JPL

Space Interferometry Mission

SIM

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KITE and MAM Technology Milestones (last technology gates for phase B)

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Dec 2 ,2002

Outline

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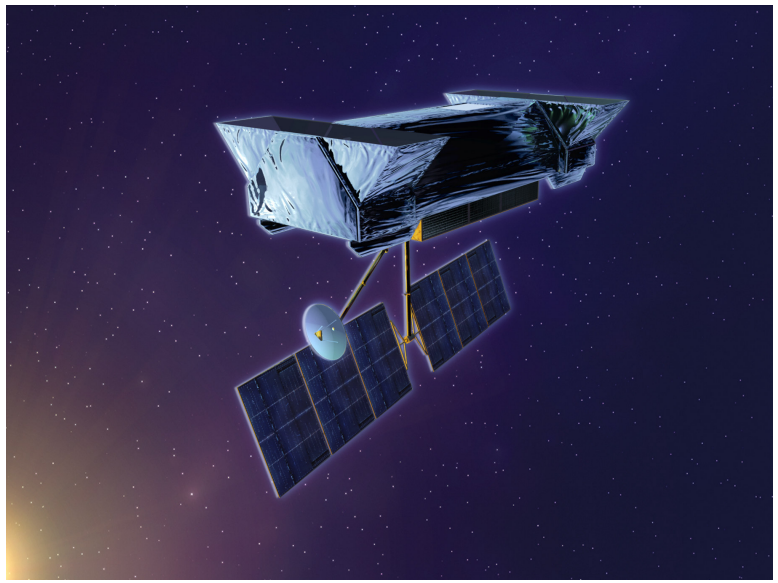
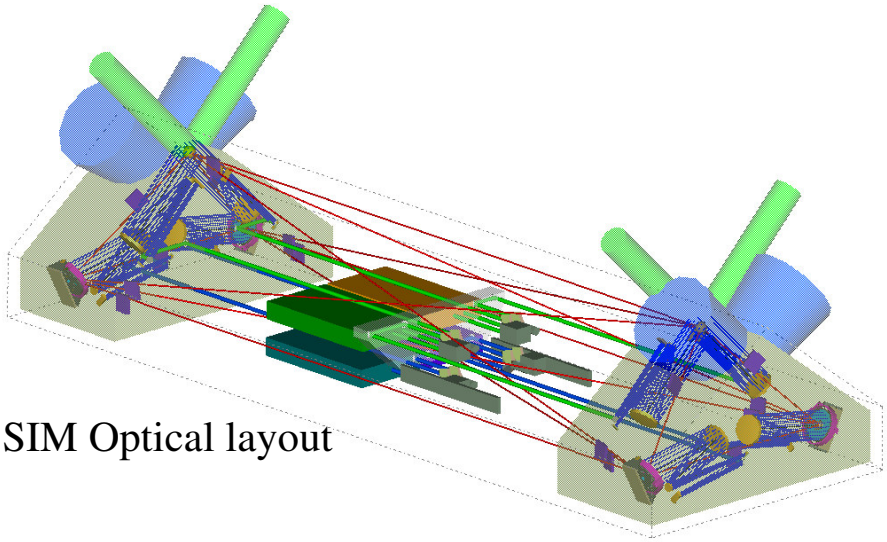
- KITE and MAM milestones, their relation to SIM
  - System level demonstration of the basic 3uas narrow angle requirement
- Commom concepts
  - SIM error budget, adopted to MAM and KITE
  - Field independent and Field dependent errors
  - SIM observation sequence, how data is analysed
- KITE milestone
  - Subsystems, Absolute Metrology,Metrology Pointing
  - Field dependent systematic errors
  - Experiment results
- MAM milestone
  - MAM Experiment description
  - Progression of experiments
  - MAM experiment results
- Summary

SIM





SIM Optical layout

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- SIM consists of 1 science interferometer (and spare) and 2 guide interferometers
  - The baselines of all the interferometers are nominally parallel
- A laser metrology optically ties the guide interferometers to the science interferometer(s)

- The guide interferometer locks onto bright (7mag) guide stars and provides attitude knowledge of the guide baseline (and also the science baseline) at the uas level.

How SIM Works (1)

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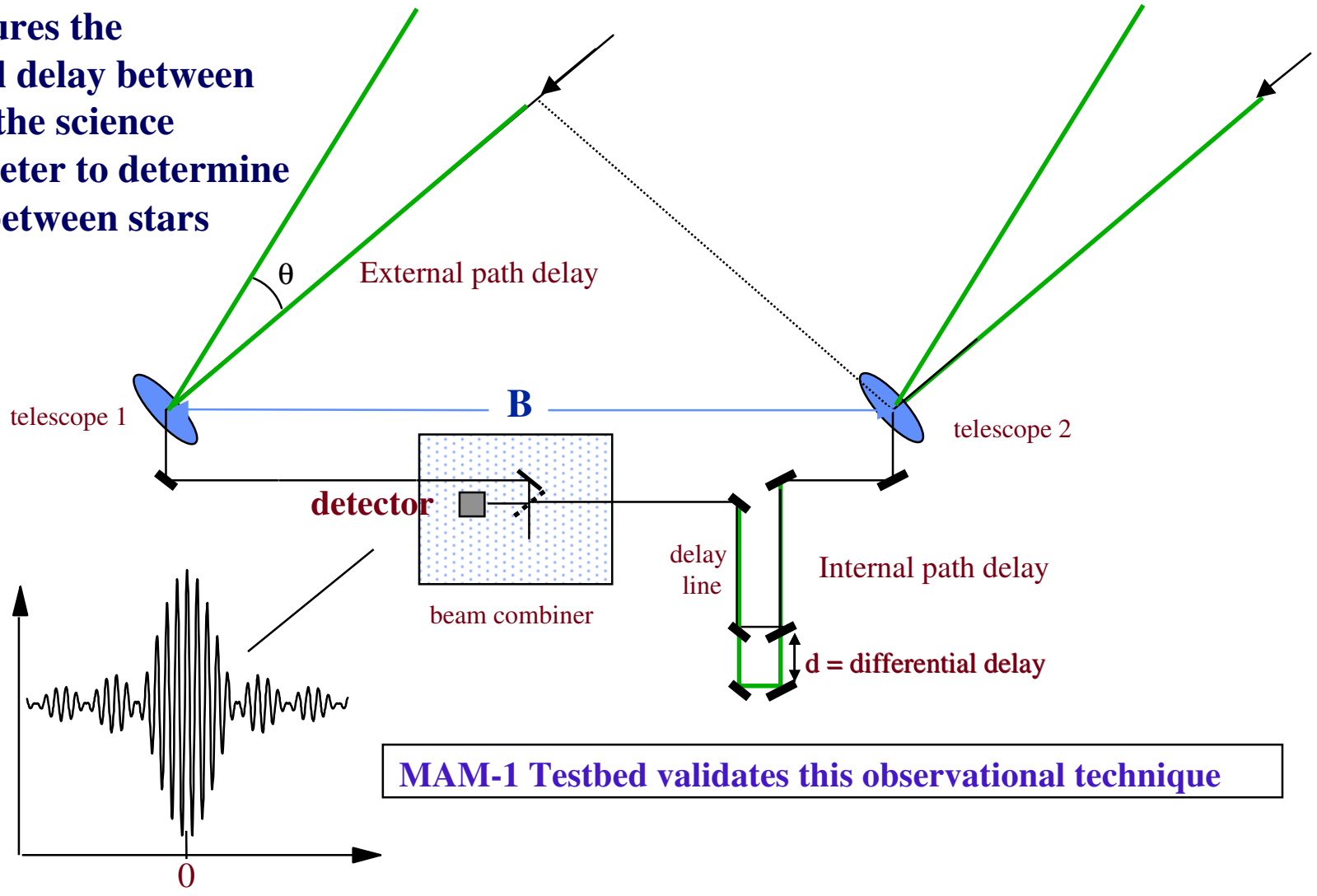
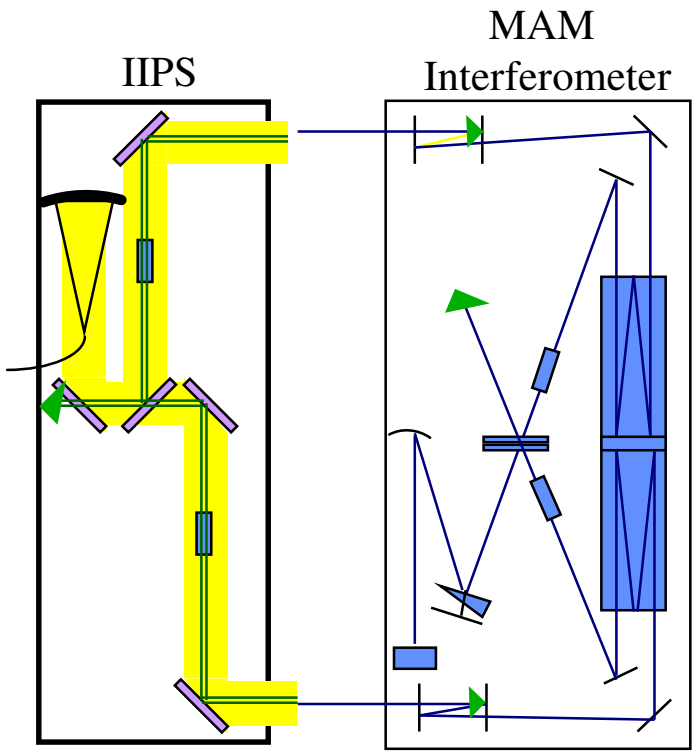
SIM measures the differential delay between stars with the science interferometer to determine the angle between stars



MAM-1 Testbed validates this observational technique

Microarcsecond Metrology Testbed

- Demonstration of SIM's fundamental measurement technique -- use of differential delay and stellar fringe position to measure relative star positions
- Inverse interferometer pseudostar (IIPS) articulates over MAM field of regard
  - MAM measures IIPS motion
  - IIPS internal metrology provides consistency test
- Technology Gate #4 -- Show the rms error meets the flight "basic requirement" for the narrow angle case:
  - 0.5 deg articulation



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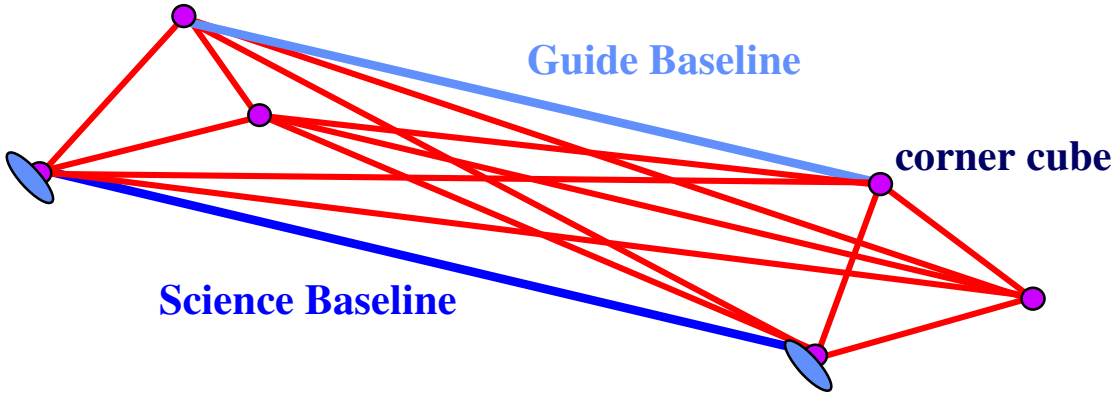
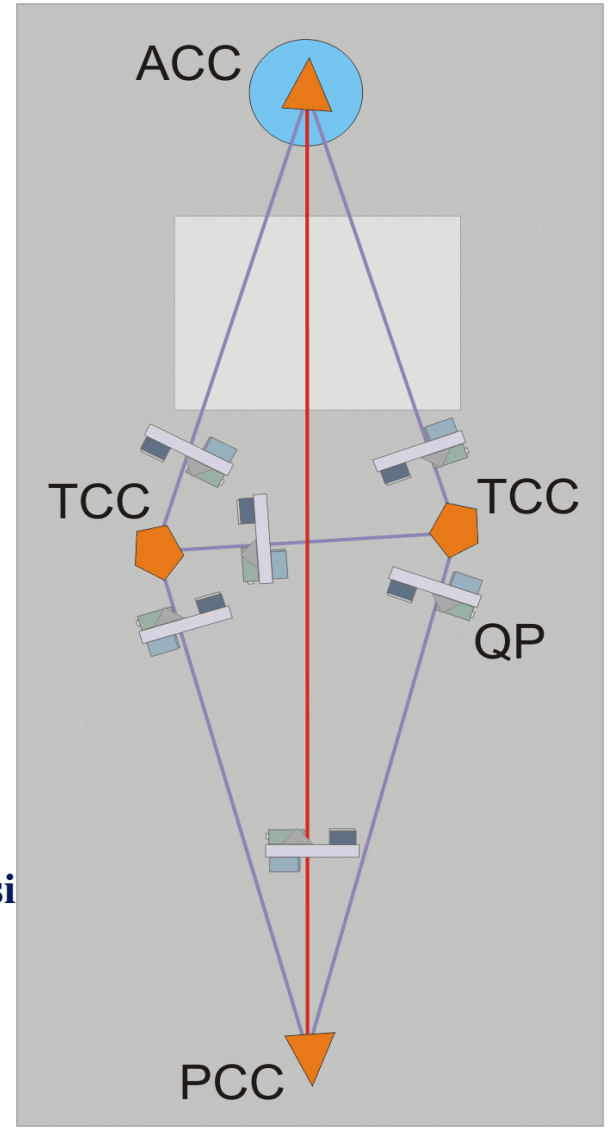
Kite Testbed





- Demonstration of external metrology truss in planar configuration
  - 4 fiducials (2 corner cubes + 2 triple corner cubes)
  - 6 metrology gauges connecting the 4 vertices
- Redundant truss allows a consistency experiment (5vs1)
- Account for CC imperfections using CC calibration and model
- Technology Gate #3 -- Show the rms error meets flight "basi requirement" for the various cases of:
  - 0.5 deg articulation (Narrow Angle)
  - 7.5 deg articulation (Wide Angle)
  - Simulated PSS thermal deformation

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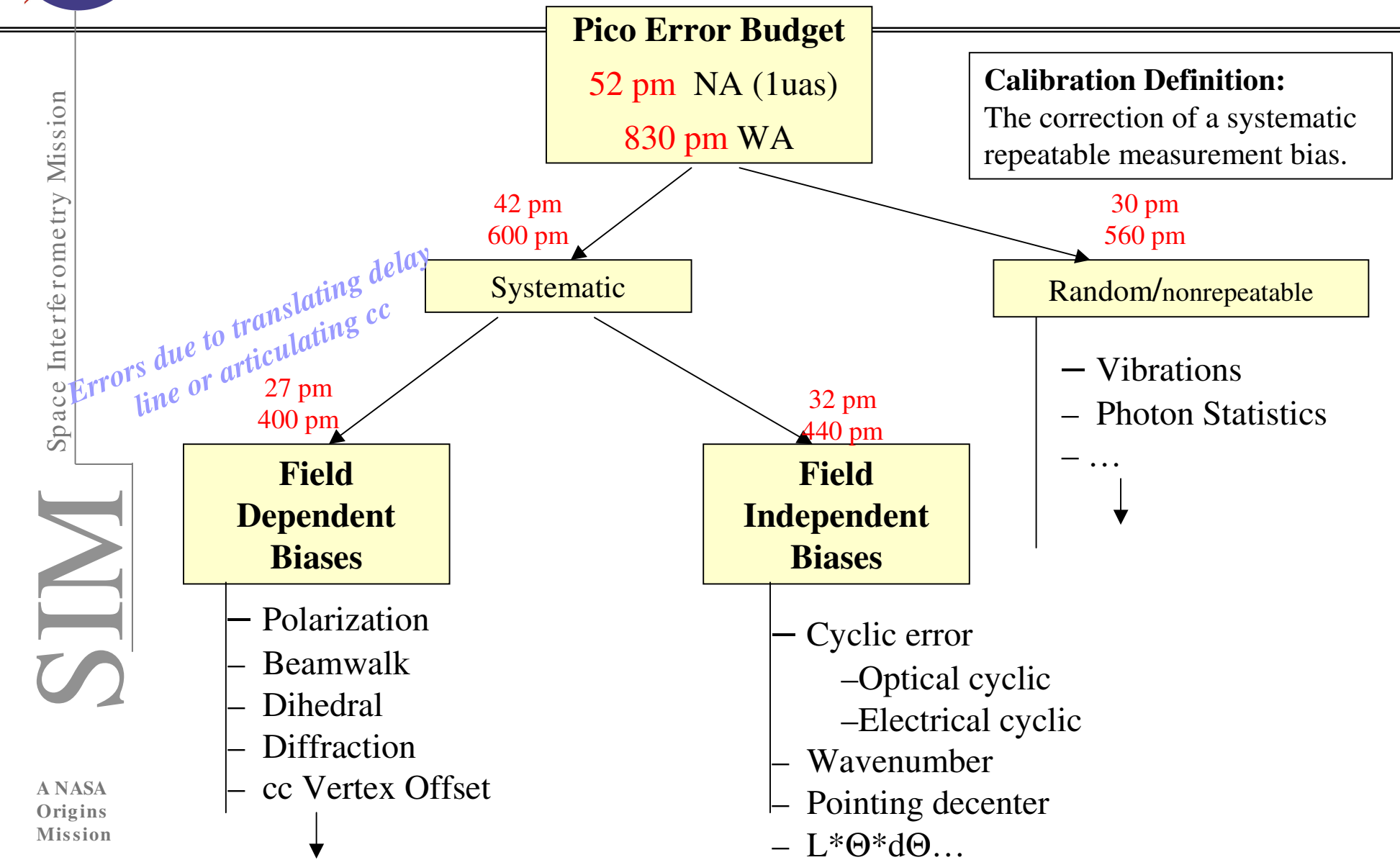
MAM TA Error Budget



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SIM Observation Scenarios

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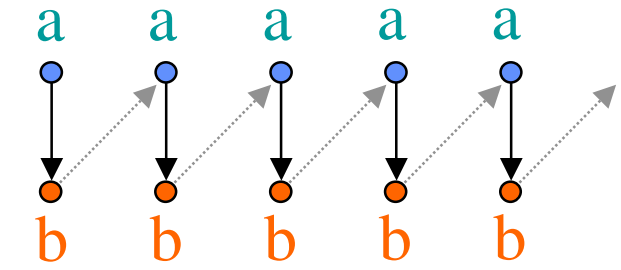
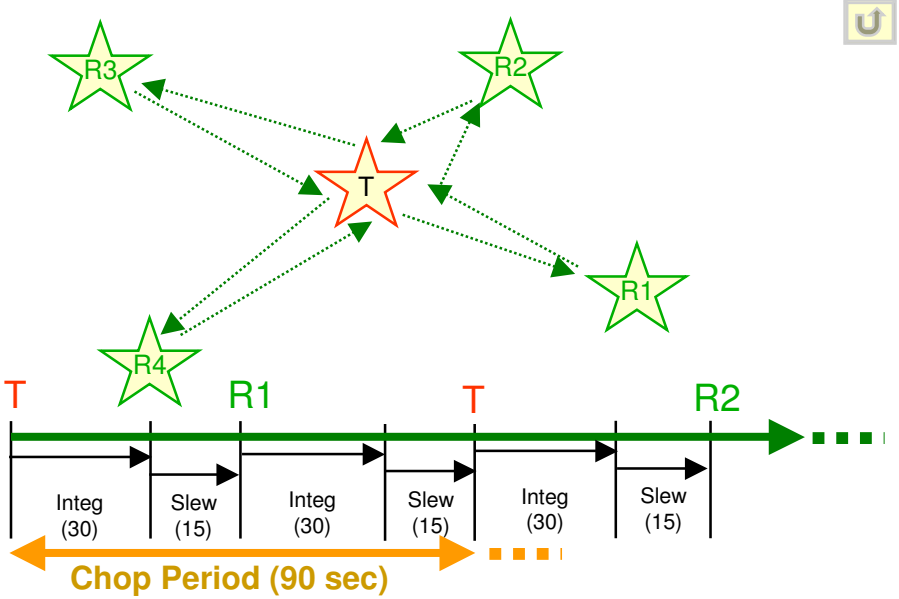
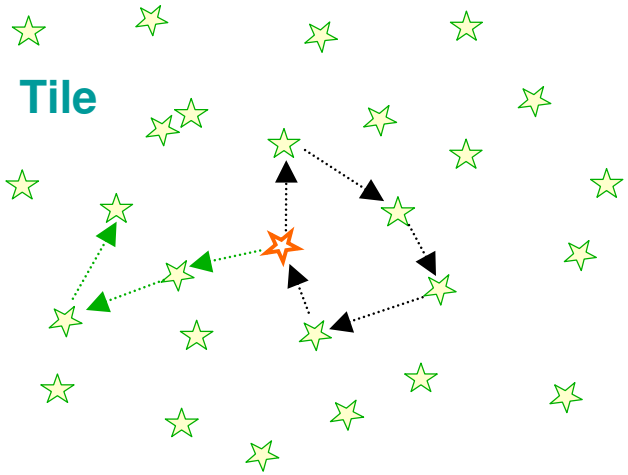
Narrow Angle

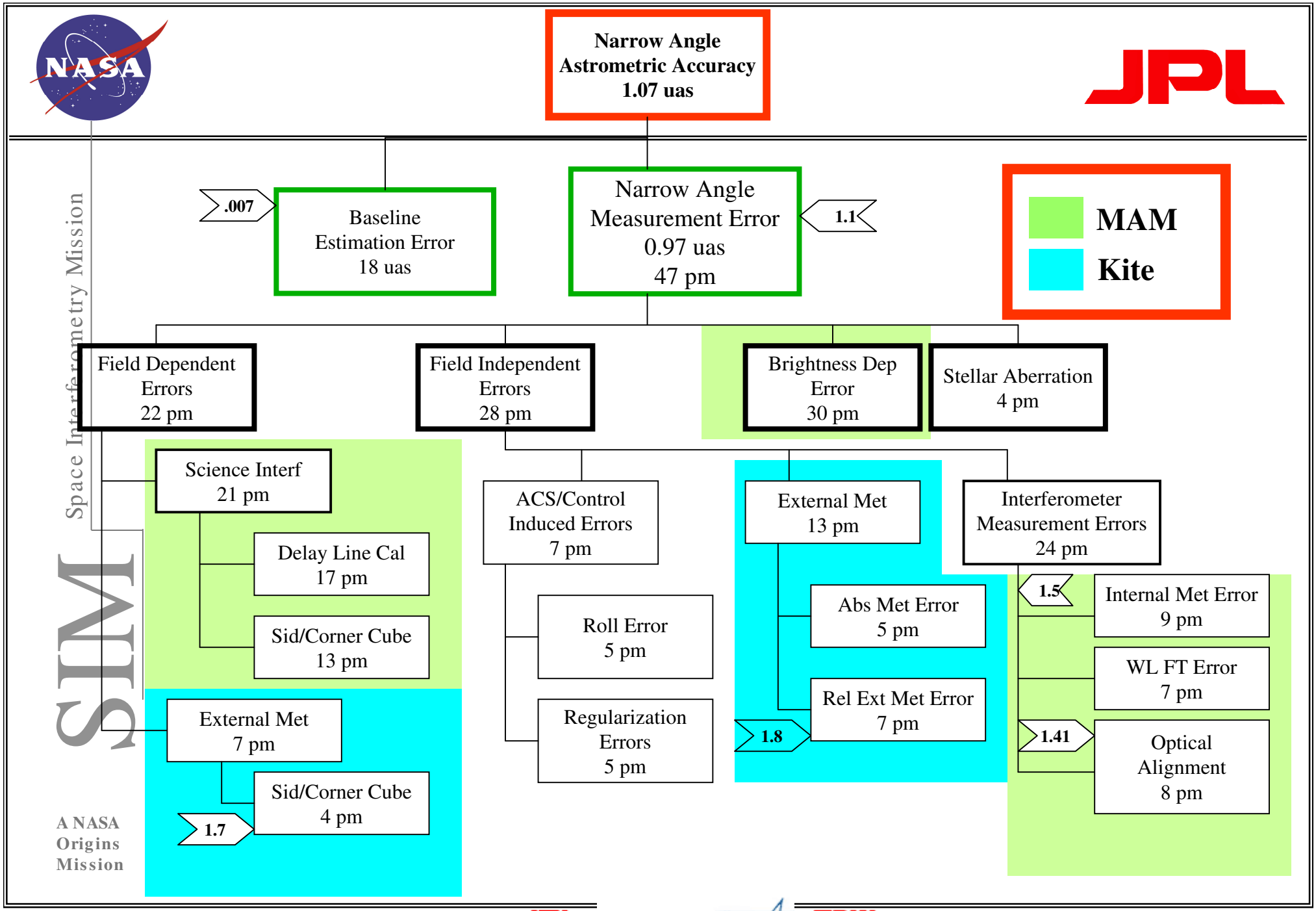




Tile



Wide Angle Measurement


Narrow Angle
Astrometric Accuracy
1.07 uas
.007
Baseline
Estimation Error
18 uas
Narrow Angle
Measurement Error
0.97 uas
47 pm
1.1
MAM
Kite
Field Dependent
Errors
22 pm
Field Independent
Errors
28 pm
Brightness Dep
Error
30 pm
Stellar Aberration
4 pm
Science Interf
21 pm
Delay Line Cal
17 pm
Sid/Corner Cube
13 pm
ACS/Control
Induced Errors
7 pm
Roll Error
5 pm
Regularization
Errors
5 pm
External Met
13 pm
Abs Met Error
5 pm
Rel Ext Met Error
7 pm
1.8
Interferometer
Measurement Errors
24 pm
1.5
Internal Met Error
9 pm
WL FT Error
7 pm
1.41
Optical
Alignment
8 pm
External Met
7 pm
Sid/Corner Cube
4 pm
1.7
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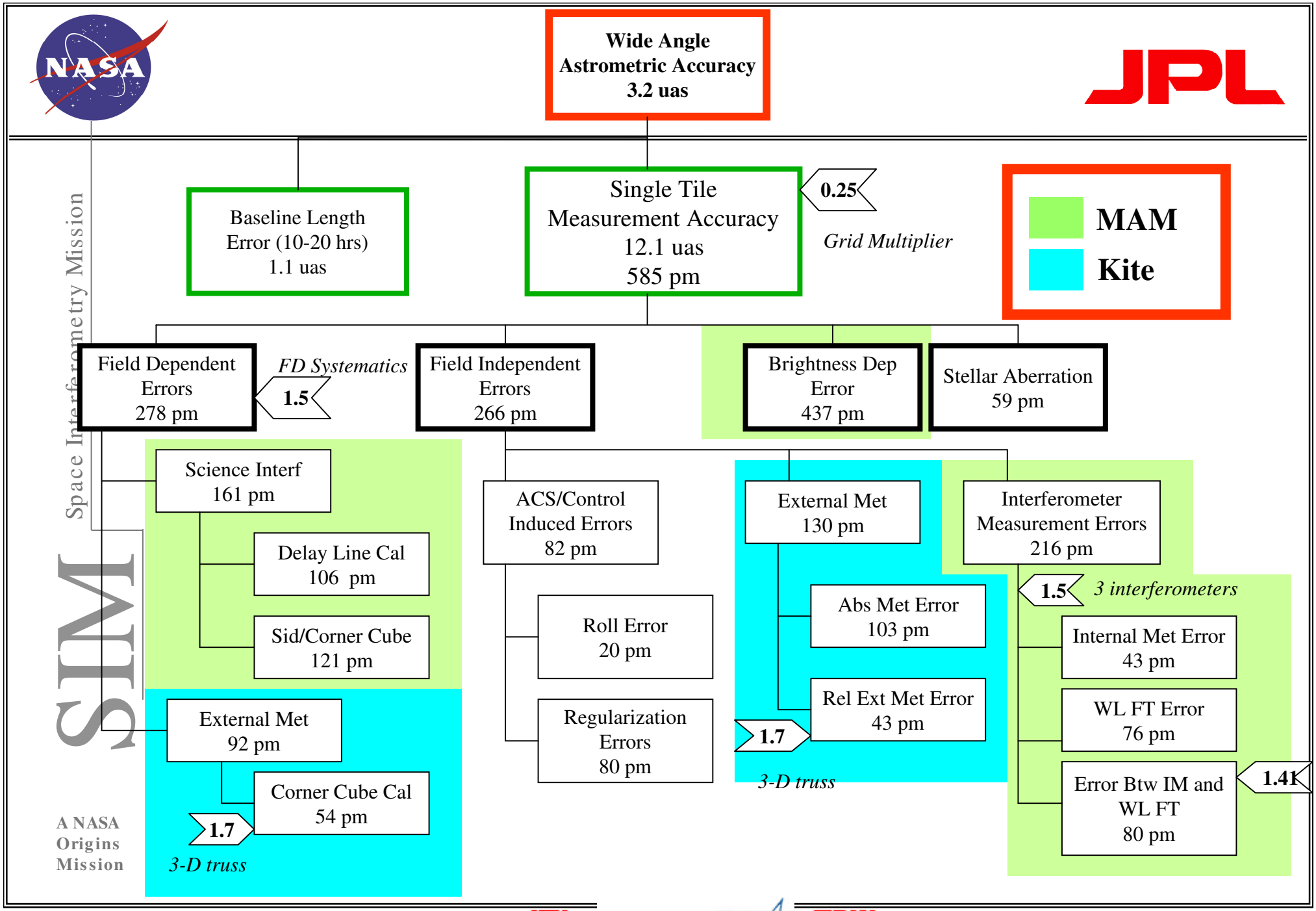
Wide Angle
Astrometric Accuracy
3.2 uas
Baseline Length
Error (10-20 hrs)
1.1 uas
Single Tile
Measurement Accuracy
12.1 uas
585 pm
0.25
Grid Multiplier
MAM
Kite
Field Dependent
Errors
278 pm
FD Systematics
1.5
Field Independent
Errors
266 pm
Brightness Dep
Error
437 pm
Stellar Aberration
59 pm
Space Interferometry Mission
SIM
Science Interf
161 pm
Delay Line Cal
106 pm
Sid/Corner Cube
121 pm
External Met
92 pm
Corner Cube Cal
54 pm
1.7
3-D truss
ACS/Control
Induced Errors
82 pm
Roll Error
20 pm
Regularization
Errors
80 pm
External Met
130 pm
Abs Met Error
103 pm
Rel Ext Met Error
43 pm
1.7
3-D truss
Interferometer
Measurement Errors
216 pm
1.5
3 interferometers
Internal Met Error
43 pm
WL FT Error
76 pm
Error Btw IM and
WL FT
80 pm
1.41
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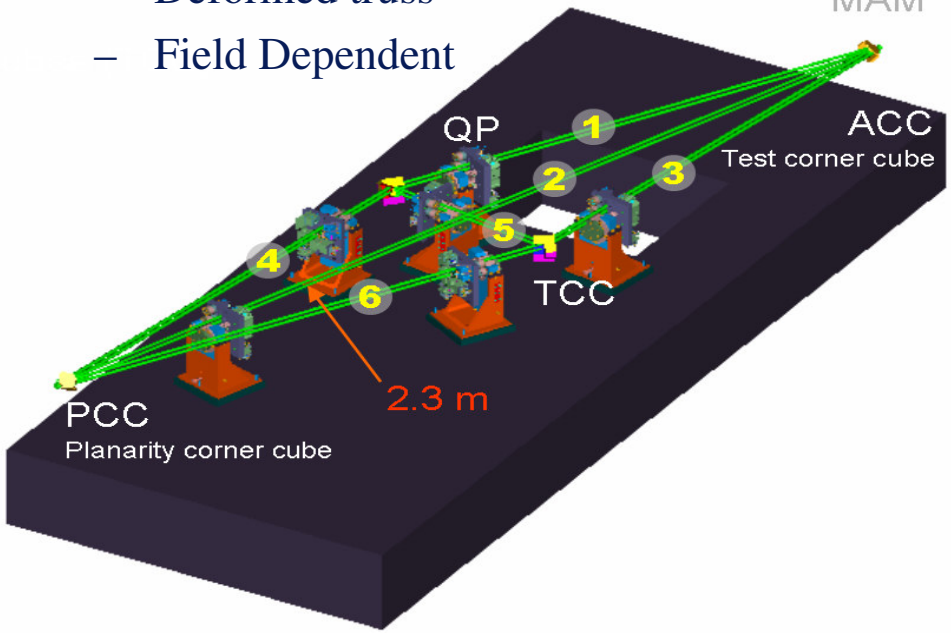
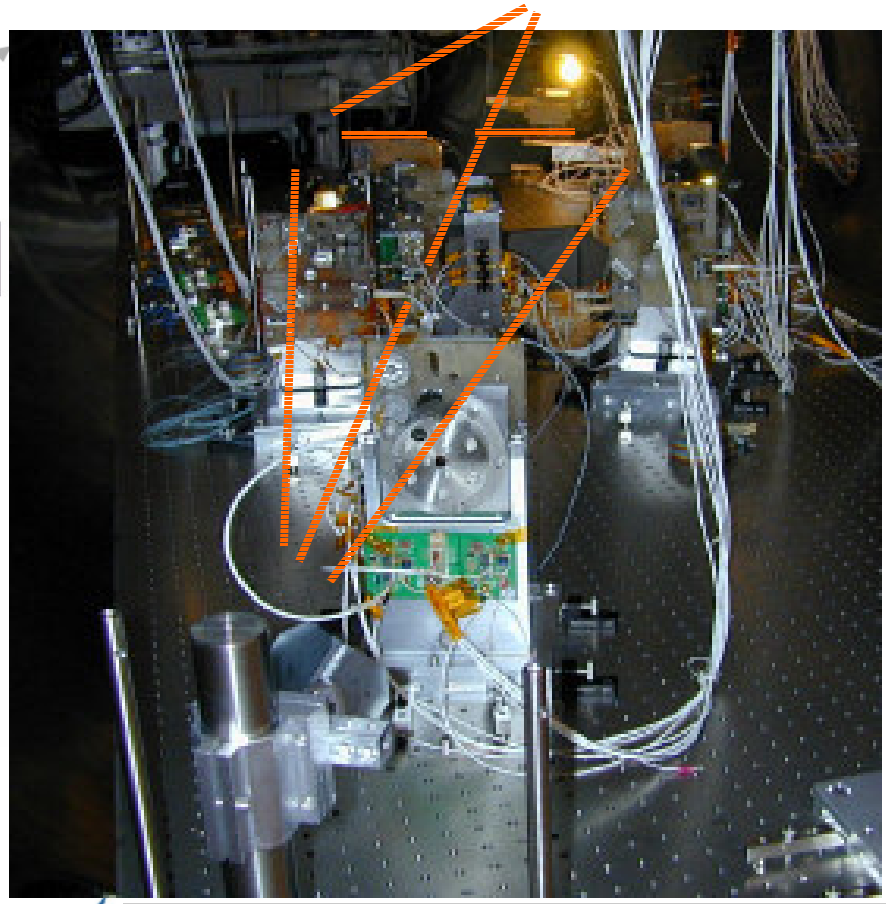
Kite Testbed Configuration

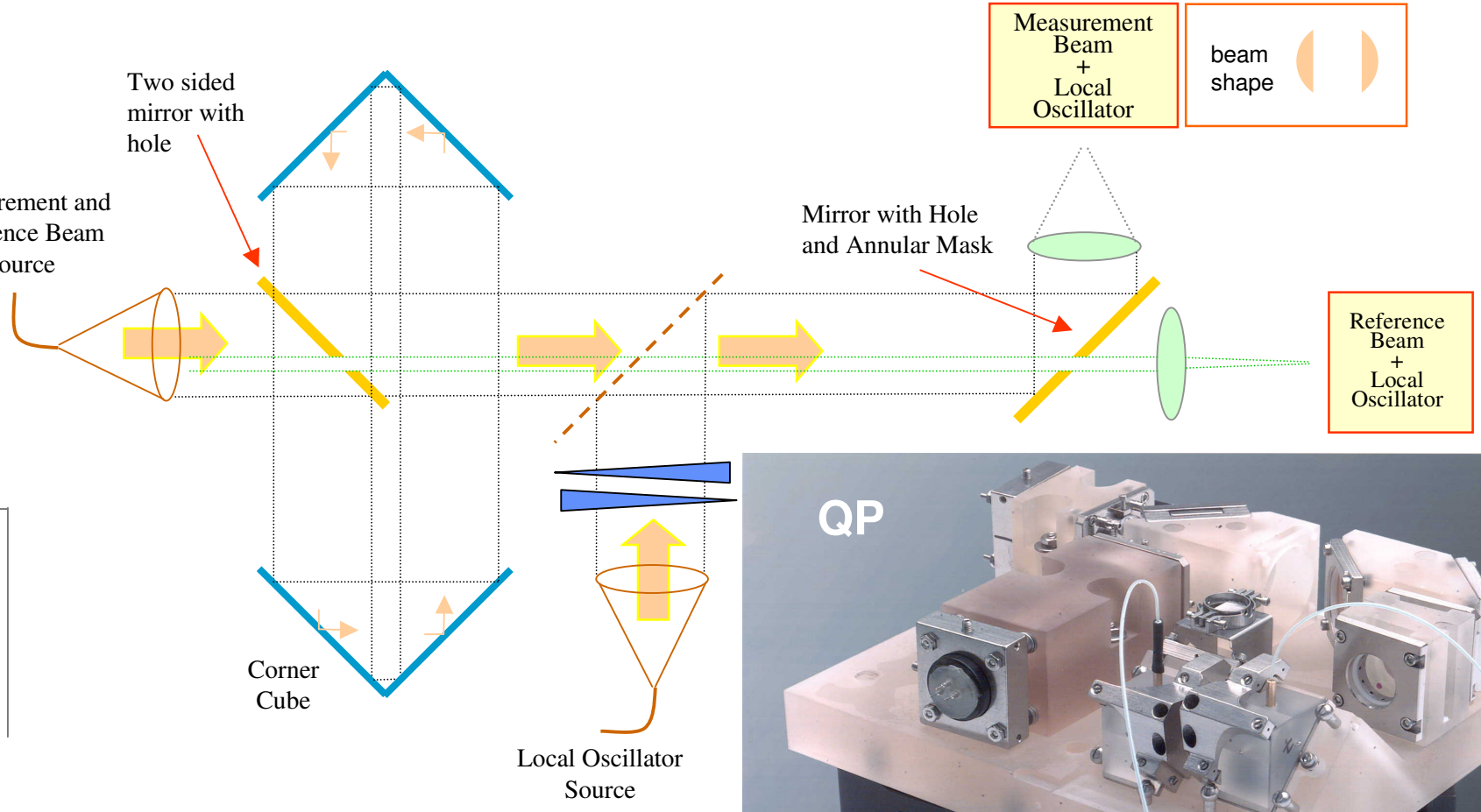
- Component/subsystem Requirements
  - Absolute metrology 3 um (goal) 10um (this milestone)
  - Metrology pointing (1urad goal)
- System level relative metrology (picometer level accuracy)
  - Field independent (quasi static)
  - Deformed truss
  - Field Dependent





- Kite table is situated in the MAM vacuum chamber
- Large aspect ratio dictated by triple corner cube constraints

Kite Beam Launcher (QP)



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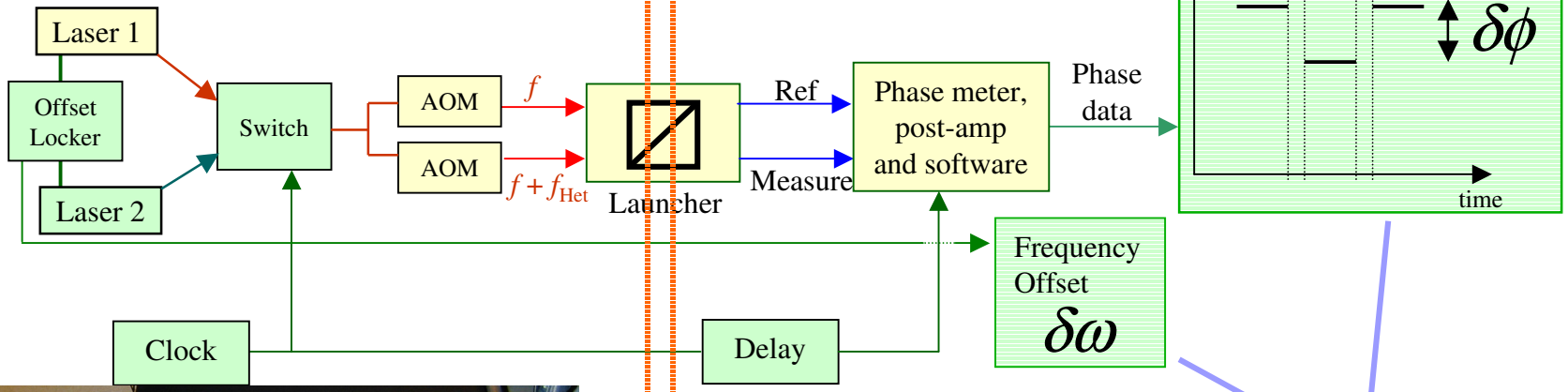
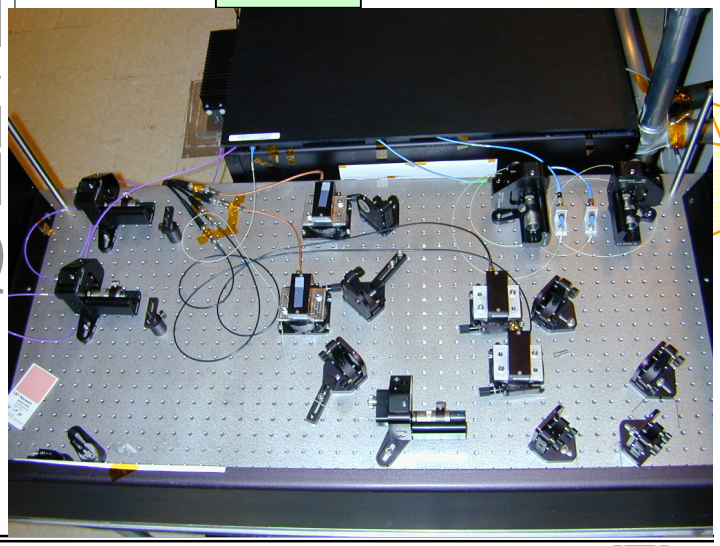
Absolute Metrology

- SIM external metrology requires knowledge of absolute distances to 3 µm
- For Kite, the requirement is 10 µm
- Based on Switched Heterodyne Architecture





L=?

$$L_{meas} = \frac{c}{2} \cdot \frac{\delta\phi}{\delta\omega}$$

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Absolute Metrology Data

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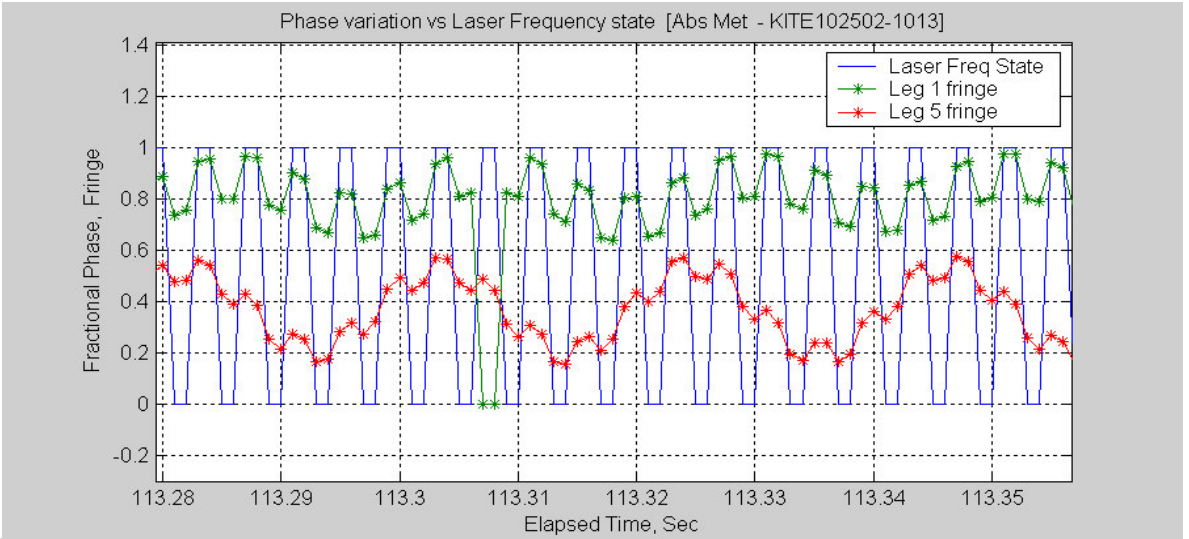
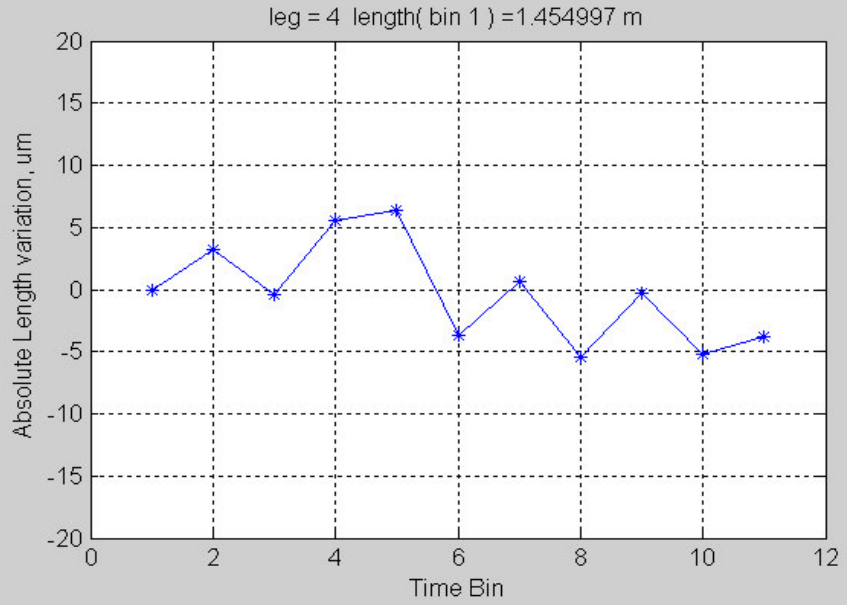
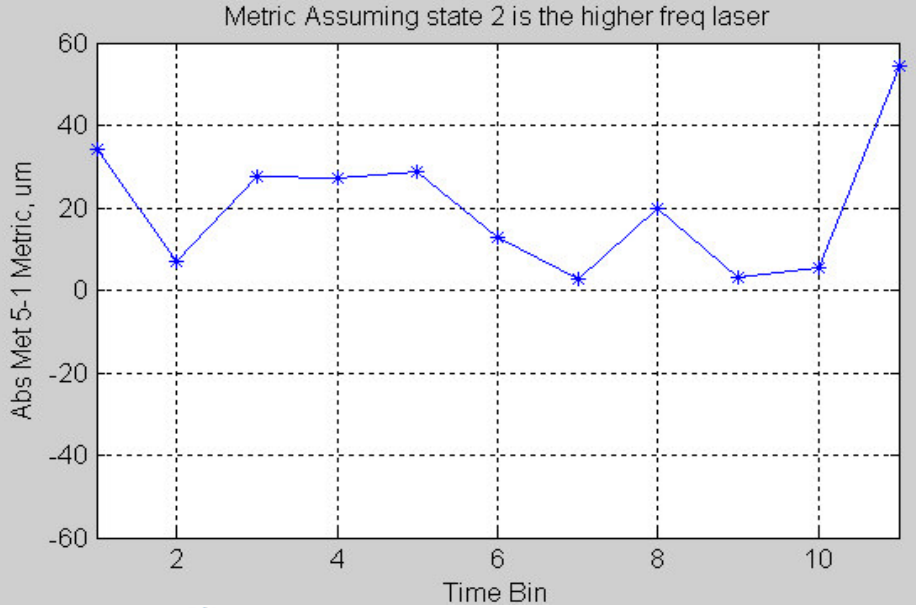
- Switch lasers and measure phase change
- Account for phase wrapping
- Use redundancy as a diagnostic
  - "5-1 Metric"
- Typical performance:
  - ~ 10 - 15um rms / gauge





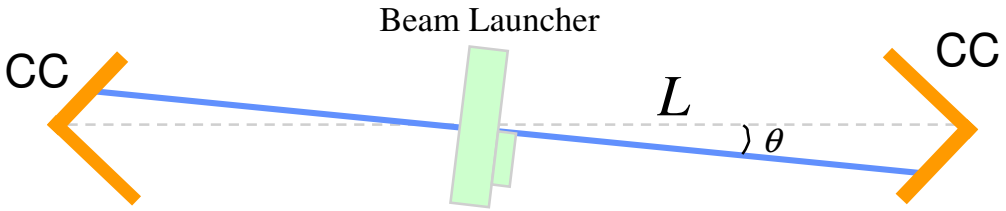


Beam Launcher Pointing

- Precision metrology requires proper pointing of the beam launchers
- For Kite, beam launcher pointing is specified in three domains: offset (DC), drift (FI time frame), and jitter (look time frame)

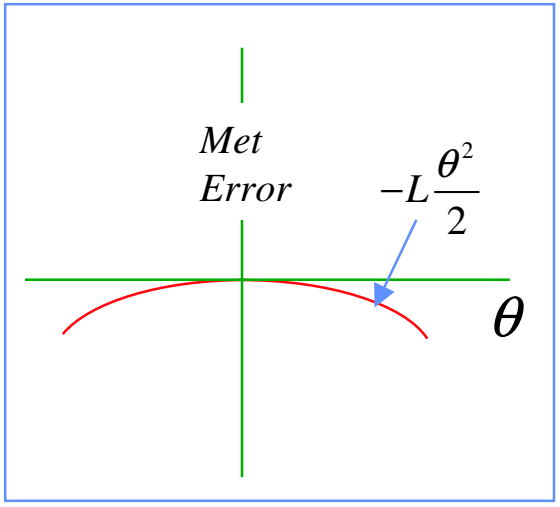
Error Type	Requirement, μrad
Offset	5
Drift	0.9 (45 s), 5 (1 hr)
Jitter (rms)	3

- Dithering frequency = 10 Hz
- Dithering radius = 200 micro-radians
- Jitter RMS = 0.08 micro-radians



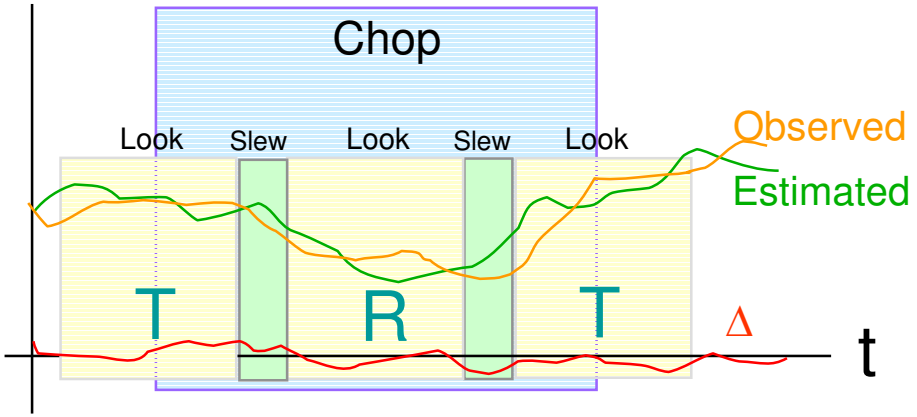
Error due to mispointing: $L(\cos\theta - 1) \approx -L\frac{\theta^2}{2}$

Minimize error by making $\theta \to 0$

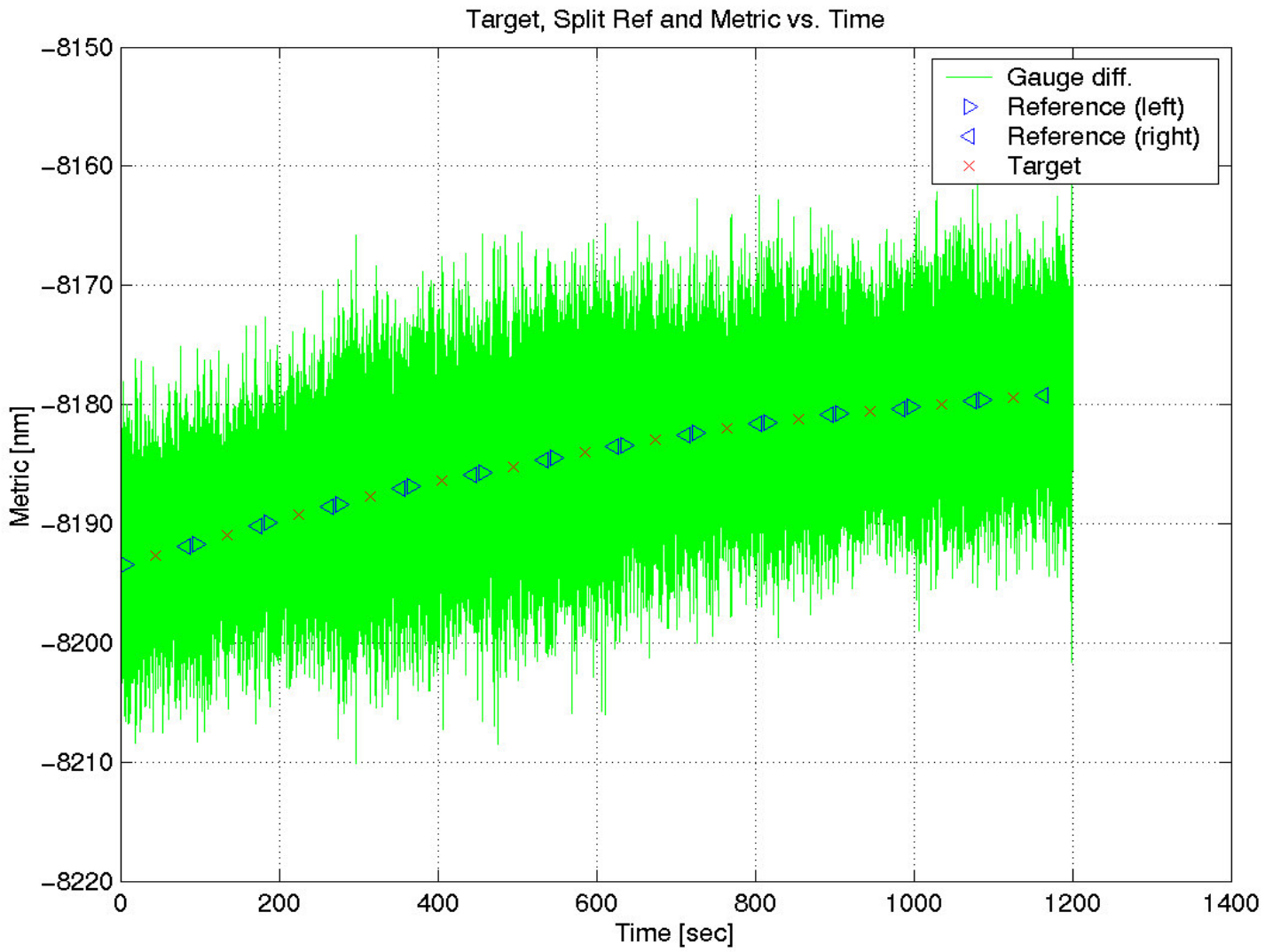


Data is Analyzed as if We Were Making a SIM Observation

- Definition of terms
  - Look
    - A segment of data yielding a single average measurement
    - Looks are separated by dead time arising from slew and settle
  - Delta
    - The difference between the reading of one gauge and the estimate using the other 5 gauges
  - Chop
    - The difference between one delta and another



From 5vs1 to chops, Quasi Static Data



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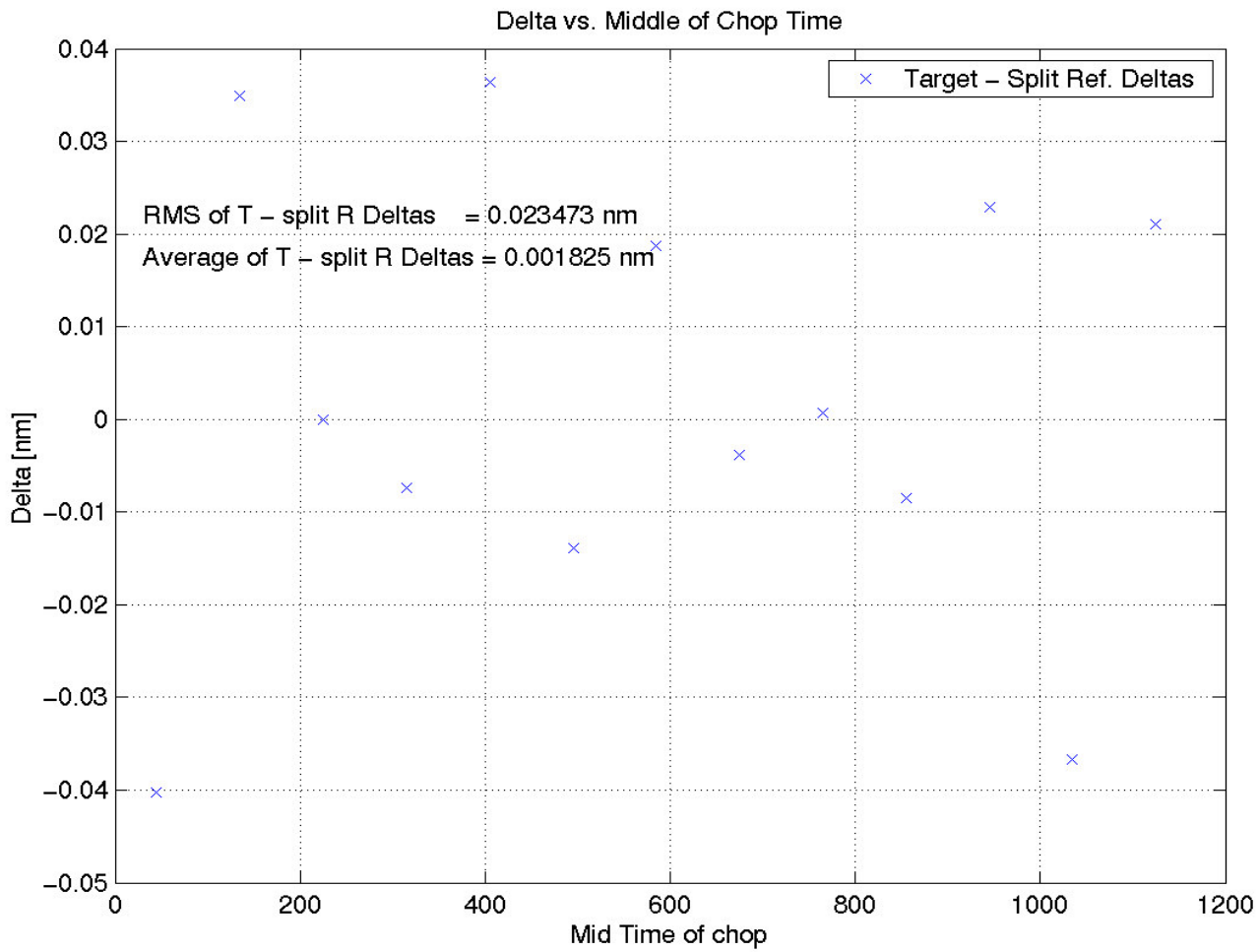
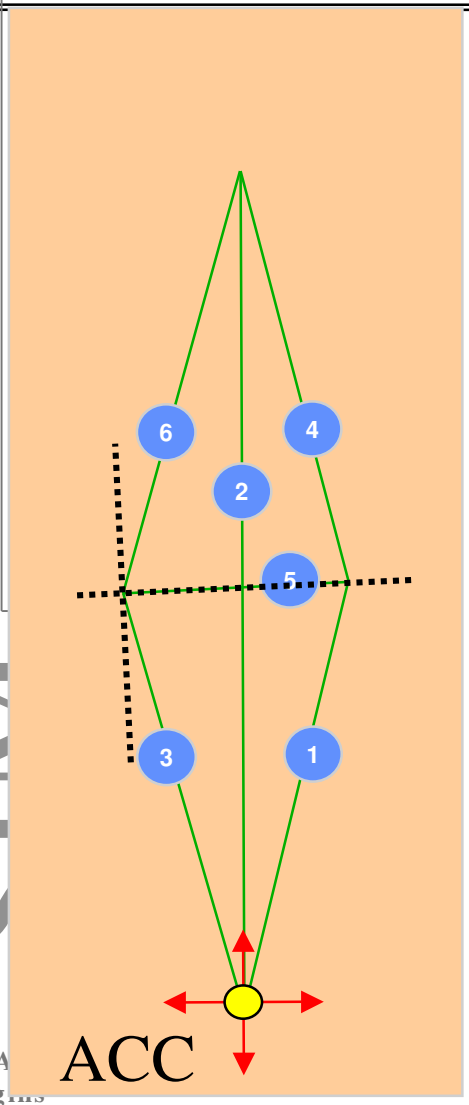
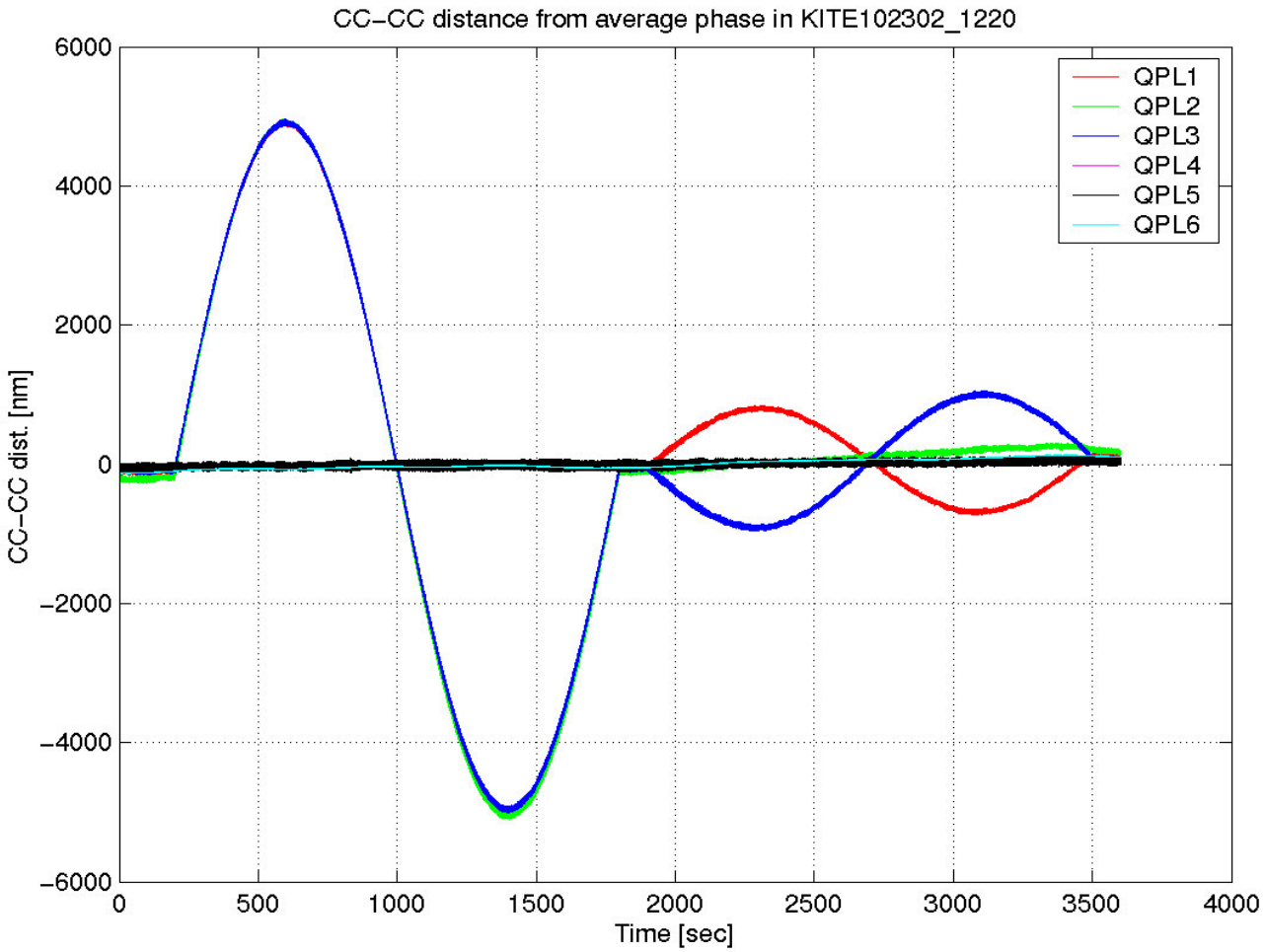
Quasi-Static (Field Independent Errors)



- Projected NA FI error = 17 pm / gauge

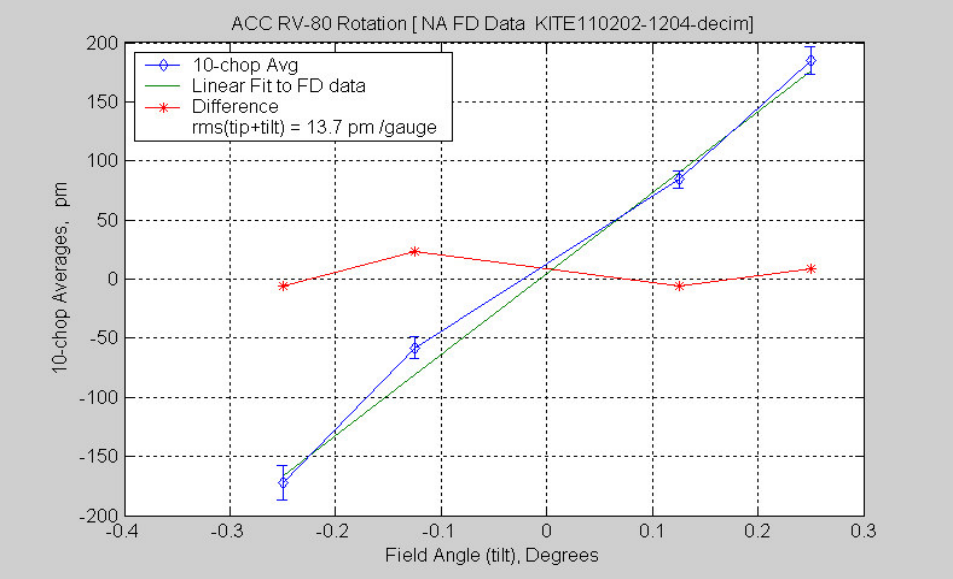
Deformed Truss Data

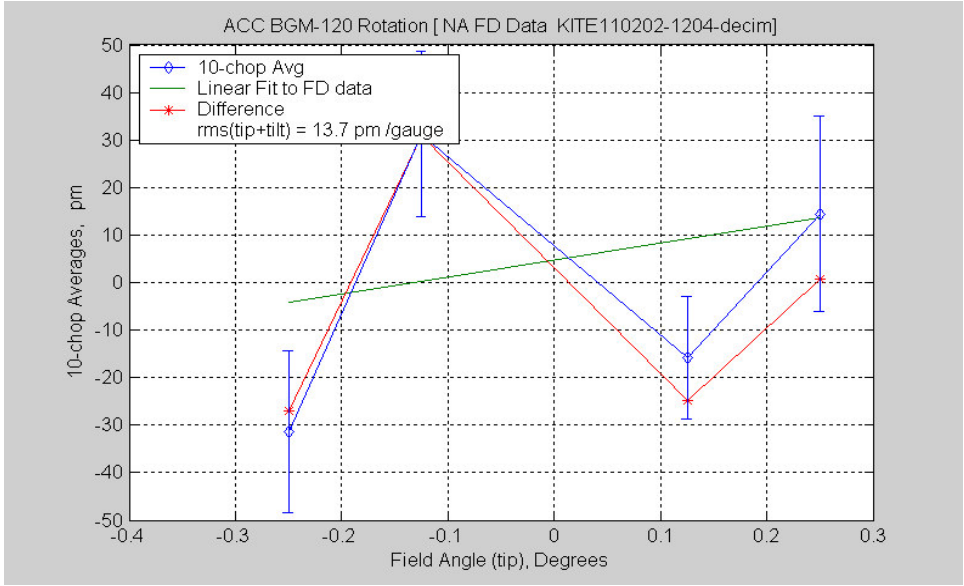




Narrow Angle FD + FI Data

- The performance metric is the rms of 10-chop averages of deltas over the field of regard, after detrend
- **Typical performance is 27 pm /** gauge over the NA field of regard
- We have achieved a **best** performance of **14 pm /** gauge
- This level approaches **SIM goal (12 pm)**





Putting the Kite results together

Per Gauge Errors, pm	Wide Angle	Narrow Angle
Deformed Truss	66 (combined)	2
Field-Independent		27 (combined)
Field-Dependent	238	
Total	247	27

Perf., pm	*SIM Goal*	*SIM Requirement*	*Kite '02 Milestone*	*Current Typical*	*Best Achieved*
Wide Angle	111	835	300	247	101
Narrow Angle	12	49	50	27	14

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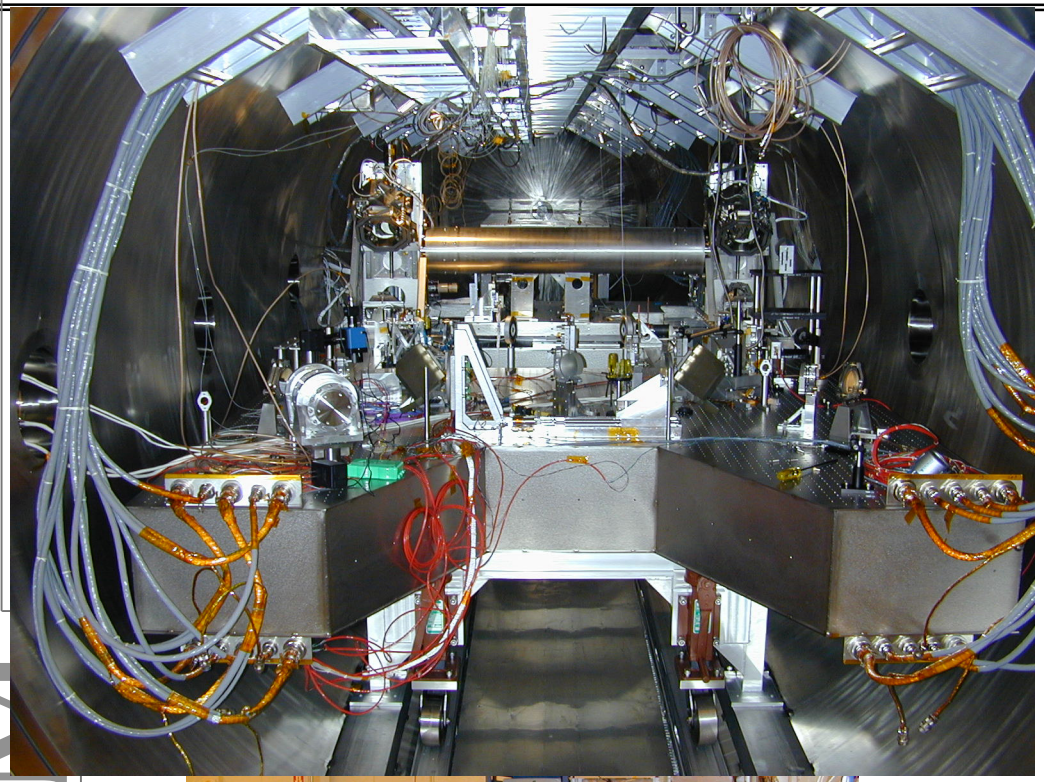
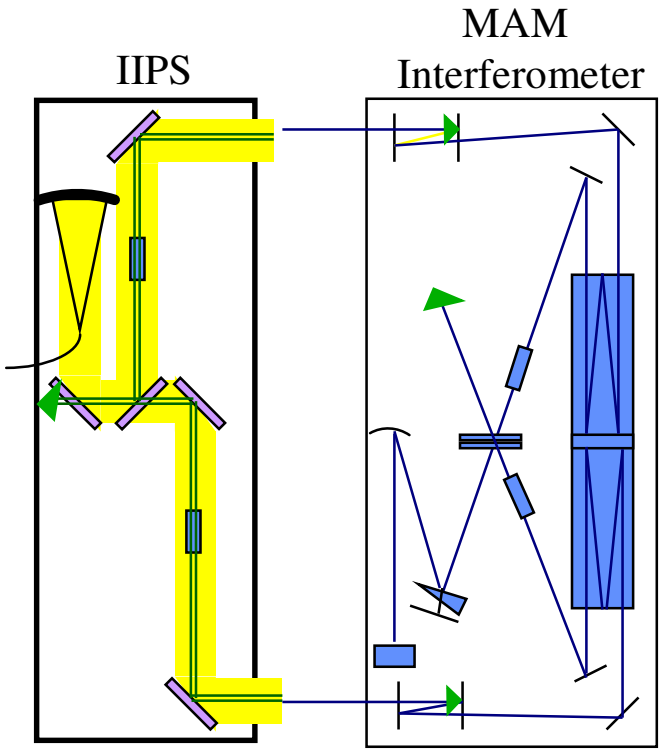
The MAM Experiment





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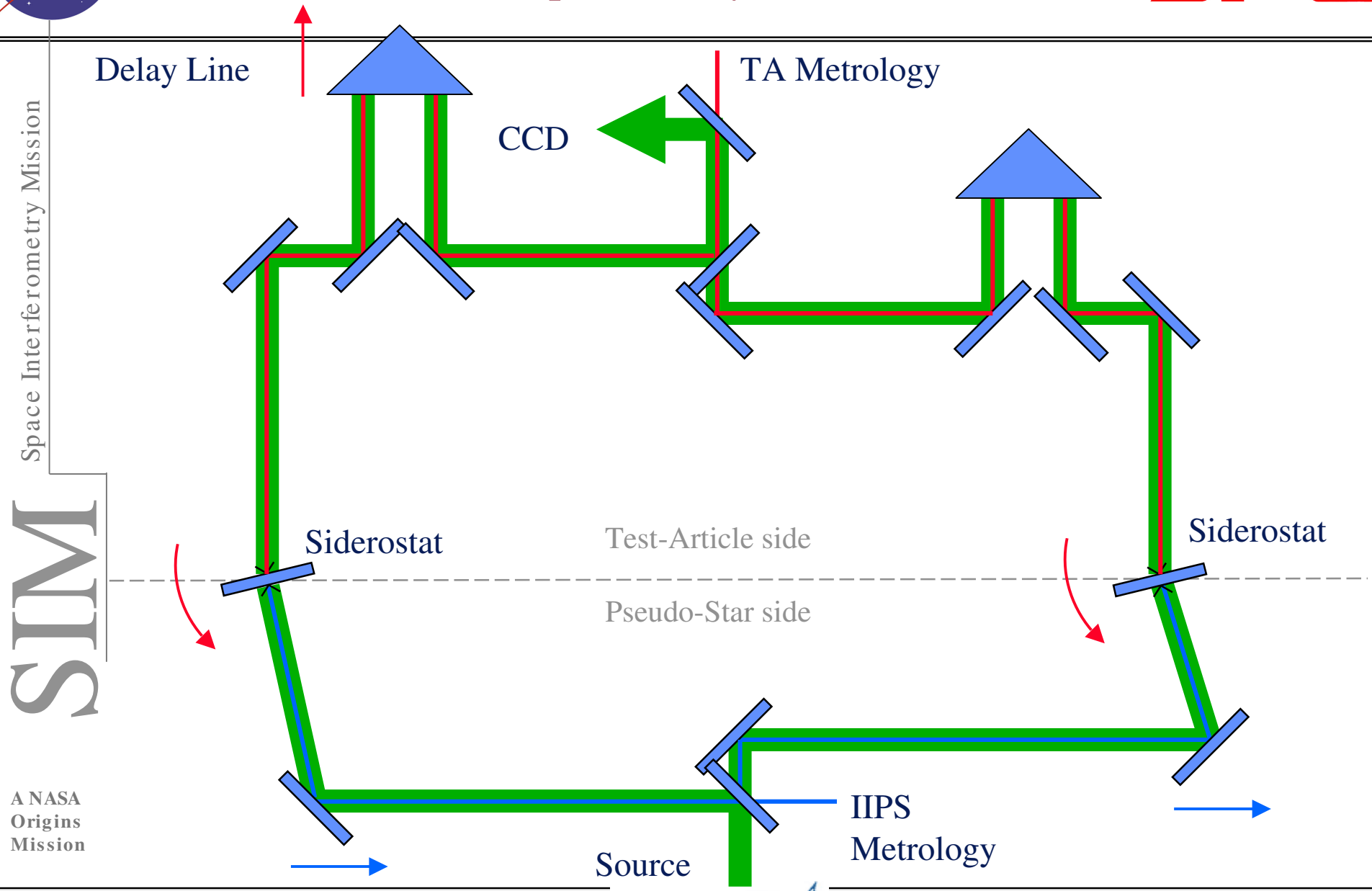
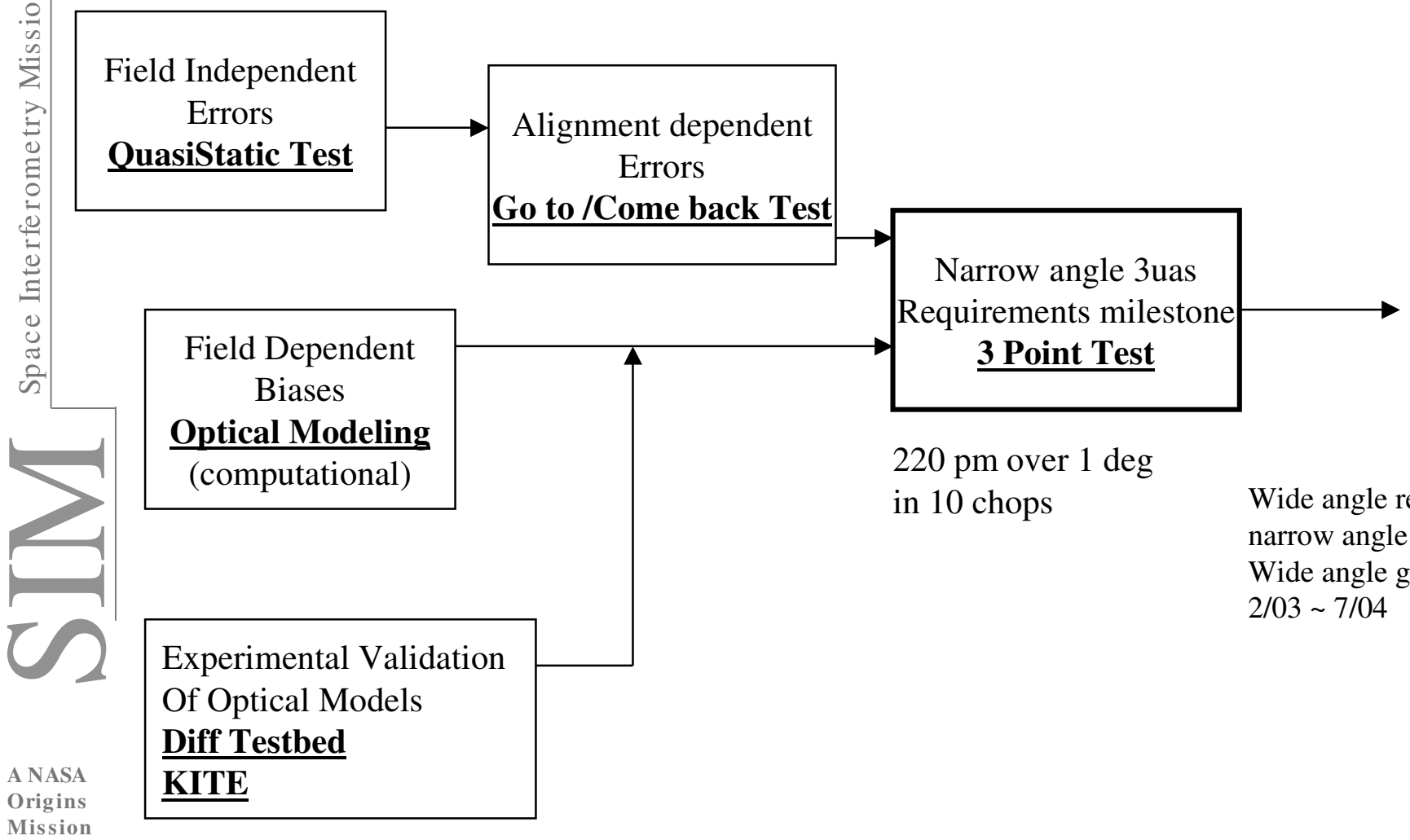
MAM Simplified Layout: IIPS Slew



Steps Along the Way



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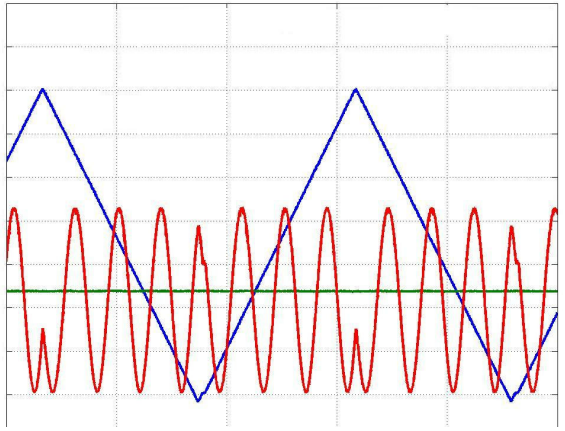
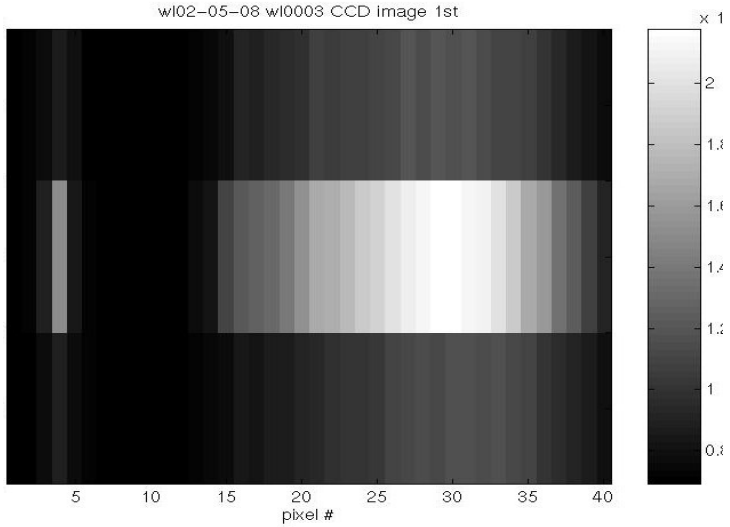
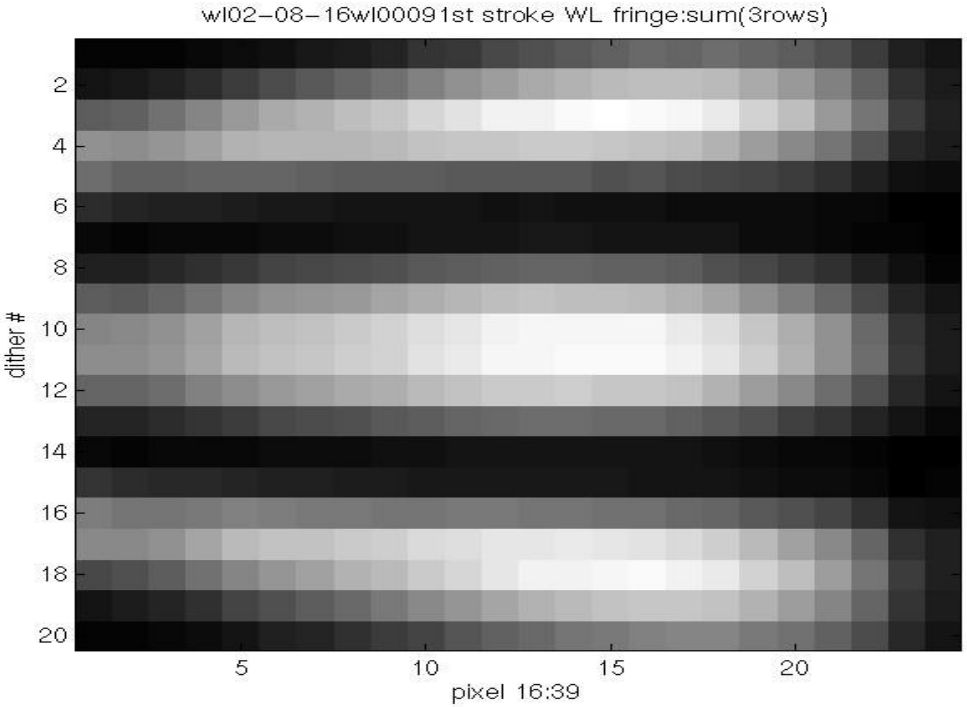
The Fringe Detection Process,
Deviations from the ideal

- White light fringes are detected by modulating the optical path in a triangle wave pattern.
  - This basic technique is used in a wide variety of commercial interferometers.
- What sets SIM/MAM white light detection apart is the ability to modulate with a waveform that is known to picometer accuracy.
  - The measurement of the modulation waveform by internal metrology (at 1Kh[illegible]) is used in the demodulation of the white lig[illegible] fringe.







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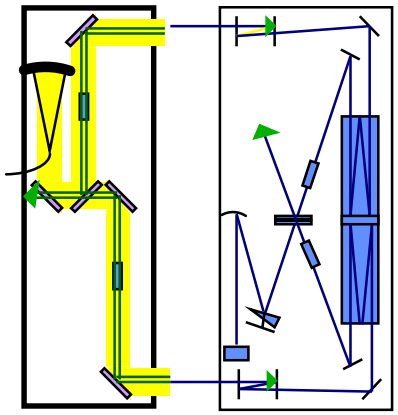
Quasi Static Test



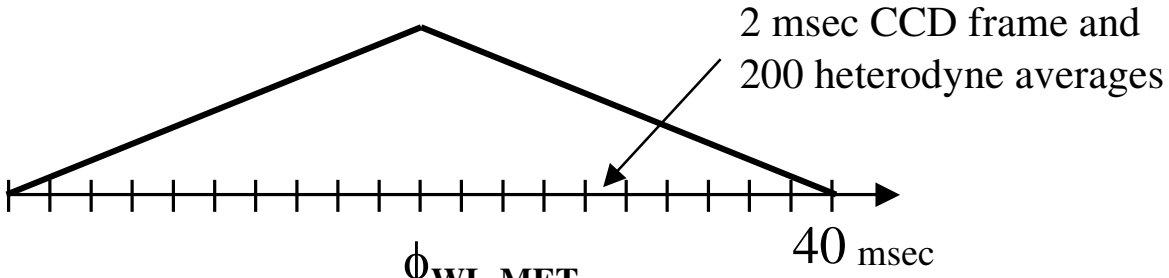
Nothing is intentionally moved

20~30nm vibration
100nm /1000 sec Optical path drift
3 urad/1000sec tip/tilt drift
10mK/hr thermal drift
Slow tilt (of vac chamber, 100's urad)

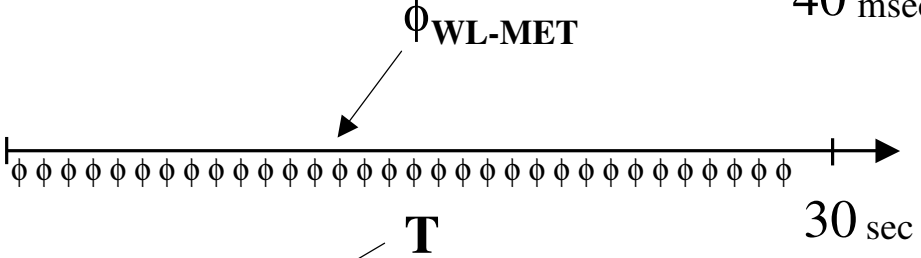
- New errors introduce because of a systems environment
  - Electrical noise (46Khz in SAF, Motor switching amp)
  - Electrical xtalk (initially -60db xtalk between SAVV channels)
  - Ground loops
    - Electrical non-linearities (120hz=> 100,120hz and 99,880hz)
  - Other(s)
- Therma/mech stability of SAVV launcher mount
- Vibration much larger now than for W.L. test in Jan 02
  - Tank is a large acoustical antenna, table needs to be isolated from tank
- Alignment related drifts/errors/servoes

Time scales

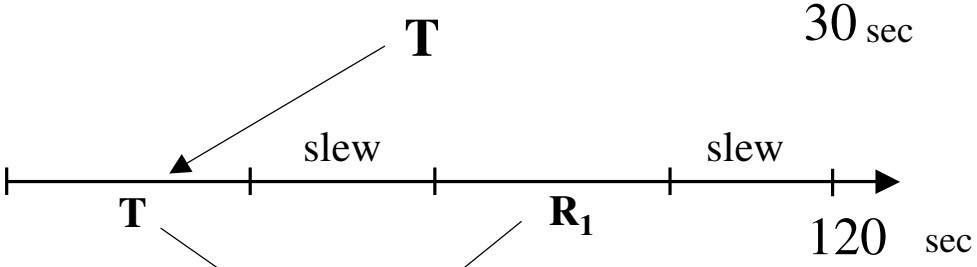
Dither modulation strokes



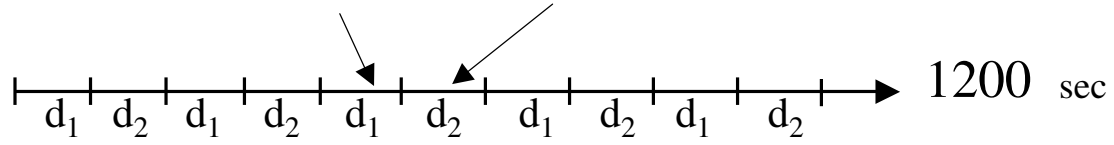
1 target star measurement



Single 1-chop measurement

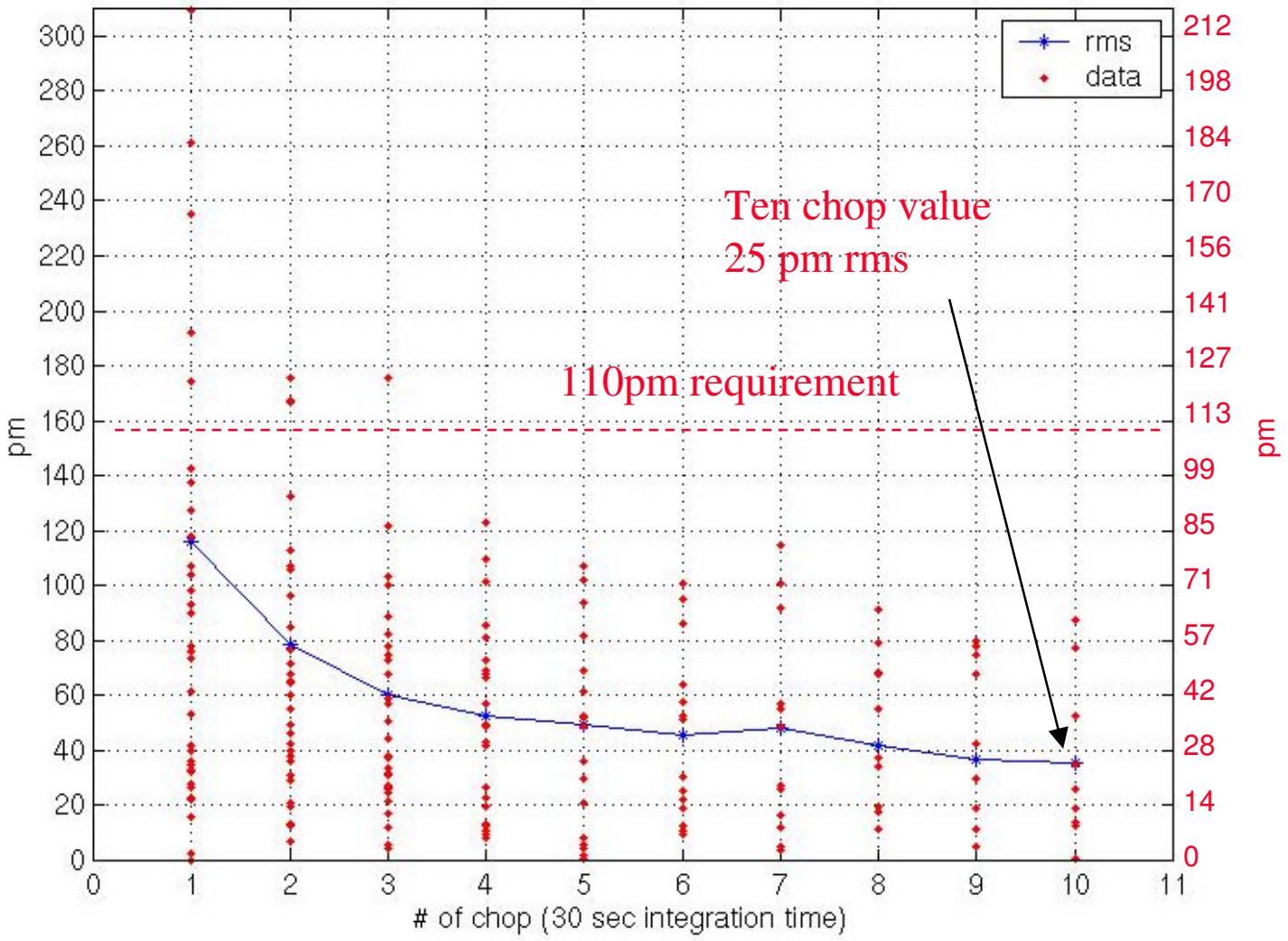


Ten 1-chop measurements



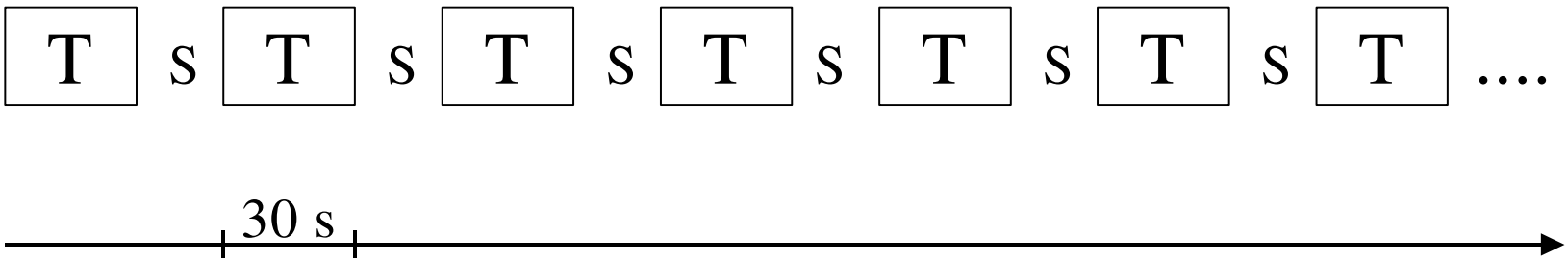
Error between white light and metrology paths as a function of the number of 30 second chops averaged together for the field independent test

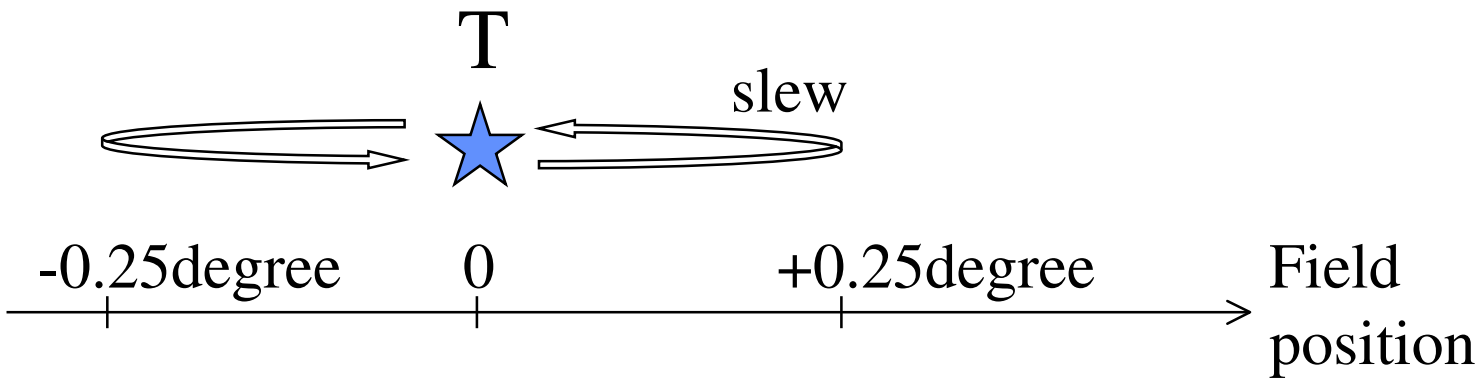
Raw TA + IIPS error



Estimated TA alone error

Go and Come-back test





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Error between white light and metrology paths as a function of the number of chops averaged together for the "go and come back" test.

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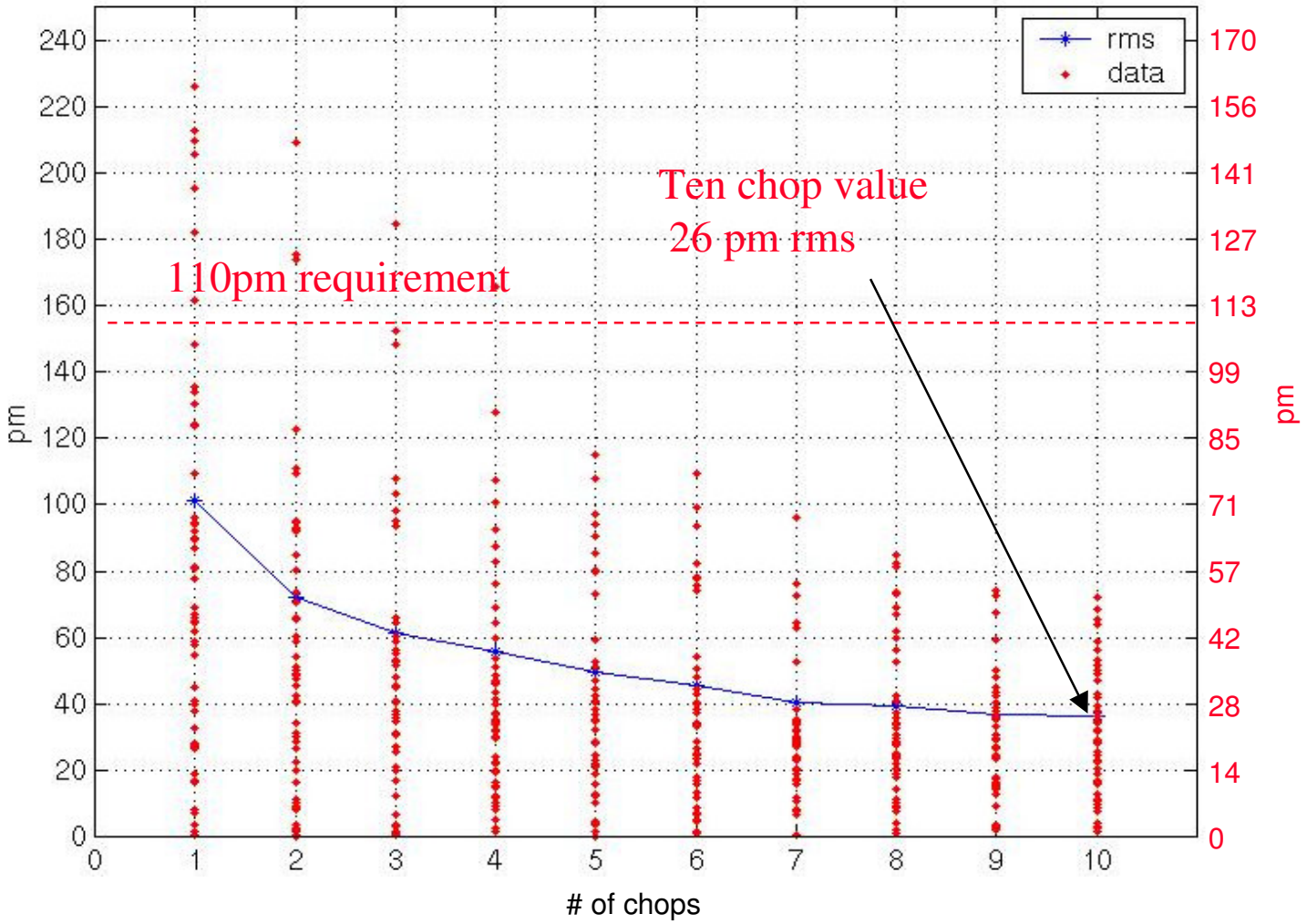
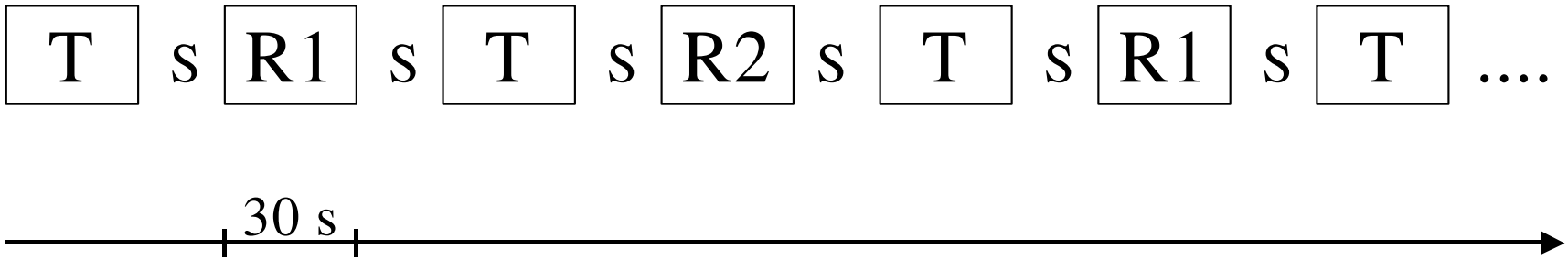
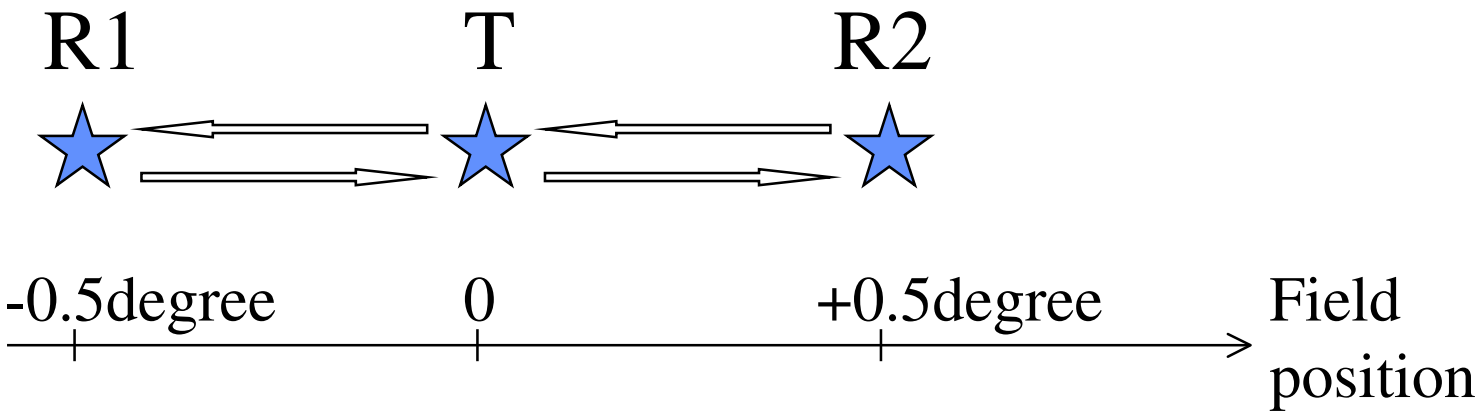
Raw TA + IIPS error



Estimated TA only error

Three-star field dependent test sequence





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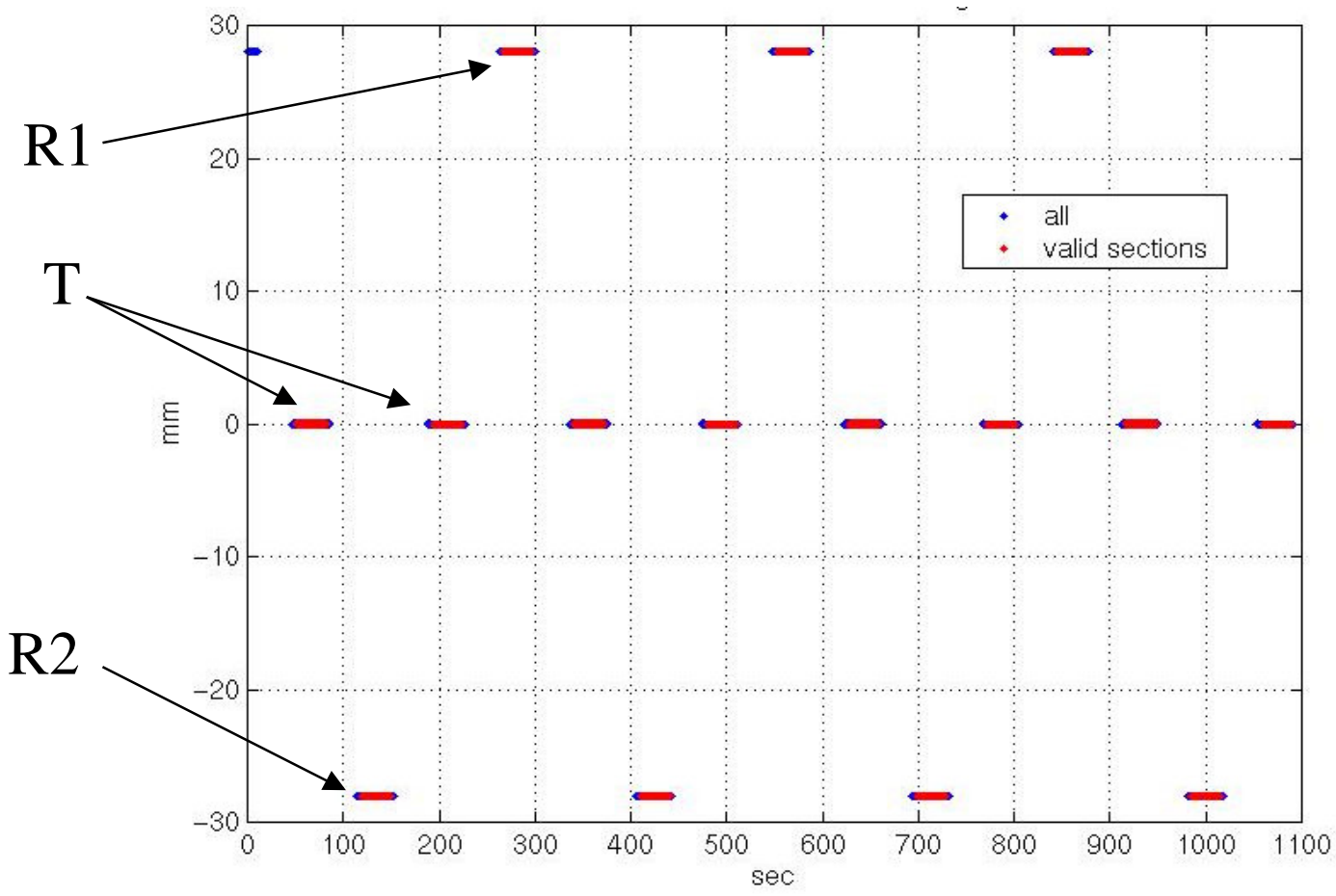
Delay line position as measured by the metrology during the 3 star field dependent test.

- The valid part of the data after each slew is highlighted in red.
- One can see the two reference stars on each side of the target one.



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Error between white light and metrology paths as a function of the number of chops averaged together for the field dependent test.

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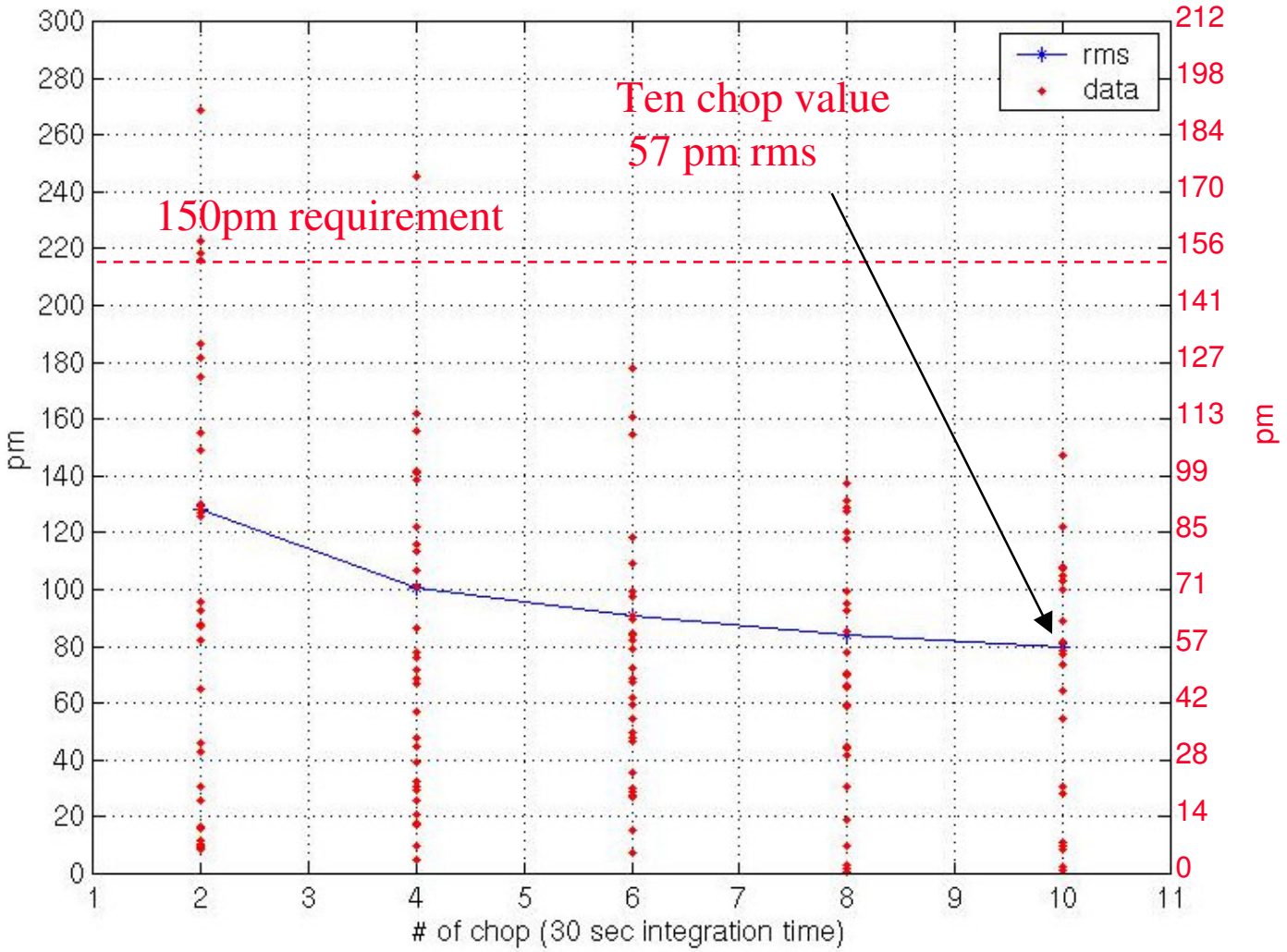
Raw TA + IIPS error



Estimated TA only error

MAM Results Summary

NA Requirements (Differential)						
MAM	Goal	Req		**Metric**	**Milestone**	**Testbed**
Astrometry	1.1	3.0	uas			**Results**
FD	29.7	118.8	pm	118.8		
FI	21.8	87.1	pm	87.1		**25**
All-in-one	36.8	147.3	pm	**147.3**	**150**	**57**

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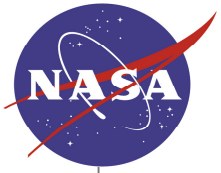

Kite and MAM Summarized

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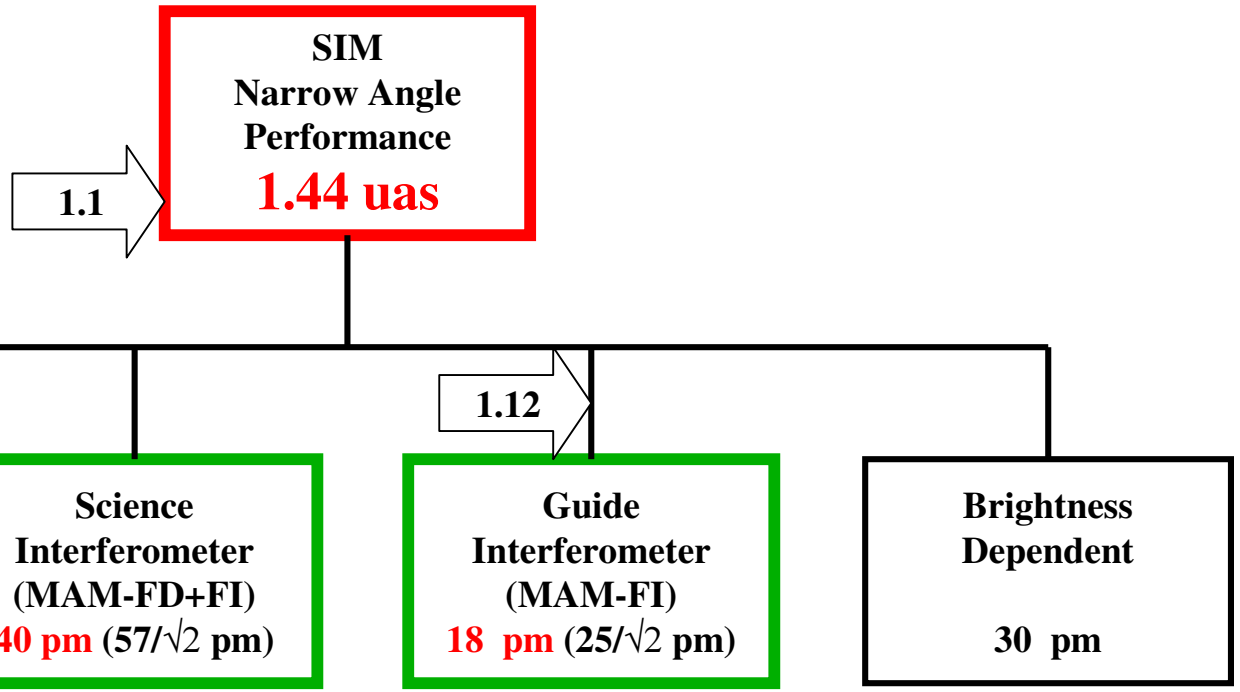
WA Requirements							
KITE	Goal	Req		Metric	Milestone		Testbed Perf
	4	30	uas				
All-in-one	111.36	835.21	pm	835.21	300.00		249.00

NA Requirements (Differential)							
KITE	Goal	Req		Metric	Milestone		Testbed Perf
	1.1	3	uas				
All-in-one	12.28	49.13	pm	49.13	50.00		27.00

WA Requirements							
MAM	Goal	Req		Metric	Milestone		Testbed Perf
	4	30	uas				
FD	241.5	1811.25	pm	1811.25			???
FI	143	1072.5	pm	1072.5			289
All-in-one	280.66	2104.97	pm	2104.966	4000		???

NA Requirements (Differential)							
MAM	Goal	Req		Metric	Milestone		Testbed Perf
	1.10	3.00	uas				
FD	29.70	118.79	pm	118.79			
FI	21.78	87.12	pm	87.12			25.00
All-in-one	36.83	147.31	pm	147.31	150		57.00

Current Narrow Angle Performance



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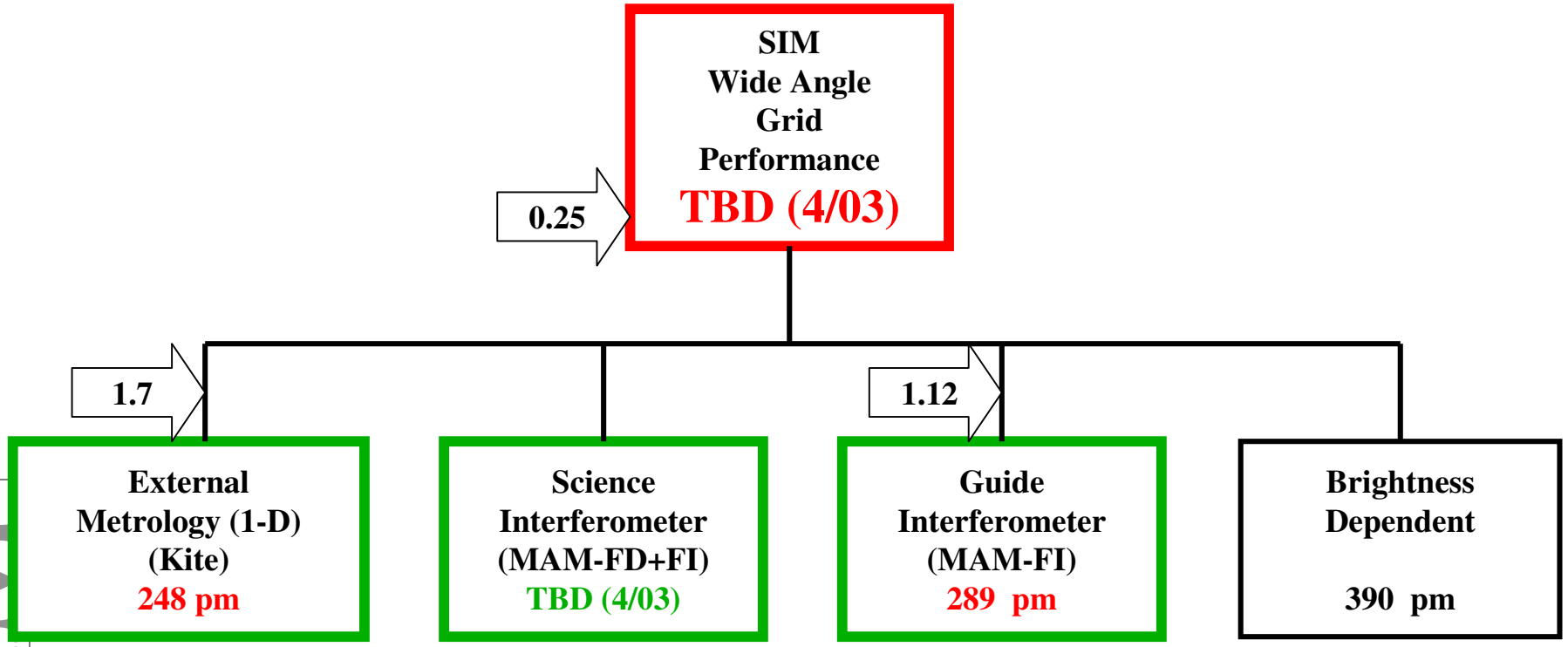
Current Wide Angle Performance



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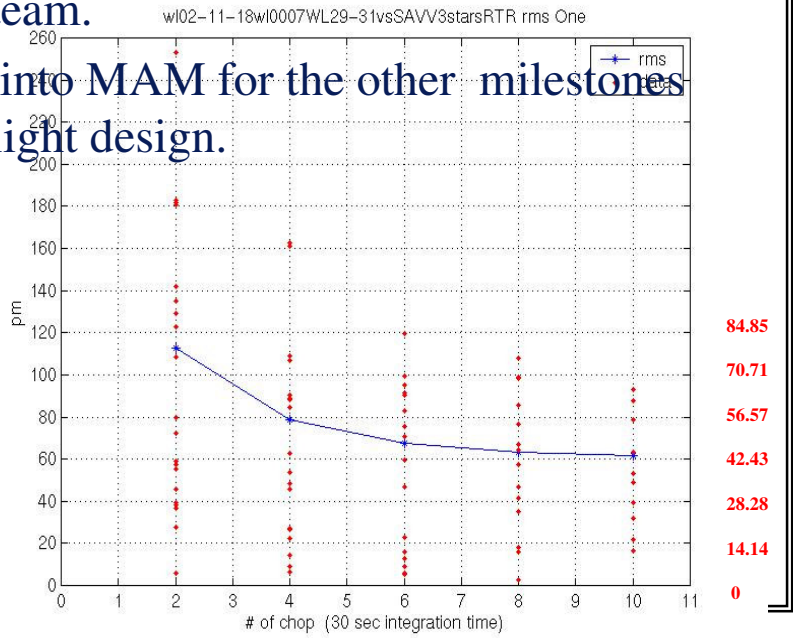
Summary

- We understand picometers.
- Both the KITE and MAM milestones have been met (basic requirements) with considerable margin. (no if's or but's)
- Just a couple of months after passing the "basic" requirements, we are close to demonstrating that we can meet the Narrow Angle "goals" of the project (1uas narrow angle)
- In the process of meeting these milestones, we've built a very strong technology team, which is being integrated into the flight design team.
  - The lessons learned are being incorporated into MAM for the other milestones for entry into phase C, as well as the SIM flight design.
- We're ready to enter phase B.



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