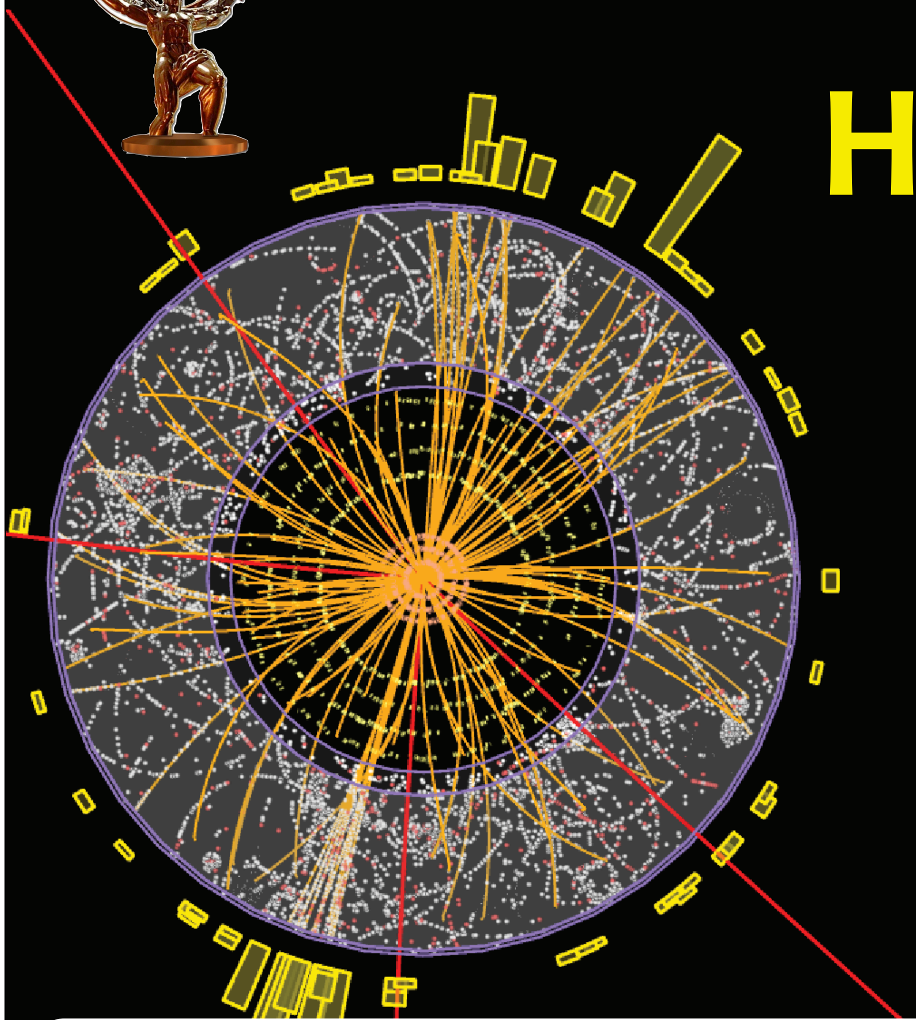
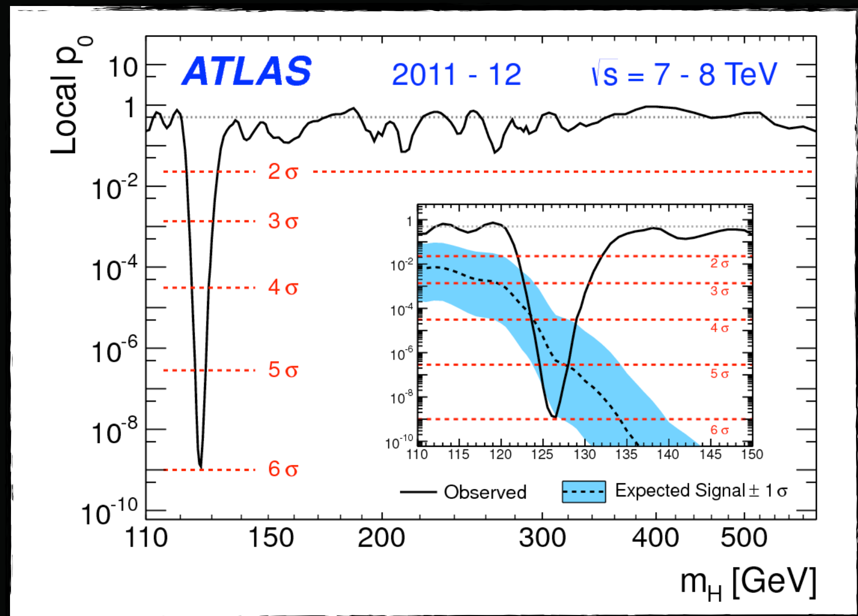
Observation of the Higgs (?) particle





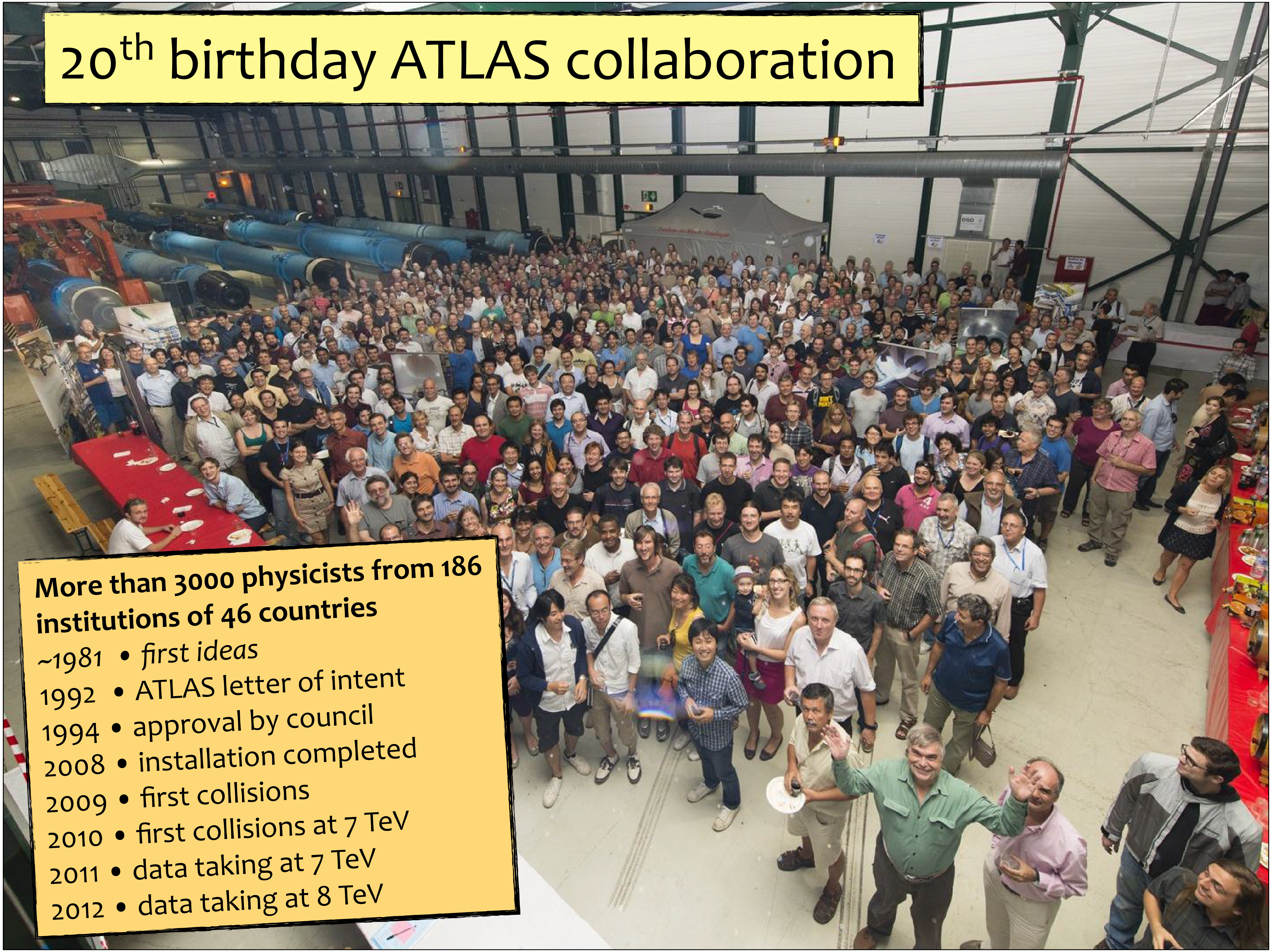
Stan Bentvelsen -
on behalf of the
Nikhef ATLAS group

IN·DEI·NOMINE·FELICITER

NIKHEF

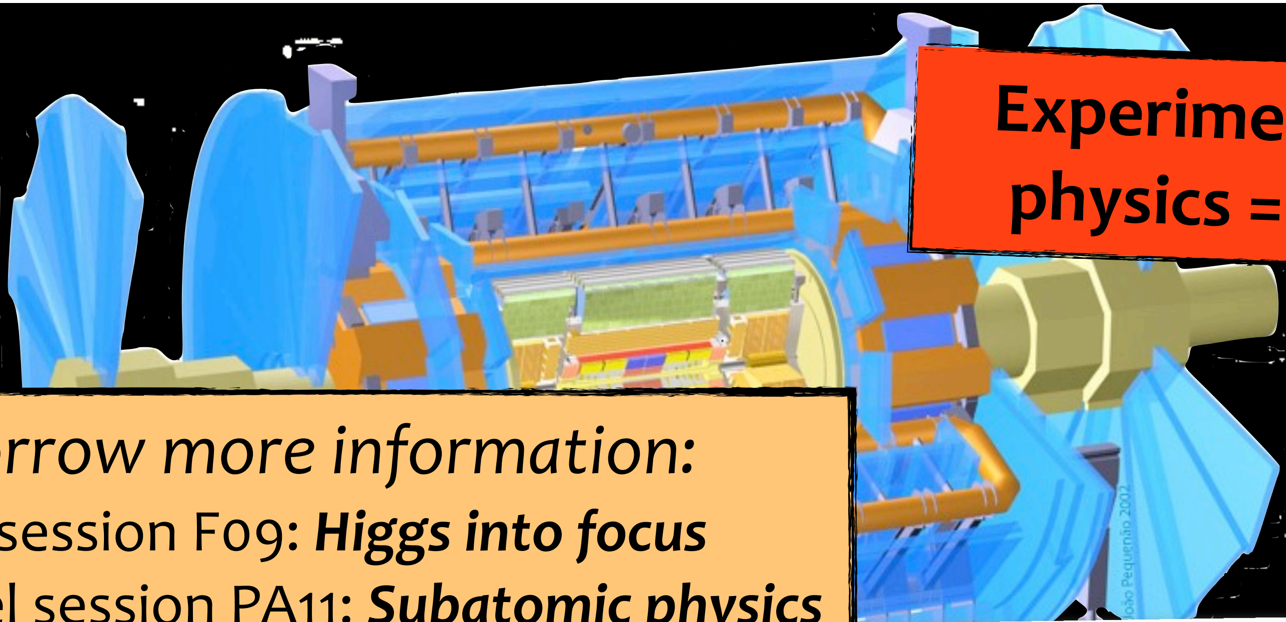
Physics@FOM
Veldhoven 2013

20th birthday ATLAS collaboration



More than 3000 physicists from 186 institutions of 46 countries

~1981 • *first ideas*
1992 • ATLAS letter of intent
1994 • approval by council
2008 • installation completed
2009 • first collisions
2010 • first collisions at 7 TeV
2011 • data taking at 7 TeV
2012 • data taking at 8 TeV



Experimental particle physics = team work

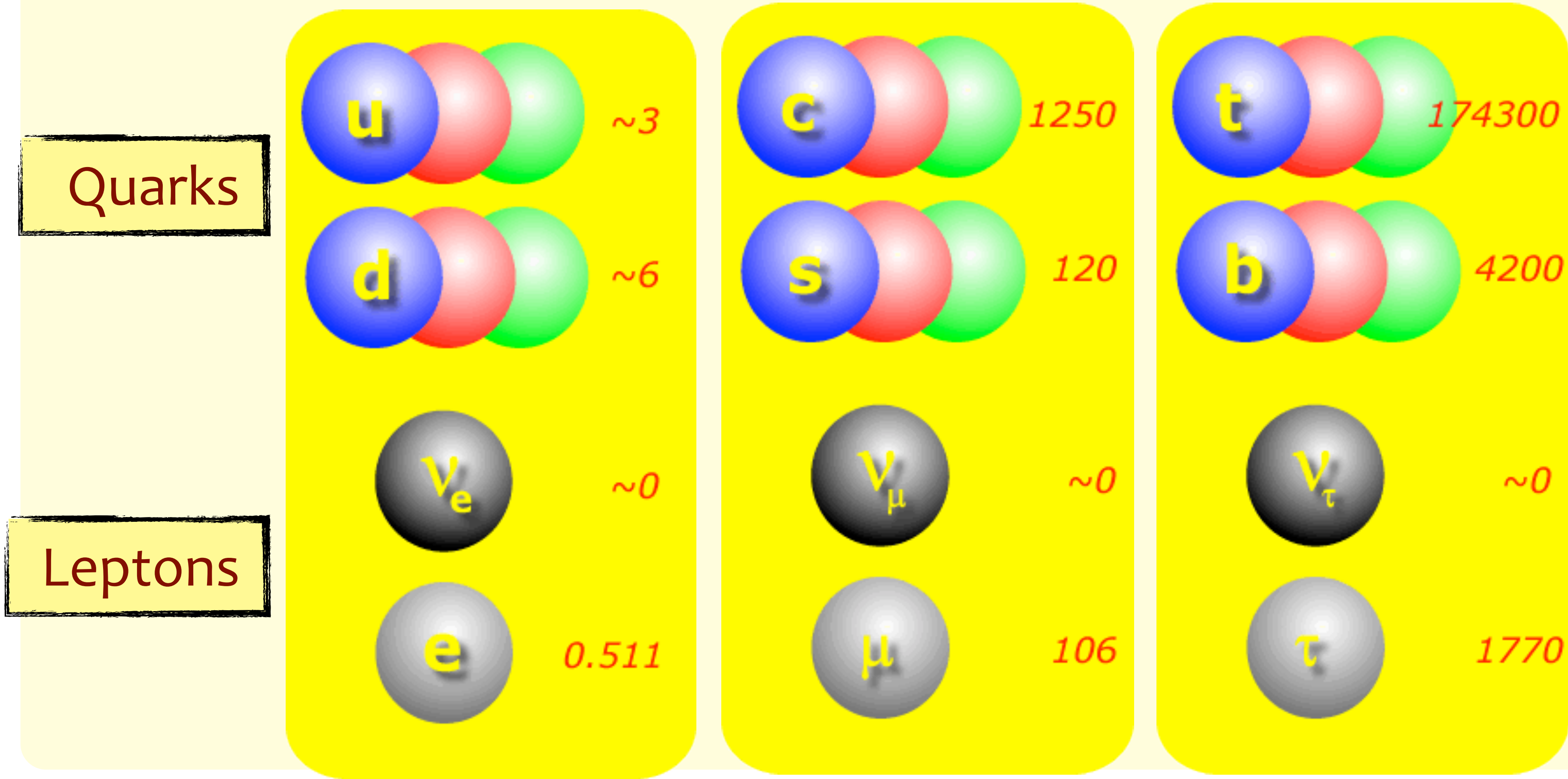
Tomorrow more information:

Focus session F09: ***Higgs into focus***

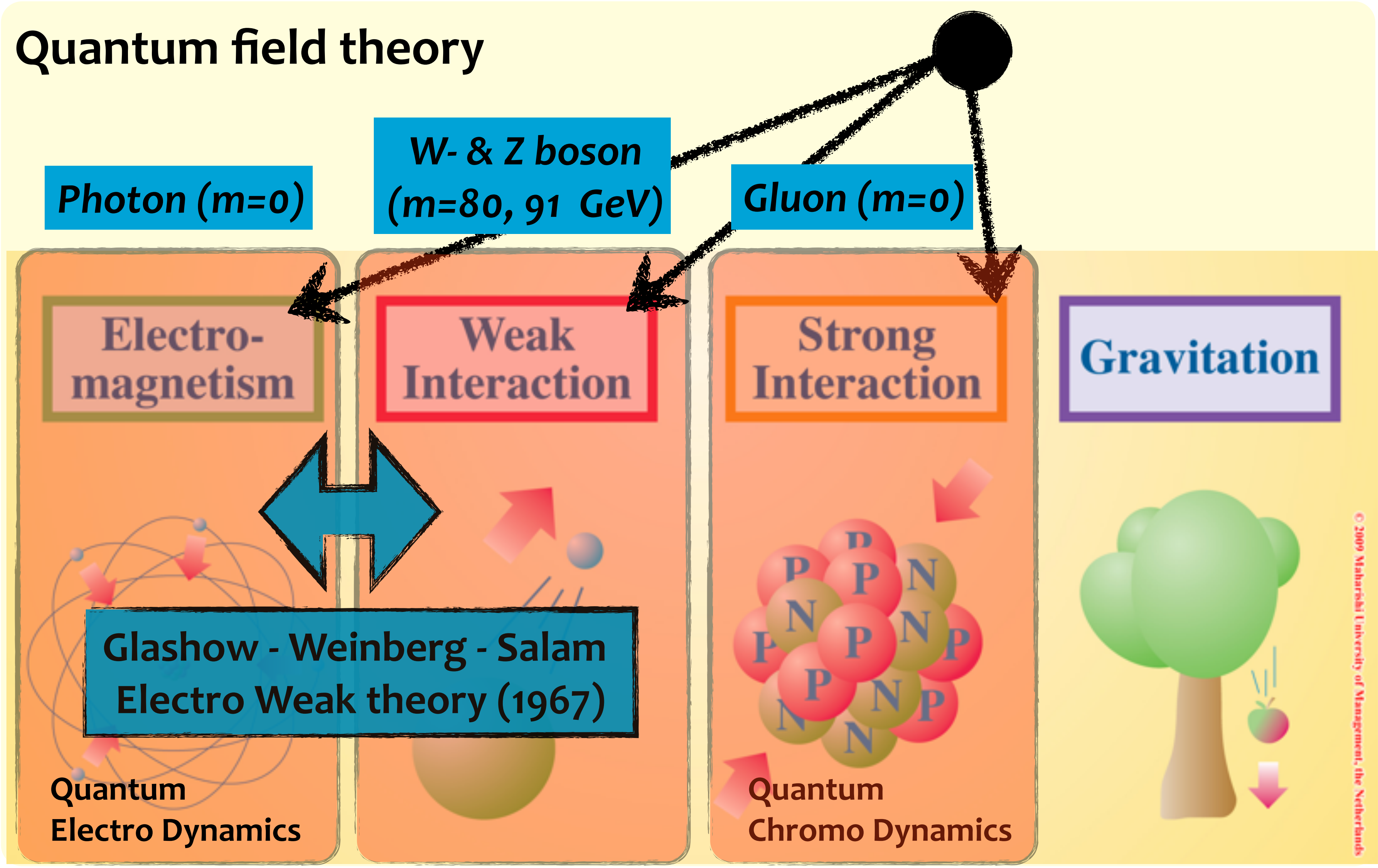
Parallel session PA11: ***Subatomic physics***

FOM/Nikhef - Radboud University - University of Amsterdam

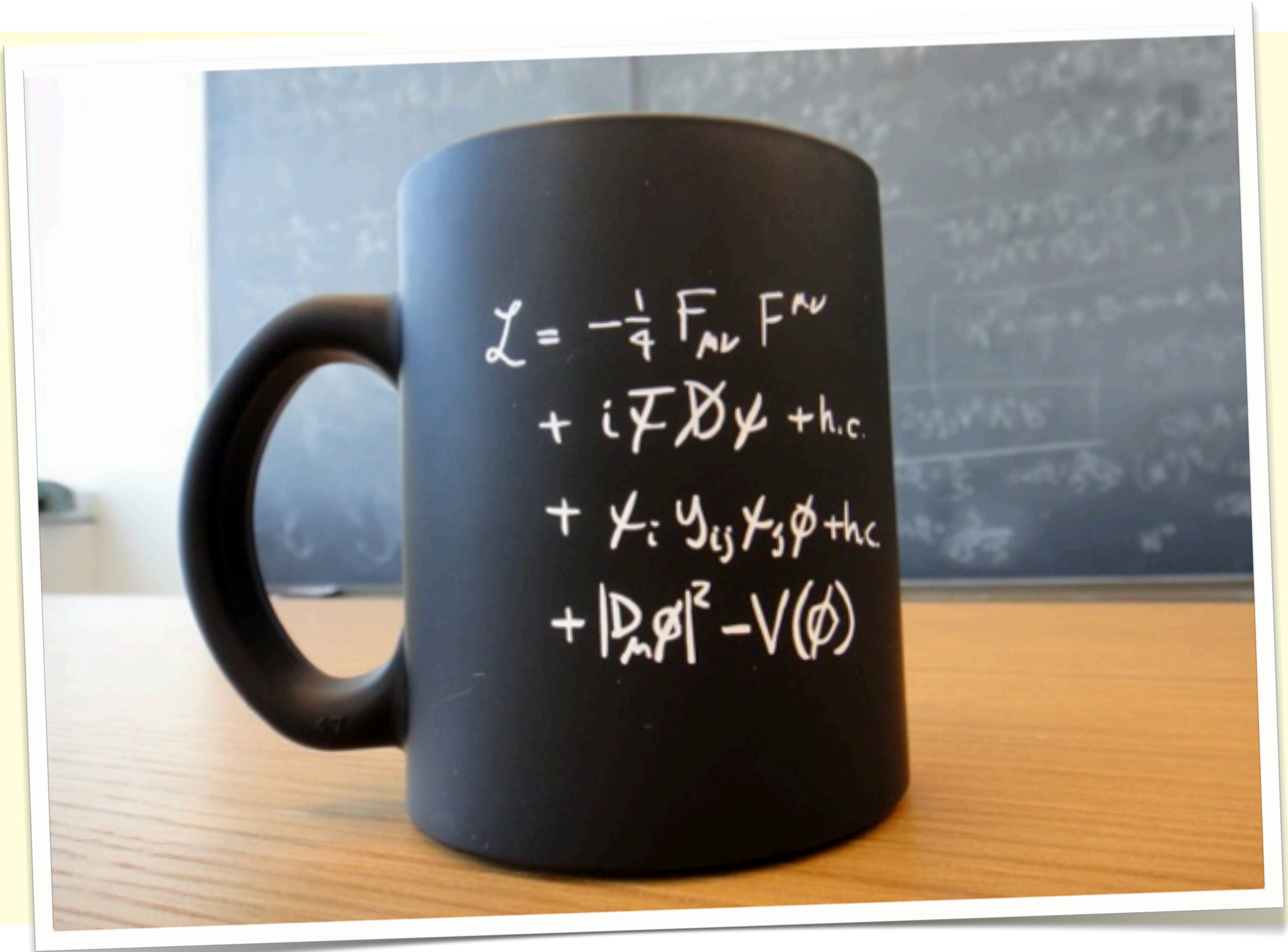
Particle physics



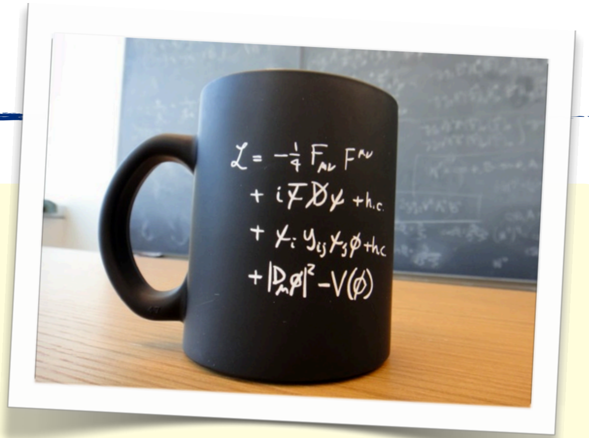
Fundamental interactions



The result: Standard Model



Status of Standard Model



- Consistent model ~1970

Nobel prize M Veltman & G 't Hooft

  - ***However:*** W- and Z-boson mass spoil symmetry

- 'Dynamic generation' of mass
  - Developed around 1964
  - In Standard Model to give W, Z-boson and fermions mass

P. Higgs and F. Englert

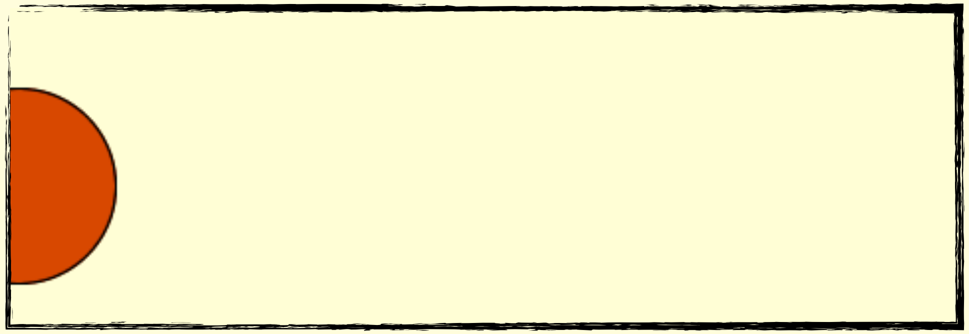
R. Brout †

- Observation Z- and W-boson in 1983
  - Big success Standard Model!

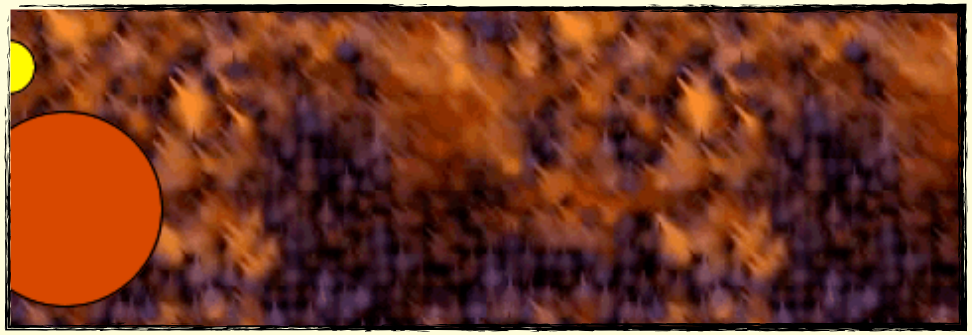
Nobel prize S van der Meer & C Rubbia

Universe as superconductor

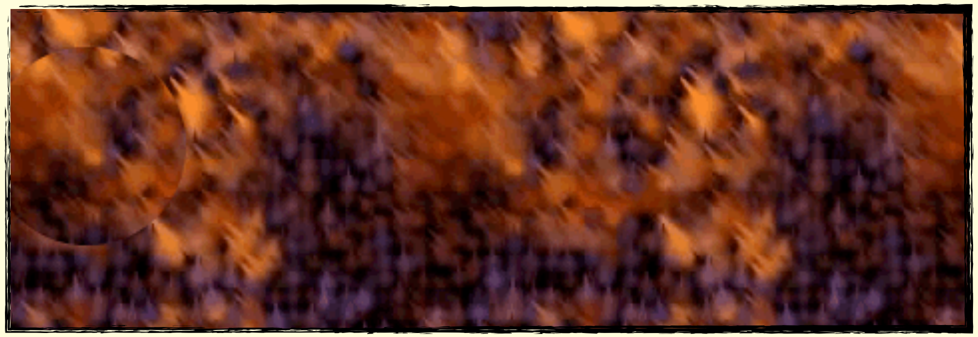
Unbroken 'symmetric' phase
particles do not have mass
move with speed of light

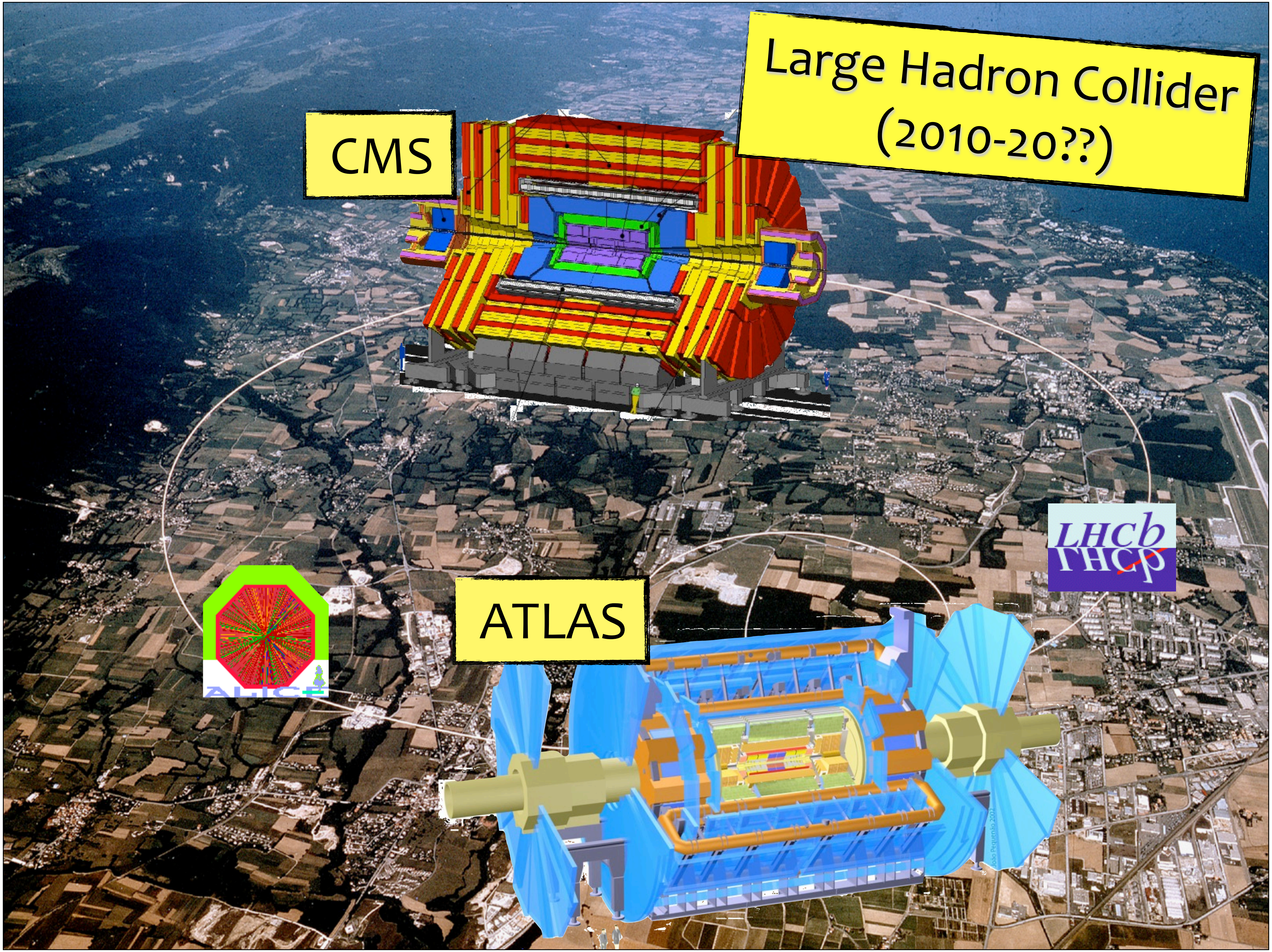


Broken phase: Higgs field
particles interact with
omnipresent field
effectively acquire a mass



"Smoking gun"
Quantum excitation
of the Higgs Field



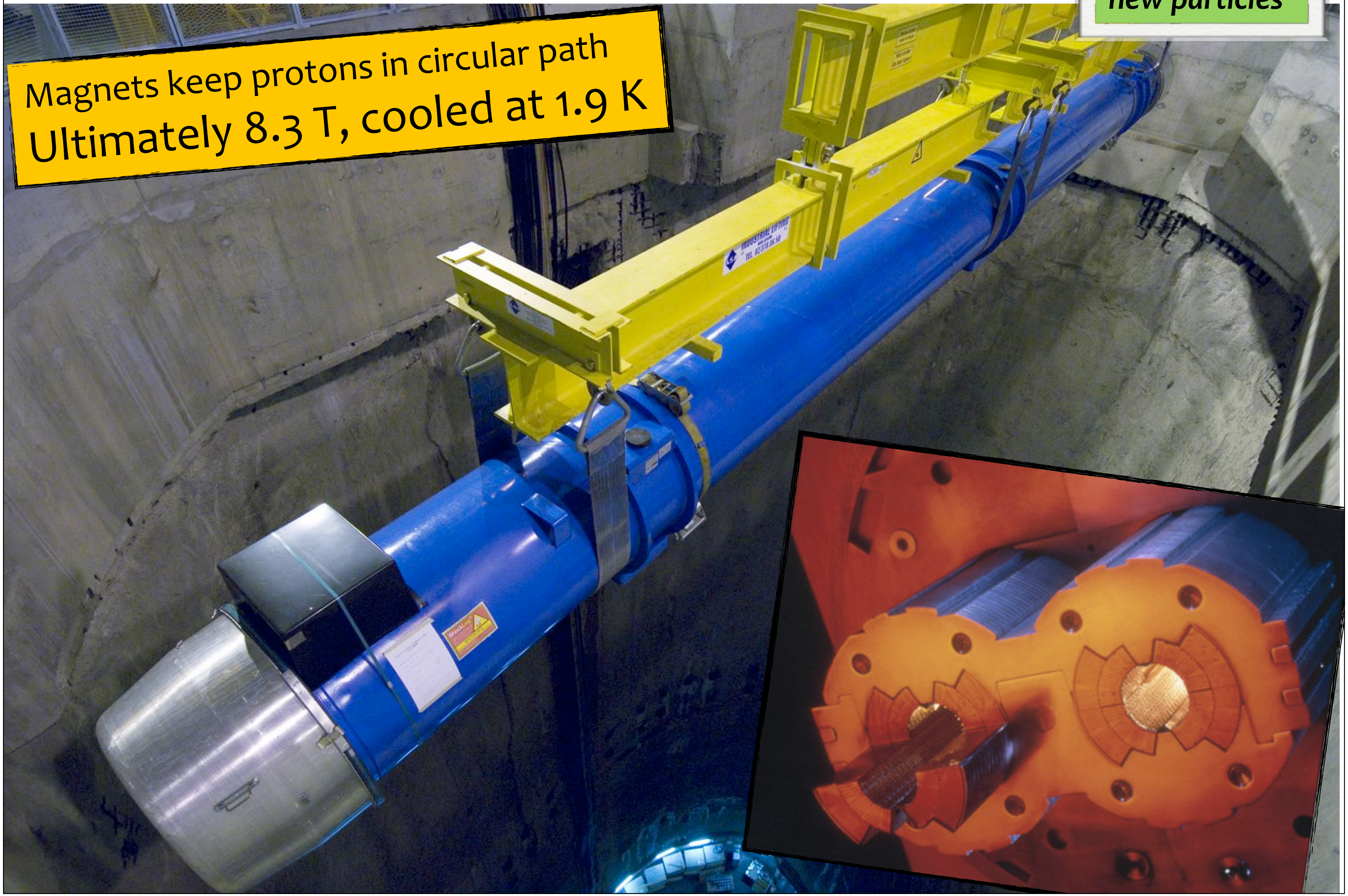


Large Hadron Collider
(2010-20??)
CMS
ATLAS
LHCb
ALICE

LHC challenge 1: ***7000+7000 GeV***

observation new particles

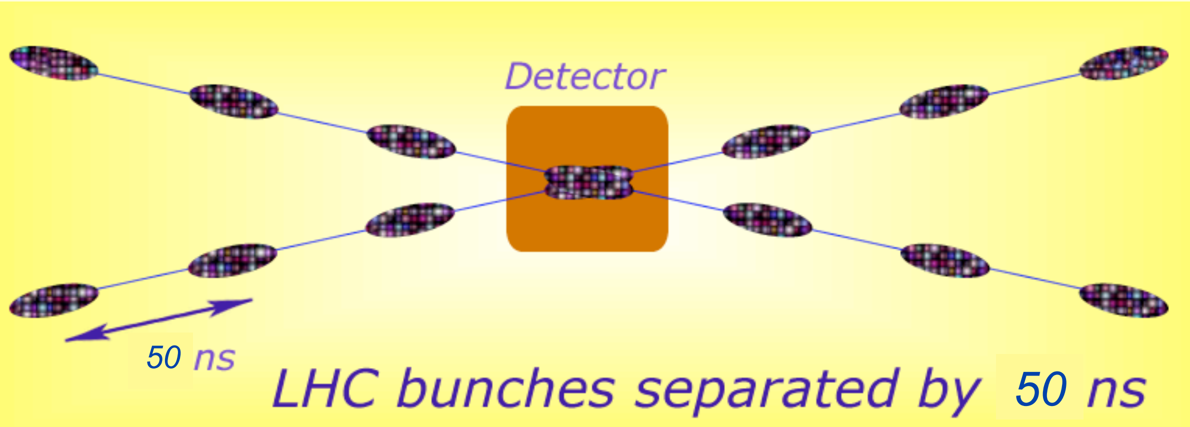
Magnets keep protons in circular path
Ultimately 8.3 T, cooled at 1.9 K



LHC challenge 2: ***Luminosity***

observation very rare processes

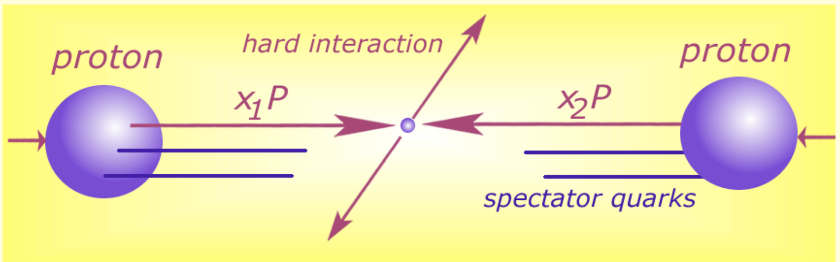
- 'Higgs production' 10 *orders of magnitude* below total cross section

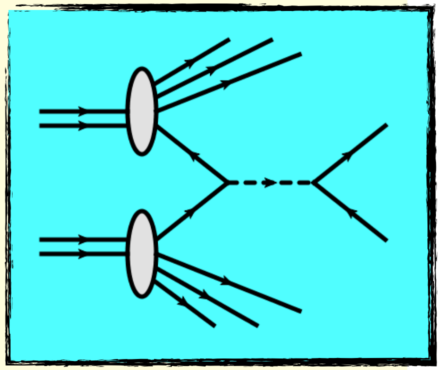


Trains of bunches - each with 10^{11} protons

- 24/7 operation March - December

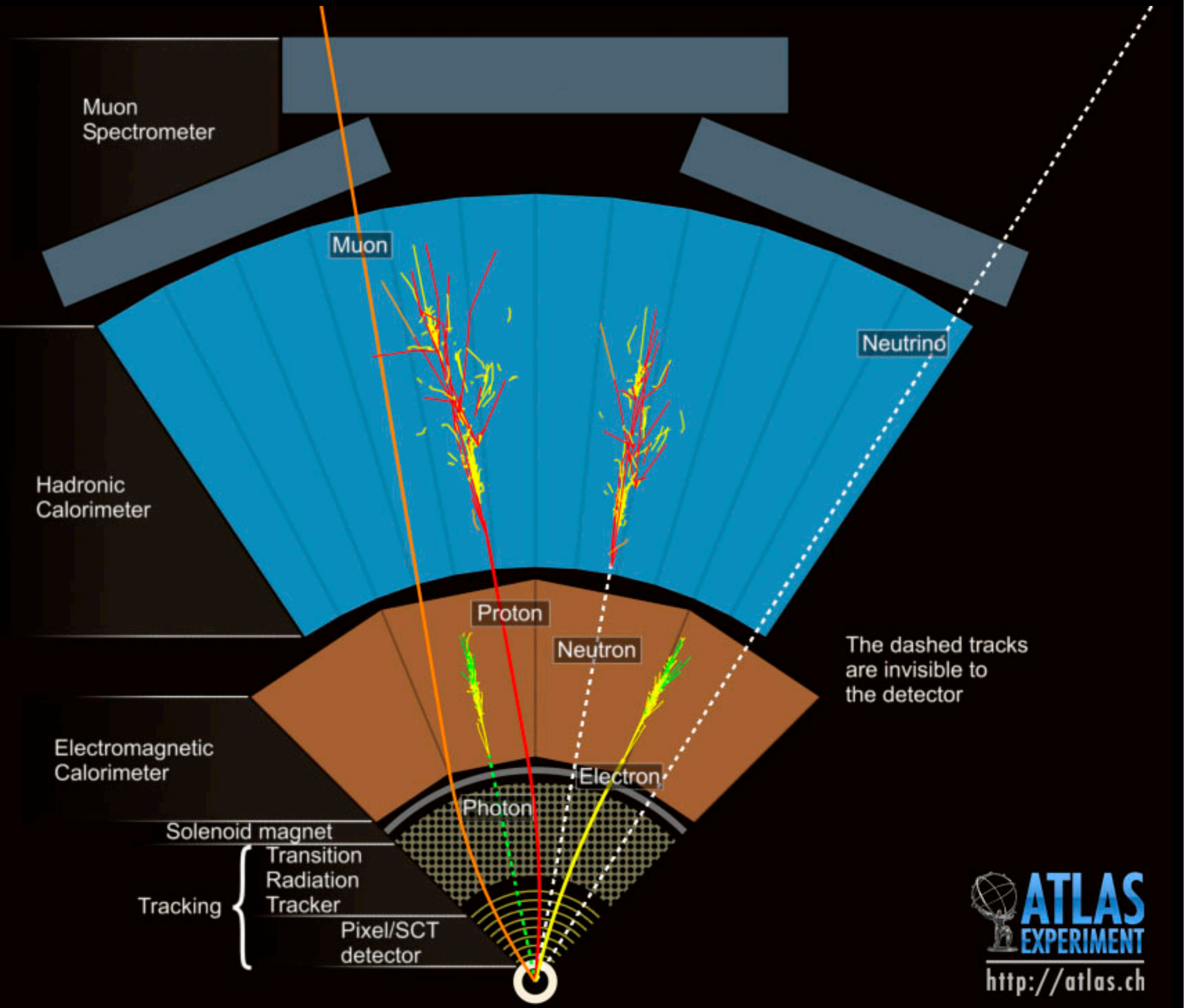
-Fill with bunches
-Ramp-up energy
-Collisions (~10 hrs)
-Recycle

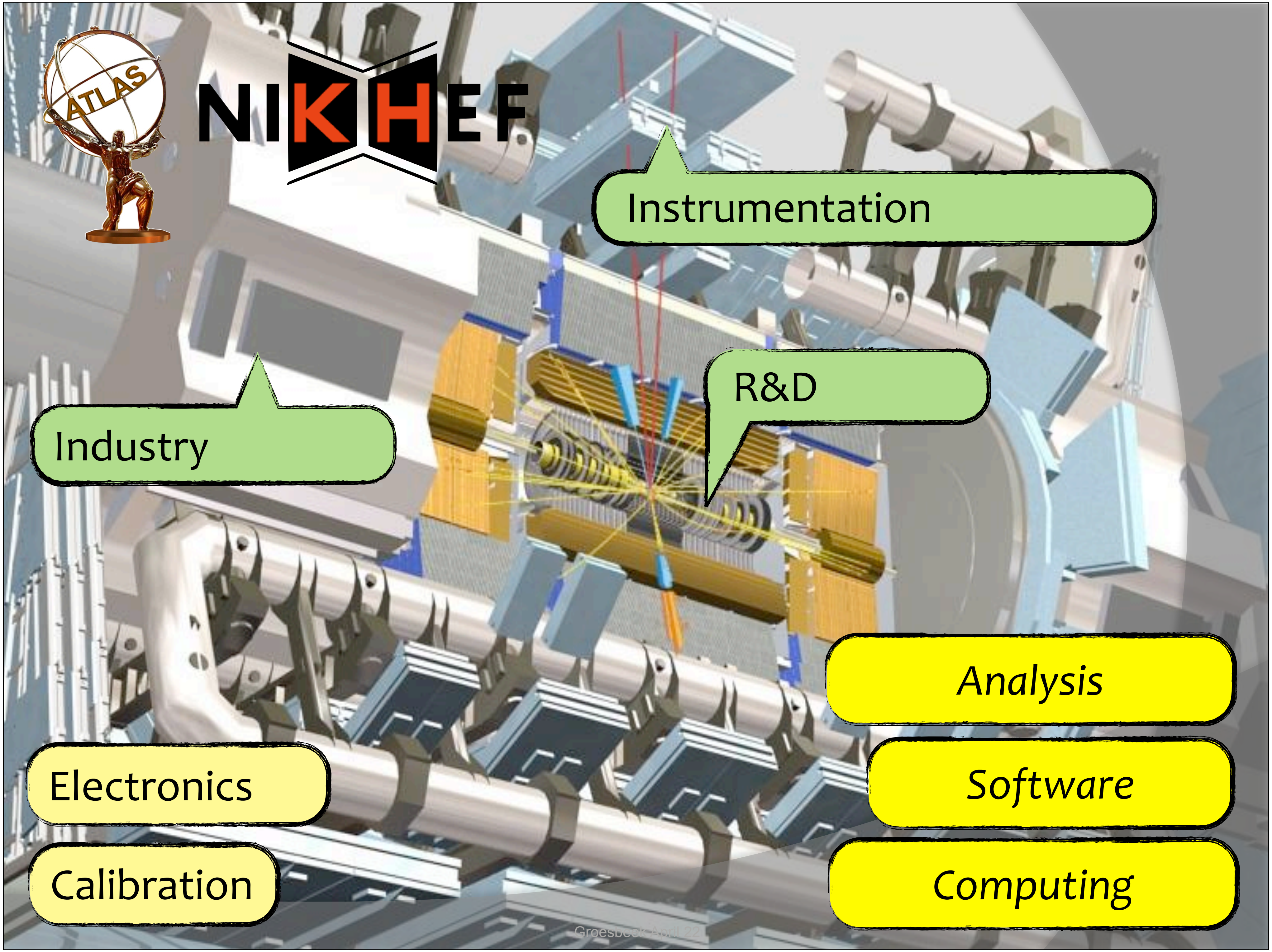


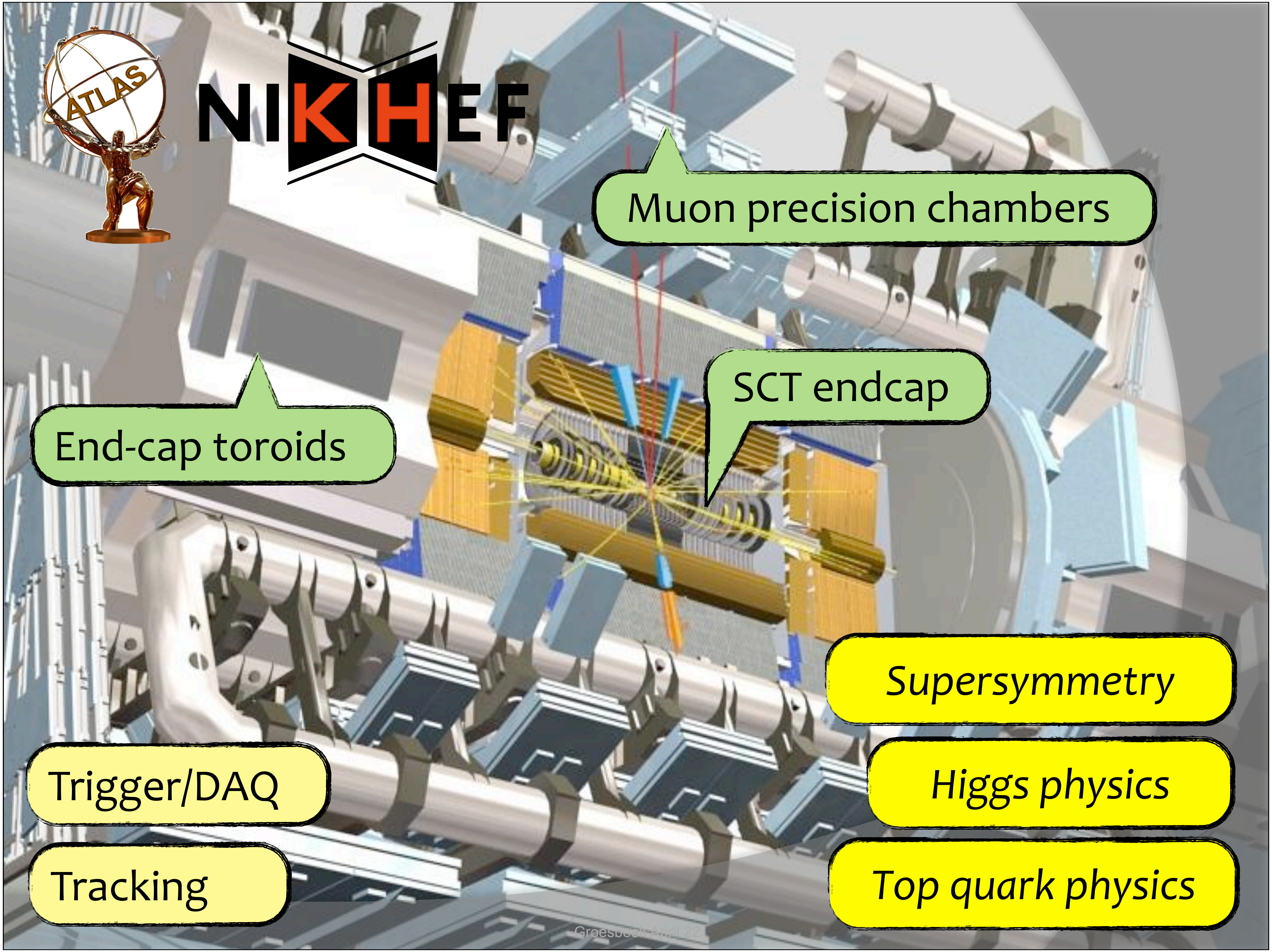


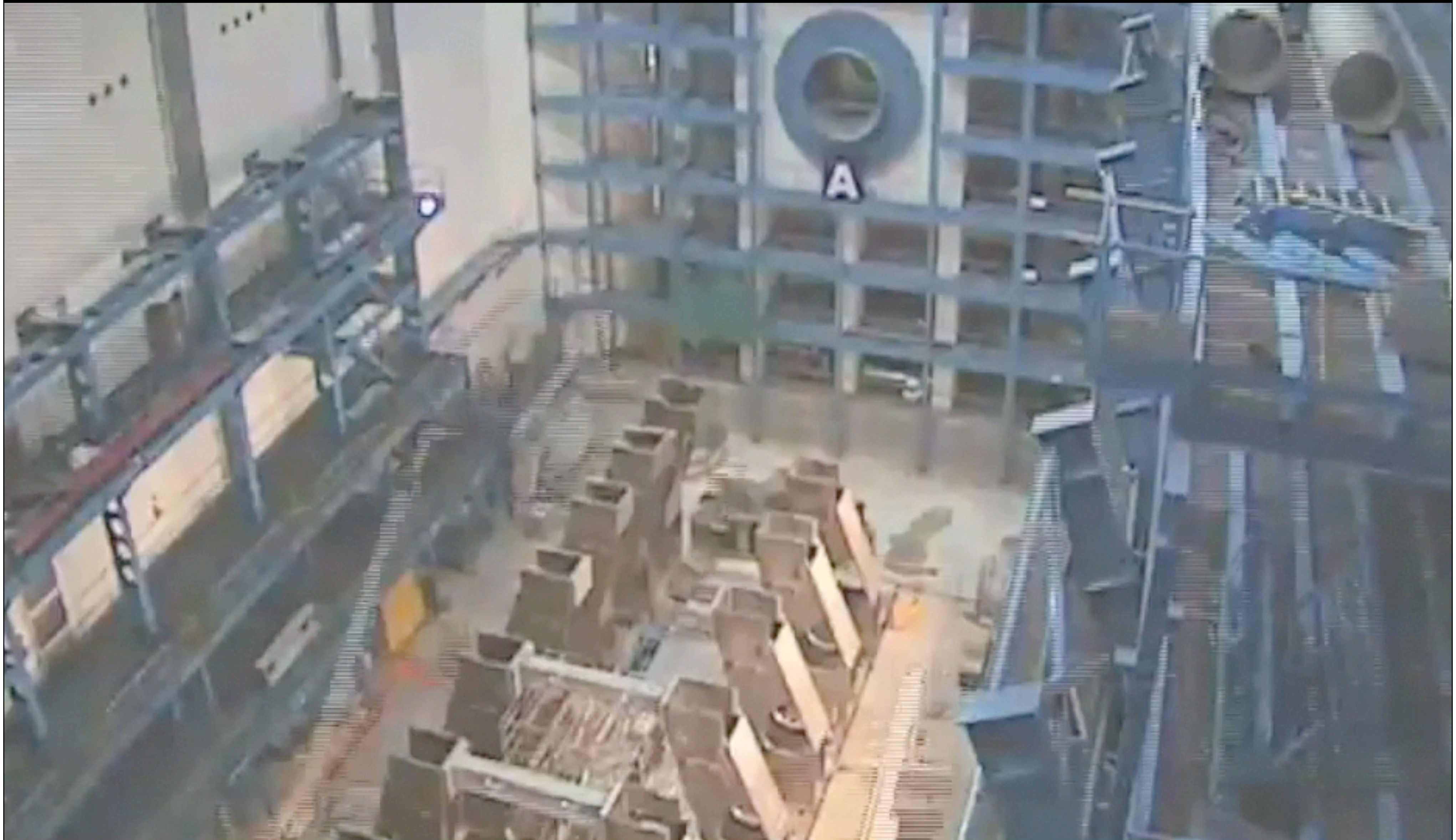
– ATLAS collecting data when LHC provides stable beams

- ***Muon chambers*** Momentum for penetrating muons
- ***Calorimeters*** Energy measurement by absorption
- ***Tracking-chambers*** Direction and momentum charged particles



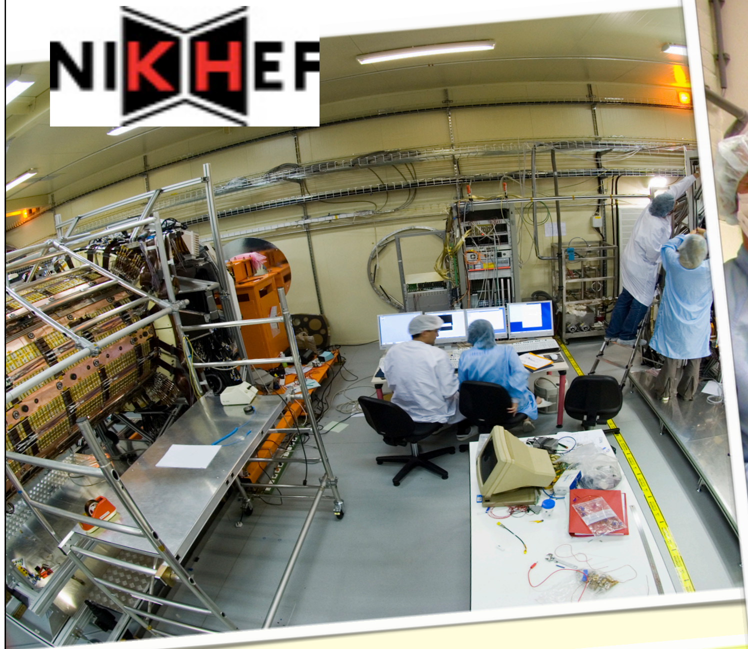

NIKHEF
ATLAS
Instrumentation
R&D
Industry
Analysis
Software
Electronics
Calibration
Computing

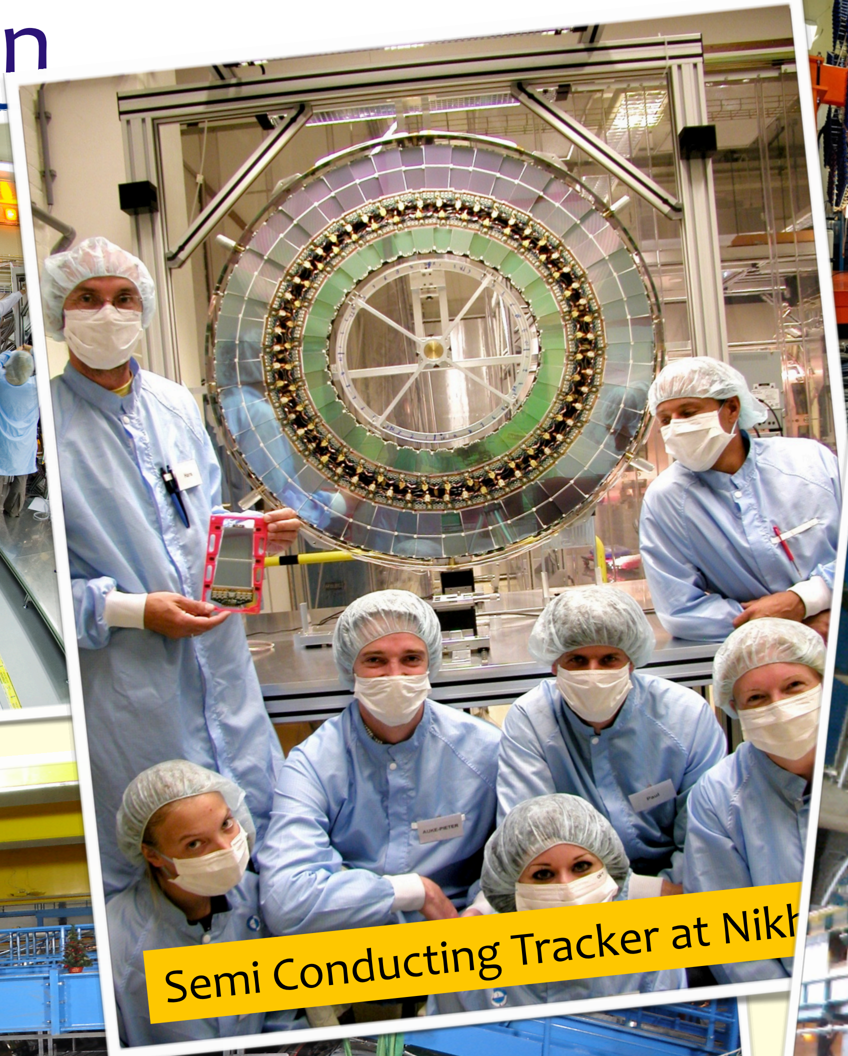

NIKHEF
ATLAS
Muon precision chambers
SCT endcap
End-cap toroids
Supersymmetry
Higgs physics
Trigger/DAQ
Top quark physics
Tracking


A

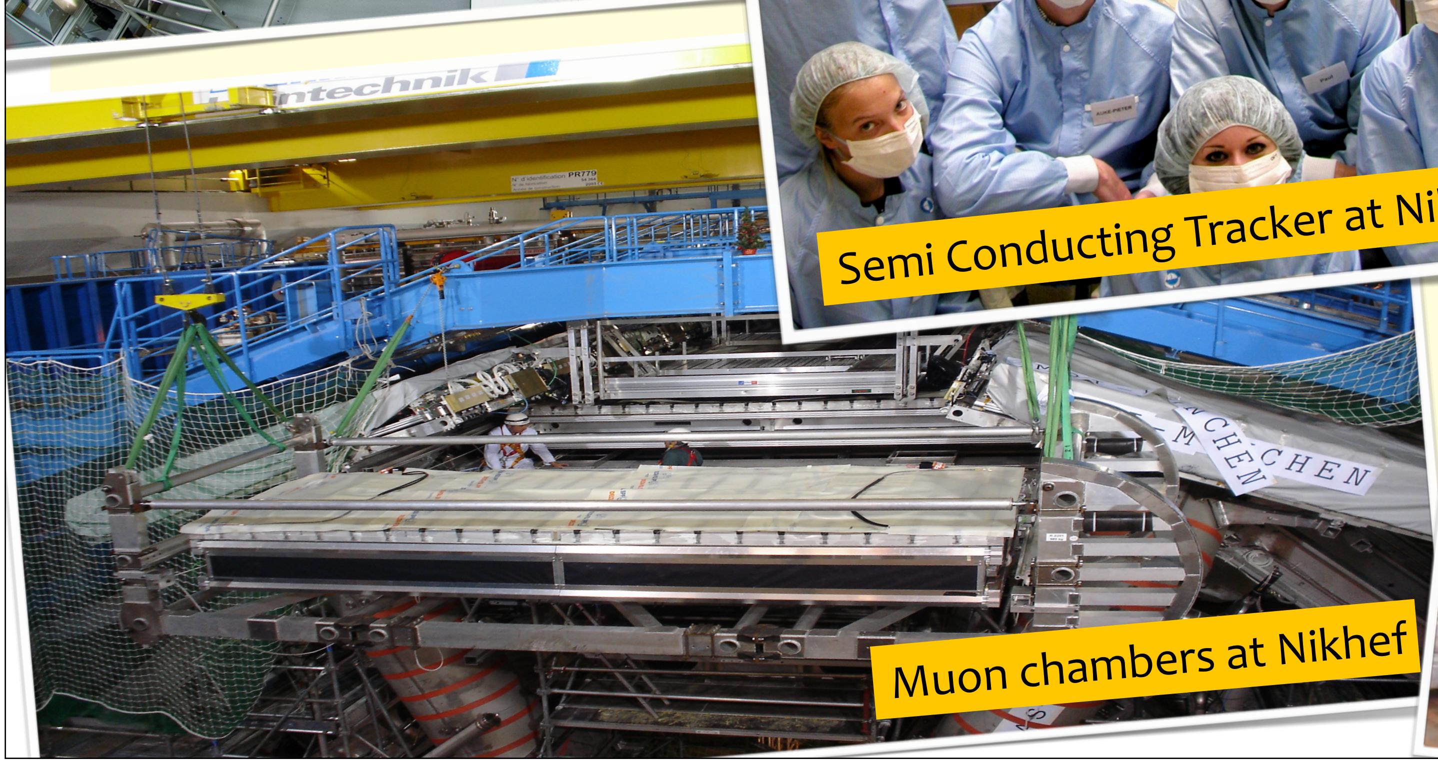
Instrumentation

NIKHEF

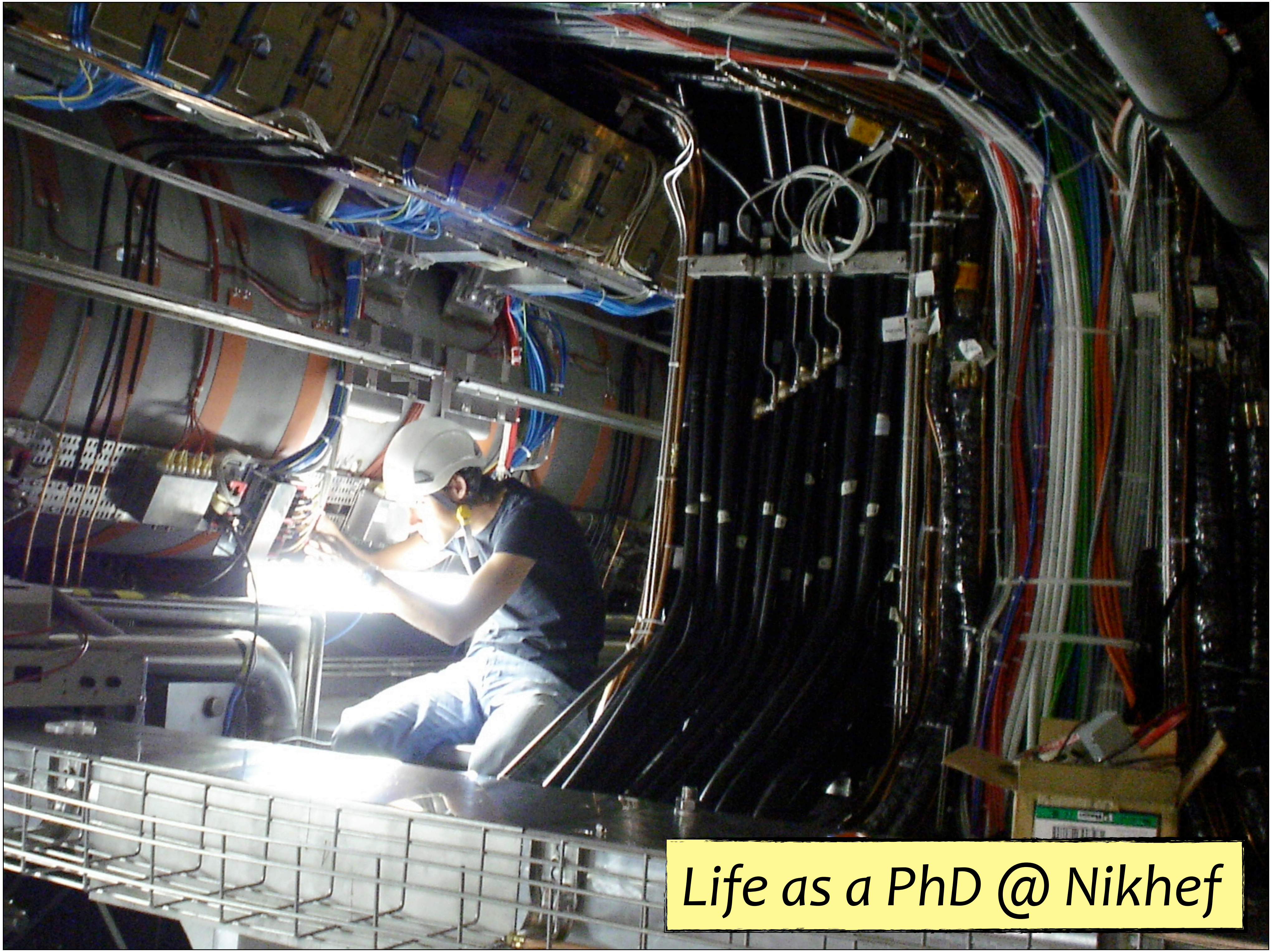




Semi Conducting Tracker at Nikhef



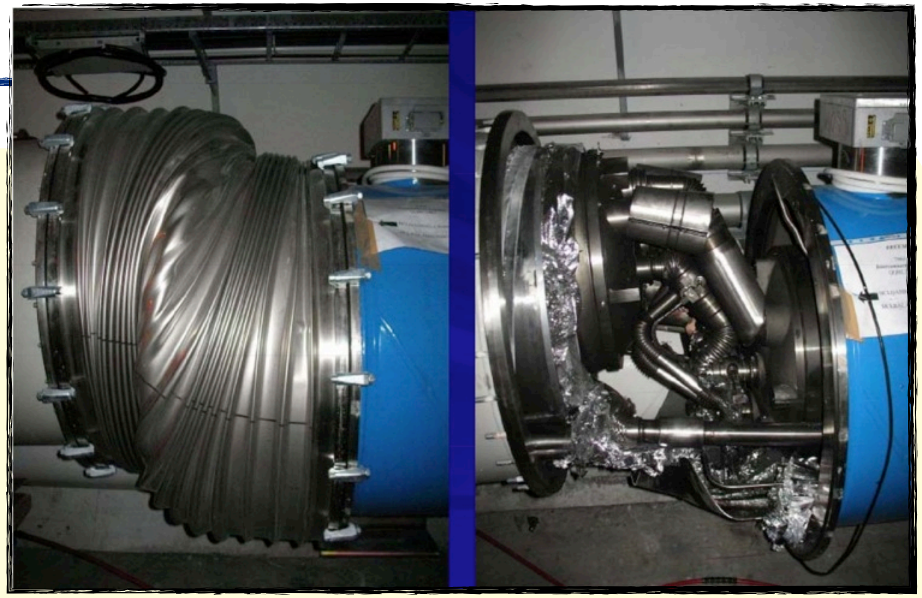
Muon chambers at Nikhef



Life as a PhD @ Nikhef

History…

- LHC schedule adjusted
  - ***2008:*** quench incident
    - *~100 di-pool magnets affected*
  - ***2010:*** LHC @ 3500/4000 GeV
  - ***2014:*** Full energy available



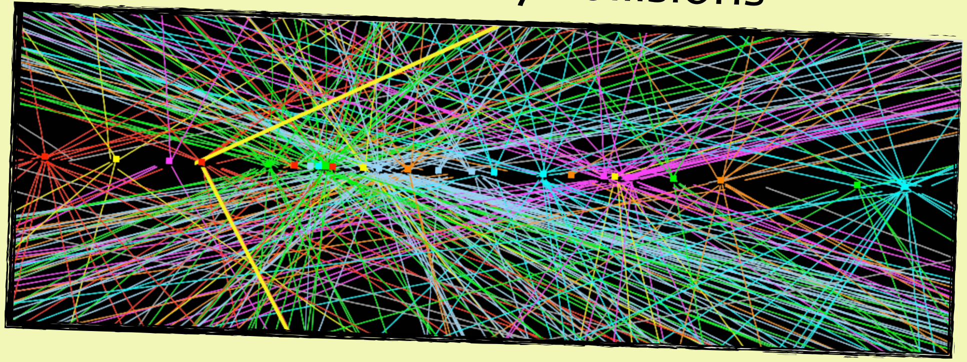
- Start operation
- ***2011:*** LHC expectations exceeded by a factor 5
- ***2012:*** Again luminosity exceeded expectations

- A total of ~1.8 10^{15} collisions!
- Excellent ATLAS performance
  - Data taking efficiencies ~94%
  - >96% channels operational!

LHC as harsh environment

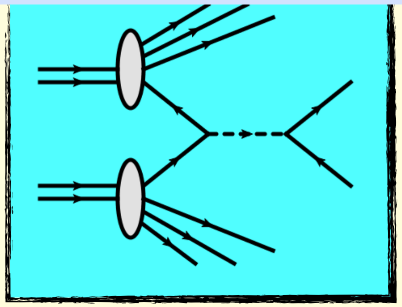
– Pile-up interactions per bunch crossing

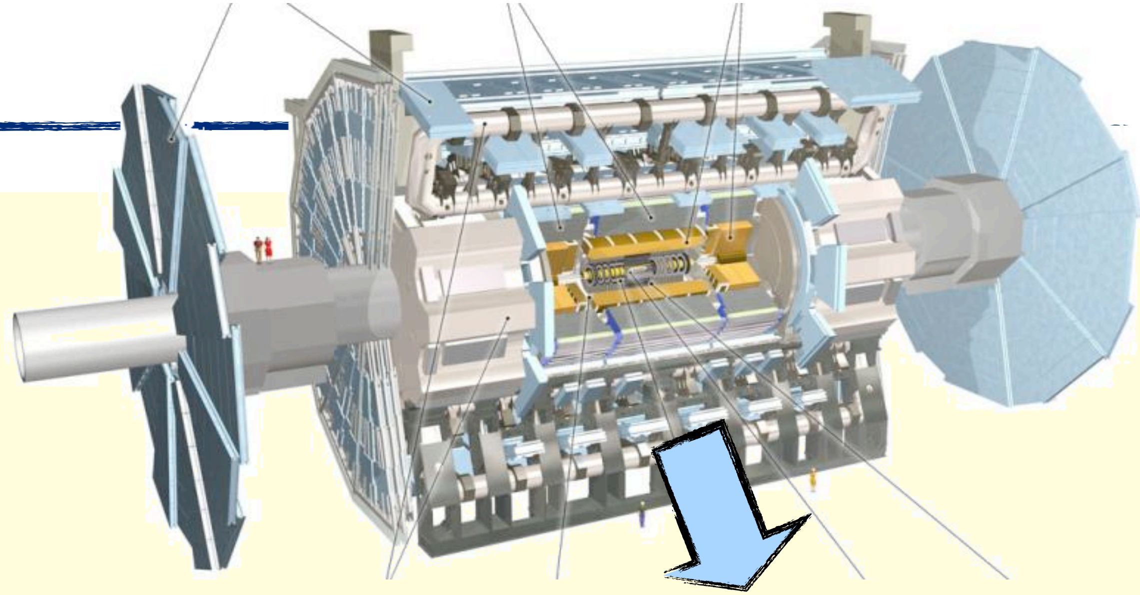
$Z \to \mu^+\mu^-$ event with 27 collisions



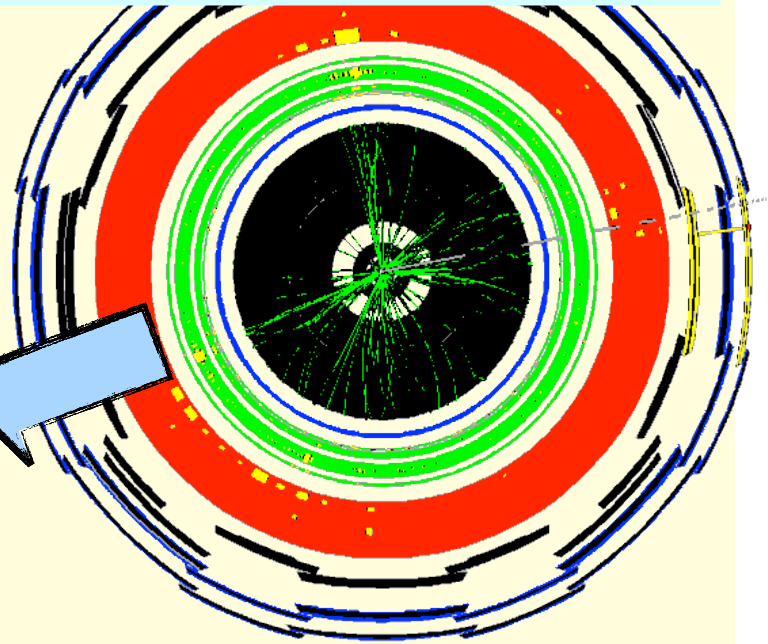
Infrastructure …

20 10^6 collisions/sec

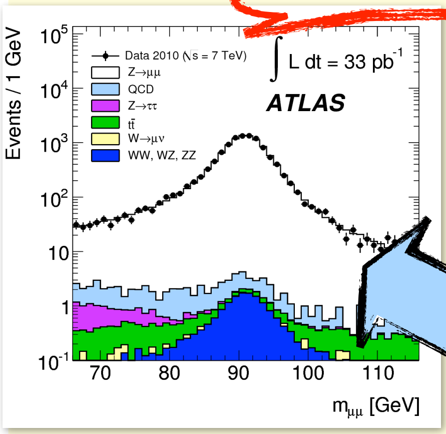




on-line trigger selection rate 600 Hz
~ 1 GB/s data collection



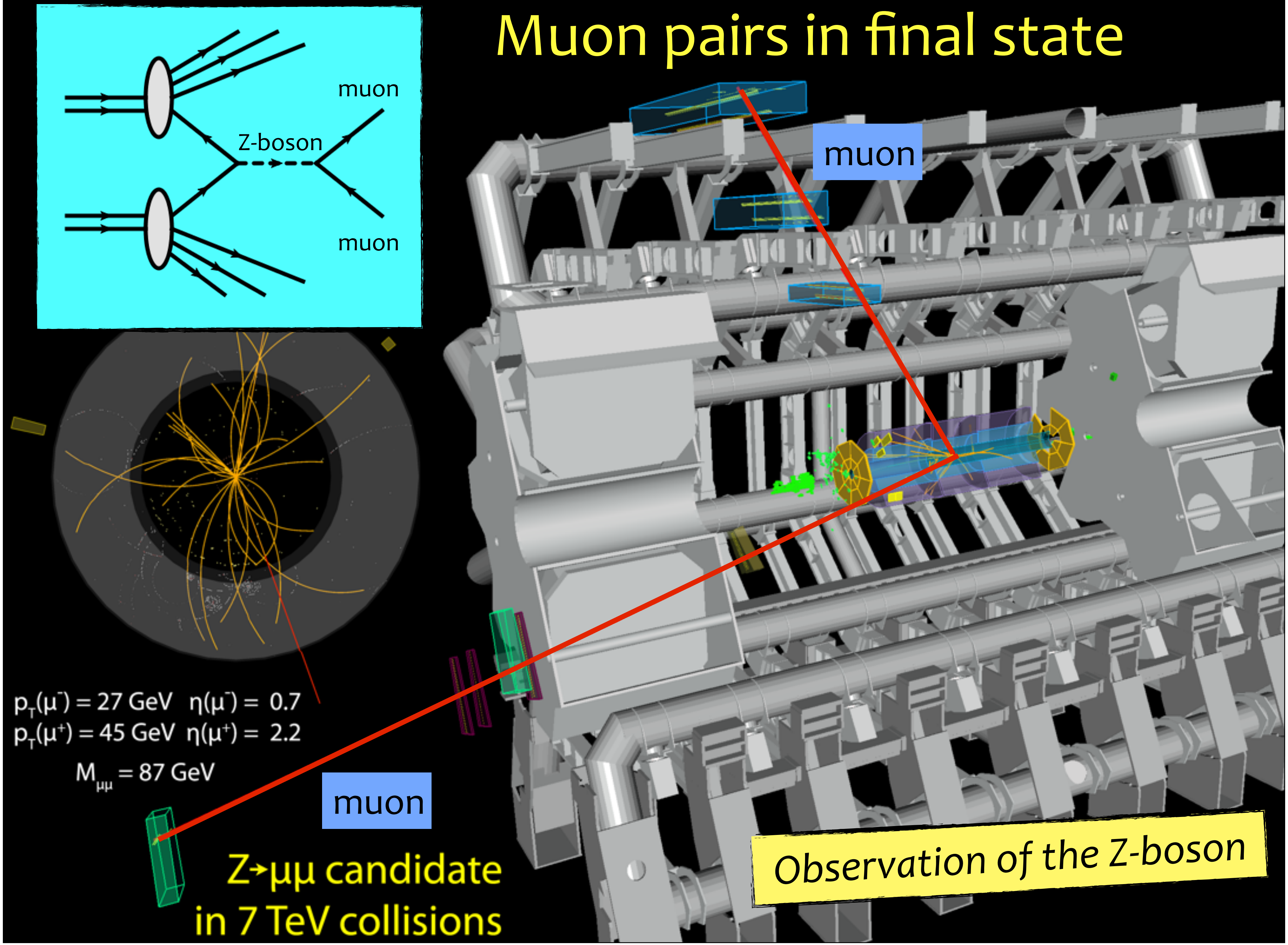
Z-mass peak



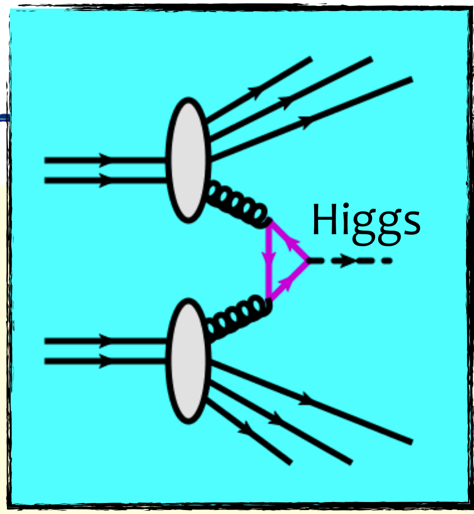
Data analysis

Data distribution using GRID infrastructure

Muon pairs in final state



Higgs search strategy



- ***Production***

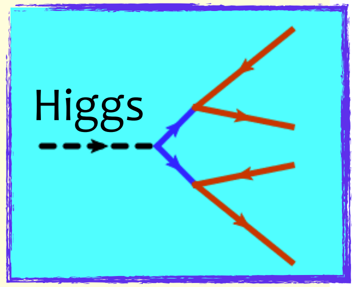
Predicted for 2012

m_H=125 GeV: 212.000

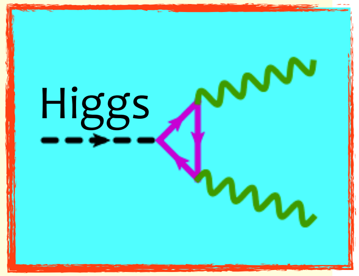
m_H=200 GeV: 77.000

- ***Decay***

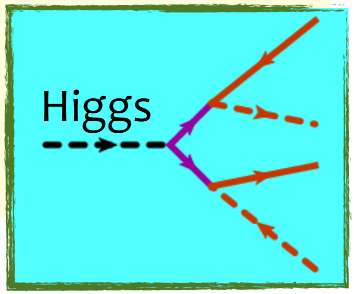
✦ $H \to ZZ^* \to 4$ leptons

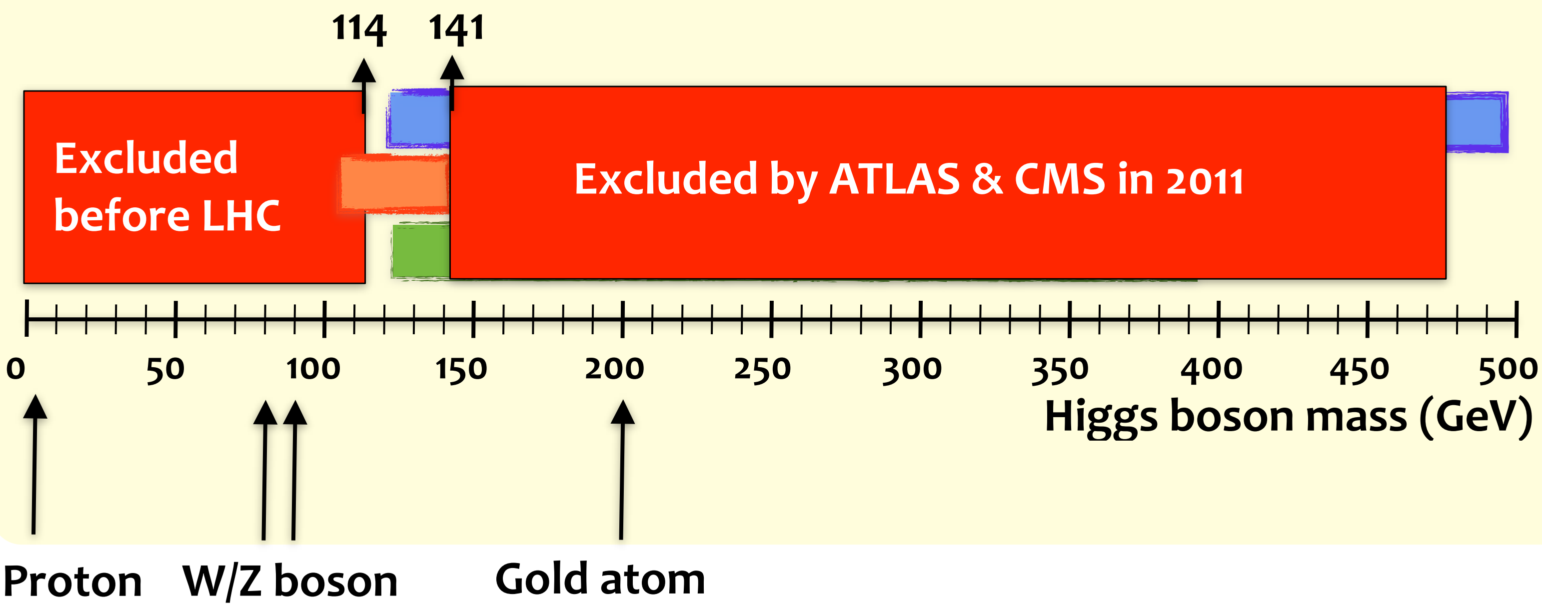


✦ $H \to \gamma + \gamma$

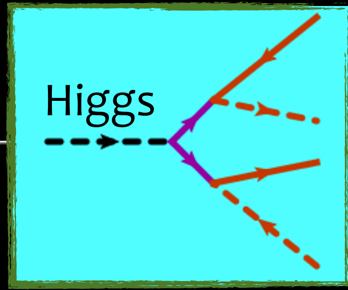


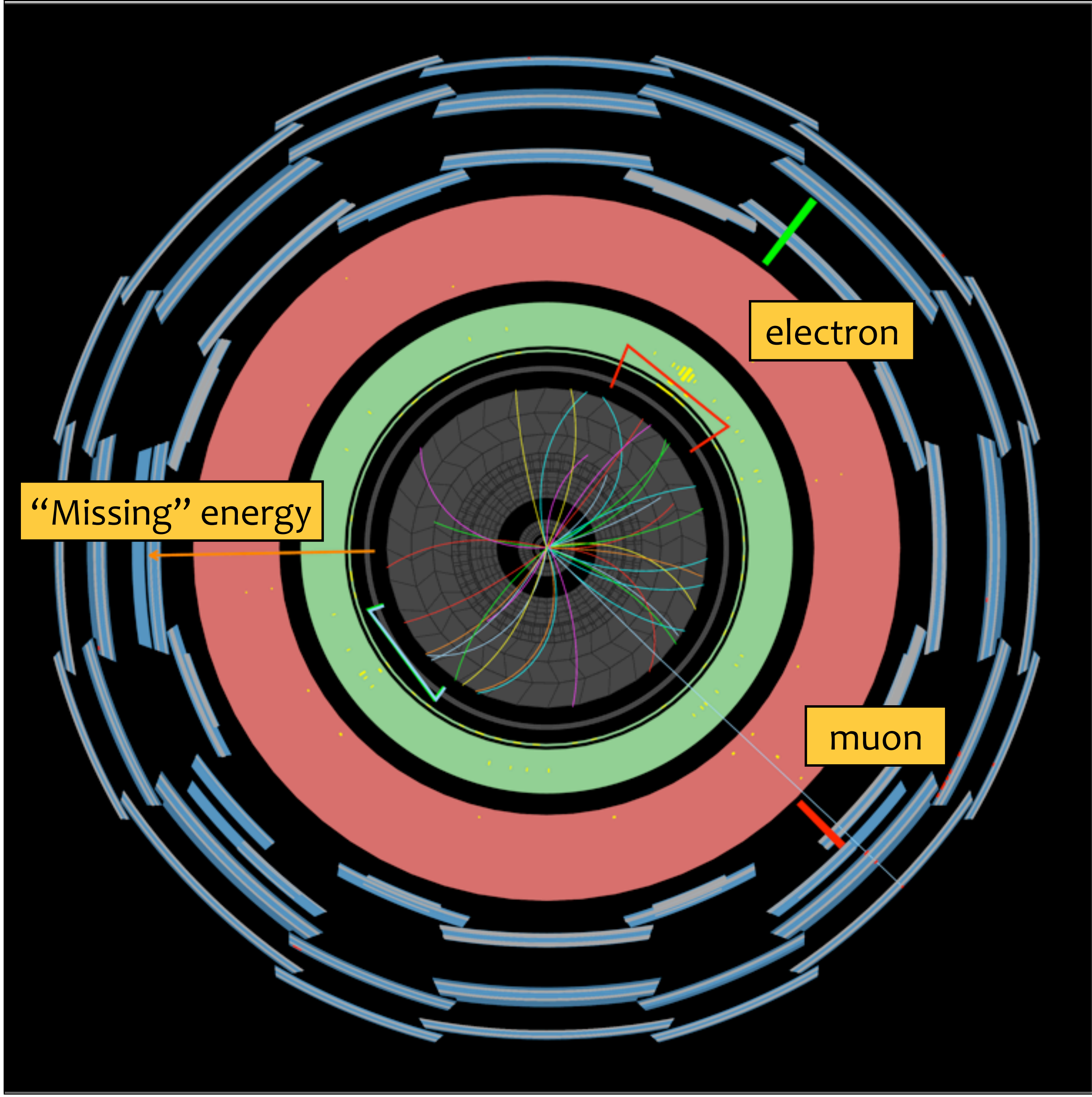
✦ $H \to WW^* \to 2$ leptons $+ 2\nu$

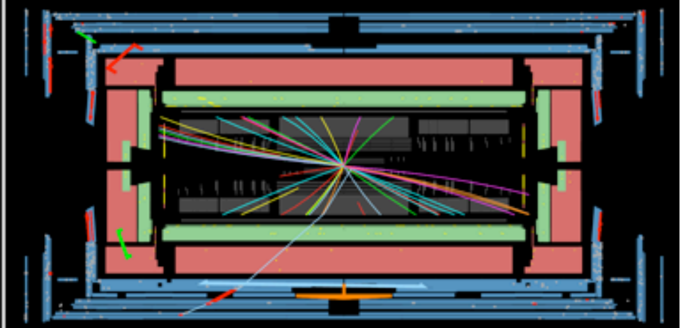




H → WW* → 2 leptons + 2 neutrinos





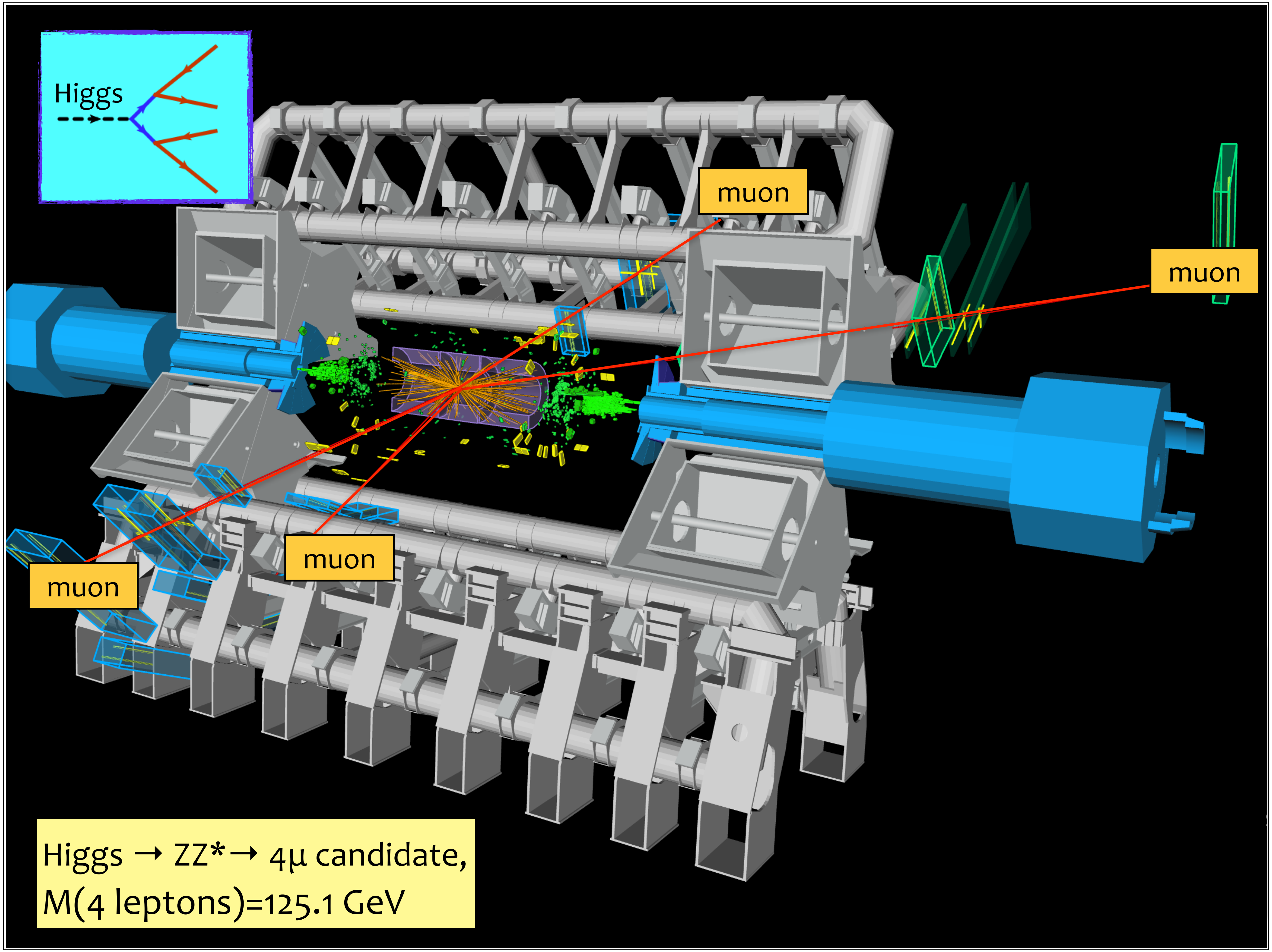


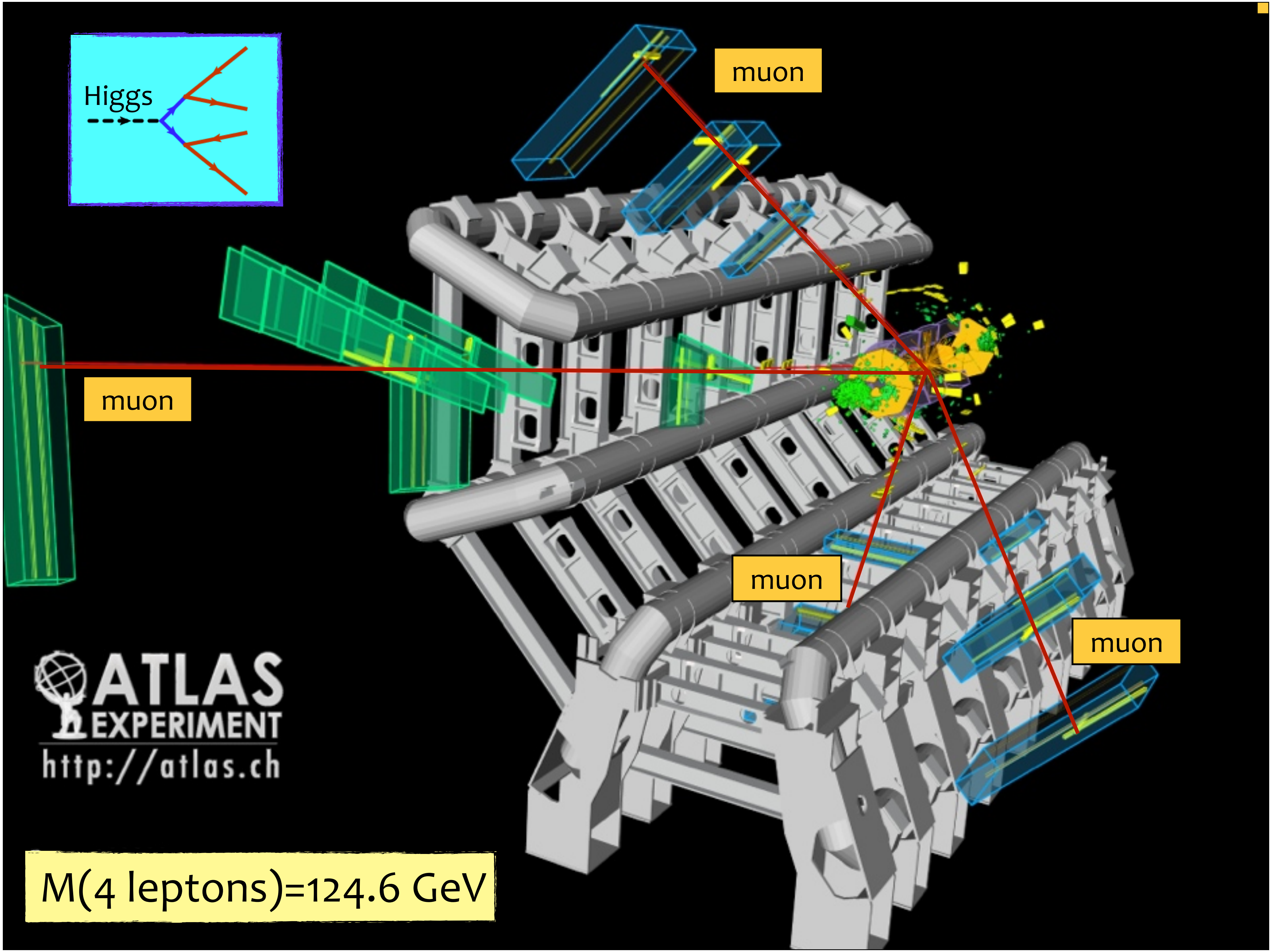
ATLAS EXPERIMENT

Run Number: 189483, Event Number: 90659667

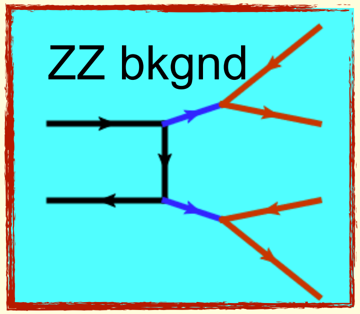
Date: 2011-09-19 10:11:20 CEST

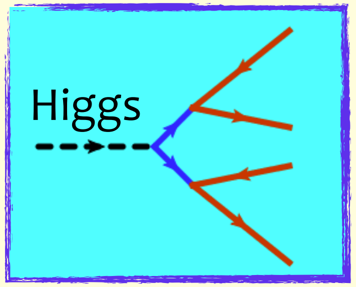
NIKHEF

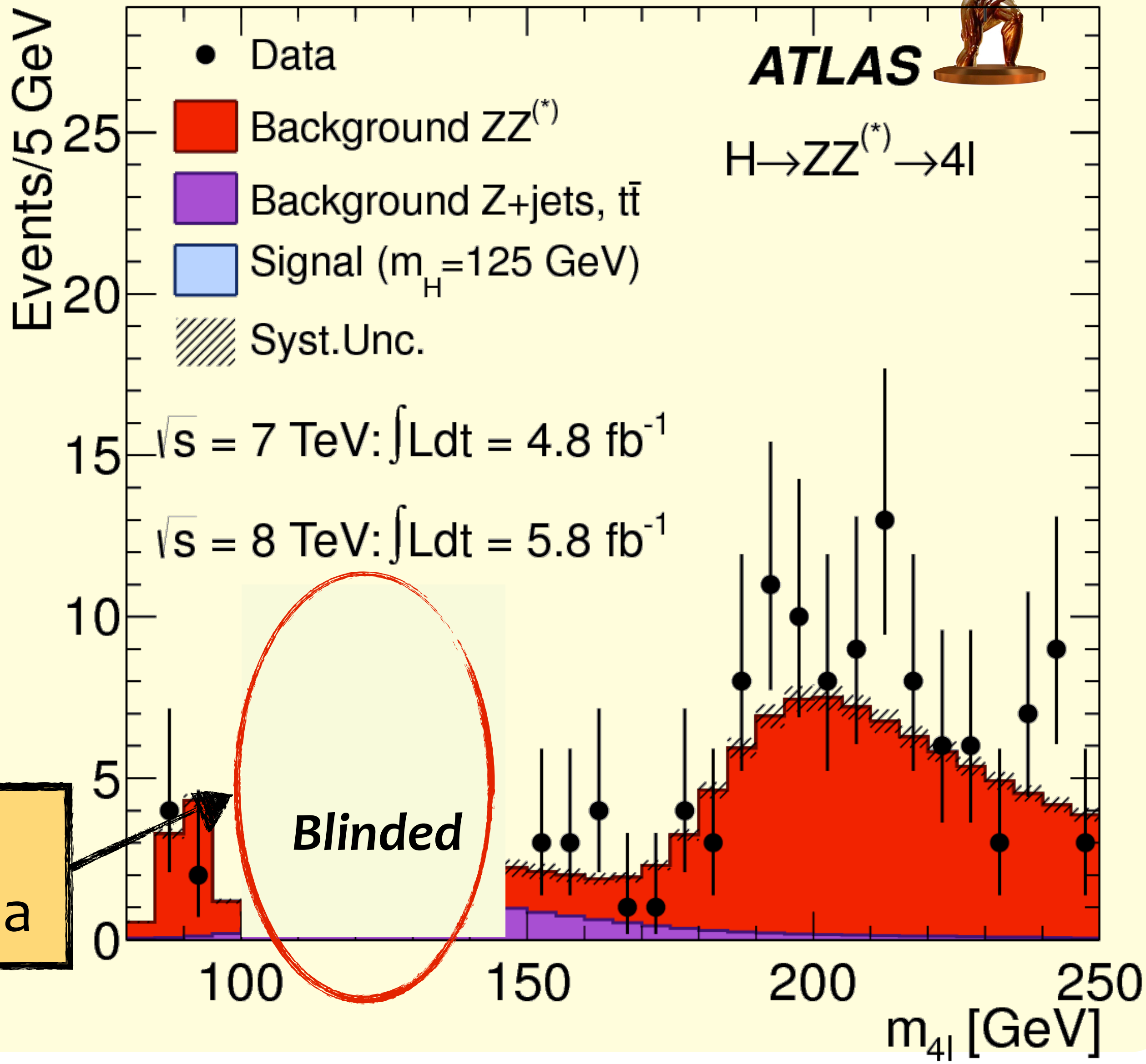

Higgs
muon
muon
muon
muon
Higgs → ZZ*→ 4μ candidate,
M(4 leptons)=125.1 GeV


Higgs
muon
muon
muon
muon
ATLAS EXPERIMENT
http://atlas.ch
M(4 leptons)=124.6 GeV

Higgs to leptons - July 2012



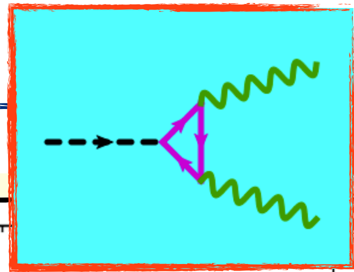




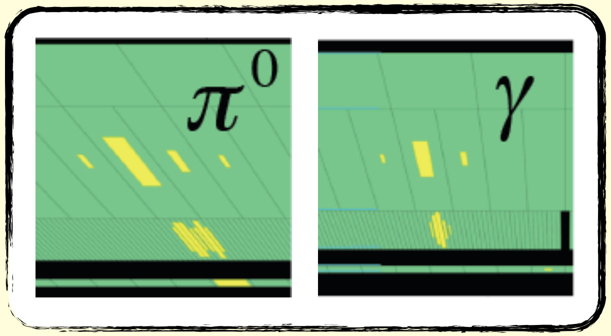
Maximum observed significance ~3.6 sigma

Higgs to 2 photons

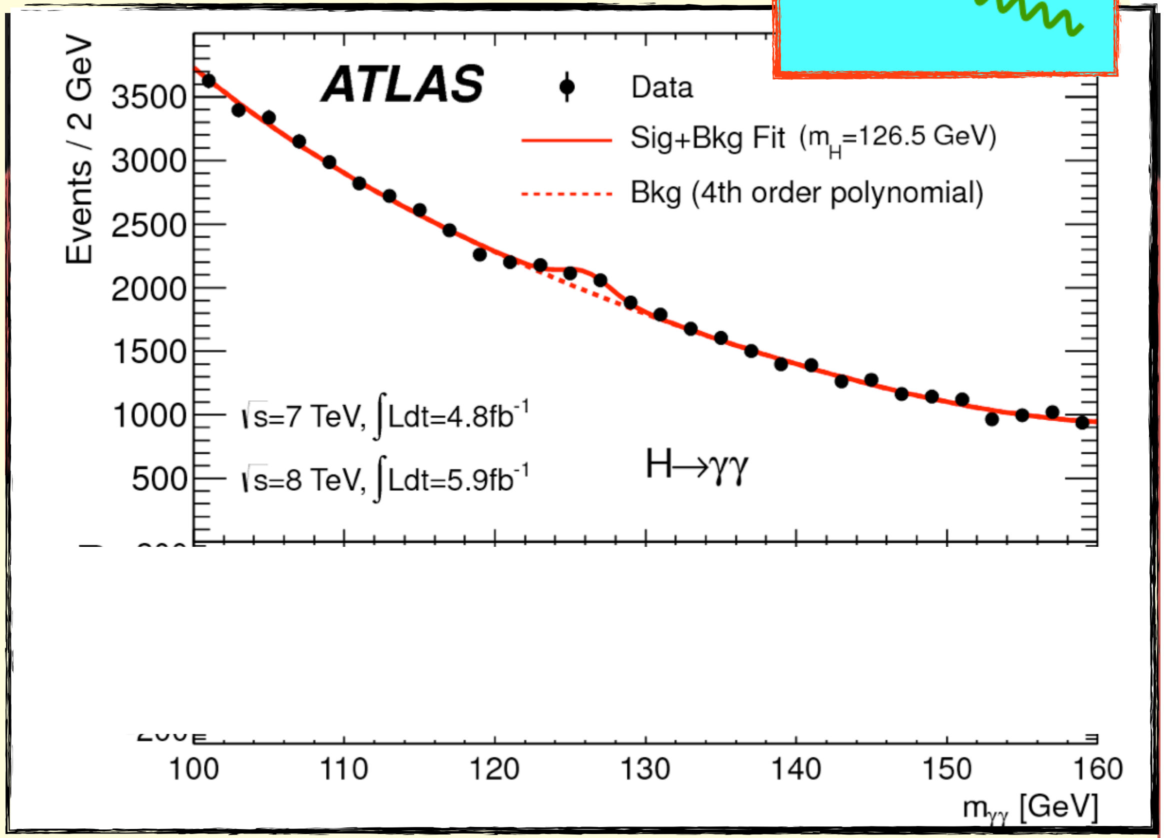
$H \rightarrow \gamma + \gamma$



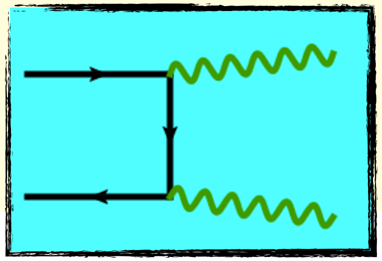
- Background
  - Fake photons
    - e.g. pion decay



Zoom energy deposition in calorimeter



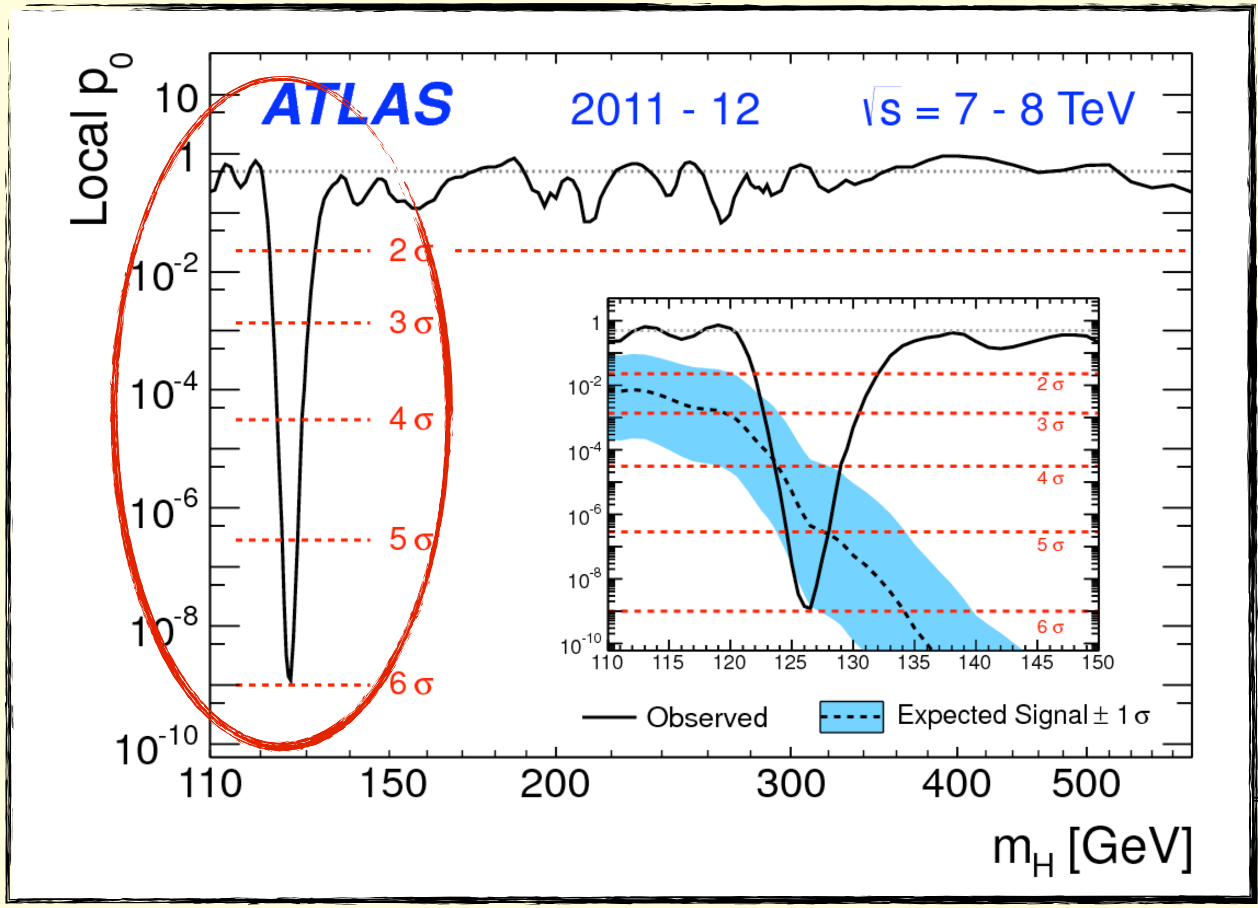
  - Prompt photons
    - non-Higgs channel

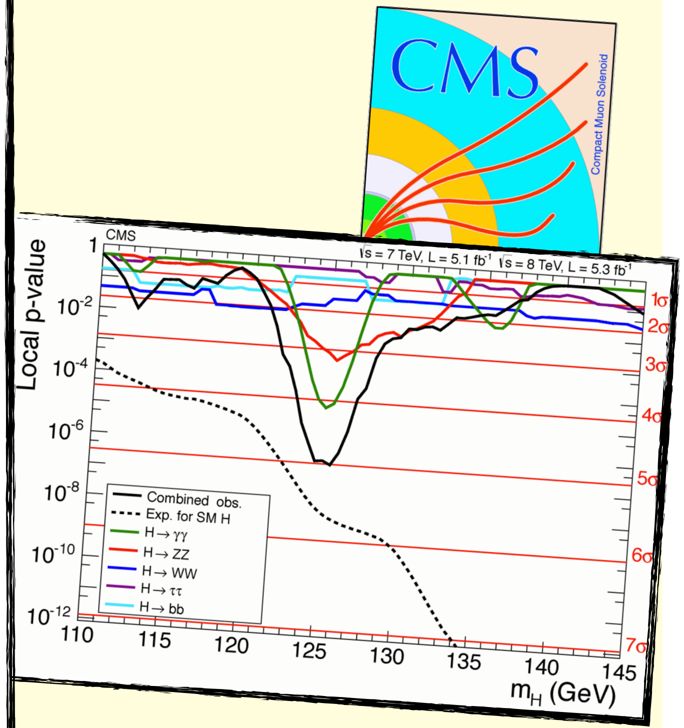


Maximum observed significance ~4.5 sigma

Scientific discovery: July 4th, 2012

- Calculate data significance for each mass



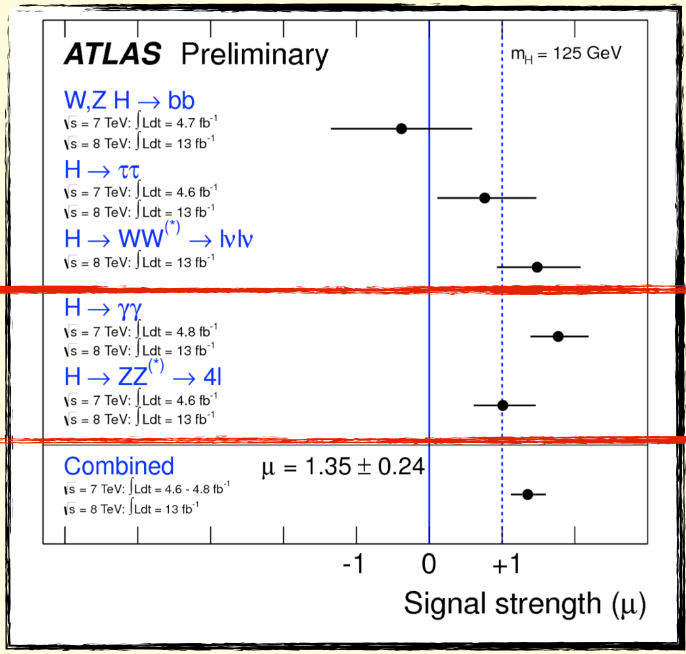


- Mass: 126.0±0.4(stat)±0.4(syst) GeV

Public announcement, July 4th 2012

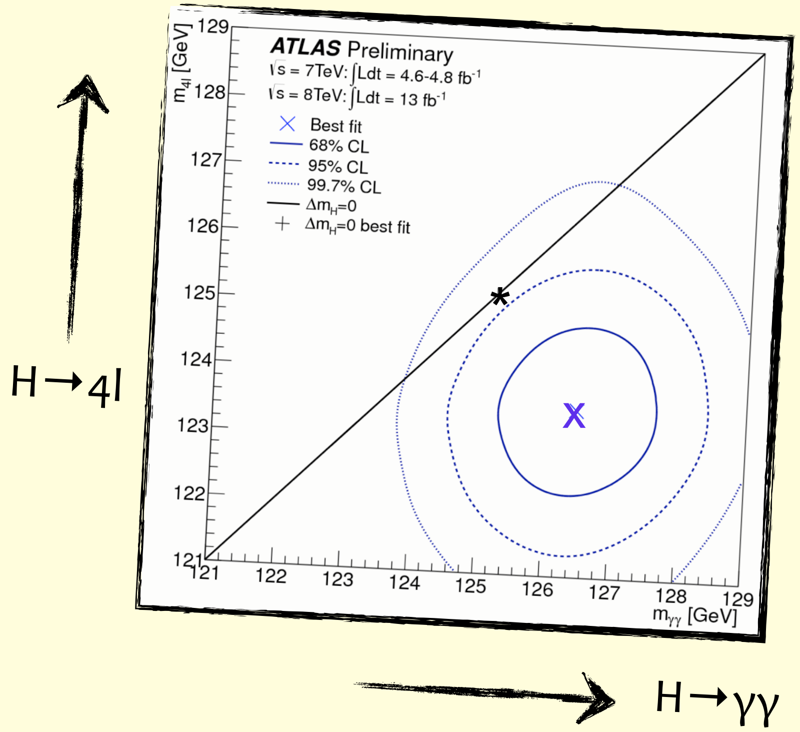
Since July 4th, 2012

- Is it a *Standard Model* Higgs?
  - Couplings to boson/fermions?



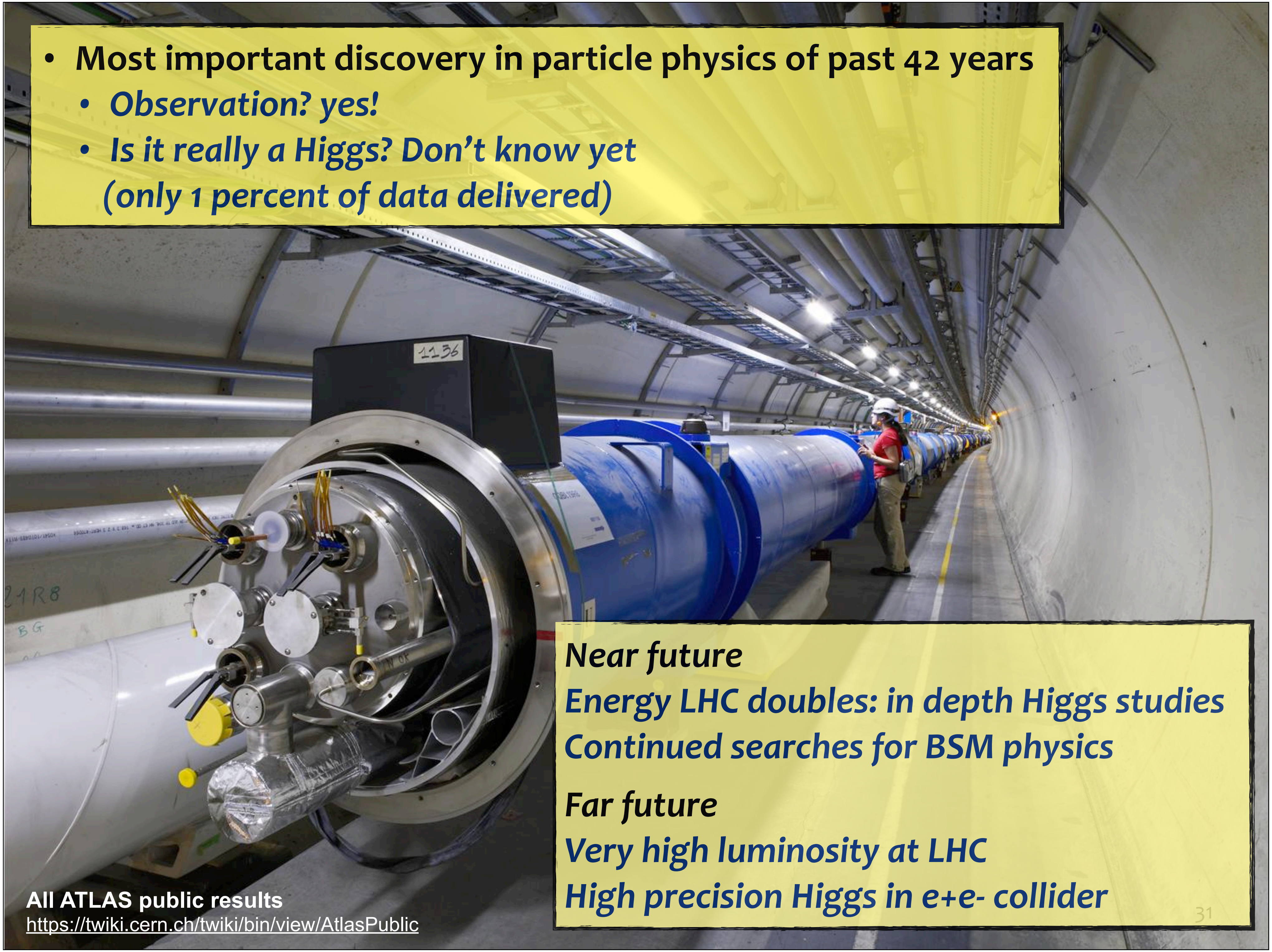
  - Much more collisions needed
- Determination spin
  - Results disclosed soon

Intriguing:
M(H→γγ) ≠ M(H→4l)?



Approximately 2/3 total data set (2011+2012) unblinded

- **Most important discovery in particle physics of past 42 years**
  - *Observation? yes!*
  - *Is it really a Higgs? Don't know yet (only 1 percent of data delivered)*



Near future

Energy LHC doubles: in depth Higgs studies

Continued searches for BSM physics

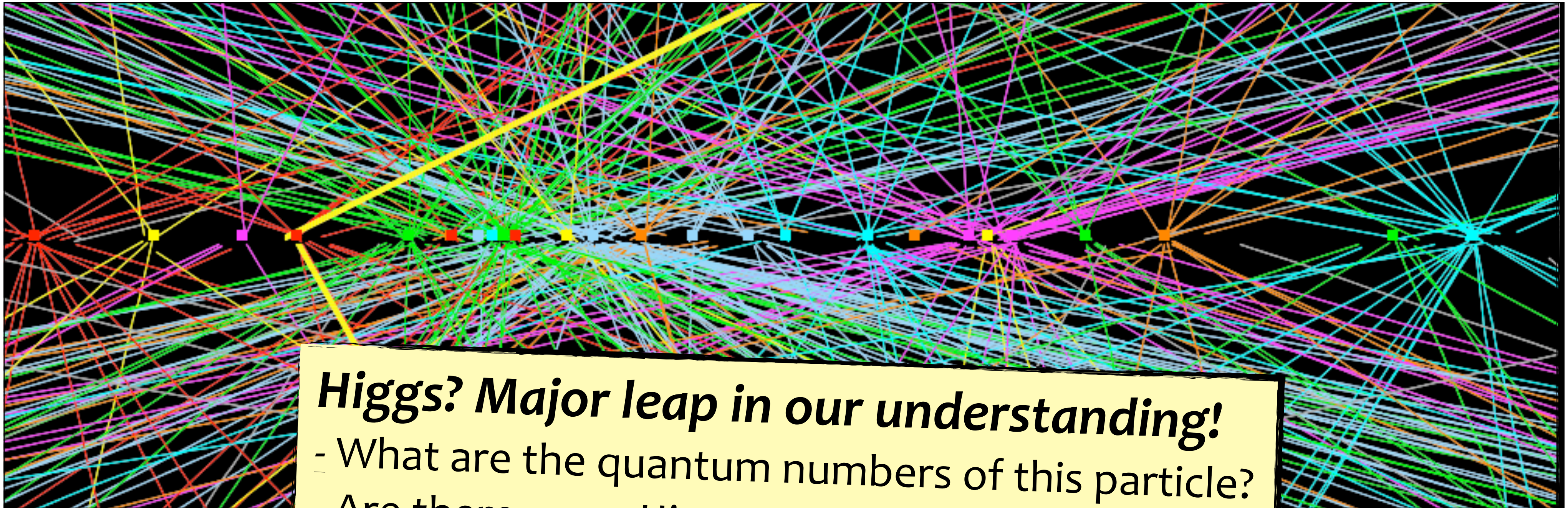
Far future

Very high luminosity at LHC

High precision Higgs in e+e- collider

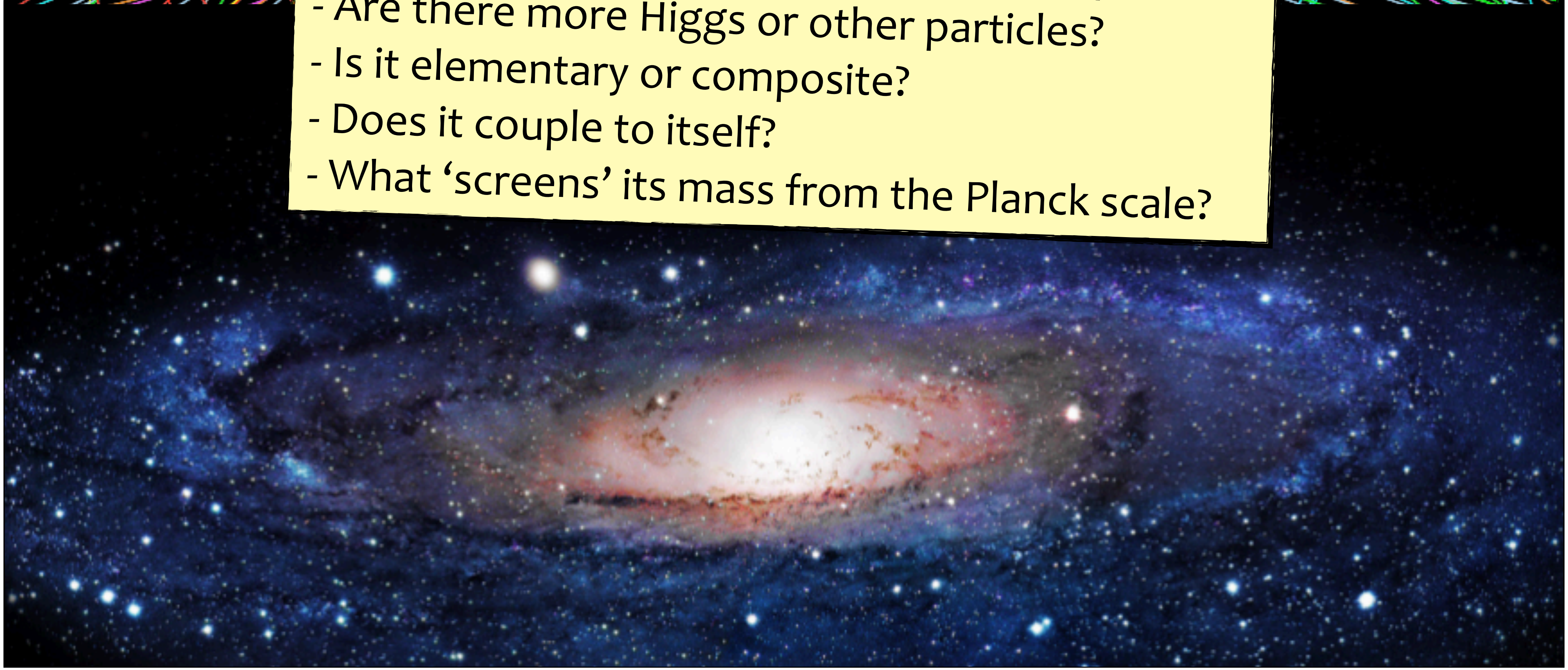
All ATLAS public results

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



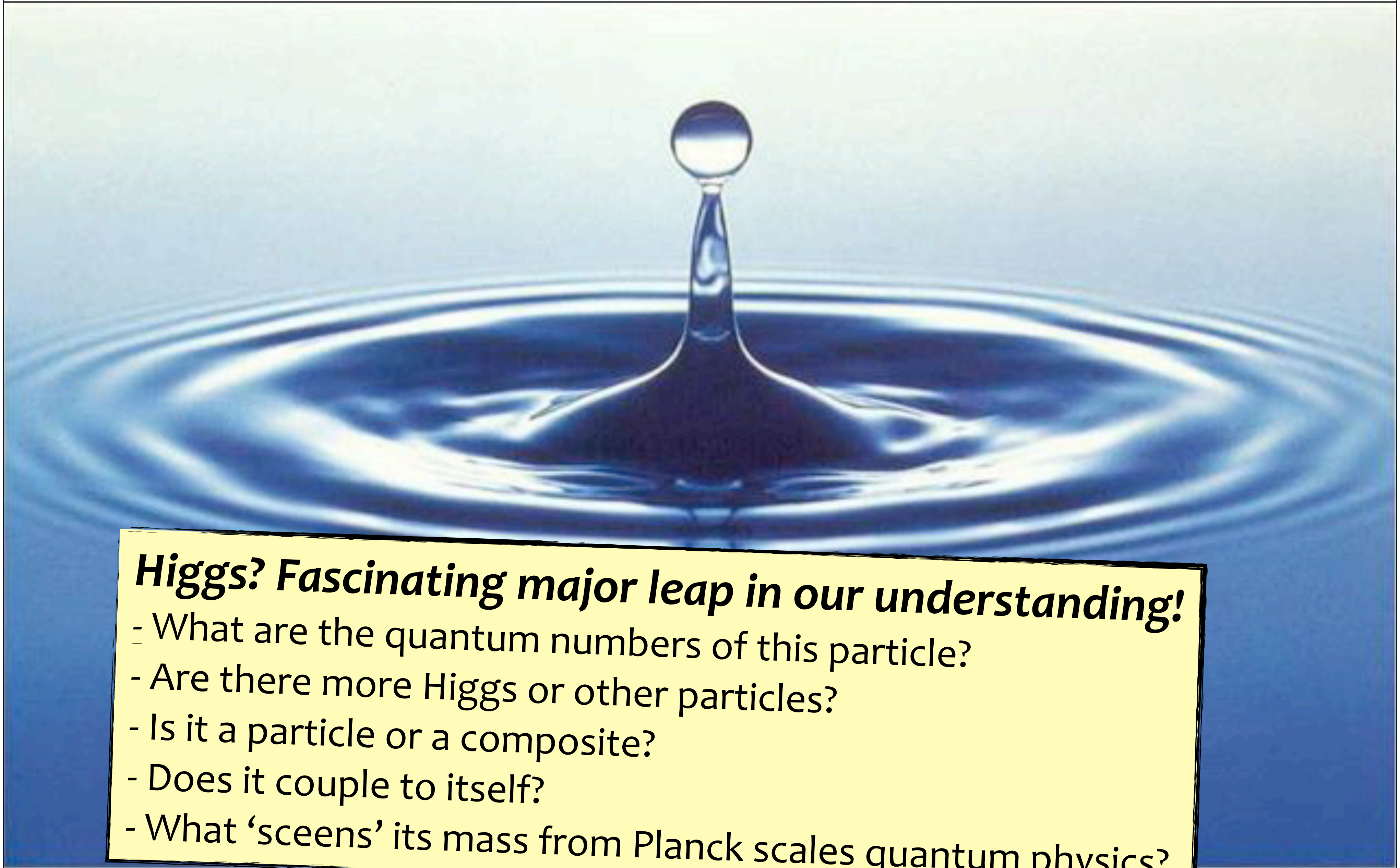
Higgs? Major leap in our understanding!

- What are the quantum numbers of this particle?
- Are there more Higgs or other particles?
- Is it elementary or composite?
- Does it couple to itself?
- What 'screens' its mass from the Planck scale?



the end

Beyond the Higgs



Higgs? Fascinating major leap in our understanding!

- What are the quantum numbers of this particle?
- Are there more Higgs or other particles?
- Is it a particle or a composite?
- Does it couple to itself?
- What ‘sceens’ its mass from Planck scales quantum physics?

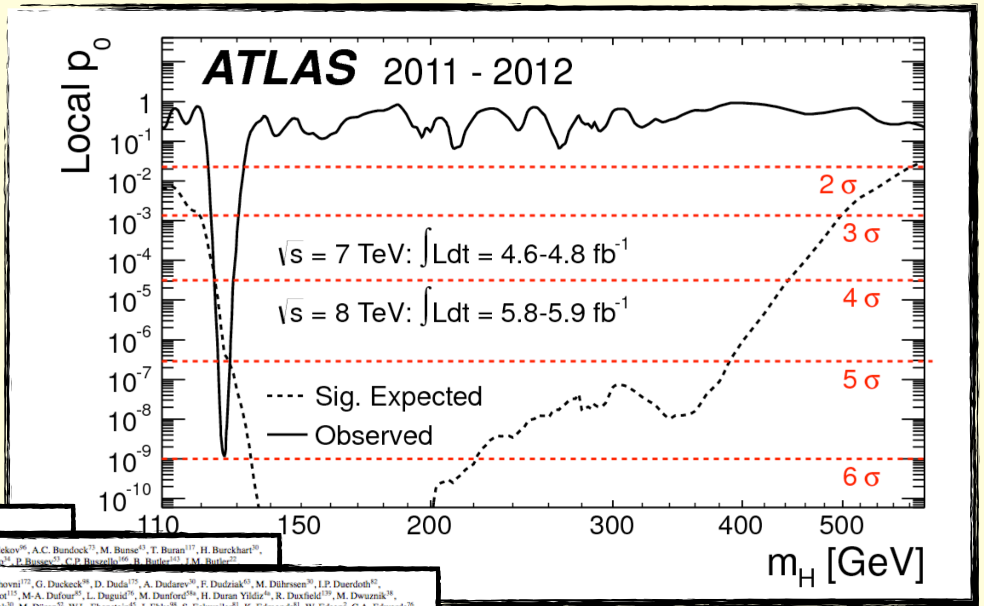
Higgs found - check - particle physics solved?

- NO - because:
  - Properties Higgs
    - s=0
    - self coupling?
  - Conceptual problems
    - Quantum gravity
    - Hierarchy problem
    - Flavor puzzle
  - Experimental clues
    - Neutrino masses
    - Coupling unification
    - Dark matter
    - Baryogenesis
    - ....

Solutions to hierarchy problem?

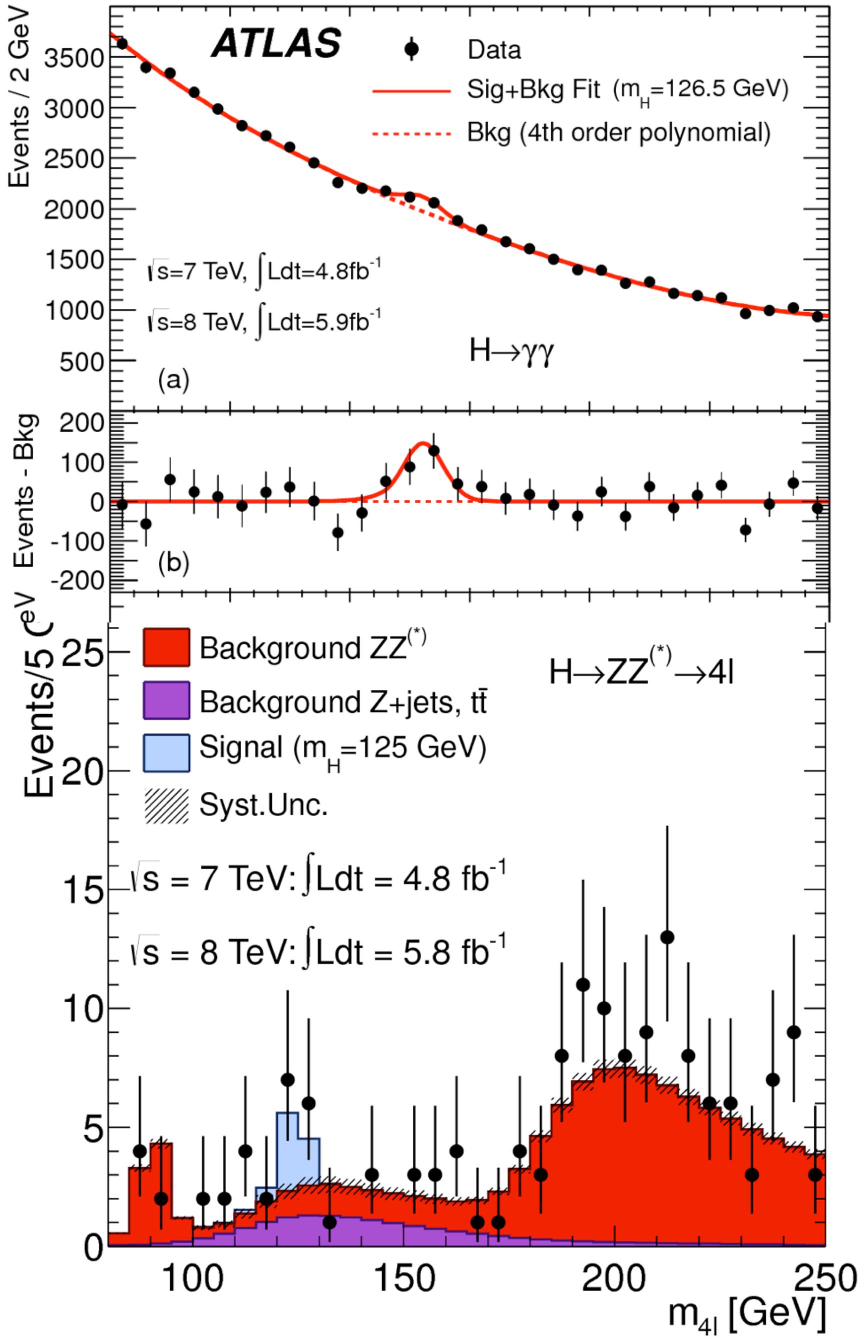
- supersymmetry: boson-fermion symmetry
- Higgs as condensate: no fundamental scalars
- Extra symmetries: non - perturbative regime around 10 TeV ("Little Higgs")
- Extra space-time dimensions
- The anthropic principle ...

Publication - international collaboration



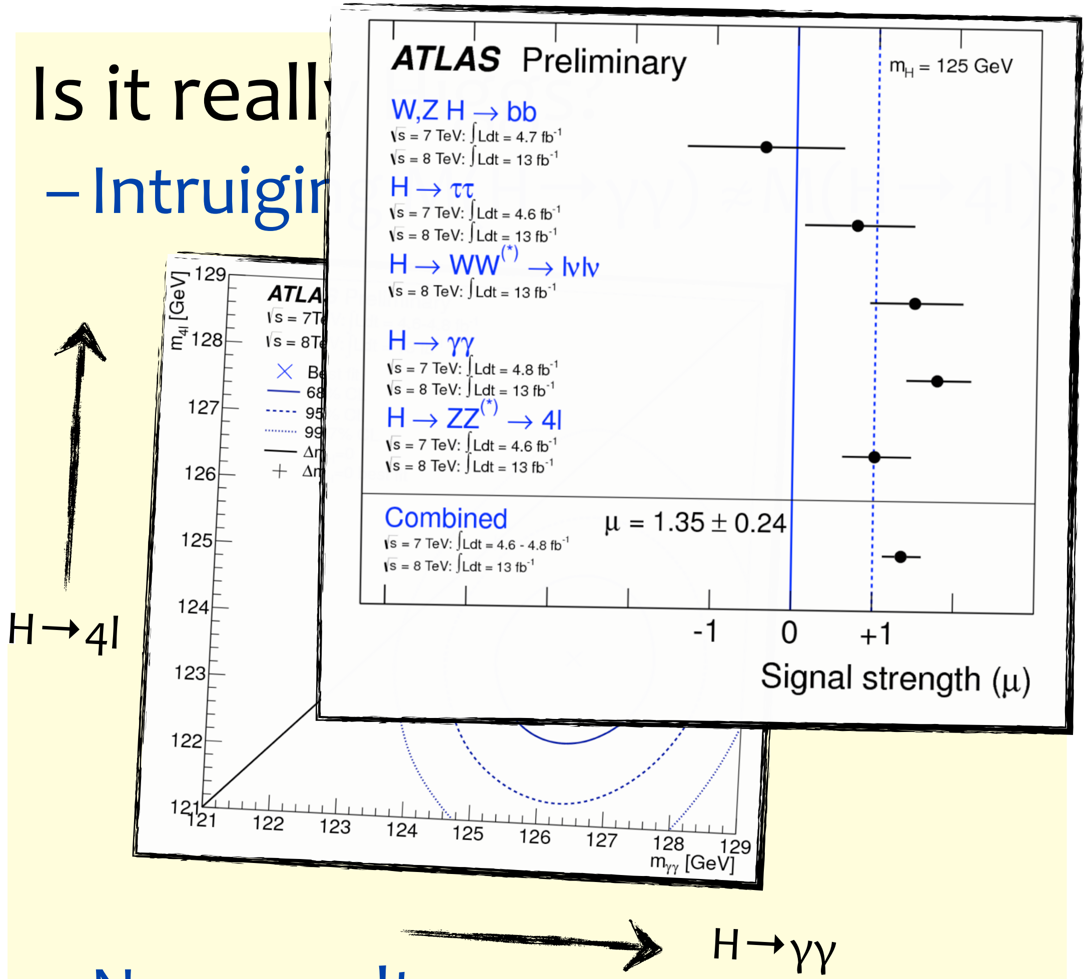
The ATLAS Collaboration

Progress since July



Is it really …?

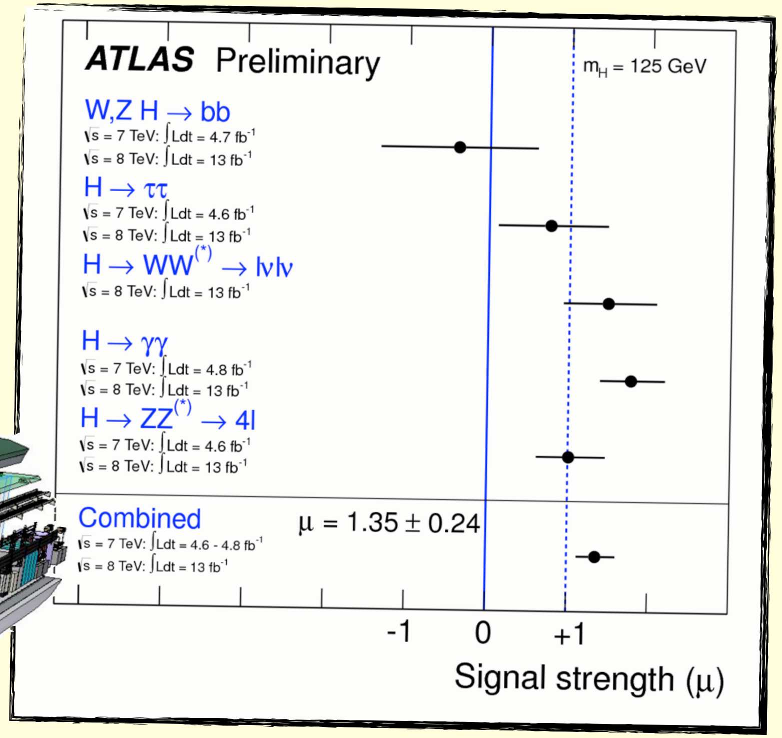
– Intruiging …

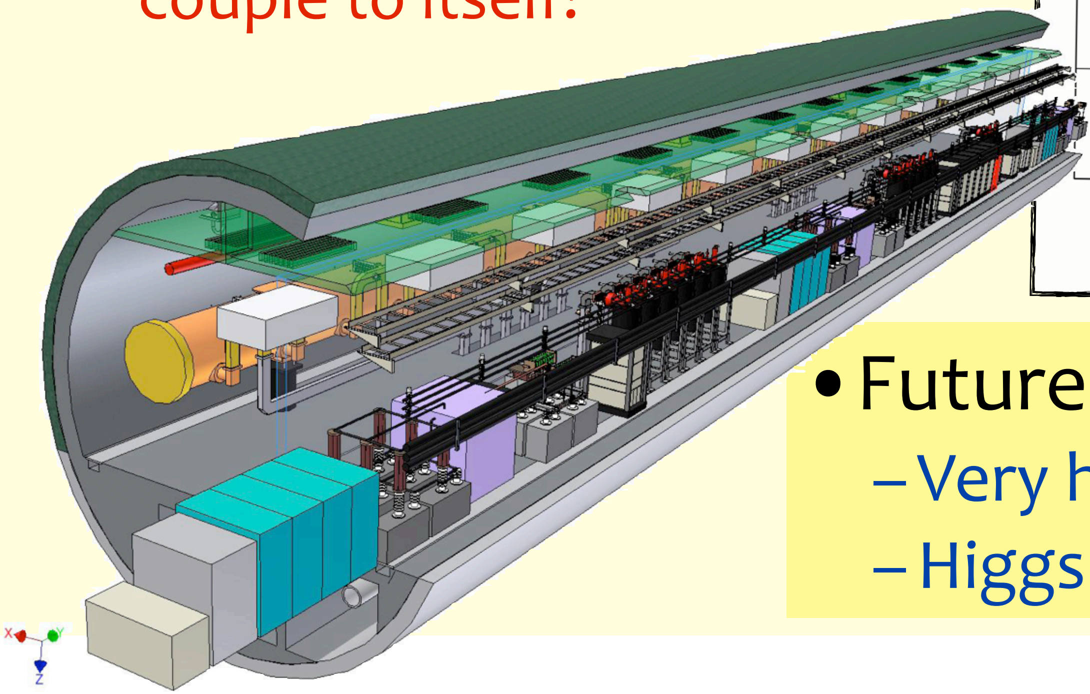


– New results
  - couplings to boson/fermions
  - Spin Higgs disclosed soon

More puzzles - Higgs?

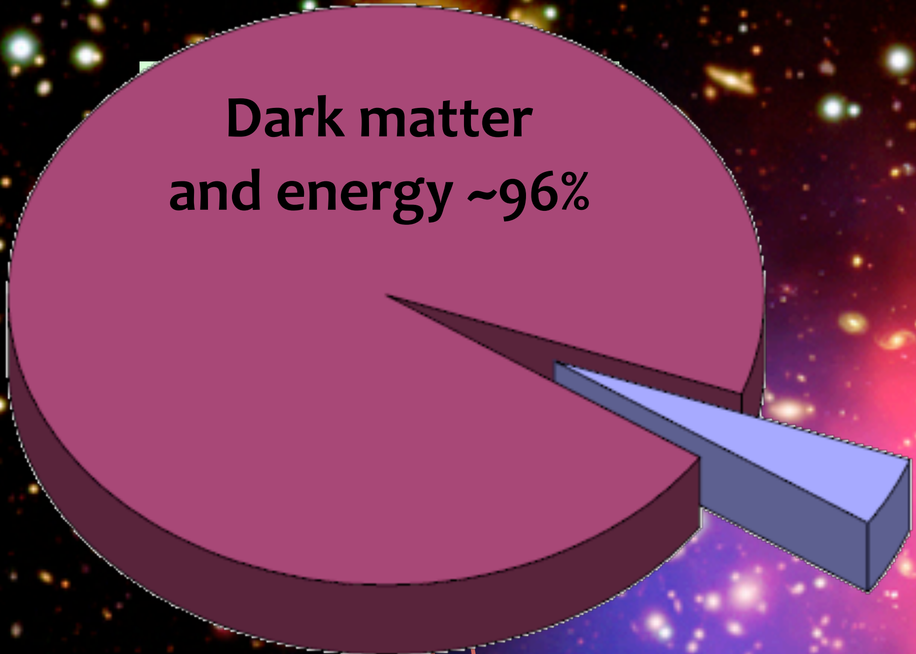
- Which role does this particle play in Standard Model?
  - Window to new physics
    - Couplings as predicted?
    - Is Higgs spin-0 boson?
  - Understanding its dynamics
    - How does Higgs couple to itself?





- Future music
  - Very high luminosity at LHC
  - Higgs in e^+e^- collider

Identification Dark Matter?



Dark matter is cold (non relativistic at freeze out), hot dark matter disfavored

WIMP with mass 10^1 - 10^3 GeV good candidates

For WIMPs in thermal equilibrium after inflation, their couplings are typical for weak cross sections

LHC has good chance of finding WIMPs!

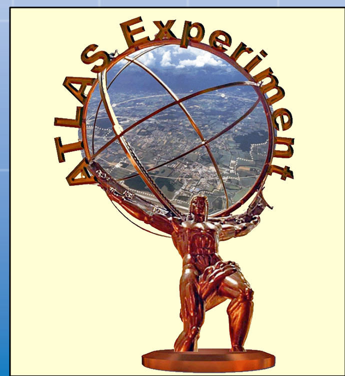
Supersymmetry supports Dark Matter candidates: neutralino's as LSP's

Crucial question for LHC: is dark matter a WIMP?

What an extraordinary time !

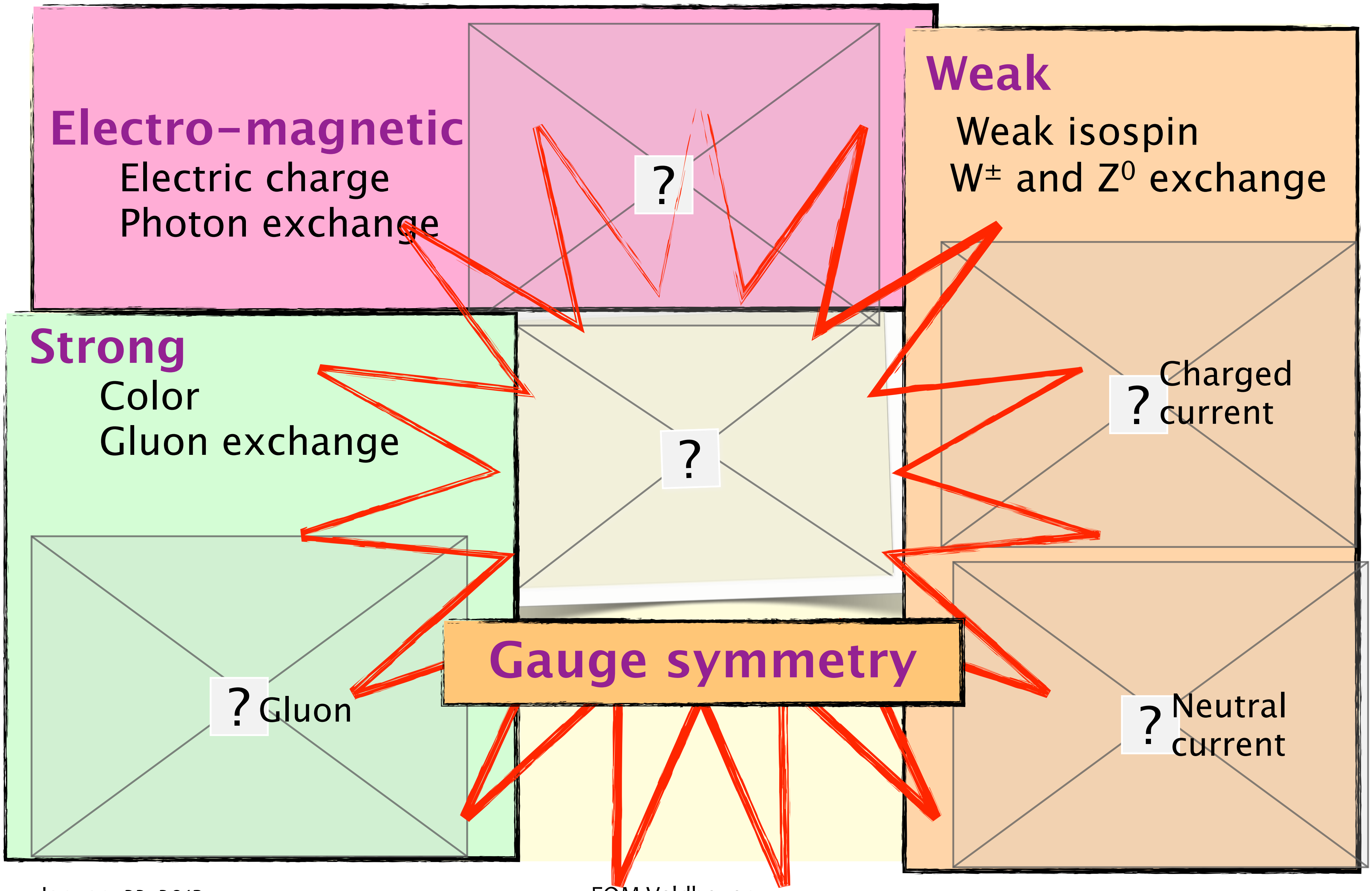
Argentina
Armenia
Australia
Austria
Azerbaijan
Belarus
Brazil
Canada
Chile
China
Colombia
Czech Republic
Denmark
France
Georgia
Germany
Greece
Israel
Italy
Japan
Morocco
Netherlands
Norway
Poland
Portugal
Romania
Russia
Serbia
Slovakia
Slovenia
South Africa
Spain
Sweden
Switzerland
Taiwan
Turkey
UK
USA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

ATLAS Collaboration

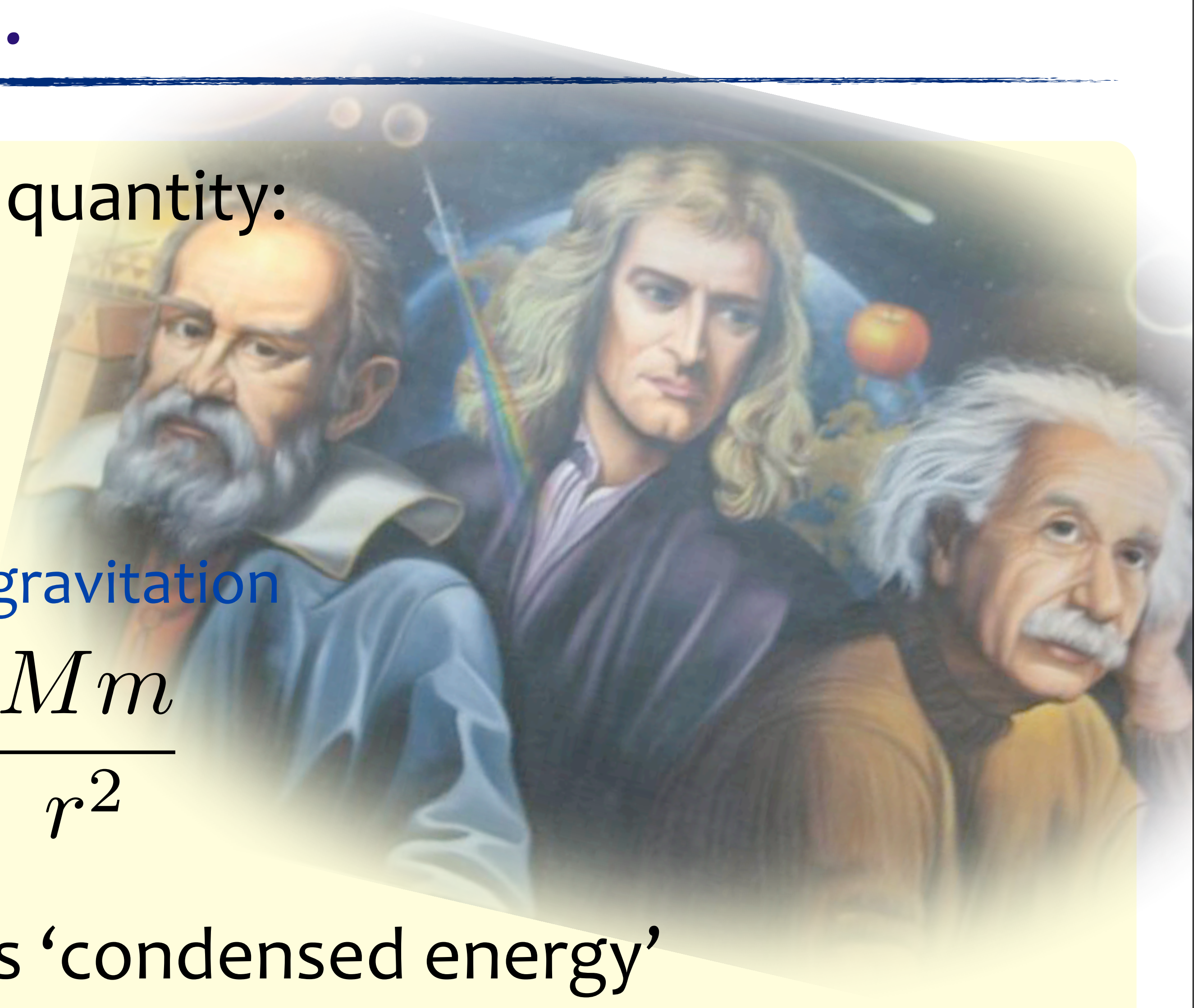


July 2010

Fundamental interactions



An open issue ...



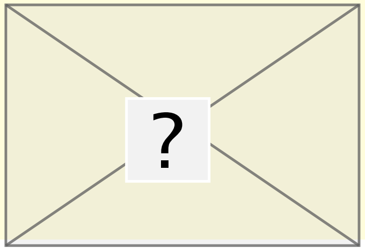
- Mass: conserved quantity:
  - Mass = inertia

$$F = ma$$

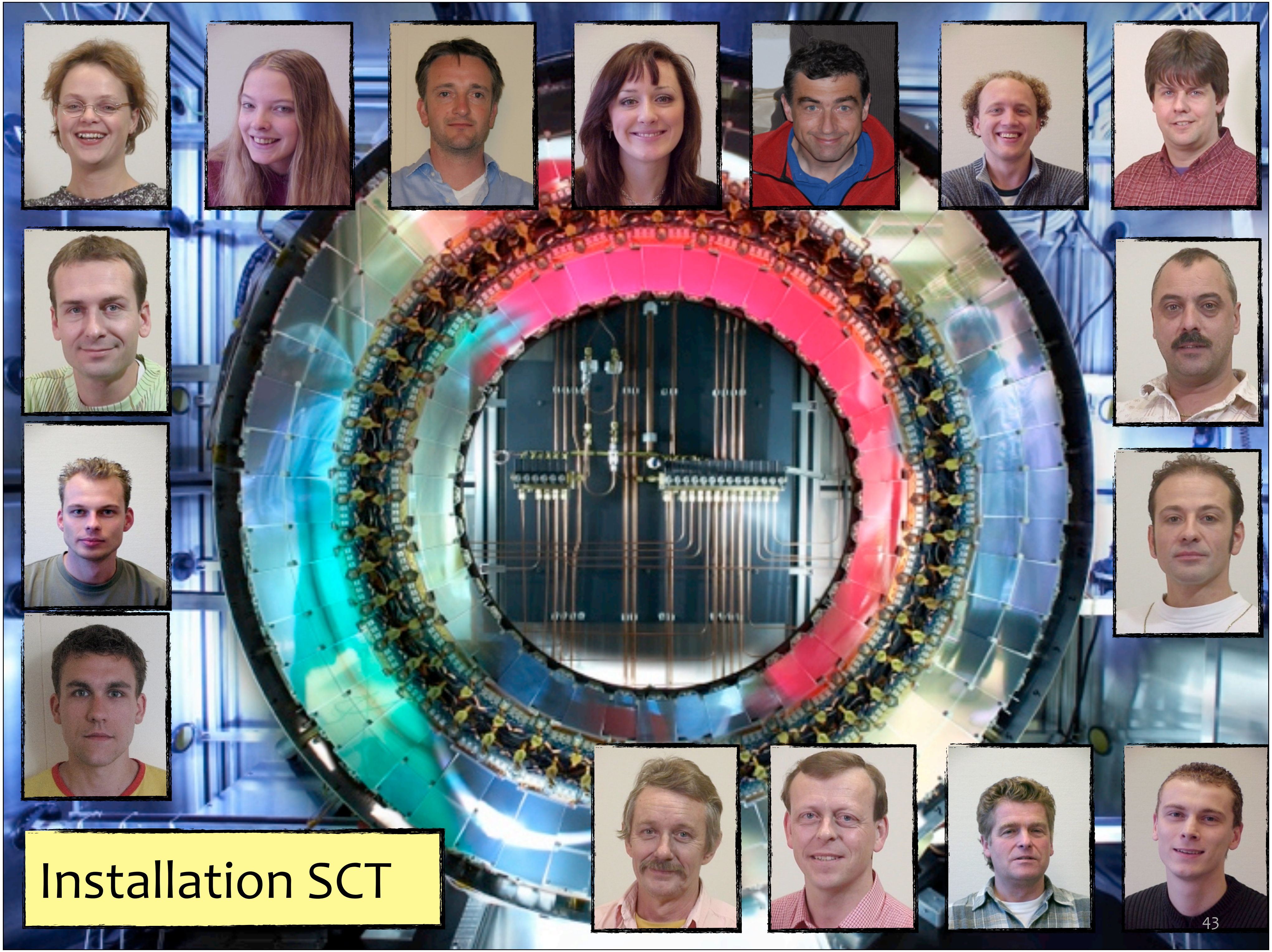
  - Mass = source of gravitation

$$F = -G\frac{Mm}{r^2}$$

- Einstein's mass as 'condensed energy'



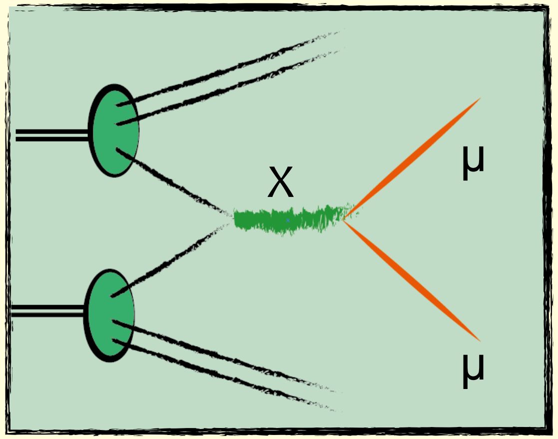
But what is 'particle mass'?

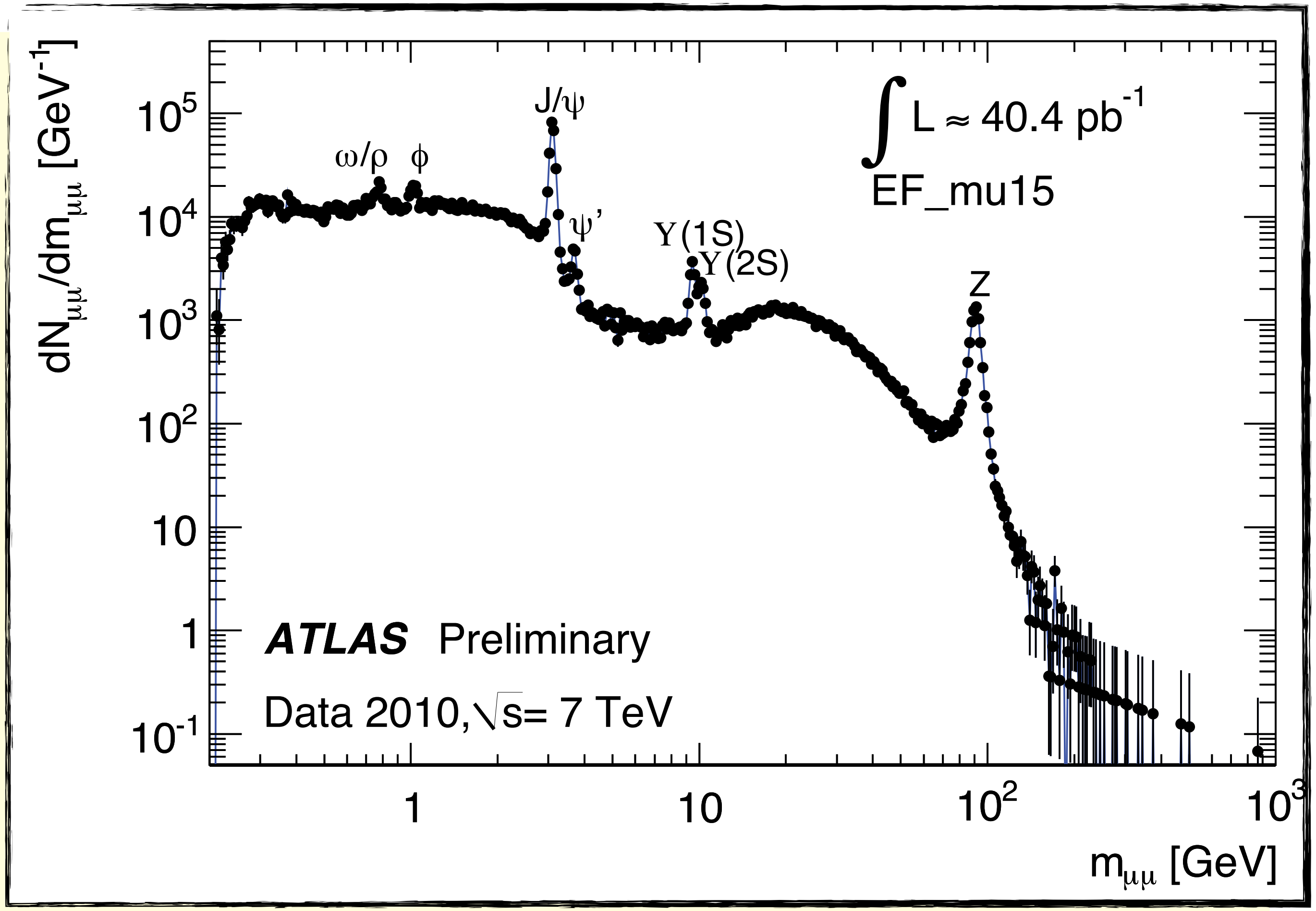

Installation SCT


enko in muon chambers

Peaks: re-discovery of 20th century physics

Resonance particles decay to two muons



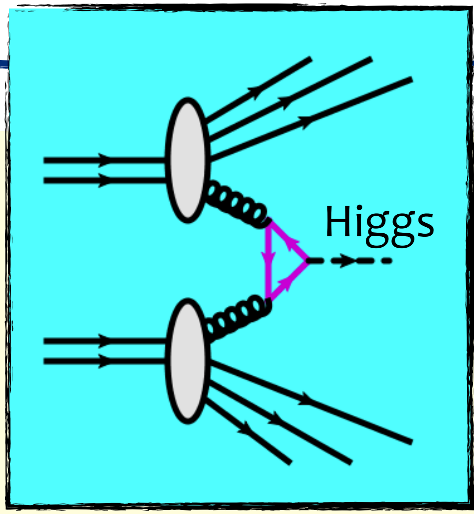


Caluclate mass of resonances with final state muons

All known particles are found back!

Search for the Higgs

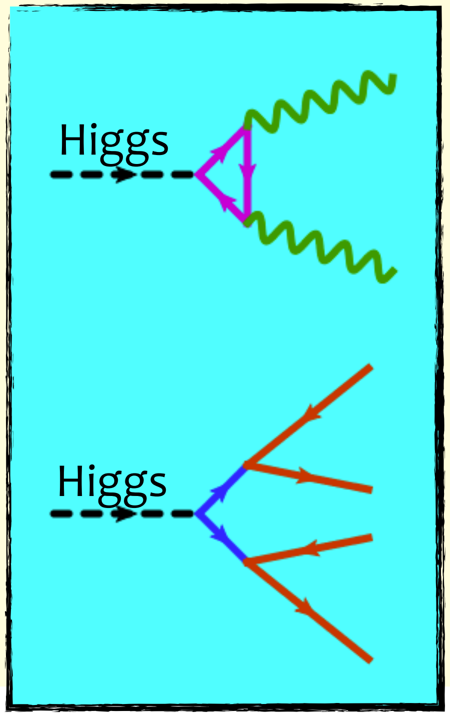
- 'Production' of Higgs
  - a number of processes



Produced in 2012
m_H=125 GeV: 212.000
m_H=200 GeV: 77.000

- 'Decay' of the Higgs

"Signal"



Higgs decay to photons

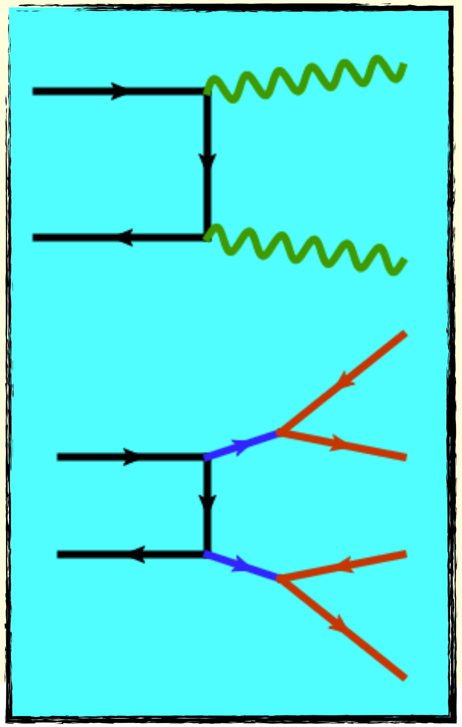
$$H \to \gamma + \gamma$$

Higgs decay to leptons

$$H \to ZZ^* \to 4 \text{ leptons}$$

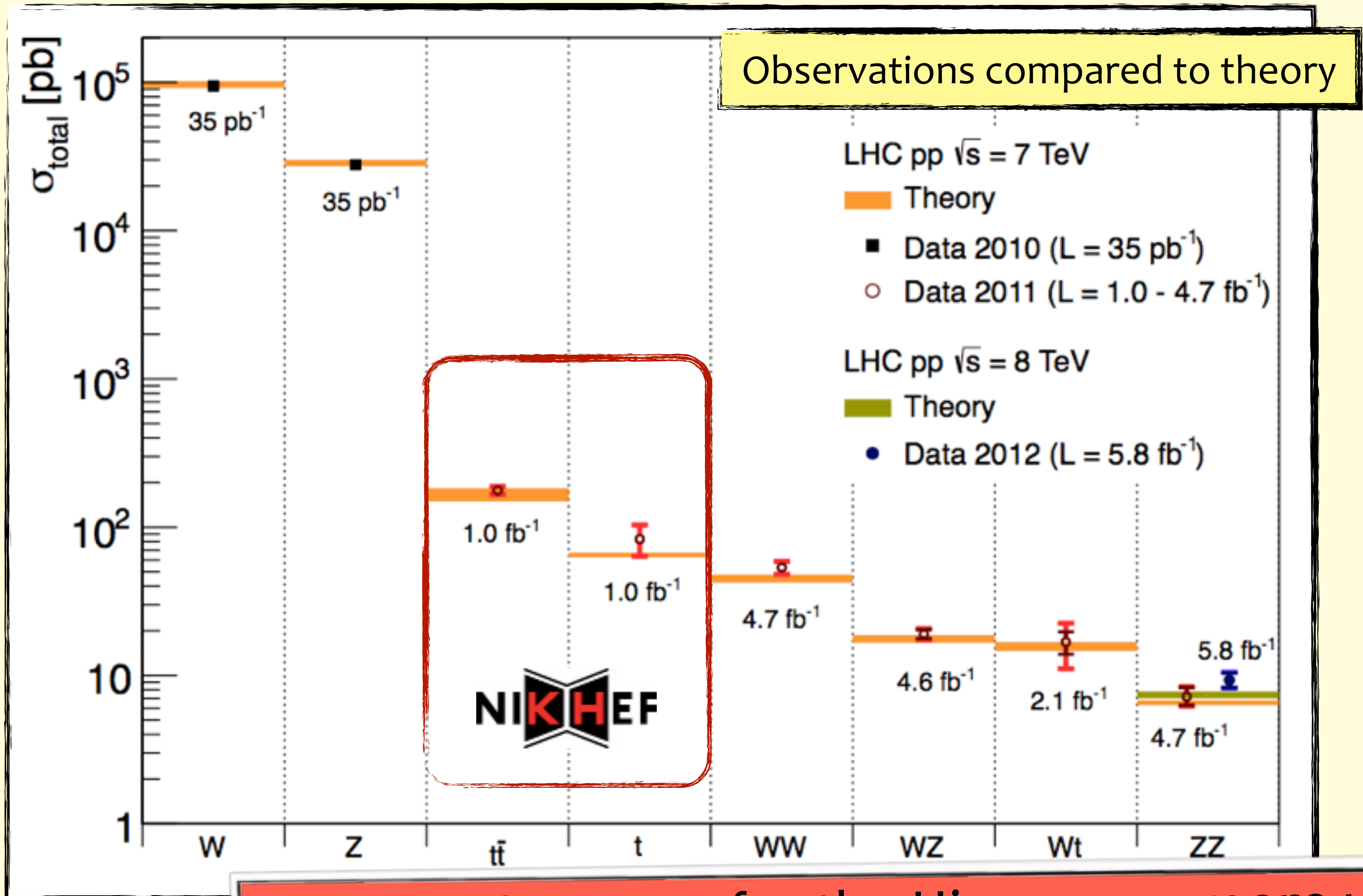
... and more decay

"Background"



Summary of '*tour-de-force*'

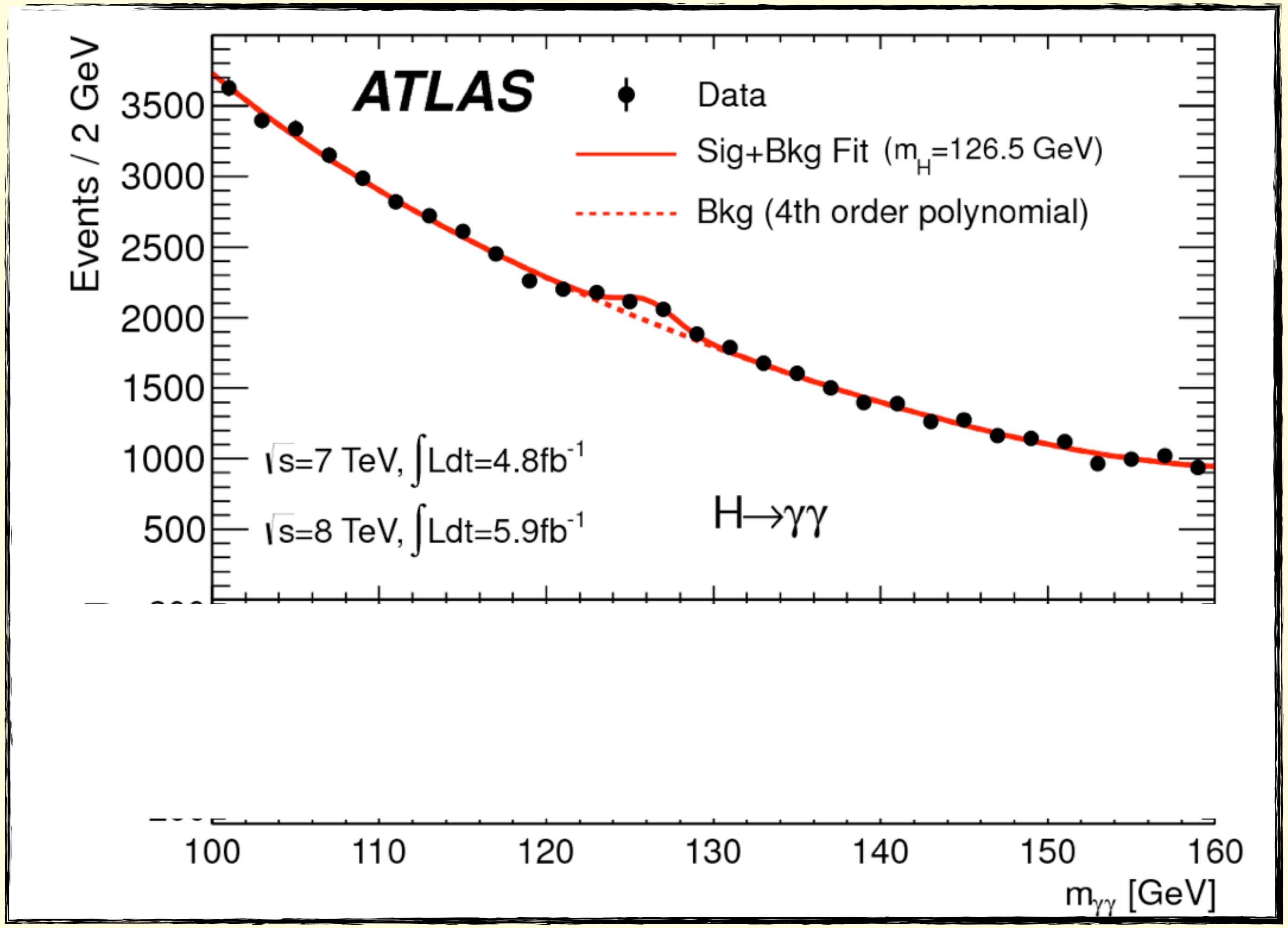
- Standard Model reigns at 7+8 TeV!

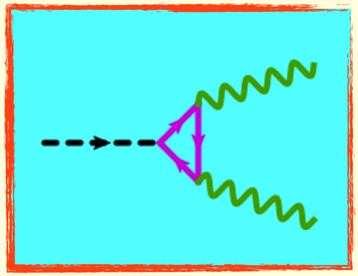


It makes the quest for the Higgs even more urgent

The ATLAS data

- H→γγ: very rare

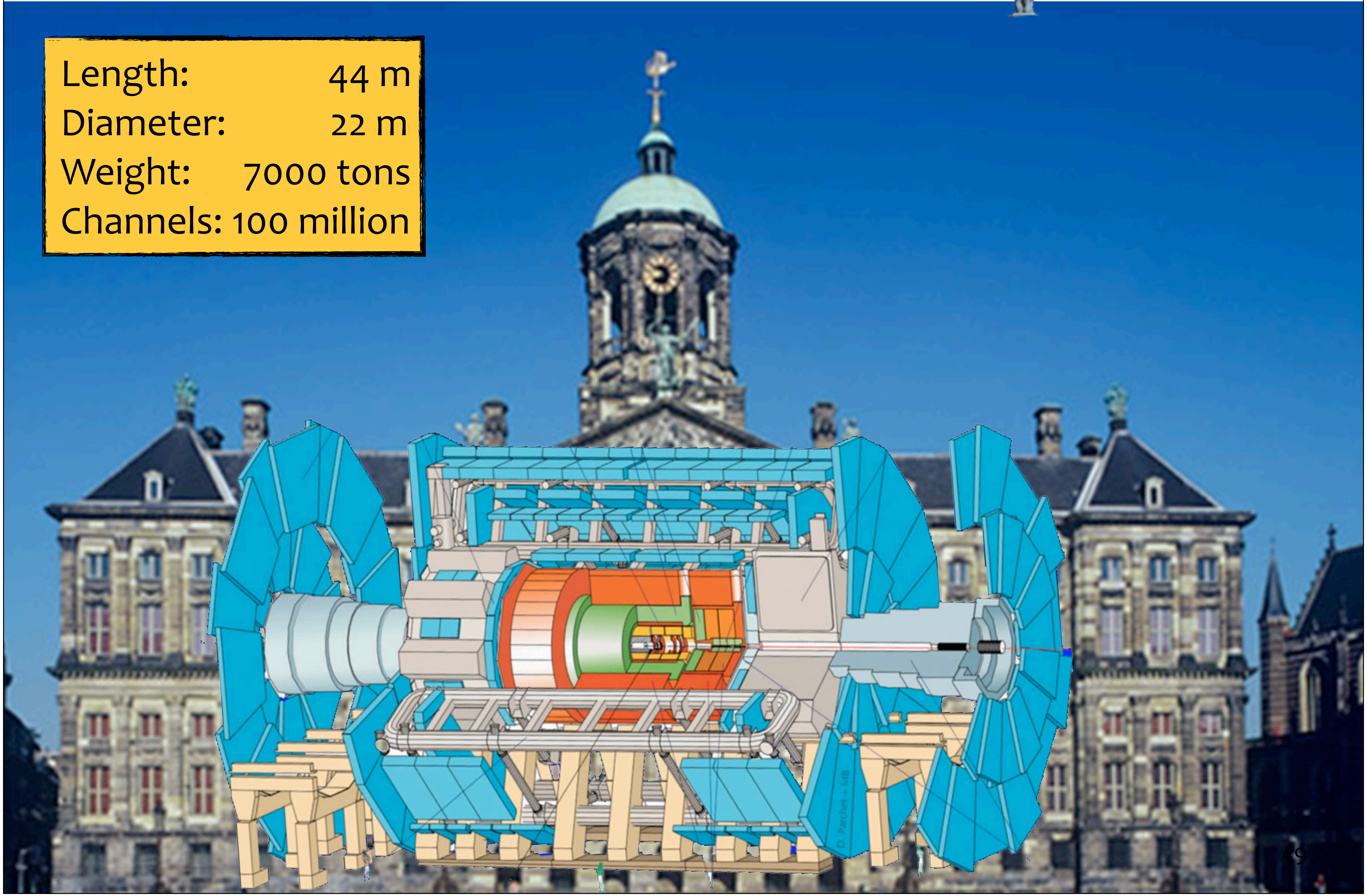




Maximum observed local significance ~4.5 sigma

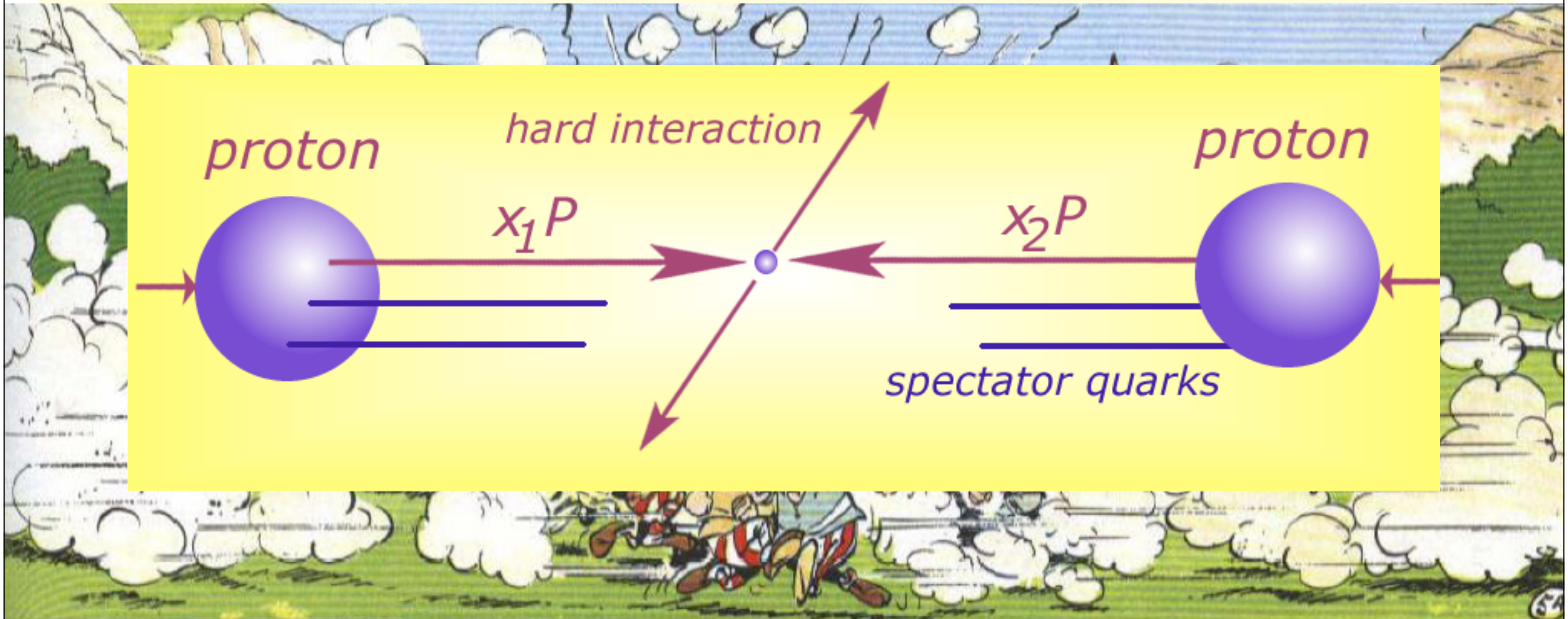
ATLAS: *the detector*

Length:	44 m
Diameter:	22 m
Weight:	7000 tons
Channels:	100 million

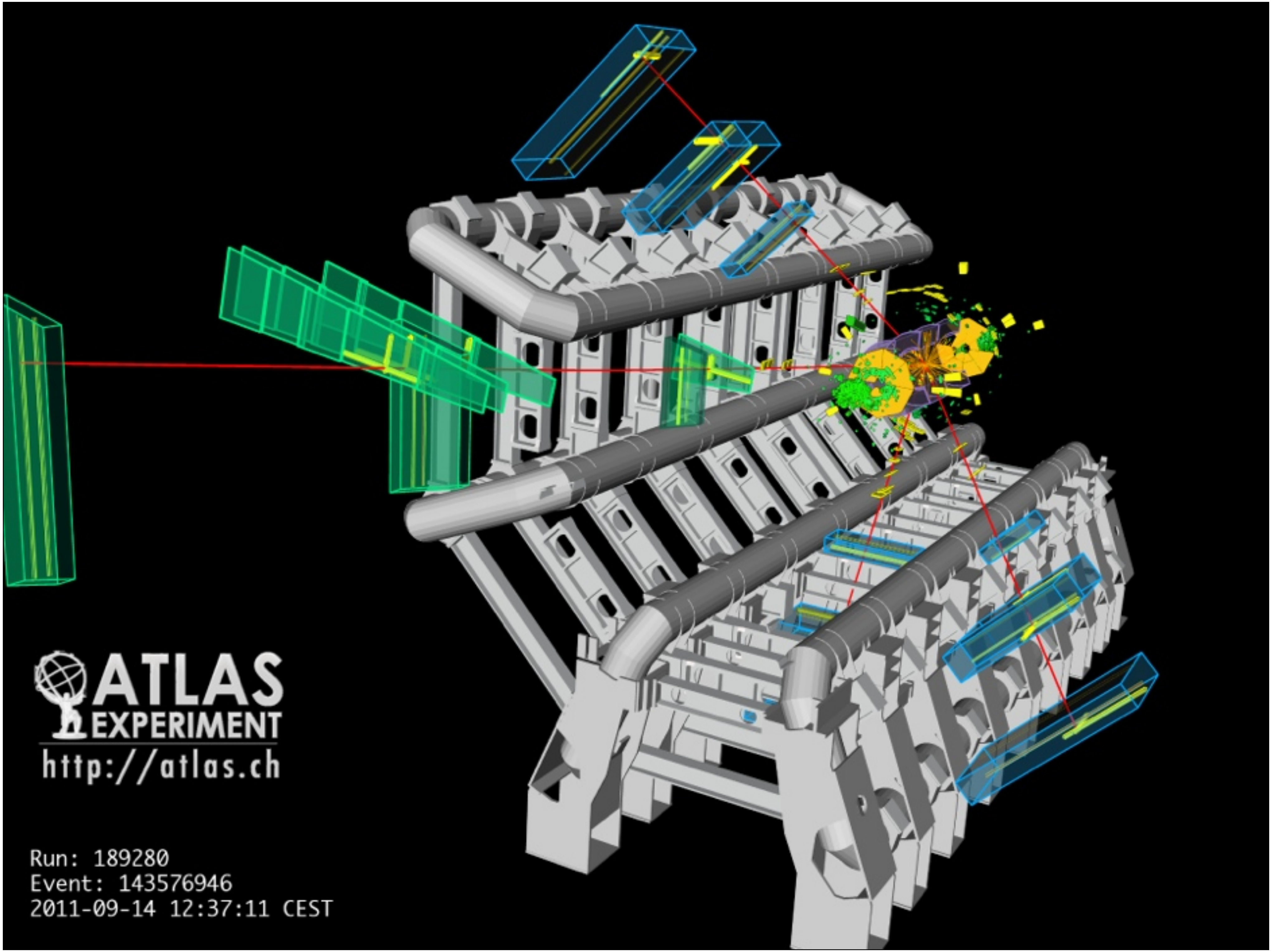


Phenomenology

- 'Hard' interactions
  - proton as bag full of (anti-) quarks and gluons

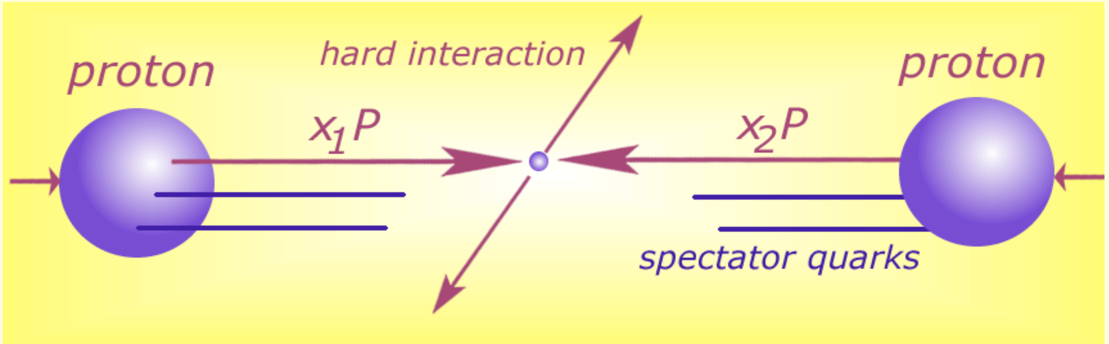


  - fraction of energy available for hard interaction

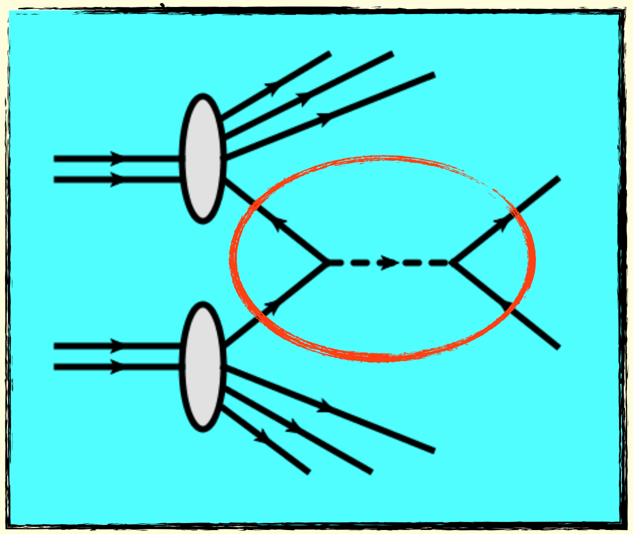

ATLAS
EXPERIMENT
http://atlas.ch
Run: 189280
Event: 143576946
2011-09-14 12:37:11 CEST

Collisions in practice

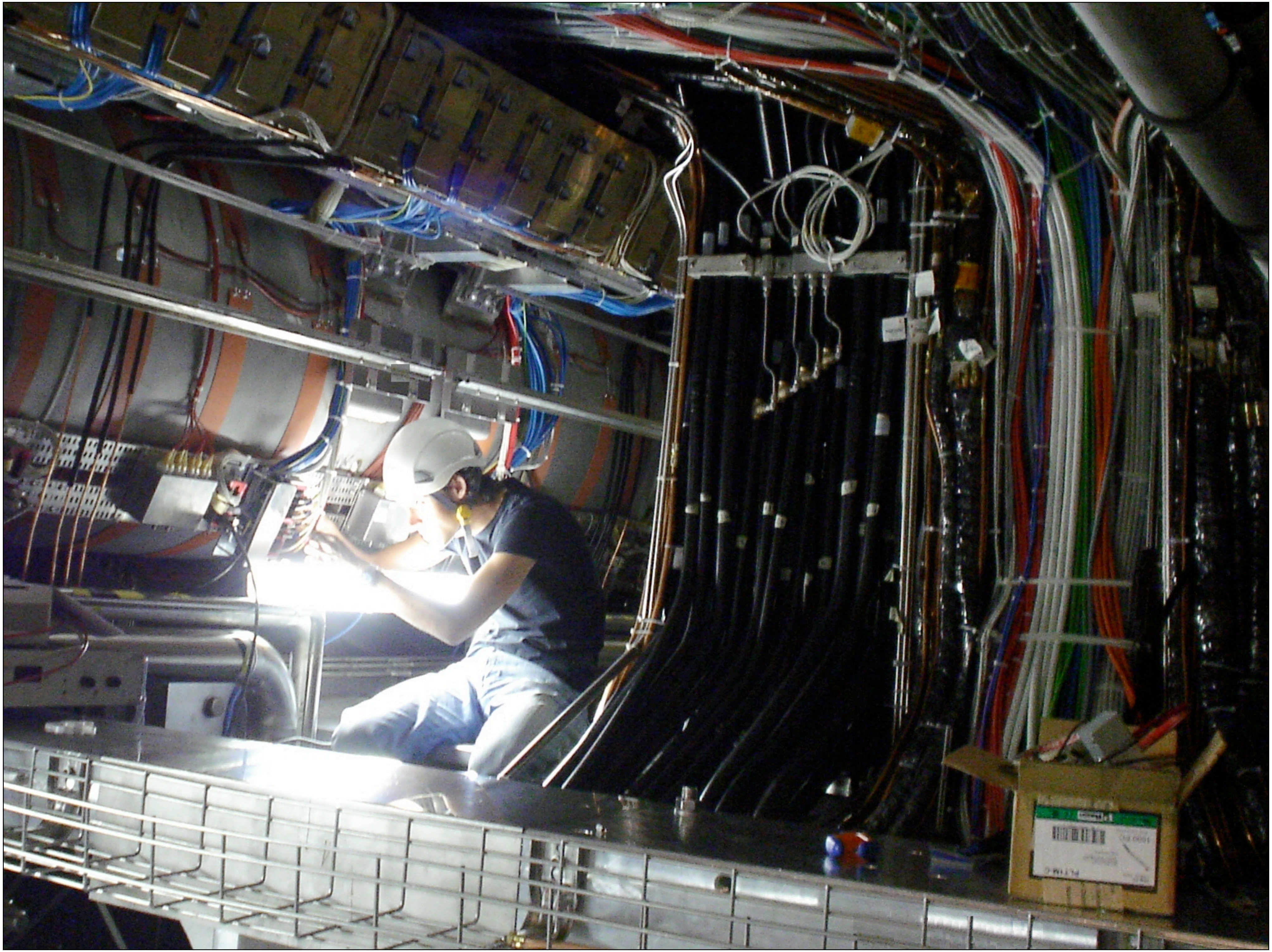
- LHC collisions 24/7
  - From March to December
  - Machine cycle:
    - Fill with bunches
    - Ramp-up energy
    - Collisions (~10 hrs)
    - Empty machine
  -



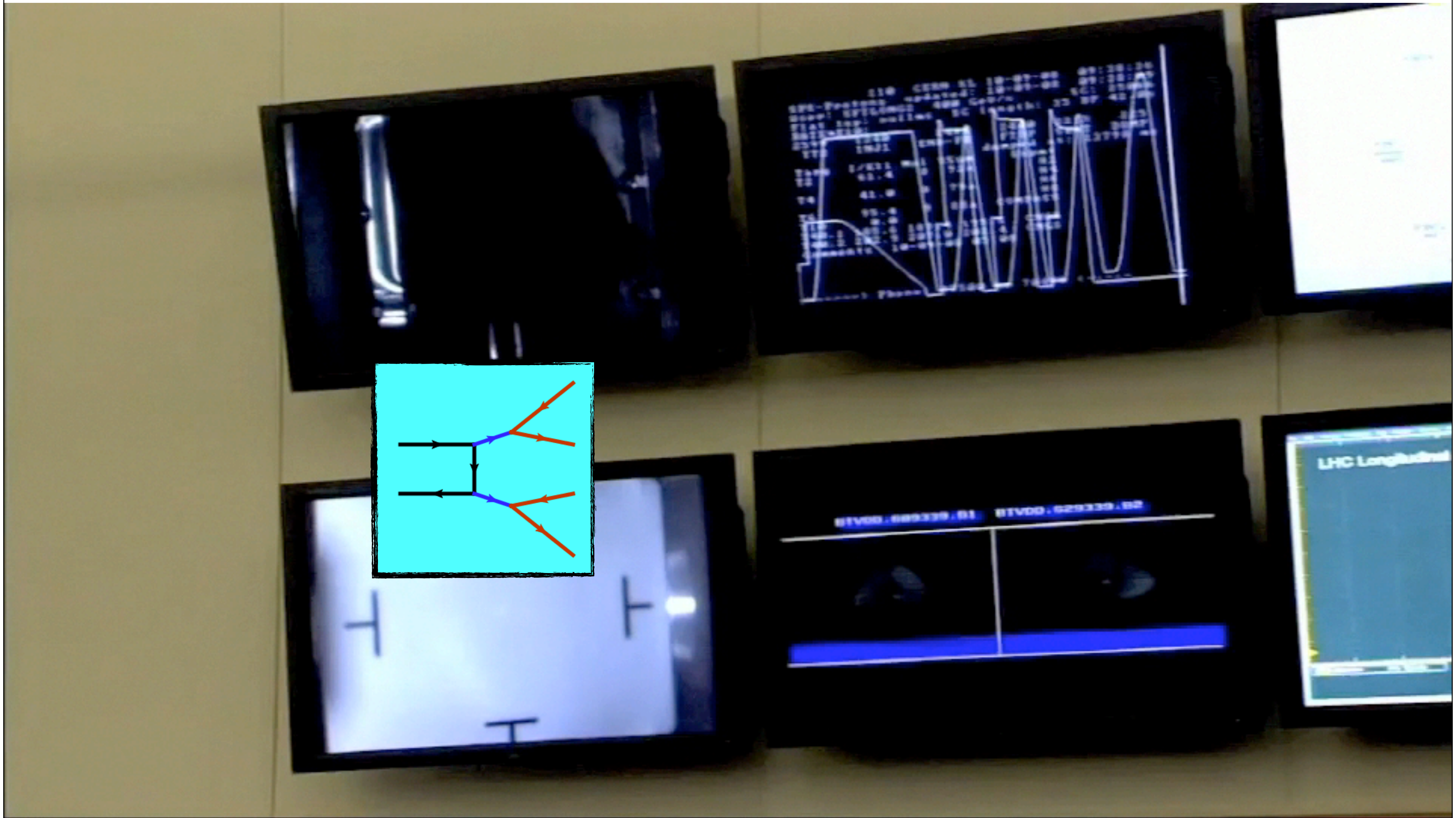
Calculate processes

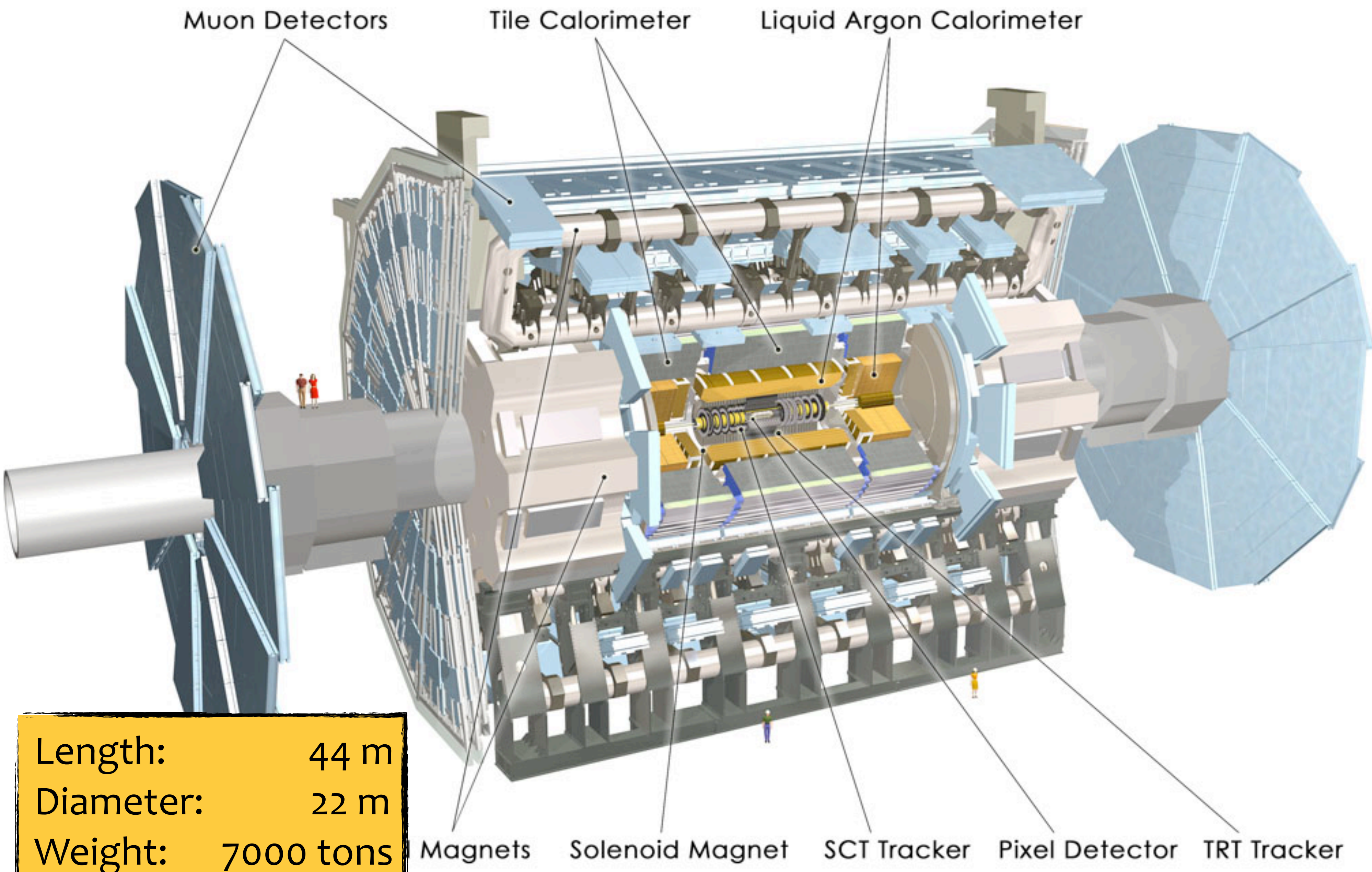


Theory ↔ Experiment



First protons in LHC (2008)





Length:	44 m
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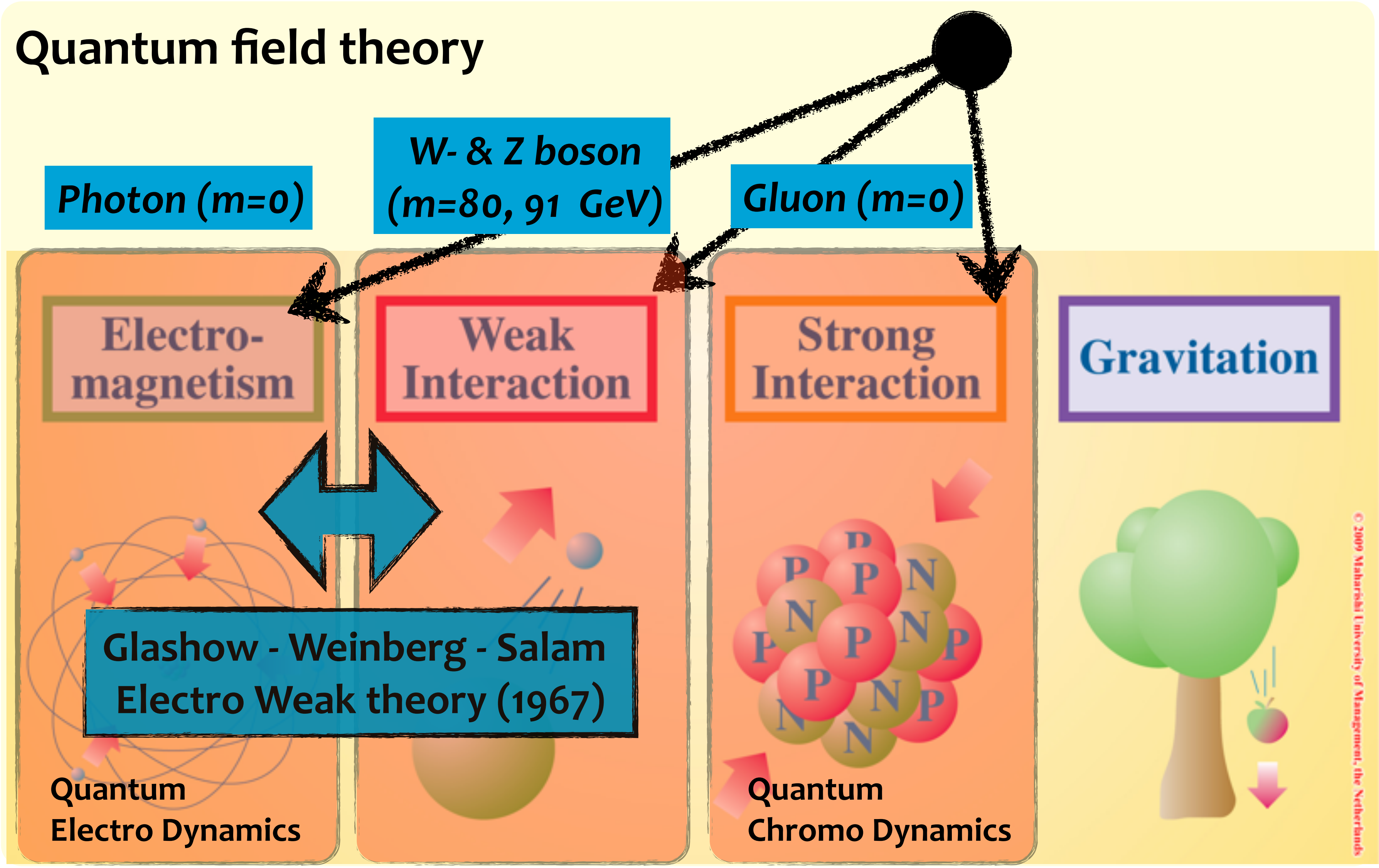
Fundamental interactions



LHC performance

- Quench incident (2008)
  - *~100 di-pool magnets affected*
  - One year delay
- Schedule adjusted -
  - 3500/4000 GeV per beam
  - Full energy available afte
- Start operation March 2
  - ***2011:*** LHC expectations exceeded by a factor 5
  - ***2012:*** Luminosity again exceeded expectations
- A total of ~1.8 10^{15} collisions!