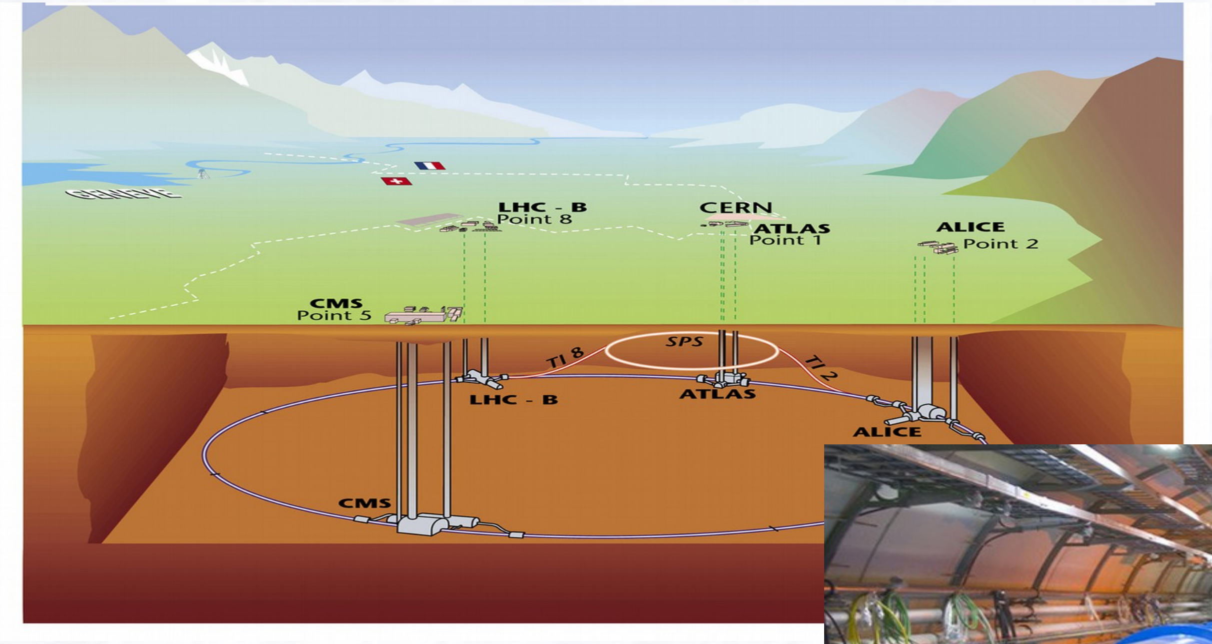
ATLAS EXPERIMENT : 25th anniversary
What was learned
What's next

Johann Collot
Univ. Grenoble Alpes, CNRS, Grenoble INP, LPSC-IN2P3

招待ありがとう

Large Hadron Collider (LHC)

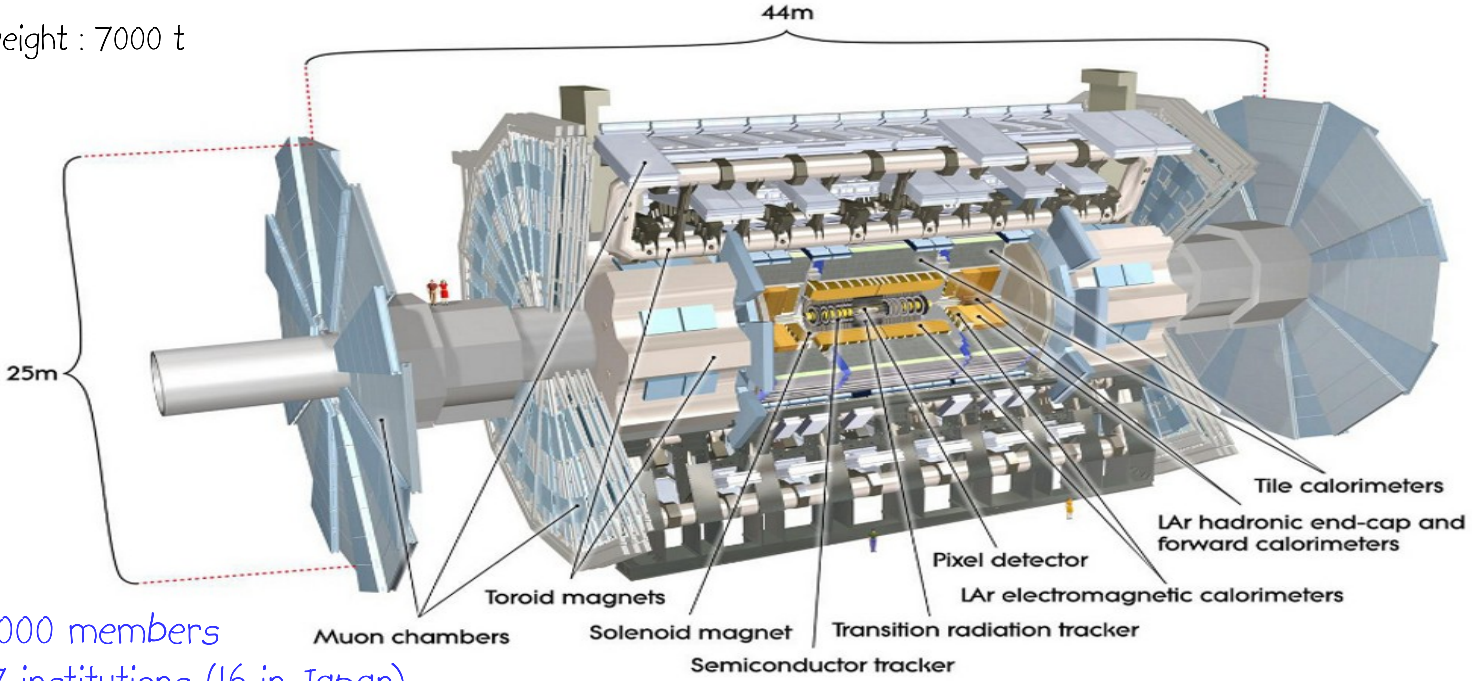


run I (2010-2012) :
7 and 8 TeV pp collisions
2 x 30 fb^{-1} delivered

run II : (2015-2018, in progress)
E_{cm} = 13 TeV
2 x 150 fb^{-1} expected

A Toroidal LHC Apparatus

weight : 7000 t



~5000 members
187 institutions (16 in Japan)
38 countries

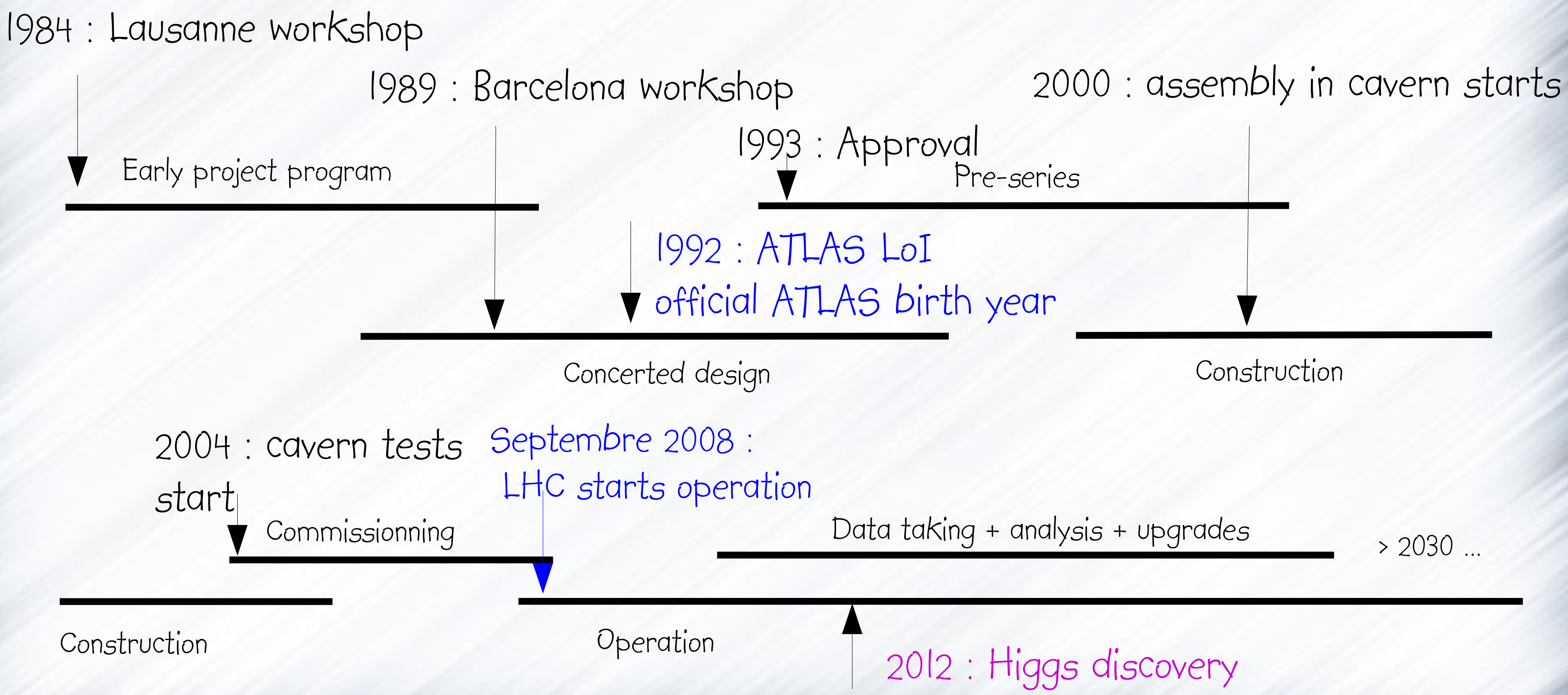
Baked by Katherine Leney of ATLAS

Together with LHC, the oldest and longest experimental project in the high-energy community.

And still like 20 years to come.

Most of the students joining ATLAS today were not born when it all started.

ATLAS in history



July 4^{th} 2012 : day of glory

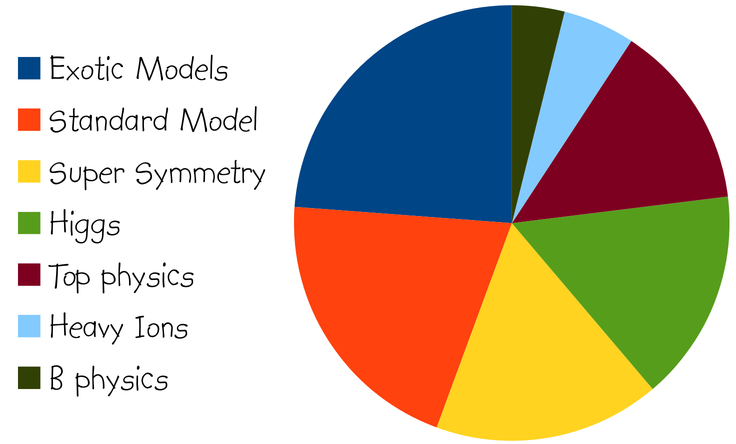
CERN's main auditorium had never been so small

What was learned since 2010

Confirmation that hadron colliders are search and discovery machines.
But also that they can deliver precision measurements in particular of the standard model parameters.

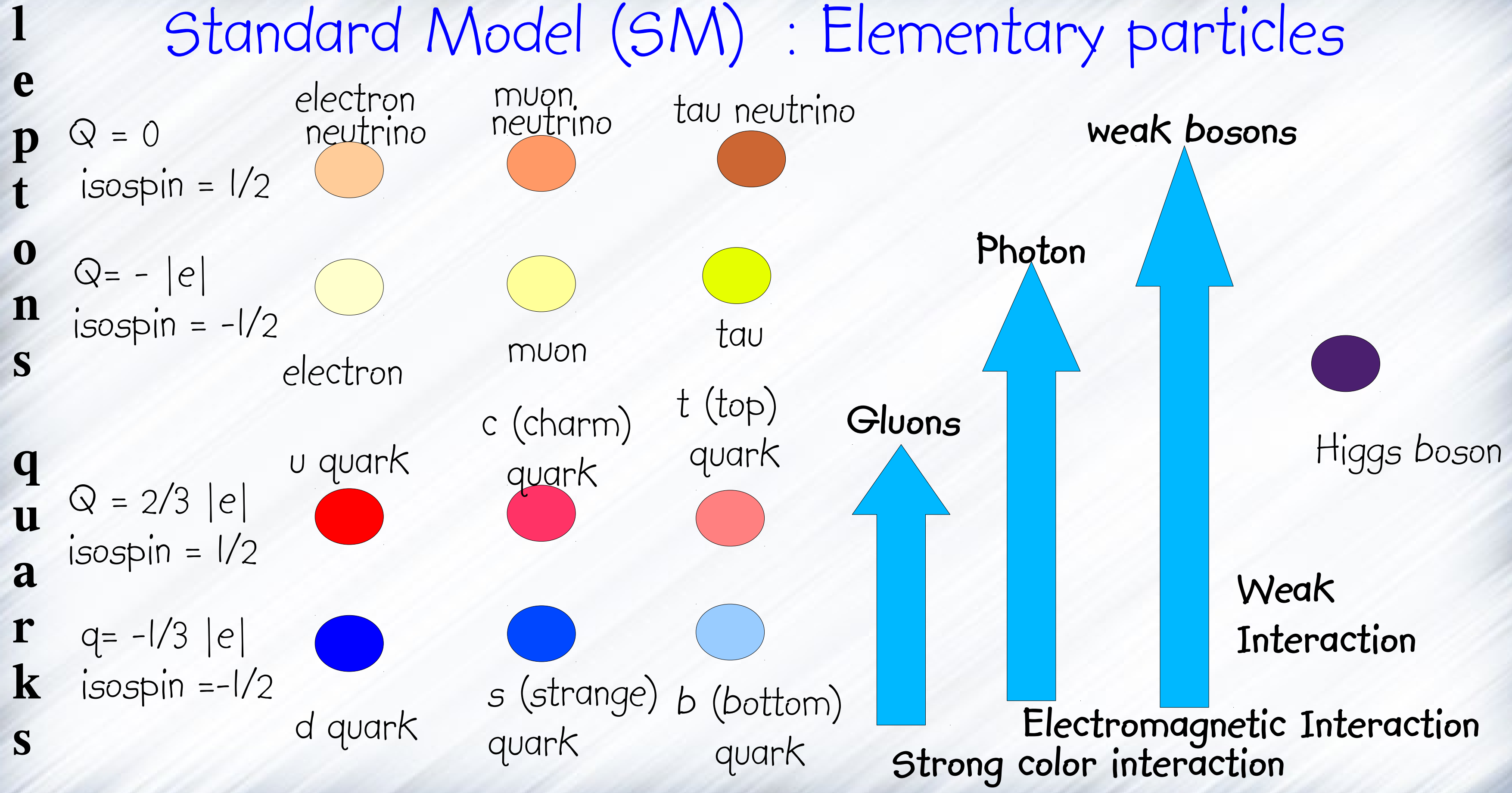
768 publications since 2010
Each bringing new knowledge !

No way to report on even 1/10 of these in 30 minutes - Apologies to my numerous ATLAS colleagues



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/Publications

Standard Model (SM) : Elementary particles



Standard Model (SM)

With massless neutrinos, SM is a 19 free-parameter model :

- 9 elementary particle masses : m_e , m_μ , m_τ , m_u , m_d , m_s , m_c , m_b , m_t
- 1 vector boson mass : m_W
- 1 weak mixing angle : θ_W
- 2 coupling constants : G_F , α_s
- 1 Higgs mass : m_h
- 4 quark mixing parameters (CKM matrix) : 3 mixing angles + 1 CP violation phase
- 1 QCD CP violation phase : $\Theta_{QCD} \approx 0$

Standard Model

Taking into account massive & mixed neutrinos, at least 7 more free parameters are needed :

3 more neutrino masses : $m_{\nu 1}$, $m_{\nu 2}$, $m_{\nu 3}$

4 lepton mixing parameters (PMNS matrix) : 3 mixing angles + 1 CP violation phase

But in fact more is needed, in particular on hadron colliders :

Parton Distribution Functions (PDF) (Empirical fit of short-scale partonic proton structure)

Parametrization of parton showering and hadronisation processes.

Simulation of interaction of particles with matter.

Standard Model : is 19 (26+) too many ?

Perhaps, but please tell us which of those should be removed and why !

PARAMETERS

The problem is more that - the W mass taken apart - none of these parameter values were ever predicted (or any other words all predictions turned out to be wrong).

Generation of elementary particle mass is far from being explained as there are still as many coupling constant values as mass values.

$m_t / m_e \approx 3.6\ 10^8$ (spread even worse if we consider neutrino masses)

Many astrophysical observations not explained : dark matter, dark energy, baryon asymmetry

Quantum gravitation is not included

There's work for many generations ahead !

Standard Model (SM)

With massless neutrinos, SM is a 19 free-parameter model :

9 elementary particle masses : m_e , m_μ , m_τ , m_u , m_d , m_s , m_c , m_b , m_t

1 vector boson mass : m_W

1 weak mixing angle : θ_W

2 coupling constants : G_F , α_s

1 Higgs mass : m_h

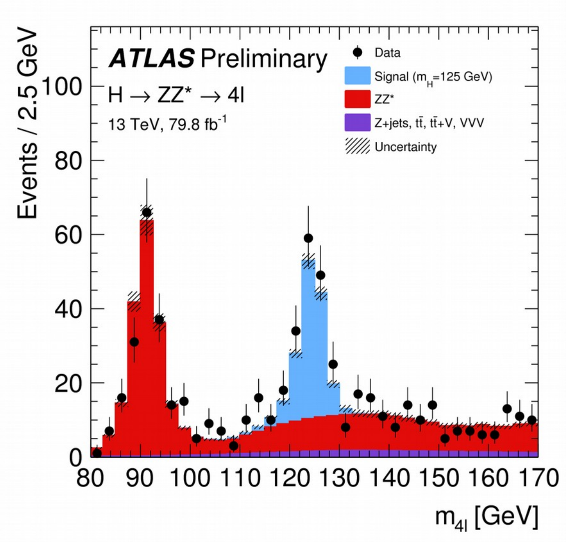
4 quark mixing parameters (CKM matrix) : 3 mixing angles + 1 CP violation phase

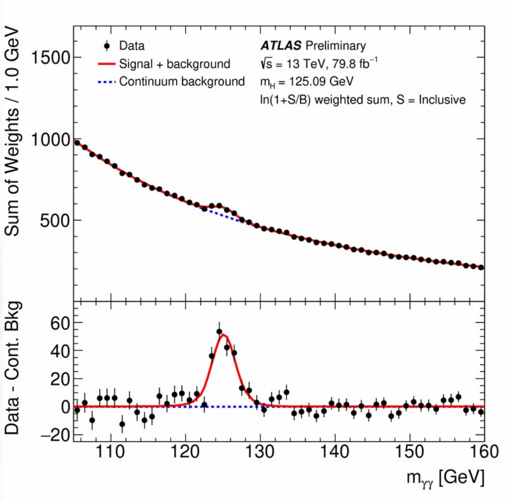
1 QCD CP violation phase : $\Theta_{QCD} \approx 0$

ATLAS & CMS prime targets in the absence of observation of new physics phenomena.

Higgs boson : m_h

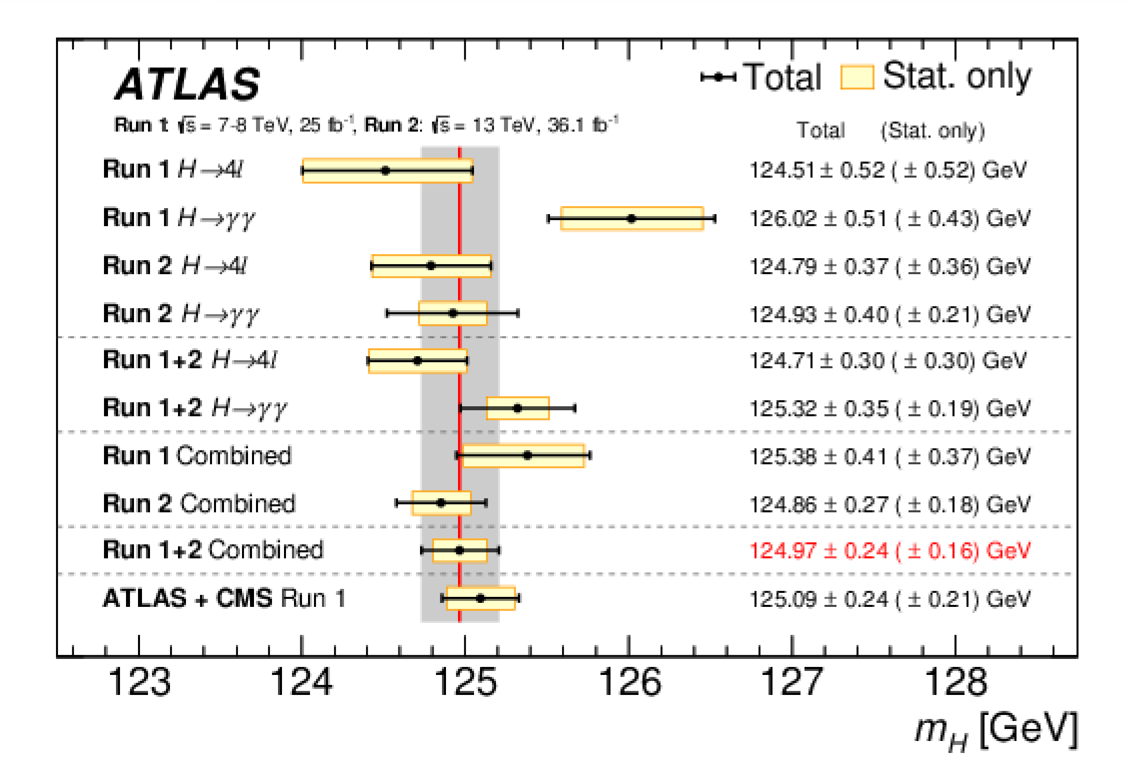
High mass resolution channels : $h \rightarrow ZZ^* \rightarrow 4\,l$; $h \rightarrow \gamma\gamma$





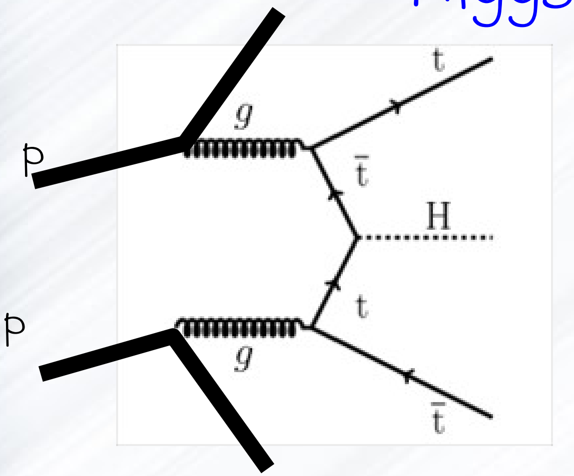
http://cdsweb.cern.ch/record/2621479 http://cdsweb.cern.ch/record/2628771

Higgs boson : m_h

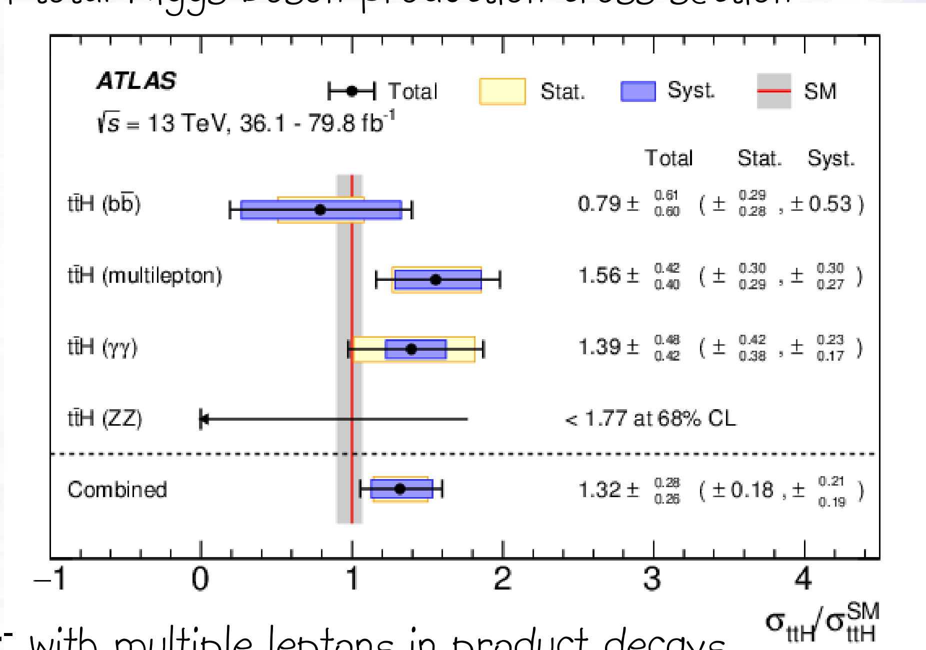


Higgs boson mass known at a 2 per mille precision already !

Higgs boson : ttH production



~ 1% of total Higgs boson production cross section

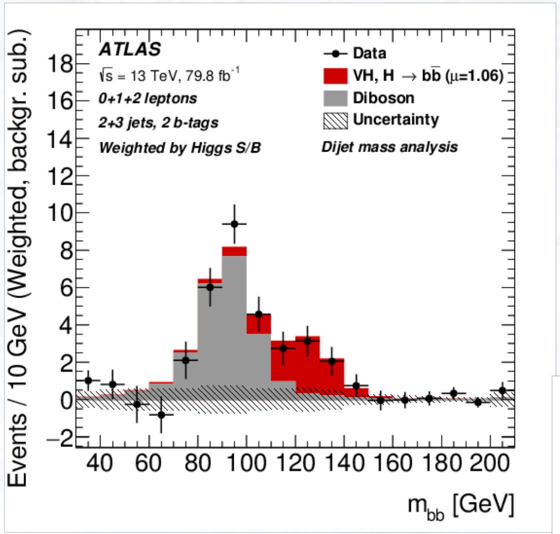


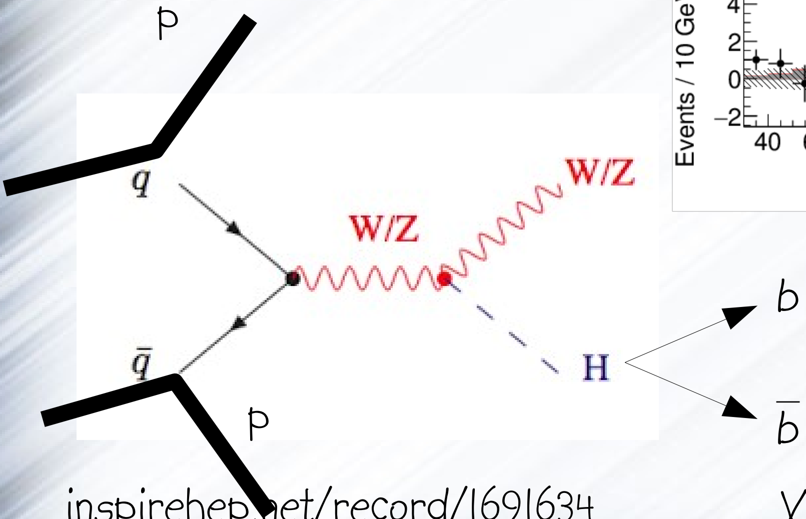
σ_{tth} (ATLAS measured value) =
670±90 (stat) ± 110 (sys) fb
(6.3 standard deviation observation)

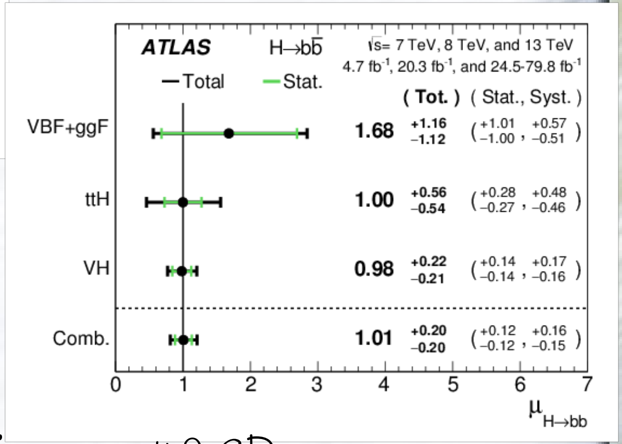
multilepton means H->WW* , ZZ*, $\tau^+\tau^-$ with multiple leptons in product decays

Phys. Lett. B 784 (2018) 173 , arXiv : 1806.0042v2

Observation of h -> b $\bar{b}$ with Wh or Zh production







inspirehep.net/record/1691634

VH ($b\bar{b}$) observed significance = 4.9 SD

H->$b\bar{b}$ observed significance = 5.3 SD

Fundamental scalar field physics

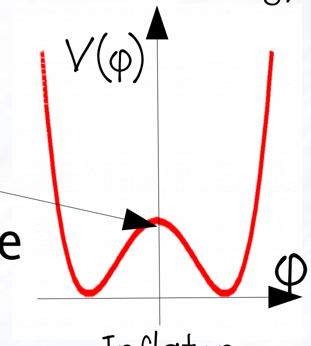
Higgs discovery confirms the existence of a new class of fundamental particles.

More Higgses are predicted by almost all Beyond the Standard Model (BSM) theories (stay tuned).

Fundamental scalar fields probably played a crucial role at the beginning of Universe

If Universe compared to a piston.
Initially vacuum energy density ρ = cte > 0

Vacuum energy



Initially
ρ = cte

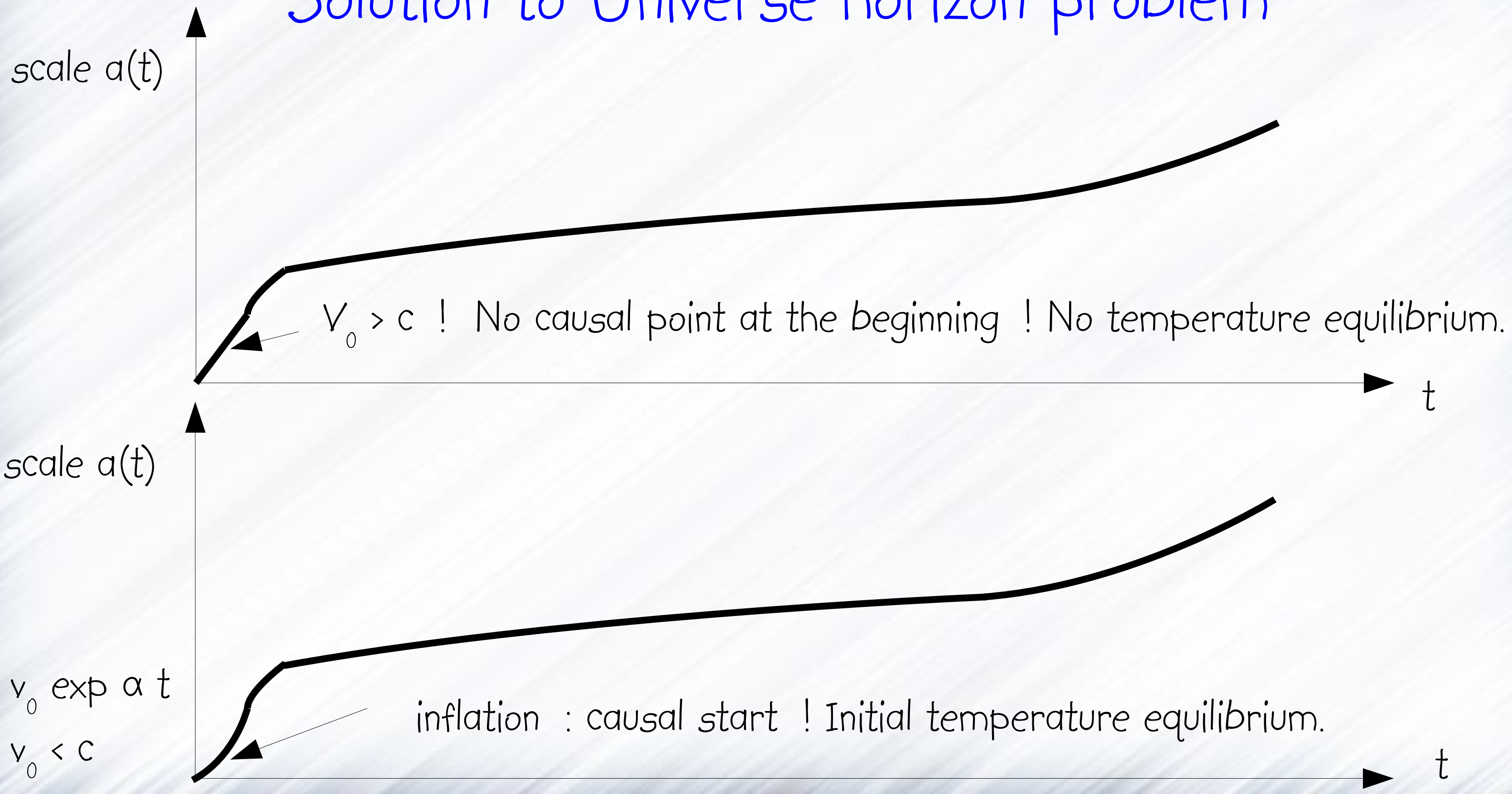
Inflaton

Universe expansion : dV > 0

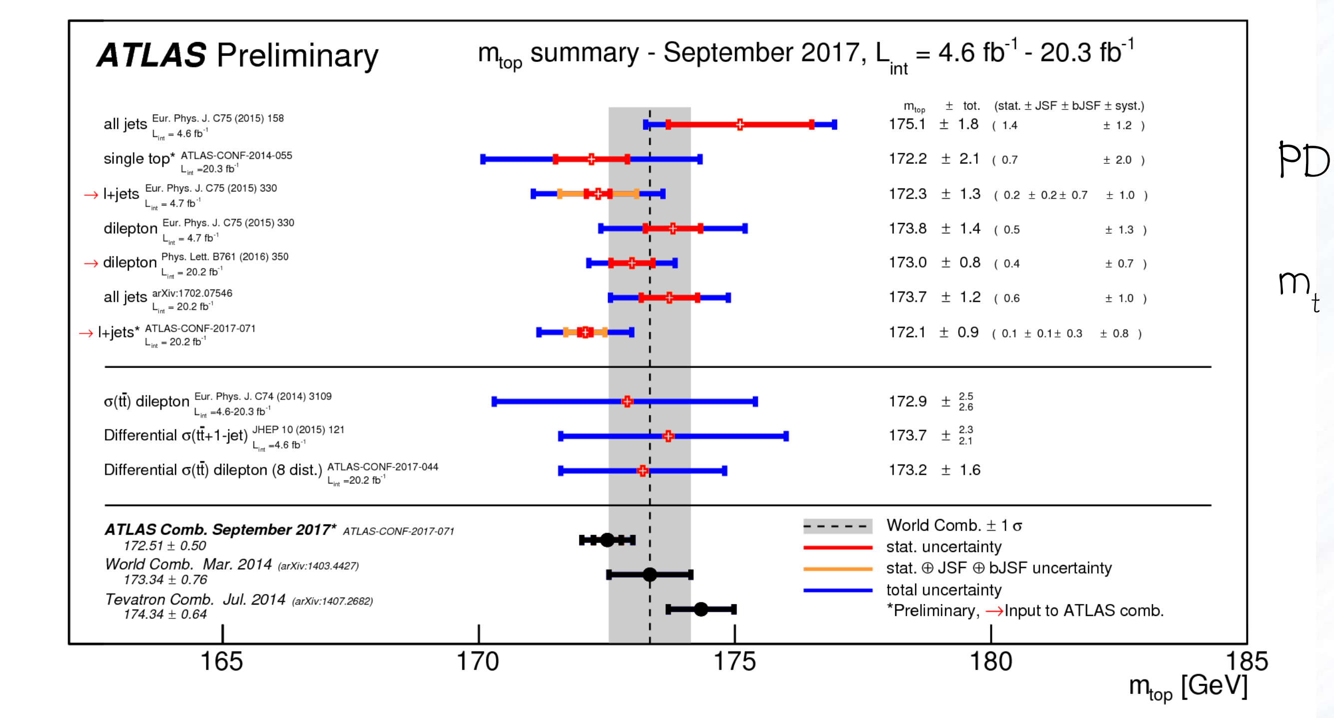
ρ dV = - $\mathbf{p}$ dV > 0

Initial pressure ($\mathbf{p}$) negative => exponential expansion => inflation

Solution to Universe horizon problem



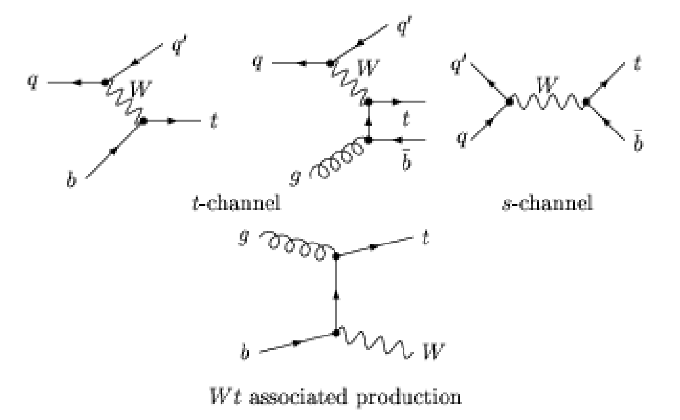
Top mass measurement

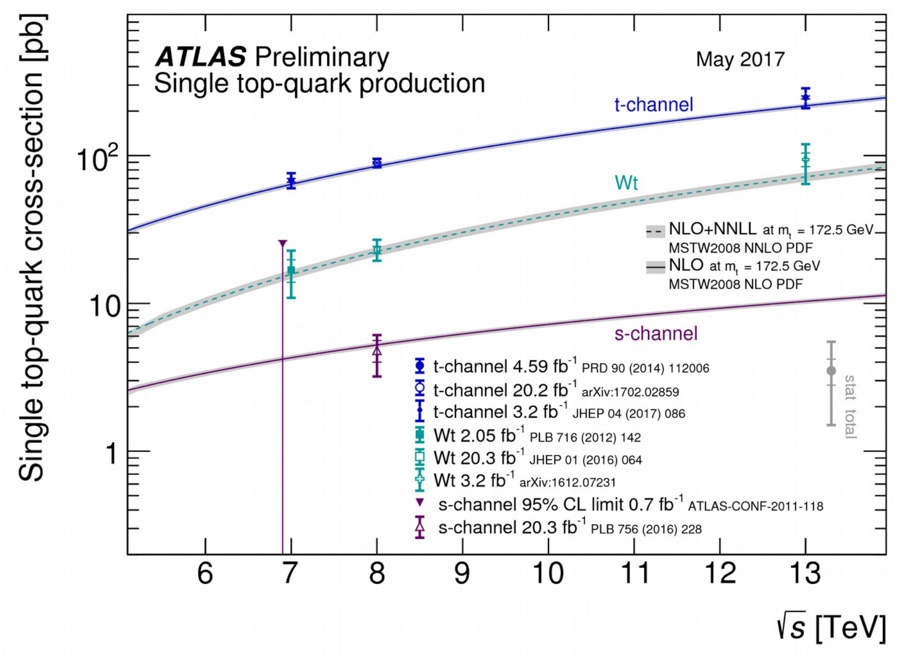


PDG 2018 average

$m_t = 173 \pm 0.4$ GeV

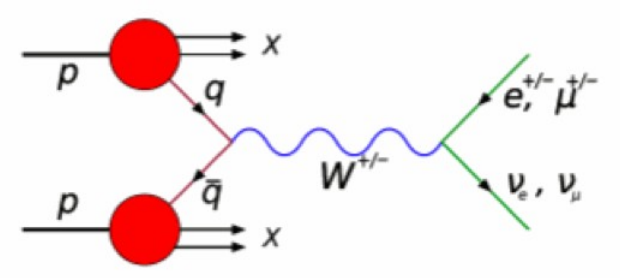
Single (electroweak) top production





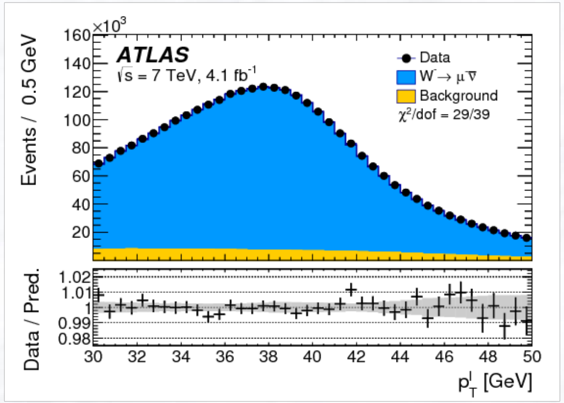
W mass (precision) measurement

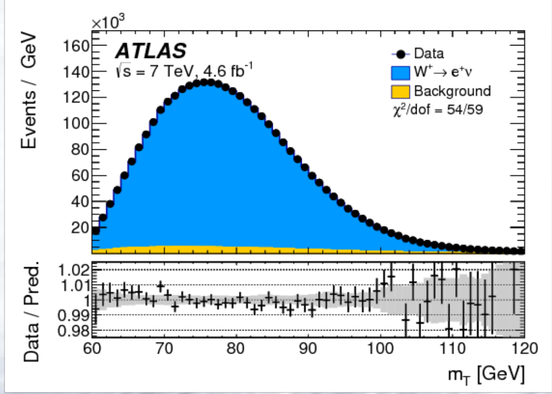
ATLAS W mass measurement
at 7 TeV (2018)



Template fits of e,μ transverse momentum
and W transverse mass distributions

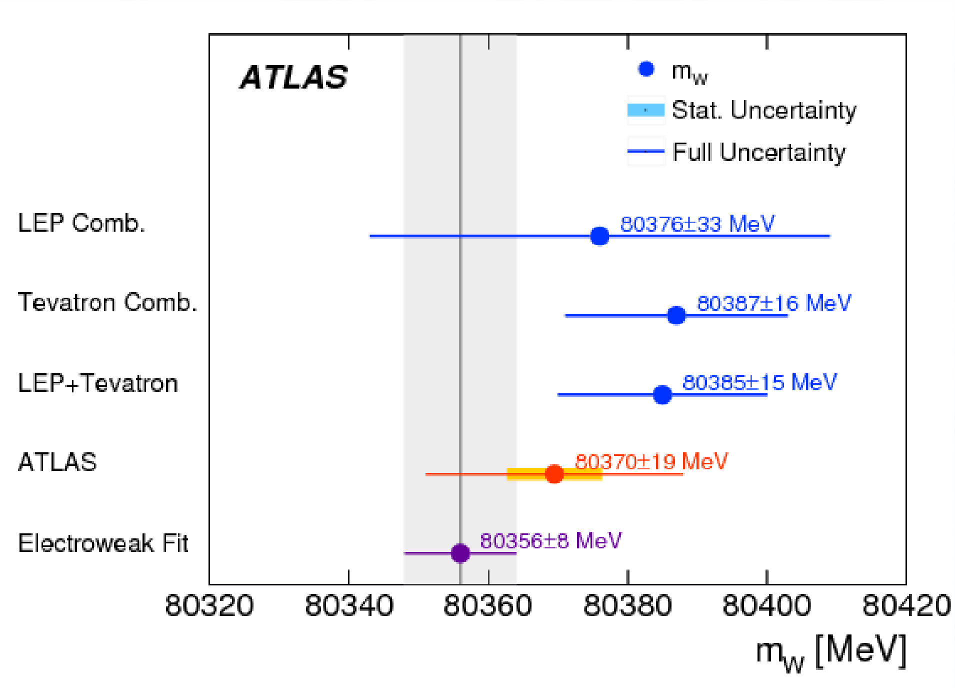
https://inspirehep.net/record/1510564





W mass (precision) measurement

Almost reaching the precision of Tevatron, but much more data to analyze.



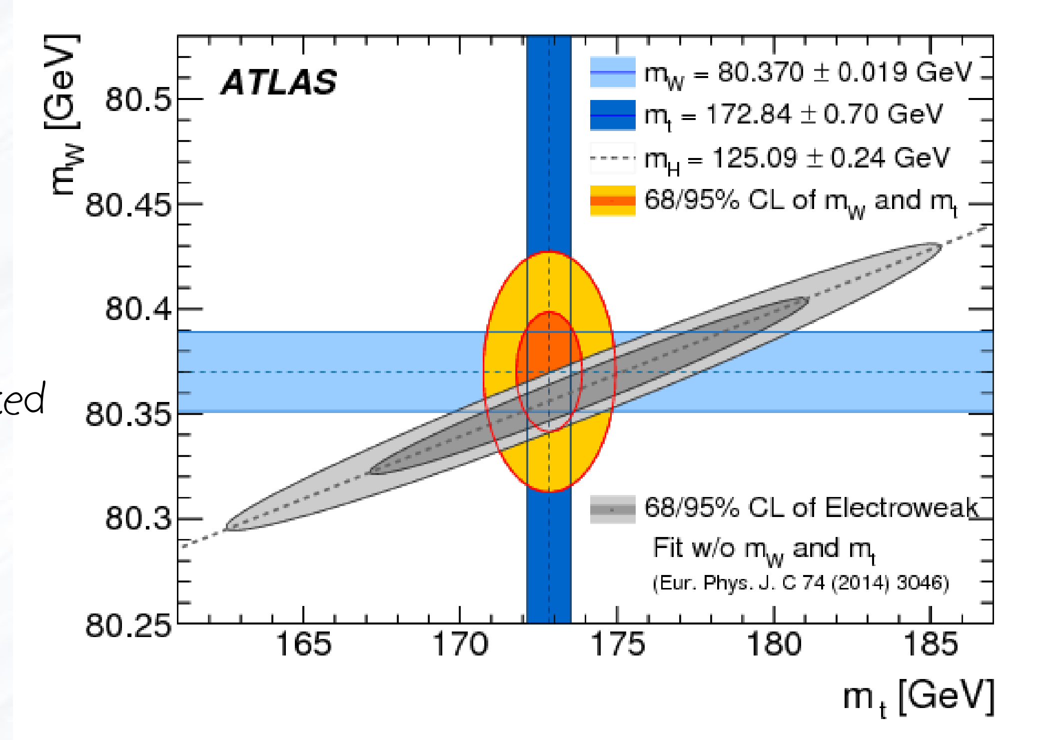
https://inspirehep.net/record/1510564

m_w - m_{top} - m_h SM consistency test

Grey contour obtained by global fit of electroweak data with as input LHC Higgs mass measurement. m_w and m_{top} let free.

Blue bands depict ATLAS separated top and W mass measurements.

Yellow contour, ATLAS combined top and W mass measurement.

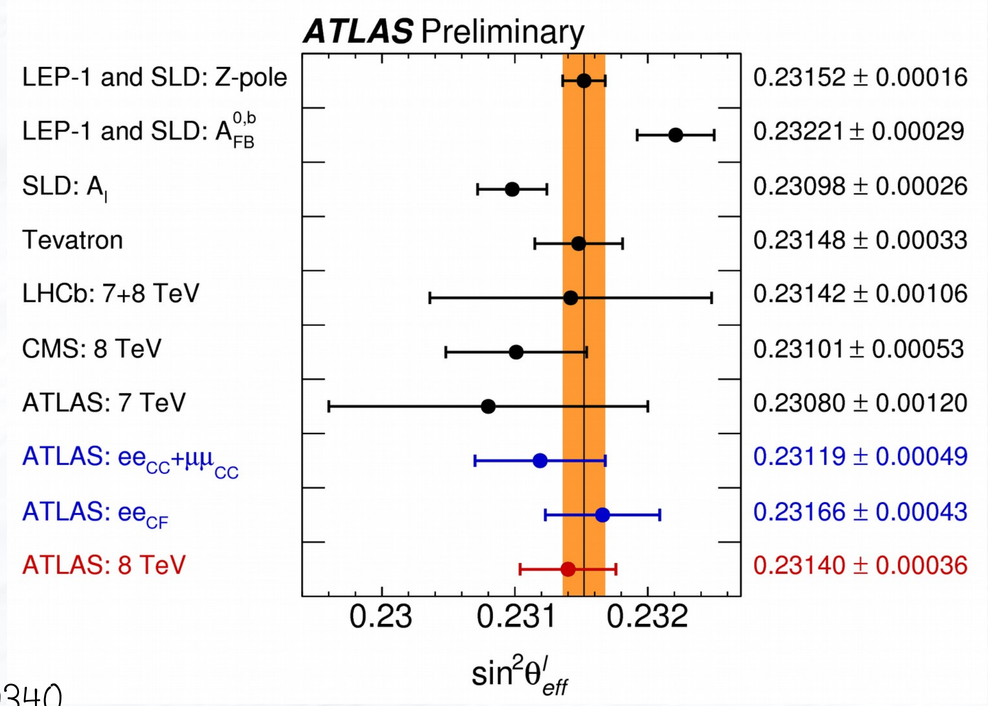


https://inspirehep.net/record/1510564

Measurement of (effective) weak mixing angle

ATLAS ICHEP 2018

Analysis of angular distribution of leptonic (e,μ) Z boson decays.



http://cdsweb.cern.ch/record/2630340

Beyond the Standard Model searches

Several hundred searches were conducted to find new physics phenomena. This is perhaps the most active analysis field of ATLAS.

- SUSY particles
- New vector bosons from new gauge symmetries
- Extra neutral or charged Higgses
- Extra dimension particles
- Compositeness
- Many other exotic models

APOLOGIES TO ALL MY ATLAS COLLEAGUES FOR NOT REPORTING ON THIS. PLEASE KEEP GOING ON, IT WILL PAY OUT SOME DAY.

Alas ! No convincing sign of new physics showed up for the time being, but the final word is very far from being said ! Stay tuned ! Even better join us & participate.

What's next

Major discovery rate over last 50 years

1973 : weak neutral currents

1974 : c quark

1977 : b quark and tau lepton

1983 : W and Z

1995 : t quark

1998 : neutrino mixing

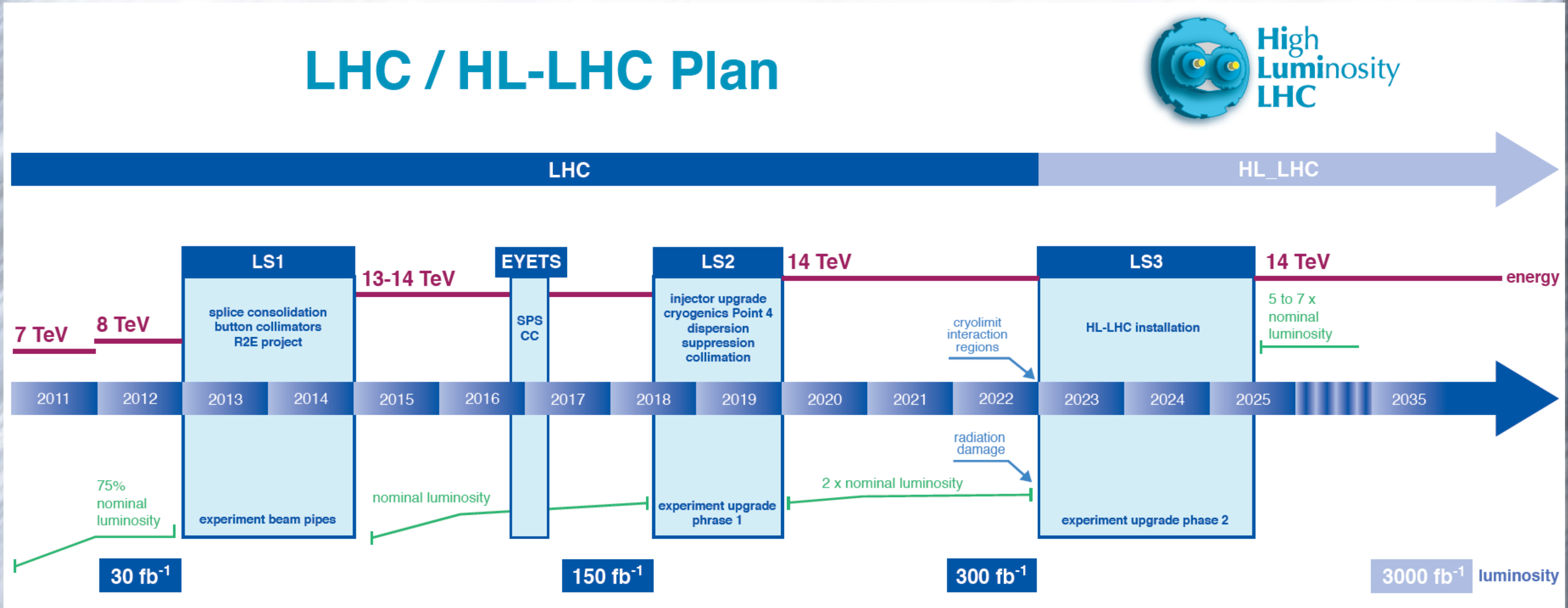
2012 : Higgs boson

1 major discovery every 5 years on average.
And max. interval = 14 years

Next discovery could be next year or in 2026.

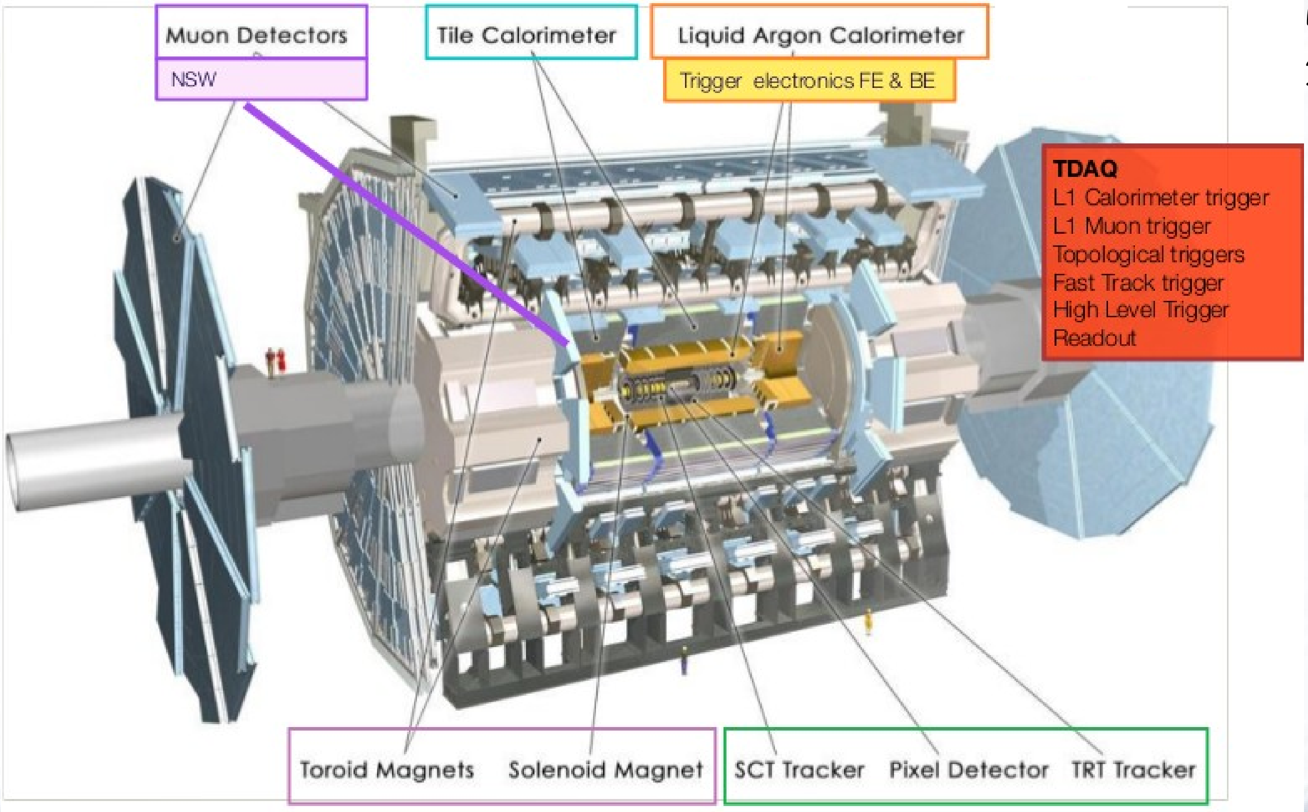
Research in fundamental physics is a school of patience (and hard but interesting work !)

Run III and high-luminosity LHC

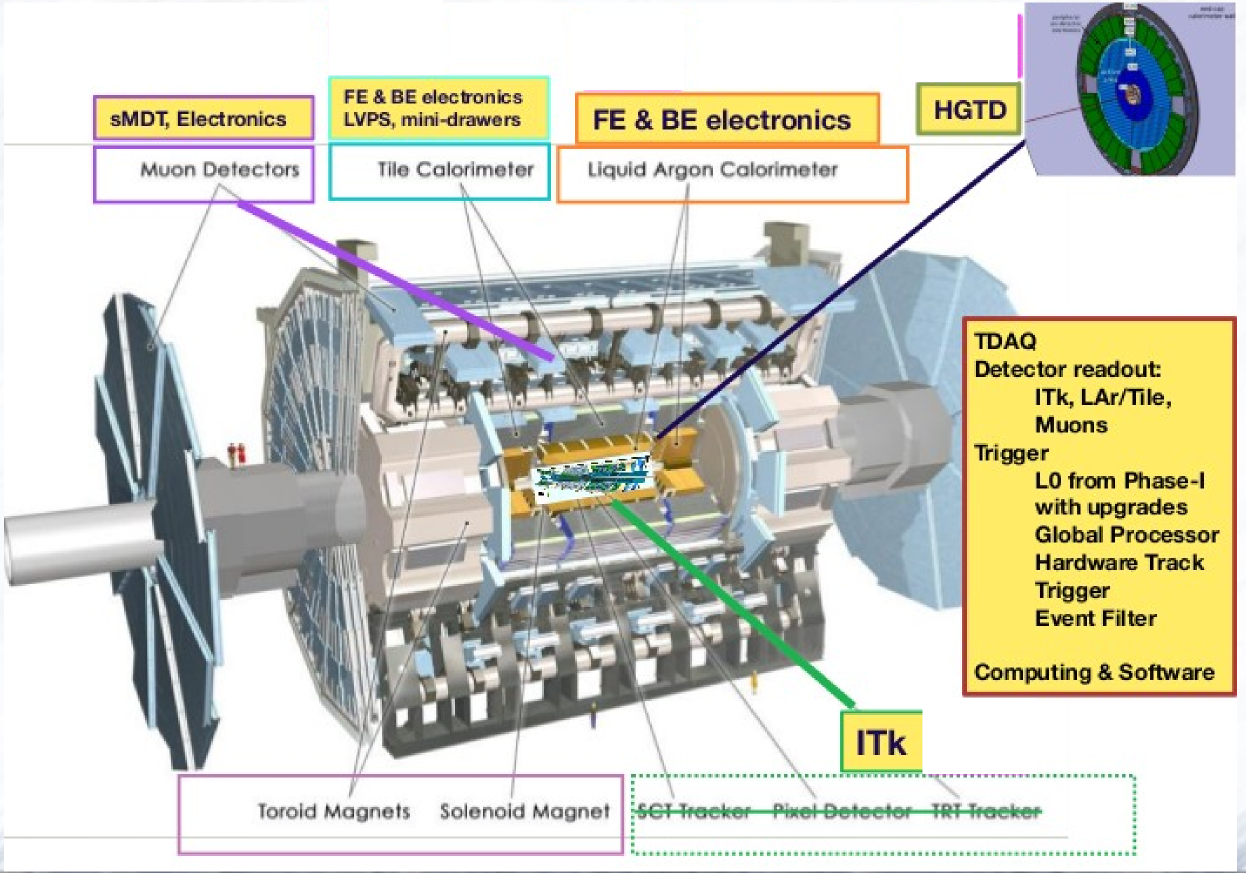


Phase-I ATLAS upgrade

before Run III
2018-2019

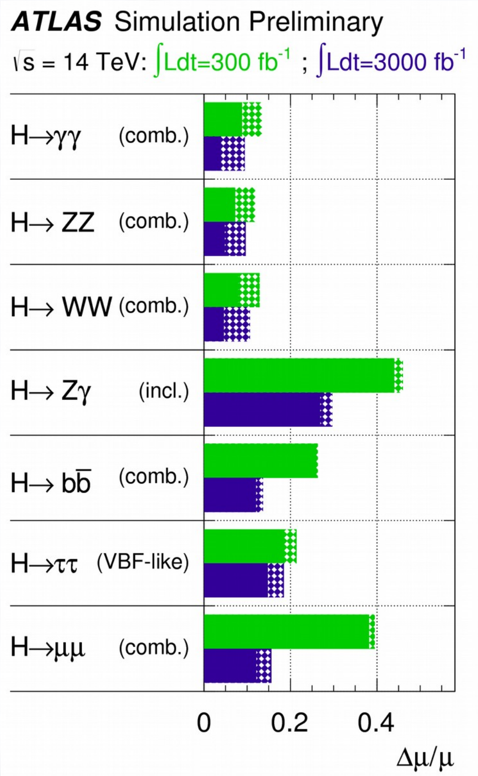


Phase-II ATLAS upgrade

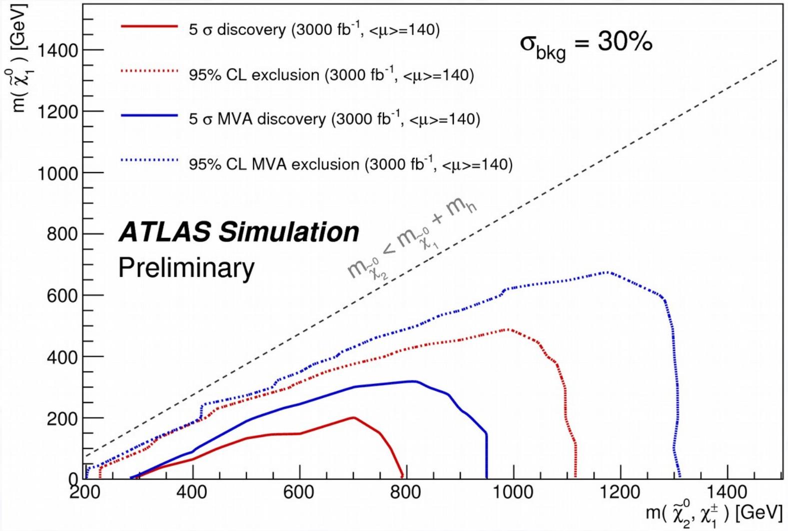


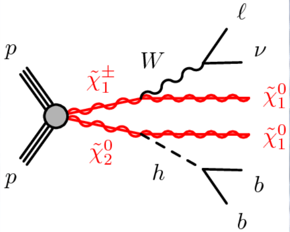
before Run IV
2023-2025

Run III and HL-LHC prospects



Will be reappraised soon for European Strategy Update



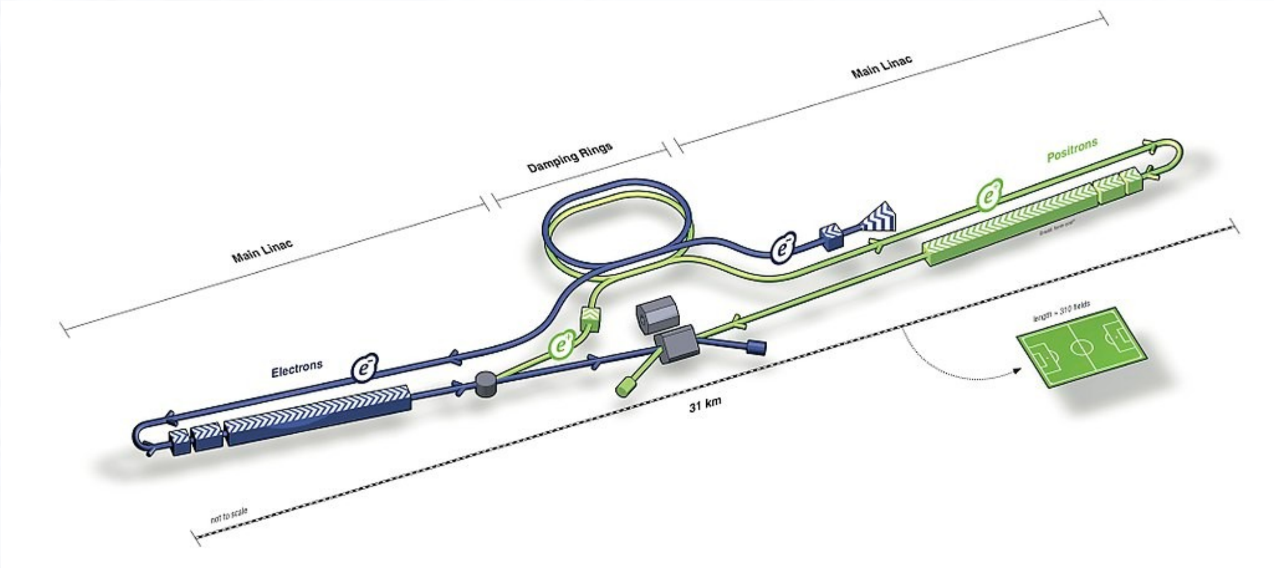


http://cdsweb.cern.ch/record/2038565

http://cdsweb.cern.ch/record/1956710

And beyond LHC

International Linear Collider : ILC

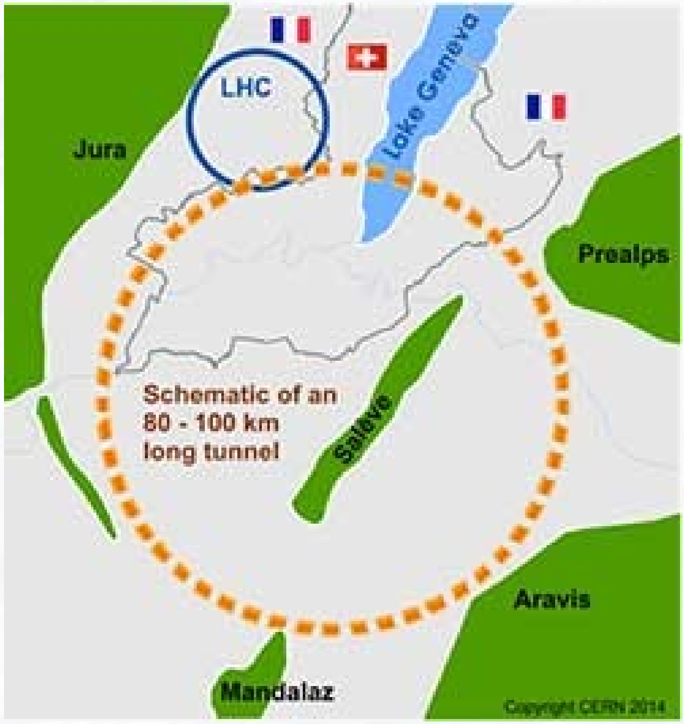


In Japan

e^+e^- collider
250-1000 GeV

starts in 2040 ?

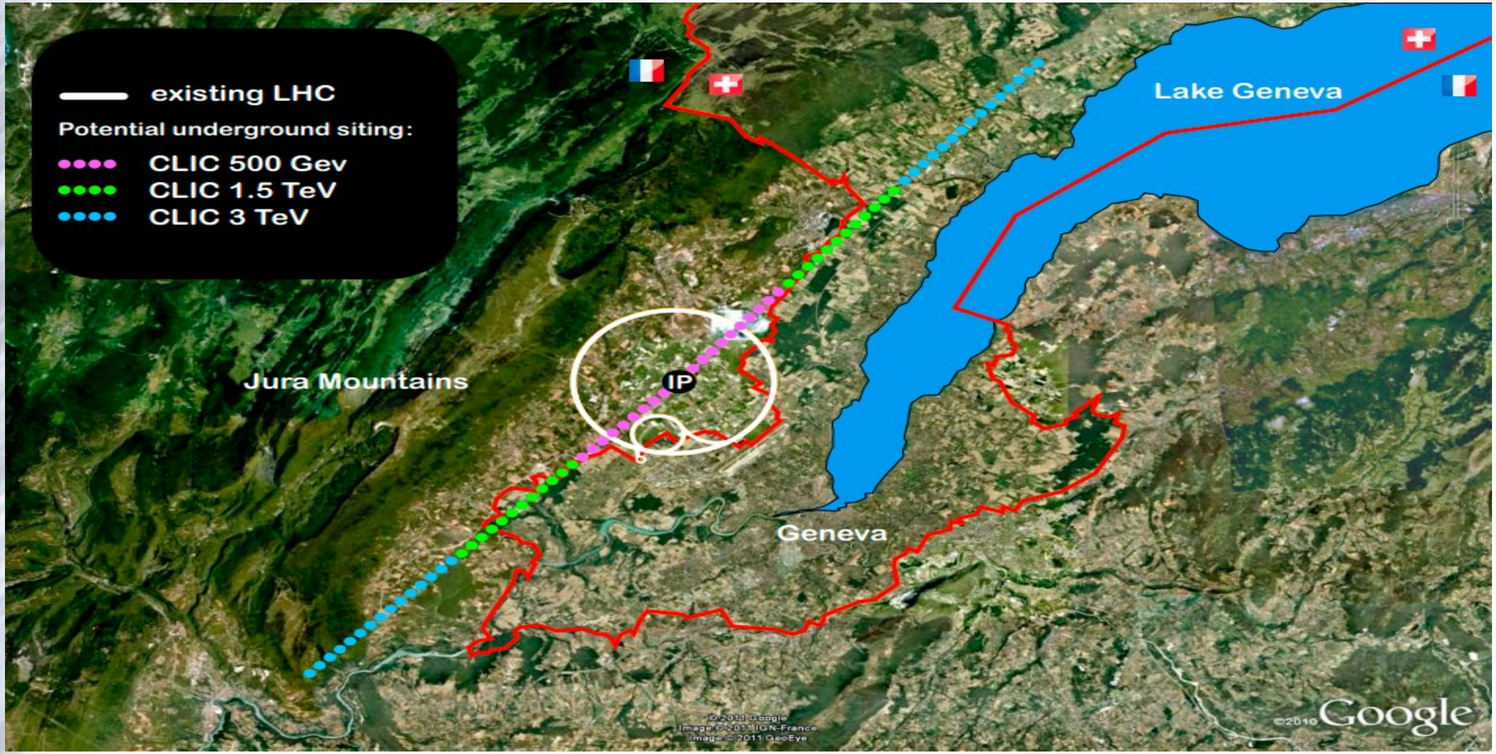
Future Circular Collider : FCC



FCC-ee : e^+e^- collider - up to 350 GeV
starts in 2040 ?

FCC-pp : pp collider - up to 100 TeV
starts in 2060 ?

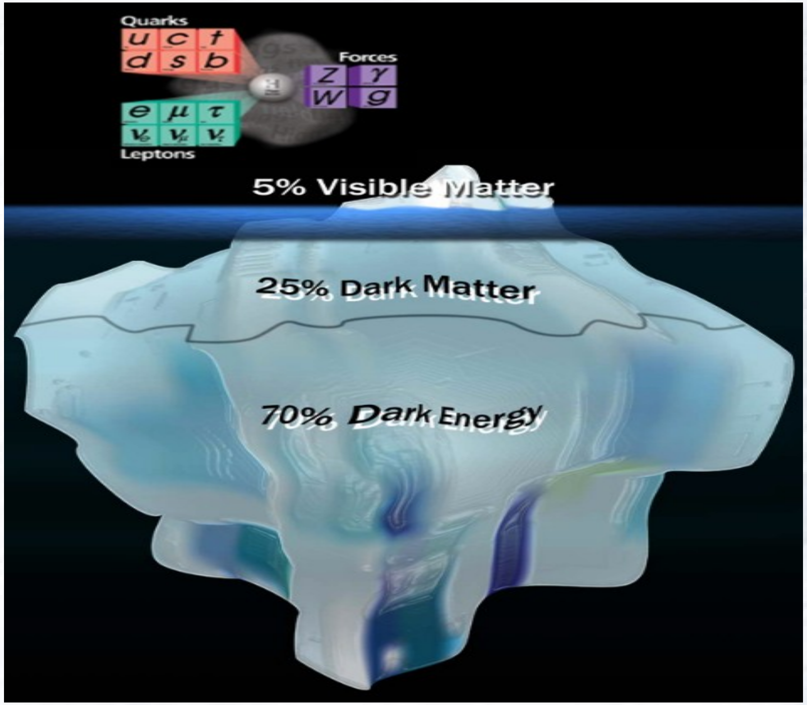
Compact Linear International collider : CLIC



e^+e^- collider starts in 2040 ?

Conclusion

- LHC has promoted fundamental scalar fields to credible physical entities. It would be strange that nature has made the Higgs boson a unique child ! No convincing BSM sign in LHC data till now.
- Future looks bright (for young students) with a clear objective : bridging micro & macro physics.



あなたの注意をありがとう