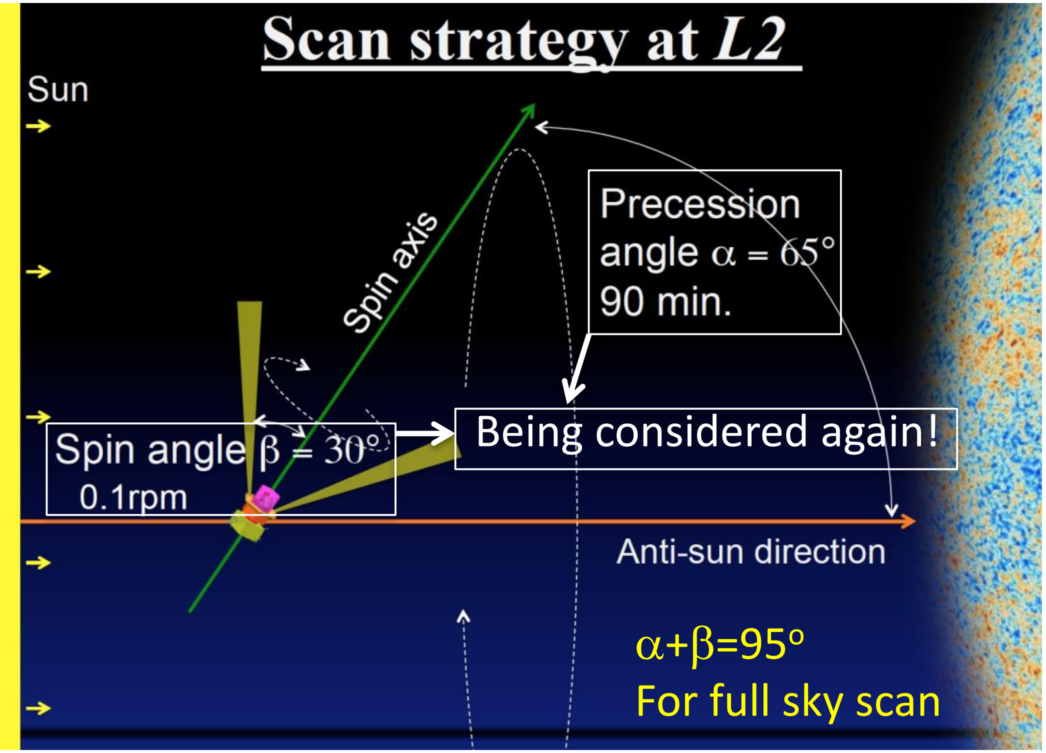
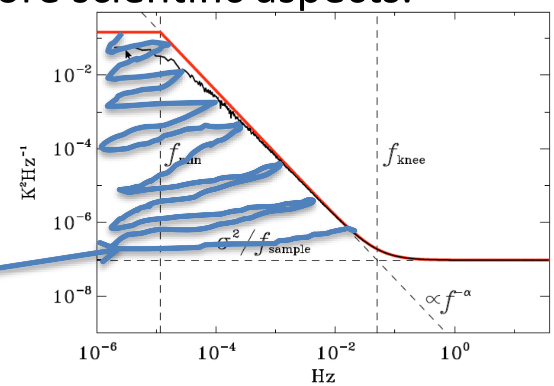
LiteBIRDにおける系統誤差とスキャン方法の関連性の研究

S. Uozumi (Okayama Univ.) for the LiteBIRD Phase-A1 working group

2017 Sep-15th JPS meeting



- LiteBIRD sky scan strategy is defined only by 3 values :
  - precession angle α (spin angle β = 95° - α)
  - Spin rate
  - Precession rate
- Current nominal values are determined on 2015-Feb Mission Definition Review.
- However, we try further optimization of the scan strategy values considering several more scientific aspects.



- **At intermediate review of Phase A-1 (in April 2017), it is determined to adopt Half Wave Plate (HWP) for mission full-success by removing 1/f noise.**
- According to design study policy, we proceed with following steps :
  1. Determine precession angle α (explained in next slide)
  2. Estimate appropriate value ranges of spin and precession rate

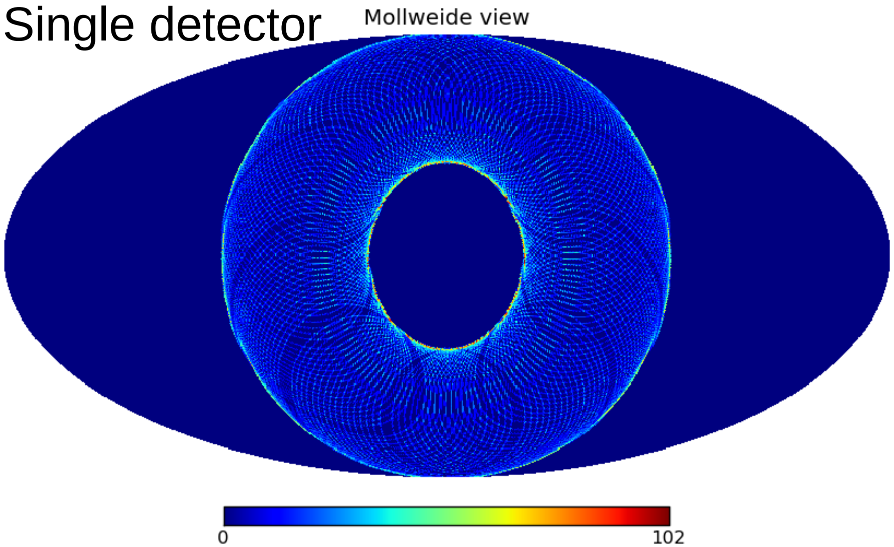
At first we need to select from two precession angle options

One-precession Hitmaps

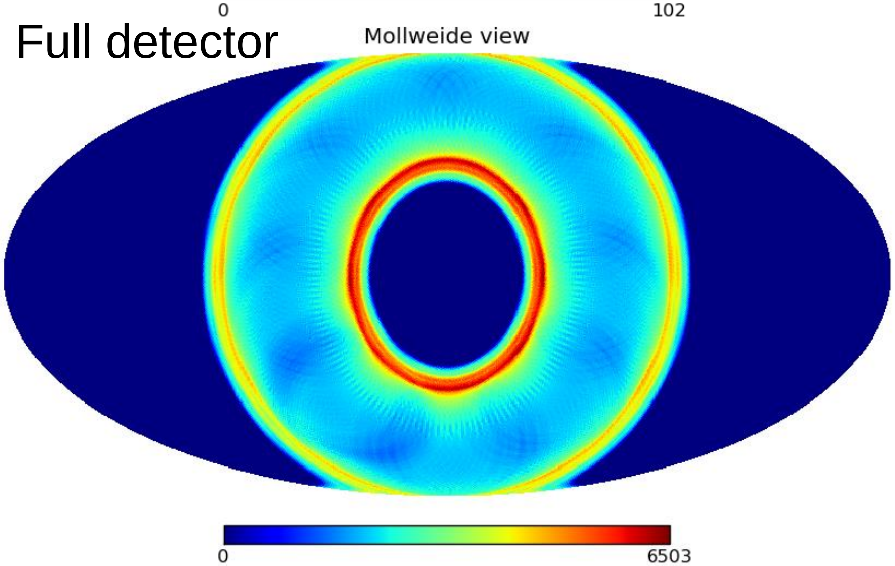
α=65°, β=30°(nominal values)

<u>Large-α option</u>

Single detector



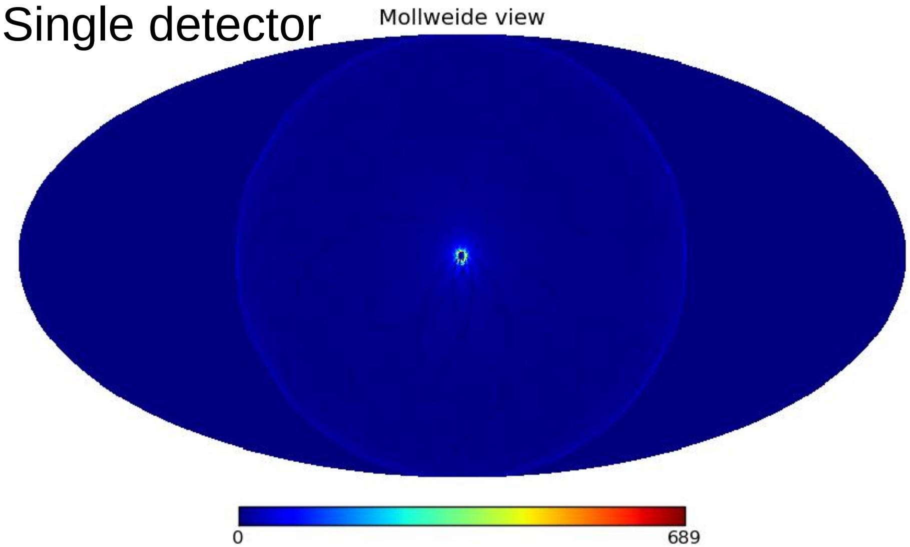
Full detector



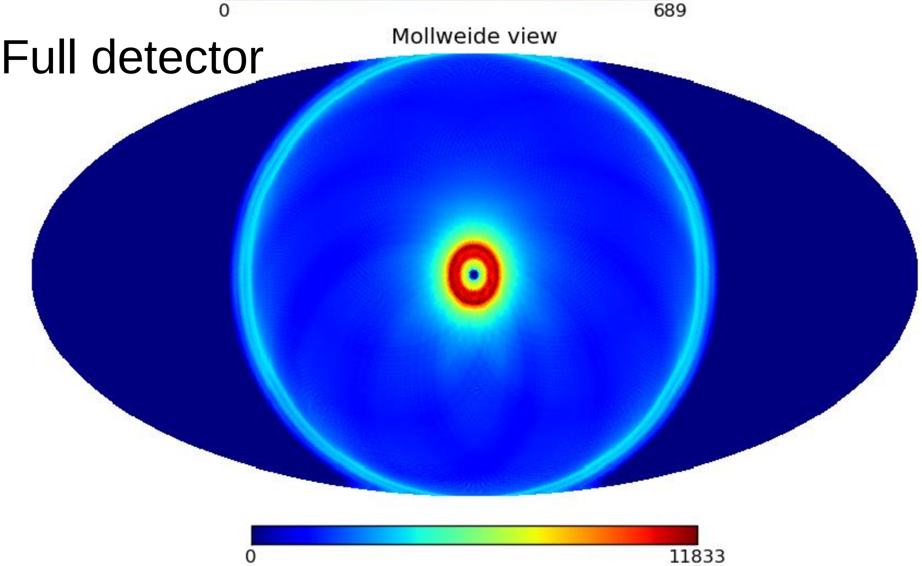
α=45°, β=50°(new values)

<u>Small-α option</u>

Single detector



Full detector



Large-alpha or small-alpha?

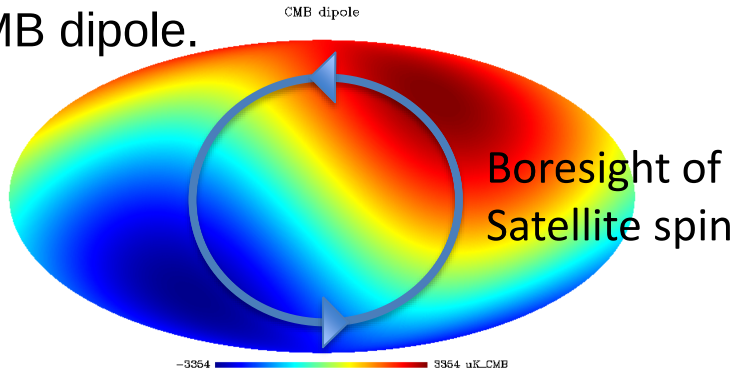
Items	Alpha=65°/Beta=30°	Alpha=45°/Beta=50°	Comments
Cross links	◯	◯	Large-α is slightly better than smaller-α
Hit uniformity	Larger hole,	Smaller hole, Larger RMS	Hits concentrate more around center hole w/ small-alpha option
Revisit time uniformity	△ (larger gaps in Δt dist.)	◯	Hole size also affects to revisit time
1/f noise mit. w/o HWP	△	△	No specific difference
Gain calib. w/ CMB dipole			
Beam calibration w/ Planets			
Thermal (External Interfaces)	**Earth+moon to 4K**: 0mW **Sun to outer shell**:794W **Shadow**: TBC	**Earth+moon to 4K**: 0mW **Sun to outer shell**: 911W **Shadow**: TBC	Light from earth/moon, Heat radiation plates, Shadow around the aperture <u>Values for α=65 are in the case of on Lissajous orbit , no orbit dependencies when α=45</u>
Thermal (Internal Interfaces)			Optical system support structure, Thermal Interfaces among the cold mission components, Thermal distribution
Optics	**Baffle requirements**: h>300mm	**Baffle requirements**: h>300mm	Side-lobe, Support Structure, Stray light <u>Values for α=65 are in the case of on Lissajous orbit , no orbit dependencies when α=45</u>
Solar panel	Requirement: > 3894 W	Requirement: > 4990 W	Sizing
Telemetry			Antennas for X/S bands
Thruster/propellant	**Propellant**: 542.0kg (Lissajous)	**Propellant**: 255.9kg (Halo)	Position of Thruster, amount of propellant
Reaction Wheel			Specification
HWP			Position/Angle
Refrigerators	2ST × 3 + JT × 2	2ST × 3 + JT × 2	Positions, Interfaces, Thermal conduction, Vibration
Focal plane detector			Thermal interfaces, Length of harness
Cost			
mass	**4K shell + absorbers + mag shield**: 83.3kg	**4K shell + absorbers + mag shield**: 89.4kg	<u>Values for α=65 are in the case of on Lissajous orbit , no orbit dependencies when α=45</u>

Already reported

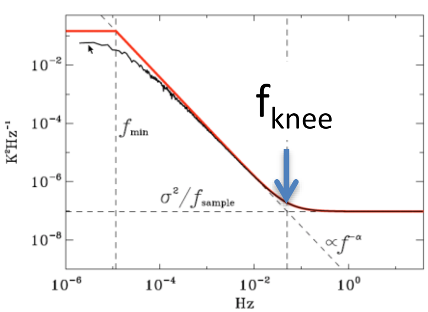
Today's topic

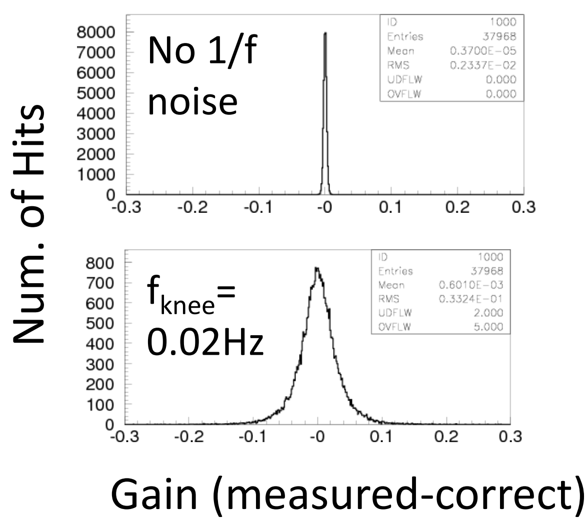
Gain calibration with CMB dipole

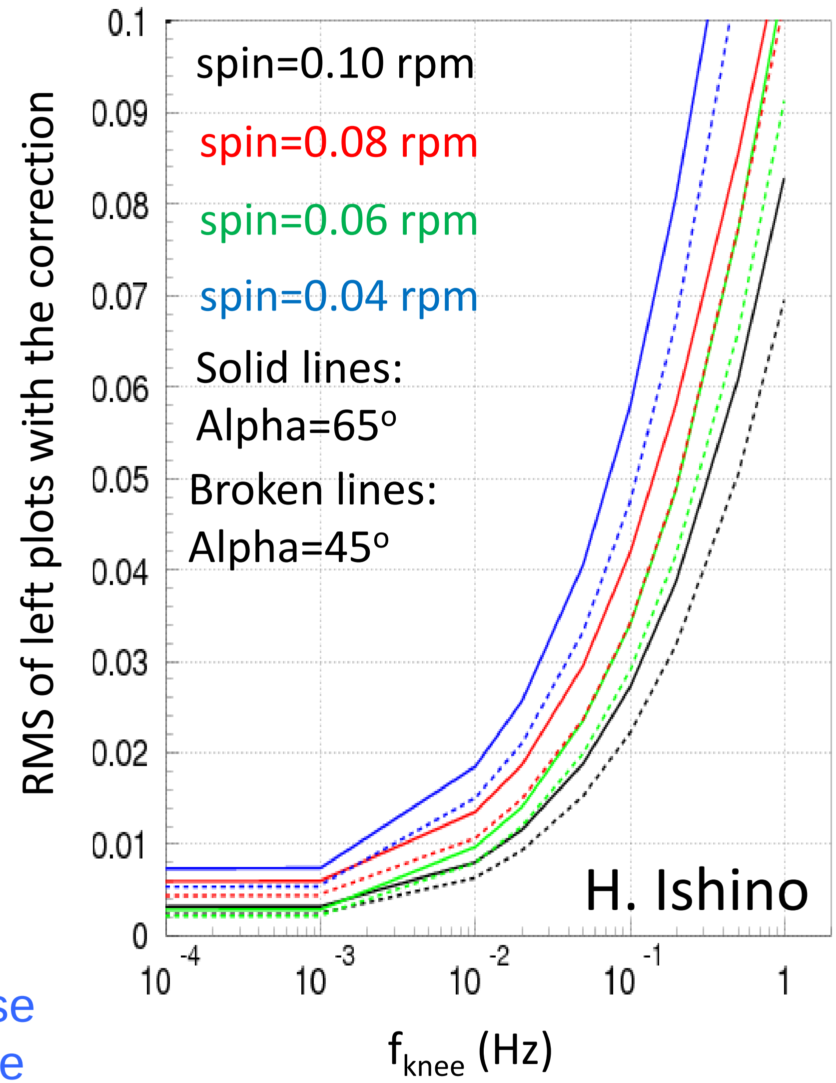
- Detector gain calibration will be done with CMB dipole.



- 1/f noise in scanned data randomly fluctuates data so that precision of the gain calibration becomes worse.



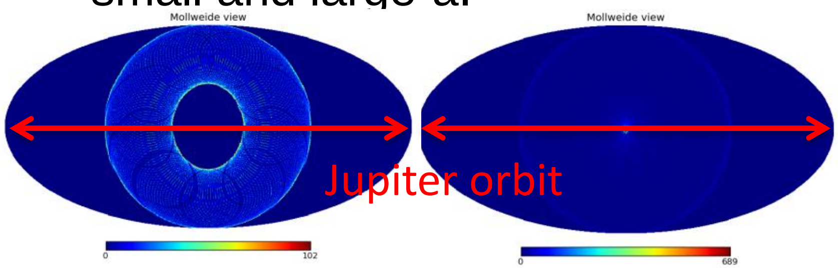




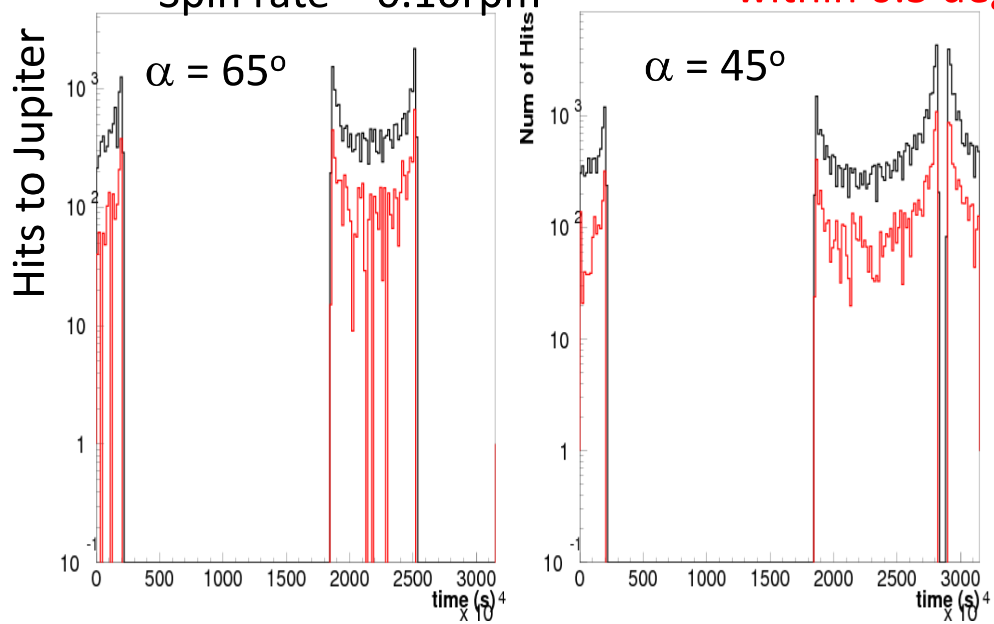
- Simulation result shows 10~20% more precise gain calibration with the small-α case than the large-α.

Beam calibration with Jupiter

- Beam calibration is done using Jupiter (and other planets).
- More visible time of Jupiter gives more precise beam calibration.
- The Jupiter visible times are simulated and compared between small and large-a.



Spin rate = 0.10rpm



Alpha	Spin (rpm)	0.5 deg.	1.0 deg.	5.0 deg.
65	0.10	3.56e2	1.46e3	3.77e4
	0.06	3.81e2	1.42e3	3.77e4
	0.02	3.49e2	1.51e3	3.88e4
45	0.10	7.13e2	2.99e3	7.78e4
	0.06	7.08e2	3.02e3	7.77e4
	0.02	6.24e2	2.78e3	7.84e4

H. Ishino

- Again for the beam calibration, the small-α shows twice more Jupiter visible time than the large-α case.

Large-alpha or small-alpha?

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Hit uniformity	Larger hole, smaller RMS	Smaller hole, Larger RMS	Hits concentrate more around center hole w/ small-alpha option
Revisit time uniformity	△ (larger gaps in Δt dist.)	○	Hole size also affects to revisit time
1/f noise mit. w/o HWP	△	△	No specific difference
Gain calib. w/ CMB dipole	△	○	~10% better with small-alpha option
Beam calibration w/ Planets	△	○	Planet visible time ~x2 longer with small alpha-option
Thermal (External Interfaces)	**Earth+moon to 4K**: 0m **Sun to outer shell**:794W **Shadow**: TBC	**th+moon to 4K**: 0mW **un to outer shell**: 911W **Shadow**: TBC	Light from earth/moon, Heat radiation plates, Shadow around the aperture <u>Values for α=65 are in the case of on Lissajous orbit , no orbit dependencies when α=45</u>
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Solar panel			Sizing
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Decision will be done in next week

Move to optical/engineering assessment

Try slow scans

Satellite spin rate (rpm)	Precession time (hrs)
0.1	1.51
0.075	2.013
0.05	3.02
0.025	6.04
0.0125	12.08
0.01	15.1
0.005	30.2
0.0025	60.4

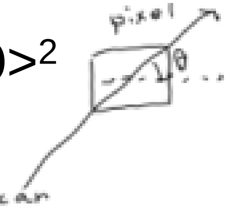
←Current nominal value

How slow can we allow ?

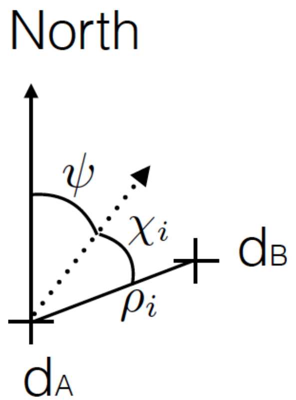
- In principle faster spin is preferred.
- However considering technical, cost and telemetry rate issues, we have to find out “slowest limit” of scan speed.
- Performance with each scan speed is evaluated by :
  - Cross-links
  - Hit Uniformity

Cross-links (original definition)

$|\tilde{h}_n|^2 = \langle\cos n\theta\rangle^2 + \langle\sin n\theta\rangle^2$
n = "spin of cross-link"



Relation aiming cross-link, systematics and T ->B leakage (arXiv:1604.02290v1)



$$d_i = \frac{1}{2}(d_i^A - d_i^B)$$

incident with the pointing centre. We denote the beam decomposed into spherical harmonics as $b_{\ell k}^X$ and the temperature sky is denoted by $a_{\ell m}^T$. The error on the differenced signal between the two detectors within a pair is then

$$\delta d_i^e = \frac{1}{2}\sum_{\ell m}\sqrt{\frac{4\pi}{2\ell+1}}\left(b_{\ell m}^A a_{\ell m}^{T*} - b_{\ell m}^B a_{\ell m}^{T*}\right), \quad (10)$$

$$\approx \frac{1}{2}\sum_{\ell}\sqrt{\frac{4\pi}{2\ell+1}}\left(\delta b_{\ell,2}^i a_{\ell,2}^{T*} + \delta b_{\ell,-2}^i a_{\ell,-2}^{T*}\right), \quad (11)$$

Beam :

$$B(\theta,\phi) = \frac{1}{2\pi q\sigma^2} e^{-\frac{\theta^2}{2\sigma^2}(\cos^2\phi + q^{-1}\sin^2\phi)} \quad (29)$$

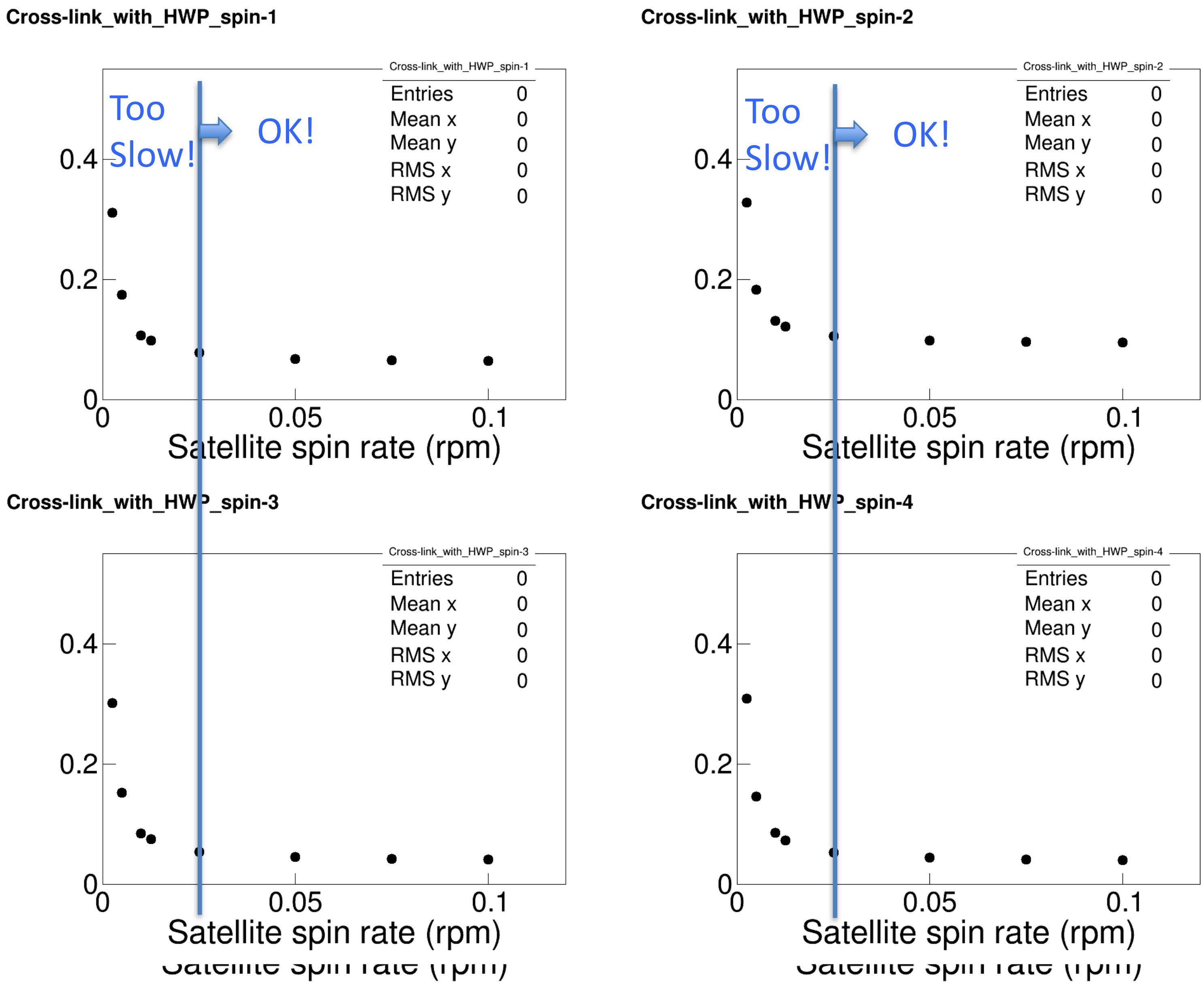
$$\Delta C_\ell^{BBg} = \frac{1}{8}\langle|\tilde{h}_2|^2\rangle\,|\delta g_1 + i\delta g_2|^2\, C_\ell^{TT}, \quad (26)$$

$$\Delta C_\ell^{BBp} = \frac{1}{32}\langle|\tilde{h}_1|^2\rangle\left|\rho_1 e^{i\chi_1} + \rho_2 e^{i(\chi_2+\pi/4)}\right|^2 \ell^2 C_\ell^{TT}, \quad (27)$$
$$+ \frac{1}{32}\langle|\tilde{h}_3|^2\rangle\left|\rho_1 e^{-i\chi_1} + \rho_2 e^{-i(\chi_2-3\pi/4)}\right|^2 \ell^2 C_\ell^{TT}$$

$$\Delta C_\ell^{BBe} = \frac{1}{4}\left|\Im\left[\frac{\delta b_{\ell 2}^1 + \delta b_{\ell 2}^2}{b_{\ell 0}}\right]\right|^2 C_\ell^{TT} \quad (28)$$
$$+ \frac{1}{8}\langle|\tilde{h}_4|^2\rangle\left|\frac{\delta b_{\ell 2}^1 - \delta b_{\ell 2}^2}{b_{\ell 0}}\right|^2 C_\ell^{TT},$$

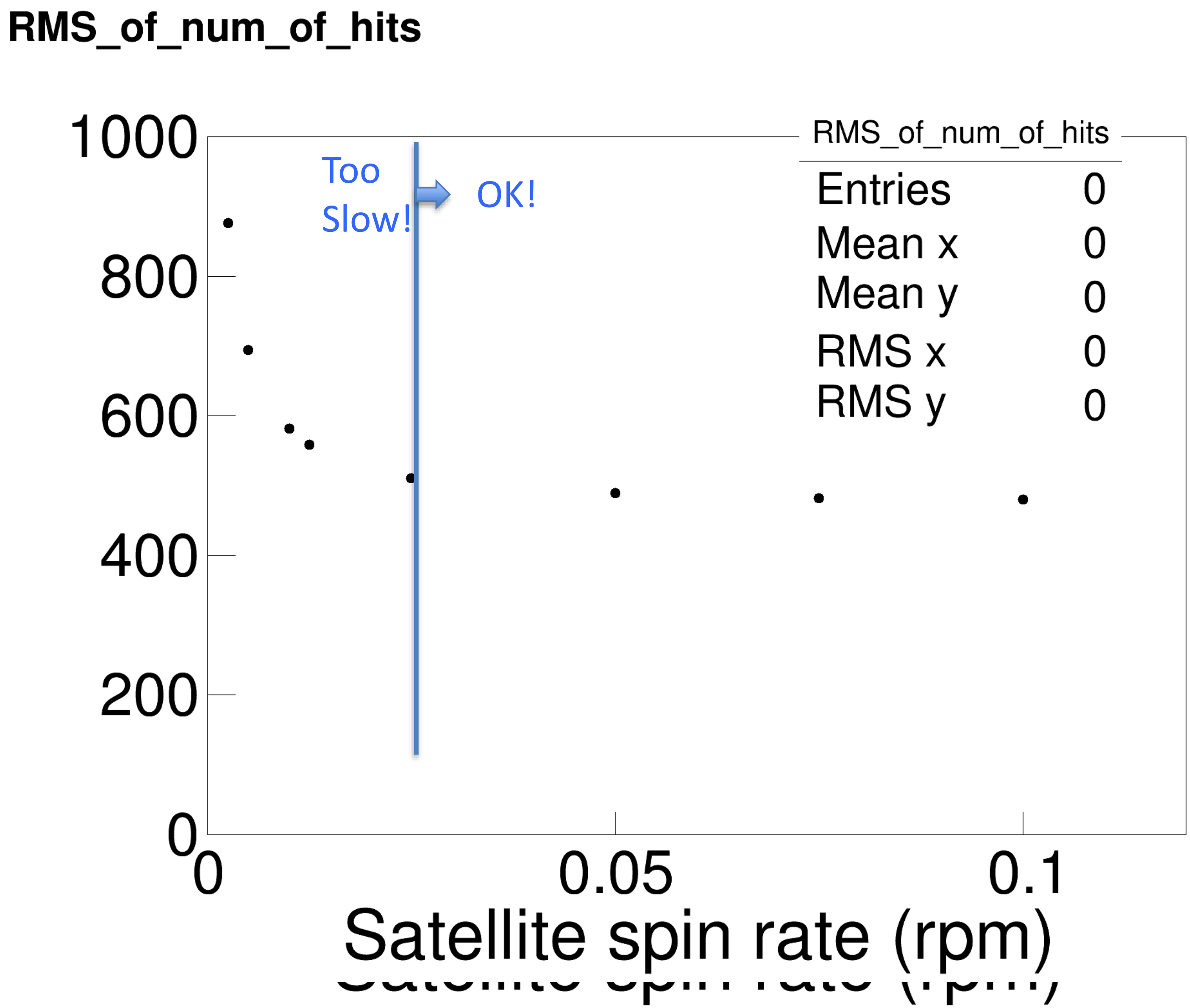
Symbol	Description	Value set to in relevant simulation
ψ	The orientation of the scan direction with respect to North	Varies with scan strategy, position and time
$\tilde{h}_n$	The average of the complex exponential of the orientations for a pixel, $\langle e^{in\psi}\rangle_{\text{hits}}$	Varies with scan and pixel
FWHM	the full width at half the maximum of the beam	7 arcmin for all the simulations
δg_i	The differential gain between the two detectors in pair i	0.01 for both detector pairs
ρ_i	The angle between the two beam centres in pair i	0.1 arcmin for both (1.5% of the FWHM)
χ_i	The orientation of the second beam from the first in a detector pair i relative to the direction of the scan	0 and $\pi/4$
$b_{\ell m}$	The spherical harmonic decomposition of the temperature beam	That of an elliptical Gaussian — see equation (29)
$\delta b_{\ell m}^i$	The spherical harmonic decomposition of the difference of the temperature beams of pair i	That of an elliptical Gaussian — see equation (29)
q	Ellipticity parameter for the elliptical Gaussian beam. Note that $q = 1$ is axisymmetric (see equation 29). q is also the ratio of the major and minor axes of the ellipse.	1.05 and 1

Cross-link v.s. Satellite spin rate (small-α case)



Hit uniformity v.s. Satellite spin rate

(Small-alpha option)



Summary

- The LiteBIRD sky scan strategy is optimized and being decided whether we will take which precession angle

  (large-α=65^{o} or small-α=45^{o}).
- Comparison study shows small-a option is preferable.

- Slow speed scan is tested and we found that spin rate must be greater than ~0.0025 rpm.

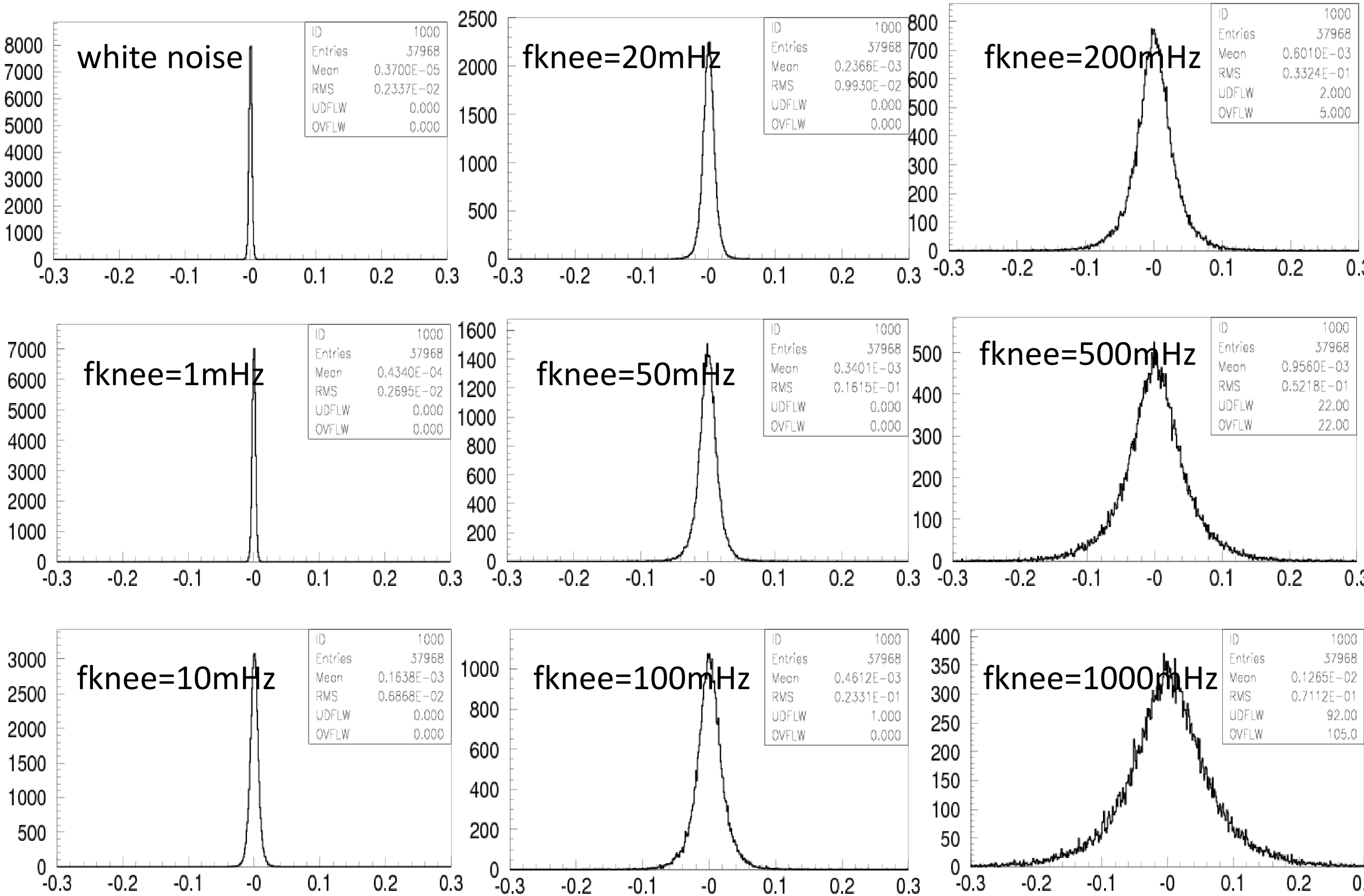
  Precession rate is also being considered.

- According to those study results, the scan strategy will be defined in next week, and we will proceed to engineering study of the Satellite.

Backups

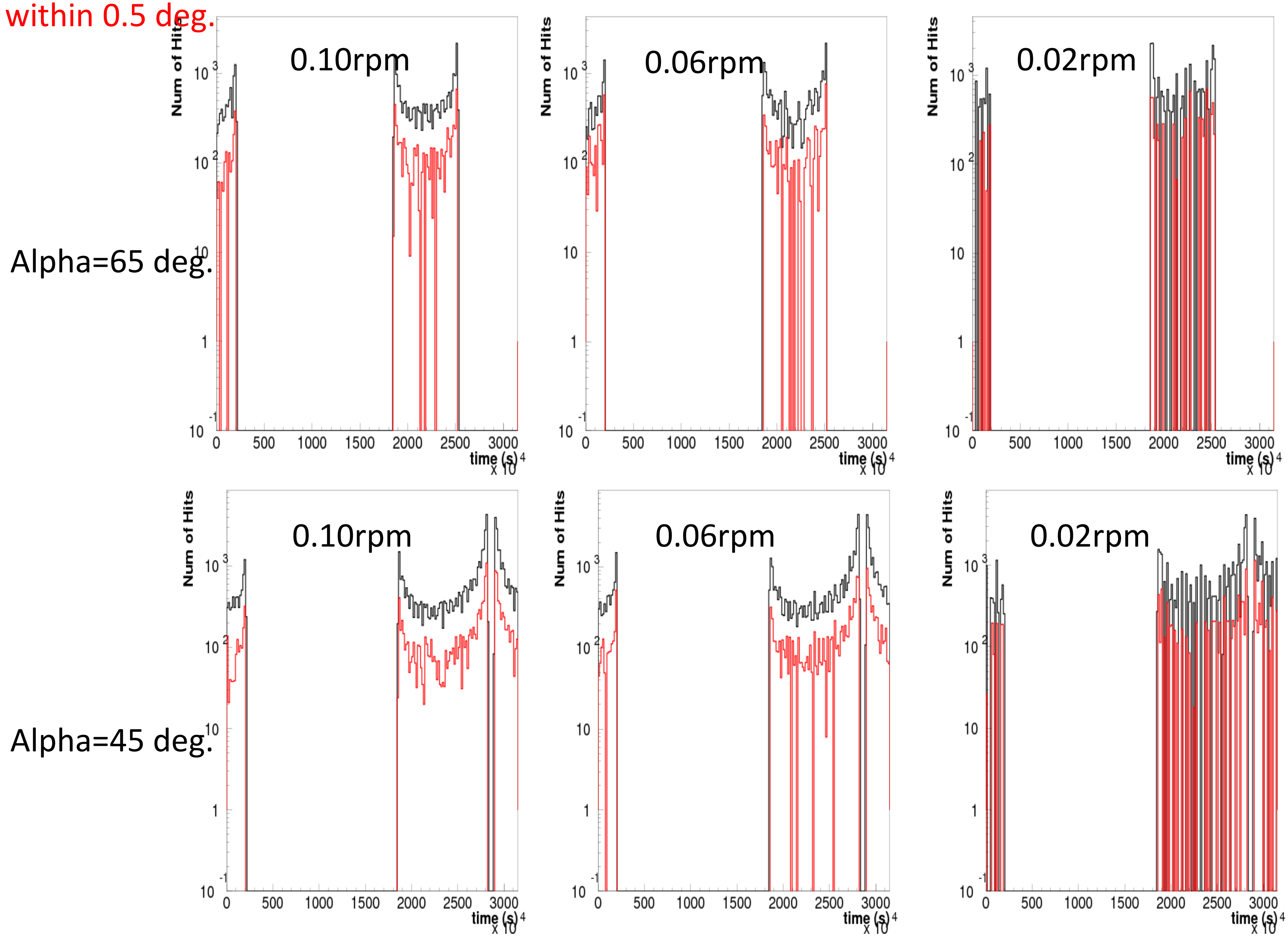
Alpha=65 deg. spin rate = 0.1rpm

Gain measurement per 819.2 sec



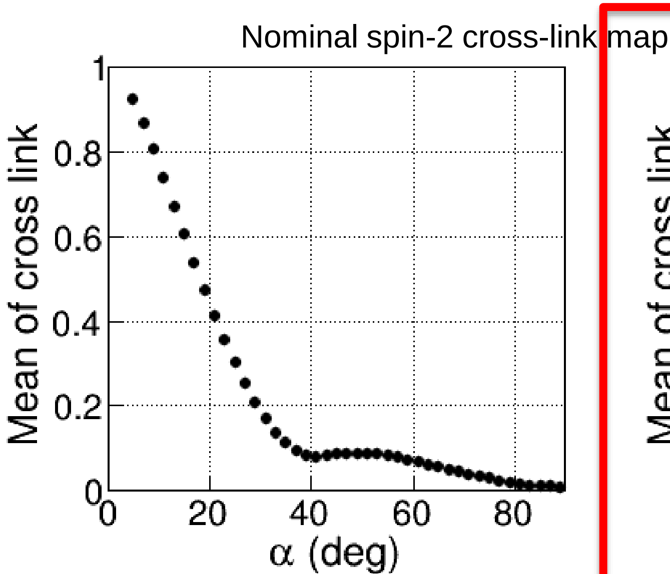
within 1 deg.

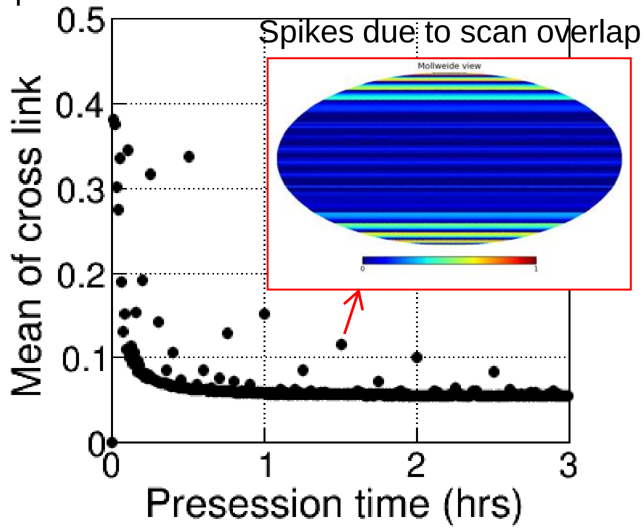
within 0.5 deg.

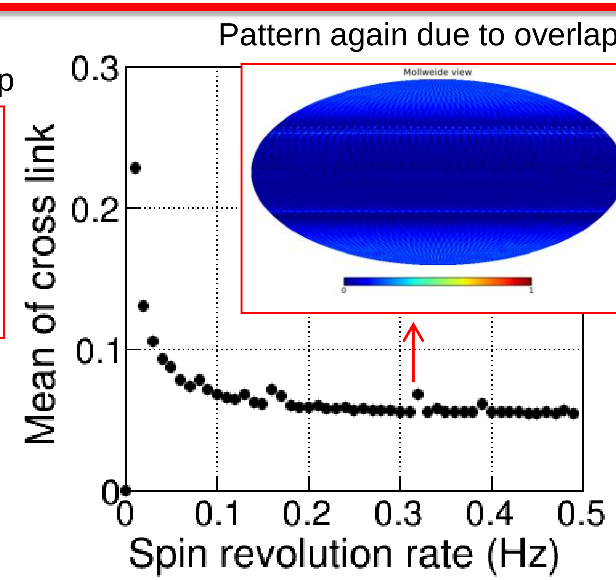


Past study with precession time & spin rate

Nominal values : α=65°, β=30°, $\alpha+\beta$=95°, precession time=1.51hrs, spin revolution rate=0.3rpm
(large-alpha option)







- In principle, we prefer
  - Fast spin (in range of < 0.3 rpm)
  - Not too fast, not too slow precession time
    (it also relates with ADR recycling dead time, I will show later)
- Descope option in case of HWP mulfunction, faster spin helps destriping
- CMB dipole gain calibration prefer faster scan
- But telemetry limitation requires slow scan.
- Where is the allowed region of those parameters?