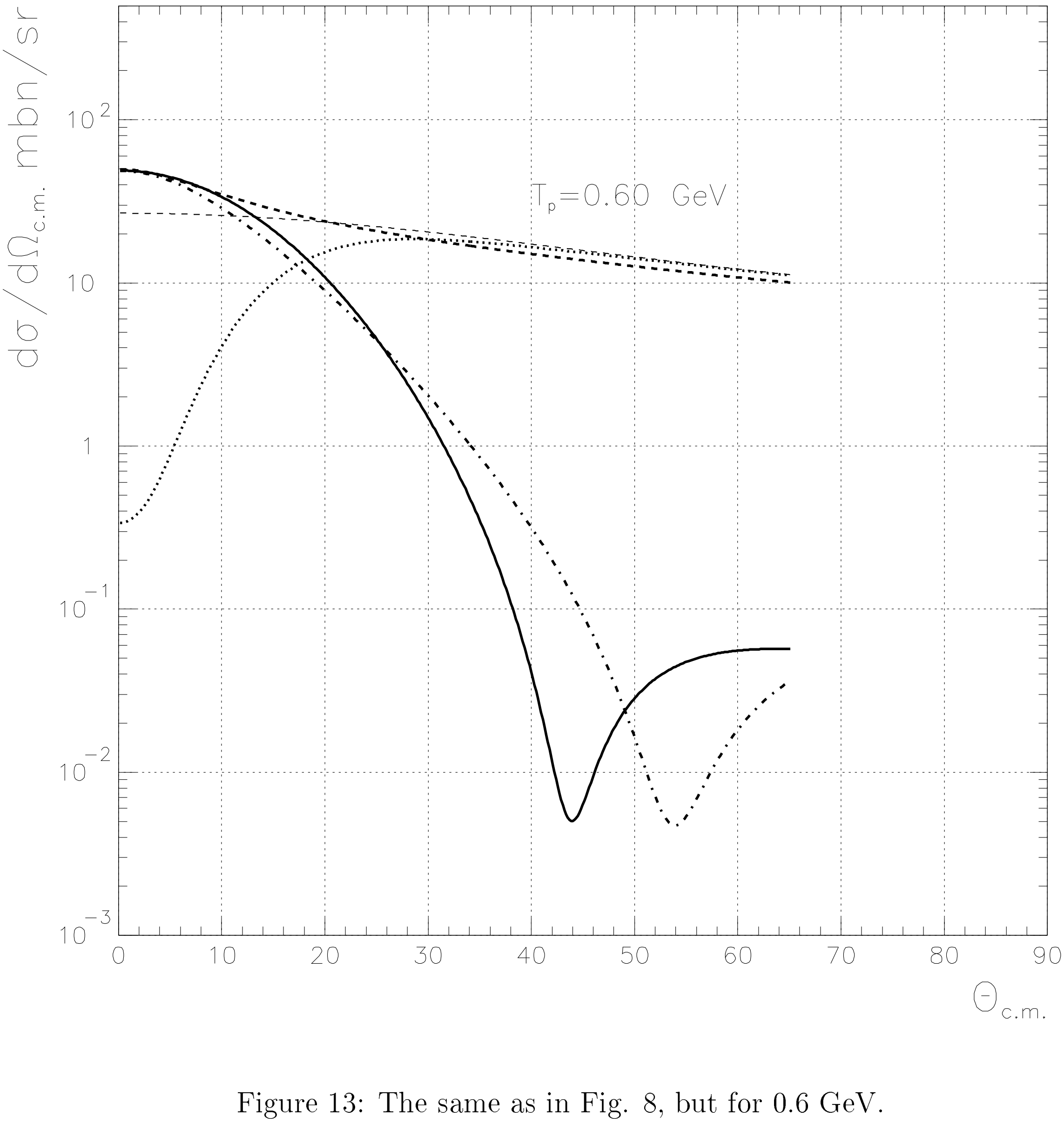

Figure 13: The same as in Fig. 8, but for 0.6 GeV.

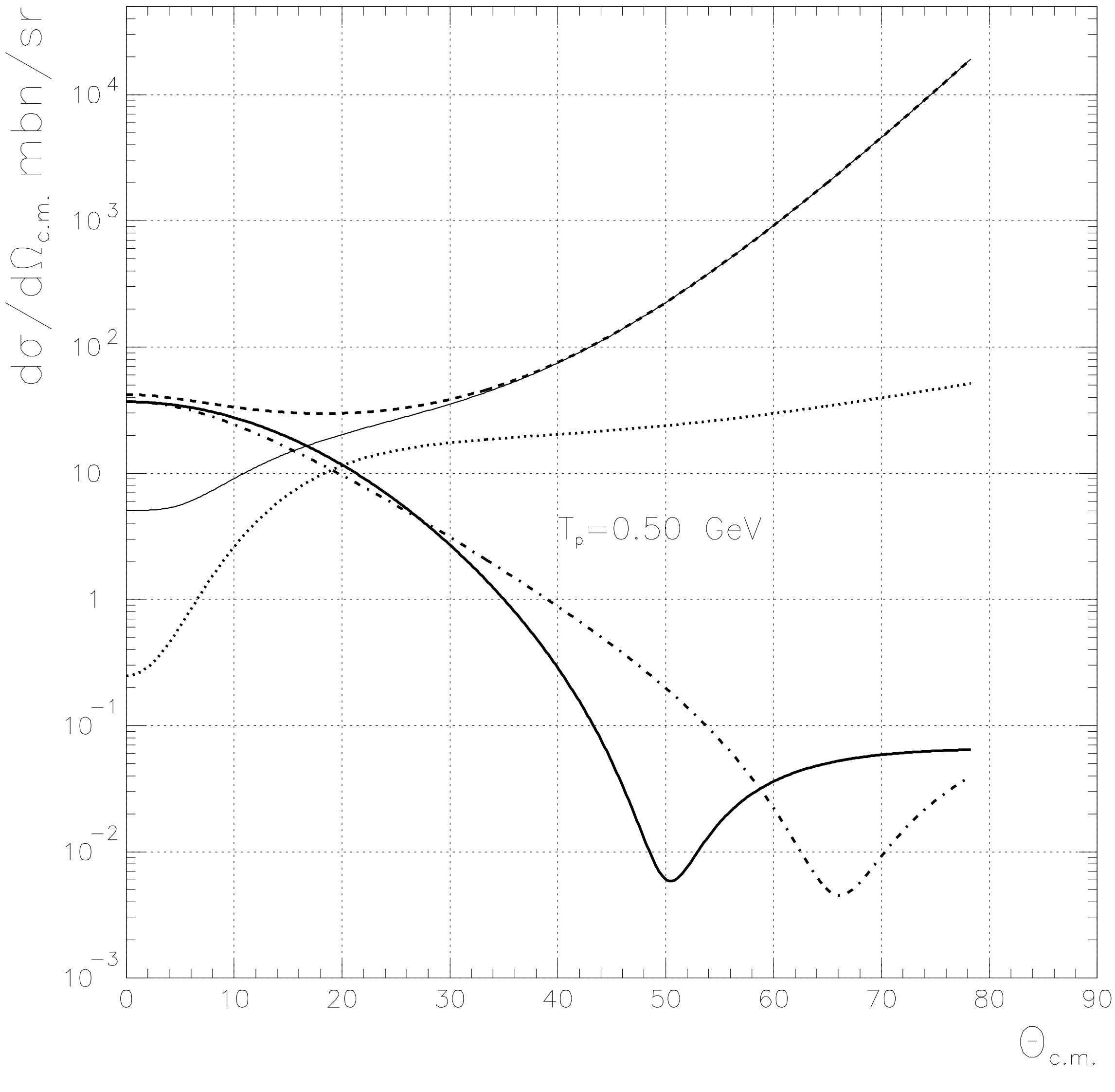

Figure 14: The same as in Fig. 8, but for 0.5 GeV. At this energy there is a crucial dependence on the parameter of diffraction slope in pN-amplitude.

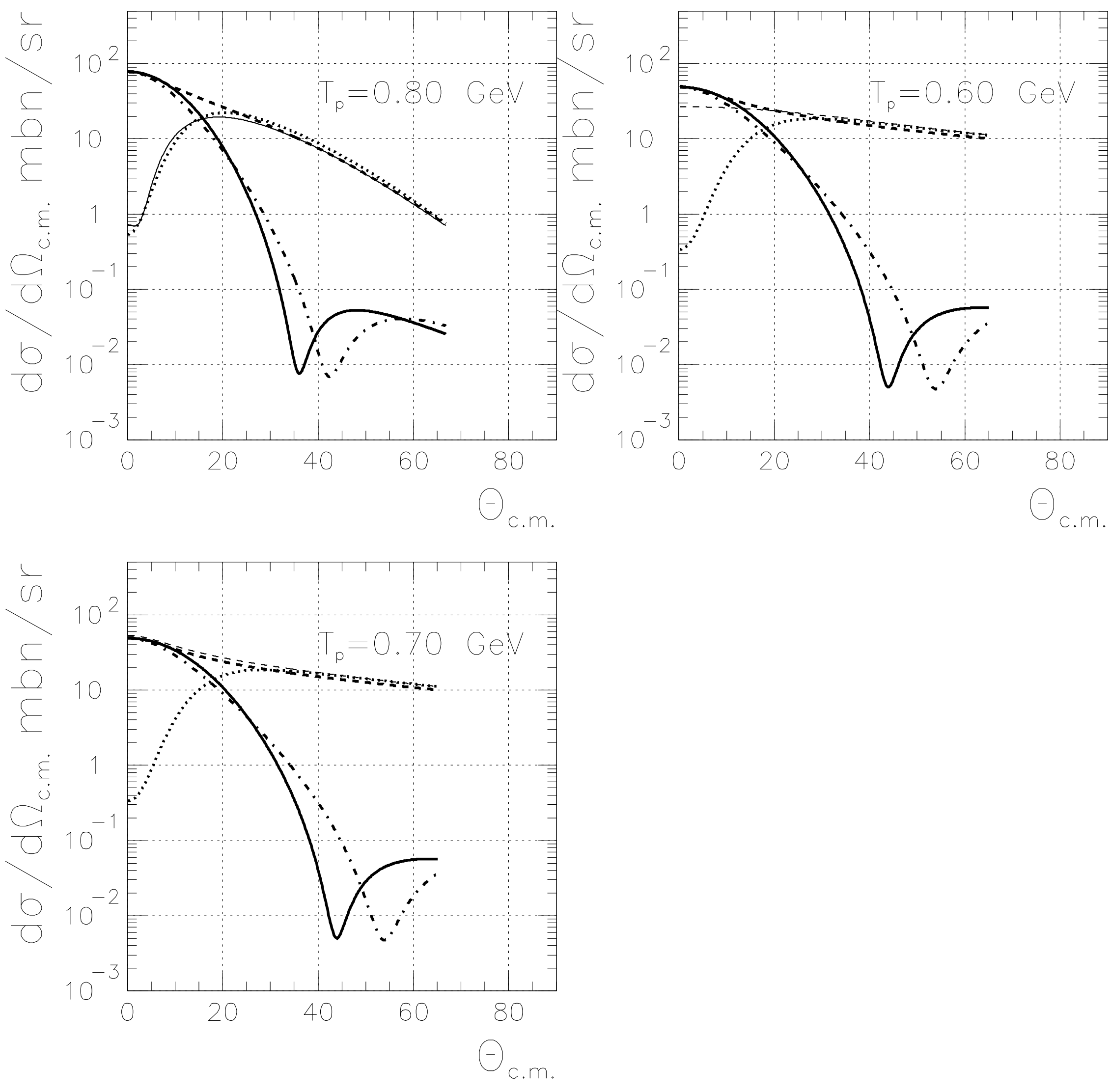

Figure 15: The same as in Fig. 8, but for 0.6, 0.7 and 0.8 GeV.

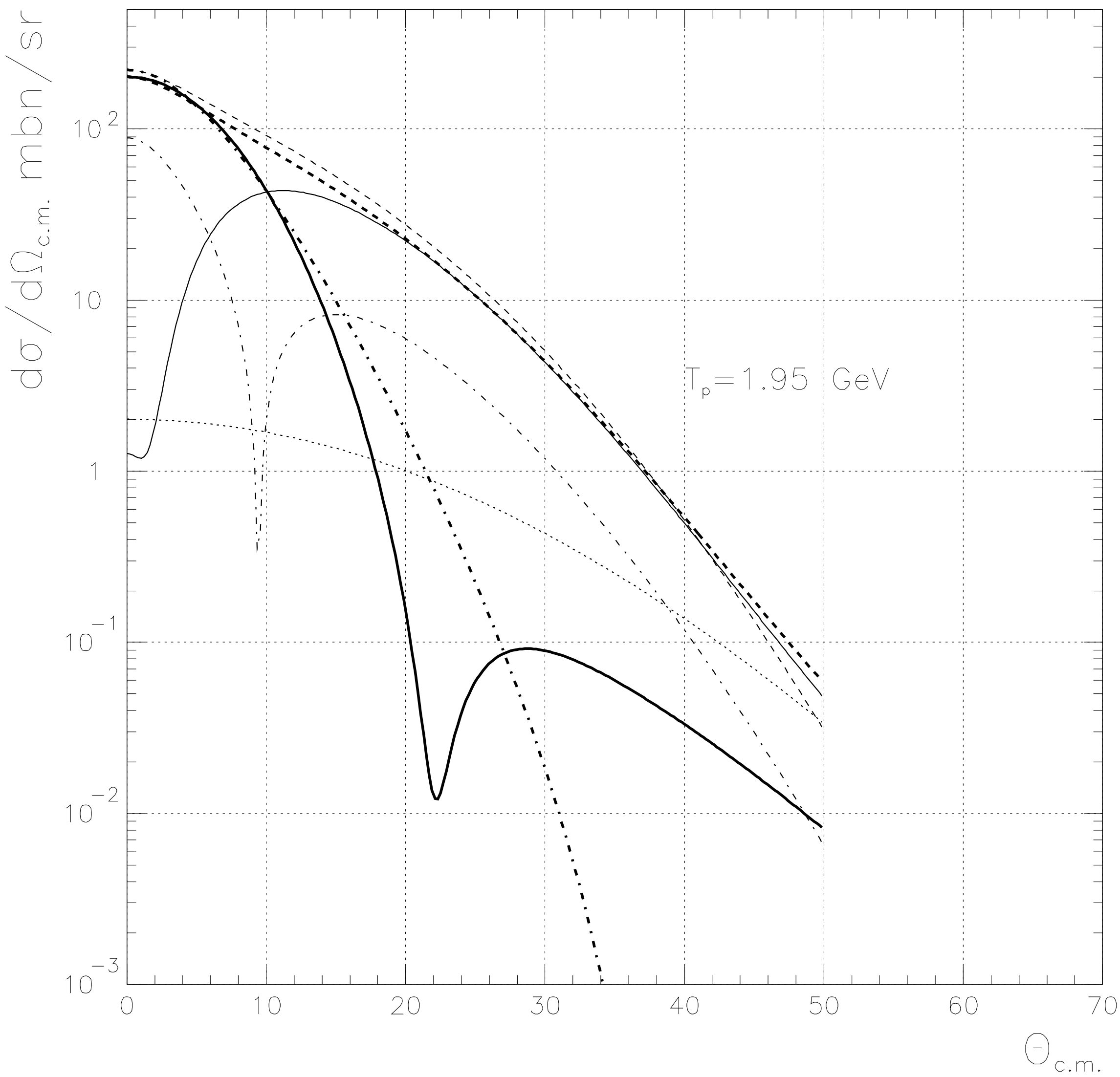

Figure 16: The contribution of the single and double scattering terms to the *pd* elastic and inelastic scattering. Full thick line – elastic (with one Gaussian); all other curves with RSC 5-gaussian from Glauber-Franco Eq.(3.18). Dashed-dotted (thick) – single scatt. in elastic pd (including interference pn- and pp-amplitudes) = $|S(q/2)(f_p + f_n)|^2$; Dashed (thick) - elastic plus inelastic pd-scatt. by Eq.(3.16) from Glauber-Franco (1966); Dotted thin – pure double scattering in the (total) pd-scattering; Dashed-dotted (thin) — absolute value of the interference term of the single and double scattering in the (total) pd-scattering; Full thin — inelastic cross section; Dashed (thin) — $|(f_p + f_n)|^2$ — single pN- scattering (including interference pn- and pp-amplitudes) for the elastic+inelastic *pd* scattering.