

Exploring farther: machines for new knowledge



Exploring farther: machines for new knowledge

Host: **Paola Catapano**

Speakers: **Edda Gschwendtner, Mike Seidel,
Roxanne Guenette, Petra Merkel, Werner Riegler,
Cristina Botta, Andreas Lintermann**



ACCELERATORS



DETECTORS



COMPUTING



ACCELERATORS



DETECTORS



COMPUTING



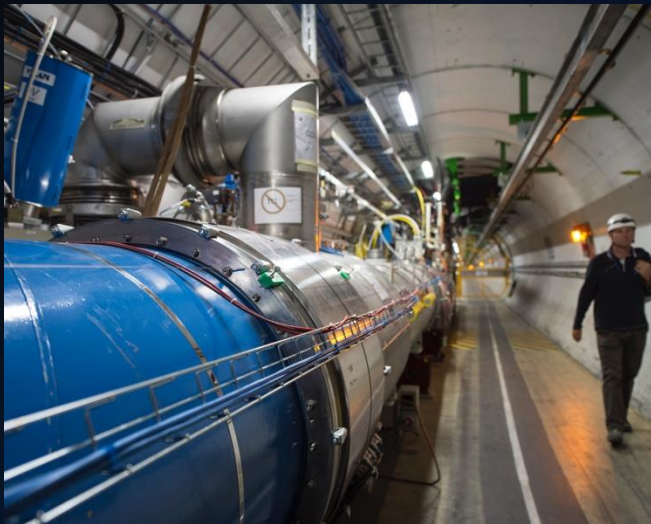
Session 1

Advanced particle beam accelerators

Mike Seidel

Accelerator Physicist, Center for Accelerator Science and Engineering, Paul Scherrer Institute
Full Professor, Particle Accelerator Physics Laboratory, EPFL





Particle physics



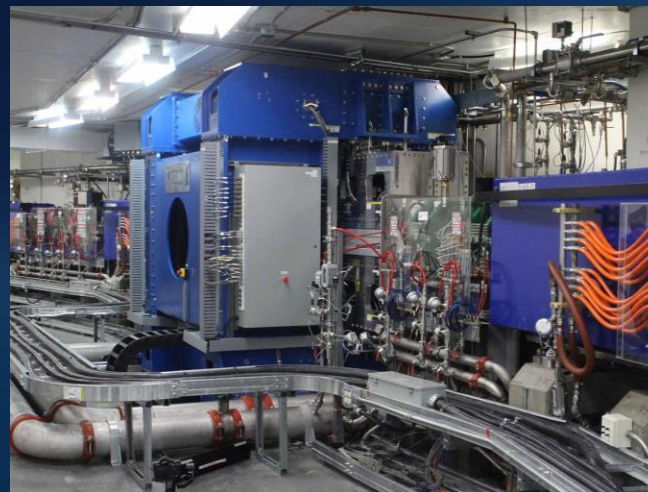
Security – cargo scanner



Industrial - Ion implantation



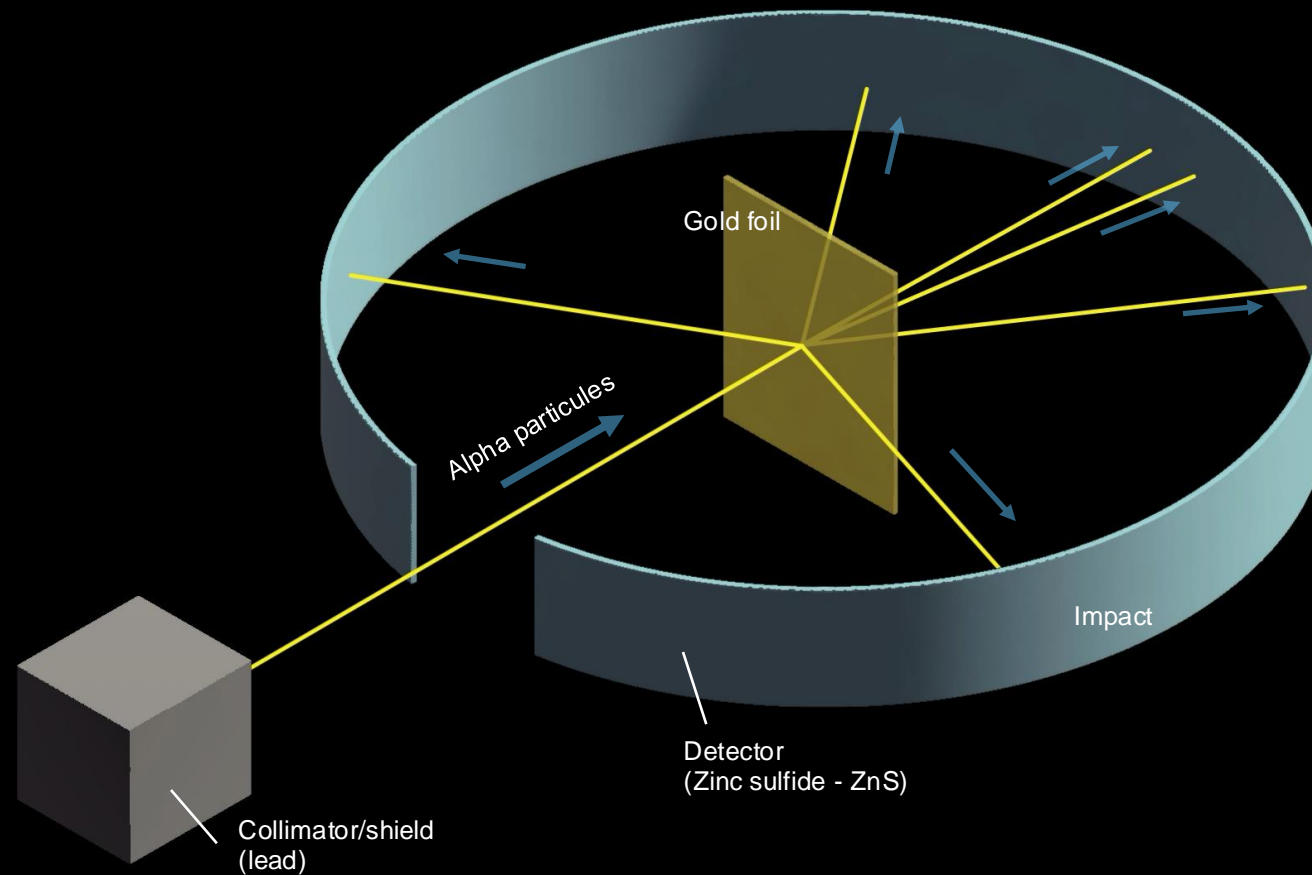
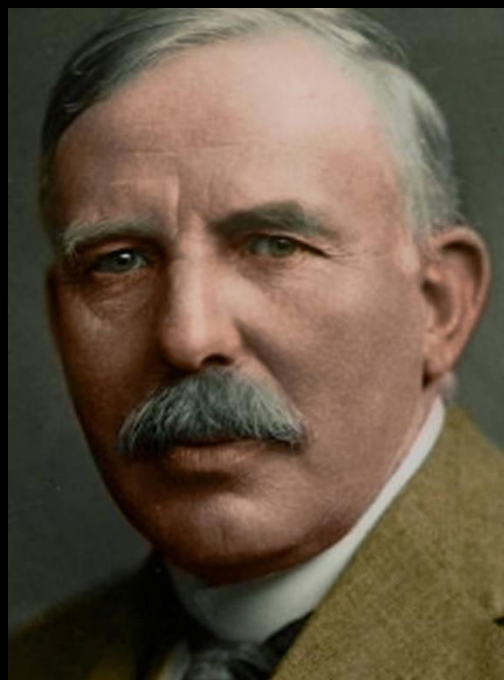
Medicine

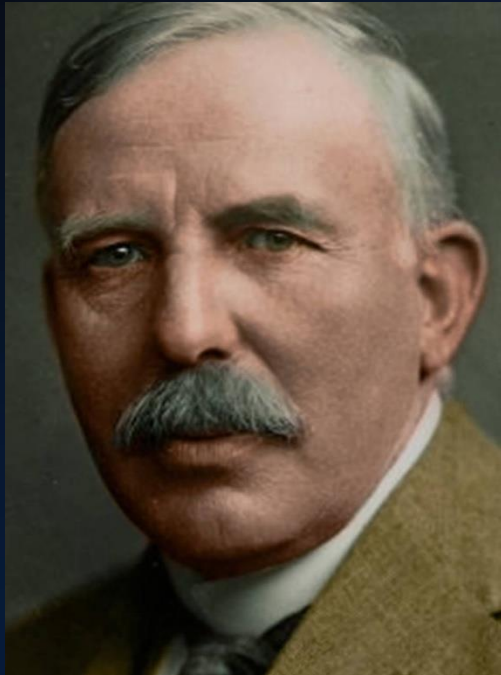


Biology, material science, ...



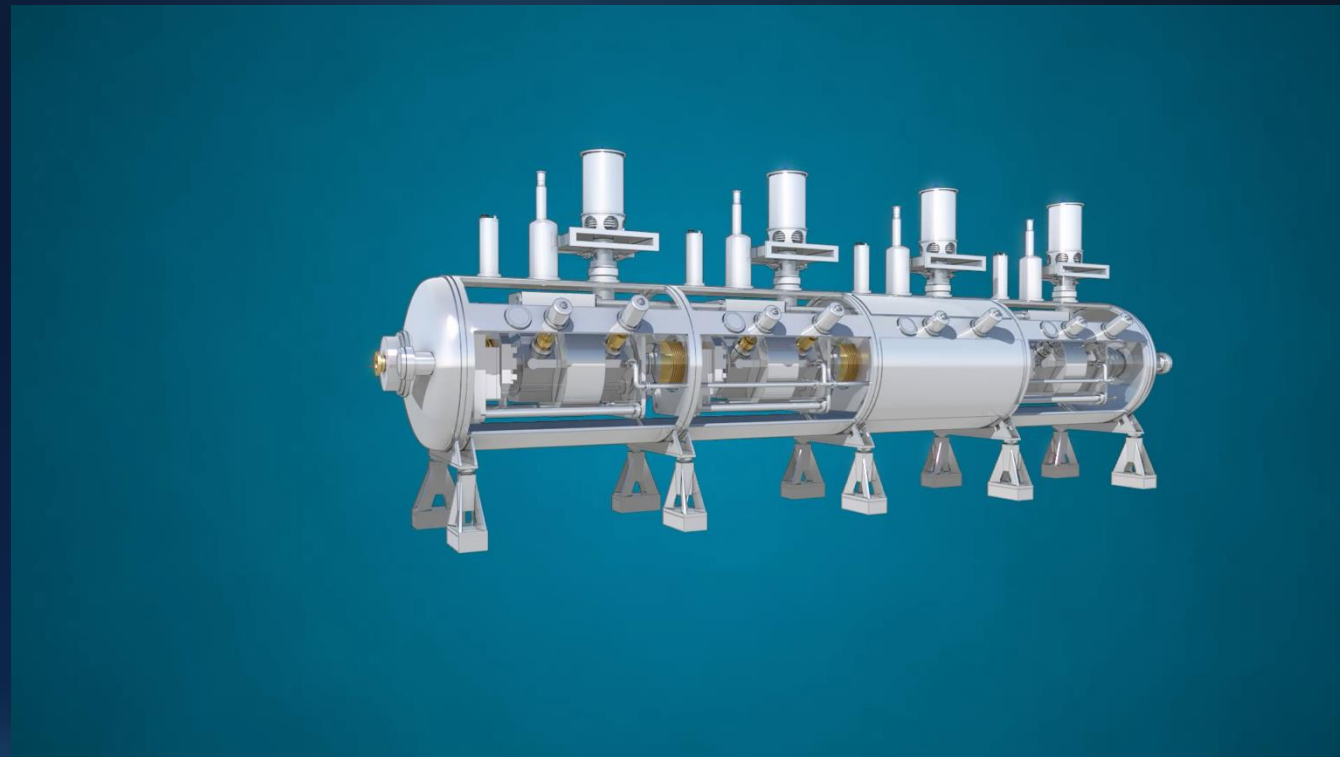
Industrial - sterilisation





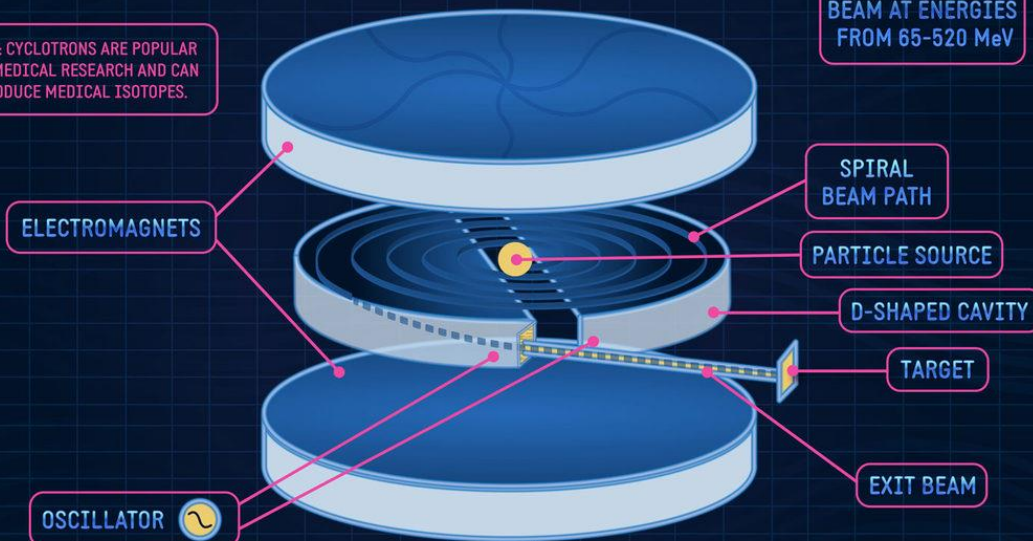
“I have long hoped for a source of positive particles more energetic than those emitted from natural radioactive substances.”

*Ernest Rutherford,
from his address to the Royal Society, 1928*



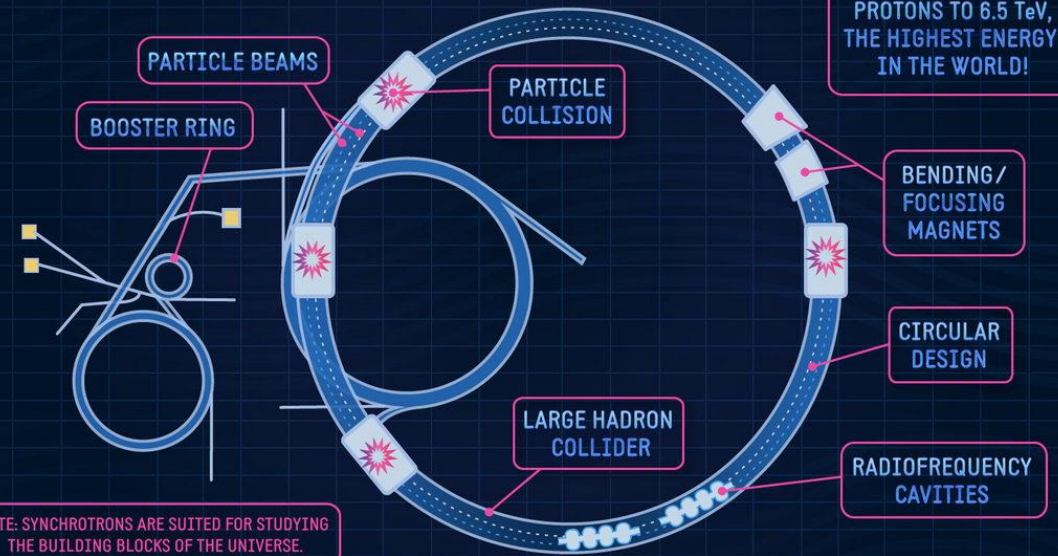
CYCLOTRONS *THE WORKHORSES*

NOTE: CYCLOTRONS ARE POPULAR FOR MEDICAL RESEARCH AND CAN PRODUCE MEDICAL ISOTOPES.



TRIUMF EXTRACTS BEAM AT ENERGIES FROM 65-520 MeV

SYNCHROTRONS *THE HEAVY LIFTERS*

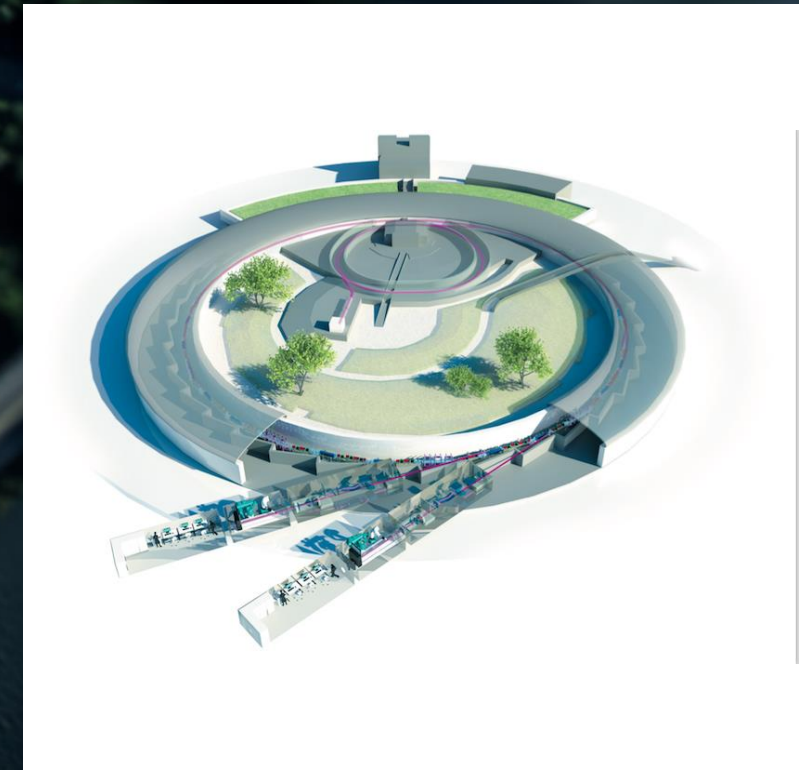


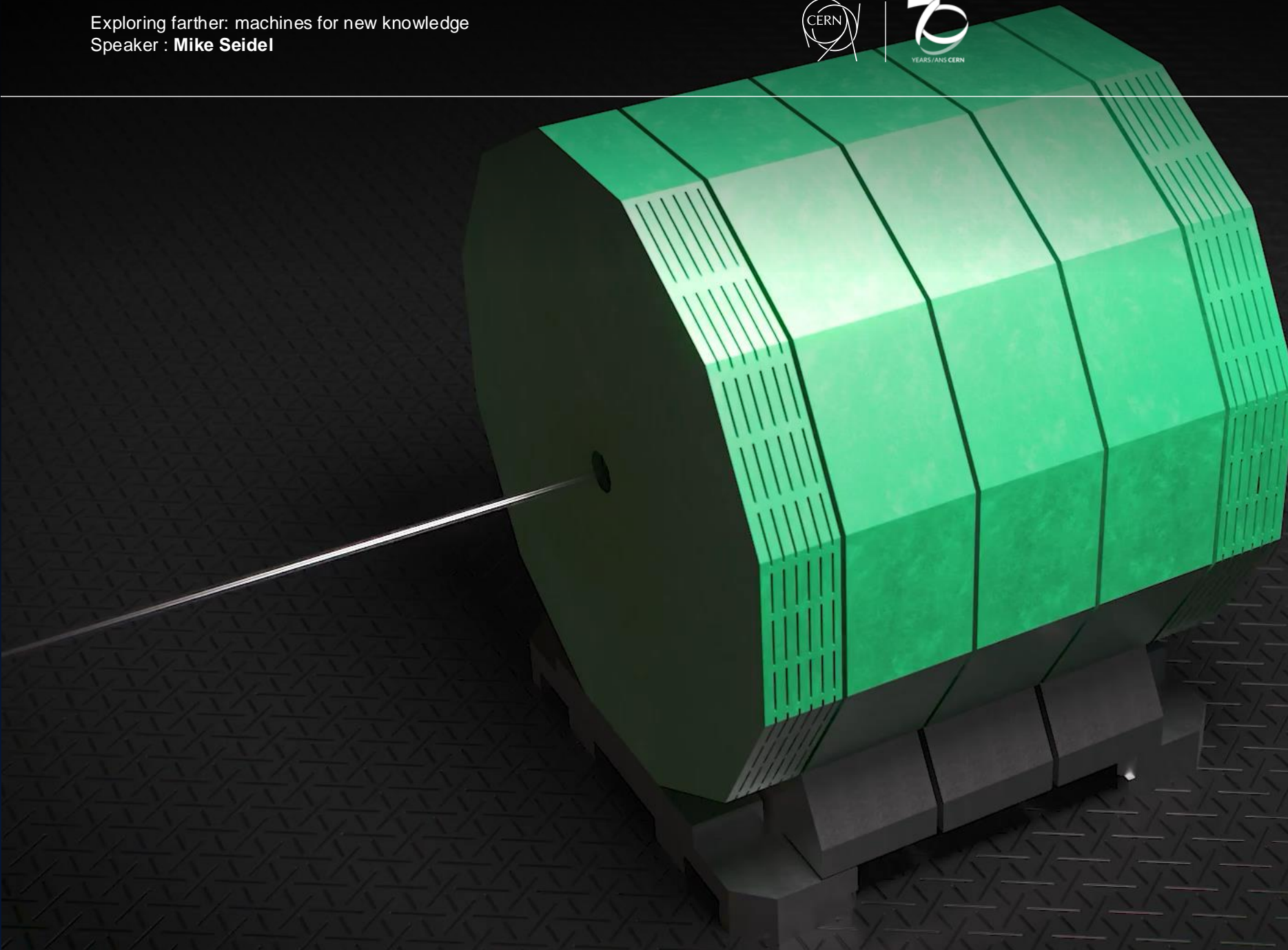
THE LHC ACCELERATES PROTONS TO 6.5 TeV, THE HIGHEST ENERGY IN THE WORLD!

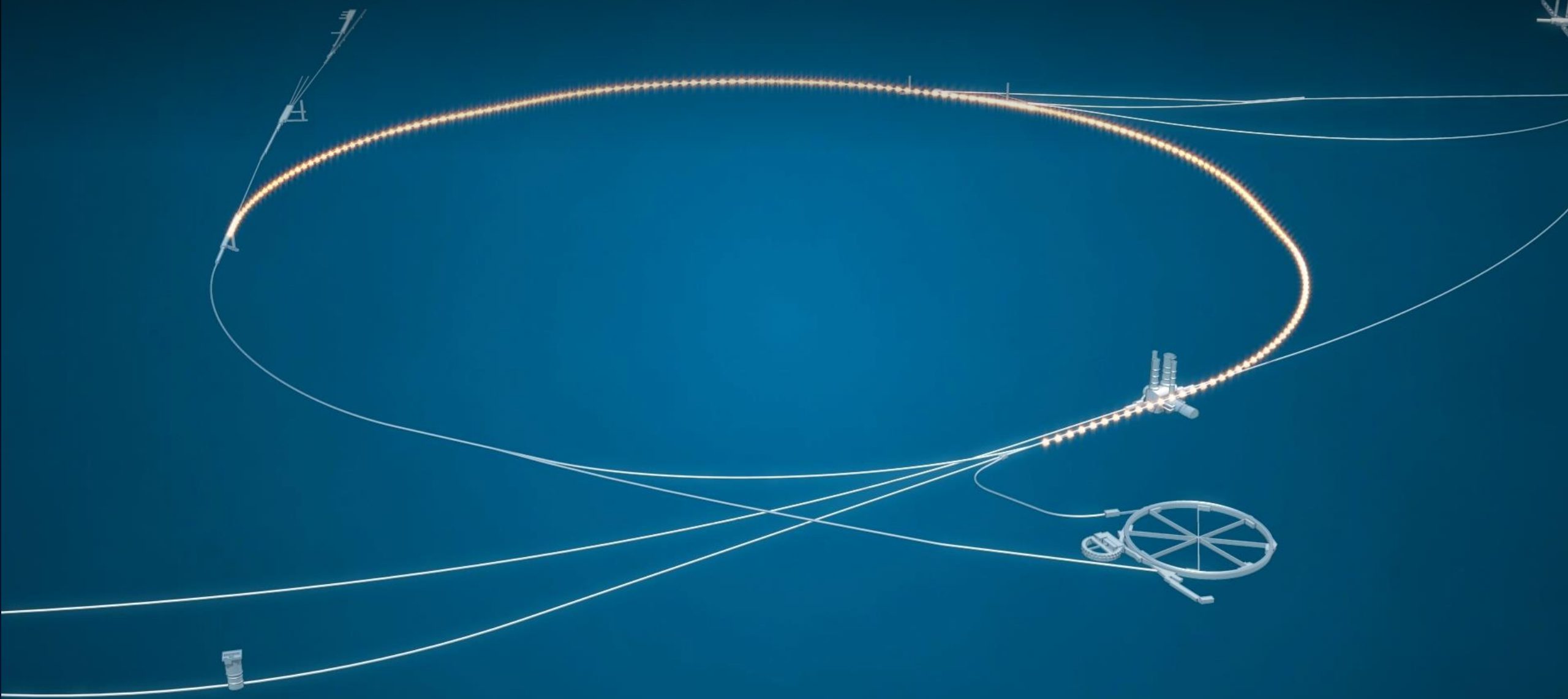
NOTE: SYNCHROTRONS ARE SUITED FOR STUDYING THE BUILDING BLOCKS OF THE UNIVERSE.

European Synchrotron Radiation Facility (ESRF)

Grenoble







Session 1

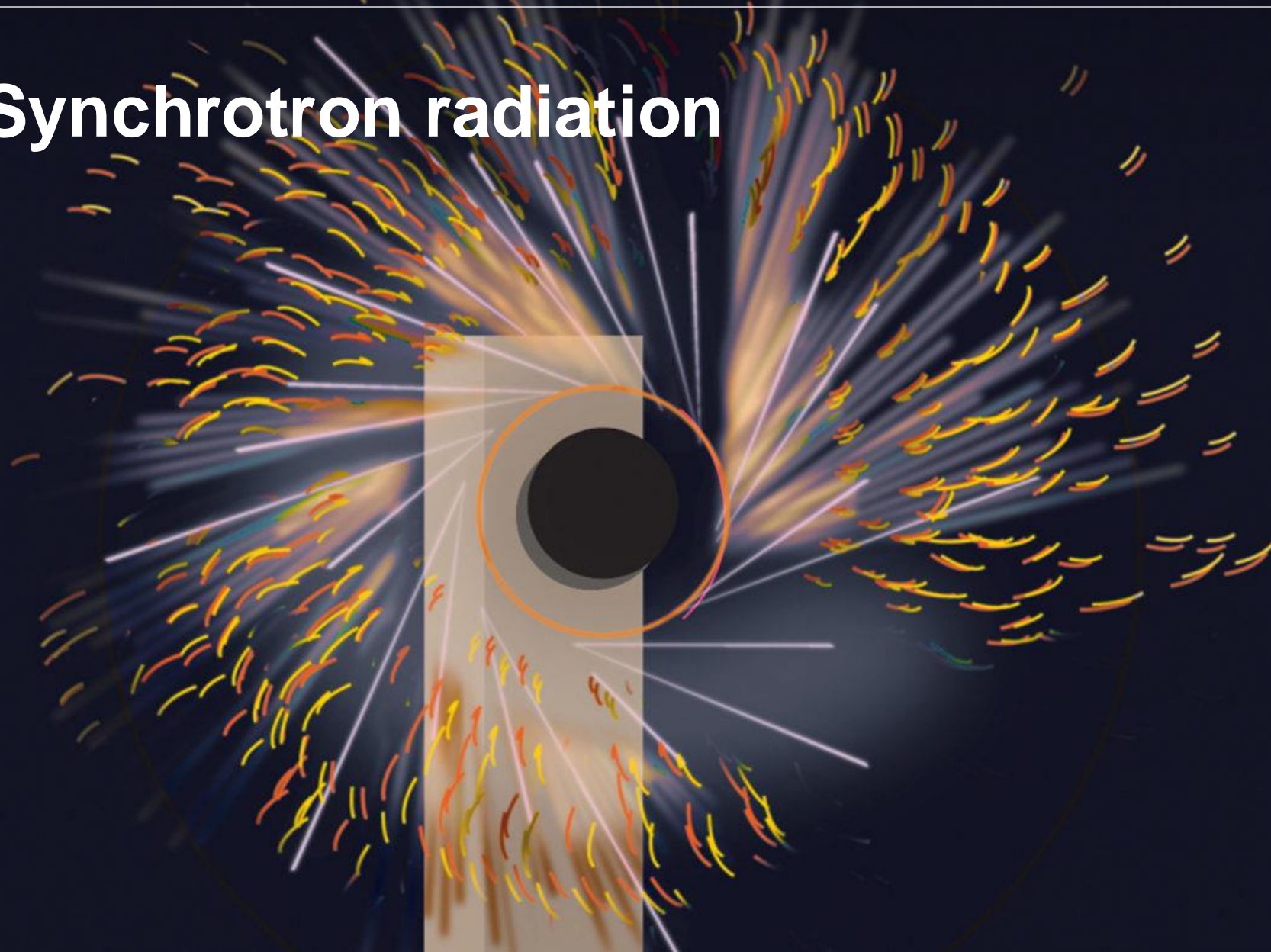
Advanced particle beam accelerators

Mei Bai

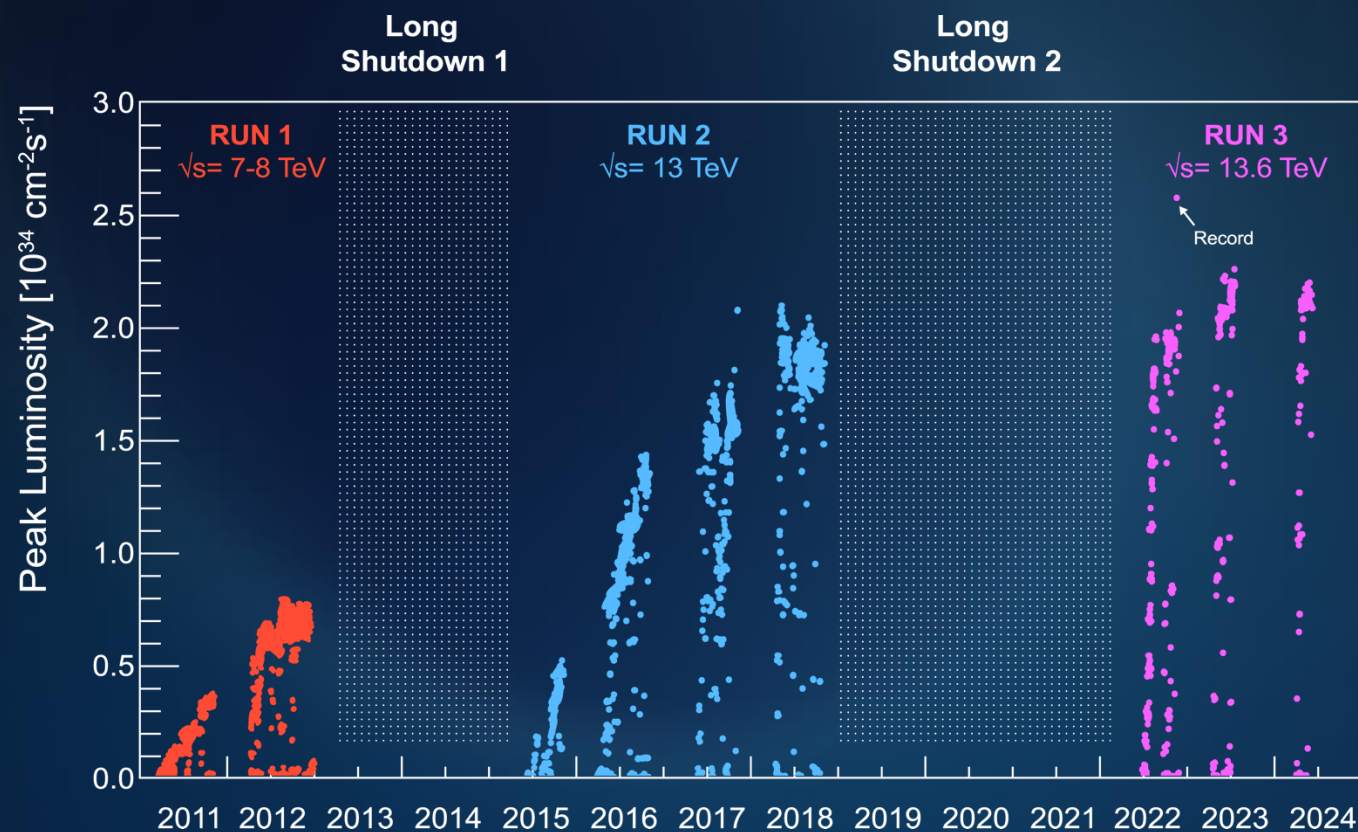
Accelerator Physicist, SLAC National Accelerator Laboratory, Stanford University



Synchrotron radiation



LHC performance











Session 1

Advanced particle beam accelerators

Edda Gschwendtner

Senior Physicist and Project Leader of AWAKE, Beams Department, CERN

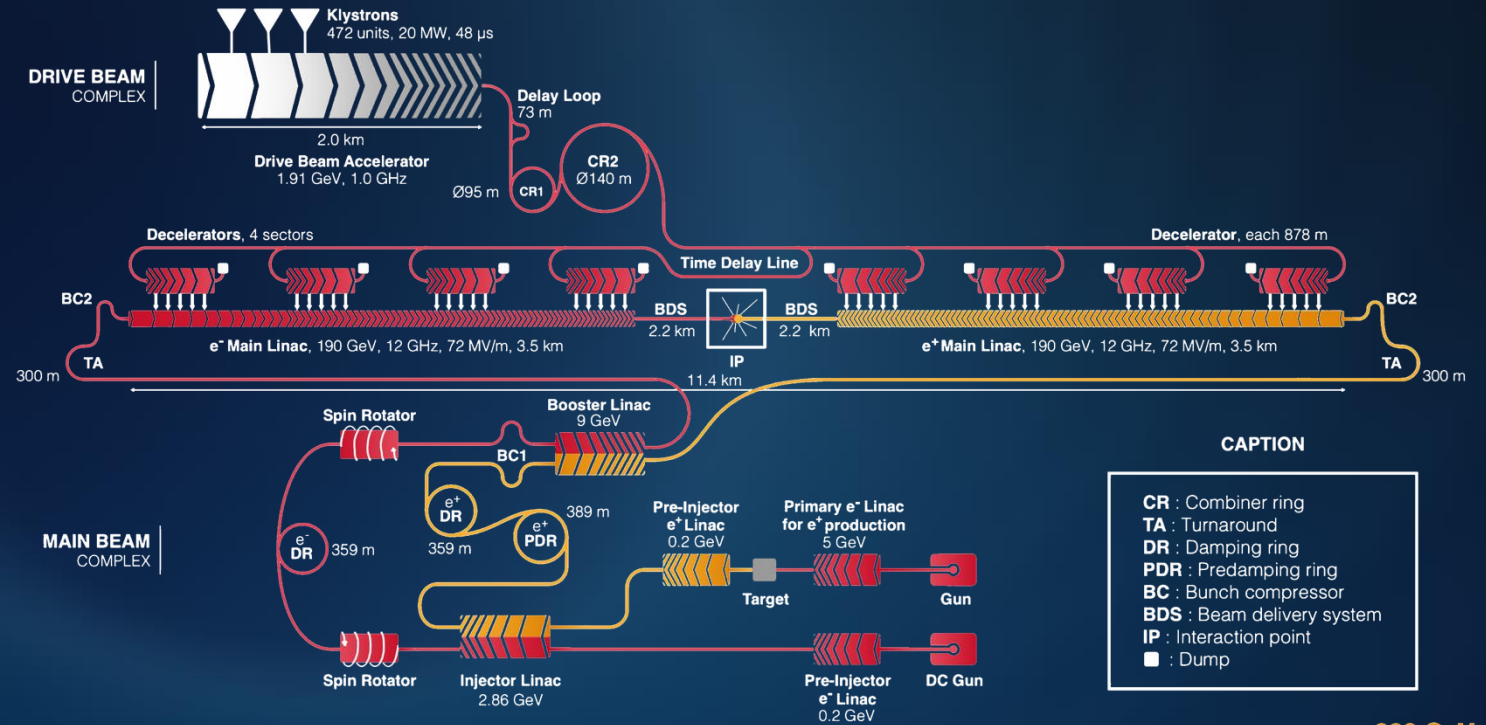
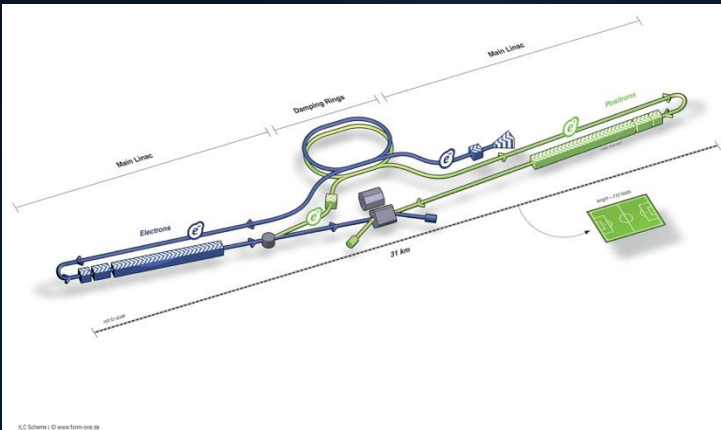




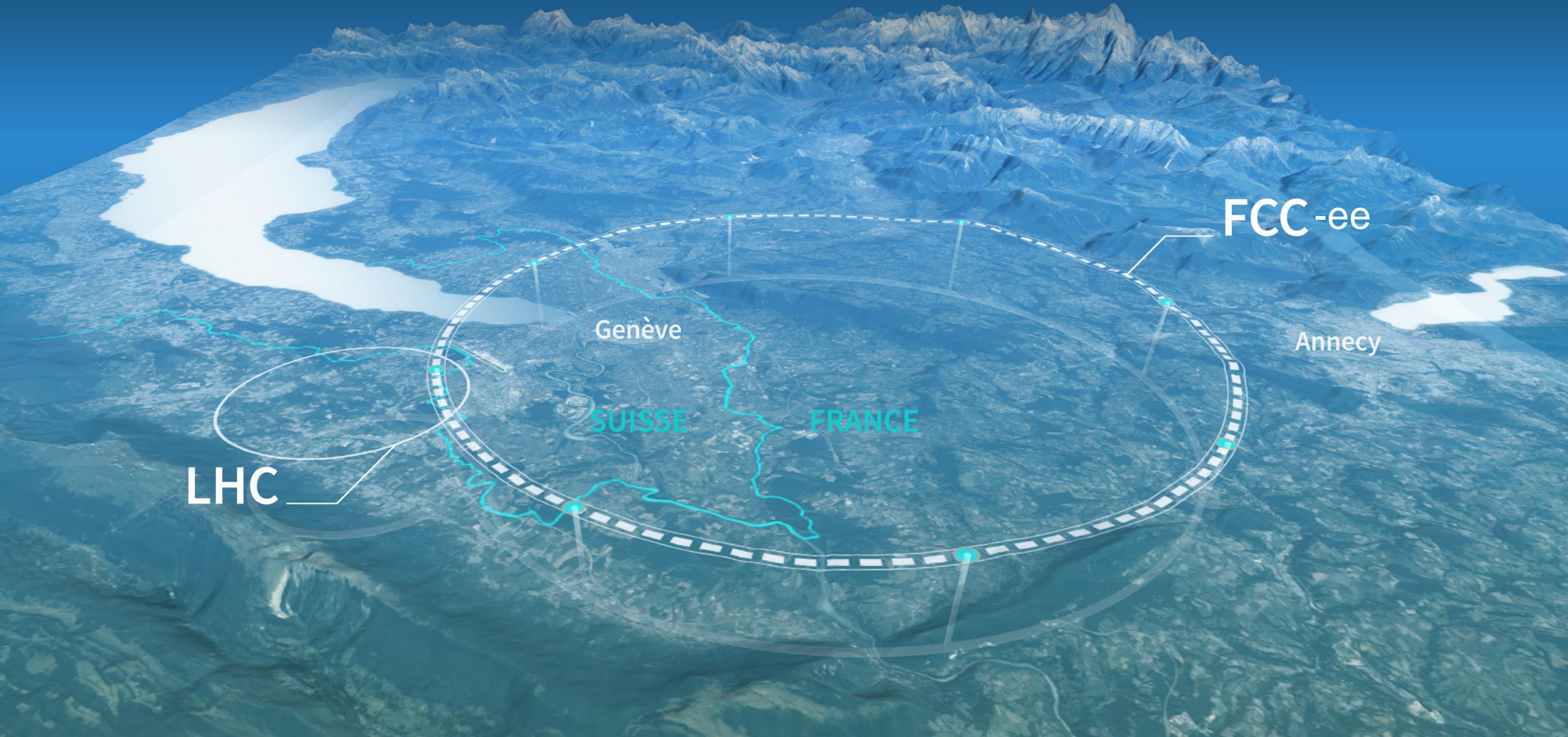
Exploring farther: machines for new knowledge



Linear Colliders



380 GeV



LHC

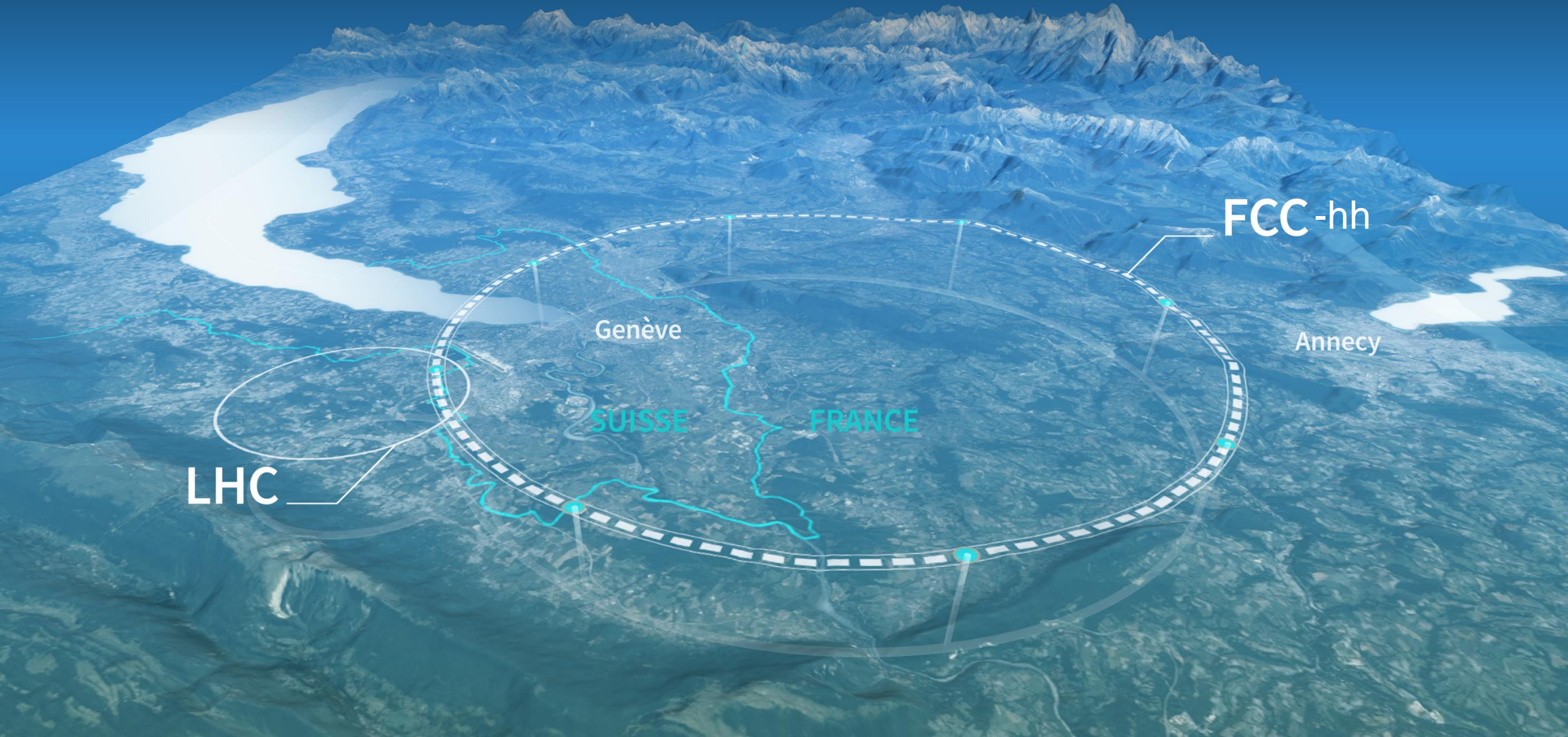
Genève

SUISSE

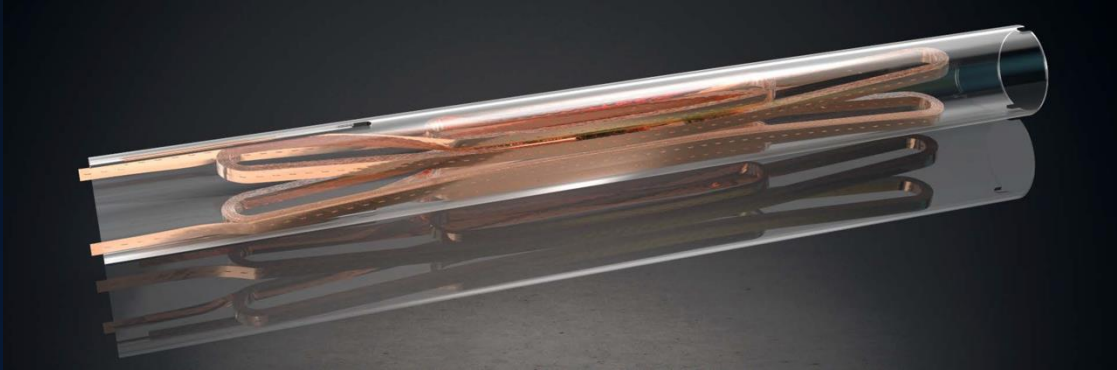
FRANCE

FCC-ee

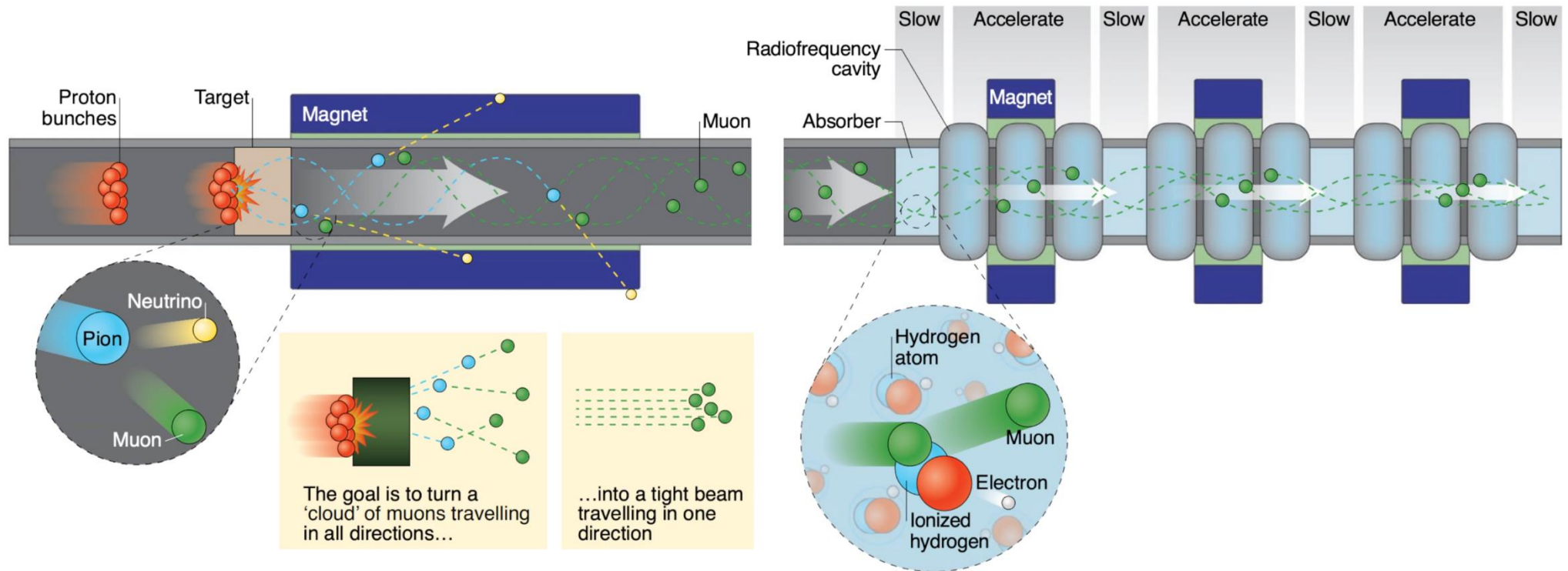
Annecy



FCC-hh magnet development



Muon production and cooling





Session 1 – Q&A

Advanced particle beam accelerators

Mei Bai

Accelerator Physicist, SLAC National Accelerator Laboratory, one of the 17 US Department of Energy national laboratories, operated by Stanford University

Edda Gschwendtner

Senior Physicist and Project Leader of AWAKE, Beams Department, CERN

Mike Seidel

Accelerator Physicist, Center for Accelerator Science and Engineering, Paul Scherrer Institute
Full Professor, Particle Accelerator Physics Laboratory, EPFL



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DETECTORS



COMPUTING



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Session 2

Enhanced detectors

Werner Riegler

Technical Coordinator of ALICE and leader of the experiment studies
for the Future Circular Hadron Collider, Experimental Physics department, CERN

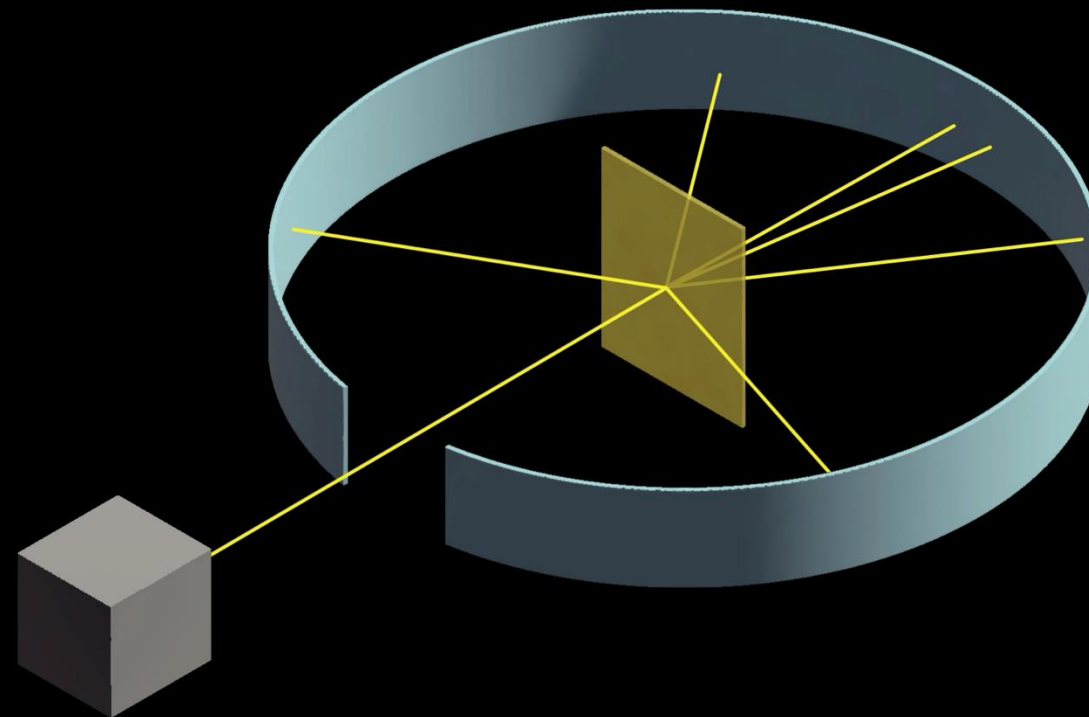




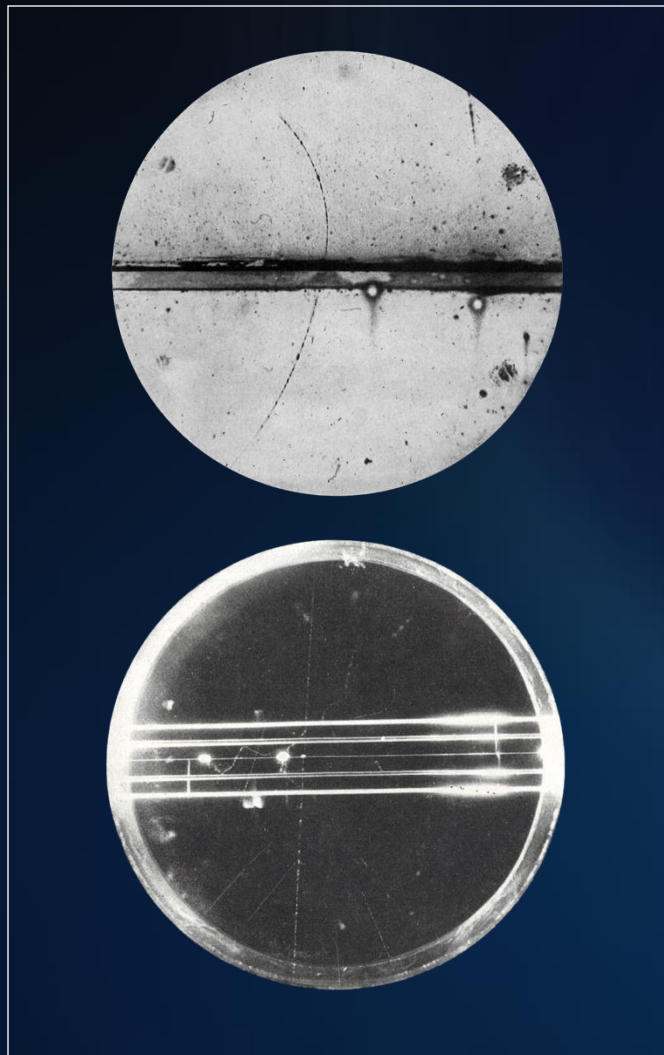
“Measure what can be measured,
and make measurable what cannot be measured.”

Galileo GALILEI

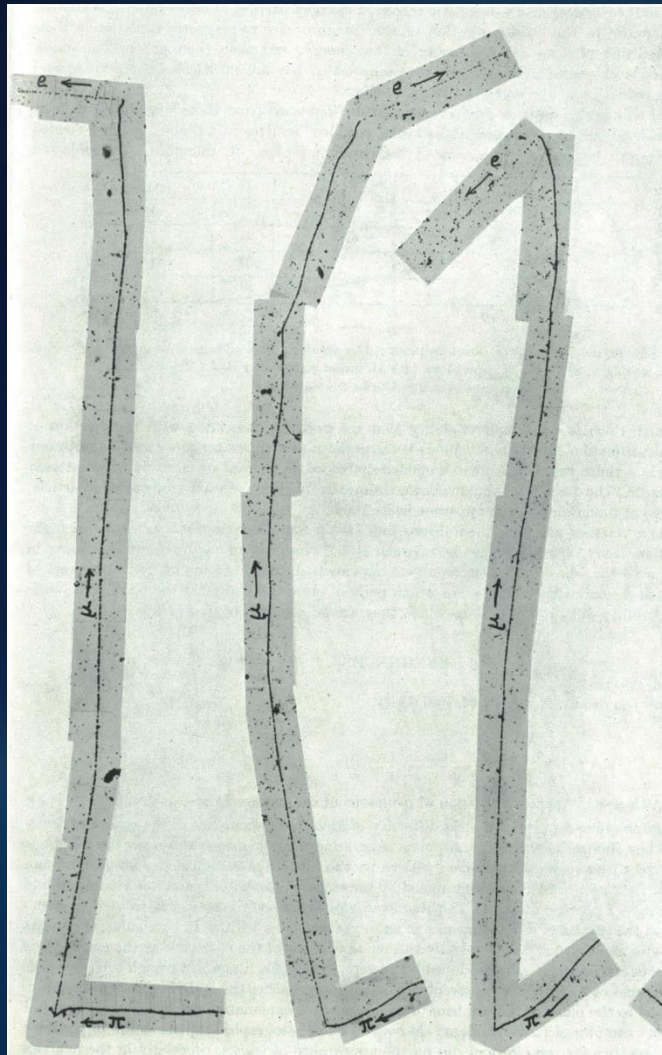
Rutherford's Discovery of the Nucleus 1911



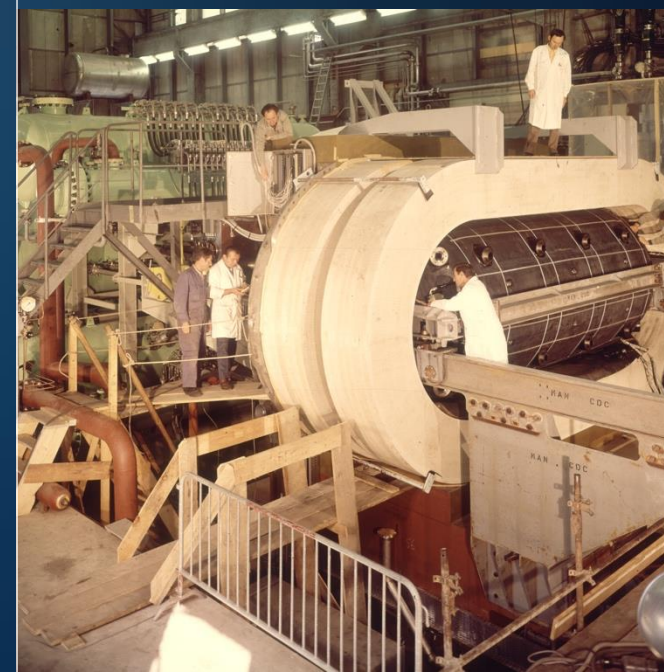
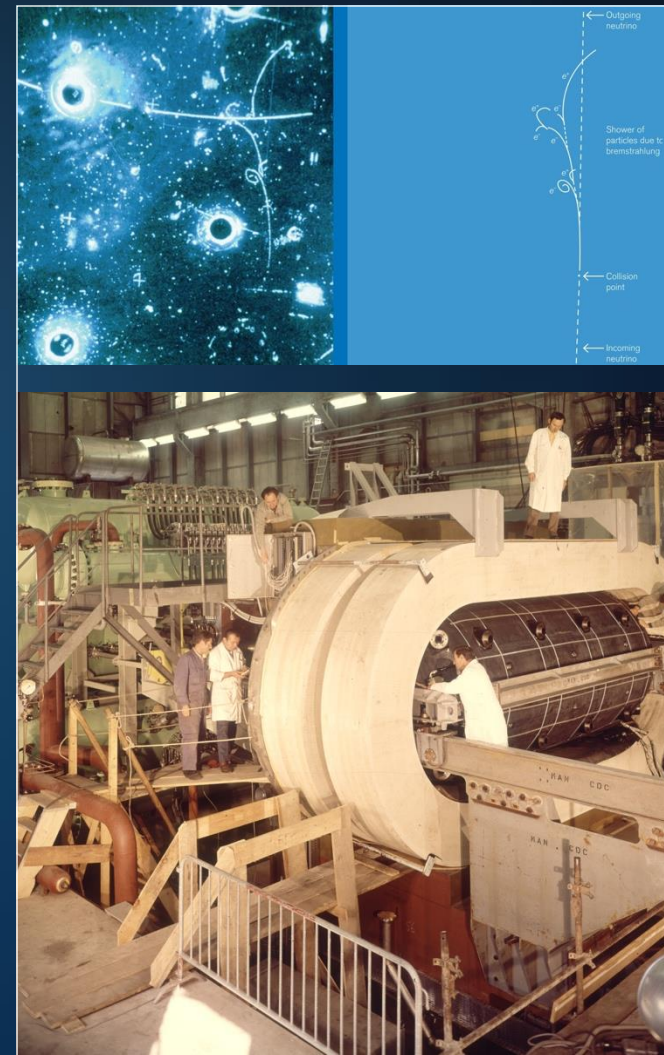
Cloud Chamber 1910 – 1950ies

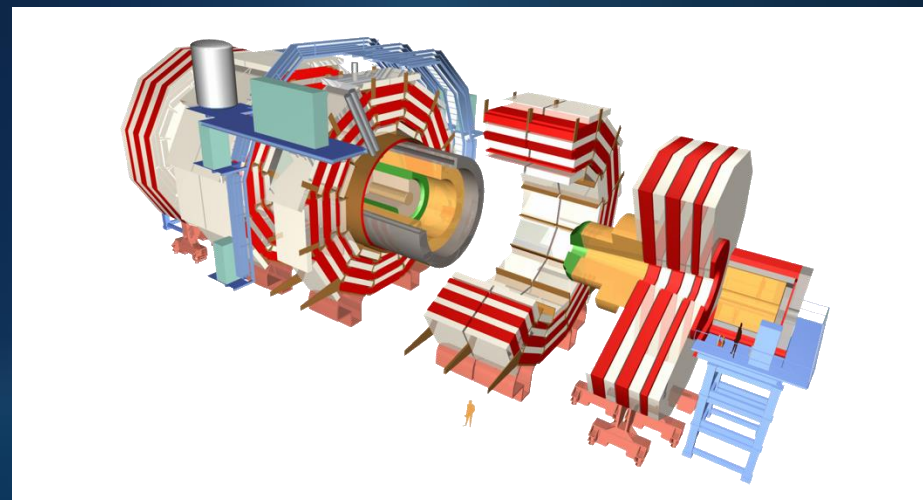
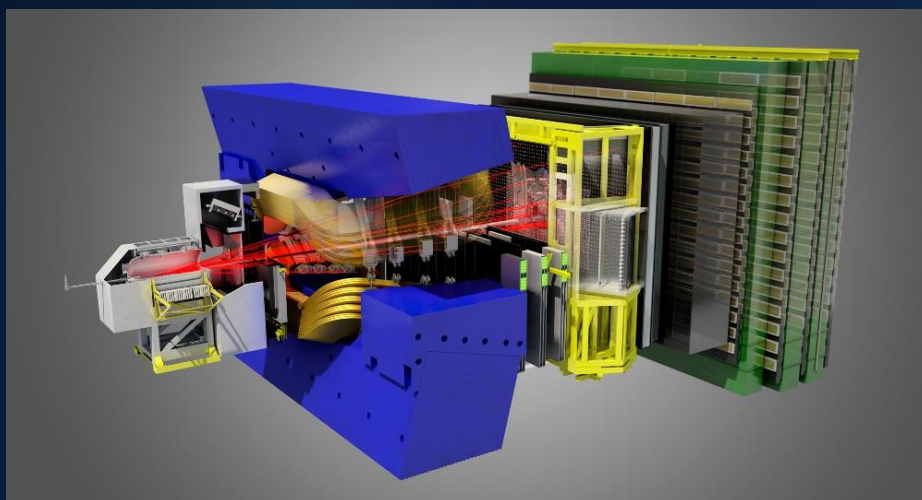
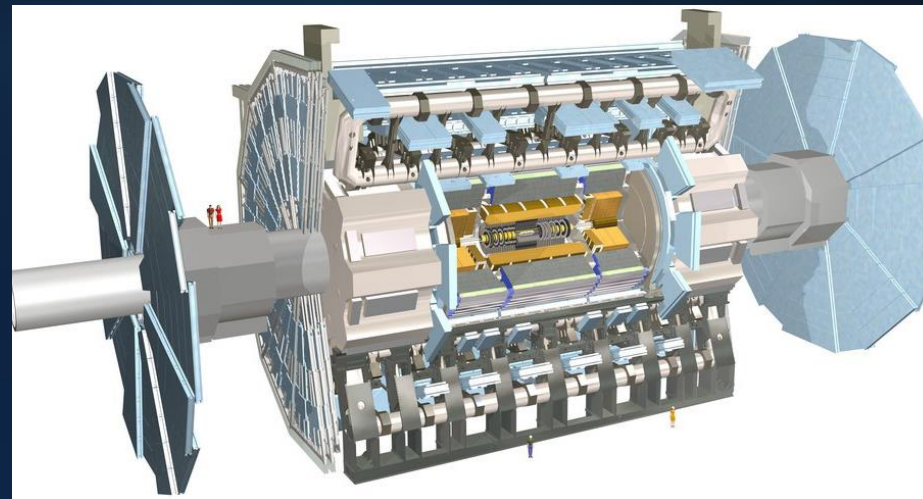
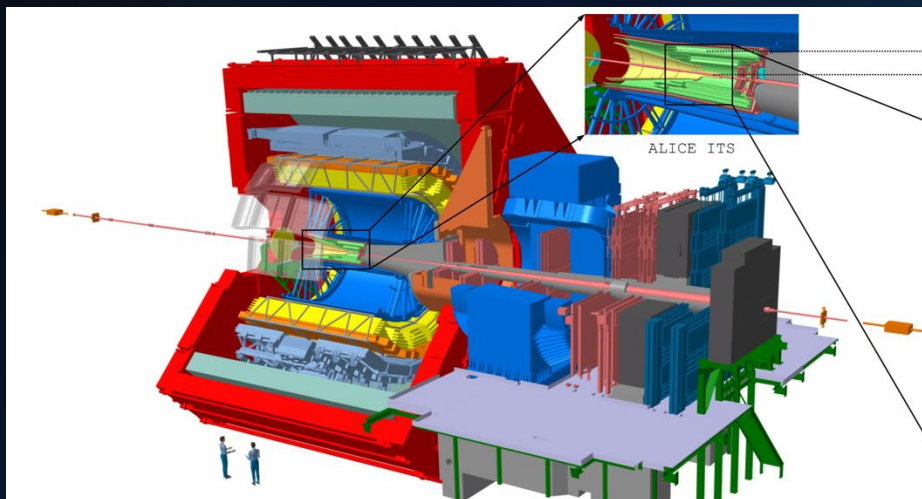


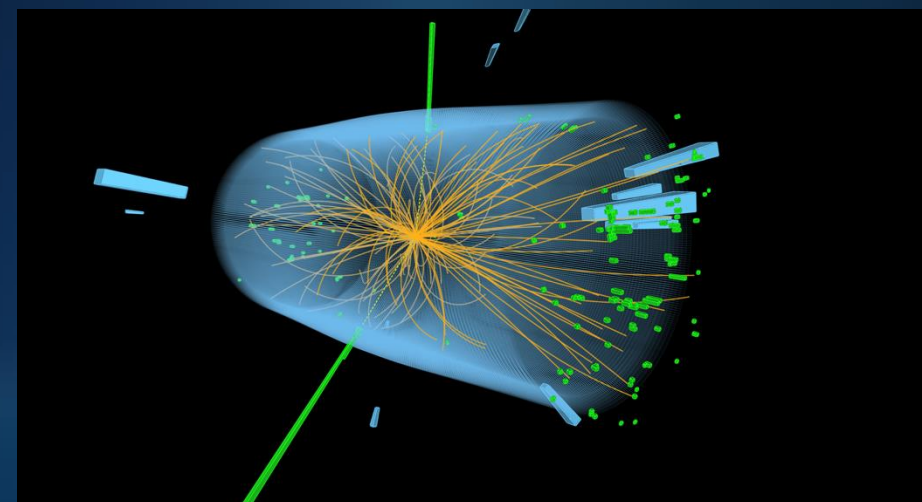
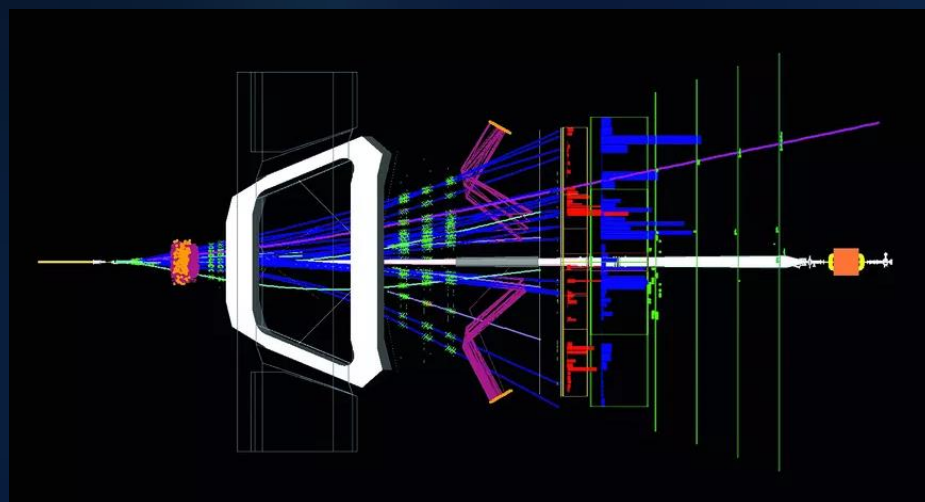
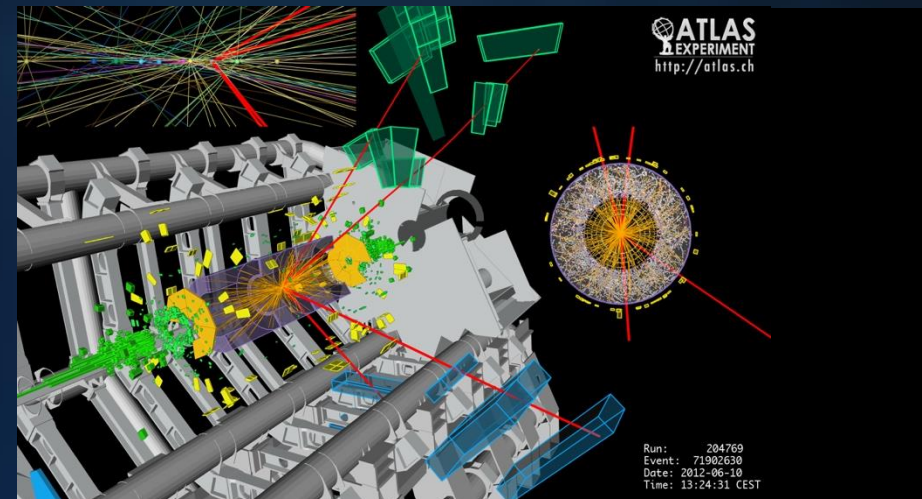
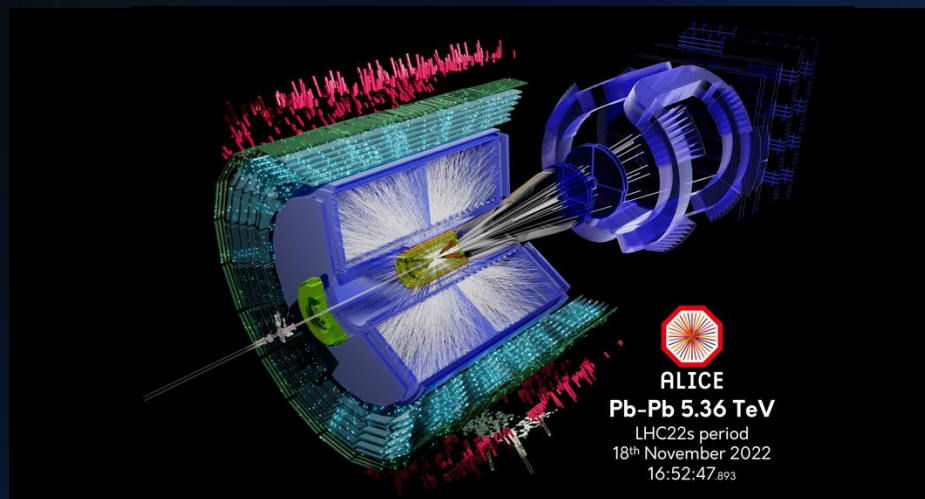
Photographic emulsions 1930ies to present

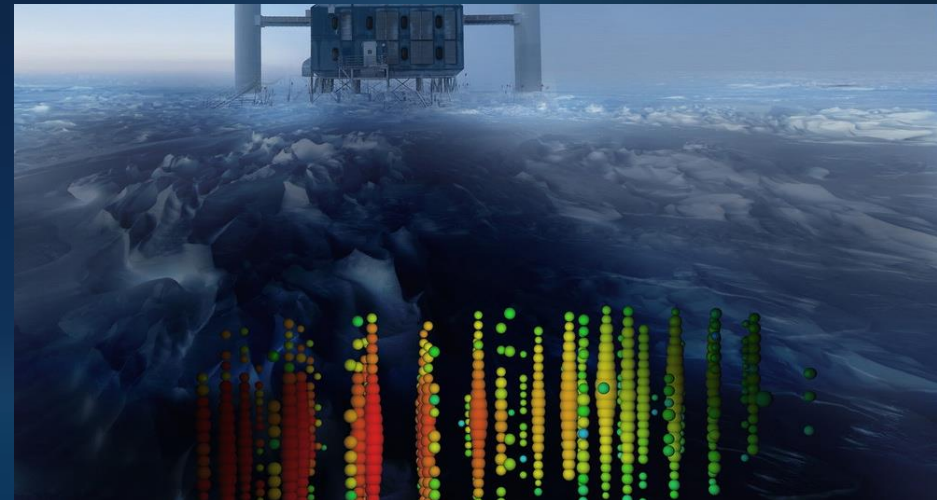
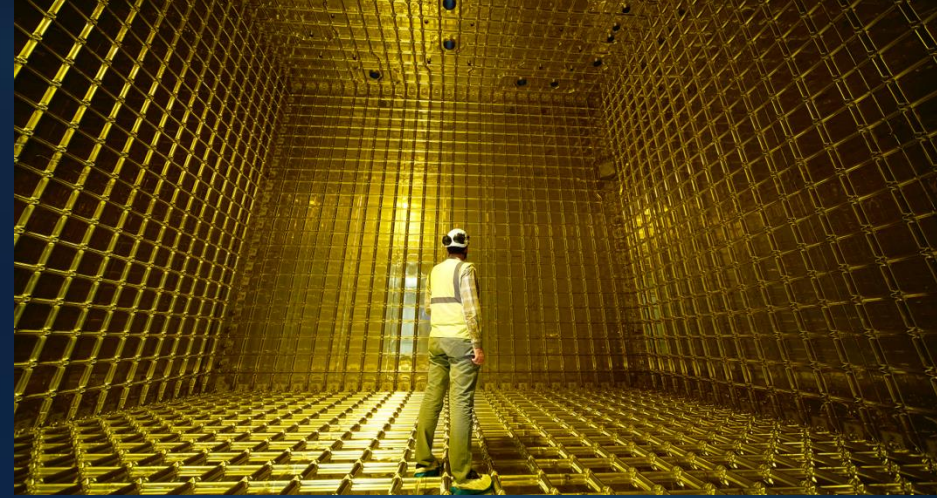


Bubble Chamber 1950 – 1980ies











C.T.R. Wilson

Cloud Chamber



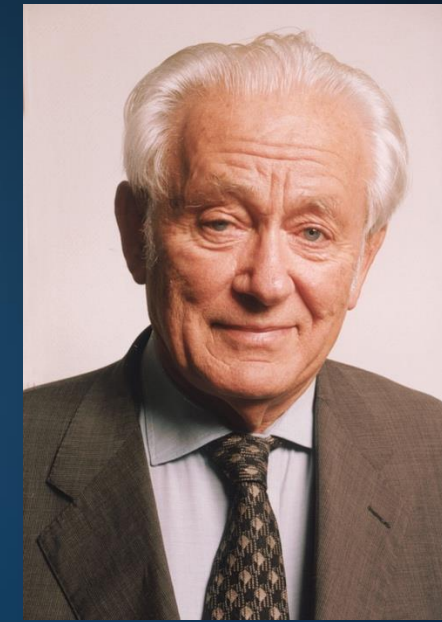
Marietta Blau

Nuclear Emulsions



Donald Glaser

Bubble Chamber



Georges Charpack

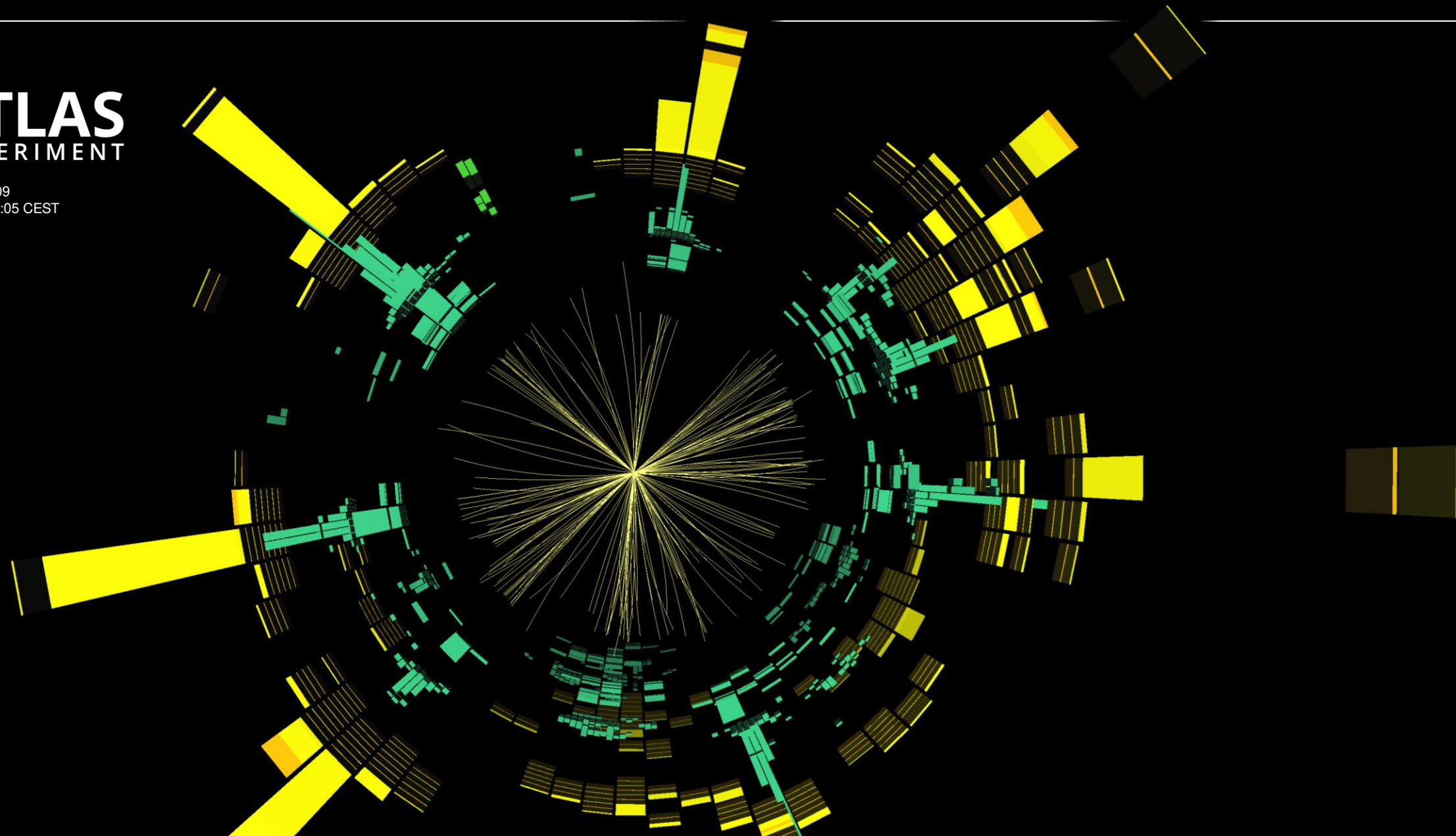
Wire Chamber



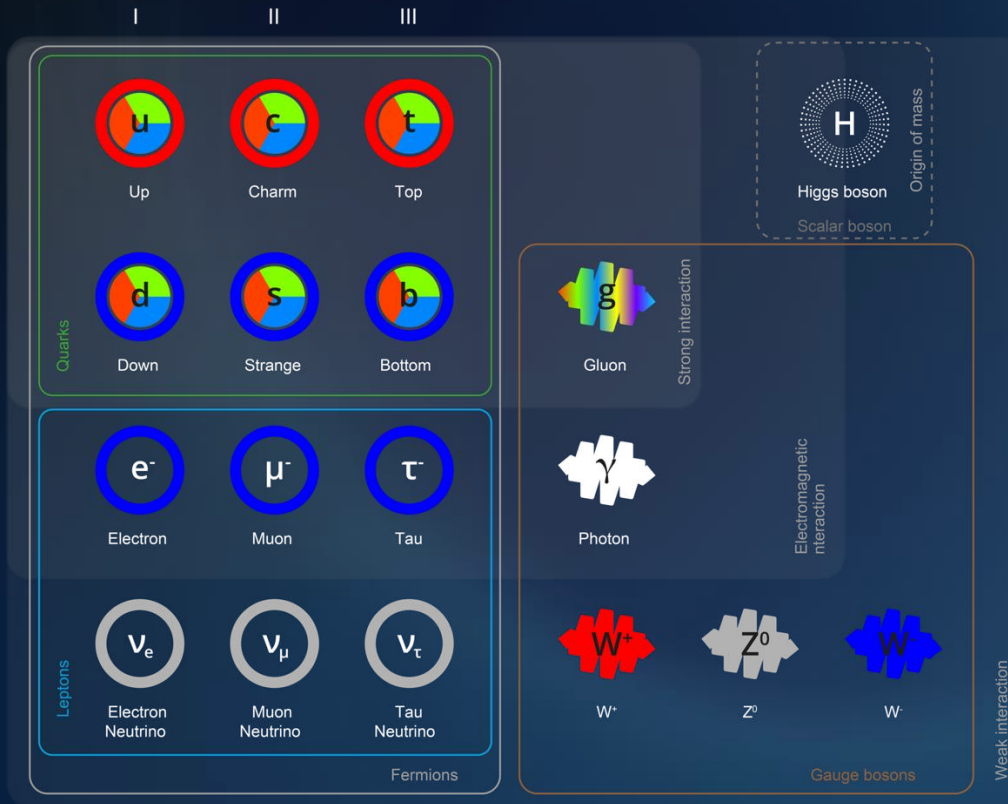
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Event: 1358542809

2016-06-02 18:19:05 CEST



The fundamental standard model particles



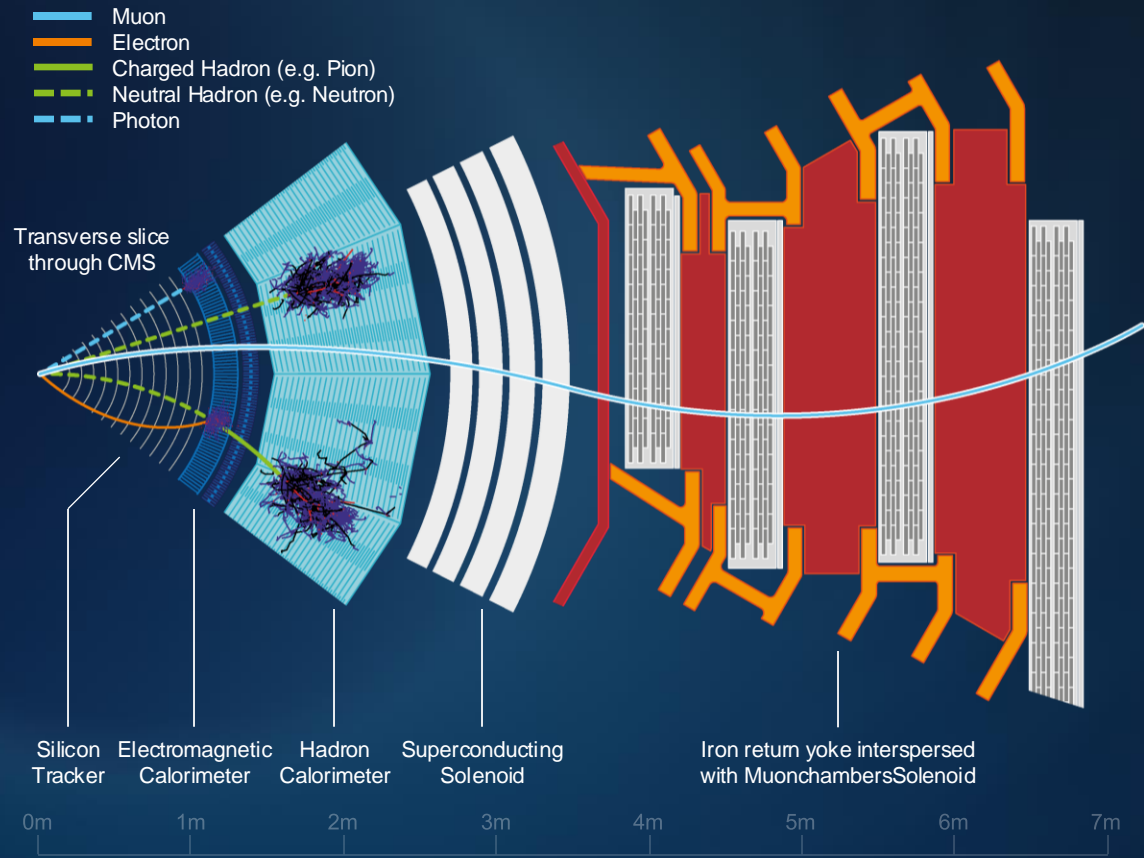
<http://pdg.lbl.gov>

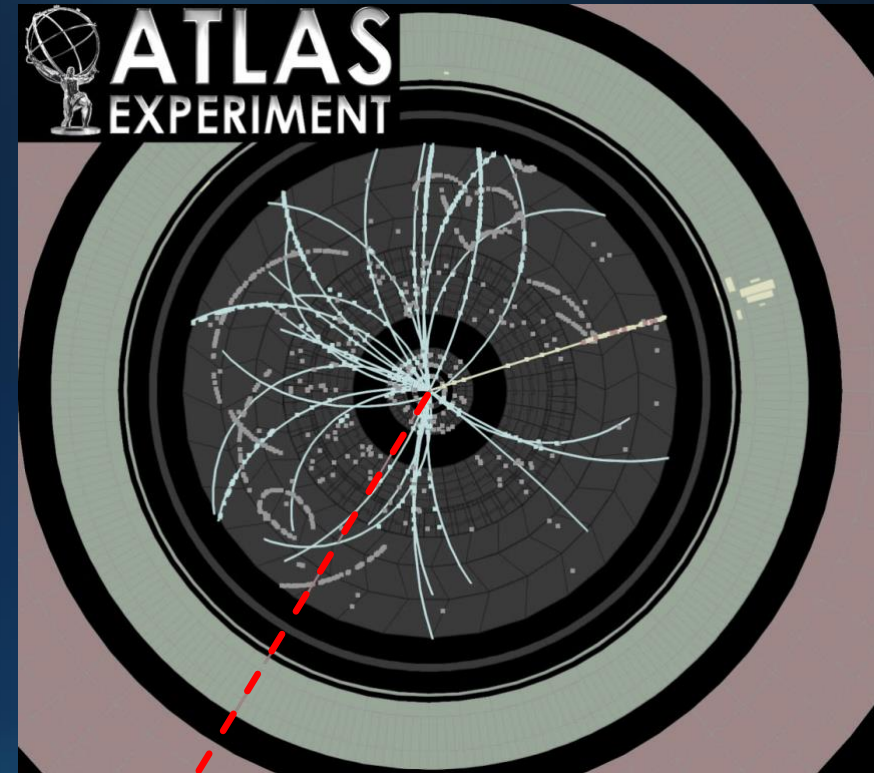
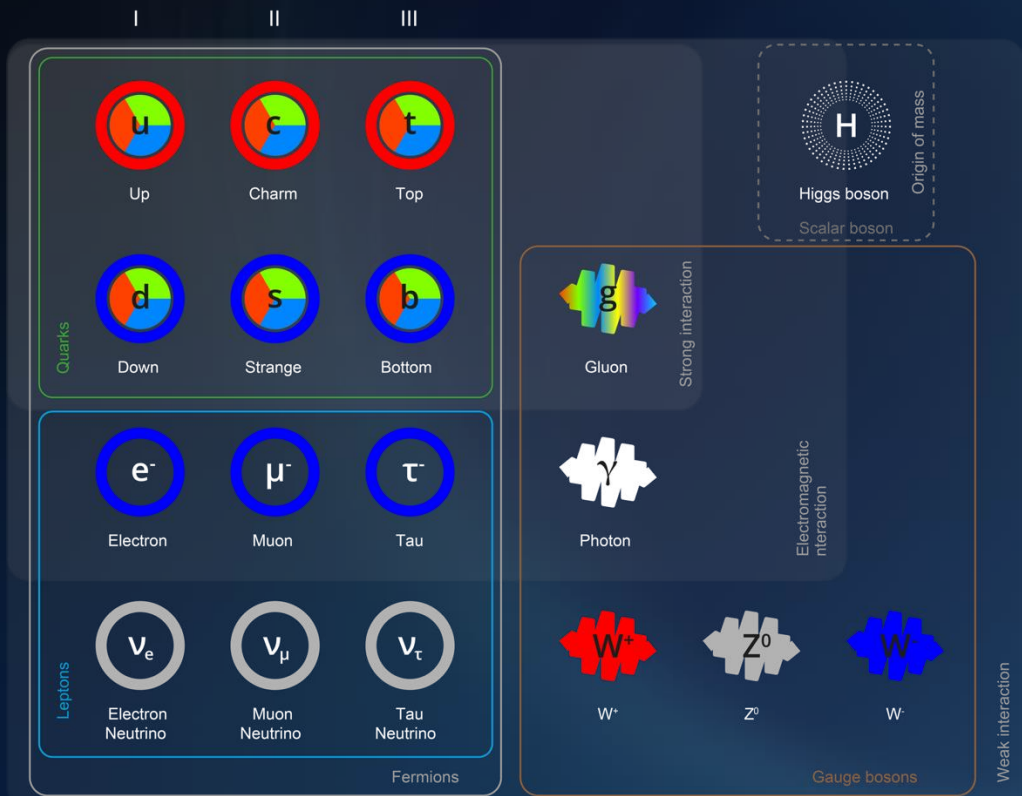
~ 180 Selected Particles

$\pi^+, \pi^0, \pi^-, \eta, \eta', \rho^0, \omega, \phi, \eta(1300), \eta(1405), \eta(1450), \eta(1700), \eta(2160), \eta(2220), \eta(2230), \eta(2300), \eta(2756), \eta(2950), \eta(3097), \eta(3512), \eta(3598), \eta(3930), \eta(4180), \eta(4260), \eta(4360), \eta(4413), \eta(4440), \eta(4500), \eta(4560), \eta(4700), \eta(4750), \eta(4810), \eta(4830), \eta(4870), \eta(4910), \eta(4940), \eta(4960), \eta(5040), \eta(5070), \eta(5125), \eta(5210), \eta(5280), \eta(5340), \eta(5400), \eta(5582), \eta(5620), \eta(5775), \eta(5912), \eta(5972), \eta(6040), \eta(6060), \eta(6080), \eta(6100), \eta(6170), \eta(6190), \eta(6200), \eta(6240), \eta(6280), \eta(6300), \eta(6350), \eta(6400), \eta(6420), \eta(6440), \eta(6450), \eta(6480), \eta(6500), \eta(6520), \eta(6540), \eta(6560), \eta(6580), \eta(6600), \eta(6620), \eta(6640), \eta(6660), \eta(6680), \eta(6700), \eta(6720), \eta(6740), \eta(6760), \eta(6780), \eta(6800), \eta(6820), \eta(6840), \eta(6860), \eta(6880), \eta(6900), \eta(6920), \eta(6940), \eta(6960), \eta(6980), \eta(7000), \eta(7020), \eta(7040), \eta(7060), \eta(7080), \eta(7100), \eta(7120), \eta(7140), \eta(7160), \eta(7180), \eta(7200), \eta(7220), \eta(7240), \eta(7260), \eta(7280), \eta(7300), \eta(7320), \eta(7340), \eta(7360), \eta(7380), \eta(7400), \eta(7420), \eta(7440), \eta(7460), \eta(7480), \eta(7500), \eta(7520), \eta(7540), \eta(7560), \eta(7580), \eta(7600), \eta(7620), \eta(7640), \eta(7660), \eta(7680), \eta(7700), \eta(7720), \eta(7740), \eta(7760), \eta(7780), \eta(7800), \eta(7820), \eta(7840), \eta(7860), \eta(7880), \eta(7900), \eta(7920), \eta(7940), \eta(7960), \eta(7980), \eta(8000), \eta(8020), \eta(8040), \eta(8060), \eta(8080), \eta(8100), \eta(8120), \eta(8140), \eta(8160), \eta(8180), \eta(8200), \eta(8220), \eta(8240), \eta(8260), \eta(8280), \eta(8300), \eta(8320), \eta(8340), \eta(8360), \eta(8380), \eta(8400), \eta(8420), \eta(8440), \eta(8460), \eta(8480), \eta(8500), \eta(8520), \eta(8540), \eta(8560), \eta(8580), \eta(8600), \eta(8620), \eta(8640), \eta(8660), \eta(8680), \eta(8700), \eta(8720), \eta(8740), \eta(8760), \eta(8780), \eta(8800), \eta(8820), \eta(8840), \eta(8860), \eta(8880), \eta(8900), \eta(8920), \eta(8940), \eta(8960), \eta(8980), \eta(9000), \eta(9020), \eta(9040), \eta(9060), \eta(9080), \eta(9100), \eta(9120), \eta(9140), \eta(9160), \eta(9180), \eta(9200), \eta(9220), \eta(9240), \eta(9260), \eta(9280), \eta(9300), \eta(9320), \eta(9340), \eta(9360), \eta(9380), \eta(9400), \eta(9420), \eta(9440), \eta(9460), \eta(9480), \eta(9500), \eta(9520), \eta(9540), \eta(9560), \eta(9580), \eta(9600), \eta(9620), \eta(9640), \eta(9660), \eta(9680), \eta(9700), \eta(9720), \eta(9740), \eta(9760), \eta(9780), \eta(9800), \eta(9820), \eta(9840), \eta(9860), \eta(9880), \eta(9900), \eta(9920), \eta(9940), \eta(9960), \eta(9980), \eta(10000)$

There are Many more

e^\pm	$m_e = 0.511 \text{ MeV}$	} EM
μ^\pm	$m_\mu = 105.7 \text{ MeV} \sim 200 m_e$	
γ	$m_\gamma = 0, Q = 0$	
π^\pm	$m_\pi = 139.6 \text{ MeV} \sim 270 m_e$	} EM, Strong
K^\pm	$m_K = 493.7 \text{ MeV} \sim 1000 m_e$	
p^\pm	$m_p = 938.3 \text{ MeV} \sim 2000 m_e$	
K^0	$m_{K^0} = 497.7 \text{ MeV} \quad Q=0$	} Strong
n	$m_n = 939.6 \text{ MeV} \quad Q=0$	





Session 2

Enhanced detectors

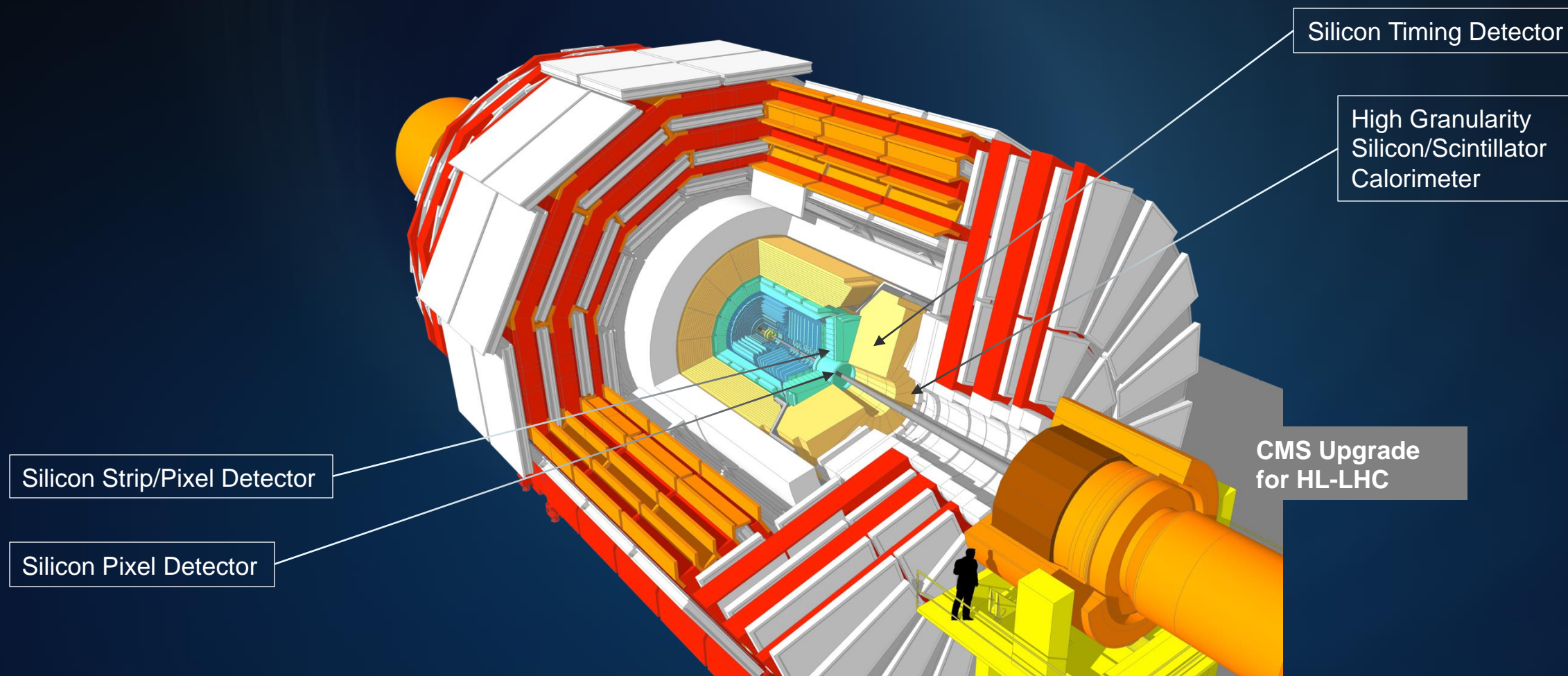
Petra Merkel

Senior Scientist and Detector R&D Coordinator, Fermilab



Silicon Detectors

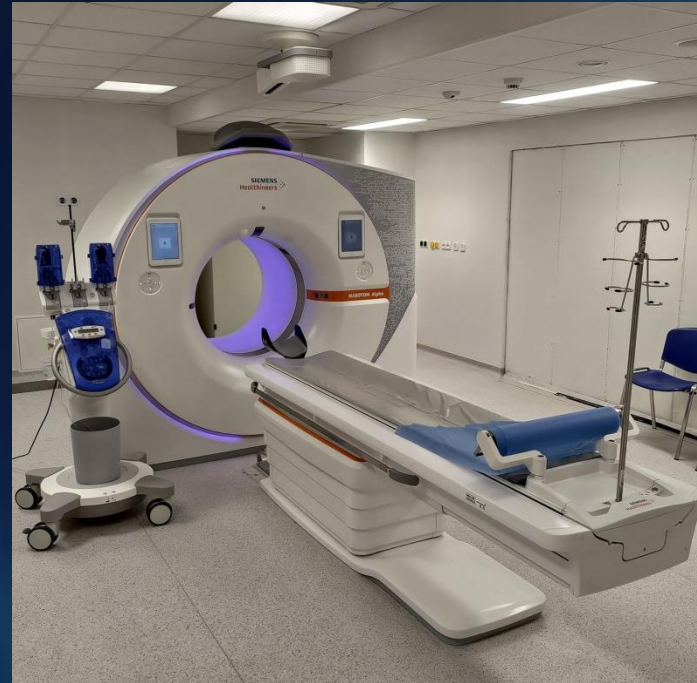
from high-tech novelty to ubiquitous workhorse



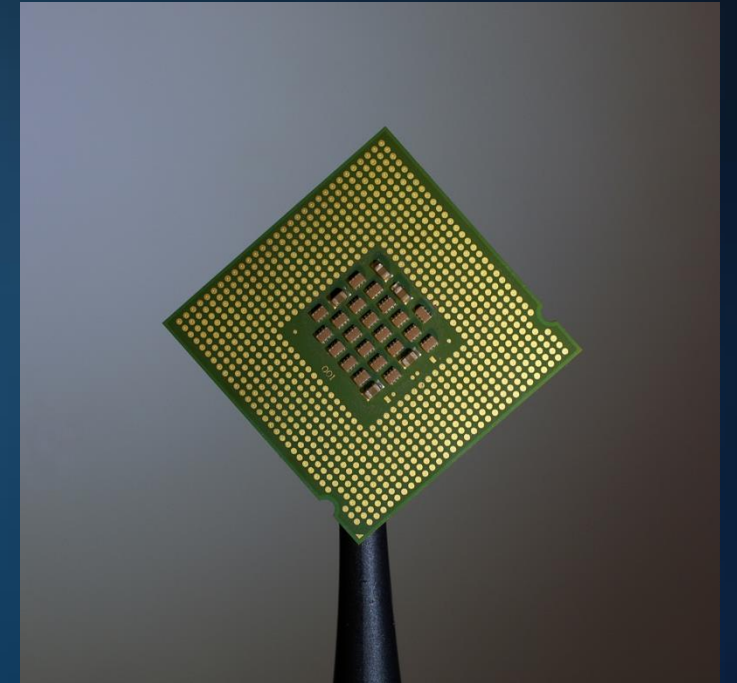
Silicon technology is everywhere



Phone cameras

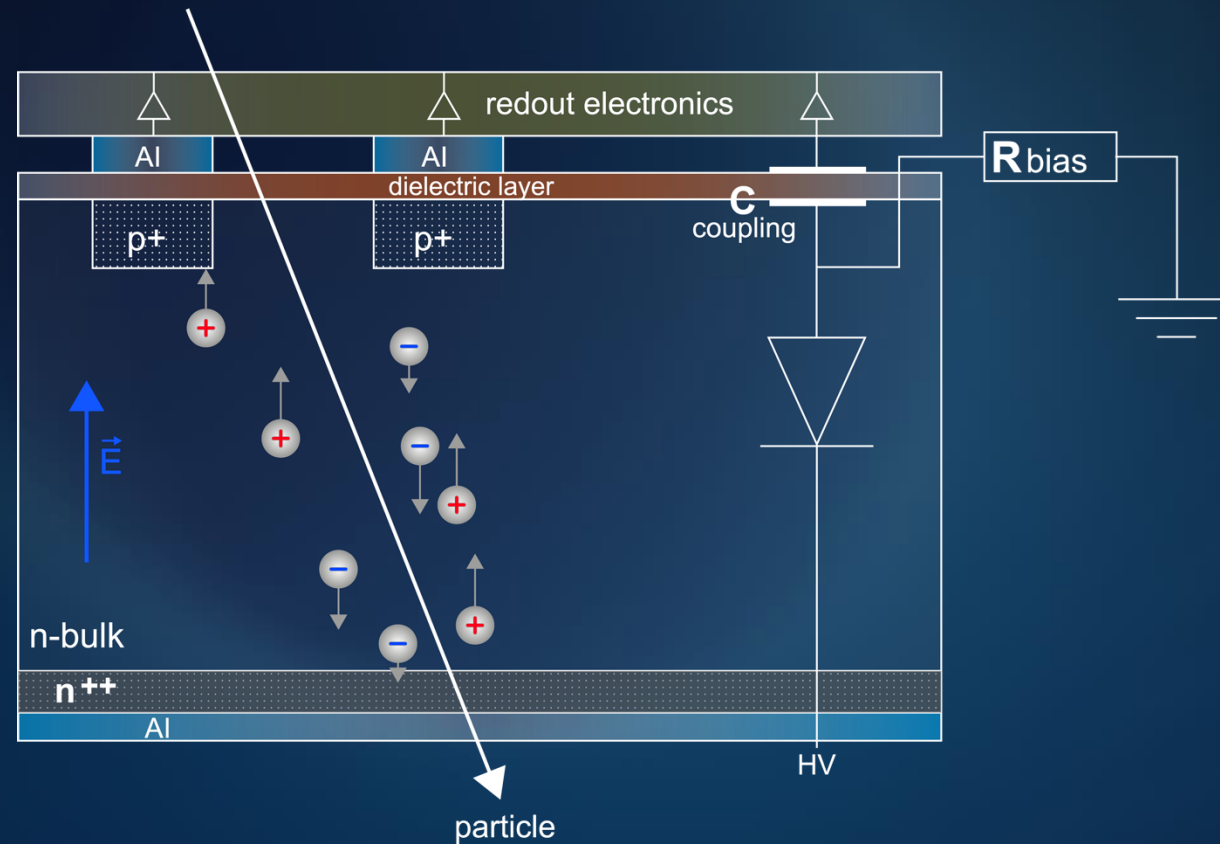


X-ray CT scanner

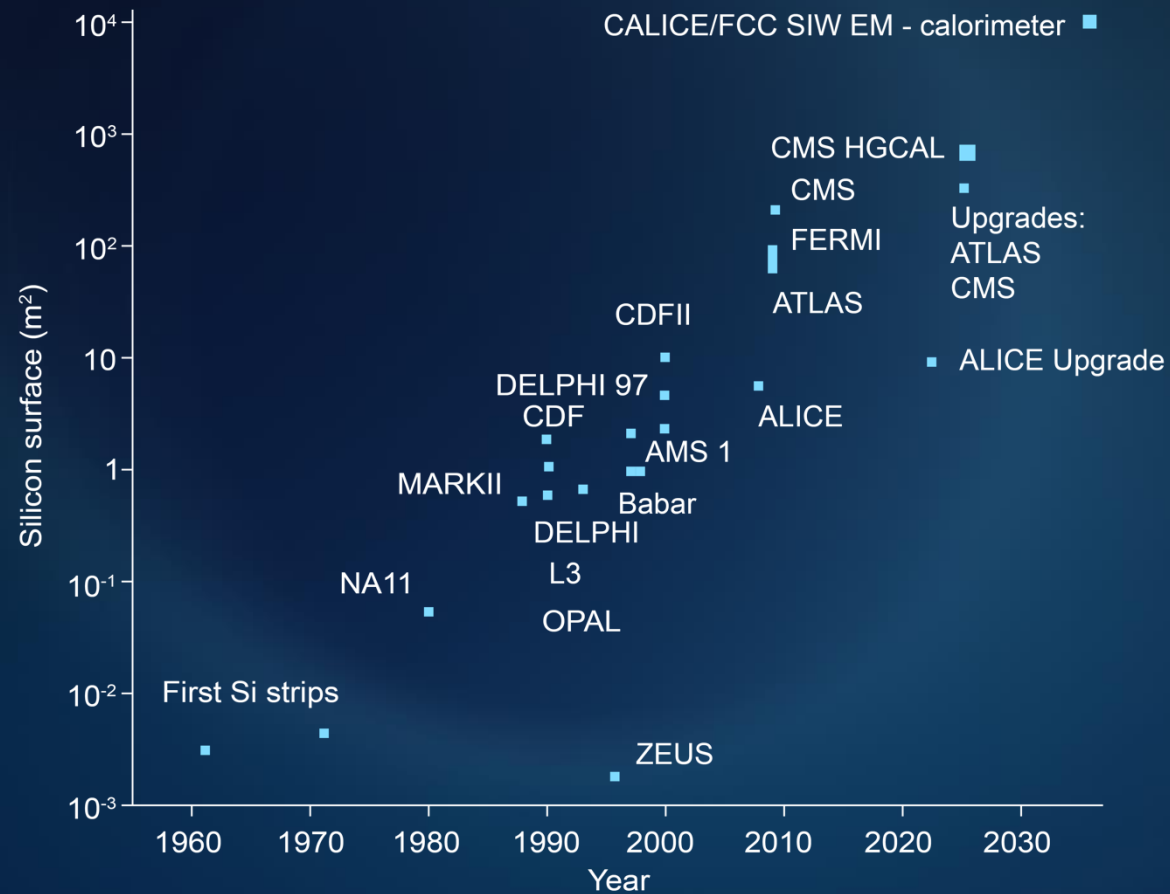


Computer chips

Working principle of a silicon detector



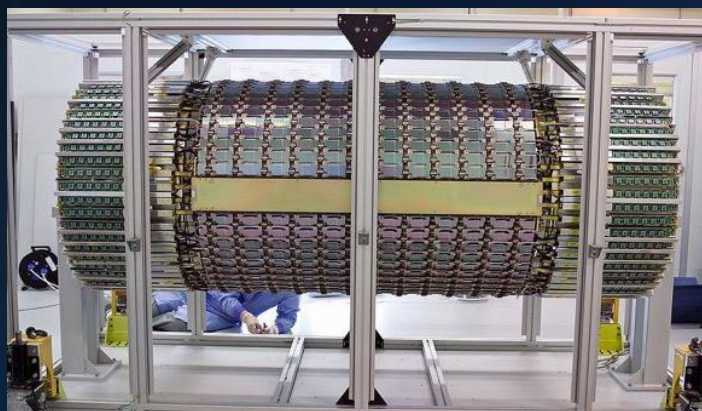
Scalability



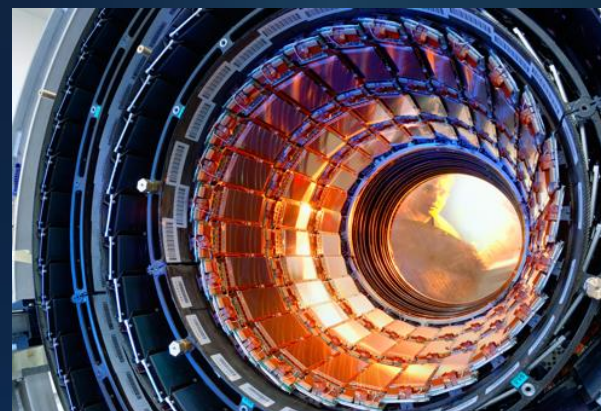
Silicon trackers at the heart of all LHC experiments

Giant, ultra-fast and very complex 3D camera

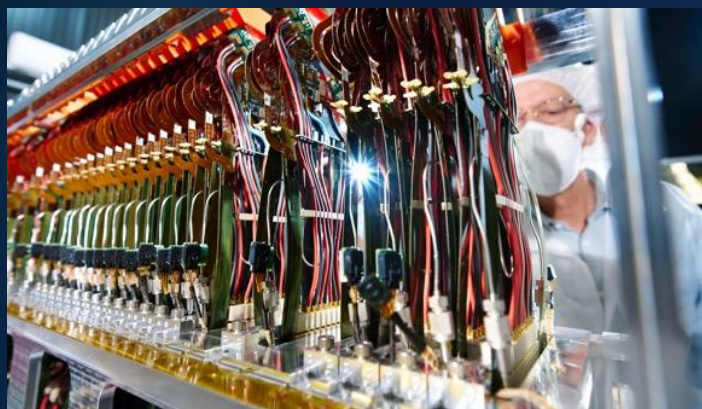
ATLAS



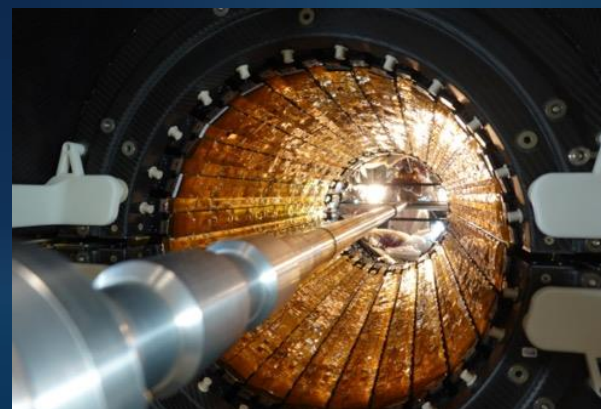
CMS



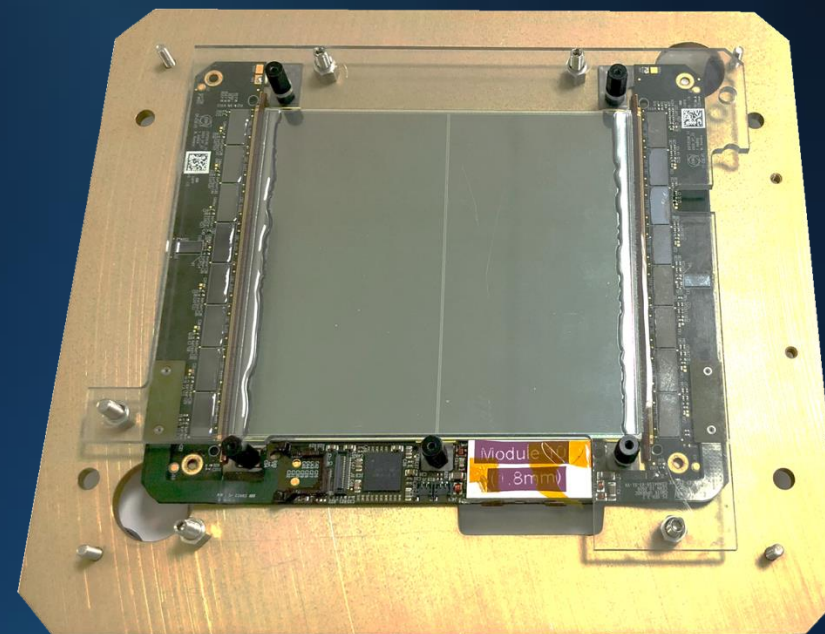
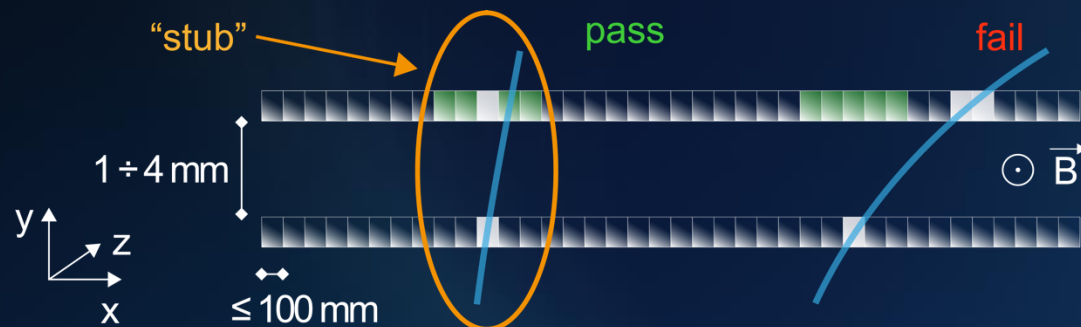
LHCb



ALICE



Increasingly powerful accelerators

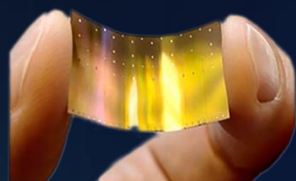


Increasingly powerful accelerators => call for smarter detectors

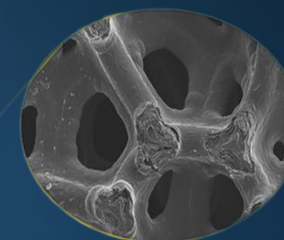
An example of novel concepts: distinguish low and high momentum particles on detector

Strive for almost massless detectors

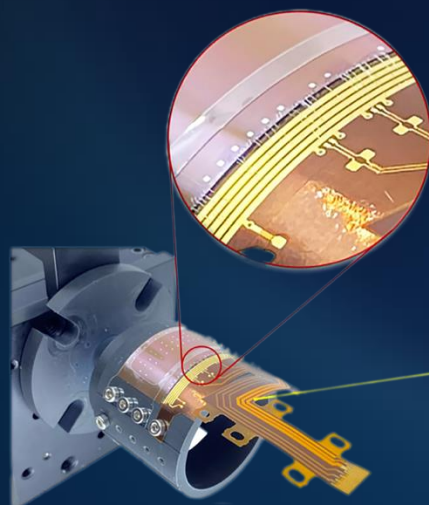
curved MAP sensor



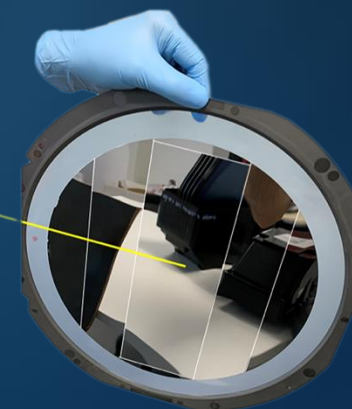
carbon foam

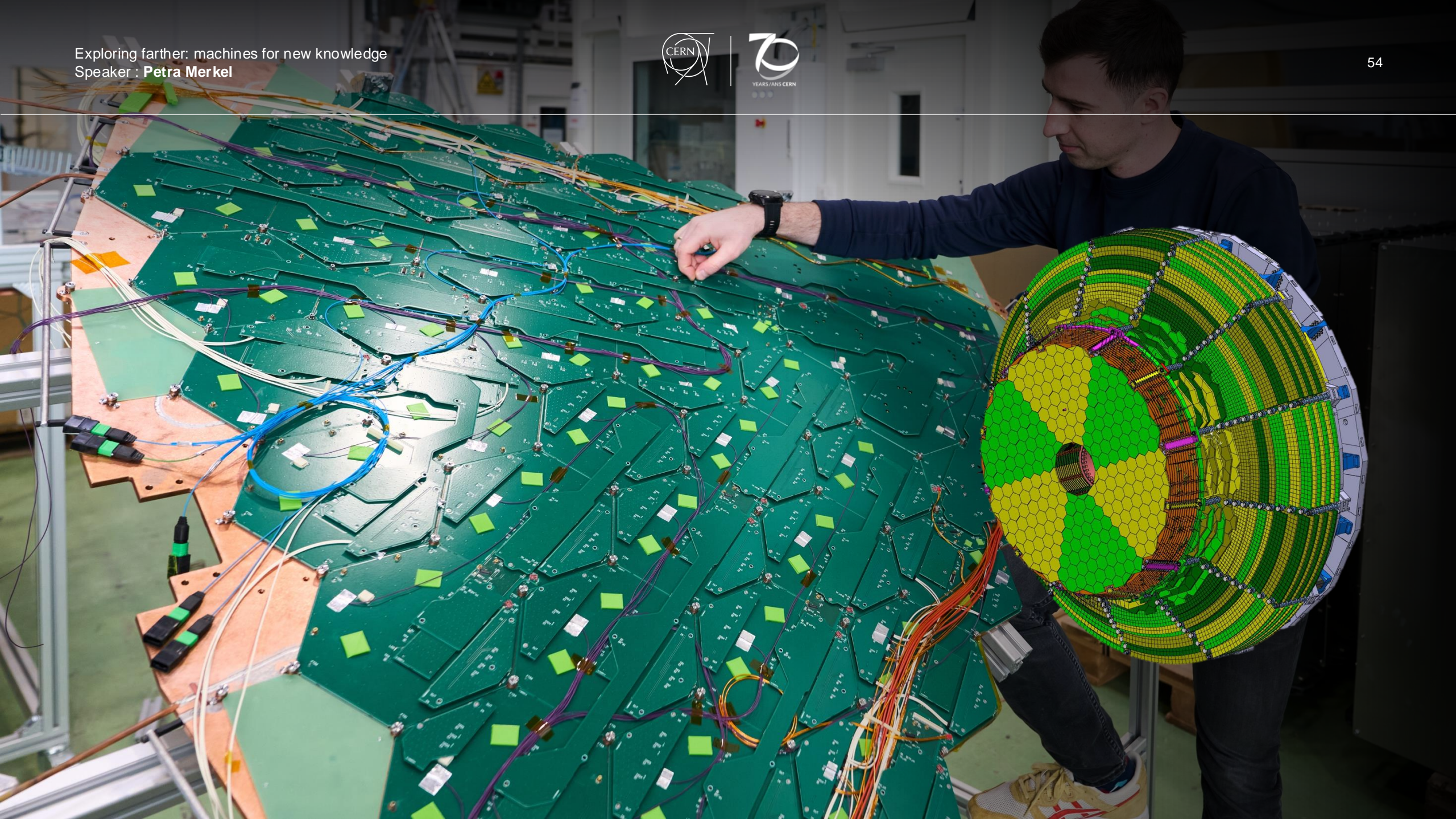


wire bonding

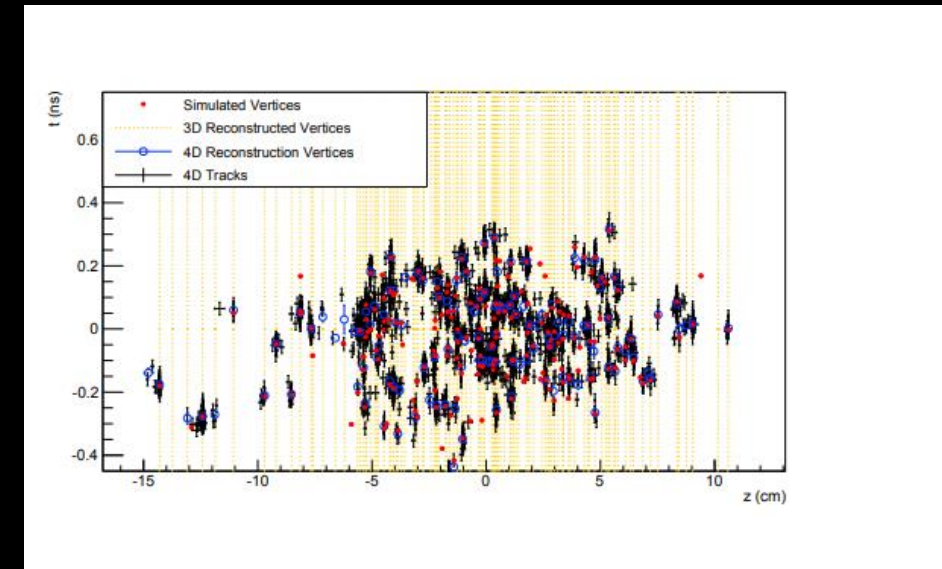
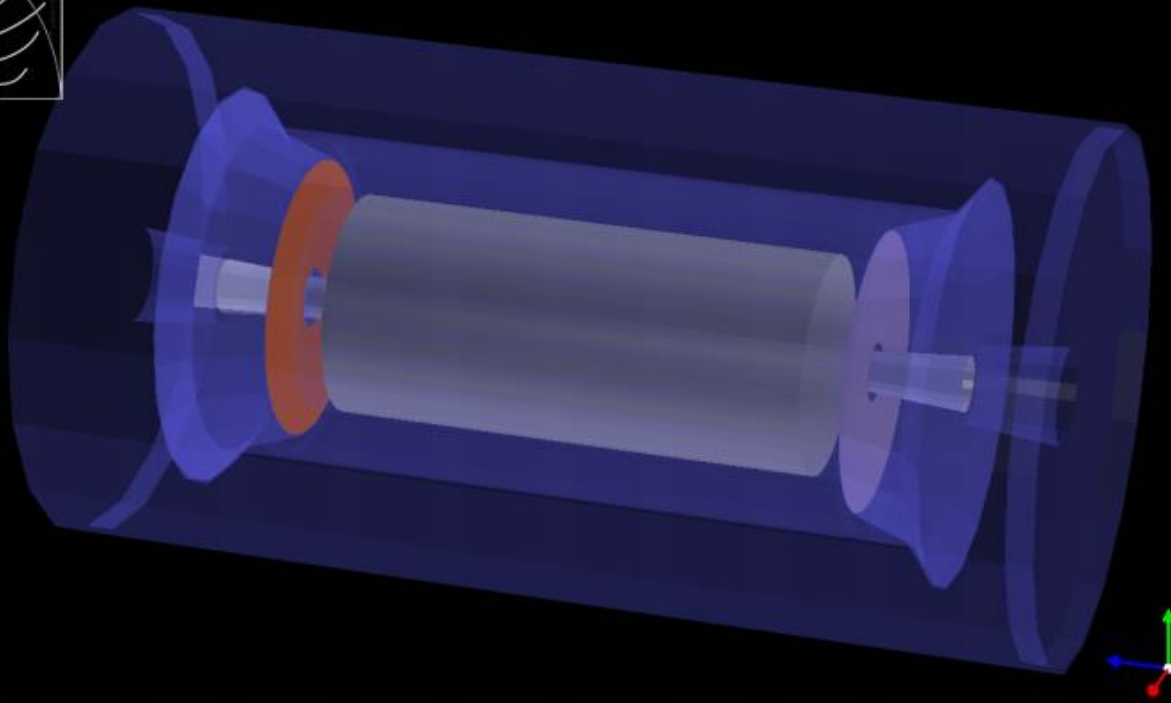


stitching





CMS timing layer



Session 2

Enhanced detectors

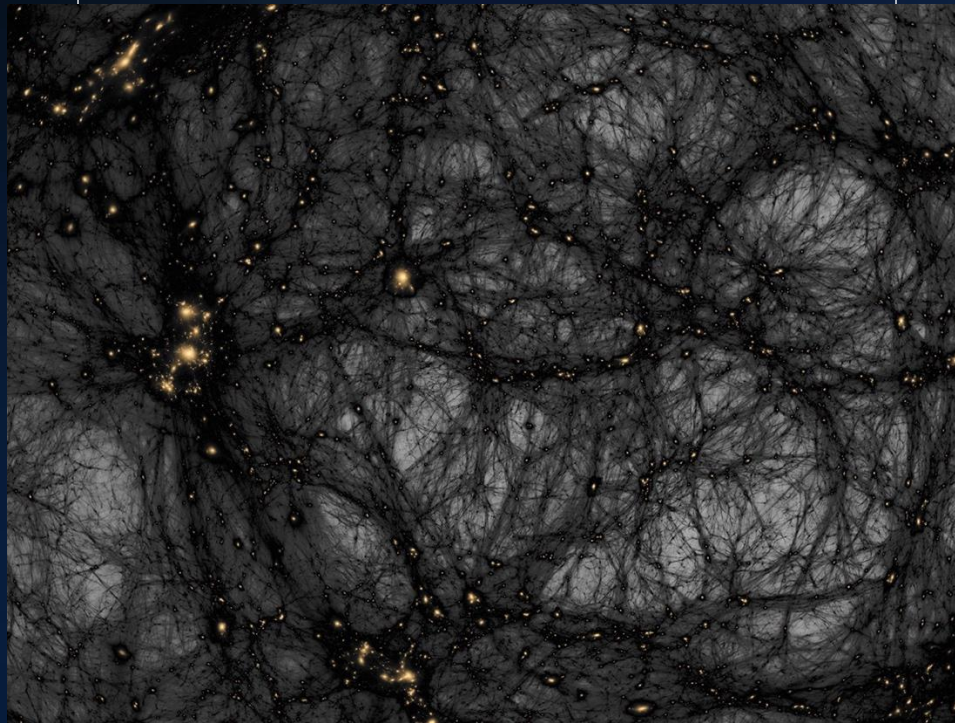
Roxanne Guenette

Professor of Particle Physics, Department of Physics and Astronomy, University of Manchester

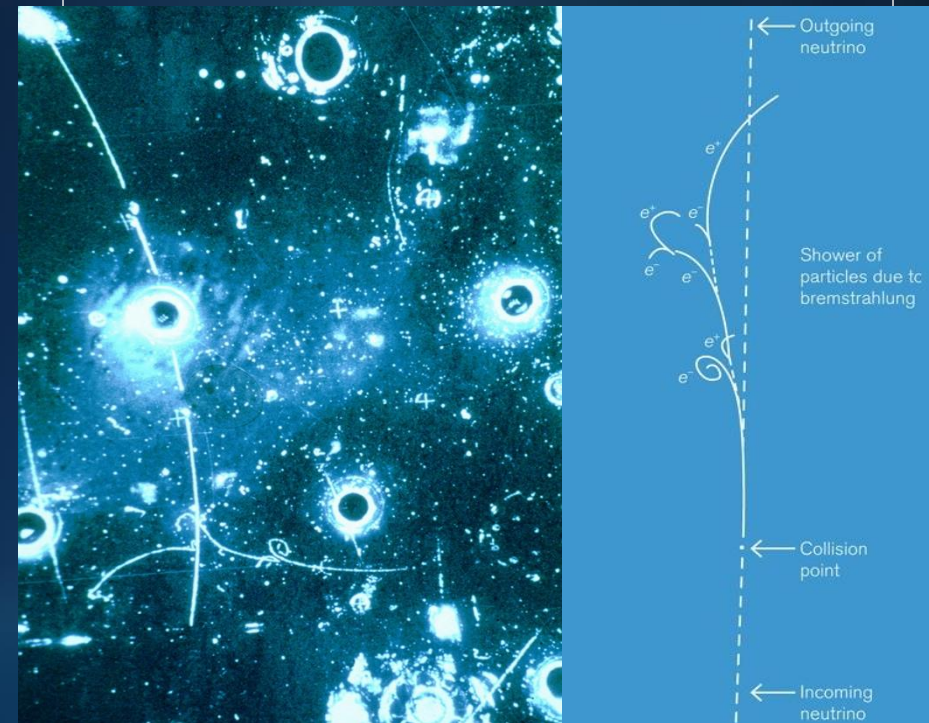


Understanding our Universe

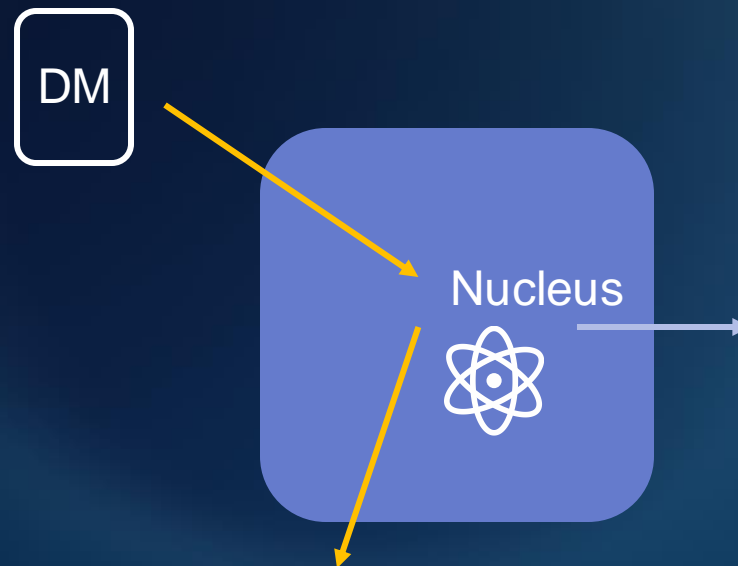
What is Dark Matter?



What can the elusive neutrinos tell us about our Universe?



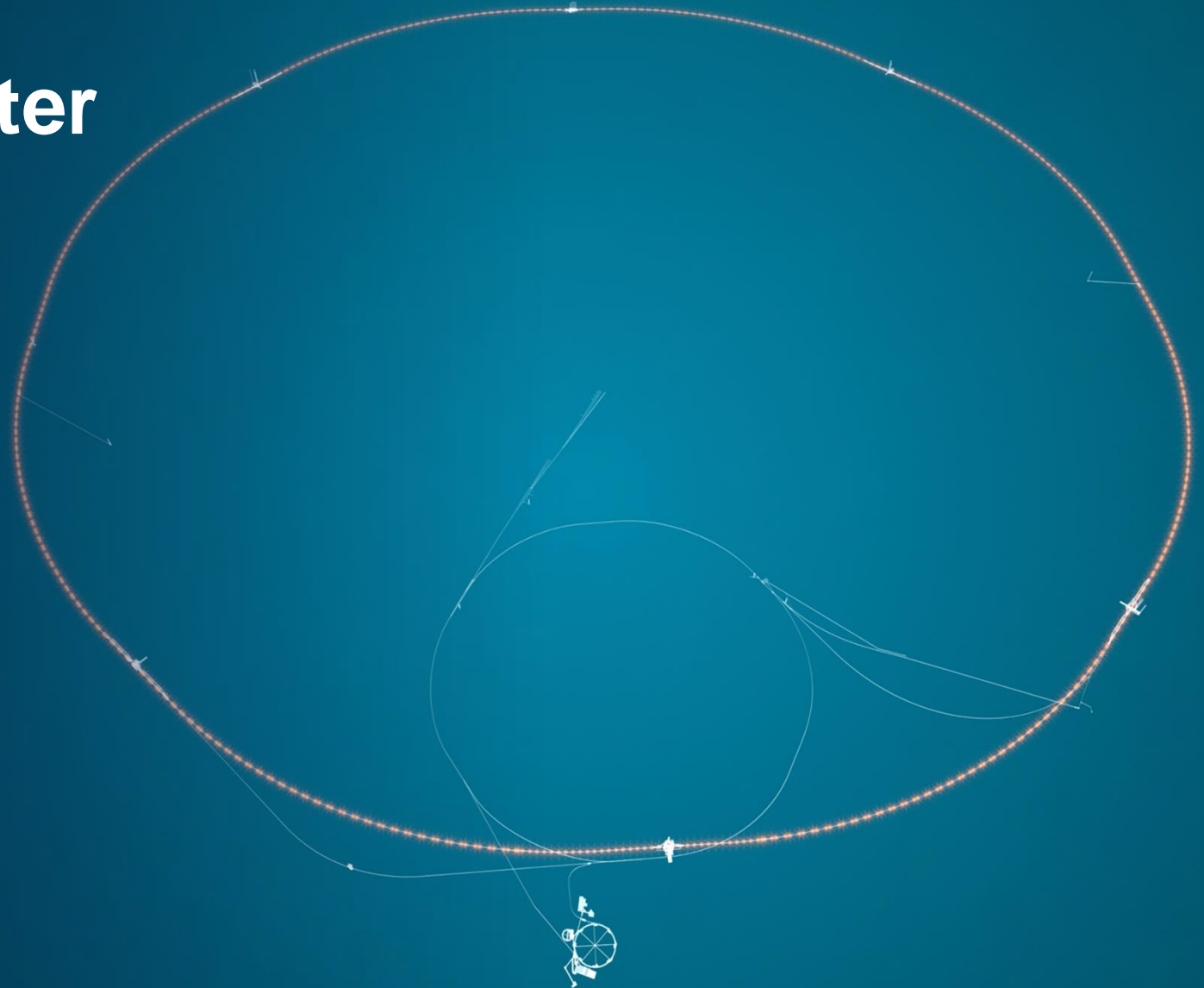
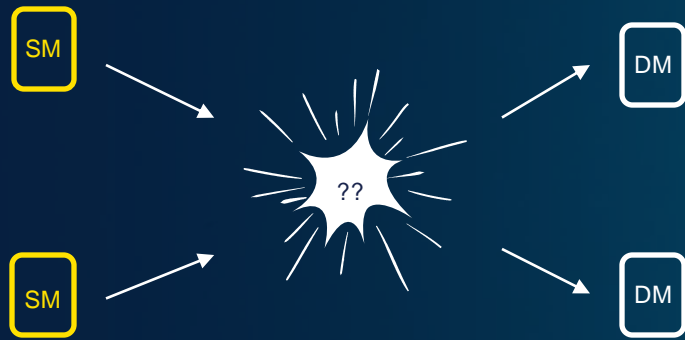
Hunting for Dark Matter



Hunting for Dark Matter

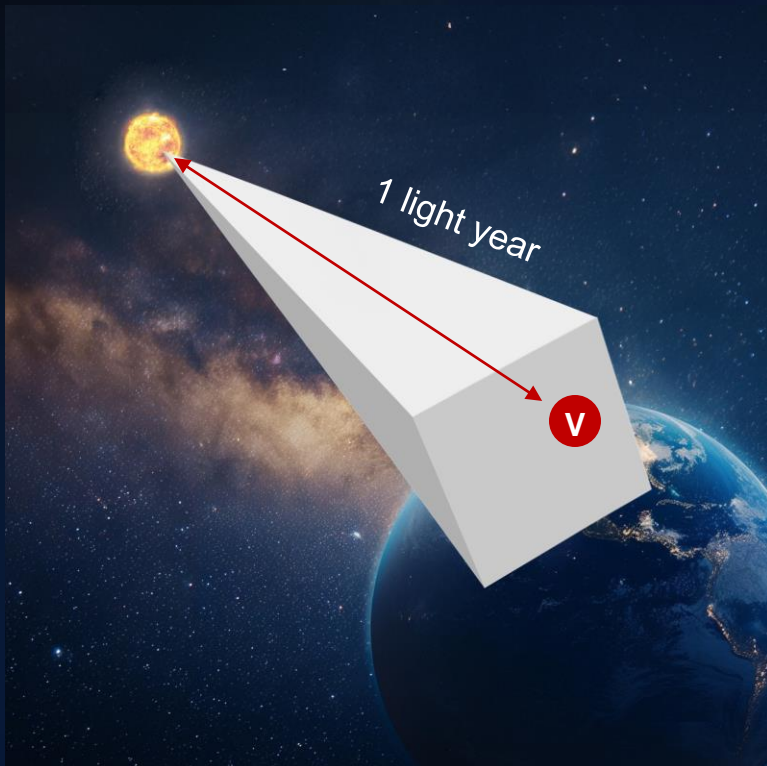


Hunting for Dark Matter



How to detect neutrinos?

To be sure to detect 1 neutrino:



Luckily, sources produce MANY neutrinos!



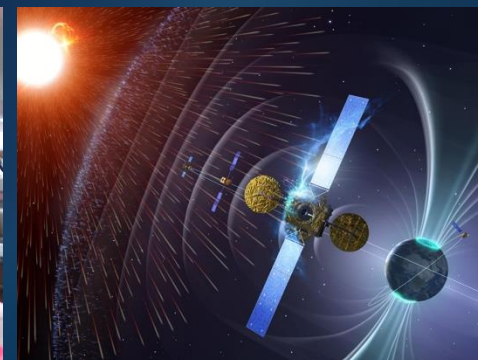
Nuclear reactors



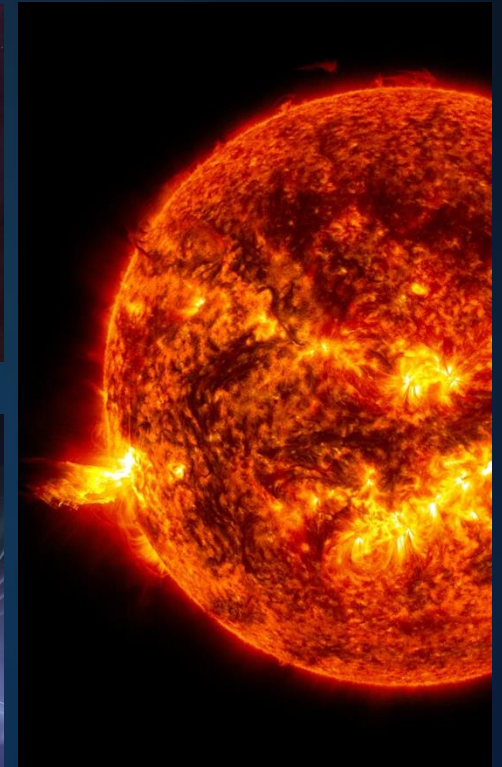
Supernova neutrinos



Accelerators neutrinos



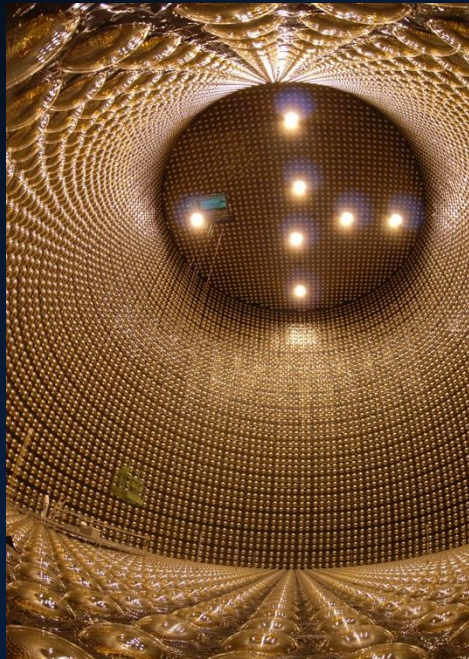
Cosmic rays → atmospheric neutrinos



Solar neutrinos

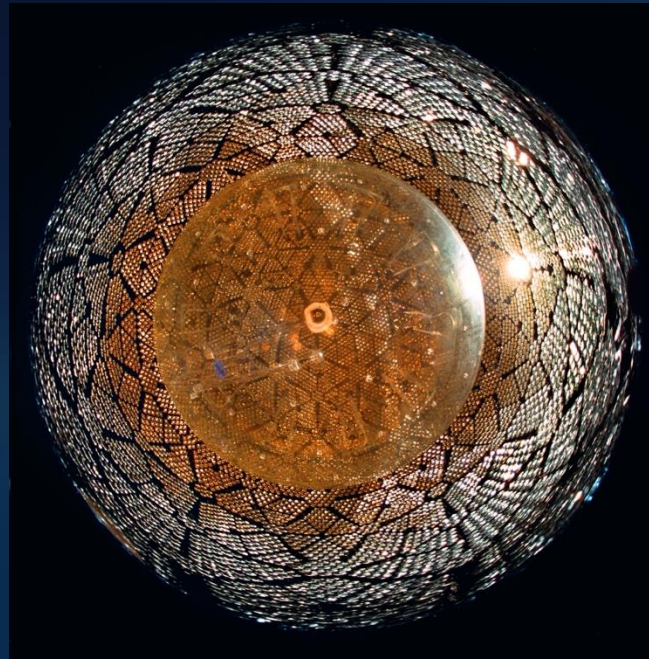
We need very large detectors!

SuperK:
50 000 tonnes water



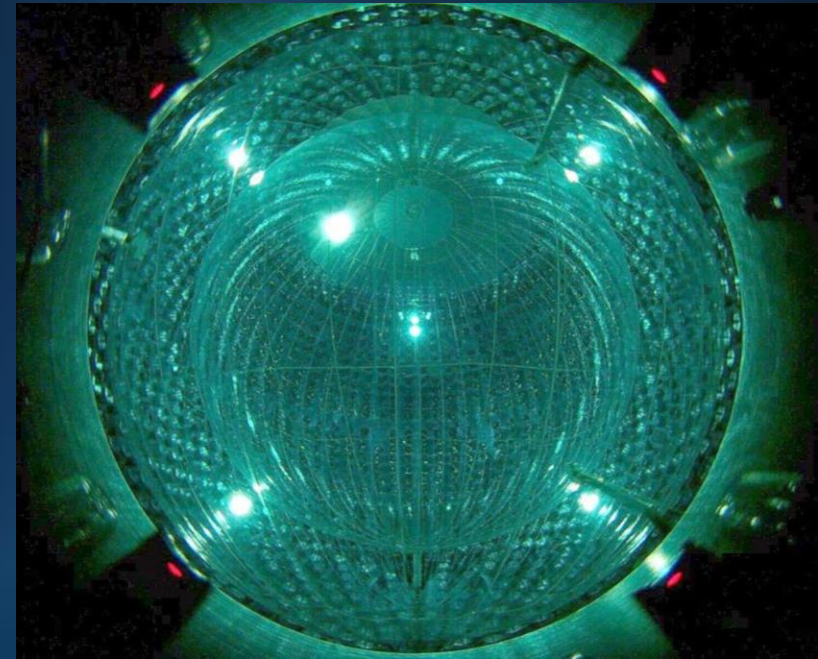
Credit: SK Collaboration

SNO:
1000 tons heavy water



Credit: SNO Collaboration

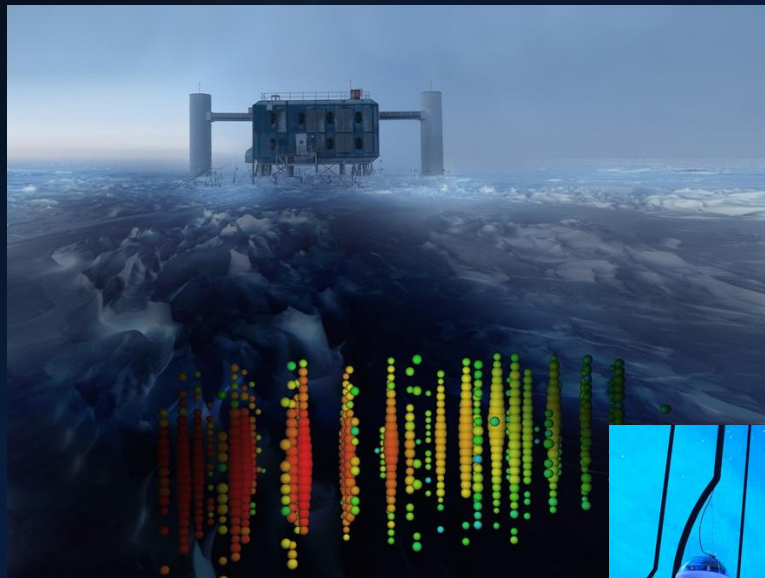
Borexino:
300 tons Liquid Scintillator



Credit: Borexino Collaboration

We can use Nature to make them even bigger!

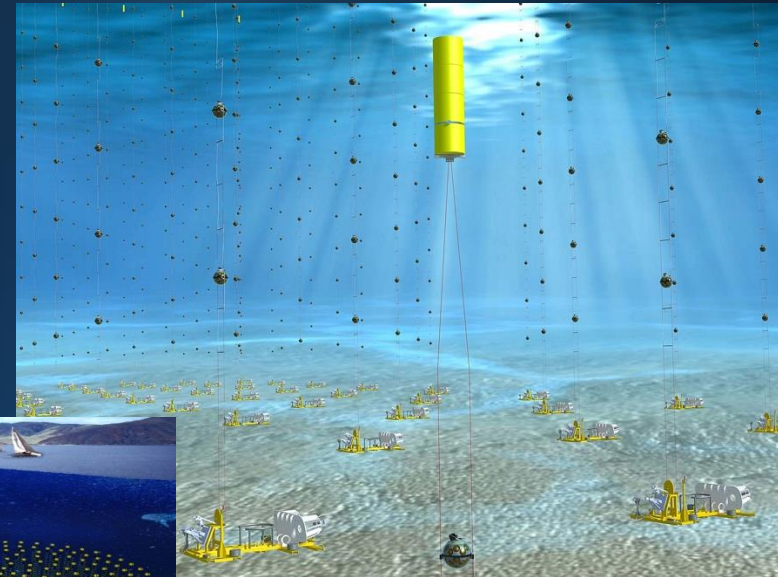
IceCube: km³ ice detector
at the South Pole



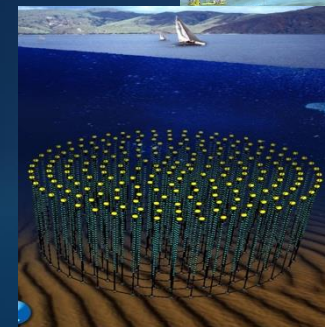
Credit: IceCube/NSF



Km³Net: km³ water detector
in the Mediterranean Sea

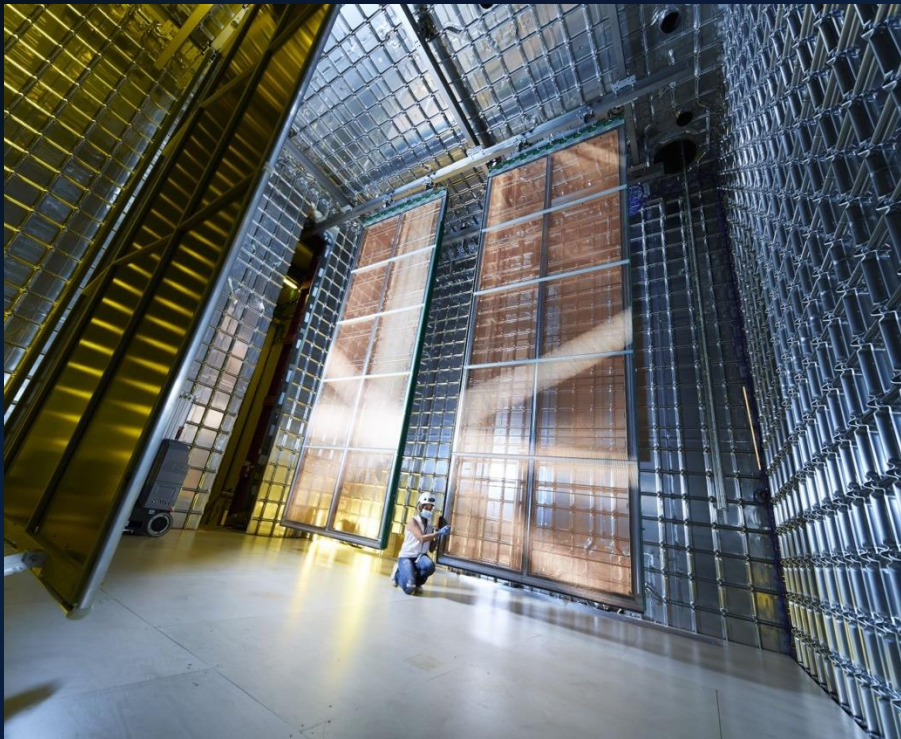


Credit: KM3net website



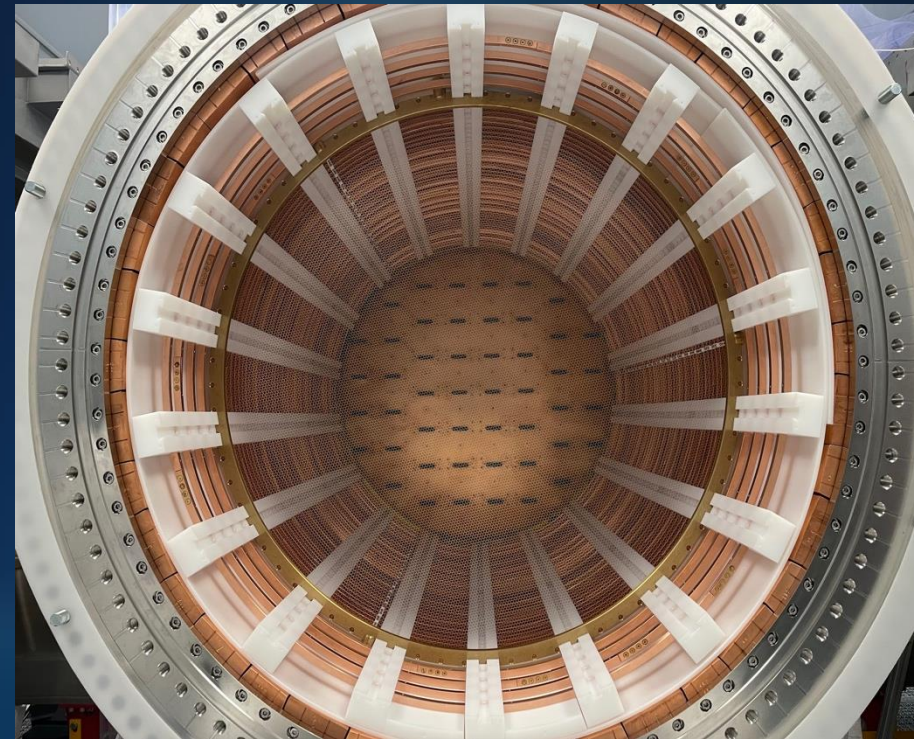
Imaging neutrinos in high resolution with Noble Element Detectors

ProtoDUNE detector: Liquid Argon



Credit: DUNE Collaboration

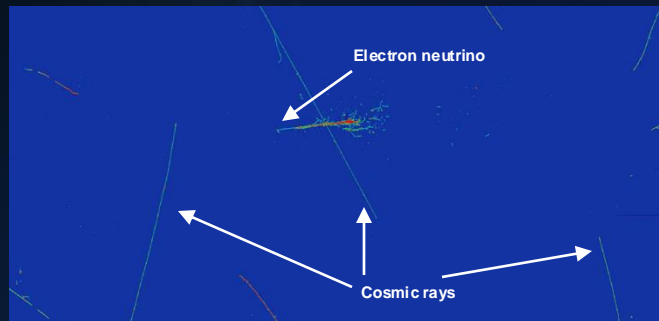
NEXT detector: Gas Xenon



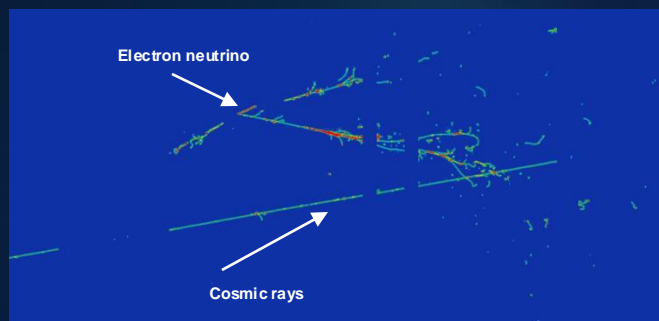
Credit: NEXT Collaboration

Imaging neutrinos in high resolution with Noble Element Detectors

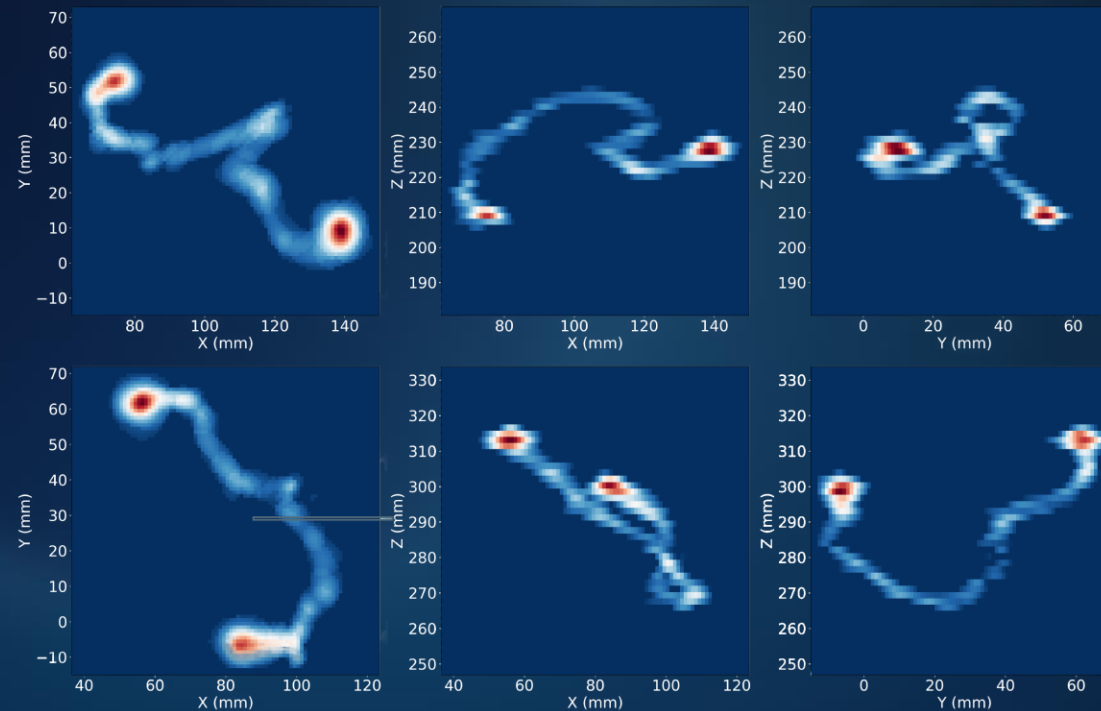
MicroBooNE Experiment (Liquid Argon)



MicroBooNE Experiment (Liquid Argon)



NEXT Experiment (Gas Xenon)

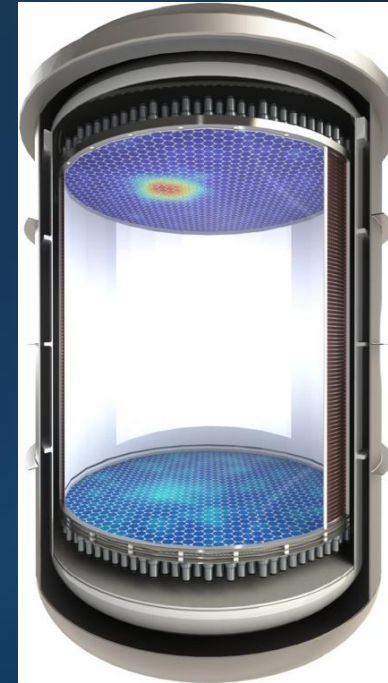


The next generation of experiments

XLZD: ~50 tonnes of Liquid Xenon



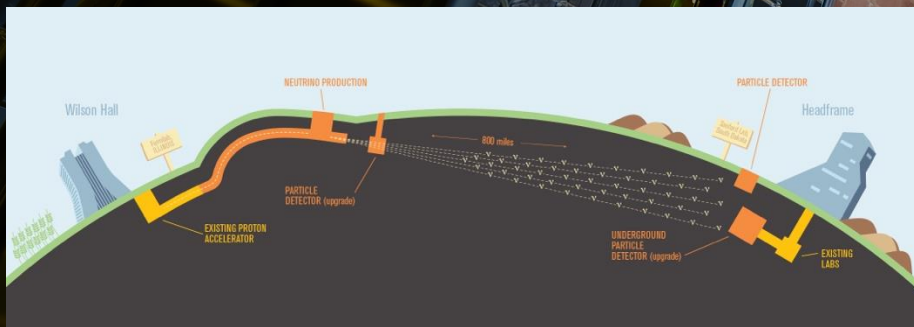
XENONnT detector



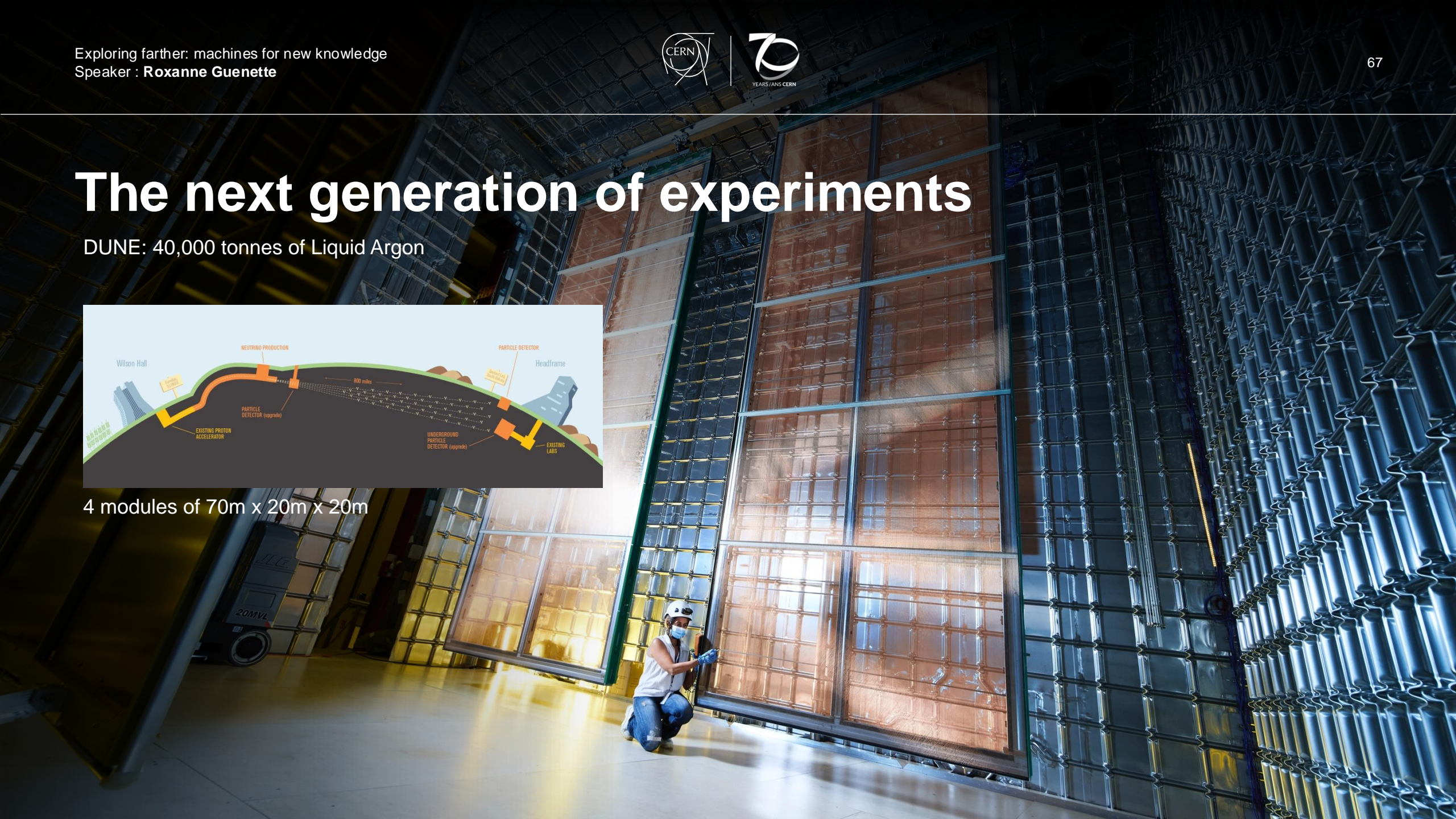
1 detector of 2.6
diameter by 2.6m height

The next generation of experiments

DUNE: 40,000 tonnes of Liquid Argon



4 modules of 70m x 20m x 20m



How to go even larger?

To build larger Xenon detectors, we need more Xenon!
Only 50-100 tonnes of Xe are produced per year

Xenon production is tightly coupled
to oxygen extraction for steelmaking

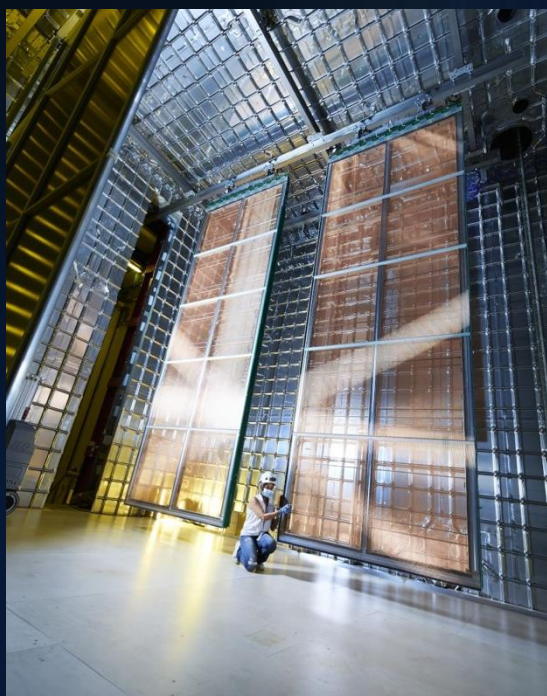


Linde Air Separation Unit

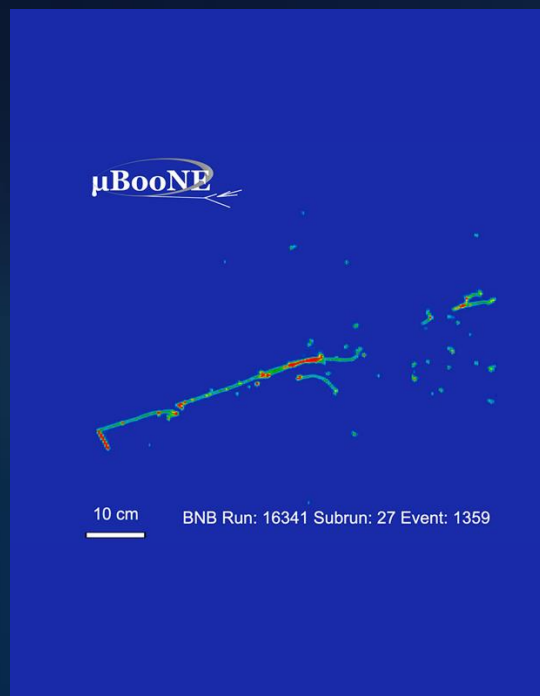


Rare Event Searches

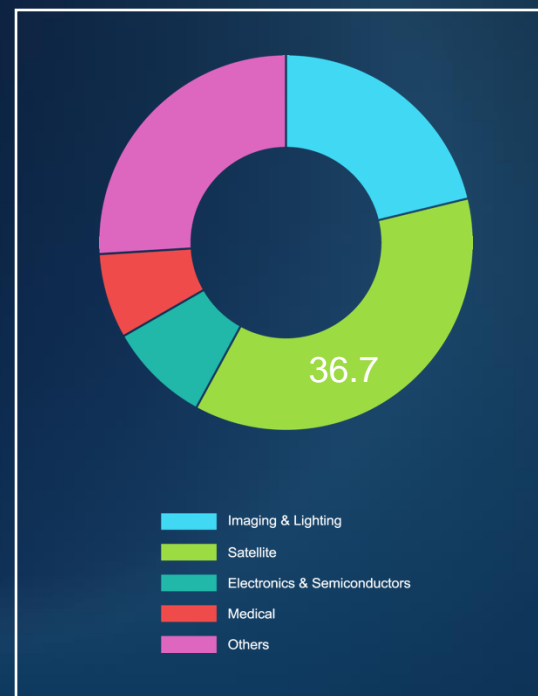
Cryostat technologies
from natural gas industry



Machine learning for
image reconstruction



Global Xenon Market Share,
By Application, 2021



Photons from
positron annihilation





“Measure what can be measured,
and make measurable what cannot be measured.”

Galileo GALILEI

Session 2 – Q&A

Enhanced detectors

Roxanne Guenette

Professor of Particle Physics, Department of Physics and Astronomy, University of Manchester

Petra Merkel

Senior Scientist and Detector R&D Coordinator, Fermilab

Werner Riegler

Technical Coordinator of ALICE and leader of the experiment studies for the Future Circular Hadron Collider, Experimental Physics department, CERN



ACCELERATORS



DETECTORS



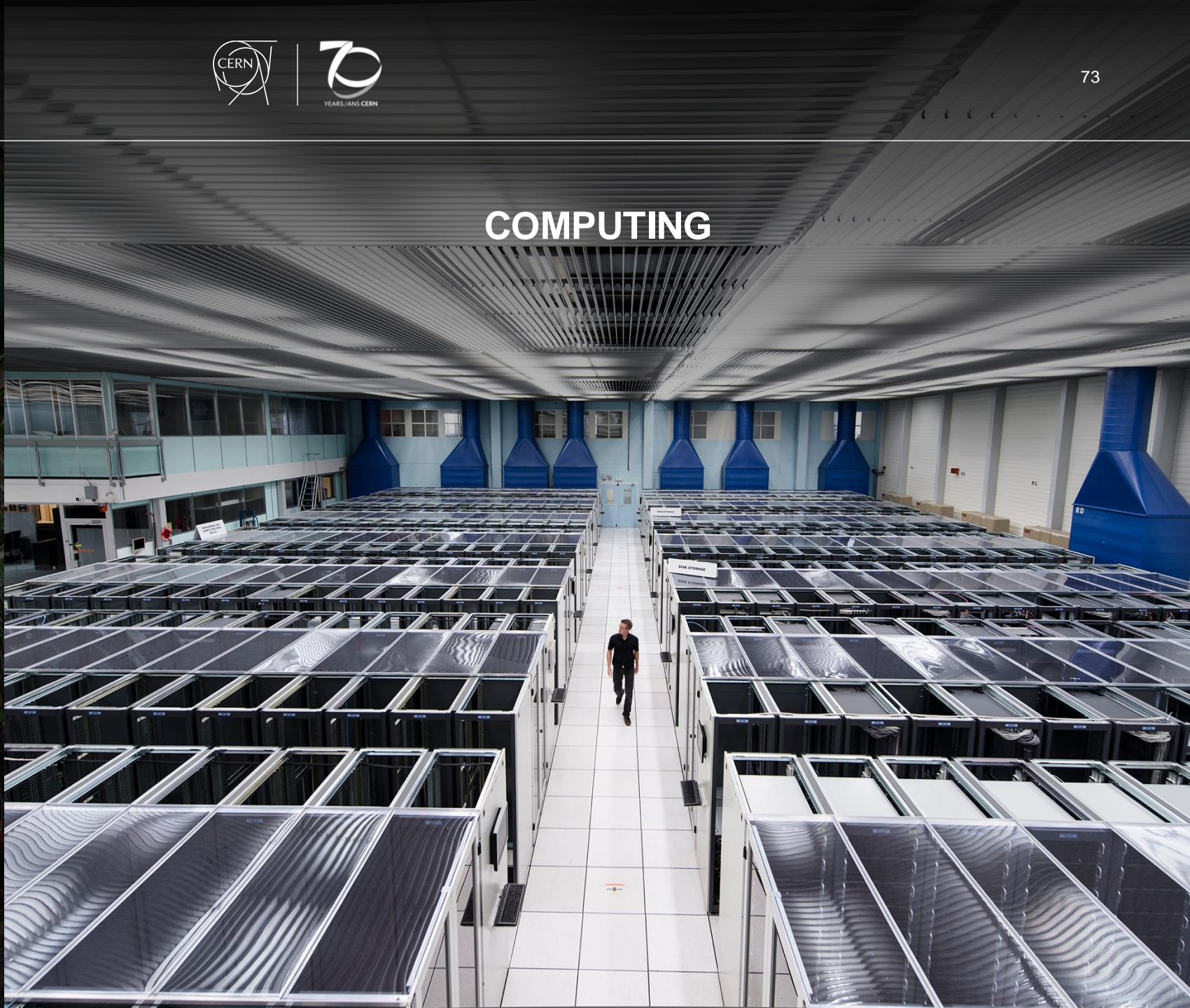
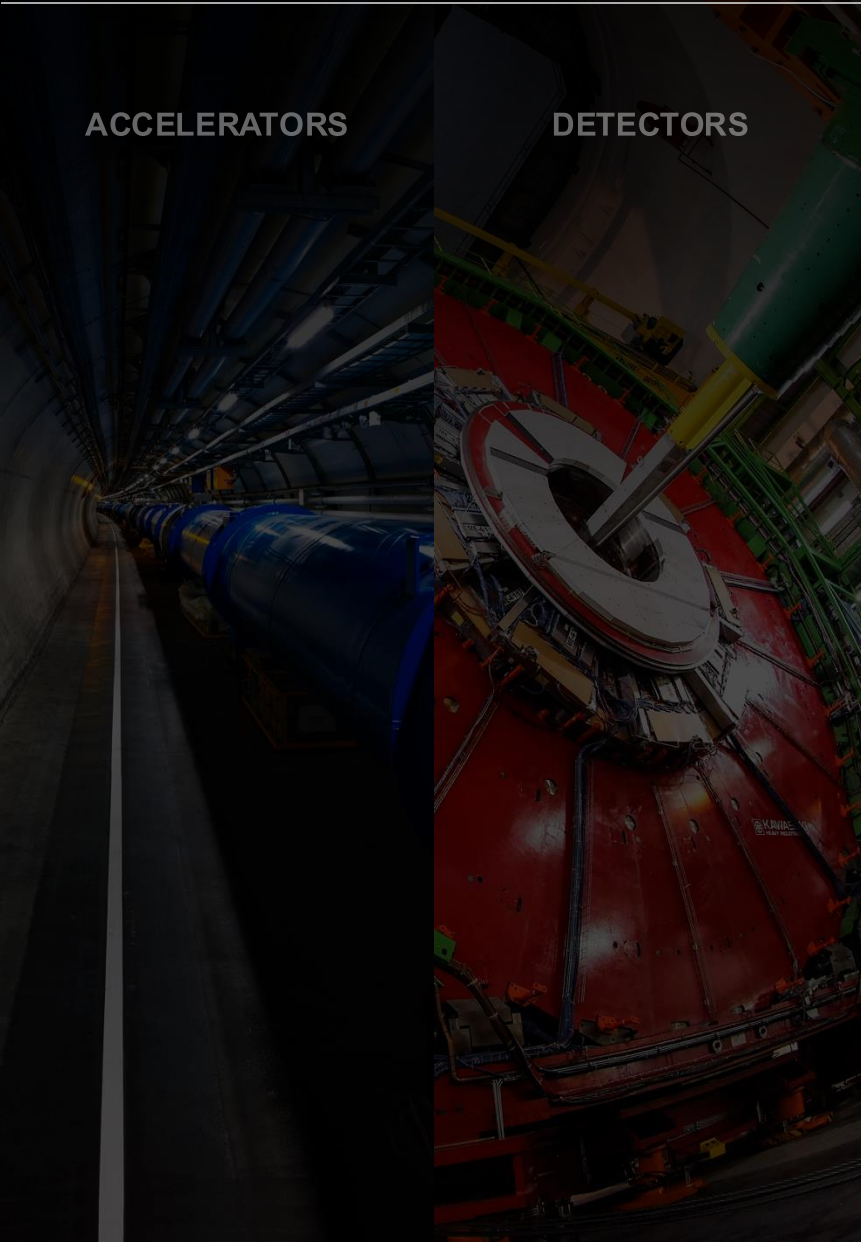
COMPUTING



ACCELERATORS

DETECTORS

COMPUTING



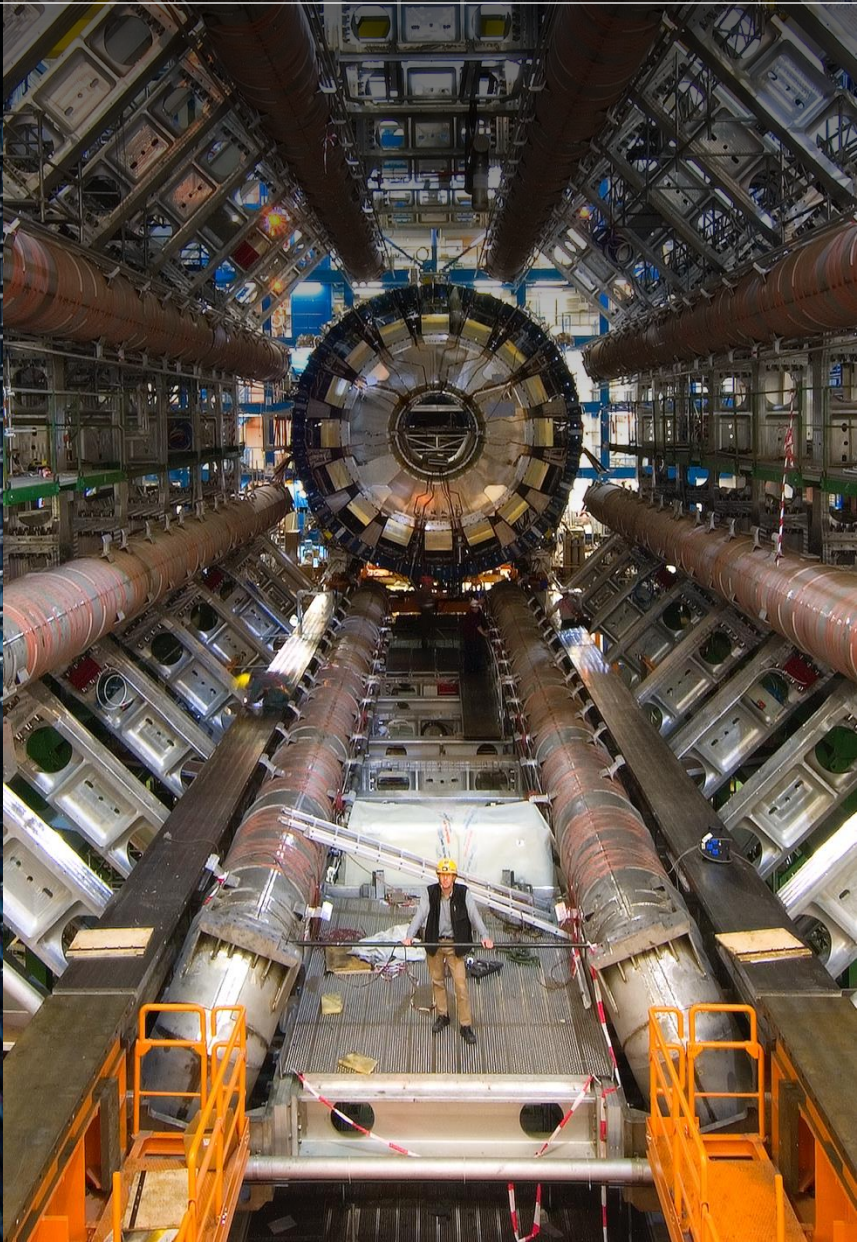
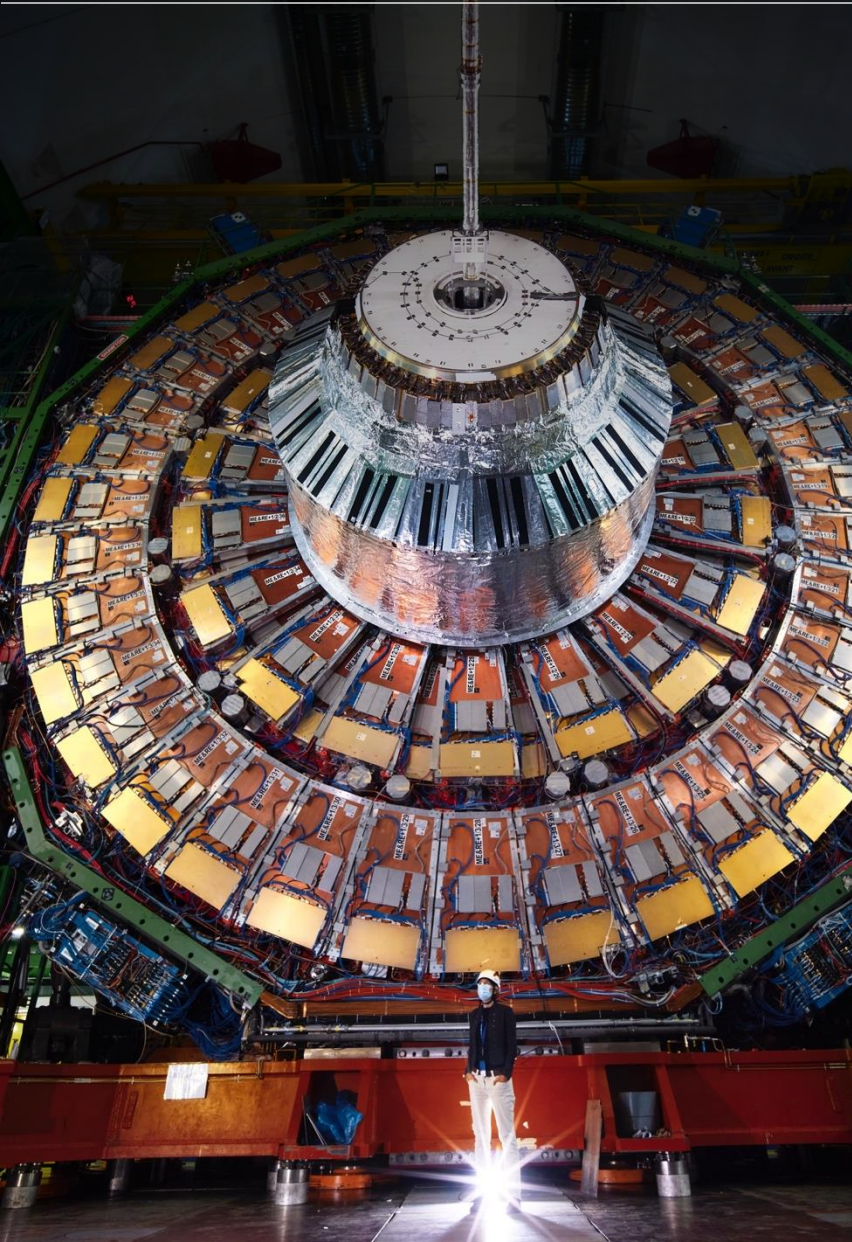
Session 3


Intelligent computing systems

Cristina Botta

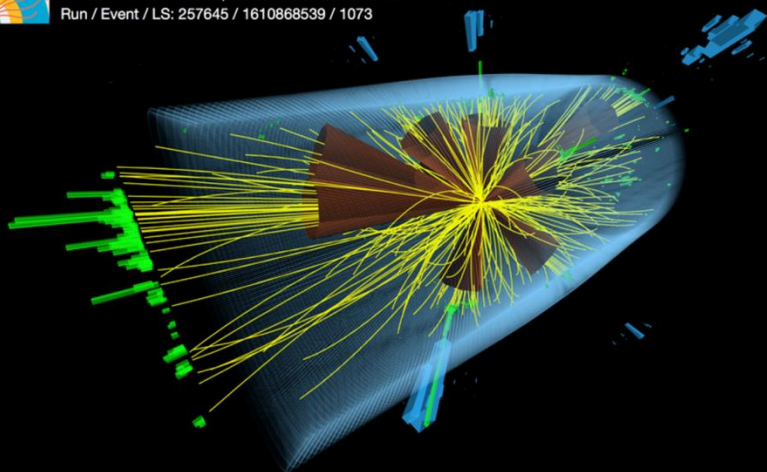
Physicist, Experimental Physics department, CERN







CMS Experiment at the LHC, CERN
Data recorded: 2015-Sep-28 06:09:43.129280 GMT
Run / Event / LS: 257645 / 1610868539 / 1073



low energy, light
quarks/gluons:
1'000'000'000/sec

pairs of heavier quarks,
bottom quarks:
100'000/sec

Z, W bosons:
1'000 events/sec

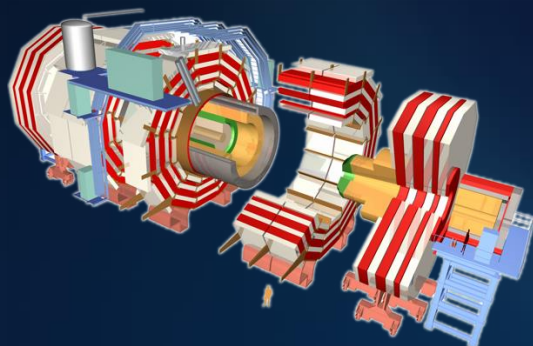
pairs of the heaviest
quarks top quarks:
10/sec

few Higgs bosons per minute!
... and similar or lower event rate (?)
for the New Physics we are searching for

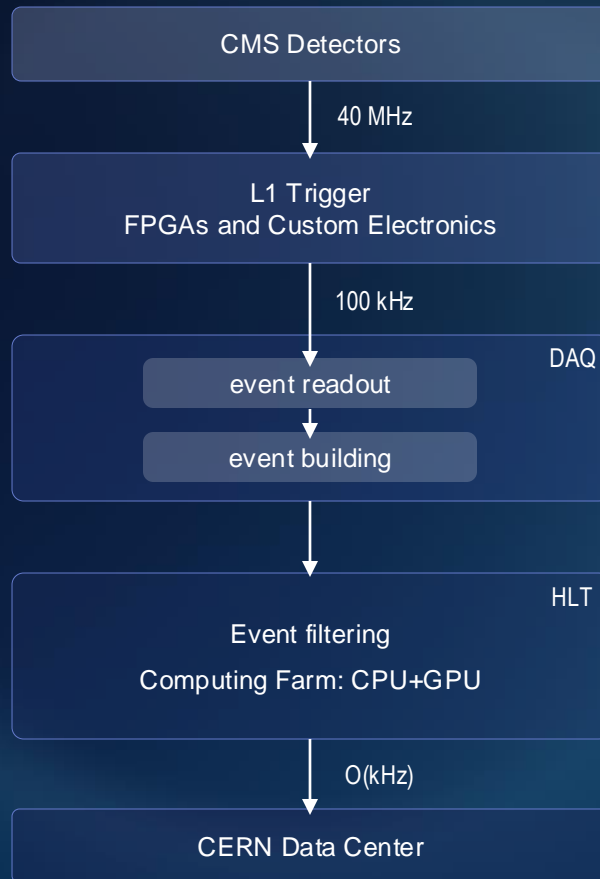




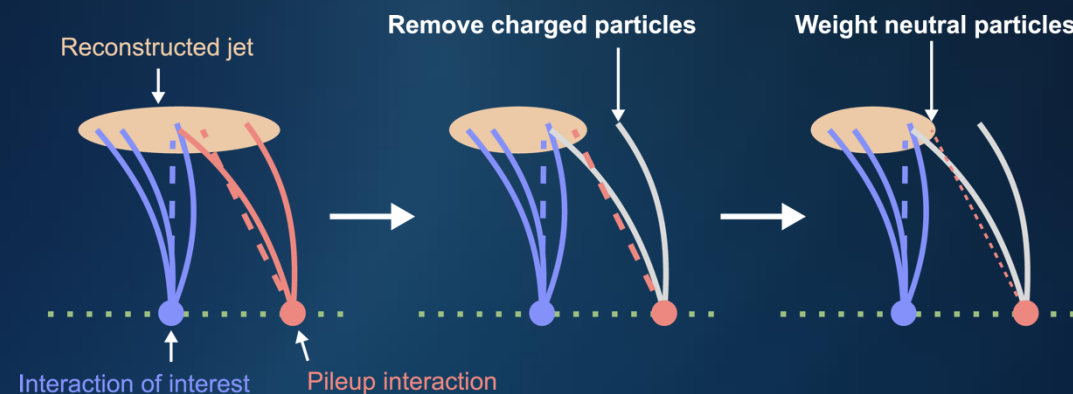
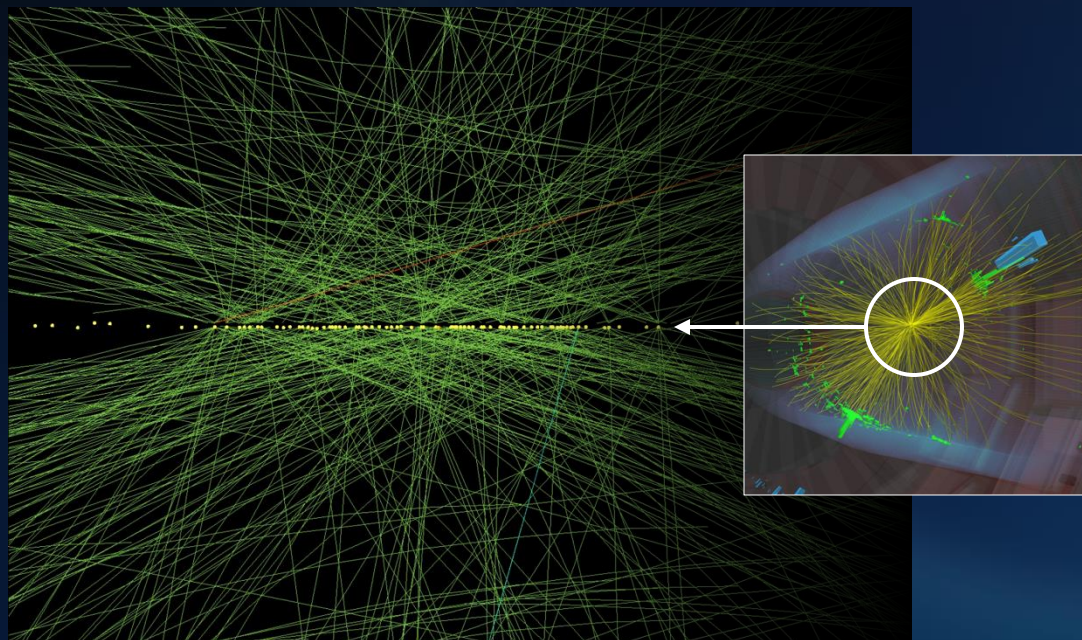
CMS L1 Trigger



CMS High Level Trigger

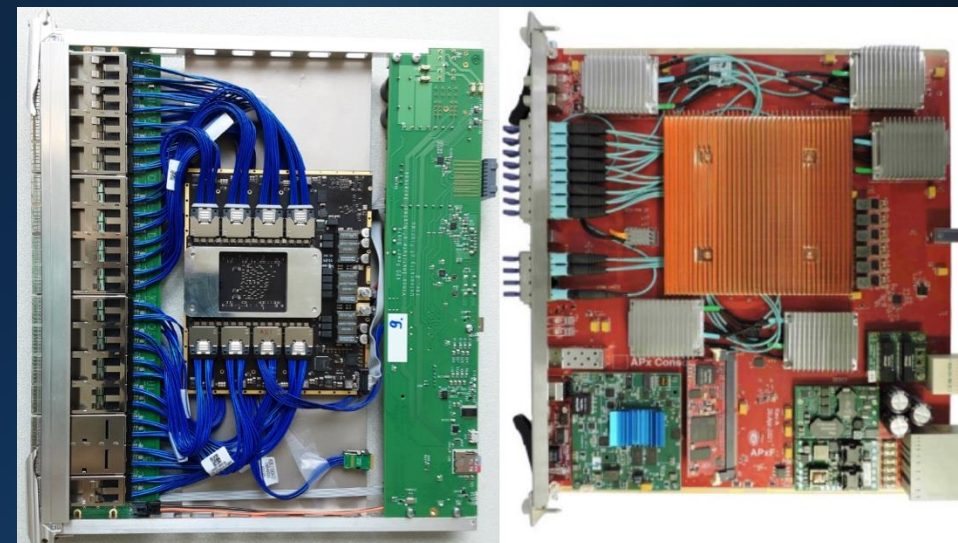
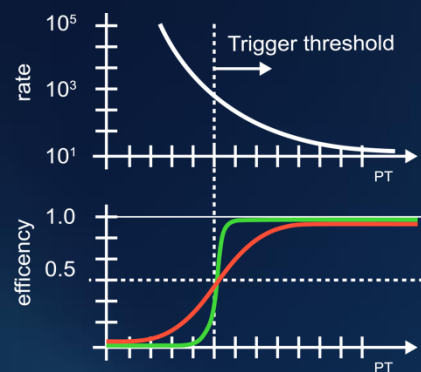
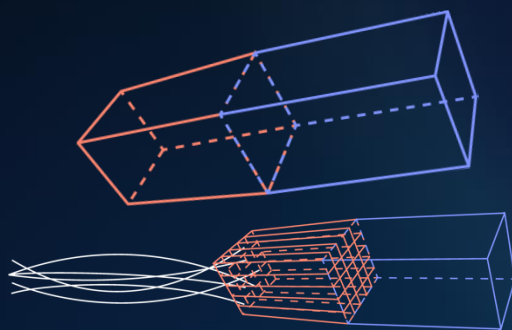


High Luminosity LHC: up to 200 proton-proton collision per bunch crossing



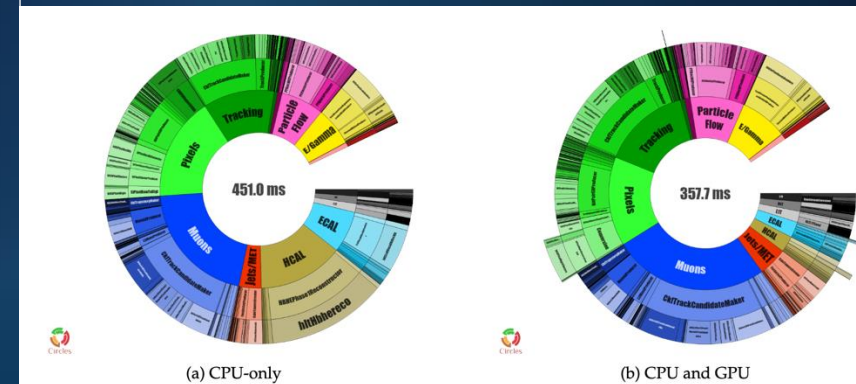
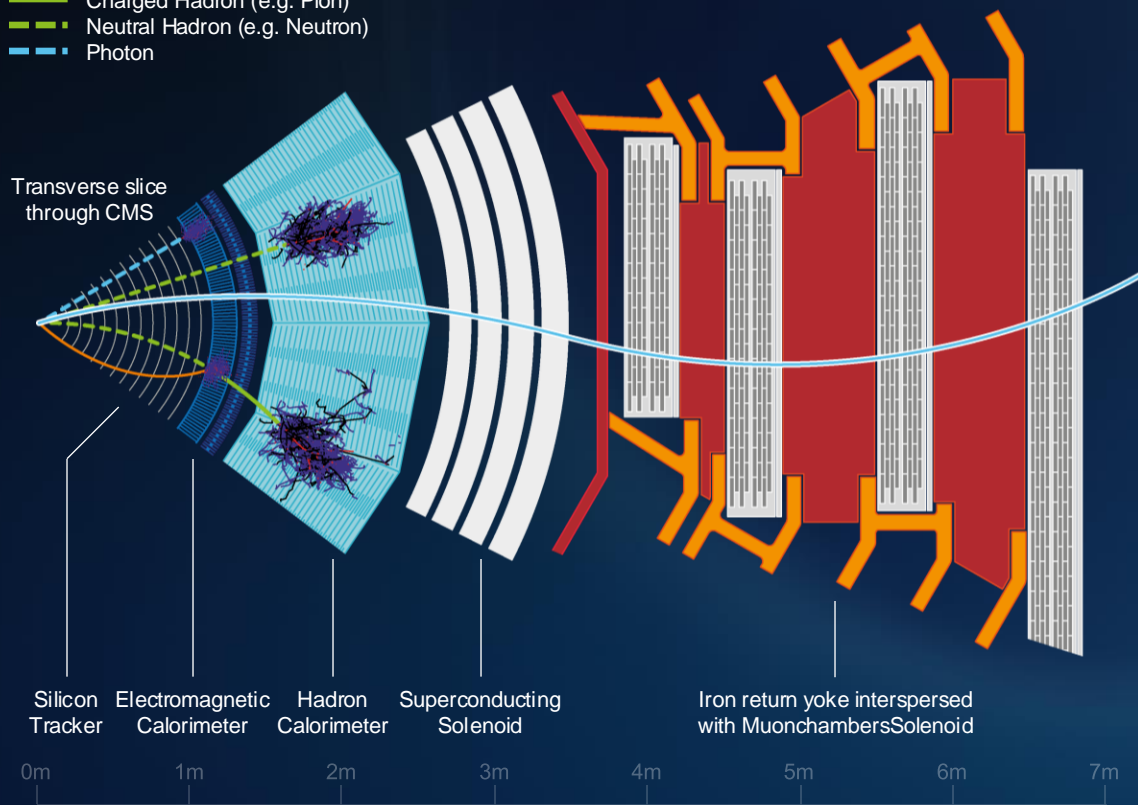
New CMS L1 Trigger for HL-LHC

From 2 Tb/s to 63 Tb/s (1/10 of the internet traffic)



CMS High Level Trigger

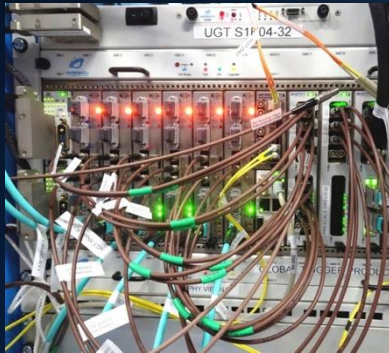
- Muon
- Electron
- Charged Hadron (e.g. Pion)
- Neutral Hadron (e.g. Neutron)
- Photon





NextGen

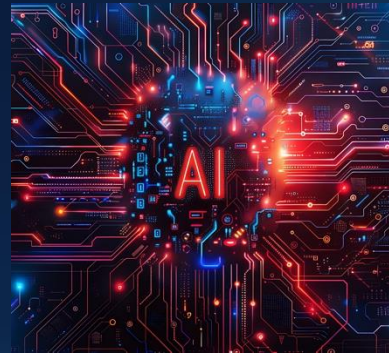
Next Generation Triggers



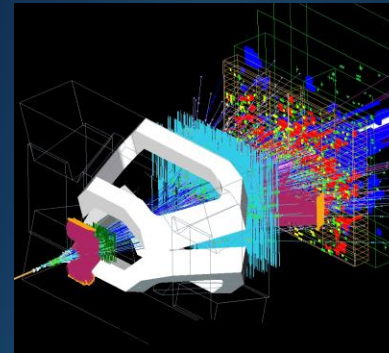
Experiment: Trigger Systems



Heterogeneous Computing



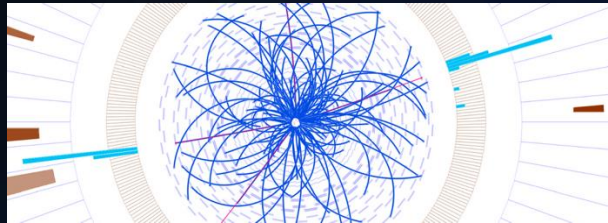
Artificial Intelligence



Physics Simulation



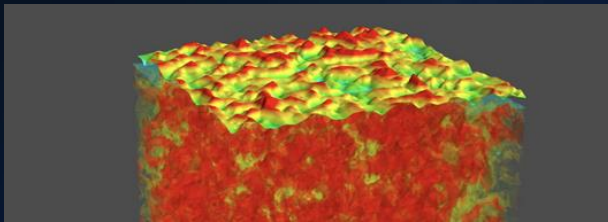
Education and Training



New theory models as benchmarks
for new trigger systems



software developments for
heterogeneous architectures



New strategies for physics simulation



Hardware and services for
large scale training and simulation



Hardware-aware AI optimisation



Fast inference of complex network

Session 3

Intelligent computing systems

Andreas Lintermann

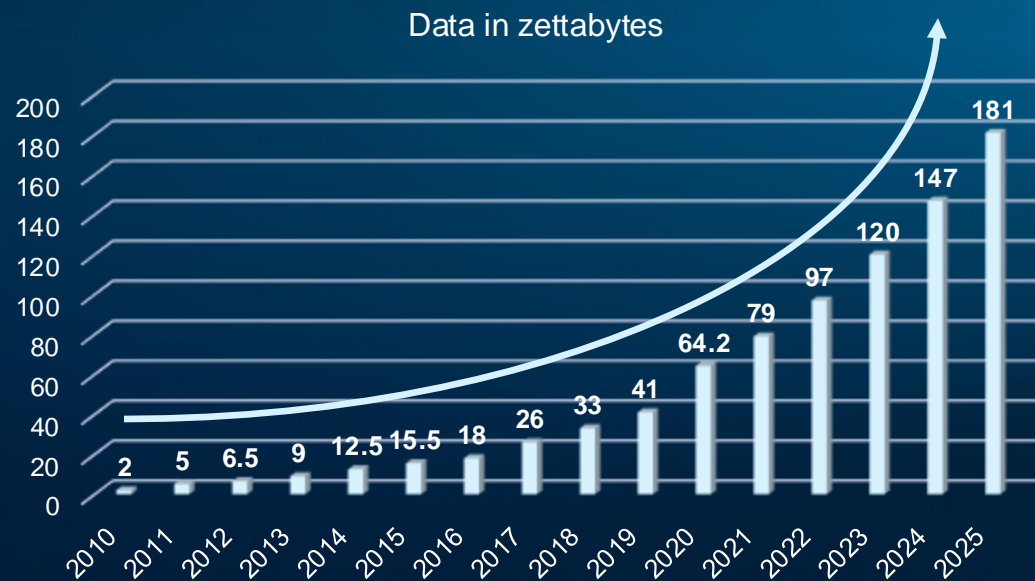
Coordinator of the European Center of Excellence in Exascale Computing RAISE and leader of the Simulation and Data Laboratory "Highly Scalable Fluids & Solids Engineering" at the Jülich Supercomputing Centre, Forschungszentrum Jülich



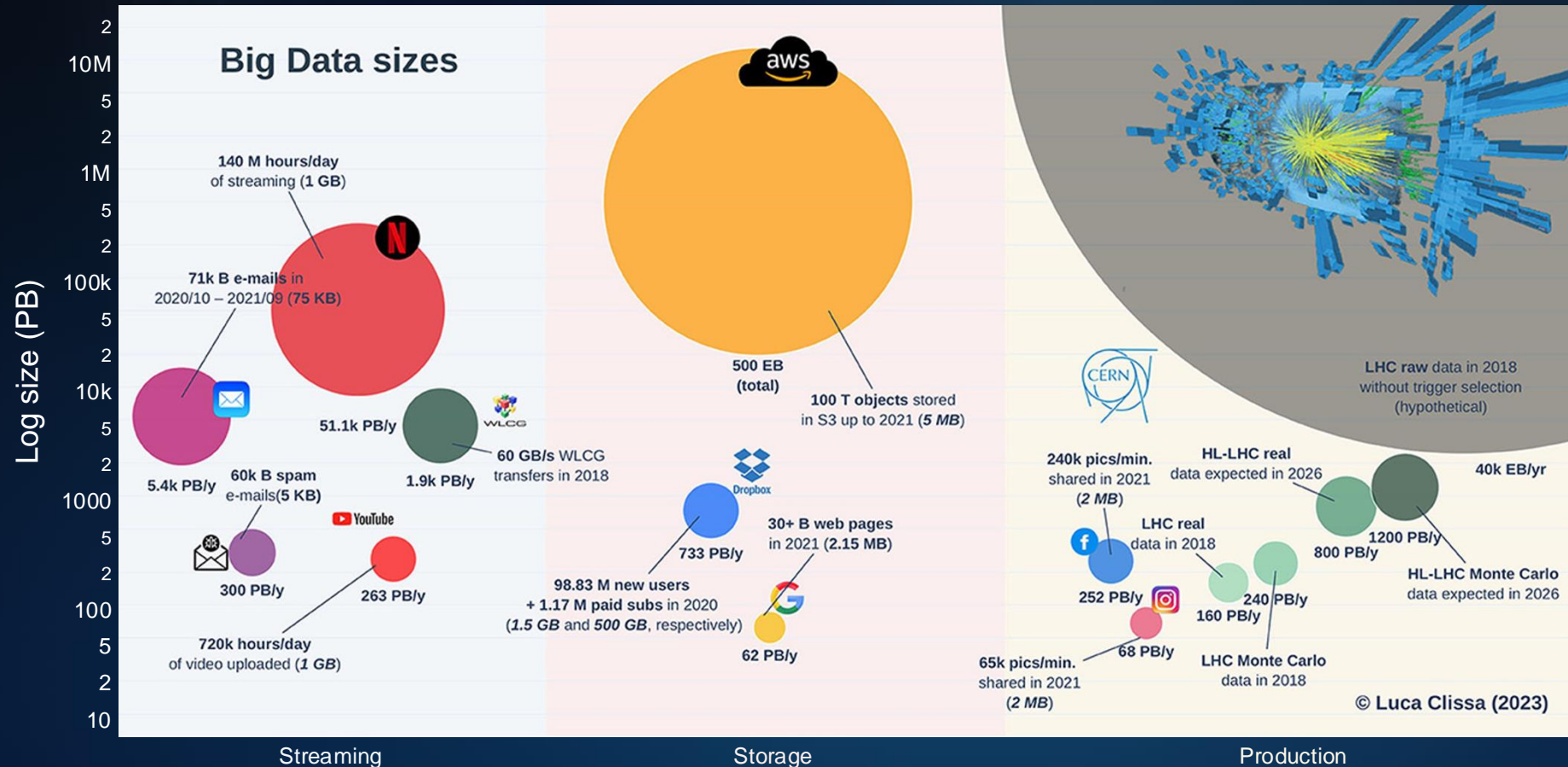
A massive growth in data

Data / Information created, recorded, copied, and consumed world-wide

181 ZB = 1.81×10^{11} TB



Big Data



A comprehensive survey of data production, storage, and streaming in science and industry

How can this amount of data be processed?



Massive amount of data

How can this amount of data be processed?

The concept of parallel data processing / computing



Massive amount of data
split into pieces

Parallel input

⋮

⋮

High-Performance
Computing Systems

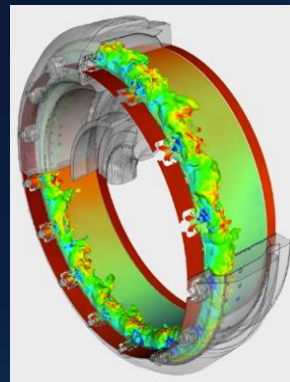
Millions of compute cores

Special hardware for special purpose

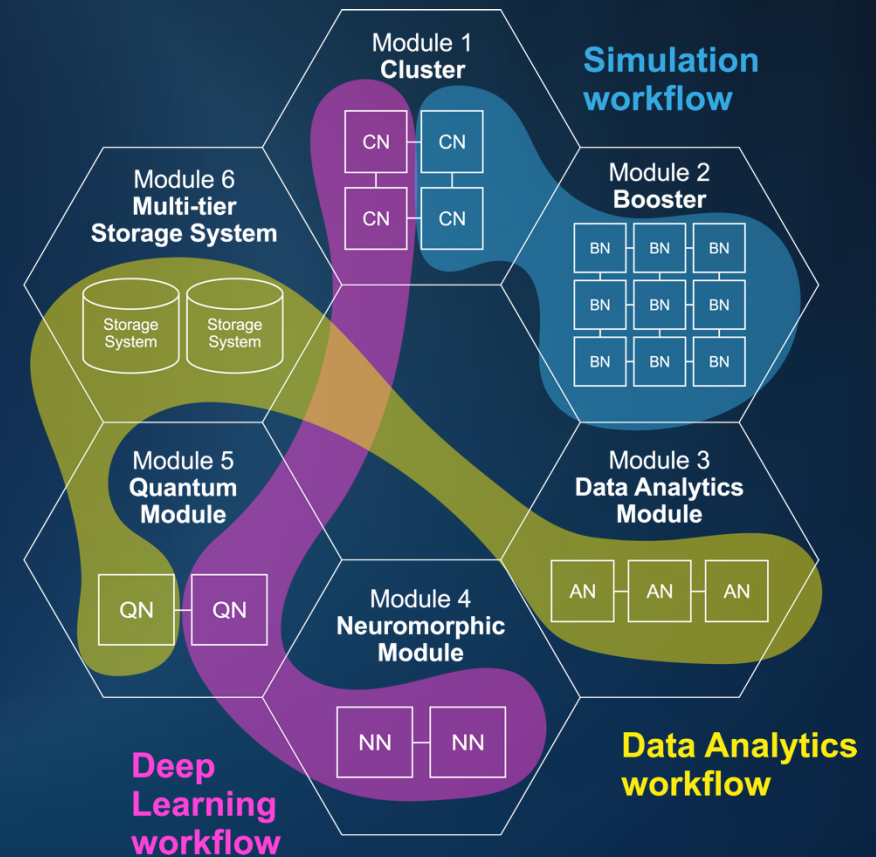
Modular Supercomputing Architectures: Heterogeneous Computing



Complex hardware

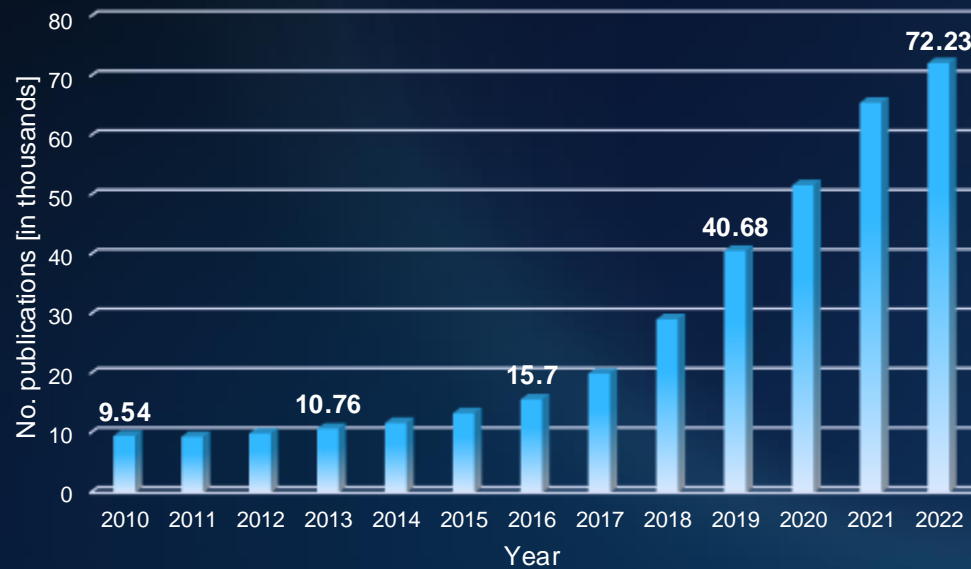


Complex tasks

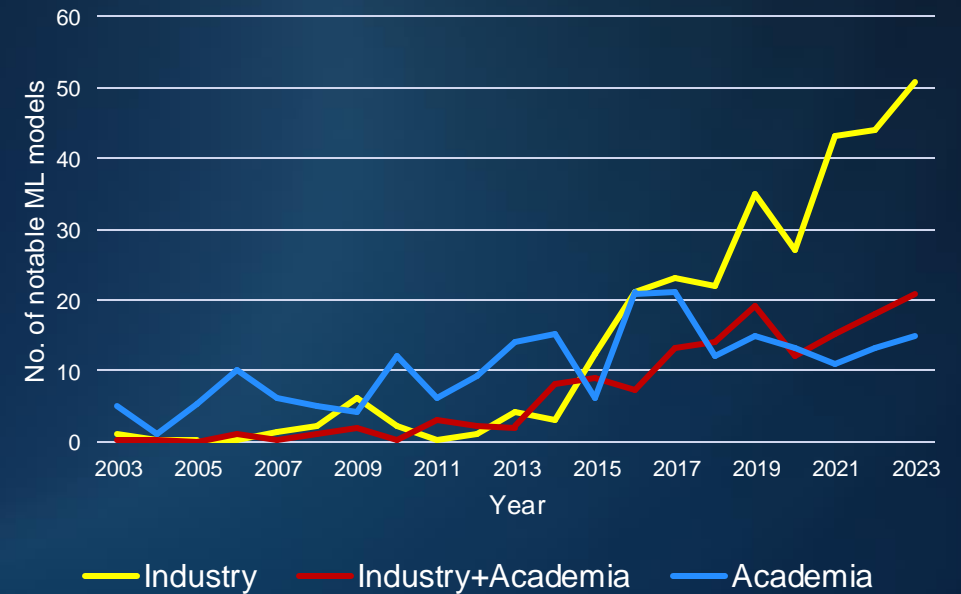


The role of AI in science and industry

Number of ML Publications

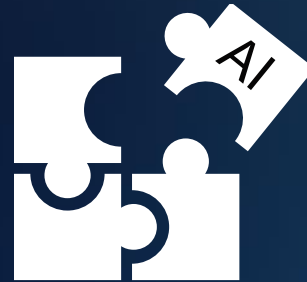


Number of notable ML models

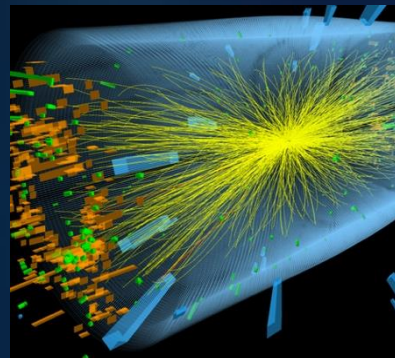


The role of AI in science / industry / society

Prediction, modeling, acceleration, automatization, replacement of traditional methods



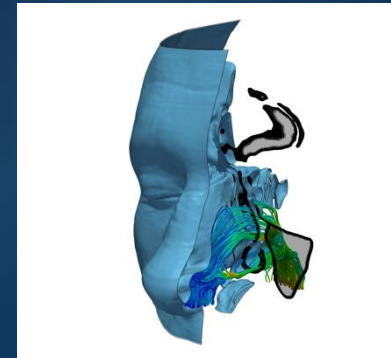
Engineering



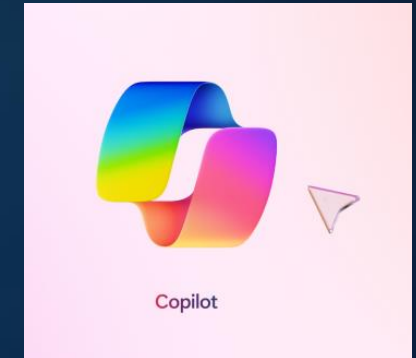
High-Energy Physics



Entertainment



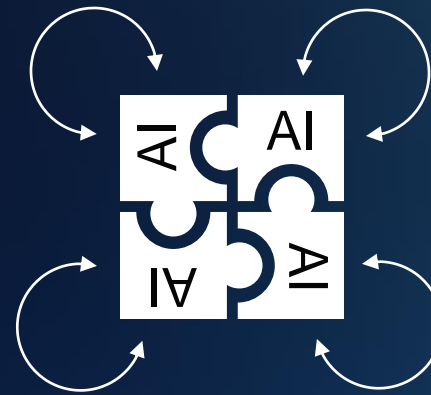
Medicine



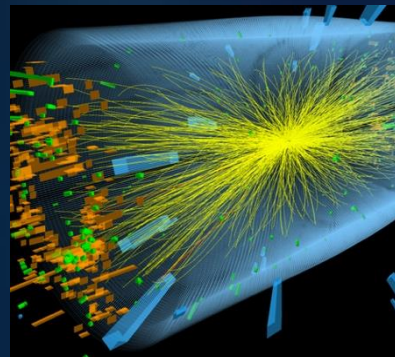
Personal assistant

AI trends: from single- to multi-purpose

Foundational models as AI trained on heterogeneous data



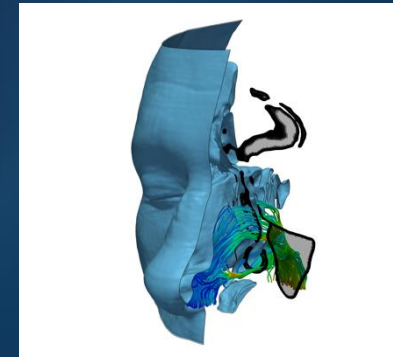
Engineering



High-Energy Physics



Entertainment



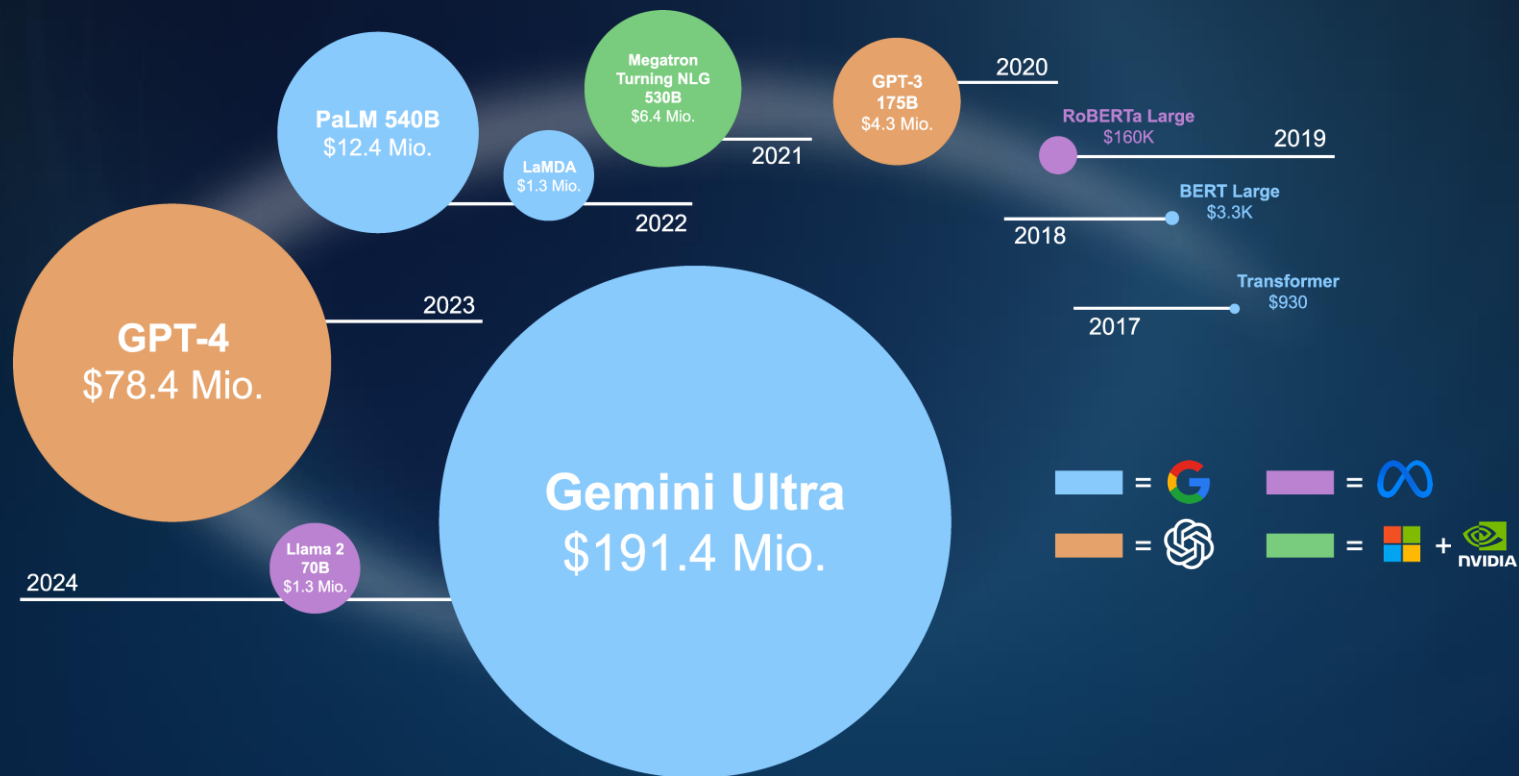
Medicine



Personal assistant

The cost of AI training

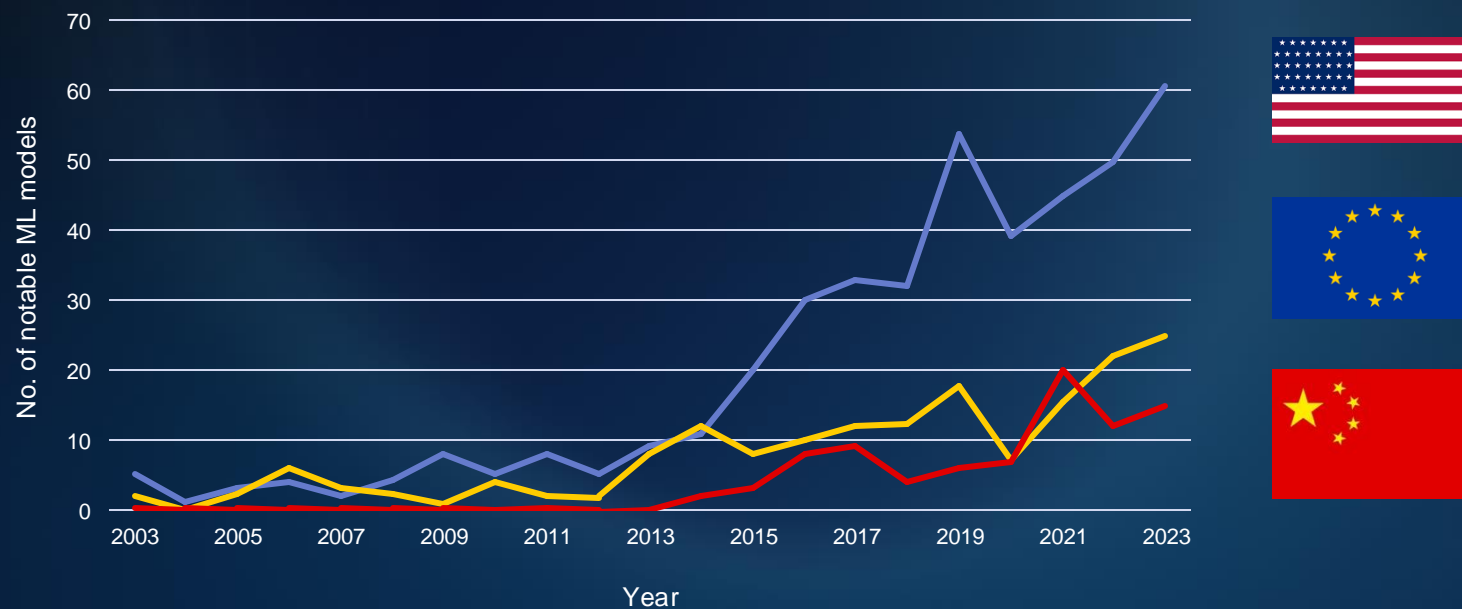
Massive increase of costs: hardware, energy, etc.



World-wide AI developments

How to keep up with the developments?

Number of notable ML models by geographics region



EuroHPC: HPC in Europe

Infrastrutture

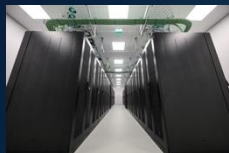
JUPITER
1 EFlop



MELUXINA
18.29 PFlops



DEUCALION
5.01 PFlops



MARENOSTRUM 5
295.81 PFlops



LUMI
539.13 PFlops



KAROLINA
12.91 PFlops



VEGA
10.05 PFlops



DISCOVERER
5.94 PFlops



LEONARDO
315.74 PFlops



AI and HPC landscape in europe

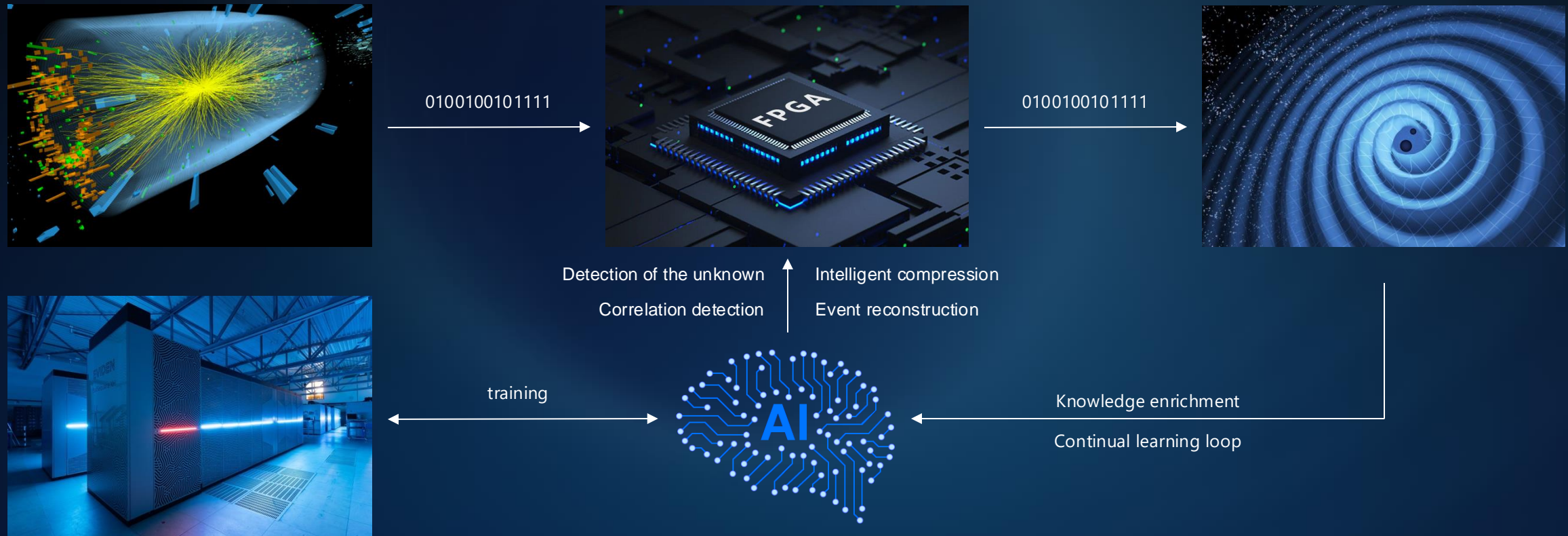
Support of Projects & Education; Access to knowledge



The future of data processing

Dealing with large streaming data

Of the Zettabytes of data produced by CERN's HL-LHC, 99.9% cannot be inspected



Asking AI to generate the Tour de France



Session 3 – Q&A

Intelligent computing systems

Cristina Botta

Physicist, Experimental Physics department, CERN

Andreas Lintermann

Coordinator of the European Center of Excellence in Exascale Computing RAISE and leader of the Simulation and Data Laboratory "Highly Scalable Fluids & Solids Engineering" at the Jülich Supercomputing Centre, Forschungszentrum Jülich



Exploring farther: machines for new knowledge

Host: **Paola Catapano**

Speakers: **Edda Gschwendtner, Mike Seidel,
Roxanne Guenette, Petra Merkel, Werner Riegler,
Cristina Botta, Andreas Lintermann**



**CERN PUBLIC
EVENTS —
SEASON 2024**
CERN's 70th
Anniversary

More information and registration three weeks
before each event on visit.cern

Plus d'informations et inscription trois semaines avant
chaque événement sur visit.cern

Programme of Events

Unveiling the Universe

30 January

**From particle physics
to medicine**

7 March

**The virtuous circle
of knowledge and
innovation**

18 April

**CERN: an extraordinary
human endeavour**

As part of the Cineglobe festival

19 May

**The case of the (still)
mysterious Universe**

6 June

**Exploring farther:
machines for new
knowledge**

4 July



CERN & Society
Foundation

