analysis of KL tests at BTF

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outline

• BTF setup and data samples
• analysis of ADC information
  – data preparation
  – data quality cuts
  – energy loss in TOF counters
  – linearity and resolution with 2 KL layers
  – comparison between 1 and 2 KL layers
• analysis of TDC information
  – estimates of time resolution with 1 and 2 KL layers
BTF setup and data samples
readout chain 1

PM signals, adapted to 50 Ohm and properly delayed are sent directly to CAEN V792 QDC.

Energy scan with both KL layers

<table>
<thead>
<tr>
<th>energy (MeV)</th>
<th>runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>168-170</td>
</tr>
<tr>
<td>100</td>
<td>162-164</td>
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<tr>
<td>150</td>
<td>156-158</td>
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<tr>
<td>200</td>
<td>150-152</td>
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<tr>
<td>250</td>
<td>141-146</td>
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<tr>
<td>300</td>
<td>135-137</td>
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<tr>
<td>350</td>
<td>124-129</td>
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</tbody>
</table>
readout chain 2

PM signals, adapted to 50 Ohm and properly delayed are splitted and sent to CAEN V792 QDC and, after discrimination (leading edge), to CAEN V775 TDC (was incorrectly indicated as 1290 in some previous talks).

Energy scan with both KL layers

<table>
<thead>
<tr>
<th>energy (MeV)</th>
<th>runs</th>
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<tbody>
<tr>
<td>75</td>
<td>227-229</td>
</tr>
<tr>
<td>100</td>
<td>190-192</td>
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<tr>
<td>150</td>
<td>218-220</td>
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<tr>
<td>200</td>
<td>215-217</td>
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<tr>
<td>250</td>
<td>206-208</td>
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<td>300</td>
<td>203-205</td>
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<tr>
<td>350</td>
<td>193-195</td>
</tr>
</tbody>
</table>
additional data with readout chain 2

- run 317 at 100 MeV without the 3 TOF slabs (1 inch each) in front of KL
- runs 277-284 at 100 MeV with increased HV (+60 V)
analysis of ADCs
data preparation

• pedestals: they change from run to run and had to be recomputed for each run

• equalization: default hardware equalization was modified in the first scan multiplying PM 8 by 1.4 and in the second one multiplying PM 9 by 1.3 (see plots comparing PM9 in red to PM 8 in second scan, before and after equalization)
energy reconstruction

after pedestal subtraction and equalization we can define the energy seen by KL in two ways:

• sum of the 12 PM signals

• sum of the 6 modules signals where each module energy is defined as
  \[ E_{\text{mod}} = 4 \times \frac{\text{PM}_{\text{left}} \times \text{PM}_{\text{right}}}{\text{PM}_{\text{left}} + \text{PM}_{\text{right}}} \]
  (the factor 4 is inserted to keep the same scale as for the first definition)

• the two algorithms give comparable results, the second one will be used in the following
data quality cuts

- The major problem comes from the Poisson distribution of the number of electrons in the 10ns spill.
- To get the correct mean energy and resolution we need to select single particle spills.
- On runs where the TOF data are available (all but 317) the sample can be enriched in single particle events by requiring that a TOF channel sees a single particle.
- We will show that even after this selection KL sees electromagnetic showers not centered in the vertical plane. These events can be rejected using KL energy centroid.
- Finally when the TDC information is available further cuts can be applied on the TDC counts of the central KL modules.
cut on TOF amplitude

- To select single particles we cut between 400 and 600 counts in the second scan data (200 and 260 on first scan) on the raw Adc 0 ch 12 distribution (TOF)

multiplicity seen by TOF

effect on KL total energy
Using the definition of the module energy we can define the energy centroid

\[
x = \frac{(E_{\text{mod}2} + E_{\text{mod}5}) - (E_{\text{mod}0} - E_{\text{mod}3})}{E_{\text{mod}0} + E_{\text{mod}1} + E_{\text{mod}2} + E_{\text{mod}3} + E_{\text{mod}4} + E_{\text{mod}5}}
\]

electrons hitting side modules?

After TOF cut: multielectrons in central module removed, electrons in side modules reduced
KL centroid cut

- To further reduce electrons in lateral modules (events not fully contained) we define centroids in both KL layers
  - \( x_1 = \frac{(E_{mod2} - E_{mod0})}{(E_{mod0} + E_{mod1} + E_{mod2})} \)
  - \( x_2 = \frac{(E_{mod5} - E_{mod3})}{(E_{mod3} + E_{mod4} + E_{mod5})} \)

and ask for \( x_1^2 + x_2^2 < (0.3)^2 \)
effect of centroid cut, TDC cut

- centroid cut (in blue), as expected, reduces the secondary peaks, but not as much as the TOF cut (in red)
- it also does not remove completely the low energy tail: we can improve requiring that the 4 PMs of the central modules of the 2 layers have TDC>0 (not in overflow) when TDC info is available (in green).
overview of all cuts

- black: no cut
- red: TOF cut
- blue: centroid cut
- green: centroid cut and TDC>0 cut
- magenta: centroid cut and TOF cut
- brown: all the above cuts

On data taken with readout 1 we can use TOF and centroid cut
On data taken with readout 2 we can use all the cuts but for run 317 where we can use only centroid and TDC.
Energy loss in TOF

- computing the total energy, with the same cuts (centroid and TDC) data at 100 MeV from run 190 and run 317 (with and without the 3 TOF slabs in front of KL) we get:
  - run 190: 1008 +- 3 a.u.
  - run 317: 1279 +- 9 a.u.

- we conclude that at 100 MeV 21% of the energy is lost in TOF

- to take this into account
  - in linearity studies with readout chain 2 we insert a fake point at 0 energy with reconstructed energy -271 +- 9, with readout 1 the 0 energy point is set at -596+-20 (factor 2.2 explained later)
  - in resolution estimation we subtract 21 MeV from the beam energy
linearity

lines are 3 points fits through the 0 energy fake point, 75 MeV and 100 MeV

no splitter

slope 27.8 a.u. / MeV

with splitter

slope 12.8 a.u. / MeV
comparison between the 2 energy scans:

a factor 2.2 instead of 2 between the unsplitted and splitted amplitudes
resolution

- to evaluate the energy resolution we have the following problems:
  - above 100 MeV we loose longitudinal containment as shown in previous slide
  - the fluctuations of the energy lost in TOF cannot be neglected
- therefore we cannot provide a meaningful fit to the resolution as a function of the energy.
resolution estimates

neglecting the constant term we estimate the resolution in 4 ways

• taking the cleanest sample without TOF (only TDC and centroid cuts) at 100 MeV we find 23%, corresponding to 7.2% at 1 GeV. This is an upper bound.

• assuming that the cut on TOF we cannot apply in this case could improve the resolution by the same amount we observe on another 100 MeV run we would get 6.8% at 1 GeV.

• taking the cleanest sample (all cuts) at 75MeV we have 28%, assuming that the effective energy reaching KL is 54 MeV, and neglecting the fluctuations of energy deposition in TOF, we get 6.5% at 1 GeV

• similarly at 100 MeV (79 MeV effective energy) we have 25% corresponding to 7% at 1 GeV
comparison with undigitized simulation
(Pietro's first simulations)
KL1 versus KL1+KL2

KL1 just contains 75 (54!) MeV.

At 100 (79!) MeV KL1 contains $\frac{1}{2}$ of the energy.

But at 100 MeV only 50% of the KL1 events have signal in SW.
analysis of TDCs
data quality checks and cuts

- for time resolution studies ALL the quality cuts discussed above were applied
- no attempt was made to correct for time slewing effects due to the discriminator threshold
measurements

- **single PM resolution:**
  - we measure the time difference between the signals from the 2 PMs of one module (DeltaT) and divide by $\sqrt{2}$ the sigma of the resulting distribution

- **counter resolution:**
  - to measure a TOF we should average the time measurements from the 2 PMs and subtract a constant term and the time measurement from a reference counter
  - the contribution of a KL module to the TOF measurement would be affected by an error which is then the combination in quadrature of the resolutions of the 2 PMs divided by 2, which turns out to be the same quantity measurable from the width of DeltaT/2.
time difference between the signals from the 2 PMs reading the same KL module

100 MeV, central module of KL1:

\[ \sigma = 16.9 \text{ counts} \]

implies a single PM resolution of
\[ 16.9 \times 35 / \sqrt{2} = 420 \text{ ps} \]

and a counter resolution of
\[ 16.9 \times 35 / 2 = 295 \text{ ps} \]

(V775 as used in BTF should have 35 ps/count)
estimates of time resolution

• the measured resolution depends upon the energy in 2 ways
  – time slewing of the signal (no attempt to correct for this effect)
  – shower shape

• a standard approach to measure time resolution in calorimeters is to combine the DeltaT values obtained on all the hit modules in a weighted average were the weights are the signal amplitudes

• warning: the DeltaT distributions for the different modules and the different runs peak at different position, to combine them run and module dependent offsets should be applied

• to estimate the resolution achievable combining either the information from 2 KL layers or the information from 1 KL layer and 1 layer of scintillators we have computed the weighted average from the 2 central KL modules in layers 1 and 2.

• note: we tried to use runs with 1 KL layer and an SW plane but we could not understand TDCs from SW (no correlation with ADCs).
results

<table>
<thead>
<tr>
<th>beam energy (MeV)</th>
<th>single counter resolution (ps)</th>
<th>2 counters combined resolution (ps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>440</td>
<td>230</td>
</tr>
<tr>
<td>100</td>
<td>295</td>
<td>180</td>
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<td>150</td>
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<td>90</td>
</tr>
<tr>
<td>350</td>
<td>110</td>
<td>60</td>
</tr>
</tbody>
</table>

→ despite the non optimal choice of PMs for timing applications 1 KL layer provides time resolutions of few hundreds of ps and the combination with a second layer of KL or scintillator improves it by a factor $\geq \sqrt{2}$. 
conclusions

- the analysis of KL data from BTF gives:
  - energy and time response in line (accounting for the lack of calibrations) with what expected from KLOE (5.4% /sqrt(E) and 56 ps /sqrt(E))
  - reference values for the tuning of simulated response to electrons
- and suggests to equip KL with TDCs and use it for TOF measurements next year (1 layer + 1 layer of scintillators)