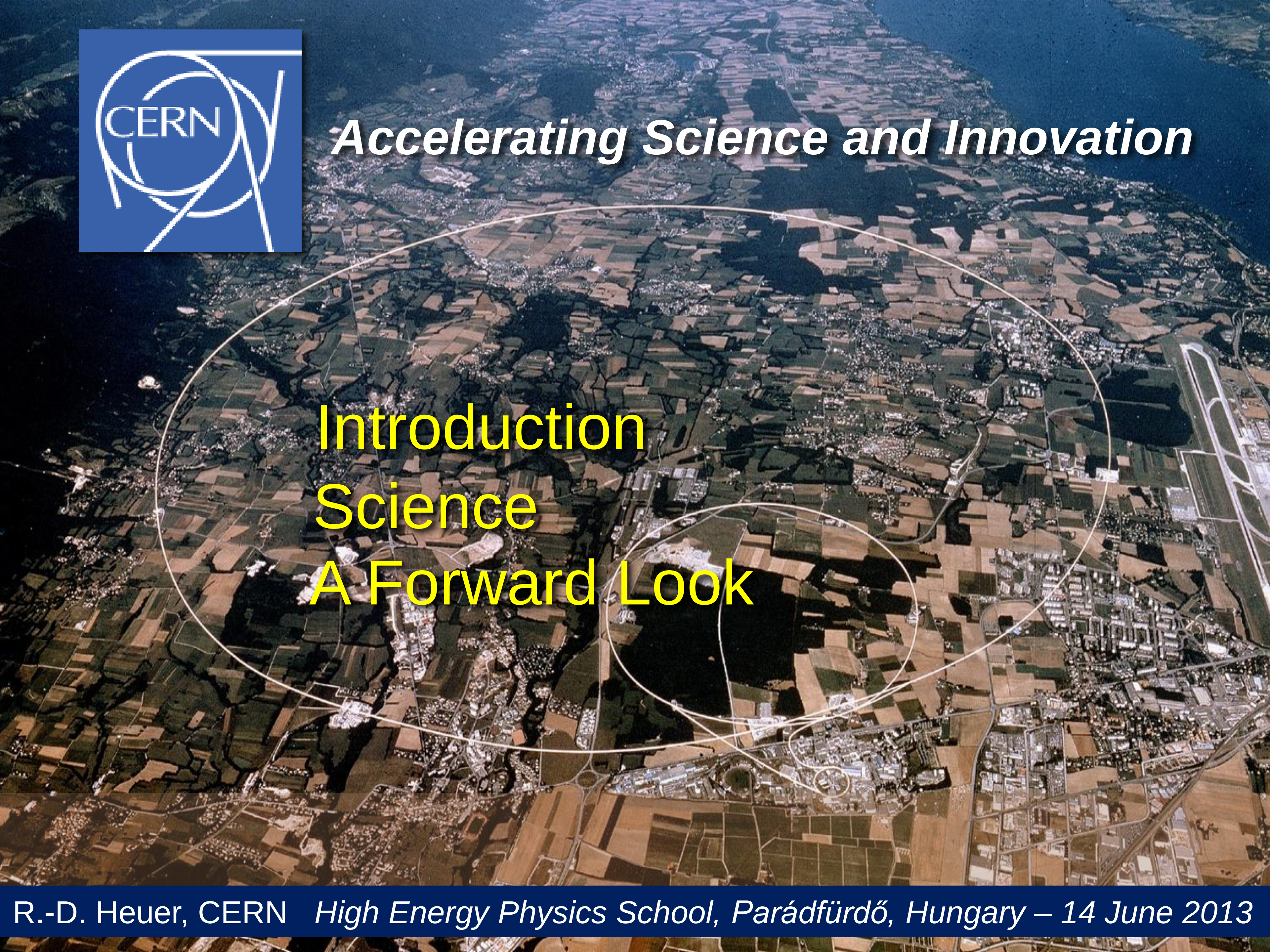
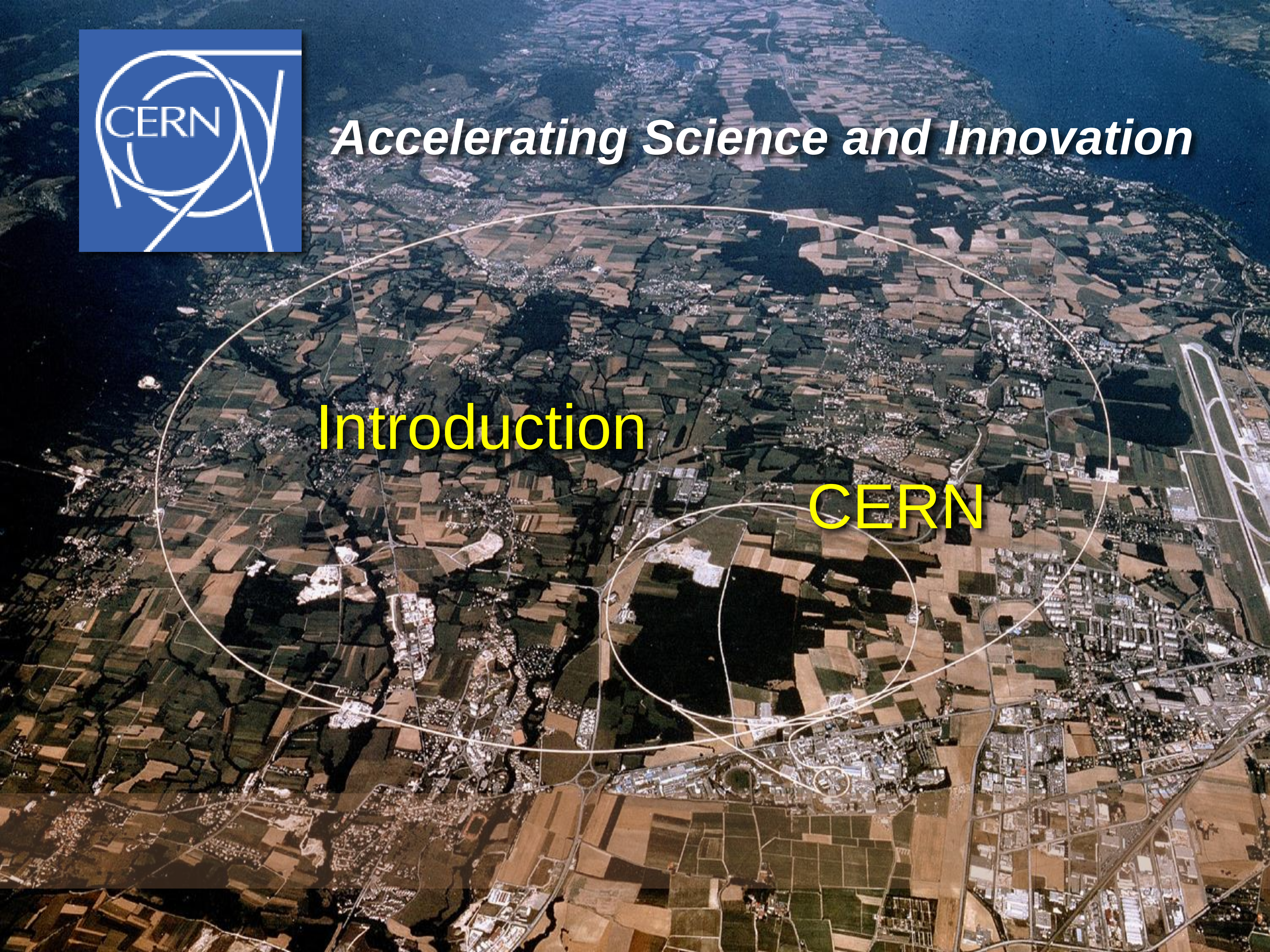


Accelerating Science and Innovation

Introduction
Science
A Forward Look

R.-D. Heuer, CERN *High Energy Physics School, Parádfürdő, Hungary – 14 June 2013*

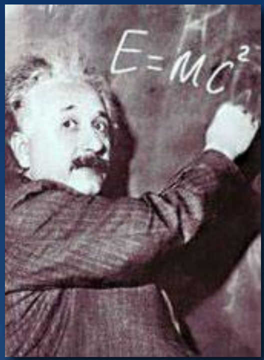

Accelerating Science and Innovation
Introduction
CERN

Innovation
Education
CERN
uniting people
Research

The Mission of CERN

- Push back the frontiers of knowledge

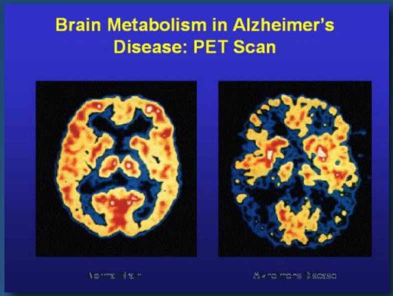
  E.g. the secrets of the Big Bang …what was the matter like within the first moments of the Universe's existence?



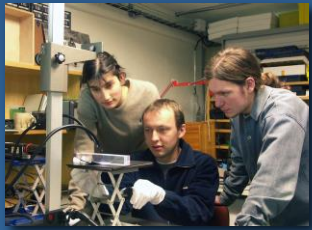
- Develop new technologies for accelerators and detectors

  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
~ 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

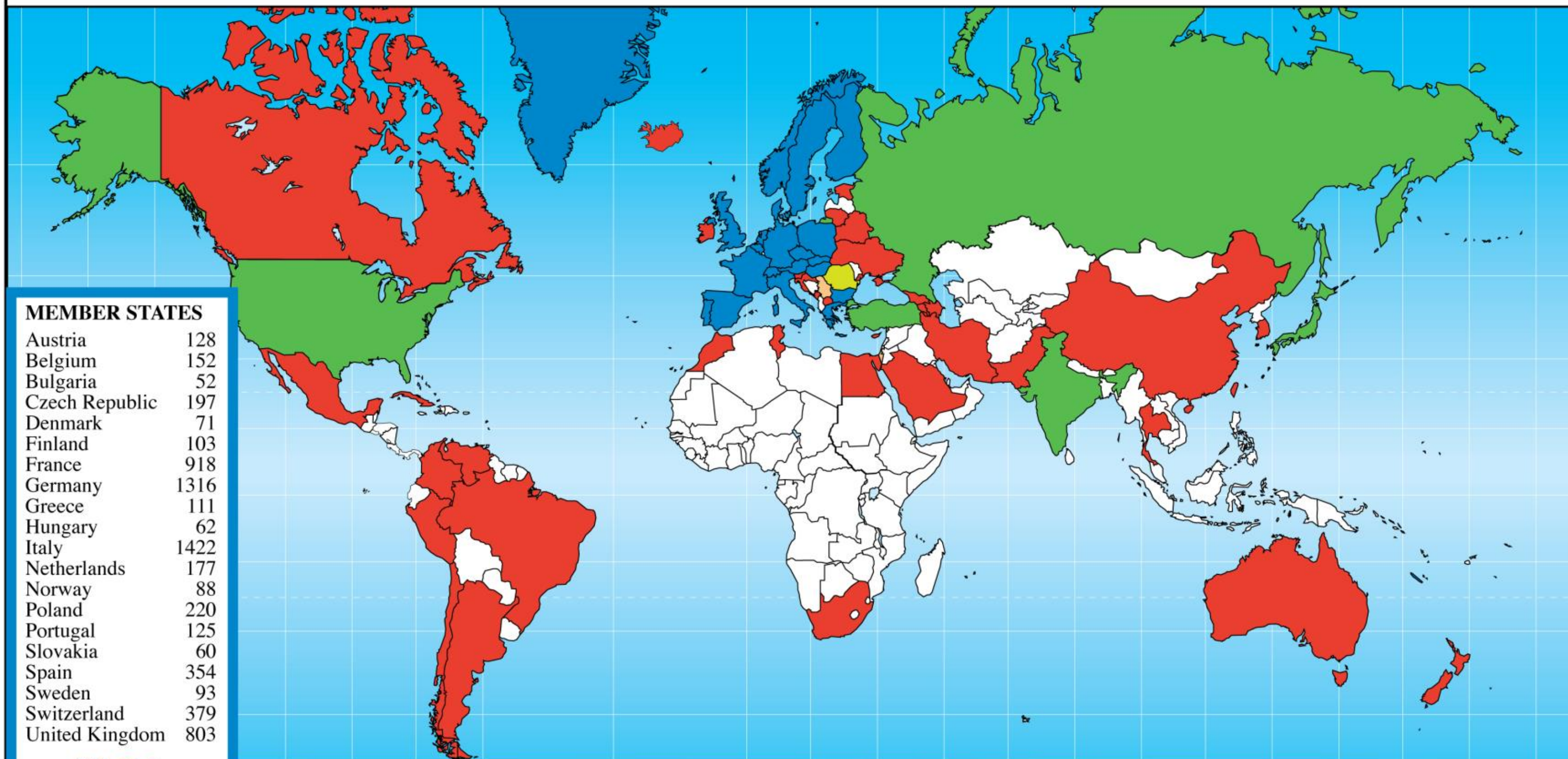
Associate Members in Pre-Stage to Membership: Israel, Serbia

Applicant States for Membership or Associate Membership: Brazil, Cyprus (awaiting ratification), Pakistan, 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

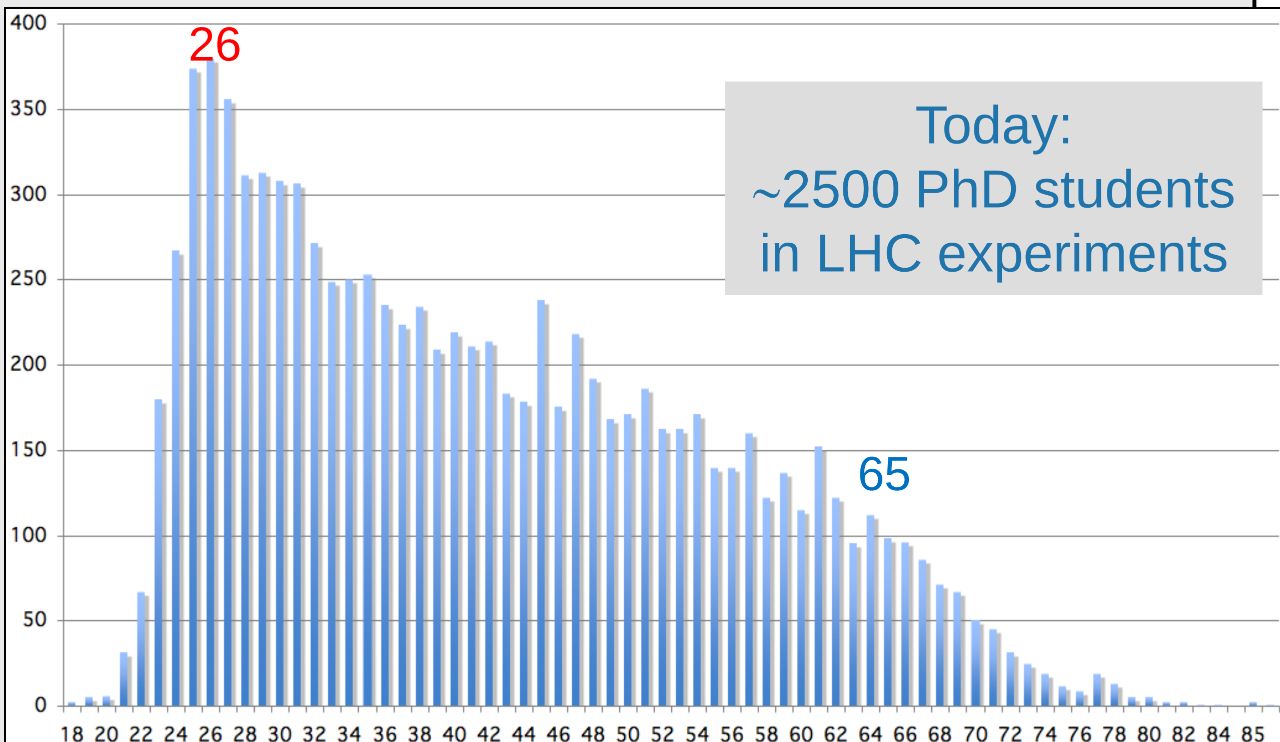
Argentina	19
Armenia	15
Australia	32
Azerbaijan	2
Belarus	22
Brazil	107
Canada	168
Chile	7
China	114
China (Taipei)	69
Colombia	10
Croatia	24
Cuba	3
Cyprus	7
Egypt	11
Estonia	17
Georgia	10
Iceland	4
Iran	23
Ireland	8
Korea	96
Lithuania	13
Malta	1
Mexico	41
Montenegro	1
Morocco	10
New Zealand	9
Pakistan	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

Age Distribution of Scientists

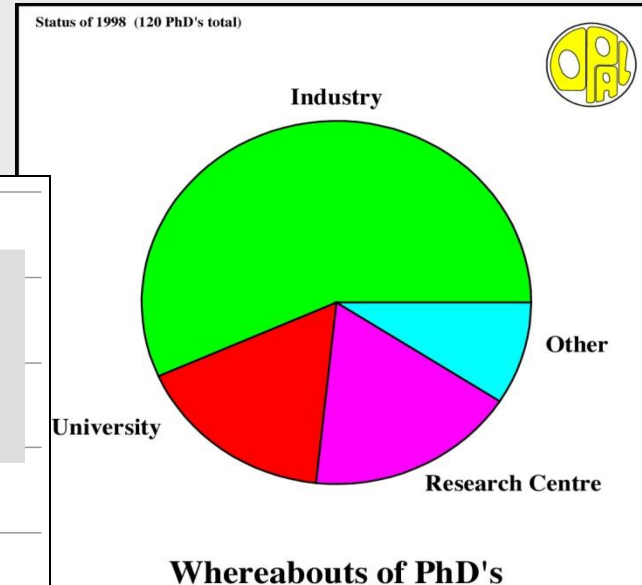
- and where they go afterwards

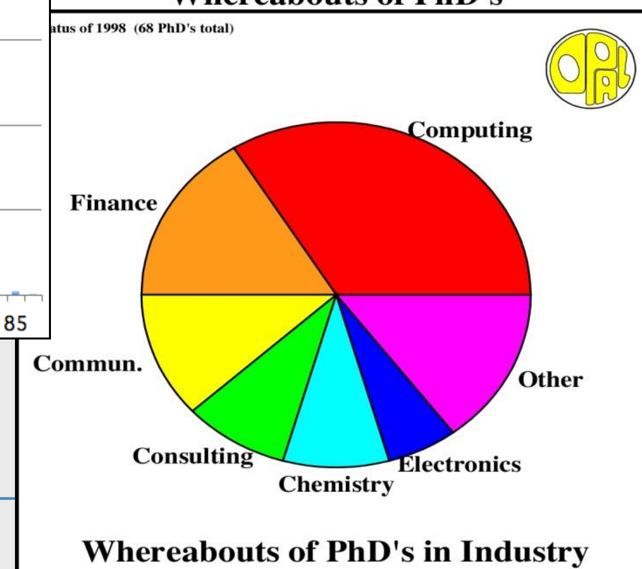
Survey in March 2009



Today:
~2500 PhD students
in LHC experiments

They do not all stay: where do they go?



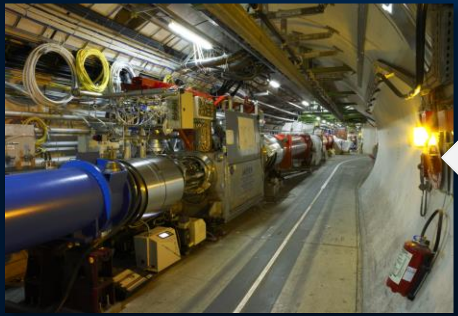


CERN: Particle Physics and Innovation

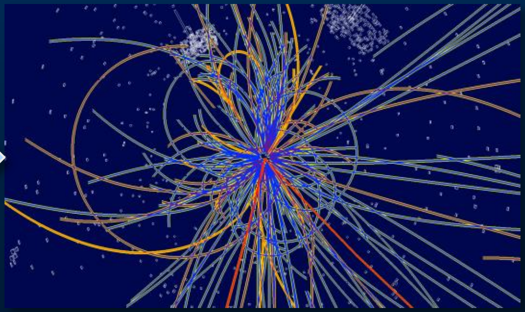
Innovation
Education
CERN
uniting people
Research

- Interfacing between fundamental science and key technological developments

- CERN Technologies and Innovation



Accelerating particle beams



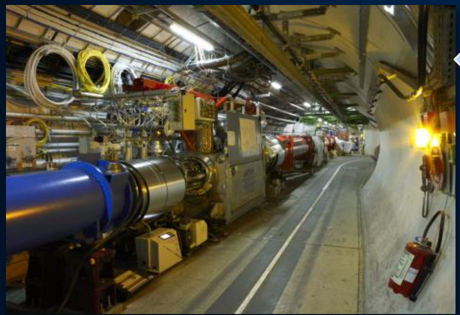
Detecting particles

Large-scale computing (Grid)

Innovation CERN Education
uniting people
Research

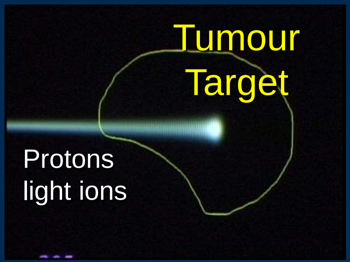
CERN Technologies and Innovation
Example: Medical applications

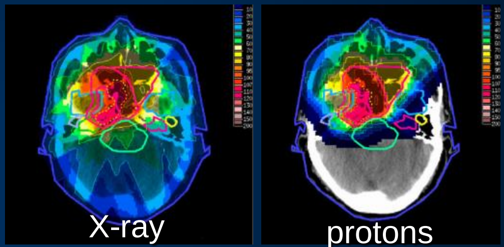
Combining Physics, ICT, Biology and Medicine to fight cancer



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

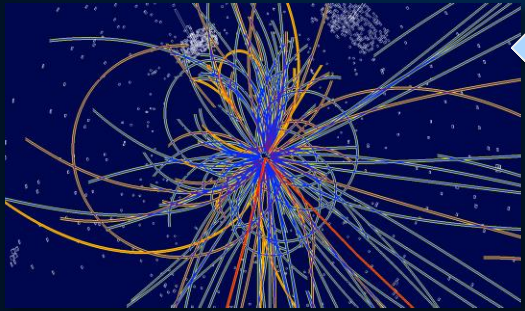
Hadron Therapy





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)

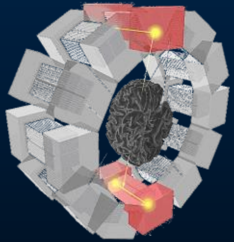


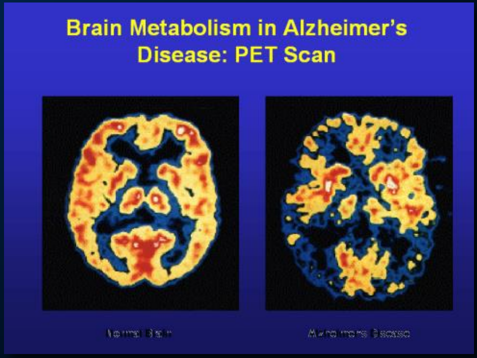
Detecting particles

Imaging

PET Scanner

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

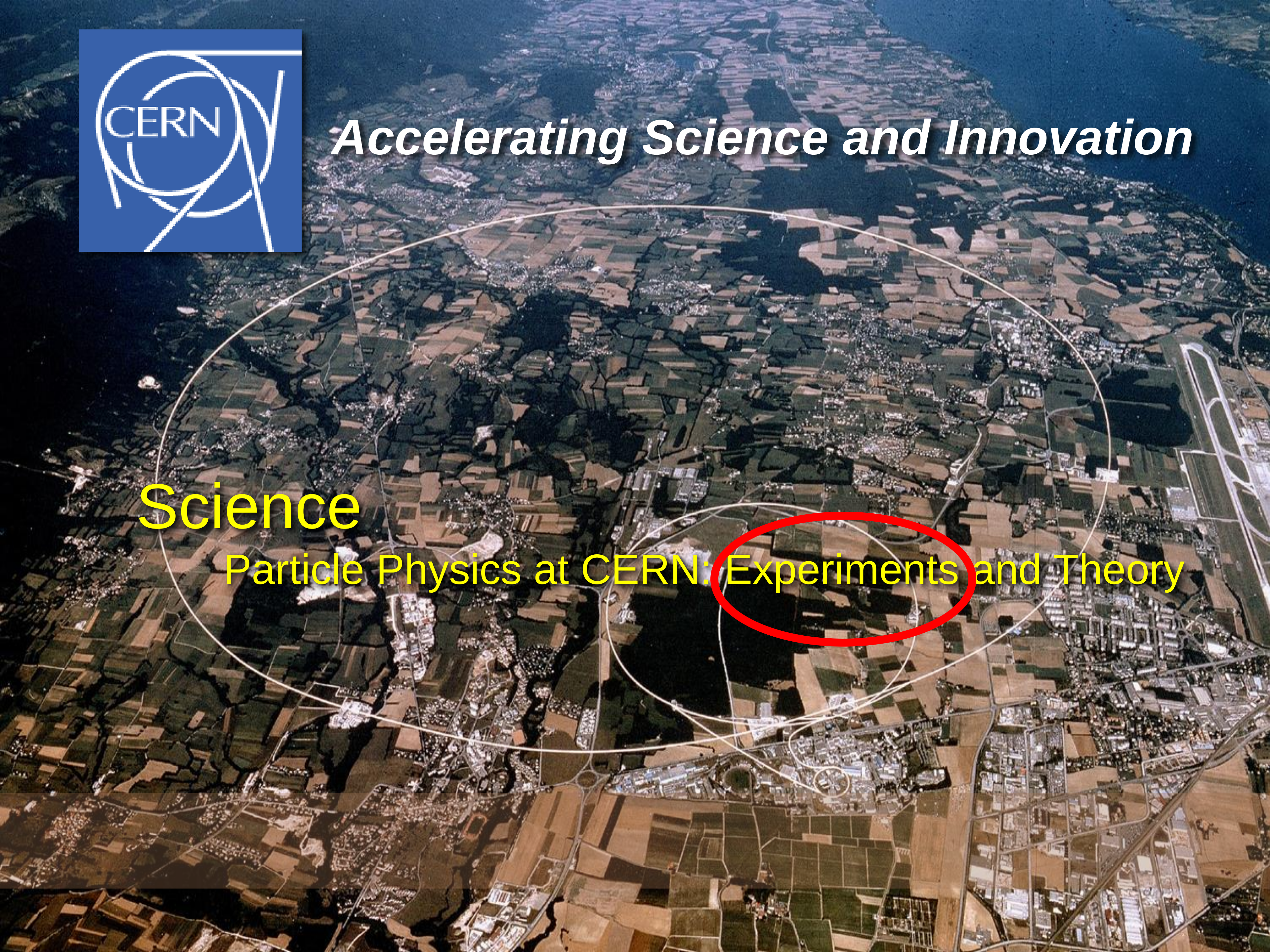




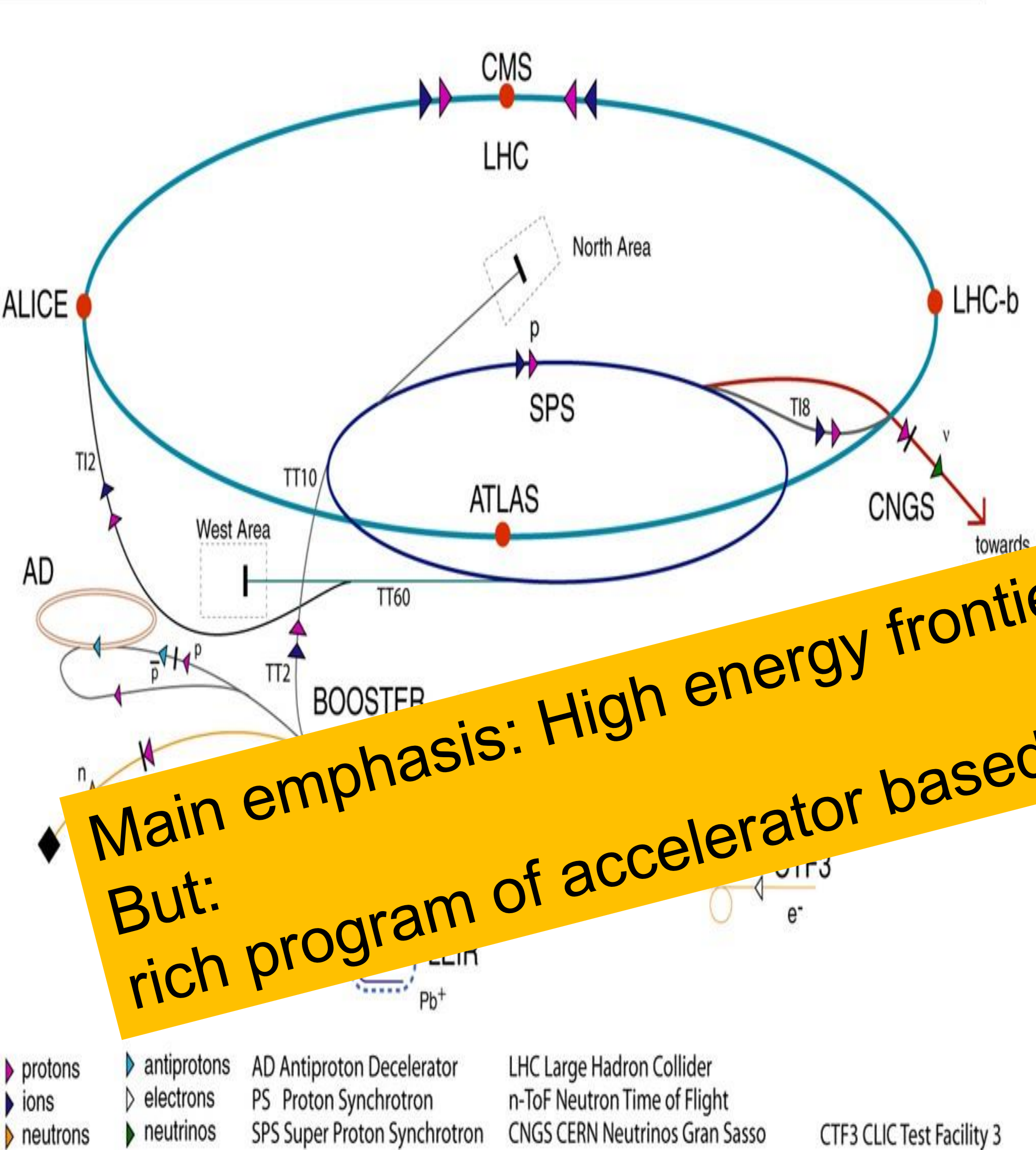
Accelerating Science and Innovation

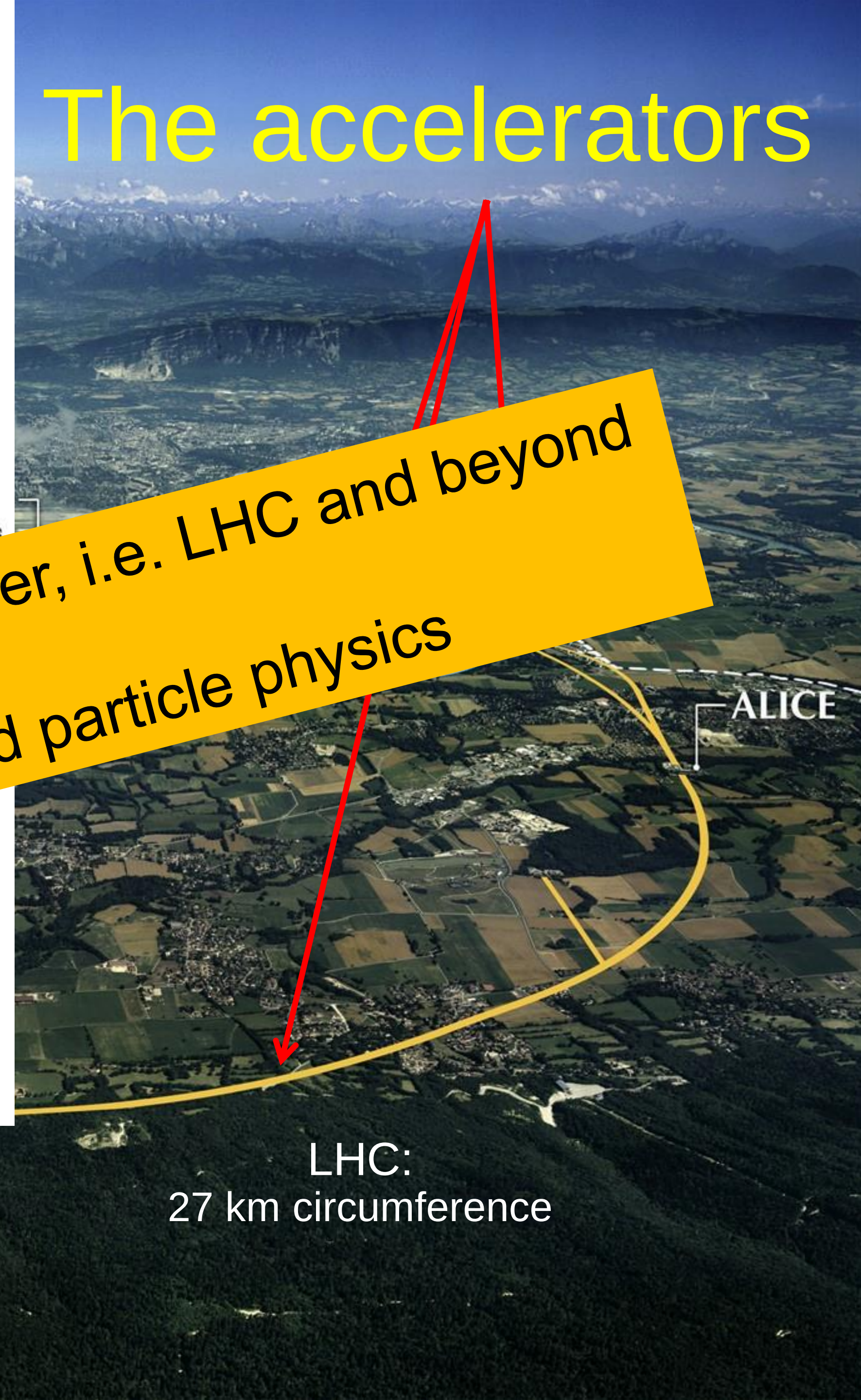
Science

Particle Physics at CERN: Experiments and Theory



The accelerators





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

But:

rich program of accelerator based particle physics

LHC:
27 km circumference

The Particle Physics Landscape at CERN

High Energy Frontier
LHC

Hadronic Matter
deconfinement
non-perturbative QCD
hadron structure

Low Energy
heavy flavours / rare decays
neutrino oscillations
anti-matter

Non-accelerator
dark matter
astroparticles

Multidisciplinary
climate, medicine

Non-LHC Particle Physics = o(1000) physicists / o(20) experiments

In the past few years

Several breakthroughs !

Steady progress of other programs

New mid-term and long-term projects started or in discussion

Fixed Target Physics

Antiproton Physics

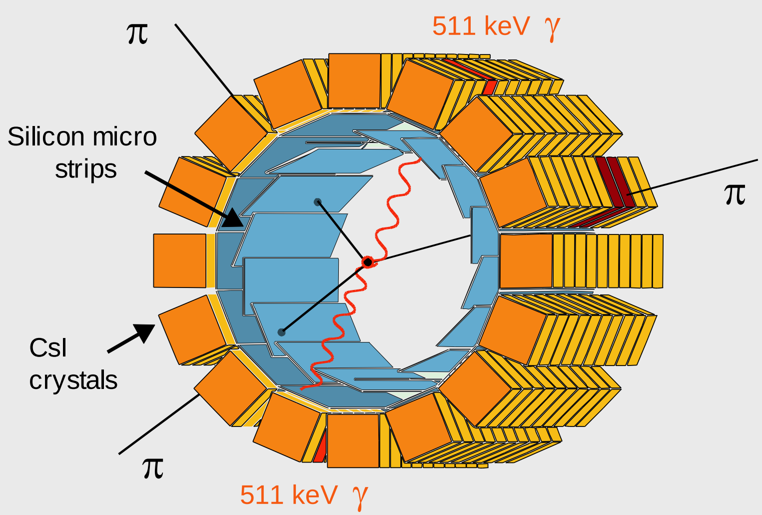
Cold antiprotons
("manufacturing anti-matter")

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

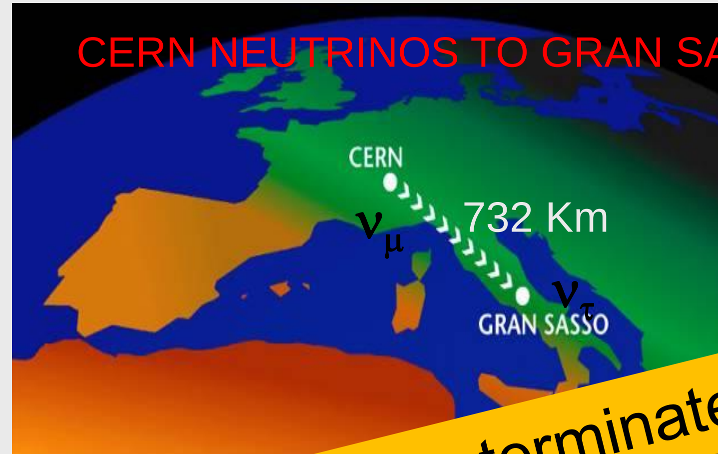
Anti-H annihilations detected

ATHENA (→ ALPHA)

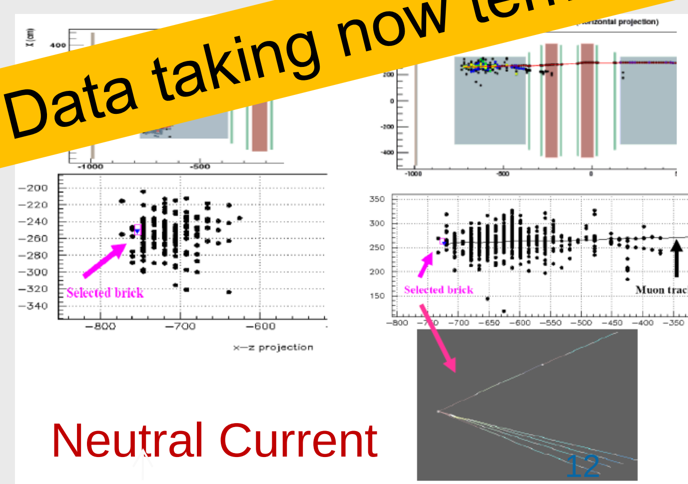
anti-H (pe^+) + matter → $\pi^+\pi^- + \gamma\gamma$



Neutrino Physics



Data taking now terminated



OPERA

Neutral Current

Charge Current

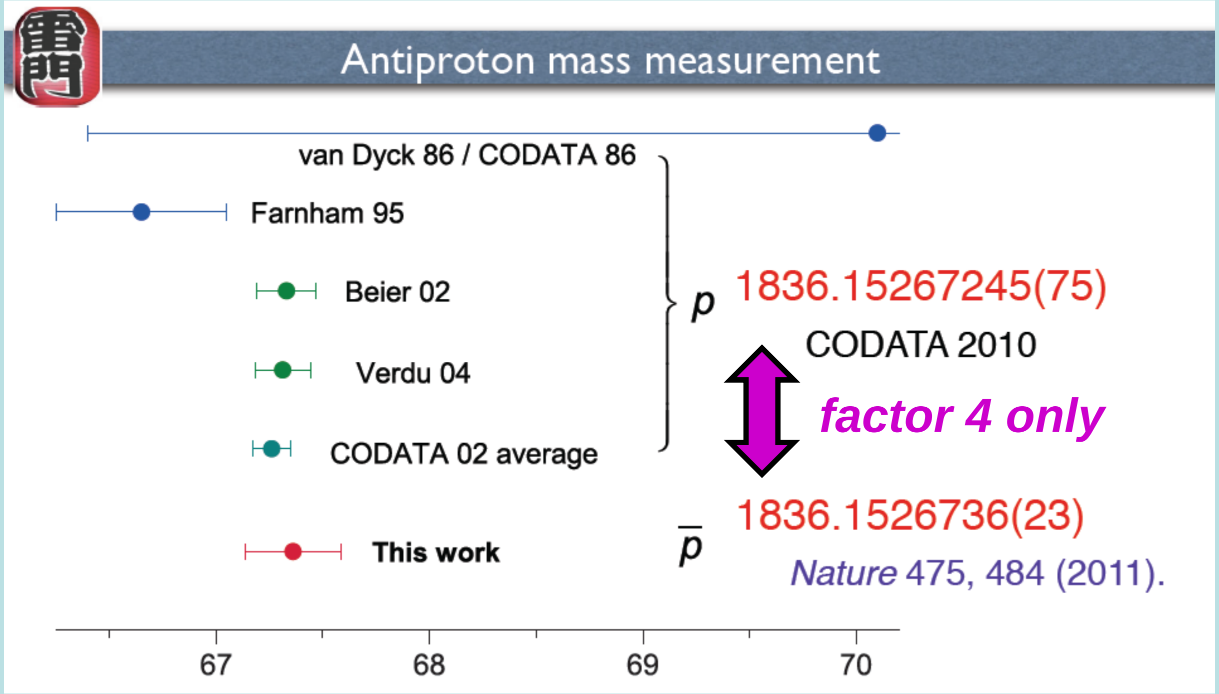
Breakthroughs… ALPHA

nature

First successful trapping of Anti-Hydrogen atoms
Trapping times of more than 15mn regularly achieved

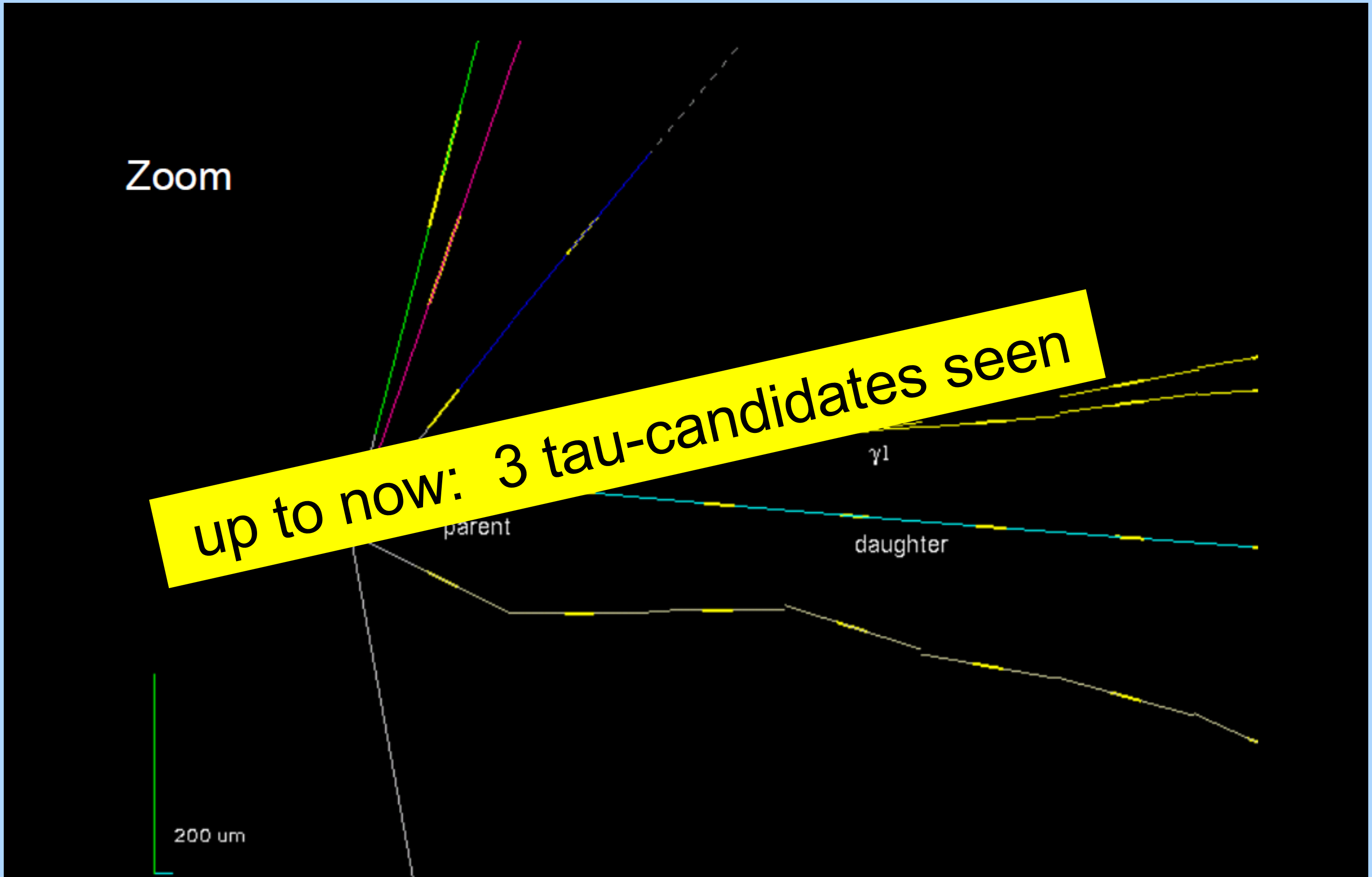
Breakthroughs… ASACUSA

nature



CNGS - OPERA

First υ_τ Candidate

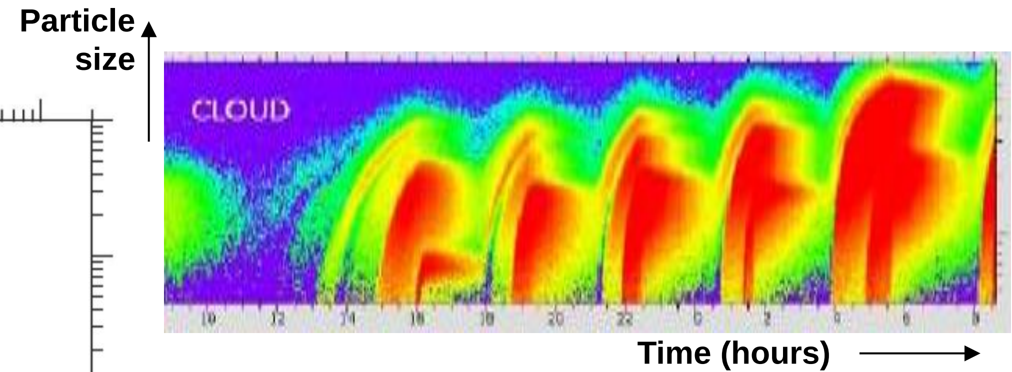


up to now: 3 tau-candidates seen

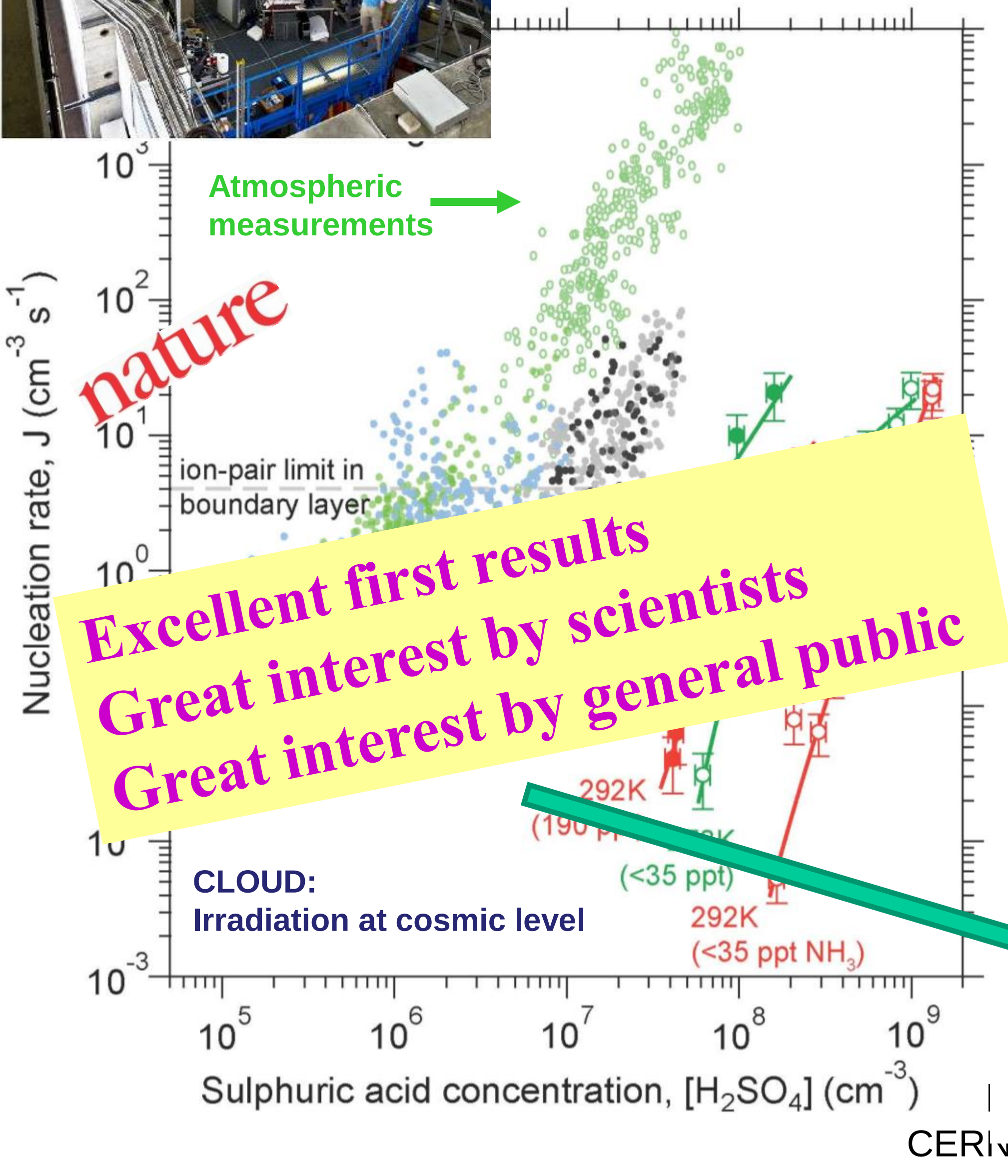
Muonless event 9234119599, taken on 22 August 2009, 19:27 (UTC)
(as seen by the electronic detectors)

Breakthroughs… CLOUD

Aerosol nucleation under controlled conditions



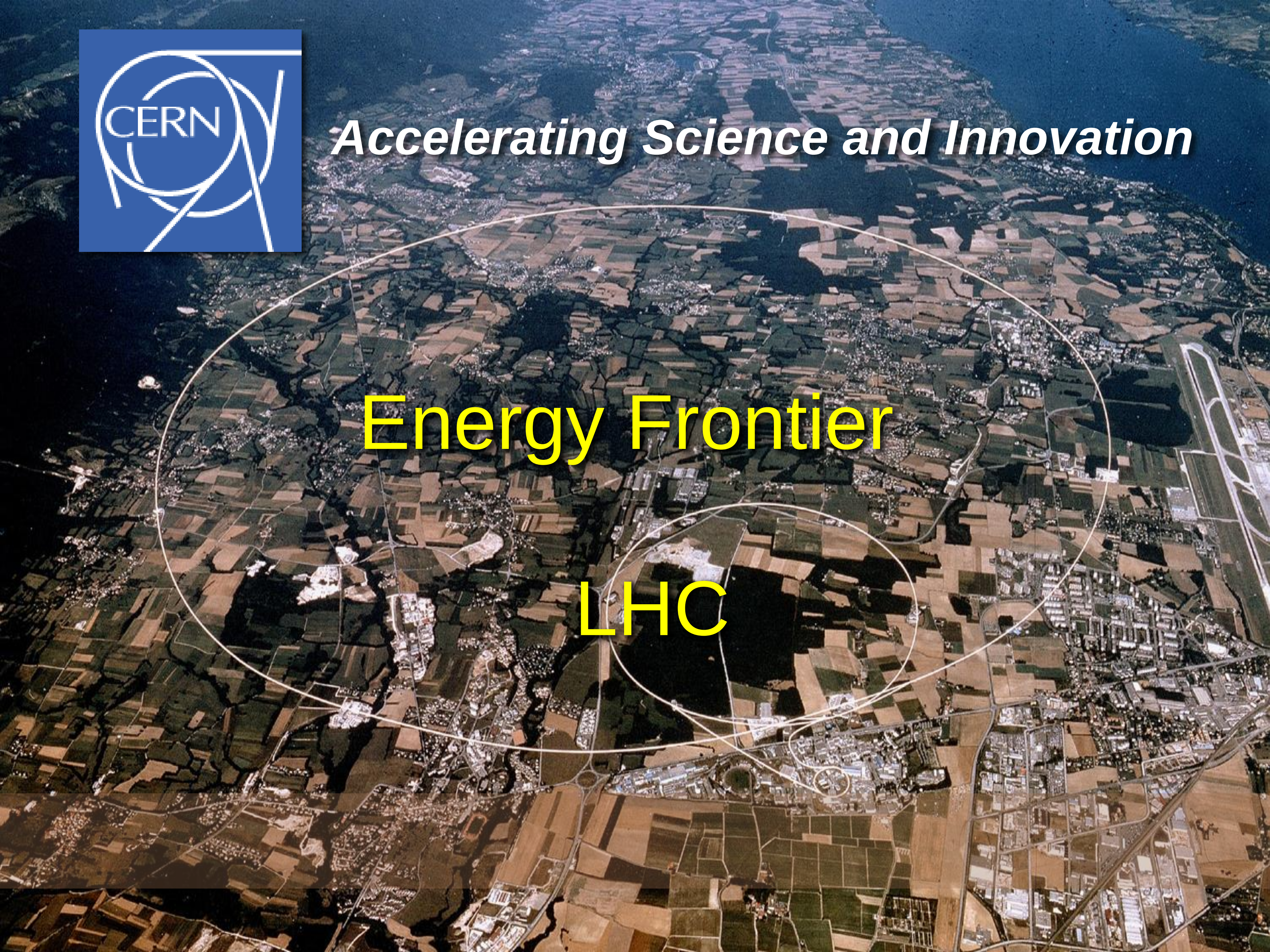
Nucleation depends on traces of organic vapors (tertiary process) and is sensitive to cosmic rays ionization



Excellent first results
Great interest by scientists
Great interest by general public

Atmospheric nucleation rates however not reproduced with $H_2SO_4 + NH_3$ only, other (yet unknown) organic compounds needed.

More studies ongoing at lower temperature


CERN
Accelerating Science and Innovation
Energy Frontier
LHC

Past few decades

"Discovery" of Standard Model

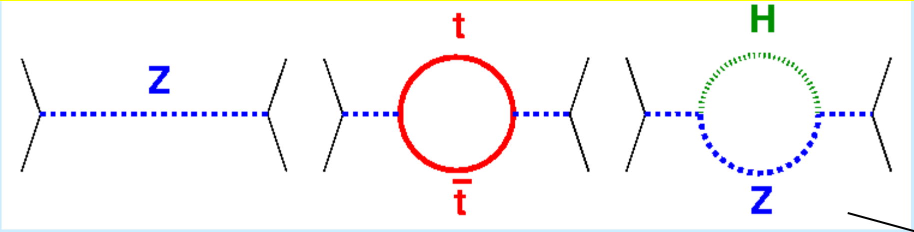
through synergy of

hadron - hadron colliders (e.g. Tevatron)

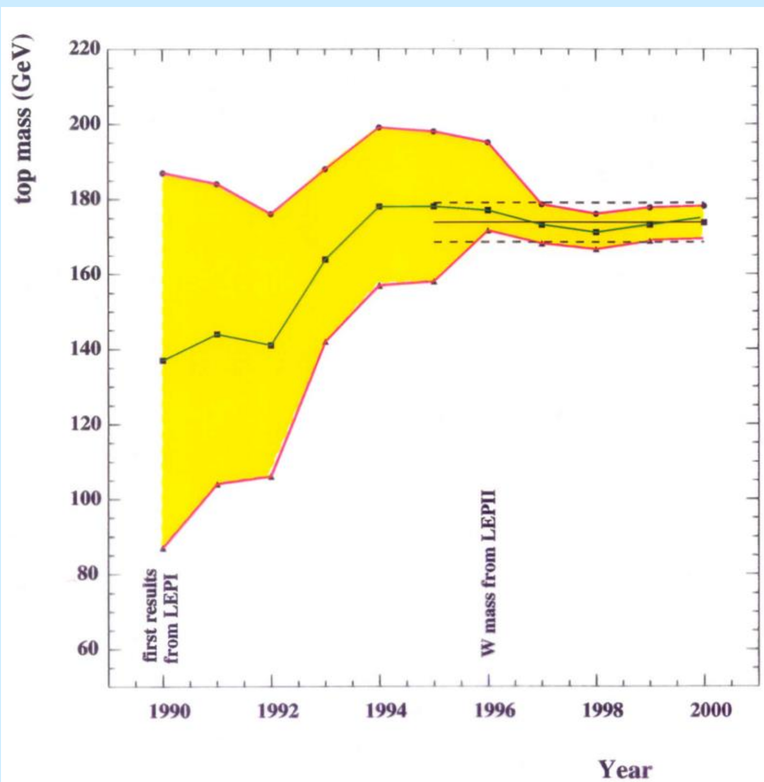
lepton - hadron colliders (HERA)

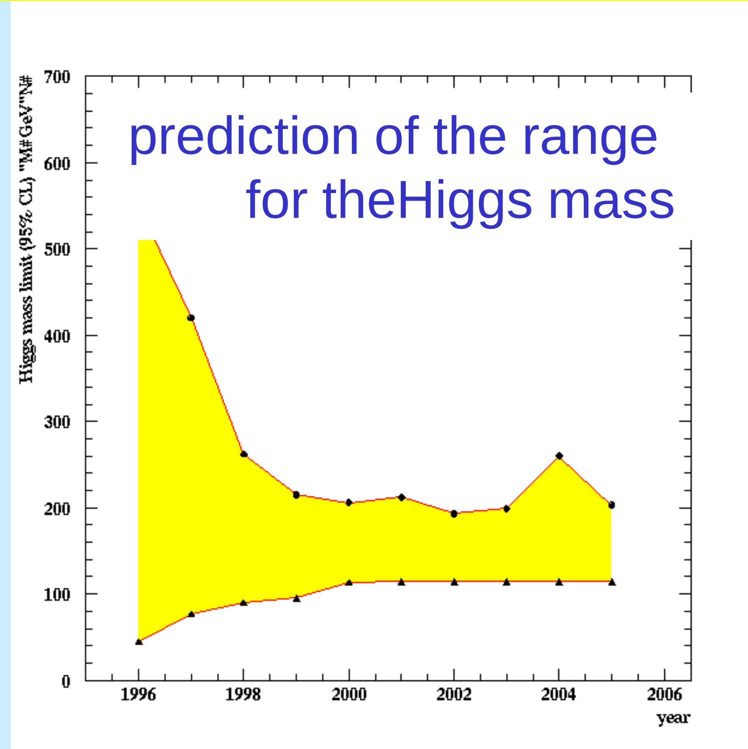
lepton - lepton colliders (e.g. LEP)

Test of the SM at the Level of Quantum Fluctuations



indirect determination of the top mass





possible due to

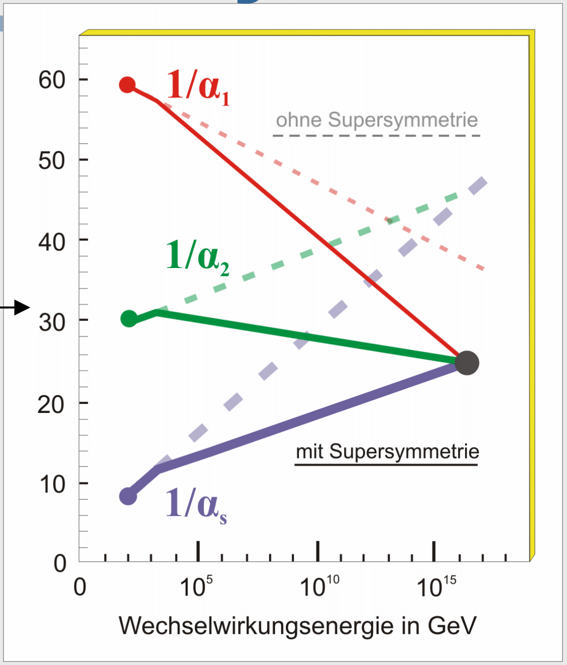
- precision measurements
- known higher order electroweak corrections

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

Key Questions of Particle Physics

origin of mass/matter or
origin of electroweak symmetry breaking

unification of forces



fundamental symmetry of forces and matter

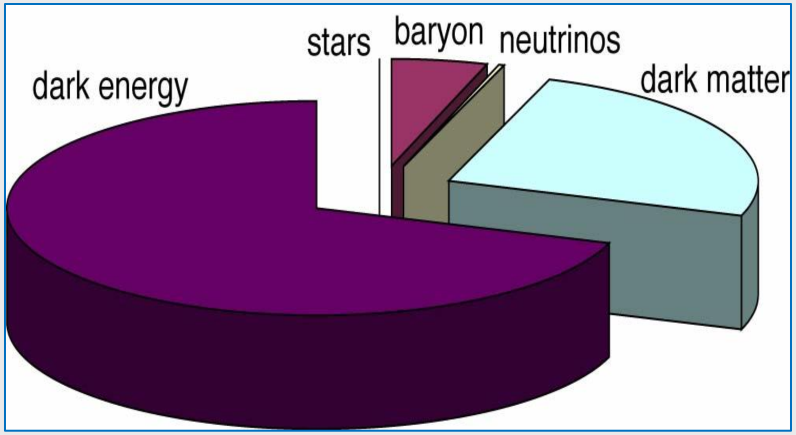
where is antimatter

unification of quantum physics and general relativity

number of space/time dimensions

what is dark matter

what is dark energy

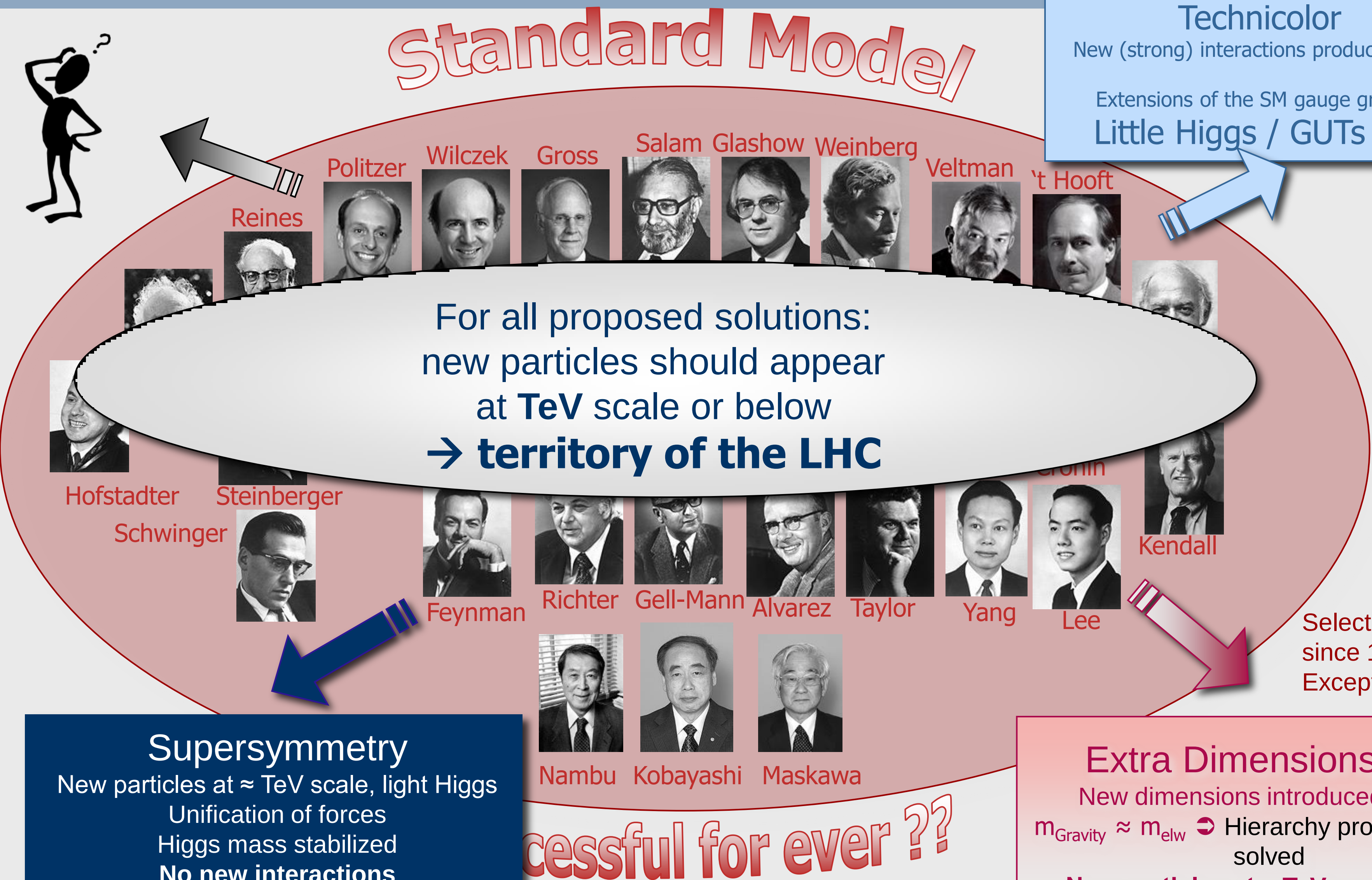


Solutions?

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

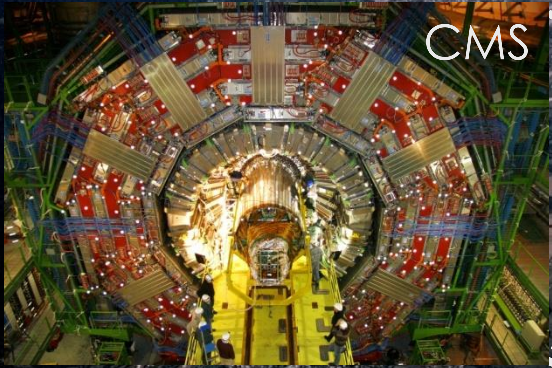
Extra Dimensions
New dimensions introduced
$m_{Gravity} \approx m_{elw}$ ➲ Hierarchy problem solved
New particles at ≈ TeV scale

CERN

2010: a New Era in Fundamental Science

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

2010: a New Era in Fundamental Science



Exploration of a new energy frontier
Proton-proton and Heavy Ion collisions
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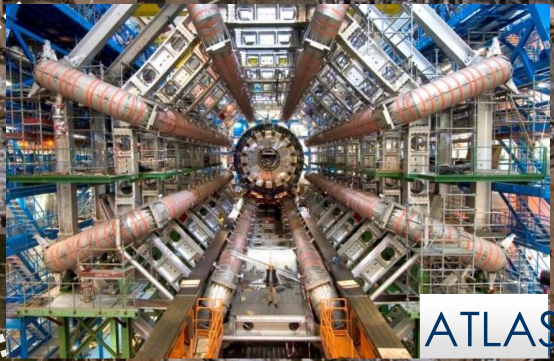
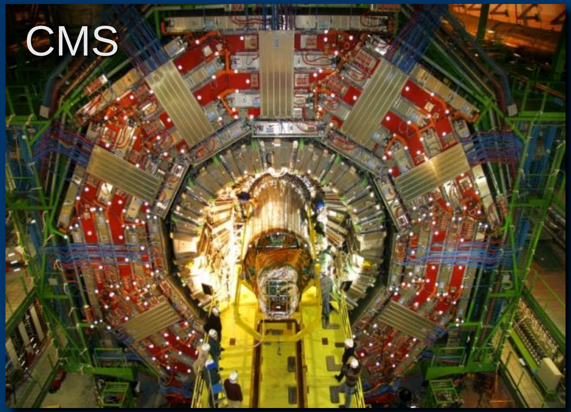
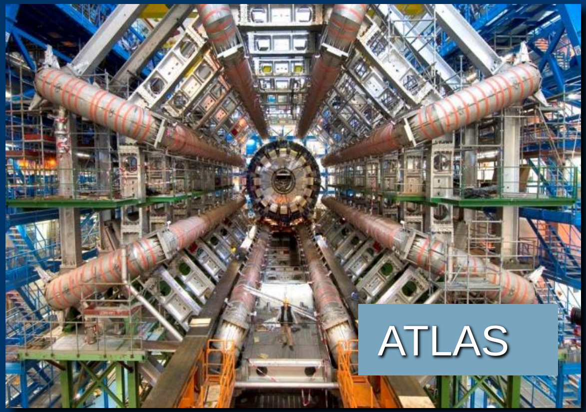


LHC Experiments → complementary

Specialised detector to study b-quarks → CPV



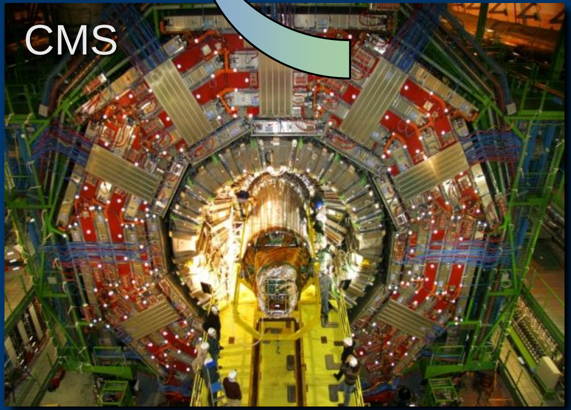


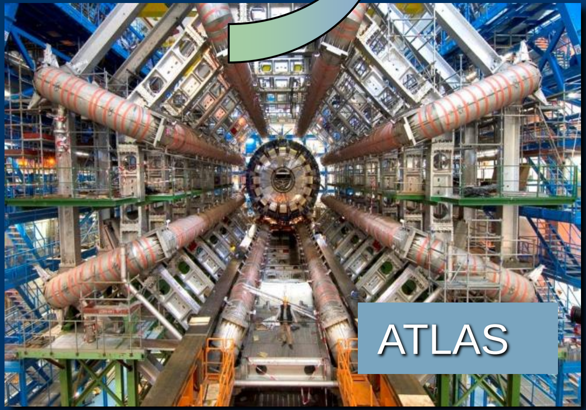
General purpose detectors

Specialised detector to study heavy ion collisions

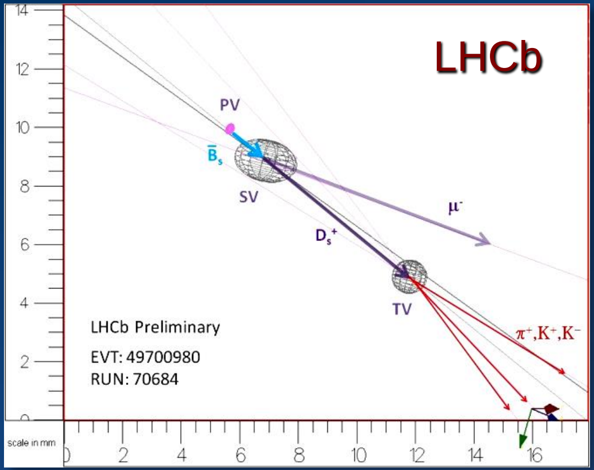
LHC Experiments → complementary

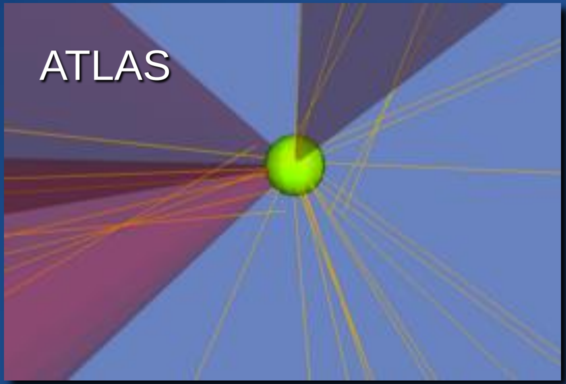
Overlap in physics reach





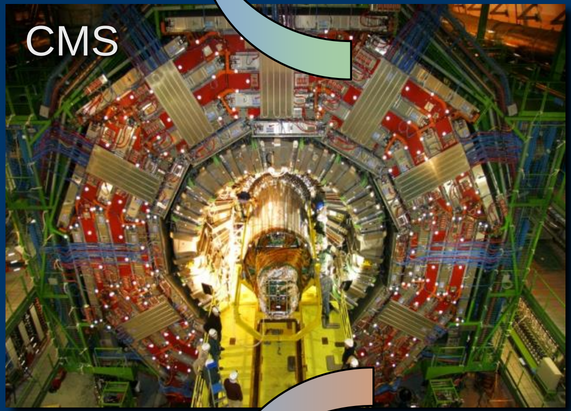
Key feature: reconstruct secondary vertex

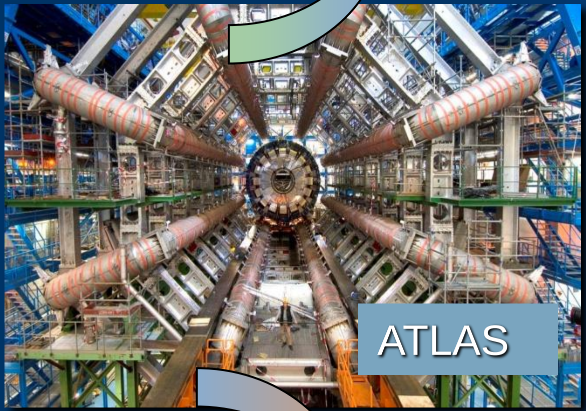


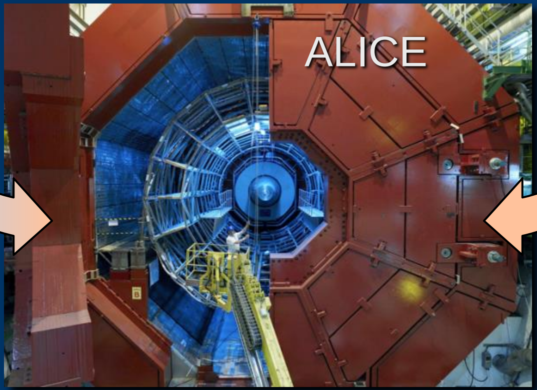


LHC Experiments → complementary

Overlap in physics reach

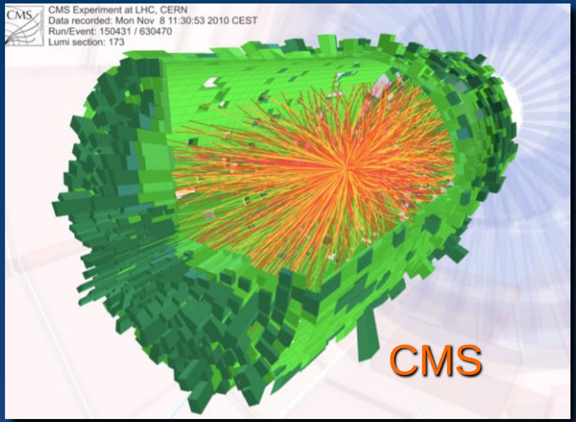


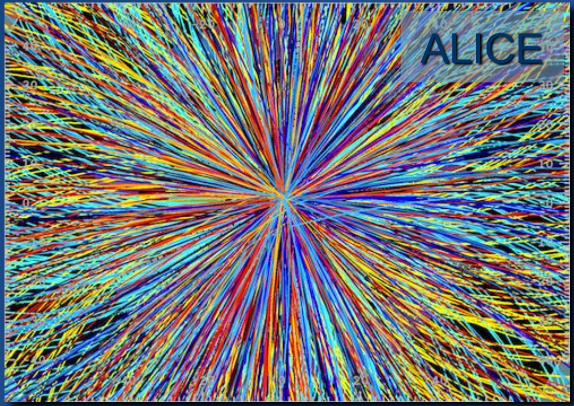


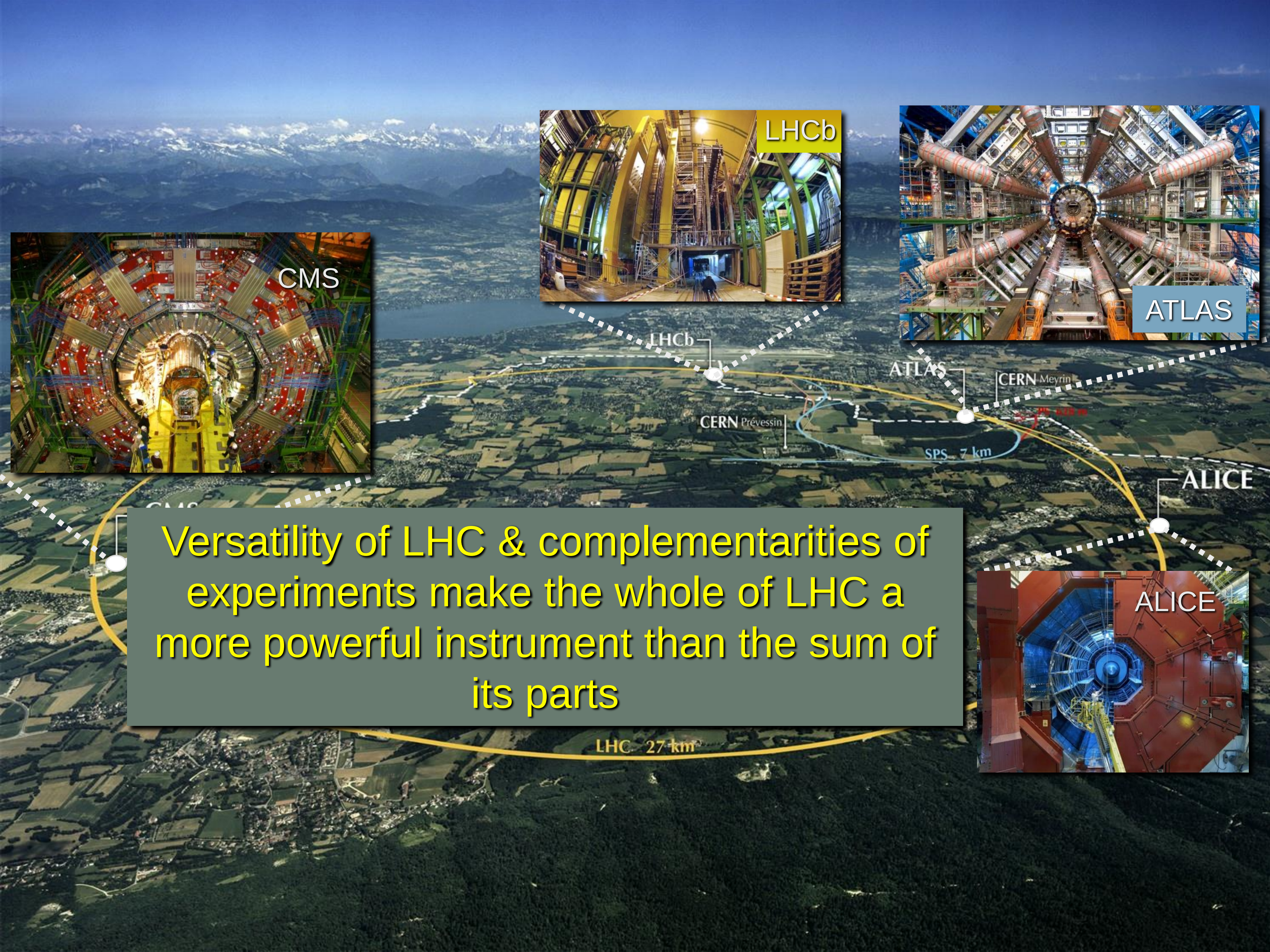


Overlap in physics reach

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

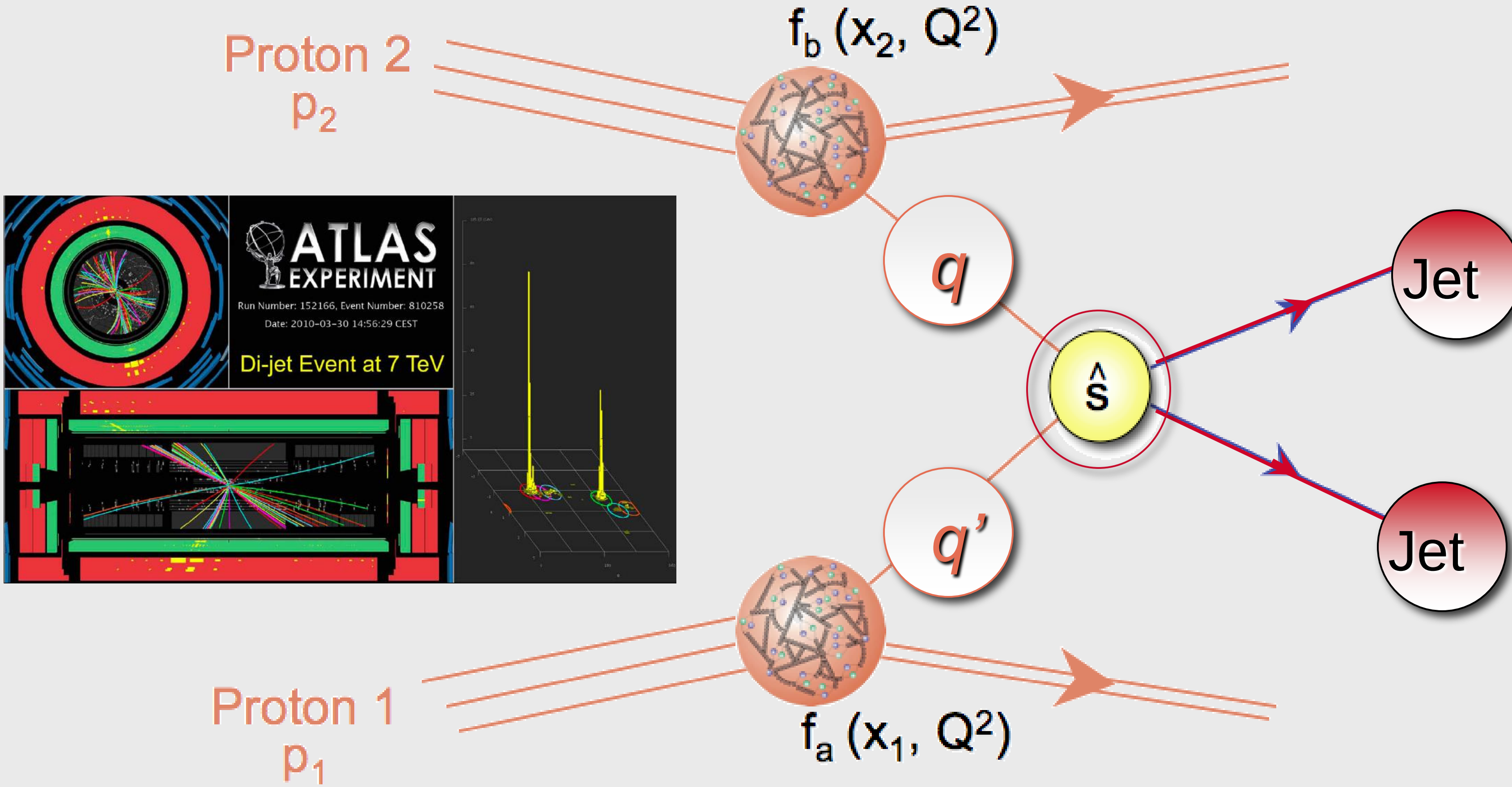






Versatility of LHC & complementarities of experiments make the whole of LHC a more powerful instrument than the sum of its parts

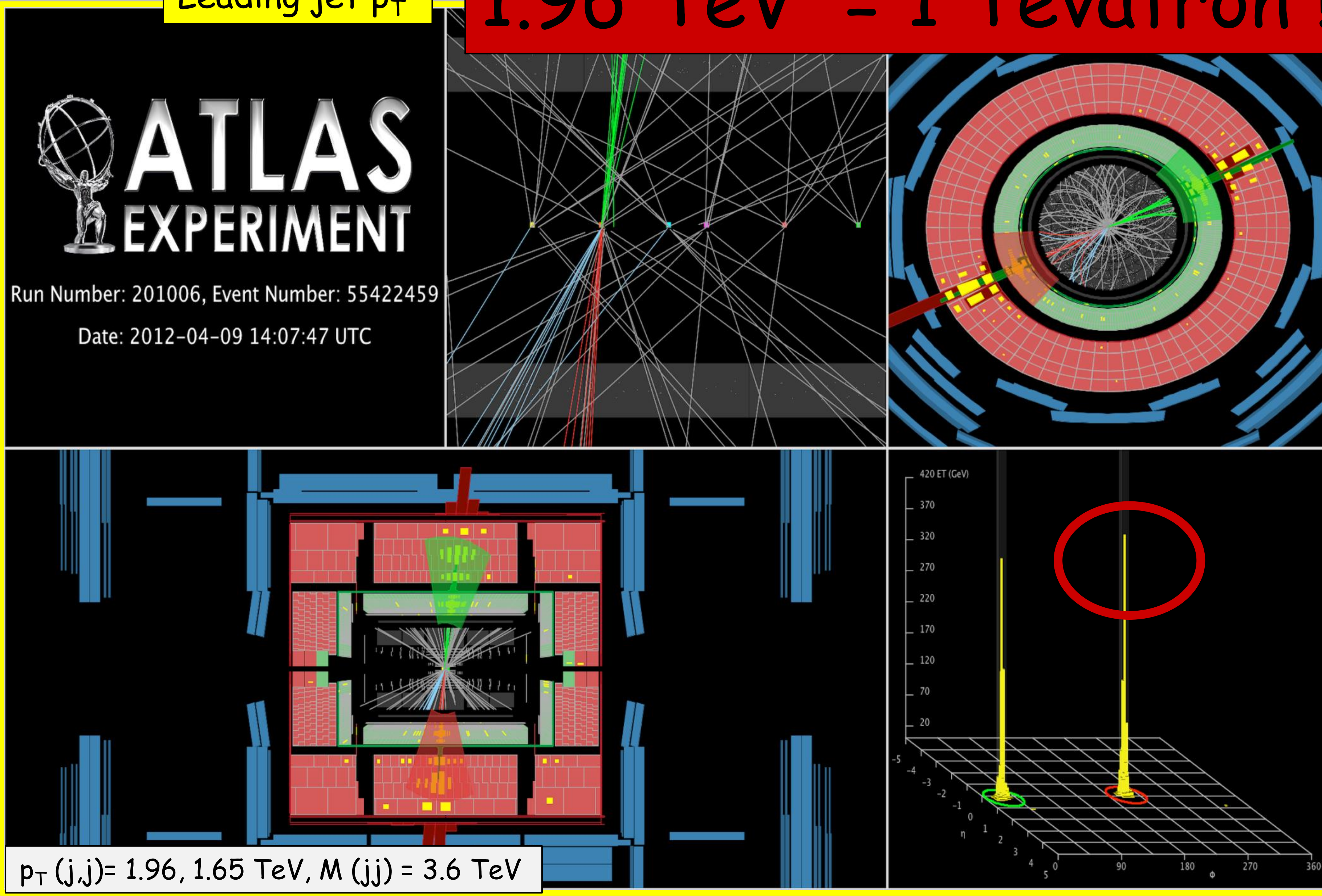
Basic processes at LHC



Di-jet event recorded by ATLAS on 9 April 2012 at $\sqrt{s}$=8 TeV

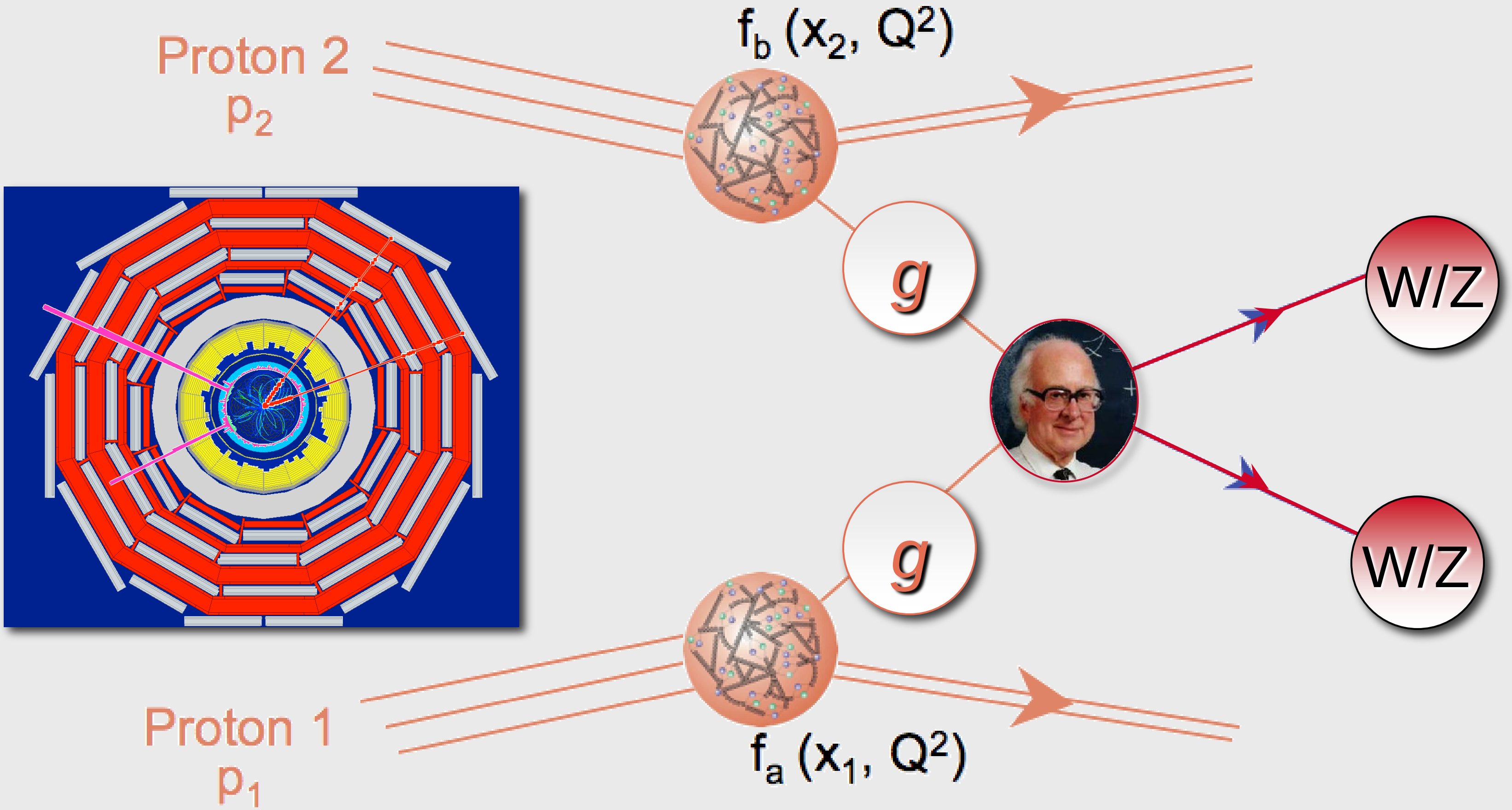
Leading jet p_T

1.96 TeV = 1 Tevatron !!

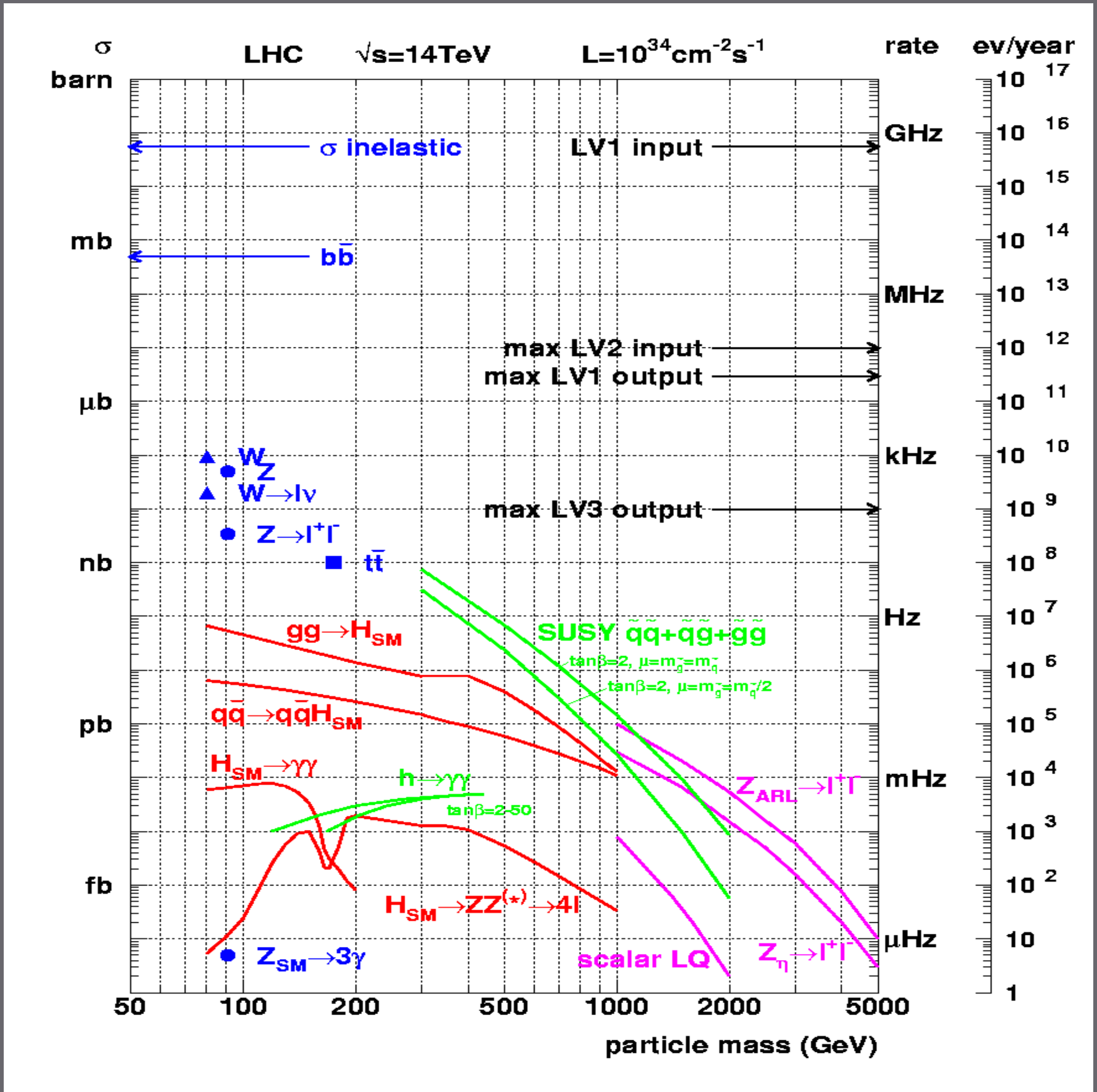


p_T (j,j)= 1.96, 1.65 TeV, M (jj) = 3.6 TeV

Basic processes at LHC



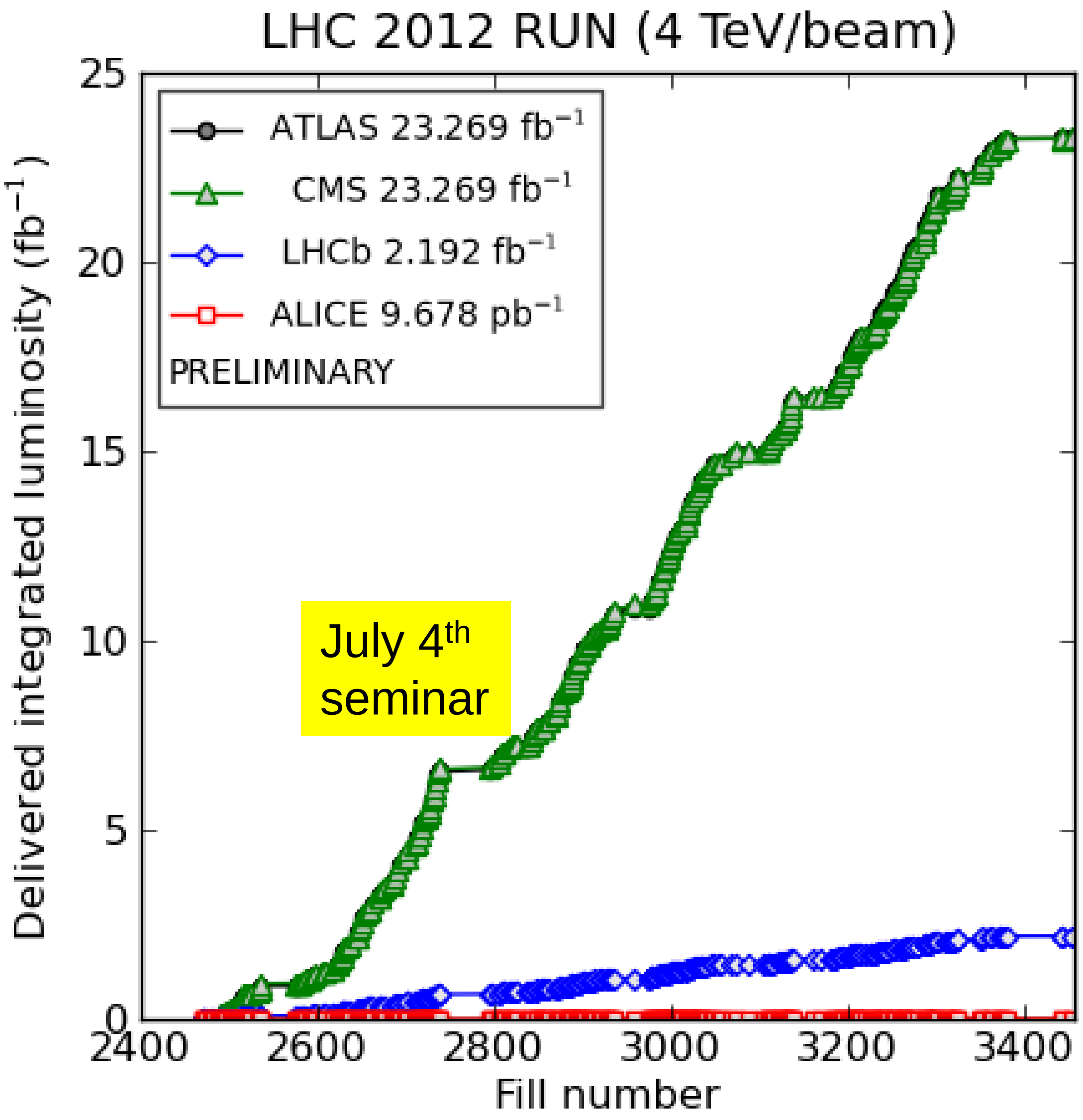
Cross sections at the LHC



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

New Physics!!
We want to keep!!

Evolution of Integrated Luminosity 2012



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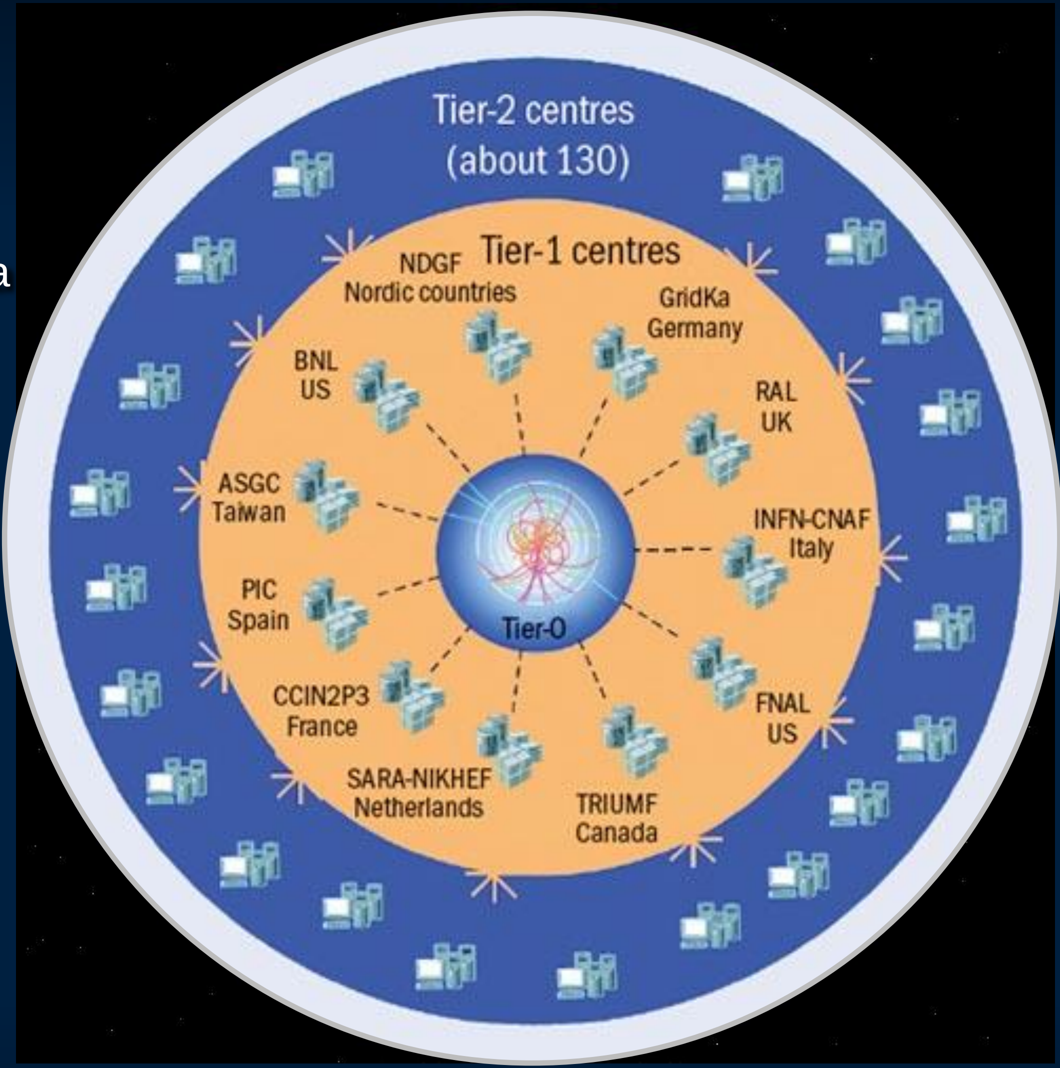
The Worldwide LHC Computing Grid

Tier-0 (CERN): data recording, reconstruction and distribution

Tier-1: permanent storage, re-processing, analysis

Tier-2: Simulation, end-user analysis



nearly 160 sites, 35 countries

~250'000 cores

173 PB of storage

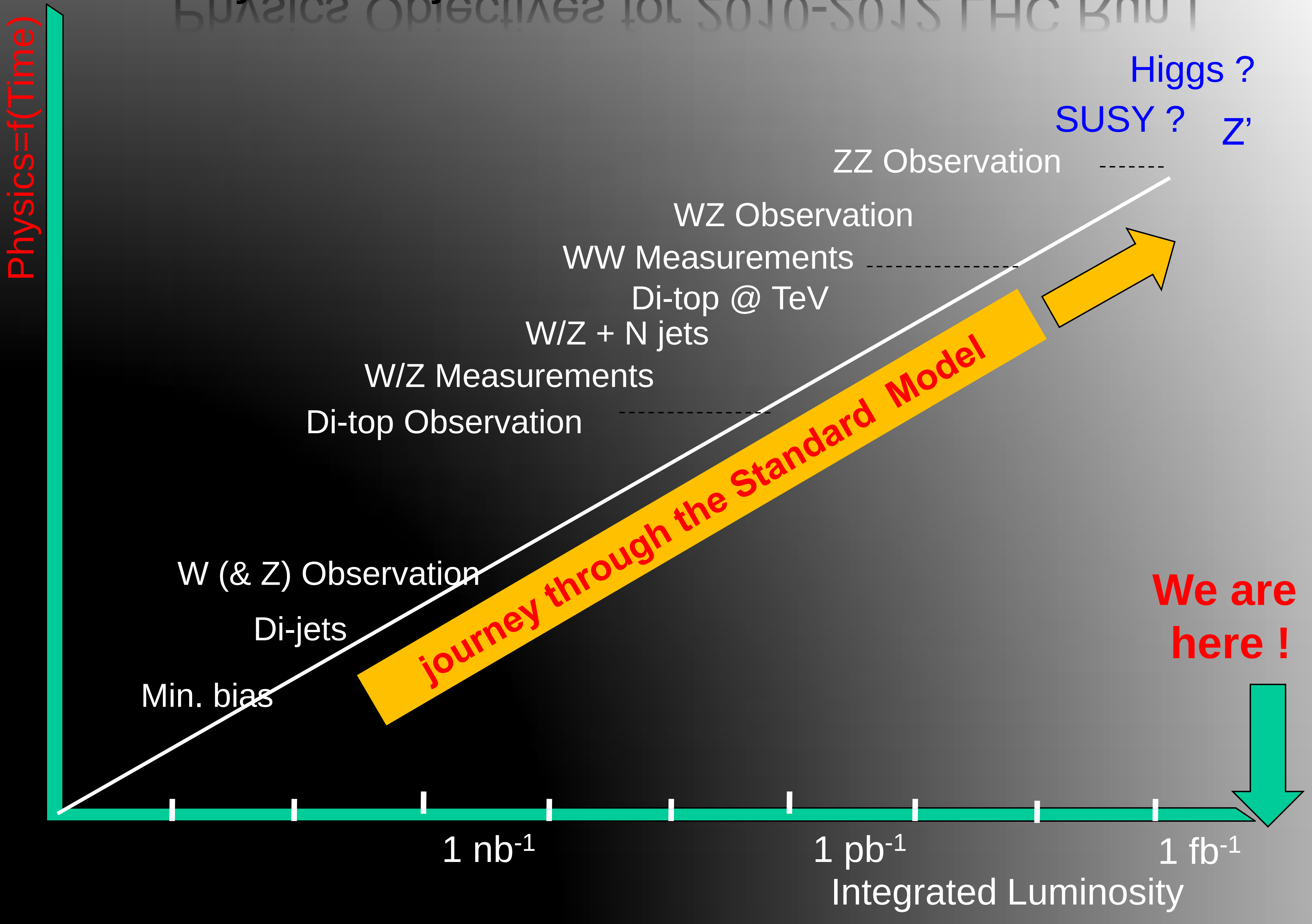
> 2 million jobs/day

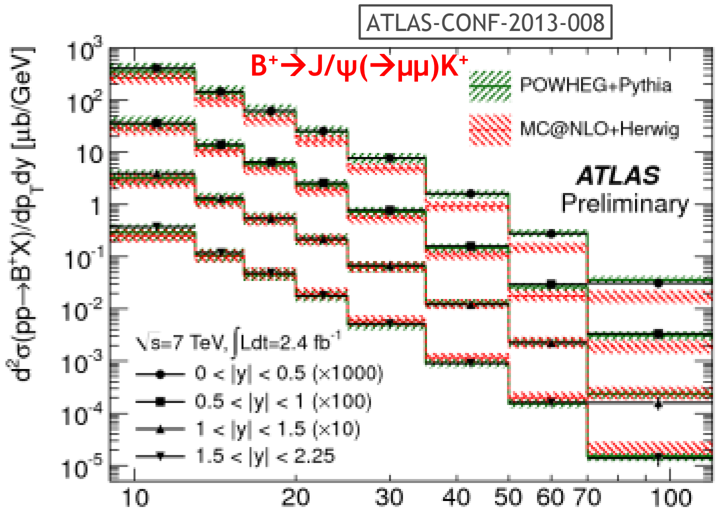
10 Gb links

WLCG:
An International collaboration to distribute and analyse LHC data

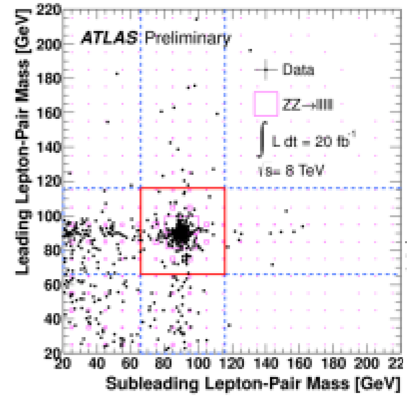
Integrates computer centres worldwide that provide computing and storage resource into a single infrastructure accessible by all LHC physicists

Physics Objectives for 2010-2012 LHC Run I

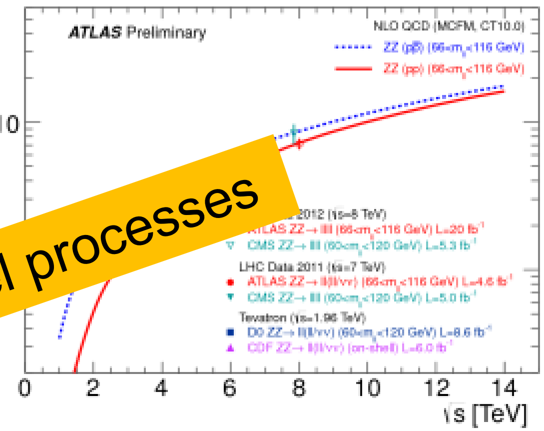




B⁺ production (2011 data)



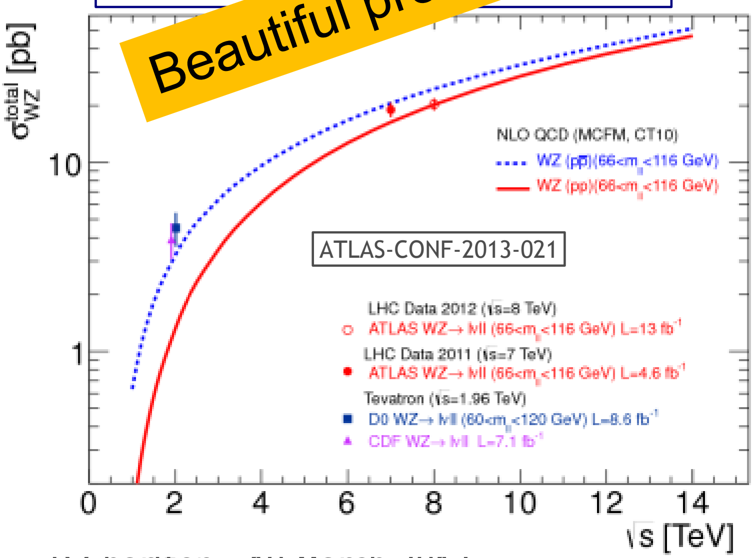
$ZZ \to 4\ell$ (20 fb^{-1} @ 8 TeV)

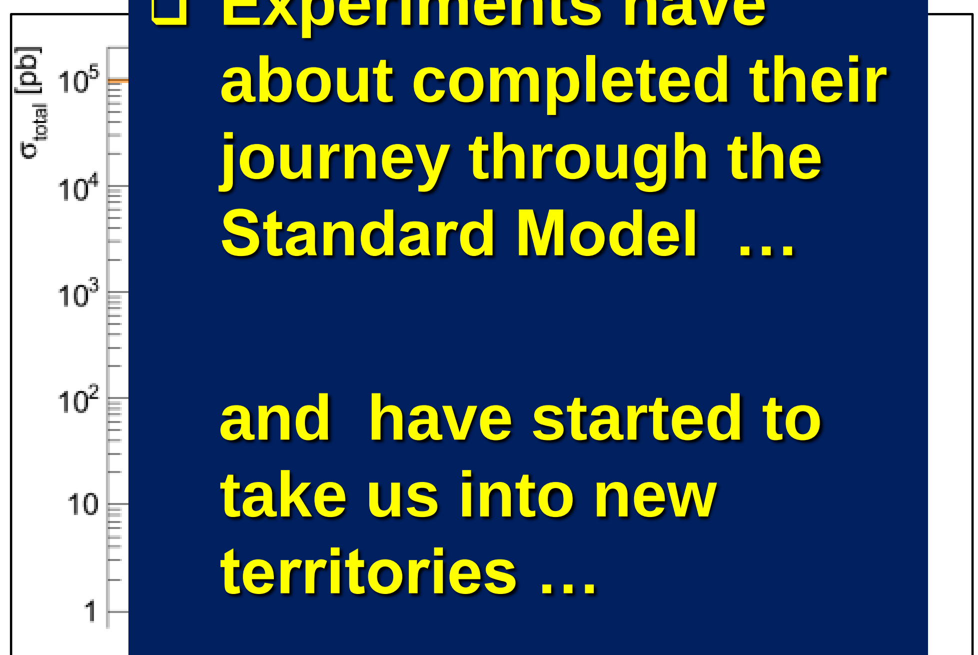


A tiny p... our ...urements

Beautiful precision measurements of Standard Model processes

$WZ \to 3\ell\nu$ (... TeV)



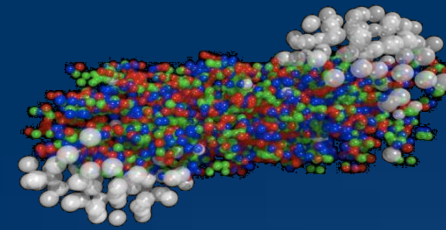


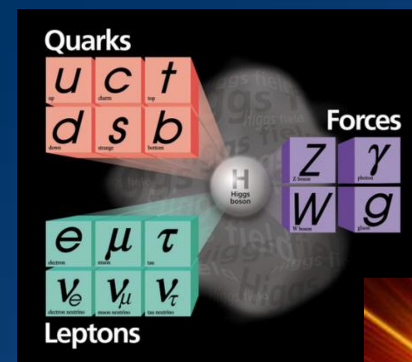
- **Experiments have about completed their journey through the Standard Model …**

  and have started to take us into new territories …

The study of LHC data will allow us to answer some of the key questions ...

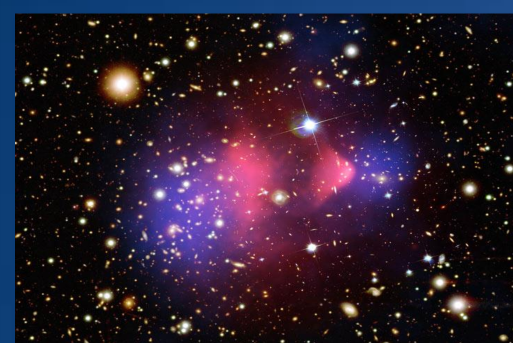
Will we understand the primordial state of matter after the Big Bang before protons and neutrons formed?





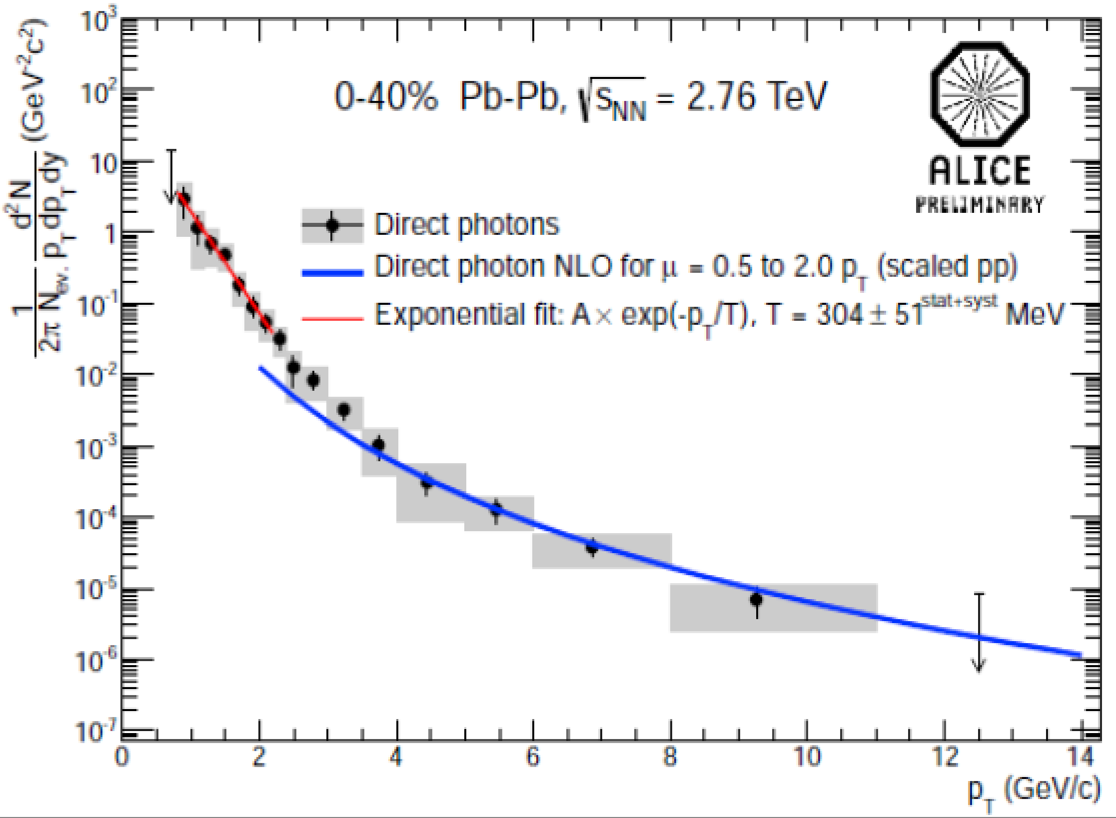
Have we found the Higgs particle that is 'responsible for giving mass' to all particles?

Will we find the reason why antimatter and matter did not completely destroy each other?



Will we find the particle(s) that make up the mysterious 'dark matter' in our Universe? And what's 'dark energy'?

Low p_T direct photons → a direct thermometer for the temperature of the fireball

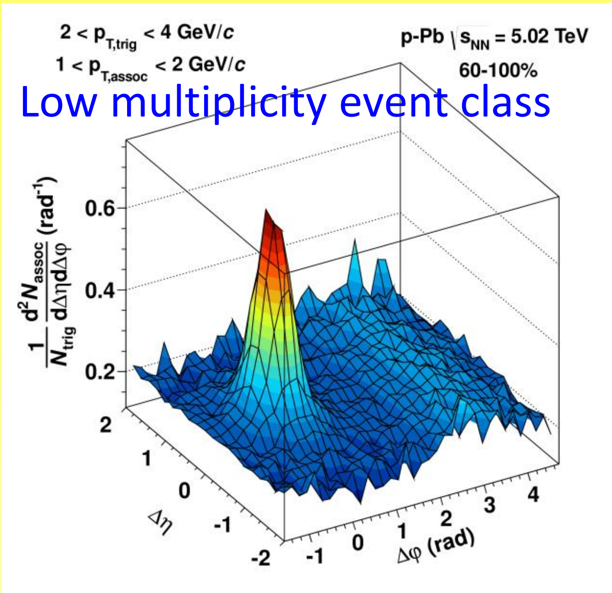


Integrated over fireball history: T = 304 MeV
initial temperature > 450 MeV
highest temperature ever measured in the laboratory

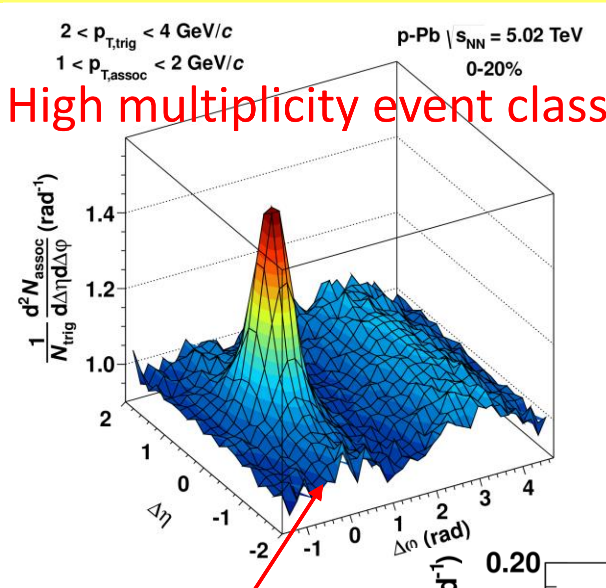
around 3.5×10^{12} K

Correlations

Low multiplicity event class



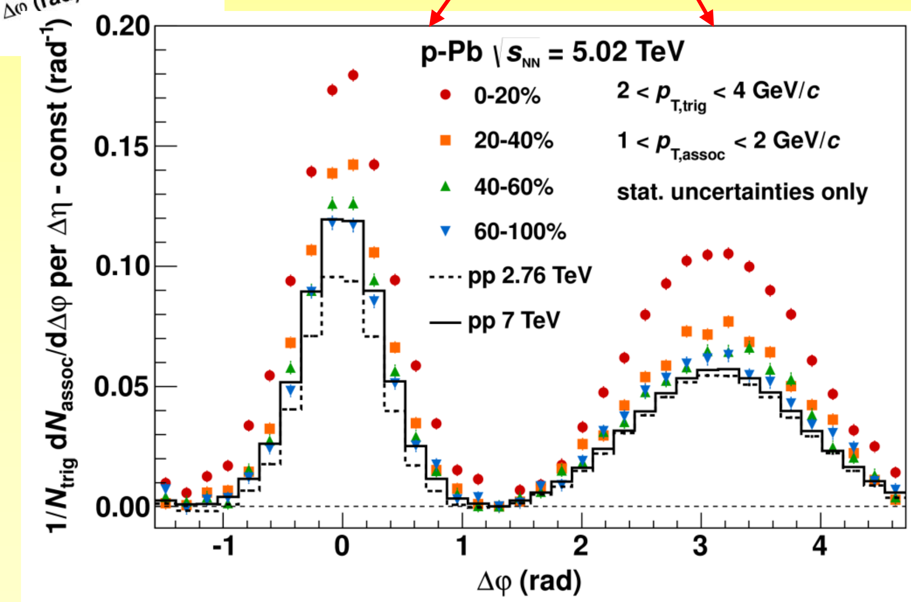
High multiplicity event class



Phys.Lett. B719 (2013) 29-41

Excess on both near-side (NS) and away-side (AS) going from p-p/low multiplicity -> high multiplicity events

Qualitatively similar to CMS ridge



Projection on Δϕ – pPb and pp data

- Correlations for pairs of trigger and associated particles, p_T,trig>p_T,assoc, as f(Δϕ,Δη), defined as associated yield per trigger particle

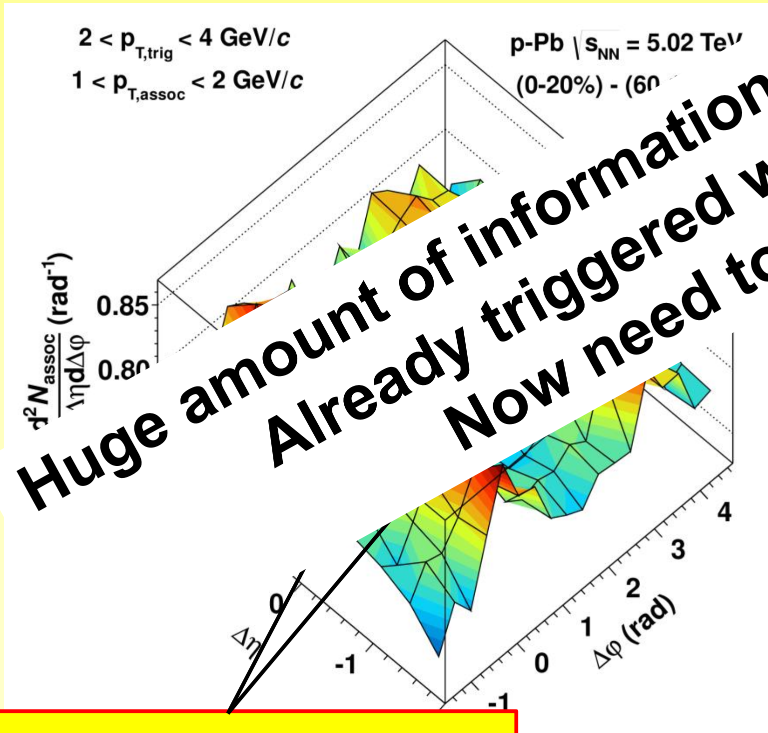
Subtracting the low-mult from the high-mult

- A double-ridge structure appears, with remarkable properties:
  - Shape of the distributions decomposed into a Fourier series, in terms ... e coefficients v_n of the corresponding single particle azimuthal dist...
    - v_2 is the dominant component
    - v_2 and v_3 increase with p_T and v_2 also with multiplcity
  - **Same yield near and away side for all classes of p... suggest common underlying process**
  - Width independent of yield
  - possible explanations? CGC?? Flow??

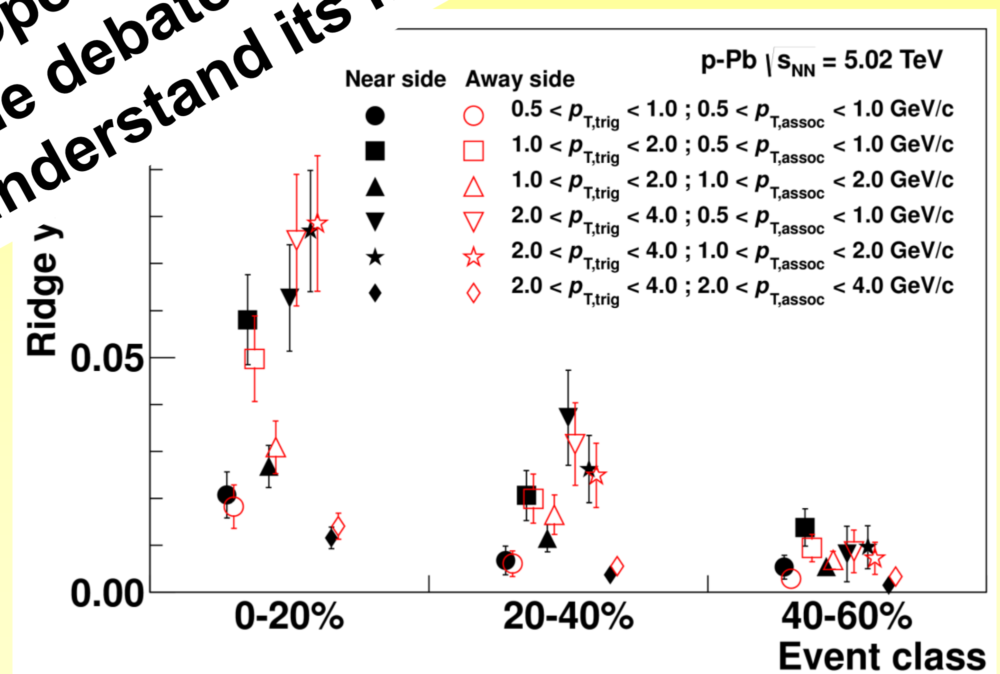
Huge amount of information, opening a new window in the field

Already triggered wide debate in the community

Now need to understand its meaning



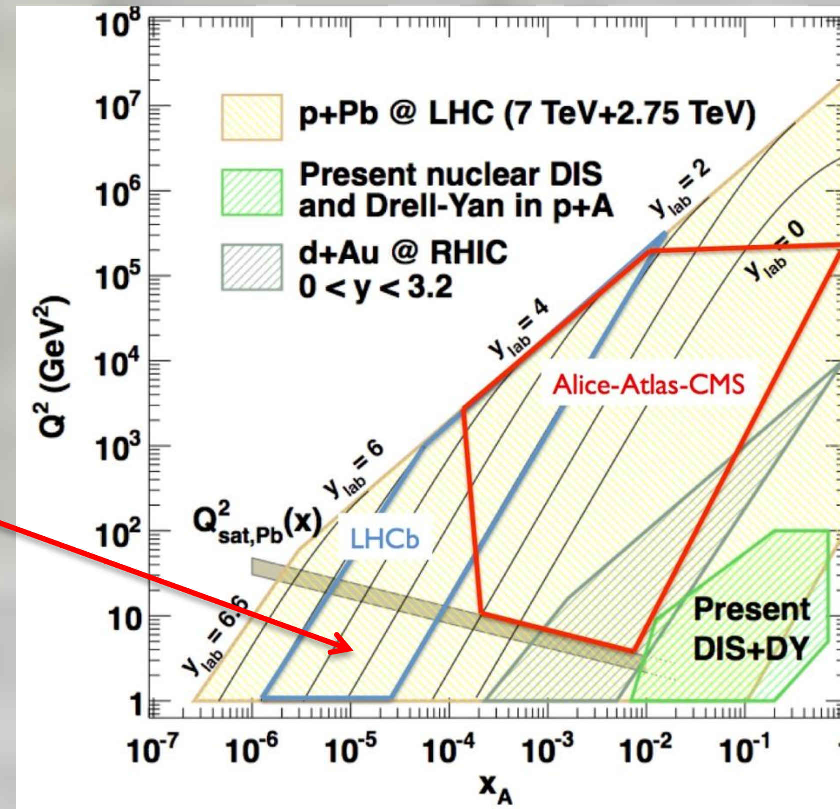
Double-ridge structure



Also observed by ATLAS

pA/Ap LHCb 2013 run

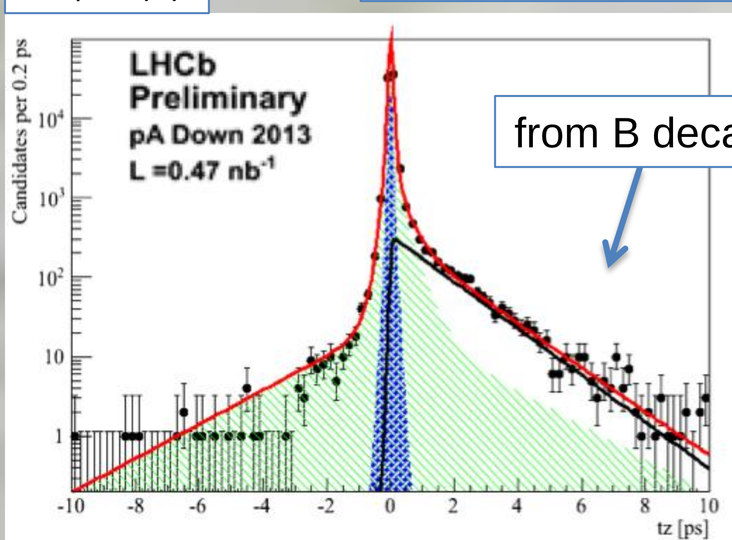
- Smooth pA/Ap LHCb run (data on both directions, and with magnet UP & DOWN)
- 2/nb collected (x10 what expected)
- Analyses started: particle multiplicities, resonances (D , J/ψ , Υ) as probes of DY process in a low (x, Q^2) area specific of LHCb only

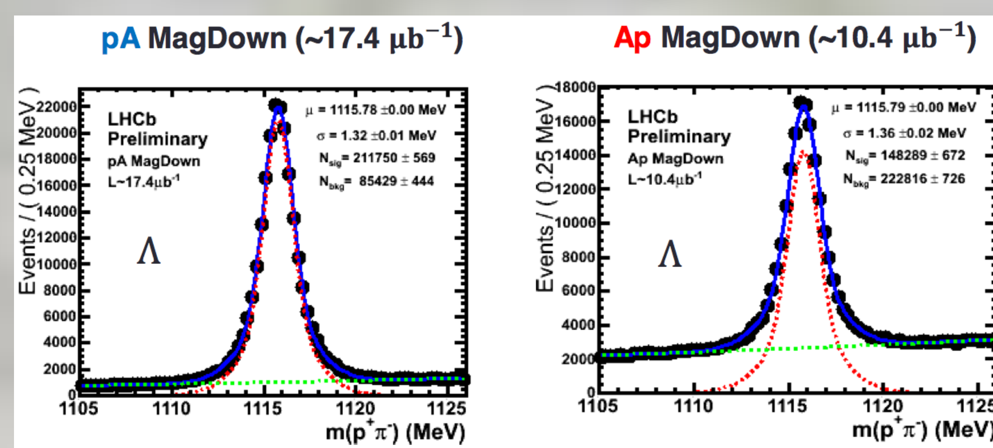


coverage

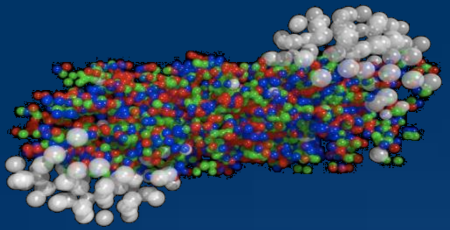
- pp : $2.0 < \eta < 5.0$
- pA: $1.5 < \eta < 4.5$
- Ap: $-5.5 < \eta < -2.5$

J/ψ→μμ





The study of LHC data will allow us to answer some of the key questions ...



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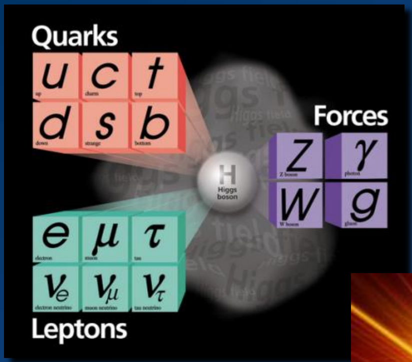

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Dark Matter

Astronomers & astrophysicists over the next two decades using powerful new telescopes will tell us how dark matter has shaped the stars and galaxies we see in the night sky.

Only particle accelerators can produce dark matter in the laboratory and understand exactly what it is.

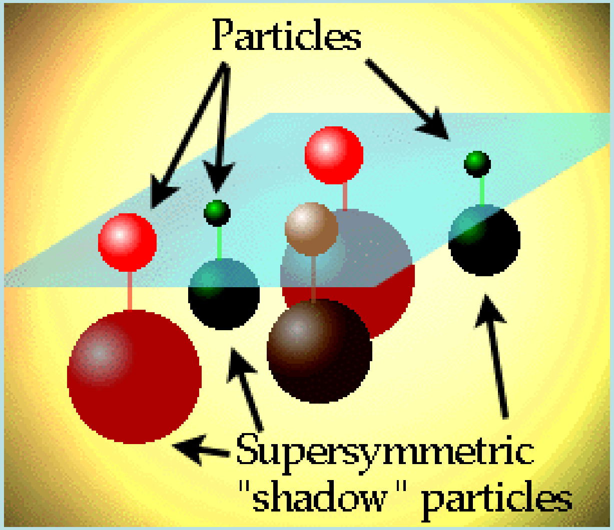
Composed of a single kind of particle
or
more rich and varied (as the visible world)?

LHC may be the perfect machine to study dark matter.

Supersymmetry

- unifies matter with forces

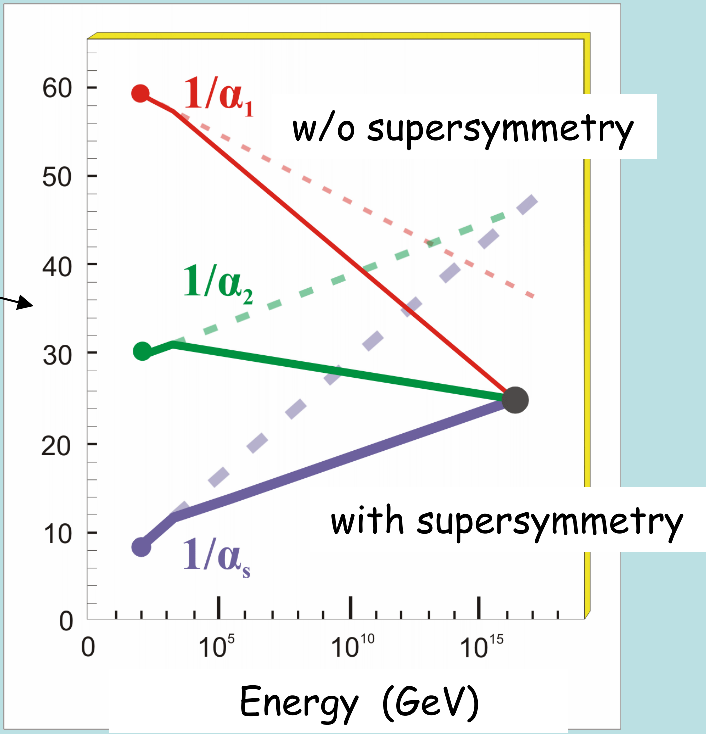
  for each particle a supersymmetric partner (*sparticle*) of opposite statistics is introduced



- allows to unify strong and electroweak forces

  $\sin^2\theta_W^{SUSY} = 0.2335(17)$

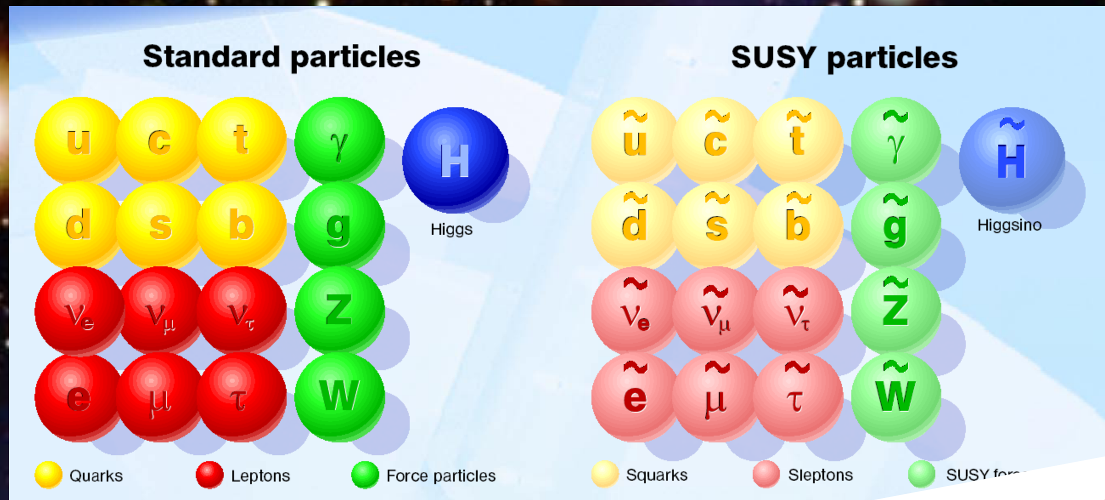
  $\sin^2\theta_W^{exp} = 0.2315(2)$

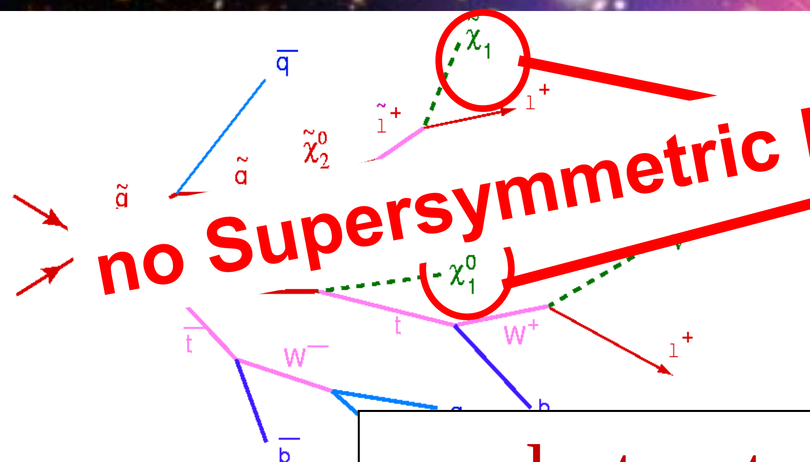


- provides link to string theories
- provides Dark Matter candidate

  (stable Lightest Supersymmetric Particle)

Supersymmetry: A New Symmetry in Nature





3 isolated leptons
+ 2 b-jets
+ 4 jets
+ E_t^{miss}

no Supersymmetric Particles discovered yet .....

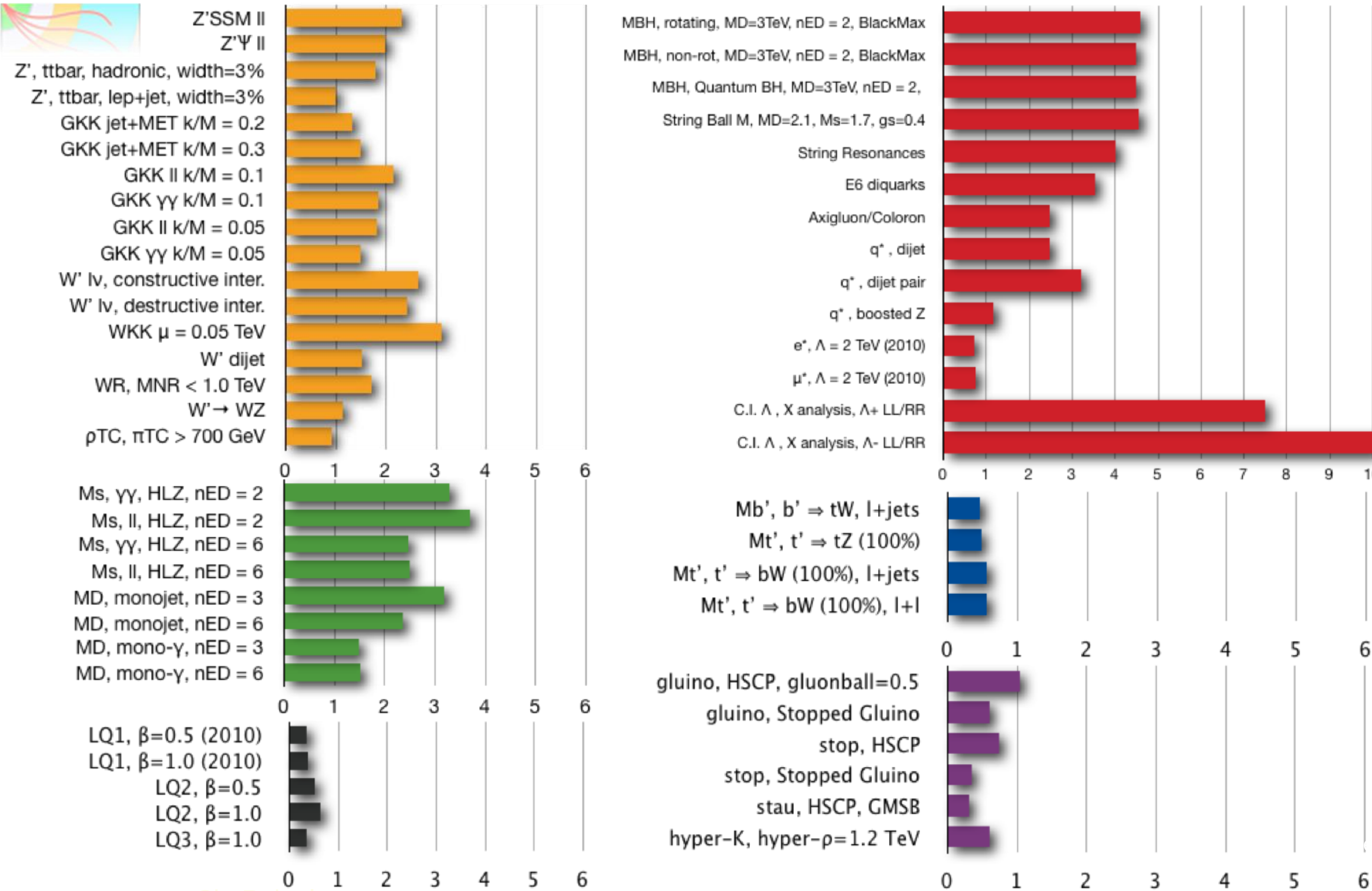
...ndidate Particles for Dark Matter
⇒ Produce Dark Matter in the lab

SUSY particle production at the LHC

. . . but potential for discovery of SUSY particles sizeable in the coming years

...n Marusa Bradac

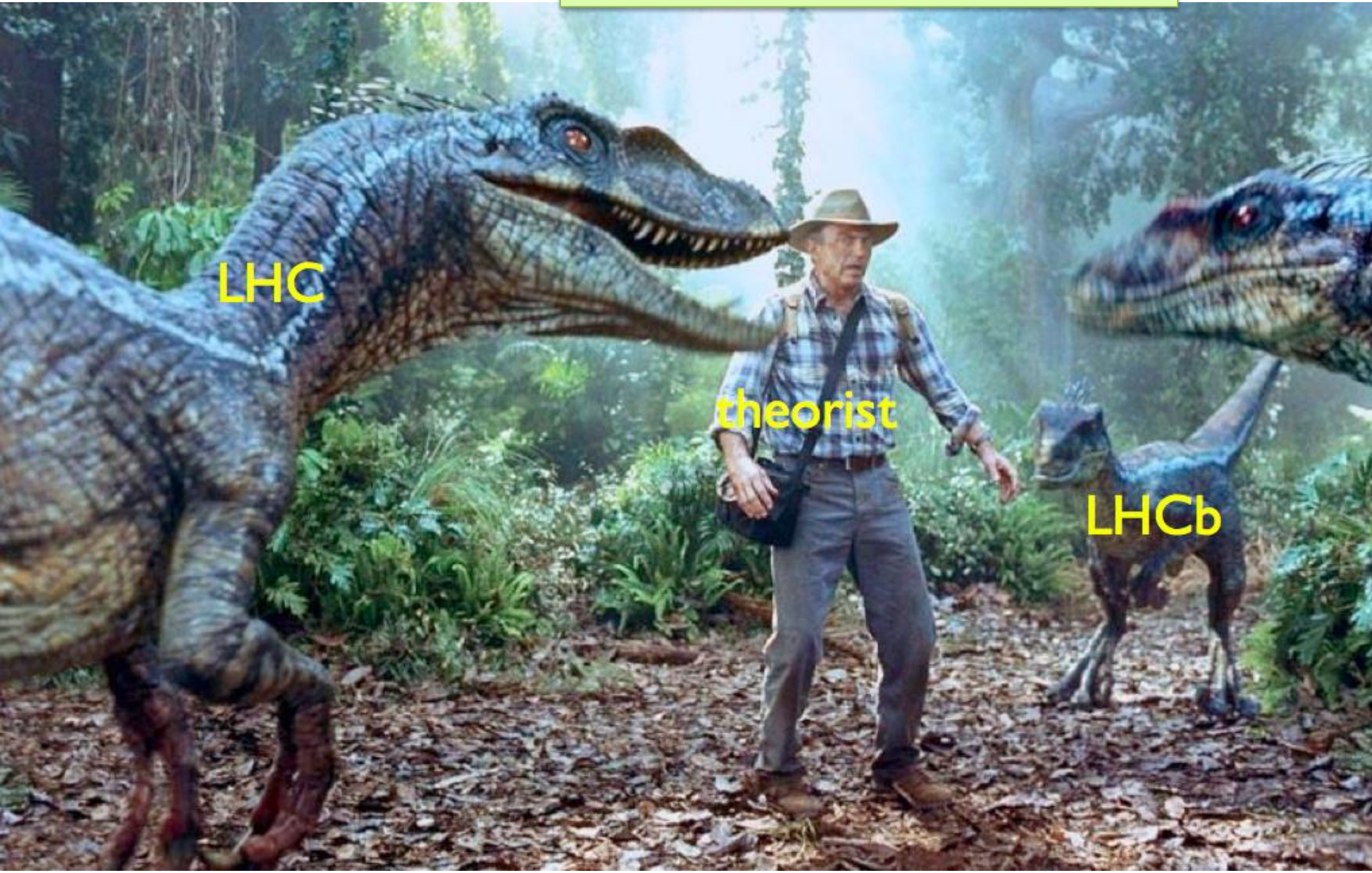
CMS Exotica: Summary for Moriond 2012



Sh. Rahatlou

Murayama, ICFA Seminar, 2011 CERN

LHC and Theory…



LHC results should allow,
together with dedicated dark matter searches,
first discoveries in the dark universe

– around 73% of the Universe is in some mysterious "dark energy". It is evenly spread.

Challenge:
get first hints about the world of
dark energy in the laboratory

The Higgs is Different!

All the matter particles are spin-1/2 fermions.
All the force carriers are spin-1 bosons.

Higgs particles are spin-0 bosons (scalars).
The Higgs is neither matter nor force.
The Higgs is just different.
This would be the first fundamental scalar ever discovered.

The Higgs field is thought to fill the entire universe.
Could it give some handle of dark energy (scalar field)?

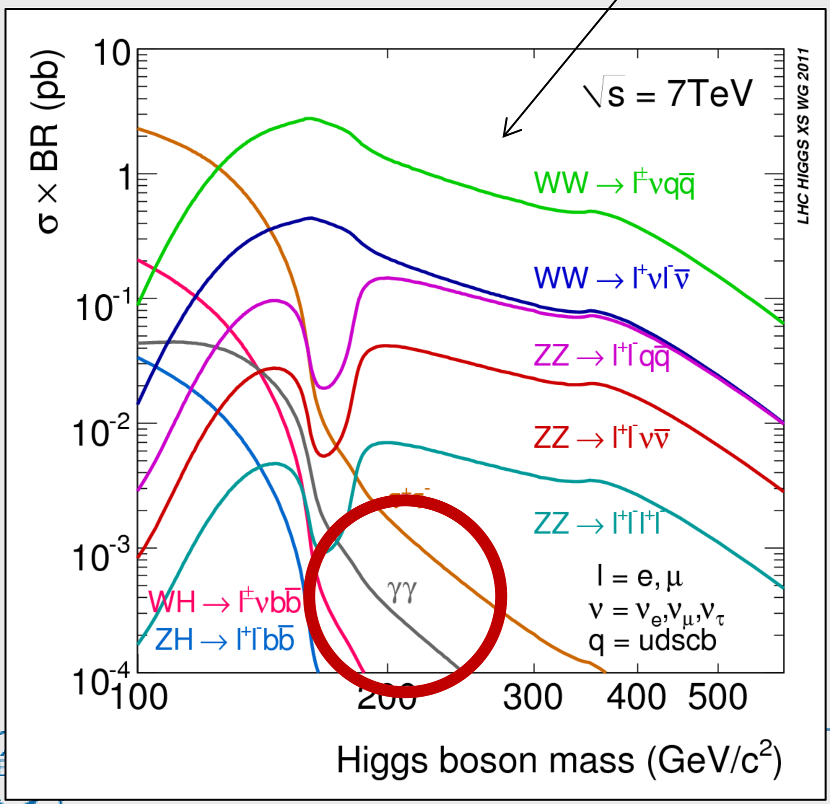
Many modern theories predict other scalar particles like the Higgs.
Why, after all, should the Higgs be the only one of its kind?

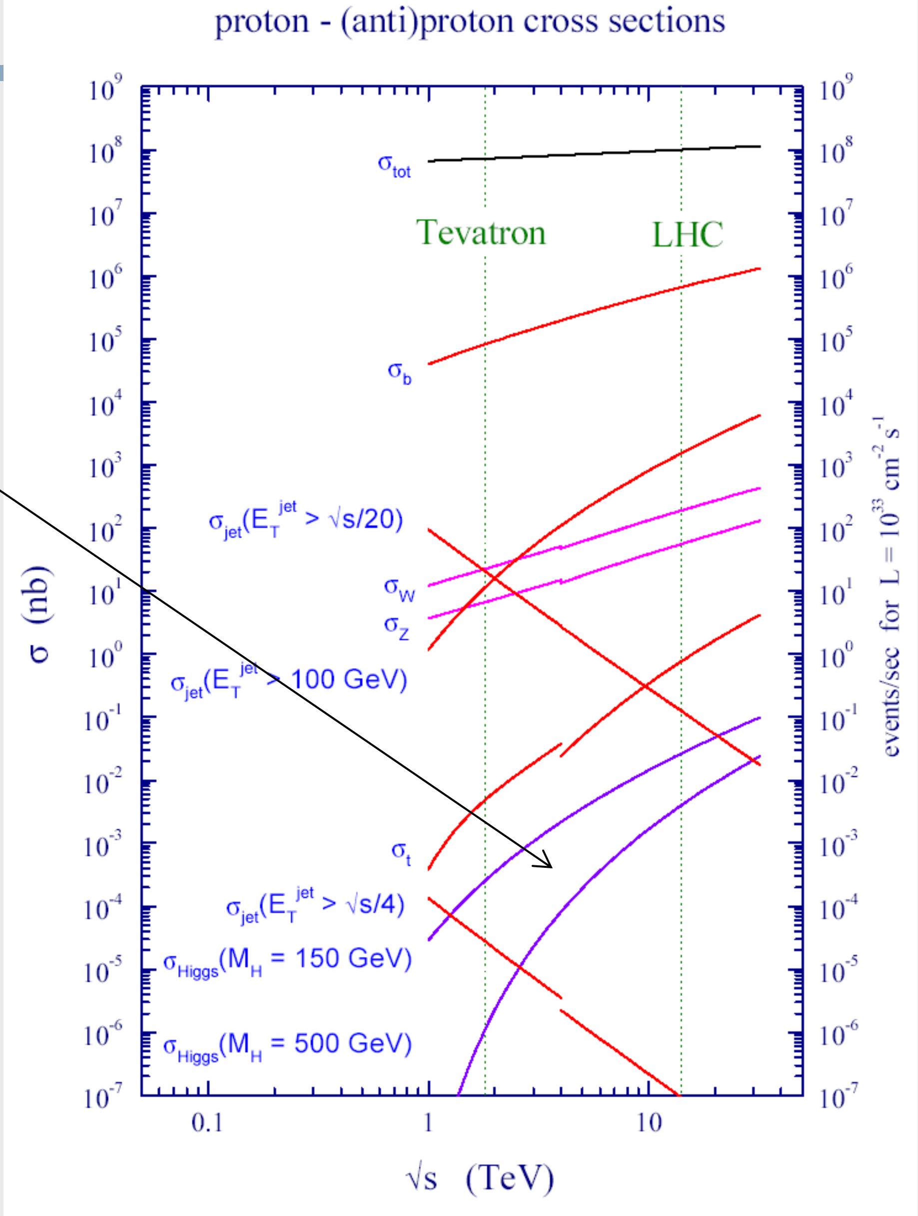
LHC can search for and study new scalars with precision.

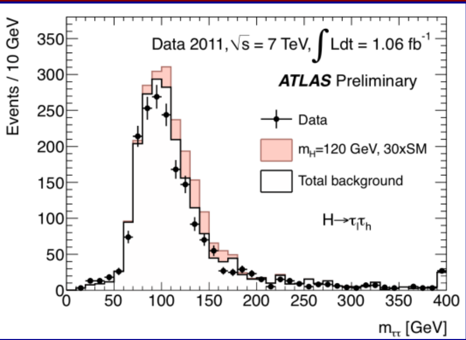
Search for the Higgs-Boson at the LHC

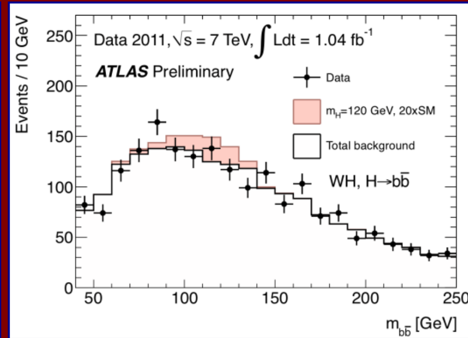
Production rate
of the Higgs-Bosons
depends on its mass

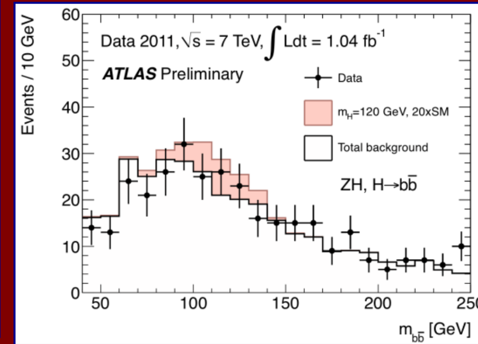
as well as its decay possibilities

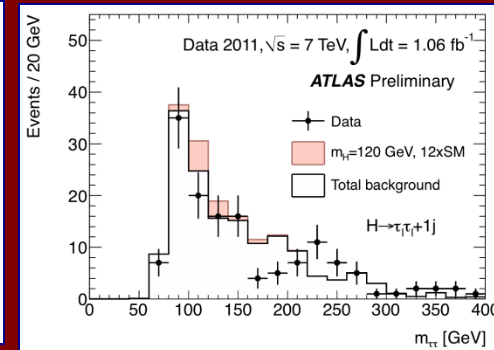


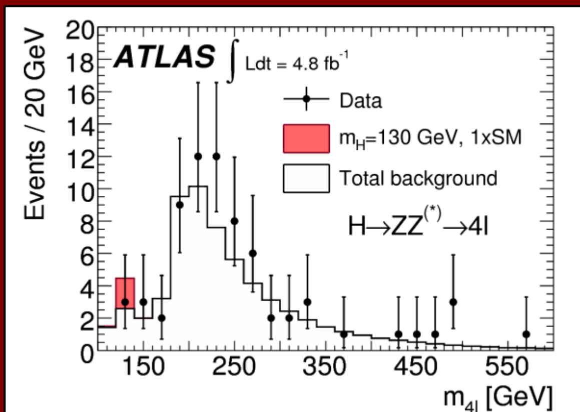


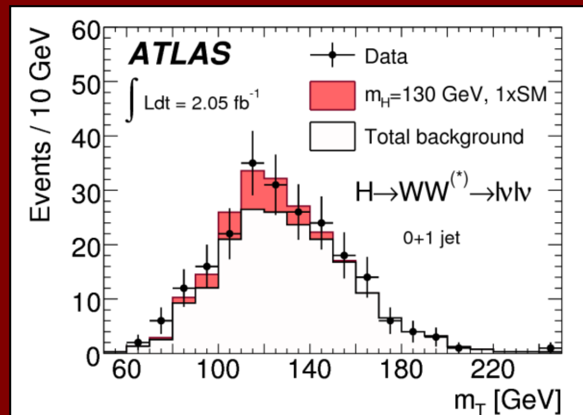

Data 2011, √s = 7 TeV, ∫Ldt = 1.06 fb-1
ATLAS Preliminary
Data
mH=120 GeV, 30xSM
Total background
H→τlτh
Events / 10 GeV
mττ [GeV]

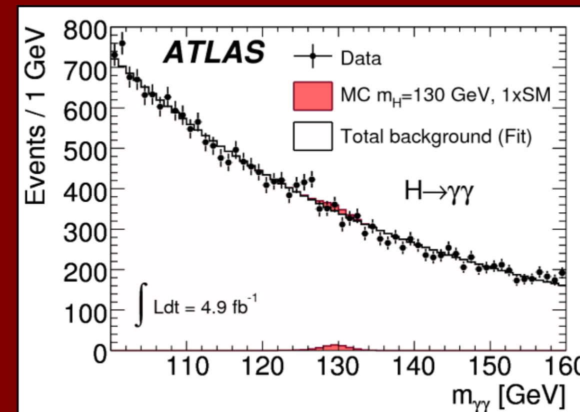

Data 2011, √s = 7 TeV, ∫Ldt = 1.04 fb-1
ATLAS Preliminary
Data
mH=120 GeV, 20xSM
Total background
WH, H→bb̄
Events / 10 GeV
mbb̄ [GeV]


Data 2011, √s = 7 TeV, ∫Ldt = 1.04 fb-1
ATLAS Preliminary
Data
mH=120 GeV, 20xSM
Total background
ZH, H→bb̄
Events / 10 GeV
mbb̄ [GeV]

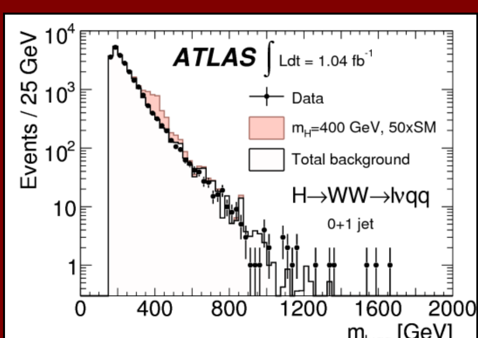

Data 2011, √s = 7 TeV, ∫Ldt = 1.06 fb-1
ATLAS Preliminary
Data
mH=120 GeV, 12xSM
Total background
H→τlτl+1j
Events / 20 GeV
mττ [GeV]

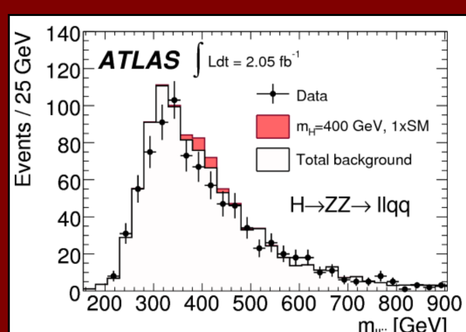

ATLAS ∫Ldt = 4.8 fb-1
Data
mH=130 GeV, 1xSM
Total background
H→ZZ(*)→4l
Events / 20 GeV
m4l [GeV]

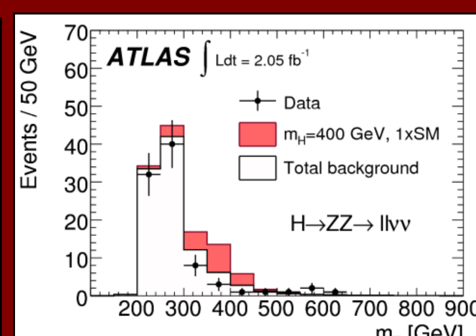

ATLAS
∫Ldt = 2.05 fb-1
Data
mH=130 GeV, 1xSM
Total background
H→WW(*)→lνlν
0+1 jet
Events / 10 GeV
mT [GeV]

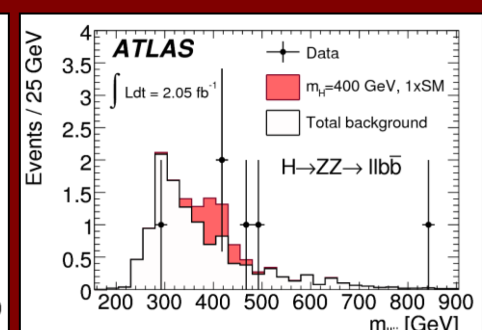

ATLAS
Data
MC mH=130 GeV, 1xSM
Total background (Fit)
H→γγ
∫Ldt = 4.9 fb-1
Events / 1 GeV
mγγ [GeV]

SM Higgs

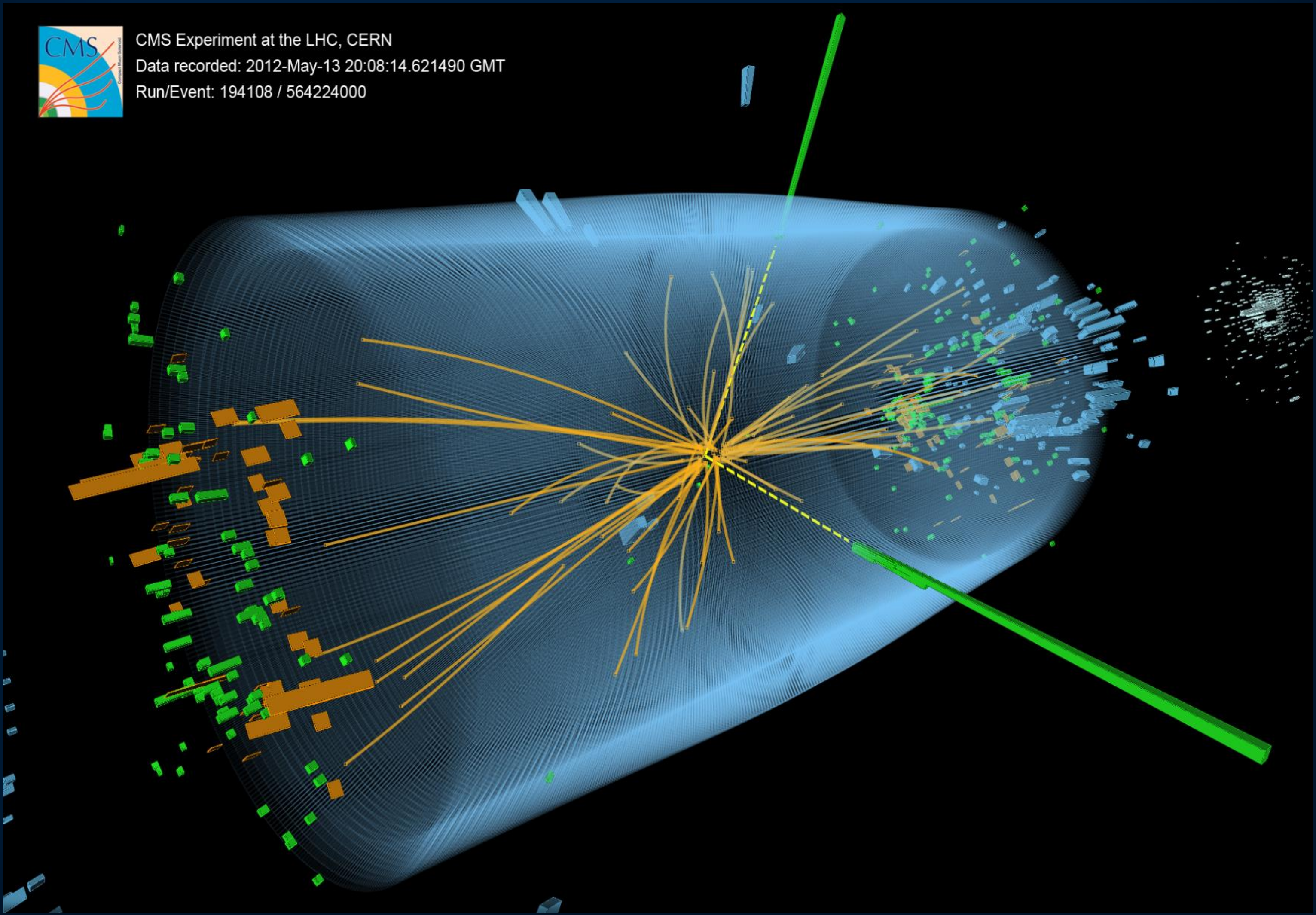

ATLAS ∫Ldt = 1.04 fb-1
Data
mH=400 GeV, 50xSM
Total background
H→WW→lνqq
0+1 jet
Events / 25 GeV
mlνqq [GeV]


ATLAS ∫Ldt = 2.05 fb-1
Data
mH=400 GeV, 1xSM
Total background
H→ZZ→ llqq
Events / 25 GeV
mlljj [GeV]


ATLAS ∫Ldt = 2.05 fb-1
Data
mH=400 GeV, 1xSM
Total background
H→ZZ→ llνν
Events / 50 GeV
mT [GeV]


ATLAS
∫Ldt = 2.05 fb-1
Data
mH=400 GeV, 1xSM
Total background
H→ZZ→ llbb̄
Events / 25 GeV
mlljj [GeV]

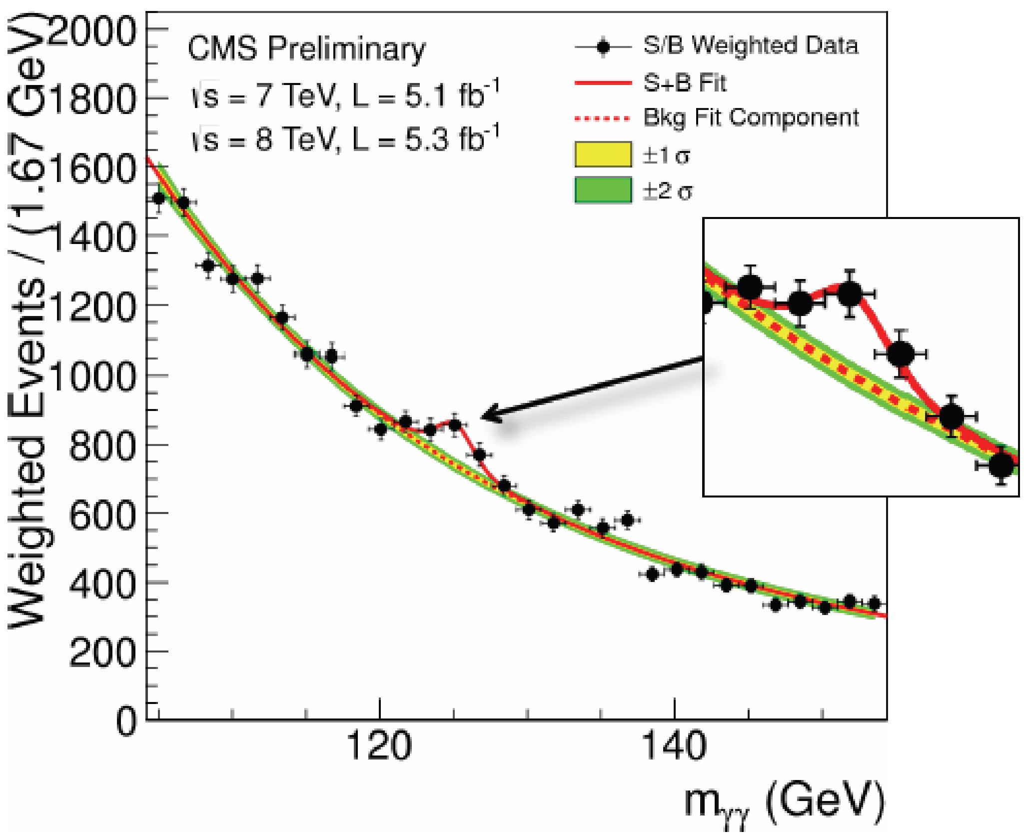
4 July 2012: CERN scientific seminar
"CERN experiments observe particle consistent with long-sought Higgs boson"



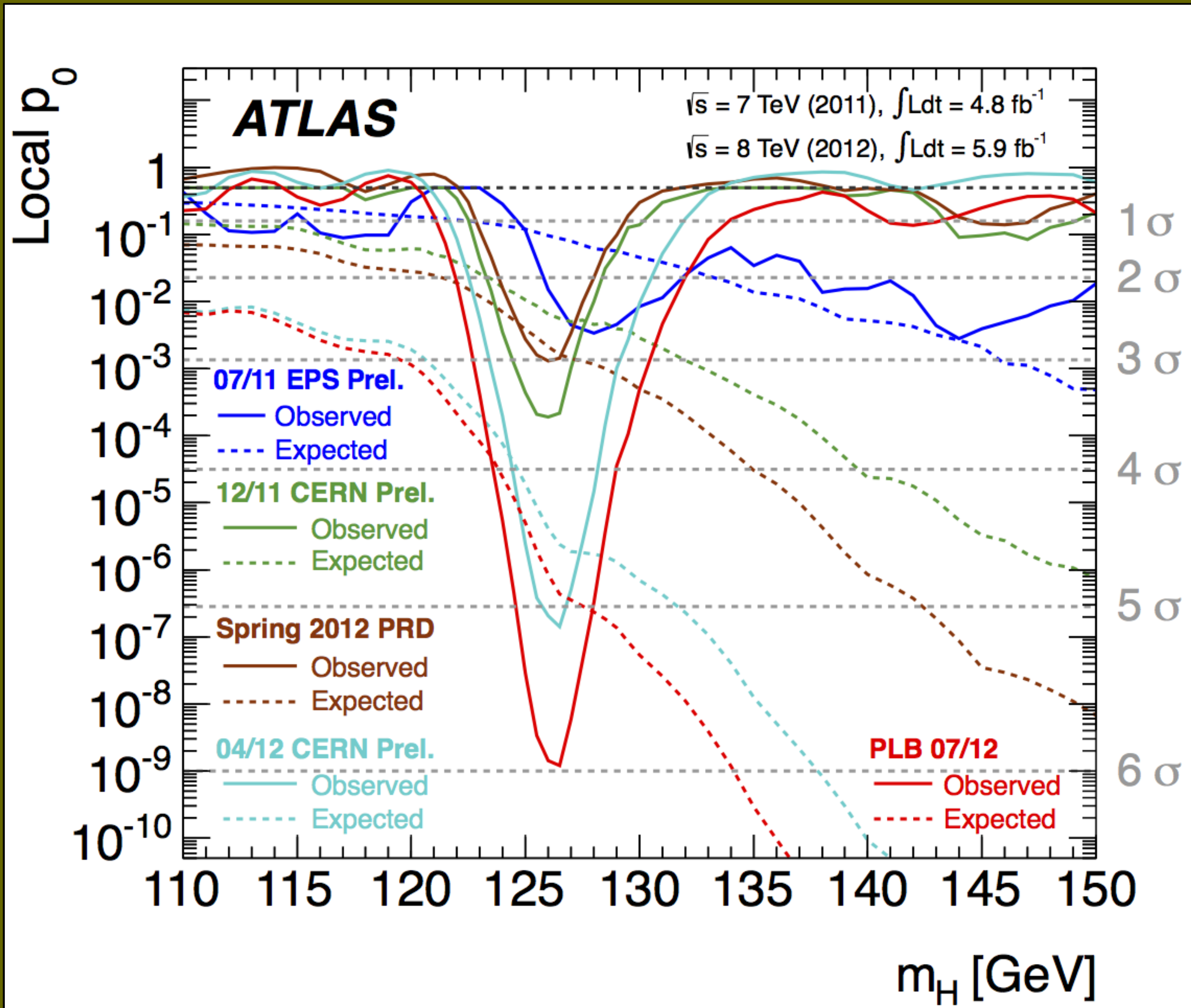
A historical day : 4th July 2012

S/B Weighted Mass Distribution

- Sum of mass distributions for each event class, weighted by S/B
  - B is integral of background model over a constant signal fraction interval



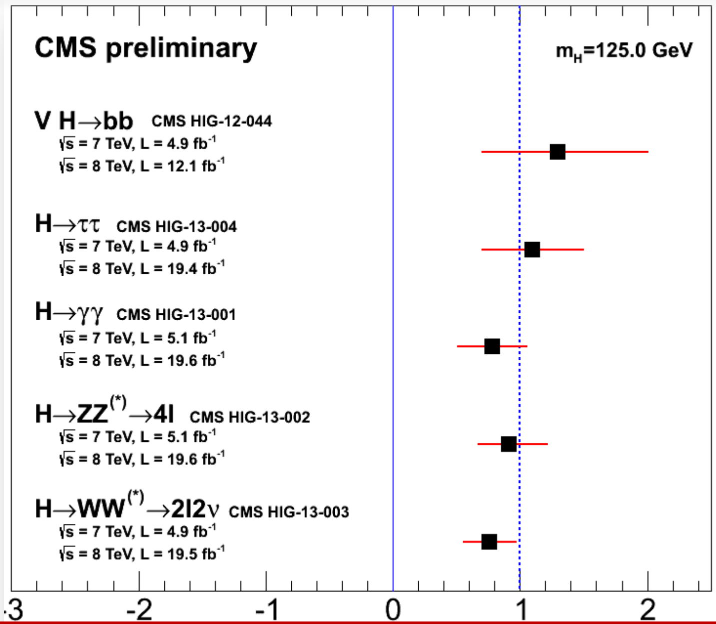
Evolution of the excess with time



March 2013

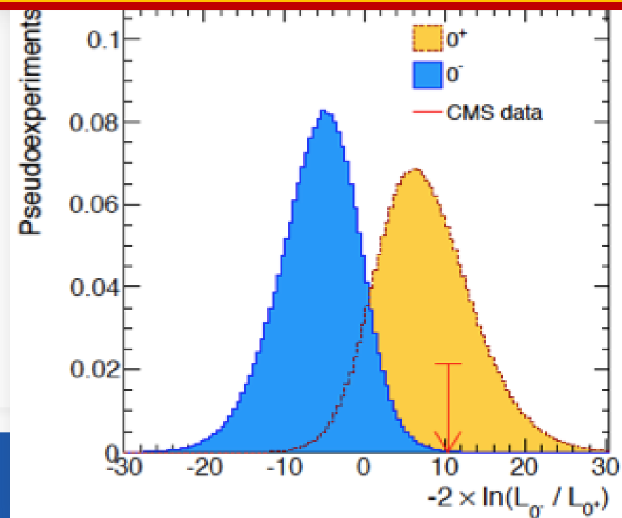
We have a Higgs boson!

- But what kind of Higgs is it?
  - 5 main channels shown at right
    - All are determined at m=125 GeV except for the ZZ channel which uses the best fit m_{ZZ}=125.8
    - *Full combination with best combined mass value will result in different signal strengths than those seen here.*
- Consistent with SM
  - But can't rule out a BSM Higgs!
- New significance values:
  - $H \rightarrow ZZ \rightarrow 4l$: 6.7 σ (7.2 exp.)
  - $H \rightarrow WW$: 4.1 σ (5.1 exp.)
  - $H \rightarrow \gamma\gamma$: 3.2 σ (4.2 exp.)
  - $H \rightarrow \tau\tau$: 2.9 σ (2.6 exp.)
- New mass values
  - ZZ: m_H = 125.8 ± 0.5 (stat.) ± 0.2 (syst.)
  - γγ: m_H = 125.4 ± 0.5 (stat.) ± 0.6 (syst.)
  - ττ: $m_H = 120^{+9}_{-7}$ (stat+syst) GeV



NEW

It has the properties of a Higgs boson



… but that's only the beginning !
What's next ?

… it is a Higgs Boson !
… is it *the* Higgs Boson (of the Standard Model) ?
or one of several ?

… its properties could give information on Dark Matter
… its properties could give first hints on Dark Energy

Physics programmme at the LHC beyond 2030

The Couplings roadmap

Test Higgs boson couplings depending on available L:

- Total signal yield tested at 10-20% … ay
- Couplings to Fermions … eV
- Loop coupli…
- … ested at 30%
- … ouplings
- … Quark fermion couplings
- … ukawa direct measurement ttH: κ_t
- Test second generation fermion couplings: κ_μ
- Higgs self-couplings couplings HHH: κ_H

~ 30 fb^{-1}

LHC Upgrade

14 TeV

~ 3000 fb^{-1}

Looking only at the studies of the Higgs Boson

There is much more physics beyond the Higgs

Update of the European Strategy for Particle Physics

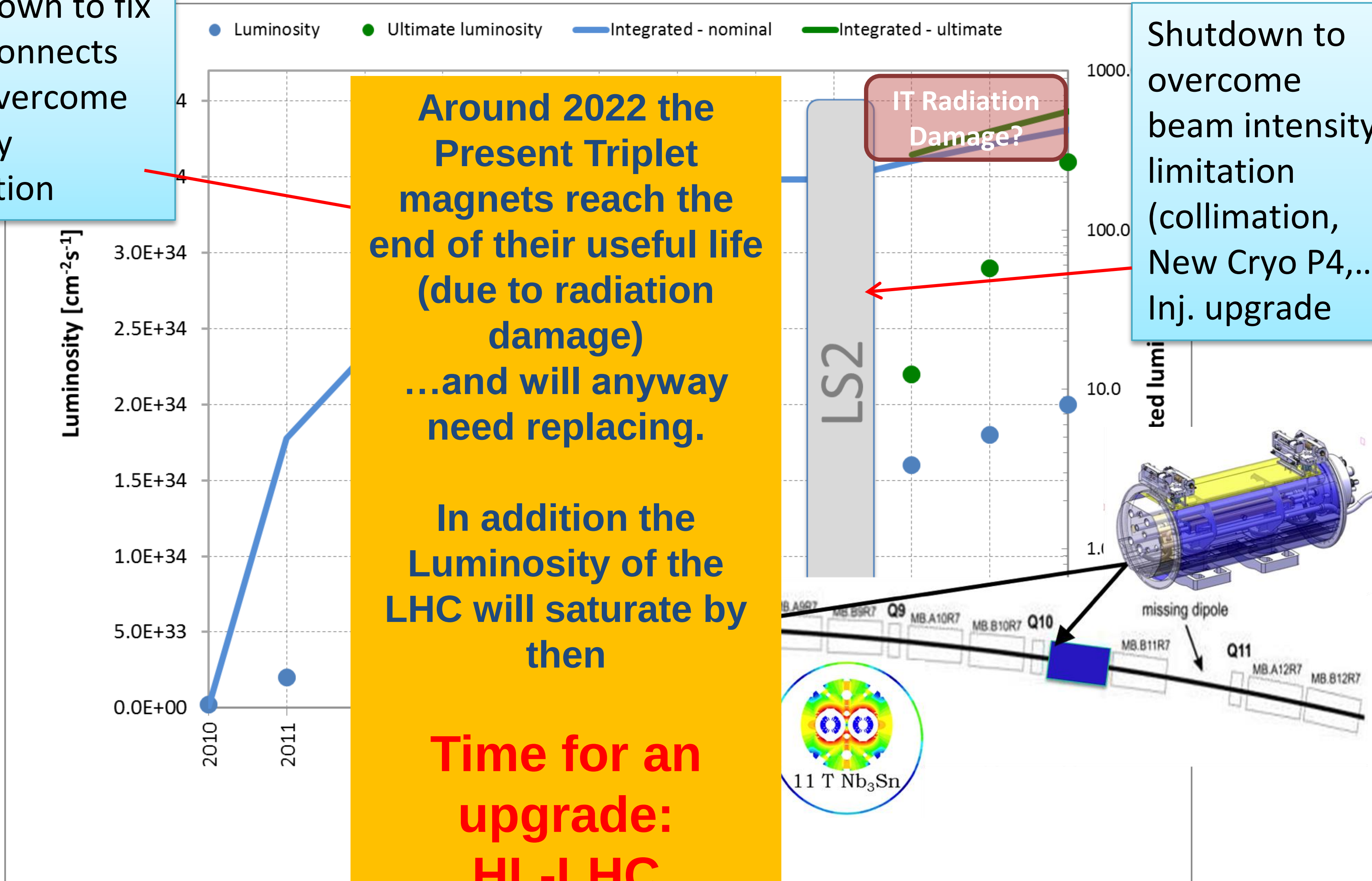
High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

c) The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme.
Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.

Luminosity: Best Guess for the next 10 years

Shutdown to fix interconnects and overcome energy limitation



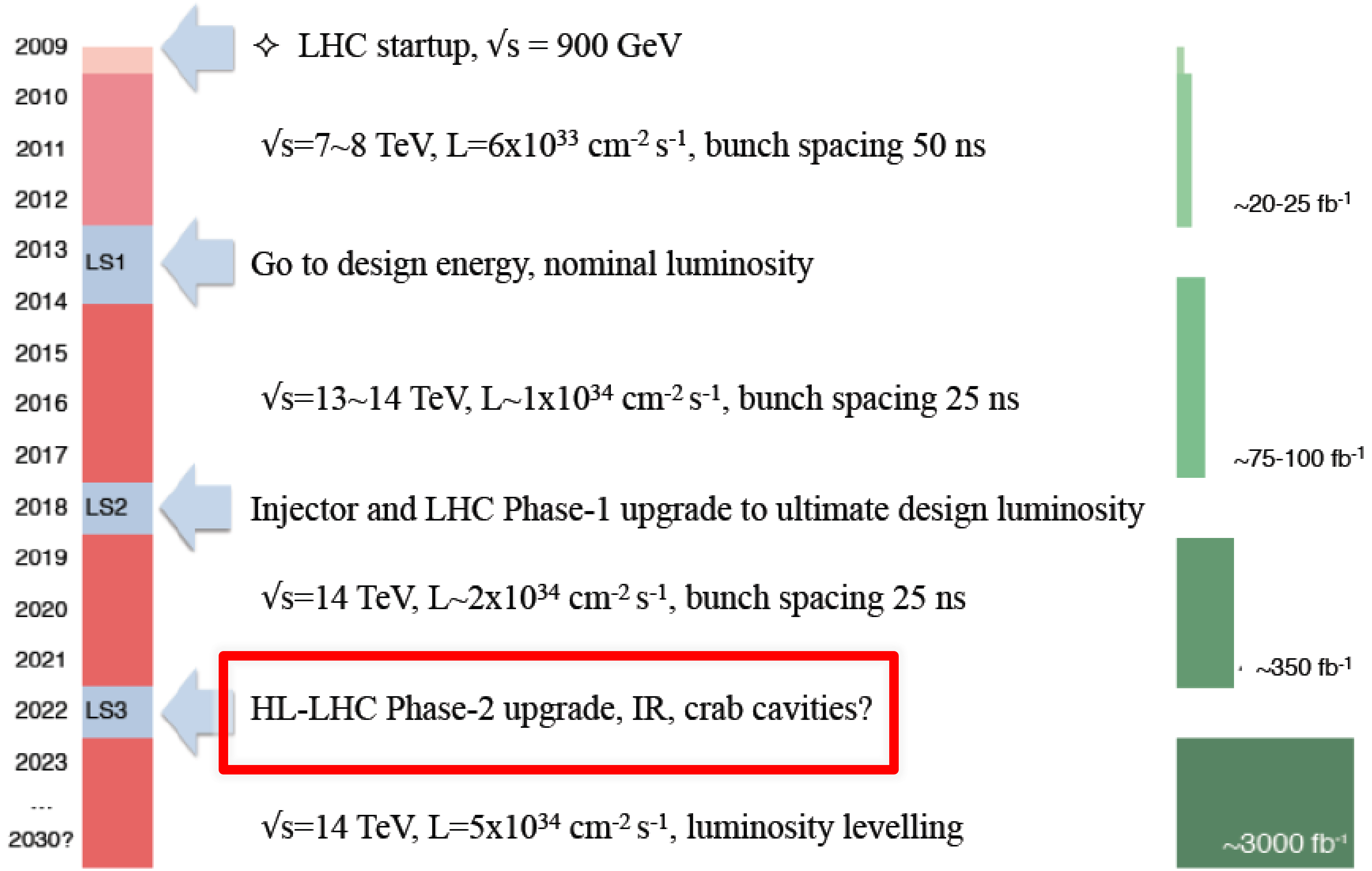
Around 2022 the Present Triplet magnets reach the end of their useful life (due to radiation damage)
…and will anyway need replacing.

In addition the Luminosity of the LHC will saturate by then

Time for an upgrade: HL-LHC

Shutdown to overcome beam intensity limitation (collimation, New Cryo P4,…) Inj. upgrade

The LHC roadmap to fully exploit the physics potential



LHC and Injectors 2013/14

- LS1 ongoing as planned
- Restart of accelerator chain in 2014
  - mid June PSB, Isolde
  - mid July east area
  - mid October SPS
- Restart LHC 2015 (commissioning, then physics)

LHC

Key message

There is a progra

with th

ev design luminosity

14 TeV high luminosity (HL-LHC)

Upgrades to accelerator complex, detectors, and computing Grid are vital to fully exploit the physics potential of LHC


beyond LHC ?

Next decades

Road beyond Standard Model

At the energy frontier through synergy of

hadron - ha... ...iders (LHC, (V)HE-LHC?)

... - hadron colliders (LHeC ??)

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

LHC results vital to guide the way at the energy frontier

Deliberation document on the European Strategy for Particle Physics

High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

d) To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. ***CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.***

This covers all colliders mentioned before, albeit with different priority

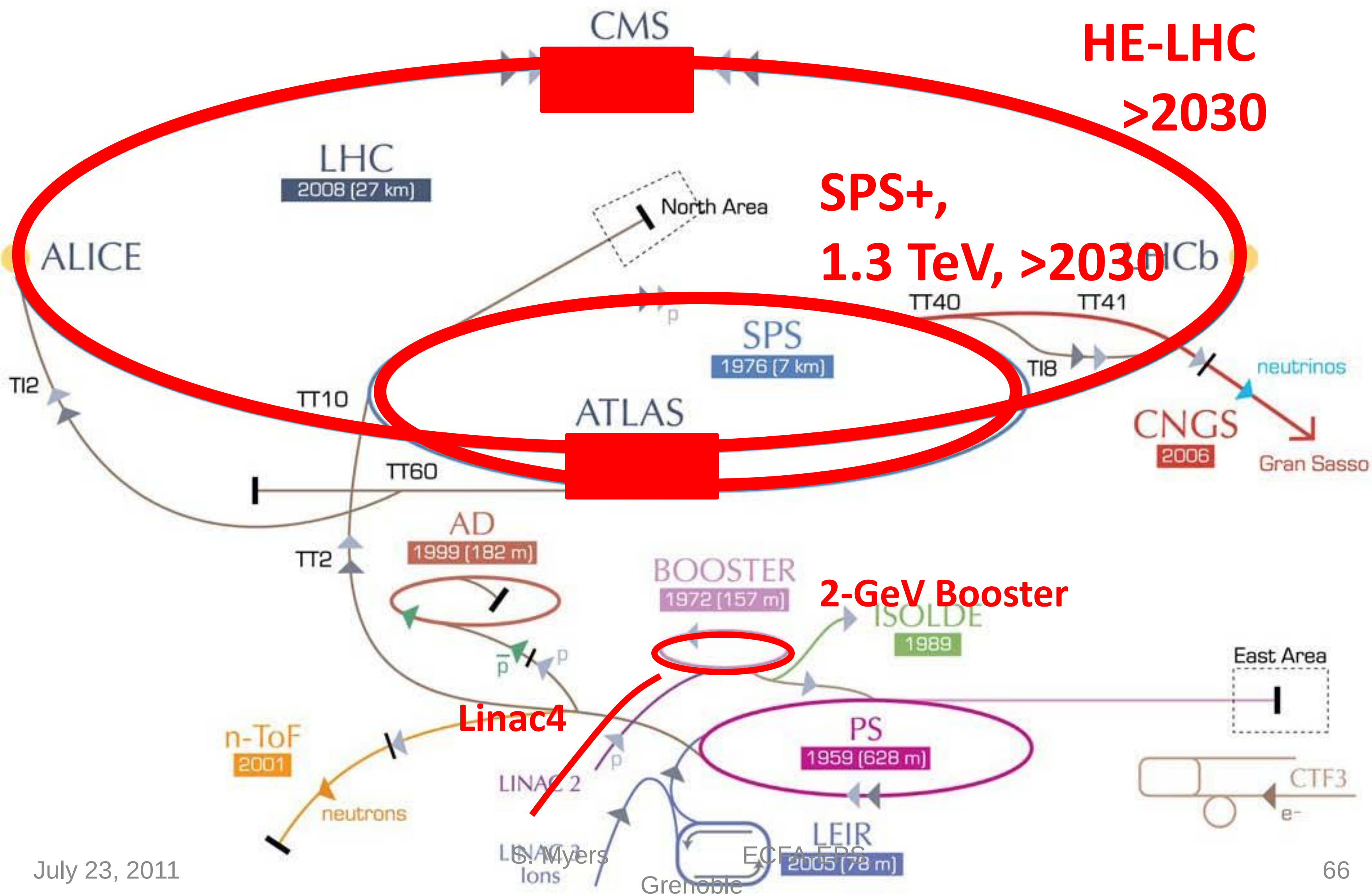
High Energy Hadron – Hadron Colliders

HE – LHC and VHE-LHC

Study of New Physics Phenomena

main challenge: High-Field Magnets

HE-LHC – LHC modifications



HE-LHC

- HE-LHC dipole design will piggy back on the high gradient quadrupole R&D needed for HL-LHC
  - Would allow an increase in energy by factor of 2-2.5

Beyond High Energy LHC

- **First studies on a new 80 km tunnel in the Geneva area**
  - **42 TeV with 8.3 T using present LHC dipoles**
  - **80 TeV with 16 T based on Nb_3Sn dipoles**
  - **100 TeV with 20 T based on HTS dipoles**

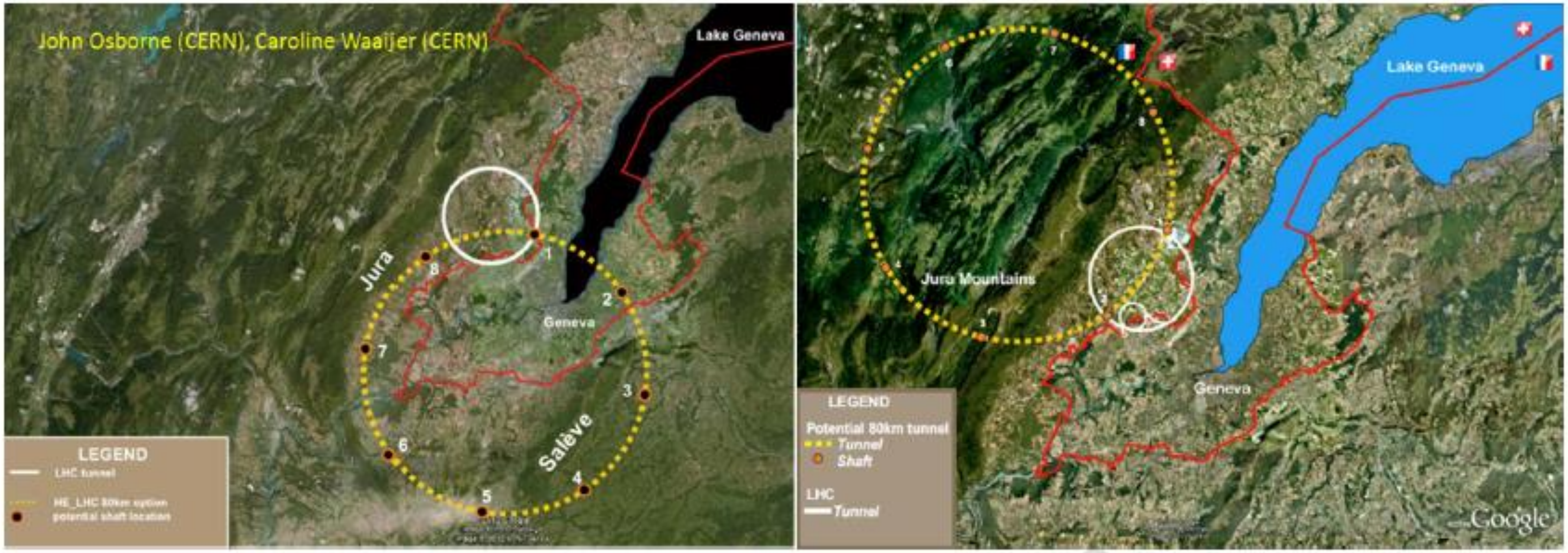
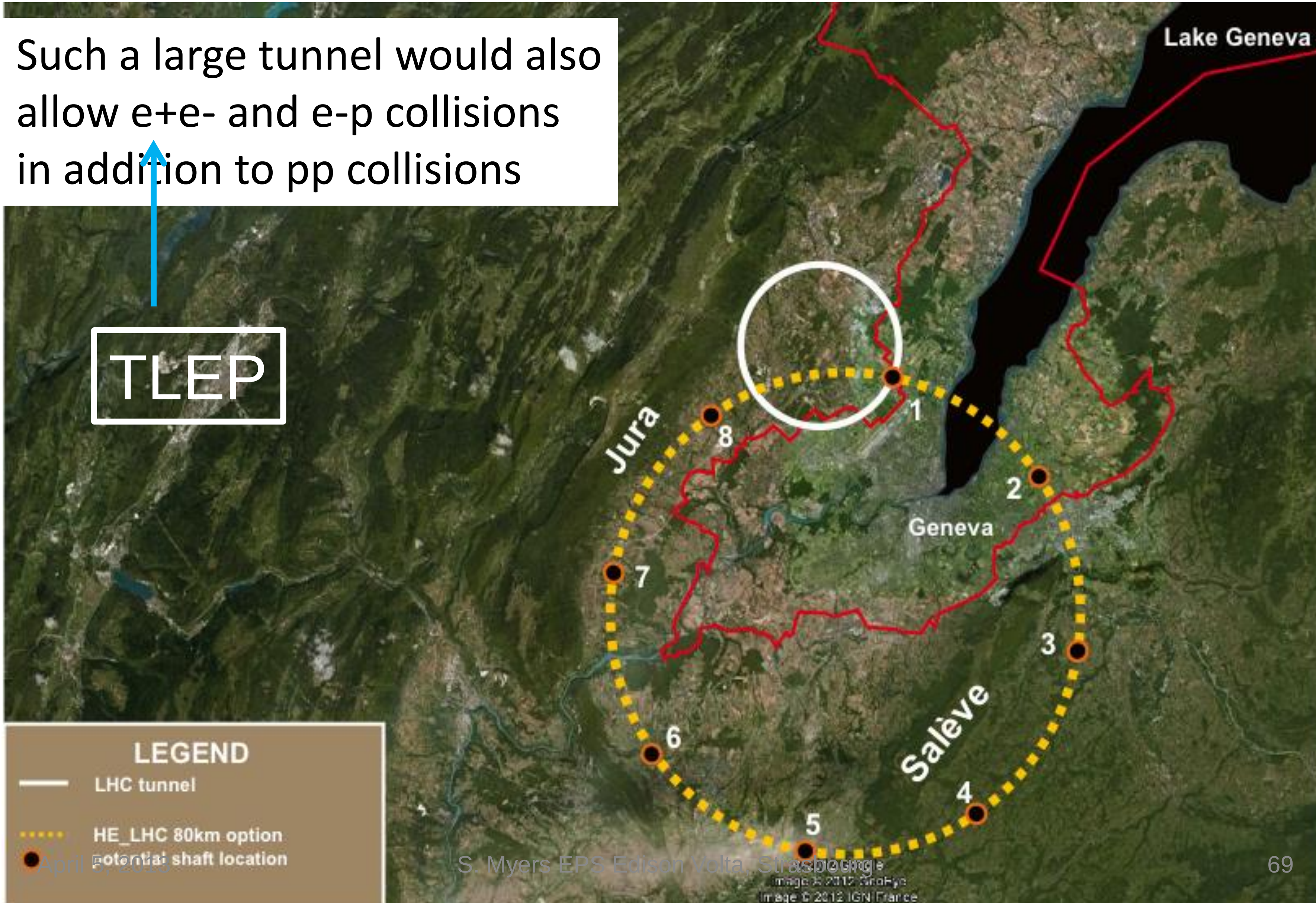


Figure 9. Two possible location, upon geological study, of the 80 km ring for a Super HE-LHC (option at left is strongly preferred)

VHE-LHC

Such a large tunnel would also allow e+e- and e-p collisions in addition to pp collisions



HE-LHC and VHE-LHC

- VHE-LHC needs a (at least) 80km tunnel

In conjunction with the high field magnets would allow a factor of (2-2.5)x(80/27) =

6-7.5 times LHC (42- 52 TeV/beam)

- HE-LHC → VHE-LHC

("80 km" study together with TLEP)

Logic ("roadmap"): exploit synergy effects between HL-LHC, HE-LHC, VHE-LHC (and TLEP), in particular high field magnet development

Lepton – Lepton Colliders

Linear e^+e^- Colliders: ILC / CLIC

Both projects are global endeavours

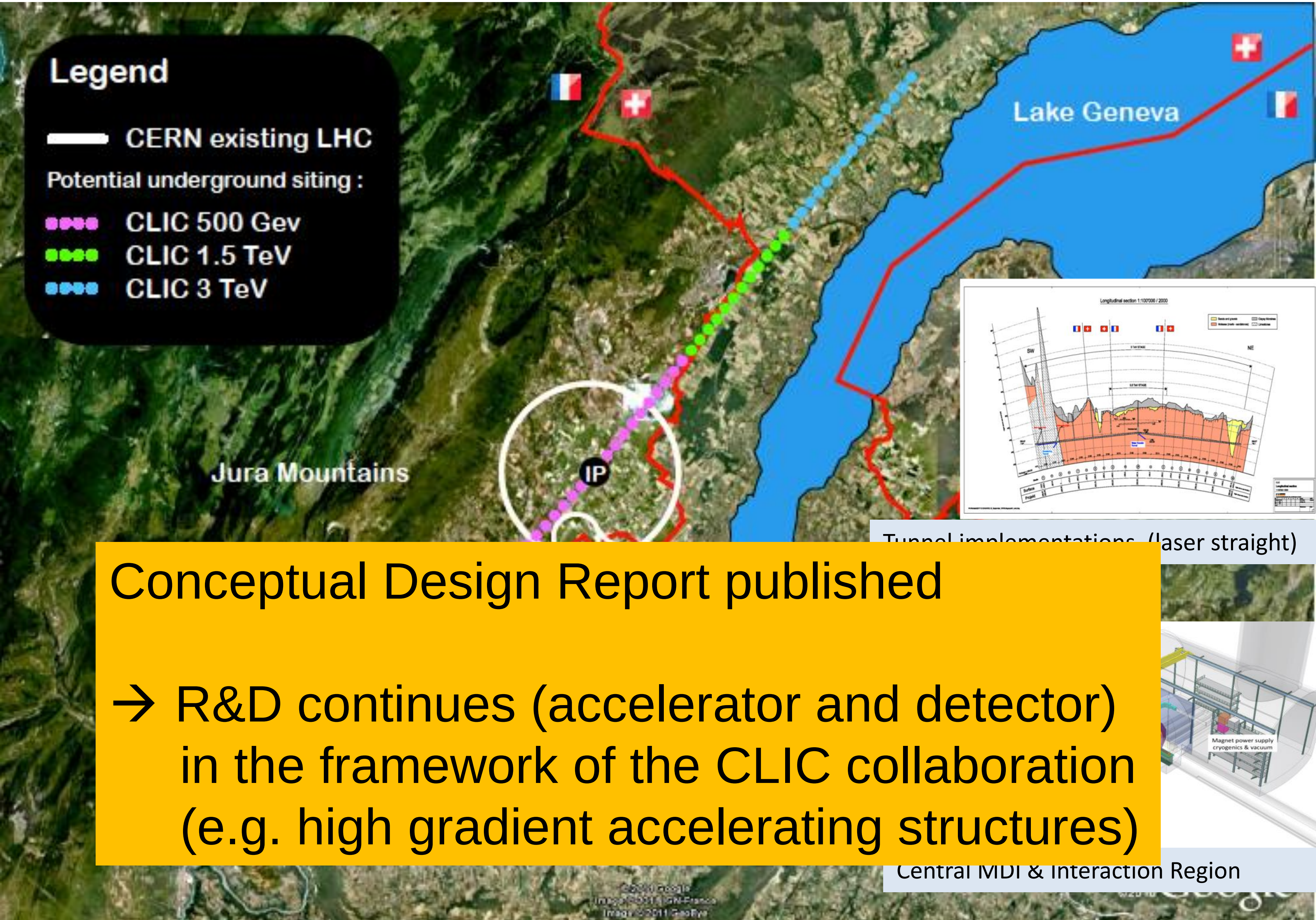
and at CERN part of the LC effort

Wide range of Physics topics, e.g.

- Higgs couplings, in particular **self coupling**
- precision studies of Z, W, and **Top**
- new physics phenomena

Very interesting after the discovery of a Higgs Boson

CLIC near CERN



Conceptual Design Report published

→ R&D continues (accelerator and detector) in the framework of the CLIC collaboration (e.g. high gradient accelerating structures)

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High-priority large-scale scientific activities

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at CERN ILC efforts will continue
in the framework of the LC efforts

e) There is a strong scien ron collider, complementary t properties of the Higgs boson and othe d precision and whose energy can be upgraded. sign Report of the International Linear Collider (ILC) has pleted, with large European participation. The initiative from the Ja nese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. ***Europe looks forward to a proposal from Japan to discuss a possible participation*.**

Deliberation document on the European Strategy for Particle Physics

Study performed for a dedicated neutrino area at the SPS:

- To enable large scale detector development and tests for neutrino detectors

and/or

- To install a short baseline experiment

Decision to be taken in the framework of the next 5-years plan

neutrino sector.

CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.

Fixed Target Program (examples)

- HIE-Isolde as approved and ongoing
- AD and ELENA as approved; extension for GBAR and addition of a storage ring under consideration
- n-TOF (with EAR2) as approved
- CNGS terminated
- high gradient accelerator R&D (“AWAKE”)

Key message

Program at the energy frontier with the LHC for at least 20 years

R&D, Studies for the next projects ongoing

Global collaboration vital