Hadron Physics Programs at HIRFL-CSRm: Plan and Status*

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Abstract An internal target experiment at HIRFL-CSRm is planned for hadron physics, which focuses on hadron spectroscopy, polarized strangeness production and medium effect. A conceptual design of Hadron Physics Lanzhou Spectrometer (HPLUS) is discussed. Related computing framework involves event generation, simulation, reconstruction and final analysis. The R&D works on internal target facilities and sub-detectors are presented briefly.

Key words hadron physics, spectrometer, HIRFL-CSR, HPLUS

1 Introduction

The Cooling Storage Ring project on the Heavy Ion Research Facility at Lanzhou (HIRFL-CSR) is under commissioning, that consists of a main ring (CSRm), an experimental ring (CSRe), and a radioactive beam line (RIBLL2) to connect the two rings[1], shown in Fig. 1.

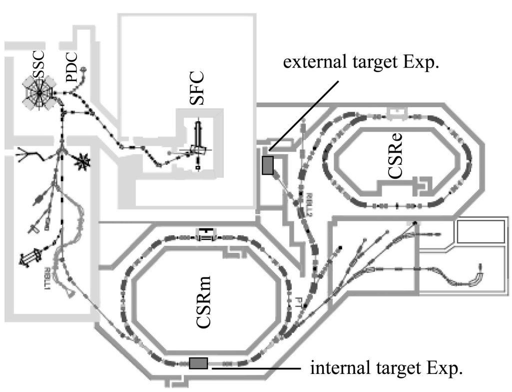

Fig. 1. HIRFL-CSR complex.

CSRm can provide proton/deuteron beams with momentum 3.7GeV/c, and heavy ion beams with maximum energy from 0.5GeV/u ($^{238}U^{72+}$) up to 1.1GeV/u ($^{12}C^{6+}$). With these beam conditions the machine provides very good opportunities in both hadron physics research on non-perturbative QCD[2—6] and heavy ion research in terms of nuclear equation of state and exotic nuclear structure etc. An internal target experiment for hadron physics and an external target experiment for heavy ion collisions will be built at HIRFL-CSR complex. This letter is concentrated on the internal target experiment, named Hadron Physics LanzhoU Spectrometer (HPLUS).

2 Physics Case

2.1 Hadron spectroscopy

Spectroscopy is a main approach to get information of fundamental interactions from atomic, nuclear

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and hadronic system. Based on conventional constituent quark model, meson and baryon spectroscopy are established with $q\bar{q}$ and qqq system, respectively. But there are still some hadron resonances not explained well, especially recent experiments give evidence for multi-quark components.

Nucleon resonance $N^*(1535)$ with $J^P = \frac{1}{2}^-$, considered as the first L=1 orbital excitation state, has a mass higher than the lowest $J^P = \frac{1}{2}^+$ radial excitation state $N^*(1440)$. Although the pentaquark state Θ^+ still needs confirmation by experiment, the pentaquark components in proton and excited baryons are presumed to explain $N^*(1535)$ has a large coupling to strangeness ($K\Lambda$ and $K\Sigma$) and be heavier[7]. One of the programs on HPLUS@CSRm is set to look for "missing" N^* and Δ^* resonances and study their $s\bar{s}$ components.

Di-baryon search through NN scattering is a good experiment to have a practice at the beginning. The pp elastic scattering and single-pion or double-pion production channels should be done to compare with other spectrometer running at equivalent accelerator like COSY@Jülich.

Light scalar resonances $a_0/f_0(980)$ ($J^P = 0^+$) are discussed as compact 4-quark states (qq—$\bar{q}\bar{q}$) for the identified $K\bar{K}$ decay mode, while constituent quark model treats them as conventional $q\bar{q}$ states. More experimental data are required and WASA@COSY has listed a_0/f_0 production as one of their main intents.

Also decays of η and η' mesons are important programs on WASA to study symmetries and symmetry breaking. A close contact between HPLUS@CSRm and WASA@COSY is well established for future hadron physics proposals .

2.2 Polarized strangeness production

Polarized H/D laser-driven target and polarized p/d beams are considered for phase II of HPLUS@CSRm. Polarized ϕ meson production is postulated to probe strangeness content of nucleon. A recent experiment on ϕ meson production near threshold from ANKE@COSY, gives a significant enhancement of ϕ/ω production ratio of a factor 8 compared to Okubo-Zweig-Iizuka rule prediction[8]. Total cross section data for ϕ-production in pp collisions are very scarce. At low excess energy there are only four data points: excess-energy ϵ=83MeV (DISTO collaboration), ϵ=18.5, 34.5, 75.9MeV (ANKE collaboration). So polarized ϕ meson production program is set on HPLUS@CSRm for further investigation.

Another program on excitation modes of hyperon Λ^* and Σ^* is suggested to study reaction mechanism of strangeness production through pp and pn interactions[9].

2.3 Medium effect

In nuclear matter the change of hadron mass and width can give important information to chiral symmetry breaking restoration. Through comparison of proton-nuclei and proton-proton collisions one can investigate the medium effect of ϕ meson through charged Kaon-pair detection and ρ, ω, η mesons through lepton-pair detection.

3 Conceptual design for HPLUS

With the intent of physical channels listed in Table 1, it is supposed that both charged and neutral particles should be detected by HPLUS with sufficient coverage and resolution.

Table 1. Physical channels of interest.

channels	$E^{k}_{\text{thresh.}}$/GeV	physical interest
$pp\to pn\pi^+/pp\pi^0$	0.29/0.28	machine training and
$pp\to pp\pi^+\pi^-$	0.60	dibaryon search
$pp\to pN^*\to pK^+\Lambda$	1.58	baryon spectroscopy
$pp\to n\Delta^*\to nK^+\Sigma^+$	1.79	baryon spectroscopy
$pN\to\ldots a_0/f_0(980)$	2.5	scalar meson resonances
$pp\to pp\eta/pp\eta'$	1.26/2.40	symmetry breaking
$pp\to pp\phi\to ppK^+K^-$	2.59	OZI rule violation
$pN\to NK\Lambda^{(*)}/NK\Sigma^{(*)}$	>1.6/1.8	strangeness production
$dd\to\alpha\eta$	1.12	η-meson nuclei
$pA\to\ldots\phi,\rho,\omega,\eta$	sub-threshold	medium effect

For the conceptual design there are three considerations. First, the internal experiment is a fixed target case, which has a large forward distribution of products. According to the phase space simulation, about 90% charged particles and neutrons are emitted forward within polar angle 90° in the lab frame.

So the design of the forward detector is very important. Second, the typical luminosity of HPLUS is about $10^{32}\text{cm}^{-2}\cdot\text{s}^{-1}$ and the total cross section of pp collision at $\sqrt{s}$ ~3GeV approaches 50mb, so the total event rate is about 10^6/s, that sets a great challenge for tracking detectors and DAQ system. Third, a general type spectrometer has more freedom in future for varying hadron physics intent. A large acceptance is also required for differential cross section measurement to provide more information than existed spectrometers.

The main sub-detectors are described as followed, respectively:

1) Solenoid and Tracking Detector (TD)

A uniform magnetic field along the beam line is supplied by superconducting solenoid magnet. Multi-Wire Drift Chambers (MWDC) and Time Projection Chamber (TPC) are the main tracking detectors in the solenoid.

2) Time-of-Flight (TOF) Stop Detector

Both plastic scintillator and Multi-gap Resistive Plate Chamber (MRPC) are satisfied with TOF requirements to identify charged particles. TOF detector can also give fast trigger signals.

3) Electromagnetic Calorimeter (EMC)

The CsI(Tl) crystal calorimeter is chosen to detect photons and electrons with nearly 4π coverage. A kind of large area Photodiode (PD) is considered as photodetector for each crystal cell.

4) T0 and Vertex Detector

T0 detector provides start signal of TOF, that is one of the most important and difficult issues in the conceptual design. To determine the interaction point and decay vertices, the vertex detector is suggested to help reconstruct tracks efficiently.

5) Hadronic Calorimeter (HC)

A sampling hadronic calorimeter is planned to detect neutrons.

6) Cherenkov Detector

As a option the Cherenkov detector (DIRC) is planned to identify high momentum charged particles for complement with TPC and TOF at lower momentum region.

A primary configuration of HPLUS based on above considerations is given to start detector simulation and optimization, as shown in Fig. 2.

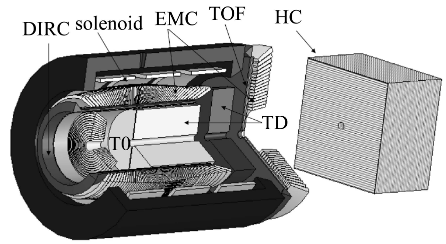

Fig. 2. HPLUS conceptual design configuration.

4 Computing framework

In order to estimate the flexibility of physical objectives, to optimize the conceptual design and to finally analyze experimental data, a complete software platform must be developed with four major packages for event generation, simulation, reconstruction and analysis.

Event generation is going to generate physical channels and backgrounds with certain rates. In this energy regime interaction processes are based on hadrons not quarks, so each event can be divided into two steps called reaction and decay. Within reaction step beam interacts with target strongly to create hadron resonances. Then short lived particles decay to final products which can be detected in the spectrometer. Generally particle decay modes and branching ratios are provided in PDG summary tables, so the decay step can be realized directly by Monte Carlo techniques. To describe reaction step we use phase space generator to give kinematic boundaries and also want to develop dynamic corrections from Effective Field Theories (EFT).

Simulation and reconstruction both deal with interactions between particles and detectors, but perform the exactly opposite tasks. Simulation package imports particles's ID and 4-momenta record from event generation to simulate detector response primarily at Hit level including position, time and deposited energy information. Then each sensitive detector element with simulated readout module and electronics like ADC or TDC, converts Hit record to raw data just the same as experimental data format, called digitization. Reconstruction package converts simulated or experimental raw data to useful spatial and physical quantities using calibration database. After coming back to Hit level and using the analysis tool package we can reconstruct full physical event.

Computing work is based on ROOT platform. Event generation involves phase space generator, Pluto++ and Pythia6. GEANT4 application is used to perform detector simulation. Reconstruction and analysis tools are developed with ROOT library.

5 R&D works

A hydrogen/deuterium pellet target facility developed in Uppsala, Sweden, is transported to Lanzhou and its testing platform is under construction. The pellet diameter ranges from 25 to 35μm, and thus an effective target thickness of 10^{15}—10^{16}atoms/cm^2 is expected[11]. A polarized H/D laser-driven target developed in MIT/Duke is considered to take over. The polarized hydrogen gas has been produced at a thickness of 1.5×10^{15}atoms/cm^2, with 58.2% degree of dissociation and 50.5% polarization in the storage cell[12].

The growth of CsI(Tl) crystal with ϕ11cm×35cm is achieved in our institute. A cubic CsI(Tl) sample (1cm×1cm×1cm) coupled with PD and APD has been tested at 25℃, and the energy resolution for 662keV gamma-ray is 11.3% and 5.1%, respectively. The prototype of Multi-Wire Drift Chamber (MWDC) has be constructed and tested in the institute. The layer efficiency increases exponentially to 96% at the HV plateau, and overall position resolution better than 200μm is achieved. TOF detector including MRPC module, plastic scintillator and their readout electronics is designed and developed at USTC. A prototype TPC with GEM (30cm×20cm) readout is under development at Tsinghua University.

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