Energy calibration of the threshold of Medipix for ATLAS

Céline Lebel
Université de Montréal
lebel@lps.umontreal.ca

presenting for the
Institut of Experimental and Applied Physics
of the Czech Technical University in Prague
People involved in this project

• Institut of Experimental and Applied Physics of the Czech Technical University in Prague
  – Stanislav Pospíšil
  – Jan Jakůbek
  – Josef Uher
  – Vlastimil Král
  – Michal Platkevič
  – Vladimír Tichý

• Charles University
  – Michal Suk
  – …

• Université de Montréal
  – Claude Leroy
  – Céline Lebel
Outline

• Medipix
• Medipix in ATLAS: challenges foreseen
• Energy calibration of the low threshold
  – Equalization
  – Photons: Decreasing Flux
  – Alphas
  – Electrons
  – Neutrons
• Summary and Outlook
Medipix2 device - a single X-ray photon counting pixel detector

- Planar pixellated detector (Si, GaAs, CdTe, thickness: 300/700/1000mm)
- Bump-bonded to Medipix readout chip containing in each pixel cell:
  - amplifier,
  - double discriminator
  - and counter

**Medipix2**
- Pixels: 256 x 256
- Pixel size: 55 x 55 \(\mu m^2\)
- Area: 1.5 x 1.5 cm\(^2\)

**Medipix2 Quad**
- Pixels: 512 x 512
- Pixel size: 55 x 55 \(\mu m^2\)
- Area: 3 x 3 cm\(^2\)
LHC
ATLAS

Height: 22m
Width: 44 m
Weight: 7000 tons
Medipix in ATLAS: the challenge

• ATLAS environment has high radiation fluxes
• Problem: is the device radiation hard?
  – We don’t know.
• The data acquisition must be optimized to obtain the maximum information in the shortest time.
• What kind of information are we looking for?
  – Composition and spectroscopic characteristics of the radiation field inside ATLAS
    • Number of particles, energy and type
Approach for ATLAS: Layers

All events are accepted

Particles depositing less than X keV are rejected

Minimum ionizing particles are rejected

Counting mode: all particles deposit more than X MeV in a single pixel

Low threshold
Approach for ATLAS: multiple area

<table>
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Adaptation of the Medipix2 device for position sensitive detection of neutrons

Silicon pixel detector can not detect neutrons directly. Conversion of neutrons to detectable radiation in a converter layer (via nuclear reactions or recoiled protons) deposited on the detector surface is needed.

**Converter materials for thermal neutrons:**

- **$^6\text{Li}:** $^6\text{Li} + n \rightarrow a \text{ (2.05 MeV)} + ^3\text{H} \text{ (2.72 MeV)}$

- **$^{10}\text{B}:**
  - $^{10}\text{B} + n \rightarrow a \text{ (1.47 MeV)} + ^7\text{Li} \text{ (0.84 MeV)} + g \text{ (0.48 MeV)}$
  - $^{10}\text{B} + n \rightarrow a \text{ (1.78 MeV)} + ^7\text{Li} \text{ (1.01 MeV)}$

- **$^{113}\text{Cd}:**
  - $^{113}\text{Cd} + n \rightarrow ^{114}\text{Cd} + g \text{ (0.56 MeV)} + \text{ conversion electrons}$

- **$^{155}\text{Gd}:**
  - $^{155}\text{Gd} + n \rightarrow ^{156}\text{Gd} + g \text{ (0.09, 0.20, 0.30 MeV)} + \text{ conversion electrons}$

- **$^{157}\text{Gd}:**
  - $^{157}\text{Gd} + n \rightarrow ^{158}\text{Gd} + g \text{ (0.08, 0.18, 0.28 MeV)} + \text{ conversion electrons}$

**Converter for fast neutrons:** polyethylene foil

**Detector:**

150 – 700 mm thick silicon pixel detector
(pixel size 55 mm) bump bonded to
Medipix-2 readout chip.
Equalization and parameters
Equalization

• Medipix is composed of 65536 pixel channels. All are not created equal!
  – Pixelman allows for the equalization of the low threshold (THL)
    • This is a small but necessary adjustment

• Two methods:
  – Use noise edge
    • Useful to remove the noisiest pixels
  – Use noise center
    • Centers the noise → This puts the necessary offsets so that all pixels read the same energy
Parameters to adjust

THL

FBK

IKrum
Particle detection
Photons can be detected in silicon only by transferring their energy to charged particles.

- **Photoelectric effect**: All energy transferred to the material.
- **Compton diffusion**: Energy partially transferred to the material.
- **Pair production**: All energy transferred to the material.
Photons

Setup for sources
Photons – $^{55}$Fe

- Production of X-rays with $h\nu = 6$ keV
  - Primary interaction in silicon: Photoelectric effect
    - Energy of the photoelectrons:
      \[ E = h\nu - BE \]
    - For silicon, 1.8 keV is the binding energy of the K-shell (predominant at that photon energy)

  Energy deposited by the photoelectron
  Range of such electrons: $< 1 \mu m$ ($dE/dx = 7.33$ keV/\(\mu m\))

- Deposition is always in a single pixel!
Photons - 6 keV X-Rays (1 sec)

- THL-FBK = 0.0000
- THL-FBK = 0.0024
- THL-FBK = 0.0049
Photons – 6 keV X-Rays
Photons – $^{241}$Am

- Decays to $^{237}$Np, emitting alphas and gammas.
  - Main gamma lines:
    - 59.5 keV at 35.9 % and 26.3 keV at 2.4 %
- At 59.5 keV:
  - Photoelectric effect with the K-shell
- Energy of the electron: 57.7 keV
- Range using CSDA approximation: ~30 μm

(Source: http://www.physics.nist.gov/PhysRefData/Star/ESTAR.html)
Photons – 60 keV

THL-FBK = 0.0000  THL-FBK = 0.0049  THL-FBK = 0.1074
Photons – 60 keV gammas

\[ \text{THL-FBK} = 0.0163 \rightarrow E = 58 \text{ keV} \]
Alphas
Alphas

- Bethe-Bloch

\[-\frac{1}{\rho} \frac{dE}{dx} = 4\pi r_e^2 m_e c^2 z^2 \frac{N_{\text{Avogadro}} Z}{A} \frac{1}{\beta^2} \left[ \ln \left( \frac{2m_e c^2 \beta^2 \gamma^2}{I} \right) - \beta^2 - \frac{\delta}{2} - \frac{C}{Z} \right] \]
Changing Alpha Energy

The threshold is too low. These energies cannot calibrate the threshold with this FBK.

\[ E_\alpha = 4.20 \text{ MeV} \]
\[ E_\alpha = 1.41 \text{ MeV} \]
\[ E_\alpha = 0.69 \text{ MeV} \]
Raising FBK

E_α = 4.20 MeV

E_α = 0.74 MeV

Tentatively:
THL-FBK = 1.1719 → 735 keV
About full depletion voltage ...

4.478 MeV deposit $\rightarrow$ Range of $\sim 21$ μm
Collection starts at 40 V $\rightarrow$ $V_{fd} = 46 \pm 1$ V
Cluster Size as function of $U_{\text{bias}}$
Does the threshold depend on the USB or the Medipix used?

NO!

Cluster size average (pixels)

THL-FBK

USB1-Medipix1
USB2-Medipix2
USB1-Medipix2 (with USB2 equalization)
Electrons
\textbf{THL-FBK} = 0.0000

**Source** $^{90}\text{Sr-Y}$

Average electron energy: 935 keV $\rightarrow$ mip
THL-FBK = 0.0275

THL-FBK=0.0000

Electrons
THL-FBK = 0.0519

THL-FBK = 0.0275
THL-FBK = 0.0842

Electrons
THL-FBK = 0.1324

THL-FBK = 0.0842

Electrons
THL-FBK = 0.2875

THL-FBK=0.1324
**THL-FBK = 0.5194**

Electrons

THL-FBK = 0.2875
**THL-FBK = 0.6000**

Electrons

THL-FBK=0.5194
Some – very preliminary – results

\[ E_\alpha = 4.20 \text{ MeV} \]

\[ E_\alpha = 0.69 \text{ MeV} \]

Electrons
Some – very preliminary – results

Normalized flux vs. THL-fbk

- 6 keV X-Rays
- 60 keV Gammas
- Electrons
Neutrons
Neutrons
detection through reaction with Polyethylene

- Using the reaction
  \[ n + ^1\text{H} \rightarrow p + n \]
- Fast neutrons from reactor

Thank you, Radek Skoda, for making this measurement possible!
Position of the polyethylene layer
Results obtained at the reactor Sparrow
Importance of threshold

THL-FBK = 0.1459  FBK = 128
THL-FBK = 0.6268  FBK = 200
THL-FBK = 0.8929  FBK = 200
Examples of response of MEDIPIX-USB device to fast monochromatic neutrons: 17MeV neutrons, flux about $10^4$ n/(s.cm$^2$)

- The direction of the neutrons with respect to the image was upstream (from bottom to top). The huge background is due to gamma rays which accompany neutrons. Half of the sensor (the right-hand side) was covered with a CH$_2$ foil about 1.3 mm thickness.
- One can clearly recognize long and rather thick tracks of recoiled protons (up to 2 mm, vertically oriented) and big tracks and clusters generated via $^{28}$Si(n,γ)$^{25}$Mg, $^{28}$Si(n,p)$^{28}$Al nuclear reactions in the body of the silicon detector. These events are displayed on the dense background caused by tracks and traces of electrons from interactions of gamma rays. One can even recognize that proton tracks shapes follows a Bragg law.
Conclusions

- **ONE** energy (58 keV) has been definitively attributed to a threshold value.
- A threshold has been identified to isolate the contribution of heavy charged particle from electrons.
- All USB and Medipix give the same variation as a function of effective threshold.
- **Photons**, Heavy charged particles, and Electrons give specific tracks which can be identified.
- Adding a Polyethylene layer allows the detection of fast neutrons.
Outlook

• More energy lines must be attributed to specific values of THL-FBK
  – Different X-Rays!

• More on neutrons

• Analysis of heavy charged particle tracks: influence of plasma effect in silicon
Děkuji vám!

Thank you!