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Particle Physics and Technology Snowmass 2001 Summary

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- ## The Past

  Particle Physics had significant impact in the R&D of many technological areas.

- ## The Present

  What are technologies currently doing/not doing for us?

- ## The Future

  What are the key areas and problems were we need R&D to sustain the progress in our field?

  What technologies are being developed in other fields that could benefit HEP?

Particle Physics and Technology

- Advances in Technology are what enables our research and allows us to progress in our field:
  - e^-e^+ klystrons, cavities, accelerating structures, ...
  - p^+p^- superconducting magnets, particle detection, computing, ...

  continuation of proven approach but extremely sophisticated...

- We need to continue to use new technologies to our advantage:
  - to get better accelerators, detectors, analysis environments;
  - benefit from commecial mass production;
  - share the development effort;
  - improve our research

- Technologies get more complex (or complicated):
  - allow for integration time;
  - an "almost working" component can make a system unusable.

Benefits from Particle Physics Technology

Particle Physics Technology has benefited society at large in many areas:

- 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...

The list of particle beam applications comes from Alan Jackson, LBNL.

Silicon Detectors and Chips

Talks by Mary Bishay, FNAL, on the CDF silicon vertex detector and by Lucien Cremaldi, U of Mississippi, on CMS pixel detector. and IEEE Nuclear and Plasma Science Society, NPSS, technology lectures and sessions.

- Key issue is Radiation Damage. HEP radiation tolerance requirements above military and space science needs.
- Thinner wafers and low multiple scattering require advanced support structures.
- Larger wafer sizes, 300mm, also allow for new applications, higher volume, and reduced cost.

Talk by Robert Wilson, Colorado State U, on Silicon Avalanche Photo Diodes, APD
and Roger Rusack, U of Minnesota.

- 1987 to 1996 bringing APD technology to reality
- 1996 to 2001 establishing technology
- 2002+ in use by HEP

Silicon Detectors and Chips, cont.

Presentations by Sherwood Parker, U of Hawaii, on silicon radiation sensors with three dimensional electron arrays,
Dave Winn, Fairfield U, Silicon Micromachined Photodetectors, and IEEE NPSS technology lectures and sessions, James Fleming.

- **Normal planar diodes have electrodes confined to the silicon surface.**
- **With P and N electrodes penetrating through the substrate, tolerance to bulk radiation damage, order-of-magnitude faster signals, and high efficiencies are achieved.**
- **Using chemical etching in electric fields, precise mechanical structures can be created: 0.5 to 25 μm walls for mm length (2mm Si wafer).**
- **Double sided processing allows the detector to be on the front and readout electronic on the back.**

Silicon is going 3-d !

Silicon Detectors and Chips, cont.

Talk by Alessandro Marchioro, CERN, on Future of Radiation Hard Electronics
and IEEE NPSS technology lectures, Yuan Taur, IBM.

- Chip technology is at the three atom layer, tunneling effects are limiting: welcome to Quantum Mechanics.
- 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 (enclosed layout transistor, ELT and guard rings), and going to smaller μm technology will help radiation tolerance.
- HEP-mixed analog/digital designs require considerable R&D investment before smaller feature sizes can be exploided. (Obsolecense requires us to follow industry.)
- Power consumption: smaller fabrication size helps but leakage current becomes significant.
- Power in the cables...

Calorimeters and Crystals

**Talk by Dave Winn, Fairfield U, on Cerenkov Compensation for Precision Calorimeter,
Randy Ruchti, U of Notre Dame, on plastic/organic scintillators,
and Ren-Yuan Zhu, Caltech, on new lead tungsten crystals and on Sapphire Crystal Development for LIGO.**

- Using Cerenkov light (in addition to ionization information) and apply a compensation, hadronic resolution can be improved, eliminating the const term.

- Scintillator advancements improve speed, rad tolerance, and efficiency.

- $PbWO_4$ very compact, large radiation length.

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

Trigger and DAQ

Talk by Patrick Le Du, CEA Saclay, on next generation trigger and DAQ.

- Level 1 trigger becomes integrated part of readout chips.
- Use commodity products (ASIC, FPGA, VME, PCI, Ethernet network switches).
- Online/Offline boundaries, level 2 and 3 merge, same PC hardware (flexibility).
- Medical imaging has similar needs.

Talk by Daniel Kaplan, Illinois Institute of Technology, on BTeV trigger.

- Smart segment finding algorithm in FPGA finds tracks at level 1.

Talk by Joel Butler, FNAL, on fault tolerance in computing in the BTeV trigger.

- Hundreds of CPUs used in the trigger system, how to know they are working and how to react in case of failure.
- Collaboration with computer science established.

Computing

The GRID is coming...

Talk by Robert Wilson and IEEE NPSS technology session.

- Large efforts are underway in the European contries 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.
- Switching service provider will not be as easy as 1-800-ATT with our data volumes.
- Toolkit versus vendors.

We need to benefit from it!

Computing, cont.

Talk by Daniel Whiteson, UCB, on Multivariant Algorithms

- We have been using in our analyses multidimensional cuts (very little).
- We have always been skeptical of likelihoods and neural networks.
- Support Vector Machines
  - define boundary surface between signal and background region as vector function;
  - easy/fast way to evaluate your events;

Talk by Kevin Sterner, UPenn, on National Scalable Cluster Project.

- We have a lot of data and are an interesting testbeds for new CS ideas and techniques.
  - Example: National Digital Mammography Archive
- Commodity computing advances faster than our data grow!
- General approaches versus approaches using application specific knowledge.

Computing, cont.

Talk by Robert Ryne, LBNL, on High Perf. Comp. for Accelerator.

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

Detector and R&D Programs

Talk by Martin Breidenbach, SLAC, on NLC detector R&D.

- 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).
- Program similar to TNRLC (generic university based detector research progream) for SSC R&D is needed.

Talk by Michael Procario, DOE, on the 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.

Areas where R&D is Needed

There are several areas in particle physics that require R&D work vital to the progress in our field.

- CCD radiation-tolerance
- Pixel and CCD readout speed
- Low mass support structures
- Radiation hard electronics
- Mixed analog and digital chip design
- Calorimeter energy resolution, energy flow calorimetry
- Alignment technology
- Fast timing and triggering
- Inexpensive readout of millions of Si vertex and Si-W calorimeters
- Fault tolerant computing
- Collaborative working tools
- Nanomechanics

Large $ resources are spent on silicon based production and laser research by non-HEP.

Sociological

The Past:

Our field was attractive to many students as it was fast/dynamic research in a small community. One could learn/explore so much in a very 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, we are for 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.

Conclusions

- There is a long list of technologies developed or enhanced by particle physics that is of general benefit to society:
  - particle beams and synchrotron light sources
  - medical treatment and imaging
  - nano-litography
  - superconductivity
  - massive parallel processing and Terascale simulations
  - data mining, networked dataflow, the web...
- There are a lot of great technologies out there that we can use to benefit our work and field.
- 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 beams but also detector and our analysis environment.
- Detector R&D is needed for all future colliders, e.g. NLC/Tesla (radiation-tolerance, mechanical support structures, readout speed, calorimetry, ...).