Separation of *Flip* and *Non-Flip* parts of ***np***→***pn*** (0º) Charge Exchange reaction at energies 0.55 – 2.0 GeV

R.A. Shindin

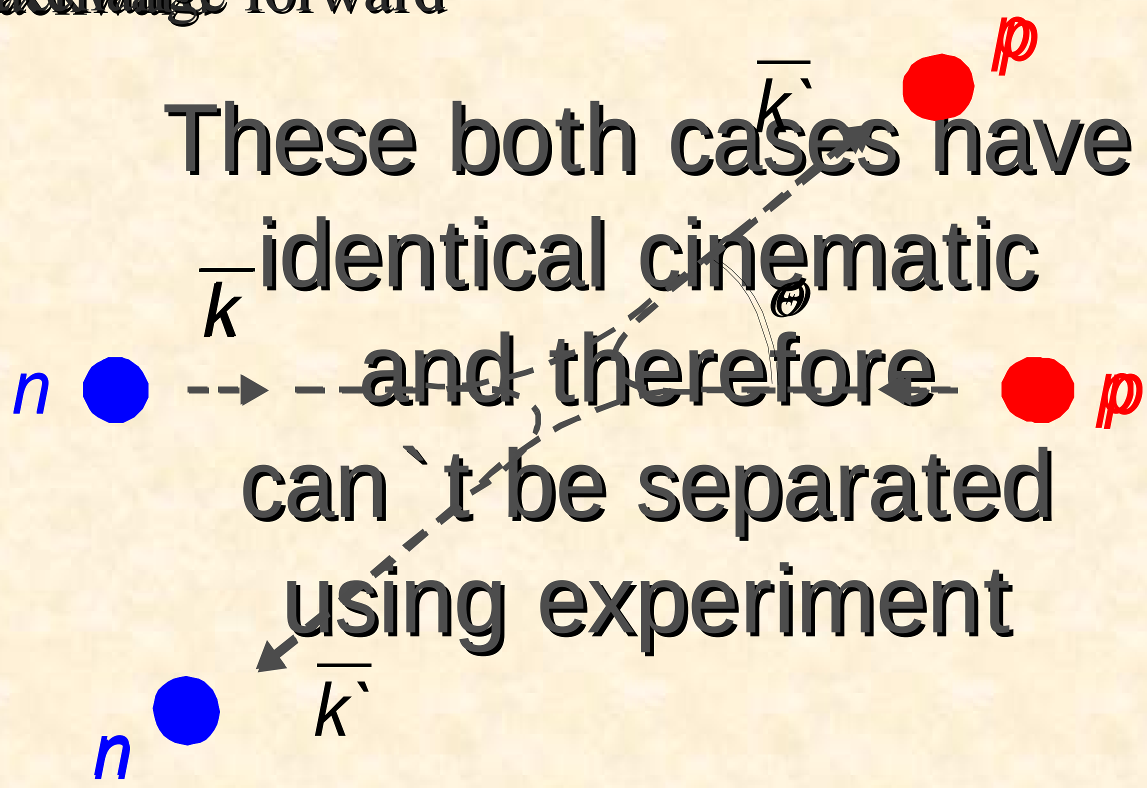
- *NN* formalism and Charge Exchange process
- ***R****dp* measurements and tools
- *Dean* formula and *Luboshitz* remark
- *Goldberger-Watson* amplitudes and
  the *Flip* and *Non-Flip* parts of *np*-elastic scattering
- Delta-Sigma experimental data of the ratio ***R****dp* at 0°,
  respective values of the ratio $r^{nf/fl}$ and
  good agreement with the Phase Shift Analysis

np interaction in the c.m.s.

$$-t = P^2_{CM} \cdot 4\sin^2\Theta/2$$

Charge Exchange forward

Elastic backward



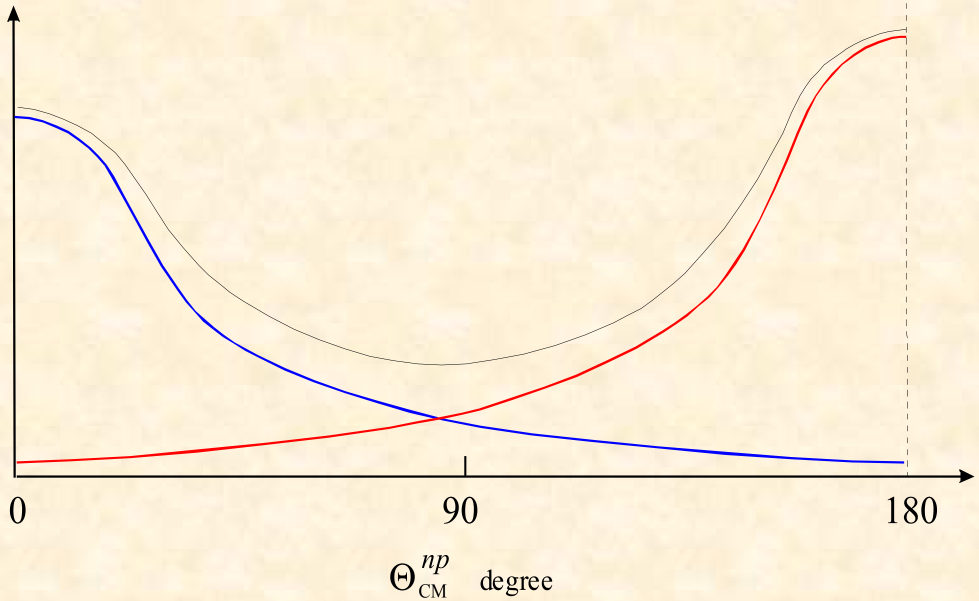
These both cases have identical cinematic and therefore can`t be separated using experiment

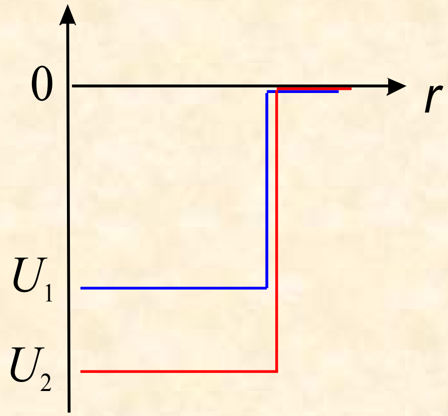
$$-t = P^2_{CM} \cdot (1 - 4\sin^2\Theta/2)$$

Born approach

$$\sigma(\theta) = \left|\int e^{-i\mathbf{k}_f\mathbf{r}} U e^{i\mathbf{k}_i\mathbf{r}} d\tau\right|^2$$

$$U = U_1 + U_2 \cdot P_{12}$$





$$\sigma(\theta) = \left|\int e^{-i(\mathbf{k}_f-\mathbf{k}_i)\mathbf{r}} U_1 d\tau + \int e^{-i(\mathbf{k}_f+\mathbf{k}_i)\mathbf{r}} U_2 d\tau\right|^2$$

Enrico Fermi, in book Yadernaya Fizika 1951

General view of the NN scattering matrix

$$M(k',k) = M_0(k',k)\frac{1-(\tau_1\tau_2)}{4} + M_1(k',k)\frac{3+(\tau_1\tau_2)}{4}$$

If both nucleons are identical then $\langle pp|M|pp\rangle = \langle nn|M|nn\rangle = M_1$

For the np elastic scattering we have $\langle np|M|np\rangle = \langle pn|M|pn\rangle = \frac{1}{2}(M_1+M_0)$

For the Charge Exchange $\langle np|M|pn\rangle = \langle pn|M|np\rangle = \frac{1}{2}(M_1-M_0)$

1964 г. Октябрь — Т. LXXXIV, вып. 2

УСПЕХИ ФИЗИЧЕСКИХ НАУК

539.12

ПОЛЯРИЗОВАННАЯ ПРОТОННАЯ МИШЕНЬ В ОПЫТАХ С ЧАСТИЦАМИ ВЫСОКИХ ЭНЕРГИЙ

С. М. Биленький, Л. И. Лапидус, Р. М. Рындин

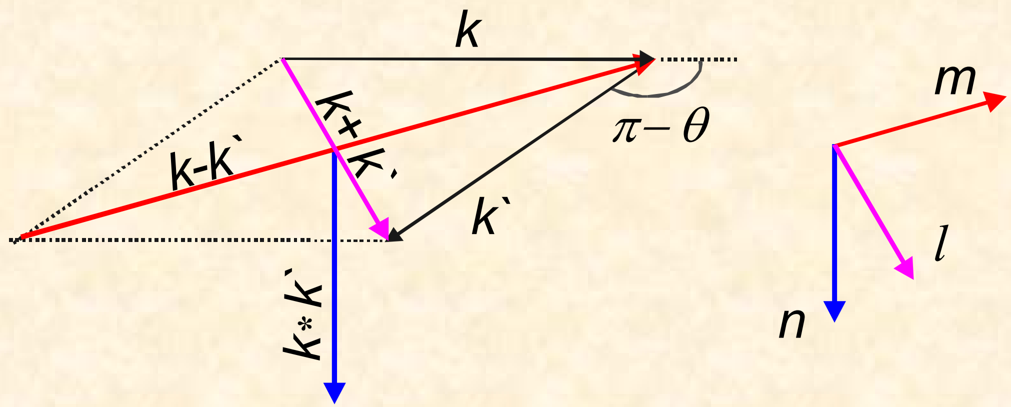
СОДЕРЖАНИЕ

$$M_T^{np-np}(k',k) = B_T\bar{S} + \left\{ \begin{array}{l} C_T\left[(\sigma_1 n)+(\sigma_2 n)\right] \\ \frac{1}{2}G_T\left[(\sigma_1 m)(\sigma_2 m)+(\sigma_1 l)(\sigma_2 l)\right] \\ \frac{1}{2}H_T\left[(\sigma_1 m)(\sigma_2 m)-(\sigma_1 l)(\sigma_2 l)\right] \\ N_T(\sigma_1 n)(\sigma_2 n) \end{array} \right\} \bar{T}$$

$$\bar{S} = \frac{1}{4}\left(1-(\sigma_1\sigma_2)\right)$$

$$\bar{T} = \frac{1}{4}\left(3+(\sigma_1\sigma_2)\right)$$

$$n = \frac{k\times k'}{|k\times k'|}, \quad m = \frac{k-k'}{|k-k'|}, \quad l = \frac{k+k'}{|k+k'|}$$



According to the antisymmetry of two fermions wave function relative to the total permutation, including permutation of scattering vector ($k` \to -k`$), permutation of spin and isotopic-spin ($n \leftrightarrow p$), we define

$$P_{1,2}(\sigma) \cdot P_{1,2}(\tau) \cdot \Psi(k', k) = -\Psi(-k', k)$$

$$P_{1,2}(\sigma) = \frac{1}{2}(1 + \sigma_1 \sigma_2) \qquad P_{1,2}(\tau) = \frac{1}{2}(1 + \tau_1 \tau_2)$$

$$-P_{1,2}(\sigma) \cdot \Psi(k'_n, k) = \Psi(-k'_p, k)$$

$$-P_{1,2}(\sigma) \cdot M^{\mathbf{np-np}}(k', k) = M^{\mathbf{np-pn}}(-k', k)$$

Charge-Exchange **np→pn**(θ)

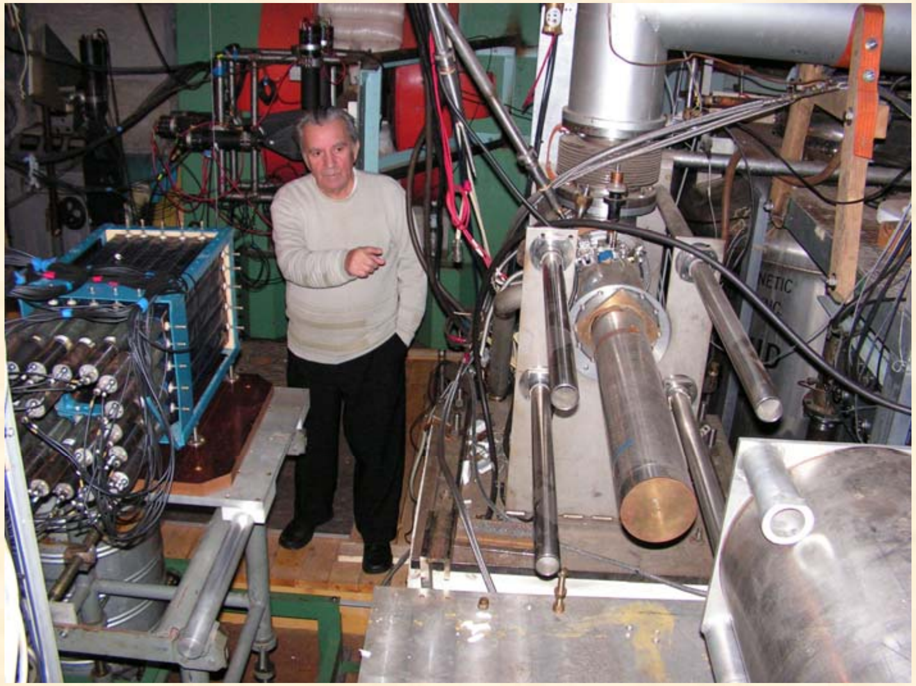
$$M_T^{np-pn}(-k',k) = B_T\bar{S} - \left\{ \begin{array}{l} C_T\left[(\sigma_1 n)+(\sigma_2 n)\right] \\ \frac{1}{2}G_T\left[(\sigma_1 m)(\sigma_2 m)+(\sigma_1 l)(\sigma_2 l)\right] \\ \frac{1}{2}H_T\left[(\sigma_1 m)(\sigma_2 m)-(\sigma_1 l)(\sigma_2 l)\right] \\ N_T(\sigma_1 n)(\sigma_2 n) \end{array} \right\} \bar{T}$$

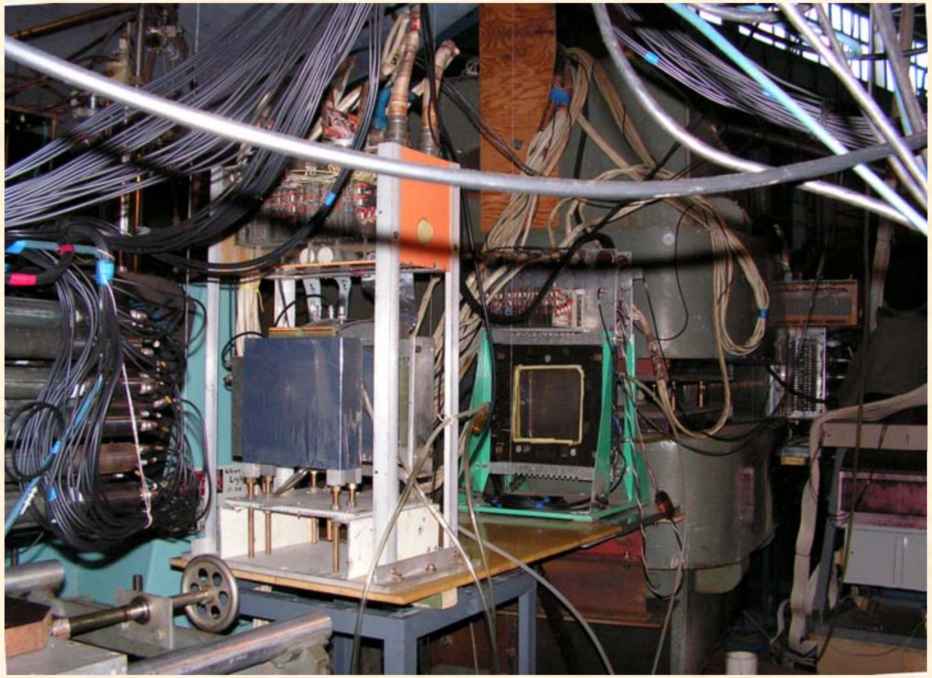
$$M^{np-np}(k',k) = SS + ST \qquad M^{np-pn}(-k',k) = SS - ST$$

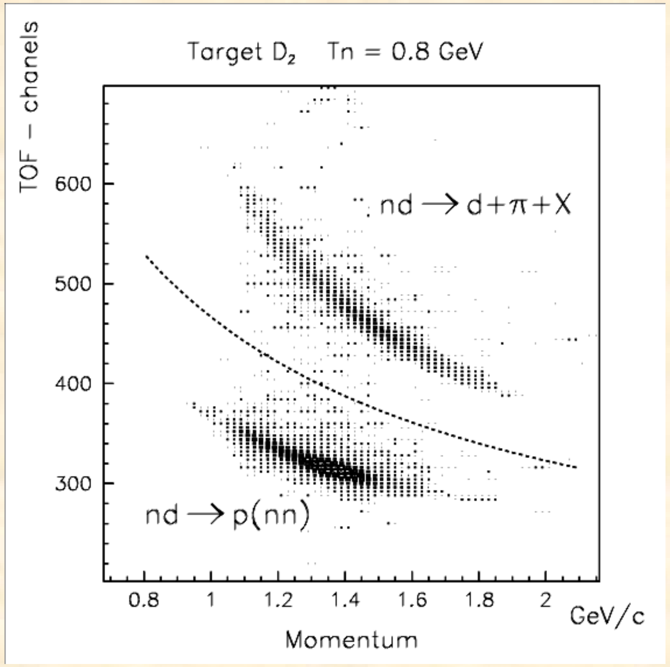
$$\frac{d\sigma}{dt}\left(\mathbf{np} \to \mathbf{np}(\pi-\theta)\right) = \frac{d\sigma}{dt}\left(\mathbf{np} \to \mathbf{pn}(\theta)\right)$$

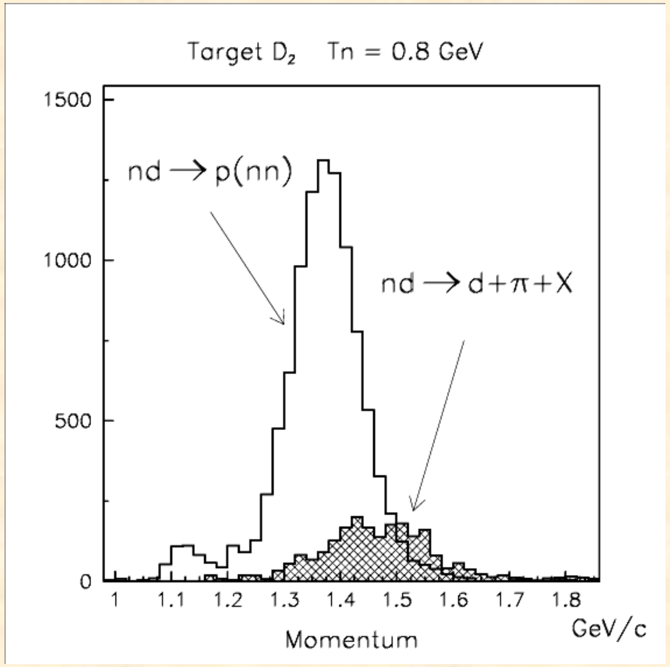
*R*dp measurements and tools

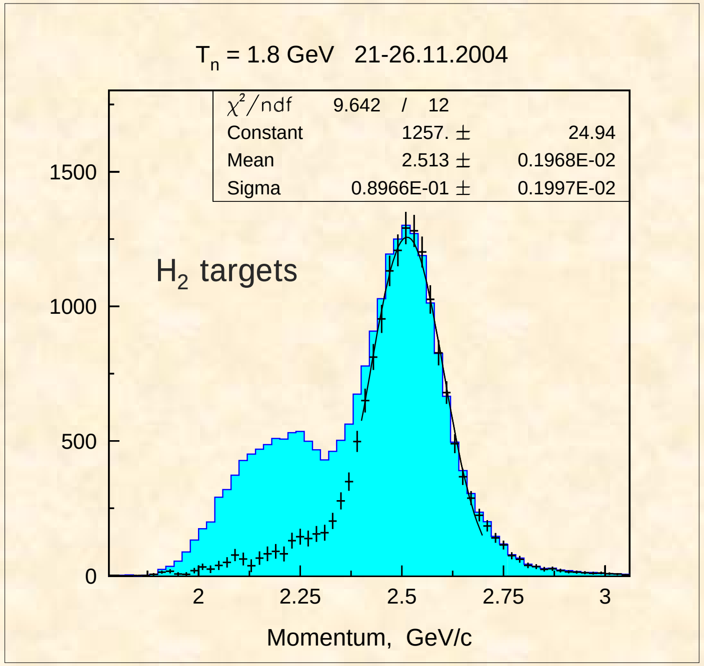
The Delta-Sigma experiment intends to obtain a complete *np* data set at the zero angle: the measurements of total cross section differences $\Delta\sigma_L$ (*np*) and $\Delta\sigma_T$(*np*), spin-correlation parameters A_{00kk}(*np*) and A_{00nn}(*np*) as well as unpolarized measurements of values σ_{tot}(*np*), $d\sigma/dt(np \rightarrow pn)$. For the Direct Reconstruction of the *Re* parts of the Scattering Amplitudes we measure also the ratio *R*dp = $d\sigma/dt(nd)$ / $d\sigma/dt(np)$ for the charge exchange quasi-elastic and elastic processes at 0° using the D2 and H2 targets. It will allow one of some sign uncertainties to be eliminated.

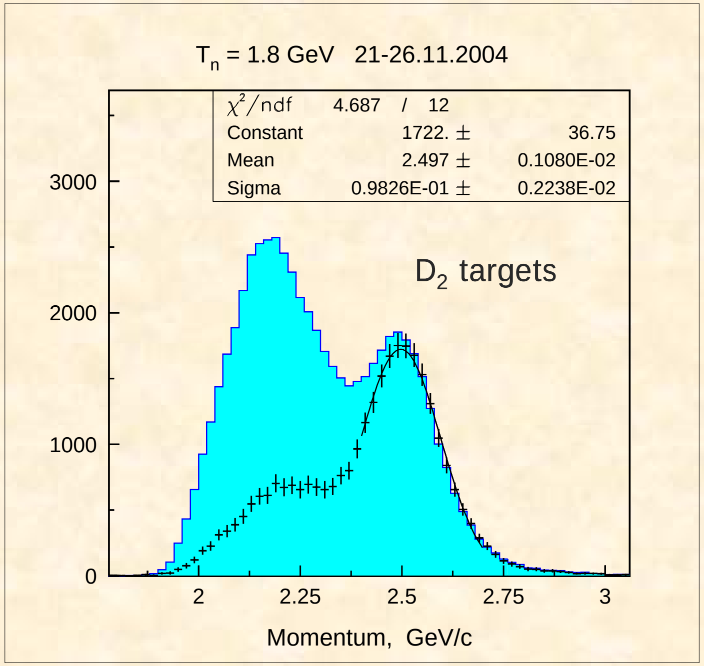





Target D$_2$ Tn = 0.8 GeV
TOF – chanels
600
500
400
300
nd → d+π+X
nd → p(nn)
0.8
1
1.2
1.4
1.6
1.8
2
GeV/c
Momentum


Target D$_2$ Tn = 0.8 GeV
1500
1000
500
0
nd → p(nn)
nd → d+π+X
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
GeV/c
Momentum


T$_n$ = 1.8 GeV 21-26.11.2004
χ²/ndf 9.642 / 12
Constant 1257. ± 24.94
Mean 2.513 ± 0.1968E-02
Sigma 0.8966E-01 ± 0.1997E-02
H$_2$ targets
1500
1000
500
0
2
2.25
2.5
2.75
3
Momentum, GeV/c


T$_n$ = 1.8 GeV 21-26.11.2004
χ²/ndf 4.687 / 12
Constant 1722. ± 36.75
Mean 2.497 ± 0.1080E-02
Sigma 0.9826E-01 ± 0.2238E-02
D$_2$ targets
3000
2000
1000
0
2
2.25
2.5
2.75
3
Momentum, GeV/c

Dean formula

Using the impulse approximation the differential cross section of $nd \rightarrow p(nn)$ reaction can be expressed by the *Flip* and *Non-Flip* contributions of charge exchange $np \rightarrow pn$ process:

$$\frac{d\sigma}{dt}_{nd \rightarrow p(nn)} = \left(1 - F(t)\right)\frac{d\sigma}{dt}^{Non\text{-}Flip}_{np \rightarrow pn} + \left(1 - \frac{1}{3}F(t)\right)\frac{d\sigma}{dt}^{Flip}_{np \rightarrow pn}$$

$$\lim_{t \rightarrow 0} F(t) = 1 \quad \Rightarrow \quad \frac{d\sigma}{dt}_{nd \rightarrow p(nn)} = \frac{2}{3} \cdot \frac{d\sigma}{dt}^{Flip}_{np \rightarrow pn}$$

$$\boldsymbol{R}_{\mathrm{dp}} = \frac{\frac{d\sigma}{dt}\left(nd \rightarrow p(nn)\right)}{\frac{d\sigma}{dt}(np \rightarrow pn)} = \frac{2}{3} \cdot \frac{1}{1 + \boldsymbol{r}^{\mathrm{nfl/fl}}}$$

N.W. Dean: Phys. Rev D 5 1661; Phys. Rev D 5 2832

Measurement of neutron-proton spin obsevables at 0°
using highest energy polarized d, n probes

The citation from Dean

"Then one obtains

$$\frac{d\sigma}{d\Omega}(ad \rightarrow bpp) = \left(1 - S(\vec{\Delta})\right)\frac{d\sigma_{nf}}{d\Omega} + \left(1 - \frac{1}{3}S(\vec{\Delta})\right)\frac{d\sigma_{fl}}{d\Omega}$$

Which is simply a generalization of the result found originally for $K^{+}d \rightarrow K^{0}pp$ by Lee.

For the non-charge-exchange r... however, no such simple result ...

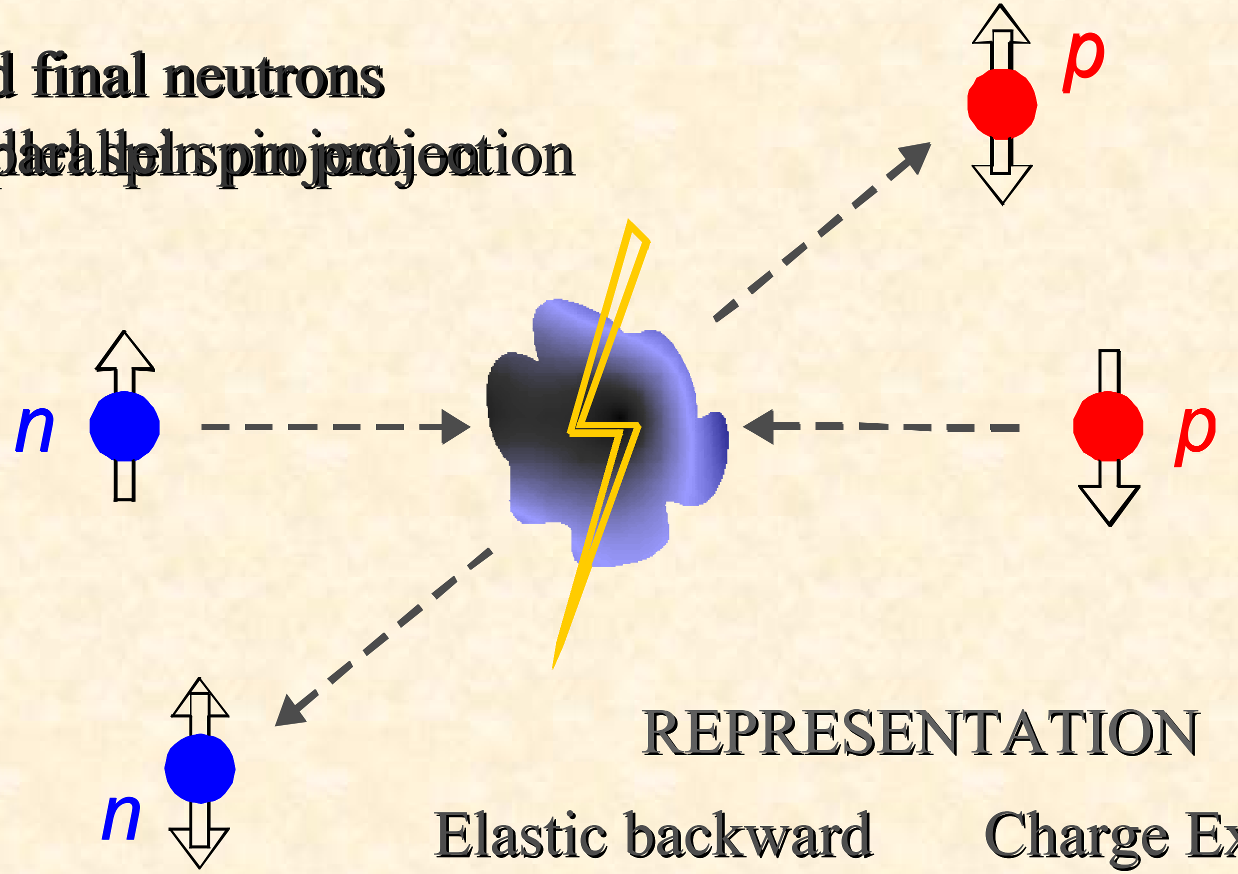
wrong approach which used amplitudes of np-np(180)

N.W. Dean, Phys. Rev. D 5 (1972) 2832-2835

Neutron beam energy

Spin Singlet interaction S = 0

Initial and final neutrons
have antiparallel spin projection / **have parallel spin projection**



REPRESENTATION

Elastic backward	Charge Exchange
Spin-Flip / ***Non-Flip***	***Spin-Flip*** / ***No Spin-Flip***

Goldberger-Watson amplitudes representation

$$M\left(k',k\right) = a + b\left(\sigma_n^{(1)}\sigma_n^{(2)}\right) + c\left(\sigma_n^{(1)} + \sigma_n^{(2)}\right) + e\left(\sigma_m^{(1)}\sigma_m^{(2)}\right) + f\left(\sigma_l^{(1)}\sigma_l^{(2)}\right)$$

$$\frac{d\sigma}{dt}^{Non\text{-}Flip} = |a|^2 \qquad \frac{d\sigma}{dt}^{Flip} = |b|^2 + 2|c|^2 + |e|^2 + |f|^2$$

$$a(\pi-\theta) = \frac{1}{4}(B+G+N) \qquad a^{CEX}(\theta) = \frac{1}{4}(B-G-N)$$

$$b(\pi-\theta) = \frac{1}{4}(3N-B-G) \qquad b^{CEX}(\theta) = \frac{1}{4}(G-B-3N)$$

$$c(\pi-\theta) = C \qquad c^{CEX}(\theta) = C$$

$$e(\pi-\theta) = \frac{1}{4}(G+2H-B-N) \qquad e^{CEX}(\theta) = \frac{1}{4}(N+2H-B-G)$$

$$f(\pi-\theta) = \frac{1}{4}(G-2H-B-N) \qquad f^{CEX}(\theta) = \frac{1}{4}(N-2H-B-G)$$

Directly unitary transition

$$a^{CEX} = -\frac{1}{2}(a+b+e+f) \qquad a = -\frac{1}{2}\left(a^{CEX}+b^{CEX}+e^{CEX}+f^{CEX}\right)$$

$$b^{CEX} = -\frac{1}{2}(a+b-e-f) \qquad b = -\frac{1}{2}\left(a^{CEX}+b^{CEX}-e^{CEX}-f^{CEX}\right)$$

$$c^{CEX} = c \qquad c = c^{CEX}$$

$$e^{CEX} = -\frac{1}{2}(a-b-e+f) \qquad e = -\frac{1}{2}\left(a^{CEX}-b^{CEX}-e^{CEX}+f^{CEX}\right)$$

$$f^{CEX} = -\frac{1}{2}(a-b+e-f) \qquad f = -\frac{1}{2}\left(a^{CEX}-b^{CEX}+e^{CEX}-f^{CEX}\right)$$

If scattering angle θ equal 0°, then:

$$c = c^{CEX} = 0 \qquad b = f \qquad b^{CEX} = e^{CEX}$$

If to use now the next labels:

$$c_1 = a_T^{CEX} \qquad \tilde{c}_1 = a_T$$

$$c_2 = b_T^{CEX} = e_T^{CEX} \qquad \tilde{c}_2 = b_T = f_T$$

$$c_3 = f_T^{CEX} \qquad \tilde{c}_3 = e_T$$

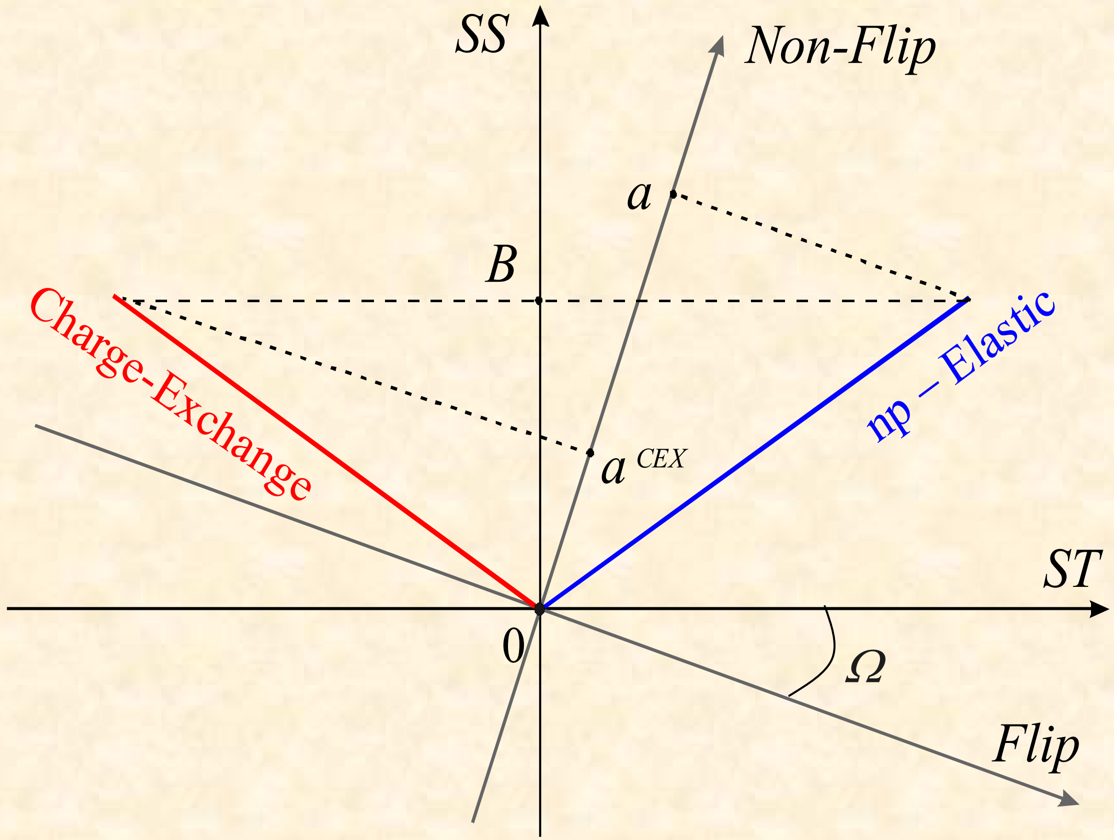
Then we obtain the formulas:

$$c_1 = -\frac{1}{2}\left(\tilde{c}_1 + 2\tilde{c}_2 + \tilde{c}_3\right) \qquad \tilde{c}_1 = -\frac{1}{2}\left(c_1 + 2c_2 + c_3\right)$$

$$c_2 = -\frac{1}{2}\left(\tilde{c}_1 - \tilde{c}_3\right) \qquad \tilde{c}_2 = -\frac{1}{2}\left(c_1 - c_3\right)$$

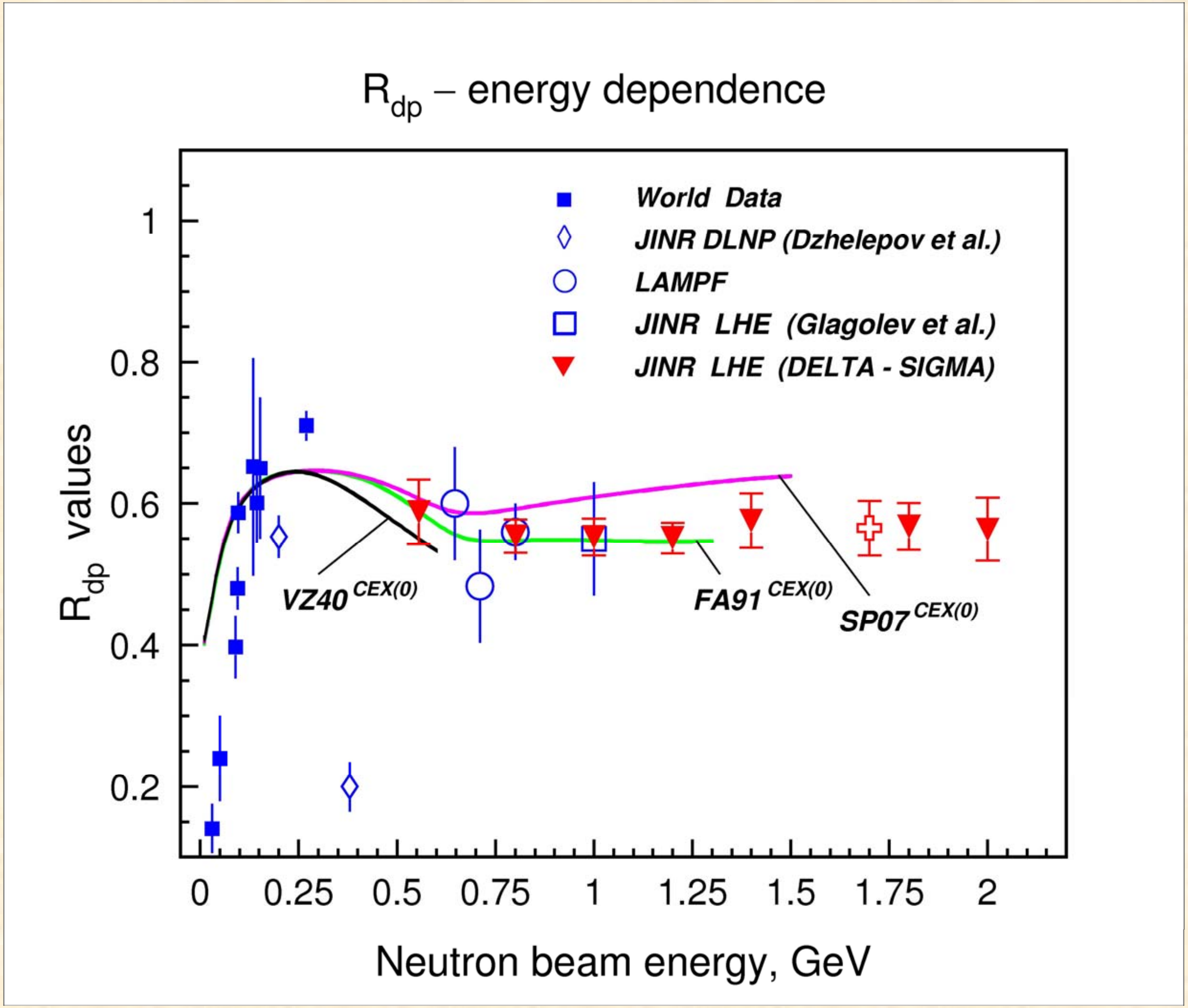
$$c_3 = -\frac{1}{2}\left(\tilde{c}_1 - 2\tilde{c}_2 + \tilde{c}_3\right) \qquad \tilde{c}_3 = -\frac{1}{2}\left(c_1 - 2c_2 + c_3\right)$$

V.L.Luboshitz, V.V.Luboshitz: in *Proceedengs of the XIV International Seminar on Interaction of Neuterons with Nuclei,* Dubna (2007) E3-2007-23, p.64-74.



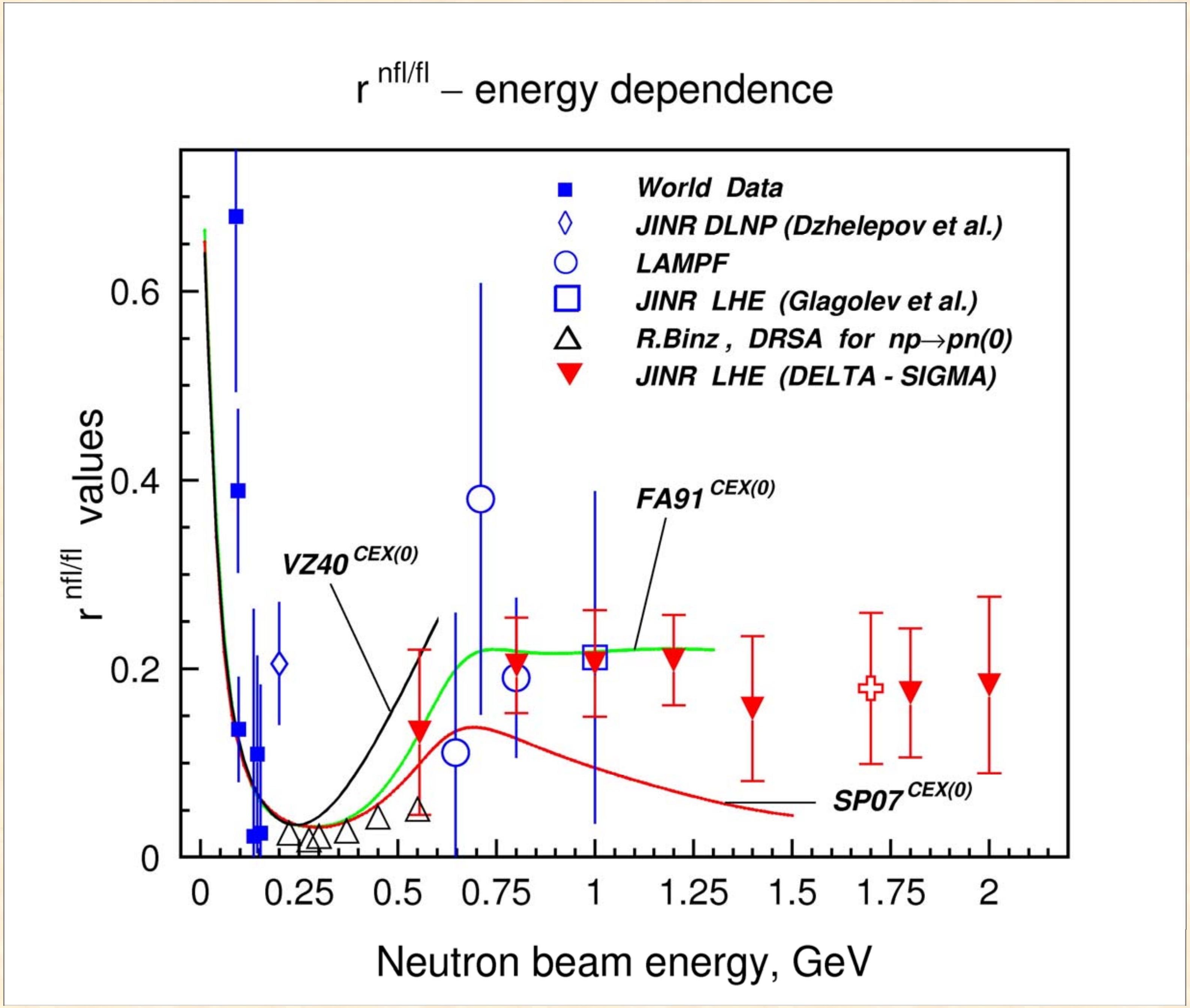
If the amplitudes ***a*** and ***a***^{CEX} are identical then the *Non-Flip* equals to the *SS* amplitude

*R*dp



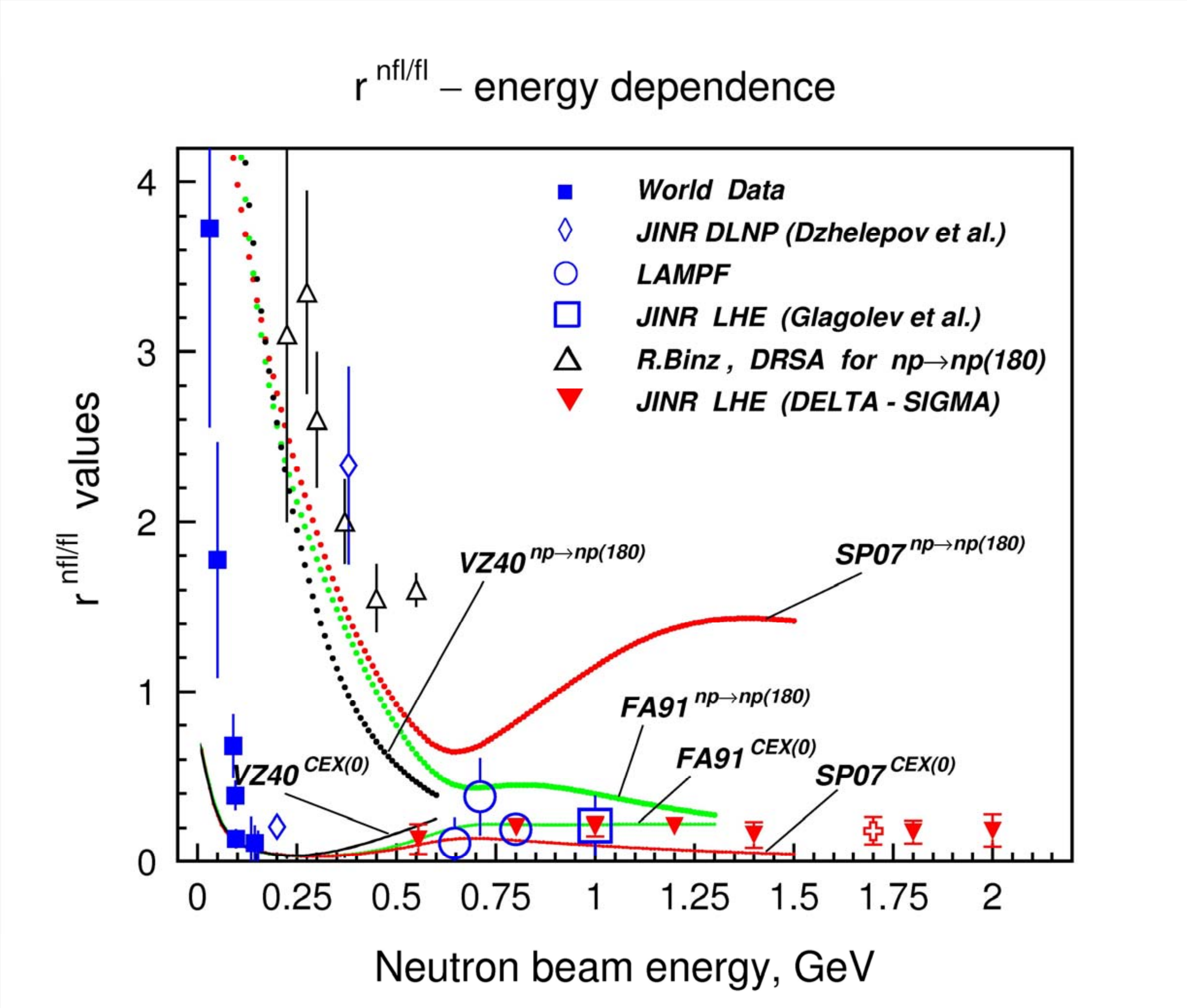
R_dp – energy dependence
World Data
JINR DLNP (Dzhelepov et al.)
LAMPF
JINR LHE (Glagolev et al.)
JINR LHE (DELTA - SIGMA)
VZ40 CEX(0)
FA91 CEX(0)
SP07 CEX(0)
R_dp values
Neutron beam energy, GeV
1
0.8
0.6
0.4
0.2
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2

$r^{nfl/fl}$



r nfl/fl – energy dependence
World Data
JINR DLNP (Dzhelepov et al.)
LAMPF
JINR LHE (Glagolev et al.)
R.Binz , DRSA for np→pn(0)
JINR LHE (DELTA - SIGMA)
FA91 CEX(0)
VZ40 CEX(0)
SP07 CEX(0)
r nfl/fl values
0.6
0.4
0.2
0
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
Neutron beam energy, GeV

$r^{nfl/fl}$



r nfl/fl – energy dependence
World Data
JINR DLNP (Dzhelepov et al.)
LAMPF
JINR LHE (Glagolev et al.)
R.Binz , DRSA for np→np(180)
JINR LHE (DELTA - SIGMA)
VZ40 np→np(180)
SP07 np→np(180)
FA91 np→np(180)
FA91 CEX(0)
VZ40 CEX(0)
SP07 CEX(0)
r nfl/fl values
Neutron beam energy, GeV
0
1
2
3
4
0.25
0.5
0.75
1.25
1.5
1.75

CONCLUSION

- Using *Dean* formula and the values of $\boldsymbol{R_{dp}}$ ratio we define the ratio $\boldsymbol{r}^{nfl/fl}$ and separate ***Flip*** & ***Non-Flip*** parts of *np–pn Charge Exchange* forward process
- Good agreement with *PSA* solution have been obtain due to the unitary transformation
- Consistency between the theory and experimental data show that the ratios $\boldsymbol{R_{dp}}$ and $\boldsymbol{r}^{nfl/fl}$ is a good observables and it will be used as an additional constraint for DRSA method