Precision Mechanics, Thermal Management, and Power

Future Instrumentation Needs

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Acknowledgments

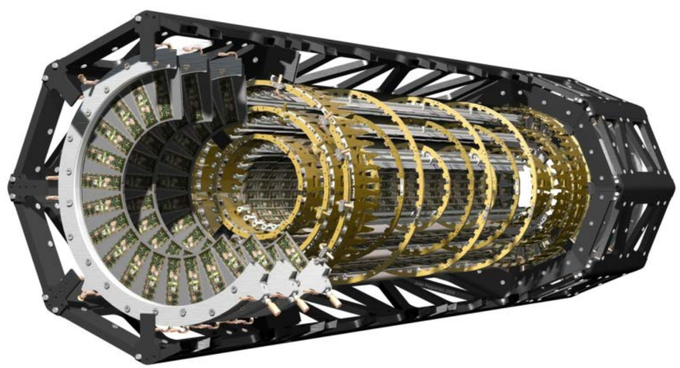
- Thanks to whitepaper colleagues Bill Cooper and David Lynn, and my collaborators on ATLAS who have worked on a variety of these topics

Introduction

- Refers generically to structures and methods which support precision tracking/vertex detectors/imagers and are/may be/have
  - Long radiation length
  - Radiation tolerant
  - Mechanically robust (precise, stable, etc…)
  - High thermal conductivity
  - Efficient power delivery, reduced cabling
- Originates from Energy Frontier legacy but also may apply to a variety of Intensity Frontier (vertex detectors….) and Cosmic Frontier (focal planes…) applications

Cont.

- Significant aspects of this are already well established through application to running or recent experiments.



- What is potential for improved performance, what are the needs, are there new directions or capabilities?
- What is natural to develop in the course of a particular experiment and what is of generic interest?

Conditions

Operating/Environmental Conditions	
Max Operating Temperatures	40 °C
Min Operating Temperatures	-50 °C
Ionizing Radiation TID	50 - 1000 Mrad
Non-ionizing radiation Levels	1-10 x 10^{15} n_{eq}/cm^2
Magnetic Fields	> 2 T
Typical Sensor Area	100 m^2
Typical Power Densities	~ 100mW/cm^2
Total Power	100 KW
Precision	~10 microns → optical

- 1^{st} pass driven by HL/HE hadron colliders
- LC: power cycling, → motion, vibrations, ultra light and thin
- Cosmic: vacuum compliance, lower T, miniaturization, manufacturing

Requirements

Requirements
Long radiation length materials
High stiffness/mass ratio (i.e. stability)
Radiation tolerant materials
Dual (or triple) purpose elements
Large scale manufacturability
Minimal thermal and humidity effects
Precision placement and survey

- Low mass to avoid MCS and conversions
- Materials properties
- Integrated functions
- Radiation resistance
- Manufacturing

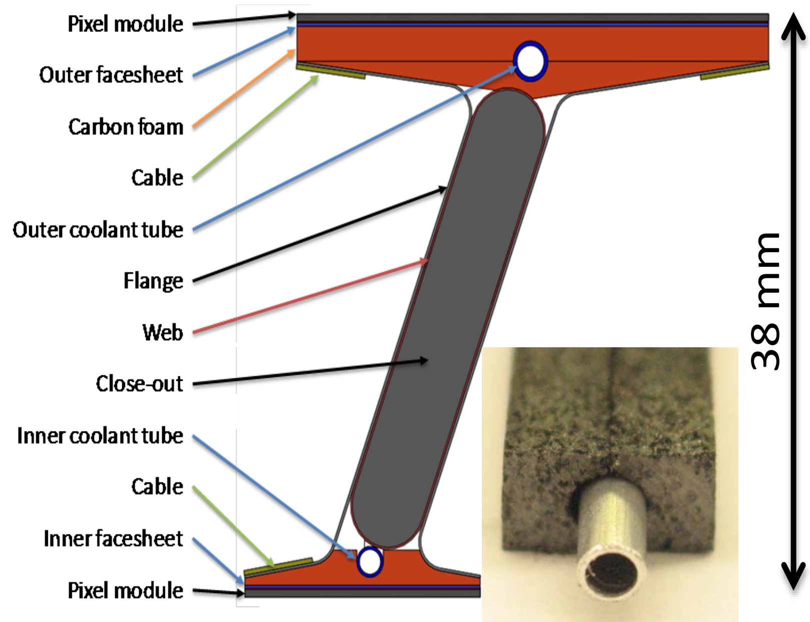
Materials

- Past/present implementations have driven the field mainly to carbon materials/composites, liquid and 2-phase coolants
- Other materials (metals, ceramics, foams, polymers) are found typically in niche applications
- Requires infrastructure – facilities, techs, eng
- Question is whether additional R&D could lead to capabilities (wrt requirements) which
  - go significantly beyond present state-of-the-art
  - add QA, cost, and/or manufacturing advantages

Present Materials Selection

	Structural (stiff)	Thermally Conductive	Low (long) Radiation Length
Carbon based materials			
Carbon Foam	✓(as core material)	✓✓	✓✓✓
Carbon Fiber Reinforced Plastic	✓✓✓	✓✓✓	✓✓
Carbon Honeycomb	✓✓(as core material)	X	✓✓✓
TGP	X	✓✓✓	✓✓
Polymers/Plastics			
Peek	✓	X	✓✓
Liquid Crystal Polymer	✓	X	✓✓
Ceramics			
Alumina	✓✓✓	✓	✓
Beryllia	✓✓✓	✓✓✓	✓✓
Aluminum Nitride	✓✓✓	✓✓✓	✓
Metals			
Beryllium	✓✓✓	✓✓✓	✓✓
Aluminum	✓✓	✓✓✓	✓
Titanium	✓✓	✓	X
Stainless Steel	✓✓	✓	X

Example Structures



- Typically a cured (or co-cured) structure composed of fibers, a polymer matrix, additional elements such as foam, honeycomb, embedded cooling channels, electrical interconnects
- Low mass CF structure/specialized materials
- Embedded thermal aspect, thin walled pipes, engineered interfaces
- Embedded electrical functions

R&D Directions

- Materials
- Thinning and mass reduction
- Coolants – liquid and gas
- Measurement methods
- Structures and integration
- Database

Specifics (1)

- Multiple Functions
  - Shielding and grounding
  - integration of electrical components, functions
  - co-cure methods
- Improved materials
  - new ceramics,
  - new carbon or other types of low density foams
  - adhesives
  - high modulus fibers, among others
  - Thinning methods
- Engineered composites
  - new arrangements and configurations which could yield improved, or even novel, properties
  - laminate orientations and mixed materials.

Specifics(2)

- Materials science and nanotechnology
  - For example, nano-particle dispersions have been shown to dramatically improve thermal conductivity and strength of polymers
  - Very dependent on engagement with materials science community
  - Likely to require special processes which we would need to acquire
- Spin-offs
  - other fields may benefit from developments originating in HEP (BES, NP, Accelerators, Astro)
  - Additional funding sources can sustain R&D capabilities through the inevitable funding cycles.
- Measurement techniques and QA
  - Characterization of materials, components, and structures in R&D, fabrication, & in situ
  - 3D metrological methods
  - acoustical microscopy
  - large area automated inspection, thermal imaging
  - precision survey, both static and dynamic.

Specifics(3)

- Cooling methods
  - Further development of liquid and 2-phase methods
  - Gas flow
  - Interaction with materials, interfaces, foams, adhesives
- 3D printing
  - May be of particular interest once materials become more varied
- Simulation and Modeling
  - Can be critical to understanding the behavior of both components and complex structures
  - Understanding performance and reliability
  - Create a well established understanding of basic materials properties in order enable modeling of more complex structures
  - Engagement with industrial and academic collaborators

Database

- Identifying and specifying materials of interest, and their properties, can sometimes be difficult to coordinate.
- For design, modeling, and simulation, it is important that workers use common and agreed upon values.
- A public access database of materials properties should be established.
  - The database would include physical, structural, thermal, and radiation hardness properties.
- The database could later be extended to include specific processes and techniques to match materials to low-mass detector requirements.
- Of value across multiple frontiers

Motion Control and Actuators

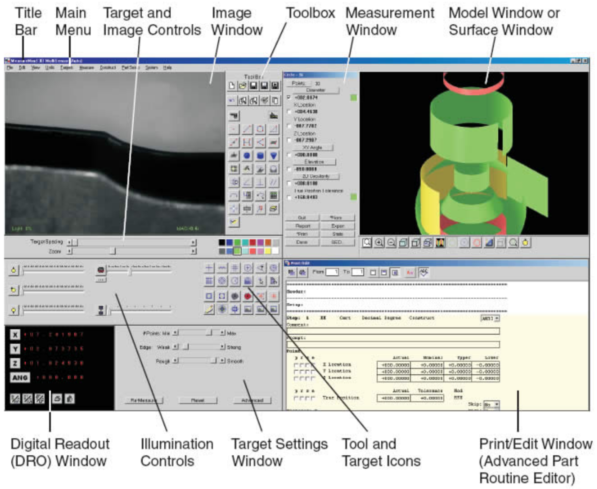
- Well developed commercial aspect driven by photonics, manufacturing, robotics, QA
- Important tool for the fabrication of precision sensor arrays, etc.
  - R&D lies in application to large area and high throughput fabrication
  - Interaction with optical metrology tools
- Use in-situ for alignment, positioning of “layers”
- Custom application to focal planes (M.Levi presentation)

Metrology

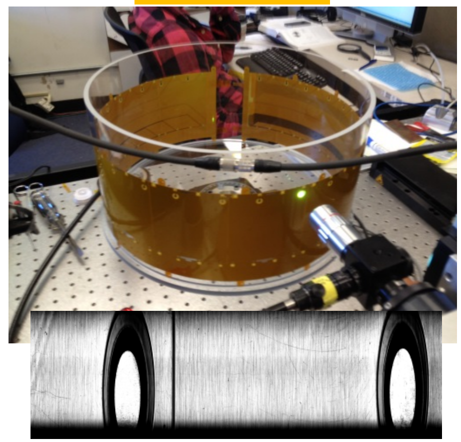
- Precision, non-contact mechanical measurement
- R&D, construction, in-situ alignment & monitoring
- Optical and touch probe CMM's
- ESPI/TV Holography
- Frequency Scan Interferometer (FSI)
- Laser rangefinding displacement sensor
- Confocal probe

Examples

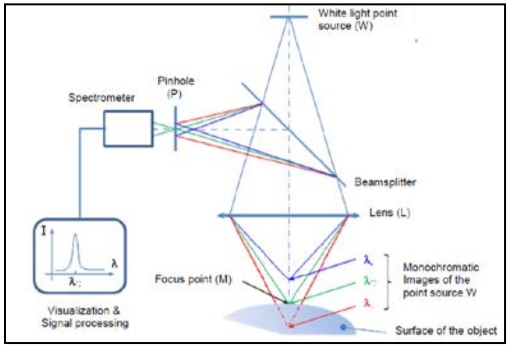
Coordinate Measurement

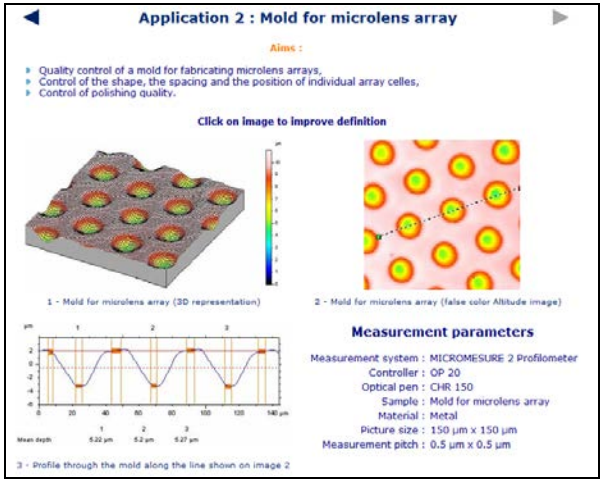


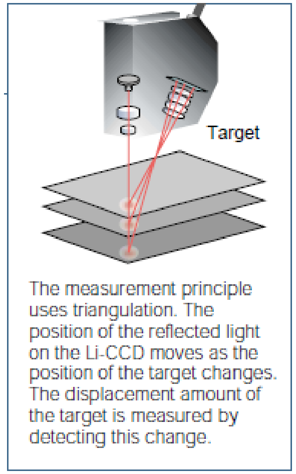
Imaging

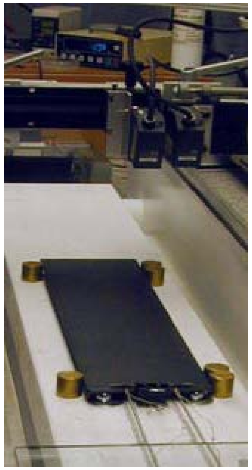


3D Confocal Microscopy



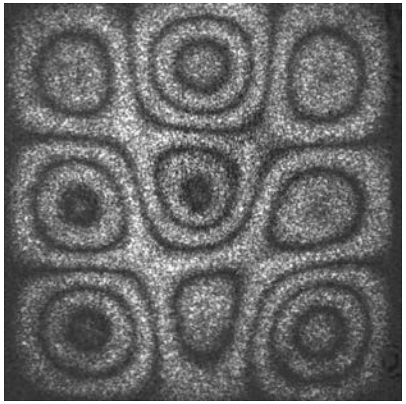






Laser Scanning

TV Holography/ESPI



Metrology

Technology	Application	Resolution	Interface	Ease/Speed
CMM-touch	Large objects	x/y/z ~ μm's	commercial	Teach mode
CMM-optical Imaging	In plane location Small heights	x/y/z ~ μm's	Commercial or custom	same
ESPI	Dynamics	x/y/z ~ μm's	commercial	R&D tool
FSI	In-situ alignment Stability	One axis	custom	System design
Laser Displacement	Flexible heights R&D tests	z ~ μm's	User defined	User defined, 1 KHz
Confocal Probe	Precision heights Small area	10-100 nm	Limited use commercial or user	User defined, 100 Hz–2 KHz

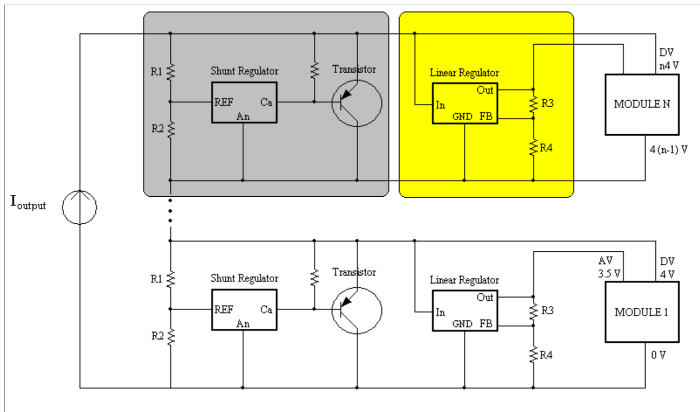
Research Directions

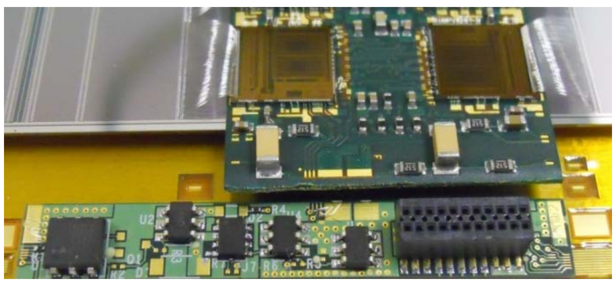
- Mainly driven by experimental needs
- 3D imaging over large areas is a rapidly developing field due to industrial QA
  - Understanding the capabilities of this technology may help realize new approaches across frontiers
- Active systems which combine metrology with motion control and actuation

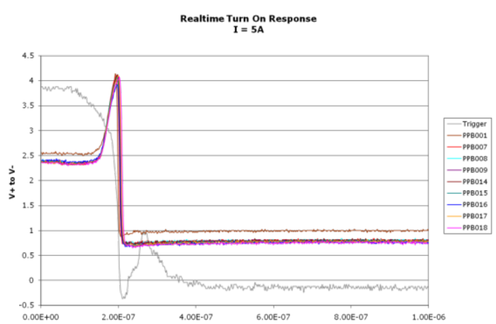
Power Distribution

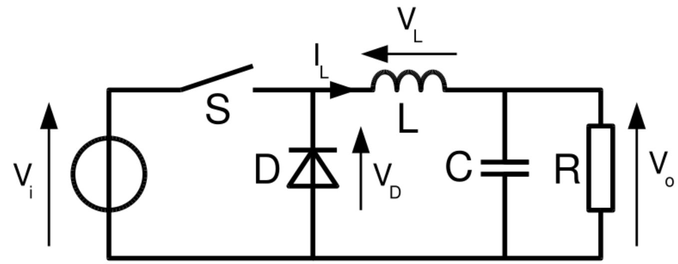
- For large systems with limited access space services cross section can be a major issue
- Inefficient distribution demands extra cooling
- Required approaches feature
  - DC-DC conversion methods
  - Serial current distribution
  - Multiplexing
  - Monitoring and control functions
  - Power cycling in the LC application
- Must respect demands on reliability, low noise, grounding and shielding, interaction with mechanics and cooling

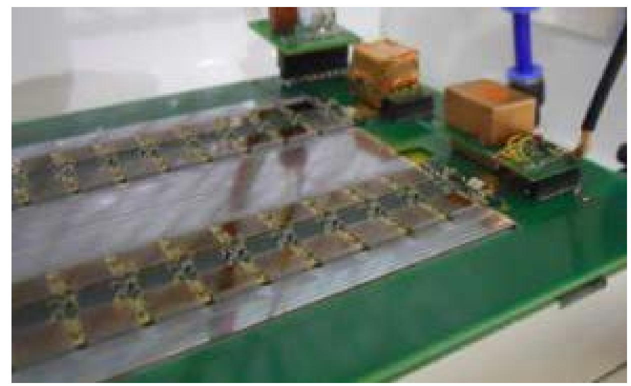
Examples

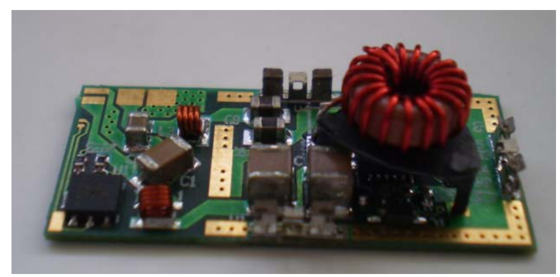












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Research Areas and Directions

- Radiation hard regulators, drivers, switching converters, charge pumps, HV low leakage switches
- Low mass inductors, air core inductors, low profile inductors
- Power cycling methods, stabilization, turn-on
- Low mass shields
- Control and monitoring architectures
- System design
- Low mass cables – flexible circuits, aluminum
- Connectors

Collaboration

- Collaboration has already been a hallmark of this area
- Important contributions from universities, labs, and industry (including SBIR)
  - Typically major infrastructure provided at labs
  - New products, capabilities from industry
  - Innovation, ideas, analysis, components, experimental connections at universities
- All should be encouraged and supported
- Possibility to work with other DOE Science offices on common areas

Conclusions

- Already a well established aspect of advanced instrumentation
- A variety of applications across the 3 frontiers
- Potential for important new developments and improvements in materials, structures, methods
- Requires on-going support for infrastructure
- Potential spin-offs to science and industry, good area for collaborative engagement
- Should develop a shared knowledge base which can grow as we learn more