NPS Calibration

- Proposal based on experience with DVCS/Hall A PbF2 calorimeter

- Experience from the WACS experiment

Credit: C. Munoz-Camacho, B. Wojtsekhowski

NPS calibration proposal (from experience with Hall-A PbF_2 calorimeter)

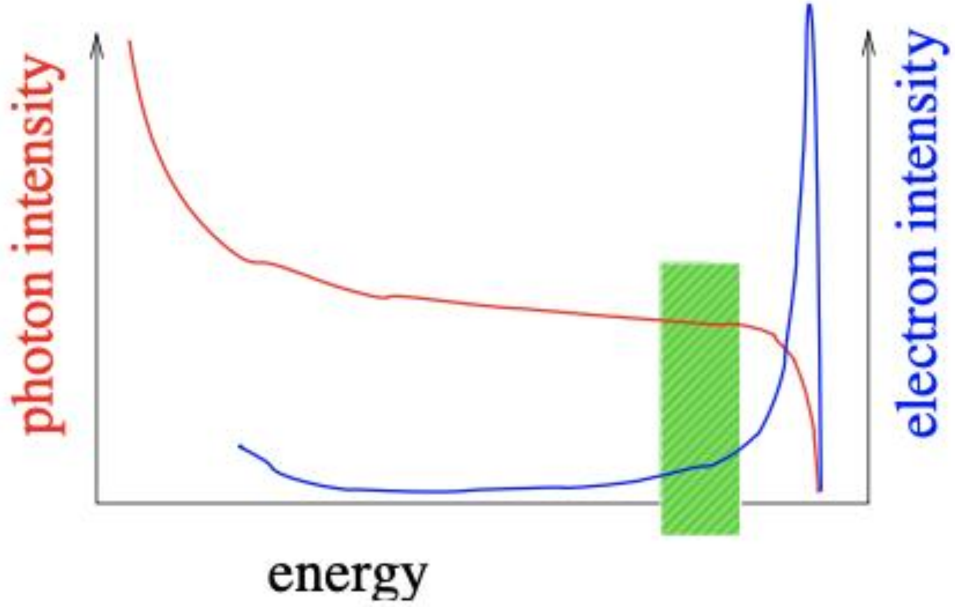
1) Cosmics: vertical rays (traversing one single column) deposit a relatively well defined MIP-energy peak
    - 10-20% calibration with about 24h of data. A couple of iterations (i.e. HV adjustments) usually needed.
    - Limitation: Energy deposit (and so PMT HV) far from running conditions.
2) Elastic calibration (p'-> HMS; e'-> NPS): The best way!
    - Requires change of HMS polarity and several HMS angles to cover NPS horizontally. For vertical coverage, NPS needs to move back.
    - Some kinematics settings and beam times worked out by J. Murphy for NPS
    - Disadvantage: it takes 24h of invasive time (including the 2 polarity changes and 1-2 shifts of data taking)
3) Exclusive π^0: monitoring the 2-photon invariant mass and the proton missing mass squared allows for continuous non-invasive calibration
    - Disadvantage: 2 clusters per event -> not 1-to-1 calibration, and several iterations needed
    - Limitation: about 24h of data is required (interpolation sometimes needed in case of rapid variation of coefficients)
4) LED pulses: new for NPS, to be tested.
    - Each crystal can be probed by an individual pulsed LED, continuously during data taking (separate DAQ trigger)
    - Continuous *relative* calibration of each channel
    - Potential disadvantage: crystal response to LED might be different from electromagnetic shower
    - Limitation: stability of LEDs over time, radiation damage of LED (plastic) enclosures…

Calibration of the calorimeter in WACS 2002 experiment

Radiation damage vs. depth in crystal

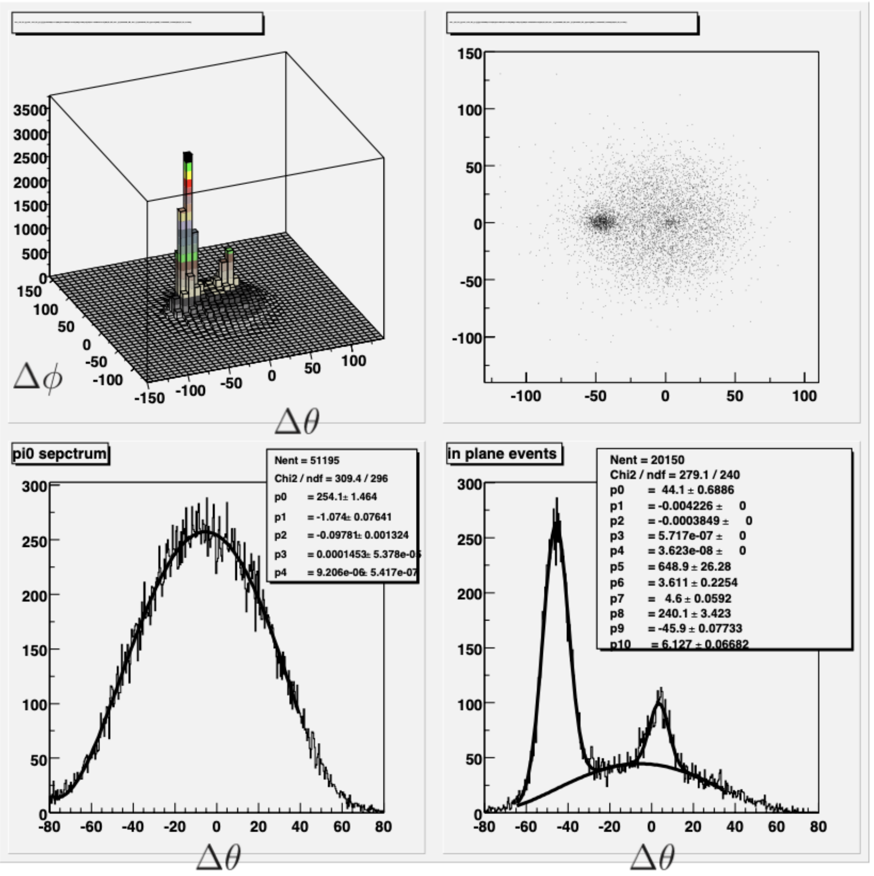
New in this experiment: 1000 times higher γ flux
15 times better d.f. , mixed electron-photon beam

- Electron/photon energy spectra



Kinematical proton-photon correlation

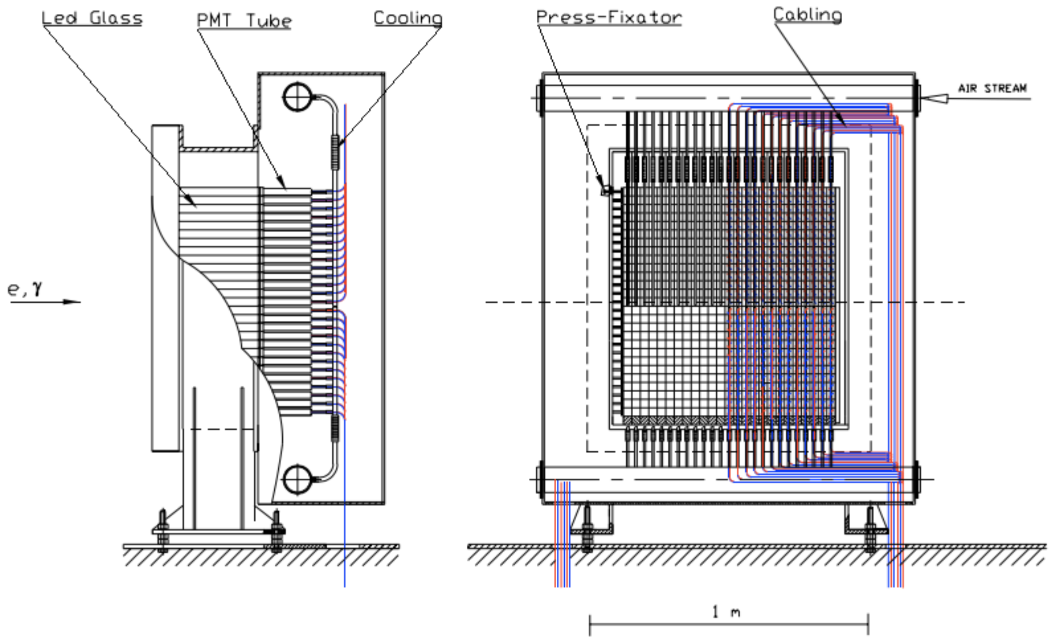
$$\Delta\theta = \theta^{\gamma}_{expected} - \theta^{\gamma}_{observed}$$
$$\Delta\phi = \phi^{\gamma}_{expected} - \phi^{\gamma}_{observed}$$



$|\Delta\phi| > 15$ $|\Delta\phi| < 10$

3.7.3 Electromagnetic Calorimeter

The calorimeter is made up of a total of 704 lead-glass blocks, with a FEU-84/3 PMT optically coupled to the rear of each block. The lead-glass is arranged in 22 columns and 32 rows, as shown in Fig. 18, leading to a cross-sectional area of $128 \times 88 cm^2$. It is housed within a light-proof containment structure with interlocked doors at the rear for easy access to the PMT's. Figure 4.8: Diagram of the RCS calorimeter which shows the arrangement of the lead-glass blocks, the forced-air cooling system and the cabling, within the support structure. From the angular resolution requirements and the lead-glass properties shown in tab. 4.4, the individual blocks were chosen to have the dimensions $4 \times 4 \times 40$ cm^3. They were wrapped in aluminized Mylar film and black Tedlar to ensure there was no exposure to external light, which could seriously damage the PMT's. Individual tubes were coupled to the lead-glass by optical grease and pressed into contact by springs attached between a grid of steel supports and the base of the tube. The PMT is one of the essential tools in experimental physics. It is used to produce and amplify an electrical signal from optical photons, in this



In order to calibrate the calorimeter elastic *ep* data were taken with the following rearrangements of the experimental setup:

- The photon spectrometer and the HRS were positioned to elastic *ep* kinematic.
- The copper radiator was removed.
- Deflection magnet was turned off.

The requirement to have very clean *ep* elastic data is very important for calorimeter calibration. This implied a condition to run under low current to avoid from background events that could not be removed by kinematic cuts. We usually ran up to 10 μA current, except for a few cases where it was necessary to test the performance of the calorimeter under

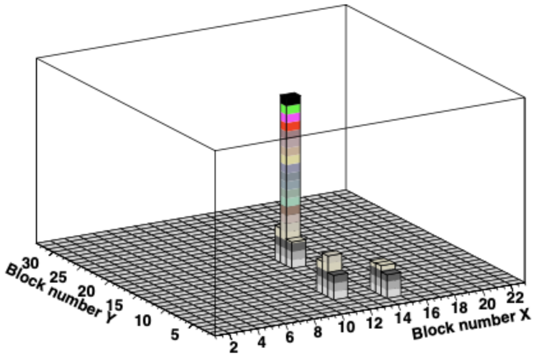


Figure 26: Elastic *ep* event sample in calorimeter, beam current was 10 μA.

lead glass blocks. The radiation dose each block receives causes the latter to lose its ability to pass Čerenkov light making it less transparent. This causes the Čerenkov light produced in the calorimeter blocks to be absorbed before reaching the cathode of the PMT, leading to the energy resolution loss of the calorimeter. Another reason of energy resolution loss is the non-uniform reduction of each block's transparency. The significant part of the particle's energy is deposited in the first 10-20 cm of the block. The latter makes the front part of each block less transparent than the rest of it. This makes the collected light on PMT's cathode highly instable quantity, since it becomes dependent on the position within the block where an electromagnetic shower was initiated. All factors described above contribute to the worsening of the energy resolution.

A study of the calorimeter energy resolution versus total collected beam charge has been performed. The resolution is calculated for 1 GeV according to the following formula:

$$\sigma_E[\%]|_{E=1GeV} = \sigma_E[\%]|_E\sqrt{E[GeV]} \tag{5.50}$$

By the time the experiment came to an end, the total radiation dose is estimated to be 30 Coulomb and the energy resolution had fallen from 4.9 % at the beginning to 11 %, see Tab. 4 and Fig. 4. The resolution of 11 % was enough in order to discriminate the RCS events from the background.

6.3. Annealing of the radiation damage

The front face of the calorimeter during the experiment was protected by plastic material with an effective thickness of 10 g/cm^2. For the majority of the time the calorimeter was located at a distance of 5-8 m and an angle of 40-50° with respect to the electron beam direction. The transparency of 20 lead-glass blocks was measured after the experiment, the results of which are shown in Fig. 21. This plot shows the relative transmission through 4 cm of glass in the direction transverse to the block length at different locations. The values were normalized to the transmission through similar lead-glass blocks which were not used in the experiment. The transmission measurement was done with a blue LED (λ_{max} of 430 nm) and a Hamamatsu photo-diode (1226-44).

A UV technique was developed and used in order to cure radiation damage. The UV light was produced by a 10 kW total power 55-inch long lamp[9], which was installed vertically at a distance of 45 inches from the calorimeter face and a quartz plate (C55QUARTZ) was used as an infrared filter. The intensity of the UV light at the face of the lead-glass blocks was found to be 75 mW/cm^2 by using a UVX digital radiometer[10]. In situ UV irradiation without disassembly of the lead-glass stack was performed over an 18 hour period. All PMTs were removed before irradiation to ensure the safety of the photocathode. The resultant improvement in transparency can be seen in Fig. 21. An alternative but equally effective method to restore the lead-glass transparency, which involved heating of the lead-glass blocks to 250°C for several hours, was also

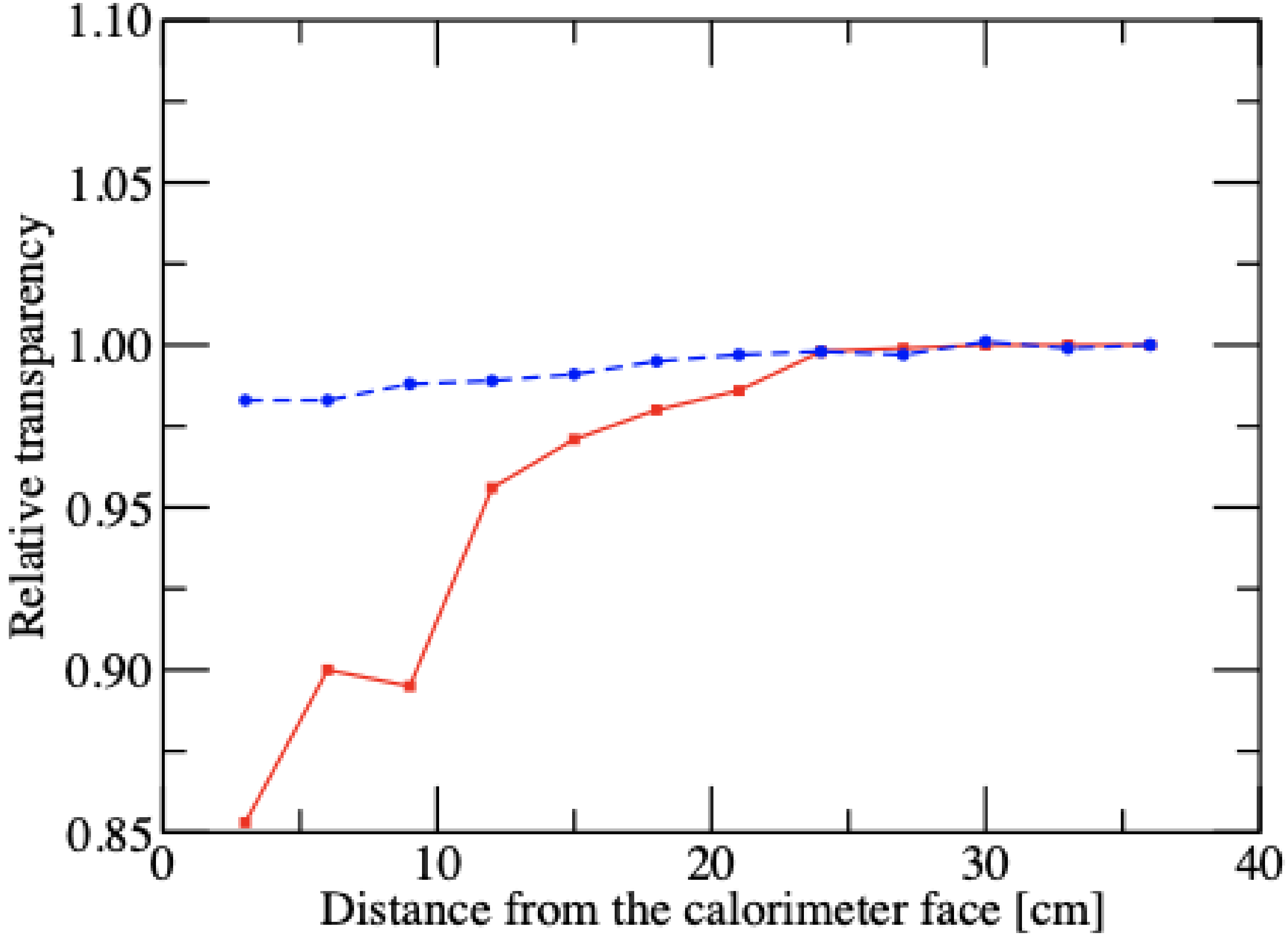


Figure 21: The blue light attenuation in 4 cm of lead-glass vs distance from the front face of calorimeter measured before (solid) and after (dashed) UV irradiation.