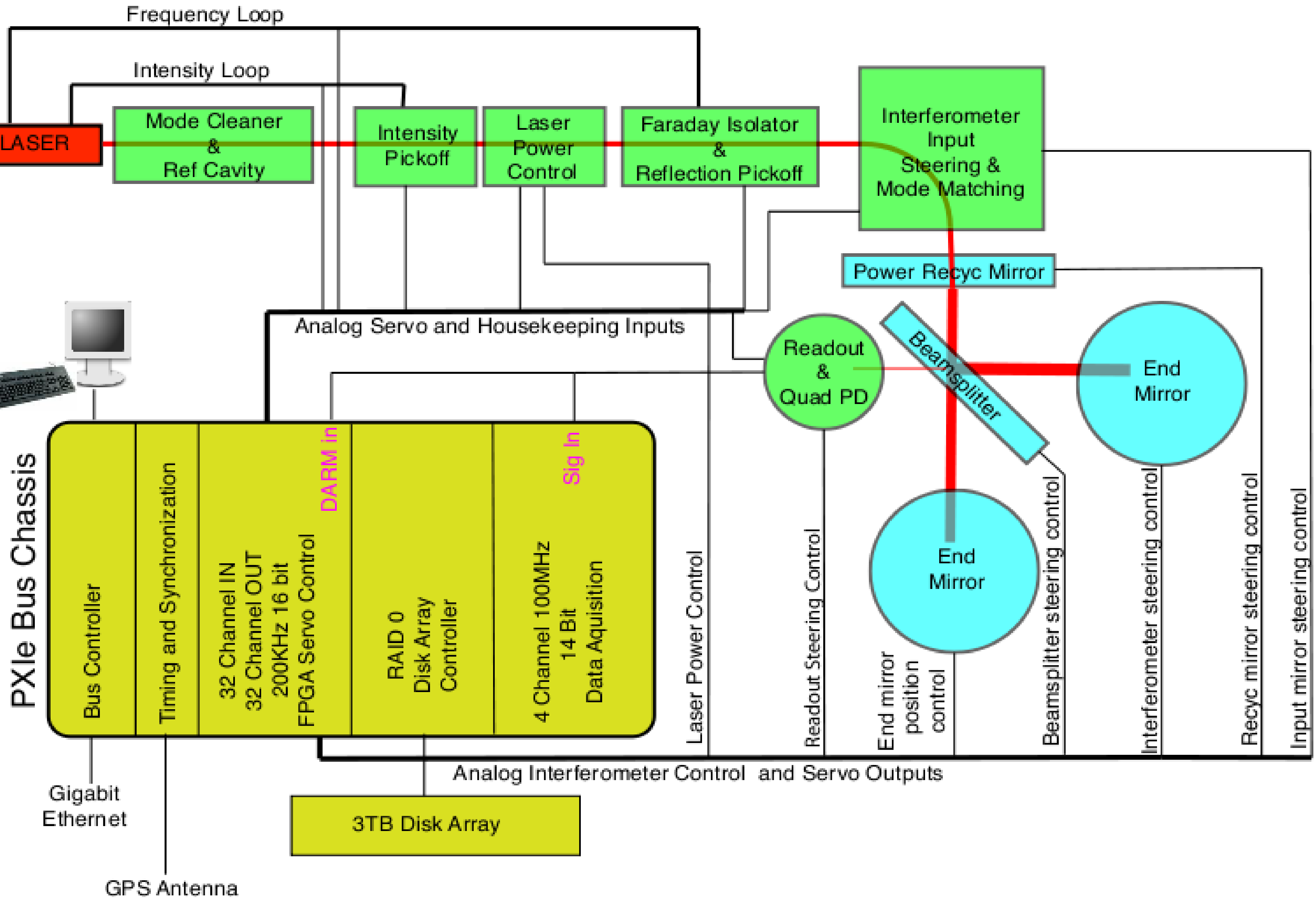
Integrated
Cost, Schedule, Resources

The Fermilab Holometer



Frequency Loop
Intensity Loop
LASER
Mode Cleaner & Ref Cavity
Intensity Pickoff
Laser Power Control
Faraday Isolator & Reflection Pickoff
Interferometer Input Steering & Mode Matching
Power Recyc Mirror
Beamsplitter
Readout & Quad PD
End Mirror
End Mirror
Analog Servo and Housekeeping Inputs
PXIe Bus Chassis
Bus Controller
Timing and Synchronization
32 Channel IN
32 Channel OUT
200KHz 16 bit
FPGA Servo Control
DARM in
RAID 0
Disk Array
Controller
4 Channel 100MHz
14 Bit
Data Aquisition
Sig In
Laser Power Control
Readout Steering Control
End mirror position control
Beamsplitter steering control
Interferometer steering control
Recyc mirror steering control
Input mirror steering control
Analog Interferometer Control and Servo Outputs
Gigabit Ethernet
GPS Antenna
3TB Disk Array

Mechanical Systems

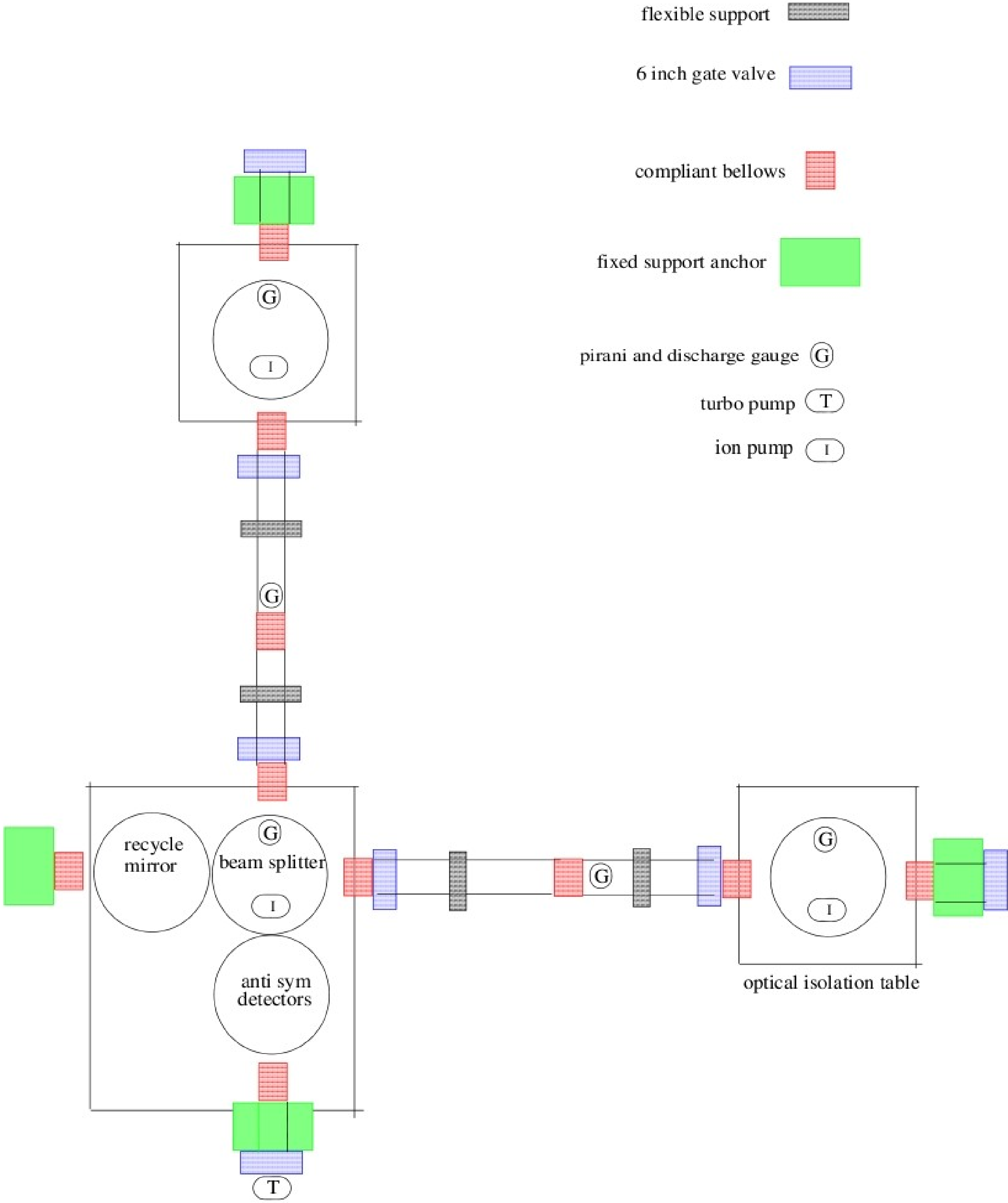
Not to scale. The service vessels are 2 feet in diameter. The arm length is 40 meters.

10 supports per arm.

Four “optical bench” supports per interferometer

Laser Table
No vacuum;
covered with acoustic baffling.

Height offset by ~ 1 foot to allow translation and rotation.



Elements

- Optics
  - Laser Table Optics
  - Interferometer Optics
  - safety
- Electronics
  - DAC System
  - Intensity & freq servos
  - Ops Space Compute
  - FNAL Compute
  - safety
- Mechanical
  - Vacuum Vessels
  - Vacuum Pumps
  - Support Stands
  - Baffles
  - Laser Table Mech.
  - Portable Clean Room
  - Operations Space
  - safety

Phases

- **Design:** Ongoing since Spring, 2009, ending in design review in February, 2010
- **Construction:** Purchase optics, electronics, and vacuum; fabricate stands and servo electronics. March-May 2010
- **Operations (commissioning):** Assemble vacuum, optics, and electronics, and make it work. June-Dec 2010.
- **Operations (measure):** 1 move & measure takes ~ month(s); repeat until June 2013.

Cost Roll Up

- Design
  - $226k M&S
  - $98k non-scientist salary (fully loaded)
- Construction ($1.55M with 50% contingency)
  - $977k M&S
  - $58k non-scientist salary (fully loaded)
- Operations ($675k/year w/50% contingency)
  - $970k M&S
  - $381k non-scientist salary (fully loaded)

Table 7: Duration of Tasks

Task	Design ongoing until March, 2010	Construction March 2010 - June 2010
DAC System	purchase one system; 4 weeks lead time	purchase second system; 4 weeks lead time
Laser Table Optics	small table training and development; 12 weeks	purchase; 4 week lead time
Interferometer Optics	"	purchase; 10 week lead time
Intensity and Frequency Servos	"	
Operations Site Computing	requirements analysis and implementation plan; 2 weeks	purchase; 1 month lead time
Fermilab Computing	analyze disk/tape/robot options; 2 weeks	
Vacuum Vessels and Tubes	vet design; 8 weeks	purchase; 10 weeks lead time
Vacuum Pumps and Instrumentation	"	"
Support Stands	design; 2 weeks	fabricate; 8 week lead time
Baffles	design and prototype; 7 weeks	fabricate; 4 week lead time
Laser Table (mechanical)	design; 2 weeks	fabricate baffle; 4 week lead time
Portable Clean Room		purchase; 6 week lead time
Safety	review laser and vacuum design and operations plans; 1 week	
Warehouse	8 weeks specify	8 weeks bid and approve

Table 7: Duration of Tasks

Table 8 M&S Costs

Task	Design	Construction	Operations
DAC System	$54K	$54K	
Laser Table Optics	$140K	$140K	
Interferometer Optics		$68K	
Intensity and Frequency Servos	$32K	$32K	
Operations Site Computing		$40K	
Fermilab Computing			$70K for 70 TByte
Vacuum Vessels and Tubes		$250K	
Vacuum Pumps and Instrumentation		$175K	
Baffles		$10K	
Portable Clean Room		$48K (Terra Universal web)	
Support Stands		$30K	
Laser Table (mechanical)		$120K	
Safety		$10K (goggles, partitions, interlocks)	
Warehouse			$900K
TOTAL	$226K	$977K	$970K

Table 8: M&S Costs

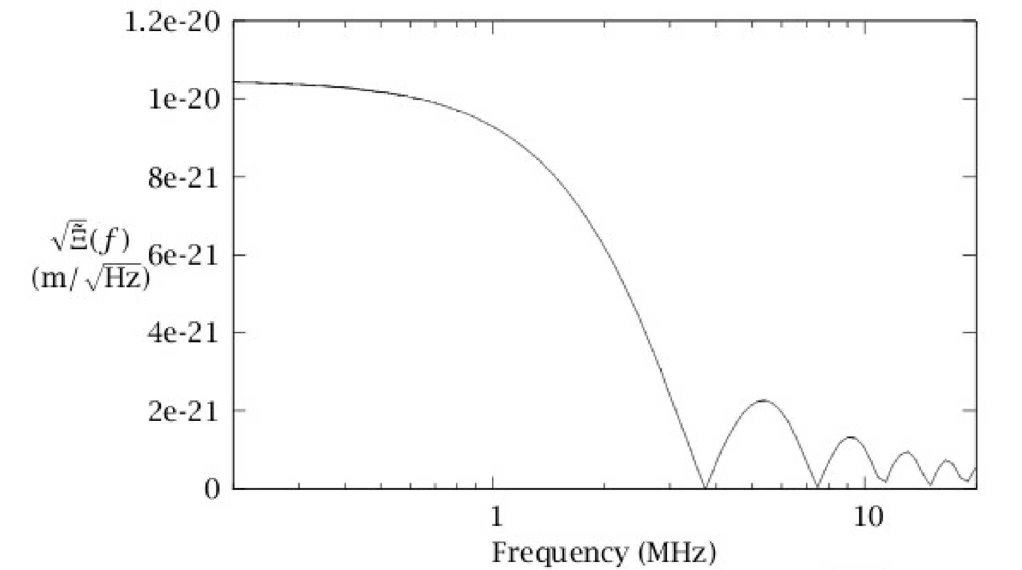
Table 9 FTE-months

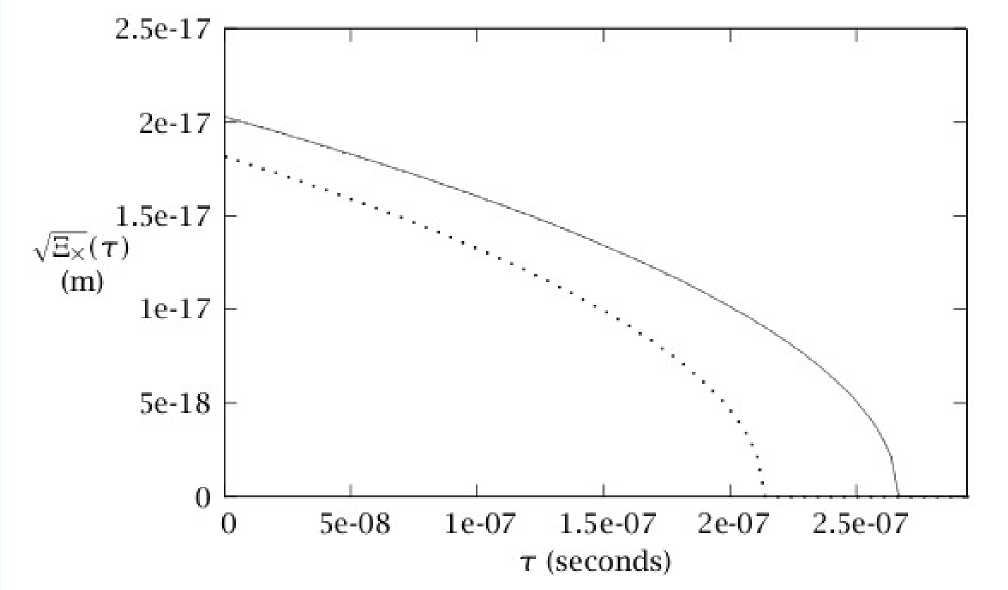
Task	Design	Construction	Commissioning (6 months)	Measurement
DAC System				
Laser Table Optics	1.00 EP	1.00 EP	1.00 EP	
Interferometer Optics				
Optics Mounts				
Intensity and Frequency Servos	2.00 EE; 0.50 MT	4.00 ET	0.50 ET	
On Site Computing	0.25 CP		0.25 CP	
Off Site Computing	0.25 CP			
Vacuum Vessels and Tubes	0.25 ME		1.00 MT	continuing 0.25 FTE MT
Vacuum Pumps and Instrumentation	0.25 ME		1.00 MT	continuing 0.25 FTE MT
Support Stands	0.25 ME		1.00 MT	
Baffles	1.00 ME		1.00 MT	
Laser Table (mechanical)	0.25 ME		1.00 MT	
Portable Clean Room			1.00 MT	
Safety				
Warehouse				continuing 0.5 FTE MT
TOTAL non scientist FTE months	6.0	5.00	7.75	continuing 1.0
Cost w/OPTO/vac/fringe/overhead	$98k	$58k	$84k	$297k

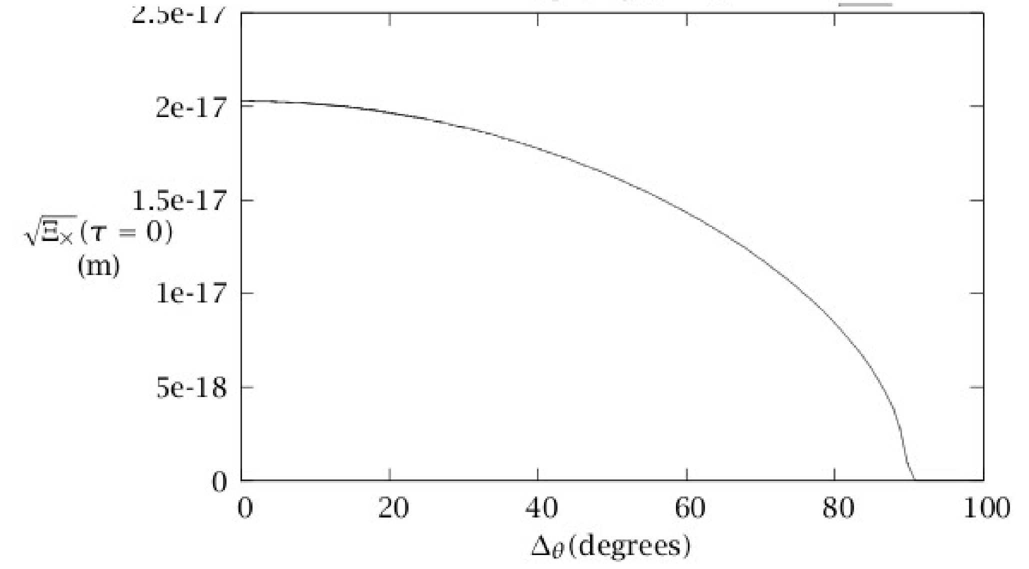
Table 9: FTE months non scientist effort: CP=computing professional; MT=mechanical tech; EE=Electronics Engineer; ET=Electronics tech; ME=mechanical engineer; EP=engineering physicist. The FTE cost uses PPD rates for FY2009 inflated by 3%, with OPTO, vacation, fringe, and overhead included.

Strategy

Need a working space of 40x40 meters minimum; 40x80 allows incremental modulation from max to 0; 80x80 is excessive.







Scientific Team

- Craig Hogan (Head, FNAL CPA); Rainer Weiss (MIT emeritus; co-founder of COBE and LIGO); Stanley Whitcomb (LIGO Chief Scientist); Stephan Meyer (U Chicago; director KICP; COBE, SPT)
- Sam Waldman (MIT; LIGO optics&control expert) Detailed design and commissioning of optics and electronics.
- Dick Gustafson (Michigan; LIGO optics and operations) mechanical, optics, laser expertise

Scientific Team

- Ray Tomlin (FNAL EP) lasers and mechanical support
- Aaron Chou (FNAL Wilson Fellow; co-spokesman of GammeV) Synergy with optical cavity development for future Axion searches
- Jason Steffen (FNAL Brinson Fellow; spokesman of GammeV Chase) Vacuum, laser
- Erik Ramberg (FNAL Scientist; Head of Meson Test Beam Facility) logistical support

Scientists

- William Wester (FNAL Scientist) built wire chambers for CDF; ASIC experience; vacuum and mechanical specs for interferometers
- Chris Stoughton (FNAL Scientist) SDSS data analysis; developing optics, electronics, control expertise at FNAL
- Chou and Meyer had funding for graduate students from U. Chicago.
- Other scientists at FNAL expressed interest pending approval

Work Breakdown Structure

- Optics: Optical design simulated; cost estimate from quotes and recent procurements (Sam Waldman)
  - Ray Tomlin, Chris Stoughton, and Aaron Chou in Linac Laser Lab
- Electronics: Data access/control cost from quote (Stephan Meyer)
  - Need EE time to design analog controls
- Mechanical: Vacuum system cost from quote (William Wester); other mechanical systems (clean room, stands) from recent experience
  - Need ME time to vet the vacuum design, stands, baffles, clean rooms.

Conclusions

a) Holometric Noise probes the fundamental nature of matter and energy.

b) Building the interferometers with sufficient sensitivity is within the capabilities of the team.

c) The FTE and M&S requirements are modest. Specifically, construction costs are well under $2M threshold for format CDR and and for OMB line-item budget requests.

Conclusions

d) The techniques overlap substantially with current, funded Axion research. Scientist time spent on the interferometers will help build expertise necessary for future Axion experiments. There are no direct conflicts with other resources at FNAL.

e) Expertise from MIT, U Chicago, and Caltech strengthens the team and is essential for its success.

Conclusions f)

1) Technical Risks: conservative interferometer design; we plan to purchase all elements for intensity and frequency stabilization. Vacuum vessels will allow suspended optics, if necessary. Mechanical and electronics are straightforward.

2) Management Risks: need MOUs with divisions

3) Schedule Risks: need ME and EE to finalize design. There are no "drop dead" dates; can move schedule forward or back for funding or personnel reasons; the team is ready.