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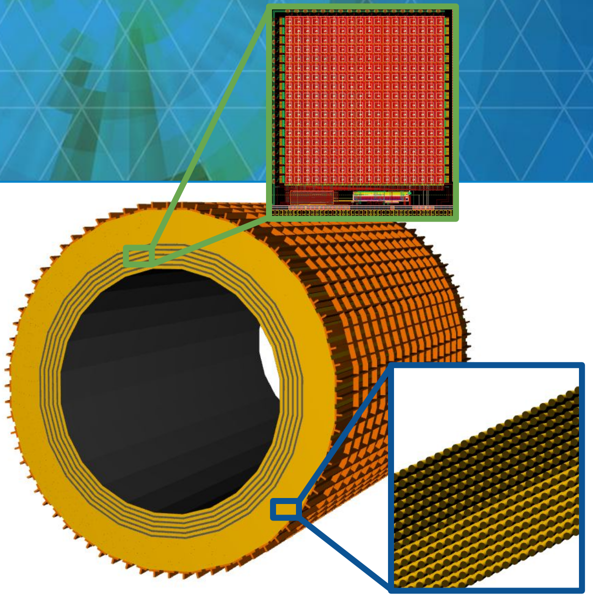
Barrel Imaging Calorimeter (BIC) **Calibration Outline**



Calibration Outline

- The Barrel Imaging Calorimeter consists of two independent detectors, a Pb/ScFi calorimeter and a Si-radiator calorimeter.
- For the Pb/ScFi calorimeter calibration we will use a combination of meson decays, electrons, and kinematic methods - based on experience from GlueX and the HERA experiments.
- The Silicon/radiator calorimeter has a 3-step calibration process:
    a. Absolute pixel energy calibration using a radioactive source during stave assembly.
    b. In-situ position alignment and calibration (identical to the tracker) and energy calibration of the layers using cosmics.
    c. Overall imaging cluster energy calibration using the same methods as for the Pb/ScFi calorimeter.
- During reconstruction: Match clusters from both systems based on their position and energy information

In More Details

General Outline of Detector Calibration

- Treat Pb/ScFi and Imaging AstroPix as **two separate calorimeters**
  - Both measure energy and position, but each is better at different aspects.
  - Calibrate each separately as if they are separate detectors, where one detector can be treated as a part of the passive radiator material of the other.
  - Sampling fractions: Pb/ScFi ~ 10%, Si layers ~ 0.5%
  - In reconstruction, match both calibrated measurements of each shower (energy, position) and combine the information to infer the final measurement.

- **Calibration/Monitoring tools at hardware level**:
  - Monitor the calorimeter performance with independent hardware calibration to check the stability during regular calibration runs (**LED relative light monitoring systems**).
  - For the AstroPix layers, the module production and testing phase will include **source calibrations of chips (absolute energy calibration for each pixel).**

- Envisioned **energy and position calibration for Pb/ScFi** will follow well-established in-situ calibration methods that have been explored in ep colliders and other experiments like GlueX:
  - Following the GlueX calibration method, **the positions of the hits, z,** are calibrated using a sample of pion-enriched charged tracks, comparing the track position projected to the BCAL to the time difference between the two ends of the BCAL. For the same sample of tracks, the point times are calibrated by projecting the time sum of the two ends back to the interaction point using the momentum and trajectory of the track and comparing it to the appropriate accelerator bunch time.
  - The attenuation within the scintillating fibers and the ratio of the gains between each end of a BCAL cell are then extracted by comparing the size of the signal at each end with the z position, calculated from the time difference. The **overall gain for each BCAL cell** is then determined using decay photons of the neutral pion ($\pi^0 \rightarrow \gamma\gamma$).

General Outline of Detector Calibration

- Checks of the **linearity of the response** and systematic uncertainty evaluations **the wide energy range** well above $\pi^0 \rightarrow \gamma\gamma$ can be then obtained:
    - Using the **well-known in-situ calibration methods** used in HERA experiments as **kinematic peak method and double angle method**, which give the calibration point close to the electron beam energy.
    - Using the **exclusive processes** that can give calibration points at lower than e beam energies. Examples used at HERA include the quasi-elastic ρ^0-events (ZEUS) and QED-Compton scattering (H1).
    - Further cross checks and tests of the ECal linearity at even smaller energies can be performed **based on the known resonance masses**, e.g., $J/\psi \rightarrow ee$.
    - Moreover, tracking momentum measurements will be better than those of the calorimeter up to large scattered electron energies at BCal. **Comparing ECal energy with tracker momentum measurements** (E/p) is therefore a further tool for calibration studies.

- The **position calibration for AstroPix layers** will follow the general procedure of tracker detectors. This includes Metrology measurements of detector components (modules, staves) with Coordinate Measurement Machine measurements; comics' and single track MIPs alignment, with magnet off and on; and optical survey of the mechanical structure with position monitoring. The last two steps will be repeated over the course of the experiment.

- The **absolute energy calibration** of AstroPix will happen in the following steps

    - As a part of the production process, assembled AstroPix modules will be automatically calibrated. First the the threshold of each pixel can be adjusted individually by means of a pixel tune DAC (available with v4 of the chip) using injection pulses. Then the absolute calibration will be performed with radioactive sources.

    - When installed in detector the chips will be calibrated using cosmic runs. Finally the overall cluster energy reconstructed in imaging layers will be calibrated using the methods described above for the clusters registered in SciFi/Pb part of the calorimeter (photons of the neutral pion, and methods described in linearity checks).

Exact GlueX Calibration Steps

Note: GlueX-BCAL has ADCs for all channels and TDCs on the inner three layers

1. **Cosmics:** initial calibration is done with cosmics (timing and ADC using MIPs); external triggering (scintillator paddles) and self-triggering employed; without magnetic field and sometimes in coordination with the inner drift chamber tracks.

2. **Beam:** (work with ”points”; a point is a hit registered at both ends; single-ended hits are not used)

   a. Whole detector: Remove ADC and TDC hardware timing offsets (globally for BCAL). Obtained by lining up the timing peak for all hits at zero.
   b. Per channel: 1 number to move the TDC distributions mean to coincide with the ADC distribution mean. Average these offsets and apply to base time for TDC.
   c. Timewalk correction (per channel).
   d. Make correlated offset to each end of the BCAL to set Z=0 at the center. Add time to one and and subtract same time to other end.
   e. Make correlated offset to each end of the BCAL to set global time correct. Add same time to both ends.
   f. Extract point position from end-time difference.
   g. Calibrate the point time offset from tracking. Using showers means a quadratic form for z_track info, with the linear term being the effective speed of light in the fibers.
   h. Extract attenuation length and gain ratio (per channel: upstream divided by downstream)
   i. Fine-tune the gain balancing using $\pi^0 \rightarrow \gamma\gamma$ (bootstrap/iterative)

3. **LED pulser:** used for relative timing shifts and gain shifts; has been effective in monitoring online and offline. Shirt crew and expert operators review ig.

4. **AI:** GlueX has an AI program for monitoring, which is a supervised system, trained by people, but effective in flagging changes to shift crew.

5. **Hadrons:** GlueX has done limited studies with protons, pions and neutrons. Mostly simulations but some with data.

BCAL

One flex cable with 10 Bcal LED miniboards mounted on 10 acrylic light guide, covered with black cover