Building ASCI* based on the COSI' mission performance

**All-Sky Compton Imager*

'COmpton Spectrometer and Imager

AHEAD Progress Meeting, Coimbra, 18-19 April 2018.

Aleksandar GOSTOJIC [1]

P. von BALLMOOS [1], P. JEAN [1], L. HANLON [2]

[1] IRAP Toulouse, [2] UCD Dublin,
UCB Berkeley, LBNL Berkeley, NTHU & NCU, Taiwan

COSI: Flight 2016.

Balloon + gondola

Start:
New Zealand
16th May 2016.

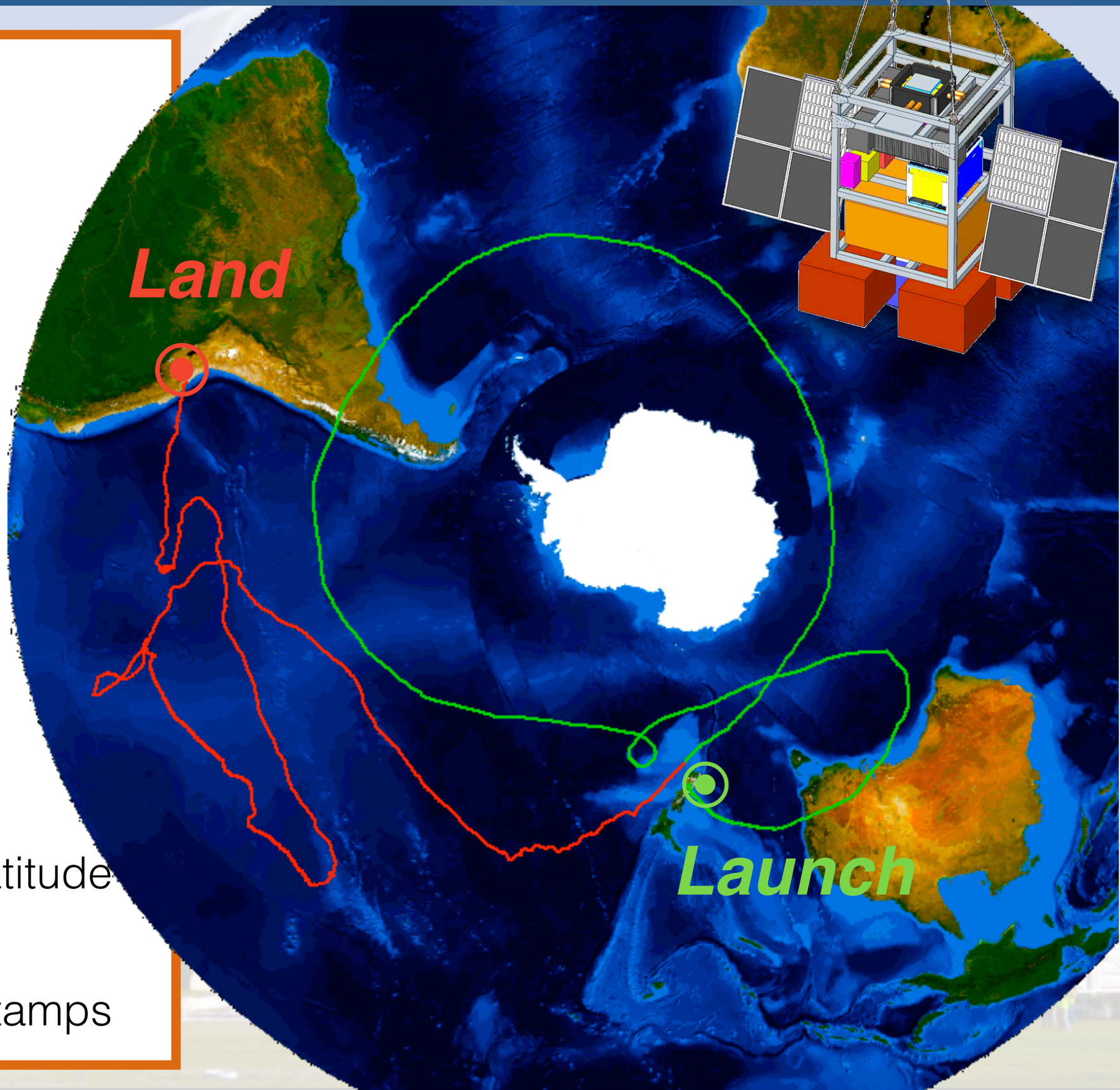
End:
South America
2. July 2016

Flight time (data):
46+ days!

Support data:

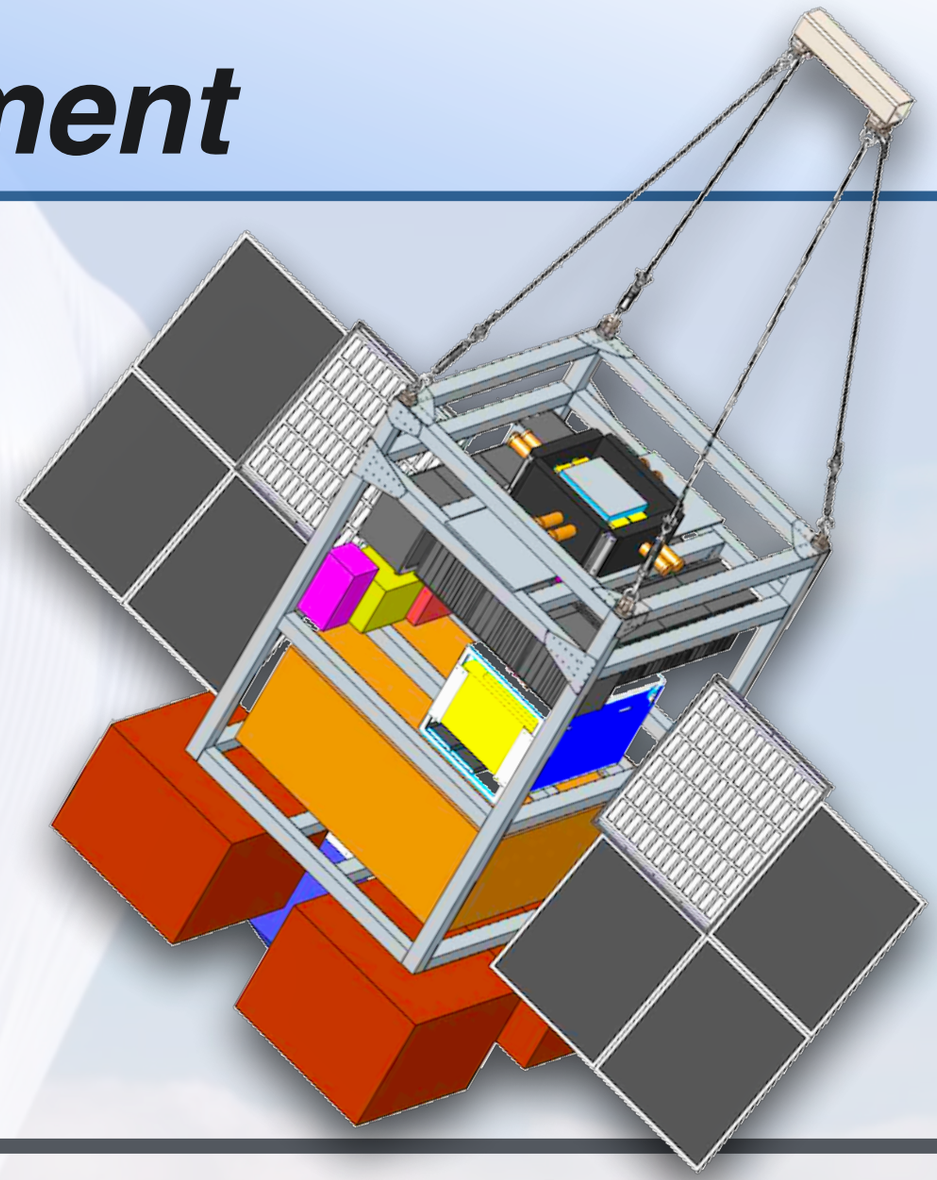
Geolocation:
altitude, longitude, latitude

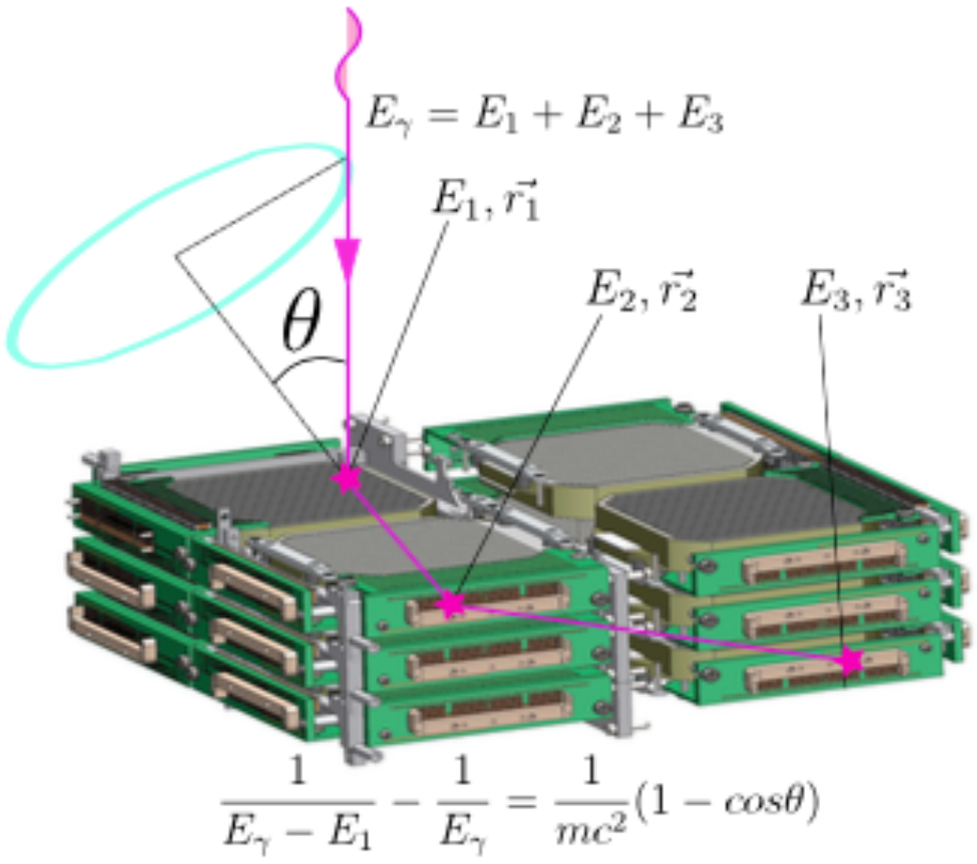
ACS count rates:
total, lifetimes, timestamps



COSI: Instrument

- Balloon-borne telescope: 0.2 - 10. MeV
- Double-sided strip Ge detectors (GeDs)
- 12 GeD: ~ 8x8 cm² x 1.5 cm w/
  37 x 2 mm strips / 0.25 mm gaps
- Controlled cryostat
- ACS: CsI panels
- Electronics + balloon gondola

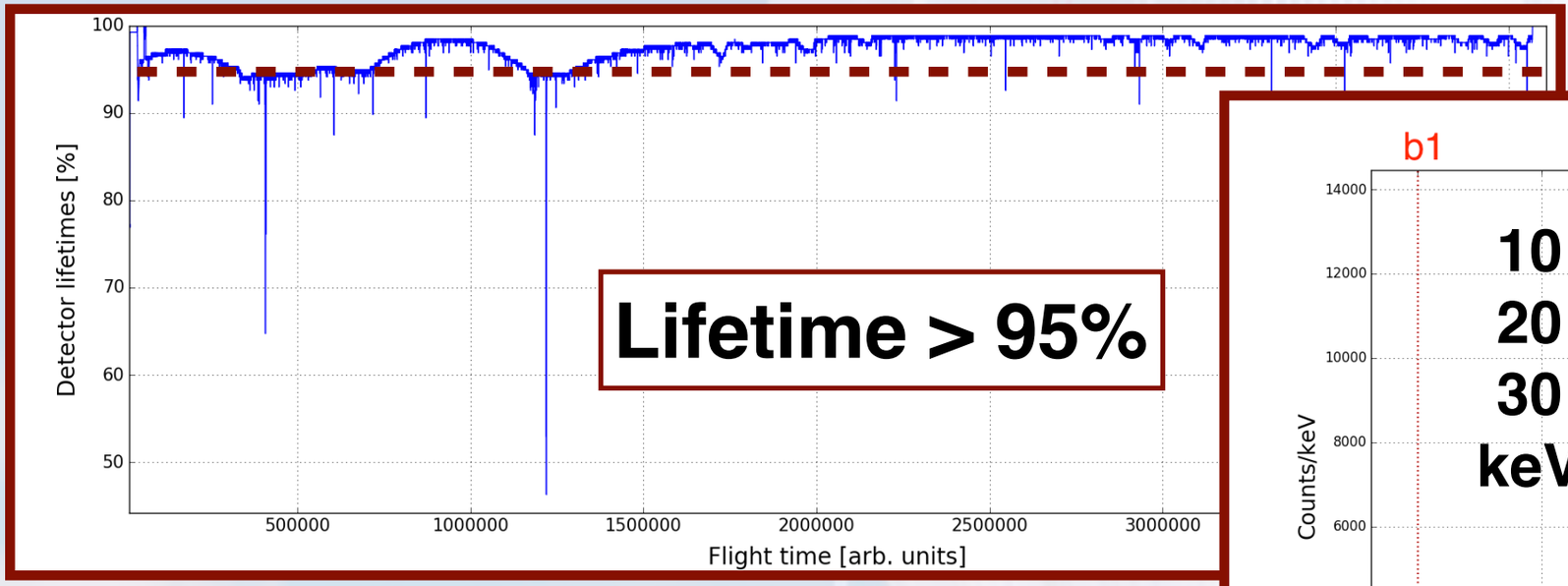


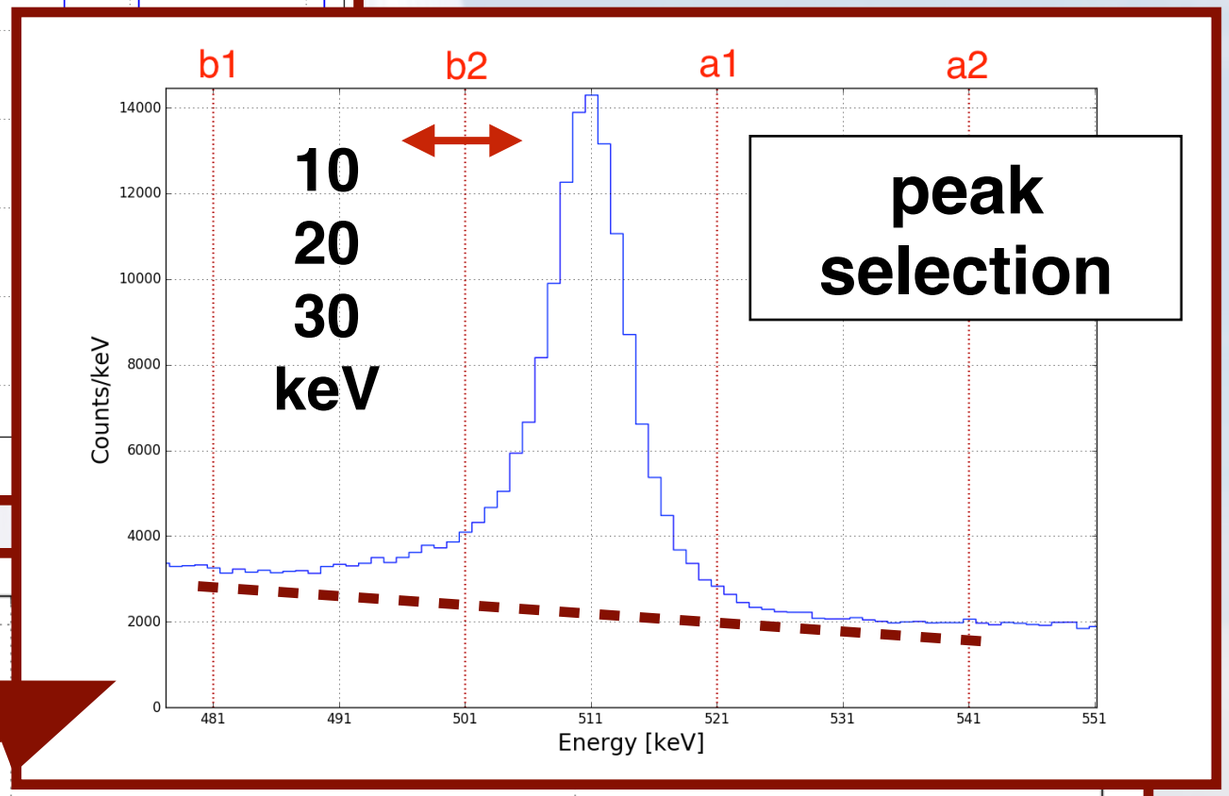


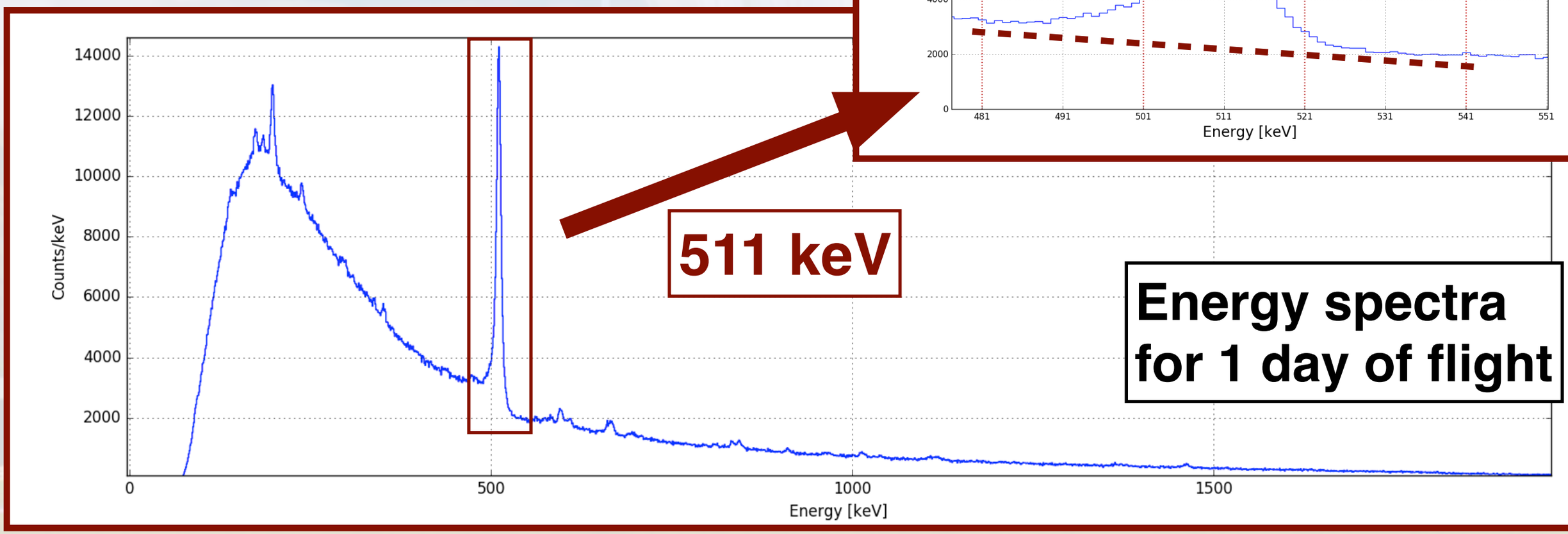
- Energy res: 1.5-3.0 keV FWHM
- Angular res: up to ~4° FWHM
- Field-of-view: almost 1/4 of sky
- X/Y res: 2. mm or less
- Depth-of-int: ~0.2 mm RMS

COSI: 511 keV as bkg. indicator

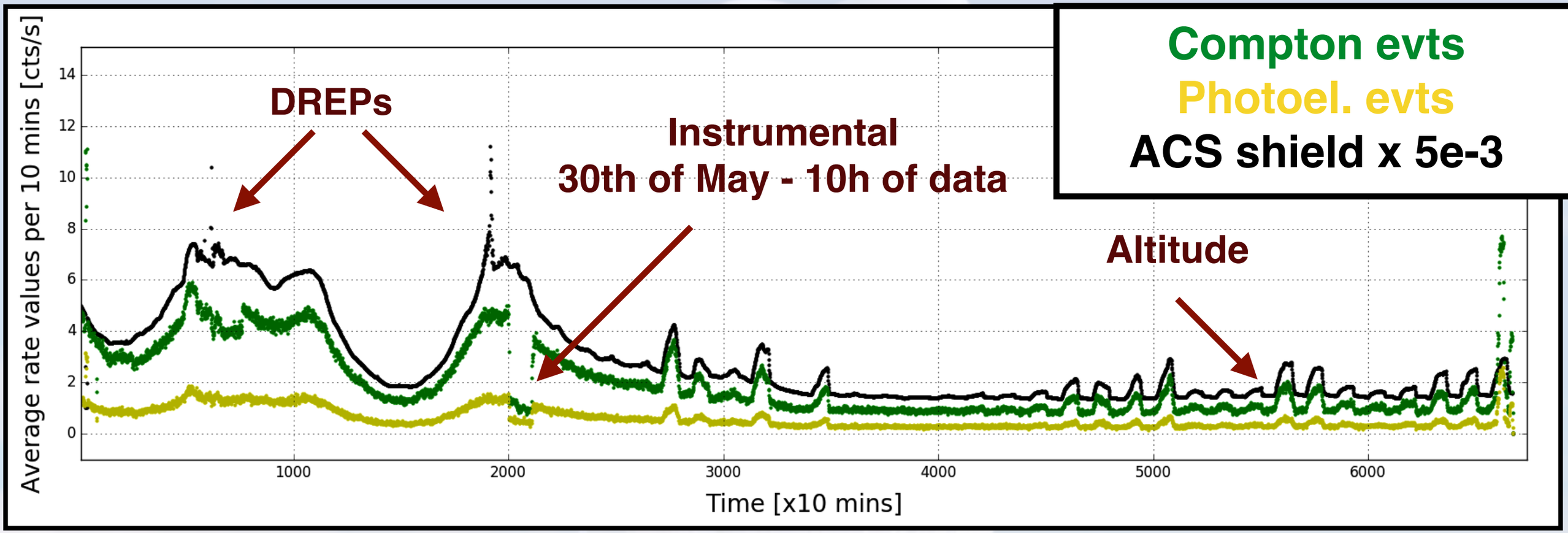
Data extraction and pre-analysis - Berkley: events + ACS + flight data







COSI: 511 keV rates



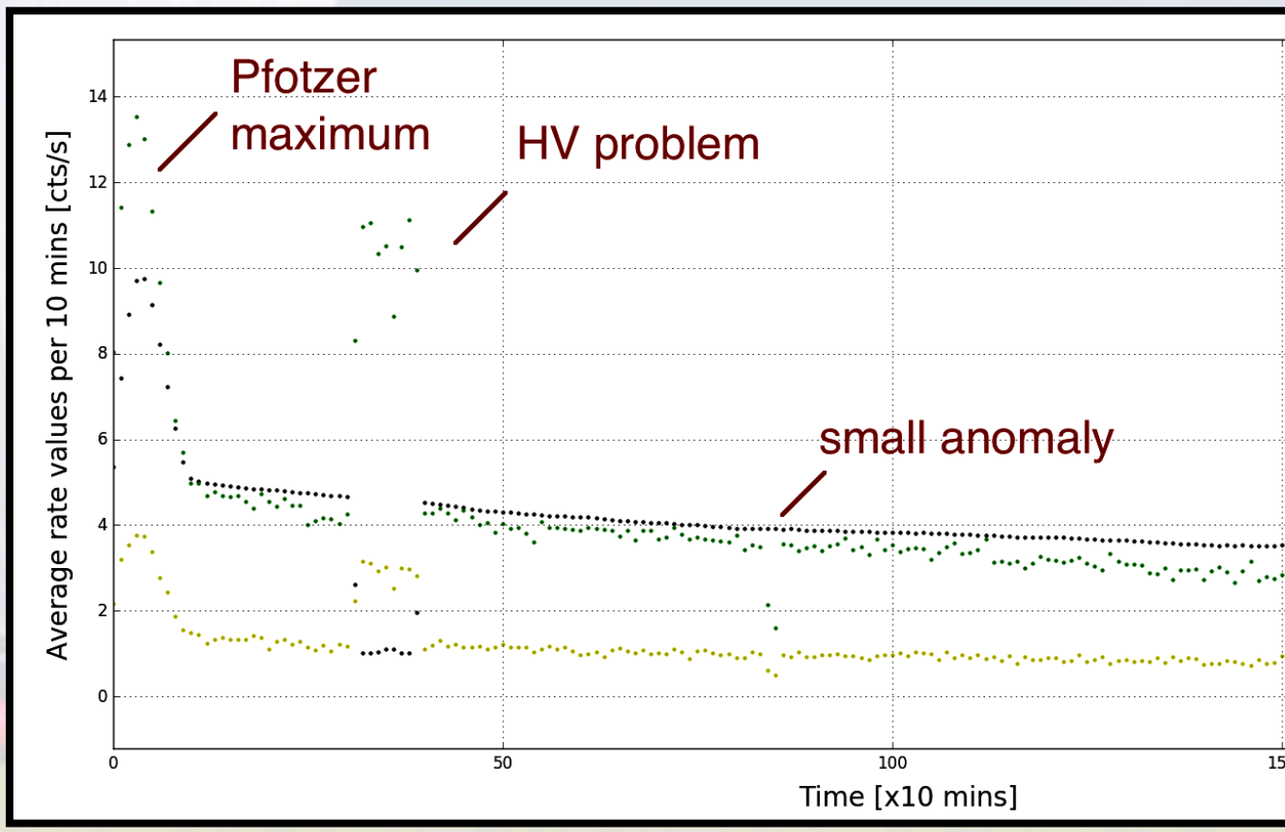
511 keV rates:

Avg. per 10 min of flight time

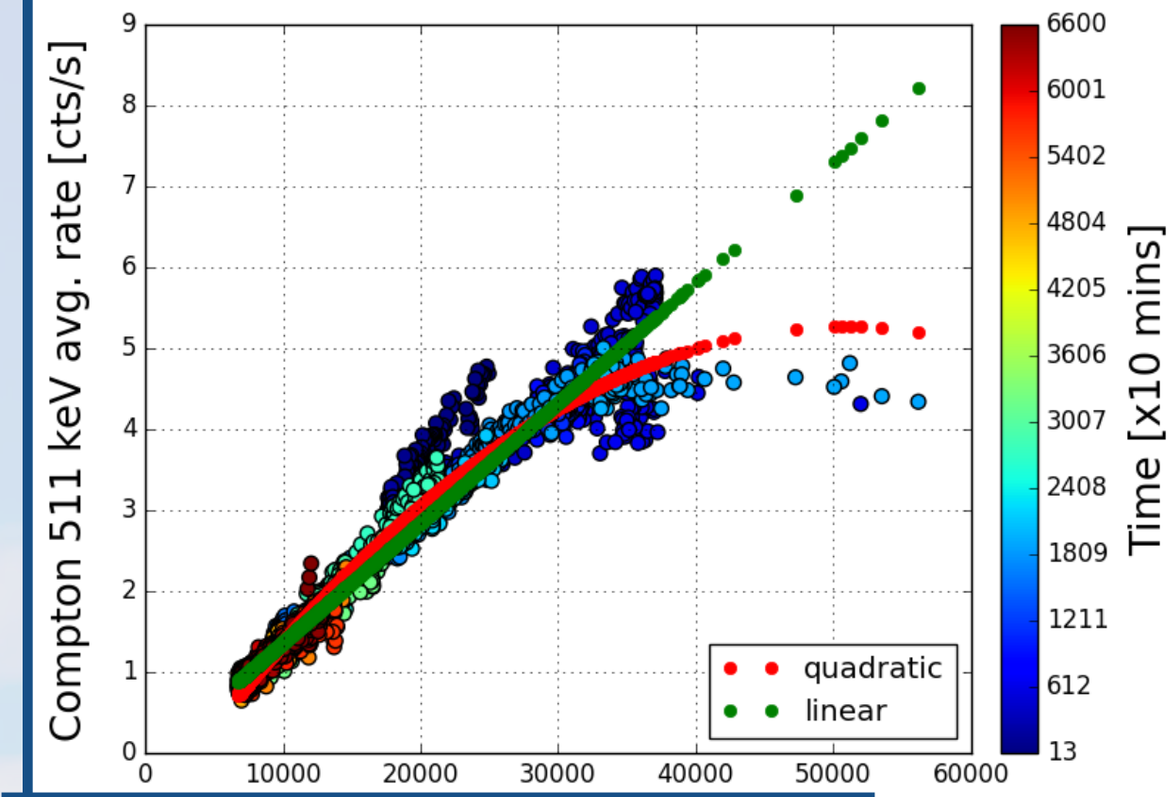
Statistical error ~ 3-4%

Excluded events:

- ***instrumental malfunctions***
- ***small anomalies***



COSI: 511keV rates



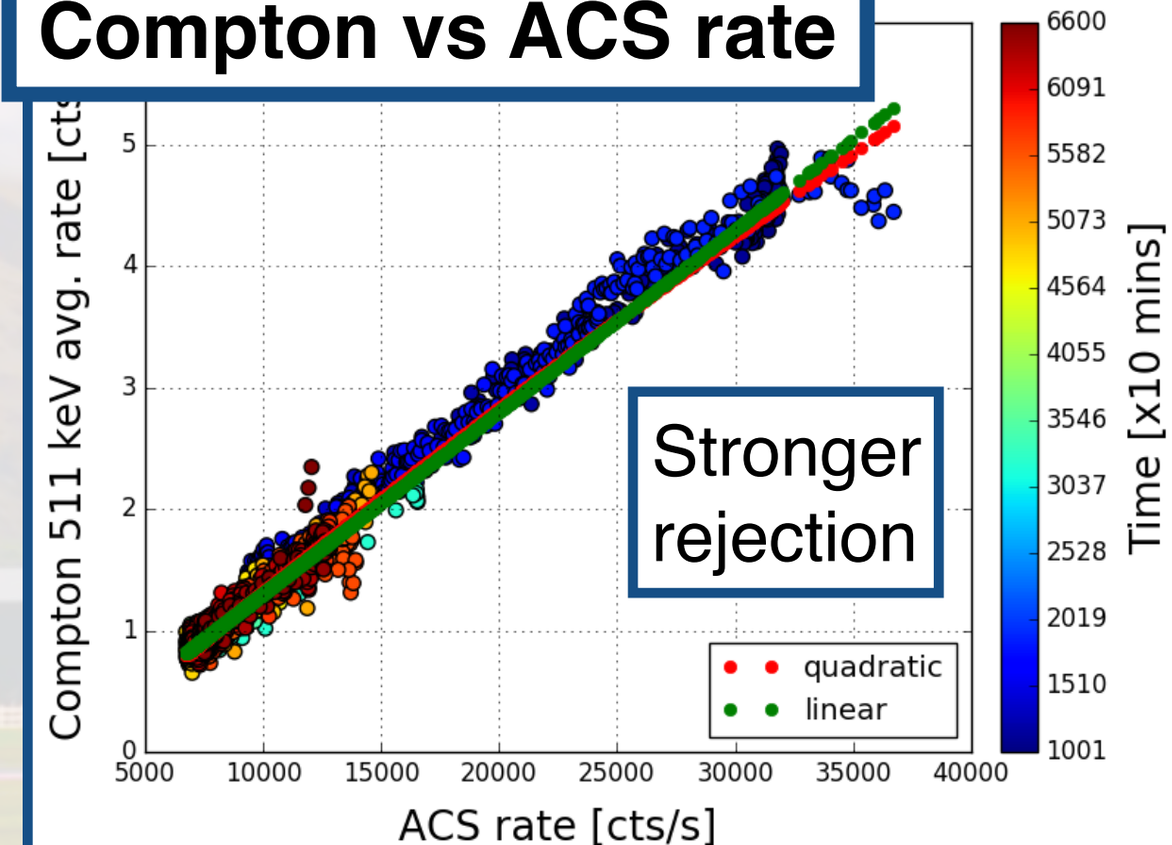
LINEAR: $R_{511} = 0.11 + 1.46 \times 10^{-4} \times R_{ACS}$

QUAD: $R_{511} = -0.77 + 2.39 \times 10^{-4} \times R_{ACS} - 2.36 \times 10^{-9} \times R_{ACS}^2$

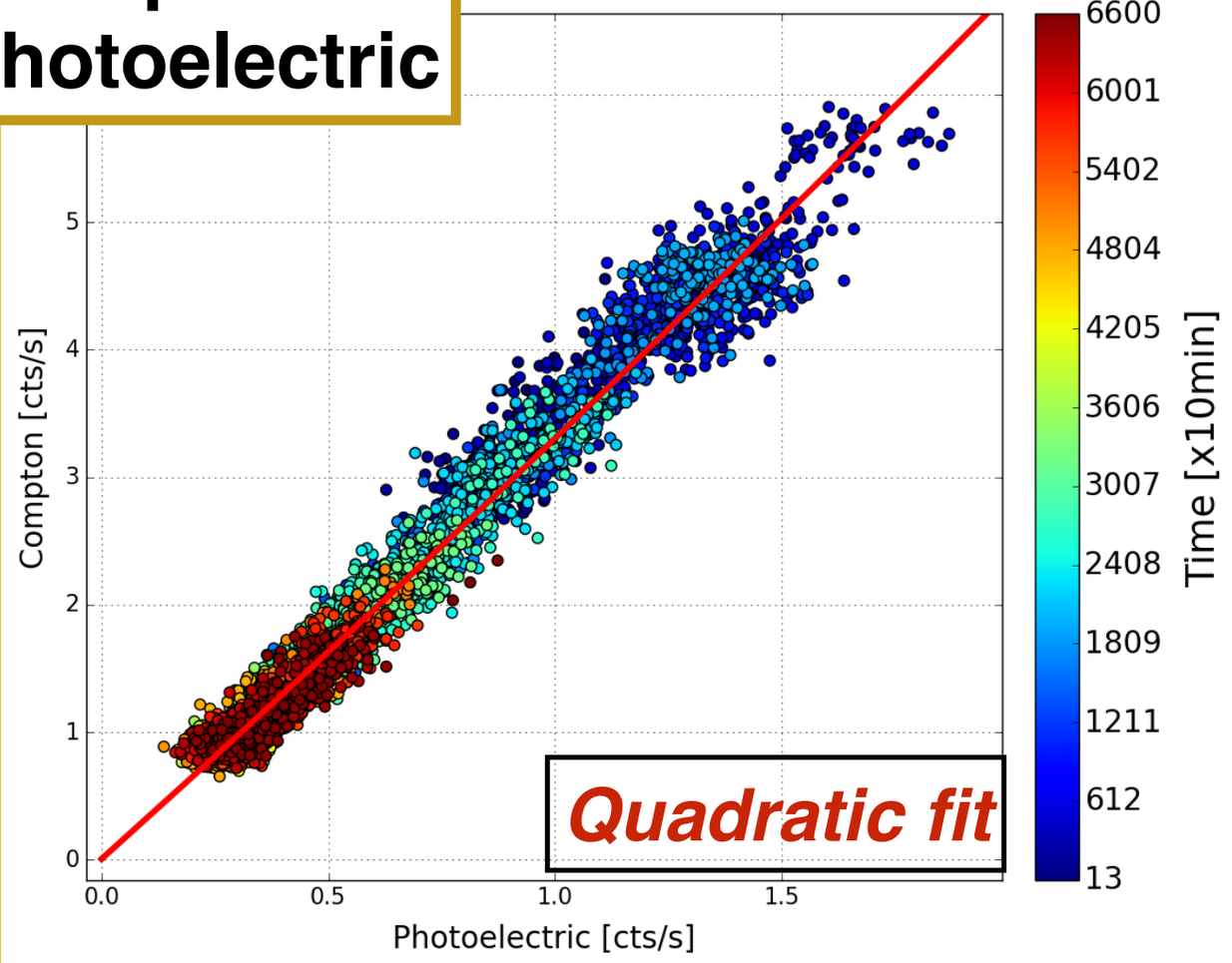
LINEAR': $R_{511} = -0.19 + 1.49 \times 10^{-4} \times R_{ACS}$

QUAD': $R_{511} = -0.29 + 1.65 \times 10^{-4} \times R_{ACS} - 0.47 \times 10^{-9} \times R_{ACS}^2$

Compton vs ACS rate

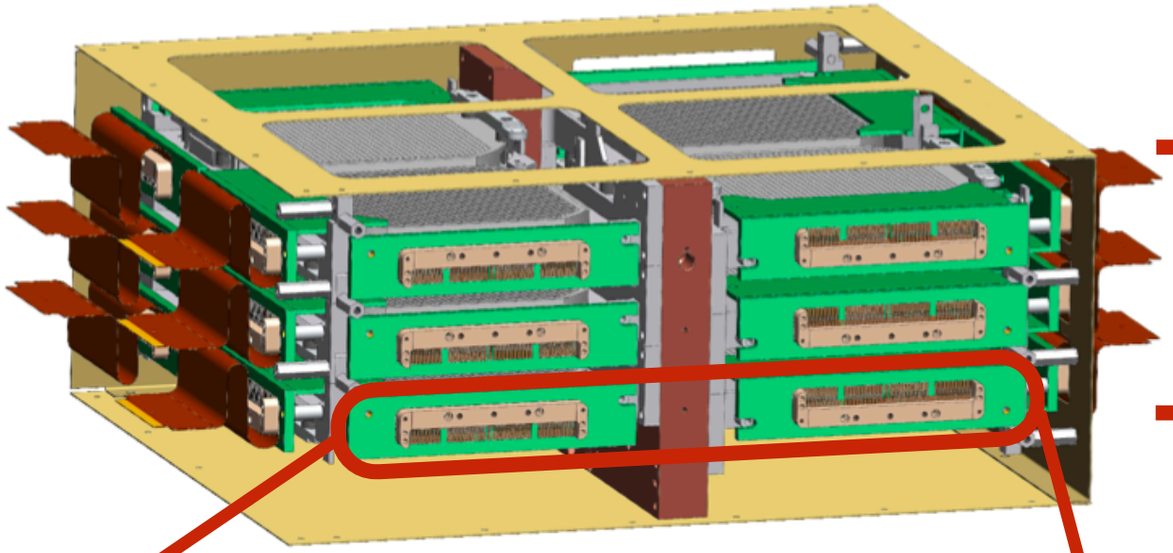


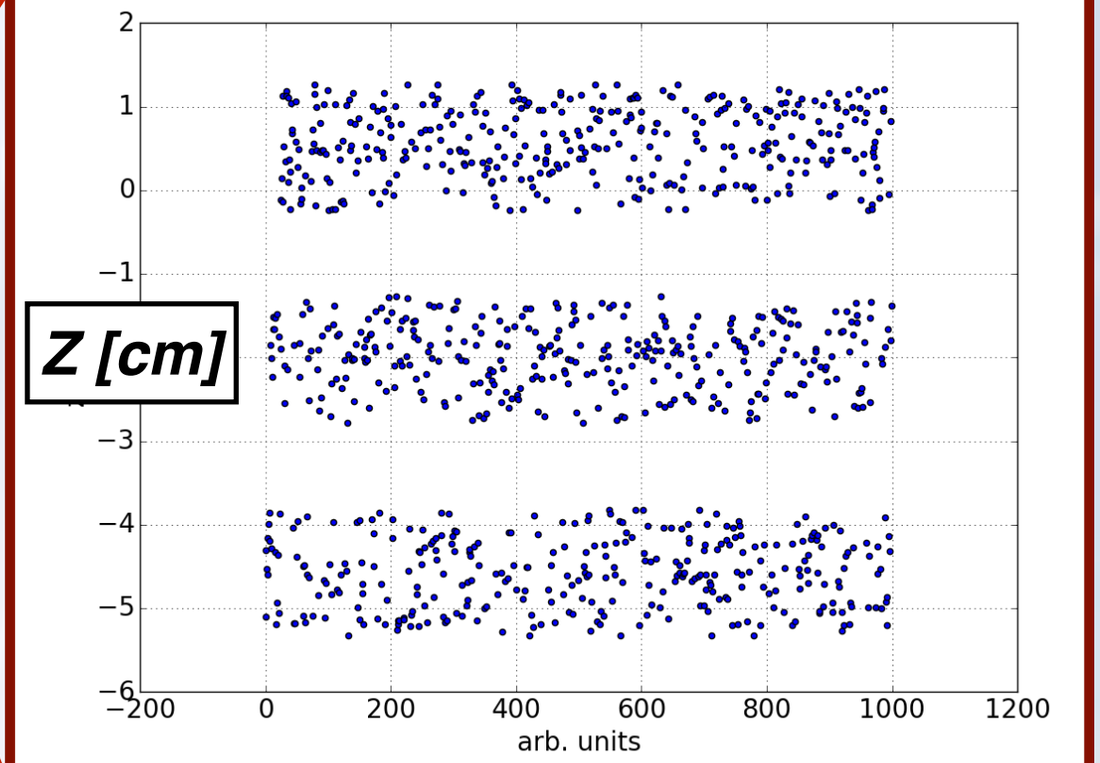
Compton vs photoelectric

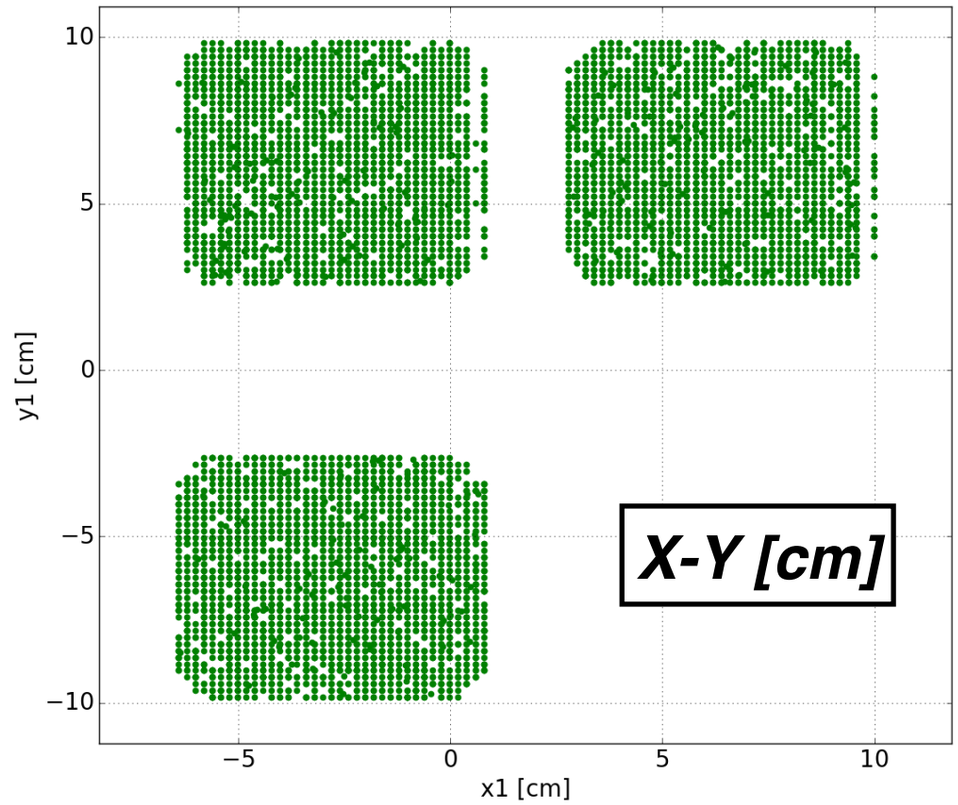


$$R_{511}^{CO} = 6.863 \times 10^{-3} + 3.191 \times R_{511}^{PE} + 0.102 \times (R_{511}^{PE})^2$$

COSI: GeDs ON / OFF

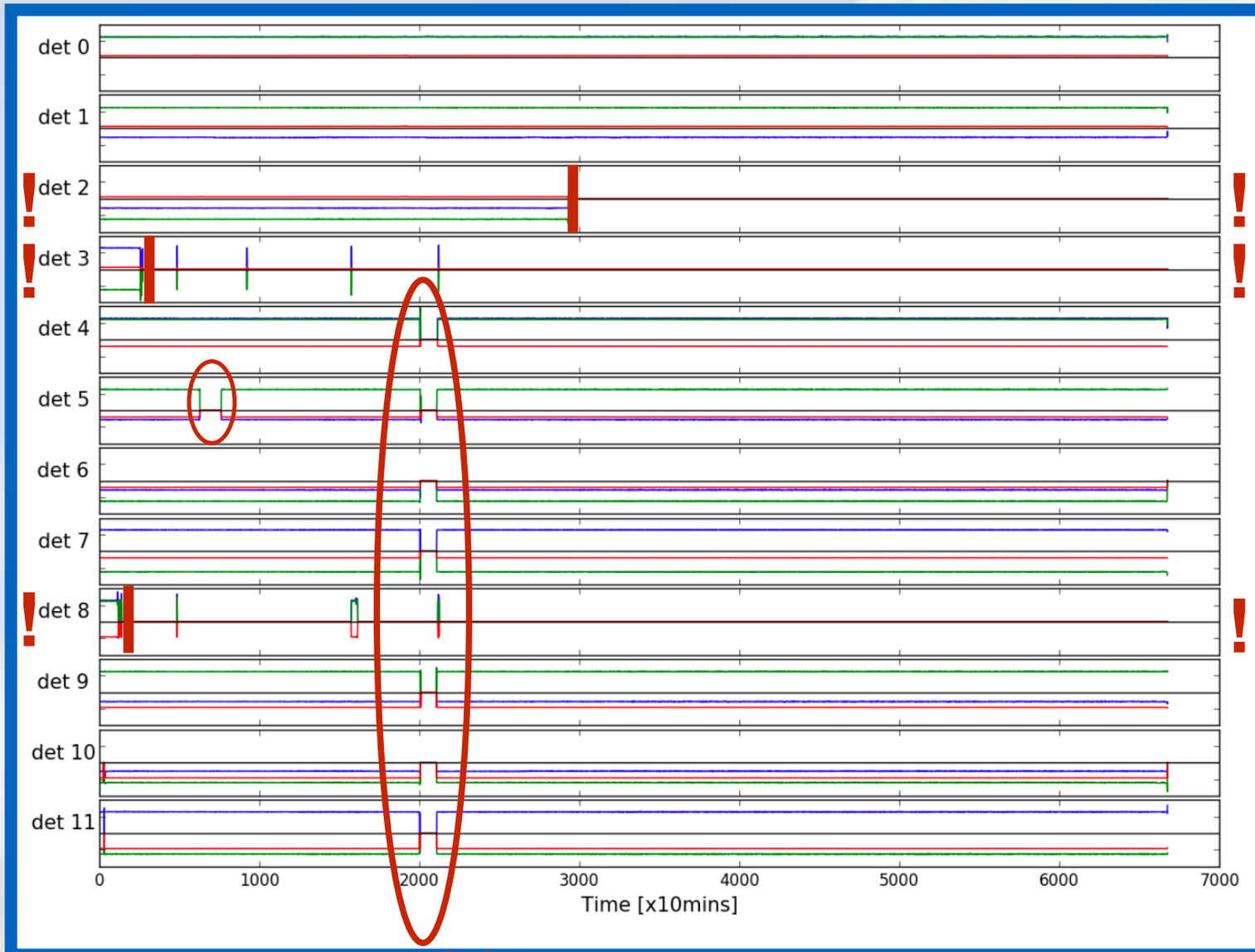






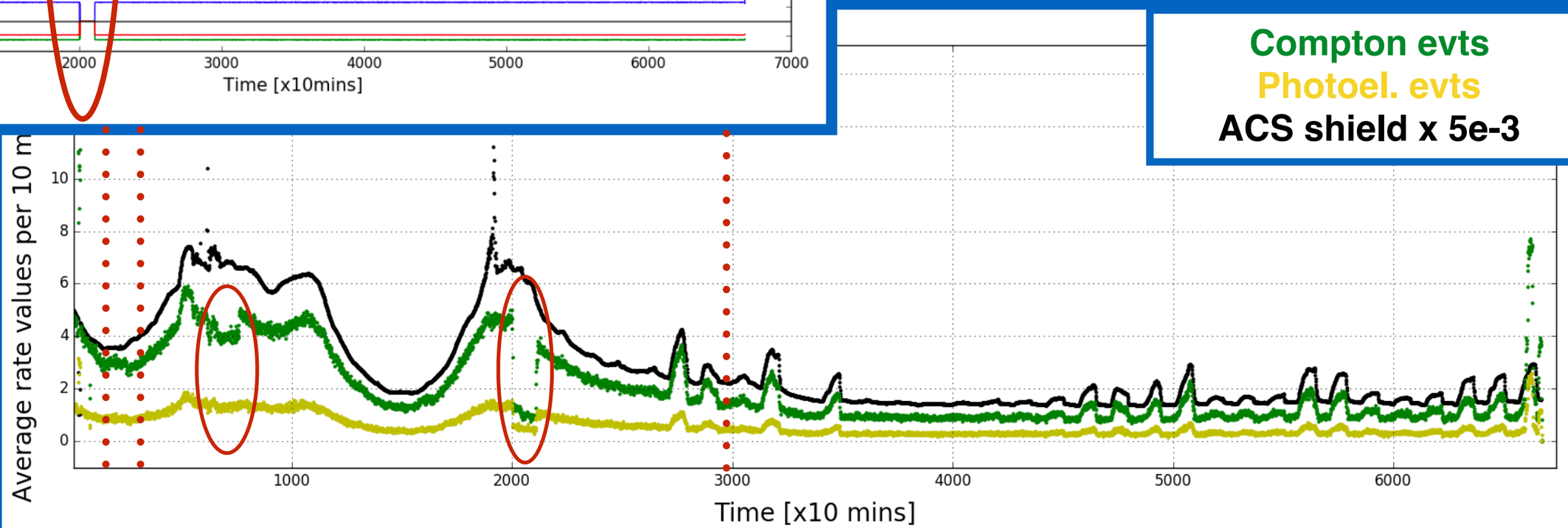
- *"Confirm" geometry*
- *3 layers of 2x2 GeDs*
- *GeD ~ 8 x 8 x 1.5 cm³*
- *37 strips per GeD*
- *Search for malfunctioning GeDs*

COSI: GeDs ON / OFF



- 12 GeDs: 0 - 11
- Loss of detectors: 2,3,8
- Loss of 2 bottom rows of GeDs
- Small problems
- 4 “configurations"

PASSIVE ACTIVE MATERIAL RATIO !



Cut-off rigidity estimation

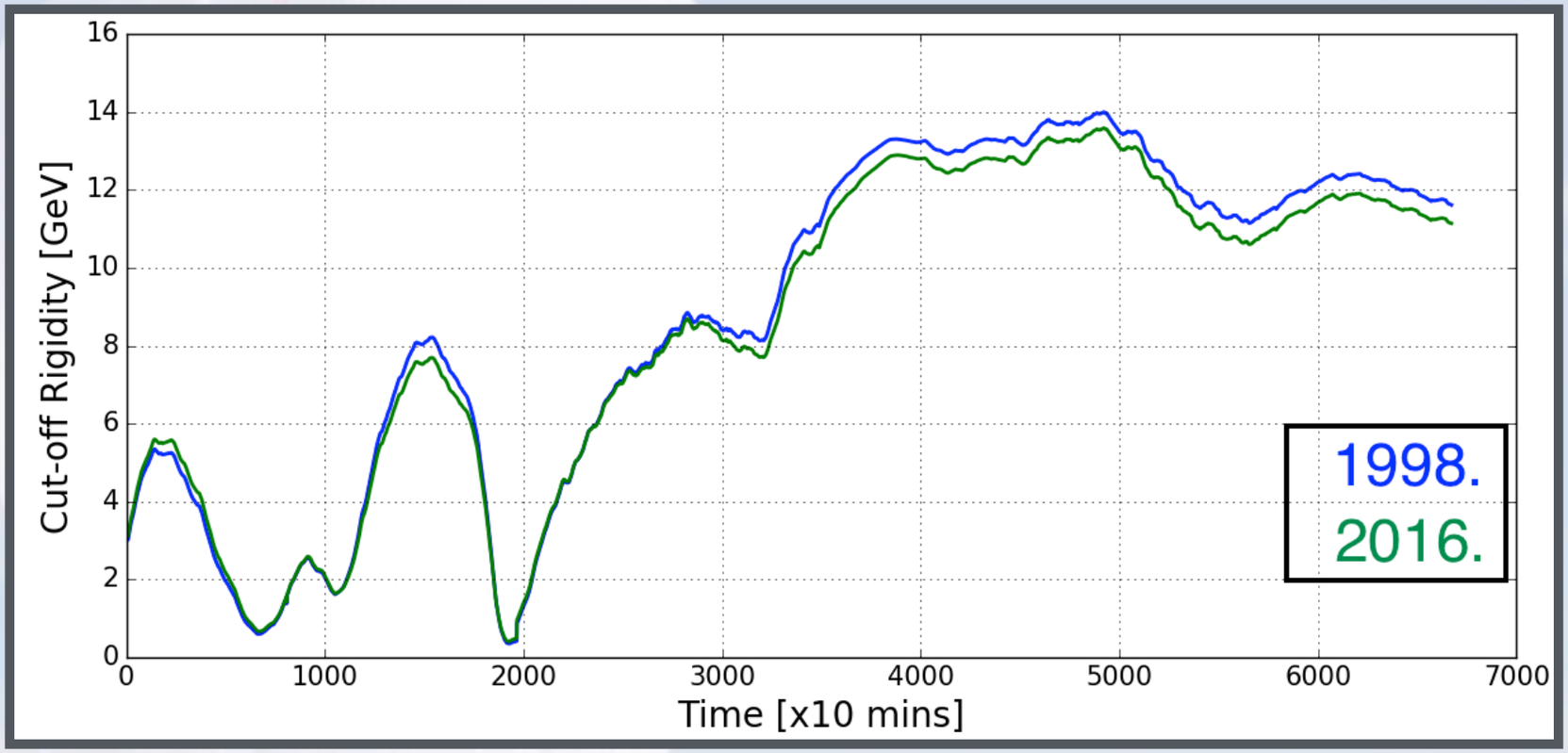
Shifted dipole approximation

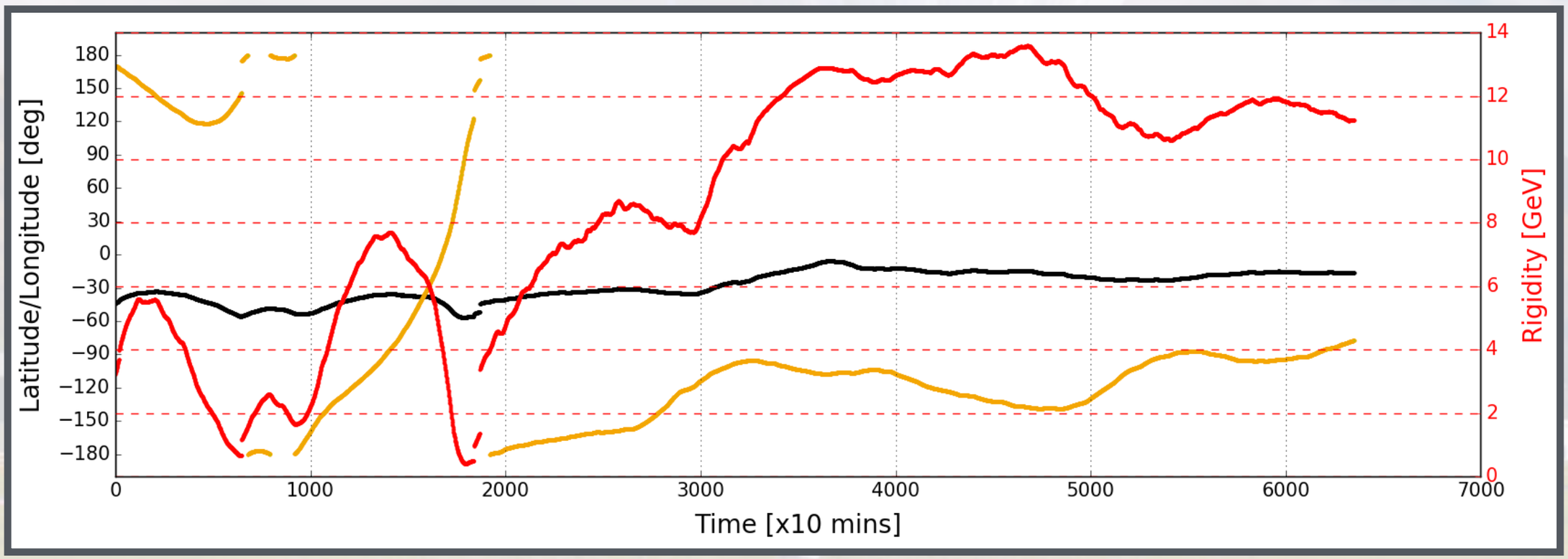
*Geoloc. (**lat, lon, alt**)→*

Geomagnetic coords.

IGRF coeffs. (2016)→

dipole coordinates.





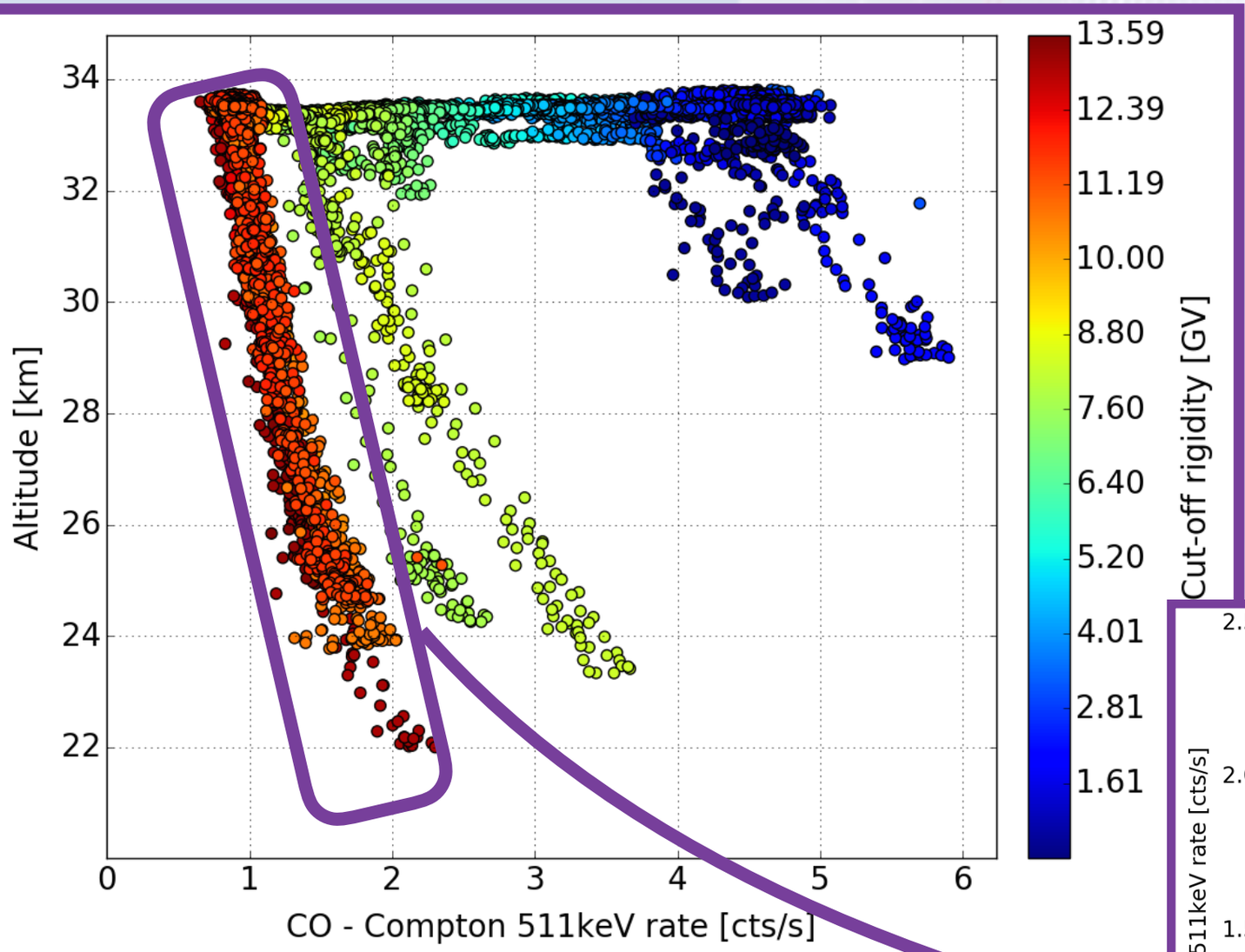
LAT

LON (deg.)

RIG (GeV)

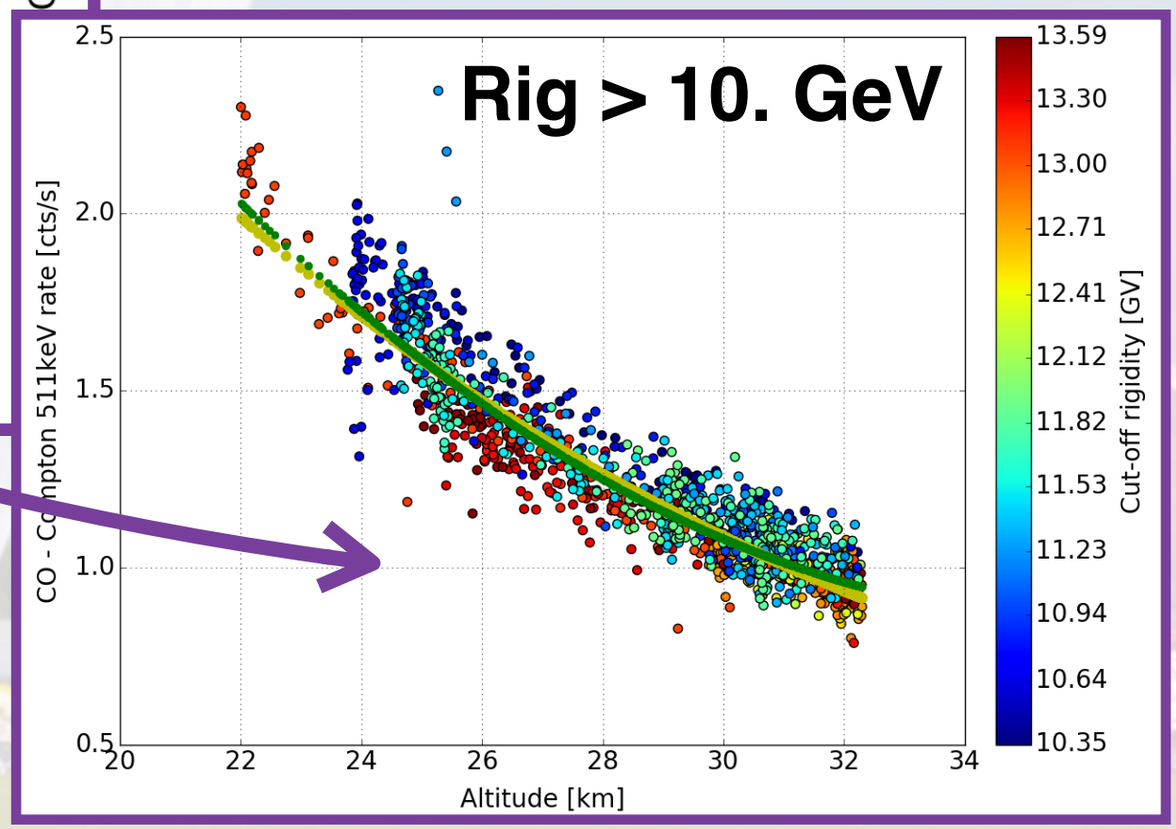
Background modeling: Altitude

Background: Ability to extrapolate outside the atmosphere !



1. Altitude [km]
2. Cut-off rigidity [GeV]

$$R_{511}(t) \equiv \{ f[R_{cut\text{-}off}(t)] \times g[Altitude(t)] \}$$

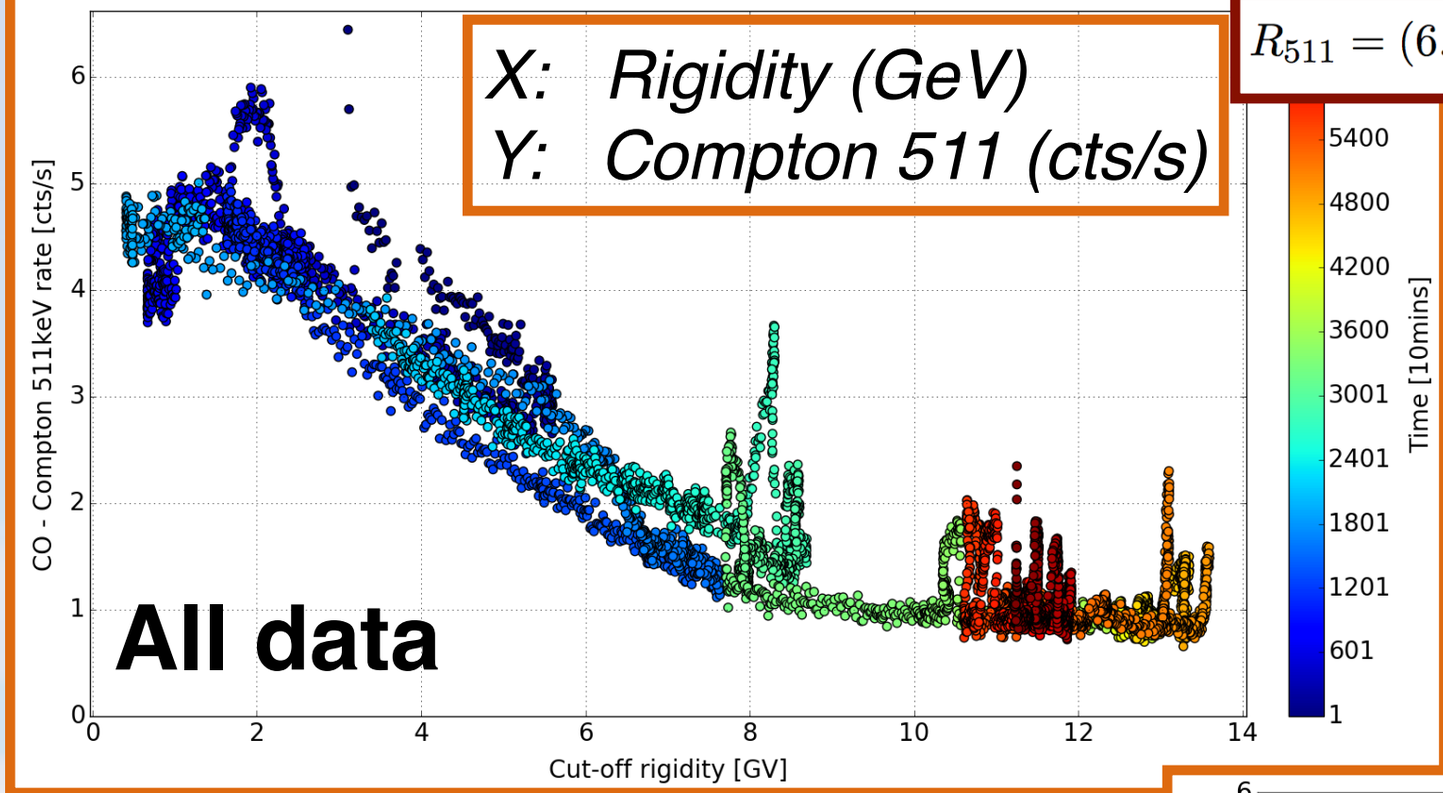


exponential / polynomial fit:

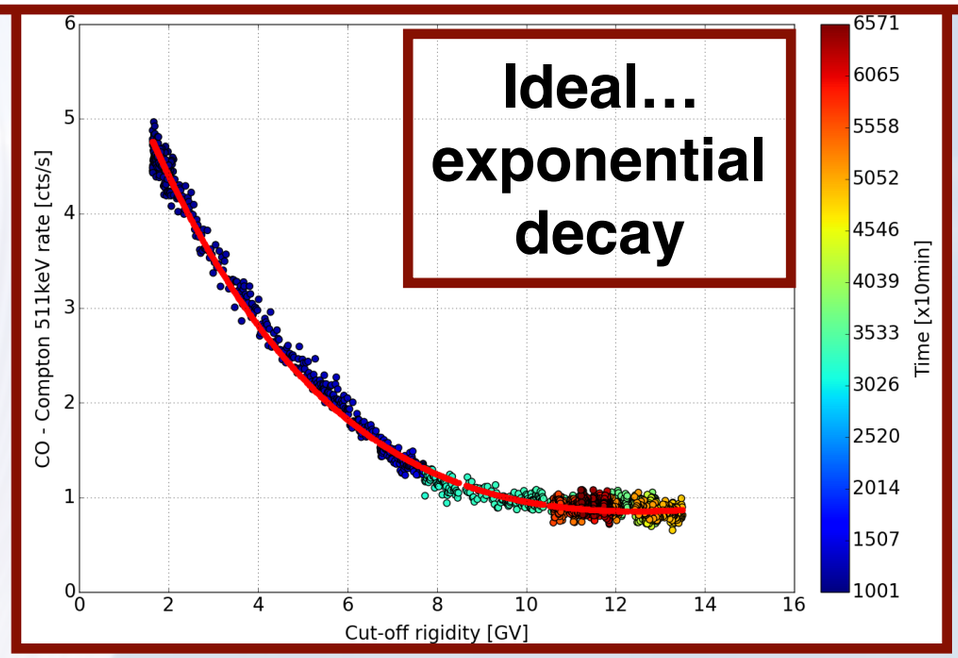
$$R_{511} = f_1 \times e^{f_2 \times Altitude}$$

$$R_{511} = p_0 + p_1 \times Altitude + p_2 \times Altitude^2$$

Background modeling: Rigidity



$$R_{511} = (6.78 - 0.9 \times Rigidity + 0.04 \times Rigidity^2) \times e^{-0.08 \times Rigidity}$$

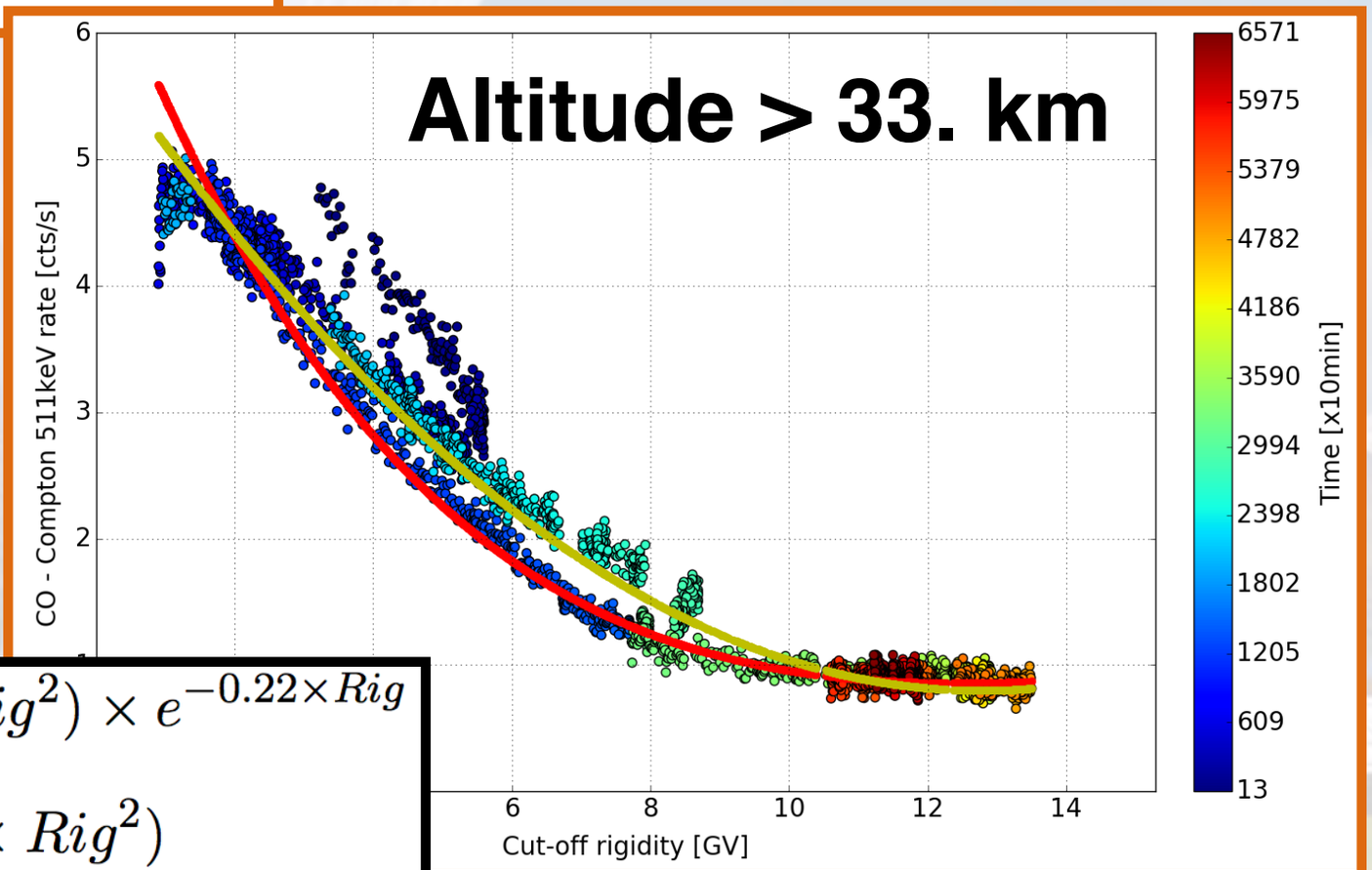


However:

problem - unknown:

1. polynomial x exp.

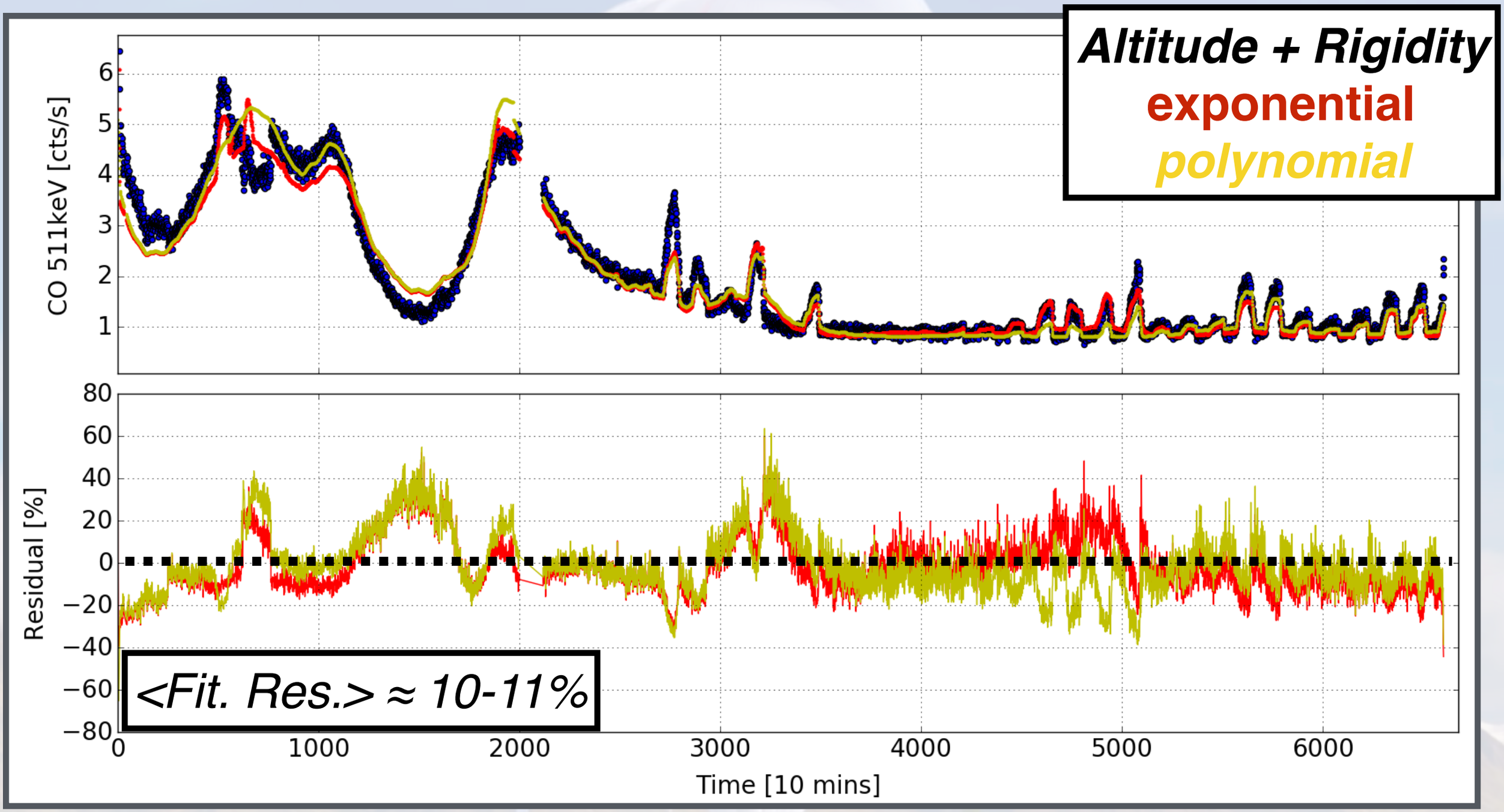
2. polynomial



$$R_{511} = (5.77 + 0.45 \times Rig - 6.6 \times 10^{-6} \times Rig^2) \times e^{-0.22 \times Rig}$$

$$R_{511} = (5.88 - 0.70 \times Rig + 0.03 \times Rig^2)$$

Background modeling: "Model 0"



$$R_{511} = \left((29.58 + 4.47 \times Rig + 0.18 \times Rig^2) * e^{0.06 \times Rig}\right) \times e^{-0.05 \times Alt}$$

$$R_{511} = 5.80 - 2.26 \times 10^{-2} \times (Rig \times Alt) + 2.57 \times 10^{-5} \times (Rig \times Alt)^2$$

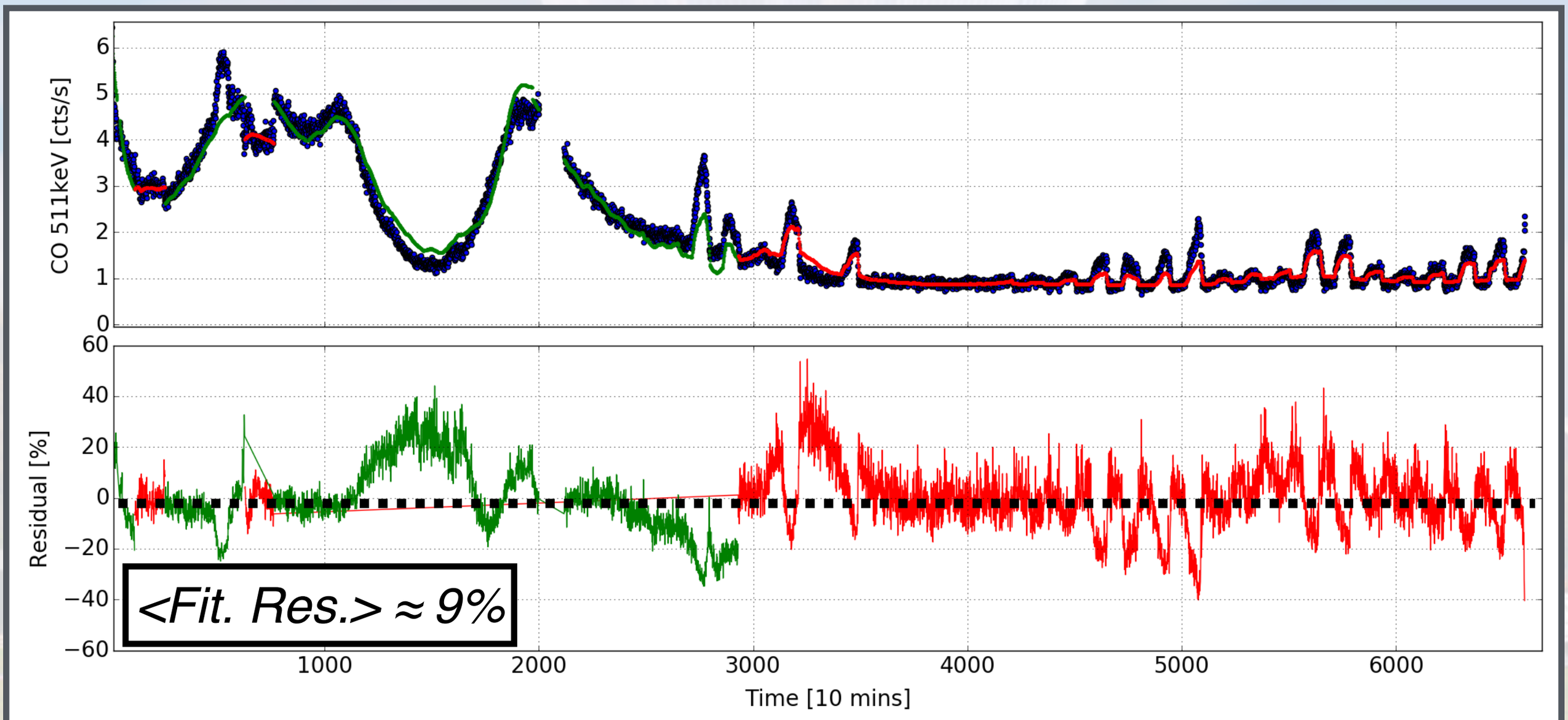
Background modeling: "Model 1"

Take into account different "configurations": ***ALL / -1 / -2 / -3 GeDs***

Apply one of the above models, e.g. ***2nd order polynomial:***

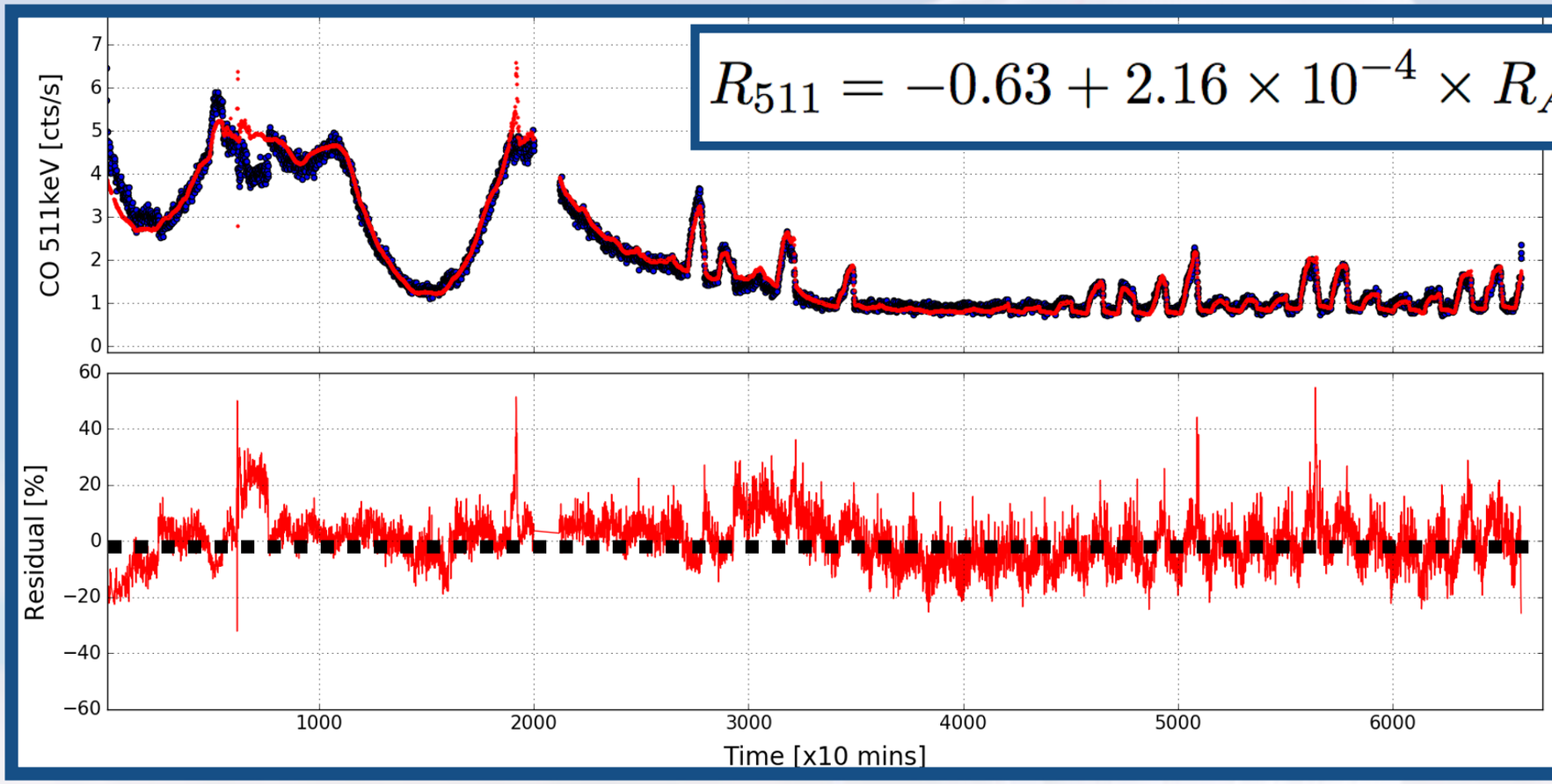
$R_{511}(t) = p_1 + p_2 \cdot \mathbf{x(t)} + p_3 \cdot \mathbf{x(t)}^2$; $\mathbf{x(t)} = [\text{Altitude}(t) \cdot \text{Rigidity}(t)]$

Parametrize the same function for each period



Background estimation: ACS rate

$$R_{511} = -0.63 + 2.16 \times 10^{-4} \times R_{ACS} - 1.56 \times 10^{-9} \times R_{ACS}^2$$

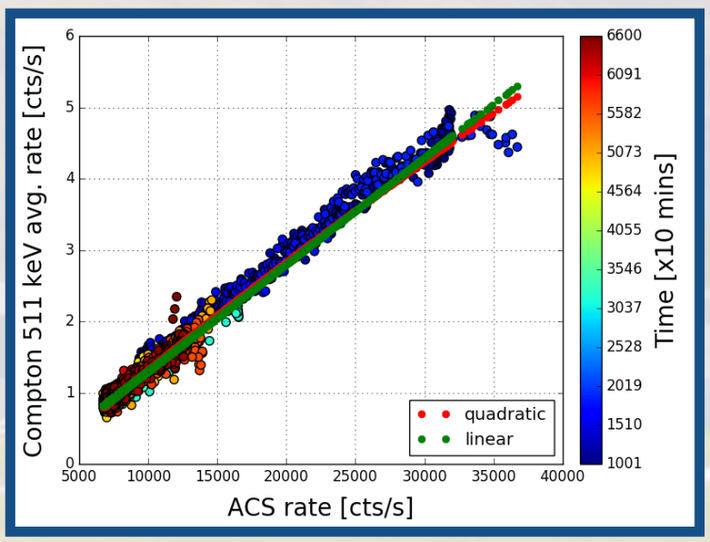


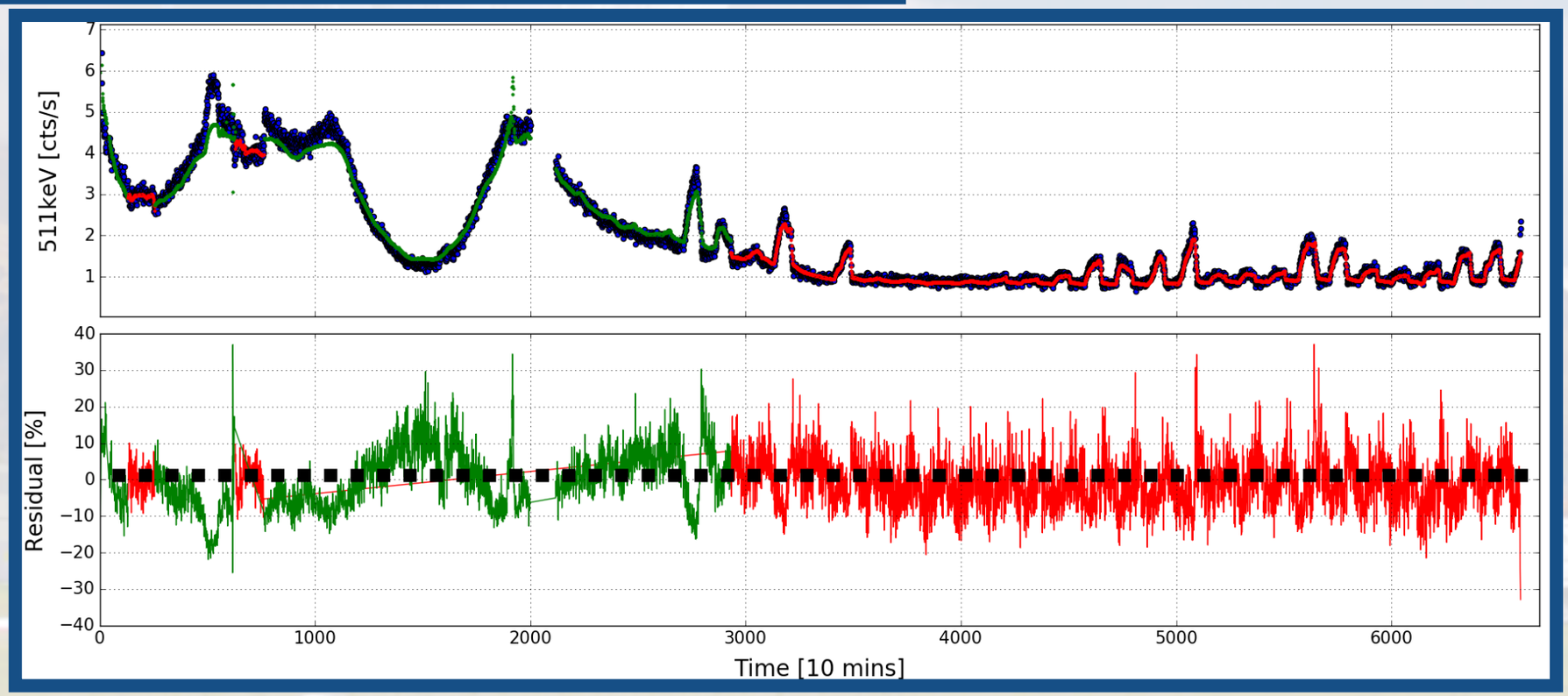
Quadratic fit:

<Fit. Res.0> ≈ 6.9%

<Fit. Res.1> ≈ 5.9%

CO 511 vs ACS



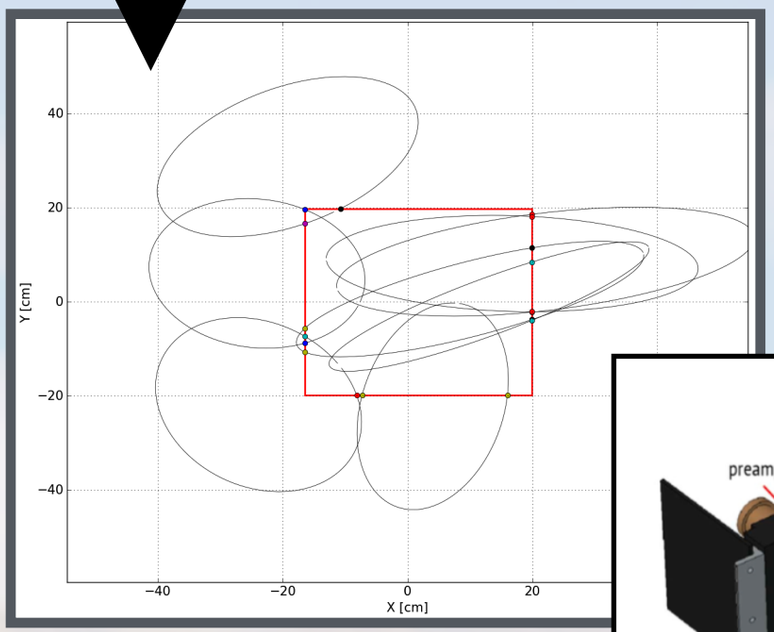


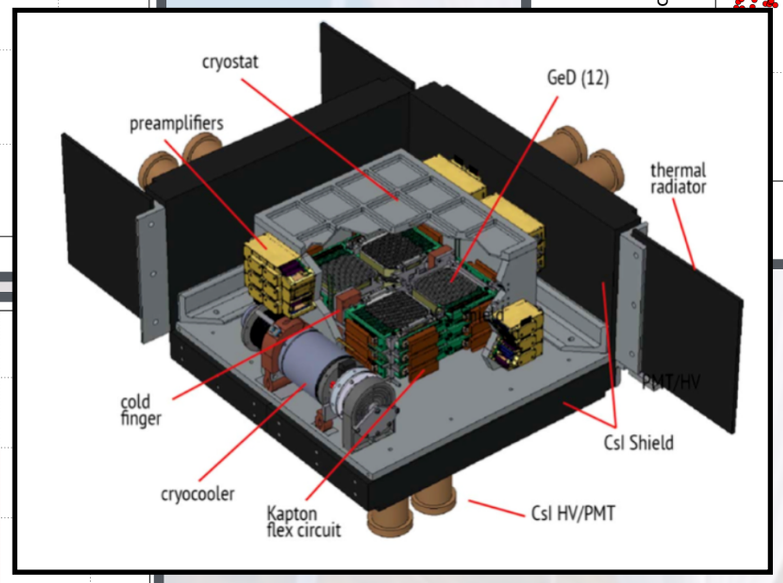
Background: improvements

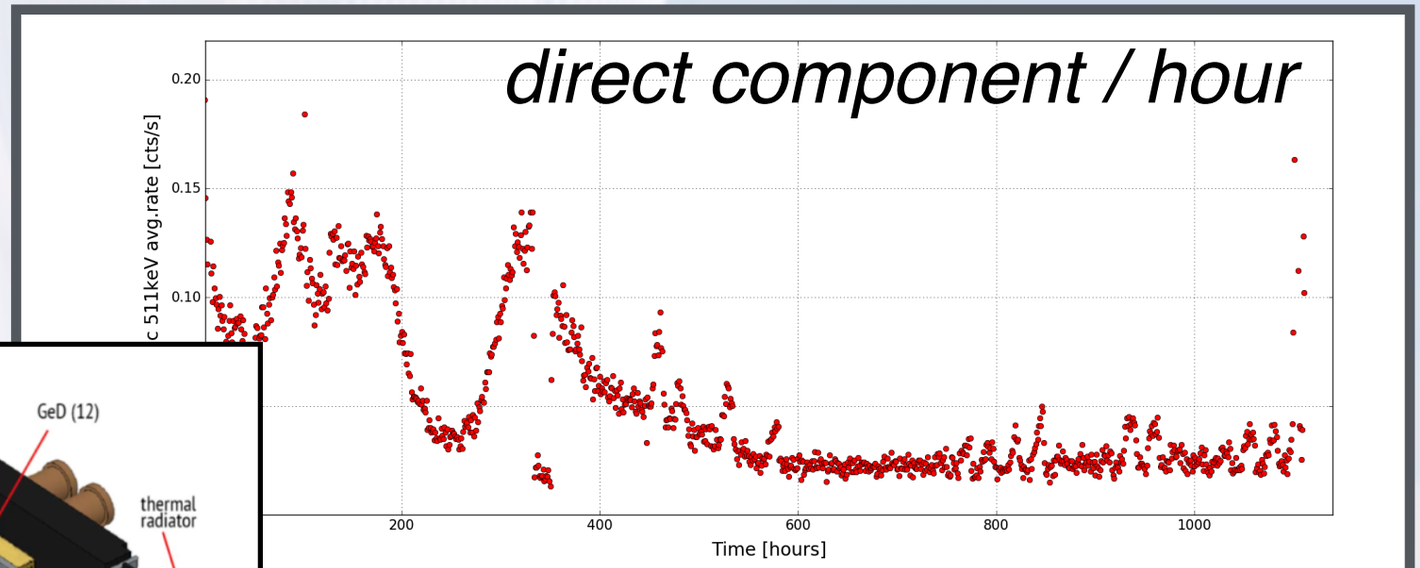
1. Delayed component: *F(t) ≡ Atmo.(t) + prompt(t)* + delayed(t)**

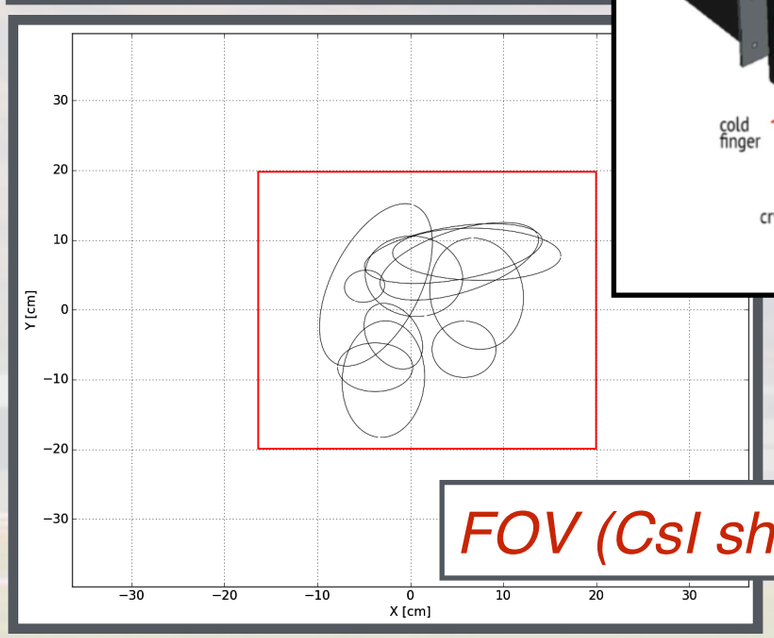
Compton events → $\theta_{Compton} \leq 30^{o}$ + downward evts.

(no backscatter) + FOV (CsI shields) selection







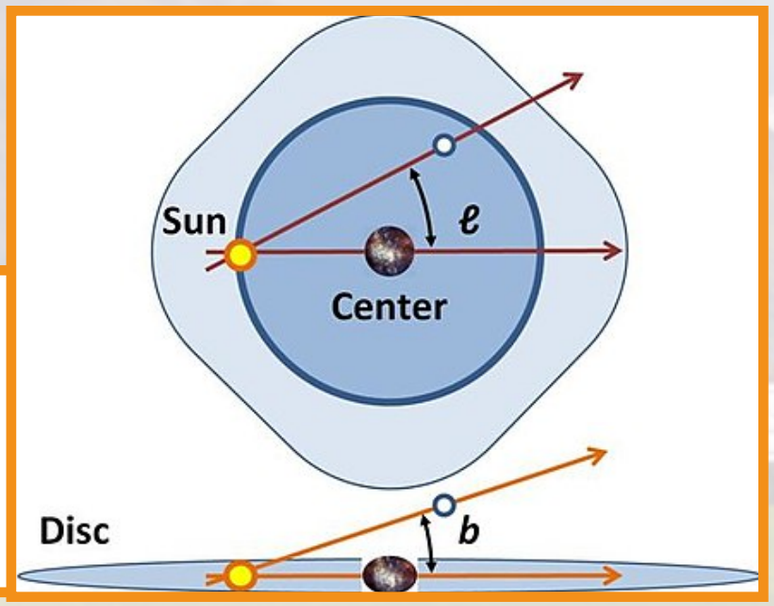


FOV (CsI shields)

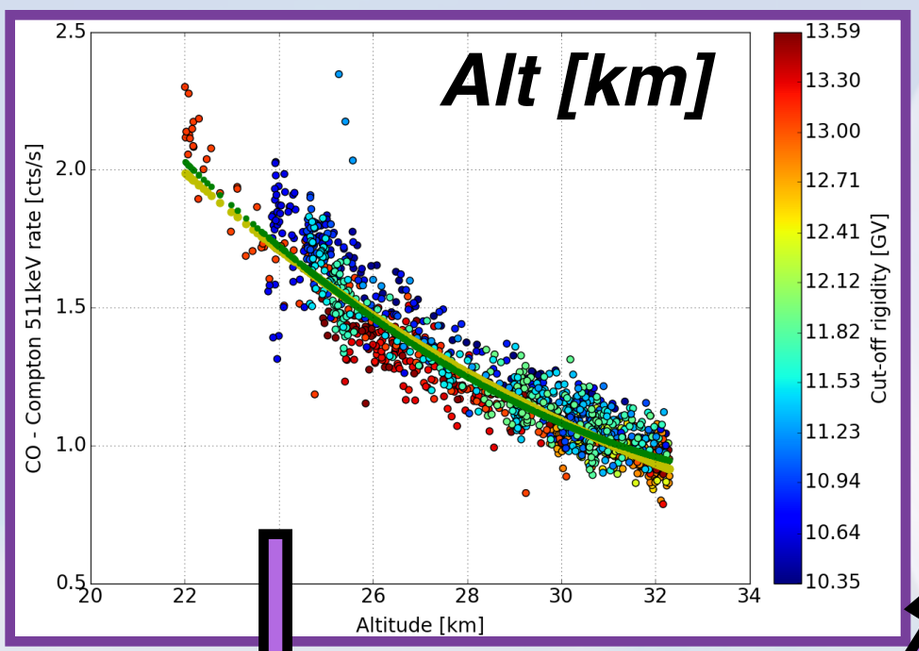
2. Galactic Center

Instrument orientation

Effect evts. rate?



Background: Simulations / ASCI



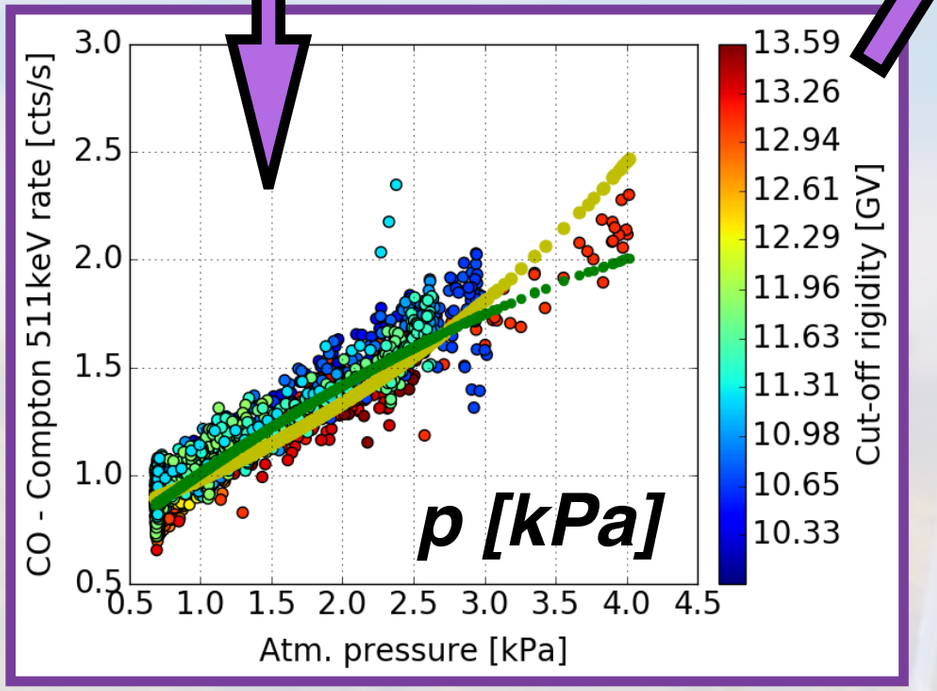
Expressing altitude as atmospheric pressure

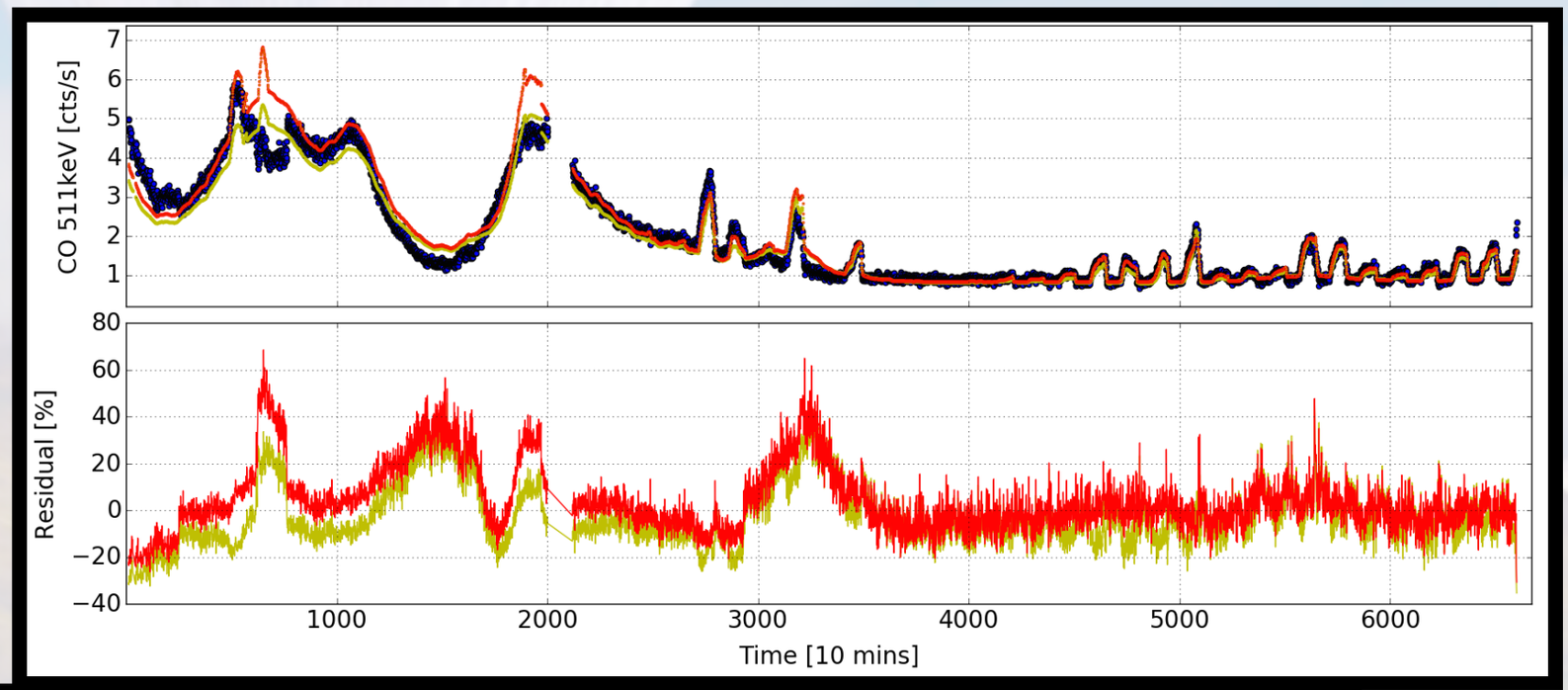
$$\mathbf{T}[K] = -131.21 + 0.00299 \cdot \mathbf{Alt}[km] \cdot 1000.$$

$$\mathbf{p}[kPa] = 2.488 \cdot [\ (\mathbf{T}+273.1)/216.6\ ]^{(-11.388)}$$

$$R_{511}(t) = 0.73 \cdot e^{+(0.3 \cdot \mathbf{p})}$$

$$R_{511}(t) = 0.53 + 0.52 \cdot \mathbf{p} - 0.04 \cdot \mathbf{p}^2$$



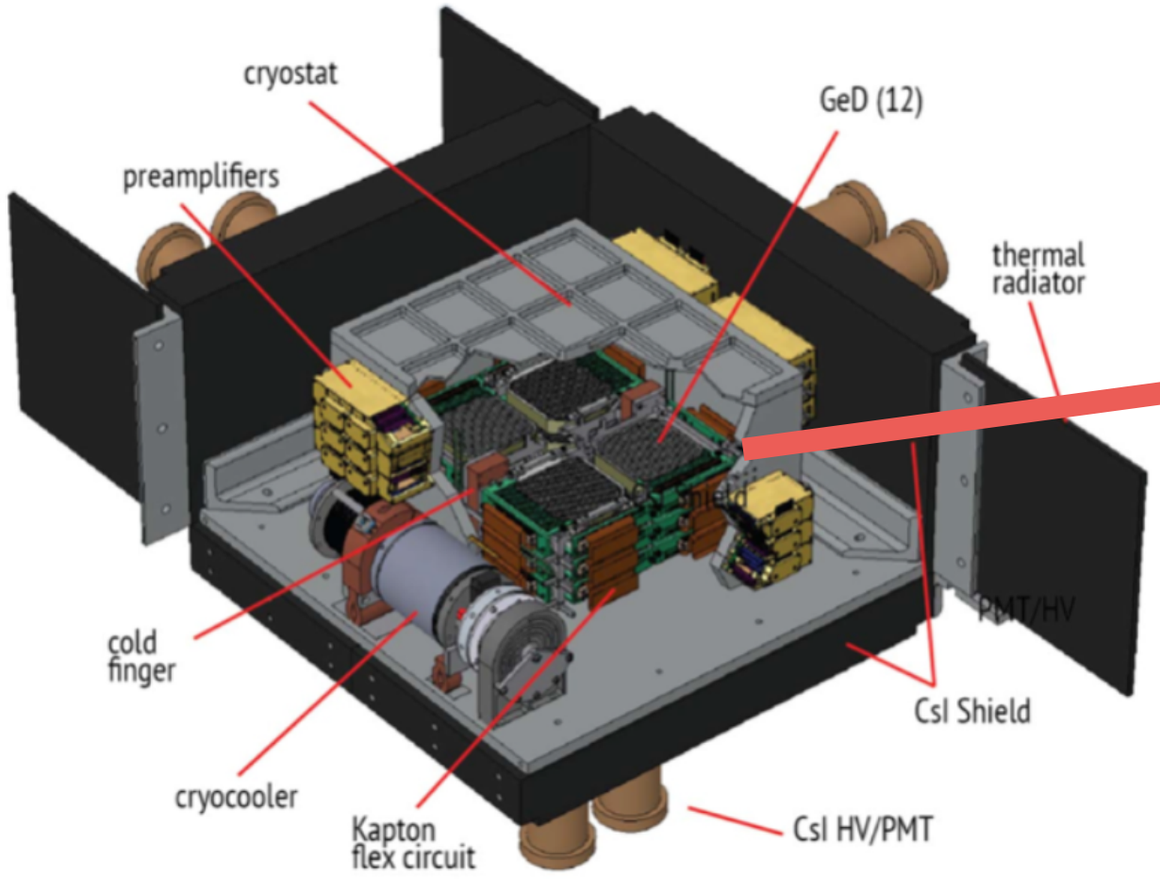


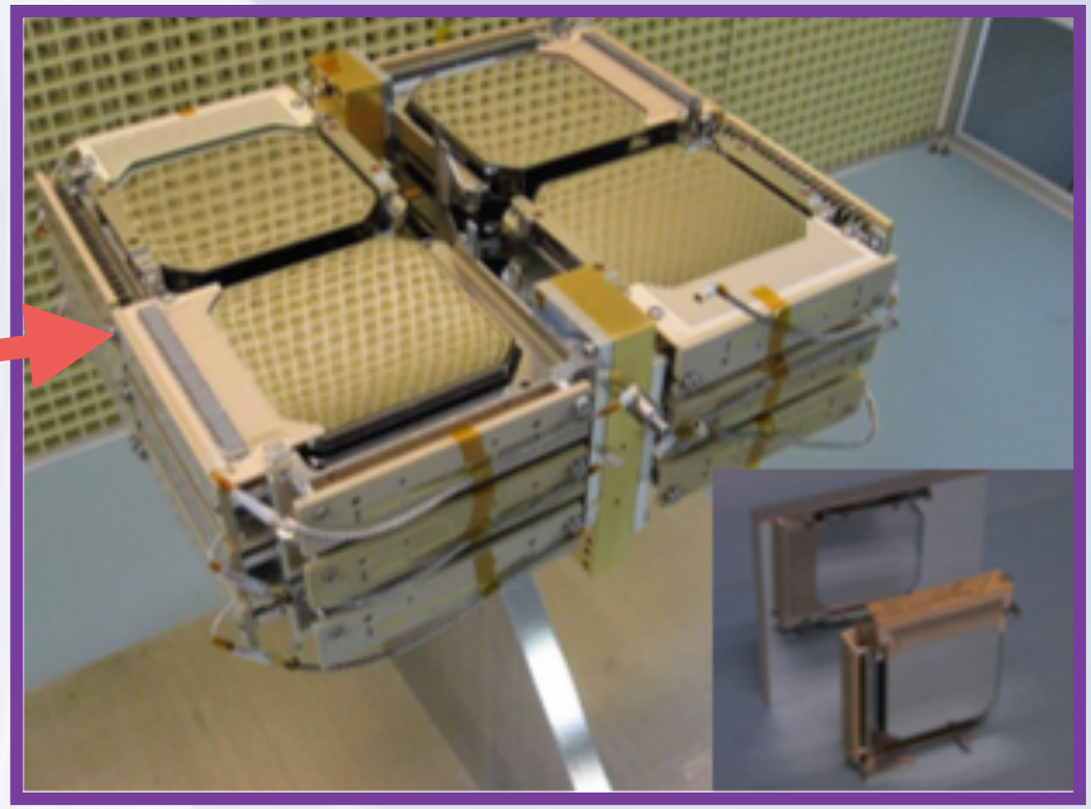
$$R_{511}(t) = (6.72 - 0.84 \cdot \mathbf{Rig} + 0.03 \cdot \mathbf{Rig}^2) \times (0.68 + 0.11 \cdot \mathbf{p} + 0.06 \cdot \mathbf{p}^2)$$

<Fit.Res.> ≈ 9-10%

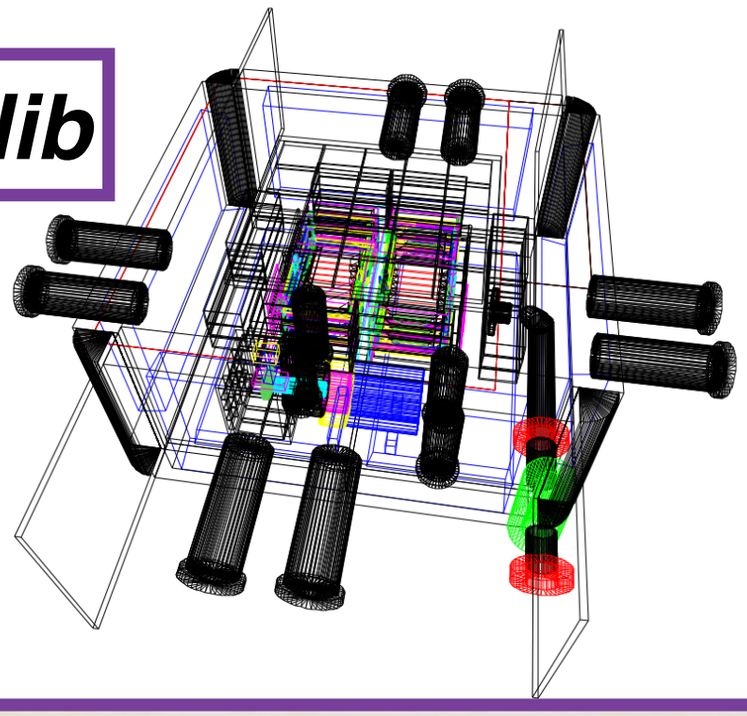
in orbit? pressure ; rigidity → 0.

ASCI: COSI as a building block



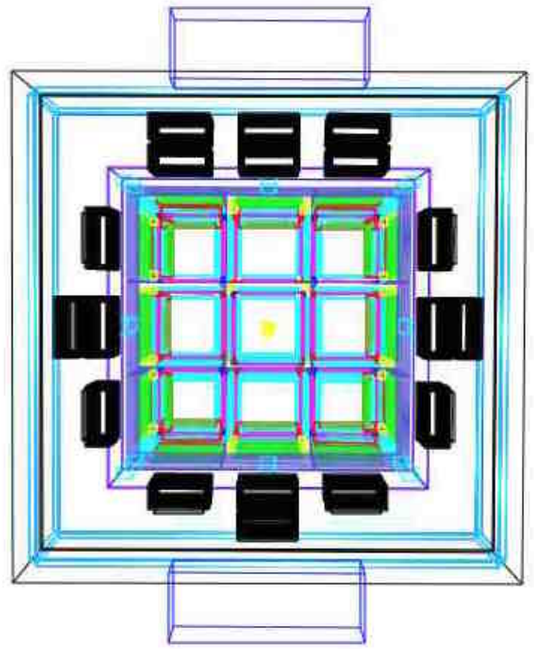


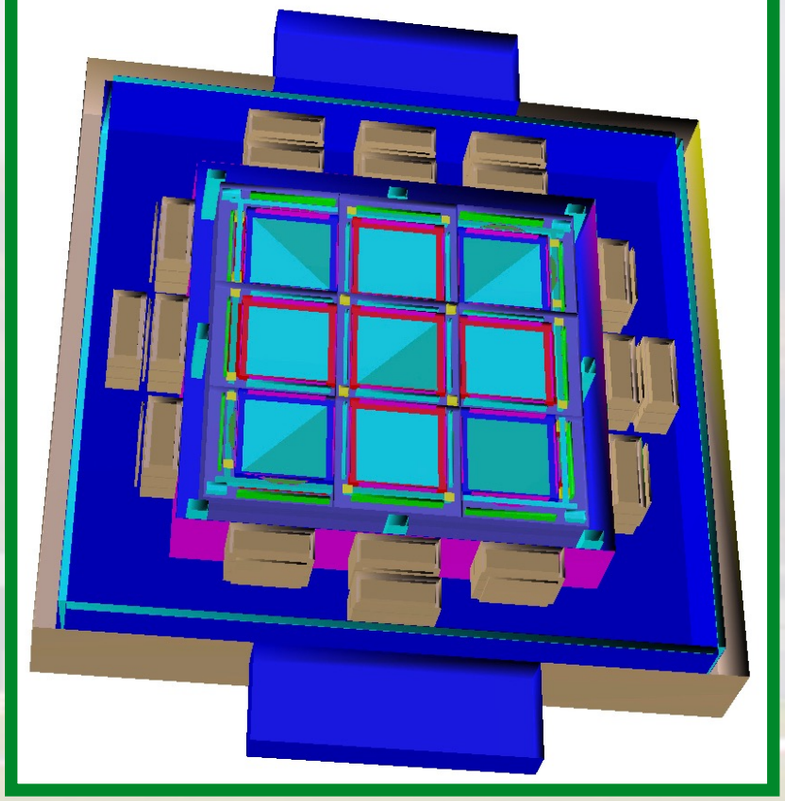
MEGAlib

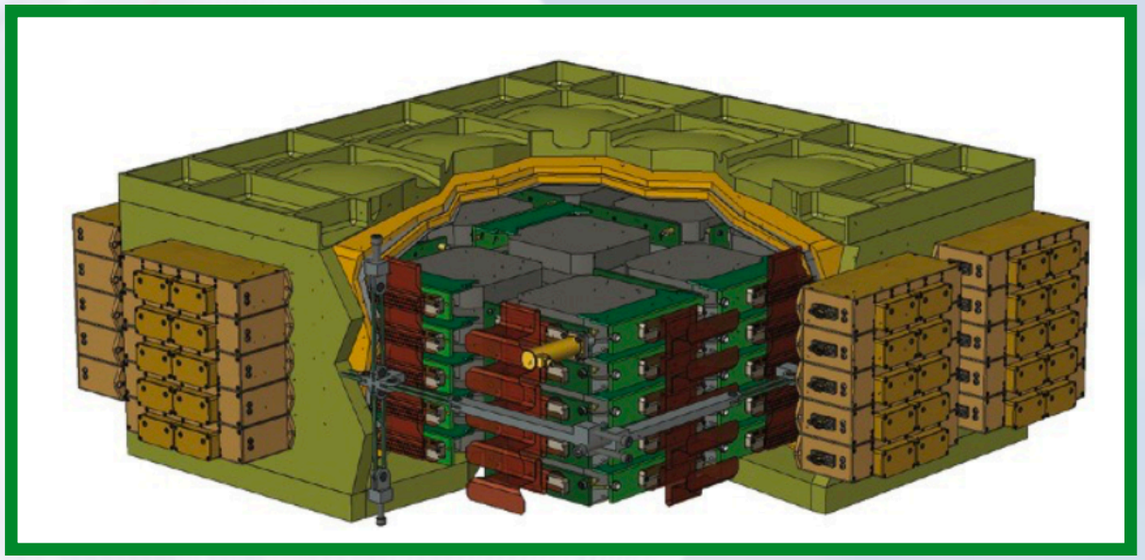


- 37 Ge strips (GeD/Wafer)
- Ge Wafer /w PC boards
- 4 x 3 stacks /w cold fingers
- Cryostat + PreAmps + cryocooler
- 6* CsI ACS: 4 side + 2 bot in Al housing /w PMTs

ASCI: Detector geometry idea







- **45 GeD**: 5 rows of 9 GeD
- **GeD:** 100 x 100 x 15 mm^3

  ~100 strips: 2 mm pitch, 0.25 mm gaps

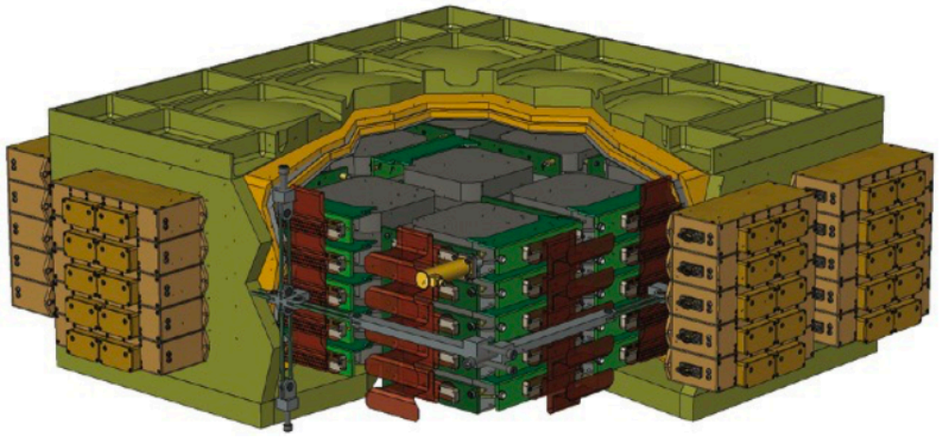
  Guard ring and thermal isolation
- **Cryostat:** at 85 K with IR isolation
- **Performance** (~COSI):

  Position: **<2. mm** in X-Y ; **0.2 mm** D.O.I

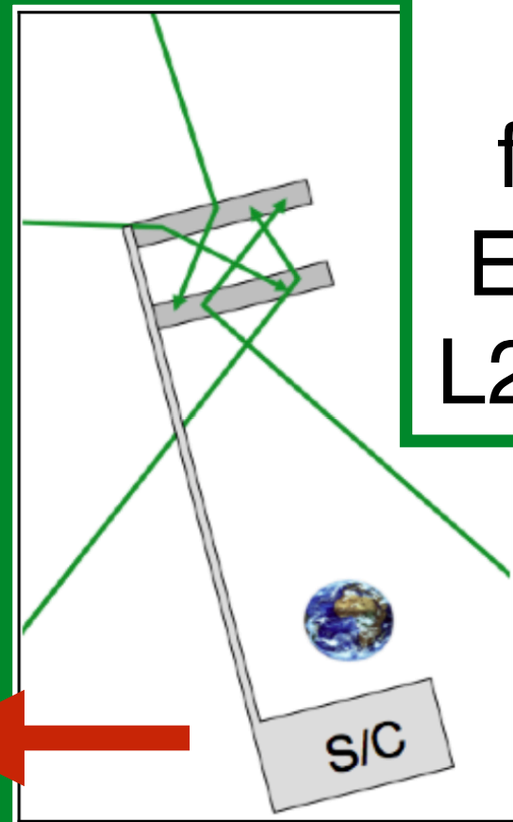
  Energy: **1. - 3. keV** FWHM

ASCI: In space

Compact “ 360° ” GeD head



Far from Earth: L2 orbit



4π FOV + low background

Deployable mast

Energy range		0.1 – 10 MeV
Spectral resolution (10 MeV - 0.1 MeV)		0.2 – 1 % FWHM
Field of view		4 π at all times
Angular resolution	511 keV	2.7° (4.5° at sensitivity limit)
	847 keV	2.1° (3.5° at sensitivity limit)
	1809 keV	1.6° (2.7° at sensitivity limit)
Narrow line sensitivity	511 keV	$2.6 \cdot 10^{-6}$ ph·cm^{-2}·s^{-1}
(any DC source after T_{obs}= 3 year)	847 keV	$1.1 \cdot 10^{-6}$ ph·cm^{-2}·s^{-1}
	1809 keV	$7.2 \cdot 10^{-7}$ ph·cm^{-2}·s^{-1}
Continuum sensitivity	500 keV	$4.2 \cdot 10^{-5}$ ph·cm^{-2}·s^{-1}MeV^{-1}
(any DC source, T_{obs}= 3 year)	5 MeV	$1.5 \cdot 10^{-6}$ ph·cm^{-2}·s^{-1}MeV^{-1}
Polarization sensitivity (MDP)	1 Crab	0.2% (statistical limit only)
3 σ, any DC source, 200-500 keV	0.1 Crab	2.4%
T_{obs}=3 year	0.01 Crab	23.6%
GRB sensitivity (5 σ)		~ 10^{-6} erg/cm^2
Timing		1 μsec relative, 1 ms absolute
Timing		1 μsec relative, 1 ms absolute

Ongoing and future work

Complete the work regarding background

- Finish secondary contributions

- Finish publication

Connection between COSI and ASCI ?

- Is the background model applicable?

number of detectors, passive material, balloon vs satellite… ?

- Can the main geometry be improved?

detector head / mast design / materials …

ASCI final performance

- Find the performance estimate with the best possible background estimation

Thank you