Polarization Measurement of Crab Nebula by Hitomi-SGD

Sep. 18\textsuperscript{th}, 2018 T. Mizuno @ polarization research group meeting on behalf of the SGD team (see also Katsuta+16, NIMA, and Watanabe+18, PASJ submitted)
Hitomi SGD as a **Polarimeter**

- **Si-CdTe** Compton Camera + BGO shield
- Constrain incident angle using Compton kinematics
  - efficient background suppression (θ-cut)
  - polarization measurement (φ-measurement)

\[
\cos \theta = 1 + \frac{m_e c^2}{E_1 + E_2} - \frac{m_e c^2}{E_2}
\]

Lei+97 (Concept of Compton polarimeter)
We carried out a beam test at SPring-8 in Nov. 12-14, 2015 (48 hr)

AE, DPU, and thermostat bath (CC inside) were installed in a hatch of BL08W

We used a full CC prototype (32 layers of Si, 8 layers of bottom CdTe, and 2x4 layers of side CdTe) (although some channels were not able to read-out)
Results of 122 keV Beam

- We divided data into two and fit two datasets individually

**Modulation factor for 100% polarized beam of two $$\phi$$ ranges**

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>$$\varphi_{pol}$$ (deg)</th>
<th>$$Q_1$$</th>
<th>$$Q_2$$</th>
</tr>
</thead>
<tbody>
<tr>
<td>122.2</td>
<td>-1.4</td>
<td>0.679 ± 0.003</td>
<td>0.637 ± 0.003</td>
</tr>
<tr>
<td>21.1</td>
<td>0.685 ± 0.005</td>
<td>0.639 ± 0.004</td>
<td></td>
</tr>
<tr>
<td>43.6</td>
<td>0.701 ± 0.007</td>
<td>0.653 ± 0.005</td>
<td></td>
</tr>
<tr>
<td>88.6</td>
<td>0.649 ± 0.004</td>
<td>0.648 ± 0.004</td>
<td></td>
</tr>
<tr>
<td>178.6</td>
<td>0.675 ± 0.005</td>
<td>0.637 ± 0.004</td>
<td></td>
</tr>
</tbody>
</table>

$$Q_1 = 0.667 \pm 0.018$$  
$$Q_2 = 0.642 \pm 0.007$$

Standard deviation of $$Q_{100}$$ ($$Q_1$$, $$Q_2$$) at various beam polarization angles is 1.1-2.7%  
Measured $$Q_1$$ and $$Q_2$$ agree with simulation prediction in $$\leq$$3%  
=>$\text{Systematic uncertainty of } Q_{100}\text{ is } \sim 3\%$
(Hitomi) SGD observed Crab Nebula on March 25, 2016

- Opportunity to demonstrate the concept of “Compton Camera Polarimeter”
- Only 8.6 ks on-source duration (exposure ~5 ks), only 4/6 of Cameras in operation

-> Accurate and precise BG estimation is a key
Light Curve

- **Red**: Crab obs.
- **Blue**: One-day earlier (Black=Red-Blue)
- Count rates consistent during Earth occultation (white area) -> can use data of one-day earlier as BG
Event Selection

- \( E = 60 - 160 \text{ keV} \)
- \( \theta_{\text{geom}} = 50 - 150 \text{ deg} \) (angle from the boresight)
- \(|\text{OFFAXIS}| \leq 30 \text{ deg} \) (\( \theta_K - \theta_{\text{geom}} \) where \( \theta_K \) is the angle determined with Compton kinematics)
  - Source\_rate \sim BG\_rate \rightarrow \text{Accurate and precise BG estimation is a key}
RXJ 1856.5-3754

- RXJ 1856.5-3754 (isolated NS/SNR, faint for SGD) observed in ~ 1day exposure
- Crab BG (one-day earlier, black) ~ RXJ 1856.5-3754 (green) in various parameters -> use the latter as “background”
Polarization Measurement (1)

- Fit azimuth angle distribution (BG incl.) with “background(data)+sinusoidal(simulation)”
  \[ n_{\text{exp}}(\phi_i) = n_{\text{sim}}(\phi_i) \left( 1 - Q \cos(2(\phi_i - \phi_0)) \right) + n_{\text{bkg}}(\phi_i), \]

- (with only 5ks exposure) Polarization detected at >99% confidence with \( \phi_0 = 67\,\text{deg} \) and \( Q = 0.144 \) (\( Q_{100} = 0.65 \))
(Look at the polarization angle (PA) for a cross-check)

PA = 110 ± 13 deg, PD = 22 ± 11%

PA consistent with the direction of the spin axis (-> seems OK)
Summary

- MC calibrated with SP8 Beam Test
- Accurate & precise BG estimate using real data (one-day earlier and RXJ 1856.5-3754)
- Only 5ks observation, but
  - Polarization detected at >99% significance
    - Proof of high sensitivity
    - PA = 110 ± 13 deg, PD = 22 ± 11%
    - Consistent with previous measurements (result seems OK)
Backup Slides