



THE DISCOVERY OF THE HIGGS BOSON

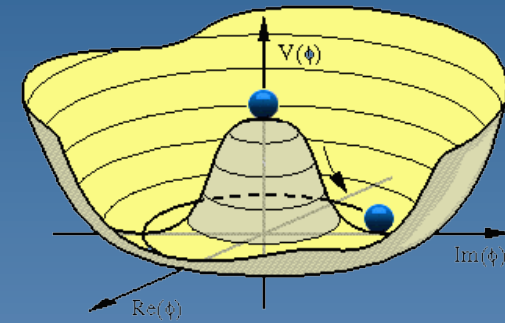
Ivo van Vulpen (Uva/Nikhef)

CERN in Geneva, Switzerland

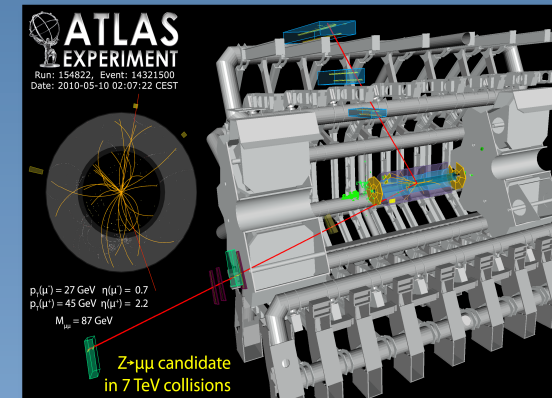


Things to remember

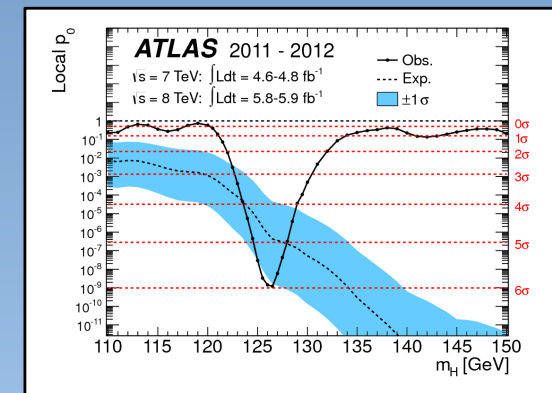
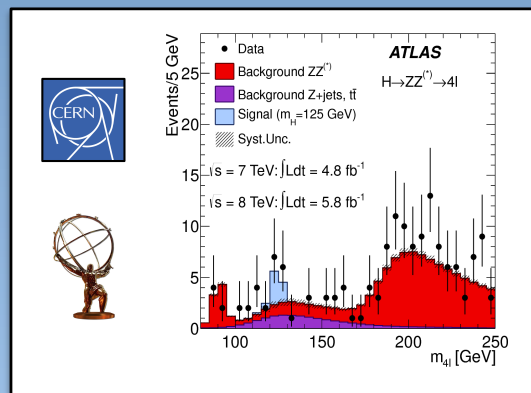
1) Higgs mechanism is at the heart of the Standard Model



2) LHC and ATLAS detector operating fine!

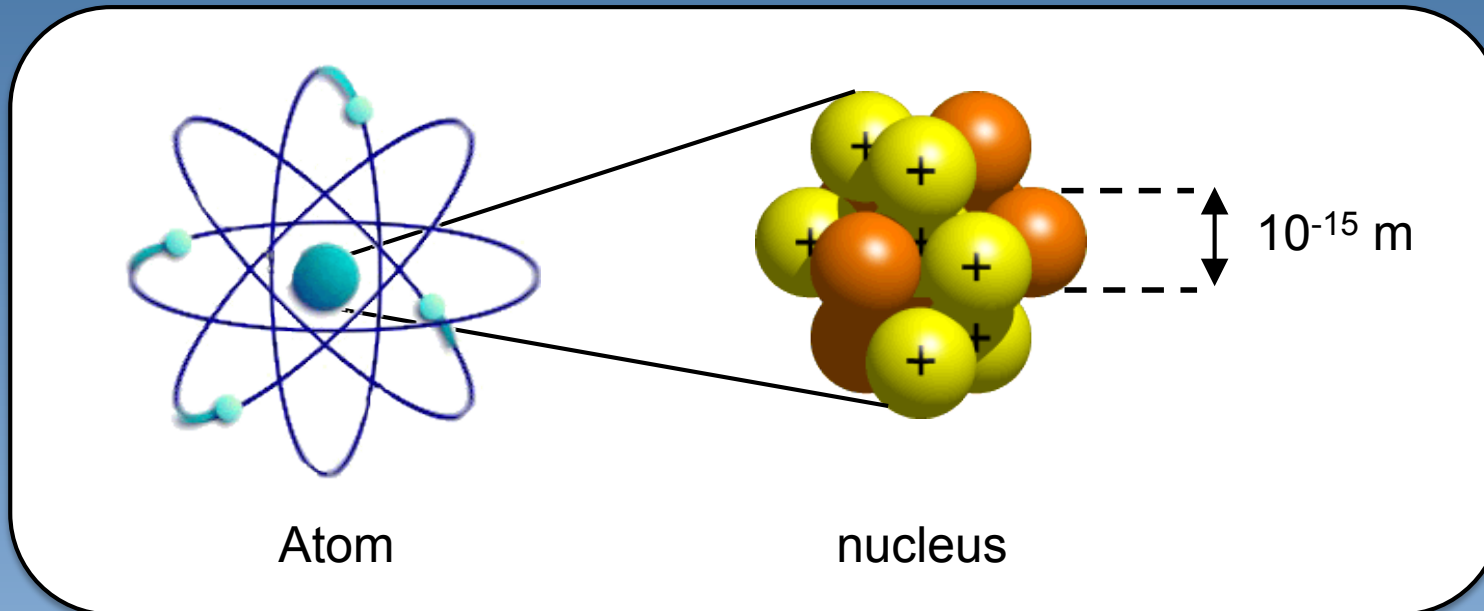


3) Discovery of the Higgs boson (interpretation)



Particle Physics

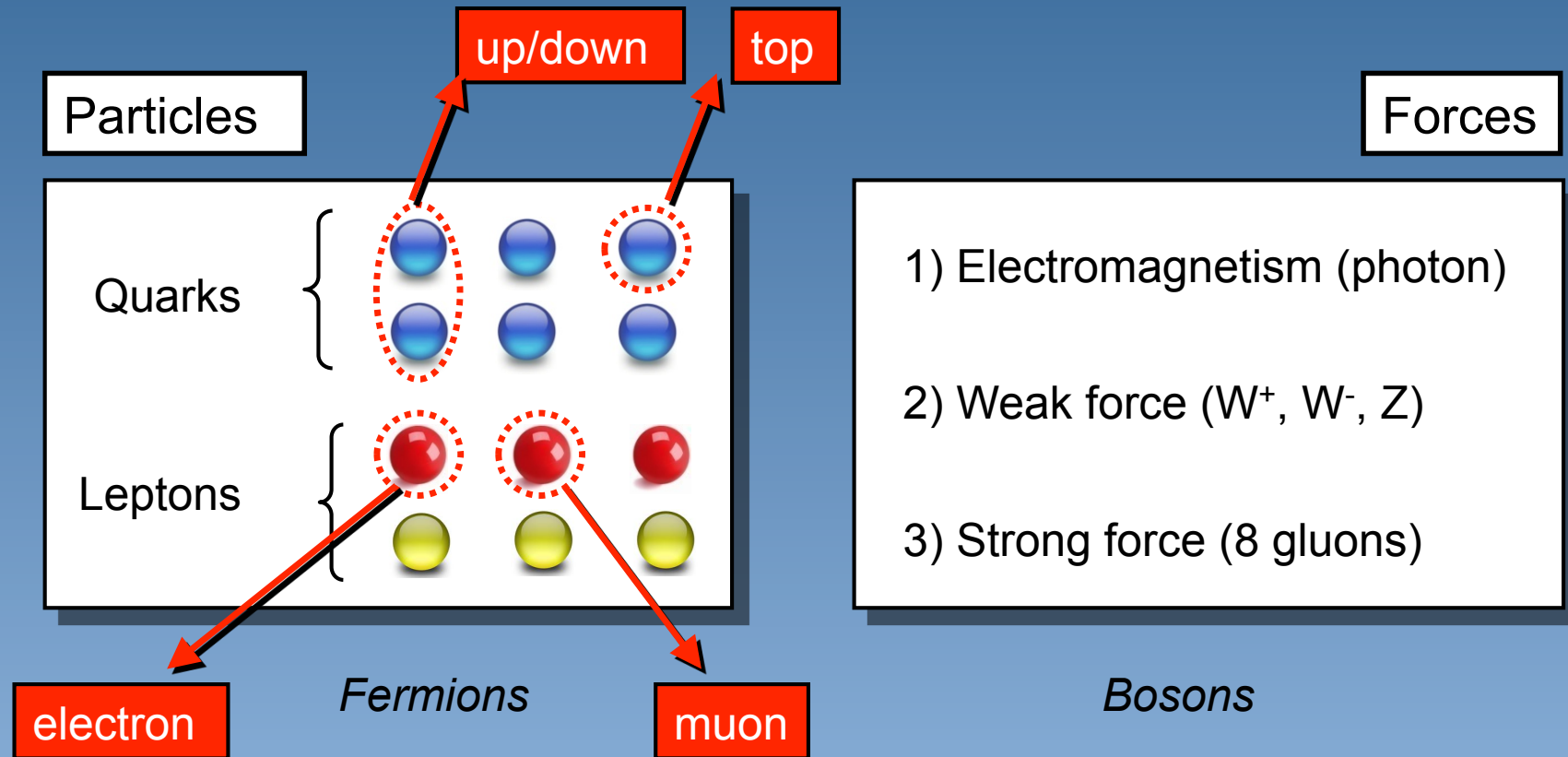
Studies nature at distance scales $< 10^{-15}$ m



Standard Model:

Quantumfield theory that describes phenomena down to 10^{-18} m

The Standard Model



The Standard Model

$$SU(2)_L \otimes U(1)_Y \otimes SU(3)_C$$

Weak iso-spin, hypercharge, colour

Standard Model based on local gauge invariance (symmetries)

Free electron

$$\mathcal{L}_e = i\bar{\psi}\gamma_\mu\partial^\mu\psi - m\bar{\psi}\psi$$

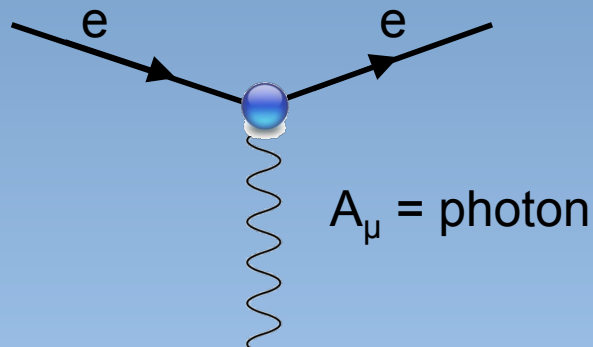
Extra symmetry requirement

Local gauge invariance

$$\psi(x) \rightarrow e^{i\alpha(x)}\psi(x)$$

Introduce covariant derivative (vector-field)

$$\partial_\mu \rightarrow D_\mu \equiv \partial_\mu - iqA_\mu$$



‘automatic’ force carriers and interactions’

In the Standard Model

$$SU(2)_L \otimes U(1)_Y \otimes SU(3)_C$$

Electroweak:
 W^+, W^-, Z, γ

QCD:
8 gluons

What is missing in our Standard Model ?

GOOD THINGS:

- 'understand' origin of forces
- Excellent agreement data
- Connection EM / Weak force



NOT-SO-GOOD THINGS:

- No massive gauge bosons ($W^\pm, Z$)
- No massive fermions (all particles)
- Vector boson scattering diverges

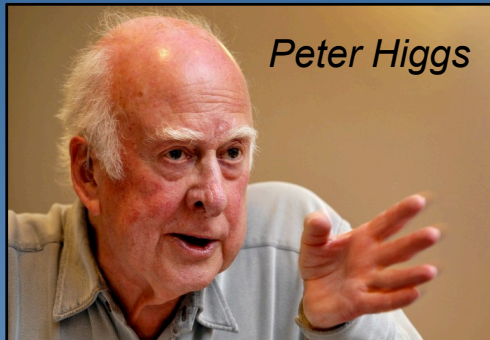


Higgs mechanism



Dark matter
Dark energy
Matter/anti-matter
Nature of gravity
Beginning of time

The Higgs mechanism

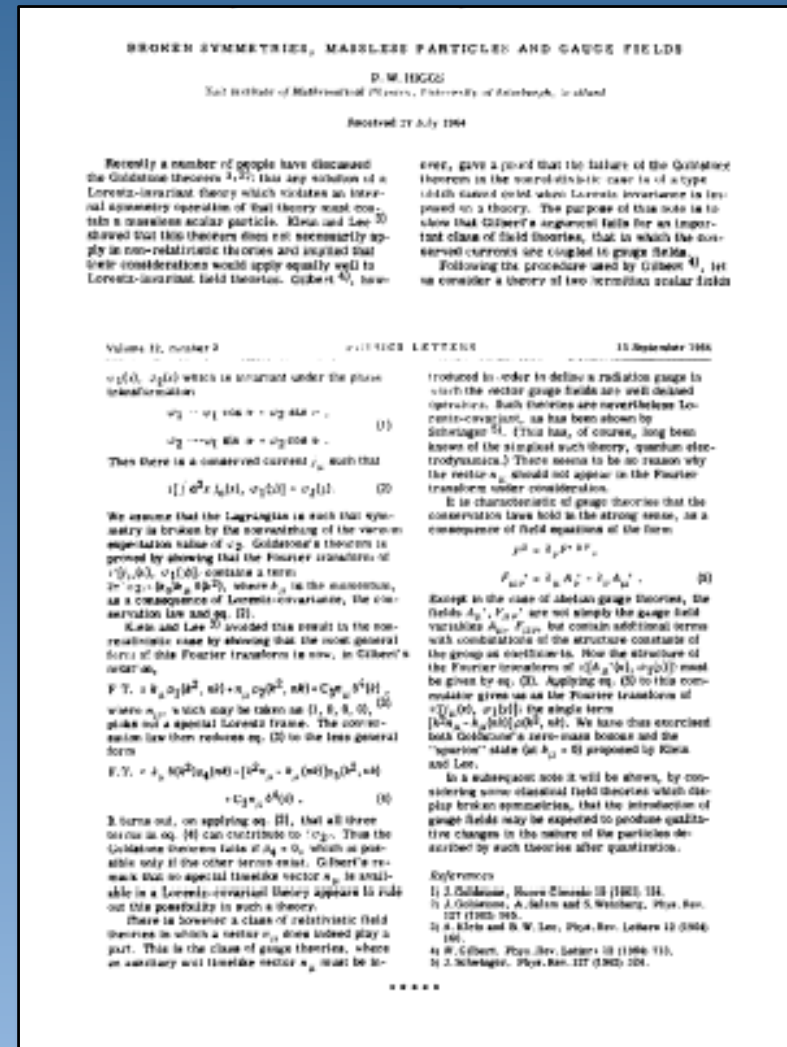


Peter Higgs

Massive gauge bosons in a local gauge invariant theory

$$SU(2)_L \otimes U(1)_Y \otimes SU(3)_C$$

There has to be a Higgs boson



- September 1964 -

(In)famous Higgs boson



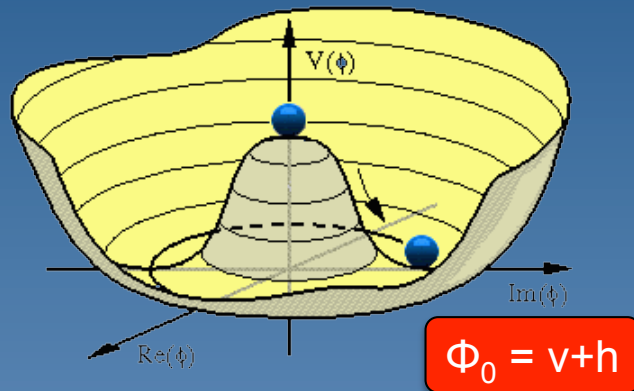
The Higgs boson



Paris Hilton

Being famous is not the same as being important

The Higgs mechanism



- 1) Add iso-spin doublet Φ (4 d.o.f.), with $Y_\Phi = +1$
- 2) Potential: $V(\Phi) = \mu^2\Phi^2 + \lambda\Phi^4$, with $\mu^2 < 0$

Gauge bosons

($V = W^+, W^-, Z, \gamma$)

$$L(\phi) = \underbrace{(D_\mu \phi)(D^\mu \phi)} - V(\phi)$$

$$\propto \vec{V}^2 \quad \text{mass } V$$

$$\propto h \vec{V}^2 \quad \text{---} \text{---} \text{---}$$

$$\propto h^2 \vec{V}^2 \quad \text{---} \text{---} \text{---}$$

+ scalar particle

Fermions

($\psi = e, \mu, \dots$)

$$L(\psi) = \underbrace{\bar{\psi} \phi \psi} + \dots$$

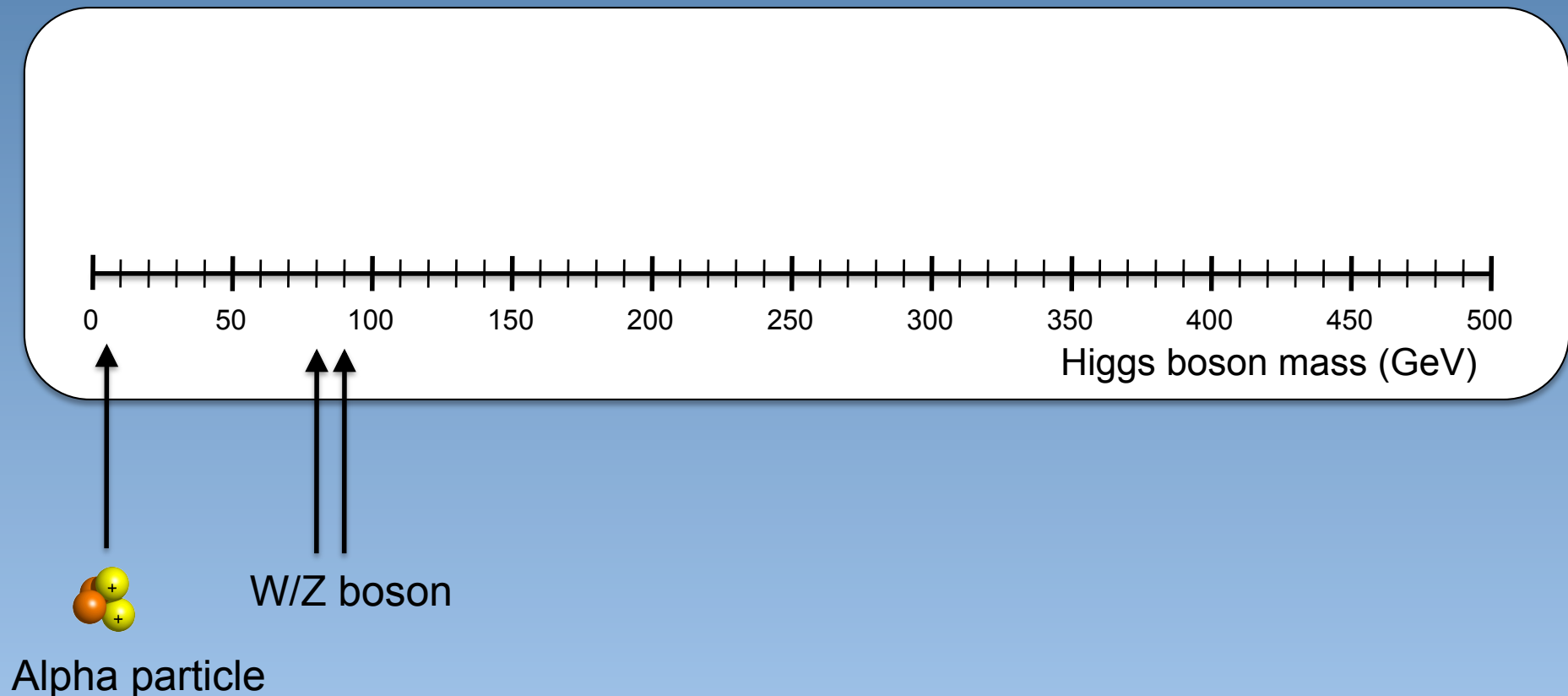
$$\propto m_\psi \bar{\psi} \psi \quad \text{mass } \psi$$

$$\propto \left(\frac{m_\psi}{v}\right) \bar{\psi} h \psi \quad \text{---} \text{---} \text{---}$$

"the Higgs couples to mass"

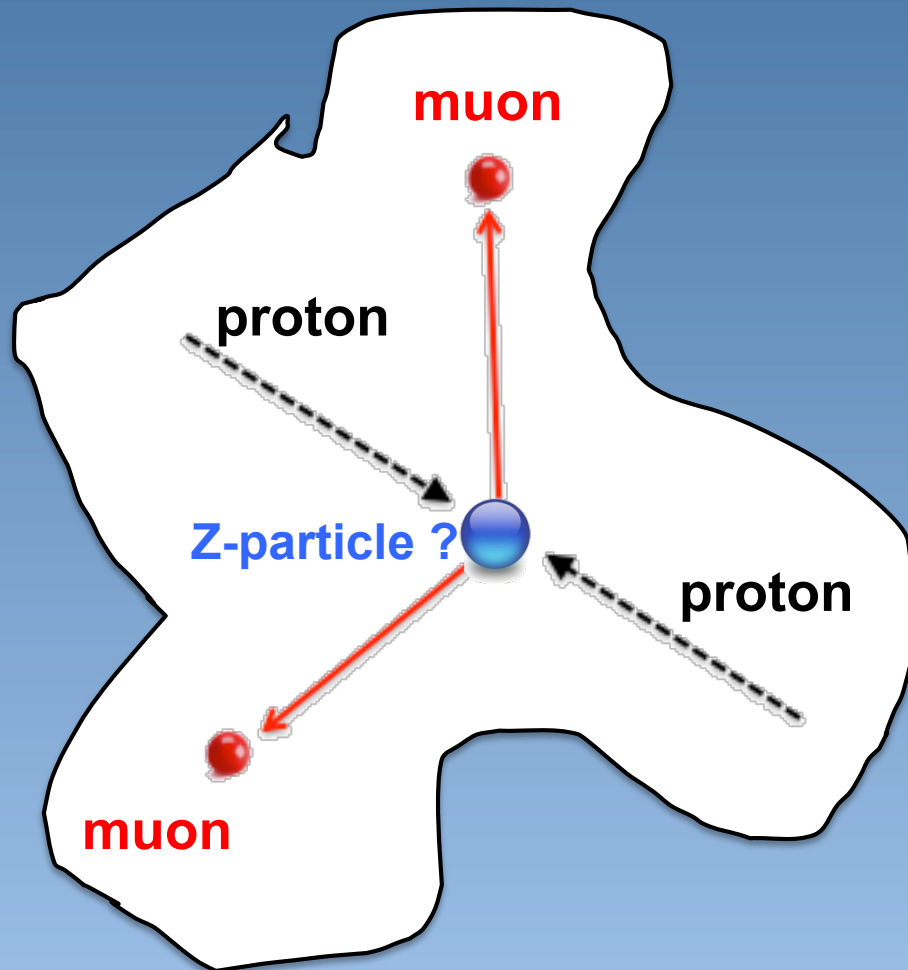
The mass of the Higgs boson

*Properties of the Higgs boson are known ... as a function of its **unknown** mass*

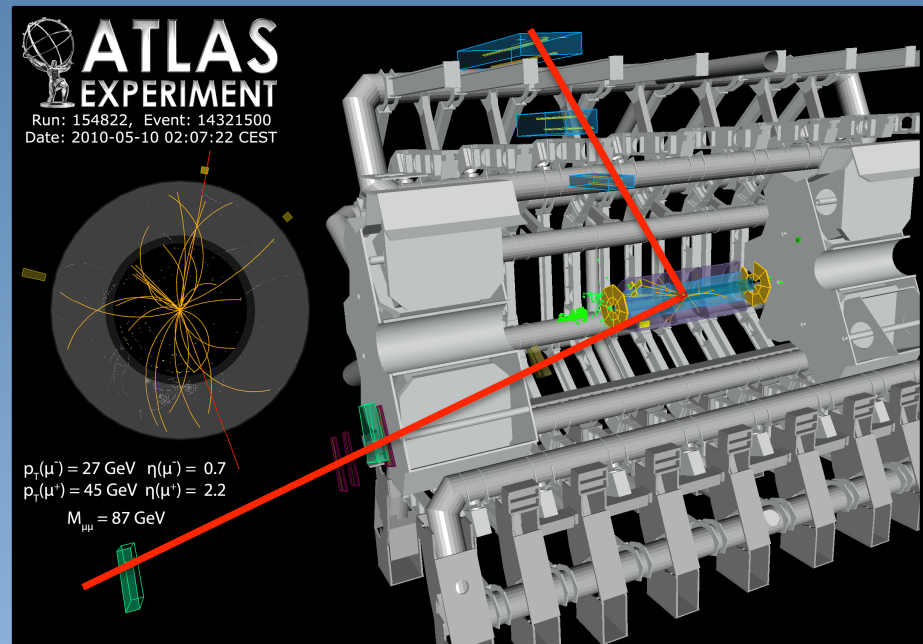


How do you discover a Z particle ?

Deviations from the prediction without a Z boson



2-muons as seen in the ATLAS detector



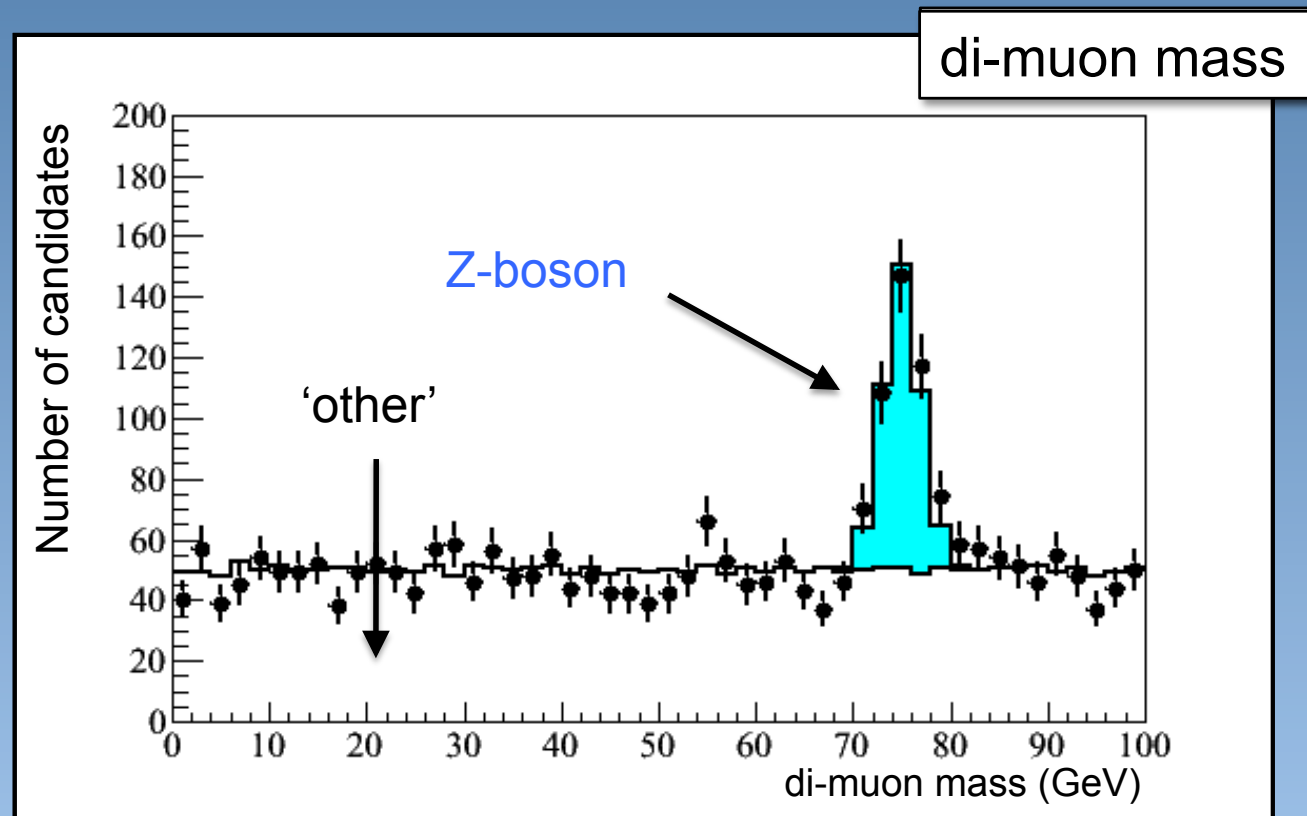
What is the fingerprint of the Z particle:
→ the di-muon mass

di-muon mass



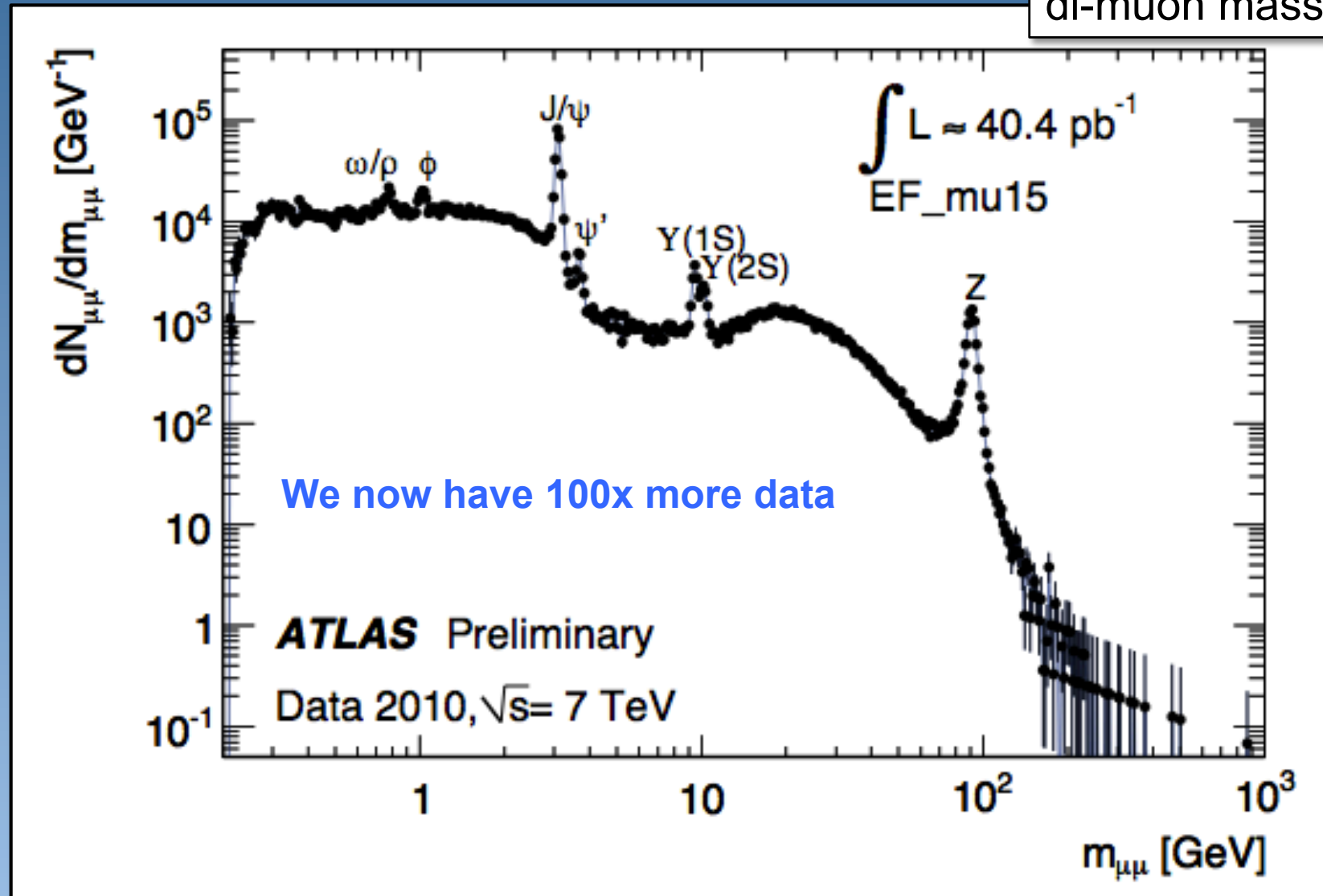
'other': no preference/structure

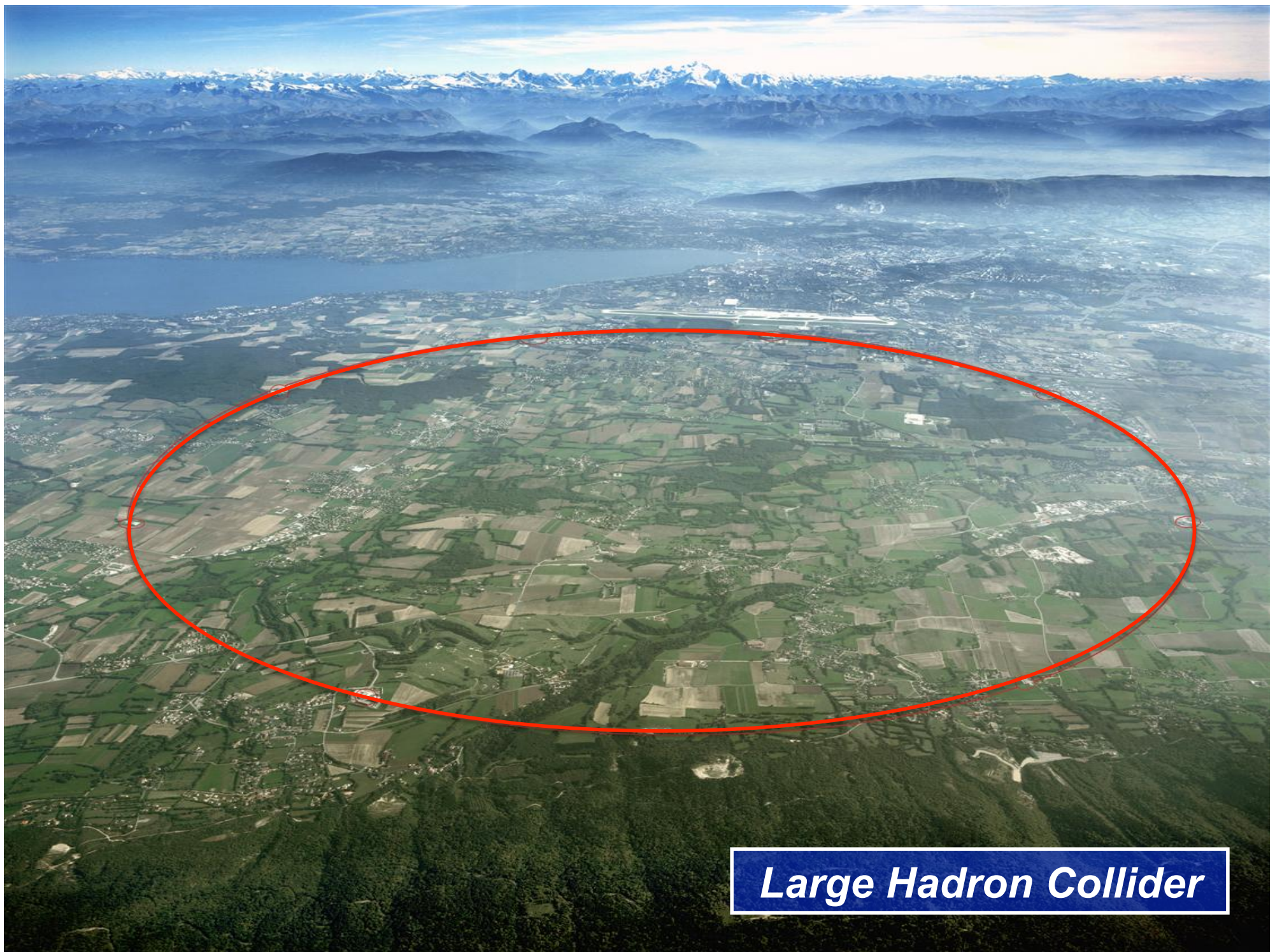
Z-boson: Breit-Wigner $\otimes$ resolution



Di-muon resonances seen at the LHC

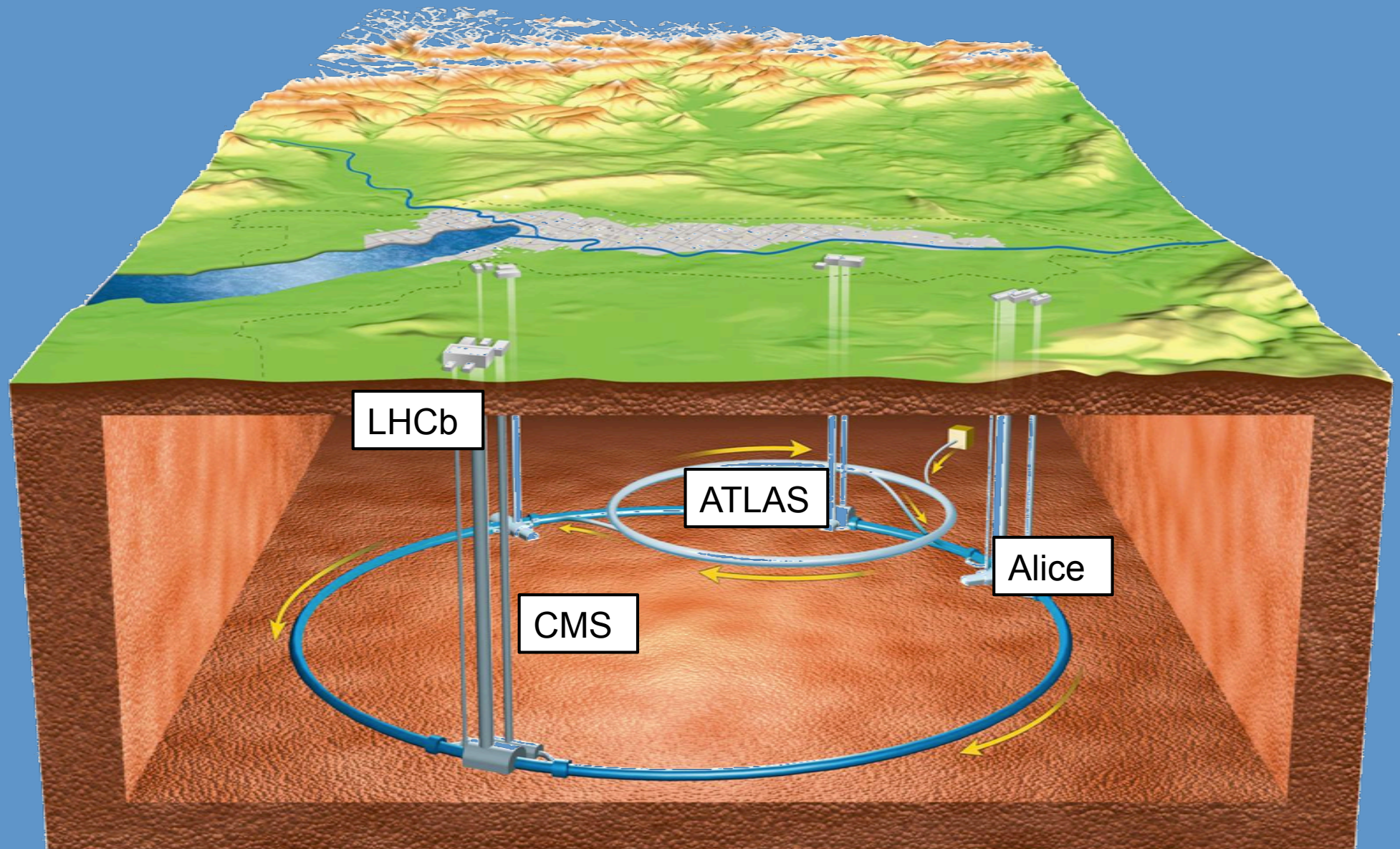
di-muon mass





Large Hadron Collider

The Large hadron collider



Acceleration is 'easy'



High energy: 7/8 (14) TeV

Energy limited by strength of 1234 dipole magnets, with $B = 8.4 \text{ T}$ at 1.9 K

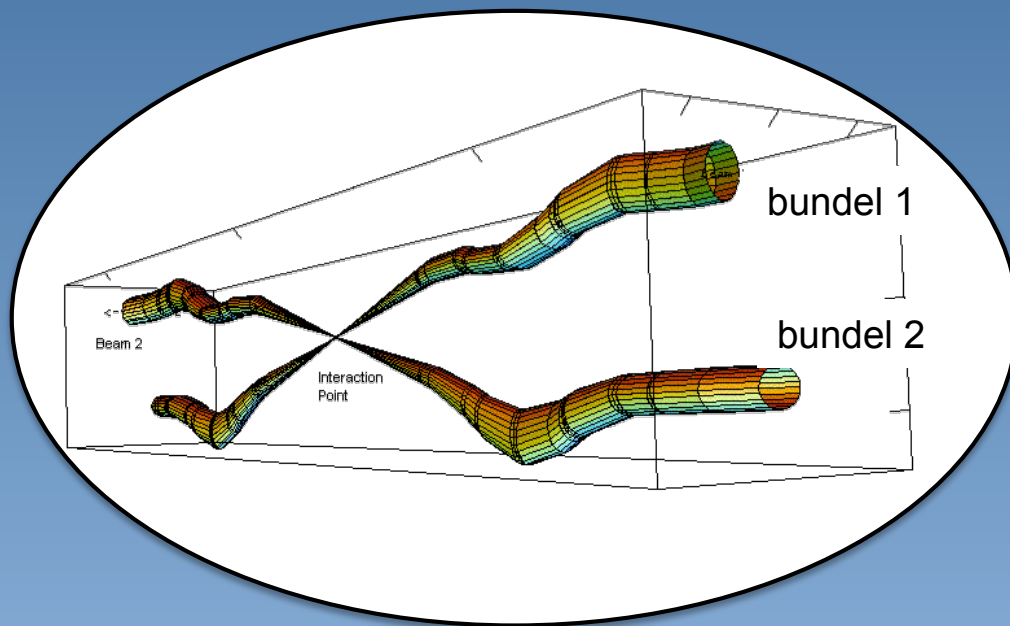
→ *Production of heavy particles (few TeV)*

High intensity: $10^{33/34} \text{ cm}^{-2}\text{s}^{-1}$

40 million collisions per second

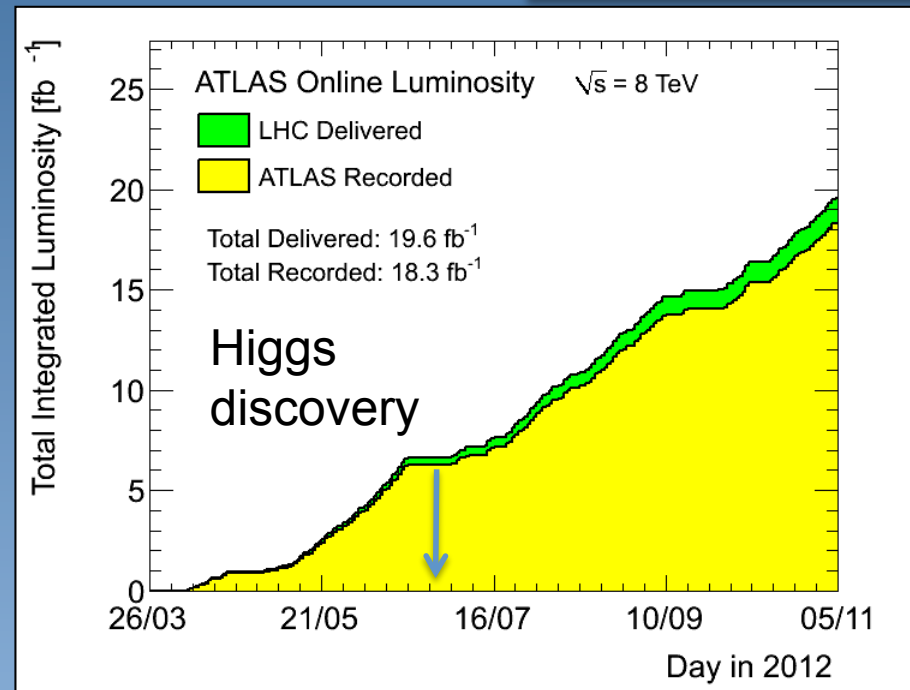
→ *Look for rare processes*

LHC data-set 2011+ 2012



40 million collisions per second
Only 200 Hz to tape

LHC Luminosity

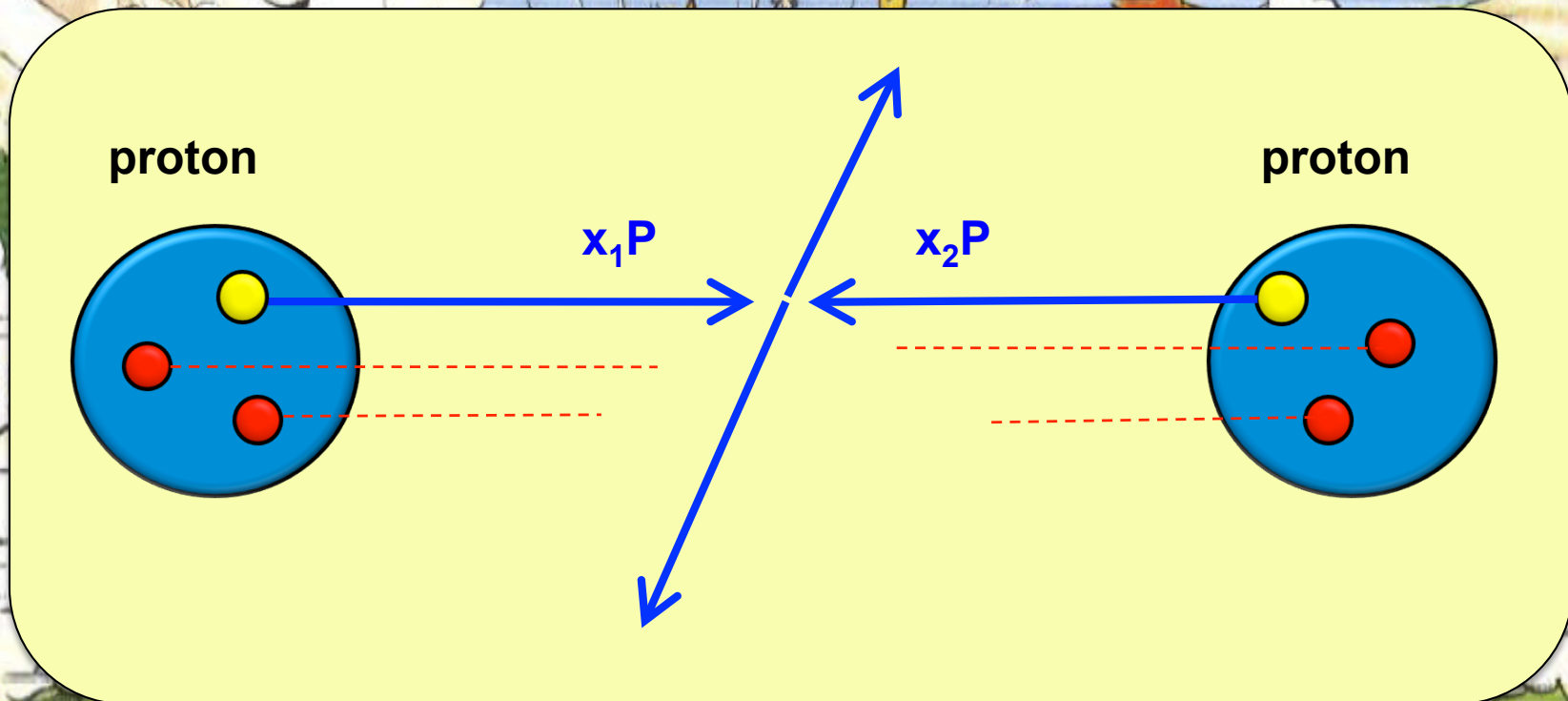


ATLAS (2011): 4.8 fb^{-1} at $\sqrt{s}=7$ TeV
ATLAS (2012): 19.6 fb^{-1} at $\sqrt{s}=8$ TeV

Note: almost all results in this talk are
from data up to discovery

Phenomenology of proton-proton collisions

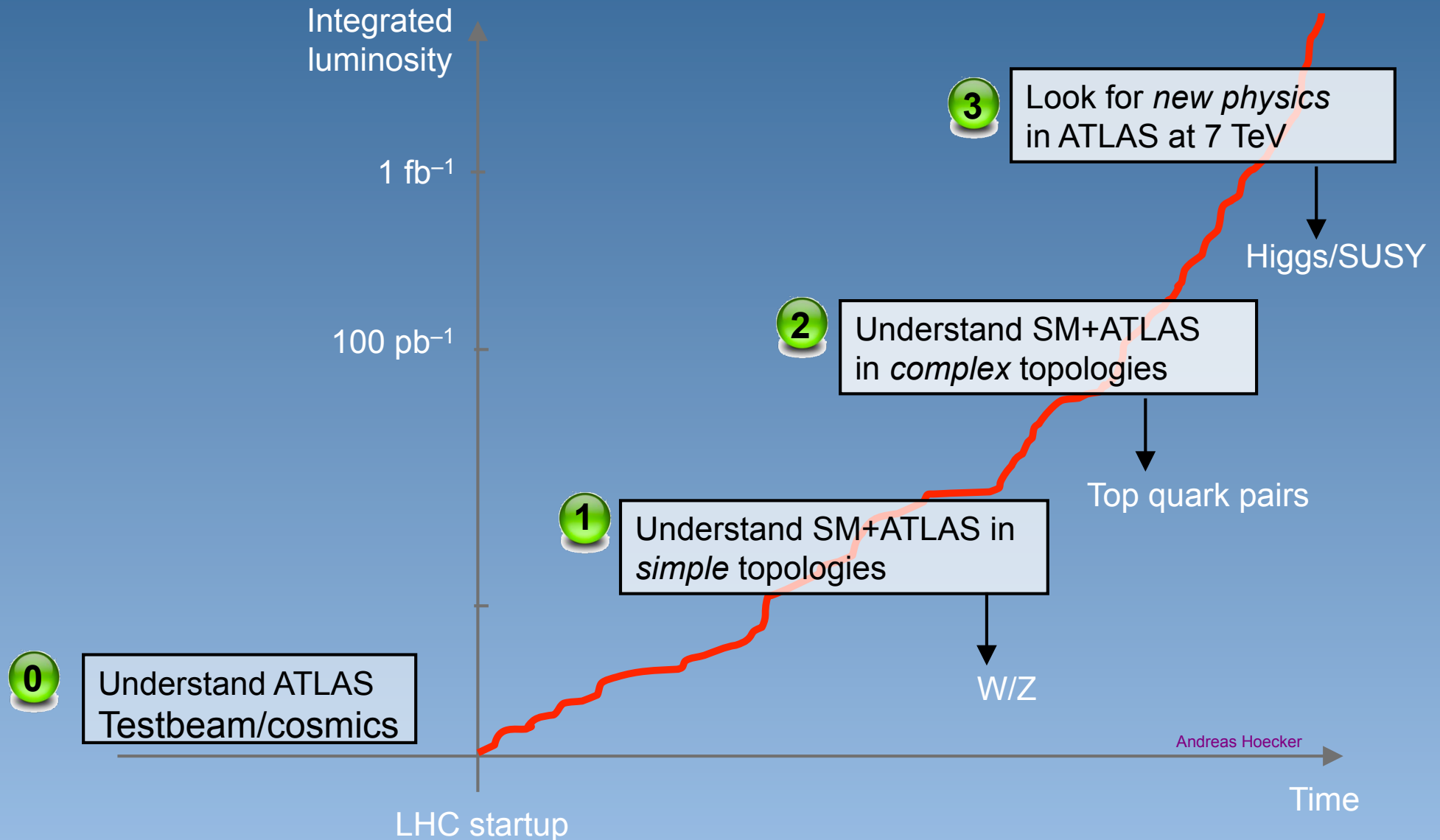
“Proton is a bag full of (anti-)quarks and gluons”



Only a fraction of the collision energy available for ‘hard’ interaction

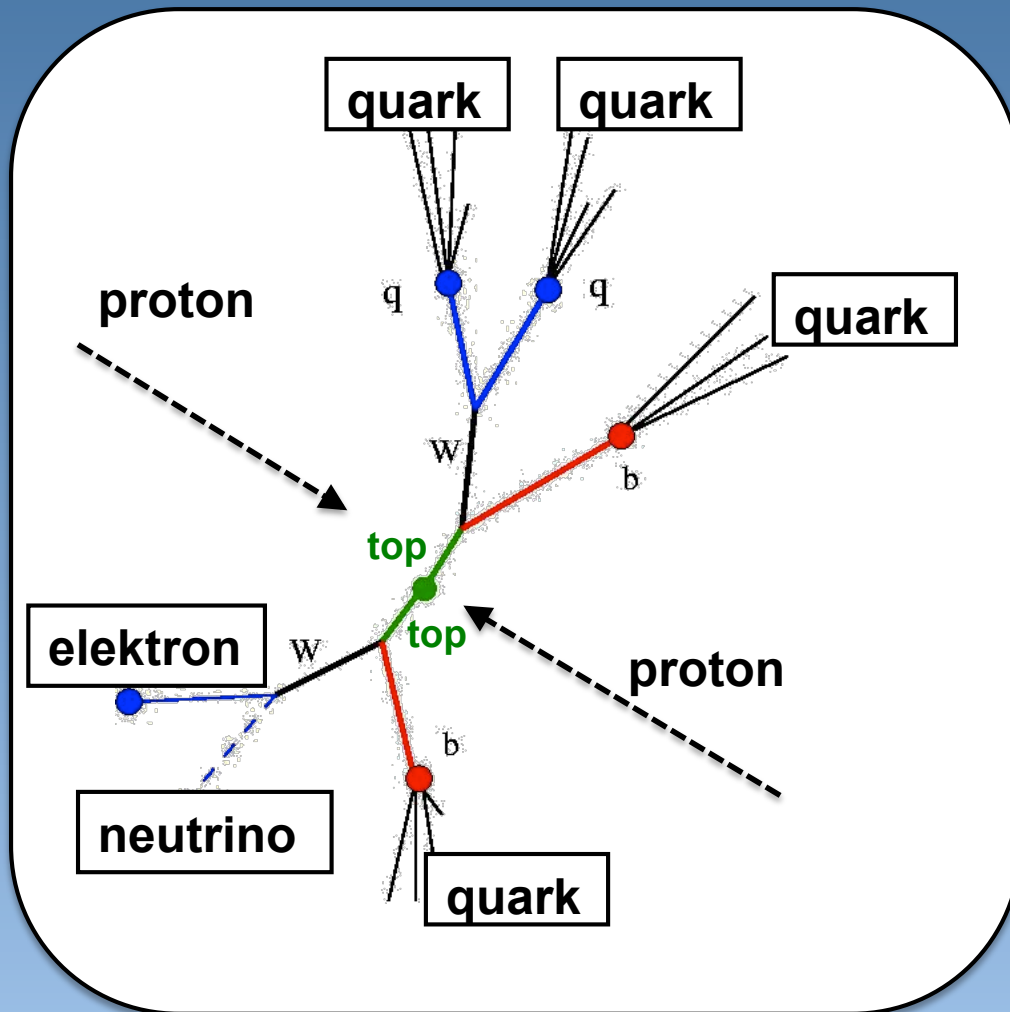
LHC start-up programme

New detector and new energy scale

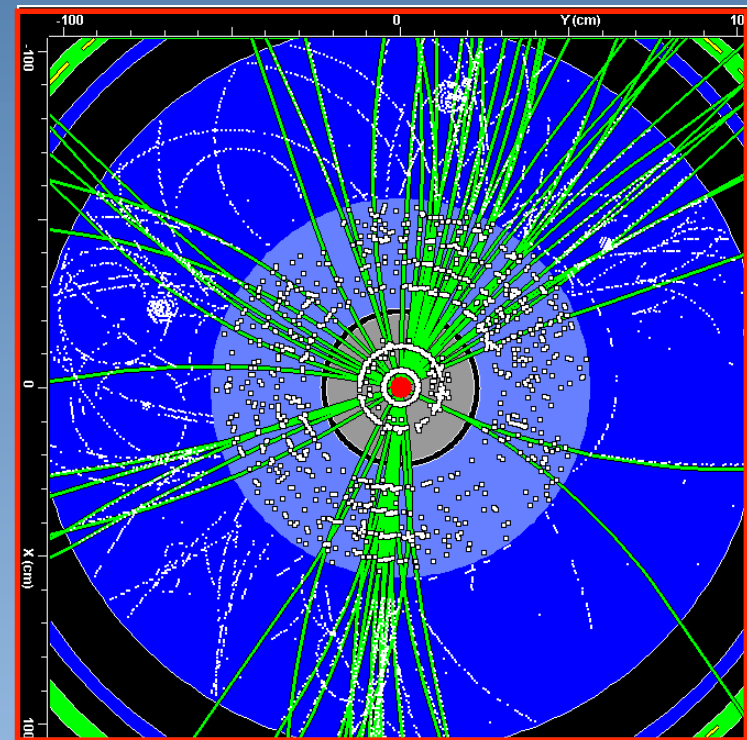


Interpreting LHC events

top quark pair-production

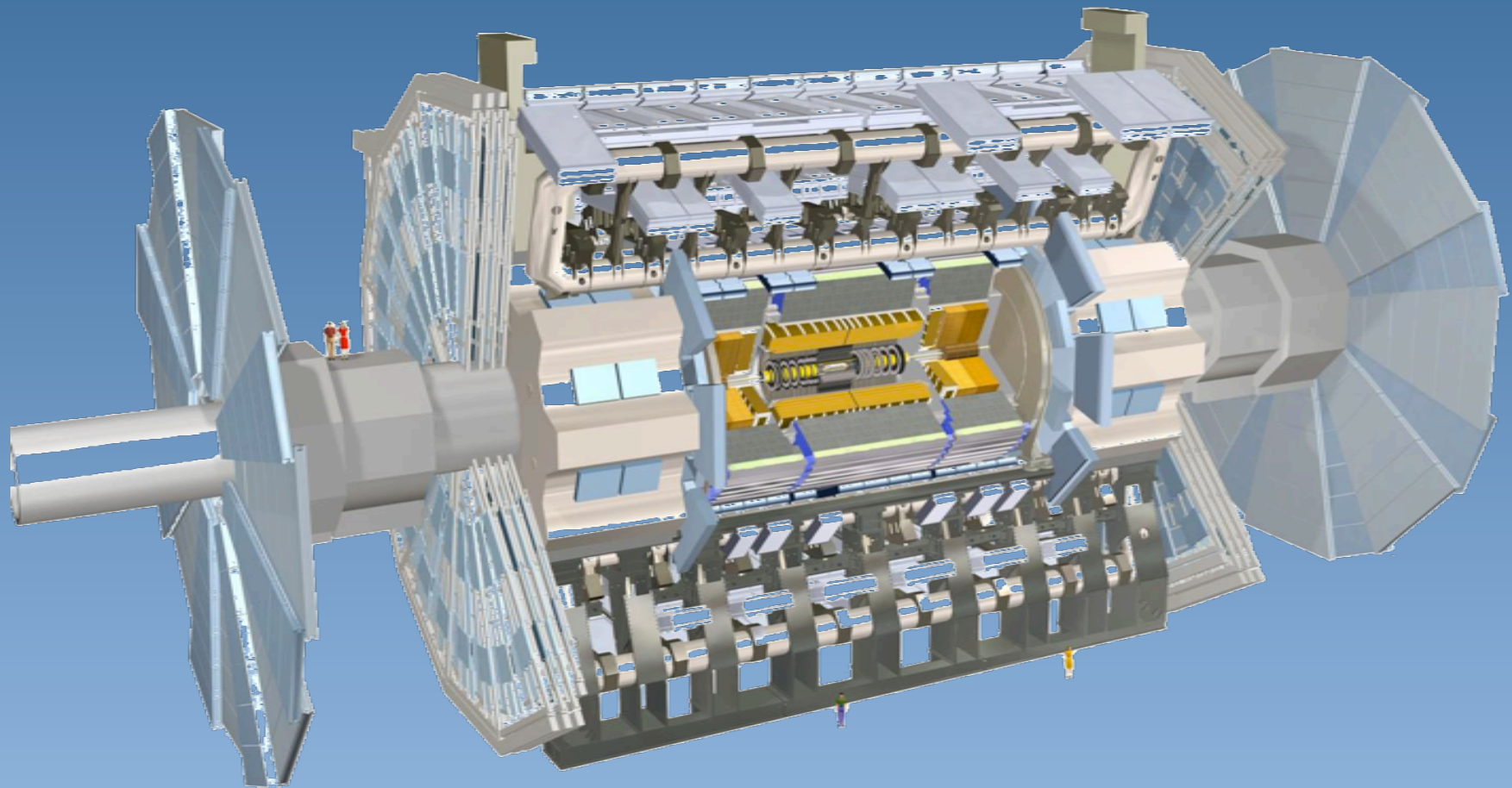


Simulation top quark production



The ATLAS detector

(as a computer model)



The Atlas detector really exists

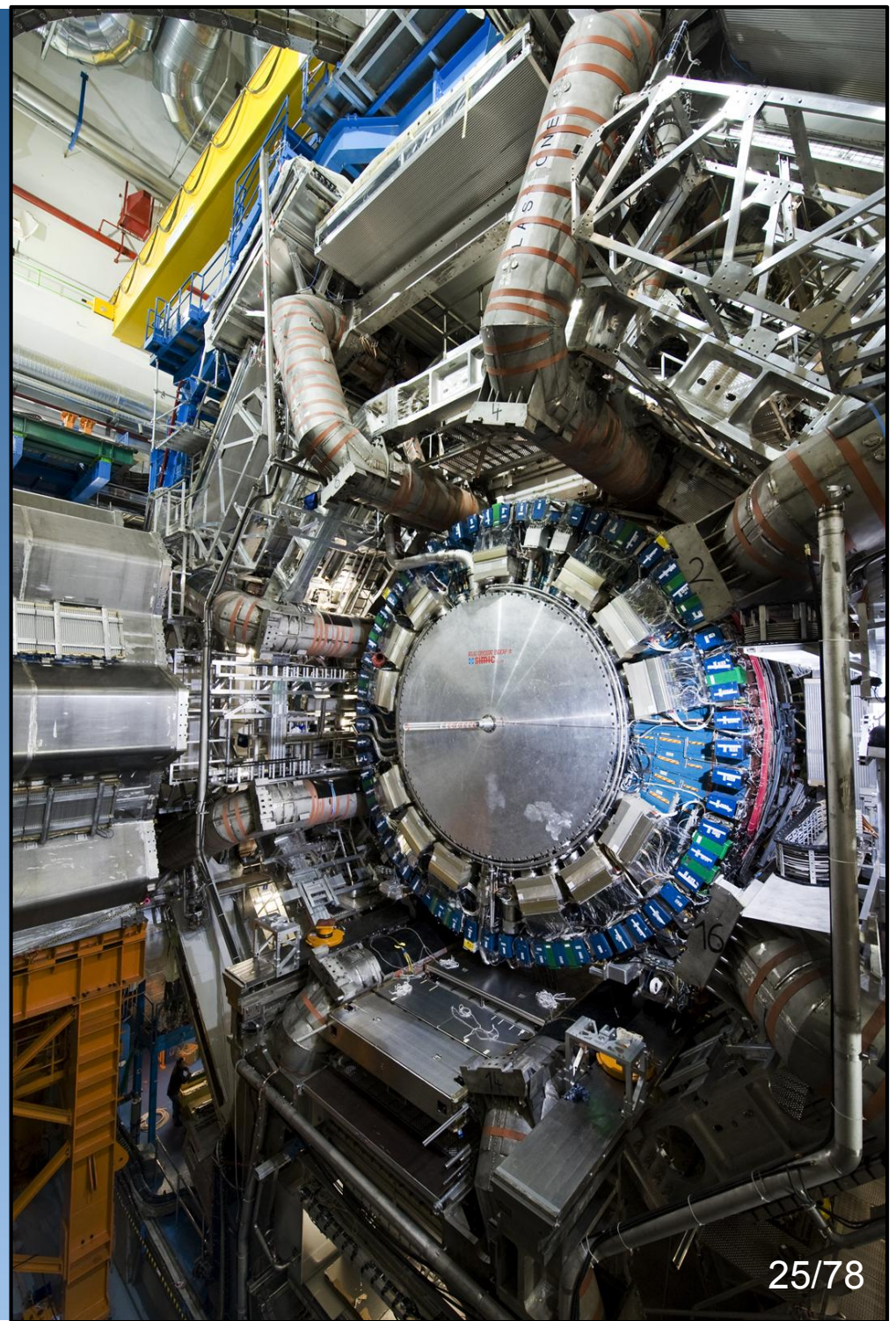
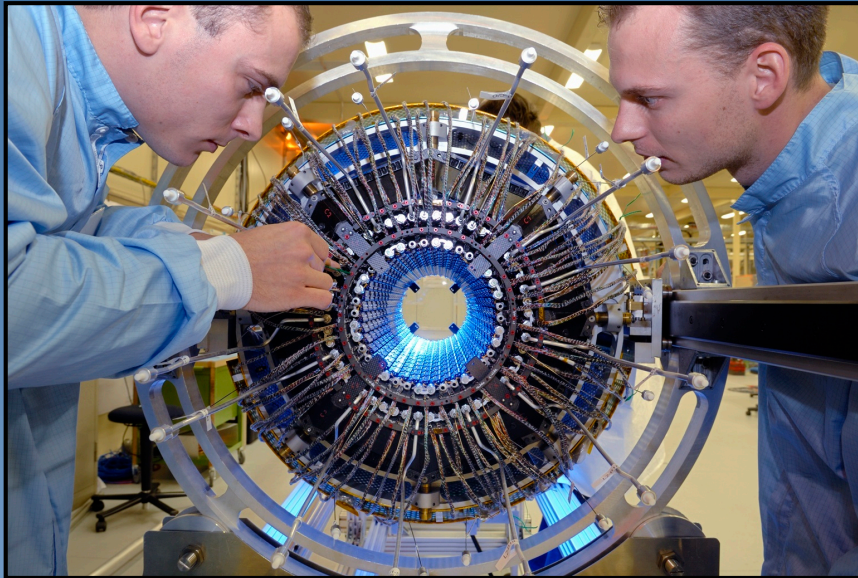


current boss

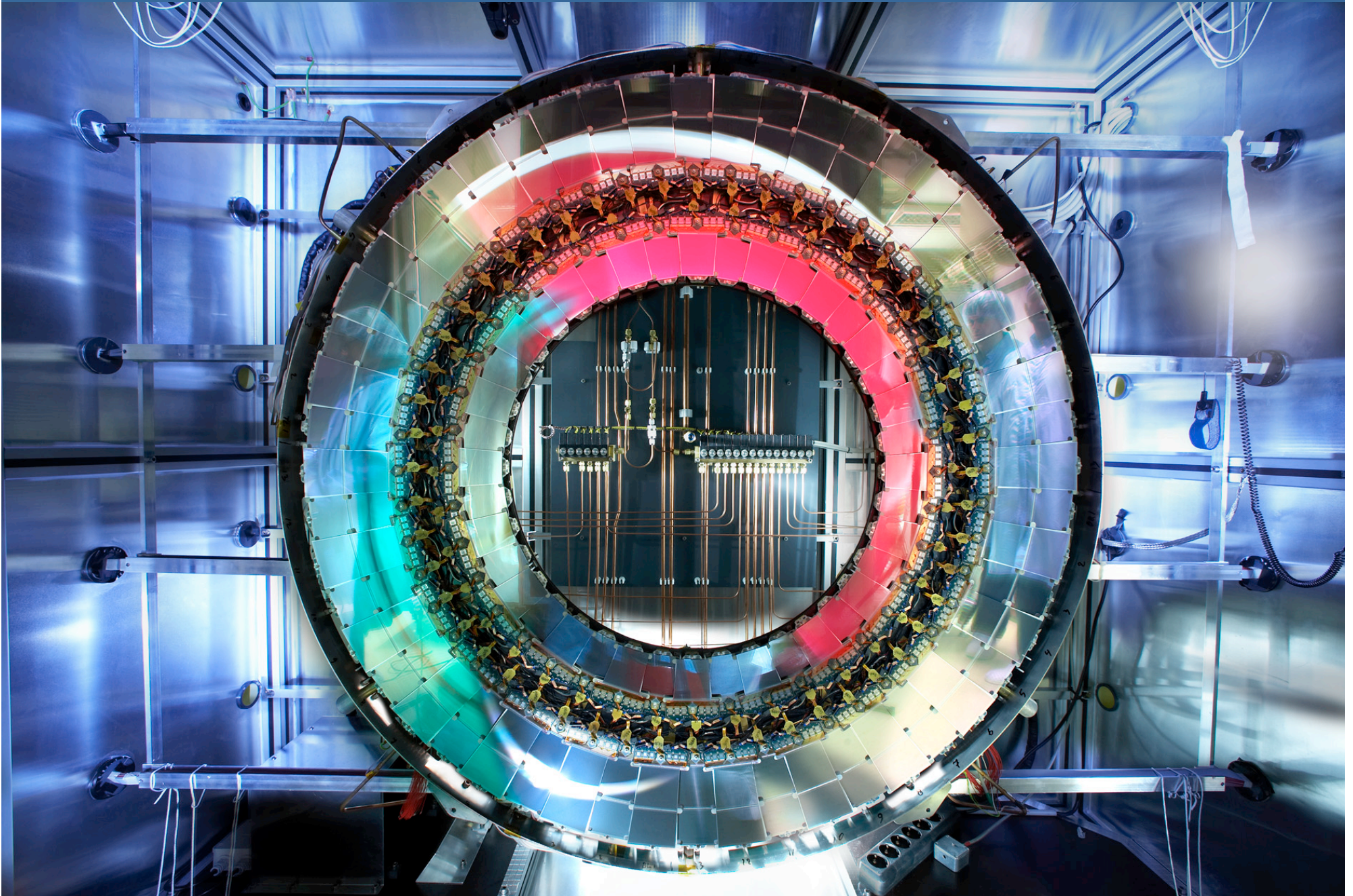
old boss

The ATLAS detector

(in real life)



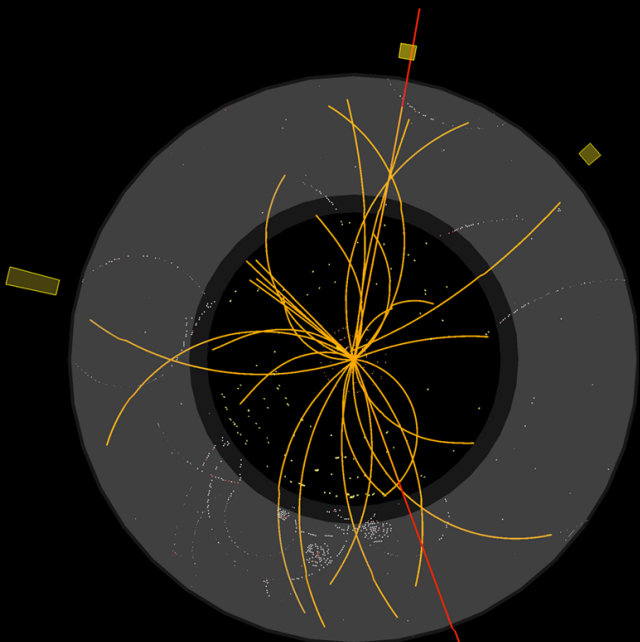
Part of the ATLAS detector has been designed and built at Nikhef





ATLAS EXPERIMENT

Run: 154822, Event: 14321500
Date: 2010-05-10 02:07:22 CEST



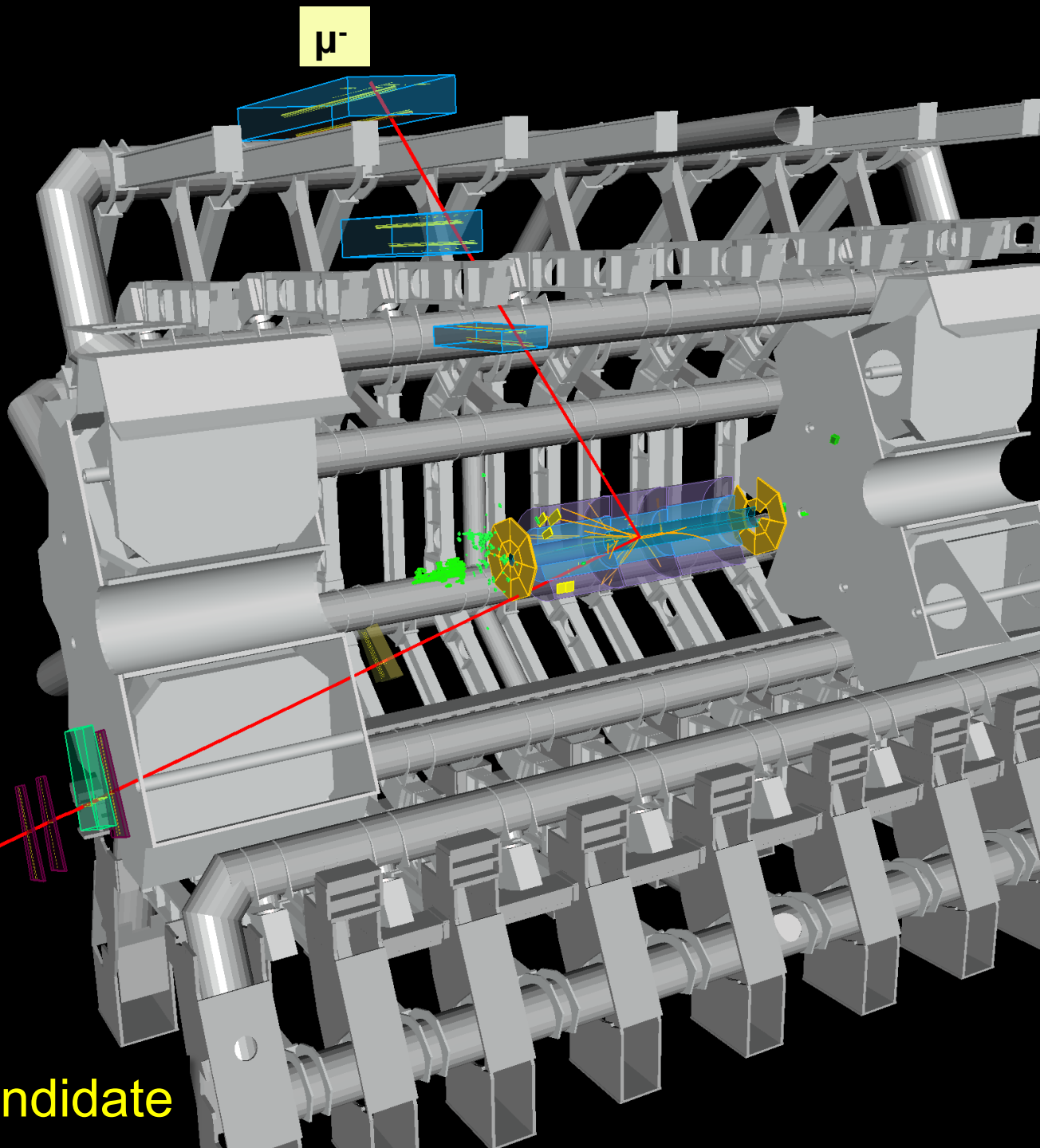
$p_T(\mu^-) = 27 \text{ GeV}$ $\eta(\mu^-) = 0.7$
 $p_T(\mu^+) = 45 \text{ GeV}$ $\eta(\mu^+) = 2.2$

$M_{\mu\mu} = 87 \text{ GeV}$

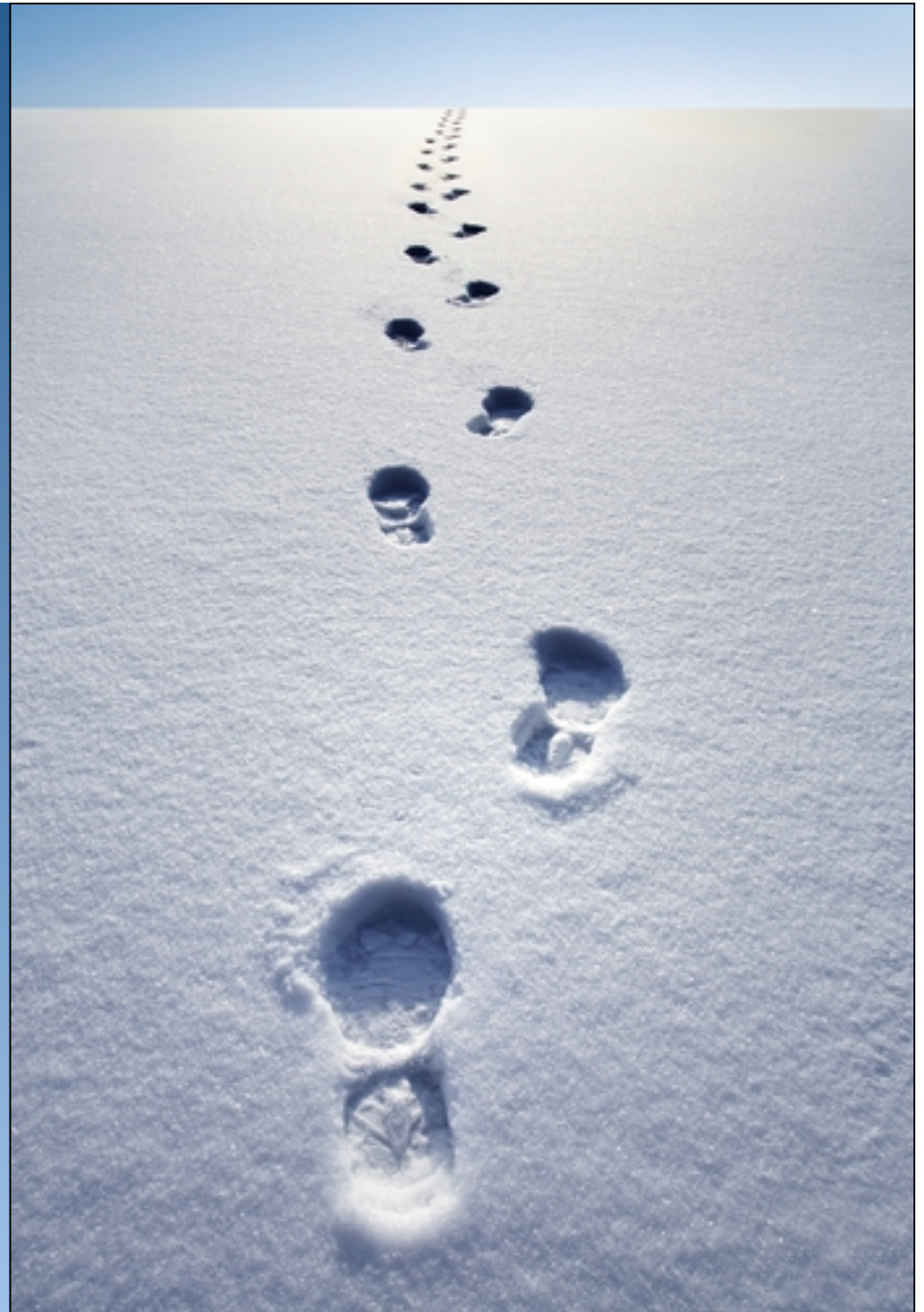
μ^+

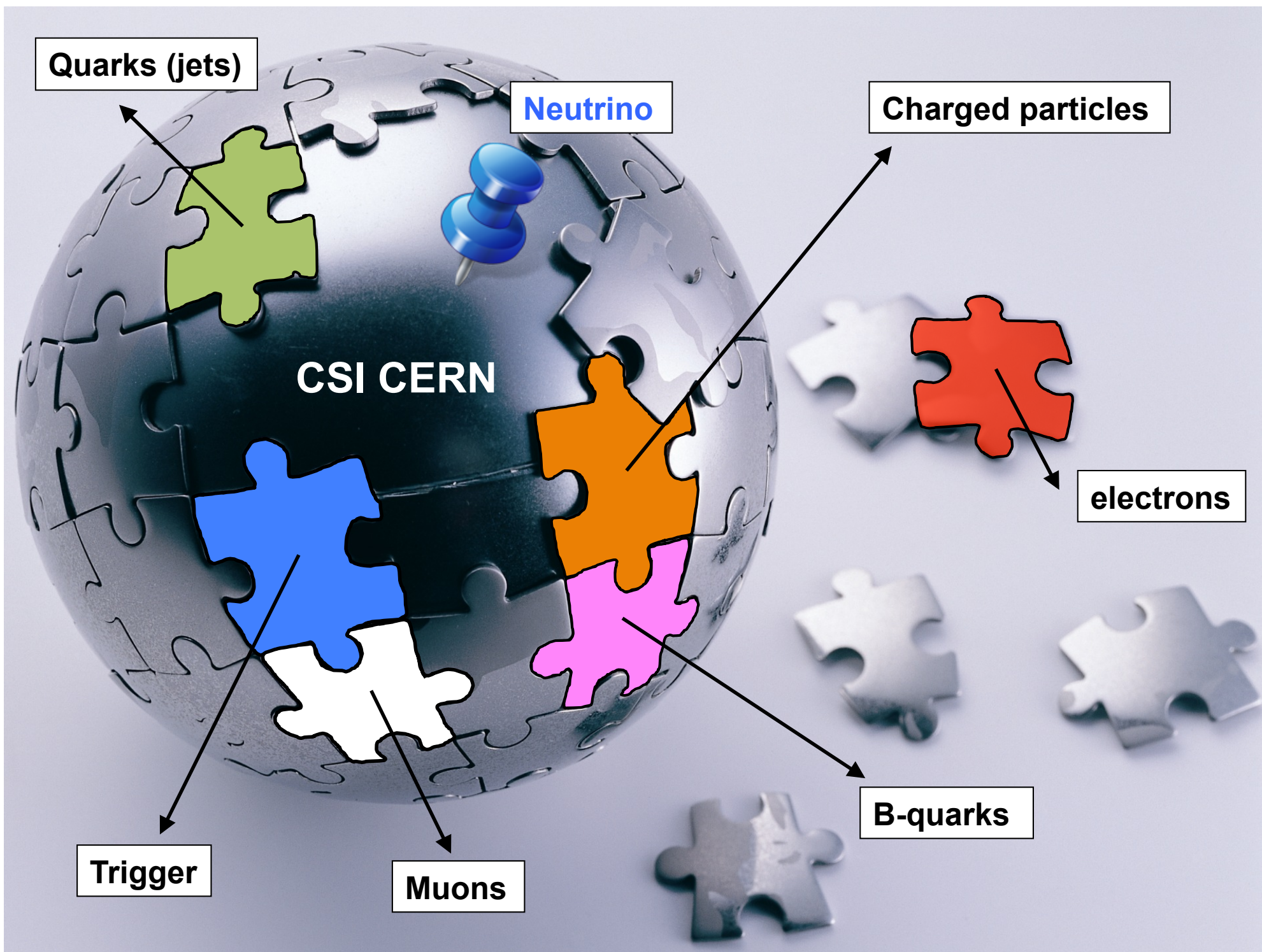


$Z \rightarrow \mu^+\mu^-$ candidate



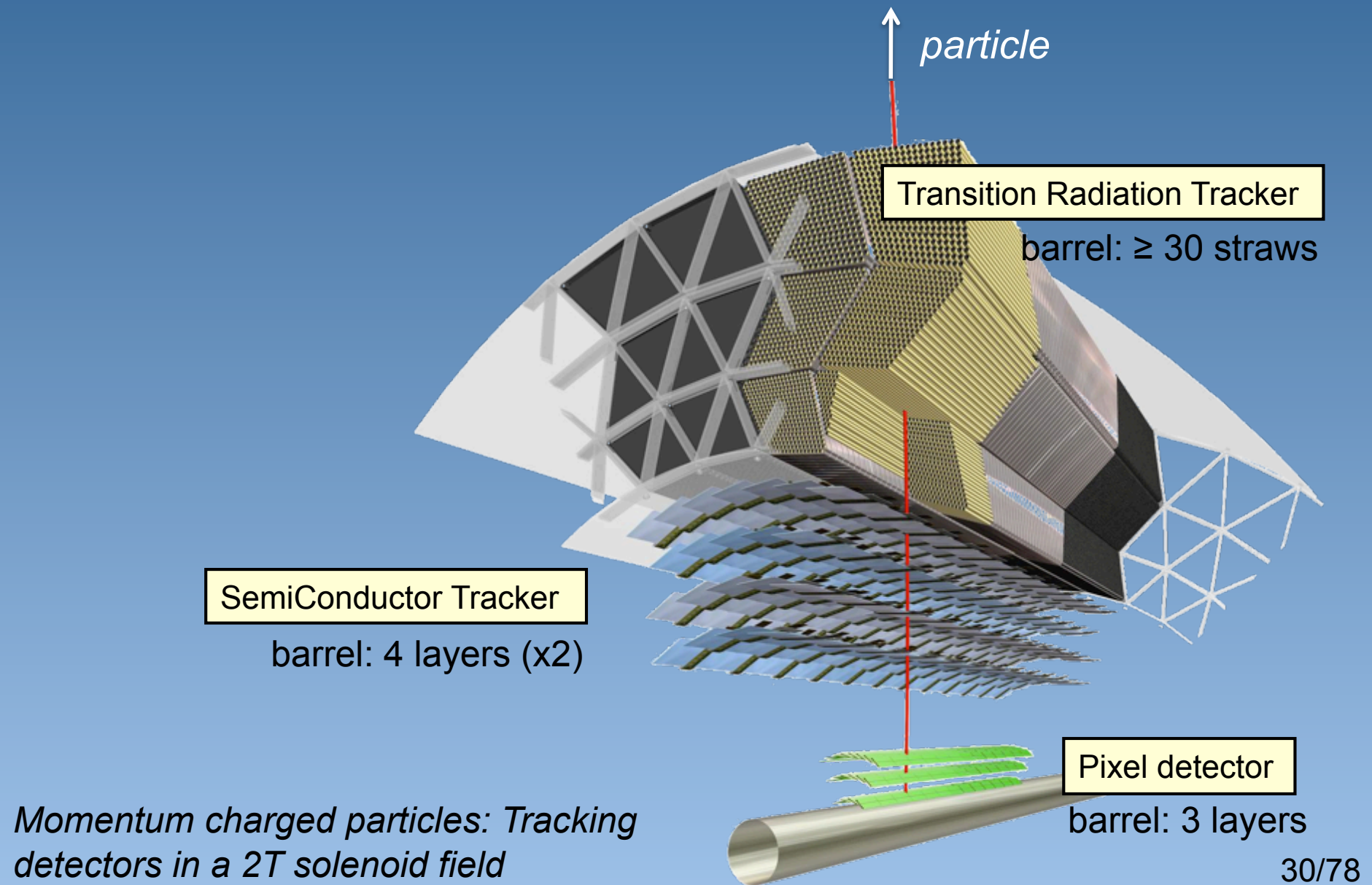
Rabbit, car or human ?





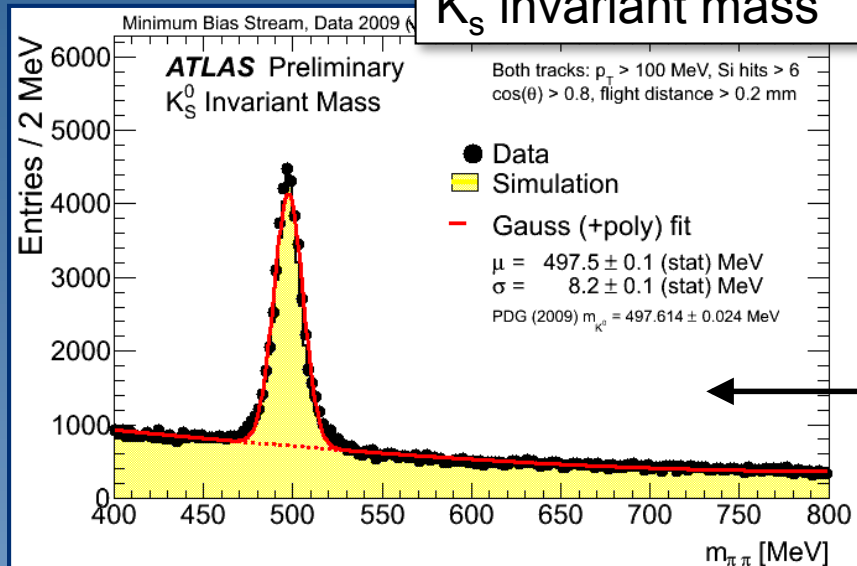
Complex structure ATLAS detector ?

Wide range of particle types / characteristics

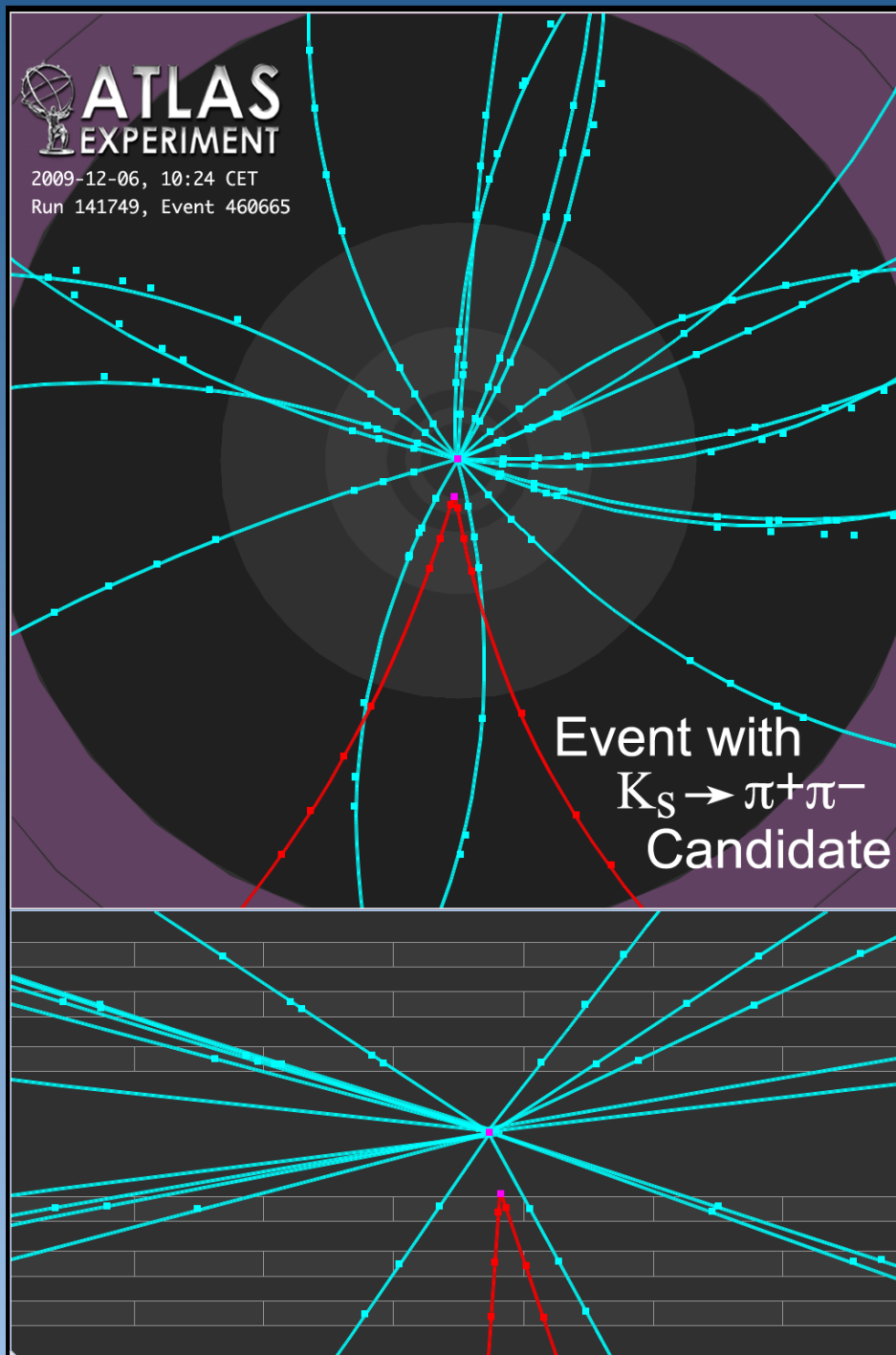
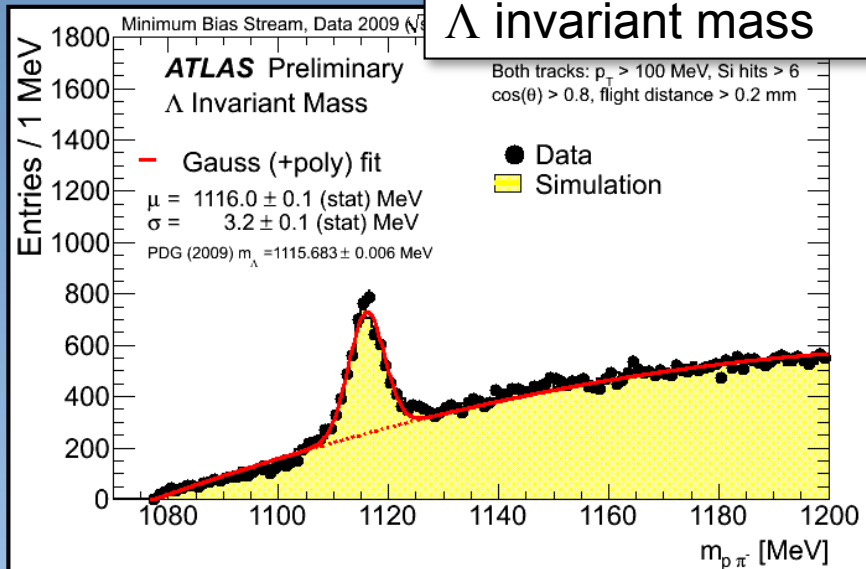


Secondary vertices

K_S invariant mass



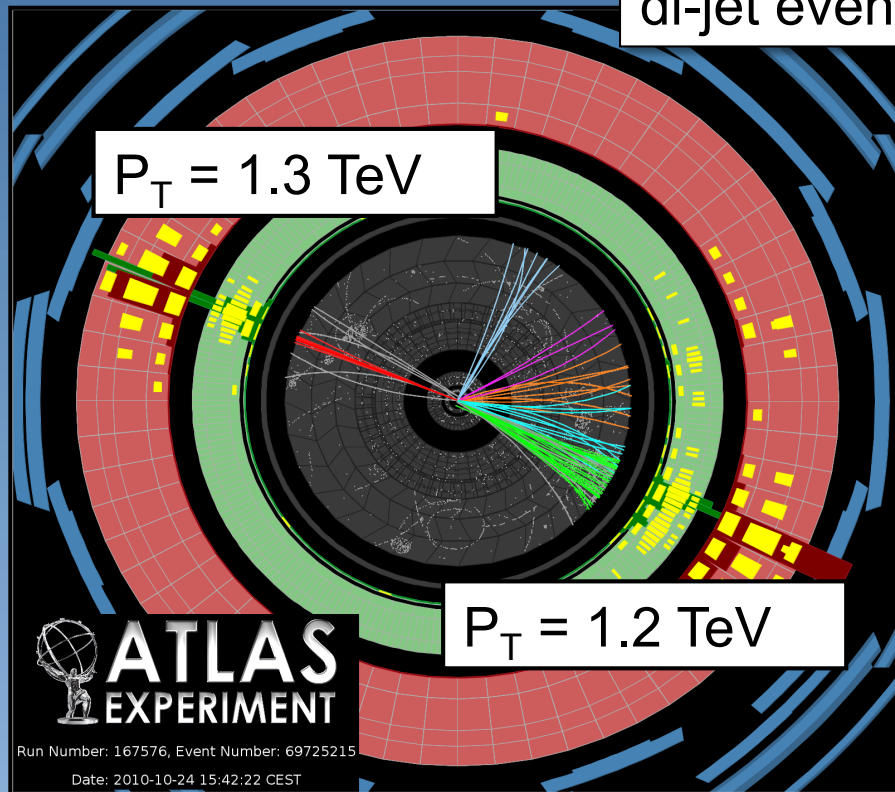
Λ invariant mass



Quark (jet) reconstruction

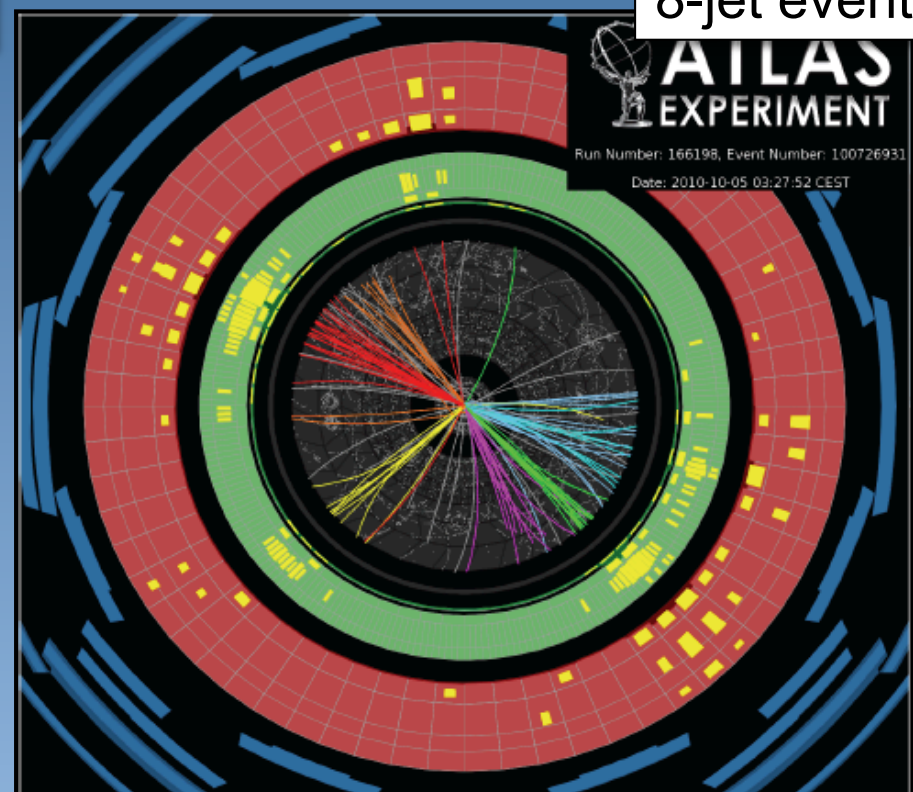
Tracker and calorimeters

di-jet event



High transverse momentum

8-jet event

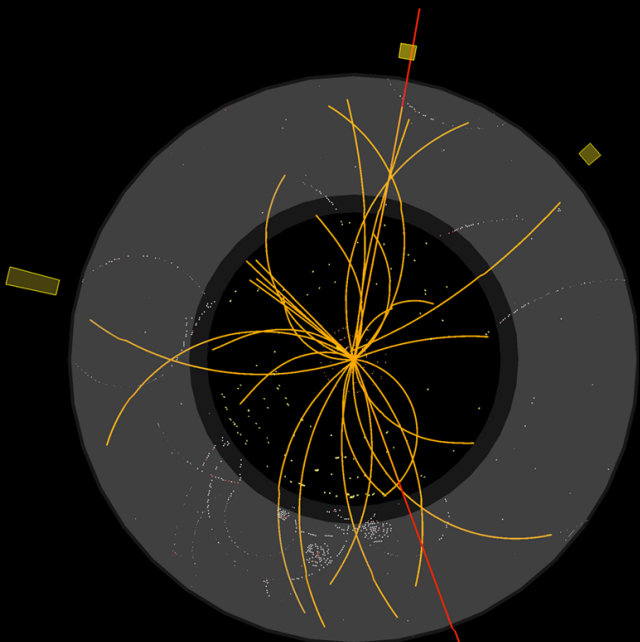


Multi-jet: 8 jets with $P_T > 60 \text{ GeV}$



ATLAS EXPERIMENT

Run: 154822, Event: 14321500
Date: 2010-05-10 02:07:22 CEST



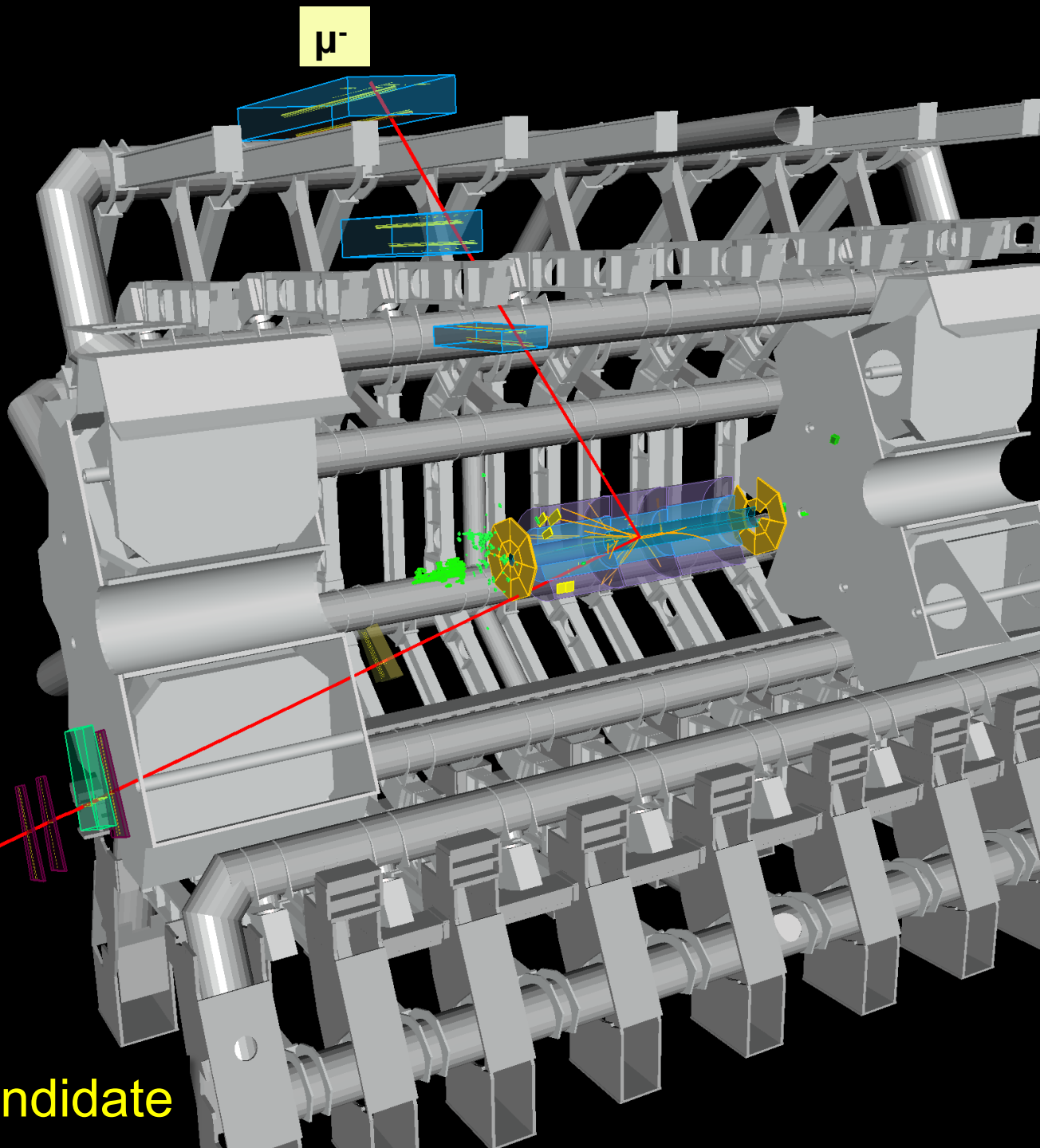
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$M_{\mu\mu} = 87 \text{ GeV}$

μ^+

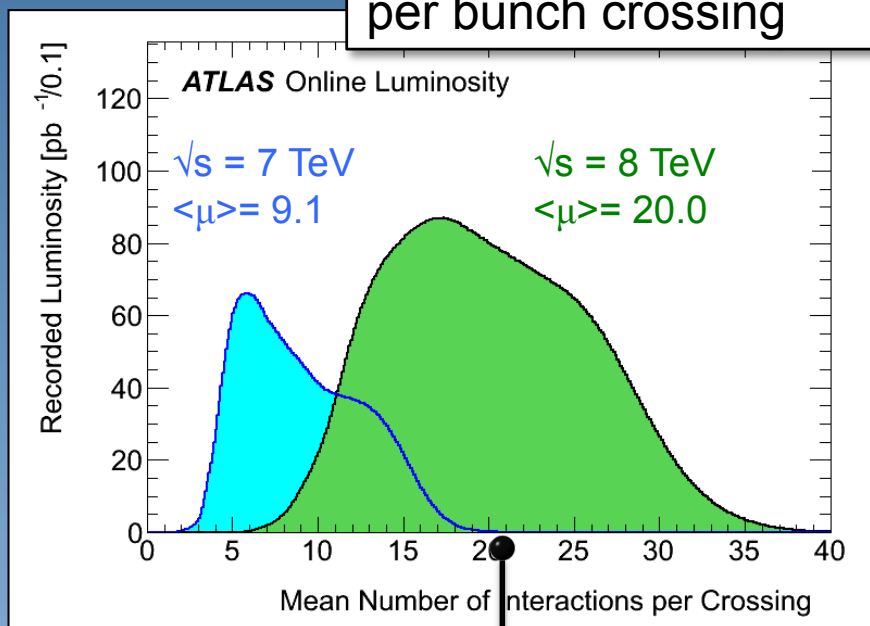


$Z \rightarrow \mu^+\mu^-$ candidate

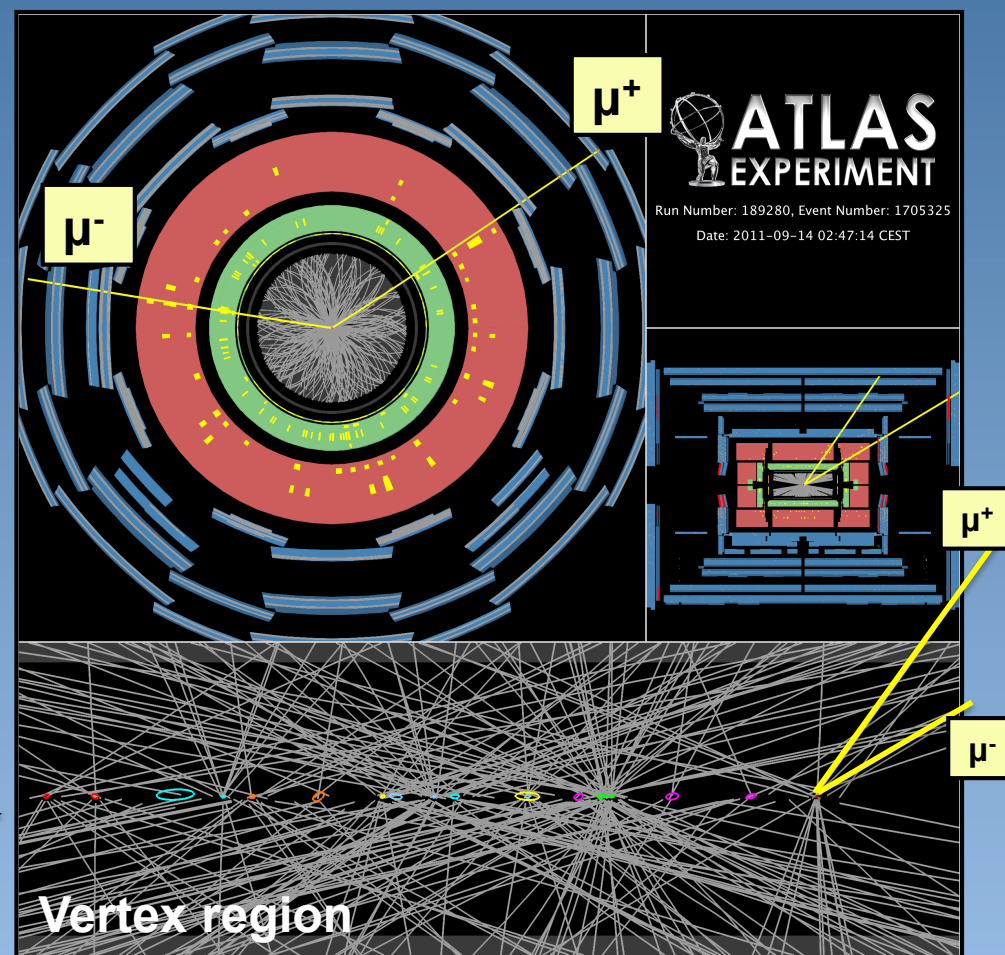


LHC is not a quiet environment

Number of interactions
per bunch crossing

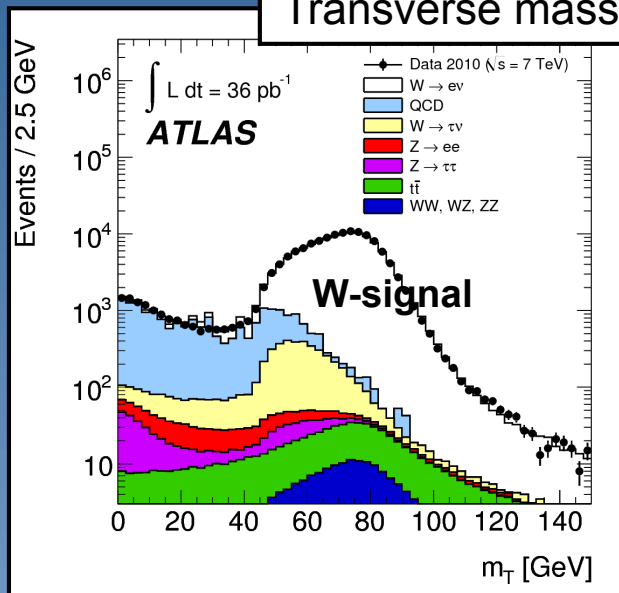


$Z \rightarrow \mu^+\mu^-$ event with 20 vertices



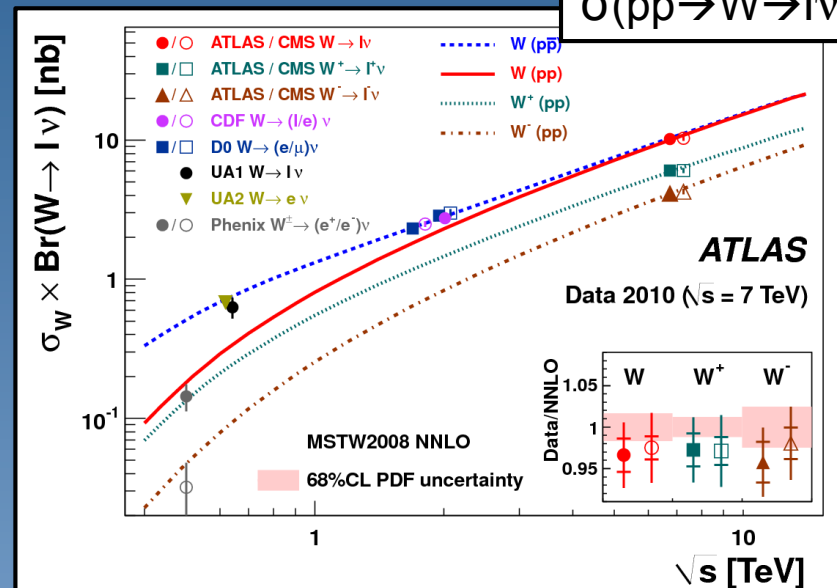
W and Z boson production at the LHC

Transverse mass

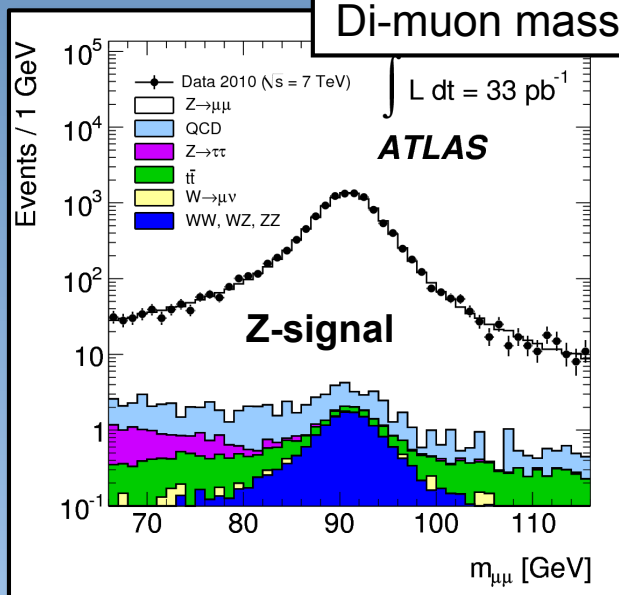


W-boson

$\sigma(pp \rightarrow W \rightarrow l\nu)$

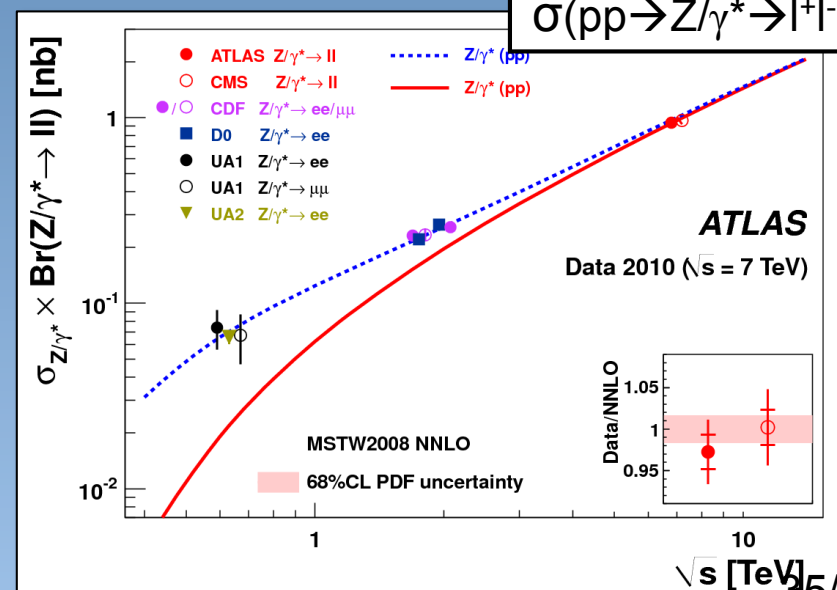


Di-muon mass



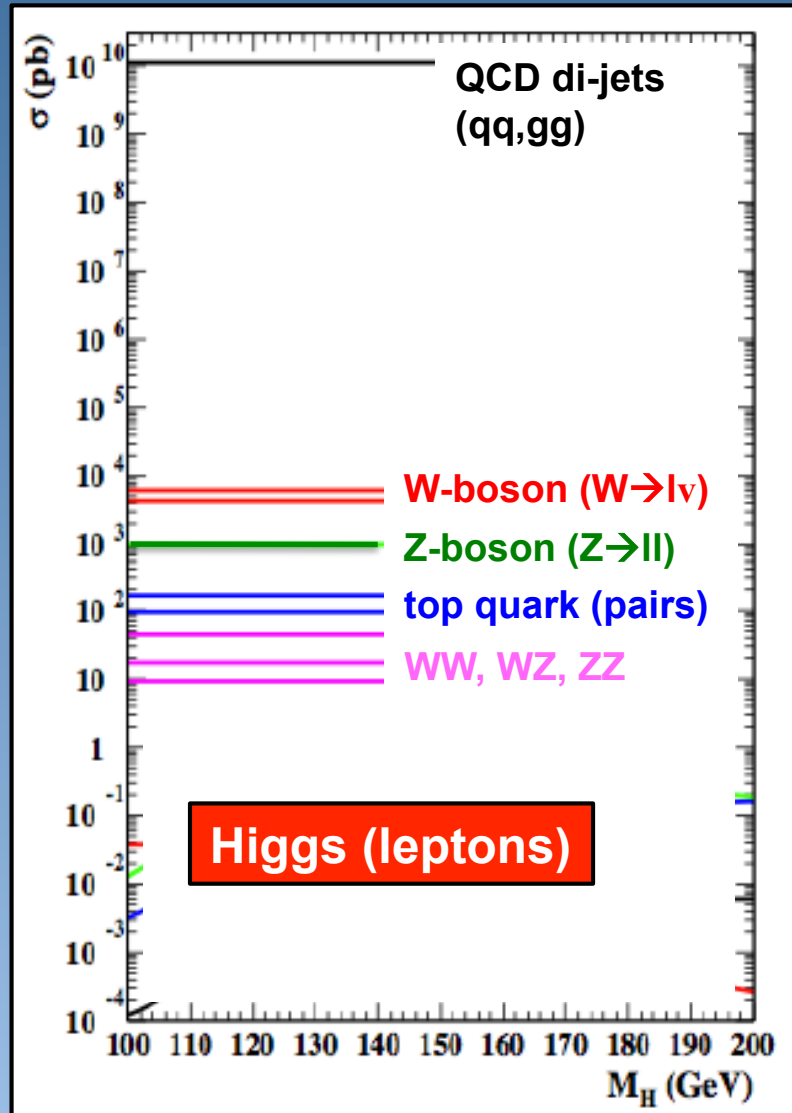
Z/γ*-boson

$\sigma(pp \rightarrow Z/\gamma^* \rightarrow l^+l^-)$



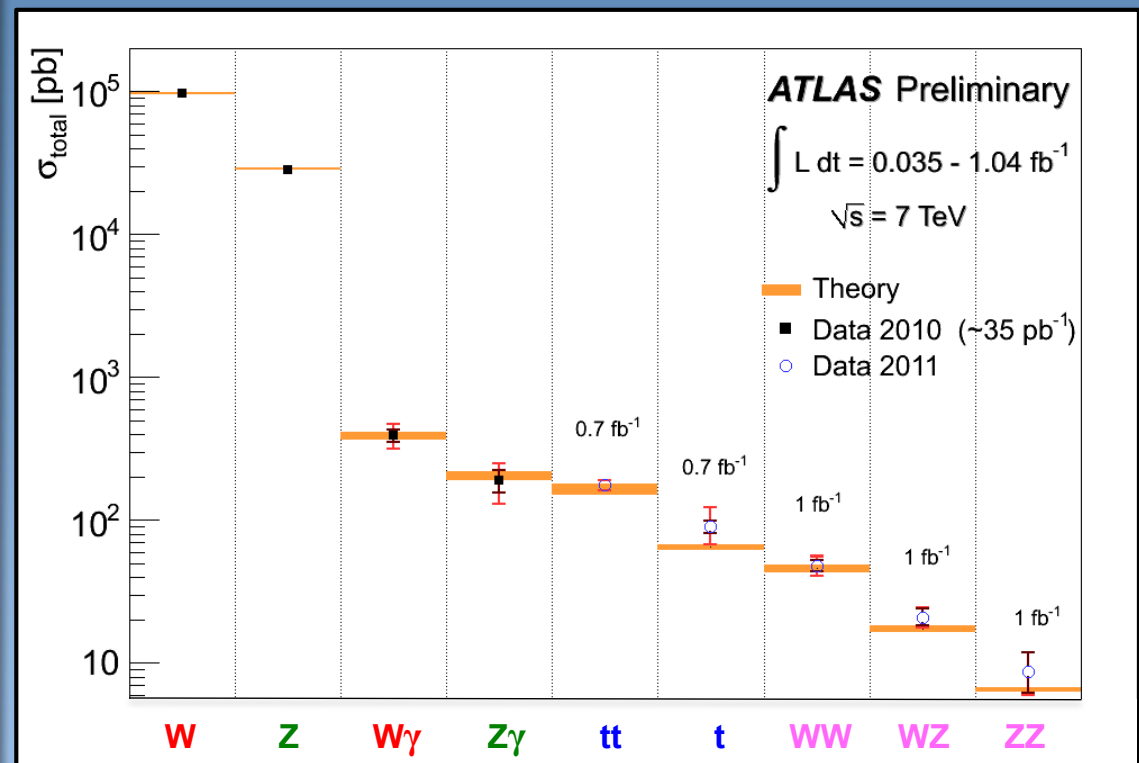
Standard Model processes at the LHC

predicted cross-sections



*Note: many many many jets (quarks/gluons):
→ look for leptons (electrons/ muons)*

ATLAS measurements



G. Asad⁶, B. Abbott¹¹, H. Al-Haddad¹¹, A.A. Abdelhalim⁴, A. Abdelrazek¹¹⁸, O. Abidinov¹⁰, B. Al¹¹²
M. Abolins⁸⁸, H. Abramowicz¹⁶⁵, H. Abres¹¹⁶, E. Acert^{350,360}, B.S. Acharya^{164,166}, M. Aders²⁰, D.L. Adams²
T.N. Ady⁵⁶, J. Adelman¹⁷⁸, M. Adlerhof³⁰, S. Adomei⁶⁶, P. Adragna⁷⁸, T. Aduy¹²⁹, S. Aefsky²²,
J.A. Aguilar-Saavedra^{124b,x}, M. Aharaoka⁸¹, S.P. Ahlen², F. Ahles⁴⁸, T. Akai¹⁶⁸, M. Ahsan⁶
G. Aielli^{133,138}, T. Akdogan¹⁸⁸, T.P.A. Åkesson⁶⁰, G. Akimoto¹⁰⁵, A.V. Akimov⁹⁴, M.S. Alam¹, M.A. Alam⁷⁶
S. Albers¹⁵⁰, M. Albrecht²⁹, L.B. Aplebeke⁶⁰, M. Alroba^{30,360}, F. Alvarado³⁰, G. Alerba²⁶, G. Alexander¹⁸³

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B. Fathollahzadeh¹⁸⁸

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[illegible]

Haller⁴¹, S. Hillert²⁰, S.J. Hillier¹⁷, I. Hinchliffe¹⁴, E. Hines¹²⁰, M. Hirose¹¹⁶, F. Hirsch⁴²,
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⁸³, M. Holdfield⁸¹, M. Holder¹⁴¹, A. Holmes¹¹⁸, S.O. Holmgren^{146a}, T. Holy¹²⁷
ner¹⁷, Y. Homma⁶⁷, T. Horazdovsky¹²⁷, C. Horn¹⁴³, S. Horner⁴⁸, K. Horton¹¹⁸
S. Hou¹⁶¹, M.A. Houlden⁷³, A. Houtamada^{138a}, J. Howarth⁸², D.F. Howell¹¹⁸
I. Hruba¹²⁶, T. Hyryova⁴, P.J. Hu¹⁷⁵, S.-C. Hu¹⁴, G.S. Huang¹¹¹, Z. Huback¹²⁷
T. Hui¹⁷, R.W.H. Hui¹⁷, C. Hui¹⁷, B. Hui¹⁷, B. Hui¹⁷, B. Hui¹⁷, B. Hui¹⁷

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D. Lellouch¹⁷¹, J. Lelouchas¹⁹, M. Lelschow²⁴, V. Lenderman¹⁸⁸, K.J.C. Lester^{148k}, T.
B. Lenzi¹⁵⁶, K. Leonhardt⁴³, C. Leroy⁶², J.R. Lessard⁶⁰, J. Lesser^{144a}, C.G. Lester¹,
J. Levêque¹⁵⁸, D. Levin⁸⁷, L.J. Levinson¹⁷¹, M.S. Levitski¹²⁸, M. Lewandowski²¹, M.
S. Li²⁸, X. Li^{28g}, Z. Lian¹⁰², Z. Liang^{118g}, B. Libert¹³, P. Lichard²⁰, M. Lichtne¹⁰²,
R. Lifshitz¹⁶², H. Lin¹⁵¹, L.J. Lilley¹, A. Limosani¹⁰, M. Limper⁶³, S.C. Lin^{151a,f}, F. Linde¹⁰²,
E. Lippele¹, L. Liptai¹⁰², A.A. Litke¹⁰², A.A. Litke¹⁰², A.A. Litke¹⁰², A.A. Litke¹⁰²,
H. Liu¹⁰², H. Liu¹⁰², H. Liu¹⁰², H. Liu¹⁰², H. Liu¹⁰², H. Liu¹⁰², H. Liu¹⁰², H. Liu¹⁰²,
A. Bobinski¹⁰², R.M. Lofgren¹⁰², P. Lofgren¹⁰², P. Lofgren¹⁰², P. Lofgren¹⁰², P. Lofgren¹⁰²,
A. Logozin¹⁰², C.W. Lo¹⁰², C.W. Lo¹⁰², C.W. Lo¹⁰², C.W. Lo¹⁰², C.W. Lo¹⁰², C.W. Lo¹⁰²,
R.E. Long¹⁷¹, I. Lopes¹⁰², I. Lopes¹⁰², I. Lopes¹⁰², I. Lopes¹⁰², I. Lopes¹⁰², I. Lopes¹⁰²,
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L. Lu¹⁰², H. Lubatti¹⁰², H. Lubatti¹⁰², H. Lubatti¹⁰², H. Lubatti¹⁰², H. Lubatti¹⁰², H. Lubatti¹⁰²,
F. Luehring¹⁰², G. Luisi¹⁰², G. Luisi¹⁰², G. Luisi¹⁰², G. Luisi¹⁰², G. Luisi¹⁰², G. Luisi¹⁰²,
J. Lundberg¹⁰², J. Lundberg¹⁰², J. Lundberg¹⁰², J. Lundberg¹⁰², J. Lundberg¹⁰², J. Lundberg¹⁰²,
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F. Malek¹⁰⁵, U. Mallik⁶
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A. Manah⁵⁴, P.M. Mani
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S. Marti-Carvajal¹⁰⁶
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F. Marzano^{132a}, A. Ma
M. Ma⁸², I. Maesa¹⁰⁴
P. Matricorn¹¹⁵, H. Ma
S.J. Maxfield¹²³, E.N. M
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J. Meinelhard⁴⁸, B. Mes
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J. Meyer¹⁷³, J. Meyer
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G. Micheli¹²⁴, L. Mi
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A. Negri^{110a,110b}, G. N

S. Odaka⁶⁶, J. Odier⁶⁹
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A.G. Olchevski¹⁰⁵, M. O
J. Olszewski¹⁰⁴, J. O
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L. Poggiali¹¹⁵, T. Pos
V. Polychnon¹²⁴, P. Pog
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X. Prudent⁴⁸, H. Przy
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G. Redlinger²⁴, R. Res
D. Reljic¹²⁴, C. Remba
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S. Riecke¹, M. Rijstora
G. Rivoltella¹⁰⁴, F. R
J. R. R. R. R. R. R. R.
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A. Romanioncu¹⁰⁶, V.M.
M. Rose⁷⁸, G.A. Rosen

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H. Sandaker¹²³, H.G. Sande²⁸¹, M.
S. Sandovos¹⁷⁴, D.P.C. Sander¹²⁹,
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O. Sasaki¹, T. Sasaki¹⁰⁸, N. Saso
I. Sawyer¹²⁴, M.D. Saxon¹¹, L.P.
J. Schaefer¹²³, S. Schaefer¹²³, A.
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D. Silverstein¹⁴³, S.B. Silverstei
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T.B. Sjursen¹³, L.A. Skinner¹⁴,
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S. Soler¹²⁷, J. Soler¹²⁷, U. Sold
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M. Spouta¹²⁶, T. Spreitzer¹⁰⁸,
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P. Starovoirov¹⁰⁴, A. Staud⁶, P.
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A. Tapp¹¹⁷, N. Taubman¹⁰³, Y. T

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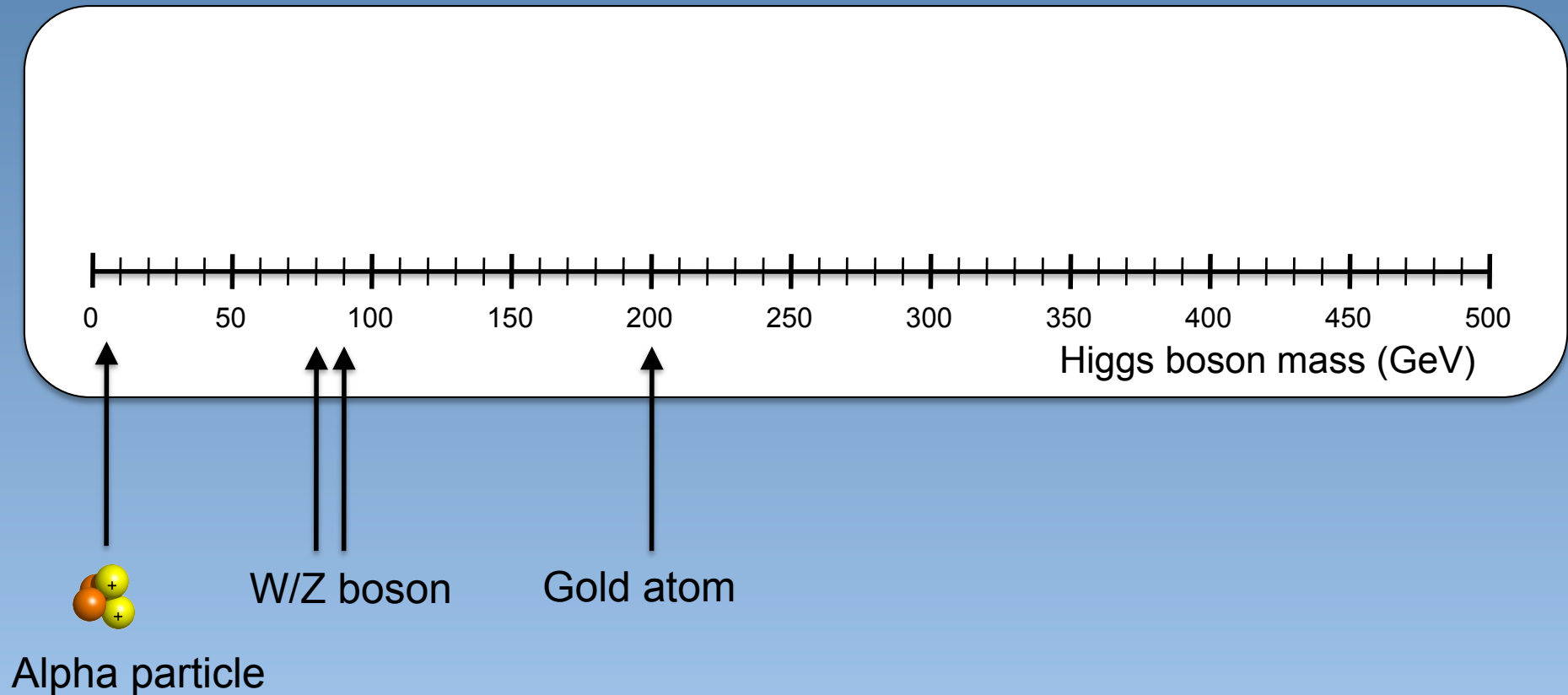
Trigger:
From 40 MHz (LHC) to a few hundred Hz



Bottleneck: disk space

Selecting interesting physics from an e-nor-mous background

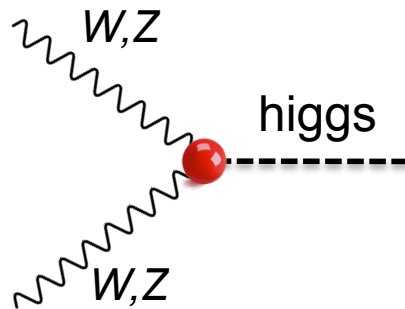
The mass of the Higgs boson



How can you produce a Higgs particle ?

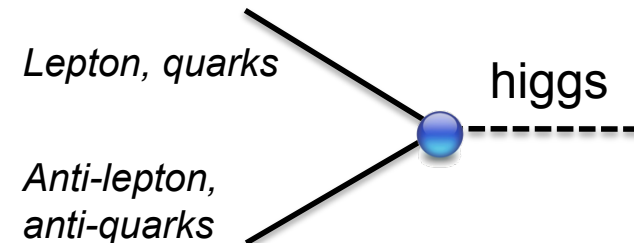
Gauge bosons

*Massive gauge boson ?
... then it coupling to the Higgs!*



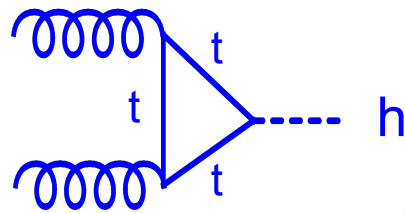
Fermions

*Massive fermion ?
... then it couples to the Higgs!*

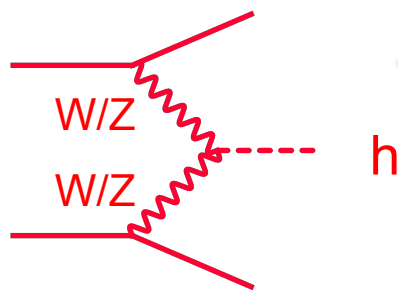


Higgs boson production

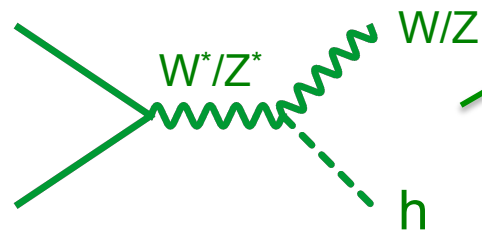
Production of the Higgs boson



Gluon fusion

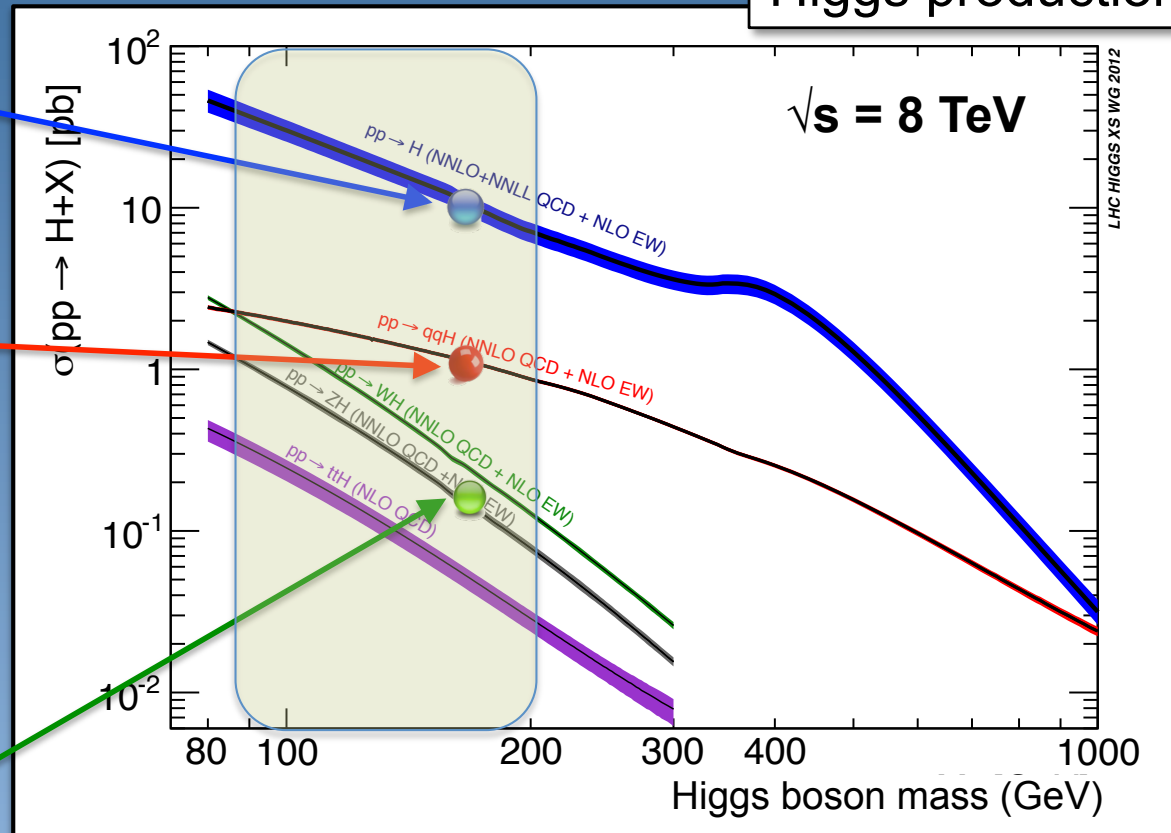


Vector boson fusion



Associated production

Higgs production



How many Higgs bosons have been produced at the LHC (until July 4th) ?



If the Higgs boson exists:

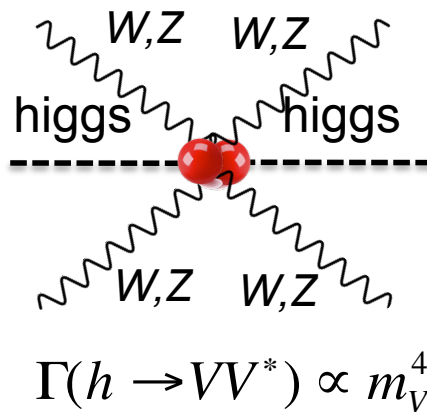
$m_h = 125 \text{ GeV: } 212.000$

$m_h = 200 \text{ GeV: } 77.000$

How does the Higgs boson decay ?

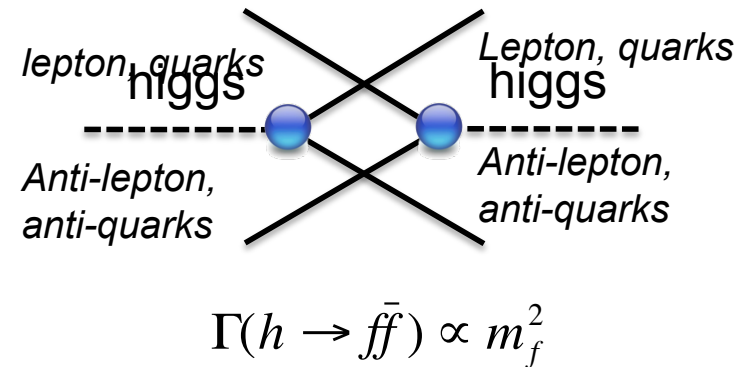
Gauge bosons

*Massive gauge boson ?
... then it coupling to the Higgs!*



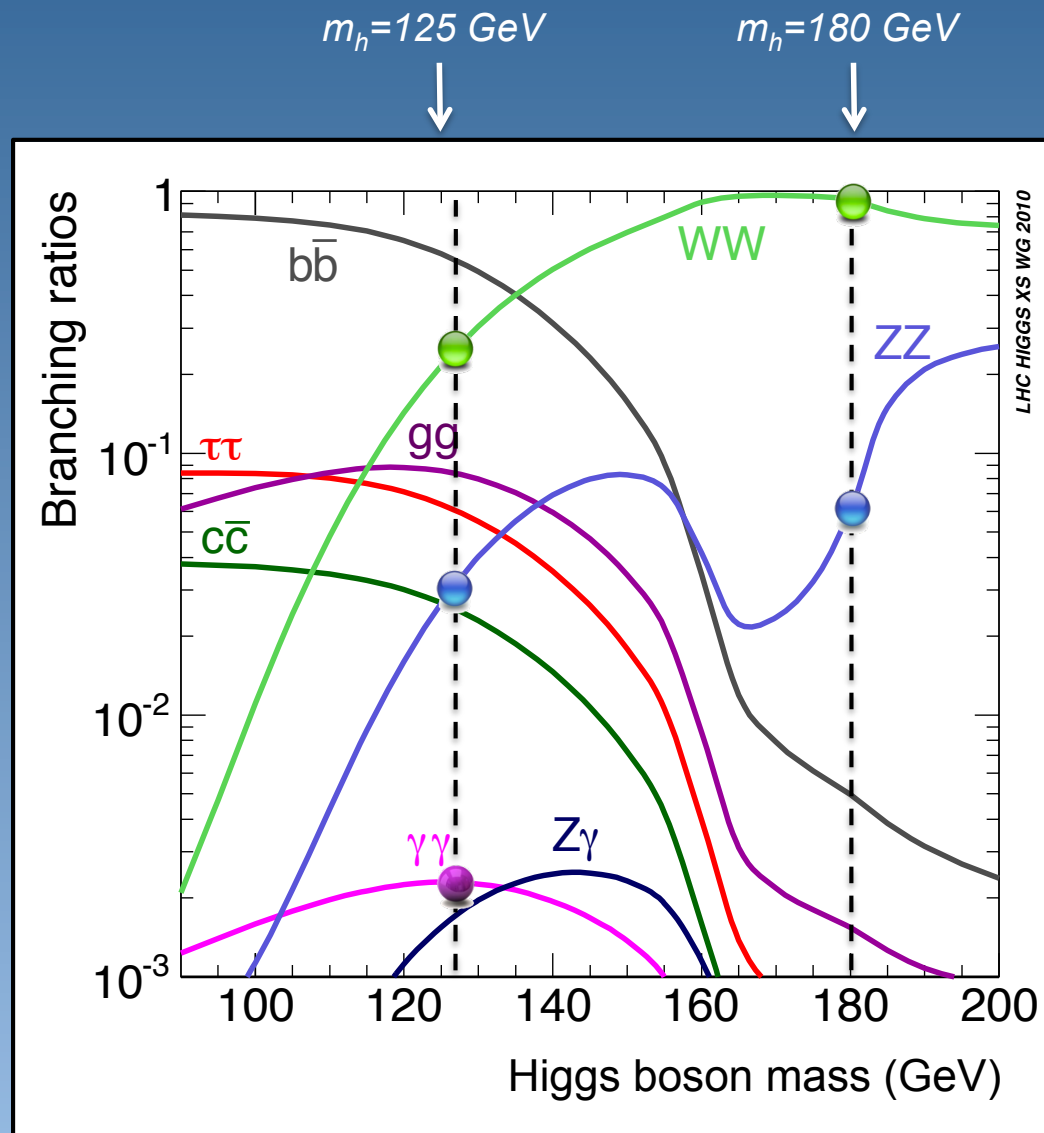
Fermions

*Massive fermion ?
... then it couples to the Higgs!*



Higgs boson production

Decay of the Higgs boson



Subsequent gauge boson decay

$W \rightarrow qq$ 67%

lv 33%

$Z \rightarrow qq$ 70%

$\nu\nu$ 20%

ll 10%

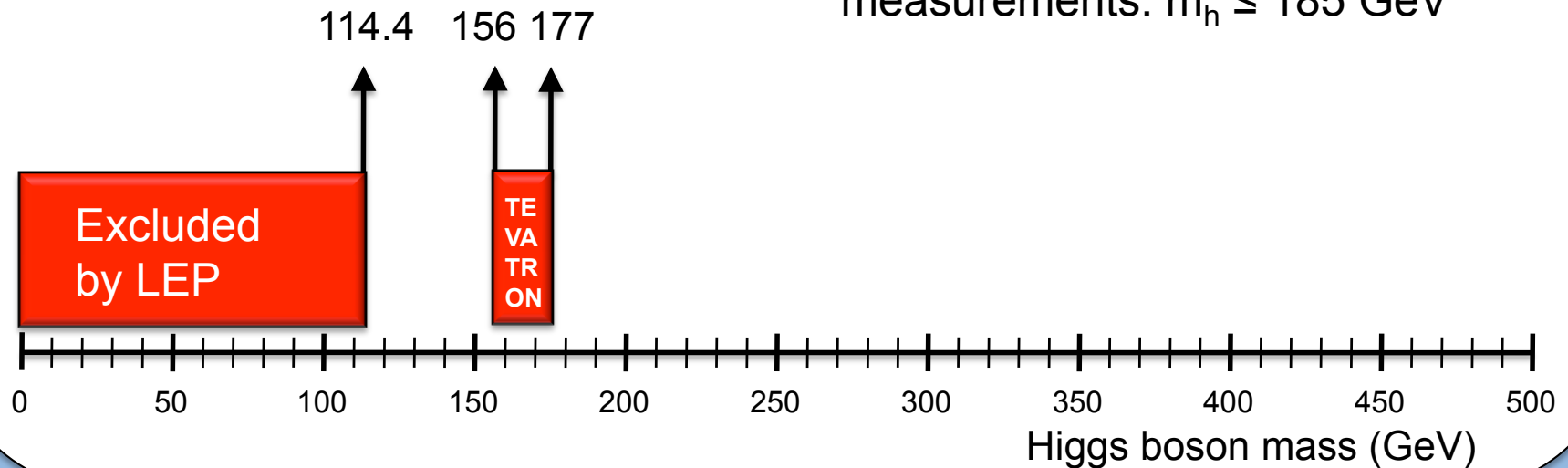
1 W/Z gauge boson off-shell

Status beginning of last year

Indirect:

Theory: $m_h \leq 600$ GeV

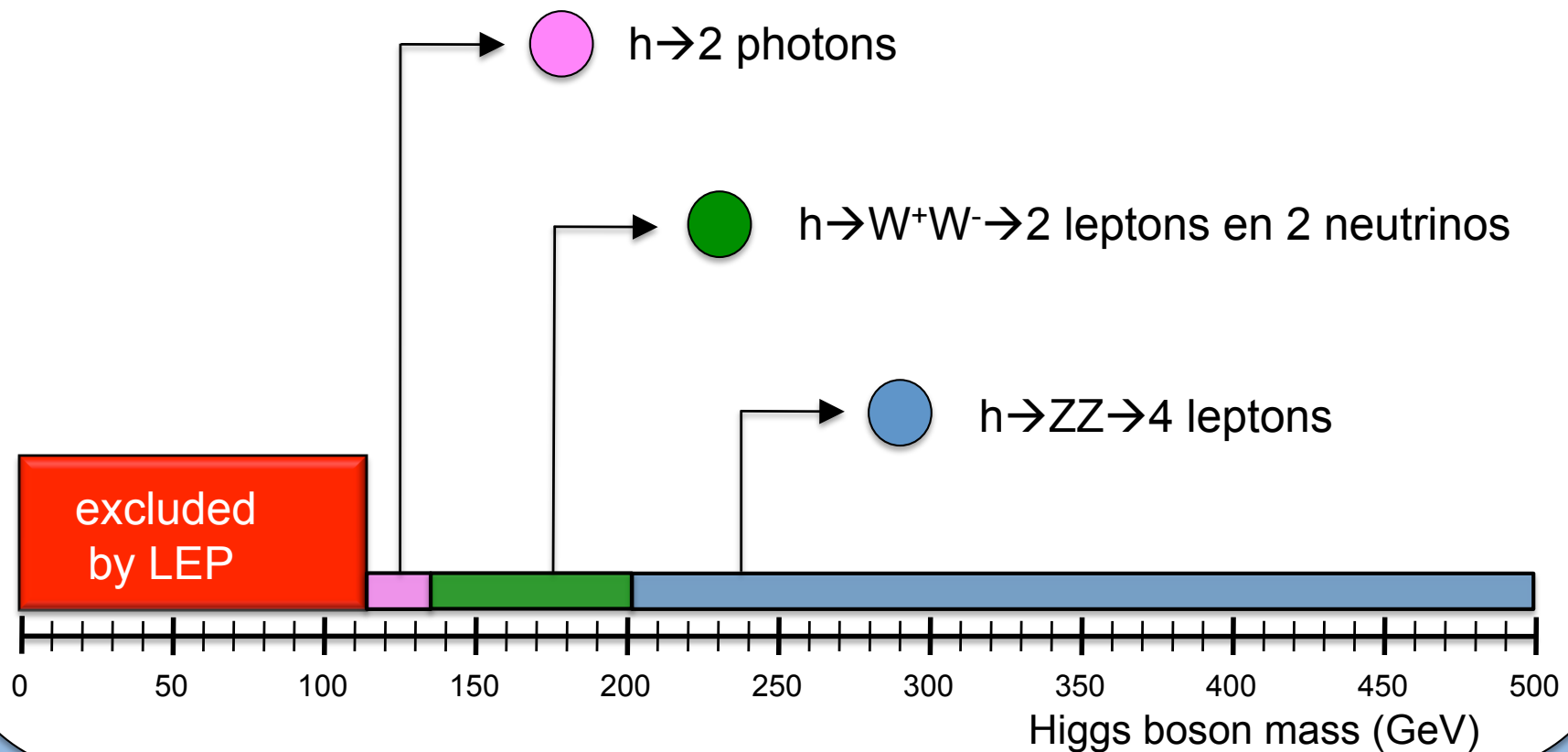
Electroweak precision-measurements: $m_h \leq 185$ GeV



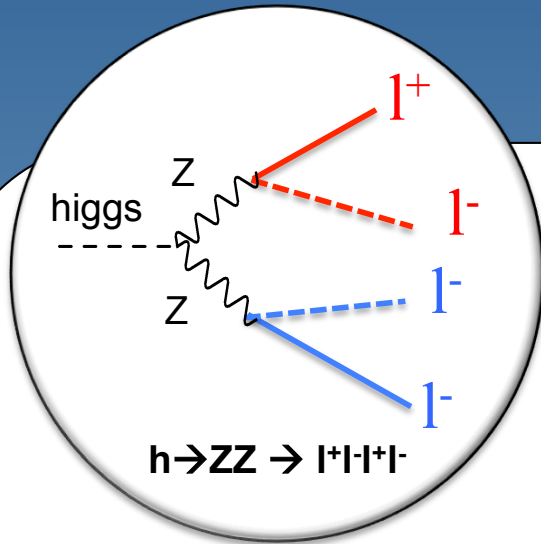
Experiments at the LHC Sensitive for mass range: 114-1000 GeV 45/78

The clearest fingerprint of the Higgs boson

For every mass here are multiple channels: these are most sensitive ones



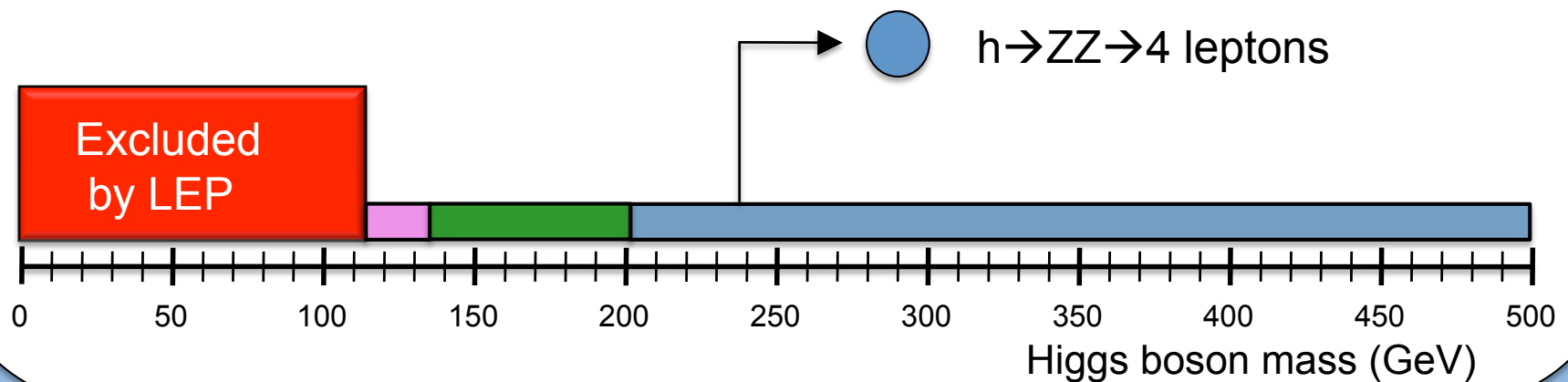
High mass's: $m_H > 200$ GeV



The golden channel

- 4 leptons (e/μ)
- very rare: Higgs of ZZ

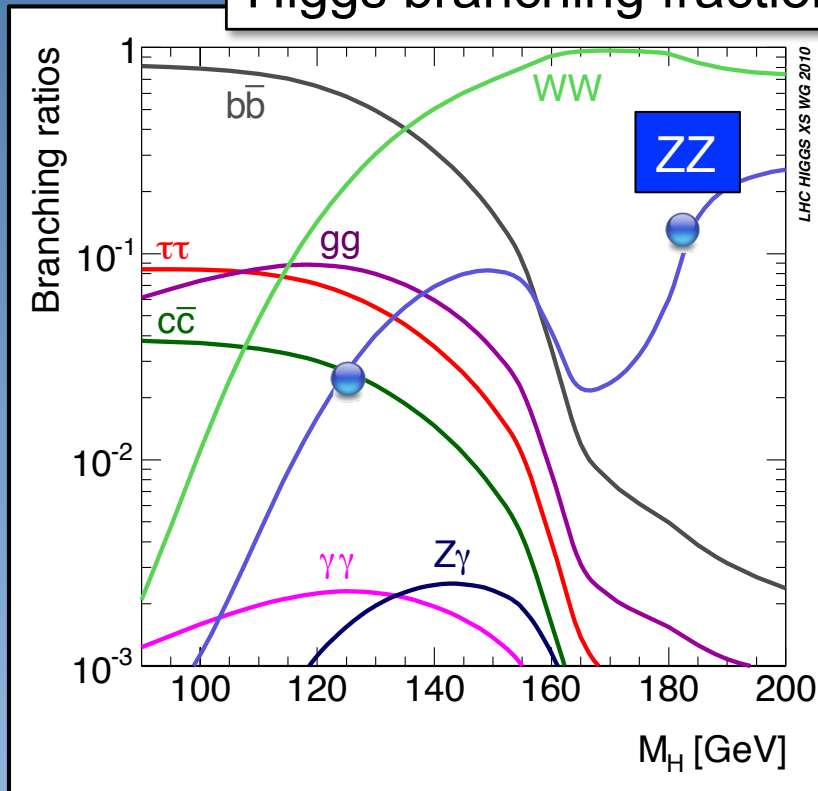
Fingerprint: 4-lepton mass



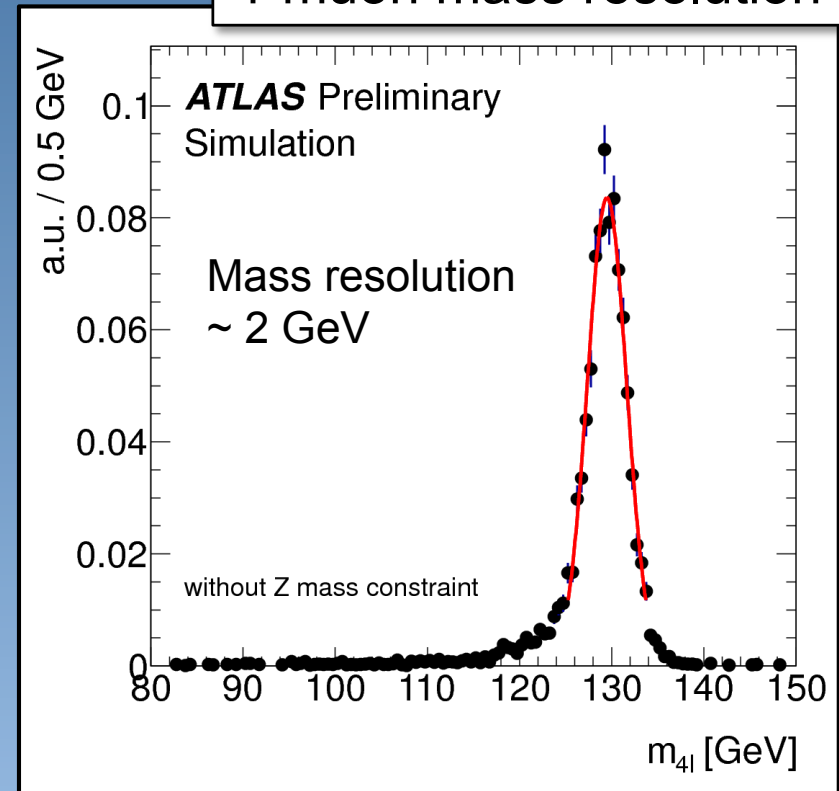
Higgs $\rightarrow$ $ZZ \rightarrow$ 4 leptons

Small number of beautiful collisions

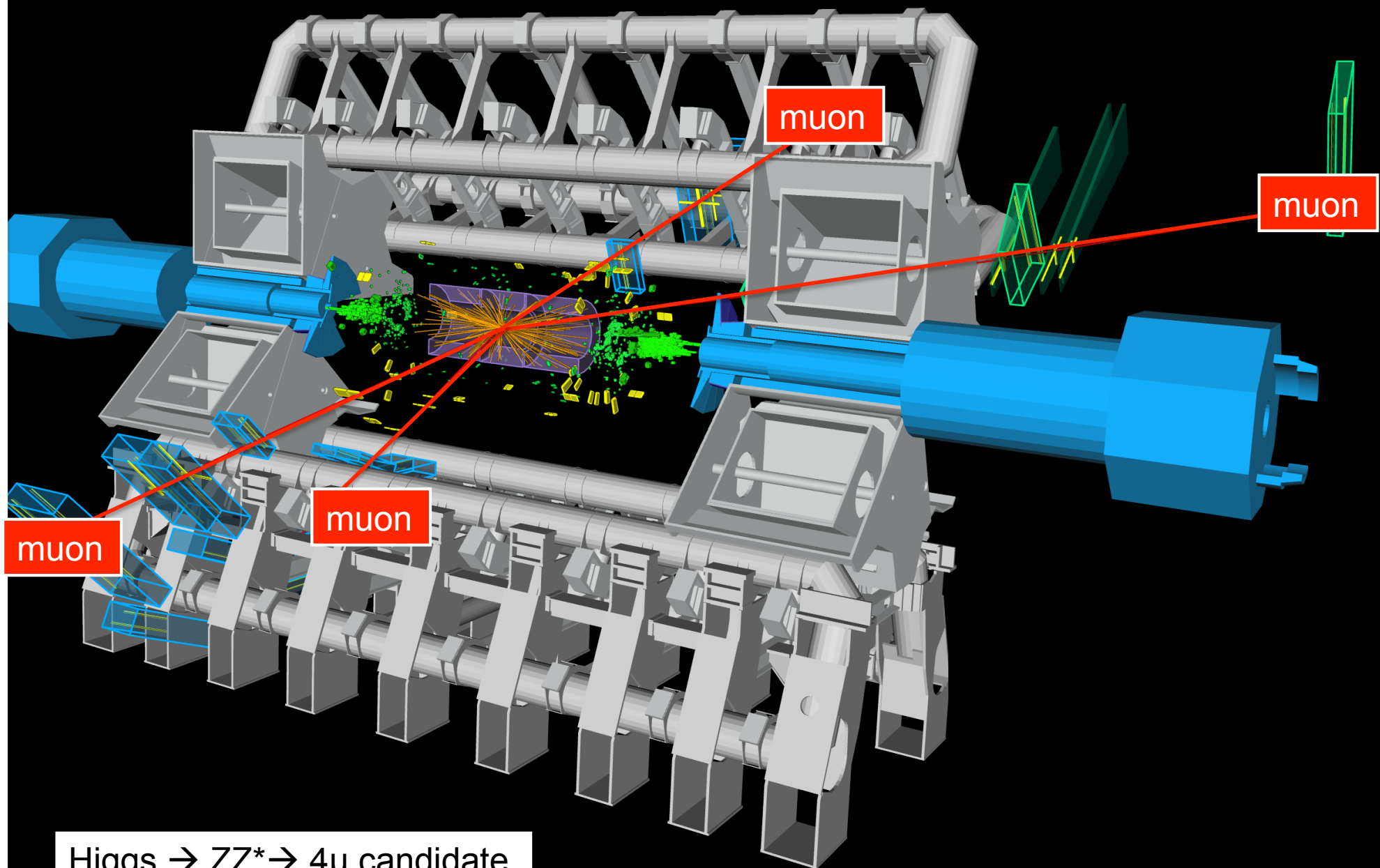
Higgs branching fraction



4-muon mass resolution



Note: if $m_h = 125$ GeV: only 1 in 8,000 Higgs bosons results in a 4 lepton (lepton = electron or muon) final state



Higgs $\rightarrow$ ZZ $\rightarrow$ 4 leptons: small sample of beautiful events

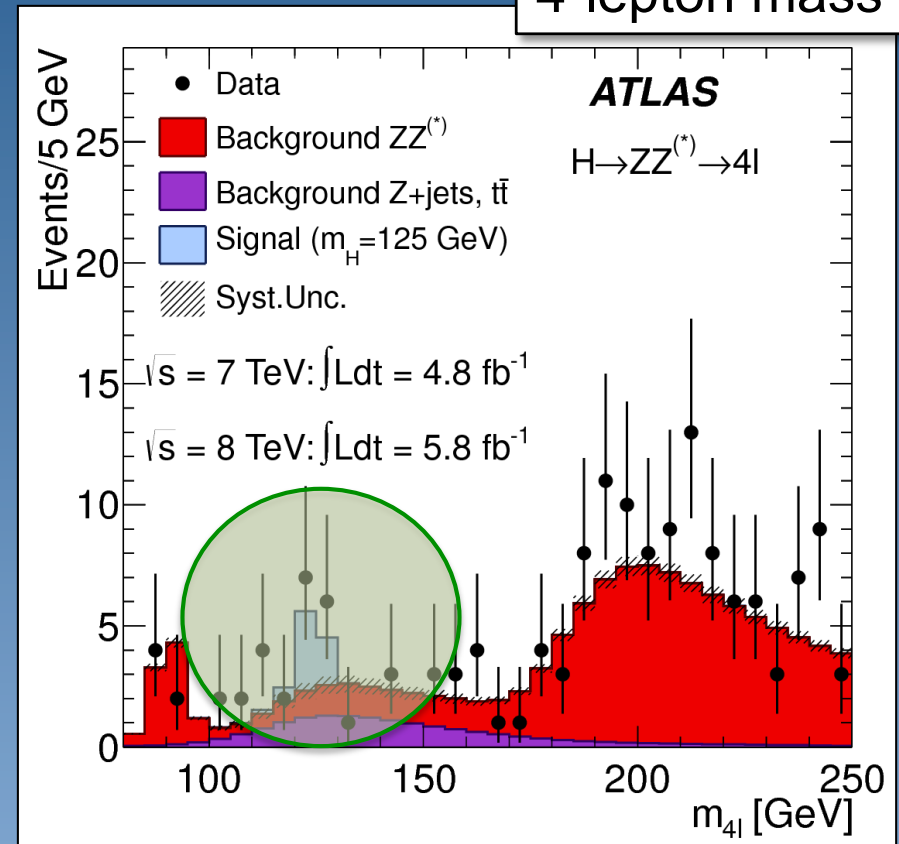
Example: 125 GeV Higgs

1) Theory: $H \rightarrow ZZ \rightarrow 4l$ ($l=e, \mu$):

$$\left. \begin{array}{l} \Gamma(h \rightarrow ZZ) = 2.64 \% \\ \Gamma(Z \rightarrow ll) = 3.37 \% \end{array} \right\} 1.25 \cdot 10^{-4}$$

2) ATLAS detector: reconstruct 4 μ detector acceptance, Atlas muon reconstruction and selection criteria

4-lepton mass



$$m_{4l} = 125 \pm 5 \text{ GeV}$$

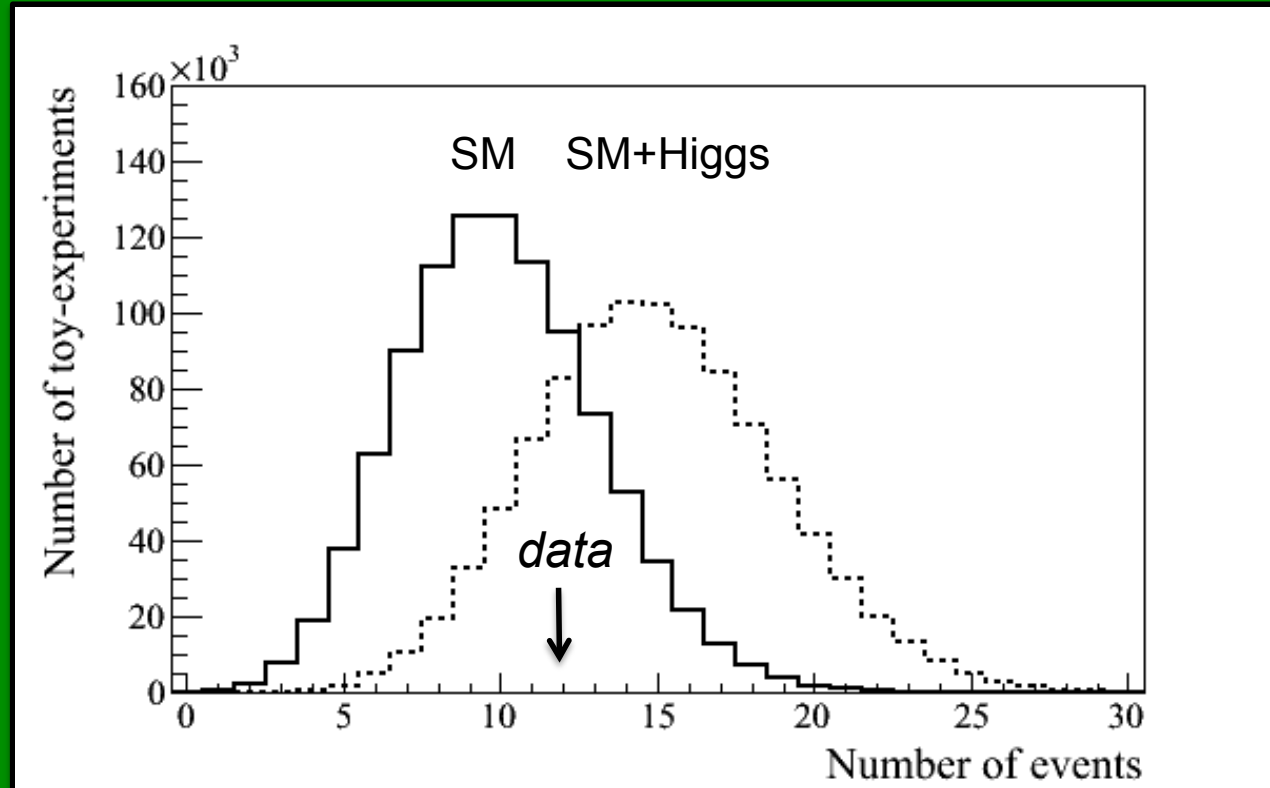
Expectation: SM (+Higgs)
Observation: Data

4.8 (10.1)
13

EXAMPLE: Quantifying compatibility with SM hypothesis

Measurement

SM	10
Higgs	5
Data	12



For a given number of events, the p-value is:

1) Expected excess (p-value)

2) Observed excess (p-value)

*“The probability to observe as many events as this number (or even more) under the assumption that the Higgs does **not** exist”*

→ Can be translated into a (gaussian) significance

Quantifying an excess: p-value

Measurement

SM	10
Higgs	5
Data	12

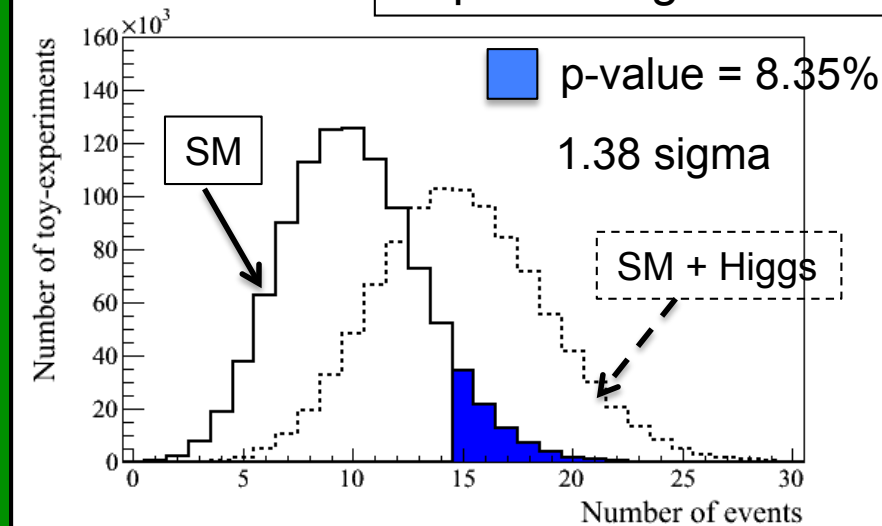
p-value $< 2 \cdot 10^{-7} \rightarrow$ discovery!



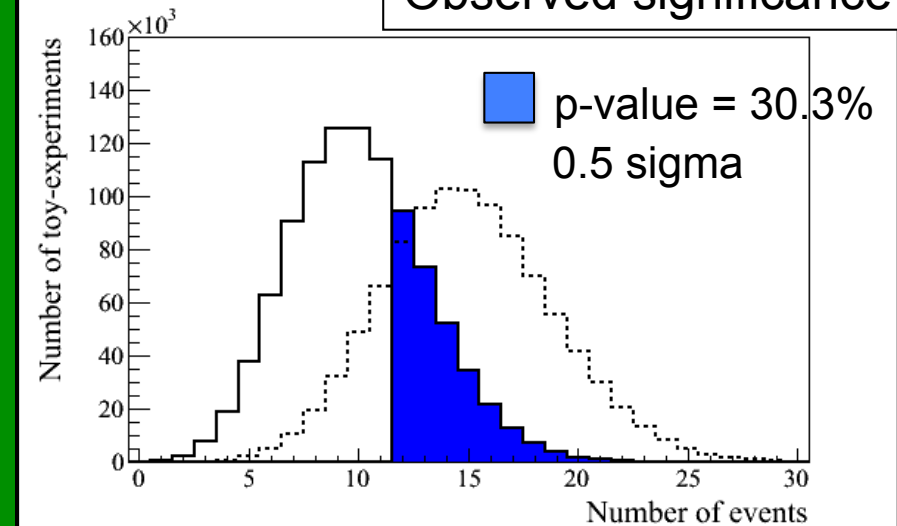
1) What is the expected significance ?

2) What is the observed significance ?

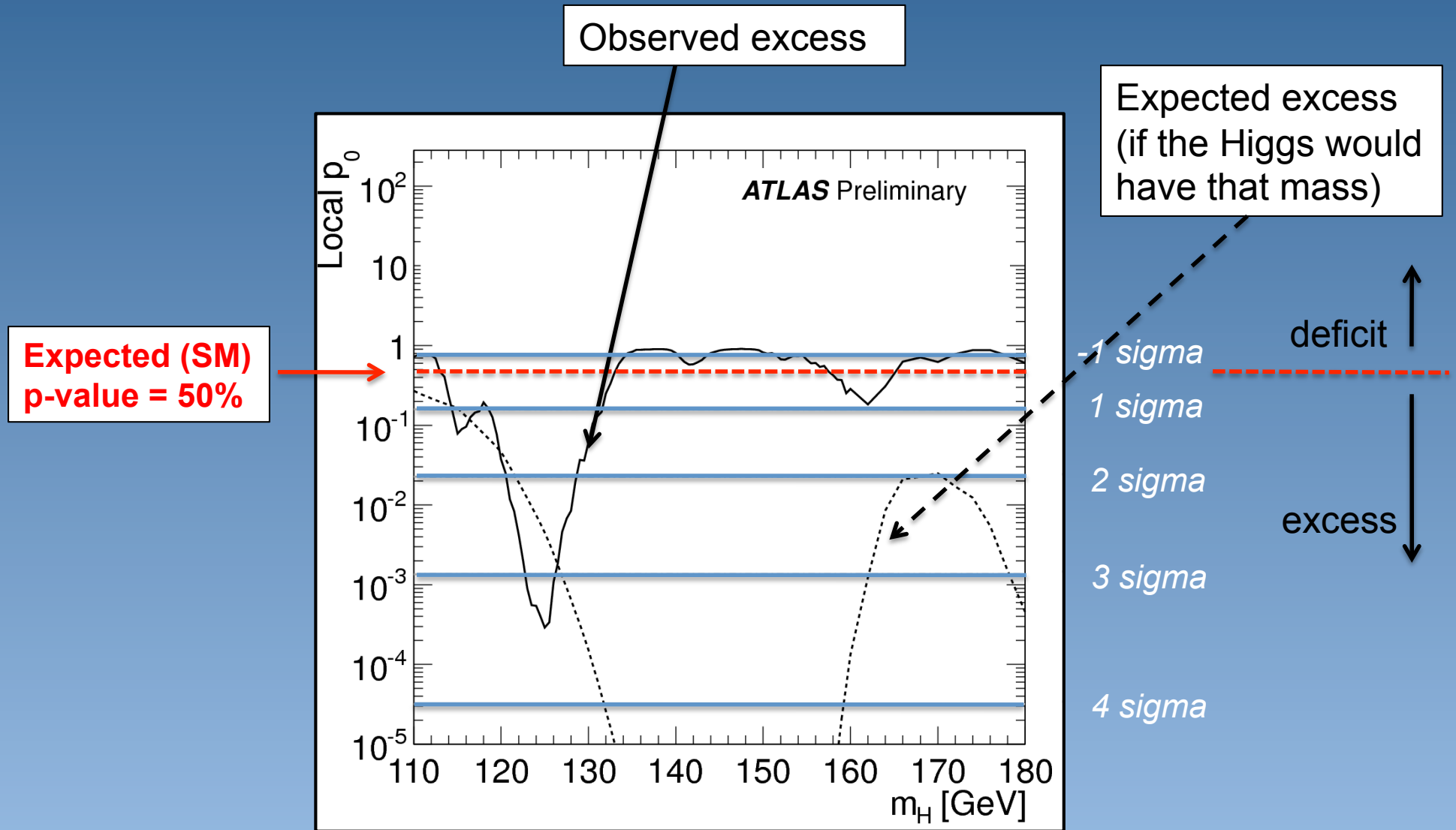
Expected significance



Observed significance

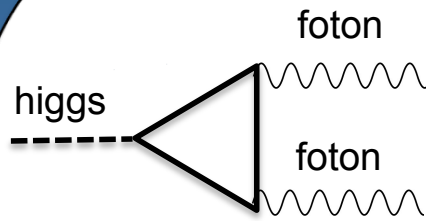


Quantifying the excess:



The low-mass region

0.2%



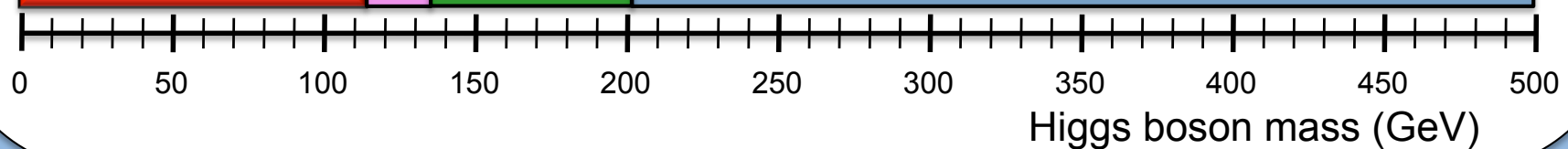
$h \rightarrow \gamma\gamma$ decay

 $h \rightarrow 2$ photons

- 2 energetic isolated photons
- detector sensitive for 'fake' signals

Fingerprint: 2-photon mass

excluded
by LEP



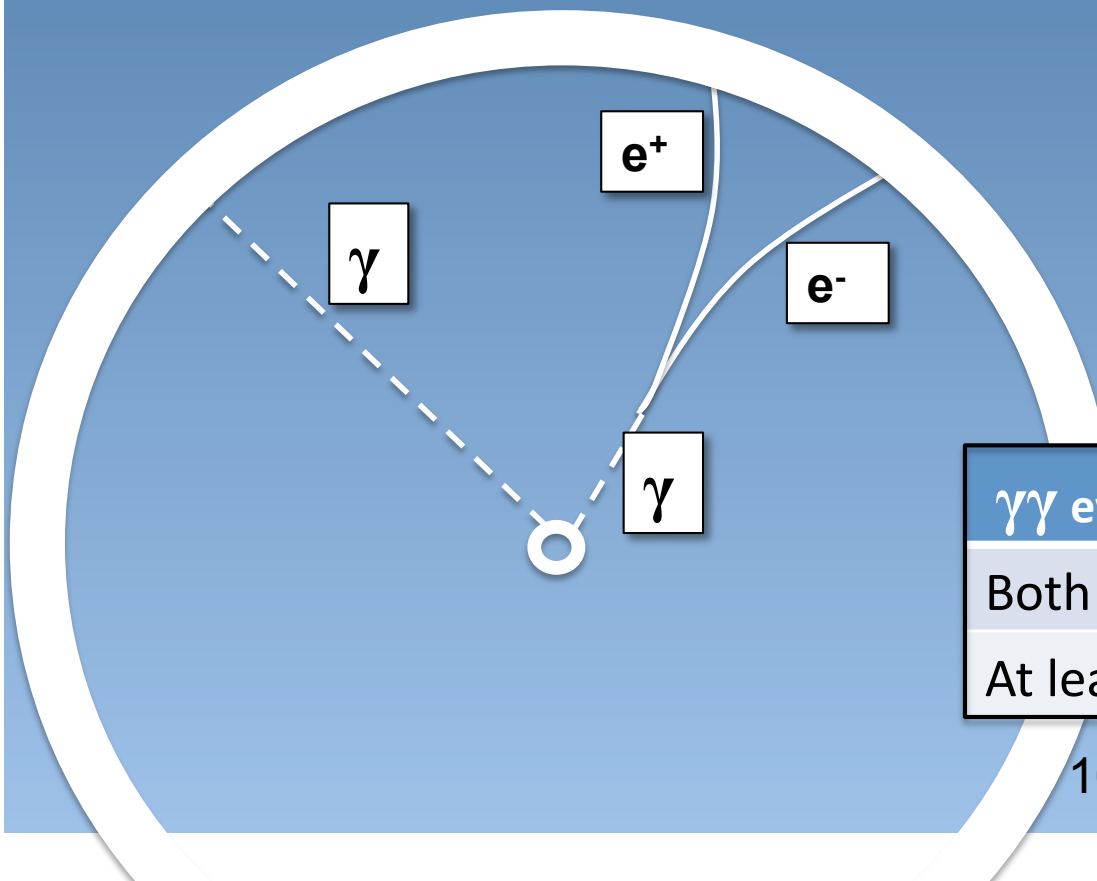
Photon identification and event selection

Selection: 2 isolated photons: $P_T > 40$ (30 GeV)

40% selection efficiency



“Elk nadeel hep z'n voordeel”



$\gamma\gamma$ event classification	Fraction
Both unconverted	41%
At least 1 converted	59%

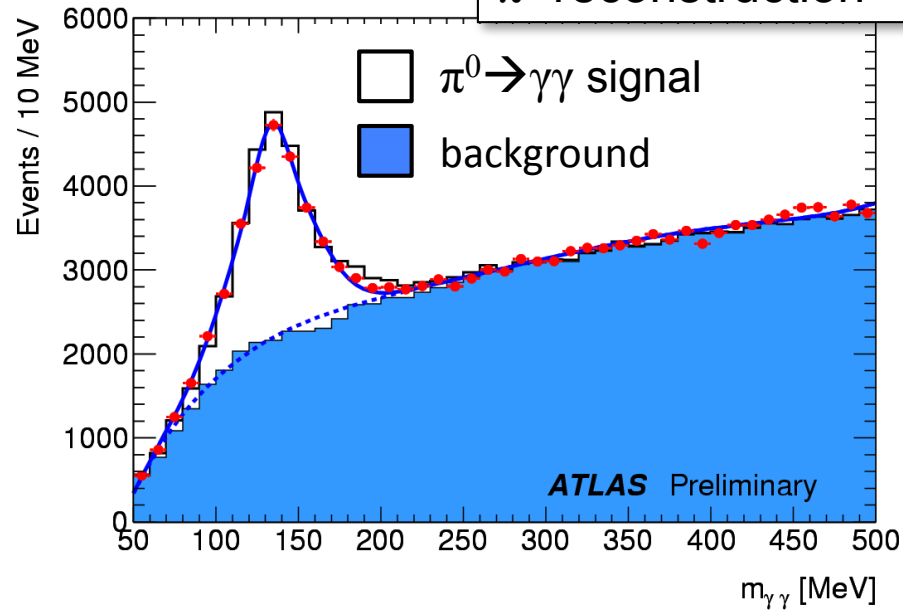
10 separate topology-categories

55/78

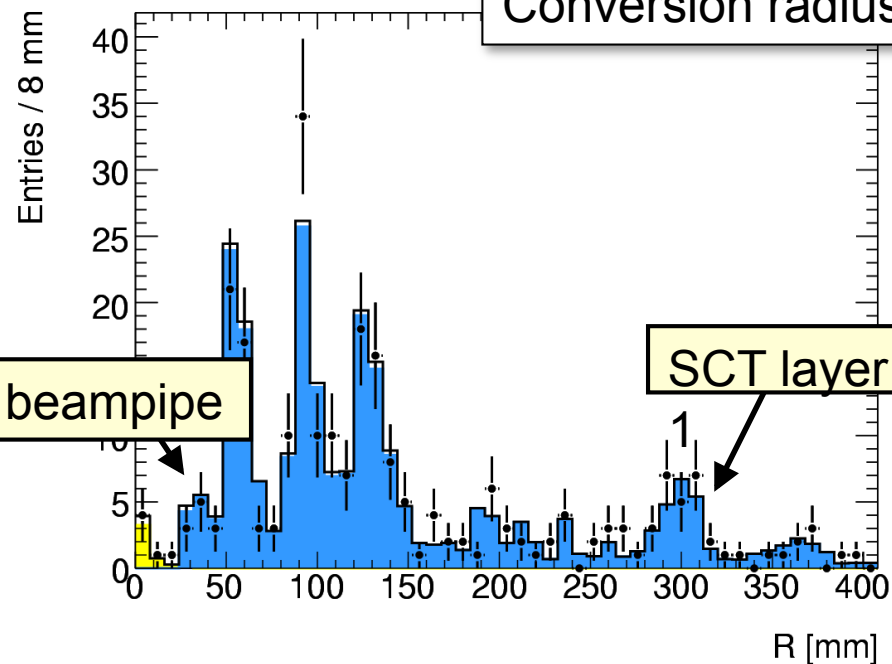
Photon conversions

Clean electron sample
Good material description in MC

π^0 reconstruction

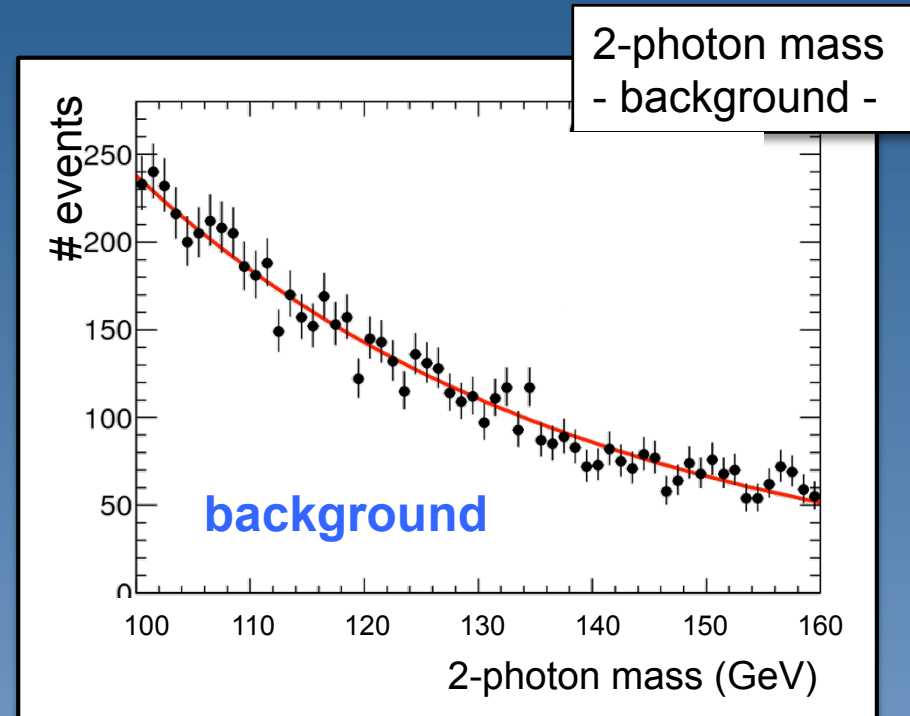


Conversion radius

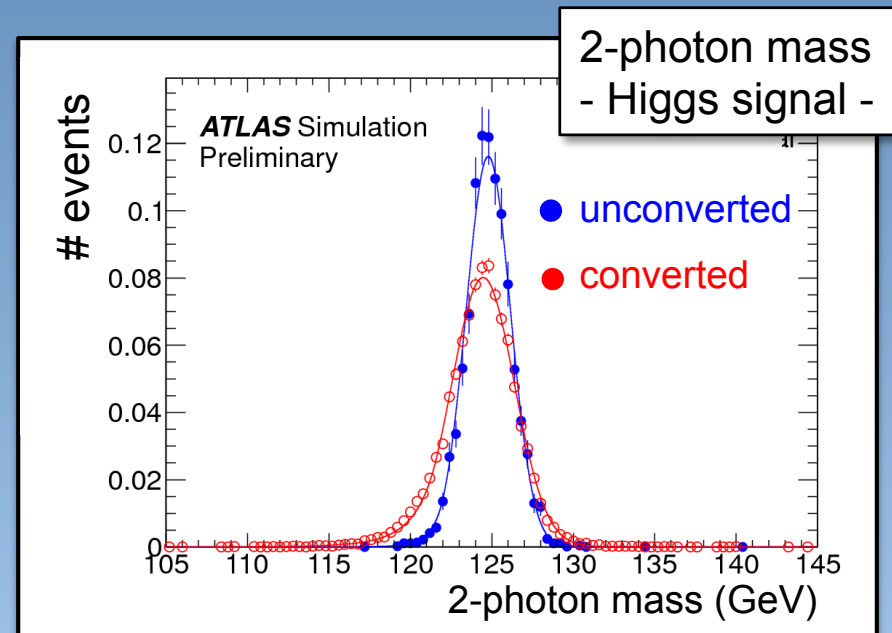


Di-photon events

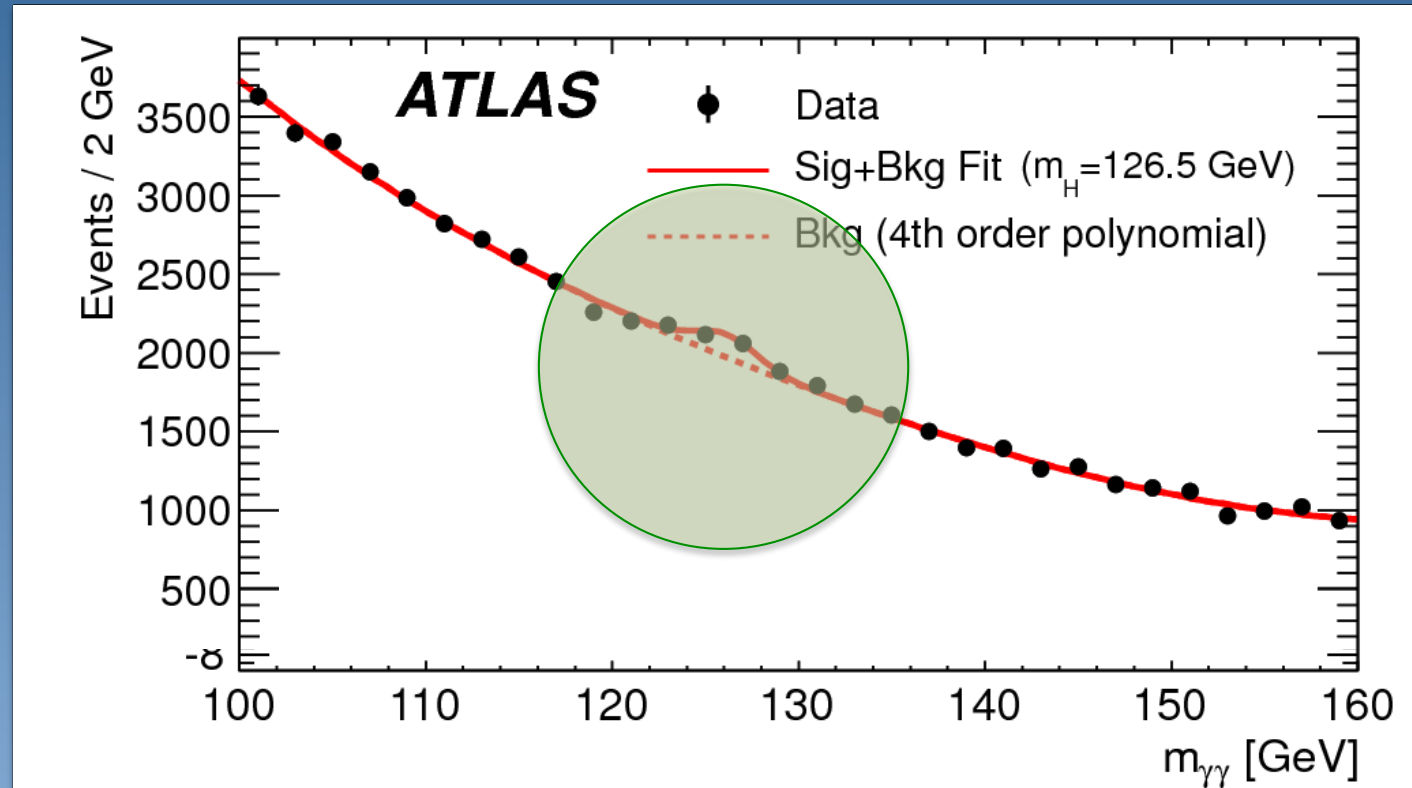
Other origin
59,000 events



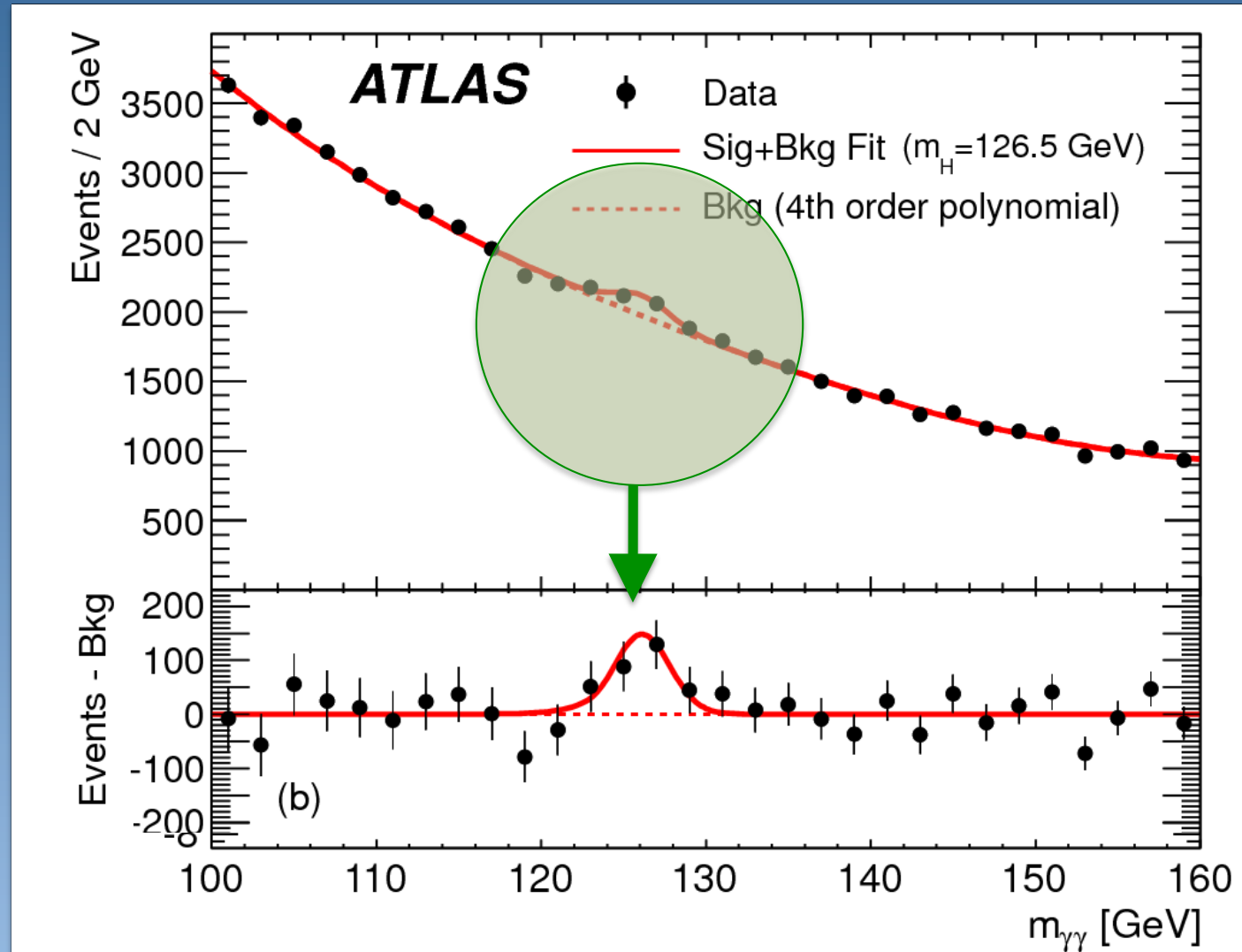
Higgs
190 events



The ATLAS data



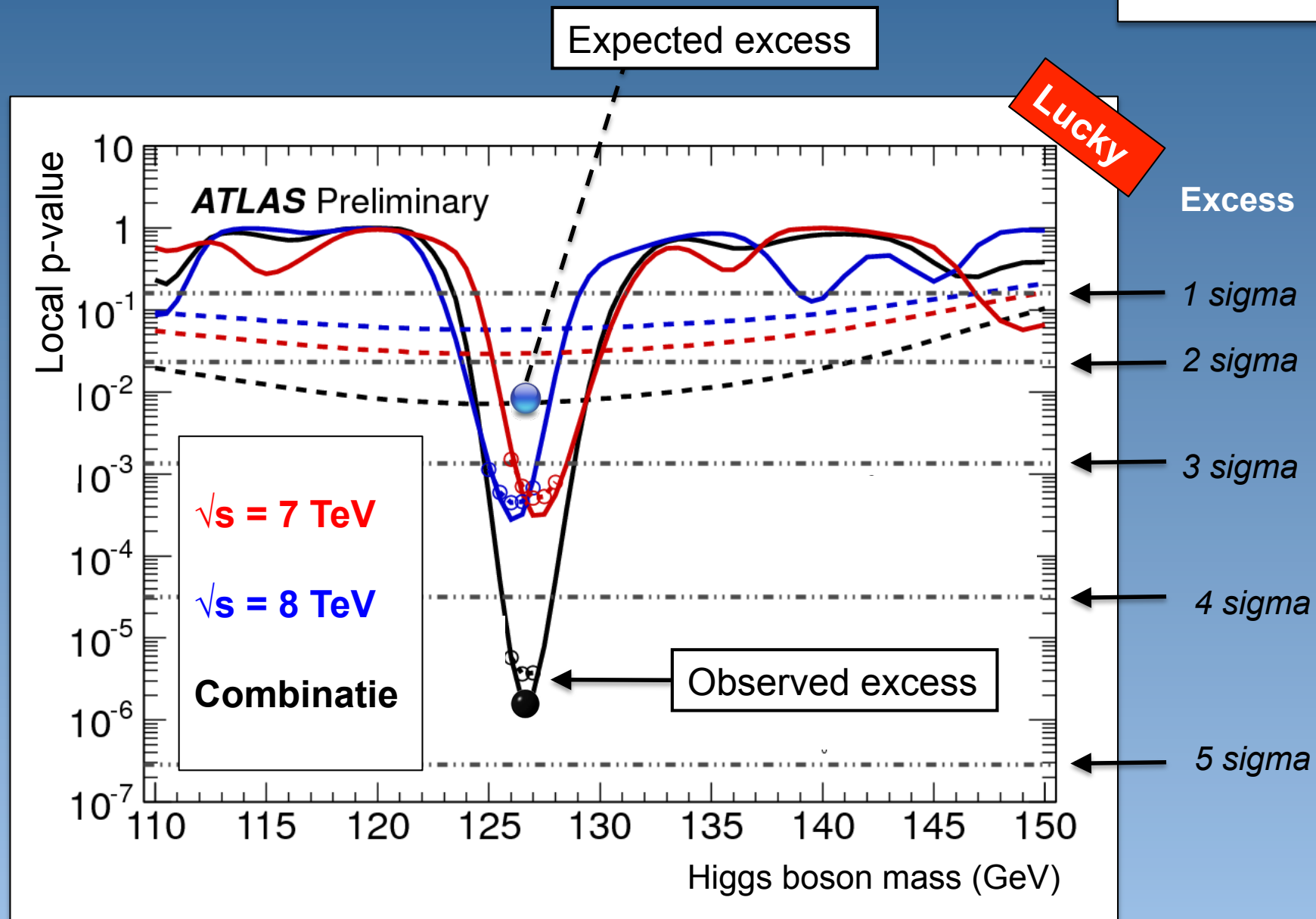
The ATLAS data



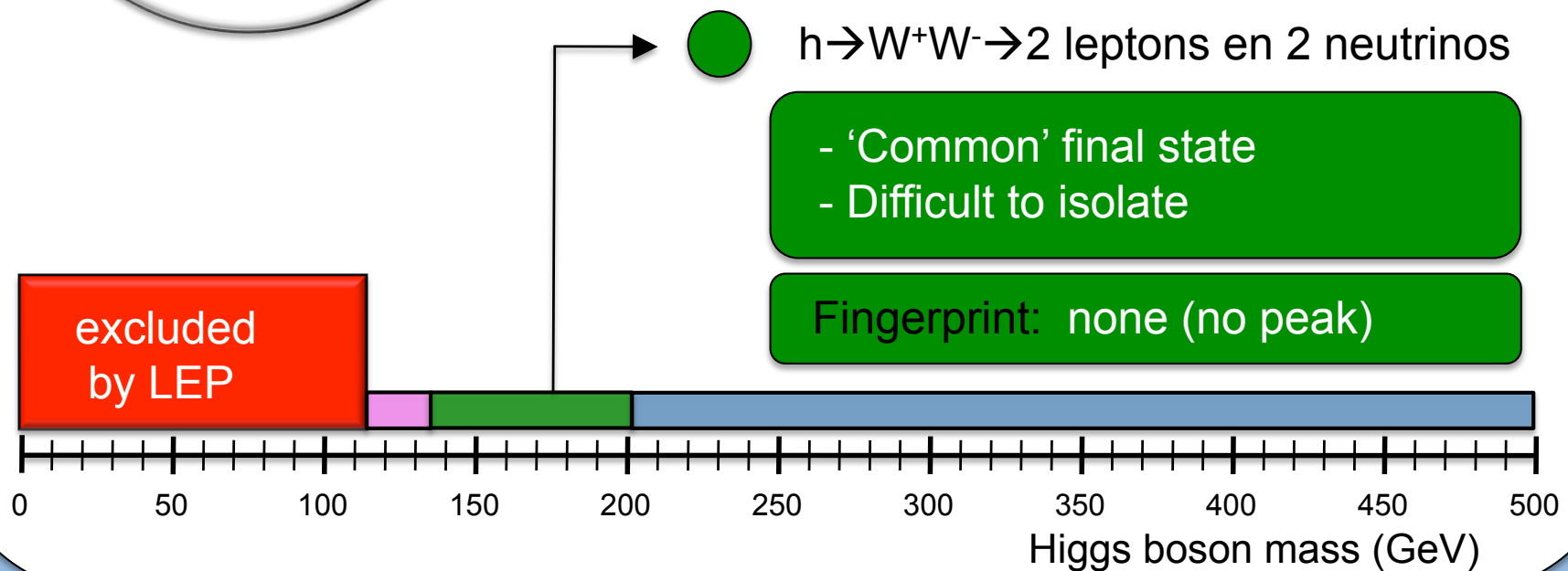
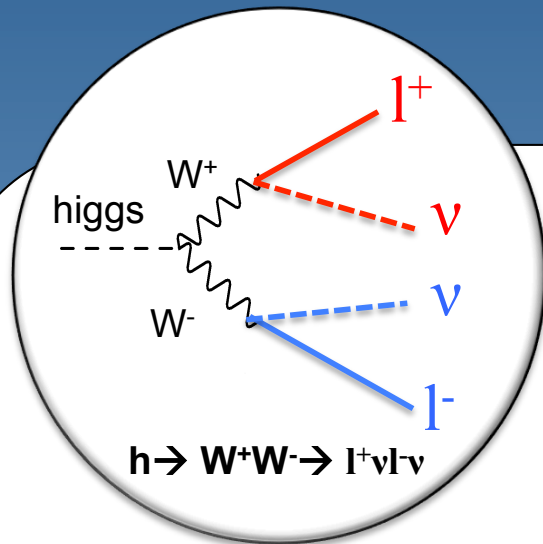
Quantify the significance ?

The excess in a single channel: $h \rightarrow \gamma\gamma$

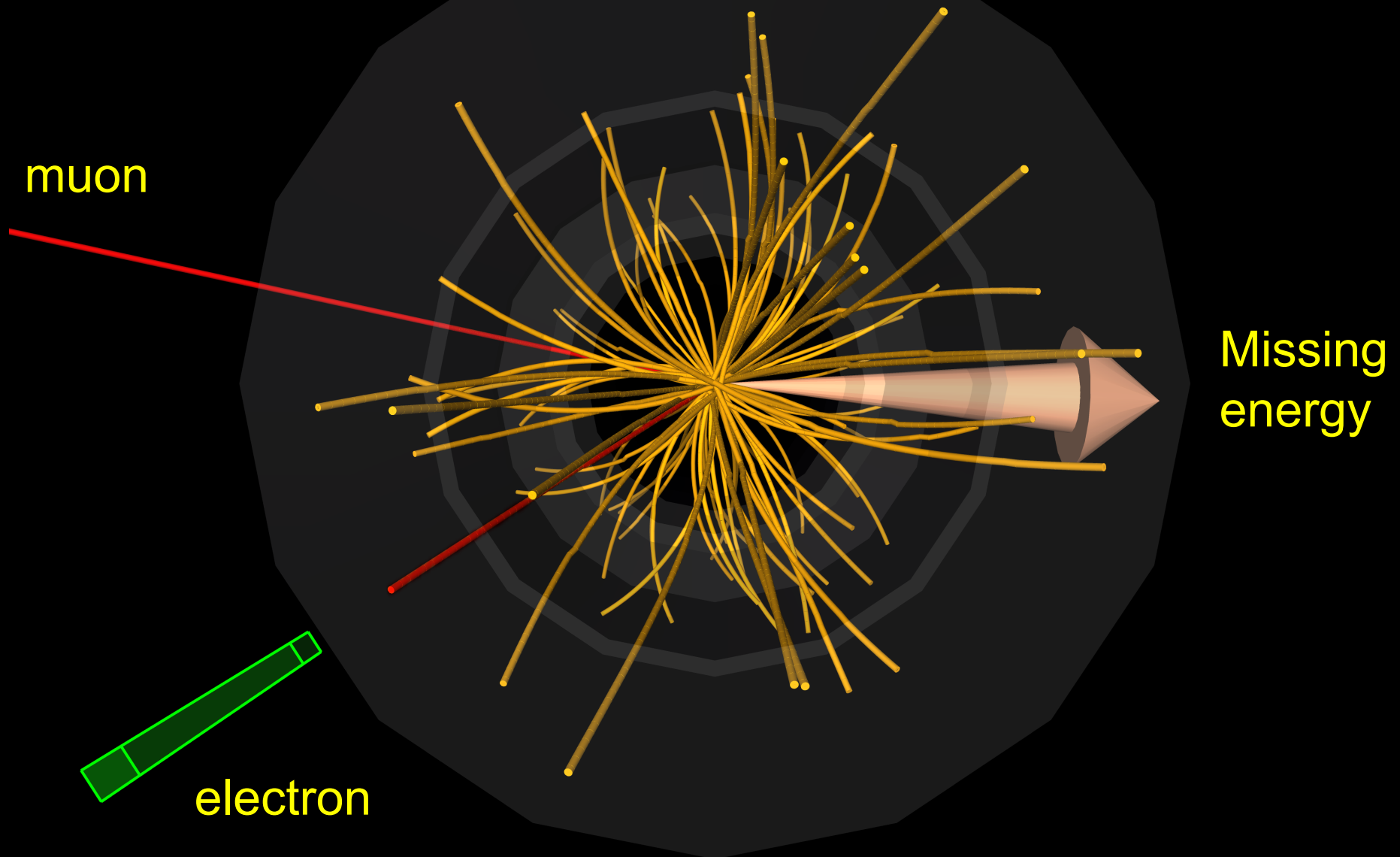
- expected
- observed



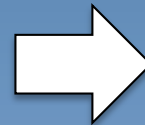
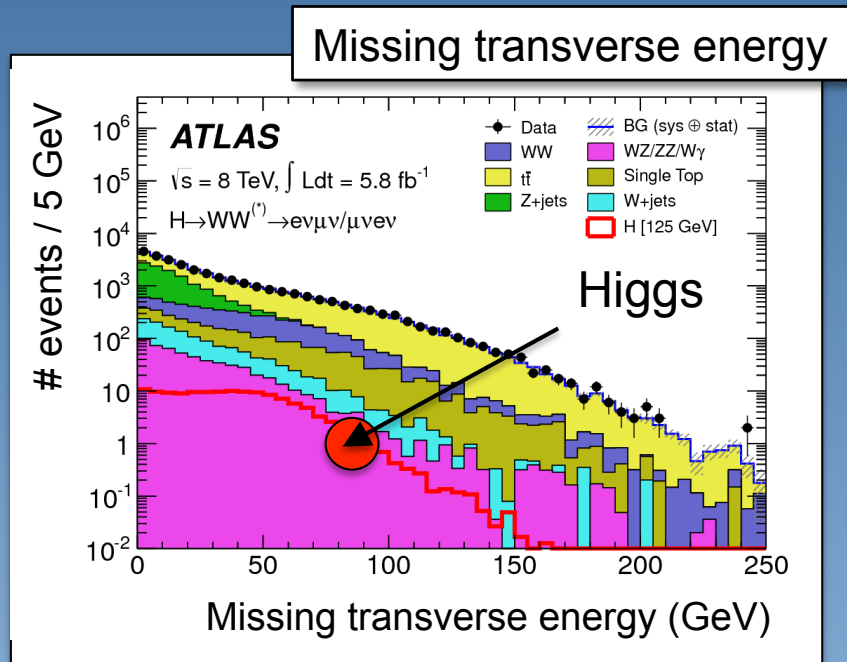
Mid-range: $130 < m_H < 200$ GeV



Final state: 2 leptons and 2 neutrino's + jets



The possible Higgs signal is well hidden



Delicate multi-dimensional selection

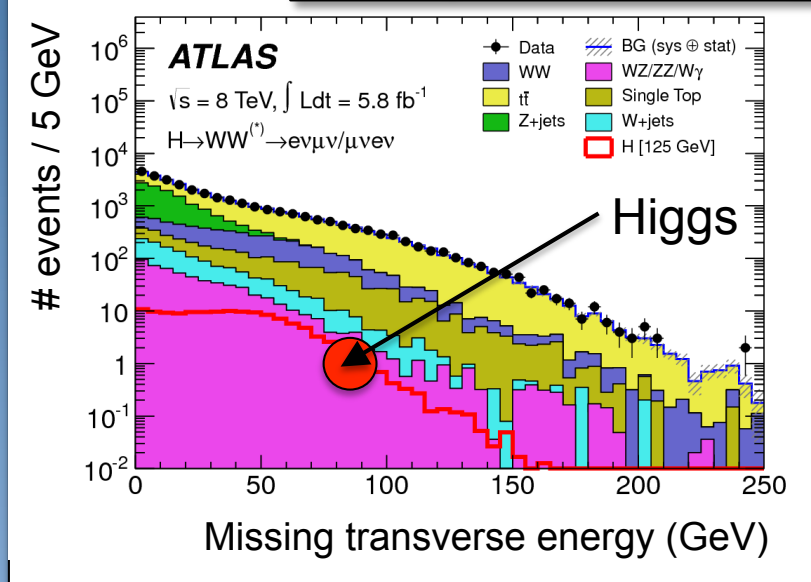
signal < 1/1,000 of background

Looking for diamonds

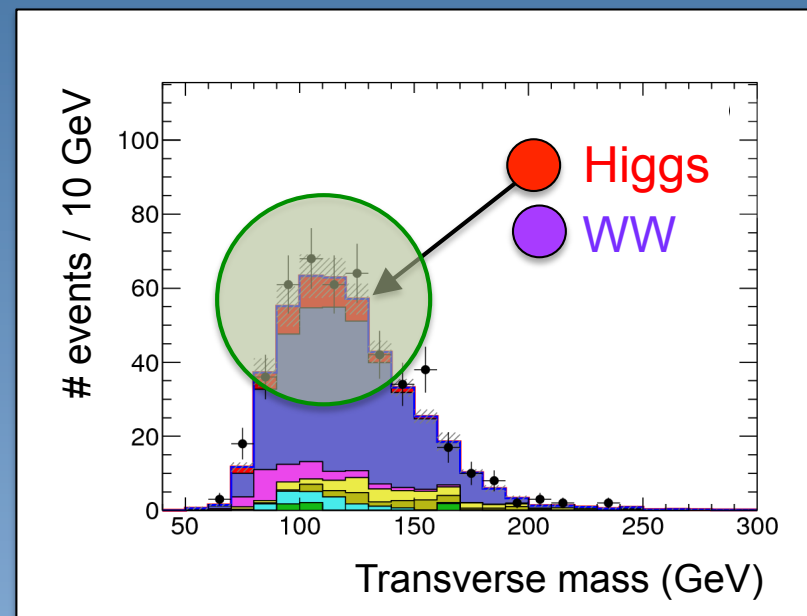


The possible Higgs signal is well hidden

Missing transverse energy



S/B ~ 1/1,000

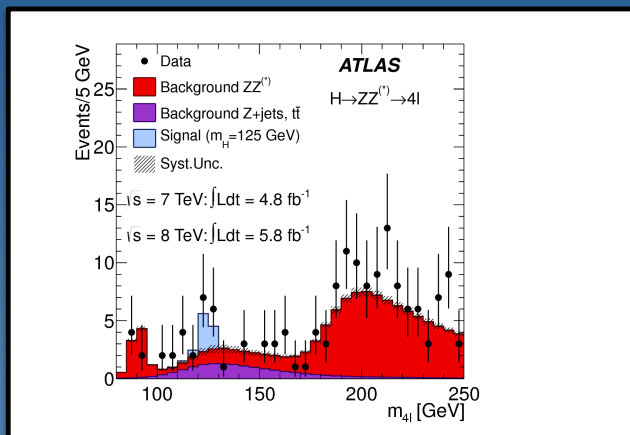


S/B ~ 1/10

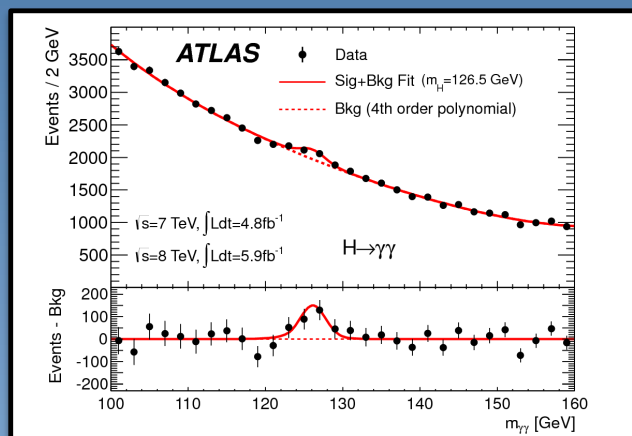
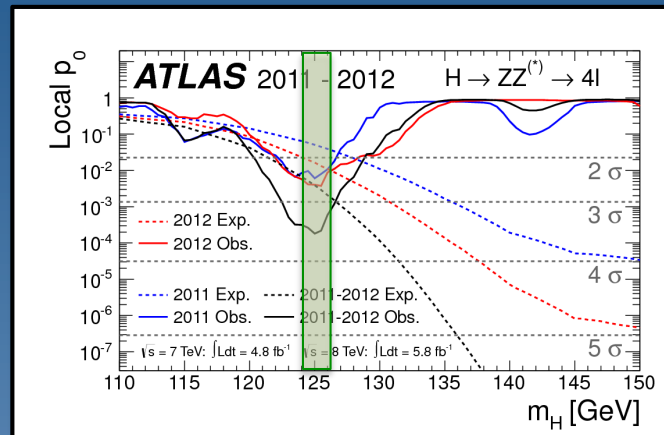
Combine the evidence

$h \rightarrow \gamma\gamma$, $h \rightarrow ZZ^*$ and $h \rightarrow WW^*$

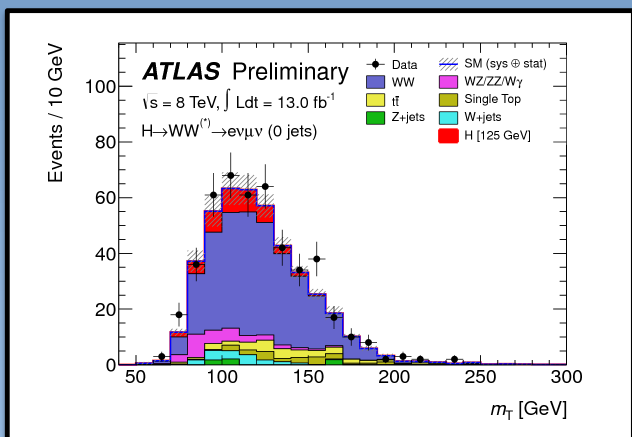
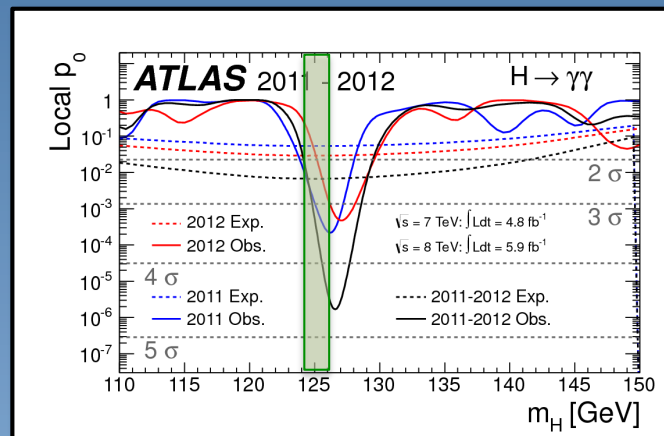




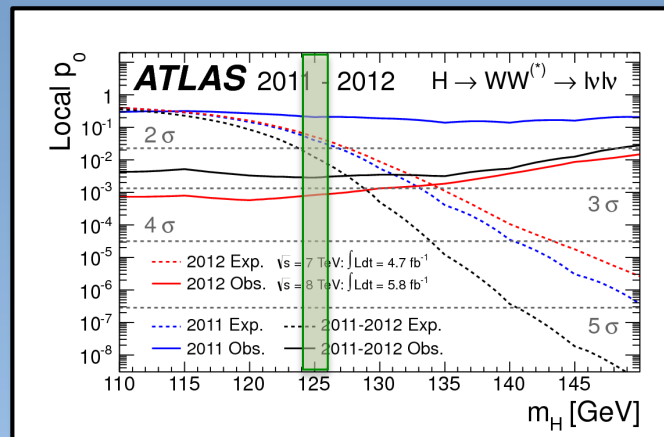
$H \rightarrow ZZ$



$H \rightarrow \gamma\gamma$

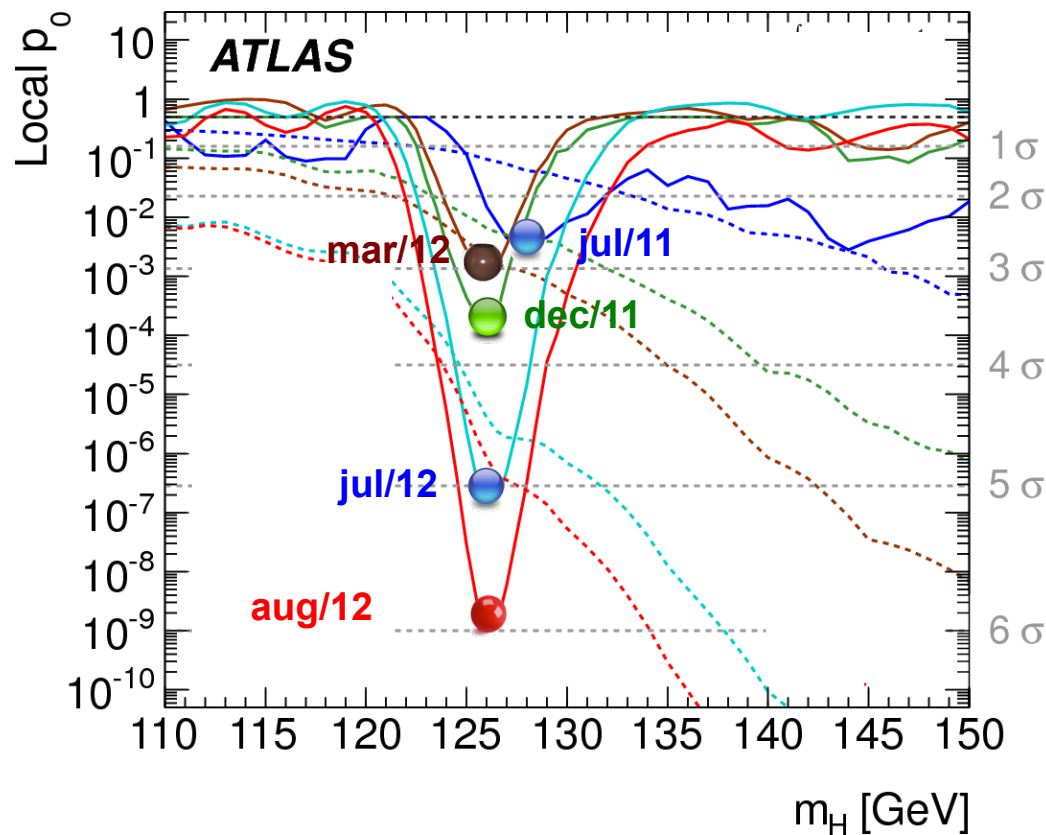


$H \rightarrow WW$



A discovery in slow-motion

Time-line higgs discovery



$$m_h = 126.0 \pm 0.4 \text{ (stat)} \pm 0.4 \text{ (syst) GeV}$$

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)



CERN-PH-EP-2012-218

Accepted by: Physics Letters B

Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC

The ATLAS Collaboration

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

Abstract

A search for the Standard Model Higgs boson in proton-proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s} = 7 \text{ TeV}$ in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8 \text{ TeV}$ in 2012. Individual searches in the channels $H \rightarrow ZZ^{(0)} \rightarrow 4\ell$, $H \rightarrow \gamma\gamma$ and $H \rightarrow WW^{(0)} \rightarrow \ell\nu\ell\nu$ in the 8 TeV data are combined with previously published results of searches for $H \rightarrow ZZ^{(0)} \rightarrow 4\ell$, $WW^{(0)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \rightarrow ZZ^{(0)} \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-6} , is compatible with the production and decay of the Standard Model Higgs boson.

arXiv:1207.7214v2 [hep-ex] 31 Aug 2012

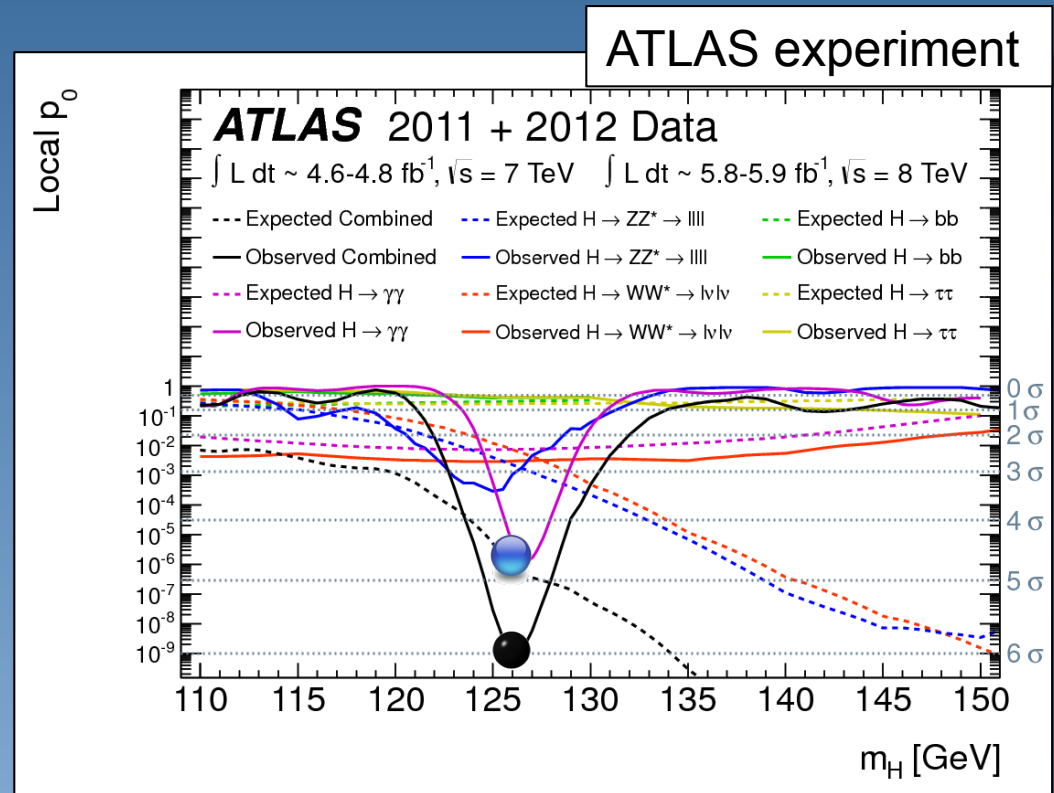
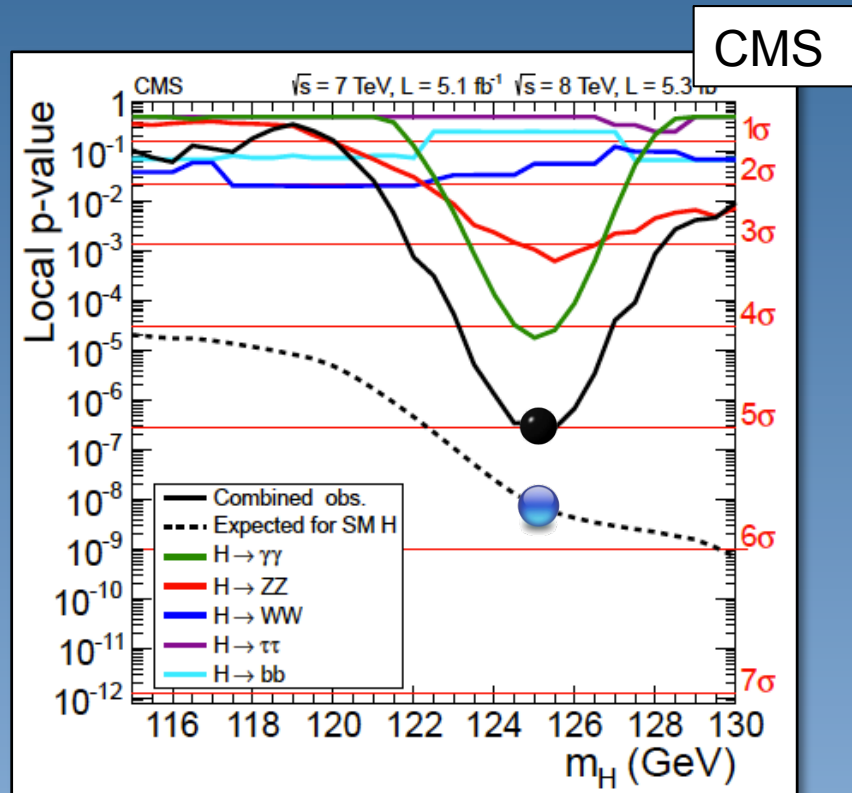
'Are you sure Ivo ?'

'Yes Diederik, we're pretty sure'

'Independent cross-check ?' 'Yep!'



Comparison results from ATLAS and CMS experiments



Conclusion (in July):

● expected
● observed

- 2 experiments observe new particle
- CMS more sensitive than ATLAS
... but ATLAS was lucky
- ATLAS had highest observed significance

Presentation CMS en ATLAS experiment: Higgs boson discovery



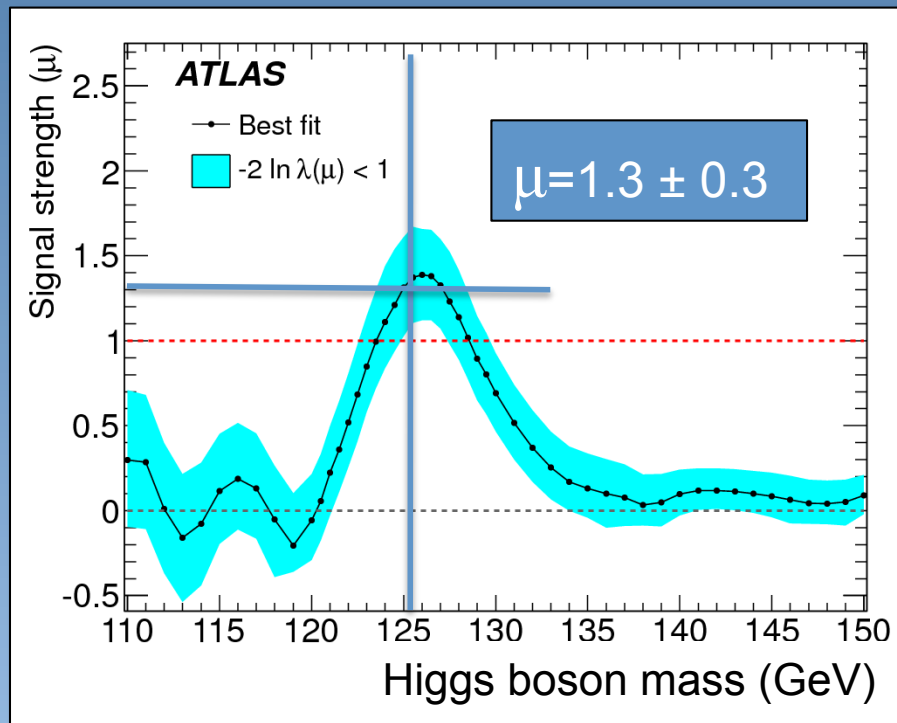
Is it the SM Higgs boson ?

SM: all properties are well predicted ... as a function of it's mass

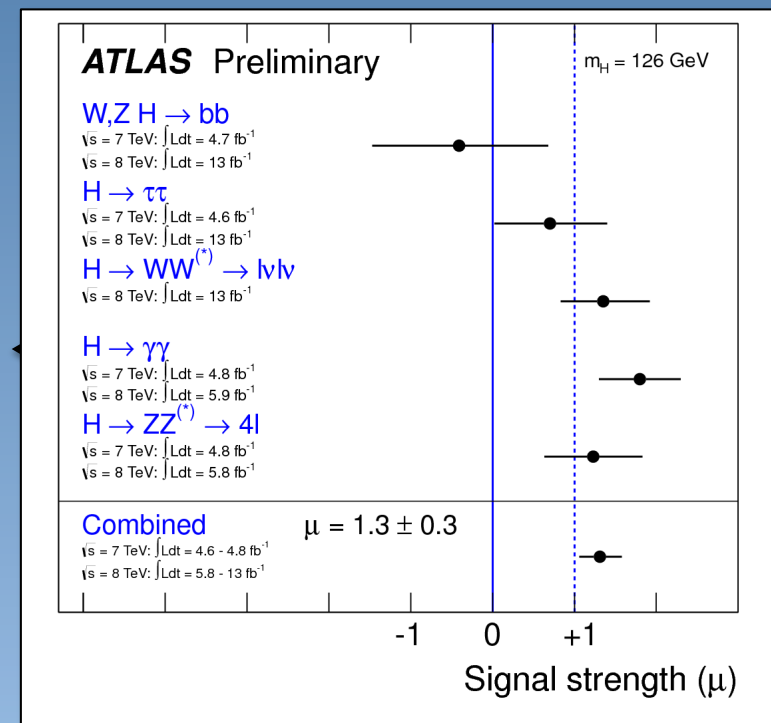
SuSy: 5 Higgs bosons, lightest one is like the SM Higgs boson,
... but slightly different

Looking at the Excess: signal strength (μ) compared to SM

Overall production cross-section scaling

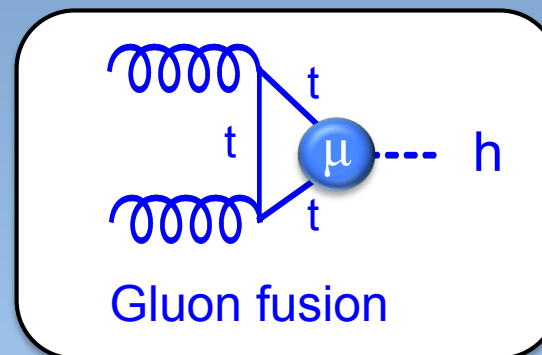
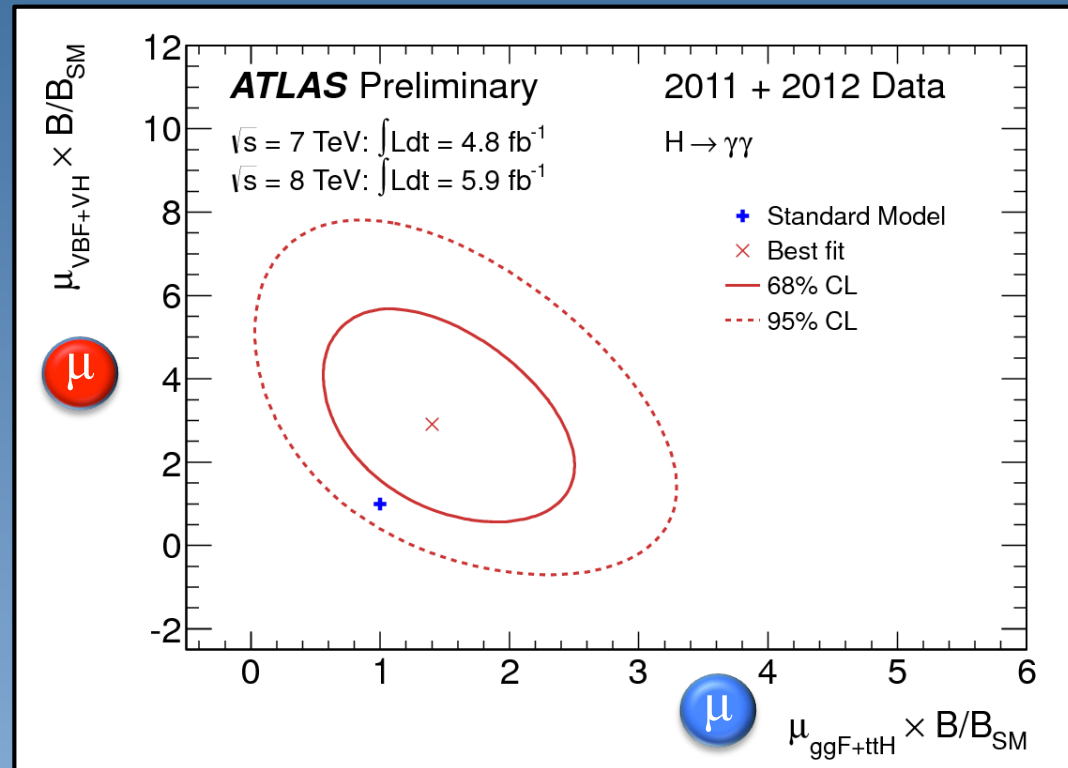
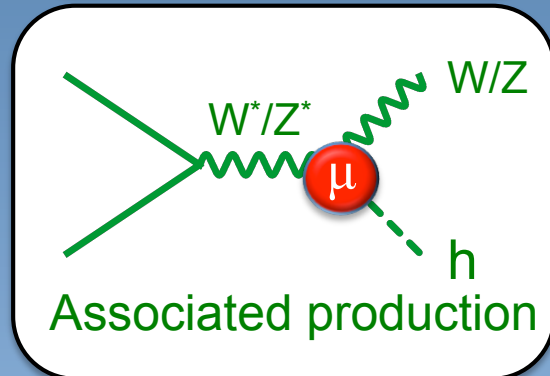
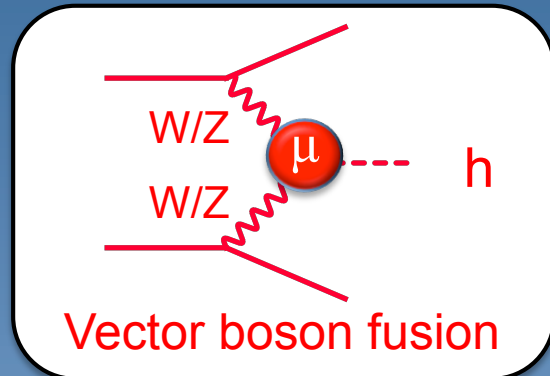


Coupling to gauge bosons and fermions



Properties: [couplings]

coupling to gauge bosons  and fermions (Yukawa) 



Properties: [spin/CP]

Prediction: the Higgs boson is a scalar particle

Spin 1 ? No!

- produced through gluon-gluon fusion (2x spin-1)
- decays to 2 photons (2x spin-1)

Spin-0 ? Spin-2

Spin/CP parameters: look at decay angles in $gg \rightarrow H \rightarrow ZZ \rightarrow 4 \text{ leptons}$

Not many plots/numbers public yet

Some 'tiny' issues in a world with a Higgs field:

- Radiative corrections (from top) to Higgs mass are huge $\propto \Lambda^2$. Extreme fine-tuning to get light Higgs.
Note: one of the motivations for super-symmetry
- Higgs does not give any hint to particle masses or dark matter
- Contribution to $\rho_{Higgs}^{vac} (\Omega_\Lambda)$ factor 10^{54} off

Knowledge on mass Higgs boson

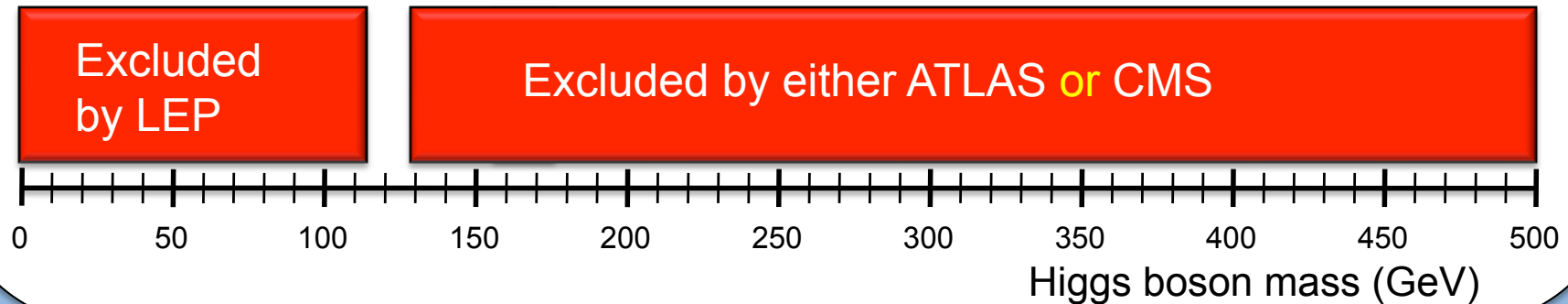
It's here



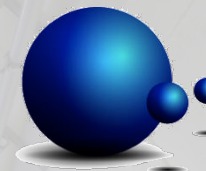
Indirect:

Theory: $m_h \leq 600$ GeV

Electroweak precision
measurement: $m_h \leq 185$ GeV



Summary



- 1) Large Hadron Collider and experiments are working fan-tas-tic!
- 2) Search for the Higgs boson in 2011+2012
Discovery !!
- 3) Standard Model has serious shortcomings
Looking forward to new physics (SuSy, extra dimensions, ...)

All ATLAS public results: papers, numbers and plots
<https://twiki.cern.ch/twiki/bin/view/AtlasPublic>

Ivo.van.Vulpen@nikhef.nl

backup

REFERENCES

ATLAS experiment

All ATLAS public results: publications, numbers and plots

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

Higgs paper: *“Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC”*, Phys. Lett. B716 (2012) or <http://arxiv.org/abs/1207.7214>

CMS experiment

All CMS public results: publications, numbers and plots

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults>

Higgs paper: *“Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC”*, Phys. Lett. B716 (2012) or <http://arxiv.org/abs/1207.7235>