Status of TOF
— TOF Performance and Evaluation

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on behalf of BT0F and ETOF group
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@ Huazhong Normal Univ.
Outline

• **BTOF**
  - Performance and comparison
  - Aging of Scintillator
  - Aging of PMT
  - How to do next? Replacing parts or new one?

• **ETOF**
  - Progress of upgrade
  - Performance Evaluation
## TOF comparisons

### TOF with Plastic Scintillator + PMT

<table>
<thead>
<tr>
<th>Detectors</th>
<th>Times</th>
<th>Scintillator</th>
<th>Size(LxWxH)(cm)</th>
<th>PMT</th>
<th>Time reso.(ps)</th>
<th>Life time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DELPHI</td>
<td>1990</td>
<td>NE110</td>
<td>350 X 20 X 2</td>
<td>EMI19902KB</td>
<td>1200</td>
<td>11</td>
</tr>
<tr>
<td>CLEOII</td>
<td>1992</td>
<td>BC408</td>
<td>280 X 10 X 5</td>
<td>XP2020</td>
<td>139</td>
<td>10</td>
</tr>
<tr>
<td>NA49</td>
<td>2000</td>
<td>BC408</td>
<td>(12-48)X(1-1.25)</td>
<td>R3478</td>
<td>80</td>
<td>11</td>
</tr>
<tr>
<td>BELLE</td>
<td>2002</td>
<td>BC408</td>
<td>255 X 6 X 4</td>
<td>R6680</td>
<td>90</td>
<td>8</td>
</tr>
<tr>
<td>CDFII</td>
<td>2003</td>
<td>BC408</td>
<td>279 X 4 X 4</td>
<td>R7761</td>
<td>100</td>
<td>9</td>
</tr>
<tr>
<td>BESIII</td>
<td>2008</td>
<td>BC408</td>
<td>230X5.7-6.5X5</td>
<td>R5924</td>
<td>67~70</td>
<td>16??</td>
</tr>
</tbody>
</table>
The performances of BTOF (since 2009)

<table>
<thead>
<tr>
<th>Year (data)</th>
<th>Time resolution</th>
<th>Efficiency%</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009 (jpsi/psip)</td>
<td>67ps</td>
<td>~97</td>
<td>PMT HV are same during the 3 years</td>
</tr>
<tr>
<td>2010 (psi3770)</td>
<td>70ps</td>
<td>~96</td>
<td></td>
</tr>
<tr>
<td>2011 (psi3770)</td>
<td>70ps</td>
<td>~94</td>
<td></td>
</tr>
<tr>
<td>2012 (psip/jpsi)</td>
<td>67ps</td>
<td>~97</td>
<td>The HV of PMTs were adjusted from 2012</td>
</tr>
<tr>
<td>2013 (4260/4360)</td>
<td>68ps</td>
<td>~96</td>
<td></td>
</tr>
<tr>
<td>2014 (R scan)</td>
<td>70ps</td>
<td>~94</td>
<td></td>
</tr>
<tr>
<td>2015 (R scan)</td>
<td>67ps</td>
<td>~92</td>
<td></td>
</tr>
</tbody>
</table>

- The table above shows the results of barrel TOF, the data sample are Bhabha events
- The efficiencies are given by double layers
- The change of time resolution can be caused by different bunch lengths at different energy points
- The time resolution is stable, the efficiency drops slightly each year
- HV tuning is done in 2012 and 2016 since 2009
1. **Plastic natural aging is the main reasons**
   - Light yield decreasing
   - Transparency decreasing
2. **Irradiation has a little effects**

Until now, the accumulated dose in scintillators are about 1000 rad. 8 year later, the scintillators can still work.

2006, TOF group made irradiation test on plastic scintillator
Aging of Plastic Scintillator (2)

The average decreasing rate of Light yield: 7%/year

• Same data samples are used as study of light yield.
• The raw measured QTC with |z|<5cm at different time point is fitted with an Landau function with Gaussian convolution to describe the difference of TOF counters.
• Two corrections:
  – The attenuation length decreased with time, it is corrected at each time point.
  – TOF monitor result is employed to correct the changes of TOF electronics.
• The MPV of corrected QTC is normalized.
Aging of Plastic Scintillator (3)

- The high voltages of TOF system are set in 2009, it provide us an opportunity to study the aging effect under same data taking conditions.
- Transparency decreasing of plastic scintillator can be described by Attenuation length decreasing:
- Attenuation length calibration:

\[
Q_1 = A_1 \times \frac{Q_0}{\sin \theta} \times \exp \left( -\frac{l/2+z}{L_{Attlen}} \right)
\]

\[
Q_2 = A_2 \times \frac{Q_0}{\sin \theta} \times \exp \left( -\frac{l/2-z}{L_{Attlen}} \right)
\]

\[
\log \left( \frac{Q_1}{Q_2} \right) = \log \left( \frac{A_1}{A_2} \right) + \frac{2 \cdot z}{L_{Attlen}}
\]
• About ~30 data samples, from 2009/6 to 2015/05 are used. The data of one day in each month is used for attenuation length and relative gain calibration,
• The average attenuation-rate of attenuation length is 3.5% every year.
• The efficiency of TOF system is found to be decreased at the beginning of 2012. It is caused by TOF aging effect, the attenuation length and light yield are studied.
• The change of time resolution is not observed.
Aging of PMT (1)

• The factors affecting the life time of PMT R5924
  – Mechanical shock: Fine-mesh PMT is very fragile
  – HV changing too fast
  – Accumulating total charge of anode:
    • 360 C is the limit of life time
  – To save the life time and increase the capability of anti-magnetic field
    • 10 times preamplifier is placed in BESIII TOF

Fine-mesh and its PMT
The aging of PMT (2)

- The total events is $1.7 \times 10^{13}$ (from the table below)
- For each PMT, the hit rate is 0.04/event
- The mean charge of each PMT hit is 12 pC (before FEE)
- The total accumulated charge for each PMT is 8.2 C
- The average dynode current is 144 nA

<table>
<thead>
<tr>
<th>year</th>
<th>time (month)</th>
<th>BES usage (%)</th>
<th>hour</th>
<th>rate (万/秒)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014-2015</td>
<td>11</td>
<td>36.55</td>
<td>2894.76</td>
<td>30</td>
</tr>
<tr>
<td>2013-2014</td>
<td>10</td>
<td>37</td>
<td>2664</td>
<td>30</td>
</tr>
<tr>
<td>2012-2013</td>
<td>10</td>
<td>30</td>
<td>2160</td>
<td>30</td>
</tr>
<tr>
<td>2011-2012</td>
<td>6</td>
<td>46</td>
<td>1987.2</td>
<td>30</td>
</tr>
<tr>
<td>2010-2011</td>
<td>7</td>
<td>43</td>
<td>2167.2</td>
<td>30</td>
</tr>
<tr>
<td>2009-2010</td>
<td>5</td>
<td>51</td>
<td>1836</td>
<td>30</td>
</tr>
<tr>
<td>2008-2009</td>
<td>6</td>
<td>50</td>
<td>2160</td>
<td>30</td>
</tr>
</tbody>
</table>

- PMT should be safe!
- If possible: taking some PMT out, to evaluate its performance changing
How about next (1)?

- To 2024, another 8 years:
  - Light yield: decreasing to 44% comparing to present light yield
  - Attenuation length: decreasing to 1.3 m
  - PMT: should be OK.

Light strength in the middle: decreasing to 32%

To let the PMT signal is at the same level as present
- PMT HV increasing about 200V – 250 V
- Or decreasing the thresholds of electronics, some tests Need to consider to do.

Time resolution and efficiency should be ensured to be still OK!
How about next (2)?

- **Conservative:** Ensure the TOF long life time
  - Several PMT tests
  - Electronics test, including the thresholds decreasing
  - Plastic scintillator replacing? 2 MRMB

- **Radical:** Upgrade to 50ps (Intrinsic 30 ps plus non-intrinsic 40ps) for better $\pi/K$ separation, especially for the higher energy?
  - MRPC option?
    - Long strip option: time resolution is not so good
    - Small pad + two end readout: 
      time reso.: $\sim$50ps?; limited space
  - Cerenkov option?
    - Cerenkov ring for positions or CCT for timing
How about next? (3)

- **CCT (Correlated Cerenkov Timing)** has been given up too.
  - Its principle is to measure the time of the Cerenkov light to separate particles.
  - Simulation was made in ten years ago
  - Spending: level of 100 MRMB

Number of photoelectrons in right or left PMT versus hit position from CCT simulation.

\[ \delta t'_{\text{c}} = \delta t_{\text{c}} + \delta t_{\text{d}} (\sin \theta_e - \sin \alpha_e) + \delta \eta' \]

\[ \cos \theta = \beta (\cos \phi - \cos \alpha) \]

\[ \alpha = \theta + \phi \]

\[ \alpha > \sin^{-1} (\beta \eta) \]
Outline

• BTOF
  – Performance and comparison
  – Scintillator Aging
  – PMT aging
  – How to do next? Replacing parts or new one?

• ETOF
  – Progress of upgrade in past year
  – Performance
ETOF Progress

- Design and review and beam test in 2013–2014
- Mass production 2014.9–2015.3
- Two modules running in BESIII in 2014–2015
- Whole system testing and running
  - 2015.4–2015.7 Time reso. is 80ps, efficiency: >96%
  - Pass the review requested by the Chinese Academy of Sciences in 2015.7

Review passed

Whole system test under cosmic-ray, the average intrinsic time reso. is 58ps
## Tasks and subsystems

### MRPC module
**USTC:** Li Cheng, Sun Yongjie, …

### FEE and its support board
**IHEP:** Jiang Xiaoshan, Dai Hongliang, Zhang Jie …

### TDIG
**USTC:** Liu Shubin, Cao Ping …

### Trigger
**IHEP:** Liu Zhen-an, Zhao Jingzhou, Gong Wenxuan …

### DAQ
**IHEP:** Zhu Kejun, Ji Xiaolu …

### HV system & gas monitor
**IHEP:** Wu Zhi, Xu Meihang …

### Gas & Slow Control
**IHEP:** Luo Xiaolan, Ye Mei …

### Mechanical & Installation
**IHEP:** Ma Xiaoyan, Chen Ming Ming …

### Software & Simulation
**IHEP:** Sun Shengsen, …
**Giessen:** Kühn Wolfgang, Matthias Ullrich …

(CTTP: Coincidence_Test_Threshold_Power)
A lot of problems, resolved finally

- **Electronics, self-check?**
  - Lab ~ 30ps, BES ~ 60ps
- **Dark current too high?**
  - Control the water in source gas
  - Use copper or Teflon tube
  - Filter by molecular sieve or silica gel
- **Dark rage too high?**
  - Electromagnetic interference
  - Shielding box and electrical grounding
- **Multi-peaks in TOT**
- **Gas leaking in box**

- **Limited space?**
- **Material for electronics box?**
- **Lost beam?**
- **Sparks?**
- **Big signal shock?**
- **Thermolysis?**
- **Anti-irradiation?**
- **Thresholds VS charge?**
- **Signal cables selection and routing?**

**Installing**
- Uninstalling old ETOF?
- Positioning?
- Shielding stainless steel?
- Cabling method?
- Electrical grounding: Box is insulated from BESIII in front end.
  - Gas pipe: copper + Teflon + copper
Installing of new ETOF

- Open Door → take off old ETOF → installing new ETOF → test: 8.1–10.7, 2015
- Installing in Day/Testing in Night
- Limited space/endure radiation from Uranium
- Work on holidays of High-temperature and National Days

Many subsystems cooperated together!
- Mechanics
- Gas
- HV
- Electronics
- Trigger
- DAQ
- Supported team

Installed MRPC
More Pictures (1)
More Pictures (2)
Preliminary result of ETOF(MRPC)

- **Event start time**
  - Time resolution: 60ps for combined
  - Entries
  - Event start time/ns

- **Time resolution 70ps for one-end**
  - Delt time/ns
  - Entries

- **Efficiency ~98%**
  - Efficiency
  - Module

- **Resolution/ps**
  - Module
  - Resolution/ps
  - east, west, combine

- **Efficiency**
  - Module
  - Efficiency
  - east, west, layer
Comparisons

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Year</th>
<th>Resolution (ps)</th>
<th>Lifetime (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAR TOF</td>
<td>2003</td>
<td>86</td>
<td>~13</td>
</tr>
<tr>
<td>STAR MTD</td>
<td>2014</td>
<td>90</td>
<td>~</td>
</tr>
<tr>
<td>ALICE TOF</td>
<td>2009</td>
<td>80-90</td>
<td>~7</td>
</tr>
<tr>
<td>BESIII ETOF</td>
<td>2016</td>
<td>60</td>
<td>~</td>
</tr>
</tbody>
</table>

Key focus for life time of MRPC
- Gas
- HV
- Front-end Electronics
Summary

• BTOF
  – Plastic scintillator: light yield and attenuation length to decrease a lot
  – PMT: should be OK
  – Increasing HV of PMT: should ensure the 70 ps time resolution and 98% efficiency
  – Some tests need to do
  – Upgrade options: MRPC/Cerenkov

• ETOF
  – Hard work under good cooperation from many groups for 3 years and 60ps is obtained, the best in the world in MRPC TOF project
Thanks!