Technological Synergies in Instrumentation R&D with non-HEP Experimental Programs and Industry

Cinzia Da Vià, The University of Manchester, UK
& University of Stony Brook, USA

Outline

- *High Energy Physics Instrumentation R&D Assets*
- *R&D Instrumentation Synergies:*
  - *Particle Accelerators*
  - *Electrical and Civil Engineering*
  - *Data Acquisition Systems*
  - *Data Analysis and Simulation*
  - *Radiation Detectors*
  - *Human Capital*
- *Case Studies*
- *Industry*
- *Reflections and Conclusions*

High Energy Physics Instrumentation Assets

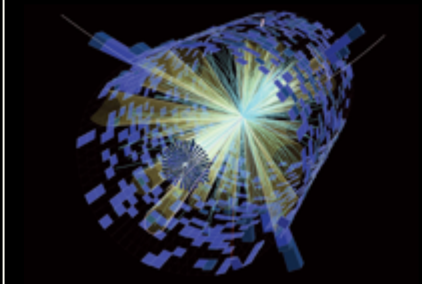
Particle Accelerators:
- Vacuum
- Surfaces
- Magnets
- Cooling
- Superconductors

Electrical &Civil Engineering:
- Tunnels
- Infrastructures
- Power distribution
- Large Underground installations

RADIATION HARD

Radiation Detectors:
- Electronics
- Sensors (gas, solid state, scintillators)
- Integration
- Support structures

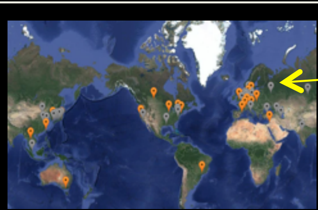
Data Acquisition Systems:
- Electronics
- Links (electro-optical)
- Big data (storage & distribution)
- Triggering (machine learning, AI)



Data analysis & Simulation:
- Theory
- Data libraries
- Software
- Big Data (analysis)

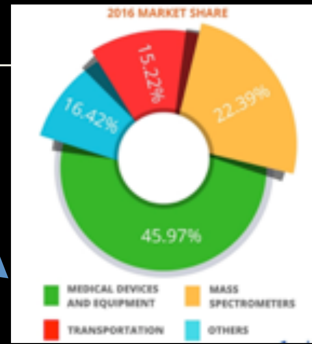
Human Capital:
- Ingenuity
- Large Scale Operations
- Coordination
- Education
- Global Collaboration

Non-HEP Synergies with Particle Accelerators



Synchrotron light sources
50 in the world
- Biology/medicine
- Chemistry
- Material Science
- Technology

Superconducting magnets



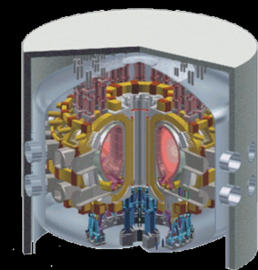
67 working
by 2024
130 operational

Particle therapy

In 2018 50% of cancer patients underwent radiotherapy as part of their treatment. 80% are treated with H-E X-Rays. 200000 patients have been treated with charged hadrons thanks to the improved depth-dose distribution

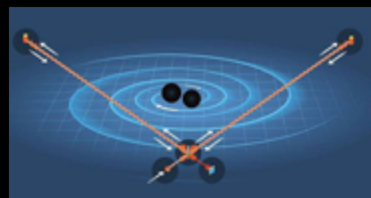
High Intensity Neutron sources

Fusion Facilities



- JET
- ITER
- DEMO

Surface Coating (Klystrons)
Vacuum Magnetic Birefringence
Axion searches



Gravitational waves
Multi-Messenger Astronomy

Ultra vacuum Technology

Cryogenics

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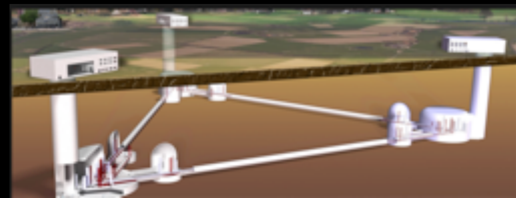
Non-HEP Synergy with Electrical, Material and Civil Engineering

Tunnels for trains
streets etc

Power Systems

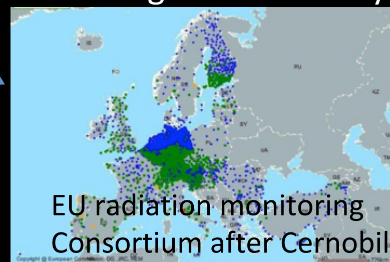
Robotics



Gravitational Waves
Multi-messengers Astronomy

XXL cavern installations
for Dark Matter
and neutrino searches

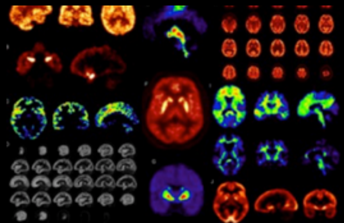
Cosmic rays/
AUGER
Radio Astronomy
SKA



Environmental
monitoring

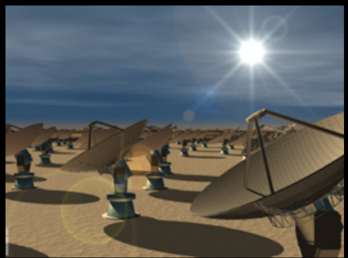
Non-HEP Synergy with (big) Data Acquisition Systems

International Data Corporation (IDC) estimates the amount of data in the world will reach 163 trillion gigabytes by 2025 – Storage and share will be an issue



Medicine

Satellites/space

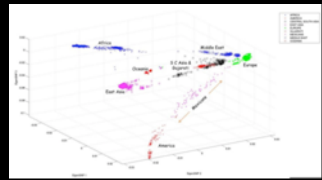


Astronomy
Radio-Astronomy
Dark Matter
Gravitational Waves
Multi-messengers

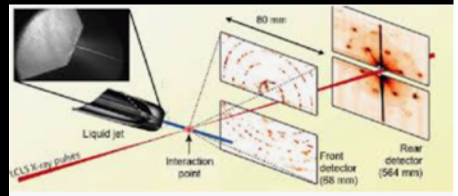
SKA will generate 200 teraflops and storage of about 1.5 petabytes by 2020. https://www.computerworld.com.au/article/392735ska_telescope_generate_more_data_than_entire_internet_2020/

LHC in 2025 2500 petabytes/year (10^{18})

Proteomics
Genomics

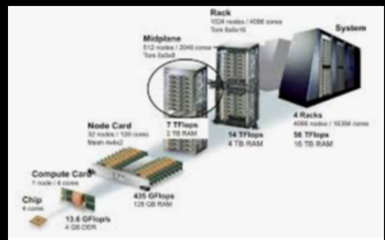


The Swiss Institute of Bioinformatics generates up to 30 Terabites/week in DNA sequencing



XFELS

The Blue Brain Project



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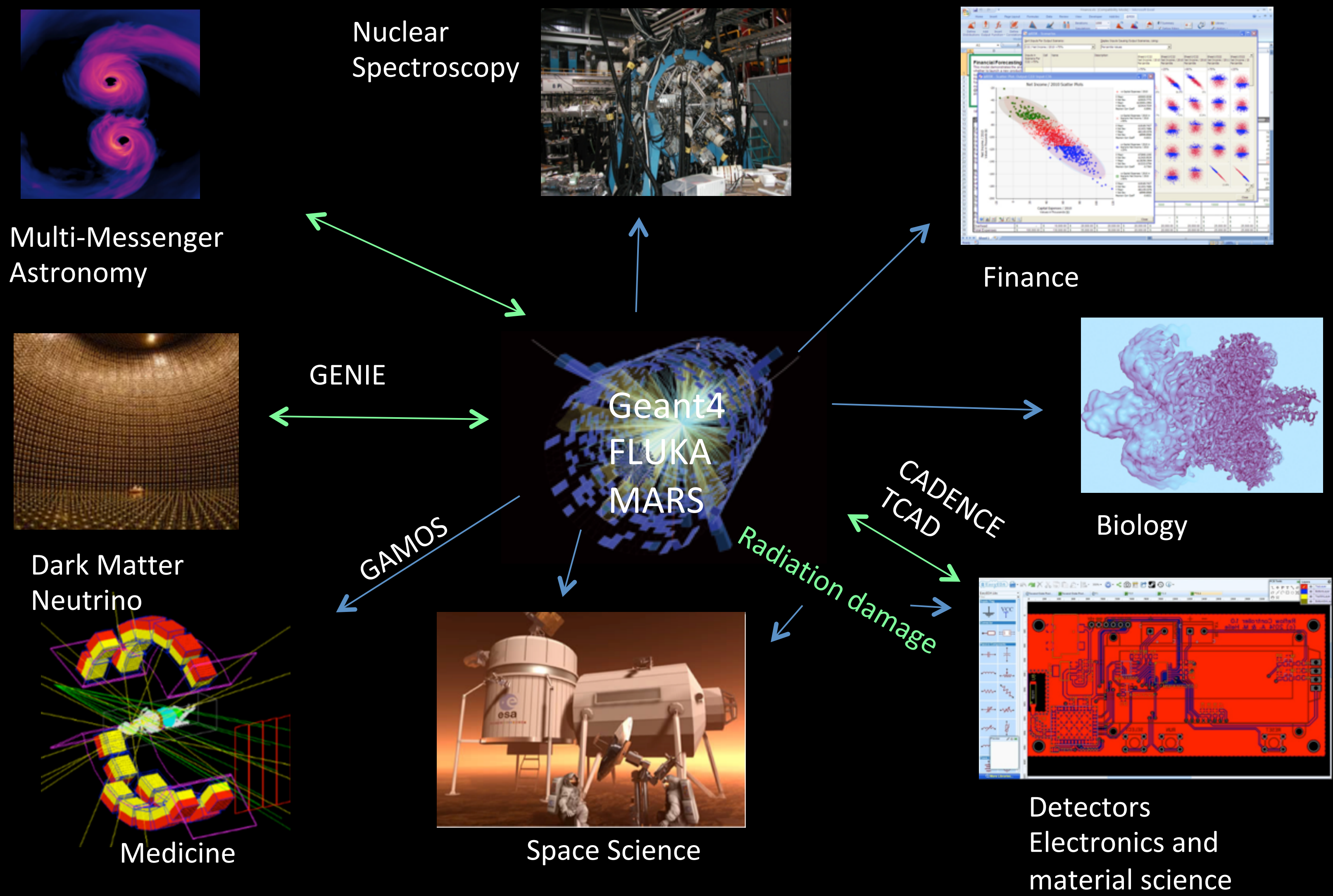
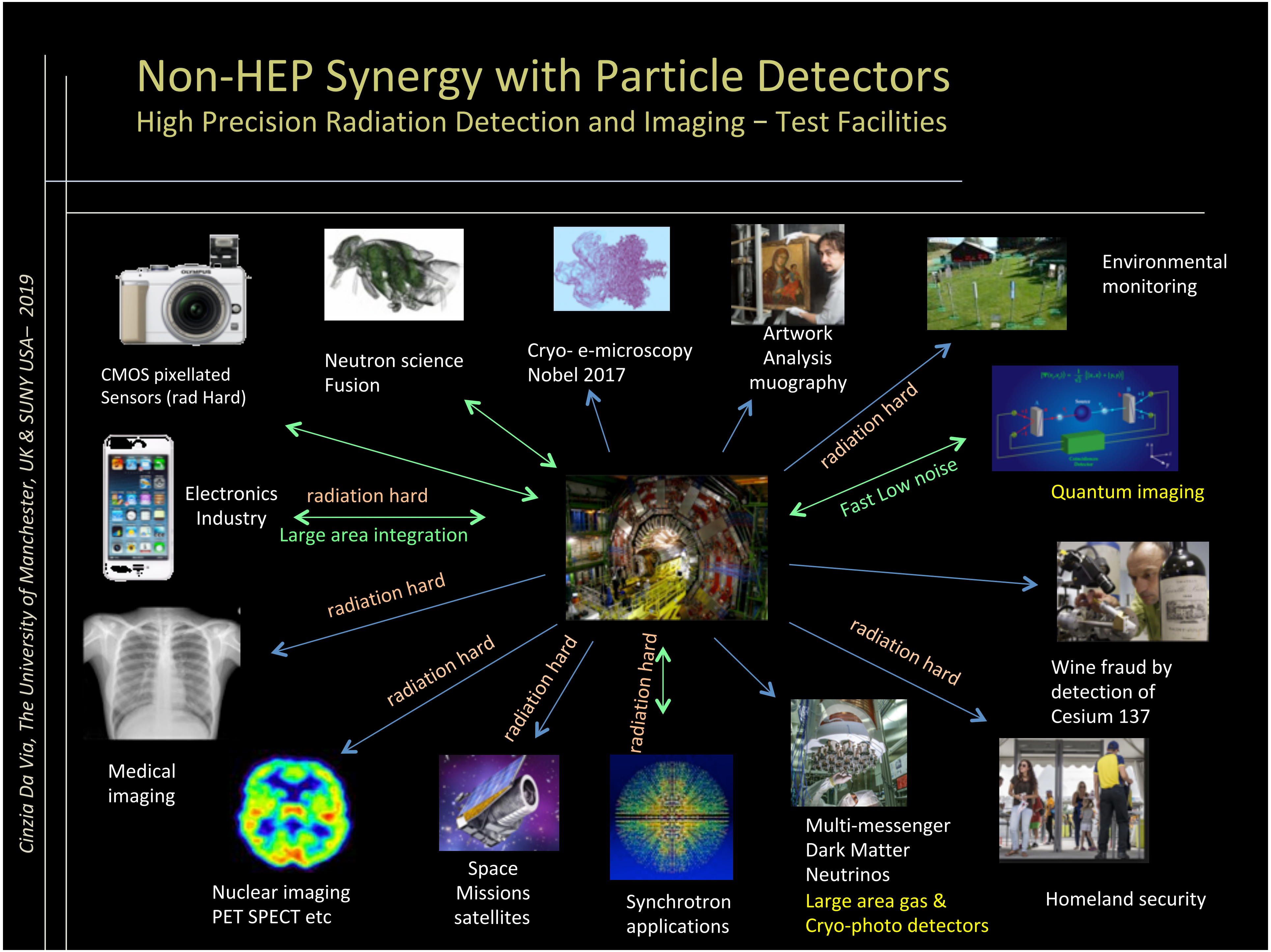
Non-HEP Synergy with Data Analysis and Simulation




Non-HEP Synergy with Particle Detectors
High Precision Radiation Detection and Imaging – Test Facilities
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CMOS pixellated Sensors (rad Hard)
Neutron science Fusion
Cryo- e-microscopy Nobel 2017
Artwork Analysis muography
Environmental monitoring
radiation hard
Fast Low noise
Quantum imaging
Electronics Industry
radiation hard
Large area integration
radiation hard
Wine fraud by detection of Cesium 137
radiation hard
radiation hard
radiation hard
radiation hard
Medical imaging
Nuclear imaging PET SPECT etc
Space Missions satellites
Synchrotron applications
Multi-messenger Dark Matter Neutrinos
Large area gas & Cryo-photo detectors
Homeland security

Evidence of Converging Detector Requirements and R&D needs among disciplines →The ERDIT Platform

ERDIT
www.erdit.eu
European Radiation Detectors and Imaging Technology

	HEP	SYNC	Neutron ESS	Beam monitoring	Astronomy	Hadron Therapy	Medical Imaging Pre-clinical Imaging	Electron Microscopy	Environmental radiation monitoring IAEA
Radiation type	p, n, γ	X-rays	n	p, n, γ, e^-	λ=300nm to 28µm	N, p, γ, light ions (protons to oxygen)	X-rays	e	γ
Max Intensity	$12x10^{15}$ ncm^{-2}	2700 pulses	10^{8} ncm^{-2}	10^{17} ncm^{-2} (p, n) 10MGy (e^-)	from 1 photon/ hour/pixel to 1E9 photons/s/ pixel	conventional accelerator up to 10^10 ions /s Laser > 10^7/cm2 (ps pulses, low repetition rate ~ 1/s)	CT: 10^9 g/mm²/s, General X-ray: 10^8 g/mm²/s Angiography: 10^8 g/mm²/s Mammography: 10^7 g/ mm²/s	20 Mrads	100 µSv/h (~100,000 cts/s)
timing	25ns 10ps	4.5 MHz 10ps	1us	Sub ns	from 2000 frames/s to 1 frame/ hour	Up to MHz (singles rate) 10ps	CT: 5000 frames/s General X-ray: - Angiography: 1-60 frames/s Mammography: - 10ps	1000 frames/s	
Pixel size (Min)	50x50 um²	10x10 um²	50x50 um²	50x50 um²	10x10 um²	50x50 um²	CT: 1000 mm General X-ray: 150-200 mm Angiography: 150-200 mm Mammography: 85 mm	10x10 um²	
Spectral resolution	yes	yes	no	yes	no , moderate possible with APD	yes	Today: not used, Future: yes	yes	< 1.5% @ 662 keV
Detector size (max)	2500m² (ILC cal)		80m²	100 cm²	Optical 9Kx9K NIR 4Kx4K	40x40 cm2	CT: 10 x 100 cm² (segmented), General X-ray : 43x43 cm² Angiography: 30x40 cm² Mammography: 24x30 cm²	8k x 8k pixels	6 cm³

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Medipix and Timepix : **55x55um^2 256 x 256 pixels**

https://medipix.web.cern.ch

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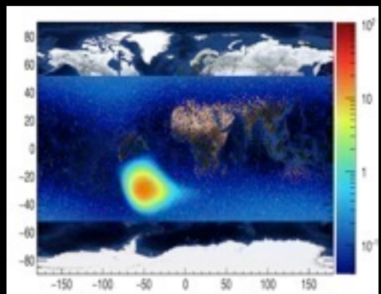
Space weather and dosimetry



Mixed field radiation monitoring and dosimetry

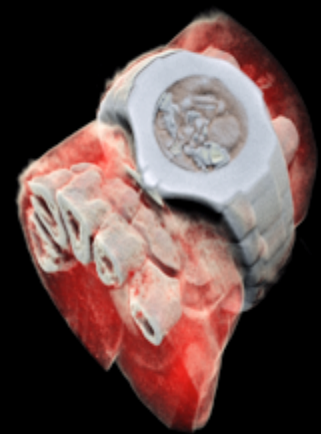
NASA/Univ. Houston/IEAP Prague

Cultural heritage studies

Investigation of art using colour X-ray imaging

InsightArt, Prague

Medical colour X-ray imaging

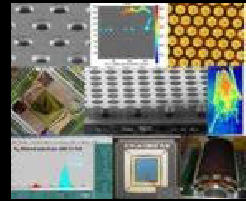


World first colour X-ray image of a living human

- Clearer images
- Lower dose
- Material separation

MARS Bioimaging, NZ

Micro Pattern Gas Detectors beyond HEP

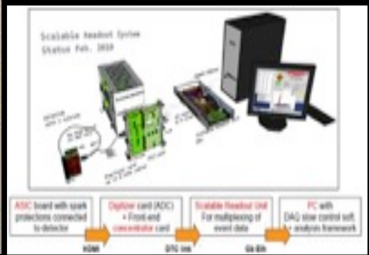


CERN RD51

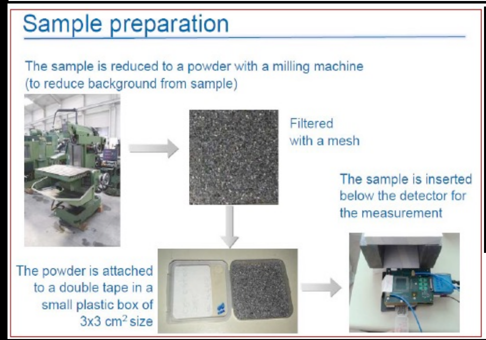
"Thanks to the generic R&D approach of RD51 (the collaboration dedicated to MPGD technologies)
For the first time *after the Geiger Counter,* ***gaseous detectors leave labs to match society needs"***

NEUTRON detection: D20 diffractometer @ILL, GEMs @ISIS, n-detection at ESS using RD51 tools

SRS read-out

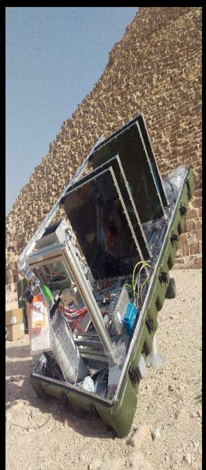


Radioactive waste treatment



2-h measurement only with **GEMpix** to reach the legal sensitivity limit of 30Bq/g for ^{55}Fe

F.Murtas, M.Silari, J.Leidner, J.Alozy, M Campbell

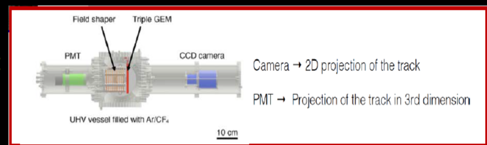


MUOGRAPHY

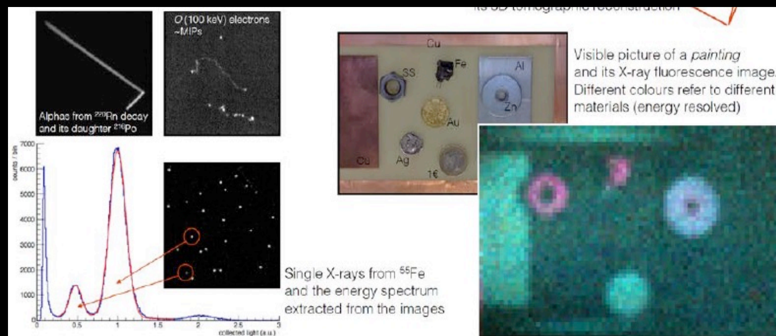
Discovery of a big void in Khufu's Pyramid

Nature 552 (2017) 386

X-ray detection via **GEM optical read-out** for 3-D imaging, non-invasive inspections, …



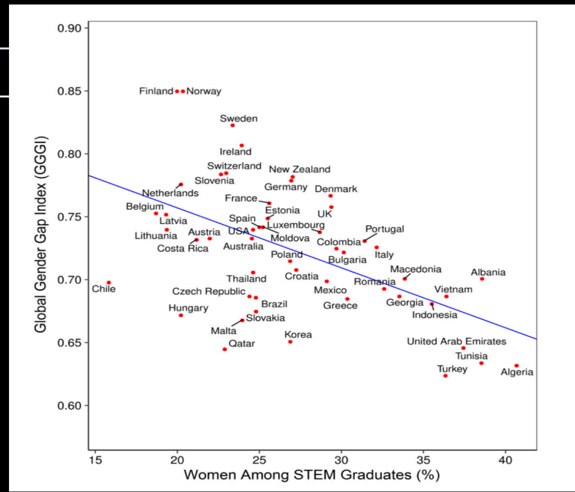
F. Brunbauer, Thesis, 2018



Synergy with Human Capital

- Inclusion
- Diversity
- Sociology
- Diplomacy in action

→ No political or religious barriers



Women in STEM "Paradox"
The percentage of women with STEM degrees is lower in more gender-equal countries, as measured by the WEF
[Gender Gap Index. Image from Stoet & Geary, 2018.]

Governance and management
of large international Collaborations and Complex Structures

Knowledge transfer
peer-to-peer
industry

- Education (outreach)
- Networking
- Mentoring

→ The key role of Schools

- Analysis & Problem-Solving.
- Interpersonal & Leadership Skills.
- Project Management & Organization.
- Research & Information Management.
- Self-Management & Work Habits.
- Written & Oral Communication.

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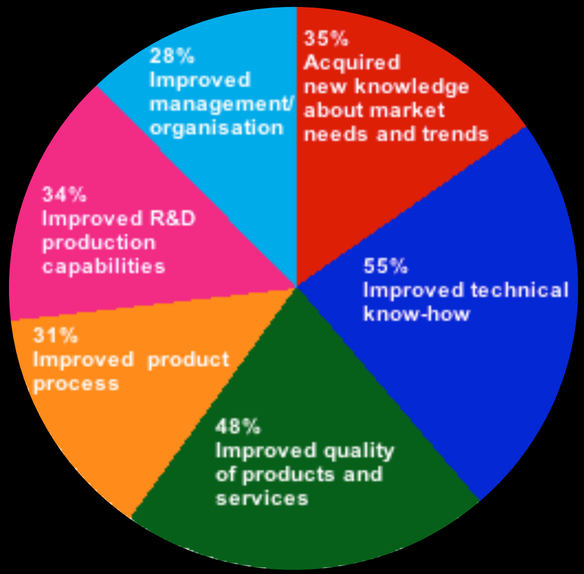
HEP & Industry

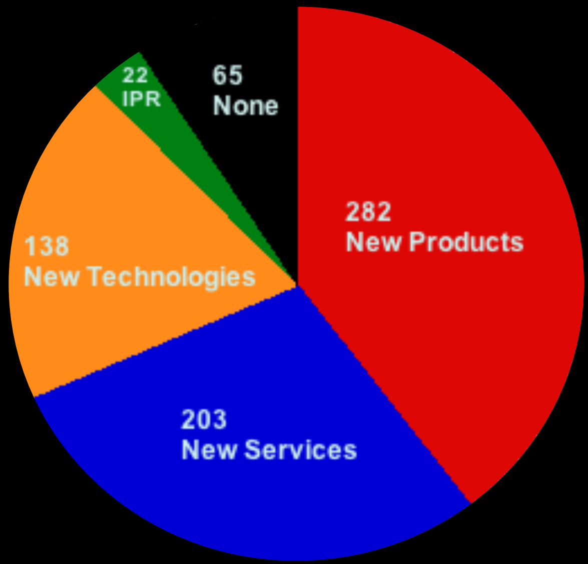
Data from Florio, Giffoni, Giunta, Sirtori
ISSN 2279-6916 Dpt Economia, Roma Tre

2017 Survey on 668 SME suppliers from 33 EU Countries working with CERN from 1995-2008

Thanks to CERN:



Because of the work with CERN:



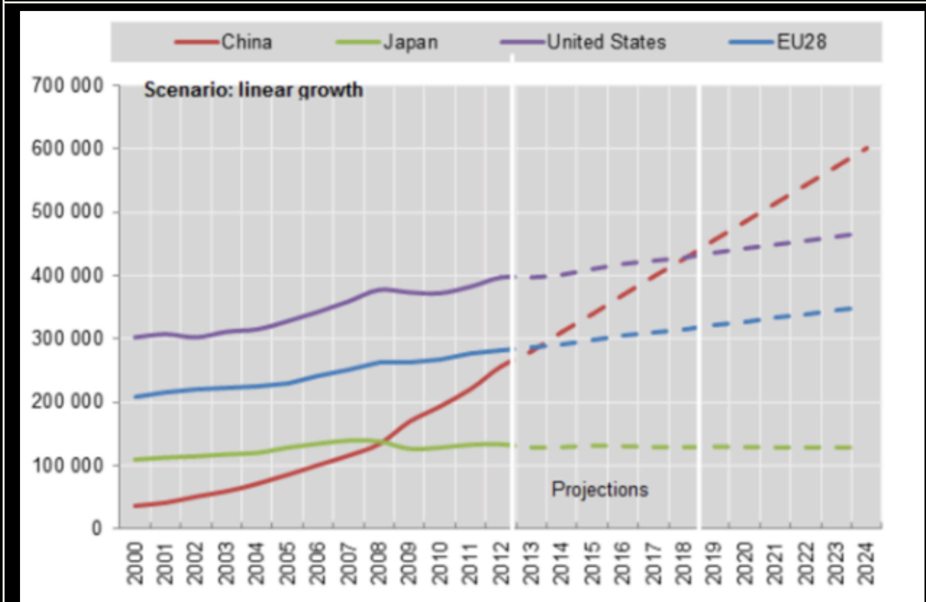
"The estimated coefficients of this "CERN effect" are statistically significant for the whole sample but higher for high-tech firms. As expected,… in most cases the coefficients are not significant for firms receiving orders for "off-the-shelf" products".

R&D Coordination involving Industry from the start is more efficient

→ FUNDS ←

Funding: Forecast on Science and Technology spending from OECD

Organization for Economic Cooperation and Development



OECD Science, Technology and Industry Outlook 2014 - © OECD 2014

European countries are diverging in R&D as some move closer to their R&D/GDP targets (Denmark, Germany) and others (Portugal, Spain) fall further behind.

In most countries, 10% to 20% of business R&D is funded with public money, using various investment instruments and government targets.

Current special funding programs available in specific subjects
→ Quantum information, Robotics

12/11/14 - Squeezed R&D budgets in the EU, Japan and US are reducing the weight of advanced economies in science and technology research, patent applications and scientific publications and leaving China on track to be the world's top R&D spender by around 2019, according to a new OECD report.

The OECD Science, Technology and Industry Outlook 2014 finds that with R&D spending by most OECD governments and businesses yet to recover from the economic crisis, the OECD's share in global R&D spending has slipped from 90% to 70% in a decade.

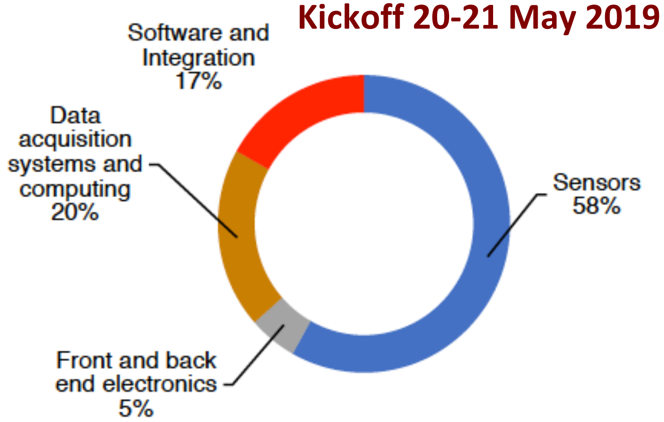
Annual growth in R&D spending across OECD countries was 1.6% over 2008-12, half the rate of 2001-08 as public R&D budgets stagnated or shrank in many countries and business investment was subdued. China's R&D spending meanwhile doubled from 2008 to 2012.

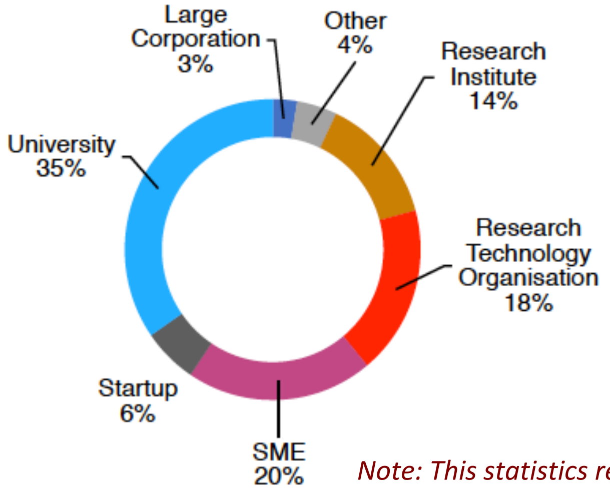
Gross domestic expenditure on R&D (GERD) in 2012 was USD 257 billion in China, USD 397 billion in the United States, USD 282 billion for the EU28 and USD 134 billion in Japan.

Funds for multi-disciplinary detectors and imaging R&D
The 2018 ATTRACT Call

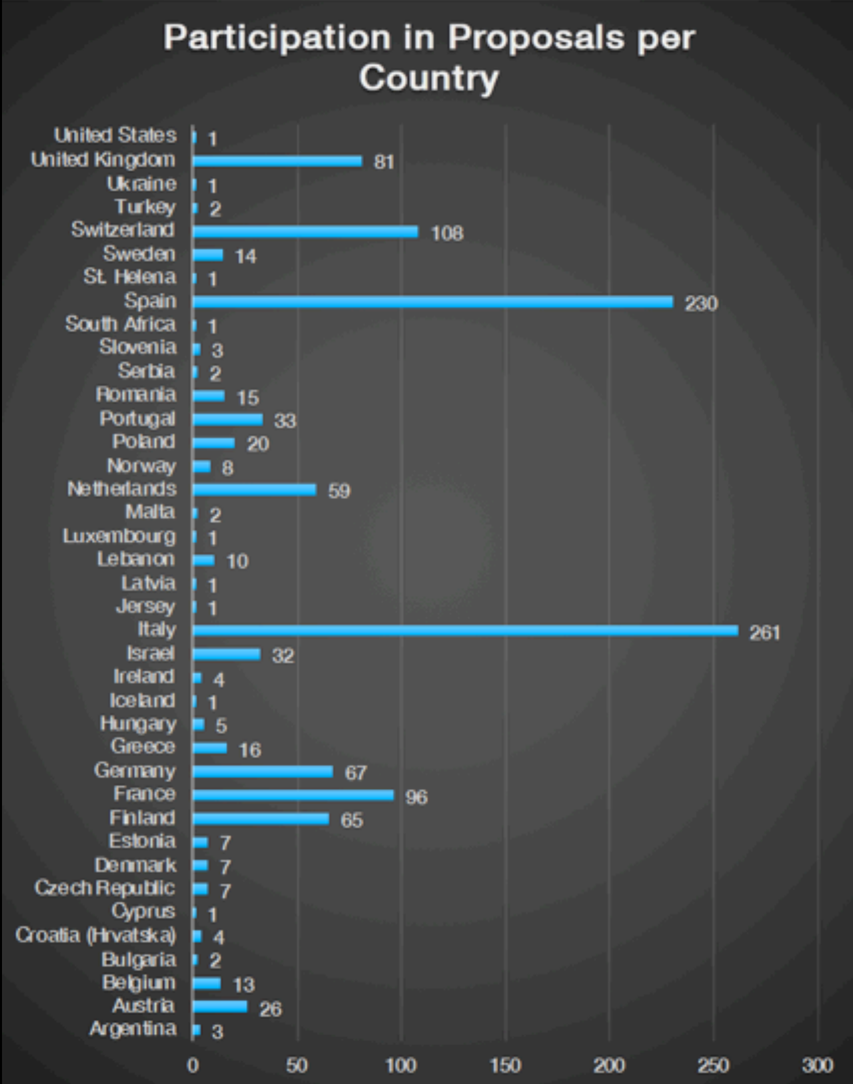
Initiative bringing together Europe's fundamental research and industrial communities to lead the next generation of detection and imaging technologies

Total Proposals received:1211
Financed: 170 /100keuro
Kickoff 20-21 May 2019 CERN





Note: This statistics refers to submitted proposals



Possible Coordination of R&D Among Fields

Technology Centered versus Discipline Centered R&D
With a trend of flat investment in science and technology assure resources effectively to get faster to a specific interdisciplinary common technological goals. More specific Discipline Centered Research should also be supported in parallel.

Generation of a critical mass
Pooling resources to build similar research infrastructures or to tackle common technical goals to generate a larger "crowding-in effect"→ Advancement of market access and supply chain integration. Lower price

Fostering Human Capital
Collaborations within the same R&D environment on different disciplines allow personal development, effective mobility, associated increase in diversity, **networking** and assures maintenance of technological know-how

Blue Sky Research with industry on board from the start
"The Usefulness of Useless Knowledge" by Abraham Flexner. And industry happy to be part of it even at a loss… *"IBM was not very cooperative at the beginning of the LHC R&D then the results came…"*

Reflections & Conclusions

- Synergies between HEP and other fields and industry are an evidence nowadays since many programs (scientific and societal) have converging requirements and goals

- One possible way to better exploit these synergies is by "lowering" historical (with exceptions, e.g. medicine, electronics) inter-disciplinary barriers and invest in common technology centered research together with discipline driven goals.

- This approach can solve some of the questions this symposium addresses like identifying the best practices to retain technological know-how and boost careers in instrumentation. → Important role of Instrumentation schools, consortia, meetings

- In my view the organization of this common work is possible if Researchers, together with Industry and Policymakers (Funding Agencies, Research Labs, EU) would seat together to efficiently identify funding schemes in dedicated common areas

- With a special mention to the support of innovative "impossible" ideas.

Acknowledgements

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16-CERN EP Dpt, 19-JUNO, 29 CEPC, 46-Extrlow Material Budget ALICE, 60-PCB, 62-Future Dark Matter Searches, 64-Gravitational Waves, 75-Mathusla, 84-APPEC86-PIK, 93-Nuclotron, 87 RD51, 97-Darwin, 106-R&D on long and near baseline neutrinos systems, 113-Vacuum Magnetic Birefringence & Axion Searches, 117 Pierre Auger Telescope, 126 DUNE (LBNE-LBNO), 131 DUNE near, 161 MAGIS-1K,167-Fermilab neutrino facilities.

Also thanks to:

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I probably forgot important information and to mention key contributions
--Apologies--