GCR Anisotropy Effects on Dose Measurements with MTR/DOSTEL

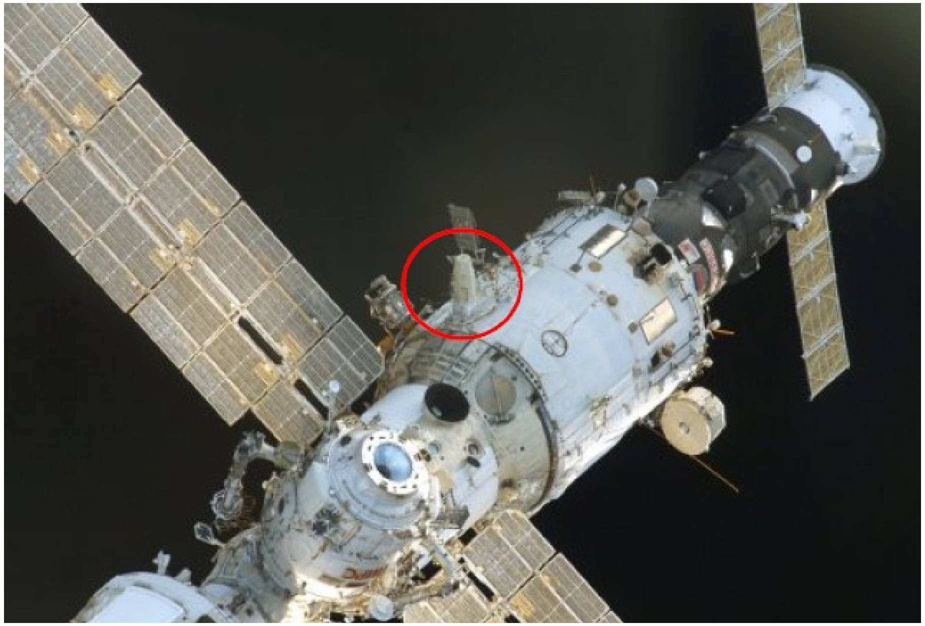
J. Labrenz[1], S. Burmeister[1], T. Berger[2] , G. Reitz[2]
[1] CAU Kiel
[2] DLR Köln

Outline

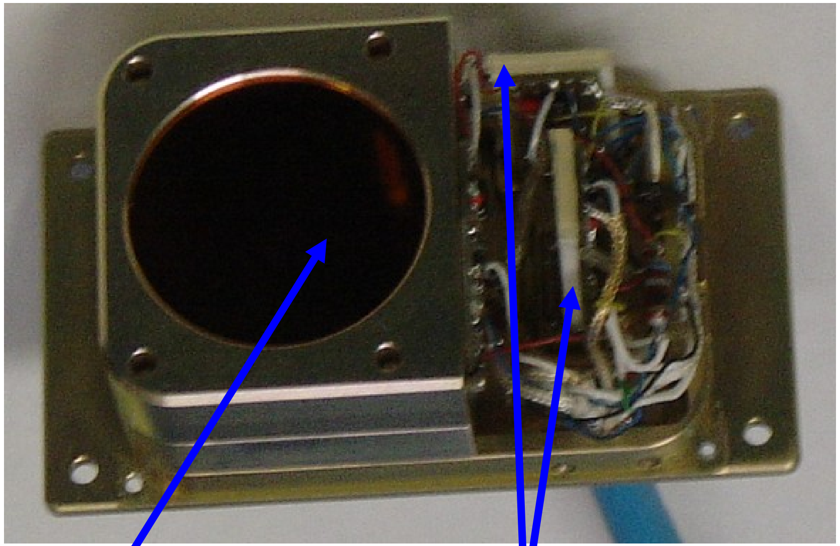
- Introduction
- Motivation
- Comparison of DOSTEL count rates with Geometric factors (Sullivan)
- Geometric Monte Carlo Model
- Differences between single and telescope detector for different radiation fields
- Summary / Conclusion

-**MTR 1**: Feb 2004 – Aug. 2005
outside the ISS

-MTR 2B: Oct. 2007-Nov. 2008
inside the ISS

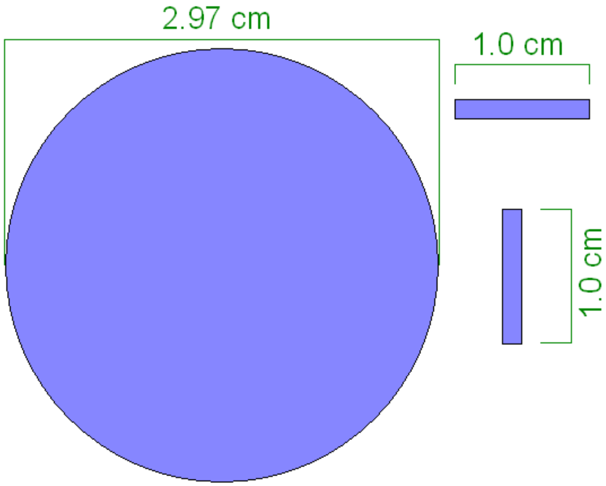


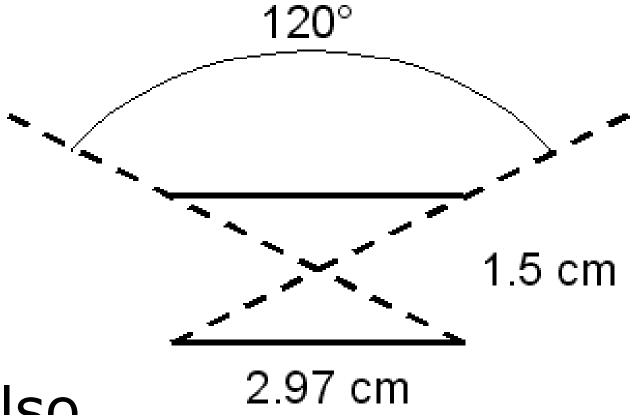
DOSTEL



Canberra PIPS
behind capton foil

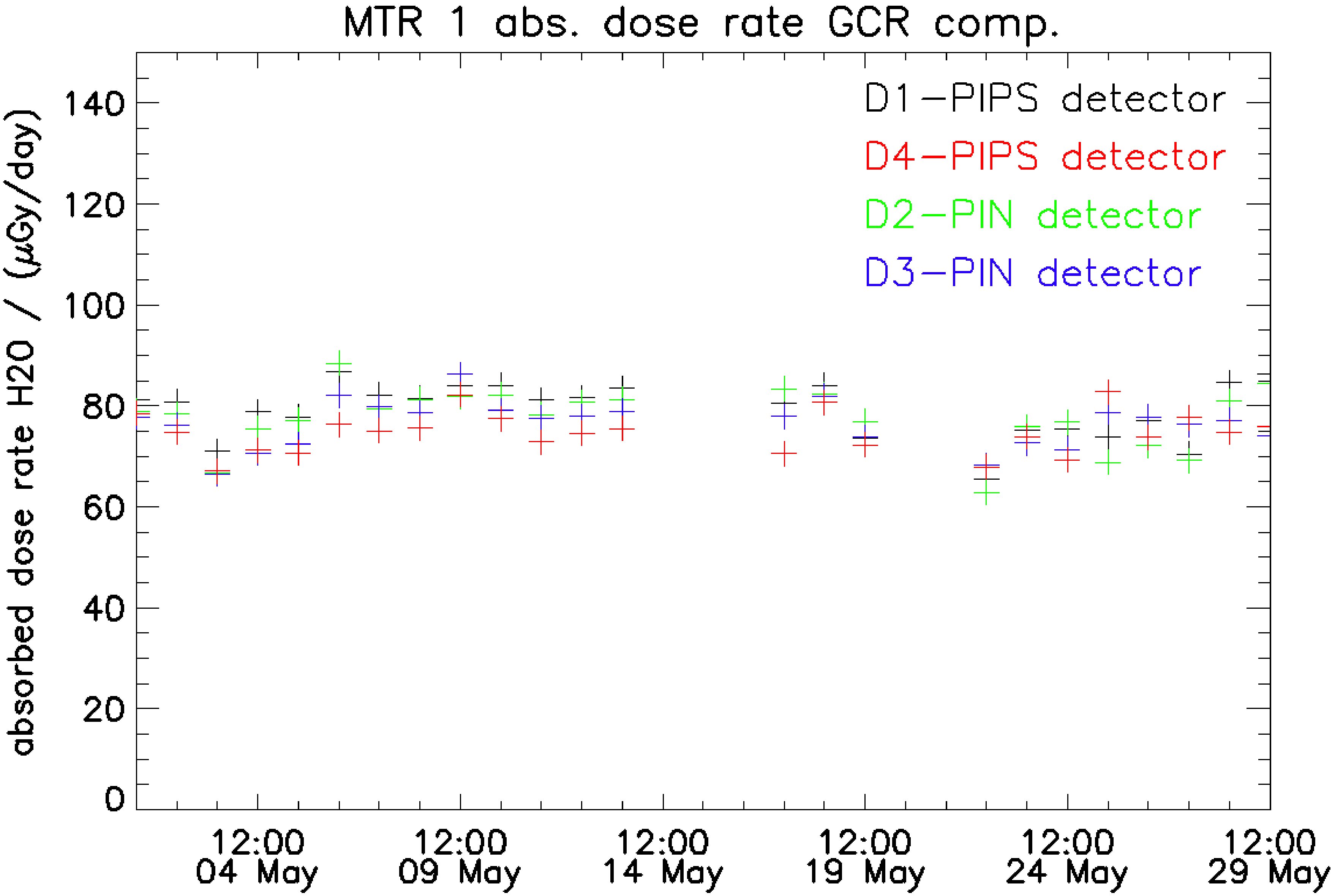
HAMAMATSU
PIN diodes





- Two silicon detectors (Canberra PIPS) in a telescope geometry (D1,D4).
- PIPS operate in telescope mode, but also as single detectors. (6 hour change)
- In addition 2 Hamamatsu PIN diodes (D2,D3) perpendicular to the PIPS.

DOSTEL


MTR 1 abs. dose rate GCR comp.
absorbed dose rate H2O / (µGy/day)
0
20
40
60
80
100
120
140
D1–PIPS detector
D4–PIPS detector
D2–PIN detector
D3–PIN detector
12:00 04 May
12:00 09 May
12:00 14 May
12:00 19 May
12:00 24 May
12:00 29 May

Motivation

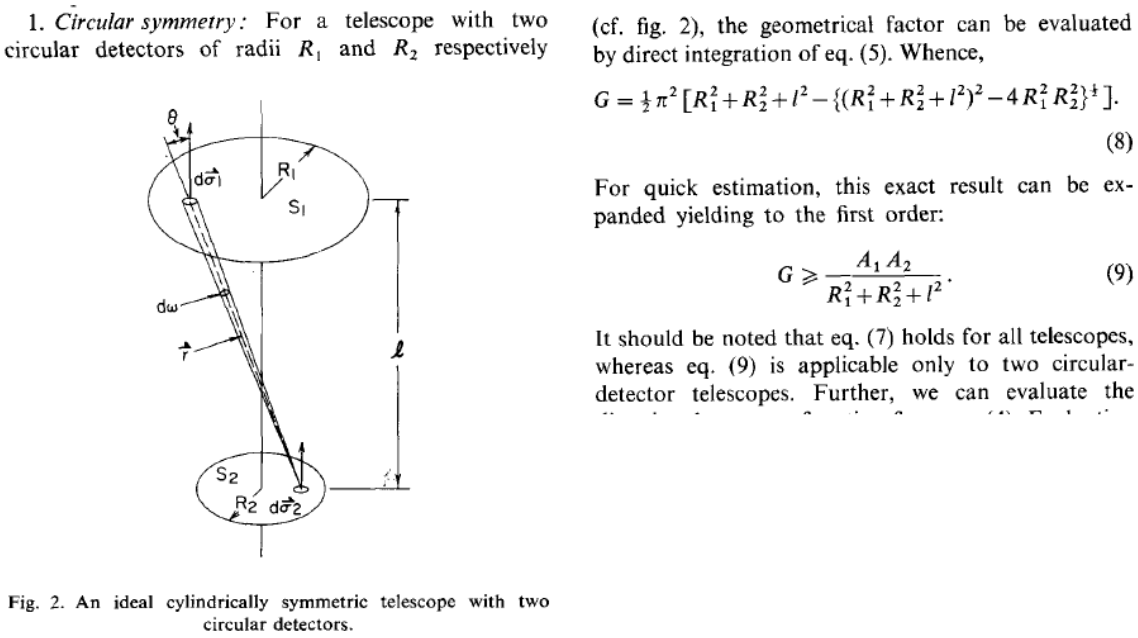
– The DOSTEL changes every 6 hours between single and telescope mode.

Single mode:	PIPS and PINS act as single detectors
Telescope mode:	PIPS act as telescope and PINS as single Detectors

– This allows a comparison of single and telescope detector measurements of the GCR component with DOSTEL.

– For this, measured count and dose rate ratios, obtained from the energy deposition spectra, were compared to theoretical ratios between single and telescope detectors.

Geometric Factor (Sullivan)



1. *Circular symmetry:* For a telescope with two circular detectors of radii R_1 and R_2 respectively (cf. fig. 2), the geometrical factor can be evaluated by direct integration of eq. (5). Whence,

$$G = \tfrac{1}{2}\pi^2[R_1^2+R_2^2+l^2-\{(R_1^2+R_2^2+l^2)^2-4R_1^2R_2^2\}^{\frac{1}{2}}]. \tag{8}$$

For quick estimation, this exact result can be expanded yielding to the first order:

$$G \geqslant \frac{A_1 A_2}{R_1^2+R_2^2+l^2}. \tag{9}$$

It should be noted that eq. (7) holds for all telescopes, whereas eq. (9) is applicable only to two circular-detector telescopes. Further, we can evaluate the

Fig. 2. An ideal cylindrically symmetric telescope with two circular detectors.

J.D. Sullivan, Geometric factor and directional response of single and multi-element particle telescopes, Nuclear Instruments and Methods, Volume 95, Issue 1, 1 August 1971, Pages 5-11.

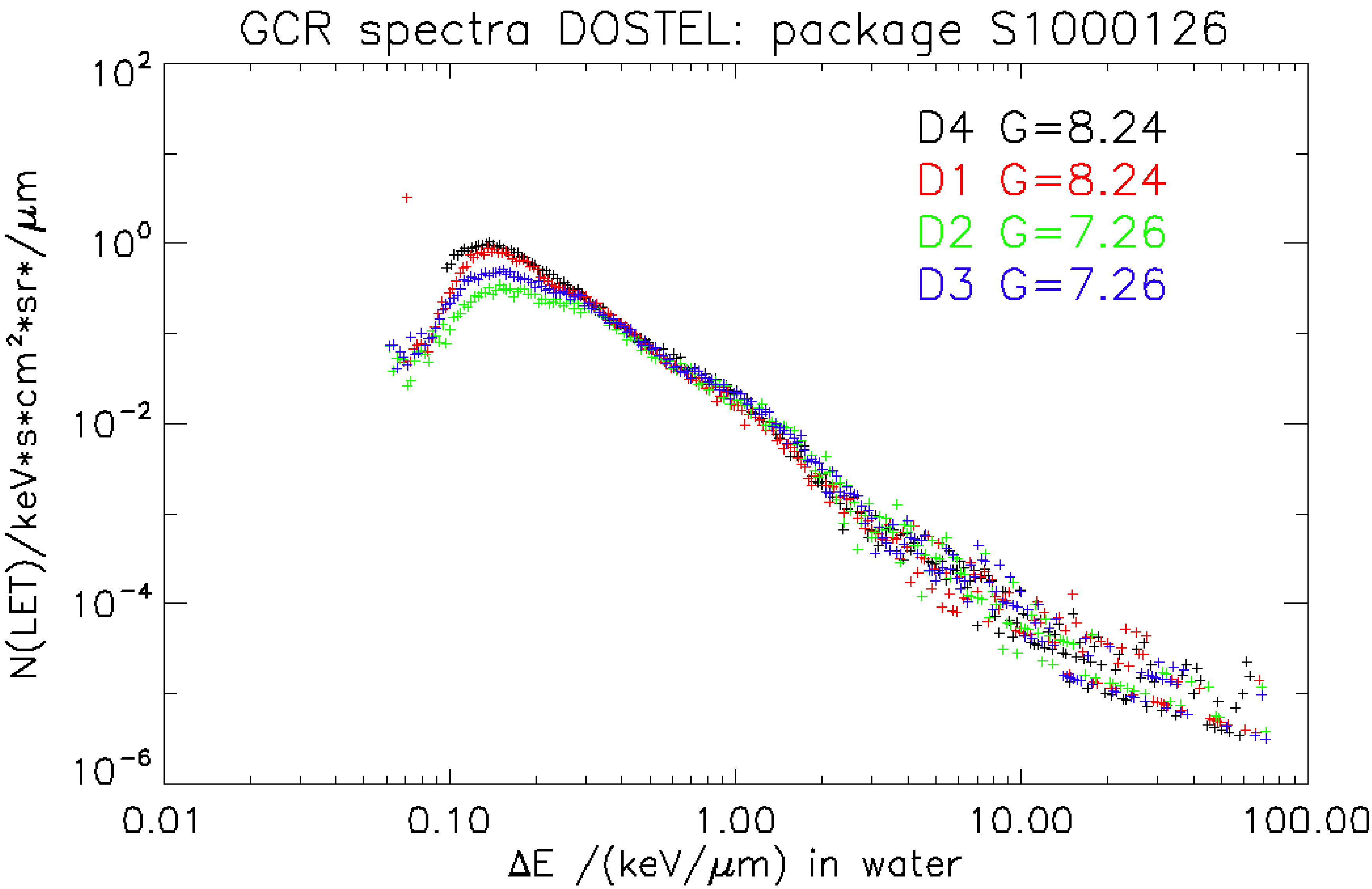
PIPS (D1,D4):

Telescope: $R_1=R_2=1.485$ cm $l=1.50$ cm → $G_{tel}= 8.24$ cm^2 sr

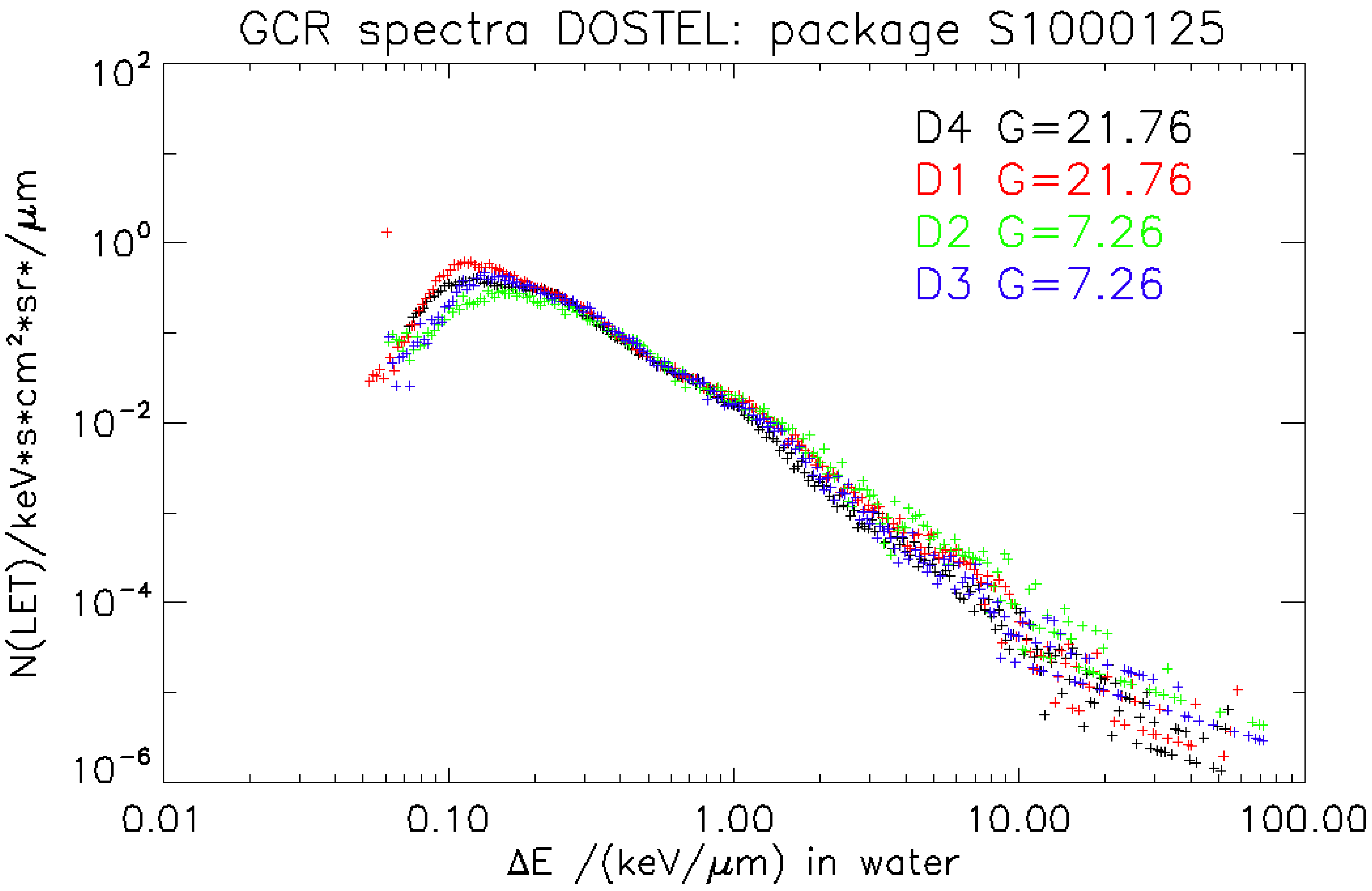
Single: $R_1=R_2=1.485$ cm $l=0.0$ cm → $G_{sin}=21.76$ cm^2 sr

PINS (D2,D3): → $G = 7.26$ cm^2 sr

LET spectra MTR 1 telescope detectors



LET spectra MTR 1 single detectors



DOSTEL GCR Count Rates

Upper PIPS detector:

D1: $$\frac{\text{Count rate single mode spectra}}{\text{Count rate telescope mode spectra}} = 2.13$$

Lower PIPS detector:

D4: $$\frac{\text{Count rate single mode spectra}}{\text{Count rate telescope mode spectra}} = 1.91$$

PIN Diodes:

D2: $$\frac{\text{Count rate single mode spectra}}{\text{Count rate telescope mode spectra}} = 0.966$$

D3: $$\frac{\text{Count rate single mode spectra}}{\text{Count rate telescope mode spectra}} = 1.00$$

All spectra from April to June2004 where used, to avoid geo-magnetic differences for the different spectra types.

Monte-Carlo-Model

- Theoretical count rate ratio for an isotropic field between a single and a telescope detector (Sullivan):

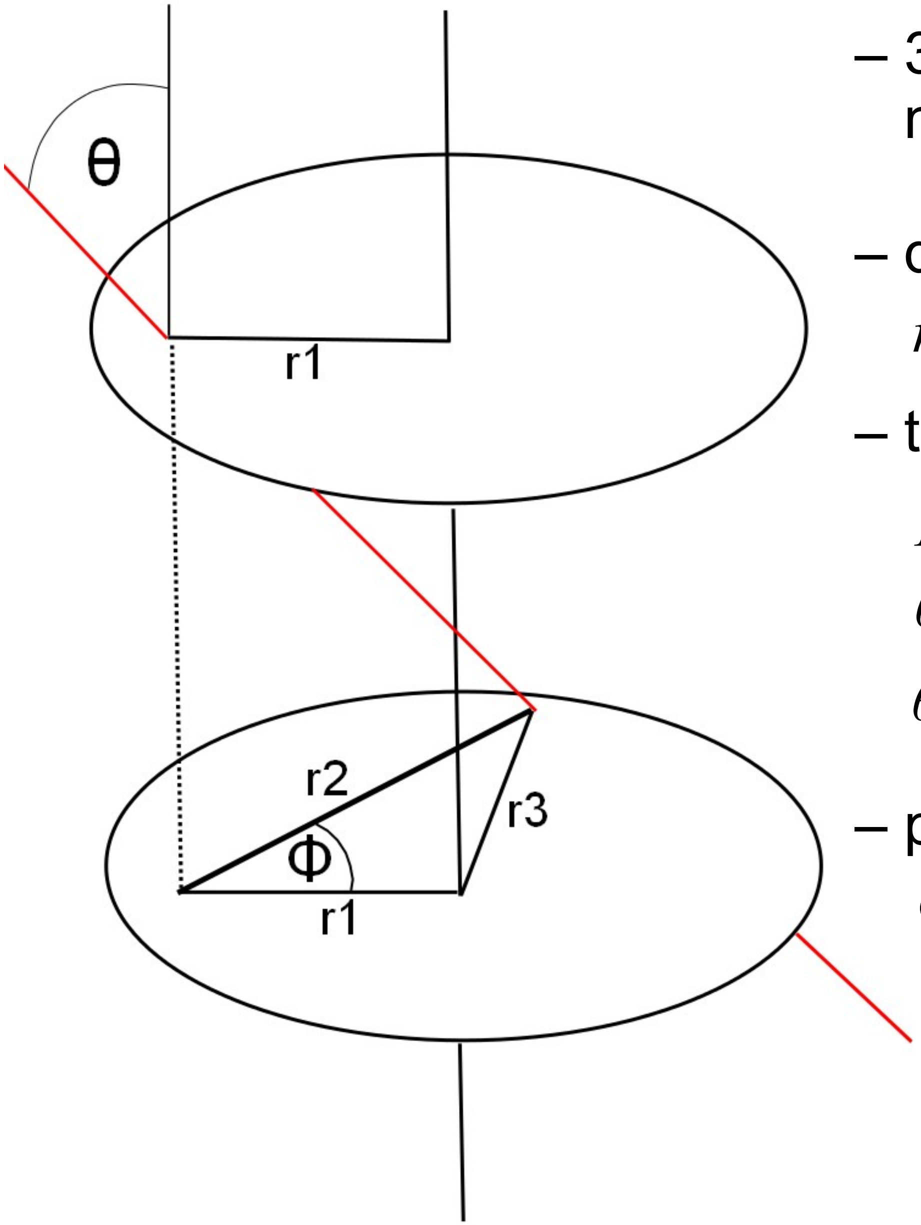
$$\text{Ratio} = 21.76\ \text{cm}^2\ \text{sr} / 8.24\ \text{cm}^2\ \text{sr} = \underline{2.64}$$

- Measured count rate ratio between single and telescope mode for the lower PIPS detector (D4) :

$$\text{Ratio} = \underline{1.91}$$

- To explain these differences, a simple Monte-Carlo-Model was used to obtain the theoretical count rate ratios between a single and a telescope detector for different anisotropic GCR distributions.

Monte-Carlo-Model



- 3 independent series of random numbers between 0 and 1 (a,b,c)
- distance to center of first detector

  $r1 = \sqrt{a} * R,\ R = Radius\ of\ detector$
- theta angle:

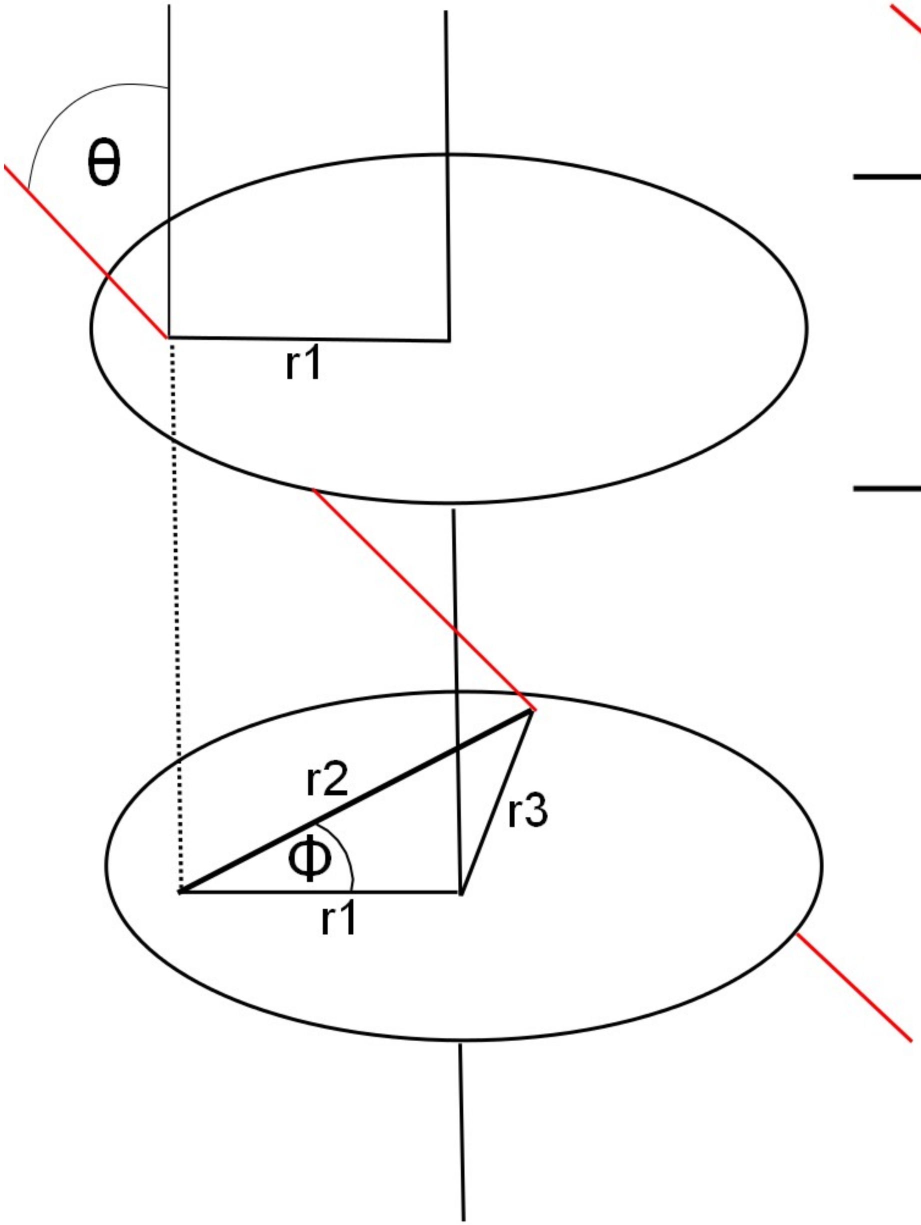
  $$P = \int \cos(\theta) * \sin(\theta) d\theta = 0.5 \cos^2(\theta)$$

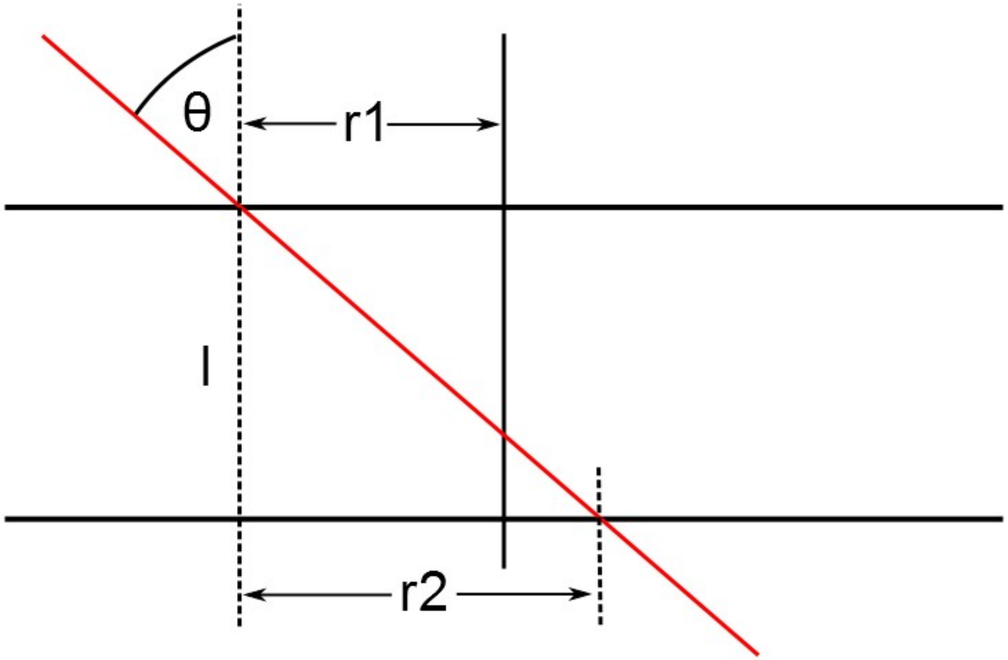
  $$\theta \approx arcos(\sqrt{P})$$

  $$\theta = arcos(\sqrt{b}), (isotropic)$$
- phi angle:

  $$\Phi = 2 * \Pi * c$$

Monte-Carlo-Model

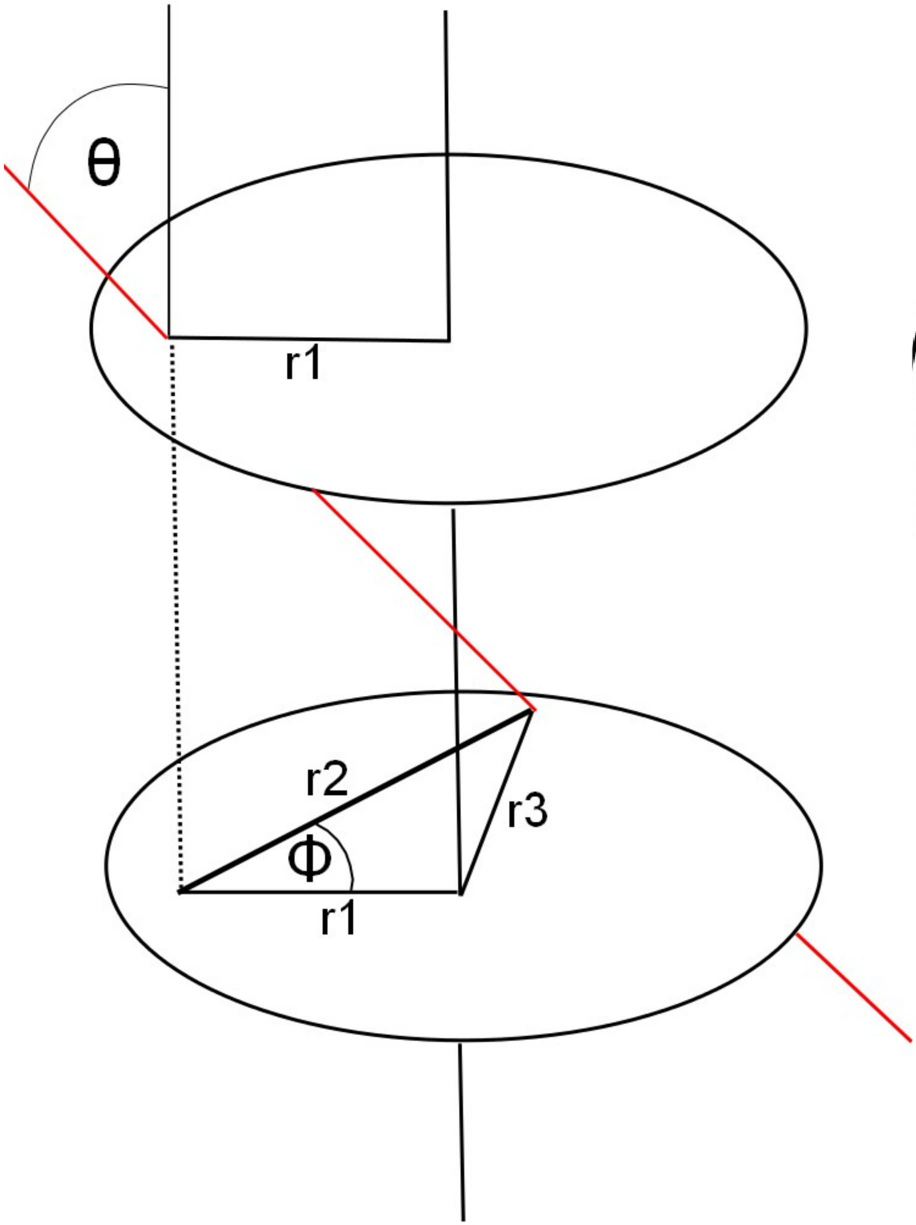


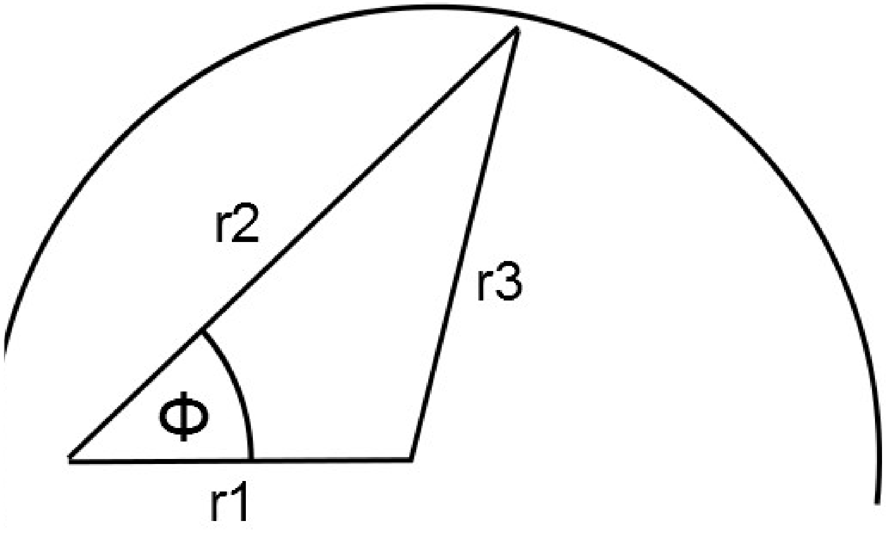


- r2: projected distance between points of impact on first and second detector

$$r2 = l * \tan(\theta)$$

Monte-Carlo-Model





– r3: distance between point on- and center of- second detecor

– with law of cosine:

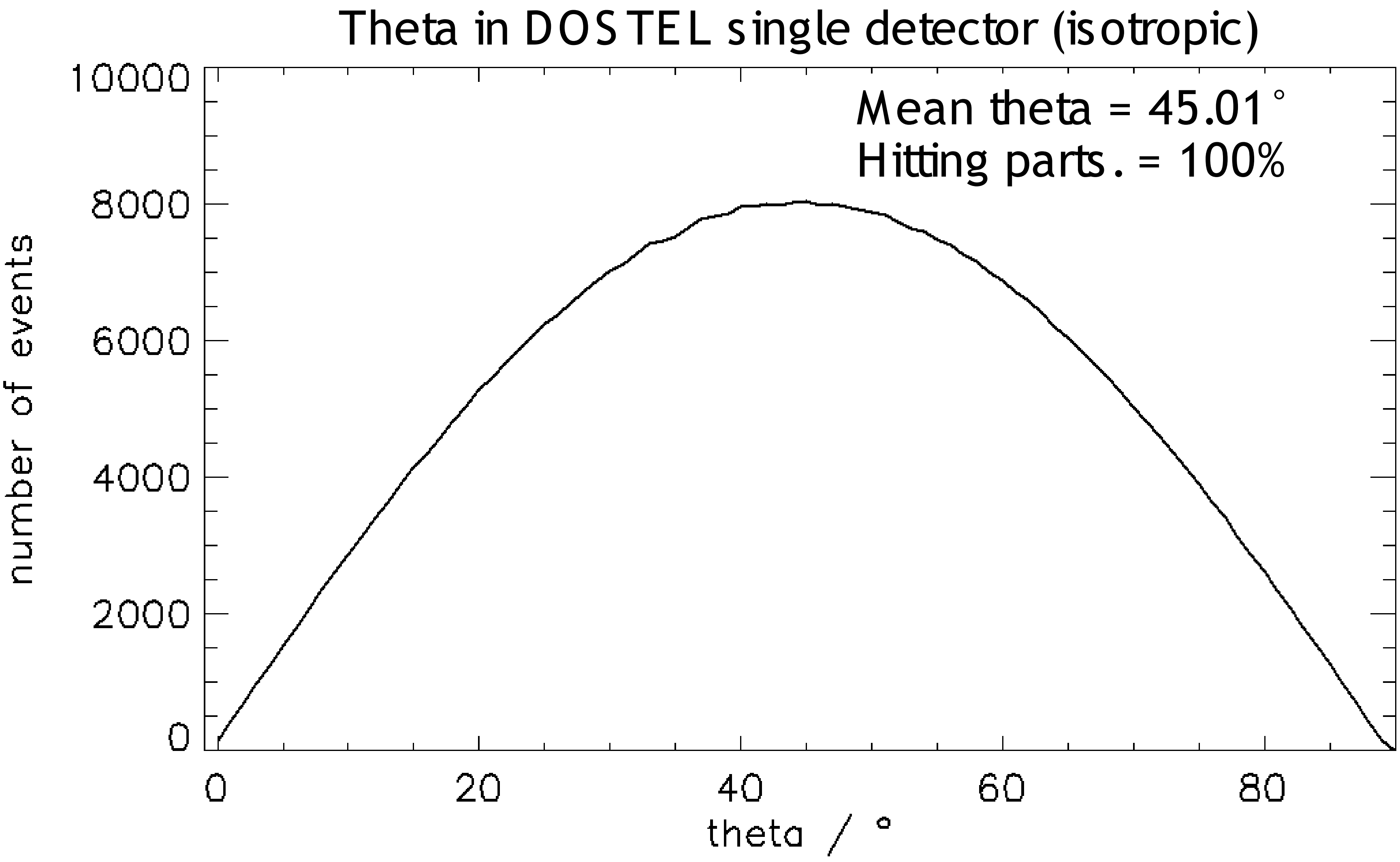
$$r3 = \sqrt{r1^2 + r2^2 - (2 * r1 * r2 * \cos(\Phi))}$$

Monte-Carlo-Model

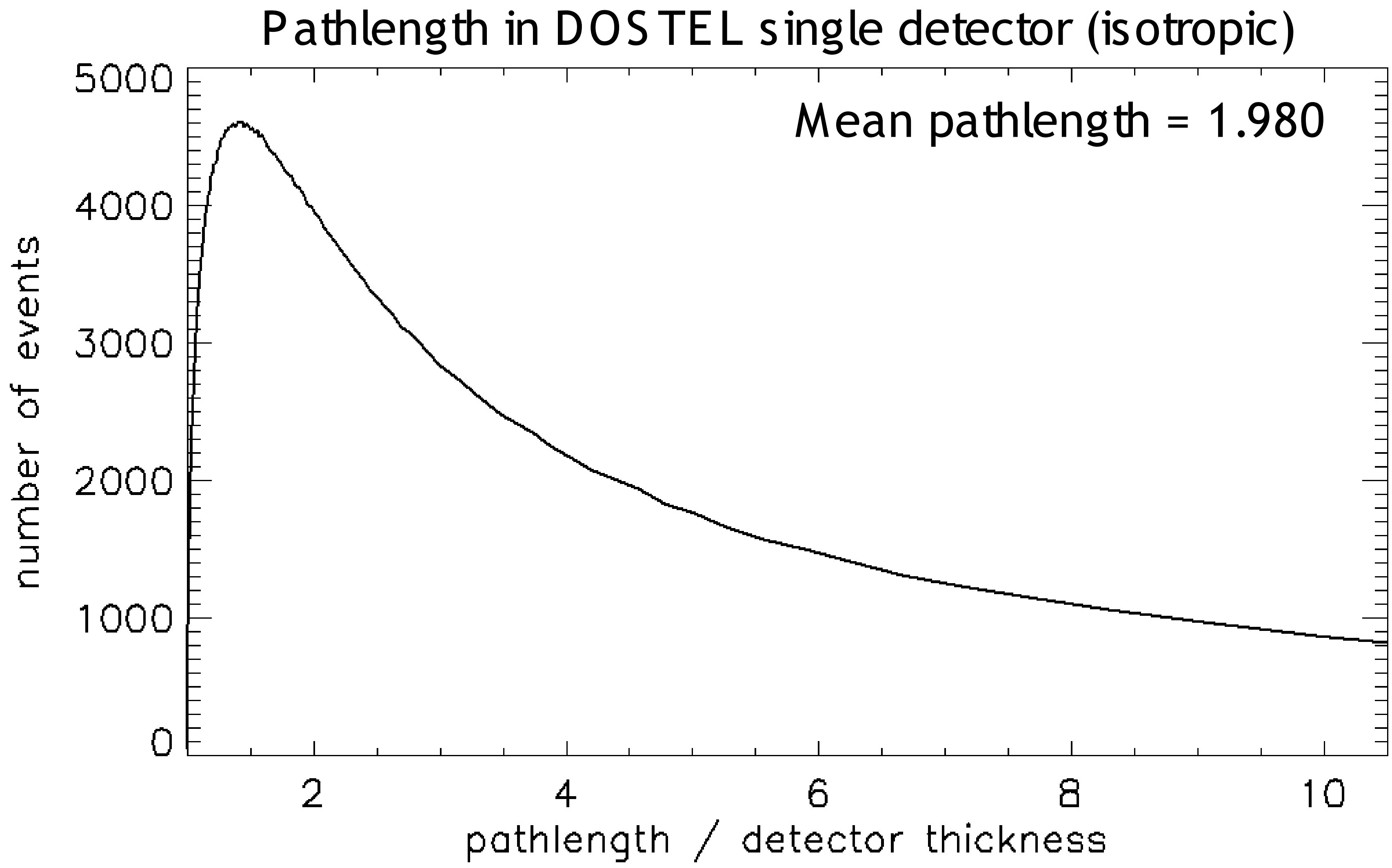
- If r3 is less then R (1.485 cm), then the particle hits both detectors and only these particles are counted.
- For telescope detector a distance of l=1.50 cm between the detectors was used.
- For single detector mode the distance was set to 0.0 cm
- The number of particles hitting the detector are counted, to get the ratio of the geometric factors between single and telescope detector.
- The mean theta angles and the corresponding mean path length in the detectors were analyzed.

CAU

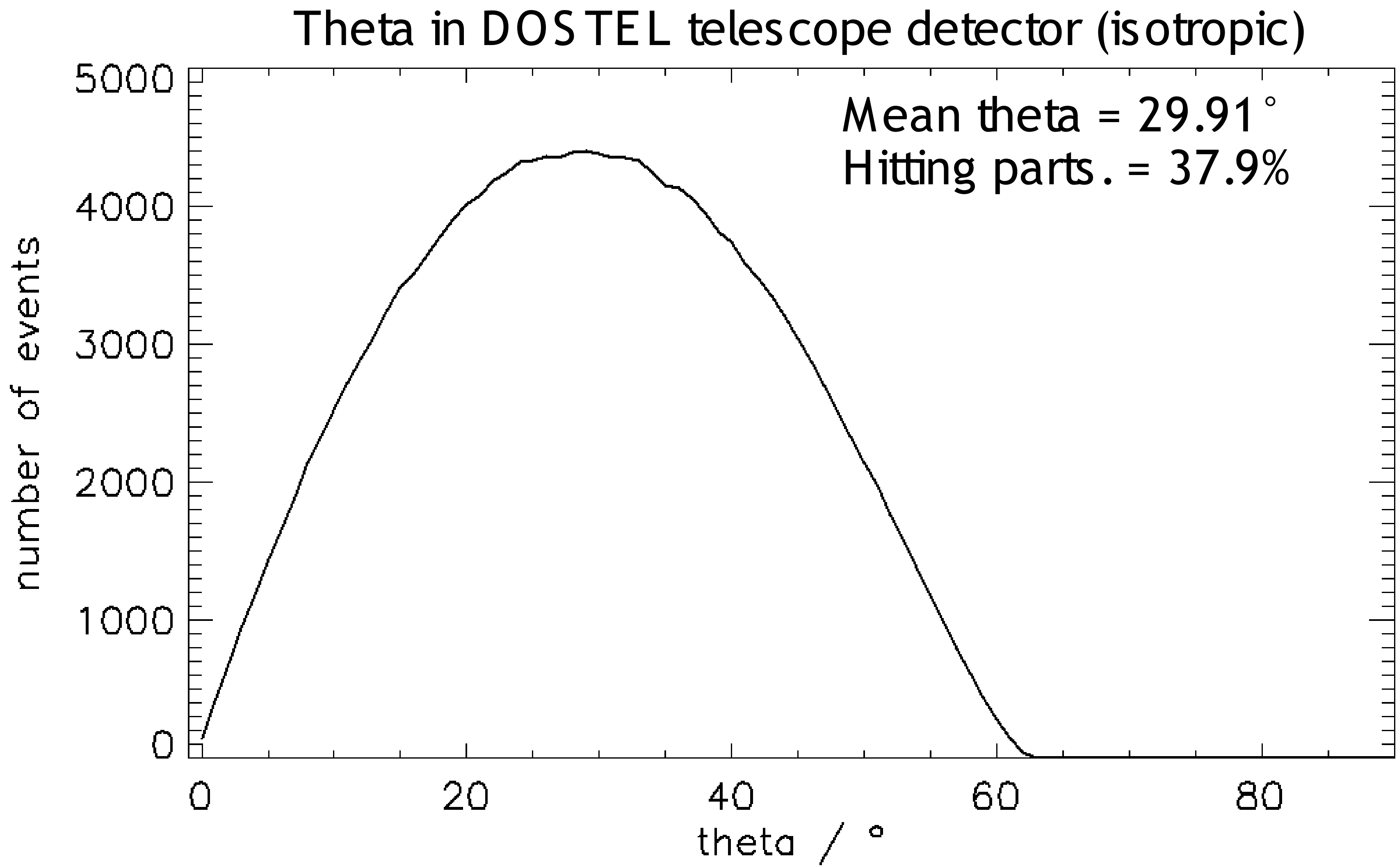
Results isotropic field



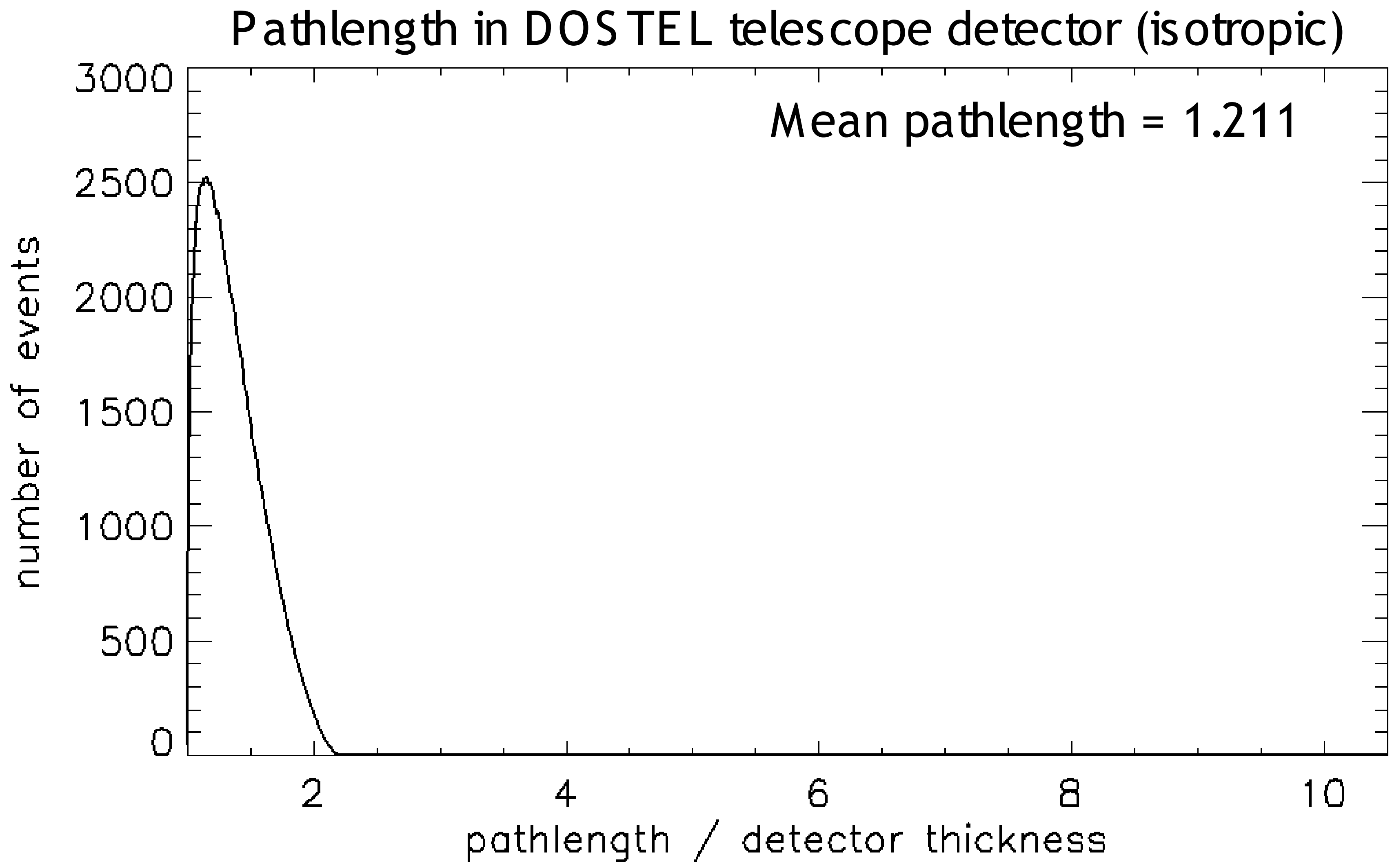
Results isotropic field



Results isotropic field



Results isotropic field



Results isotropic field

– Geometric factors calculated with Sullivan formula:

Telescope mode: $G_{Tel} = 8.24\ \text{cm}^2\ \text{sr}$
Single mode: $G_{Sin} = 21.76\ \text{cm}^2\ \text{sr}$
$G_{Sin} / G_{Tel} = \underline{2.64}$

– Geometric factor calculated with model for isotropic field:

$\text{hits}_{Sin} / \text{hits}_{Tel} = 100.0\% / 37.88\% = \underline{2.64}$

– Count rate ratio DOSTEL:

$N_{sin} / N_{tel} = \underline{1.91}$

Different theta distribution

Isotropic (cos^1):

$$P=\int\cos(\theta)*\sin(\theta)d\theta=0.5\cos^2(\theta)$$

$$\theta\approx arcos(\sqrt{P})$$

$$\theta=arcos(\sqrt{b})$$

Cos^2:

$$P=\int\cos^2(\theta)*\sin(\theta)d\theta=\frac{1}{3}\cos^3(\theta)$$

$$\theta\approx arcos(\sqrt[3]{P})$$

$$\theta=arcos(\sqrt[3]{b})$$

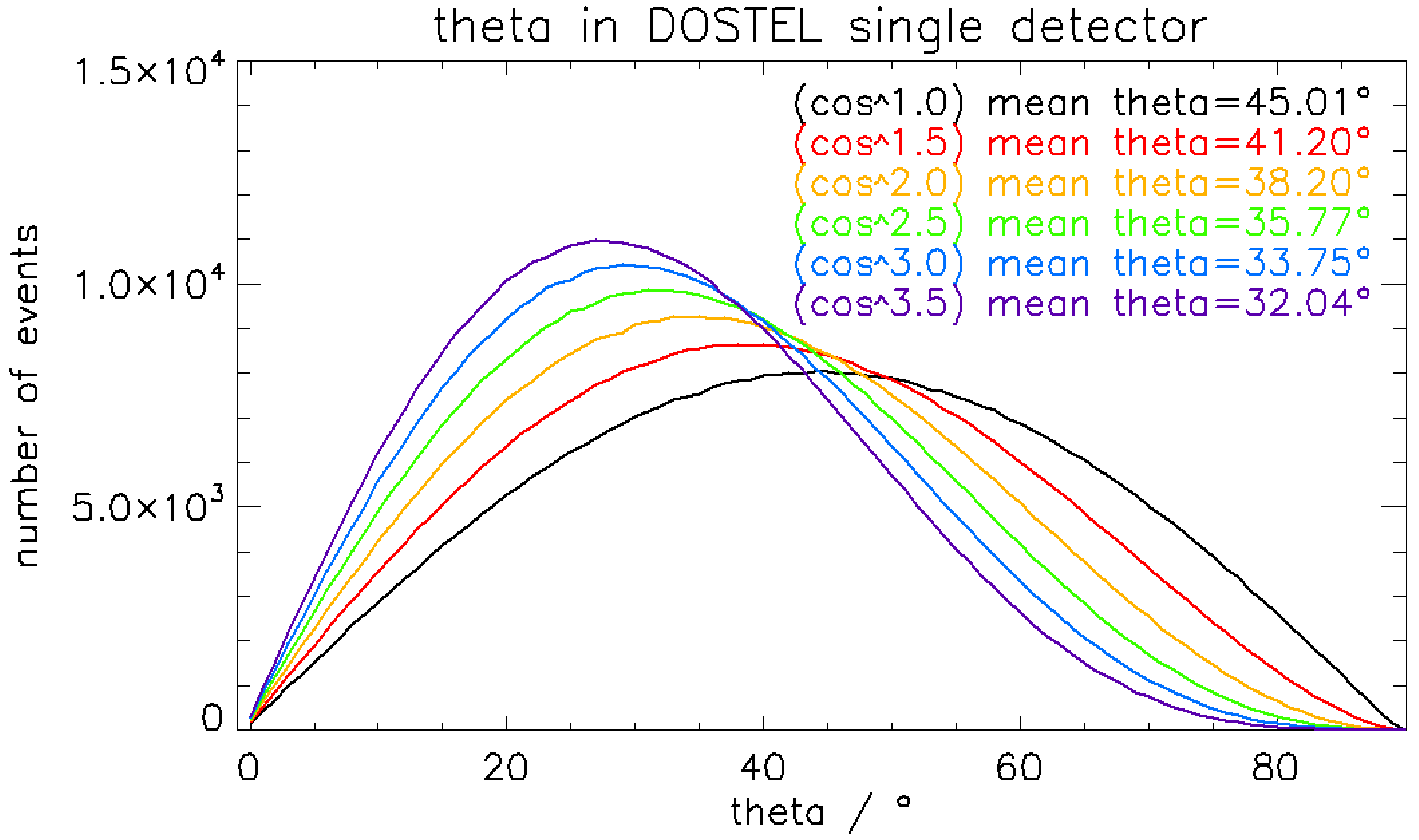
Cos^n:

$$P=\int\cos^n(\theta)*\sin(\theta)d\theta=\frac{1}{n+1}\cos^{n+1}(\theta)$$

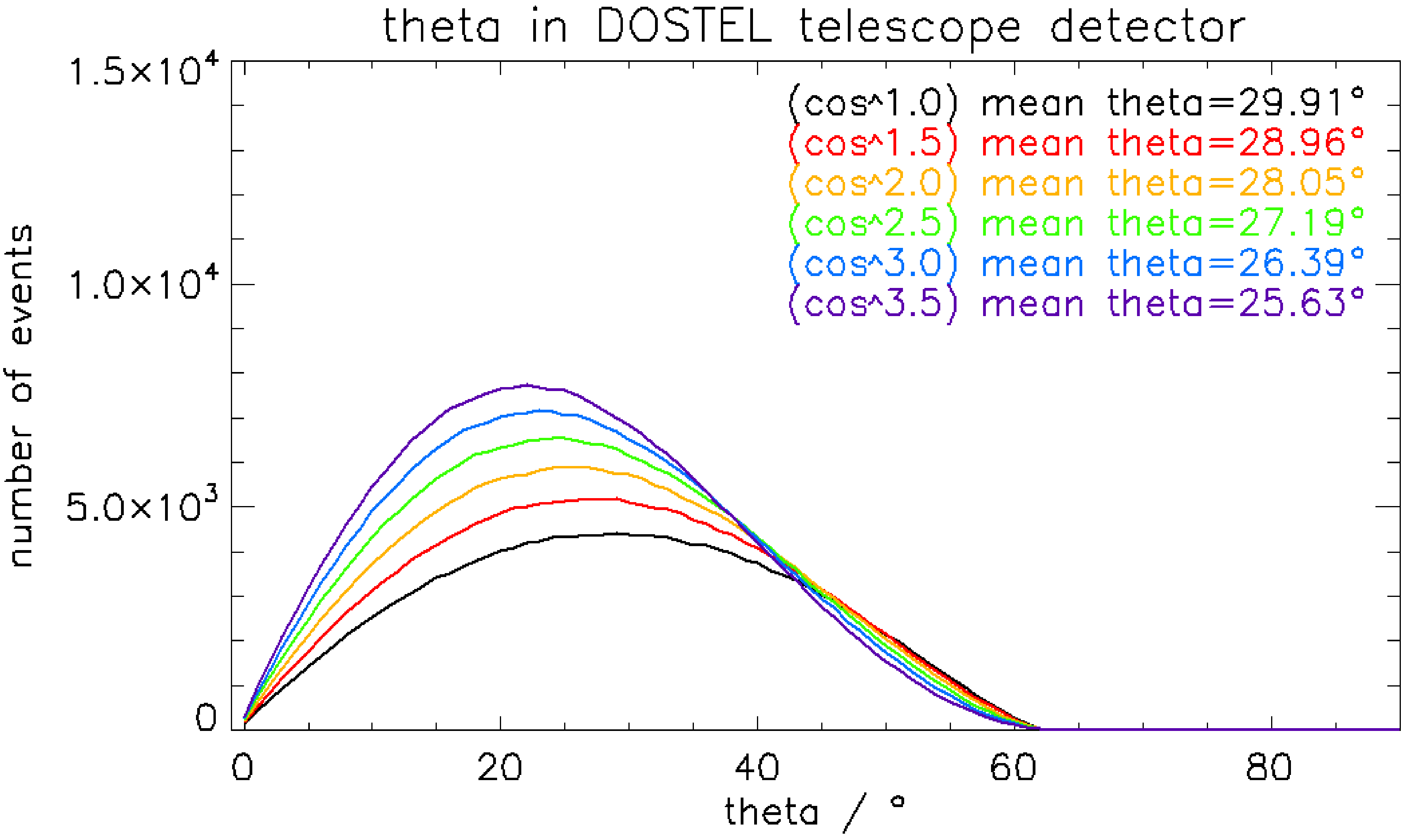
$$\theta\approx arcos(\sqrt[n+1]{P})$$

$$\theta=arcos(\sqrt[n+1]{b})$$

Model: theta single detector



Model: theta telescope detector



Count rate ratio for different theta distribution

Simulated ratio of particle numbers in single and telescope detectors:

Cos^1: 100% /37.9% =2.64

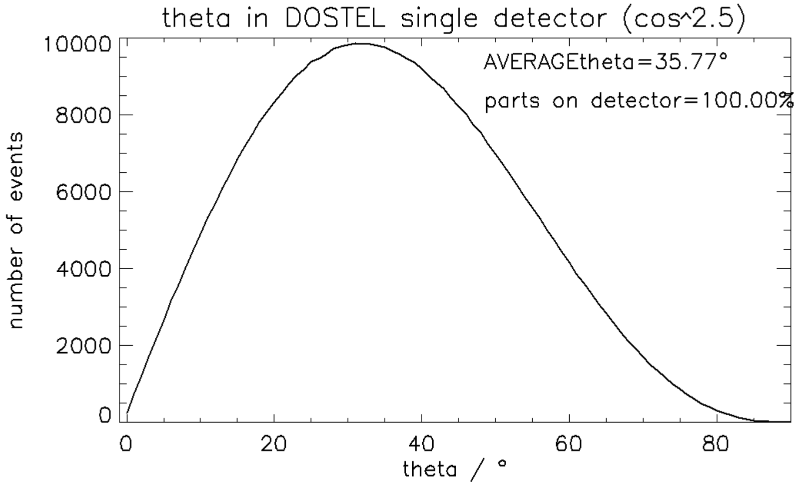
Cos^1.5: 100% /43.4% =2.30

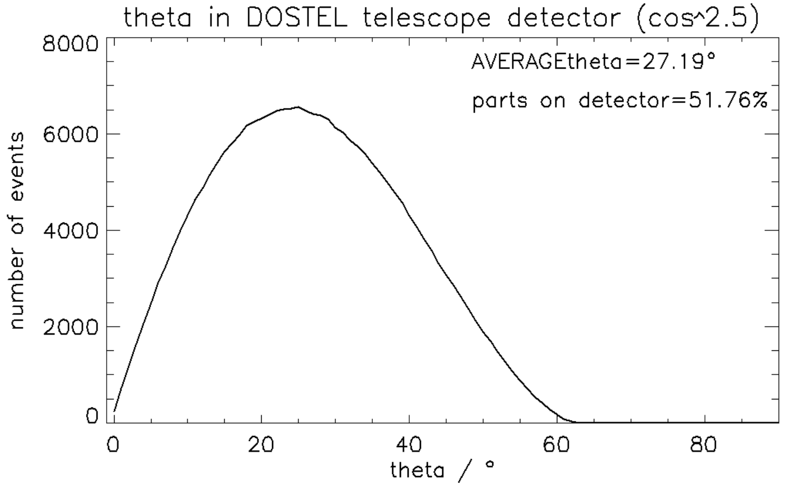
Cos^2: 100% /48.0% =2.08

Cos^2.5: 100% /51.8% =<u>1.93</u>

Cos^3: 100% /55.0% =1.82

Cos^3.5: 100% /57.7% =1.73





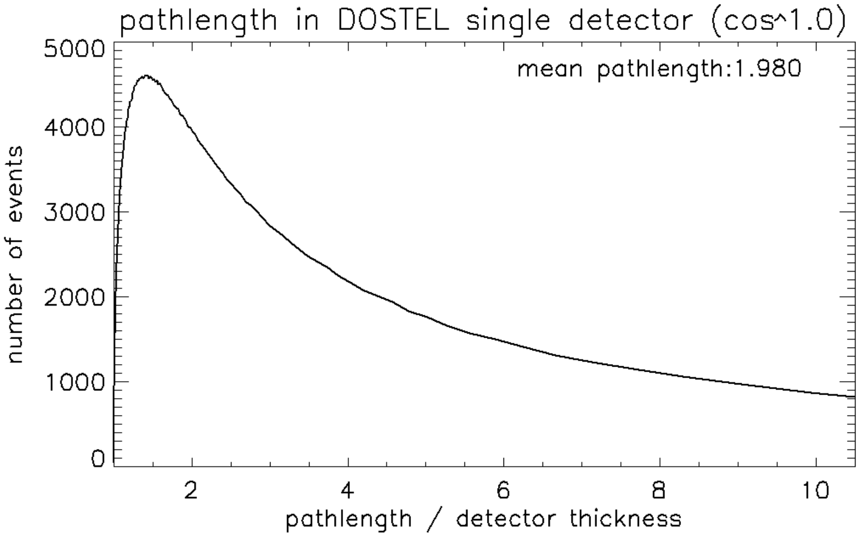
- Cos^2.5 is closest to measured ratio (1.91)

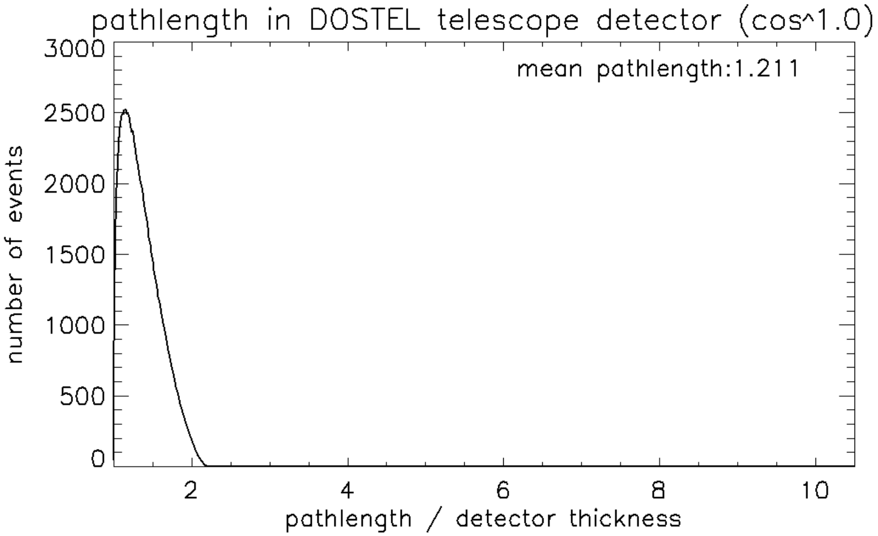
Theoretical abs. dose rate ratio

- The second measured value to compare with the model is the absorbed dose.

- The absorbed dose is proportional to the number of particles multiplied with the mean particle pathlength.

- The count rate ratio multiplied with the pathlength ratio equals the absorbed dose rate ratio.





DOSTEL: Absorbed Dose

Upper PIPS detector:

$$D1: \frac{\text{Absorbed dose in single mode spectra}}{\text{Absorbed dose in telescope mode spectra}} = \underline{2.32}$$

Lower PIPS detector:

$$D4: \frac{\text{Absorbed dose in single mode spectra}}{\text{Absorbed dose in telescope mode spectra}} = \underline{2.35}$$

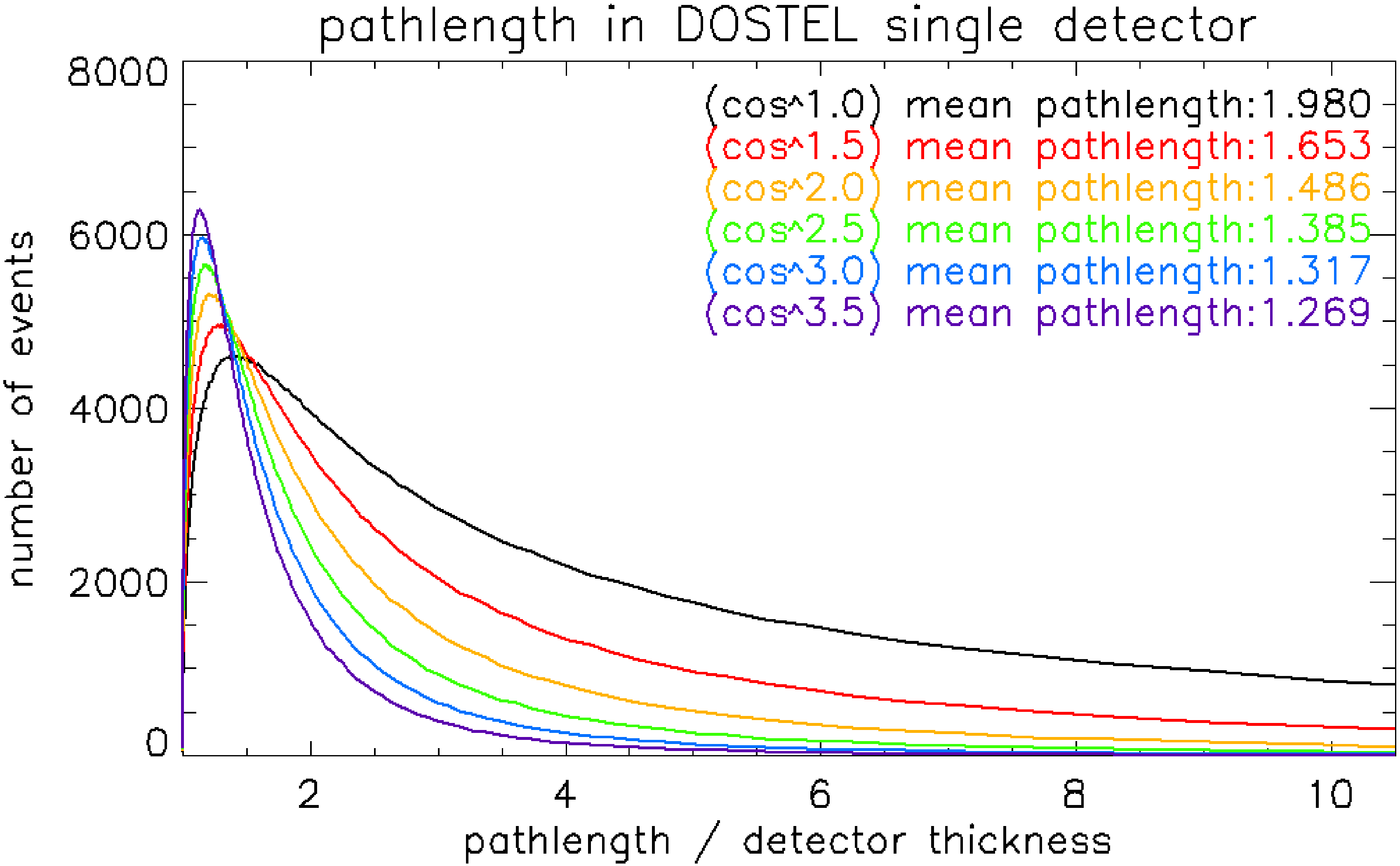
PIN Diodes:

$$D2: \frac{\text{Absorbed dose in single mode spectra}}{\text{Absorbed dose in telescope mode spectra}} = 0.97$$

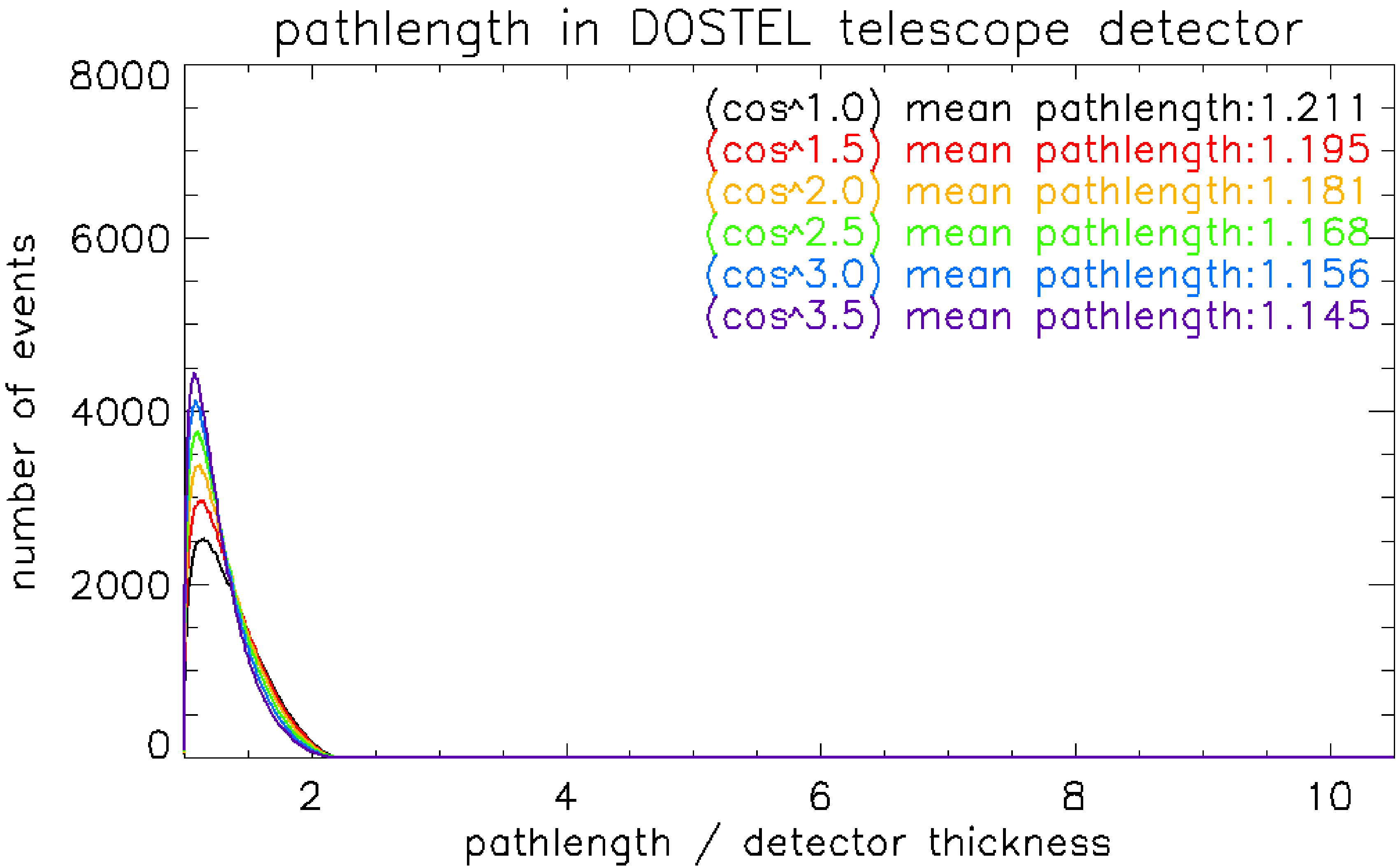
$$D3: \frac{\text{Absorbed dose in single mode spectra}}{\text{Absorbed dose in telescope mode spectra}} = 1.01$$

All spectra from April to July 2004 where used, to avoid geo magnetic differences for the different spectra types.

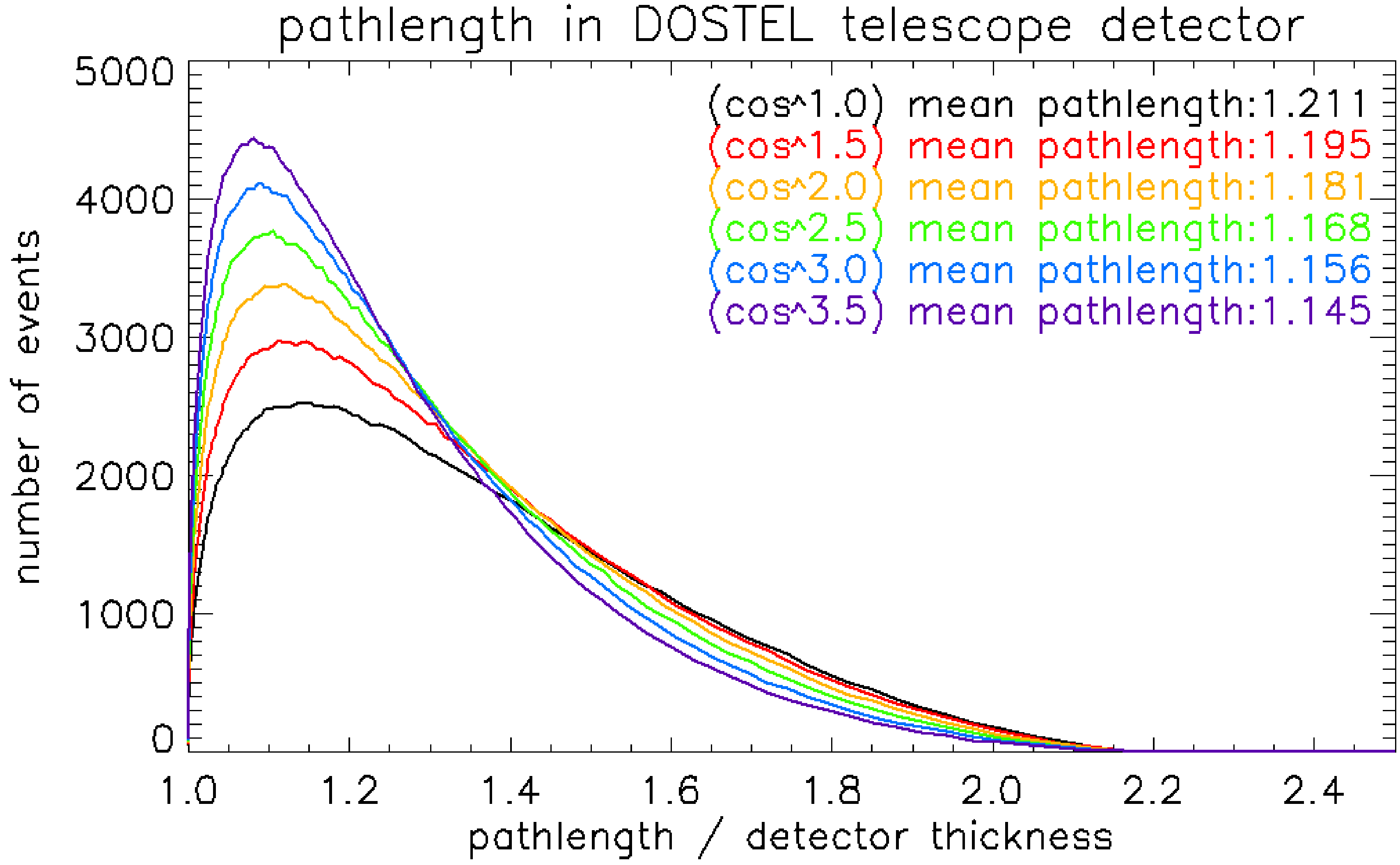
Model: pathlength single detector



Model: pathlength telescope detector



Model: pathlength telescope detector



Absorbed Dose Ratio

Simulated ratio of absorbed dose in single and telescope detectors:

Cos^1: 100% /37.9% * 1.98 /1.21 = 4.32

Cos^1.5: 100% /43.4% * 1.65 /1.20 = 3.17

Cos^2: 100% /48.0% * 1.49 /1.18 = 2.63

Cos^2.5: 100% /51.8% * 1.39 /1.17 = 2.29

Cos^3: 100% /55.0% * 1.32 /1.16 = 2.09

Cos^3.5: 100% /57.7% * 1.27 /1.15 = 1.91

- Cos^2.5 is closest to measured ratio (2.32, 2.35) again.

Summary

For a radiation field with a Cos^2.5 theta distribution the theoretical ratio of particles in single and telescope mode detectors is:

$$N_{single} / N_{telescope} = 100\% / 51.8\% = \underline{1.93}$$

This is in good camparison to the particle number ratio measured with the lower DOSTEL detector ($\underline{1.91}$) during MTR1 mission phase.

The corresponding pathlength ratio,

$$Path_{single} / path_{telescope} = 1.39 / 1.17 = 1.19$$

then leeds to a theoretical absorbed dose ratio of:

$$D_{single} / D_{telescope} = 1.93 * 1.19 = \underline{2.29}$$

This theoretical absorbed Dose ratio is also in good comparison to the DOSTEL measurements ($\underline{2.32, 2.35}$).

Conclusion

- An isotropic field could not explain the DOSTEL measurements during MTR1.

- A comparison of DOSTEL data with results of a simple Monte-Carlo-Modell with different theta distribution showed:

- A cos^2.5 theta distributed radiation field outside the ISS can explain the differences between single and telescope detectors for MTR DOSTEL during MTR1 mission phase.

- This anisotropy, changes the mean pathlength in the DOSTEL telescope from 1.21 to 1.17, which have a minor effect on the LET-spectra and so on mean Quality factors.

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Thank you for your attention.