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Status of Baryon Spectroscopy and Possible N* Program at Lanzhou CSR*

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Abstract: Status of baryon spectroscopy and recent progress of the baryon program from J/Ψ decays at Beijing Electron-Positron Collider (BEPC) are briefly reviewed. Possible N* program at Lanzhou CSR is discussed.

Key words: baryon spectroscopy; excited nucleon state; lanzhou CSR

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1 Status of Baryon Spectroscopy

Baryons are the basic building blocks of our world. If we cut any piece of object smaller and smaller, we will finally reach the nucleons, i. e., the lightest baryons, and we cannot cut them smaller any further. So without mentioning any theory, we know that the study of baryon structure is at the forefront of exploring microscopic structure of matter. From theoretical point of view, since baryons represent the simplest system in which the three colors of QCD neutralize into colorless objects and the essential non-Abelian character of QCD is manifest, understanding the baryon structure is absolutely necessary before we claim that we really understand QCD.

Spectroscopy has long proved to be a powerful tool for exploring internal structures and basic interactions of microscopic world. Ninety years ago detailed studies of atomic spectroscopy resulted in the great discovery of Niels Bohr's atomic quantum theory. Forty to sixty years later, still detailed studies of nuclear spectroscopy resulted in Nobel Prize winning discoveries of nuclear shell model and collective motion model by Aage Bohr et al. Comparing with the atomic and nuclear spectroscopy at those times, our present baryon spectroscopy is still in its infancy[1]. Many fundamental issues in baryon spectroscopy are still not well understood[2]. The possibility of new, as yet unappreciated, symmetries could be addressed with accumulation of more data. The new symmetries may not have obvious relation with QCD, just like nuclear shell model and collective motion model.

There are two basic questions for the baryon spectroscopy: (1) what is a baryon composed of ? and (2) what are the forces between its constituents? For the first question, we know there are three valence quarks, sea quarks and gluons inside

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a baryon, but we are not sure whether the three valence quarks are constituent or current quarks, whether they are well separated from each other or combined into a diquark cluster plus a single quark; whether the sea quarks are in the form of $q\bar{q}$ soup or mesons; whether the gluons are particle-like or flux-tubes, whether they are constituent or only virtual fields. For the second question, we know at short distance between quarks the force can be described by one gluon exchange; at medium range, some people now believe it is necessary to introduce meson exchange force; at long distance, the most commonly used force in quark models is the infinitely large linear confinement potential($\sim kr$). But in reality, the infinitely large confinement potential is obviously wrong. For such potential, a quark in a hadron cannot be separated from other quarks or antiquark in the same hadron, while in real world a quark can be easily separated from others by hadronic decays. For a physical baryonic state, the bag size of quarks should have fluctuation at different time. For the time of smaller bag size, there should be three constituent quarks; for the time of larger bag size, an additional constituent $q\bar{q}$ should be pull out from sea quarks. Especially for spatial excited baryonic states, the bag size should be larger than the spatial ground baryonic states, and hence they should have more (qqq)($\bar{q}$q) components. How to describe the strong force is still a problem. After more than twenty years of QCD, such basic questions have still not solved. The situation is obvious not satisfactory. The physics of nucleon resonance excitation continues to provide a major challenge to hadron physics.

The main source of information for the baryon internal structure is their mass spectrum, various production and decay rates. Our present knowledge of this aspect came almost entirely from partial-wave analyses of πN total, elastic, and charge-exchange scattering data of more than twenty years ago[1]. Only very recently, a new generation of experiments on N* physics with electromagnetic probes has been started at new facilities such as CEBAF at JLAB, ELSA at Bonn, GRAAL at Grenoble and SPRING8 at JASRI. Some nice results on $\Delta \to p\gamma$[3], N* (1 535) $\to p\gamma$[4] and $\gamma p \to K^+ \Lambda$[5] etc. have been produced.

On theoretical side, Chiral Perturbation Theory is not amenable to N* physics, lattice QCD has only recently begun to contribute to this field in a very limited scope[6]. Most of the theoretical work on the nucleon excitation spectrum has been based on phenomenological models. Among these models, the most systematic and successful ones are the constituent quark models (CQM) within a nonrelativistic[7] or relativistic framework[8], and the chiral constituent quark models (CCQM)[9]. Both CQM and CCQM assume three constituent quarks for a baryon. The difference is that CQM assumes one-gluon-exchange force between quarks while the CCQM includes meson-exchange force in addition. A relative new approach is a collective constituent model for the nucleon, in which the resonances are interpreted as rotations and vibrations of a symmetric top with a prescribed distribution of the charge and magnetization[10].

Despite the over all success, none of these models has been able to explain the properties of N*(1 440), N*(1 535) and Λ*(1 405) without difficulty. In the simple three-quark picture of baryons, N*(1 440) should be the first radial excitation state of the nucleon; N*(1 535) should be the first orbital angular momentum ($L=1$) excitation state of the nucleon; while Λ*(1 405) should be the $L=1$ excitation state of the hyperon, i. e., (uds)-baryon. The failure of the three-quark models in explaining properties of these lowest spatial excited baryonic states is natural since these spatial excited states are more sensitive to the long-range force between quarks while the three-quark models assume an improper confinement potential (kr). Additional constituents seem to be needed. These spatial excited states have been suggested to be hybrid (qqqg) baryon[11] and/or meson-nucleon bound states[12].

Another problem for above models is that they predict many N^* states which have not been observed in $\pi N \to \pi N$ reactions. A possible explanation is that the "missing" states are weakly coupled to πN and mainly coupled to other channels such as ρN, ωN, $\pi\Delta$, or $K\Lambda$ [13]. However, some models, such as the diquark-quark cluster model[14], predict a fewer number of excited states due to the reduced numbers of degrees of freedom.

To examine the structure of the low-lying spatial excited baryon states and to search for the "missing" N^* states are a few key issues for the present electromagnetic production experiments[15].

2　Baryon Program at BEPC from J/Ψ decays

Joining the new effort on studying the excited nucleons, N^* baryons, at new facilities such as CEBAF at JLAB, ELSA at Bonn, GRAAL at Grenoble and SPRING8 at JASRI, we also started a baryon resonance program at BES[16], at Beijing Electron-Positron Collider (BEPC). The J/Ψ and Ψ' experiments at BES provide an excellent place for studying excited nucleons and hyperons — N^*, Λ^*, Σ^* and Ξ^* resonances[17]. The corresponding Feynman graph for the production of these excited nucleons and hyperons is shown in Fig. 1 where Ψ represents either J/Ψ or Ψ'.

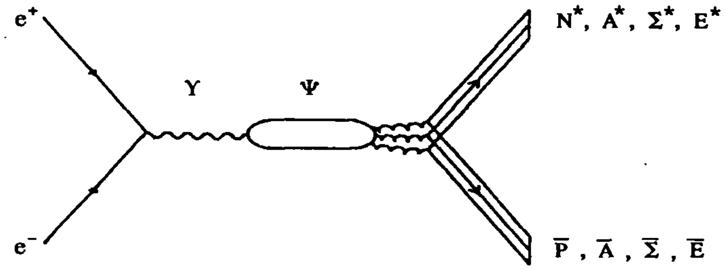

Fig. 1　$\bar{p}N^*$, $\bar{\Lambda}\Lambda^*$, $\bar{\Sigma}\Sigma^*$ and $\bar{\Xi}\Xi^*$ production from e^+e^- collision through Ψ meson.

Comparing with other facilities, our baryon program has advantages in at least three obvious aspects:

(1) We have pure isospin 1/2 πN and $\pi\pi N$ systems from $J/\Psi \to \bar{N}N\pi$ and $\bar{N}N\pi\pi$ processes due to isospin conservation, while πN and $\pi\pi N$ systems from πN and γN experiments are mixture of isospin 1/2 and 3/2, and suffer difficulty on the isospin decomposition[18].

(2) Ψ mesons decay to baryon-antibaryon pairs through three or more gluons. It is a favorable place for producing hybrid (qqqg) baryons [19], and for looking for some "missing" N^* resonances 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[8, 20] 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.

BES started data-taking in 1989 and was upgraded in 1998. The upgraded BES is named BESII while the previous one is called BESI. BESI collected 7.8 million J/Ψ events and 3.7 million Ψ' events. BESII has collected 58 million J/Ψ events.

Based on 7.8 million J/Ψ events collected at BESI before 1996, the events for $J/\Psi \to \bar{p}p\pi^0$ and $\bar{p}p\eta$ have been selected and reconstructed with π^0 and η detected in their $\gamma\gamma$ decay mode[16]. The corresponding $p\pi^0$ and $p\eta$ invariant mass spectra are shown in Fig. 2 with clear peaks around 1 500 and 1 670 MeV for $p\pi^0$ and clear enhancement around the $p\eta$ threshold, peaks at 1 540 and 1 650 MeV for $p\eta$. Partial wave analysis has been performed for the $J/\Psi \to \bar{p}p\eta$ channel[16] using the effective Lagrangian approach[21,22] with Rarita-Schwinger formalism[23—26] and the extended automatic Feynman Diagram Calculation (FDC) package[27]. There is a

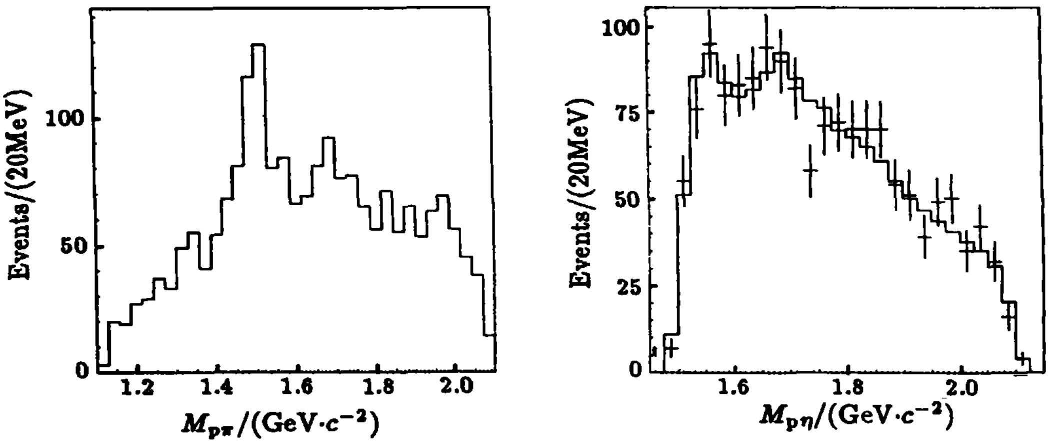

Fig. 2 Left: $p\pi^0$ invariant mass spectrum for $J/\Psi \to \bar{p}p\pi^0$; right: $p\eta$ invariant mass spectrum for $J/\Psi \to \bar{p}p\eta$. BESI data[16].

definite requirement for a $J^P = \frac{1}{2}^-$ component at $M = (1\ 530 \pm 10)$ MeV with $\Gamma = (95 \pm 25)$ MeV near the ηN threshold. In addition, there is an obvious resonance around 1 650 MeV with $J^P = \frac{1}{2}^-$ preferred, $M = (1\ 647 \pm 20)$ MeV and $\Gamma = 145^{+80}_{-45}$ MeV. These two N^* resonances are believed to be the two well established states, S_{11} (1 535) and S_{11} (1 650), respectively. In the higher $p\eta$ ($\bar{p}\eta$) mass region, there is an evidence for a structure around 1 800 MeV; with BESI statistics we cannot determine its quantum numbers.

With 58 million new J/Ψ events collected by BESII of improved detecting efficiency, we have one order of magnitude more reconstructed events for each channel. Preliminary results for $J/\Psi \to p\bar{n}\pi^-$ and $J/\Psi \to pK^-\bar{\Lambda}$ + h. c. channels are shown in Fig. 3 and Fig. 4, respectively.

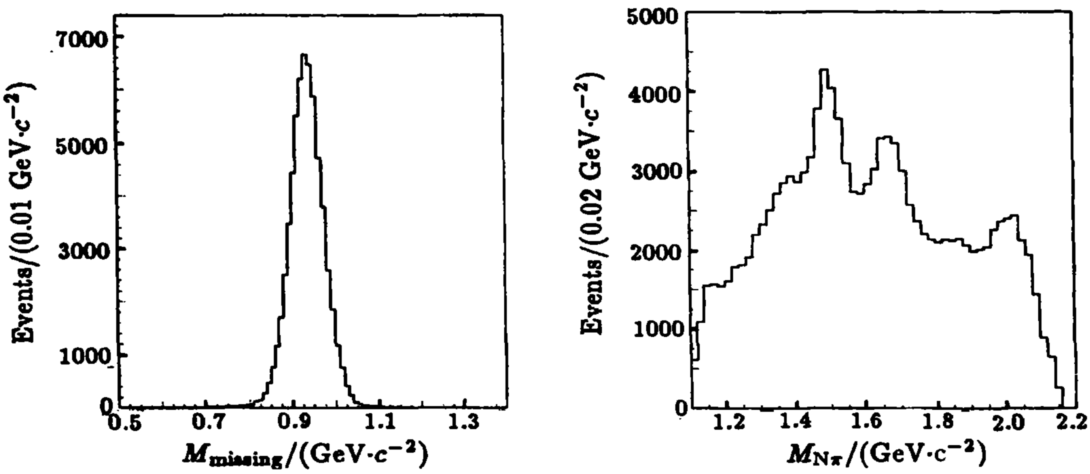

Fig. 3 Left: missing mass spectrum against $p\pi^-$ for $J/\Psi \to \bar{n}p\pi^-$; right: $p\pi^-$ & $\bar{n}\pi^-$ invariant mass spectrum for $J/\Psi \to \bar{n}p\pi^-$. Preliminary BESII data[28].

For $J/\Psi \to p\bar{n}\pi^-$ channel, proton and π^- are detected. With some cuts of backgrounds, the missing mass spectrum shows a very clean peak for the missing antineutron with negligible backgrounds; The $N\pi$ invariant mass spectrum of 28, 904 reconstructed events from half BESII data looks similar to the $p\pi$ invariant mass spectrum for $J/\Psi \to p\bar{p}\pi^0$ as in Fig. 2, but with much higher statistics. Besides two very clear peaks around 1 500 and 1 670 MeV, the peak around 2 020 MeV becomes clearer. This could be a "missing" N^*. For the decay $J/\Psi \to \bar{N}N^*$ (2 020), the orbital angular momentum of $L=0$ is much preferred due to the suppression of the centrifugal barrier factor for $L \leqslant 1$. For $L=0$, the spin-parity of N^* (2 020) is limited to be $\frac{1}{2}^+$ and $\frac{3}{2}^+$. This may be the reason that the N^* (2 020) $\frac{3}{2}^+$ shows up as a peak in J/Ψ decays while no peak shows up for πN invariant mass spectra in πN and γN production processes which allow all $\frac{1}{2}^{\pm}$, $\frac{3}{2}^{\pm}$, $\frac{5}{2}^{\pm}$ and $\frac{7}{2}^{\pm}$ N^* resonances around 2.02 GeV to overlap and interfere with each other there.

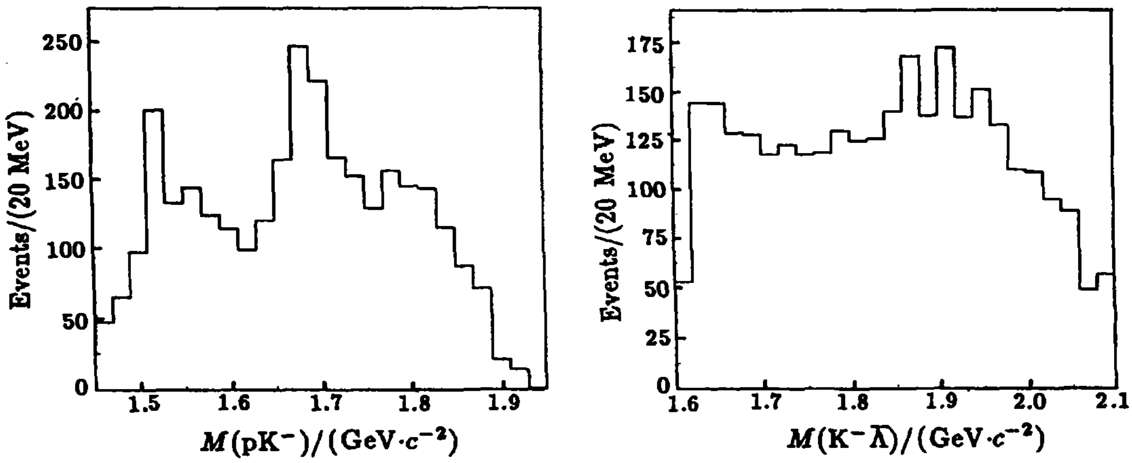

Fig. 4 Left: pK invariant mass spectrum for $J/\Psi \to pK\Lambda$; right: $K\Lambda$ invariant mass spectrum for $J/\Psi \to pK\Lambda$. Preliminary BESII data[28].

For $J/\Psi \to pK^-\bar{\Lambda}$ and $\bar{p}K^+\Lambda$ channels, there are clear Λ^* peaks at 1.52, 1.69 and 1.8 GeV in pK invariant mass spectrum, and N^* peaks near $K\Lambda$ threshold and 1.9 GeV for $K\Lambda$ invariant mass spectrum. The SAPHIR experiment at ELSA[5,29] also observed a N^* peak around 1.9 GeV for $K\Lambda$ invariant mass spectrum from photo-production.

We are also reconstructing $J/\Psi \to \bar{p}p\omega$, $pK\Sigma$, $\bar{p}p\pi^+\pi^-$ and other channels. Partial wave analyses of various channels are in progress[26,30]. Results from these analyses will provide a new way for exploring the internal structure of baryons[31,32].

A major upgrade of the collider to BEPCII is planned to be finished in about 4 years. A further two order of magnitude more statistics is expected to be achieved. Such statistics will enable us to perform partial wave analyses of plenty important channels for both meson spectroscopy and baryon spectroscopy from the J/Ψ and Ψ' decays. We expect BEPCII to play a very important role in many aspects of light hadron spectroscopy, such as hunting for the glueballs and hybrids, extracting $u\bar{u}+d\bar{d}$ and $s\bar{s}$ components of mesons, and studying excited nucleons and hyperons, i. e., N^*, Λ^*, Σ^* and Ξ^* resonances.

3 Possible N* Program at Lanzhou CSR

The construction of Lanzhou CSR will be completed soon[33]. It will be able to deliver proton beam for kinematic energies up to 2.8 GeV. This provides another good opportunity for studying N^*

resonances by using nuclear targets of nα cluster structure, such as ^{4}He, ^{12}C, ^{40}Ca . The processes are illustrated in Fig. 5 for the simplest case of pα reaction.

The advantages of such processes for studying N^* resonances are: (1) the meson-baryon system in the final states is limited to be pure isospin 1/2; (2) N^* resonances here are dominantly produced from σN coupling, which is different from all other available experiments.

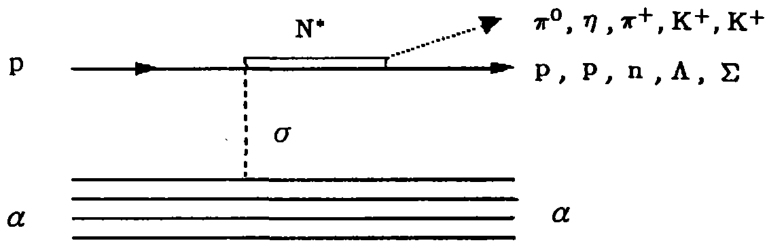

Fig. 5 Possible N^* processes from pα reaction.

The N^* production from αp reaction was previously studied[34] with α beam of 4. 2 GeV and a very primitive detector detecting α inclusively at a fixed angle. The maximum mass for N^* production was 1. 7 GeV. Only a peak may be corresponding to N^* (1 440) was observed. Relevant theoretical studies were performed by Oset group [35].

For proton beam of kinetic energy 2. 8 GeV, the maximum mass for the N^* will be extended to about 2. 8 GeV. With a modern 4π detector, many exclusive channels can be studied with partial wave analyses to obtain much more information about various N^* resonances.

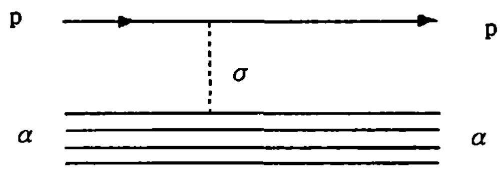

Fig. 6 Dominant mechanism for pα elastic scattering.

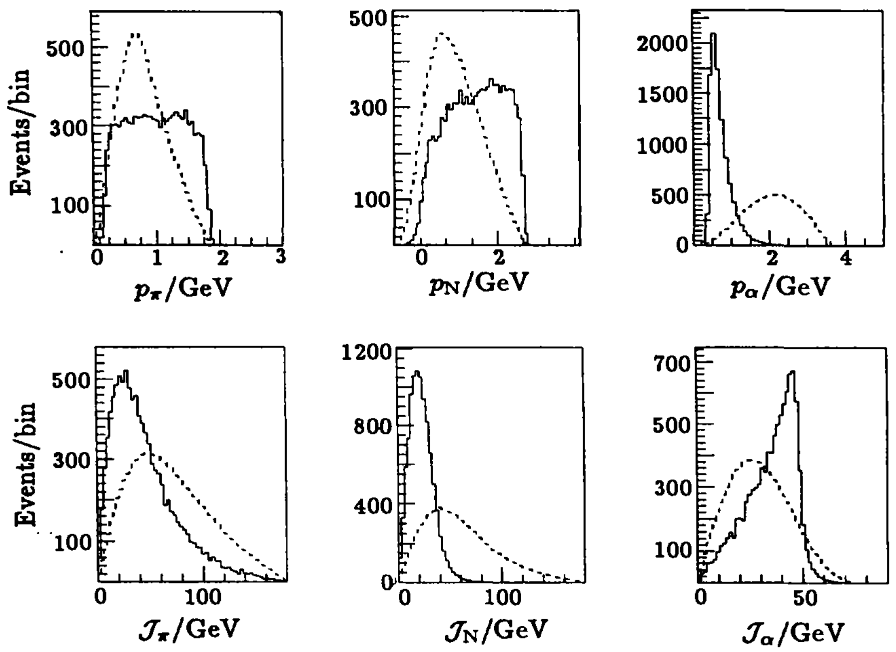

Fig. 7 Monte Carlo simulation of momentum and angular distributions for the case of N^* (1 700) $\frac{1}{2}^+$ to πN with proton beam of kinetic energy 2 GeV compared with phase space distribution (dashed curves).

The relevant $\sigma\alpha\alpha$ coupling in this process can be determined by pα elastic scattering which can be measured simultaneously with above processes at CSR. The dominant mechanism for the pα elastic scattering should be the t-channel σ exchange as shown in Fig. 6 since $\pi\alpha\alpha$ coupling is forbidden by the isospin conservation.

For the purpose of the detector design, here we also provide some simple Monte Carlo simulation results for the N* production as shown in Fig. 7 and Fig. 8, taking N* (1 700) $\frac{1}{2}^+$ as an example.

With a comparison study of $p\alpha \to \alpha\Lambda K^+$, $p^{12}C \to {}^{12}C\Lambda K^+$ and $p^{40}Ca \to {}^{40}Ca\Lambda K^+$, one may even explore the N*-nuclear interaction.

With the proton beam and a good 4π detector at CSR, a lot of interesting N* physics can be carried out.

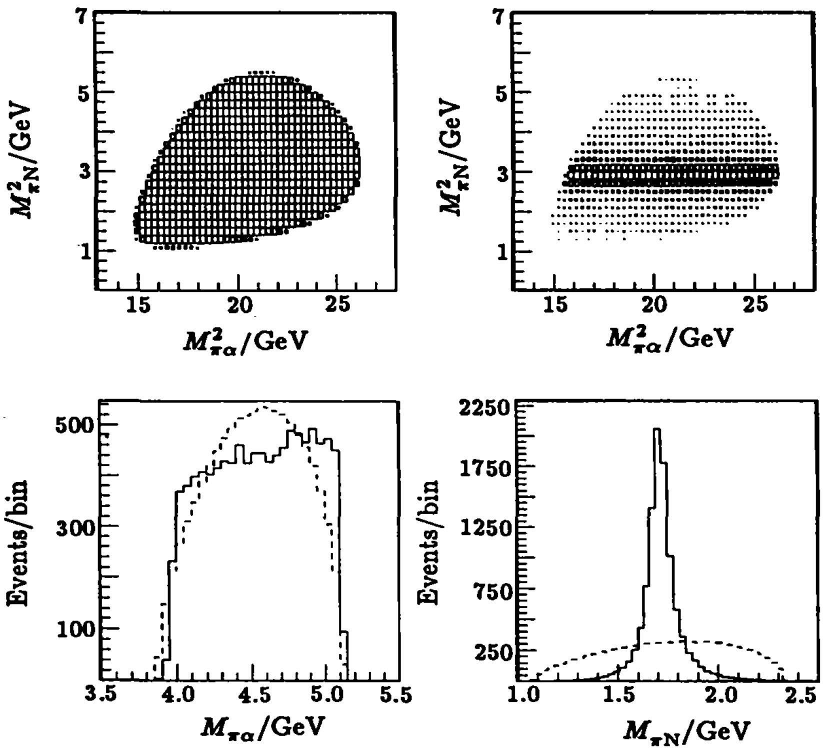

Fig. 8 Monte Carlo simulation of invariant mass distributions for the case of N* (1 700) $\frac{1}{2}^+$ to πN with proton beam of kinetic energy 2 GeV compared with phase space distribution (top-left and dashed curves).

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重子谱现状及兰州 CSR 可开展的 N* 研究项目*

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摘　要: 概述了重子谱研究现状及在北京正负电子对撞机通过 J/Ψ 衰变开展重子谱研究的最新进展. 探讨了在兰州 CSR 可开展的核子激发态研究项目.

关 键 词: 重子谱; 核子激发态; 兰州 CSR

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