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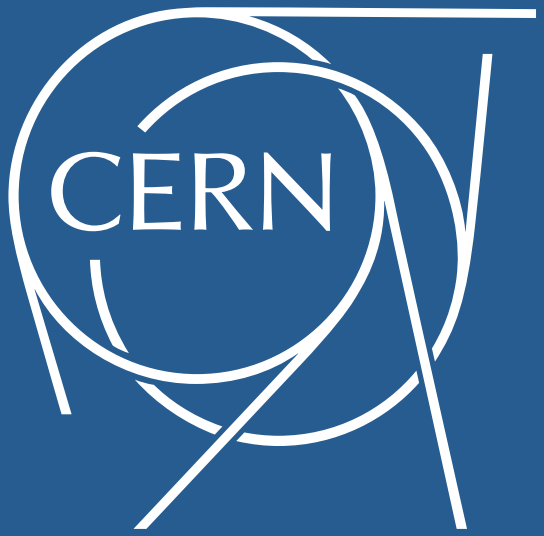

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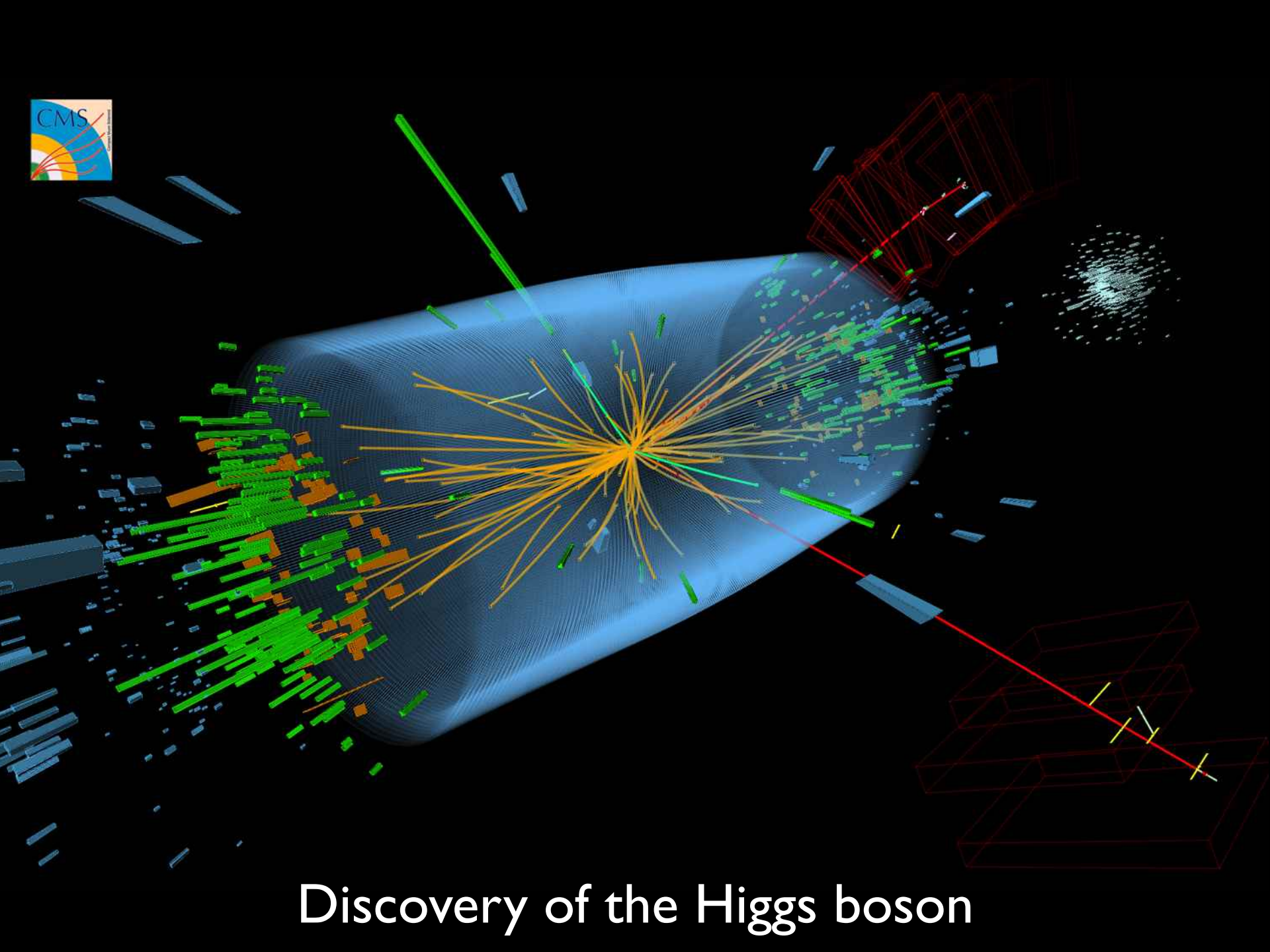

Discovery of the Higgs boson

Physics Letters B 716 (2012) 1–29

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Physics Letters B

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Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

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.

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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 $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8$ TeV in 2012. Individual searches in the channels $H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H \to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \to ZZ^{(*)} \to 4\ell$ and $H \to \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of $126.0 \pm 0.4\,(\text{stat}) \pm 0.4\,(\text{sys})$ GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.

1. Introduction

The Standard Model (SM) of particle physics [1–4] has been tested by many experiments over the last four decades and has been shown to successfully describe high energy particle interactions. However, the mechanism that breaks electroweak symmetry in the SM has not been verified experimentally. This mechanism [5–10], which gives mass to massive elementary particles, implies the existence of a scalar particle, the SM Higgs boson. The search for the Higgs boson, the only elementary particle in the SM that has not yet been observed, is one of the highlights of the Large Hadron Collider [11] (LHC) physics programme.

Indirect limits on the SM Higgs boson mass of $m_H < 158$ GeV at 95% confidence level (CL) have been set using global fits to precision electroweak results [12]. Direct searches at LEP [13], the Tevatron [14–16] and the LHC [17,18] have previously excluded, at 95% CL, a SM Higgs boson with mass below 600 GeV, apart from some mass regions between 116 GeV and 127 GeV.

Both the ATLAS and CMS Collaborations reported excesses of events in their 2011 datasets of proton–proton (pp) collisions at centre-of-mass energy $\sqrt{s} = 7$ TeV at the LHC, which were compatible with SM Higgs boson production and decay in the mass region 124–126 GeV, with significances of 2.9 and 3.1 standard deviations (σ), respectively [17,18]. The CDF and DØ experiments at the Tevatron have also recently reported a broad excess in the mass region 120–135 GeV; using the existing LHC constraints, the observed local significances for $m_H = 125$ GeV are 2.7σ for CDF [14], 1.1σ for DØ [15] and 2.8σ for their combination [16].

The previous ATLAS searches in 4.6–4.8 fb^{-1} of data at $\sqrt{s} = 7$ TeV are combined here with new searches for $H \to ZZ^{(*)} \to 4\ell$,[1] $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$ in the 5.8–5.9 fb^{-1} of pp collision data taken at $\sqrt{s} = 8$ TeV between April and June 2012.

The data were recorded with instantaneous luminosities up to 6.8×10^{33} cm^{-2} s^{-1}; they are therefore affected by multiple pp collisions occurring in the same or neighbouring bunch crossings (pile-up). In the 7 TeV data, the average number of interactions per bunch crossing was approximately 10; the average increased to approximately 20 in the 8 TeV data. The reconstruction, identification and isolation criteria used for electrons and photons in the 8 TeV data are improved, making the $H \to ZZ^{(*)} \to 4\ell$ and $H \to \gamma\gamma$ searches more robust against the increased pile-up. These analyses were re-optimised with simulation and frozen before looking at the 8 TeV data.

In the $H \to WW^{(*)} \to \ell\nu\ell\nu$ channel, the increased pile-up deteriorates the event missing transverse momentum, E_T^{miss}, resolution, which results in significantly larger Drell–Yan background in the same-flavour final states. Since the $e\mu$ channel provides most of the sensitivity of the search, only this final state is used in the analysis of the 8 TeV data. The kinematic region in which a SM Higgs boson with a mass between 110 GeV and 140 GeV is

[1] The symbol ℓ stands for electron or muon.

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Physics Letters B

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Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC ☆

CMS Collaboration *

CERN, Switzerland

This paper is dedicated to the memory of our colleagues who worked on CMS but have since passed away. In recognition of their many contributions to the achievement of this observation.

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ABSTRACT

Results are presented from searches for the standard model Higgs boson in proton–proton collisions at $\sqrt{s} = 7$ and 8 TeV in the Compact Muon Solenoid experiment at the LHC, using data samples corresponding to integrated luminosities of up to 5.1 fb^{-1} at 7 TeV and 5.3 fb^{-1} at 8 TeV. The search is performed in five decay modes: $\gamma\gamma$, ZZ, W^+W^-, $\tau^+\tau^-$, and $b\bar{b}$. An excess of events is observed above the expected background, with a local significance of 5.0 standard deviations, at a mass near 125 GeV, signalling the production of a new particle. The expected significance for a standard model Higgs boson of that mass is 5.8 standard deviations. The excess is most significant in the two decay modes with the best mass resolution, $\gamma\gamma$ and ZZ; a fit to these signals gives a mass of $125.3 \pm 0.4\,(\text{stat.}) \pm 0.5\,(\text{syst.})$ GeV. The decay to two photons indicates that the new particle is a boson with spin different from one.

1. Introduction

The standard model (SM) of elementary particles provides a remarkably accurate description of results from many accelerator and non-accelerator based experiments. The SM comprises quarks and leptons as the building blocks of matter, and describes their interactions through the exchange of force carriers: the photon for electromagnetic interactions, the W and Z bosons for weak interactions, and the gluons for strong interactions. The electromagnetic and weak interactions are unified in the electroweak theory. Although the predictions of the SM have been extensively confirmed, the question of how the W and Z gauge bosons acquire mass whilst the photon remains massless is still open.

Nearly fifty years ago it was proposed [1–6] that spontaneous symmetry breaking in gauge theories could be achieved through the introduction of a scalar field. Applying this mechanism to the electroweak theory [7–9] through a complex scalar doublet field leads to the generation of the W and Z masses, and to the prediction of the existence of the SM Higgs boson (H). The scalar field also gives mass to the fundamental fermions through the Yukawa interaction. The mass m_H of the SM Higgs boson is not predicted by theory. However, general considerations [10–13] suggest that m_H should be smaller than ~1 TeV, while precision electroweak measurements imply that $m_H < 152$ GeV at 95% confidence level (CL) [14]. Over the past twenty years, direct searches for the Higgs boson have been carried out at the LEP collider, leading to a lower bound of $m_H > 114.4$ GeV at 95% CL [15], and at the Tevatron proton–antiproton collider, excluding the mass range 162–166 GeV at 95% CL [16] and detecting an excess of events, recently reported in [17–19], in the range 120–135 GeV.

The discovery or exclusion of the SM Higgs boson is one of the primary scientific goals of the Large Hadron Collider (LHC) [20]. Previous direct searches at the LHC were based on data from proton–proton collisions corresponding to an integrated luminosity of 5 fb^{-1} collected at a centre-of-mass energy $\sqrt{s} = 7$ TeV. The CMS experiment excluded at 95% CL a range of masses from 127 to 600 GeV [21]. The ATLAS experiment excluded at 95% CL the ranges 111.4–116.6, 119.4–122.1 and 129.2–541 GeV [22]. Within the remaining allowed mass region, an excess of events near 125 GeV was reported by both experiments. In 2012 the proton–proton centre-of-mass energy was increased to 8 TeV and by the end of June an additional integrated luminosity of more than 5 fb^{-1} had been recorded by each of these experiments, thereby enhancing significantly the sensitivity of the search for the Higgs boson.

This Letter reports the results of a search for the SM Higgs boson using samples collected by the CMS experiment, comprising data recorded at $\sqrt{s} = 7$ and 8 TeV. The search is performed in

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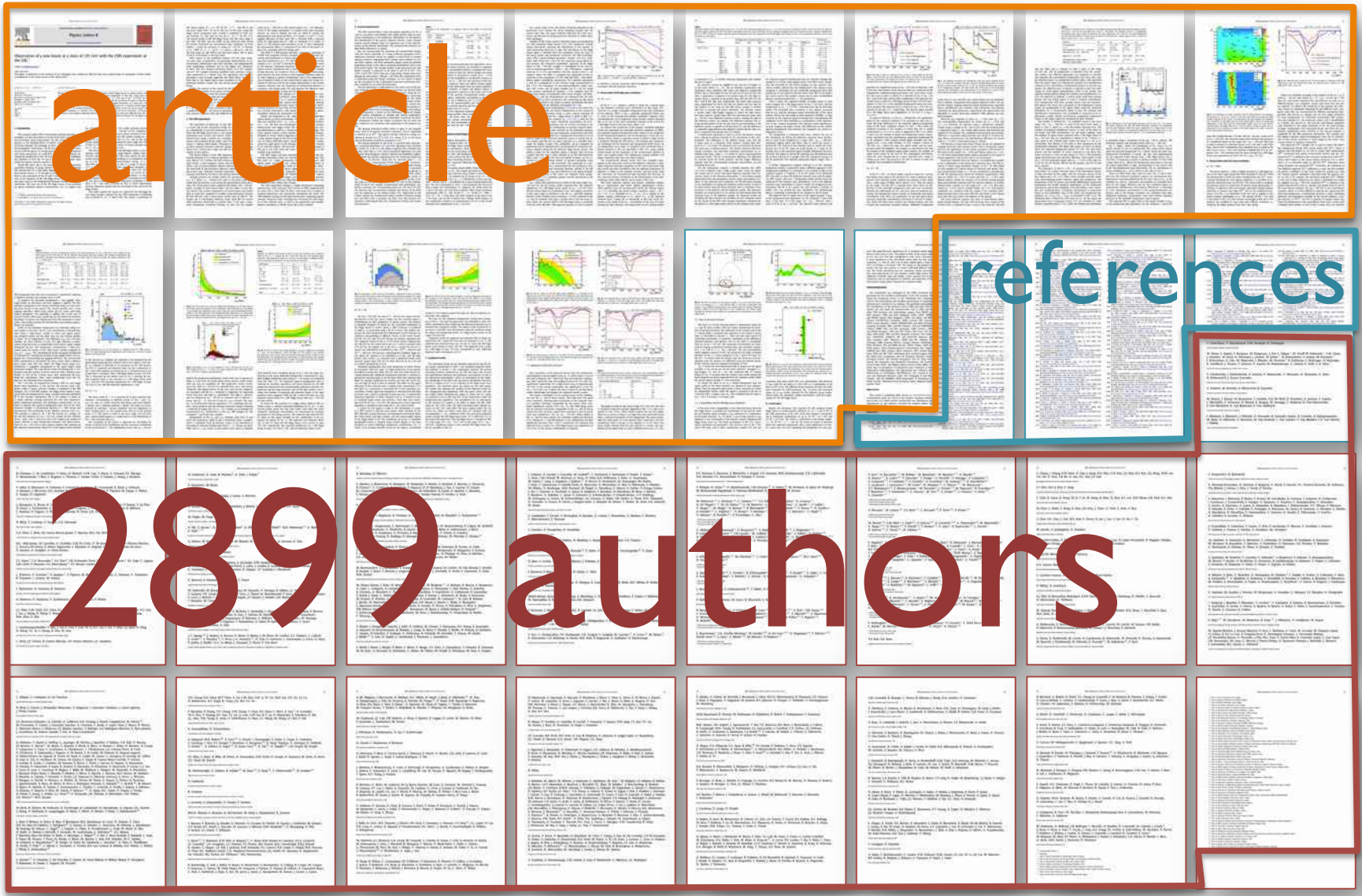
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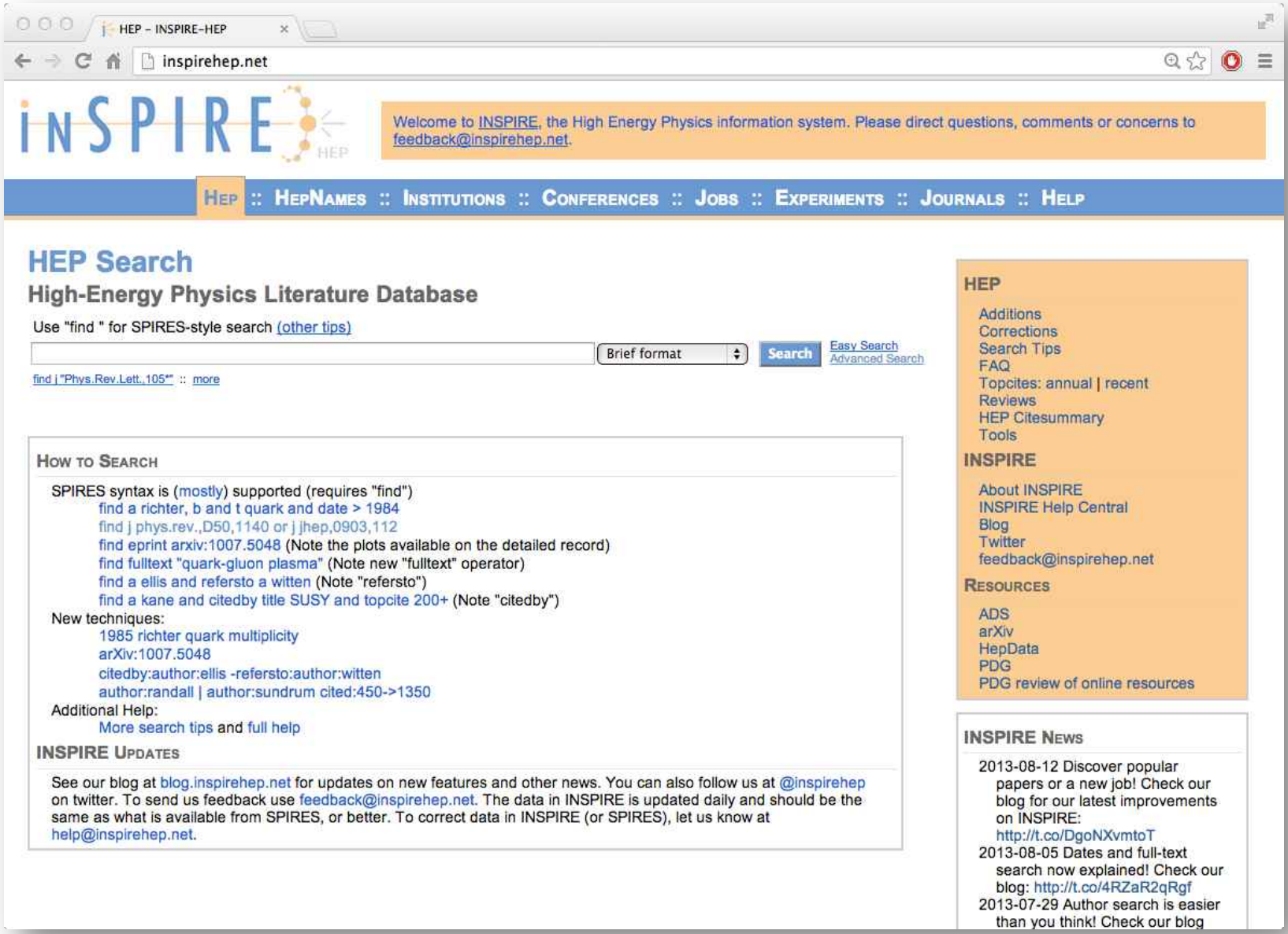
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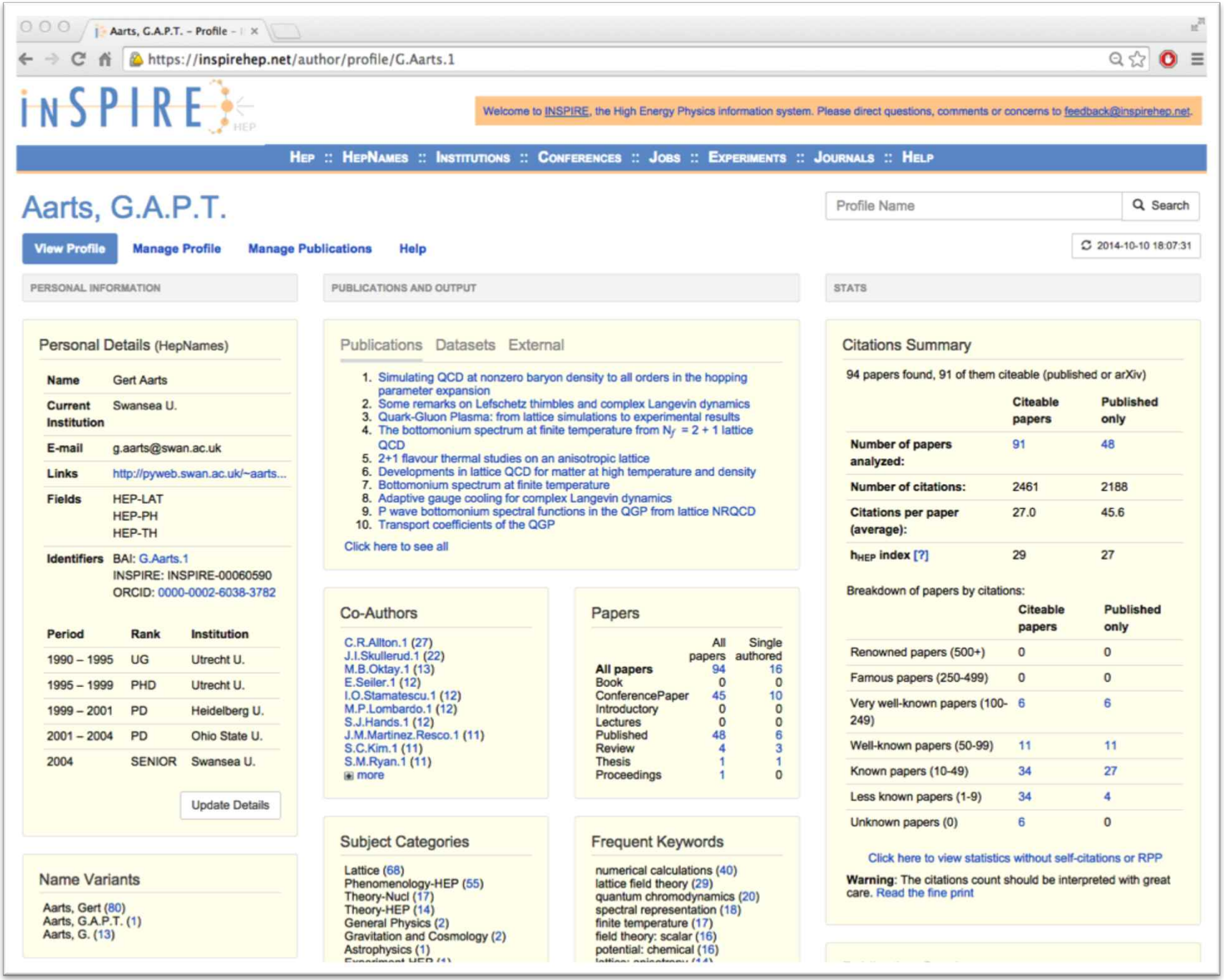
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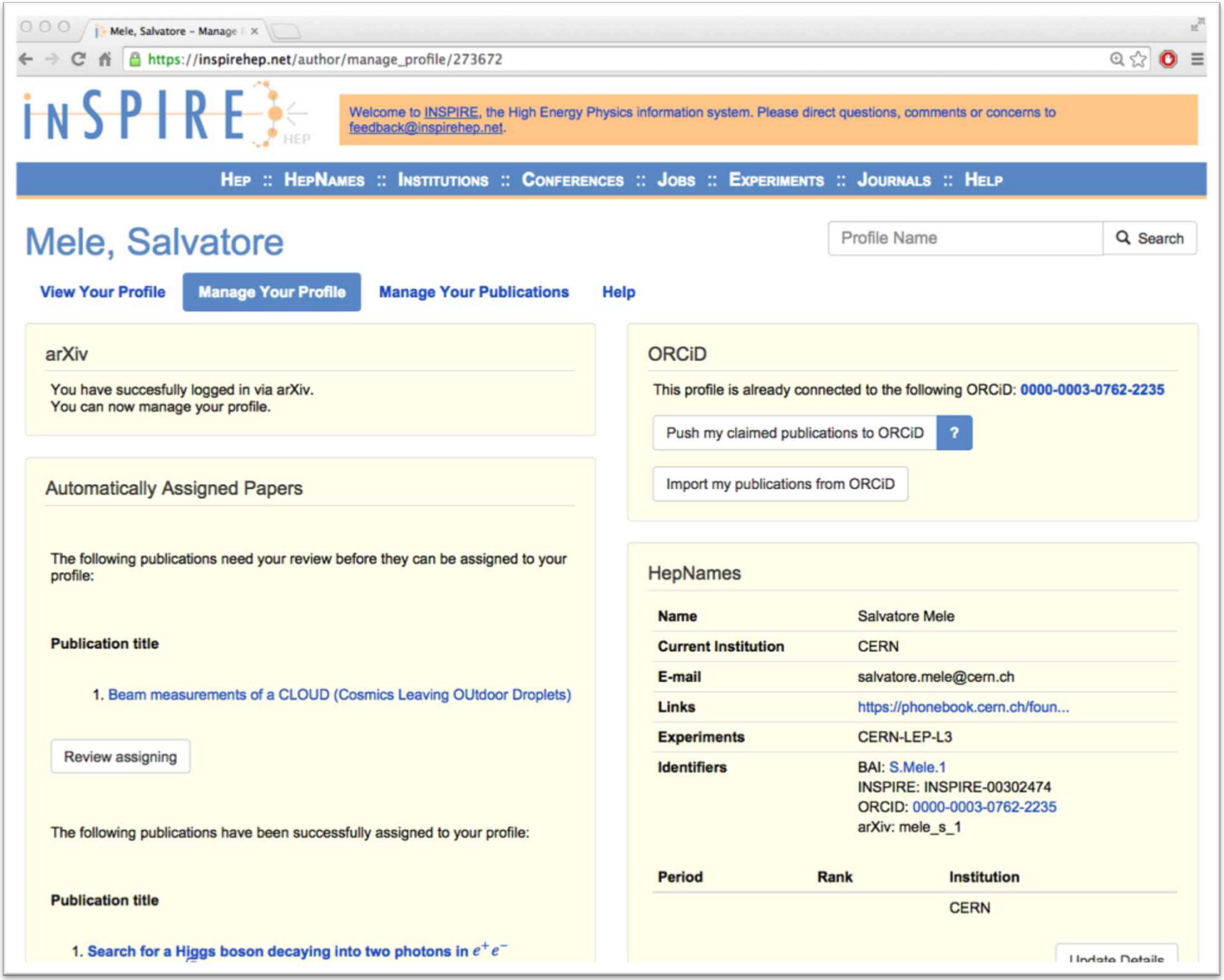
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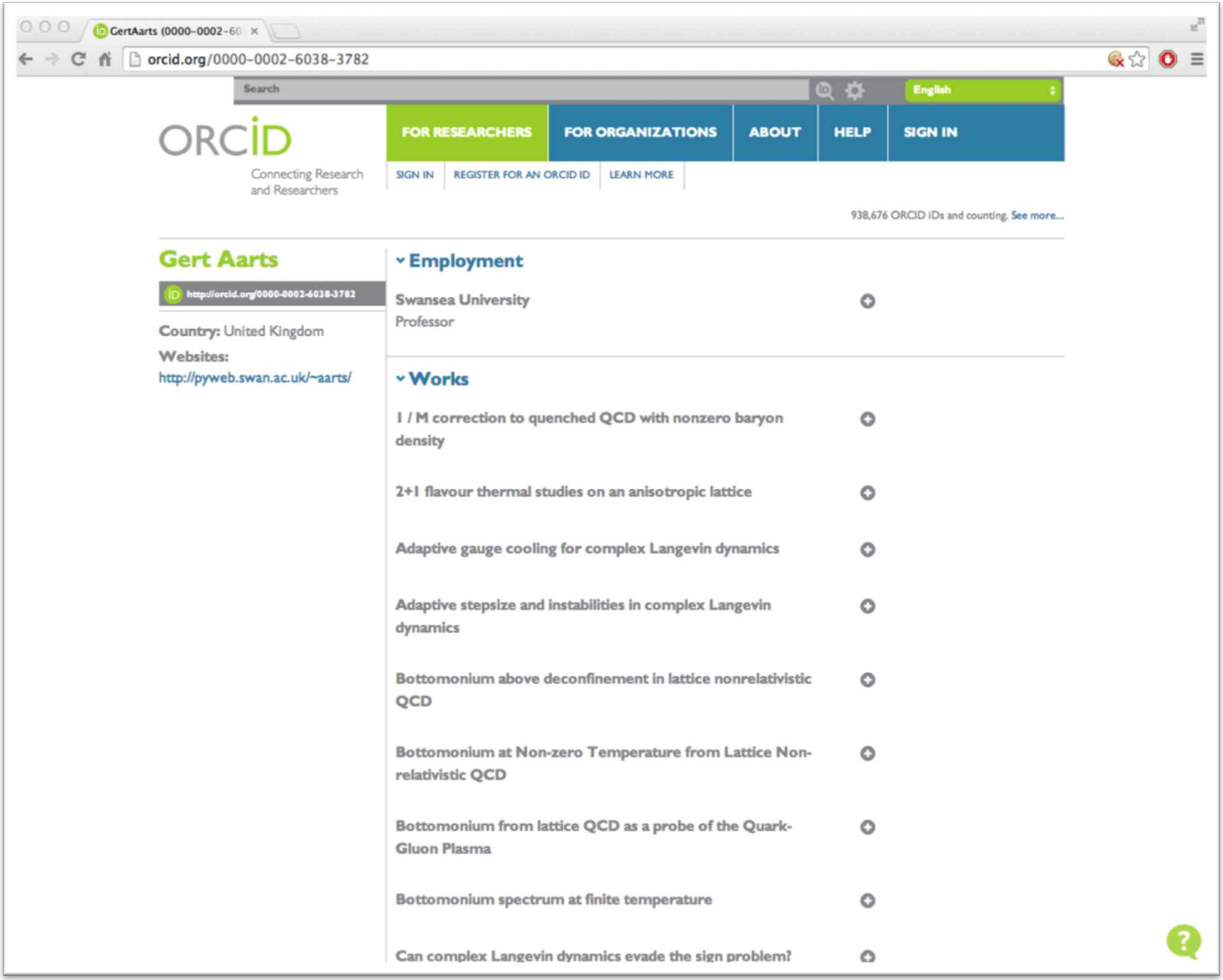
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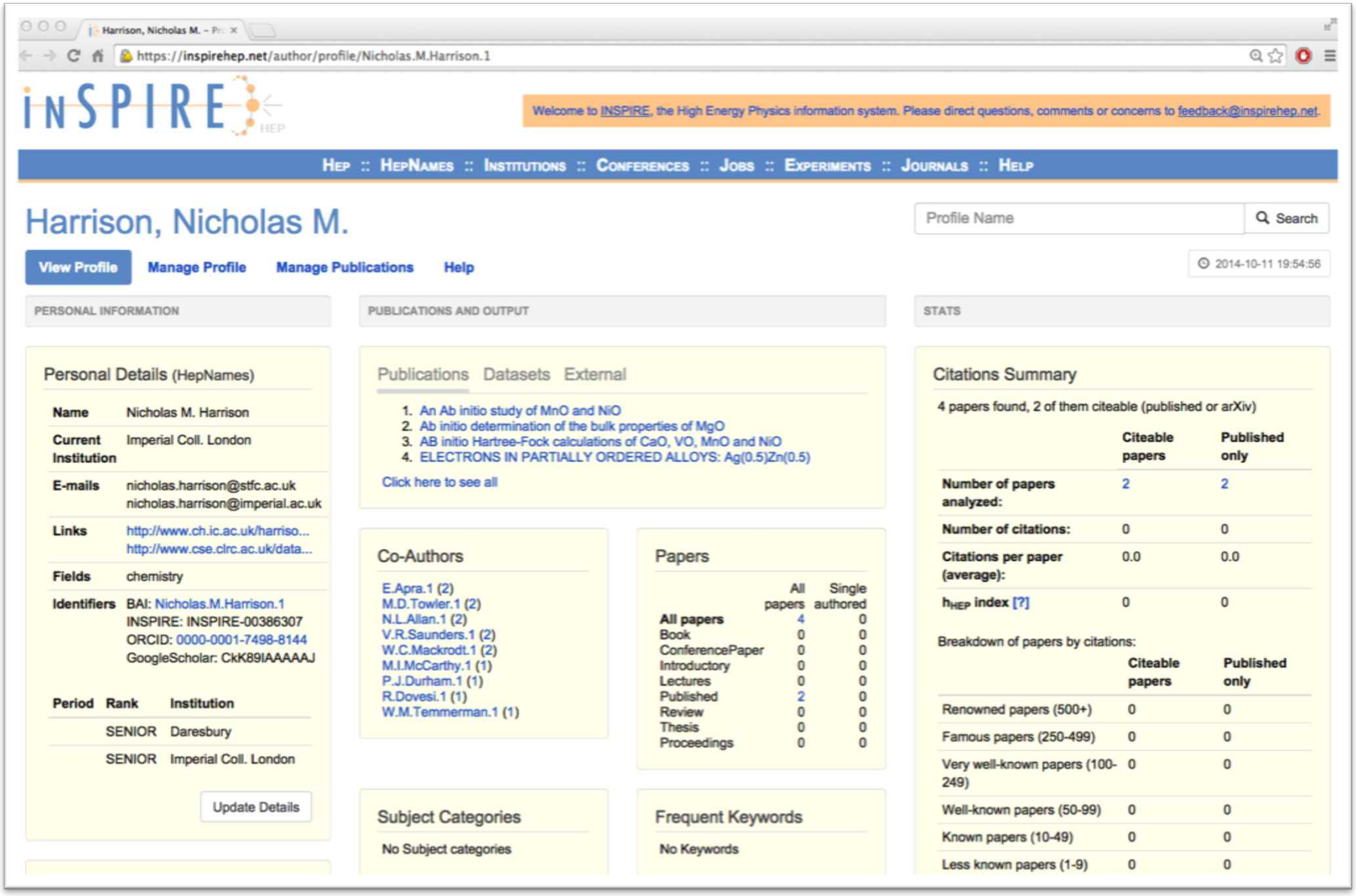
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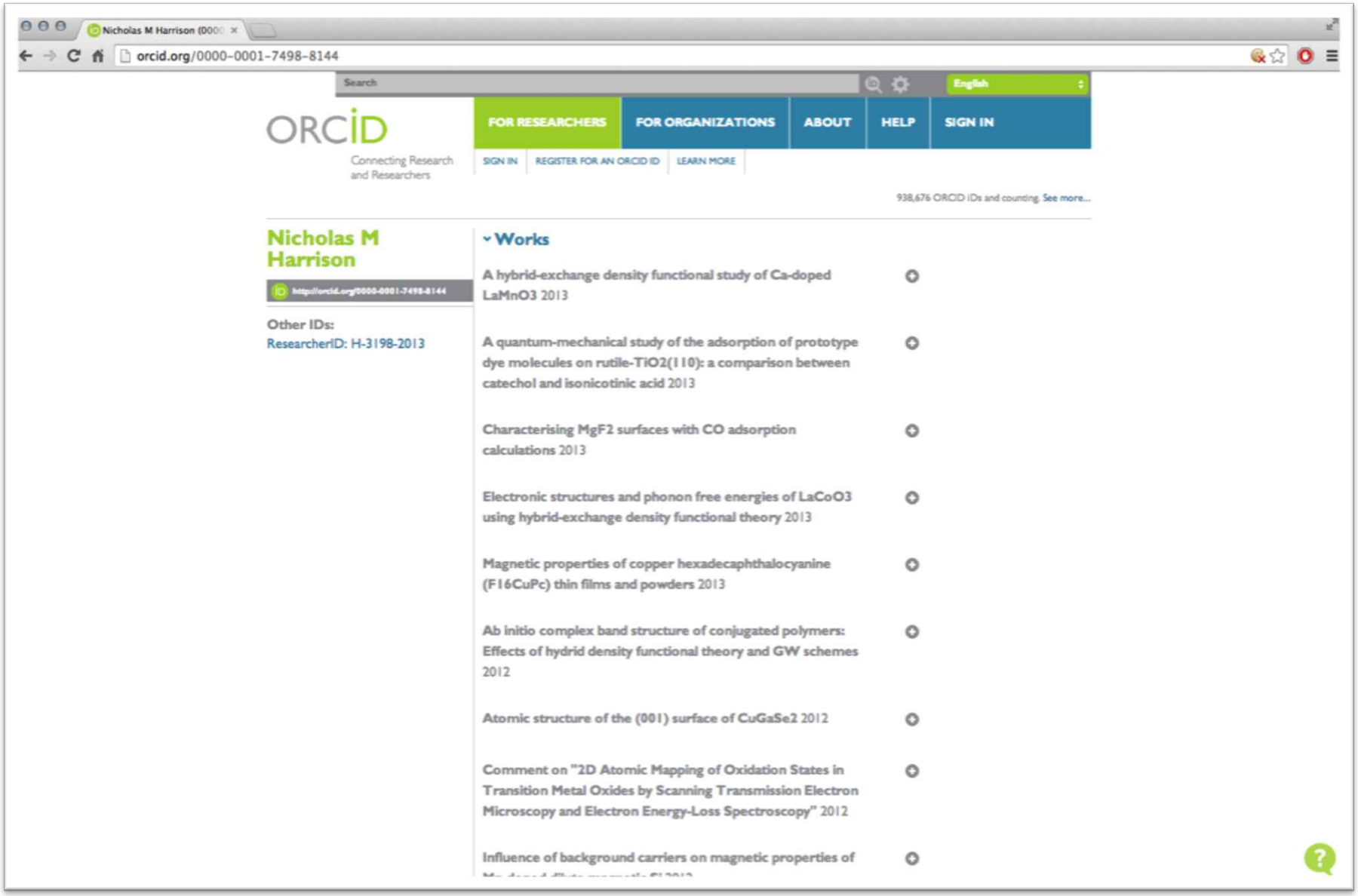
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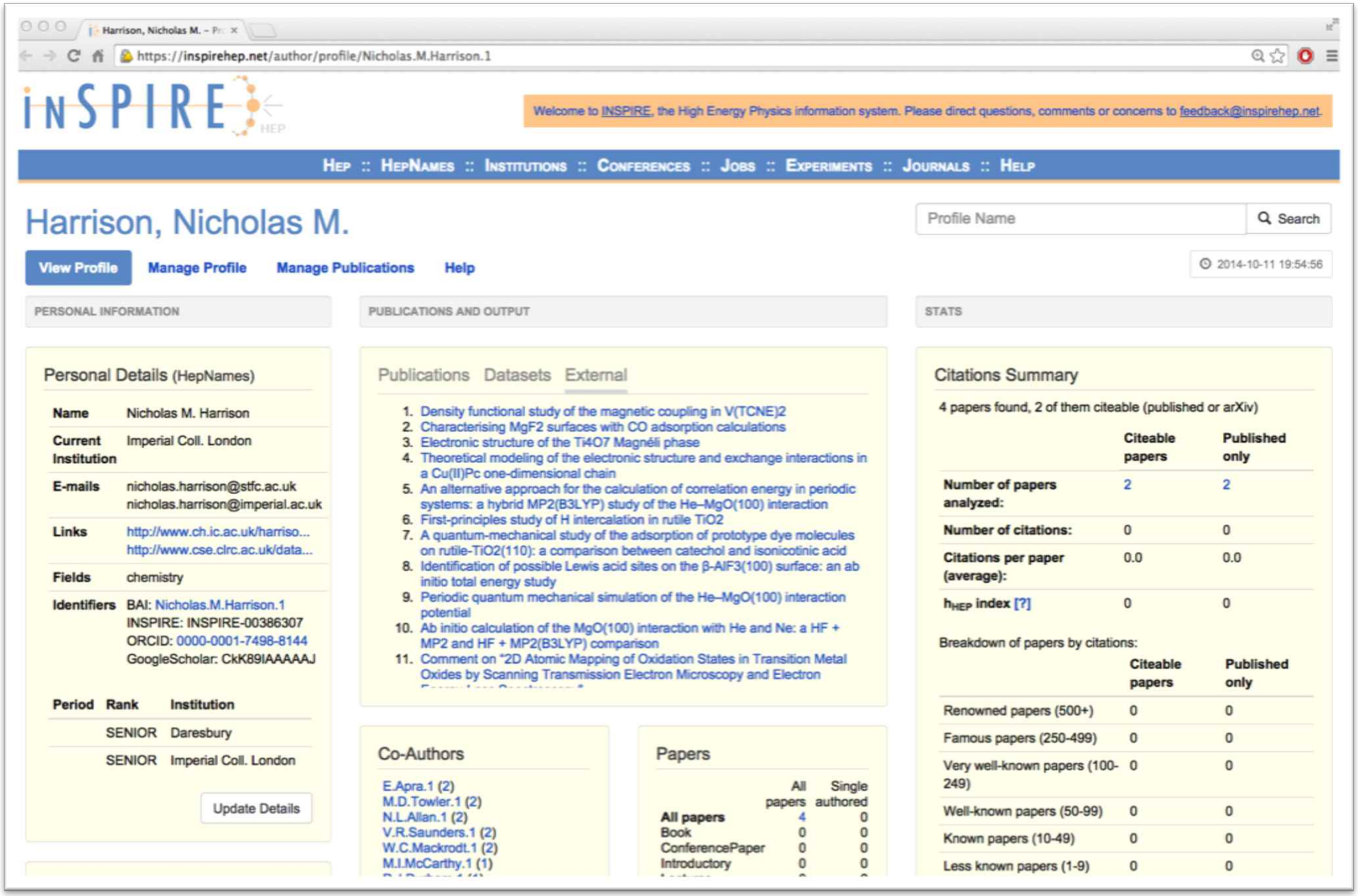
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5. An alternative approach for the calculation of correlation energy in periodic systems: a hybrid MP2(B3LYP) study of the He–MgO(100) interaction
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7. A quantum-mechanical study of the adsorption of prototype dye molecules on rutile-TiO2(110): a comparison between catechol and isonicotinic acid
8. Identification of possible Lewis acid sites on the β-AlF3(100) surface: an ab initio total energy study
9. Periodic quantum mechanical simulation of the He–MgO(100) interaction potential
10. Ab initio calculation of the MgO(100) interaction with He and Ne: a HF + MP2 and HF + MP2(B3LYP) comparison
11. Comment on "2D Atomic Mapping of Oxidation States in Transition Metal Oxides by Scanning Transmission Electron Microscopy and Electron
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The Nobel Prize in Physics 2013

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François Englert

Prize share: 1/2

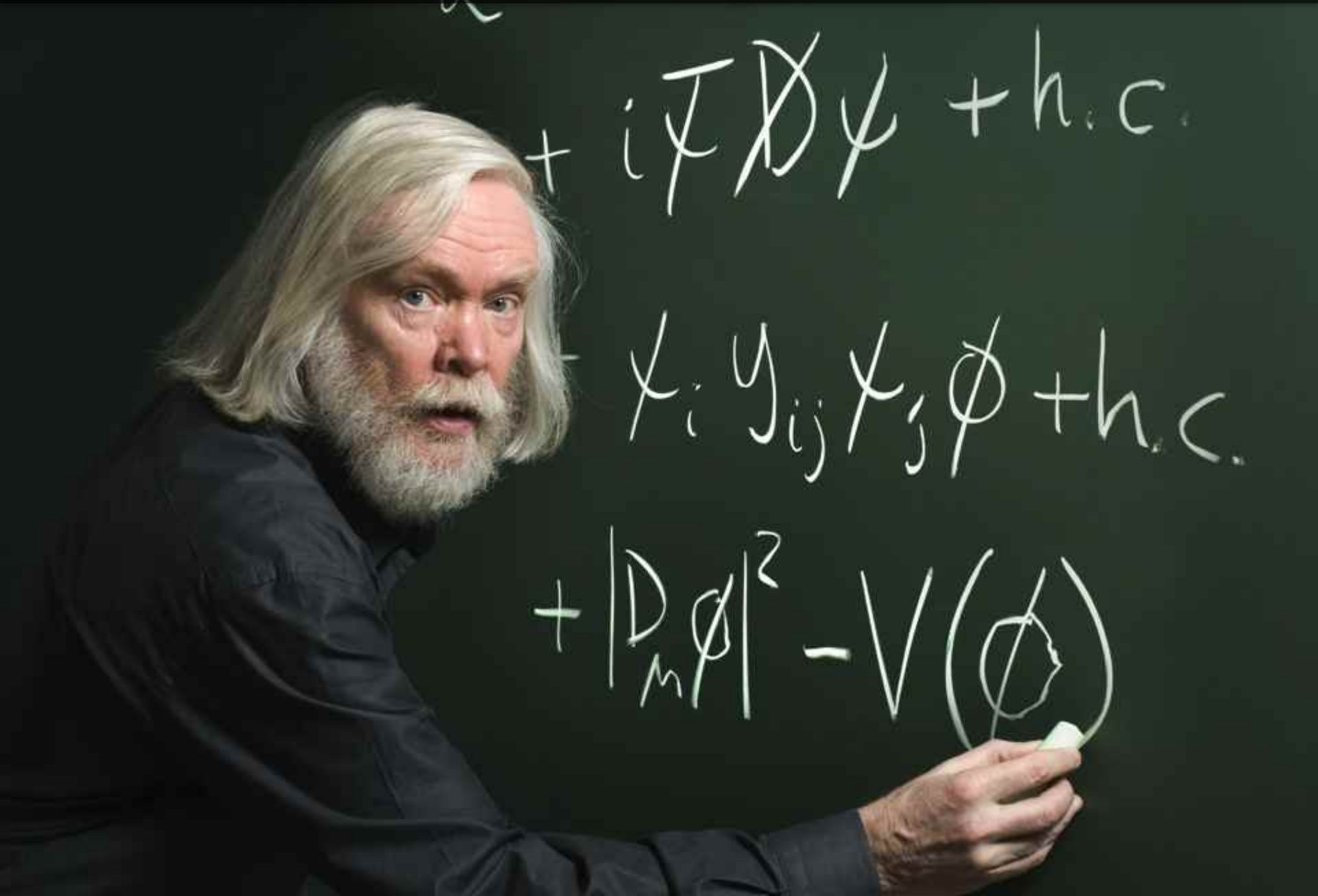
Photo: A. Mahmoud

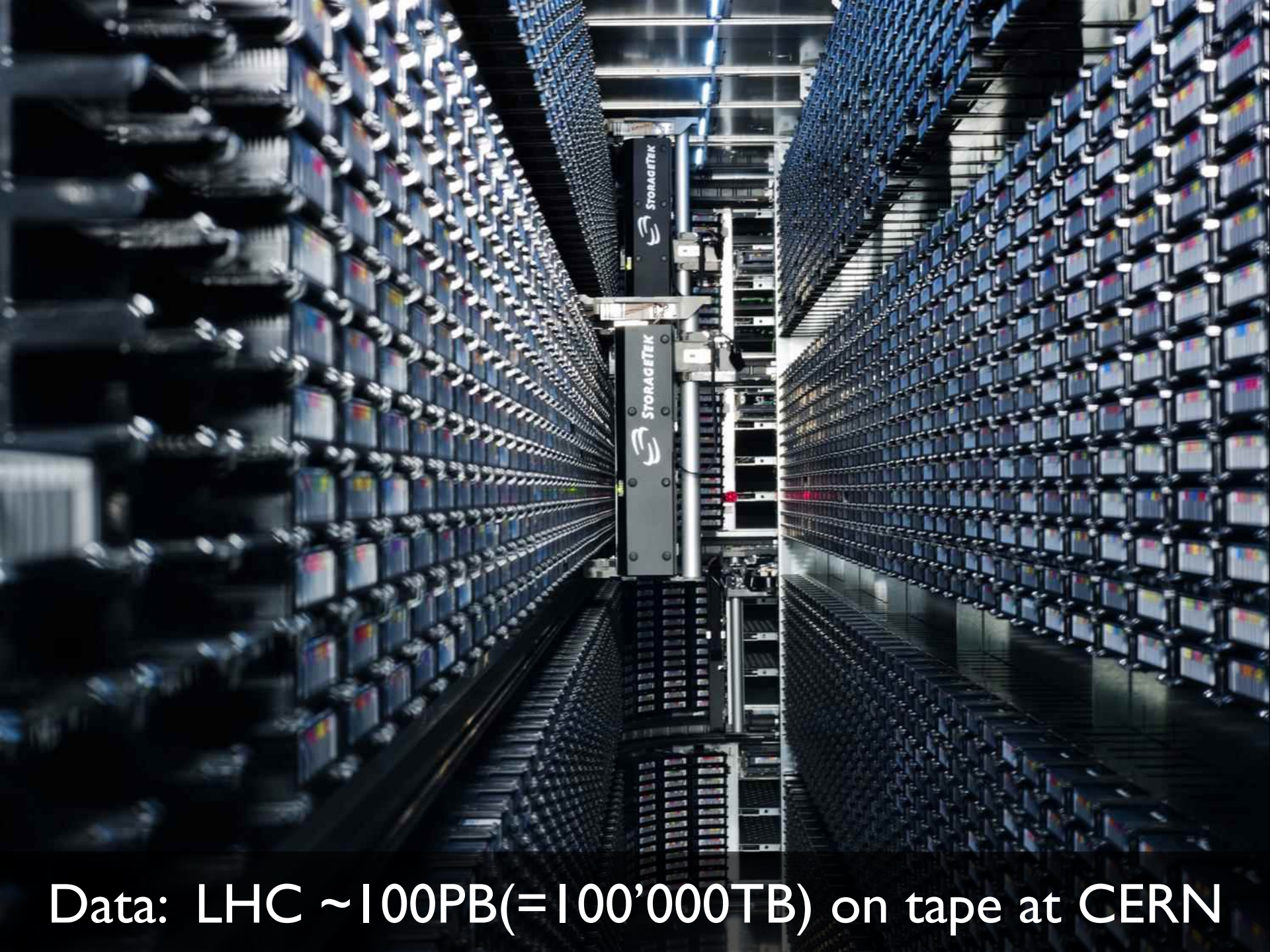
Peter W. Higgs

Prize share: 1/2

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

What does a theorist need?





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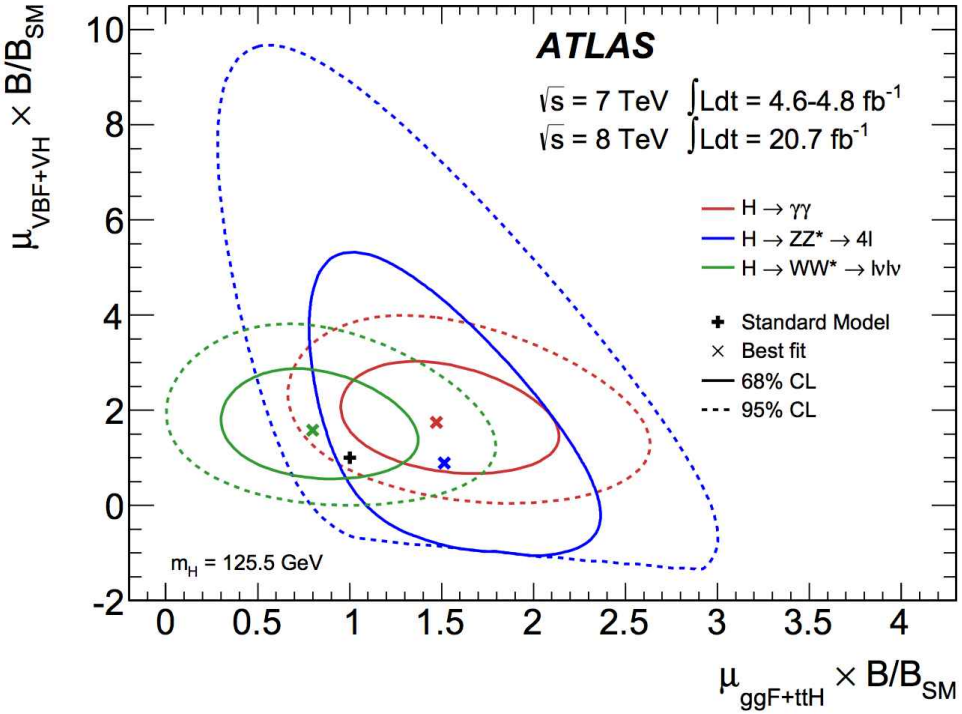
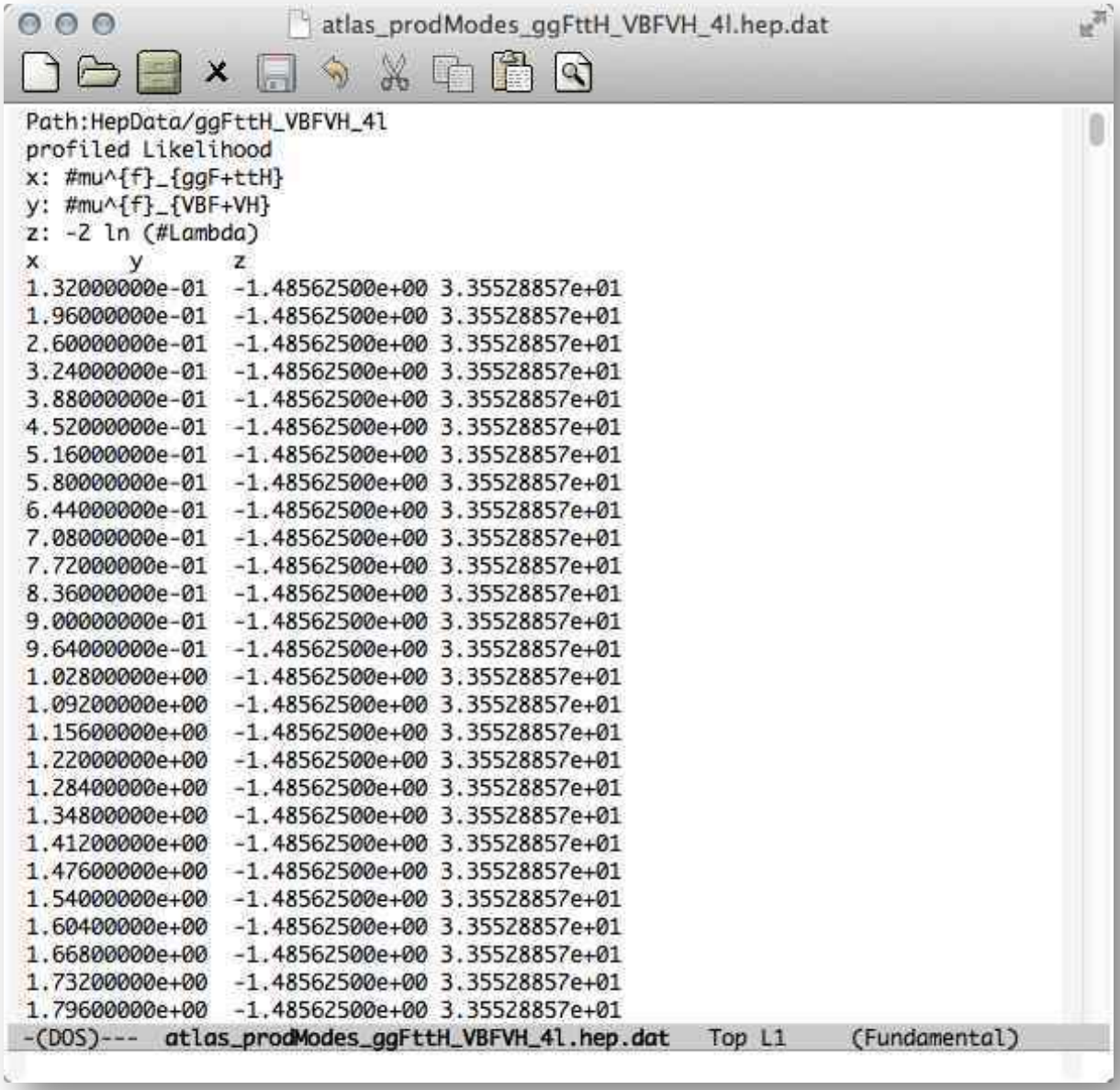


Figure 7: Likelihood contours for the $H \to \gamma\gamma$, $H \to ZZ^* \to 4\ell$ and $H \to WW^* \to \ell\nu\ell\nu$ channels in the ($\mu_{\mathrm{ggF}+ttH} \times \mathrm{B/B_{SM}}, \mu_{\mathrm{VBF}+VH} \times \mathrm{B/B_{SM}}$) plane for a Higgs boson mass $m_H = 125.5$ GeV. The branching-ratio scale factors $\mathrm{B/B_{SM}}$ can *a priori* be different for the different final states. The sharp lower edge of the $H \to ZZ^* \to 4\ell$ contours is due to the small number of events in this channel and the requirement of a positive pdf. The best fits to the data (×) and the 68% (full) and 95% (dashed) CL contours are indicated, as well as the SM expectation (+).

Data: How does the Higgs Boson behave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Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC

ATLAS Collaboration (Georges Aad (Freiburg U.) *et al.*) *Show all 2923 authors*

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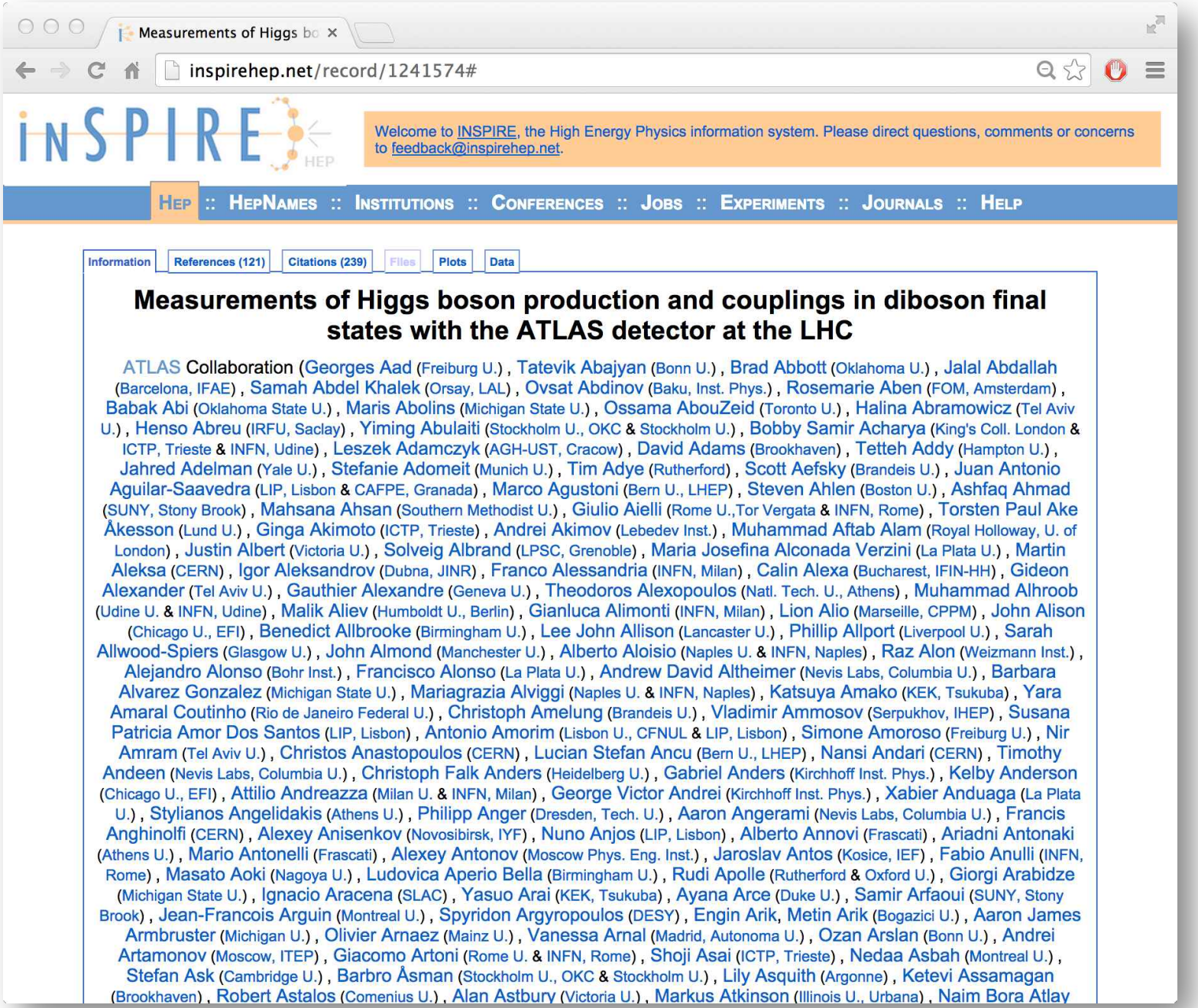
Keyword(s): INSPIRE: Higgs particle: hadroproduction | Higgs particle: coupling | vector boson: fusion | p p: scattering | CERN LHC Coll | ATLAS | Higgs particle: decay modes | vector boson: pair production | vector boson: leptonic decay | mass spectrum: two-photon | mass spectrum: (4lepton) | dilepton: mass spectrum | transverse energy: missing-energy | Higgs particle: mass | experimental results | 7000: 8000 GeV-cms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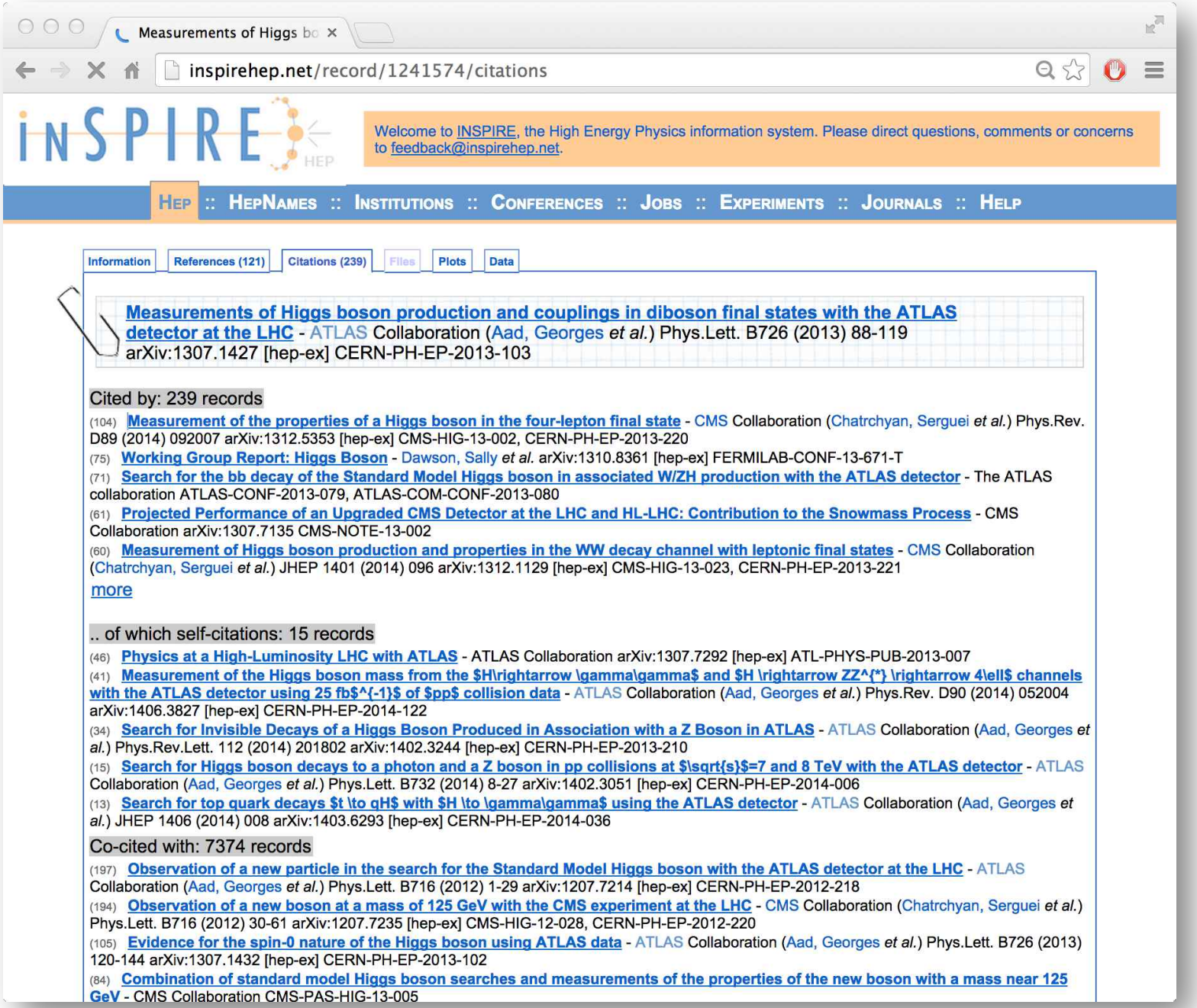
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Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC

ATLAS Collaboration (Georges Aad (Freiburg U.) *et al.*) Show all 2923 authors

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Keyword(s): INSPIRE: Higgs particle: hadroproduction | Higgs particle: coupling | vector boson: fusion | p p: scattering | CERN LHC Coll | ATLAS | Higgs particle: decay modes | vector boson: pair production | vector boson: leptonic decay | mass spectrum: two-photon | mass spectrum: (4lepton) | dilepton: mass spectrum | transverse energy: missing-energy | Higgs particle: mass | experimental results | 7000: 8000 GeV-cms

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SUMMARY:

CERN-LHC. Measurements of the cross-section times branching ratio for a standard model-like Higgs boson. The results are based on the complete pp collision data sample recorded by the ATLAS experiment at the CERN Large Hadron Collider at centre-of-mass energies of 7 TeV and 8 TeV, corresponding to an integrated luminosity of about 25 fb-1 The following table gives links to the -2ln(likelihood) values for the three channels in the (mu_ggF+ttH*B/BSM,mu_VBF+VH*B/BSM) plane for a Higgs boson mass mH = 125.5 GeV. The display link shows the data as a 2-D grid and the files are the originals from the ATLAS collaboration.

DATASETS:

Description: -2 log Likelihood for the H → γγ channel in the (μ_ggF+ttH * B/BSM, μ_VBF+VH * B/BSM) plane for a Higgs boson mass mH = 125.5 GeV.

Go to the record

Description: -2 log Likelihood for the H→ ZZ*→ 4l channel in the (μ_ggF+ttH * B/BSM, μ_VBF+VH * B/BSM) plane for a Higgs boson mass mH = 125.5 GeV.

Go to the record

Description: -2 log Likelihood for the H→ WW*→ lνlν channel in the (μ_ggF+ttH * B/BSM, μ_VBF+VH * B/BSM) plane for a Higgs boson mass mH = 125.5 GeV.

Data from Figure 7 from: Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC

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Description: -2 log Likelihood for the H→ ZZ*→ 4l channel in the (μ_ggF+ttH * B/BSM, μ_VBF+VH * B/BSM) plane for a Higgs boson mass mH = 125.5 GeV.

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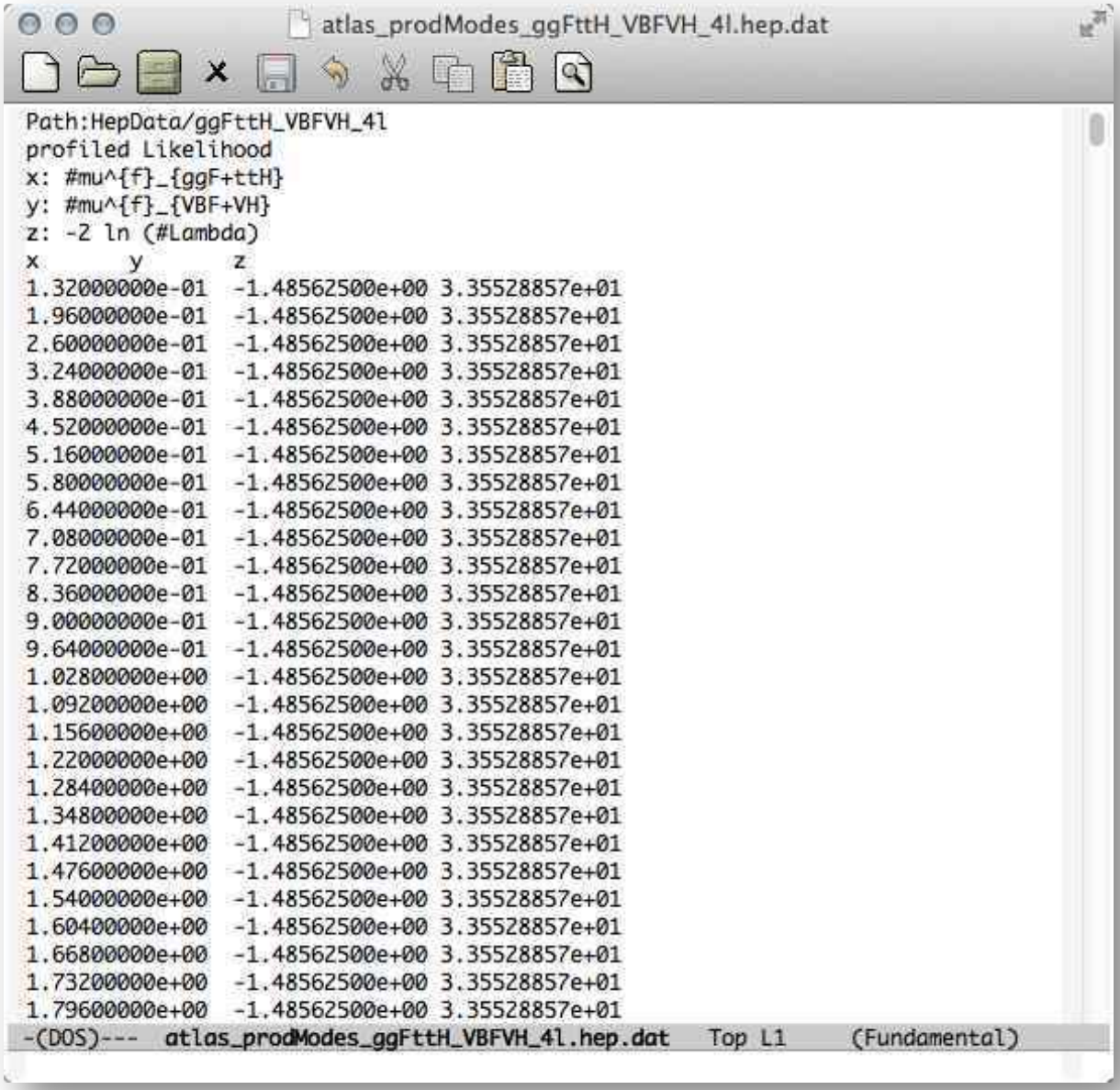
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September 17 at 10:42am ·

Higgs likelihoods from ATLAS! For theorists, this is kind of like...wistfully asking for maybe a pony, and having someone give you a unicorn. Awesome.

On the presentation of the LHC Higgs Results - INSPIRE-HEP
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We put forth conclusions and suggestions regarding the presentation of the LHC Higgs results that may

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(5) Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC - ATLAS Collaboration (Aad, Georges *et al.*) Phys.Lett. B716 (2012) 1-29 arXiv:1207.7214 [hep-ex] CERN-PH-EP-2012-218
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6. ATLAS Collaboration, "Data from Figure 7 from: Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC: $H \to \gamma\gamma$," http://doi.org/10.7484/INSPIREHEP.DATA.A78C.HK44
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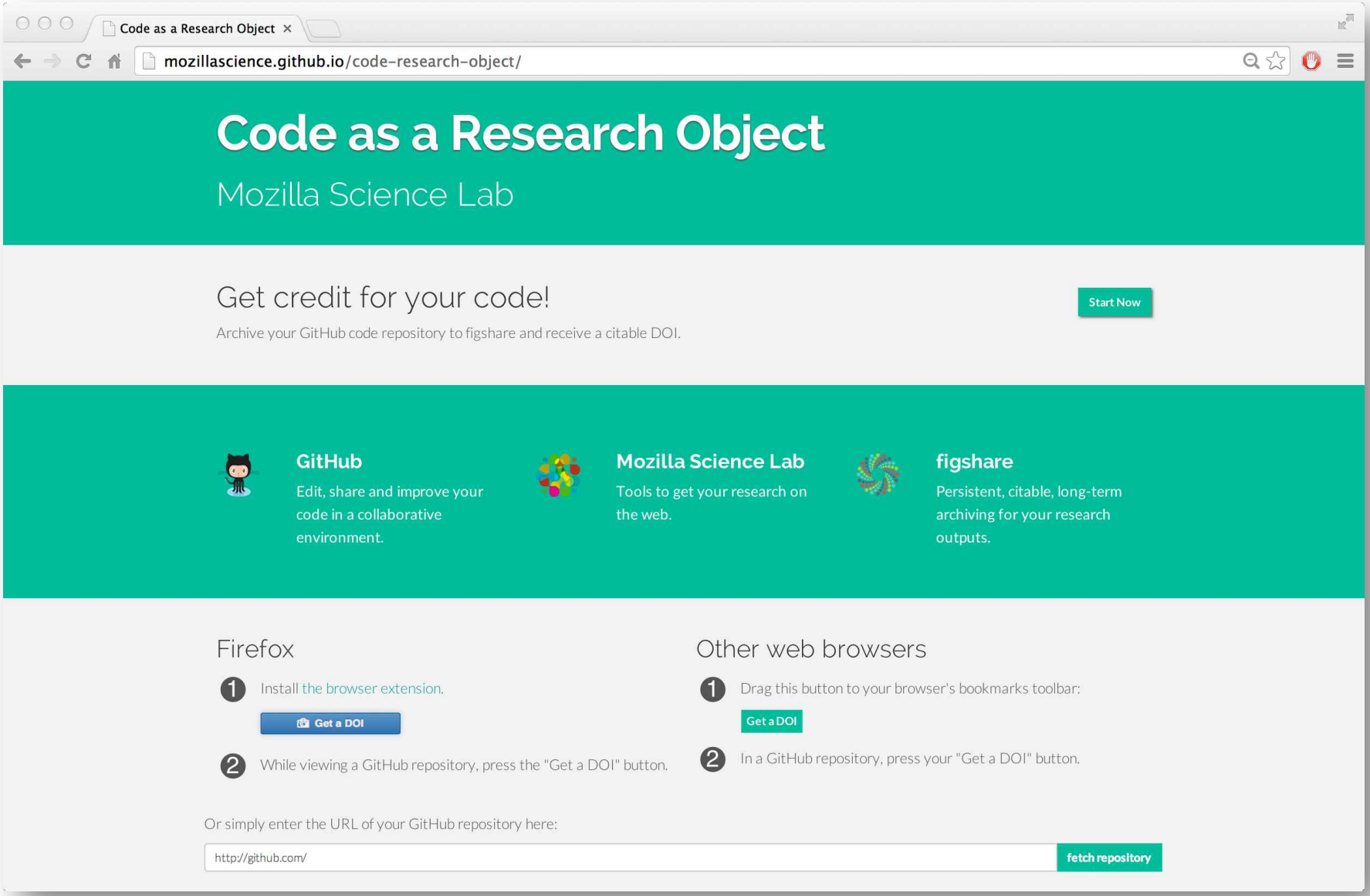
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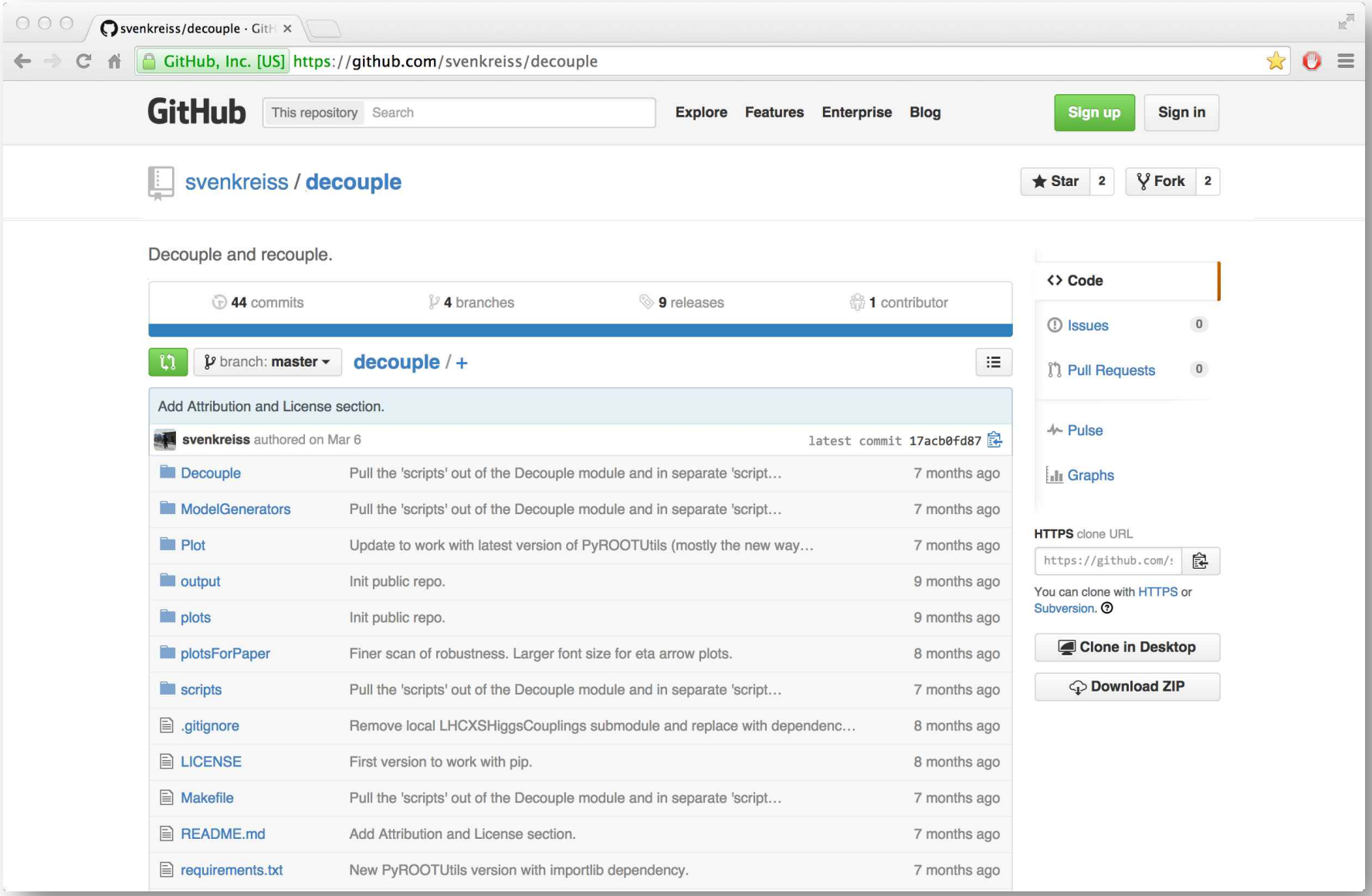
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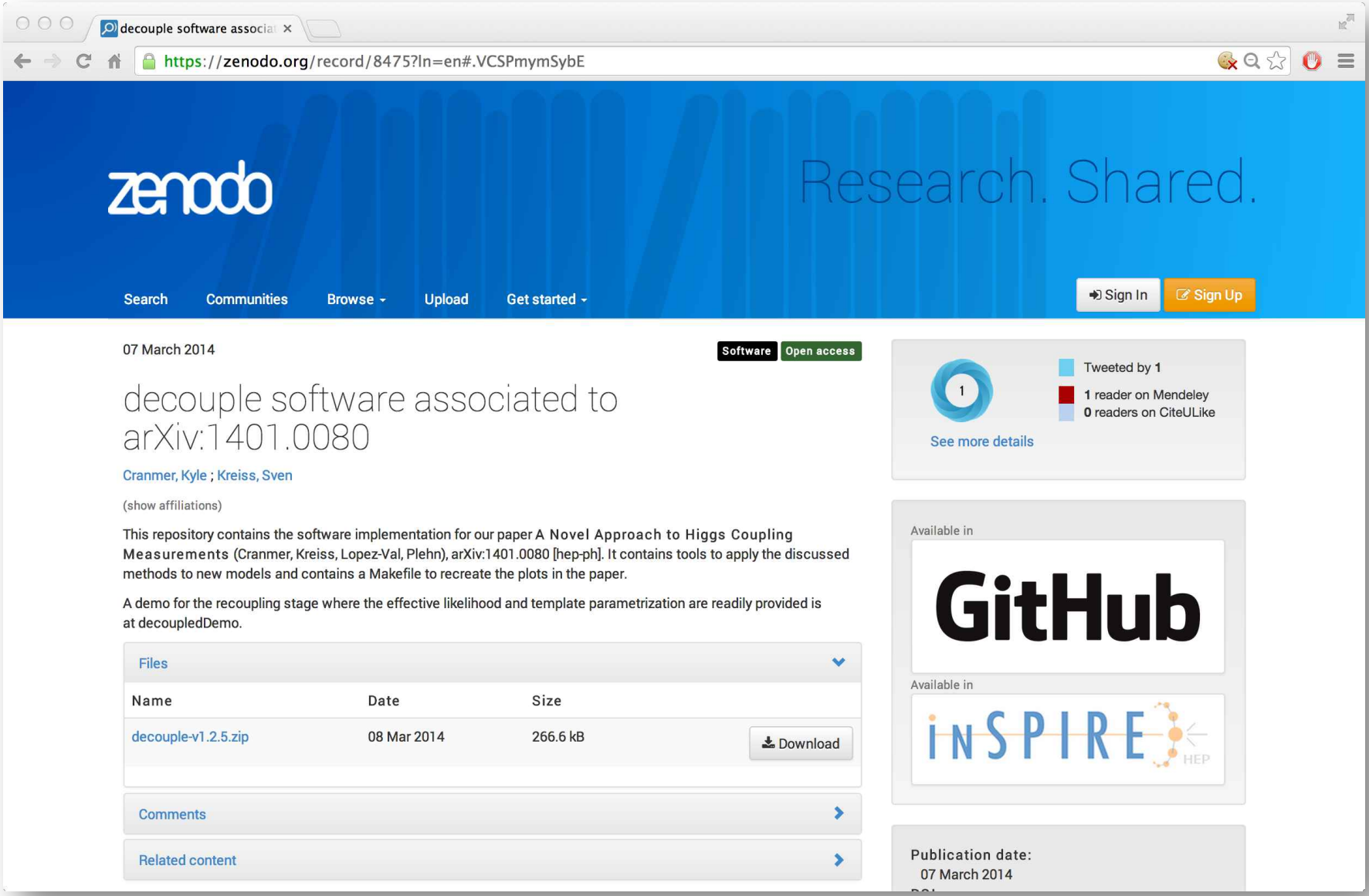
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Cranmer, Kyle ; Kreiss, Sven
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This repository contains the software implementation for our paper A Novel Approach to Higgs Coupling Measurements (Cranmer, Kreiss, Lopez-Val, Plehn), arXiv:1401.0080 [hep-ph]. It contains tools to apply the discussed methods to new models and contains a Makefile to recreate the plots in the paper.
A demo for the recoupling stage where the effective likelihood and template parametrization are readily provided is at decoupledDemo.
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Cranmer, Kyle; Kreiss, Sven (New York University)

Cite as: (2013) Zenodo, http://doi.org/10.5281/zenodo.8475

Description:

This repository contains the software implementation for our paper **A Novel Approach to Higgs Coupling Measurements** (Cranmer, Kreiss, Lopez-Val, Plehn), arXiv:1401.0080 [hep-ph]. It contains tools to apply the discussed methods to new models and contains a Makefile to recreate the plots in the paper.

A demo for the recoupling stage where the effective likelihood and template parametrization are readily provided is at decoupledDemo.

This dataset complements the following publication:
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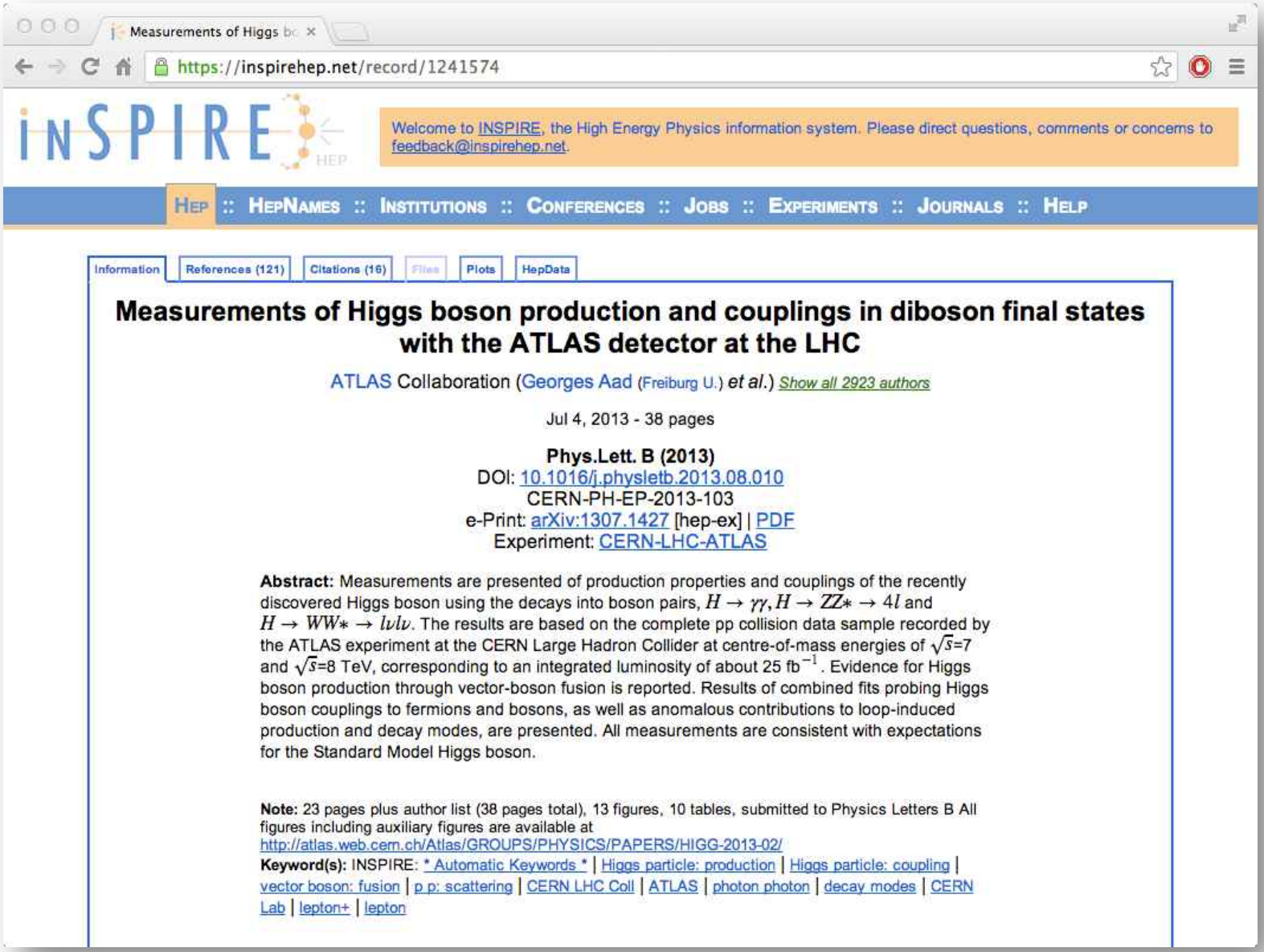
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Phys.Lett. B (2013)
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Experiment: CERN-LHC-ATLAS
Abstract: Measurements are presented of production properties and couplings of the recently discovered Higgs boson using the decays into boson pairs, $H \to \gamma\gamma, H \to ZZ* \to 4l$ and $H \to WW* \to l\nu l\nu$. The results are based on the complete pp collision data sample recorded by the ATLAS experiment at the CERN Large Hadron Collider at centre-of-mass energies of $\sqrt{s}$=7 and $\sqrt{s}$=8 TeV, corresponding to an integrated luminosity of about 25 fb^{-1}. Evidence for Higgs boson production through vector-boson fusion is reported. Results of combined fits probing Higgs boson couplings to fermions and bosons, as well as anomalous contributions to loop-induced production and decay modes, are presented. All measurements are consistent with expectations for the Standard Model Higgs boson.
Note: 23 pages plus author list (38 pages total), 13 figures, 10 tables, submitted to Physics Letters B All figures including auxiliary figures are available at http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2013-02/
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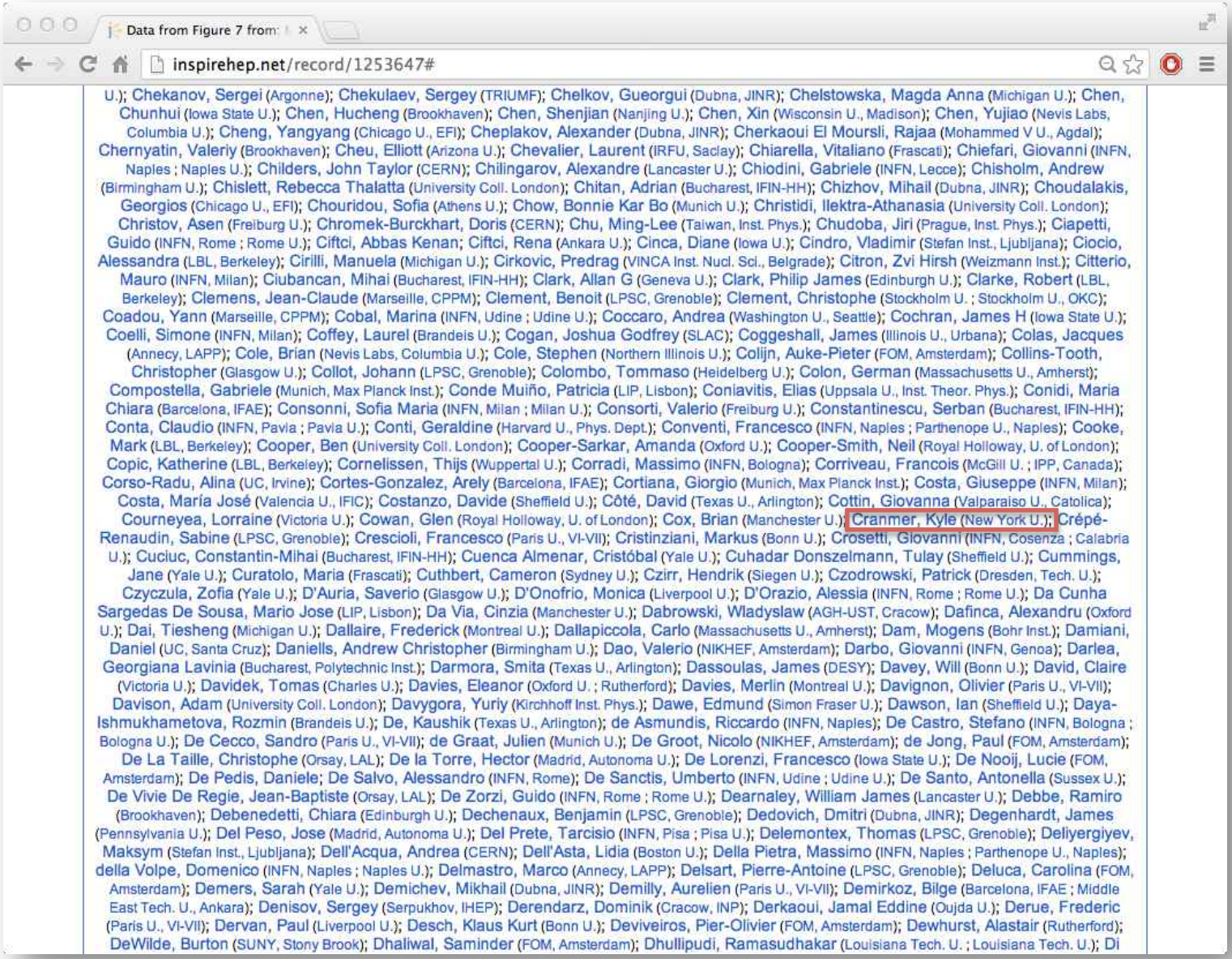
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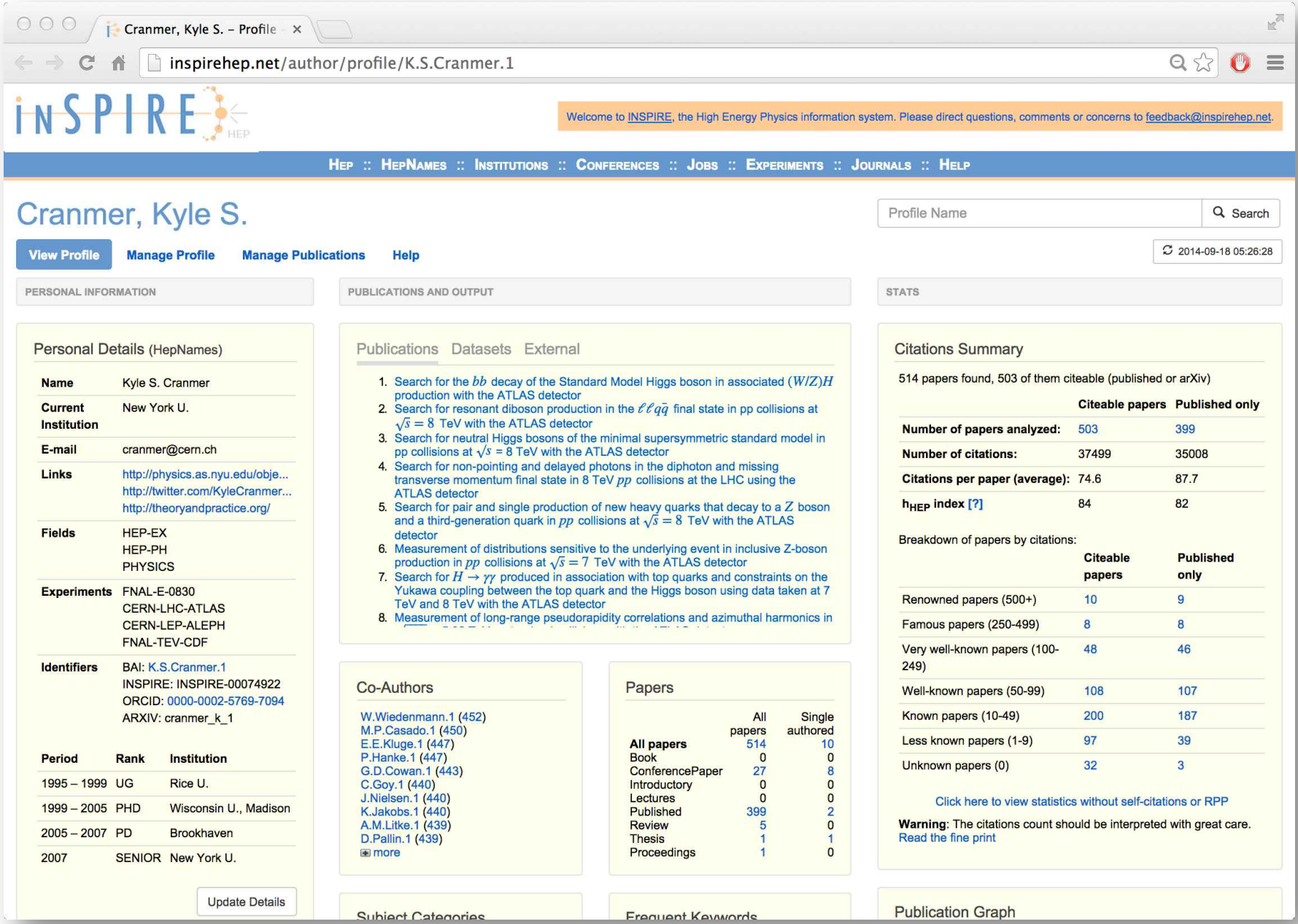
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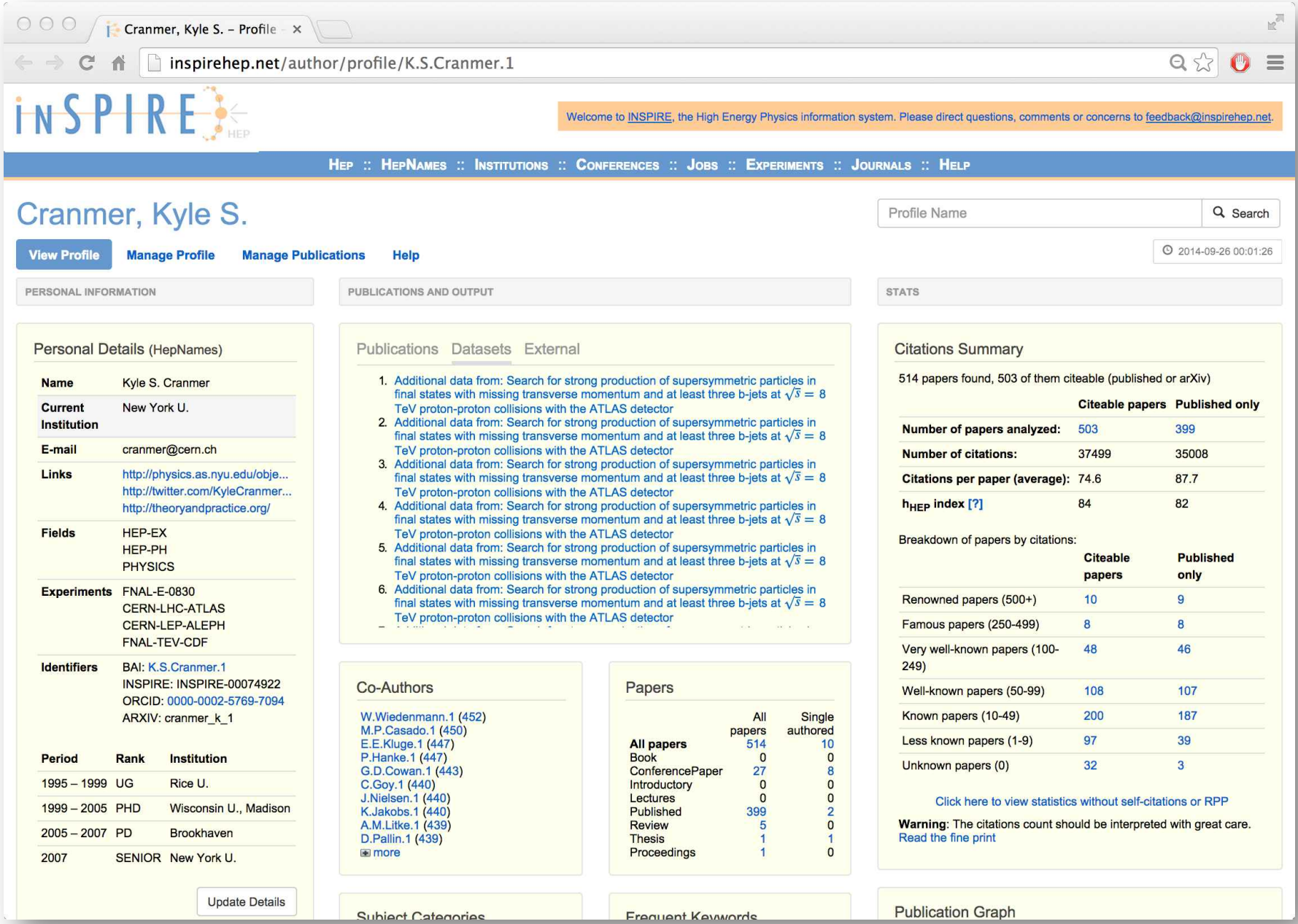
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Fields HEP-EX
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PHYSICS
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CERN-LHC-ATLAS
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Period Rank Institution
1995 – 1999 UG Rice U.
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2005 – 2007 PD Brookhaven
2007 SENIOR New York U.
Update Details
Publications Datasets External
1. Additional data from: Search for strong production of supersymmetric particles in final states with missing transverse momentum and at least three b-jets at $\sqrt{s} = 8$ TeV proton-proton collisions with the ATLAS detector
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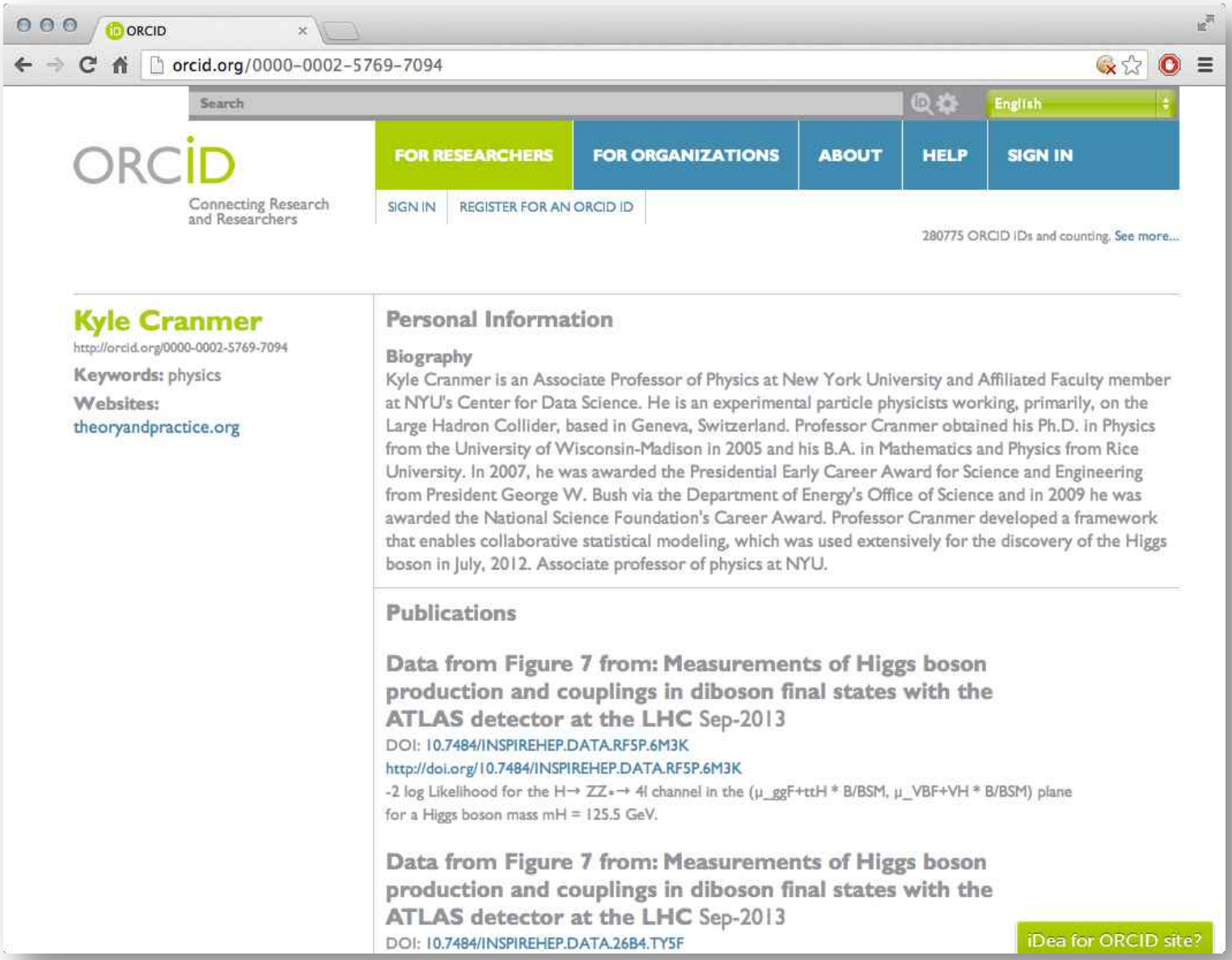
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Kyle Cranmer is an Associate Professor of Physics at New York University and Affiliated Faculty member at NYU's Center for Data Science. He is an experimental particle physicists working, primarily, on the Large Hadron Collider, based in Geneva, Switzerland. Professor Cranmer obtained his Ph.D. in Physics from the University of Wisconsin-Madison in 2005 and his B.A. in Mathematics and Physics from Rice University. In 2007, he was awarded the Presidential Early Career Award for Science and Engineering from President George W. Bush via the Department of Energy's Office of Science and in 2009 he was awarded the National Science Foundation's Career Award. Professor Cranmer developed a framework that enables collaborative statistical modeling, which was used extensively for the discovery of the Higgs boson in July, 2012. Associate professor of physics at NYU.
Publications
Data from Figure 7 from: Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC Sep-2013
DOI: 10.7484/INSPIREHEP.DATA.RF5P.6M3K
http://doi.org/10.7484/INSPIREHEP.DATA.RF5P.6M3K
-2 log Likelihood for the H→ ZZ*→ 4l channel in the (μ_ggF+ttH * B/BSM, μ_VBF+VH * B/BSM) plane for a Higgs boson mass mH = 125.5 GeV.
Data from Figure 7 from: Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC Sep-2013
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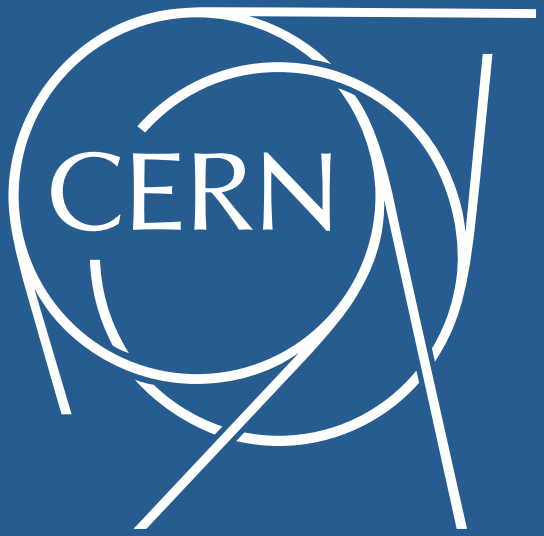

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