

Photon-Counting Pixel Detector Designs for ITER X-Ray Crystal Spectroscopy System

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Controlled nuclear fusion is considered the ultimate energy source for humanity. Magnetic-confinement tokamaks are representative facilities such as the International Thermonuclear Experimental Reactor (ITER), the Experimental Advanced Superconducting Tokamak (EAST), etc. ITER is expected to start operation around 2035 and become the first magnetic-confinement fusion reactor to achieve self-heating and $Q=10$. To effectively monitor the state of the plasma, ITER's diagnostic system requires efficient detection of various particles, including neutrons, gamma rays, and X-rays, to ensure the safe operation of the facility.

The X-Ray Crystal Spectroscopy (XRCS) system is a critical component of ITER's diagnostic system, responsible for monitoring plasma impurity levels and the condition of the first wall materials. The detector must achieve single-photon sensitivity for Xe and W spectral lines (about 3-9 keV), with a large panel. While hybrid photon-counting detectors are commercially available, they are typically optimized for the 6-20 keV energy range. Additionally, the front panels are often tightly integrated with backend electronics, making them unsuitable for operation in ITER's high neutron flux environment.

The Centre de Physique des Particules de Marseille (CPPM) and the Institute of High Energy Physics (IHEP) of the Chinese Academy of Sciences are collaborating to develop a photon-counting detector capable of single-photon resolution at 3 keV for ITER's XRCS system. In this talk we will present studies based on two different technology paths, focusing respectively on the front-end level and the system level.

A new MAPS design is based on a CIS process and aims to utilize stitching technology to achieve a large-area, low-dead-zone detector panel. The detector features a logical pixel size of $100\ \mu\text{m} \times 100\ \mu\text{m}$. Two front-end structures were achieved to address the size discrepancy between logical pixels and diodes: The CSA front-end structure with an analog-sum scheme has a good energy linearity and an ENC less than 40 e⁻; While the ALPIDE-like front-end structure with a digital-sum scheme achieves an ENC of less than 11 e⁻.

Meanwhile, tests on the system level based on the BPIX detector were carried out. To ensure the suitability for the ITER application environment, the performances of the detector are studied across several key areas: All components are vacuum compatible; The detector should have magnetic field resistance since the magnetic field is expected to be approximately 0.2 T at the mounting location. Furthermore, the detector will work in an environment with a fast neutron flux of about $10^4\ \text{n/s}\cdot\text{cm}^2$. In this talk, we will show the test results of those items.

Authors: LI, Mujin (IHEP); Prof. WEL, Wei (IHEP); Prof. LI, Zhenjie (IHEP); Prof. ZHANG, Jie (IHEP); Ms CHANG, Chenzhuo (IHEP); Dr CUI, Shanshan (IHEP); PANGAUD, Patrick (CPPM); Prof. BARBERO, Marlon (CPPM); Ms XU, Danwei (CPPM)

Presenter: LI, Mujin (IHEP)

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