

Complementary studies on N^* from e^+e^- , pp and $p\bar{p}$ collisions*

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Abstract Complementary to the conventional experimental studies on N^* from πN and $\gamma^{(*)}N$ reactions, the e^+e^- , pp and $p\bar{p}$ collisions can give novel insights into these N^* resonances. While the e^+e^- collisions through production and decay of vector charmonium ψ provide a nice isospin filter for a simultaneously study of N^* , Δ^* , Λ^* , Σ^* and Ξ^* , the pp collisions should be the best place for producing those Δ^{*++} with large coupling to ρ^+p though $pp \rightarrow n\Delta^{*++}$ reaction, and the $p\bar{p}$ collisions should be the best place for looking for those N^* with large coupling to σN .

Key words N^* resonances, e^+e^- collision, pp collision, $p\bar{p}$ collision

PACS 14.20.Gk, 13.66.Bc, 13.75.Cs

1 Introduction

There are two well-known problems for the classical 3q constituent quark models. The first one is the mass reverse problem for the lowest excited states. In the simple 3q constituent quark model, the lowest spatial excited baryon is expected to be a (uud) N^* state with one quark in orbital angular momentum $L=1$ state, and hence should have negative parity. Experimentally^[1], the lowest negative parity N^* resonance is found to be $N^*(1535)$, which is heavier than two other spatial excited baryons: $\Lambda^*(1405)$ and $N^*(1440)$. In the classical 3q constituent quark model, the $\Lambda^*(1405)$ with spin-parity $1/2^-$ is supposed to be a (uds) baryon with one quark in orbital angular momentum $L=1$ state and about 130 MeV heavier than its N^* partner $N^*(1535)$; the $N^*(1440)$ with spin-parity $1/2^+$ is supposed to be a (uud) state with one quark in radial $n=1$ excited state and should be heavier than the $L=1$ excited (uud) state $N^*(1535)$, noting the fact that for a simple harmonic oscillator potential the state energy is $(2n+L+3/2)\hbar\omega$. So for these three lowest spatial excited baryons, the classical quark model picture is already failed. The second problem is that in many

of its forms it predicts a substantial number of ‘missing N^* states’ around 2 GeV/ c^2 , which have not so far been observed^[2]. Since the more number of effective degrees of freedom the more predicted number of excited states, the ‘missing N^* states’ problem is argued in favor of the diquark picture which has less degree of freedom and predicts less N^* states^[3]. For example, in diquark models, the two quarks forming the diquark are constrained to be in the relative S -wave, and hence cannot combine the third quark to form $(20,1_2^+)$ -multiplet baryons. Experimentally, not a single $(20,1_2^+)$ -multiplet baryon has been identified yet^[1]. However, non-observation of these ‘missing N^* states’ does not necessarily mean that they do not exist. In the limit that the γ or π couples to one quark in the nucleon in the γN or πN reactions, the $(20,1_2^+)$ -multiplet baryon cannot be produced^[4]. Considering higher order effects, they may have weak coupling to πN and γN , but may be too weak to be observed by presently available πN and γN experiments^[2, 4].

To solve the mass order reverse problem, it seems necessary to go beyond the simple quenched 3q quark models. In fact the spatial excitation energy of a quark in a baryon is already comparable to pull a $q\bar{q}$ pair from the gluon field. Even for the proton, the

Received 7 August 2009

* Supported by National Natural Science Foundation of China (10875133, 10821063), Chinese Academy of Sciences (KJCX3-SYW-N2) and Ministry of Science and Technology of China (2009CB825200)

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well established \bar{d}/\bar{u} asymmetry with the number of \bar{d} more than \bar{u} by an amount $\bar{d} - \bar{u} \approx 0.12$ ^[5] demands its 5-quark components to be at least 12%. The 5-quark components can be either in the form of meson cloud, such as $n(\text{udd})\pi^+(\text{u}\bar{d})$, or in other forms of quark correlation, such as penta-quark configuration $[\text{ud}][\text{ud}]\bar{d}$ with $[\text{ud}]$ -diquark correlation. In either meson cloud model or penta-quark model, the mass order reverse problem of $N^*(1535)$ and $\Lambda^*(1405)$ can be easily explained. In the meson cloud models^[6, 7], the $N^*(1535)$ is explained as a $K\Lambda$ - $K\Sigma$ quasi-bound state while $\Lambda^*(1405)$ is a dynamically generated state of coupled KN - $\Sigma\pi$ channels. In the penta-quark models^[8–10], the $N^*(1535)$ is mainly a $[\text{ud}][\text{us}]\bar{s}$ state while $\Lambda^*(1405)$ is mainly a $[\text{ud}][\text{sq}]\bar{q}$ state with $q\bar{q} = (u\bar{u} + d\bar{d})/\sqrt{2}$.

These unquenched models give interesting predictions for the $SU(3)$ partners of the $\Lambda^*(1405)$ and $N^*(1535)$. For example, the penta-quark models^[9] predict a $\Sigma^*(1/2^-)$ resonance with a mass around $\Sigma^*(1385) - 3/2^+$ and a $\Xi^*(1/2^-)$ around $\Xi^*(1530) - 3/2^+$. These predicted states are still ‘missing’ from PDG list^[1]. However, possible evidence for their existence in J/ψ decays^[11] and $K^-p \rightarrow \Lambda\pi^+\pi^-$ reaction^[12] has recently been pointed out.

To look for these ‘missing’ baryon resonances to establish correct picture for the baryon structure, the scheduled high statistics γp and Kp experiments are necessary. Here we want to show that the e^+e^- , pp and $p\bar{p}$ collisions could also play unique complementary role and should be explored.

2 N^* from $e^+e^- \rightarrow \psi \rightarrow \bar{N}N^*$

The J/ψ and ψ' experiments at BES provide an excellent place for studying excited nucleons and hyperons – N^* , Λ^* , Σ^* and Ξ^* resonances^[13]. Comparing with other facilities, the BES baryon program has advantages in at least three obvious aspects:

(1) For the $c\bar{c} \rightarrow \bar{N}N\pi$ and $\bar{N}N\pi\pi$ processes, the πN and $\pi\pi N$ systems are expected to be dominantly isospin 1/2 due to that the isospin-conserving three-gluon annihilation of the constituent c -quarks dominates over the isospin violating decays via intermediate photon for the baryonic final states, while πN and $\pi\pi N$ systems from πN and γN experiments are mixture of isospin 1/2 and 3/2 with similar strengths, and hence suffer difficulty on the isospin decomposition;

(2) ψ mesons decay to baryon-antibaryon pairs through three or more gluons. It is a favorable place for producing hybrid (qqqg) baryons, and for looking

for some ‘missing’ N^* resonances, such as members of possible $(20, 1_2^+)$ -multiplet baryons, which have weak coupling to both πN and γN , but stronger coupling to $g^3 N$;

(3) Not only N^* , Λ^* , Σ^* baryons, but also Ξ^* baryons with two strange quarks can be studied. Many QCD-inspired models^[2] are expected to be more reliable for baryons with two strange quarks due to their heavier quark mass. More than thirty Ξ^* resonances are predicted where only two such states are well established by experiments. The theory is totally not challenged due to lack of data.

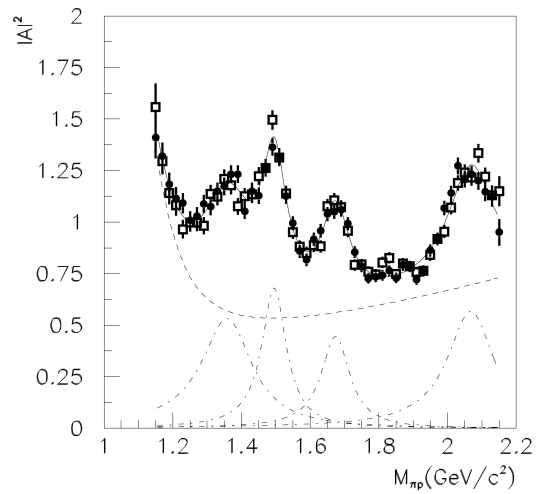


Fig. 1. Data divided by MC phase space vs $p\pi$ invariant mass for $J/\psi \rightarrow \bar{p}\pi^- \bar{n}$ (solid circle) and $\bar{p}\pi^+ n$ (open square) from Ref. [14].

A typical example showing the isospin and spin filter effect is given by the study of $J/\psi \rightarrow p\bar{n}\pi^- + \text{c.c.}$ channel^[14]. The data vs $p\pi$ invariant mass divided by Monte Carlo phase space including the detection efficiency are shown in Fig. 1. At low $p\pi$ invariant mass, the tail from nucleon pole term, expected from theoretical considerations^[15, 16], is clearly seen. There are clearly four peaks around 1360 MeV, 1500 MeV, 1670 MeV and 2065 MeV. Note that the well known first resonance peak ($\Delta(1232)$) in πN and γN scattering data does not show up here due to the isospin filter effect of the J/ψ decays. While the two peaks around 1500 MeV and 1670 MeV correspond to the well known second and third resonance peaks observed in πN and γN scattering data, the two peaks around 1360 MeV and 2065 MeV have never been observed in πN invariant mass spectra before. The one around 1360 MeV should be from $N^*(1440)$ which has a pole around 1360 MeV^[1, 17, 18] and which is usually buried by the strong Δ peak in πN and γN experiments; the other one around 2065 MeV may be due

to the long sought “missing” N^* resonance(s). For the decay $J/\psi \rightarrow \bar{N}N^*(2065)$, the orbital angular momentum of $L = 0$ is much preferred due to the suppression of the centrifugal barrier factor for $L \geq 1$. For $L = 0$, the spin-parity of $N^*(2065)$ is limited to be $1/2^+$ and $3/2^+$. This may be the reason that the $N^*(2065)$ shows up as a peak in J/ψ decays while only much broader structures show up for πN invariant mass spectra above 2 GeV in πN and γN production processes^[19] which allow all $1/2^\pm$, $3/2^\pm$, $5/2^\pm$ and $7/2^\pm$ N^* resonances around 2.05 GeV to overlap and interfere with each other there. A simple Breit-Wigner fit^[14] gives the mass and width for the $N^*(1440)$ peak as $1358 \pm 6 \pm 16$ MeV and $179 \pm 26 \pm 50$ MeV, consistent perfectly with the PDG pole value for the $N^*(1440)$, i.e., 1365 ± 15 MeV and 190 ± 30 MeV, respectively. For the new N^* peak above 2 GeV the fitted mass and width are $2068 \pm 3_{-40}^{+15}$ MeV and $165 \pm 14 \pm 40$ MeV, respectively. A partial wave analysis indicates that the $N^*(2065)$ peak contains both spin-parity $1/2^+$ and $3/2^+$ components^[14]. Very recently, a detailed partial wave analysis of the $J/\psi \rightarrow p\bar{p}\pi^0$ channel concludes besides a $1/2^+$ $N^*(2100)$ a $3/2^+$ N^* around 2040 MeV is needed to fit the data^[20].

The $p\bar{n}\pi^- + c.c.$ channel has also been studied from ψ' decays^[21]. The $N^*(1440)$ becomes the largest signal and there are obvious structures for $M_{N\pi} > 2$ GeV in the $N\pi$ invariant mass spectra as shown in Fig. 2. But due to low statistics at BES II, no conclusive information can be drawn for the N^* resonances with mass above 2 GeV.

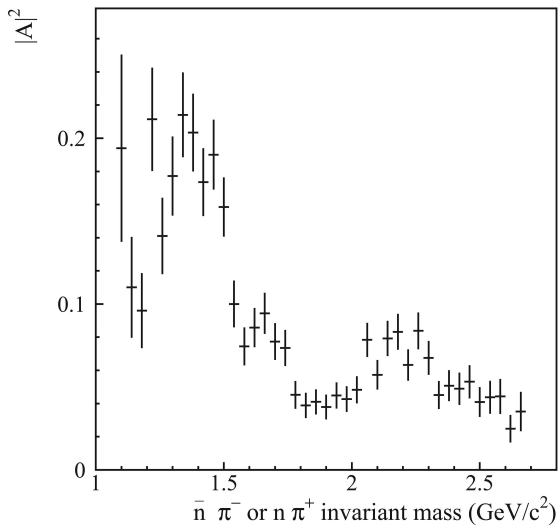


Fig. 2. Data divided by efficiency and phase space vs $\bar{n}\pi^-$ (or $n\pi^+$) invariant mass for $\psi' \rightarrow p\bar{n}\pi^- + c.c.$ from Ref. [21].

Another very interesting result comes from the study of $J/\psi \rightarrow \bar{p}p\eta$ and $J/\psi \rightarrow pK^-\bar{\Lambda} + c.c.$

channels on the $N^*(1535)$ resonance. In $J/\psi \rightarrow \bar{p}p\eta$, as expected, the $N^*(1535)$ gives the largest contribution^[22]. In $J/\psi \rightarrow pK^-\bar{\Lambda} + c.c.$, a strong near-threshold enhancement is observed for $K\Lambda$ invariant mass spectrum^[23] as duplicated in Fig. 3. The $K\Lambda$ threshold is 1609 MeV. The near-threshold enhancement is confirmed by $J/\psi \rightarrow nK_s\bar{\Lambda} + c.c.$ ^[24]. Since the mass spectrum divided by efficiency and phase space peaks at threshold, it is natural to assume it comes from the sub-threshold nearby $N^*(1535)$ resonance. Then from BES measured branching ratios of $J/\psi \rightarrow \bar{p}p\eta$ ^[22] and $\psi \rightarrow pK^-\bar{\Lambda} + c.c.$ ^[23], the ratio between effective coupling constants of $N^*(1535)$ to $K\Lambda$ and $N\eta$ is deduced to be around 1^[25]. Recently, by treating the peak as dynamically generated with unitary chiral theory, then the peak is a coherent effect of $N^*(1535)$ pole and background, and the ratio between effective coupling constants of $N^*(1535)$ to $K\Lambda$ and $N\eta$ is deduced to be around 0.6^[26].

With previous known value of $g_{N^*(1535)N\eta}$, the obtained new value of $g_{N^*(1535)K\Lambda}$ is shown to reproduce recent $pp \rightarrow pK^+\Lambda$ near-threshold cross section data^[27] as well. There are also indications for the large $g_{N^*(1535)K\Lambda}$ from partial wave analysis of $\gamma p \rightarrow K\Lambda$ reactions^[28], the large $g_{N^*(1535)N\eta'}$ coupling from $\gamma p \rightarrow p\eta'$ reaction at CLAS^[29] and from $pp \rightarrow pp\eta'$ reaction^[30], and large $g_{N^*(1535)N\phi}$ coupling from $\pi^- p \rightarrow n\phi$, $pp \rightarrow pp\phi$ and $pn \rightarrow d\phi$ reactions^[31, 32], but smaller coupling of $g_{N^*(1535)K\Sigma}$ from comparison of $pp \rightarrow pK^+\Lambda$ to $pp \rightarrow pK^+\Sigma^0$ ^[33].

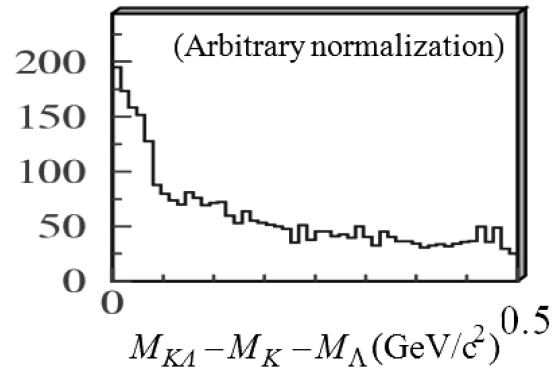


Fig. 3. Invariant mass spectrum divided by efficiency and phase space vs $M_{K\Lambda} - M_K - M_{\Lambda}$ for $J/\psi \rightarrow pK^-\bar{\Lambda} + c.c.$ from Ref. [23].

The observed decay pattern of the $N^*(1535)$ supports the picture that there is a large mixture of the $[[ud][us]\bar{s}]$ pentaquark component in the $N^*(1535)$. It not only gives a natural explanation of the mass reverse problem of the lowest excited states but also explains naturally its large couplings to the $N\eta$, $N\eta'$ and $K\Lambda$ meanwhile small couplings to the $N\pi$ and

$K\Sigma$. In the decay of the $[[ud][us]\bar{s}]$ pentaquark component, the $[ud]$ diquark with isospin $I = 0$ is stable and keeps unchanged while the $[us]$ diquark is broken to combine with the \bar{s} to form either $K^+(u\bar{s})\Lambda([ud]s)$ or $\eta(\bar{s}\bar{s})p([ud]u)$.

If this picture of large 5-quark mixture is correct, there should also exist the $SU(3)$ nonet partners of the $N^*(1535)$ and $\Lambda^*(1405)$, i.e., an additional $\Lambda^* 1/2^-$ around 1570 MeV, a triplet $\Sigma^* 1/2^-$ around 1360 MeV and a doublet $\Xi^* 1/2^-$ around 1520 MeV^[9]. There is no hint for these baryon resonances in the PDG tables^[1]. However, as pointed out in Ref. [11], there is in fact evidence for all of them in the data of J/ψ decays. According to PDG^[1], the branching ratios for $J/\psi \rightarrow \bar{\Sigma}^-\Sigma^*(1385)^+$ and $J/\psi \rightarrow \bar{\Xi}^+\Xi^*(1530)^-$ are $(3.1 \pm 0.5) \times 10^{-4}$ and $(5.9 \pm 1.5) \times 10^{-4}$, respectively. These two processes are $SU(3)$ breaking decays since Σ and Ξ belong to $SU(3)$ $1/2^+$ octet while $\Sigma^*(1385)$ and $\Xi^*(1530)$ belong to $SU(3)$ $3/2^+$ decuplet. Comparing with the similar $SU(3)$ breaking decay $J/\psi \rightarrow \bar{p}\Delta^+$ with branching ratio of less than 1×10^{-4} and the $SU(3)$ conserved decay $J/\psi \rightarrow \bar{p}N^*(1535)^+$ with branching ratio of $(10 \pm 3) \times 10^{-4}$, the branching ratios for $J/\psi \rightarrow \bar{\Sigma}^-\Sigma^*(1385)^+$ and $J/\psi \rightarrow \bar{\Xi}^+\Xi^*(1530)^-$ are puzzling too high. A possible explanation for this puzzling phenomena is that there were substantial components of $1/2^-$ under the $3/2^+$ peaks but the two branching ratios were obtained by assuming pure $3/2^+$ contribution. In fact, a recent re-examination of some old data of the $K^-p \rightarrow \Lambda\pi^+\pi^-$ reaction reveals that besides the well established $\Sigma^*(1385)$ with $J^P = 3/2^+$, there is indeed some evidence for the possible existence of a new Σ^* resonance with $J^P = 1/2^-$ around the same mass but with broader decay width. This possibility could also be easily checked with the high statistics BESIII data in near future.

With 10^9 $\psi'(3686)$ and 10^{10} J/ψ events at BESIII, the N^* , Δ^* , Λ^* , Σ^* and Ξ^* can be well explored for masses up to 2740 MeV, 2450 MeV, 2570 MeV, 2490 MeV and 2360 MeV, respectively. Not only J/ψ and ψ' but also χ_{cJ} can have enough statistics for studying these baryon resonances. Because the χ_{cJ} cannot decay to hadrons through one virtual photon as vector charmonia do, the χ_{cJ} decays provide an even better isospin filter for studying baryon resonances.

3 N^* from $pp \rightarrow NN^*$

The proton beams at COSY/Juelich and CSR/Lanzhou can provide pp collisions with center-of-mass (CM) energies up to 3 GeV. The $pp \rightarrow NN^*$ reac-

tion can provide another useful source of information on N^* resonances. Many results from baryonic channels in charmonium decays can be cross-checked by corresponding channels from pp collisions. For example, comparing $J/\psi \rightarrow \bar{p}K^+\Lambda$ with $pp \rightarrow pK^+\Lambda$, they share the same $K^+\Lambda$ resonances and the same t-channel exchange interaction for $\bar{p}\Lambda$ and $p\Lambda$. The large $N^*(1535)\Lambda K$ coupling observed in $J/\psi \rightarrow \bar{p}K^+\Lambda$ should also have some reflection in $pp \rightarrow pK^+\Lambda$, for which some very precise near-threshold data are now available from COSY experiments^[27, 34]. Indeed a theoretical prediction without including the $N^*(1535)$ contribution^[35] is obviously underestimating the near-threshold data of COSY as shown by the dotted line in Fig. 4. After adding the contribution from the $N^*(1535)$ with its coupling to $K\Lambda$ determined from J/ψ decays^[25], the data can be reproduced perfectly as shown by the solid line in Fig. 4. While the $p\Lambda$ final state interaction (FSI) is pointed out to play important role to reproduce the cross section data^[36], the Dalitz plot data^[27] clearly show that both $p\Lambda$ FSI and $N^*(1535)$ contribution are important.

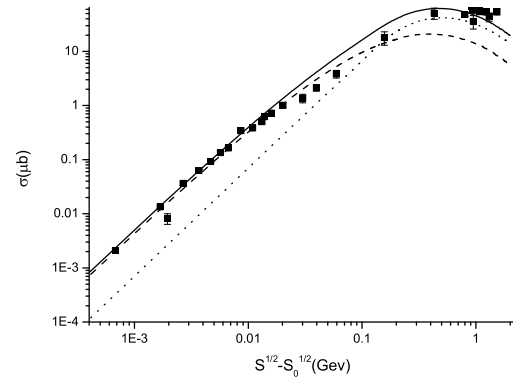


Fig. 4. The cross section of the reaction $pp \rightarrow pK^+\Lambda$ as a function of the excess energy without (dotted line) and with (solid line) including the contribution from $N^*(1535)$ compared with data. From Ref. [25].

The $N^*(1440)$ peak in the $n\pi^+$ invariant mass spectrum observed in the $J/\psi \rightarrow \bar{p}n\pi^+$ reaction^[14] is also observed in the corresponding $pp \rightarrow pn\pi^+$ reaction by the CELSIUS-WASA Collaboration^[37]. It is found that the t-channel σ -meson exchange plays dominant role for the production of the $N^*(1440)$ resonance^[38]. This suggests that the $pp \rightarrow NN^*$ reaction is a good place for looking for those “missing” N^* with large coupling to $N\sigma$. The $pp \rightarrow pn\pi^+$ reaction at higher energies should be explored at COSY and CSR.

Recently, the CELSIUS-WASA Collaboration observed an s-channel resonance-like structure around 2.36 GeV in the $pn \rightarrow d\pi^0\pi^0$ reaction^[39]. It is just around $NN^*(1440)$ threshold. Note that the $N^*(1440)$ has the same quantum number of nucleon and has a large coupling to $N\sigma$. It is likely to form a $NN^*(1440)$ quasibound state by t-channel σ and other meson exchanges as deuteron as a bound state of pn . Then the $NN^*(1440)$ quasibound state decays in to $d\sigma$ due to the large $N^*(1440)N\sigma$ coupling.

Besides the complementary study on the isospin $1/2$ N^* resonances, the pp collisions can also provide a new excellent source for studying their isospin $3/2$ partners, i.e., Δ^{+++} resonances. The spectrum of isospin $3/2$ Δ^{+++} resonances is of special interest since it is the most experimentally accessible system composed of 3 identical valence quarks. However, our knowledge on these resonances mainly comes from old πN experiments and is still very poor^[1]. A recent study^[40] on $pp \rightarrow nK^+\Sigma^+$ reaction suggests that the reaction is an excellent place for looking for those “missing” Δ^{+++} with large coupling to pp^+ .

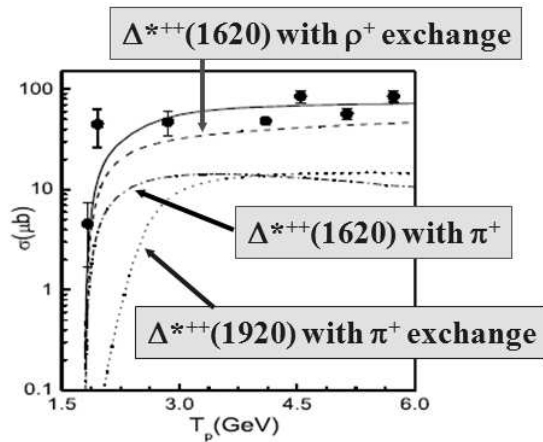


Fig. 5. Total cross section vs kinetic energy of proton beam for the $pp \rightarrow nK^+\Sigma^+$ reaction: data^[41, 42] and calculation (solid curve for sum of other curves)^[40].

At present, little is known about the $pp \rightarrow nK^+\Sigma^+$ reaction. Experimentally there are only a few data points about its total cross section versus energy^[41, 42]. Theoretically a resonance model with an effective intermediate $\Delta^{+++}(1920)$ resonance^[43] and the Jülich meson exchange model^[44] reproduce the old data at higher beam energies^[41] quite well, but their predictions for the cross sections close to threshold fail by order of magnitude compared with very recent COSY-11 measurement^[42]. Recently this reaction was restudied^[40]. With an effective Lagrangian approach, contributions from a previous ignored

sub- $K^+\Sigma^+$ -threshold resonance $\Delta^{+++}(1620)1/2^-$ are fully included in addition to those already considered in previous calculations. It is found that the $\Delta^{+++}(1620)$ resonance gives an overwhelmingly dominant contribution for energies very close to threshold, with a very important contribution from the t-channel ρ exchange as shown in Fig. 5. This solve the problem that all previous calculations seriously underestimate the near-threshold cross section by order(s) of magnitude.

A important implication of this study is that the $pp \rightarrow n\Delta^{+++}$ may provide a good source for exploring $\rho^+p \rightarrow \Delta^{+++}$ and should be further studied at COSY and CSR.

A more recent measurement of the $pp \rightarrow nK^+\Sigma^+$ reaction near its threshold by ANKE collaboration^[45] gives a much smaller cross section than those by COSY-11. This would mean much smaller $\Delta^{+++}(1620)$ contribution and $n\Sigma^+$ FSI. Since both detectors are not 4π solid angle detectors, there is model dependence to deduce the total cross section from a fraction of 4π solid angle measurement. A good Dalitz plot measurement with a good 4π solid angle detector would be very helpful to settle down the contradiction.

4 N^* from $p\bar{p} \rightarrow \bar{N}N^*$

The antiproton beam at PANDA/FAIR is going to perform $p\bar{p}$ collision experiment with beam momenta ranging from 1.5 to 15 GeV. The $p\bar{p}$ collisions could provide a much richer source for the production of baryon resonances than e^+e^- collisions. All the final states of e^+e^- collisions and much more other states are accessible by $p\bar{p}$ collisions. A large portion of $p\bar{p}$ final states contain baryons and should not be wasted at PANDA/FAIR.

Recently, a proposal is made to study N^* resonances with $p\bar{p} \rightarrow \bar{p}n\pi^+$ reaction^[45]. Due to absence of the Δ^{++} production for this reaction, the contribution of the Δ excitation is much smaller than in the corresponding $pp \rightarrow pn\pi^+$ reaction. It is found that for the beam momenta around $1.5 \sim 3$ GeV, the contribution of the Roper resonance $N^*(1440)$ produced by the t-channel σ exchange dominates over other contributions due to its known large coupling to $N\sigma$ ^[1, 46], as shown by the predicted $n\pi^+$ invariant mass spectrum for the reaction at $T_{\bar{p}} = 2.88$ GeV in Fig. 6. This will provide the cleanest place for studying the properties of the Roper resonance and the best place for looking for other “missing” N^* resonances with large coupling to $N\sigma$.

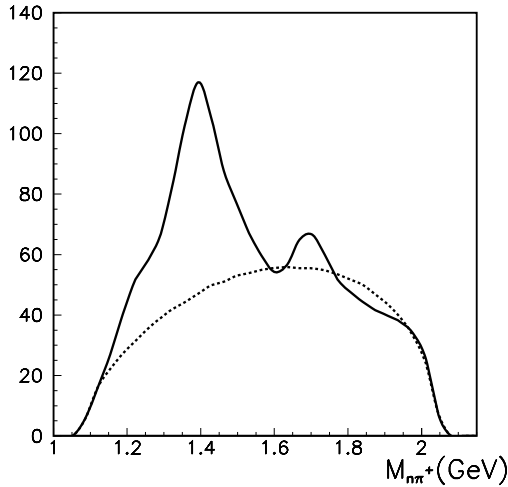


Fig. 6. Predicted $n\pi^+$ invariant mass spectrum (solid curve) for the $\bar{p}p \rightarrow \bar{p}n\pi^+$ reaction at $T_{\bar{p}} = 2.88$ GeV, compared with phase space distribution (dashed curve)^[46].

Another interesting possibility is that the poorly known Ω^* resonances may be produced and studied by PANDA/FAIR experiment while they cannot be studied from charmonium decays due to limited energy.

5 Summary and prospects

In summary, complementary to the conventional experimental studies on N^* from πN and $\gamma^{(*)}N$ reactions, the e^+e^- , pp and $\bar{p}p$ collisions can give novel insights into these N^* resonances.

The e^+e^- collisions through production and decay of charmonia ψ and χ_{cJ} provide a nice isospin filter for a simultaneously study of N^* , Δ^* , Λ^* , Σ^* and Ξ^* .

With $10^9 \psi'(3686)$ and $10^{10} J/\psi$ events at BESIII, the N^* , Δ^* , Λ^* , Σ^* and Ξ^* can be well explored for masses up to 2740 MeV, 2450 MeV, 2570 MeV, 2490 MeV and 2360 MeV, respectively. Many new baryon resonances should be observed.

The pp collisions should be the best place for producing those Δ^{*++} with large coupling to ρ^+p though $pp \rightarrow n\Delta^{*++}$ reaction. It is also a nice place for studying the N^* resonances with large coupling to $N\sigma$. The COSY/Jülich is short of a good 4π solid angle detector for both charged and neutral particles for a comprehensive study of the baryon spectrum. The study of this aspect should be continued at Lanzhou CSR with the schedule 4π solid angle detector HPLUS for both charged and neutral particles^[47].

The $\bar{p}p$ collisions should be the best place for looking for those N^* with large coupling to σN and for the study of the poorly known Ω^* resonances. A large portion of $\bar{p}p$ final states contain baryons and should not be wasted at the forthcoming PANDA/FAIR experiment with the antiproton beam. Instead PANDA should play important role on baryon spectroscopy.

With e^+e^- experiment at BESIII/BEPC II, pp experiment at HPLUS/Lanzhou, $\bar{p}p$ experiment at PANDA/FAIR joining the force of $\gamma^{(*)}$ experiments at CEBAF/JLAB, ELSA, Spring-8, and K beam experiment at JPARC for the study of baryon spectrum, a new era of baryon spectrum study is foreseeing to come.

I would like to thank Bo-chao Liu, Ju-jun Xie, Jia-jun Wu, Huan-ching Chiang, Peng-nian Shen, Jian-xiong Wang, Zhen Ouyang, Xu Cao, Hu-shan Xu and my BES collaborators for collaboration on relevant issues presented here.

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