TESLA

S2E Simulations on Jitter Tolerance for the European XFEL Project

- Optional Multi-Klystron Operation -

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TESLA-S2E-24

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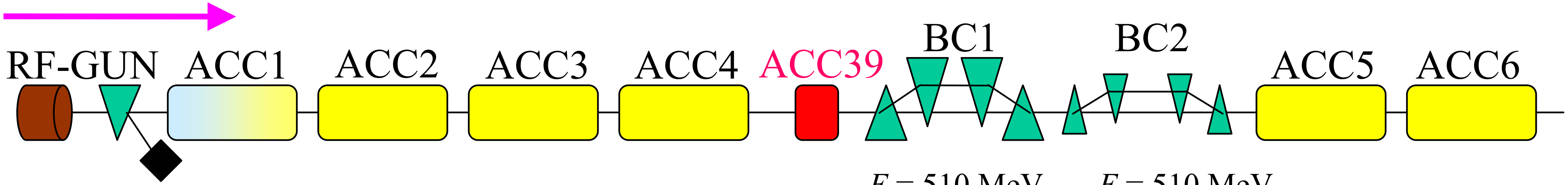
New Lattice for TESLA XFEL – 4th Version

With TESLA XFEL Injector, $\varepsilon_n = 0.9\ \mu m$

$\sigma_z = 1.76$ mm → 113 μm → 23 μm →

Q=1.0 nC

e-beam



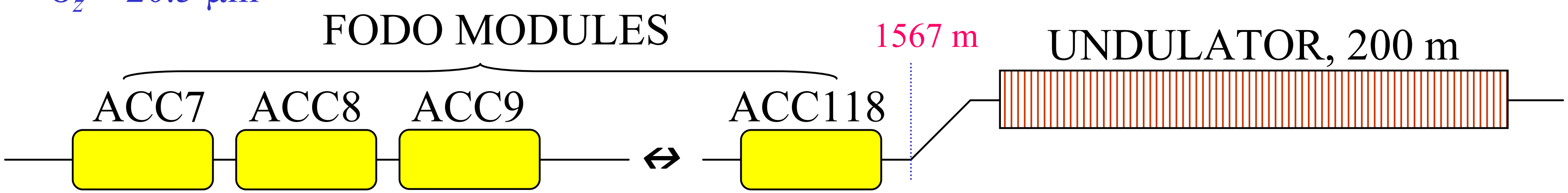
RF-GUN	ACC1	ACC2	ACC39	BC1	BC2	ACC5
60 MV/m	11.5 MV/m	20.5 MV/m	34.8 MV/m	E = 510 MeV	E = 510 MeV	20.65 MV/m
38 deg	25.0 MV/m	-29.6 deg	160.6 deg	$\sigma_\delta \sim 1.89\%$	$\sigma_\delta \sim 1.88\%$	0.0 deg
	-18.3 deg			R_{56} = 87 mm	R_{56} = 4.8 mm	
				θ = 3.95 deg	θ = 0.93 deg	

ASTRA with Space Charge

0.0 m — 12.0444 m

To the end of Linac : ELEGANT with CSR
with geometric wakefields
without space charge

$\sigma_z = 20.5\ \mu m$ →



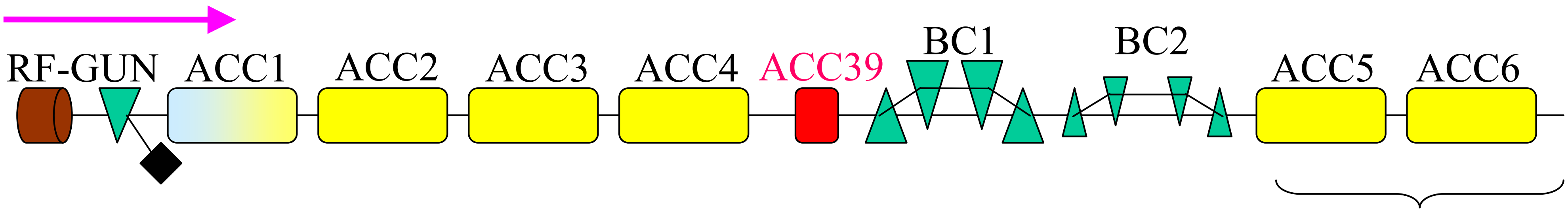
20.65 MV/m
0.0 deg

E = 20.0 GeV
$\sigma_\delta = 0.008\%$
$\sigma_x = 37.3\ \mu m$, $\sigma_y = 31.6\ \mu m$, $\sigma_z = 20.5\ \mu m$
$\varepsilon_{nx} = 1.5\ \mu m$, $\varepsilon_{ny} = 0.94\ \mu m$

All projected parameters !

New Klystron Layout for Jitter Study

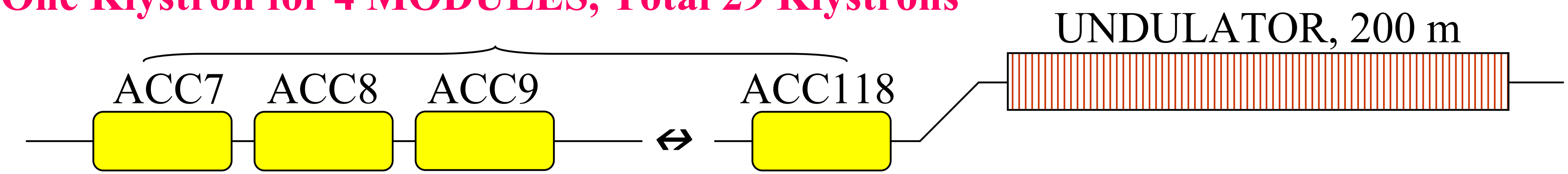
Here K.No means Klystron number per module !



K.No = 1 2 1 1 1 2

One Klystron for 4 MODULES

One Klystron for 4 MODULES, Total 29 Klystrons



Mliti-Klystron before BC2 reduces the jitter sensitivity in ACC234 and ACC39 modules

Controllable Jitter Tolerance from Dr. Simrock

For both 1.3 GHz TESLA Module & 3.9 GHz 3rd Harmonic Module

For the short term period (1 min)
RF Phase Error < 0.1 degree (rms)
RF Amplitude Error (dV/V) < 0.03% (rms)

Reference !!!

For the mid-term period (1 hour)
RF Phase Error < 0.3 degree (rms)
RF Amplitude Error (dV/V) < 0.09%

Controllable jitter tolerance depends on charge fluctuation !

$$Q = Q_0(1 + 0.03\Delta\phi_l)(1 + (\Delta E / E)_l)(1 + (\Delta V / V)_g)$$

One feedback cycle : 10 μs + 4 μs delay = 14 μs

Dr. Simrock may improve these tolerances in the near future !

New Jitter Sensitivity Threshold

By the help of S2E simulations, let's apply artificial jitter or error to all important components (GUN, ACC1 ~ ACC57, ACC39, BC1 and BC2) in order to investigate the sensitivity $p_{\text{sensitivity}}$ of those components on the longitudinal phase space at the end of linac.

New Jitter Sensitivity Threshold at the end of Linac :

- **change in bunch length σ_s within +10%**
- **change in beam energy within 0.005%**
- **change in peak-to-peak energy deviation (δ=dE/E) within +0.1%**
- **change in bunch arrival time within 50 fs**

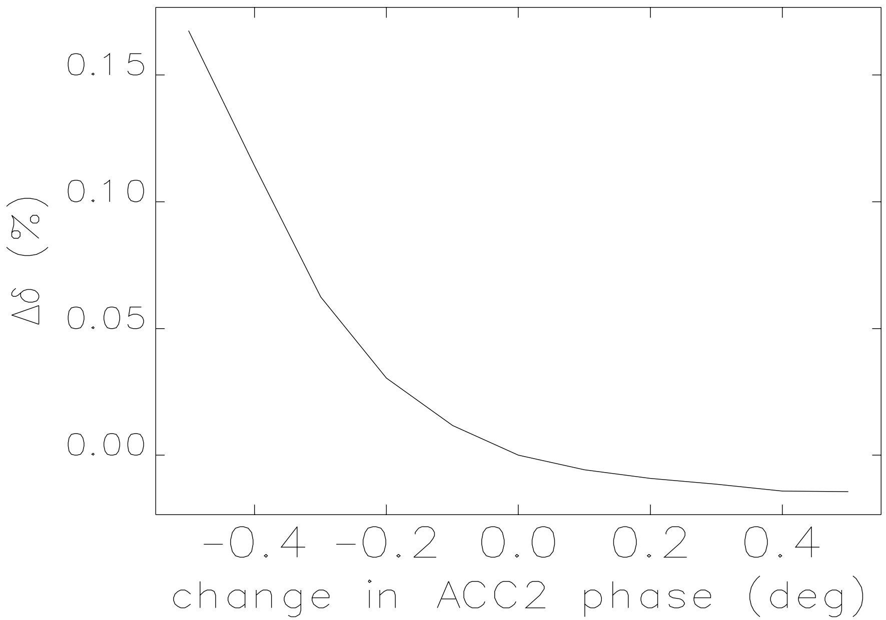
Then choose the tolerance $p_{\text{tolerance}}$ which gives

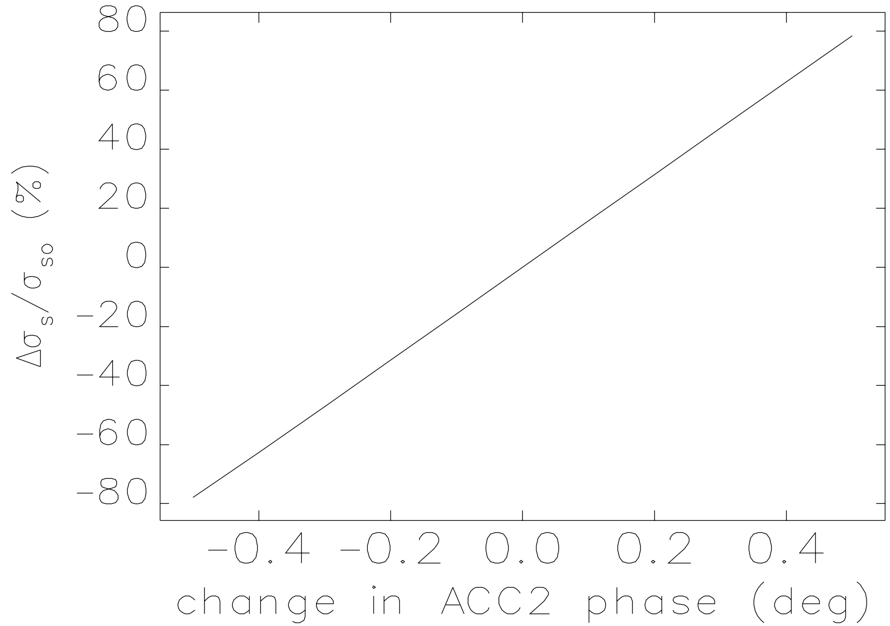
$$\sqrt{\sum_{i=1}^{n}\left(\frac{p_{tolerance}}{p_{sensitivity}}\right)^2} < 1$$

Let's check FEL performance under above tolerances with S2E simulations.

Most Sensitive Sources in $\delta = dE/E$ and σ_s

ACC2, ACC3, and ACC4 phase are the most sensitive jitter sources.



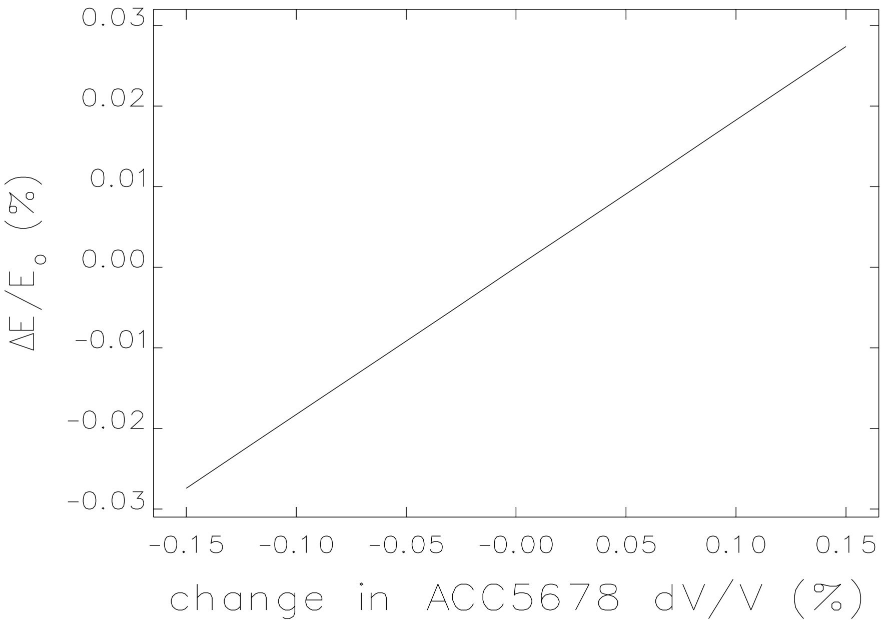


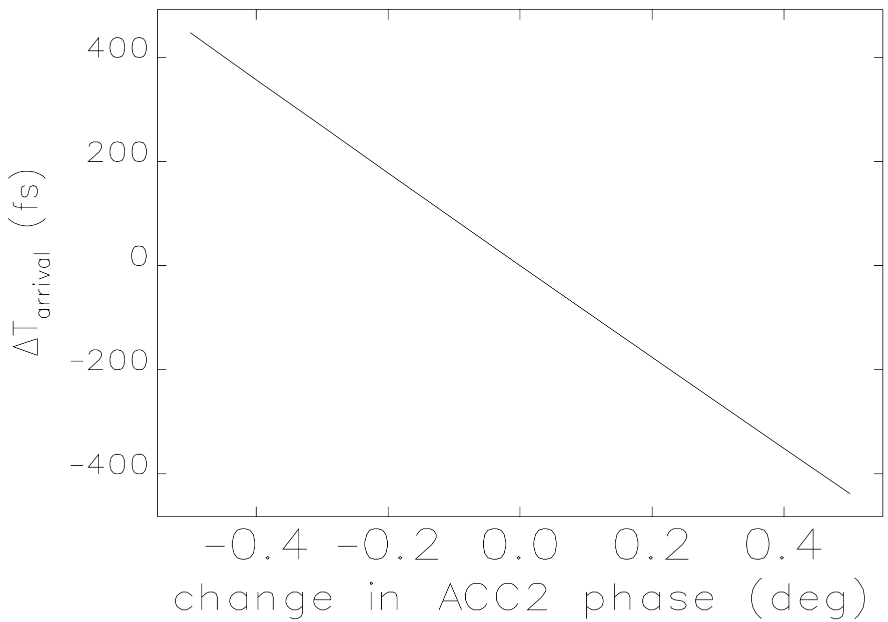
Sensitivity in energy deviation ~ -0.375 deg

Sensitivity in bunch length ~ 0.065 deg

Most Sensitive Sources in $\Delta E/E_o$ and $\Delta T_{arrival}$

ACC5678 dV/V is the most sensitive jitter sources in $\Delta E/E_o$
ACC2, ACC3, and ACC4 phase are the most sensitive jitter sources in $\Delta T_{arrival}$





Sensitivity in energy change ~ 0.028%

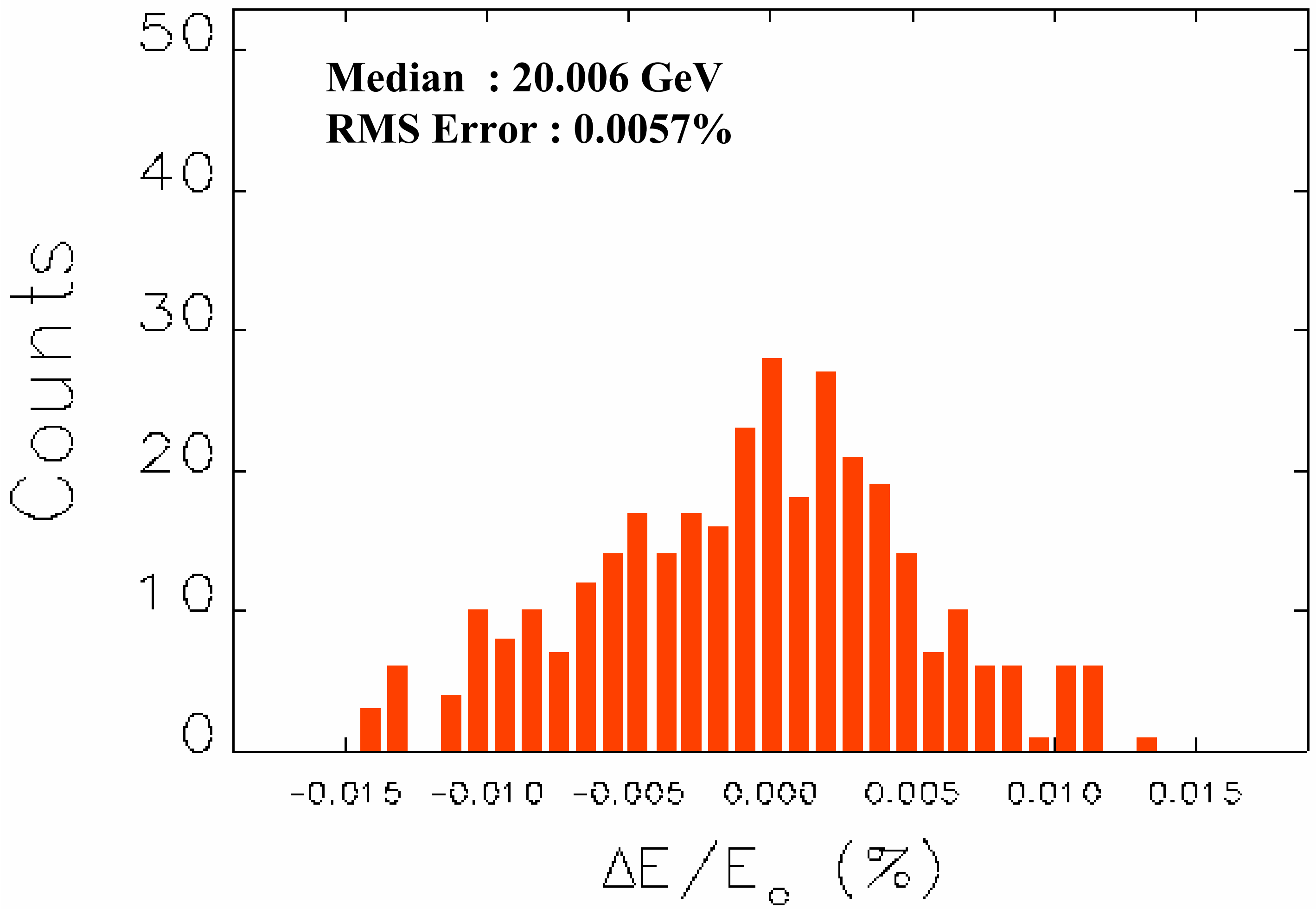
Sensitivity in arrival time ~ -0.056 deg

Sensitivity & Tolerance Set for each Klystron

For one macro pulse or one bunch train

	Sensitivity	Tol. Set A (rms)	Tol. Set B (rms)
dT	0.50 ps	0.1 ps	0.3 ps
dQ	- 6.10%	1.0%	1.5%
ACC1C1234 Phase	0.20 deg	0.05 deg	0.07 deg
ACC1C1234 dV/V	- 0.17%	0.02%	0.03%
ACC1C5678 Phase	0.10 deg	0.05 deg	0.07 deg
ACC1C5678 dV/V	-0.08%	0.02%	0.03%
ACC234 Phase	-0.056 deg	0.05 deg	0.07 deg
ACC234 dV/V	-0.06%	0.02%	0.03%
ACC39 Phase	-0.08 deg	0.05 deg	0.07 deg
ACC39 dV/V	0.19%	0.02%	0.03%
BC1 dI/I	0.02%	0.02%	0.02%
BC2 dI/I	0.31%	0.02%	0.02%
ACC5678 Phase	4.19 deg	0.05 deg	0.07 deg
ACC5678 dV/V	0.028%	0.02%	0.03%

S2E Simulations with 331 Random Error Set A



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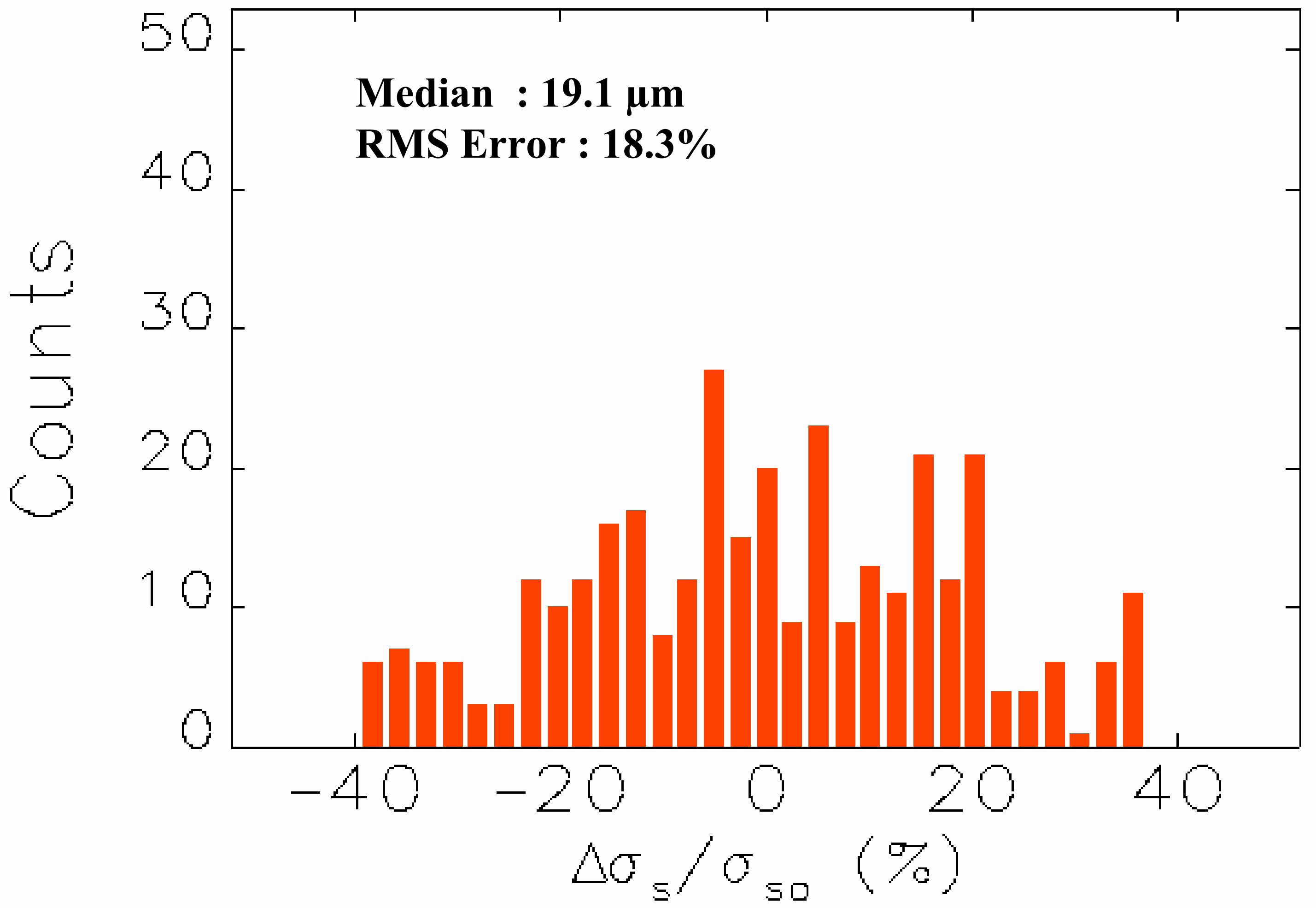

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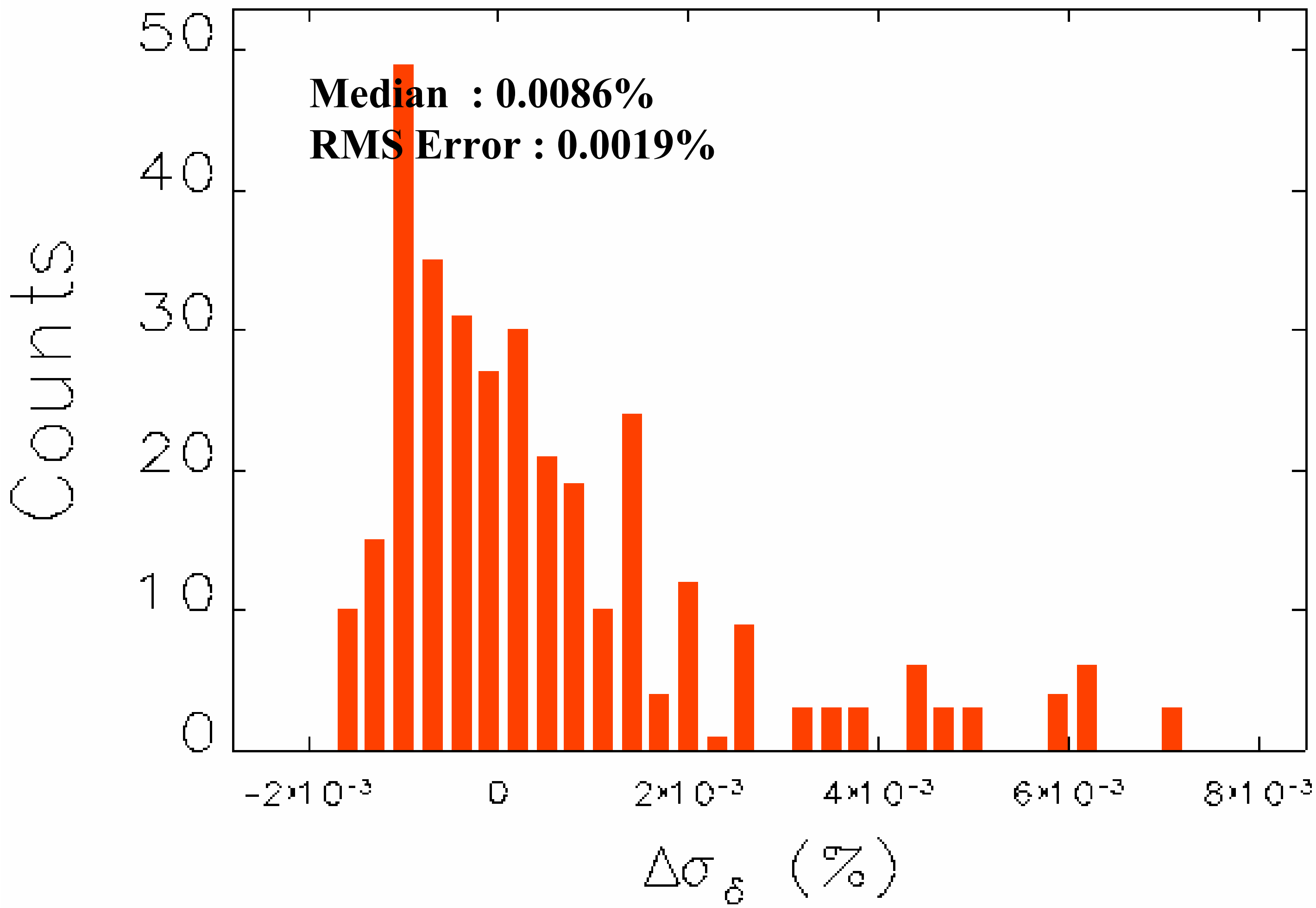

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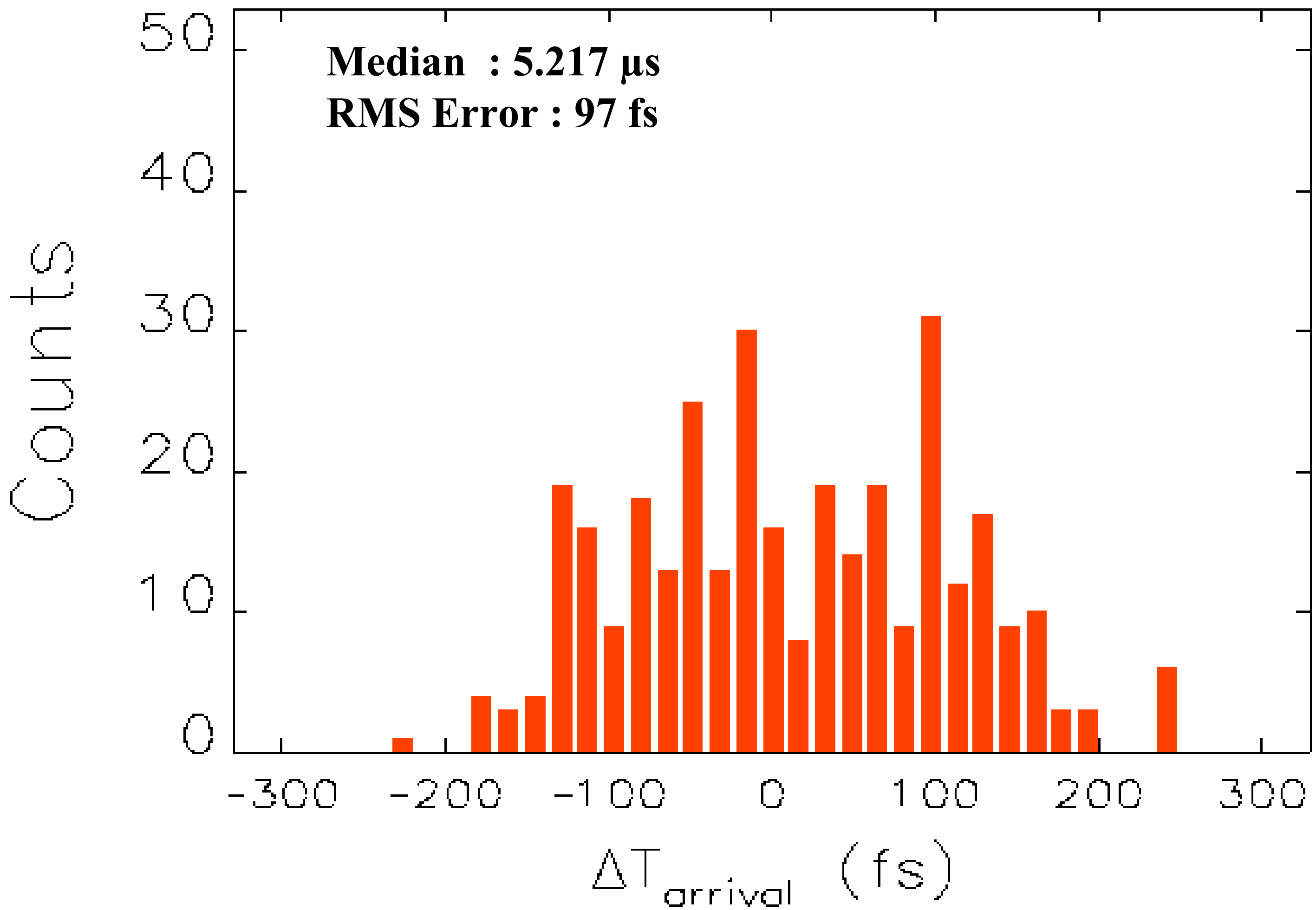

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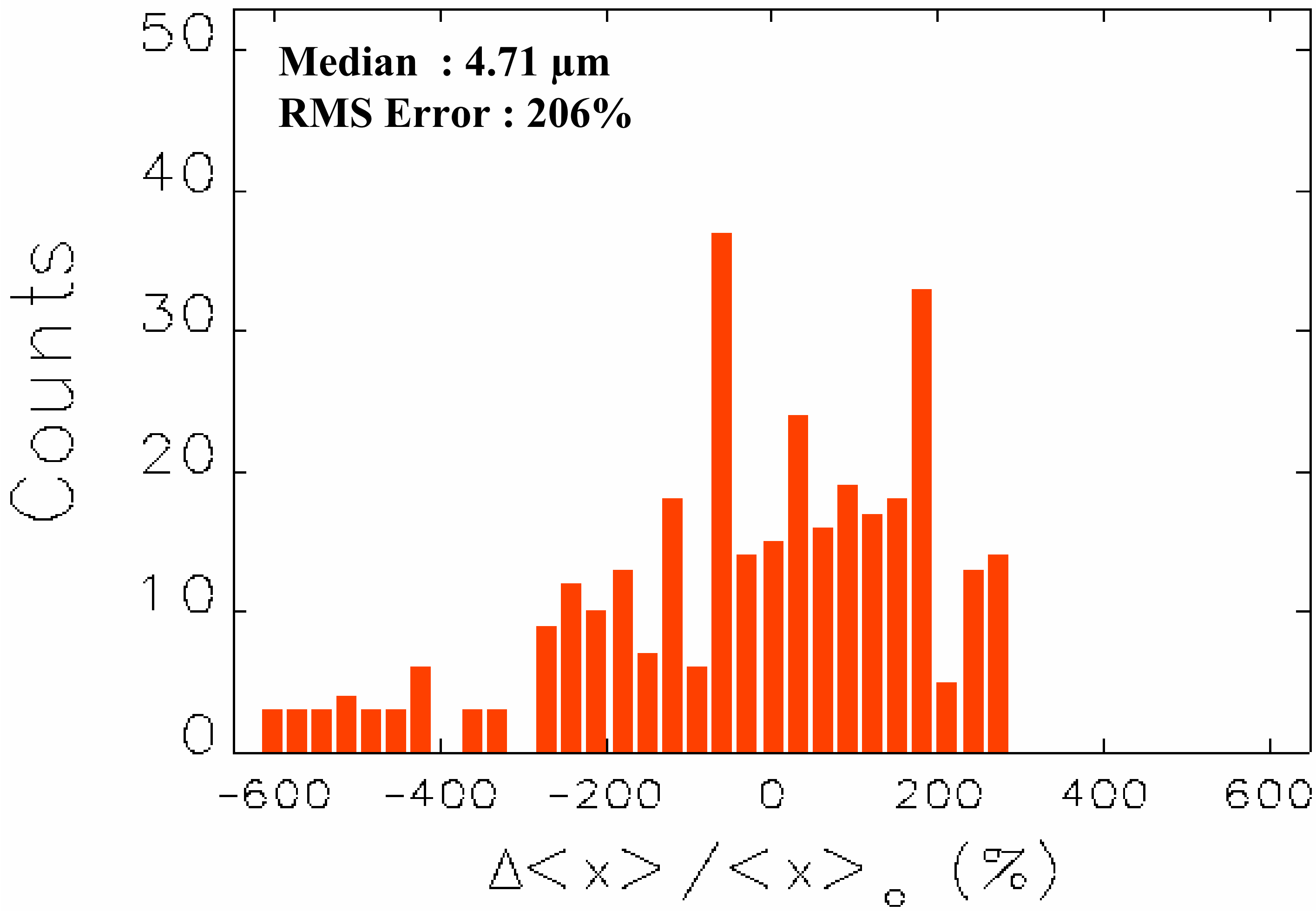

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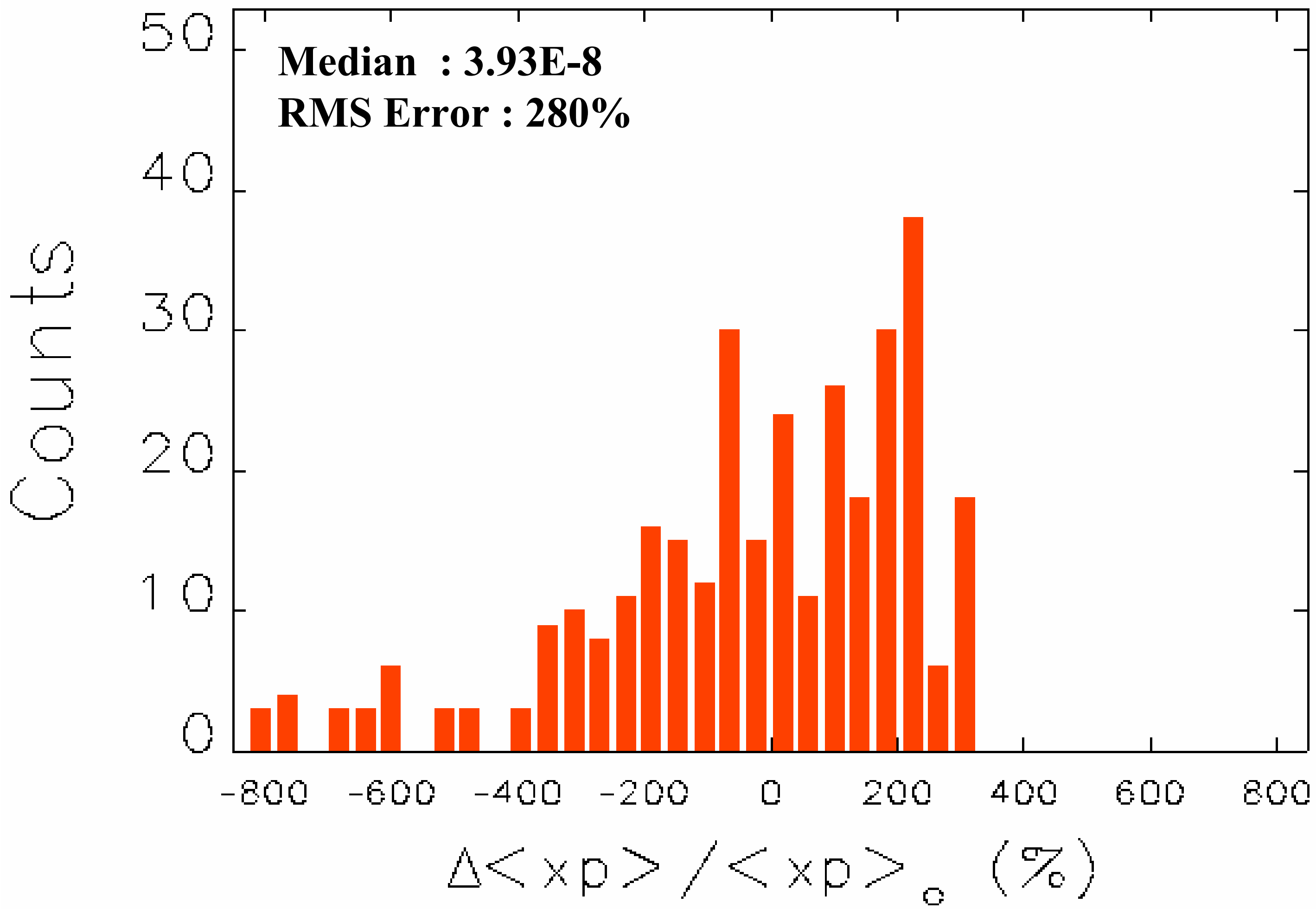

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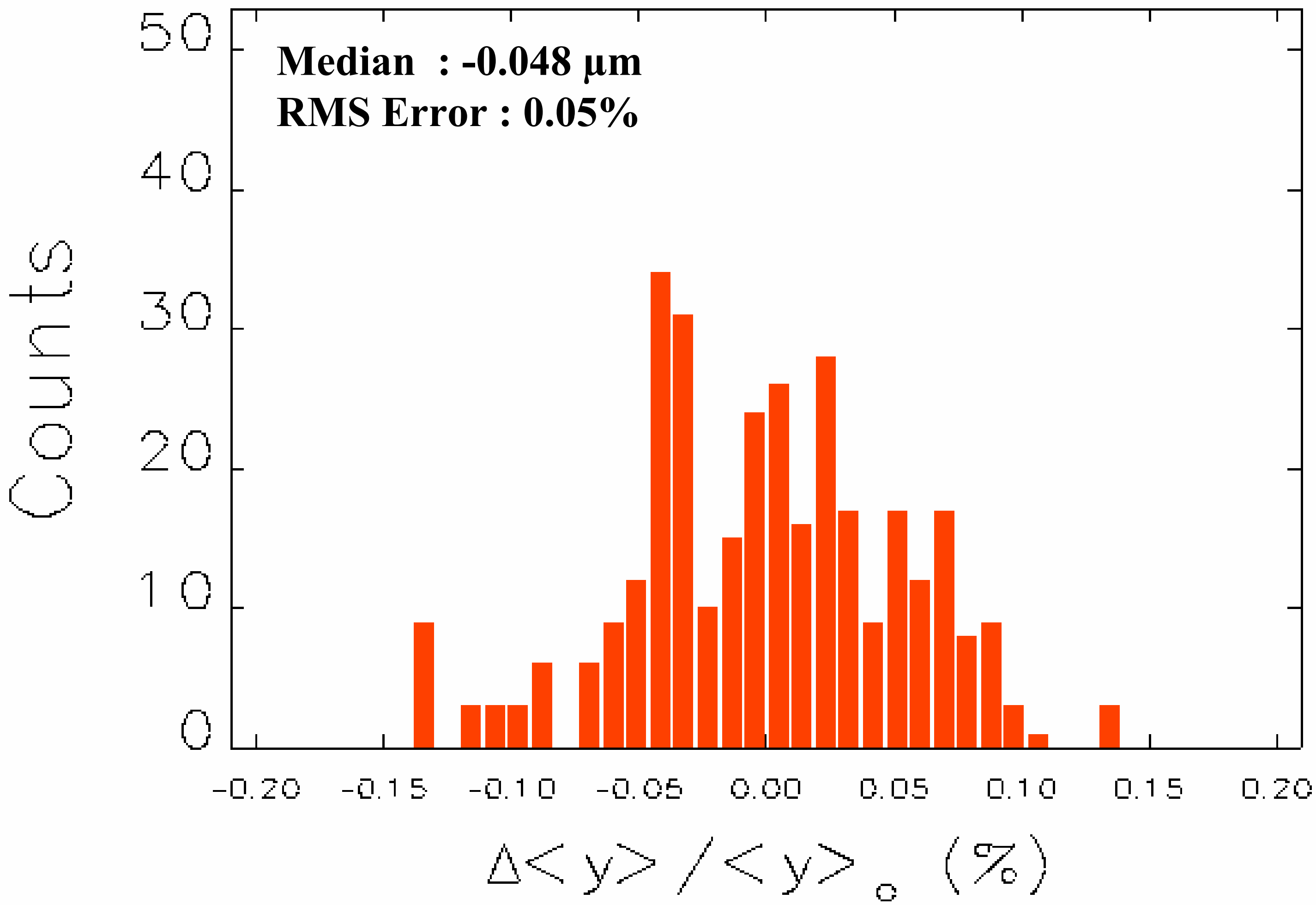

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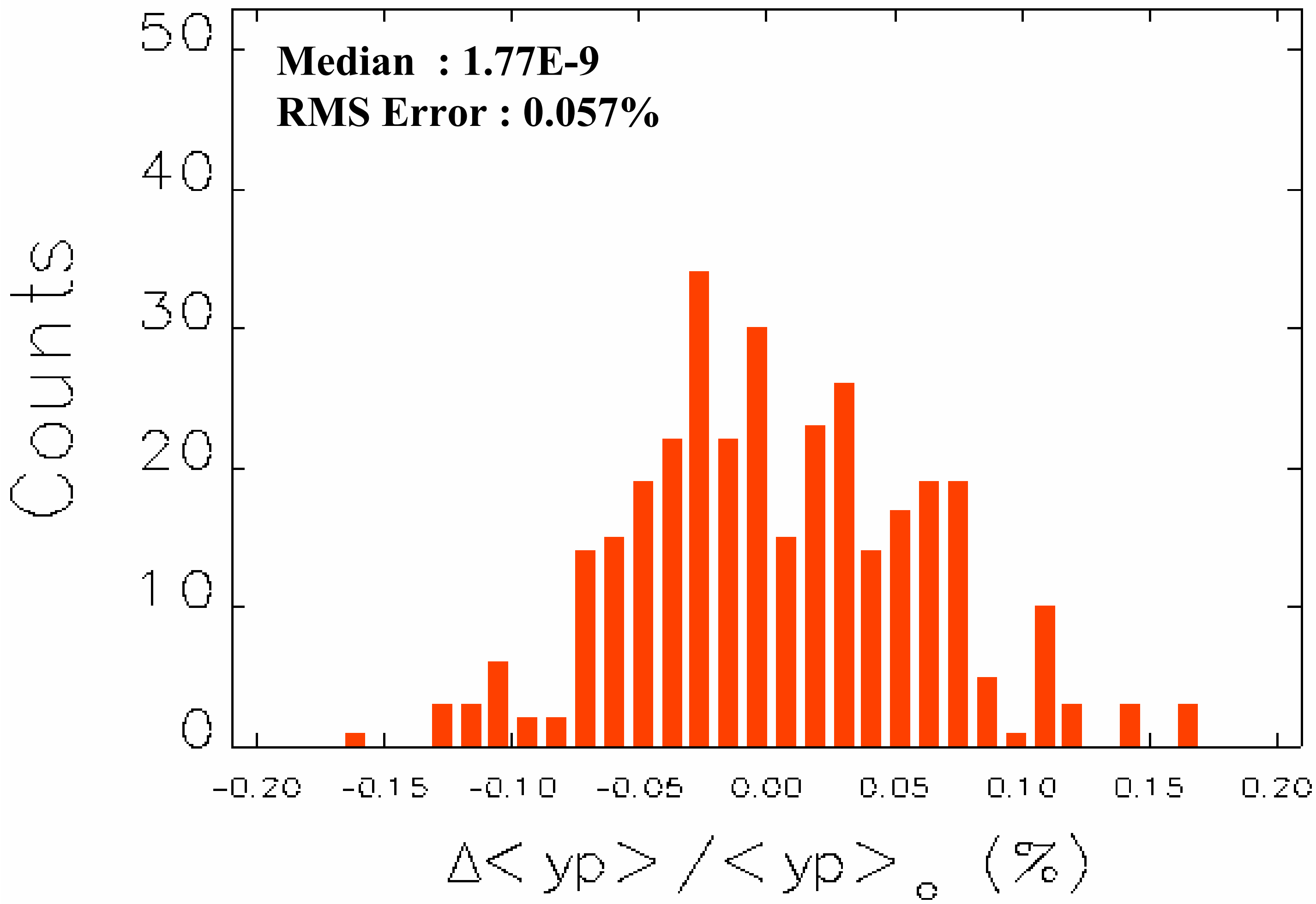

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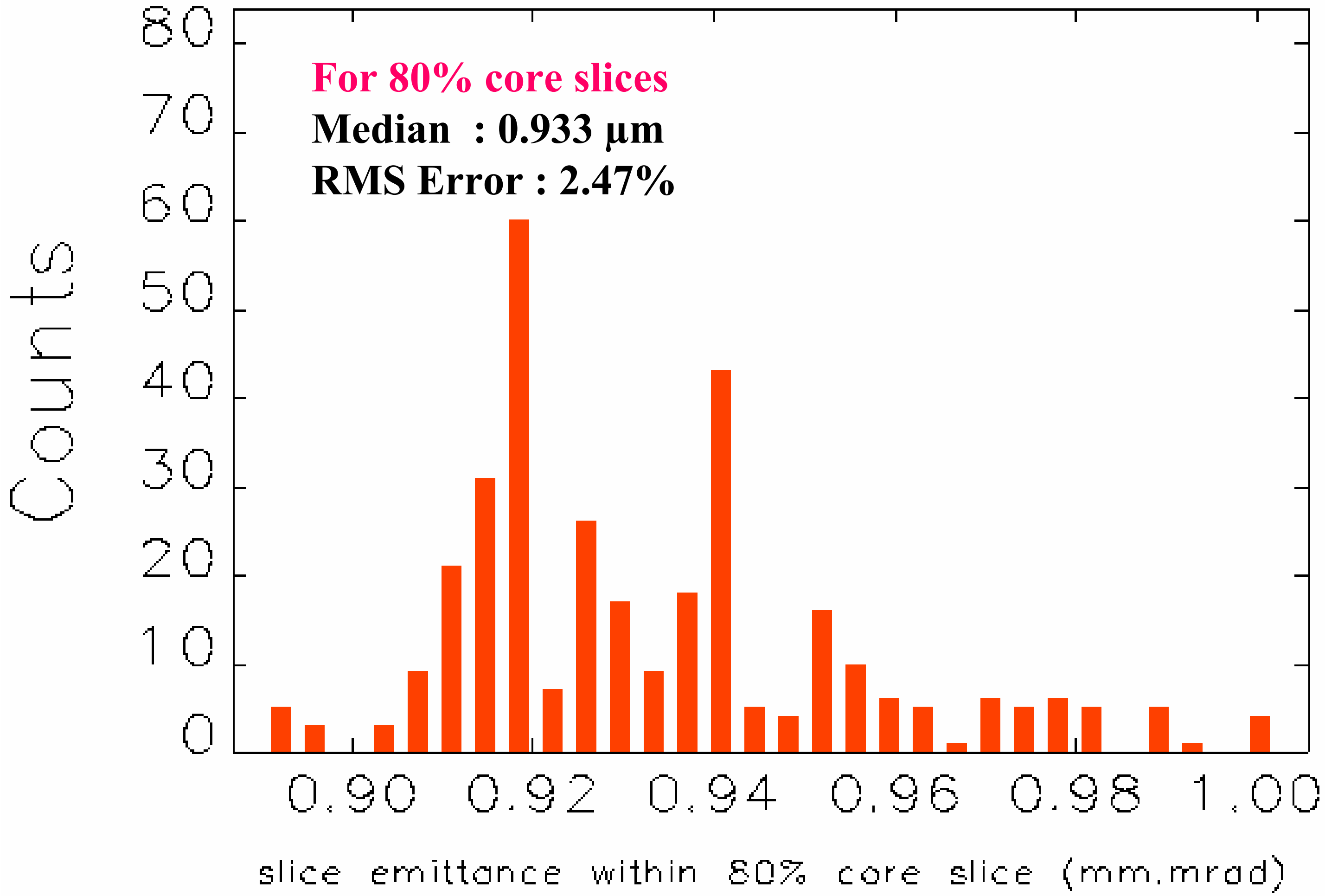

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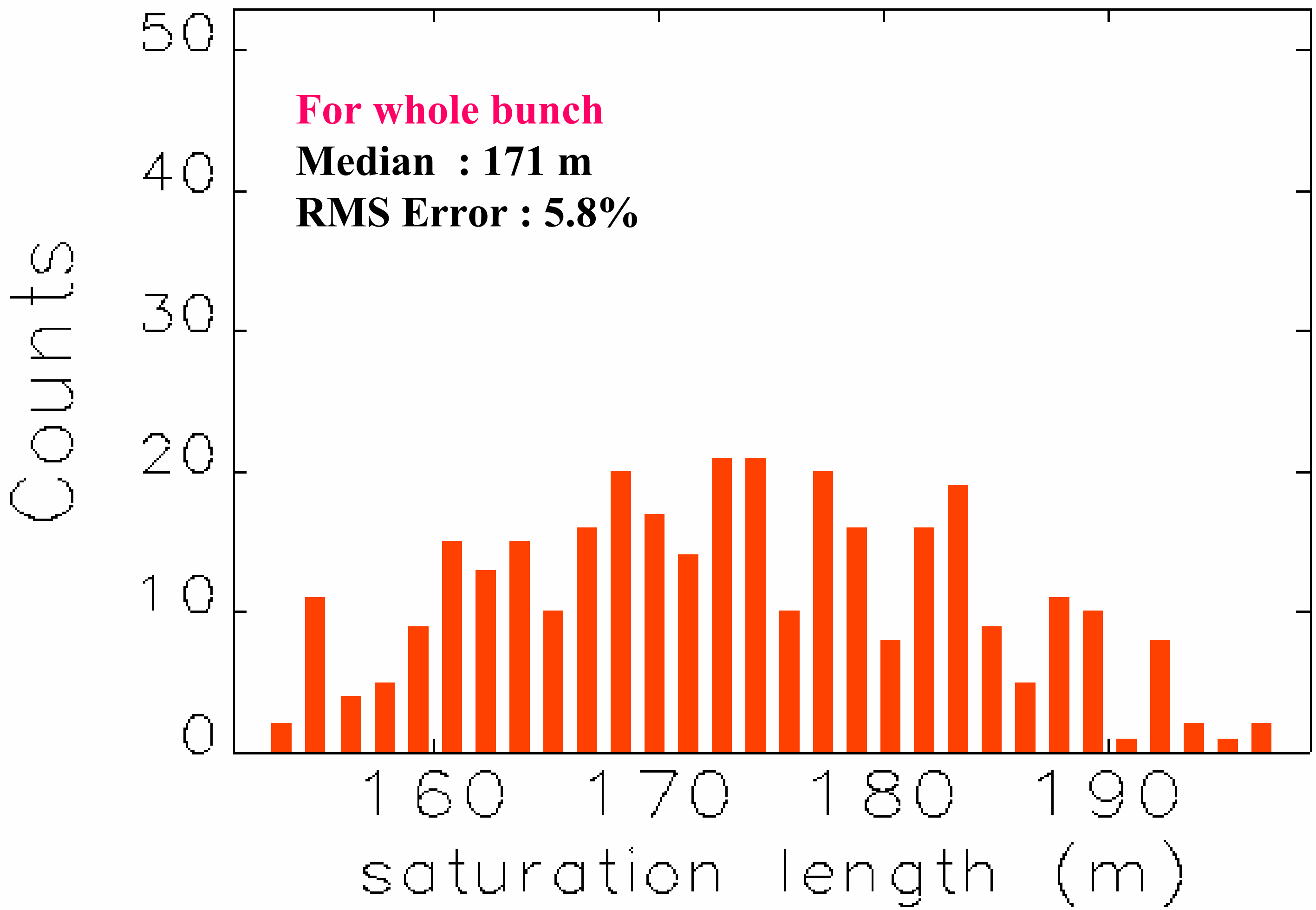

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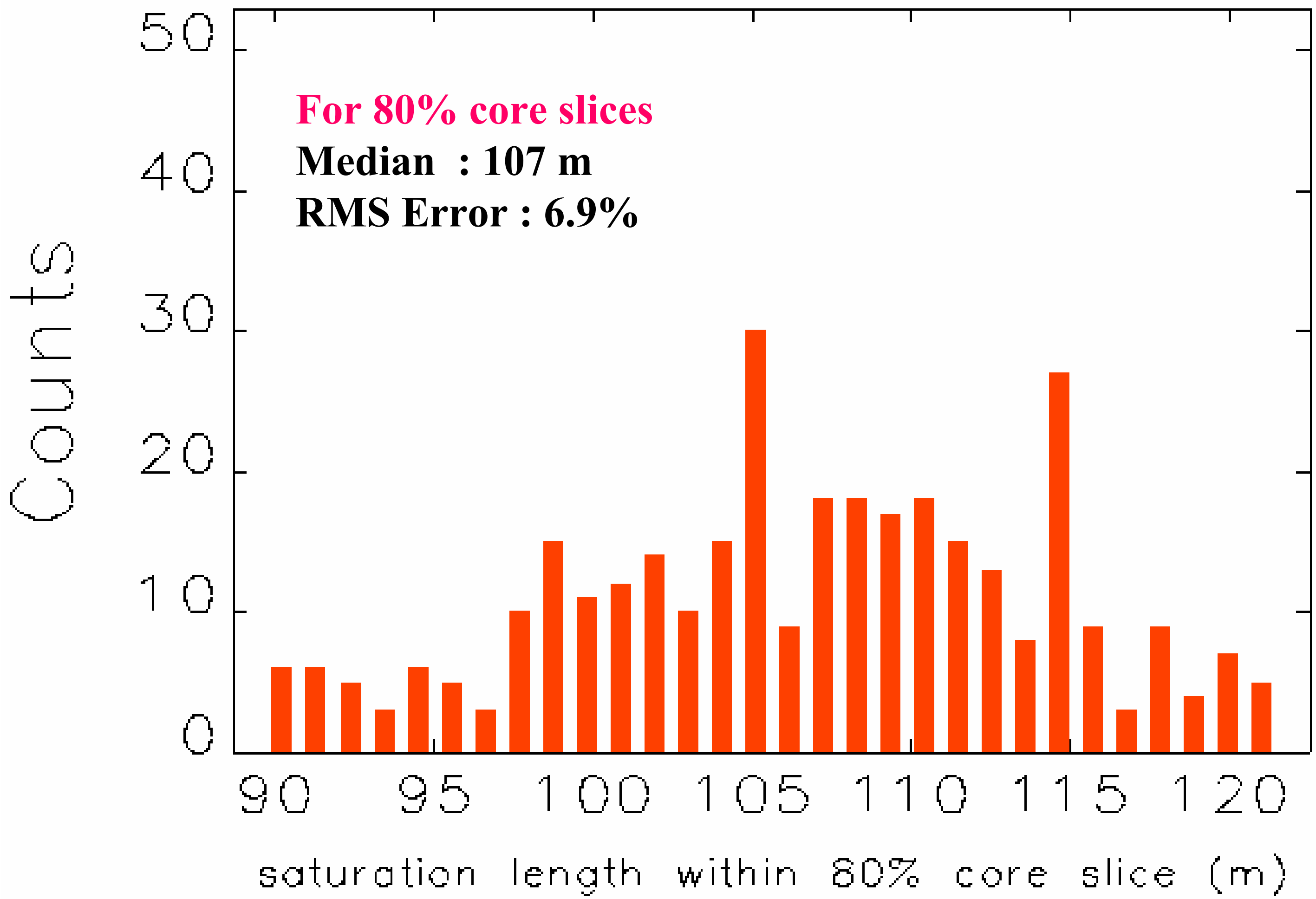

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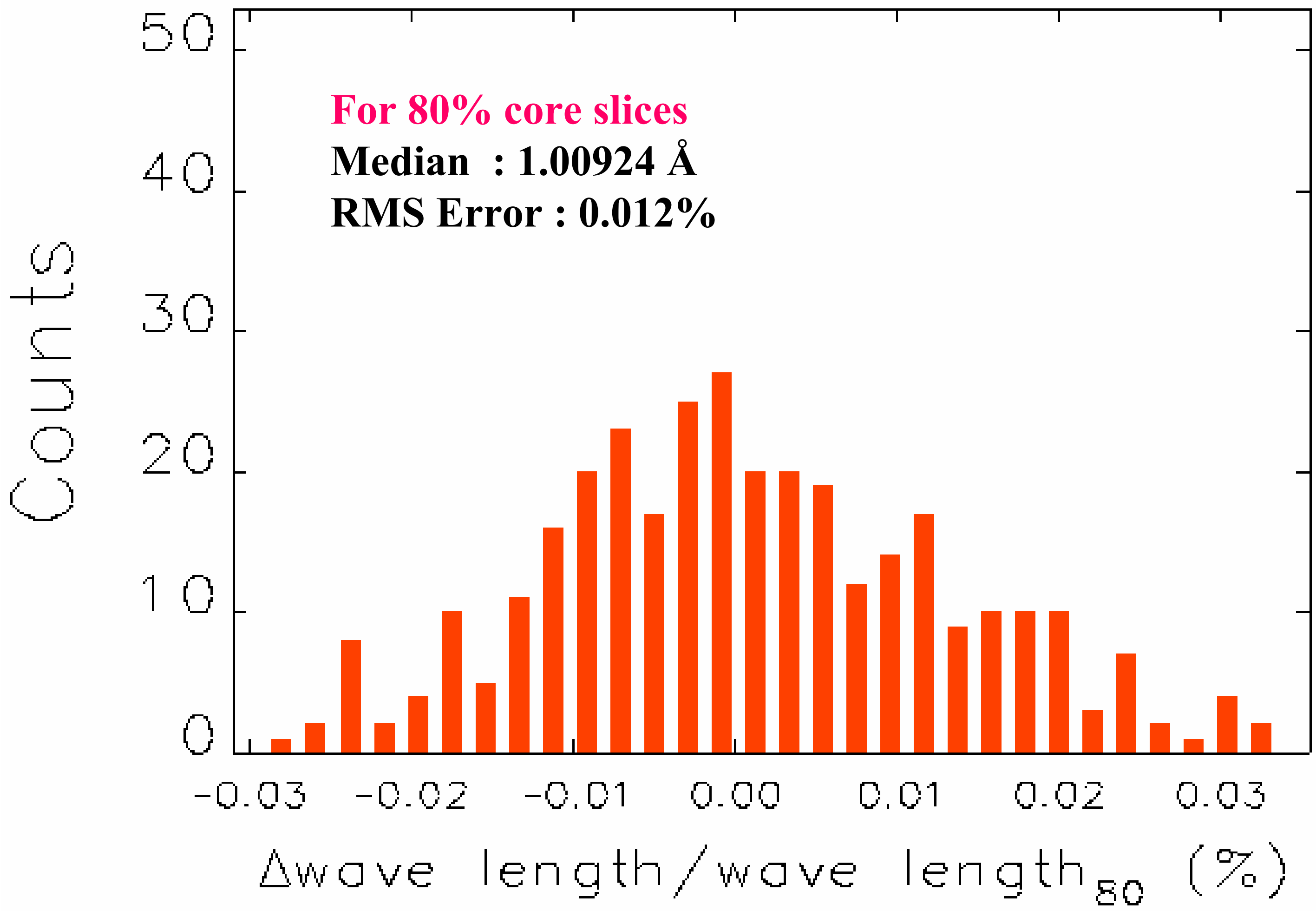

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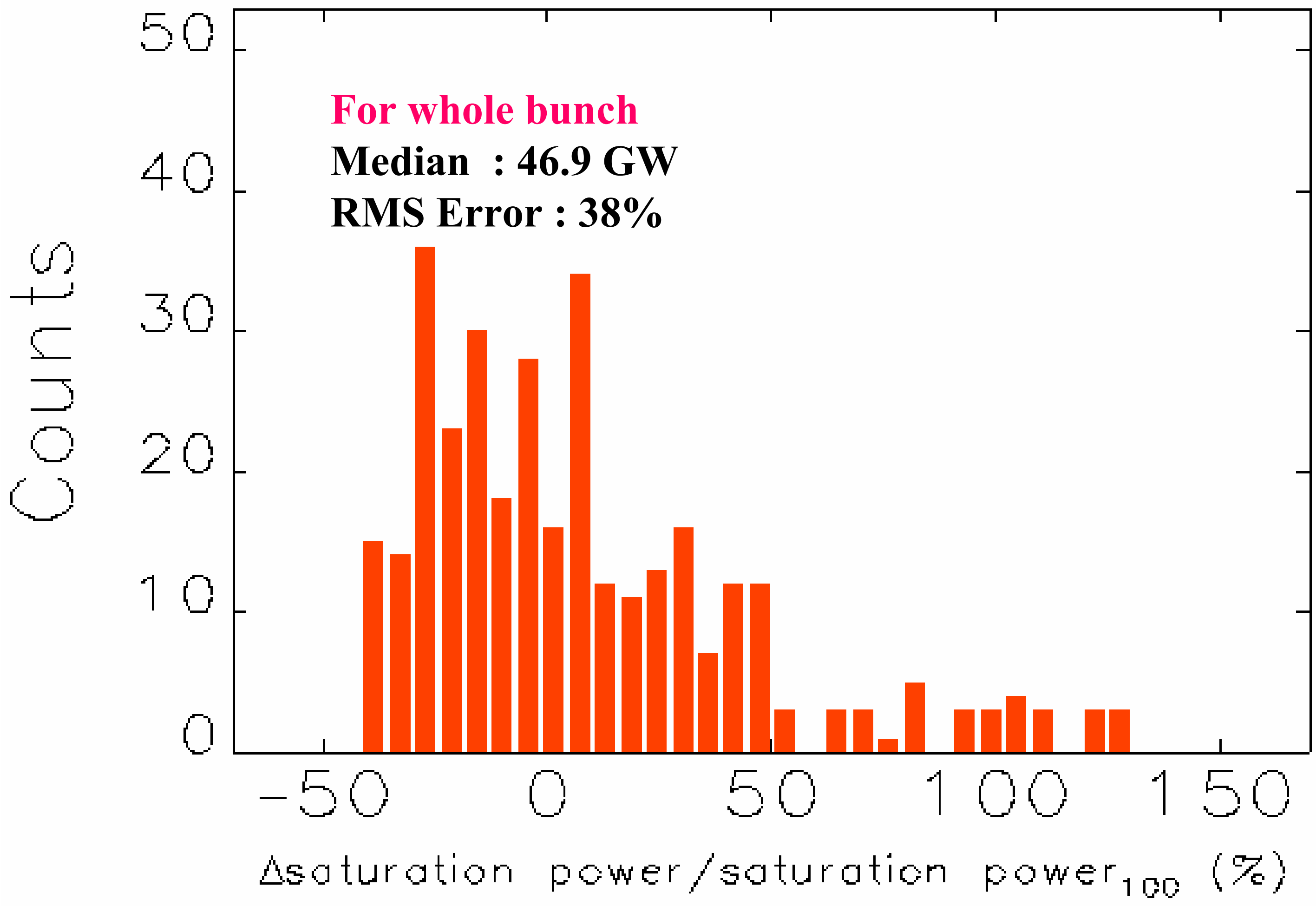

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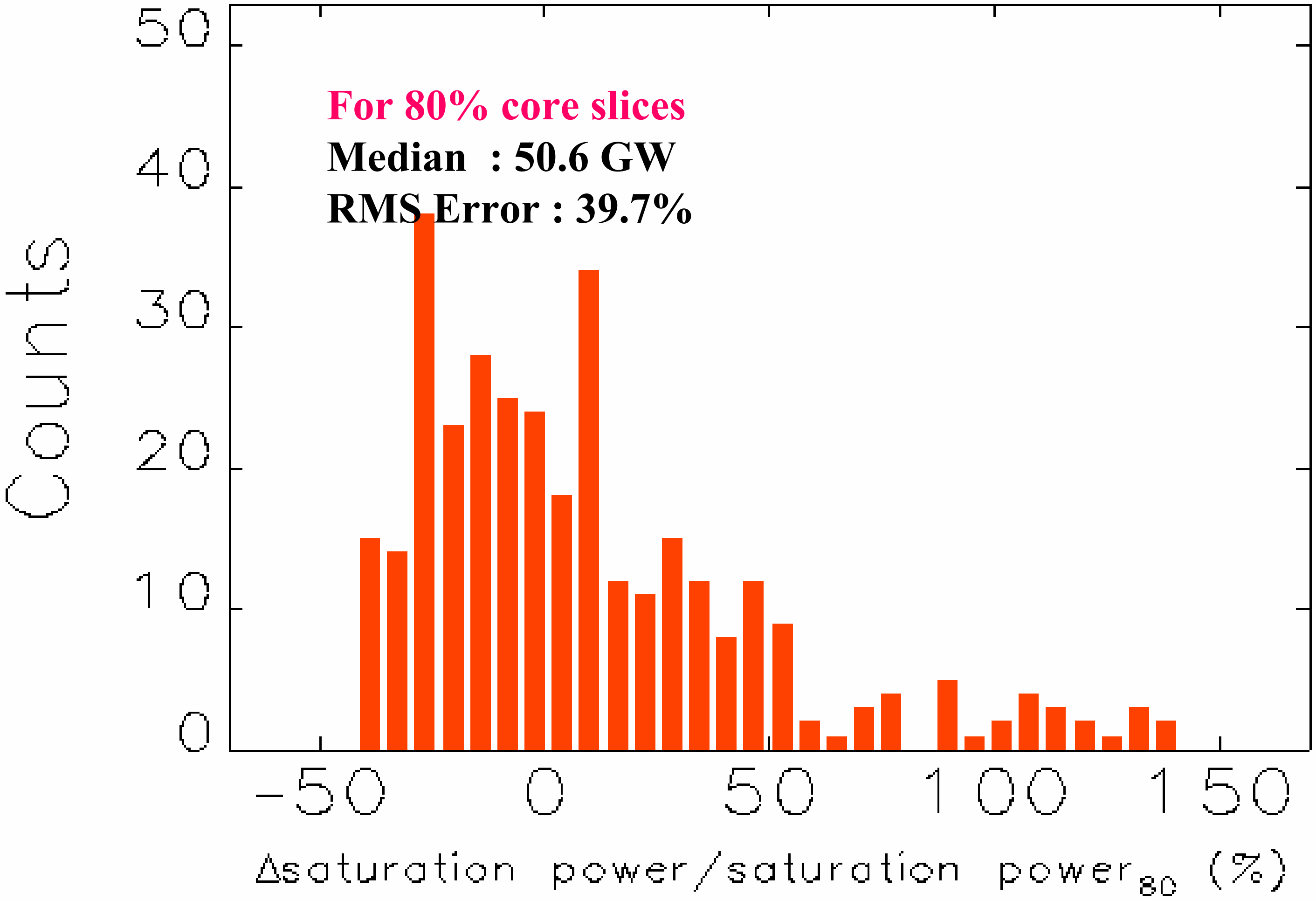
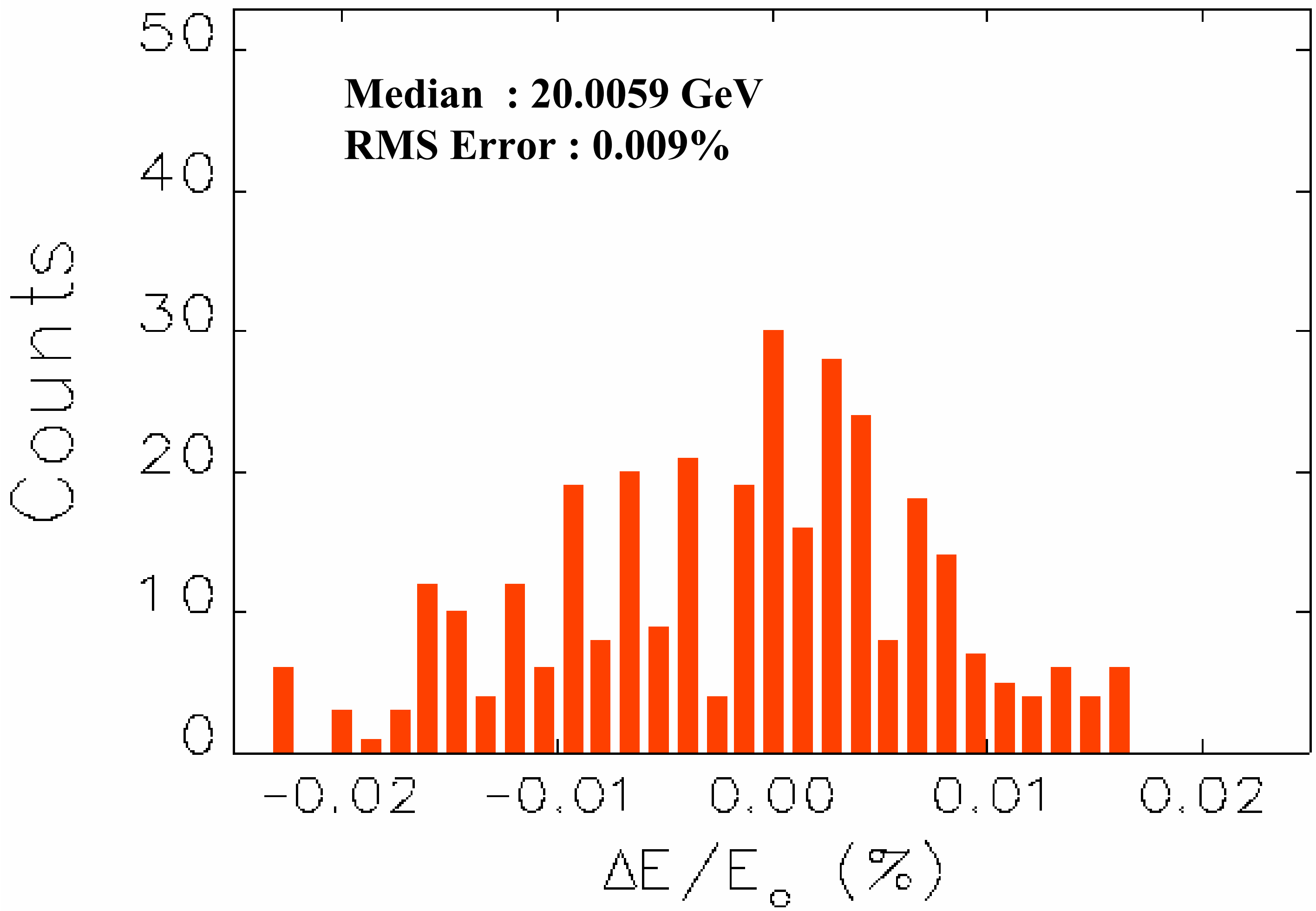
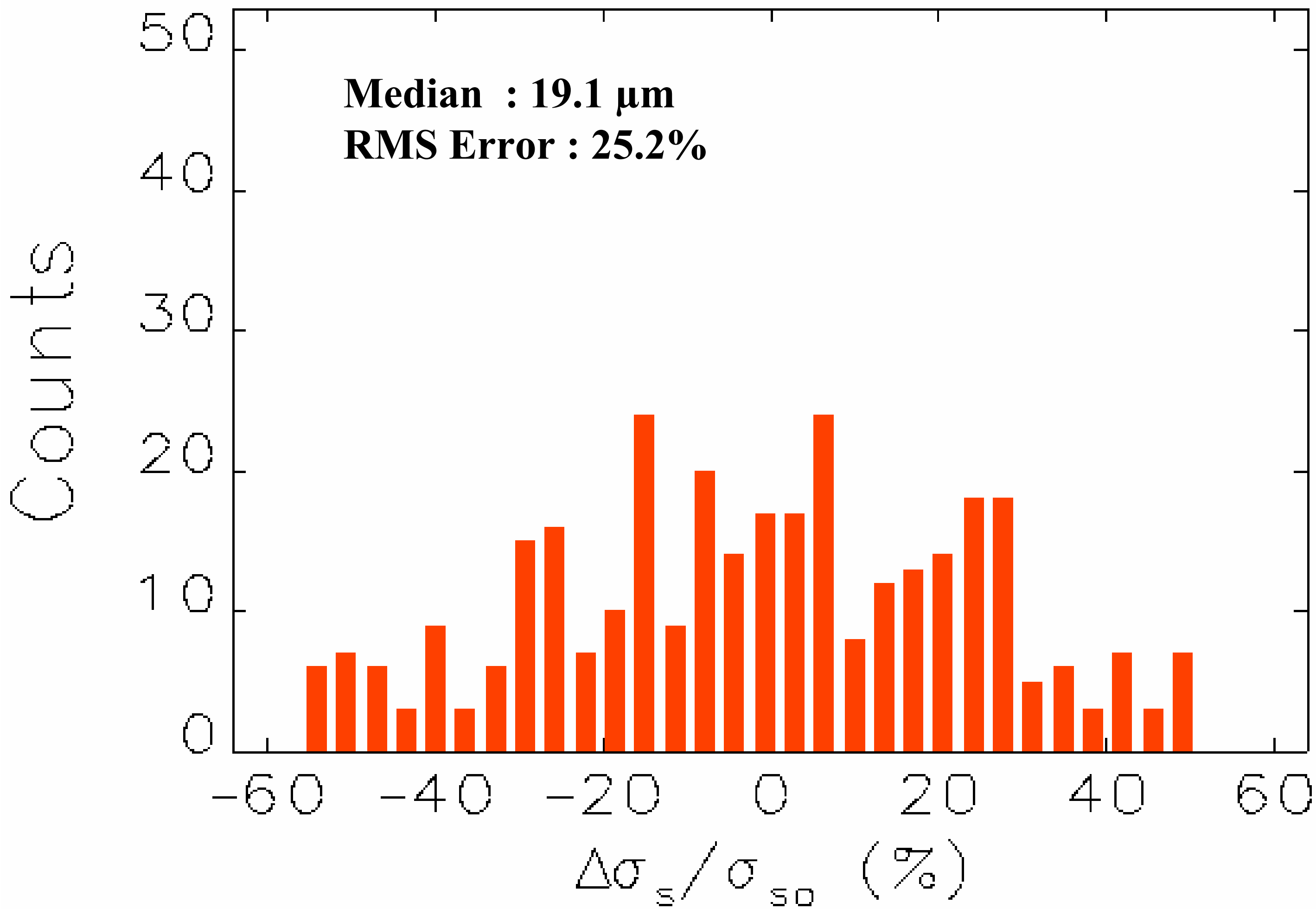


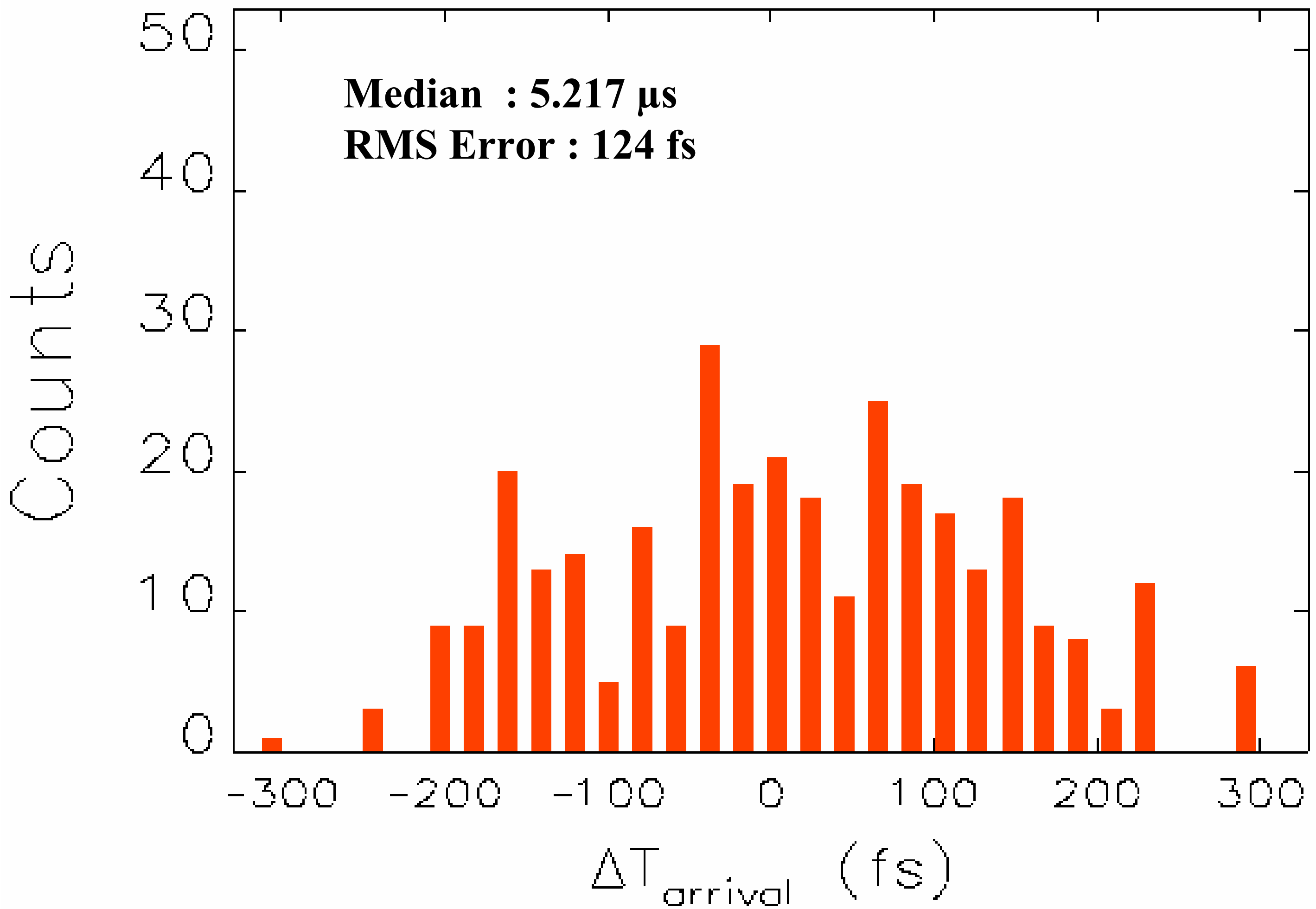
S2E Simulations with 327 Random Error Set B



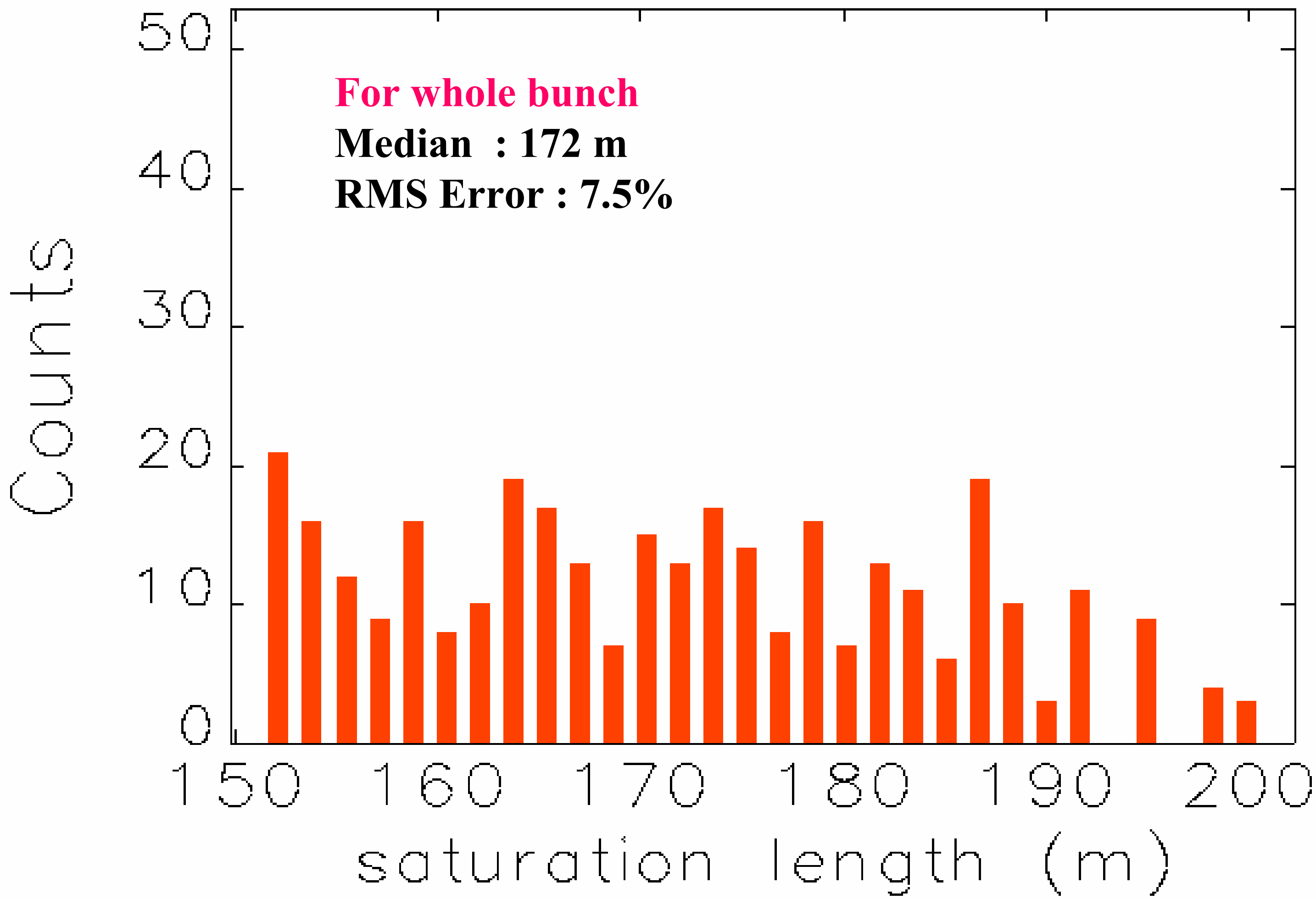
S2E Simulations with 327 Random Error Set B



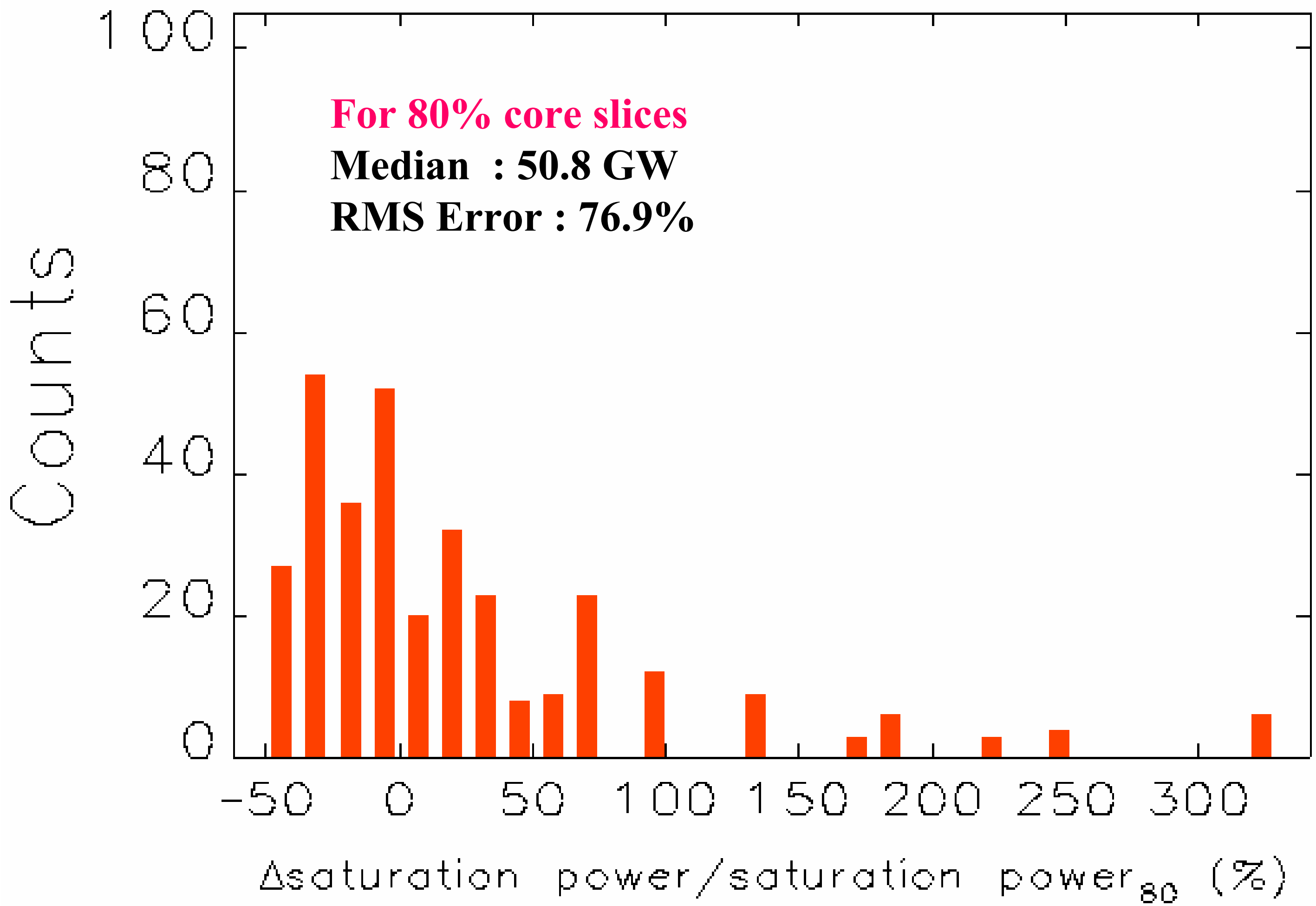
S2E Simulations with 327 Random Error Set B



S2E Simulations with 327 Random Error Set B



S2E Simulations with 327 Random Error Set B



Summary

After considering the space charge force at Gun, CSR in BCs, and geometric wakefields in linac, we have investigated jitter tolerance in the new TESLA XFEL lattice.

At the moment, it seems that we may control phase jitters by the multi-klystron operation before BC2.

The most difficult points are ACC234 phase and ACC5678 dV/V

We should discuss these results with respect to users aspect (specially power).

Acknowledgments

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