Dual readout with tiles for calorimetry.

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on behalf of the

RD52 / DREAM Collaboration

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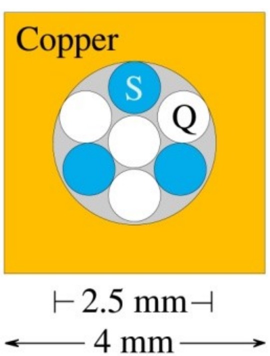
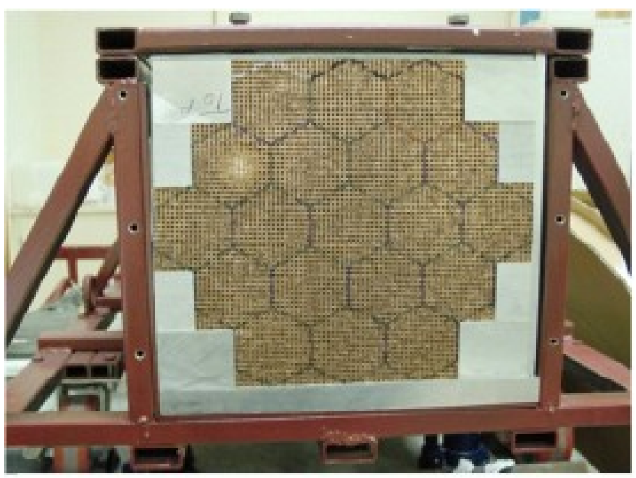
The dual readout method.

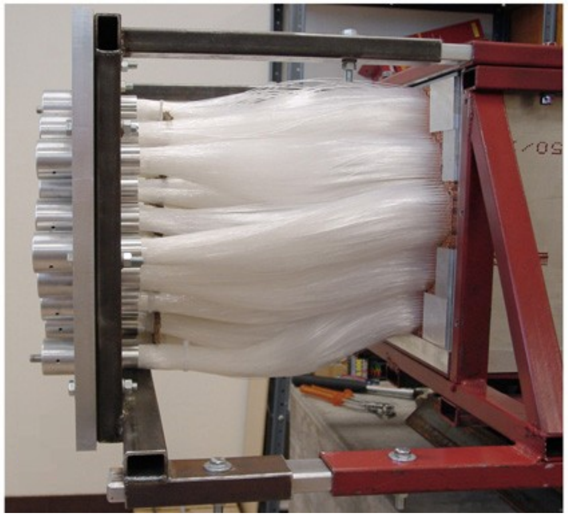
- In the calorimeters the energy resolution for hadrons and jets is limited by the large fluctuations of the e.m. energy fraction f_{em} in the shower.

- In non-compensating calorimeters (where $e/h \neq 1$) it is possible to eliminate the effects of these fluctuations by measuring event by event the f_{em} .

- This was done in 2003 in the DREAM calorimeter with two active media:
  - scintillating fibers for the signal *S* from the *dE/dx* of all the charged particles.
  - quartz or plastic fibers for the signal *Q* of Cherenkov light mostly from the e.m. component of the shower.







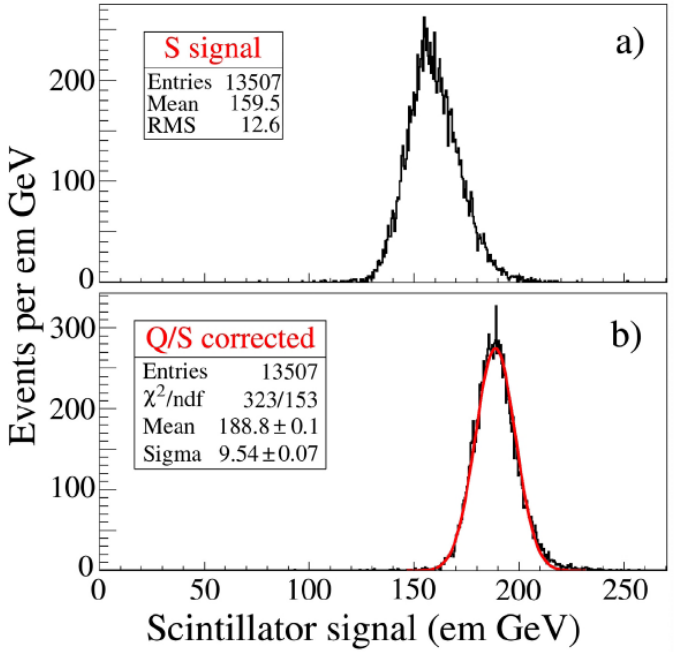
- ✓ In DREAM f_{em} was measured from the ratio of the signals Q and S:

$$\frac{Q}{S} = \frac{f_{em} + 0.21\,(1 - f_{em})}{f_{em} + 0.77\,(1 - f_{em})}$$

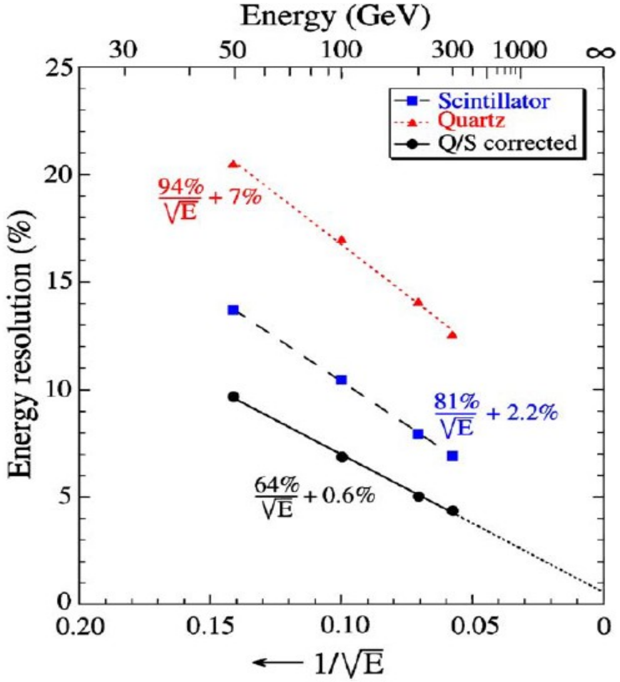
where 0.21 and 0.77 are the ratios h/e for the Q and S signals.

- ✓ From the measured f_{em} the energy of the shower was corrected.
- ✓ In DREAM the resolution was limited by the small Cherenkov photon yield (8-18 ph.e. per deposited GeV).

"Jets" 200 GeV (pions interacting in a target).



Energy resolution (%).



Dual readout in crystals.

- ✓ In the last years extensive studies were performed to extend the dual readout method to homogeneous calorimeters with crystals .
- ✓ In the crystals a fraction of the light yield is given by Cherenkov emission (1% in BGO, up to 15% in PWO).
- ✓ The peculiar features of the Cherenkov light were exploited to separate the two types of light: directionality, timing, spectral properties and polarization of the light.
- ✓ Cherenkov yield was up to 60 ph.e./GeV in PBO doped with molybdenum.
- ✓ Two e.m. calorimeters (BGO and PBO crystals) were also tested .

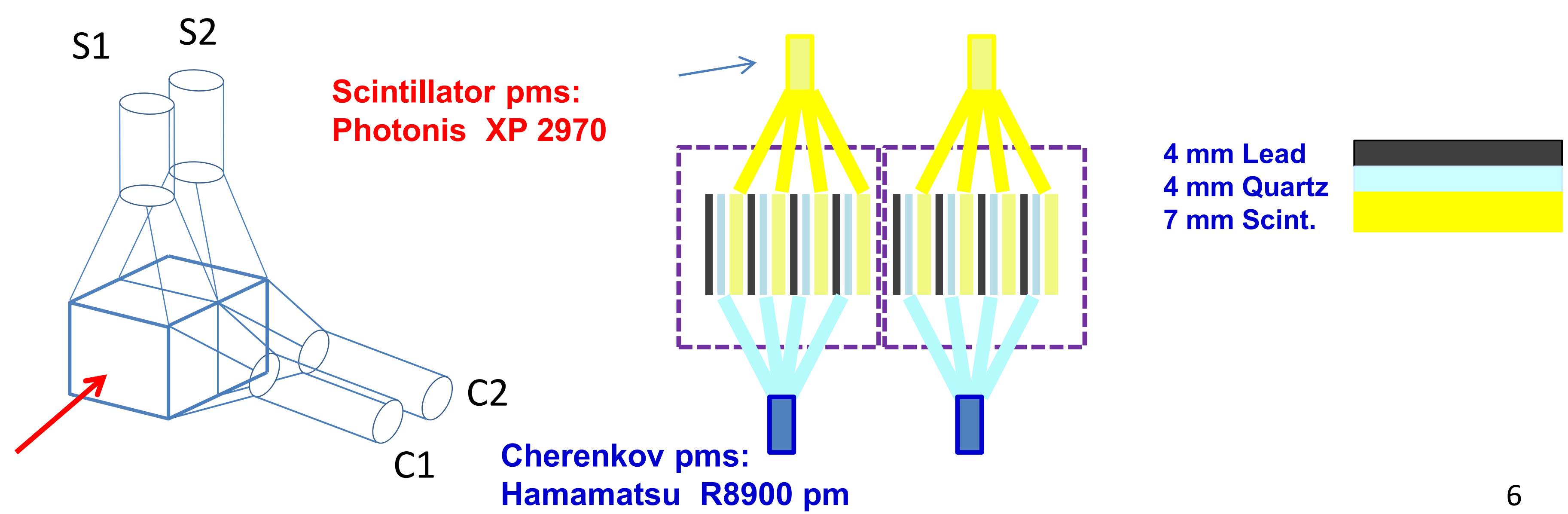
A new large fiber dual readout calorimeter tested in 2012 by the RD52 Collaboration.

- ✓ It is composed of 11 modules. Each module is 2.5 m long (10 λ_{int}) and 9.2 x 9.2 cm^2 lateral dimensions, with scintillating and clear fibers for the readout and lead or copper used as absorber.
- ✓ Two papers have been accepted for publication on NIM .

Dual readout with tiles.

The possibility to use the dual readout technique also in a calorimeter with tiles has been studied.

- We have tested a small detector with 9 x 9 cm^2 tiles.
- The detector is divided in two sections.
  Each section is: 4 x (4mm Lead + 4 mm Quartz + 7 mm Scint. tiles).
- Its total lenght is ≈ 6 R.L. and the Molière radius is 3.7 cm.
- In each section the signals from the quartz tiles and from the scintillator tiles were separately readout by light guides grouped on the photocathodes.

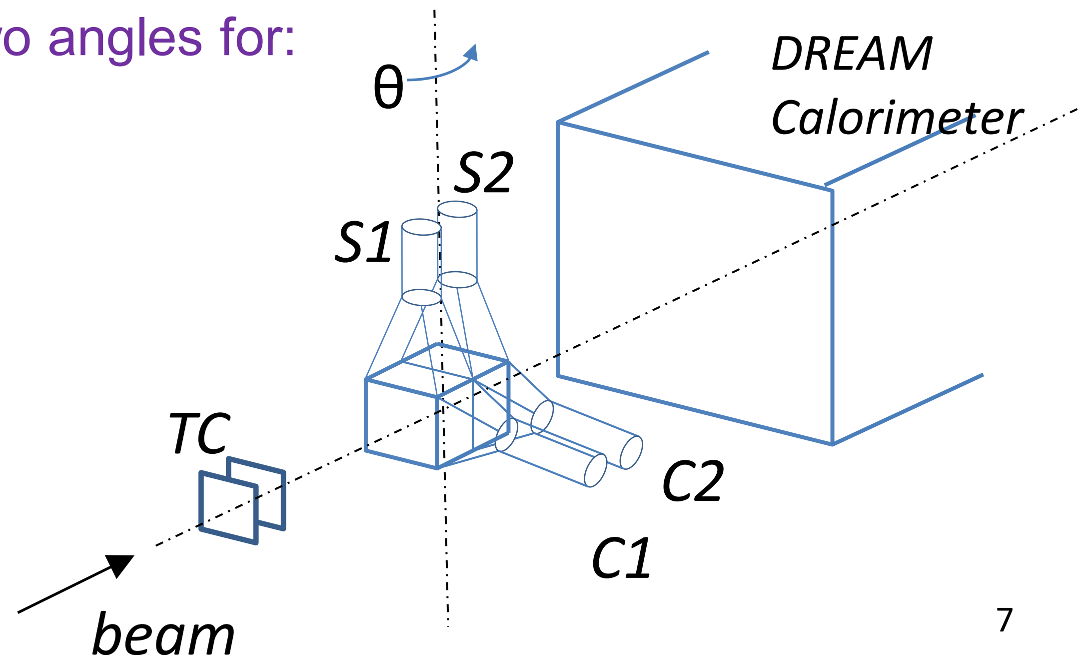


Test beam.

The small detector was tested in the H8 beam at CERN-SPS.

- It was positioned on a rotating platform upstream of the DREAM calorimeter.
- Data were taken with the detector oriented for normal impinging beams ($\theta=0^o$) and tilted at $\theta=12^o$ with the beam direction. This last orientation slightly improves the collection of Cherenkov photons.
- The signals were recorded with the 4 channels of a Tektronix digital oscilloscope (0.8 ns / sample).
- Data were collected at the two angles for:

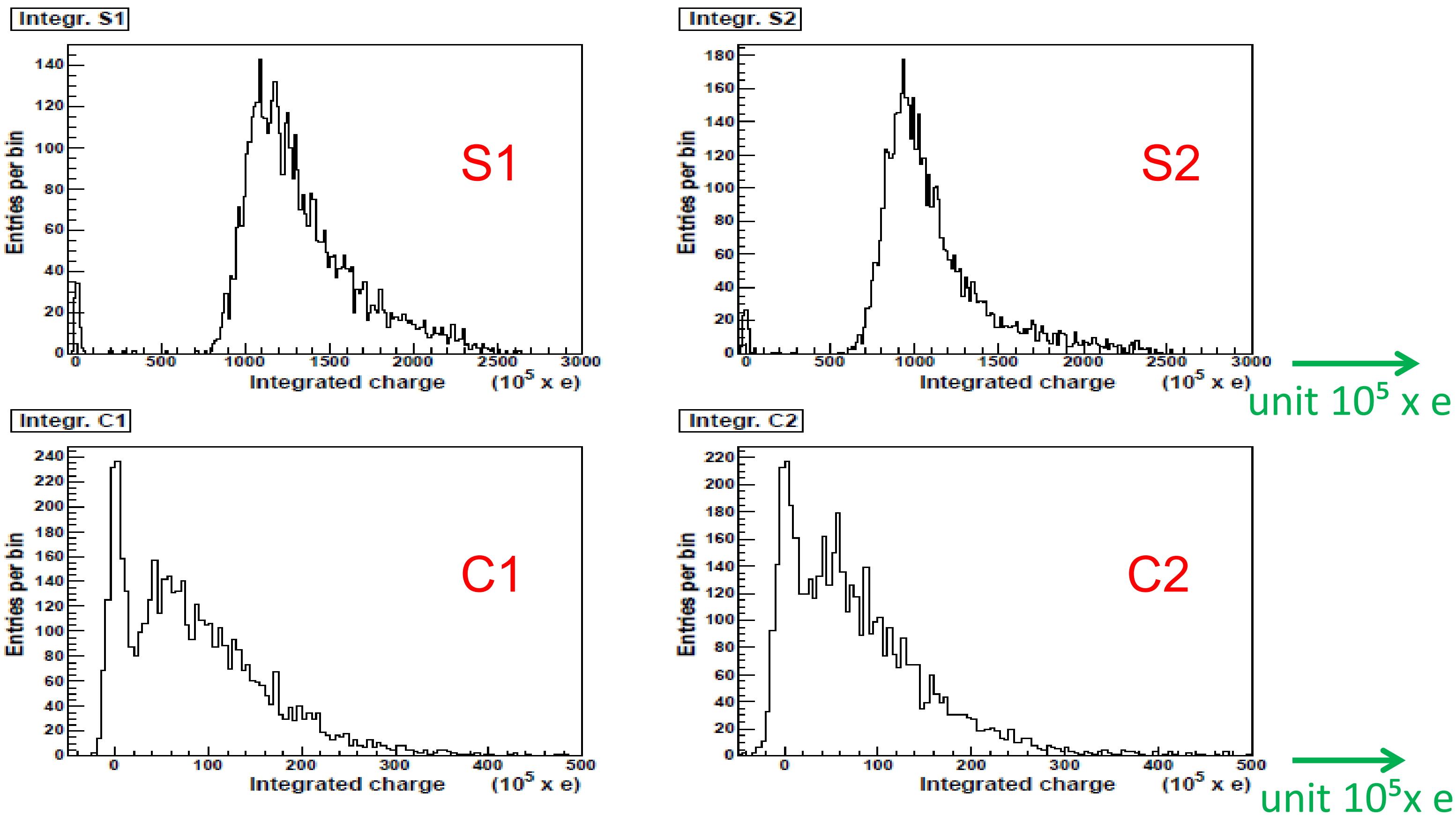
  - 180 GeV muons and
  - 80 GeV electrons.



Analysis of the muon signals.

- Muons were selected in a 180 GeV electron beam with a cut on the energy measured in the DREAM calorimeter.
- The average Cherenkov signals were 8 mV at $\theta=0^o$ and 10 mV at $\theta=12^o$.

$\theta=12^o$



Charge distributions for the scintillator signals (S1 and S2) with a 48 ns gate and for Cherenkov signals (C1 and C2) with a 32 ns gate.

The large fraction of events with no signal in the Cherenkov distributions suggests a small average number of the collected photoelectrons.

We have fitted the q charge distributions for C1 and C2 with a Poisson function for the photoelectron statistics convoluted with a Gaussian function to account for the noise fluctuations:

$$f(q) = A \cdot \sum_{k=0}^{N} \frac{m^k e^{-m}}{k!} \cdot \frac{1}{\sqrt{2\pi}\sigma_q} \cdot e^{-\frac{(q-q_e \cdot k-q_0)^2}{2(\sigma_q)^2}}$$

where:

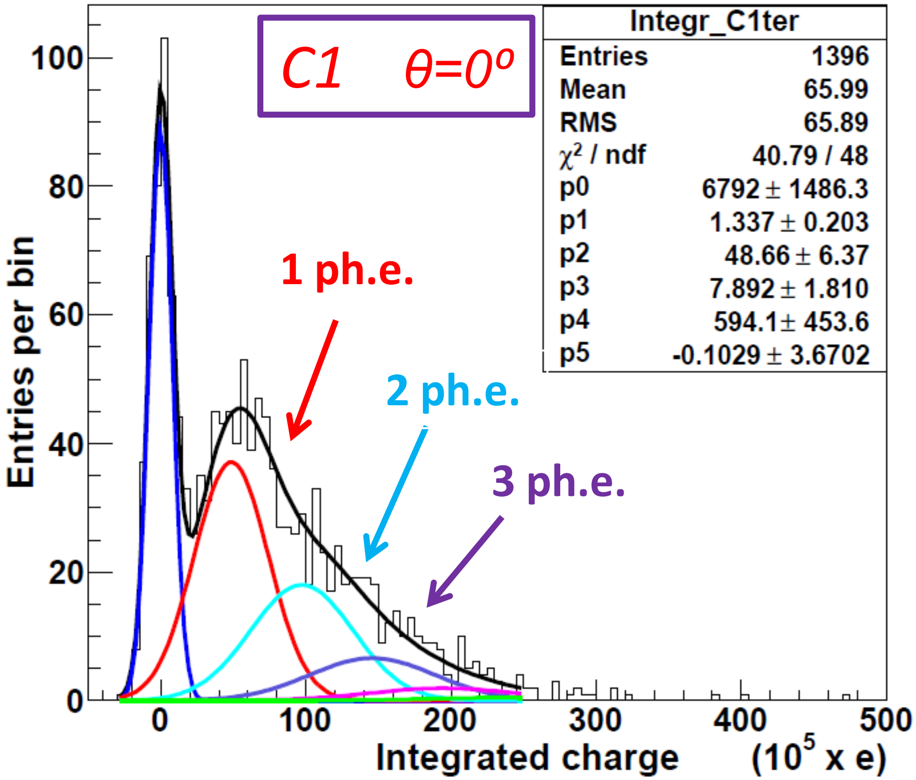
- k is the number of photoelectrons,
- m the average number of photoelectrons,
- q_e the charge collected for 1 photoelectron from which the gain of the pm,
- σ_q the noise at the anode of the pm,
- q_0 a negligible offset in the distribution.

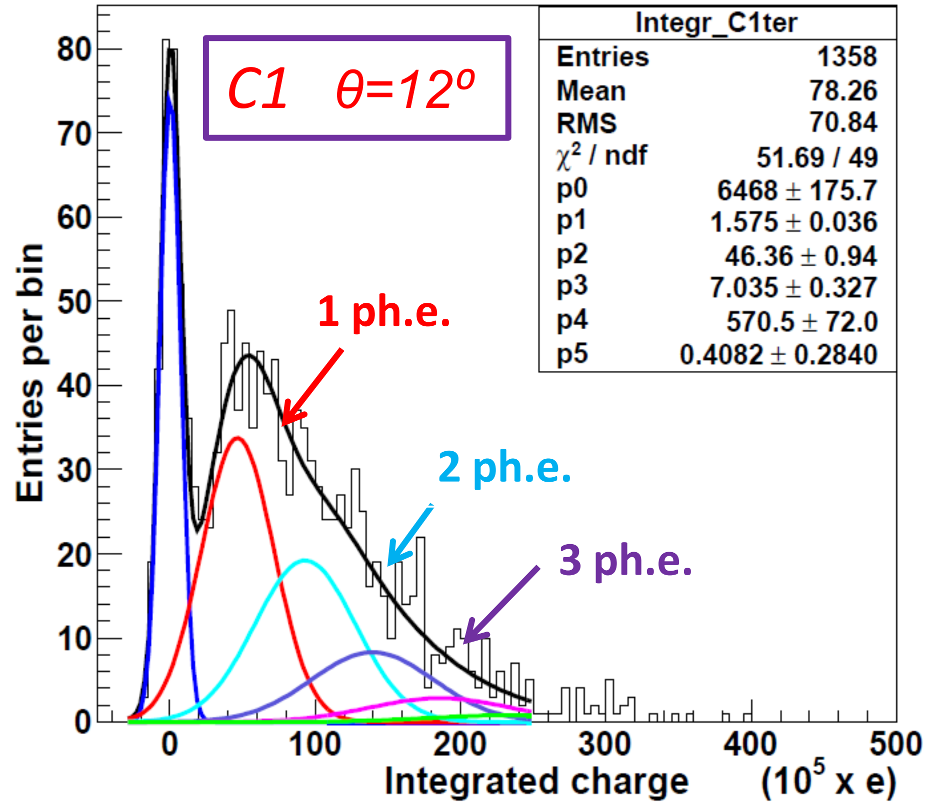
The noise term consists of two contributions: $\sigma_q{}^2 \propto \sigma_S{}^2 + \sigma_e{}^2$

$\sigma_S \propto \sqrt{k}$ a shot noise from the number of photoelectrons,

σ_e an electronic noise (dark current, background, white noise ..).

Fit of the muon signals and pm calibration:





Average signals:

$\langle N_{ph.e.} \rangle$	$\theta=0^o$	$\theta=12^o$
pm C1	1.30	1.63
pm C2	1.38	1.68

Gain of the pm tubes:

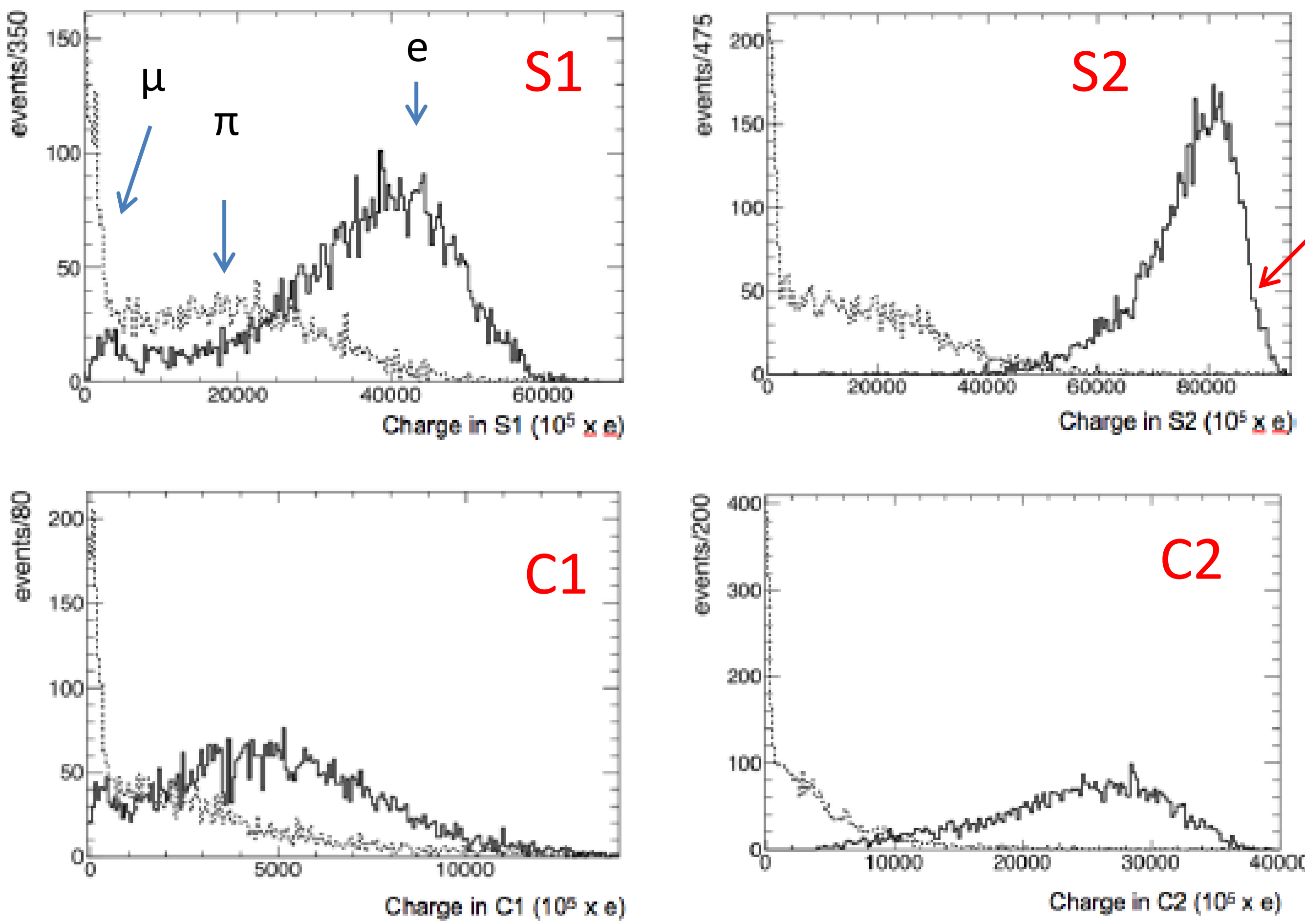
pm C1 = $4.5 \cdot 10^6$

pm C2 = $3.9 \cdot 10^6$

Analysis of 80 GeV electrons.

- The electrons were selected with a cut on the correlations in the Cherenkov signals measured in the two sections of the detector.
- The HV was too high in S2 and caused a saturation for large signals.
- In the rest of the analysis we consider only the Cherenkov signals.

θ=12°



Saturation from a too high voltage in the S2 pm.

Cherenkov light yield for electrons.

- From the charge spectra we measure the average charge in C1 ad C2.
- We had measured the pm gains in the analysis of muon signals.

→ We find the average number of Cerenkov photoelectrons:

	$\theta=0^o$	$\theta=12^o$
pm C1	101	109
pm C2	540	612

- From a GEANT simulation the deposited energies for $\theta=0^o$ and $\theta=12^o$ *are*:

1.42 / 1.55 GeV in Section 1
11.35 / 12.15 GeV in Section 2

- Then the Cherenkov light yield is:

70 ph.e. / GeV in Section 1
50 ph.e. / GeV in Section 2

- The fraction (energy only in the quartz tiles) / (energy in the Section) from GEANT is 0.18 in Section 1 and 0.14 in Section 2. The ratio 1.3 of these numbers justifies the ratio 1.4 in the measured light yields in C1 and C2.

Conclusions (1)

- ✓ We have studied a small (only 6 R.L.) detector with lead, quartz and scintillator tiles.
- ✓ The measured Cherenkov light yield ≈ 50 ph.e./GeV is very interesting and comparable with that already measured in other dual readout detectors (crystals, new fiber calorimeters).
- ✓ With this light yield in a full containement e.m. calorimeter with the same sampling the contributions to the resolution from:

  - the sampling fluctuations : $\sigma_{sampl} \approx \frac{16\%}{\sqrt{E(GeV)}}$
  - and the fluctuations from Cherenkov light yield: $\sigma_{phe} \approx \frac{14\%}{\sqrt{E(GeV)}}$

  are comparable.

Conclusions (2)

- ✓ A test of a similar tile detector with full longitudinal and lateral containment of the shower should be interesting.
- ✓ In a new prototype the quartz tiles could be replaced by UV transparent plastic tiles with similar refractive index,
- ✓ or by wave shifter tiles. This solution would avoid reflections inside the tiles due to the directionality of the Cherenkov light and could improve the collection of the Cherenkov signal.
- ✓ Of course one should consider to use tiles also for dual readout in hadronic calorimeters.

A GEANT simulation of the detector for 80 GeV electrons was performed to calculate the energy deposited in the two sections.