EAS Thermal Neutron Detector Array to Add into LHAASO

Xinhua Ma
Institute of High Energy Physics (IHEP),
Chinese Academy of Sciences (CAS)

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outline

1. Physical motivation
2. EN-detector
3. PRISMA-YBJ: early study at high altitude
4. ENDA to add into LHAASO
1. Physical motivation

- Hadrons are the backbone of the shower development, very sensitive to primary composition.
- hadrons can generate amount of fast neutrons in ground media (soil, building, etc.). Fast neutrons are moderated to thermal neutrons.
At the same primary energy, thermal neutrons generated by light components (such as proton) are one order more than one by heavy components (such as iron). It is very good for primary component separation.
- Thermal neutrons are 2-3 orders more than hadrons.
- thermal neutrons are 1-2 orders at high altitude more than one at sea level
2. EN-detector

EN-detector (electron-neutron detector), developed by Yuri Stenkin et al., can detect both thermal neutrons and “charged” components.


**PRISMA** (PRImary Spectrum Measurement Array)

neutron / noise separation

Q_{\text{total}}

\begin{align*}
\text{pulse height} & \quad 100 \\
Q_{\text{trigger}} & \quad 80 \\
T, \mu s & \quad 60 \\
Q_{\text{trigger}} & \quad 40 \\
Q_{\text{total}} & \quad 20 \\
Q_{\text{trigger}} & \quad 0 \\
T, \mu s & \quad 0
\end{align*}

electrons / neutron separation in one shower

Q_{\text{trigger}}

\begin{align*}
\text{electrons in shower} & \quad 1000 \\
\text{noise} & \quad 800 \\
\text{neutron} & \quad 600 \\
\text{Q_{\text{total}}} & \quad 400 \\
\text{Q_{\text{trigger}}} & \quad 200 \\
\text{Q_{\text{total}}} & \quad 0
\end{align*}
3. early study at high altitude

PRISMA-YBJ:
4 EN-detectors
4300m a.s.l.
Yangbajing Tibet, China,
from Jan. 2013.
In March 2016 move to Tibet University in Lhasa

thermal neutron lateral distribution

\[ \rho_n(r) = \rho_0 \times e^{-\left(\frac{r}{r_0}\right)} + \rho_1 \times e^{-\left(\frac{r}{r_1}\right)} \]

<table>
<thead>
<tr>
<th>$N_{10}$ intervals</th>
<th>$\chi^2/ndf$</th>
<th>$\rho_0 (m^{-2})$</th>
<th>$\rho_1 (m^{-2})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lg(N_{10}) &lt; 4.8$</td>
<td>2.44/8</td>
<td>9.0 ± 6.8</td>
<td>3.41 ± 0.32</td>
</tr>
<tr>
<td>$4.8 &lt; \lg(N_{10}) &lt; 5.4$</td>
<td>2.69/7</td>
<td>222 ± 65</td>
<td>7.17 ± 0.65</td>
</tr>
<tr>
<td>$\lg(N_{10}) &gt; 5.4$</td>
<td>20.1/7</td>
<td>456 ± 230</td>
<td>18.7 ± 2.3</td>
</tr>
</tbody>
</table>

hadron lateral distribution, KASCADE HCAL, sea level

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Our preliminary result indicates that no significant slope changing above 3PeV

Result of PRISMA-YBJ from Nn measurement

Slope is close to 2.73, i.e. close to that below 1 PeV
lunar tidal effect

superimposed epoch analysis

Pure And Appl. Geophys. 174 (2017) 2763-2771
Response of PRISMA-YBJ to 2015 Nepal earthquakes

Journal of Environmental Radioactivity 208-209 (2019) 105981
4. ENDA (EN-Detector Array) to add into LHAASO

ENDA-64 (1100m²)

- 3 cables to each detector: HV, LV, Rdyn, Sdyn, Variations (Spare)
- To data center & power supply
  - Power: ~500 Watt
  - Data: ~50Mb/day
- White Rabbit clock system

ENDA-400 (10000m²)
Under supports by Tibet University, Institute for Nuclear Research RAS, Institute of High Energy Physics CAS, Hebei Normal University (HNU) and Sichuan University, ENDA-64 are made and will be added into LHAASO in 2019.

EN-detectors at HNU
FADCs are made by Sichuan University.
ENDA-16 at Yangbajing from Dec. 2018
One coincident event

\( \rho_e (\text{m}^{-2}) \) at ENDA

\( \rho_e (\text{m}^{-2}) \) at YBJHA

neutrons at ENDA

muons at YBJHA
Linear fitting $\lg(y) = \lg(k) + \lg(x)$

<table>
<thead>
<tr>
<th>Detector of ENDA</th>
<th>Detector of YBJ-HA-ED</th>
<th>slope $\lg(k)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>$-0.020 \pm 0.007$</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>$-0.195 \pm 0.007$</td>
</tr>
<tr>
<td>13</td>
<td>2</td>
<td>$-0.181 \pm 0.006$</td>
</tr>
<tr>
<td>16</td>
<td>3</td>
<td>$0.011 \pm 0.006$</td>
</tr>
</tbody>
</table>
Linear fitting \( y = a + bx \)

\( b = 0.36 \pm 0.01 \)  \( a = 1403 \pm 77 \)
The cores fall into ENDA-16.

ENDA-16 detects neutrons only far from cores.

Simulation: PoS(ICRC2019)431
LHAASO at the knee region

- ED : $e$
- MD, WCDA: $\mu$
- WFCTA: $\bar{\chi}$
- WCDA++: $\gamma$ family at core $\rightarrow \pi^0$
- ENDA: thermal neutrons $\rightarrow \pi^+\pi^-$

$\rightarrow$ Full particle measurement of cosmic showers!

$\rightarrow$ significant capability of component separation and energy determination!

Thanks!