Исследование протон-протонных столкновений при пучковом импульсе 1683 МэВ/c.

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План изложения

1. Введение.
2. Экспозиция водородной камеры и отбор событий.
3. Упругое рассеяние.
4. Экспериментальные спектры реакции $pp \rightarrow pn\pi^+$ и сравнение с моделью OPE .
5. Парциально-волновой анализ реакций $pp \rightarrow pn\pi^+$ и $pp \rightarrow pp\pi^\circ$.
5. Результаты парциально волнового анализа.

Задача: определить вклады различных волн в сечения процесса рождения одиночного пиона в области энергий ниже 1 ГэВ.

35-см пузырьковая водородная камера, находящаяся в магнитном поле 1.48T, облучалась протонным пучком с импульсом
1686 МэВ/с.
Получено около $9*10^4$ кадров.
Проводился поиск 2-х лучевых событий, затем выполнялись измерения треков и после геометрической реконструкции события следовал кинематический фит.

События могли принадлежать реакции упругого pp-рассеяния или процессам с рождением пионов:

$$pp \rightarrow pp$$

$$pp \rightarrow pn\pi^+$$

$$pp \rightarrow pp\pi^\circ$$

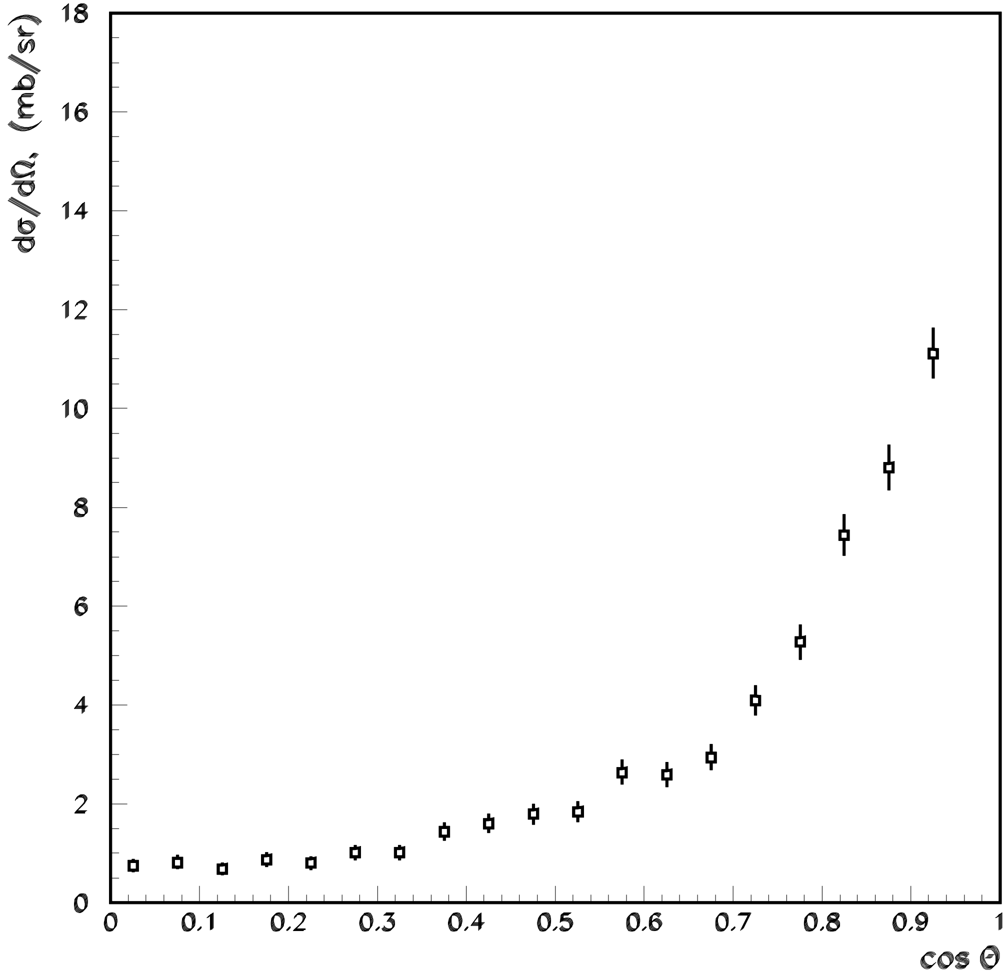
$$pp \rightarrow d\pi^+$$

$$pp \rightarrow d\pi^+\pi^\circ$$

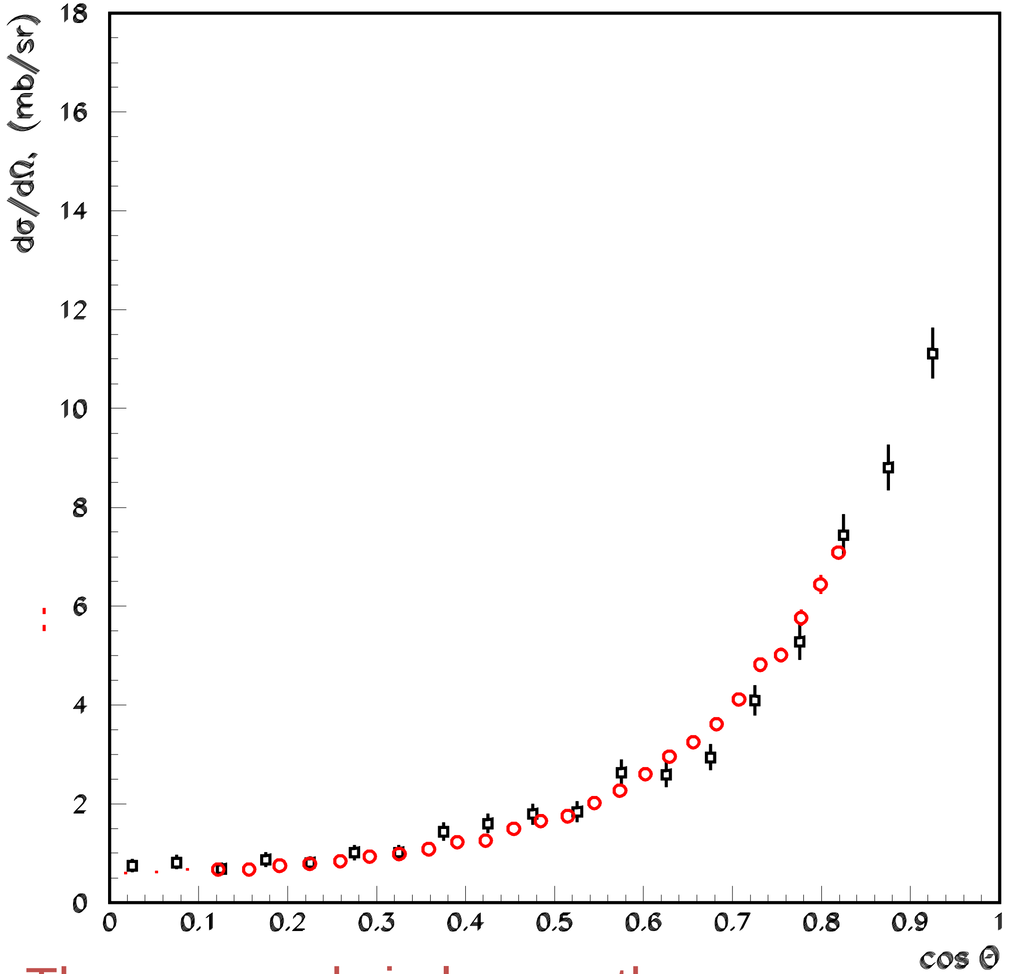
Отбор событий производился по кинематическому фиту с χ^2 критерием на 1% доверительном уровне.

Отобрано всего 7457 событий.

Differential elastic cross section

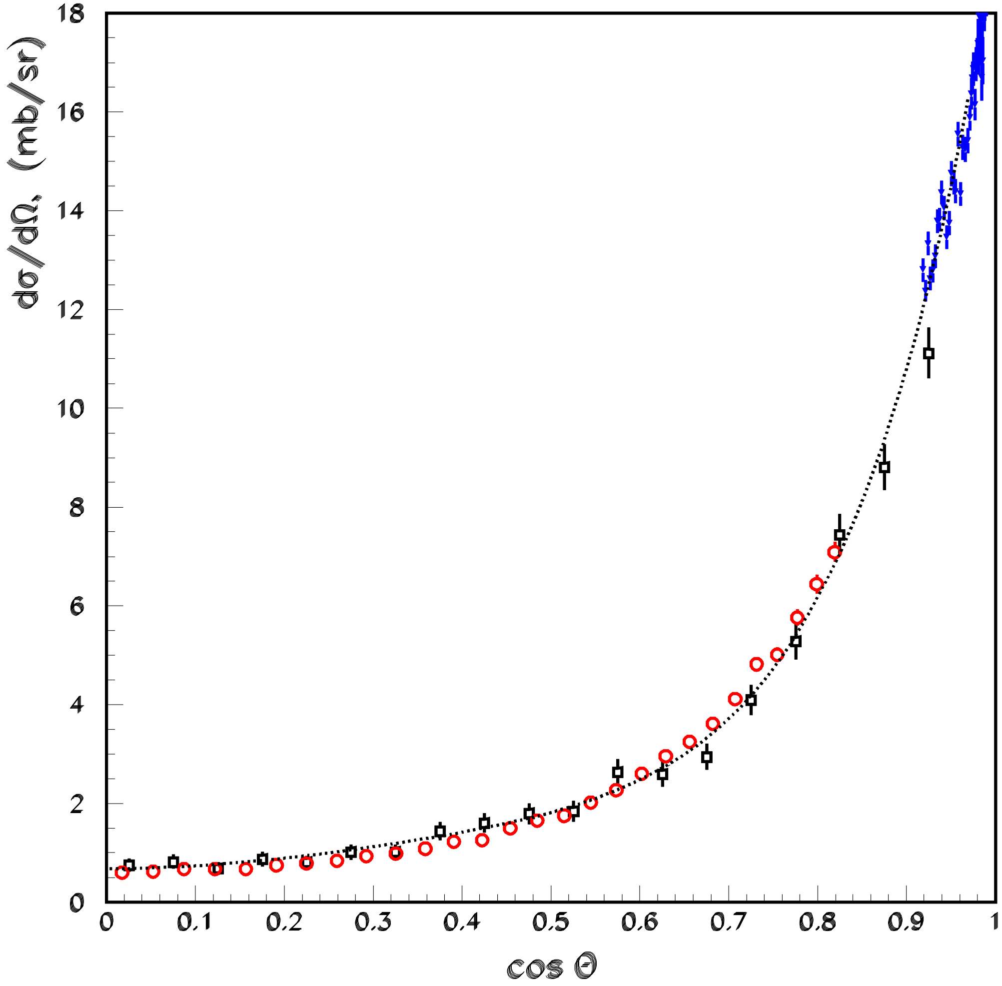


Elastic differential cross section



The open red circles are the measurements of the EDDA experiment taken at the incident moment of 1689.5 MeV/c.

Elastic differential cross section



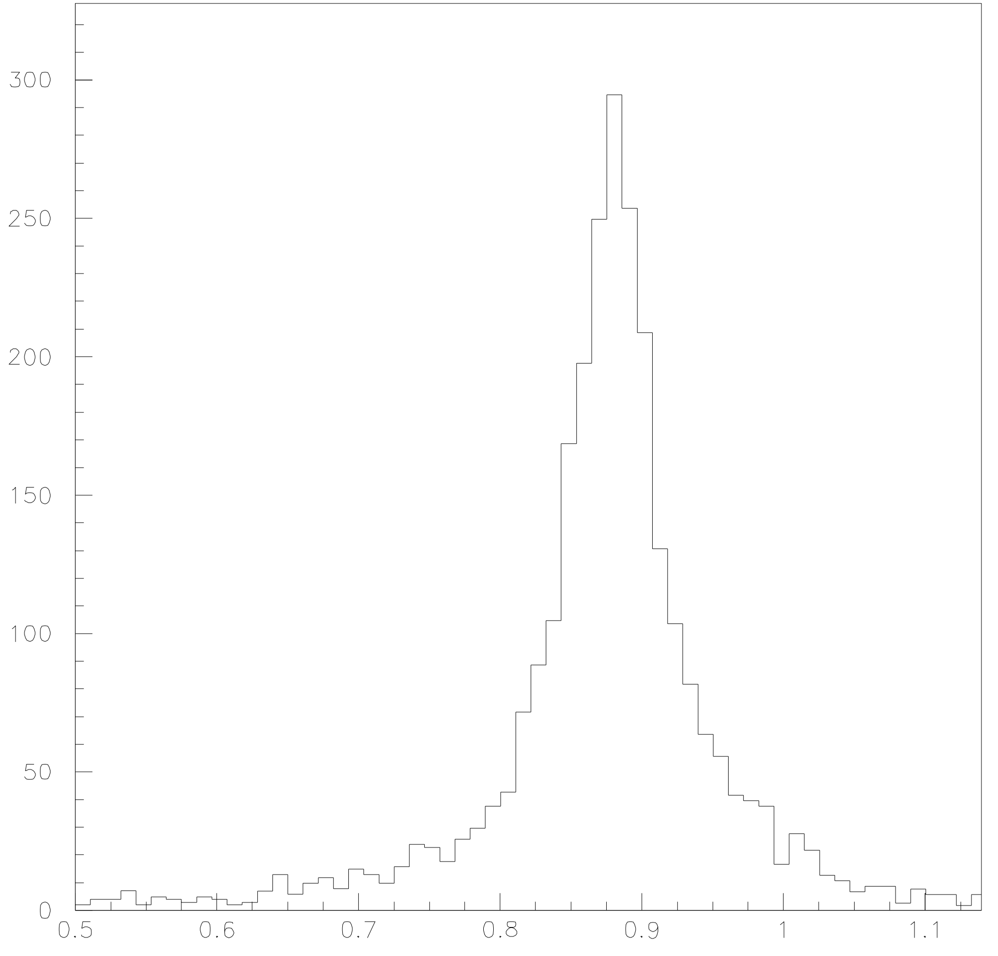
The blue triangles – the data of Dobrovolsky et al. taken at 1685.7 MeV/c

The cross section of elastic scattering: $\sigma_{el} = 23{,}7 \pm 0.6$ mbn

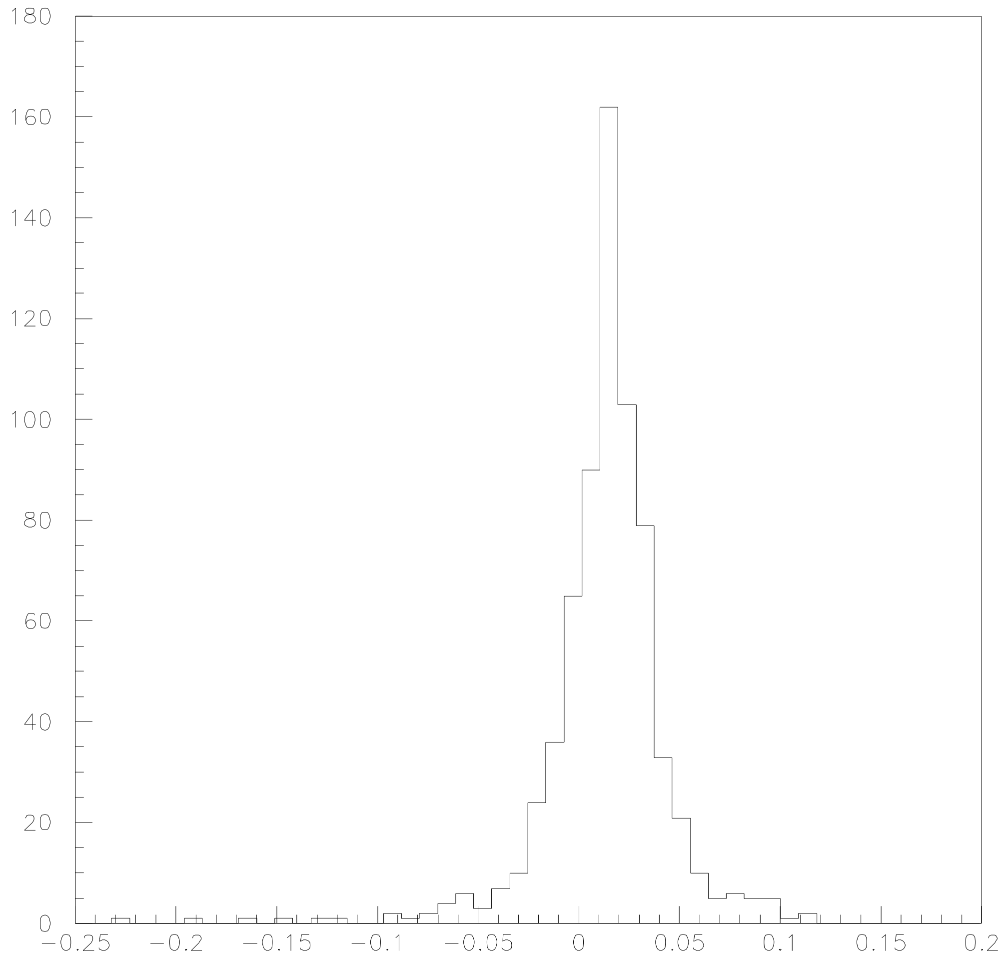
$\sigma_{pp \to pn\pi+} = 18.9 \pm 0.6$ mbn

$\sigma_{pp \to pp\pi o} = 4.50 \pm 0.17$ mbn

$\sigma_{pp \to d\pi+} = 0.05 \pm 0.02$



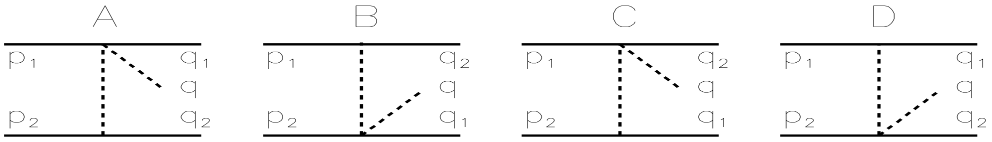
Missing mass squered neutron



Missing mass squared π^{o}-meson

One-pion exchange model.

According to OPE model the main role in the reaction
$NN \to NN\pi$ is played by the pole diagrams.



The matrix element of any diagram can be presented as a product of three factors: the propagator, the amplitude of the πN scattering and the πNN vertex function

$$M_i \sim T(z_i, y_i^2, k_i^2)\, G(k_i^2) / (k_i^2 + \mu^2)$$

where z_i is the total energy of the πN system, y_i^2 is the four-momentum transfer square in the πN scattering vertex, k_i^2 is the four-momentum square of the virtual pion and μ^2 is the pion mass squared.

The form factor function of the πNN vertex taking into account the nonpole diagram contributions was not determined in the frame of the OPE model. The following form was suggested for the form factor by Suslenko and Gaisak:

$$G(k_i^2)=\alpha\mu^2 /[k_i^2 + (\alpha +1)\, \mu^2]$$

The choice of α in the range 8-9 gave a good description of the experimental data in the energy range 600-1000 MeV.

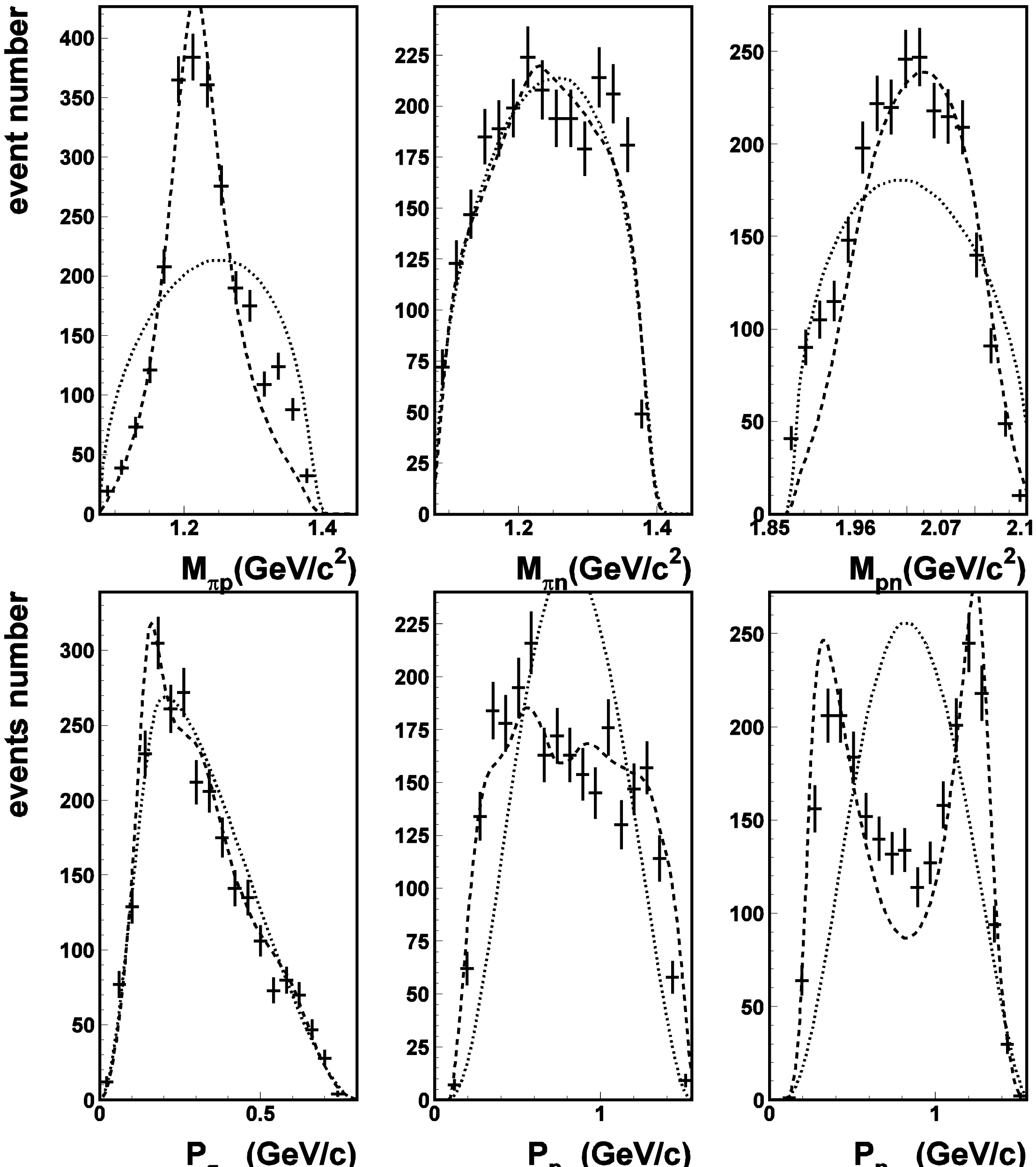
The πN scattering amplitude Ƭ(zi, yi2, ki2) and its off-shell behaviour were taken according Ferrary and Selleri, where off-shell corrections were introduced into partial waves. We confined ourselves to the P_{33}-wave only assuming the leading role of the Δ_{33}-resonance in the πN scattering. The partial off-shell f_{33} amplitude was taken in the form

$$f_{33}(z_i, k_i^2) = \Gamma(k_i^2)\, f_{33}(z_i; -\mu^2)$$

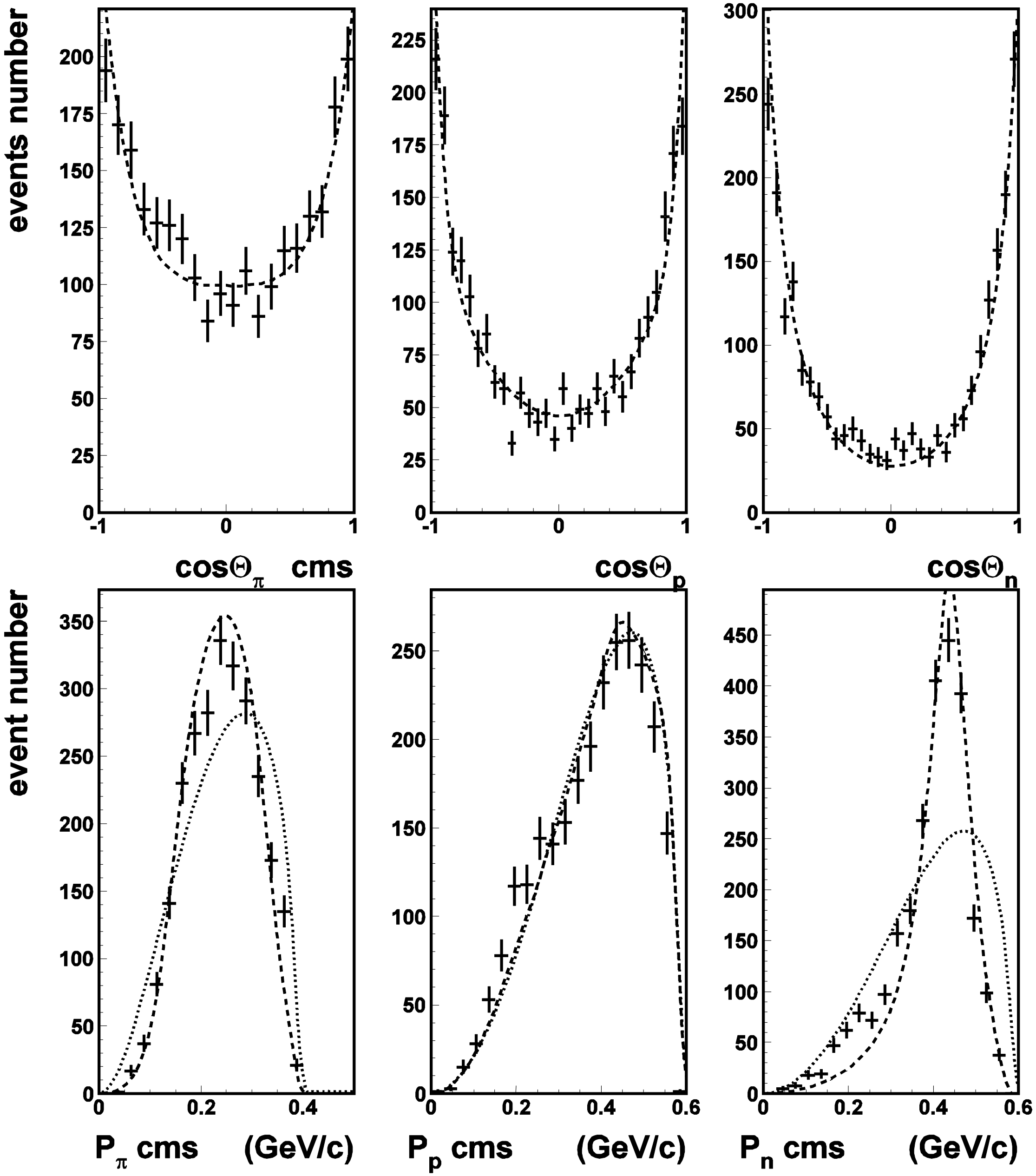
where $\Gamma(k_i^2)$ is the off-shell correction factor calculated by F.Selleri in the frame of dispersion relations, while on-shell partial f_{33} amplitude was taken in Breit-Wigner form.

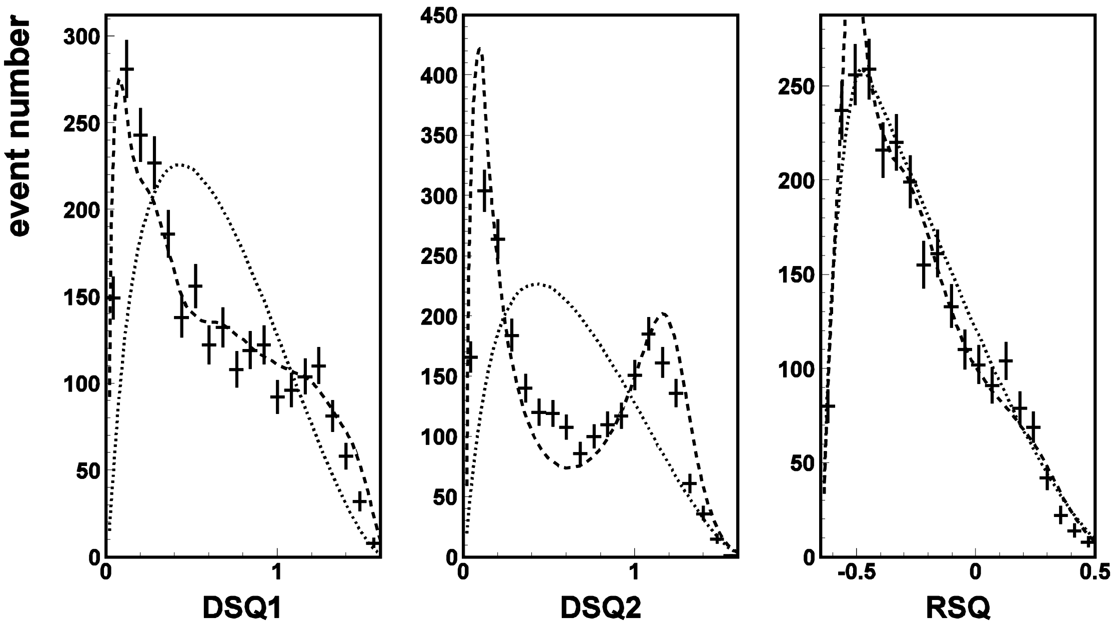
The reaction matrix element is the sum of the matrix elements of the diagrams

$$M = M_A - M_B - M_C + M_D$$



event number
events number
$M_{\pi p}(GeV/c^2)$
$M_{\pi n}(GeV/c^2)$
$M_{pn}(GeV/c^2)$
P_π (GeV/c)
P_p (GeV/c)
P_n (GeV/c)


events number
cosΘ$_\pi$ cms
cosΘ$_p$
cosΘ$_n$
event number
P$_\pi$ cms (GeV/c)
P$_p$ cms (GeV/c)
P$_n$ cms (GeV/c)


event number
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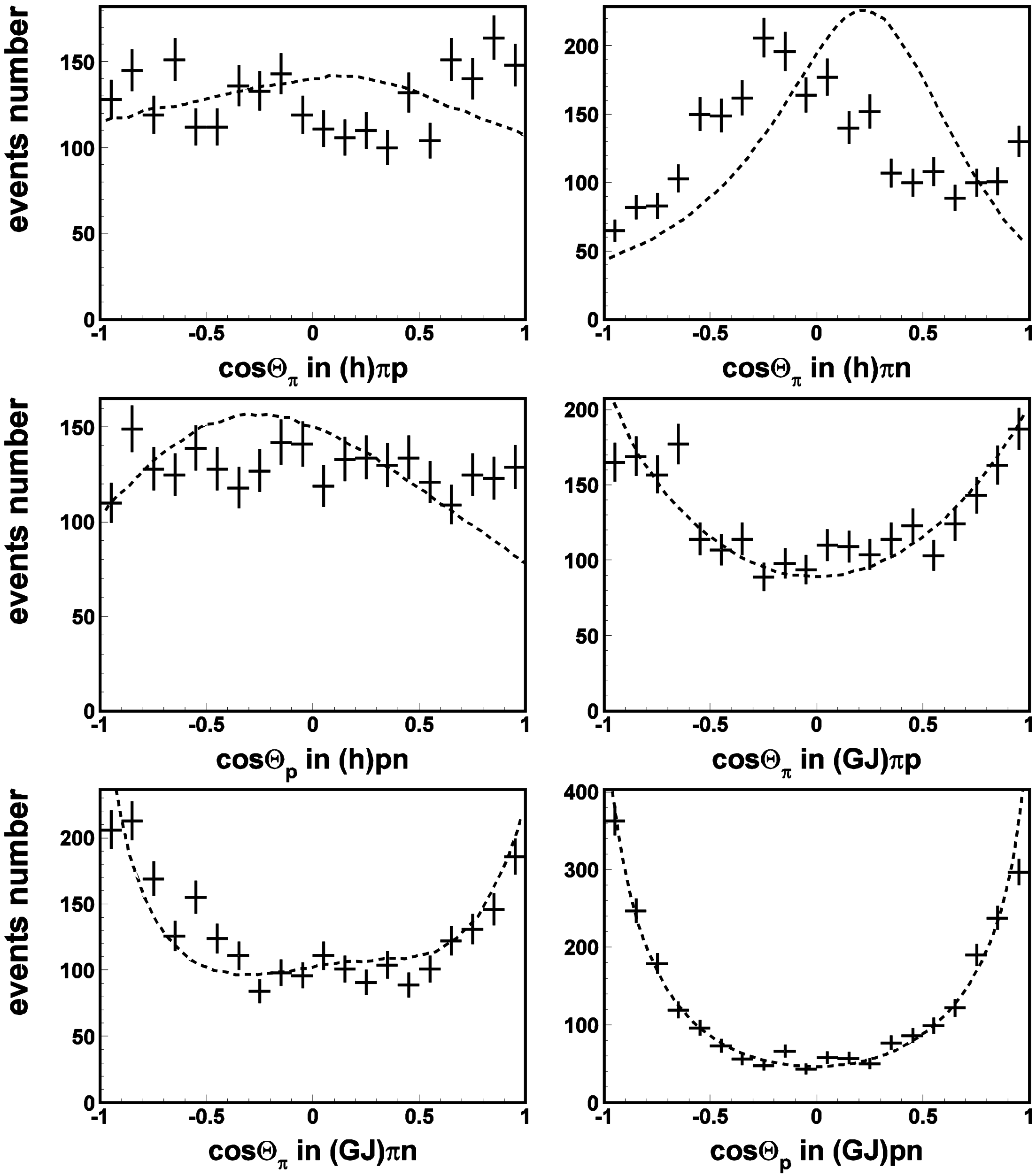
250
200
150
100
50
0
0
1
DSQ1
450
400
350
300
250
200
150
100
50
0
0
1
DSQ2
250
200
150
100
50
0
-0.5
0
0.5
RSQ



events number
cosΘ_π in (h)πp
cosΘ_π in (h)πn
events number
cosΘ_p in (h)pn
cosΘ_π in (GJ)πp
events number
cosΘ_π in (GJ)πn
cosΘ_p in (GJ)pn

$$np \to pp\pi^- \tag{1}$$

$$d\sigma = \frac{(2\pi)^4|A|^2}{4|\boldsymbol{k}|\sqrt{s}}\, d\Phi_3(P, q_1, q_2, q_3)\ , \qquad P = k_1 + k_2\ , \tag{2}$$

$$d\Phi_m(P, q_1 \ldots q_m) = \delta^4(P - \sum_{i=1}^{3} q_i) \prod_{i=1}^{3} \frac{d^3 q_i}{(2\pi)^3 2q_{0i}}\ . \tag{3}$$

$$A = \sum_{\alpha} A^{\alpha}_{tr}(s) Q^{in}_{\mu_1 \ldots \mu_J}(SLJ) A_{2b}(i, S_2 L_2 J_2)(s_i) \times$$
$$Q^{fin}_{\mu_1 \ldots \mu_J}(i, S_2 L_2 J_2 S' L' J)\ . \tag{4}$$

To suppress contributions of amplitudes at high relative momenta we introducedthe Blatt-Waisskopf form factors. Thus the energy depended part of the partial wave amplitudes with production of the resonance, for example, in the two-particle system 12 (e.g. πp) and the spectator particle 3(n) has the form

$$A = A_{tr}^{\alpha} A_{2body}^{S2,L2,J2}(s_{12}) q^{L} k_{3}^{L'} / (F(q^2,L,R) F(k_3,L',r_3))^{1/2}$$

where q is the momentum incident proton and k_3 is the momentum of the spectator particle. For the description of the energy dependence of the πN system we taken two resonances Δ(1232) and Roper N(1440). Resonance contributions are parameterized as follows:

$$A_{2body}^{S2,L2,J2}(s_{12}) = k_{12}^{L2} / [F(k_{12},L_2,r_{12})^{1/2} (M_R^2 - s_{12} - M_R \Gamma)]$$

$$\Gamma = \Gamma_R M_R k_{12}^{\ 2L2+1} F(k_R^2,L_2,r_{12}) / [(s_{12})^{1/2} k_{\ R}^{2L2+1} F(k_{12}^2,L_2,r_{12})]$$

Here s_{12} is the invariant energy squared in the channel 12, k_{12} is the relative momentum of particles 1 and 2 in the teir rest system and r_{12} is the effective radius.

$$A^{\alpha}_{tr}(s) = \frac{a^{\alpha}_1 + a^{\alpha}_3\sqrt{s}}{s - a^{\alpha}_4}\, e^{ia^{\alpha}_2}, \tag{5}$$

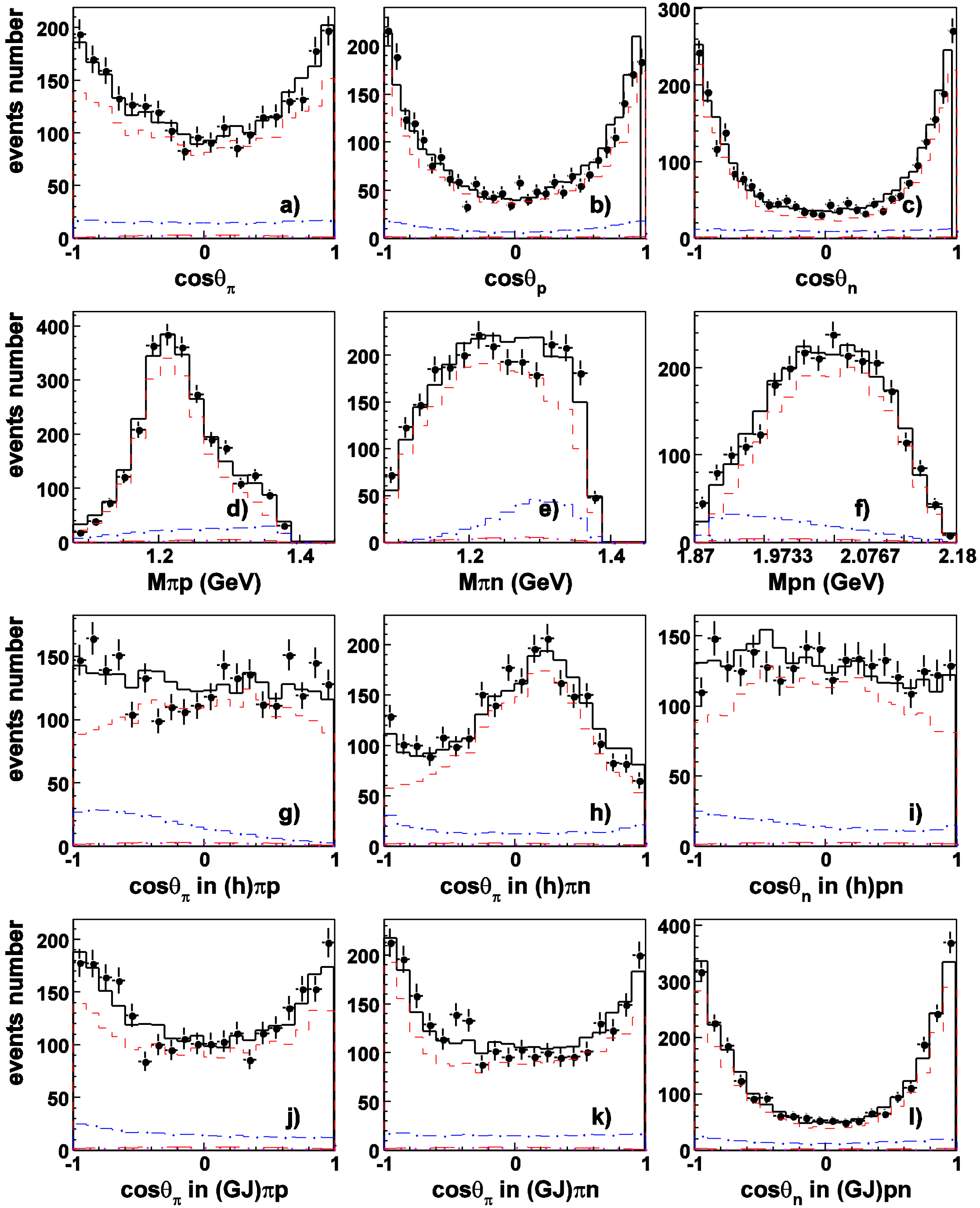
$$A^{\beta}_{2b}(s_i) = \frac{\sqrt{s_i}}{1 - \frac{1}{2}r^{\beta}q^2 a^{\beta}_{pp} + iqa^{\beta}_{pp}q^{2L}/F(q, r^{\beta}, L)}, \tag{6}$$

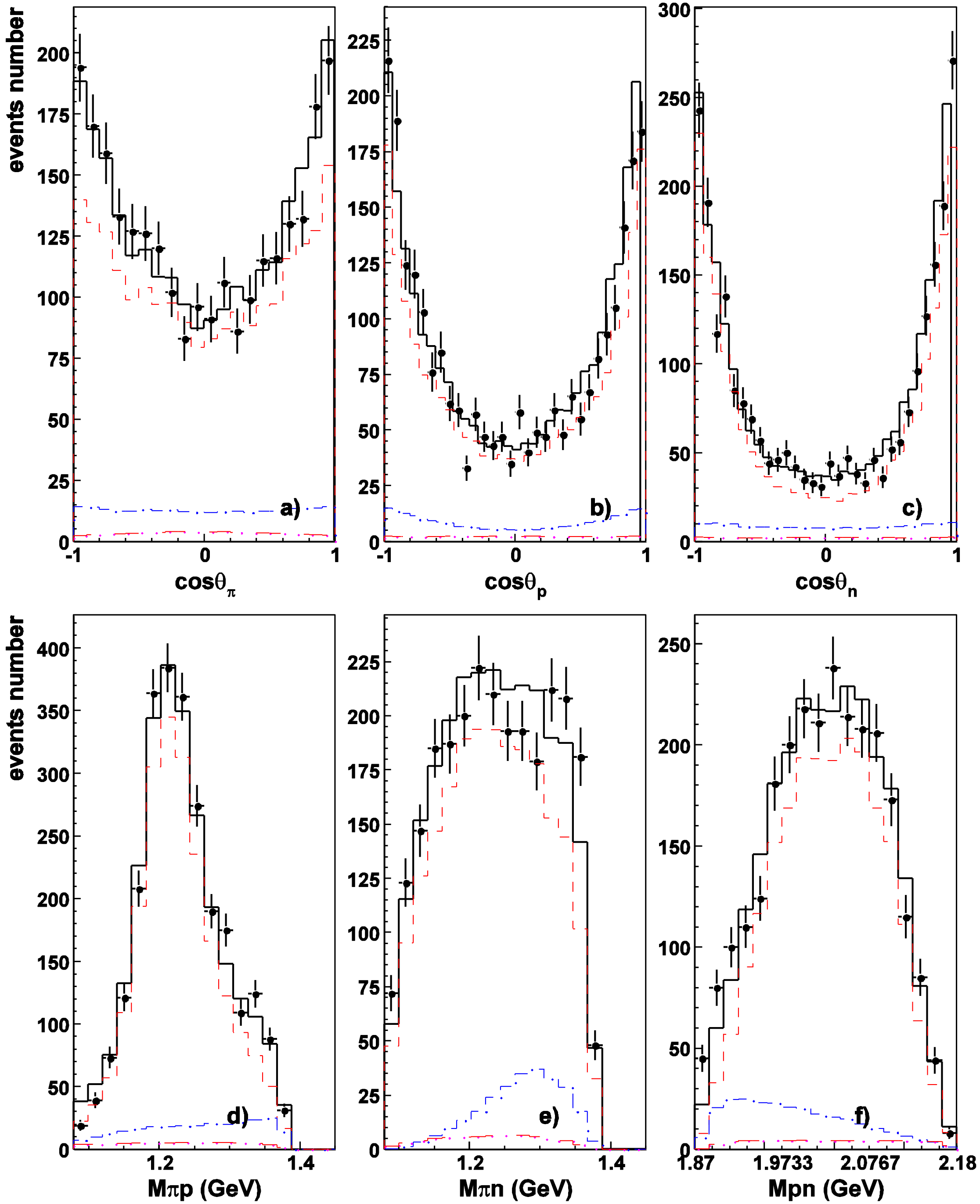
where multiindex β denotes possible combinations of a kinematical channel i and quantum numbers S_2, L_2 and J_2, a^{β}_{pp} is a pp-scattering length and r^{β} is the effective range of the pp system. The $F(q, r, L)$ is the Blatt-Weisskopf form factor (it is equal to 1 for $L = 0$) and q is a relative momentum in the pp-system:

$$q = \frac{\sqrt{s_i - 4m^2_p}}{2} \tag{7}$$

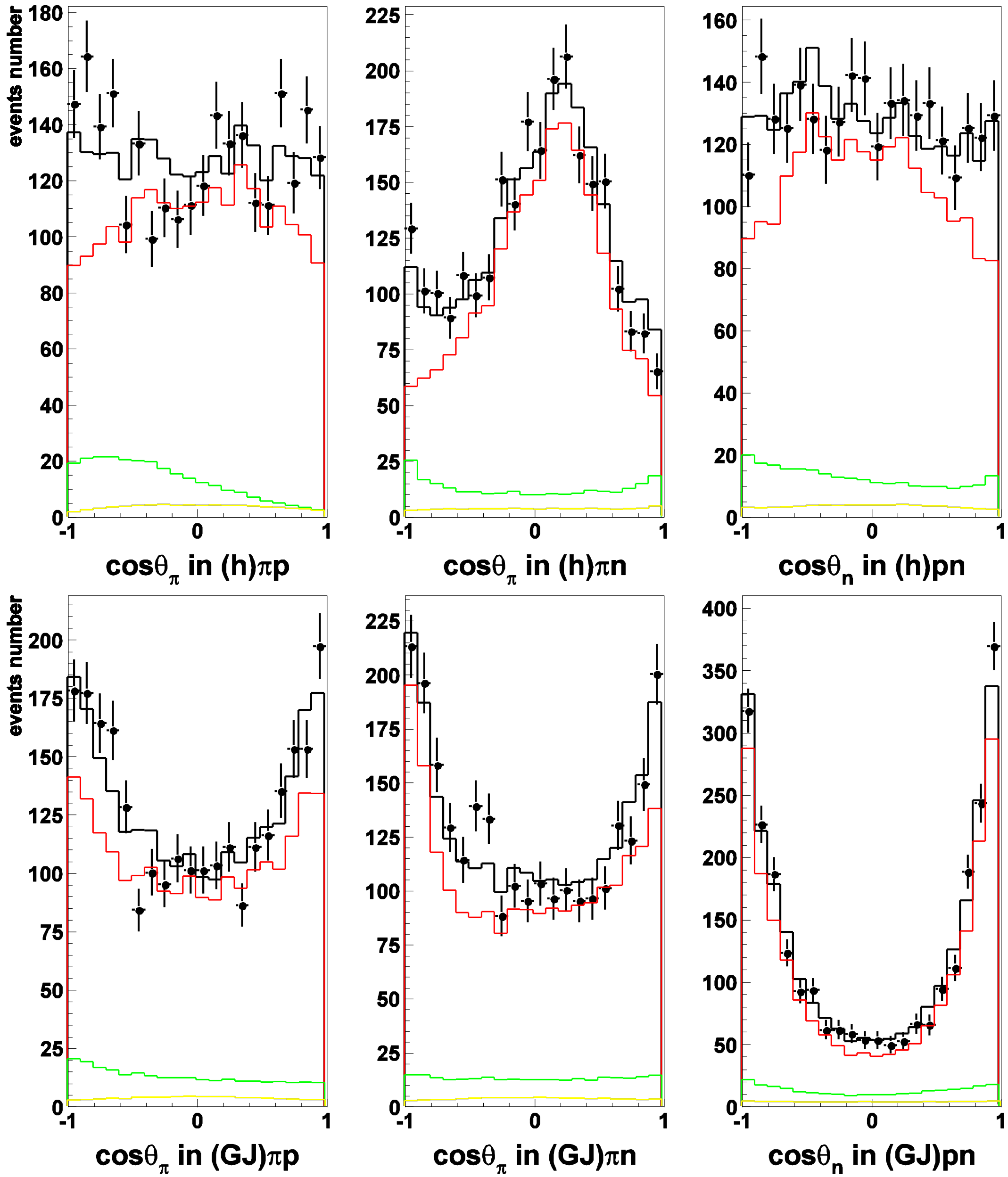
Для начальной pp системы были взяты состояния
с полным угловым моментом J ≤ 2,
и орбитальным моментом L=0,1,2,3,4,5

Для конечного состояния трех частиц мы ограничились орбитальными моментами L_2=0,1, 2 и L' =0,1, 2,3,4,5


events number
a)
b)
c)
d)
e)
f)
g)
h)
i)
j)
k)
l)
cosθ_π
cosθ_p
cosθ_n
Mπp (GeV)
Mπn (GeV)
Mpn (GeV)
cosθ_π in (h)πp
cosθ_π in (h)πn
cosθ_n in (h)pn
cosθ_π in (GJ)πp
cosθ_π in (GJ)πn
cosθ_n in (GJ)pn



events number
a)
b)
c)
cosθπ
cosθp
cosθn
events number
d)
e)
f)
Mπp (GeV)
Mπn (GeV)
Mpn (GeV)


events number
cosθ_π in (h)πp
cosθ_π in (h)πn
cosθ_n in (h)pn
cosθ_π in (GJ)πp
cosθ_π in (GJ)πn
cosθ_n in (GJ)pn

Начальные парциальные состояния, дающие наибольшие вклады в реакцию $pp \rightarrow pn\pi^+$.

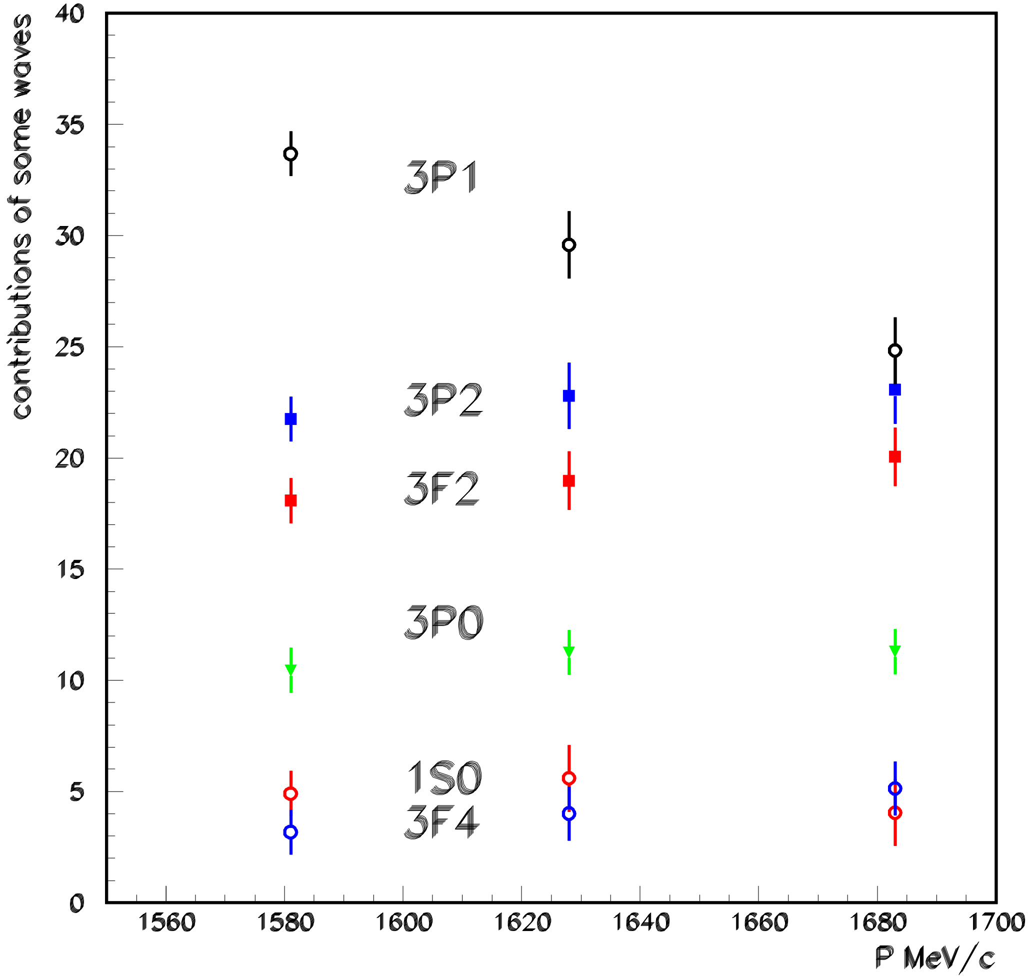
Изовекторные состояния (I=1)

$^3P_0$	11.3±1.%
$^3P_1$	24.8±3.%
$^3P_2$	23.0±5 %
$^1D_2$	6.5±1. %
$^3F_2$	20.1±2.%
3F4	5.13 ±2.%

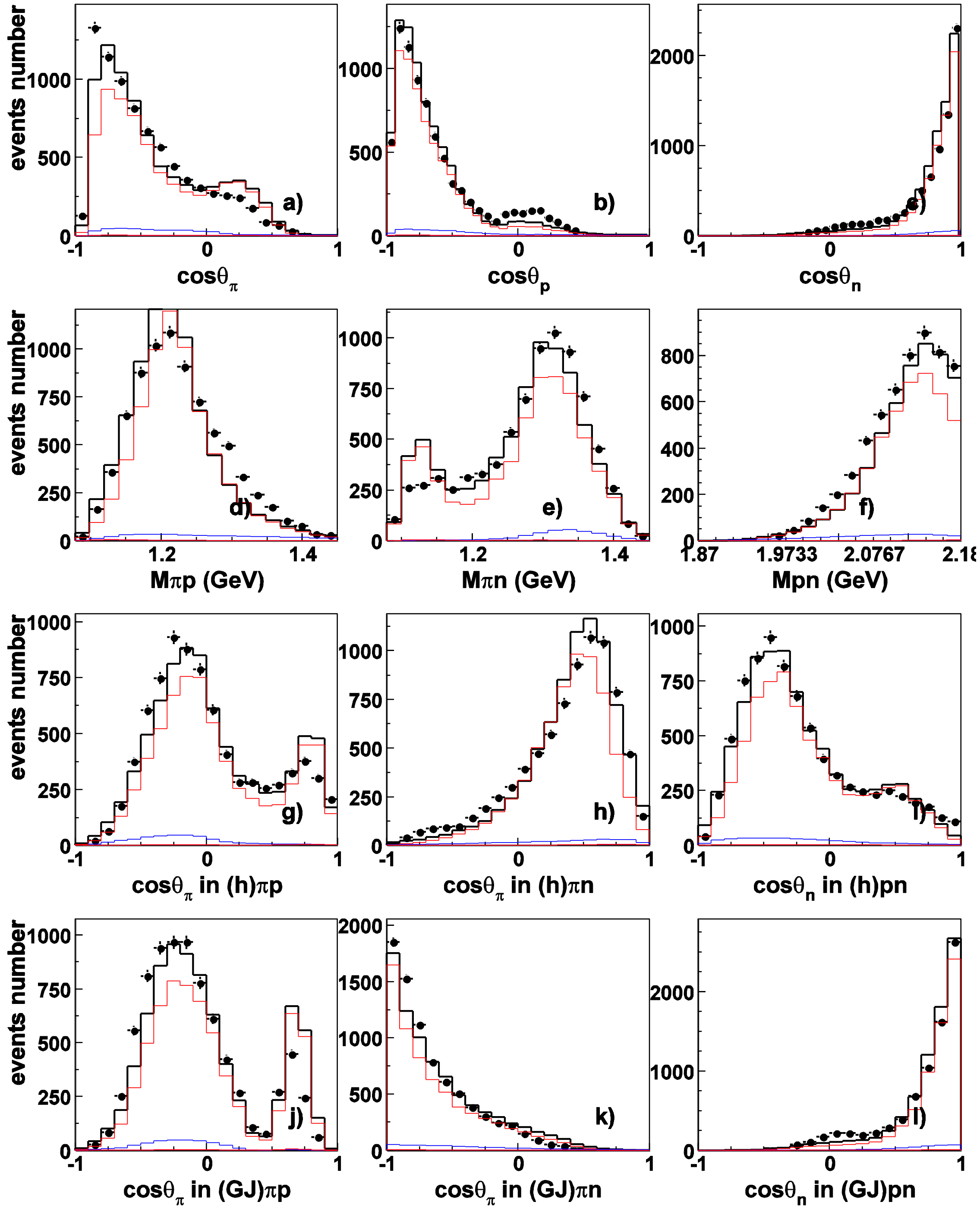
$^3P_2$ состояние распадается в три канала $\Delta(1232)p$, $P_{11}(1440)p$ и $(^3P_2)_{pn}\pi$.

$^3P_1$ состояние распадается в $\Delta(1232)p$, P11(1440)p и $(^3P_1)_{pn}\pi$.

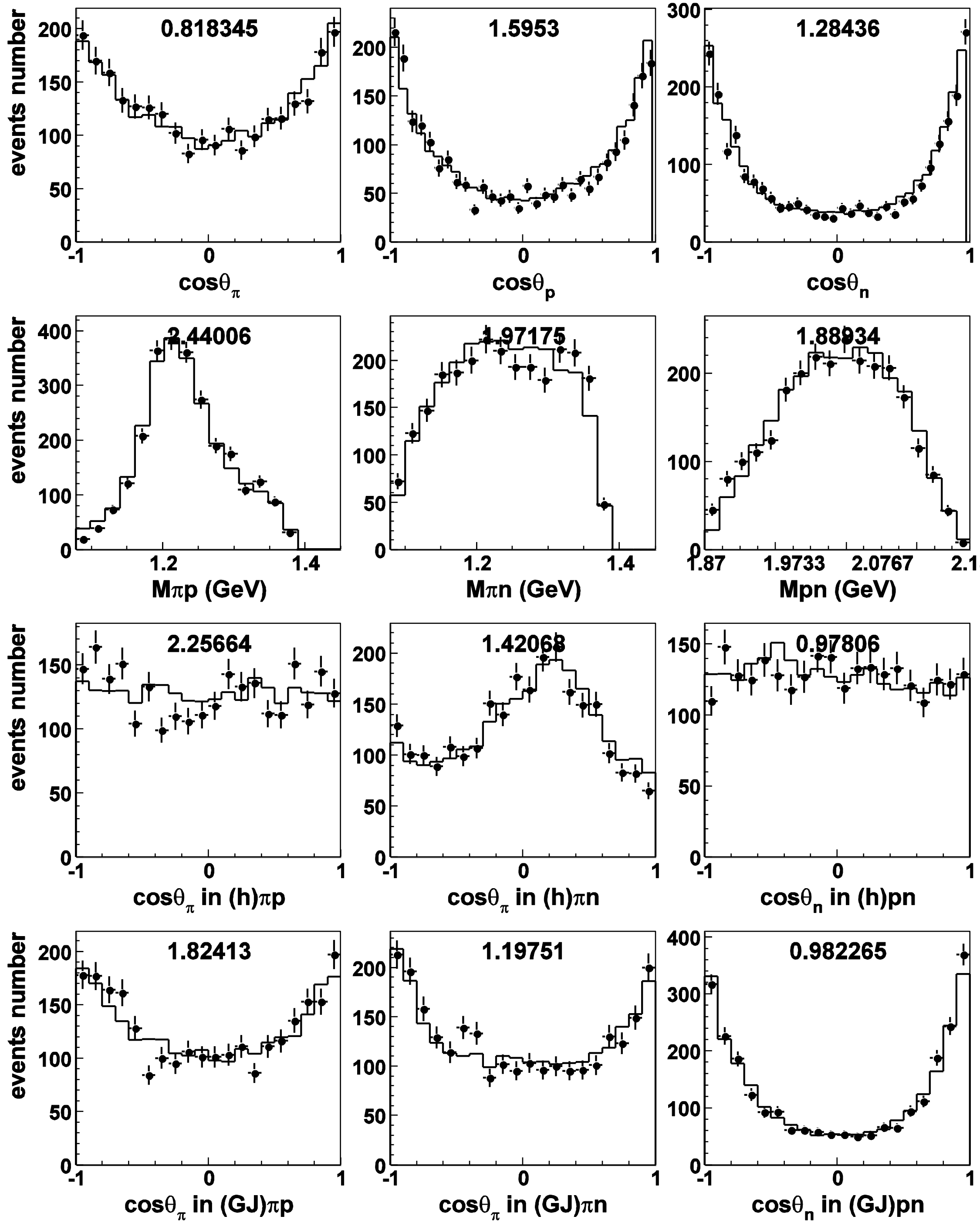
$^3F_2$ - в основном в $\Delta(1232)p$


contributions of some waves
3P1
3P2
3F2
3P0
1S0
3F4
P MeV/c
0
5
10
15
20
25
30
35
40
1560
1580
1600
1620
1640
1660
1680
1700

T=1300 MeV



events number
cosθπ
cosθp
cosθn
a)
b)
c)
Mπp (GeV)
Mπn (GeV)
Mpn (GeV)
d)
e)
f)
cosθπ in (h)πp
cosθπ in (h)πn
cosθn in (h)pn
g)
h)
i)
cosθπ in (GJ)πp
cosθπ in (GJ)πn
cosθn in (GJ)pn
j)
k)
l)



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2.44006
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2.25664
1.42068
0.97806
1.82413
1.19751
0.982265
events number
cosθ_π
cosθ_p
cosθ_n
Mπp (GeV)
Mπn (GeV)
Mpn (GeV)
cosθ_π in (h)πp
cosθ_π in (h)πn
cosθ_n in (h)pn
cosθ_π in (GJ)πp
cosθ_π in (GJ)πn
cosθ_n in (GJ)pn