Accelerators at CERN

Lyn Evans

Welsh Teachers Programme

Tuesday 24th February 2015

CERN was founded 1954: 12 European States

"Science for Peace"

Today: 20 Member States

~ 2300 staff
~ 1000 other paid personnel
> 11000 users

Budget (2013) ~1000 MCHF

Member States: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, the Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom

Candidate for Accession: Romania

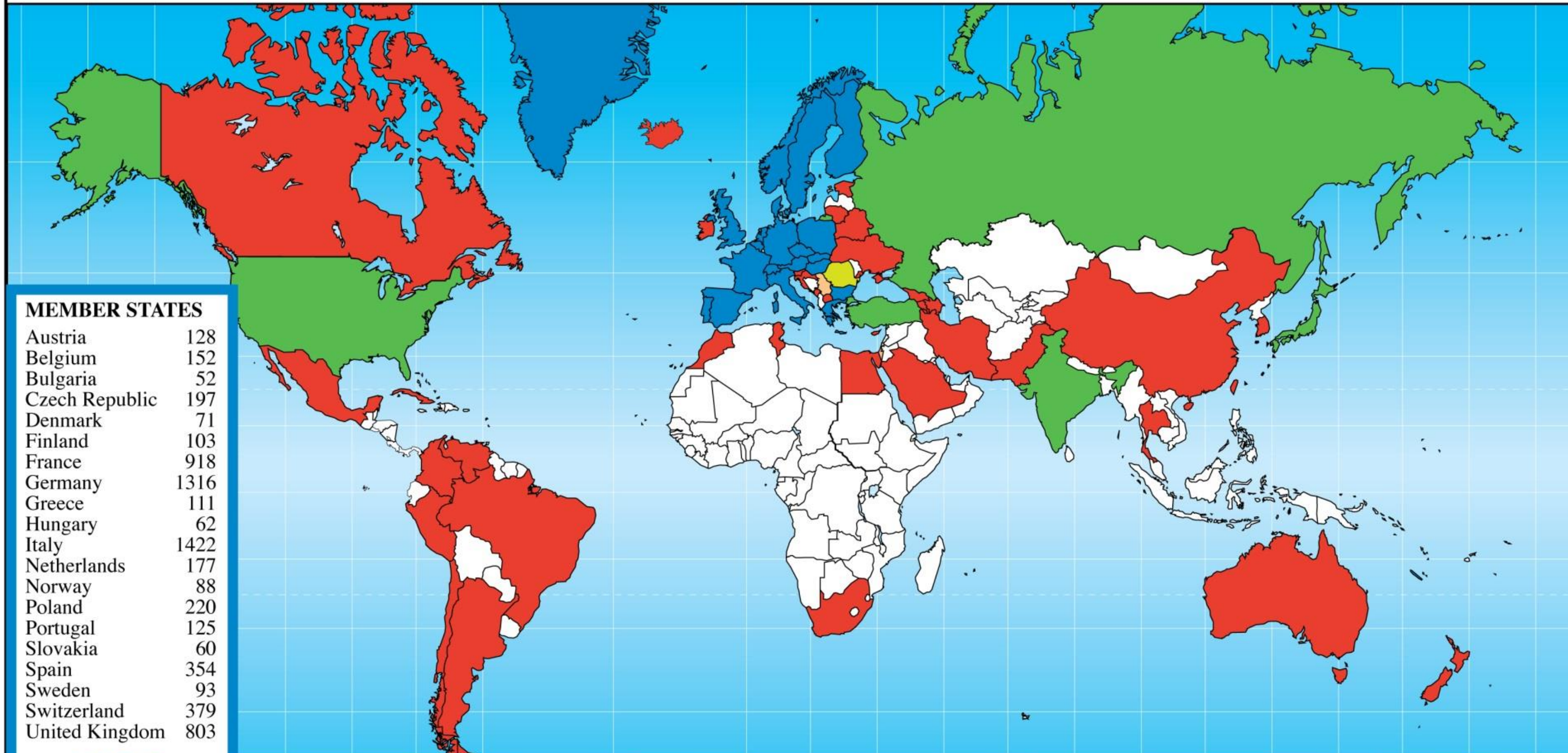
Associate Members in Pre-Stage to Membership: Israel, Serbia

Applicant States for Membership or Associate Membership:
Brazil, Cyprus (awaiting ratification), Russia, Slovenia, Turkey, Ukraine

Observers to Council: India, Japan, Russia, Turkey, United States of America; European Commission and UNESCO

Science is getting more and more global

Distribution of All CERN Users by Location of Institute on 14 January 2013



MEMBER STATES

Austria	128
Belgium	152
Bulgaria	52
Czech Republic	197
Denmark	71
Finland	103
France	918
Germany	1316
Greece	111
Hungary	62
Italy	1422
Netherlands	177
Norway	88
Poland	220
Portugal	125
Slovakia	60
Spain	354
Sweden	93
Switzerland	379
United Kingdom	803

6831

OBSERVERS

India	146
Japan	238
Russia	883
Turkey	94
USA	1757

3118

CANDIDATE FOR ACCESSION

Romania	88

ASSOCIATE MEMBER IN THE PRE-STAGE TO MEMBERSHIP

Israel	63
Serbia	31

OTHERS

Argentina	19
Armenia	15
Australia	32
Azerbaijan	2
Belarus	22
Brazil	107
Canada	168
Chile	7
China	114
China (Taipei)	69
Colombia	10
Croatia	24
Cuba	3
Cyprus	7
Egypt	11
Estonia	17
Georgia	10
Iceland	4
Iran	23
Ireland	8
Korea	96
Lithuania	13
Malta	1
Mexico	41
Montenegro	1
Morocco	10
New Zealand	9
Pakistan	22
Peru	2
Saudi Arabia	3
Slovenia	30
South Africa	25
Thailand	5
T.F.Y.R.O.M.	2
Tunisia	1
Ukraine	25
Venezuela	1

959

CERN Education Activities

Scientists at CERN
Academic Training Programme

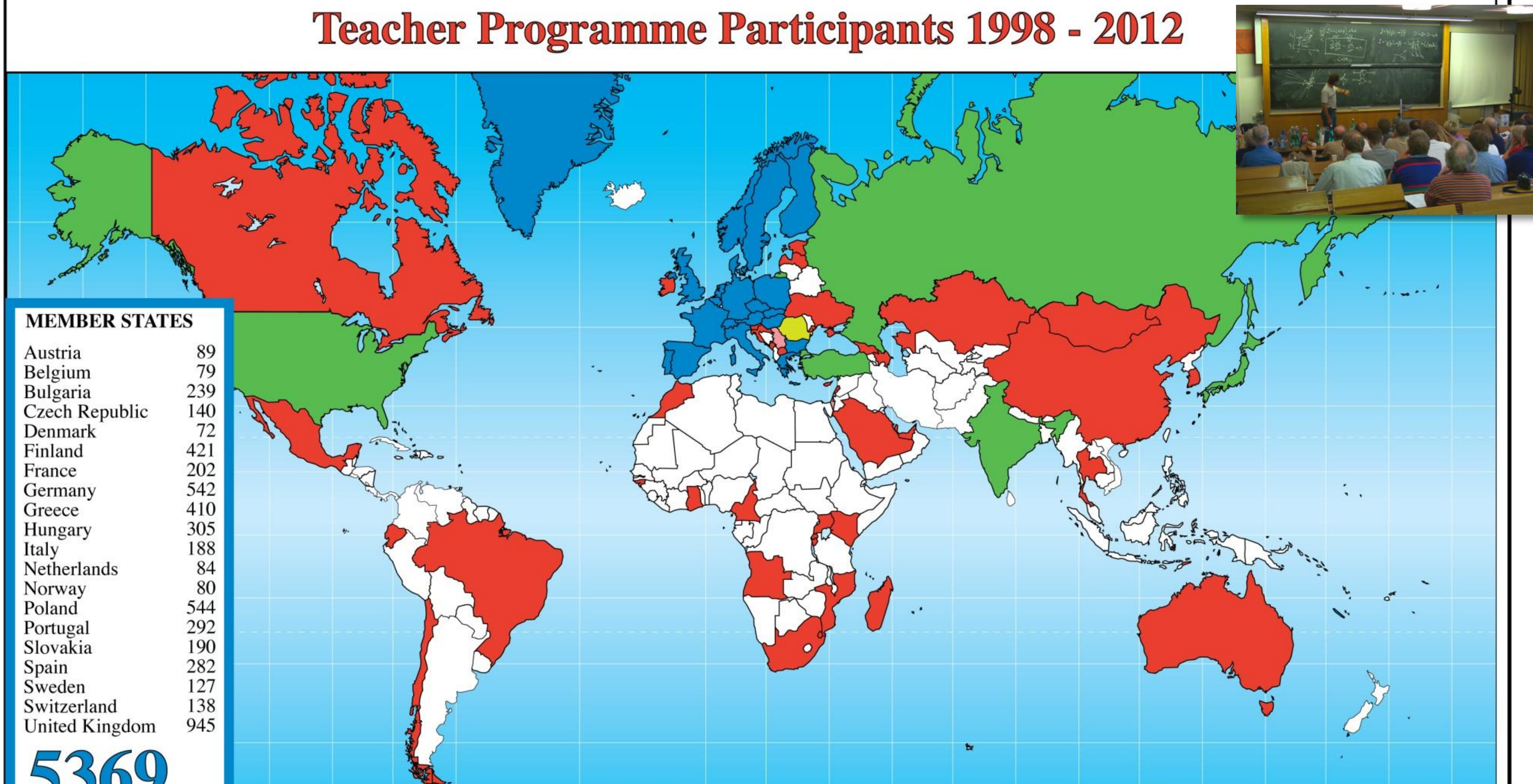
Young Researchers
CERN School of High Energy Physics
CERN School of Computing
CERN Accelerator School

Physics Students
Summer Students Programme

CERN Teacher Schools
International and National Programmes

CERN Teacher Programme

Teacher Programme Participants 1998 - 2012



MEMBER STATES

Austria	89
Belgium	79
Bulgaria	239
Czech Republic	140
Denmark	72
Finland	421
France	202
Germany	542
Greece	410
Hungary	305
Italy	188
Netherlands	84
Norway	80
Poland	544
Portugal	292
Slovakia	190
Spain	282
Sweden	127
Switzerland	138
United Kingdom	945

5369

CANDIDATE FOR ACCESSION

Romania	11

ASSOCIATE MEMBER IN THE PRE-STAGE TO MEMBERSHIP

Israel	4
Serbia	12

OBSERVER STATES

India	2
Japan	4
Russia	163
Turkey	3
USA	61

233

OTHERS

Angola	4
Australia	3
Azerbaijan	1
Brazil	83
Burundi	1
Cameroon	3
Canada	2
Cape Verde	3
Chile	3
China	1
Croatia	1
Cyprus	8
Ecuador	2
Estonia	35
Georgia	55
Ghana	6
Guinea Bissau	1
Ireland	3
Kazakhstan	3
Kenya	2
Latvia	1
Lebanon	1
Madagascar	2
Malta	36
Mexico	5
Mongolia	1
Montenegro	13
Morocco	2
Mozambique	17
Qatar	1
Rwanda	15
Sao Tome	3
Saudi Arabia	1
Singapore	2
Slovenia	21
South Africa	6
South Korea	44
Swaziland	1
Thailand	6
T.F.Y.R.O.M.	11
Timor-Leste	4
Uganda	1
Ukraine	57
U.A.E.	1

472

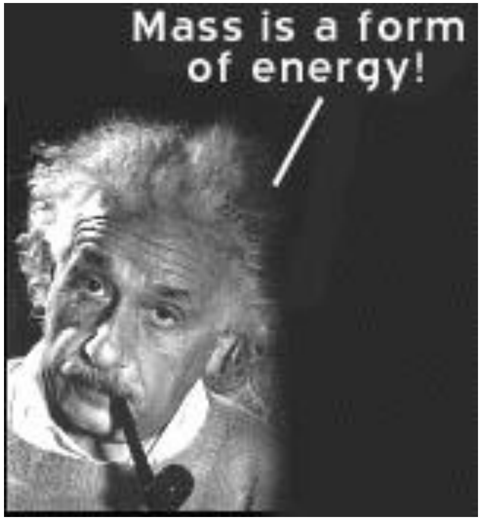
When one accelerates a particle…

It does not necesserily go much faster

Its mass increases

$$E = m c^2$$

In an interaction, it can transform its energy into massive particles



…one transforms energy into mass

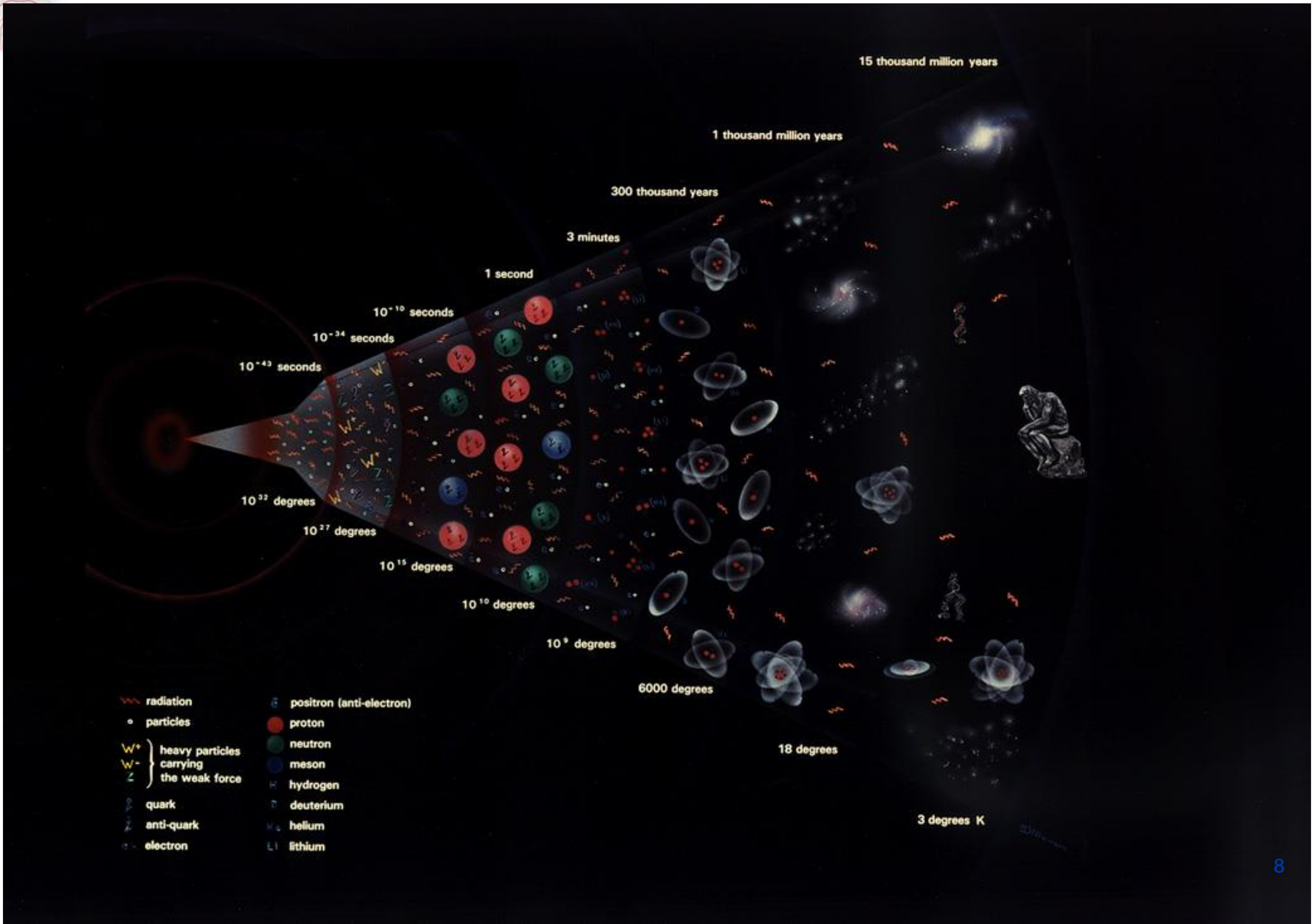
Energy, mass and temperature

1 electron Volt (eV) $= 1.8 \times 10^{-36}$ kG

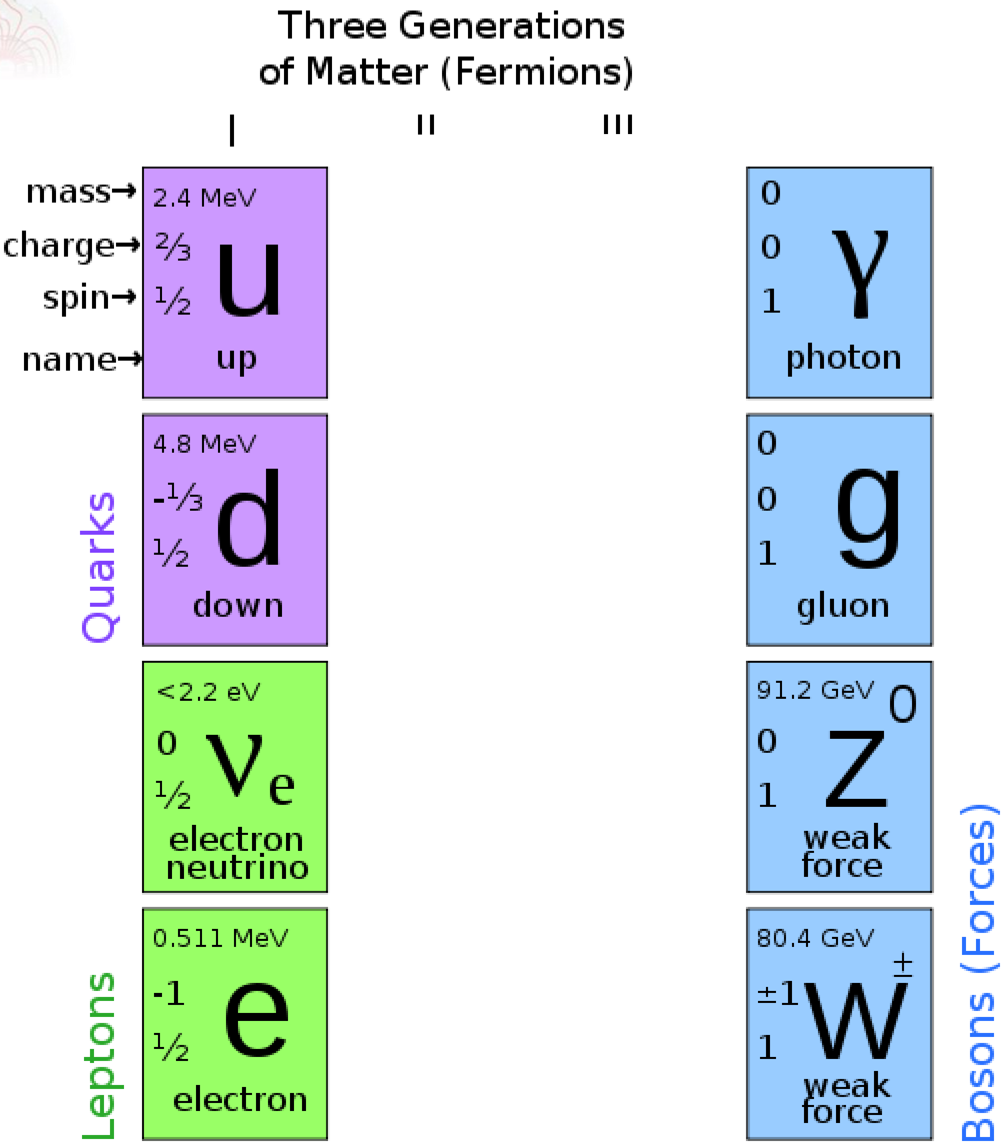
$= 11.600\ ^{o}C$

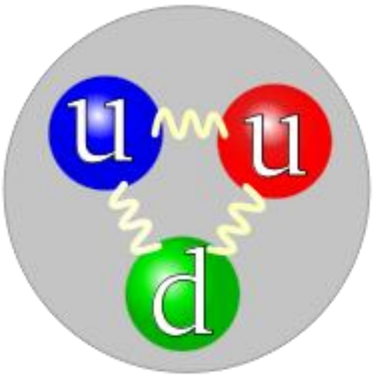
1 Tera electron Volt (TeV) $= 10^{16}\ ^{o}C$

The Big Bang

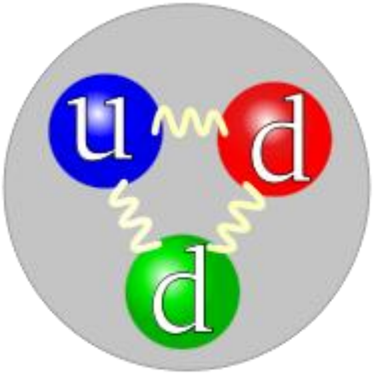

15 thousand million years
1 thousand million years
300 thousand years
3 minutes
1 second
10^{-10} seconds
10^{-34} seconds
10^{-43} seconds
10^{32} degrees
10^{27} degrees
10^{15} degrees
10^{10} degrees
10^{9} degrees
6000 degrees
18 degrees
3 degrees K
radiation
particles
heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
hydrogen
deuterium
helium
lithium

The Standard Model



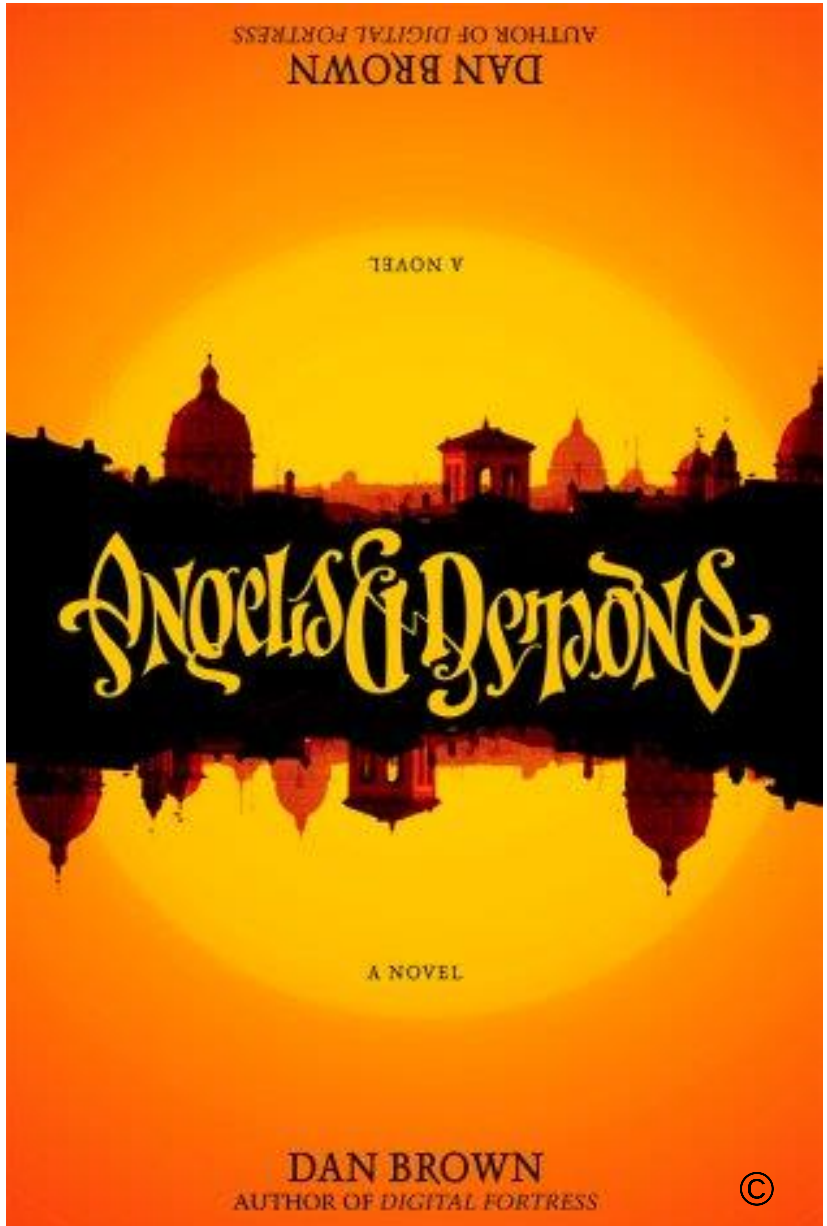


Proton



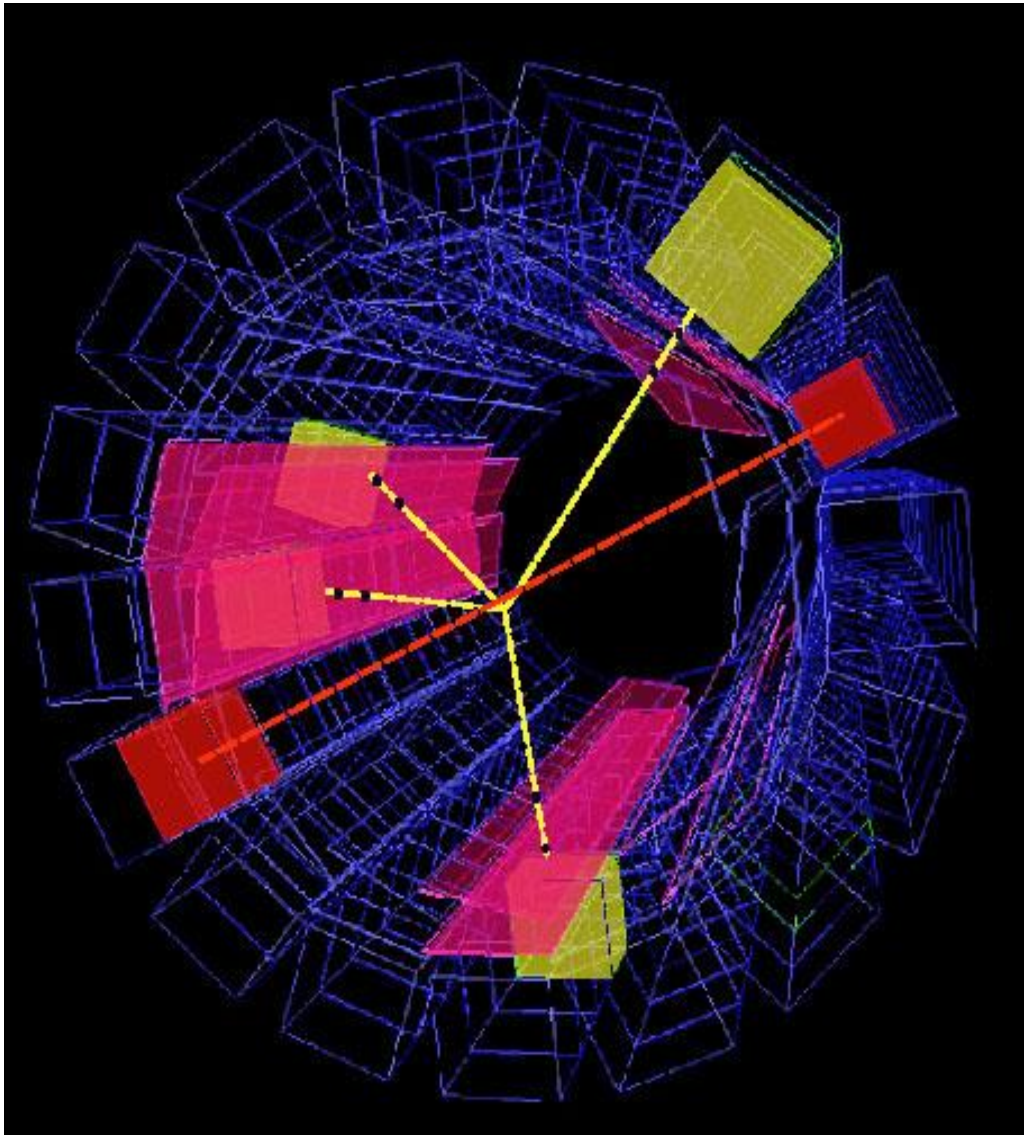
Neutron

Angels & Demons

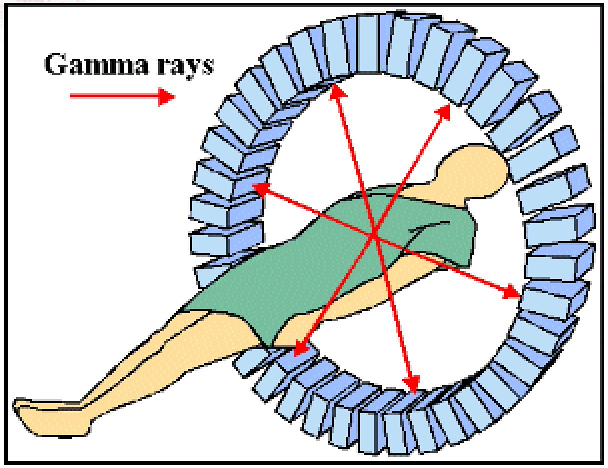


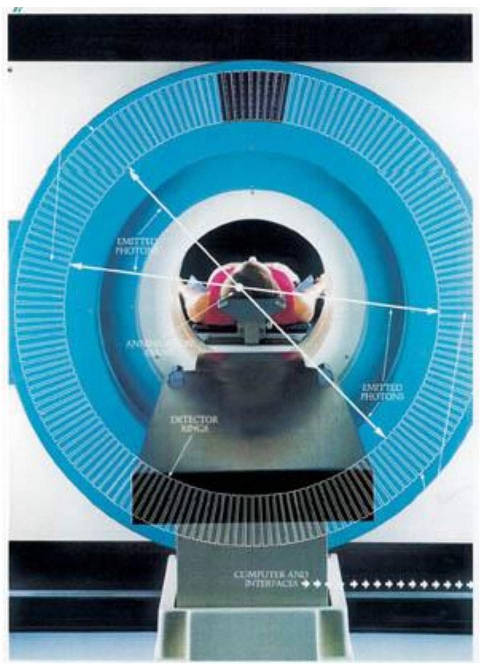
Antiprotons

Matter-antimatter Annihilation

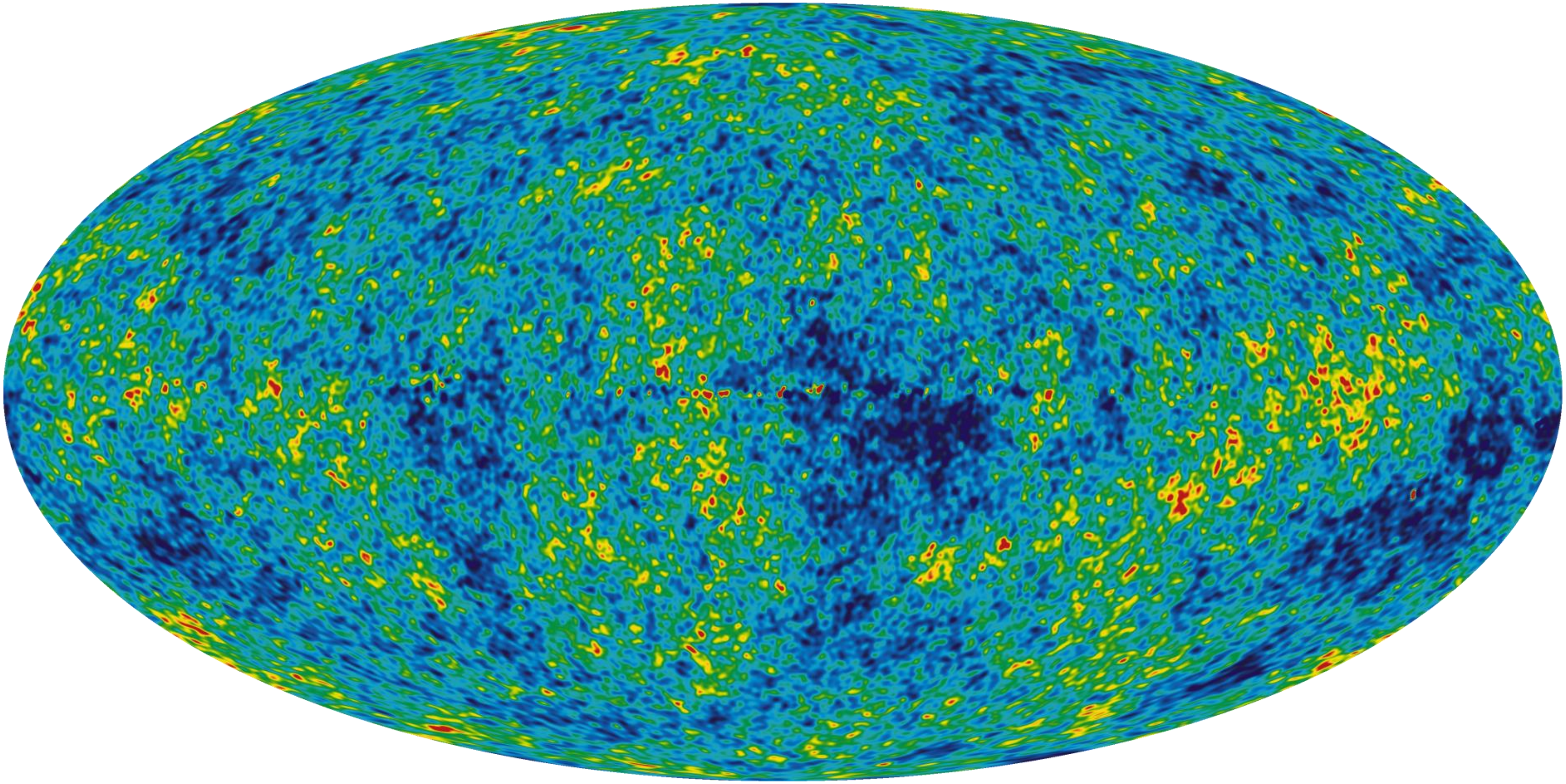


Positron Emission Tomography
PET/CT Scanning



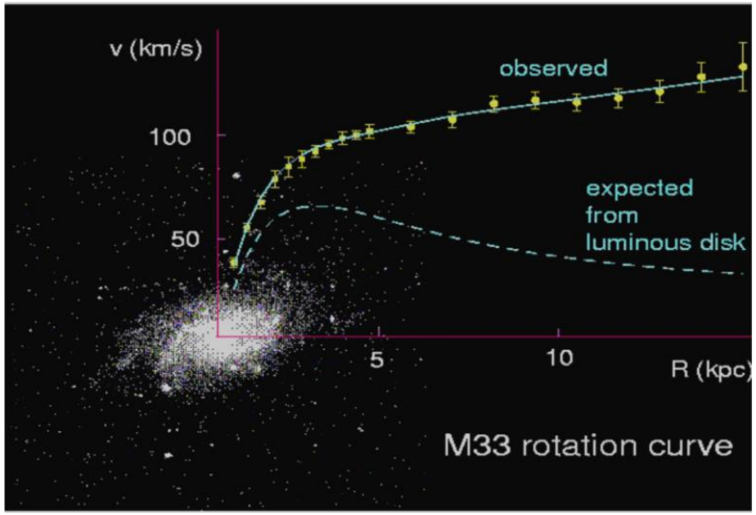


Cosmic Microwave Background



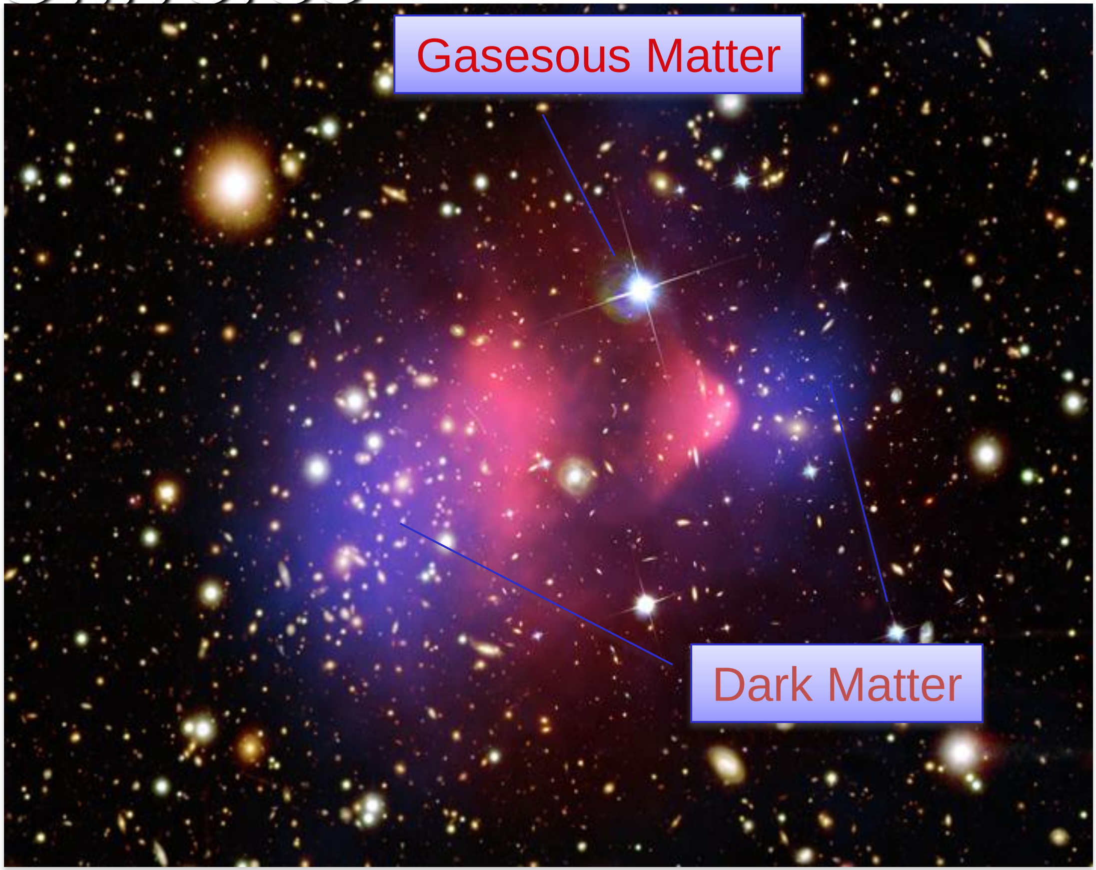
Dark Matter

The LHC and the Dark Side of the Universe



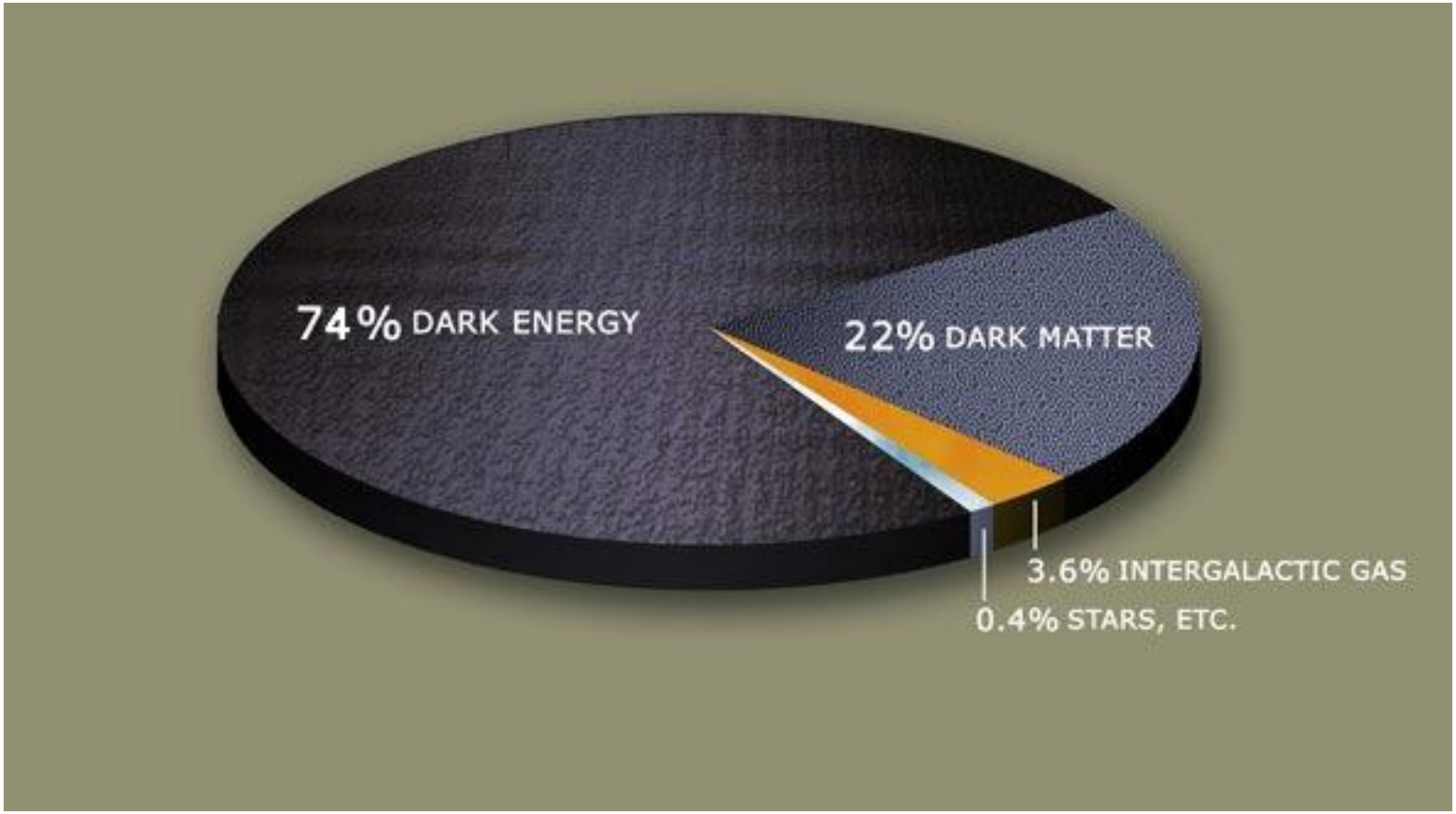
Dark (invisible) matter!
Interacts gravitationally but does not shine

A new class of particles?
"Superparticles"
Doubling of known particles!



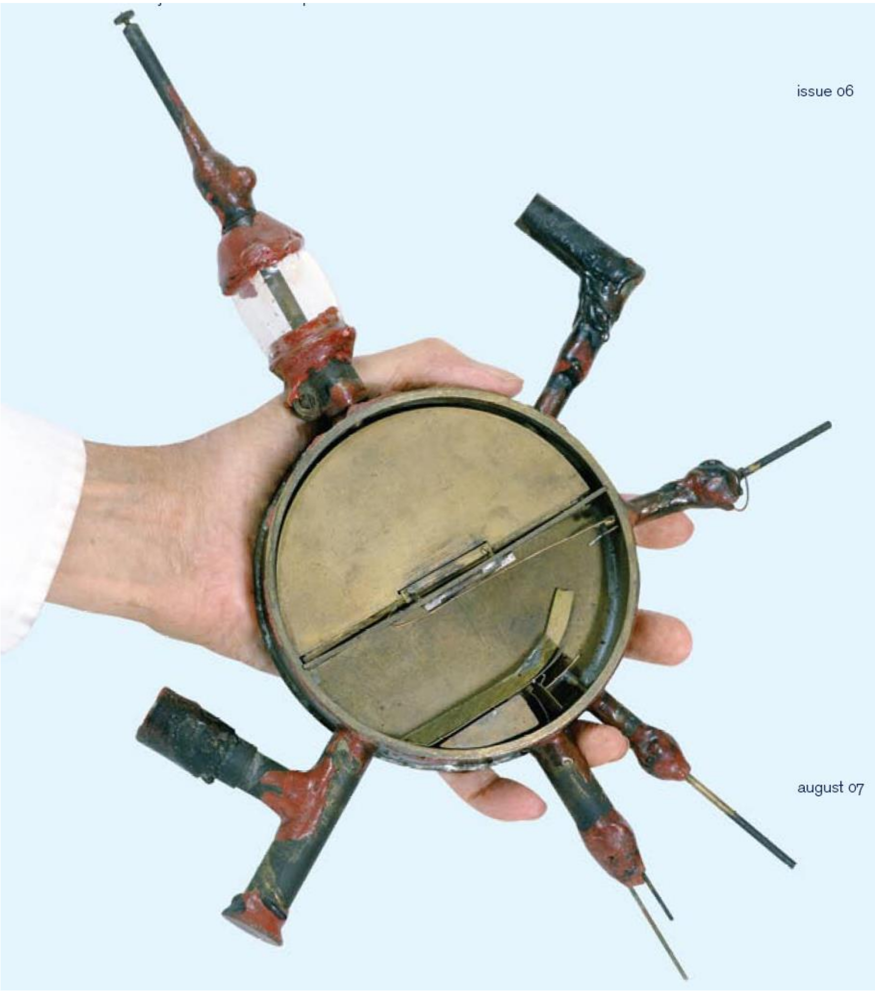
Dark Matter appears to be made of weakly interacting massive particles.
Lightest super-particle has these properties !

Dark Matter Pie

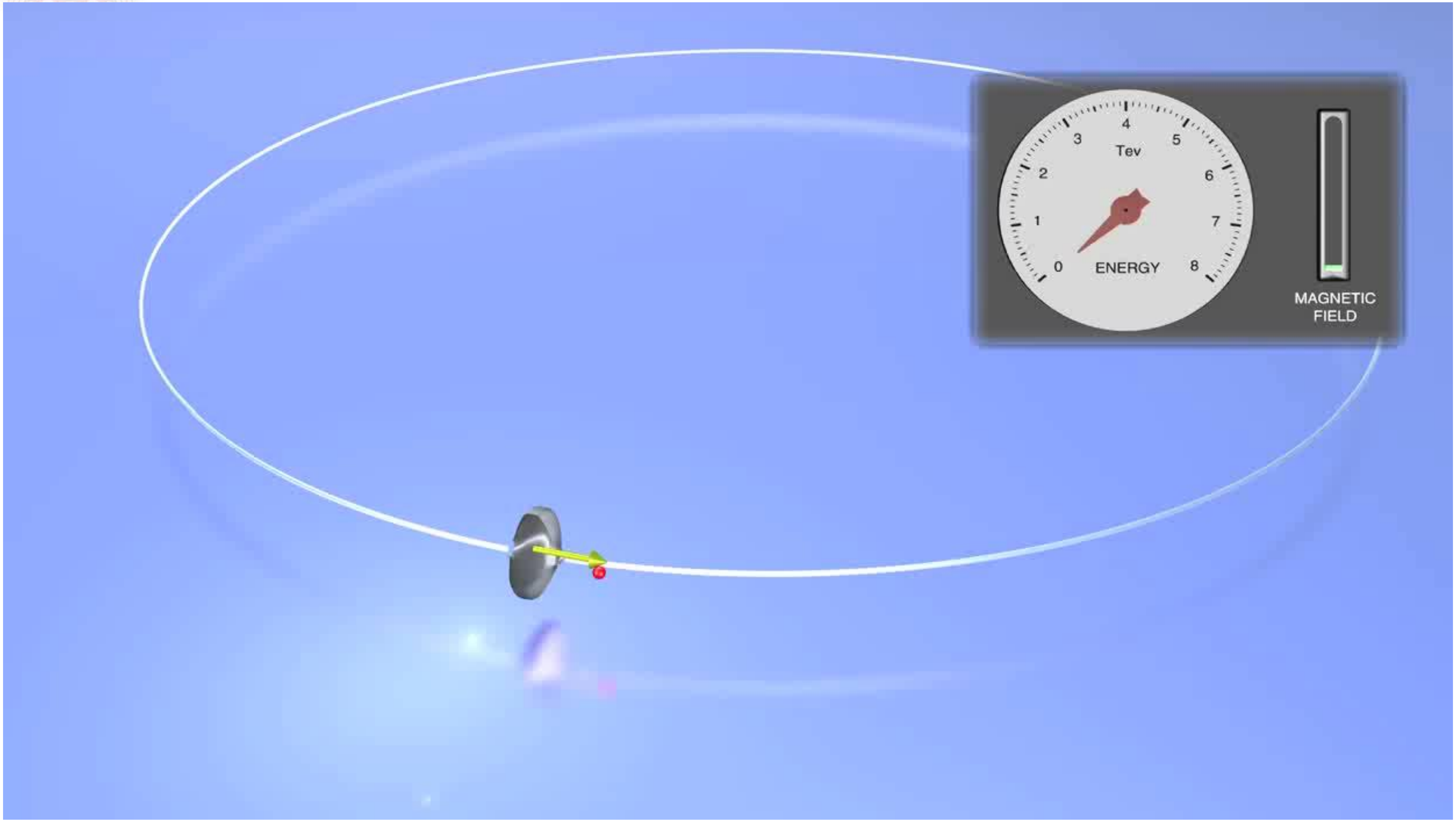


The first circular accelerator
Lawrence and Livingston's 80 keV cyclotron (1930)

Ernest O. Lawrence

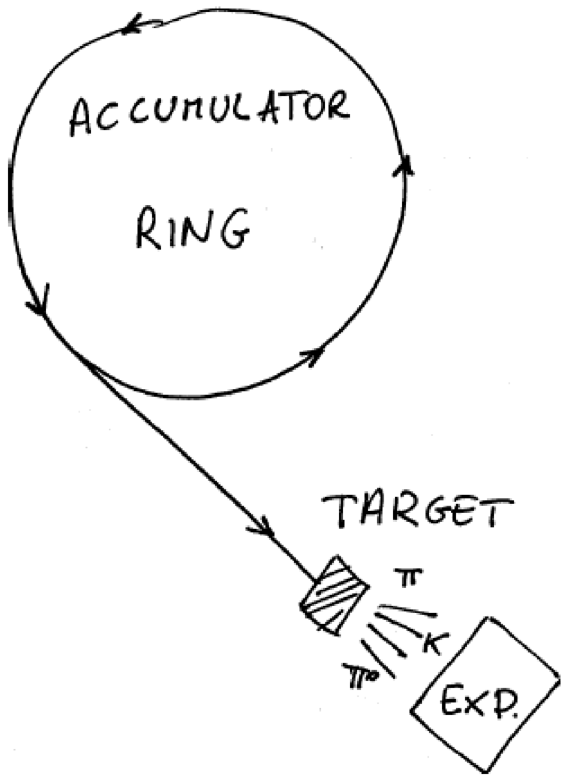


Acceleration principle

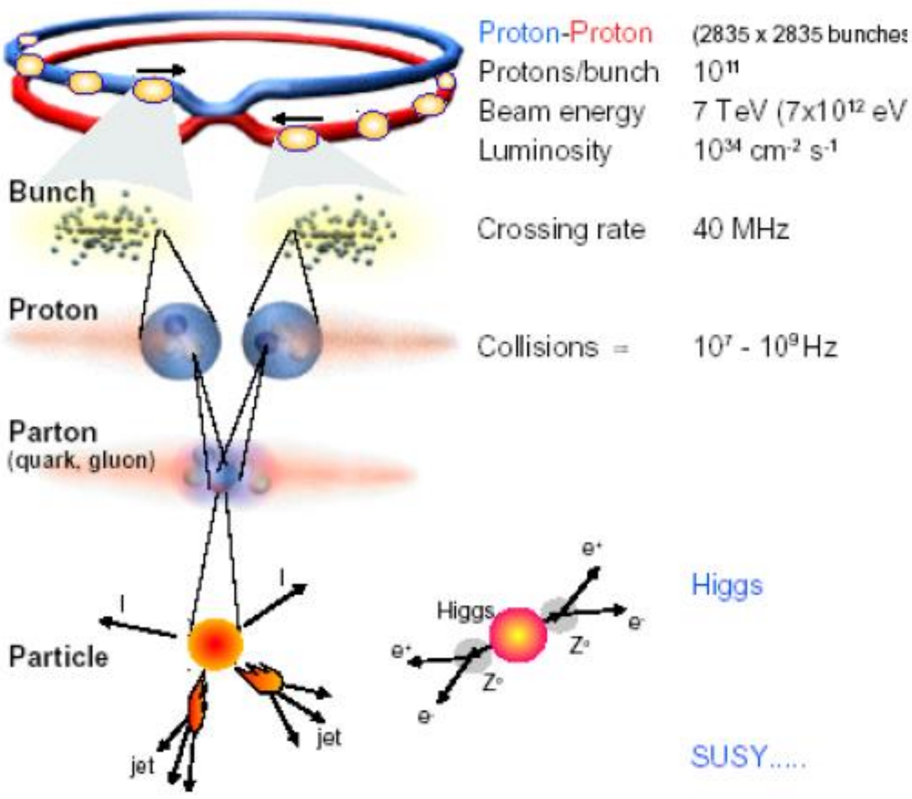


Different approaches: fixed target vs collider

Fixed target

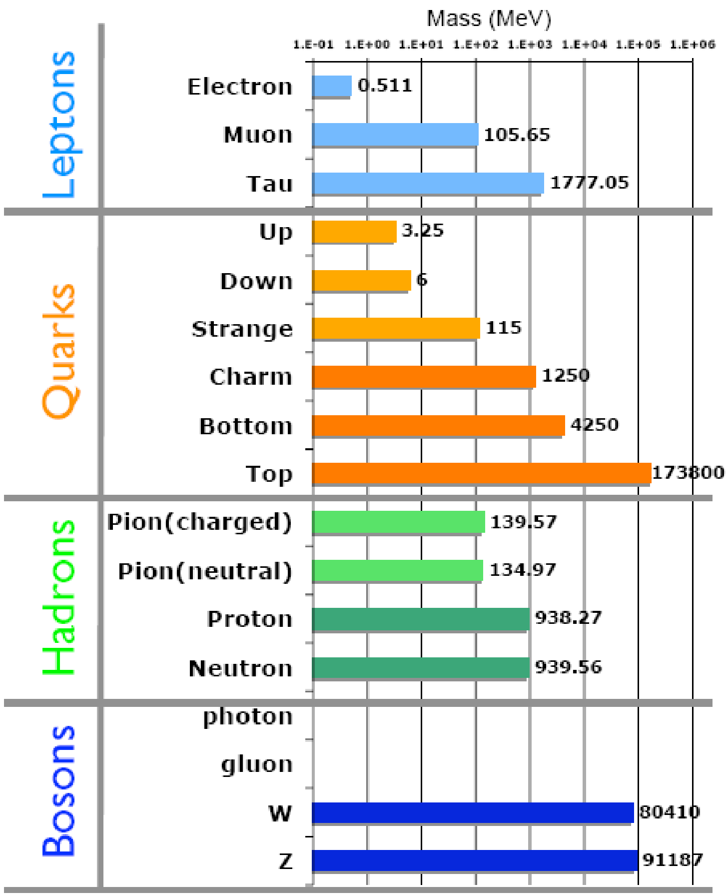


Storage ring/collider

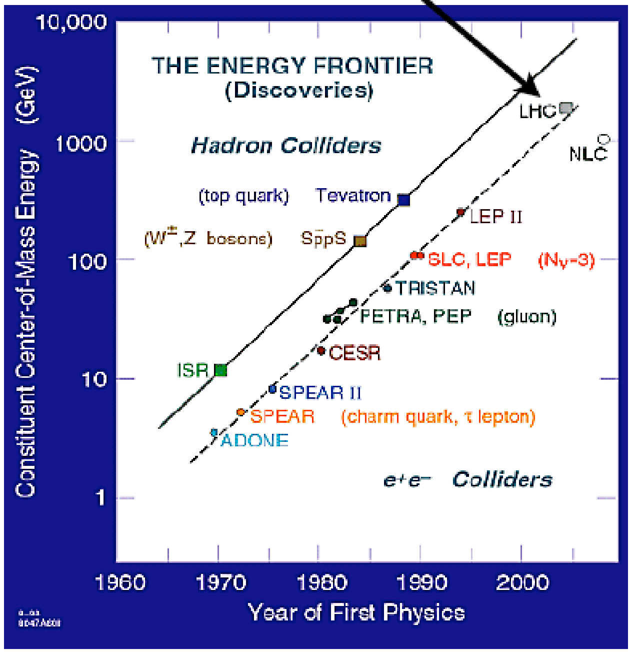


$$E_{CM} = \sqrt{2\left(E_{beam} mc^2 + m^2c^4\right)} \quad << \quad E_{CM} = 2\left(E_{beam} + mc^2\right)$$

History/energy line vs discovery



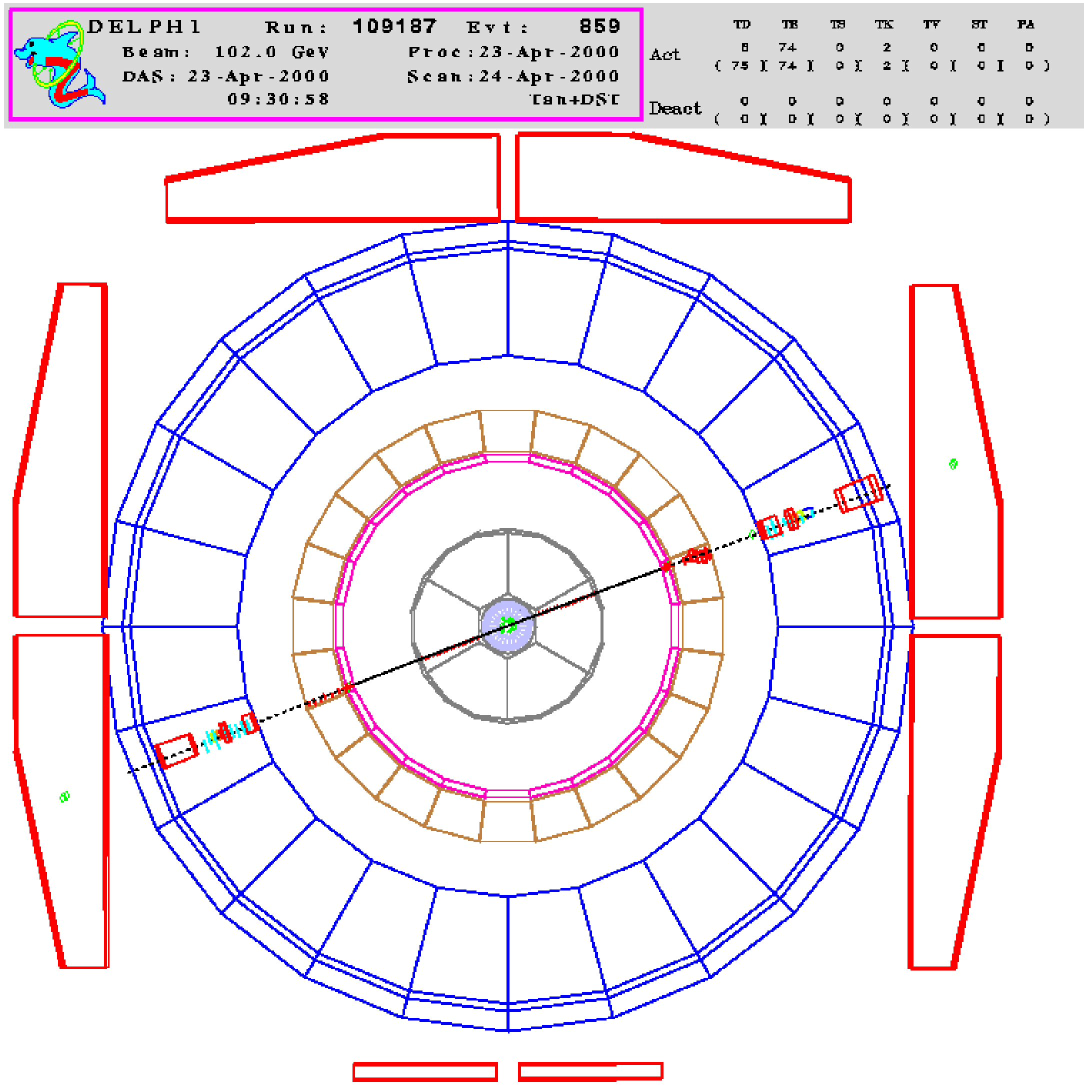
Higgs and super-symmetry ?
Or something else maybe



Behind the history plot is hidden the technological development required for each step

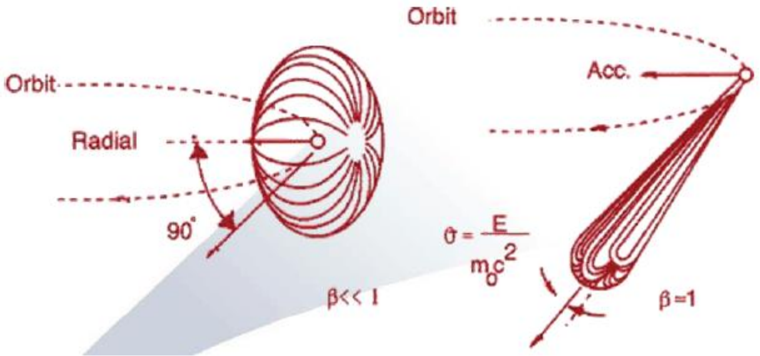
Obs: you can notice different particle species used in the different colliders electron-positrons and hadron colliders (either $\bar{p}$-p as Tevratron, p-p as LHC)

Dimuon event from DELPHI



Synchrotron radiation

- Charged particle beams bent in a magnetic field undergo centripetal acceleration and emit e-m radiation
- When beams are relativistic, radiation is emitted in a narrow cone



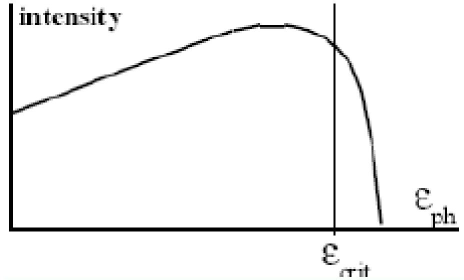
- Radiated power

$$P_{syn} = \frac{Z_0\, e^2\, c\, \gamma^4}{3\, R} N_b\, n_b\, f_{rev}$$

~ beam current

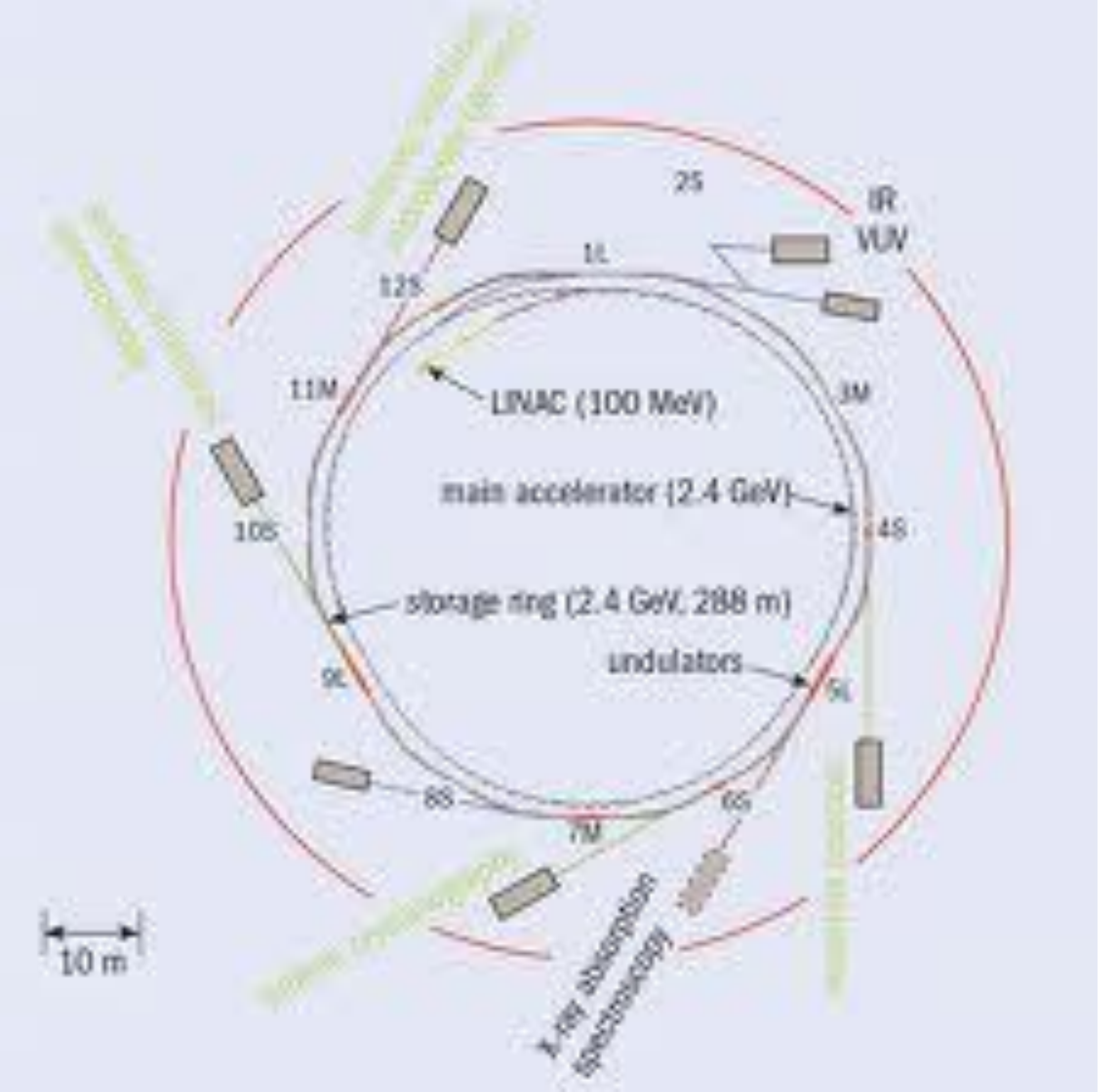
- Critical photon energy

$$u_c = \frac{3}{2} \hbar\, c\, \frac{\gamma^3}{R}$$



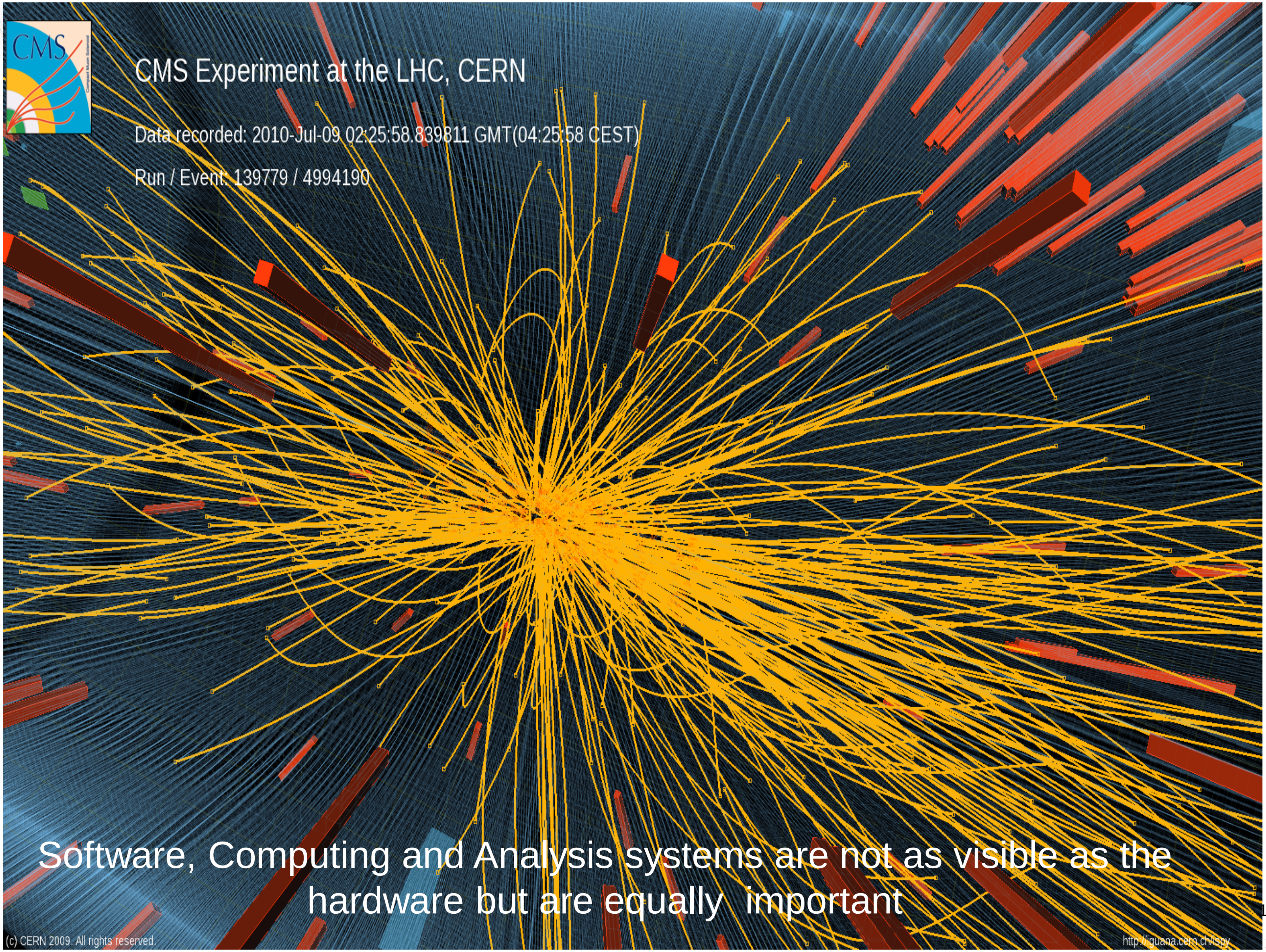
Swiss light source

Swiss light source



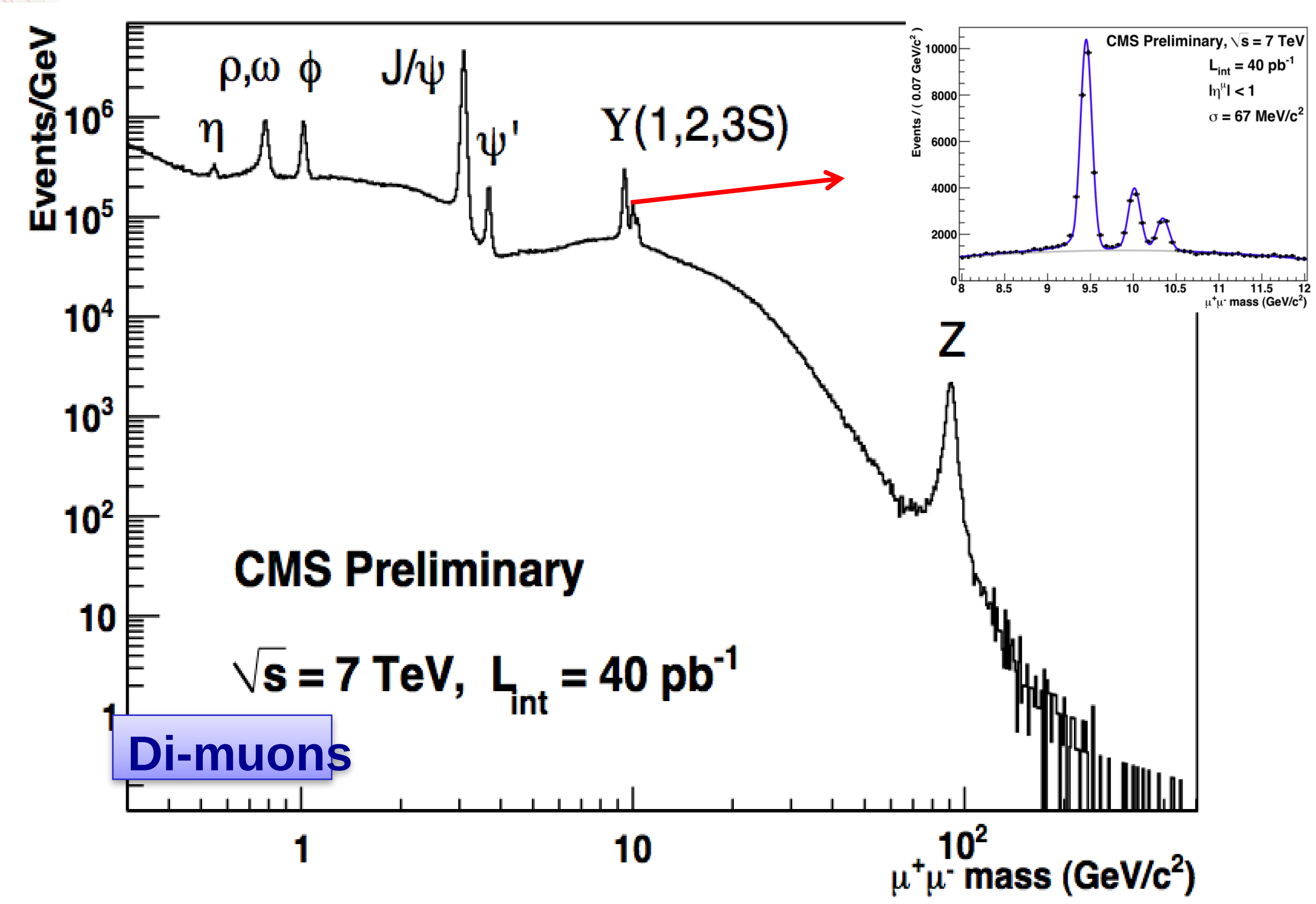
Lyn Evans – EDMS 1061056

Collisions at 7 TeV: A Big Step Up in

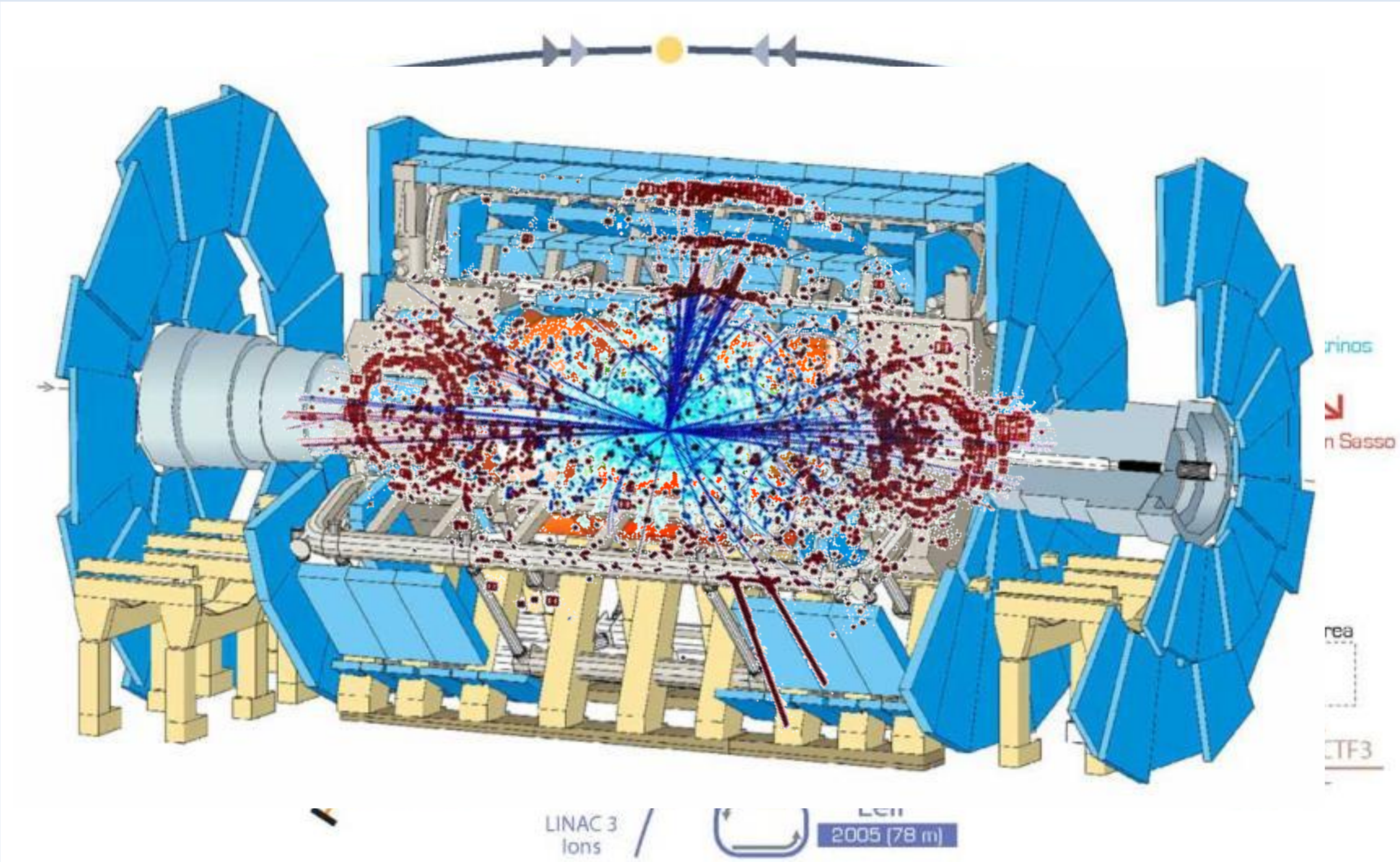


Software, Computing and Analysis systems are not as visible as the hardware but are equally important

CMS Performance:Tracking and Muons



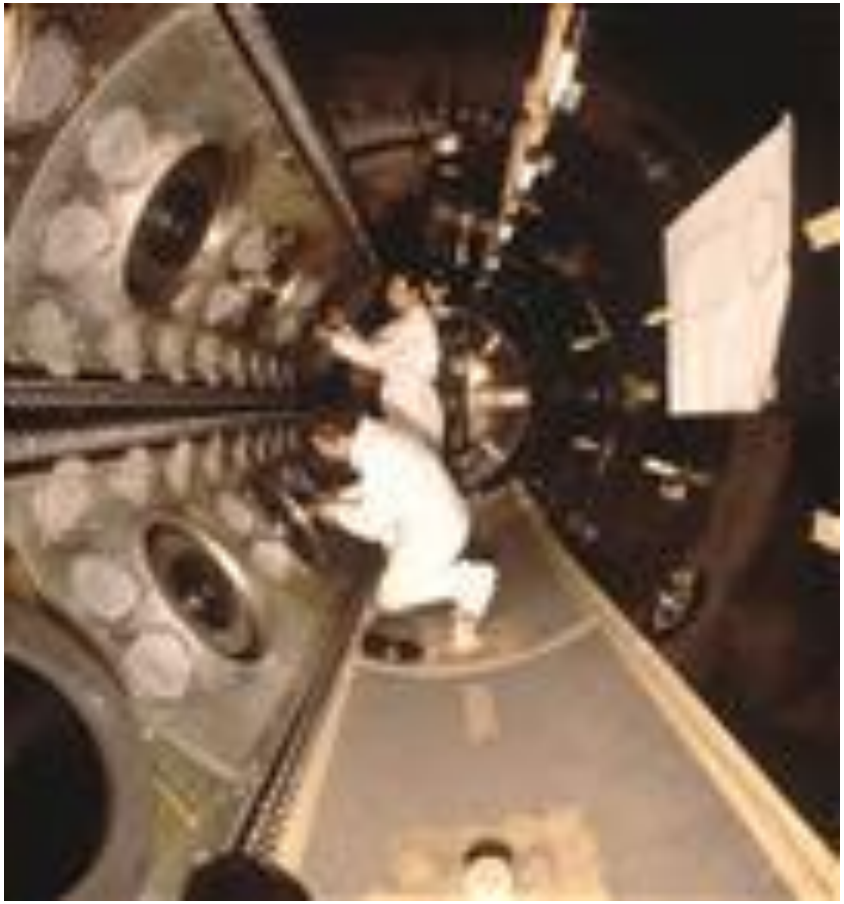
CERN's particle accelerator chain



ISR

Interaction point
with crossing angle

Gargamelle

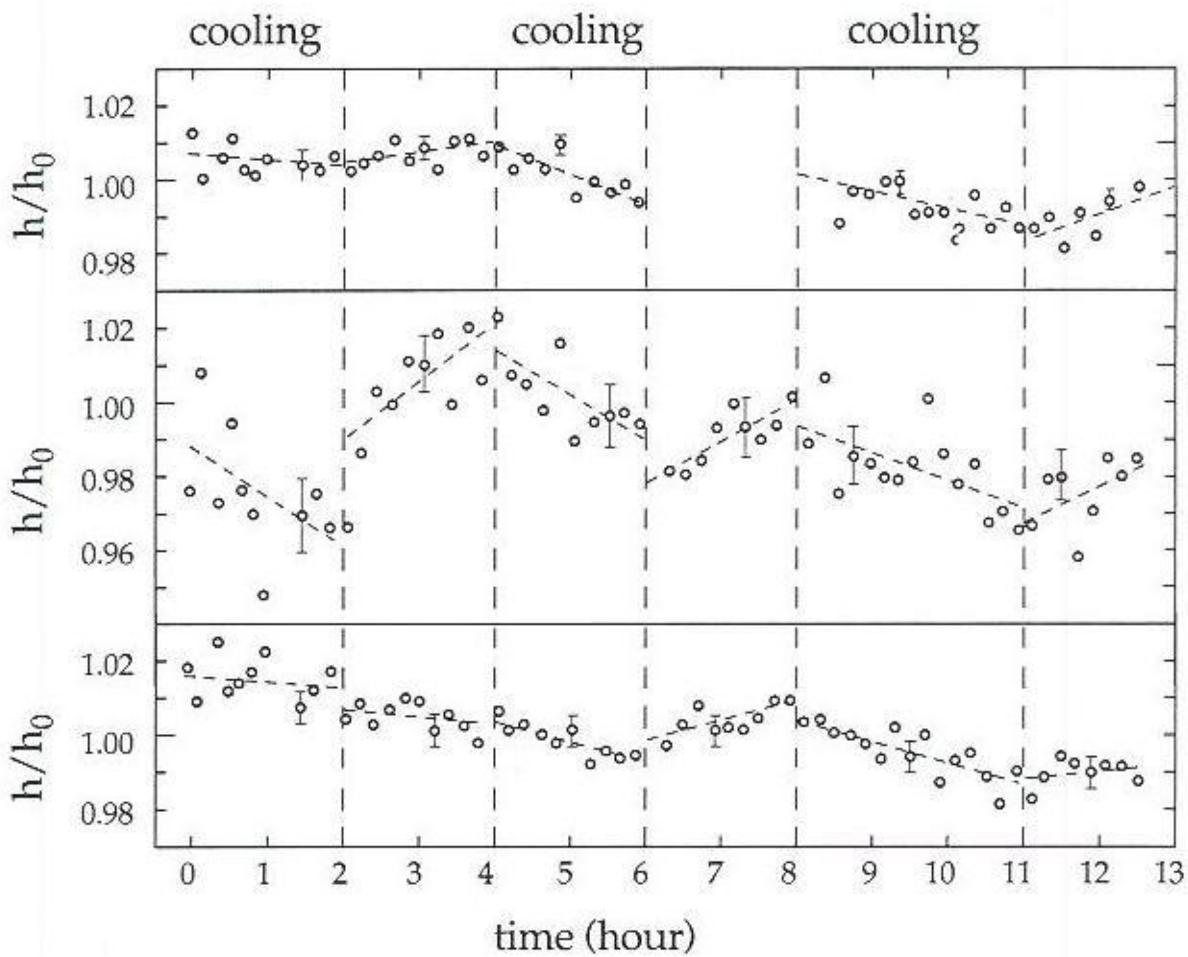


S. Van Der Meer CERN/ISR-PO/72-31

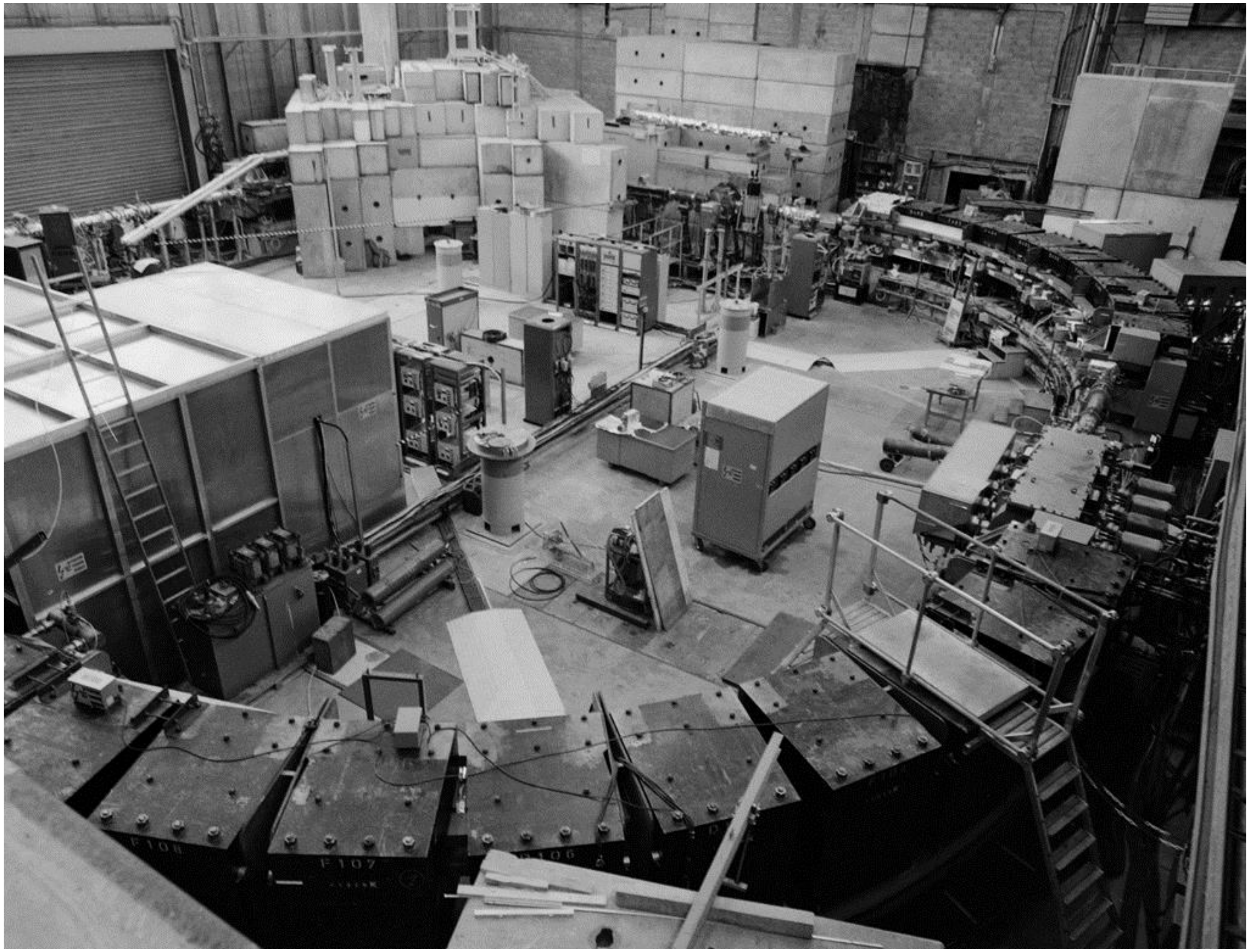
4. FINAL NOTE

This work was done in 1968. The idea seemed too far-fetched at the time to justify publication. However, the fluctuations upon which the system is based were experimentally observed recently. Although it may still be unlikely that useful damping could be achieved in practice, it seems useful now to present at least some quantitative estimation of the effect.

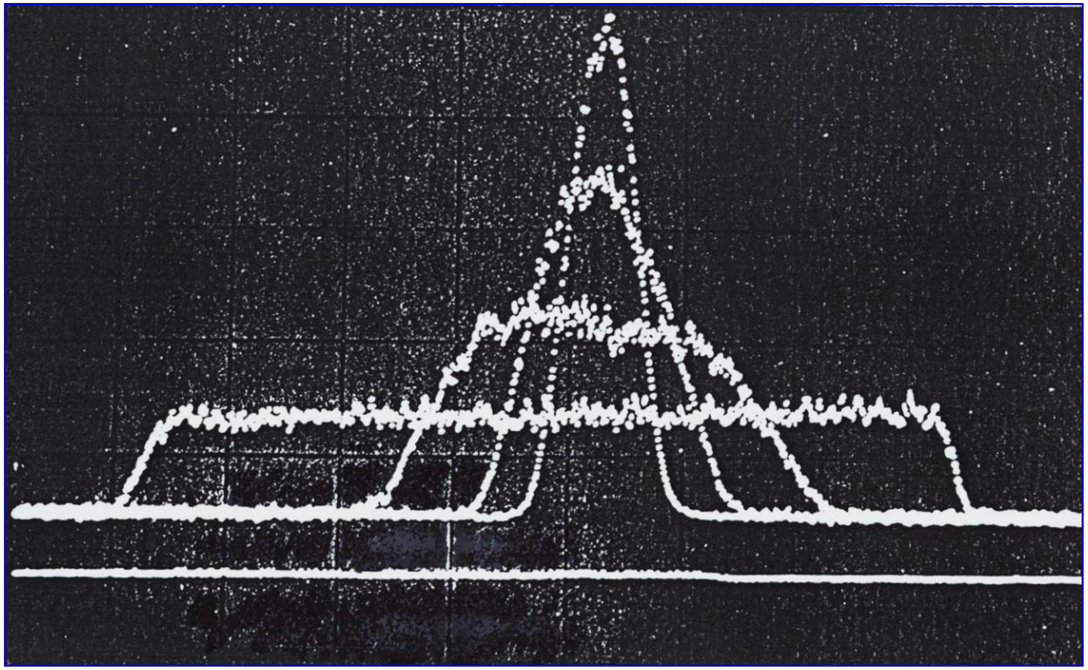
Stochastic cooling in the ISR (Schnell et al 1975)



Initial Cooling Experiment (1978)



Momentum Cooling in ICE

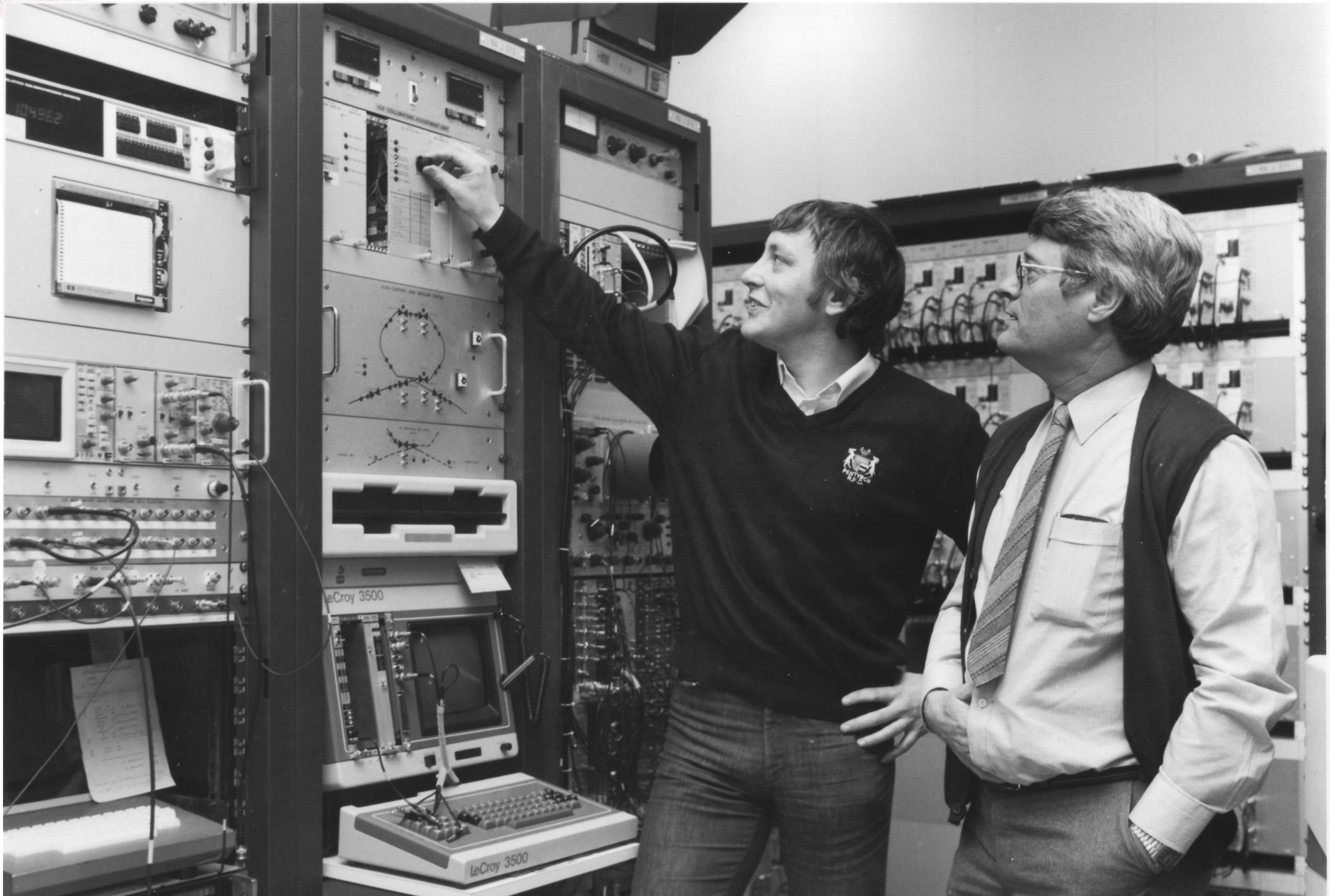


Schottky scan after 1, 2 and 4 min.

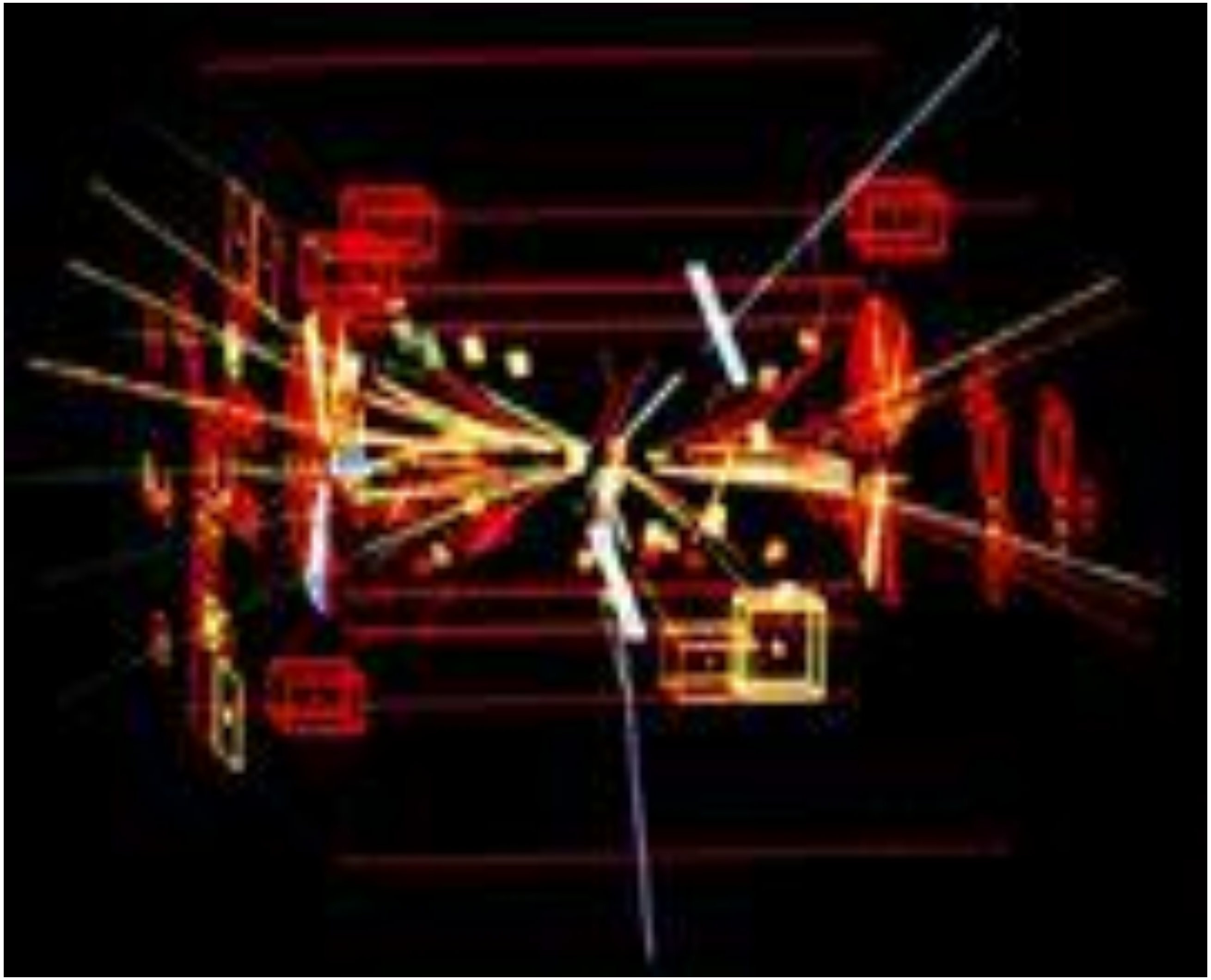
Signal height proportional to the square root of density and width proportional to $\Delta\ p/p$.

Antiprotons

The control room of the AA in 1981

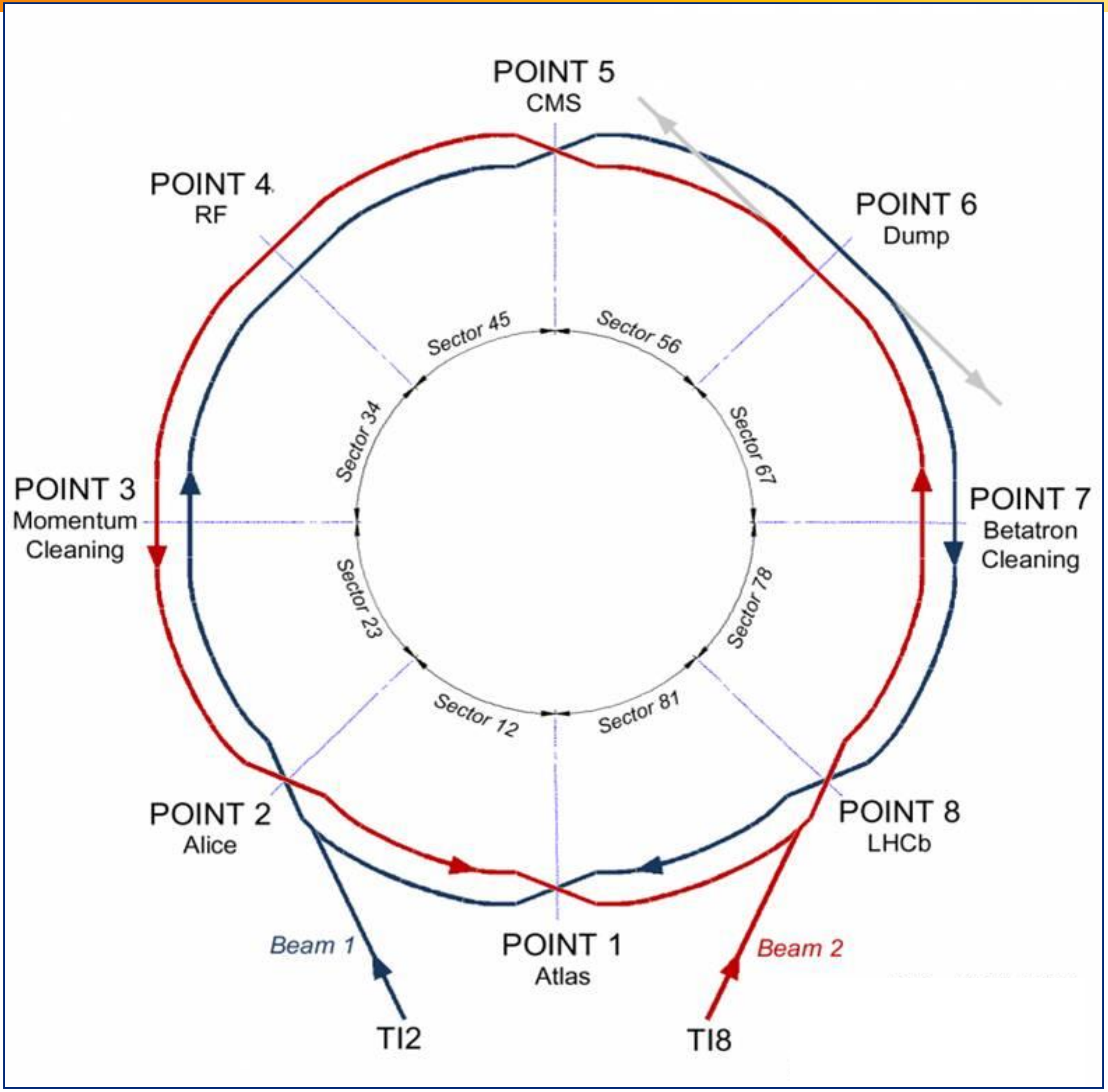

LeCroy 3500
LeCroy 3500

The first Z boson event



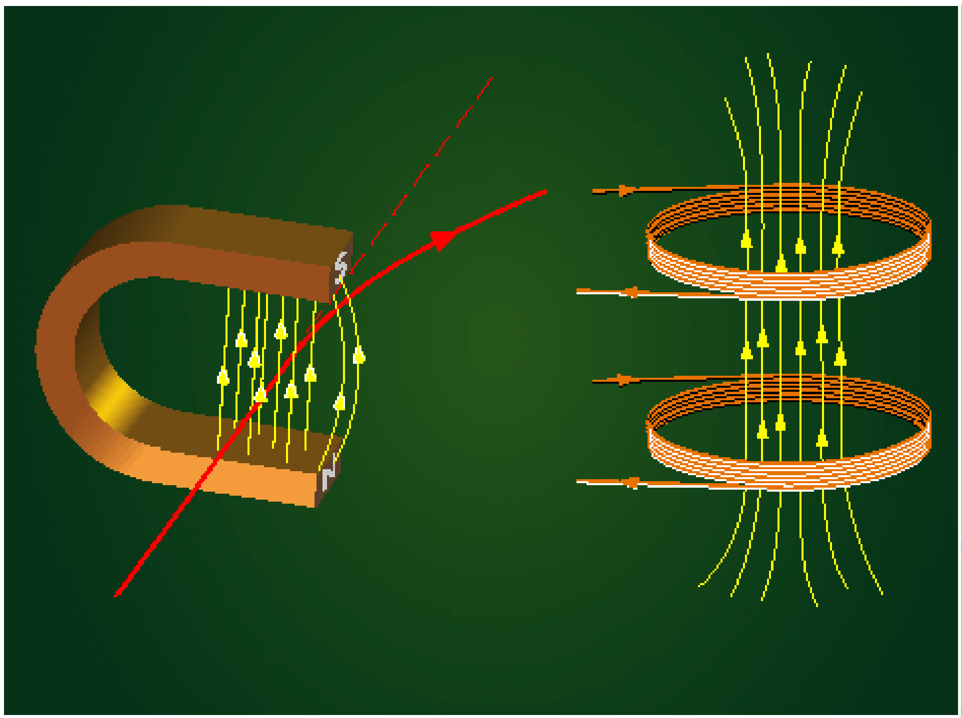
23 km of superconducting magnets

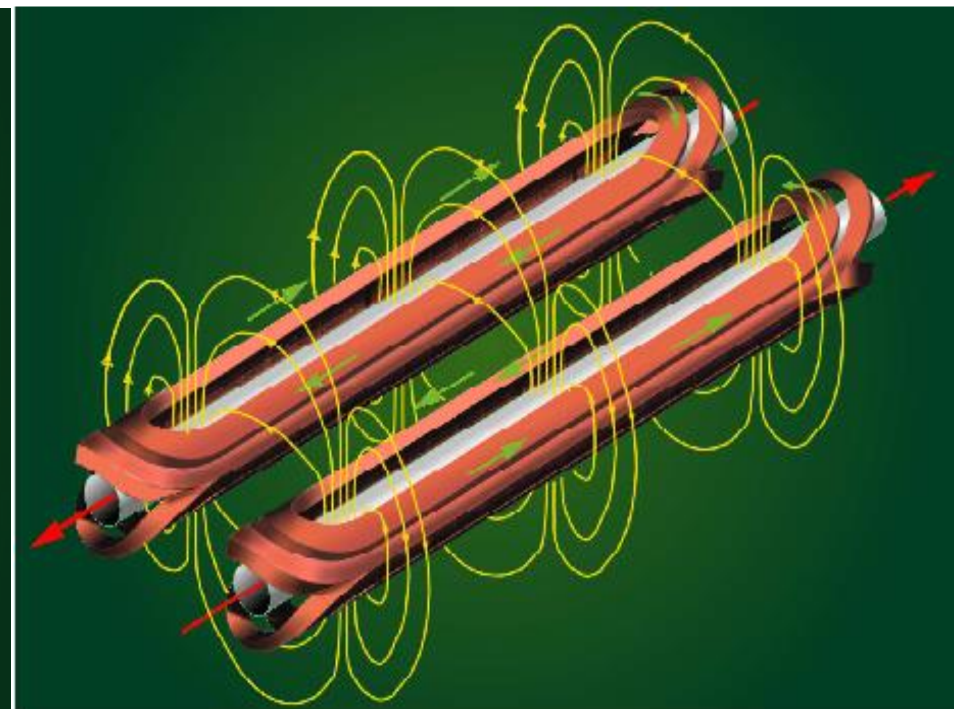
Colliding counter-rotating beams of hadrons



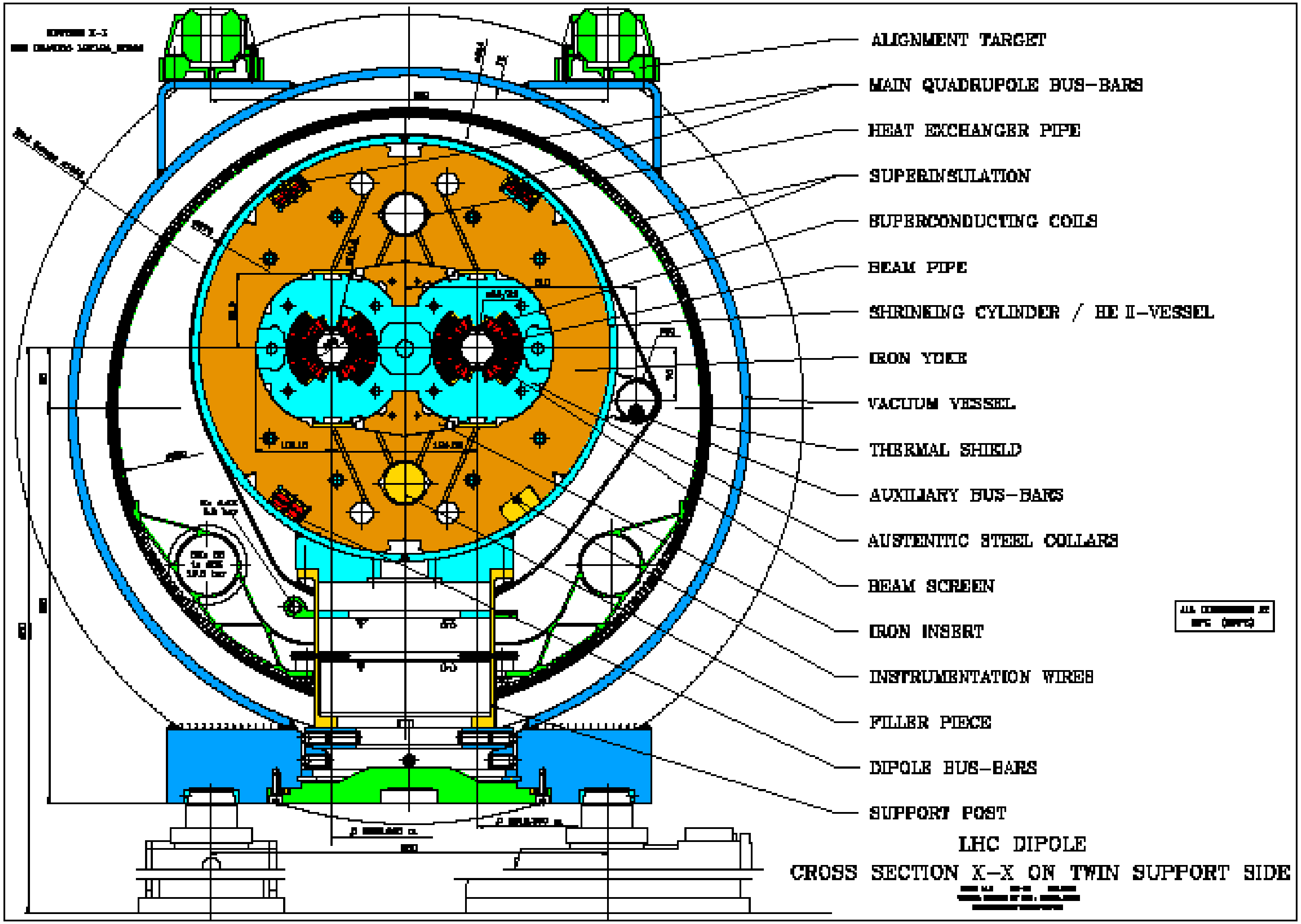
Lyn Evans

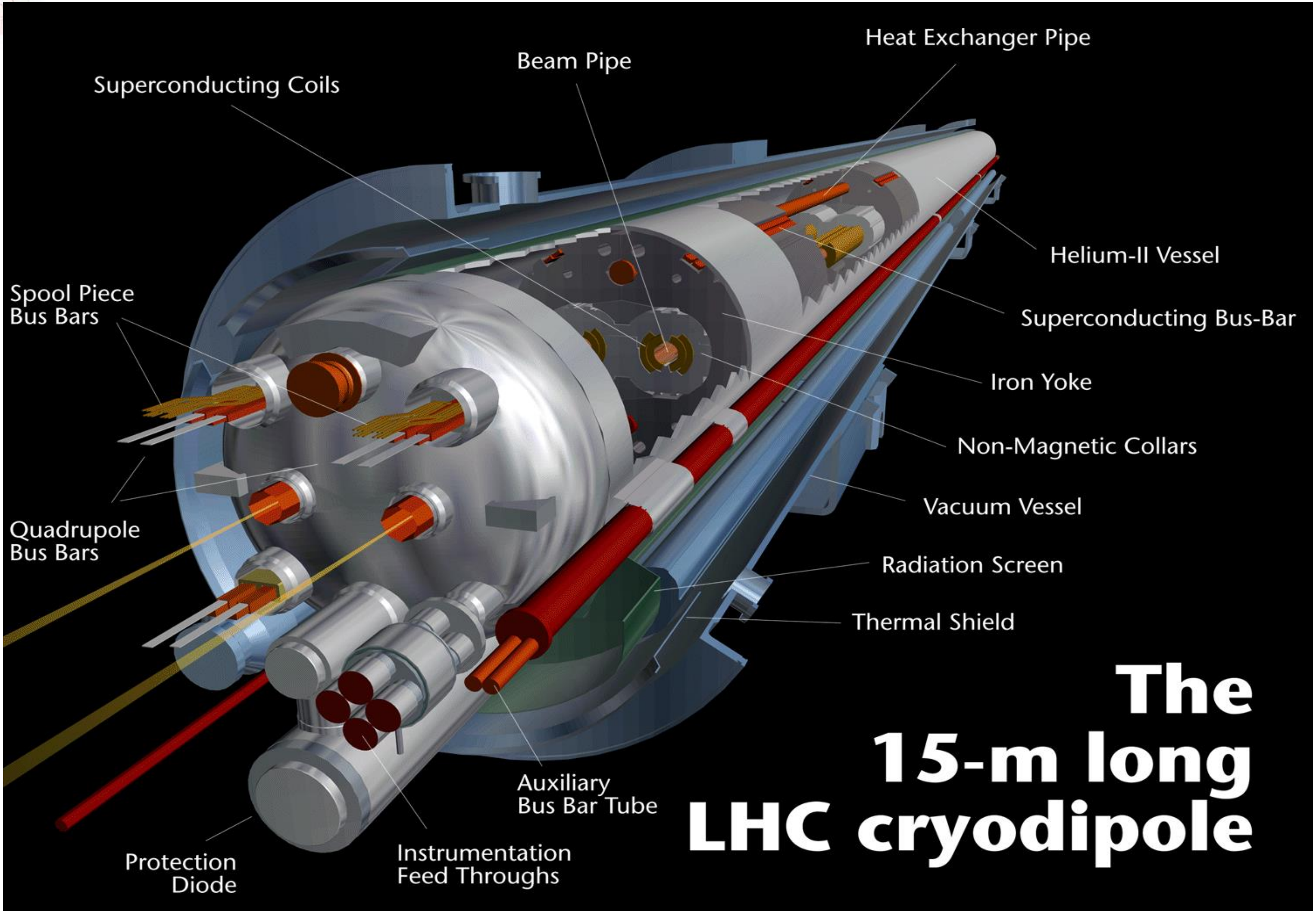
Les aimants guident les faisceaux de particules





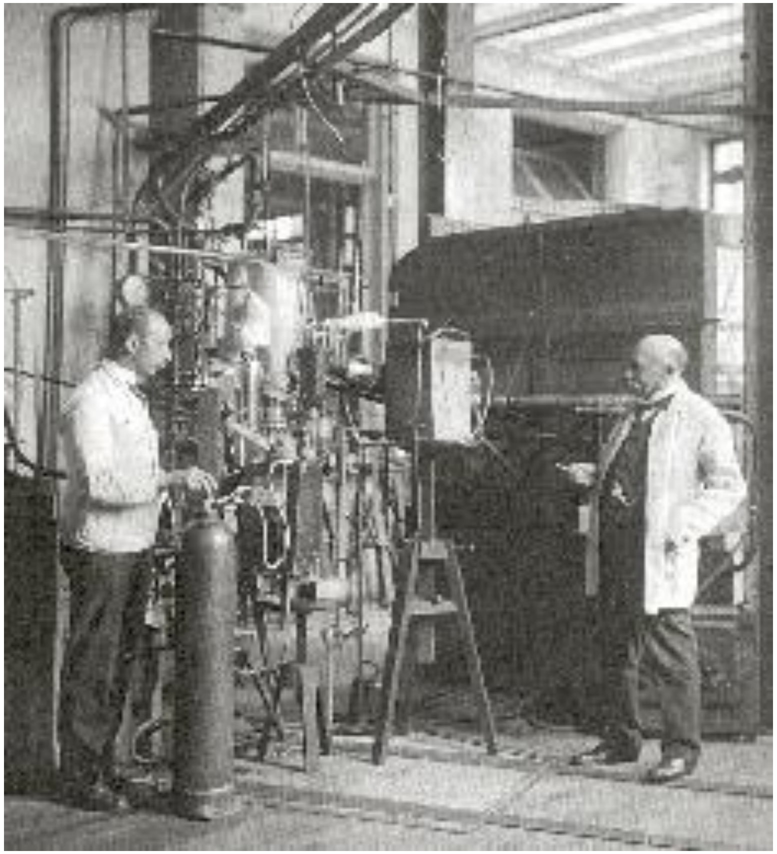
Cryodipole cross-section




Heat Exchanger Pipe
Beam Pipe
Superconducting Coils
Helium-II Vessel
Spool Piece
Bus Bars
Superconducting Bus-Bar
Iron Yoke
Non-Magnetic Collars
Vacuum Vessel
Quadrupole
Bus Bars
Radiation Screen
Thermal Shield
The
15-m long
LHC cryodipole
Auxiliary
Bus Bar Tube
Instrumentation
Feed Throughs
Protection
Diode

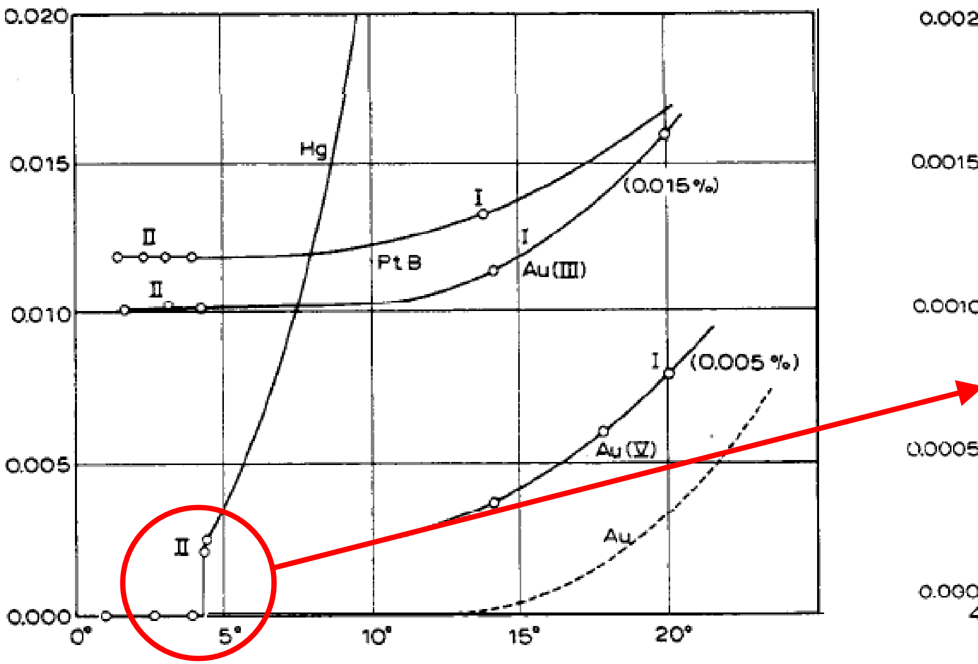
...at the physics laboratory of Leyden, helium was first liquified

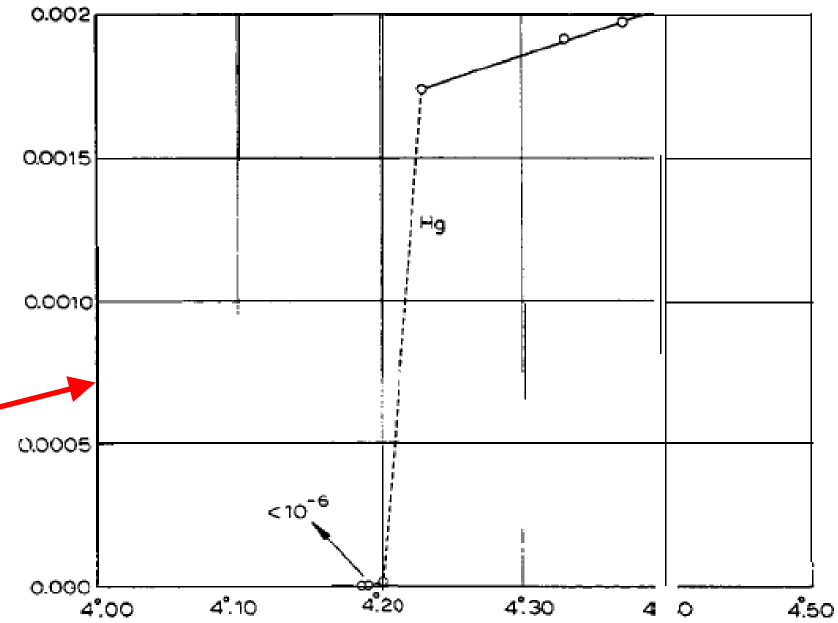
Heike Kamerlingh Onnes



“Door meten tot weten”
To knowledge through measurement

Discovery of superconductivity (1911)





Thus the mercury at 4.2°K has entered a new state, which, owing to its particular electrical properties, can be called the state of superconductivity.

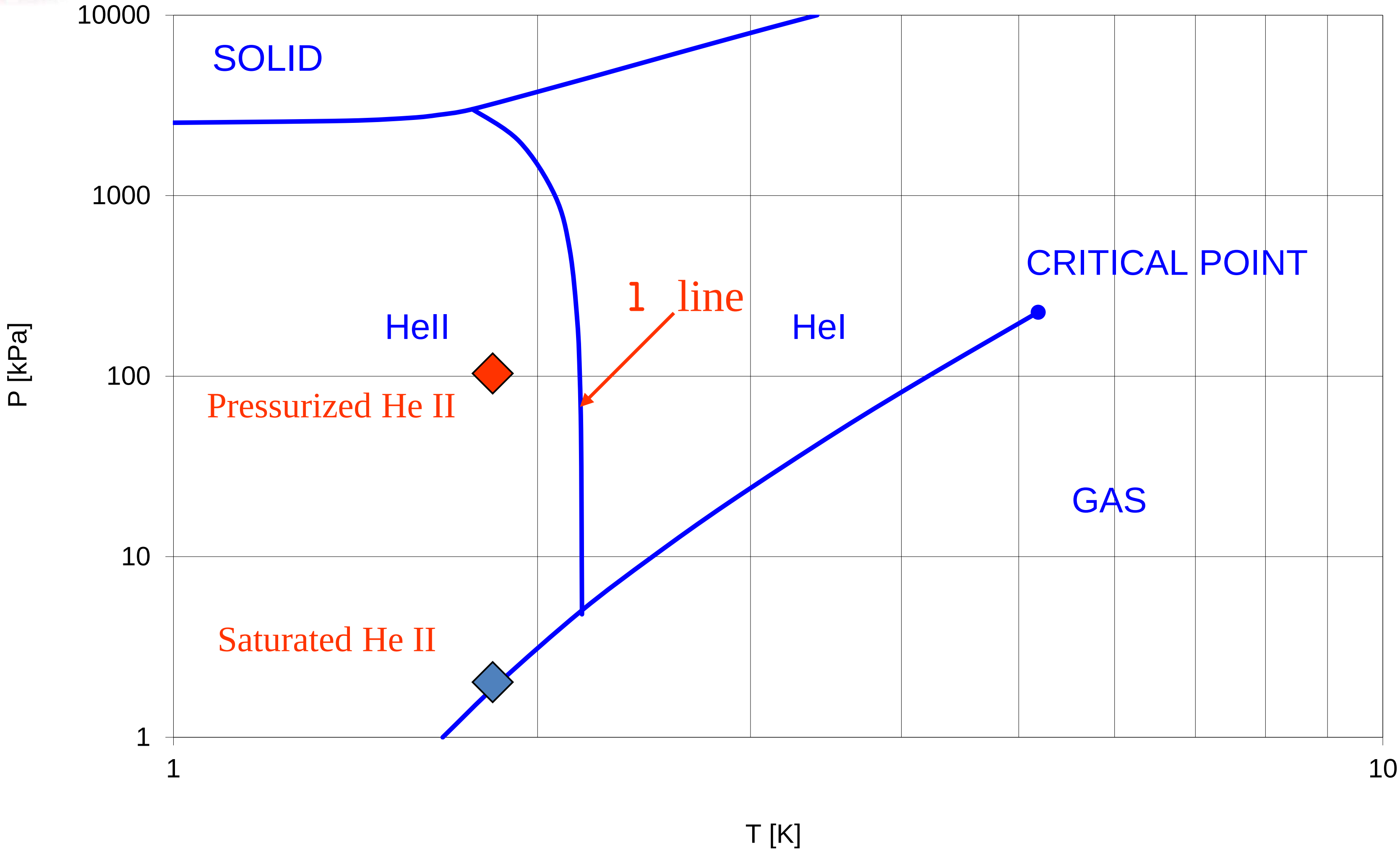
First idea of superconducting magnets (H. K. Onnes 1913)

dendum 2.) There is also the question as to whether the absence of Joule heat makes feasible the production of strong magnetic fields using coils without iron,* for a current of very great density can be sent through very fine, closely wound wire spirals. Thus we were successful in sending a current of 0.8 amperes, i.e. of 56 amperes per square millimetre, through a coil, which contained 1,000 turns of a diameter of 1/70 square mm per square centimetre at right angles to the turns.

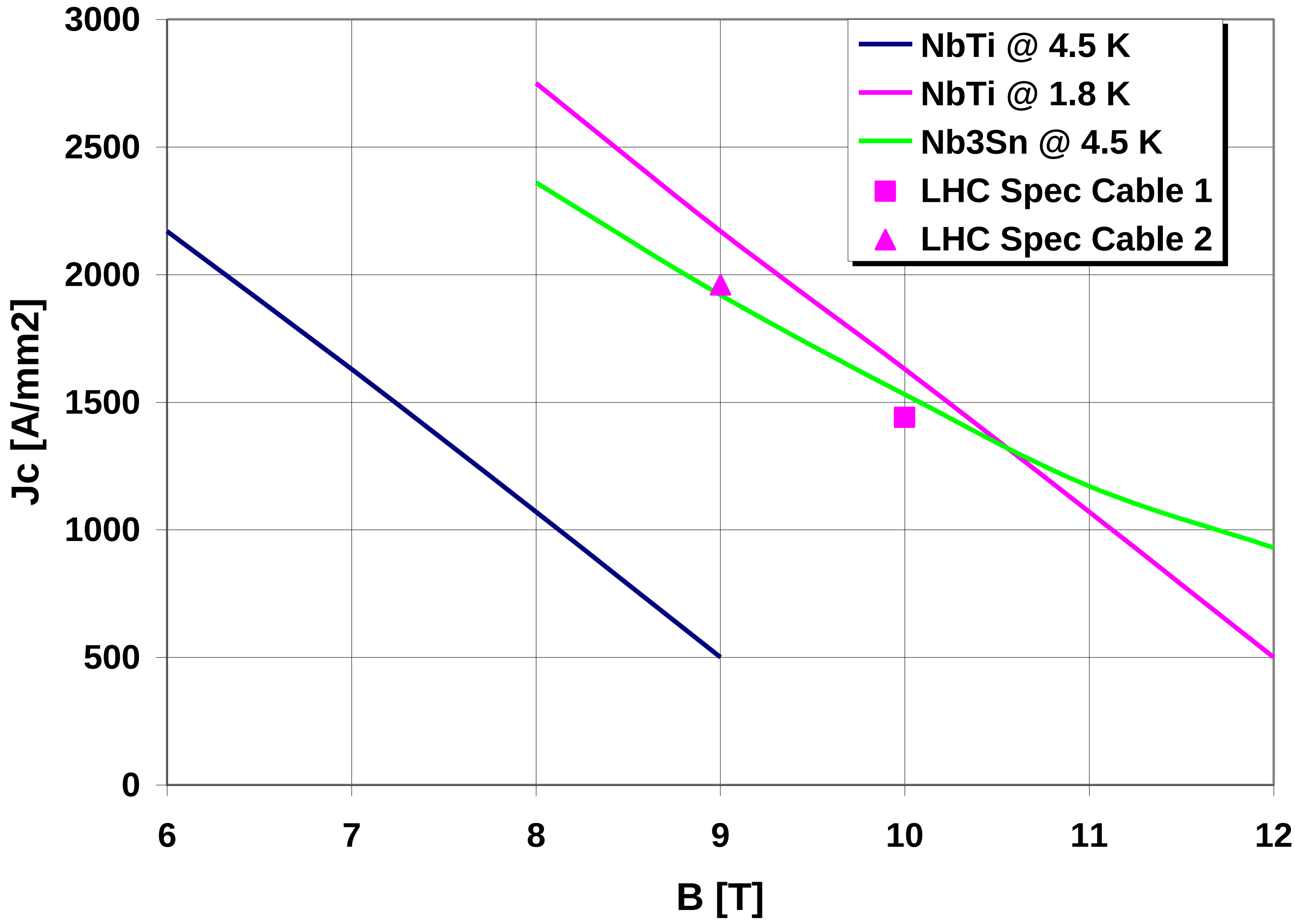
critical field of superconductors!

after this lecture was given and produced surprising results. In fields below a threshold value (for lead at the boiling point of helium 600 Gauss), which was not reached during the experiment with the small coil mentioned in the text, there is no magnetic resistance at all. In fields above this threshold value a relatively large resistance arises at once, and grows considerably with the field. Thus in an unexpected way a difficulty in the production of intensive magnetic fields with coils without iron faced us. The discovery of the

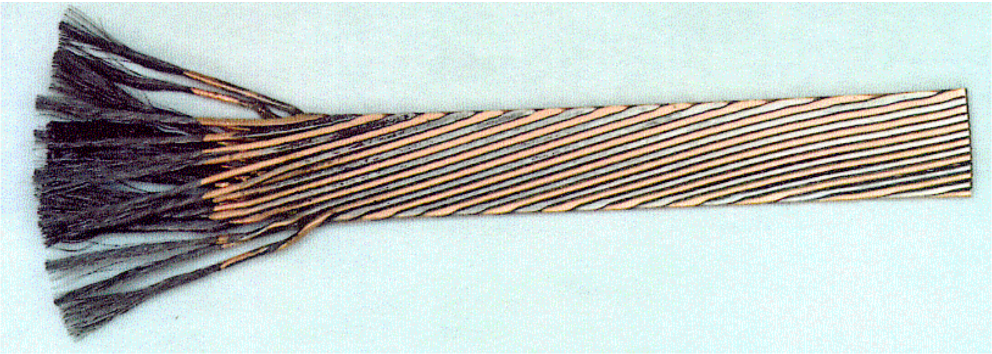
Phase diagram of helium

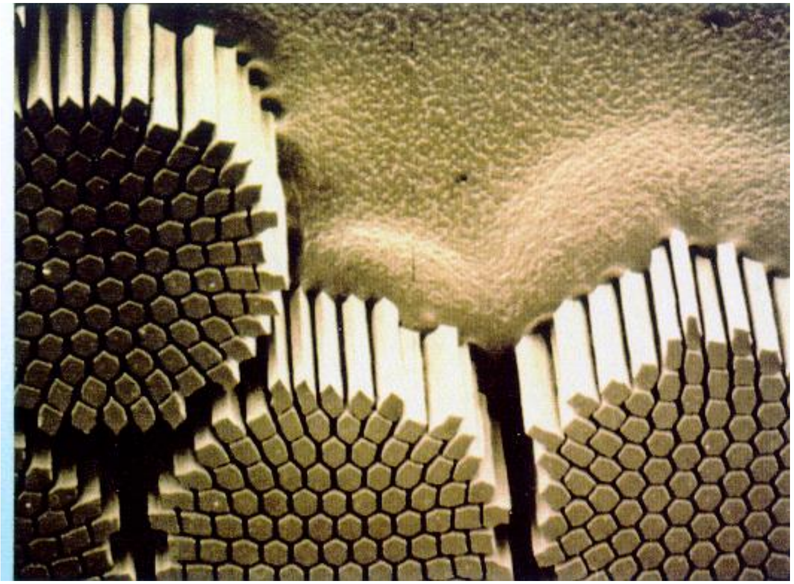


Critical current density of technical superconductors



7000 km of superconducting cable Nb-Ti

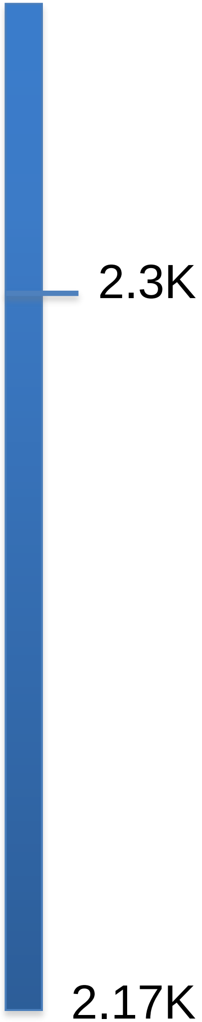




Hint of a quantum effect…?

It is very noticeable that the experiments indicate that the density of the helium, which at first quickly drops with the temperature, reaches a maximum at 2.2°K approximately, and if one goes down further even drops again. Such an extreme could possibly be connected with the quantum theory.

Superfluid Helium

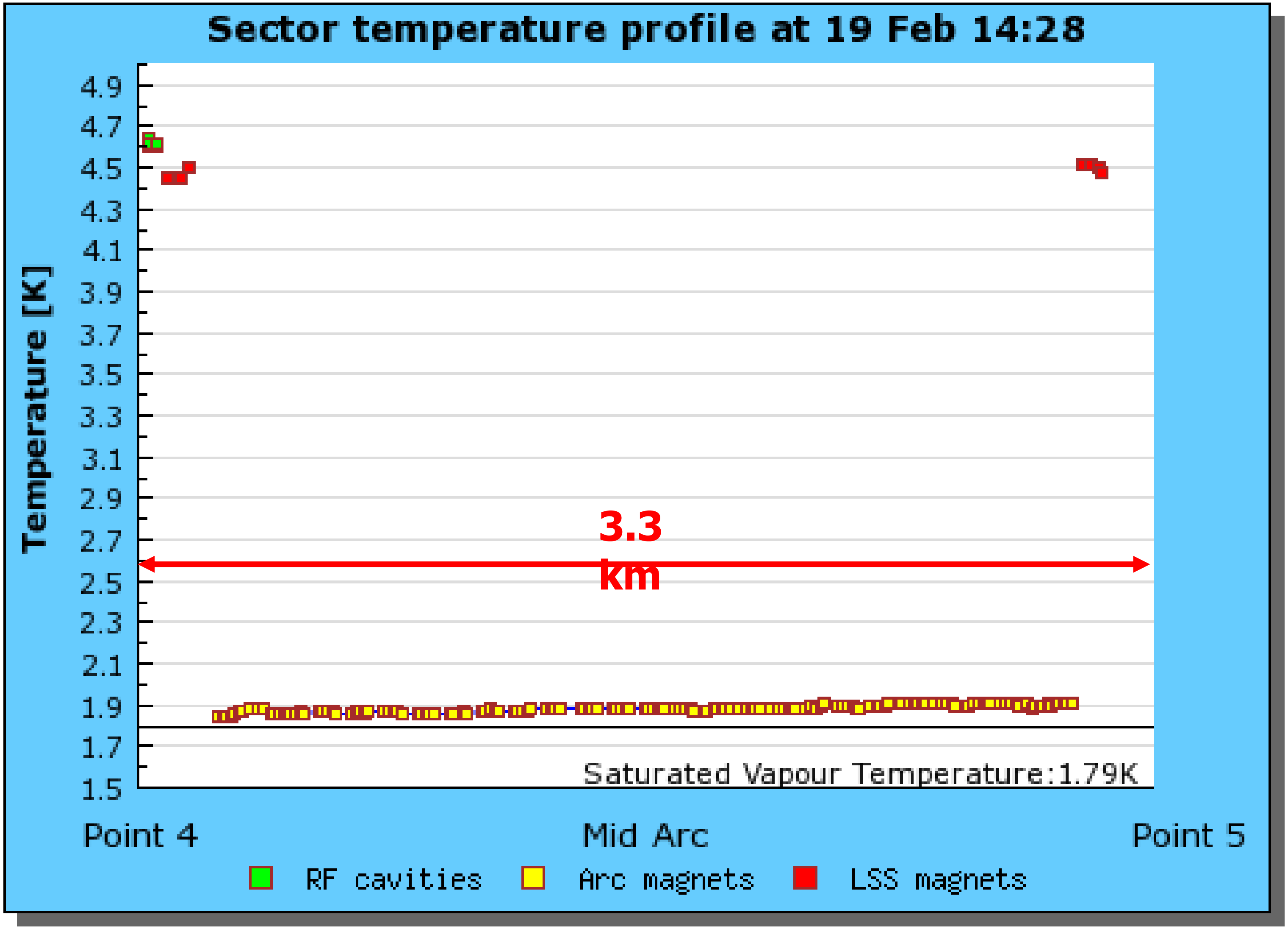


J. F. Allen

« In my PhD work in Toronto on superconductivity, I had often seen the sudden cessation of boiling at the lambda temperature T_λ but had paid it no particular attention. It never occured to me that it was of fundamental significance. »

J. Allen, Physics World, November 1988, p 29.

Superfluid Helium



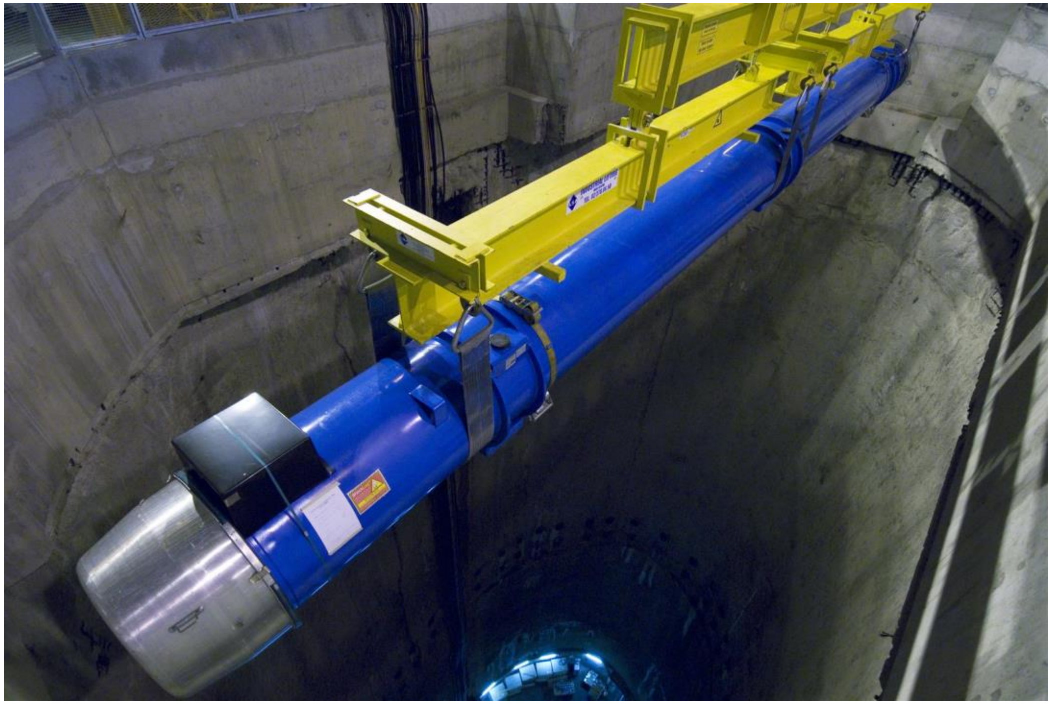
Sector temperature profile at 19 Feb 14:28
Temperature [K]
4.9
4.7
4.5
4.3
4.1
3.9
3.7
3.5
3.3
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
3.3 km
Saturated Vapour Temperature:1.79K
Point 4
Mid Arc
Point 5
RF cavities
Arc magnets
LSS magnets

Manufacturing of superconducting coils

Assembly of dipole cold masses

Cryogenic test benches

Magnet descent into the tunnel

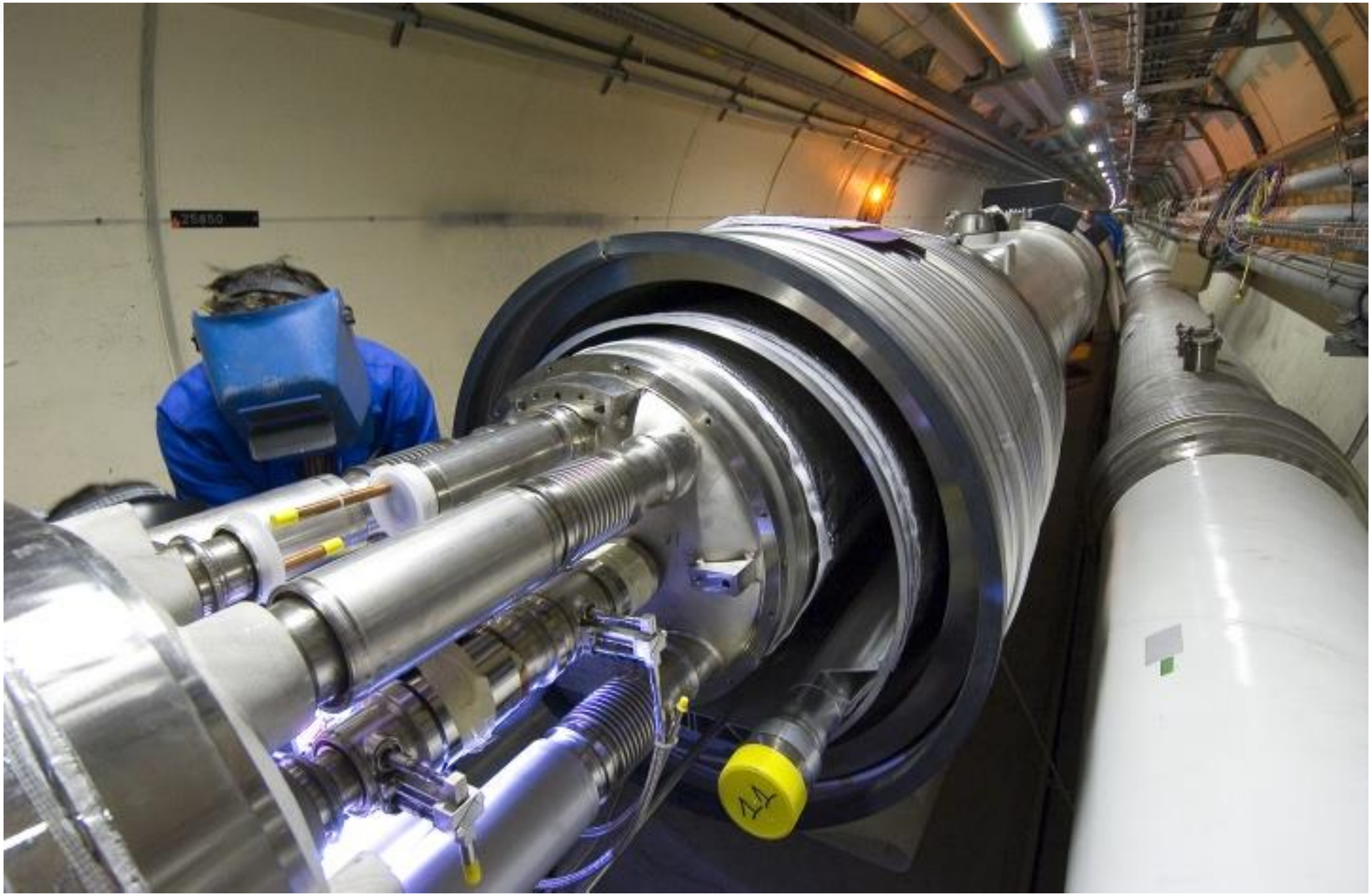


Transport in the tunnel with an optical guided vehicle

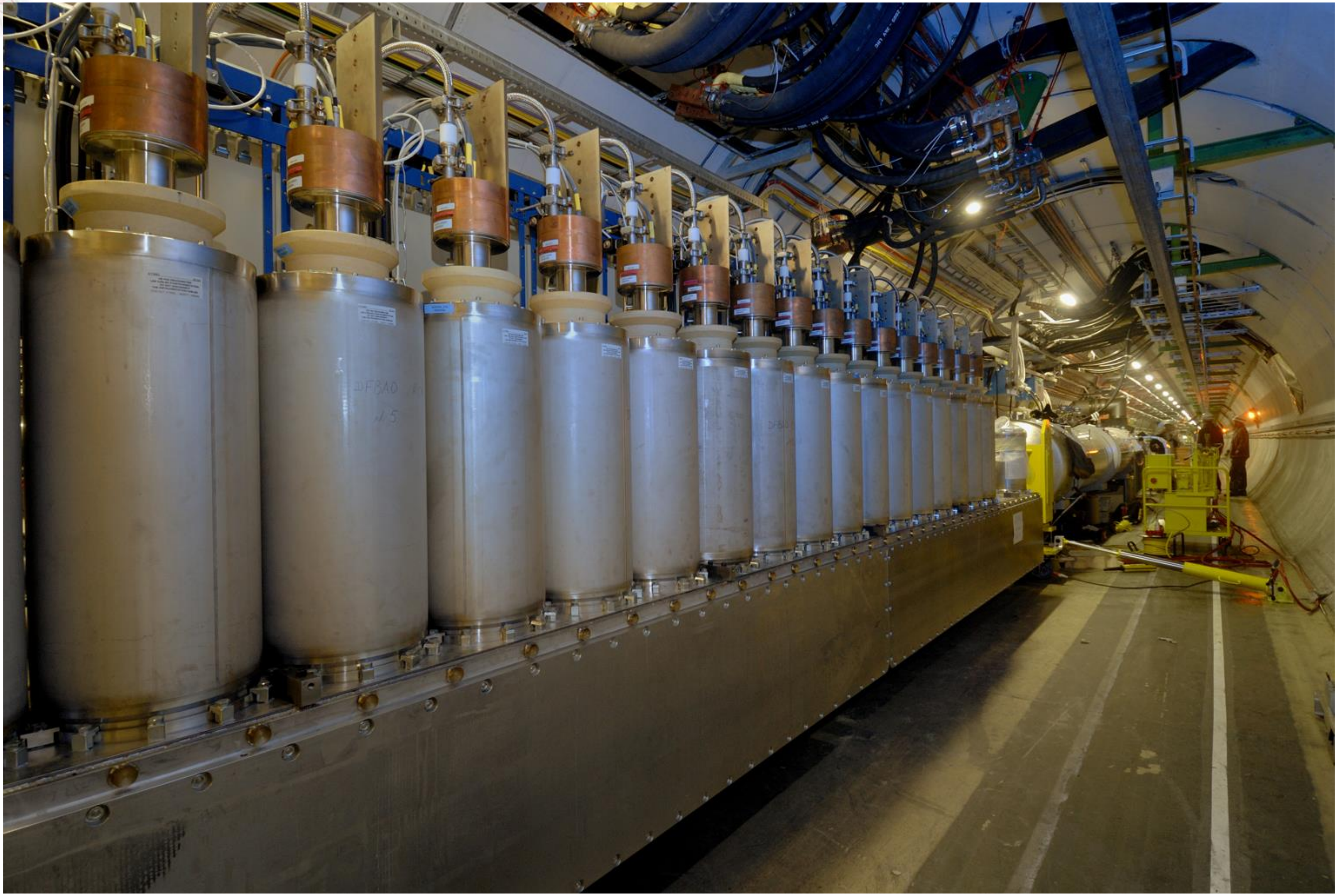
Transfer on jacks

Electrical splice

Dipole dipole interconnect



DFBAO in Sector 7-8



HTS IN THE LHC MACHINE

Powering of the LHC magnets

About <u>3 MA</u> of rated current through 1800 circuits

3286 current leads

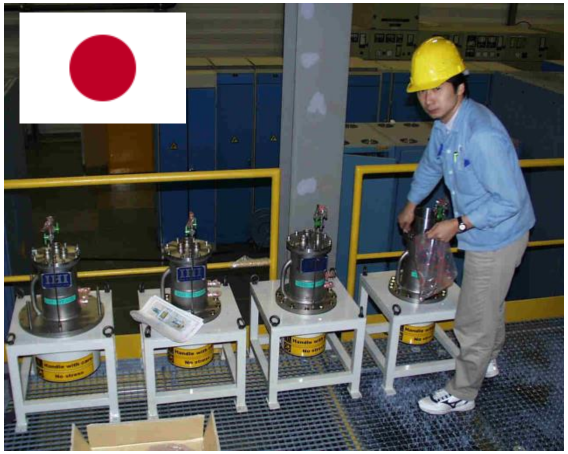
Quantity	Current rating (A)
64	13000
298	6000
820	600
2104	60-120

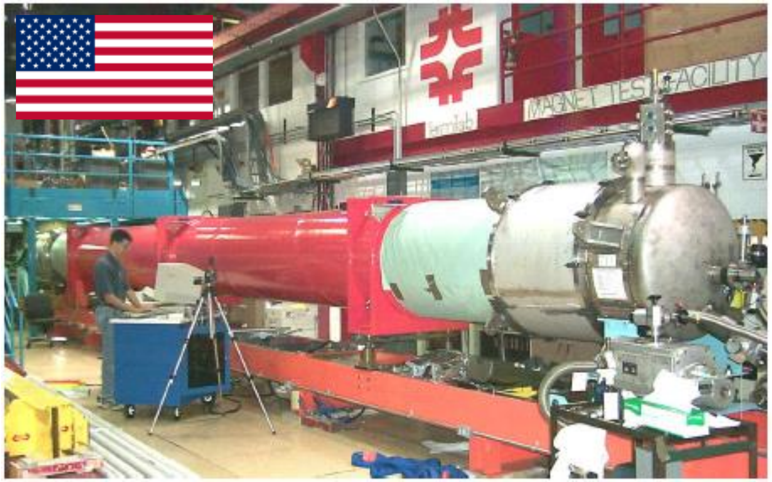
HTS (first three rows)

J_c=12500 A/cm^2 @ 77 K self field

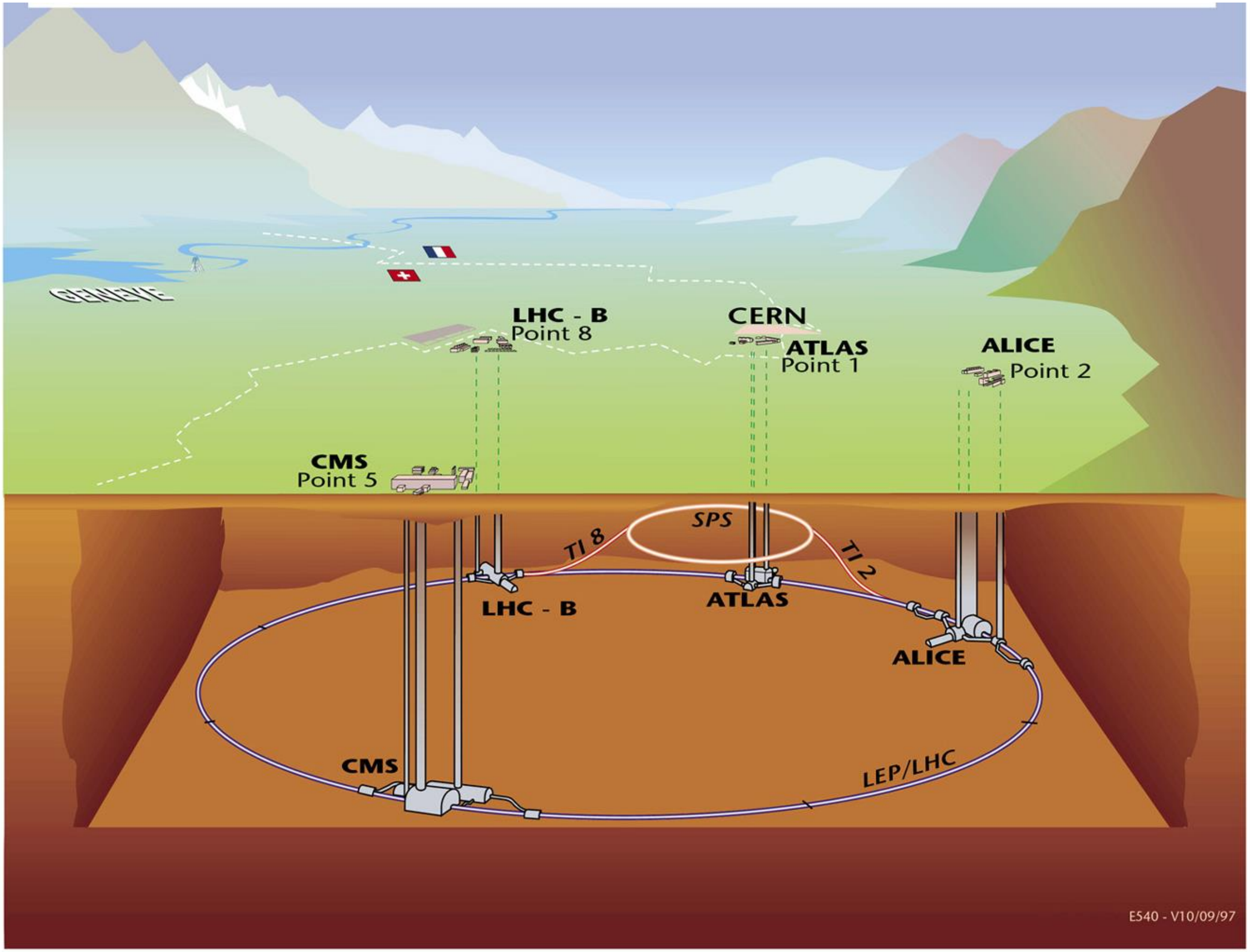
Courtesy of A. Ballarino

A global project





The LHC and its detectors

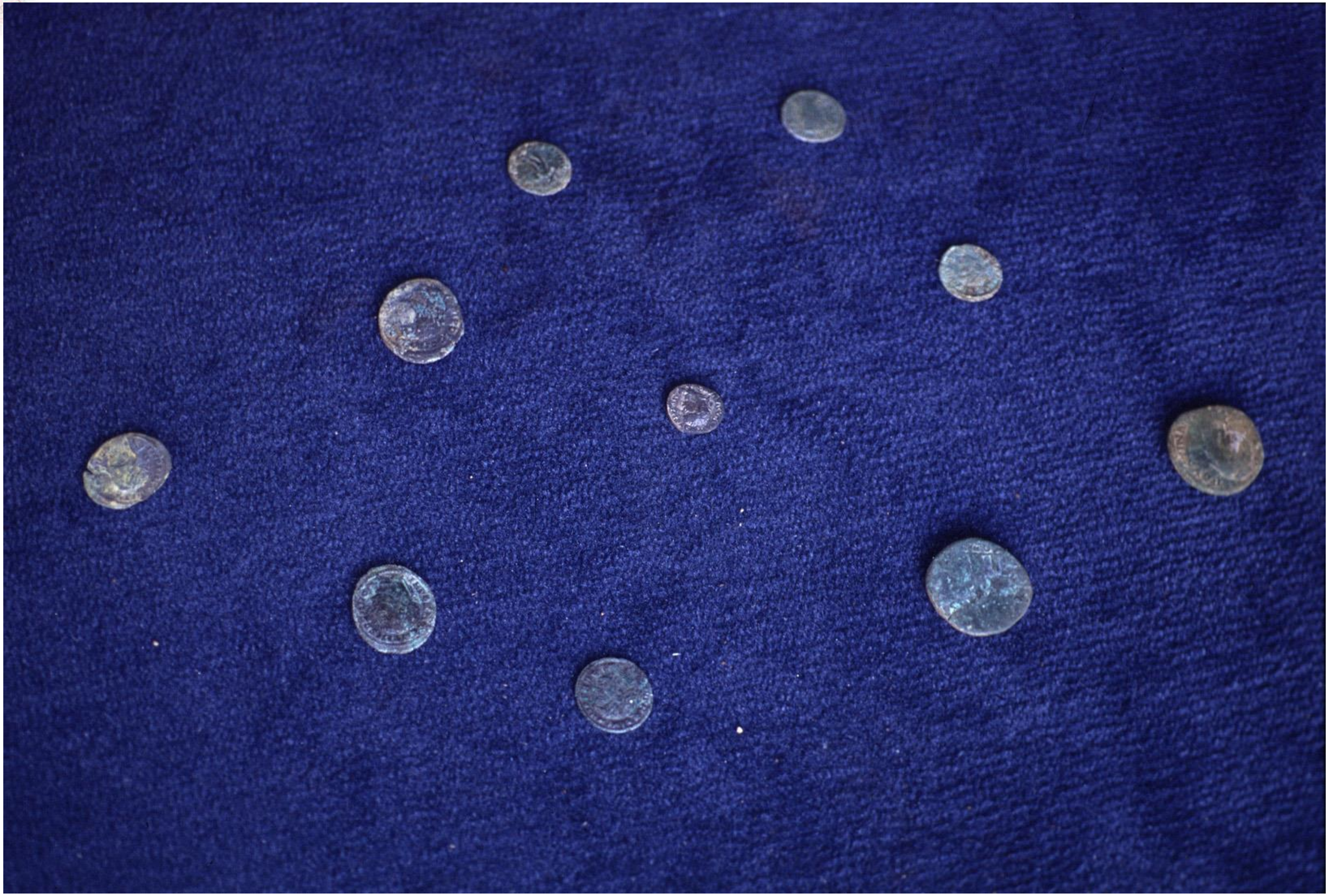


Point 1 - UX15 cavern - Concreting of vault panel n°2 - April 10, 2001 - CERN ST-CE

LHC Point 1 - UX 15 Cavern - Concrete walls 6th lift - 20-02-2003 - CERN ST-CE

Aerial view of Point 5
Gallo-roman vestiges 1998

Roman coins found during archeological excavations at Point 5

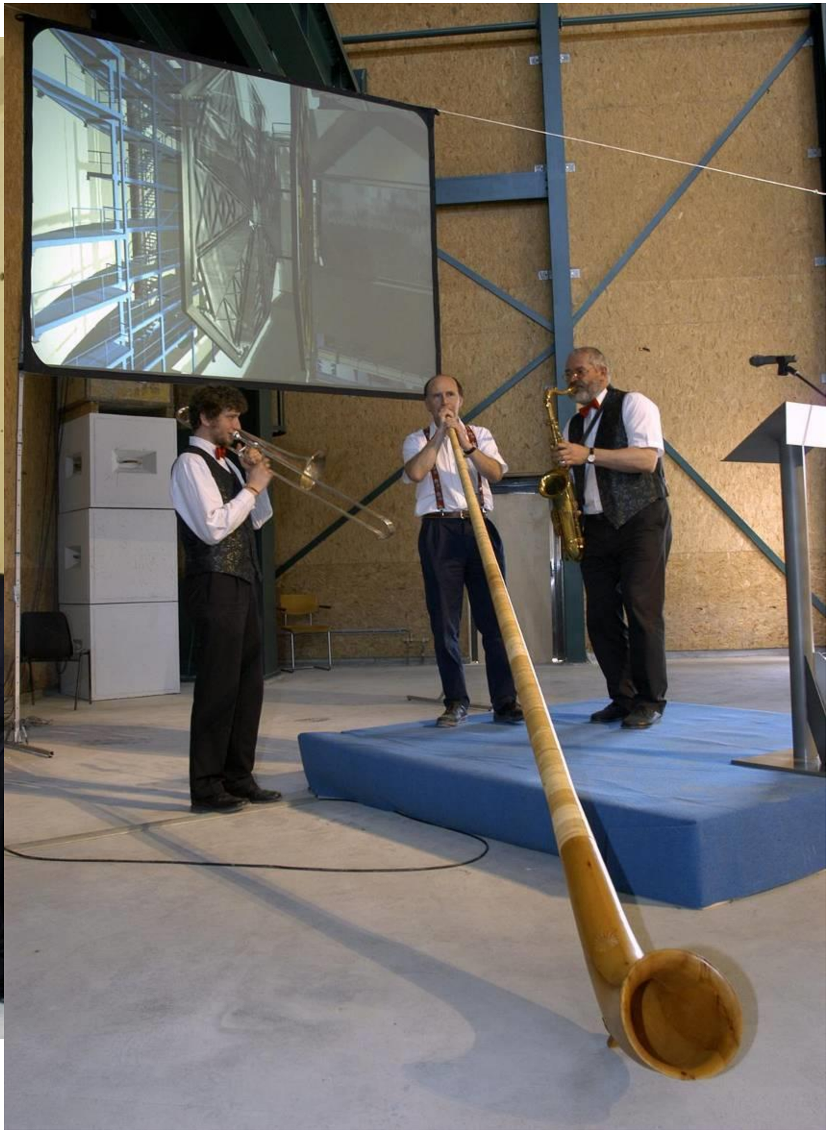


Point 5 -Excavation commencement of PM54 shaft - July 09, 1999 - CERN ST-CE

Point 1 - UX15 vault demolition of central pillar - September 20, 2000 - CERN ST-CE

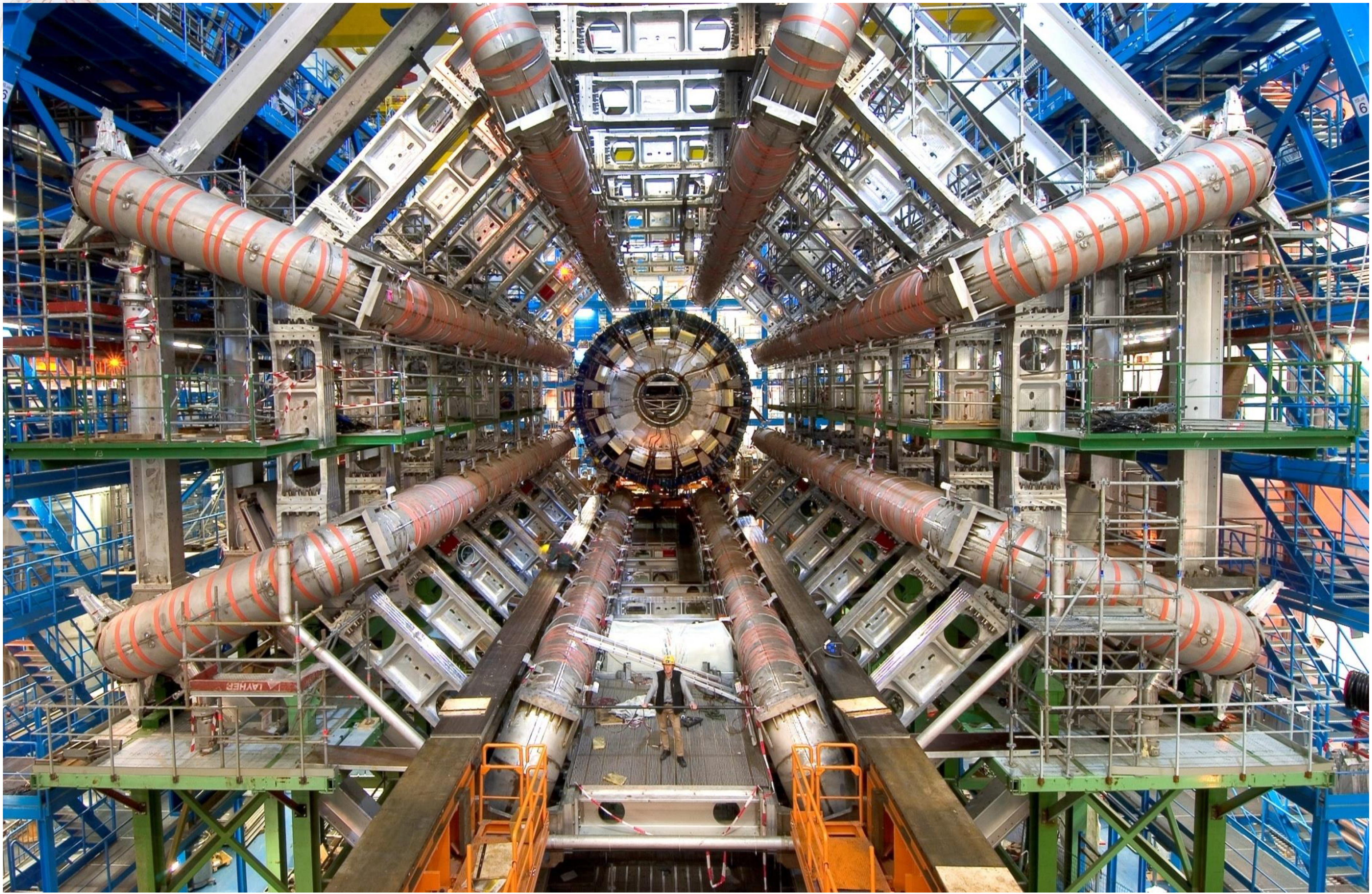
Point 5 - UXC55 cavern excavation - LEP demolition - January 23, 2002 - CERN ST-CE

ATLAS Cavern Inauguration 2003

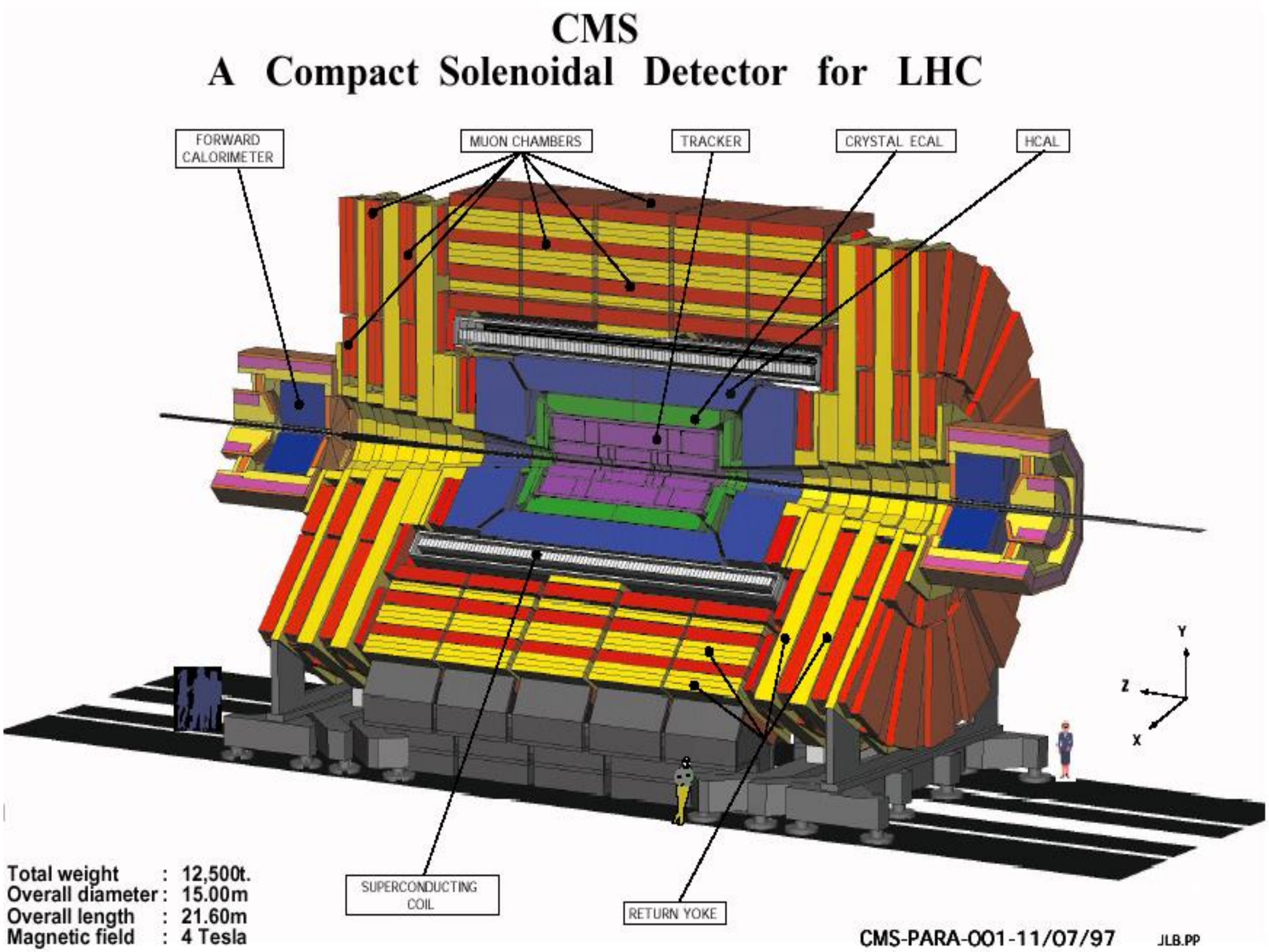


Lyn Evans

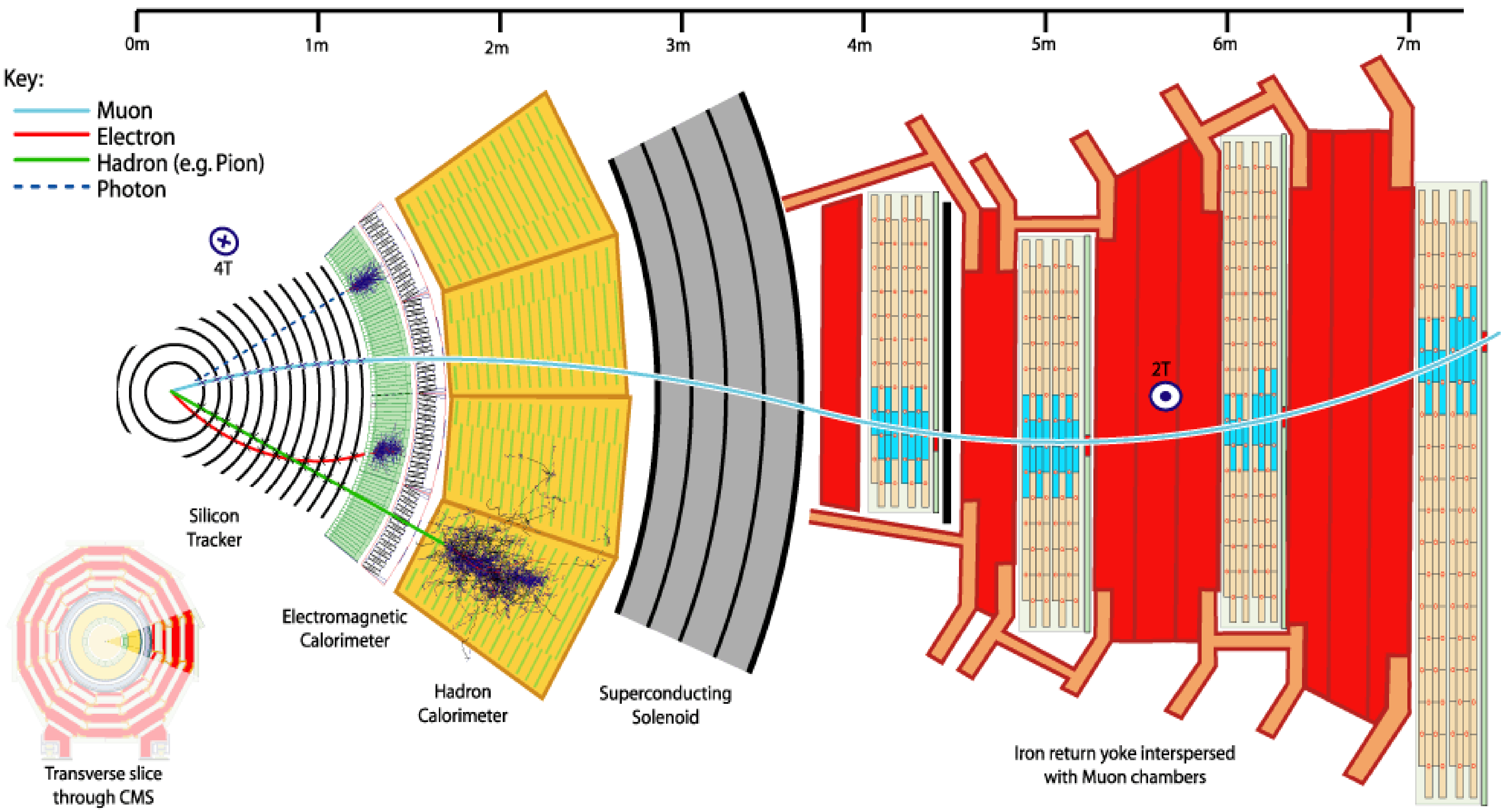
4th November 2005, the world-famous picture of the completed Barrel Toroid…



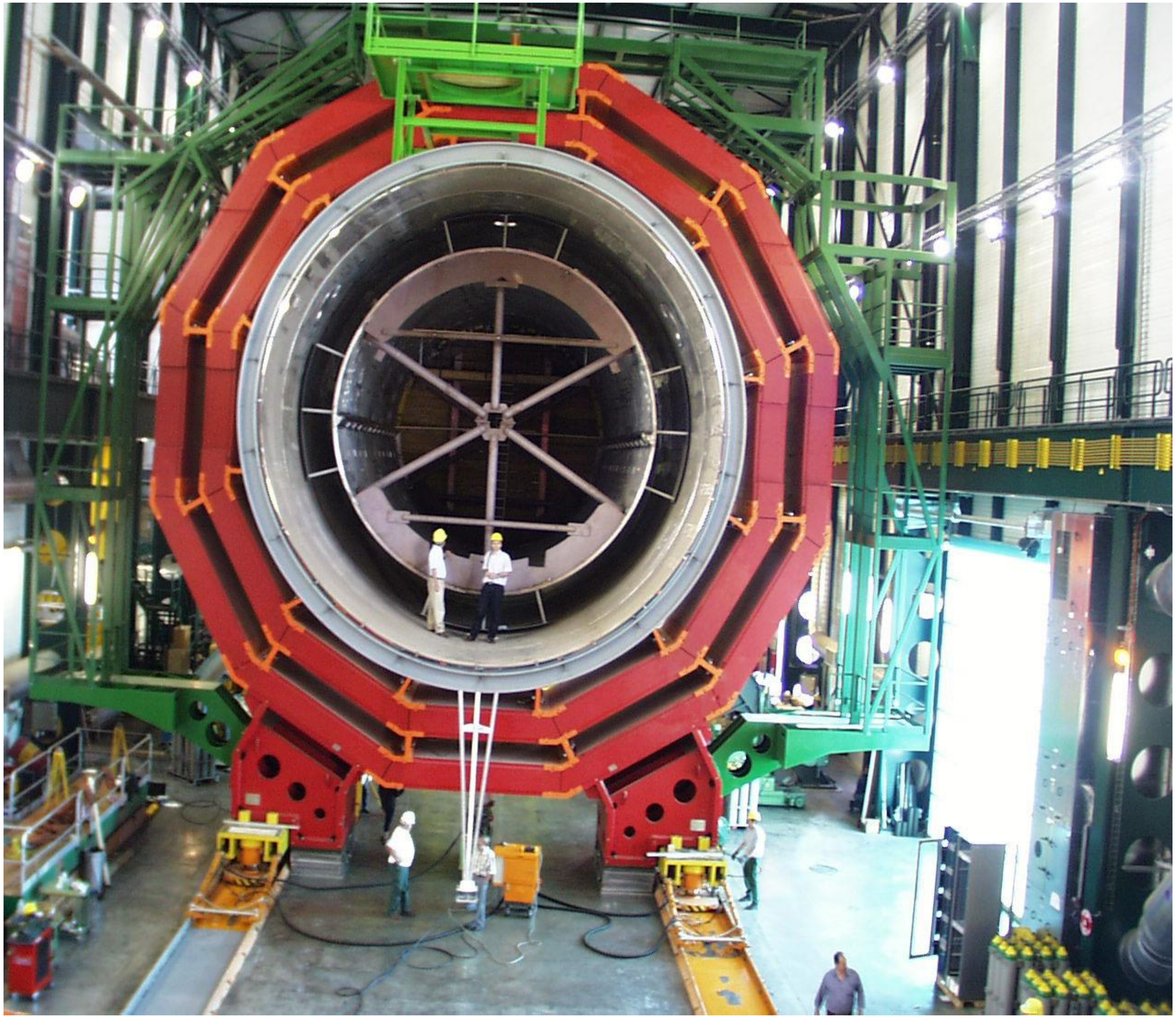
The CMS Detector



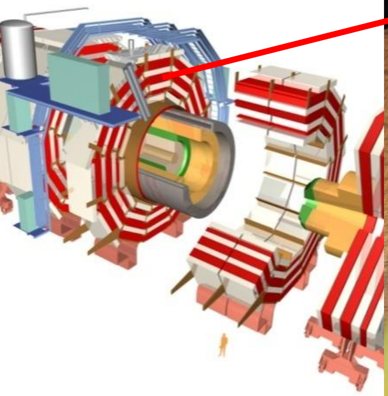
A Slice through CMS

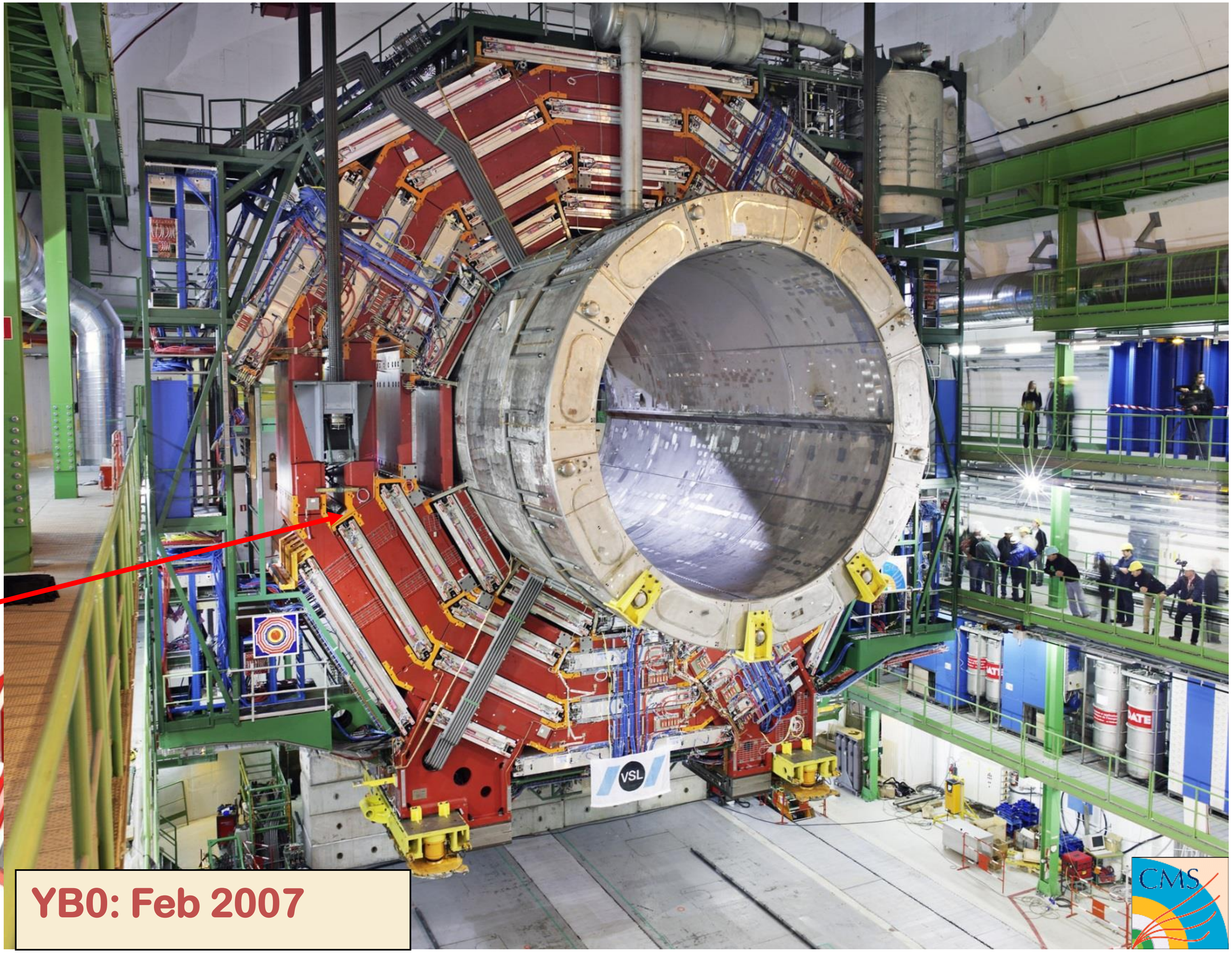


CMS Solenoid Assembly



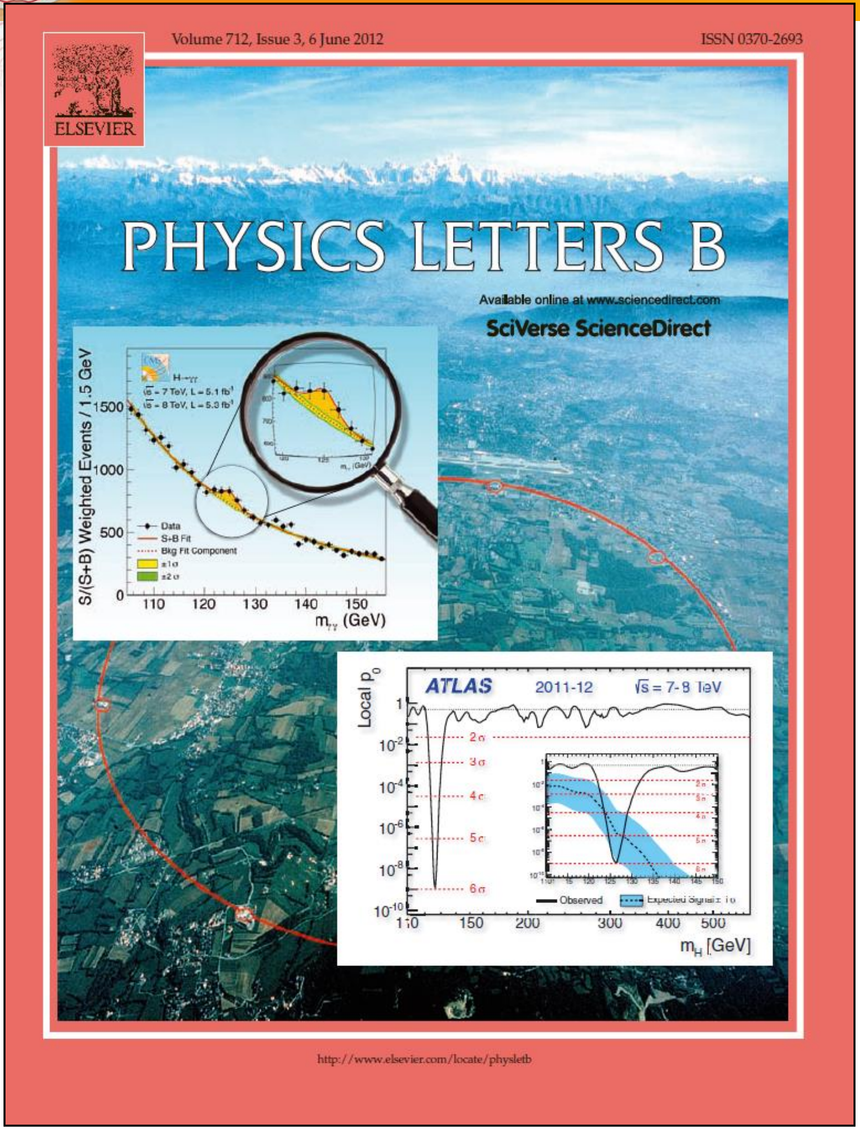
CMS: lowering of heavy elements- Nov' 06 - Jan' 08

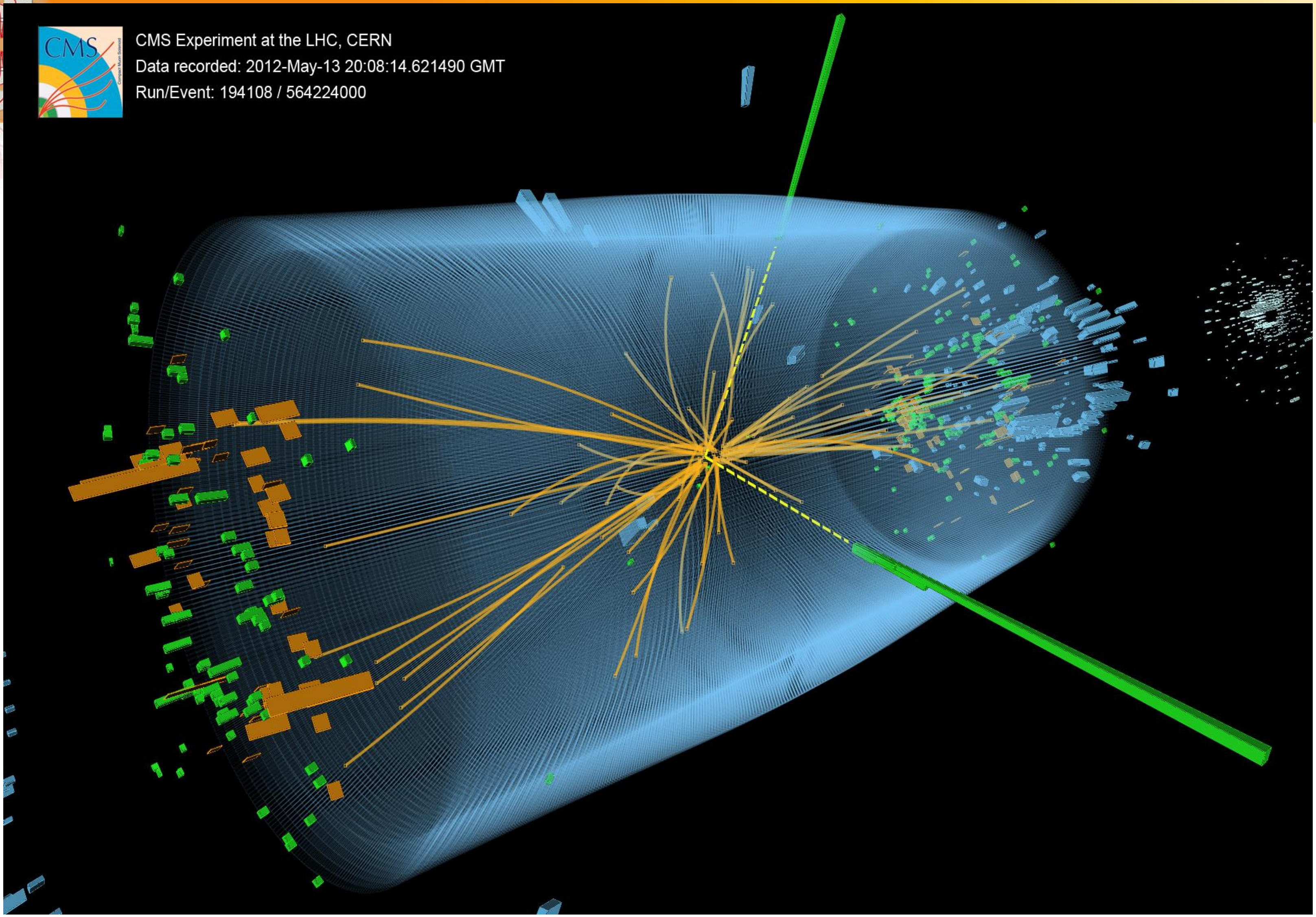




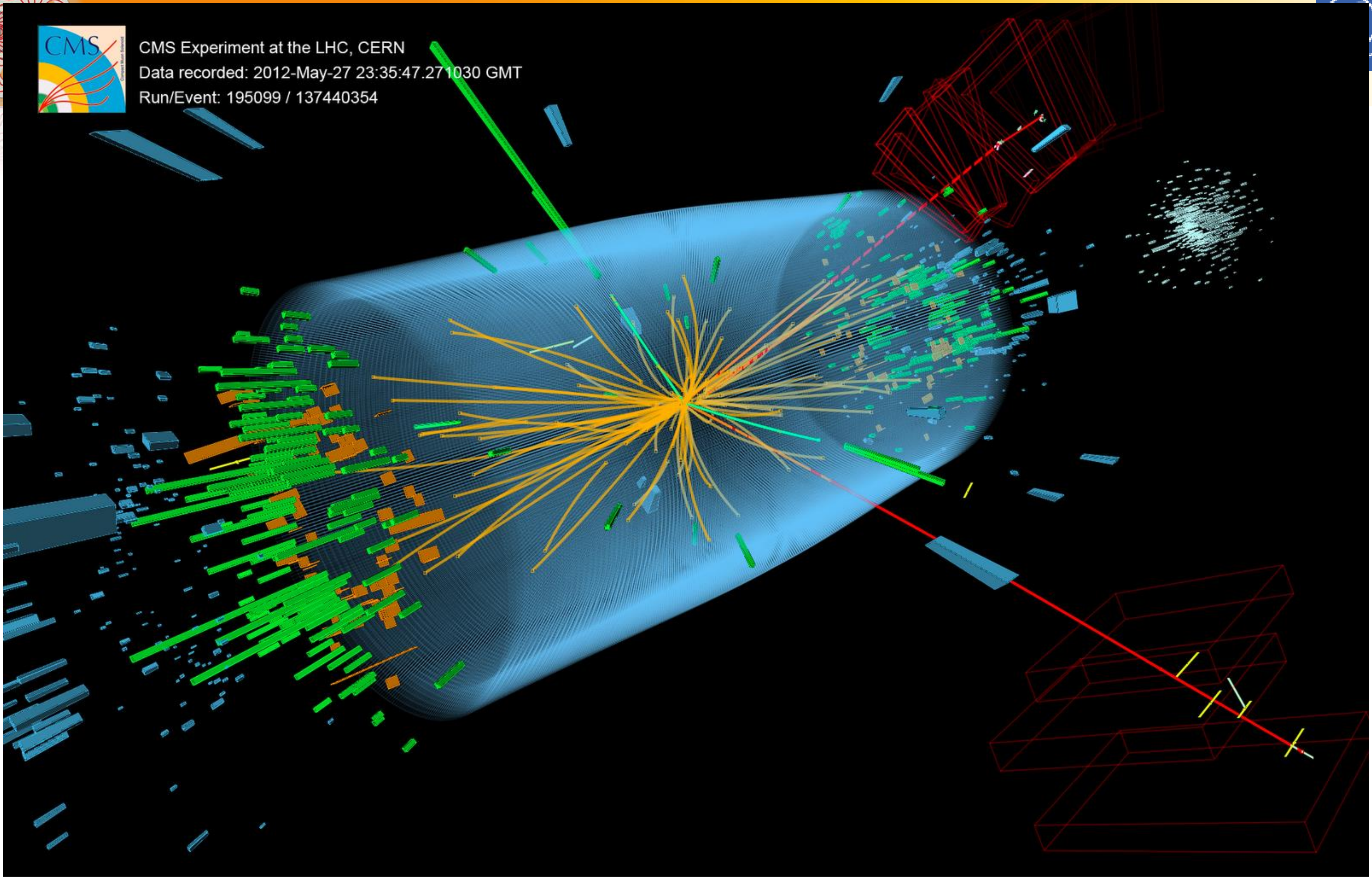
YB0: Feb 2007

The highlight of a remarkable year 2012



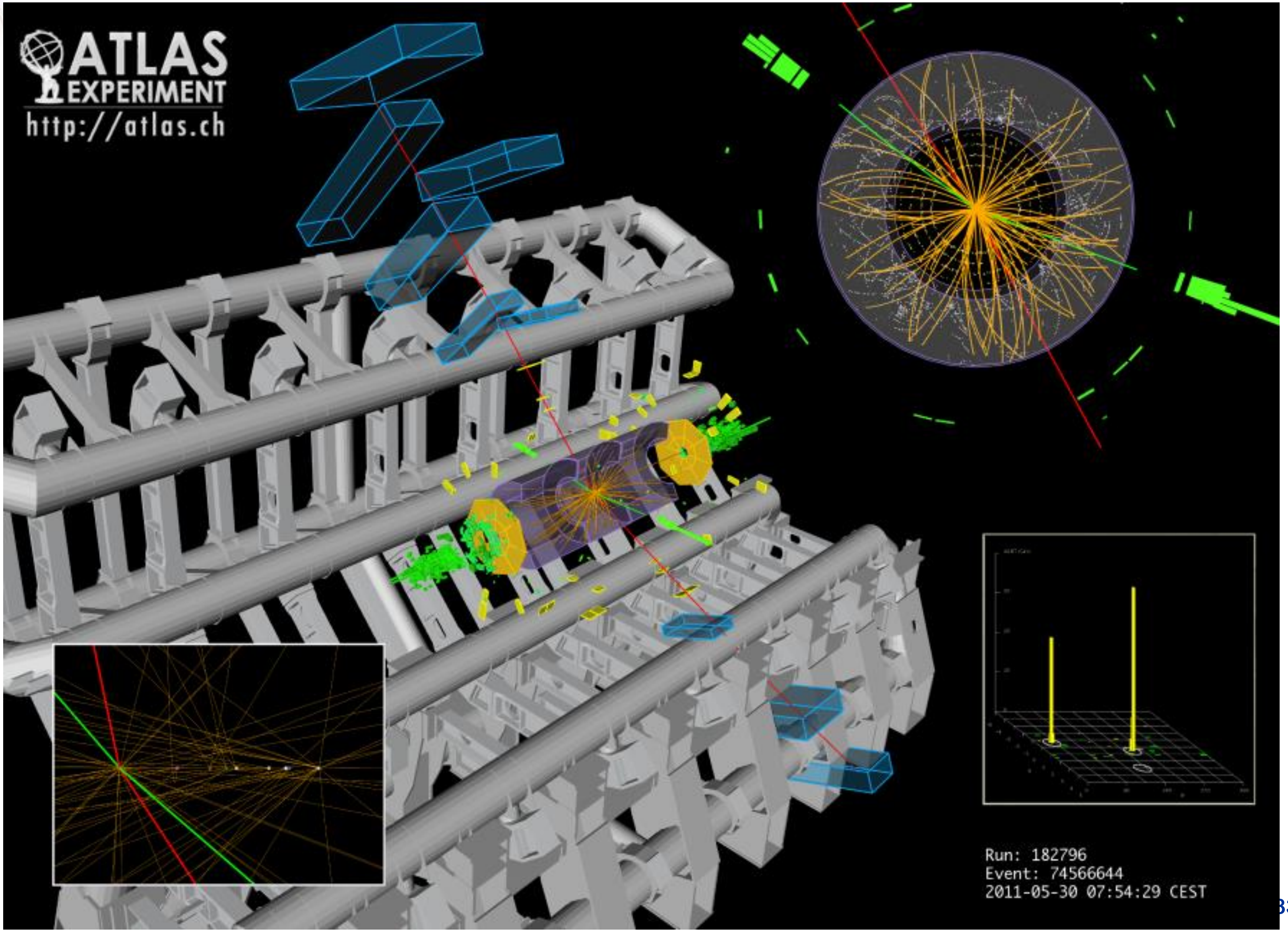


Event recorded with the CMS detector in 2012 at a proton-proton centre-of-mass energy of 8 TeV. The event shows characteristics expected from the decay of the SM Higgs boson to a pair of photons (dashed yellow lines and green towers). Full yellow lines represent the reconstructed trajectories of the charged particles produced in addition to the two photons in the same collision. The event could also be due to known standard model background processes.

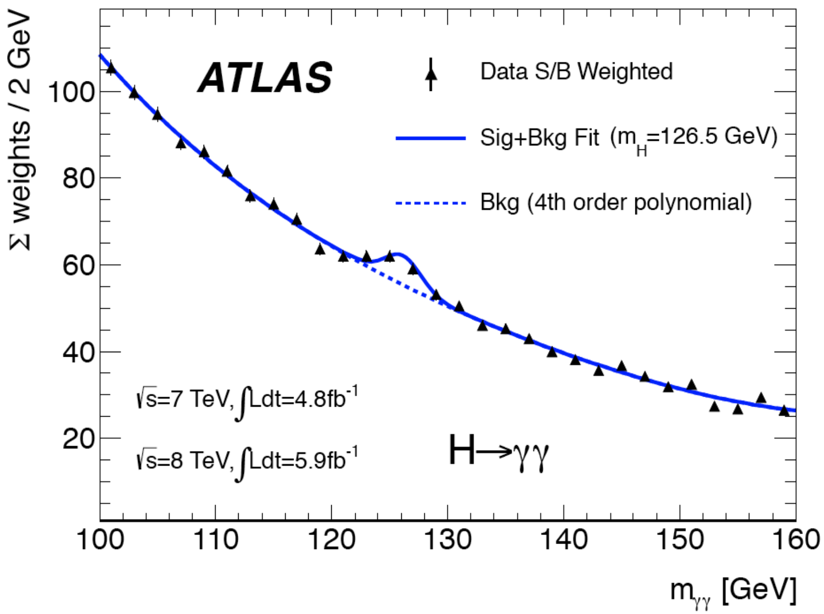


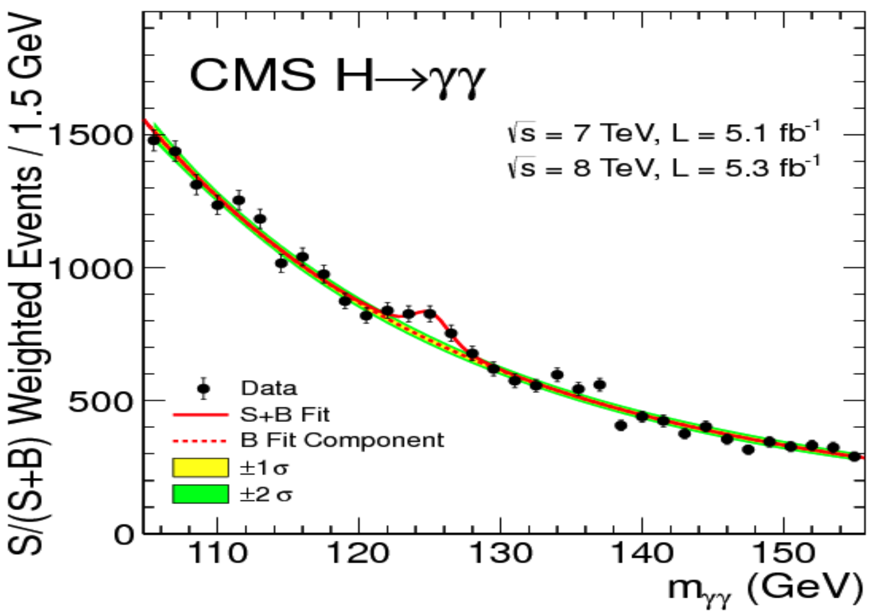
Event recorded with the CMS detector in 2012 at a proton-proton centre-of-mass energy of 8 TeV. The event shows characteristics expected from the decay of the SM Higgs boson to a pair of Z bosons, one of which subsequently decays to a pair of electrons (green lines and green towers) and the other Z decays to a pair of muons

Atlas 4 lepton

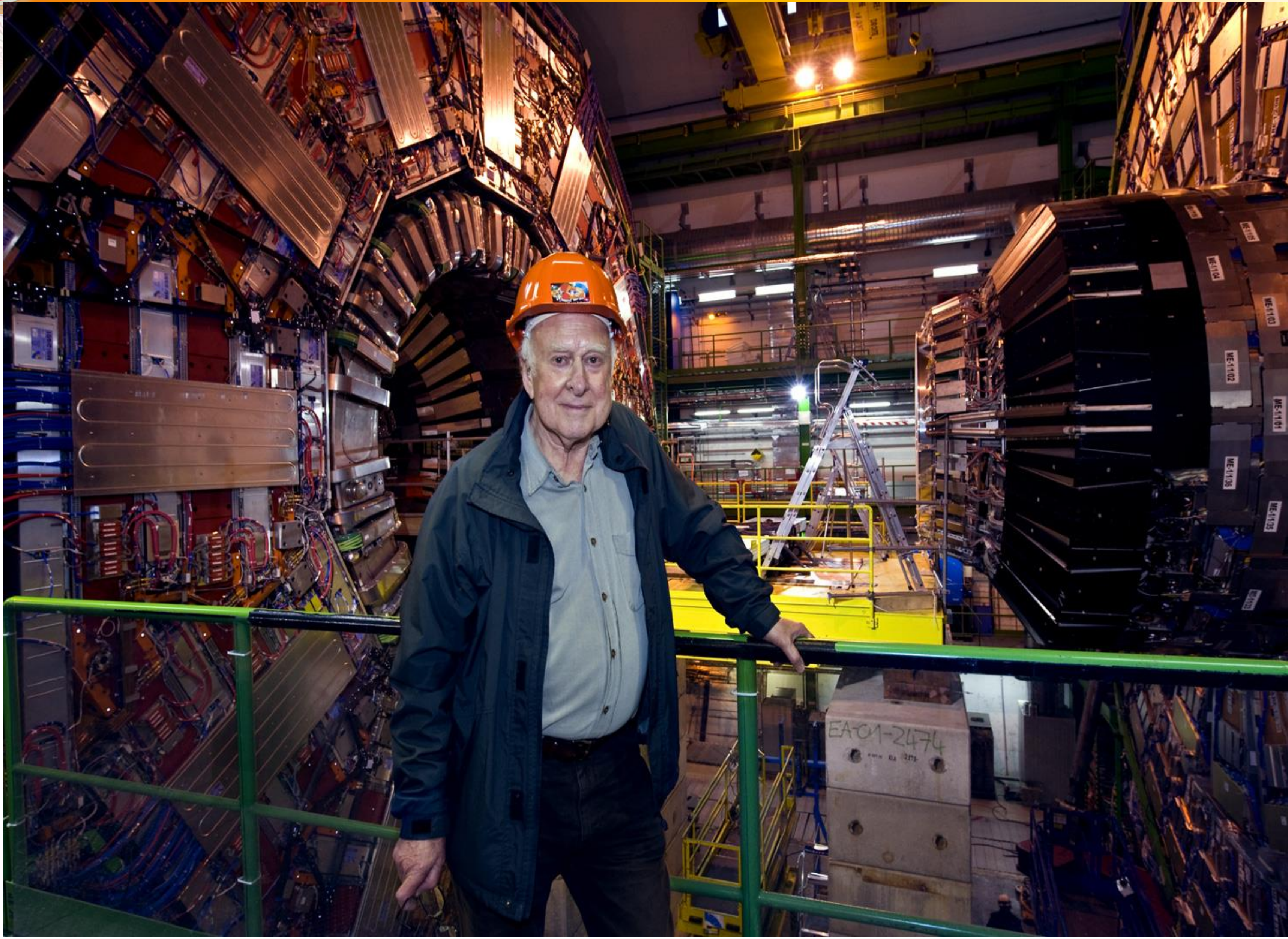


Two photon spectrum





Higgs has been seen in CMS



Bringing nations together

"…the promotion of contacts between, and the interchange of, scientists…"