CERN: A GATEWAY TO SCIENCE, TECHNOLOGY AND INNOVATION

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June20th 2017

South Asian High Energy Physics Instrumentation Workshop on Detector Technology and Applications
Kathmandu University

CERN
CH1211
Geneva, Switzerland

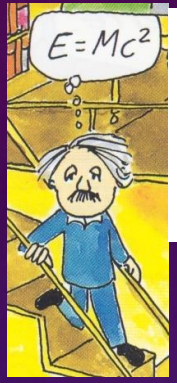
CERN

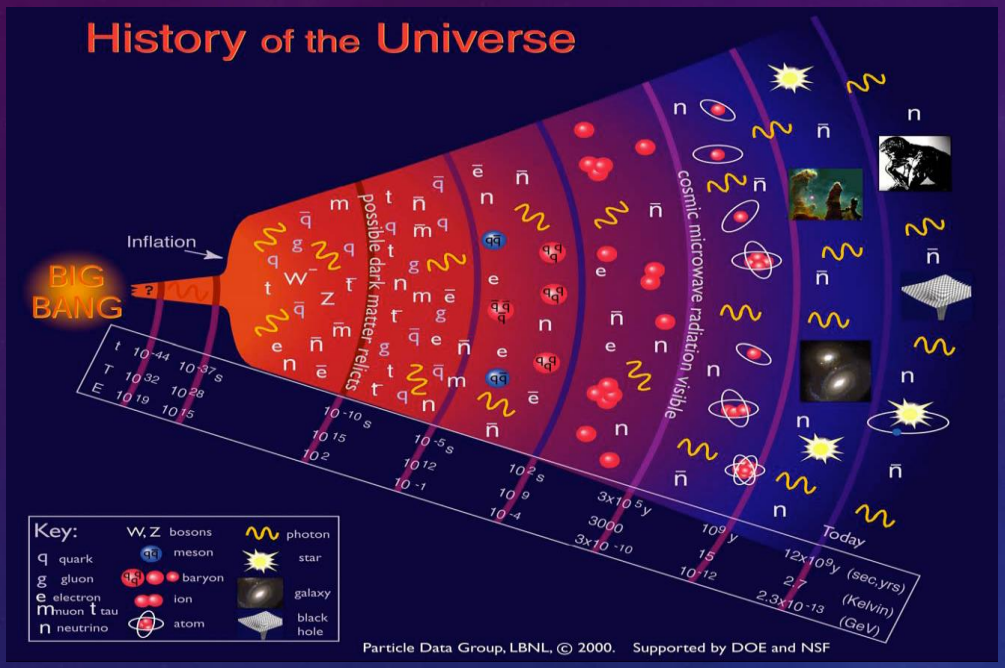
- International leadership in particle physics research
- Leading Edge Engineering & Technological partnerships with Industry, Knowledge Transfer
- Highly Skilled in Specialized Competencies
- World Wide Collaboration Network Management
- Well established Education & Outreach

The Global Innovation Index 2016 (GII) report, highlights CERN's successful innovation initiatives. (Image: GII)

What is the world made of?
What holds the world together?
Where did we come from?

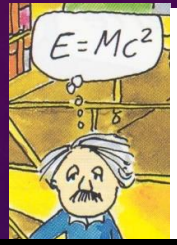
Time Machine





Primary physics targets

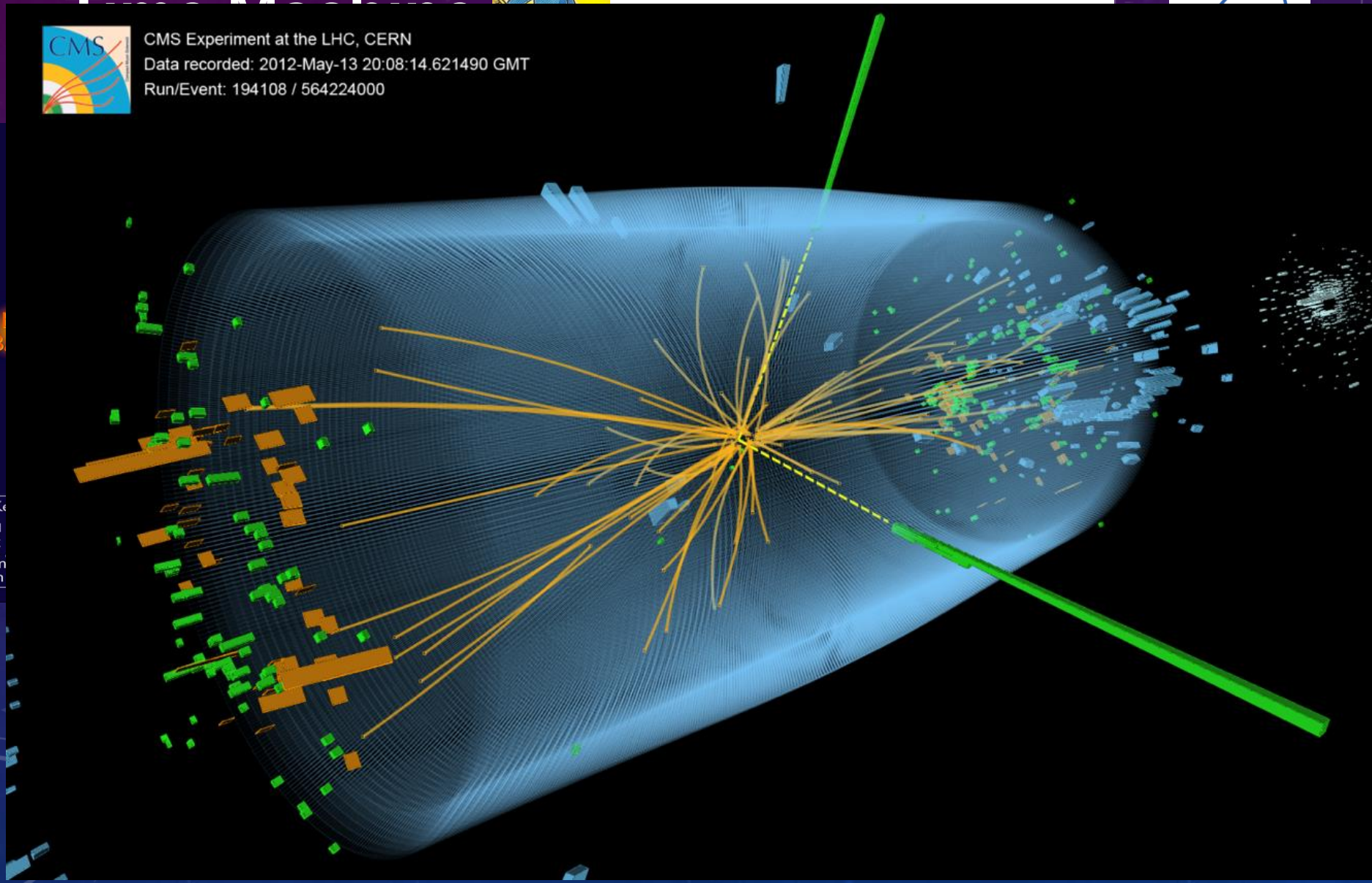
- Origin of mass .. Nature of Dark Matter .. Understanding space time … .. Matter versus antimatter .. Primordial plasma .. Higgs Boson .. SUSY$_4$.. CP Violation



CERN

Time Machine

CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000



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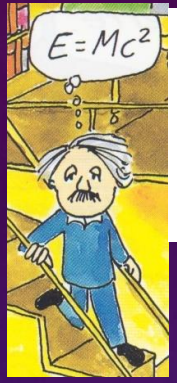

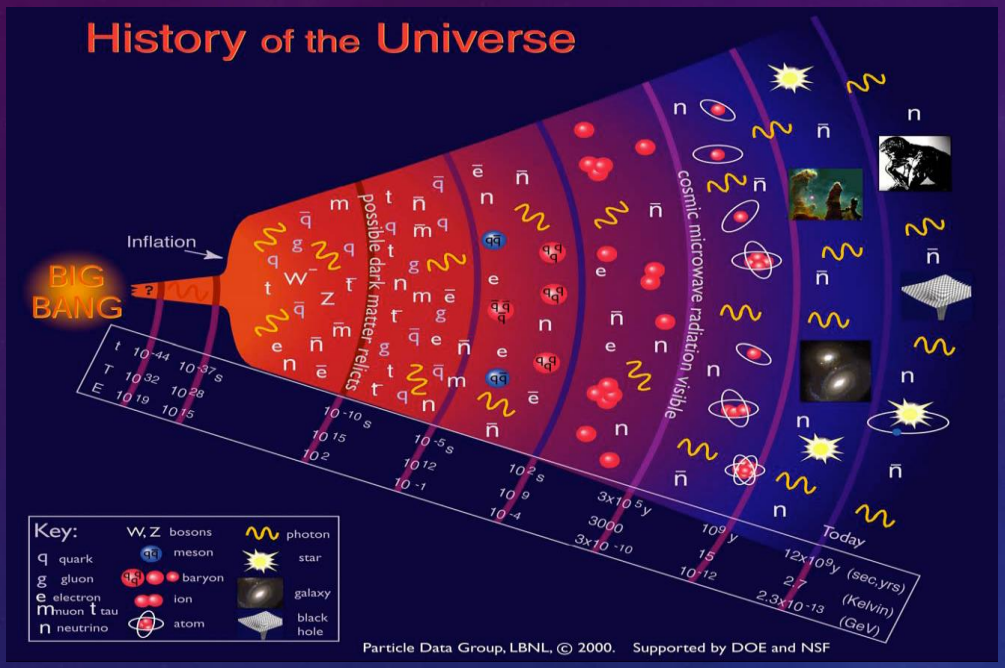

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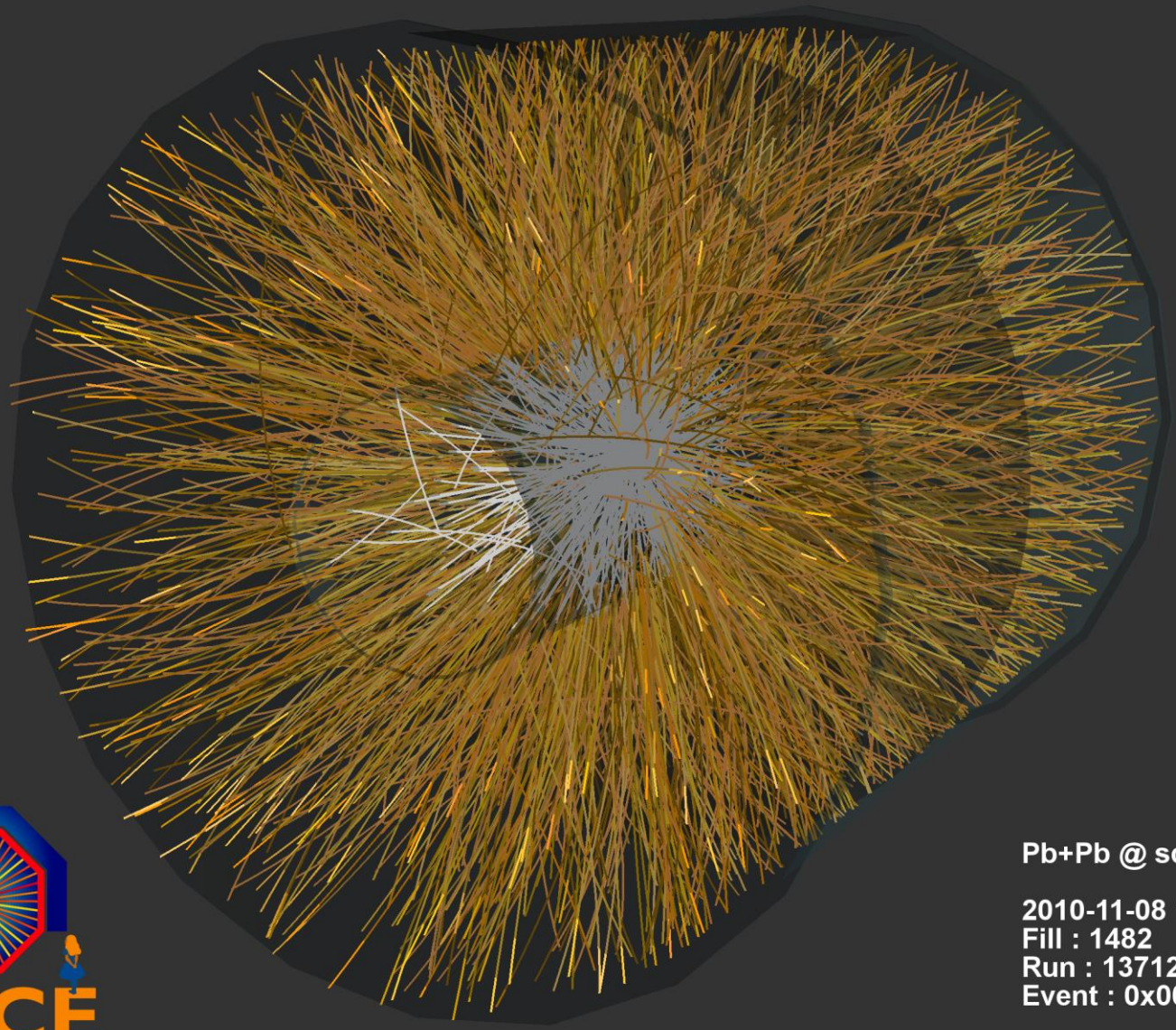
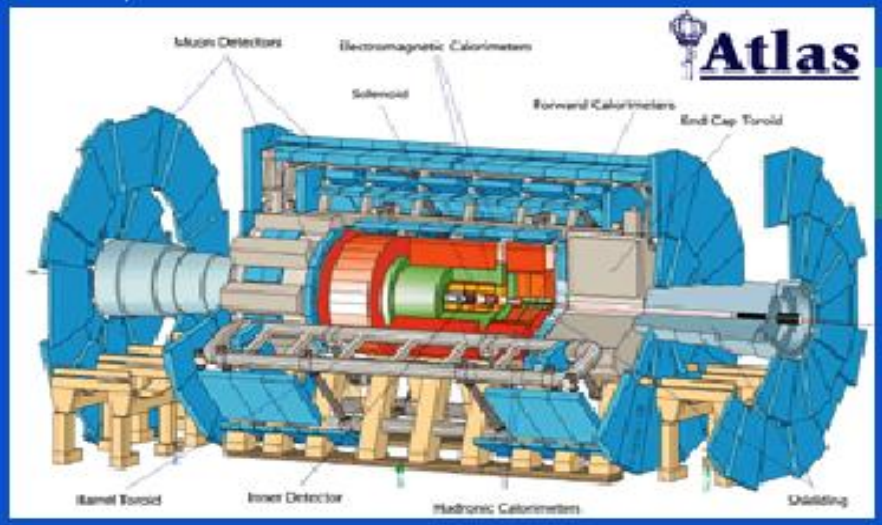
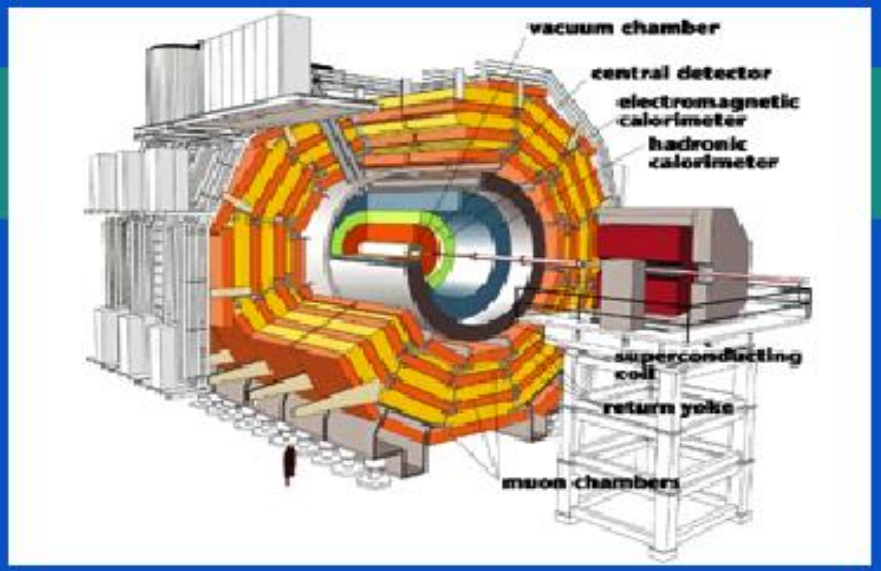


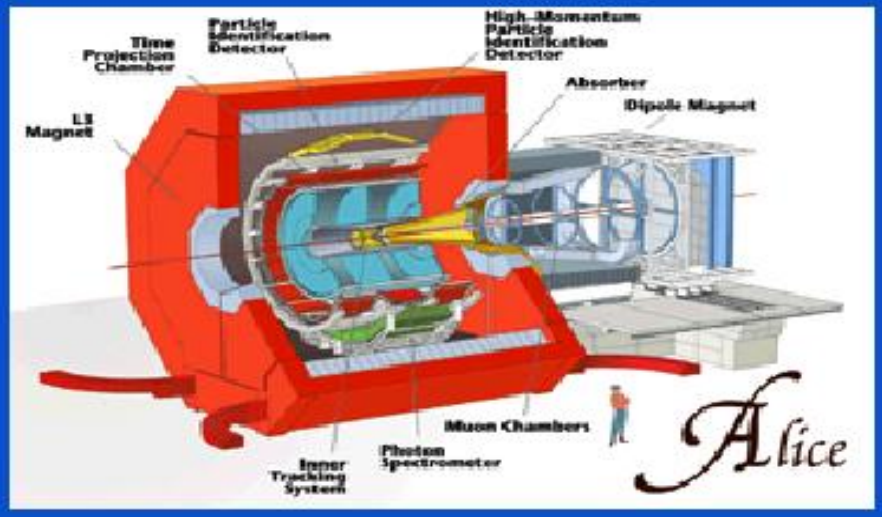
ALICE

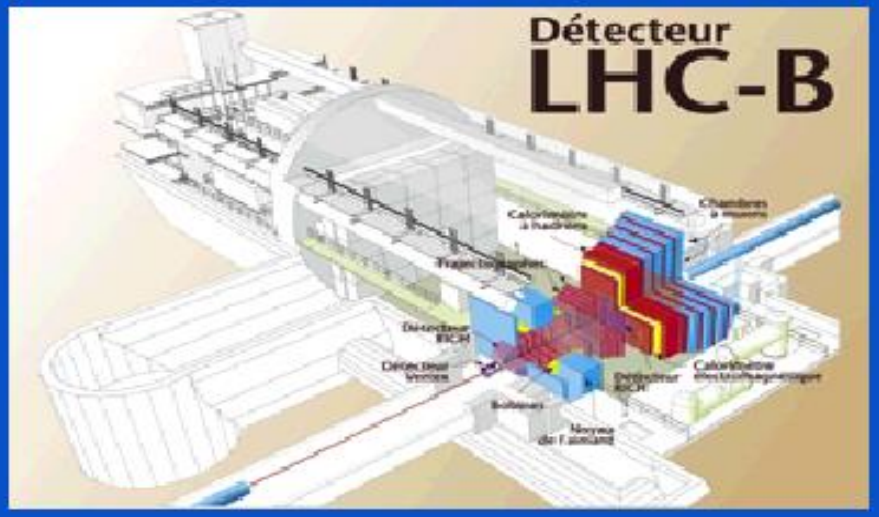
Courtesy of CERN

Tools: The LHC Experiments

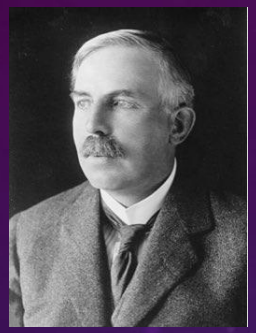




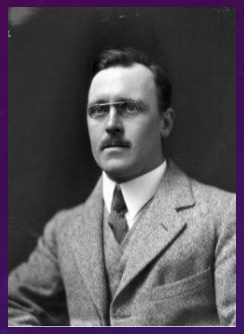




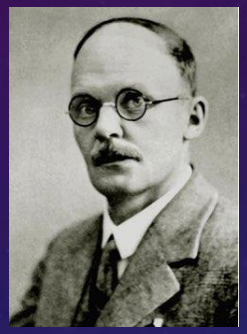
A HISTORICAL DETOUR..



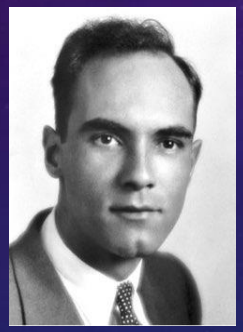
E. Rutherford



E. Marsden

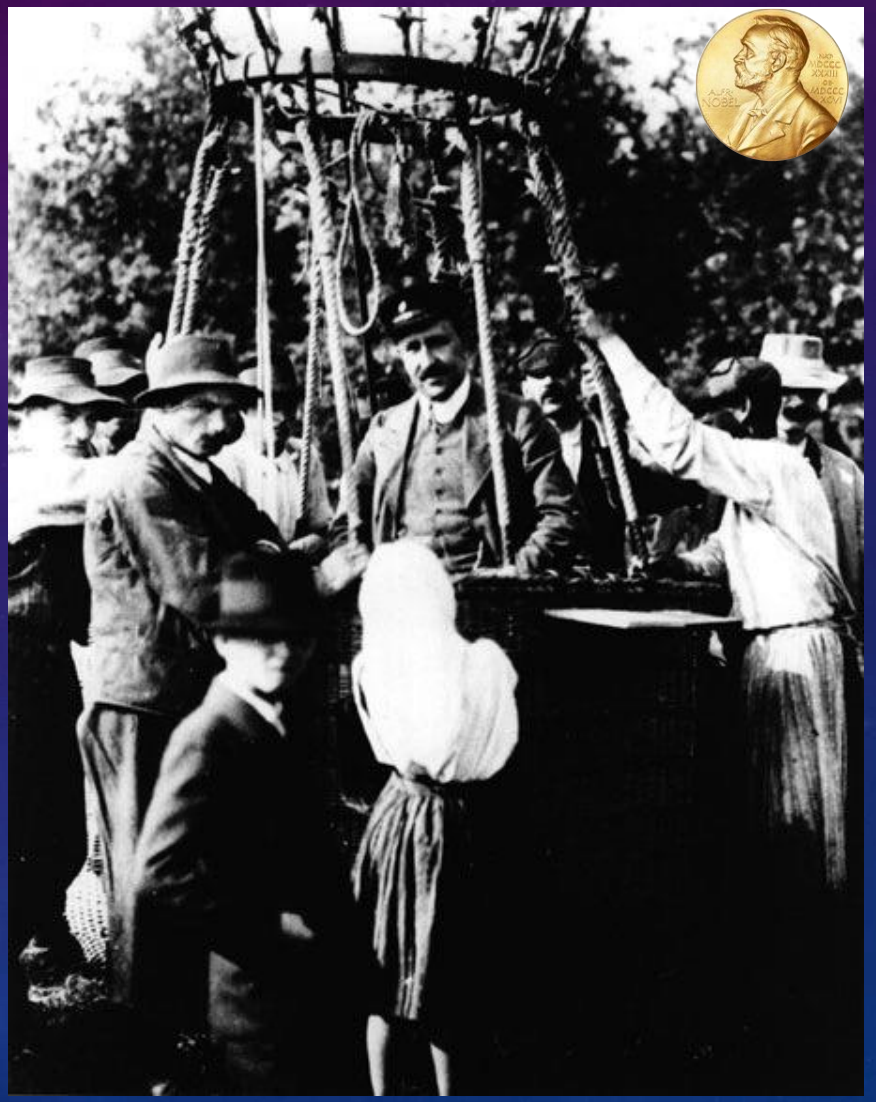


Hans Geiger

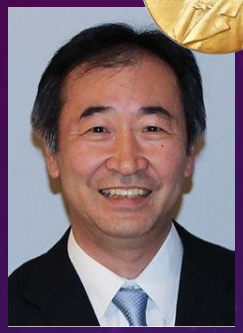


C. D. Anderson
Nobel Prize 1936

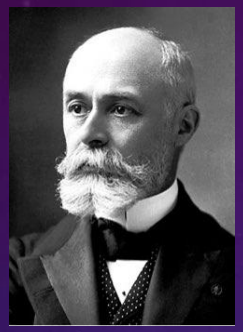
C.F. Powell
Nobel Prize 1950



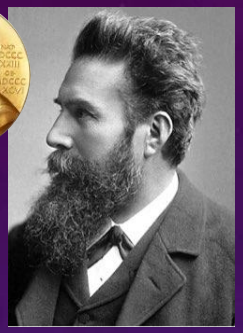
V.F. Hess, Nobel Prize 1936



T. Kajita
Nobel Prize 2015

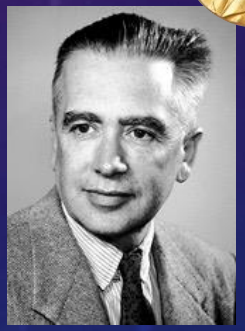


H. Becquerel
Nobel Prize 1903



W. C. Röntgen
Nobel Prize 1901

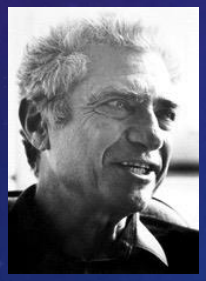
C. Rubbia



E.G. Segrè

L.M. Lederman

M. Schwartz



J. Steinberger

Nobel Prize 1988

S. van der Meer

Nobel Prize 1994

O. Chamberlain

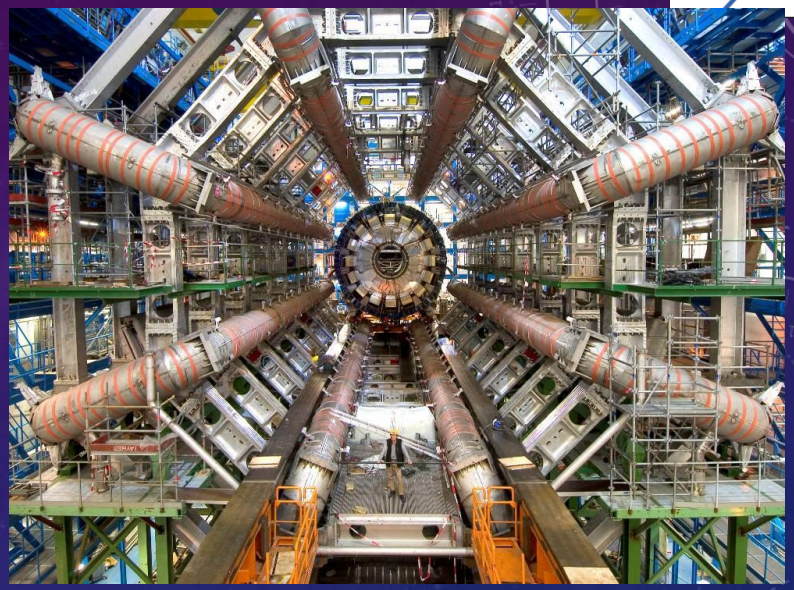
Nobel Prize 1959

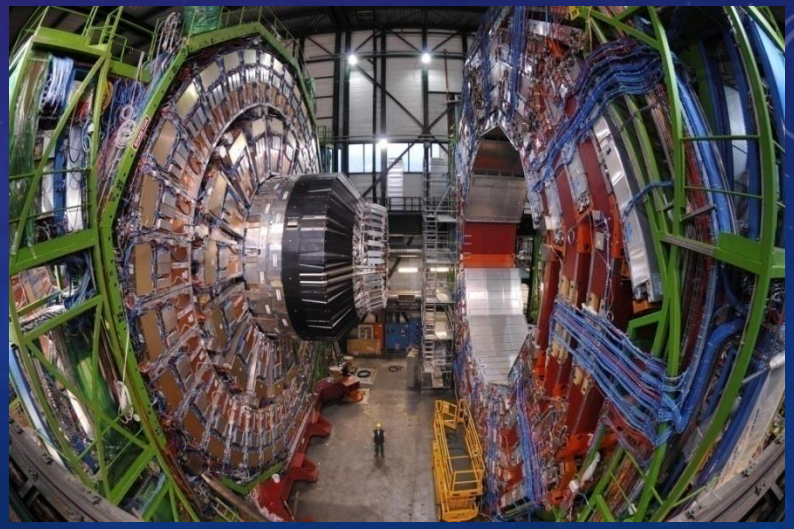
- 1927: cloud chamber (C.T.R. Wilson)
- 1948: advanced cloud chamber (P.M.S. Blackett)
- 1950: nuclear emulsion (C.F. Powell)
- 1954: coincidence method (W. Bothe)
- 1958: Cherenkov effect (P.A. Cherenkov)
- 1960: bubble chamber (D.A. Glaser)
- 1992: multiwire proportional chamber (G. Charpak)
- 2009: CCD sensor (W.S. Boyle, G.E. Smith)

The legacy of nobel prizes in HEP instrumentation and experimentation continues

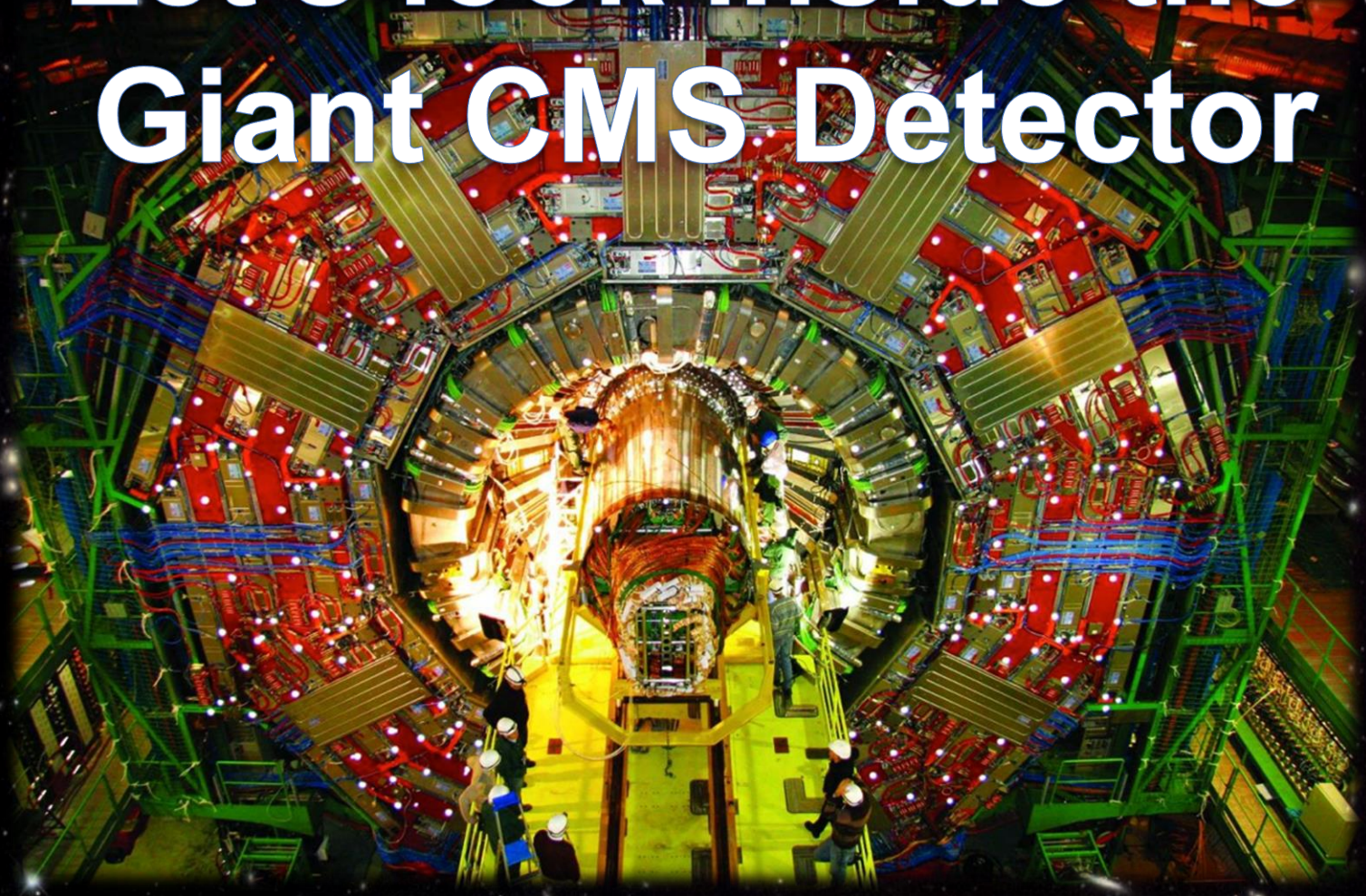
ATLAS and CMS –INSTRUMENTATION at the Leading Edge

Each detector is like a 100 megapixel camera which takes 40 million pictures per second. The largest and most complex scientific instruments ever built.



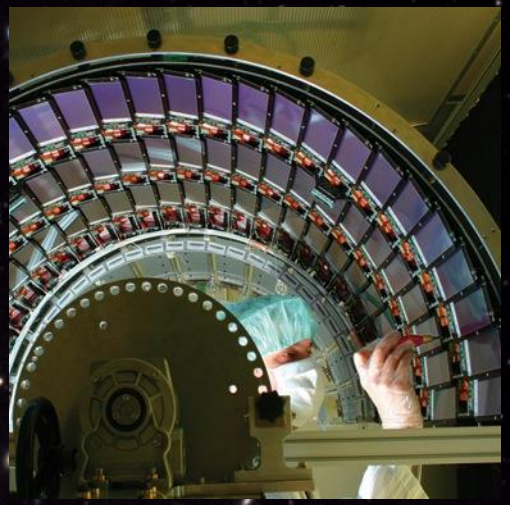


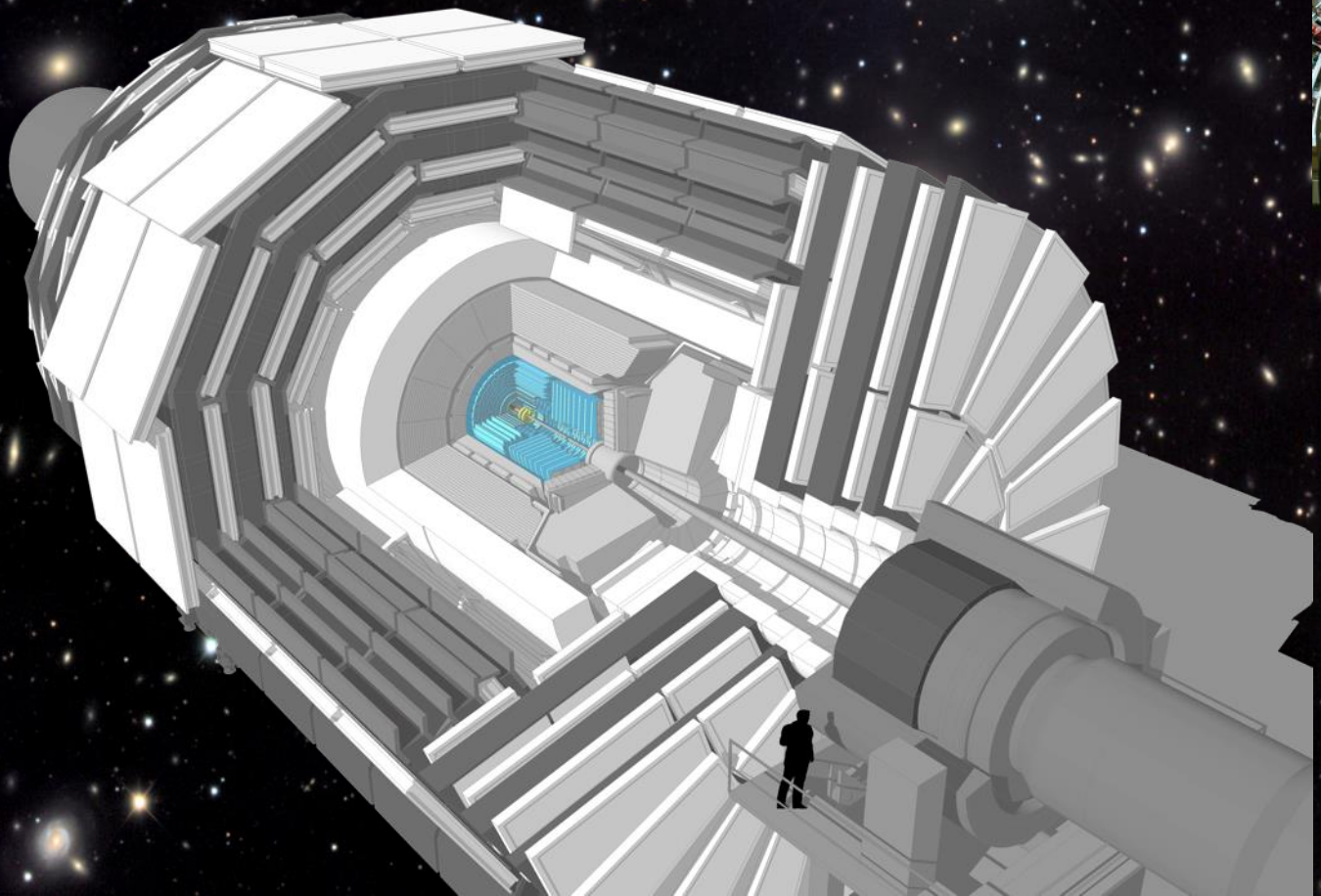
Let's look inside the Giant CMS Detector



The Layers of CMS: Tracker

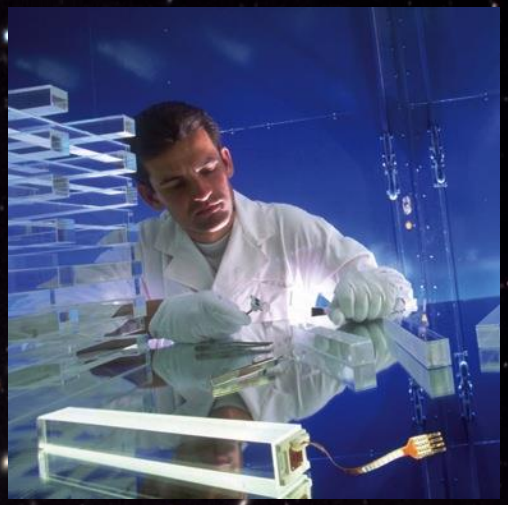
Finely segmented silicon sensors (strips and pixels) enable charged particles to be tracked and their momenta to be measured. They also reveal the positions at which long-lived unstable particles decay.

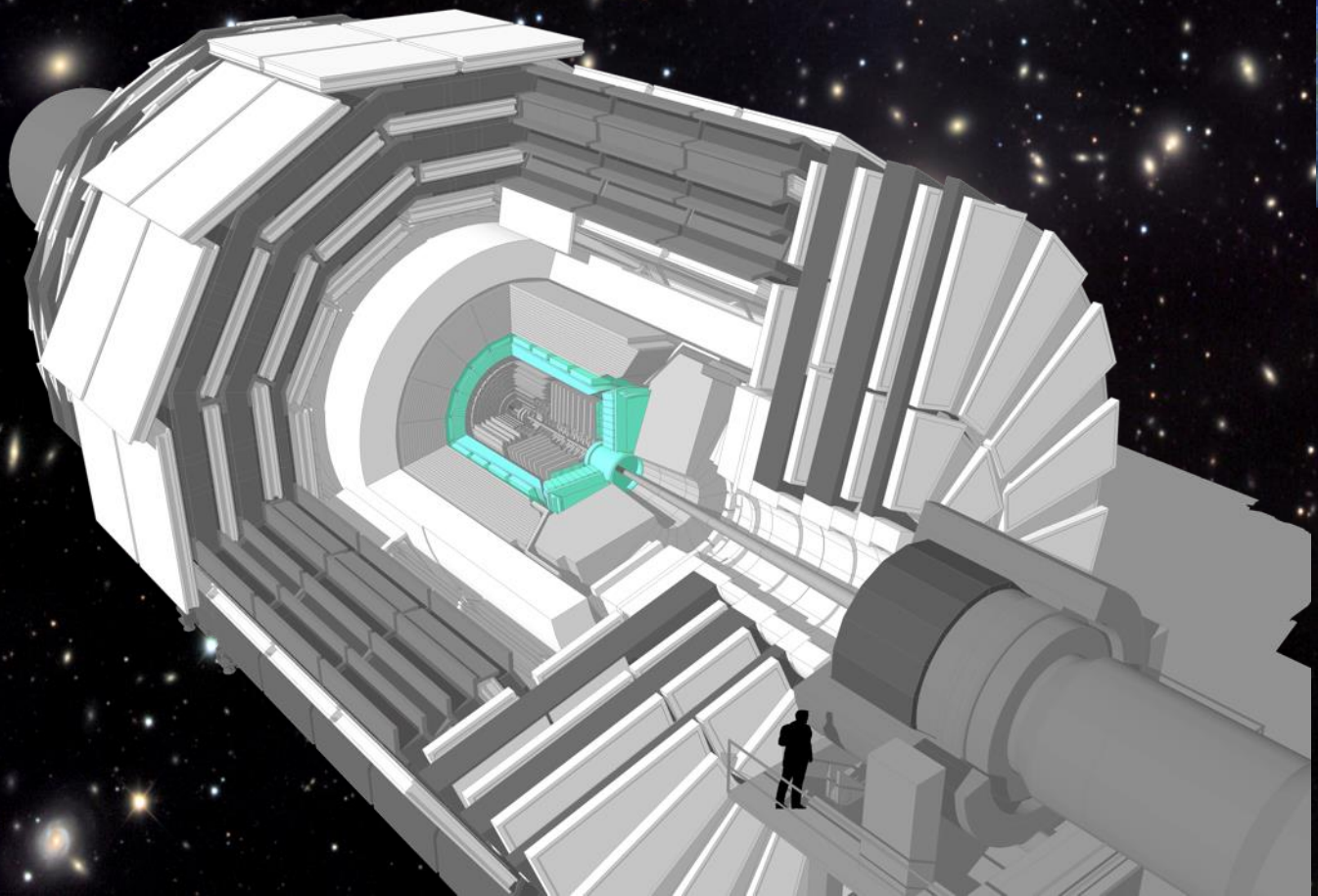




The Layers of CMS: ECAL

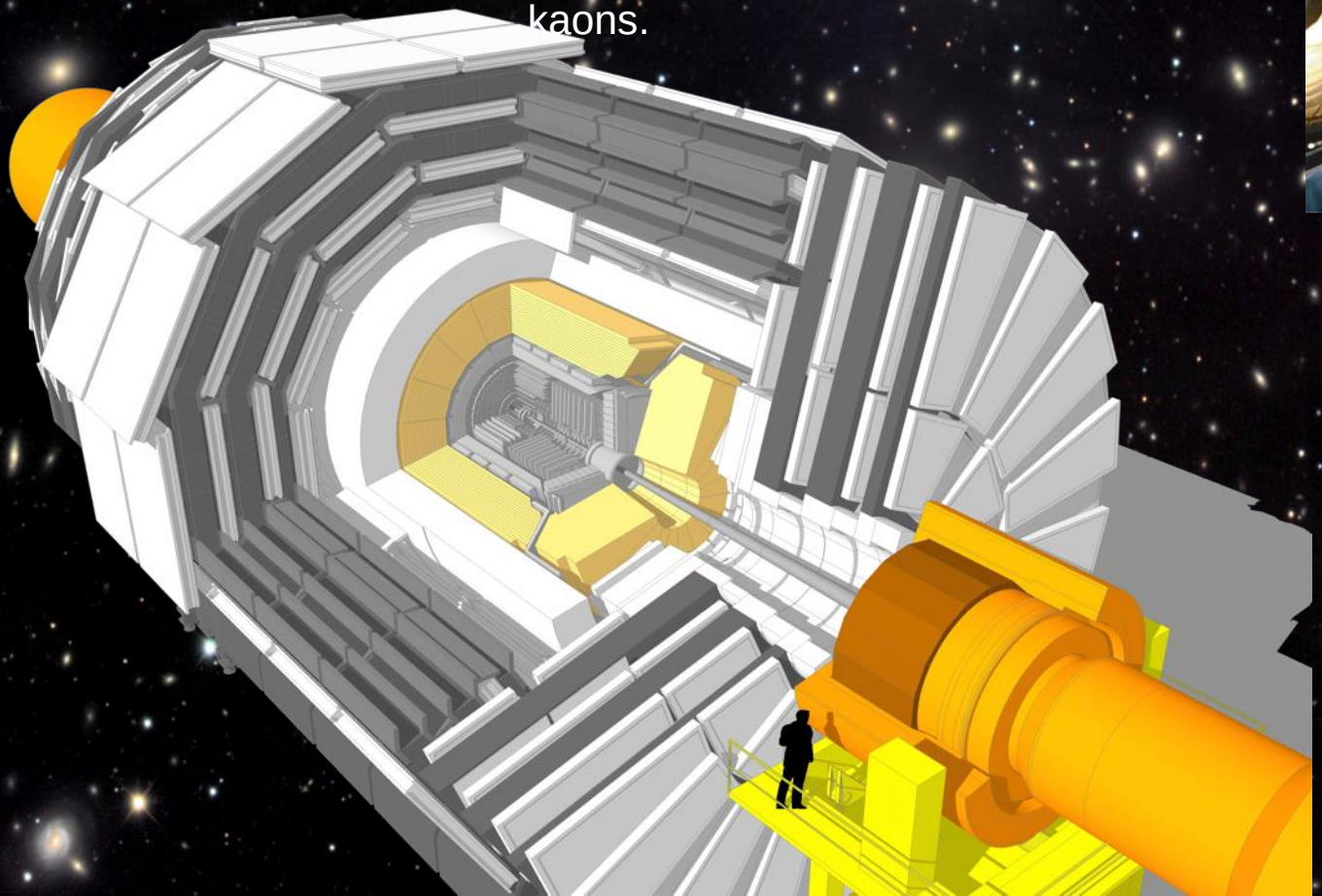
Nearly 80 000 crystals of lead tungstate ($PbWO_4$) are used to measure precisely the energies of electrons and photons. A ‘preshower’ detector, based on silicon sensors, helps particle identification in the endcaps.





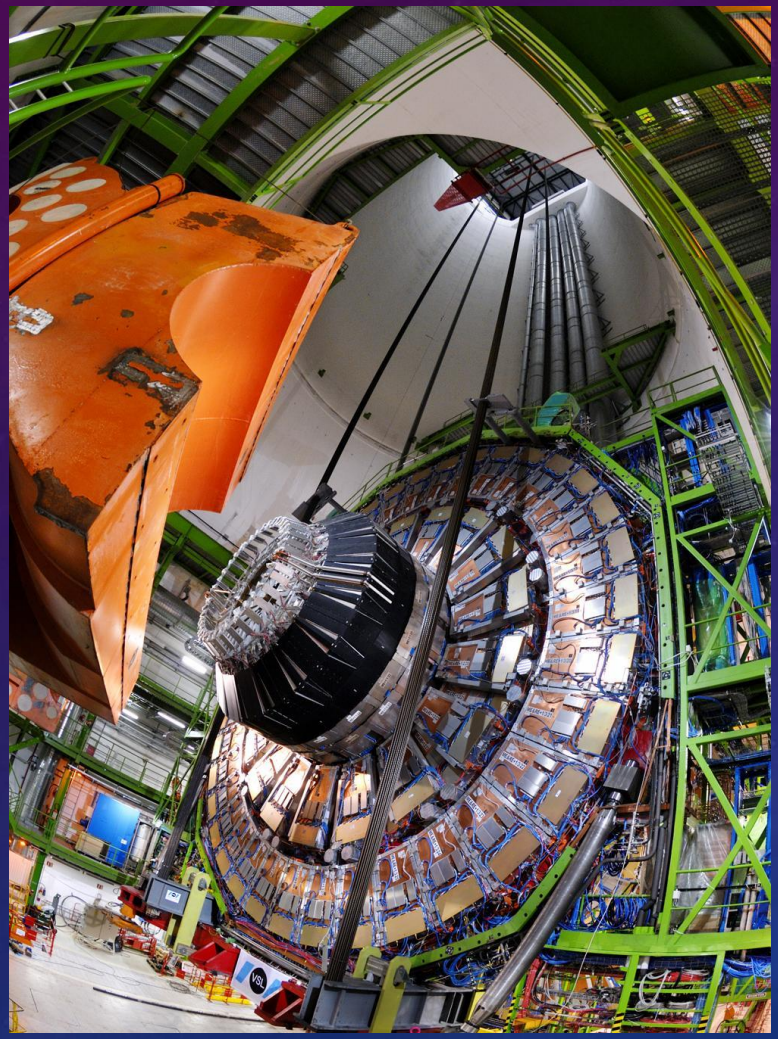
The Layers of CMS: HCAL

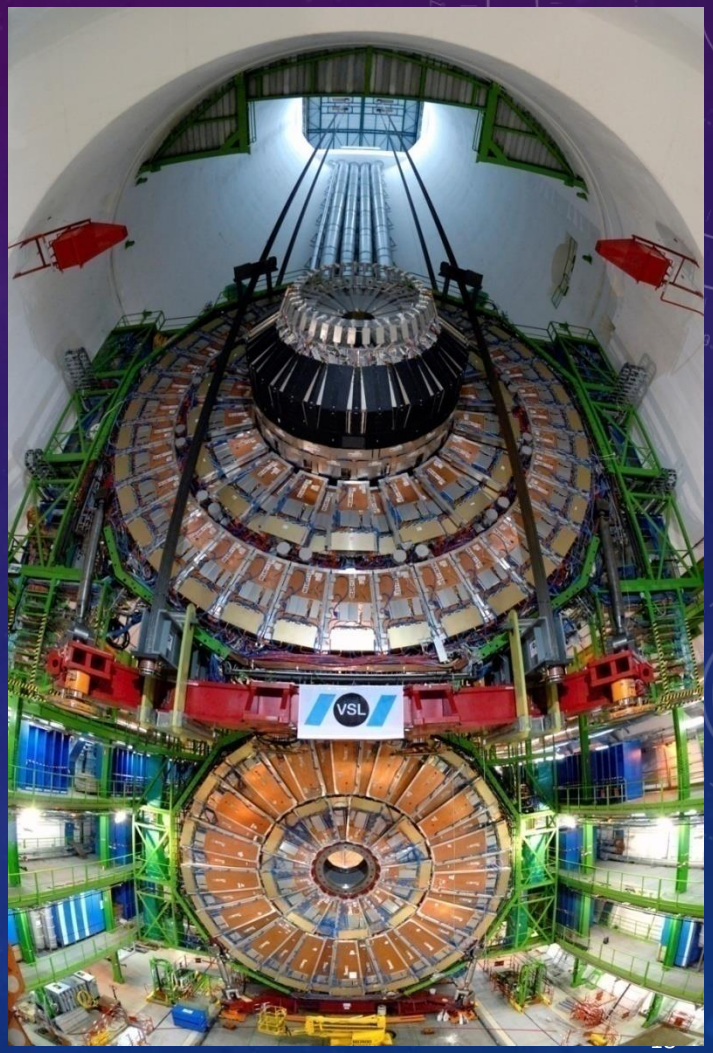
Layers of dense material (brass or steel) interleaved with plastic scintillators or quartz fibres allow the determination of the energy of hadrons, that is, particles such as protons, neutrons, pions and kaons.



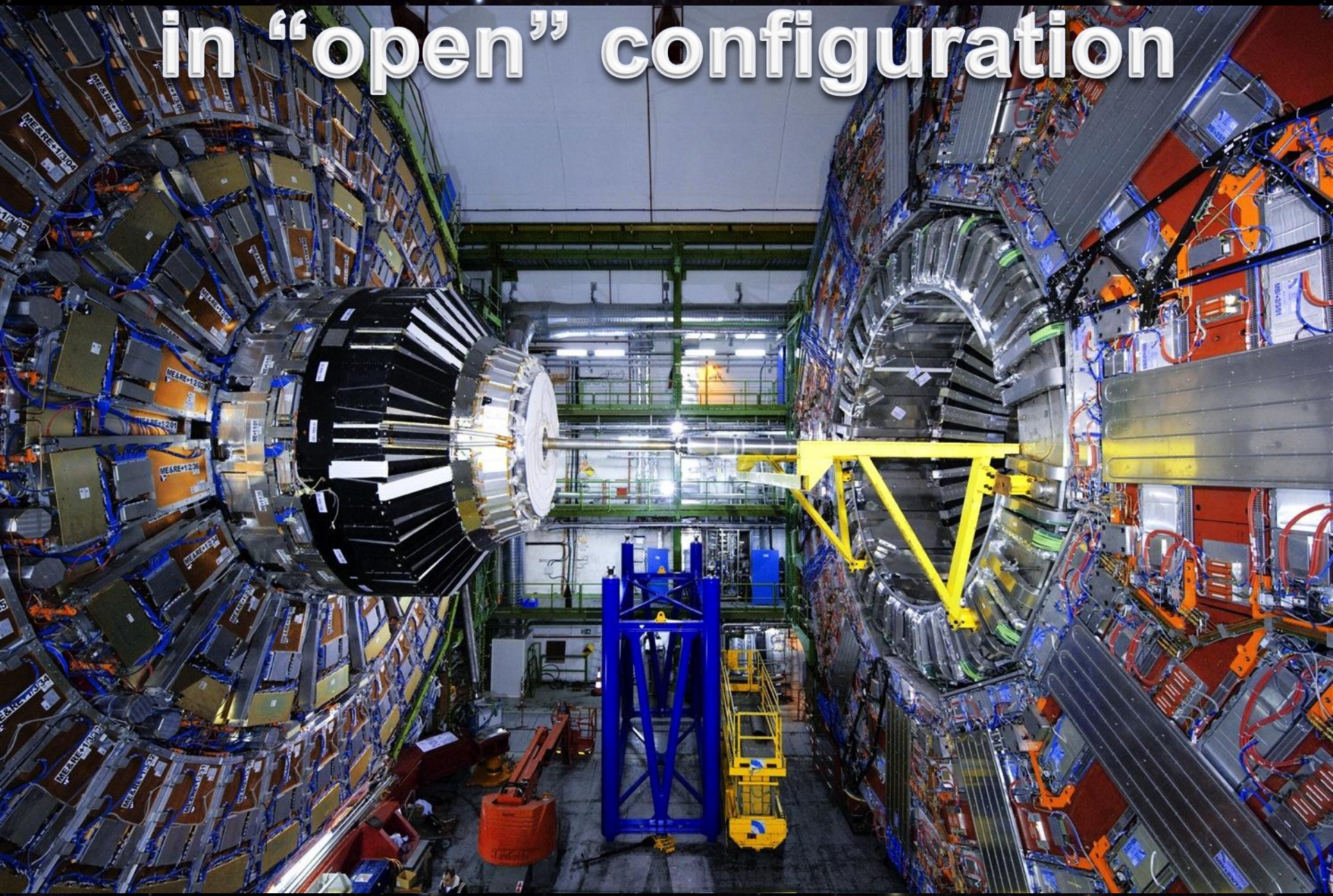
Underground Experiment Cavern (2003-4)

Spectacular Operations – “The Launch”

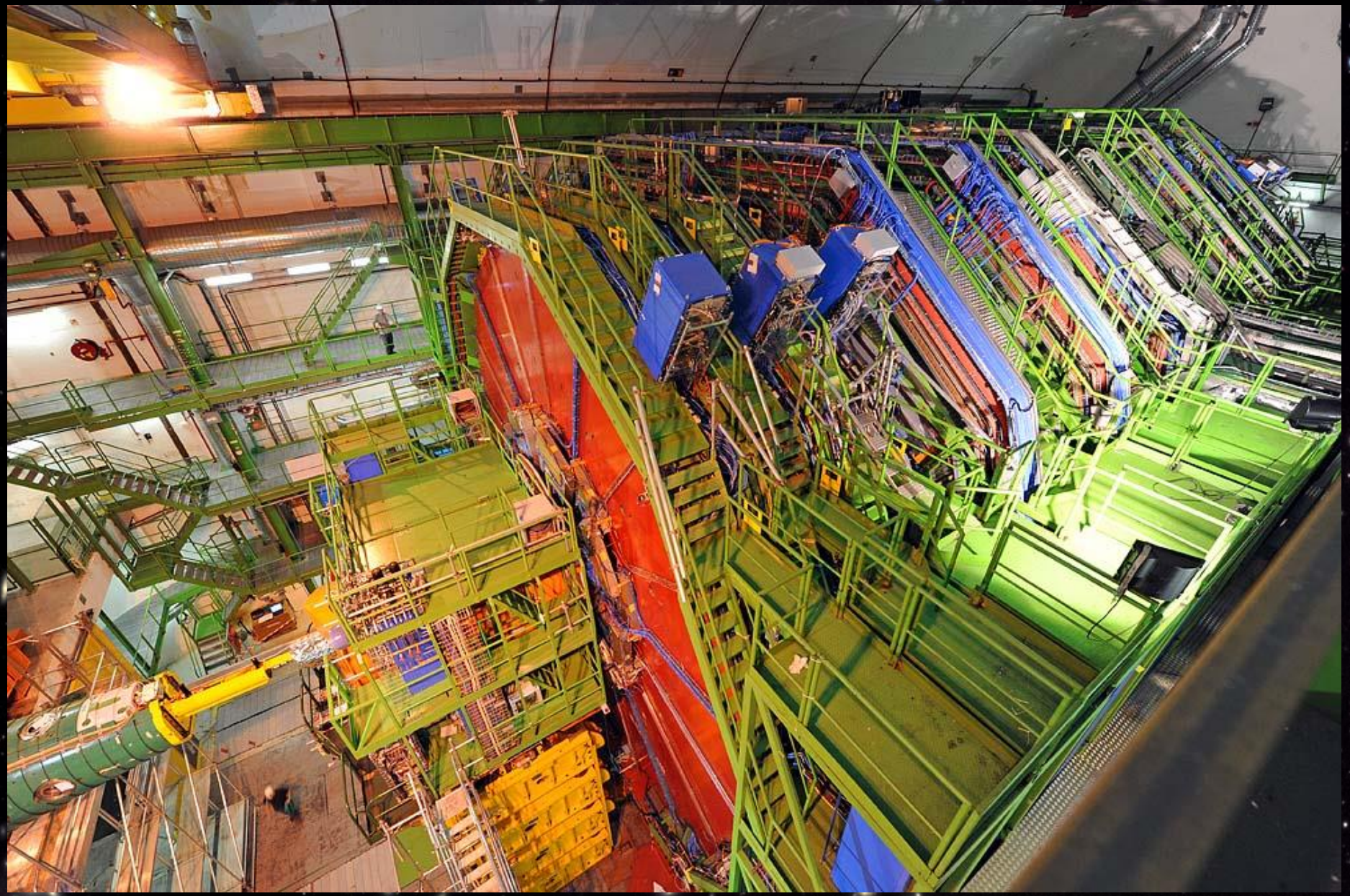




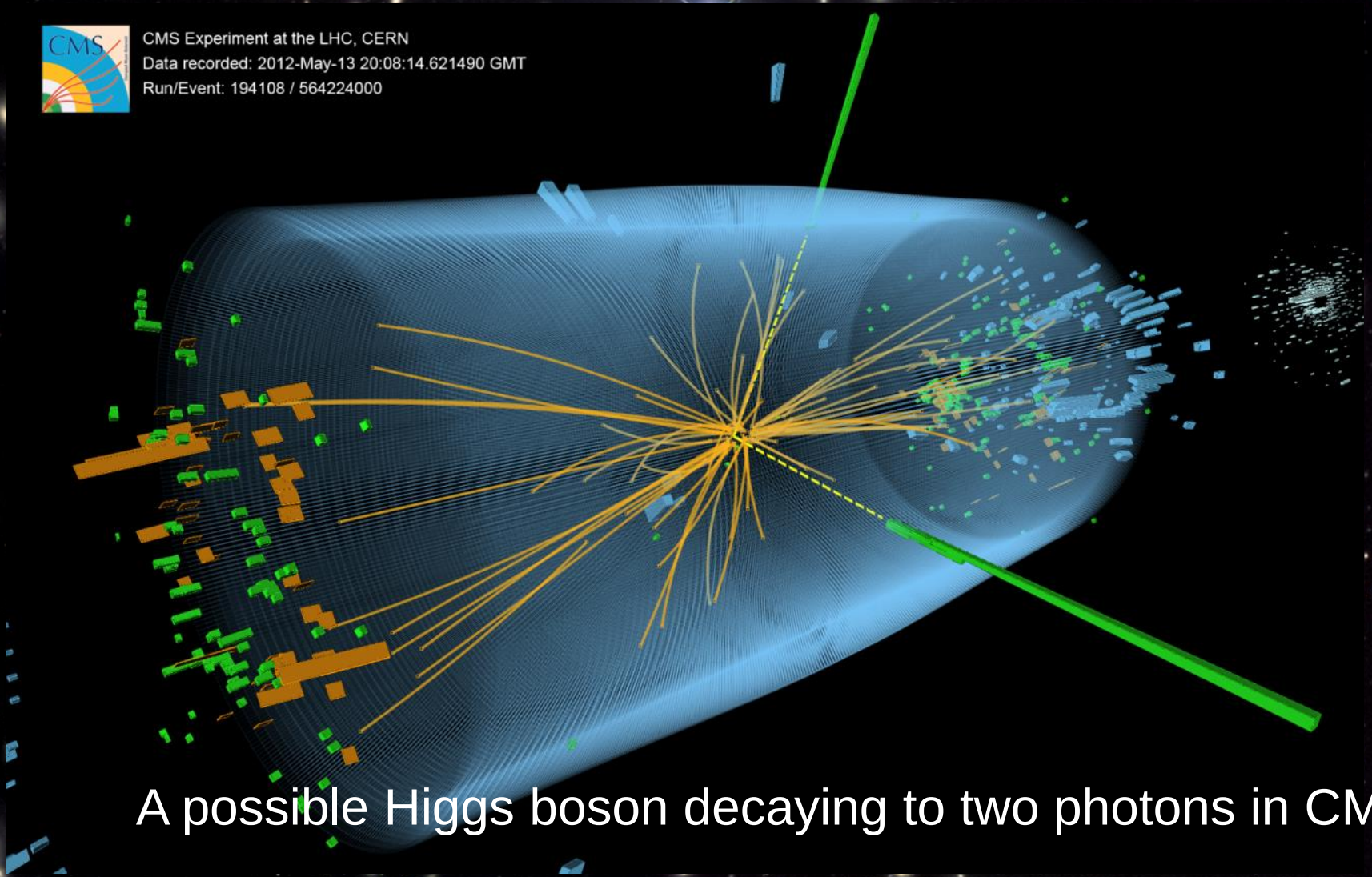
CMS Underground and in “open” configuration



CMS Underground and “closed”

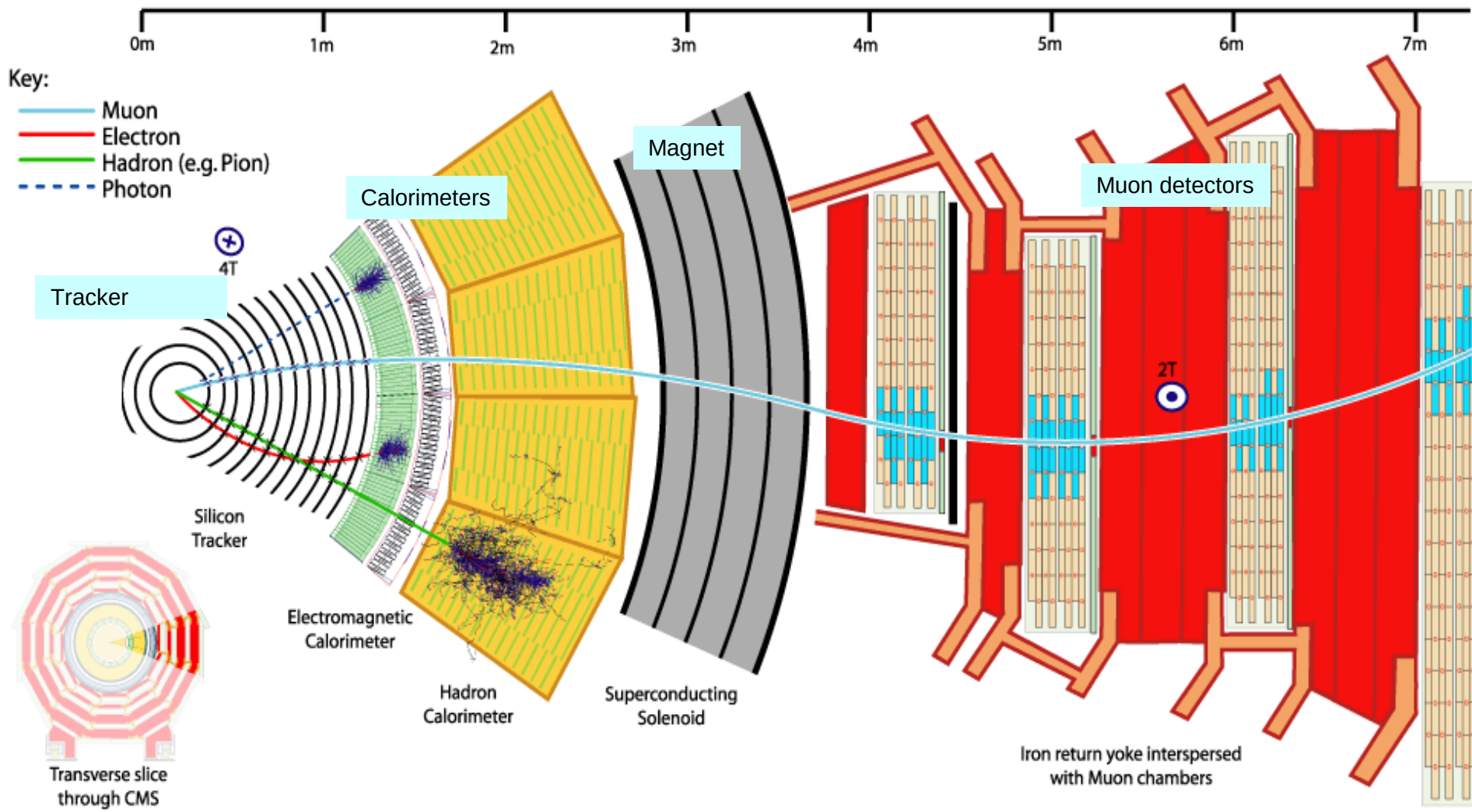


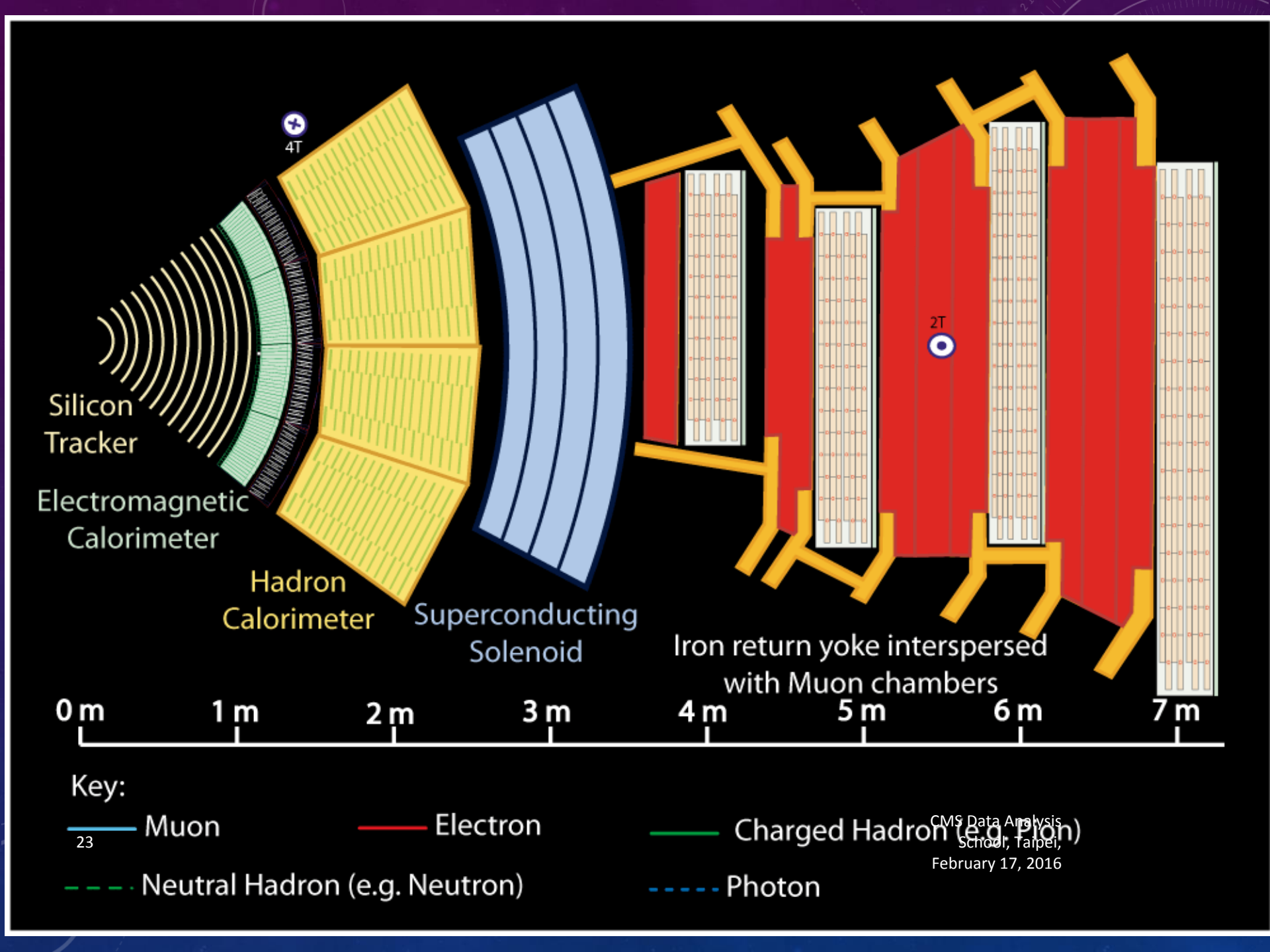
CMS takes “snapshots” of the collisions made by the LHC

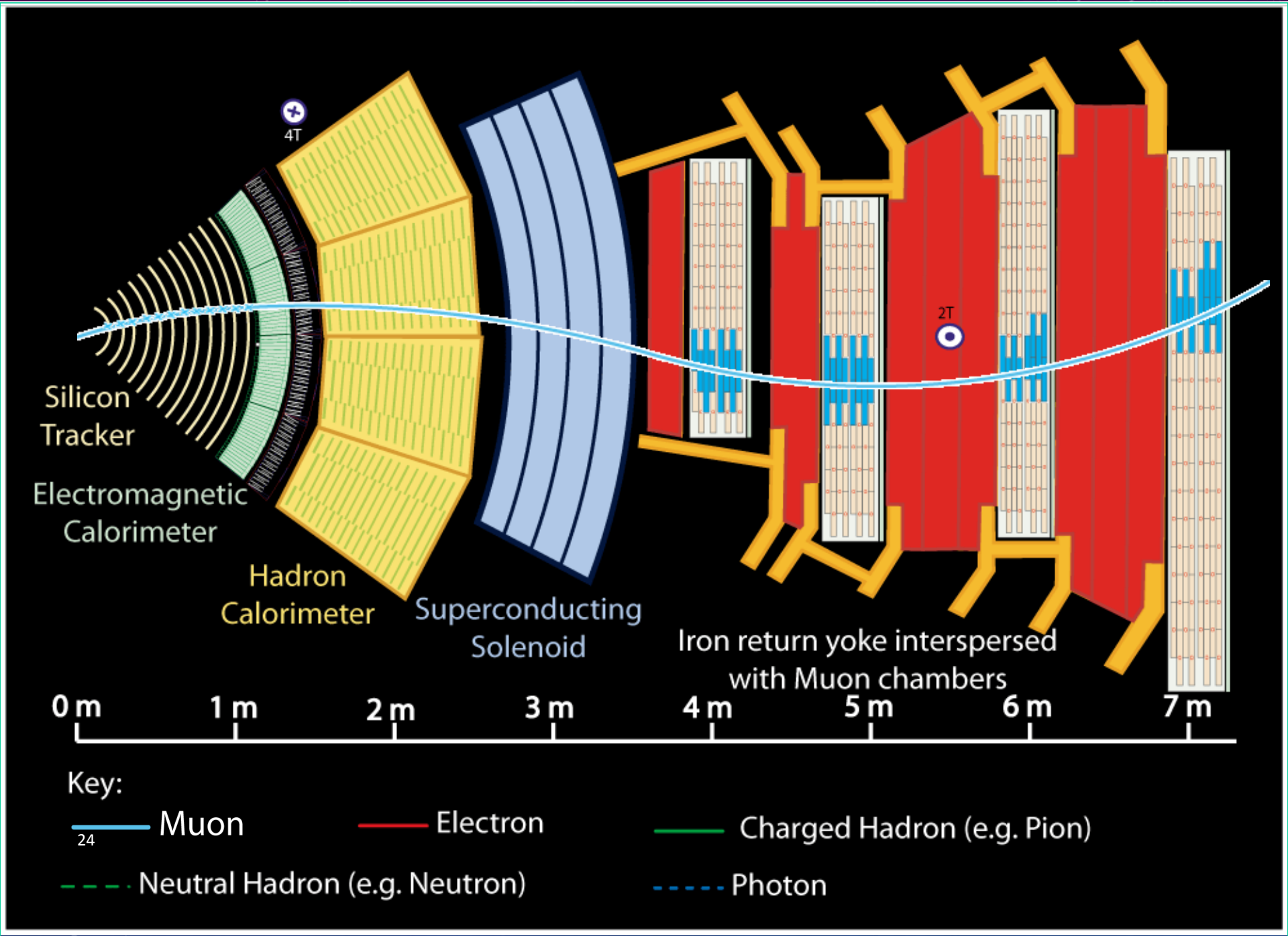


A possible Higgs boson decaying to two photons in CMS

PARTICLES IN THE DETECTOR




4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
0 m
1 m
2 m
3 m
4 m
5 m
6 m
7 m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon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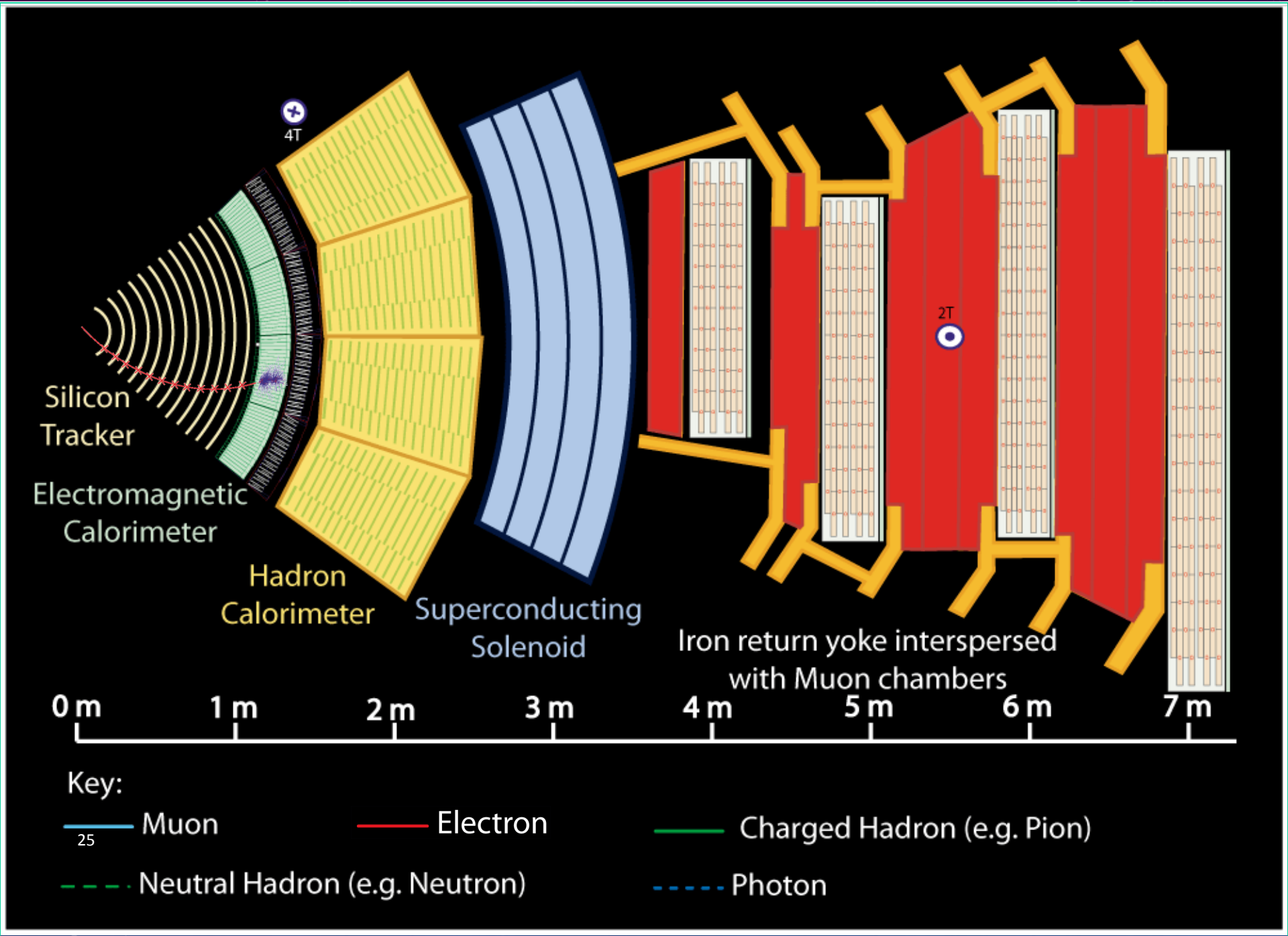
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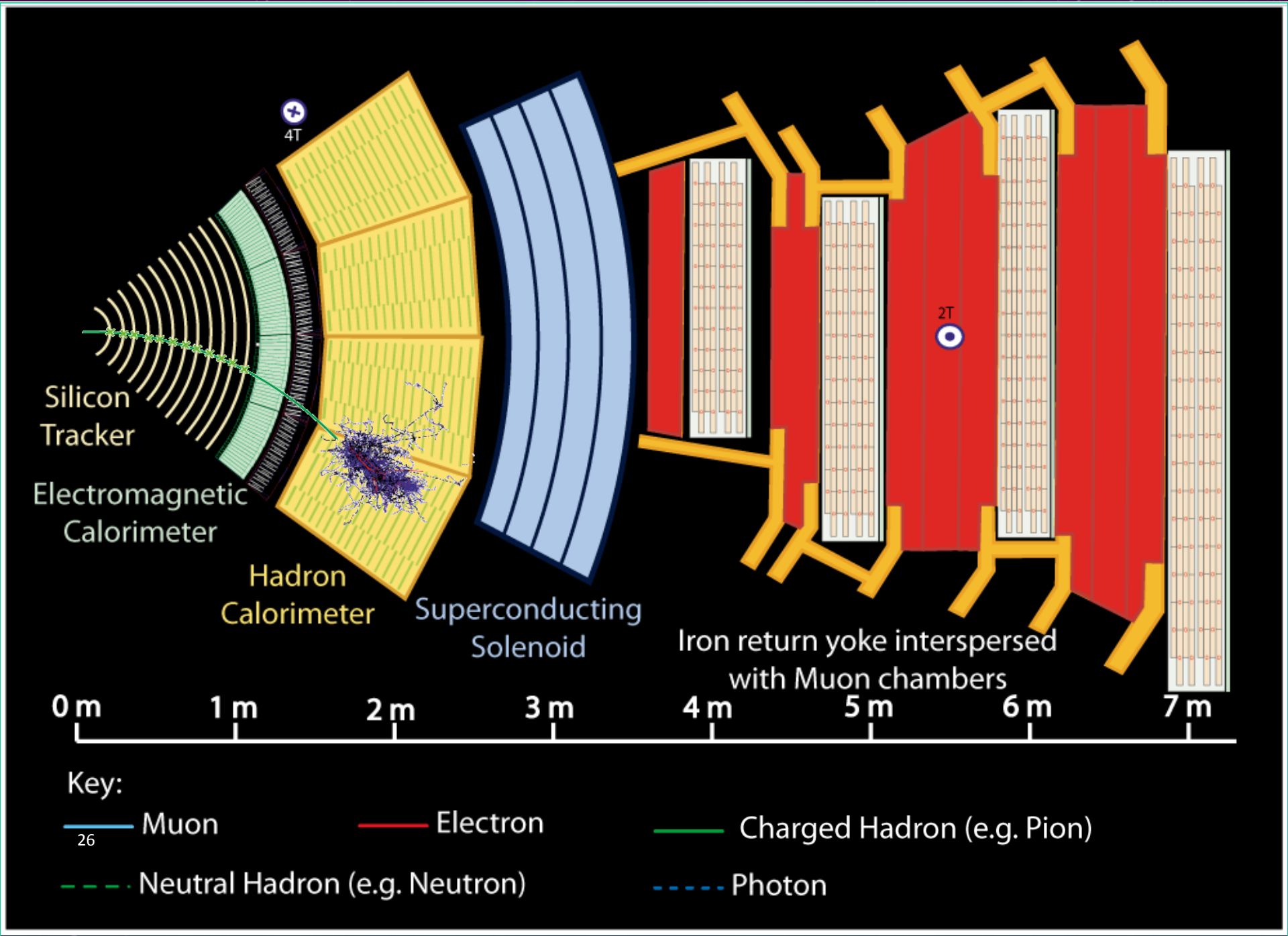
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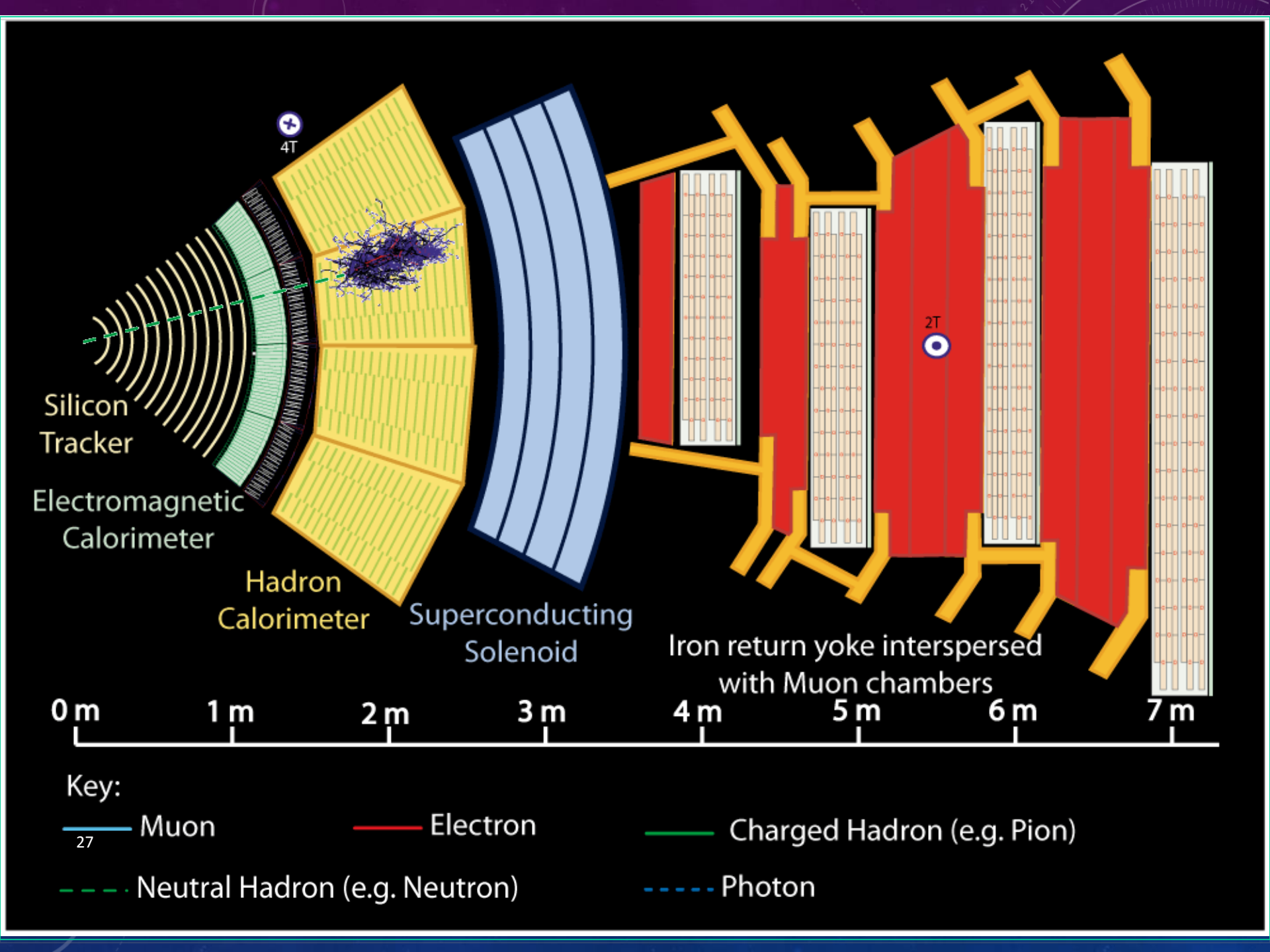
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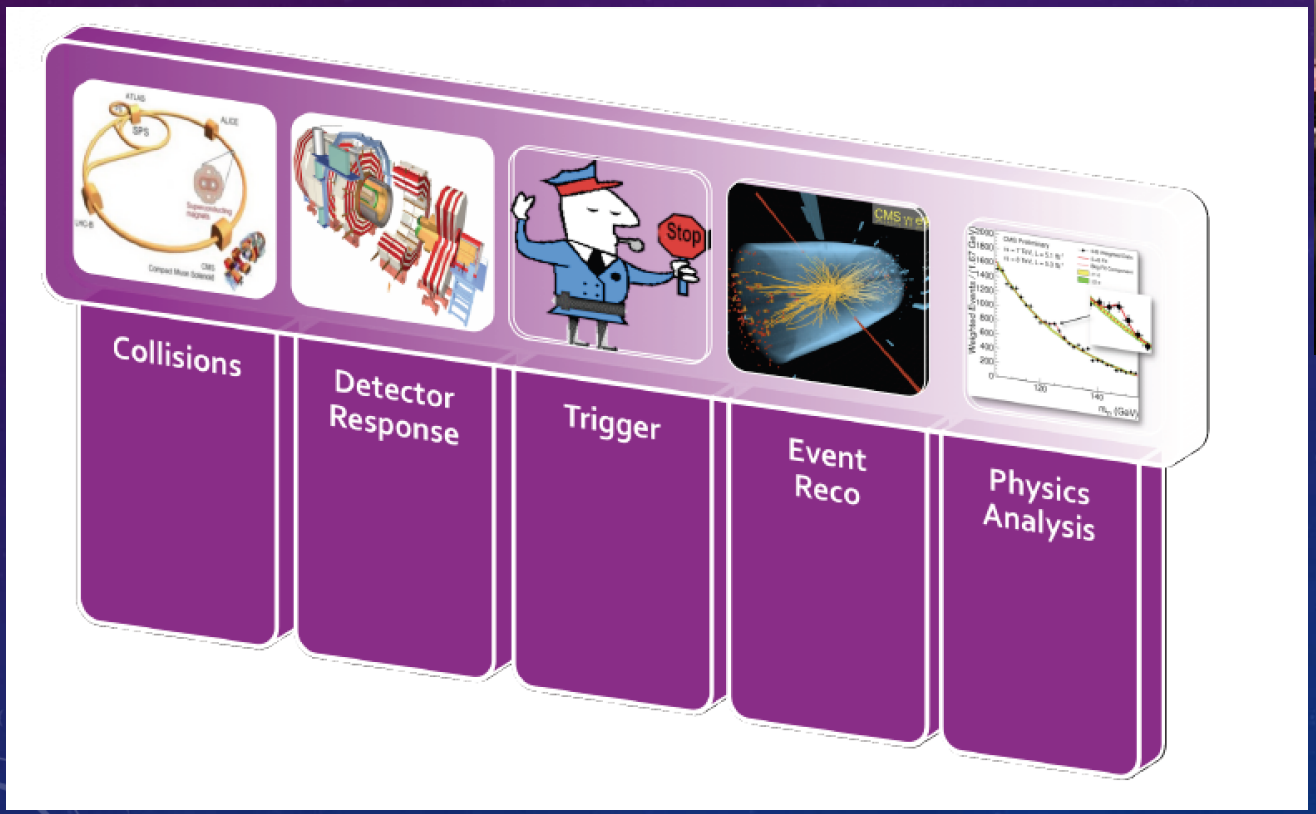
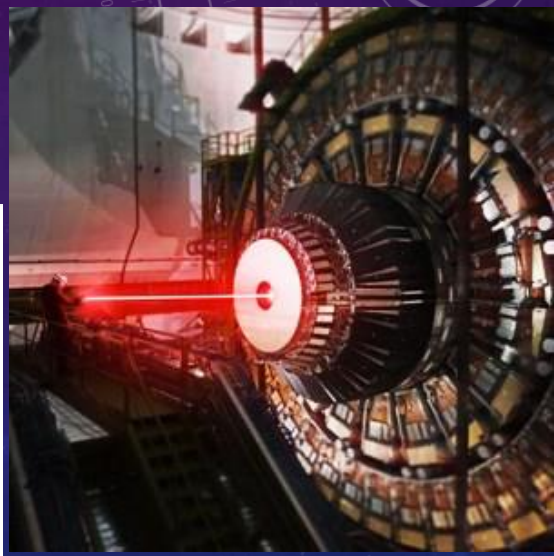
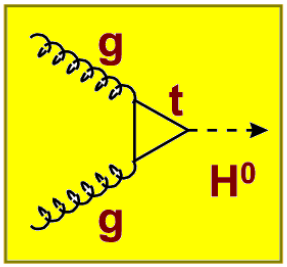
HOW TO GET TO PUBLICATIONS …

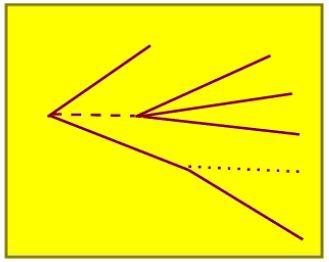




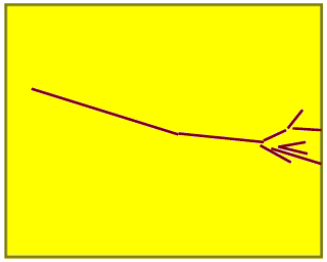
FROM PHYSICS TO RAW DATA – SIMULATIONS



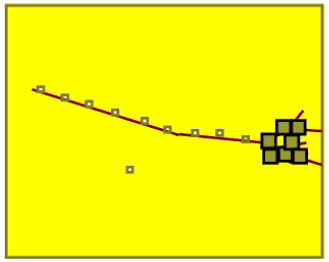
Basic physics



Fragmentation, Decay



Interaction with detector material
Multiple scattering, interactions



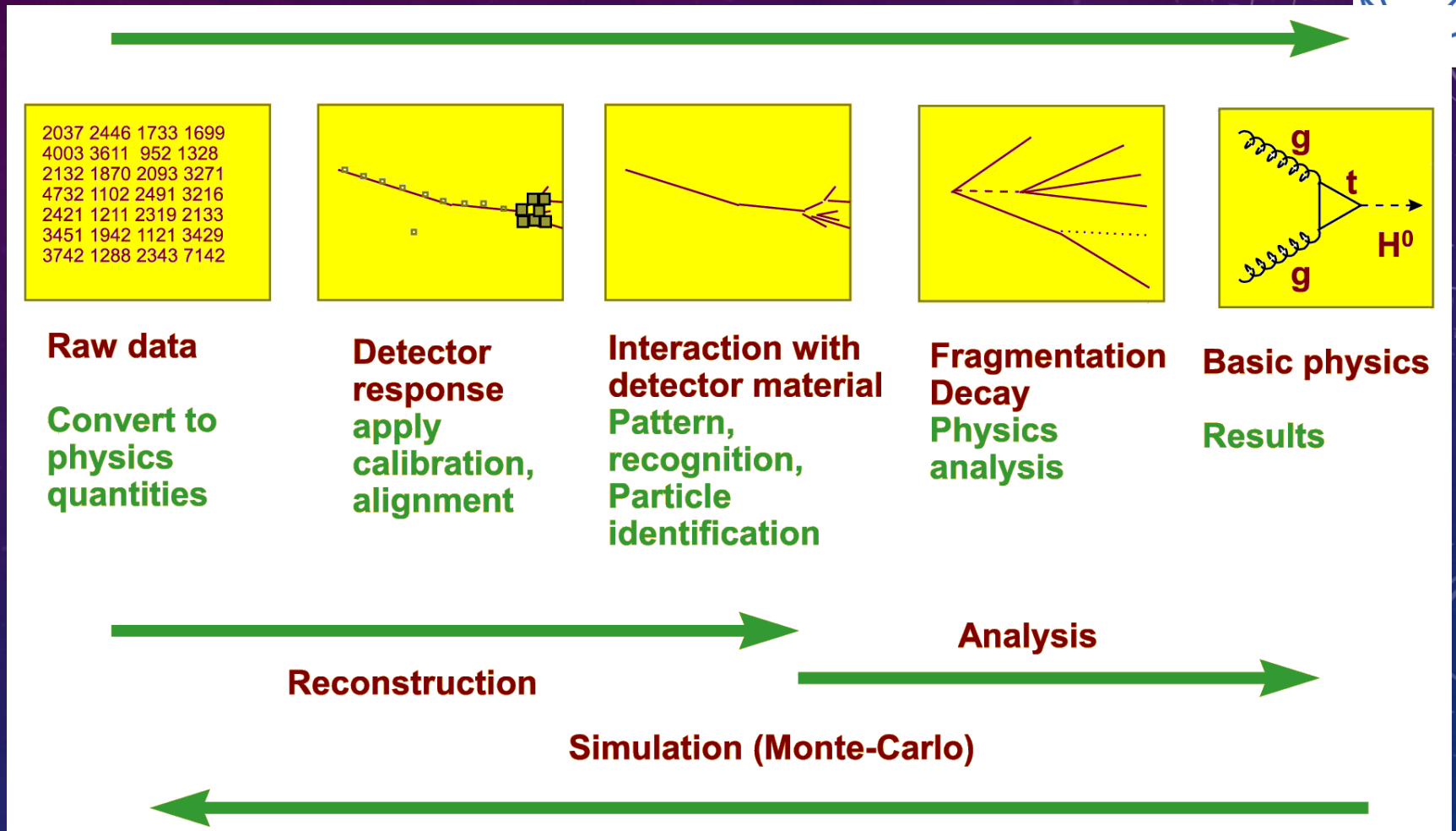
Detector response
Noise, pile-up, cross-talk, inefficiency, ambiguity, resolution, response function, alignment

Raw data

Read-out addresses, ADC, TDC values, Bit patterns

- Really recorded raw data for ATLAS/CMS ~400 MB/s
  - mainly electronics numbers
    - e.g. number of detector element where ADC (Analog-to-Digital converter) saw signal with x counts...

FROM PHYSICS TO RAW DATA – SIMULATIONS & ANALYSIS !!



- We need to go from raw data back to physics
  - reconstruction + analysis of the event(s)

TRIGGER AND DAQ – THE BRAIN OF CMS

40 MHz
COLLISION RATE

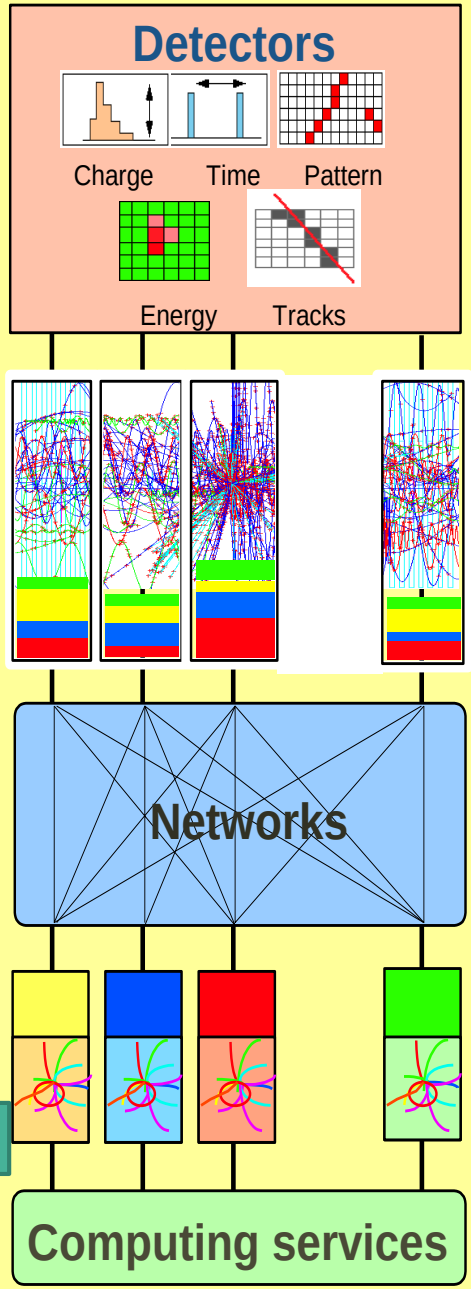
100 kHz
LEVEL-1 TRIGGER

1 Terabit/s
(50000 DATA CHANNELS)

500 Gigabit/s

Today ~1000Hz

Gigabit/s SERVICE LAN



16 Million channels
3 Gigacell buffers

1 Megabyte EVENT DATA

200 Gigabyte BUFFERS
500 Readout memories

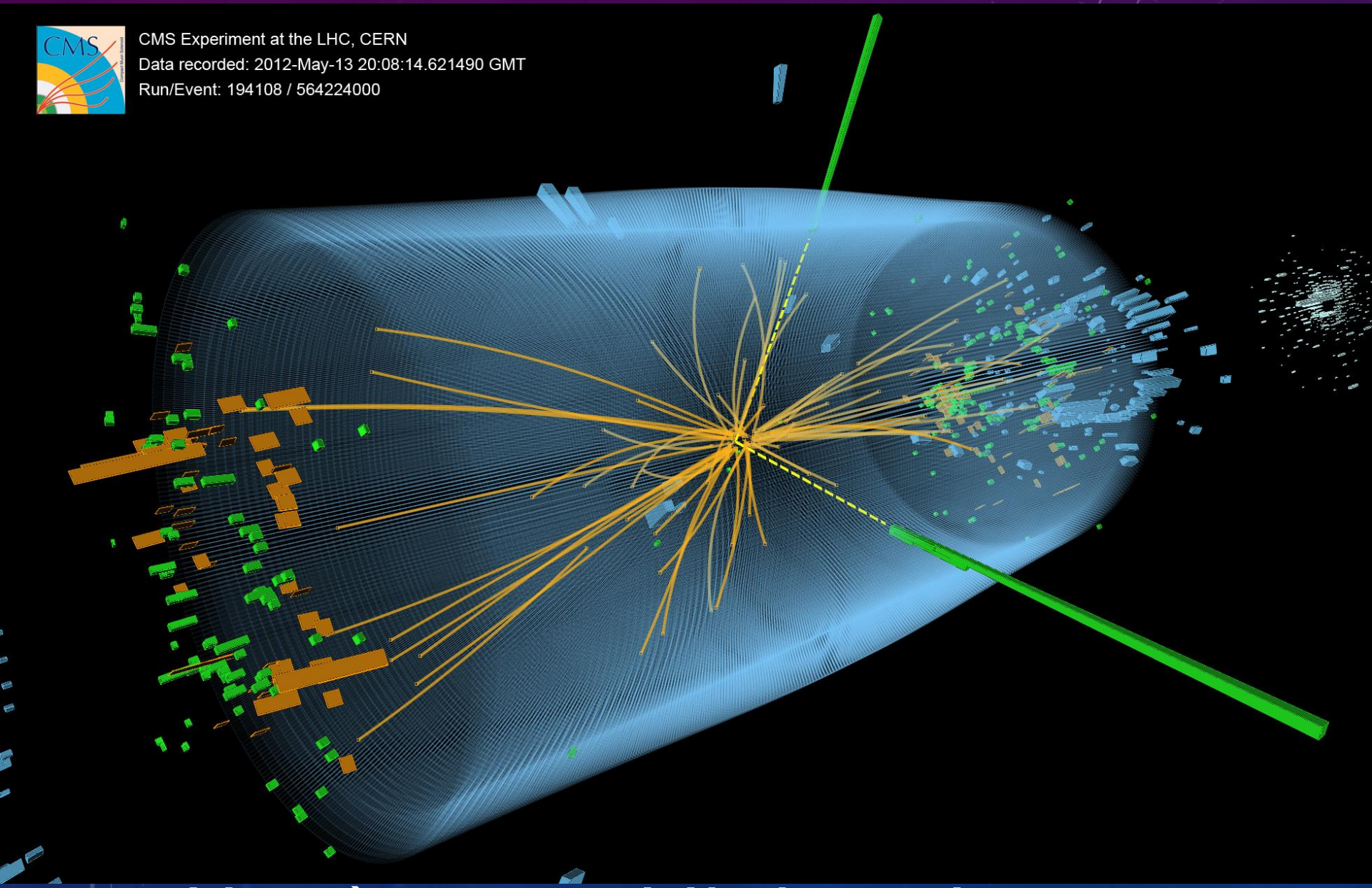
EVENT BUILDER. A large switching network (512+512 ports) with a total throughput of approximately 500 Gbit/s forms the interconnection between the sources (Readout Dual Port Memory) and the destinations (switch to Farm Interface). The Event Manager collects the status and request of event filters and distributes event building commands (read/clear) to RDPMs

5 TeraIPS

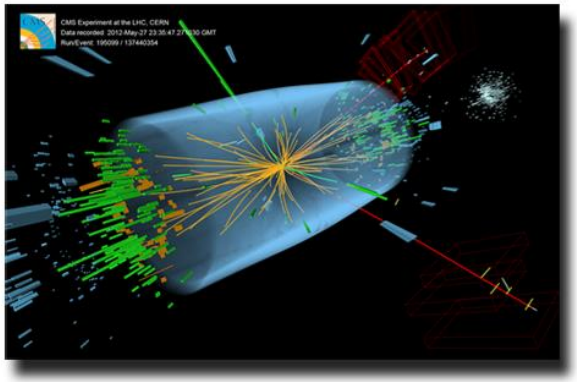
EVENT FILTER. It consists of a set of high performance commercial processors organized into many farms convenient for on-line and off-line applications. The farm architecture is such that a single CPU processes one event

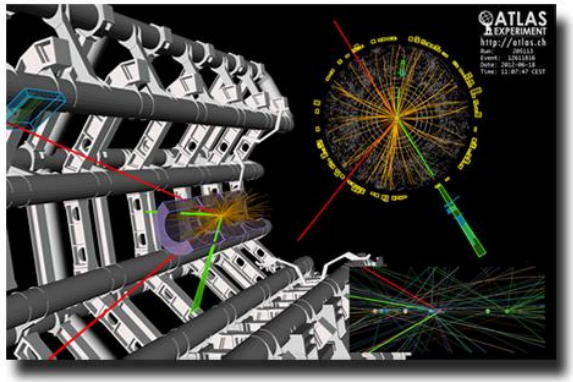
Petabyte ARCHIVE

ALL PEOPLE WORK TOGETHER TO ANALYSE THE DATA ..



Candidate H→γγ event recorded by the CMS detector in 2012





Candidate H → γγ event recorded by the CMS detector in 2012

ATLAS & CMS published > 600 papers with new results in the last 5 years
Krakow

LHC history

1983 first LHC proposal, launch of design study
1994 CERN Council: LHC approval
2010 first collisions at 3.5 TeV beam energy
2015 collisions at design energy
Plan for Upgrade to HL-LHC 2025

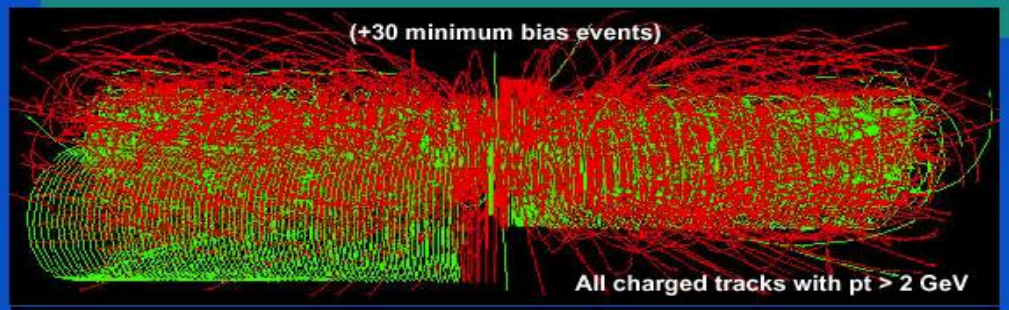
Upgrades in Experiments Now on..

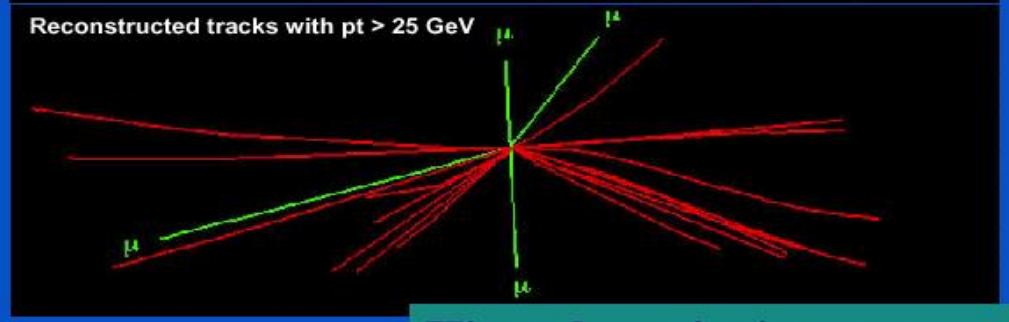
New ideas .. Taking shape for 2035-50 !!

Time to engage fully !!

The World Wide Web

Computing in LHC experiments





Higgs decay in 4 muons
1 in 10^{13} events

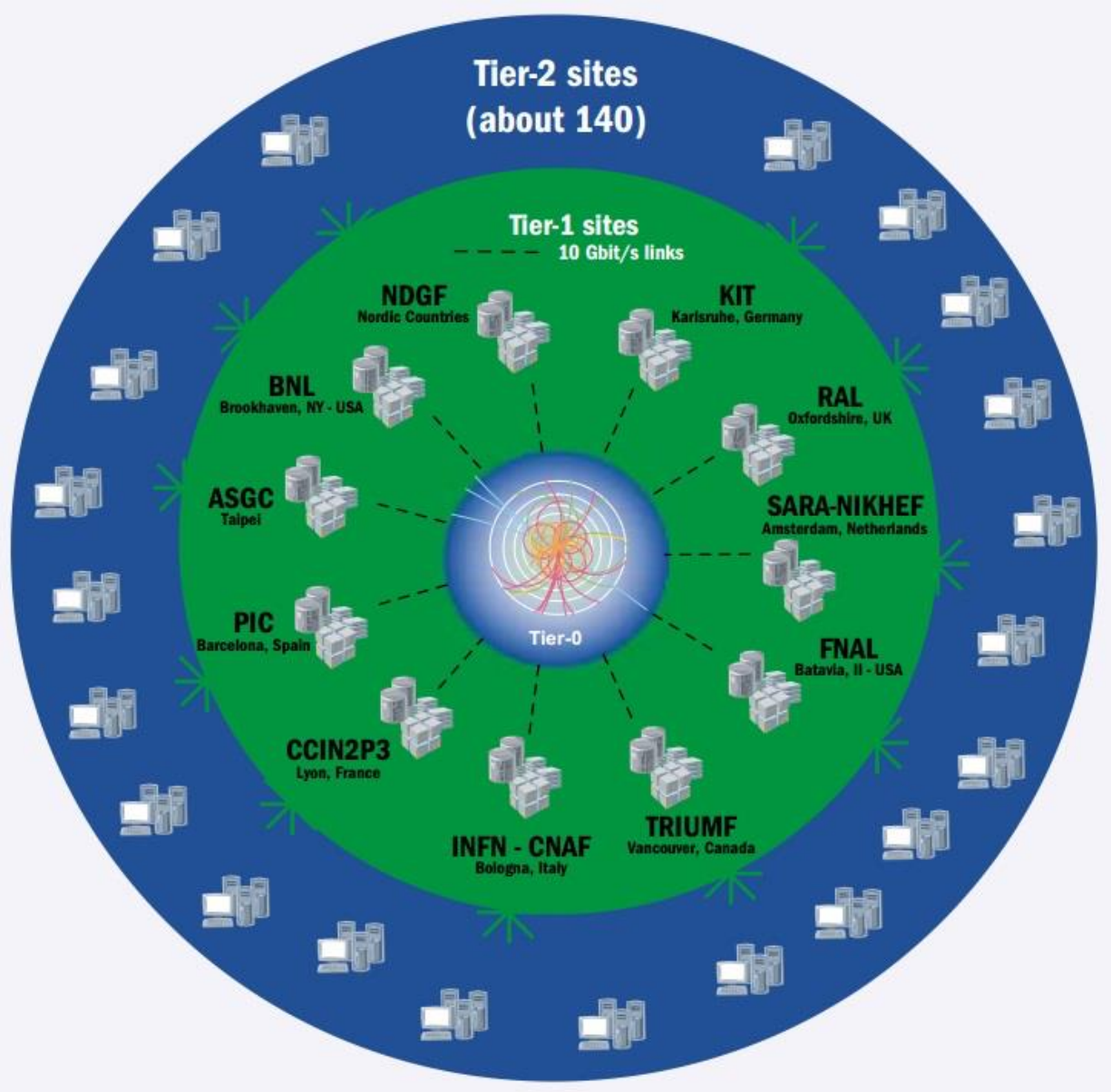
The data transmitted in ONE SECOND of LHC running

is equivalent to:

the information exchanged by WORLD TELECOM (≈ 100 million phone calls)

LHC and Computing

Data Processing & Grid Computing



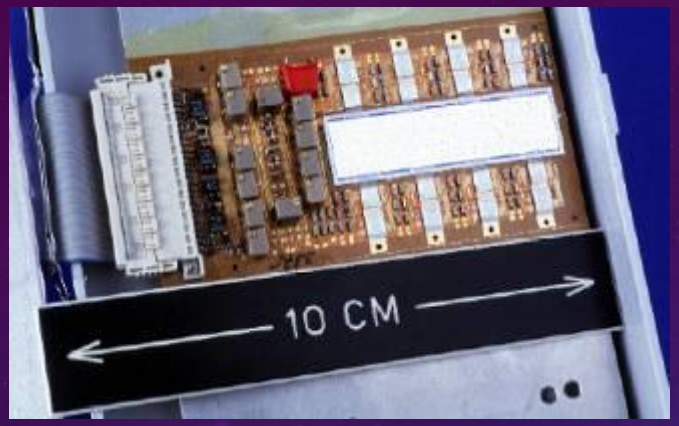
APPLICATIONS OF GRID COMPUTING

Multitude of applications from a growing number of domains

- Archeology
- Astronomy & Astrophysics
- Civil Protection
- Computational Chemistry
- Earth Sciences – Earthquake Modelling
- Financial Simulation
- Fusion
- Geophysics
- High Energy Physics
- Life Sciences
- Multimedia
- Material Sciences
- …

Infrastructure used by >10000 researchers

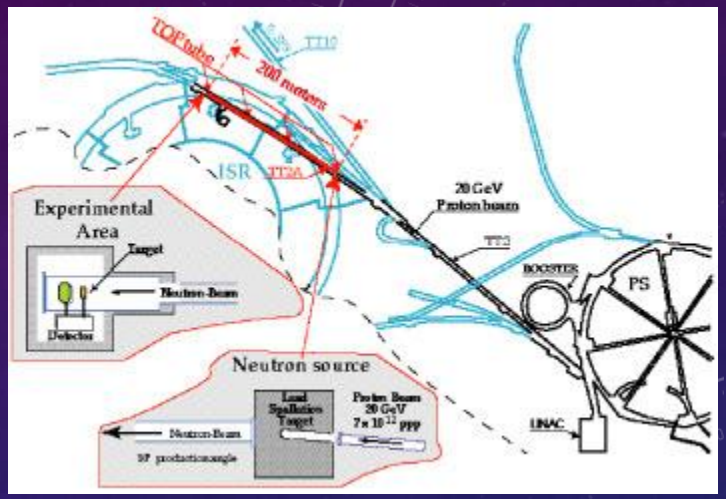
CERN = TECHNOLOGY TRANSFER



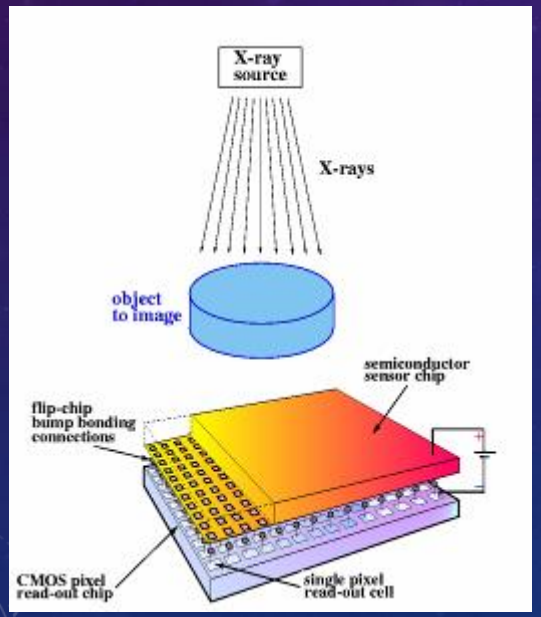
Silicon detector for a Compton camera in nuclear medical imaging

GRID Computing!

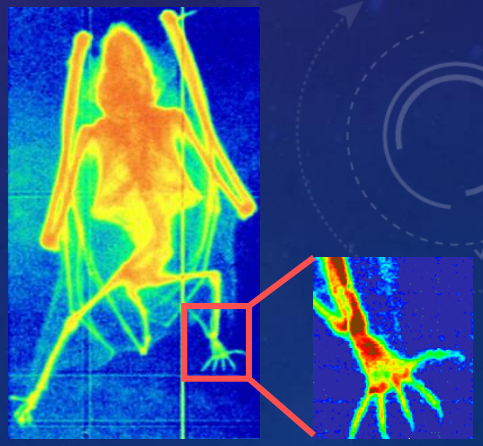
Thin films by sputtering or evaporation



Radio-isotope production for medical applications

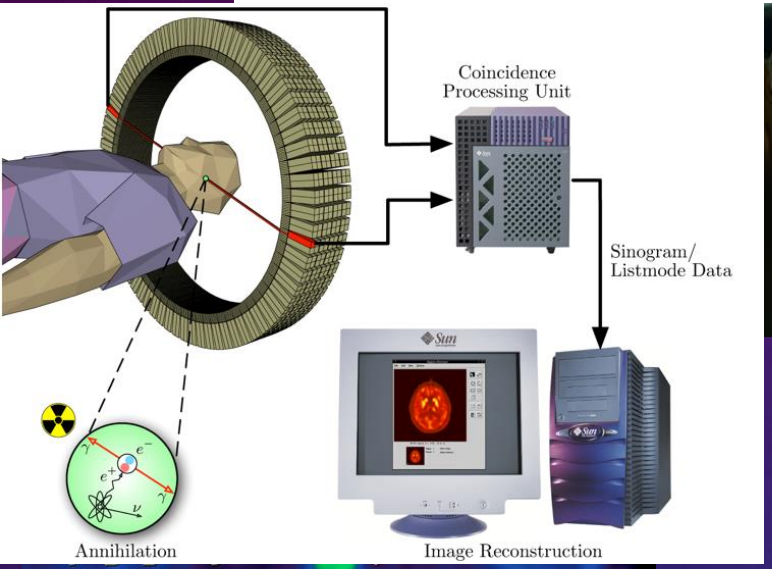


Medipix: Medical X-ray diagnosis with contrast enhancement and dose reduction

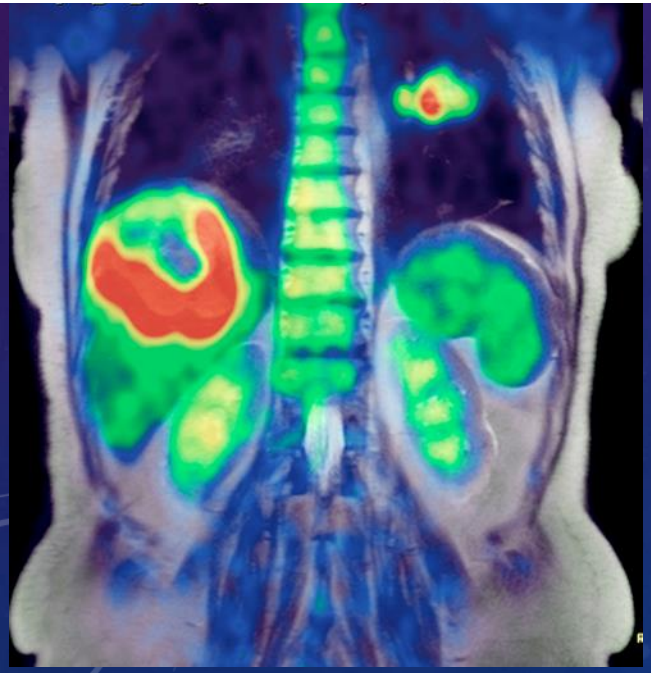


Radiography of a bat, recorded with a GEM detector

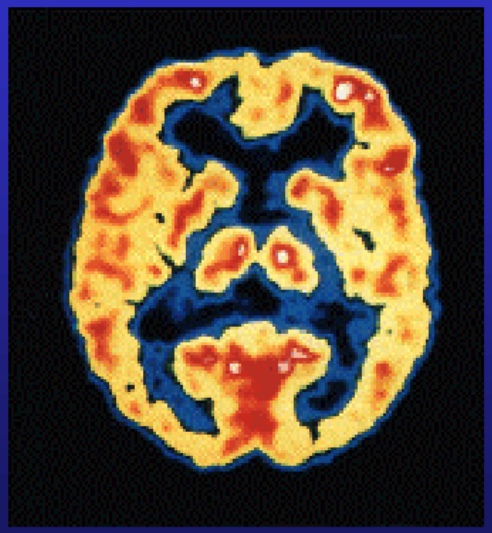
Antimatter – science fiction?

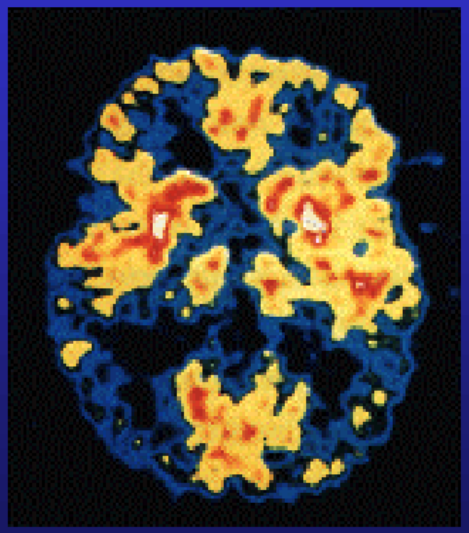


PET Scan



Brain Metabolism in Alzheimer's Disease: PET Scan

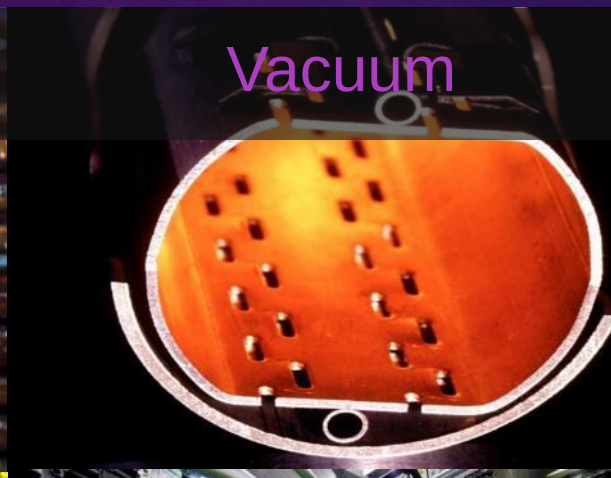


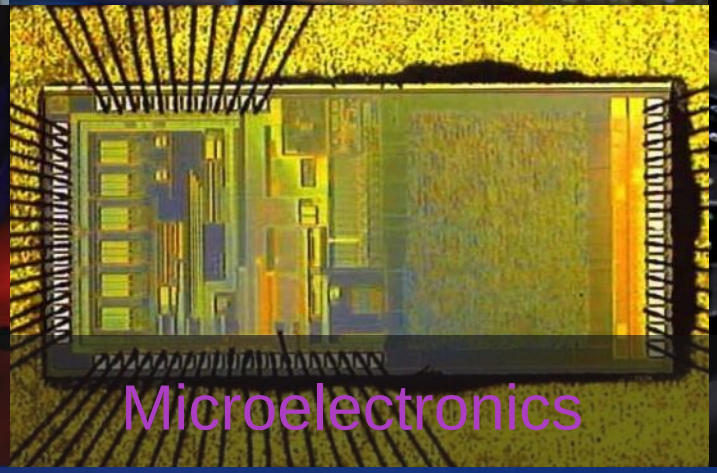


Normal Brain

Alzheimer's Disease

CERN CORE COMPETENCES





How to make therapy less harmful to patients ?

PRESS RELEASE

STOCKHOLM, SEPTEMBER 10, 2015

RAYSEARCH, CERN AND INFN SIGN LICENSE AGREEMENT IN THE FIELD OF ION BEAM THERAPY

CERN, INFN and RaySearch Laboratories AB (publ) have signed a long-term license agreement allowing RaySearch to utilize the FLUKA Monte Carlo code in its research and development in the field of ion beam therapy.

http://www.raysearchlabs.com/about/press/?year=2015&cisionid=1977472

FROM HIGH VACUUM… TO SOLAR ENERGY

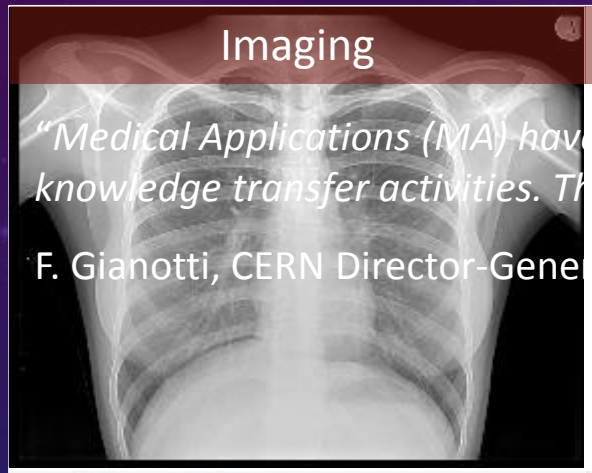
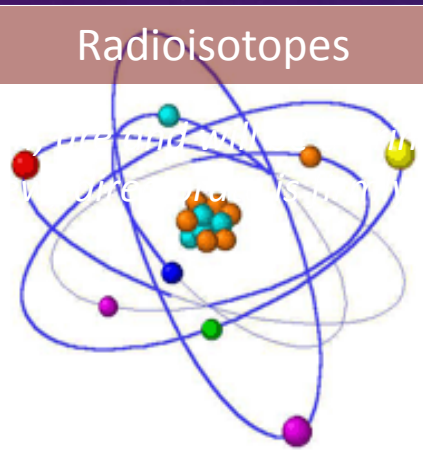
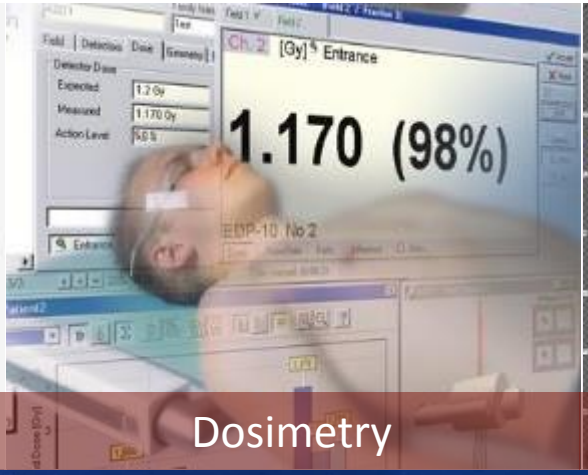
CERN Technology

Non-Evaporable Getter Coating

Industry (spin-off):

High Efficiency Solar Collectors

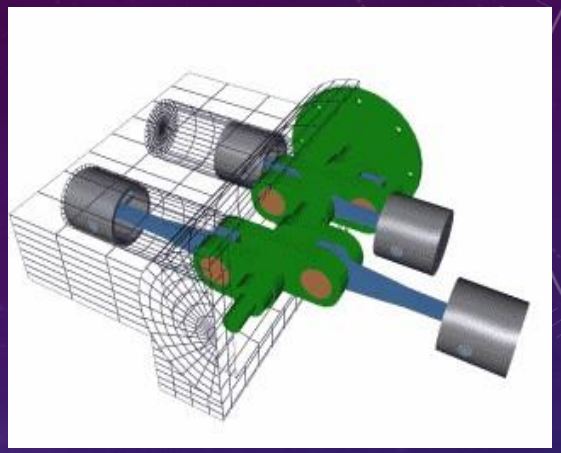
MEDICAL APPLICATIONS AT CERN

Imaging	Radioisotopes	Hadron Therapy
		
"Medical Applications (MA) hav… knowledge transfer activities. Th… F. Gianotti, CERN Director-Gene…		*…component of CERN's …mitted to this goal."*
		
MRI	Dosimetry	Planning & Simulation

BRINGING MEDICAL PHYSICS AND MEDICAL INDUSTRY TOGETHER

ICTR-PHE 2016

Bio Informatics

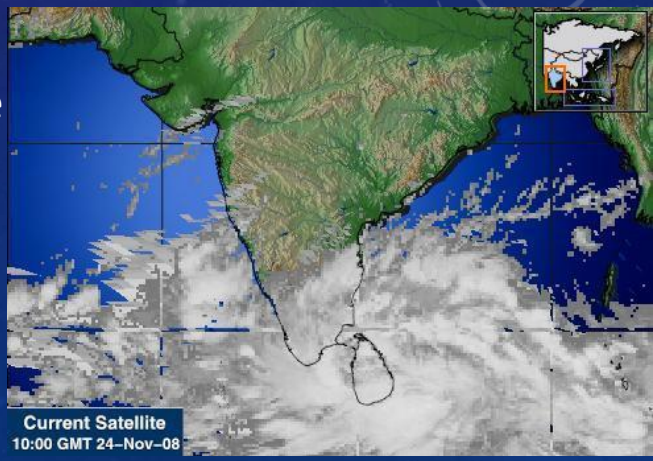


Education, Training

WEATHER GRID SYSTEM

Distributed computing allows remotely located PCs work on small sections of huge amounts of data.

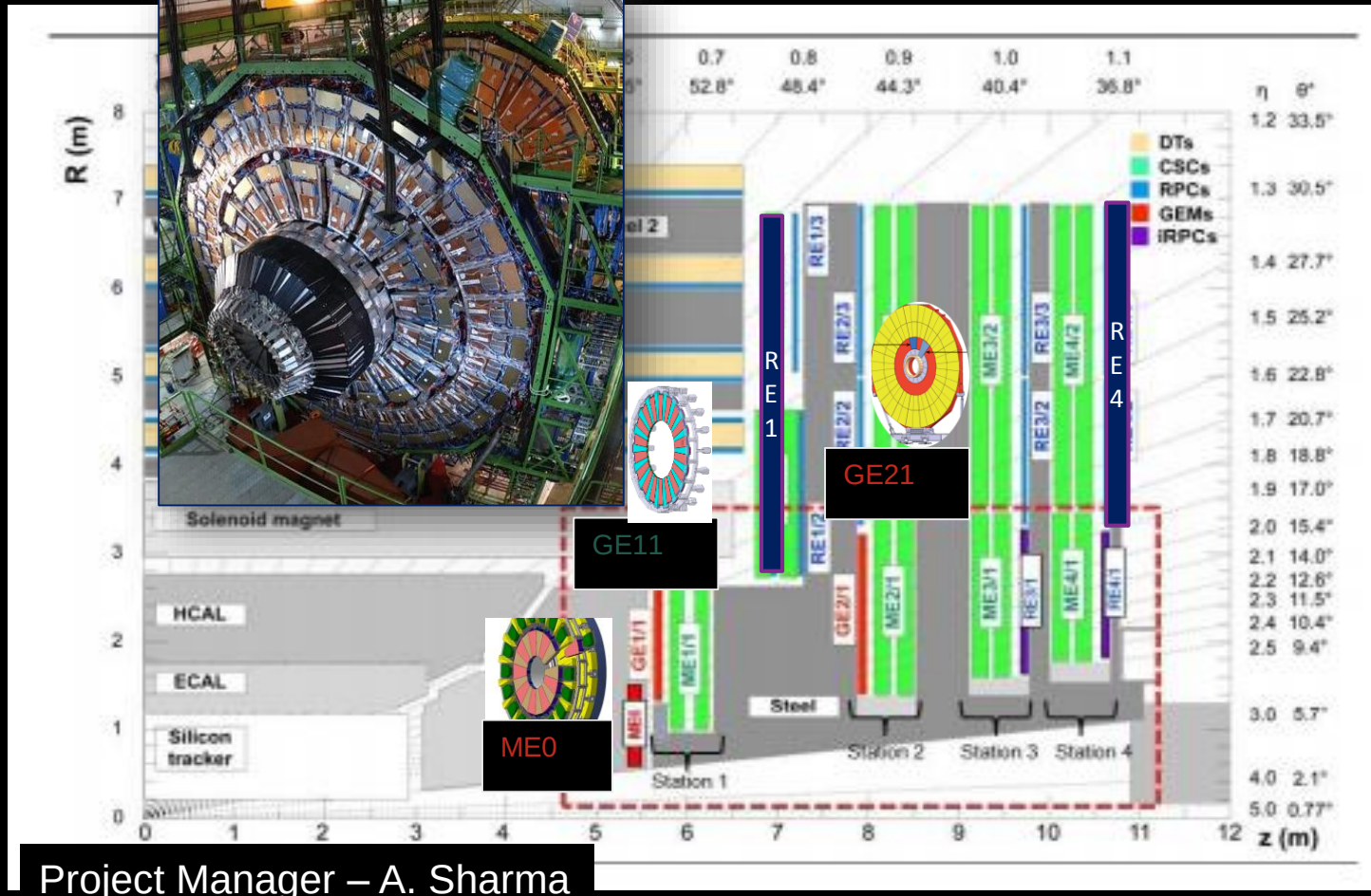
Money and human lives can and are being saved using accurate weather forecasting.



HOW TO START ?

LOST
CONFUSED
UNSURE
UNCLEAR
PERPLEXED
DISORIENTED
BEWILDERED

EXAMPLE: Forward Muon Upgrade : GEM to be installed in 2020



Project Manager – A. Sharma

EXAMPLE CMS GEM UPGRADE

- CERN technology
- Licensed to India & Pakistan

- Collaboration conceived in 2009 with

~ 10 Institutions

- 2016 ~ 40 Institutions 200 Collaborators

~ 50 % Non Member States

- Some Lack of local expertise

- Overcome by “conduit”
  - **Holding specialized schools on detector, electronics, DAQ, s/w, f/w**
  - **Sharing Competence, training**
  - **20 Workshops Organised over 6 years**
- Co-supervision of PhDs
- Production sites in Korea, India, Pakistan

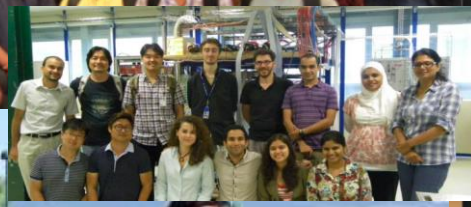
Member State Countries Participating
Italy
Germany
Finland
Belgium
Hungary
Bulgaria

NMS / AM Countries Participating / Interested

Korea
India
Pakistan
China
Egypt
Colombia
USA

Malaysia
Thailand
Iran
Qatar
Kuwait
Lithuania

Student Interns & Teachers Over 500 students from all over the world



CASE FOR **CERN-SOUTH ASIA CONSORTIUM FOR R&D IN DETECTORS, TECHNOLOGY AND APPLICATIONS (1)**

PROPOSAL

Participate in Designing and Building of an experimental detector system for Physics Goals… to answer questions about the Universe

- Doctoral Students, Post Doc's, Teachers, Faculty & students Installation, Commissioning, Operations and maintenance Coordinated by CERN with organised partnership

CASE FOR **CERN-SOUTH ASIA CONSORTIUM FOR R&D IN DETECTORS, TECHNOLOGY AND APPLICATIONS (2)**

- Engage with on-going program which is just starting
- Physics harvest from Test Beam Studies and Simulations
- Teacher & student trainings
- R&D on Technologies
- Knowledge Exchange (KT) Opportunities
- Excellent opportunity of outreach and education

Search for Hidden Particles

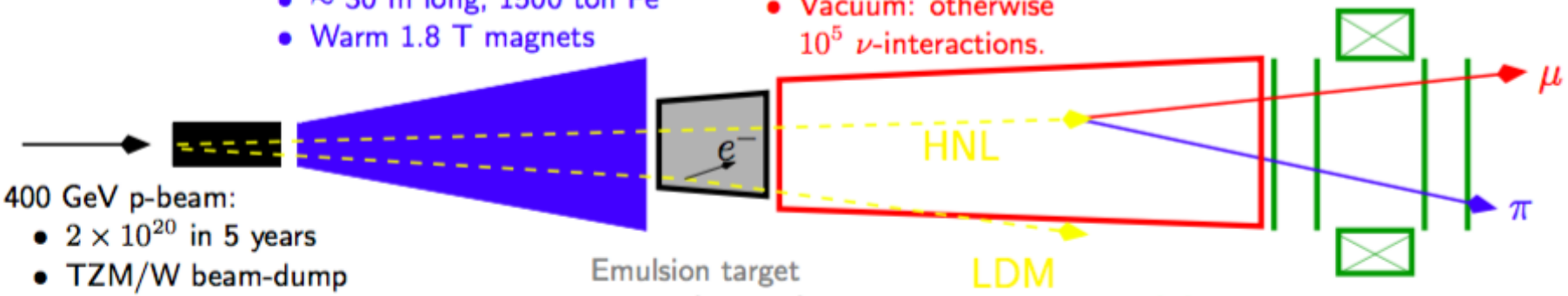
An Example !

- SHiP looks for "Hidden Sector (HS)", which very weakly interacts with the SM-sector.
- HS models can accommodate ν-mixing, Dark Matter and could explain Baryon Asymmetry in the Universe.
- Typically HS production branching ratios of $O(10^{-10})$ and long lived $c\tau$ $O(\mathrm{km})$

Principle of SHiP strategy to produce/detect HS particles:

Magnetic μ-shield (10^{11} μ/s):
- $\sim$ 30 m long, 1500 ton Fe
- Warm 1.8 T magnets

Vacuum decay-vessel
- "nothing" in, but HS-decay products out.
- Vacuum: otherwise 10^5 ν-interactions.



400 GeV p-beam:
- 2×10^{20} in 5 years
- TZM/W beam-dump
- Peak power: 2.6 MW
- Produce HS particles:
  - Heavy Neutral Leptons
  - Dark Photons
  - Axions
  - Neutralinos
  - Light Dark Matter etc..

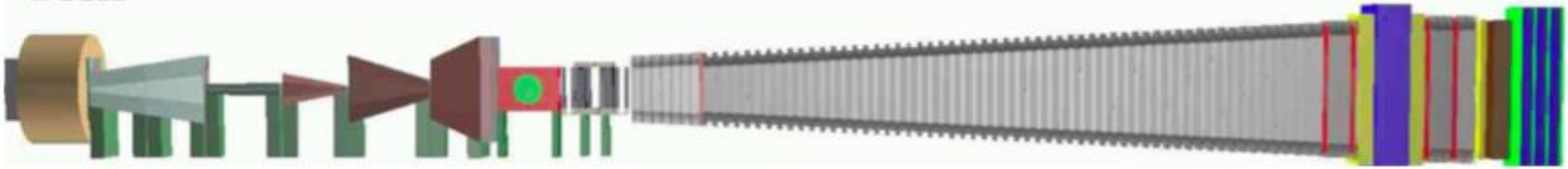
Emulsion target
- ν_τ interactions
- HS scatter on e/nucleus

HS Spectrometer
- $5 \times 10\mathrm{m}^2$ straw tubes
- Large magnet
- Calorimetry, Muon-spectrometer

- SHiP Technical Proposal: https://arxiv.org/abs/1504.04956
- SHiP Physics Paper: https://arxiv.org/abs/1504.04855, Reports on Progress in Physics, Volume 79, Number 12

Some SHiP Detector Technologies

SHiP collaboration: http://ship.web.cern.ch/ship/



Beam Delivery:

- Extraction and beam delivery from SPS, low loss Septum-magnet, Target Region

Magnets:

- Magnetic μ-shield (30 m long, 1500 tons)
- Large aperture spectrometer magnet: $5 \times 10\ \mathrm{m}^2$, 0.15 T peak-field.

Tracking:

- Interleave emulsion with "time-stamping" detectors: GEM, or Scintillating fibres: 20-30 m^2
- RPCs for muon-spectrometers several 100 m^2
- Straw tubes in vacuum.

Calorimetry:

- Pointing ECAL
- Hadronic Calorimeter, merged with muon-spectrometer?

SHiP timeline:
2018: Comprehensive Design Reports for eropean Startegy Meeting
2020: SHiP is approved
2026: SHiP commissioning and first physics data taking.

GEANT 4

HTTP://GEANT4.CERN.CH/APPLICATIONS/INDEX.SHTML

FLUKA

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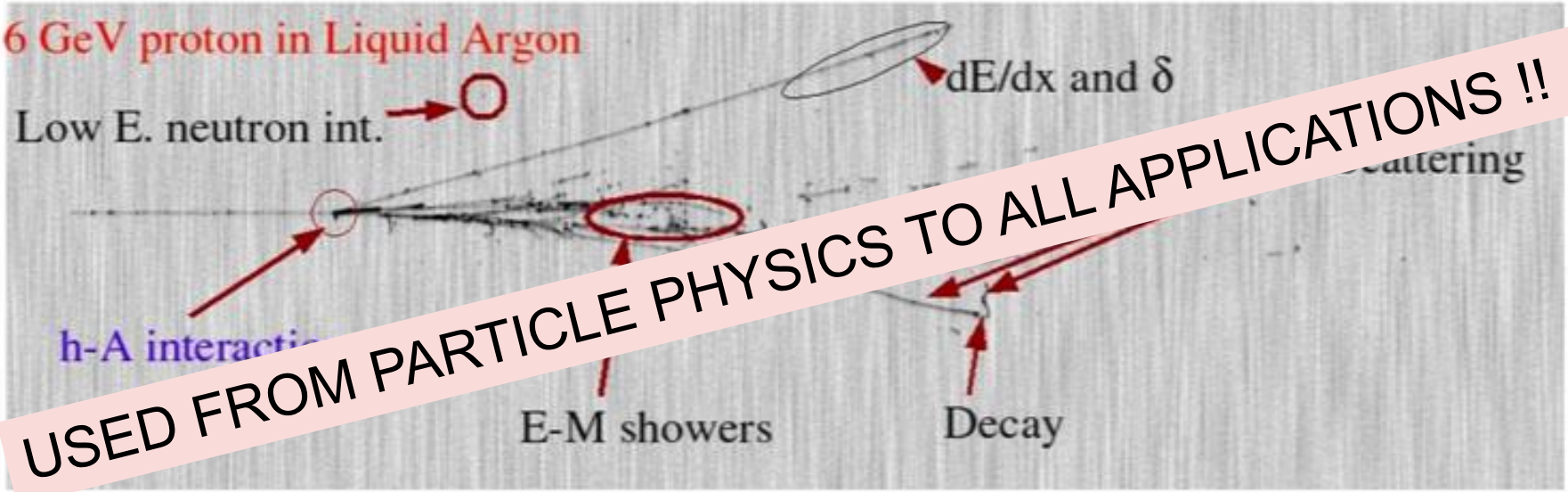

USED FROM PARTICLE PHYSICS TO ALL APPLICATIONS !!

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>2000 users

http://www.fluka.org

OUTLOOK: CERN KNOWLEDGE EXCHANGE

- CERN-South Asia Consortium
- Develop project proposal plan as white paper (Panel Discussion Tomorrow)
- Encourage high levels of engagement between academia, universities and R&D Institutions
- Translation and application of research into innovation and KT – build pathways
- Train students and teachers in this whole process which underpins all the above
- We take data ! Discover ! Something ! Win prizes !

Thank you for your attention !!

The woods are lovely, dark, and deep, But I have promises to keep, And miles to go before I sleep, And miles to go before I sleep.

Robert Frost