DELTA-SIGMA EXPERIMENT

Measurement of the cross section ratio in charge-exchange (np) reactions on D_2/H_2 at 0° and T = 1.0; 1.2 GeV

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The Delta-Sigma Experiment Research Program

1. **Using longitudinally (L) and transverse (T) polarized neutron beams and the Dubna movable polarized proton target to measure the energy dependencies of:**

   a) $\Delta\sigma_L(np)$ **and** $\Delta\sigma_T(np)$ **– the total cross section differences for parallel and antiparallel directions of beam and target polarizations, with energy steps of 100–200 MeV and expected statistical errors of 1 mb;**

   The observables $\Delta\sigma_L(np)$ ***and*** $\Delta\sigma_T(np)$ ***are linearly related to the imaginary parts of the two spin-dependent forward scattering invariant amplitudes c and d via optical theorems and allow to extract these imaginary parts.***

   b) (simultaneously and independently with the $\Delta\sigma_{L,T}(np)$ **measurements) spin-correlation parameters** $A_{00kk}(np)$ **(together with** $\Delta\sigma_L(np)$**) and** $A_{00nn}(np)$ **(together with** $\Delta\sigma_T(np)$**) with expected statistical errors of 0.02 – 0.05.**

   The $A_{00kk}(np)$ ***and*** $A_{00nn}(np)$ ***values are related to the real part of amplitudes.***

The Delta-Sigma Experiment Research Program

2. Using high intensity unpolarised neutron beam and liquid hydrogen and deuterium targets, to measure at the same energies as for 1.:

a) the ratio $R_{dp} = [d\sigma/d\Omega(nd)] / [d\sigma/d\Omega(np)]$ for elastic charge exchange process $np \rightarrow pn$ at 0° angle with 5% statistical errors.

The values of R_{dp} give an additional relation between spin-dependent NN-amplitudes and a set of such data allows to avoid an uncertainties of real parts extraction.

The data set on energy behaviors of spin-dependent observables $\Delta\sigma_{L,T}(np)$, $A_{00kk}(np)$, $A_{00nn}(np)$ and R_{dp} will be obtained for the first time over the energy range of neutron beam of 1.2–3.7 GeV.

Ratios R_{dp} and R^{ID}

The ratio R_{dp} independently defines the ratio R^{ID} :

$$R_{dp} = \frac{d\sigma/d\Omega(nd)}{d\sigma/d\Omega(np)} = \frac{2}{3} \cdot \frac{1}{(1+R^{ID})} \quad , \qquad (1)$$

Where:

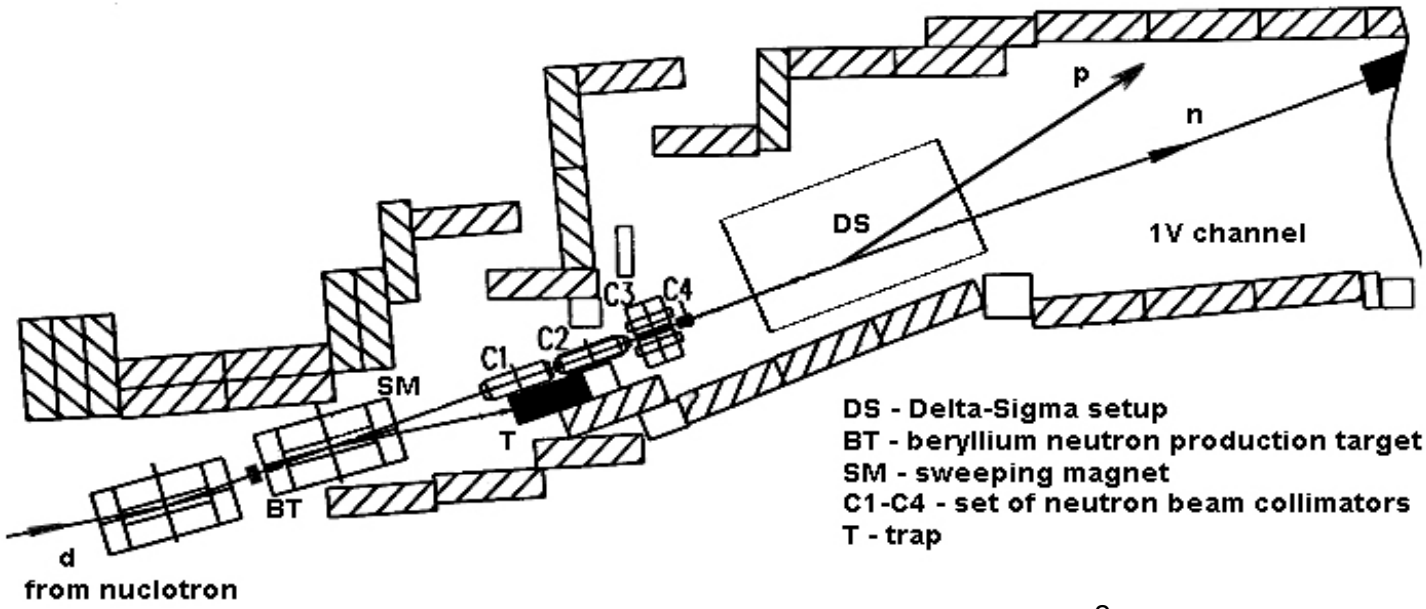
$d\sigma/d\Omega(nd)$ – differential cross-section of the quasi-elastic charge-exchange $nd \rightarrow pnn$ reaction at 0°,
$d\sigma/d\Omega(np)$ – differential cross-section of the elastic charge-exchange $np \rightarrow pn$ reaction at 0°.

R^{ID} – ratio of non spin-flip to spin-flip contributions in $np \rightarrow pn$ charge-exchange process at 0°.

$$R^{ID} = \frac{(d\sigma/d\Omega)^{SI}_{np}}{(d\sigma/d\Omega)^{SD}_{np}} \qquad (2)$$

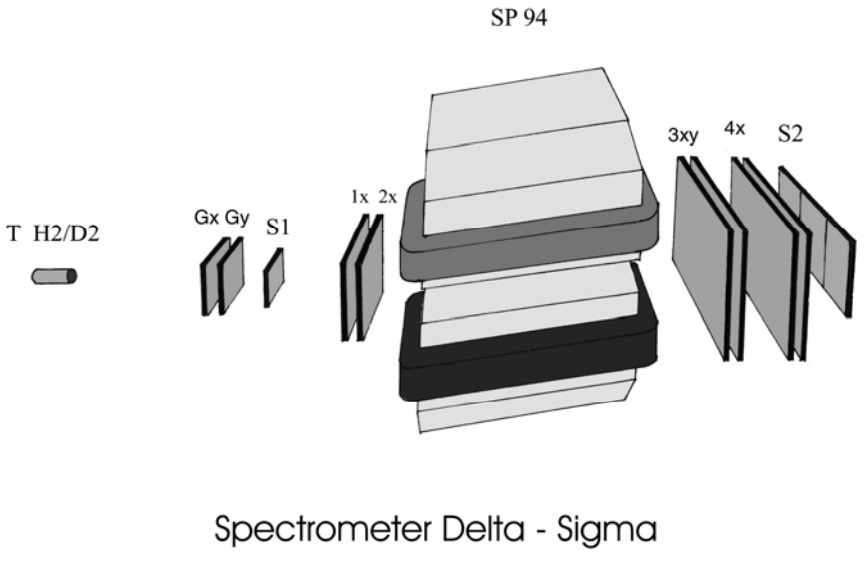
*L.I. Lapidus, J.Exp.Theor.Phys.(USSR) **32** (1957) 1437*
*N.W. Dean, Phys. Rev. D **5** (1972) 1661*
*N.W. Dean, Phys. Rev. D **5** (1972) 2832*

Delta-Sigma spectrometer

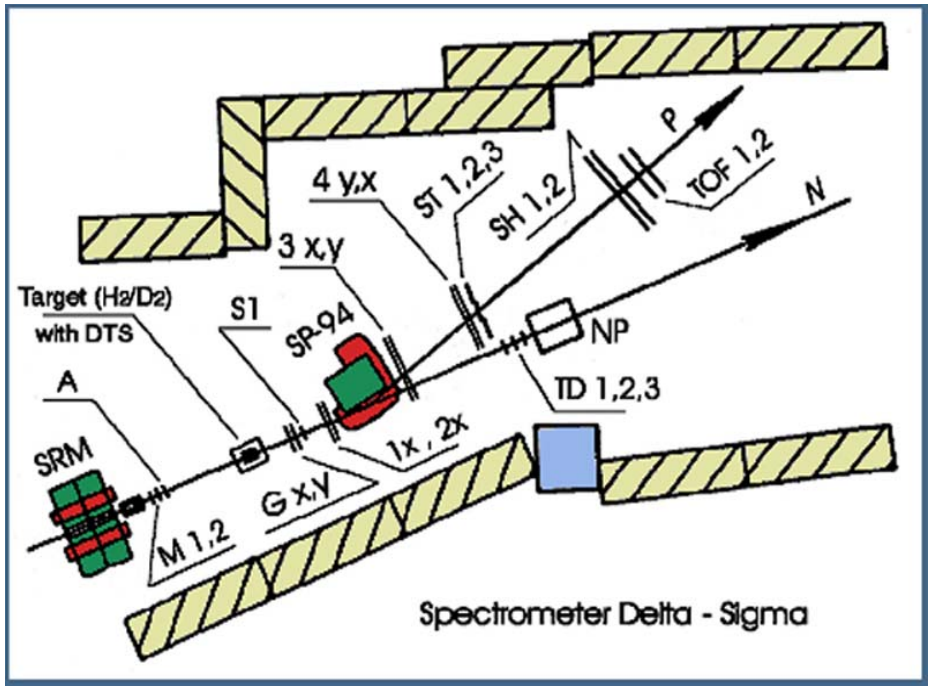


- Beryllium target – 8*8 cm^2, length - 20cm
- The average intensity of the primary deuteron beam ≈ $2*10^{10}$ d/cycle.
- $P_n=P_d/2$ with a gaussian momentum spread of FWHM ≈ 5%[1]

[1] V.G. Ableev et al., Nucl. Phys. A **393**, 941 (1983); Nucl. Phys. A **411**, 514E (1983).

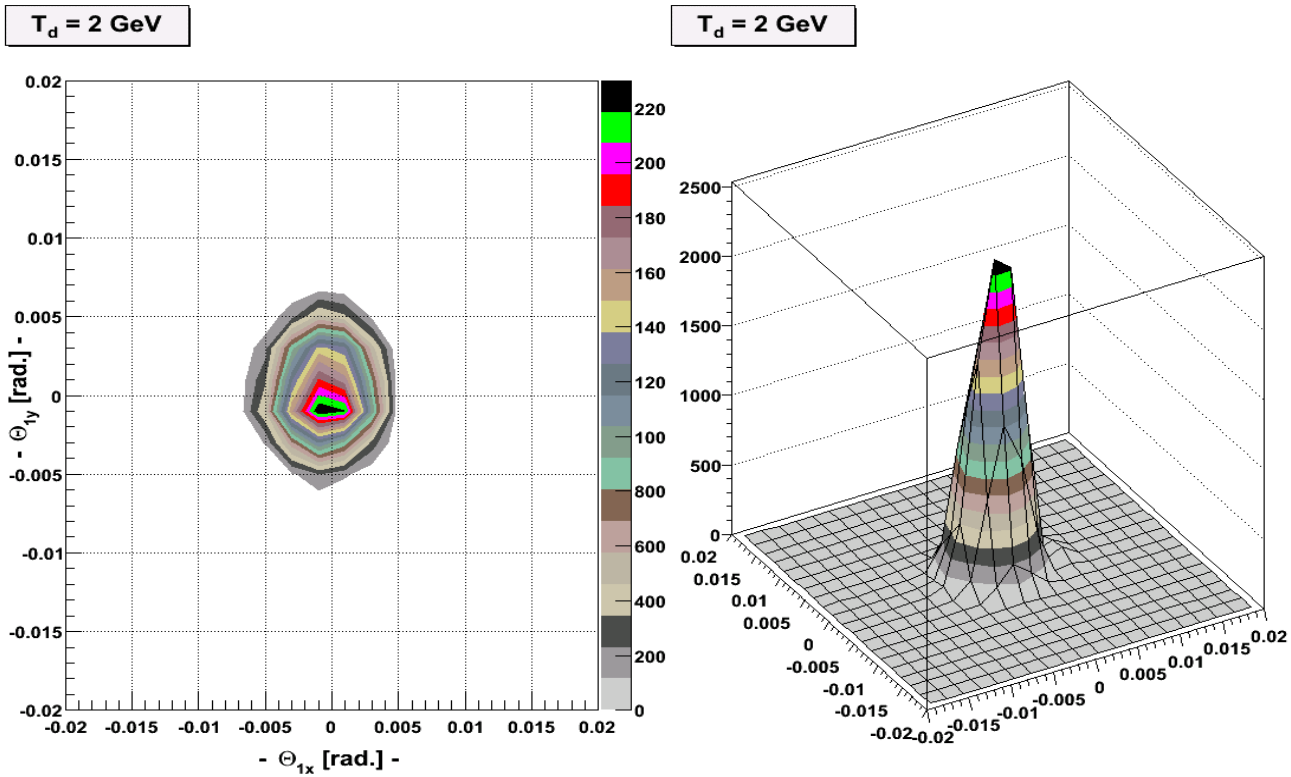


Delta-Sigma spectrometer



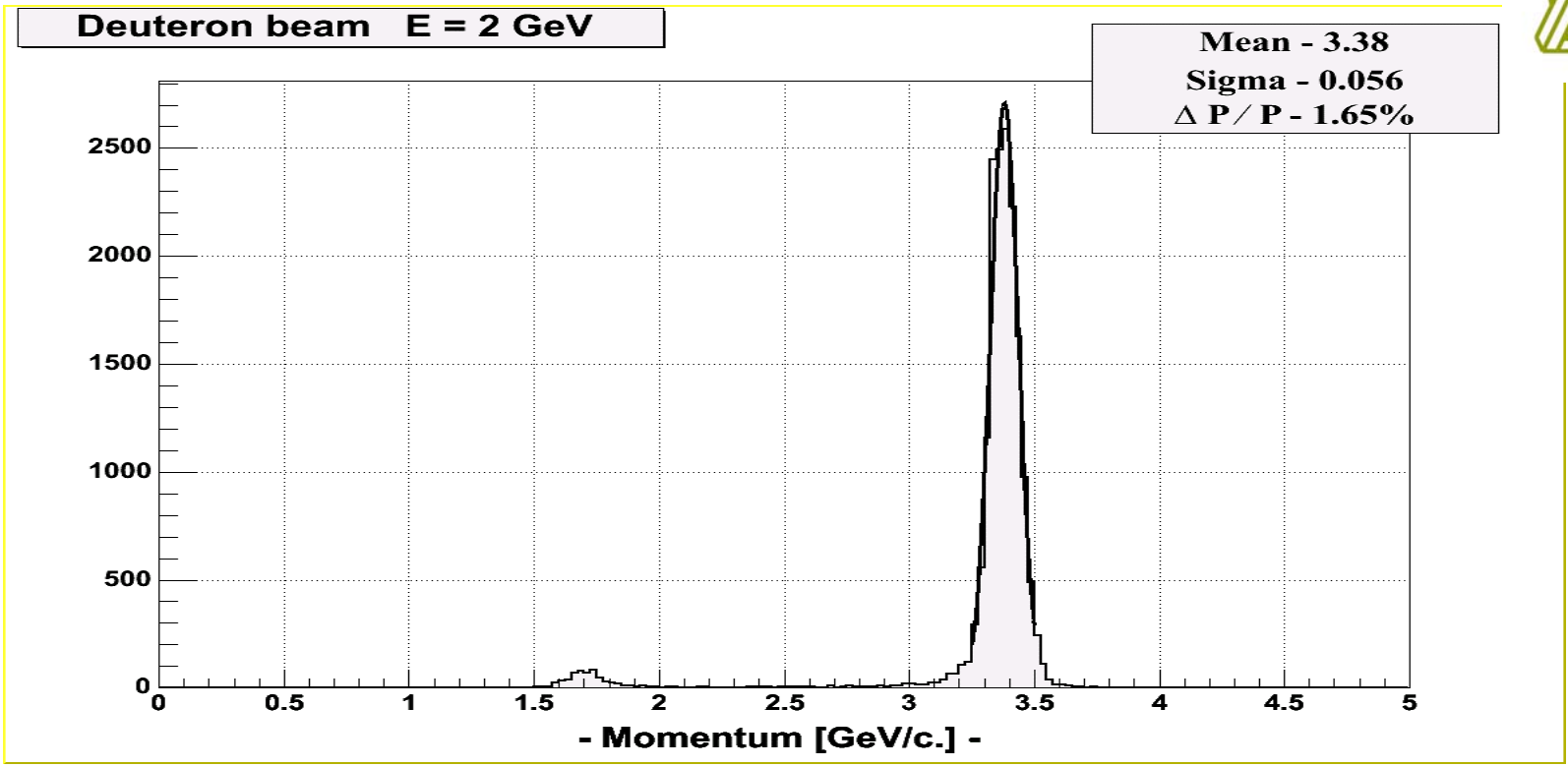
- ❑ **Magnet SP94**
- ❑ **Liquid H2/D2 Target (solid CH2 ,CD2, C)**
- ❑ **Neutron monitors (M1,2)**
- ❑ **Multiwire proportional chambers (Gx, Gy, 1x, 2x, 3x, 3y, 4x, 4y) placed in front of and behind the magnet**
- ❑ **Veto-counter (A), trigger scintillation counters (S1, ST1,2,3),**
- ❑ **Time-of-Flight system (TOF1,2)**

Primary deuteron beam. Angular distributions.



The accuracies of the angular measurement			
Measured value	Bin, mrad	Instr. error, mrad	Information taken from PCs
Θx	1.97	0.83	Gx AND 1x
Θx	1.79	0.76	Gx AND 2x
Θy	0.61	0.26	Gy AND 3y

Primary deuteron beam. Momentum specta.



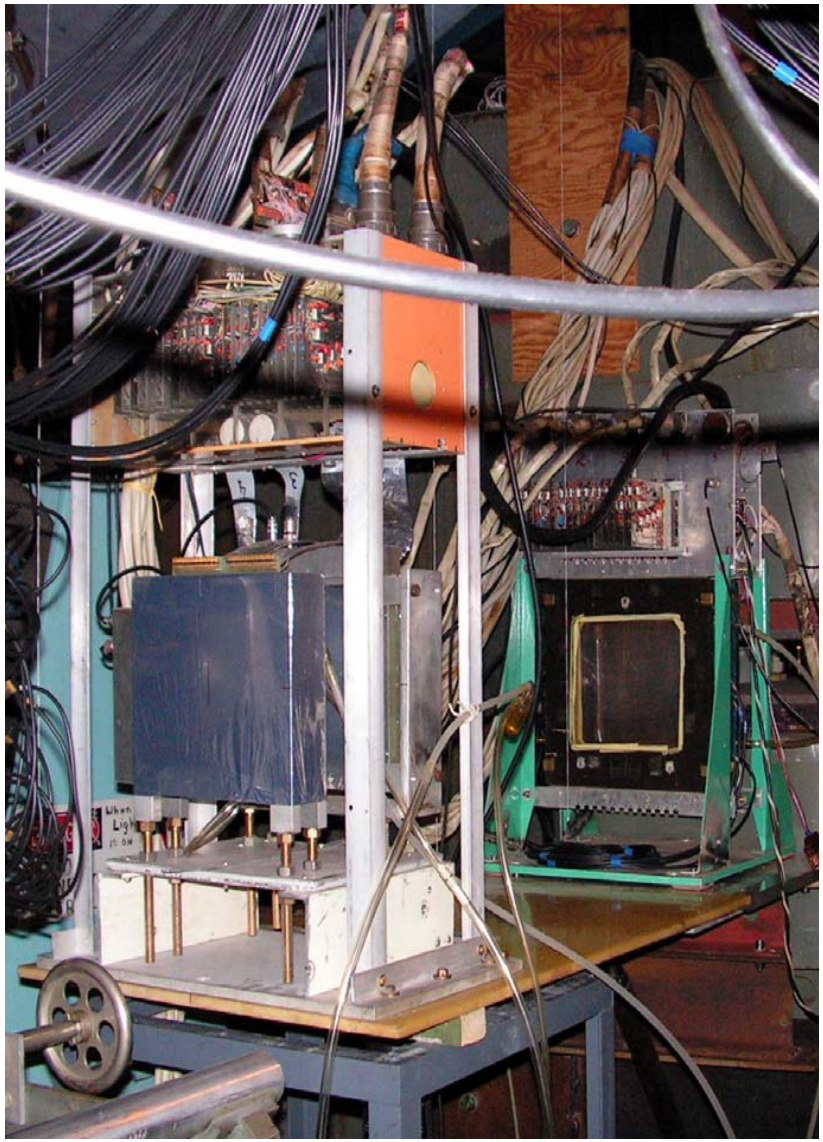
The accuracies of the momentum measurement	
ΔP/P	Information taken from PCs
1.65%	Gx AND 2x AND 4x
1.40%	Gx AND (1x OR 2x) AND ((3x AND 4x) OR 3x OR 4x)}
1.37%	Gx AND 2x AND 3x AND 4x

Targets

Cryogenic targets			
Target Matter	Length, mm	Diameter, mm	Number of atoms $*10^{23}$ cm^{-2}
H_2	340	70	14.496
D_2	340	70	16.892

Solid targets					
Target Matter	Length, mm	Width, mm	Height, mm	Number of atoms $*10^{23}$ cm^{-2}	
CH_2	150	50	40	H - 12.5	C – 6.34
CD_2	150	50	40	D - 12.5	C – 6.34
C	75	50	40	C - 6.34	

Multiwire Proportional Chambers

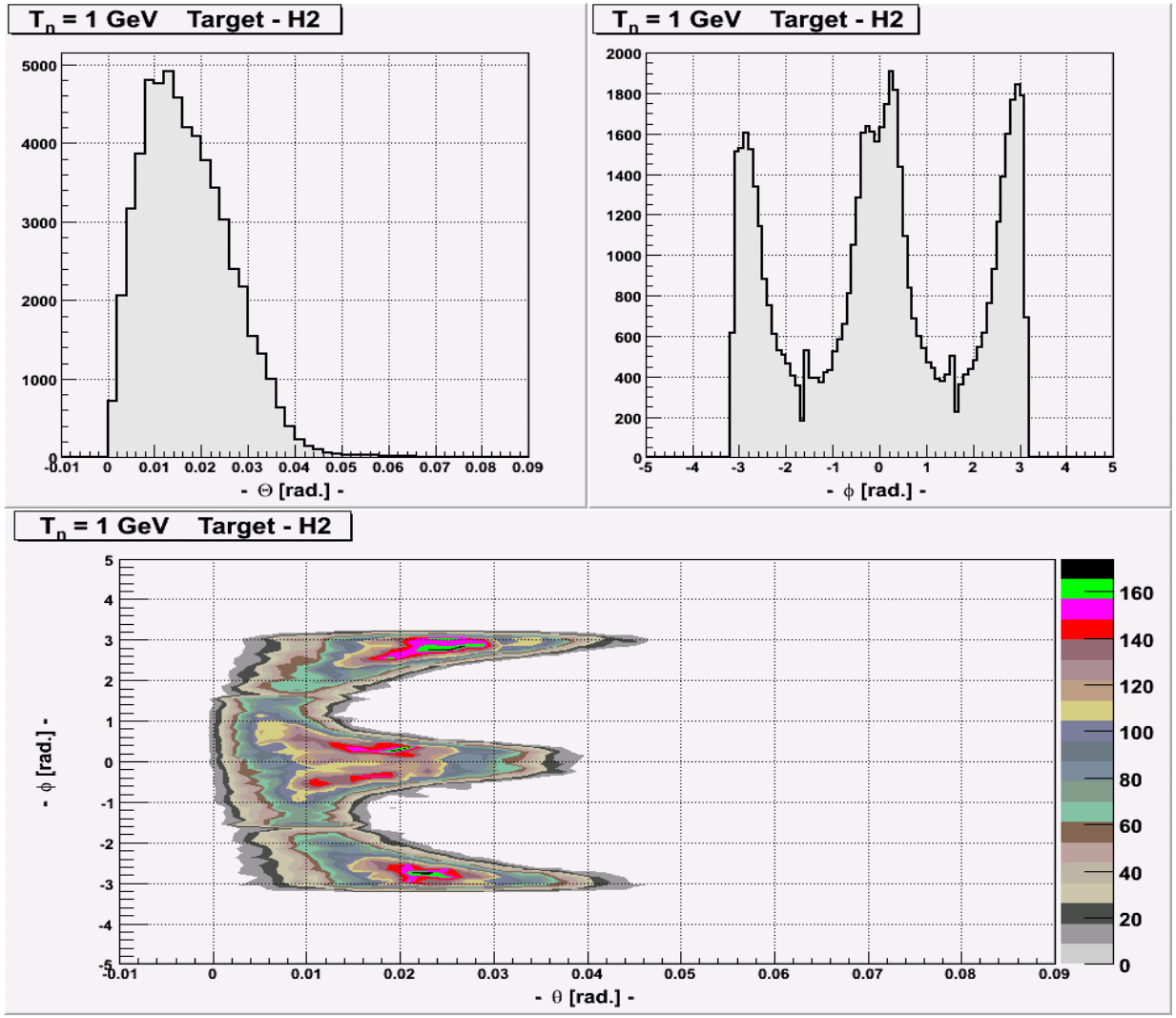


PCs name	Orientation	Number of wires	Working area, mm
Gx	Horizontal	64	128
Gy	Vertical	64	128
1x, 2x	Horizontal	96	192
3x, 4x	Horizontal	192	384
3y	Vertical	144	288

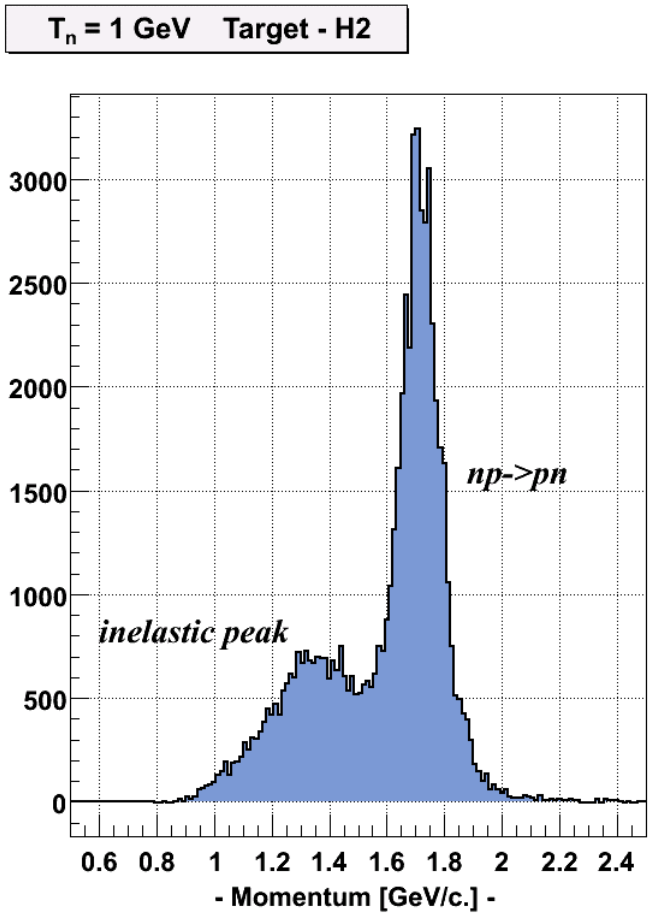
On-Line PCs efficiencies

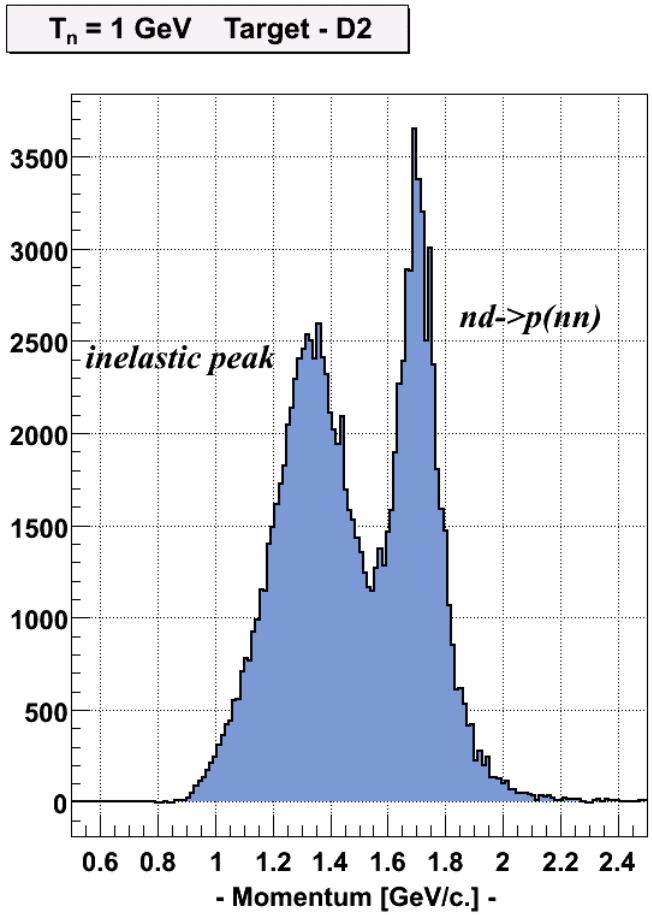
PC	Zero	All	One	Two	Cl2	Mn2
1x	0.026	0.974	0.880	0.069	0.049	0.020
2x	0.032	0.968	0.859	0.080	0.069	0.013
3x	0.049	0.951	0.512	0.393	0.388	0.005
3y	0.031	0.969	0.868	0.070	0.060	0.009
Gy	0.015	0.985	0.885	0.072	0.058	0.014
Gx	0.010	0.990	0.868	0.092	0.077	0.015
4x	0.058	0.942	0.561	0.339	0.330	0.008

Angular distribution in the θ vs φ plane



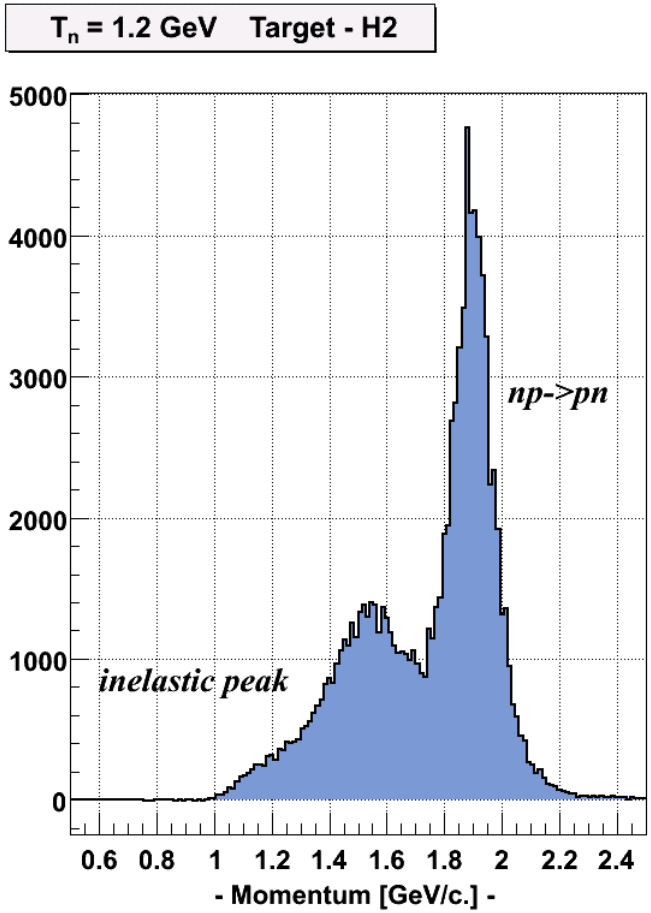
The momentum spectra of charged particles. H_2 and D_2 liquid targets neutron beam energy of 1.0 GeV.

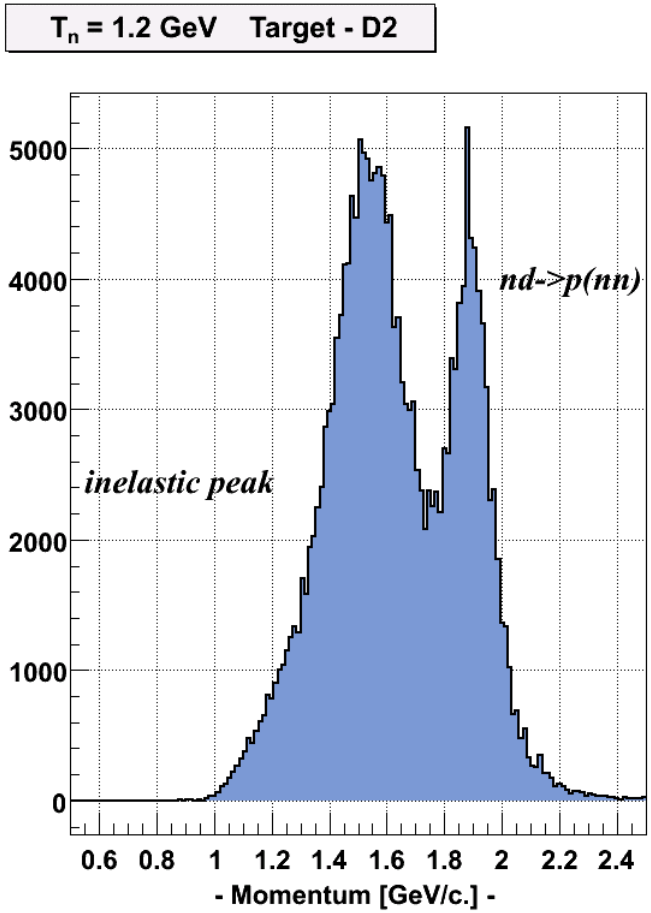




The main contribution in background (inelastic) peak is due to the binary reaction with excitation of Δ°-resonance.

The momentum spectra of charged particles. H_2 and D_2 liquid targets neutron beam energy of 1.2 GeV.





The main contribution in background (inelastic) peak is due to the binary reaction with excitation of Δ°-resonance.

Time-of-Flight System

The *np→pn* charge-exchange process is accompanied by the background reaction *np→dπ°*. Owing to this reaction kinematics the background deuterons are concentrated under the elastic proton peaks in the *np→pn* charge exchange reaction.

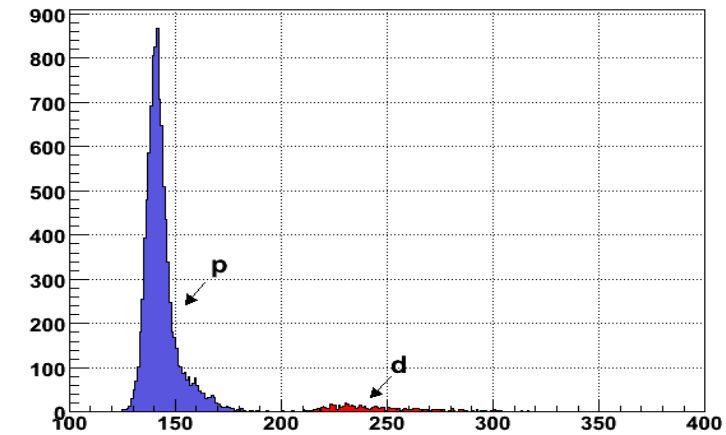
The time-of-flight of the particles was measured to suppress this background.

Next picture show a good separation of particles *d* and *p*.

The TOF efficiency = 85%

Separation of the *p* and *d* particles in the *TOF* vs *Momentum* plane

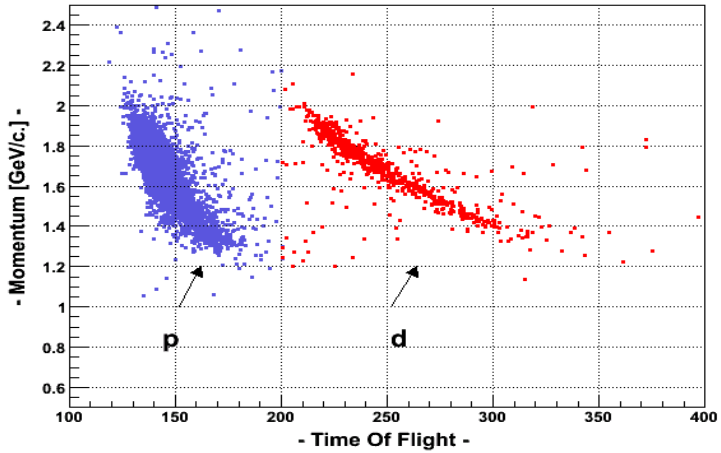
1) Time of flight



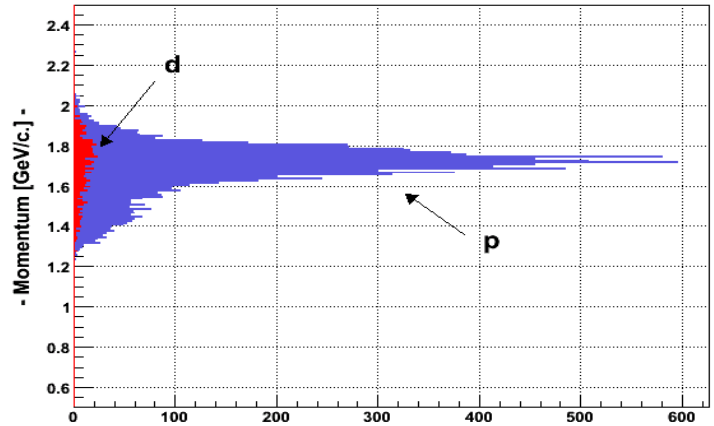
Separation of the p and d particles
in the 'time of flight' / 'momentum' plane.

T_n - 1 GeV.
Target - H_2

2) Time of flight / Momentum



3) Momentum



Differential cross section and ratio R_{dp} calculation

The reaction yield in the angular regions $0<\theta<0.012$ rad. and $0<\varphi<2\pi$ rad. was analysed to calculate the differential cross-section of *np→pn* elastic charge-exchange reactions at 0°. After the subtraction of the deuteron background in the reaction *np→dπ°* and the dummy target background the observed elastic peak was approximated by Gauss function, and the number of events in the peak was calculated.

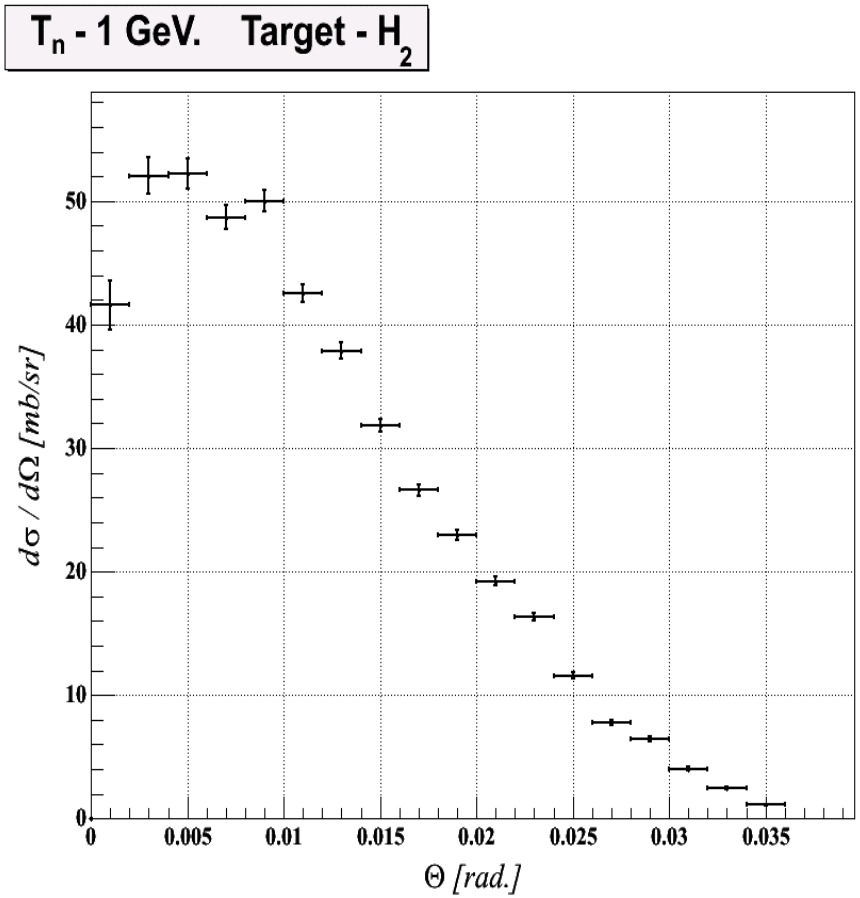
The differential cross-section was calculated with the following formula:

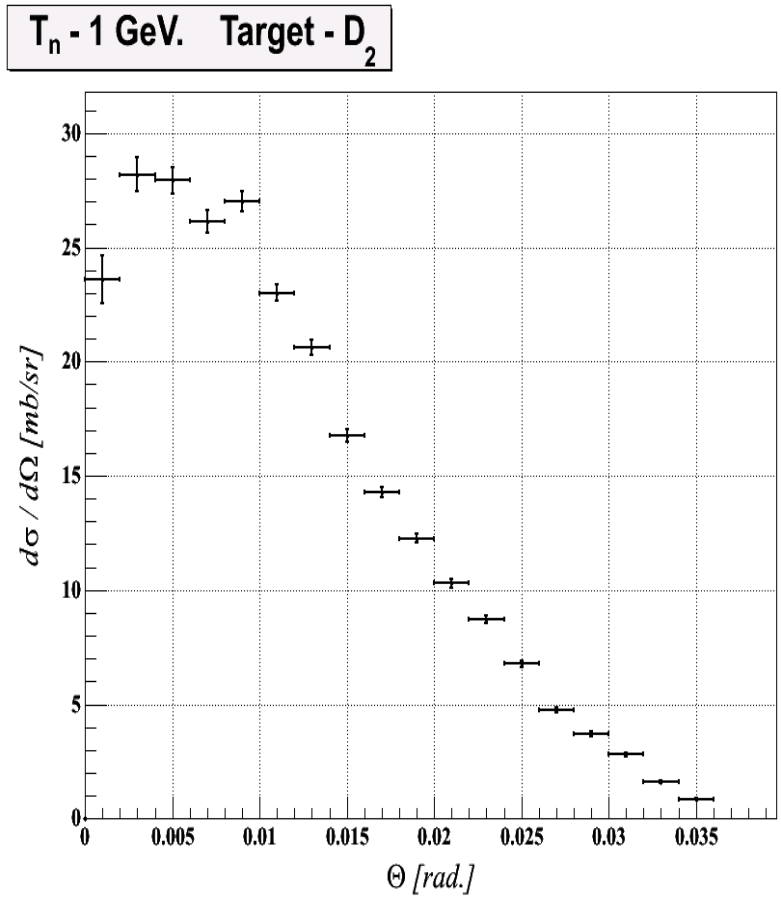
$$\frac{d\sigma}{d\Omega} = \frac{N_{events}}{(M/\varepsilon_M)\,\sin\theta\,\Delta\theta\,\Delta\varphi\,\varepsilon_{SP}\,n_{NUCL}},$$

where:

- N_{events} — **number of events in the elastic peak**
- M/ε_M — **monitor counts and efficiency of neutron monitor**
- ε_{SP} — **efficiency of the spectrometer**
- n_{NUCL} — **number of H / D in the target.**

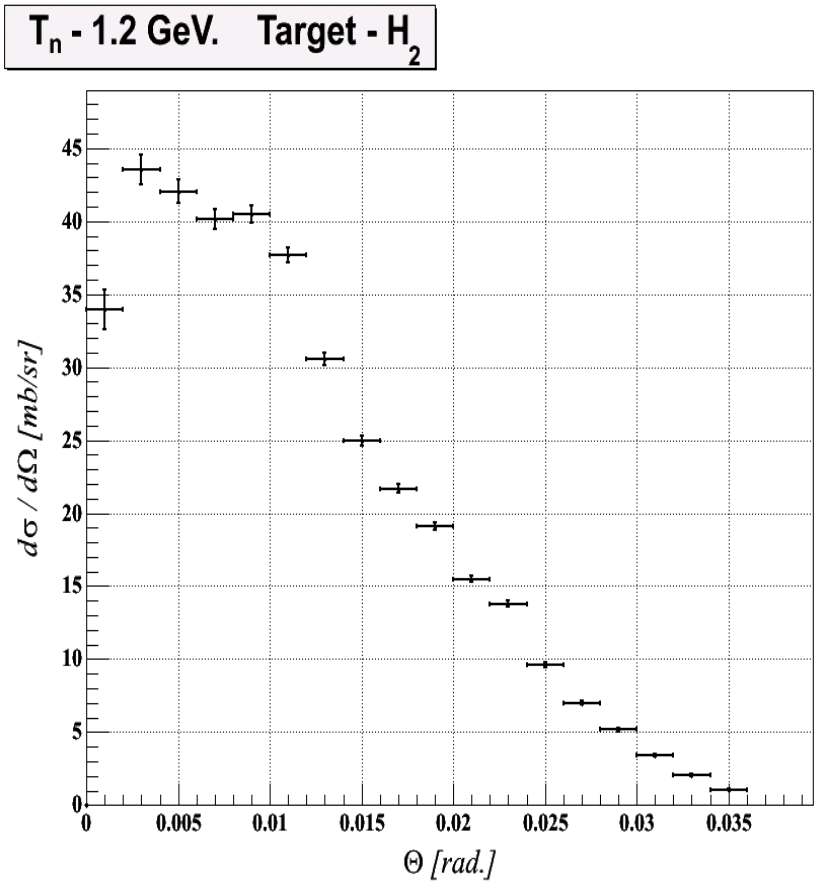
Angular dependence of differential cross section of the np→pn process near 0°, obtained with H_2 and D_2 targets at T_n = 1.0 GeV. (*estimation*)

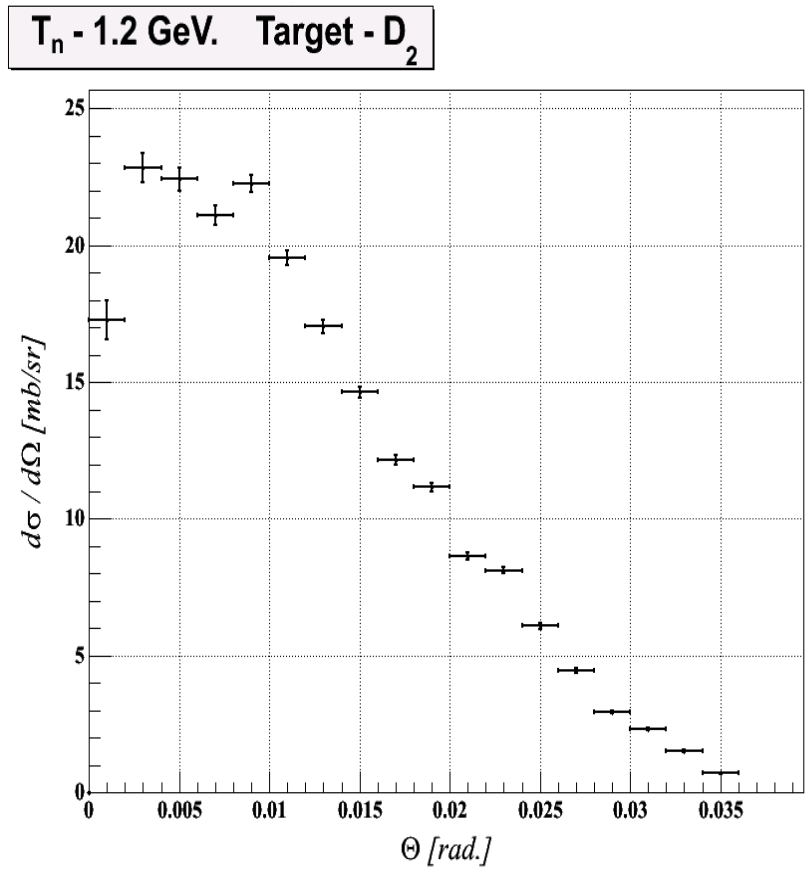




dσ/dΩ(0) ≈ 53.3 ±1.8 mb/sr (H_2) *estimation*

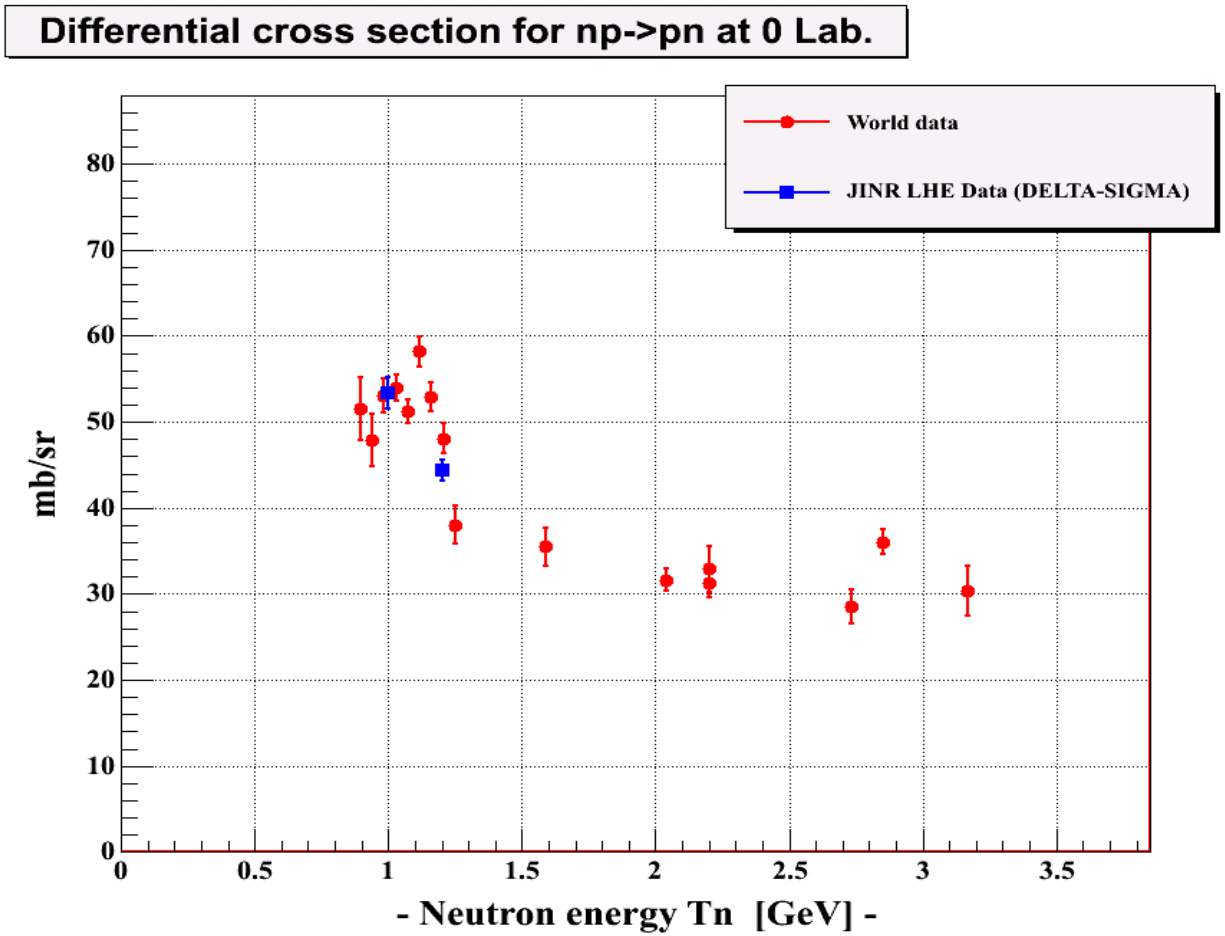
Angular dependence of differential cross section of the np→pn process near 0°, obtained with H_2 and D_2 targets at T_n = 1.2 GeV. (*estimation*)





$d\sigma/d\Omega(0) \approx 44.4 \pm 1.2$ mb/sr (H_2) *estimation*

Differential cross section for *np→pn* at 0° Lab



G. Bizard, F. Bonthonneau, J.L. Laville et al.: Nucl.Phys. B 85 (1975) 14.
G. Bizard, F. Bonthonneau, J.L. Laville et al.: Nucl.Phys. B 108 (1976) 189.

The ratio R_{dp} calculation.

- **The ratio R_{dp} was calculated with the following formula:**

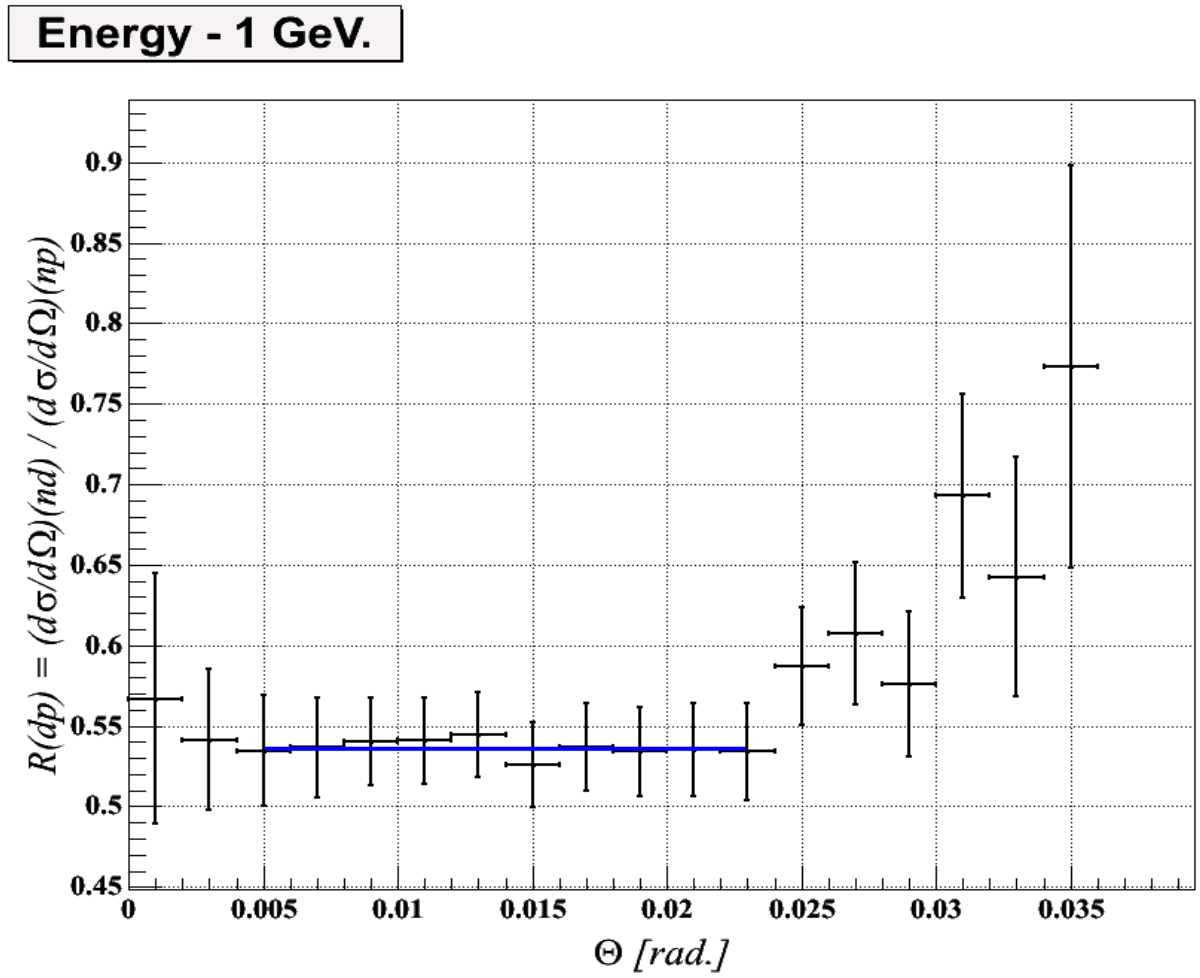
$$R_{dp} = \frac{d\sigma/d\Omega(nd)}{d\sigma/d\Omega(np)}$$

Where:

dσ/dΩ(nd) **– differential cross-section of the quasi-elastic charge-exchange** ***nd→pnn*** **reaction,**

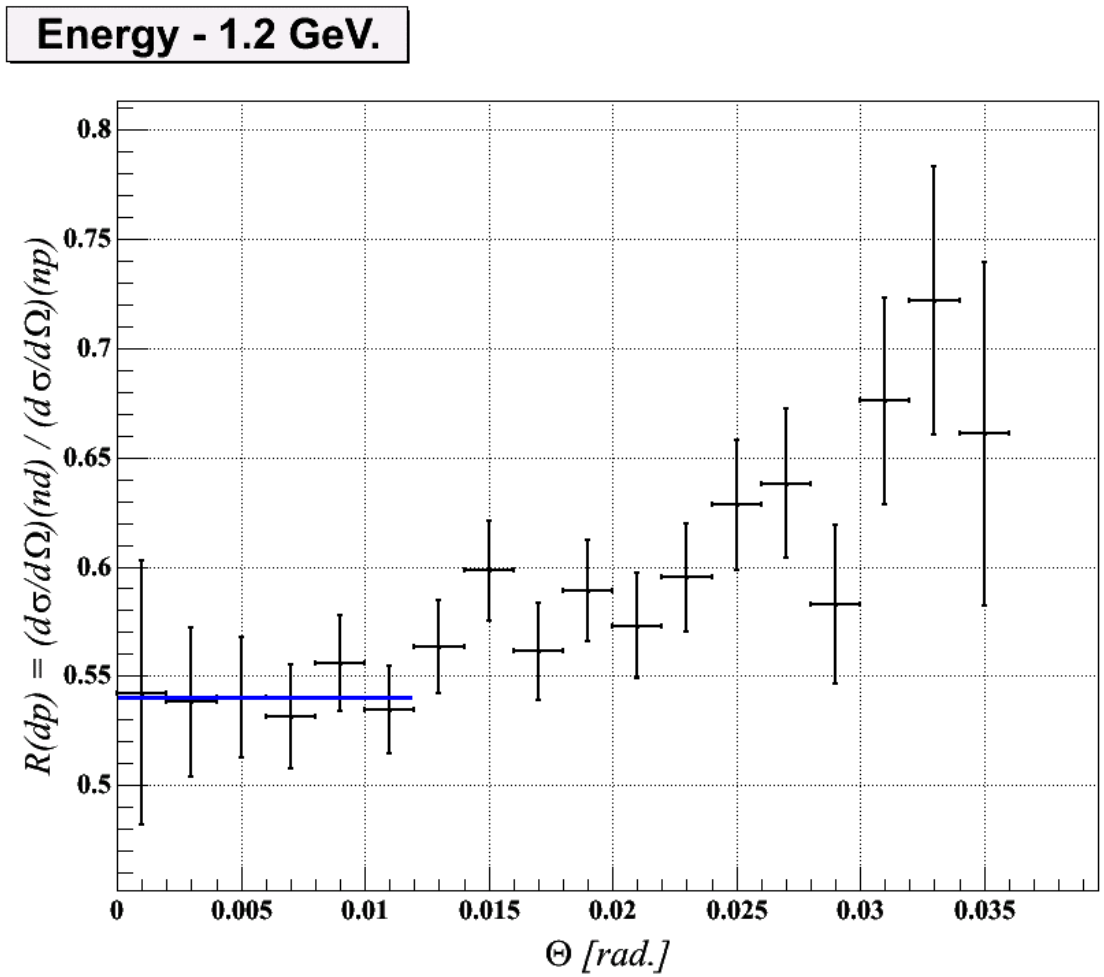
dσ/dΩ(np) **– differential cross-section of the elastic charge-exchange** ***np→pn*** **reaction.**

The ratio R_{dp} T_n =1 GeV.



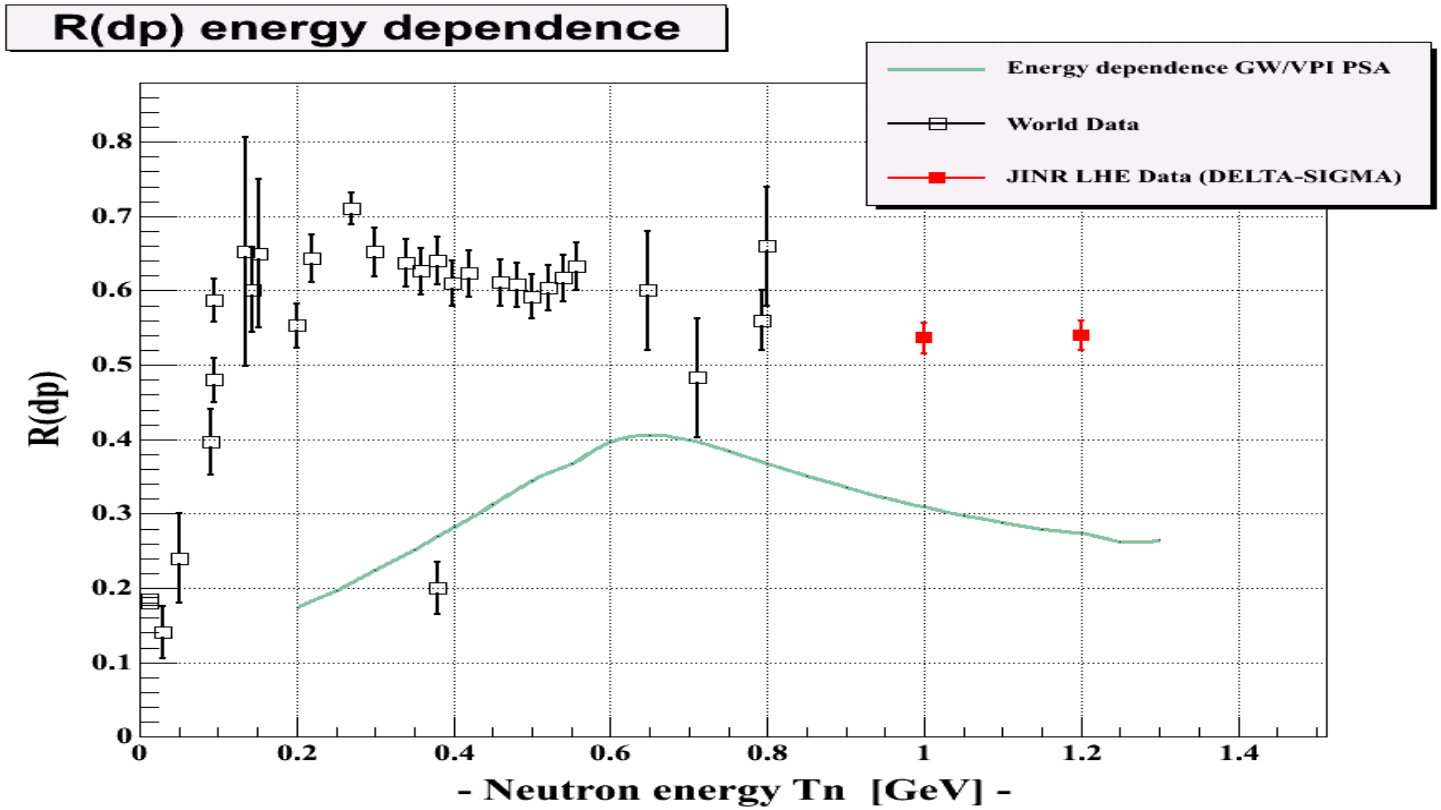
The ratio $R_{dp}(0)$ was obtained by the extrapolation of the direct line approximating of experimental $R_{dp}(\theta)$ data (with $\chi \approx 0.5$) $R_{dp}(0)=0.536 \pm 0.01$

The ratio R_{dp} T_n =1.2 GeV.



The ratio $R_{dp}(0)$ was obtained by the extrapolation of the direct line approximating of experimental $R_{dp}(\theta)$ data (with $\chi \approx 0.5$) $R_{dp}(0)=0.54 \pm 0.01$

Energy dependence of the ratio R_{dp}



Tn GeV	Pn GeV/c	Rdp	Stat. Error	Syst. error	Total error
1	1.69	0.536	0.01	0.012	0.015
1.2	1.92	0.54	0.01	0.013	0.016

Conclusion

1. The results of measurements of the ratio $R_{dp}=d\sigma/d\Omega(np) / d\sigma/d\Omega(nd)$ at 0° were obtained at the first time at Tn ≥1 GeV.

$R_{dp}(0)=0.536\pm 0.015$ (Tn = 1 GeV)
$R_{dp}(0)=0.540\pm 0.016$ (Tn = 1.2 GeV)

2. The values of the rations of non spin-flip to spin-flip contributions in *np→pn* charge-exchange reaction at 0°:

$$R^{ID} = \frac{2}{3\,R_{dp}(0)} - 1\,, \qquad (4)$$

were obtained at the first time at Tn≥1 GeV.

$R^{ID} \approx 0.25\pm0.03$ (at Tn = 1.0 GeV.)
$R^{ID} \approx 0.25\pm0.03$ (at Tn = 1.2 GeV.)