BESIII

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1 The BESIII experiment

BESIII is a multi-purpose detector operating at the e^+e^- storage ring BEPCII at the Institute of High Energy Physics, IHEP, in Beijing. The machine is the only one currently running in the center-of-mass energy range $\sqrt{s} \approx 2 \div 4.6\,\text{GeV}$. It has achieved the design luminosity of $\mathcal{L} = 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$ and up to now it has collected the world largest samples of J/ψ, $\psi(3686)$, $\psi(3770)$, $\psi(4040)$, $Y(4260)$ and $Y(4360)$.

The LNF group is working since 2013 in the upgrade of the BESIII Inner tracker (IT) with a new Cylindrical GEM (CGEM) detector. The project, that since 2014 also includes groups from Mainz, Uppsala and IHEP, has been recognized as a Great Relevance Project within the Executive Program for Scientific and Technological Cooperation between Italy and P.R.C. for the years 2013-2015 and it is being funded by the European Commission within the call H2020-MSCA-RISE-2014 which lasted until 2018.
The group is also involved, together with the Perugia group, in the analysis of several physics processes involving baryons and light hadrons.

2 Physics analysis

2.1 G-parity violation in some J/ψ decays

In the limit of isospin conservation, the J/ψ decay into $\pi^+\pi^-$ should be purely electromagnetic. Nevertheless, the measured branching fraction $BR(J/\psi \to \pi^+\pi^-)$ exceeds by more than 4 standard deviations the expectation obtained according to BABAR data on the $e^+e^- \to \pi^+\pi^-$ cross section [1]. The possibility that the two-gluon plus one-photon intermediate state, usually neglected, could be responsible for such a high branching fraction has been discussed [2], and a phenomenological model to quantify its contribution has be proposed [3].
The preliminary result of the measurement of the $e^+e^- \to \pi^+\pi^-$ cross section in the J/ψ mass energy region which is under way in BESIII, does corroborate such a strong G-parity violation phenomenon.
The same phenomenological model [3], used to compute the strong G-parity-violating contribution in the decay $J/\psi \to K^+K^-$, gives a value compatible with zero, in agreement with the expectations, that can be inferred by comparing the rates of $J/\psi \to K^+K^-$ and $J/\psi \to K_S K_L$ decays.

2.2 Observation of Λ polarization and measurement of the relative phase of electric and magnetic Λ form factors

By means of the self-analysing weak decays of Λ hyperons into protons and pions, $\Lambda \to p\pi^-$ and $\overline{\Lambda} \to \overline{p}\pi^+$, it is possible to measure their polarization in the annihilation process $e^+e^- \to \Lambda\overline{\Lambda}$. The amplitude, at Born level, depends on two form factors, G_E^Λ and G_M^Λ, that are functions of the squared four-momentum transferred, q^2, of the virtual photon. The imaginary part of these form factors that induces a polarization of final hyperons along the direction orthogonal to the scattering plane. So that, by measuring such a polarization, is it possible to access

the relative phase between G_E^Λ and G_M^Λ, i.e., $\Delta\phi = \arg\left(G_E^\Lambda/G_M^\Lambda\right)$ [4]. The usual expectation is $\Delta\phi \simeq 0^o$, as it is the relative phase at the threshold, where $G_E^\Lambda = G_M^\Lambda$.
BESIII measures for the first time ever the relative phase to be, instead, $\Delta\phi = 37° \pm 12° \pm 6°$ [5] at $\sqrt{q^2} = 2.396$ GeV, about 165 MeV away from the $\Lambda\overline{\Lambda}$ production threshold.
The relative phase of the proton form factors seems to follow a similar behavior [4], the possibility that such a value of $\Delta\phi$ could be due to presence of a zero for the Λ electric form factor in the space-like region, i.e., for negative q^2's, in under study.
By analysing the reasonant process $ee \to J/\psi \to \Lambda\overline{\Lambda}$, BESIII has determined [6] the precise value of the polarization parameters of the Λ. Here it is measured a relative phase $\Delta\phi = 42.3° \pm 0.6° \pm 0.59°$.

A multidimensional analysis enables a model-independent measurement of the decay parameters for $\Lambda \to p\pi^-$ (α_-), $\overline{\Lambda} \to \overline{p}\pi^+$ (α_+) and $\overline{\Lambda} \to \overline{n}\pi^0$ (α_0). The obtained value $\alpha_- = 0.750 \pm 0.009 \pm 0.004$ differs of 5σ from the PDG value. This value, together with the measured $\alpha_- = 0.758 \pm 0.010 \pm 0.007$, allows for the most precise test of CP violation in Λ decays so far: $A_{CP} = (\alpha_- + \alpha_+)/(\alpha_- - \alpha_+) = -0.006 \pm 0.012 \pm 0.007$. This is the most sensitive test of matter-antimatter symmetry (CP symmetry) involving Lambda particles and offers prospects for further searches for new sources of CP symmetry violation in baryon decay, using the large J/Ψ data sample accumulated at BESIII.

2.3 Angular distributions of $J/\psi \to \Lambda\overline{\Lambda}$ and $J/\psi \to \Sigma^0\overline{\Sigma^0}$

The measured baryon-antibaryon angular distributions in the processes $e^+e^- \to J/\psi \to \Lambda\overline{\Lambda}$ and $e^+e^- \to J/\psi \to \Sigma^0\overline{\Sigma^0}$ have different behaviors, being proportional to $\left(1+\cos^2(\theta)\right)$ and $\left(1-\cos^2(\theta)\right)$, respectively. This feature is not observed in the case of $\psi(3686)$, where for both channels the angular distributions are indeed proportional to $\left(1+\cos^2(\theta)\right)$.
The Λ and Σ^0 angular distributions in the case of J/ψ can be explained by means of an effective model, which is based on the SU(3)-driven Lagrangian density $\mathcal{L}_{\Sigma\Lambda} = (G_0+G_1)\Sigma^0\overline{\Sigma}^0 + (G_0-G_1)\Lambda\overline{\Lambda}$ [10]. In the framework of such a model, the interplay between leading and sub-leading contributions to the J/ψ coupling to the baryon-antibaryon final state does determine the modulus and the sign of the polarization parameters for the two mesons J/ψ and $\psi(3686)$.

2.4 Strong and electromagnetic amplitudes of the J/ψ decays into baryons and their relative phase

The Feynman amplitude for the decay of the J/ψ meson into baryon-antibaryon can be written as a sum of three sub-amplitudes: a purely strong, a purely electromagnetic and a mixed strong-electromagnetic. Assuming that the strong and mixed strong-electromagnetic sub-amplitudes have the same phase, the branching ratio of the decay contains an interference term that depends on the relative phase φ between strong and electromagnetic sub-amplitudes.
We calculate this phase, by using an effective strong Lagrangian density and considering, as final states, pairs of baryons belonging to the spin-1/2 SU(3) octet. Moreover, we obtain the purely strong, purely electromagnetic and mixed strong-electromagnetic contributions to the total branching ratio and hence the moduli of the corresponding sub-amplitudes, for each pair of baryons. Finally we use the purely electromagnetic branching ratio to calculate the Born non-resonant cross section of e^+e^- annihilations into baryon-antibaryon at the J/ψ mass. By taking advantage from all available data, we obtain the relative phase between strong and electromagnetic sub-amplitudes: $\varphi = (73 \pm 8)°$.

3 The BESIII CGEM Inner Tracker

Based on the experience of the KLOE2-CGEM Inner Tracker, we started developing a three-layer triple-GEM detector [11] with analog readout as IT for the BESIII experiment. The analog readout is the most important improvement with respect to KLOE2, and offers the best compromise between improved spatial resolution and reasonable number of instrumented channels.

3.1 Construction in LNF Clean Room

In 2018 the third layer L3 has been constructed in all five cylinders and assembled with the Vertical insertion Machine (VIM), moreover the new L2 have been completely constructed.

- In the first half of 2018 the 5 electrodes composing L3 were produced and assembled in the Vertical Insertion Machine. The completed L3 was satisfactorily tested for gas tightness, instrumented with HV connectors, and tested for a first series of cosmic ray runs. These tests evidenced a not completely satisfactory behaviour under HV, some sectors could be turned on to final HV values only after a long period of conditioning. Nevertheless, the completed L3 was eventually brought up to operational point, and a surface scan with a radioactive source showed no particularly inefficient areas.
- As for layer L2, all the 5 cylinders have been constructed in the second half of 2017, but an accident occurred in December while getting ready for final assembly with the Vertical Insertion Machine: one anode strip was broken in an un-repareable way, so that it was decided not to use it and to do a new anode that was immediately procured at CERN. The new anode foil having been delivered at LNF in January 2018, L2 was completed after L3, tested for gas tightness, instrumented, and sent to Ferrara in July 2018. But this L2 immediately showed that one of the 3 GEM cylinders had no HV connection on 2 of its 4 sectors, due to broken tracks on the GEM surface. This reduced signal amplification (only 2 working GEMs out of 3) over a half of the detector area, and implied a loss of efficiency, confirmed by a surface scan of L2 with a radioactive source, judged to be not acceptable for installation in BESIII.
- The reason for the broken tracks was not completely understood, so the group decided to make a new L2 after the Summer, including additional tests at every construction stage, to make sure to install only perfect cylinders in the future L2. An additional change in the assembly was also decided, in order to reduce the instabilities seen in L3 operation: we decided against use of a set of blocking pins introduced by BESIII with respect to the KLOE2 procedure: these pins had the purpose to keep the 5 electrode cylinders steady during rotations of the Vertical Insertion machine, but eventually we judged that removal of this degree of freedom created more problems than it solved.

  L2 was remade in the second half of 2018 with these changes in the procedure, turned on with no difficulty,

3.2 High and Low voltage systems

The CGEM IT High Voltage distribution system has been developed by the LNF SEA group. The CGEM IT High Voltage distribution system allows to supply independently all the macro/micro sectors of the three CGEM layers, with the possibility to disconnect a single micro-sector in case of local discharges. The system is made of an active section to generate the single layer seven voltages, and a passive section to distribute each voltage to the required lines.

It is a quite complex system as it is made of:

1. one SY 4227LC crate
2. two A1515CG Boards
3. two Radial - Redel conversion Boxes
4. three HV custom cables to connect the Radial Redel Boxes to the High voltage Patch Panels
5. six High Voltage Patch Panels

6. thirty-six custom cables to route micro/macro sectors and cathode lines to the High Voltage Transition Boxes located near the detector
7. seventy-two custom macro/micro and cathode connections implemented with very short and light cables to simplify the Tracker insertion procedure (these cables must be connected to the detector before insertion).

HV cable production has been completed and fully tested in 2018 and it is currently used to supply the three layers of CGEM during the integration tests.

The Low voltage distribution chain has been designed to supply the 80 TIGER boards used to readout the 3 CGEM layers. Also this system is made of several components:

1. two SY5527 crates
2. four A2519 LV Boards
3. six custom cables from A2519 LV boards to GEMROC modules
4. eighty custom cables from GEMROC to LVPATCH boards
5. eighty very light (and short) custom cables from LVPATCH boards to the TIGER boards (also these cables must be connected before the detector insertion procedure)

LV cable production has been completed and fully tested within first half of 2018 and is currently used to supply the CGEMs front-end boards.

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