CERN and High Energy Physics

An Overview

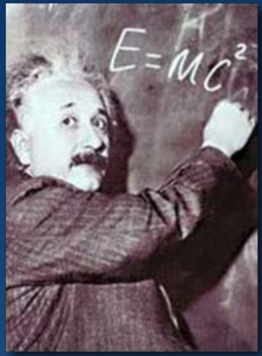
Rolf-Dieter Heuer
Blois
20 July 2010

Innovation
Education
CERN
uniting people
Research

The Mission of CERN

- Push back the frontiers of knowledge

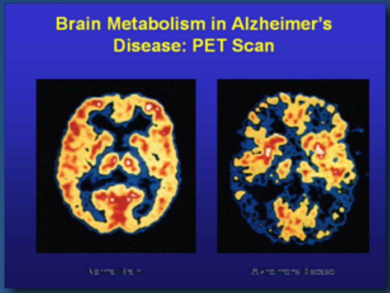
  E.g. the secrets of the Big Bang …what was the matter like within the first moments of the Universe's existence?



- Develop new technologies for accelerators and detectors

  Information technology - the Web and the GRID

  Medicine - diagnosis and therapy

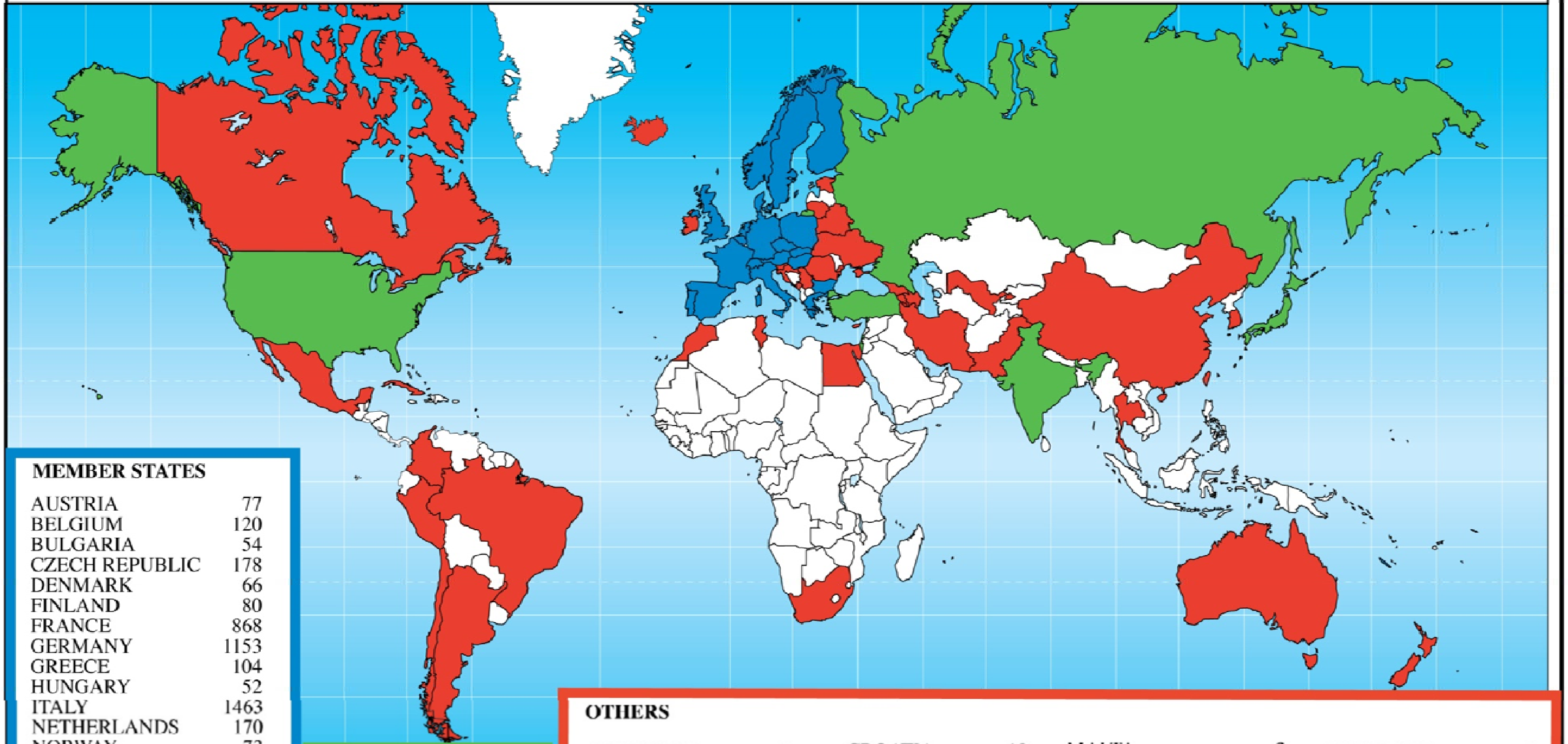


- Train scientists and engineers of tomorrow

- Unite people from different countries and cultures

CERN in Numbers

Distribution of All CERN Users by Nation of Institute on 20 January 2010



MEMBER STATES

AUSTRIA	77
BELGIUM	120
BULGARIA	54
CZECH REPUBLIC	178
DENMARK	66
FINLAND	80
FRANCE	868
GERMANY	1153
GREECE	104
HUNGARY	52
ITALY	1463
NETHERLANDS	170
NORWAY	73
POLAND	191
PORTUGAL	122
SLOVAKIA	55
SPAIN	311
SWEDEN	71
SWITZERLAND	362
UNITED KINGDOM	732

6302

OBSERVER STATES

INDIA	91
ISRAEL	49
JAPAN	204
RUSSIA	901
TURKEY	60
USA	1618

2923

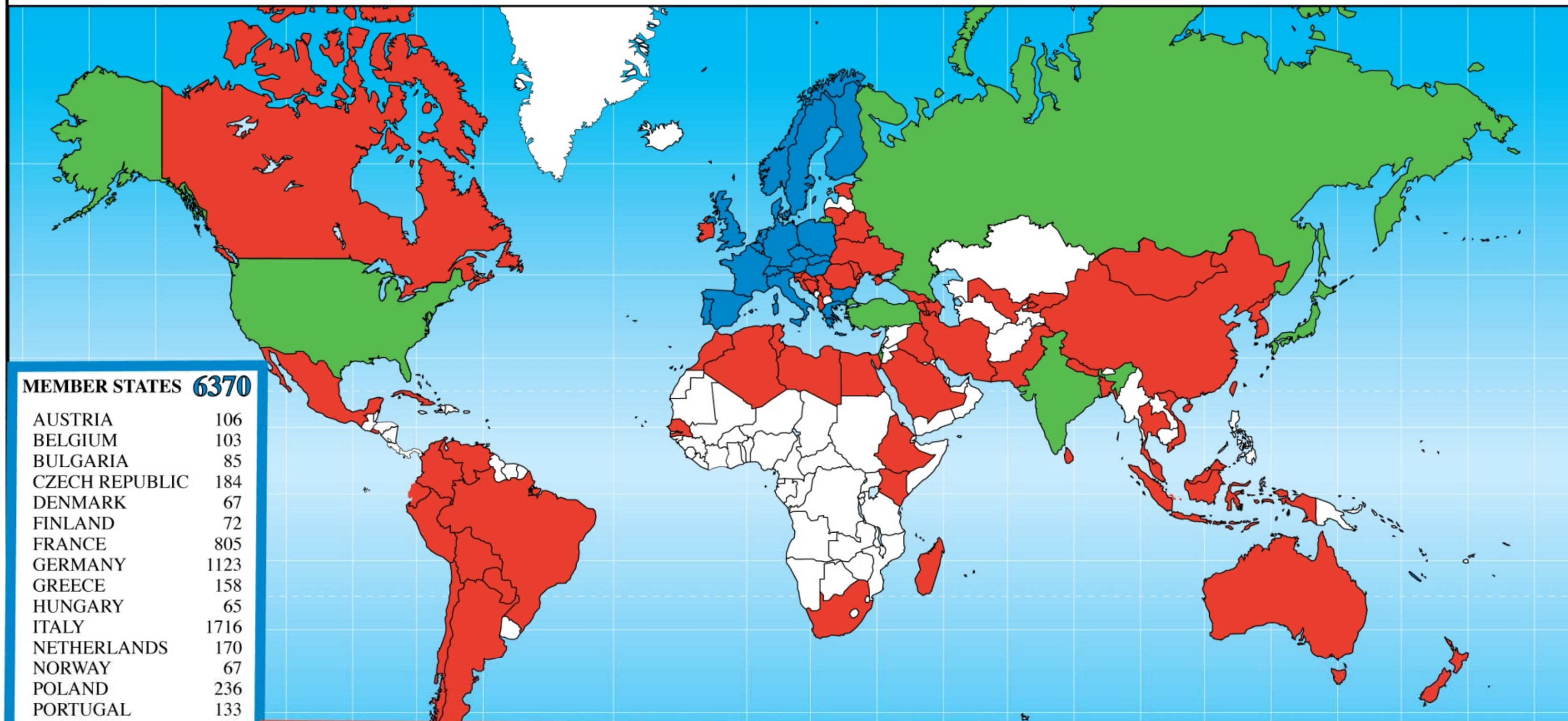
OTHERS

ARGENTINA	8	CROATIA	18	MALTA	2	THAILAND	1
ARMENIA	16	CUBA	4	MEXICO	33	TUNISIA	1
AUSTRALIA	17	CYPRUS	8	MONTENEGRO	1	UKRAINE	17
AZERBAIJAN	1	EGYPT	3	MOROCCO	6	UZBEKISTAN	1
BELARUS	19	ESTONIA	9	NEW ZEALAND	8		
BRAZIL	77	GEORGIA	10	PAKISTAN	15		
CANADA	141	ICELAND	1	PERU	1		
CHILE	2	IRAN	15	ROMANIA	59		
CHINA	78	IRELAND	14	SERBIA	20		
CHINA (TAIPEI)	53	KOREA	64	SLOVENIA	17		
COLOMBIA	9	LITHUANIA	5	SOUTH AFRICA	8		

762

CERN in Numbers

Distribution of All CERN Users by Nationality on 20 January 2010



MEMBER STATES 6370

AUSTRIA	106
BELGIUM	103
BULGARIA	85
CZECH REPUBLIC	184
DENMARK	67
FINLAND	72
FRANCE	805
GERMANY	1123
GREECE	158
HUNGARY	65
ITALY	1716
NETHERLANDS	170
NORWAY	67
POLAND	236
PORTUGAL	133
SLOVAKIA	78
SPAIN	330
SWEDEN	67
SWITZERLAND	200
UNITED KINGDOM	605

OBSERVER STATES 2444

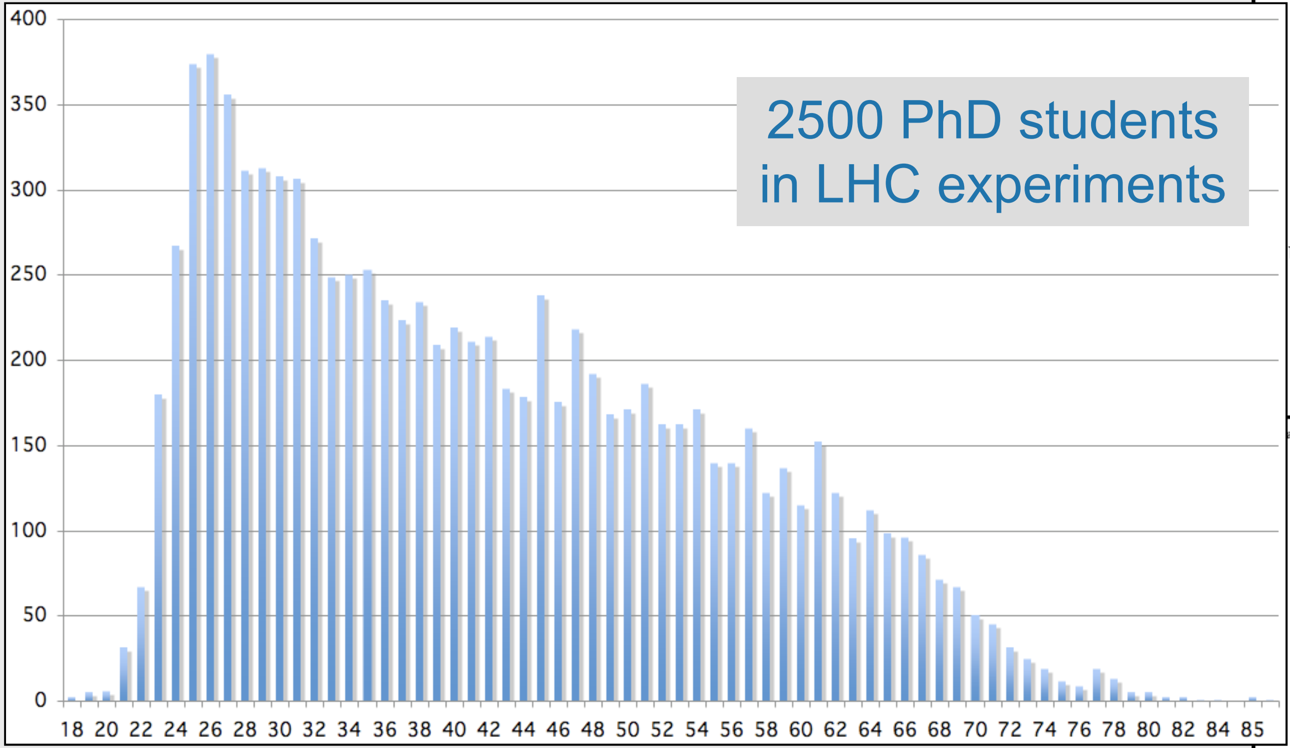
INDIA	158
ISRAEL	51
JAPAN	229
RUSSIA	1027
TURKEY	87
USA	892

OTHERS 1205

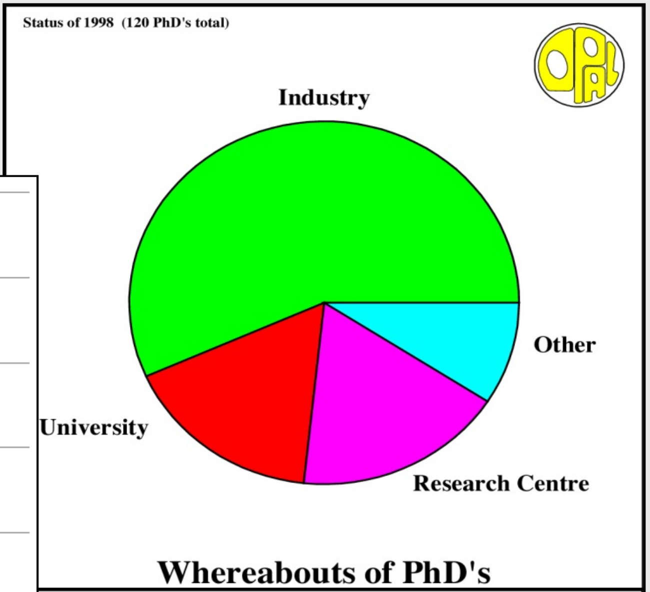
ALBANIA	2
ALGERIA	8
ARGENTINA	11
ARMENIA	24
AUSTRALIA	20
AZERBAIJAN	5
BANGLADESH	3
BELARUS	36
BOLIVIA	2
BOSNIA AND HERZEGOVINA	1
BRAZIL	79
CANADA	136
CHILE	3
CHINA	202
CHINA (TAIPEI)	41
COLOMBIA	19
CROATIA	24
CUBA	4
CYPRUS	12
ECUADOR	2
EGYPT	6
EL SALVADOR	1
ESTONIA	9
ETHIOPIA	1
GEORGIA	31
GIBRALTAR	1
HONG KONG	2
INDONESIA	1
IRAN	20
IRAQ	1
IRELAND	20
KENYA	2
KOREA, D.P.R.	3
KOREA REP.	85
KYRGYZSTAN	1
LEBANON	8
LITHUANIA	9
LUXEMBOURG	5
LIBYA	1
MADAGASCAR	3
MALAYSIA	7
MALTA	3
MAURITIUS	1
MEXICO	46
MOLDOVA	1
MONGOLIA	1
MOROCCO	16
NEPAL	3
NEW ZEALAND	10
PAKISTAN	33
PALESTINE (O.T.).	1
PARAGUAY	1
PERU	2
ROMANIA	101
SAN MARINO	1
SAUDI ARABIA	2
SENEGAL	1
SERBIA	34
SINGAPORE	1
SLOVENIA	20
SOUTH AFRICA	9
SRI LANKA	6
SYRIA	2
THAILAND	1
TUNISIA	5
UKRAINE	40
UZBEKISTAN	2
VENEZUELA	5
VIET NAM	6

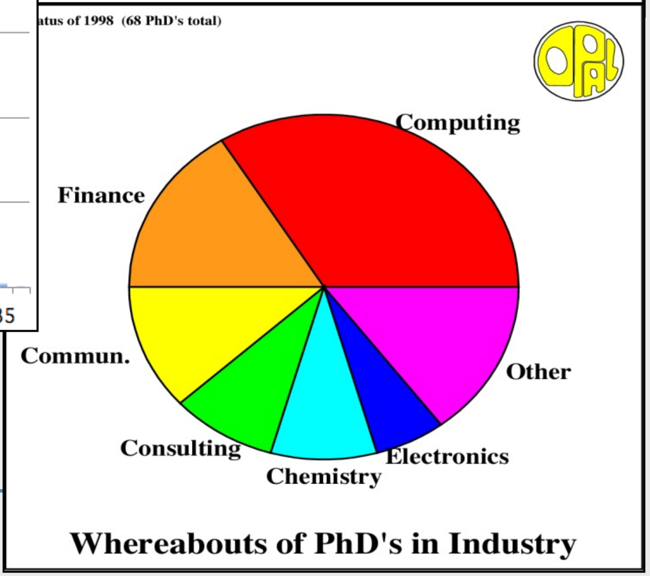
Age Distribution of Scientists
- and where they go afterwards

Survey in March 2009



They do not all stay: where do they go?

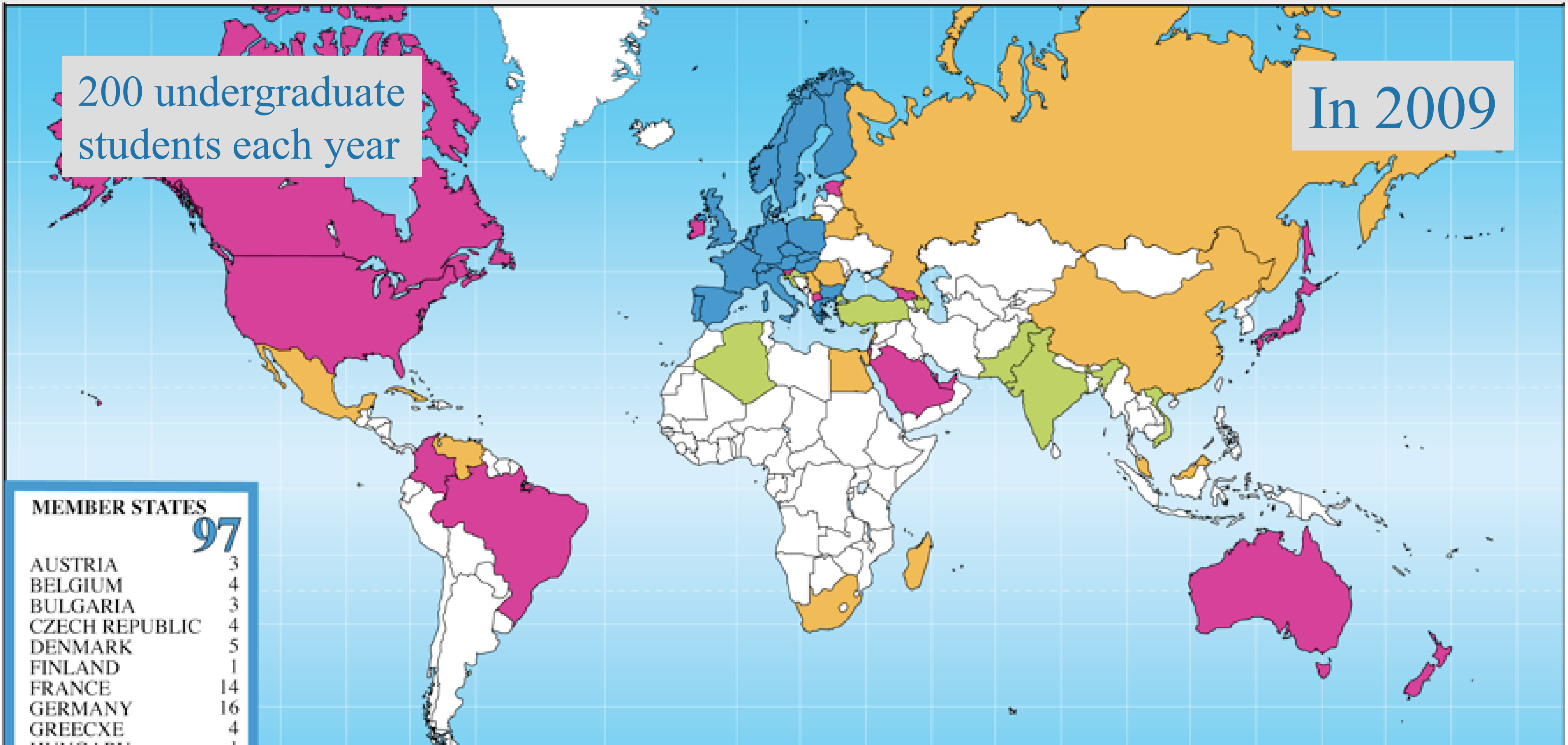




Summer Students @ CERN

200 undergraduate students each year

In 2009



MEMBER STATES 97

AUSTRIA	3
BELGIUM	4
BULGARIA	3
CZECH REPUBLIC	4
DENMARK	5
FINLAND	1
FRANCE	14
GERMANY	16
GREECXE	4
HUNGARY	1
ITALY	7
NETHERLANDS	5
NORWAY	3
POLAND	2
PORTUGAL	1
SLOVAKIA	3
SPAIN	4
SWEDEN	7
SWITZERLAND	1
UNITED KINGDOM	9

SUPPORTED BY CERN 22

BELARUS	1	MAURITIUS	1
CHINA	1	MEXICO	1
CUBA	1	ROMANIA	1
EGYPT	1	RUSSIA	9
LEBANON	1	SERBIA	1
MADAGASCAR	1	SOUTH AFRICA	1
MALAYSIA	1	VENEZUELA	1

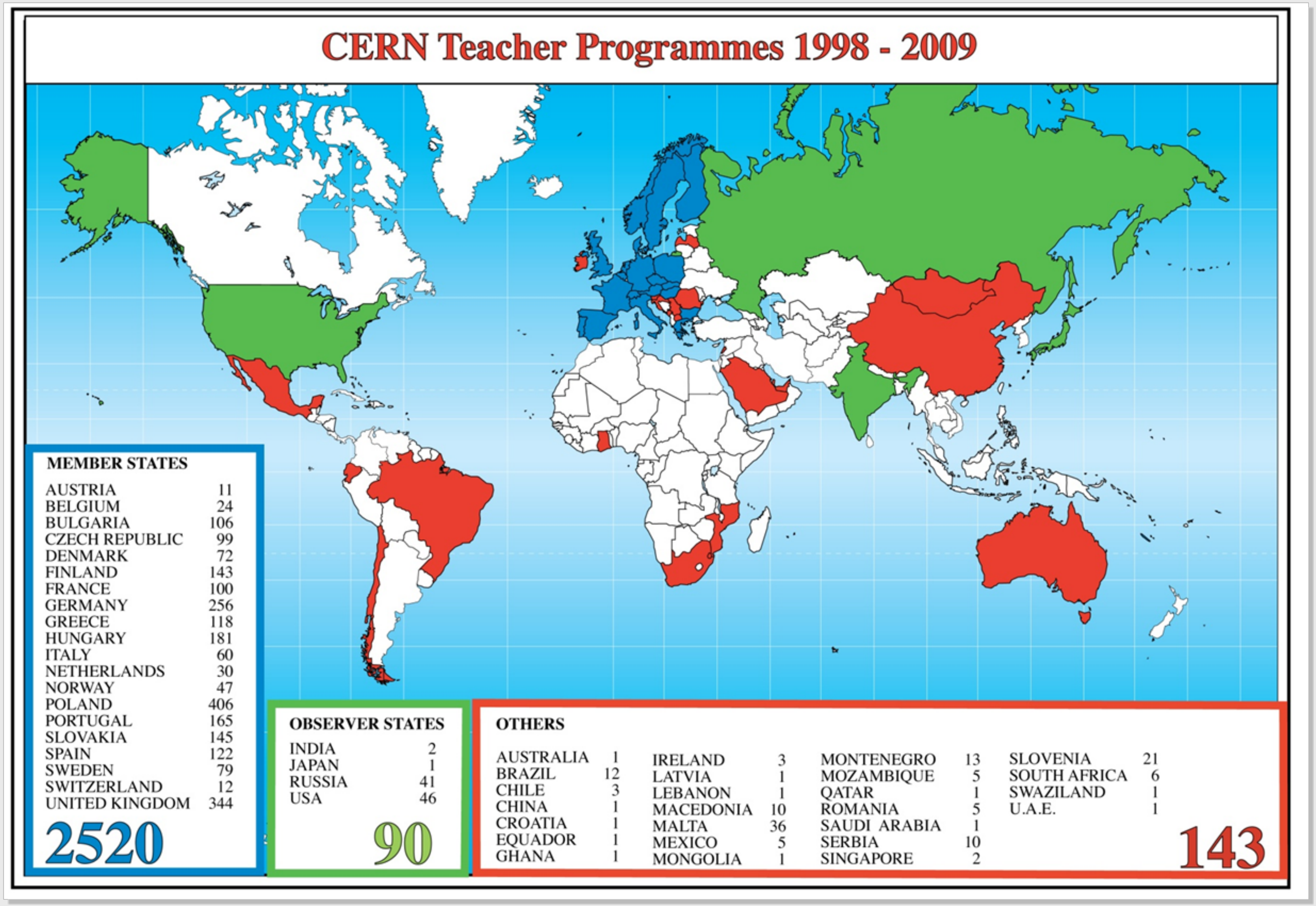
EXTERNAL SUPPORT 52

AUSTRALIA	2	JAPAN	5
BRAZIL	1	MACEDONIA	5
CANADA	6	N. ZEALAND	2
COLOMBIA	1	QATAR	2
ESTONIA	2	SAUDI A	2
GEORGIA	1	SLOVENIA	1
IRELAND	1	UAE	1
ISRAEL	4	USA	16

BOTH SOURCES 38

ALGERIA	2	TURKEY	3
AZERBAIJAN	2	VIETNAM	4
CROATIA	3		
CYPRUS	3		
INDIA	11		
MALTA	3		
PAKISTAN	4		
PALESTINE	3		

CERN Teacher Programmes



Past few decades

“Discovery” of Standard Model

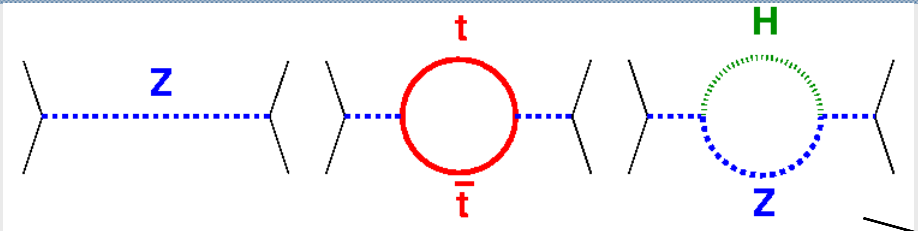
through synergy of

hadron - hadron colliders (e.g. Tevatron)

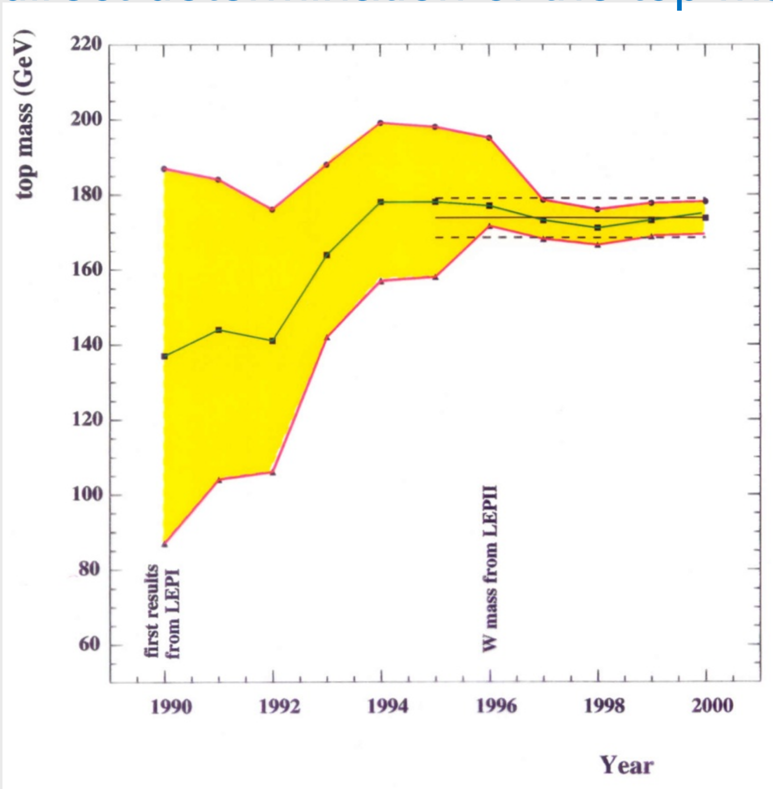
lepton - hadron colliders (HERA)

lepton - lepton colliders (e.g. LEP)

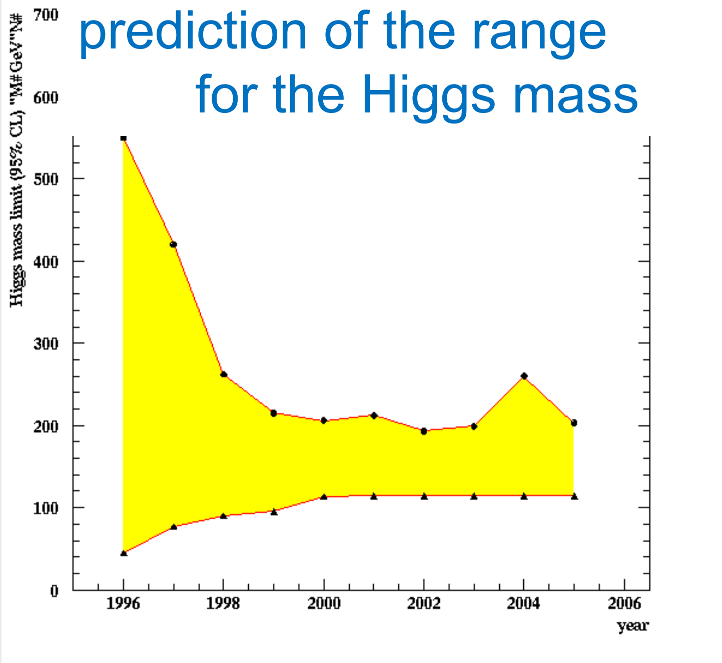
Test of the SM at the Level of Quantum Fluctuations



indirect determination of the top mass



prediction of the range for the Higgs mass



possible due to

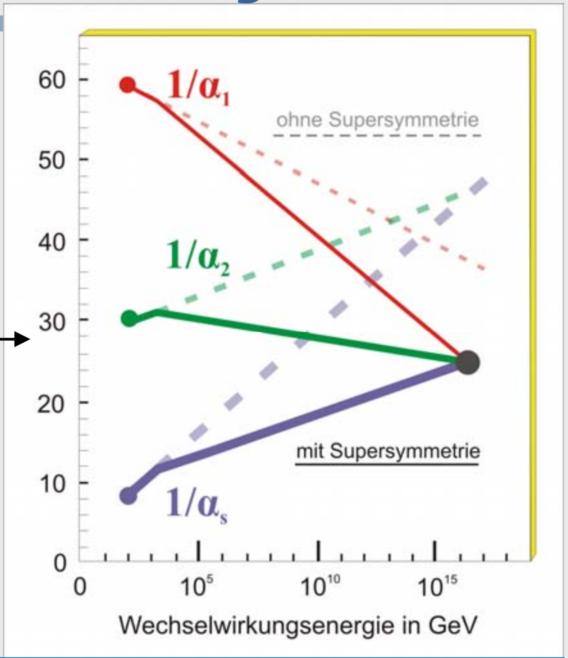
- precision measurements
- known higher order electroweak corrections

$$\propto \left(\frac{M_t}{M_W}\right)^2, \ln\left(\frac{M_h}{M_W}\right)$$

Key Questions of Particle Physics

origin of mass/matter or
origin of electroweak symmetry breaking

unification of forces



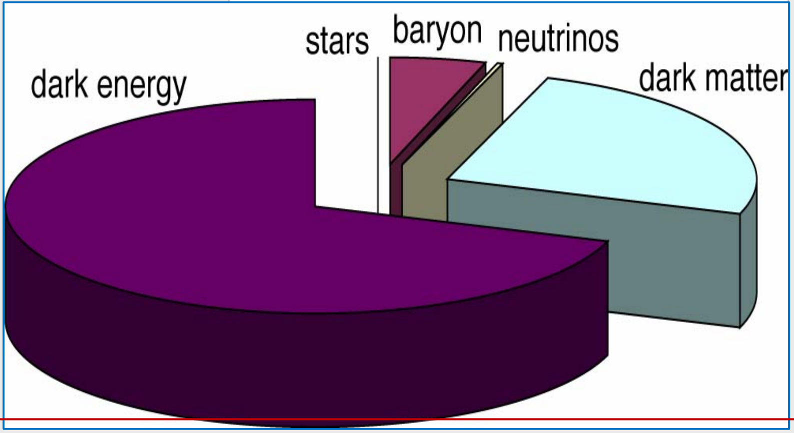
fundamental symmetry of forces and matter

unification of quantum physics and general relativity

number of space/time dimensions

what is dark matter

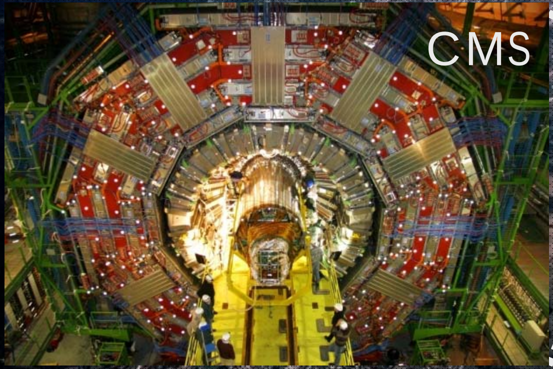
what is dark energy



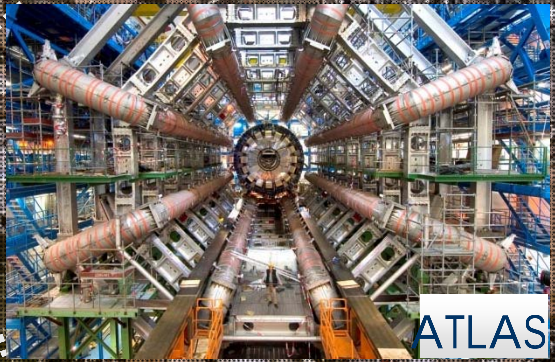
→ with the Large Hadron Collider
at the Terascale now entering the 'Dark Universe'

Enter a New Era in Fundamental Science

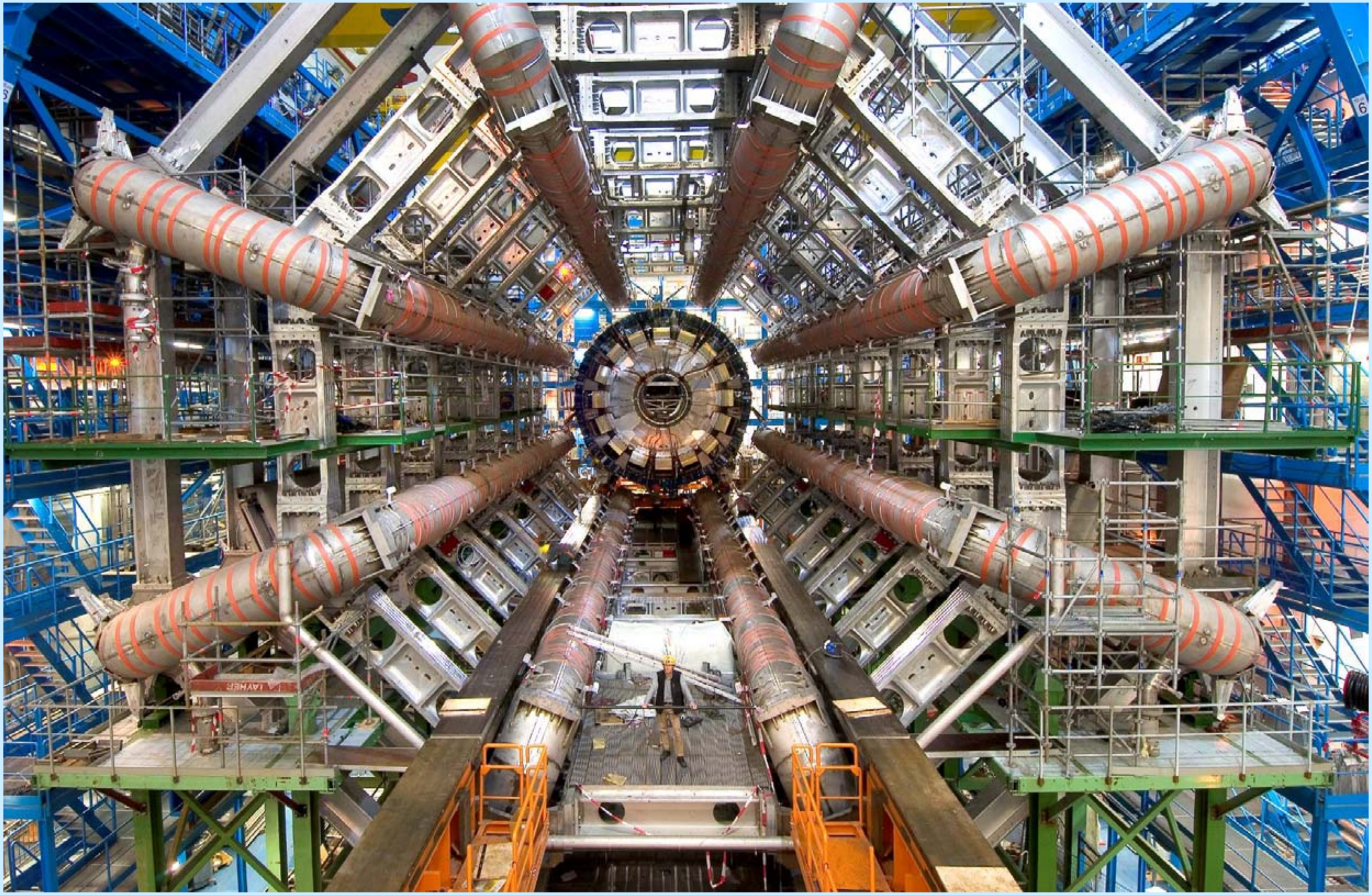
Start-up of the Large Hadron Collider (LHC), one of the largest and truly global scientific projects ever, is the most exciting turning point in particle physics.



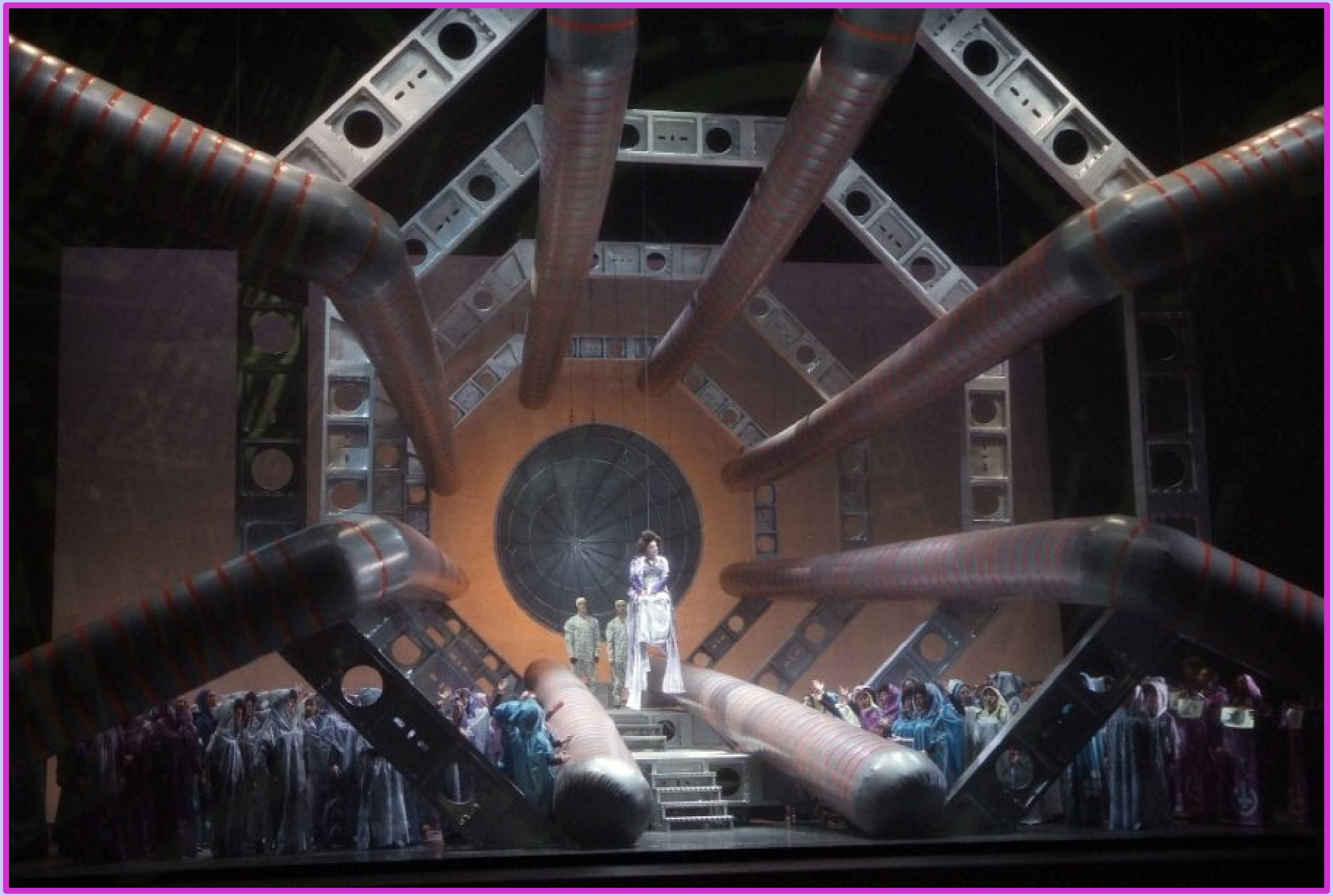
Exploration of a new energy frontier



the largest and most complex detectors



To select and record the signals from the 600 million proton collisions every second, huge detectors have been built to measure the particles traces to an extraordinary precision.



Hector Berlioz, “Les Troyens”, opera in five acts
Valencia, Palau de les Arts Reina Sofia, 31 October -12 November 2009

LHC fills lecture halls because it…

- addresses fundamental science questions
- stimulates general interest
- fascinates and inspires
- stimulates fantasy
- increases knowledge
- educates
- trains scientists and engineers for tomorrow
- drives innovation and technology
- and, and, and

→ use this interest to promote our field and basic science in general

CERN: Scientific Strategy

- Full exploitation of LHC physics potential
  - Reliable operation (including consolidation and LINAC 4)
  - Remove bottlenecks to benefit from nominal luminosity for both machine and detectors
  - Focused R&D and prototyping for High-Luminosity LHC
  - Re-establish standards for technical and general infrastructure
- Preparation for the long-term future (>2015)
  - Energy frontier
    - **CLIC/ILC** collaboration and R&D (for detectors and machine)
    - Generic R&D for **High-Energy LHC** (i.e. high field magnets)
  - R&D for high-power proton sources (HP-SPL) e.g for v-physics
- World-class fixed-target physics program

Fixed Target Physics

Antiproton Physics

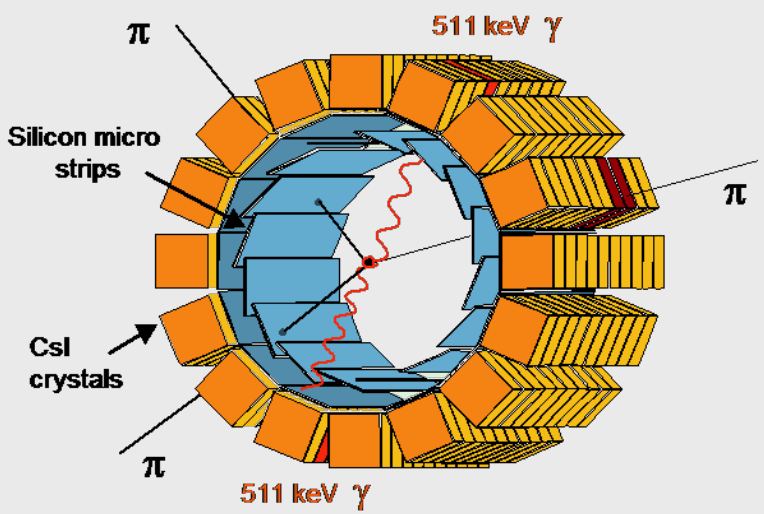
Cold antiprotons
("manufacturing anti-matter")

1. PS $p \rightarrow \bar{p}p$ 10^{-6}/collision
2. AD deceleration + cooling
   stochastic + electron
3. Extraction @ ~ 0.1c
4. Produce thousands of *anti-H*

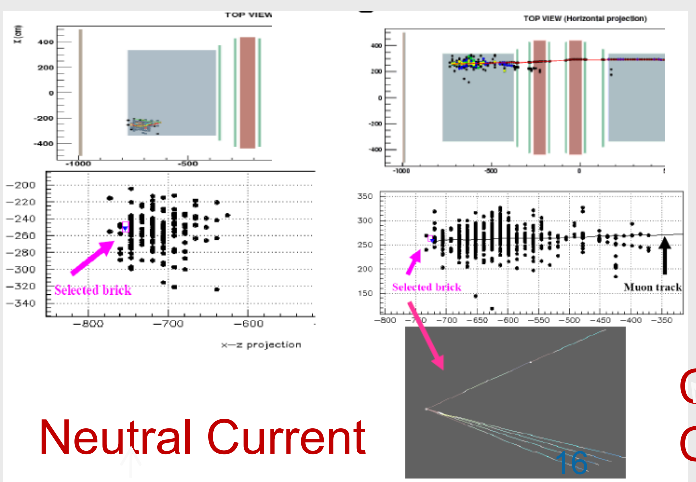
Anti-H annihilations detected

ATHENA (→ ALPHA)

anti-H ($\bar{p}e^+$) + matter → $\pi^+\pi^-$ + $\gamma\gamma$



Neutrino Physics

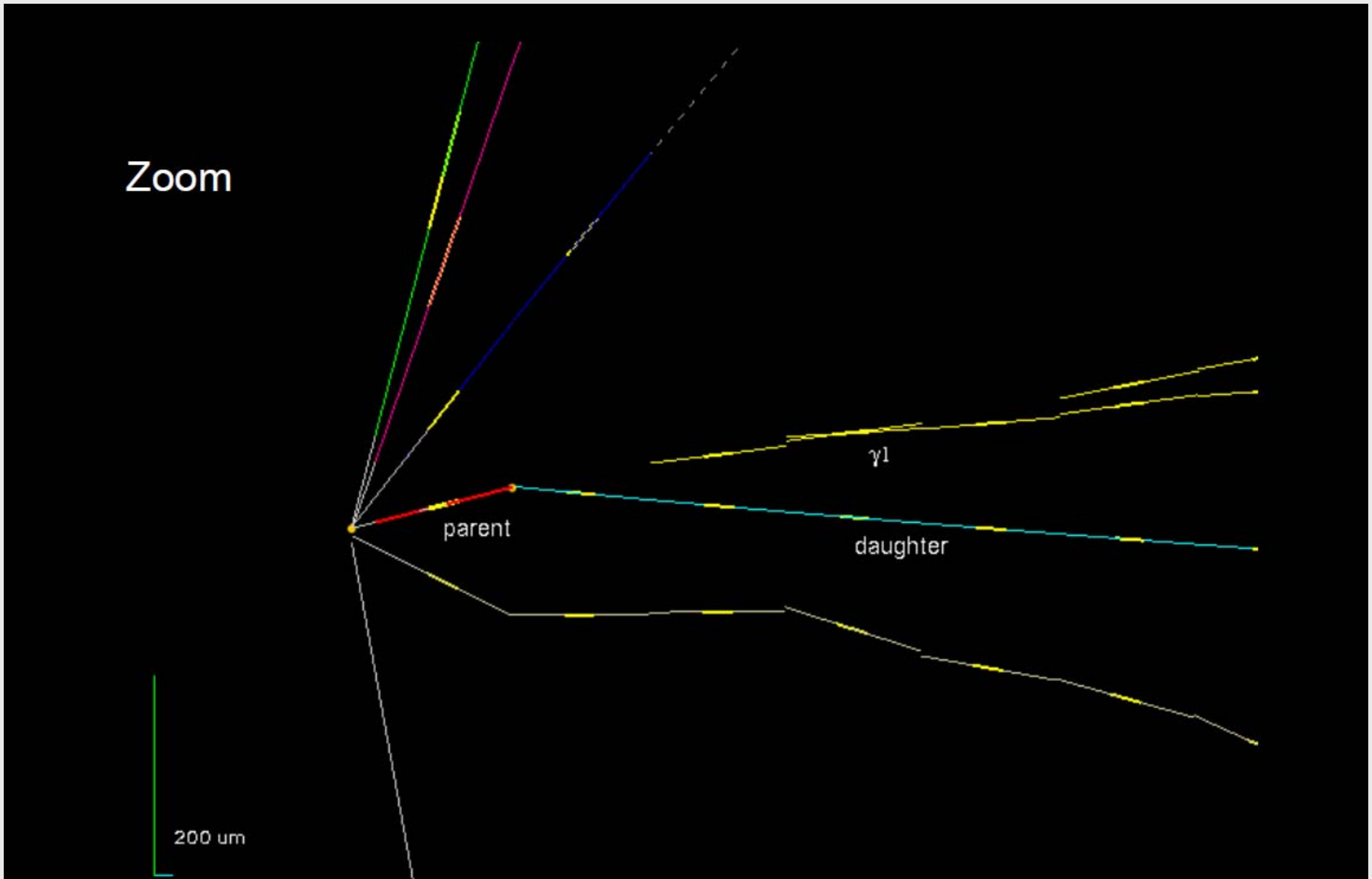


OPERA

Charge Current

CNGS - OPERA

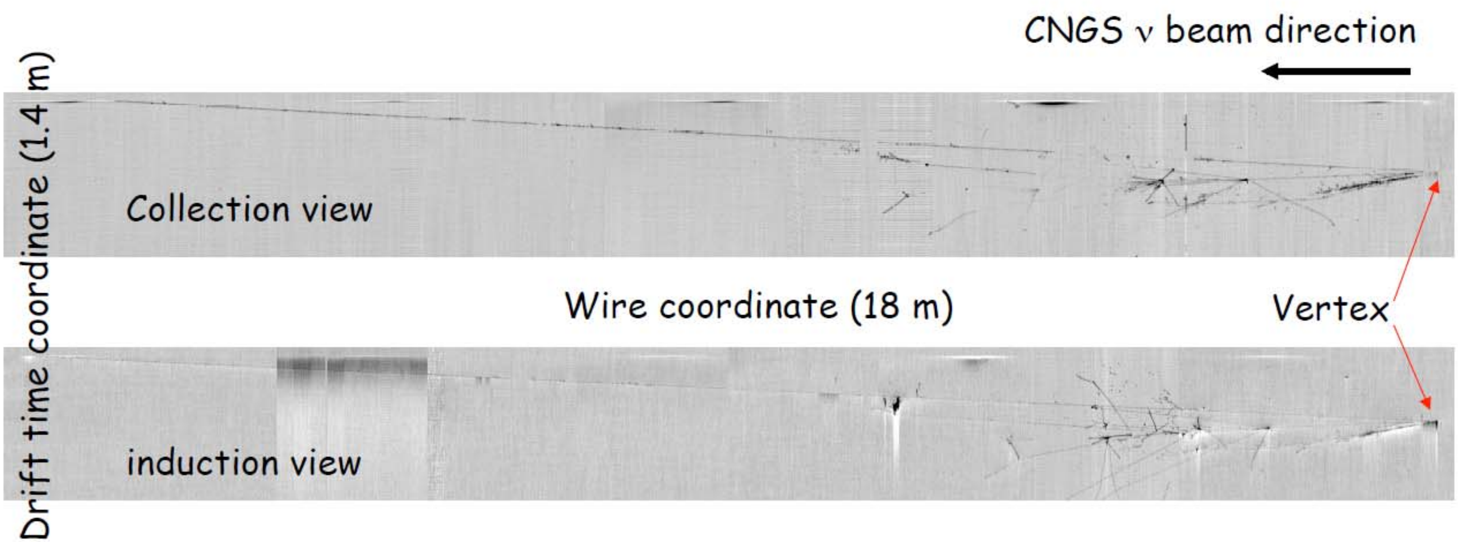
First υ_τ Candidate



Muonless event 9234119599, taken on 22 August 2009, 19:27 (UTC)
(as seen by the electronic detectors)

CNGS - ICARUS

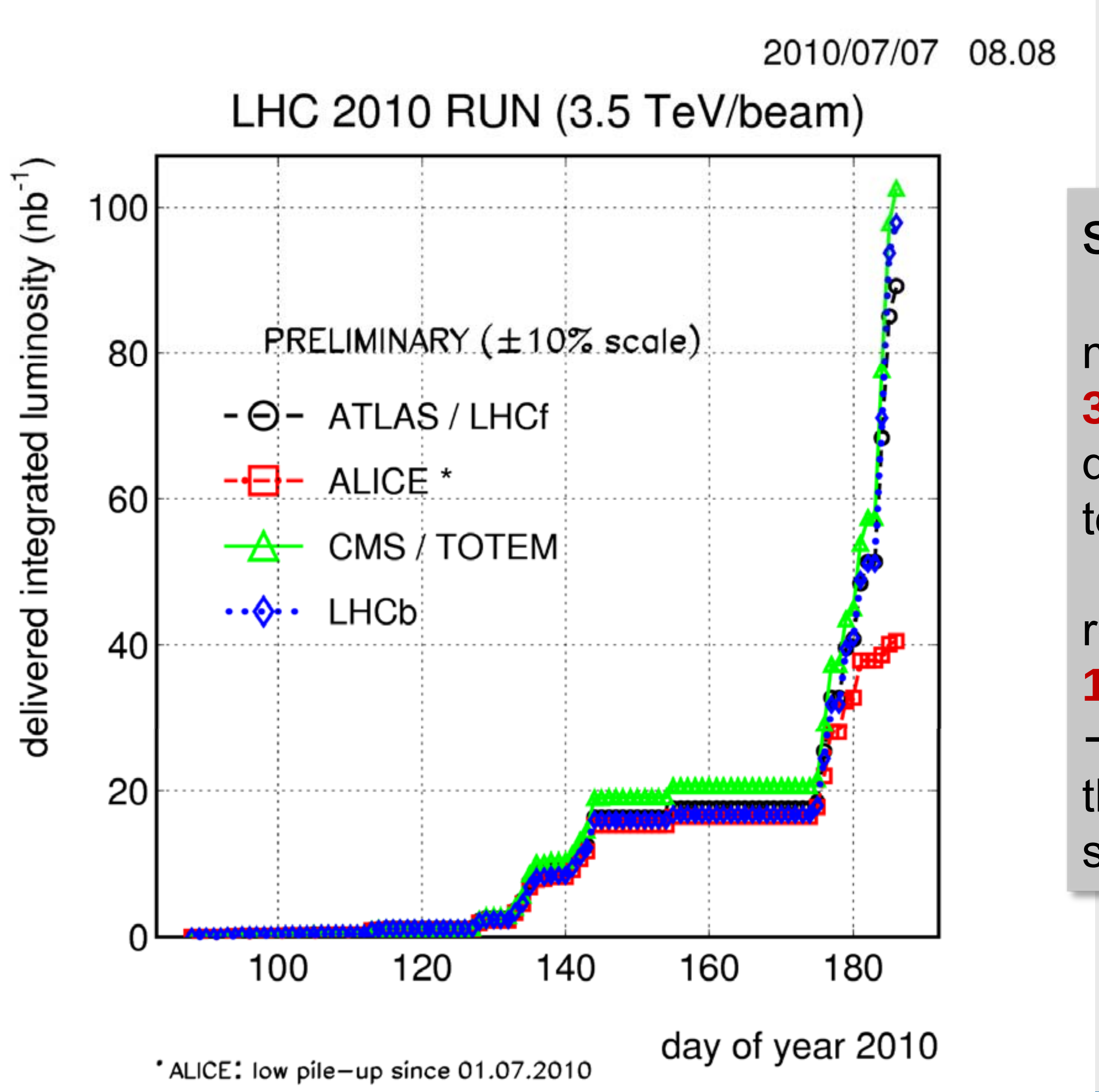
The first CNGS neutrino interaction in ICARUS T600



- Leading muon (crossing horizontally the whole cryostat)
- Two charged particle tracks undergoing hadronic interactions
- Two γ converting at 14 and 16 cm from vertex (π^0?)
- Vertex not fully visible in collection view, due to locally wrong wire biasing


CERN
Accelerating Science and Innovation
LHC

LHC Integrated Luminosity



status today:

more than
350/nb
delivered
to the experiments

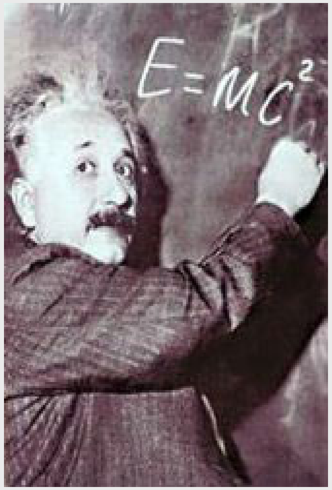
record peak luminosity
$1.6 \cdot 10^{30}$ /cm²/s
→increase by more than factor 1000 since start March 30

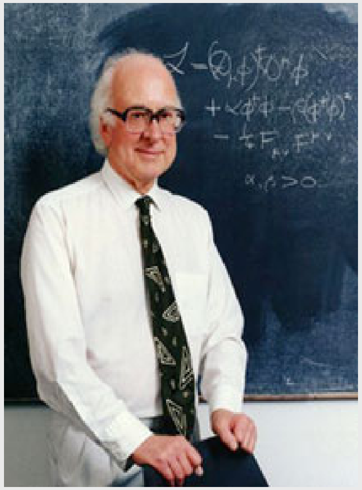
LHC Experiments Summary

- So far, so good….
- Experiments tracking nicely the machine evolution, eagerly awaiting more data
- Computing infrastructure supports magnificently the swift data analysis
- Experiments are re-discovering the Standard Model (only top quark missing…..)
- …exciting times !

The Science

We are poised to tackle some of the most profound questions in physics:





Newton's unfinished business… what is mass?

Nature's favouritism… why is there no more antimatter?

The secrets of the Big Bang… what was matter like within the first second of the Universe's life?

Science's little embarrassment… what is 96% of the Universe made of?

LHC Strategy (I)

Full exploitation of the LHC physics potential
→ maximize integrated luminosity useful for physics

- Longer running periods (~ two years)
- Longer shutdowns in between, coordinated activities between experiments and experiments/machine

- Physics Run 2010/11 @ 7 TeV
- decide about slightly higher energy later in the run

- Shutdown 2012 to prepare LHC towards 14 TeV (copper stabilizer consolidation, He-release valves, . . .)

- Physics Run 2013/14/15 @ ~ 14 TeV

LHC@7TeV: New Physics Reach

New Physics : approximate LHC reach (one experiment) for some benchmark scenarios ($\sqrt{s}$ = 7 TeV, unless otherwise stated)

Z′ (SSM): Tevatron limit ~ 1 TeV (95% C.L)

50 pb^{-1} : exclusion up to ~ 1 TeV (95% C.L.)
500 pb^{-1} : discovery up to ~ 1.3 TeV
exclusion up to ~ 1.5 TeV
1 fb^{-1} : discovery up to ~ 1.5 TeV

W′ : Tevatron limit ~ 1 TeV (95% C.L)

10 pb^{-1} : exclusion up to 1 TeV
100 pb^{-1} : discovery up to ~ 1.3 TeV
1 fb^{-1} : discovery up to ~ 1.9 TeV
exclusion up to ~ 2.2 TeV

SUSY ($\tilde{q},\tilde{g}$) : Tevatron limit ~ 400 GeV (95% C.L)

100 pb^{-1} : discovery up to ~ 400 GeV
1 fb^{-1} : discovery up to ~ 800 GeV

2010-2013+: Decisive Years

- Experimental data will take the floor to drive the field to the next steps:

- LHC results
- Θ_{13} (T2K, DChooz, etc..)
- υ masses (Cuore, Gerda, Nemo…)
- Dark Matter searches
- …….

Particle Physics Strategy (short term)

European Strategy for Particle Physics
first established 2006
update planned for 2012

Input from LHC mandatory

→ Need to have interpretation of LHC results ready

→ Need close collaboration exp/theory
LHC and LC

LHC Strategy (II)

Full exploitation of the LHC physics potential
→ maximize integrated luminosity useful for physics

- LHC operation until around 2030, aim at $\int L dt \approx 3000$/fb

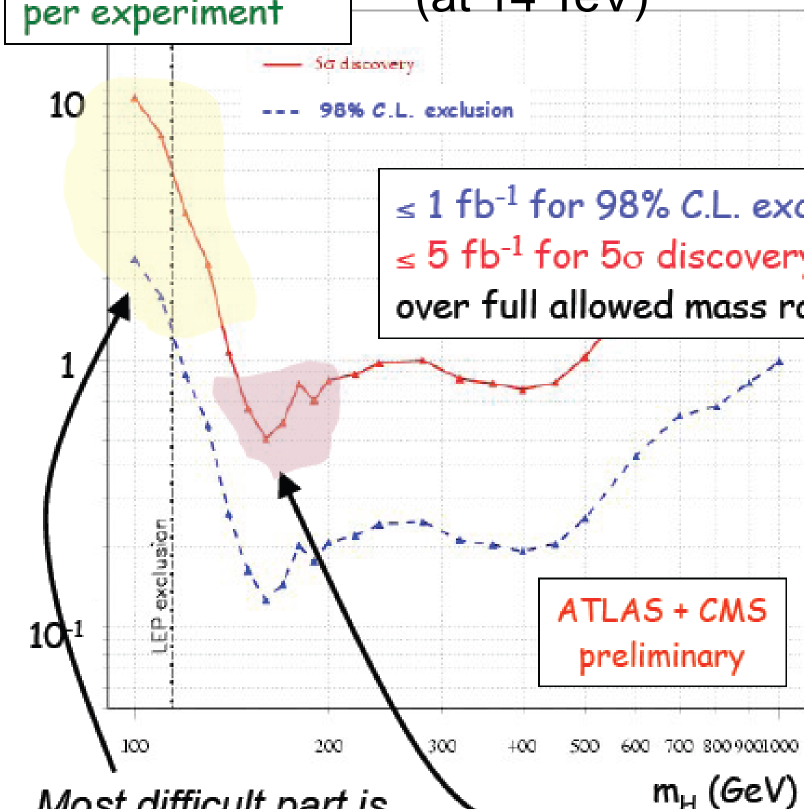
- Between 2010 and ~2020: ~design luminosity (~10^{34}/cm^2/s)
  connection of LINAC4 most likely ~2016
  detector modifications to optimize data collection

- High Luminosity LHC (HL-LHC) from ~2020/21 to ~2030
  luminosity around 5×10^{34}/cm^2/s, luminosity leveling
  new Inner Triplet around 2020/21 (combine both phases)
  detector upgrades around 2020/21 → R&D NOW

SM Higgs Reach

Needed ∫Ldt (fb^{-1}) per experiment

(at 14 TeV)

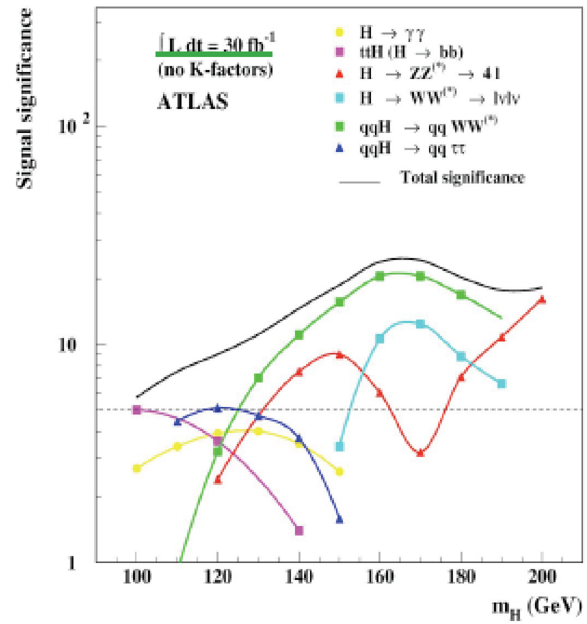


≤ 1 fb^{-1} for 98% C.L. exclusion
≤ 5 fb^{-1} for 5σ discovery
over full allowed mass range

ATLAS + CMS preliminary

Most difficult part is M_h~115 GeV

Early discovery already Possible with 1fb^{-1} $H \to WW^{(*)} \to 2l$



With 1fb^{-1} of understood data:

- *potential to exclude almost all m_h values*
- *potential to discover higgs with m_h~165 GeV*

LHC will give us an answer!

25/07/2007 HEP 2007 C

55

but it will take time. . .

Key Messages

- Need to clear the cloud of TeV-scale physics to obtain clear views
- LHC and HL-LHC with prospects towards 2030
- **Synergy of colliders**
- **LHC results decisive**

Next decades (?)

Road beyond Standard Model

through synergy of

hadron - hadron colliders (LHC)

lepton - hadron colliders (LHeC ??)

lepton - lepton colliders (LC ?)

Linear e^+e^- Colliders

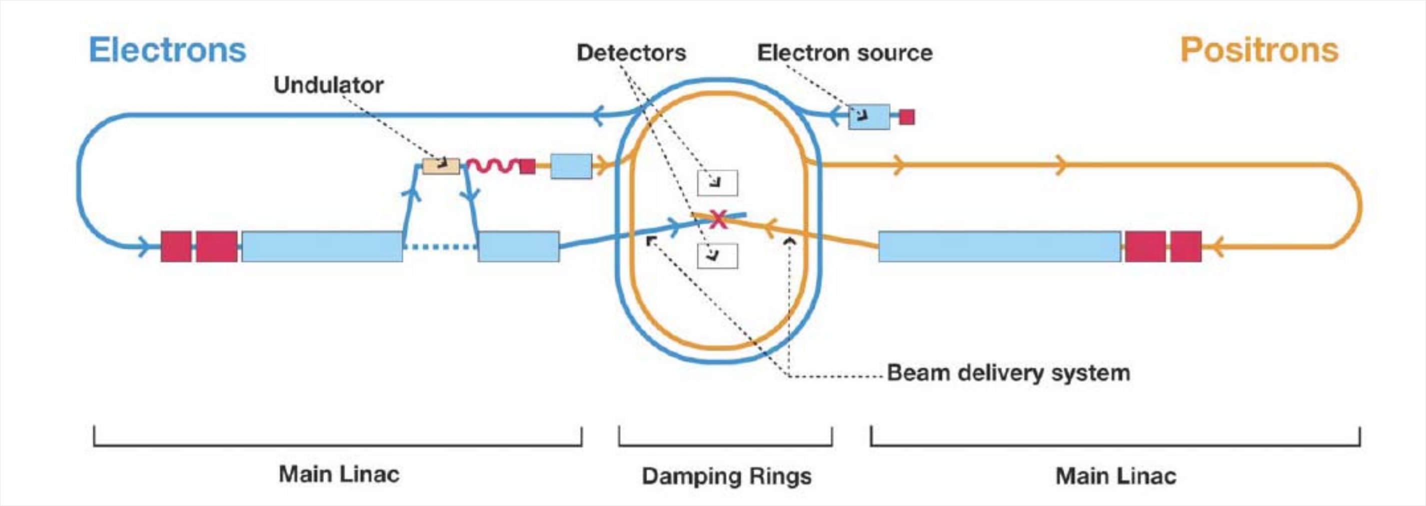
- The machine which will complement and extend the LHC best, and is closest to be realized, is a Linear e^+e^- Collider with a collision energy of at least 500 GeV.

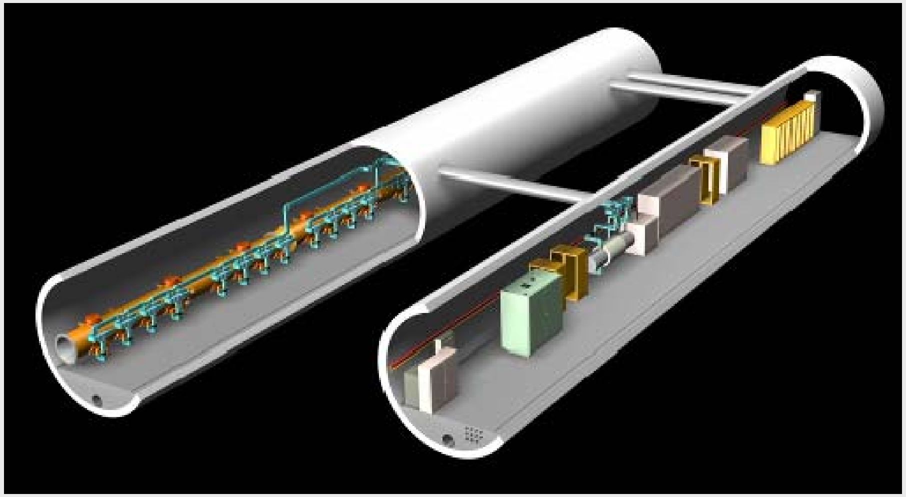
PROJECTS:

$\Rightarrow$ TeV Colliders (CMS energy up to 1 TeV) $\rightarrow$ Technology ~ready
ILC with superconducting cavities

$\Rightarrow$ Multi-TeV Collider (CMS energies in multi-TeV range) $\rightarrow$ R&D
CLIC $\rightarrow$ Two Beam Acceleration

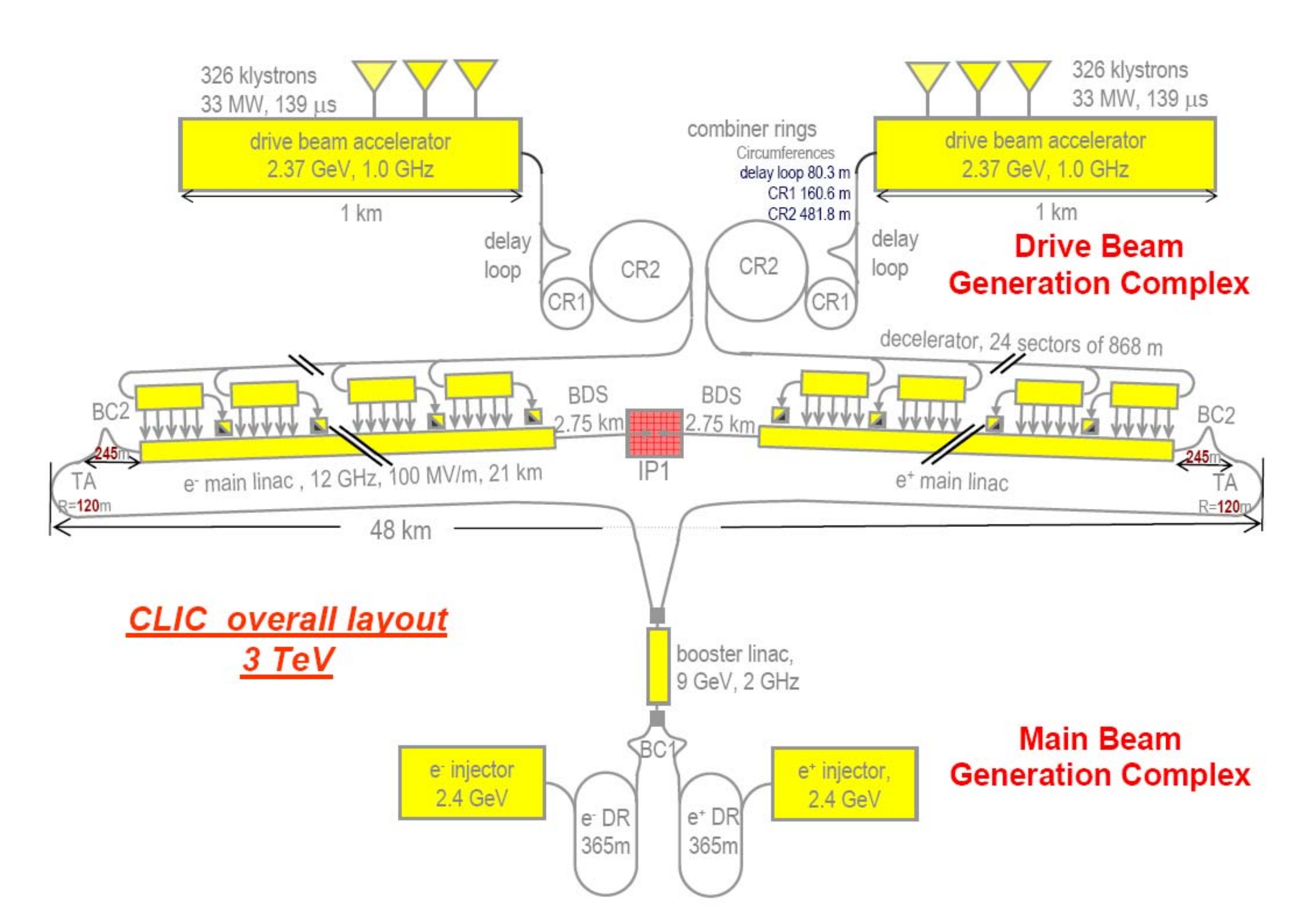
The International Linear Collider





Energy	250 Gev x 250 GeV
# of RF Units	560
# of Cryomodules	1680
# of 9-cell Cavities	14560
Accelerating Gradient	31.5 MeV/m
Peak luminosity	2 10^{34} $cm^{-2}s^{-1}$
Rep. Rate	5 Hz
IP	σ_x 350 – 620 nm; σ_y 3.5 – 9.0 nm
Total Power	~230 MW
2 Detectors Push-pull	

CLIC Overall Lay-out



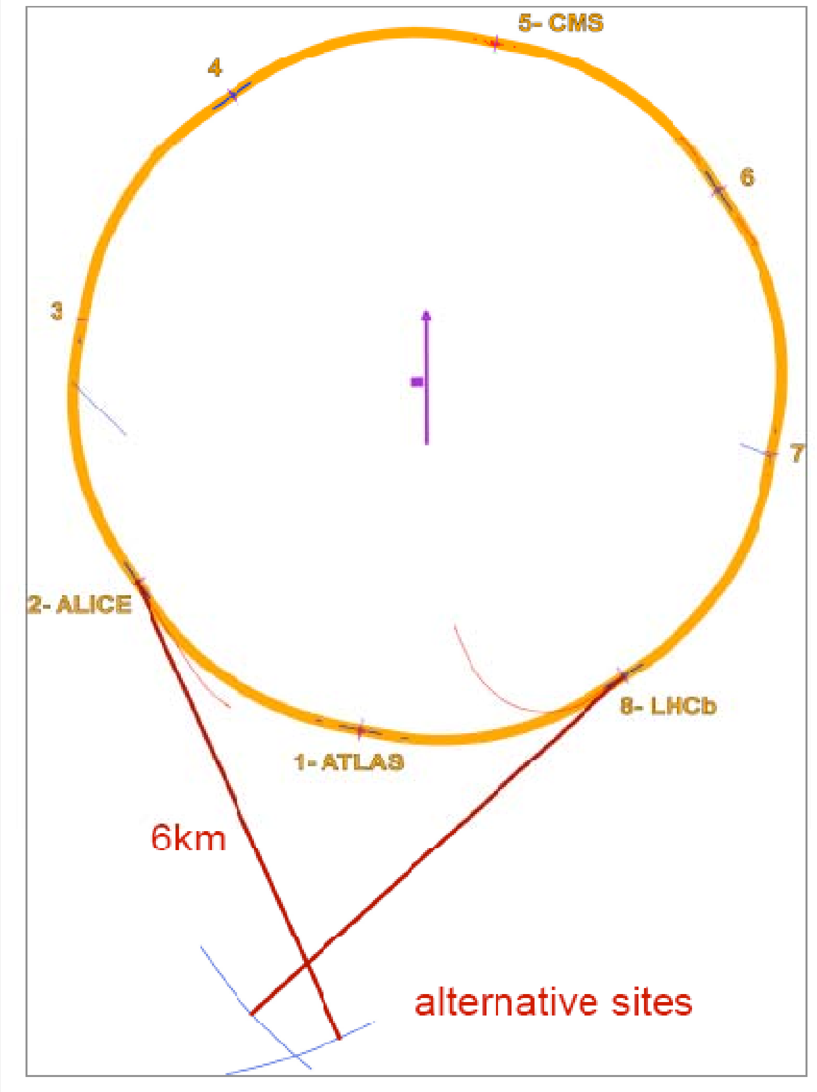
Key Messages

- Need to clear the cloud of TeV-scale physics to obtain clear views
- LHC and HL-LHC with prospects towards 2030
- **Synergy of colliders**
- **LHC results decisive**

- ILC could be constructed now
- CLIC more R&D needed
- Converge towards one LC project

- Detector R&D mandatory for all projects

Large Hadron electron Collider: possible layouts



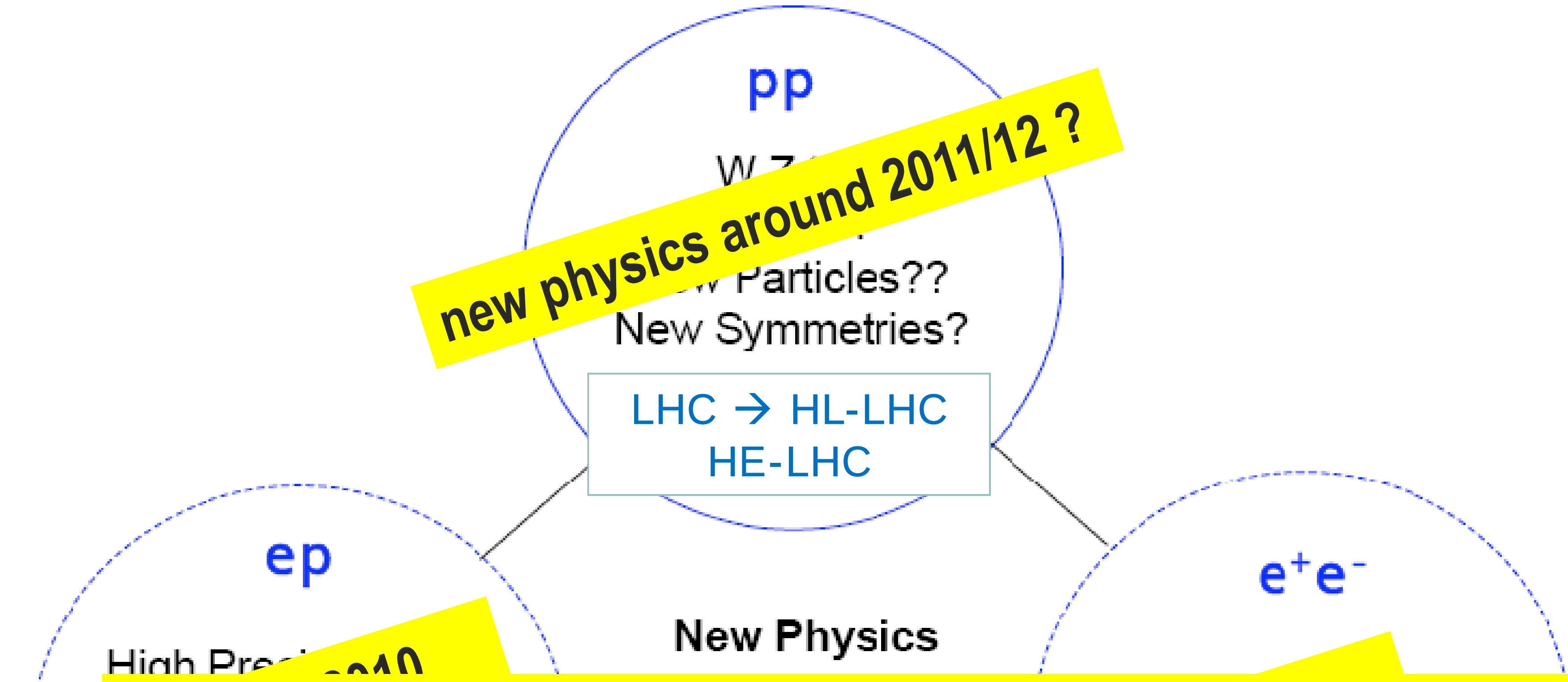
40 - 140 GeV
on
1 - 7 TeV

ring-ring solution:
L $\leq 10^{33}$

linac-ring solution:
L few 10^{31}

Would be the successor of HERA at higher cms

The TeV Scale (far) beyond 2010



Great opportunities ahead at the TeV scale

first window of opportunity for enabling decision on the way forward (earliest) around 2012 (?)

Results from LHC will guide the way

Expect

- period for decision enabling on next steps earliest 2012 (at least) concerning energy frontier
- (similar situation concerning neutrino sector Θ_{13})

We are NOW in a new exciting era of accelerator planning-design-construction-running

and need

- intensified efforts on R&D and technical design work to enable these decisions
- global collaboration and stability on long time scales (don‘t forget: first workshop on LHC was 1984)

→ more coordination and more collaboration required

CERN: Opening the door…

- Council opened the door to greater integration in particle physics when it recently unanimously adopted the recommendations to examine the role of CERN in the light of increasing globalization in particle physics.
  - *Particle physics is becoming increasingly integrated at the global level.*
  - *Council's decision contributes to creating the conditions that will enable CERN to play a full role in any future facility wherever in the world it might be.*

- The key points agreed by Council include:
  - *All states shall be eligible for Membership, irrespective of their geographical location;*
  - *A new Associate Membership status is to be introduced to allow non-Member States to establish or intensify their institutional links with CERN;*
  - *Participation of CERN in global projects wherever sited.*

- Applications for Membership from Cyprus, Israel, Serbia, Slovenia and Turkey have already been received by the CERN Council, and are undergoing technical verification.

We need to define the most appropriate organizational form for global projects NOW and need to be open and inventive (scientists, funding agencies, politicians. . .)

Mandatory to have accelerator laboratories in all regions as partners in accelerator development / construction / commissiong / exploitation

Planning and execution of HEP projects today need global partnership for *global, regional and national* projects

in other words: for the whole program

Use the exciting times ahead to establish such a partnership

Particle Physics can and should play its role as

spearhead in innovations as in the past

now and in future