

Proposal of a downstream e- μ identifier for MICE

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Contents.

- A. Global features and physics constraints
- B. Detailed description
 1. Aerogel radiator
 2. Light collecting tubes
 3. Photomultiplier
 4. Mechanical layout
- C. Optical performances and detection efficiency
- D. Cost estimates

A. Global features and physics constraints

The identification of electrons and muons downstream the solenoid magnet is strongly influenced by their momentum and spatial distributions (Figure 1). The particle simulations presently available show that both electrons and muons have broad and continuous momentum distributions ($0 < p_e < 300 \text{ MeV}/c$ and $0 < p_\mu < 400 \text{ MeV}/c$).

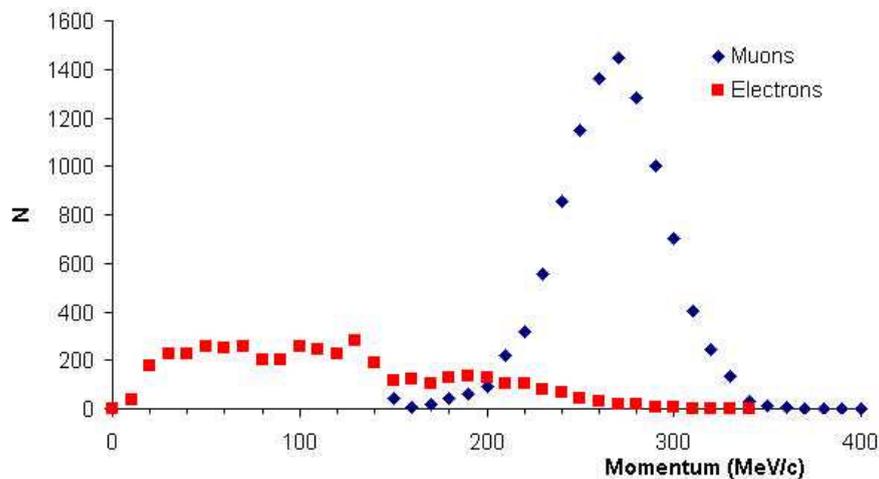


Figure 1. Momentum distributions of muons and electrons.

In my opinion, a threshold Cerenkov detector looks as the simplest device to perform this identification. As far as possible it should be designed to give no response for muons while having in principle 100 % efficiency in detecting electrons.

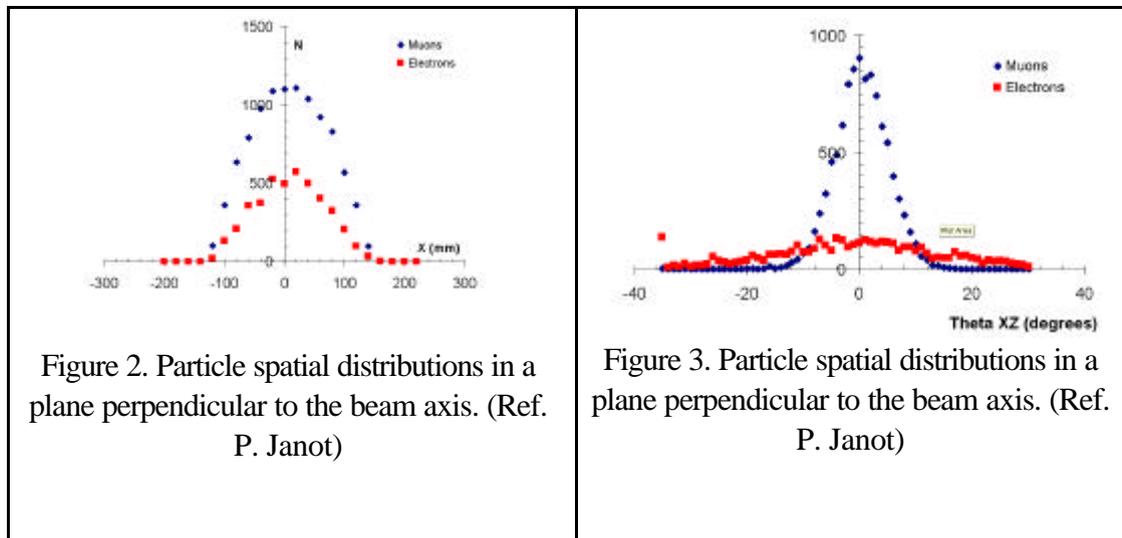
In the momentum ranges given here, we cannot use solid or liquid Cerenkov radiators (with index of refraction $n > 1.2$) since the higher energy muons ($p_\mu > 160 \text{ MeV}/c$)

would then generate Cerenkov photons in such materials. On the other hand, we cannot use (pressurized) gas radiators (with $n-1 \cong 0.005$) as part of the decay electrons ($p_e < 5$ MeV/c) would give no light and would be confused with muons. This is the basic argument to propose aerogel radiators ($1.01 < n < 1.06$). An adequate value of the index of refraction is discussed later in this document. However the optimum index of refraction should obviously be determined following more detailed particle simulations unavailable at the moment.

Although the tracking devices inside the solenoid certainly help in decreasing mis-identifications, we prefer to base the present device on a genuine "standalone" operation.

The stray magnetic field of the solenoid should not be neglected and partly justifies the location of the photodetector(s) away from the solenoid. In addition, electrons or muons along the solenoid axis should not hit these photodetectors as they could generate spurious Cerenkov photons in the glass envelopes. As an example, a fully relativistic electron generates about 40 photoelectrons from Cerenkov light produced in a 2 mm thick glass sheet.

The gross geometrical features of the threshold detector are determined by the angular and spatial distributions of particles at its entrance window. The presently available simulations (P. Janot's files evaluated 50 cm downstream of the solenoid) do not show any correlation between angles, positions and energies of the incoming particles. The geometrical aperture of the proposed design was chosen to be twice as large as requested by Janot's data: our aim is to take into account the defocusing of particles in the stray magnetic field of the solenoid. (Figures 2 and 3).



Taking into account a defocusing due to the stray magnetic field the RMS "beam spot" diameter is expected to be about 60 cm. The position distribution has a roughly gaussian shape. The divergence of particle directions has also a gaussian shape with a FWHM of about 60 degrees. These features constrain the geometrical aperture (about 60 cm in diameter) and the optical acceptance of the device.

B. Detailed description

Sketches of the essential parts of the system are shown in Figures 4 and 5.

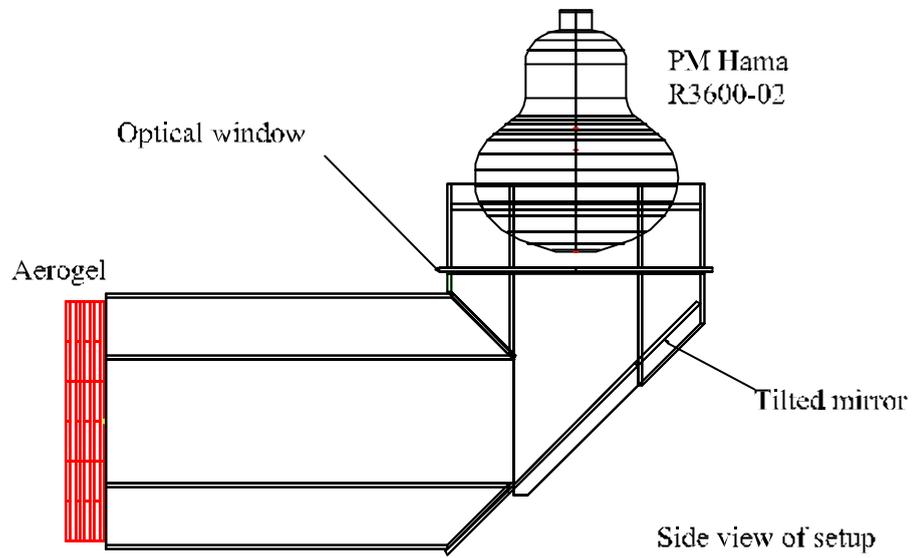


Figure 4. Meridian cut (side view) through the optical system.

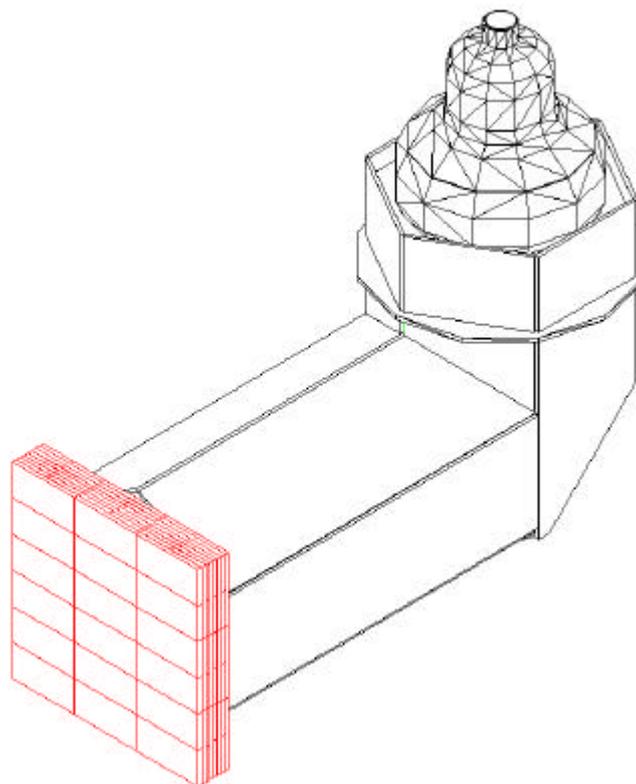


Figure 5. Perspective view of the optical parts.

The optical characterization of the whole setup has been performed by accurate 3D-optical ray tracing, taking into account realistic surface properties of the mirrors (spectral and angular reflectivities), the bulk scattering inside aerogel materials, transmittance of the window and the typical quantum efficiency of standard photomultipliers. The overall light collection efficiency reaches about 80%.

Several items are discussed in the following points.

1. Aerogel radiator

The aerogel radiator used here has an index of refraction $n=1.02$ and a total thickness of 10 cm. The transverse size is 60 cm x 60 cm. It is constructed with blocks of aerogel of typical dimensions 20 cm x 10 cm x 2.5 cm. (These dimensions depend from the manufacturer).

The thickness is chosen on the basis of the small photoelectron yield with low energy electrons (Fig. 6).

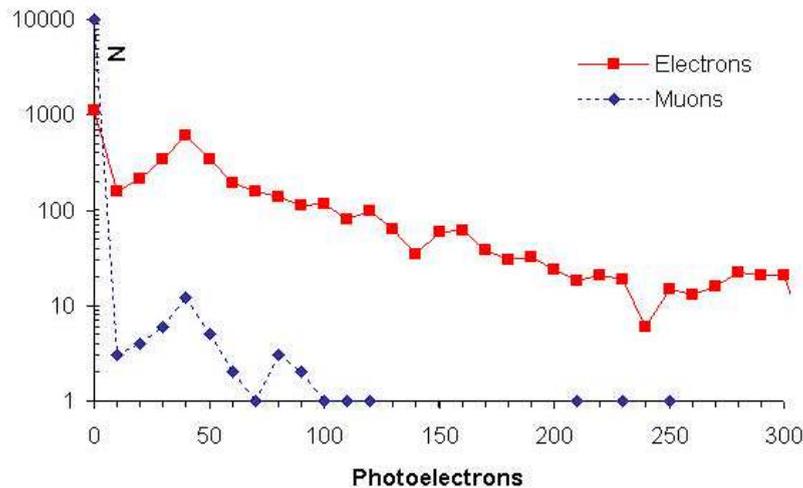


Figure 6. Semilog distribution of the number of photoelectrons induced by Cerenkov light in a 10 cm thick aerogel slab with $n=1.02$ (assuming a 100% light collection efficiency).

The choice of the appropriate index of refraction for the radiator is governed by the relative light yield of electrons and muons. For electrons the most probable number of photoelectrons is about 40, while for muons only the high-energy part of their energy spectrum will bring some contribution.

It is safe to fix a detection threshold of 10 photoelectrons since the photon collection efficiency and unavoidable losses have still to be taken into account. With these conditions, the detection efficiencies of electrons and muons versus the index of refraction are shown in Figure 7. The detection efficiency ε_i is defined as

$$e_i = \frac{\text{Nr of particles of type } i \text{ above threshold}}{\text{Total nr of particles of type } i} \quad \text{with } i = \text{electron or muon}$$

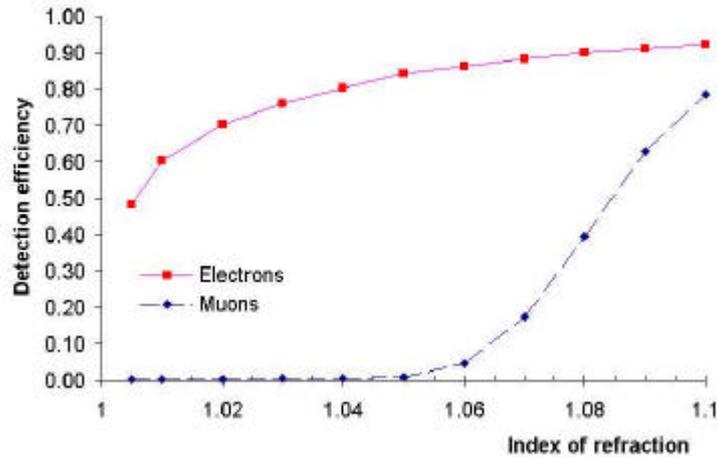


Figure 7. Detection efficiency for electrons and muons versus the index of refraction of the radiator.

It is clearly seen that some compromise is needed here: a higher index improves the electron detection efficiency, but also increases the rejection of muons. To get a quantitative estimation, we could for instance define a figure of merit $F(n)$

$$F(n) = e_e \times (1 - e_m)$$

which would reach a maximum for the best compromise between the electron detection and the "muon losses". (Figure 8).

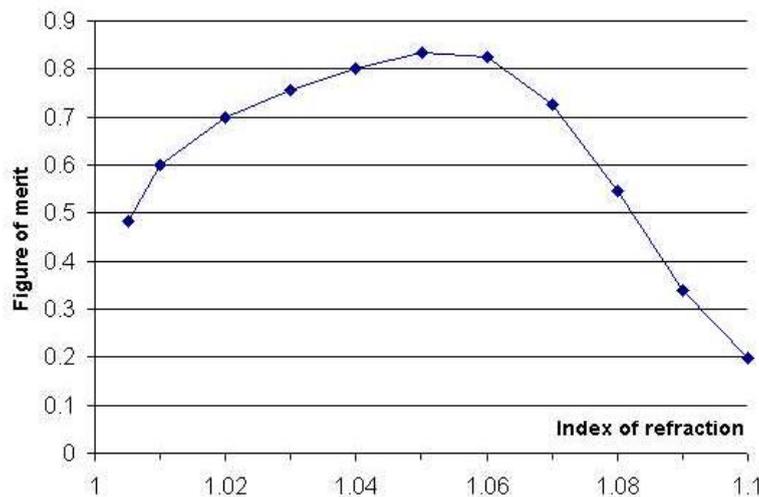


Figure 8. Figure of merit of the global detection efficiency as a function of the index of refraction of the radiator.

A broad maximum is clearly seen around $n = 1.04$ to 1.06 , independently of the relative populations of electrons and muons. Further refinements to still optimize the index should be undertaken when more particle files will be available.

The published literature (Ref. Buzykaev et al. NIM A433(1999)396 and BELLE internal reports) shows that aerogel is quite absorbing for violet and blue light as shown in Figure 9. These properties are included in the present proposal.

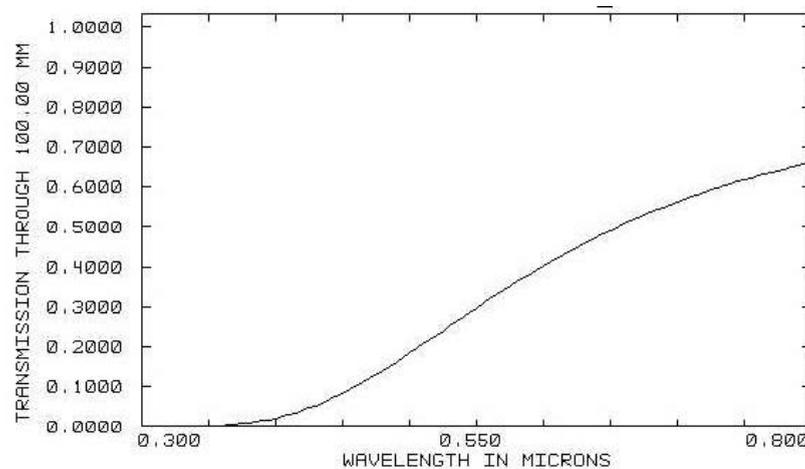


Figure 9. Internal transmission of a 10-cm thick piece of aerogel versus wavelength in the visible region.

In order to increase the light output from aerogel, one could imagine stacks of 25-mm thick aerogel tiles interspersed with wavelength-shifting foils as is done for the AMS and Phenix experiments. In this way, one benefits: a) from the conversion to visible light of the UV-part of Cerenkov emission spectrum, and b) from the much better transparency of aerogel to larger wavelength. This improvement is left for further studies and simulations.

Aerogel is quite hygroscopic and has to be maintained at all times in a dry atmosphere to keep its optical properties. Our design foresees the whole setup to be vacuum tight, although it should always be operated very near to the atmospheric pressure. It is best to fill the containment vessel with some inert dry gas (nitrogen or helium).

This explains the need for an optical window isolating the photodetector volume. We plan to use a 7-mm thick glass sheet made from Schott B270 material.

2. Light collecting tubes

For reasons of availability, cost and handling, the large light collecting tubes are all constructed from aluminized PMMA plastic sheets or (more expensive) optical glass plates (again 7 mm thick Schott B270). These plates are arranged to form a prismatic tube with a hexagonal cross section circumscribed to a circle of 57 cm diameter. This size matches the sensitive area of the photodetector.

In this study the reflectivity of the aluminized plastic sheets is taken to be about 90% (as used for the Cerenkov detector of the HARP experiment). It is however possible (A. Braem, private communication) to benefit from recent developments based on a multilayer of Aluminium, Magnesium fluoride MgF_2 and Hafnium oxide HfO_2 to reach reflectivities as high as 96% in the interesting visible domain (250 to 500 nm). (Figure 10).

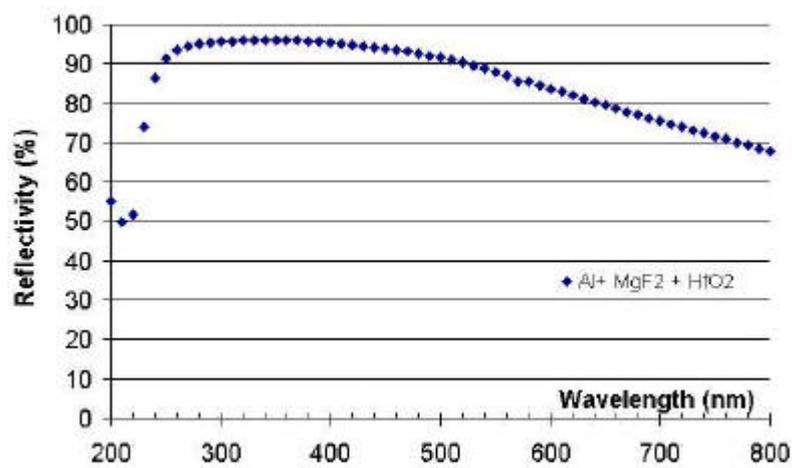


Figure 10. Reflectivity of a multilayer Al + MgF₂ + HfO₂.

The length along the beam axis is determined by optimization of the light collection efficiency: too long tubes increase the number of reflections (and losses), while shorter tubes generate too many rays (emitted at large angles and) reflected backwards by the tilted plane mirror (and subsequently absorbed back by the aerogel radiator).

It is possible to keep the same geometry if larger apertures (and subsequent multi-PM configurations) are requested.

A plane mirror tilted at 45 degrees reflects light at 90 degrees to the optical beam axis towards the photodetector. It can also be made from aluminized PMMA plastic or Schott B270 optical glass.

3. Photomultiplier

The proposed system uses a single 20-inch diameter photomultiplier Hamamatsu R3600-02 (same as those at Kamiokande) with a standard bialkali photocathode. This particular PM has the advantage of having a rather large gain $3 \cdot 10^6$ adapted to the low light yields of aerogel radiators.

As indicated before this PM is mounted in a volume separated from the radiator section. It allows easy access to the PM without disturbing the dry environment of the aerogel and avoiding possible damages to the mirrors.

The optical simulations show there is no need for a Winston cone.

As far as cost is concerned, it is seen that, for the present optical acceptance, the single-PM option is much cheaper, and geometrically more efficient than multi-PM configurations.

4. Mechanical layout

A perspective view of the containment vessel is shown in figure 11

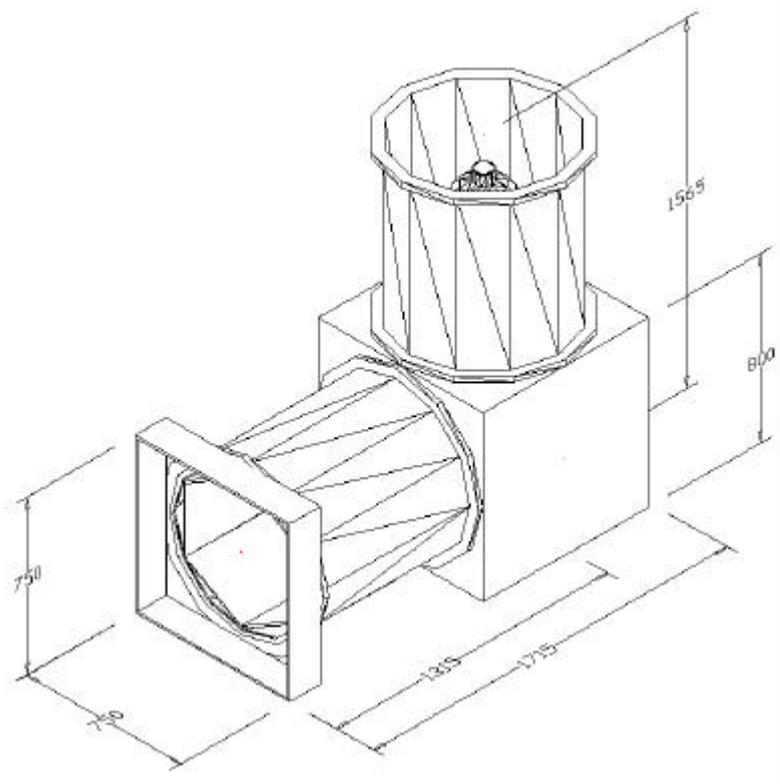


Figure 11. Perspective view of the containment vessel.
All dimensions are in millimeters.

It is planned to construct the different parts with Nickel-plated soft steel sheets 5 to 15 mm thick. Once again this is based on arguments of weight, costs and machinability. The use of soft steel is also beneficial as it shields the photodetector from the stray field of the solenoid. Whenever possible all parts should be welded and separately checked against leaks.

The entrance and exit windows (not shown here) for the particles could be made with relatively thin foils, typically 0.5 mm stainless steel.

The assembly is reasonably straightforward with four different big pieces, prepared separately and bolted together with O-rings at the appropriate places:

- the radiator box
- an horizontal pipe containing the light collecting tube. This pipe is made by rolling a single sheet of steel and welding the ends together. Flanges are welded later.
- a "central" cubic box containing a large tilted mirror and its orientation controls. This box also supports the glass window. It is obtained by welding flat sheets of steel.
- a vertical light collecting tube containing the PM tube, its mumetal shielding and the HV circuitry.

C. Estimated optical performances and detection efficiency.

The simulation of the optical system with all features defined above (reflectivities, bulk scattering in aerogel, diffusive layers inside the aerogel box, transmission in the window...) is performed with Zemax v.19_08_02.

A graphical summary is shown in figure 12 as a false color intensity distribution on the photocathode of the R3600 photomultiplier. The overall light collection efficiency is about 77% assuming no polarization dependent reflections.

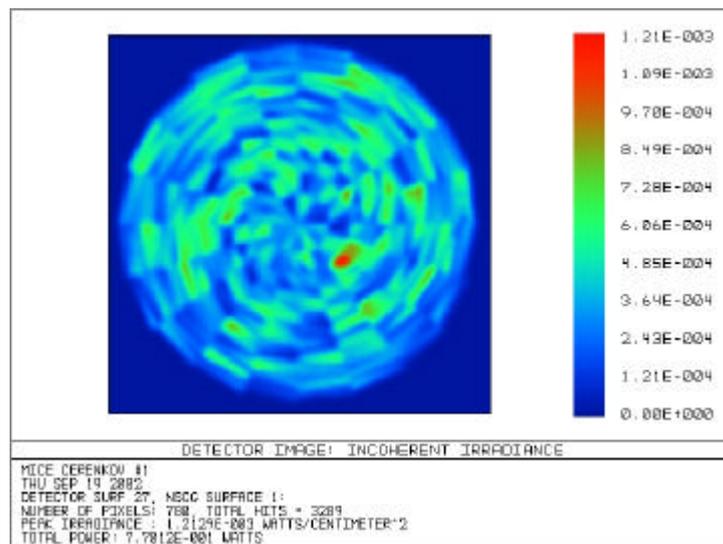


Figure 12 Intensity distribution on the photocathode of the R3600-02 photomultiplier. The light collection efficiency is 77%.
 No polarization effects were taken into account.

A consequence of the overall light collection efficiency is that the theoretical threshold of 10 photoelectrons stated above corresponds to 7-8 photoelectrons generated in the photomultiplier. Finally assuming additional photon losses to about 25%, we are left with the actual detection of at least 5 photoelectrons.

D. Cost estimates (in kEuro)

Item	Supplier	Delivery (after order)	Costs (no VAT) kEuro	Note
Aerogel	Matsushita		37	6
	Airglass			5
Glass plates	Schott	9-11 weeks	14	
Cutting + Packaging		TBD*	1	
Aluminization	A. Braem	TBD*	2.5	4
Supports		TBD*	4	
Containment vessels (raw steel plates + flanges)			0.5	
Machining + Welding	Industry	TBD*	15	1
Ni plating	Industry		4	
Assembly + Tests		TBD*	4	
2 Photomultipliers R3600-02	Hama'		16	2
+ve HV supply	CAEN		?	
Mumetal shielding	Imphy			
Mechanical supports		TBD*	5	
Slow controls (sensors...)			?	1
Transports/Shippin		TBD*	1	
Miscellaneous		TBD*	1	3
Total			105	7
Contingency 10%			10	
TOTAL			115	

Notes.

* = TBD : to be defined

1. Pressure and temperature sensors with their respective controllers.
Measurement of the absolute water vapor content inside the vessel.

2 Including one spare photomultiplier.
Beware that it requires a positive HV supply.

3 Administrative and management costs.

4. Private communication with A. Braem and Cl. David(CERN 11.09.2002)

Price is given for HARP-like layers Al + MgF₂ giving a reflectivity of about 90% in the visible range.

It is proposed for MICE to use an Al + Hf₂O₃ coating: it is much stronger mechanically, has a somewhat narrower bandwidth (250 to 500 nm) but with 96% reflectivity.

5. Airglass aerogel

Standard Slabs of 60 x 60 x 2 cm³

6. Matsushita Electric Works

Masaru Yokoyama

1048 Kadoma, Kadoma-shi, Osaka 571

Japan

email: yokoyama@crl.mew.co.jp

tel: *81-6-909-7383

fax: *81-6-904-7104

Here is an example of what they can make (this dates from 1998):

Size: 110mm*110mm*10mm-thickness

Refractive Index: 1.015, 1.03, and 1.05

Transparency: Transmittance at wavelength 550nm >90% (thickness=10mm)

Price (FOB) 50,000 yen/liter (for orders >100 liter)

100,000 yen/liter (for orders <100 liter) = 843 Euro/liter

They can make aerogel having refractive index of 1.015, 1.025, 1.03 and 1.055.

It is also possible to make aerogel-having indices between 1.01 and 1.055 optionally.

The aerogel having an intermediate refractive index will be cost 20% or 30% higher than normal index. The tolerance will be +/-0.02, so the tile will have the value of (n - 1) to within 6%.

7. BELLE modules 180 modules Aerogel and 3" PM R6233 cost 40MYen.

(June 2002). This is about 1900 Euro/module.

Ref. <http://utkhii.px.tsukuba.jp/~highpt/2002>

To cover the same area 600 x 600 mm as MICE, we would strictly need 36 BELLE modules, corresponding to a cost of 36 x 1900 Euro/module = 68400 Euro.

But to get some overlap between the modules let's assume we need about 50 modules at a cost of 50 x 1900 Euro/module = 95000 Euro.

Remark. The BELLE's modules do not seem to have any magnetic shielding.