

Search for Higgs boson decay to invisible particles

Dr. Kétévi Adiklè Assamagan



What we aim for ...

- **Review Higgs boson discovery channels and properties**
- **The case for physics beyond the Standard Model of particle physics**
- **Search for dark sector states**
- **Higgs decay to invisible particle and interpretation for dark matter**

The 'Standard Model'

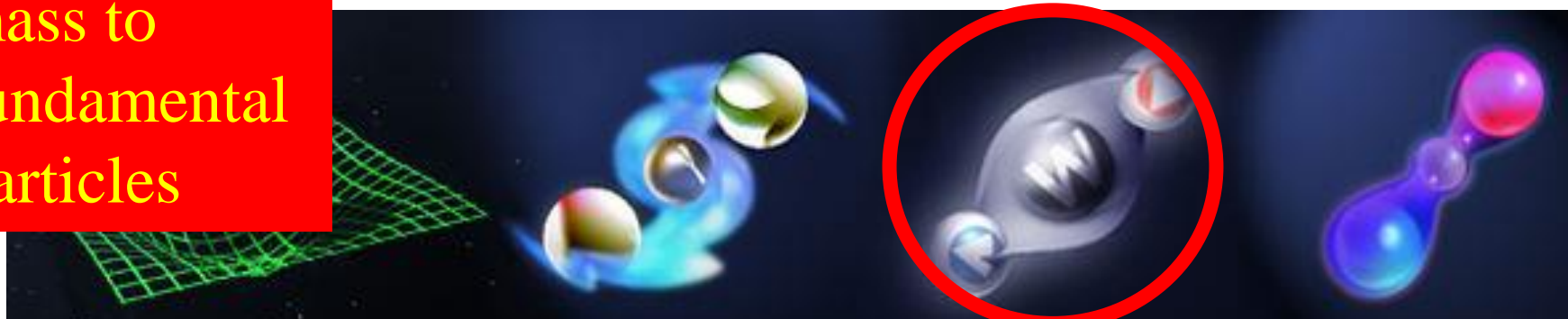
= Cosmic DNA

The matter particles



The Higgs boson gives mass to fundamental particles

The fundamental interactions



Gravitation

electromagnetism

weak nuclear force

strong nuclear force

Without Higgs ...

... there would be no atoms

- massless electrons would escape at the speed of light

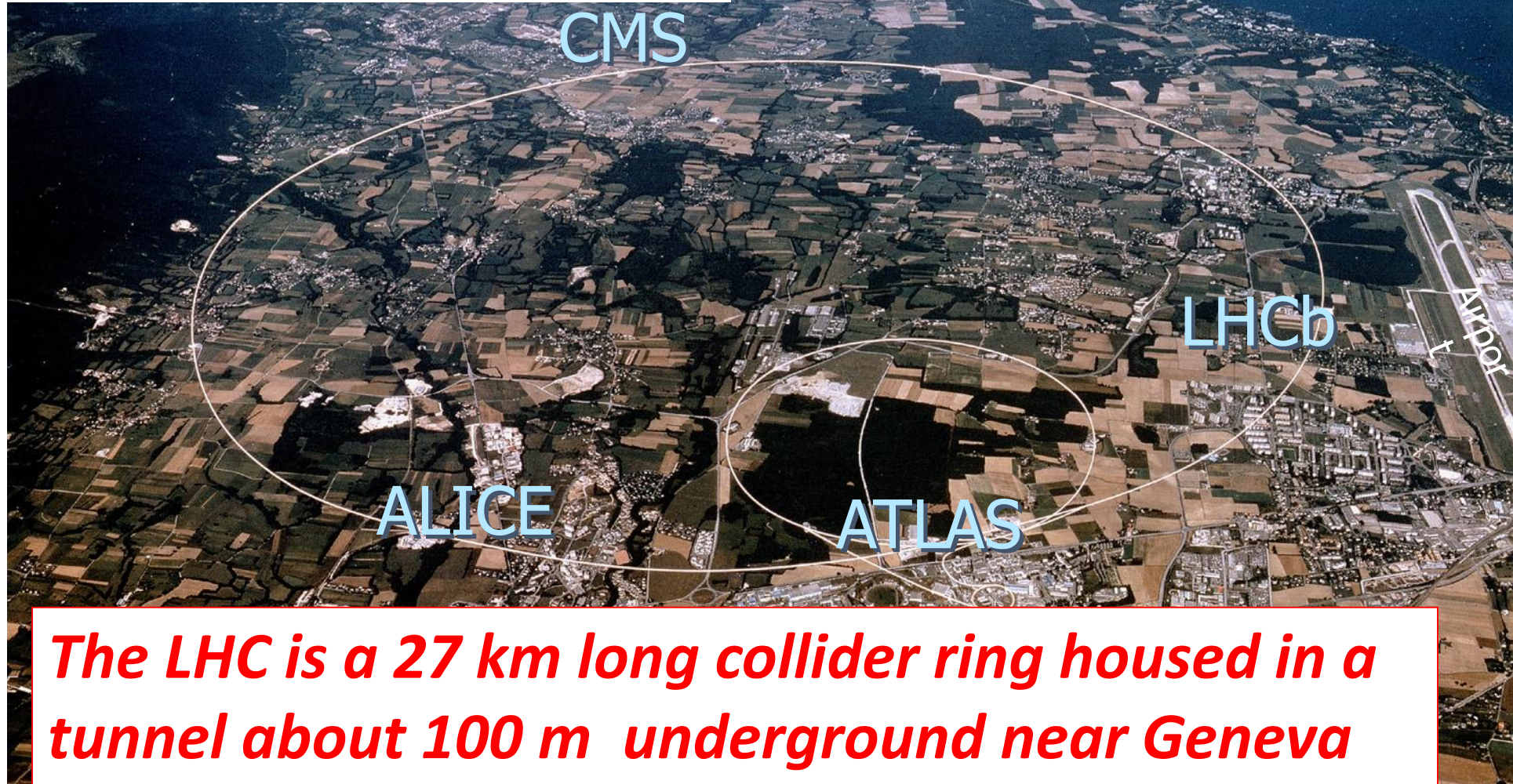
... there would be no heavy nuclei

... weak interactions would not be weak

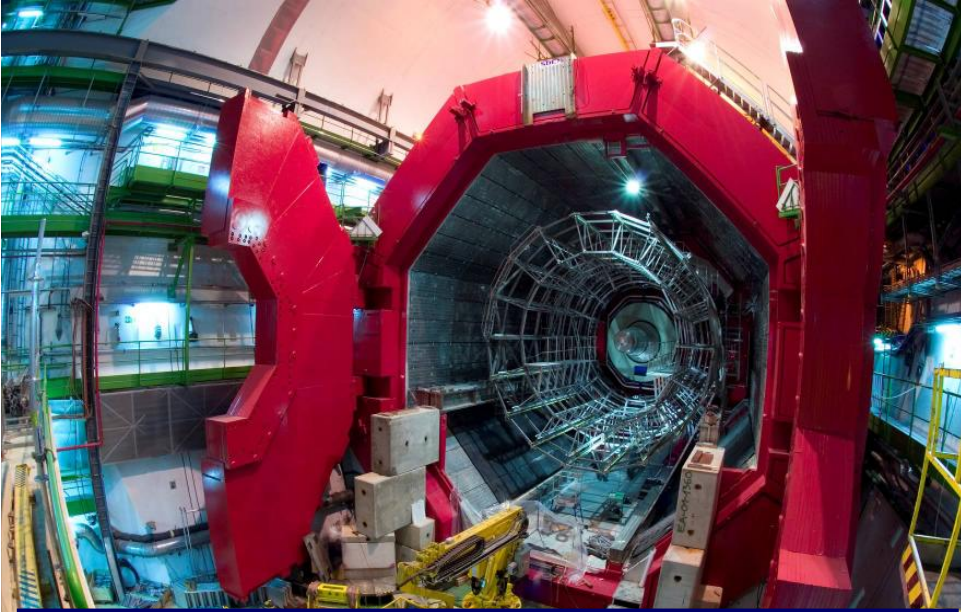
- Life would be impossible: everything would be radioactive

Its existence is a big deal!

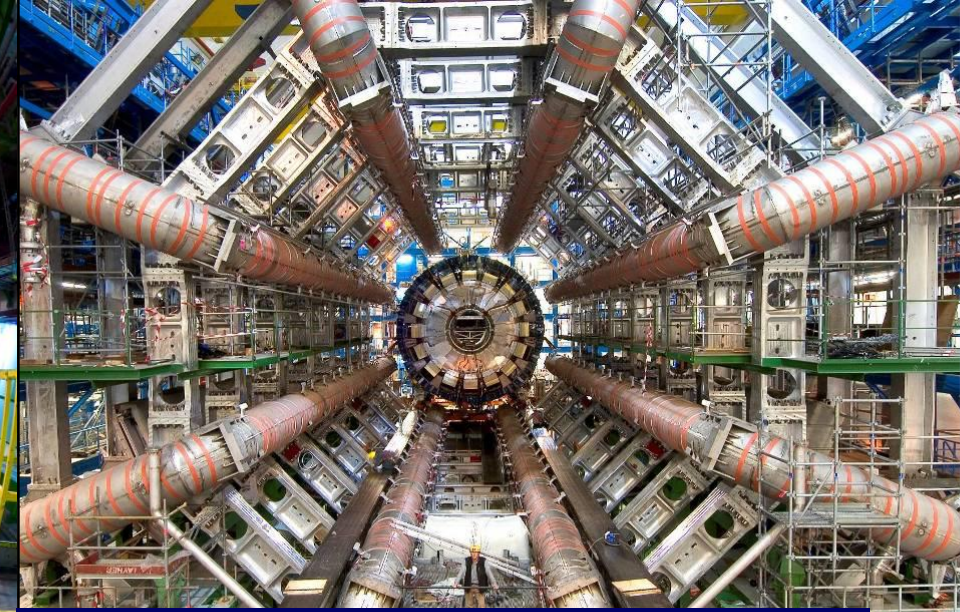
***The LHC machine
Proton-Proton Collisions
Heavy Ion Collisions***



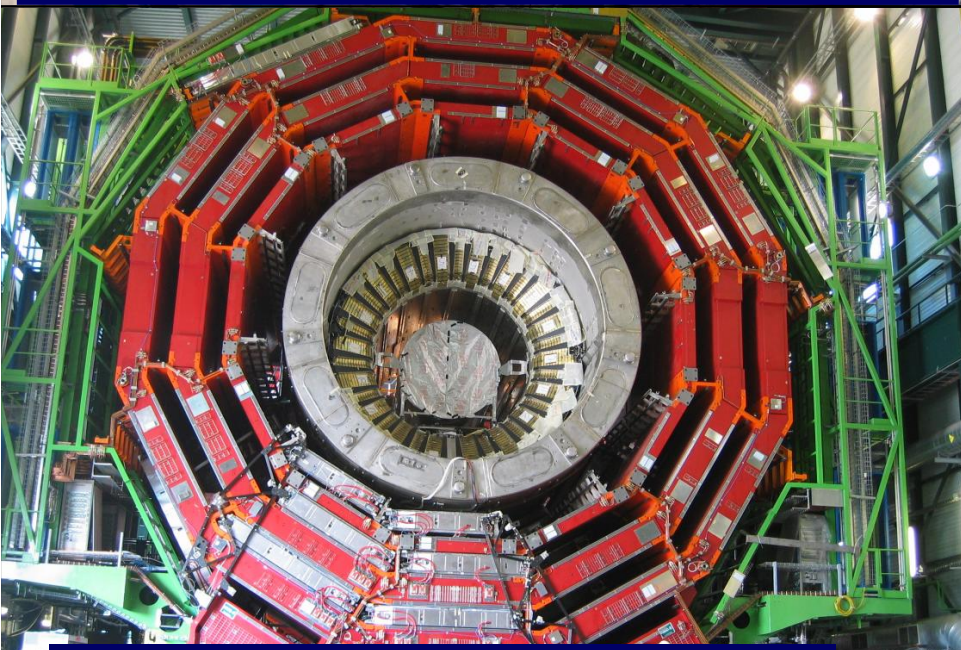
The LHC is a 27 km long collider ring housed in a tunnel about 100 m underground near Geneva



ALICE: Primordial cosmic plasma



ATLAS: Higgs and dark matter

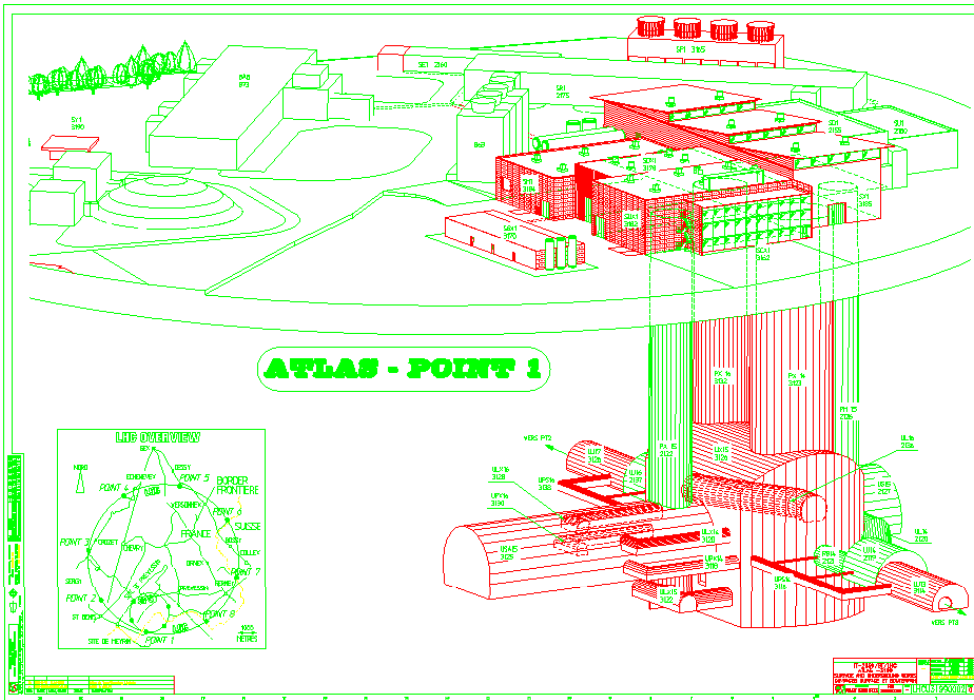


CMS: Higgs and dark matter

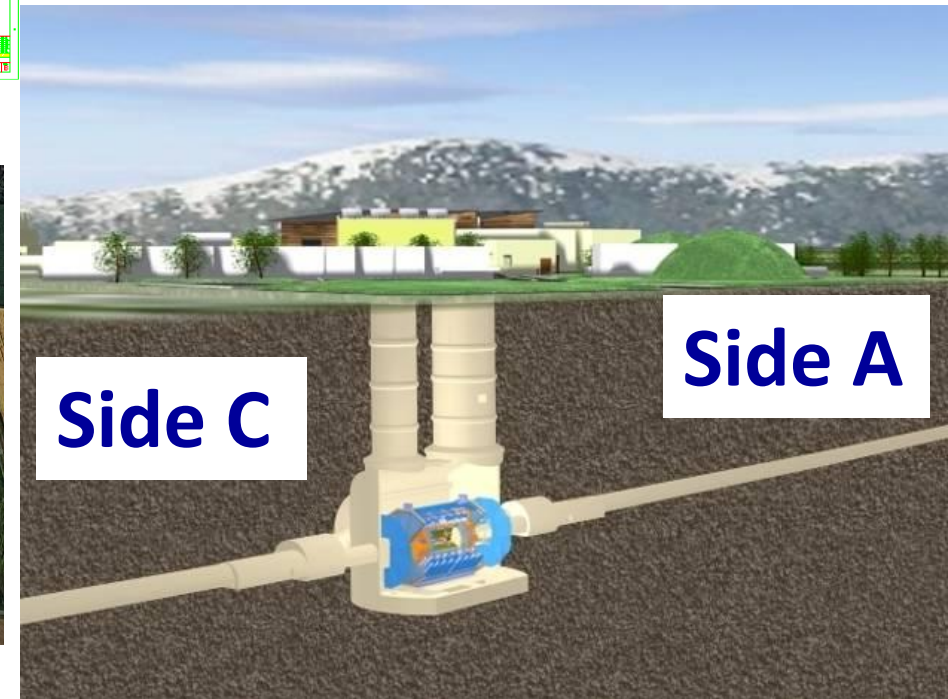
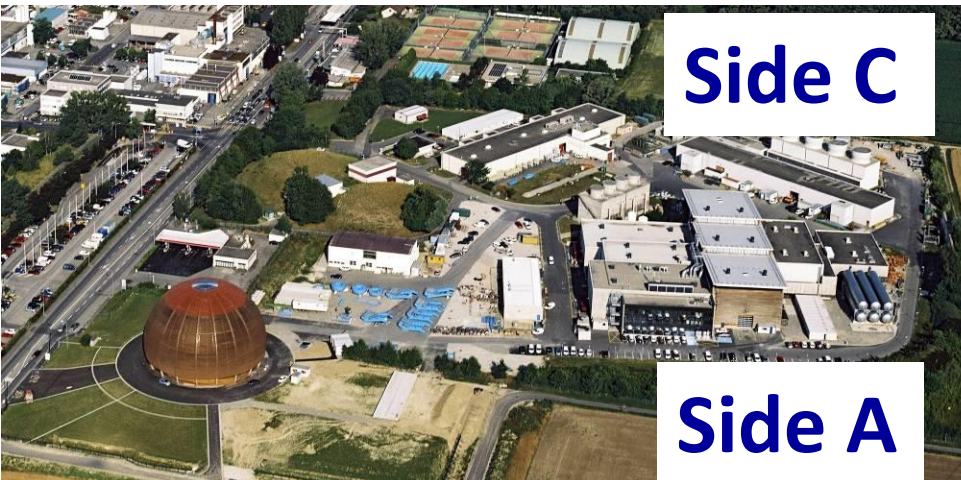


LHCb: Matter-antimatter difference

The Underground Cavern for the ATLAS Detector



Length = 55 m
Width = 32 m
Height = 35 m





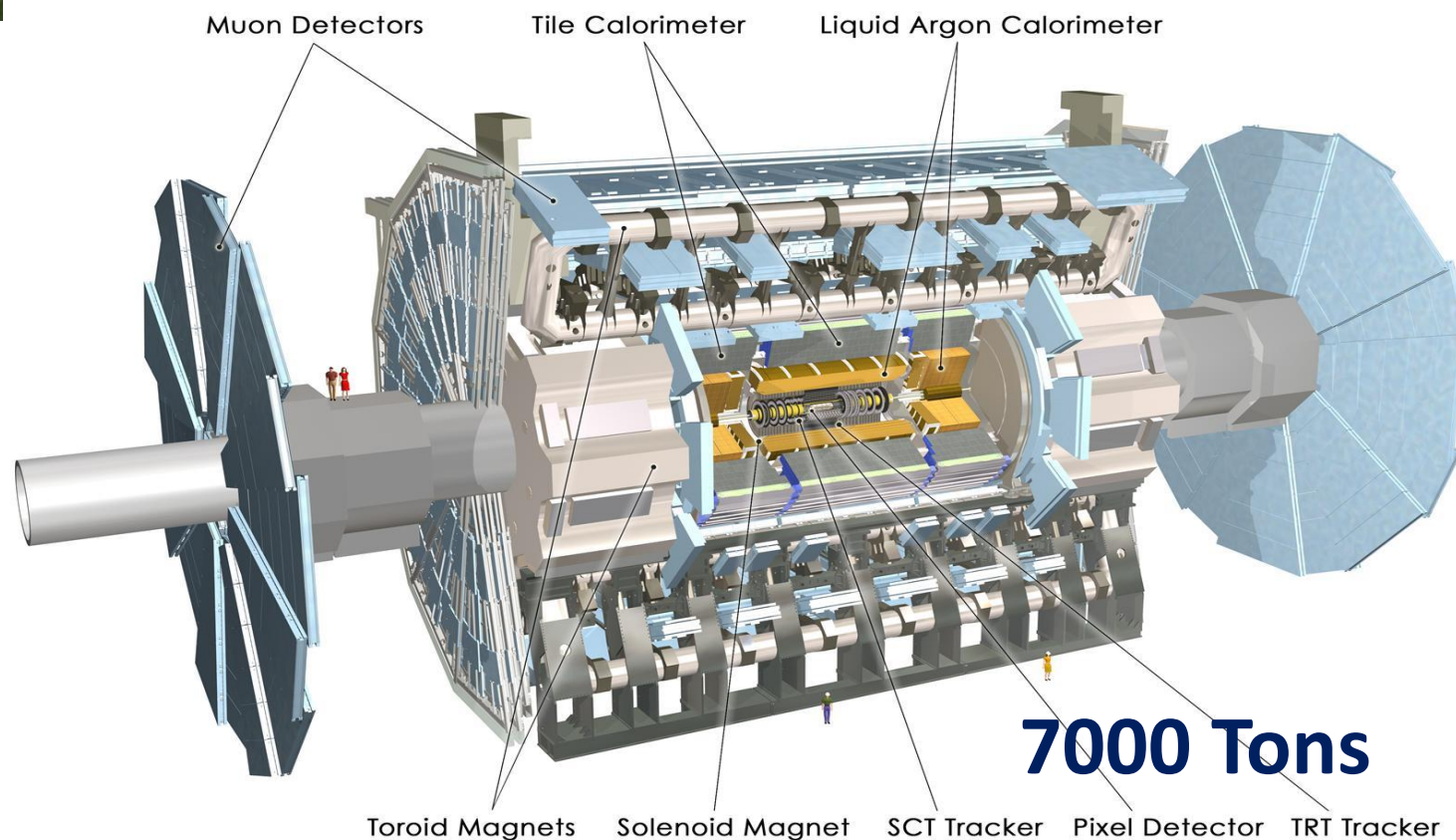
ATLAS Detector at the LHC

3300 Physicists

550M Suisse Franks

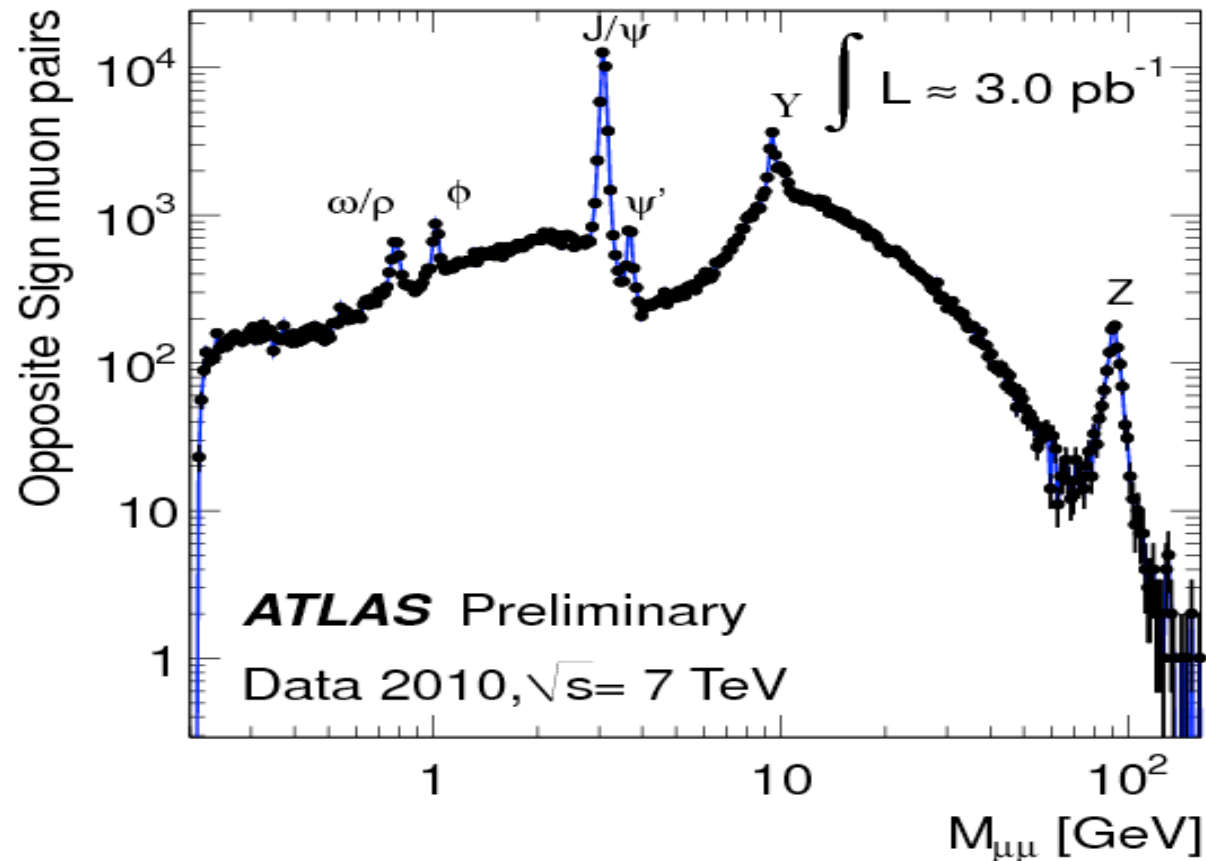
45 m

24 m



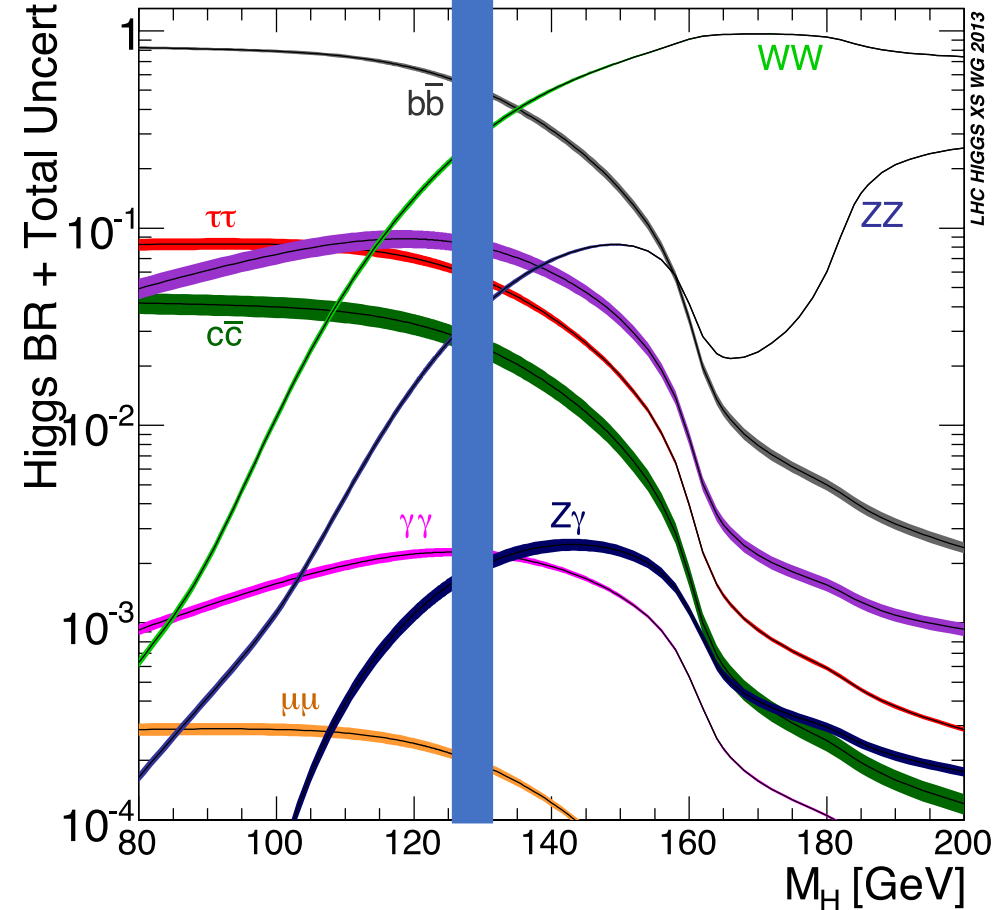
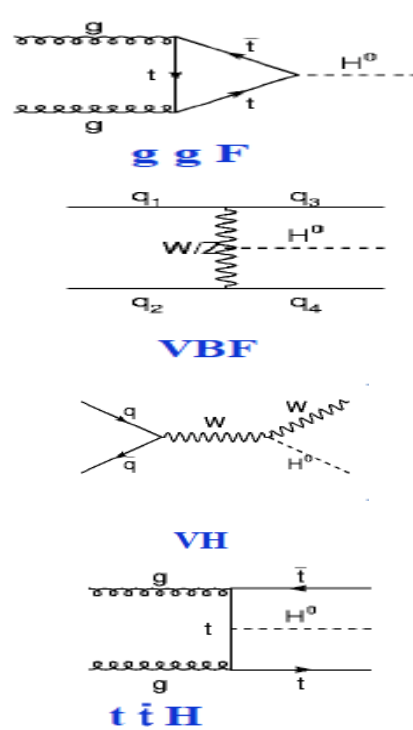
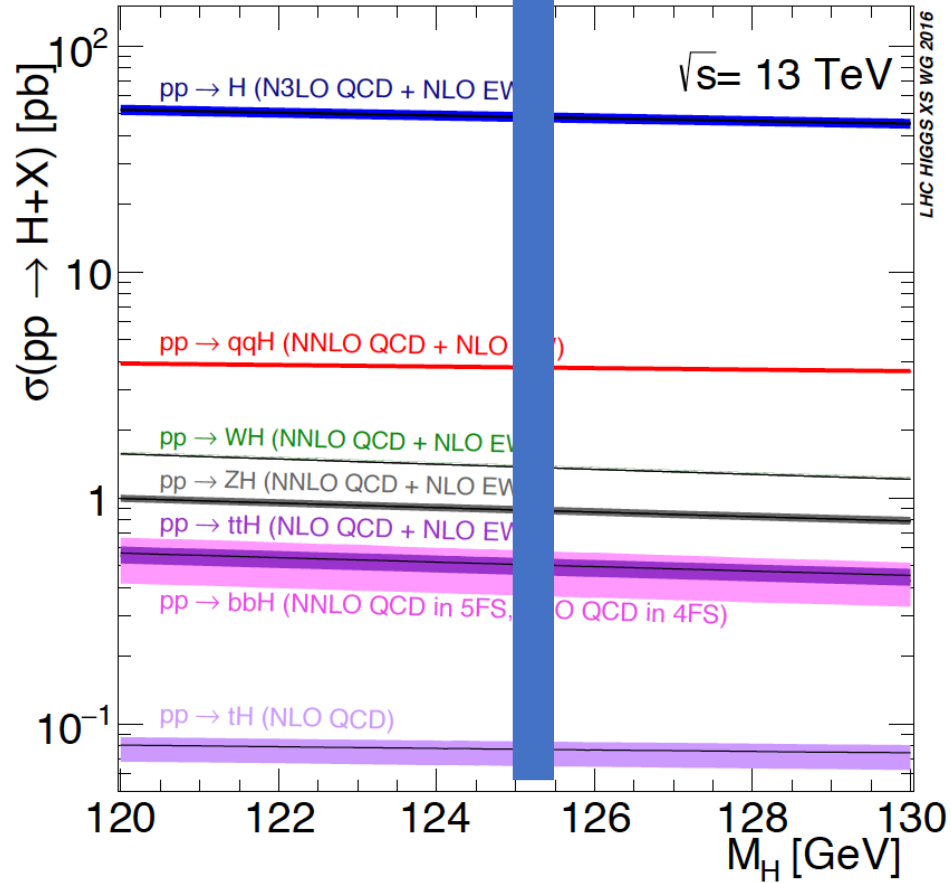
Confirming previous measurements or discoveries

- Before we do new searches, we have to show that we measure accurately what is already known

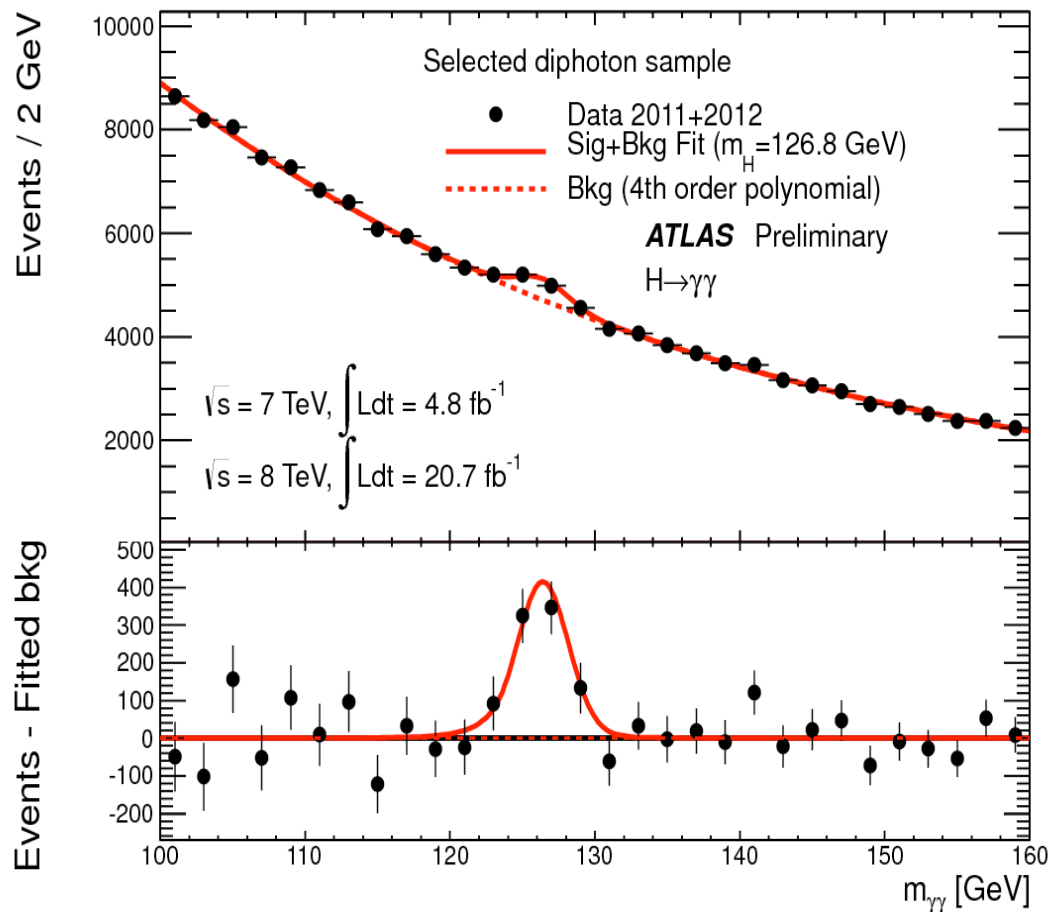


Higgs boson production and decays

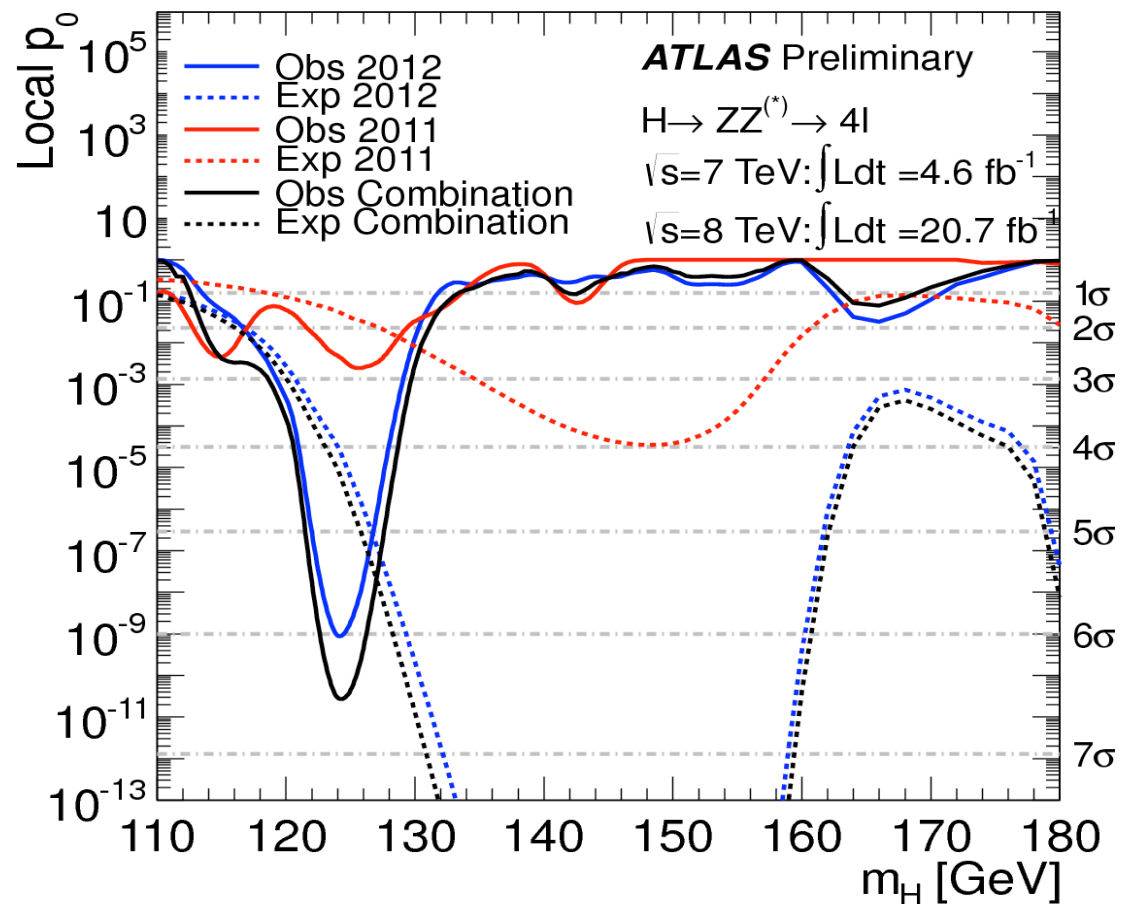
The ATLAS CMS Experiments at the LHC have discovered, independently, a Higgs boson with mass around 125 GeV using these productions and decay modes



The Higgs Boson Discovery

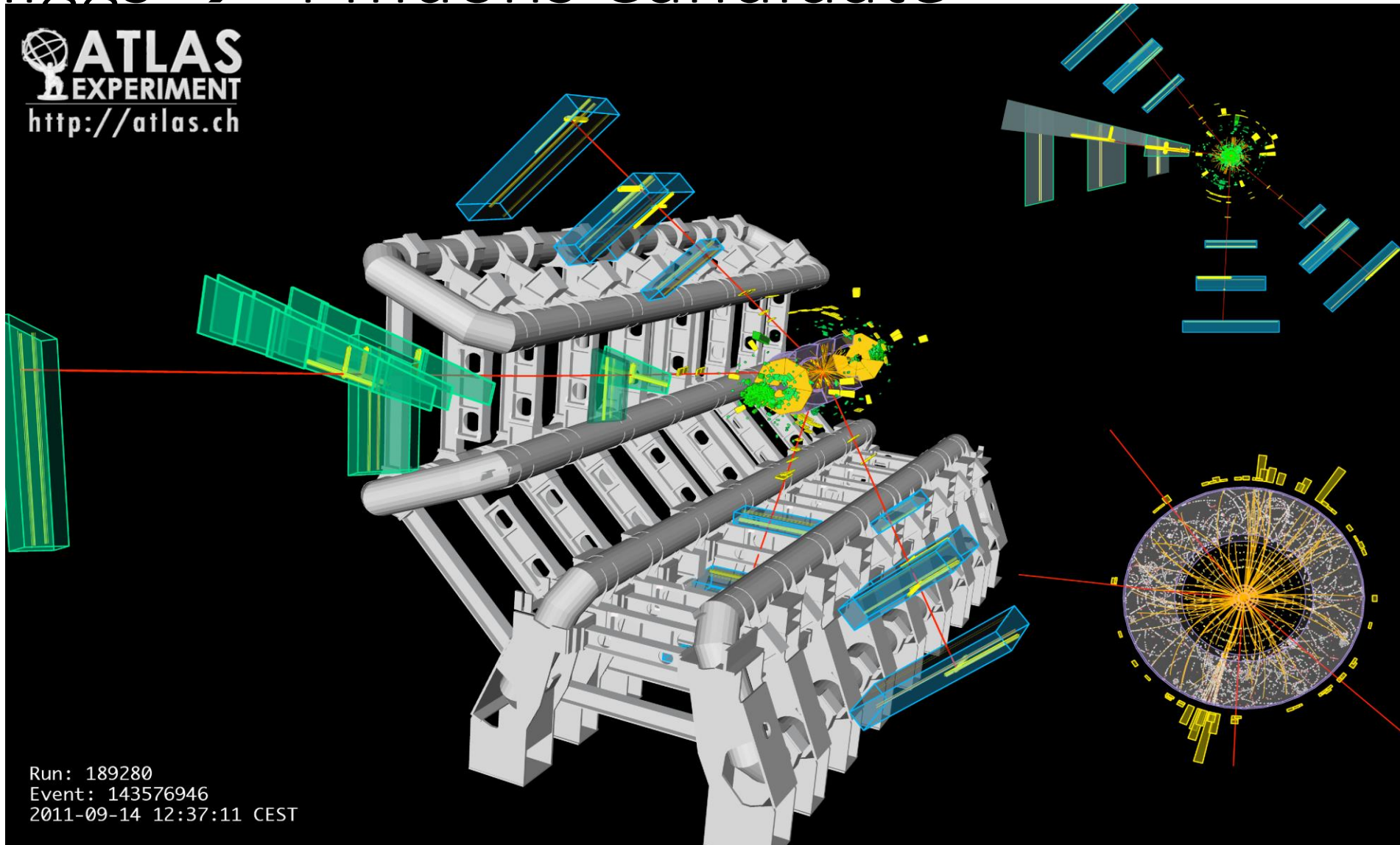


Single channel discovery: 7.4σ

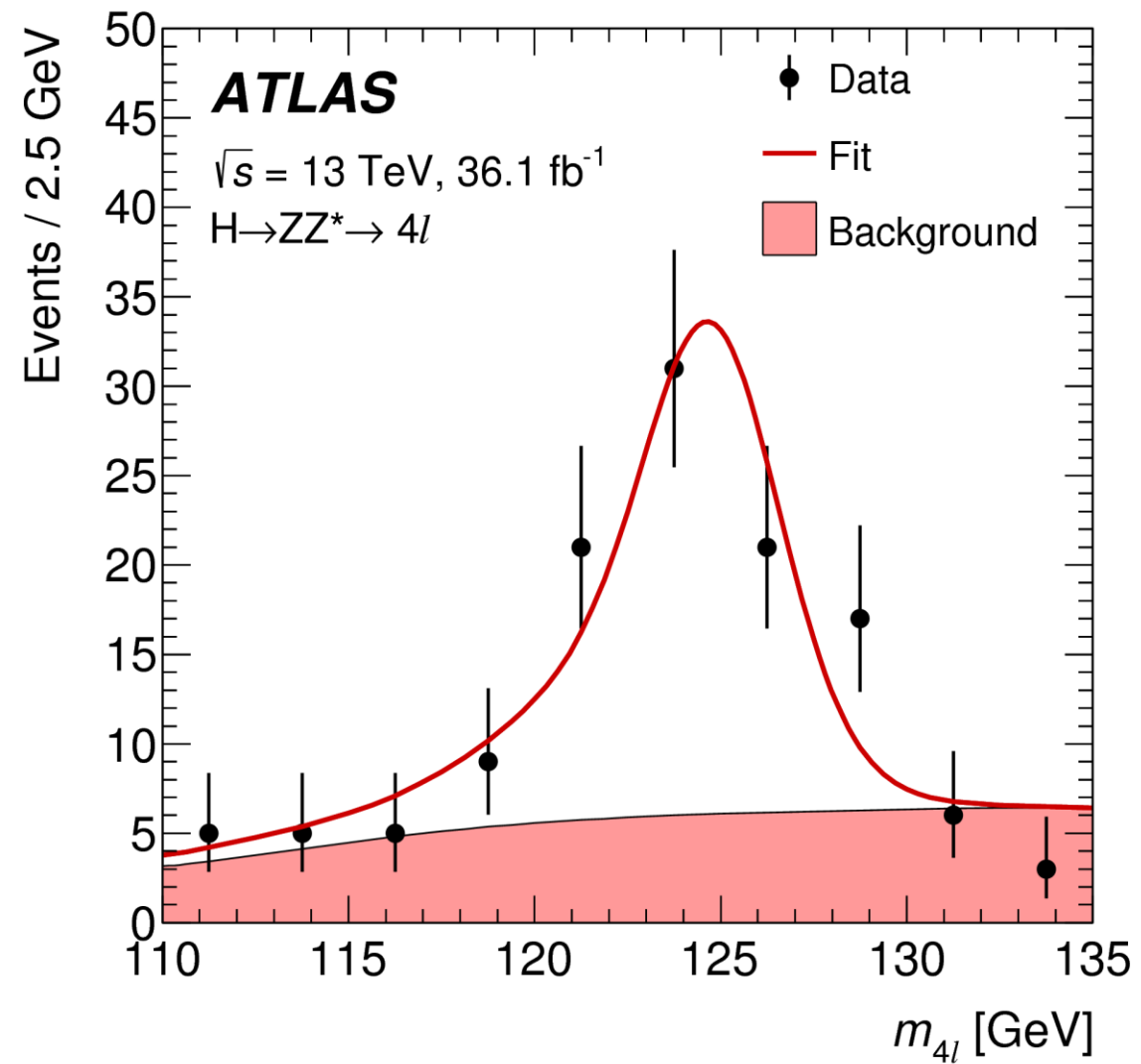
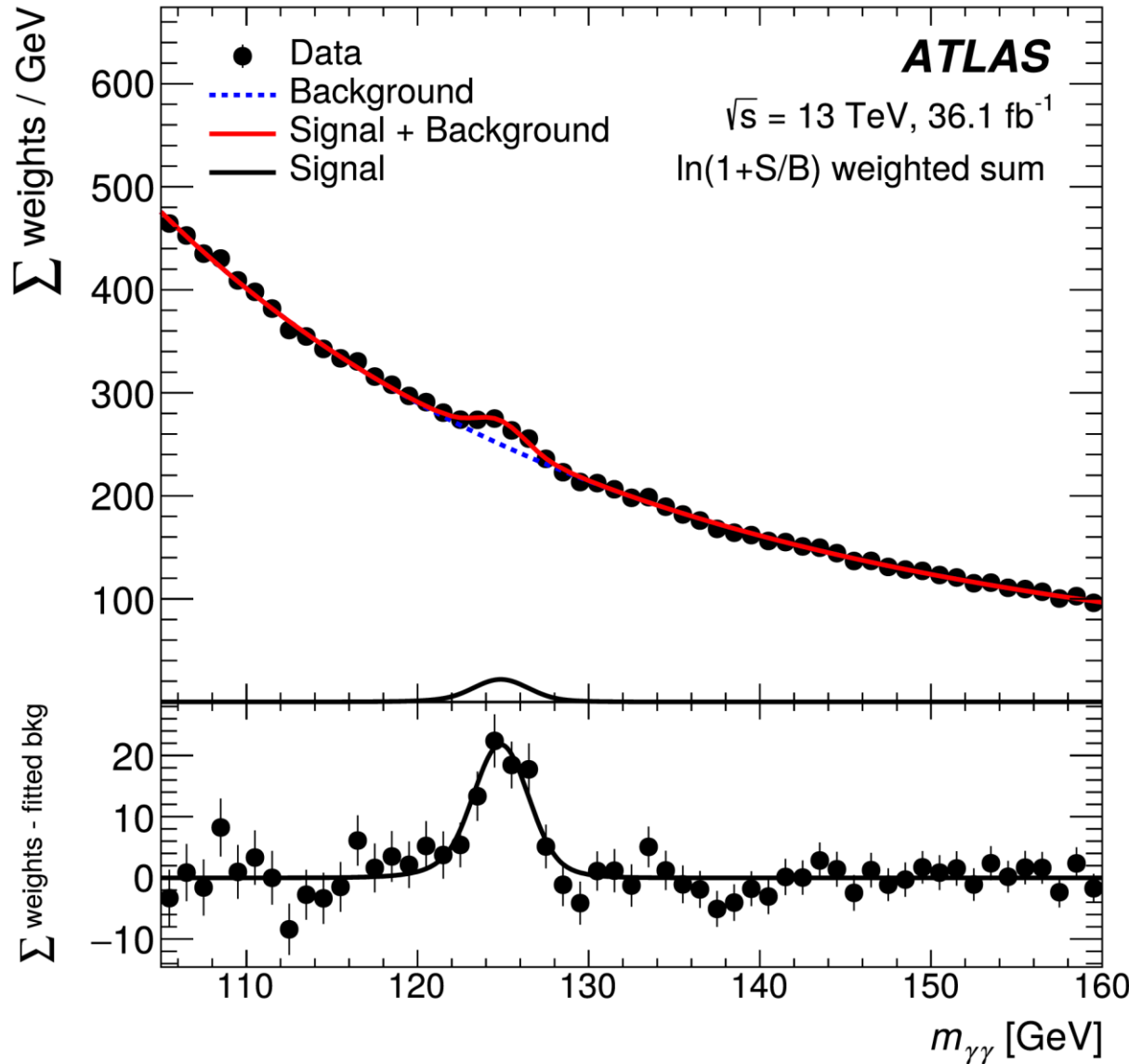


Single channel discovery: 6.6σ

Higgs \rightarrow 4 muons Candidate

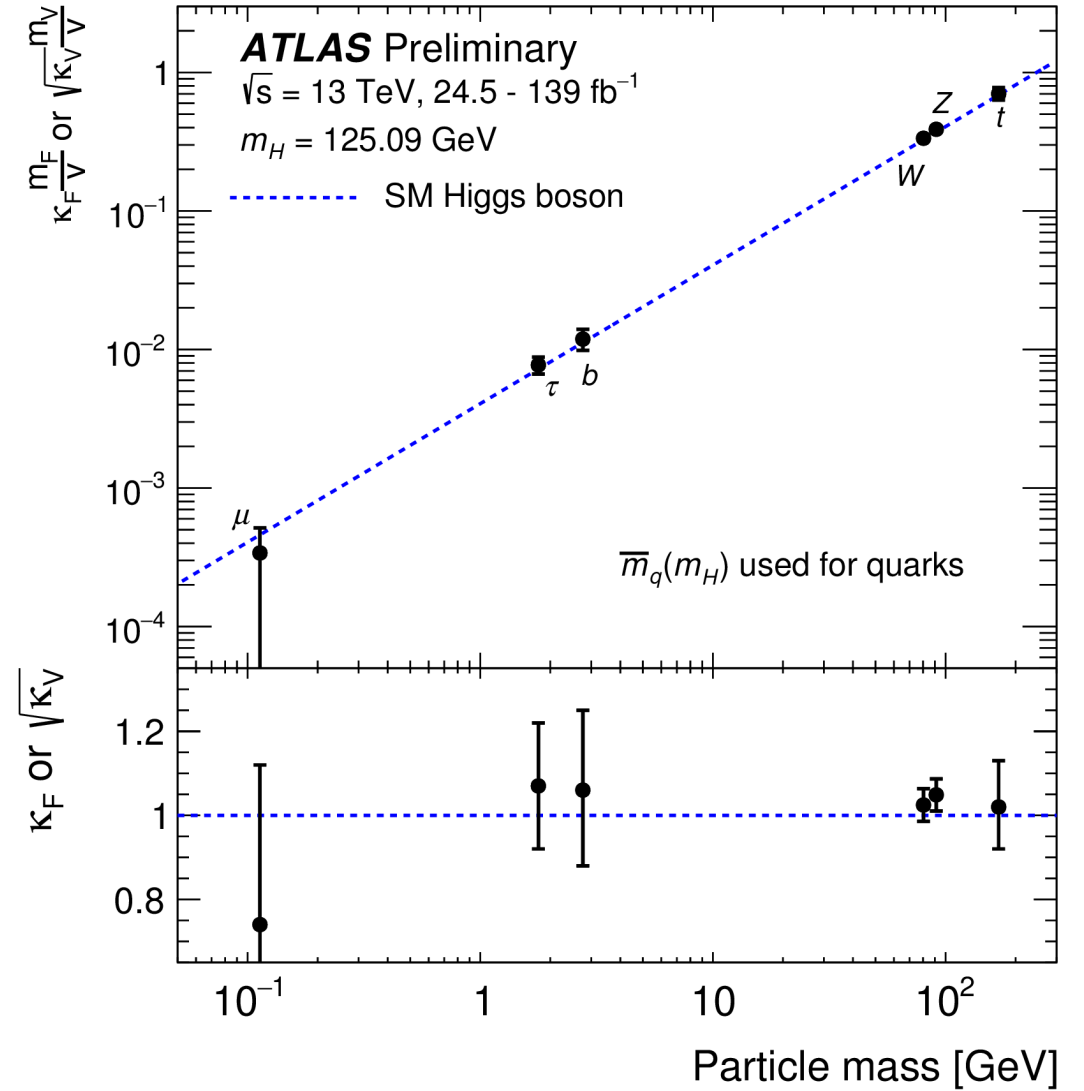


Higgs $\rightarrow \gamma\gamma, ZZ$



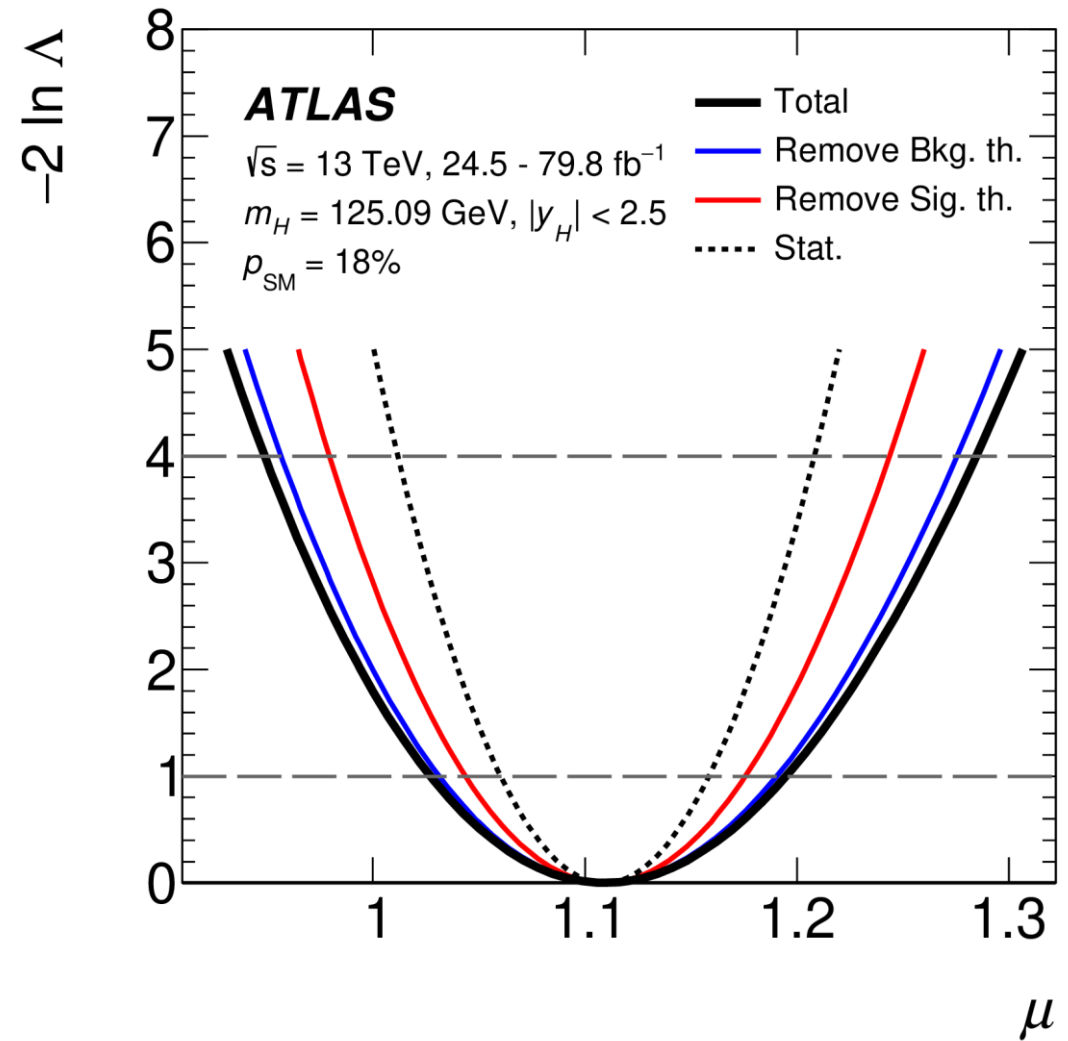
Discovery confirmed in later measurements

Higgs coupling measurements

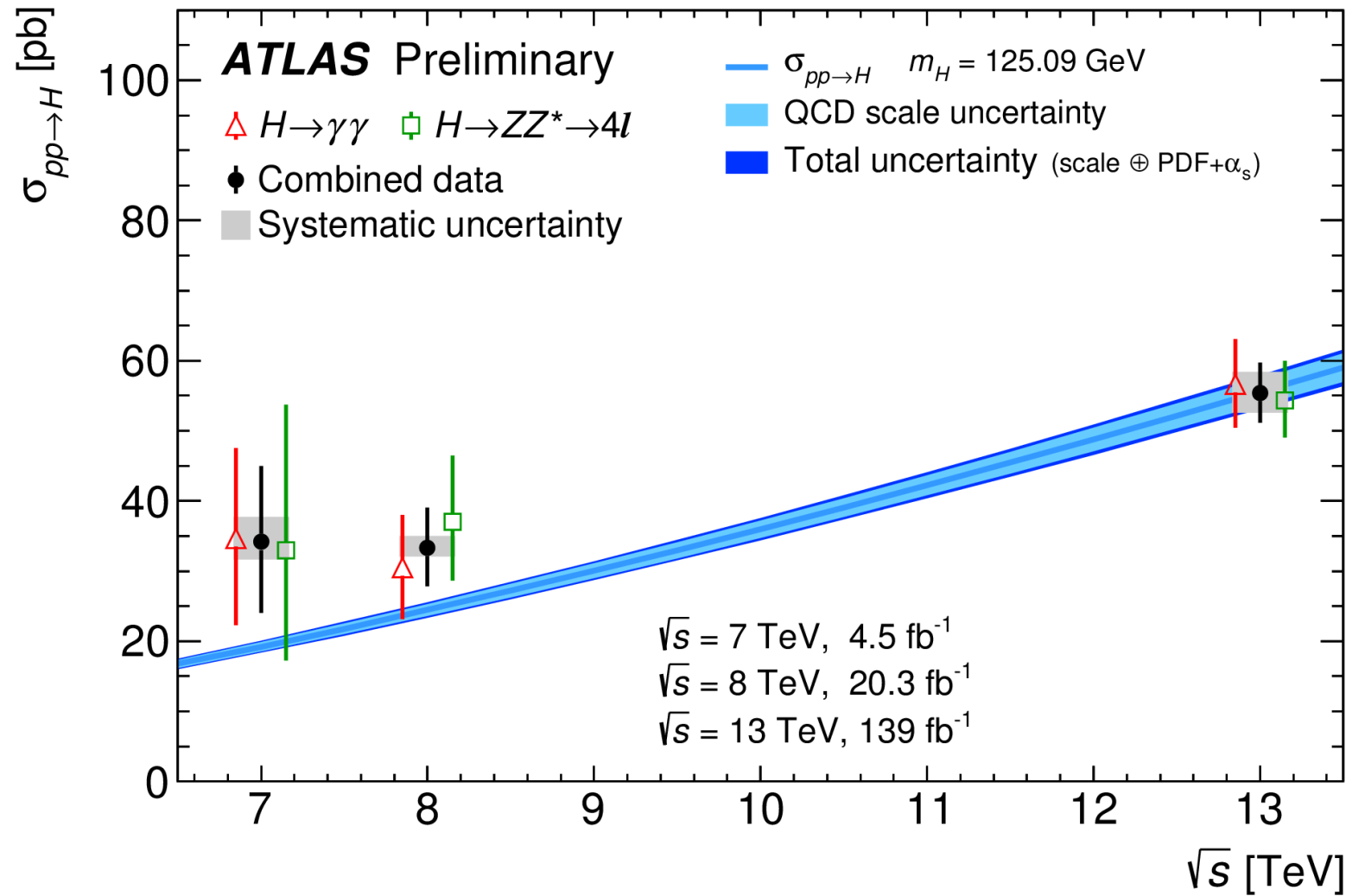
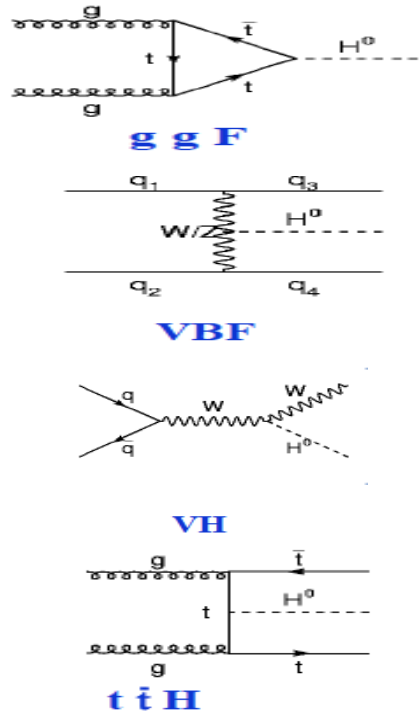


Signal Strength relative to SM

$$\mu = 1.11^{+0.09}_{-0.08}$$

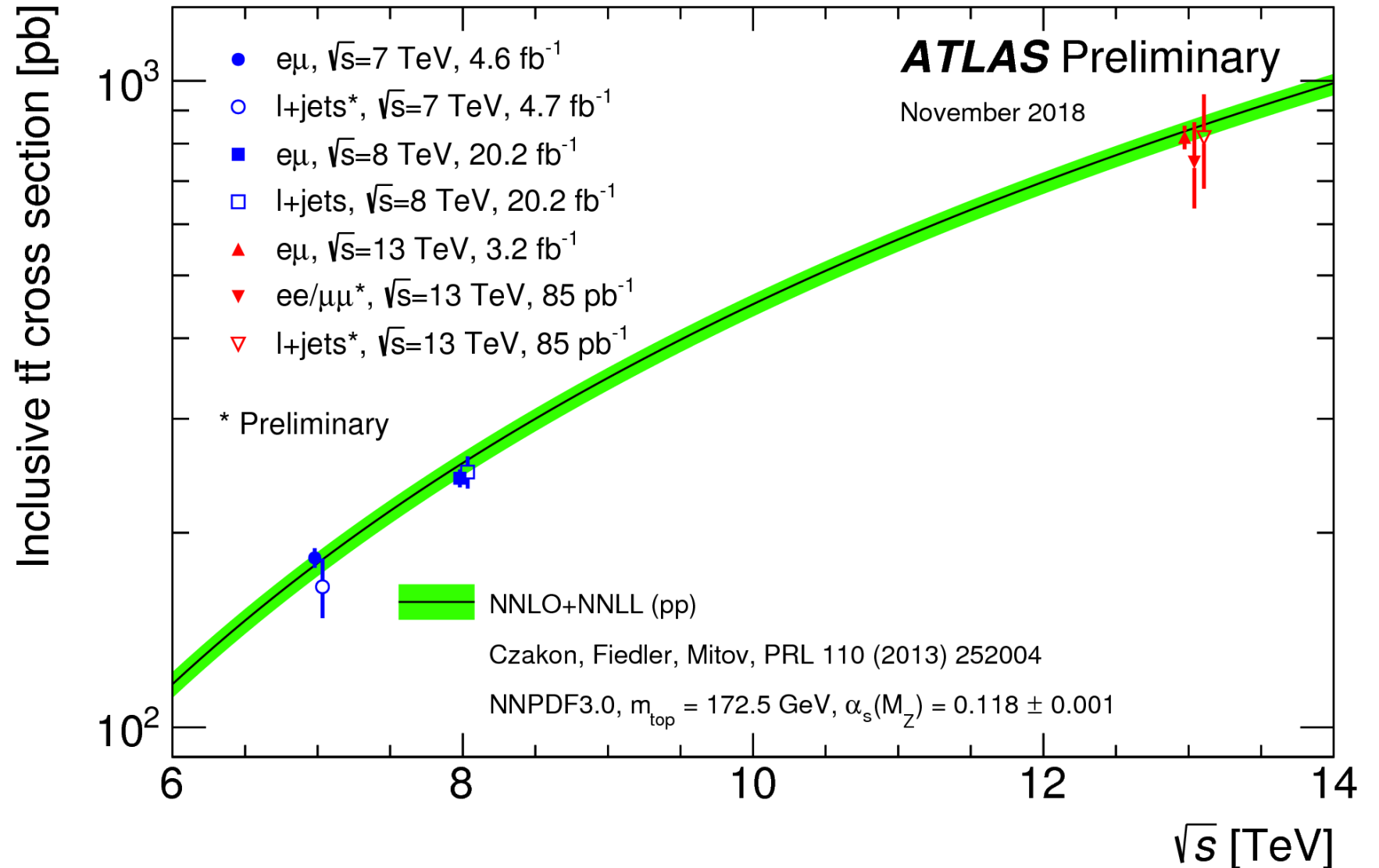


pp → H + X Cross section measurements



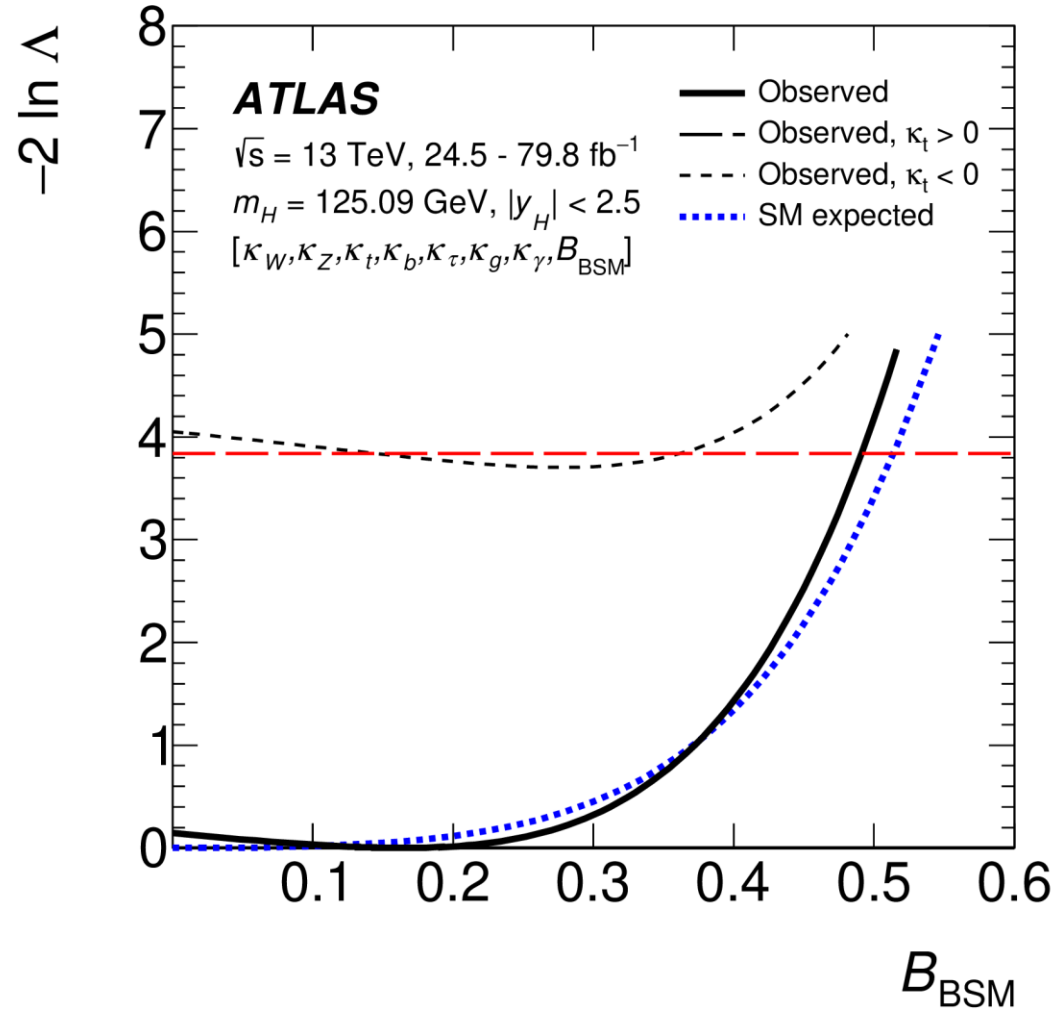
Top-quark sector

Summary of ATLAS measurements of the top-pair production cross-section as a function of the center-of-mass energy compared to the NNLO QCD calculation complemented with NNLL resummation (top++2.0).



H \rightarrow BSM contribution to the Higgs width

BR [H \rightarrow BSM] < ~45%



Search for new physics

- **Higgs Discovery confirmed in later measurements**
- **Measurement of properties consistent with expectations from the SM**
- **But are there more than one Higgs boson?**
 - **Beyond-the-Standard-Model (BSM) Higgs searches**
- **We can use the Higgs boson as a portal to “new physics” :**
 - **Can we search for new physics in the decay of the Higgs boson?**
 - **Or in association with it?**
 - **Or in the small deviations in the properties with respect to the SM expectations?**

The Dark Matter Hypothesis

- Proposed by Fritz Zwicky, based on observations of the Coma galaxy cluster
- The galaxies move too quickly
- The observations require a stronger gravitational field than provided by the visible matter
- **Dark matter?**



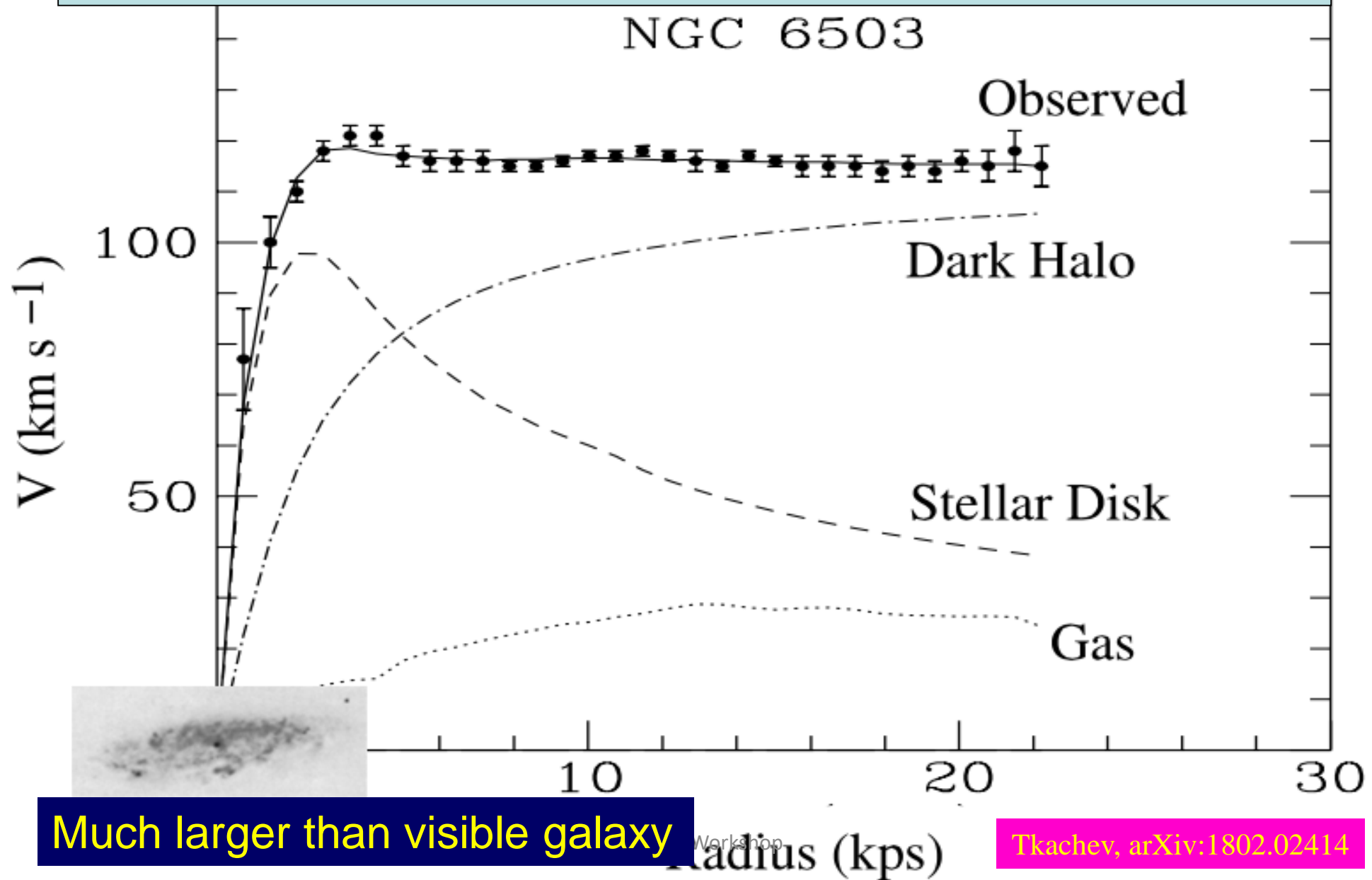
The Rotation Curves of Galaxies

- Measured by Vera Rubin
- The stars also orbit ‘too quickly’
- Her observations also required a stronger gravitational field than provided by the visible matter
- **Further strong evidence for dark matter**



Scanned at the American
Institute of Physics

Sample Rotation Curve: NGC 6503



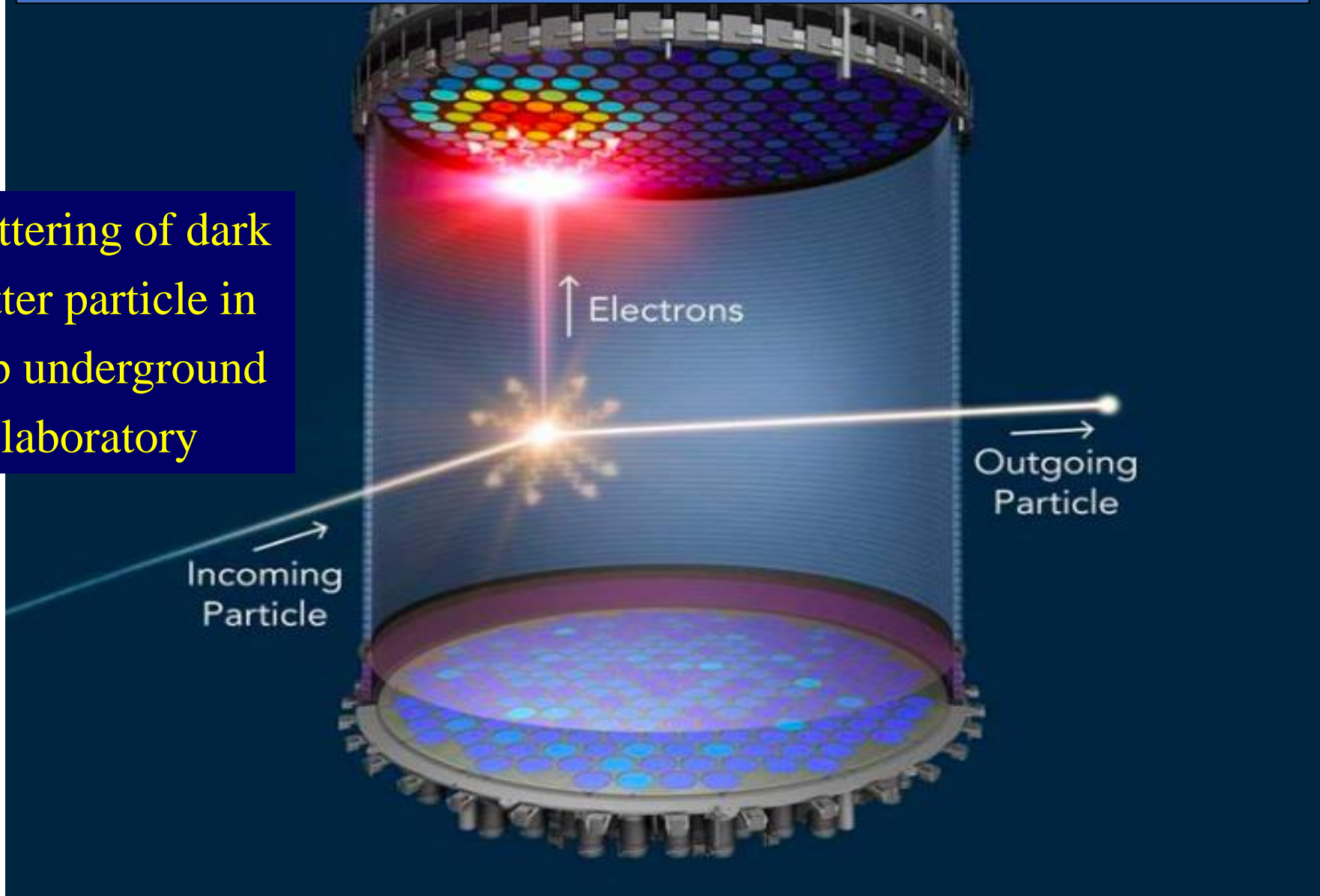
Much larger than visible galaxy

Workshop

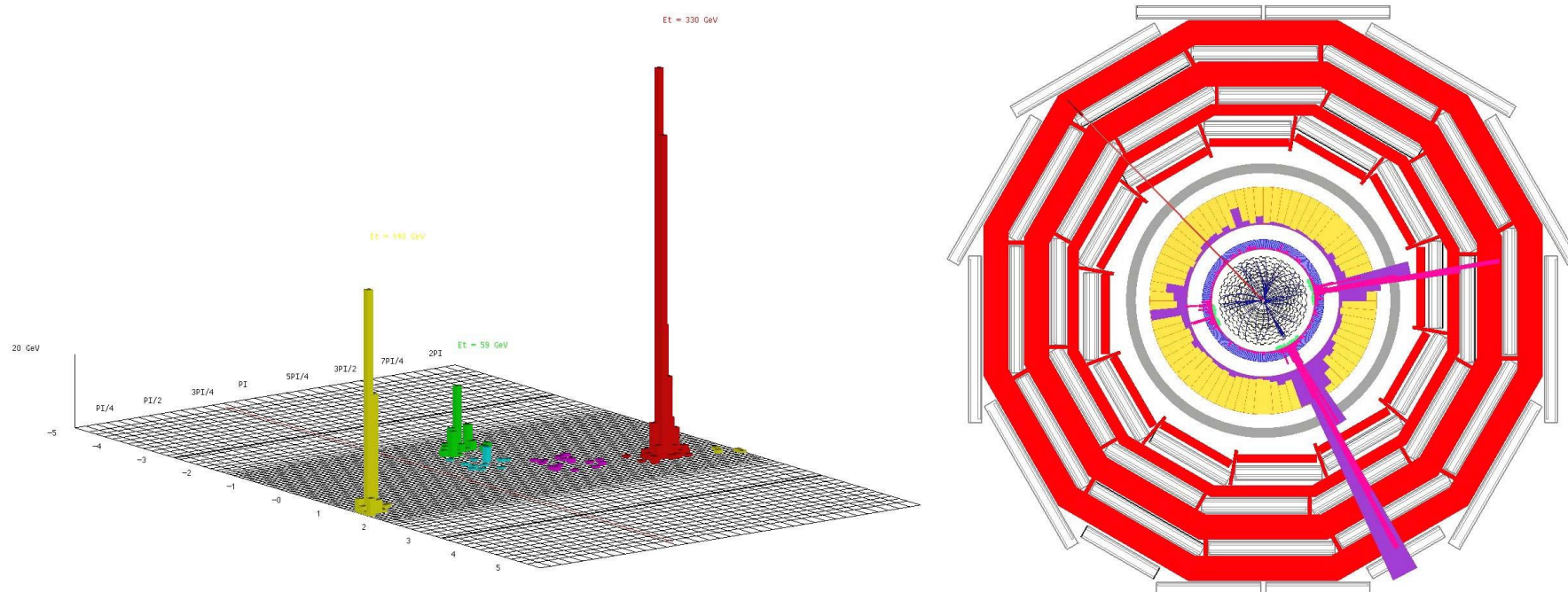
Tkachev, arXiv:1802.02414

Direct Dark Matter Detection

Scattering of dark matter particle in deep underground laboratory



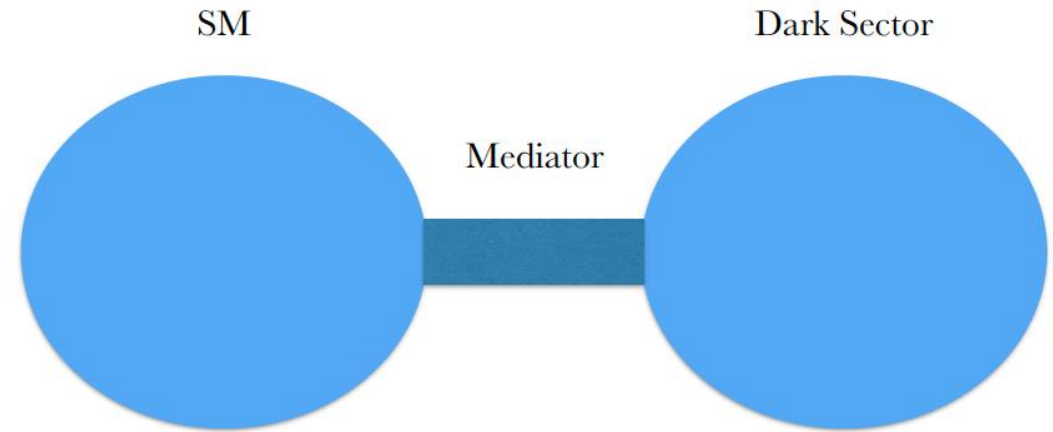
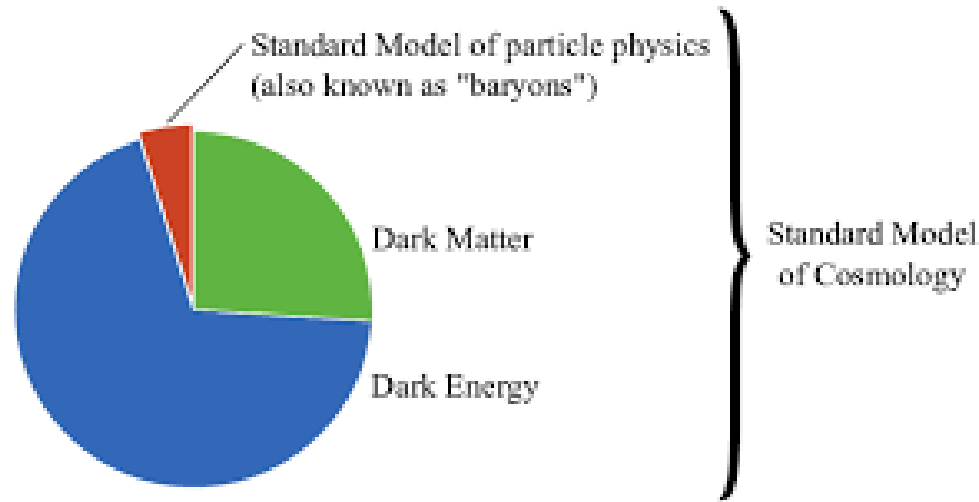
Classic Dark Matter Signature at LHC



Missing transverse energy
carried away by dark matter particles

Dark Sector

- Dark Sector states as “New Physics” beyond the SM

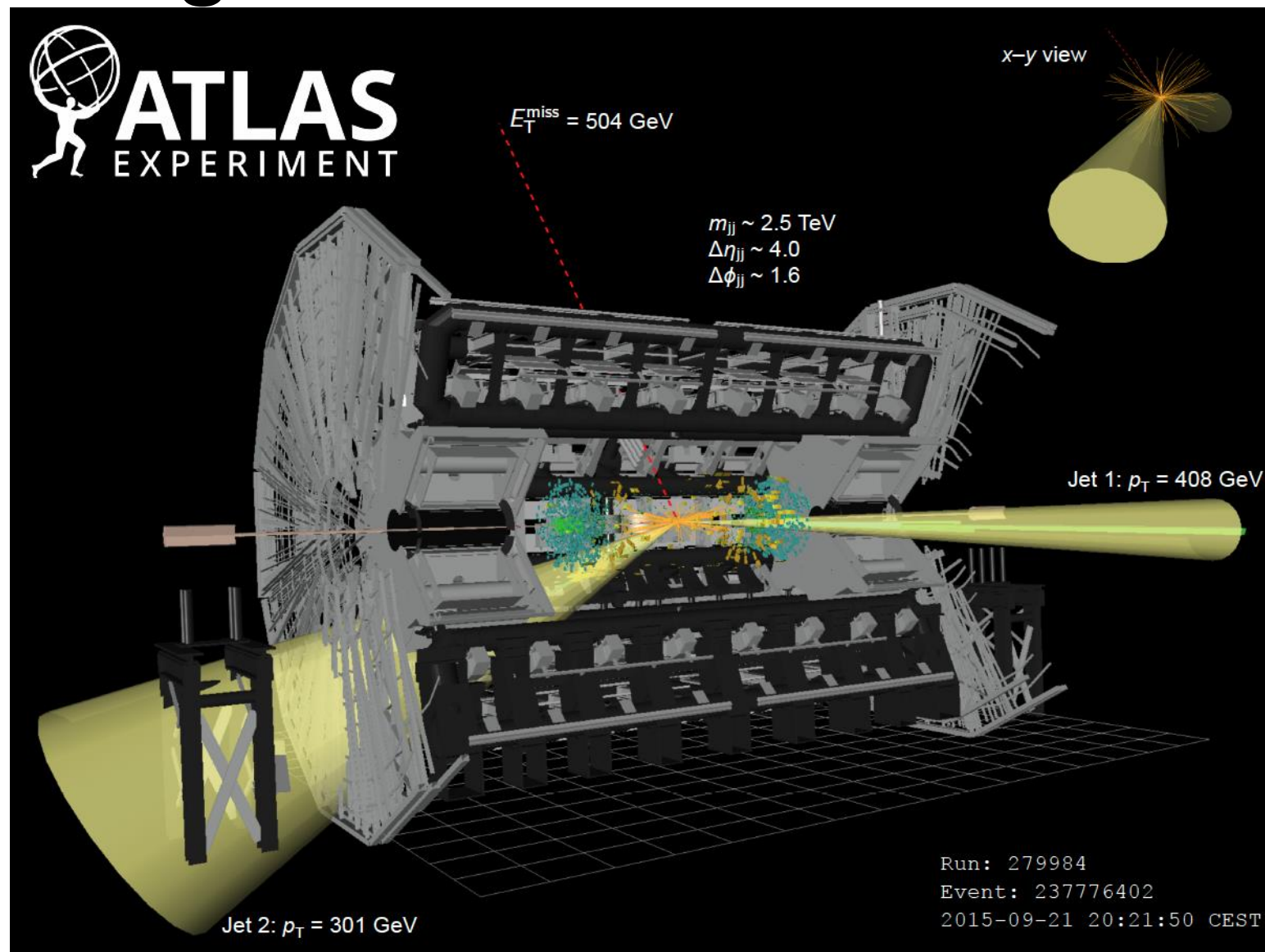


Need new force / interaction to connect SM to Dark Sector — portals. Weak couplings through kinetic mixing, Higgs or mass mixings

Dark Matter could just be one example of Dark Sector States

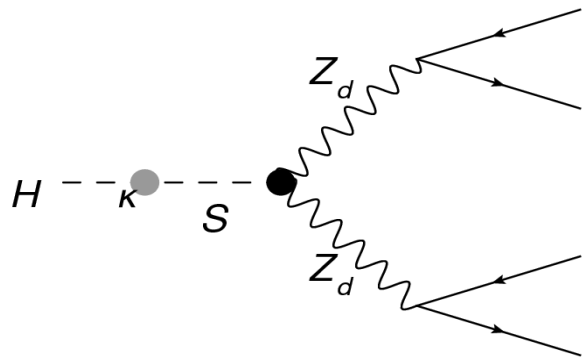
Some Classic Signatures at LHC

Missing transverse energy carried away by Dark Matter particles

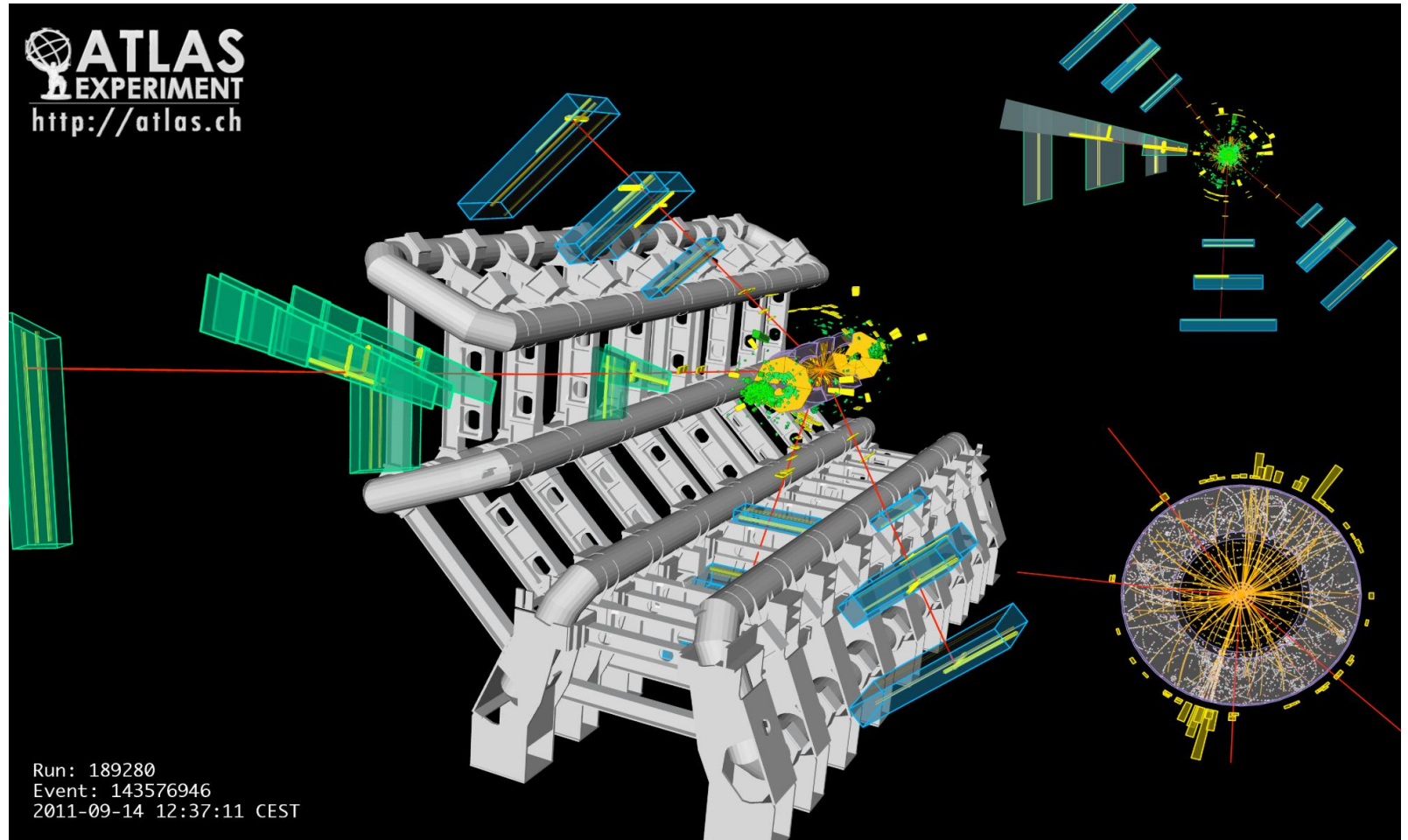


Some Classic Signatures at LHC

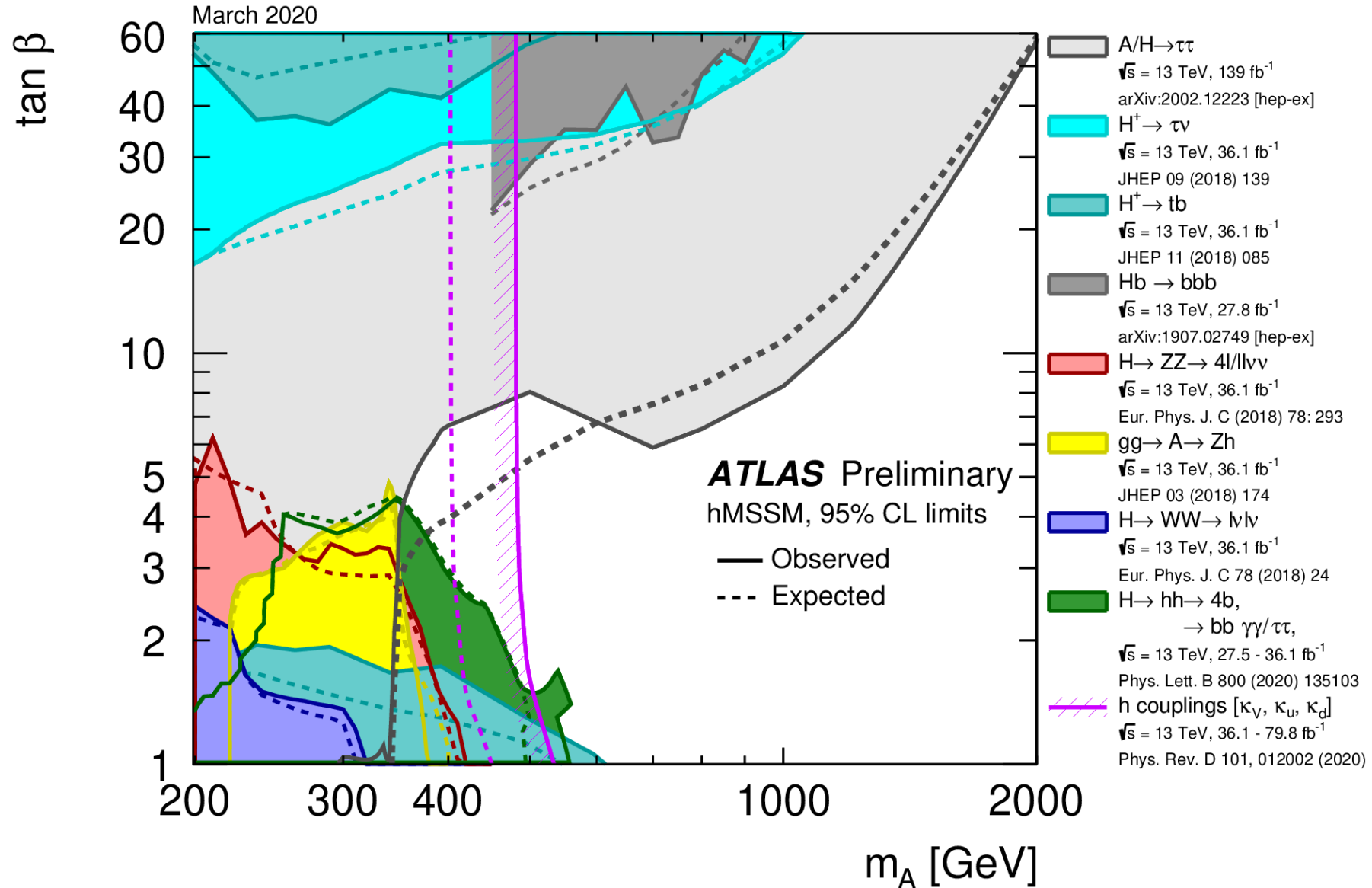
Dark Sector
States decaying
to SM particles



$S / H \rightarrow Z_d Z_d \rightarrow 4l$
where S = Dark Scalar
 Z_d = Dark Vector Boson

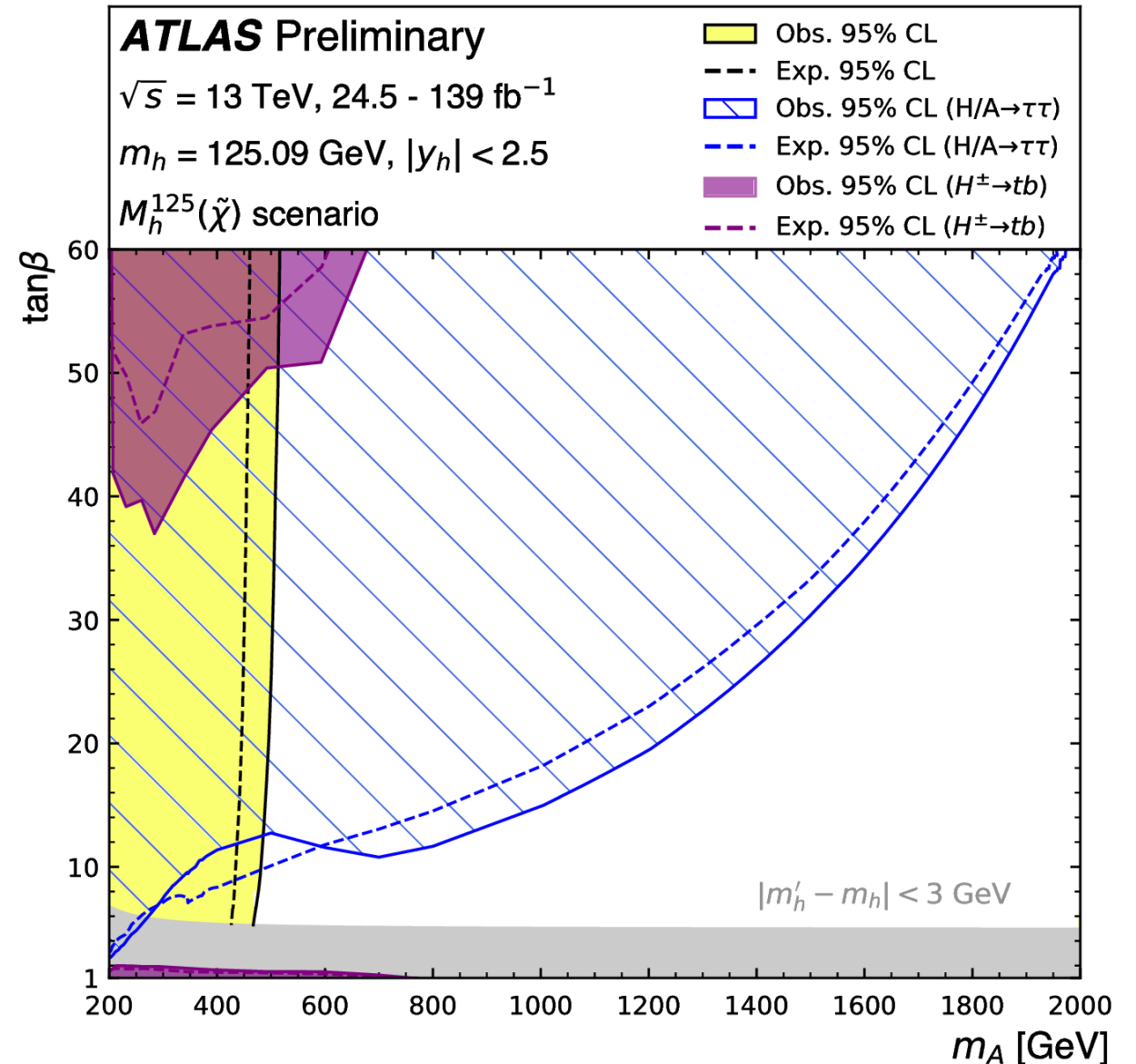


BSM Higgs exclusion in the hMSSM



MSSM constraints from modified Higgs boson production cross sections and decay branching fractions

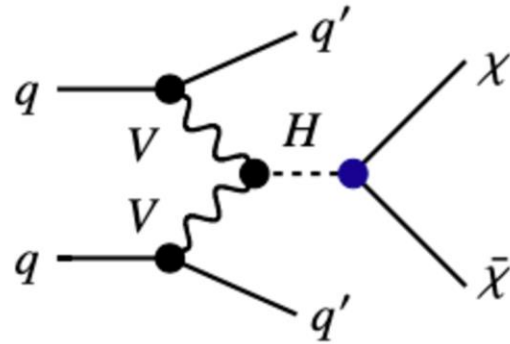
Exclusion contours in the $(m_A, \tan\beta)$ plane for the $M_h^{125}(\tilde{\chi})$ scenario of the MSSM



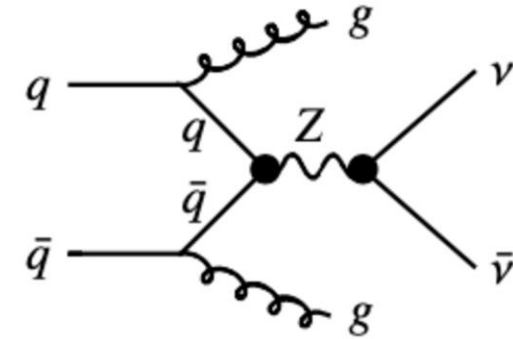
H \rightarrow invisible

- **Some Dark Sector particle χ , neutral and stable over the range of the detector**
 - It is not a neutrino. A BSM-Particle
 - Its mass $m_\chi < m_H / 2$ such that $H \rightarrow \chi\chi$. The detector would be insensitive to such a decay so we call it $H \rightarrow$ invisibles
- **If it is “invisible”, how do we detect it?**
 - Since the particle χ does not interact with the detector, it will escape, undetected, with some kinetic energy
 - By using conservation of 4-moment, after accounting for all the other detected particles, we can infer how much energy/momentum is carried away, therefore missing
 - So we can measure the missing transverse energy or the missing momentum
 - **χ could be a candidate for Dark Matter particle**

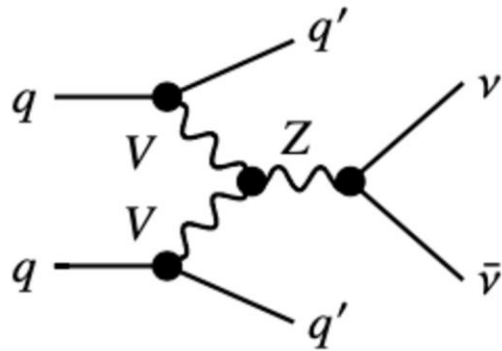
H \rightarrow invisible



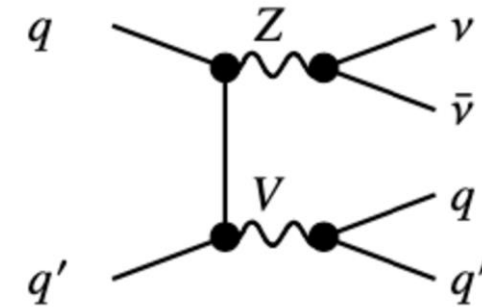
(a) Signal process



(b) Example diagram for the strong Z+jets background process

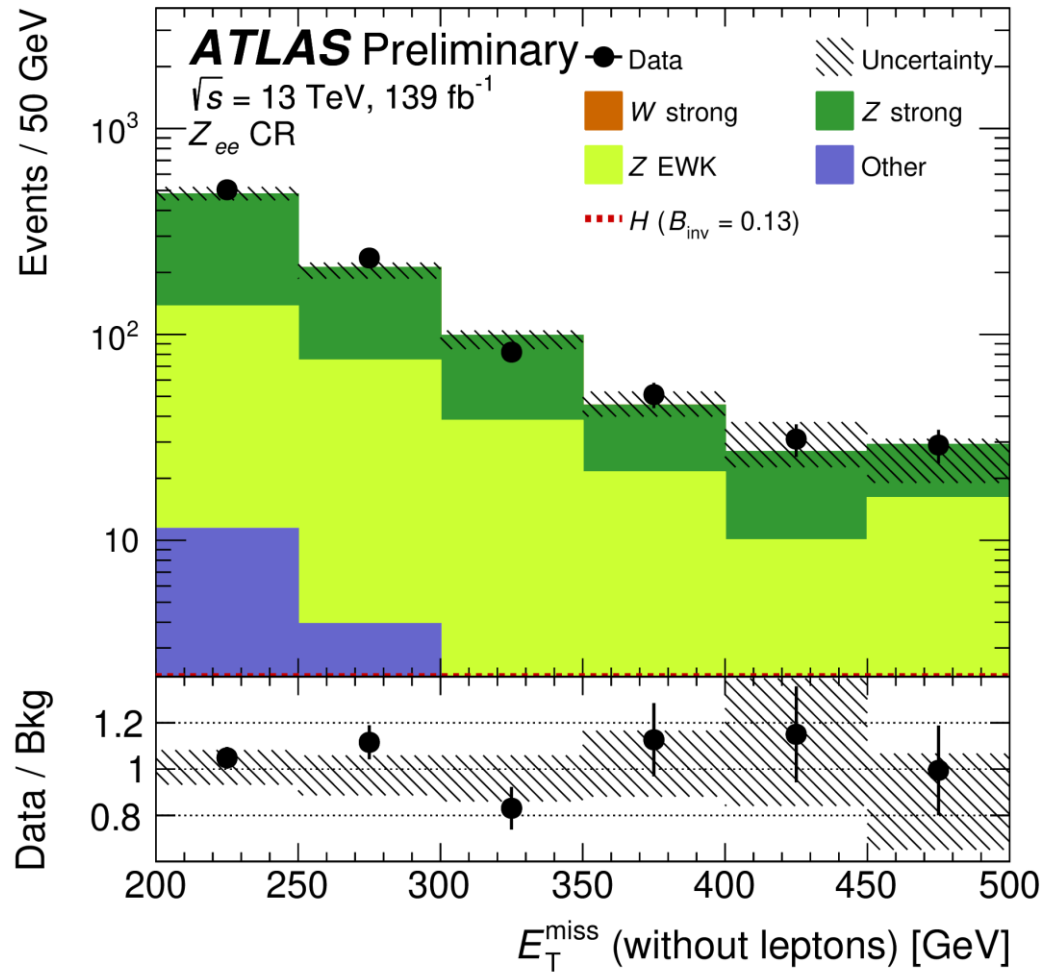


(c) Example diagram for the electroweak VBF Z+jets background process



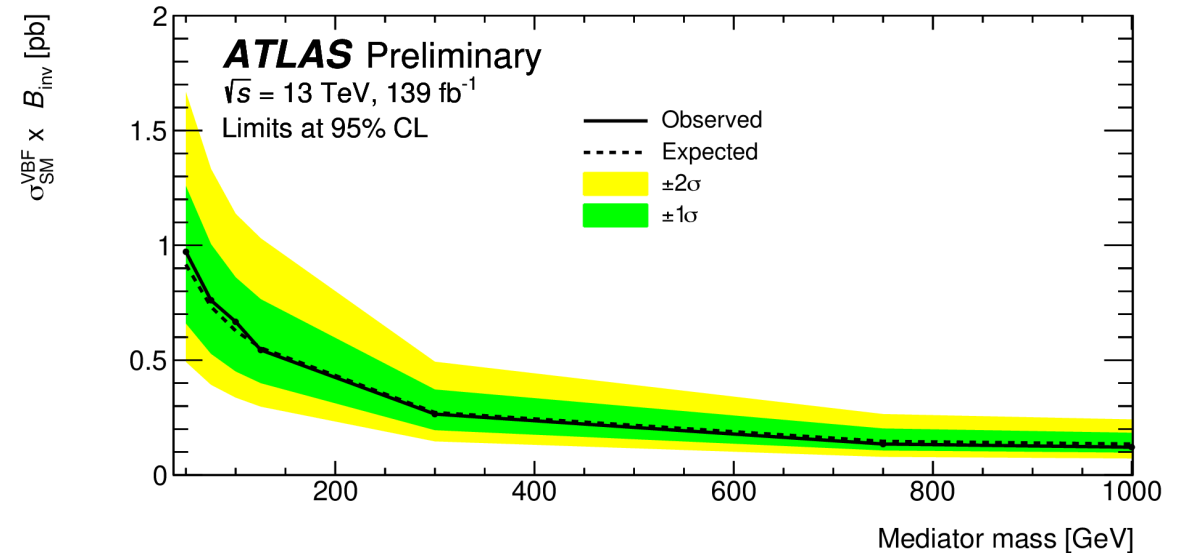
(d) Example diagram for the electroweak diboson process

H \rightarrow invisible



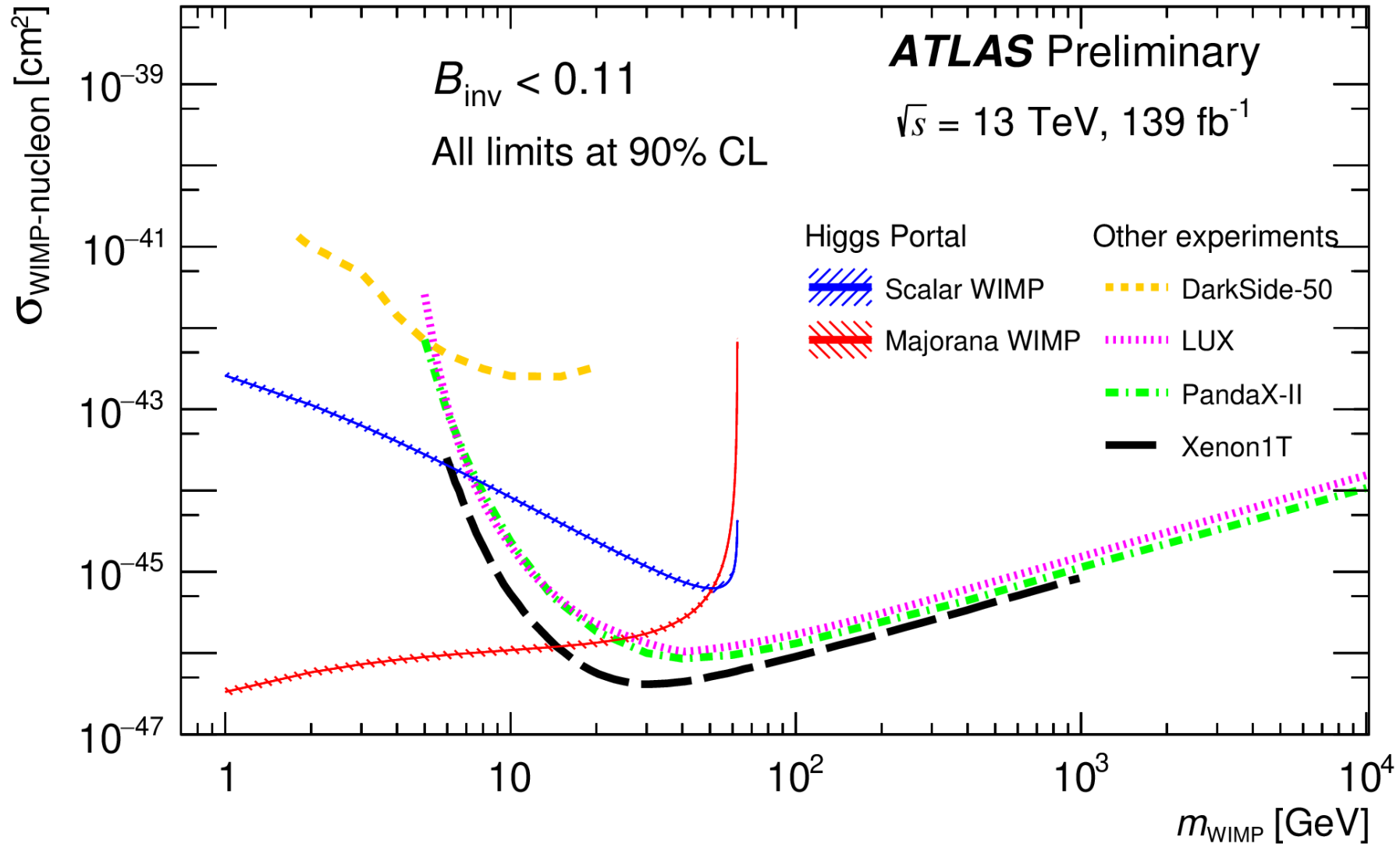
**Branching Ratio Limit < 0.13
at 95% Confidence Level**

**Upper bound on the Cross Section x BR
of a generic scalar**

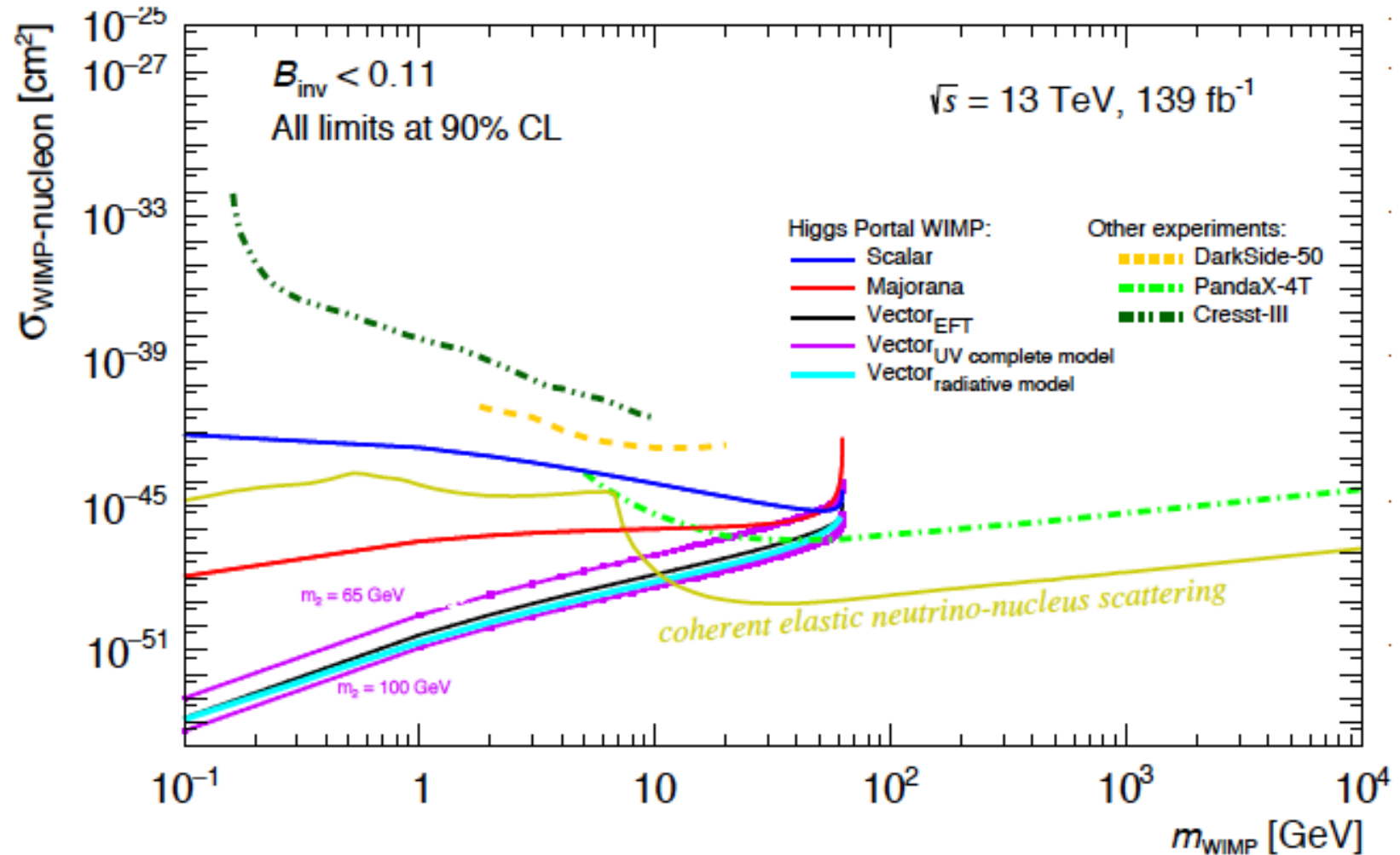


H \rightarrow invisible — Dark Matter interpretation

Upper bound of the DM-Nucleon Scattering Cross Section



H \rightarrow invisible — Dark Matter interpretation



Work I did with a graduate student from Morocco.

Published here <https://doi.org/10.31526/lhep.2022.270>

Broader Impact

1. **Community Outreach through QuarkNet**
 - ❖ Professional development programs for physics teachers and pupils
2. **Targeted outreach toward US URM and MSI**
 - ❖ Improved and sustained engagements with URM and MSI to increase participation



3. **International Outreach**
 - ❖ Shorter-term visits for research
 - ❖ International physics school
 - ❖ Mentorship / coaching

U.S. ATLAS
Education and Outreach Event

Motivation
The ATLAS Experiment is a worldwide effort with over 3000 physicists and engineers - with a strong participation from 45 US universities and national labs (US-ATLAS) - at the CERN International Laboratory located in Geneva, Switzerland. The project aims to improve our understanding of the Universe - its birth, evolution, current state, and future. The research offers a wide range of practical applications and educational opportunities. This event will serve as an informal introduction to ATLAS research and discuss US-ATLAS programs that new students and university groups can get involved in.

June 2, 2021
Virtual Event

Panel Discussion Moderators:
Kathryn Grimm (California State University, East Bay)
Aleida Perez (Brookhaven National Laboratory)

Panelists:
Noel Blackburn (Brookhaven National Laboratory)
Anna Goussiou (University of Washington, Seattle)
Mark Kruse (Duke University)
Chilufya Mwewa (Brookhaven National Laboratory)
Sahal Yacoub (University of Cape Town)
Blanca Nino (California State University, Fresno)

Organizing Committee:
Kérelvi A. Assamagan (Brookhaven National Laboratory)
Dhiman Chakraborty (Northern Illinois University)
Kathryn Grimm (California State University, East Bay)
Anna Goussiou (University of Washington, Seattle)

Invited Speakers:
Oliver Keith Baker (Yale University)
Young-Ke Kim (University of Chicago)
Peter Onyisi (University of Texas, Austin)
Srinil Rajagopalan (Brookhaven National Laboratory)
Reina Camacho Toro (Sorbonne Université, France)
Mayda Velasco (Northwestern University)

Registration and Agenda:
<https://indico.bnl.gov/event/11077/>

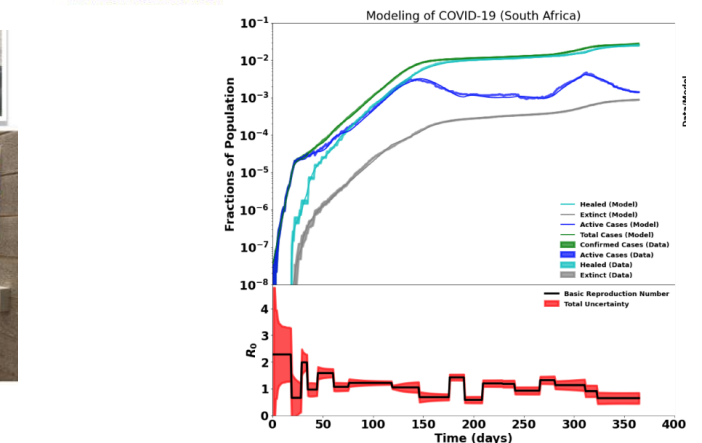
U.S. DEPARTMENT OF ENERGY ATLAS EXPERIMENT



QuarkNet Workshop

THE SIXTH BIENNIAL
African School of Fundamental Physics and Applications
July 19-30, 2021
Virtual Edition

www.africanschoolofphysics.org



Conclusions

- **The Standard Model of particle physics is a very successful theory**
 - Yet, there things we do not understand, e.g. the nature of Dark Matter
- **The discovered Higgs boson may be used as probe or portal to “new physics”**
 - By searching for BSM particles in the decays of the Higgs boson, e.g. $H \rightarrow$ invisible
- **So far, no signal of “new physics” detected**