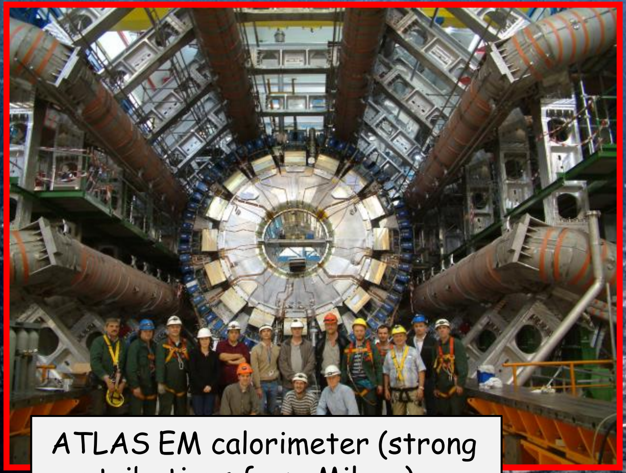
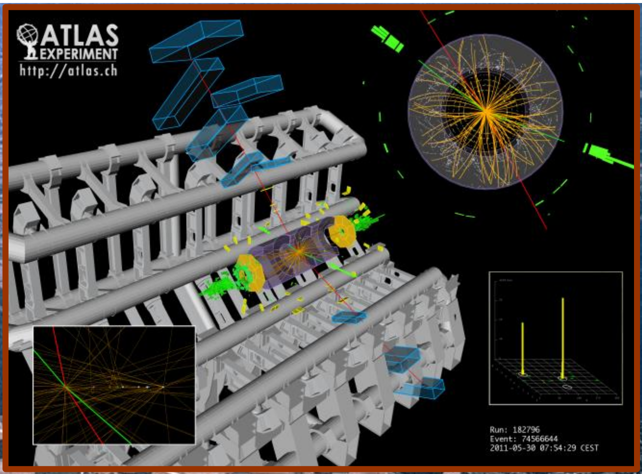
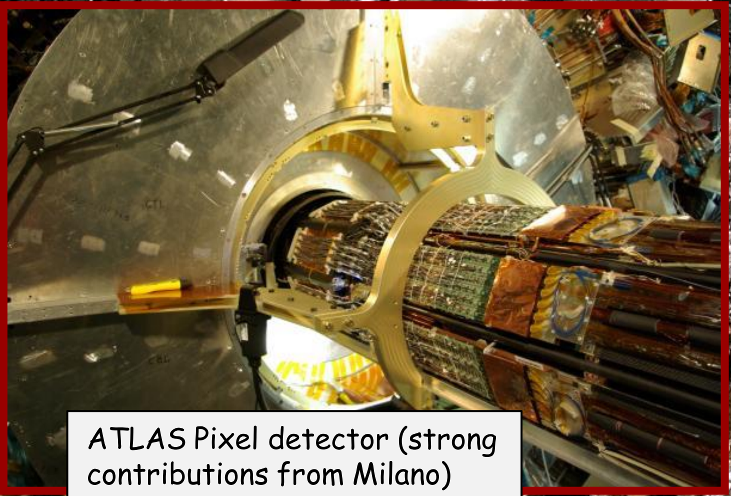


ATLAS EM calorimeter (strong contributions from Milano)



The Higgs boson and other recent results from the ATLAS experiment at the LHC

Fabiola Gianotti
CERN, Physics Department
Milano, 6/5/2013



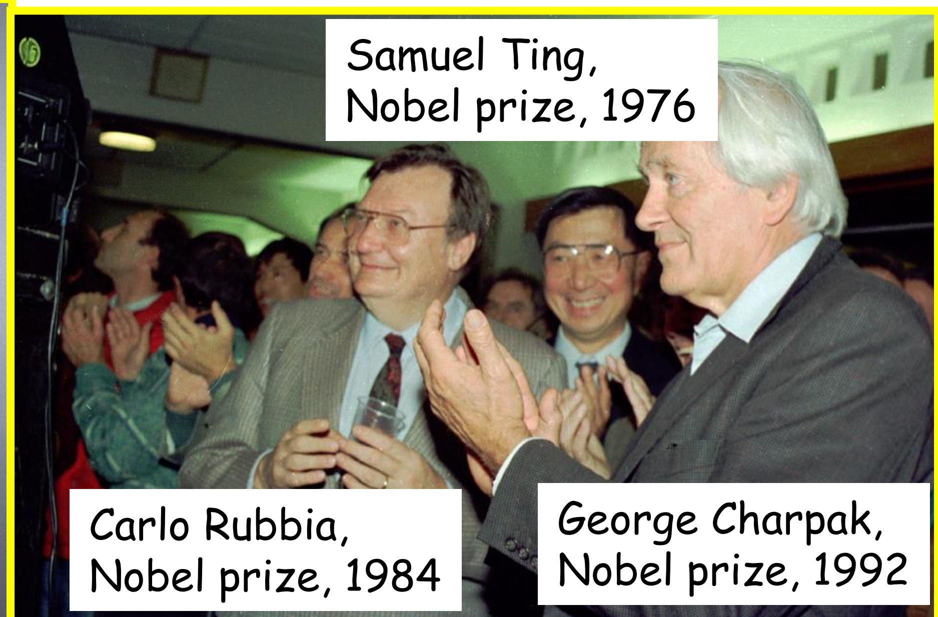
ATLAS Pixel detector (strong contributions from Milano)

CERN: European Organization for Nuclear Research
The world's largest particle physics laboratory
(based in Geneva, Switzerland)

More than 50 years of:

- fundamental research and discoveries (and Nobel prizes ...)
- technological innovation and technology transfer to society
  (e.g. the World Wide Web)
- training and education (young scientists, school students and teachers)
- bringing the world together (10000 scientists from > 60 countries)


CERN staff member T. Berners-Lee, inventor of the WEB, with Kofi Annan and CERN DG Luciano Maiani



CERN was founded 1954: 12 European States
Today: 20 Member States

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

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

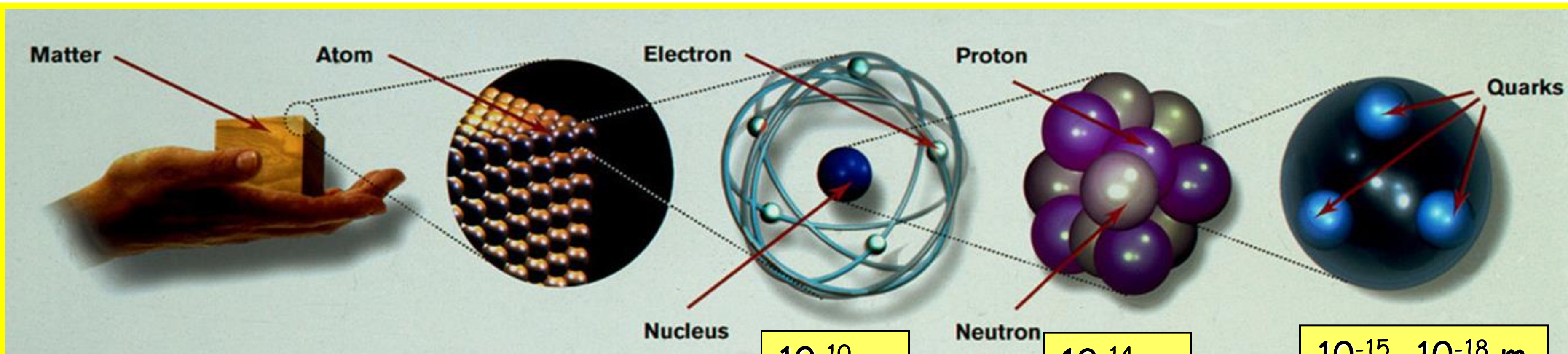
~ 2300 staff

> 10000 users

Budget (2012) ~1000 MCHF: each Member State contributes in proportion to its income: Italy: ~ 11% (~ 80M€ → 1 cappuccino/abitante), return: +10%

CERN's primary mission is SCIENCE

Study the elementary particles (e.g. the building blocks of matter: electrons and quarks) and the forces that control their behaviour at the most fundamental level



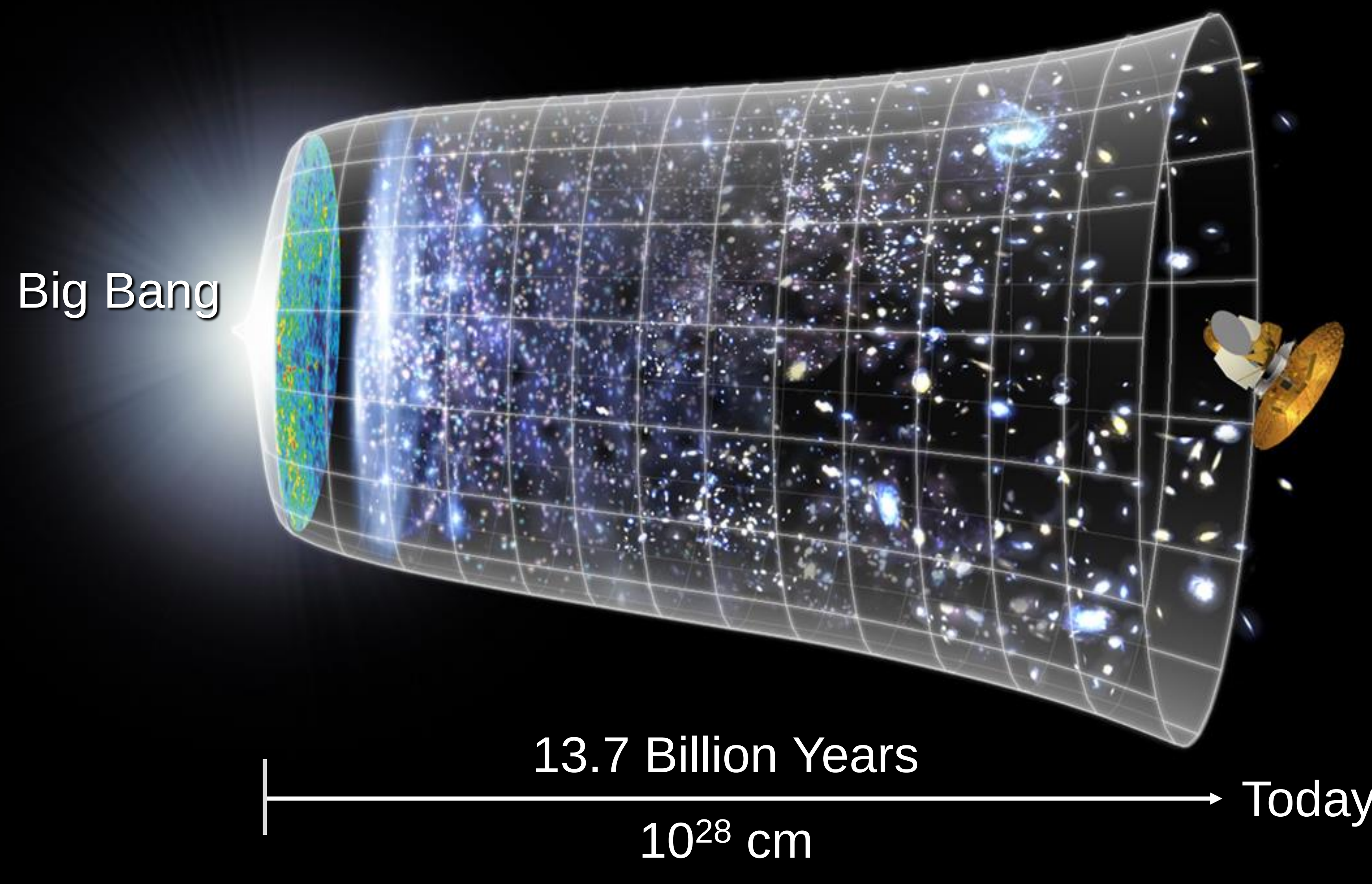
10^{-10} m

10^{-14} m

10^{-15} -10^{-18} m

Particle physics aims at understanding the fundamental laws of nature and therefore also the structure and evolution of the Universe
→ from the very small to the very big …

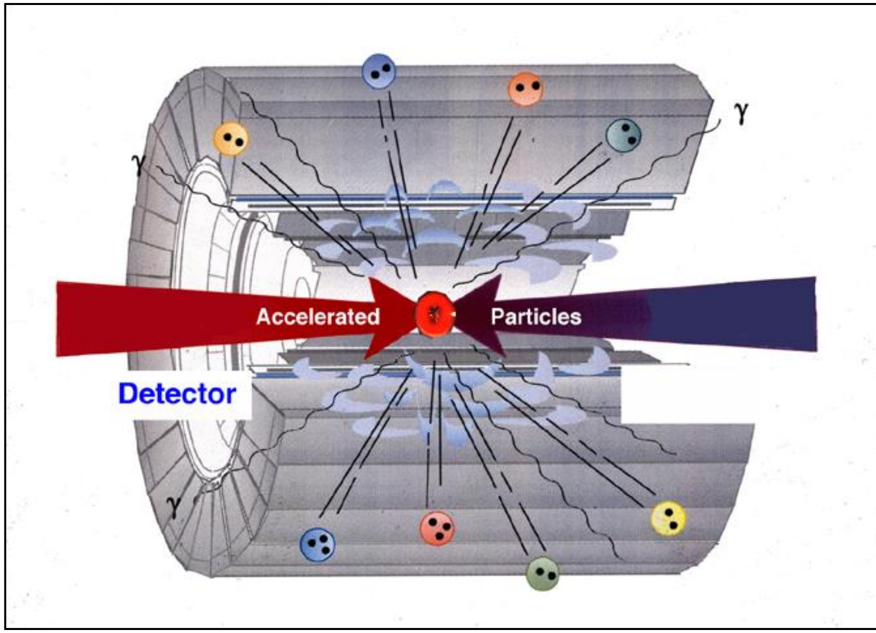
Evolution of the Universe



Therefore, we need three things:

Accelerators: underground tunnels (usually rings) containing electric fields to accelerate particles to very high energy (incrementally at each turn), and magnets to bend the beams inside the ring and bring them into collision

Powerful giant microscopes to explore the smallest constituents of matter !!



Detectors: massive instruments which register the collision products and allow to identify the produced particles and measure their energy and trajectory.

Computing: to store, distribute and analyse the vast amount of data produced by the detectors and thus reconstruct the "event" occurred in the collision.

The Large Hadron Collider (LHC) at CERN

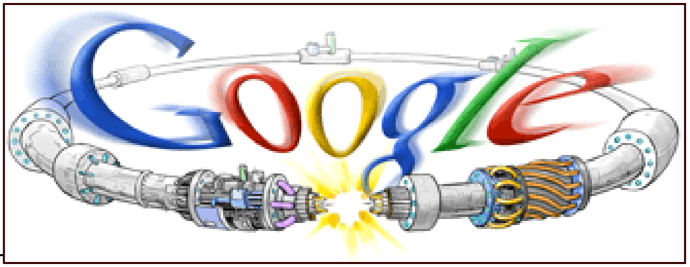
the most powerful accelerator

.... and also ....

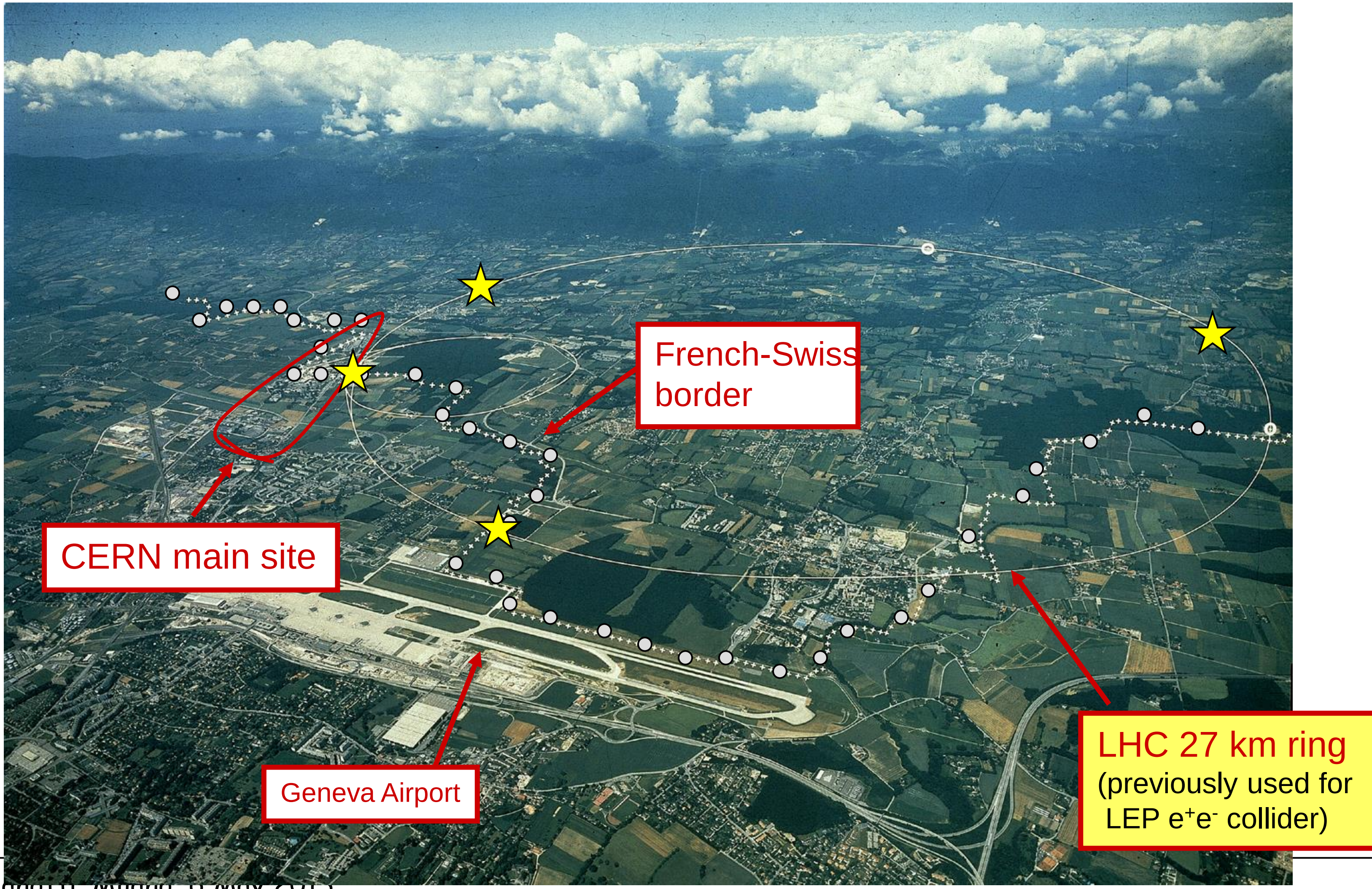
the most high-tech and complex detectors
the most advanced computing infrastructure
the most innovative concepts and technologies
(cryogenics, new materials, electronics, data transfer and storage, etc. etc…)
the widest international collaborations

ever achieved in accelerator particle physics.
One of the most ambitious projects in science in general.

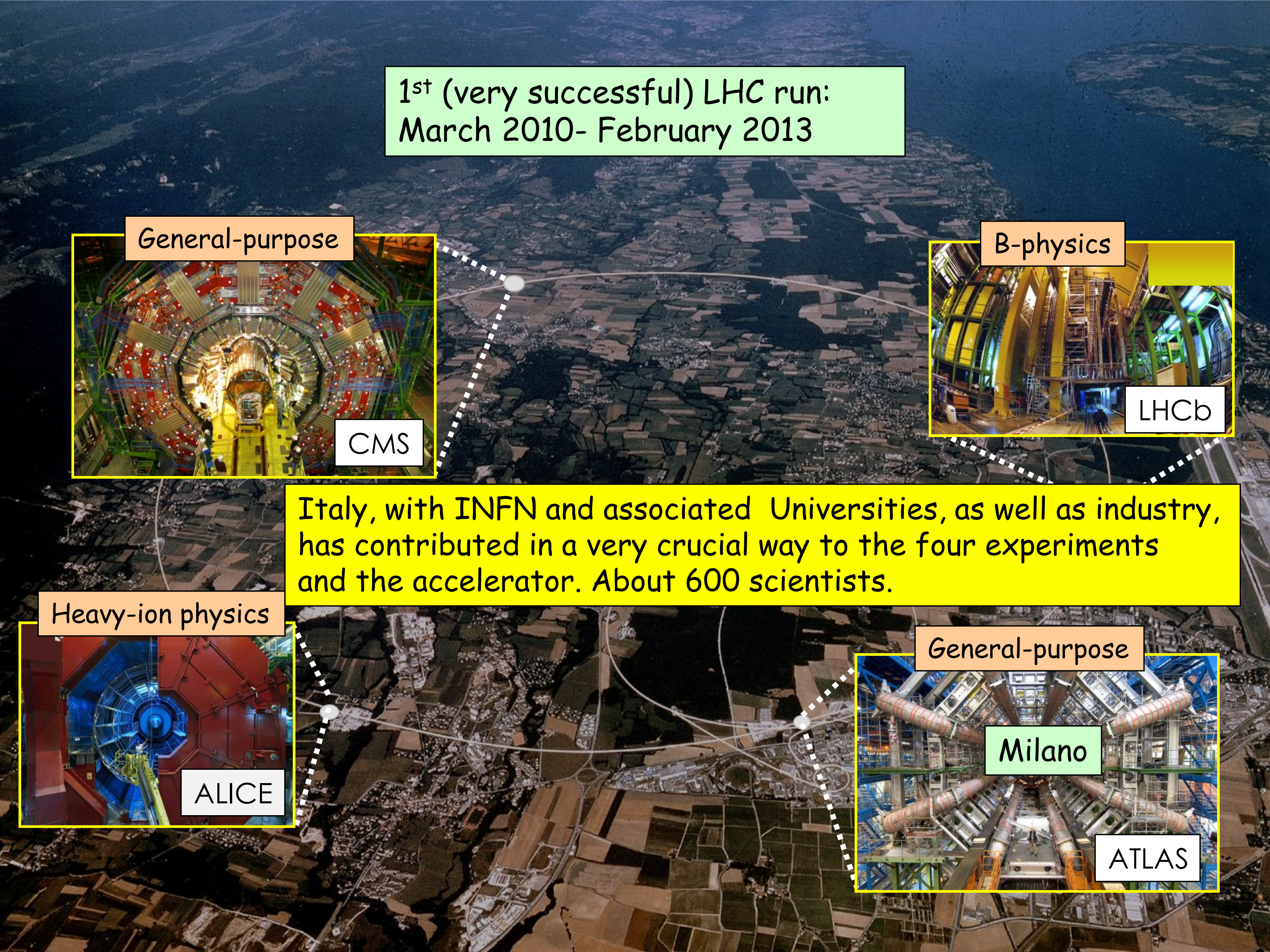
Operation started 20 November 2009
(> 20 years from concept to start of operation)



- LHC: 27 km accelerator ring, 100 m below ground, across French-Swiss border
- Two proton beams accelerated in opposite directions
  Beam energy until today: 4 TeV → $\sqrt{s}$=8 TeV (x4 Tevatron)
- Design energy (to be achieved in 2015): $\sqrt{s}$ ~ 14 TeV (1 TeV= 10^{-7} Joule)
- They collide at four points, where four big experiments have been installed



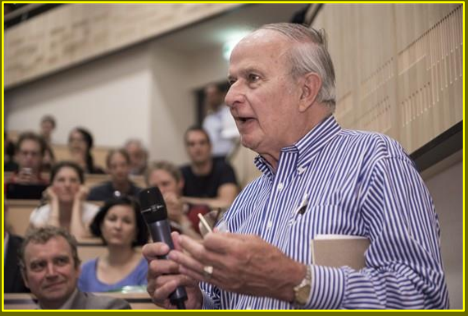
1st (very successful) LHC run:
March 2010- February 2013



Italy, with INFN and associated Universities, as well as industry, has contributed in a very crucial way to the four experiments and the accelerator. About 600 scientists.

An historical day : 4^{th} July 2012

The culmination of a long path …



Few milestones of a long path ...

1984 : First studies for a high-energy pp collider in the LEP tunnel
1989 : Start of SLC and LEP e^+e^- colliders
1993 : SSC is cancelled → US physicists join the LHC
1994 : LHC approved by the CERN Council
1995 : Top-quark discovered at the Tevatron
1996 : Construction of LHC machine and experiments start
2000 : End of LEP2
2003 : Start of LHC machine and experiments installation
2009 : 23 November: first LHC collisions ($\sqrt{s}$ = 900 GeV)

> 20 years from conception to start of operation

2010 : 30 March: first collisions at $\sqrt{s}$ = 7 TeV
2012 : 1st May: collision energy to $\sqrt{s}$ = 8 TeV
2012 : 4th July: discovery of a Higgs-like boson
2013 : 14th February: end of "Run 1" → start 2-year shut-down (LS1)

+ 20 years of physics exploitation ?

The LHC has required:
- innovative technologies (superconducting magnets, cryogenics, electronics, computing, ..)
- new concepts, lot of ingenuity to address challenges and solve problems
- huge efforts of the worldwide community (ideas, technology, people, money)

Most challenging component of the accelerator: 1232 high-tech superconducting dipole magnets needed to bend high-E beams inside the 27 km (existing/LEP) ring

→ ~8.3T max B-field affordable from technology for large-scale production

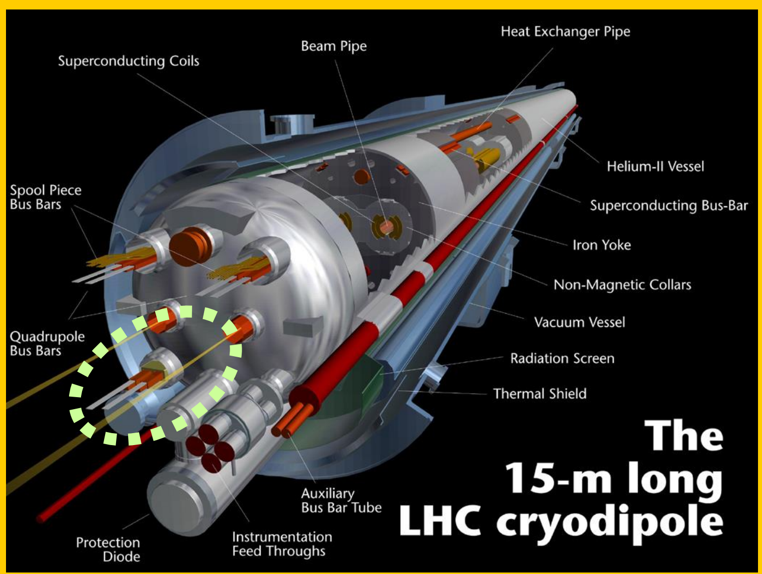
→ 7 TeV per beam max energy

Cfr: Tevatron: 700 dipoles, ~4T

$$p(\text{TeV}) = 0.3\ B(\text{T})\ R(\text{km})$$

Dipoles made of 7600 km of NbTi superconducting cable (12 kA current)

Work at 1.9K in a bath of 120 tons of superfluid Helium



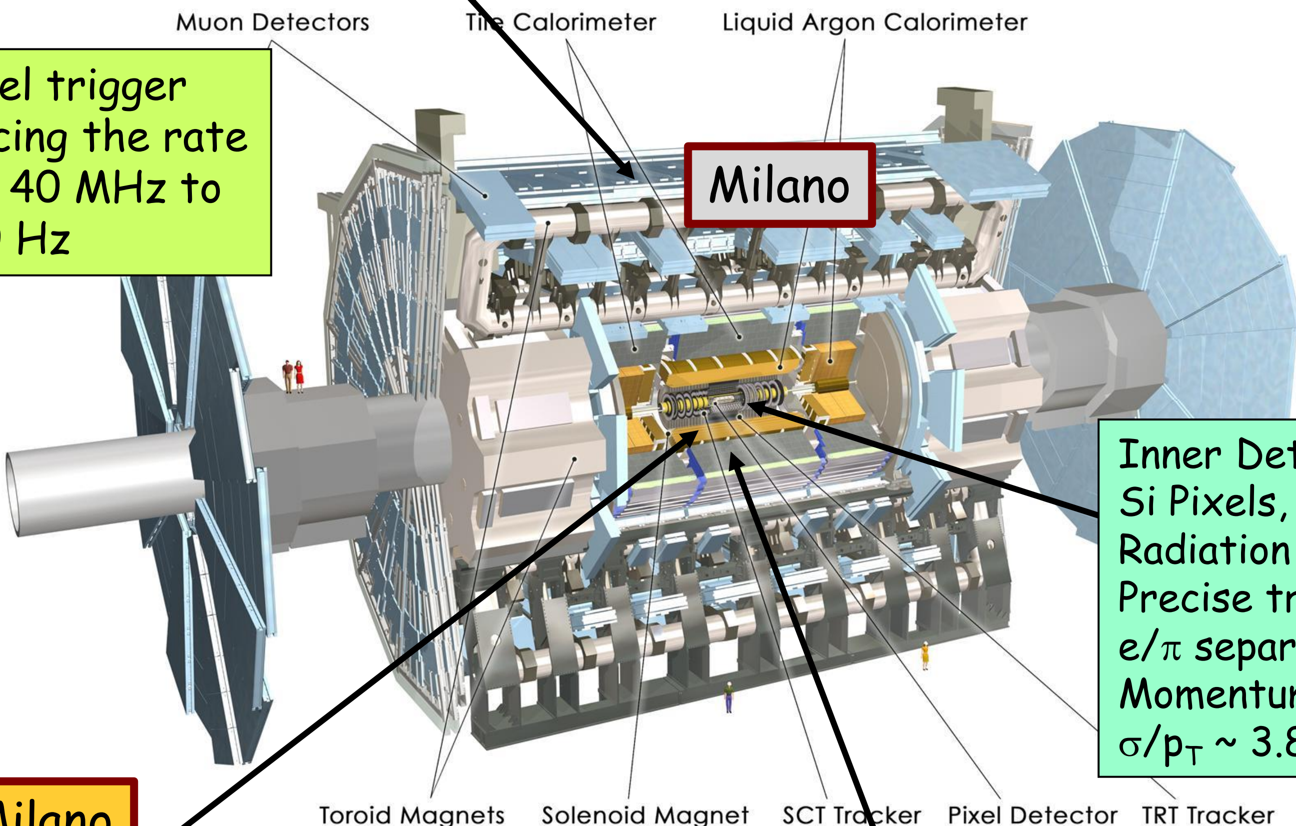
The 15-m long LHC cryodipole

2015: collision energy ~ 14 TeV after repair/consolidation of magnet interconnects during LS1 (following Sept. 2008 accident)

Built by 3 leading European industries: Alstom (France), Ansaldo (Italy), Babcok-Noell (Germany)

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to E_μ ~ 1 TeV

3-level trigger reducing the rate from 40 MHz to ~200 Hz



Milano

Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing,
e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T(\text{GeV}) \oplus 0.015$

Milano

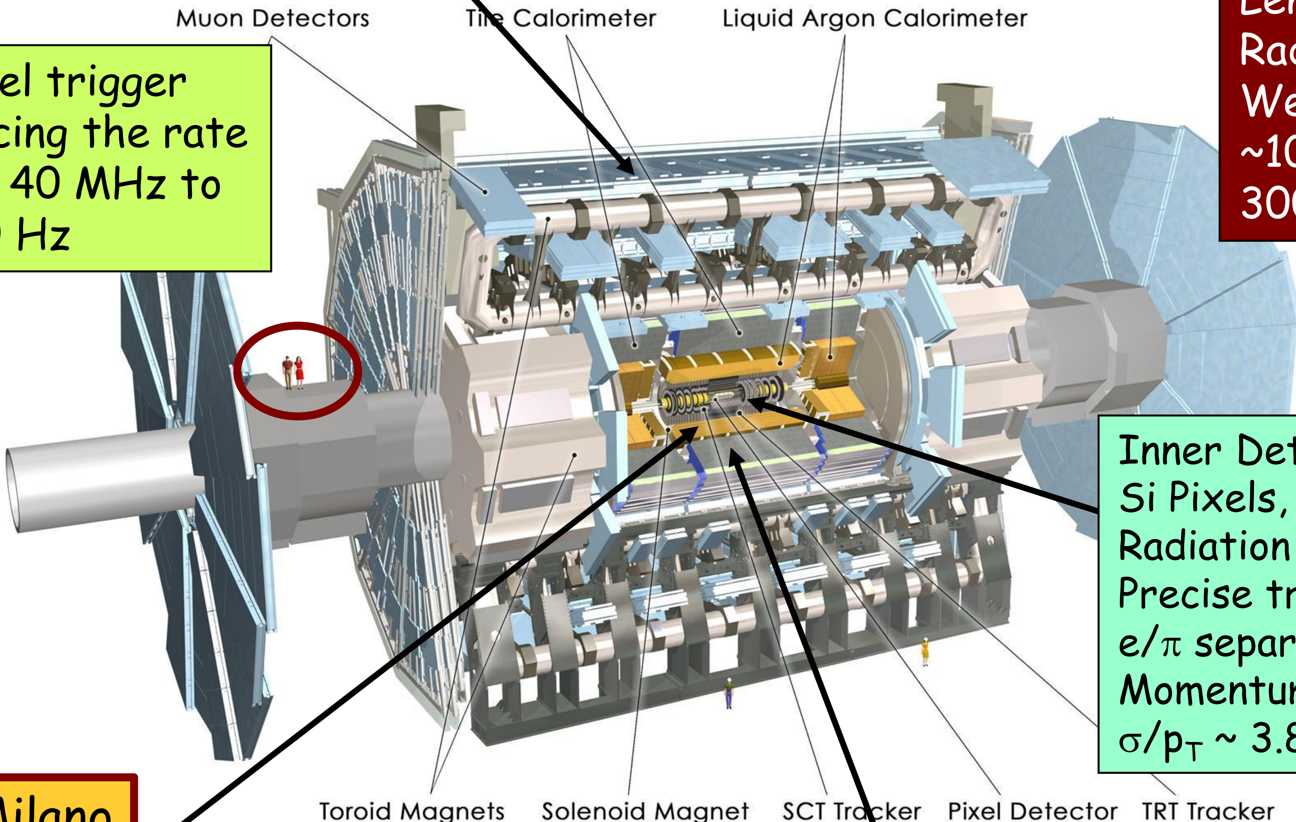
EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to $E_\mu \sim 1$ TeV

3-level trigger reducing the rate from 40 MHz to ~200 Hz

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables



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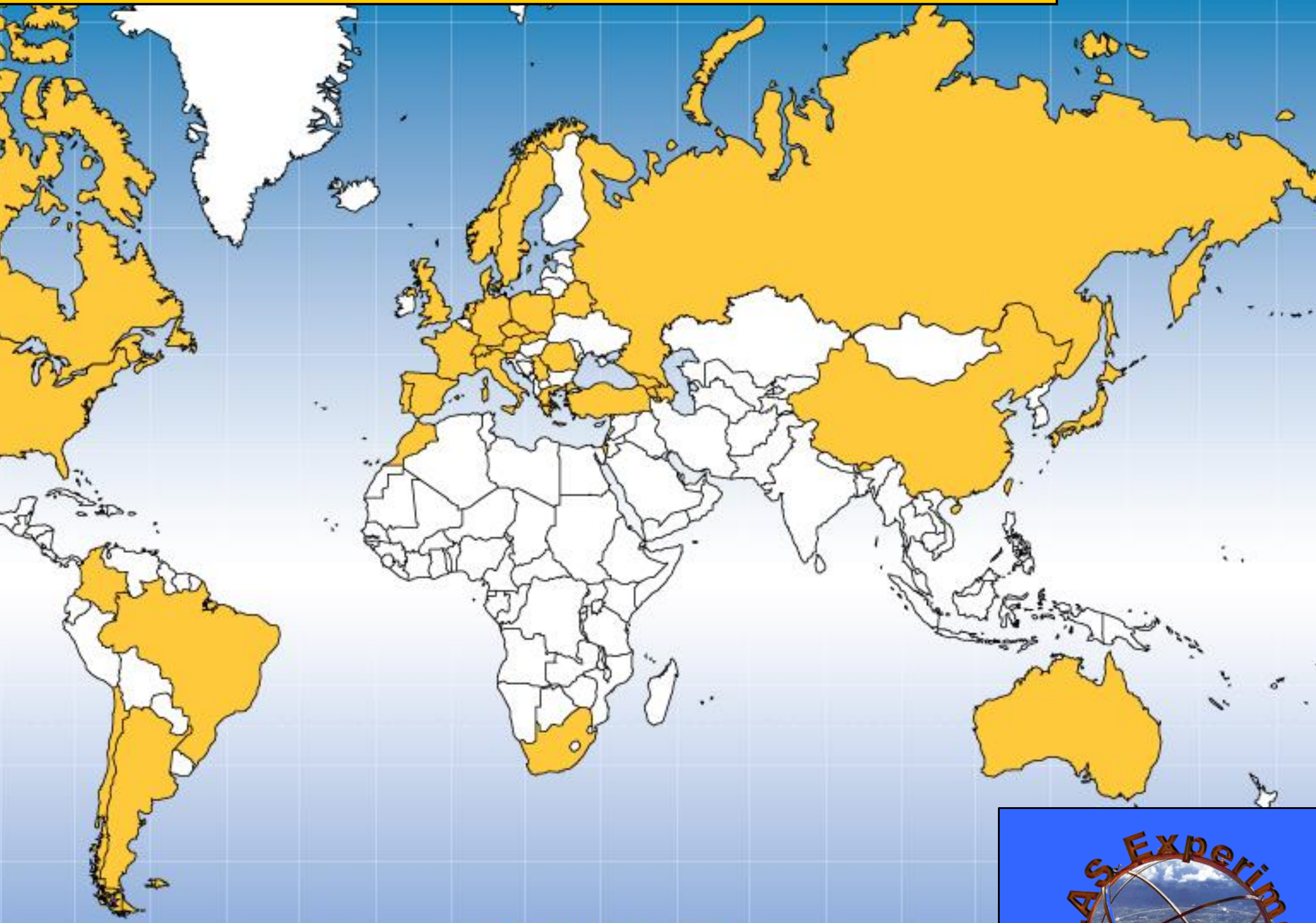
Milano

EM calorimeter: Pb-LAr Accordion
e/γ trig
E-resolu

city

- Size : to measure and absorb high-E particles from the collision
- 10^8 independent sensitive elements: to track ~1000 particles per event and reconstruct their trajectories with ~10 μm precision
- Fast response (25-50 ns): 40 million beam-beam collisions per second

~ 3000 scientists from 177 Institutions from 38 Countries



Argentina
Armenia
Australia
Austria
Azerbaijan
Belarus
Brazil
Canada
Chile
China
Colombia
Czech Republic
Denmark
France
Georgia
Germany
Greece
Israel
Italy
Japan
Morocco
Netherlands
Norway
Poland
Portugal
Romania
Russia
Serbia
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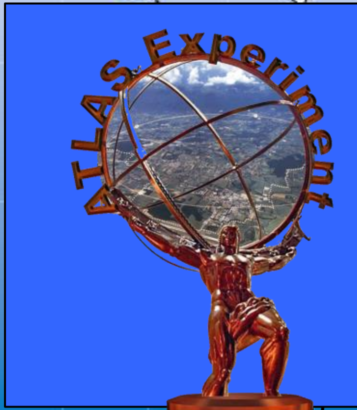
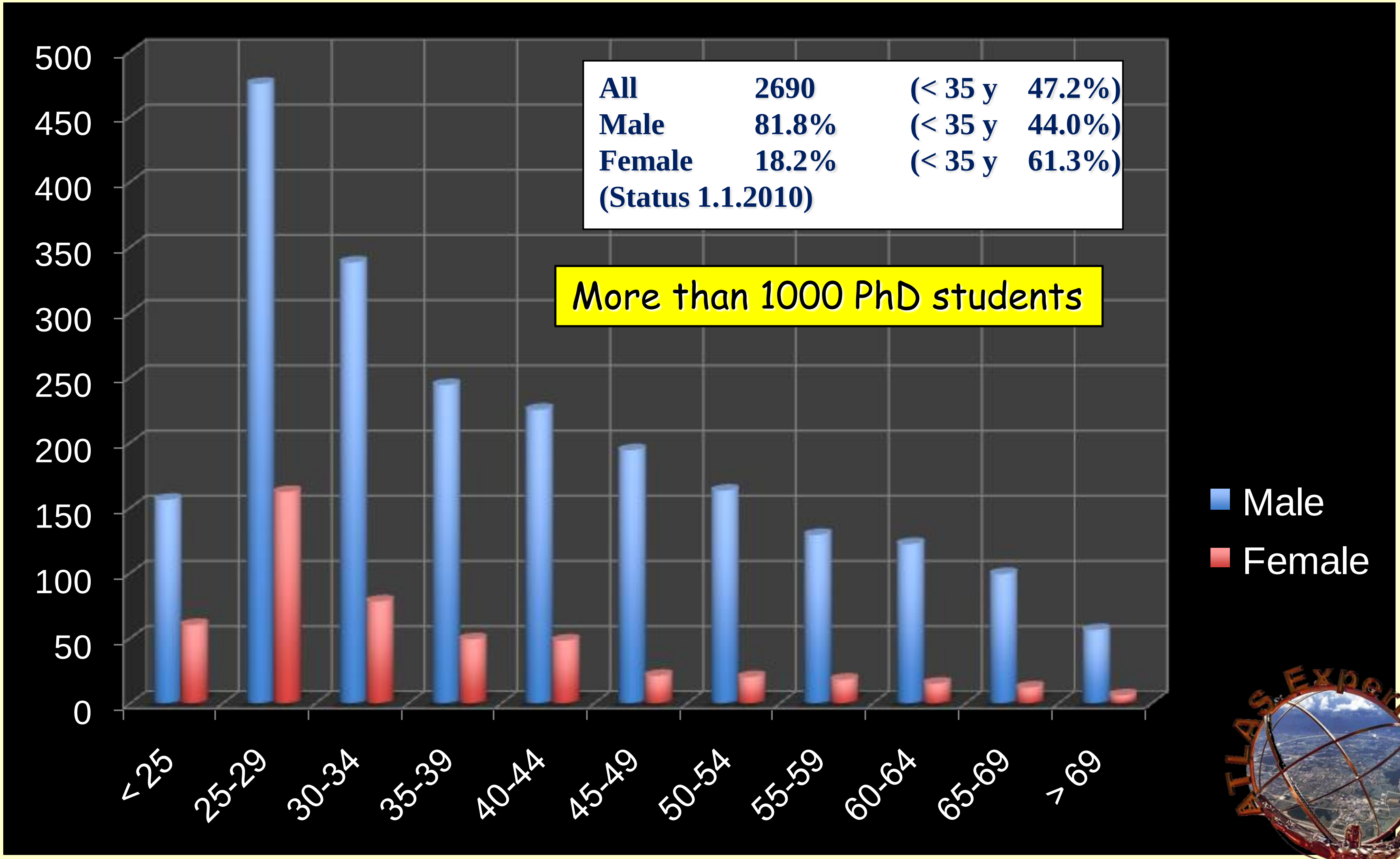
Slovenia
South Africa
Spain
Sweden
Switzerland
Taiwan
Turkey
UK
USA
CERN
JINR

ATLAS Collaboration



Age distribution of the ATLAS population



~ 3000 scientists from 177 Institutions from 38 Countries

Italy:
- 13 groups (INFN, Universities)
- ~ 200 scientists (~60 students)
- Contributed to all detector components, software and computing, physics (Higgs discovery !), upgrade

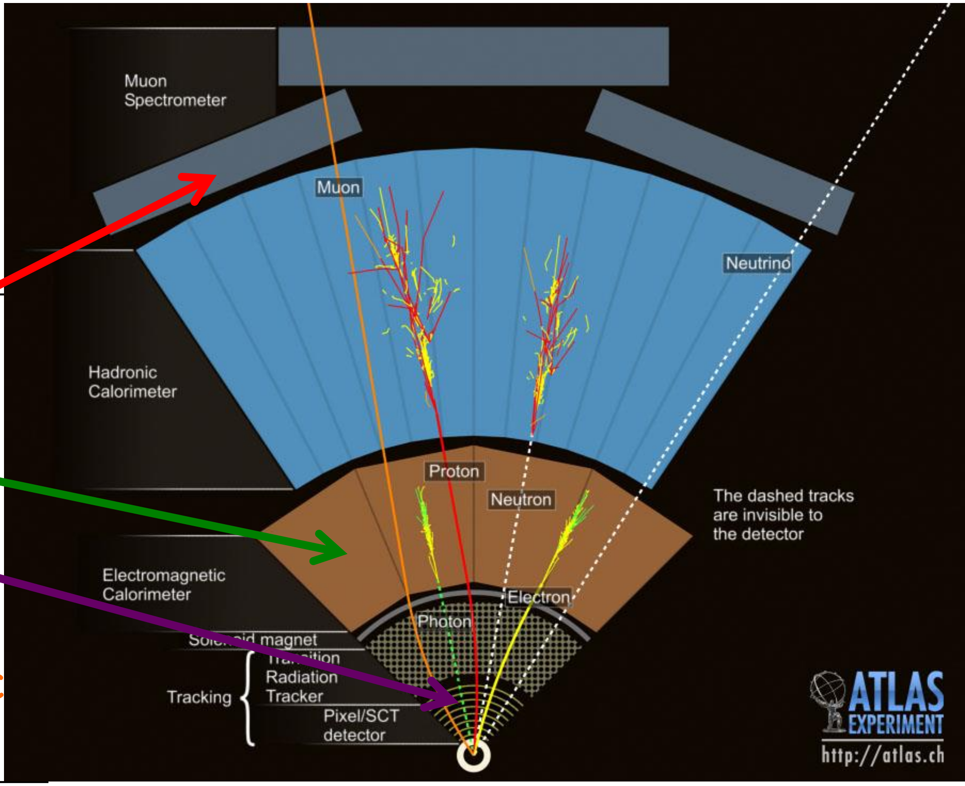
Milano INFN, Physics Department and LASA:
- ~ 40 scientists (~15 students)
- Team leader: Francesco Tartarelli

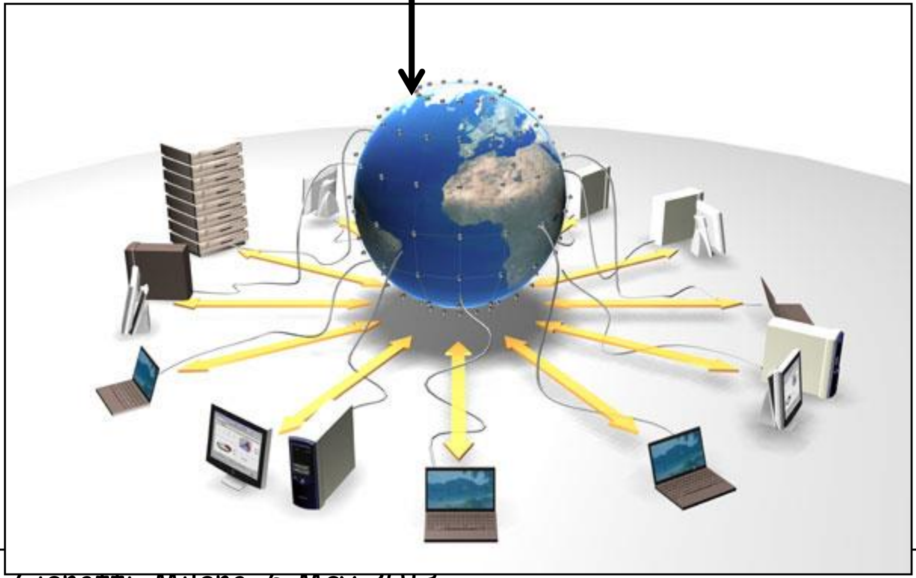
Argentina	M
Armenia	N
Australia	N
Austria	P
Azerbaijan	P
Belarus	R
Brazil	R
Canada	S
Chile	S
China	S
Colombia	S
Czech Republic	S
Denmark	S
France	Switzerland
Georgia	Taiwan
Germany	Turkey
Greece	UK
Israel	USA
Italy	CERN
Japan	JINR

ATLAS Collaboration

Contributi milanesi ad ATLAS

- Magnete toroidale superconduttore
- Calorimetro elettromagnetico ad argon liquido
- Rivelatore a Pixels di Silicio
- Infrastruttura di calcolo e Griglia LHC
- Analisi dati: fotoni, tau's, missing transvserse energy, tracking, Higgs, etc → risultati di fisica e pubblicazioni



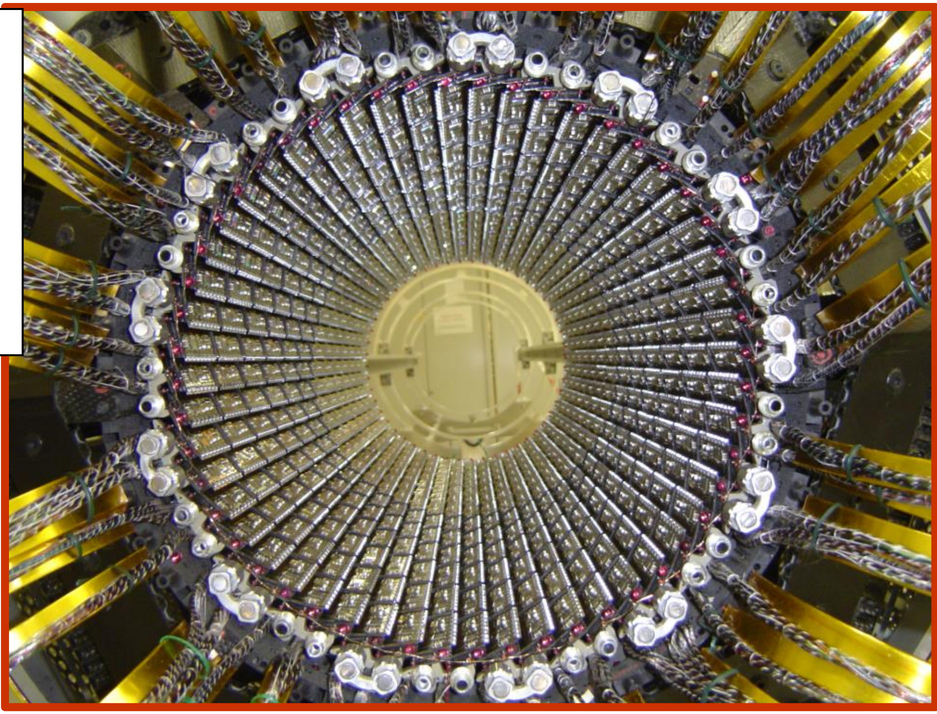


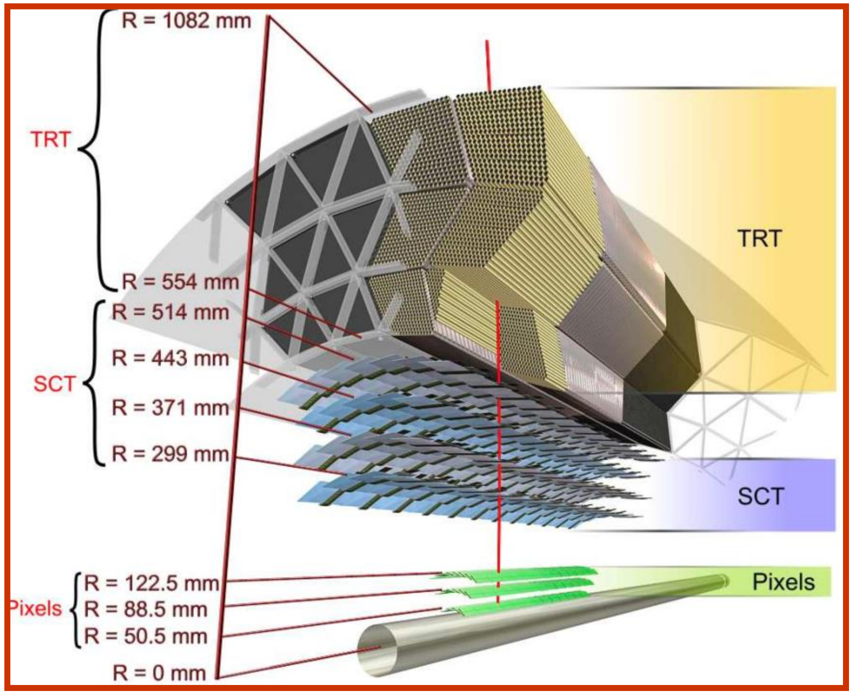
And upgrades for high-luminosity LHC operation !

Pixel detector:

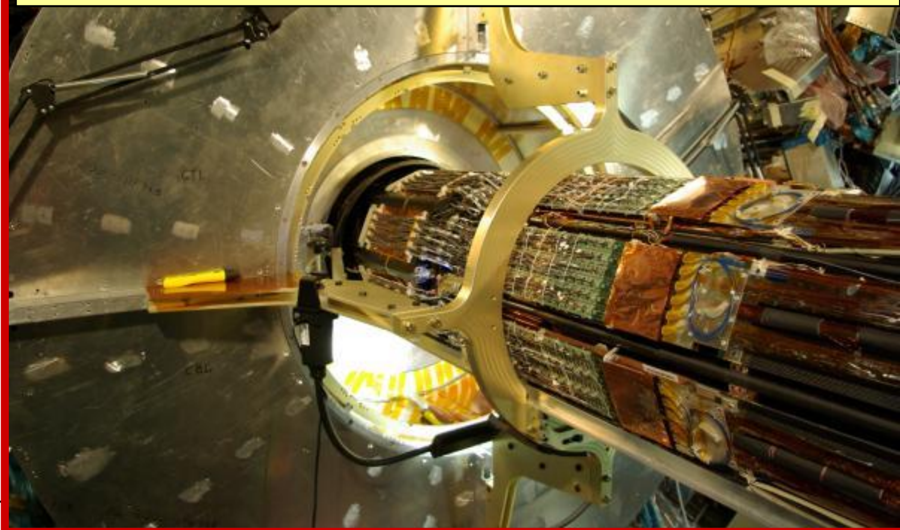
- 3 layers at ~ 5, 10, 13cm from beam line
- ~ 80 million high-tech Si pixels:
  50μm wide, 400μm long, 250μm thick

High detector granularity needed in very dense track environment surrounding the beam





Pixels (+ beam pipe) installation in ATLAS, June 2007

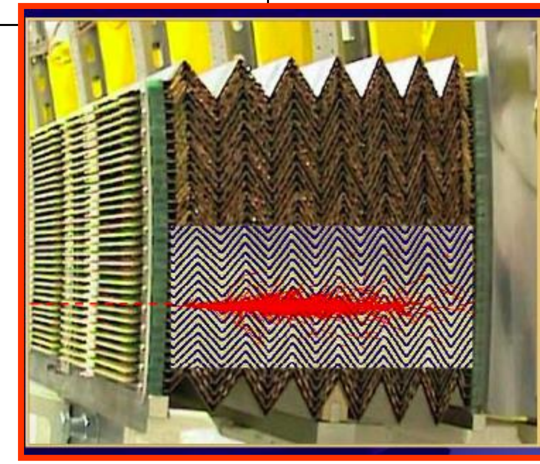


Milano: construction, test beam, alignment commissioning, operation, data analysis

Electromagnetic calorimeter:

- Measure the energy and position of electrons and photons with high precision
- Lead plates and readout electrodes immersed in liquid-argon bath

Electrodes in the test lab in Milano



Installation in the ATLAS cavern, October 2004

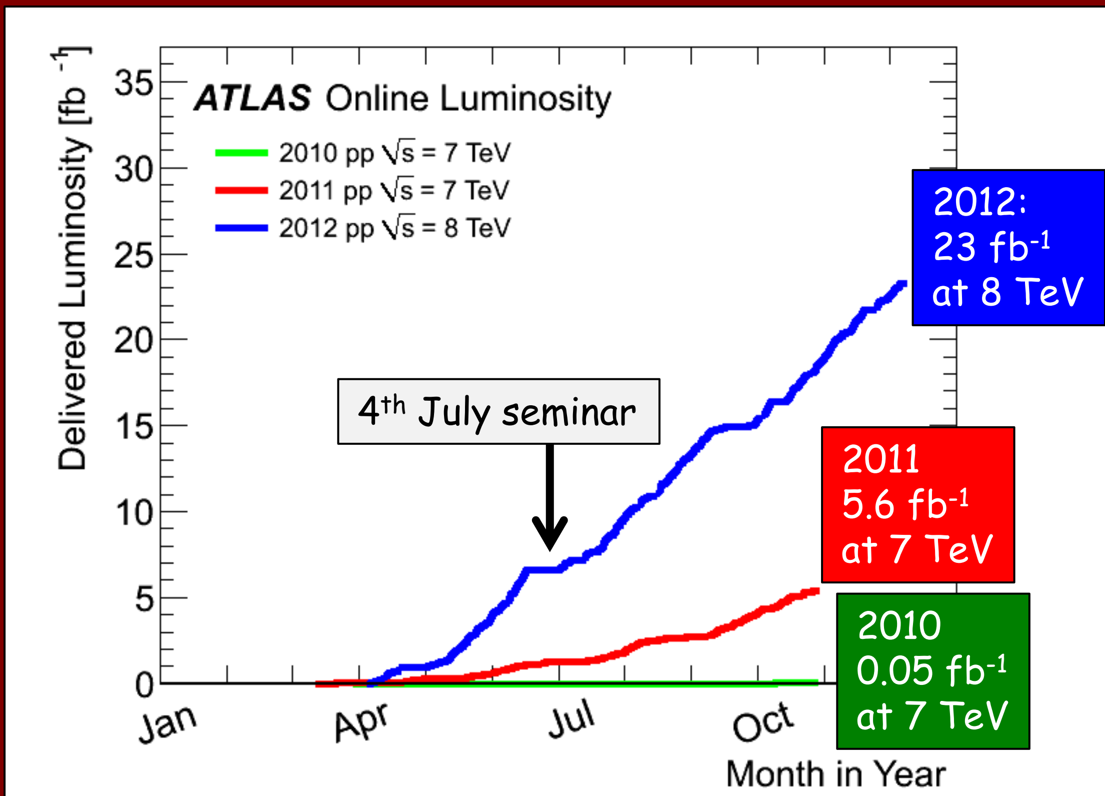
Milano: construction, electronics, test beam, commissioning, calibration, operation, data analysis

30 March 2010: first proton-proton collisions at an unprecedented energy → exploration of a new energy frontier started

Since then:

- ❑ Accelerator, detectors, computing (WLCG Grid) performed far beyond expectation
  → huge amount of data recorded and analyzed (ATLAS: 5 billion events)
- ❑ Standard Model and known particles "rediscovered" and measured in new E regime
- ❑ Many physics scenarios beyond SM explored and constrained/ruled out
- ❑ Higgs boson discovered by ATLAS and CMS

Excellent machine design and construction quality + great competence of the operation team → superb performance of the LHC in the first run
→ one of the key ingredients for the fast discovery of the Higgs boson



Max peak luminosity: ~ 7.7 $\times 10^{33}$ cm^{-2} s^{-1}

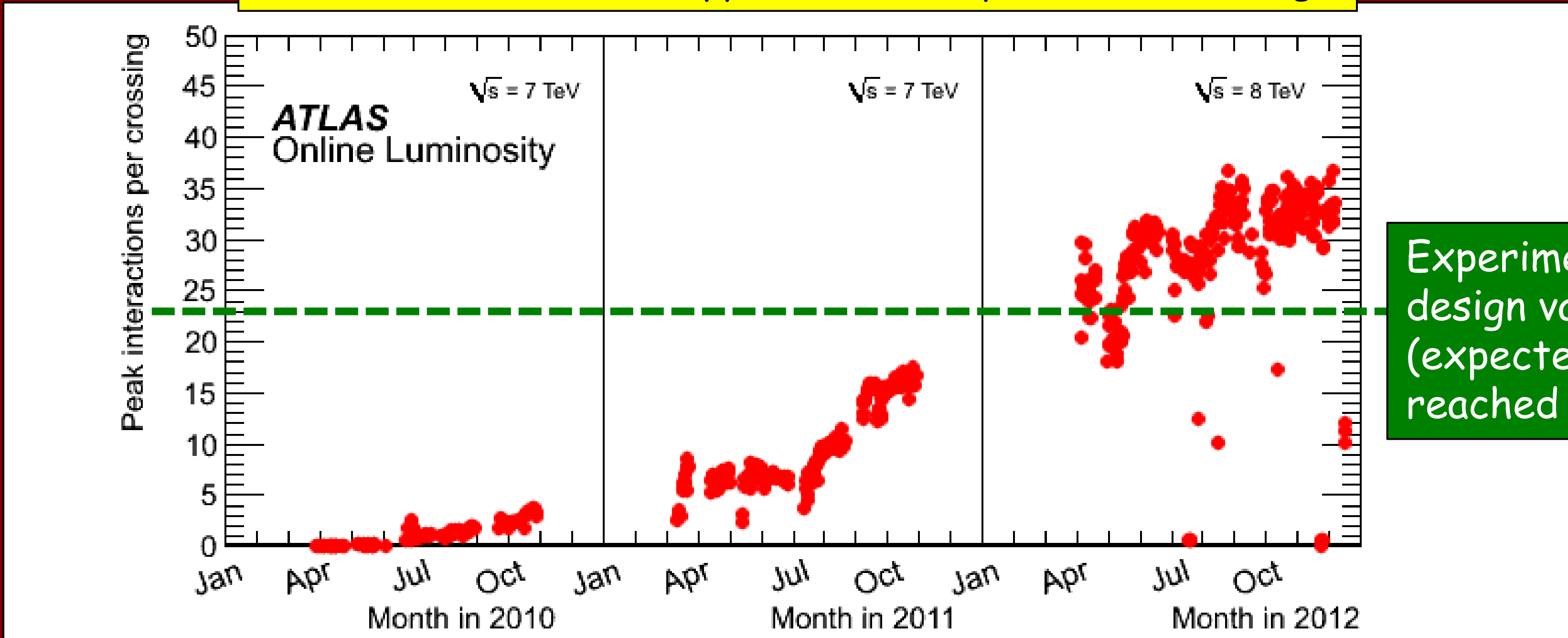
$N = \int L dt \times \sigma(pp \rightarrow X)$

$$L = \frac{N^2 k_b f}{4\pi\sigma_x^*\sigma_y^*}F = \frac{N^2 k_b f\gamma}{4\pi\epsilon_n\beta^*}F$$

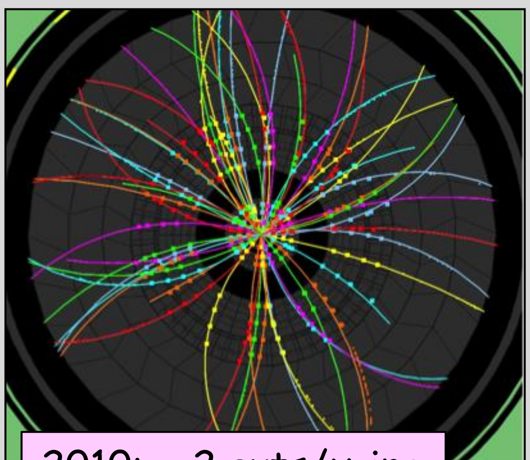
$$\sigma^* = \sqrt{\beta^*\epsilon}$$

N ≈1.5 x 10^{11} p/bunch, k_b =1370 bunches (bunch spacing 50 ns) → 2x10^{14} p/beam (70% of design)
Stored beam energy: ~ 140 MJ → robust beam instrumentation and machine protection system
β* = 0.6 m, ϵ_n = emittance ≈ 2.5 μ → σ = beam size at interaction point ≈ 20 μ

The prize to pay for the high luminosity: pile-up
(number of simultaneous pp interactions per bunch crossing)



Experiment's design value (expected to be reached at $L=10^{34}$!)

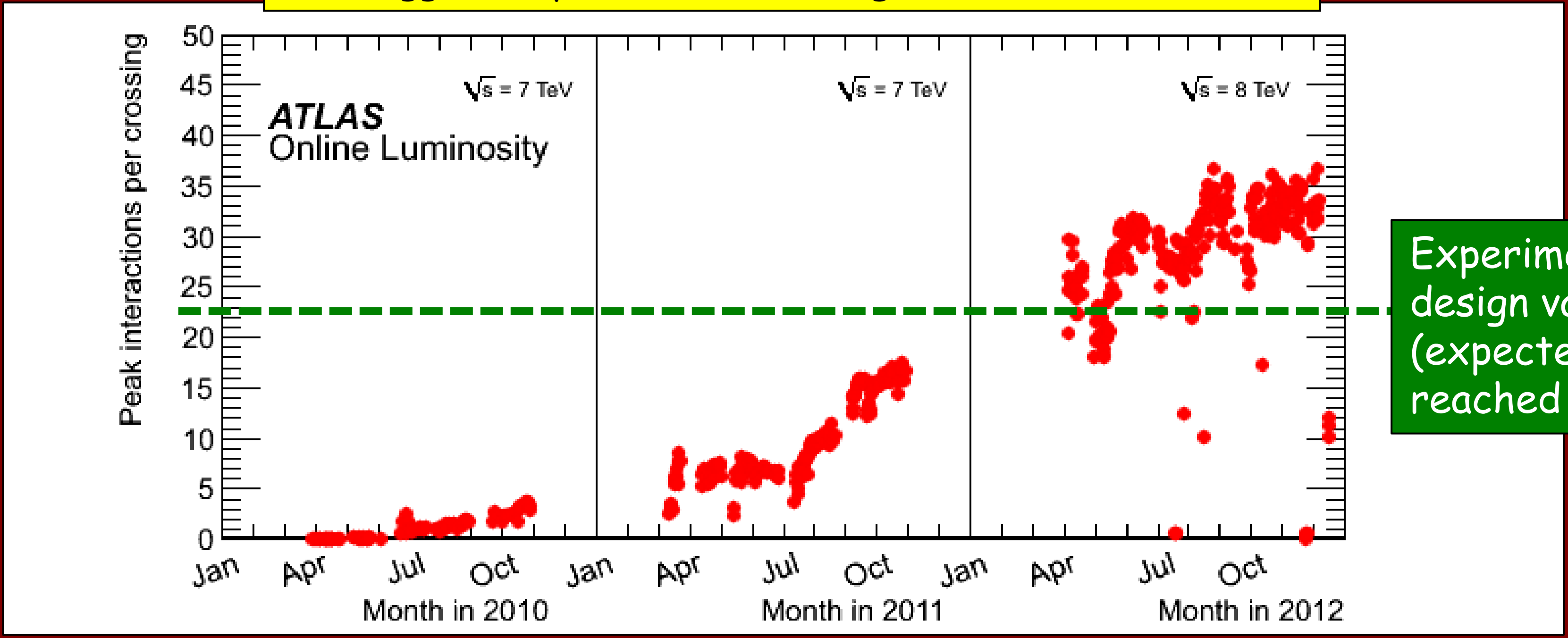


2010: ~ 2 evts/x-ing

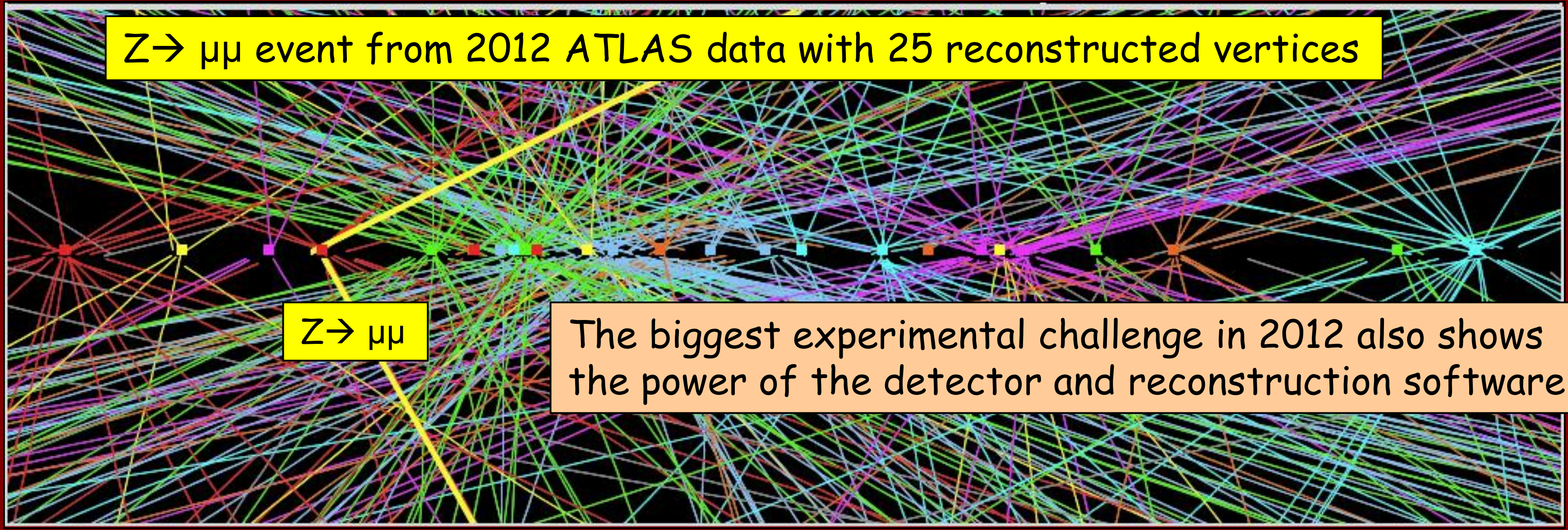
2011: ~ 10 evts/x-ing

2012: ~ 20 evts/x-ing

The prize to pay for the high luminosity: pile-up
(the biggest experimental challenge in 2012)



Experiment's design value (expected to be reached at $L=10^{34}$!)

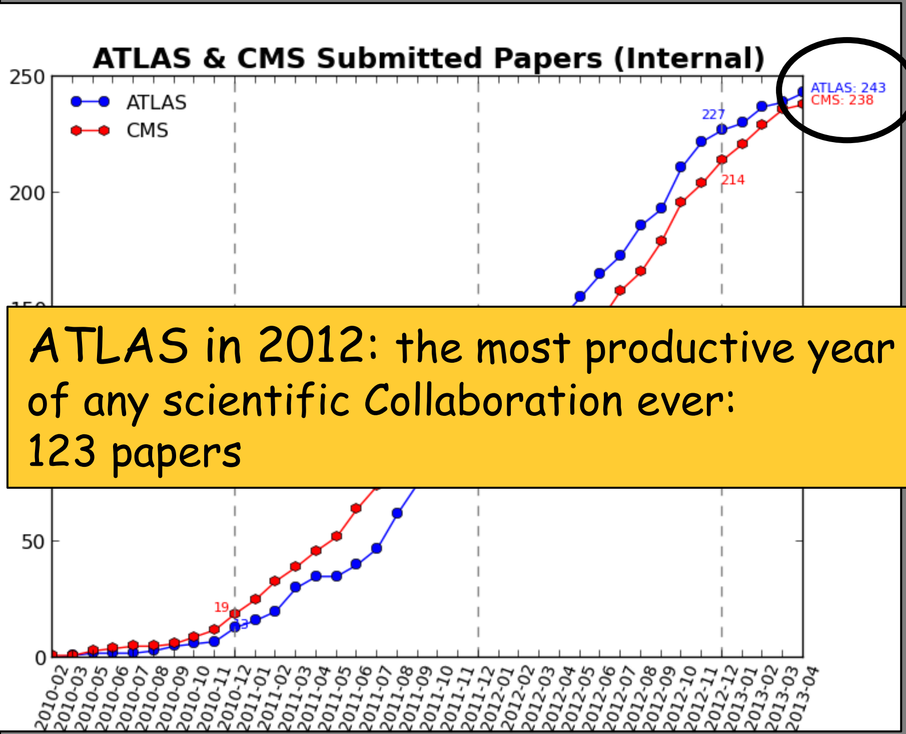


Z→ μμ event from 2012 ATLAS data with 25 reconstructed vertices

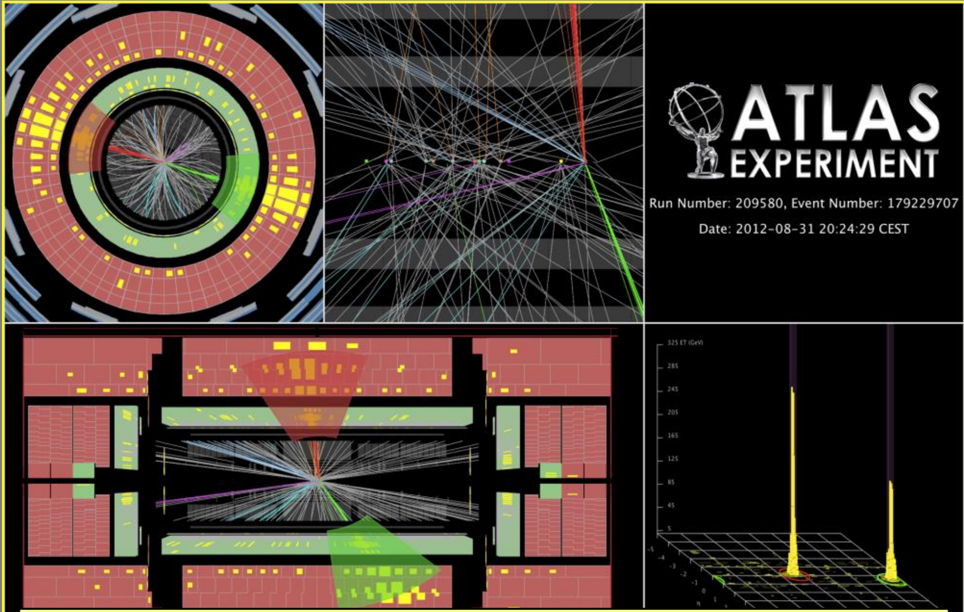
Z→ μμ

The biggest experimental challenge in 2012 also shows the power of the detector and reconstruction software

A huge scientific output



ATLAS in 2012: the most productive year of any scientific Collaboration ever: 123 papers



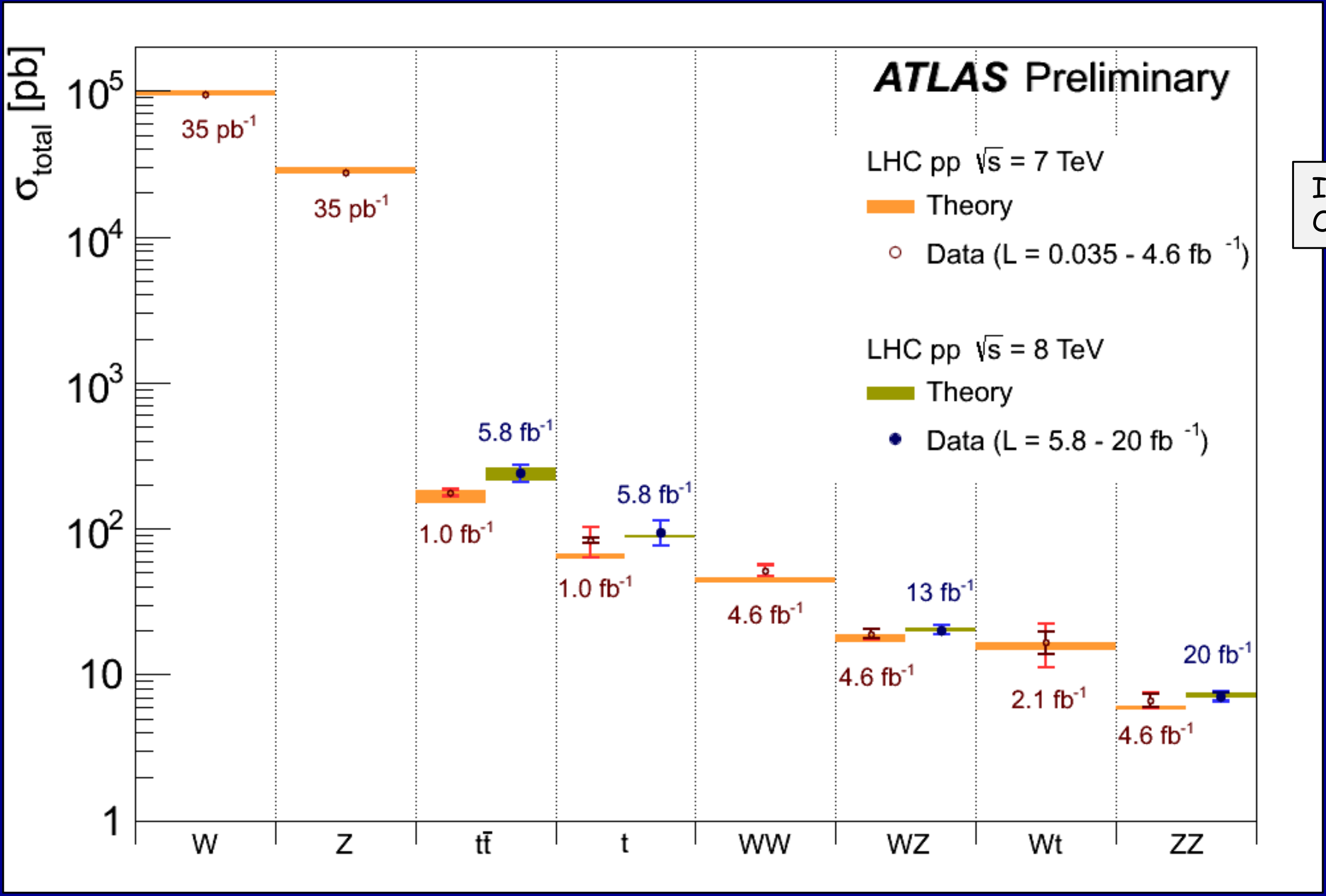
m_{jj} = 4.7 TeV $p_T(j_{1,2})$ = 2.3-2.2 TeV, E_T^{miss} = 47 GeV

Number of events in the full 2010-2012 ATLAS dataset (~ 25 fb^{-1}) after all selections:

W → lν ~ 100 M
Z→ ll ~ 10 M
tt → l+X ~ 0.4 M
Higgs candidates ~ 600
Note: ~1 H→ γγ (~1 H→ 4l) produced every 50' (14h) at 7x 10^{33}

l=e,μ

Cross-section measurements of known processes (examples …)



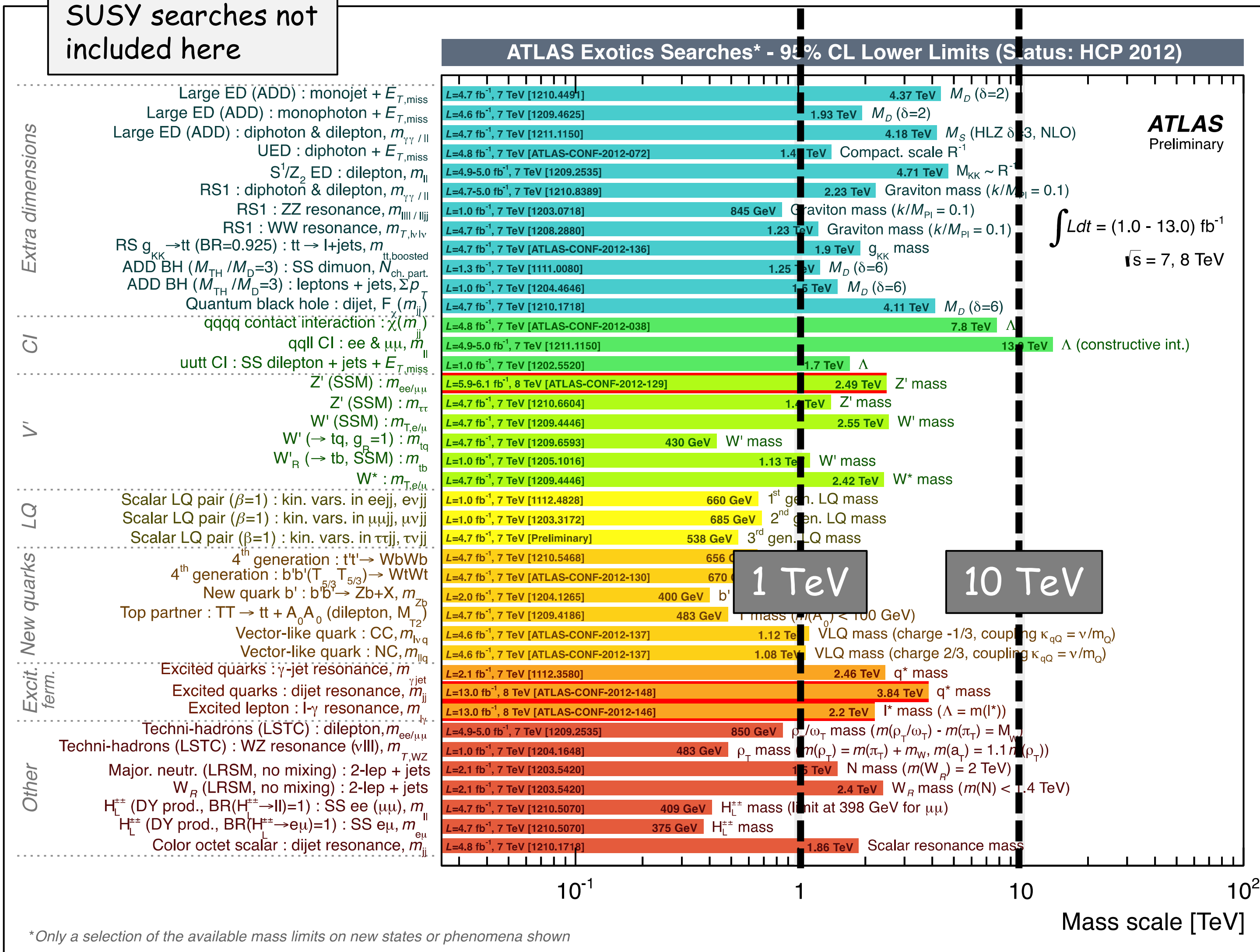
Inner error: statistical
Outer error: total

- Test SM at 7-8 TeV; constrain theory predictions; backgrounds to searches
- Good agreement with SM expectation
- Experimental precision starts to challenge theory uncertainty (e.g. tt)

Searches for physics beyond the SM

Huge number of models and topologies investigated

SUSY searches not included here



Exotics Models:

Extra dimensions:
- RS KK Graviton
  - (dibosons, dileptons, diphotons)
- RS KK gluons (top antitop)
- ADD (monojets, monophotons, dileptons, diphotons)
- KK Z/gamma boosns (dileptons)

Grand Unification symmetries
- (dielectons, dimuons, ditaus)
- Leptophobic topcolor Z' boson
  - (dilepton ttbar, l+j, all had)

S8- color octet scalars (dijets)
String resonance (dijets,)
Benchmark Sequential SM Z', W'
W' (lepton+MET, dijets, tb)
W* (lepton+MET, dijets)
Quantum Black Holes (dijet)
Black Holes (l+jets, same sign leptons)
Technihadrons (dileptons, dibosons)
Dark Matter
- WIMPs (Monojet, monophotons)

Excited fermions
- q*, Excited quarks (dijets, photon+jet)
- l*, excited leptons (dileptons+photon)

Leptoquarks (1st, 2nd, 3rd generations)
Higgs -> hidden sector
- (displaced vertices, lepton jets)

Contact Interaction
- llqq CI
- 4q CI (dijets)

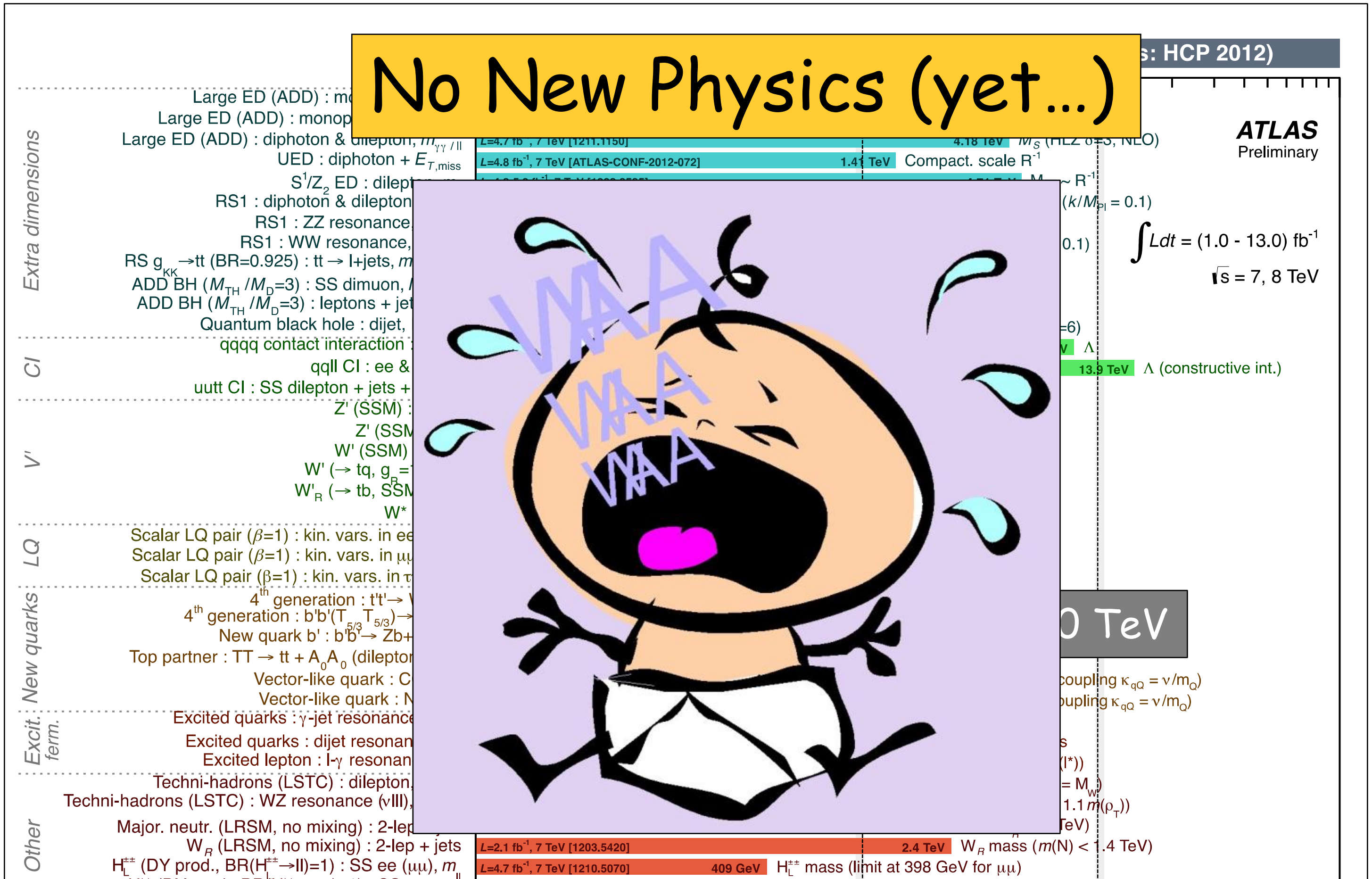
Doubly charged Higgs (
- multi leptons, same sign leptons)

4th generation
- t'->Wb, t'->ht, b'-Zb, b'->Wt
  - (dileptons, same sign leptons, l+J)

VLQ-Vector Like quarks
Magnetic Monopoles (and HIP)
Heavy Majorana neutrino and RH W

Searches for physics beyond the SM

Huge number of models and topologies investigated



No New Physics (yet…)

Exotics Models:

Extra dimensions:
- RS KK Graviton (dibosons, dileptons, diphotons)
- RS KK gluons (top antitop)
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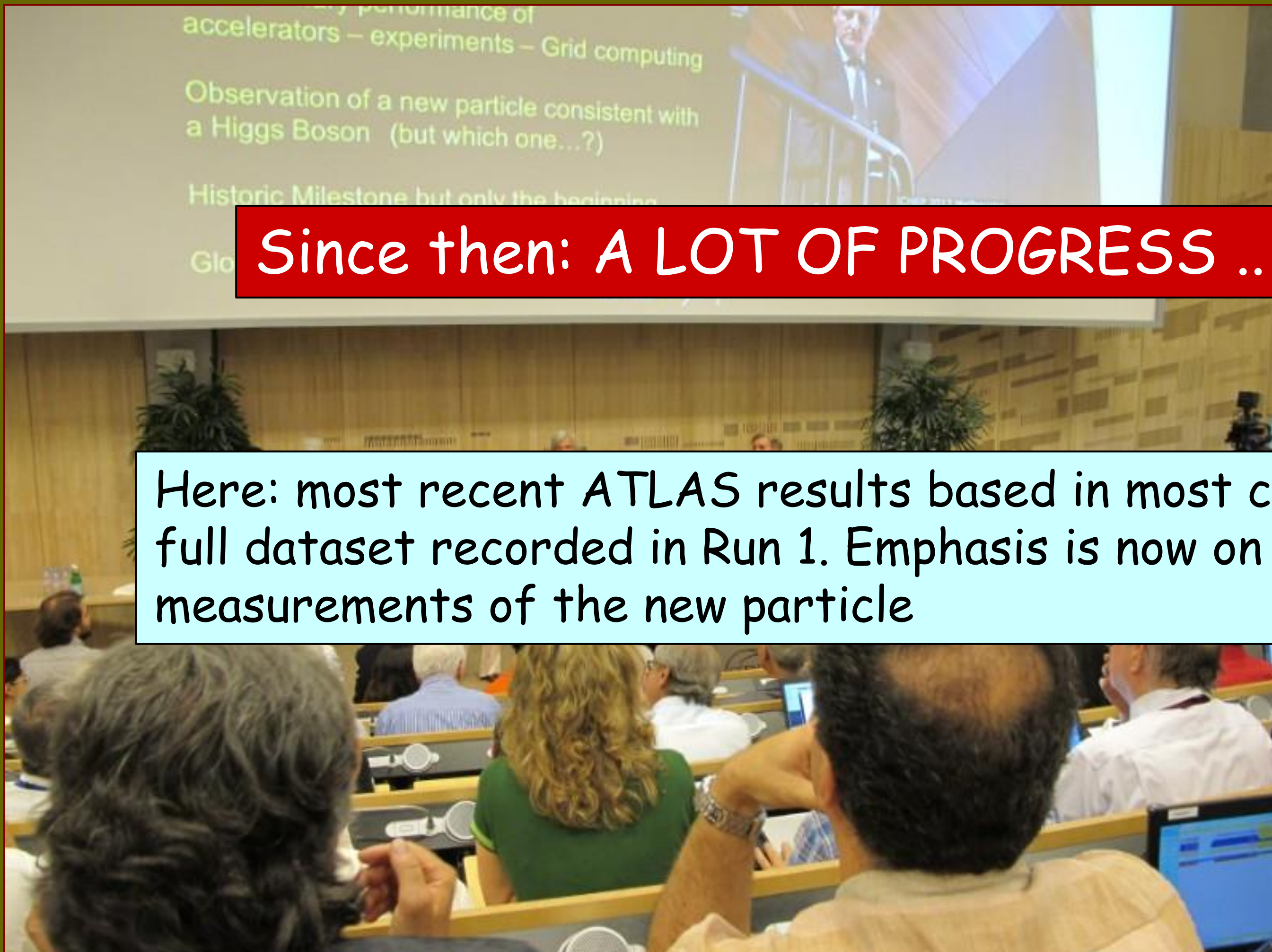
4th generation
- t'->Wb, t'->ht, b'->Zb, b'->Wt

…0 TeV

But
- ❑ searches far from being complete → surprises may hide in present data
- ❑ $\sqrt{s}$ today ~ 1.7 smaller than design value and integrated luminosity ~12 smaller → 2015++

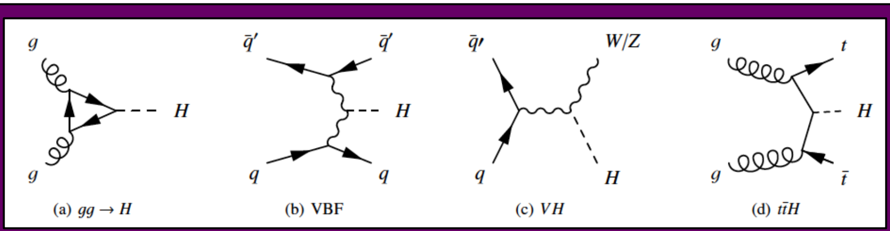
An historical day : 4^{th} July 2012

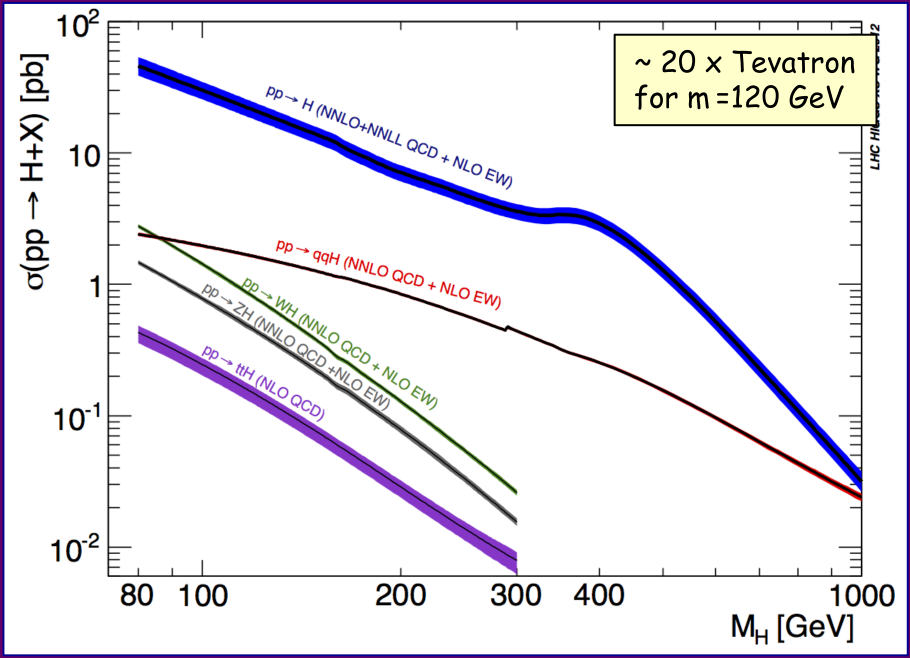


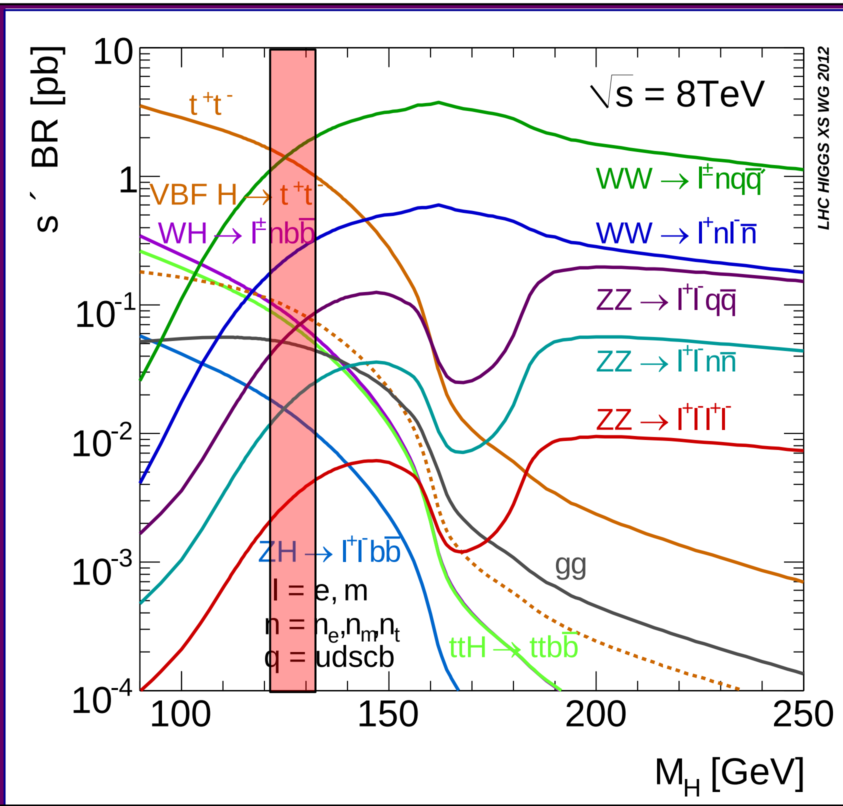
Since then: A LOT OF PROGRESS ..

Here: most recent ATLAS results based in most cases on full dataset recorded in Run 1. Emphasis is now on property measurements of the new particle

SM Higgs production cross-section and decay modes







Most sensitive channels (decreasing order) for 120 < m < 130 GeV:

$H\to ZZ^* \to 4l$, $H\to \gamma\gamma$, $H\to WW^* \to l\nu l\nu$

$H\to \tau\tau$

$W/ZH\to W/Z\ bb$

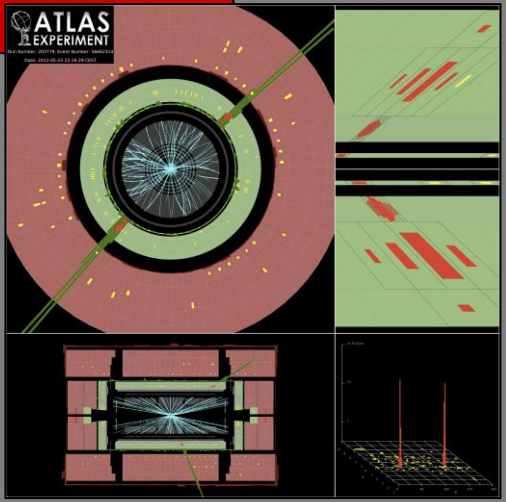
Challenges: tiny rates, small S/B, complex final states

Huge efforts of theory community to compute NLO/NNLO cross-sections for signal and for (often complex !) backgrounds.

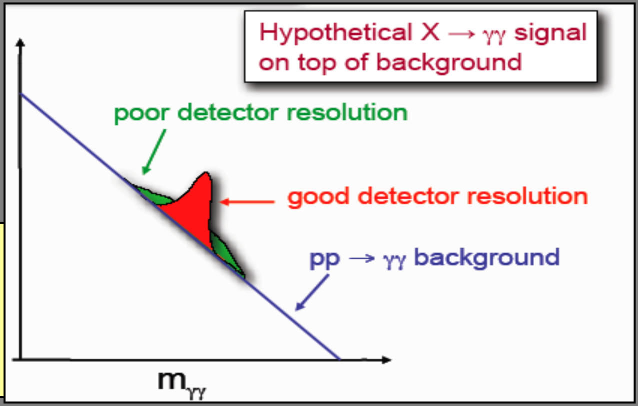
$H \rightarrow \gamma\gamma$

$\sigma \times BR \sim 50$ fb $m_H \sim 126$ GeV

- Simple topology: two high-p_T isolated photons $E_T(\gamma_1, \gamma_2) > 40, 30$ GeV
- Main background: $\gamma\gamma$ continuum (irreducible)
- Background smooth but HUGE → small S/B ratio (~ 3%)



Most crucial experimental issue: excellent $\gamma\gamma$ mass resolution (electromagnetic calorimeter) to observe narrow signal peak above background

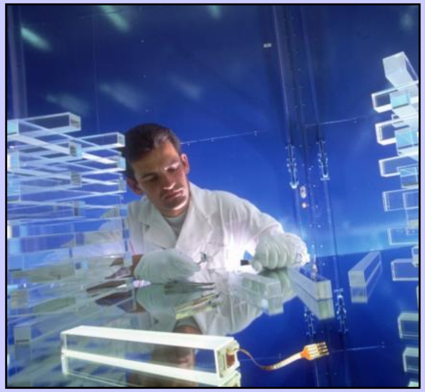


After all selections, expect ($m_H \sim 126$ GeV):
~ 400 signal events
~ 16000 background events in mass window

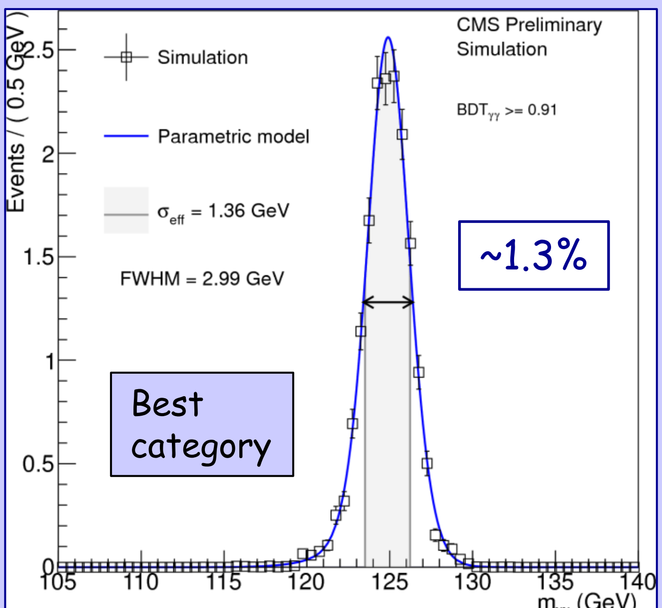
To increase sensitivity to specific production processes (→ measure as many Higgs couplings as possible) events divided into categories, e.g. events with two high-mass forward jets (→ enhance contribution of VBF process), events with additional leptons (→ enhance WH/ZH), etc.

ATLAS and CMS calorimetry: the complementarity

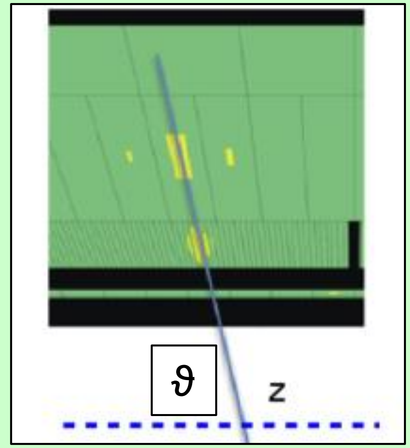
CMS

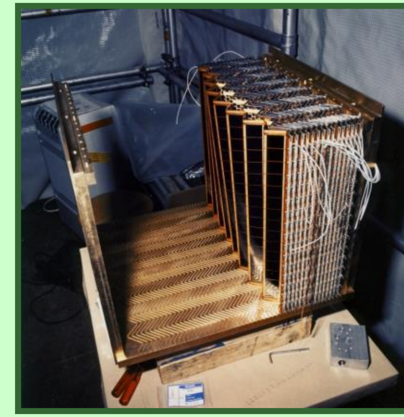


Lead-tungstate crystals (homogeneous):
- ❑ excellent E-resolution: 2-5%/√E
- ❑ no longitudinal segmentation → event vertex from tracks (more sensitive to pile-up)

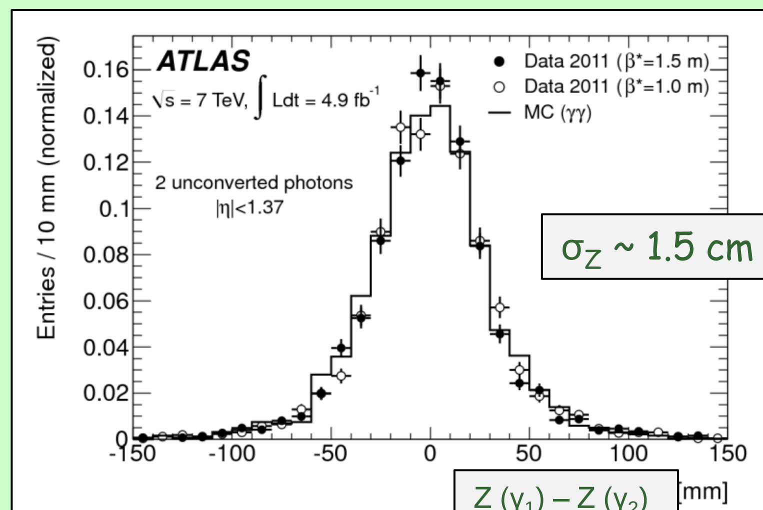


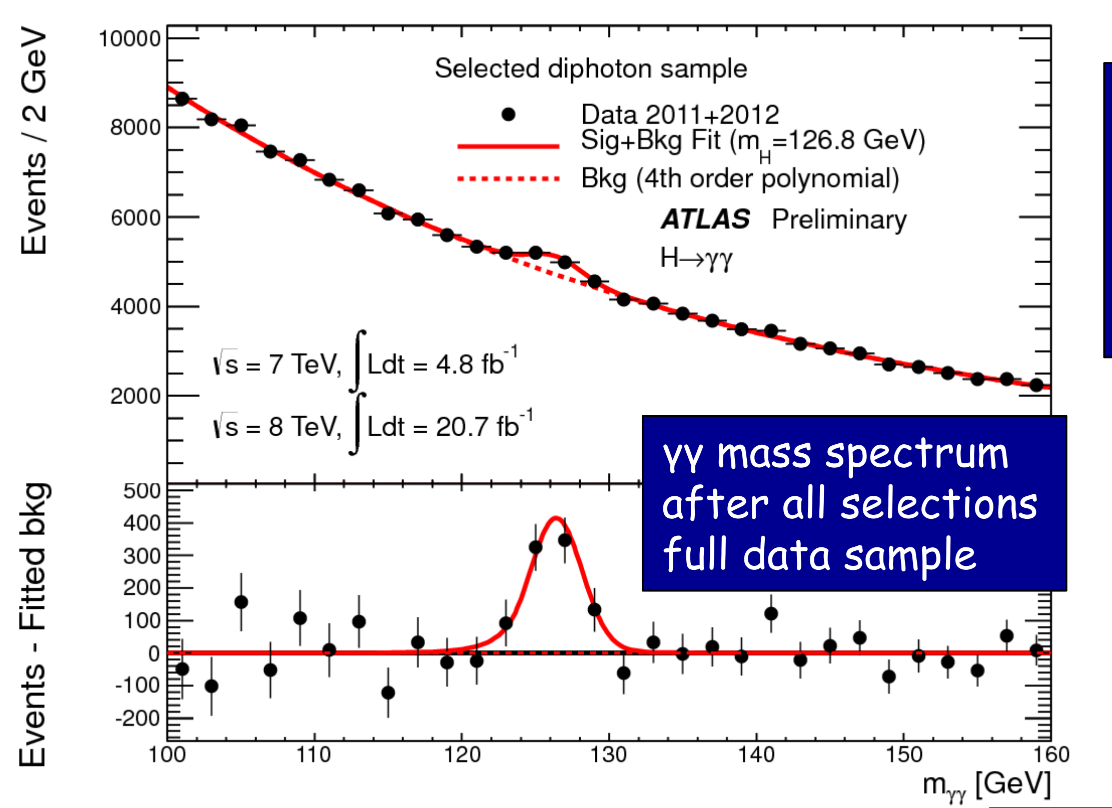
ATLAS





Lead/liquid-argon (sampling):
- ❑ good E-resolution: ~10%/√E
- ❑ longitudinal segmentation → vertex from photon direction → pile-up robust

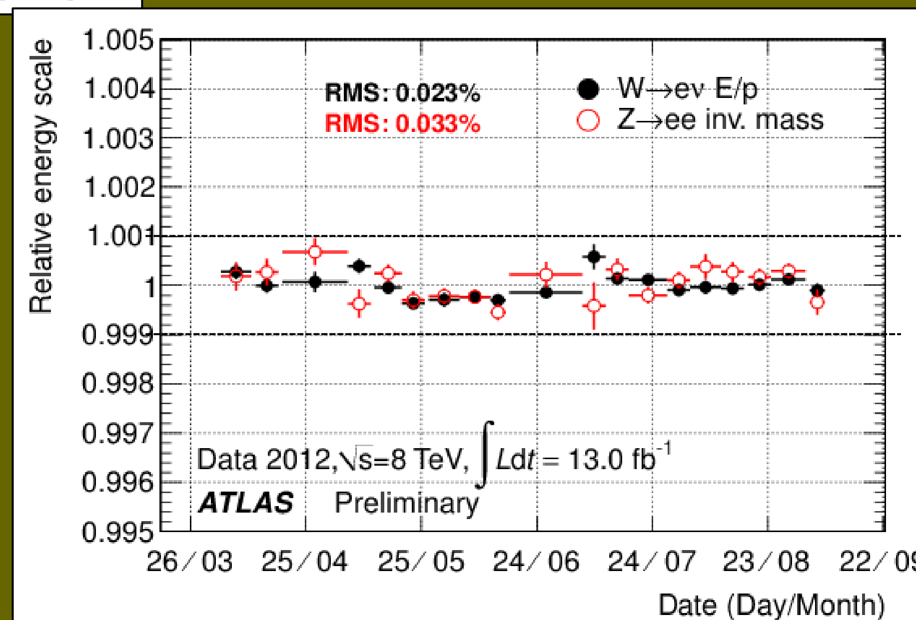




γγ mass spectrum after all selections full data sample

- Clear peak at m_H ~ 126.5 GeV:
- Probability it comes from background fluctuation: ~ 10^{-13} → 7.4 σ signal significance (4.1 σ expected from SM H)

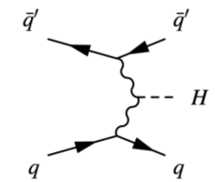
Stability of EM calorimeter vs time during 2012 run better than 0.1%



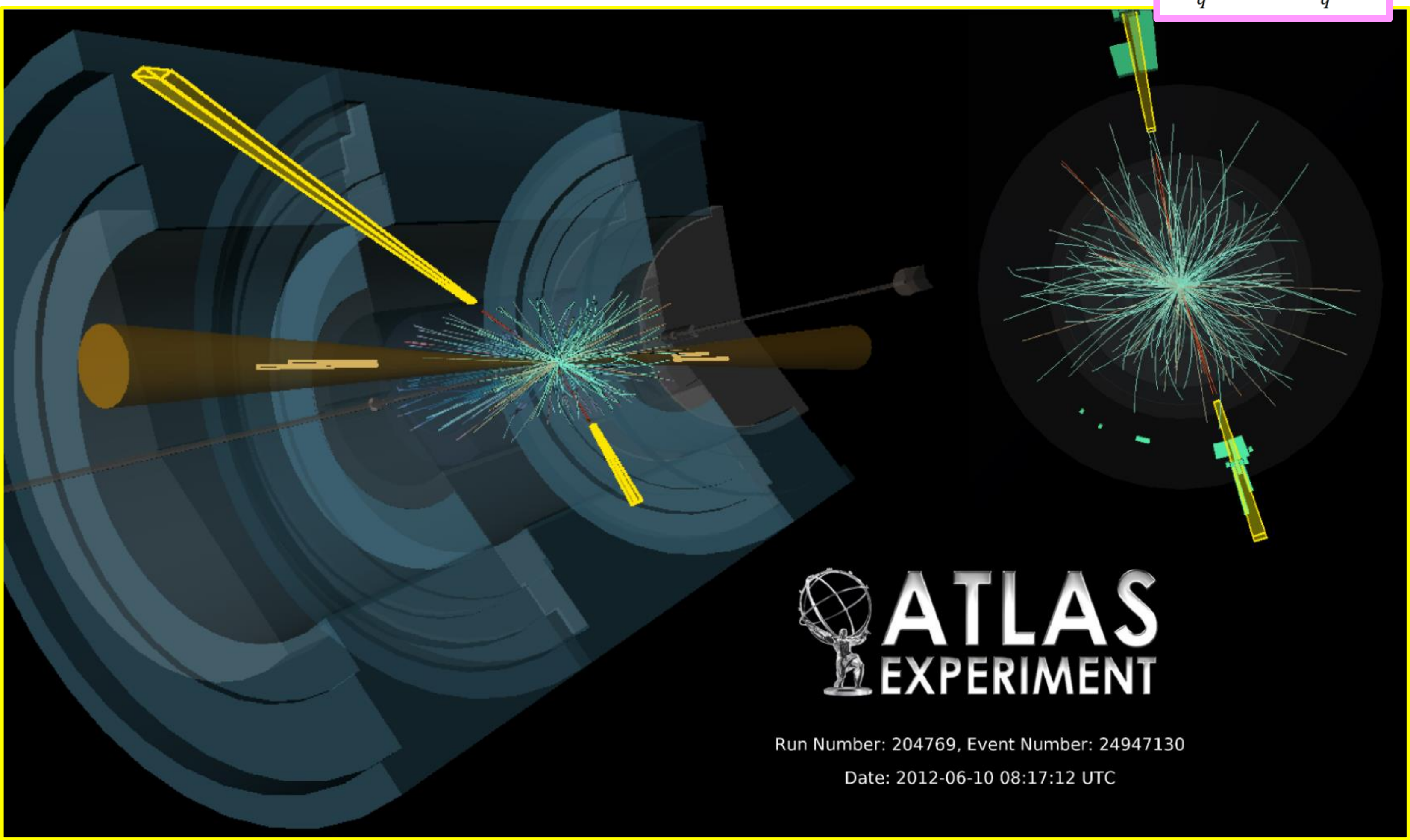
H→ γγ candidate with $m_{\gamma\gamma}$= 126.9 GeV

E_T (γ_1, γ_2) = 80.1, 36.2 GeV,
E_T (j_1, j_2) = 121.6, 82.8 GeV, η (j_1, j_2) = 2.7, -2.9, m (jj)= 1.67 TeV

σ_{SM} (VBF) ~7%



Likely from Vector-Boson-Fusion production



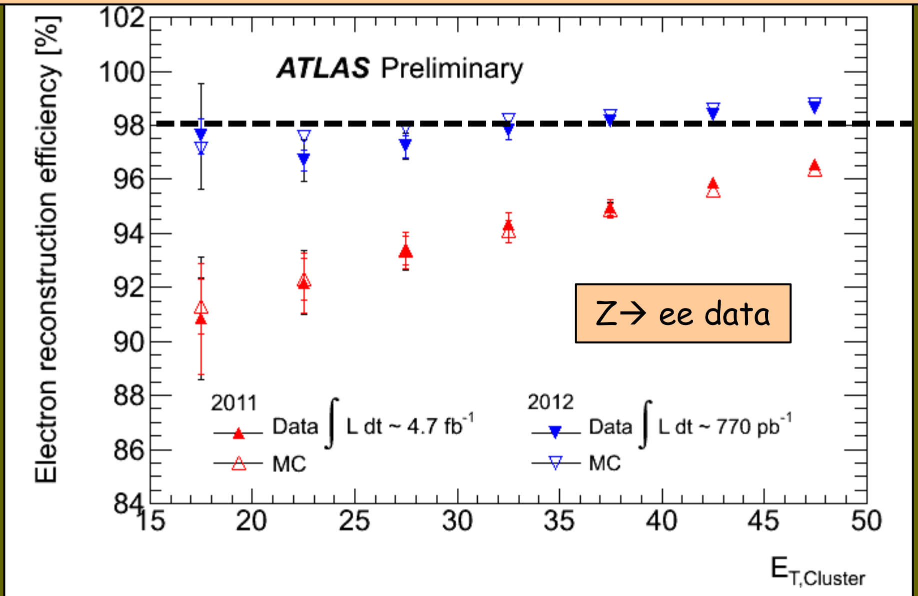
$H \rightarrow ZZ^* \rightarrow 4l$ (4e, 4μ, 2e2μ)

σ x BR ~ 2.5 fb m_H ~ 126 GeV

- Very small cross-section, but:
  -- mass can be fully reconstructed → events cluster in a (narrow) peak
  -- pure: S/B ~ 1
- Events with 4 leptons $p_T^{1,2,3,4}$ > 20, 15, 10, 7-6 (e-μ) GeV selected
- Main backgrounds: $ZZ^{(*)}$: irreducible

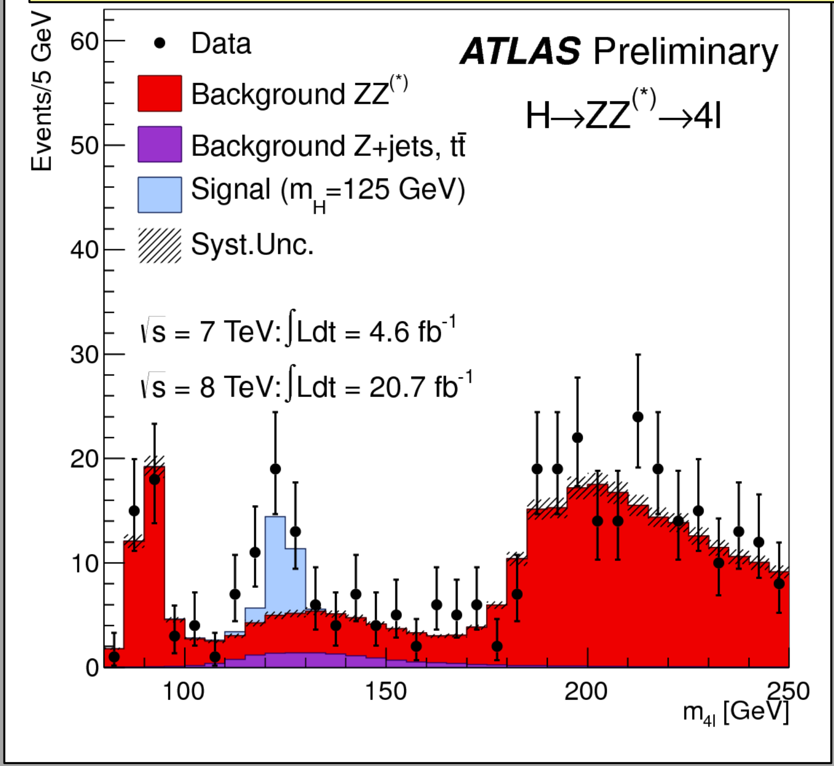
Crucial experimental aspect: high lepton acceptance, reconstruction and identification efficiency down to lowest p_T to capture as much as possible of the (tiny) signal

Improved e± reconstruction to recover Brem losses



Huge efforts made at the end of 2011 to improve e± reconstruction and identification efficiency at low p_T and pile-up robustness paid dividends
→ crucial ingredient for fast discovery

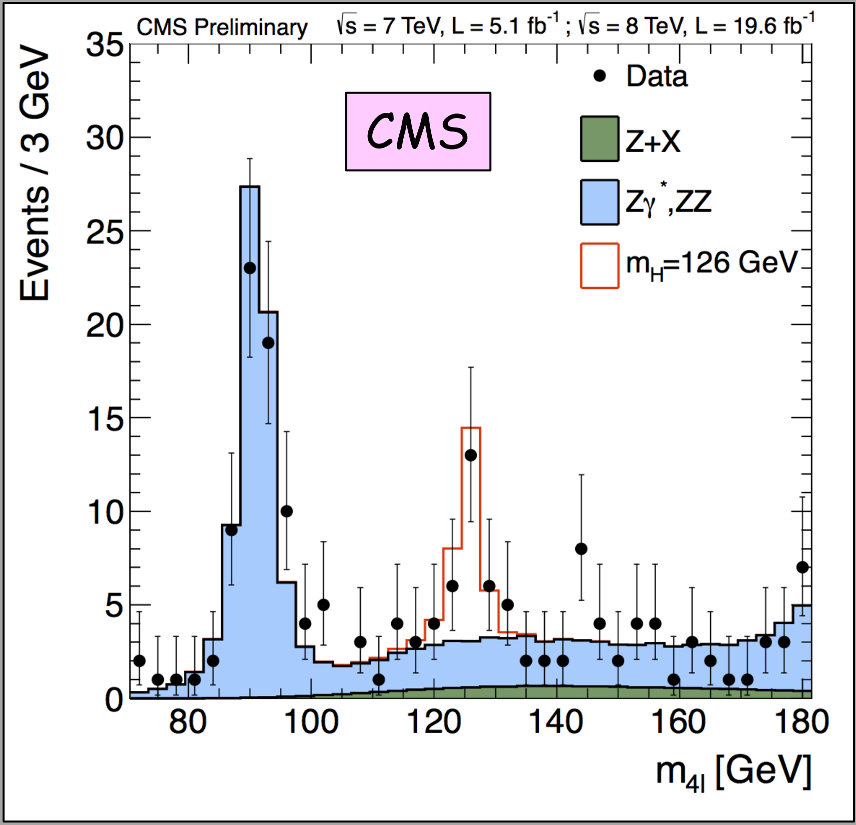
4l mass spectrum after all selections; full data sample



In the region 125 ± 5 GeV

Observed	32 events
Expected from background only	11.1 ± 1.4
Expected from Higgs signal	15.9 ± 2.1

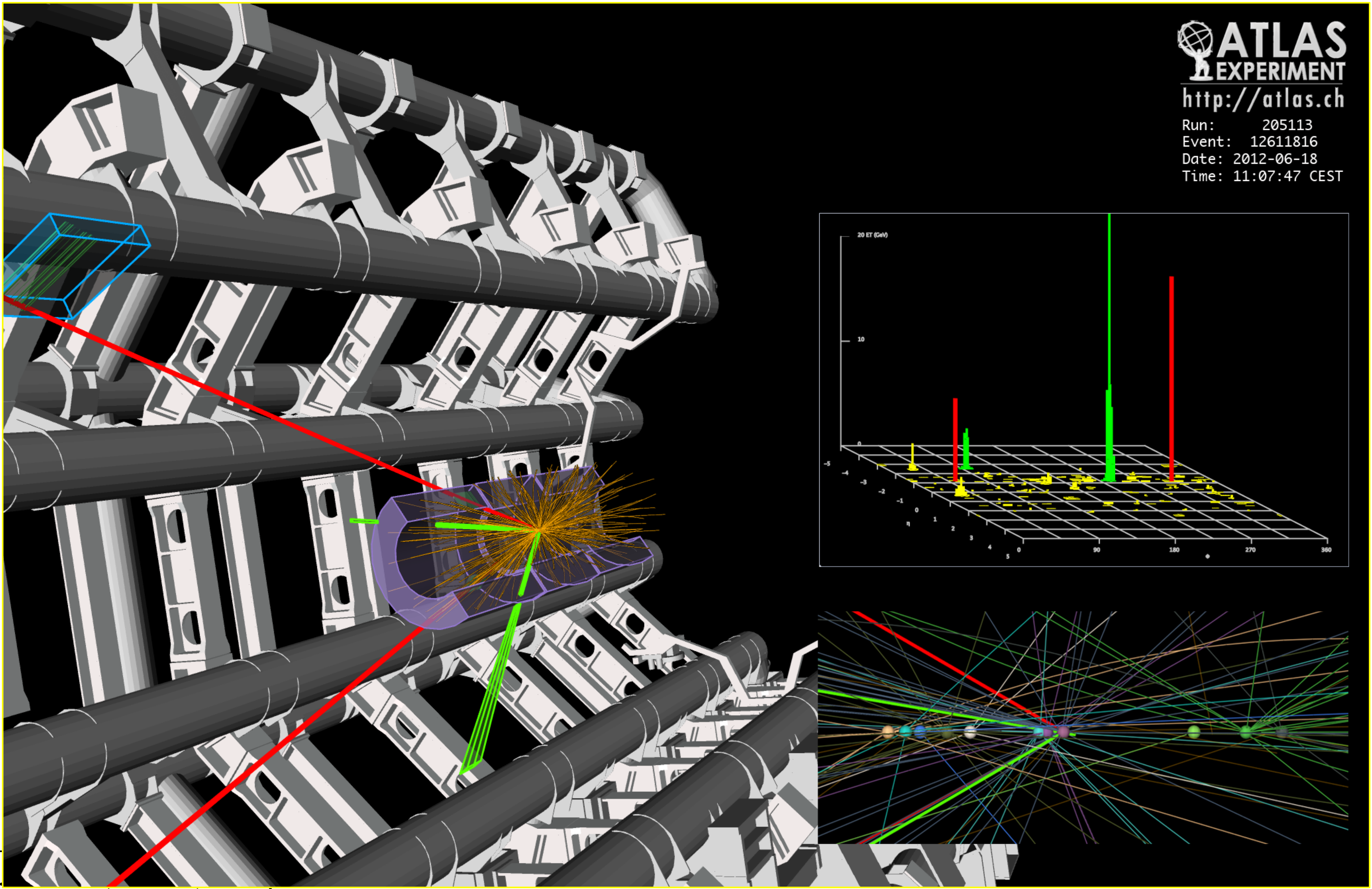
	4μ	2e2μ	4e
Data	13	13	6
Expected S/B	1.9	~1.3	1.1
Reducible/total B	15%	~50%	50%



- Clear peak at $m_H \sim 124.5$ GeV
- Probability it comes from background fluctuation: $\sim 10^{-10} \rightarrow 6.6\ \sigma$ signal significance (4.4 σ expected from SM H)

2e2μ candidate with $m_{2e2\mu}$= 123.9 GeV

p_T (e,e,μ,μ)= 18.7, 76, 19.6, 7.9 GeV, m (e^+e^-)= 87.9 GeV, m($\mu^+\mu^-$) =19.6 GeV
12 reconstructed vertices

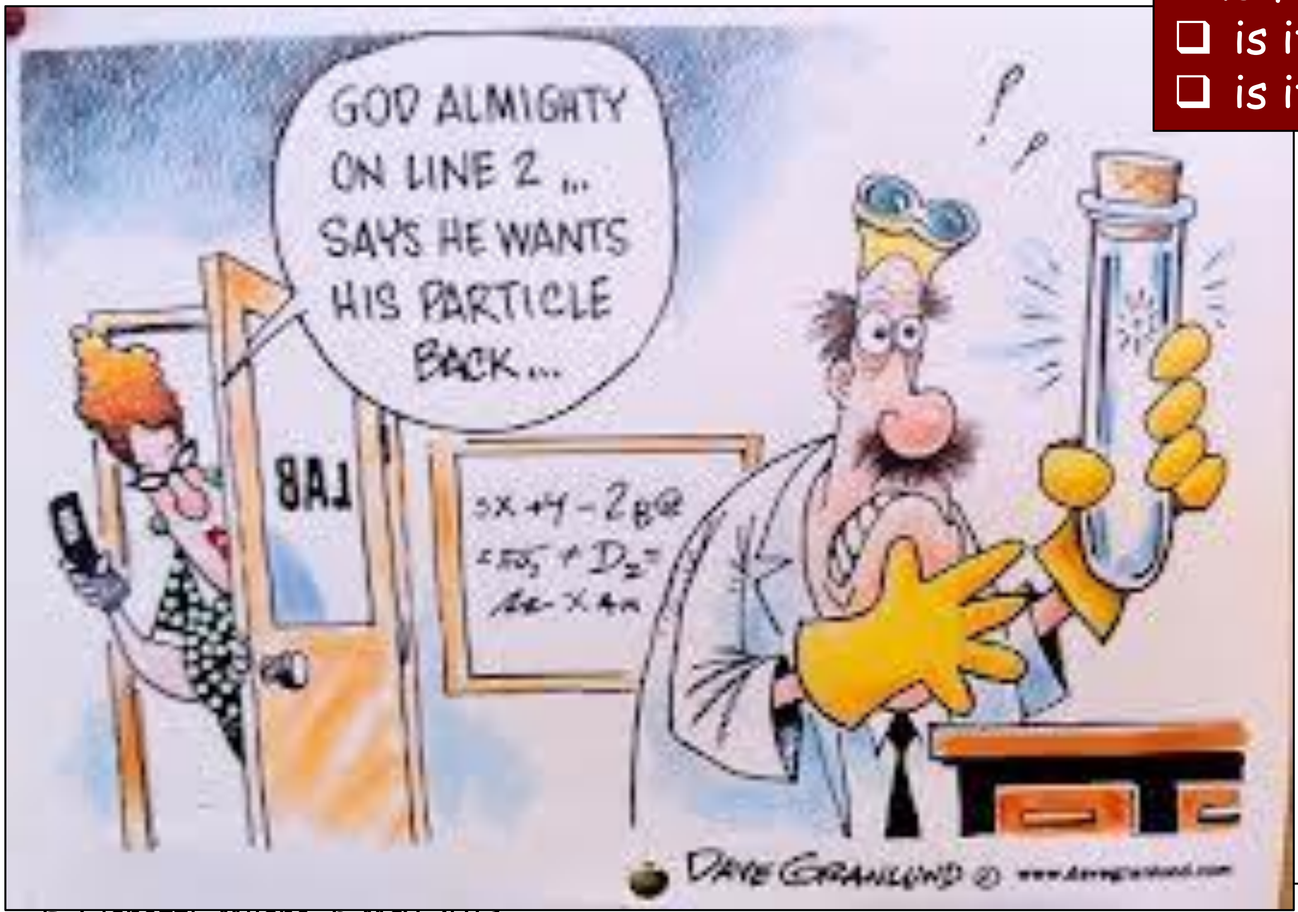


Putting all channels together: 10 σ significance or probability that what ATLAS observes comes from background fluctuation: 10^{-24} !

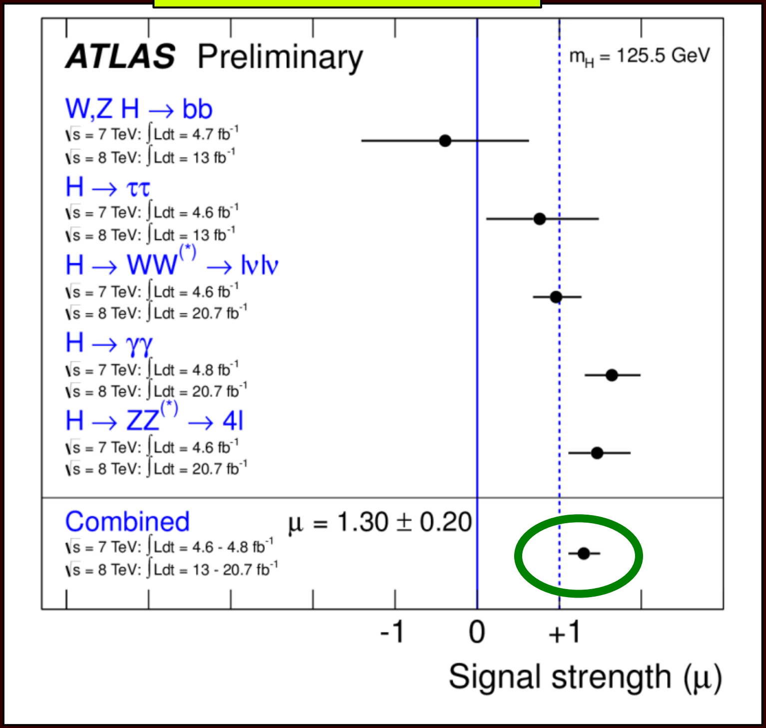
↓

A new phase: measuring the properties of the new particle
(only a few examples here …)

The first 2 questions:
- ❑ is it A Higgs boson ?
- ❑ is it THE SM Higgs boson ?



Signal strength



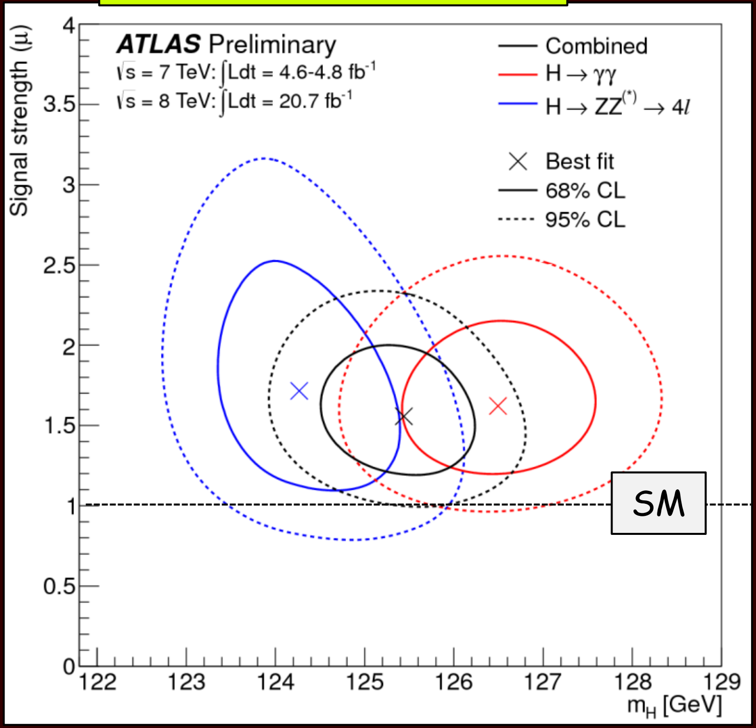
μ = measured signal production rate normalized to SM Higgs expectation at m_H = 125.5 GeV

Best-fit value for m_H=125.5 GeV:

μ = 1.3 ± 0.13 (stat) ± 0.14 (syst)

→ in agreement with SM expectation

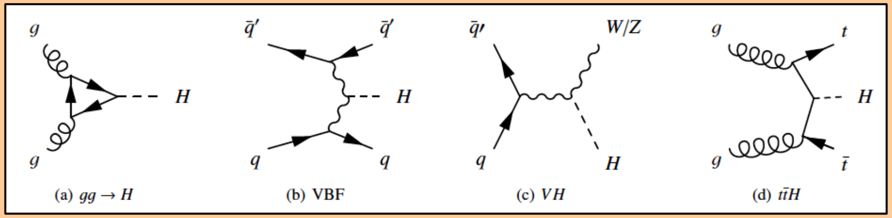
Mass measurement

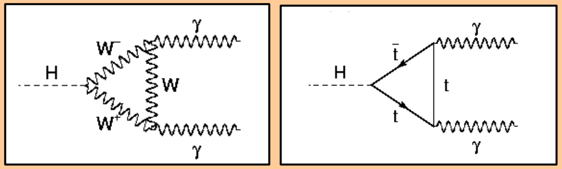


Measured mass from high-resolution H→ γγ and H→ 4l channels:

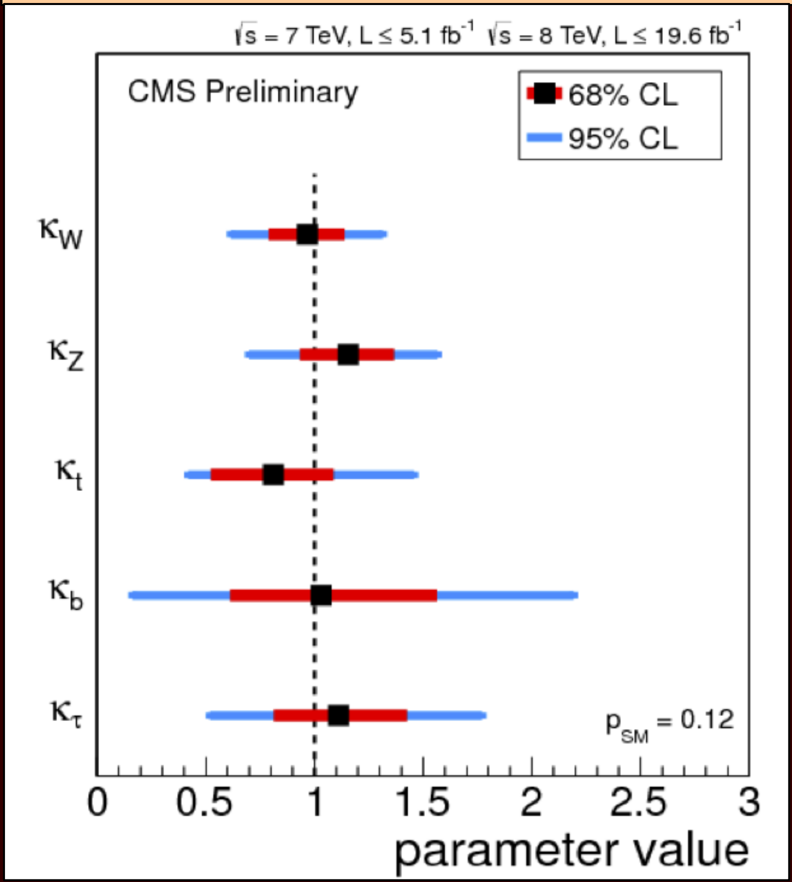
m_H(combined) =125.5 GeV ± 0.2 (stat) $^{+0.5}_{-0.6}$ (syst) GeV

Couplings

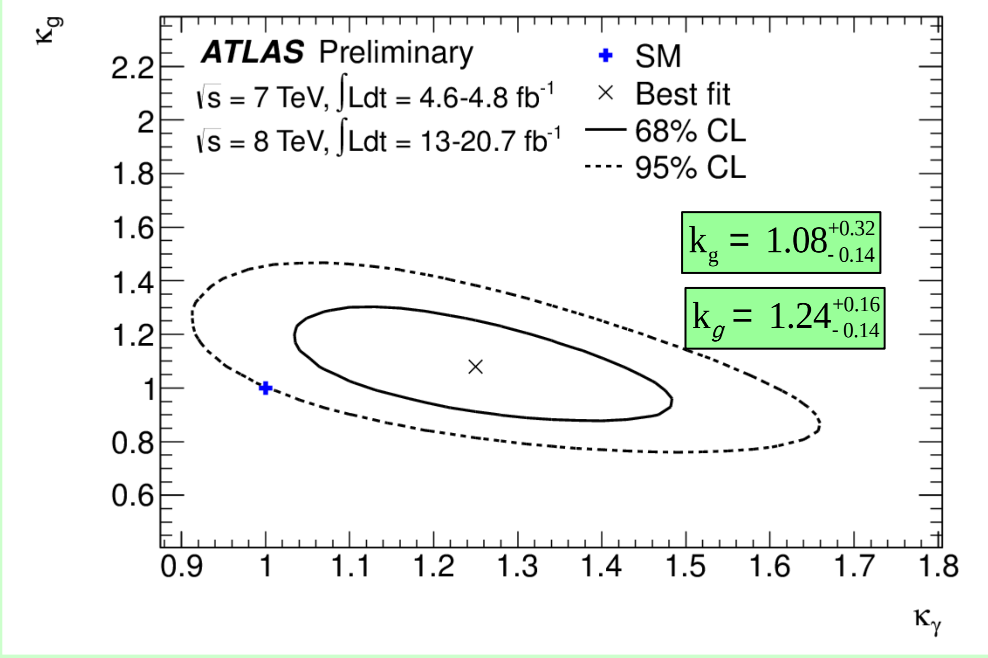




$$k_i^2 = \frac{G_i^{data}}{G_i^{SM}}$$



New particles in the gg → H and H→ γγ loops ?



→ 1st "fingerprint" of a Higgs boson: it couples to particles with strength proportional to their masses (to accomplish its job → Higgs mechanism): indeed what we observe !

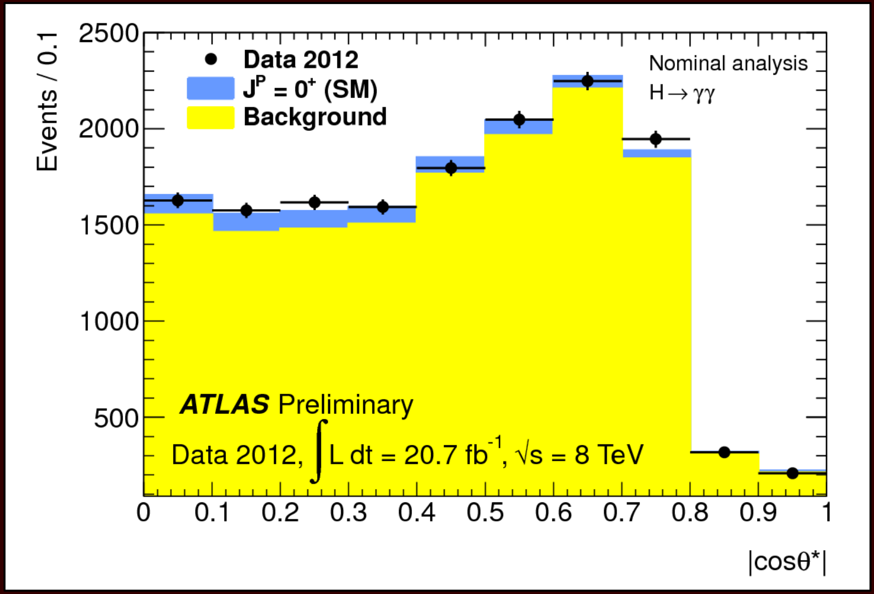
→ No significant New Physics contributions observed (within present uncertainty)

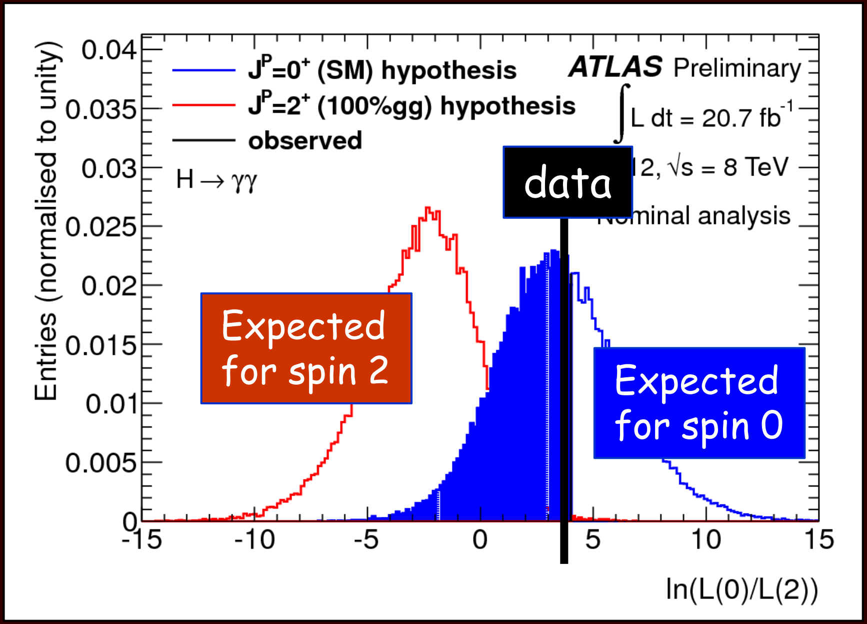
2^{nd} "fingerprint" of a Higgs boson: spin zero

H→ γγ

Spin information from distribution of polar angle θ* of the di-photon system in the Higgs rest frame

Compare θ* distribution in the region of the peak for:
- spin-0 hypothesis: flat before cuts
- spin-2 hypothesis: ~ $1+6\cos^2\theta^* + \cos^4\theta^*$ for Graviton-like (minimal models)

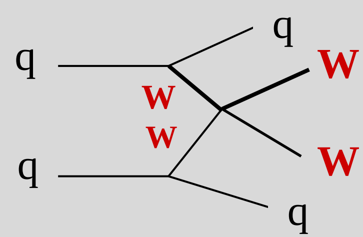


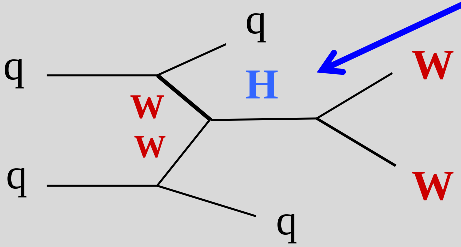


Data disfavour 2^+ hypothesis at 99.3% CL. (66% CL) for pure gg → G (mixture of gg/qq → G)

If this is the first elementary scalar, consequences also for Universe evolution (inflation triggered by a scalar field)

Two additional questions



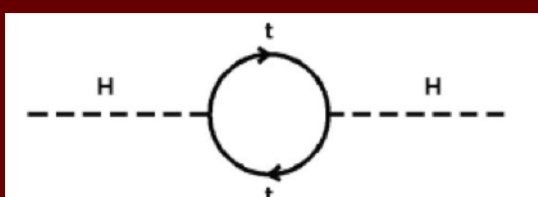


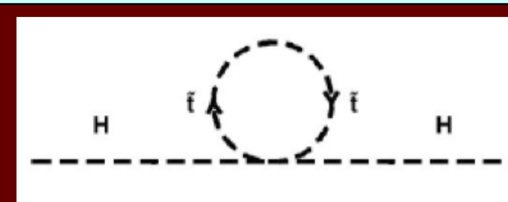
Does this new particle fix the SM problems at high energy ?

This process violates unitarity: $\sigma \sim E^2$ at $m_{WW} \sim$ TeV
(divergent cross section → unphysical)
if this process does not exist

→ Important to verify that the new particle accomplishes this task → a "closure test" of the SM
→ Need $\sqrt{s} \sim 14$ TeV and $\sim 3000\ fb^{-1}$

Why is the Higgs so light ? → Is m_H stabilized by ~TeV scale new physics (e.g. SUSY) or is it fine-tuned ?





In the SM, top-loop corrections to m_H diverge as $\sim \Lambda^2$ (energy scale up to which the SM is valid)

Searches for stop quarks so far unsuccessful
Will continue with more data and energy in 2015++

The next steps …

With the data recorded in "Run 1" (~25 fb^{-1} per experiment):

- 4-5 σ from each of $H \rightarrow \gamma\gamma$, $H \rightarrow l\nu l\nu$, $H \rightarrow 4l$ per experiment (in part achieved already)
- ~3 σ from $H \rightarrow \tau\tau$ and ~3 σ from $W/ZH \rightarrow W/Zbb$ per experiment (the latter already achieved at the Tevatron)
- Separation $0^+/2^+$ and O^+/O^- at 4σ level combining ATLAS and CMS
- Improved measurements of couplings (in particular combining ATLAS and CMS)

Further ahead (present LHC plans):

2013-2014: shut-down (LS1)
2015-2017: $\sqrt{s}$ ~ 14 TeV, L ~ 10^{34}, ~ 100 fb^{-1}
2018: shut-down (LS2)
2019-2021: $\sqrt{s}$ ~ 14 TeV, L ~ $2x10^{34}$, ~ 300 fb^{-1}
2022-2023: shut-down (LS3)
2023- 2030 ?: $\sqrt{s}$ ~ 14 TeV, L ~ $5x10^{34}$, ~ 3000 fb^{-1} (HL-LHC)

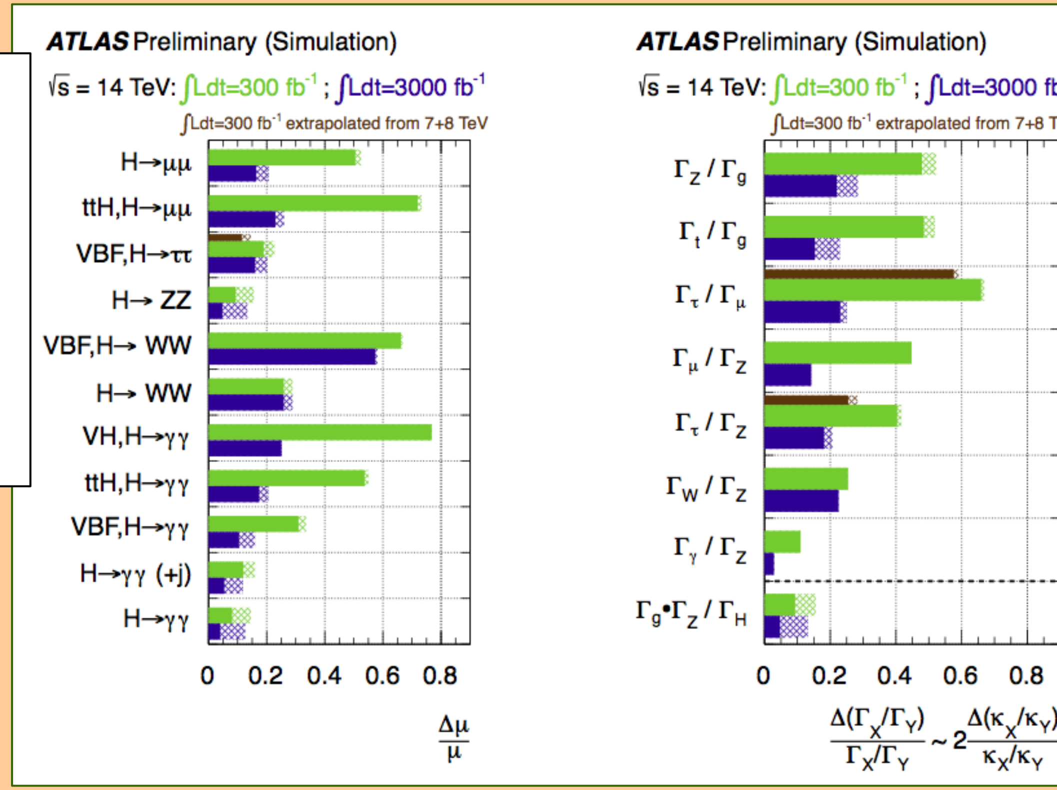
With 100-300 fb^{-1} :

- Mass can be measured to 0.1% (~ 100 MeV) dominated by e/μ/γ E-scale systematics
- Spin/CP can be determined to > 5σ for a pure 0^+ state.

Without constraints, ratios of couplings can be measured with typical precisions:

- 10-50% with ~ 300 fb^{-1}
- 3-25% with 3000 fb^{-1}

per experiment.
Down to few % in some cases if less conservative systematics (e.g. theory error halved)

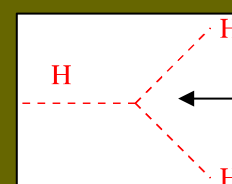


Measurements of rare decays with 3000 fb^{-1} :

- ttH → ttγγ: 200 events
- H → μμ : 6σ

per experiment

Higgs self-couplings: ~ 3σ per experiment expected from HH → bbγγ channel with 3000 fb^{-1}; HH→ bbττ also promising
~ 30% measurement of λ/λ_{SM} may be achieved

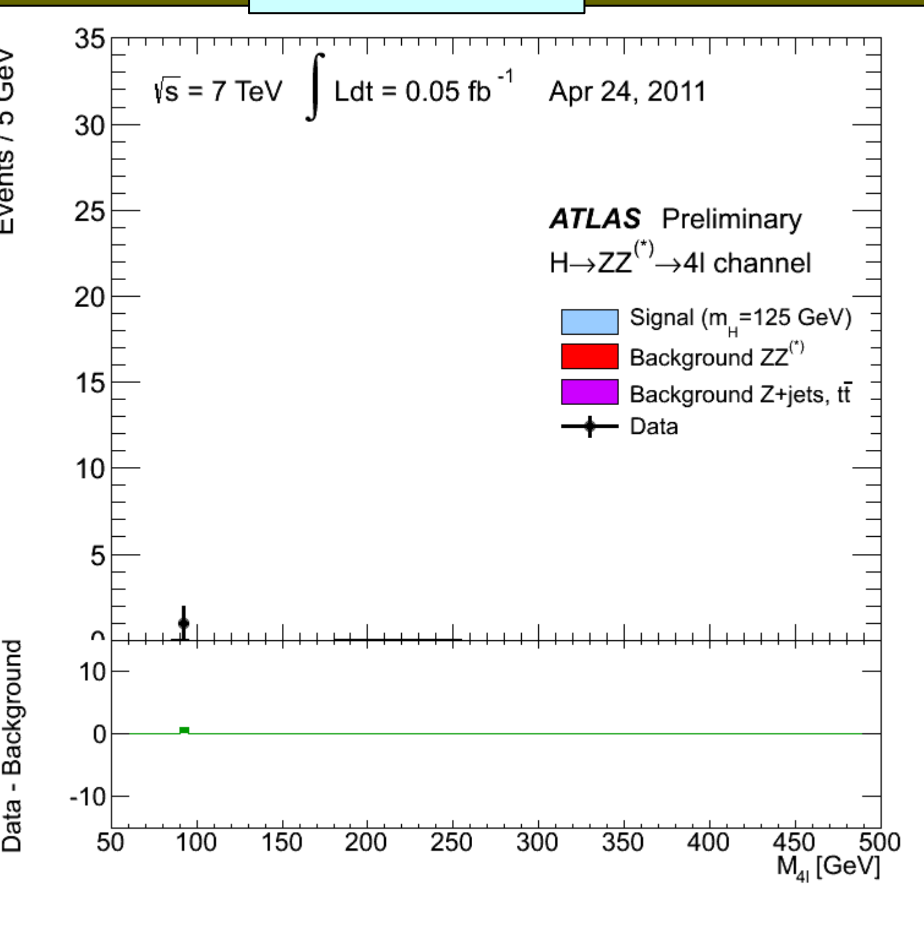


~ λv
$m_H^2 = 2\lambda v^2$

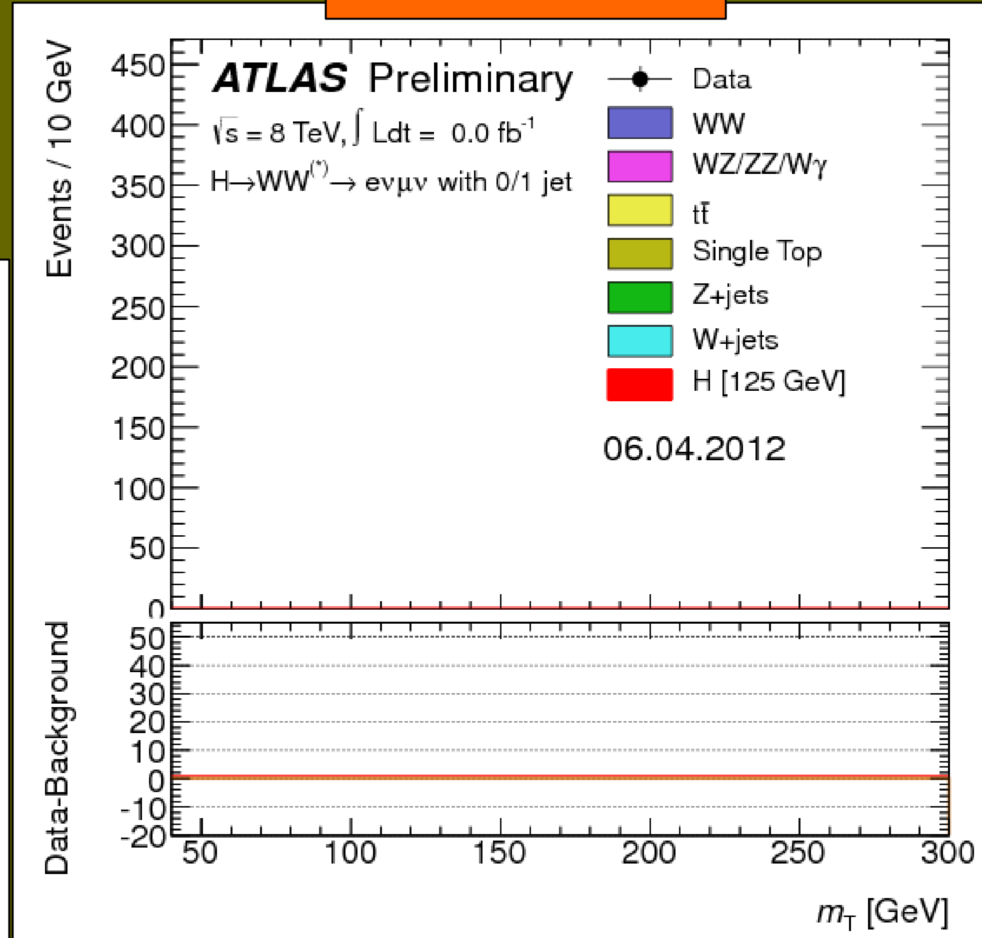
Note: -- these results are very preliminary (work of a few months) and conservative
-- physics potential of LHC upgrade is much more than just Higgs

Birth and evolution of a signal

H→ ZZ*→ 4l



H→ WW*→ lνlν



Conclusions

The first LHC run (2010-2012) has been EXTRAORDINARY !
Machine and experiments (and people !) have been stressed and have been performing beyond "design specifications" during three demanding but very exciting years.

ATLAS has recorded ~ 27 fb^{-1} and has operated very effectively and smoothly in all its components: from detector/trigger to software and computing and release of physics results

The ATLAS physics output, summarized so far in ~ 240 papers on collision data and 470 Conference notes, includes:

- Detailed measurements of SM at 7-8 TeV
- Searches for new physics in a huge number of topologies and scenarios → limits reach several TeV in many cases → moving to ~14 TeV is now necessary to make progress
- The discovery of a very special particle, which looks like the SM scalar

The era of precise measurements of our new friend has started. In parallel, the quest for New Physics at the TeV scale continues → LHC and its upgrade will have a lot to say

These accomplishments are the results of more than 20 years of talented work and extreme dedication of those involved in the LHC project

More in general, they are the results of the vision, tenacity and painstaking work of the full HEP community (accelerator, instrumentation, computing, experimental physics, theory)

THANK YOU !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