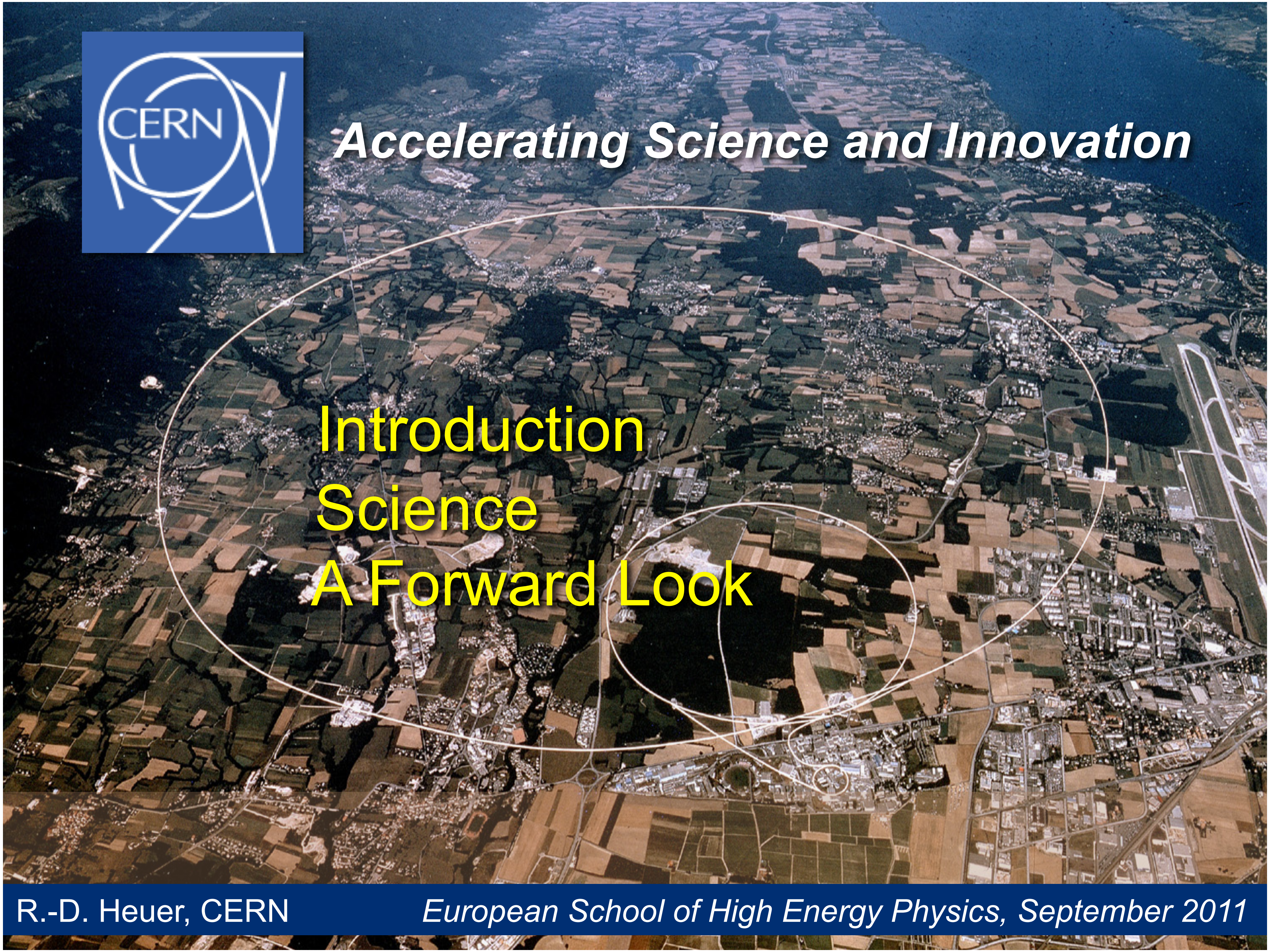
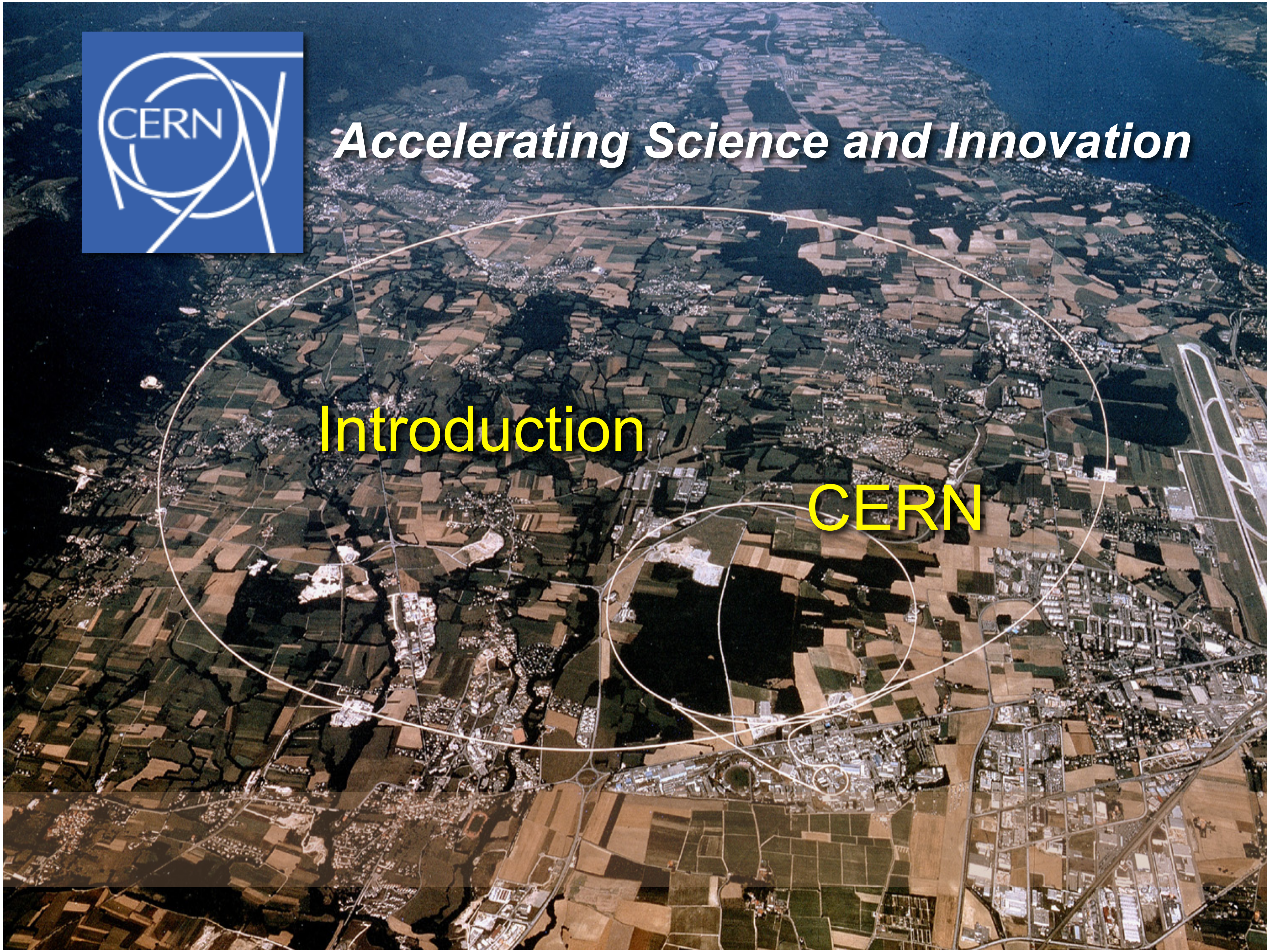


Accelerating Science and Innovation

Introduction
Science
A Forward Look

R.-D. Heuer, CERN

European School of High Energy Physics, September 2011

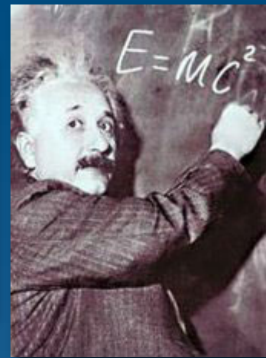

CERN
Accelerating Science and Innovation
Introduction
CERN

Innovation
Education
CERN
uniting people
Research

The Mission of CERN

- Push back the frontiers of knowledge

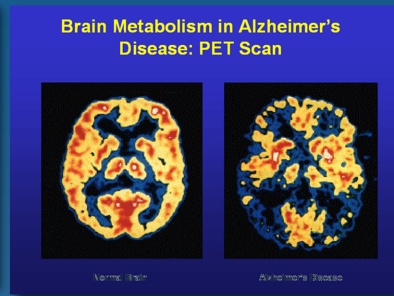
  E.g. the secrets of the Big Bang …what was the matter like within the first moments of the Universe's existence?



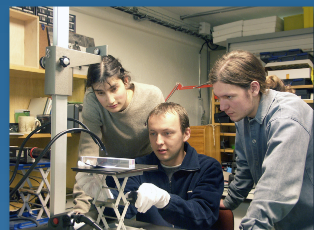
- Develop new technologies for accelerators and detectors

  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 was founded 1954: 12 European States

"Science for Peace"

Today: 20 Member States

~ 2300 staff
~ 790 other paid personnel
> 10000 users

Budget (2011) ~1000 MCHF

Countries applying for membership:
Cyprus, Israel, Serbia, Slovenia, Turkey

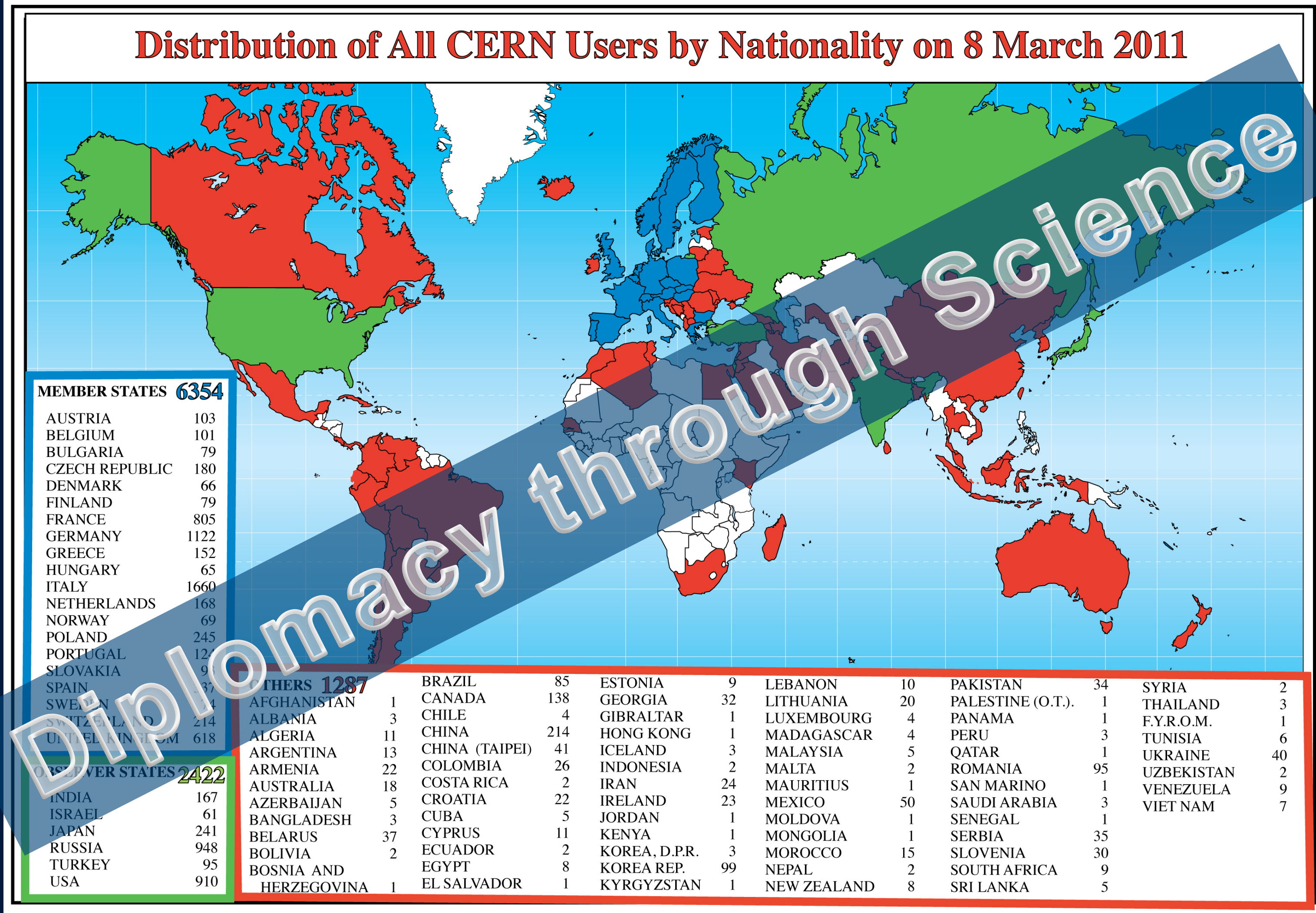
Latest News last Friday: Agreement signed admitting Israel to Associate Membership in Accession to Membership

...es: Austria, Belgium, Bulgaria, ...epublic, Denmark, Finland, France, Germany, ...ece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom

1 Candidate for Accession: **Romania**

8 Observers to Council: India, Israel, Japan, the Russian Federation, the United States of America, Turkey, the European Commission and UNESCO

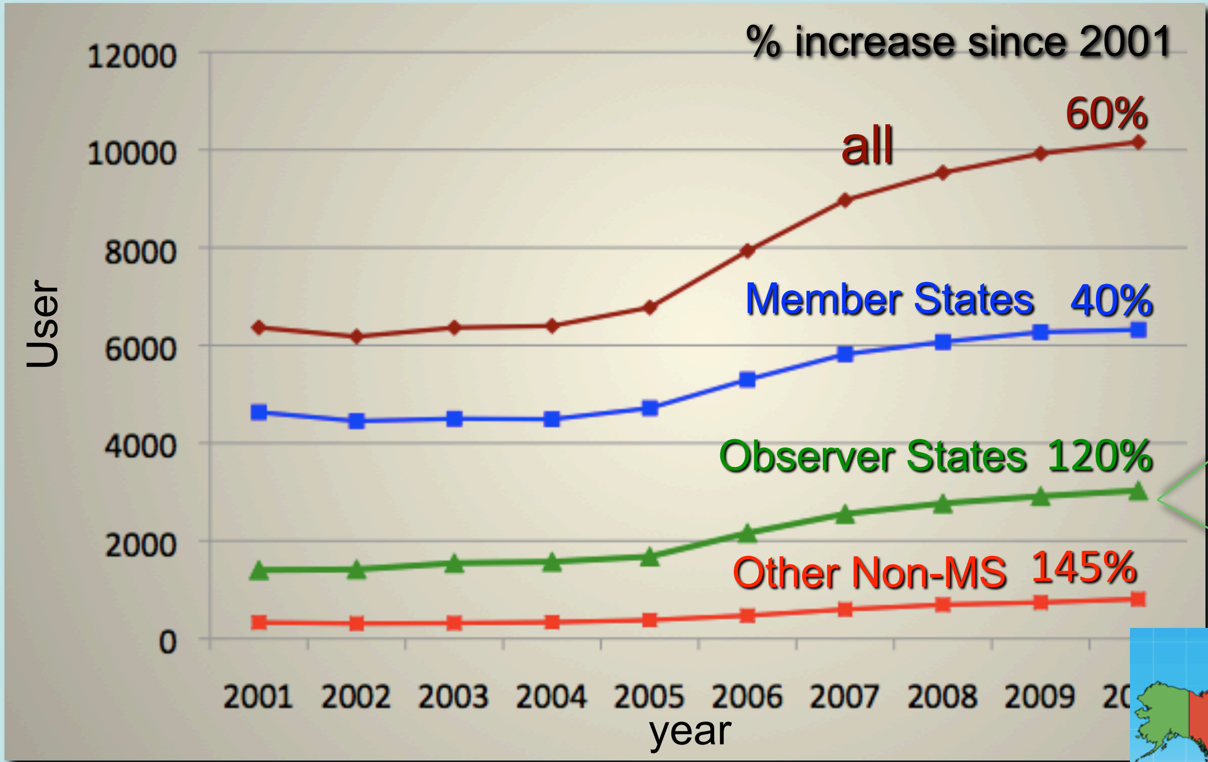
Science is getting more and more global

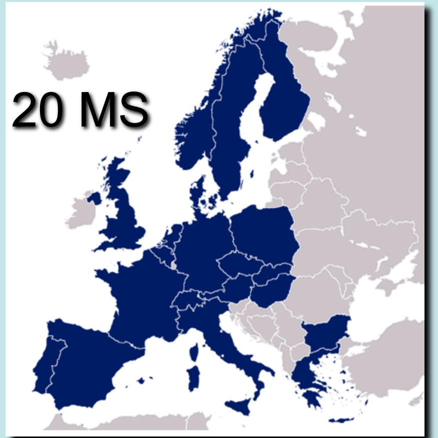


Operating very high profile Research Infrastructures is a very effective way to avoid brain drain – and promote brain gain

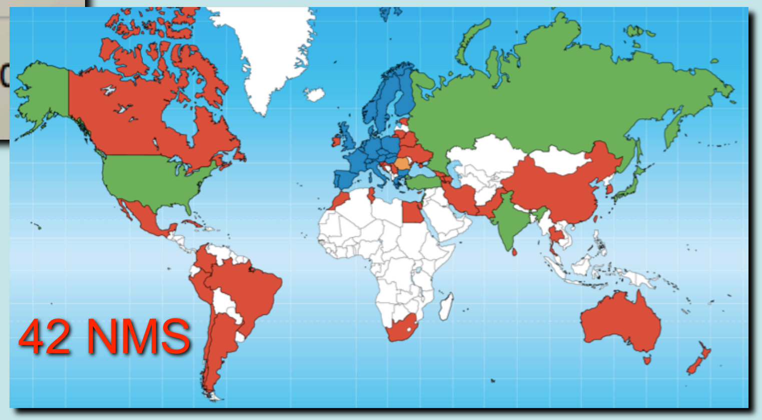
Impact of LHC on Evolution of CERN Users

Evolution of the number of CERN users by geographical location of the home institute: 2001-2010





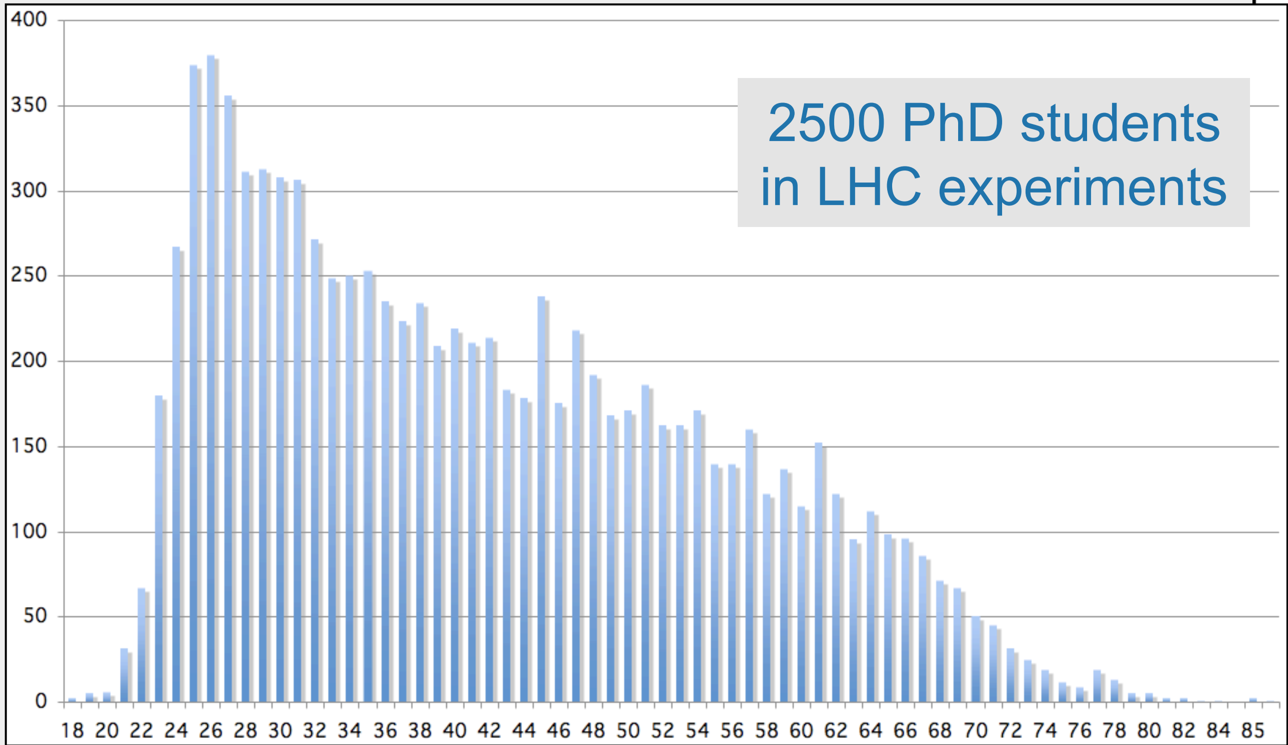
6 Observer States:
India, Israel, Japan, Russia, Turkey, USA



Age Distribution of Scientists

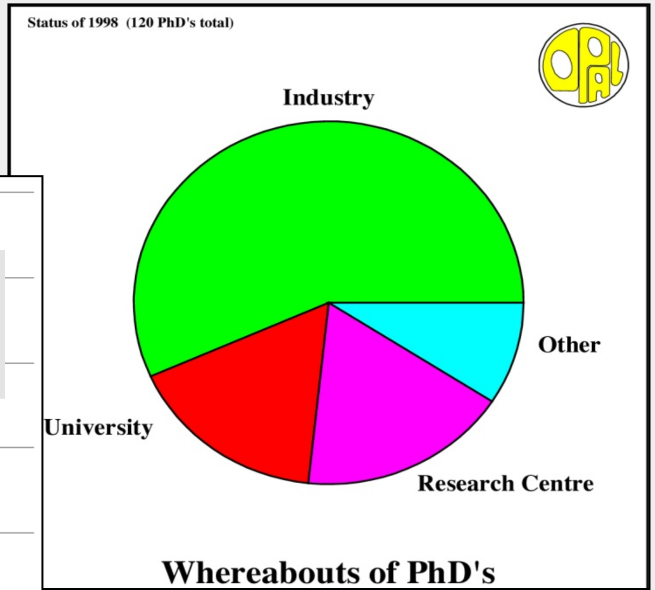
- and where they go afterwards

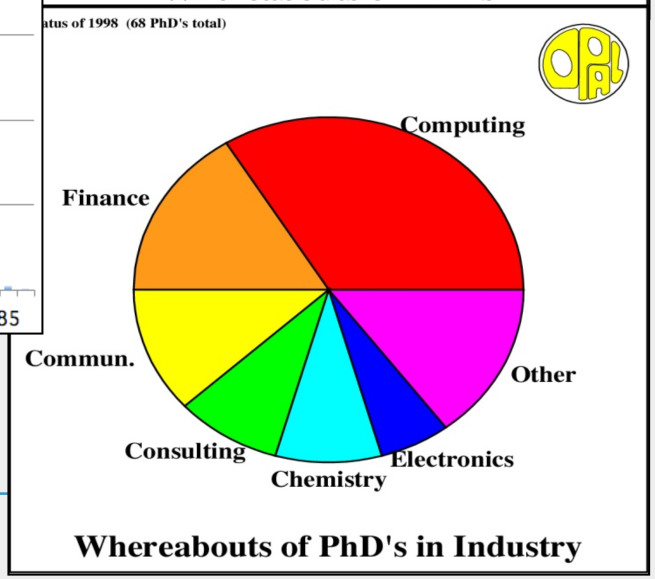
Survey in March 2009



2500 PhD students in LHC experiments

They do not all stay: where do they go?



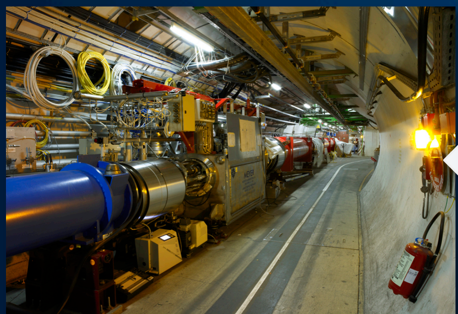


Innovation
Education
CERN
uniting people
Research

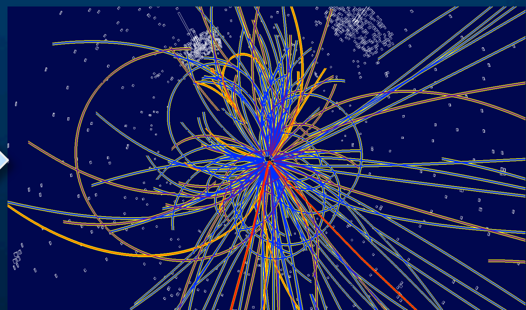
CERN: Particle Physics and Innovation

- **Interfacing** between fundamental science and key technological developments

- **CERN Technologies and Innovation**



Accelerating particle beams



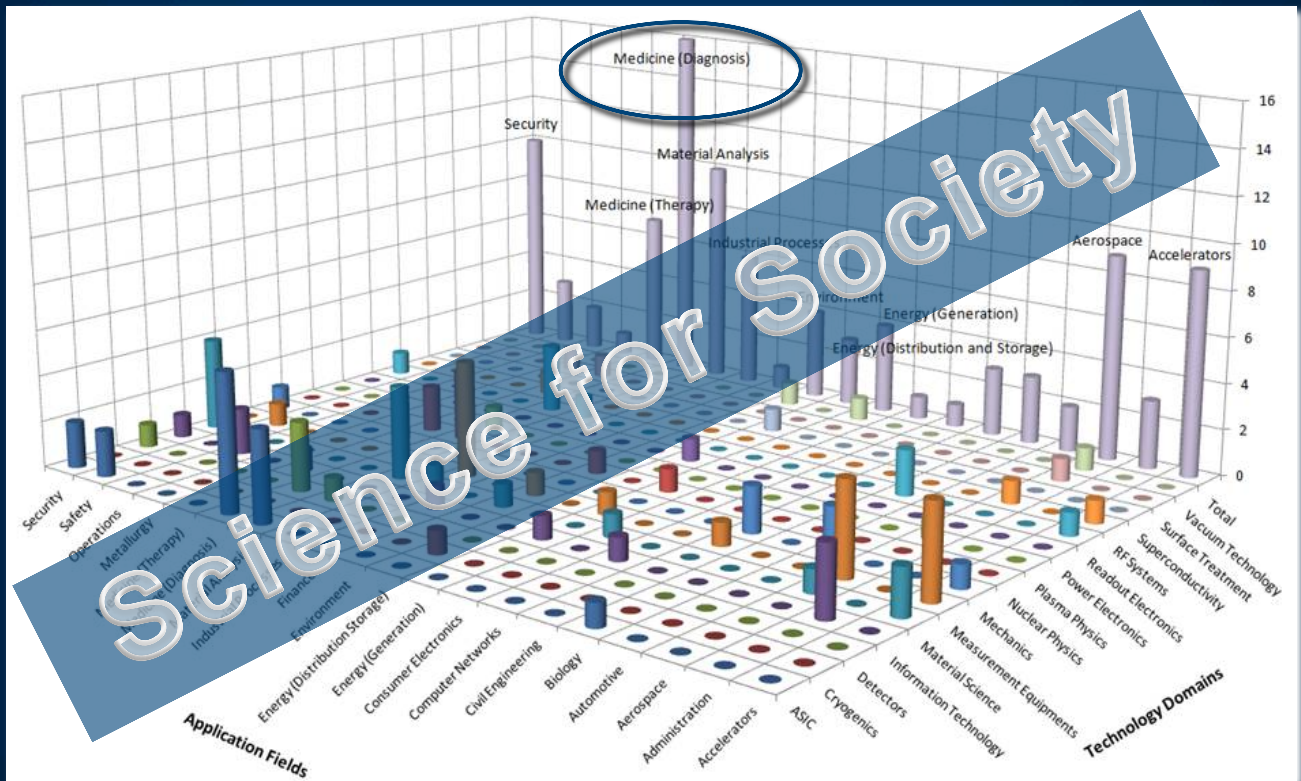
Detecting particles

Large-scale computing (Grid)

CERN Technologies and Innovation

Innovation · Education · Research — CERN uniting people

Cutting edge Research Infrastructures play a key role in a knowledge driven society

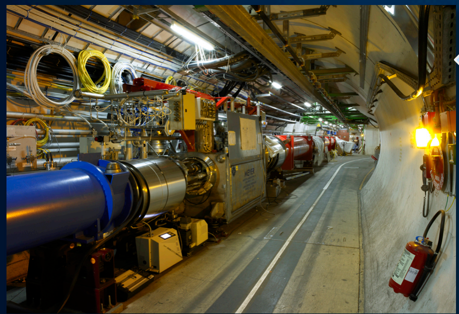


Knowledge is – and will be more and more – the most precious resource for a sustainable development

Innovation
Education
CERN
uniting people
Research

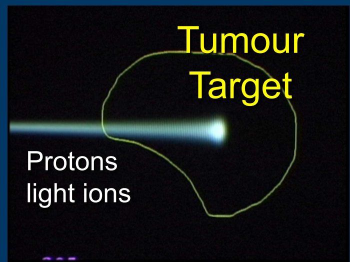
CERN Technologies and Innovation
Example: Medical applications

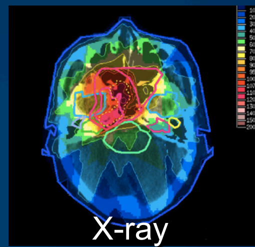
Combining Physics, ICT, Biology and Medicine to fight cancer

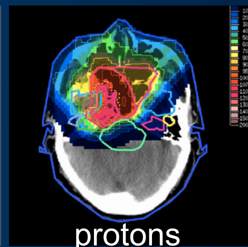


Accelerating particle beams
~30’000 accelerators worldwide
~17’000 used for medicine

Hadron Therapy

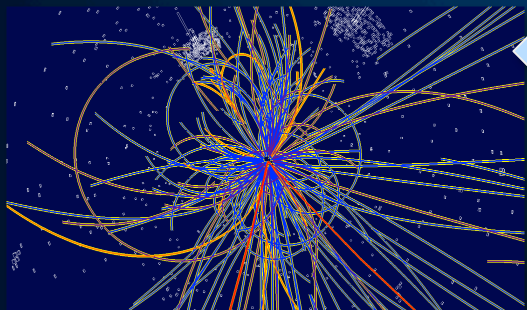






Leadership in Ion Beam Therapy now in Europe and Japan

>70’000 patients treated worldwide (30 facilities)
>21’000 patients treated in Europe (9 facilities)

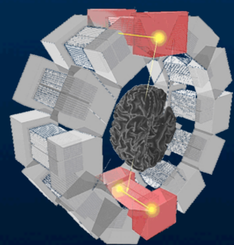


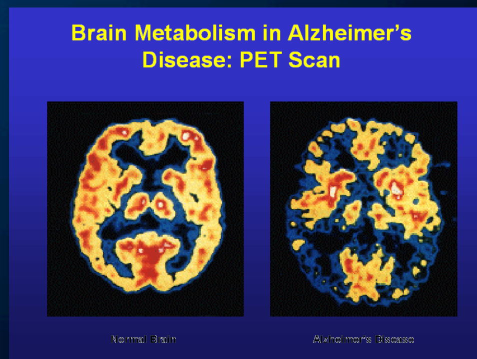
Detecting particles

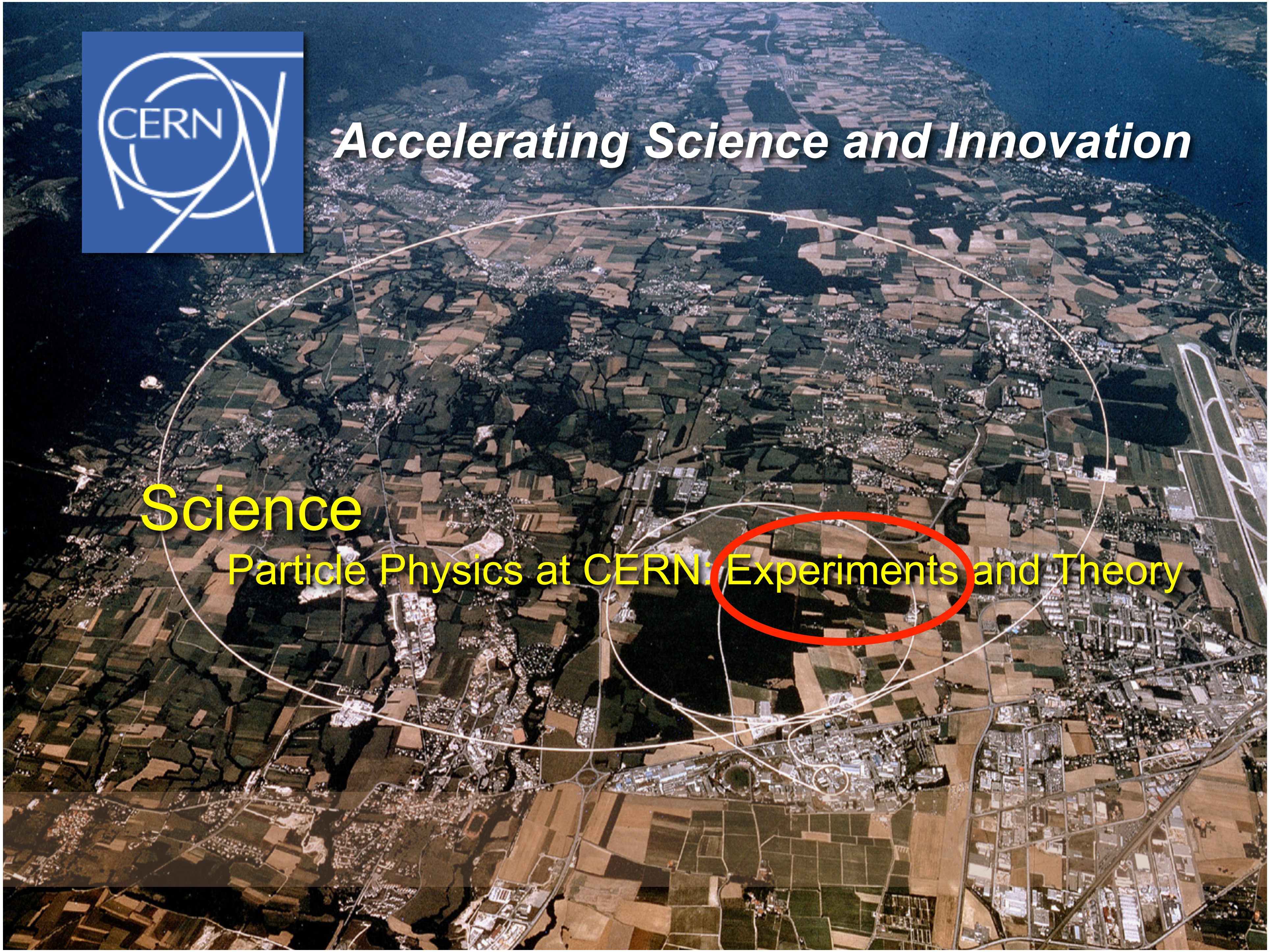
Imaging

PET Scanner

Clinical trial in Portugal for new breast imaging system (ClearPEM)



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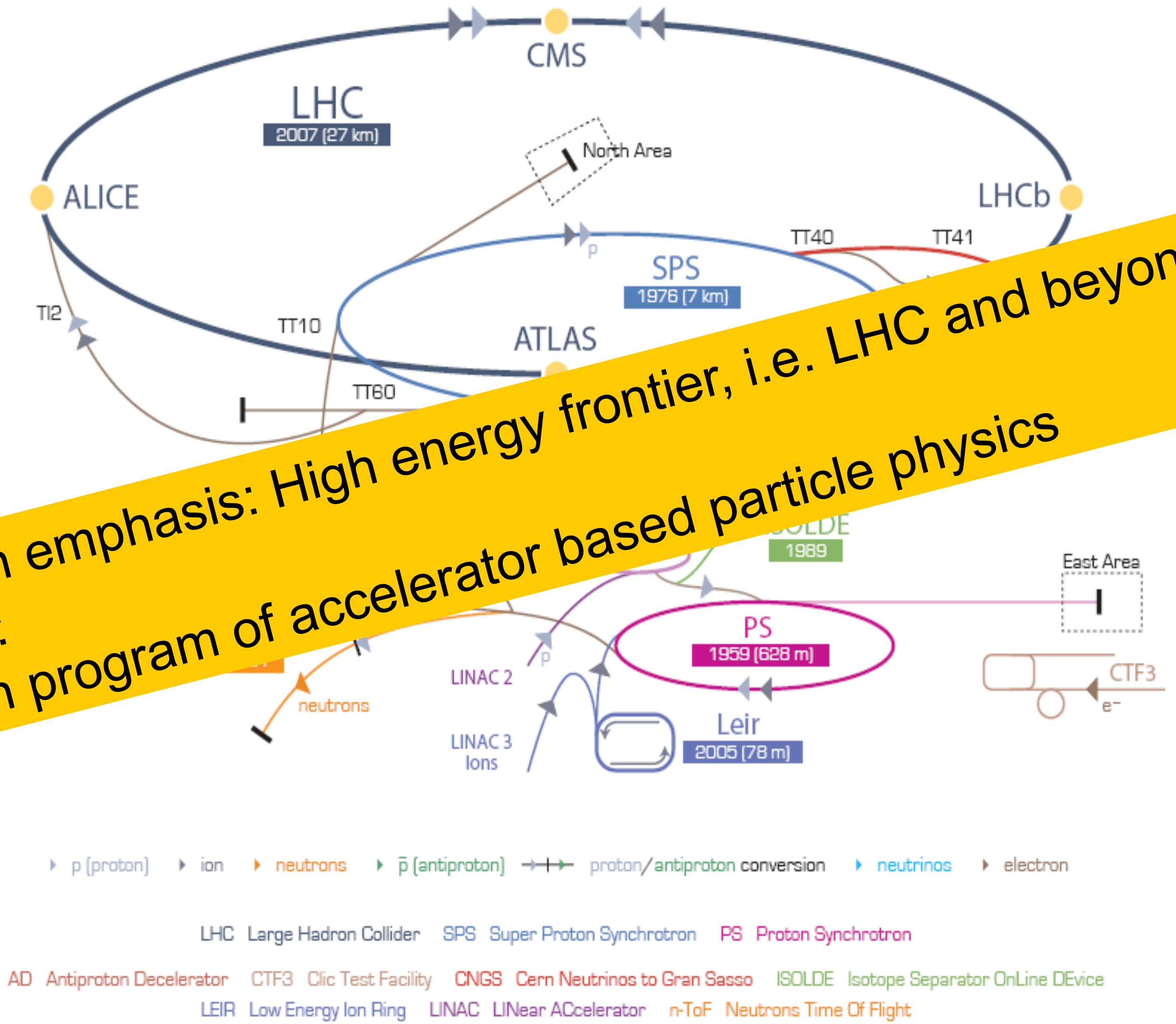
Science
Particle Physics at CERN: Experiments and Theory

Main emphasis: High energy frontier, i.e. LHC and beyond

But:

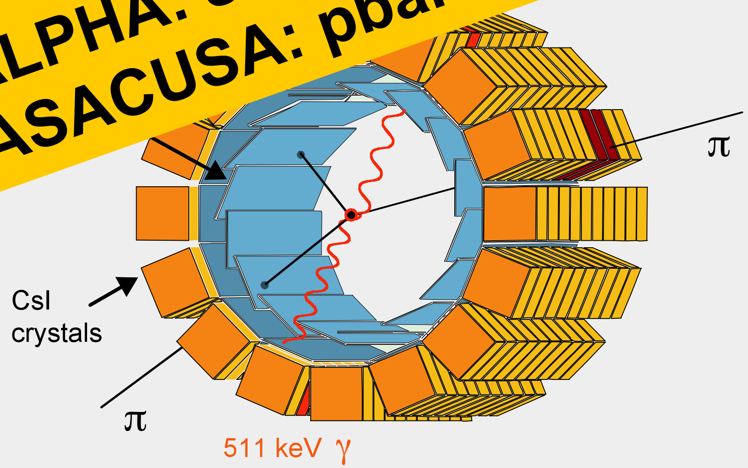
rich program of accelerator based particle physics



Fixed Target Physics

Antiproton Physics

Cold antiprotons
("manufacturing anti-matter")
1. PS $p \rightarrow pp$ 10^{-6}/collision
2. AD deceleration + co…
stochastic…
3. Ext…

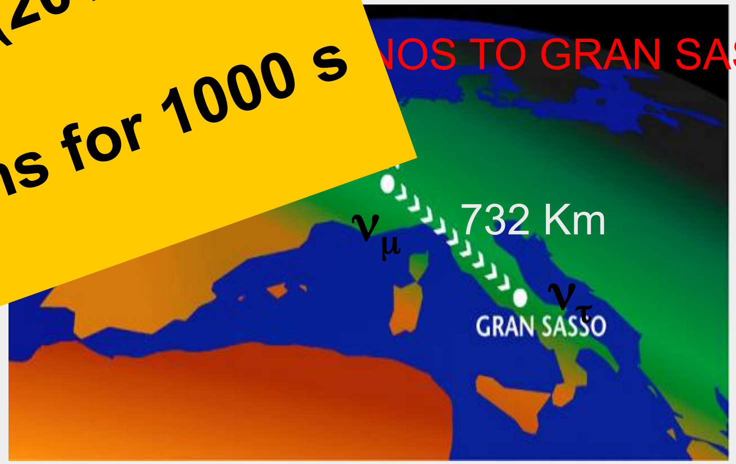


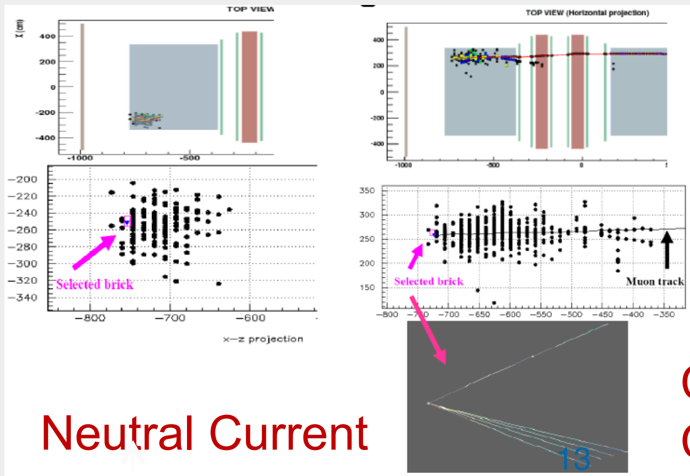
AD-Results published in Nature (2011):

ALPHA: storage of Anti-H Atoms for 1000 s

ASACUSA: pbar mass to 10^{-9}

…no Physics

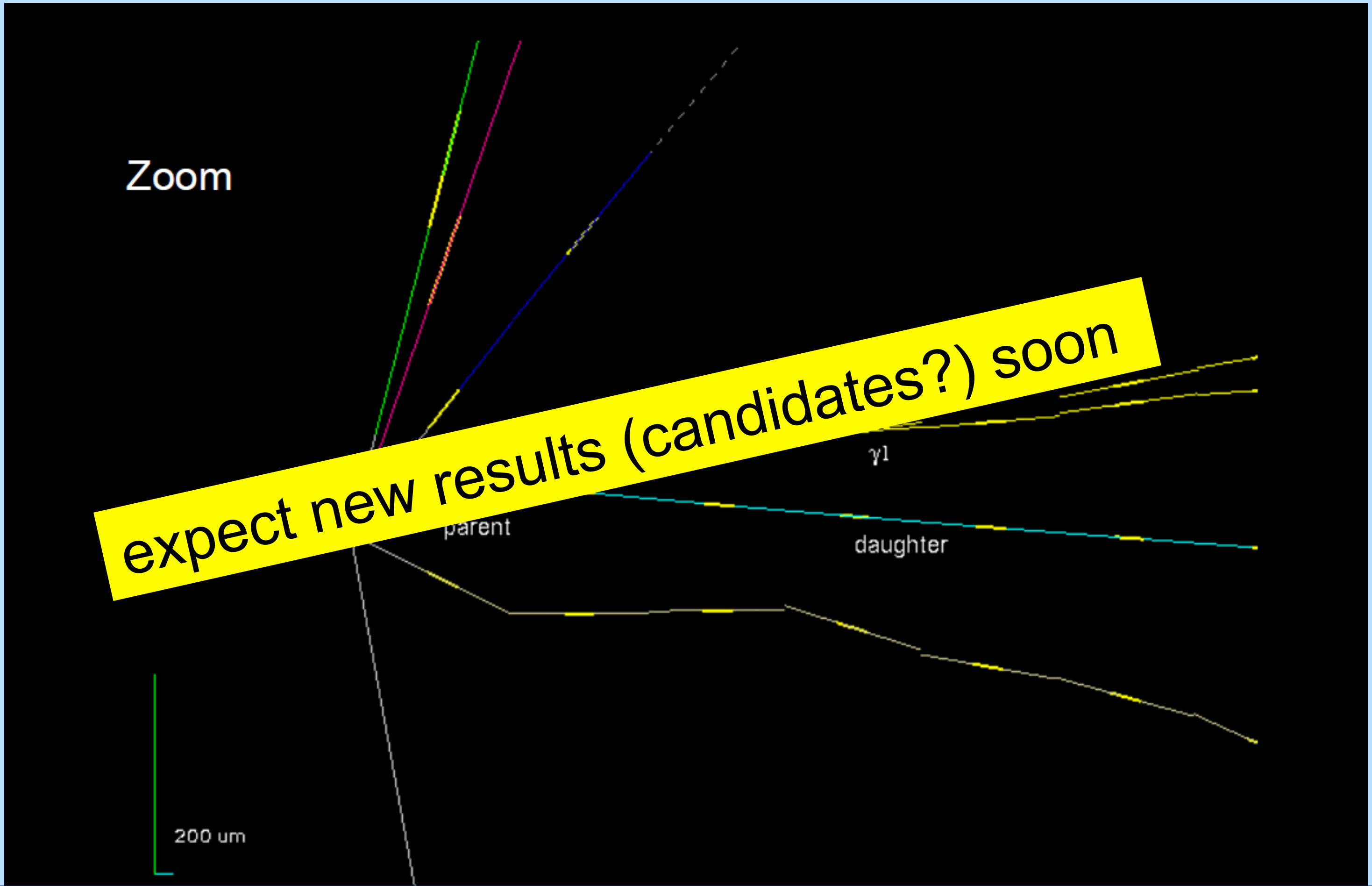




OPERA

CNGS - OPERA

First υ_τ Candidate



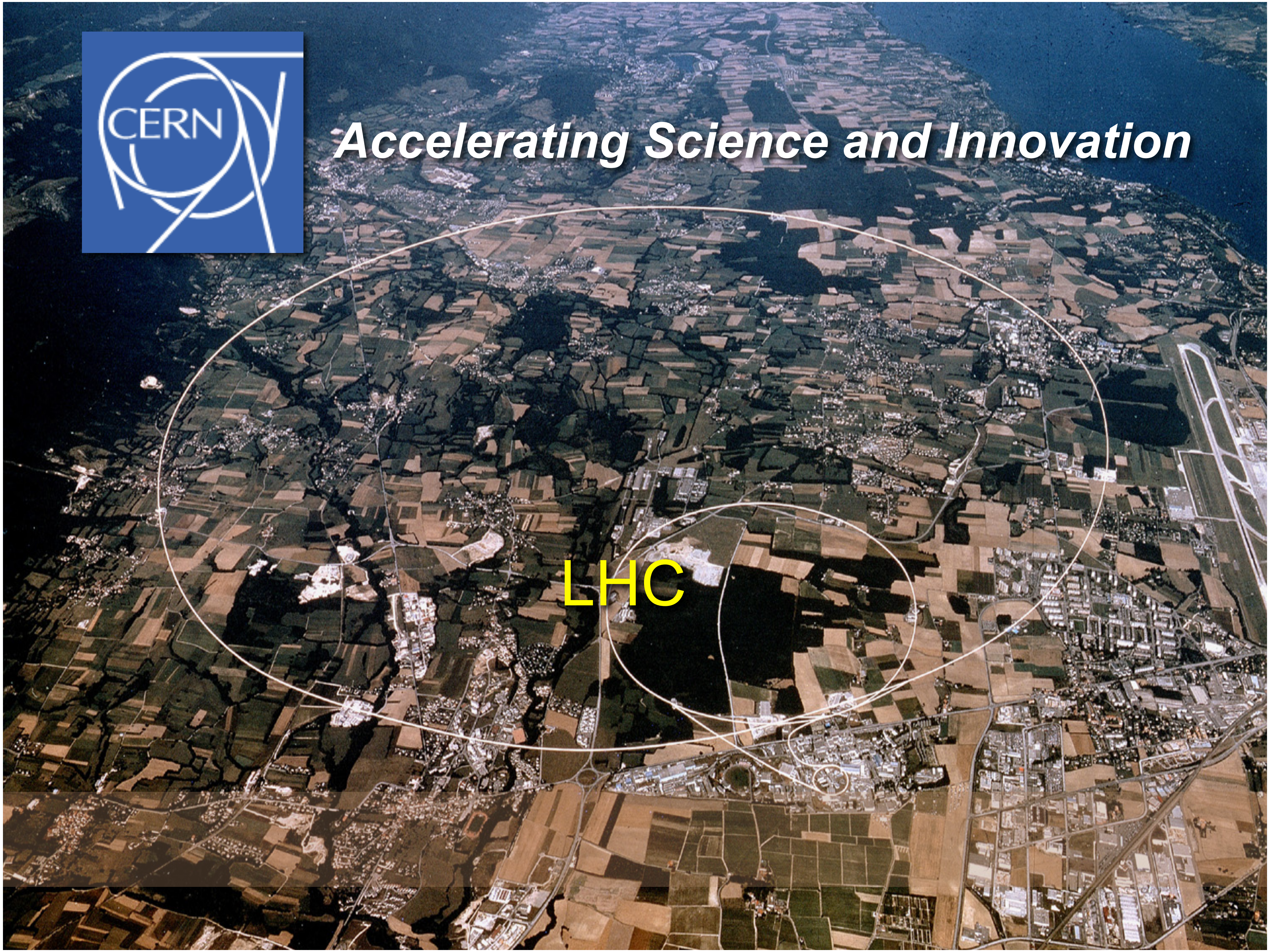
Muonless event 9234119599, taken on 22 August 2009, 19:27 (UTC)
(as seen by the electronic detectors)

The CLOUD Experiment

- Experiment using cloud chamber to study possible link between cosmic-rays and cloud formation.
  - Studies suggest that cosmic-rays may have an influence on the amount of cloud cover through the formation of new aerosols (tiny particles suspended in the ai… cloud drop…
- Under… …ng the …cosmic-rays, …mate.
- F… time high-energy physics accelerator used to study atmospheric and climate science.

First results published in Nature (August 2011):

cosmic rays enhance aerosol formation


CERN
Accelerating Science and Innovation
LHC

Past few decades

"Discovery" of Standard Model

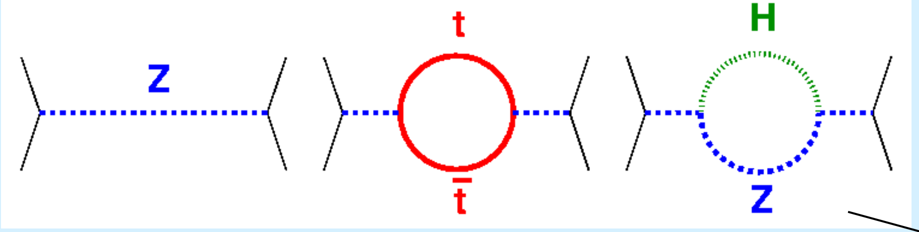
through synergy of

hadron - hadron colliders (e.g. Tevatron)

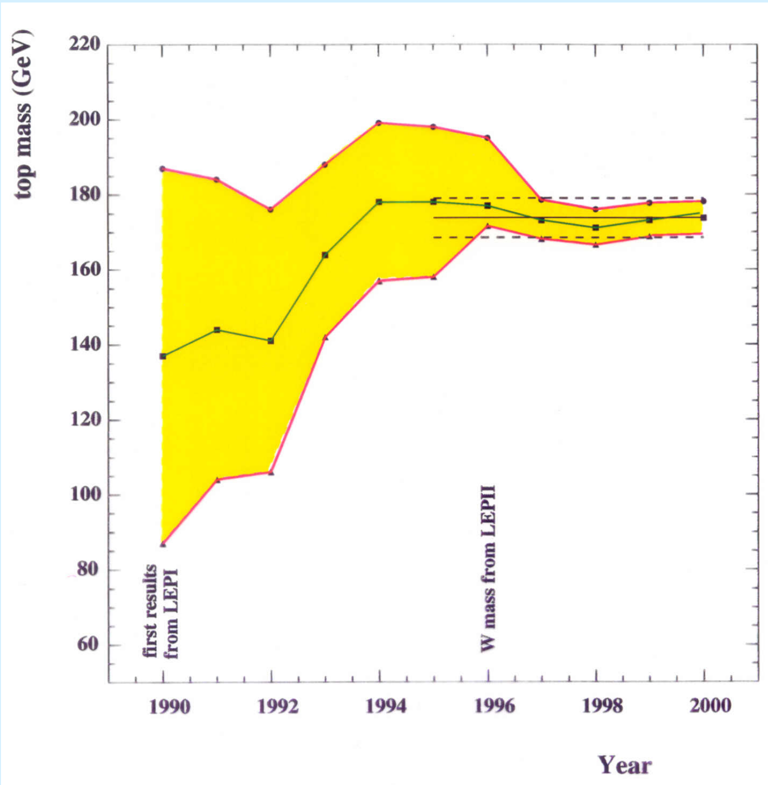
lepton - hadron colliders (HERA)

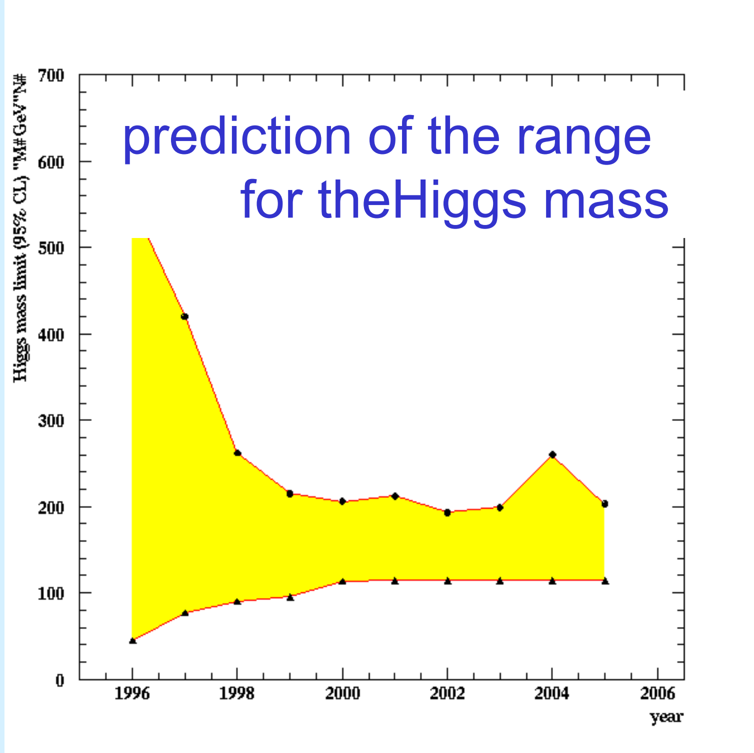
lepton - lepton colliders (e.g. LEP)

Test of the SM at the Level of Quantum Fluctuations



indirect determination of the top mass





possible due to

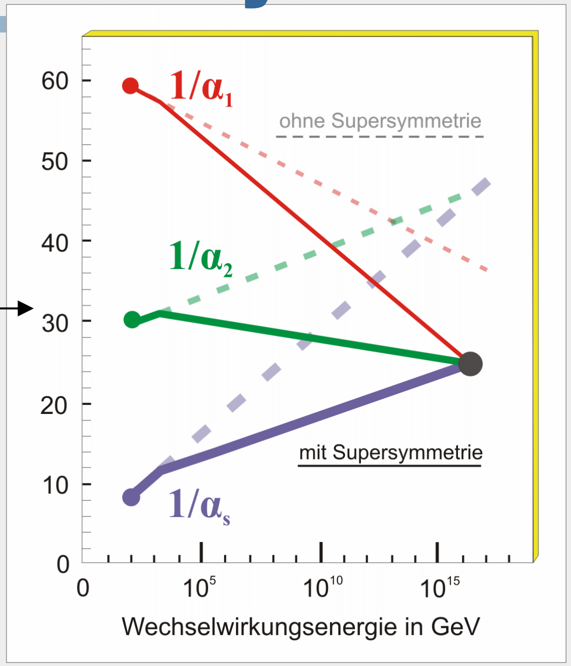
- precision measurements
- known higher order electroweak corrections

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

Key Questions of Particle Physics

origin of mass/matter or
origin of electroweak symmetry breaking

unification of forces



fundamental symmetry of forces and matter

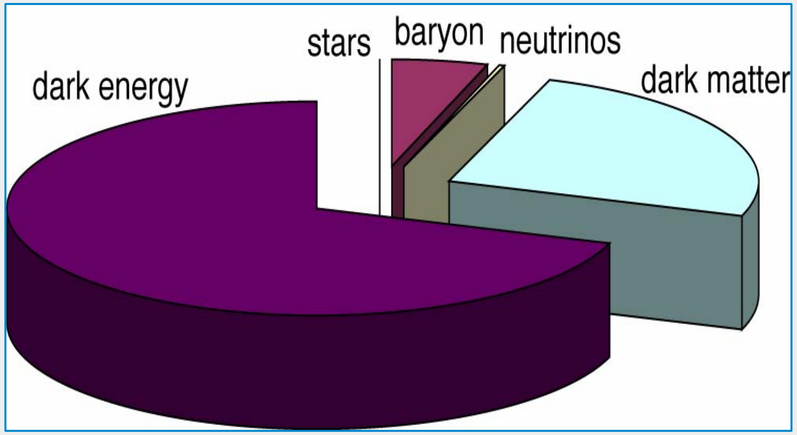
where is antimatter

unification of quantum physics and general relativity

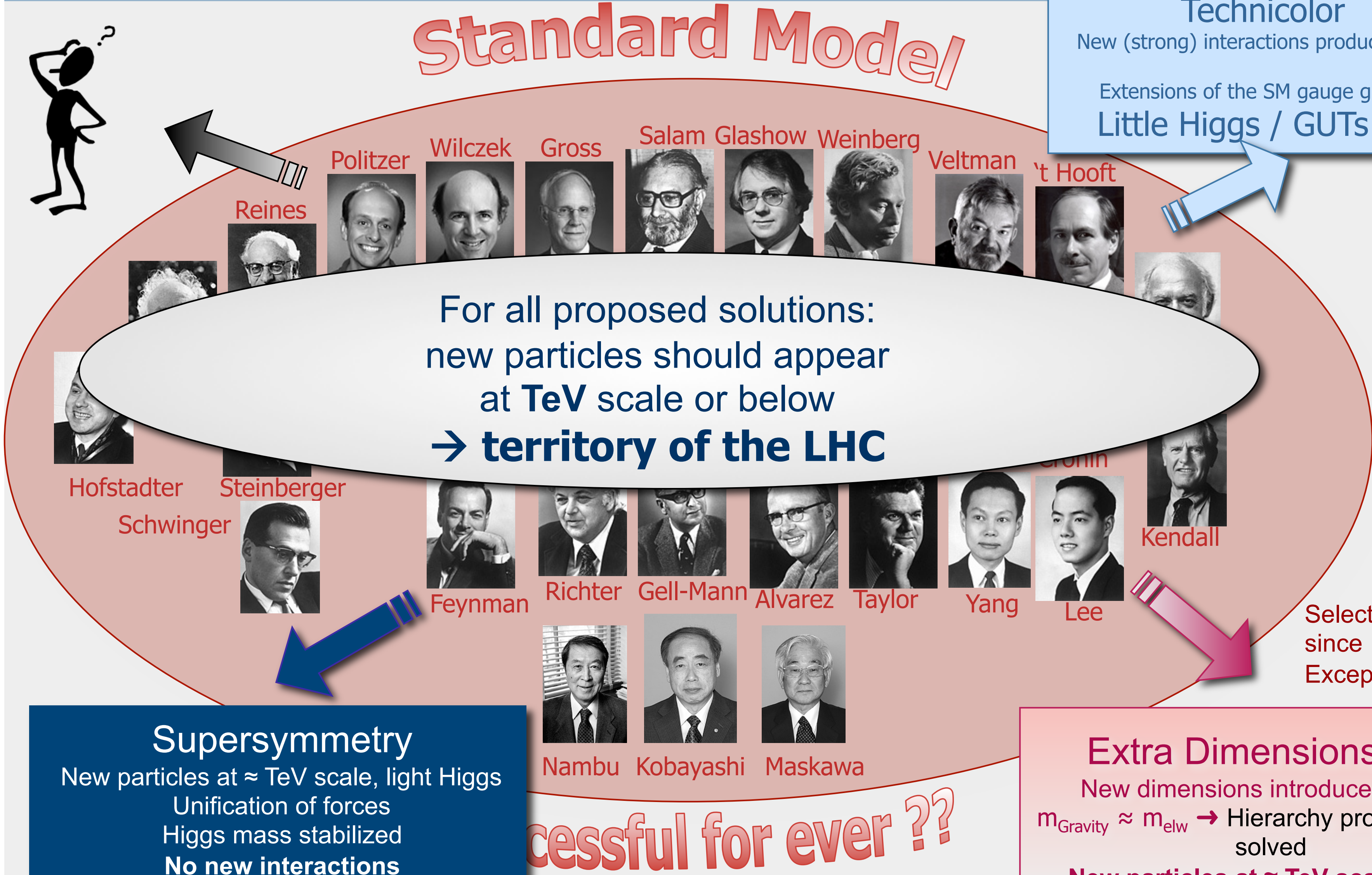
number of space/time dimensions

what is dark matter

what is dark energy



Solutions?



For all proposed solutions:
new particles should appear
at **TeV** scale or below
→ **territory of the LHC**

Technicolor
New (strong) interactions produce EWSB

Extensions of the SM gauge group :
Little Higgs / GUTs / …

Selected NP
since 1957
Except P. Higgs

Supersymmetry
New particles at ≈ TeV scale, light Higgs
Unification of forces
Higgs mass stabilized
No new interactions

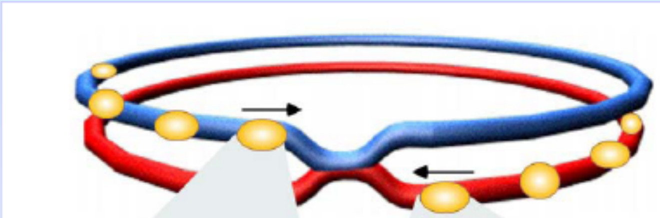
Extra Dimensions
New dimensions introduced
$m_{Gravity} \approx m_{elw}$ → Hierarchy problem solved
New particles at ≈ TeV scale

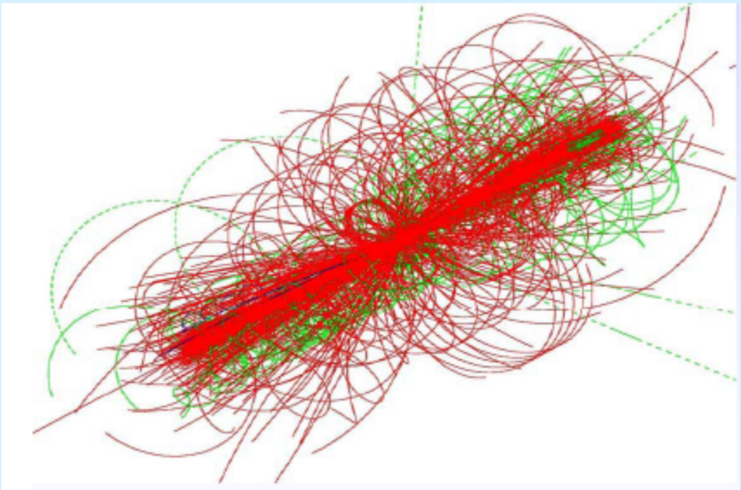
Enter a New Era in Fundamental Science

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
Proton-proton and Heavy Ion collisions
at E_{CM} up to 14 TeV

Proton-Proton Collisions at the LHC





- 2808 + 2808 proton bunches
  separated by 7.5 m
  → collisions every 25 ns
  = 40 MHz crossing rate

- 10^{11} protons per bunch

- at 10^{34}/cm^2/s
  ≈ 35 pp interactions per crossing
  pile-up

→ ≈ 10^9 pp interactions per second !!!

- in each collision
  ≈ 1600 charged particles produced

enormous challenge for the detectors
and for data collection/storage/analysis

Experimental Challenge

High Interaction Rate: $N = L\sigma = 10^{34} \times 100 \times 10^{-27}$

pp interaction rate 10^9 interactions/s
data for only ~100 out of the 40 million crossings can be recorded per sec (100 – 150 MB/sec)
need fast, pipelined, intelligent electronics and sophisticated data-acquisition

High Energy and Large Particle Multiplicity

~ <20> superposed events in each crossing
~ 1000 tracks stream into the detector every 25 ns
need highly granular detectors with good time resolution for low occupancy
large detectors, a large number of channels

High Radiation Levels

radiation hard (tolerant) detectors and electronics

Physics Requirements

Follow from requirements to observe Higgs boson whether it is heavy or light, to observe Supersymmetry if it is there (missing energy), to find other new physics if it is there; all this in the presence of a huge background of standard processes (QCD)

Very good muon identification and momentum measurement

trigger efficiently and measure charge of a few TeV muons

High energy resolution electromagnetic calorimetry

~ 0.5% @ E_T~50 GeV

Powerful inner tracking systems

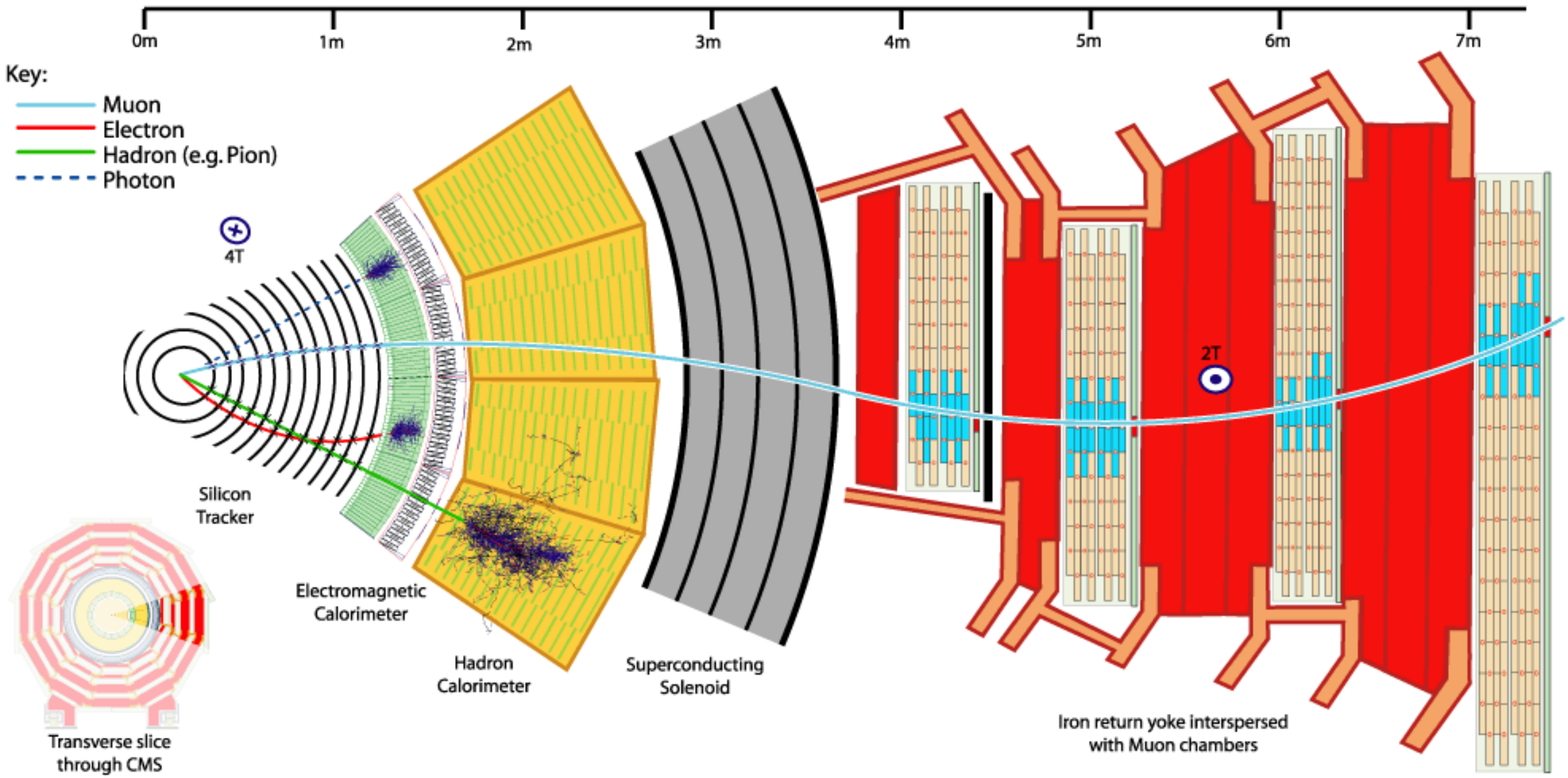
factor 10 better momentum resolution than at LEP

Hermetic calorimetry

good missing E_T resolution

(Affordable detector)

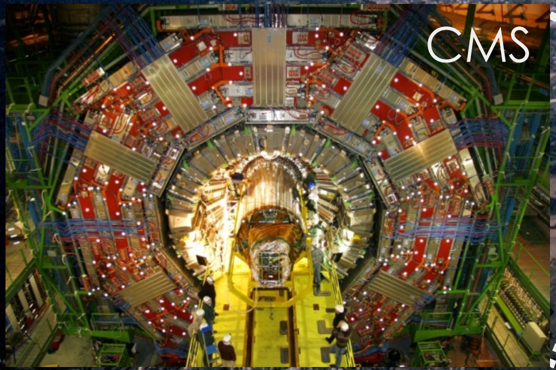
‘Generic’ experimental set-up



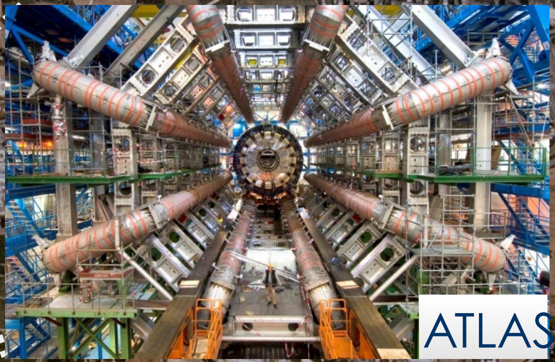
Deflection ~ BL^2/p → need high B (s.c.) and large magnets; need high resolution position measurements (10 -100μ) at large p; also energy and position measurement through total absorption (photon, electron, hadron)

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.

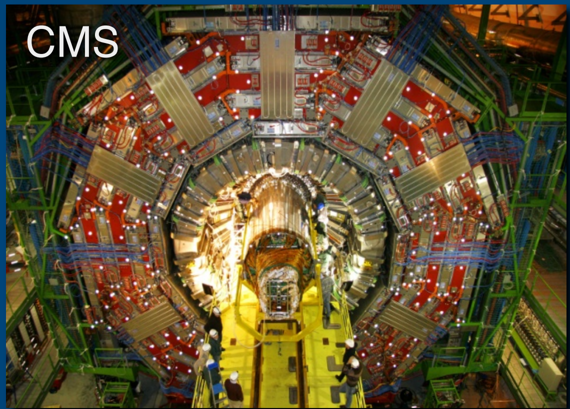


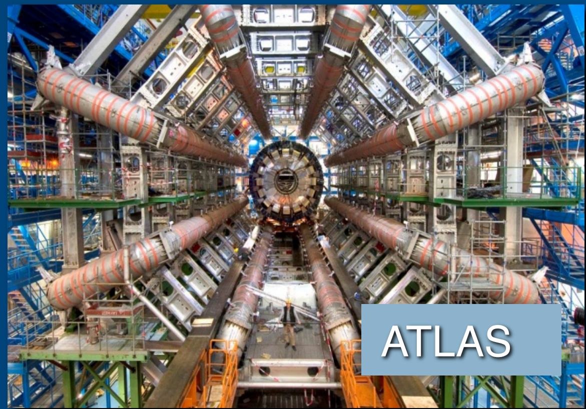
Exploration of a new energy frontier
Proton-proton and Heavy Ion collisions
at E_{CM} up to 14 TeV



LHC Experiments → complementary

Specialised detector to study b-quarks → CPV



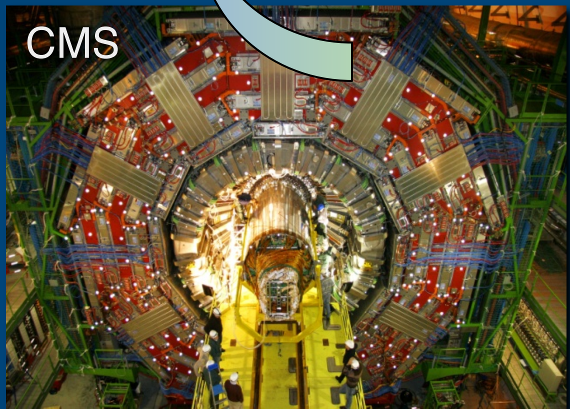


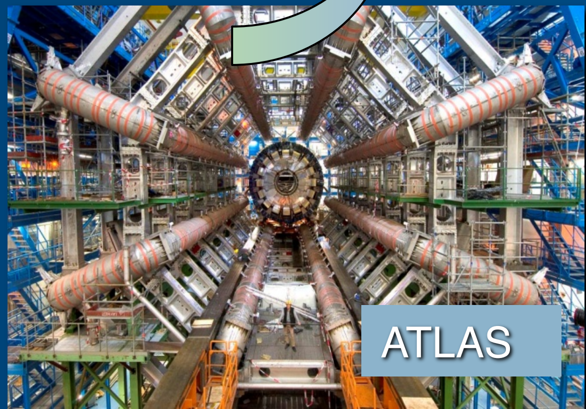
General purpose detectors

Specialised detector to study heavy ion collisions

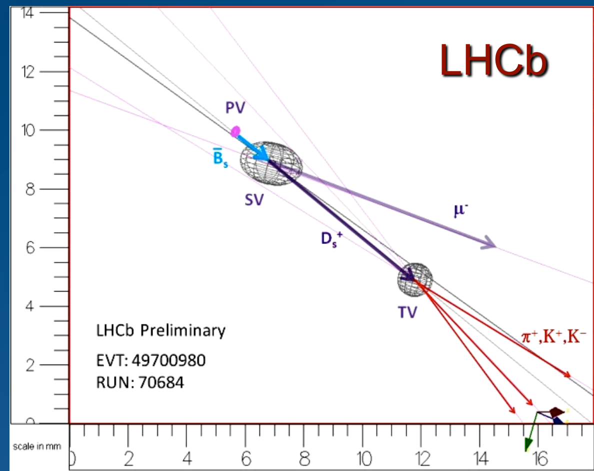
LHC Experiments → complementary

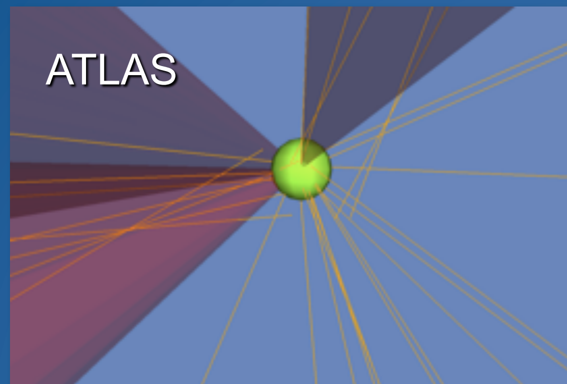
Overlap in physics reach





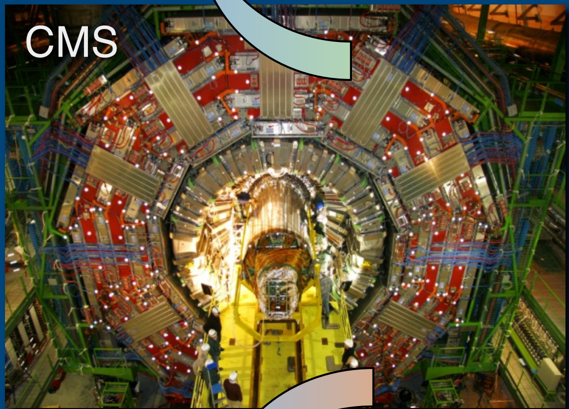
Key feature: reconstruct secondary vertex

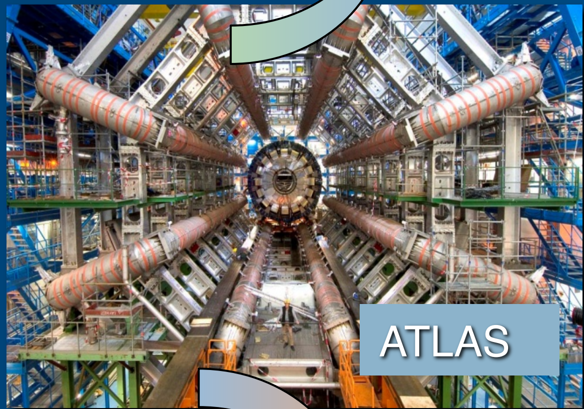




LHC Experiments → complementary

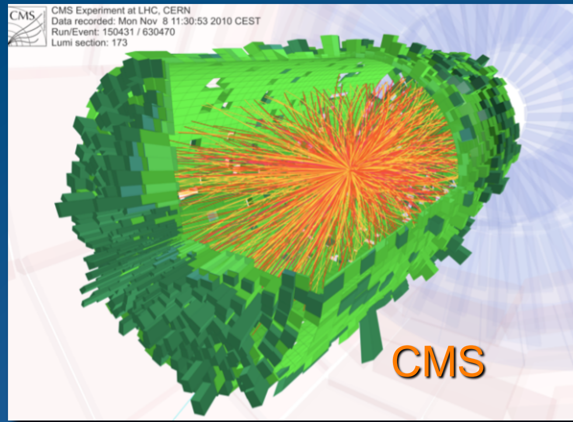
Overlap
in physics
reach

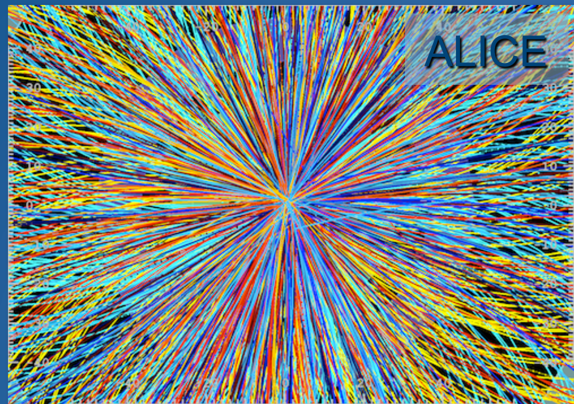


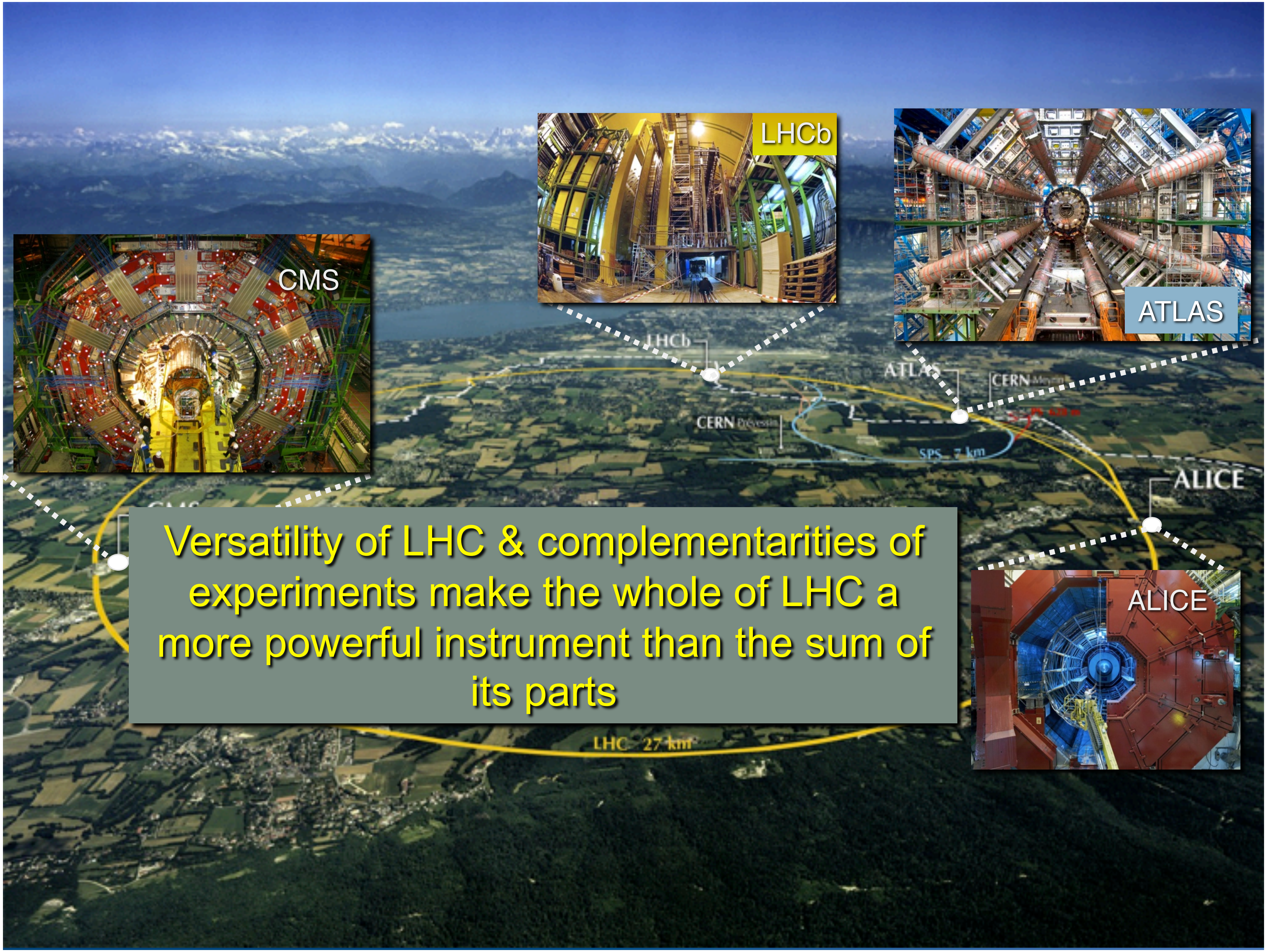


Overlap
in physics
reach

Key feature: reconstruct
> 20’000 charged tracks
in one event

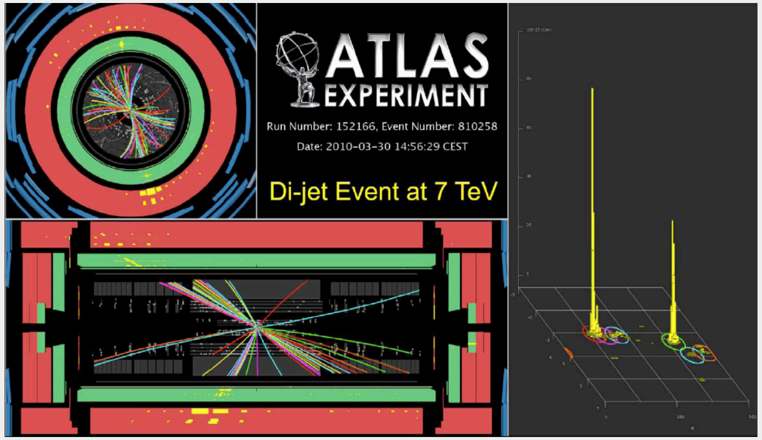


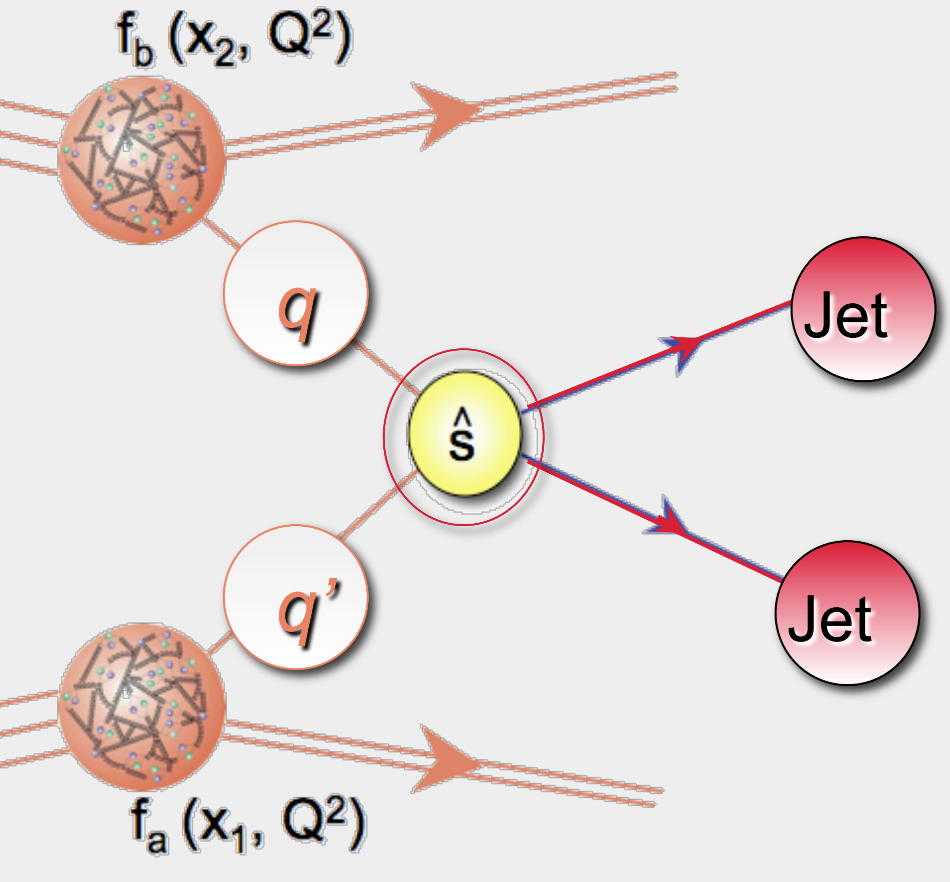




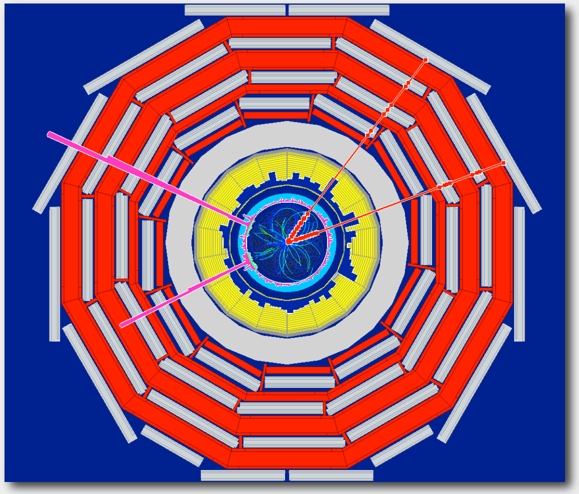
Versatility of LHC & complementarities of experiments make the whole of LHC a more powerful instrument than the sum of its parts

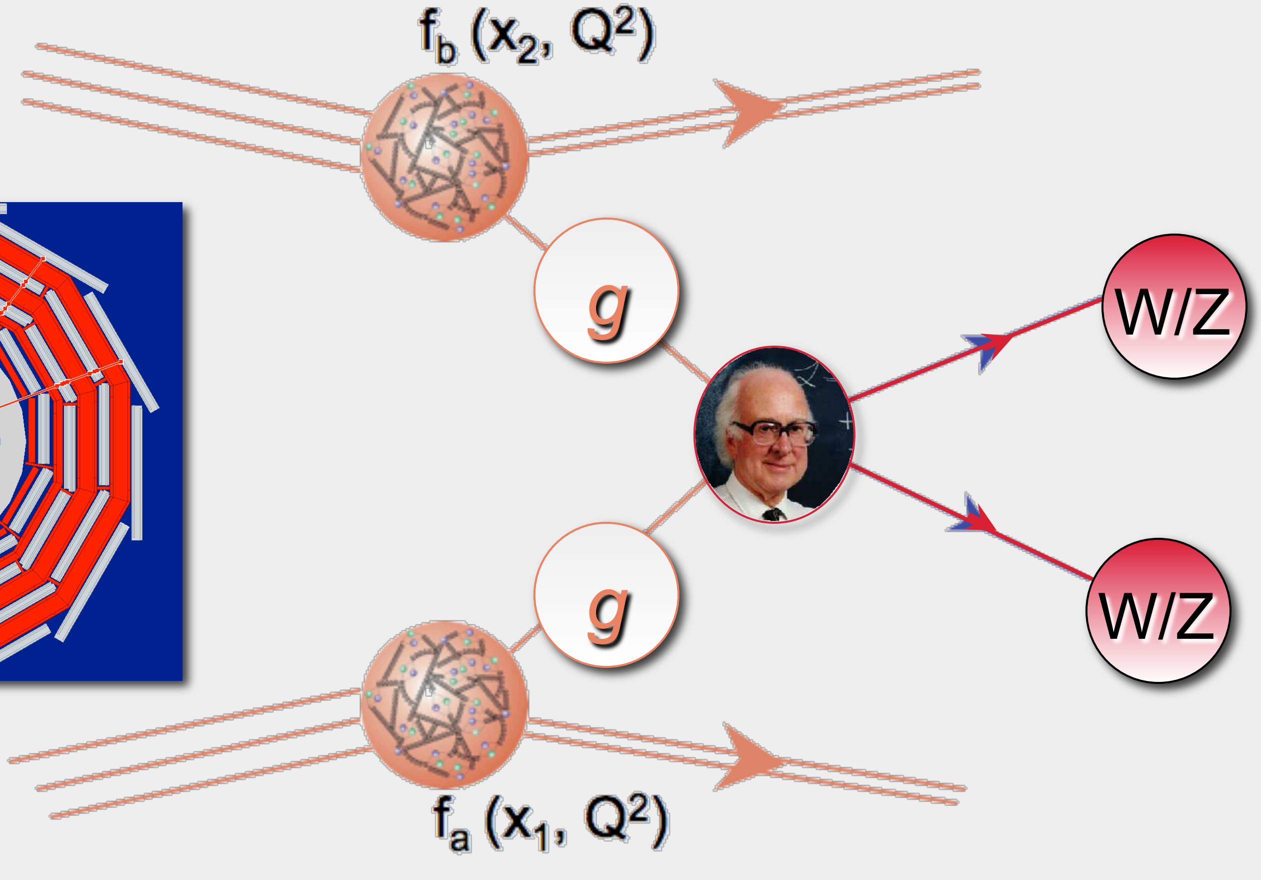
Basic processes at LHC



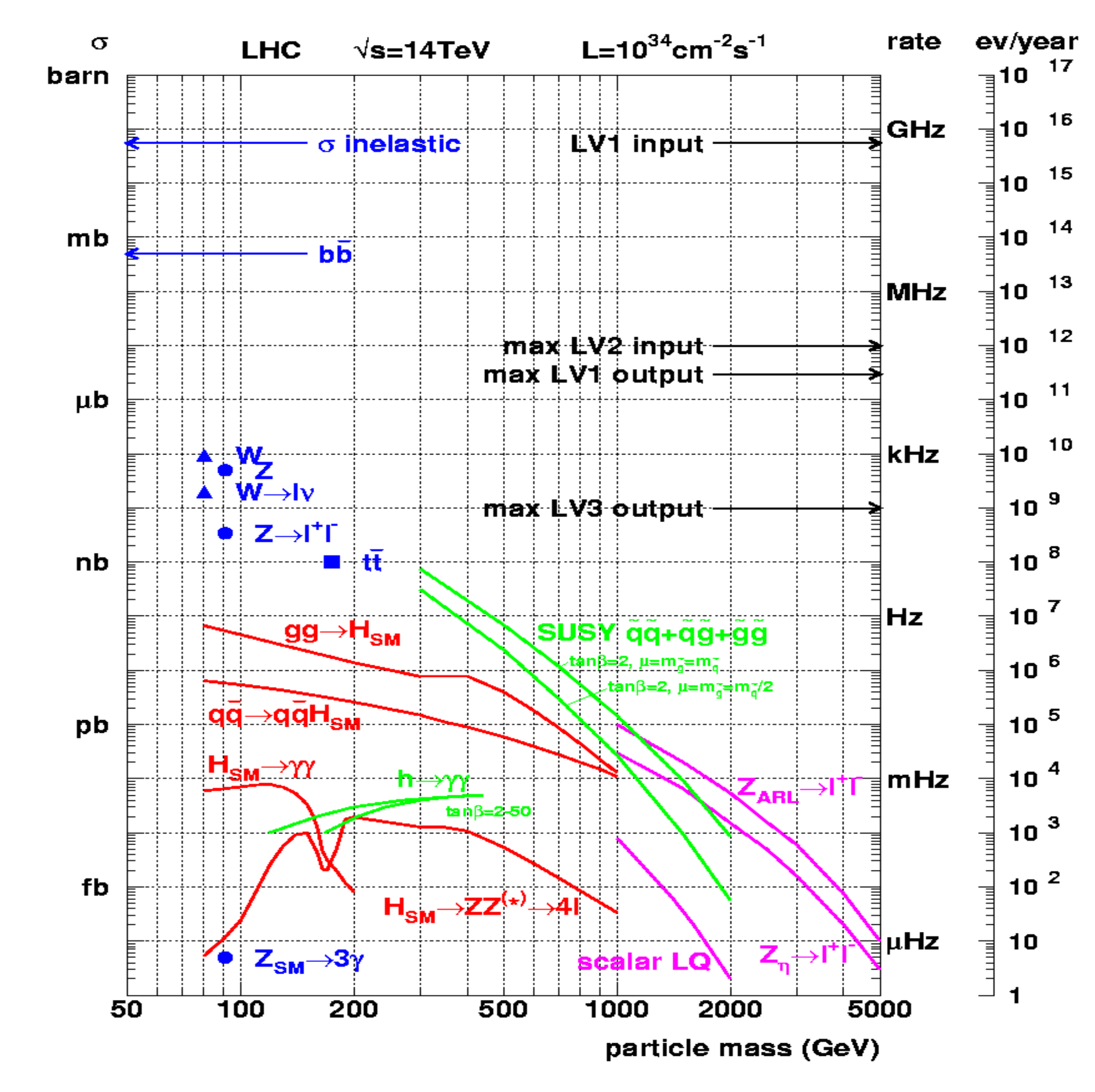


Basic processes at LHC





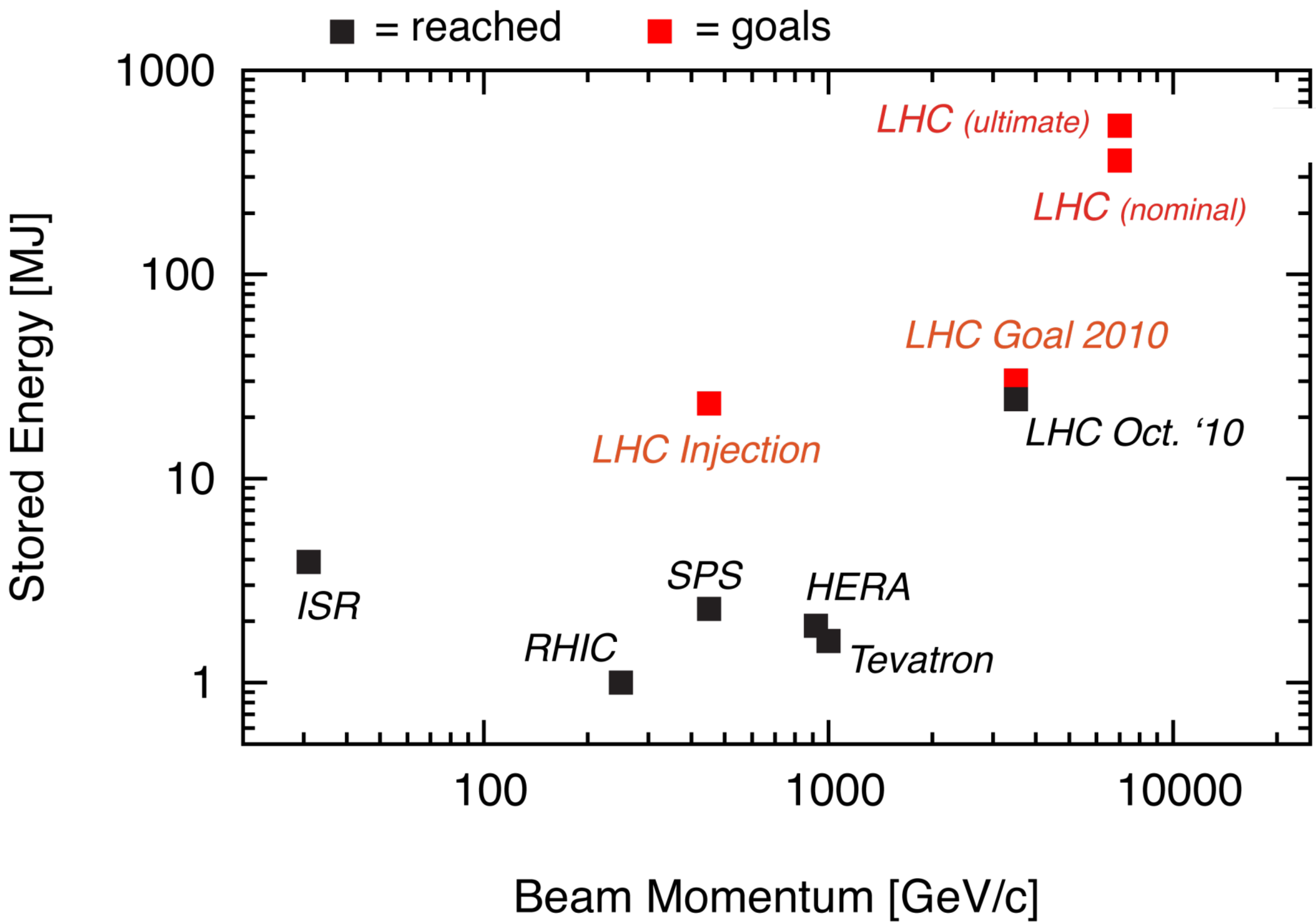
Cross sections at the LHC



"Well known" processes. Don't need to keep all of them …

New Physics!!
We want to keep!!

Stored Energy in the LHC



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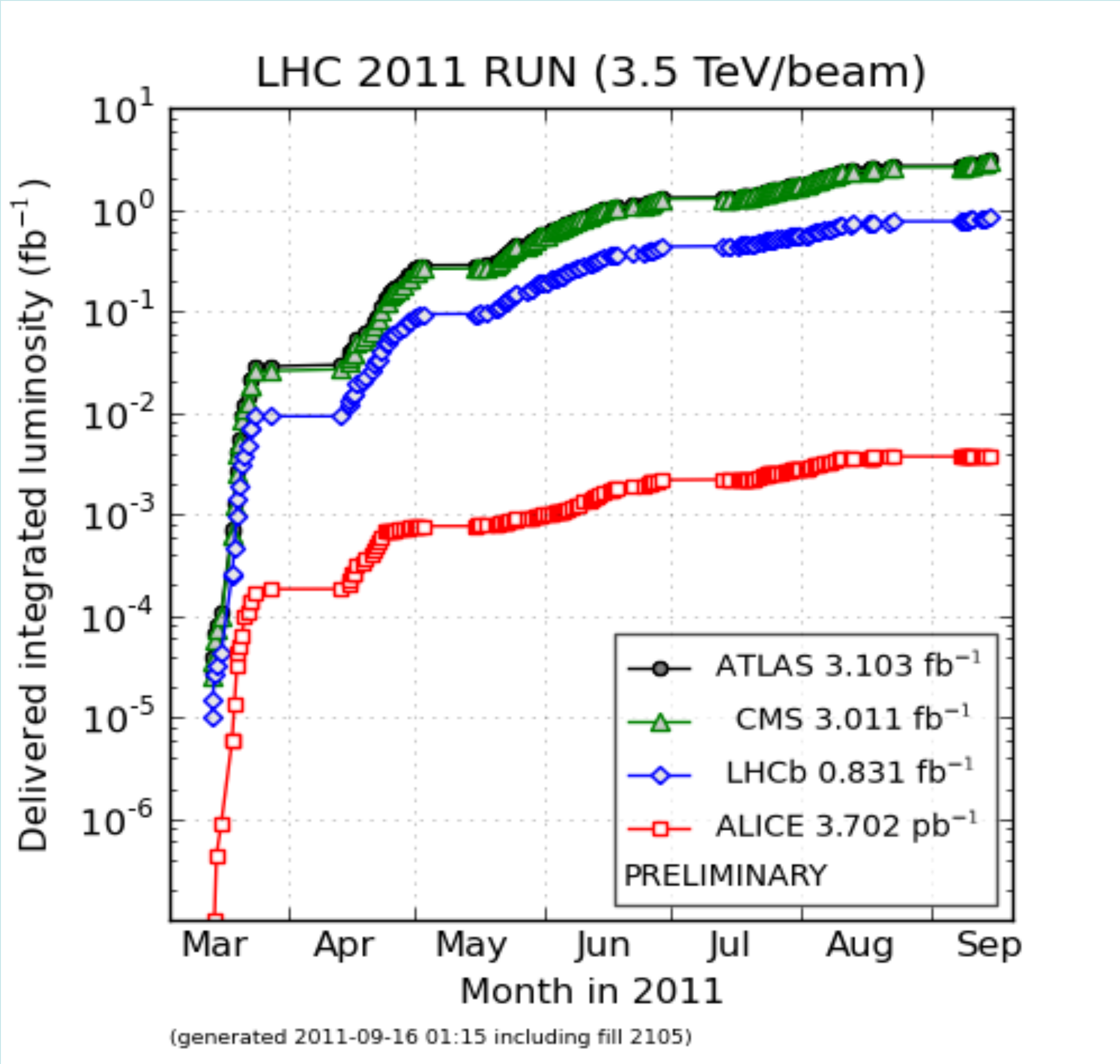
LHC Luminosity for 2011 Proton Run

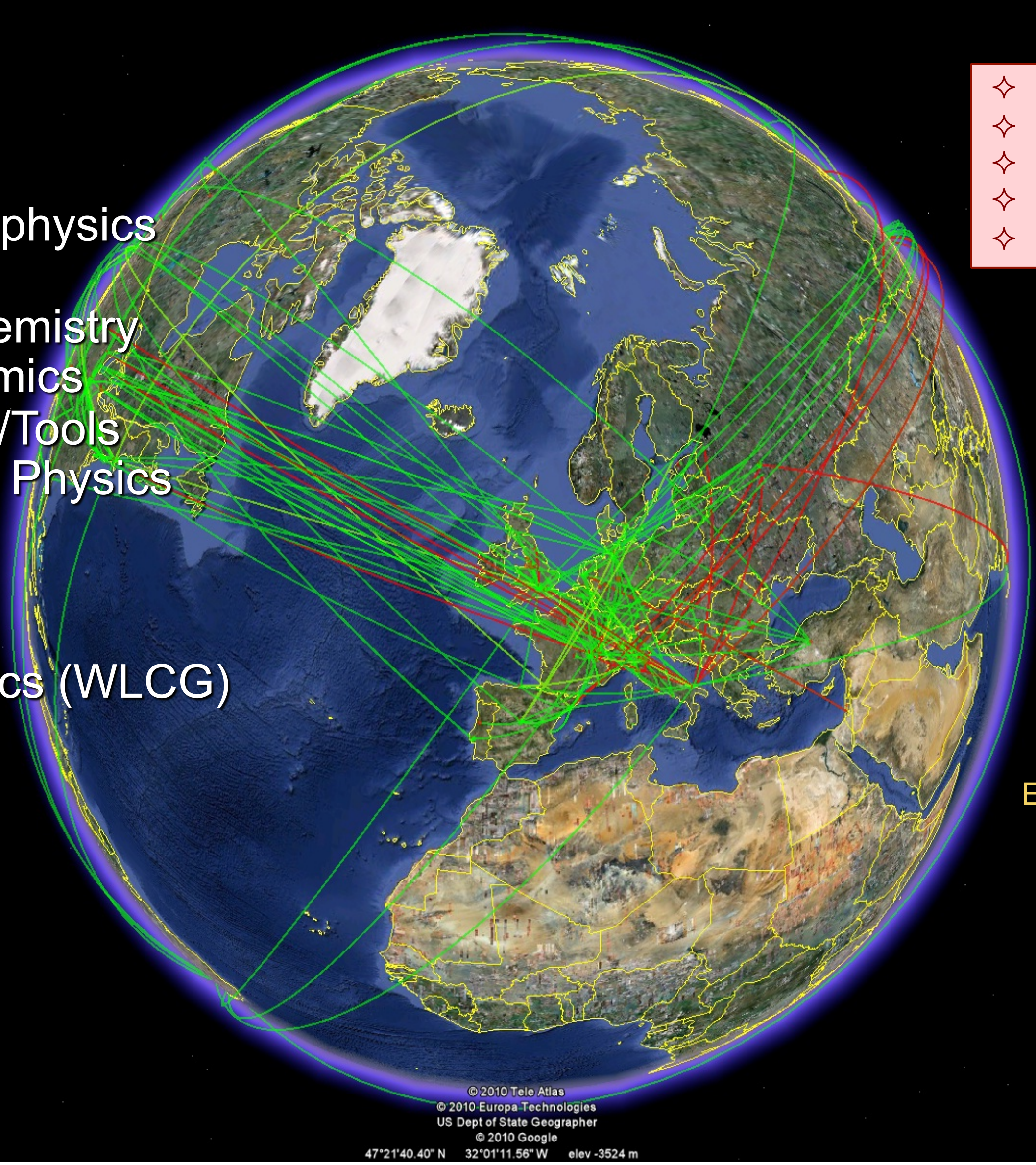


Grid Computing and CERN

Running jobs: 117948.0
Transfer rate: 4.94 GiB/sec

- 285 sites in 48 countries
- ~250k CPU cores
- ~100 PB disk
- Large number of users
- 1M jobs/day

Astronomy & Astrophysics
Civil Protection
Computational Chemistry
Comp. Fluid Dynamics
Computer Science/Tools
Condensed Matter Physics
Earth Sciences
Finance
Fusion
High Energy Physics (WLCG)
Humanities
Life Sciences
Material Sciences
Social Sciences



GÉANT

egee Enabling Grids for E-sciencE

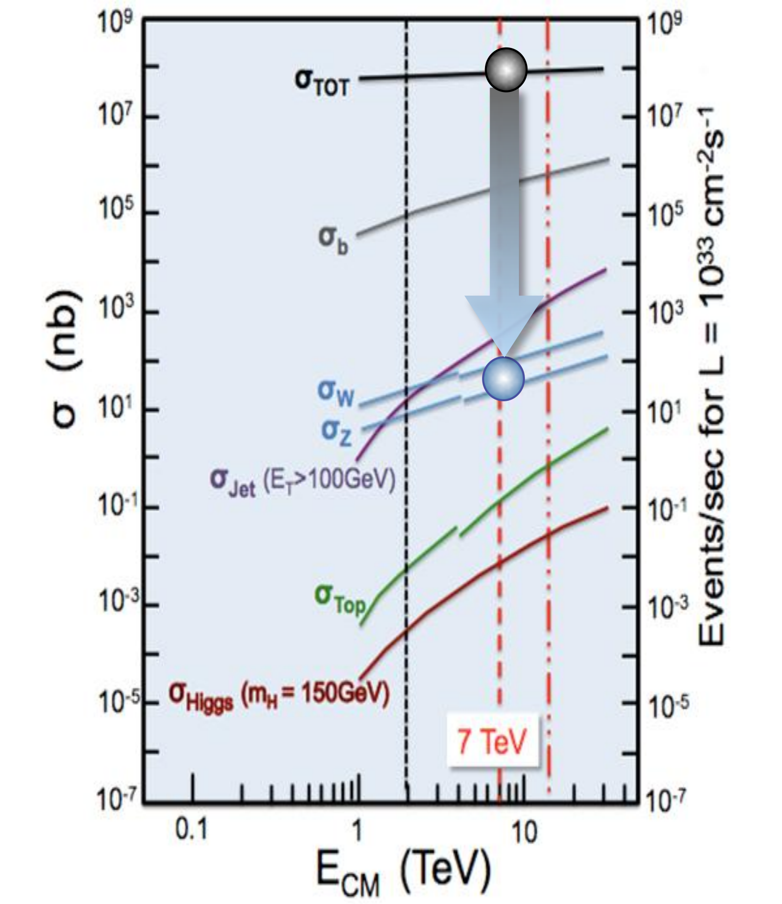
EGEE-III INFSO-RI-222667

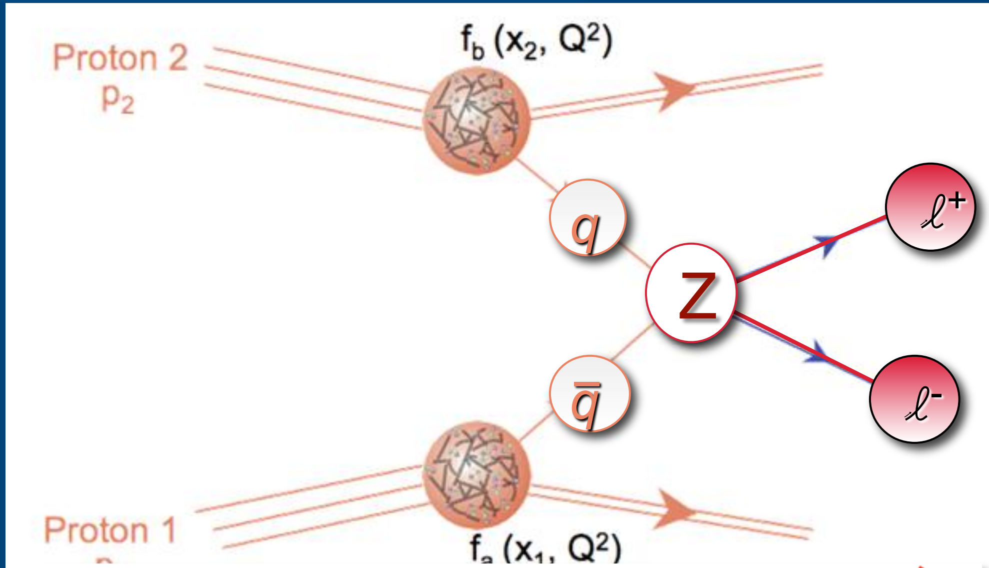
egi

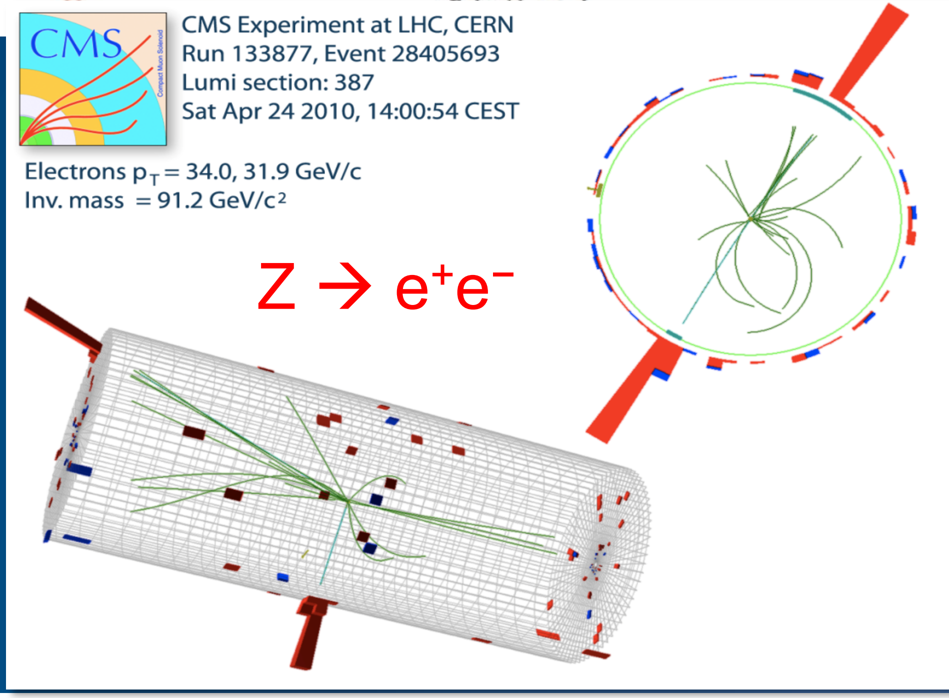
LCG

©2010 Google

W and Z production at 7 TeV

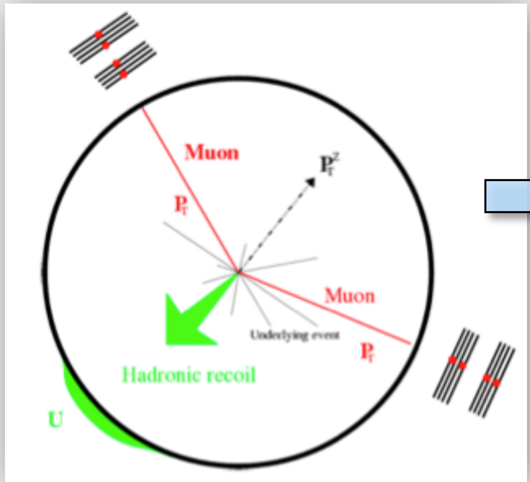


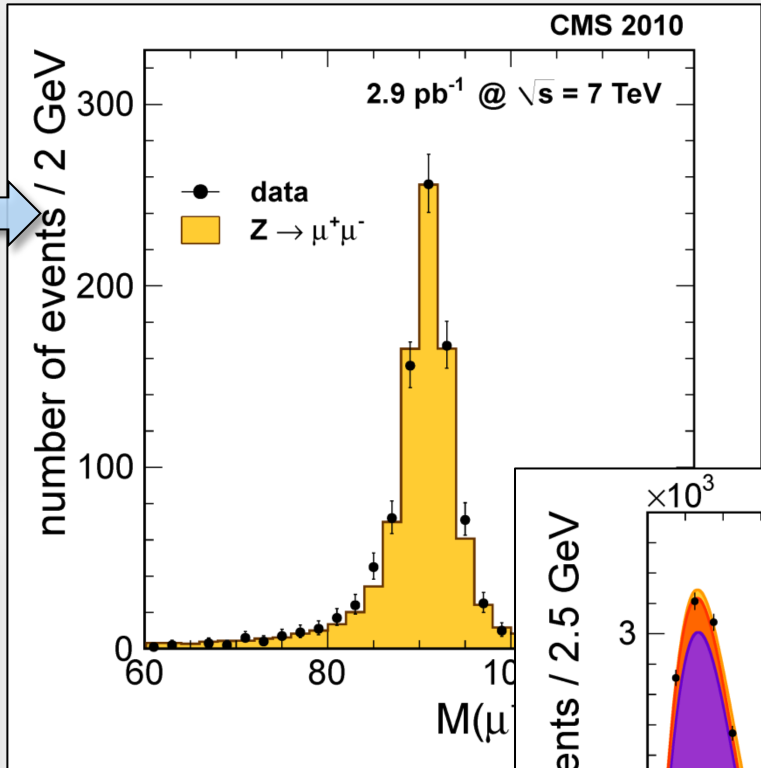




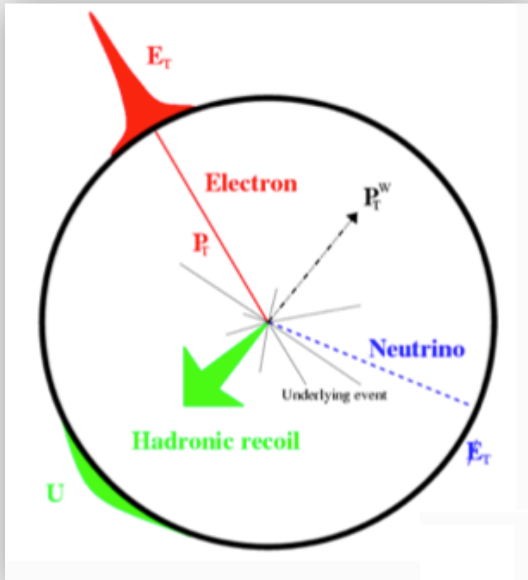
W and Z production at 7 TeV

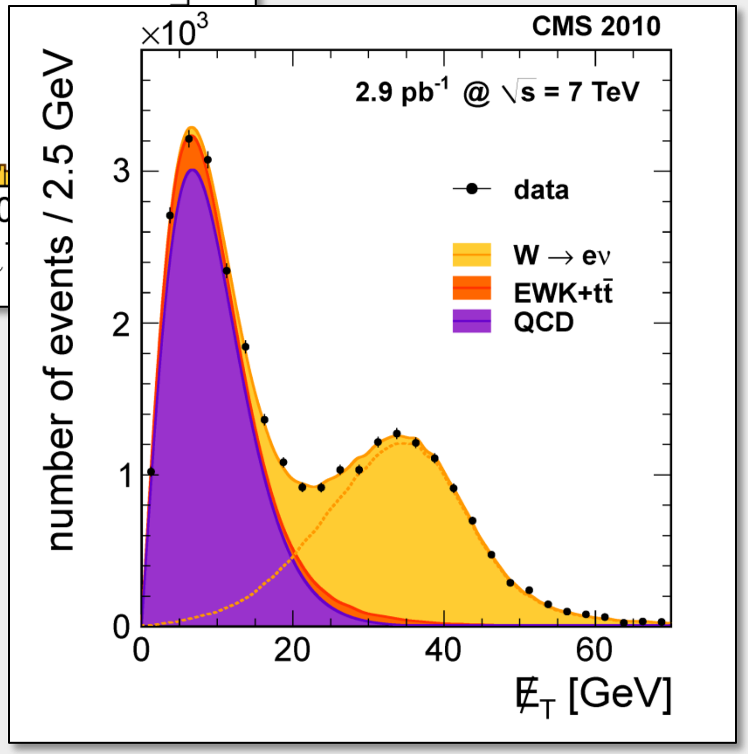
Z





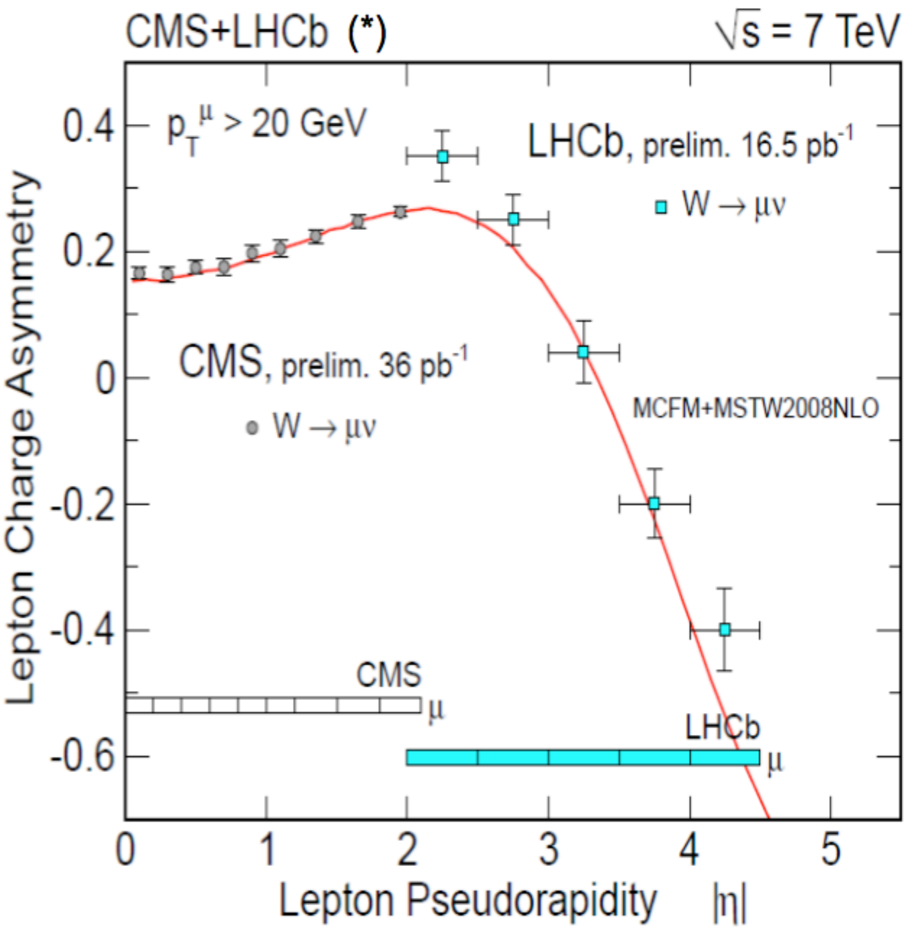
W

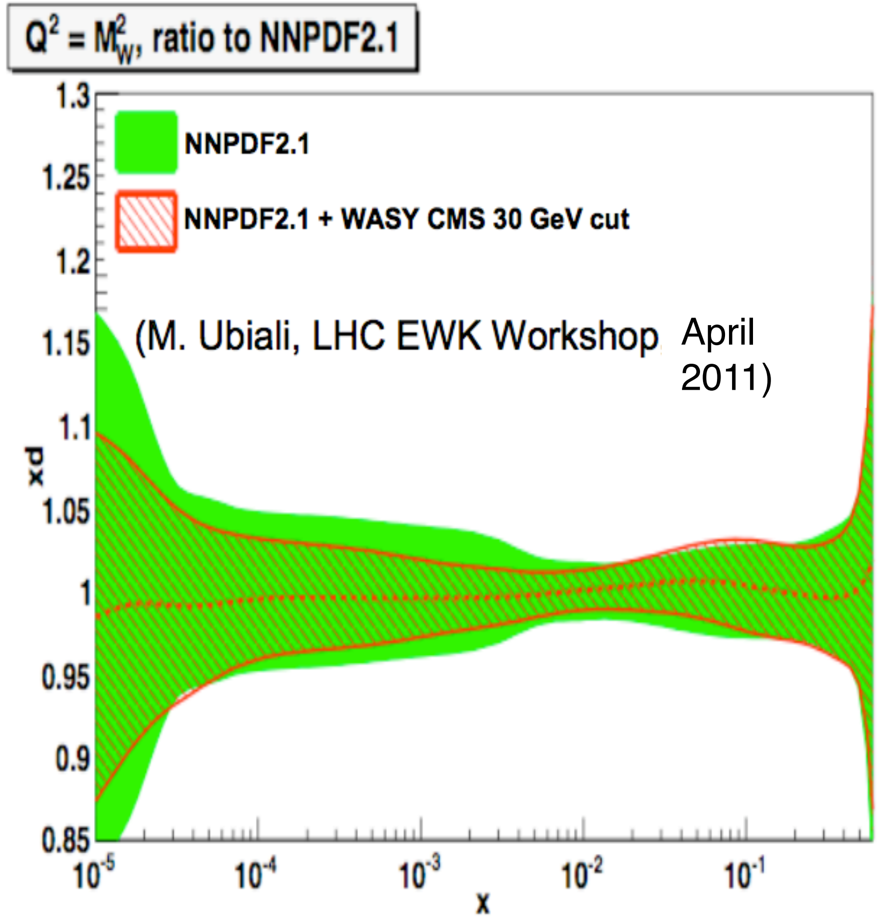




Lepton charge asymmetry in inclusive W

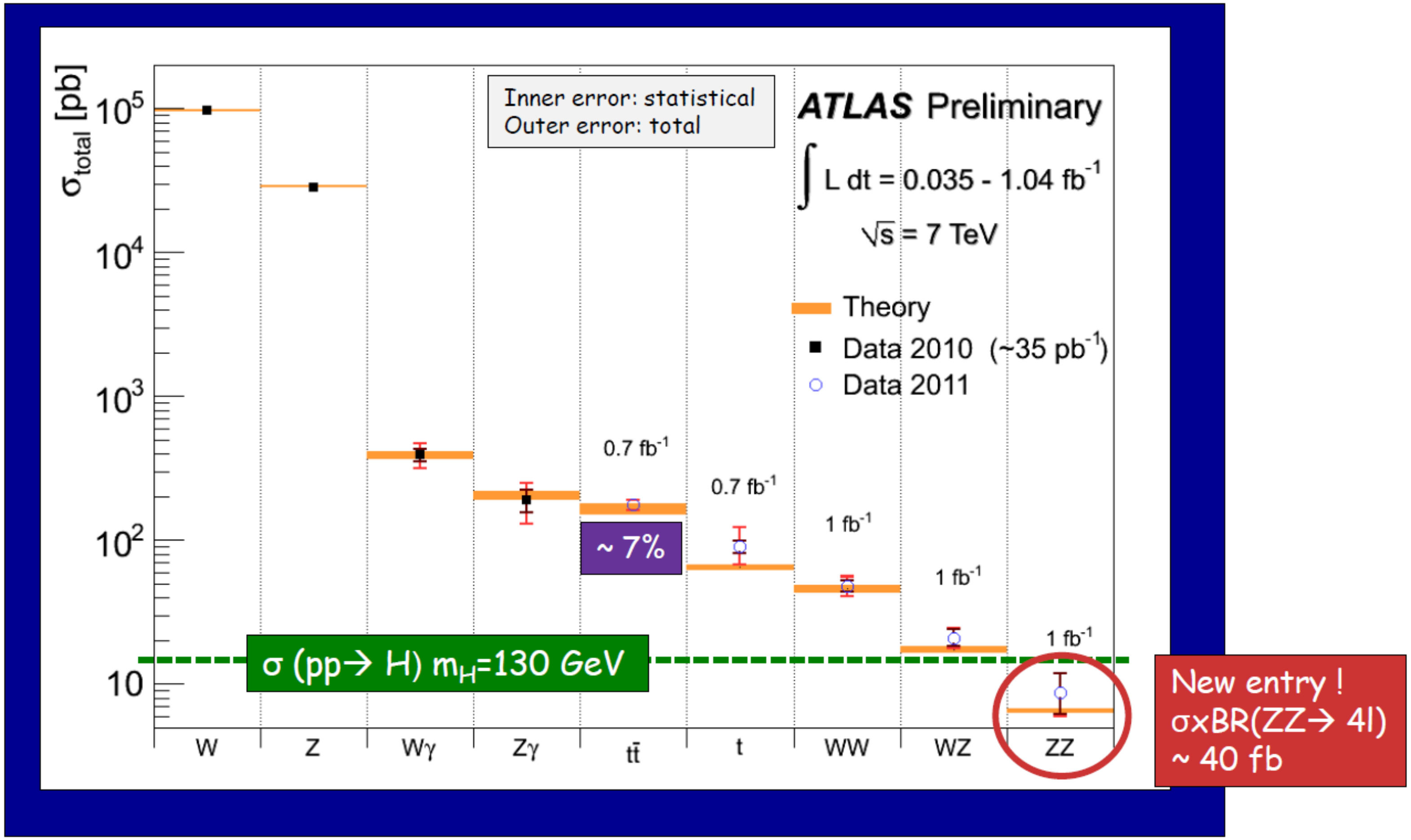
We are able to produce precision EWK measurements good enough to constrain significantly the PDF global fits.





(M. Ubiali, LHC EWK Workshop April 2011)

Summary of main electroweak and top cross-section measurements

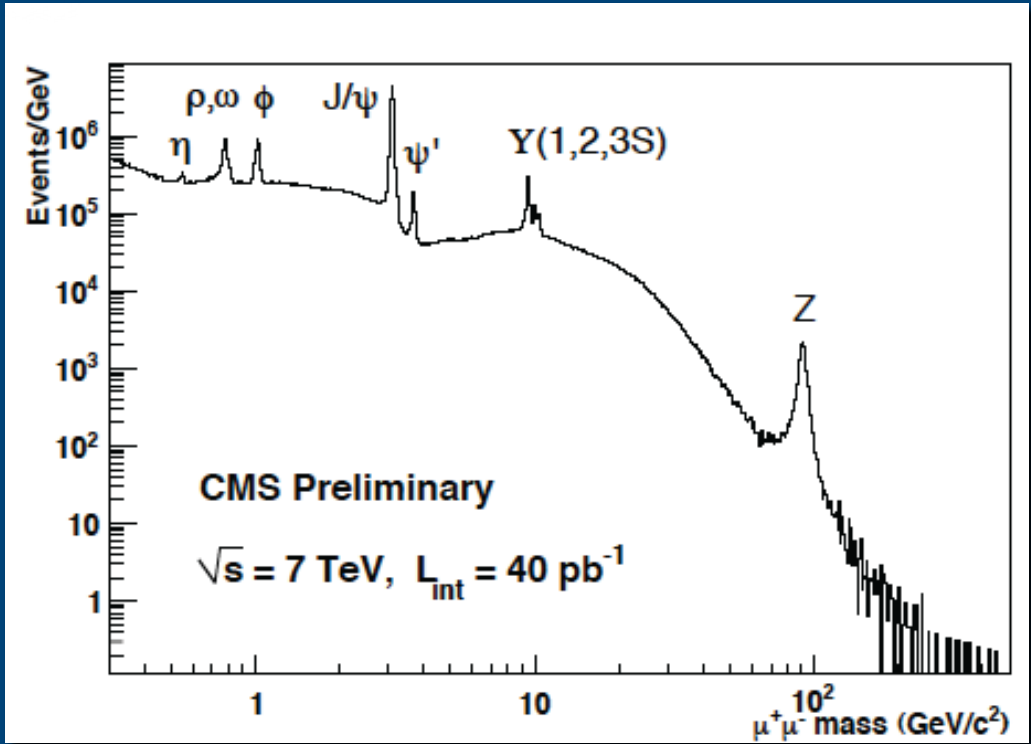


Good agreement with SM expectations (within present uncertainties)

Experimental precision starts to challenge theory for e.g. tt (background to most H searches)

Measuring cross-sections down to few pb (~ 40 fb including leptonic branching ratios)

Excellent performances 2010

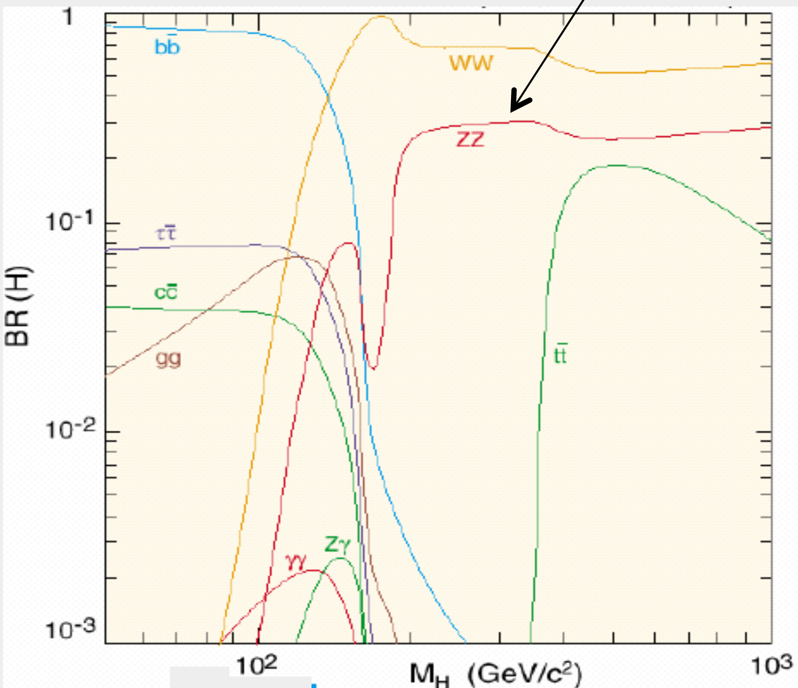


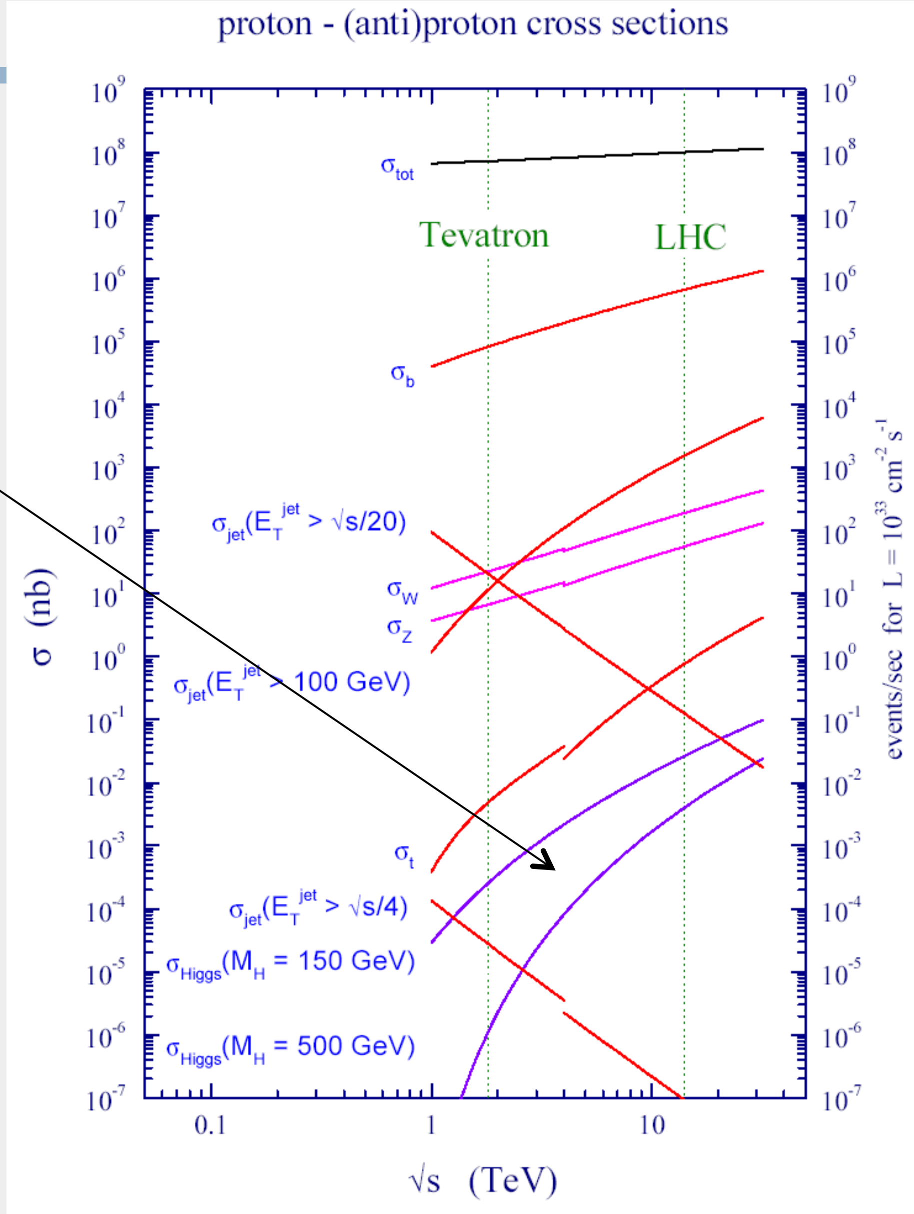
- Experiments demonstrated readiness in the exploitation of the 7 TeV p-p and 2.76 TeV Pb-Pb data;
- Analyses proceeded very rapidly;
- Experiments have about completed their journey through the Standard Model … and have started to take us into uncharted territories …

Search for the Higgs-Boson at the LHC

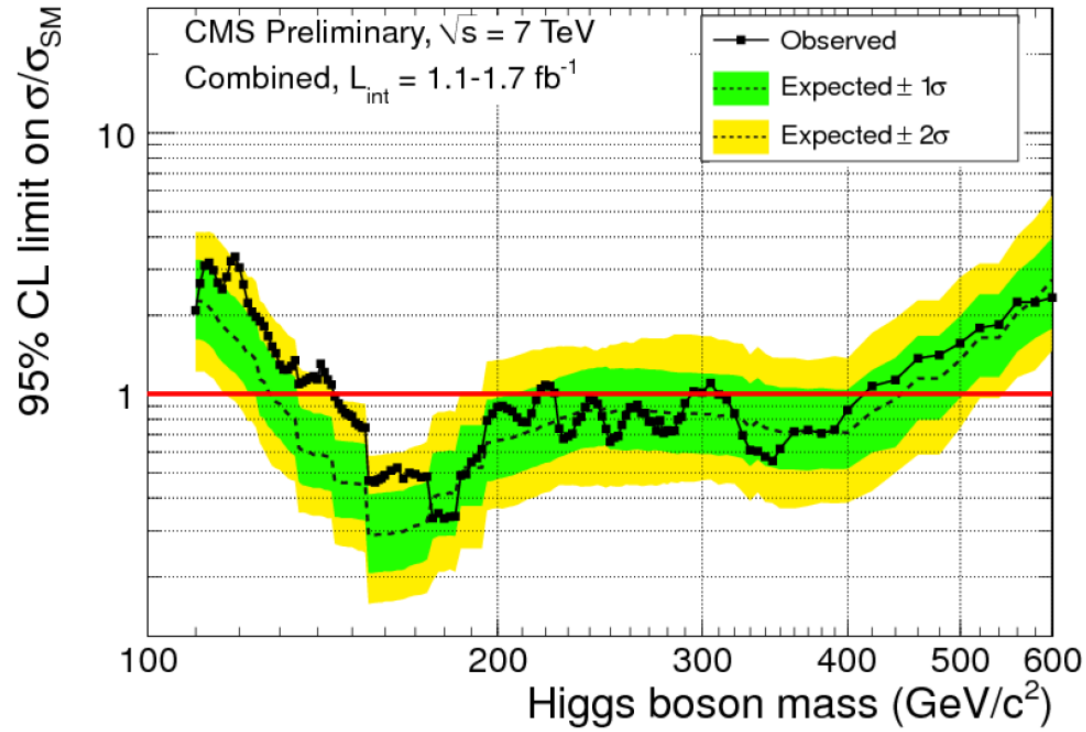
Production rate of the Higgs-Bosons depends on its mass

as well as its decay possibilities ("Signature (or picture)" as seen in the detector)





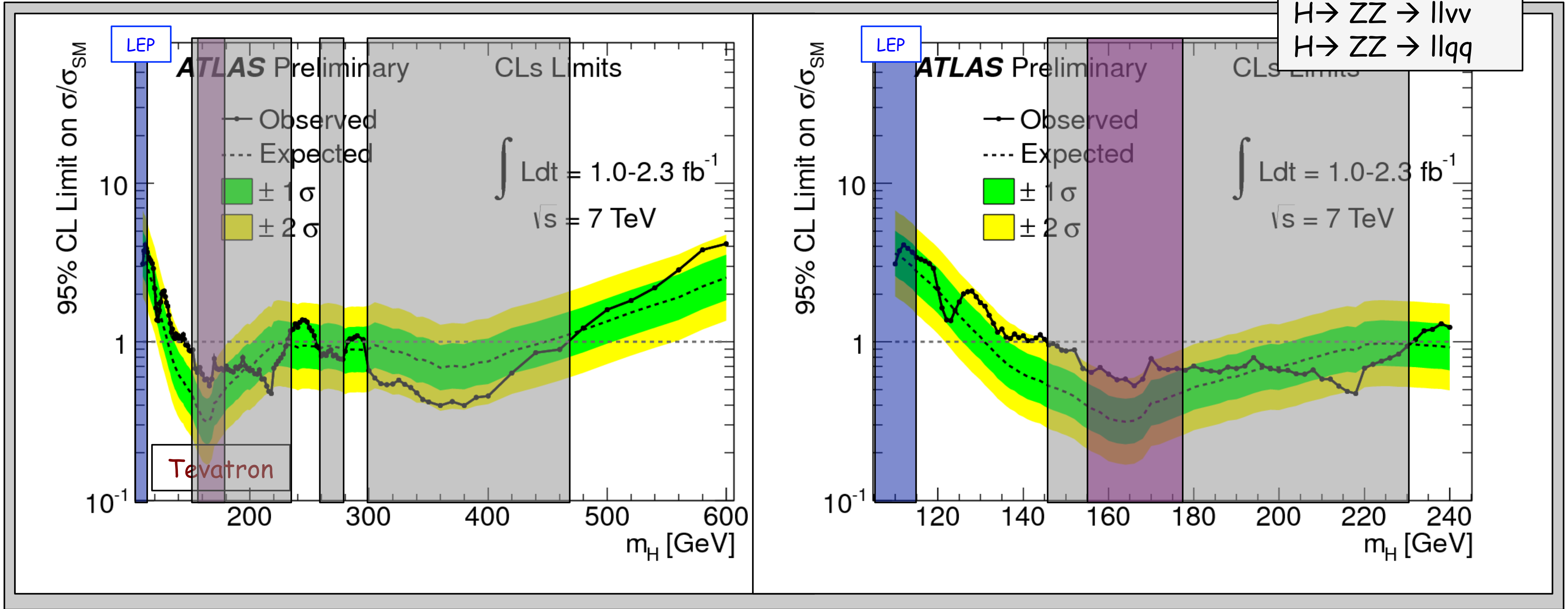
CMS SM Higgs Search



Expected exclusion mass range: 130 – 440 GeV
Observed exclusion mass range: 145-216, 226-288, 310-400 GeV

All channels together → combined constraints

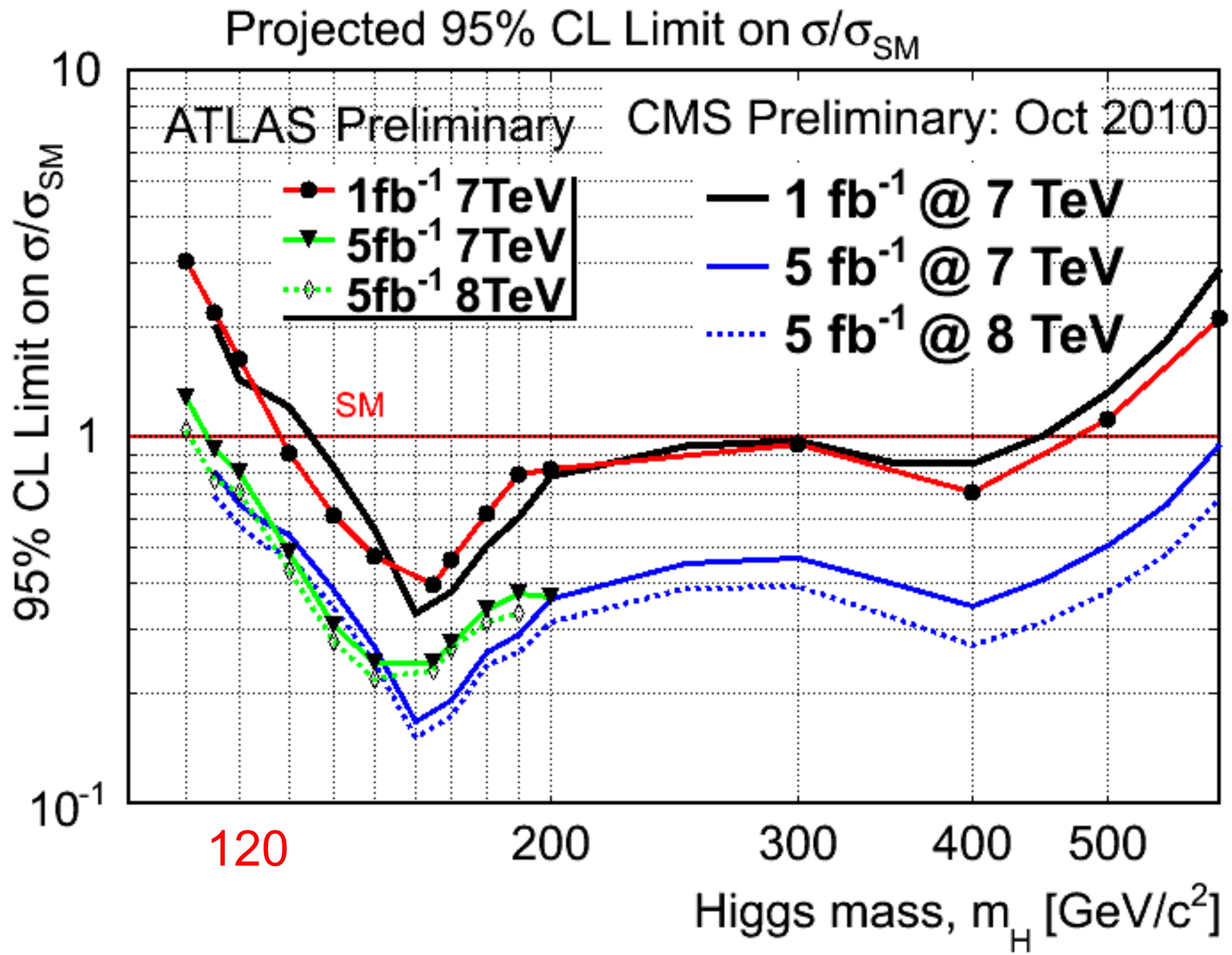
H→γγ
H→ ττ
W/ZH→ lbb+X
H→ WW(*)→ lνlν
H→ ZZ(*) → 4l
H→ ZZ → llνν
H→ ZZ → llqq



Excluded by ATLAS at 95% CL : 146-466 GeV, except 232-256, 282-296 GeV
Expected if no signal at 95% CL : 131-447 GeV

- LHC provides first direct exclusion (95% CL) of a large mass range until now unexplored
- The best-motivated low-mass region (EW fit: m_H < 161 GeV 95% CL) still open to exploration
- Data are within ±2σ of expectation for no signal over full m_H range → no significant excess

CMS & ATLAS Projections Compared



Summary of Prospects

SM Higgs Search Prospects (Mass in GeV)			
ATLAS + CMS ≈ 2 x CMS	**95% CL exclusion**	**3 σ sensitivity**	**5 σ sensitivity**
1 fb^{-1}	**120 - 530**	**135 - 475**	**152 - 175**
2 fb^{-1}	**114 - 585**	**120 - 545**	**140 - 200**
5 fb^{-1}	**114 - 600**	**114 - 600**	**128 - 482**
10 fb^{-1}	**114 - 600**	**114 - 600**	**117 - 535**

SM-Higgs Boson, if it exists between masses of (114 - 600 GeV) will either be discovered or ruled out in ≈ next twelve months

→ **Decided to run in 2012**

Key message

LHC and the Standard Model

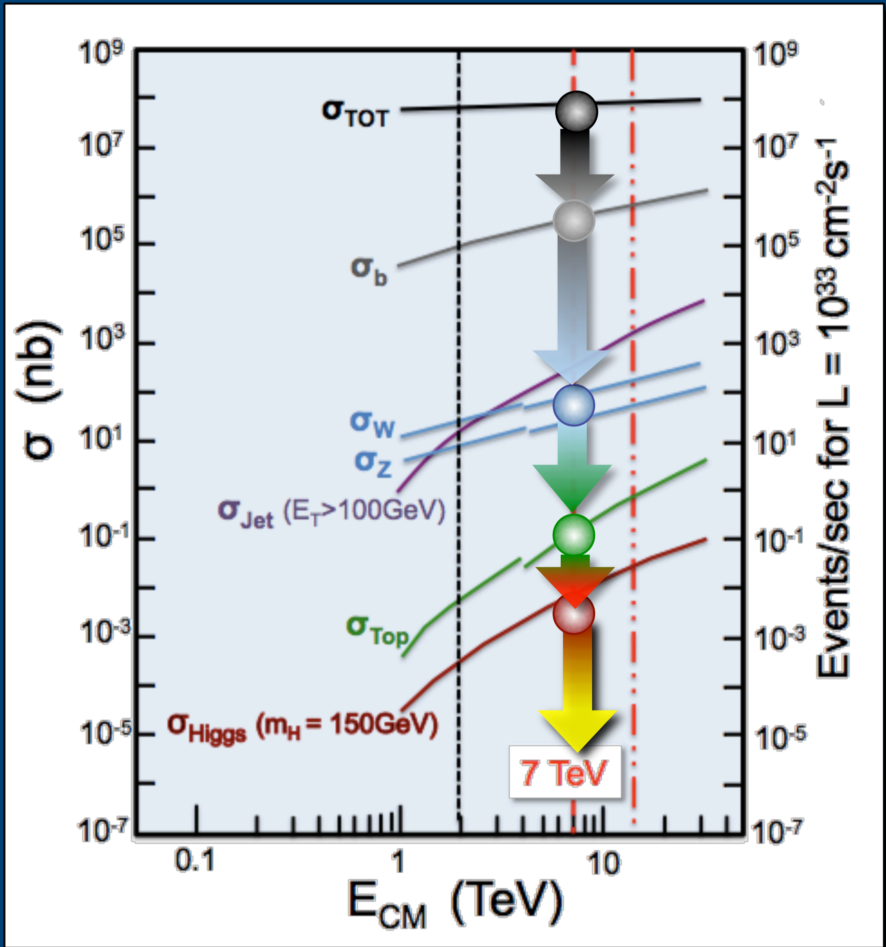
Finding the Higgs: Discovery

Excluding the SM-Higgs: Discovery

Reminder:

LHC is poised to clarify the mechanism by which elementary particles acquire mass

The 2011 and 2012 run …

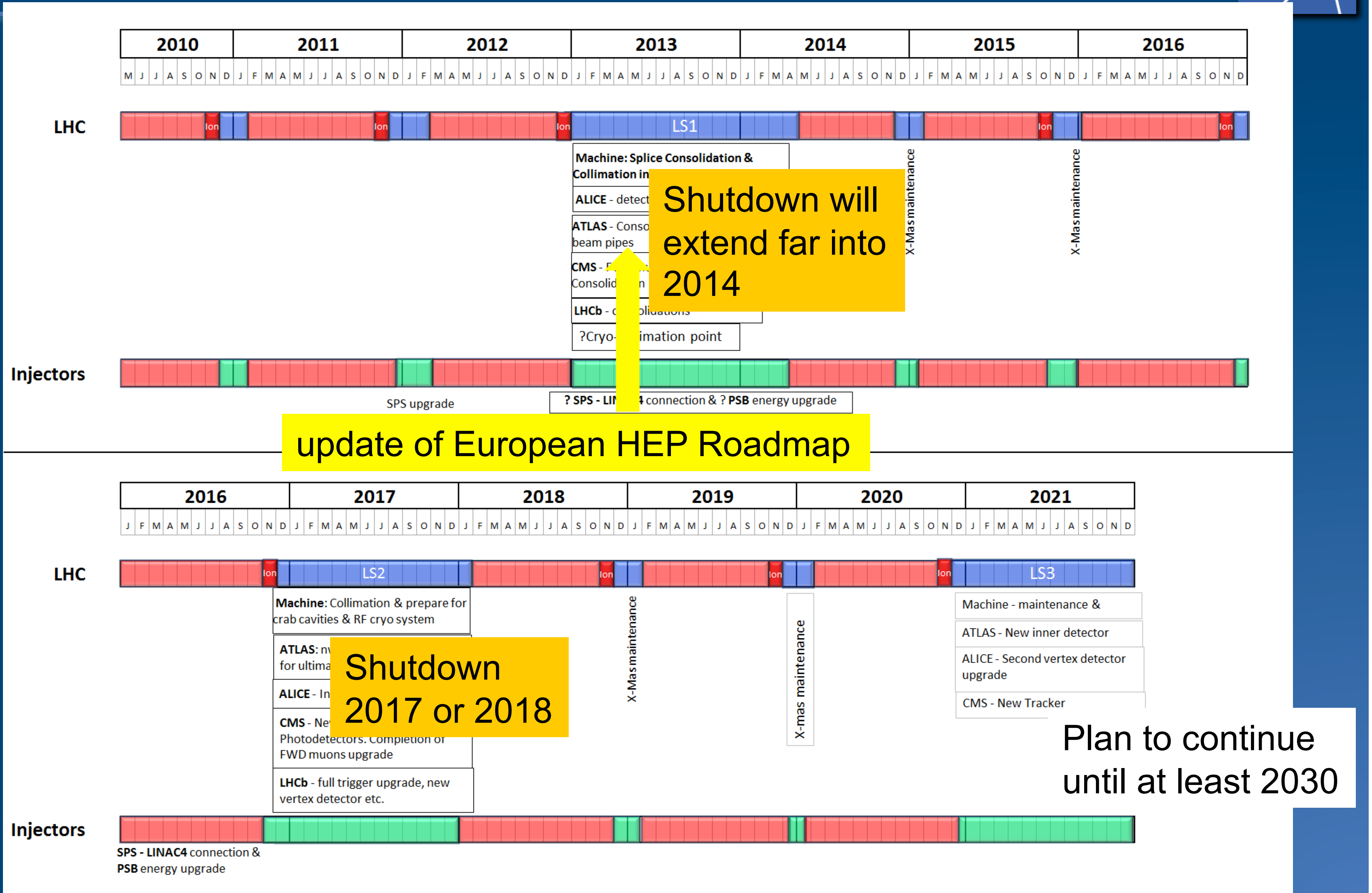


Search for physics beyond SM

- Discovering new particles
- Making precise measurements of properties of known particles/forces: e.g. LHCb: $B_s \rightarrow \mu^+\mu^-$

→ we are entering new territory !

New ***Rough Draft*** 10 year plan




beyond LHC ?

Road beyond Standard Model

through synergy of

hadron - hadron colliders

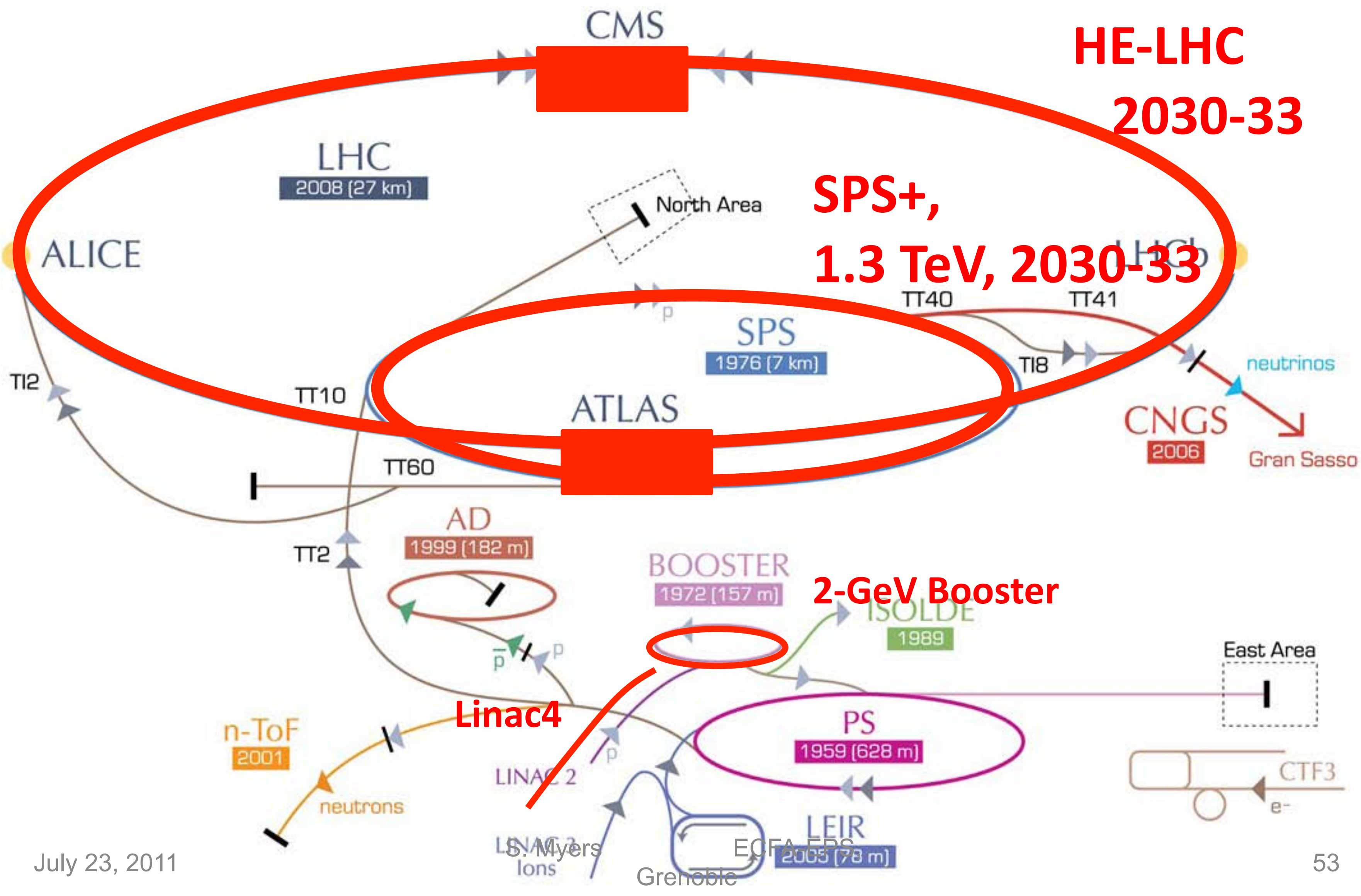
lepton - hadron colliders

lepton - lepton colliders

High Energy Hadron – Hadron Collider

HE - LHC

HE-LHC – LHC modifications



HE-LHC – main issues and R&D

- ***high-field 20-T dipole*** *magnets based on Nb_3Sn, Nb_3Al, and HTS*
- ***high-gradient quadrupole magnets*** *for arc and IR*
- ***fast cycling SC magnets*** *for 1-TeV injector*
- ***emittance control*** *in regime of strong SR damping and IBS*
- *cryogenic handling of* ***SR heat load*** *(first analysis; looks manageable)*
- *dynamic* ***vacuum***

Lepton – Hadron Collider

LHeC

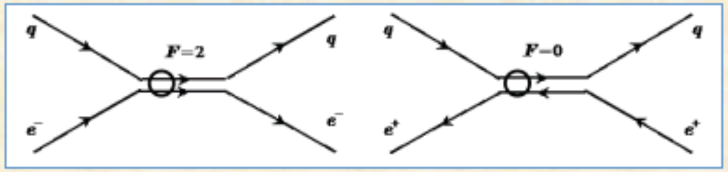
Determining Leptoquark Quantum Numbers

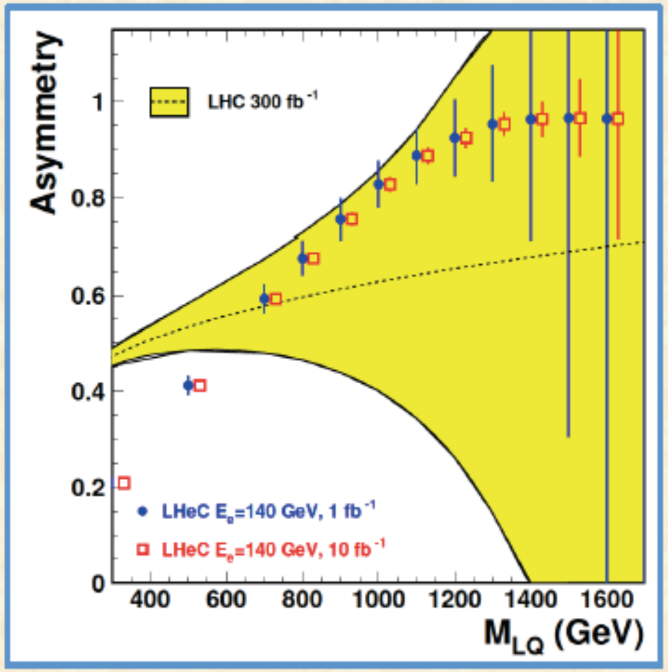
Single production gives access to quantum numbers:

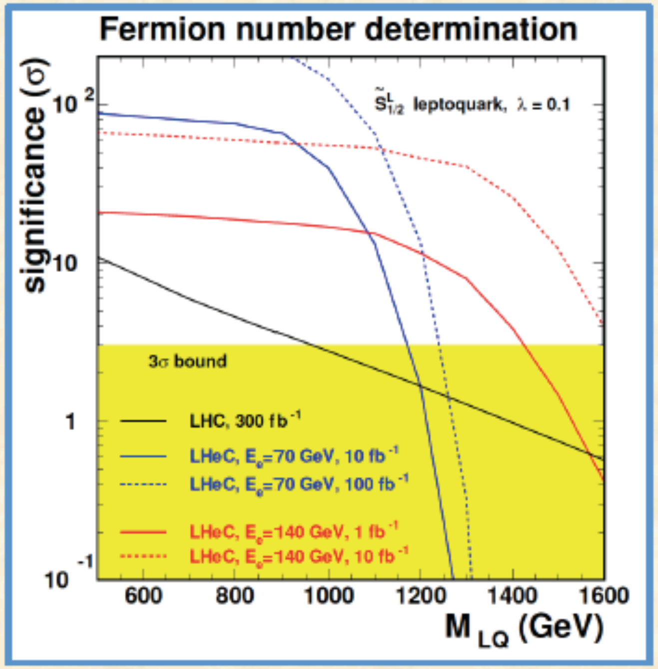
- fermion number (below)   - spin (decay angular distributions)
- chiral couplings (beam lepton polarisation asymmetry)

- Fermion number *F* from asymmetry in e+/e-p cross sections
- Much cleaner accessible in DIS

$$A = \frac{\sigma_{e^-} - \sigma_{e^+}}{\sigma_{e^-} + \sigma_{e^+}} \begin{cases} >0 \text{ for } F=2 \\ <0 \text{ for } F=0 \end{cases}$$

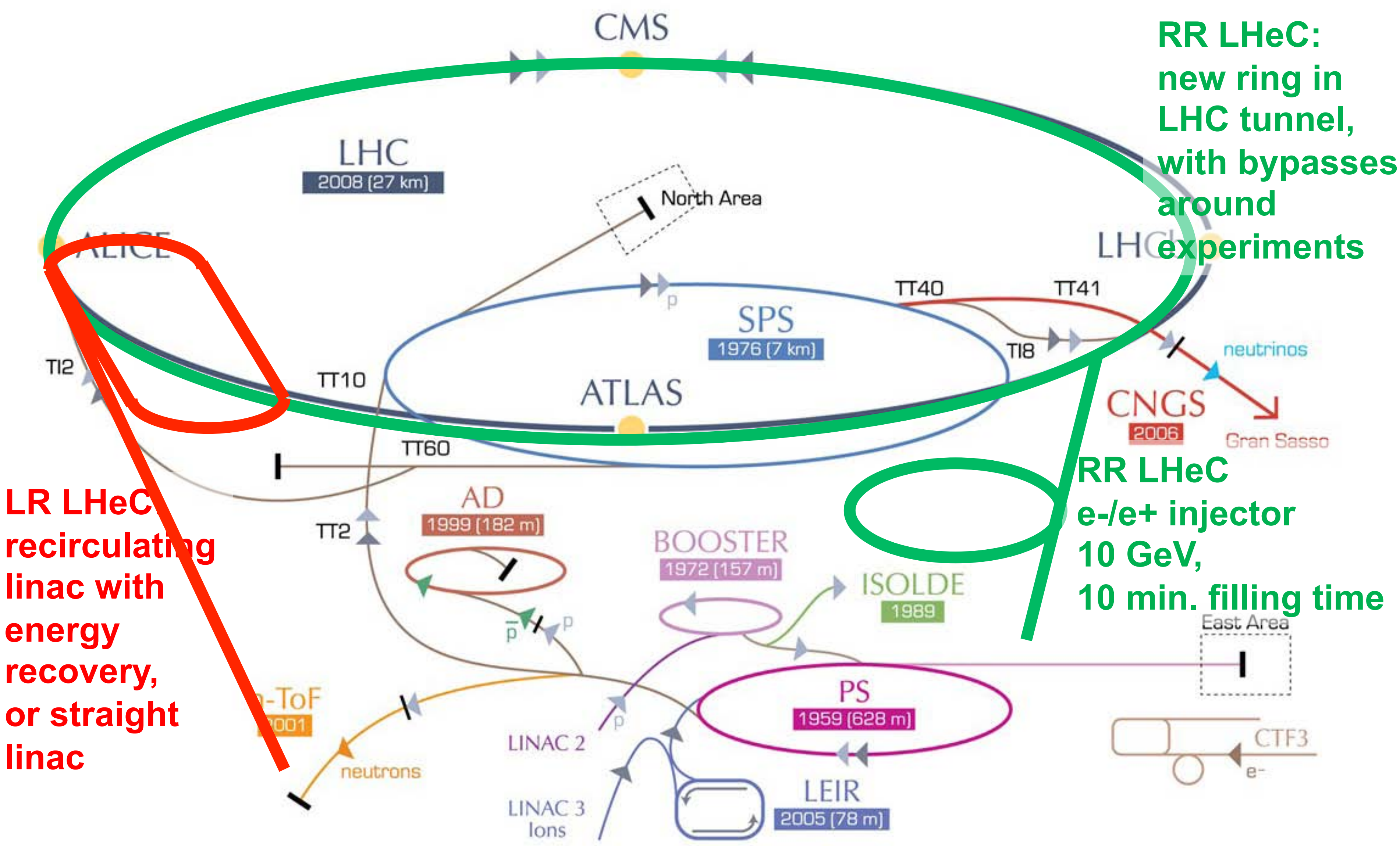






Studies for “low`` lumi assumptions for pp and ep

LHeC options: RR and LR



Frank Zimmermann, UPHUK4 Bodrum 2010

Lepton – Lepton Colliders

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.

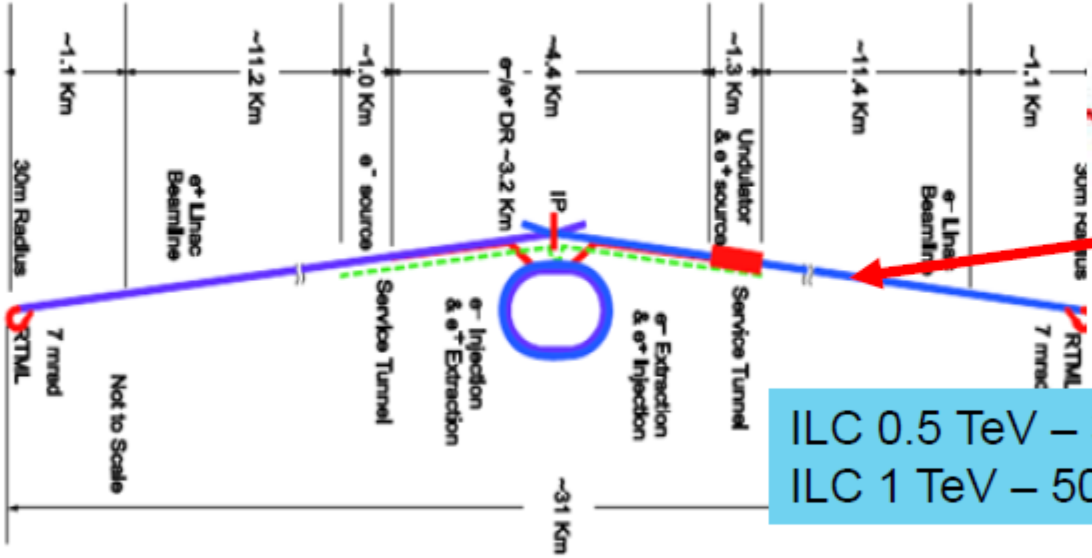
PROJECTS:

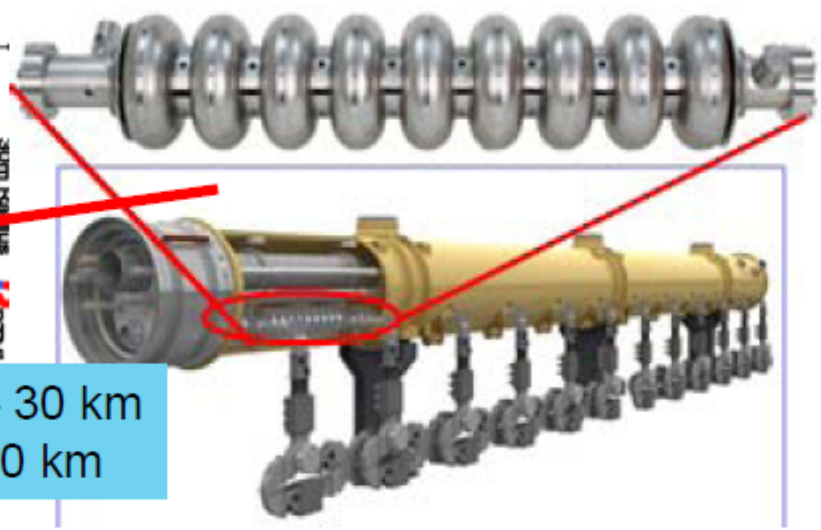
⇒ TeV Colliders (CMS energy up to 1 TeV) → Technology ~ready
ILC with superconducting cavities

⇒ Multi-TeV Collider (CMS energies in multi-TeV range) → R&D
CLIC → Two Beam Acceleration

Linear Collider layouts

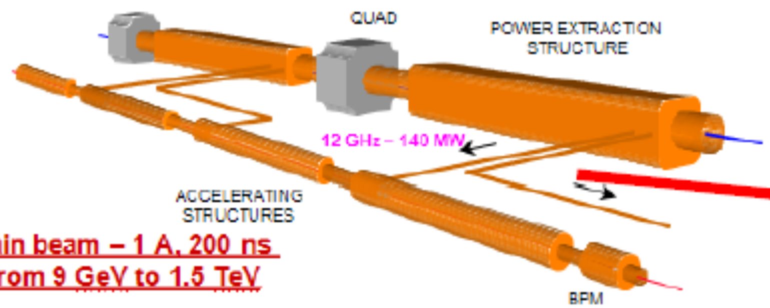
http://www.linearcollider.org/cms http://clic-study.web.cern.ch/CLIC-Study/



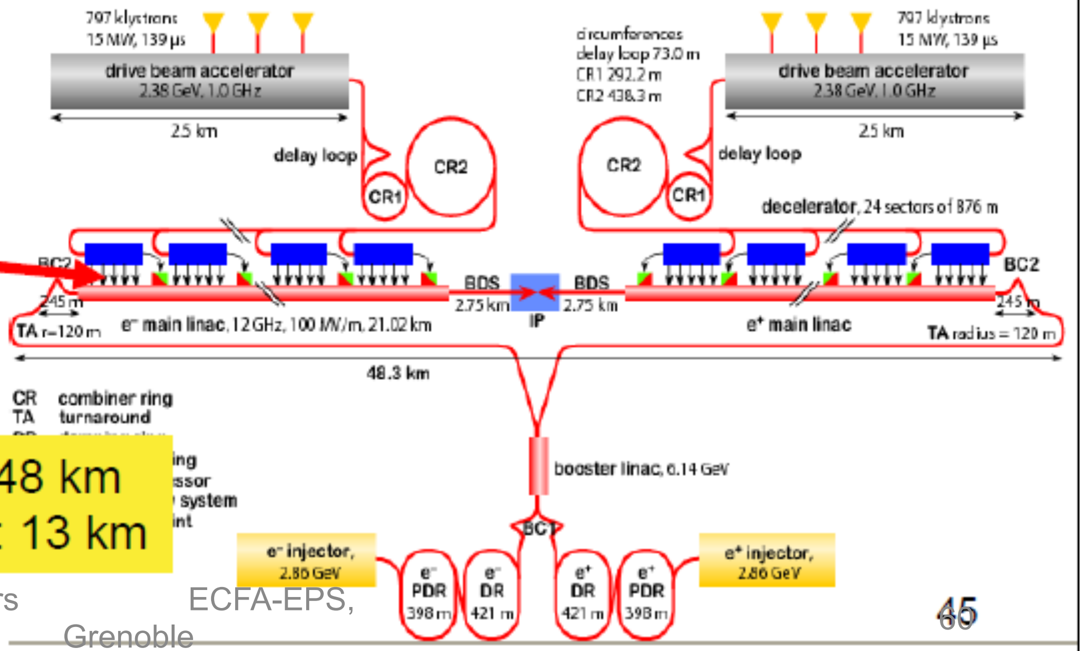


ILC 0.5 TeV – 30 km
ILC 1 TeV – 50 km

Drive beam - 95 A, 300 ns
from 2.4 GeV to 240 MeV



Main beam – 1 A, 200 ns
from 9 GeV to 1.5 TeV



CLIC 3 TeV: 48 km
CLIC 0.5 TeV: 13 km

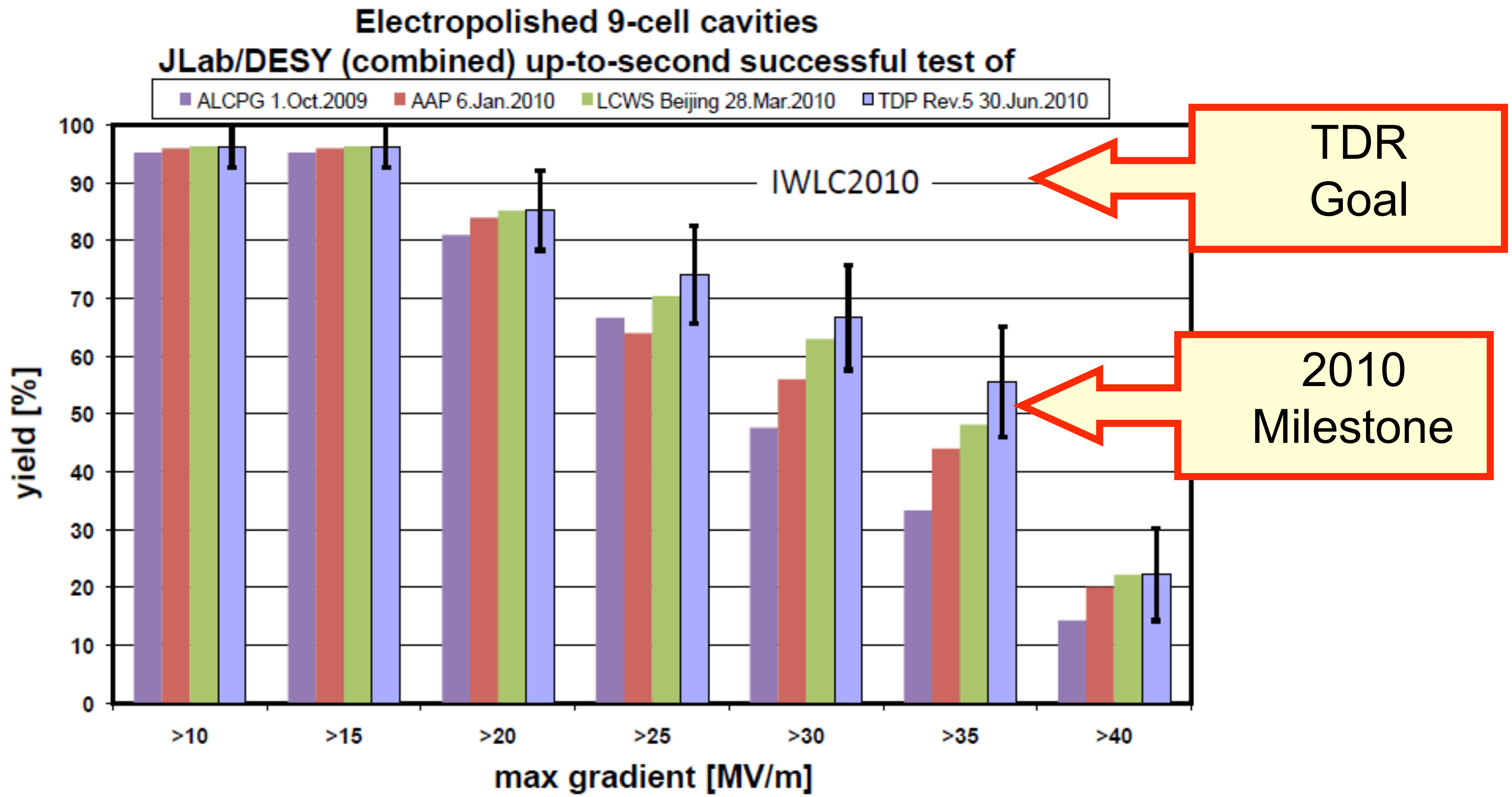
The ILC SCRF Cavity

Figure 1.2-1: A TESLA nine-cell 1.3 GHz superconducting niobium cavity.

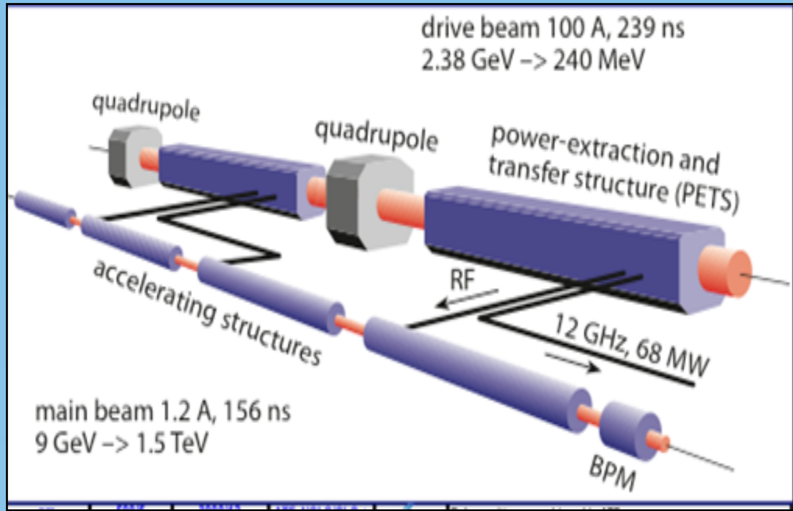
- Achieve high gradient (35MV/m); develop multiple vendors; make cost effective, etc

- Focus is on high gradient; production yields; cryogenic losses; radiation; system performance

Cavity Gradient Milestone Achieved

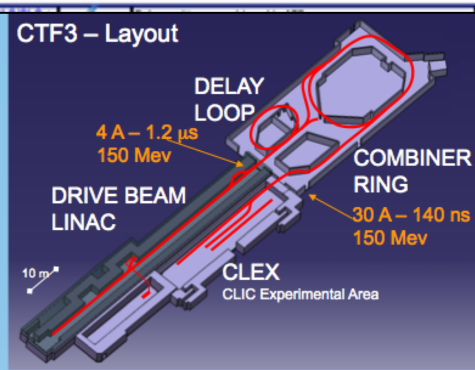


Feasibility studies and the CDR



Feasibility issues:

- Drive beam generation
- Beam driven RF power generation
- Accelerating Structures
- Two Beam Acceleration
- Ultra low emittances and beam sizes
- Alignment
- Vertical stabilization
- Operation and Machine Protection System



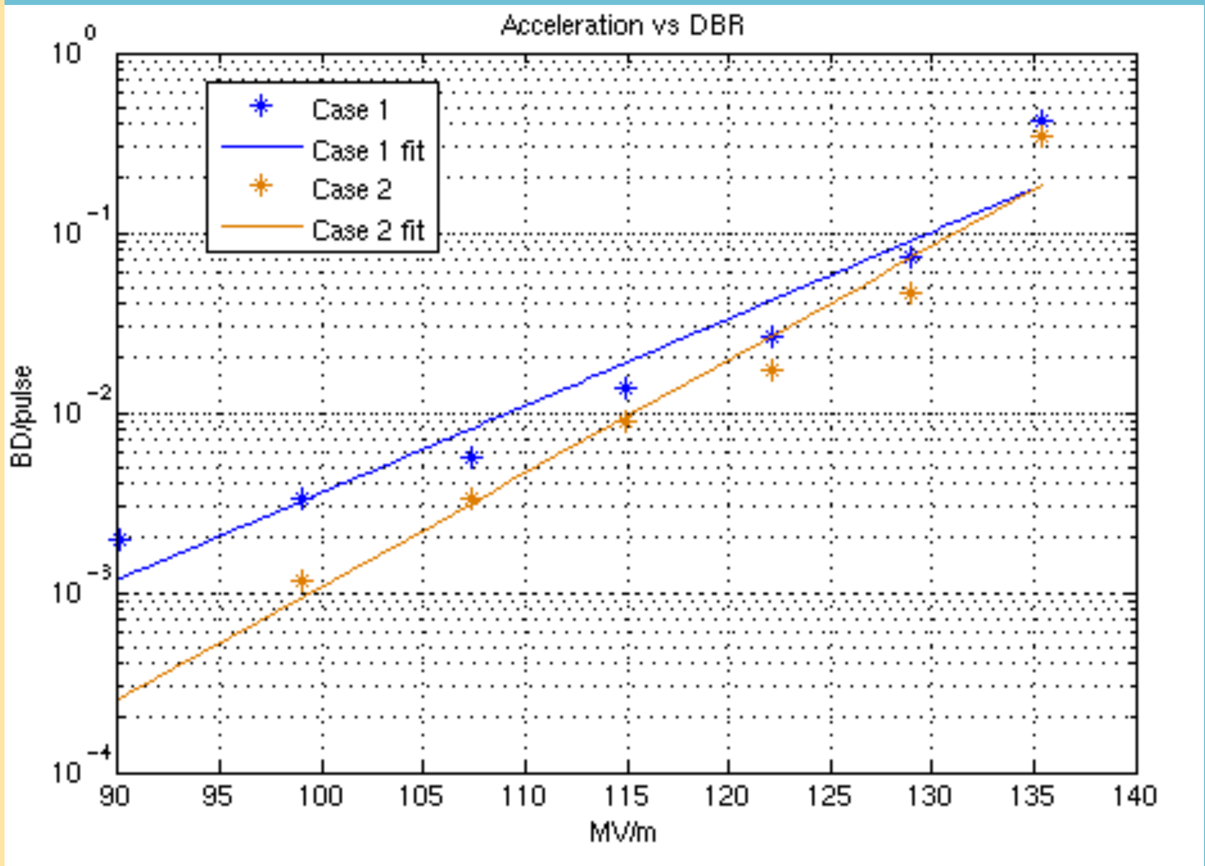
CDRs:

- Vol 1: The CLIC accelerator and site facilities
  - CLIC concept with exploration over multi-TeV energy range up to 3 TeV
  - Feasibility study of CLIC parameters optimized at 3 TeV (most demanding)
  - Consider also 500 GeV, and intermediate energy ranges
- Vol 2: The CLIC physics and detectors
- Vol 3: CLIC study summary
  - Summary and input to the European Strategy process, including possible implementation stages for a CLIC machine as well as costing and cost-drives
  - Proposing objectives and work plan of post CDR phase (2012-16)
- Timescales:
  - By end 2011: Vol 1 and 2 completed
  - Spring/mid 2012: Vol 3 ready for the European Strategy Open Meeting

Two Beam Test Stand (TBTS) results 2011

- Well established two beam acceleration experiments
- Calibration converging, structure correctly tuned
- Interesting breakdown studies started

Very preliminary, RF parts in early conditioning phase
Blue: all components, Orange: limited to structures



2011 : CTF3 TBTS running for full after winter shut-down. Gradients of 110 – 130 MV/m are routinely reached (20% above CLIC target).

Status and major issues of Linear Colliders

ILC

- 0.5 TeV upgradable to 1 TeV
- Mature SC-RF technology (TESLA- Flash- XFEL)
- CDR in 2007, TDR in 2012
- Global Intern. collaboration & organisation (GDE)

CLIC

- extension in multi-TeV range
- Novel scheme of Two Beam Acceleration (TBA): CTF1,2,3
- CDR in 2011, TDR in 2016?
- Multi-lateral Int. Collaboration of 41 volunteer Institutes

Extremely fruitful collaboration between CLIC and ILC
Joint working groups on common issues with great synergies

Joint IWLC Workhop (18-22/10/2010 @ CERN)
Next Joint LCWS (26-30/09/2011 @ GRANADA/SPAIN)
http://www.ugr.es/~lcws11/index.php

Towards single Linear Collider community and….

Possibly future joined project based on Physics requests (LHC results) and technology choice as best trade off between performance, maturity, risk, cost, etc….

Key message LC

High Priority Items for Linear Collider Projects

ILC and CLIC projects → LC project

Construction Cost

Power Consumption

Value Engineering

Next decades

Road beyond Standard Model

through synergy of

hadron - hadr (LHC, HL-, HE?-LHC)

l... adron colliders (LHeC ??)

lepton - lepton colliders (LC (ILC or CLIC) ?)

LHC results will guide the way at the energy frontier

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

Opening the door…

- Membership for Non-European countries
- New Associate Membership defined
- Romania in accession to membership
- Negotiations started with Cyprus, Israel, Serbia, Slovenia, and Turkey concerning membership

  concluded last Friday with Israel
- Several countries expressed interest in associate membership
- New Relations with International Organizations in Geneva

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