Detector^{+} Applications of Particle Physics

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Argonne National Laboratory

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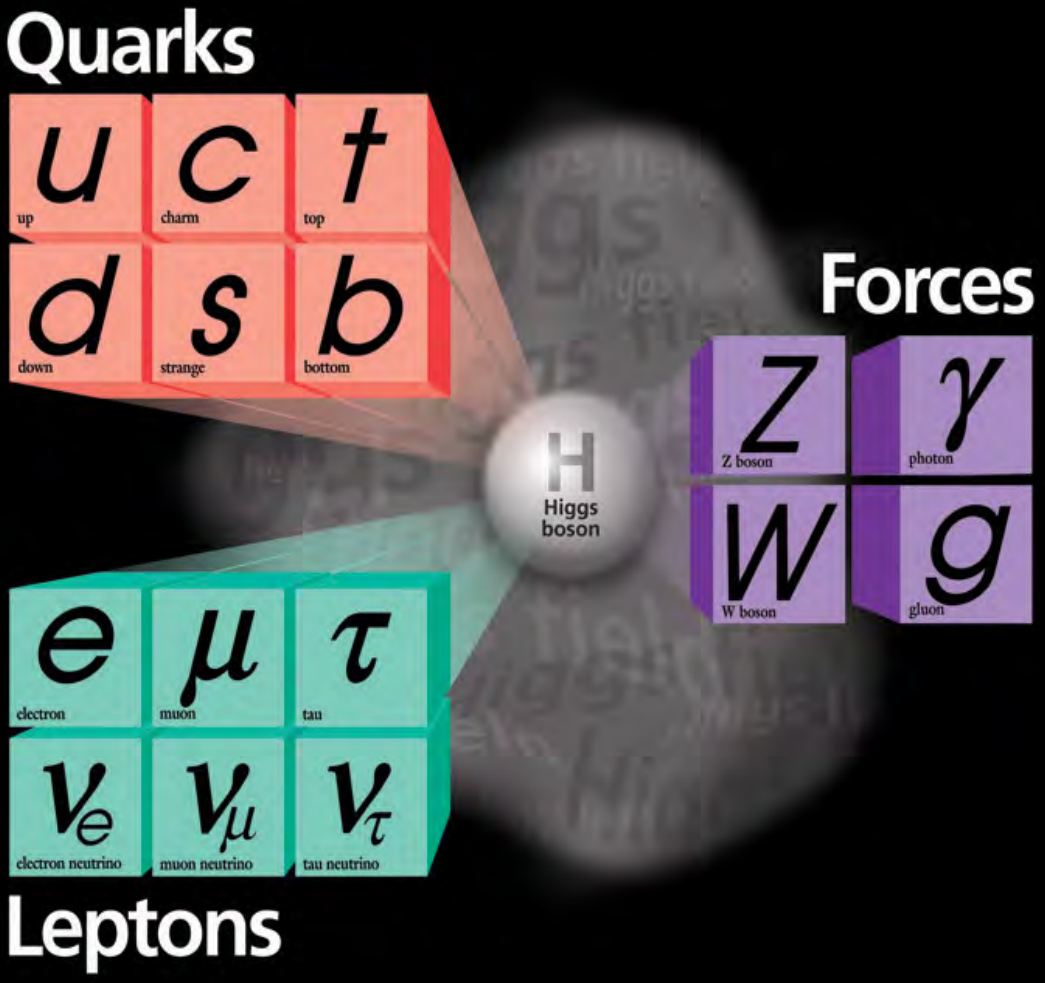
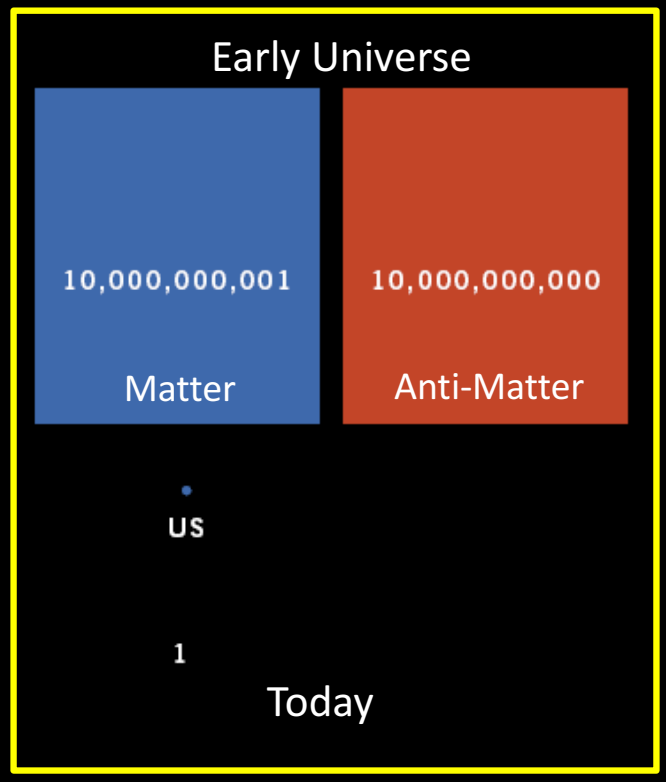
ICFA Seminar

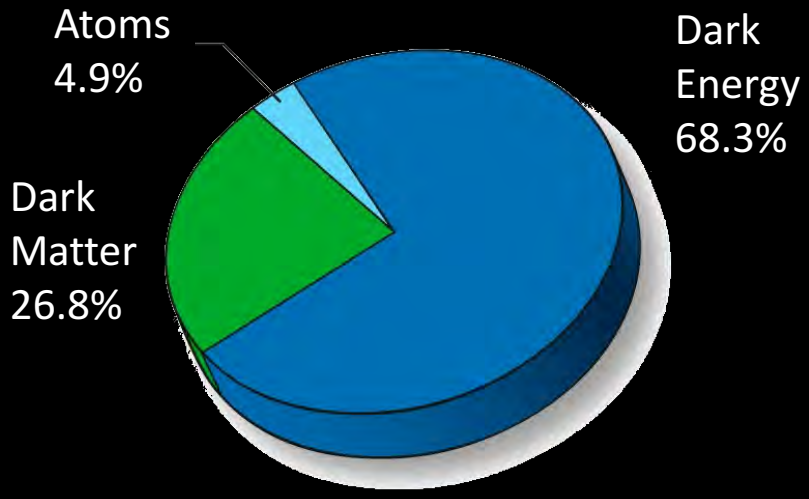
November 8, 2017

Ottawa, Canada

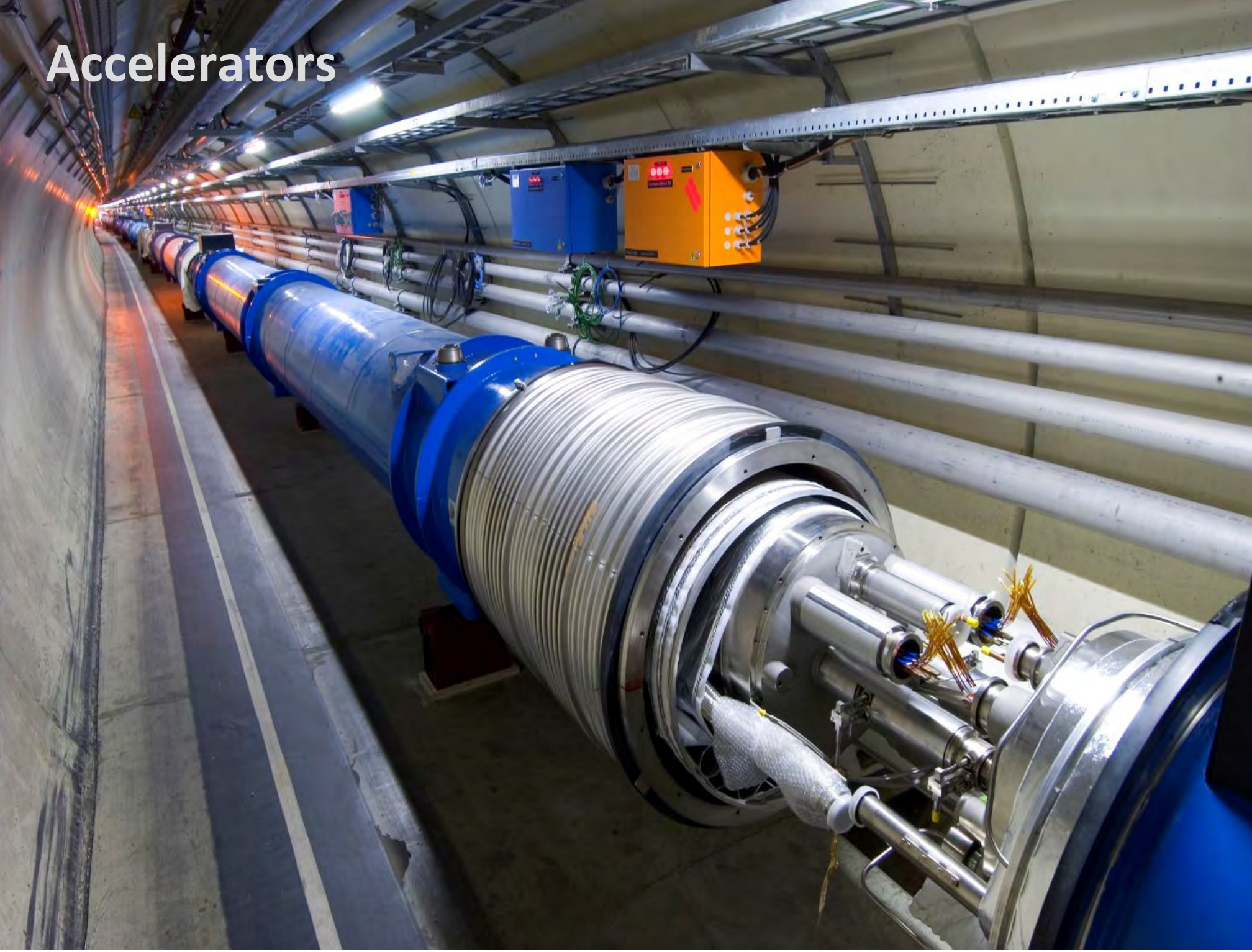
The Field of Particle Physics

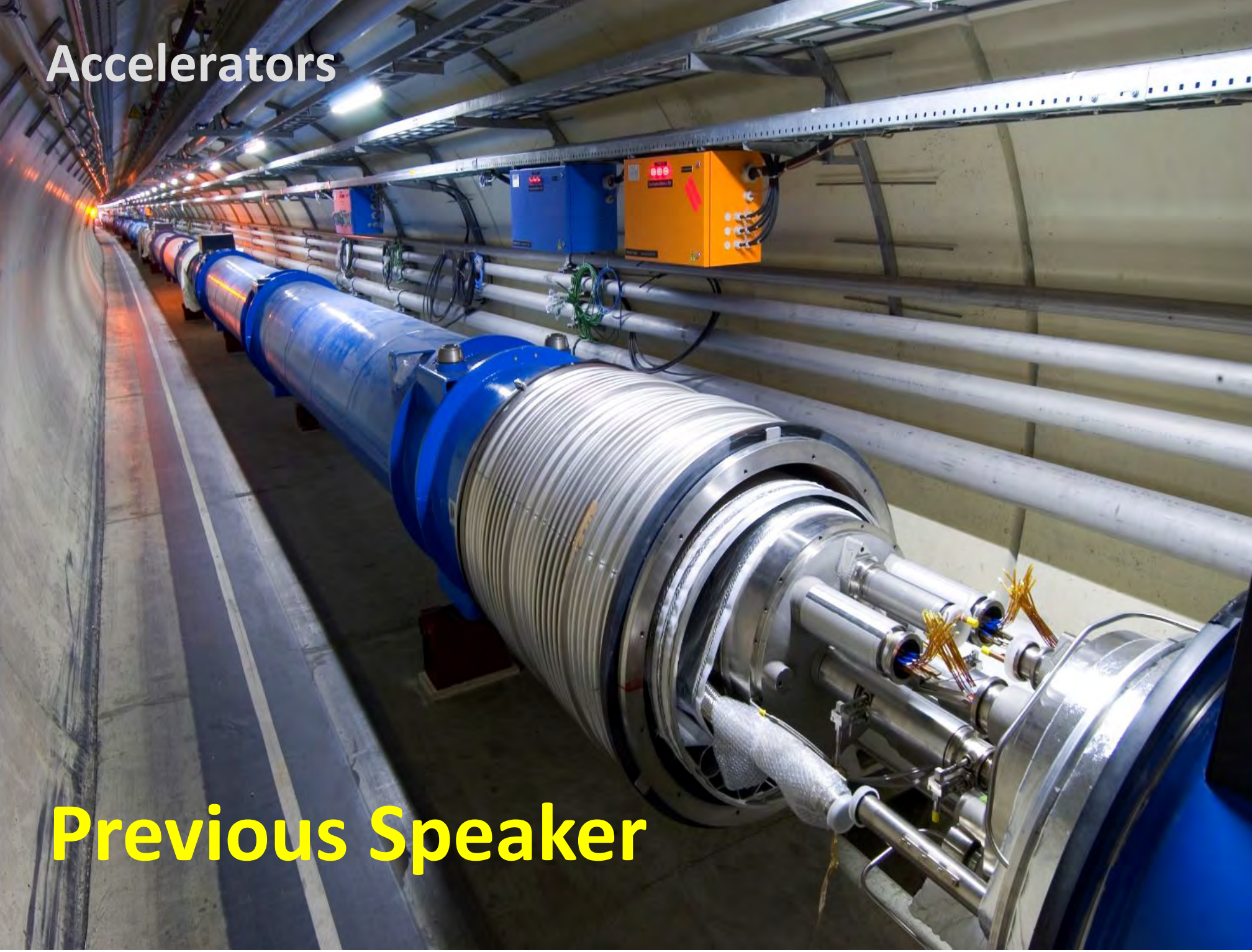




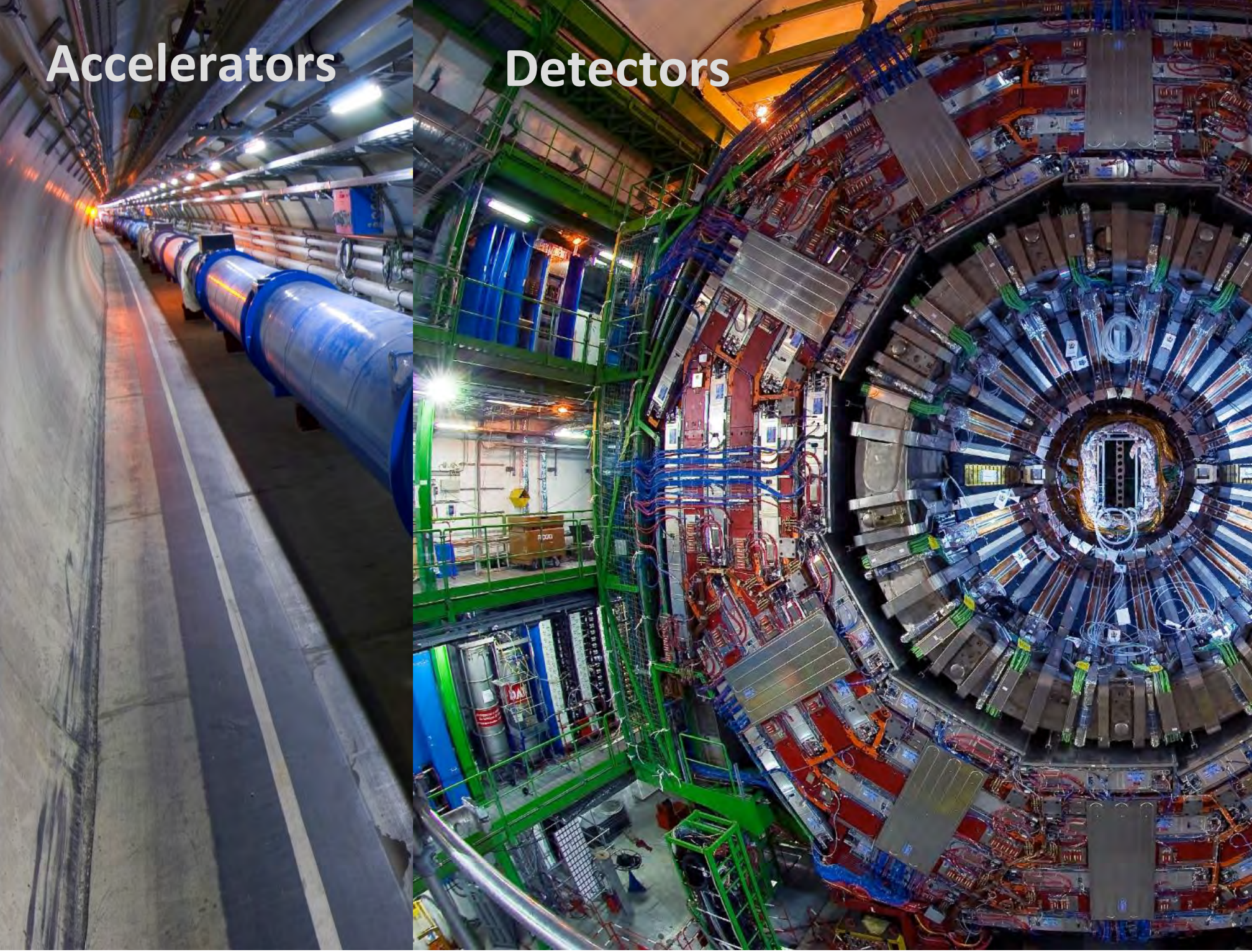


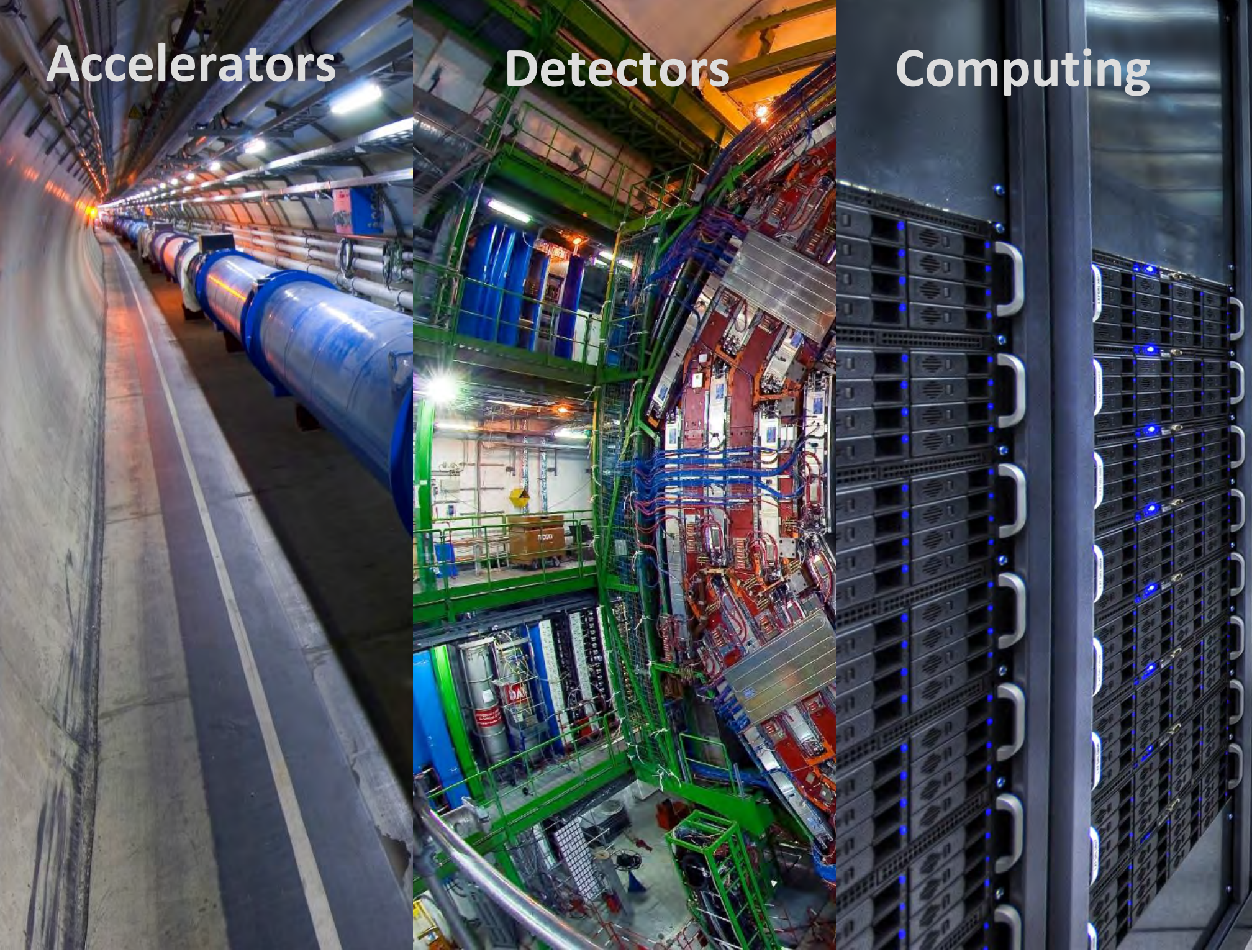
Accelerators



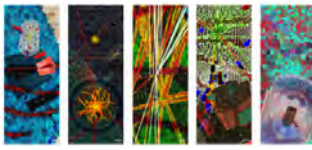


Previous Speaker


Accelerators
Detectors


Accelerators
Detectors
Computing

Elements of Particle Physics Detectors



Radiation Damage

Very precise low-mass tracking

High Rate

Photon Measurement

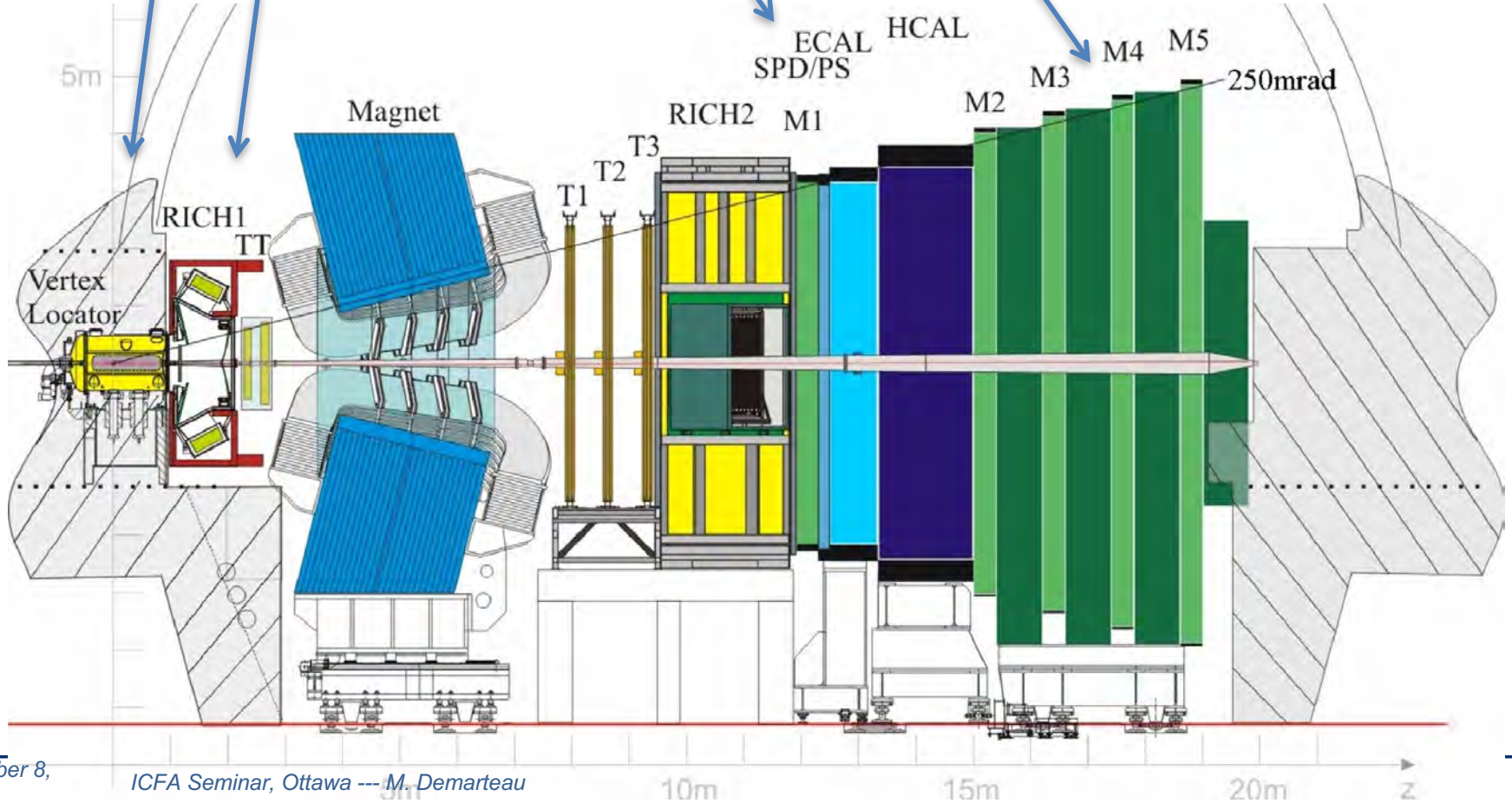
Big Data

Calorimetry

Compute Intensive

Muon Tracking

Simulation

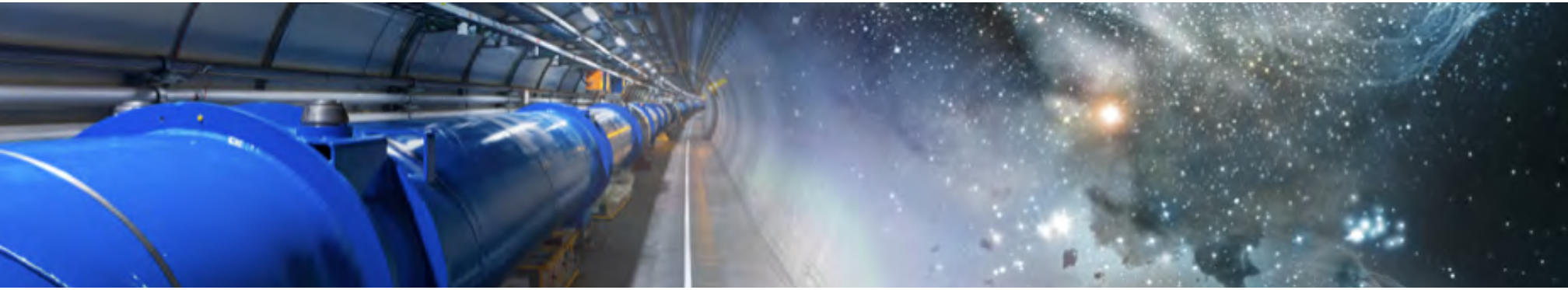


Outline

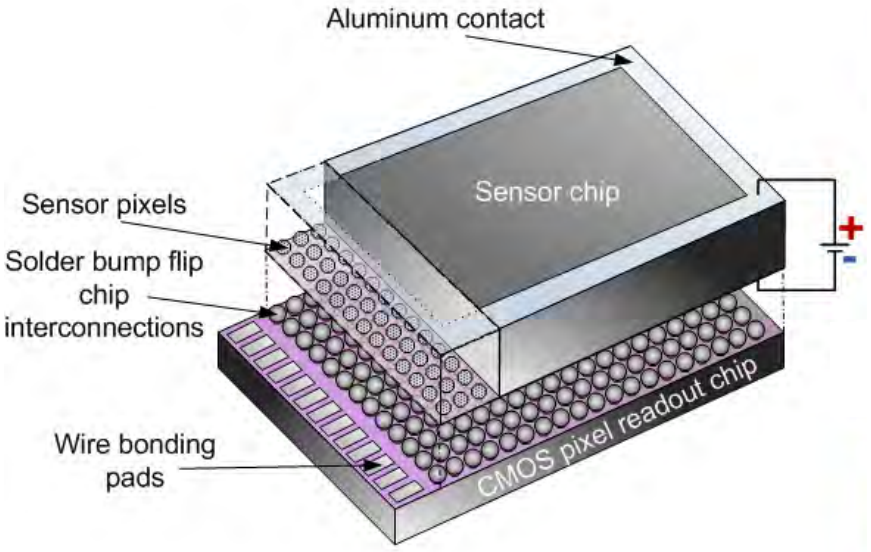
- Detector Technology
- Computing, Software and Data Management
- Particle Physics Facilities
- Conclusions

Detector Technology

A major area of connections
of particle physics

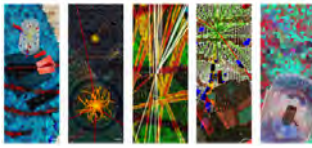


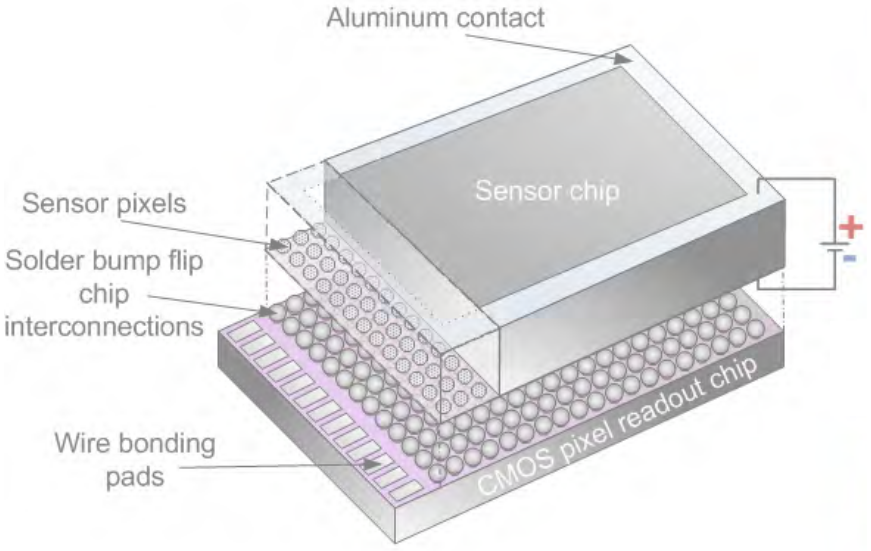
Silicon Technology



- The silicon detector and readout technology for particle detectors was enabled by the semi-conductor industry

Silicon Technology





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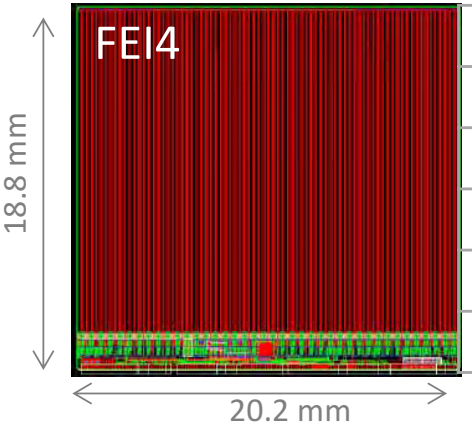
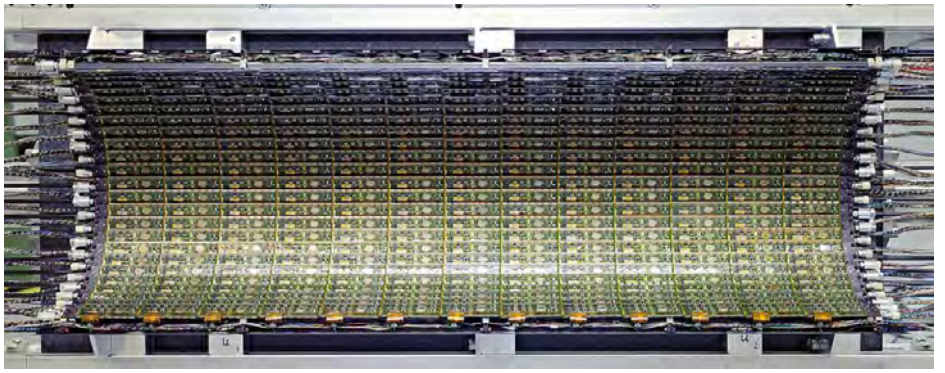
Application Specific Integrated Circuit



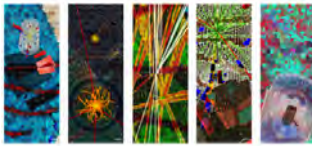
Pixel size	50x50 μm^2
Chip size	> 20x20 mm^2
Transistor count	500M – 1G
Technology	65 nm
Readout Rate	1 – 4 Gb/s
Trigger Rate	~ 1MHz

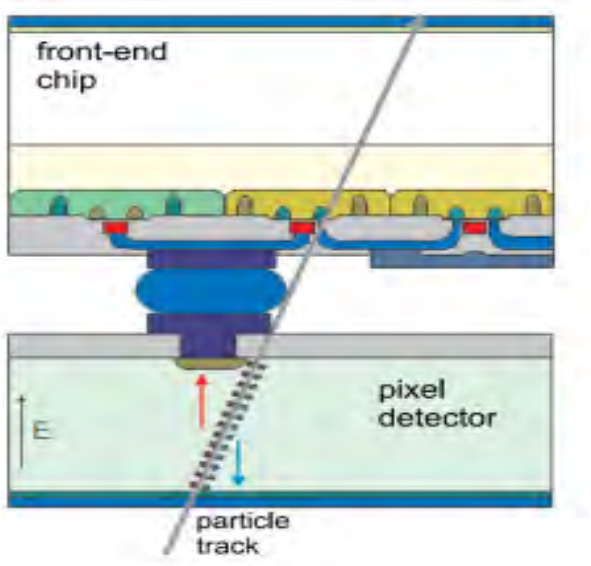
- Particle Physics customized the technology and has taken it to unprecedented scale



ATLAS Pixel Detector

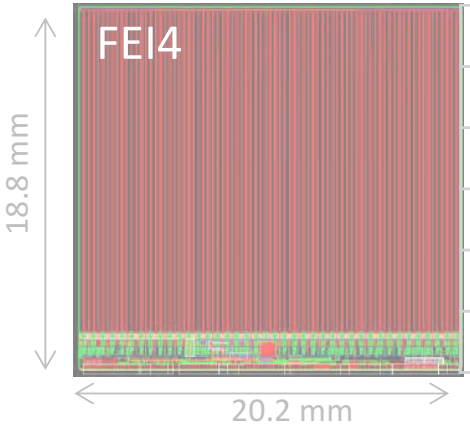
Silicon Technology





- **Diagnostics measurements to ensure electrical connectivity quickly showed its applicability for x ray detection**

Application Specific Integrated Circuit



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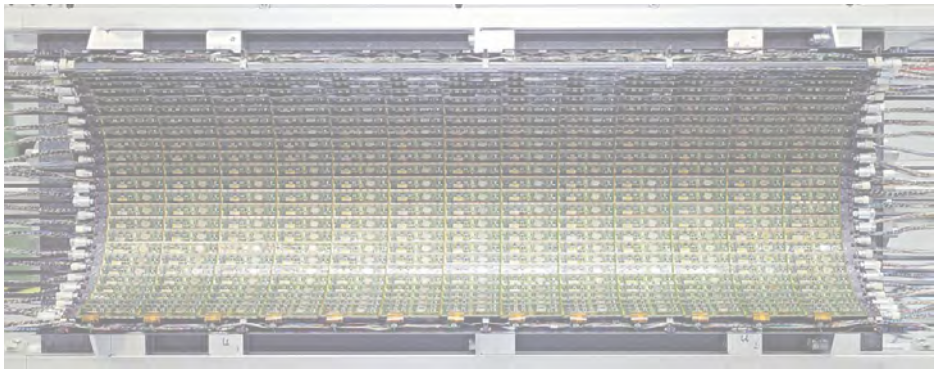
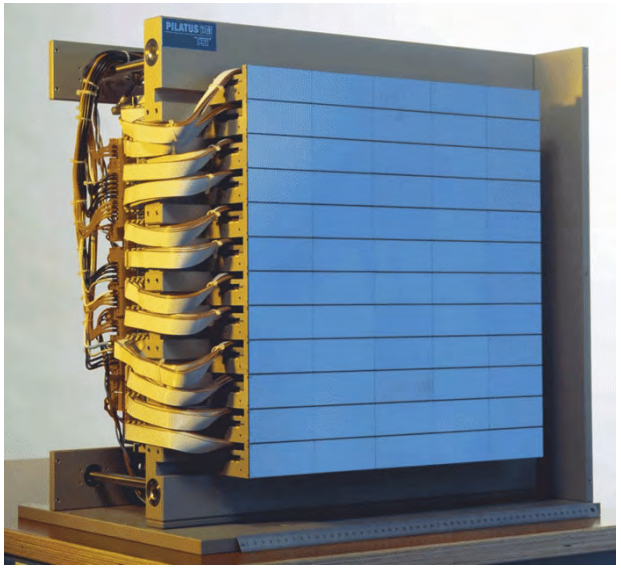


ATLAS Pixel Detector

X-Ray Detectors

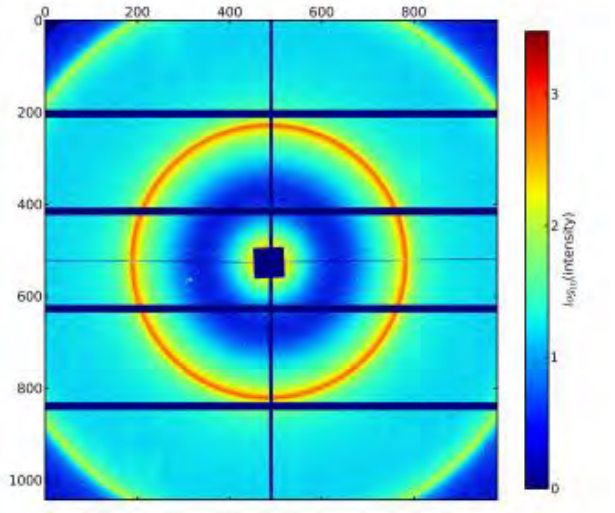
CMS Pixel detector

- Development of CMS pixel detector led directly to development of X-ray detectors
- Spin-off company from CMS development at the Paul Scherrer Institute: DECTRIS.

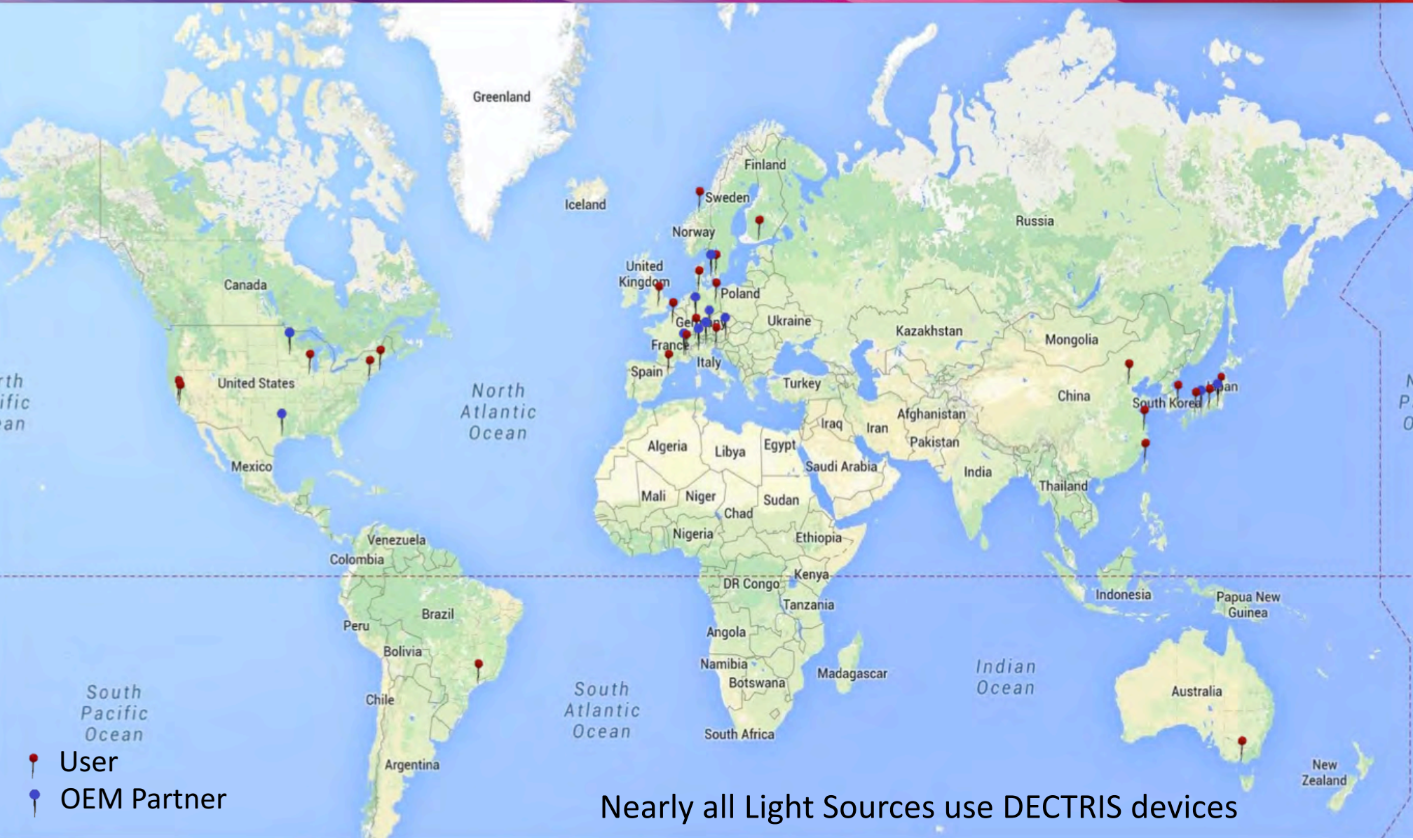


Pilatus X-ray detector

Pilatus Diffraction Pattern

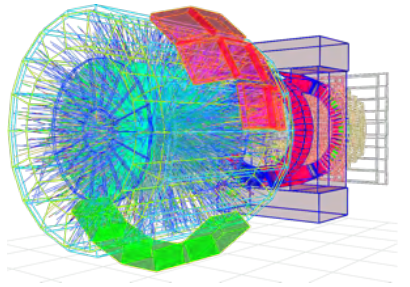


Photon Science Enabler

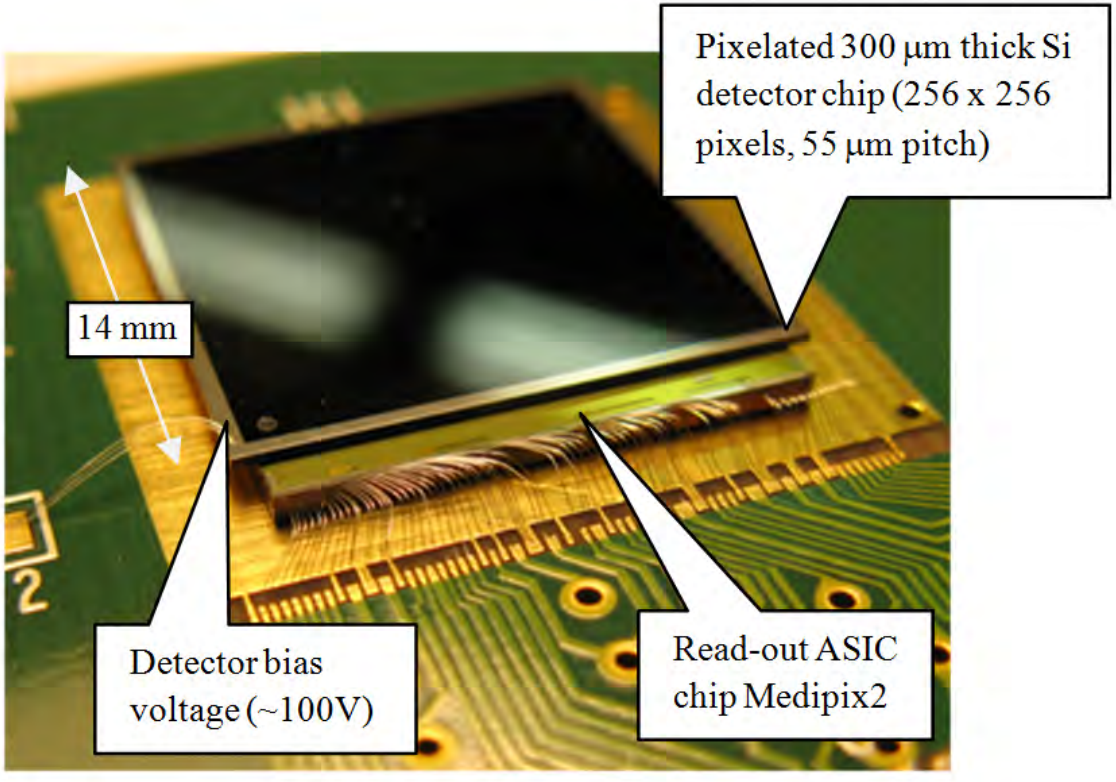


Nearly all Light Sources use DECTRIS devices

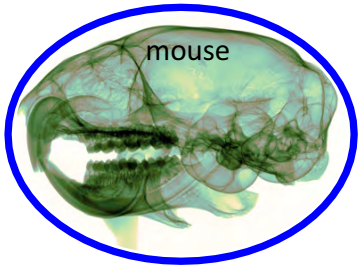
MediPix and TimePix



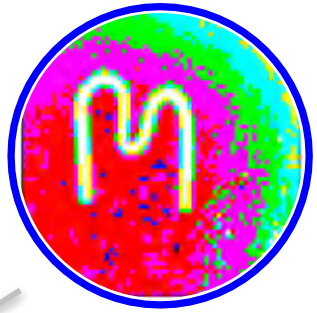
- Development of an ASIC for the ALICE experiment at the LHC at CERN led to the development of an imaging application:
  - Medipix: single photon counting ASIC
  - Timepix: added time measurement
  - Medipix3: counts photons with energy thresholds and timing

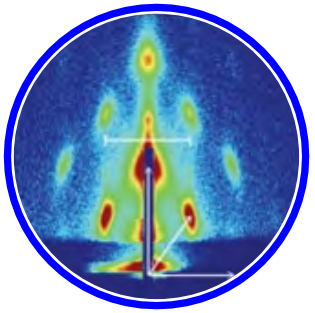


MediPix and TimePix

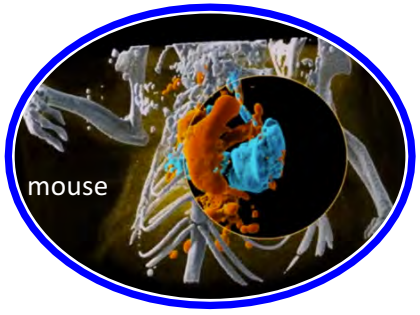


X-ray Imaging





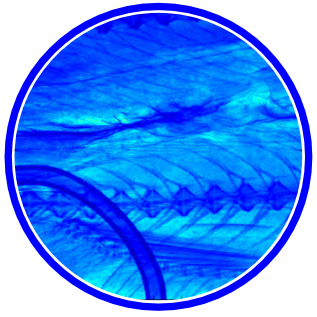
Grazing Incidence SAXS



In vivo 3D tomography

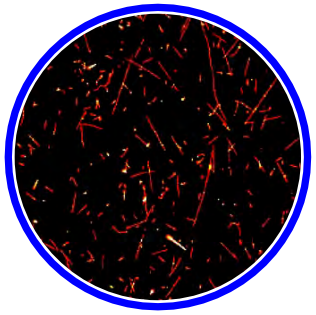
Dosimetry on International Space Station

X-ray Fluorescence

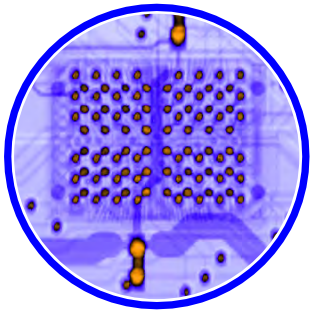


Small-angle X-ray Scattering (SAXS)

X-ray diffraction
2011 R&D 100 award

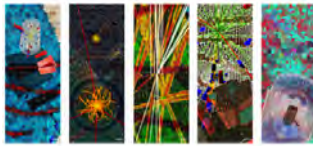


Particle monitoring



Non-destructive materials testing

Companies Using MediPix / TimePix



ADVACAM Imaging the Unseen www.advacam.com/

mars Medipix All Resolution System http://www.marsbioimaging.com/

AMSTERDAM SCIENTIFIC INSTRUMENTS http://www.amscins.com/

X-RAY IMAGING EUROPE http://www.xi-europe.com/

PANalytical http://www.panalytical.com/

Quantum DETECTORS http://quantumdetectors.com/

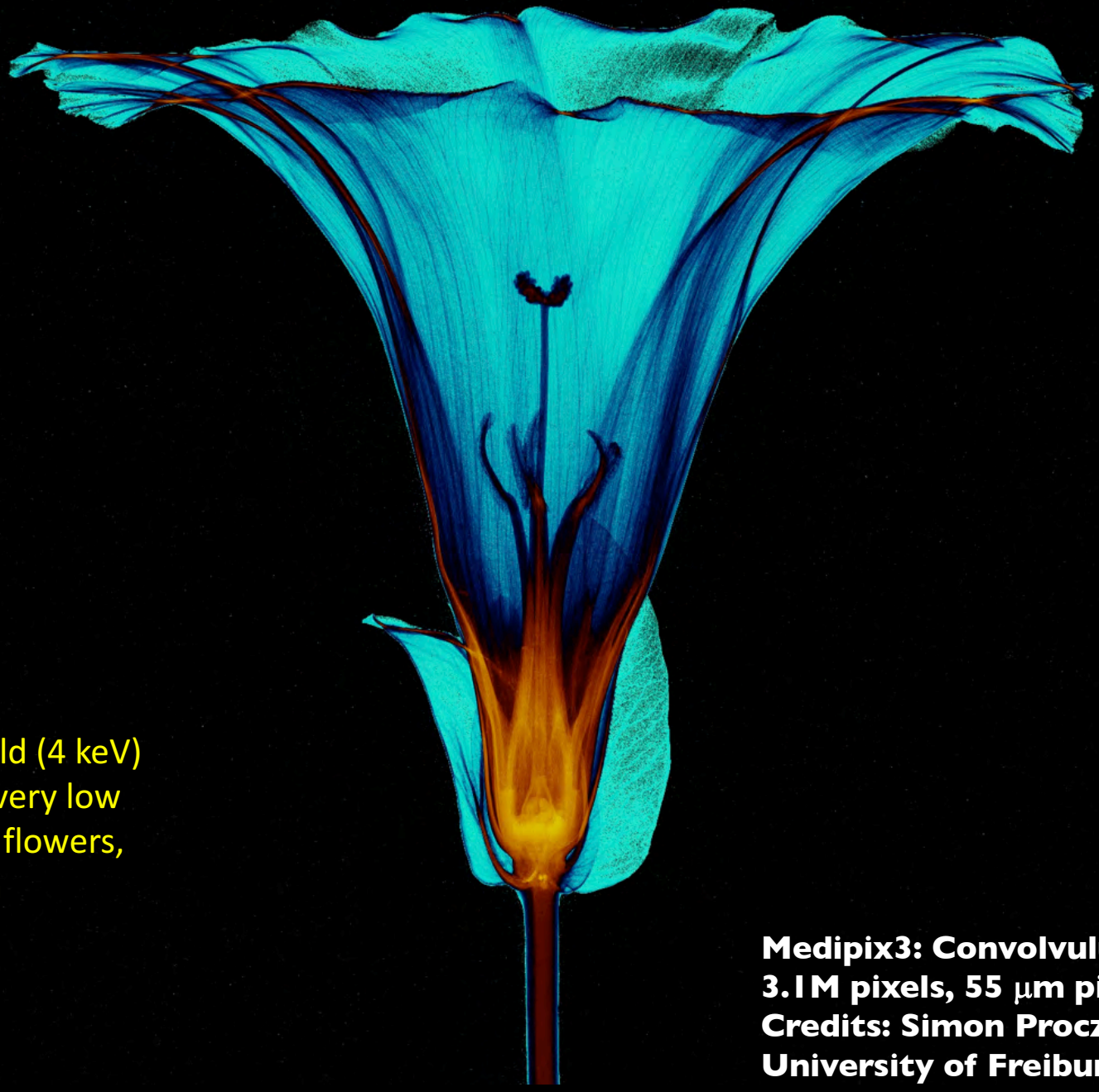
kromek detect image identify https://www.kromek.com/

XRAY IMATEK PHOTON COUNTING DETECTORS http://xray-imatek.com/

X-Spectrum http://www.x-spectrum.de/

JABLOTRON CREATING ALARMS http://www.jablotron.com/

Plus Light and Neutron Sources

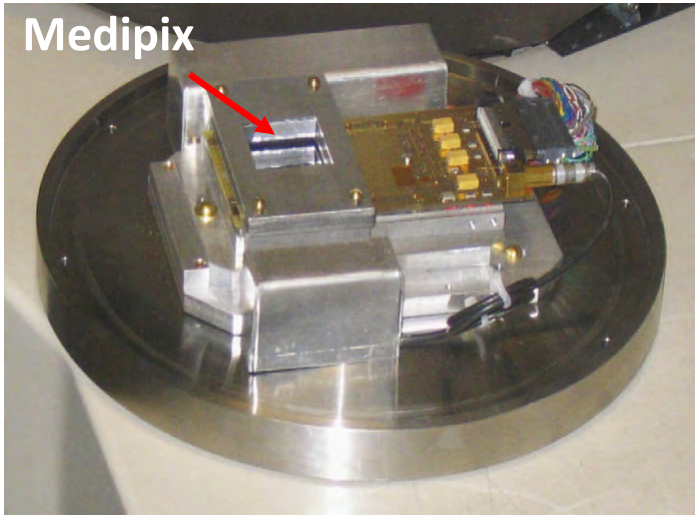


Low energy threshold (4 keV) enables imaging of very low contrast media, like flowers, with high resolution

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

Advancing Cryo-Electron Microscopy

- The quest for obtaining the best image resolution of biological material avoiding sample damage and destruction by the electron beam



CMOS node	**250nm**
Pixel Array	**256 x 256**
Pixel pitch	**55μm**
ENC	**110e^{--}**
Minimum detectable charge	**~500e^{-}**

Noiseless direct detection of electrons in Medipix2 for electron microscopy, *NIM* A546 (2005) 160–163
Direct electron detection methods in electron microscopy, *NIM A*513 (2003) 317-321

Advancing Cryo-Electron Microscopy

- The quest for obtaining the best image resolution of biological material avoiding sample damage and destruction by the electron beam

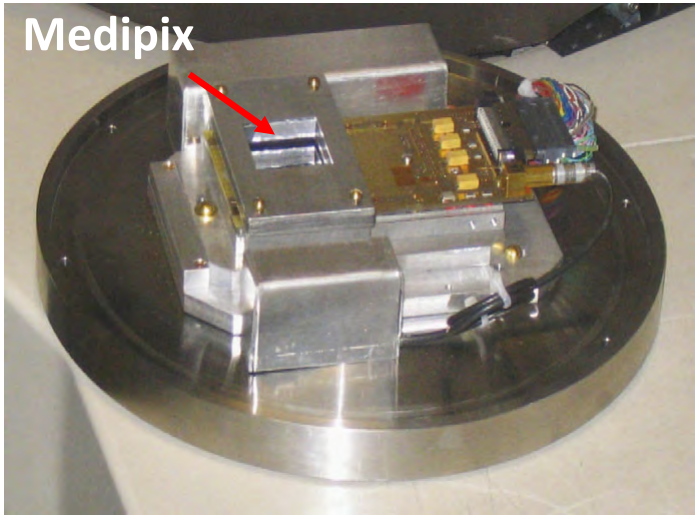
Electron imaging with Medipix2 hybrid pixel detector

G. McMullan[a], D.M. Cattermole[a], S. Chen[a], R. Henderson[a], X. Llopart[b], C. Summerfield[a], L. Tlustos[b], A.R. Faruqi[a,*]

[a] *MRC Laboratory of Molecular Biology, Hills Road, Cambridge CB2 2QH, UK*
[b] *PH Division, CERN, 1211 Geneva 23, Switzerland*

Received 24 June 2006; received in revised form 4 October 2006; accepted 17 October 2006

Ultramicroscopy, **107** (2007) 401-413



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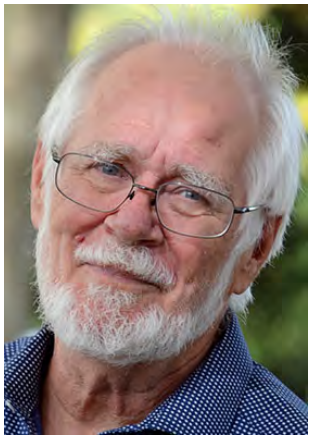
2017 Nobel Prize in Chemistry

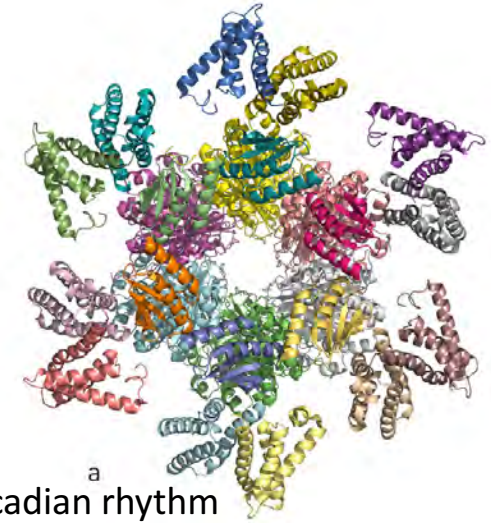


Jacques Dubochet
University of Lausanne

Joachim Frank
Columbia University

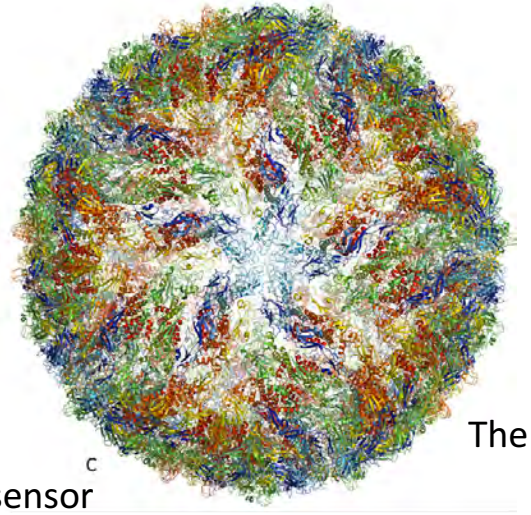
Richard Henderson
MRC Lab, Cambridge

"For developing cryo-electron microscopy for the high-resolution structure determination of biomolecules in solution".



Protein for circadian rhythm

Ear pressure sensor



The Zika virus.

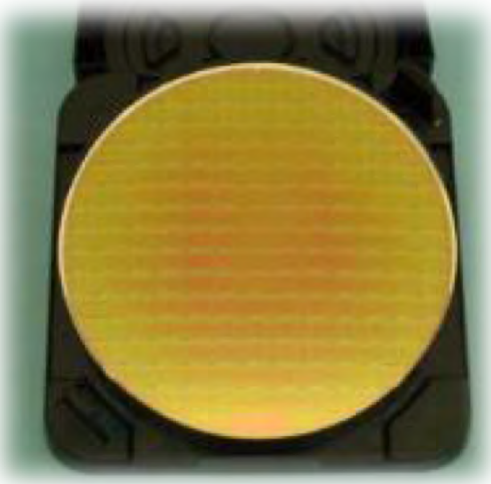
- Although CMOS technology is currently being used for cryo-EM imaging, Medipix effort help advance the technology

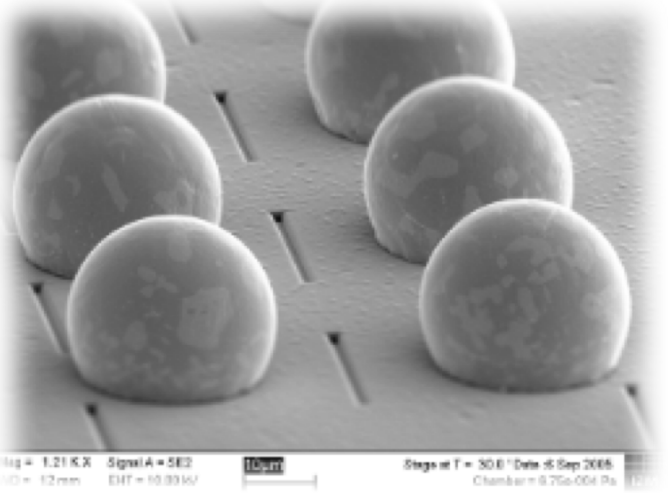
With thanks to Paula Collins

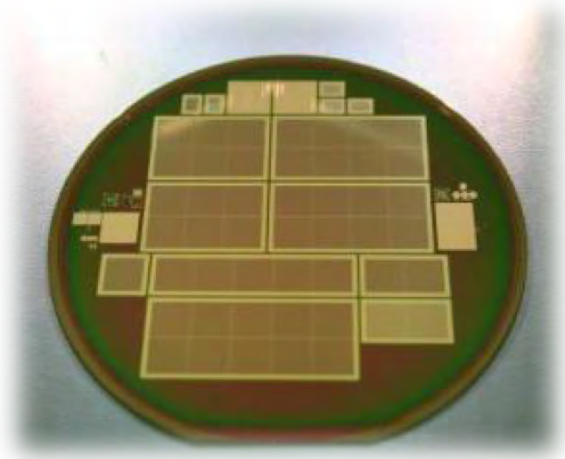
Ultra-Fine Pitch Bonding

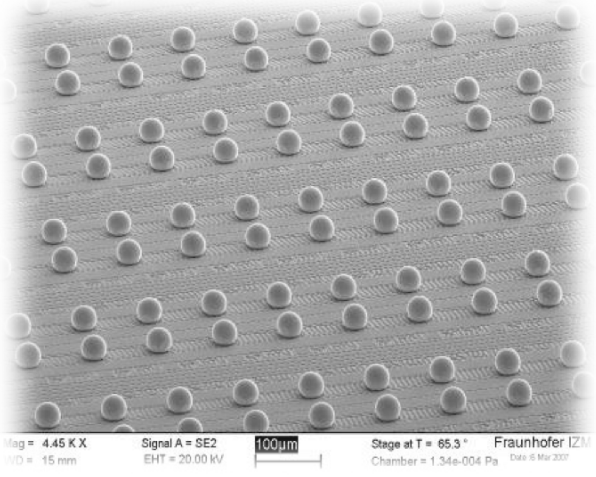
- Electrically connecting the sensor to the readout at ultra-fine pitch, high density; particle physics drives technology to scale and technical limits

- ATLAS pixel detector
  - SnPb bumps
  - ~1150 modules
  - >18,600 readout chips







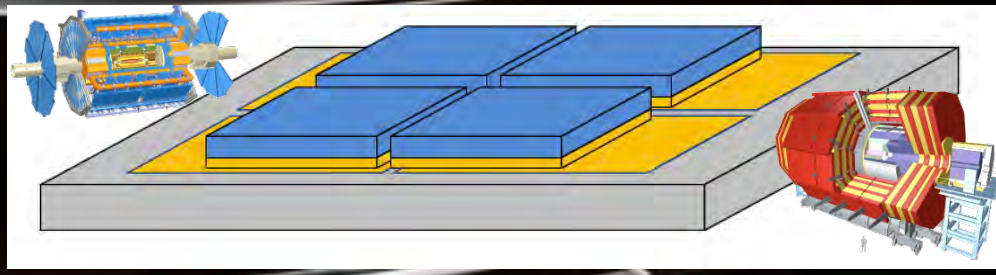


- CMS pixel detector upgrade
  - SnAg bumps
  - ~300 modules
  - ~7000 readout chips

Adaptive LED Headlights

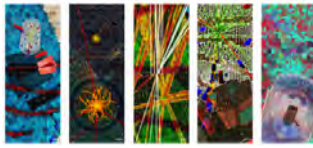
Fraunhofer | DAIMLER | OSRAM | Infineon

Four LED chips, each 256 pixels, 125µm size, connected to driver electronics chip through gold-tin porous sponge bond

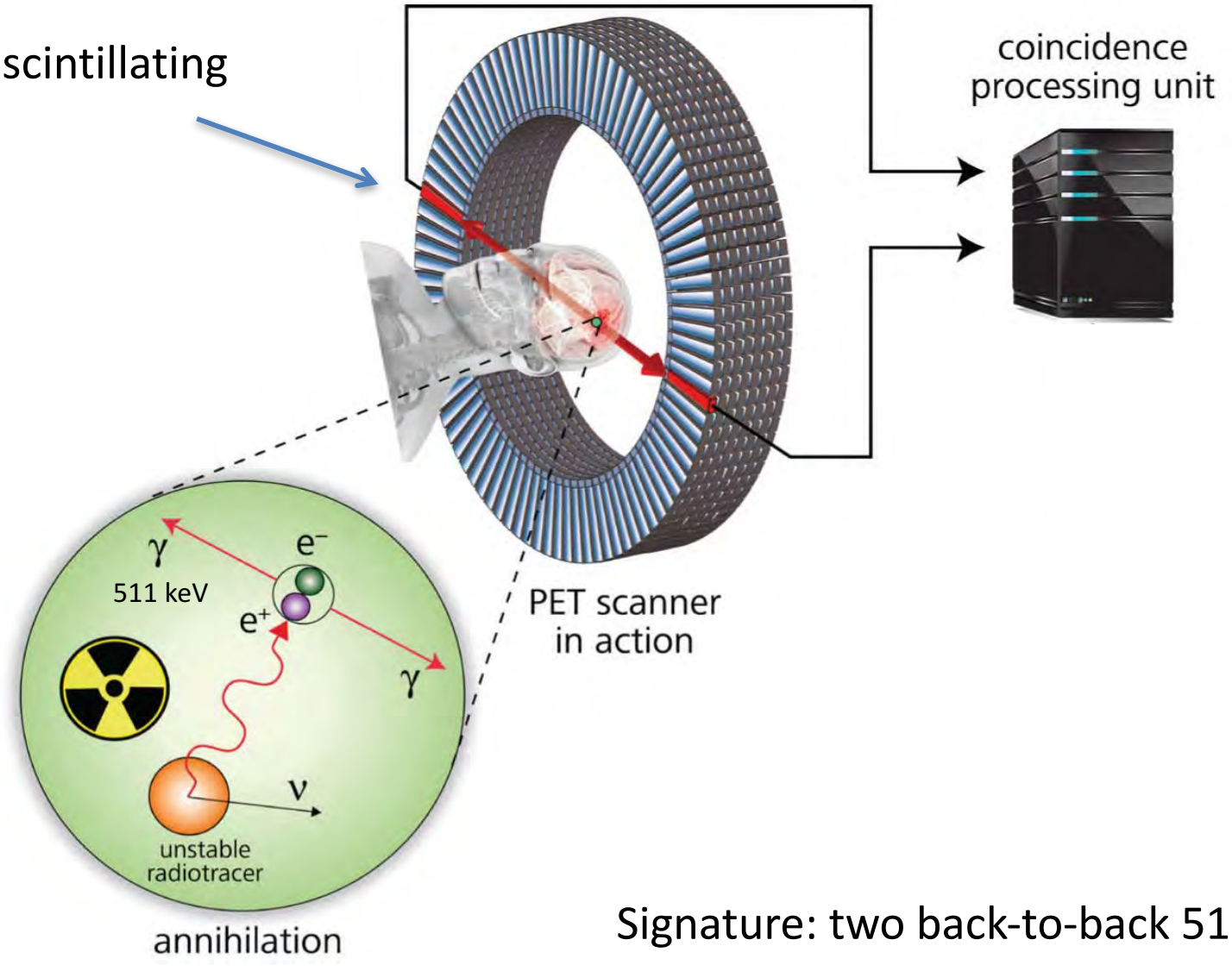


Adaptive LED Headlights

Positron Emission Tomography

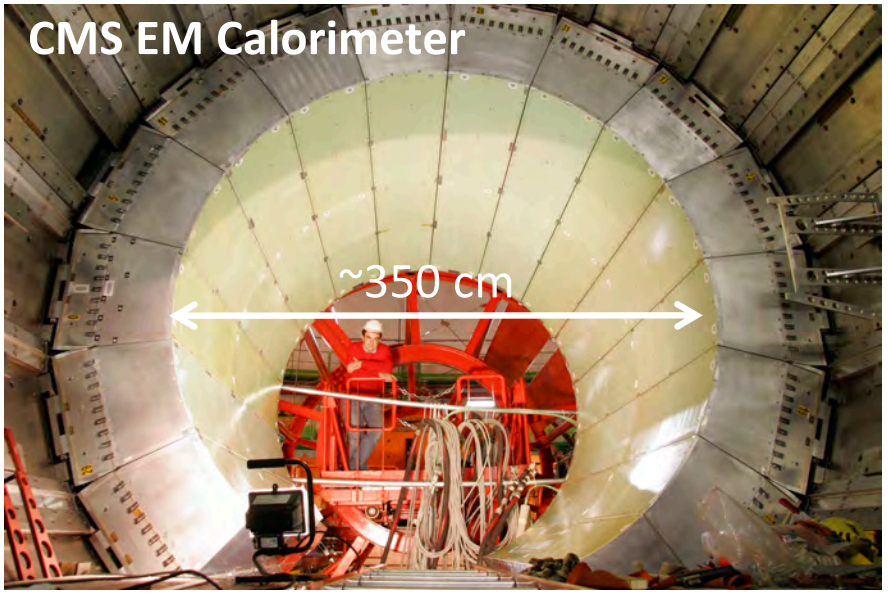


Array of scintillating crystals



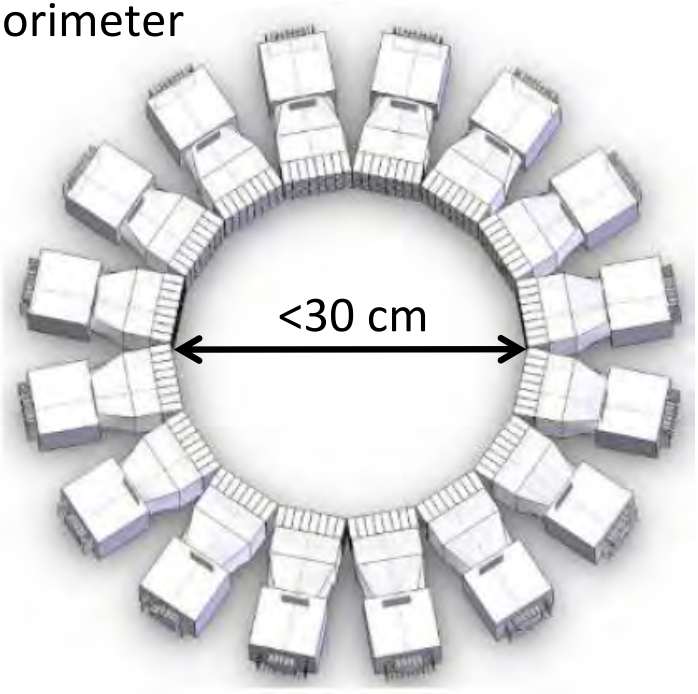
Signature: two back-to-back 511 keV γ's

Calorimetry

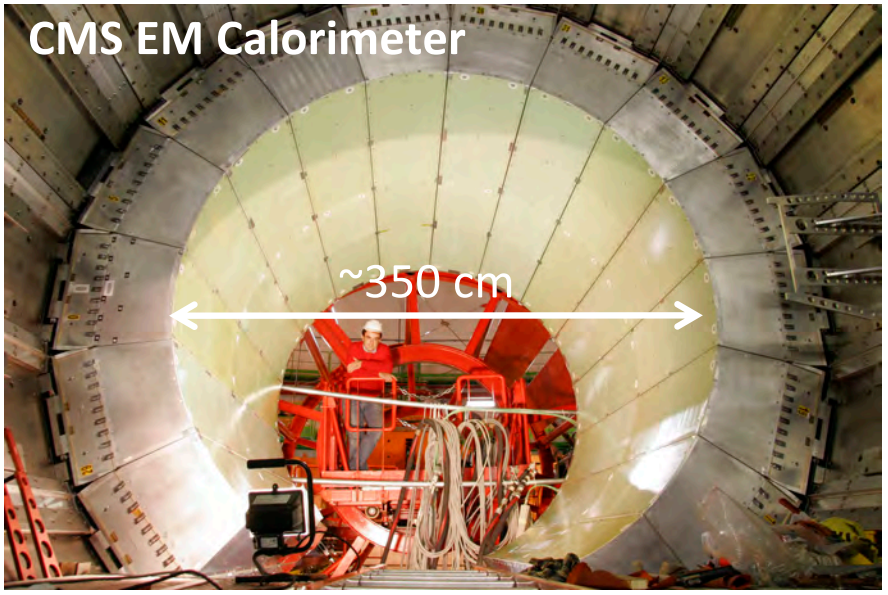


$$H \rightarrow \gamma\gamma$$

PET Calorimeter



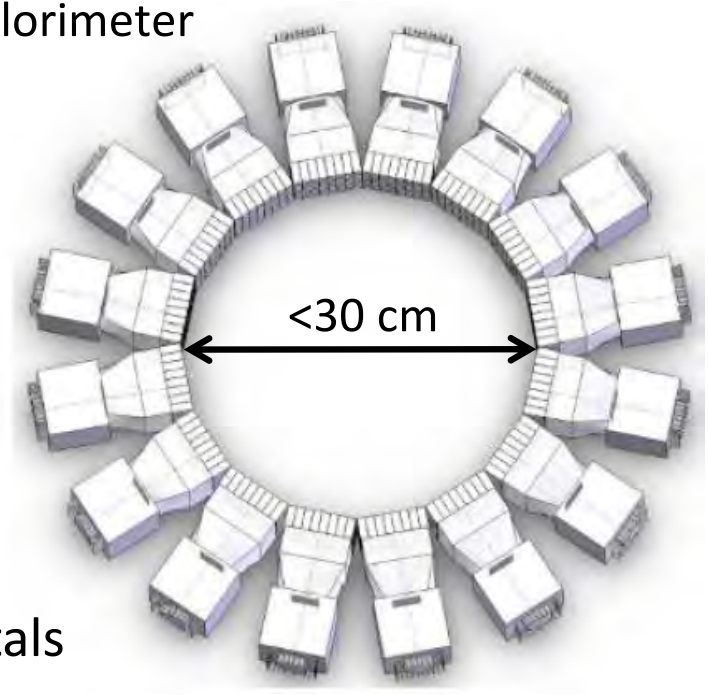
Calorimetry



$H \rightarrow \gamma\gamma$

~80,000 crystals

PET Calorimeter

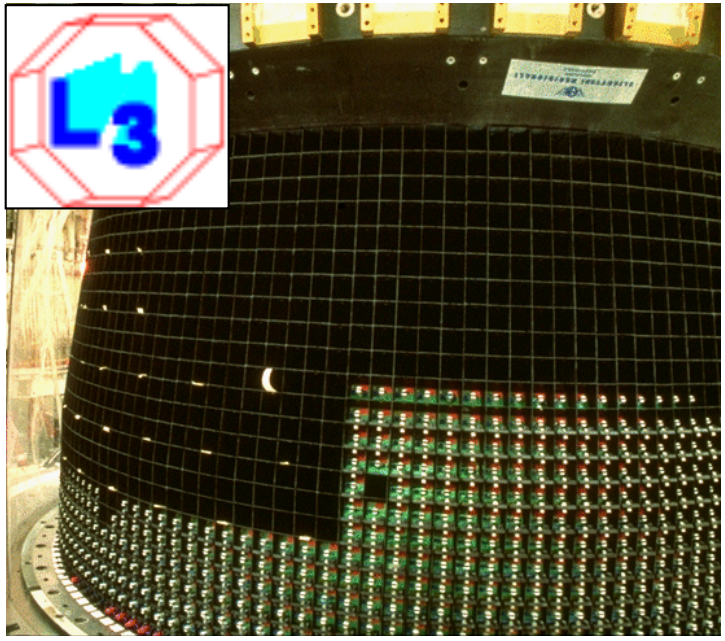


First PET scanners used BGO

Crystal development driven by Particle Physics !

< 1,000 crystals

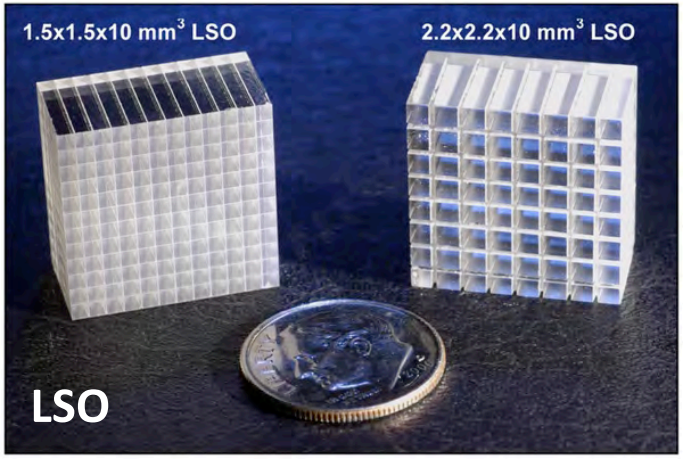
BGO Crystal Development



- The L3 experiment at LEP built the 1st BGO crystal calorimeter consisting of 11,400 BGO crystals with total volume of 1.5 m^3
- Led Shanghai Institute for Ceramics (SIC) to the multi-crucible growth technology allowing growth of up to 36 crystal ingots per oven

- Particle physics opened PET 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

LYSO Crystal Development



- LSO (Lutetium Orthosilicate) crystals invented and developed at Schlumberger (Charles Melcher)

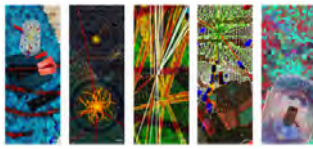
- Radiation damage studies of Lead Tungstate (PWO) crystals for CMS at the LHC showed that yttrium doping was effective to improve crystal radiation hardness.

Philips GEMINI TF PET/CT

LYSO crystals: 4x4x22mm

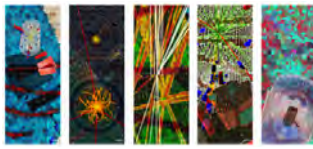
- Led to the development of cerium doped Lutetium Yttrium Orthosilicate (LYSO) crystals which currently dominates the PET market

Cultural Heritage



- The use of particle detectors for tomography dates back to Louis Alvarez.
- Refinement of particle physics detectors can lead to new exciting discoveries:

Cultural Heritage

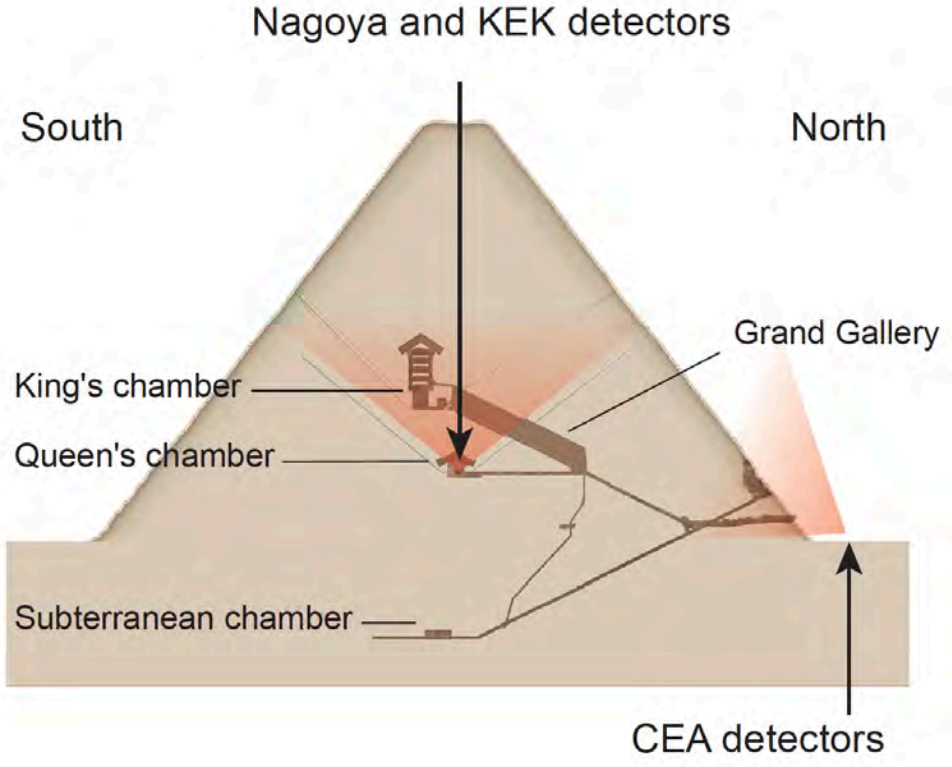


- The use of particle detectors for tomography dates back to Louis Alvarez.
- Refinement of particle physics detectors can lead to new exciting discoveries:

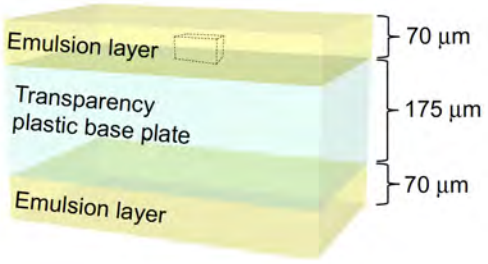
November 2, 2017:
"Inside Giza's Great Pyramid, Scientists Discover a Void"

Khufu's Pyramid

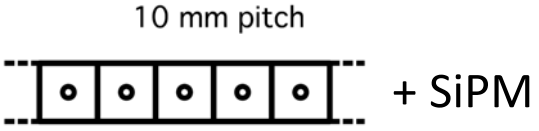
- Tomography of the Great Pyramid of Khufu (Cheops, IVth dynasty 2509 – 2483 BC) using three independent particle physics detector technologies



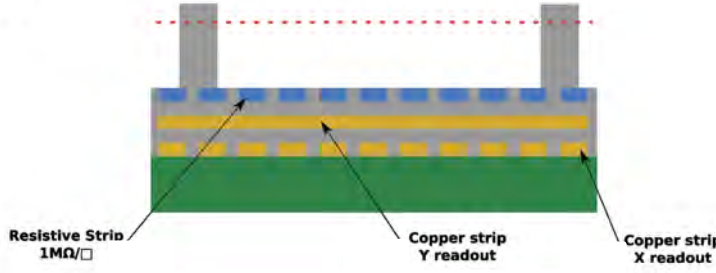
Emulsions (Nagoya)



Scintillator Strips (KEK)

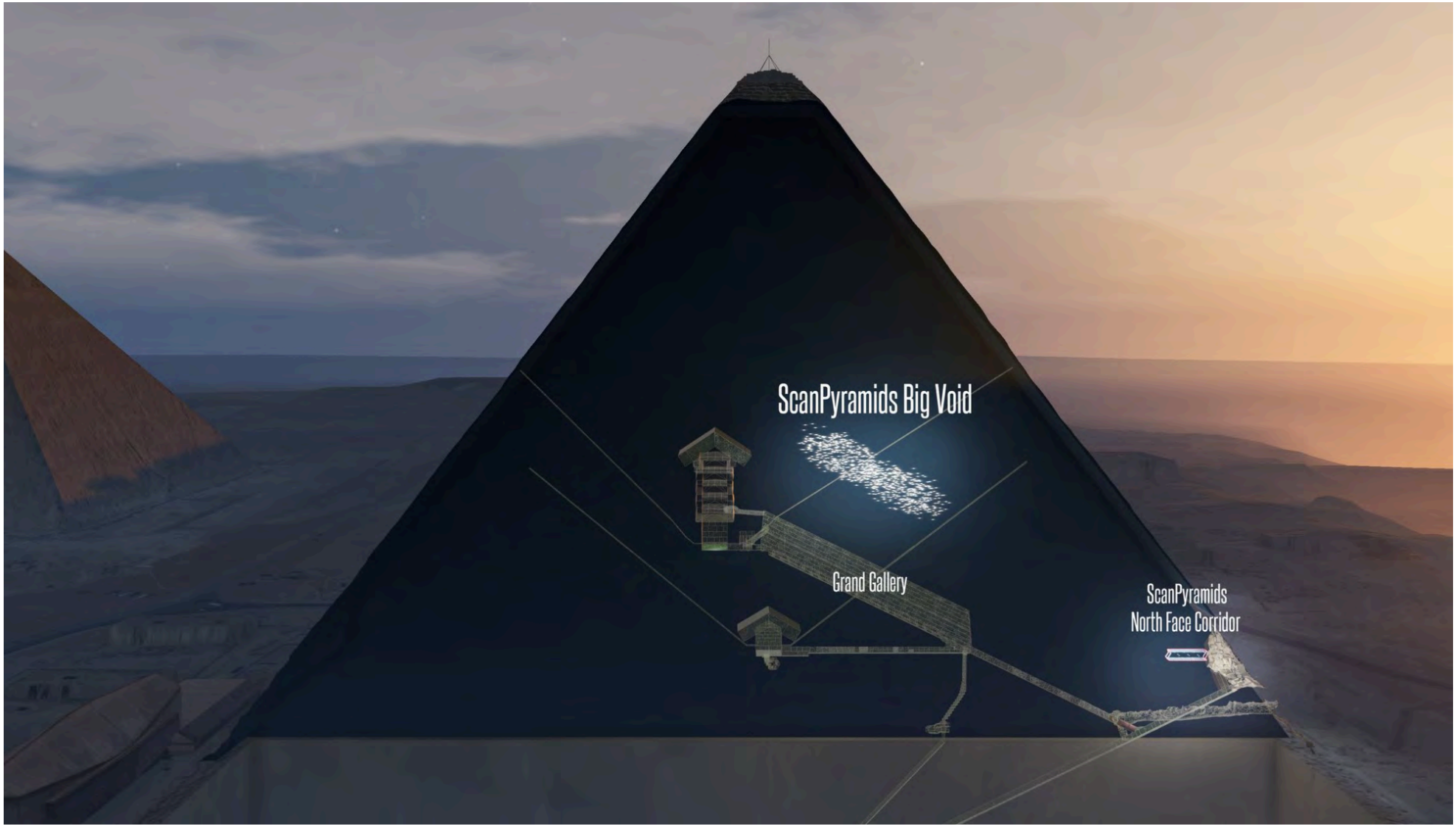


Micromegas (CEA)



https://www.nytimes.com/2017/11/02/science/pyramids-giza-void.html
Nature: doi:10.1038/nature24647

Khufu's Pyramid



https://www.nytimes.com/2017/11/02/science/pyramids-giza-void.html
Nature: doi:10.1038/nature24647

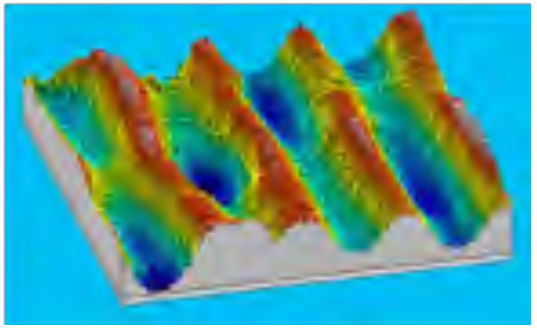
Cultural Heritage

- Precise optical metrology for silicon vertex detectors and trackers

Cultural Heritage

- Precise optical metrology for silicon vertex detectors and trackers

- Use the same **non-contact** optical metrology to scan the grooves on wax cylinders or vinyl disks, reconstruct the mechanically recorded sound by image processing and create a digital copy.



LHC Physicists Preserve Native American Voices

- The Physicist Who's Saving the Music (Wall Street Journal, August 21, 2015)

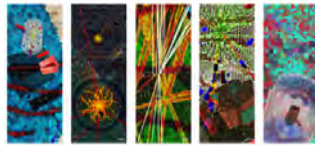
THE NEW YORKER

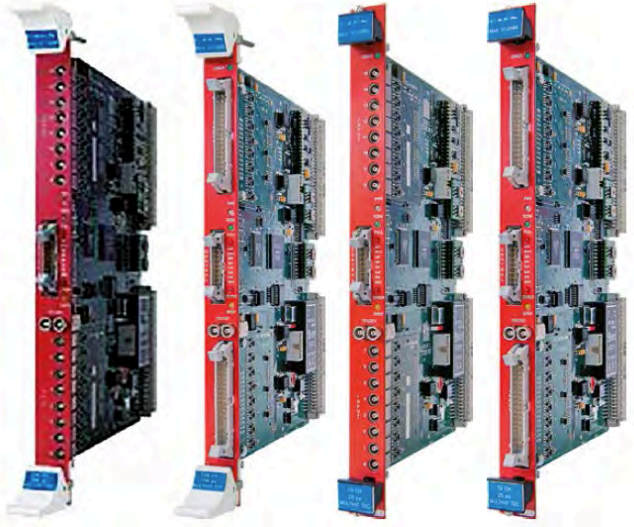
http://irene.lbl.gov/

http://www.newyorker.com/magazine/2014/05/19/a-voice-from-the-past

http://www.symmetrymagazine.org/article/june-2015/lhc-physicists-preserve-native-american-voices

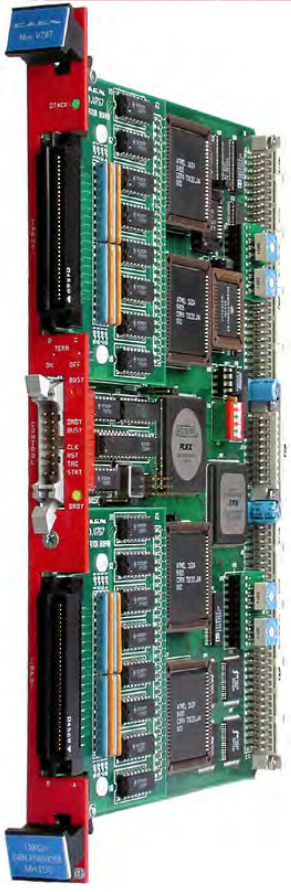
Industry Collaboration





V1290-2eSST Family

" The units features High Performance Time to Digital Converter chips developed by CERN."



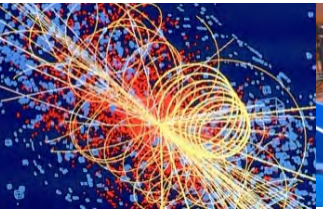
***V767**: The module hosts 4 deadtimeless TDC chips developed at CERN.*

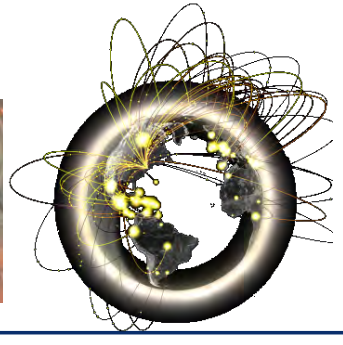
***DT5742**: Based on DRS4 chip (Paul Scherrer Institute design)*

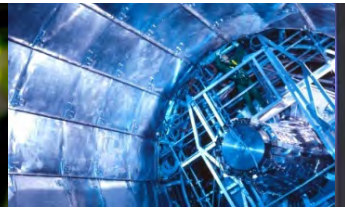
CAEN
Tools for Discovery

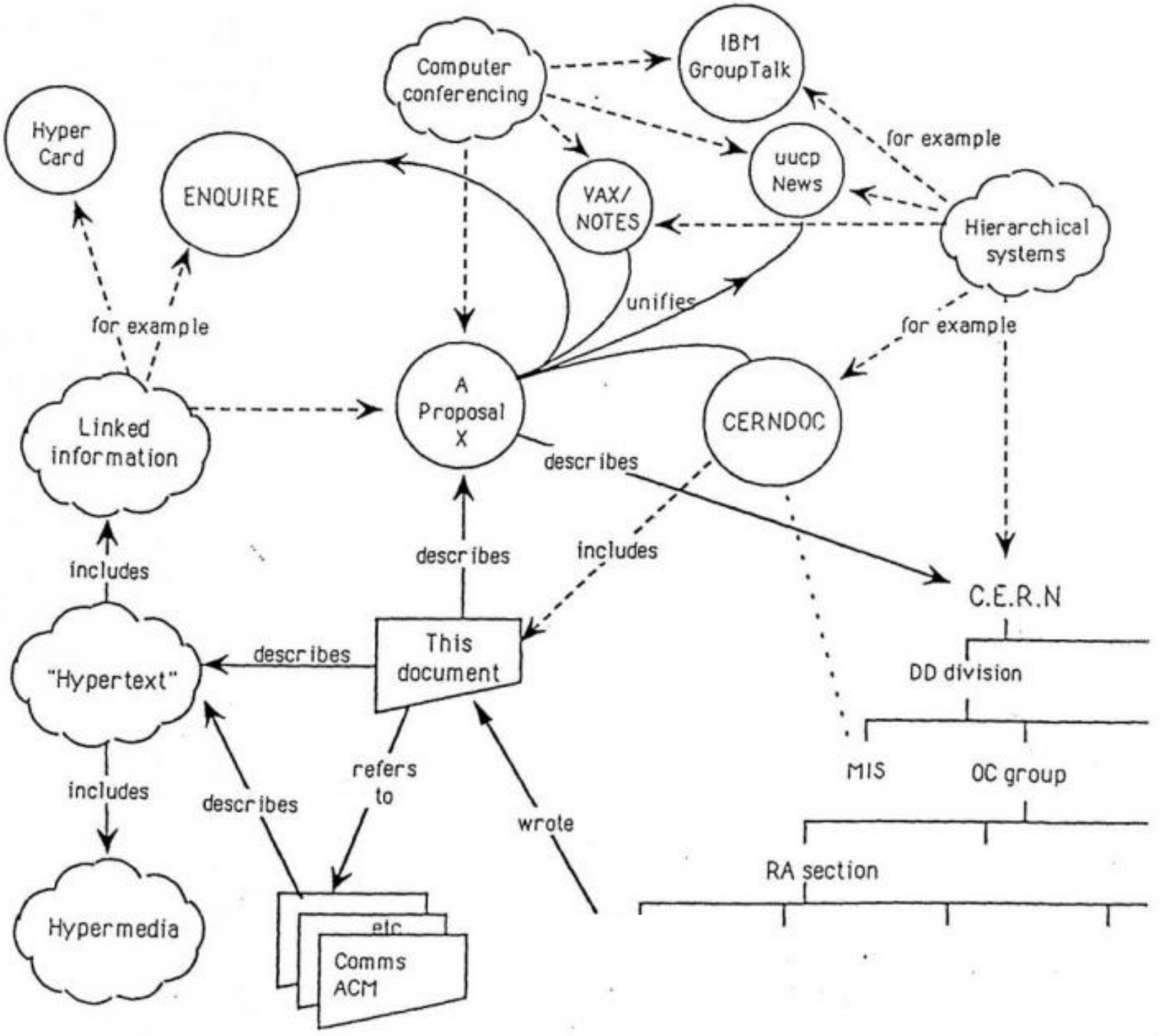
Computing, Software, Data Management

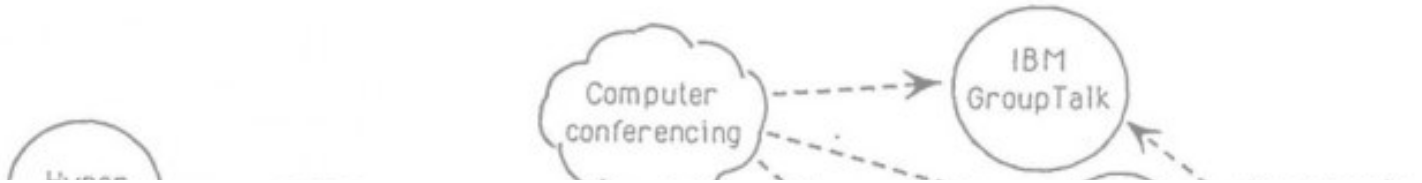
HEP has been at the forefront of big data and the need for advanced networking









Computer conferencing
IBM GroupTalk
Hyper Card
ENQUIRE
uucp News
VAX/ NOTES
for example
Hierarchical systems
unifies
for example
for example
A Proposal X
CERNDOC
Linked information
describes
includes
describes
includes
C.E.R.N
"Hypertext"
describes
This document
DD division
MIS
OC group
includes
describes
refers to
wrote
RA section
Hypermedia
etc
Comms ACM

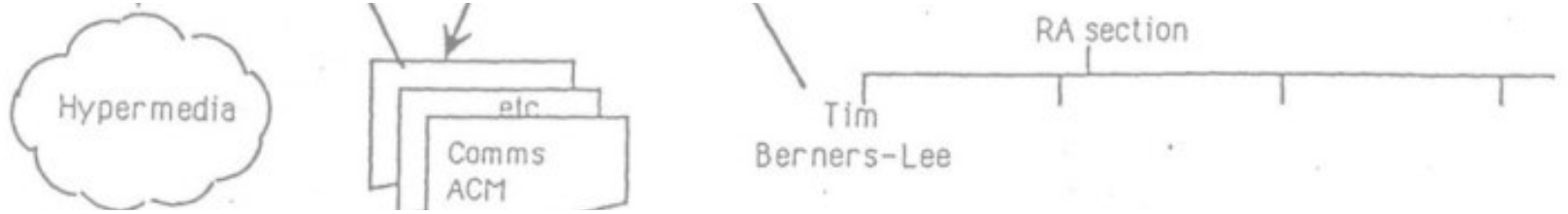


Cover Page of a 10-page proposal titled:

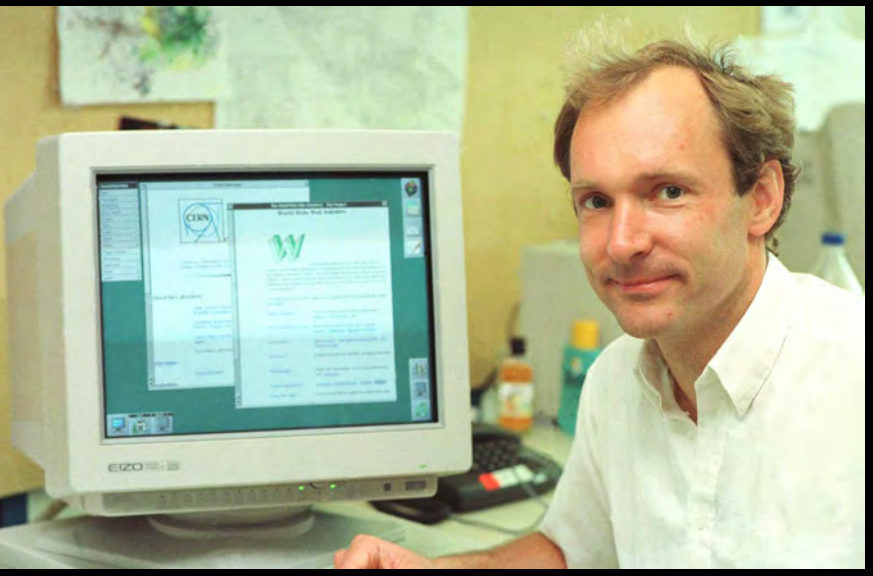
Information Management: A Proposal

Tim Berners-Lee, CERN
March 1989

This proposal concerns the management of general information about accelerators and experiments at CERN. It discusses the problems of loss of information about complex evolving systems and derives a solution based on a distributed hypertext system.

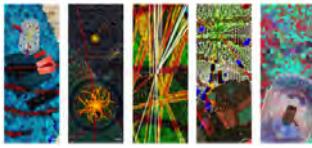


http://home.cern/about/updates/2014/03/world-wide-web-born-cern-25-years-ago



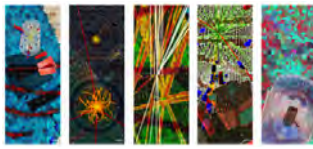
On 30 April 1993 CERN put the World Wide Web software in the public domain and made the release available with an open license, as a more sure way to maximise its dissemination, enabling the web to flourish.

Petabytes and Petaflops

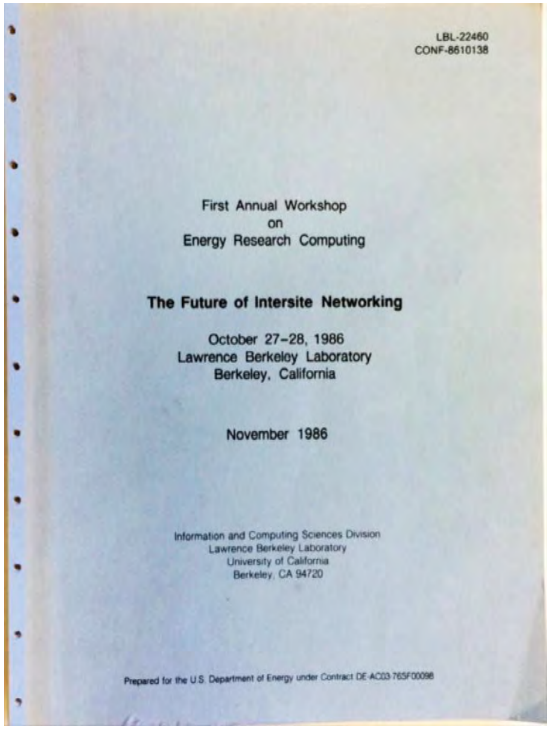


The LHC Data Challenge was recognized very early

Particle Physics and Data Networks



"Just as we expect a computer to perform as if we are the only user, we expect the network to give that same appearance."



LBL-22460
CONF-8610138

First Annual Workshop
on
Energy Research Computing

The Future of Intersite Networking

October 27–28, 1986
Lawrence Berkeley Laboratory
Berkeley, California

November 1986

Information and Computing Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

1986 workshop on:
"The Future of Intersite Networking"

1st ANNUAL WORKSHOP ON ENERGY RESEARCH COMPUTING

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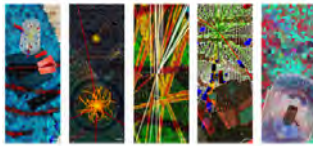
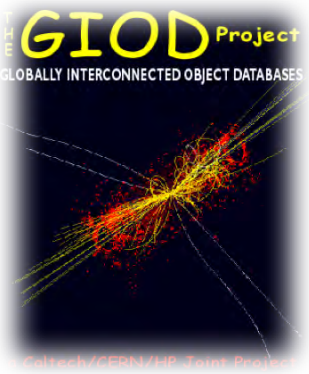
STEVE@BRL.ARPA,

From Barb Helland, HEPAP Meeting, April 1, 2016

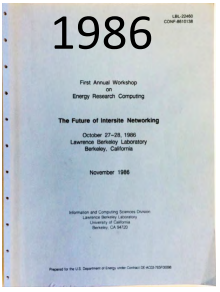
Evolution of Grids





Globally Interconnected Object Databases (GIOD, ~1997)

Models of Networked Analysis at Regional Centers (MONARC, ~1998)

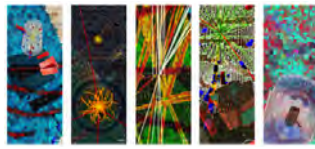


Accessing Large Data archives in Astronomy and Particle Physics (ALDAP, 1999)

"Embryonic Grid"

World-wide university and National Lab effort with collaboration from LIGO, Astrophysics community, Microsoft, Hewlett Packard, L3 communications, …

Evolution of Grids: Grid Era Begins

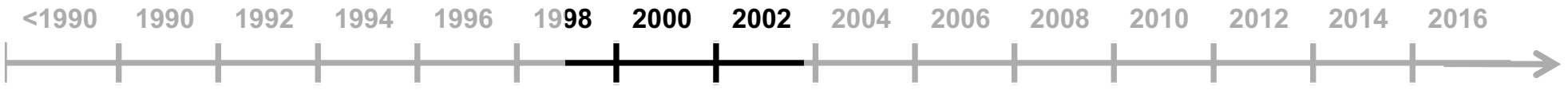


Particle Physics Data Grid (PPDG, 1999)

Grid Physics Network (GriPhyN, 2000)

International Virtual Data Grid Laboratory (iVDGL, 2002)

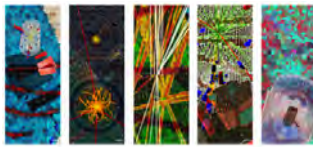
Trillium: GriPhyN + iVDGL + PPDG



"Embryonic Grid" **"Grid Era Begins"**

Strong collaboration with European efforts

Science Grids



DataTAG

Data GRID

eGee Enabling Grids for E-sciencE

the globus project™ www.globus.org

CROSSGRID

GRIP UK Particle Physics P

.....

WLCG Worldwide LHC Computing Grid

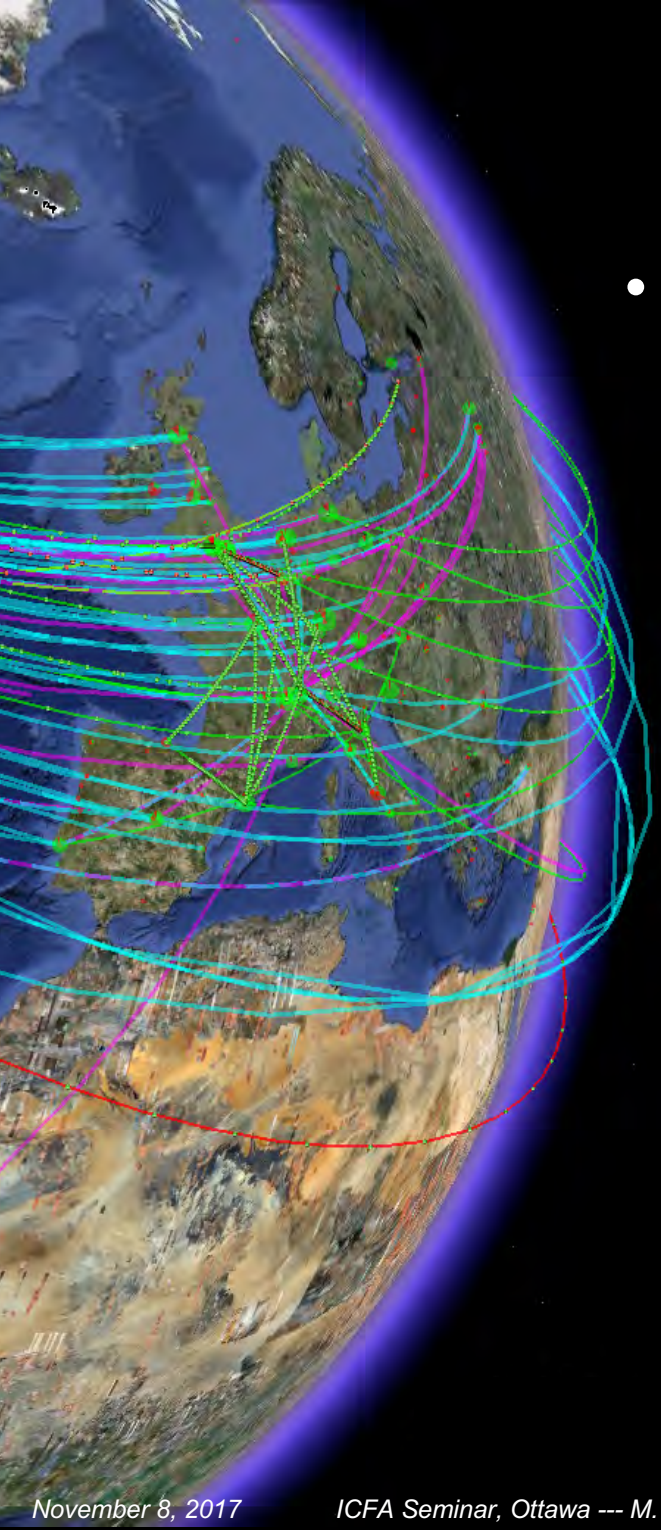
Open Science Grid

ESnet ENERGY SCIENCES NETWORK

<1990 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016

"Embryonic Grid" "Grid Era Begins" "Grid Projects" "Science Grid"

Particle Physics has been in the vanguard of the development of monitored advanced networks and computing infrastructure, including HPC, building on the needs of the experiments, notably the LHC



Global Grid

- Worldwide LHC Computing Grid has been leveraged on both sides of the Atlantic, to the benefit of the wider scientific community and particle physics

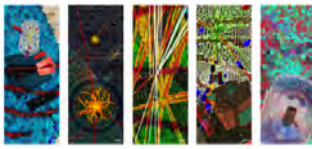
  - Europe:
    - Grids for E-sciencE
      European Grid Infrastructure

  - USA:
    - Open Science Grid (OSG)
    - ESnet:

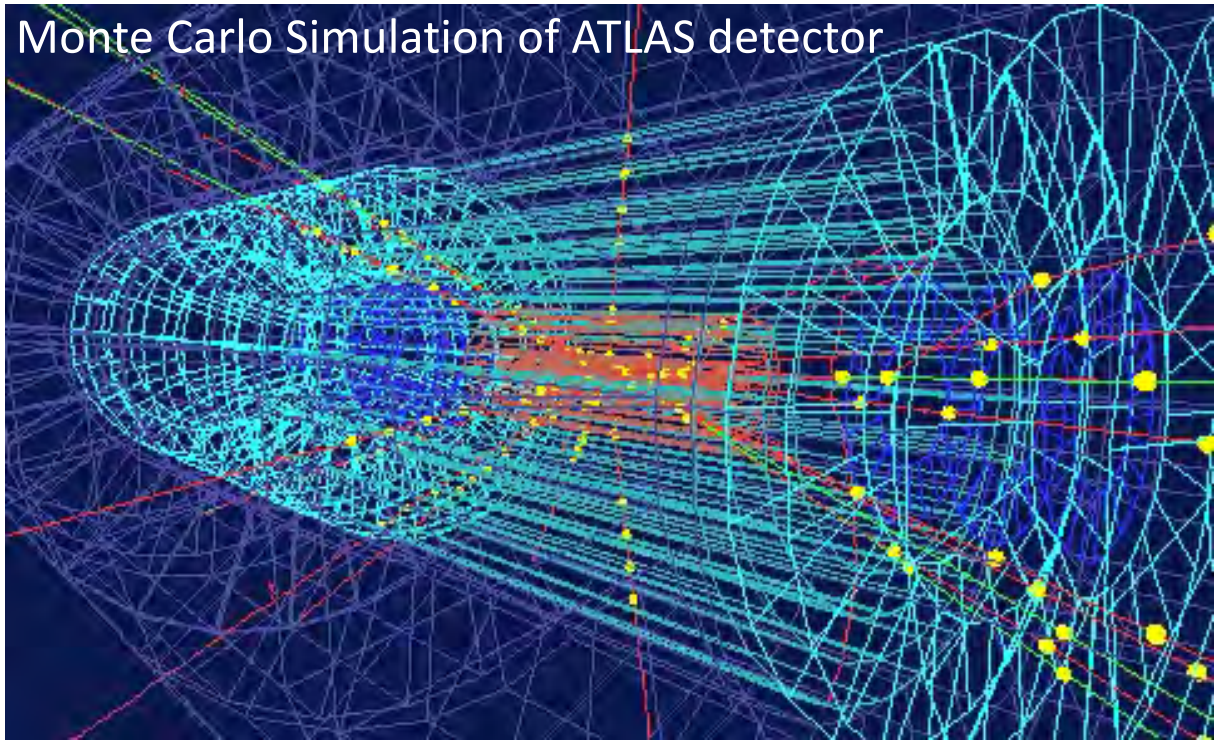
      > 400 Gb/s cross Atlantic
      > 100 PB/months

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

Modeling and Simulation



- Experiments big, difficult and expensive: need for detailed simulations



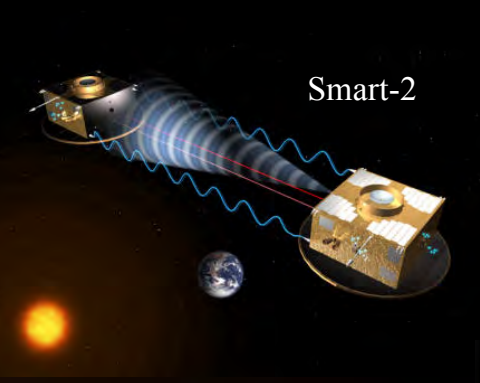
Definition at will of:

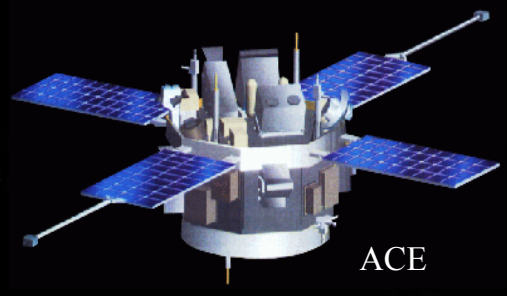
- Geometry
- Materials
- Segmentation
- Tracking through media

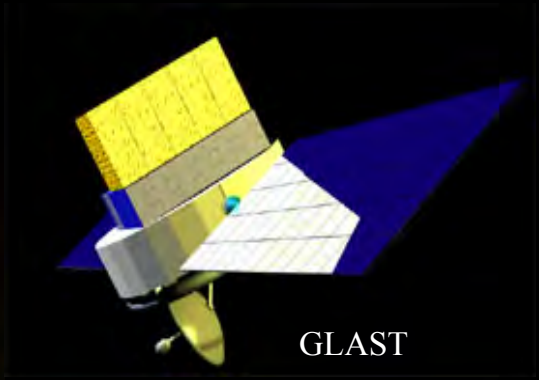
- **GEometry ANd Tracking Toolkit for detector simulations developed: GEANT**
- **Seen very broad use**

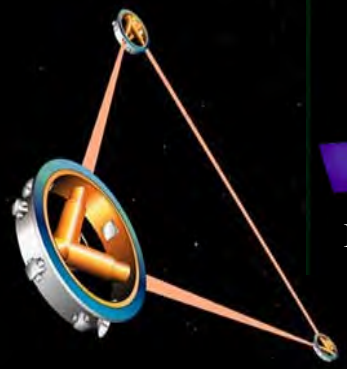
GEANT Use in Space (NASA, ESA, JAXA)

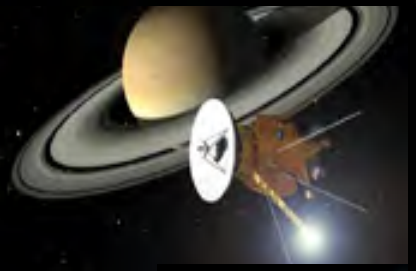
Courtesy: Makoto Asai

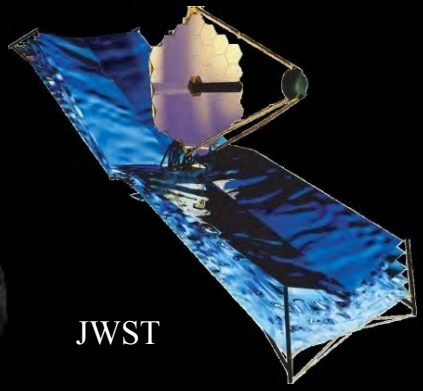


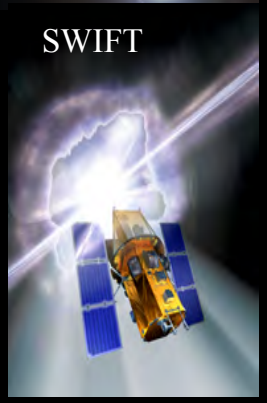


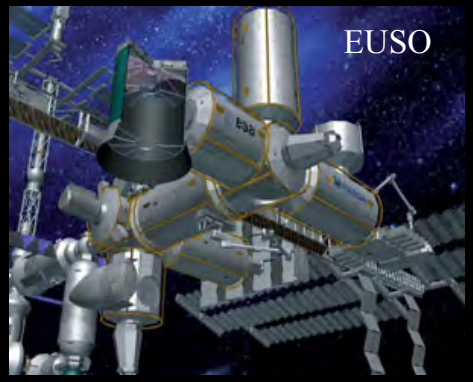


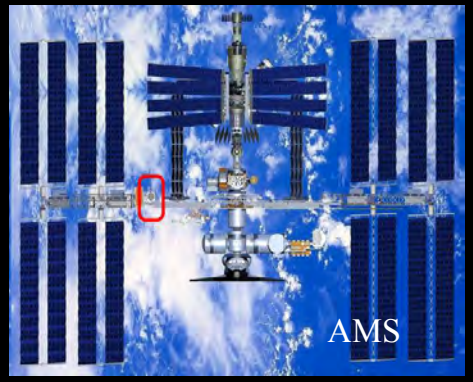


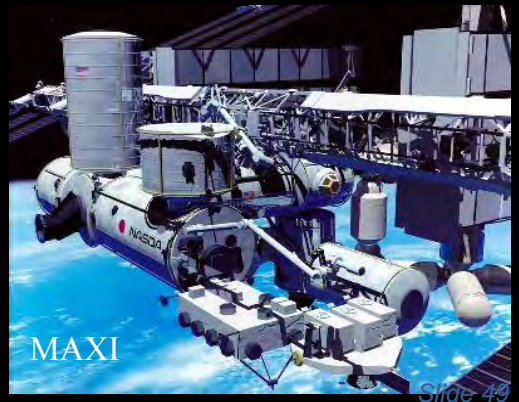






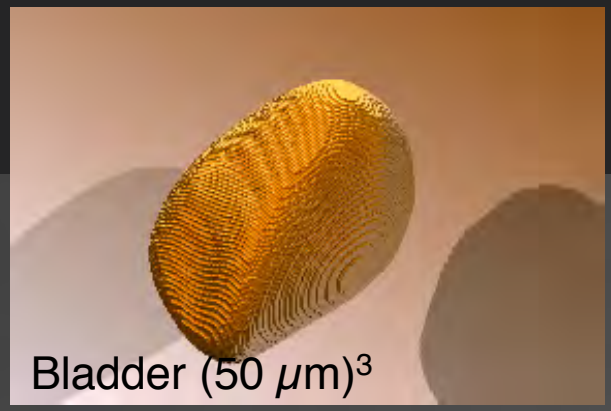


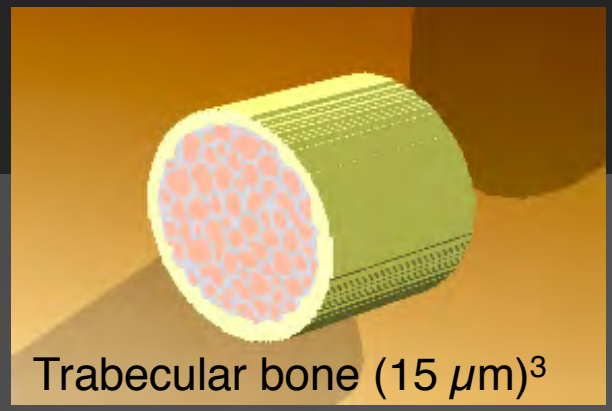




High resolution phantoms


Vertebra (25 μm)^3

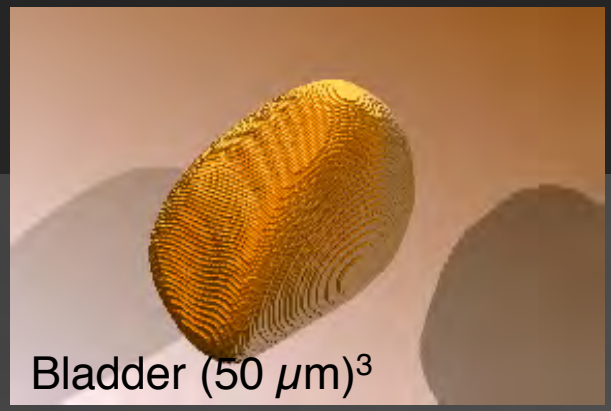

Bladder (50 μm)^3

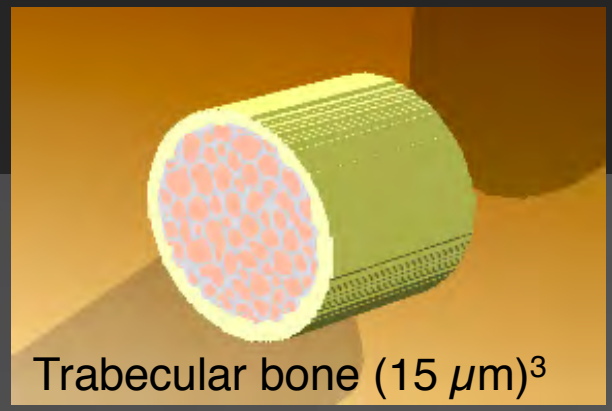

Trabecular bone (15 μm)^3

(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)

High resolution phantoms



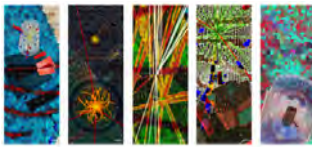


(400 μm)^3 voxelized mouse phantom

R Tasch

The Medical Community is currently a larger user of GEANT than the Particle Physics Community

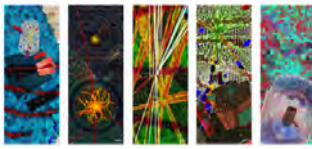
GEANT and Air Travel



- HEP Monte Carlo simulations are used for modeling of radiation exposure in (ultra-) long-haul flights

- The dose received during a flight is about ~5 – 10 μSv/hr
  - X-ray: ~ 6μSv
  - Mammogram: ~3,000 μSv.
- Second highest exposure level for crews after radon environmental exposure
  - Aircraft crew radiation exposure is close to a few mSv/year
- Simulation: a mathematical model of Airbus A340, A. Ferrari et al., Radiation Protection Dosimetry (2004), Vol. 108, No. 2, pp. 91-105
  - The shielding influence of aircraft structures and contents has proven to be significant on radiation levels onboard
- Boeing Company hosted the GEANT4 Space User's workshop in 2006, Seattle

INVENIO



- Invenio is a free software suite enabling you to run your own integrated digital library or document repository on the web
- It is a suite of applications, which provides the framework and tools for building and managing an autonomous digital library server.
- Invenio is developed since 2002 by CERN and at CERN runs:
  - CERN Document Server (1 million records)
  - INSPIRE (1 million records)
  - ILC Document Server
  - CERN Indico search engine
  - CERN Bulletin web site
  - CERN Multimedia Gallery web site

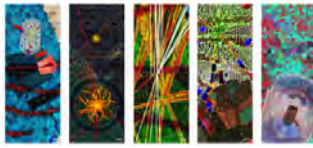
INVENIO

- **TIND, a spin-off company based in Trondheim, Norway, provides professional cloud-based services to customize and maintain INVENIO**

CERN spin-off

CERN technology

Agenda Server



2017 ICFA Seminar

6-9 November 2017
Shaw Centre, Ottawa, Ontario, Canada
Canada/Central timezone

- Overview
- Conference Location
- Timetable
- Contribution List
- Registration
- Accommodation
- Visa and Travel Information
- Social Events
- Previous Seminars
- Local Information
- Photo Gallery
- ICFA2017 Registration (by Invitation Only)
- Participants List
- How to create a TRIUMF Indico Account

For more information

ICFA2017@conferenc...

Mon 06/11 | Tue 07/11 | Wed 08/11 | Thu 09/11 | All days

Print | PDF | Full screen | Detailed view | Filter

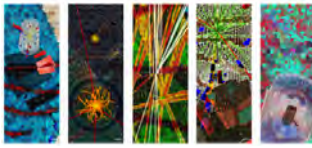
Session legend

Applications | Dark Matter | Neutrinos | Opening

see more...

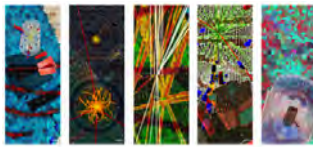
08:00	**Welcome to Canada**	*Andreas WARBURTON*
	Room 206/208, Shaw Centre	08:30 - 08:35
	Introduction	*Joachim MNICH*
	Room 206/208, Shaw Centre	08:35 - 09:00
09:00	**Americas Report**	*Nigel LOCKYER*
	Room 206/208, Shaw Centre	09:00 - 09:20
	Asia Report	*George Wei-Shu HOU*
	Room 206/208, Shaw Centre	09:20 - 09:40
	Europe Report	*Prof. Jorgen D'HONDT*
	Room 206/208, Shaw Centre	09:40 - 10:00
10:00	**Coffee Break**	
	Shaw Centre	10:00 - 10:30

TIND



http://tind.io

TIND



Canton de Fribourg

fri-tic

Techno. de l'Inform. la Com.

University of Minnesota

UM library management

Graduate Institute Geneva

NTNU
Norwegian University of Science and Technology

United Nations

UN Dag Hammarskjöld Library

Union of Concerned Scientists
Science for a healthy planet and safer world

ITU

UN Int. Telecom. Union

The Academy of Sciences of the Czech Republic

KAY

UNITED NATIONS HUMAN RIGHTS
OFFICE OF THE HIGH COMMISSIONER

UNOV
United Nations Office at Vienna

UNESCO

Intl. Bureau of Education

Universidad Zaragoza

Caltech

Caltech library management

Hes·so
University of Applied Sciences and Arts Western Switzerland

Max Planck institute

Max-Planck-Institut für extraterrestrische Physik

For Extraterrestrial Physics

CERN

EU Found. for the Improvement

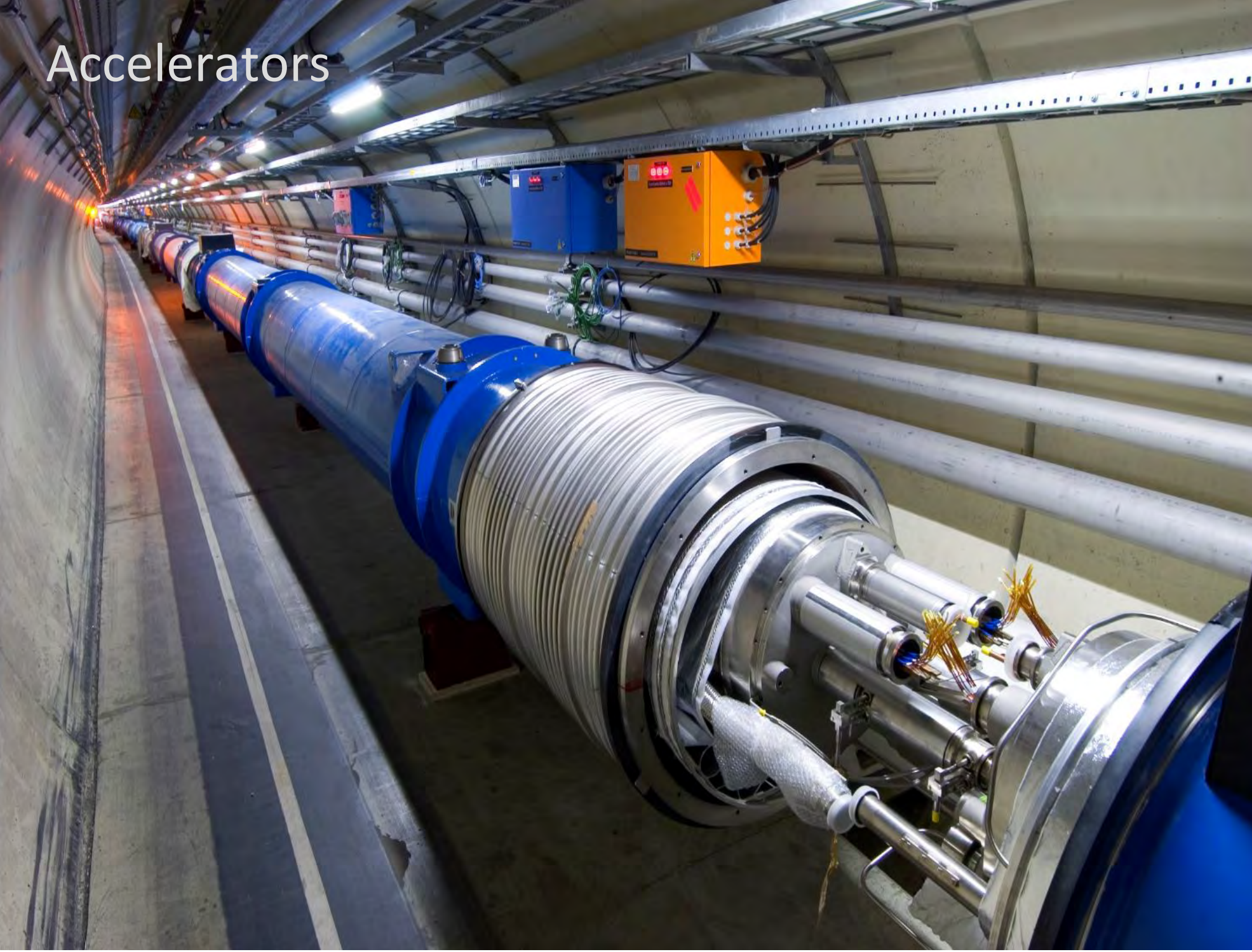
Eurofound

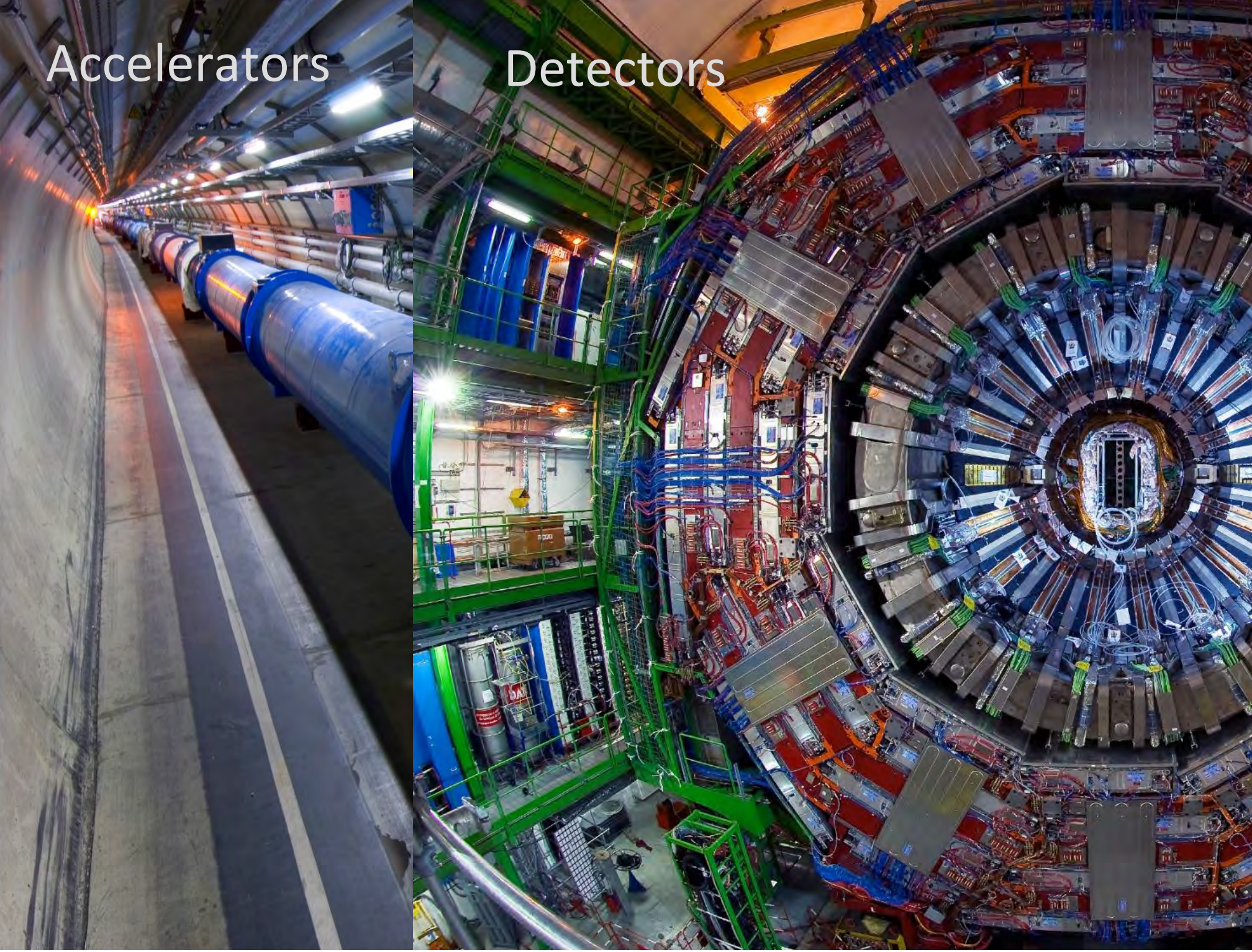
of Living and Working Conditions

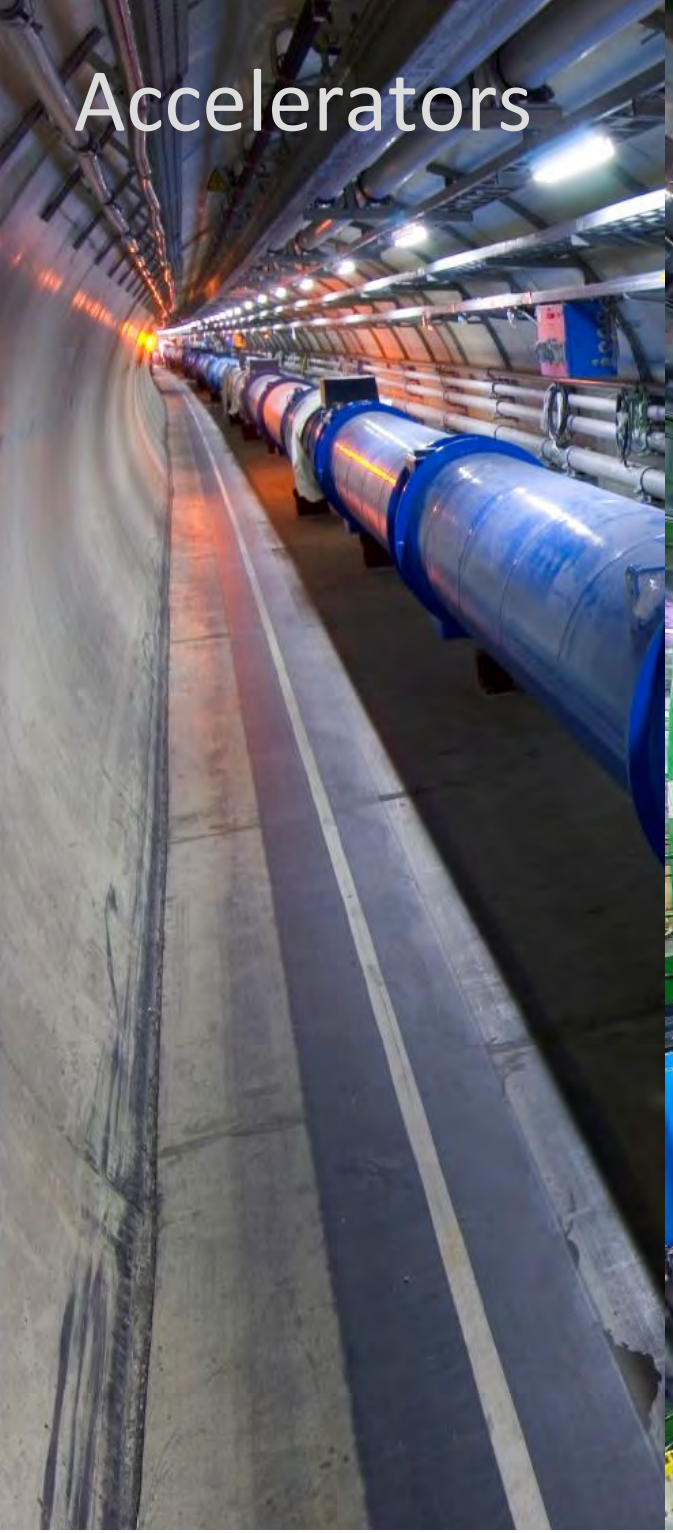
TIND

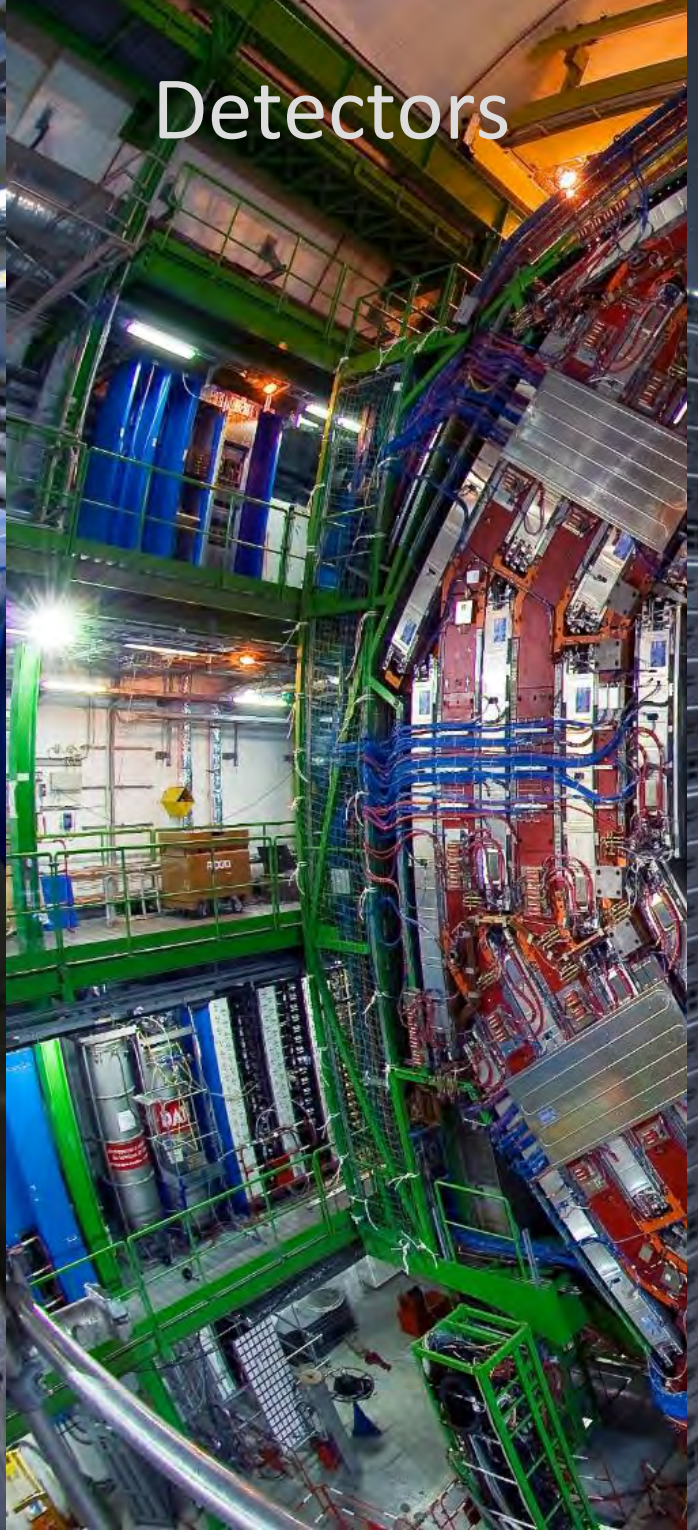
www.tind.io

Accelerators




Accelerators
Detectors

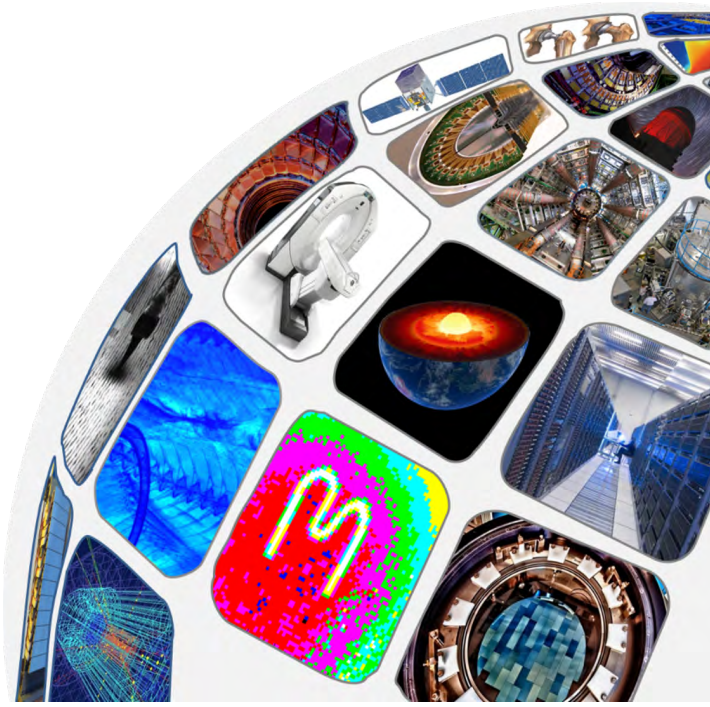

Accelerators


Detectors


Computing

The Role of ICFA and Laboratories

- Particle physics techniques, technologies and tools have a far and deep reach into society, often in very pleasantly unexpected ways.
- The path of technology diffusion into society and other science disciplines is unpredictable.
- Every laboratory should have a technology transfer department.
- A key requirement for continued and increased success is “enlightened management” to create some free energy to work on projects that are not immediately related to an approved project.



Conclusion

- ***Curiosity driven science research***
- ***Advances frontiers of technology, diffusing innovations to society in unexpected ways and improving our standard of living***
- ***Trains current and next generation scientists***
  - **Champion of Science, Technology, Engineering, Mathematics**
- ***Unites the world through science for peace***
  - **CERN granted observer status to the United Nations General Assembly, 14 Dec 2012**