Some methods which were used for Hycal offline analysis

I Larin, ITEP Moscow

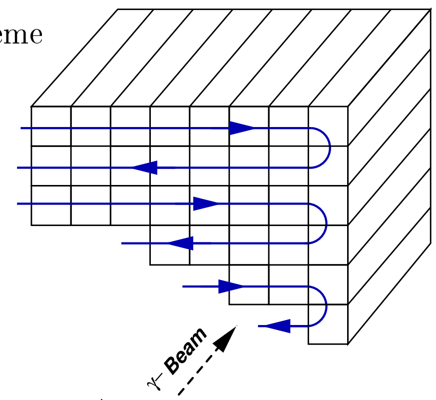
March 27, 2005

Contents

0.1 Energy Calibration: Algorithms and DST Structure

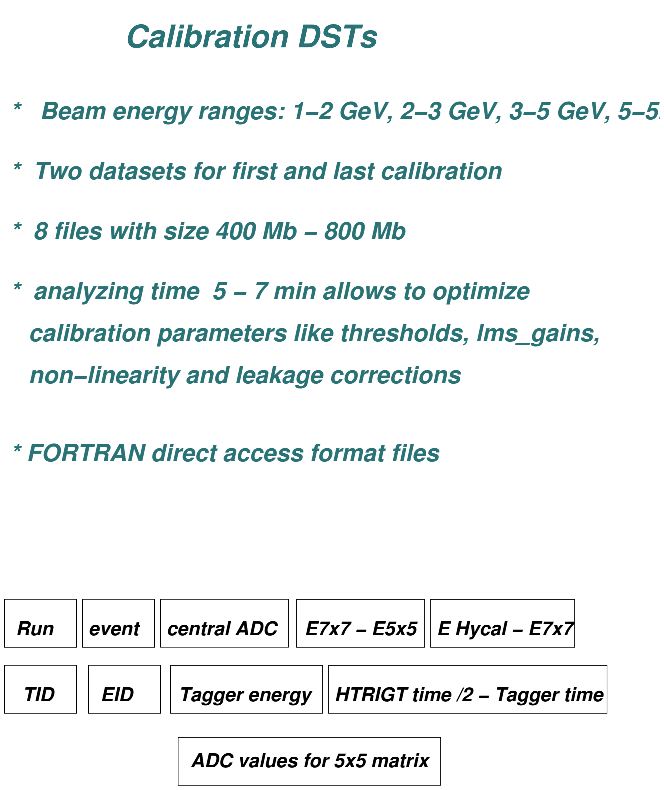
Hycal ADC energy calibration has been applied for two PRIMEX snake-scan (fig.1) data set: the first one contains runs 4132-4206; the second one - runs 5334-5419, 5442-5445.

Figure 1: The calibration snake-scan scheme

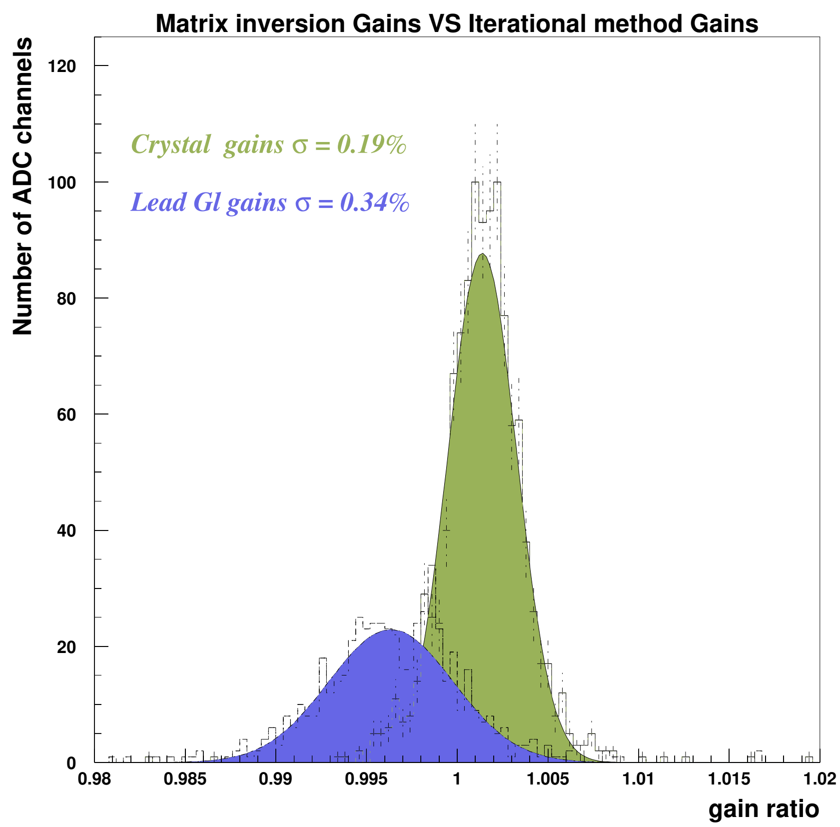


First, DST-files were created for both datasets, different files for different beam energy ranges. DST-files location on the SILO is $/mss/hallb/primex/DST/october\_2004/calib\_dst/$. File naming scheme is **clb**$i_1 i_2$**.dst**. Where i_1 is for energy range index ($1 \sim$ E = 1...2GeV, $2 \sim$ E = 2...3GeV, $3 \sim$ E = 3...5GeV, $4 \sim$ E = 5...5.5GeV); i_2 for dataset index ($1 \sim$ first dataset, $2 \sim$ last dataset, x $\sim$ transition scan dataset).

Examples of routines reading these DST can be found in cvs directory *tools/clbdst/*. Below is the summary of the DST structure:

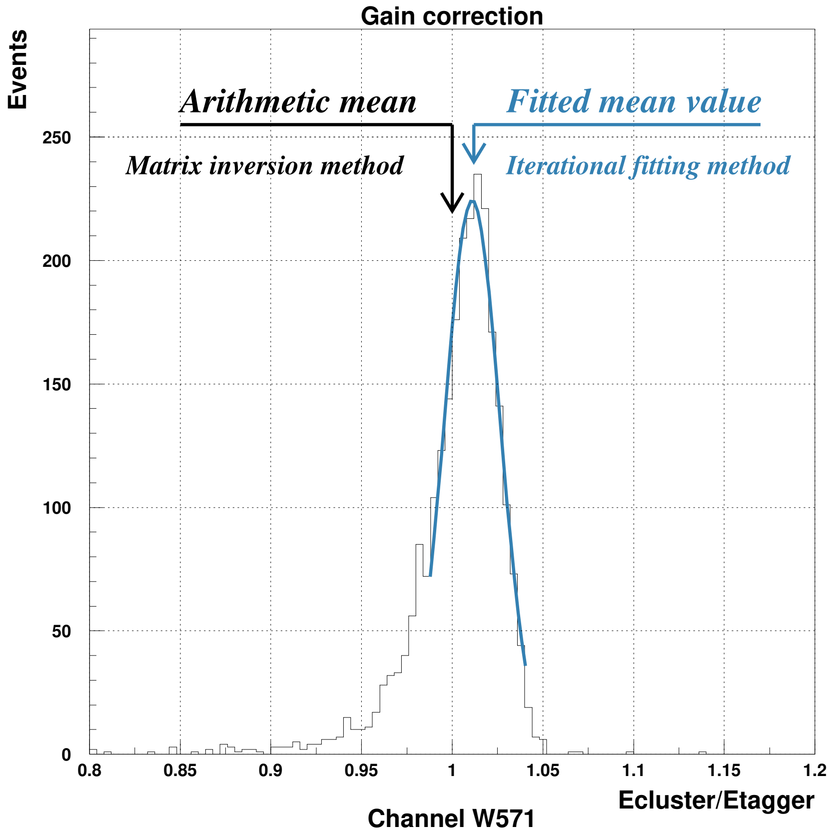


After that, DST-files have been analysed and histograms with ADC and beam energy ratio were filled for each channel (for certain beam energy). All histograms were fitted and peak position values (found from the fit) were used as a correction factors. After few iterations ($3 \div 4$) gain factors converged. This method is stable for presence of the background and for asymmetric amplitude spectra. Another method (so called "matrix inversion" method) also has been used for gain finding. Comparison of gain factors obtained with these two methods is presented on the next plot:

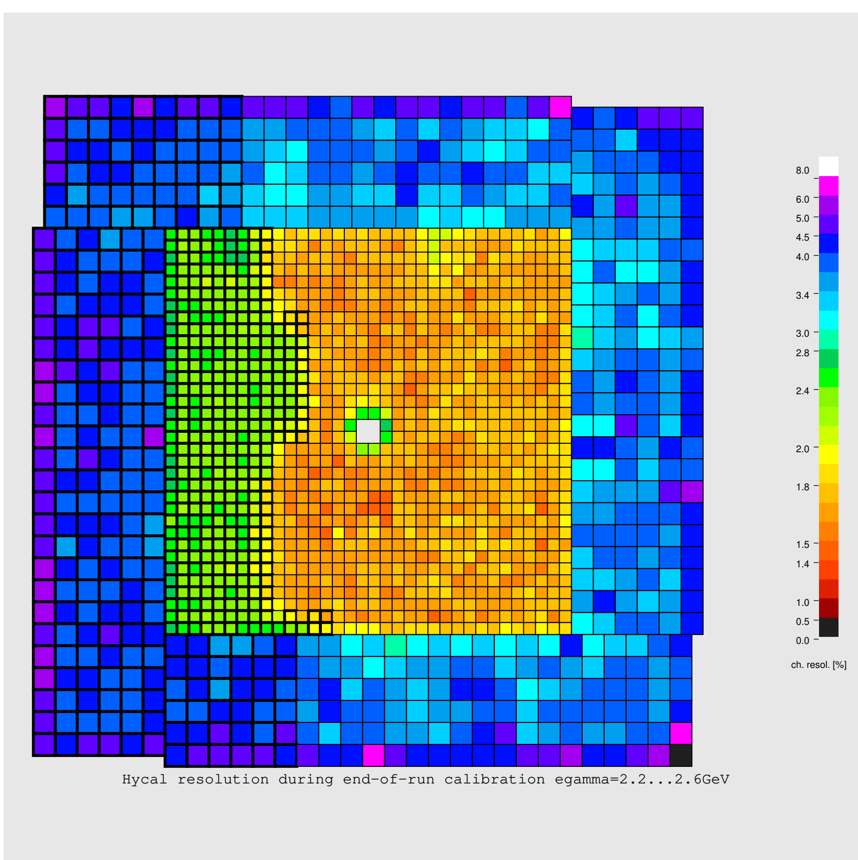


Gains from these two methods are close to each other. "Matrix inversion" method allows to produce calibration faster since it doesn't require iterations, but it gives some systemtic shift in case of asymmetric amplitude spectra (since it finds arithmetic mean of amplitude distributions instead of their maxima, fig.2). Also it works worse in case of background presence (snake scan data have practically no background).

Figure 2: An example of amplitude spectra for ratio of cluster and beam energy



The next color scheme presents Hycal energy resolution after the calibration for beam energy 2.2÷2.6GeV during the last snake-scan.



0.2 Hycal alignment, e-m shower depth coordinate correction and energy nonlinearity correction

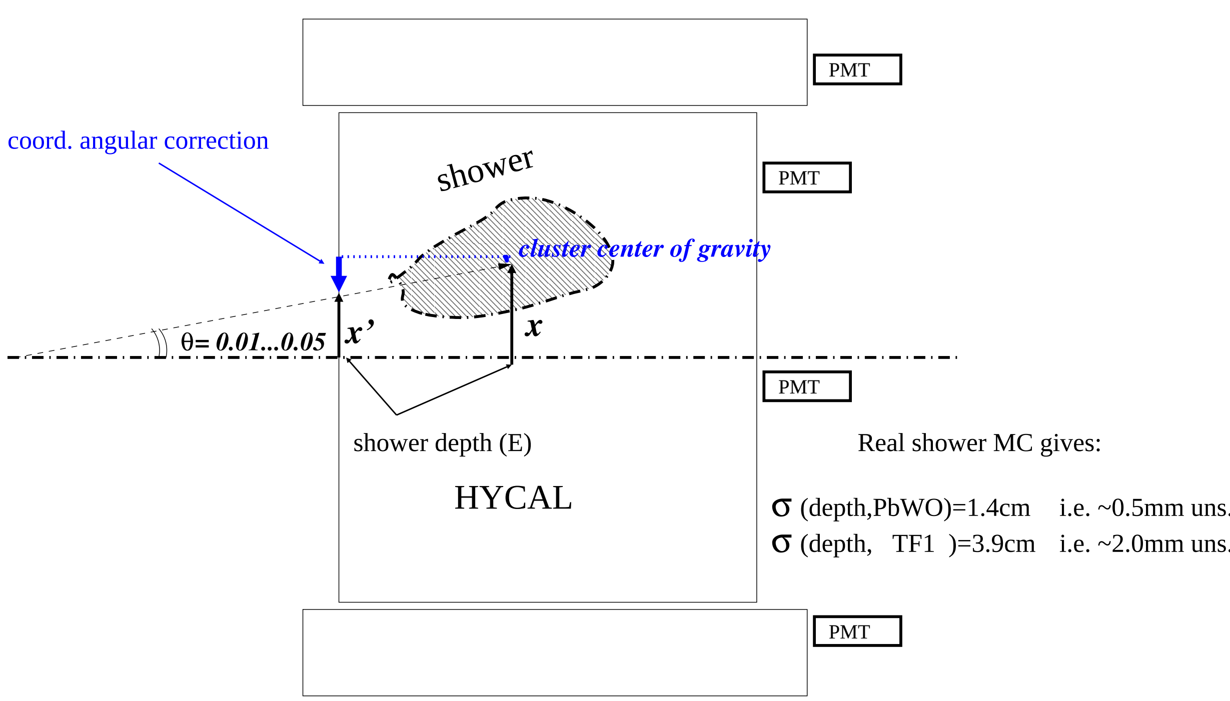
Hycal alignment constants for x and y shift between Hycal center and beam position were obtained from Compton runs ([1]) and stored into Caldb (system *glass* or *crystal*, attribute *alignment*). They are readed into offline analysis (program *prim_ana*) in the new structure introduced into header file *hycal.h*:

```
typedef struct {
float x, y, z,   // coord on the front surface of Hycal center
tx, ty, phi,     // Hycal slopes and rotation
dt;              // Global time shift between HTRIGT and TAGGER
} hycal_alignment_st;
```

Only x, y, z are filled for now. Z-coordinate corresponds to estimated upstream surface of Lead Glass or PWO modules. tx, ty, phi are reserved for Hycal rotation and *dt* for global timing alignment between Hycal time and Tagger time.

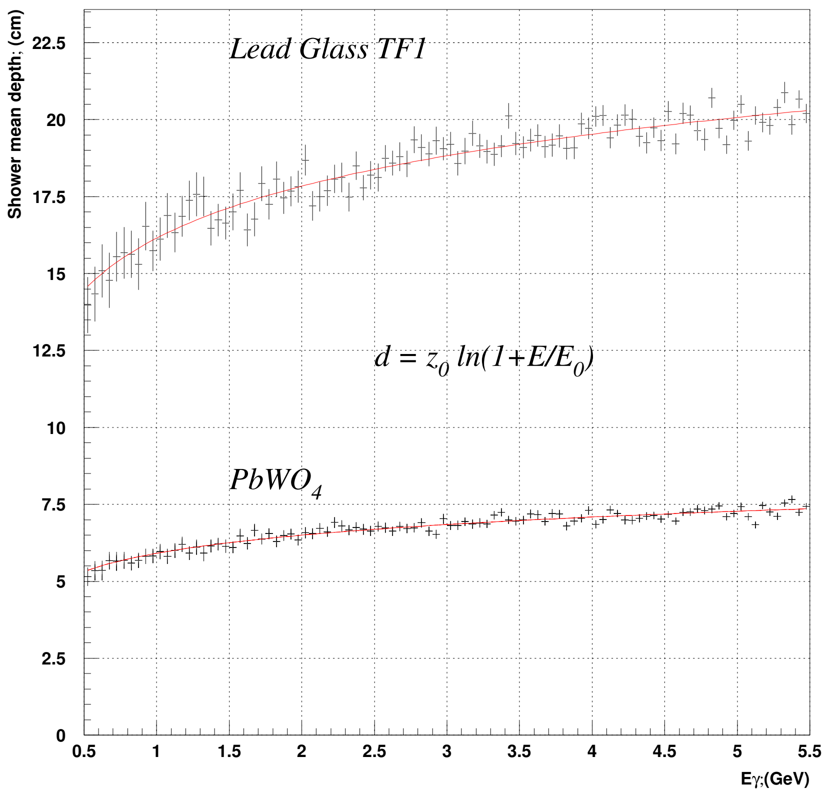
Next simple scheme represents the idea of the angular correction for coordinates:

Depth correction to coordinates:



Mean values of shower depth depends on the γ energy logarithmically (fig.3).

Figure 3: Dependence of the of shower mean depth on the γ energy for Lead Glass and PWO obrained from the GEANT



The formula for corrected coordinate is:

$$x' = \frac{x}{1+\frac{d}{z}}$$

where z is the Hycal distance from the target and d is the estimated shower depth.

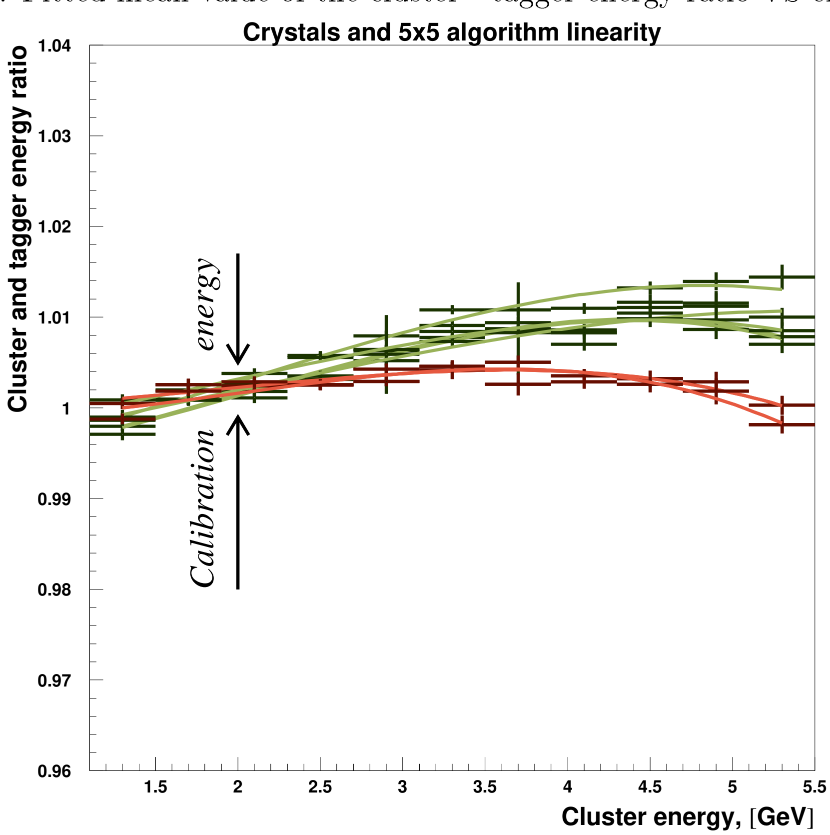
Parameters z_0 and E_0 for the mean shower depth formula (see fig.3) are found from the Monte-Carlo:

system	z_0 [cm]	E_0 [GeV]
glass	2.67	$2.84 \cdot 10^{-3}$
crystal	0.86	$1.10 \cdot 10^{-3}$

Note that one exception has been made: coordinates obtained by the simple center of gravity method have been left unchanged by alignment and angular correction and could be used as Hycal intrinsic coorinates.

It has been noted during "snake-scan" energy calibration that amplitude response of the Hycal modules is not absolutelly linear. Whatever the reason: physical processes in e-m showers, ADC linearity or something else, this effect can simply be taken into account by introducing small correction to the cluster energy. Since first calibration has the biggest statistics, it's been used for obtainig correction factor for each channel. First, energy of a cluster is calculated with the ordinary technique. After that, appropriate constants are picked up from the caldb for corresponding cluster central-*id*. The shape of the amplitude response for banch of ADCs is presented on the fig.4.

Figure 4: Fitted mean value of the cluster - tagger energy ratio VS cluster energy



All the curves comes together at the energy about 2GeV since this energy been used for calibration. It's been noted that the shapes of non-linearity could be well described with the formula:

$$E' = \frac{E_0}{1+\Delta(\alpha-\beta\Delta^2)\cdot 10^{-3}}$$
$$\text{where } \Delta \equiv E_0 - 2GeV$$

Parameters α and β are loaded into Caldb, s=$glass/crystal$, attribute = $nonlin\_e1/2$.

0.3 π^0 analysis

Each cluster has zero, one or more potential times (HTRIGT hits) which can be associated with it, and this time(s) is compared to the times of all hits in the tagger in that event. Clusters, whose potential time(s) falls within a timing window (tagger time - cluster time) of ~30 ns are chosen. As a second step, the companions of the chosen clusters are selected using the same criteria: their time should be within 30 ns of the time of the first cluster (one has to keep in mind that efficiency of such time matching decreases (from the plateau value) for clusters with energies below 0.7÷1.0 GeV).

After this "time selection" procedure, each cluster can enter more than one pair, and each pair can have several potential tagger hits associated with it. Physics distributions, such as mass or the scattering angle, are plotted such that the one pair of clusters enters only once into the mass plot (first tagger photon passed over all cuts is picked, invariant mass doesn't depend on beam energy). But it is possible that one cluster will enter the histogram several times (if it is a member of several pairs of clusters).

There are two approaches that were used in this analysis. In the first approach, the data were broken into bins of the π^0 scattering angle, θ_{π^0} where:

$$\begin{aligned} \theta_{\pi_0} &= \sqrt{{\theta^x_{\pi^0}}^2 + {\theta^y_{\pi^0}}^2} \\ \theta^x_{\pi^0} &= \frac{E_1 x_1 + E_2 x_2}{(E_1 + E_2) z}. \end{aligned} \tag{1}$$

Events are broken into the θ_{π^0} bins, from 0 to 4 degrees, and for each bin, the same certain cut on $R \equiv \frac{E_1+E_2}{Ebeam}$ is applied , and the mass of two clusters ($m = \sqrt{2E_1E_2(1 - cos\theta_{12})}$) is found. Here, θ_{12} is the opening angle between 2 clusters:

$$cos\theta_{12} = \frac{x_1x_2 + y_1y_2 + z^2}{\sqrt{x_1^2 + y_1^2 + z^2}\sqrt{x_2^2 + y_2^2 + z^2}} \tag{2}$$

The mass histogram is fitted, and the number of events in the signal

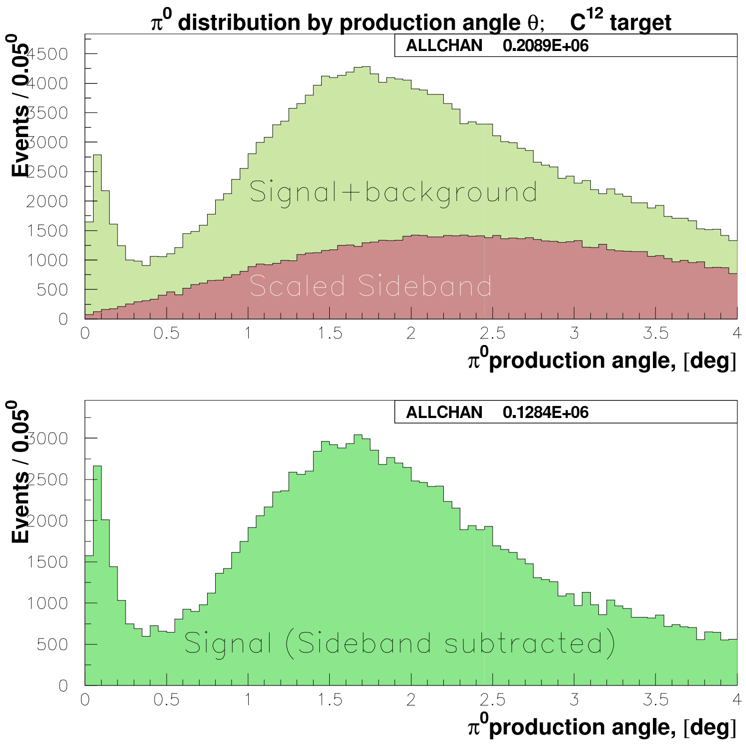


Figure 5: An example of $dN/d\theta_{\pi^0}$ distribution for the ^{12}C target. The scaled background is shown as a brown band (as described in the text).

above background, N with the associated uncertainty, ΔN is found for every θ_{π^0} bin. The number N is plotted as a function of the central value of the corresponding θ_{π^0} bin. The resulting plot is shown in the top green histogram, Fig. 5.

In the second approach, the data is broken into bins of R, not θ_{π^0}, and the mass is found for $\theta < 4$ degrees. Number of events under the π^0 mass peak is plotted as a function of R-value, as shown in Fig. 6.

The problem with the second approach is that the number of events in such plots will be $(10 \div 15\%)$ larger than the number of events resulting from the first approach, as the same cluster pairs can enter into the different bins in R, since each pair can be associated with several different tagger photons. Therefore this dN/dR distribution is not using for counting π^0s, but only for estimation of background fraction under "in-time exclusive peak". The mass constrain correction is applied for the π^0 energy (for

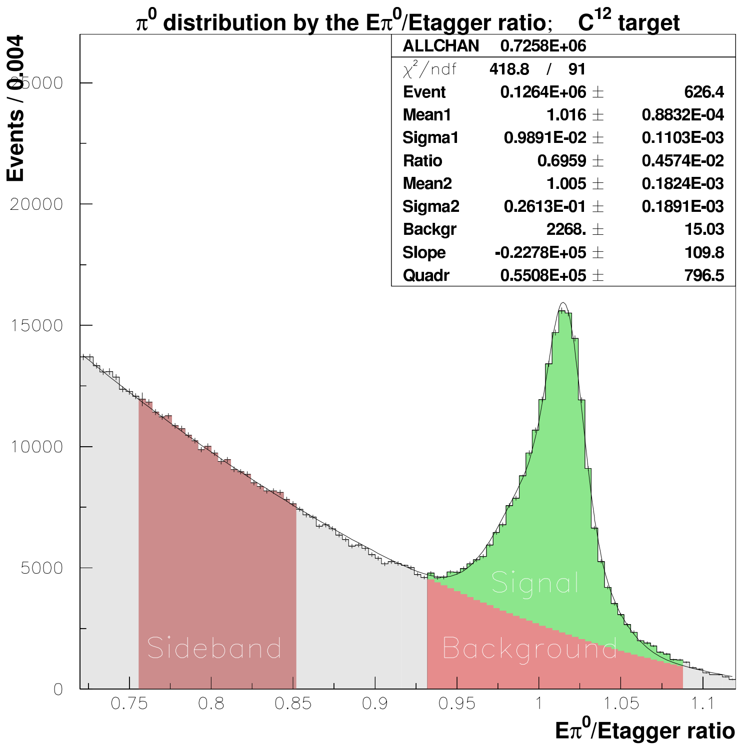


Figure 6: An example of dN/dR distribution on the ^{12}C target.

parameter R calculation, see chapter 0.4).

The plot of N vs R can be fitted to calculate the size of the background under the exclusive π^0 peak. It should be mentioned that the word *background* here means real π^0s (or events in inv. mass plot in the gaussian peak), but these "*background* π^0s" don't come from exclusive production processes (like Primakoff, coherent, etc) or they may come from any accidental (out-of-time) processes.

The fit is shown in Fig. 6, where the area under the polynomial contribution of the fit can be found, so that the number of events in the background is determined, N_b. Next, some sideband of data is chosen from the plot, from some value of R_1 to some larger value of R_2, out of the π^0 mass peak, and the number of events in that sideband is found to be N_s. The distribution of N vs θ_{π^0} can be plotted for the same range of R: $R_1 < R < R_2$, and scaled by N_s/N_b. $dN/d\theta_{\pi^0}$ distribution for the scaled sideband is shown in Fig. 5 (top brown histogram). Eventually we subtract from the orginal $dN/d\theta_{\pi^0}$ distribution estimated contribution from the "background processes" (fig. 5, bottom histogram).

0.4 π_0 Mass and Energy Constrain

The fact that the mass of π^0 is well known can be used to correct the product of the energies of two clusters, so that the resulting mass is that of π^0. Suppose, we have 2 clusters with E_1 and E_2, and the mass is found to be $m = \sqrt{2E_1E_2(1 - cos\theta_{12})}$. If the "true" reconstructed mass is the known m_{π^0}, the energies of the clusters can be modified:

$$\begin{aligned} m_{\pi^0} &= \sqrt{2E_1'E_2'(1 - cos\theta_{12})} \quad (3) \\ E_1' &= E_1 + \Delta E_1 \\ E_2' &= E_2 + \Delta E_2 \end{aligned}$$

A system of two equations can be formed and solved for ΔE_1 and ΔE_2:

$$\begin{aligned} m_{\pi^0} &= \sqrt{(E_1 + \Delta E_1)(E_2 + \Delta E_2)(1 - cos\theta_{12})} \quad (4) \\ \frac{\Delta E_1}{\Delta E_2} &= \frac{\sigma E_1}{\sigma E_2}, \end{aligned}$$

where $\sigma E_i = E_i[a \oplus \frac{b}{\sqrt{E_i}}]$, and a and b are found empirically from the energy calibration data, and are different for the PWO crystals and lead glass. This simple well-known technique allows to improve π^0 energy resolution by factor of more than 2 (for PRIMEX experiment case). Examples of distributions for π^0 and beam energy ratio after mass constrain are shown in fig.7.

Another well known parameter in this experiment is the beam energy, given precisely by the tagger E-counters (~ 0.1 percent). This knowledge can also be used to constrain the energies of the clusters. Since we're analysing exclusive production processes, we assume that beam energy must be equal to π^0 energy (energy transfered to the nucleus is less than

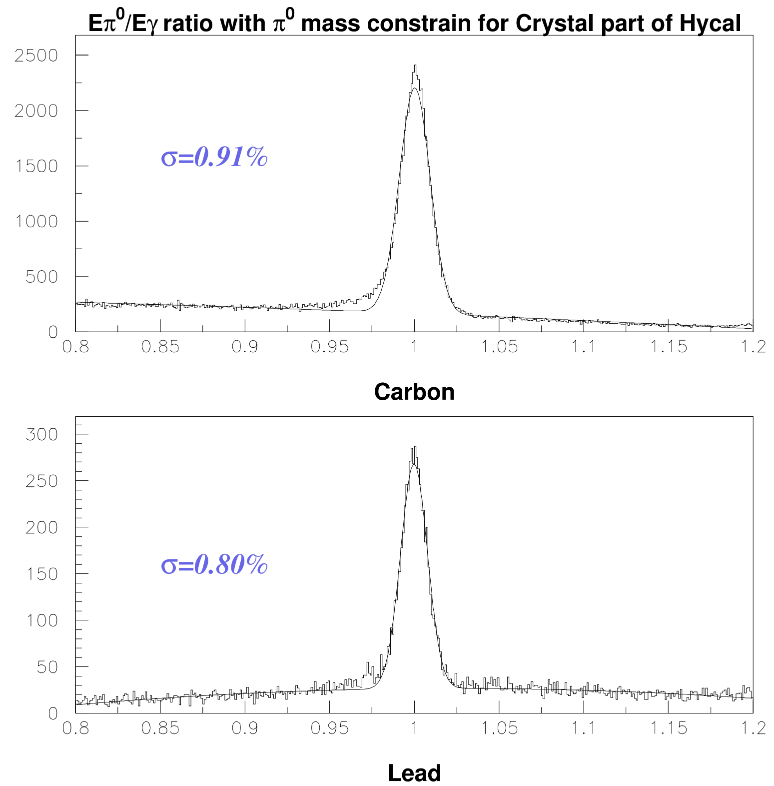


Figure 7: The ratio of $(E_1'+E_2')/Etagger$ after the application of mass constrain technique

1 MeV). This assumption is not true for accidentals and for "background processes". Therefore this technique will spread π^0 mass peak, make it look like background for "background" π^0s. It is possibly could be used for separation of Primakoff, coherent and incoherent π^0 production from other processes and accidentals. Monte-Carlo needed to proove or reject of usage such method for this "unusual" purpose.

The equations in this case will be:

$$\begin{aligned} E_1' + E_2' &= E_{tagger} \\ \frac{\Delta E_1}{\Delta E_2} &= \frac{\sigma E_1}{\sigma E_2} \end{aligned} \tag{5}$$

The resulting corrections ΔE_1 and ΔE_2 are found and applied to the energies of the clusters, and the mass is reconstructed. The effect of this technique can be seen in the figure (8): a) the resolution of the mass peak is improved by more than a factor of two after applying the energy constrain technique; b) accidental and "background" π^0s are dropped from the gaussian peak like leaves from the tree in the fall.

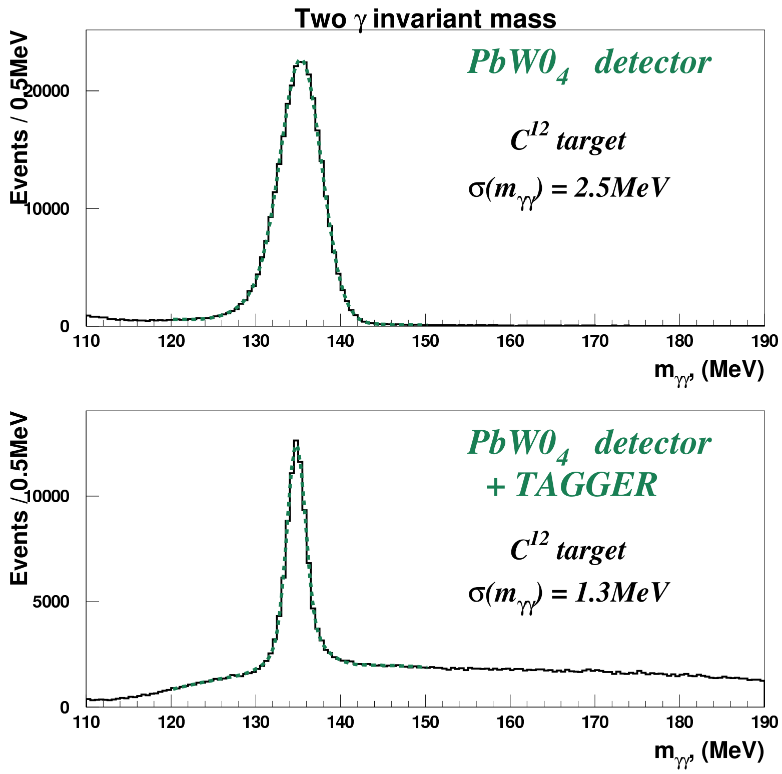


Figure 8: Mass of π_0 before and after the application of the energy constrain technique

0.5 π^0 skim files: production and "empty target / empty frame" runs

At the first stage, the skim files with only the raw data banks were created from the production runs. The following cuts were used to select events for the skim files:

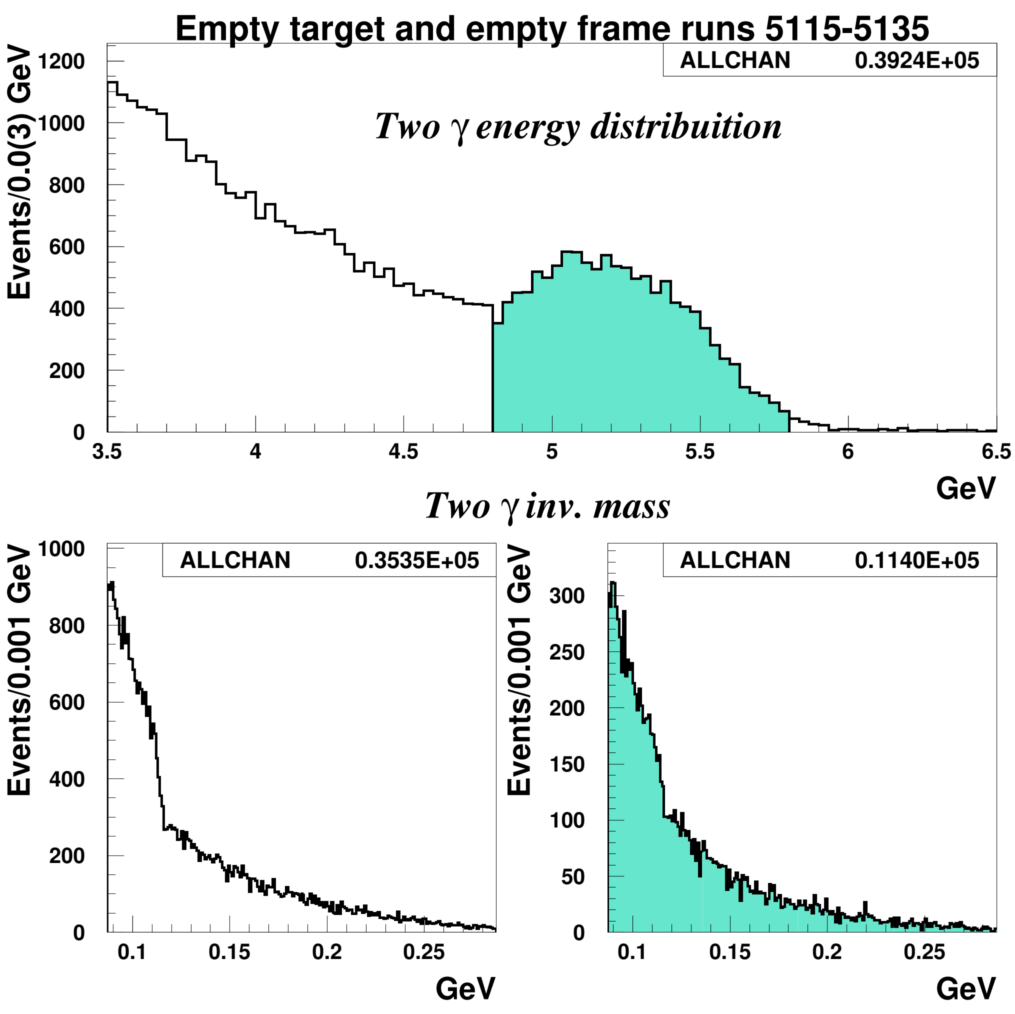
1. $E(\gamma\gamma) < 8$ GeV
2. $M(\gamma\gamma)$ >85 MeV (assuming z = 740 cm)
3. Clusters with $|x|$ and $|y|$ both less than 3.8 cm were excluded from the analysis
4. No timing cuts

These produced skim files can be found on the SILO, in the following directory:
/mss/hallb/primex/skim/october_2004/pi0_pass1. There are 401 runs in the pi0_pass1 directory with 76Gb and about 3.1M π^0. The approximate number of π^0s per run is available on the web in the PRIMEX area: *Primex* : *Subsystems* : *Hybrid Calorimeter* : *Oct−Nov* 2004 *Production Runs Summary*. The list of π^0 events with the appropriate run and event number is also stored on the silo:
/mss/hallb/primex/DST/october_2004/event_list/pi0_pass1.evelist.gz. Two files with some beam parameters from the production runs can be found in the same directory:
/mss/hallb/primex/DST/october_2004/event_list/pi0_pass1_4491_4999_erate.txt.gz and
/mss/hallb/primex/DST/october_2004/event_list/pi0_pass1_5000_5439_erate.txt.gz. These files contain the record of the number of hits in the tagger T-counters between 2 adjacent written clock triggers, and have the following format: run-number, clock-event-number, number-of-hits between the previous and current written clock event. This information could be used for cutting out beam trips out of the data.

Skim files with the same cuts as have been used for the production runs were created for the "empty target" runs (runs 5115-5131, **78802671** events total) and for the "empty frame" runs (runs 5132-5135, **22364755** events total). This statistics corresponds to a few percent of total production statistics. There is some "quasi-elastic" structure in two γ energy distribution (see the fig. below). Mass plots show no π^0-like structure in the right place in neither the whole energy spectrum (white histogram), nor in the "quasi-elastic" energy spectrum part (green histogram).

These measurements are important for making sure that the PRIMEX experiment doesn't have significant π^0s contribution from "non-target" area due to a beam imperfection. These events also could be used for study and simulation of background coming from "out of target" sources.

Mass storage location for these skim-files is
$/mss/hallb/primex/skim/october\_2004/pi0\_empty/$.
MOR-skims for these runs were also created.



0.6 PARTICLE Bank: π^0 entry

PARTICLE Bank is now filled with the reconstructed π^0s as well as any accidental 2γ pairs with the mass greater than 85 MeV. 4-momentum of corrected values using the mass constrain technique has been added (vs). Also, an array of links has been added, with the pointers to the particles or clusters which current reconstruction is using. For the $\pi^0 \to \gamma\gamma$ case the array contains numbers of two clusters which make up current π^0 reconstruction.

Name	**Type**	**Comment**
v	vect4_t	4-vector E,px,py,pz in GeV
vc	vect4_t	same as **v** but with mass constrain applied
type	int	See *kinematics.h*: geant_particles_t enum
link[8]	int	link to clusters or another particles
p	float	GeV/c
m	float	GeV/c^2
theta	float	radians
phi	float	radians
creation	vertex_t	creation vertex (probably somewhere in target)
detector	vertex_t	point at which particle entered detector

This is a bankdump example for changed *PARTICLE* bank:

HYCALCLUSTER:

row	scheme	type	#hits	id	E	time	x-coord	y-coord	z-coord	chi2	veto	x1	y1
0	5	-1	19	1698	3.04533	0	0.540706	-8.81157	731.89	0	1	-1.68368	-7.82223
1	5	-1	5	65	0.439799	0	43.7502	45.9541	731.89	0	1	38.4977	48.5359

- -

PARTICLE:

row	type	link0	link1	p	m	theta	phi	E	px	py	pz	Ec
0	7	0	1	3.47241	0.109469	0.00795189	-0.301254	3.48513	0.0263685	-0.00819296	3.4723	3.89613

Creation and detector verticies variables are unused for now.

References

[1] Yelena Prok, "Alignment Procedure for the HyCal Detector", PrimEx Note #33, March 16, 2005