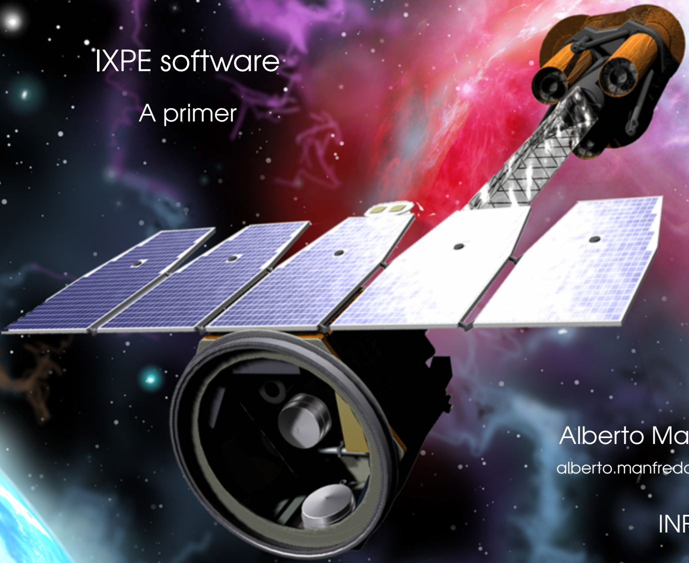
# IXPE software

## A primer

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Torino, 10 maggio 2018

# Il telescopio IXPE

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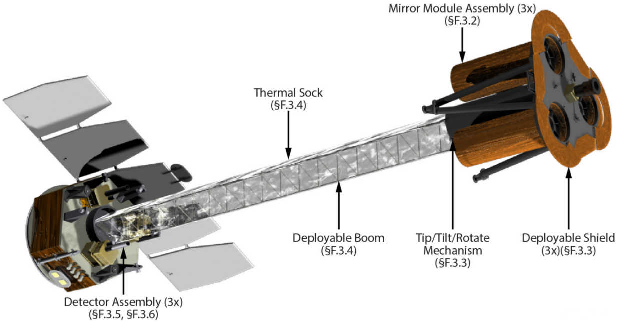
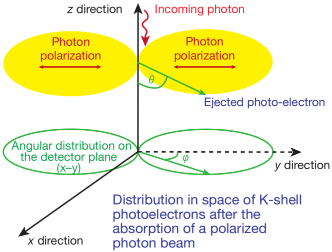
## Rappresentazione artistica




- Tre telescopi identici interamente dedicati alla polarimetria X:
  - Ridondanza totale;
  - Riduzione di effetti sistematici residui.
- Lunghezza focale: 4 m (boom estensibile).
- Orbita circolare equatoriale:
  - Altezza nominale di 540 km
  - Inclinazione di 0°

# Effetto fotoelettrico e polarimetria X

## Principio di funzionamento

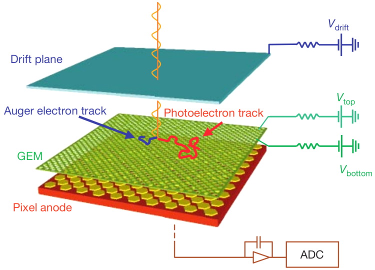


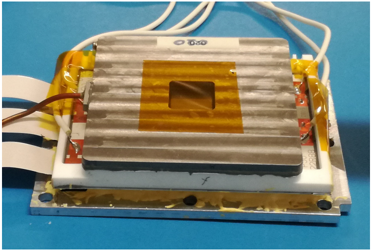

- Processo di interazione dominante a bassa energia ($< 10$ keV).
- Distribuzione di emissione dei fotoelettroni in K-shell modulata al 100% per radiazione polarizzata linearmente:

$$\frac{d\sigma_C^K}{d\Omega} \propto Z^5 E^{-\frac{7}{2}} \frac{\sin^2\theta\cos^2\phi}{(1+\beta\cos\theta)^4}$$

- Necessità di ricostruire la direzione di emissione del fotoelettrone.
- La traccia tipica di un fotoelettrone da 5 keV è $\sim \mu m$ in un solido:
  - Necessario utilizzare un mezzo gassoso.

# Il Gas Pixel Detector (GPD) come polarimetro



- Componenti di base:
  - Finestra di ingresso di Berillio (50 $\mu m$);
  - Cella di assorbimento riempita di gas (He–DME);
  - Gas Electron Multiplier (GEM) per amplificazione del segnale;
  - Matrice di pixel esagonali per la raccolta delle cariche (ASIC).
- Sensibile fino a energia molto bassa ($\sim$ 1 keV).
- Buona capacità di imaging per sorgenti estese.
- Risultato di circa 20 anni di attività di R&D.

# La polarimetria X diventa possibile

Costa et al., Nature **411**, 662–665 (2001)

**letters to nature**

## An efficient photoelectric X-ray polarimeter for the study of black holes and neutron stars

**Enrico Costa***, **Paolo Soffitta***, **Ronaldo Bellazzini†**, **Alessandro Brez†**, **Nicholas Lumb†** & **Gloria Spandre†**

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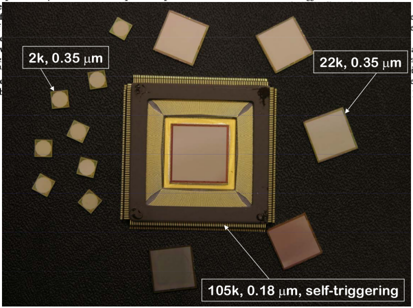
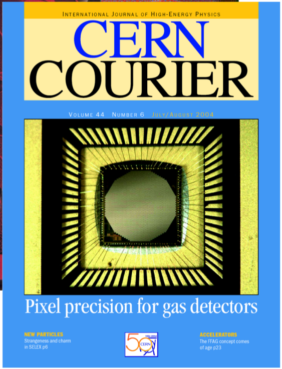
**The study of astronomical objects using electromagnetic radiation involves four basic observational approaches: imaging, spectroscopy, photometry (accurate counting of the photons received) and polarimetry (measurement of the polarizations of the observed photons). In contrast to observations at other wavelengths, a lack of sensitivity has prevented X-ray astronomy from making use of polarimetry. Yet such a technique could provide a direct picture ... gravitational f... structures of ... inaccessible, ... for example, ... field and dete... 'pencil' beam ... the polarizatio... presence of a b... instrument that makes X-ray polarimetry possible. The factor of 100 improvement in sensitivity that we have achieved will allow direct exploration of the most dramatic objects of the X-ray sky.**

The main advantage of the proposed polarimeter is its capability of investigating active galactic nuclei (quasars, blazars and Seyfert galaxies) for which polarization measurements have been suggested, crucial to understand the geometry and physics of emitting regions. We can separate synchrotron X-rays from jets[13,14] from the emission scattered by the disk corona or by a thick torus. The effects of relativistic motions and of the gravitational field of a central black hole have probably been detected by iron line spectroscopy on the Seyfert-1 galaxy MCG-6-30-15 (ref. 15) but this feature is not ubiquitous in active galactic nuclei. Polarimetry of the X-ray continuum provides a more general tool to explore the structure of emitting regions[16,17], to track instabilities and to derive direct information on mass and angular momentum[12] of supermassive black holes.

In spite of this wealth of expectations, the important but only positive result until now is the measurement, by the Bragg technique, of the polarization of the Crab nebula[18,19]. The Stellar X-ray Polarimeter[20] (SXRP) represents the state of the art for conventional methods based on Bragg diffraction and Thomson scattering. ... angle at one ... etry[22] is non- ... e sensitivity of ... arization. The ... energy which is ... inding energy. ... ed around that ... photoelectron

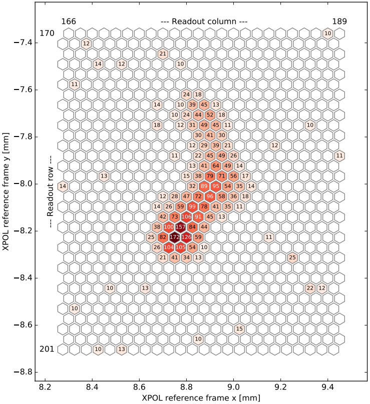






# Caratteristiche dell'ASIC

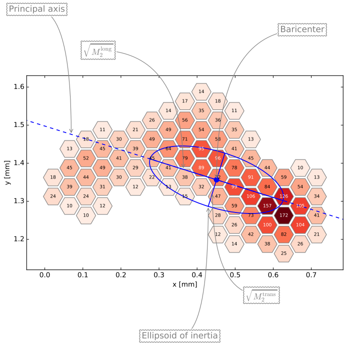
## Immagine: traccia reale di un fotoelettrone da 5.9 keV

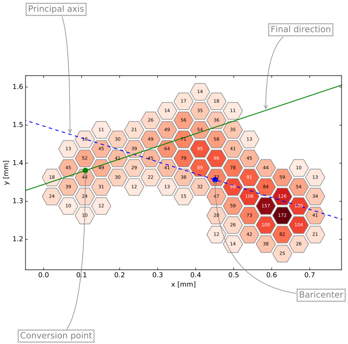



- Capacità di auto-generazione del segnale di trigger.
- Definizione interna della regione di interesse per la lettura degli eventi (dimensione tipica della finestra $< 1$ k pixels).
- Lettura multipla per la sottrazione dei piedistalli evento per evento.

# Analisi a livello di evento

## Traccia reale di un fotoelettrone da 5.9 keV

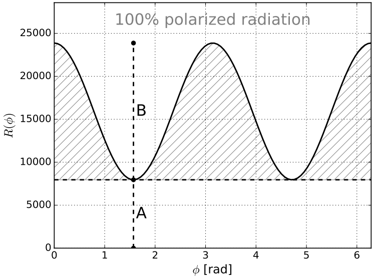


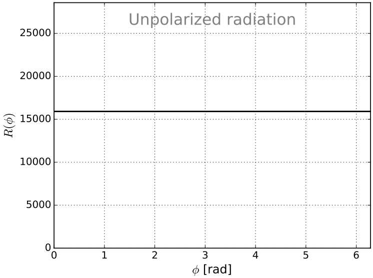




- L'analisi avviene evento per evento.
- Ricostruzione delle tracce:
  - Primo passo: baricentro, analisi dei momenti, uso della skewness delle proiezioni longitudinali per identificare il picco di Bragg.
  - Secondo passo: determinazione del punto di assorbimento e analisi dei momenti pesata per una stima più accurata della direzione di emissione.
- La morfologia degli eventi è ricca!

# Formalismo di base

## Come funziona un polarimetro?



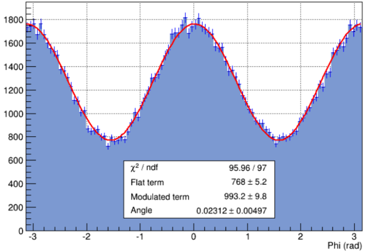

- Ogni polarimetro misura la modulazione azimutale attorno all'angolo di polarizzazione $\phi_0$ del fascio di fotoni incidente:

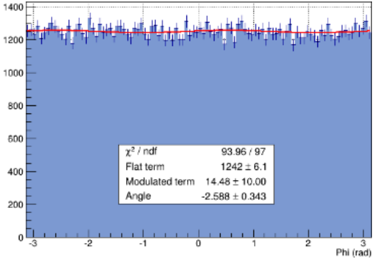
$$R(\phi) = A + B\cos^2(\phi - \phi_0)$$

- Fattore di modulazione: risposta alla radiazione 100% polarizzata:

$$\mu = \frac{R_{\rm max} - R_{\rm min}}{R_{\rm max} + R_{\rm min}} = \frac{B}{B + 2A}$$

# Performance del GPD come polarimetro

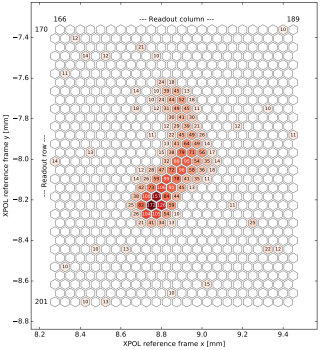



- Fattore di modulazione: 0.2 (0.7) a 2 (8) keV.
  - Stabilità su $\sim$ 3 anni dimostrata con un rivelatore sigillato;
  - Modulazione residua per radiazione non polarizzata $\sim$ 0.1%.
- Risoluzione spaziale: $\sim$ 90 $\mu$m a 5.9 keV ($\ll$ traccia).
  - Buona per un telescopio a raggi X con $\sim$ 4 m di lunghezza focale e $\sim$ 20 arcsec di risoluzione angolare.
- Risoluzione energetica (FWHM): $\sim$ 15% a 5.9 keV.
  - Abbastanza per fare polarimetria spettralmente risolta (in pochi bin di energia), quando la statistica lo permette.
- Risoluzione temporale: $\sim$ $\mu$s.
  - Più che adeguata per le scale di tempo di interesse.

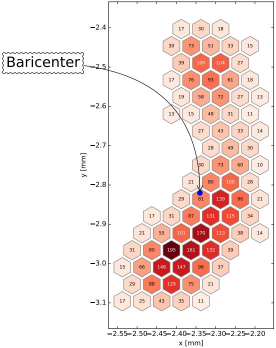
# Reconstruction Alogorithm

# Thresholding



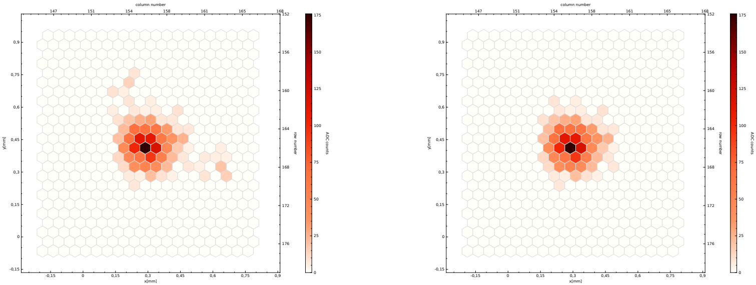

- ▷ The numbers within each pixels are the signal ADC counts, the typical noise floor being 2-4 ADC counts
- ▷ All the pixels below a fixed threshold ($\sim 2 - 3\sigma$ noise typically) are suppressed

# Clustering



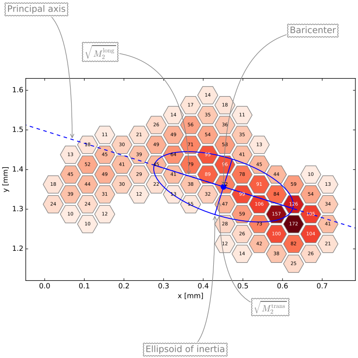

- ▷ Group together all the contiguous pixels above threshold
- ▷ The cluster with the highest total pulse height is considered the main cluster (following steps ignore all the other clusters)
- ▷ The barycenter of the main cluster is computed

# Clustering in details



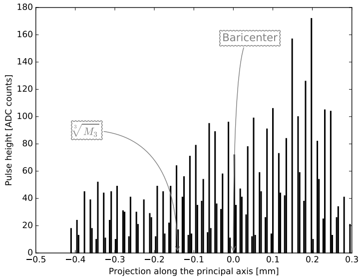

- Clustering is done with the DBSCAN algorithm
- One parameter can be tuned: the pixel density which defines the core of the cluster (number of neighbours over threshold)
- Default (optimal?) value is 4, to remove the tails

# Moment analysis - First Pass



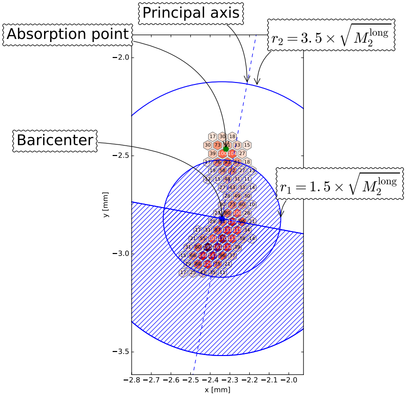

- Diagonalize the inertia tensor of the two-dimensional charge distribution around the barycenter to found principal axis
- $\sqrt{M_2^{\text{long}}}$ and $\sqrt{M_2^{\text{trans}}}$ are the semiaxes of the ellipsoid of inertia
- $M_2^{\text{long}}/M_2^{\text{trans}}$ is a proxy for the elongation of the track

# Longitudinal Track Profile



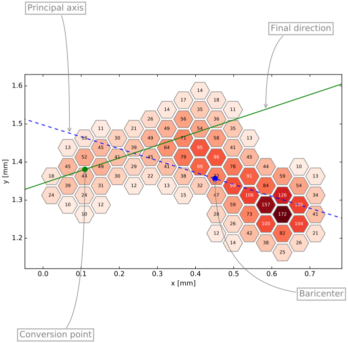

- One-dimensional projection of the charge distribution along the principal axis of the cluster
- Calculate the third moment $M_3^{\text{long}}$ of the distribution
- Skewness: $\gamma_1 = \frac{M_3^{\text{long}}}{(M_2^{\text{long}})^{\frac{3}{2}}}$
- The sign of $\gamma_1$ indicates the side of the distribution with the lowest ionization, i.e., the initial part of the track.

# Search region for the absorption point




- The first estimate of the absorption point is the barycenter of all the pixel in the non-shaded region
- The sign of the skweness is used to pick the correct half of the circle (i.e. the one eclosing to the beginning of the track)

# Moment analysis - Second Pass




- Run a second-pass moments analysis weighting the pixels according to their distance $d$ to the first estimate of the interaction point

$$w_i = e^{-\frac{d}{d_0}} \quad d_0 = 50\ \mu\text{m}$$

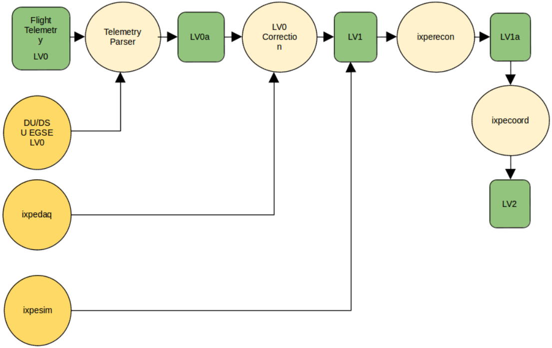
- The weighted barycenter is the new estimate of the interaction point
- The principal axis from this second step is the final track direction

# Future developments

- Selection cuts optimization in the current scheme for maximizing the modulation factor
- Background rejection via track shape discrimination
- Use of machine learning algorithms (CT, Neural net) for improved estimation of relevant physical quantities (impact point, principal axis, direction...)

# IXPE software

# IXPE software (scheme)




- ▷ Lvl0 Data received from the satellite
- ▷ Lv1 Data after telemetry parsing and corrections
- ▷ Lv1a Data after calibration and event reconstruction (still in the detecor coordinate system)
- ▷ Lv2 Data projected into sky coordinates. Compliant with ds9 and xspec

# gpdsw

- ixperecon lives inside the gpdsw package
- gpdsw hosts other related pieces of software:
  - ixpedisplay
  - ixpesim
  - ixpedaq, ixpemonitor (in development)
- and all the code these applications share (e.g. detector geometry)
- Currently gpdsw is a private repository, development often driven by hardware/calibration needs
- Will become a (bunch of) FTOOLS
- Observation simulation tool (xpobsim) developed separately - see Niccolò's lesson.

# gpdsw wiki

## IXPE GPD ground software

This meant to be the basic entry point for the Imaging X-ray Polarimetry Explorer (IXPE) software related to the Gas Pixel Detector (GPD).

## Overview

The gpdsw package covers a number of diverse and yet related areas, including:

- detector geometry;
- detector calibration;
- event reconstruction;
- detector simulation;
- data acquisition;
- data quality monitor;
- data analysis;
- support for for legacy data.

The framework is conceived as a set of C++ classes and applications with Python wrappers built through SWIG. Part of the software is implemented in pure Python and the entry point for the corresponding documentation is here.

New to gpdsw? Look at the installation notes.

Anxious to read data and do something with them? Go ahead and do it in Python.

See also our Release notes.



http://bigfoot.iaps.inaf.it/gpdsw/

# gpdsw bundle

- gpdext: collection of external libraries (a separate package)
  - cfitsio and boost are required for ixperecon
  - Qt5 for graphical products (GUI, event display)
  - GEANT4 for detector simulation
- gpdswpy (inside gpdsw): collection of python code
  - wrapping of most of the gpdsw modules (SWIG)
  - utilities for data analysis (binning, fitting, plotting etc...)
  - testing

# Lv1 FITS file

Window Subsets Help

Table Browser for 1: 102_0000020_data_trimmed.fits

| | PAKTNUMB | TRG_ID | SEC | MICROSEC | TIME | MIN_COL | MAX_COL | MIN_ROW | MAX_ROW | ROI_SIZE | ERR_SUM | PIX_PHAS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 7552571 | 12223 | 7,552571E6 | 86 | 113 | 248 | 277 | 840 | 0 | (4, 5, 3, 10, 2, 10, 5, 2, 3, 1, 4, 6, 3, 4, 7, 9, 6, 3, 9, 6, 5, 2, 5, 6, 3, 8, |
| 2 | 0 | 2 | 7552571 | 15108 | 7,552571E6 | 164 | 185 | 316 | 343 | 616 | 0 | (7, 2, 5, 2, 5, 7, 1, 3, 3, 8, 4, 7, 8, 3, 7, 5, 10, 1, 3, 7, 3, 6, 3, 6, 0, 0, |
| 3 | 0 | 3 | 7552571 | 49744 | 7,552571E6 | 228 | 251 | 44 | 69 | 624 | 0 | (5, 1, 5, 6, 4, 10, 4, 0, 11, 5, 6, 3, 13, 7, 2, 6, 8, 6, 1, 11, 1, 1, 10, 3, |
| 4 | 0 | 4 | 7552571 | 65451 | 7,552571E6 | 38 | 59 | 170 | 199 | 660 | 0 | (1, 5, 6, 10, 5, 0, 4, 4, 5, 8, 3, 3, 7, 13, 6, 2, 3, 2, 1, 5, 1, 1, 2, 4, 2, 4, |
| 5 | 0 | 5 | 7552571 | 108663 | 7,552571E6 | 126 | 149 | 120 | 145 | 624 | 0 | (8, 0, 2, 3, 6, 8, 2, 4, 7, 0, 4, 4, 14, 6, 5, 4, 0, 2, 2, 7, 4, 2, 1, 1, 6, 0, |
| 6 | 0 | 6 | 7552571 | 118915 | 7,552571E6 | 34 | 59 | 292 | 319 | 728 | 0 | (2, 6, 2, 1, 1, 6, 1, 0, 5, 11, 0, 0, 1, 9, 3, 9, 4, 0, 7, 1, 1, 4, 3, 4, 1, 6, |
| 7 | 0 | 7 | 7552571 | 121484 | 7,552571E6 | 0 | 15 | 134 | 163 | 480 | 0 | (4, 0, 3, 8, 0, 1, 4, 10, 7, 2, 4, 10, 3, 4, 5, 0, 1, 1, 4, 10, 0, 2, 6, 4, 0, |
| 8 | 0 | 8 | 7552571 | 144686 | 7,552571E6 | 256 | 281 | 168 | 197 | 780 | 0 | (6, 10, 4, 7, 3, 8, 2, 4, 0, 5, 12, 9, 3, 7, 7, 6, 4, 11, 3, 3, 9, 1, 8, 3, 2, |
| 9 | 1 | 9 | 7552571 | 170171 | 7,552571E6 | 266 | 291 | 322 | 349 | 728 | 0 | (2, 3, 1, 0, 1, 2, 3, 5, 8, 0, 1, 1, 4, 0, 1, 2, 5, 5, 2, 2, 5, 1, 1, 7, 27, 2, |
| 10 | 1 | 10 | 7552571 | 234219 | 7,552571E6 | 270 | 289 | 0 | 25 | 520 | 0 | (7, 6, 7, 6, 1, 18, 0, 6, 9, 9, 11, 5, 1, 2, 4, 6, 9, 4, 1, 2, 5, 2, 2, 4, 1, 1, |
| 11 | 1 | 11 | 7552571 | 239766 | 7,552571E6 | 264 | 287 | 244 | 271 | 672 | 0 | (9, 11, 2, 5, 3, 5, 1, 9, 3, 6, 1, 5, 2, 5, 6, 3, 1, 6, 7, 4, 12, 6, 1, 4, 7, 0, |
| 12 | 1 | 12 | 7552571 | 263907 | 7,552571E6 | 162 | 179 | 0 | 23 | 432 | 0 | (5, 2, 1, 7, 3, 4, 4, 4, 4, 9, 11, 2, 5, 4, 9, 3, 1, 2, 0, 0, 3, 4, 3, 0, 3, 5, |
| 13 | 1 | 13 | 7552571 | 283524 | 7,552571E6 | 246 | 267 | 232 | 263 | 704 | 0 | (5, 3, 1, 1, 8, 10, 11, 1, 5, 4, 3, 6, 7, 10, 4, 2, 6, 8, 3, 3, 2, 4, 9, 1, 7, |
| 14 | 1 | 14 | 7552571 | 305733 | 7,552571E6 | 130 | 153 | 154 | 181 | 672 | 0 | (1, 6, 2, 4, 6, 5, 6, 13, 8, 20, 1, 2, 4, 9, 2, 0, 3, 3, 0, 3, 3, 0, 12, 4, 4, |
| 15 | 1 | 15 | 7552571 | 311365 | 7,552571E6 | 170 | 193 | 106 | 133 | 672 | 0 | (3, 3, 6, 0, 3, 3, 8, 3, 1, 3, 1, 6, 0, 2, 0, 6, 7, 8, 6, 0, 4, 4, 1, 4, 2, 0, 2, |
| 16 | 1 | 16 | 7552571 | 336065 | 7,552571E6 | 196 | 215 | 212 | 237 | 520 | 0 | (1, 8, 6, 3, 10, 13, 9, 7, 9, 5, 1, 0, 5, 4, 7, 5, 3, 5, 1, 10, 7, 7, 1, 6, 4, |
| 17 | 2 | 17 | 7552571 | 373864 | 7,552571E6 | 194 | 217 | 254 | 285 | 768 | 0 | (0, 4, 2, 9, 9, 11, 6, 2, 2, 9, 2, 3, 4, 3, 8, 2, 5, 1, 5, 4, 3, 0, 2, 4, 0, 6, |
| 18 | 2 | 18 | 7552571 | 405598 | 7,552571E6 | 100 | 125 | 82 | 111 | 780 | 0 | (0, 9, 8, 7, 2, 4, 7, 5, 5, 4, 9, 5, 2, 4, 11, 5, 6, 7, 7, 9, 2, 0, 20, 7, 5, 9, |
| 19 | 2 | 19 | 7552571 | 411763 | 7,552571E6 | 30 | 57 | 268 | 295 | 784 | 0 | (3, 7, 8, 3, 6, 3, 3, 7, 4, 3, 6, 12, 3, 7, 5, 4, 3, 10, 1, 4, 2, 5, 0, 3, 5, 0, |
| 20 | 2 | 20 | 7552571 | 442849 | 7,552571E6 | 244 | 269 | 0 | 15 | 416 | 0 | (0, 5, 18, 0, 4, 1, 0, 24, 110, 168, 133, 56, 38, 39, 57, 35, 17, 5, 9, 3, |
| 21 | 2 | 21 | 7552571 | 493561 | 7,552571E6 | 174 | 197 | 124 | 155 | 768 | 0 | (1, 2, 9, 3, 9, 9, 1, 1, 12, 2, 8, 10, 4, 7, 9, 13, 5, 14, 4, 3, 12, 10, 10, |
| 22 | 2 | 22 | 7552571 | 496277 | 7,552571E6 | 172 | 197 | 10 | 37 | 728 | 0 | (7, 2, 13, 5, 11, 3, 2, 6, 5, 7, 3, 1, 5, 1, 1, 9, 8, 6, 5, 4, 4, 12, 5, 0, 2, |
| 23 | 2 | 23 | 7552571 | 503708 | 7,552572E6 | 62 | 87 | 0 | 25 | 676 | 0 | (1, 3, 4, 0, 9, 3, 5, 5, 3, 4, 4, 45, 7, 14, 6, 8, 8, 23, 3, 7, 3, 2, 3, 5, 8, |
| 24 | 2 | 24 | 7552571 | 532666 | 7,552572E6 | 16 | 33 | 310 | 331 | 396 | 0 | (7, 1, 5, 1, 0, 5, 3, 4, 4, 2, 1, 3, 3, 6, 8, 2, 14, 7, 7, 4, 4, 2, 2, 2, 2, 2, |
| 25 | 3 | 25 | 7552571 | 569082 | 7,552572E6 | 216 | 235 | 50 | 73 | 480 | 0 | (4, 3, 4, 3, 35, 1, 2, 2, 4, 0, 15, 2, 11, 9, 10, 10, 4, 6, 3, 3, 3, 0, 7, 2, |
| 26 | 3 | 26 | 7552571 | 581218 | 7,552572E6 | 14 | 39 | 222 | 251 | 780 | 0 | (9, 8, 4, 2, 7, 7, 6, 5, 1, 7, 3, 4, 5, 5, 1, 5, 7, 7, 4, 5, 1, 4, 8, 7, 0, 6, 2, |
| 27 | 3 | 27 | 7552571 | 621808 | 7,552572E6 | 110 | 133 | 10 | 41 | 768 | 0 | (8, 3, 3, 6, 6, 4, 3, 6, 10, 13, 0, 6, 2, 5, 6, 2, 6, 6, 4, 2, 4, 3, 5, 1, 4, 4, |
| 28 | 3 | 28 | 7552571 | 631115 | 7,552572E6 | 158 | 181 | 244 | 271 | 672 | 0 | (2, 8, 2, 12, 6, 1, 13, 6, 7, 2, 14, 4, 8, 7, 3, 14, 5, 2, 5, 4, 7, 7, 14, 6, |
| 29 | 3 | 29 | 7552571 | 638490 | 7,552572E6 | 254 | 275 | 86 | 115 | 660 | 0 | (3, 13, 1, 2, 2, 4, 1, 4, 6, 1, 1, 3, 0, 2, 3, 6, 5, 4, 2, 9, 10, 2, 1, 5, 1, 5, |
| 30 | 3 | 30 | 7552571 | 662183 | 7,552572E6 | 46 | 73 | 236 | 265 | 840 | 0 | (13, 3, 5, 13, 11, 4, 3, 4, 4, 7, 1, 4, 15, 4, 4, 6, 8, 6, 5, 7, 11, 5, 10, 2, |
| 31 | 3 | 31 | 7552571 | 678937 | 7,552572E6 | 20 | 43 | 178 | 207 | 720 | 0 | (5, 7, 5, 3, 6, 10, 3, 9, 6, 0, 8, 1, 2, 3, 1, 8, 5, 15, 6, 6, 3, 1, 6, 3, 5, 5, |
| 32 | 3 | 32 | 7552571 | 682120 | 7,552572E6 | 32 | 57 | 36 | 61 | 676 | 0 | (8, 2, 5, 10, 11, 9, 5, 1, 5, 8, 5, 9, 0, 6, 2, 5, 12, 3, 7, 5, 7, 8, 6, 2, 10, |
| 33 | 4 | 33 | 7552571 | 716697 | 7,552572E6 | 78 | 99 | 310 | 335 | 572 | 0 | (3, 7, 2, 3, 2, 5, 2, 2, 8, 8, 7, 4, 7, 1, 9, 6, 1, 5, 6, 9, 3, 9, 2, 2, 2, 0, 5, |
| 34 | 4 | 34 | 7552571 | 732067 | 7,552572E6 | 54 | 75 | 232 | 263 | 704 | 0 | (8, 1, 5, 0, 4, 5, 2, 9, 2, 4, 1, 11, 12, 3, 0, 5, 3, 5, 2, 6, 2, 5, 5, 1, 4, 3, |
| 35 | 4 | 35 | 7552571 | 747453 | 7,552572E6 | 0 | 23 | 290 | 323 | 816 | 0 | (2, 7, 0, 7, 4, 0, 6, 0, 2, 2, 4, 5, 2, 1, 3, 2, 7, 4, 13, 4, 3, 9, 4, 2, 1, 2, |
| 36 | 4 | 36 | 7552571 | 753836 | 7,552572E6 | 62 | 89 | 244 | 269 | 728 | 0 | (1, 1, 3, 7, 2, 8, 1, 7, 8, 9, 5, 5, 5, 4, 4, 6, 5, 2, 8, 3, 5, 15, 7, 3, 5, 1, |
| 37 | 4 | 37 | 7552571 | 785513 | 7,552572E6 | 80 | 103 | 198 | 225 | 672 | 0 | (3, 6, 0, 0, 5, 12, 5, 2, 1, 4, 3, 2, 4, 4, 9, 3, 7, 4, 10, 3, 3, 4, 9, 6, 0, 0, |

Lv1 EVENT table

# Lv1a FITS file

Window Subsets Help

Table Browser for 1: 001_0002453_data_recon.fits

| | NUM_CLU | NUM_PIX | TRK_EFRA | TRK_SN | TRK_SIZE | ... | TRK_PHA | TRK_PI | TRK_PHI1 | TRK_PHI2 | TRK_ABSX | TRK_ABSY | TRK_BARX | TRK_BARY | TRK_M2T | TRK_M2L | TRK_M3L | TRK_SKEW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 335 | 0,88361 | 346,83... | 247 | .. | 5451 | 5451,... | -2,2263 | -2,00217 | 1,26227 | -4,78824 | 1,14252 | -4,94882 | 0,02738 | 0,03203 | 8,750... | 0,01526 |
| 2 | 1 | 298 | 0,88047 | 381,54... | 221 | .. | 5672 | 5672,... | -1,8359 | -1,68735 | 2,83215 | 3,82747 | 2,77251 | 3,64409 | 0,02217 | 0,02789 | 0,00022 | 0,04633 |
| 3 | 1 | 226 | 0,91767 | 392,47... | 145 | .. | 4726 | 4726,... | -2,73939 | -2,9162 | -0,55475 | 5,02864 | -0,6707 | 4,97416 | 0,01475 | 0,01659 | 0,00016 | 0,07429 |
| 4 | 1 | 282 | 0,88002 | 309,62... | 215 | .. | 4540 | 4540,... | 2,61531 | 2,50368 | 0,87782 | -5,963 | 0,64231 | -5,81379 | 0,02033 | 0,04019 | 0,00102 | 0,12647 |
| 5 | 1 | 328 | 0,90663 | 384,31... | 255 | .. | 6137 | 6137,... | 0,71644 | 1,0002 | 4,67828 | -5,17293 | 4,84081 | -5,01553 | 0,0263 | 0,03619 | -0,00017 | -0,0244 |
| 6 | 1 | 265 | 0,93719 | 351,78... | 190 | .. | 4849 | 4849,... | -0,21358 | -0,05002 | -4,17738 | 4,597 | -3,9907 | 4,55577 | 0,01844 | 0,02655 | -0,00032 | -0,07462 |
| 7 | 1 | 294 | 0,91386 | 459,46... | 201 | .. | 6514 | 6514,... | -1,91068 | -1,85755 | -0,55155 | -2,28395 | -0,61307 | -2,46036 | 0,01859 | 0,02551 | 0,00023 | 0,05643 |
| 8 | 1 | 204 | 0,94982 | 428,47... | 153 | .. | 5300 | 5300,... | 3,08229 | 2,91093 | 2,50392 | 7,38855 | 2,34279 | 7,41286 | 0,01568 | 0,02102 | 6,133... | 0,02013 |
| 9 | 1 | 286 | 0,93154 | 384,90... | 205 | .. | 5511 | 5511,... | 2,53961 | 2,4409 | -1,88227 | 3,66781 | -2,01736 | 3,77373 | 0,02035 | 0,02512 | 0,00015 | 0,03803 |
| 10 | 1 | 263 | 0,87435 | 334,08... | 185 | .. | 4544 | 4544,... | 0,53431 | 0,58808 | -1,11663 | -7,00353 | -0,95209 | -6,90931 | 0,01861 | 0,02575 | -0,00055 | -0,13296 |
| 11 | 1 | 153 | 0,98374 | 359,03... | 120 | .. | 3933 | 3933,... | -3,04616 | -3,05816 | -1,64383 | 7,49991 | -1,85801 | 7,48496 | 0,01007 | 0,02358 | 0,0005 | 0,13741 |
| 12 | 1 | 282 | 0,89079 | 374,45... | 213 | .. | 5465 | 5465,... | 2,95491 | 3,02798 | 4,91103 | 0,6119 | 4,66522 | 0,64635 | 0,01806 | 0,03534 | 0,00013 | 0,01947 |
| 13 | 0 | 39 | 0, | 0, | 0 | .. | 0 | 0, | -4, | -4, | -9, | -9, | -9, | -9, | -1, | -1, | -99, ... | -99, |
| 14 | 1 | 266 | 0,8956 | 410,81... | 194 | .. | 5722 | 5722,... | -2,5706 | -2,46346 | 1,57636 | -1,25734 | 1,45161 | -1,34502 | 0,0196 | 0,02151 | 0,0002 | 0,06304 |
| 15 | 1 | 288 | 0,94458 | 378,70... | 210 | .. | 5488 | 5488,... | 1,6317 | 1,90441 | -0,85966 | 3,19788 | -0,88414 | 3,37152 | 0,02293 | 0,02404 | 0,00067 | 0,17876 |
| 16 | 1 | 279 | 0,90943 | 397,88... | 204 | .. | 5683 | 5683,... | 1,3883 | 1,44754 | -5,24176 | -1,23618 | -5,20866 | -1,07202 | 0,02096 | 0,02396 | -0,00017 | -0,04473 |
| 17 | 1 | 233 | 0,97365 | 410,68... | 187 | .. | 5616 | 5616,... | 1,26972 | 1,21038 | 4,68611 | -0,09345 | 4,73795 | 0,0545 | 0,01942 | 0,02077 | -0,00027 | -0,08941 |
| 18 | 1 | 185 | 0,90862 | 245,05... | 130 | .. | 2794 | 2794,... | 0,97885 | 0,77371 | 5,20664 | -3,11376 | 5,28106 | -3,01825 | 0,01517 | 0,01655 | -4,065... | -0,0191 |
| 19 | 1 | 280 | 0,88418 | 272,11... | 212 | .. | 3962 | 3962,... | -0,78376 | -0,47348 | -4,95661 | -6,30408 | -4,8194 | -6,44553 | 0,02629 | 0,03008 | -0,00011 | -0,02022 |
| 20 | 1 | 291 | 0,86433 | 391,71... | 197 | .. | 5498 | 5498,... | 0,61617 | 0,70979 | 6,41562 | -0,17785 | 6,54354 | -0,07287 | 0,01999 | 0,02304 | -0,00034 | -0,0977 |
| 21 | 1 | 149 | 0,97725 | 296,81... | 121 | .. | 3265 | 3265,... | -1,63125 | -1,71354 | 7,3769 | -6,2856 | 7,3651 | -6,50532 | 0,01012 | 0,02612 | 0,00014 | 0,03262 |
| 22 | 1 | 313 | 0,94073 | 410,43... | 231 | .. | 6238 | 6238,... | -1,38803 | -1,55399 | -2,53642 | 6,46487 | -2,51235 | 6,29116 | 0,02401 | 0,02695 | -0,00012 | -0,02785 |
| 23 | 2 | 215 | 0,85834 | 215,26... | 152 | .. | 2654 | 2654,... | 2,56146 | 2,47784 | -2,26849 | -2,51138 | -2,39946 | -2,4161 | 0,01952 | 0,02146 | 0,00046 | 0,14611 |
| 24 | 1 | 313 | 0,92064 | 406,72... | 232 | .. | 6195 | 6195,... | 2,35413 | 2,19378 | -2,18333 | -3,5647 | -2,31683 | -3,3934 | 0,02026 | 0,03299 | 0,00021 | 0,03506 |
| 25 | 1 | 218 | 0,84155 | 193,19... | 151 | .. | 2374 | 2374,... | 1,82003 | 1,75857 | 3,08416 | -3,06248 | 3,03639 | -2,89497 | 0,01936 | 0,02254 | 0,00088 | 0,25925 |
| 26 | 1 | 218 | 0,96936 | 405,35... | 174 | .. | 5347 | 5347,... | -3,02224 | -3,13016 | -6,98657 | -5,24525 | -7,13585 | -5,27189 | 0,01744 | 0,02054 | 0,00051 | 0,17467 |
| 27 | 1 | 292 | 0,91856 | 391,64... | 209 | .. | 5662 | 5662,... | 1,71339 | 1,56929 | -5,5609 | 3,17392 | -5,59606 | 3,41677 | 0,01677 | 0,03293 | 0,00088 | 0,14678 |
| 28 | 1 | 255 | 0,98412 | 379,81... | 197 | .. | 5331 | 5331,... | 3,06093 | 3,11866 | -4,11038 | 5,87056 | -4,28373 | 5,88184 | 0,02022 | 0,02497 | 0,00036 | 0,09184 |
| 29 | 1 | 303 | 0,89923 | 365,43... | 209 | .. | 5283 | 5283,... | 0,81384 | 1,00942 | 3,03681 | 1,38968 | 3,15327 | 1,525 | 0,02295 | 0,026 | -0,00042 | -0,10075 |
| 30 | 1 | 157 | 0,91331 | 177,82... | 115 | .. | 1907 | 1907,... | 0,21343 | 0,19522 | 6,14523 | 1,87375 | 6,27668 | 1,91836 | 0,01413 | 0,01754 | -8,498... | -0,03659 |
| 31 | 2 | 455 | 0,39476 | 188,82... | 143 | .. | 2258 | 2258,... | -2,93639 | 2,13606 | -6,69381 | -3,88256 | -6,83213 | -3,91445 | 0,01994 | 0,02104 | 0,00034 | 0,11077 |
| 32 | 1 | 213 | 0,91298 | 287,78... | 180 | .. | 3861 | 3861,... | 2,3022 | 2,01998 | 7,25649 | 4,90551 | 7,14681 | 5,02679 | 0,02004 | 0,0235 | 0,00016 | 0,04334 |
| 33 | 1 | 275 | 0,9254 | 450,66... | 194 | .. | 6277 | 6277,... | 2,28355 | 2,21497 | -0,26 | -1,20198 | -0,34795 | -1,08537 | 0,0196 | 0,0209 | 6,143... | 0,02033 |
| 34 | 1 | 142 | 0,98618 | 339,33... | 115 | .. | 3639 | 3639,... | -1,62224 | -1,63121 | 7,41467 | -4,9945 | 7,39418 | -5,26364 | 0,00705 | 0,03146 | 0,00016 | 0,02927 |
| 35 | 1 | 286 | 0,88493 | 357,47... | 209 | .. | 5168 | 5168,... | -1,75009 | -2,06498 | 3,1432 | -5,469 | 3,10921 | -5,64363 | 0,02309 | 0,02552 | 0,00015 | 0,03569 |
| 36 | 1 | 256 | 0,90308 | 375,84... | 199 | .. | 5302 | 5302,... | 1,2773 | 1,32458 | 6,10467 | -1,43473 | 6,14551 | -1,29604 | 0,02208 | 0,02275 | -0,00024 | -0,07098 |
| 37 | 1 | 259 | 0,92581 | 424,80... | 185 | .. | 5778 | 5778,... | -1,54955 | -1,62283 | 2,48974 | 3,08406 | 2,49076 | 2,93949 | 0,01839 | 0,01983 | -0,00017 | -0,06091 |

Lv1a EVENT table

# Lv2 FITS file

EVENT table

- X: Event X position (SKY frame)
- Y: Event Y position (SKY frame)
- PHI: Photoelectron emission angle in radians (SKY frame)
- PHE_U: Sin(2*PHI)
- PHE_Q: Cos(2*PHI)