e-ASTROGAM Tracker and Calorimeter Polarimetry

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1. A Few Polarimetry Concepts
Compton Polarimetry

Unpolarized Beam

$$\frac{d\sigma_{KN,U}}{d\Omega} = \frac{1}{2} r_0^2 \varepsilon^2 [\varepsilon + \varepsilon^{-1} - \sin^2 \theta]$$

Polarized Beam

$$\frac{d\sigma_{KN,P}}{d\Omega} = \frac{1}{2} r_0^2 \varepsilon^2 [\varepsilon + \varepsilon^{-1} - 2 \sin^2 \theta \cos^2 \eta]$$
Pair Production Polarimetry

- e-/e+ pair is emitted in the plane of polarization of the photon;
- The pair distribution modulation amplitude and maxima phase depend on polarization degree and angle, respectively;
- Simulation code based on MEGAlib and BoGEMMS (Bologna Geant4 Multi-Mission Simulator) for pair production regime;
- Experimental: MEGA prototype data analysis.

Nuclear conversion

Field of a nucleus

\[ \gamma \]

\[ e^- \]

\[ e^+ \]
Pair Production
Polarimetry with e-ASTROGAM

1) MEGA prototype at Duke University (100% polarized beam)
2. Polarimetric Studies of the eASTROGAM Si Tracker
e-ASTROGAM Si Tracker

Studies Performed:

- Layer Spacing Studies
- Active Volume Studies
- Tracker Volume Studies

Optimization

Simulation Conditions

Source: Mono Energetic, Power Law, Crab Source
Beam Type: Far-Field Point Source
Energy range: 0.2 – 5 MeV
Incidence angle: 0, 30, 60 and 90
N Triggers: 500,000

Si Tracker Info:
- Thickness in μm (250, 400, 500, 560, 700, 930)

Calorimeter Info:
- Nlayers (30, 40, 50, 56, 70, 112)
- Spacing in cm (0.50, 0.75, 1.00, 1.10, 1.40)
e-ASTROGAM

Si Tracker - Monoenergetic Source

- **Si Tracker Info:**
  - Thickness - 500 μm
  - Nlayers - 56
  - Spacing 1.00 cm

Results in agreement with the previous simulation.

**Simulation Conditions**

Source: Monoenergetic
Beam Type: Far-Field Point Source
Incidence angle: Normal
Energy range: 1 – 3 MeV
N Triggers: 500,000
Si Tracker Info: Thickness - 500 μm
Nlayers - 56
Spacing 1.00 cm

Source Info: Power Law (2.0)
Far-Field Point Source
500,000 Triggers

Simulation Conditions

Energy range: 0.2 – 2 MeV
Energy range: 0.8 – 5 MeV

Same conditions as Gonzalo
e-ASTROGAM

Si Tracker - Total Volume Studies

Variable Sensitive volume
Constant Interlayer spacing
Variable Number of layers
Variable Total Tracker volume

Simulation Conditions

Source: Power Law (2.0)
Beam Type: Far-Field Point Source
Energy range: 0.5 – 2 MeV
N Triggers: 500,000

TotVol = Const*(Nlayers – 1)*0.5*ZDistance
**e-ASTROGAM**

**Si Tracker - Active Volume Studies**

- Constant Sensitive volume
- Variable Interlayer spacing
- Variable Number of layers
- Variable Total Tracker volume

**ActVol = Const* (Nlayers)*LayerThickness**

**Simulation Conditions**

- Source: Power Law (2.0)
- Beam Type: Far-Field Point Source
- Energy range: 0.5 – 2 MeV
- N Triggers: 500,000
**Simulation Conditions**

Source: Power Law (2.0)
Beam Type: Far-Field Point Source
Energy range: 0.5 – 2 MeV
N Triggers: 500,000

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**e-ASTROGAM**

**Si Tracker - Active Volume Studies**

- Constant Sensitive volume
- Variable Interlayer spacing
- Variable Number of layers
- Variable Total Tracker volume

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**Graph**

- Modulation Polarization Factor vs. Si Tracker Thickness (μm)
- Points indicate different configurations:
  - Nlayers = 56, Spacing = 1 cm
  - Nlayers = 112, Spacing = 0.5 cm
  - Nlayers = 70, Spacing = 0.75 cm
  - Nlayers = 50, Spacing = 1.10 cm
  - Nlayers = 40, Spacing = 1.40 cm
  - Nlayers = 30, Spacing = 1.90 cm

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Si Tracker - Spacing Studies

- Variable Sensitive volume
- Variable Interlayer spacing
- Constant Number of layers
- Variable Total Tracker volume

Simulation Conditions

Source: Power Law (2.0)
Beam Type: Far-Field Point Source
Energy range: 0.5 – 2 MeV
N Triggers: 500,000

![Graph showing Modulation Polarization Factor vs Si tracker thickness (μm) with different spacings (1 cm, 0.75 cm, 0.5 cm).]
**e-ASTROGAM**

**Si Tracker - Spacing Studies**

- Variable Sensitive volume
- Variable Interlayer spacing
- Constant Number of layers
- Variable Total Tracker volume

**Simulation Conditions**

- Source: Power Law (2.0)
- Beam Type: Far-Field Point Source
- Energy range: 0.5 – 2 MeV
- N Triggers: 500,000

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**Graph: Modulation Polarization Factor vs. Si tracker thickness (μm)**

- Spacing 1 cm
- Spacing 0.75 cm
- Spacing 0.5 cm

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And tables to compare data

<table>
<thead>
<tr>
<th>MDP Requirements</th>
<th>eASTROGAM paper MDP</th>
<th>Simulated MDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 20 %</td>
<td>0.7%</td>
<td>0.65%</td>
</tr>
<tr>
<td>10 mCrab, 0.3-2.0 MeV, 1 year obs. time</td>
<td>Crab, 0.2-2.0 MeV, 1 Ms obs. time</td>
<td>Crab, 0.2-2.0 MeV, 1 Ms obs. time</td>
</tr>
<tr>
<td>Galactic Center, 10%</td>
<td>10 mCrab, 0.2-2.0 MeV, 1 year obs. Time</td>
<td>Galactic Center, 10.8%</td>
</tr>
</tbody>
</table>
eASTROGAM
Si Tracker Polarization Summary

So far what have we learned?

• Si Tracker seem to be close to be optimized;
• There is a small dependence on the geometry parameters;
• Although not shown results similar to Gonzalo’s were obtained (energy resolution and angular resolution);
3. Polarimetric Studies of the eASTROGAM Calorimeter
e-ASTROGAM Calorimeter

Studies Performed:

- Calorimeter Material studies
- Calorimeter Volume studies
- Planned studies

Optimization

Simulation Conditions

- Source: Mono Energetic, Power Law, Crab Source
- Beam Type: Far-Field Point Source
- Energy range: 0.2 – 3 MeV
- Incidence angle: 0, 30, 60, 90
- N Triggers: 500,000

Calorimeter Info:

- Crystal size in cm (6, 8, 10)
- Material (CsI, CdTe, CZT)

Si Tracker Info:

- eASTROGAM conditions
e-ASTROGAM

Calorimeter - Monoenergetic Source

Calorimeter info:
- Material – CsI, CdTe, CZT
- Crystal size – 8 cm

Si Tracker info:
- Thickness – 500 μm
- Nlayers - 56
- Spacing 1.00 cm

Simulation Conditions
Source: Monoenergetic
Beam Type: Far-Field Point Source
Incidence angle: Normal
Energy range: 0.5 – 3 MeV
N Triggers: 500,000

Graph showing modulation polarization factor vs energy for CsI, CdTe, and CZT materials.
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Calorimeter – Non-Monoenergetic

Calorimeter info:
- Material – CsI, CdTe, CZT
- Crystal size – 8 cm

Si Tracker info:
- Thickness – 500 μm
- Nlayers - 56
- Spacing 1.00 cm

Simulation Conditions
Source: Power Law (2.0)
Beam Type: Far-Field Point Source
Incidence angle: 0, 30, 60, 90
Energy range: 0.5 – 2 MeV
N Triggers: 500,000

Graph: Modulation polarization Factor vs Incidence angle (degrees)
- CsI
- CdTe
- CZT
e-ASTROGAM

Calorimeter – Crab Source

Calorimeter info:
- Material – CdTe
- Crystal size – 6, 8, 10 cm

Si Tracker info:
- Thickness – 500 μm
- Nlayers - 56
- Spacing 1.00 cm

Simulation Conditions
Source: Power Law (2.0)
Beam Type: Far-Field Point Source
Energy range: 0.5 – 2 MeV
N Triggers: 500,000

Incidence angle (degrees)
Modulation Polarization Factor

- CdTe size - 10 cm
- CdTe size - 8 cm
- CdTe size - 6 cm

Simulation Conditions
- Source: Power Law (2.0)
- Beam Type: Far-Field Point Source
- Energy range: 0.5 – 2 MeV
- N Triggers: 500,000

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**Calorimeter – Crab Source**

**Calorimeter info:**
- Material – CZT
- Crystal size – 6, 8, 10 cm

**Si Tracker info:**
- Thickness – 500 μm
- Nlayers – 56
- Spacing 1.00 cm

**Simulation Conditions**
- Source: Power Law (2.0)
- Beam Type: Far-Field Point Source
- Energy range: 0.2 – 2 MeV
- N Triggers: 500,000

![Graph showing modulation polarization factor against incidence angle for different CZT sizes](image)

**Graph Details:**
- **Y-axis:** Modulation Polarization Factor
- **X-axis:** Incidence angle (degrees)
- **Legend:**
  - CZT Size - 10 cm
  - CZT size - 8 cm
  - CZT size - 6 cm
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Calorimeter – Crab Source

Calorimeter info:
- Material – CZT, CdTe, CsI
- Crystal size – 6, 8, 10 cm

Si Tracker info:
- Thickness – 500 μm
- Nlayers - 56
- Spacing 1.00 cm

Simulation Conditions
Source: Power Law (2.0)
Beam Type: Far-Field Point Source
Energy range: 0.2 – 2 MeV
N Triggers: 500,000

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So far what have we learned?

- CsI crystals have the best modulation factor for normal incidence;
- Smaller crystals improve the modulation factor (6 cm);
- Other crystals should be explored;
• Using Geant4/MEGALib we have simulated the mass model for eASTROGAM telescope

• The main objective was to understand how the different geometry parameters are related

• **Si Tracker**
  - Thickness
  - Number of Layers
  - Distance between Layers
  - Active volume
  - Total volume

• **Calorimeter**
  - Material (CsI, CZT, CdTE)
  - Crystal size (6, 8 and 10 cm)
Next steps...

• Change other parameters of the calorimeter geometry
  • Crystals Size Z (with more detail)
  • Crystals Size XY
  • GAP around Crystals (Pitch)
  • Closer to realistic dimensions of the CdTe crystals.

• Perform the polarimetric study in the pair production regime

• Although not mentioned, we intend to explore the AC System changing slightly its configuration.
Thank you!
Compton Polarimetry

A pixel/voxel detector is a good candidate to perform measurements on all the standard observable parameters (spectroscopy, timing, imaging);

Efficient use of the detector: each unit acts both as a scattering and as detection elements.