Design of the large area MCP-PMT and a novel bowl-shaped MCP

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ABSTRACT

A new type of large format MCP-PMT that has a 20 inch diameter elliptical envelope as the entrance window and small MCPs mounted in the center of the glass bulb was developed in 2016 for the Jiangmen Underground Neutrino Observatory (JUNO) in China. This paper describes simulation work for upgrading the newly developed 20 inch MCP-PMT for the next generation neutrino observatories and astrophysical telescopes in which precision timing plays a crucial role. With the new design of the 20 in. MCP-PMT, the transit time spread of the prototype can be decreased from over than 10 ns to less than 3 ns and the collection efficiency is nearly 100% for a large photocathode effective area.

For the conventional MCP, the collection efficiency is limited by the open area ratio generally lower than 60%. The timing accuracy and spatial resolution are also smeared by the backscattered photoelectrons. In this work, a novel-bowl shaped MCP with an open area ratio greater than 90% is proposed. An additional thin film with a high secondary emission yield is deposited on the nickel-chromium electrode. The simulation results show that its collection efficiency is nearly 100% and the late pulse due to the photoelectron backscattering is less than 2%.

Optimization of the large format MCP-PMT

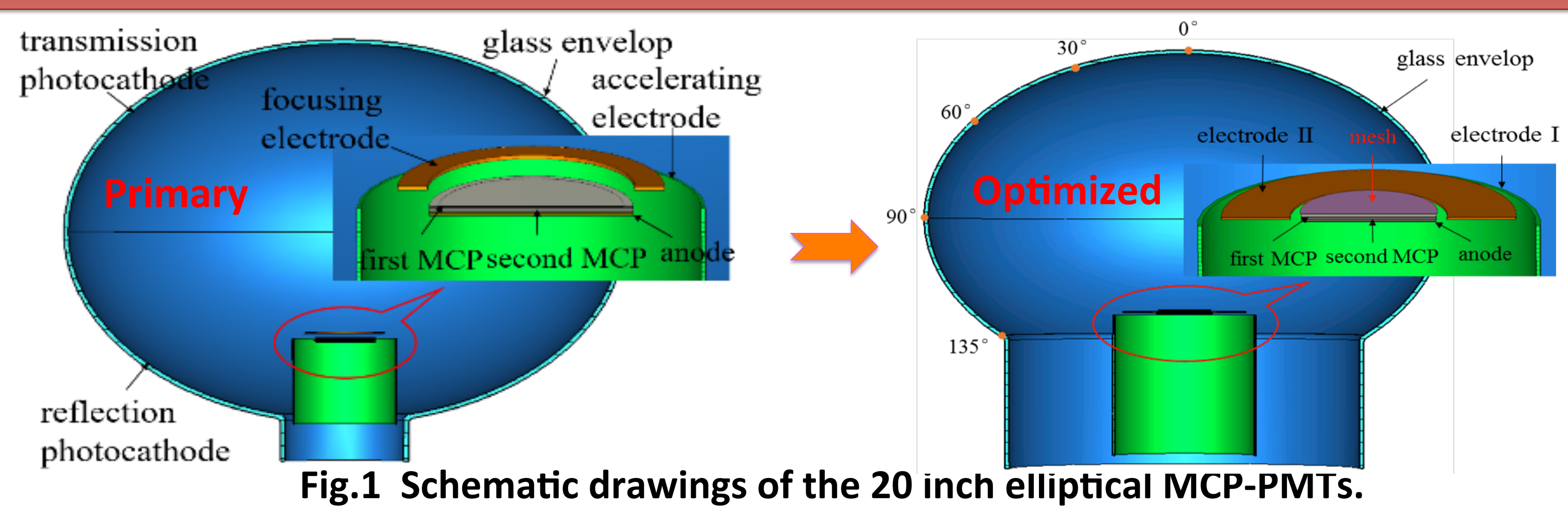


Fig.1 Schematic drawings of the 20 inch elliptical MCP-PMTs.

In the optimized 20 inch MCP-PMT, the diameters of the electrode I and electrode II are increased in order to improve the timing performance. The neck of the glass bulb is also enlarged so that the electrodes can get through.

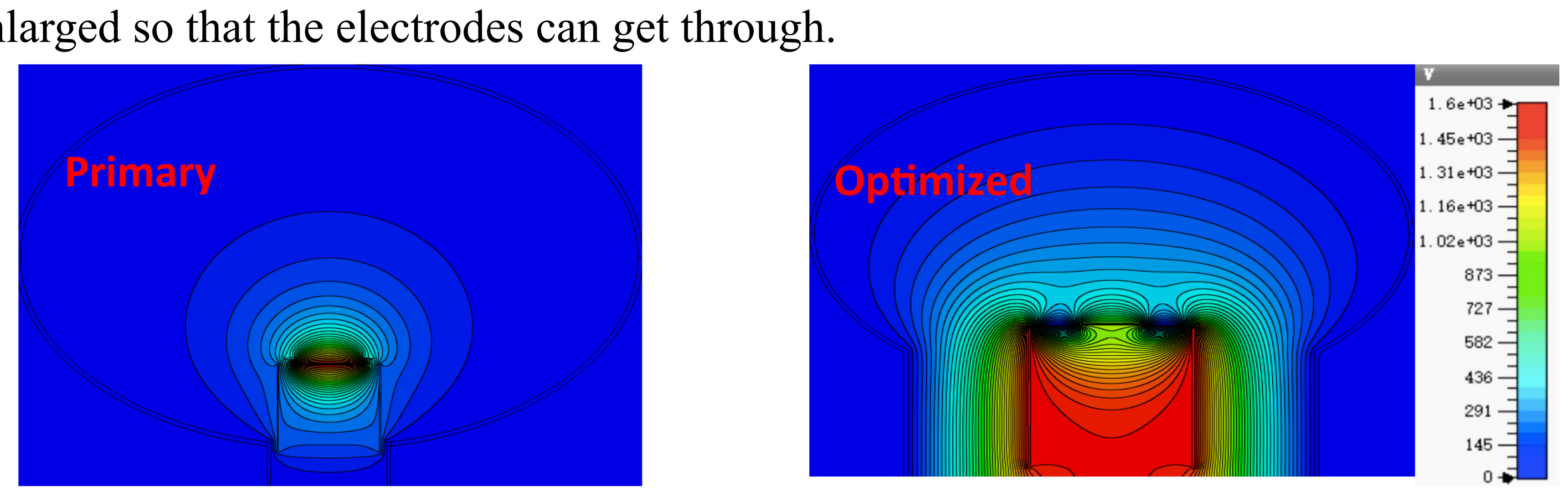
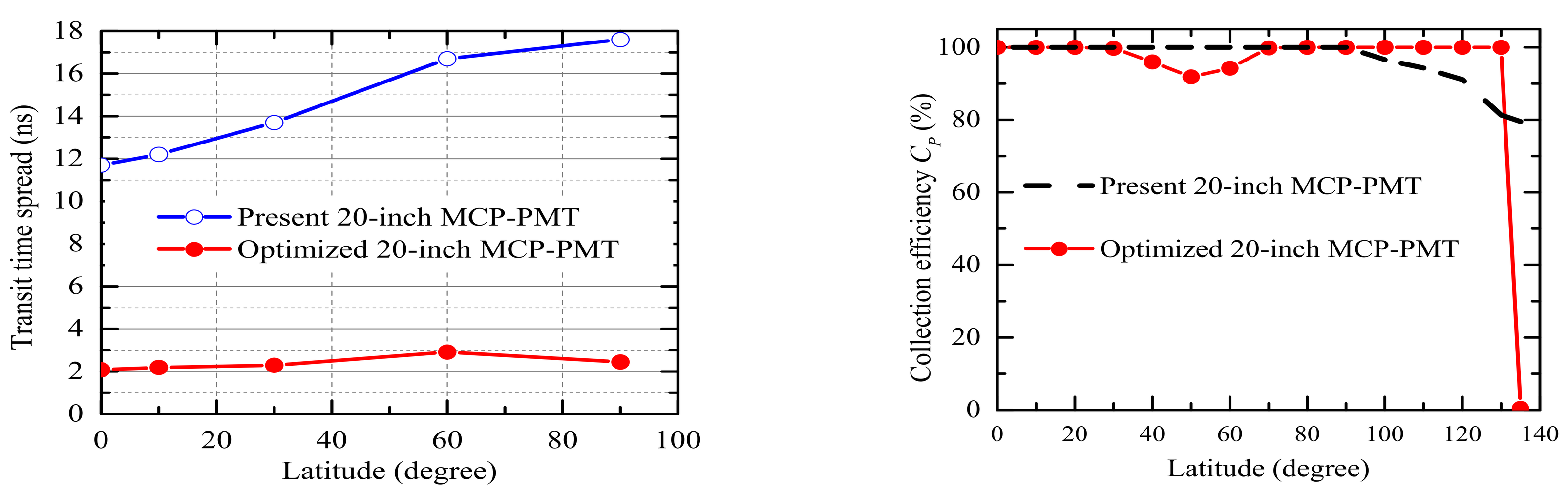


Fig.2 Electrical potential distributions of the 20 inch elliptical MCP-PMTs.

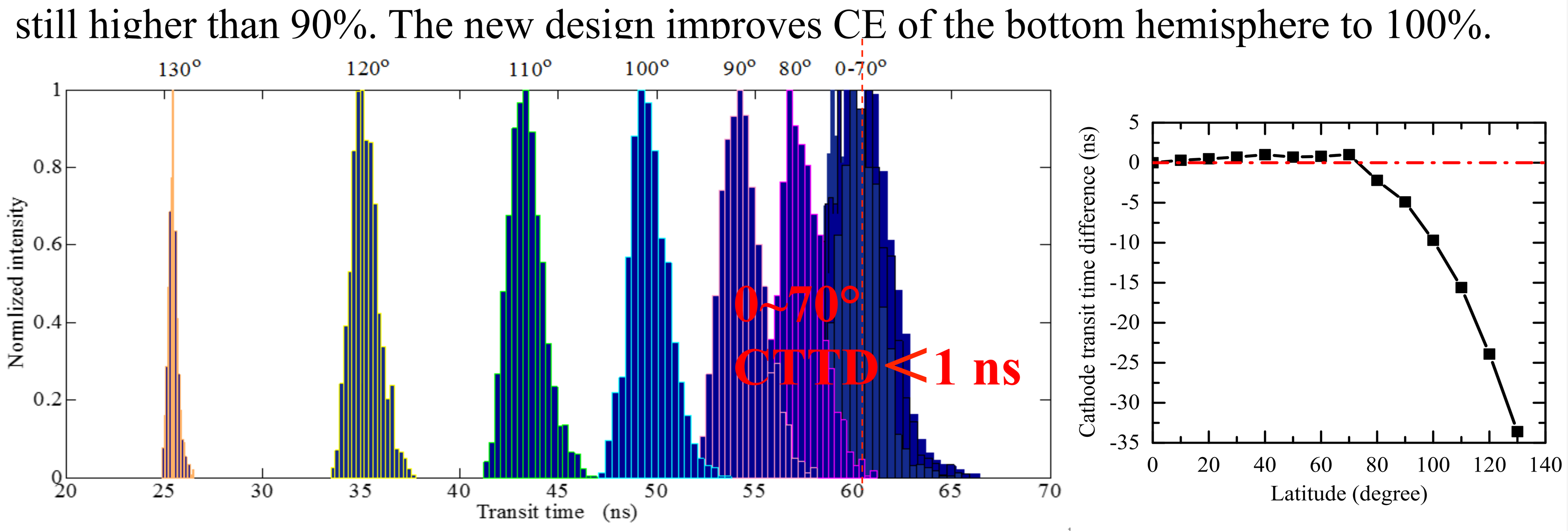
The electrical potential near the photocathode of the optimized 20 inch MCP-PMT is obviously higher than that of the primary MCP-PMT, which favors to decrease the differences in the energy and angles of the electrons.

Timing performance and Collection efficiency



Figs. 3 and 4 TTS and collection efficiency versus illuminated position on the photocathode for the two types of PMTs.

The TTS of the optimized 20-in. MCP-PMT is greatly decreased to less than 3 ns over the entire transmission photocathode. Compared with the present prototype, the collection efficiency of the new design has a slight reduction within the latitudes of 40°–60°, but it is still higher than 90%. The new design improves CE of the bottom hemisphere to 100%.



Figs. 5 and 6 Transit time distribution and Cathode transit time difference versus illuminated position on the photocathode for the two types of PMTs.

Over the latitudes of 0° to 70°, the cathode transit time spread (CTTD) is less than 1 ns. The distinct transit time difference between the top hemisphere and the bottom hemisphere indicates it would be better to just coat the photocathode on the top hemisphere and the aluminum film on the bottom hemisphere. The photocathode effective area should be defined within 70° (i.e. 480 mm) if the CTTD is expected to be less than 1 ns. Such an effective area is 20 mm larger than any existed 20- in. PMTs.

A novel bowl-shaped MCP

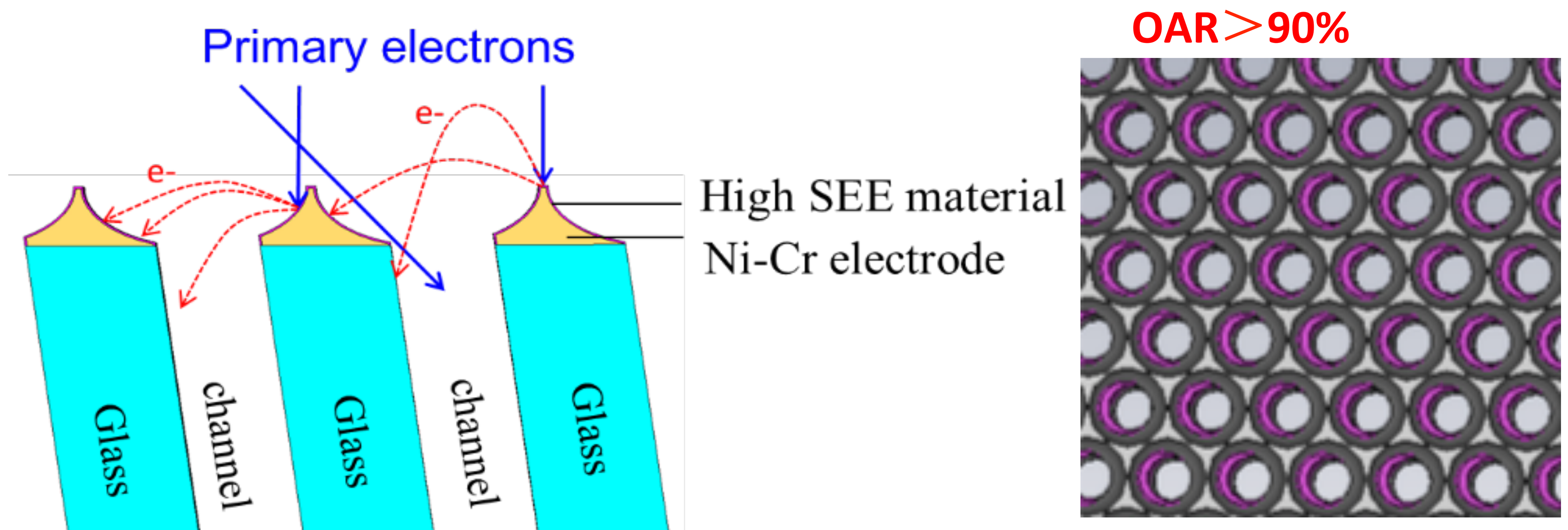


Fig. 7 Sectional (left) and top (right) views of the bowl-shaped MCP

Compared with the conventional MCP, the volume of the input electrode (dead area) of the bowl-shaped MCP is greatly reduced in order to enlarge the open area to greater than 90%. The side surfaces of the Ni-Cr electrode are specially cambered giving each entrance of the channel the shape of a bowl. An additional thin film with high SEY is deposited on the MCP input electrode to further improve CE contributed by the photoelectrons striking the electrode.

Timing performance and Collection efficiency

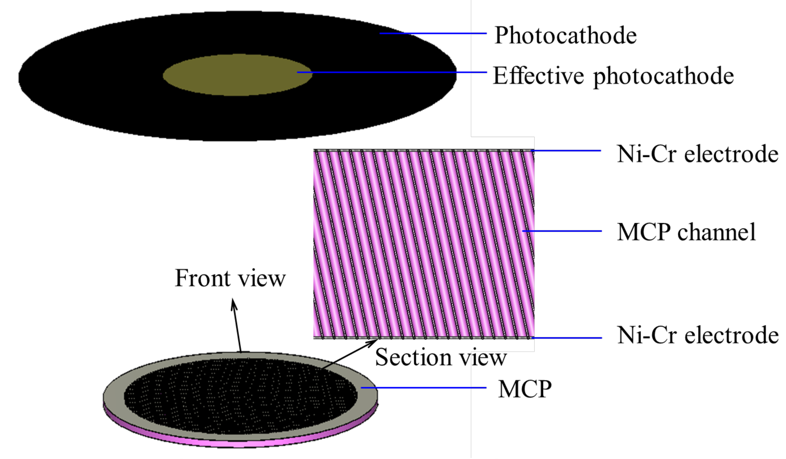


Fig. 7 3D model of the MCP-PMT for simulations.

Table 1 Electron collection efficiency of the conventional MCP and the bowl-shaped MCP

	CE
Conventional MCP	66.5%
Bowl-shaped MCP	98.8%

The collection efficiency of the bowl-shaped MCP approximates to 100%, which is significantly improved compared to the traditional MCP that has an open area ratio of 65%

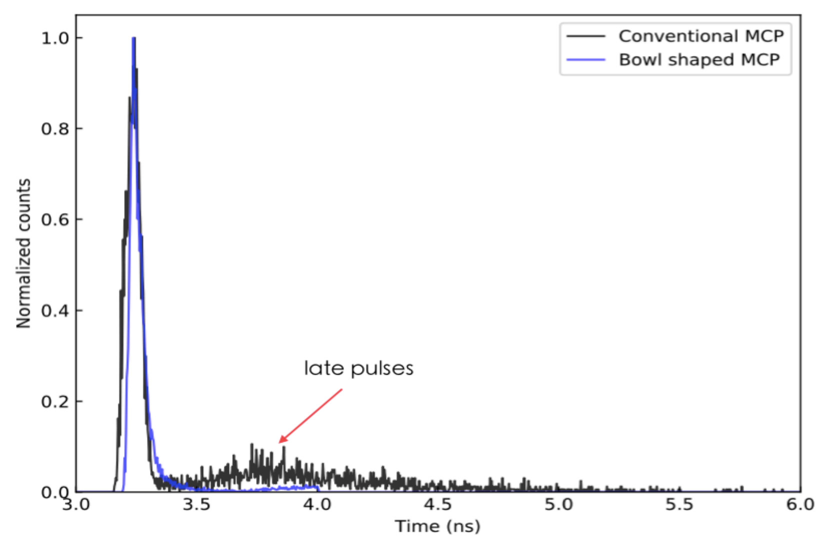
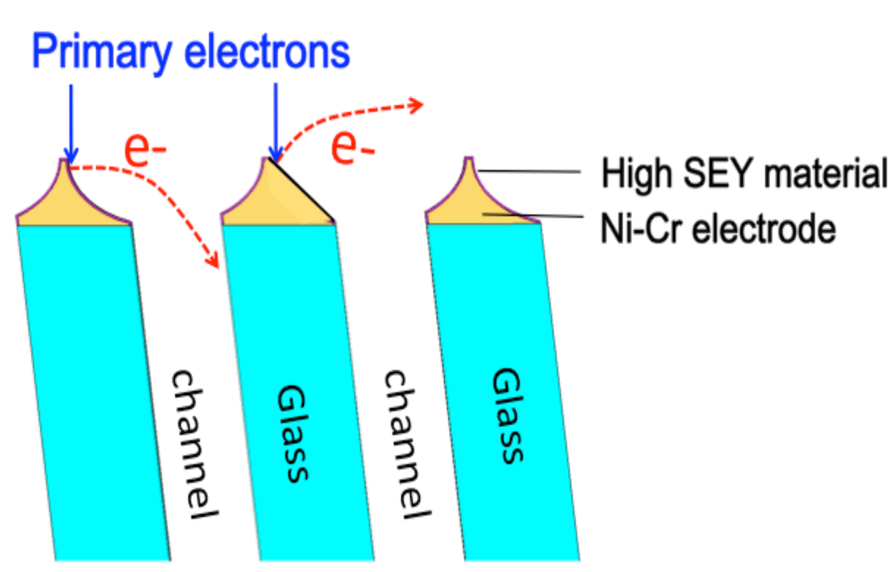


Fig. 8 Time distributions of PMT based on the bowl-shaped MCP and the conventional MCP respectively.

For the traditional one, the time distribution exhibits late pulses characterized with a small bump and a long tail. The late pulse is much wider than the main pulse. Contrastingly, the time performance of the bowl-shaped MCP is much better. The proportion of electrons with transit time longer than 3.6 ns is less than 2%.

Why is the cambered surface



The side surfaces of the Ni-Cr electrode are specially cambered instead of a planar design with the purpose of guiding the secondary electrons emitted from the electrode into the nearest channel, since the exit angle of the secondary electrons follows a cosine distribution. As a result, both the CE and the time performance can be improved.