BIST Barcelona Institute of Science and Technology

Elementary Particle Detectors and Data Handling Systems: A historical perspective

Prof. Manuel Delfino, UAB and IFAE, Director of PIC

Dialogues on the boundaries of knowledge: Big Data

MARCH 31, 2017

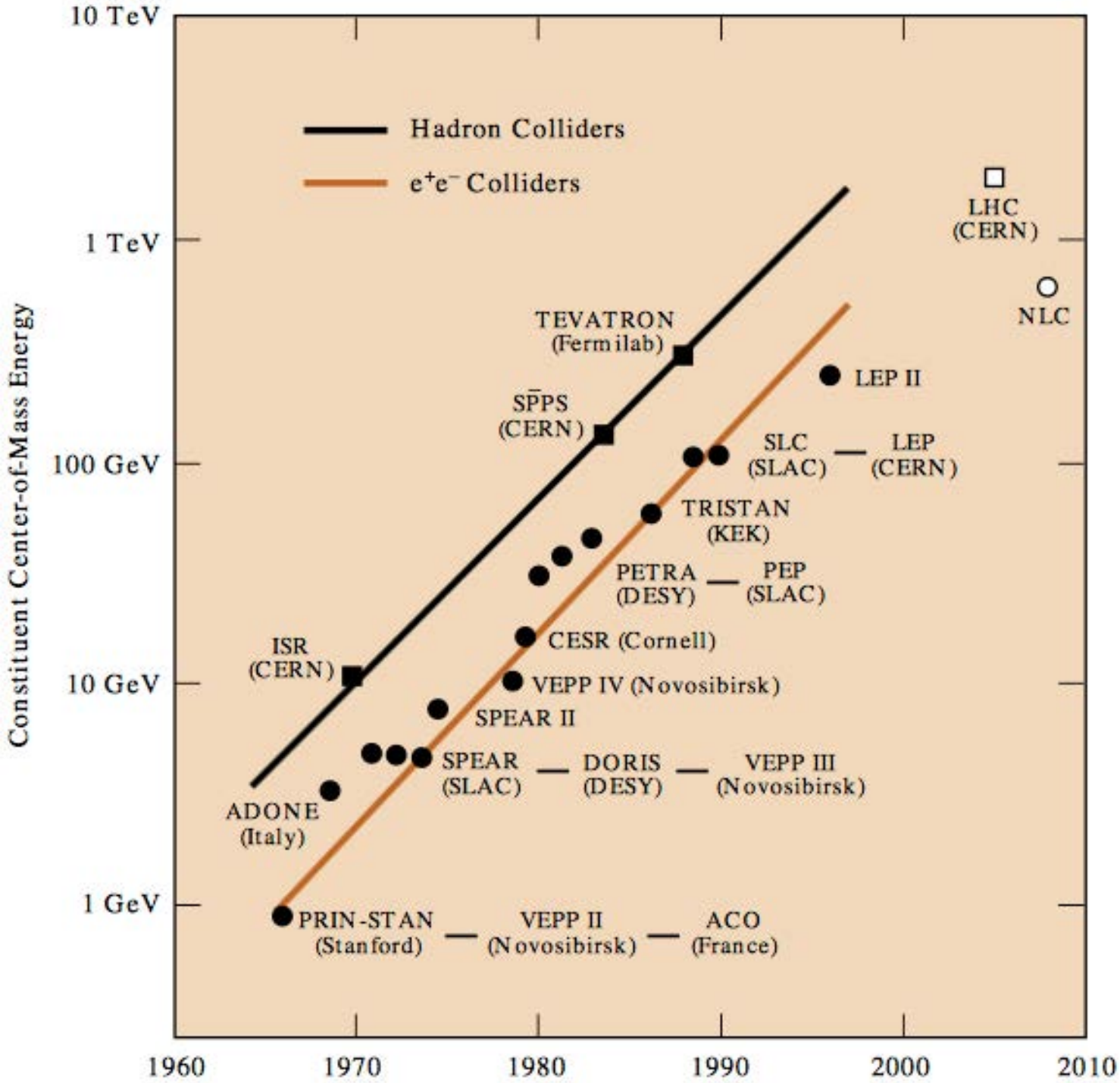
CCCB | Barcelona

Why Experimental Particle Physics = High Energy ?

- Particle accelerator beam → Particle mass + Kinetic Energy
- Collision: Beam Energy→(many, different) particles + Kinetic Energy
  - Many possible outcomes → final state topology to differentiate
  - Energy-momentum conservation → Initial Kinetic Energy limits the maximum mass that can be produced in a collision

If an accelerator doesn't find what you are looking for, the only way out is to move on to a higher energy one

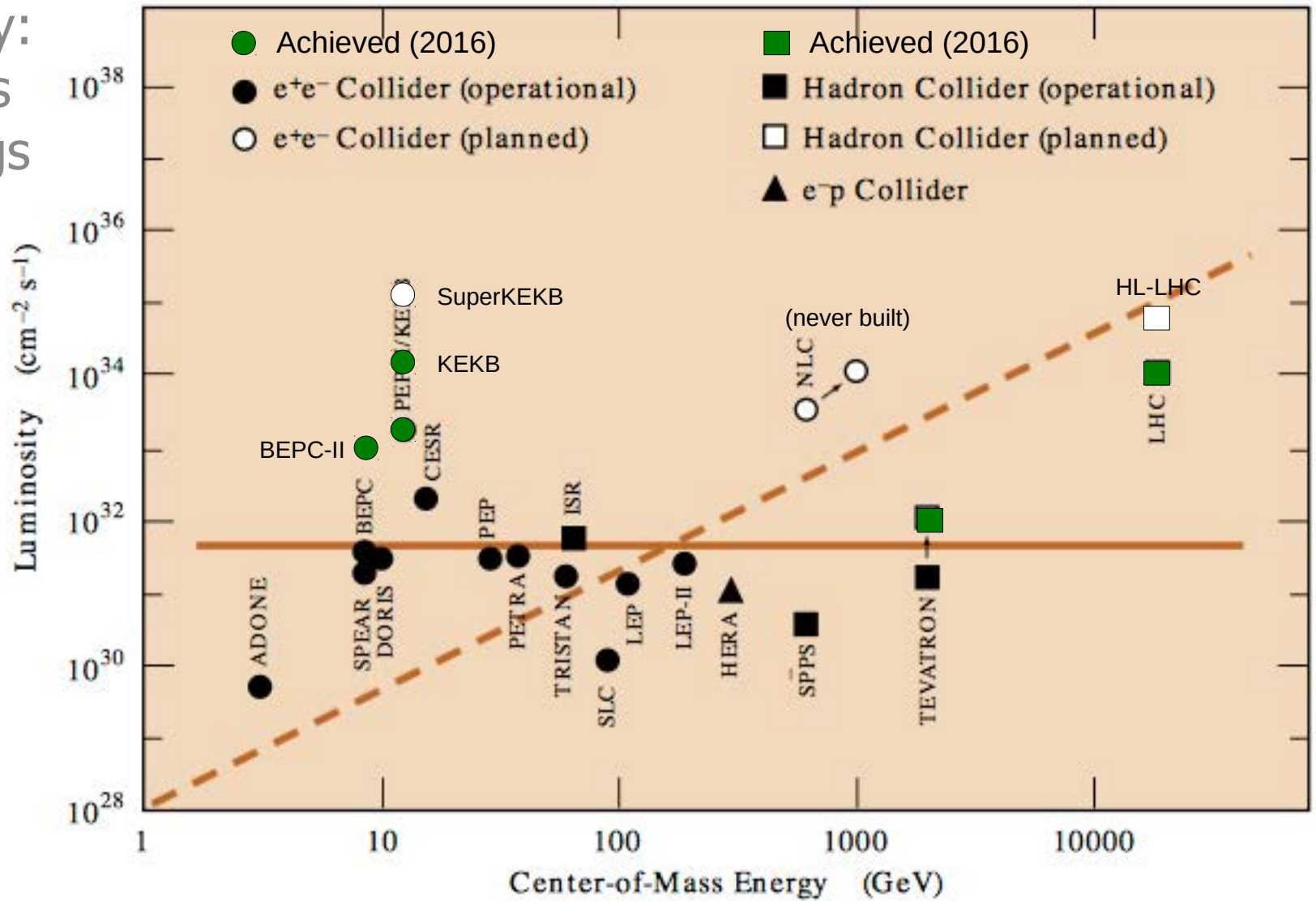
...except: If the probability of producing it is too small, strive to make your accelerator more "luminous"



Panofsky,
SLAC Beam Line,
Spring 1997,
Vol. 27, No. 1

More luminosity:

- More particles
- More crossings
- Tighter focus



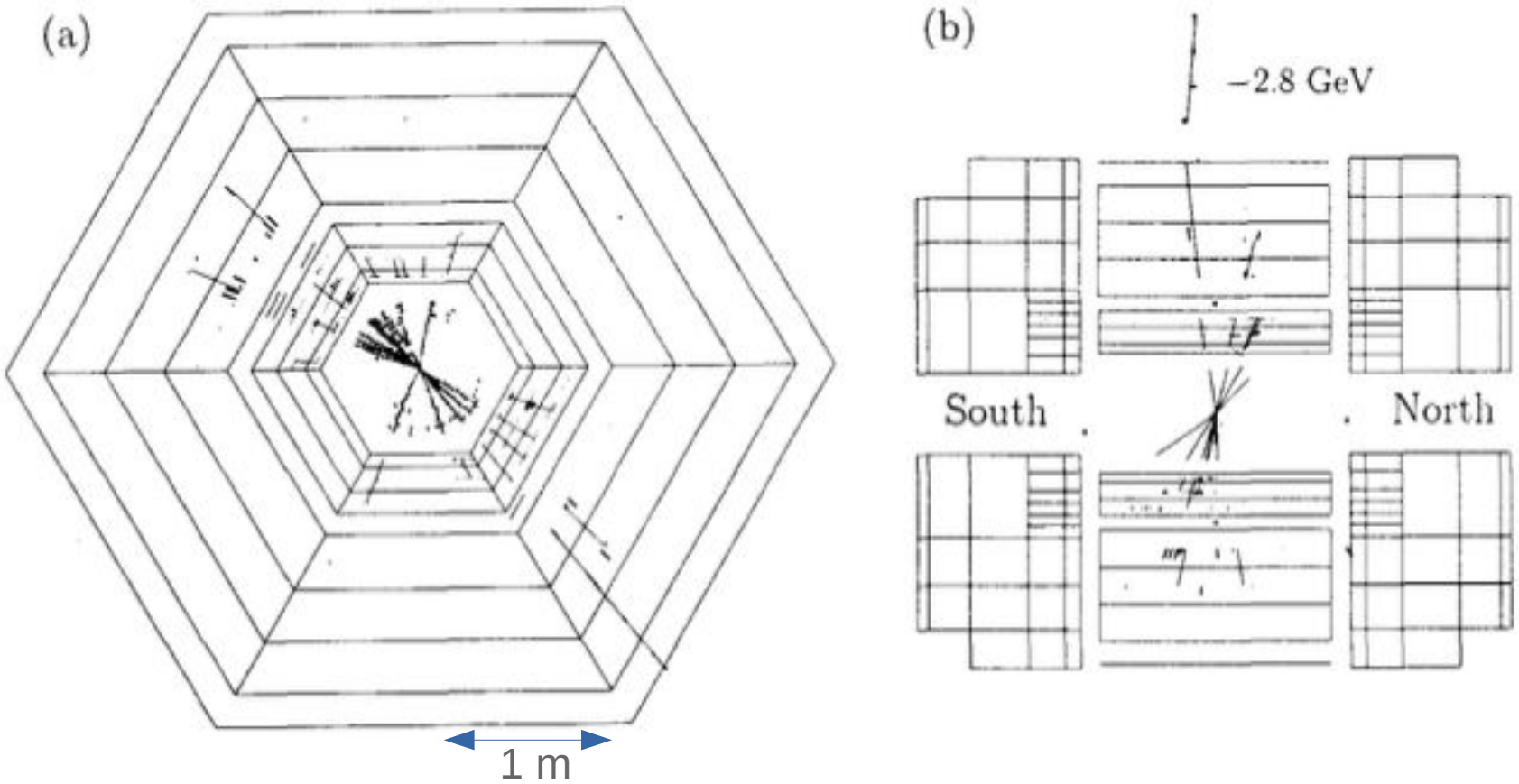
Panofsky,
SLAC Beam Line,
Spring 1997,
Vol. 27, No. 1

Note: Neutrino factories not shown

Detectors: Larger, more granular, faster, smarter

- Use bending in magnet to measure speed of produced particles
  - Magnetic force = Centripetal force $q v B = \frac{m v^2}{R}$ $v = \frac{q}{m} B R$
  - B limited → Need increasing precision in trajectories
- Number of particles produced in a collision increases with energy
  - Particles emerge in "jets", very crowded together
  - High-mass particles are unstable and decay shortly after produced
  - Need to identify the types of particles
- More luminosity:
  - 400 kHz in 1980's → 40 MHz in LHC today
  - 1 collision in 10 crossings 1970's→20 collisions in 1 LHC crossing
- More online filtering of more complex topologies.
  Yesterday's interesting physics becomes today's noise.

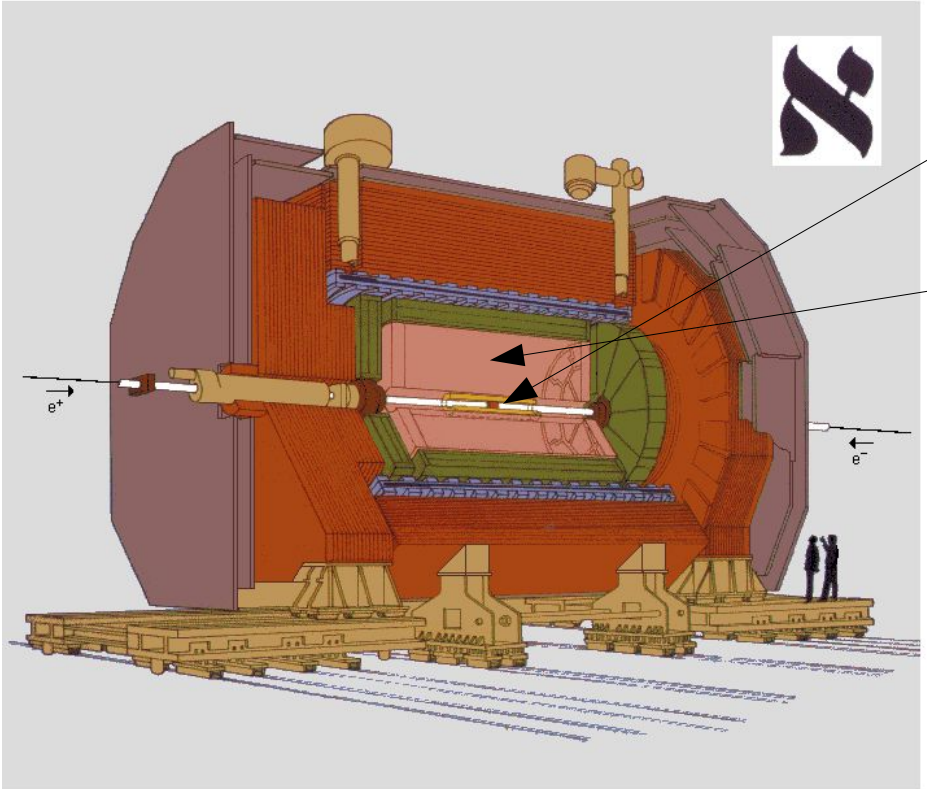
Particles produced in a 29 GeV electron-positron collision detected by the MAC apparatus at Stanford in the 1980s



- Digitization electronics managed by Motorola 68k microprocessors
- Data acquisition + event filter: VAX minicomputer (4 MB RAM, 1 GB disk, 170 MB/tape)
- 0.5 Mbps ~mile link to IBM mainframe →remote data recording, automated workflows
- Analysis supported by a *single* IBM mainframe for the *whole* laboratory – Virtual Machines
- No data access from participating institutions

(from Allaby et. al., Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 281, Issue 2, 1989, Pages 291-324, ISSN 0168-9002, http://dx.doi.org/10.1016/0168-9002(89)91327-2.)

ALEPH detector at CERN's Large Electron Positron (LEP) collider in the 1990s



Vertex Detector 100k channels

Inner Tracking Chamber

Time Projection Chamber 50k channels

Electromagnetic Calorimeter

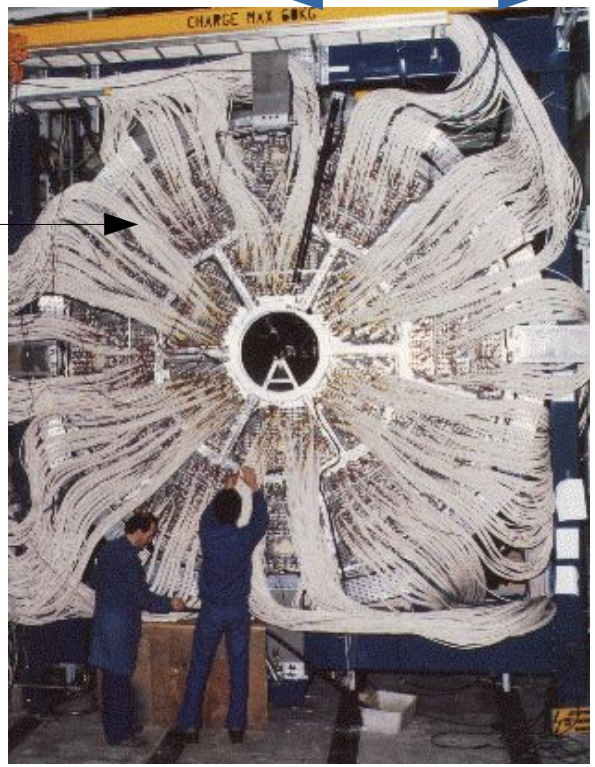
Superconducting Magnet Coil

Hadron Calorimeter

Muon Chambers

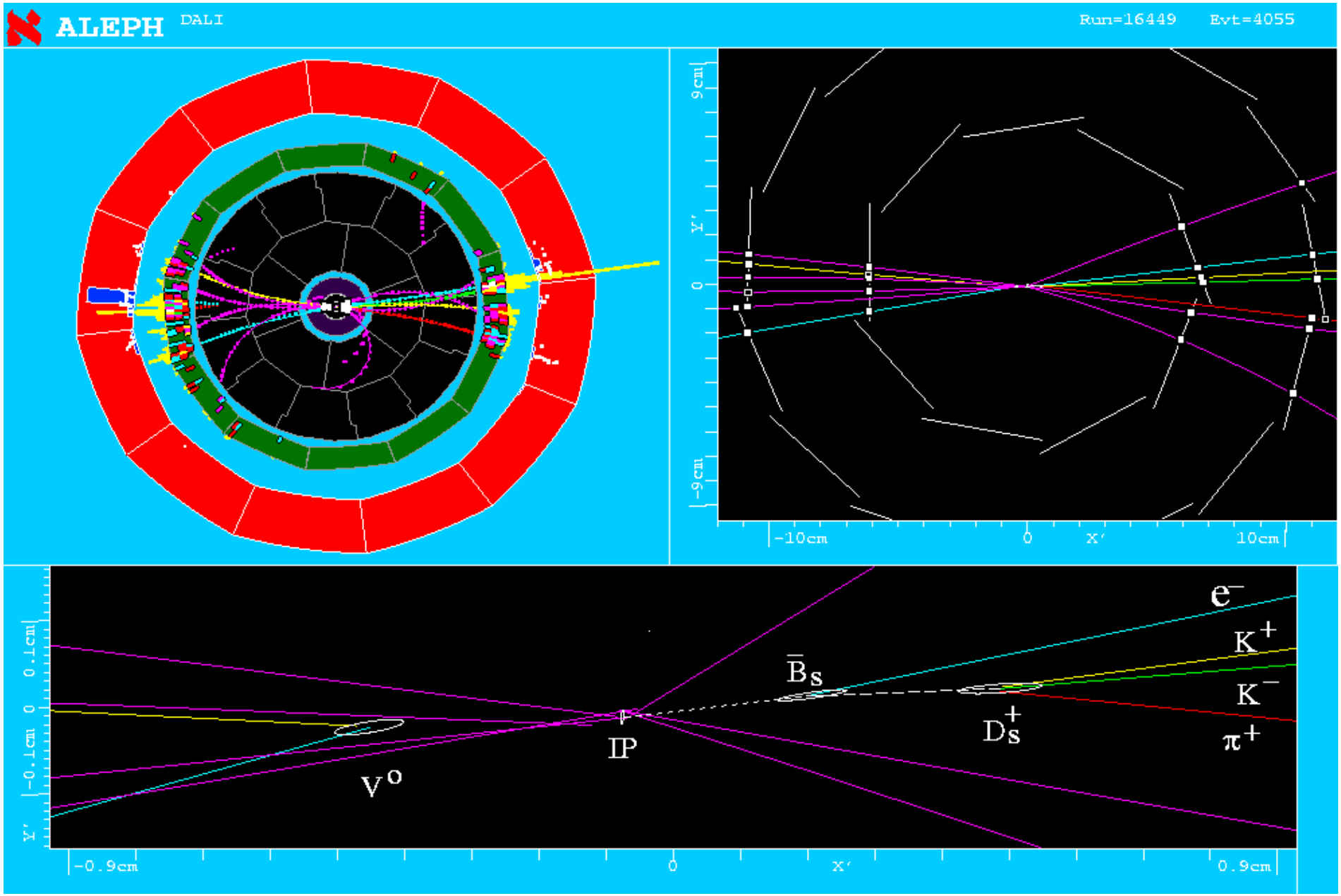
Luminosity Monitors

2 m



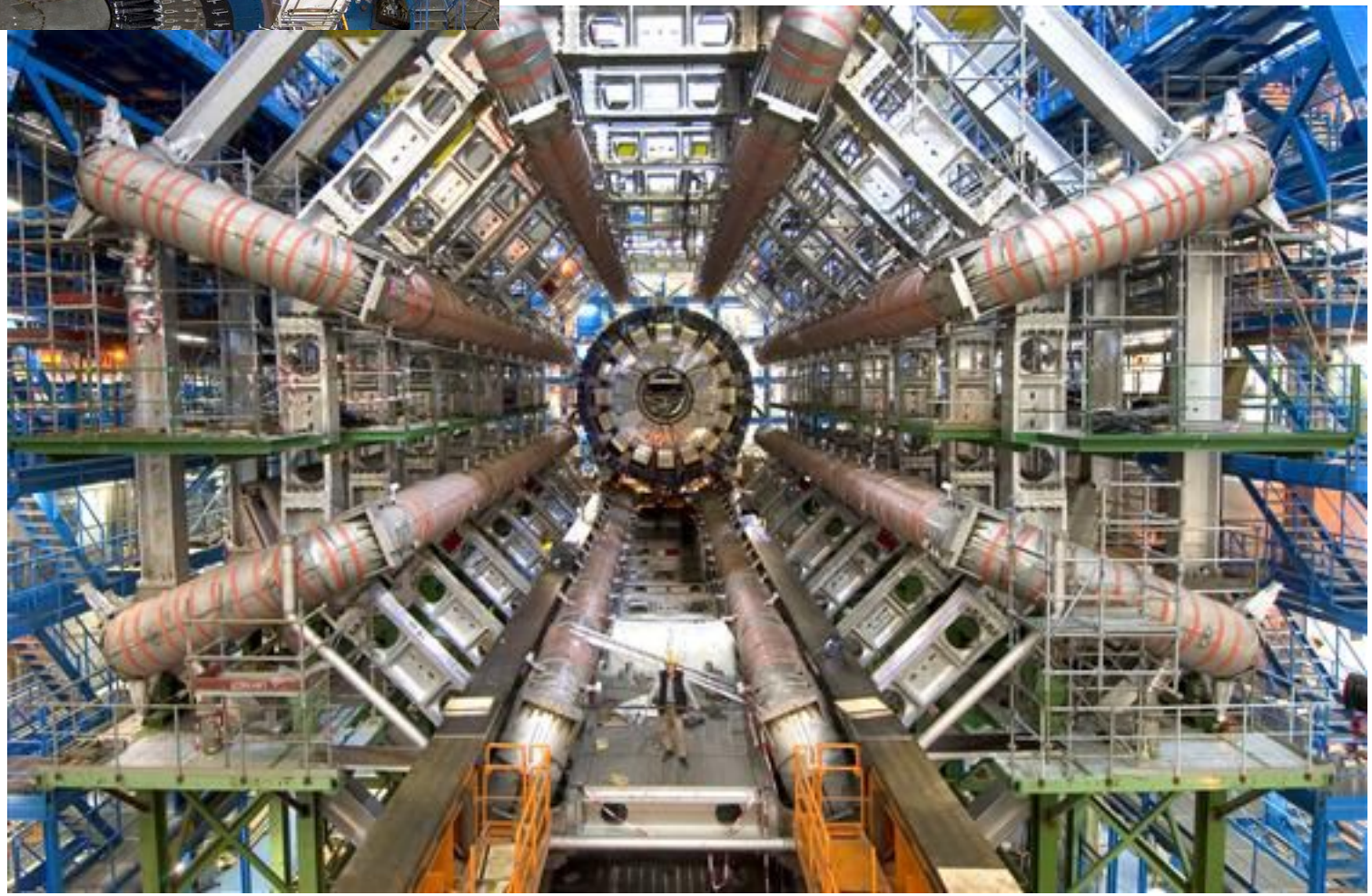
- Precision timing over 1000 m³ volume. Flash ADC's, microprocessors, software trigger
- Dedicated detector-side data processing farm (originally 12 VAX workstations on Ethernet)
- CERN fiber optic network: remote data recording to CERN data center (>5 km away)
- Data analysis:
  - Shared IBM mainframe complemented by private VAX workstation cluster
  - Duplicate data tapes shipped to some laboratories (mainly France and UK)
  - Later overtaken by SHIFT workstation and PC farms developed and operated by CERN IT

Weak Neutral Boson (Z) decaying to particles containing heavy b quarks, which in turn decay in the Vertex detector

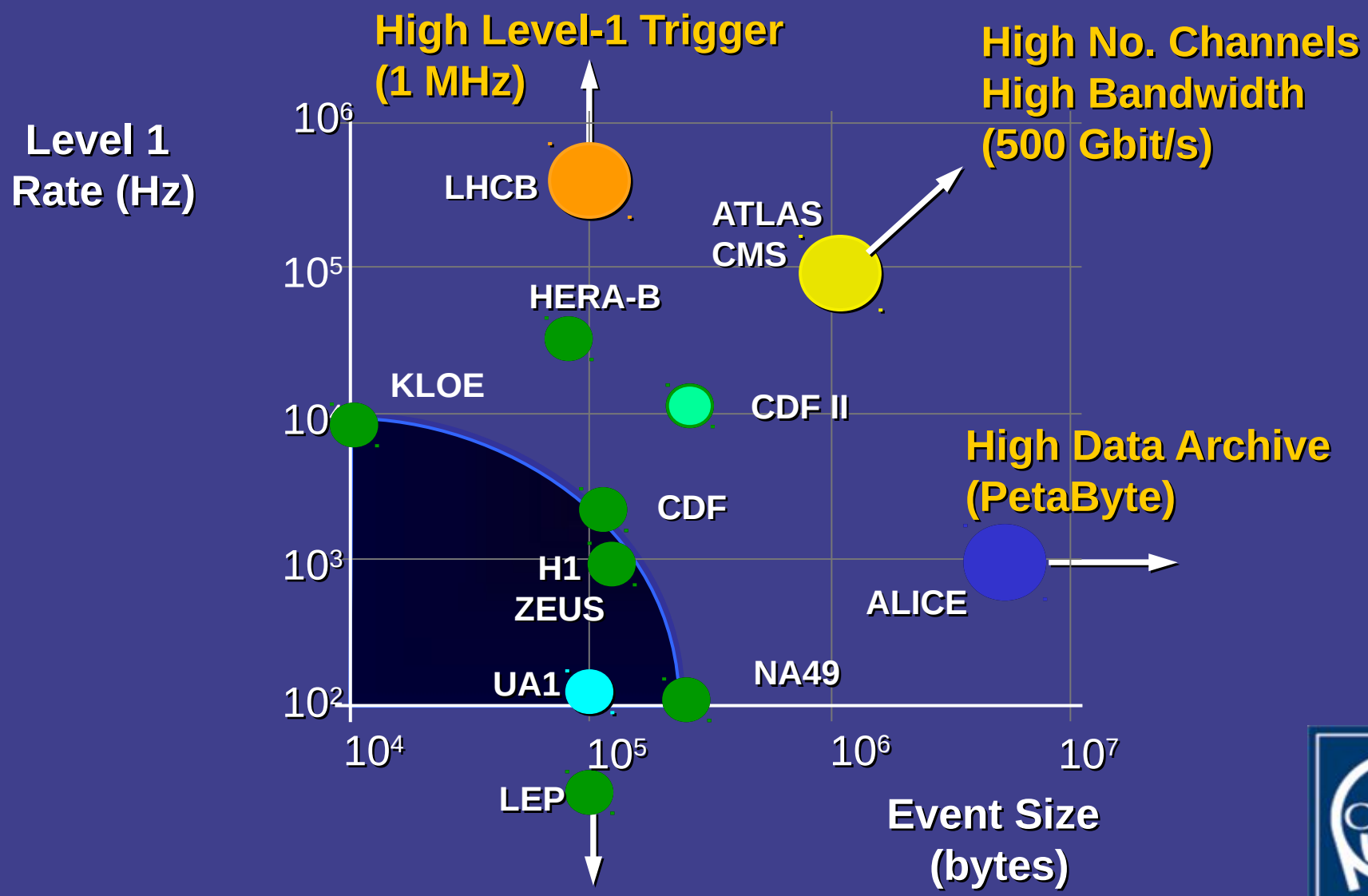


ATLAS detector at CERN's Large Hadron Collider (LHC)

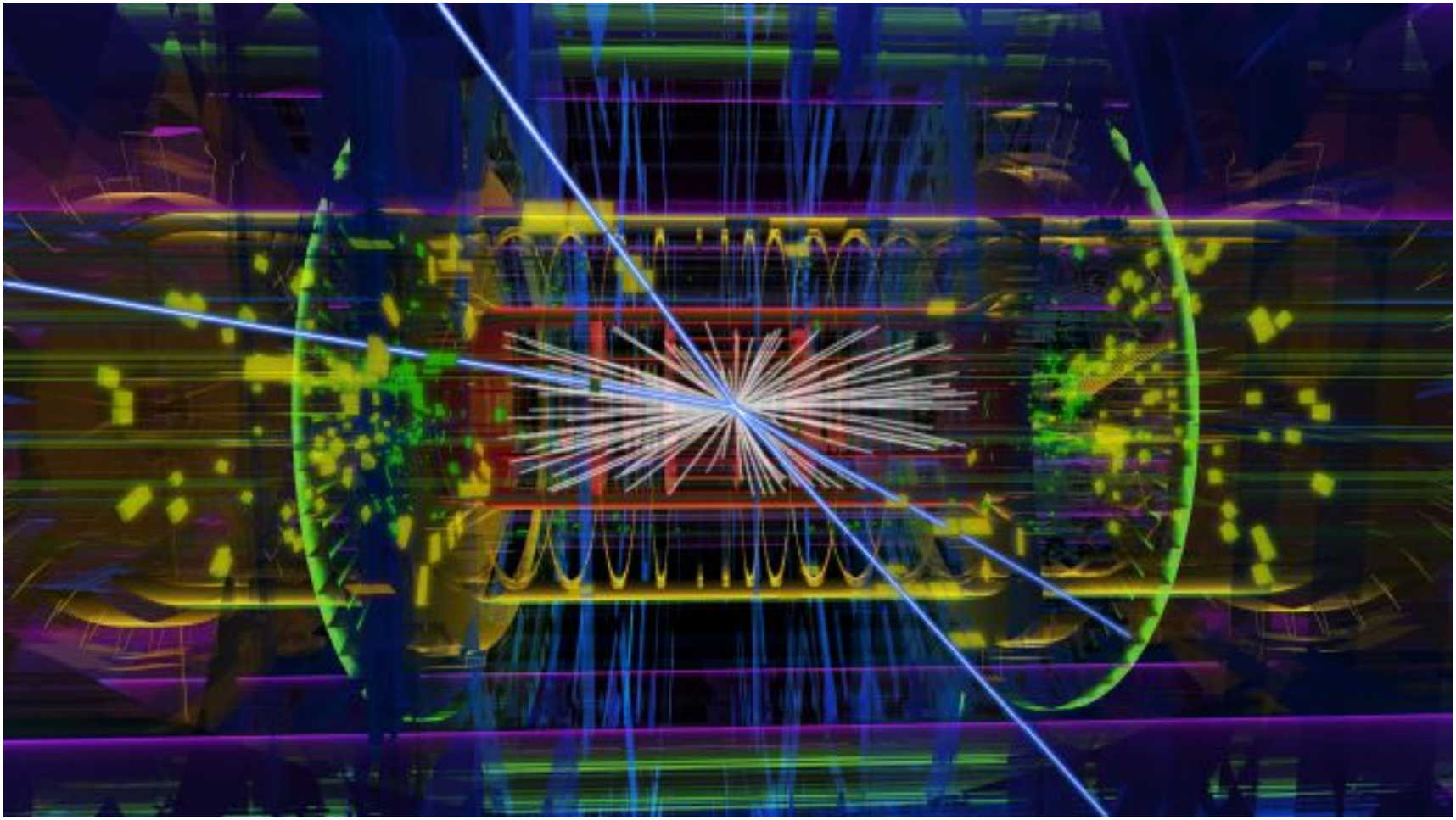
- 46 m long
  25 m diameter
  7000 Tons
- Inner track detector:
  80M pixels
  6M silicon strips
  350k channel TRT
- Data acquisition system handles 60 Petabytes per second
- Trigger+Event Filter select 100 Hz out of 1 GHz (1 in 10^7)
- More than 20 TB per day of recorded data



CERN's Large Hadron Collider (LHC): Two steps at once



Collision recorded by ATLAS with four identified muons



Astrophysics and Experimental Cosmology

- Big Bang → Early Universe dominated by elementary particle physics
- Standard Model of Particles: Quantum Gravity is a big missing piece
- Expansion of the Universe is accelerating, don't understand why

New high-tech telescope-like instruments have become an important complement to accelerators

- Air Cherenkov gamma-ray "telescopes"
- Instrumented water or ice neutrino "telescopes"
- Laser interfefometer gravitational wave detectors
- Sky surveys: ground-based or satellite-born automated telescopes
- Synthetic aperture radio telescopes

Significant computing and storage needs with complex management, access and preservation issues

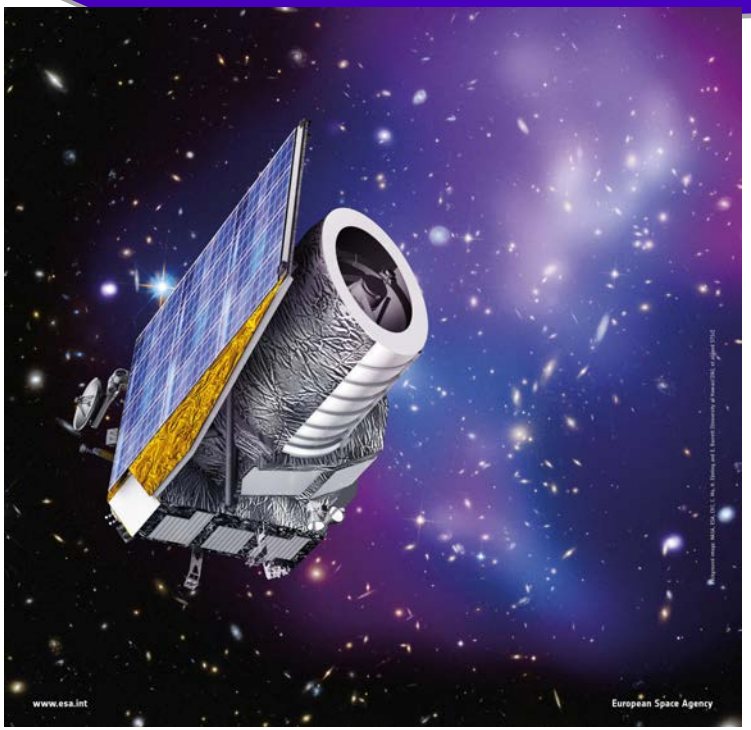
Cherenkov Telescope Array (CTA)

Artist rendering of Northern Array at ORM, La Palma, Canary Islands

1,350 members from 210 institutes in 32 countries

Large Telescope concrete pad at ORM

European Space Agency EUCLID satellite



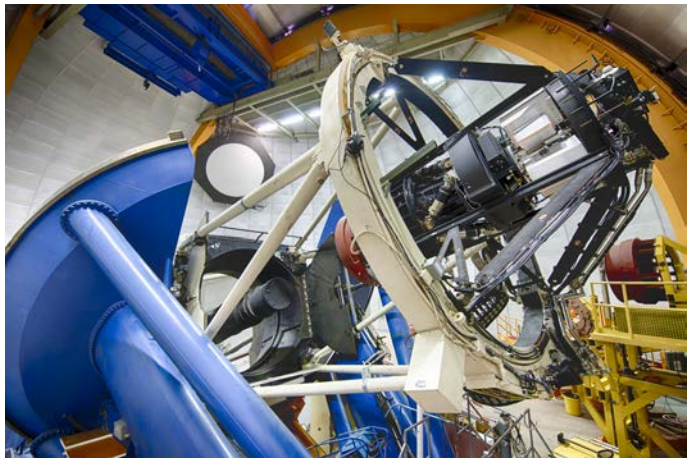
Artist rendering of EUCLID at the L2 Lagrangian point

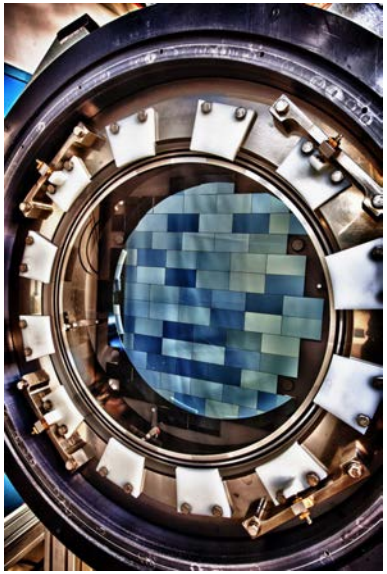
- 1400 members from 180 institutes in 16 countries
- 10 billion sources
- Data in the tens of Petabytes, possible by improved down-link speed from space to Earth
- Science Data Centers (similar to LHC Tier-1s)

Dark Energy Survey (DES)

- 400 scientists from 25 institutions in 7 countries
- Measuring 300 million galaxies
- Data management at U.S. National Center for Supercomputing Applications (NCSA) in Illinois
- PIC “Big Data” platform to speed-up analysis

Dark Energy Camera (DECam) on Blanco Telescope in Chile (Reidar Hahn, Fermilab)





DECam Focal Plane Detector (Reidar Hahn, Fermilab)

Over the last 50 years, scientists and engineers have worked hand in hand to build bigger and better instruments for particle physics, astrophysics and experimental cosmology.

These instruments are generating data of increasing complexity in increasing volumes, which must be shared at a planetary scale.

Innovation in computing and data processing domain is a key activity … and Frédéric Hemmer from CERN will tell you more about it !

PIC
port d'informació científica

Helping to turn Information into Knowledge

Maintained by a collaboration of:

IFAE Institut de Física d'Altes Energies · Excelencia Severo Ochoa · BIST Barcelona Institute of Science and Technology · Gobierno de España, Ministerio de Economía y Competitividad · Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas · Excelencia María de Maeztu · cfp CIEMAT física de partículas

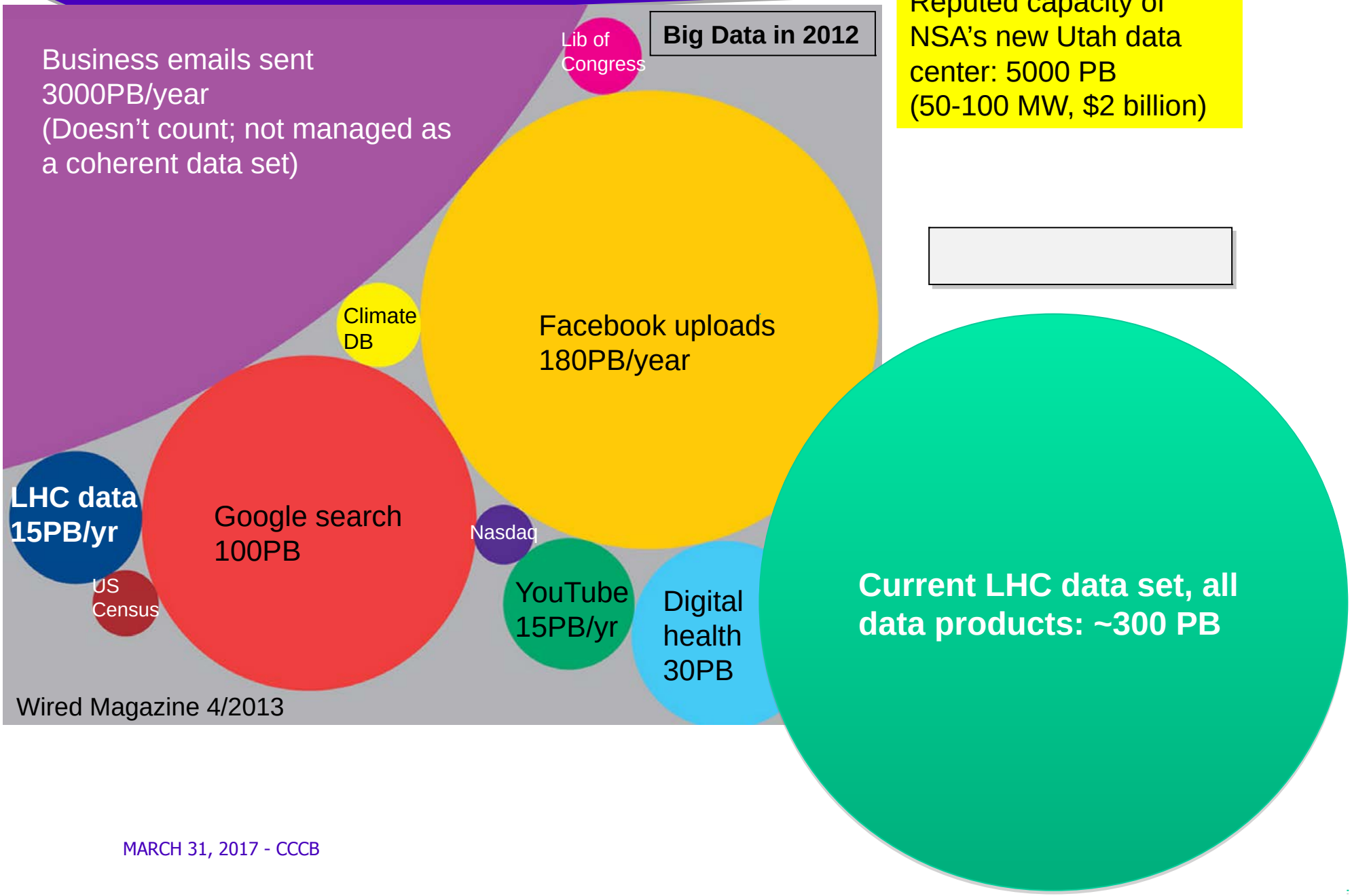
The support of UAB is gratefully acknowledged.

UAB Universitat Autònoma de Barcelona

The support of the ERDF fund 2007-13 is gratefully acknowledged.

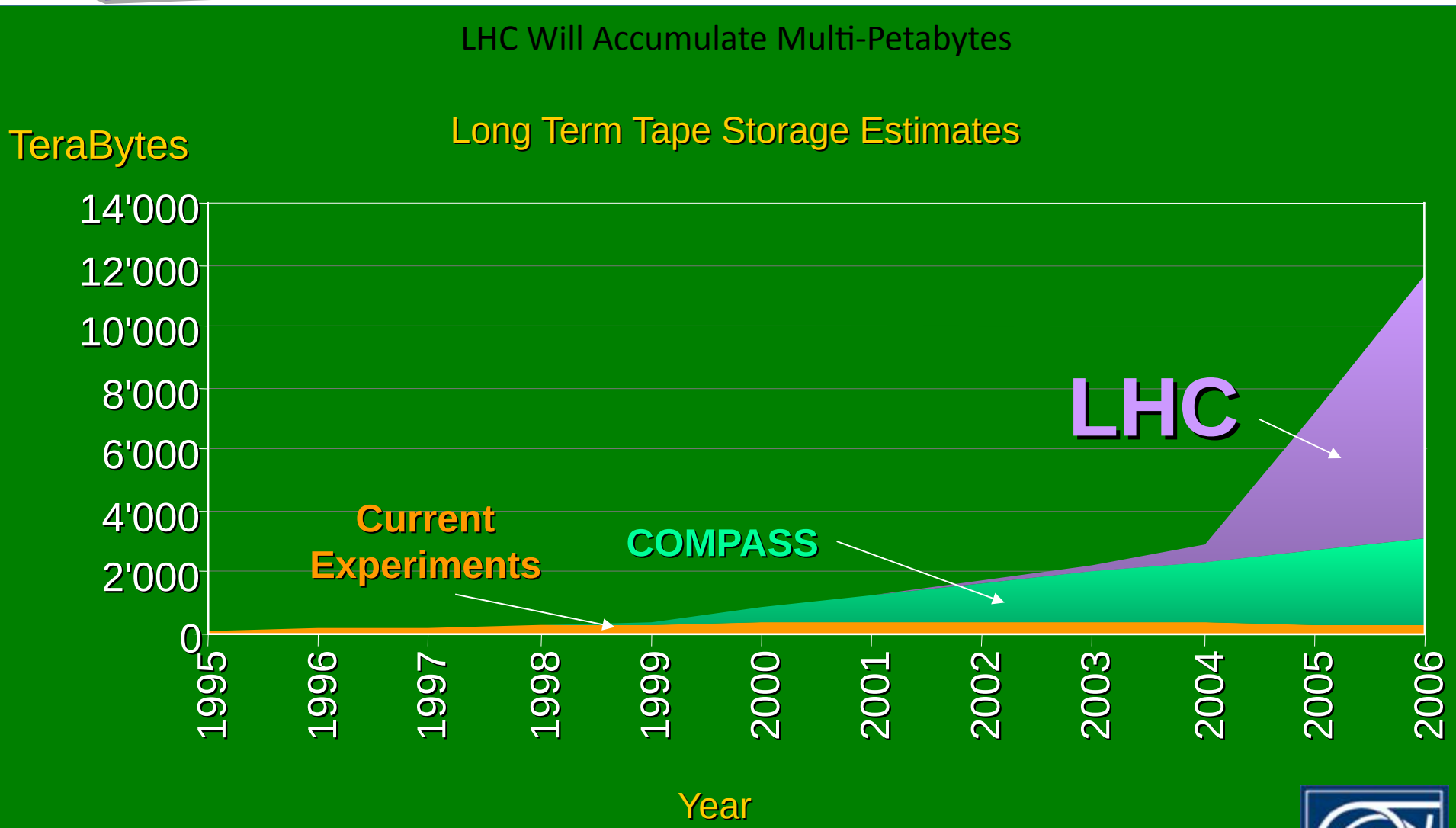
EUROPEAN UNION Investing in Your Future
European Regional Development Fund 2007-13

Additional slides



Reputed capacity of NSA's new Utah data center: 5000 PB (50-100 MW, $2 billion)

CERN presentation of LHC computing Challenge in 2000



CERN presentation of LHC computing Challeng in 2000

Complex Data = More CPU Per Byte