Detectors for High-Flux Experiments at Jefferson Lab
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Abstract:
Parity-violating electron scattering experiments at Jefferson Lab use detectors that routinely intercept and “count” scattered electrons at extremely high rates (10^10-10^13 Hz). This is because these experiments measure tiny asymmetries (∆A), typically of order 10^-10 to 10^-12, to access nuclear current weak interaction amplitudes with high precision and statistic-dominated uncertainty. Two recent ∆A measurements at Jefferson Lab, PREX-II and CREX, required fast plane detectors to count electrons at ∼2.2 GHz and ∼27 MHz, respectively. A future ∆A measurement, MOLLER, will have fast plane detectors with rates near 8 - 10 GHz. These high flux rates impose stringent readout requirements on the design and material properties of the detectors. The current designs use a novel “thick-quartz” Cerenkov radiator coupled to a pmt to capture a ∼uniform flash of light for each intercepted electron. This poster will detail the design and performance of the HRS focal plane package for PREX-II and CREX. Designed, constructed, and operated by the ISU parity group, the PREX-I/CREX detector package includes four thin-quartz detectors and eight 10 cm x 20 cm active area GEM tracking chambers for each HRS arm. The four detectors consist of the main integrating “tandem-mounters” and two auxiliary (background monitor) detectors. Additionally, we designed and installed multiple generations of Hall A Samplers (previously known as LUMO)-which count primary and secondary scattered fluxes from the target to monitor both beam and target performance.

Background and Motivation:
PREX-I/CREX:
- High precision, statistic limited measurements of ∆A.
- Require extreme control over systematic errors.
- The focal plane (FP) detector package together with Hall A standard HRSs, VDCs, and scintillating trigger systems constitute PREX-I/CREX detector system.
- R & D preparations for the FP detectors include:
  - FP simulations to get elastic peak size and expected flux rates.
  - PMT gain curve measurements.
  - Several beam tests at MAMI and SLAC for benchmarking optical MC.
  - PE yields and resolution, position, and angle dependence.
  - Precision PMT non-linearity characterization.
  - Custom GEM readout design, cosmic-ray tests and SLAC test-beam.

FP det. CAD drawing and installed in HRS:
- Random design provides independent redundant ∆A measurement (in case one detector has problem).
- Yield 24 hrs (∼200 beams in peak).
- PREX-II rate: ∼2.2 GHz and CREX rate: ∼27 MHz.
- Achieved ∼90 % GEM efficiency (preliminary).
- Three GEMs with 10 x 20 cm active area.
- Scattered flux from the target to monitor both beam and target performance.

PMT linearity and gain curve characterization:
- Detector non-linearity is one of the most important systematic errors.
- Each PMT was tested for linearity at various high voltages (HV) and several light levels.
- Multiple tests were performed to check repeatability.
- HV for a PMT was chosen based on its best linear performance.
- We also performed the linearity test after PREX-II and the exact running HVs.
- Non-linearity should contribute <1/3 % systematic as proposed.
- The following shows non-linearity of PREX-II Main detector PMTs as a function of HV. The data points within oval were taken after PREX-II running and the rest were taken before running and installation in the HRS detector box.
- A gain curve was measured for each PMT before installing them in the detector box. Up to 1800 V, the curve follows G ∝ (1 / (1-e^(-t/h)))

Small Angle Monitors (SAMs):
- SAMs are a modified design of Hall A luminosity monitors (LUMO).
- Eight SAMs symmetric around beamline, ~7 m downstream of the target.
- Three of the four pairs have unity gain to handle high rates (~100 GHz).
- They each use 3.3 x 2.0 x 1.3 cm fused silica as Cerenkov radiator.
- They are sensitive to up-down dependent asymmetry due to horizontal component of transverse polarization of electron beam.
- They could serve as diagnostic tools for target density fluctuations.
- They could also monitor and help correct potential false asymmetry.
- Thee extreme rates allow a measure of electronic noise-floor in the hall.
- Asym. distribution of slugs40 of PREX-II is given in the following figure. Data was divided into ~equal statistical chunks called “slugs”.
- BPM includes position and energy monitors.
- Width on measured A_p gets broadened by detector resolution.
- The following plot shows the sum of the detected rate in two HRSs vs run from slug1 to slug94 during PREX-II.
- A sharp fall in rate indicates target degradation.

Summary:
- A new thin-quartz Cerenkov detector concept has been developed and successfully deployed for the recent high-flux parity experiments at JLab: PREX-II and CREX.
- These detectors require radiation-hard components and are constructed of high-purity, optically-polished fused silica (Spectrosil 2000) radiator.
- The PREX-I/CREX main focal-plane detectors use total internal reflection inside the radiator, and no air-core lightguide, to direct Cerenkov light to pmt.
- The new design doubles light yield and improves resolution by ~10 compared to previous designs.
- PMT linearity and gains determined to give non-linearity of focal-plane detector pmt responses below 0.5% for PREX-II and CREX.
- SAMs worked well during CREX – provided valuable diagnostics and gave an understanding and plan to develop future MOLLER SAM.
- The same approach used to design the PREX-I/CREX detectors will be used to develop next generation high-flux detectors for MOLLER: ShowerMax ring calorimeter and SAMs.
- These new detector concepts will benefit MOLLER, as well as provide potential detector technology for future EIC applications.

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PREX-I vs PREX-II design and MC tuning:
- PREX-I used 6 mm (10 mm) thick quartz in upstream (downstream).
- PREX-II and CREX used 5 mm thick quartz in all detectors.
- Quartz thickness was chosen based on light yield and resolution.
- The resolution affects ed with e ∝ 1 / (r_1 r_2)

Quartz acceptance (x vs y):
- Comparison of PREX-I and PREX-II quartz acceptance (x vs y) for different SAMs and detector geometries.
- The following displays the sum of the detected rate in two HRSs vs run from slug1 to slug94 during PREX-II.
- A sharp fall in rate indicates target degradation.

Detected rate vs run number:
- Data was divided into ~equal statistical chunks called “slugs”.
- PREX-II and CREX collected 94 and 86 slugs respectively.
- Asym. distribution of slugs40 of PREX-II is given in the following figure.