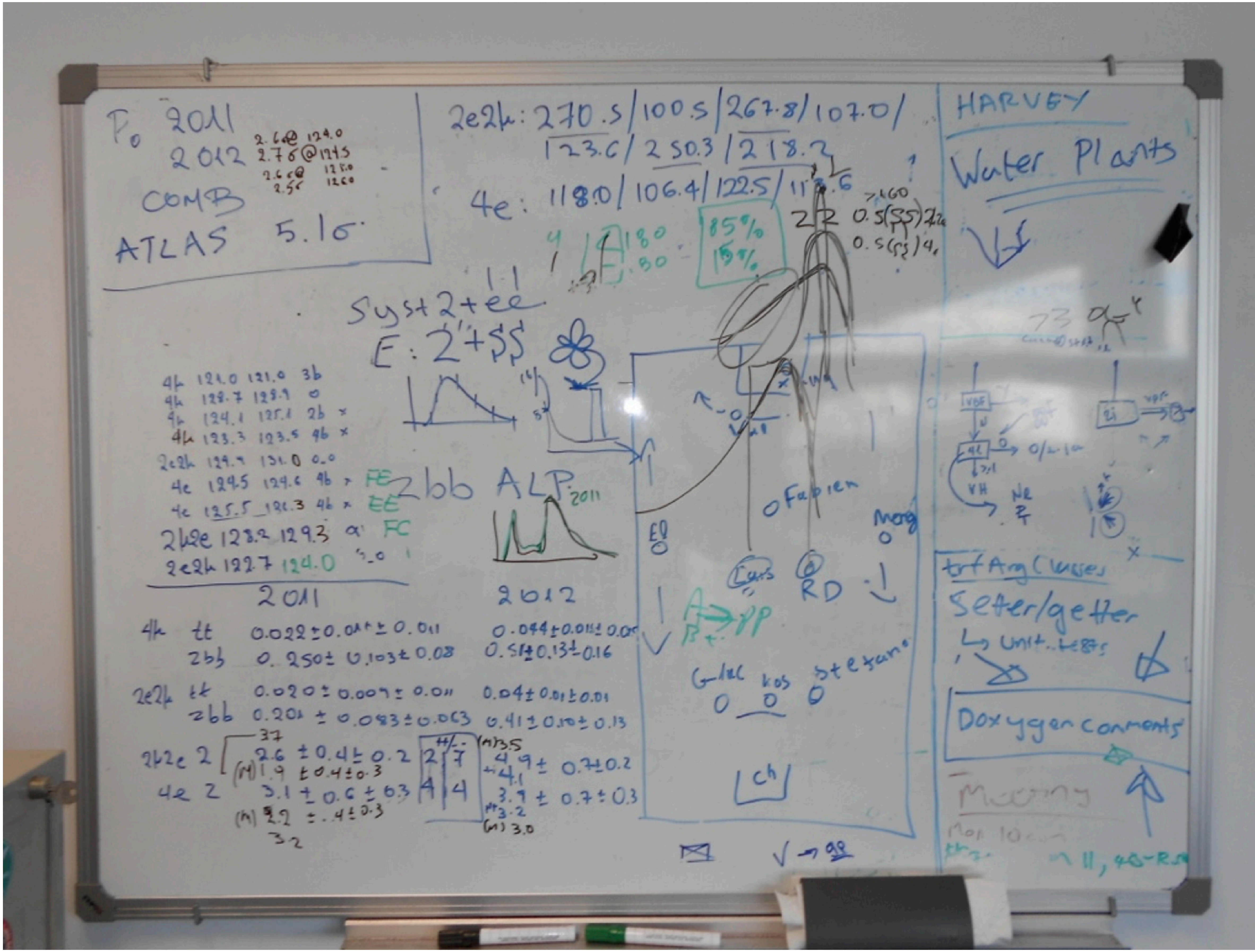
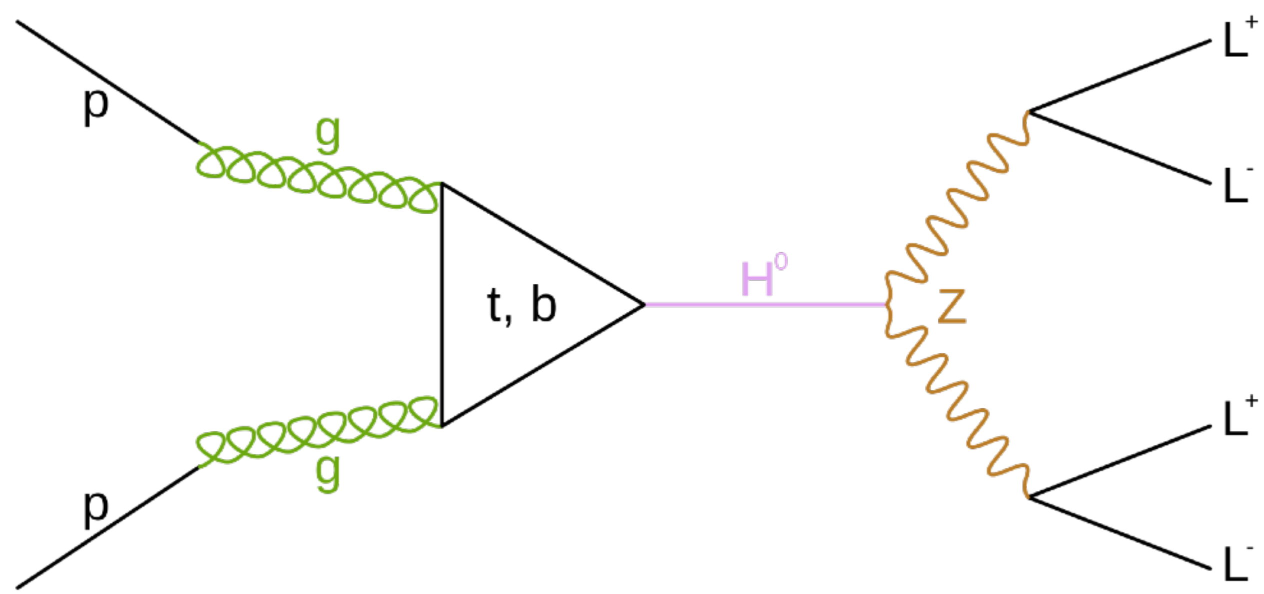
Towards the Higgs discovery,
H→ZZ→4l in ATLAS a personal prospective

Christos Anastopoulos on behalf of multiple people



P0 2011
2012
COMB
ATLAS 5.1σ
2e2μ: 270.5/100.5/267.8/107.0/
123.6/250.3/218.2
4e: 118.0/106.4/122.5/
85%
15%
Syst 2+ee
E: 2+SS
ALP 2011
Zbb
2011
2012
HARVEY
Water Plants
Setter/getter
Doxygen comments
RD

ATLAS H→4l ~1999



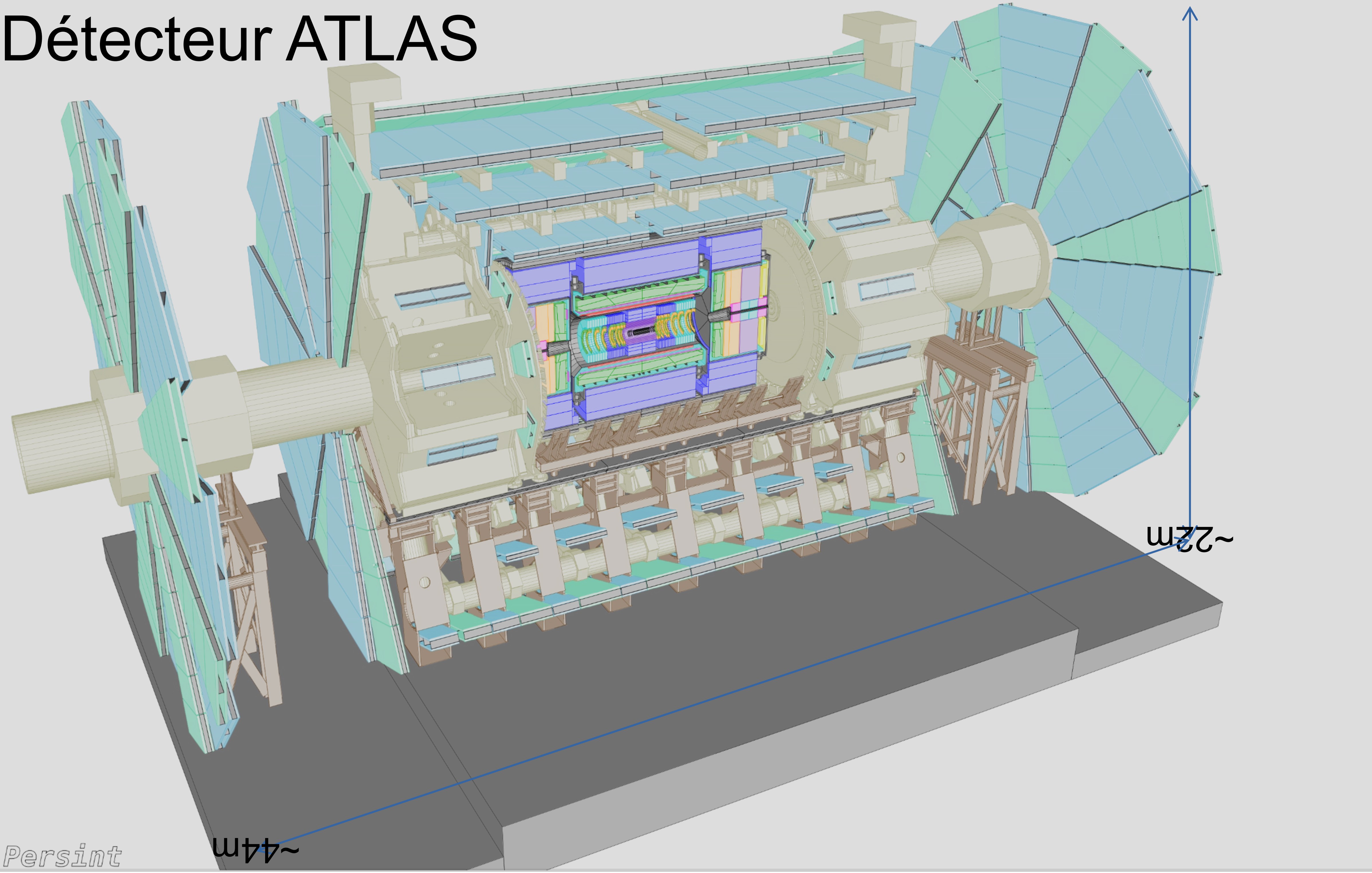
ATLAS TDR

19.2.5 $H \to ZZ^* \to 4l$

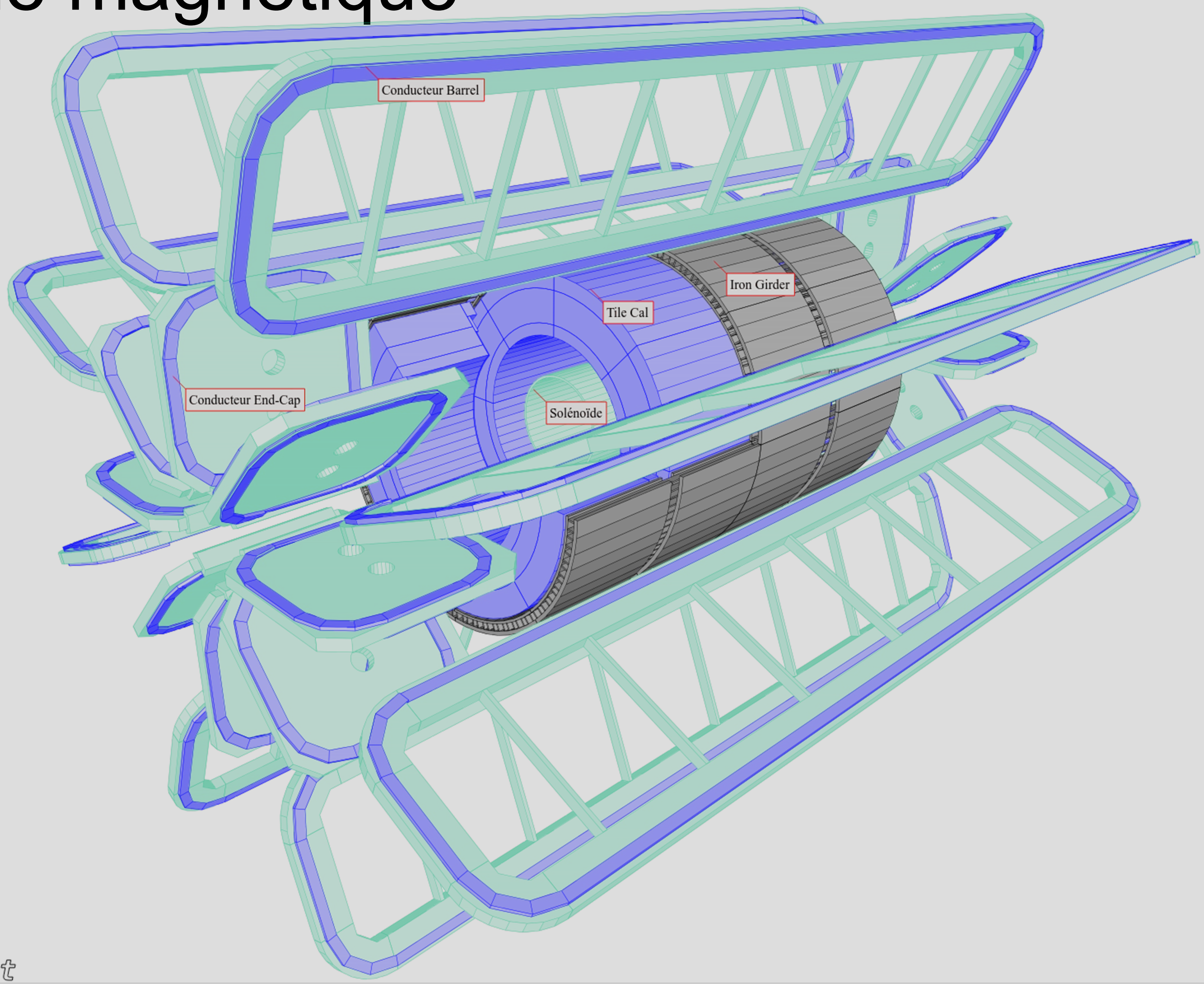
The decay channel $H \to ZZ^* \to 4l$ provides a rather clean signature in the mass range between ~120 GeV and 2 m_Z, above which the gold-plated channel with two real Z bosons in the final state opens up. The branching ratio is larger than for the $\gamma\gamma$ channel and increases with increasing m_H up to $m_H \sim 150$ GeV. A pronounced dip appears, however, for $150 < m_H < 180$ GeV, because of the opening of the $H \to WW$ channel. In addition to the irreducible background from

This is close to the time I started my undergraduate degree in Aristotle University….

Détecteur ATLAS

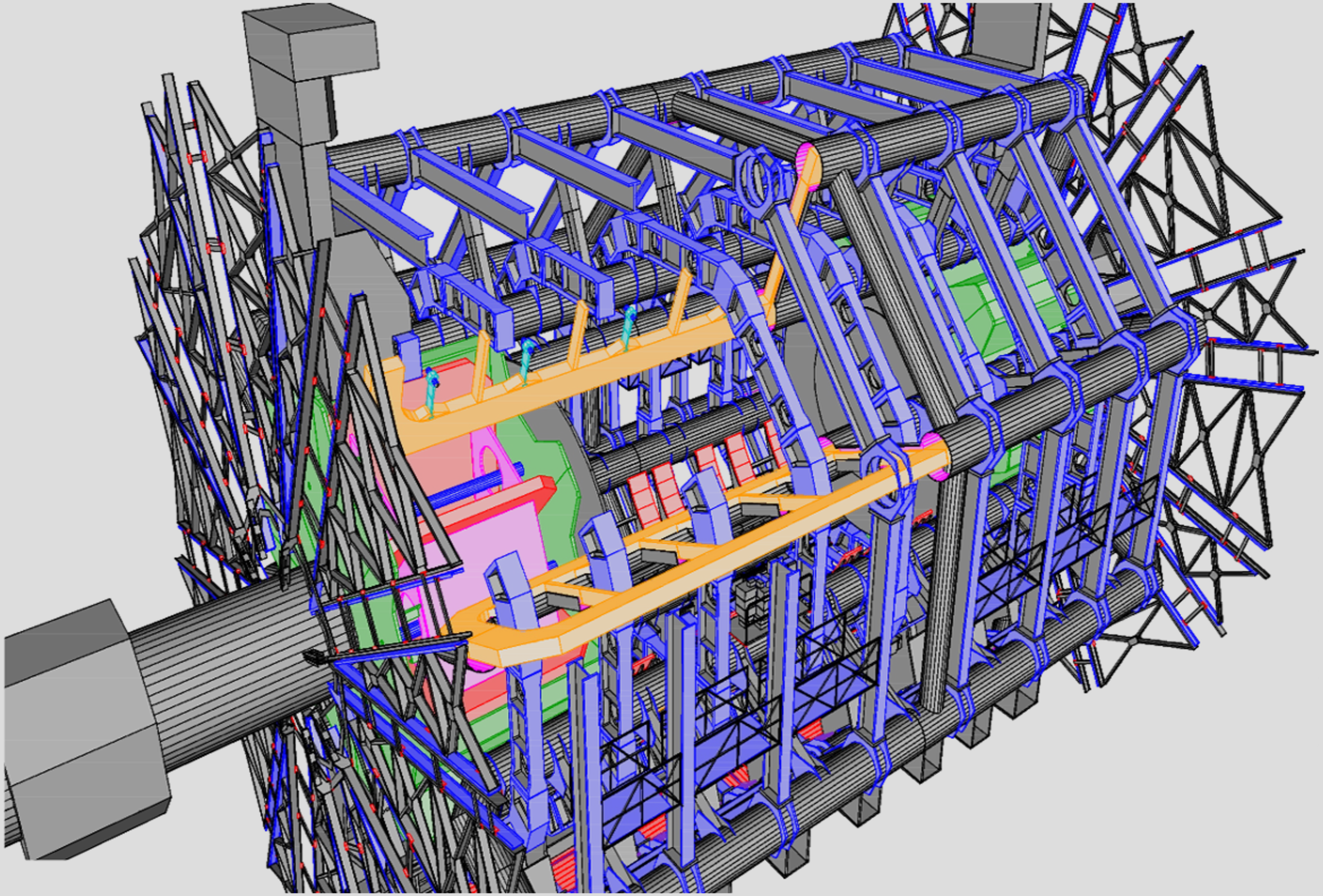


Système magnétique

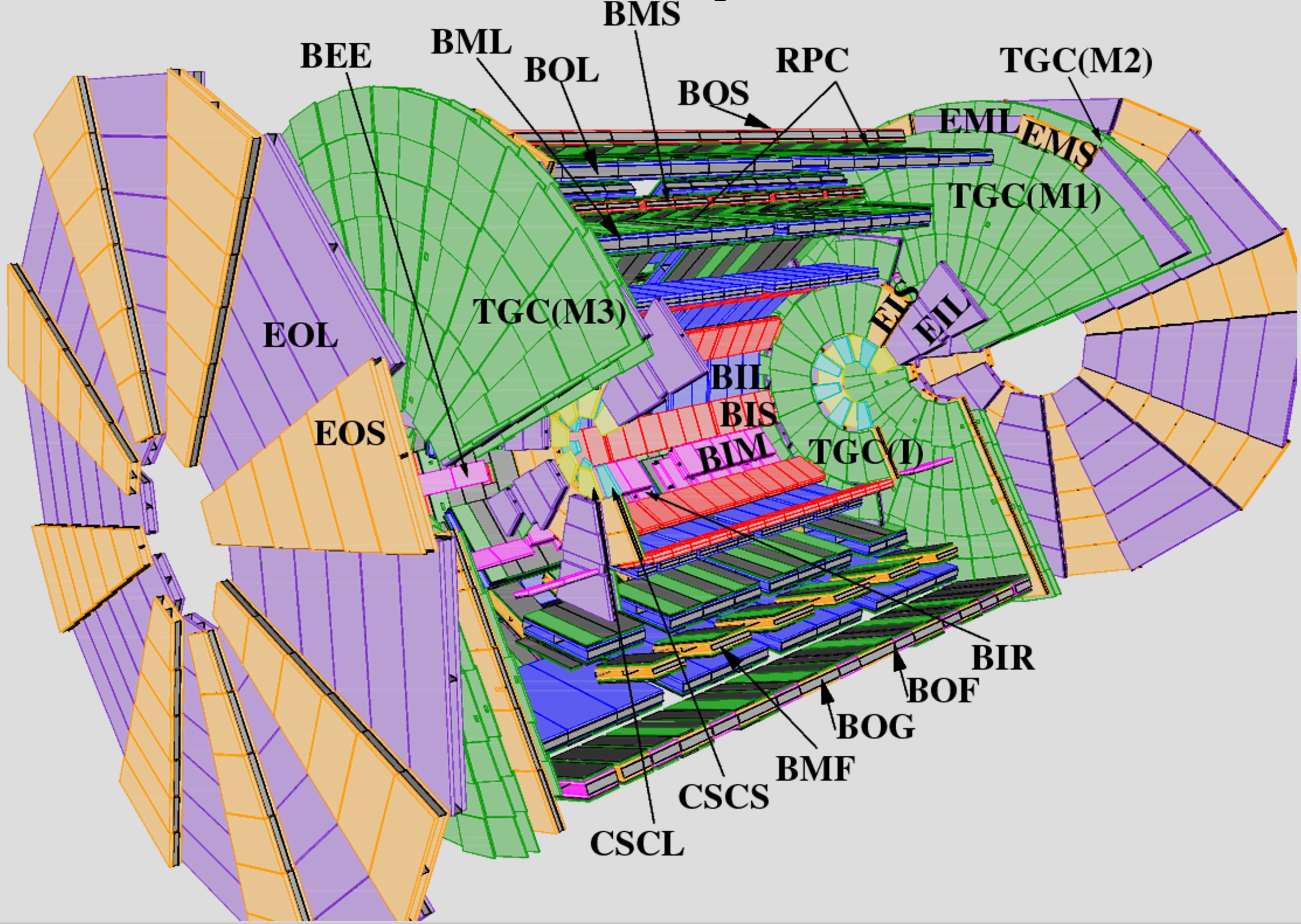


Persint

Matière inerte du spectromètre



Détecteurs de traces chargées



ATLAS H→4l ~ 2008

Jumping ~ 10 years to the ATLAS CSC book : CERN-OPEN-2008-020

Search for the Standard Model $H \rightarrow ZZ^* \rightarrow 4l$

Abstract
The Standard Model Higgs boson discovery potential through its observation in the 4-lepton (electron and muon) final state using the ATLAS detector is investigated. Fully simulated signal and background samples were produced with the latest simulation of the ATLAS detector. The samples were subsequently digitized and reconstructed using the ATLAS offline software. The analysis performance dependence on kinematic, lepton reconstruction and isolation cuts is studied for Higgs boson masses ranging from 120 to 600 GeV. The statistical and systematic uncertainties on the background estimation are evaluated and their impact on the Higgs boson discovery potential and exclusion limits is discussed.

At the time undertaking a PhD in Sheffield .

ATLAS H→4l ~ 2008-2009

Jumping ~ 10 years to the ATLAS CSC book: CERN-OPEN-2008-020

The general principles of the analysis strategy were put into place at that time.

Event Preselection	Four leptons: *LooseElectrons* or muons. p_T>7 GeVand $\|\eta\| < 2.5$, at least two with p_T>20 GeV
Event Selection	
Kinematic Cuts	Lepton quality: 2 pairs of same flavour opposite charge leptons. Electrons must be *MediumElectrons* satisfying the *CaloIso* criterion. For *H* masses of 200 GeV and higher, four *LooseElectrons* are required instead. Z, Z* and Higgs boson reconstruction: single quadruplet with $\|m_{ll1} - m_Z\| < \Delta m_{12}$ GeV, $m_{ll2} > m_{34}$.
Isolation and vertexing cuts	Muon Calorimetric isolation ($\Sigma E_T/p_T < 0.23$). Lepton Inner detector track isolation ($\Sigma p_T/p_T < 0.15$). Cut on maximum lepton impact parameter ($d_0/\sigma_{d_0} < 3.5$ for muons, $d_0/\sigma_{d_0} < 6.0$ for electrons).

Table 5: Summary of the analysis cuts for the H→ 4ℓ analysis. The two lepton pairs are denoted as m_{ll1} and m_{ll2}. The values of the mass window Δm_{12} and of the cut m_{34} are defined in Table 6.

The analysis was and has remained relatively simple.

ATLAS H→4l ~ 2008-2009

Jumping ~ 10 years to the ATLAS CSC book: CERN-OPEN-2008-020

The general principles of the analysis strategy were put into place at that time.

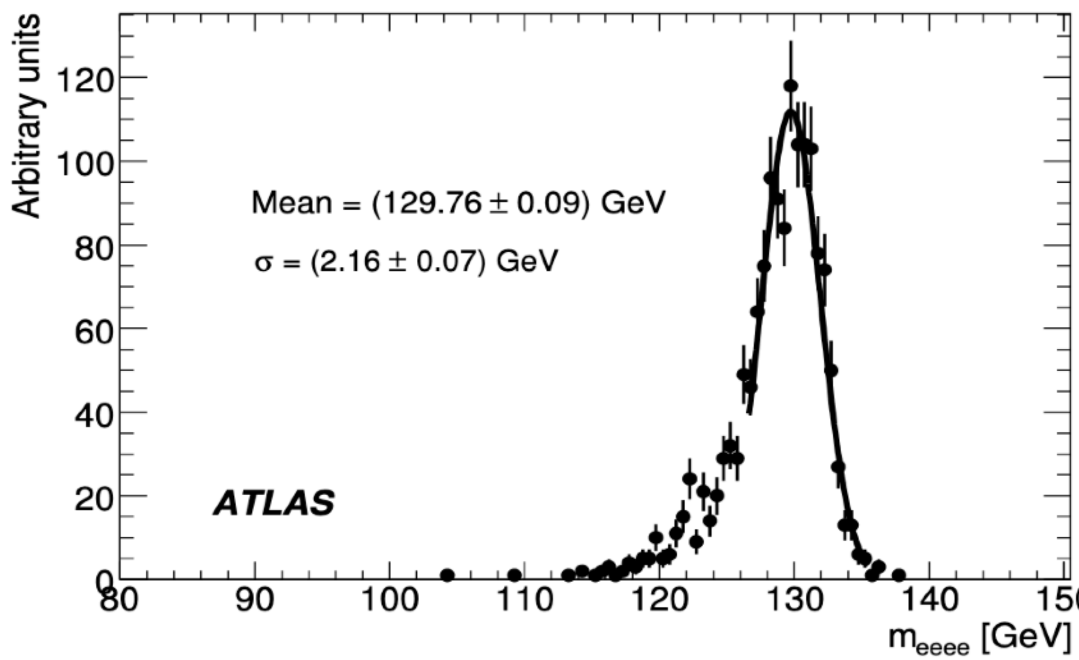


Figure 18: Reconstructed H(130 GeV)→ $4e$ mass after application of the Z-mass constraint fit.

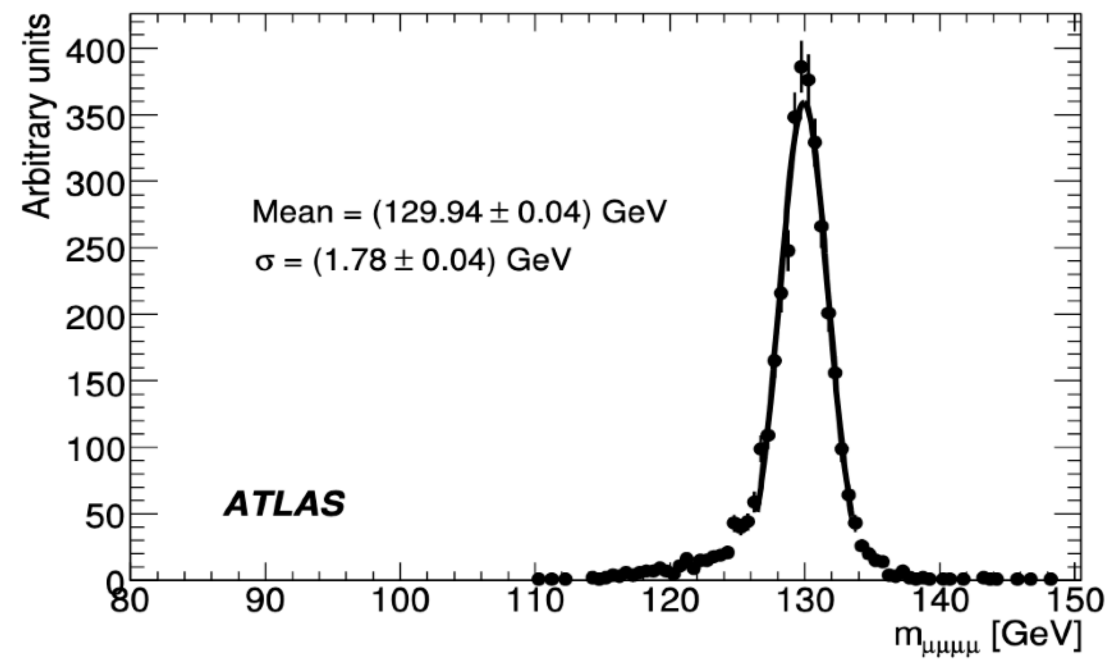
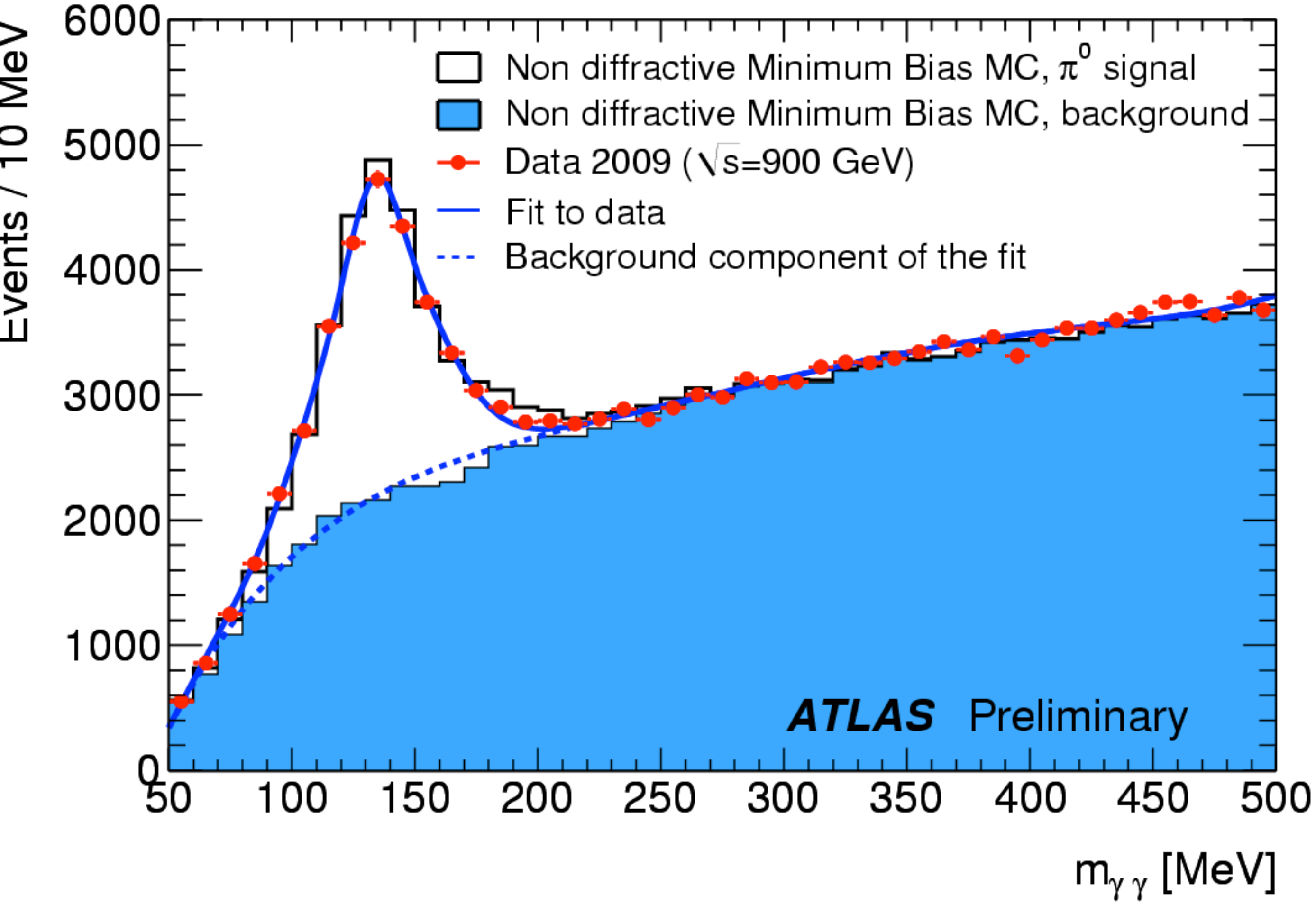


Figure 19: Reconstructed H(130 GeV)→ 4μ mass after application of the Z-mass constraint fit.

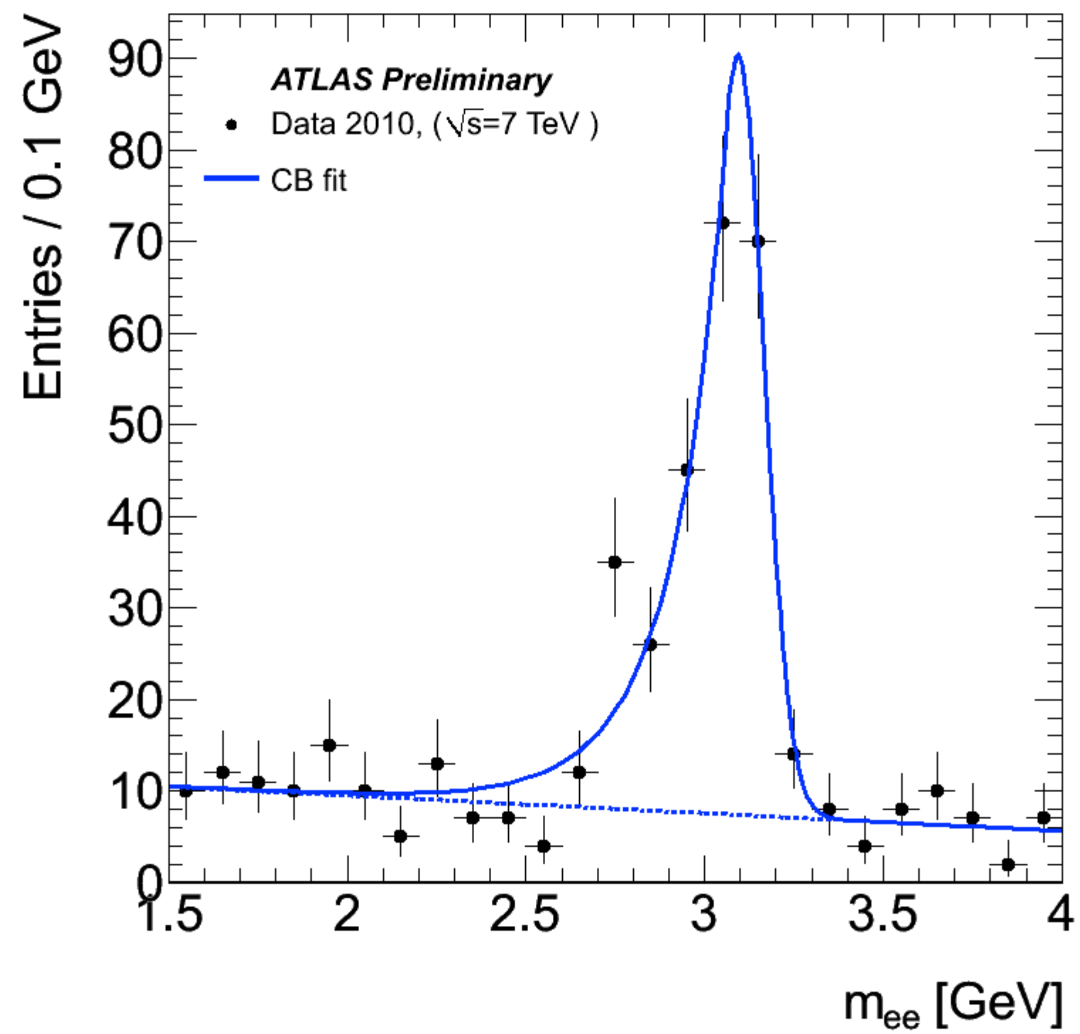
Including for example techniques like the “Z-mass constraint fit”

A personal intermezzo

The two “data analysis” I did for my PhD ….



Topological seeded photons

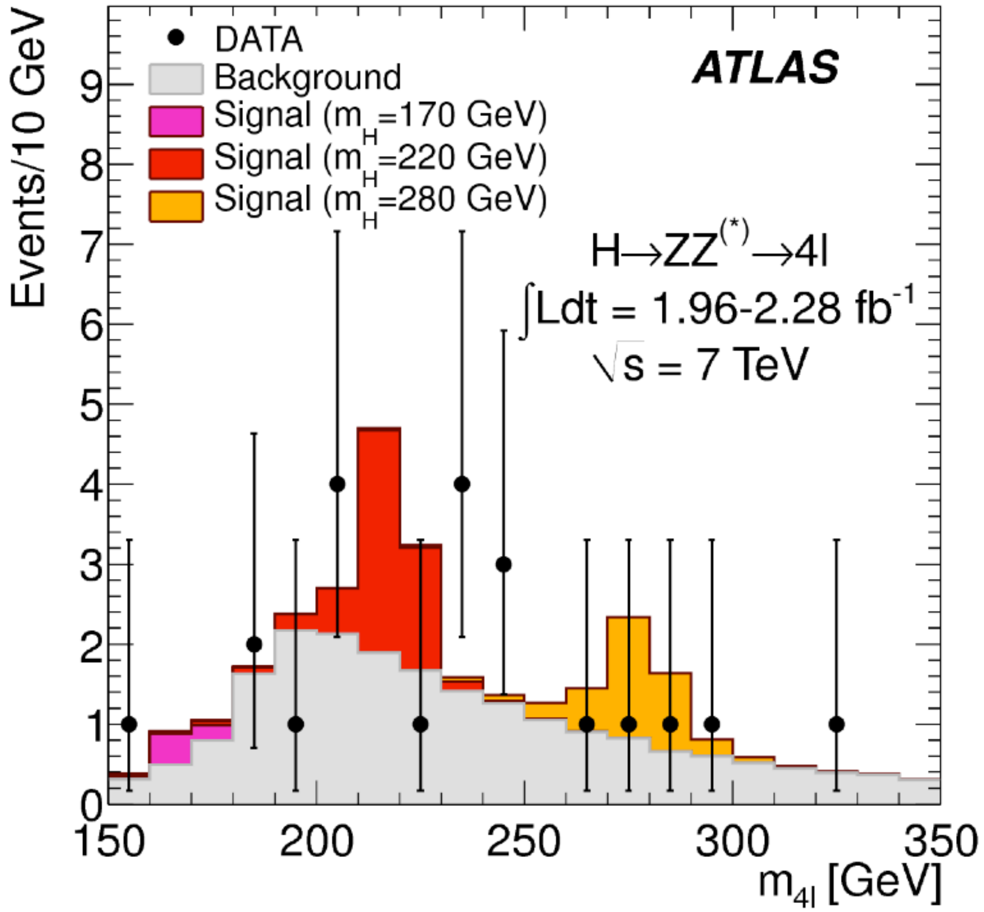


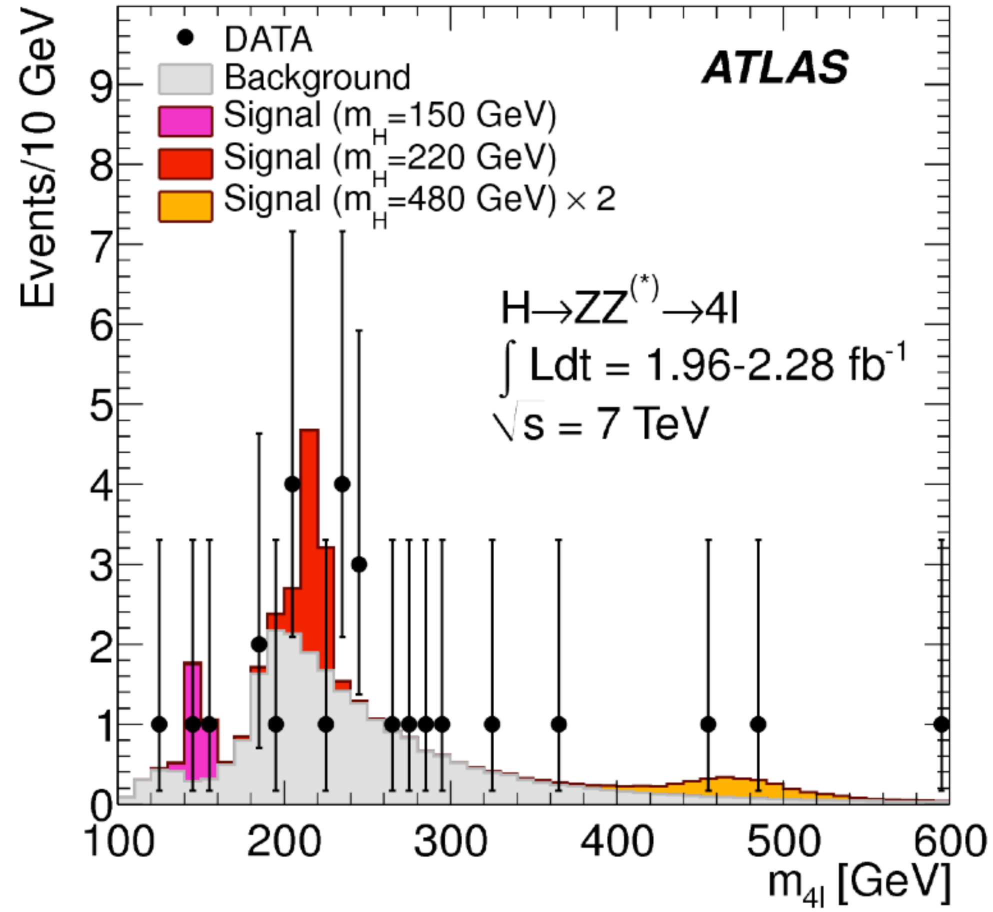
First use of **GSF** in ATLAS for analysis

The point perhaps being that the 4l ATLAS team was mainly consisting by people having strong involvement in muon or e/γ performance …

The first paper …

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2011-05/





Where the interesting point perhaps is the absence of a zoomed in plot in the mass range 100-150 …. One did not know what was not know.

The first workshop …

ATLAS HSG2 meeting in Athens

the 1/fb expected by the time of EPS conference and the ~2/fb expected by the end of summer will profoundly change the landscape in SM Higgs searches,
and will force us to re-think about the prospects and priorities for the rest of 2011.
for this reason we would like to hold a meeting in Athens between September 7 and 9 [Wed - Fri], where the current status of the analyses in our group and the planning for the rest of the year will be reviewed.

The first workshop …

Quite a lot of focus on performance, efficiencies , backgrounds

10:30 **Status of the H->ZZ->4l analysis** — 30m
Speaker: Konstantinos Nikolopoulos (Brookhaven National Laboratory (US))
Slides

11:00 **Muon Performance : Calo Muons** — 20m
Speaker: Maximilian Emanuel Goblirsch-Kolb (Max-Planck-Gesellschaft (DE))
Slides

11:20 **Muon Performance : Standalone Muons** — 20m
Speaker: Rosy Nikolaidou (IRFU-CEA - Centre d'Etudes de Saclay (CEA))
Slides

11:40 **Electron Performance : TnP et al.** — 20m
Speaker: Lydia Iconomidou-Fayard (Universite de Paris-Sud 11 (FR))
Slides

14:00 **Background Estimates in muon channel** — 20m
Speaker: Dimitris Fassouliotis (University of Athens (GR))
Slides

14:20 **Selection efficiencies using Z->μμ events** — 20m
Speaker: Eleni Mountricha (National Technical Univ. of Athens (GR))
Slides

14:40 **Electron Performance : Brem-fits et al** — 20m
Speaker: Christos Anastopoulos (CERN)
Slides

The next paper …

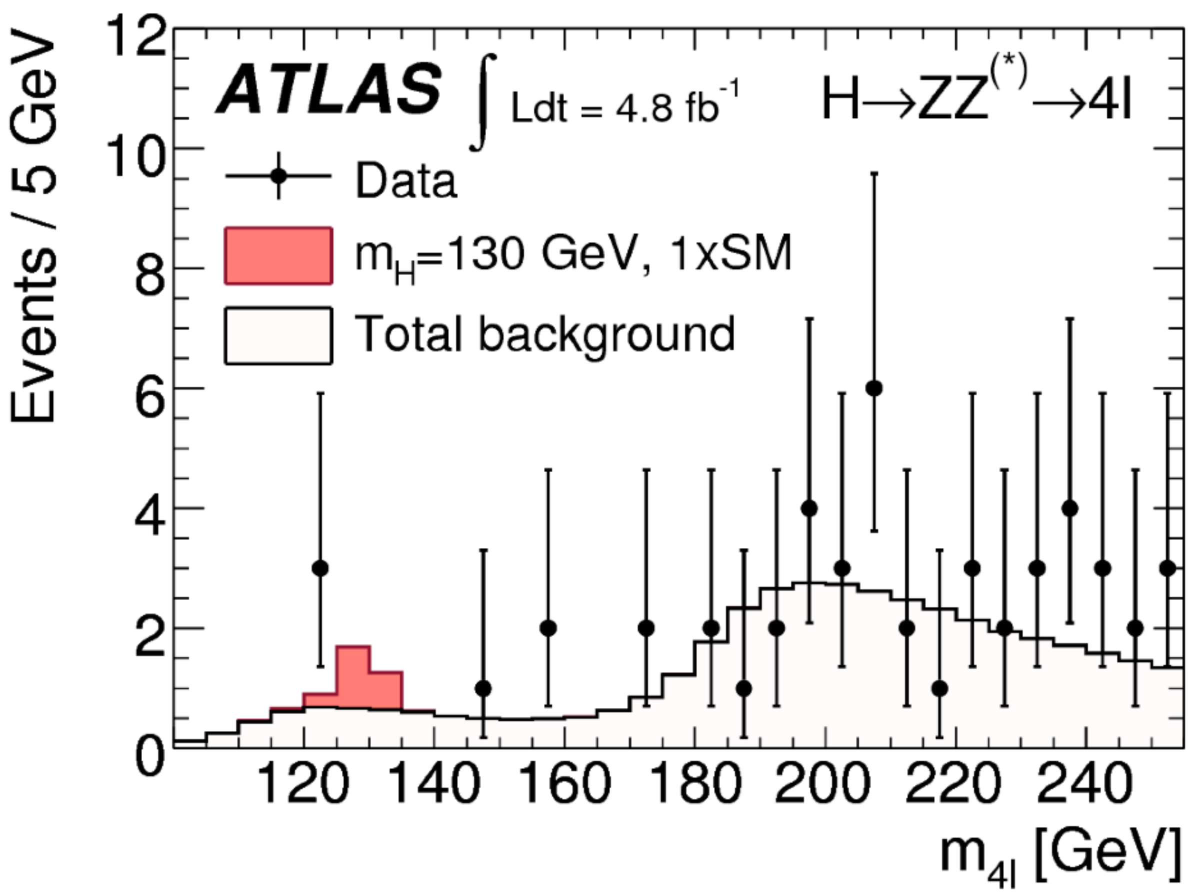
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2012-01/

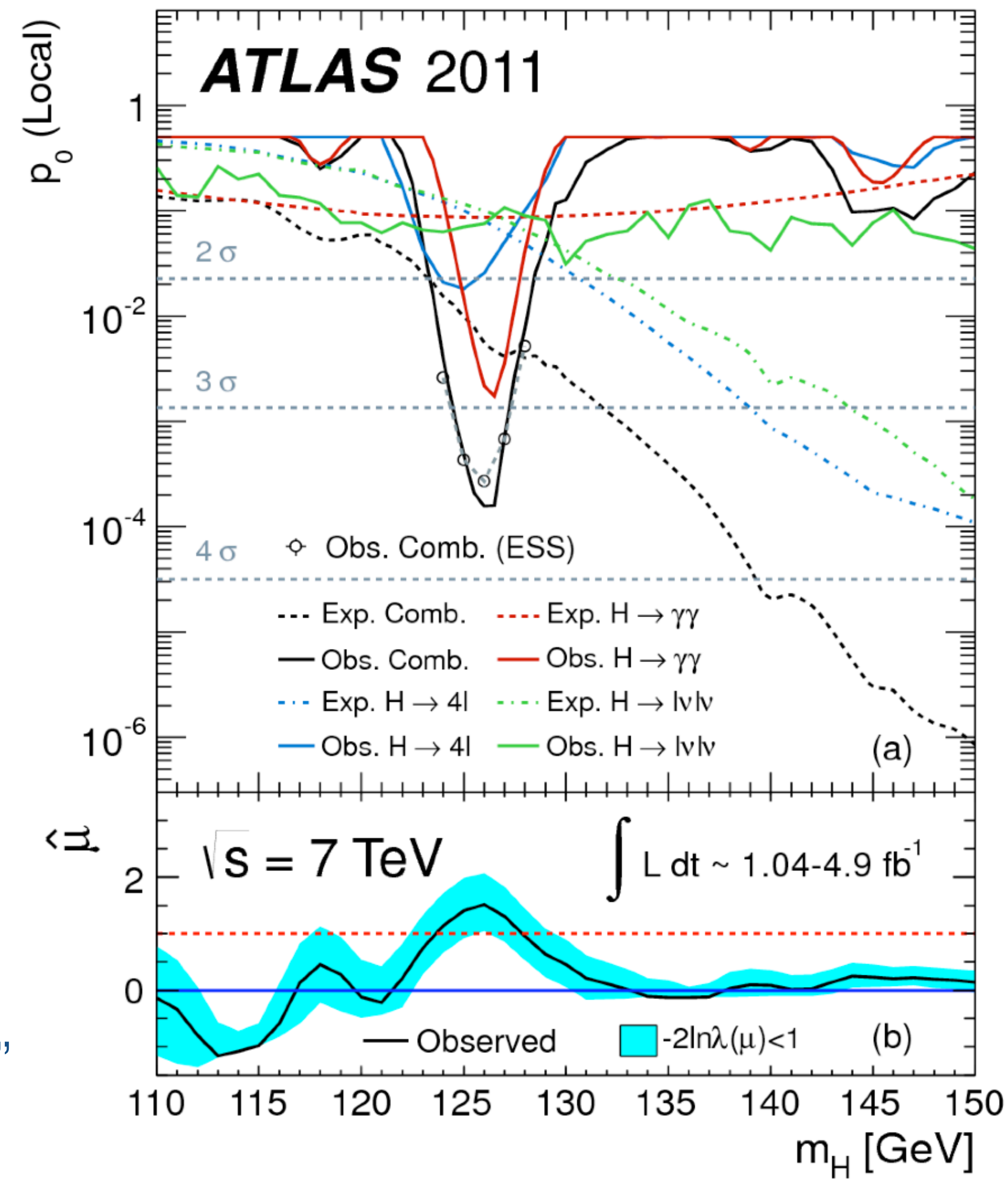
The $\sqrt{s} = 7$ TeV *pp* collision data were recorded during 2011 with the ATLAS detector at the LHC and correspond to an integrated luminosity of 4.8 fb^{-1} [14, 15]. This analysis is using more than twice the integrated luminosity of Ref. [9], including the data therein. The electron identification efficiency has been improved; furthermore the electron tracks have been refitted using a Gaussian-sum filter [16], which corrects for energy losses due to bremsstrahlung. The analysis also

At the time leading to this paper we had a “mini-crisis” in ATLAS concerning electron efficiency….
In retrospect this was an “obvious” improvement.

End of 2011 combination …

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2012-03/





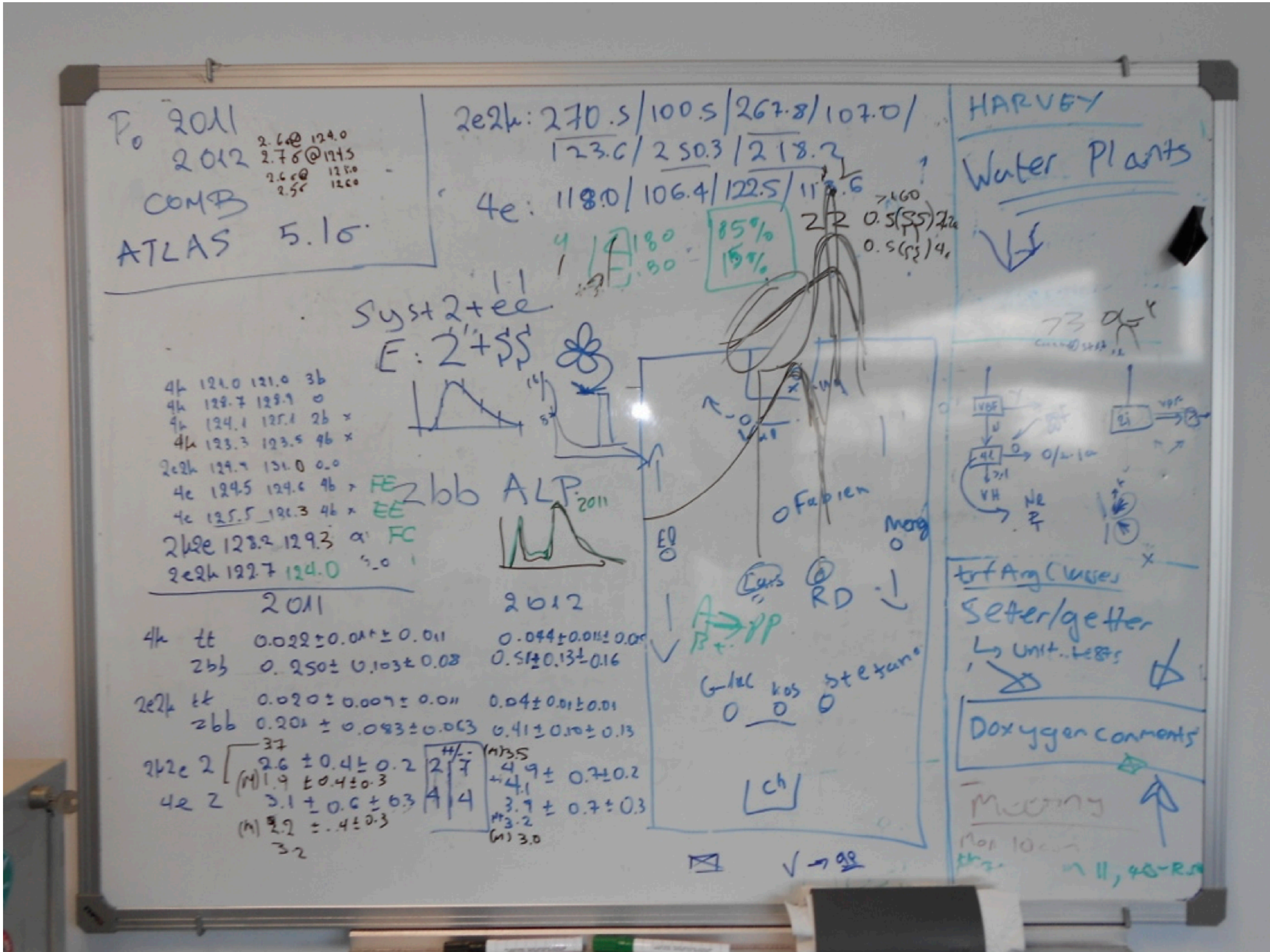
Bill Murray “Poisson statistics is not an insult”

The “long wait ….”

The next few months were an “interesting” period

- **Analysis selections and performance improvement put into stone**
- **Signal region was blinded**
- **A lot of effort on back ground estimations.**
- **Setting up the statistical framework.**
- **And making sure there is not something missing**
- **Other than that waiting for data to be collected, knowing that we will see only a hand full of events.**

Unblinding



Bill Murray "Poisson statistics is not a compliment " …

Seminar
https://indico.cern.ch/event/197461/

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

$110 < m_H < 600$ GeV

$\sigma \times BR \sim 2.5$ fb $m_H \sim 126$ GeV

- ❑ Tiny rate, BUT:
  -- mass can be fully reconstructed → events should cluster in a (narrow) peak
  -- pure: $S/B \sim 1$
- ❑ 4 leptons: $p_T^{1,2,3,4} > 20,15,10,7\text{-}6$ (e-μ) GeV; $50 < m_{12} < 106$ GeV; $m_{34} > 17.5\text{-}50$ GeV (vs m_H)
- ❑ Main backgrounds:
  -- $ZZ^{(*)}$: irreducible
  -- low-mass region $m_H < 2m_Z$: Zbb, Z+jets, tt with two leptons from b-jets or q-jets → l

→ Suppressed with isolation and impact parameter cuts on two softest leptons

Crucial experimental aspects:

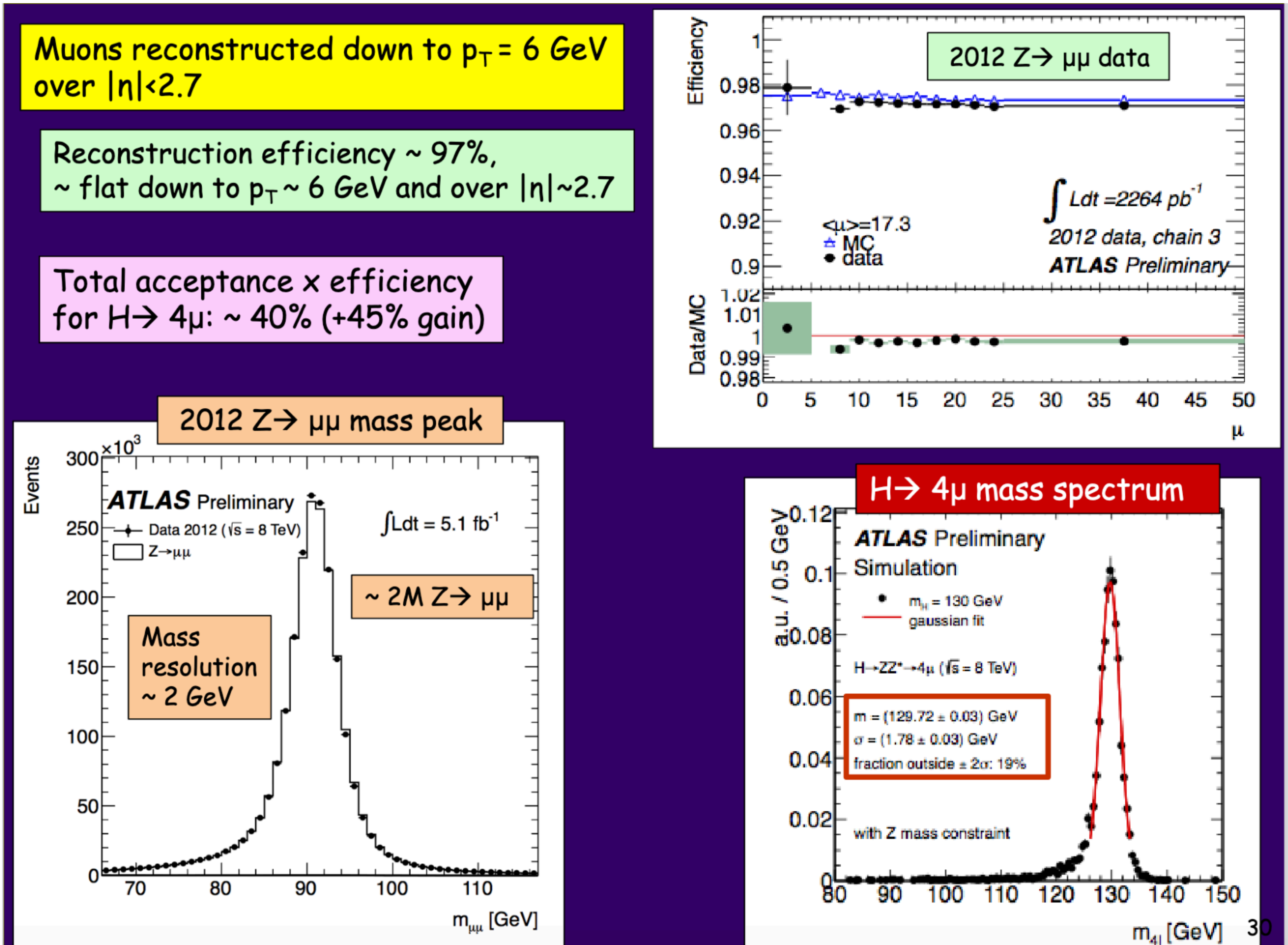
- ❑ High lepton acceptance, reconstruction & identification efficiency down to lowest p_T
- ❑ Good lepton energy/momentum resolution
- ❑ Good control of reducible backgrounds (Zbb, Z+jets, tt) in low-mass region:
  → cannot rely on MC alone (theoretical uncertainties, b/q-jet → l modeling, ..)
  → need to validate MC with data in background-enriched control regions

Main improvements in new analysis:

- ❑ kinematic cuts (e.g. on m_{12}) optimized/relaxed to increase signal sensitivity at low mass
- ❑ increased $e^{\pm}$ reconstruction and identification efficiency at low p_T, increased pile-up robustness, with negligible increase in the reducible backgrounds

→ Gain 20% (4μ) to 30% (4e) in sensitivity compared to previous analysis

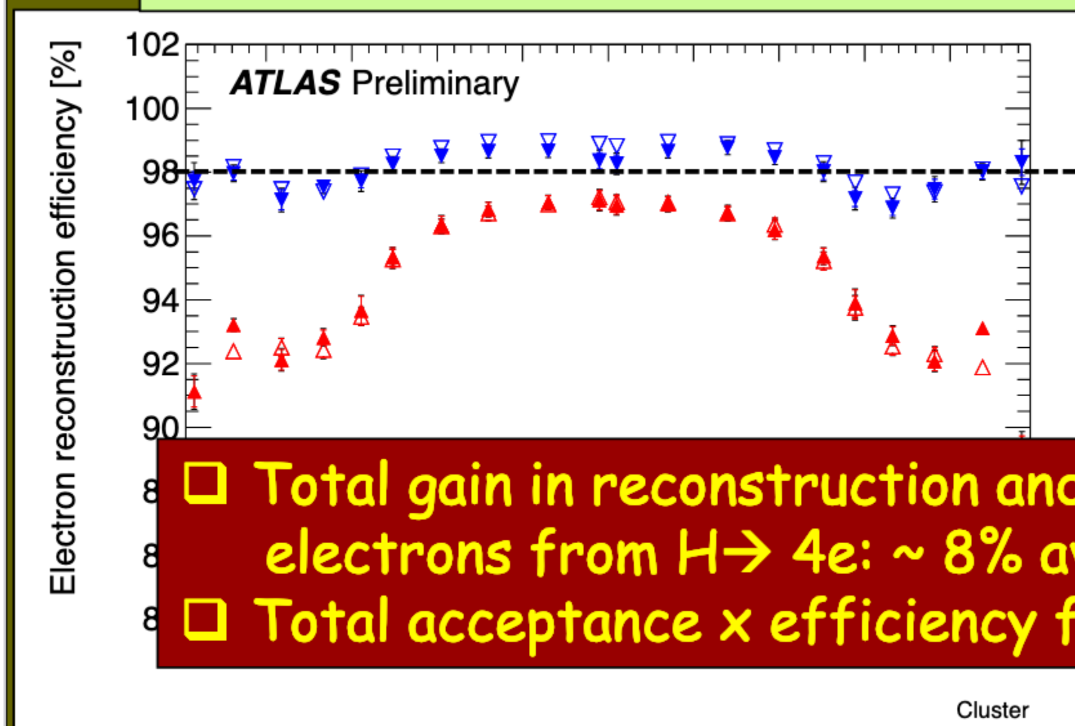
Performance

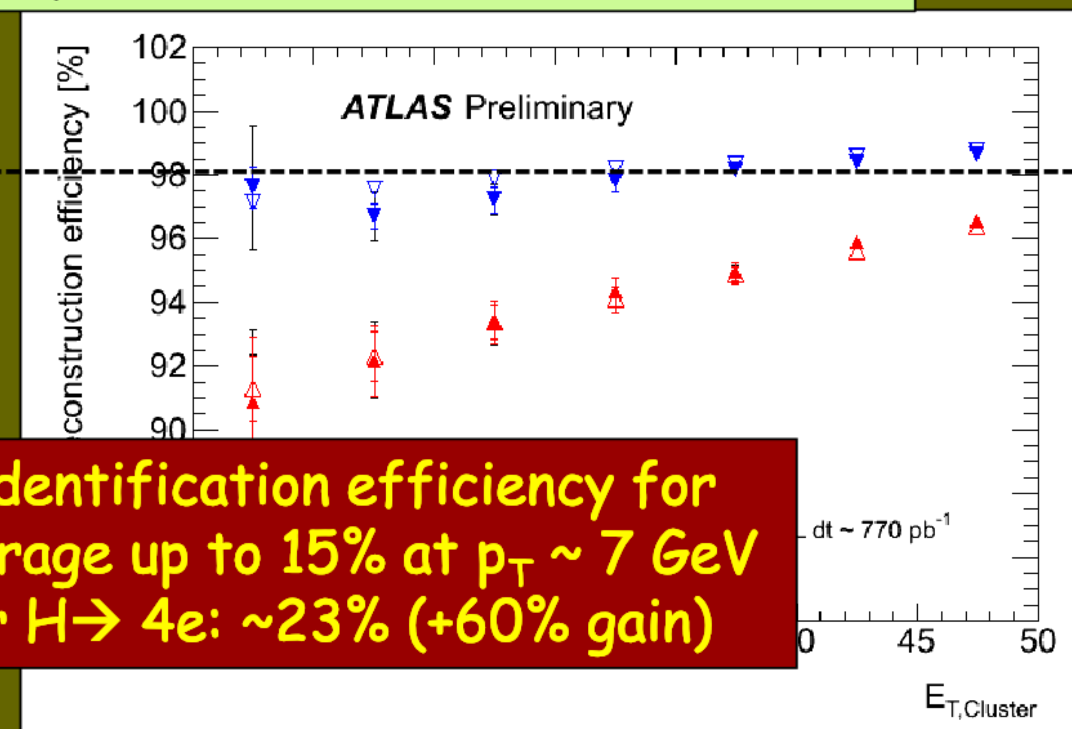


And more Performance

High efficiency for low-p_T electrons (affected by material) crucial for H→ 4e, 2μ2e

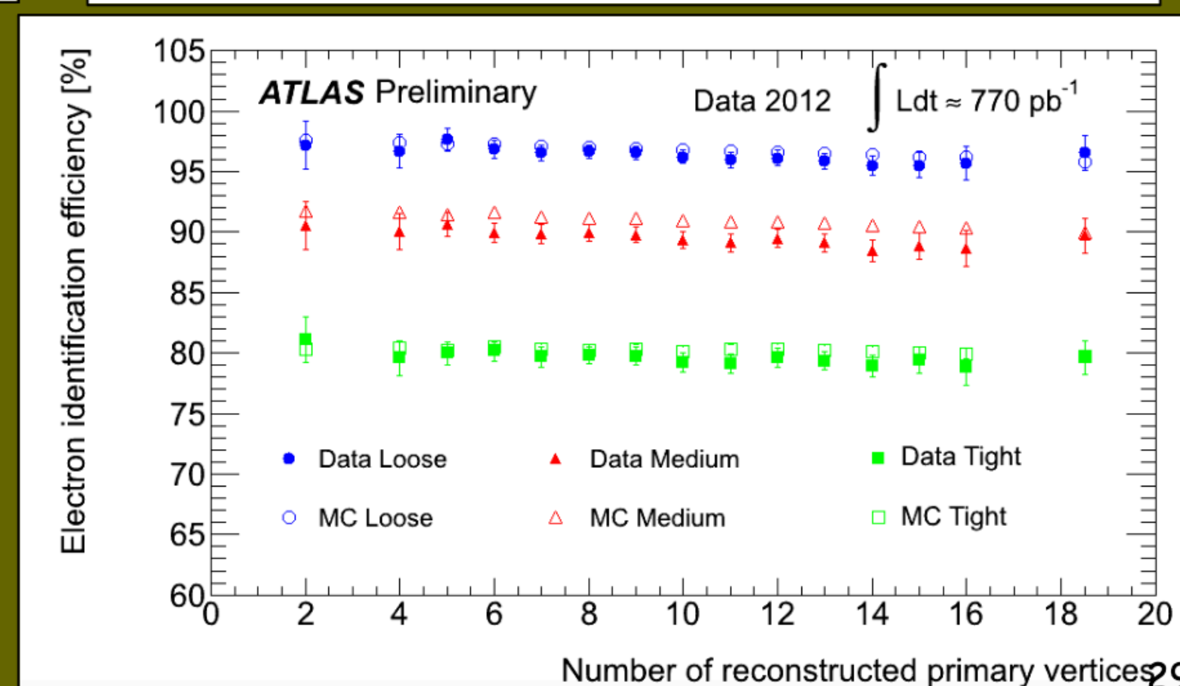
Improved track reconstruction and fitting to recover $e^{\pm}$ undergoing hard Brem
→ achieved ~ 98% reconstruction efficiency, flatter vs η and E_T





- Total gain in reconstruction and identification efficiency for electrons from H→ 4e: ~ 8% average up to 15% at p_T ~ 7 GeV
- Total acceptance x efficiency for H→ 4e: ~23% (+60% gain)

Re-optimized $e^{\pm}$ identification using pile-up robust variables (e.g. Transition Radiation, calorimeter strips) → achieved ~ 95% identification efficiency, ~ flat vs pile-up; higher rejections of fakes



Results are from Z→ ee data and MC tag-and-probe

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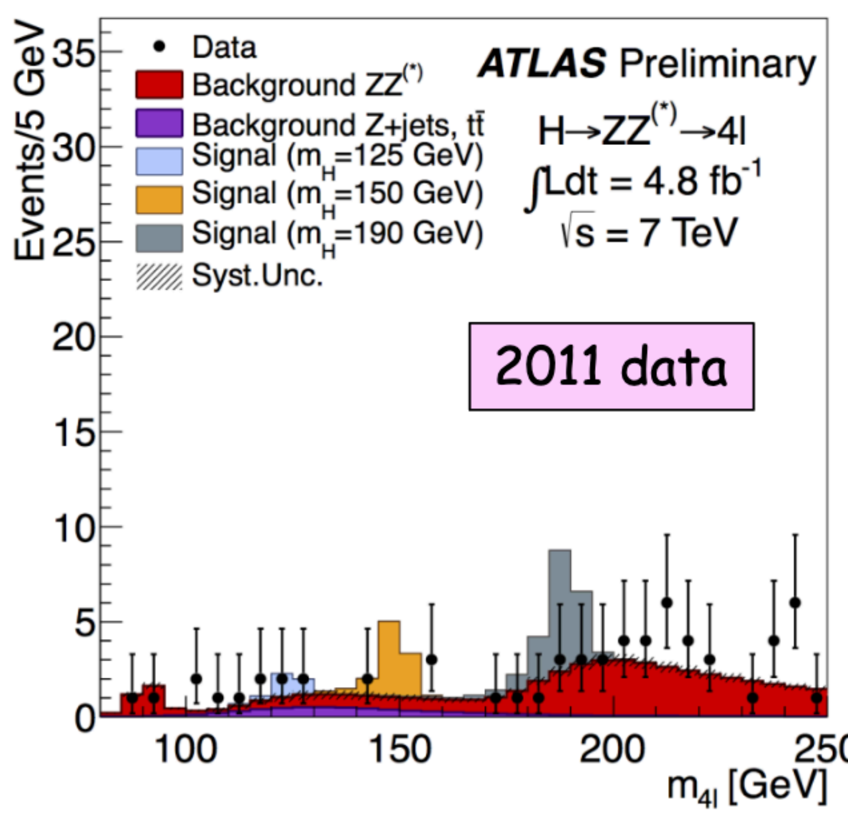
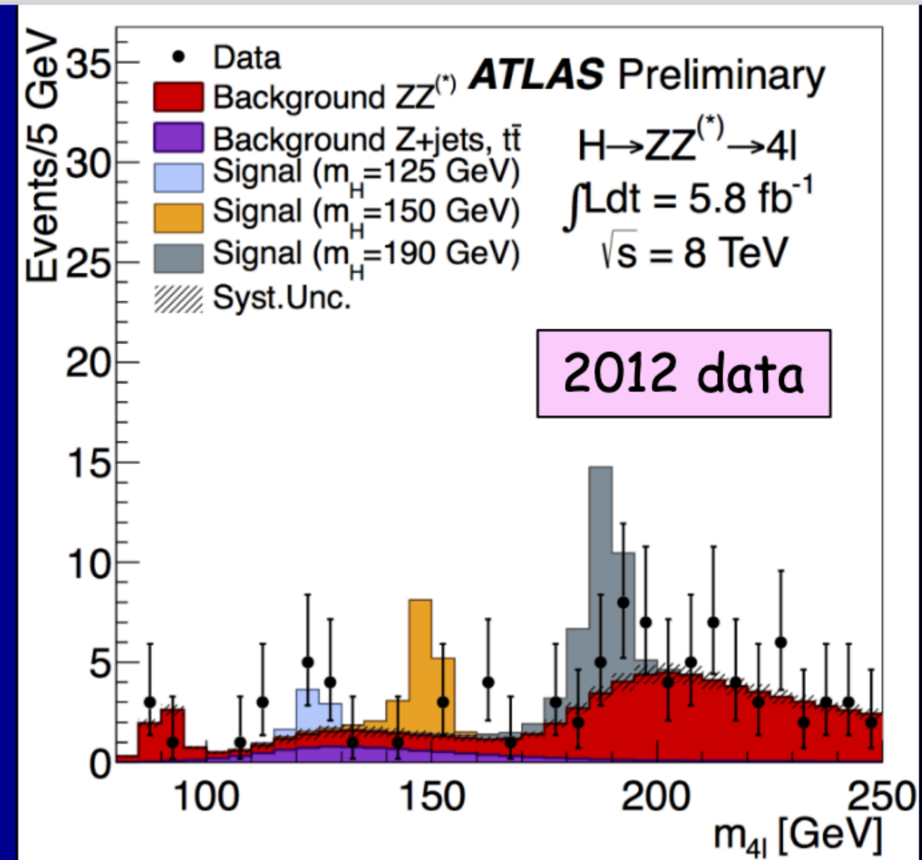
Plots that were made and re-made … until final

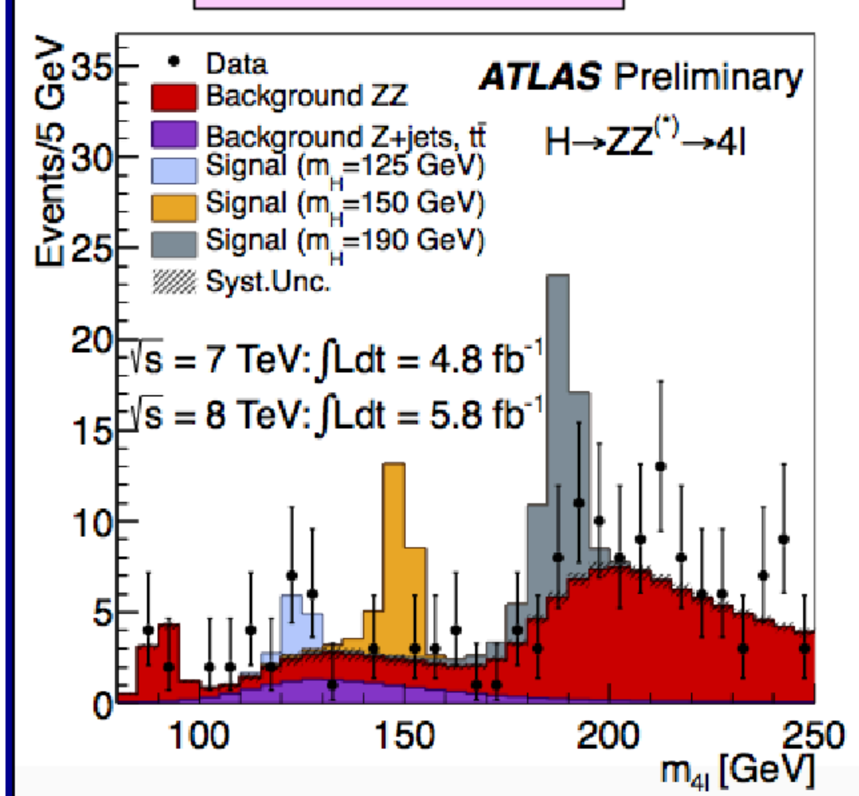


The low-mass region

m4l <160 GeV:
Observed: 39
Expected: 34± 3



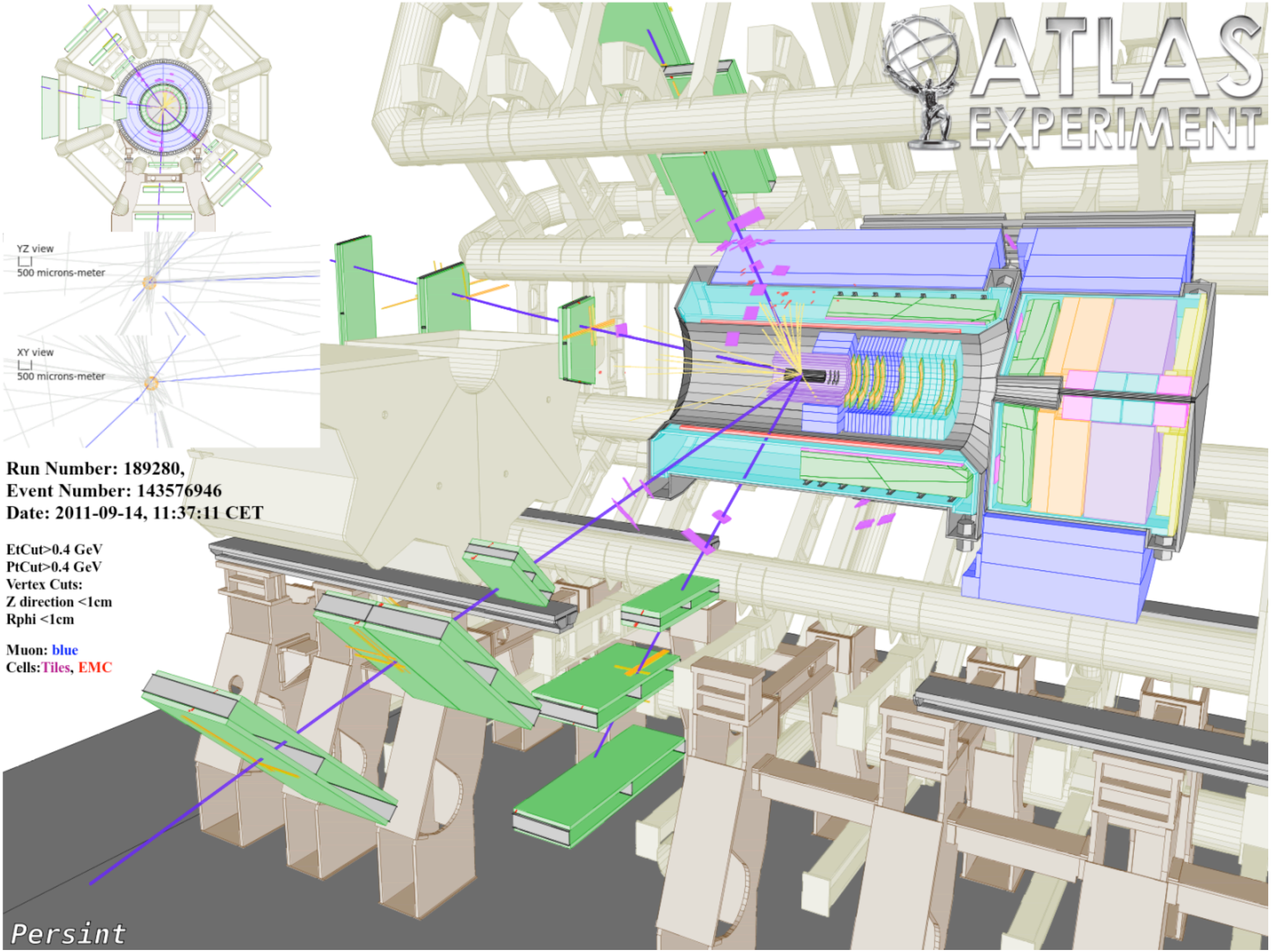
2011+2012 data

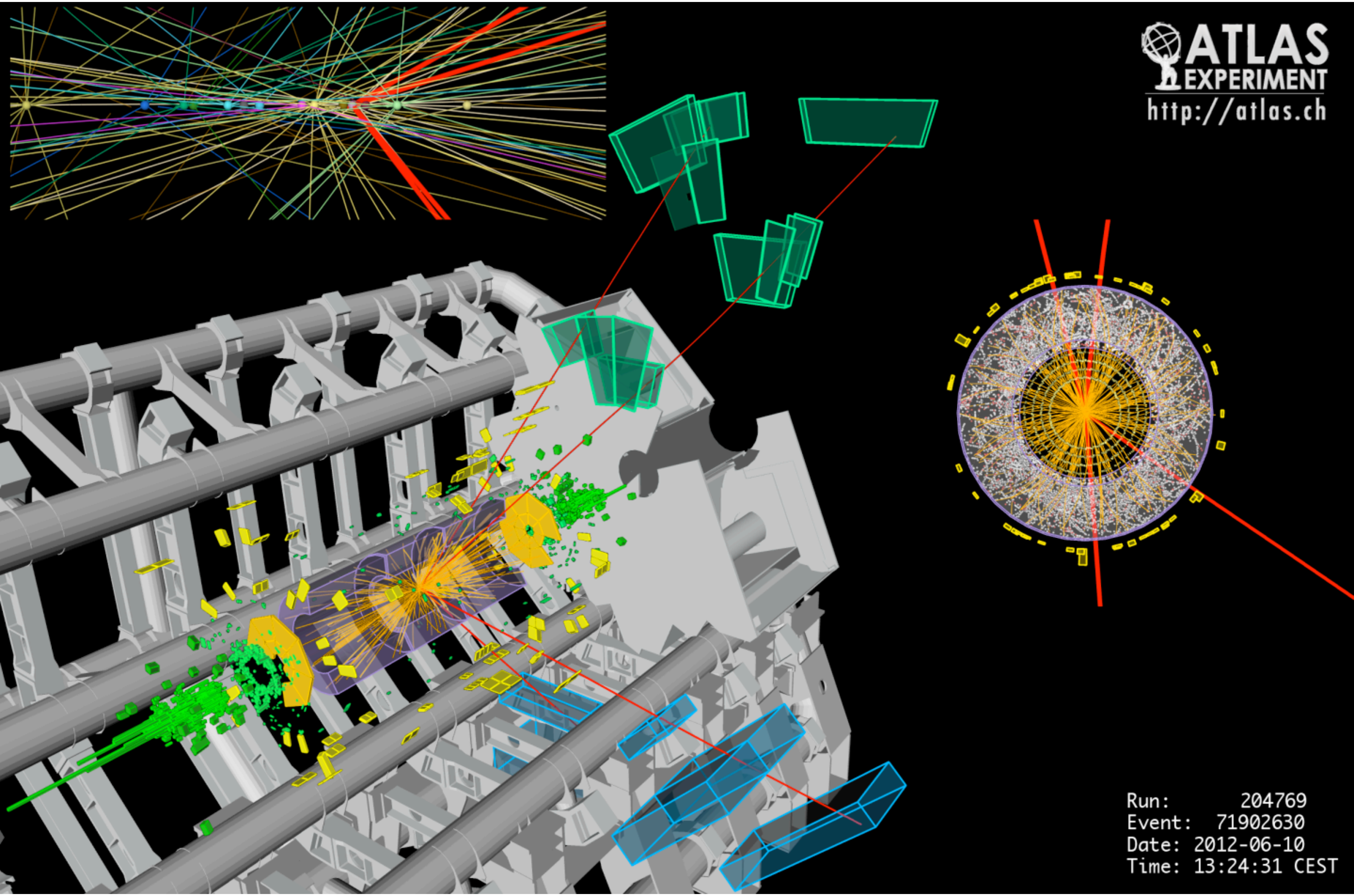


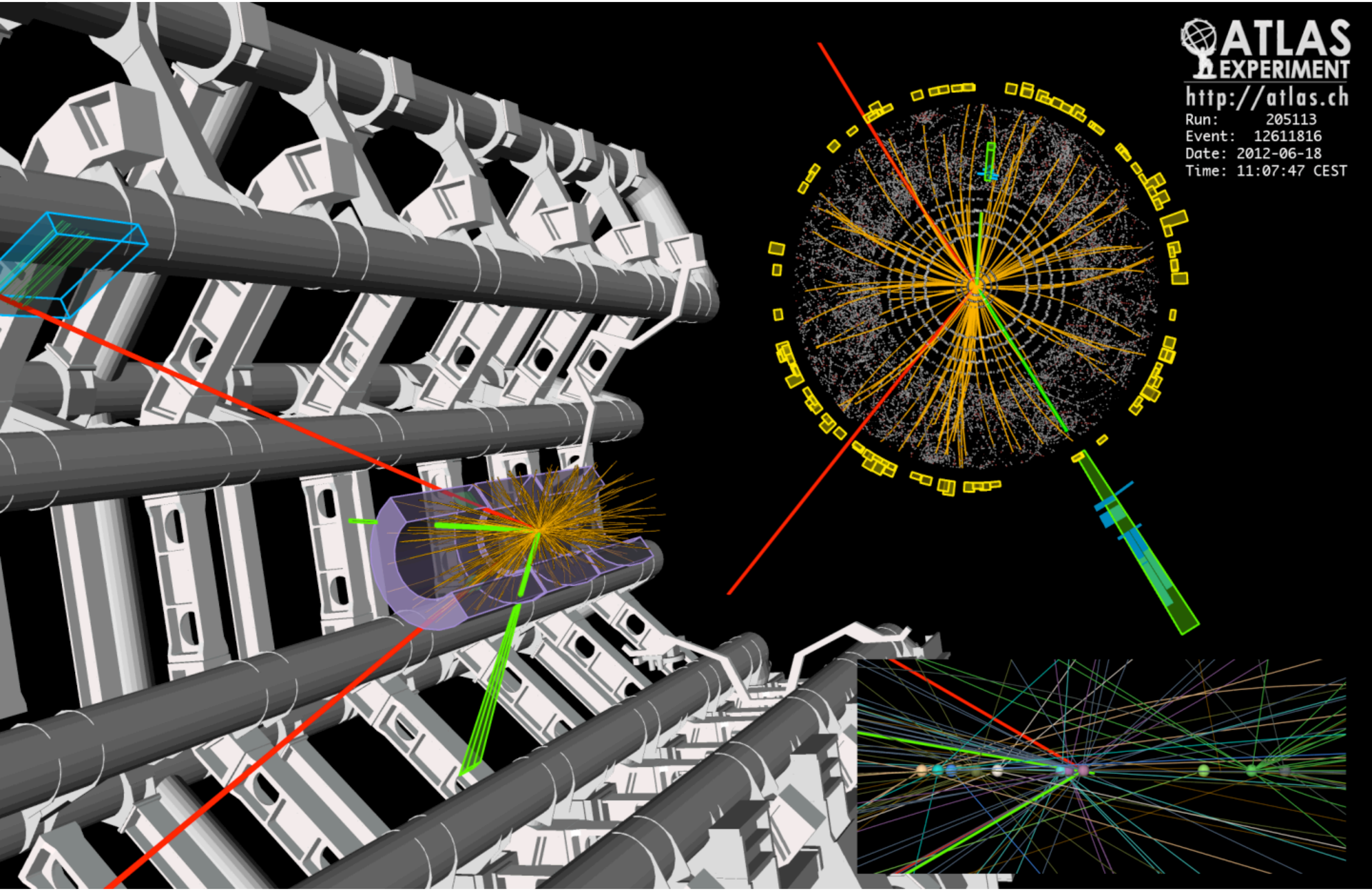
In the region 125 ± 5 GeV

Dataset	2011	2012	2011+2012
Expected B only	2±0.3	3±0.4	5.1±0.8
Expected S m_H=125 GeV	2±0.3	3±0.5	5.3±0.8
Observed in the data	4	9	13

2011+ 2012	4μ	2e2μ	4e
Data	6	5	2
Expected S/B	1.6	1	0.5
Reducible/total background	5%	45%	55%


ATLAS EXPERIMENT
YZ view
500 microns-meter
XY view
500 microns-meter
Run Number: 189280,
Event Number: 143576946
Date: 2011-09-14, 11:37:11 CET
EtCut>0.4 GeV
PtCut>0.4 GeV
Vertex Cuts:
Z direction <1cm
Rphi <1cm
Muon: blue
Cells:Tiles, EMC
Persint


ATLAS
EXPERIMENT
http://atlas.ch
Run: 204769
Event: 71902630
Date: 2012-06-10
Time: 13:24:31 CEST


ATLAS
EXPERIMENT
http://atlas.ch
Run: 205113
Event: 12611816
Date: 2012-06-18
Time: 11:07:47 CEST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HCP2012
PANINI

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

The ATLAS Collaboration

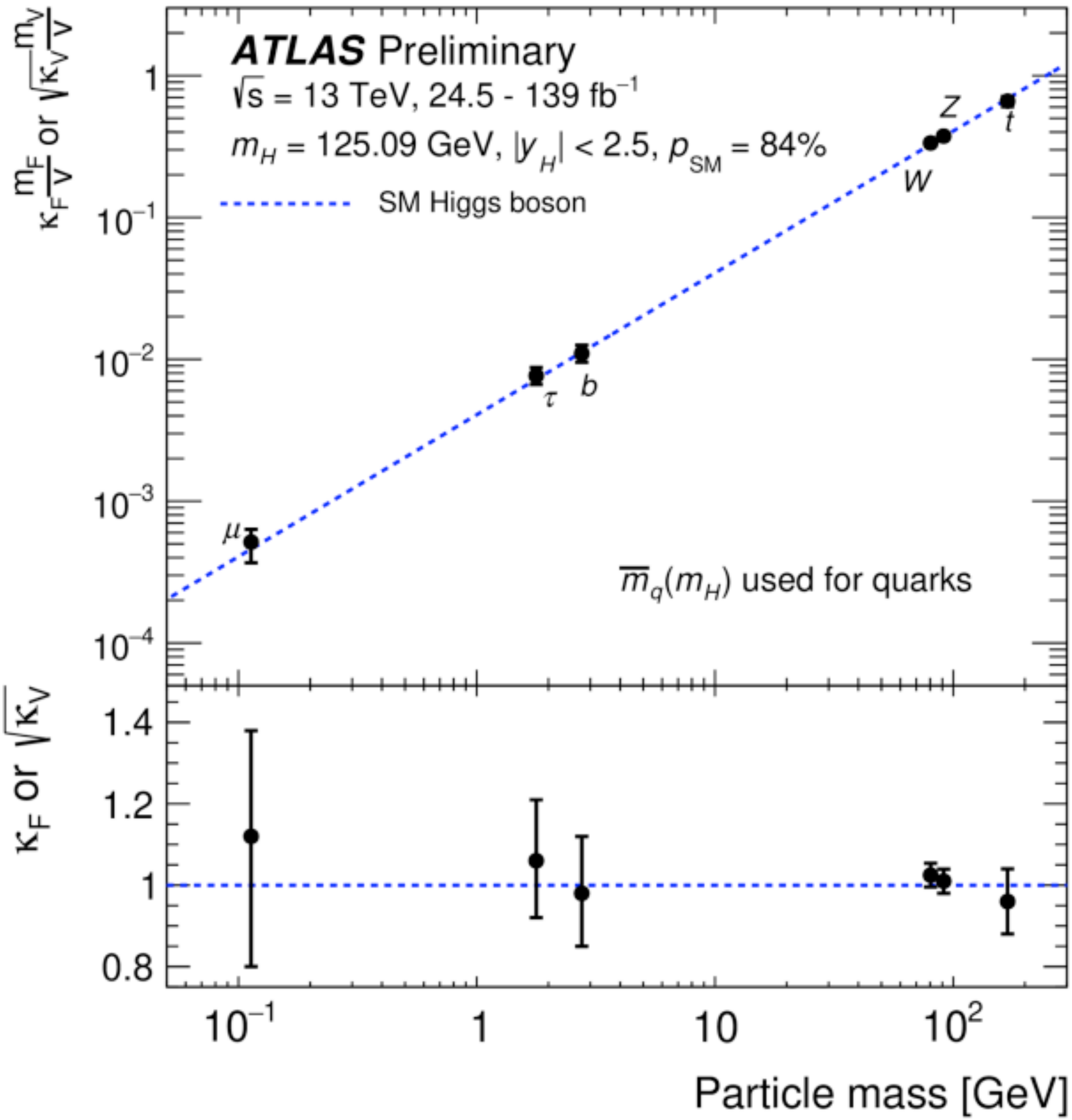
This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC

The ATLAS Collaboration

Evidence for the spin-0 nature of the Higgs boson using ATLAS data

The ATLAS Collaboration



ATLAS Preliminary
√s = 13 TeV, 24.5 - 139 fb⁻¹
m_H = 125.09 GeV, |y_H| < 2.5, p_SM = 84%
SM Higgs boson
m̄_q(m_H) used for quarks
μ
τ
b
W
Z
t
κ_F m_F/v or √κ_V m_V/v
κ_F or √κ_V
Particle mass [GeV]

Τέλος

- The discovery of the Higgs boson was made possible by carefully designed experiments and the hard work of many people in the respective collaborations.
- It is interesting that the Higgs discovery came quite early on the LHC running.
- Very close in time where we were still establishing the detector performance that played a crucial role in this discovery.
- It was both a enjoy full and stress full time for a young Post Doc like me.
- It will be hard for something else to replicate that experience.
- Last and not least a lot of very strong friendships were developed at the time