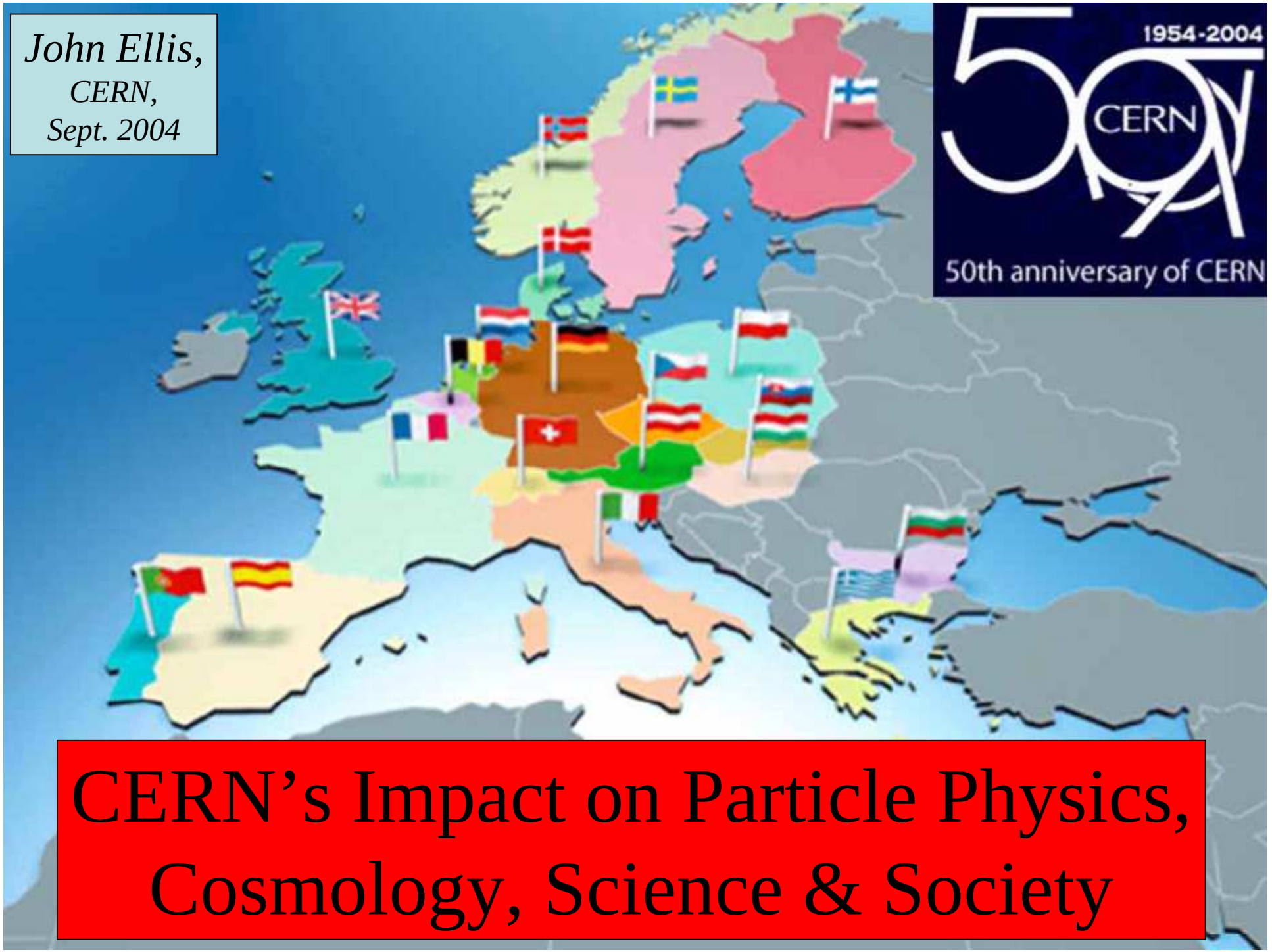
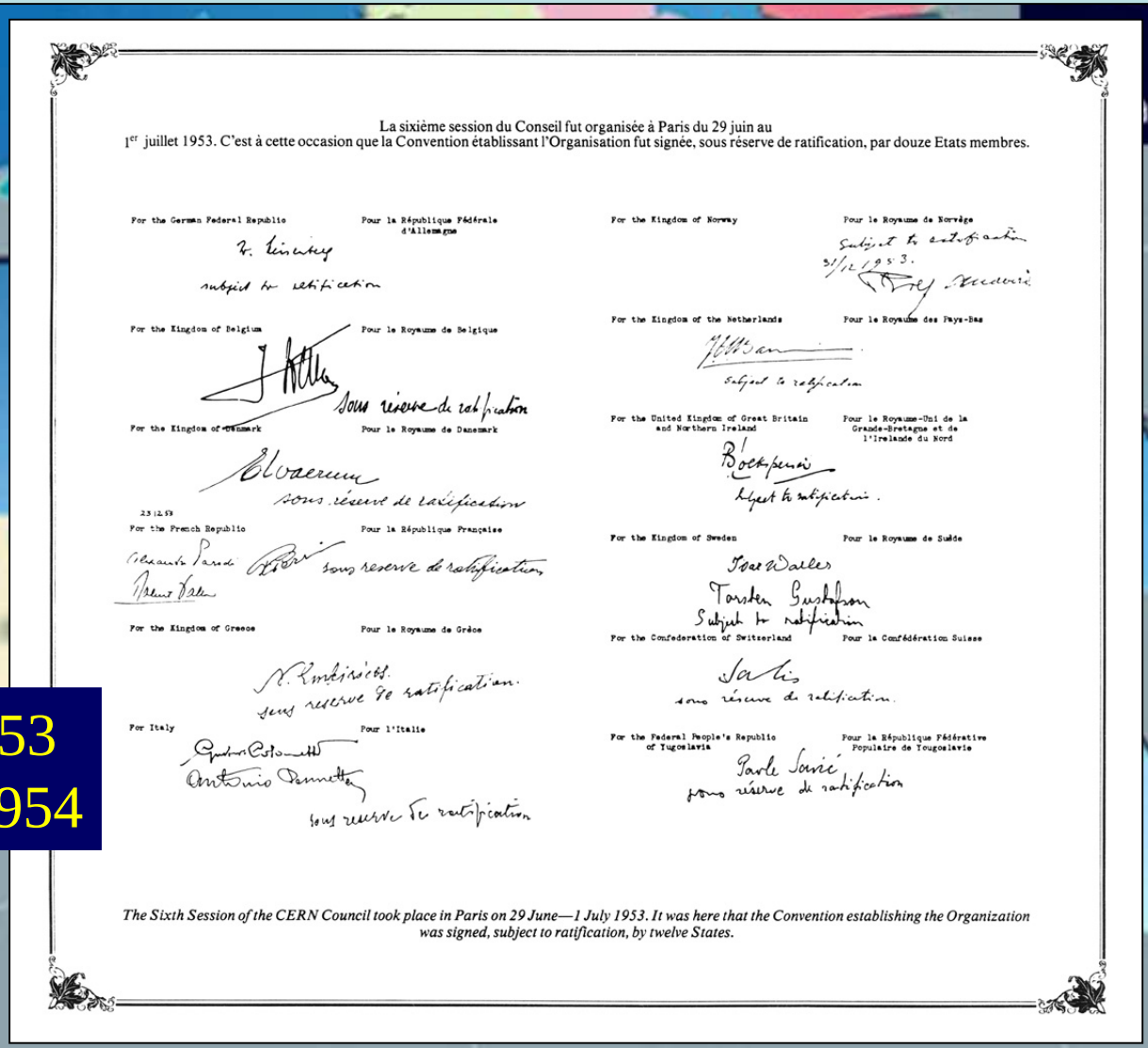
John Ellis,
CERN,
Sept. 2004



CERN's Impact on Particle Physics, Cosmology, Science & Society

CERN Convention



La sixième session du Conseil fut organisée à Paris du 29 juin au 1er juillet 1953. C'est à cette occasion que la Convention établissant l'Organisation fut signée, sous réserve de ratification, par douze Etats membres.

For the German Federal Republic — Pour la République Fédérale d'Allemagne
subject to ratification

For the Kingdom of Belgium — Pour le Royaume de Belgique
sous réserve de ratification

For the Kingdom of Denmark — Pour le Royaume de Danemark
sous réserve de ratification
23.12.53

For the French Republic — Pour la République Française
sous reserve de ratification

For the Kingdom of Greece — Pour le Royaume de Grèce
sous reserve de ratification.

For Italy — Pour l'Italie
sous reserve de ratification

For the Kingdom of Norway — Pour le Royaume de Norvège
Subject to ratification
3/12/1953.

For the Kingdom of the Netherlands — Pour le Royaume des Pays-Bas
Subject to ratification

For the United Kingdom of Great Britain and Northern Ireland — Pour le Royaume-Uni de la Grande-Bretagne et de l'Irelande du Nord
Subject to ratification.

For the Kingdom of Sweden — Pour le Royaume de Suède
Subject to ratification

For the Confederation of Switzerland — Pour la Confédération Suisse
sous réserve de ratification.

For the Federal People's Republic of Yugoslavia — Pour la République Fédérative Populaire de Yougoslavie
sous réserve de ratification

The Sixth Session of the CERN Council took place in Paris on 29 June—1 July 1953. It was here that the Convention establishing the Organization was signed, subject to ratification, by twelve States.

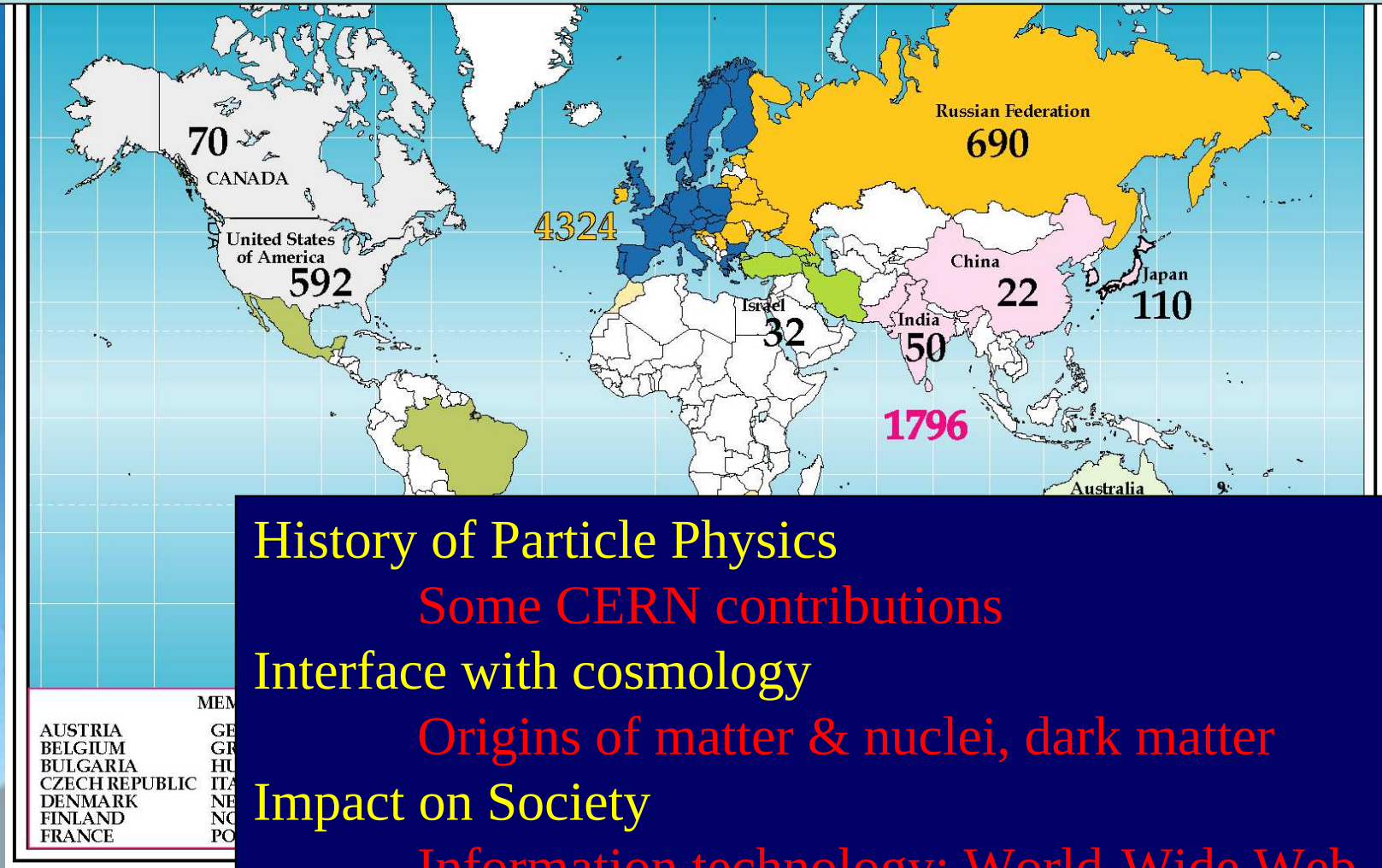
Signed 1953
Ratified 1954

CERN Member States

Member States (Dates of Accession)

AUSTRIA (1959)	DENMARK (1953)	GREECE (1953)	NORWAY (1953)	SPAIN (1/1961-12/1968-1/1983)
BELGIUM (1953)	FINLAND (1991)	HUNGARY (1992)	POLAND (1991)	SWEDEN (1953)
BULGARIA (1999)	FRANCE (1953)	ITALY (1953)	PORTUGAL (1986)	SWITZERLAND (1953)
CZECH FR (1993)	GERMANY (1953)	NETHERLANDS (1953)	SLOVAK FR (1993)	UNITED KINGDOM (1953)

Scientists using CERN, July 2003



History of Particle Physics

Some CERN contributions

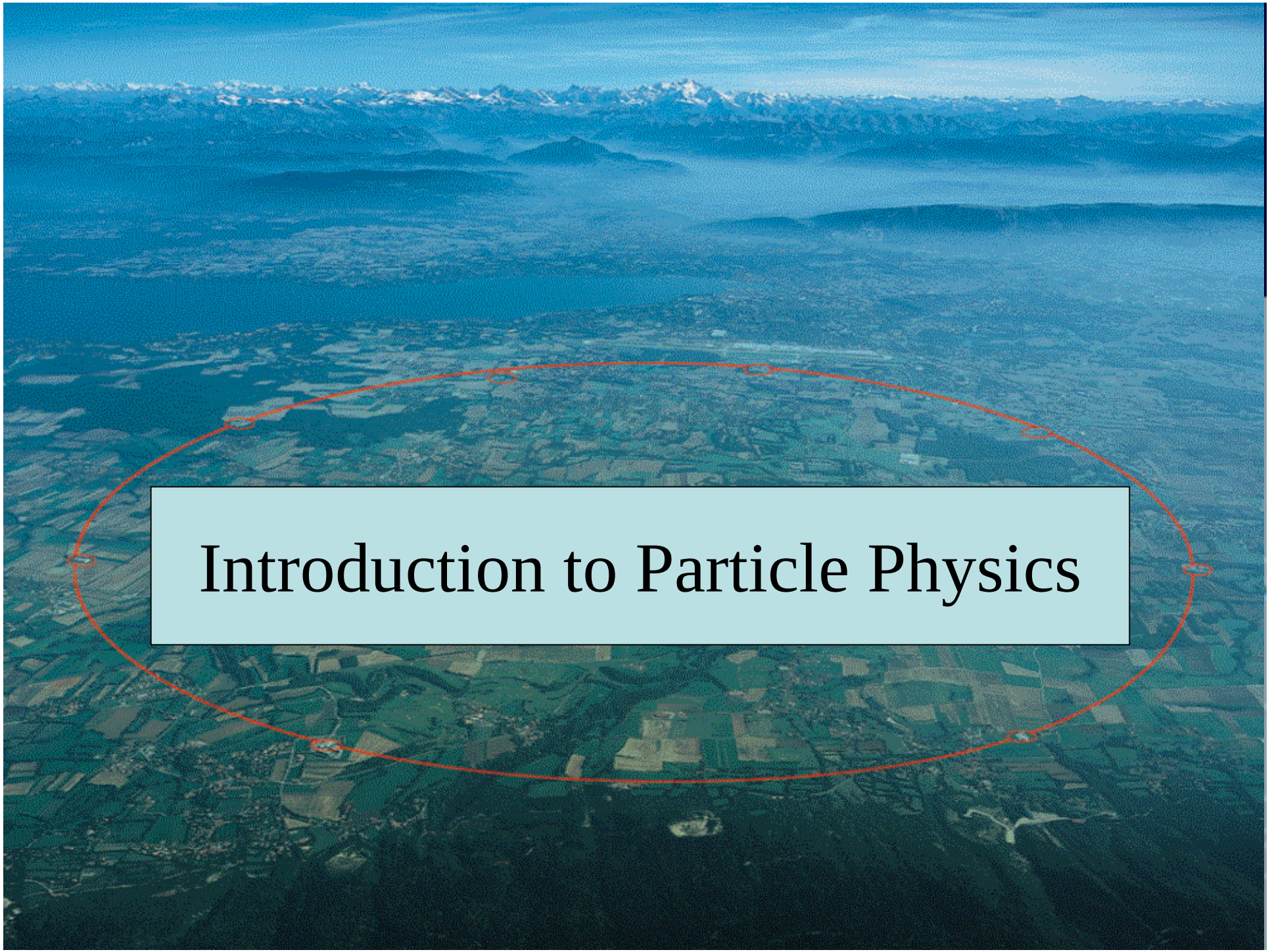
Interface with cosmology

Origins of matter & nuclei, dark matter

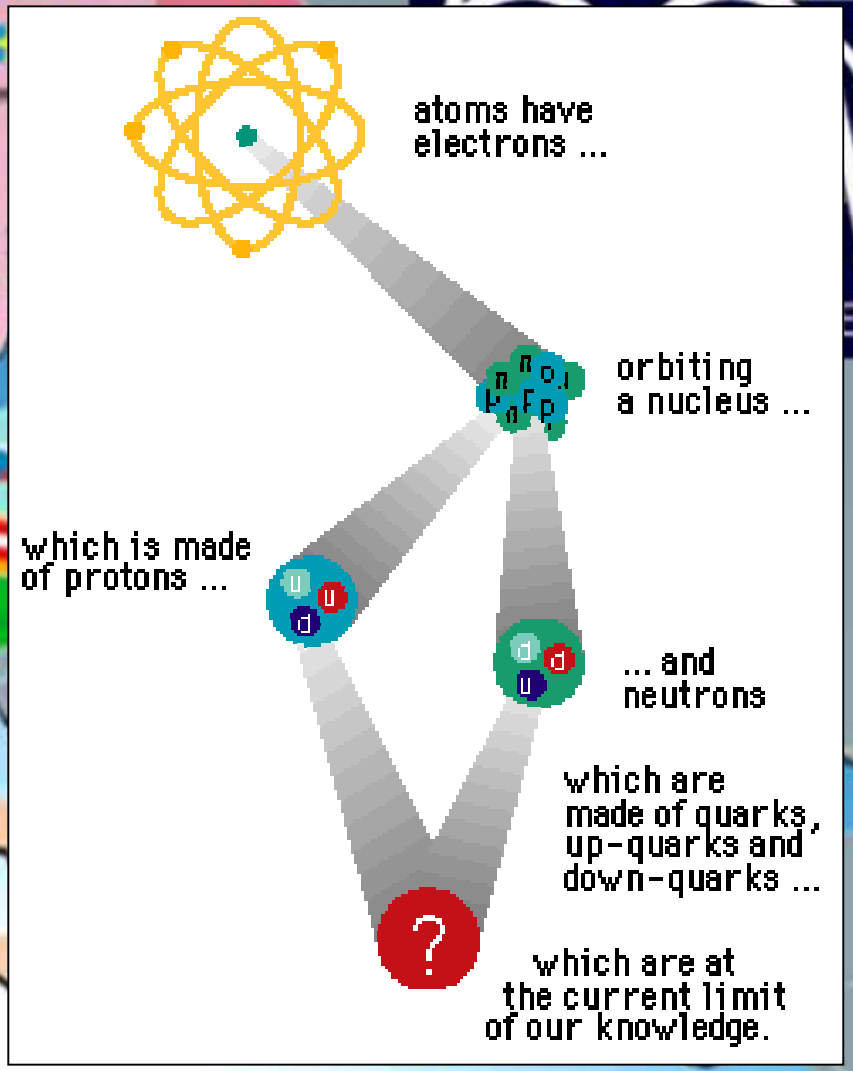
Impact on Society

Information technology: World-Wide Web, Grid

Medicine; Education & Training; Collaboration


Introduction to Particle Physics

Inside Matter



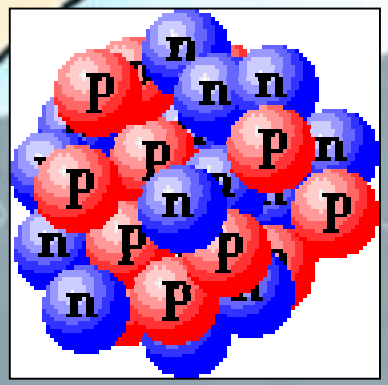
Everything is made of
the same LEGO pieces

What are they?
What holds them together?

All the different Elements …

… are made of atoms …

… whose nuclei contain Protons & Neutrons …



Periodic Table of the Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	—— VII ——	IB	IB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H															2 He
2	3 Li	4 Be									5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg									13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 106	107 107	108 108	109 109	110 110	111 111	112 112						

Naming conventions of new elements

* Lanthanide Series	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
+ Actinide Series	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

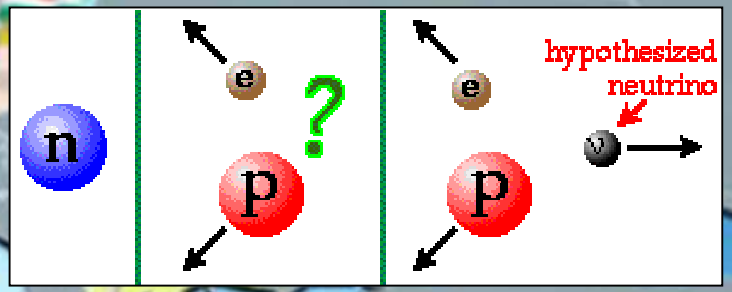
… whose structure we study at CERN

The Fundamental Forces of Nature

Electromagnetism:
gives light, radio, holds atoms together

Strong Nuclear Force:
holds nuclei together

Weak Nuclear Force:
gives radioactivity



together they make the Sun shine

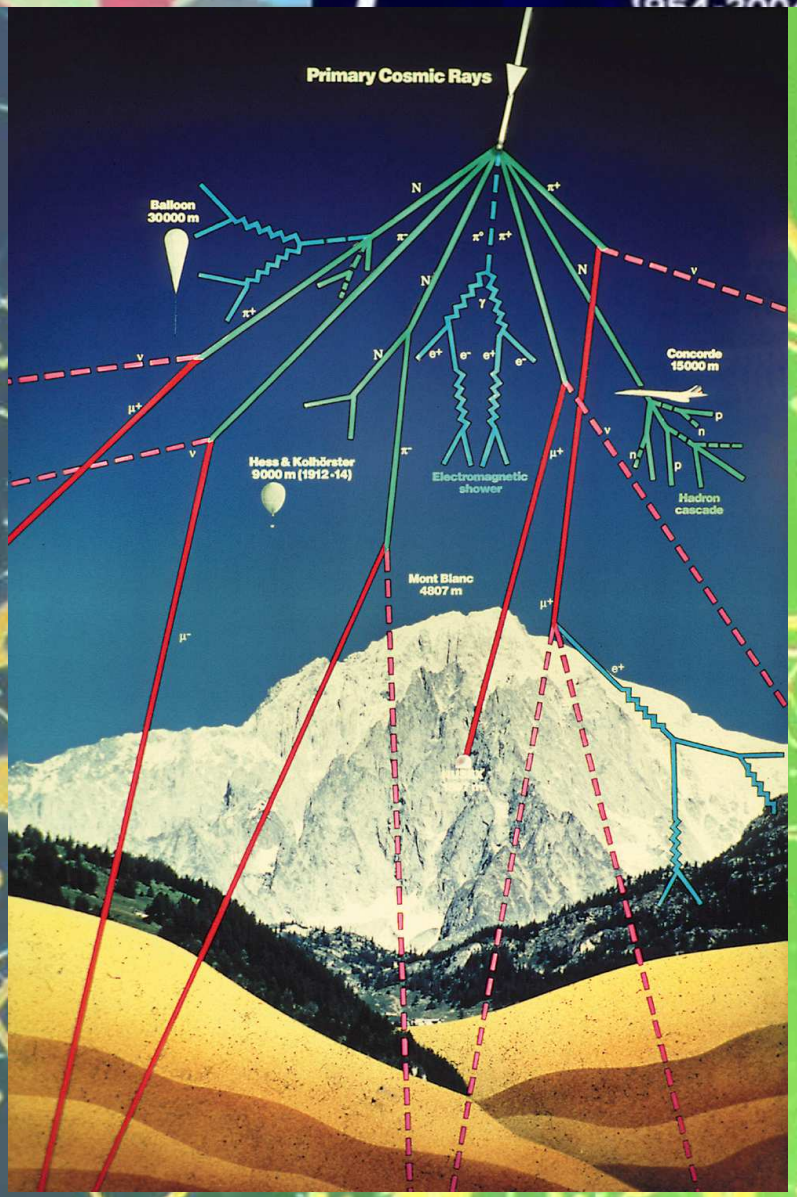
Gravity:
holds planets and stars together

50th anniversary of CERN

From Cosmic Rays to CERN

Discovered a century ago …

… cosmic-ray showers were found to contain many different types of particles …



CERN was established in 1954 to study these particles in detail

Landmarks in Particle Physics

1897 : Electron discovered by Thomson

1910 : Nucleus discovered by Rutherford

1960's : Quarks (aces) proposed by Gell-Mann (Zweig @ CERN)

1970's : Experimental evidence for quarks at SLAC (CERN)

1973 : Discovery of neutral weak interactions at CERN

1983 : Carriers of the weak interactions discovered at CERN

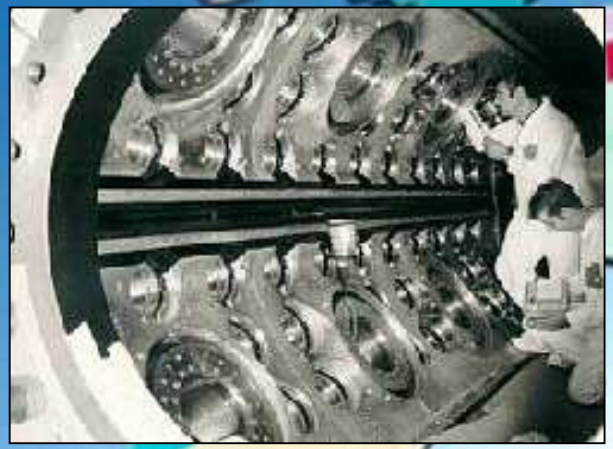
1990's : Standard Model established at CERN

1996 : Discovery of the last quark (top) at FNAL (USA)

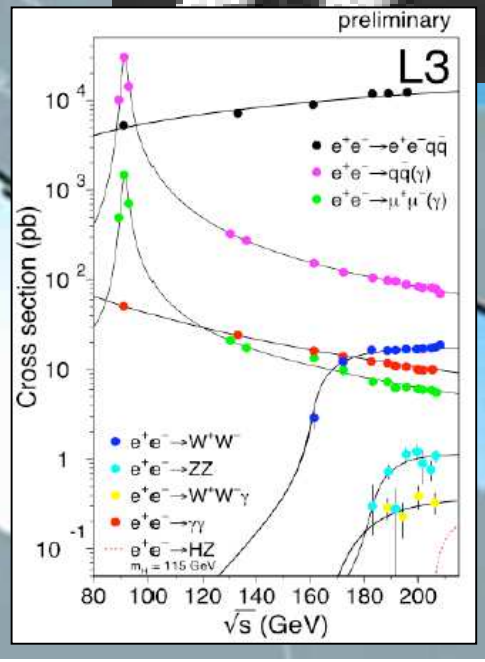
≥ 2007 : CERN will explore why particles weigh

The Standard Model of Particle Physics

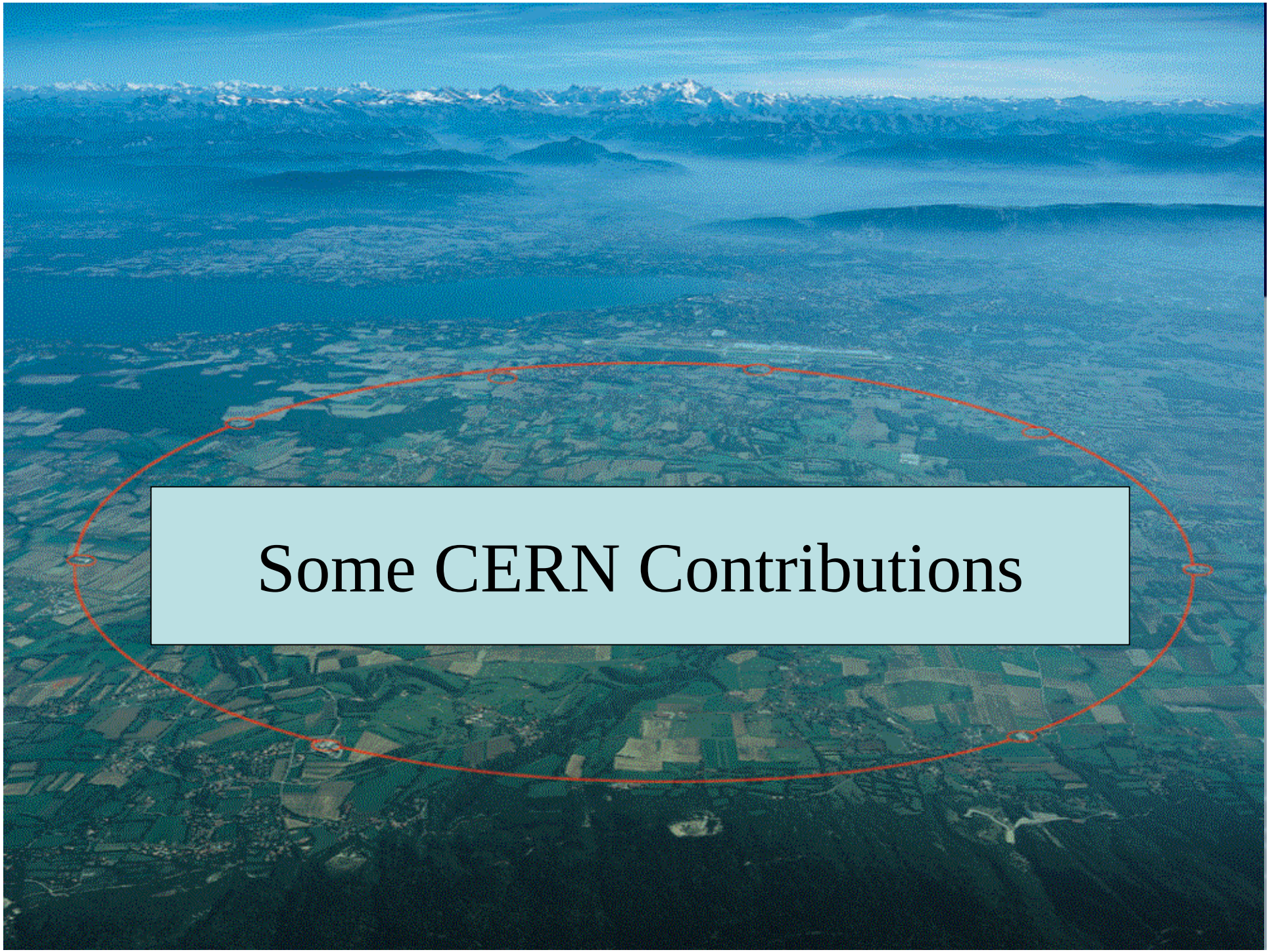
Proposed by Abdus Salam, Glashow & Weinberg



Key tests in experiments at CERN



In perfect agreement with all laboratory experiments


Some CERN Contributions

Early Days @ CERN

An early Council meeting

The construction site

The early π eν experiment

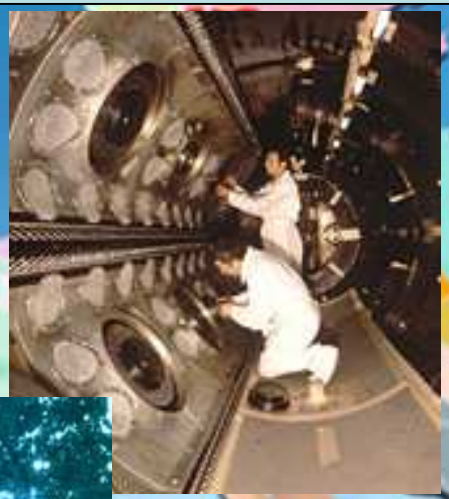
CERN's first major result: Confirmed theory of weak force

Energy record

1959

Discovery of Neutral Weak Interactions

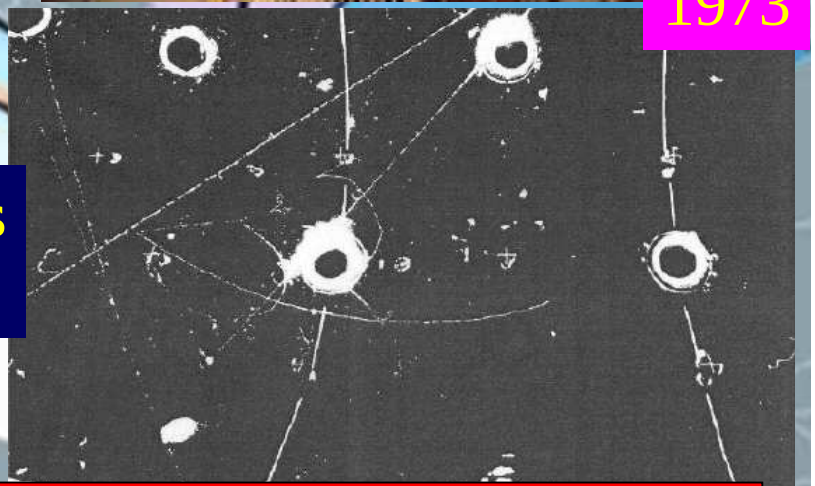
Using Gargamelle bubble chamber



1973

ν – e scattering

ν – nucleus scattering



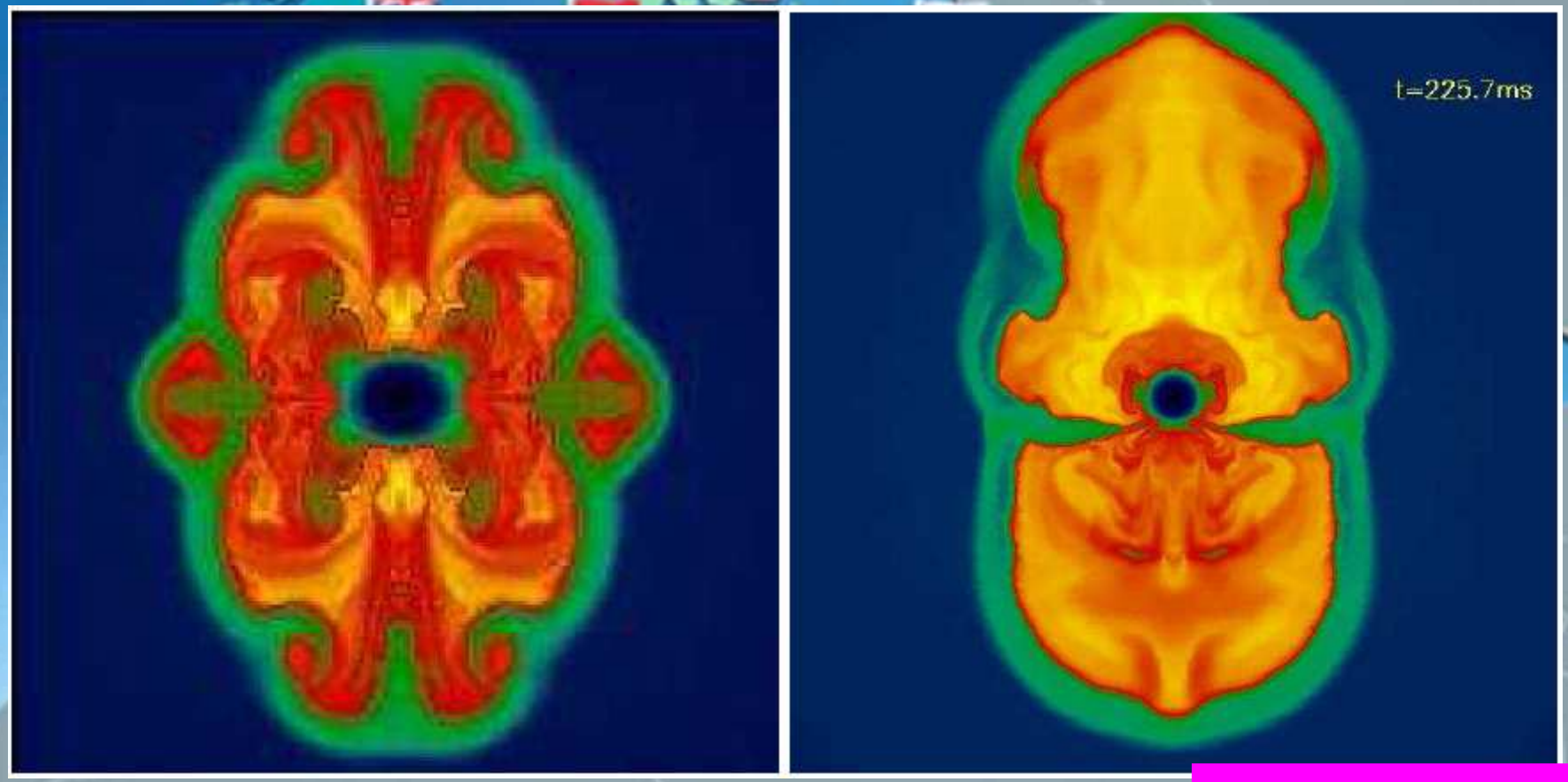
A new type of radioactivity: opened way to Standard Model

Neutral Currents help Supernovae Explode

1954-2004

50th anniversary of CERN

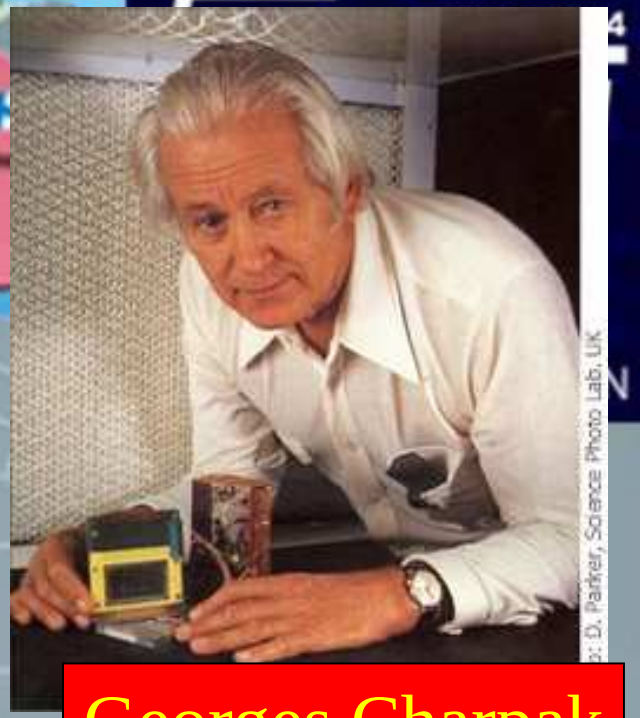
Two-dimensional simulations



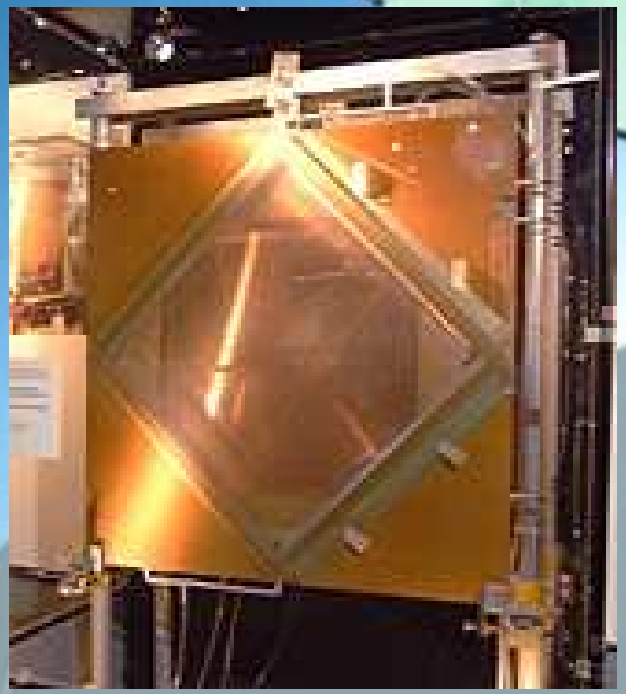
Janka et al., 2004

Multiwire Proportional Chambers (MWPCs)

Electronic detectors connected directly to computers:
revolutionized data-taking in particle physics
- and medical physics



Georges Charpak



1968

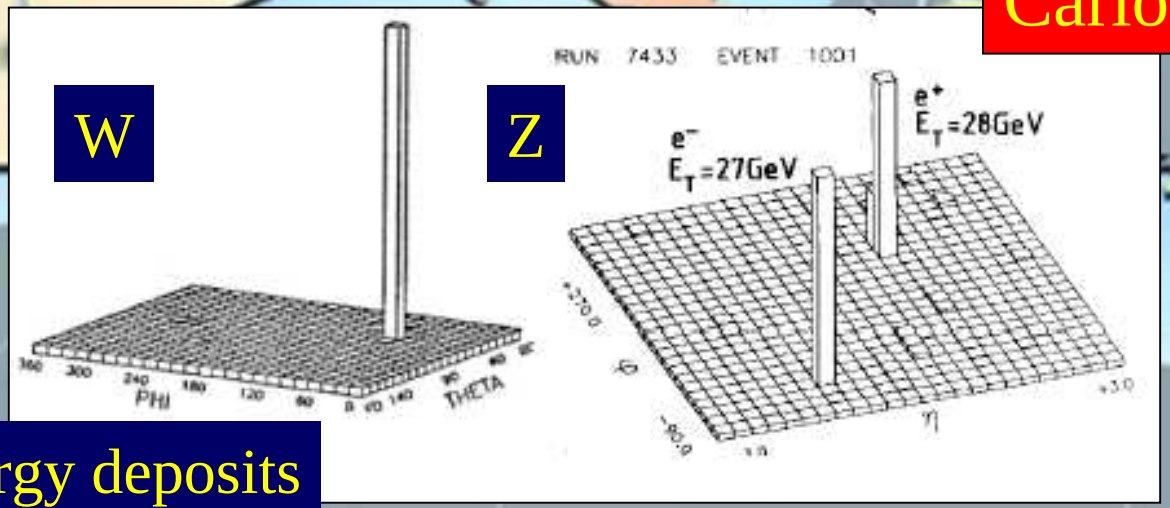
The Discovery of the W and Z

Tracks in the central detector

Carlo Rubbia et al

W

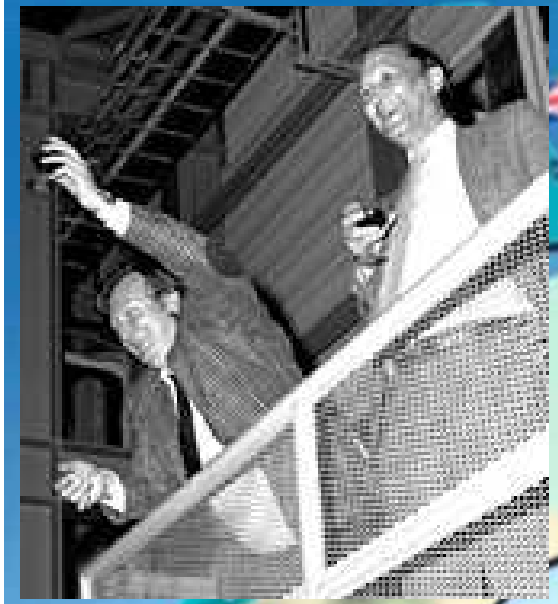
Z



Energy deposits

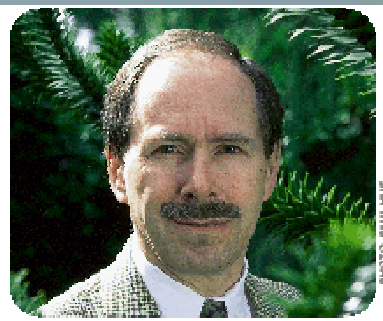
1983

Some Nobel Prize-Winners



Martinus Veltman

Professor Emeritus at the University of Michigan, Ann Arbor, USA, formerly at the University of Utrecht, Utrecht, the Netherlands.



Gerardus 't Hooft

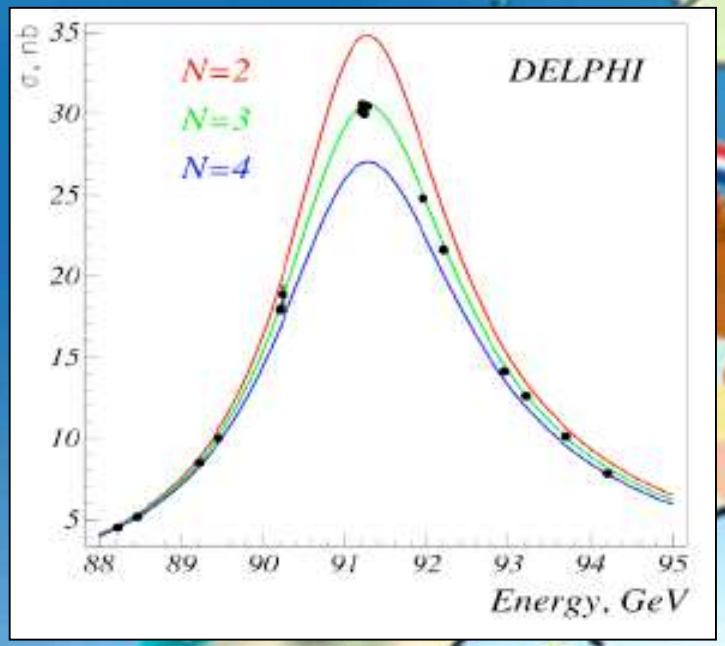
Professor at the University of Utrecht, Utrecht, the Netherlands.

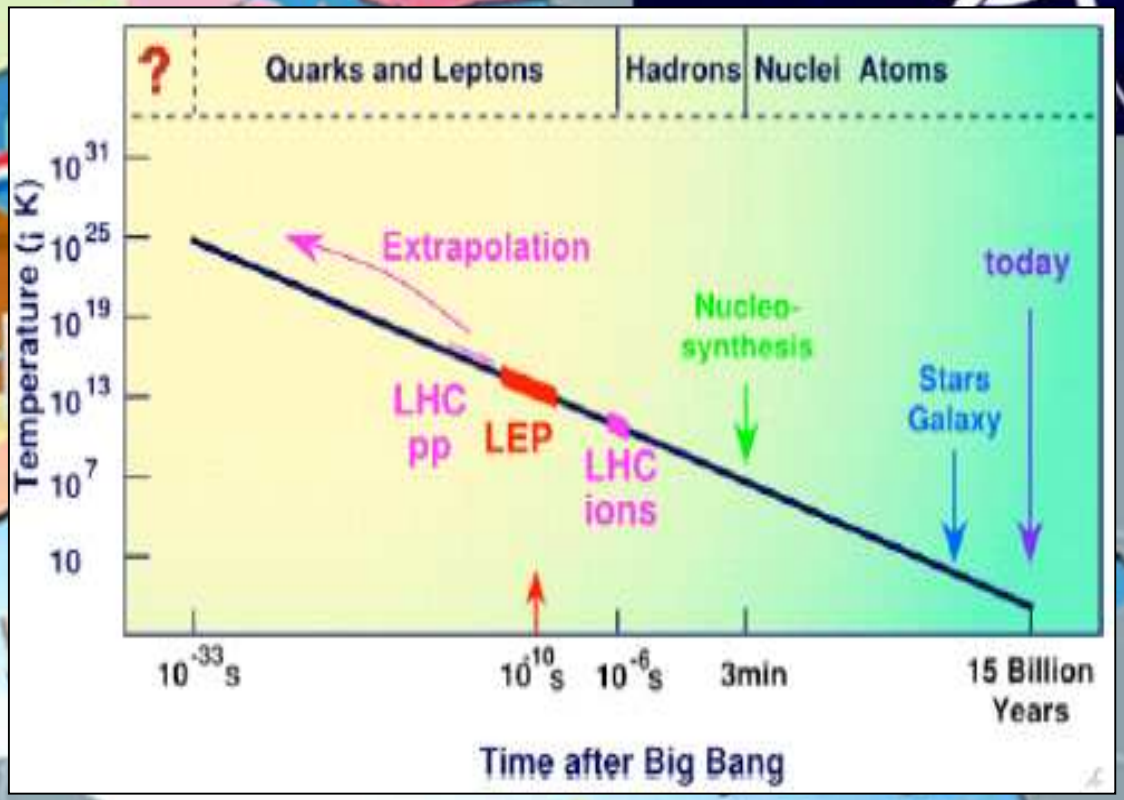
Carlo Rubbia & Simon van der Meer
Proposed and led the discovery of the W & Z particles

Georges Charpak
Inventor of electronic tracking detectors (MWPCs): used to discover W, Z, etc.

Martinus Veltman & Gerardus `t Hooft
Showed how to calculate the Standard Model accurately:
tested at LEP at CERN

Neutrinos and the Early Universe



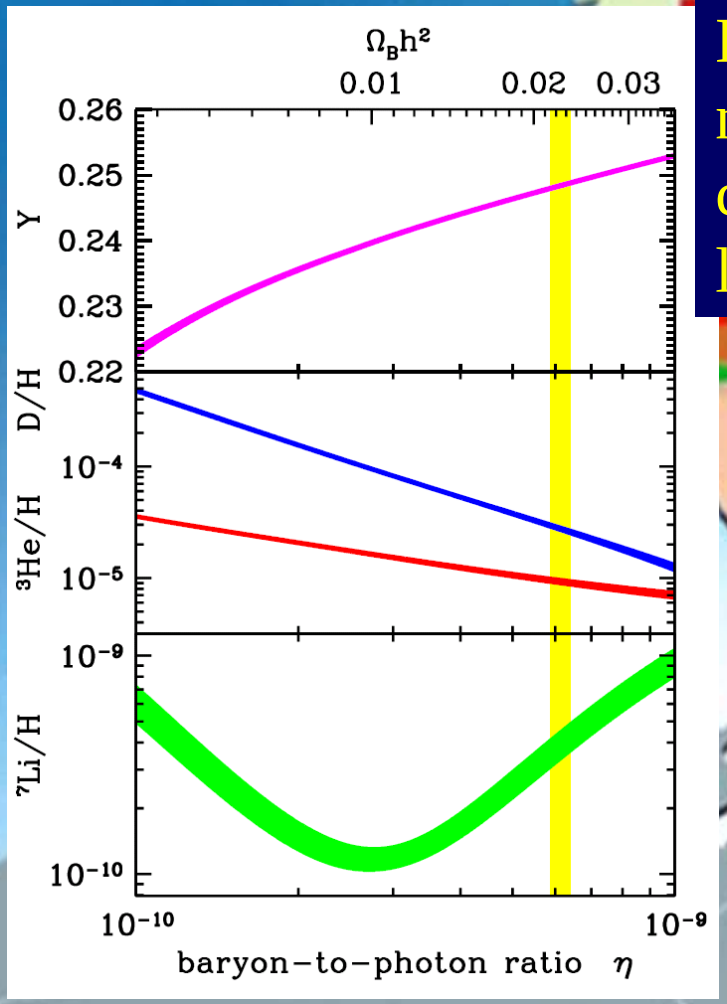


LEP experiments @ CERN determined the number of neutrino species

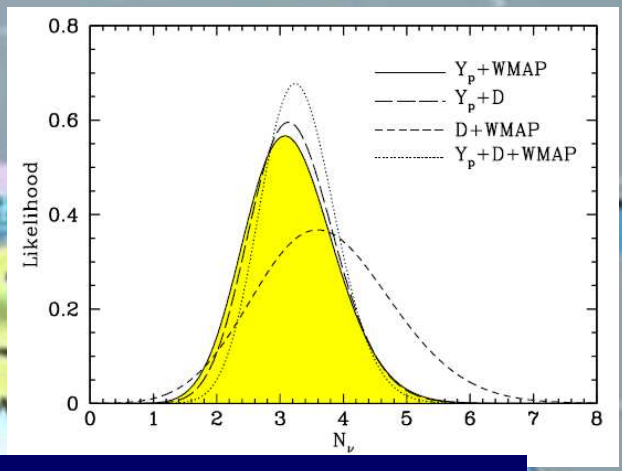
These controlled the expansion of the early Universe

1989

The Light Elements in the Universe



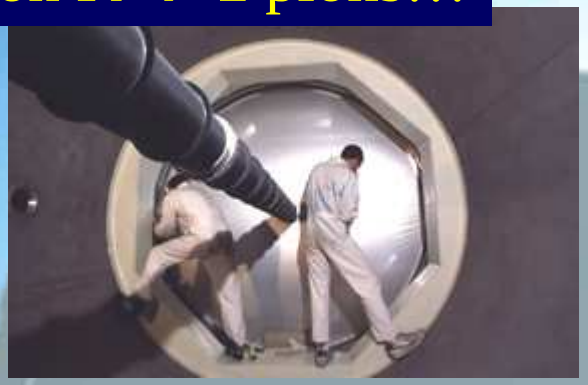
Knowing number of neutrino species, can calculate abundances of light elements: He4, …



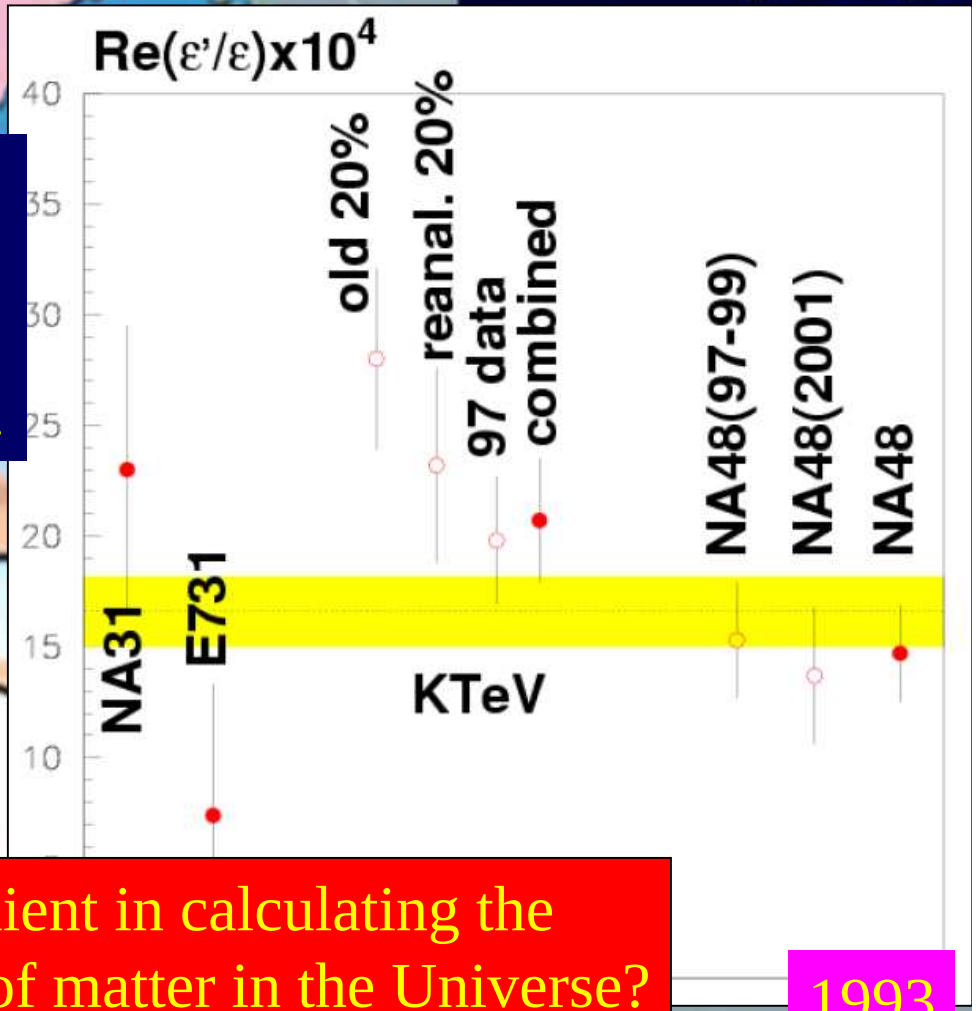
… in agreement with measured abundances, IF just three neutrinos (LEP)

Matter and Antimatter Particles Decay Differently

NA48 experiment on K → 2 pions…



…shows that K and anti-K decay Differently …

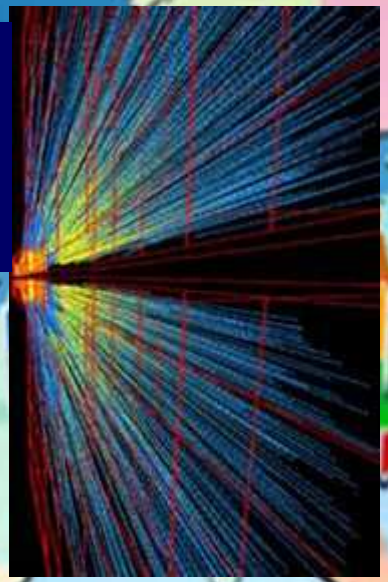


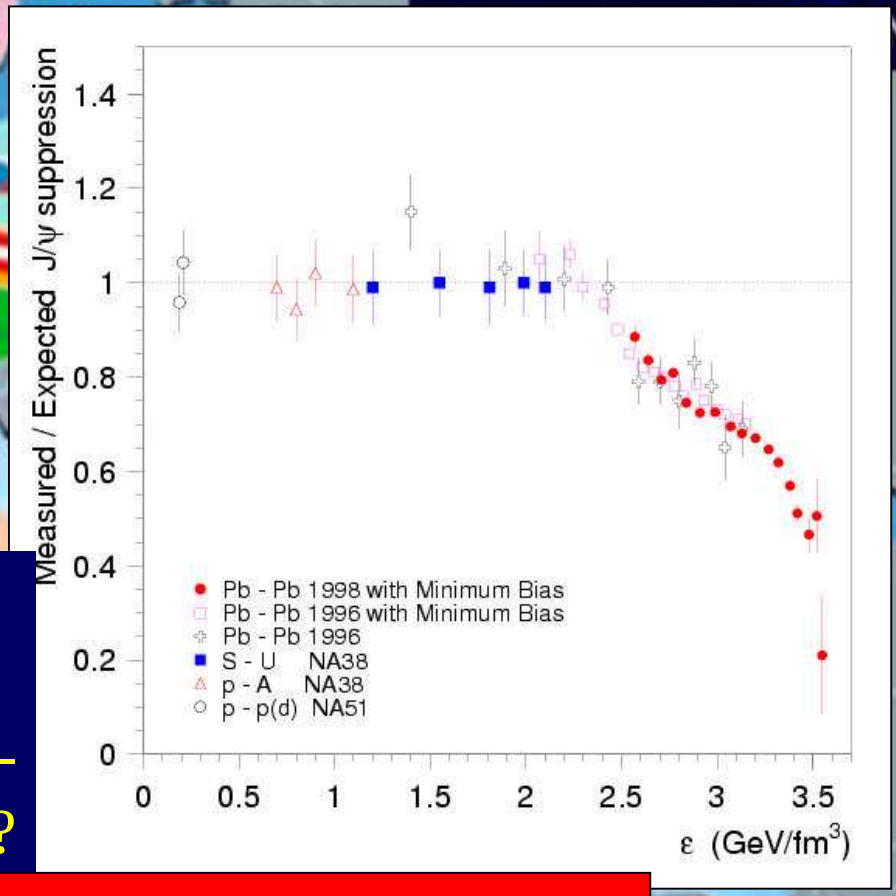
…ingredient in calculating the amount of matter in the Universe?

1993

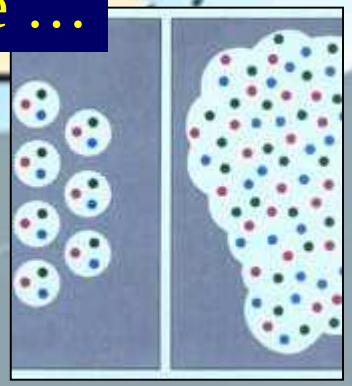
Discovery of Quark-Gluon Matter ?

Colliding heavy Nuclei …





…protons & neutrons dissolve …



…fewer mesons produced - in plasma?

State of matter in first microseconds of the Universe?

2000

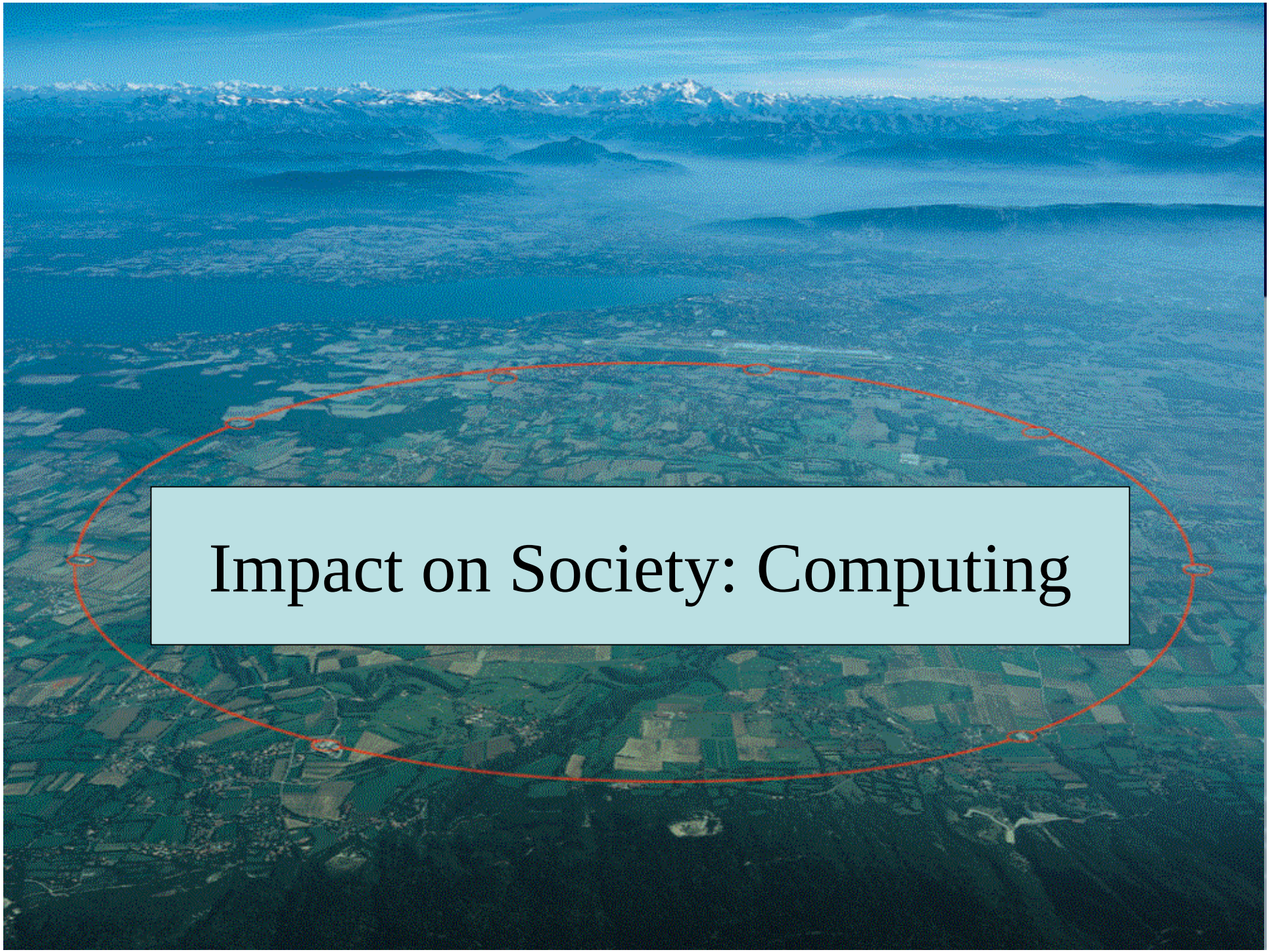
Anti-Hydrogen @ CERN

2002

First fabrication of a handful of anti-hydrogen atoms

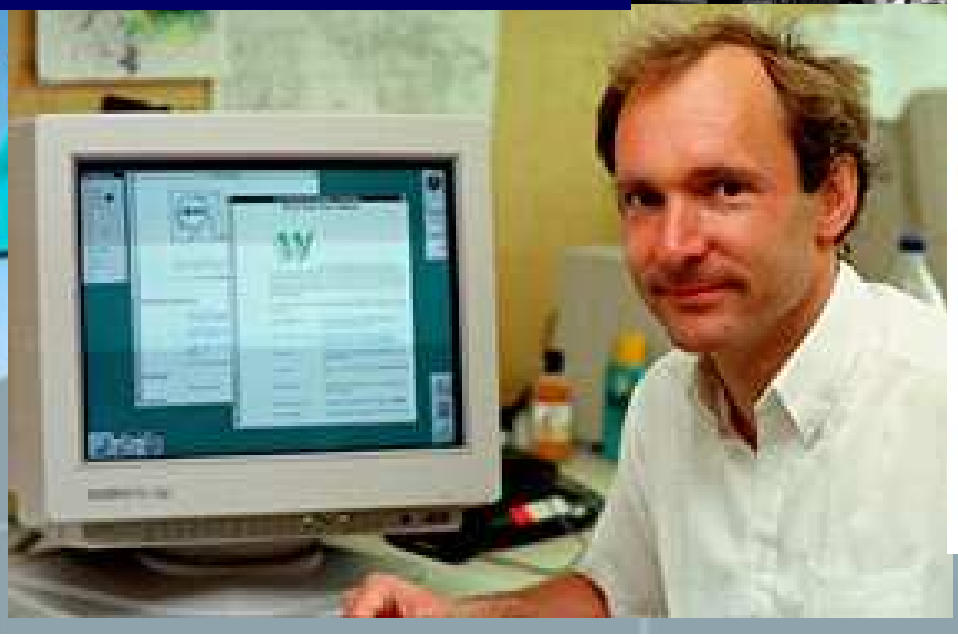
‘Industrial’ production of Hundreds of thousands of anti-hydrogen atoms

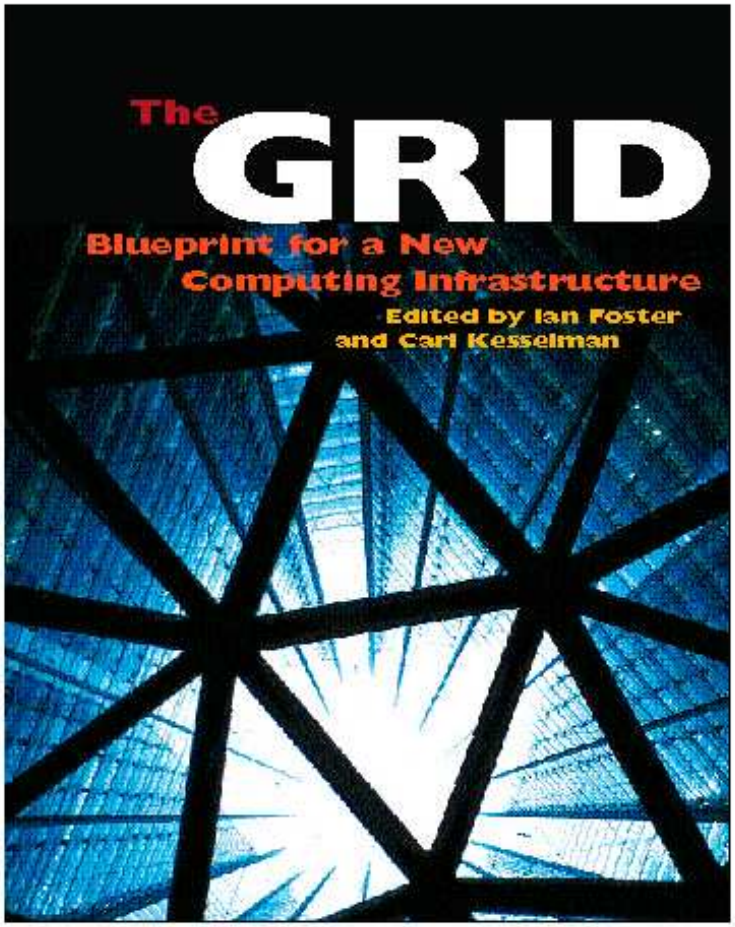
Compare hydrogen and anti-hydrogen spectra?


Impact on Society: Computing

Computing: from Supercomputers to the World-Wide Web & the Grid

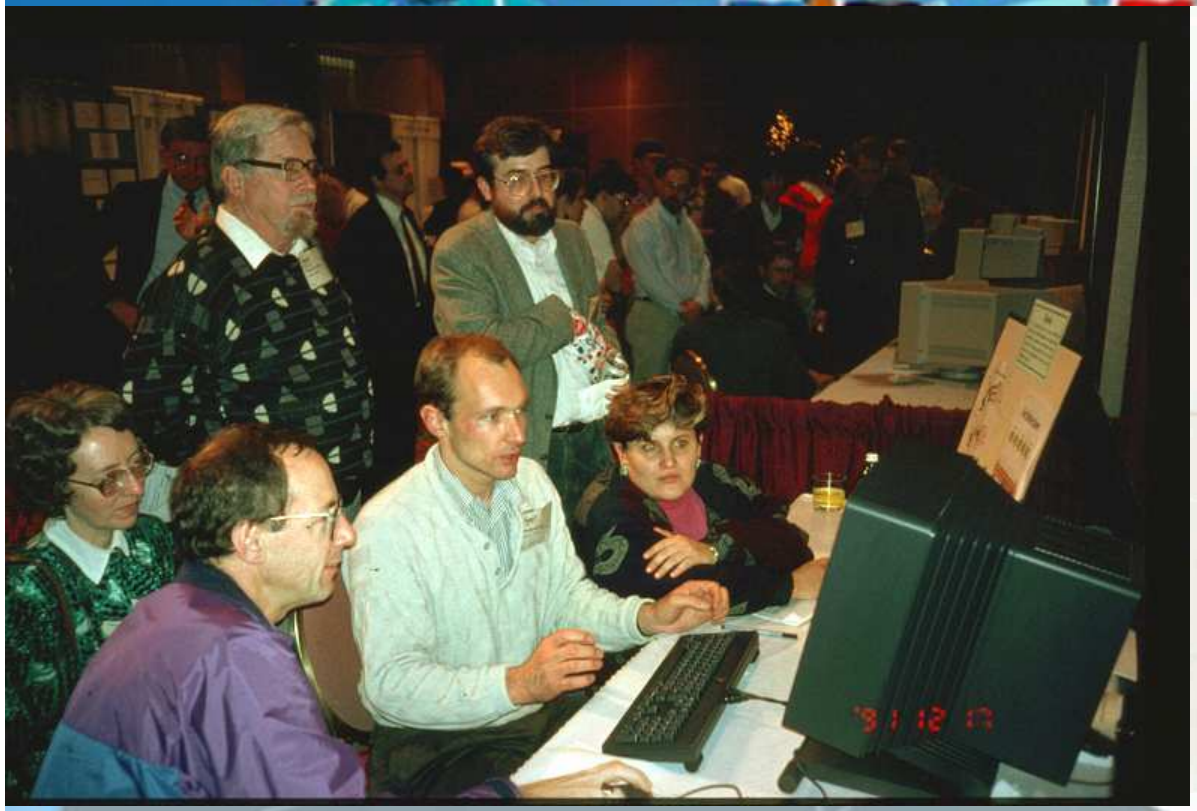
Stages in computing @ CERN:
1 – Supercomputer on site
2 – World-Wide Web to share data
3 – PC farm @ CERN
4 – Connect PCs around world to share computing resources





From Small Beginnings …

The first download, in California …



… from the first WWW server

1990

CERN's Role in the WWW

1995: → INRIA

1994: first Conference

1993: first European project

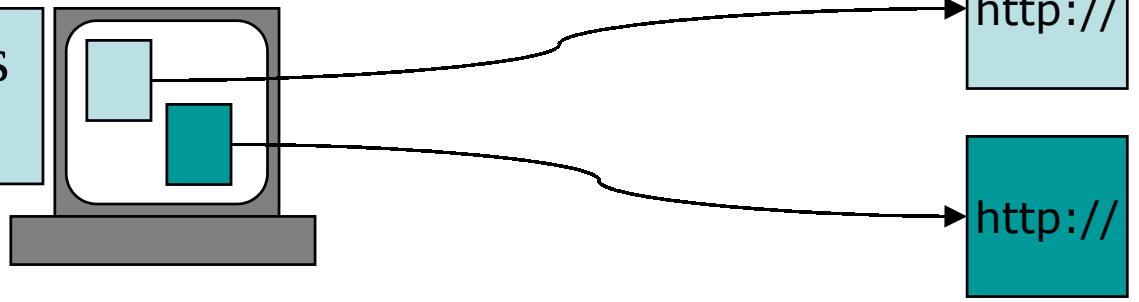
1990: first software

1989: WWW project

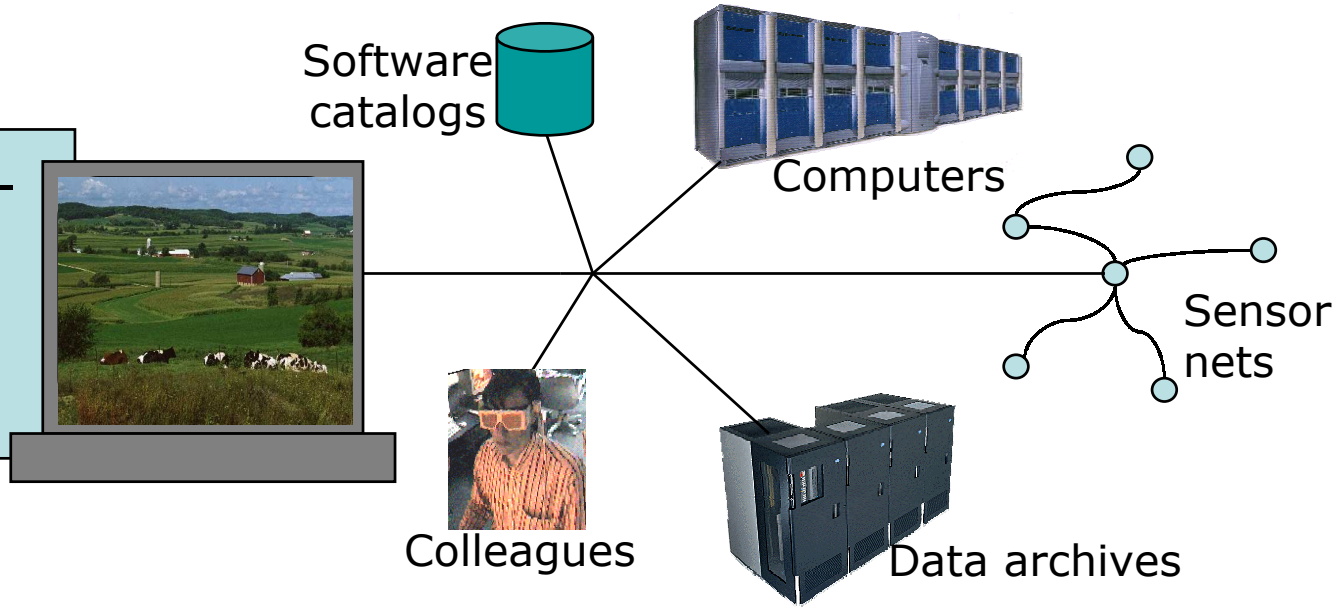
Invented @ CERN to enable physicists' collaborations to share data
First EU project @ CERN
Free release to the world

From the Web to the Grid

Web: Uniform access to HTML documents



Grid: Flexible, high-performance access to all significant resources



On-demand creation of powerful virtual computing systems

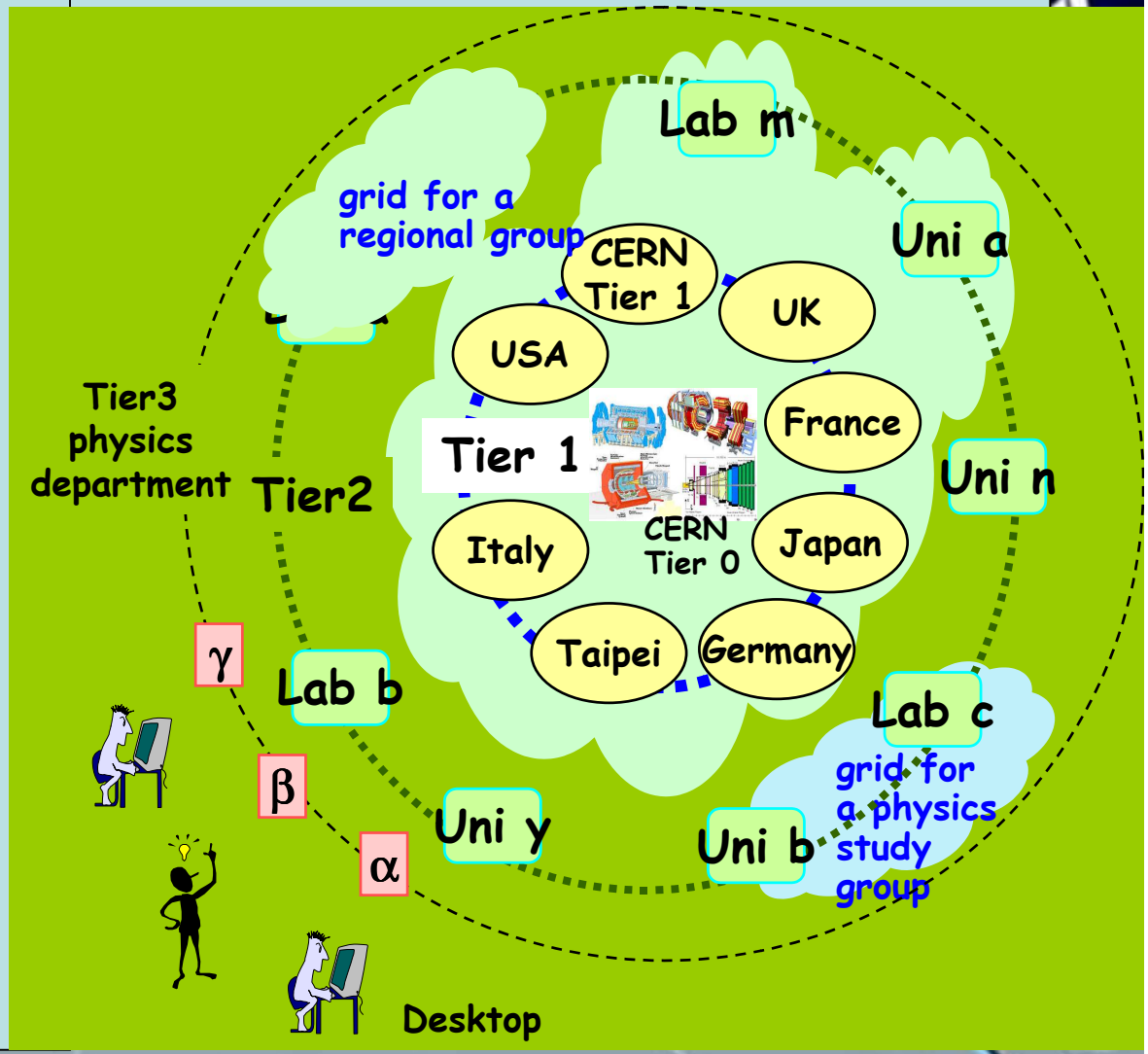
2004

LHC Computing Grid Project - LCG

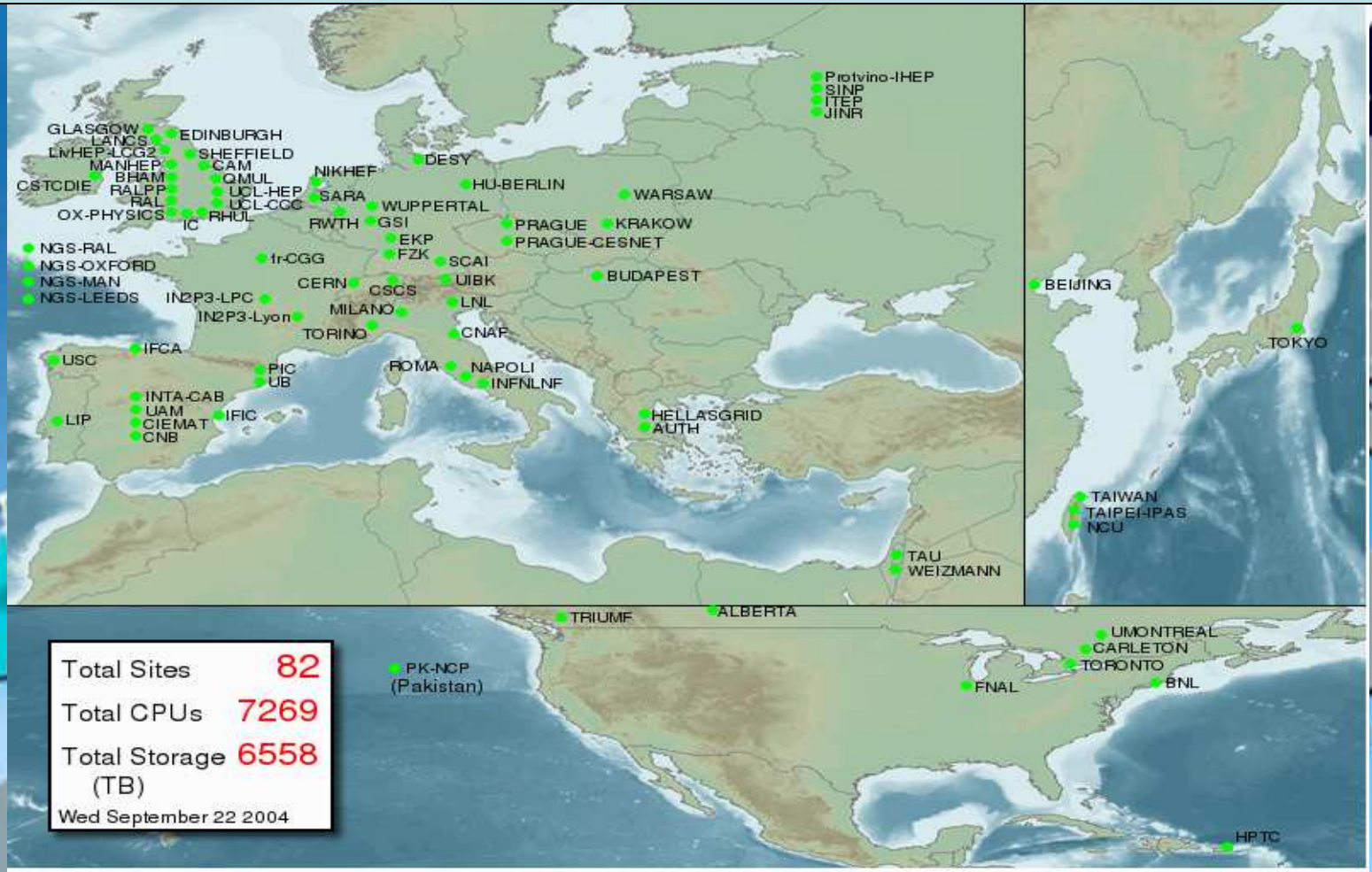
Collaboration
- LHC Experiments
- Grid projects: Europe, US
- Regional & national centres

Choices
- Go for a “Tier” hierarchy.
- Intel CPUs in standard PCs
- LINUX

Goal
- Prepare and deploy the computing environment for analyzing LHC data.



Current LCG Deployment Status

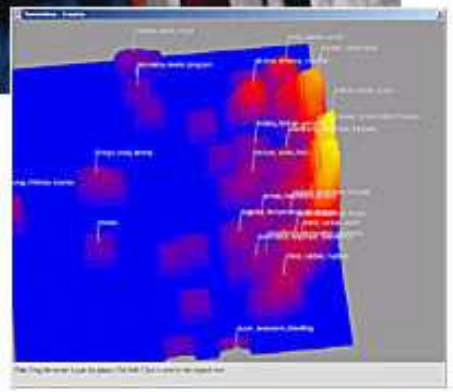


The LHC Computing Grid, LCG, which was launched in September 2003 with 12 sites contributing, has been growing very rapidly. A snapshot of the 82 sites that were actively contributing to the LCG by August 04 is shown in the map above, which also provides a dynamic view of ongoing activity on the LCG. This map can be accessed at http://goc.grid-support.ac.uk/lcg and was developed by the Grid Operations Centre based at the Rutherford Appleton Laboratory in Oxfordshire.

2004

Most LCG work is also useful for …

- **Medical/Healthcare** *(imaging, diagnosis and treatment)*
- **Bioinformatics** *(study of the human genome and proteome to understand genetic diseases)*
- **Nanotechnology** *(design of new materials from the molecular scale)*
- **Engineering** *(design optimization, simulation, failure analysis and remote Instrument access and control)*
- **Natural Resources and the Environment** *(weather forecasting, earth observation, modelling and prediction of complex systems, earthquakes)*



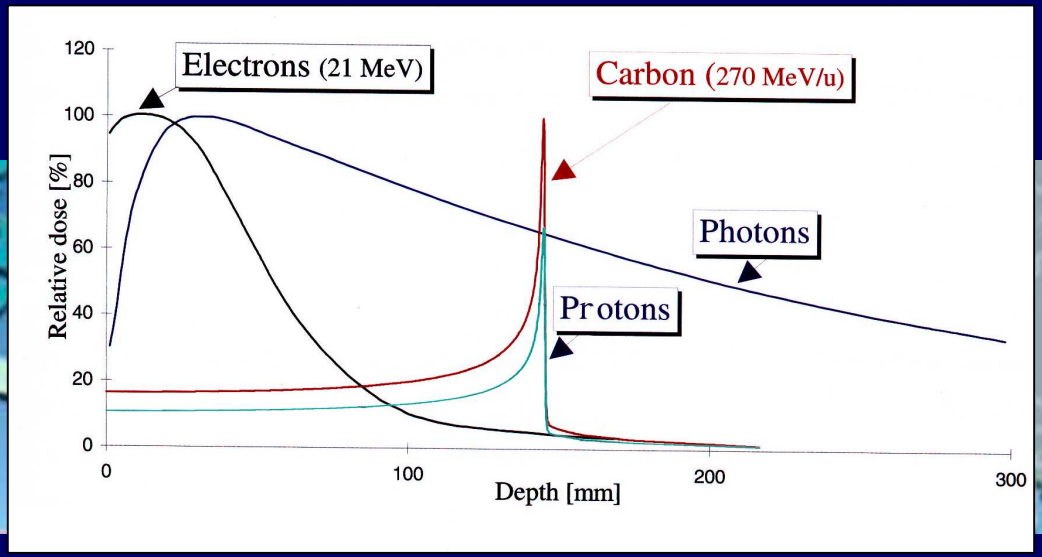

Impact on Society: Medicine

CERN & Medical Physics

- Accelerators for hadron therapy
  - Benefits, design, status of projects
- Imaging detectors for diagnostics
  - PET
  - Pixel detectors
  - Crystal detectors
- Isotope production
- A Grid application to Medicine
  - MammoGrid

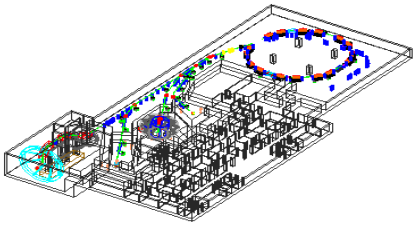
Hadron Therapy vs. Radiotherapy

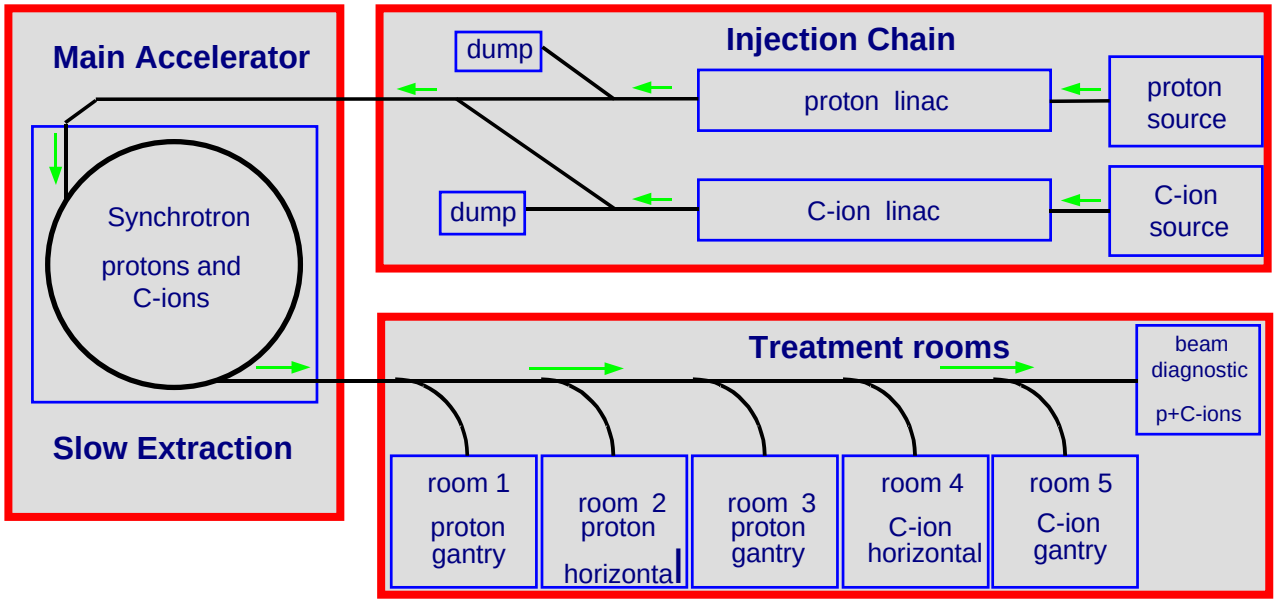
Ideal cancer treatment would be to eliminate all tumour cells, not normal cells



Photons	vs.	Hadrons
• Physical dose high near surface		• Dose highest at Bragg Peak
• DNA damage easily repaired		• DNA damage not repaired
• Biological effect lower		• Biological effect high
• Need presence of oxygen		• Do not need oxygen
• Effect not localised		• Effect is localised

Proton-Ion Medical Machine Study (PIMMS)





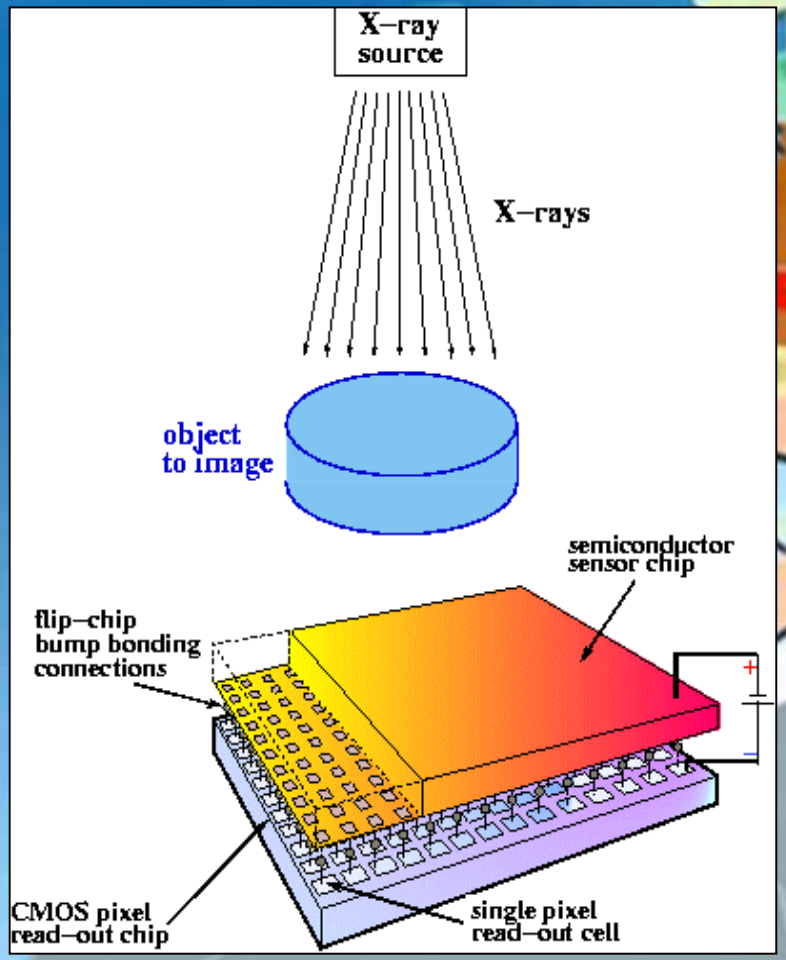
- Facility for hadrontherapy (Carbon, protons)
- Fixed beam lines and gantries for maximum flexibility
- Collaboration >1996 (Med-AUSTRON (A) and TERA (I))
- CERN hosted and supported the study
- Later joined by ONKOLOGY 2000 (CZ) - Contacts with GSI (D)

Positron-Emission Tomography (PET)

- Early detection of defects
- Started by Hoffmann et al.
- Parallel work at CERN:
  Townsend, Jeavons,
  Geneva Hospital
- Early work using MWPCs
- Continuation using crystals, cf, L3, CMS
  Crystal Clear Collaboration
- Data acquisition, Image analysis
- FP6 project on image analysis for PET

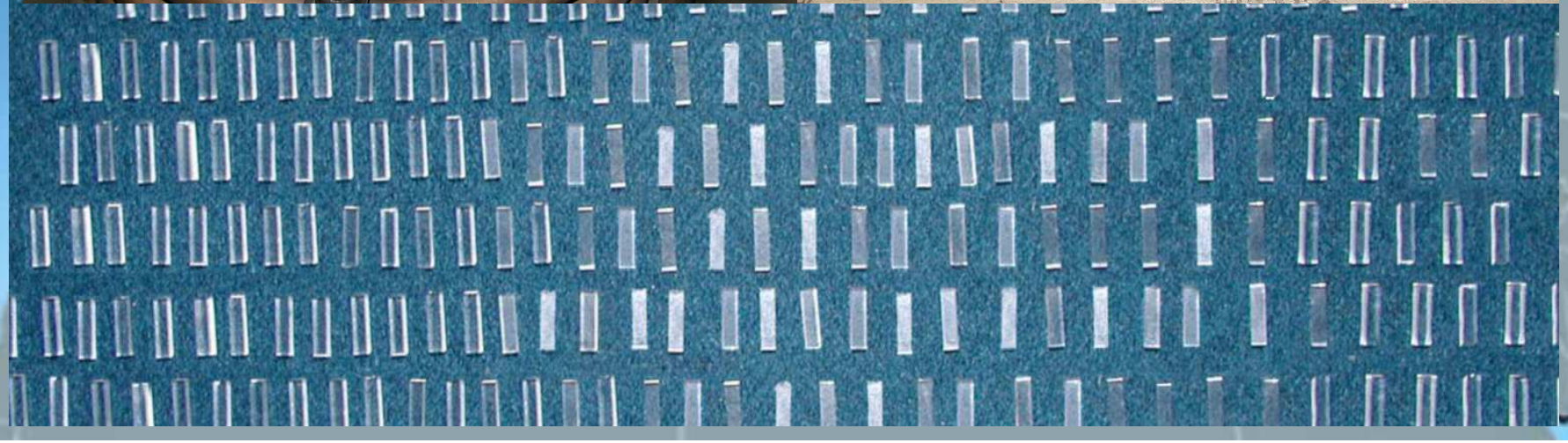
1977

Medipix



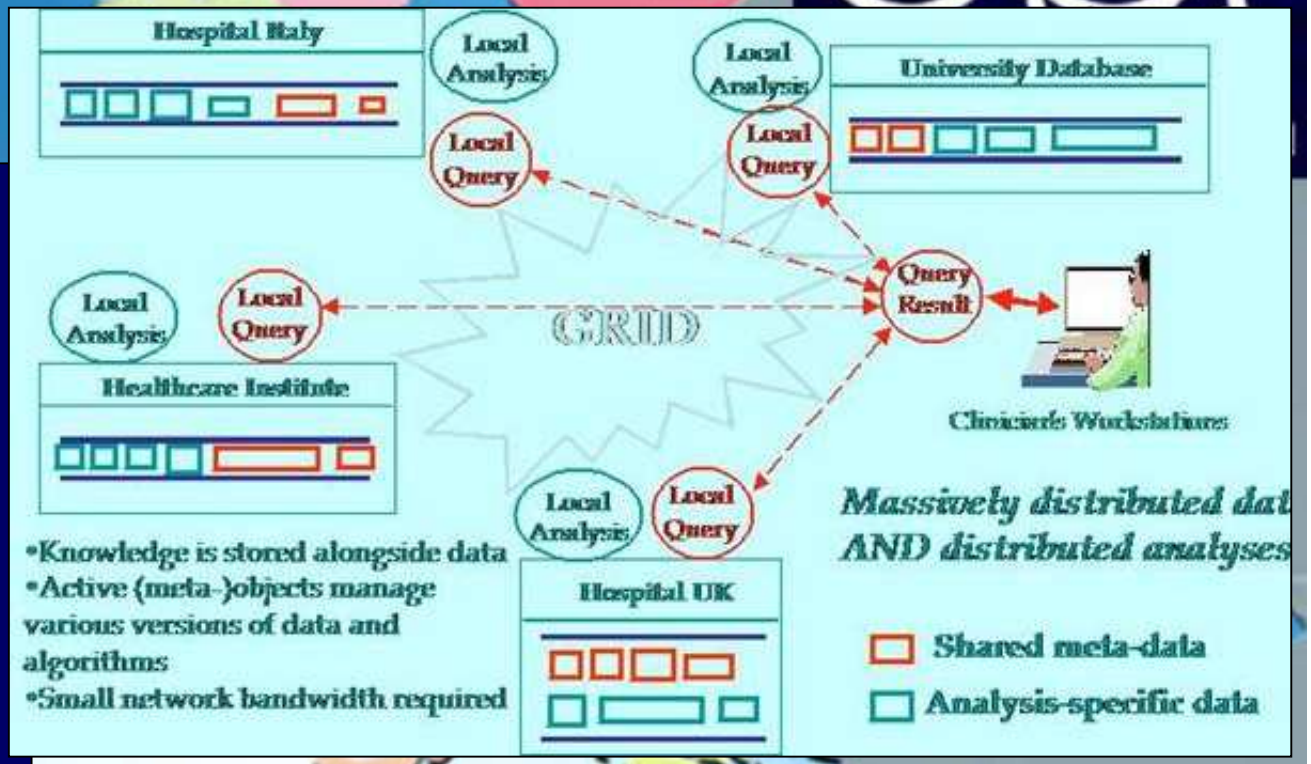
- Improved medical x-ray imaging
- Based on semiconductor pixel detectors developed @ CERN
- Count single photons, unlike film or CCD
- Transfer of technology to third parties for medical and industrial applications is under way

Crystal Clear LuAP production



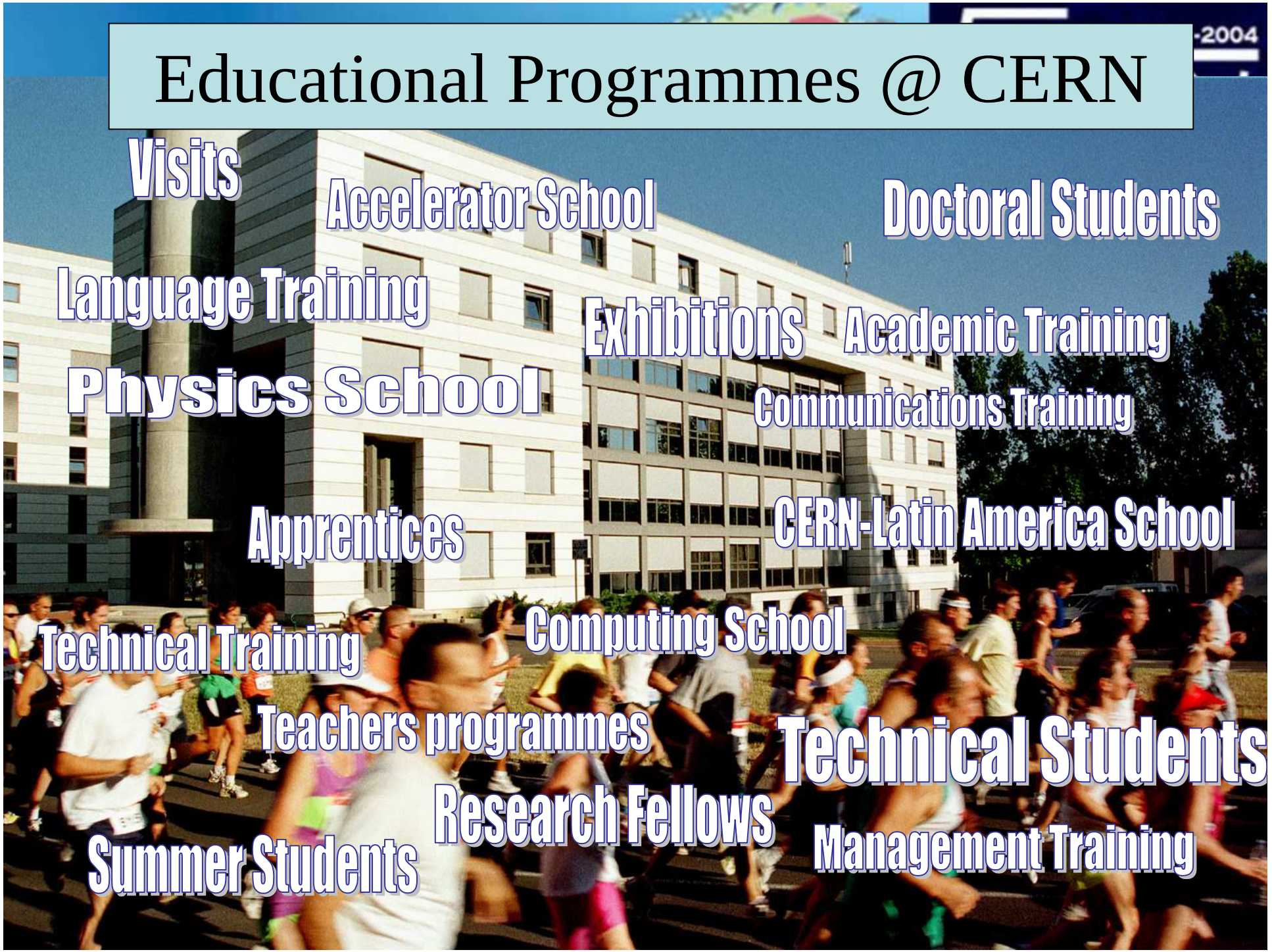
Grid for Medicine: MammoGrid

- A 2 M€ European FP5 project to build a pan-European distributed database of mammography images using GRID technologies
- **Aim:** To provide a demonstrator for use in epidemiological studies, quality control and validation of computer aided detection algorithms
- A consortium of CERN with Italian and UK universities, hospitals and SME

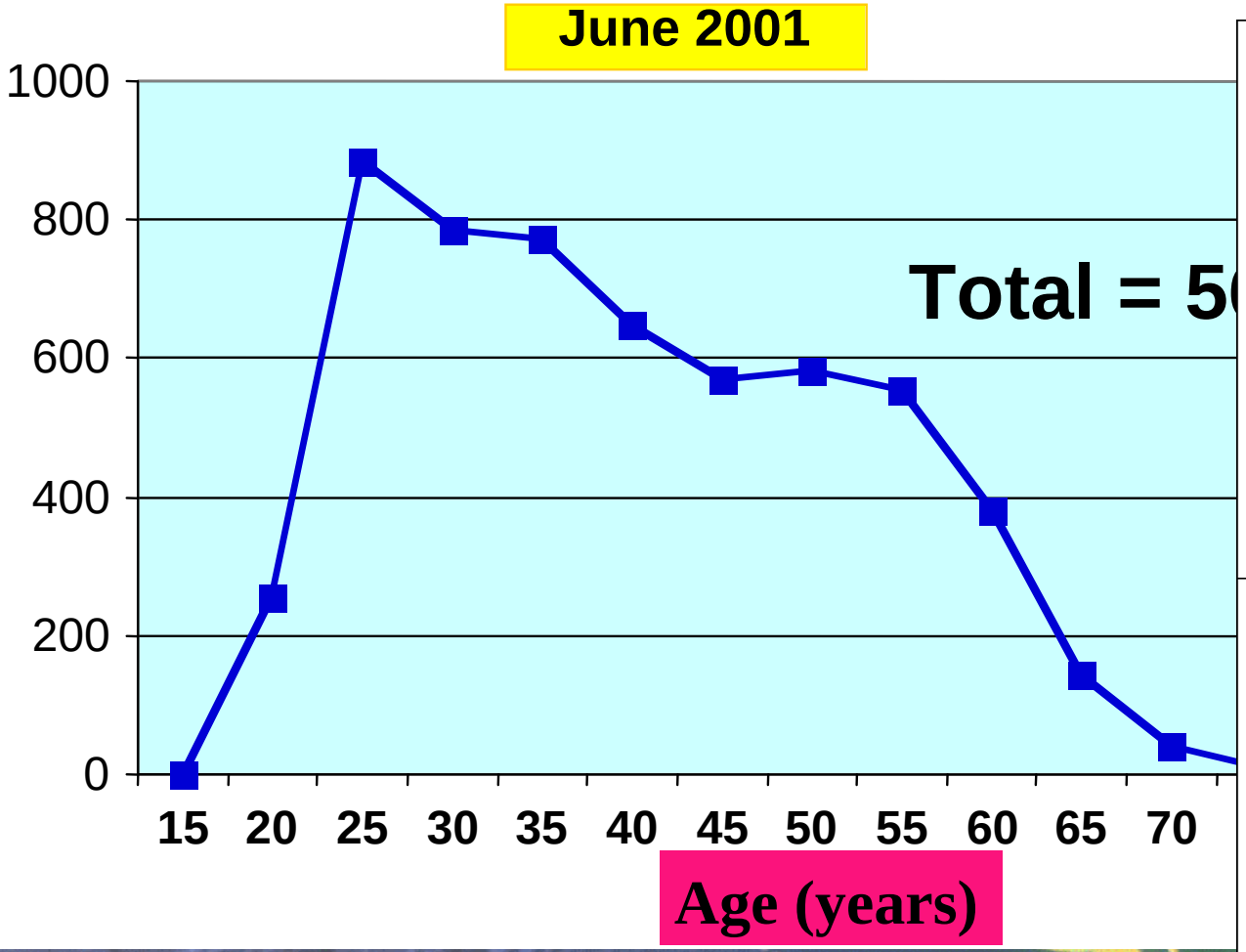


- Project concentrates on applying emerging GRID technology rather than on developing it
- MammoGrid heavily relies on technologies developed primarily in the field of High Energy Physics

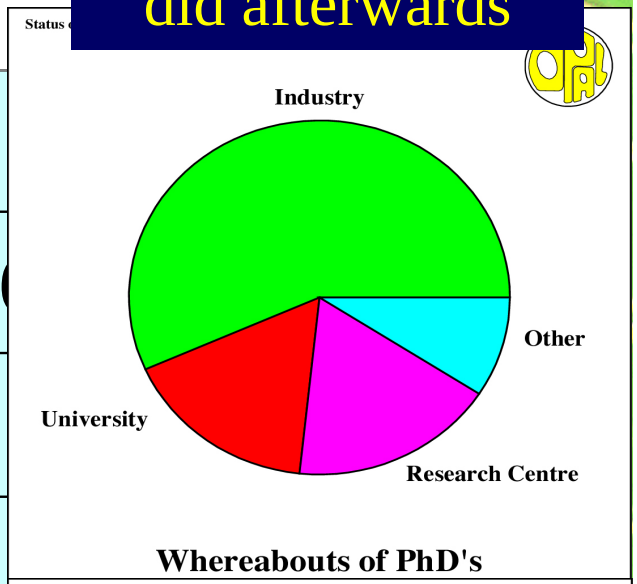

CERN as Educator

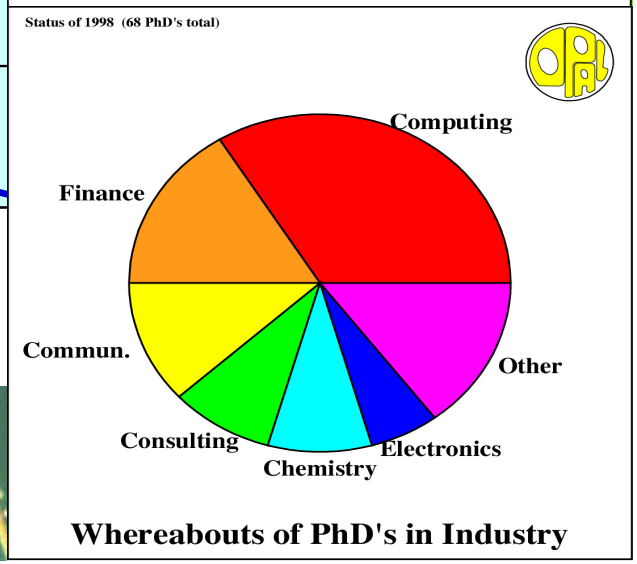

Educational Programmes @ CERN
Visits
Accelerator School
Doctoral Students
Language Training
Exhibitions
Academic Training
Physics School
Communications Training
Apprentices
CERN-Latin America School
Technical Training
Computing School
Teachers programmes
Technical Students
Research Fellows
Summer Students
Management Training

Age Distribution of Scientists using CERN



What the students did afterwards

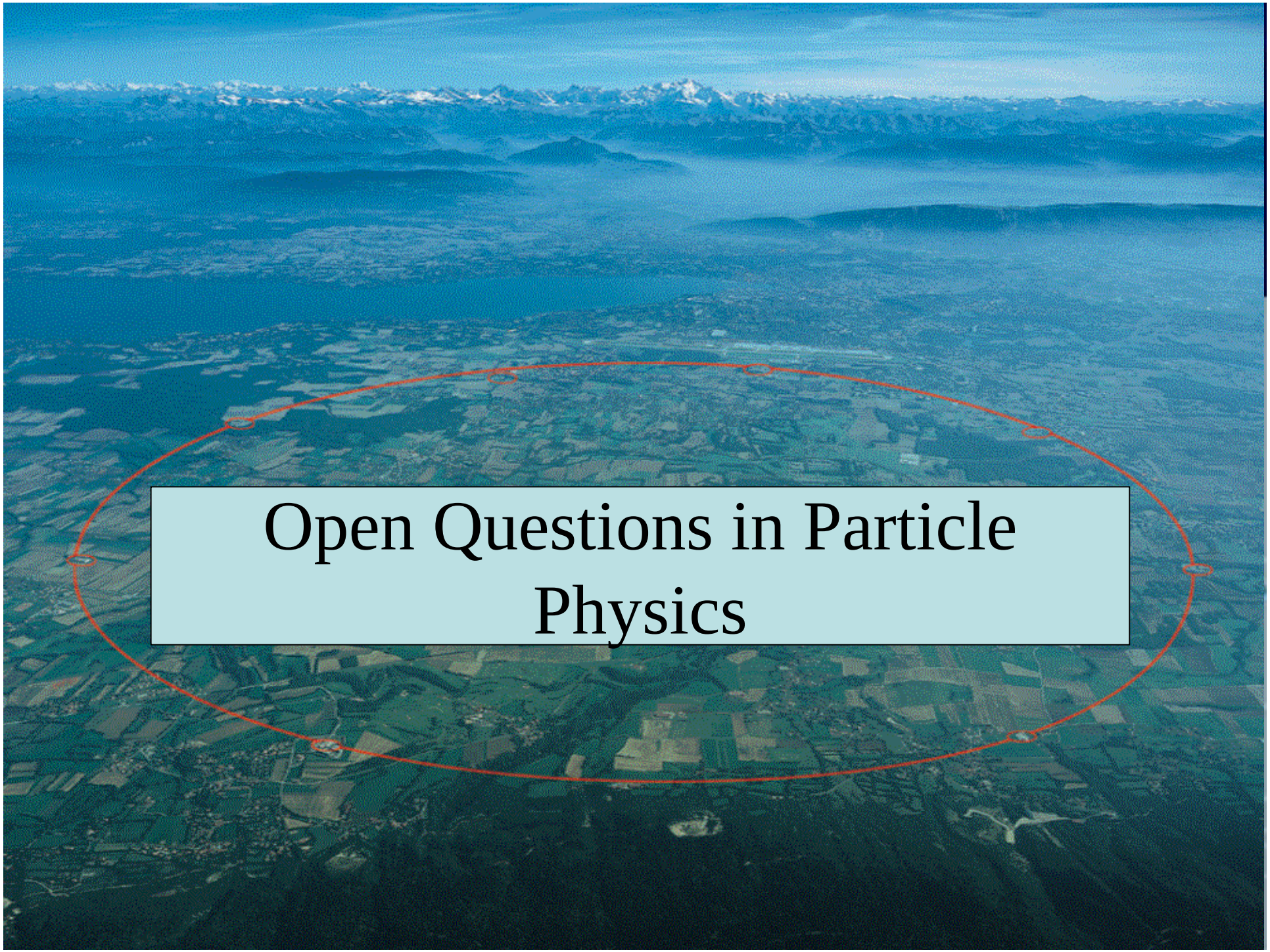





Impact on International Relations

Accelerating Particles across Frontiers

- First European international organization
  before EU, model for ESO, EMBL, …
- East-West meeting ground during Cold War
  Soviet Union/US, experiments in Russia in 1967
- Opened to Central Europe after Berlin Wall:
  CZ, HU, PL, SLO from 1991, BG from 1999
- LHC is the first global scientific project
- Bridging many political divides:
  US/Iran, Israel/Morocco, China/Taiwan,
  India/Pakistan, …


Open Questions in Particle Physics

Open Questions beyond the Standard Model

- What is the origin of particle masses?

  due to a Higgs boson?

  solution at energy < 1 TeV (1000 proton masses)
- Why so many types of matter particles?

  matter-antimatter difference?
- Unification of the fundamental forces?

  at very high energy ~ 10^{16} GeV

  indirect @ accelerators, ν physics
- Quantum theory of gravity?

  additional dimensions of space?

Some particles have mass, some do not

1954-2004 CERN 50th anniversary of CERN

Where do the masses come from?

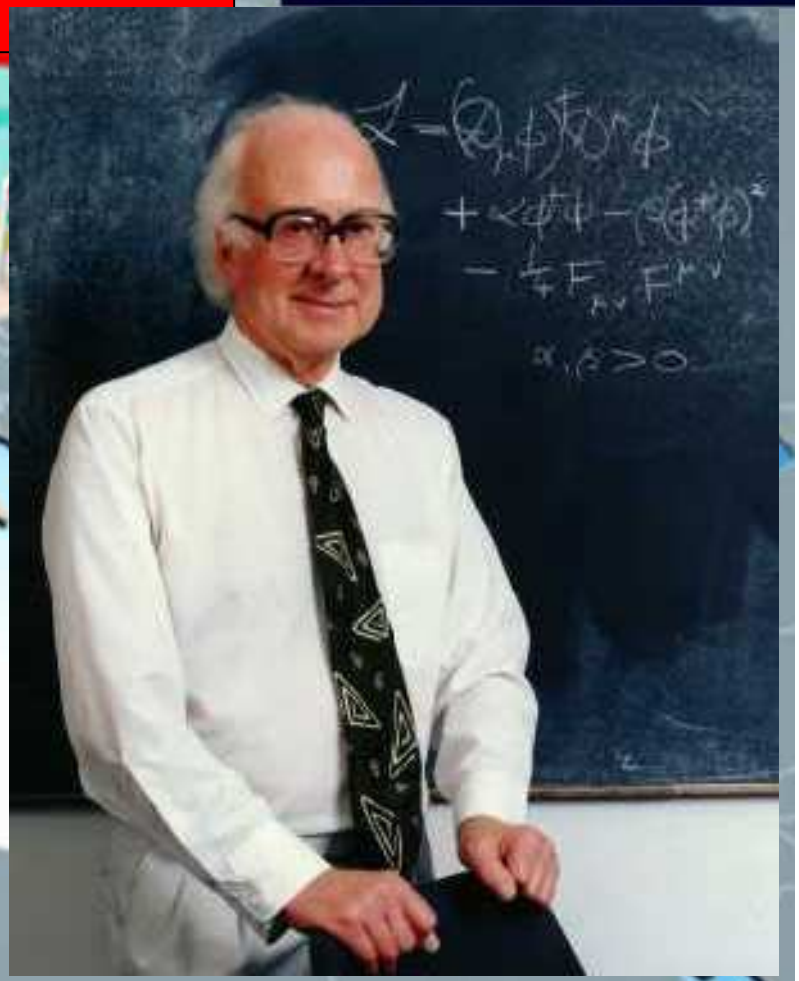
Newton:

Weight proportional to Mass

Einstein:

Energy related to Mass

Neither explained origin of Mass

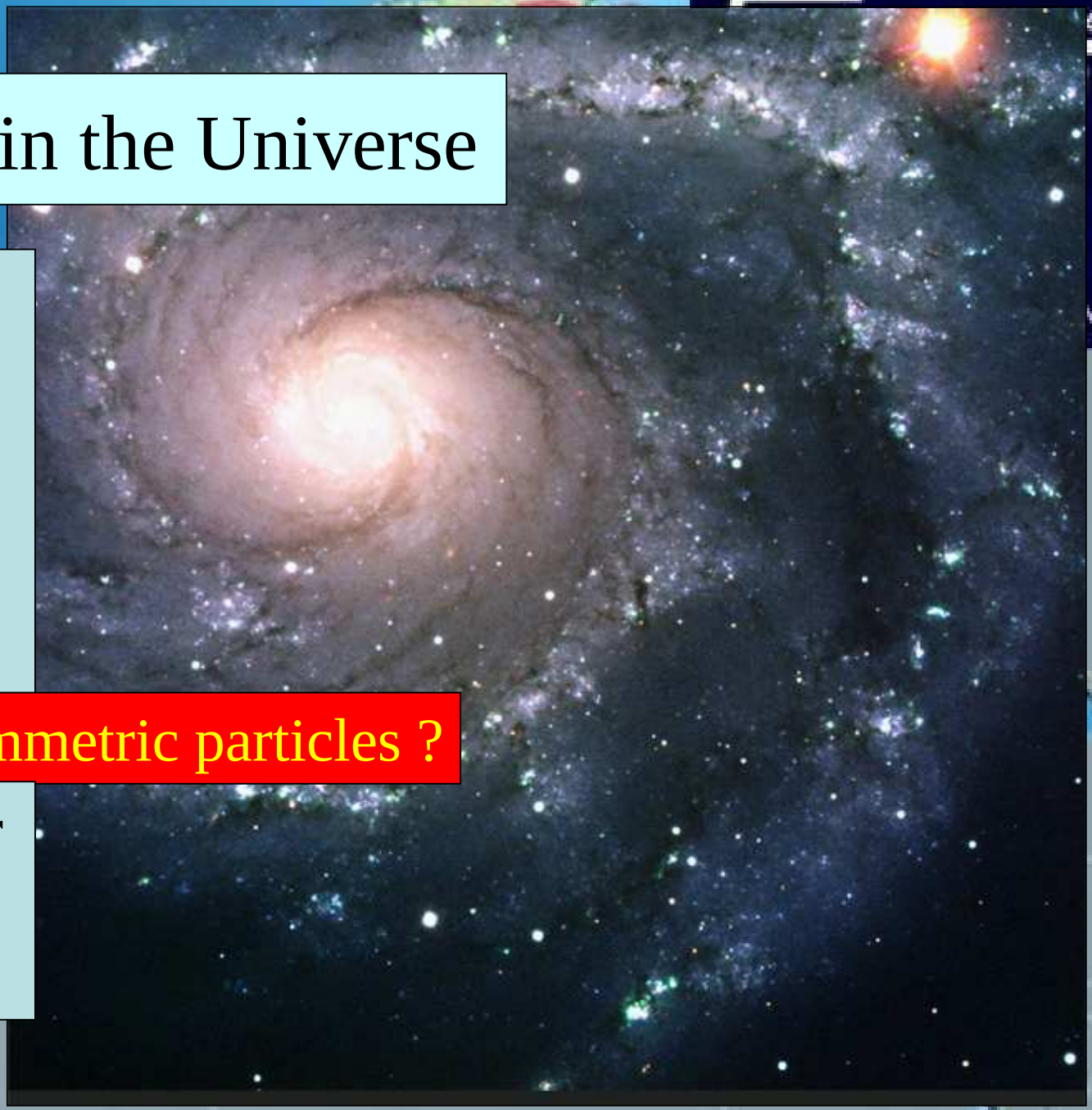


Are masses due to Higgs boson?
(yet another particle)

Illustration of the Higgs Idea

The excitation crosses the room = the Higgs boson

Dark Matter in the Universe



Astronomers say that most of the matter in the Universe is invisible

Dark Matter

Lightest Supersymmetric particles ?

We shall look for them with the LHC

What is Supersymmetry (Susy)?

- Unifies matter and force particles?
- Links fermions and bosons

  Exclusion principle vs laser coherence
- Relates particles of different spins

  0 - ½ - 1 - 3/2 - 2

  Higgs - Electron - Photon - Gravitino - Graviton
- Helps fix masses, unify fundamental forces

1973

How do Matter and Antimatter Differ?

Dirac predicted the existence of antimatter:
- same mass
- opposite internal properties:
  - electric charge, …

Discovered in cosmic rays

Studied using accelerators

Matter and antimatter not quite equal and opposite: WHY?

Why does the Universe mainly contain matter, not antimatter?

Experiments at LHC and elsewhere looking for answers

Generating the matter in the Universe

Sakharov

- Need difference between matter, antimatter

  charge symmetry broken in laboratory

- Need matter-creating interactions

  present in unified theories – not yet seen

- Need breakdown of thermal equilibrium

  possible when particle masses generate
  e.g., in decays of heavy particles

Can we calculate from laboratory measurements?


The LHC Programme