Snowmass 2001

E7: Particle Physics and Technology Working Group

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Summary Presentation to HEPAP LRP Subpanel

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E7: Particle Physics and Technology Working Group

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Particle Physics & Technology Working Group Charge

Review leading-edge technologies recently developed (or in need of development) for new experiments and theoretical or computational investigations.

Examine developments related to particle detectors, accelerators, online data acquisition systems, offline data analysis systems & networked "Grid" systems

Examine technologies developed, or to be developed, within particle physics for their potential impact on society.

Review the demands for computer science expertise and software engineering in the current and future programs.

Particle Physics & Technology

Advances in Technology enable our research & allow progress

- $e^+ e^-$: klystrons, cavities, accelerating structures, ...
- p p: superconducting magnets, particle detection, computing, ...
- continuation of proven approach but very sophisticated...

Need to use new technologies

- better accelerators, detectors, analysis environments
- benefit from commercial mass production
- share the development effort - leverage non-HEP resources
- improve HEP research

Growing complexity of new technologies

- allow for integration time
- an “almost working” component can make a system unusable

Societal Benefits from Particle Physics Technology

Proton beams: nanowriters, nanolithography, spallation neutron sources, transmutation of nuclear waste, radiation therapy, production of radio-pharmaceuticals

Deuteron/Neutron beams: boron/neutron capture therapy, neutron tubes

Heavy ion beams: fusion, ion implanters (chip industry, surface modifications, vias, ...) radiation therapy

Electron beams: radiography, radiation therapy, food sterilization, synchrotron light sources, ...

Light sources (infrared through X-rays): vibration of biological molecules, surface physics/catalysis, chemical science (combustion), environmental remediation, lithography, protein crystallography

Superconductivity: magnets, power distribution, ...

Detectors: medical, astronomy, waste management, ...

Computing: massive parallel computing, Terascale simulations, data processing, data mining, networked data flow, statistical analysis methods, the web...

HEP Technology Development: Silicon Tracking

HEP radiation tolerance requirements above military and space science needs.

Thinner wafers and low multiple scattering require advanced support structures.

Larger wafer sizes, 300mm, allow for new applications, higher volume, reduced cost.

New developments:

- **Normal planar diodes have electrodes confined to the silicon surface but with P and N electrodes penetrating through the substrate, tolerance to bulk radiation damage, order-of-magnitude faster signals, and high efficiencies are achieved (3-D silicon).**
- **Using chemical etching in electric fields, precise mechanical structures created: 0.5 to 25 μm walls for mm length**
- **Double sided processing allows the detector to be on the front and readout electronics on the back**

HEP Technology Development: Scintillation Calorimetry

Using Cerenkov light (in addition to ionization information) with compensation, hadronic resolution can be improved, eliminating the constant term.

Scintillator advances improve speed, rad tolerance, and efficiency.

$PbWO_4$ Crystals

- Very compact, large radiation length.
- New doping materials achieve fast decay time, 15 ns, and a light yield 10-fold over Y-doped $PbWO_4$

Use of APDs for readout

Energy-flow calorimetry

- Optimized for best particle shower separation/reconstruction
- Dense calorimetry & high channel counts (digital calorimeter)

HEP Technology Development: Electronics & Integrated Circuits

Chip technology approaches three atom layer: tunneling effects will limit further feature size reduction in future

We are reaching the end of Moore's law in about 2010

- After that expect a slowdown in CMOS technology with doubling every 3 to 4 years.
- Work on several fronts is needed to advance.

Defect engineering, chip layout (e.g. enclosed layout transistors & guard rings), smaller feature size should help radiation tolerance.

HEP-mixed analog/digital designs require major R&D investment before smaller feature sizes can be exploited.

- Obsolescence requires us to follow industry

Power consumption: smaller fabrication size helps but leakage current becomes significant.

HEP Technology Development: Trigger and Data Acquisition

Level 1 trigger becomes integrated part of readout chips.

Use of commodity products (ASIC, FPGA, VME, PCI, Ethernet network switches).

Online/Offline boundaries, level 2 and 3 merge, use same PC hardware (flexibility).

Medical imaging has similar needs.

Smart segment finding algorithms in FPGAs will find tracks at Level 1

Hundreds of CPUs used in the trigger system:
How to know they are working?
How to react in case of failure?

- Collaboration with computer science established.

HEP Computing: The GRID

Large efforts are underway in the European countries and the US so one can get computing resources like telephone service.

Key issue is the interface between components so they an work together.

HEP is very active, together with IT and CS groups.

Governments expect much and supporting the development generously.

GRID as toolkit rather than vendor

- Can use the GRID but it cannot solve our problems for us

HEP Computing: Algorithms & Data Handling

Multivariant Algorithms

- Limited HEP use of multidimensional cuts in analyses
- Skepticism concerning likelihoods & neural networks.

Support Vector Machines

- define boundary surface between signal and background region as vector function
- easy/fast way to evaluate events

National Scalable Cluster Project

- Large HEP data volume
  - testbed for new CS ideas & techniques.
- National Digital Mammography Archive

HEP Computing: Exploiting opportunities

Commodity computing advances faster than HEP data volume

General approaches versus approaches using application specific knowledge.

High Performance Computing for Accelerators

- At NERSC part of SciDAT (Scientific Discovery through Advanced Computing)
- Precise collider performance simulation allows narrowing down the design parameters (i.e. aperture) and thus cost savings.

HEP R&D Needed:
Example: NLC Detector

Vertex and tracking with minimal multiple scattering requires stretched CCDs and readout ASICs bounded to CCDs.

How to handle 2.8 ns bunch spacing (CCD timing, etc.)?

Silicon-tungsten calorimeter optimized for energy flow (electronic-mechanical integration).

HEP R&D Programs

DOE Advanced Detector Research Program

- Setup to support detector R&D at universities at the earliest stage.
- Program started this fiscal year, 6 proposals received support.
- 500K$/year

Suggestion that a Program similar to TNRLC (generic university based detector research program for SSC R&D) has substantial benefits

- HEP projects, particularly Babar, TeV II and LHC are benefiting from technologies developed by TNLRC

Areas where HEP R&D is needed

- CCD radiation-tolerance
- Pixel and CCD readout speed
- Low mass support structures
- Radiation hard electronics
- Mixed analog and digital chip design
- Calorimetry: energy resolution, energy flow
- Alignment technology
- Fast timing and triggering
- Cheap readout: millions of channels Si trk & Si-W cal
- Fault tolerant computing
- Collaborative working tools
- Nanomechanics

HEP Technology & Sociology

The Past:

- **HEP was attractive to students because it was fast/dynamic research in a small community. One could learn/explore much in a short time using latest state-of-the-art technology.**

The Present:

- **We have become a large community of very specialized people.**
- **Progress in our field has slowed down**
  - Over a decade at the same energy.
- **Students come to learn computing and statistical skills.**
  - We are regarded as a field of applied modern technical computing
- **Opportunities to work on state-of-the-art equipment still exist.**

The Future:

- **We will continue to attract bright students if**
  - We have fascinating scientific research where an individual can make a significant contribution
  - We develop and apply modern technologies in our day-to-day work

HEP Technology: Conclusions - I

There are many technologies developed or enhanced by particle physics that are of general benefit to society:

- Particle beams and synchrotron light sources
- Medical treatment and imaging
- Nanolithography
- Superconductivity
- Massive parallel processing
- Terascale simulations
- Data mining, networked dataflow, the web...

There are many technologies outside of HEP that can be used to benefit our field

- However…

HEP Technology Conclusions - II

Integrating/using new technologies takes time:

- to discover them and their application to/in HEP
- understand them prototype/test/shake them out in the laboratory
- transfer knowledge for production line engineering
- propose their use/design detectors based on them

Long-term, project-independent R&D funding is important at both universities and laboratories, not only for accelerator design but also for detectors & analysis environment

Detector R&D is needed for all future colliders

- e.g. NLC/Tesla (radiation-tolerance, mechanical support structures, readout speed, calorimetry, ...).