Photocathode Development in MLAPD group

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On Behalf of the Collaboration group

June 29, 2012 Chicago
1. The Motivation of MLAPC;

2. The Research work for photocathode;

3. The technique for photocathode;

4. The prototypes;

5. The status of the HZC.
Next generation Neutrino Experiment in China

60 km from Daya Bay and Haifeng

Daya Bay II

Huge Detector (LS + PMT)
Energy resolution ~ 3%/\sqrt{E}

- Neutrino target: 30m(D) × 30m(H)
- LS, LAB based: ~20kt
- Oil buffer: ~6kt
- Water buffer: ~10kt
- PMT (20’’): ~20,000

Reactor experiments:

The Main Scientific goals:

- Mass Hierarchy
- Mixing matrix elements
- Supernovae
- geo-neutrinos

The Quantum Efficiency of PMT

<table>
<thead>
<tr>
<th></th>
<th>KamLAND</th>
<th>Daya Bay II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector</td>
<td>~1 kt Liquid Scintillator</td>
<td>➢ 10 kt Liquid Scintillator</td>
</tr>
<tr>
<td>Energy Resolution</td>
<td>6%/√E</td>
<td>3%~4%/√E</td>
</tr>
<tr>
<td>Light yield</td>
<td>250 p.e./MeV</td>
<td>~1000 p.e./MeV</td>
</tr>
<tr>
<td>Photocathode coverage</td>
<td>30%</td>
<td>~80%</td>
</tr>
</tbody>
</table>

➢ High QE PMTs: SBA (35%) and UBA (43%)

SBA will be available in 12" diameter format

➢ Can we improve the Quantum Efficiency of Photocathode or Photon Detection Efficiency for the large area 20” PMT?

?? 20” UBA/SBA photocathode PMT from Hamamatsu? QE: 20% ➞ 40%

?? 20” New large area PMT? Quantum Efficiency > 40%?

or Photon Detection Efficiency: 14% ➞ 30%
The new design of a large area PMT

High photon detection efficiency + Single photoelectron Detection + Low cost

1) Using two sets of Microchannel plates (MCPs) to replace the dynode chain
2) Using transmission photocathode (front hemisphere) and reflective photocathode (back hemisphere) \(\sim 4\pi\) viewing angle!

Photon Detection Efficiency: \(14\% \rightarrow 30\% \times \sim 2\) at least!
Project team and Collaborators

Institute of High Energy Physics, CAS

R&D effort by Yifang Wang;

& Tianchi Zhao; Jun Cao; Yukun Heng, Shulin Liu, Sen Qian; et al

Collaborators

• Xi’an Institute of Optics and Precision Mechanics of CAS;
  Jinshou Tian; Xiangyan Xu; Huling Liu; Xibing Cao;
• Nanjing University;
  Ming Qi; Shenjian Chen; Shilei Zang;
• Companies for PMT or MCP production;
The Technical Workshop & Collaboration Meeting

Technical Workshop

- Kunming 20110911
- Xian 20120227
- Nanjing 20120620

Collaboration Meeting

- Beijing 20111118
- Xian 20120301
- Nanjing 20120621
1. The Motivation of MLAPC;

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The Research work for photocathode

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<tr>
<th>Technique</th>
<th>We have!</th>
<th>We need!</th>
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<tbody>
<tr>
<td>Mn</td>
<td>Mn, but Ni-Wire Technique</td>
<td></td>
</tr>
<tr>
<td>Manganese deposition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sb</td>
<td>Mn, but Ni-wire Technique</td>
<td></td>
</tr>
<tr>
<td>Antimony deposition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen Plasma</td>
<td>The technique, and better using</td>
<td>The transfer equipment to do the Oxygen Plasma in glass with MCP</td>
</tr>
<tr>
<td>Hydrogen Plasma</td>
<td>We know the benefit and try to understand this.</td>
<td>The transfer equipment to do the Oxygen Plasma in glass with MCP</td>
</tr>
<tr>
<td>Alkali Metal Source</td>
<td>The Source activated by current; The source activated by high frequency</td>
<td>The high QE photocathode</td>
</tr>
</tbody>
</table>
How to generate the antimony layer more uniform?
How to protect the MCPs not to be effected by the antimony without the transfer equipment?

How to protect the MCPs not to be effected by the Oxygen without the transfer equipment?
We need to produce the standard alkali metal generator to control the quality during the mass production process in the future.
## The Research work for photocathode

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Transfer Equipment = The photocathode + The MCP (friendly!!!)
1. The Motivation of MLAPC;

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4. The prototypes;

5. The status of the HZC.
The small prototype for producing the PC

- Anode
- Cathode
- The tunnel for Cs
- The tunnel for Sb and gas
- The tunnel for K
- CS
- K
- The tunnel for Sb and gas
The contrast of different Alkali materials

Potassium (Cesium) **chromate** VS Potassium (Cesium) **Chloride**

The Chromate ones are better than the chloride ones! Just as the choice of the SAES
<table>
<thead>
<tr>
<th>Element</th>
<th>Mass %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium chromate (\text{(Na}_2\text{CrO}_4\text{)})</td>
<td></td>
</tr>
<tr>
<td>Sodium dichromate (\text{(Na}_2\text{Cr}_2\text{O}_7\text{)})</td>
<td></td>
</tr>
<tr>
<td>Potassium chromate (\text{(K}_2\text{CrO}_4\text{)})</td>
<td></td>
</tr>
<tr>
<td>Potassium dichromate (\text{(K}_2\text{Cr}_2\text{O}_7\text{)})</td>
<td></td>
</tr>
<tr>
<td>Cesium chromate (\text{(Cs}_2\text{CrO}_4\text{)})</td>
<td></td>
</tr>
<tr>
<td>Cesium dichromate (\text{(K}_2\text{Cr}_2\text{O}_7\text{)})</td>
<td></td>
</tr>
<tr>
<td>Nickel pocket</td>
<td></td>
</tr>
</tbody>
</table>

| ICP: Inductively Coupled Plasma | XRF: X-ray fluorescence |
The relative QE of the photocathode

The Photocathode comes from ANL (QE~27%)

The Photocathode comes from CAS (QE~16%)
- **Source**: SAES? Hamamastus? Others?
- **Setup position**: inside? Outside?
- **Evaporation method**: Current? HRF?
- **Purity? Material? Impurity?**
- **The Know-How! ......**
- **Oxygen Plasma**: When? How Long?
- **Baking**: Temperature? Time?
- **Growth method**: fast? Slow?
- **Thickness of Sb**: monitor and control?
- **Anti-reflective layer**: Material? Thickness?
- **Thickness of K/Cs**: Monitor and control?
- **The Know-How! ......**

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**Composition**

**High QE photocathode**

**The growth technology**

**The AMD for Industry**
The contrast of different technique process

<table>
<thead>
<tr>
<th>ANL</th>
<th>MLAPC-Company</th>
<th>MLAPC-CAS-NEW</th>
<th>MLAPC-CAS-OLD</th>
</tr>
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<tbody>
<tr>
<td>assemble</td>
<td>assemble</td>
<td>assemble</td>
<td>assemble</td>
</tr>
<tr>
<td>baking (220°C, 24h)</td>
<td>baking (220°C, 24h)</td>
<td>baking (350°C, 24h)</td>
<td>baking (350°C, 24h)</td>
</tr>
<tr>
<td>falling temperature</td>
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<td>falling temperature</td>
<td>falling temperature</td>
</tr>
<tr>
<td>Oxygen Plasma</td>
<td>Oxygen Plasma</td>
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<td>Oxygen Plasma</td>
</tr>
<tr>
<td>Sb (25°C)</td>
<td>Sb (25°C)</td>
<td>Sb (25°C)</td>
<td>Sb (25°C)</td>
</tr>
<tr>
<td>baking (150°C, 1h)</td>
<td>baking (210°C, 1h)</td>
<td>baking (350°C, 10h)</td>
<td>baking (160°C, 1h)</td>
</tr>
<tr>
<td>K (150°C)</td>
<td>K (200°C)</td>
<td>K (160°C)</td>
<td>K (160°C)</td>
</tr>
<tr>
<td>Cs (150°C)</td>
<td>Cs (180°C)</td>
<td>Sb, K 160°C</td>
<td>Cs (180°C)</td>
</tr>
<tr>
<td>baking (210°C, 2h)</td>
<td></td>
<td>Sb (180°C)</td>
<td></td>
</tr>
<tr>
<td>Prototype</td>
<td>Prototype</td>
<td>Prototype</td>
<td>Prototype</td>
</tr>
<tr>
<td>falling temperature</td>
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Outline

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The Prototypes

- 2” MCP-PMT
- 8” Dynode-PMT
- 8” MCP-PMT
- 5” MCP-PMT
- 8” MCP-PMT
- 5” MCP-PMT
- MCP
- transmission photocathode
- Prototype
The single photoelectron spectrum and the multi-photoelectron spectrum of the PMT

- The photoelectron spectrum of the XP2020 PMT
- SPE vs the Voltage of the PMT
- SPE vs the luminance of the LED light

**-- adjust the working voltage of the LED to adjust the luminance of the LED light.**
The photoelectron spectrum of a prototype: 5” IHEP-MCP-PMT

MPE vs the luminance of the LED light

---adjust the working voltage of the LED to adjust the luminance of the LED light.
The Prototypes in factory

8” ellipse

8” spherical
The Prototypes in Lab for measurement
1. The Motivation of MLAPC;

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The Status of the HZC

The schedule:

2012-03    Equipment Arriving
Before 2012-06    Built workshop
2012-07    Equipment assemblage
2012-08    preproduction
Thanks! 谢谢！
Thanks for your attention!
Any comment and suggestion are welcomed!
Back up
1) Using two sets of Microchannel plates (MCPs) to replace the dynode chain
2) Using transmission photocathode (front hemisphere) and reflective photocathode (back hemisphere)

Total Photon Detection Efficiency: ~30%

Photon Detection Efficiency: 14% → 30% ; ×~2 at least!
The new design of a large area PMT

High photon detection efficiency + Single photoelectron Detection + Low cost

1) Using transmission photocathode (front hemisphere) and reflective photocathode (back hemisphere) ~ 4π viewing angle!!

2) Using two sets of Microchannel plates (MCPs) to replace the dynode chain

1. up MCP
2. anode
3. down MCP
4. insulated trestle table
5. transmission photocathode
6. glass shell
7. reflection photocathode
8. bracket of the cables
9. glass joint

- Quantum Efficiency:
  - Transmission photocathode: 30%
  - Reflection photocathode: 35%

- MCP Collection Efficiency: 70%

- Photon detection efficiency:
  - $30\% \times 70\% = 21\%$
  - $40\% \times 35\% \times 70\% = 9.8\%$

- Total Photon Detection Efficiency: ~ 30.8%

Photon Detection Efficiency: 15.4% → 30.8% × ~2 at least
The new design of a large area PMT

High photon detection efficiency + Single photoelectron Detection + Low cost

1) Using two sets of Microchannel plates (MCPs) to replace the dynode chain
2) Using transmission photocathode (front hemisphere) and reflective photocathode (back hemisphere)

~ 4π viewing angle!!

Quantum Efficiency:
- Transmission photocathode: 20%
- Reflection photocathode: 40%
- MCP Collection Efficiency: 60%

Photon detection efficiency:
- Transmission Photocathode: 20% * 60% = 12%
- Reflection Photocathode: 70% * 40% * 60% = 17%

Total Photon Detection Efficiency: ~30%

Photon Detection Efficiency: 14% → 30% ; ×~2 at least!
- **Ongoing R&D:**
  - **Highly transparent LS: Attenuation length:**
    - Attenuation length: $15m \rightarrow 25m$; the Light Yield (% standard): $\times 1.5$
    - Attenuation length: $15m \rightarrow 30m$; the Light Yield (% standard): $\times 2$;
  - **High light yield LS: increasing PPO%:**
    - KamLAND: $1.5g/l \rightarrow$ Daya Bay II : $5g/l$;
    - Light Yield (% standard): $30\% \rightarrow 45\%; \times 1.5$
  - **Photocathode coverage:**
    - KamLAND: $34\% \rightarrow$ Daya Bay II : $\sim 80\% \times 2 \sim 2.5$
  - **High QE “PMT”: Quantum Efficiency (or Photon Detection Efficiency) $\times 2$;**

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<th>KamLAND</th>
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<th>Daya Bay II</th>
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<tbody>
<tr>
<td><strong>Detector</strong></td>
<td>$\sim 1 \text{ kt}$</td>
<td>$\gg 10 \text{ kt}$</td>
<td>$\gg 10 \text{ kt}$</td>
</tr>
<tr>
<td>Liquid Scintillator</td>
<td>Liquid Scintillator</td>
<td>Liquid Scintillator</td>
<td>Liquid Scintillator</td>
</tr>
<tr>
<td><strong>Energy Resolution</strong></td>
<td>$6%/\sqrt{E}$</td>
<td>$2%/\sqrt{E}$</td>
<td>$3%/\sqrt{E}$</td>
</tr>
<tr>
<td><strong>Light yield</strong></td>
<td>$250 \text{ p.e./MeV}$</td>
<td>$2500 \text{ p.e./MeV}$</td>
<td>$1100 \text{ p.e./MeV}$</td>
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