Tools, Techniques and Technology Connections of High-Energy Physics

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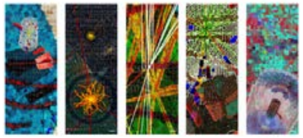
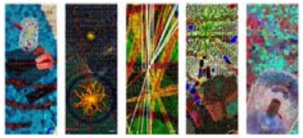
HEPAP Meeting, Bethesda

With many thanks to
L. Chatterjee, M. Cooke

Web Of Connections



- Particle physics relies on techniques, tools, and technologies to accomplish its mission.
- These tools and technologies depend critically on advances in other fields, and their value extends far beyond particle physics to other areas of science and society.
- This web of connections is extensive; There has been no formal attempt to map this web and explore future opportunities. Now is the right time to take the first steps.
- Our field is entering a new era of scientific discovery. At the same time, the pace of advancements in tools and technologies is increasing across the board.
- We are in a new environment where it is beneficial to us – and we hope to other sciences – to approach technical problems in a collaborative spirit and in partnership with other fields and with industry.

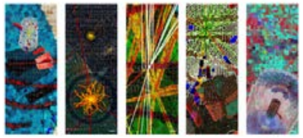


Charge from SC OHEP

- Articulate key connections and synergies between the tools, techniques and technologies developed for particle physics and other disciplines; in particular identify:
  - Current and potential impacts of particle physics on other scientific fields and society at large.
  - Benefits and potential opportunities to particle physics from exchanges with other sciences and industry.
  - Potential for HEP facilities to serve communities outside particle physics.
  - **Most importantly, identify opportunities for expanding and strengthening these connections to better contribute to national and global science and technology advances while advancing our own research goals.**

- Process followed:
  - Reviewed existing documentation on the effects of tools, techniques, technologies and skills.
  - Contacted experts, both within and outside particle physics to discuss current and potential bi-directional impacts.

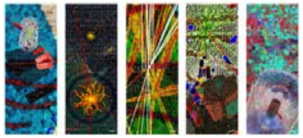
Contributing Experts



Laci Andricek, *Max-Planck-Gesellschaft Halbleiterlabor*
Tim Antaya, *Massachusetts Institute of Technology*
Makoto Asai, *SLAC*
David Asner, *Pacific Northwest National Laboratory*
Vineer Bhansali, *PIMCO*
Ian Bird, *CERN*
Amber Boehnlein, *SLAC*
Glenn Boyd, *PANNIA*
Michael Campbell, *CERN*
Manuela Cirilli, *CERN*
Bruce Chai, *Crystal Photonics GmbH*
Dhiman Chakraborty, *Northern Illinois University*
George Coutrakon, *Loma Linda University Medical Center/Northern Illinois University*
Eric Colby, *SLAC*
Peter Denes, *Lawrence Berkeley National Laboratory*
Manjit Dosanjh, *CERN*
Daniel Elvira, *Fermilab*
Michael Ernst, *Brookhaven* National Laboratory
Jeff Fang, *Shanghai Institute of Ceramics*
Paulo Fonte, *LIP Coimbra*
Alex Guenther, *Pacific Northwest National Laboratory*
Steve Ghan, *Pacific Northwest National Laboratory*
Salman Habib, *Argonne National Laboratory*
Steve Holland, *Lawrence Berkeley National Laboratory*
Robert Johnson, *University of California, Santa Cruz*
Carol Johnstone, *Fermilab*
John Krane, *Financial Services*
Thomas Kroc, *Fermilab*
John Learned, *University of Hawaii*
Wim Leemans, *Lawrence Berkeley National Laboratory*
Alan Litke, *University of California, Santa Cruz*
Thomas Ludlum, *Brookhaven National Laboratory*
Paul Mackenzie, *Fermilab*
David McDaniel, *GE Healthcare*
Peter McMurry, *University of Minnesota*
Markus Nordberg, *CERN*
Ken Olson, *Superconducting Particle Accelerator Forum of America*
Joseph Perl, *SLAC*
Klaus Peters, *University of Frankfurt*
Ruth Pordes, *Fermilab*
Erik Ramberg, *Fermilab*
Paul Rubinov, *Fermilab*
Rob Roser, *Fermilab*
Hartmut Sadrozinski, *University of California, Santa Cruz*
Reinhard Schulte, *Loma Linda University Medical Center*
Roy Schwitters, *The University of Texas at Austin*
John Shilling, *Pacific Northwest National Laboratory*
Jim Smith, *The National Center for Atmospheric Research*
Robert Sugar, *UCSB*
Christophe de la Taille, *LLR, Ecole Polytechnique*
Jennifer Thomas, *University College London*
Zhehui Wang, *Los Alamos National Laboratory*
Mark Wise, *Caltech*
Doug Worsnop, *Aerodyne Research, Inc.*
Dennis Wright, *SLAC*
Ren-yuan Zhu, *Caltech*

Contributions of all experts greatly appreciated!

About 40% of contributors outside of HEP



Outline

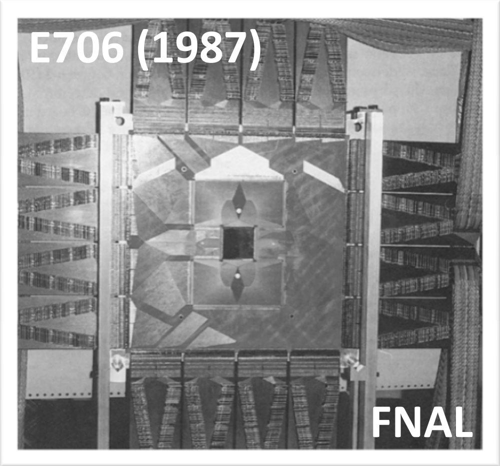
- ☐ Detector Technology
- ☐ Computing, Software and Data Management
- ☐ Accelerators
- ☐ Particle Physics Facilities
- ☐ Opportunities

Note: an ↻ indicates a connection that has come “full circle”:
particle physics -> other sciences / industry -> particle physics

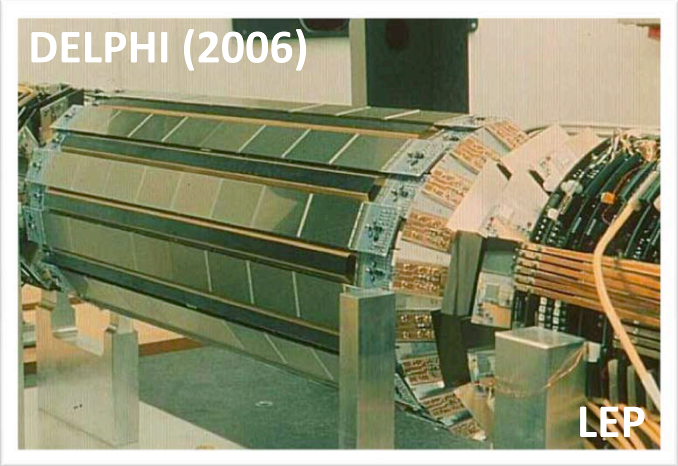
Detector Technology

A major area of connections of HEP, from medical industry to imaging detectors to industry

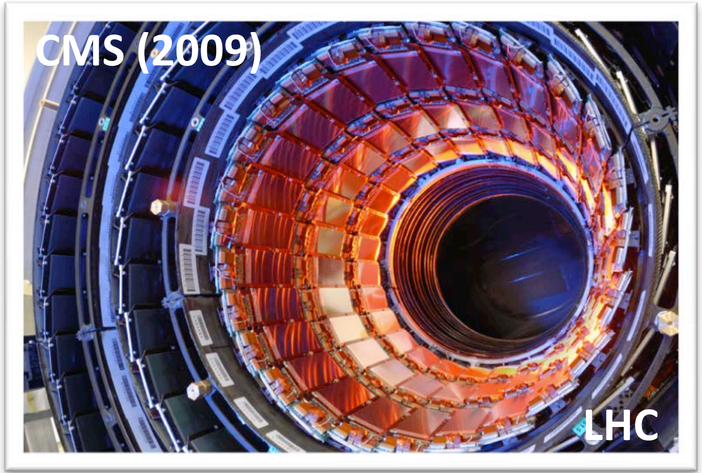
Silicon Technology



Area = 25 cm^2

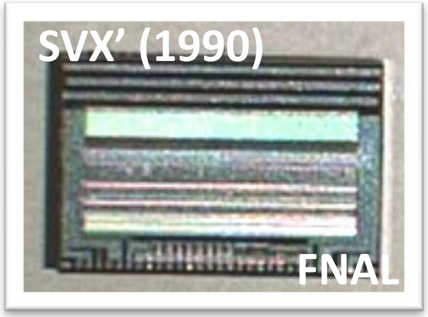


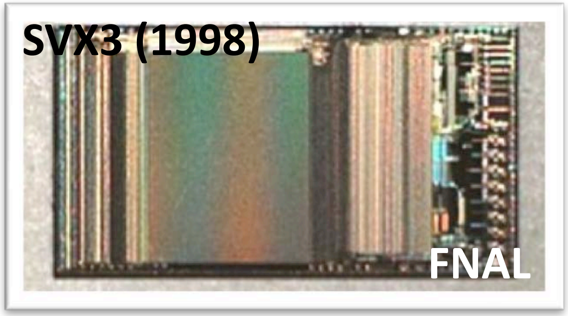
Area = 1 m^2



Area = 200 m^2

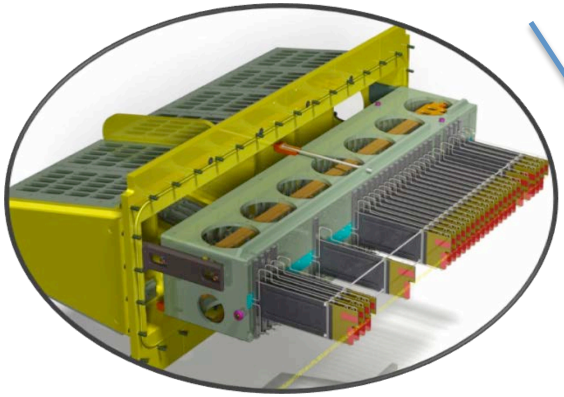
- The development of the silicon detector and readout technology for particle detectors was enabled by the semi-conductor industry
- Particle Physics has taken the technology to unprecedented scale and capability



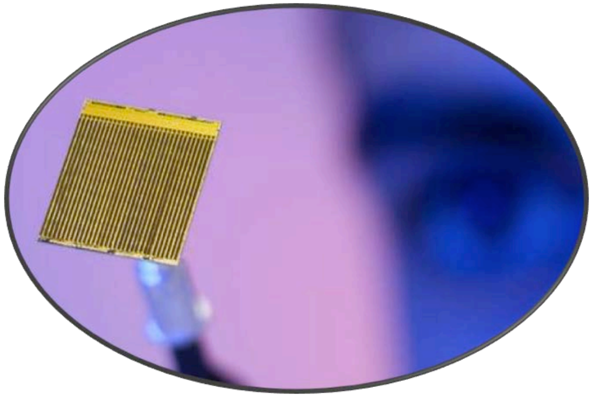


27,000 pixels
87M transistors

Application Specific Integrated Circuits



1999: Development of readout chip for ALICE experiment at the LHC ...



... Led to the development of low contrast imaging readout: MEDIPIX chip

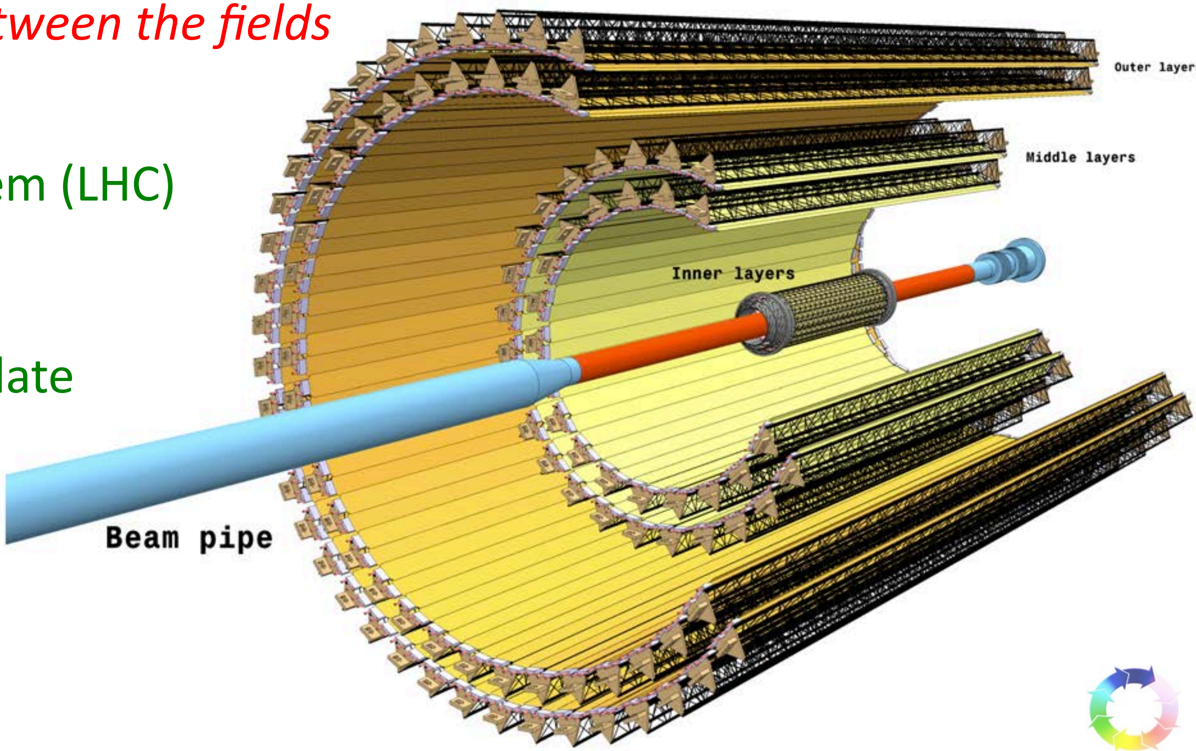
... Led to the implementation of color imaging and timing information: TIMEPIX ...

... which can be used for the new vertex detector for the LHCb experiments at the LHC (2014)

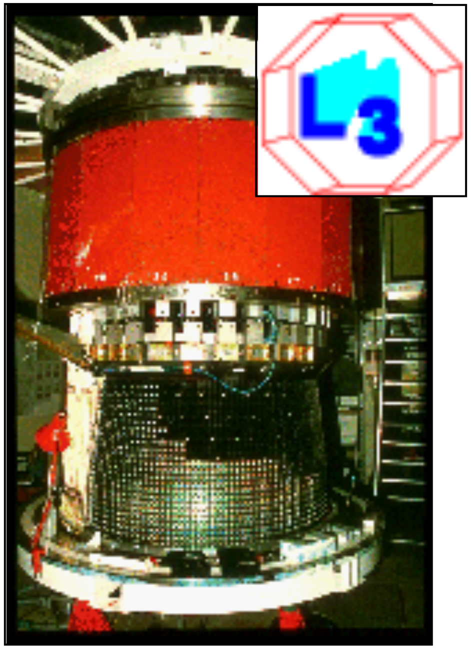
More Silicon Technology Synergies

- ☐ The Monolithic Active Pixel Technology (MAPS) – sensing medium and front-end electronics integrated in pixel – originally conceived by the particle physics community, mainly in the framework of the International Linear Collider
- ☐ Technology now being matured by the nuclear physics community
- ☐ *Development could be very helpful for HEP – and demonstrates the value of good connections between the fields*

ALICE Inner Tracking System (LHC)
~10m^2 of MAPS sensors
7 layers, 25 Giga-pixels
Largest pixel detector to date

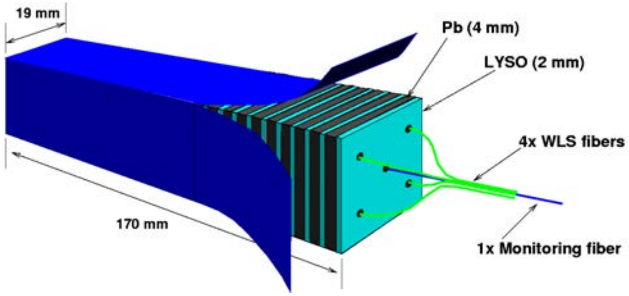


BGO Crystal Development



- ❑ Bismuth Germanate (BGO) crystal scintillator was discovered in 1970s and quickly adopted by HEP for precision EM calorimetry
- ❑ The L3 experiment at LEP built the 1st BGO crystal calorimeter consisting of 11,400 BGO crystals of 1.5 m^3, which were grown at Shanghai Institute of Ceramics (SIC)
- ❑ Although a one shot HEP market for SIC in early eighties, it led to the multi-crucible growth technology allowing growth of up to 36 crystal ingots per oven
- ❑ Opened medical market. More than 1,500 PET scanners have been built with SIC BGO by GE Healthcare
  - PET scanner cost: $250k – $600k
  - ~1.5 million PET scans/year in the US
- ❑ *The cost-effective modified Bridgman growth technology developed at SIC for BGO crystals has also been utilized in developing new crystal scintillators for HEP experiments and industry.*

LYSO Crystal Development

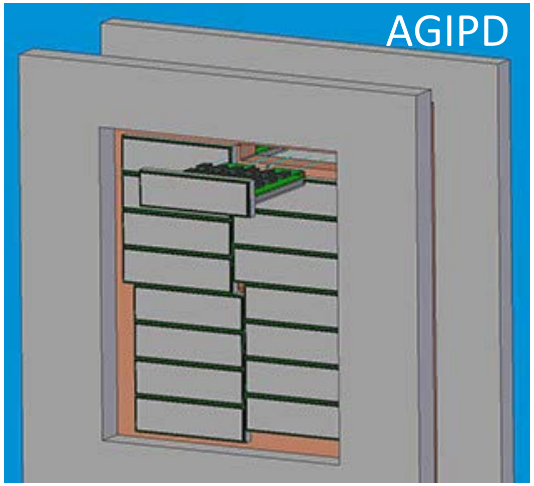


LYSO for CMS FCAL Upgrade

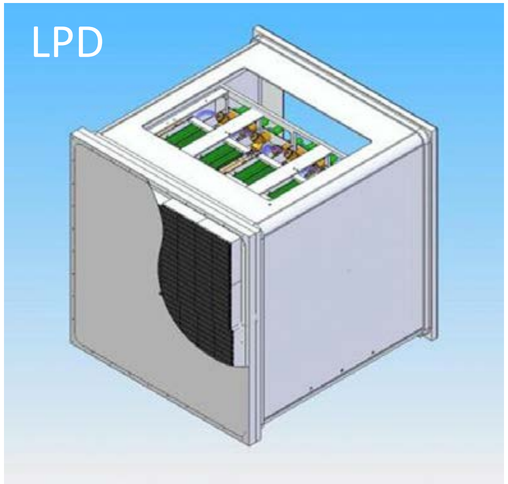
- Radiation damage studies of Lead Tungstate (PWO) crystals showed that thermal annealing of PWO crystals in oxygen atmosphere and yttrium doping were effective to improve crystal radiation hardness.
- Idea adopted by faculty of the College of Optics & Photonics at the University of Central Florida: cerium doped Lutetium Yttrium Orthosilicate (LYSO) crystals were developed
- With its brighter and faster scintillation than BGO, LYSO dominates the PET market. Thousands of LYSO-based PET scanners have been marketed by GE and Phillips.
- *HEP benefits from these development: LYSO crystals are now a candidate option for the CMS forward calorimeter upgrade*

X-Ray Detectors

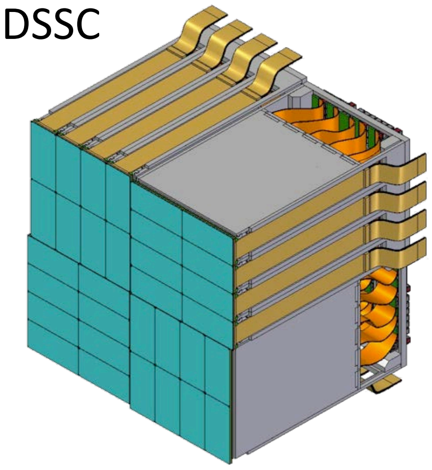
- X-ray community has teamed up with the particle physics community to develop 2D imaging x-ray detector for XFEL, with corresponding DAQ systems
- *Connection with light-source community will advance semi-conductor technologies to the benefit of the particle physics community.*



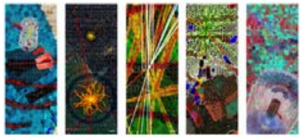
AGIPD: Hybrid pixel detector
Dynamic range/pixel/pulse
10^4 @12 keV
# of Storage cells 250 – 300
Pixel size: 200 x 200 μm^2



LPD: Hybrid pixels
Dynamic range
10^5@12 keV
Storage Cells ≈ 512
Pixel Size 500 x 500 μm^2



DSSC: DEPFET-based
Dynamic range/pixel/pulse
6000 @1 keV
Storage Cells ≈ 640
Pixel Size ≈ 236 x 236 μm^2



Opportunities

- Advances are being made in other science disciplines and in industry that particle physics – and other sciences – should take advantage of.
- Scientists need to be educated about the advances in other areas and their potential application to particle physics.
- There is great potential to create a fertile, interactive dialogue among science disciplines to develop new technologies that surmount technological barriers.
- Joint workshops could initiate such a dialogue.

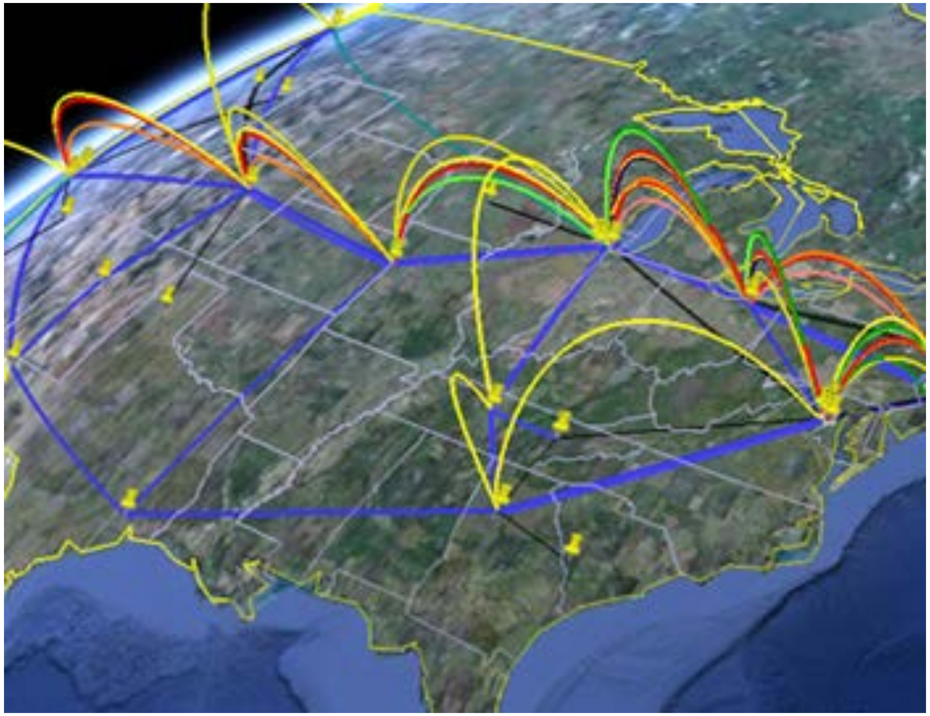
- Constant support from and dialogue with a technology's initial developers is critical for successful application of these technologies outside the fundamental sciences.

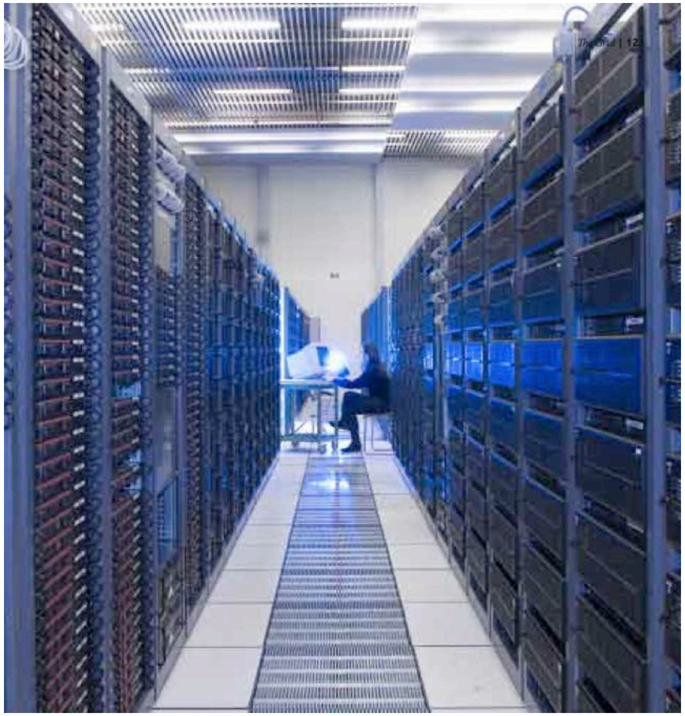
Computing, Software, Data Management

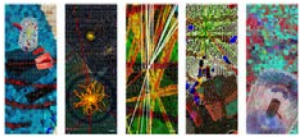
HEP has been at the forefront of big data and the need for advanced networking

“Big Data”

- As the invention of the World-Wide Web was a response to a new need for scientific collaboration, grid computing is the response to the need for increased data analysis power that can be made available by accessing remote computer installations in widely dispersed institutes. These need:
  - Reliable high-bandwidth networks to move the data
  - Access to high-compute-power systems



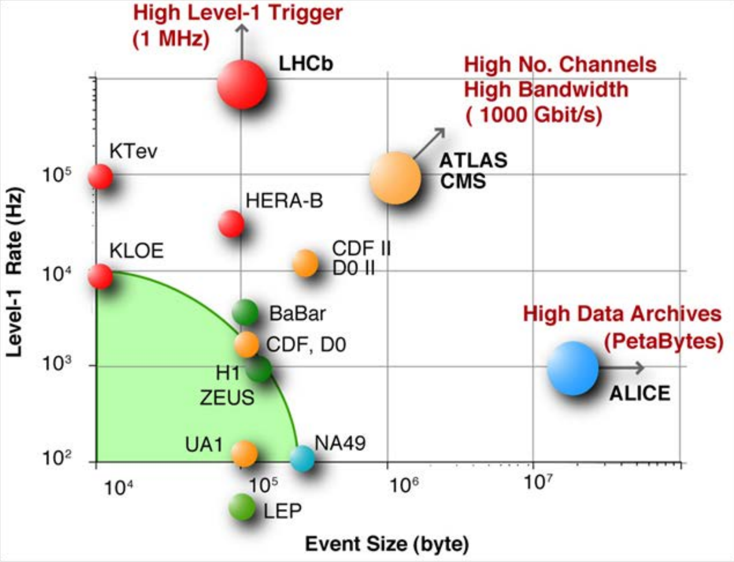




Energy Sciences Network (ESnet)

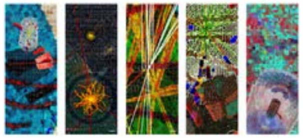
- The Energy Sciences Network (ESnet) is a communications infrastructure to support scientific research; managed and operated by the Advanced Scientific Computing Research (ASCR) program within the Office of Science

- The interplay between the particle physics community and ESnet has been very fruitful
  - HEP data flows recognized as primary driver
  - Development of the the On-demand Secure Circuits and Reservation System (OSCARS) spurred by HEP needs
  - HEP contributor and beneficiary of global collaborations with research network providers around the globe
- *Due to global nature of HEP community, particle physics benefits tremendously*



Each LHC experiment produces ~ 10 PB of data per year (1PB=10^6 GB)

Data analysis requires computing power equivalent to ~100 000 today's fastest PC processors.

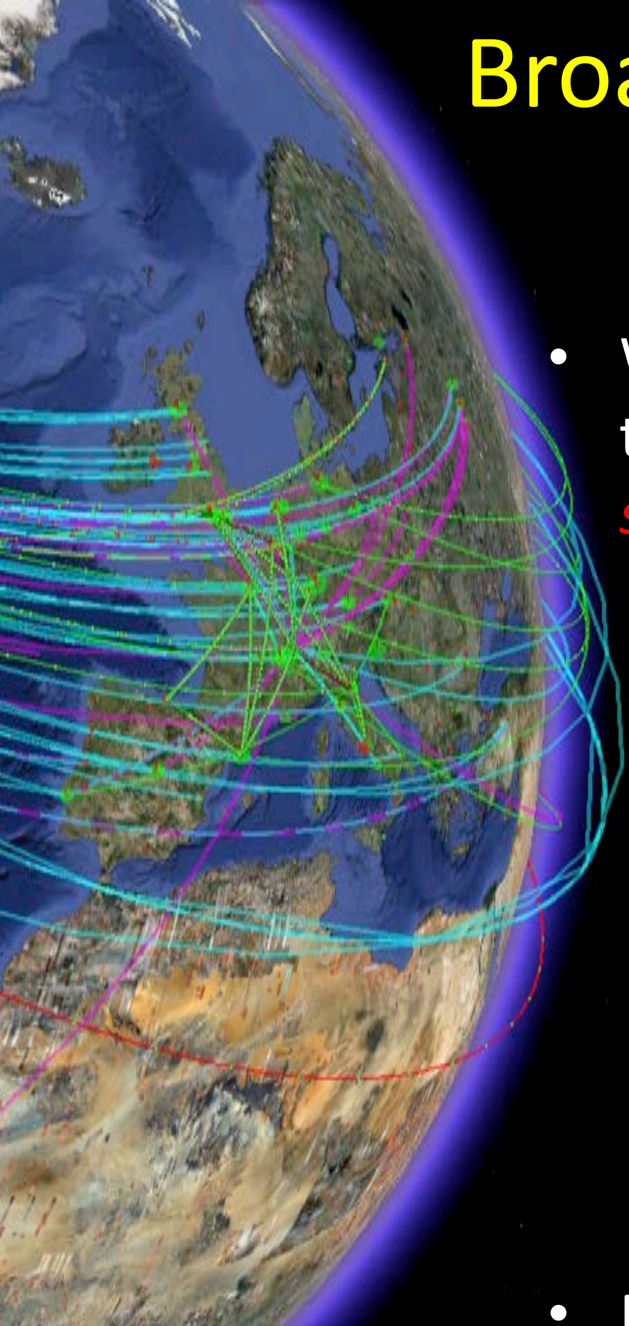


Worldwide LHC Computing Grid

- Powers LHC computing and data analysis
- Development began in 2002, initial deployment in 2008
- Depends on two major science grid infrastructures:
  - European Grid Infrastructure
  - Open Science Grid (OSG) in United States

A map of the worldwide LCG infrastructure operated by EGEE and OSG.

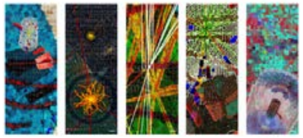
Broader Influence of the LHC Computing Grid



- WLCG has been leveraged on both sides of the Atlantic, *to the benefit of the wider scientific community and particle physics*
  - Europe:
    - Enabling Grids for E-sciencE (EGEE) 2004-2010
      110 M€ EC Funding
    - European Grid Infrastructure (EGI) 2010-2014
      25 M€ EC Funding
  - USA:
    - Open Science Grid (OSG) 2006 onwards
- Many scientific applications ➔

Archeology
Astronomy
Astrophysics
Civil Protection
Comp. Chemistry
Earth Sciences
Finance
Fusion
Geophysics
High-Energy Physics
Life Sciences
Multimedia
Material Sciences
…

Lattice QCD and Supercomputing



- The lattice quantum chromodynamics (LQCD) community has ab initio been a joint community between nuclear physics and particle physics.

- LQCD has been a contributor to the development of supercomputing from the beginning:
    - In the 70s, a leading lattice theorist programmed array processors in assembly language to attack critical phenomena problems; later wrote Fortran compiler for the FPS array processor.
    - In the 80s the same theorist contributed strongly to the Lax Report which led to the establishment of the NSF supercomputing centers and NSFNET (forerunner of the internet).
    - Also in the 80s lattice gauge theorists worked to design highly parallel machines aimed at lattice QCD.

- These efforts helped establish the massively parallel paradigm for large-scale supercomputing that has been the industry model for the last twenty years.

Example: IBM's Blue Gene Supercomputers

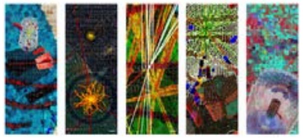
QCDOC compute card.

- The IBM Blue Gene supercomputers grew out of the Columbia QCD machines, and the team won the Gordon Bell prize for price/performance in 1998 for the QCDSP, a machine purpose-built for lattice QCD.
- A team that had been part of these projects went to IBM and designed the closely related (commercial) BlueGene/L
  - The system-on-a-chip design, tightly coupled standard processor and FP unit, torus network, and style of mechanical design were modeled on the Columbia machines.
- USQCD now exploring use of GPUs; computing industry (NVIDIA) benefiting from QCD expertise and personnel.

BG/L compute card.

- *The developments in HPC in turn have had very positive impact on particle physics.*

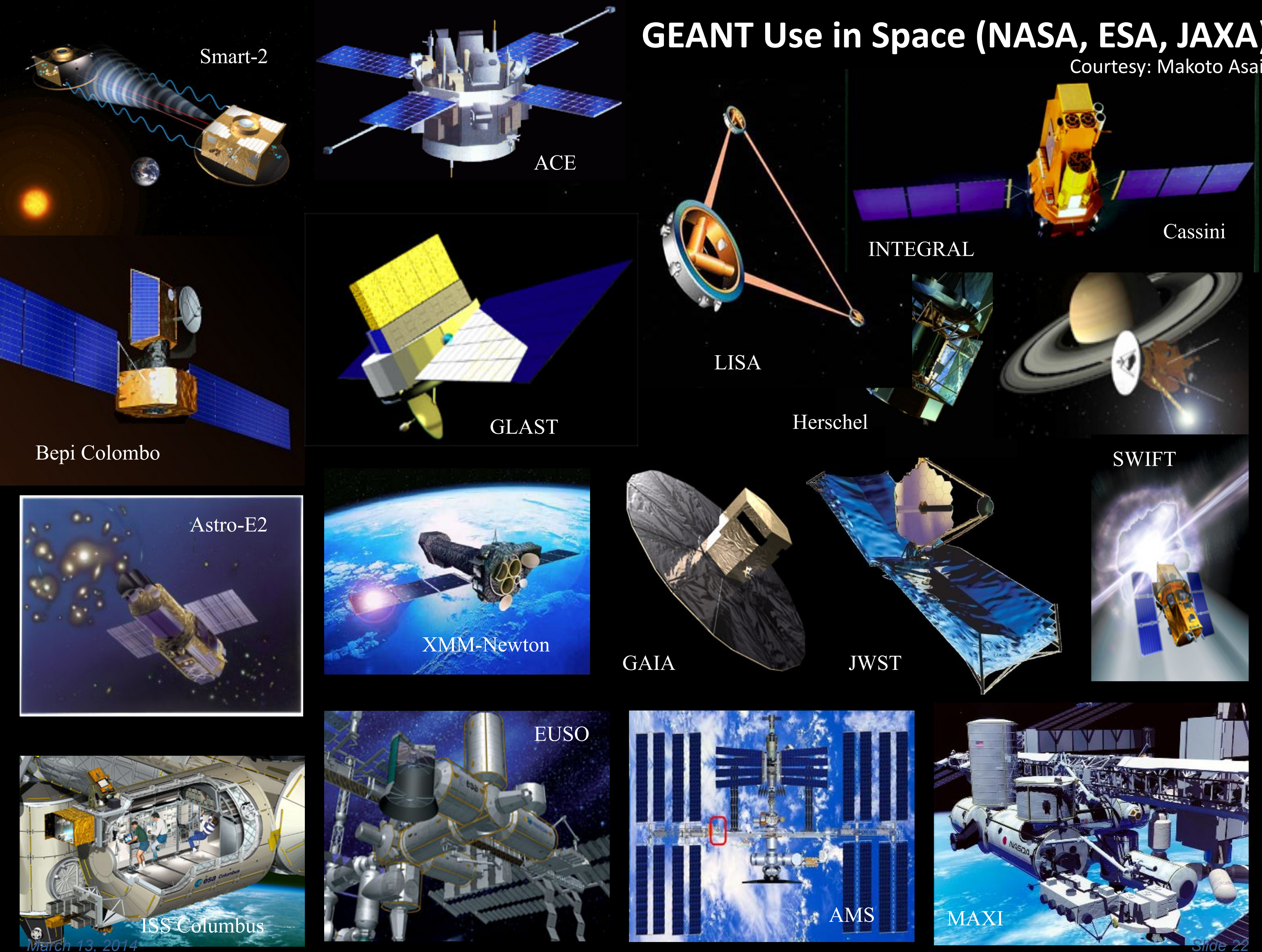
GEANT4



- The GEometry ANd Tracking Toolkit for HEP detector simulation
- Geant4, object oriented successor of Geant3, started at CHEP 1994 in San Francisco
  - December ’94: CERN RD44 project start
  - Apr ’97: First alpha release
  - Dec ’98: First Geant4 public release - version 1.0
- Its use goes currently well beyond particle physics:
  - G4NAMU: Geant4 North Americas Medical Users
    http://geant4.slac.stanford.edu/g4namu/
  - Geant4EMU: European Medical User Organization
    http://g4emu.wikispaces.com/
  - Geant4MED: Medical Physics in Japan
    http://g4med.kek.jp/
  - GAMOS: Geant Architecture for Medicine-Oriented Simulations
    http://fismed.ciemat.es/GAMOS/
  - GATE: Geant4 Application for Tomographic Emission
    http://www.opengatecollaboration.org/
  - GEANT for Space Applications initiated by the European Space Agency
    http://geant4.esa.int/
  - GEANT4-DNA: Biological damage to DNA by ionizing radiation
    http://geant4-dna.org/
  - G4Beamline: Simulation of beamlines with emphasis on muon facilities
    http://www.muonsinternal.com/muons3/G4beamline

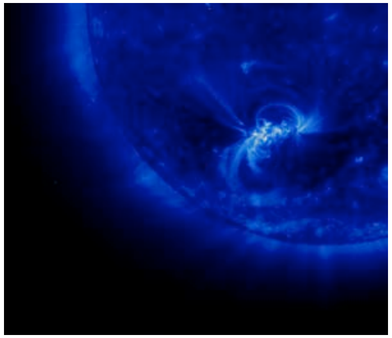
GEANT Use in Space (NASA, ESA, JAXA)

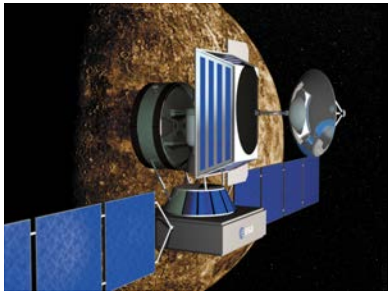
Courtesy: Makoto Asai

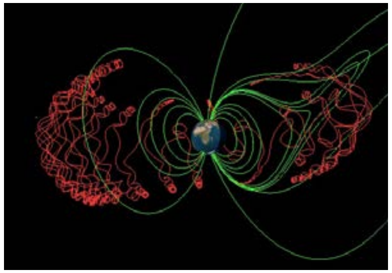


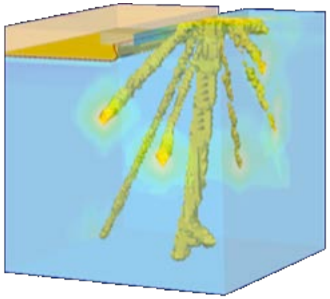
More Applications of GEANT

- ❑ Effect of Compton scattering on Gamma-ray spectrum in solar flares
- ❑ X-Ray mineralogical survey of mercury by Beppi-Colombo
- ❑ Cosmic Rays in planetary atmo-magnetospheres
- ❑ Single Event Upset (SEE) in SRAM
- ❑ Neutron radiation in proton therapy
- ❑ DNA modeling and effects of ionizing radiation

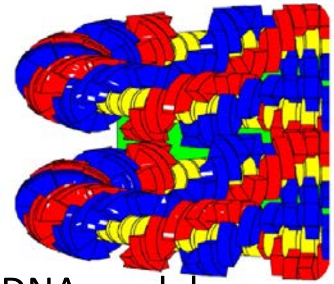




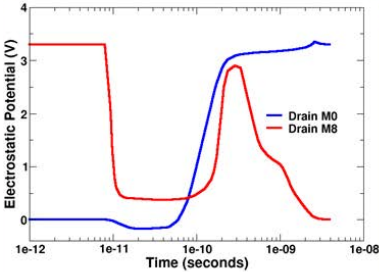




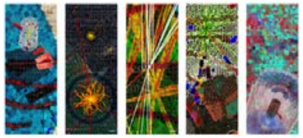
Dose calculation



DNA model



Opportunities



- Many opportunities to develop partnerships:
  - Lattice algorithm techniques in partnership with condensed matter physics
  - Data tools in partnership with computer science and other fields
  - High-performance computing and particle physics simulation techniques in partnership with other basic sciences, including computer science and applied mathematics

- A specific opportunity to explore partnerships with other sciences and industry to maintain and further develop GEANT
  - Used by many other sciences and industries
  - GEANT4 was created 20 years ago and its current architecture may not meet future needs and developments.
  - User communities may want to anticipate such transition

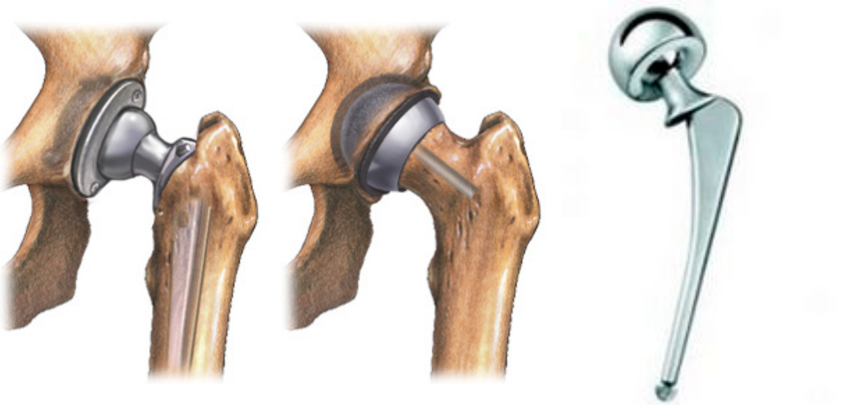
Accelerators

Mainly covered in ‘Accelerators for America’s future’ and later reports; focus here on science connections

Web of Accelerator Connections

- First particle accelerators invented in the early 20th century. Multi-disciplinary expertise continually drives the technology forward.
  - Materials scientists develop better and more sophisticated components
  - Advances in computing enable much more accurate and thorough simulations
  - Laser and plasma physics discoveries are driving the development of new types of accelerators

- Accelerators now critical for research needing high-energy, high-intensity particle beams. They power research in:
  - Particle physics
  - Nuclear physics
  - Condensed matter physics
  - Biology
  - Materials science
  - Atmospheric science
  - and more…

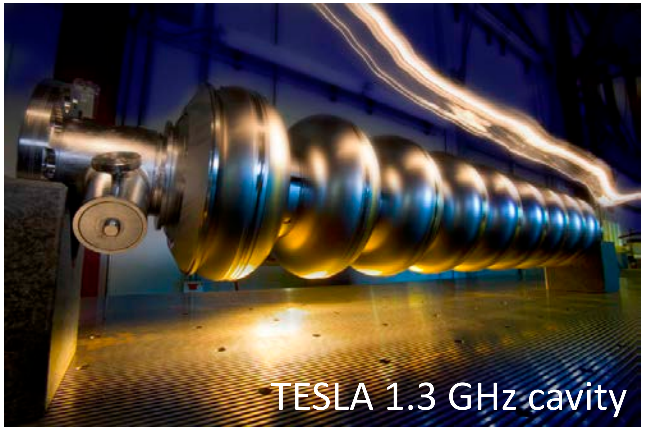


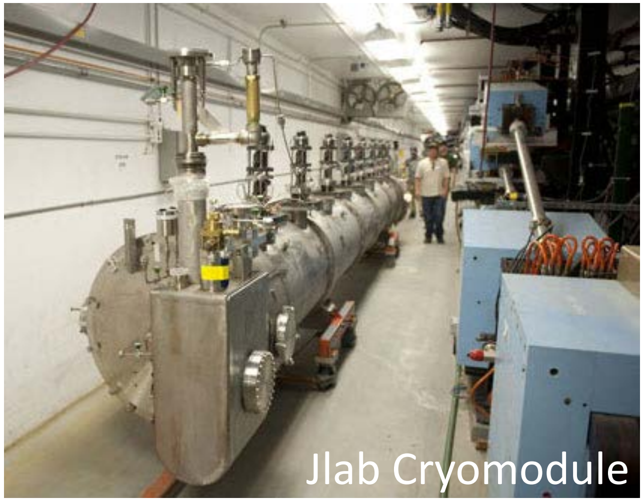
Nitrogen Ion implantation of titanium and cobalt-chrome alloys to improve surgically implantable artificial joints

- For each accelerator used for science, thousands more are in use every day in industry and medicine to produce better products and treat disease.

Superconducting Radio-Frequency R&D

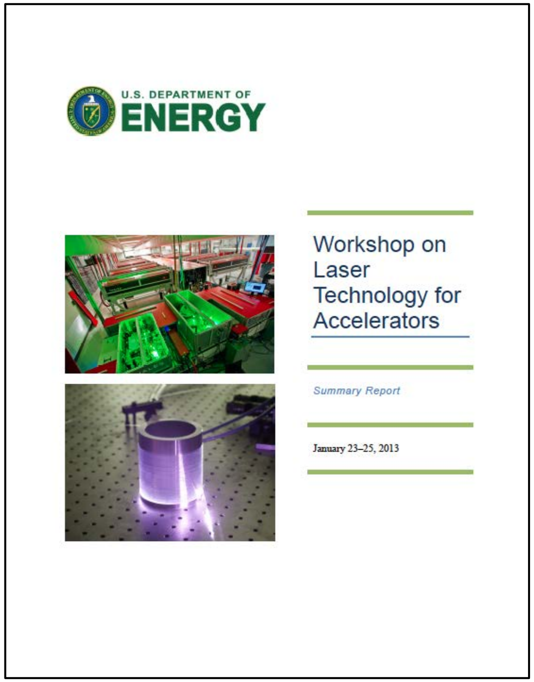
- One of the major thrusts for the next generation of discovery science particle accelerators
- SRF development driven by collaborations including accelerator science, particle physics, nuclear physics, materials science, chemistry, advanced computing, and more
- Collaboration with other disciplines will drive further leaps forward, such as:
  - materials science advances in depositing superconducting alloys as thin films on other materials
  - better understanding of effects such as magnetic vortices that interfere with superconductivity and limit cavity performance


TESLA 1.3 GHz cavity


Jlab Cryomodule

Laser-Driven Acceleration

- ❑ Major innovations in compactness and cost of accelerator technology may be required to enable future generations of particle colliders
- ❑ Laser-driven acceleration has demonstrated >100 GeV/m gradient
- ❑ Next-generation parameters for laser driven systems that will require advances in other sciences:
  - – kW average power
  - – TW/PW peak power
  - – Infrared, ultrafast lasers (<1 ps)
  - – Joule-class energy
  - – New lasing materials
  - – Efficiency >15%
  - – kHz repetition rate
  - – High-quality, stable beams
- ❑ Serves electron-positron accelerators, light sources and medical accelerators

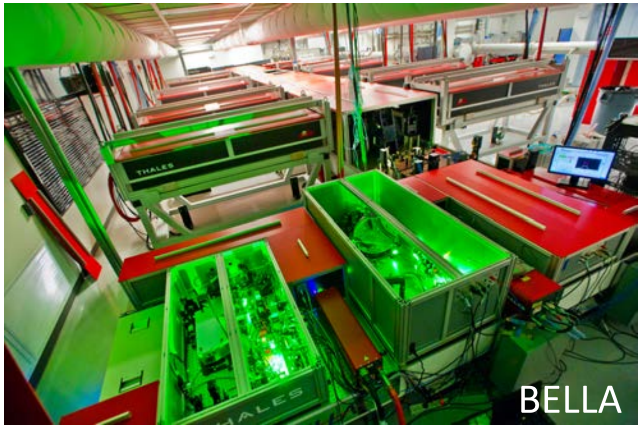


U.S. DEPARTMENT OF ENERGY

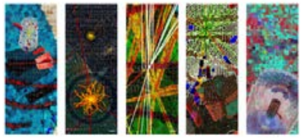
Workshop on Laser Technology for Accelerators

Summary Report

January 23–25, 2013



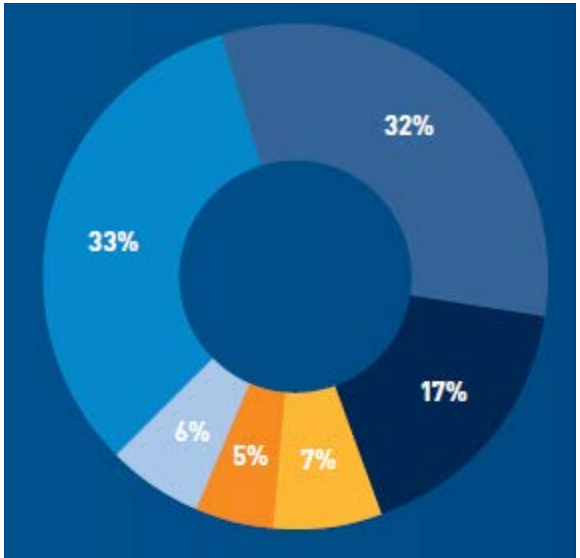
Report: http://science.energy.gov/hep/research/accelerator-rd-stewardship/workshop-reports/



Accelerators in Industry

- Science looks to industry for accelerator materials, components, diagnostics, …
- More than 30,000 accelerators used by industry in applications including:
  - Electron beam used for cross-linking polymers displaces the use of volatile chemicals in many manufacturing processes:
    - Wire insulation, heat-shrinkable films & tubing, foam, tires
  - Electron beam curing of inks, coatings & adhesives to eliminate chemical waste and reduce power consumption vs. thermal curing
  - Sterilization of medical equipment
  - Disinfection and removal of pathogens from food, water & waste water
  - Ion implantation to dope silicon and germanium in semiconductors
  - Ion beam treatment of high-speed cutting tools and artificial joints

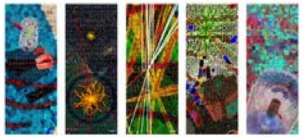
ACCELERATORS FOR AMERICA'S FUTURE



Markets for industrial electron beams total $50 billion per year.

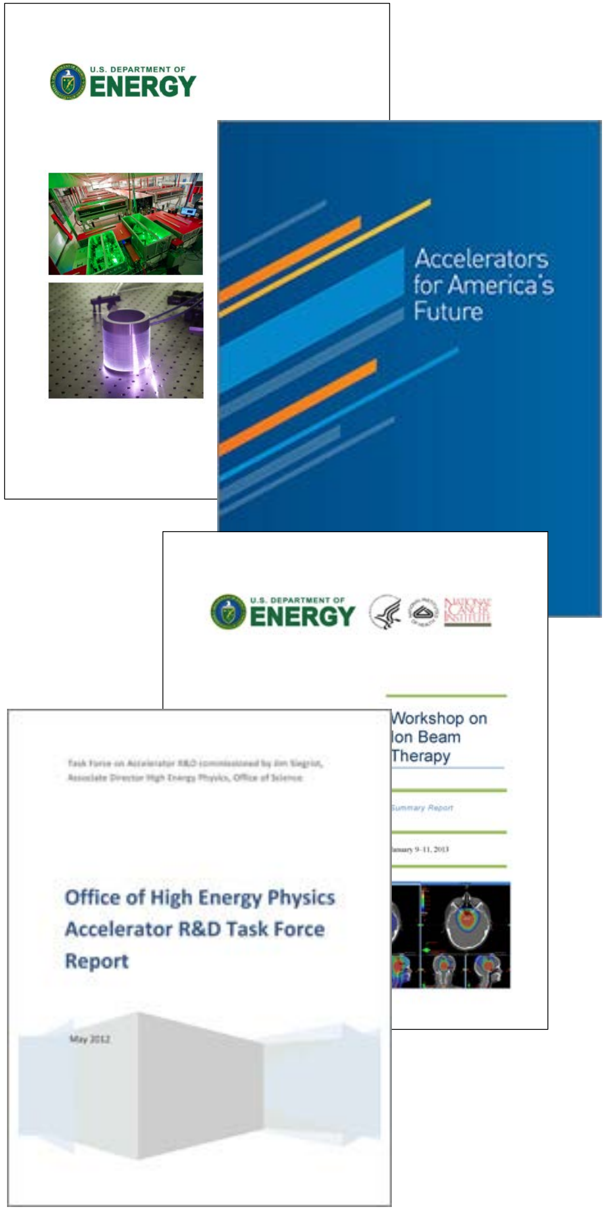
🟦	Wire cable tubing	🟨	Service
▨	Ink curing	🟧	Tires
■	Shrink film	☐	Other

Image source: IAEA Working Material on Industrial Electron Beam Processing



Opportunities

- ❑ Significant progress already made via joint workshops to survey accelerator connections, identify the most critical accelerator R&D needs that benefit all fields of science and industry, and chart the best paths forward
- ❑ Long-term Accelerator R&D Stewardship program now being developed by DOE
- ❑ Previous reports identified opportunities that could enhance connections with other sciences in the area of accelerator technology, to the benefit of all sciences and industry
- ❑ Examples include:
  - Lowering barriers to researchers working – even temporarily – on research with other fields to develop critical technologies
  - The creation of interdisciplinary teams from multiple institutions/agencies tasked with a clear mission, working for a limited duration, with funding competitively bid through a peer review process



U.S. DEPARTMENT OF ENERGY

Accelerators for America's Future

U.S. DEPARTMENT OF ENERGY

Workshop on
Ion Beam
Therapy

Summary Report

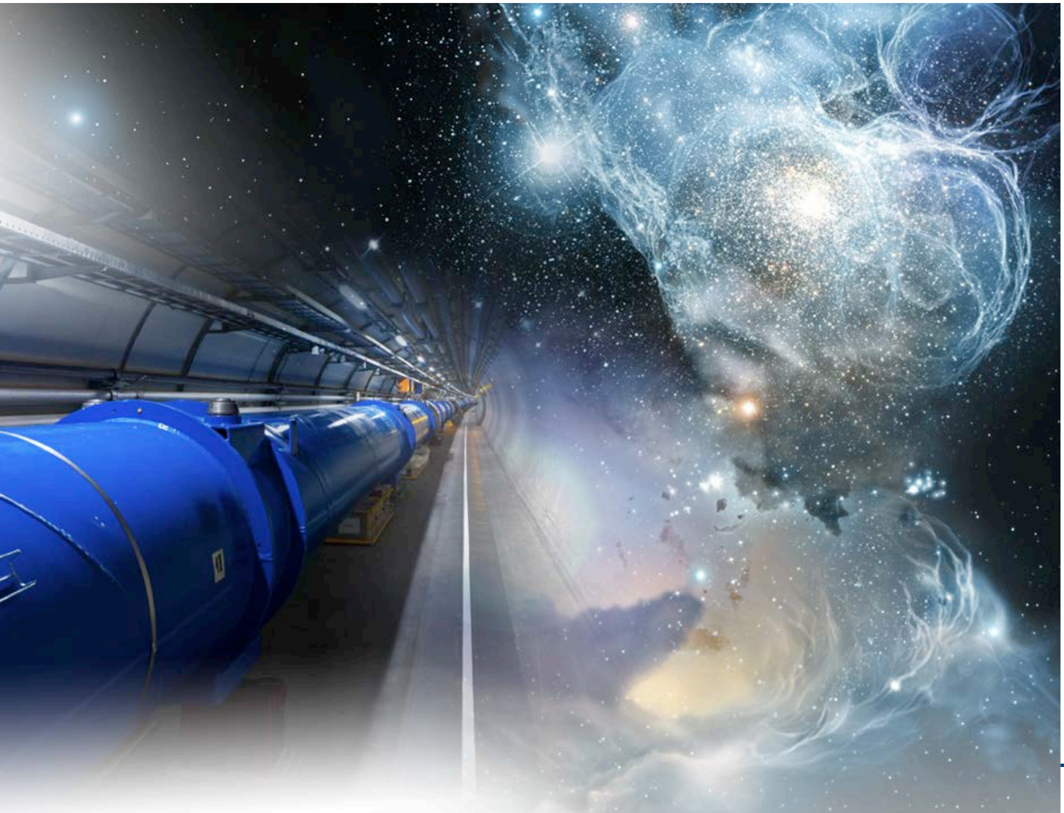
anuary 9-11, 2013

Task Force on Accelerator R&D commissioned by Jim Siegrist, Associate Director High Energy Physics, Office of Science

Office of High Energy Physics Accelerator R&D Task Force Report

May 2012

Facilities

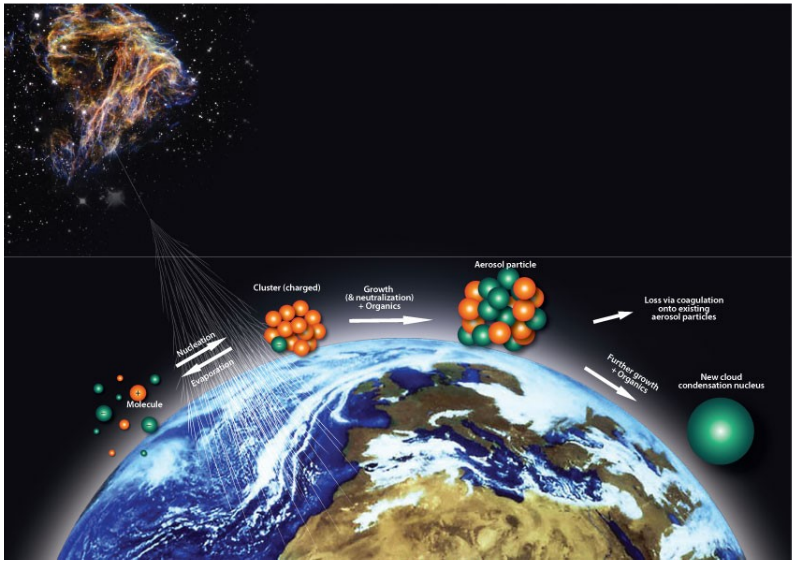


From materials science to astronomy, many sciences benefit from HEP facilities and vice-versa

HEP-Operated Facilities

- Accelerator-based particle physics sites have particle beams – protons, pions, electrons, muons – that benefit other sciences
- One example: study of nucleation of aerosol particles and their effects on the atmosphere; effects of cosmic rays in the context of seeding clouds
- Cosmics Leaving Outdoor Droplets (CLOUD) experiment at CERN
  - Based at CERN's Proton Synchrotron
  - Uses a cloud chamber to study the possible link between galactic cosmic rays and cloud formation (Nature 502, 359–363 (17 October 2013))

CLOUD experiment

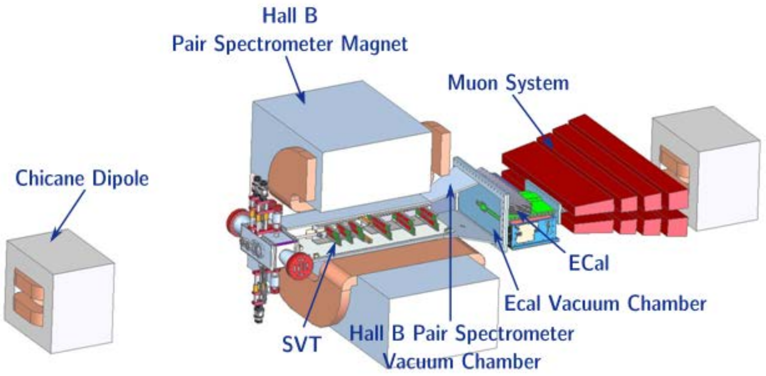


HEP-NP Synergies

- High Energy Physics and Nuclear Physics operated and supported accelerators to mutually support each discipline's experiments.

- Heavy Photon Experiment at Jefferson Lab
  - Search for hidden-sector, heavy photon in the mass range of 0.1 to 1.0 GeV
  - Weakly coupled to electrons, and decay to e^+e^-.

- SeaQuest nuclear physics experiment at Fermilab
  - Measuring contributions of antiquarks to nucleon structure using protons from the Fermilab Main Injector accelerator

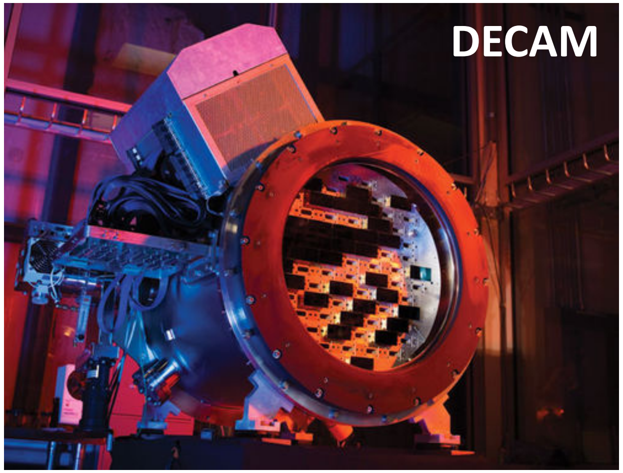


Heavy Photon Experiment in Hall B at JLab

SeaQuest
at FNAL

HEP-Built Facilities

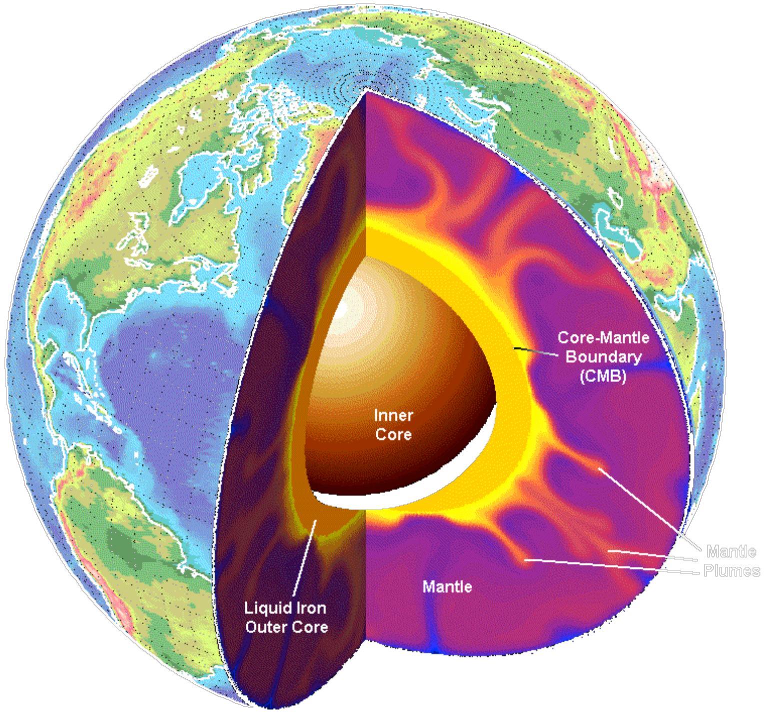
- Sky surveys
  - Cameras built by HEP in partnership with and for the benefit of particle astrophysics and the wider astronomy community: SDSS, DES, LSST



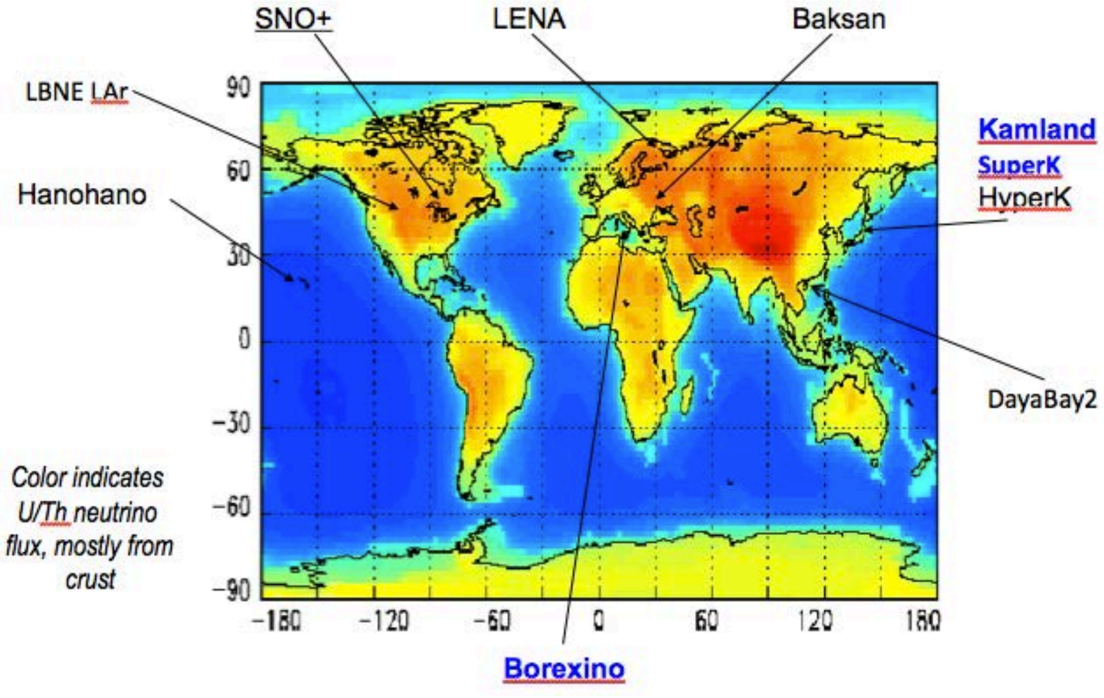
- Light sources: new lives for particle physics machines:
  - SLAC linac now drives the Linac Coherent Light Source (LCLS), creating x-ray pulses of unprecedented brilliance
  - PETRA, where the gluon was discovered, now forms the heart of the PETRA III x-ray radiation source

Detectors for GeoNeutrinos

- ❑ Understanding the center of the earth
- ❑ Total Heat Flow at surface 47 ± 2 TW
  - – Geology predicts 16-42 TW of radioactive power
    - ~20 % escapes to space as geoneutrinos
    - ~80 % heats planet



Present and possible experiments for geoneutrinos



Color indicates U/Th neutrino flux, mostly from crust

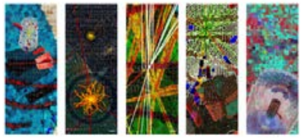
Stopped Muon Beams

- ❑ Muons provide a complementary probe to neutrons, particularly in the areas of magnetism, superconductivity and charge transport
- ❑ Requires stopped muon beams, with fluxes of the order of 10^4-10^7/s/cm^2
  - – Muon Spin Resonance (μSR) & Spectroscopy (μ^+)
    - Magnetic systems: spinglasses, colossal magnetoresistance, ...
    - Superconductors: magnetic phase diagrams, vortex phases
    - Transport: quantum diffusion, conducting polymers
    - Semiconductors
  - – Muonic Chemistry (μ^-): free radical systems
  - – Muon Catalyzed Fusion (μ^-)
  - – Potential (currently mostly theoretical) interest: Parity Violation experiments, Vacuum Polarization, muon induced fission

- ❑ Since the Los Alamos Muon Facility shut down, experiments are conducted at muon facilities at international particle physics labs

- ❑ μSR2014, held every three years: http://indico.psi.ch/internalPage.py?pageId=0&confId=2039
  Muon Spectrocopy: http://www.isis.stfc.ac.uk/instruments/muon-spectroscopy4762.html

Opportunities

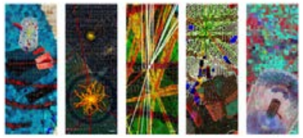


- Some particle physics facilities are a resource to the science community overall.

- There is an opportunity to evaluate the scientific potential and possible effect these facilities can have on advancing connected fields of science and on the particle physics mission itself. Specific possibilities may include:
  - Muon beams
  - Neutrino detectors
  - Atmospheric science

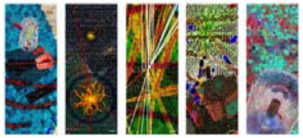
- Opportunity to explore if the joint construction model that has proved successful for sky surveys might be applicable to other joint facilities. Particle physics has contributed expertise in the construction of large, complex, multinational projects to that effort – also could explore how that model might aid other sciences.

Observations



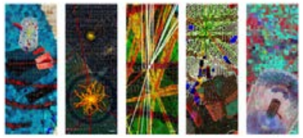
- The connections of HEP reach far and wide and have often been established serendipitously.
- Some developments in particular have made a huge impact and we suggest a more thorough follow-up evaluation.
  - World-wide web, ion/hadron therapy, PET scan, ...
- The value of these connections is substantial and they contribute to the health of the field. Particle physics and discovery science is advanced through these connections.

- The pace of technology development is increasing; other fields are extremely attractive and challenging for new generations of scientists. HEP has a lot to gain by establishing connections with other fields (and a lot to lose by not doing so).



Opportunities

- There are many opportunities for particle physics and associated fields of science to explore areas of interdisciplinary partnerships that hold promise for further development
  - Detector Technology
    - Explore new detector materials in partnership with materials science
    - Collaboratively develop instrumentation to benefit the next generation of light sources and particle physics experiments
    - Advance detector technology in collaboration with nuclear physics
  - Computing, Data Management and Software
    - Advance lattice algorithm techniques in partnership with condensed matter physics
    - Develop data tools in partnership with computer science and other fields
    - Move high-performance computing and particle physics simulation techniques forward in partnership with other basic sciences, computer science and applied mathematics



Opportunities and Conclusions

- Accelerators
    - Follow up on opportunities identified in previous reports, such as lowering barriers to researchers working with other fields to develop critical technologies of benefit to all
    - Continue joint workshops to identify critical R&D needs
- Facilities
    - Explore scientific use of HEP facilities by other fields
    - Investigate use of joint facility construction model beyond particle physics/astronomy

- ❑ Overarching opportunities that could benefit all parties and expedite technological progress include:
    - The formulation of joint strategies with other fields to address technological challenges
    - The creation of multi-disciplinary, multi-institutional research projects structured to address grand science challenges

- ❑ *There is great potential for future progress in scientific discovery through technological advancement; by working together we are stronger!*

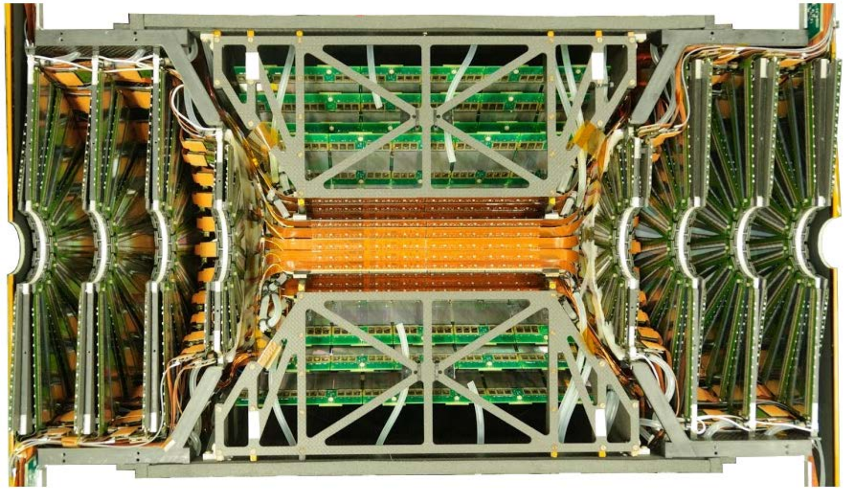
Backup: further material

Examples of Influence of Technology

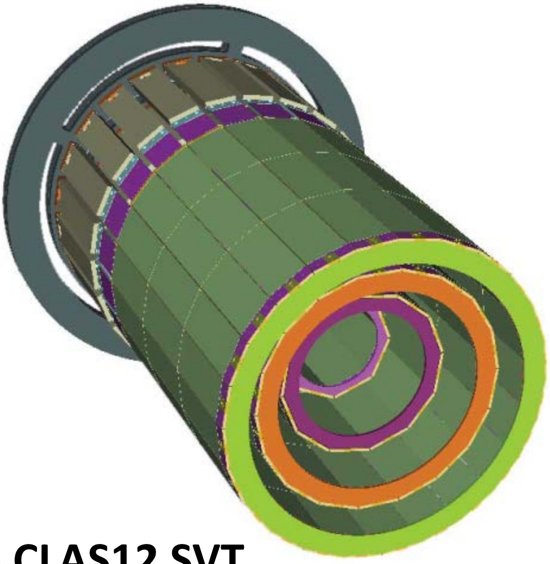
The influence of particle physics developed tools, techniques and technologies has been notable

Nuclear Physics Experiments

- ❑ Technology developed by HEP; used by nuclear physics
- ❑ PHENIX at RHIC
  - Precision Silicon Vertex Tracking
  - Strip detectors read out with Fermilab's SVX4 Application Specific Integrated Circuit (ASIC)
  - Endcap planes readout with modified Fermilab FPHX ASIC

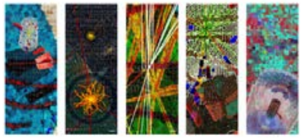


PHENIX SVT (LANL led)



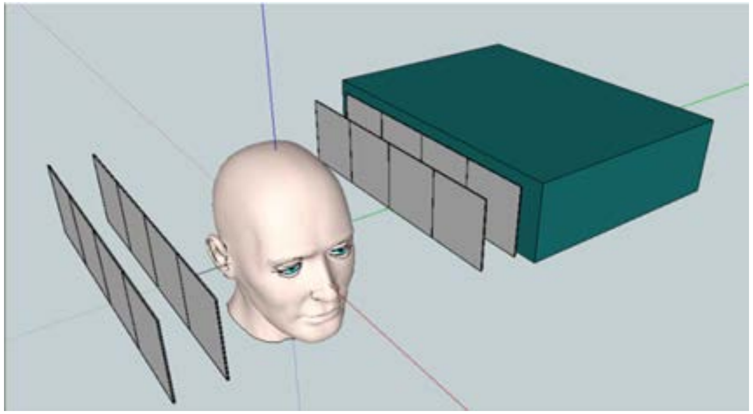
JLAB CLAS12 SVT

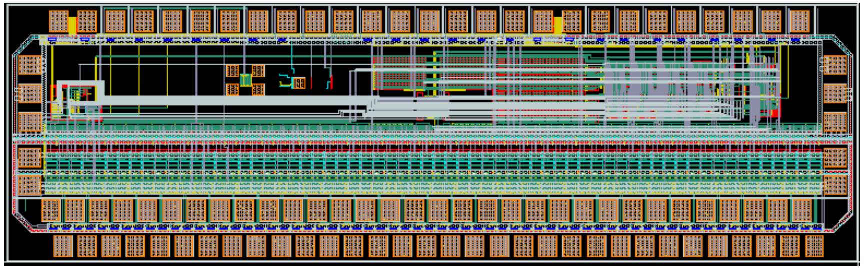
- ❑ JLab Hall B CLAS12 Si Vertex Tracker (SVT)
  - Readout uses FSSR2 ASIC, developed at Fermilab for BTeV.
  - Ladder construction based on Tevatron detectors



Proton Computed Tomography (pCT)

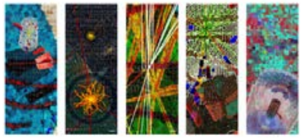
- ❑ In a pCT head scanner, planes of Silicon Strip Detectors track the proton entering and leaving the patient, before the energy loss is measured in the energy detector. Correlate the measured E-loss with the path of the proton through the patient.





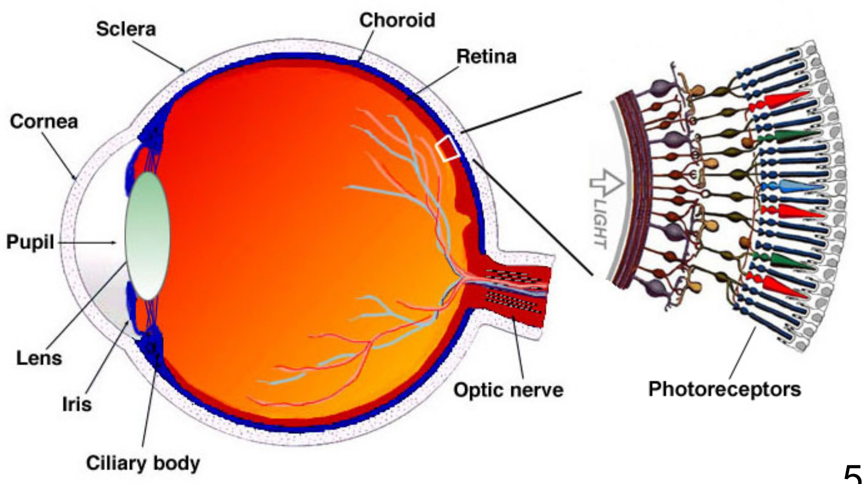
ASIC modeled after GLAST/FERMI

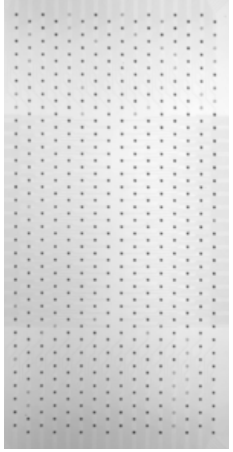
- ❑ Development based on silicon strip technology developed for ATLAS and GLAST/Fermi
  - – Data rate of 1 million protons per second needed for an image to be acquired in an acceptable time frame of a few minutes.
    - The ASIC and the DAQ are patterned after that of GLAST/Fermi, but with a 100-fold increase in speed.
- ❑ The design of the head scanner and the ability to reconstruct a billion events per image have been made possible by software developed within HEP.



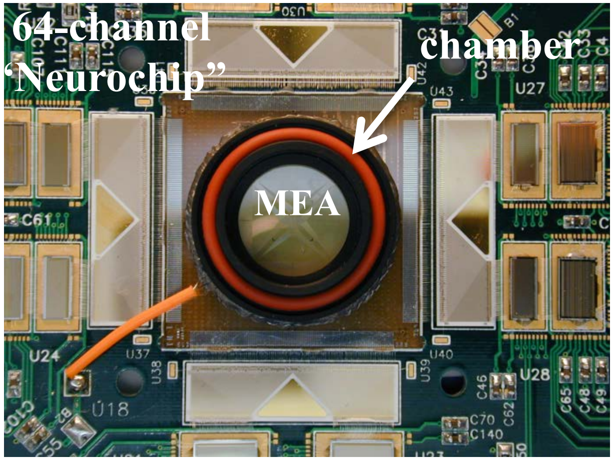
Neurobiology and Medical Applications

- Development of a “Pixel Detector” – based on experience with Mark II and LHC – for study of retinal output





512-electrode MEA

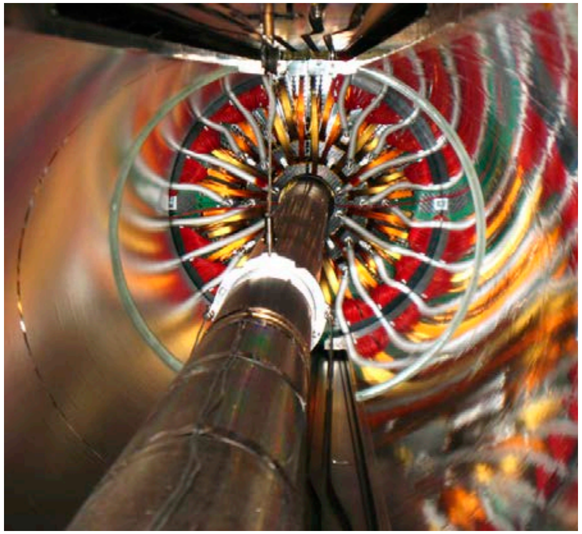


512-electrode “Neuroboard” (2003)

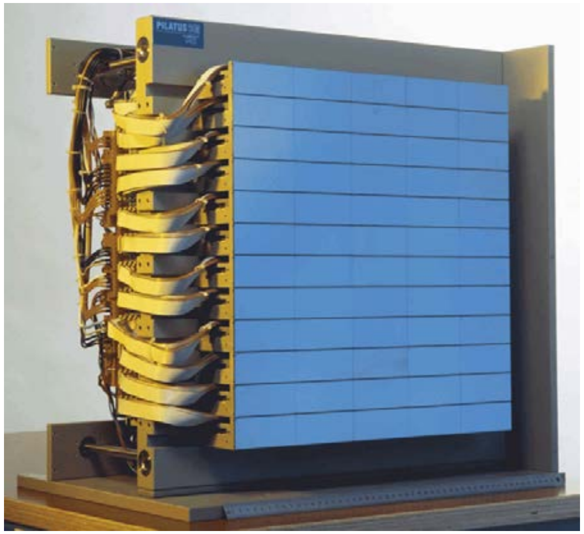
- Application of familiar particle physics techniques to neurobiology
  - **Discovery of a new functional type of primate retinal output (ganglion) cell (may be involved in motion perception)**
- Biomedical Applications
  - Retinal prosthesis studies for diseases that cause blindness due to photoreceptor degeneration (e.g. retinitis pigmentosa)

X-Ray Detectors

- Developed at PSI, it is a direct descendant of the CMS pixel detector
- Particle physics responsible for its base development; particle physicists spun off company to further develop it for basic energy science.

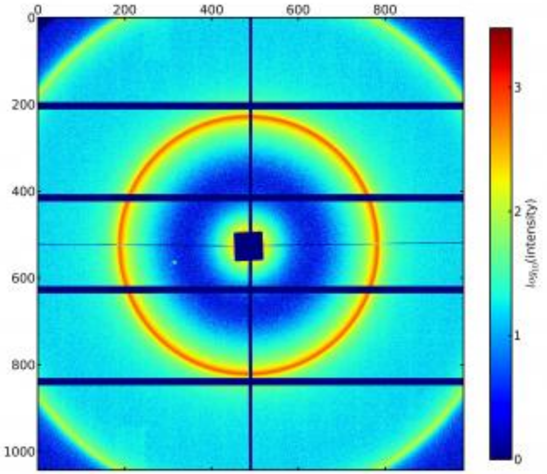


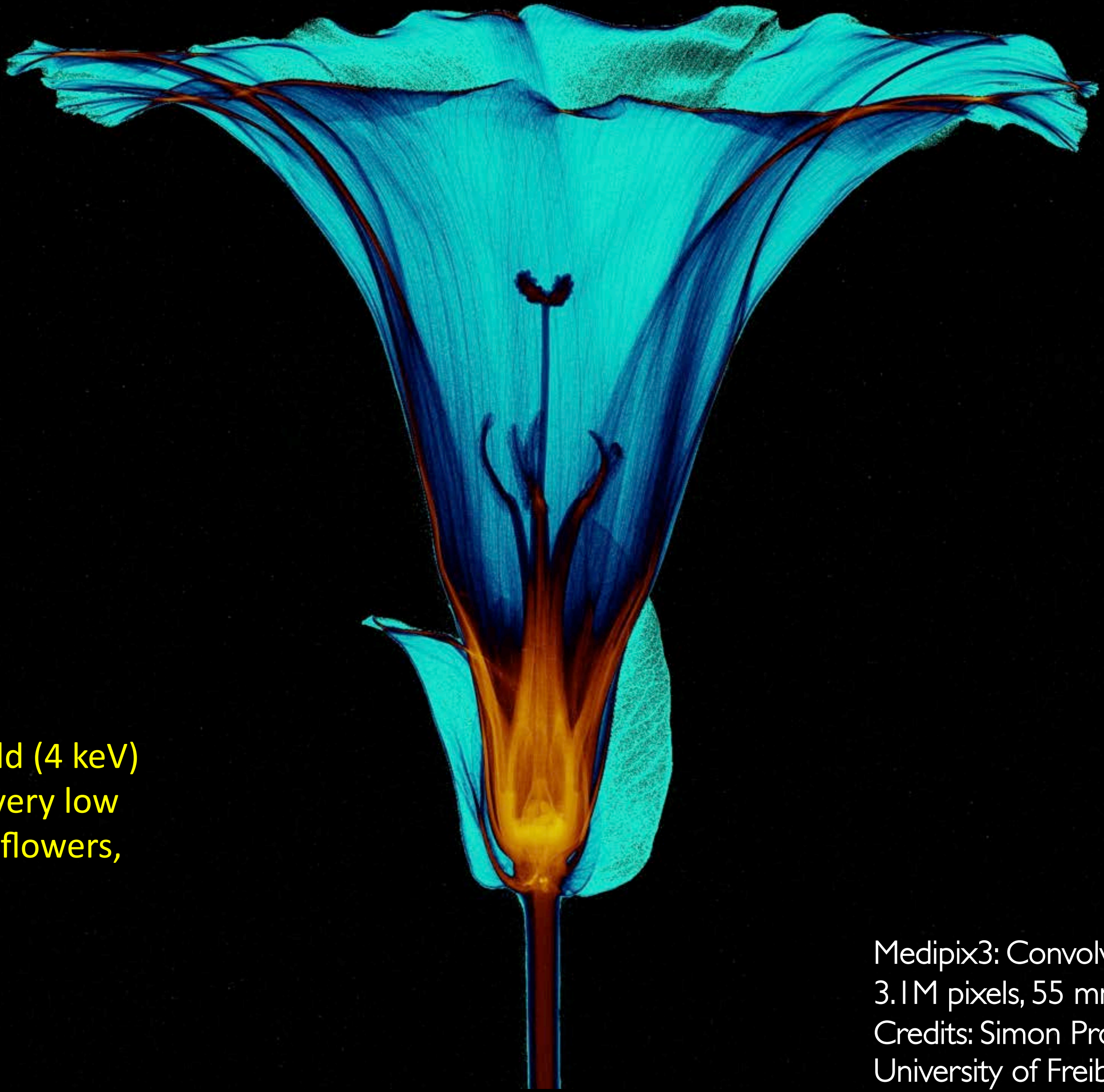
CMS Pixel detector



Pilatus X-ray detector

Pilatus Diffraction Pattern

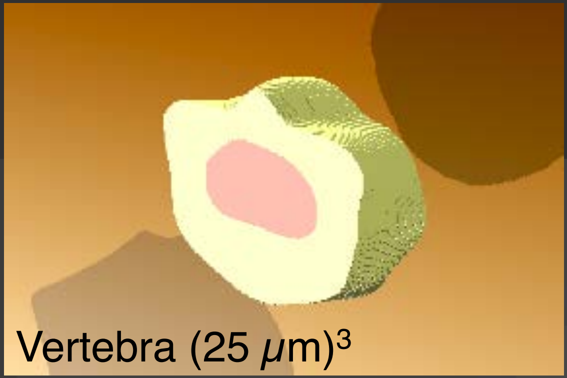




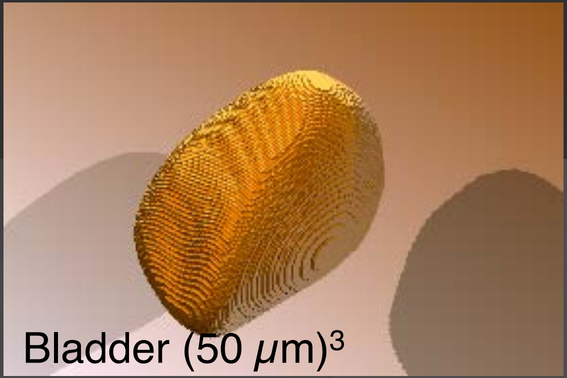
Low energy threshold (4 keV) enables imaging of very low contrast media, like flowers, with high resolution

Medipix3: Convolvulus arvensis
3.1M pixels, 55 mm pixel pitch
Credits: Simon Procz,, Ph.D. Thesis, University of Freiburg

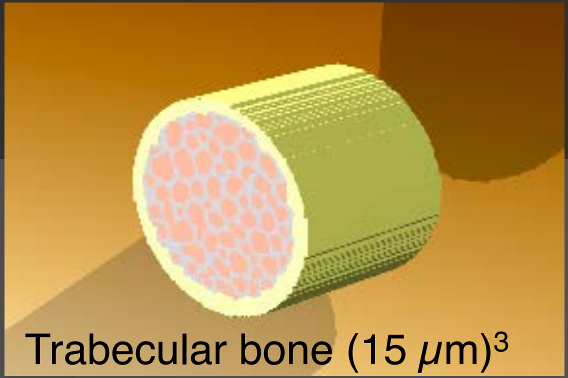
High resolution phantoms



Vertebra (25 μm)^3

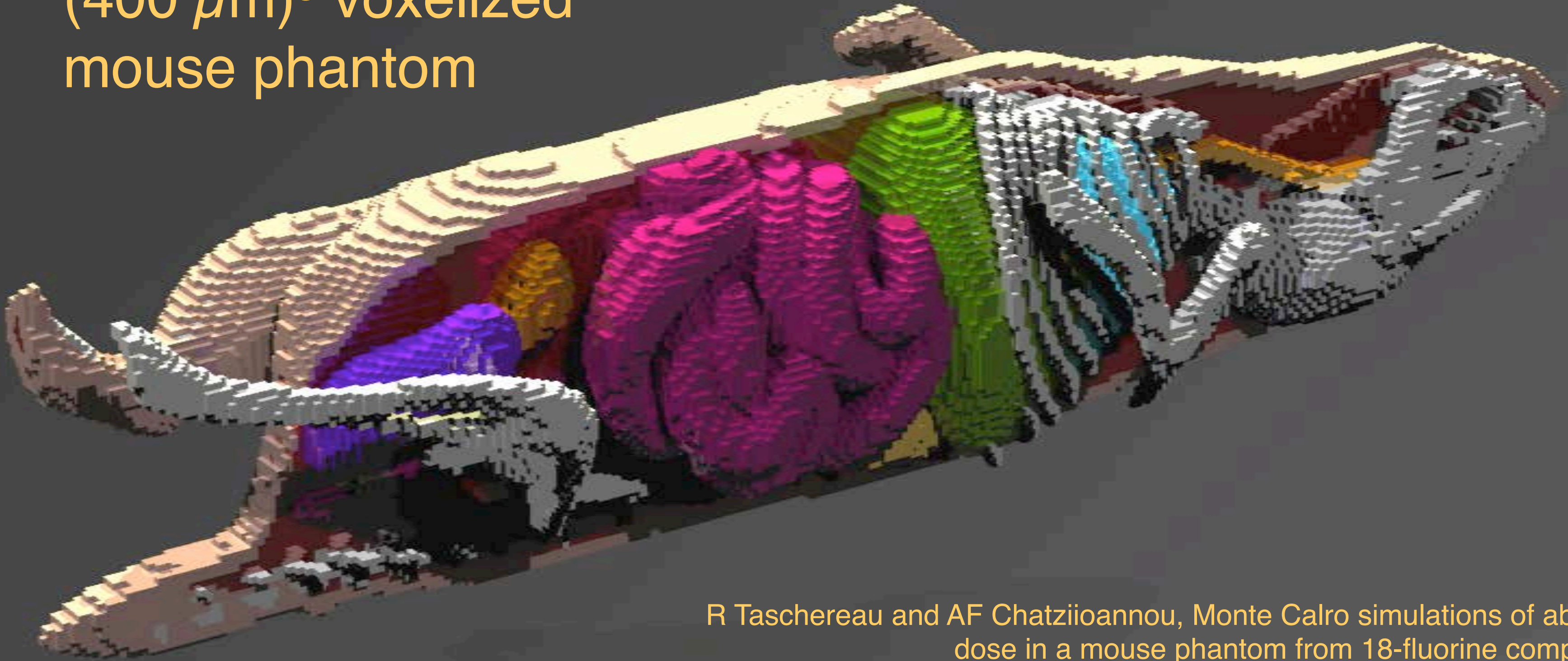


Bladder (50 μm)^3



Trabecular bone (15 μm)^3

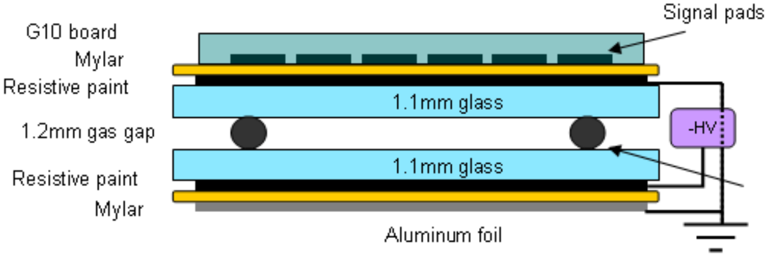
(400 μm)^3 voxelized mouse phantom



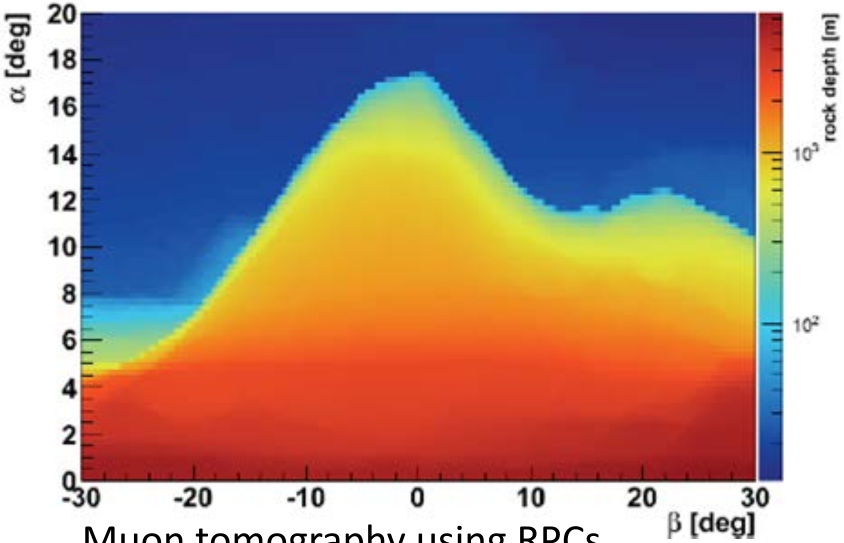
R Taschereau and AF Chatziioannou, Monte Calro simulations of absorbed dose in a mouse phantom from 18-fluorine compounds, Medical Physics, 34(3), 1026-36 (2007)

Environment

- ❑ Resistive Plate Chamber Technology used for volcano tomography using atmospheric muons



The Puy de Dome (Massive central)

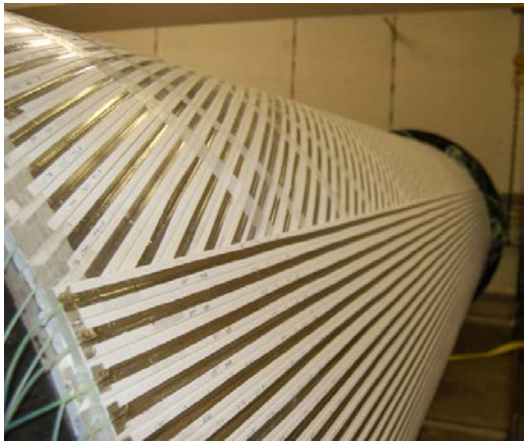


Muon tomography using RPCs (Tomuvol experiment)

- ❑ Similar measurements planned at Stromboli and Vesuvius (Mu-Ray Project) using scintillator tiles and Silicon Geiger-mode Photo-Multipliers
- ❑ Scintillator strips and Cherenkov counters used for imaging Maya ruins

Archeology

- Scintillating strips and Cherenkov counter used for imaging inside of Maya ruins



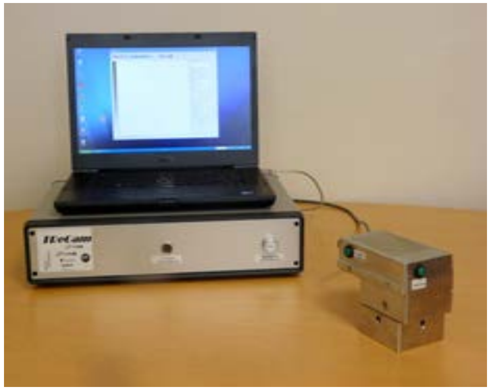
HEP ASICs for Medical Imaging

- ASIC developed for readout of Silicon PMs being used in a handheld peri-operative gamma camera called TReCam (Tumor Resection Camera) for lymphoscintigraphy
- Cancer detection through injection of a radioactive solution around the tumor; Lympho-scintigraphy then counts the lymph nodes and situate them precisely.

TReCam camera

49 x 49 mm^2 field of view LaBr$_3$:Ce crystal optically coupled to a multi-anode photomultiplier tube

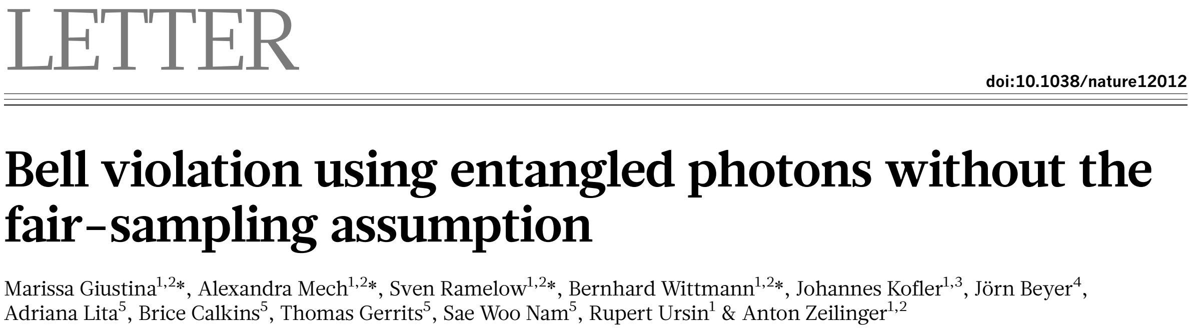
Peri-operative compact imager to aid breast cancer surgery



Data acquisition based on the SPIROC ASIC developed for CALICE

Transition Edge Sensors in Quantum Mechanics

- ❑ Test of Bell's theorem



LETTER

doi:10.1038/nature12012

Bell violation using entangled photons without the fair-sampling assumption

Marissa Giustina[1,2]*, Alexandra Mech[1,2]*, Sven Ramelow[1,2]*, Bernhard Wittmann[1,2]*, Johannes Kofler[1,3], Jörn Beyer[4], Adriana Lita[5], Brice Calkins[5], Thomas Gerrits[5], Sae Woo Nam[5], Rupert Ursin[1] & Anton Zeilinger[1,2]

- ❑ Quantum communication

nature COMMUNICATIONS

OPEN

ARTICLE

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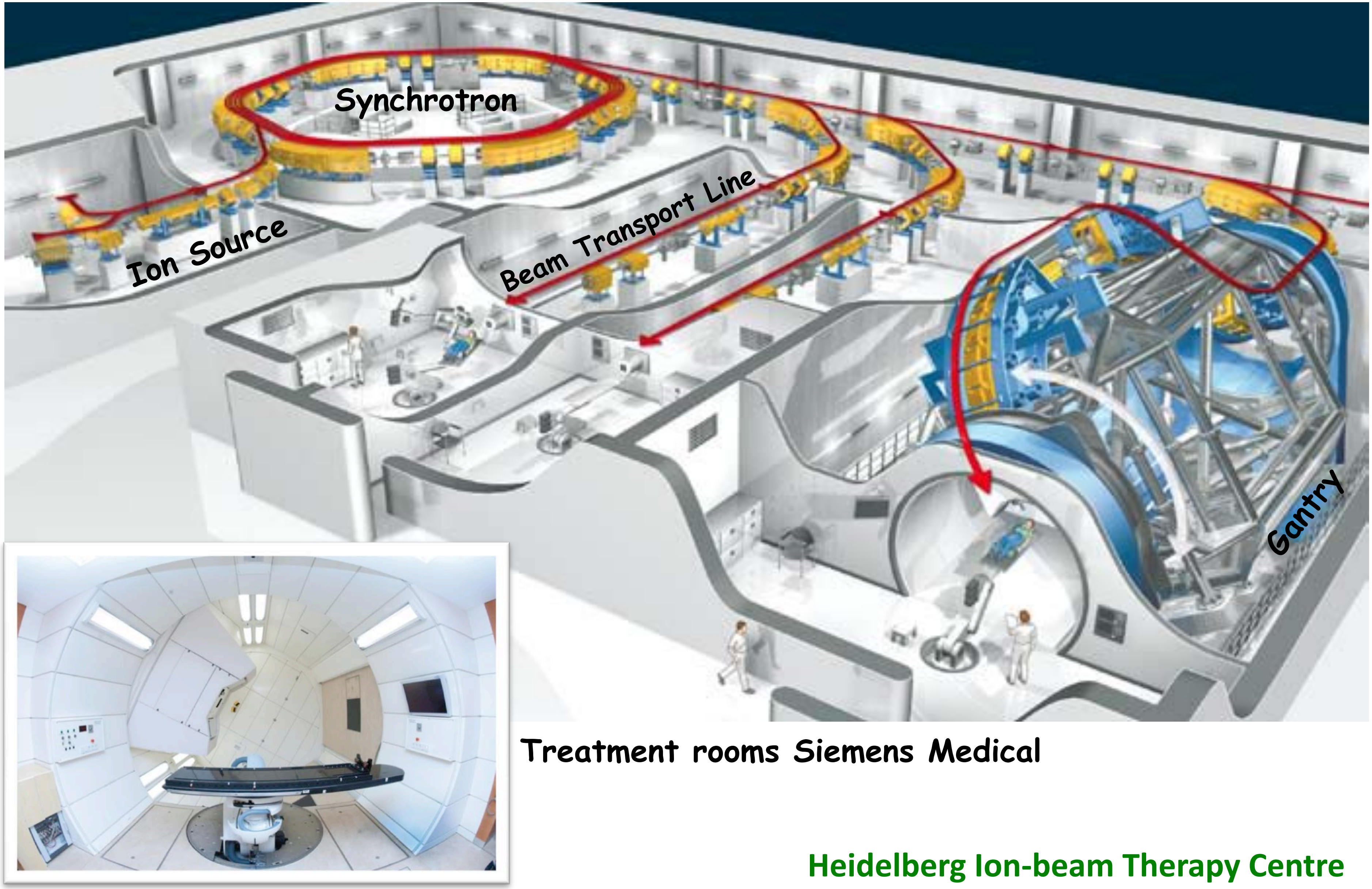
DOI: 10.1038/ncomms1628

Conclusive quantum steering with superconducting transition-edge sensors

Devin H. Smith[1,2], Geoff Gillett[1,2], Marcelo P. de Almeida[1,2], Cyril Branciard[2], Alessandro Fedrizzi[1,2], Till J. Weinhold[1,2], Adriana Lita[3], Brice Calkins[3], Thomas Gerrits[3], Howard M. Wiseman[4], Sae Woo Nam[3] & Andrew G. White[1,2]

Ion Therapy



Treatment rooms Siemens Medical

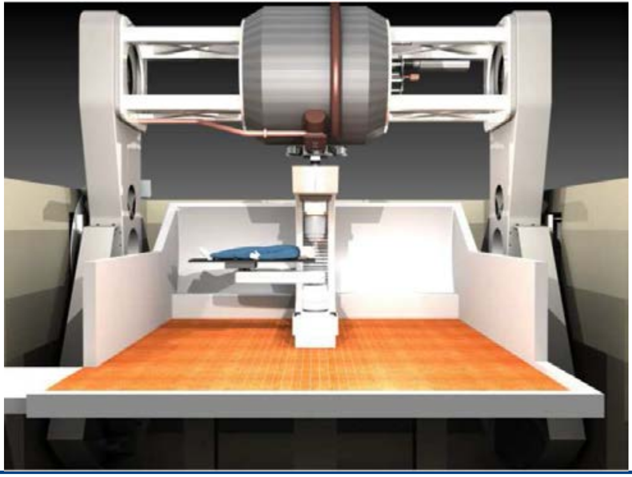
Heidelberg Ion-beam Therapy Centre

Compact Cyclotrons

- Compact superconducting proton cyclotron for proton therapy developed by MeVion:
  - Nb_3Sn Coils
  - High J_c strand- ~3000 A/mm^2

LARP

- Conductor comes straight out of the DOE HEP Conductor Development Program and extensively vetted by US LARP

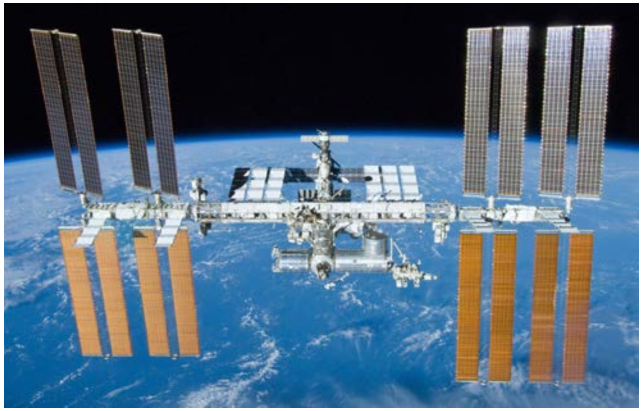


- MEVION S250 at the Siteman Cancer Center at Barnes-Jewish Hospital and Washington University School of Medicine now in clinical commissioning.

Scientific Linux

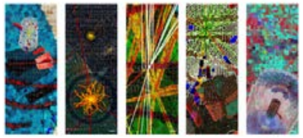
- One of the Chicago Tribune's Top 20 Innovations in Chicago that changed the world
  - 1998: Fermilab created "FermiLinux" for its experiments
  - 2004: Fermilab and CERN improved it and renamed it Scientific Linux

- More than 140,000 users run Scientific Linux
- Runs on the International Space Station
- Runs on majority of campus grid at UW-Madison, powering student research from economics to engineering



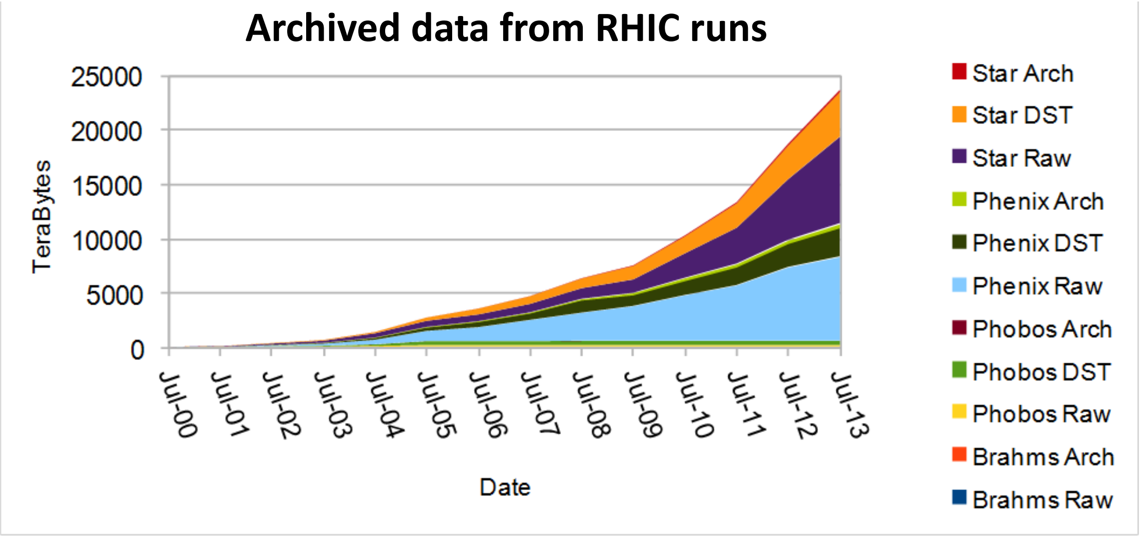
- Other notable innovations on the list: zipper, dishwasher, vacuum cleaner, open-heart surgery, sustained nuclear reaction...

http://bluesky.chicagotribune.com/originals/chi-countdown-to-20-top-chicago-innovations-bsi-20131015,0,0.html



RHIC Computing Facility…

- ❑ A shared facility with ATLAS Tier-1 Center with comparable staffs for both NP and HEP



Physics and Finance

- PhD Thesis “Symmetries, Anomalies and Effective Field Theory”, Harvard, advisor Howard Georgi (1992)
- Undergraduate at Caltech with P5 panel member
- Currently managing director and portfolio manager with Pacific Investment Managing Company (PIMCO)