

# Search for Higgs boson decay to invisible particles

*Dr. Kétévi Adiklè Assamagan*



# What I am going to do ...

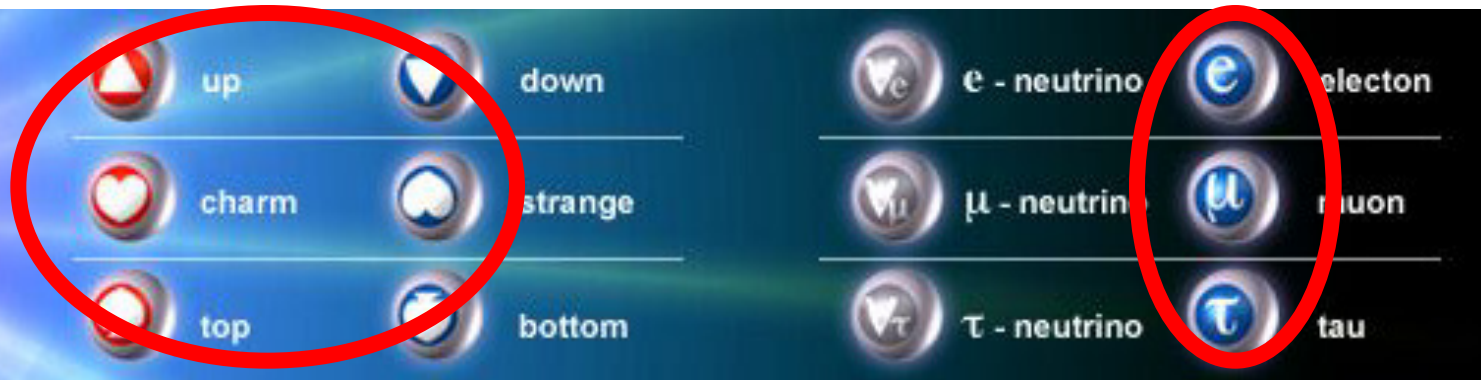
- **Review Higgs boson discovery channels and properties**
- **The case for physics beyond the Standard Model of particle physics**
- **Search for dark sector states**
- **Higgs decay to invisible particles and interpretation for dark matter**
- **Physics engagement**
- **ATLAS ITk FELIX readout test stand at BNL**

# The 'Standard Model'

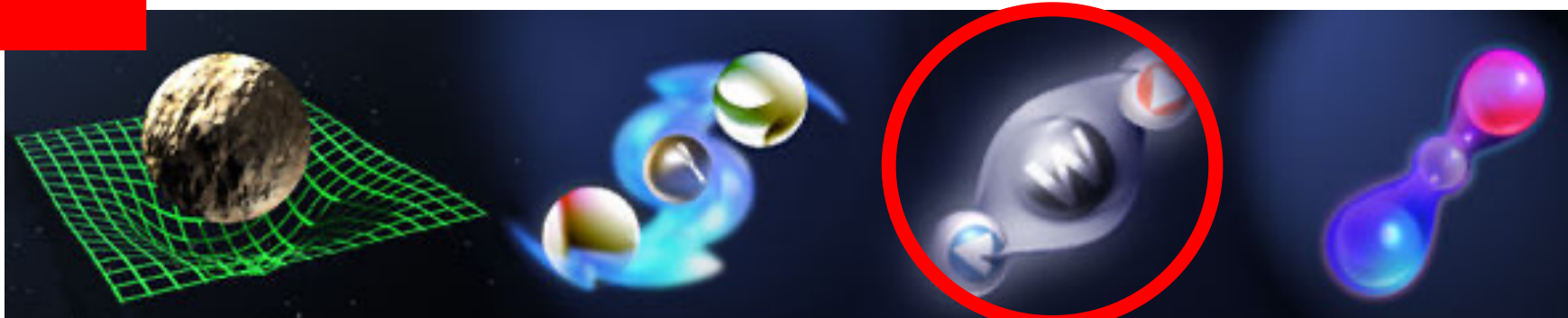
= Cosmic DNA

## 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

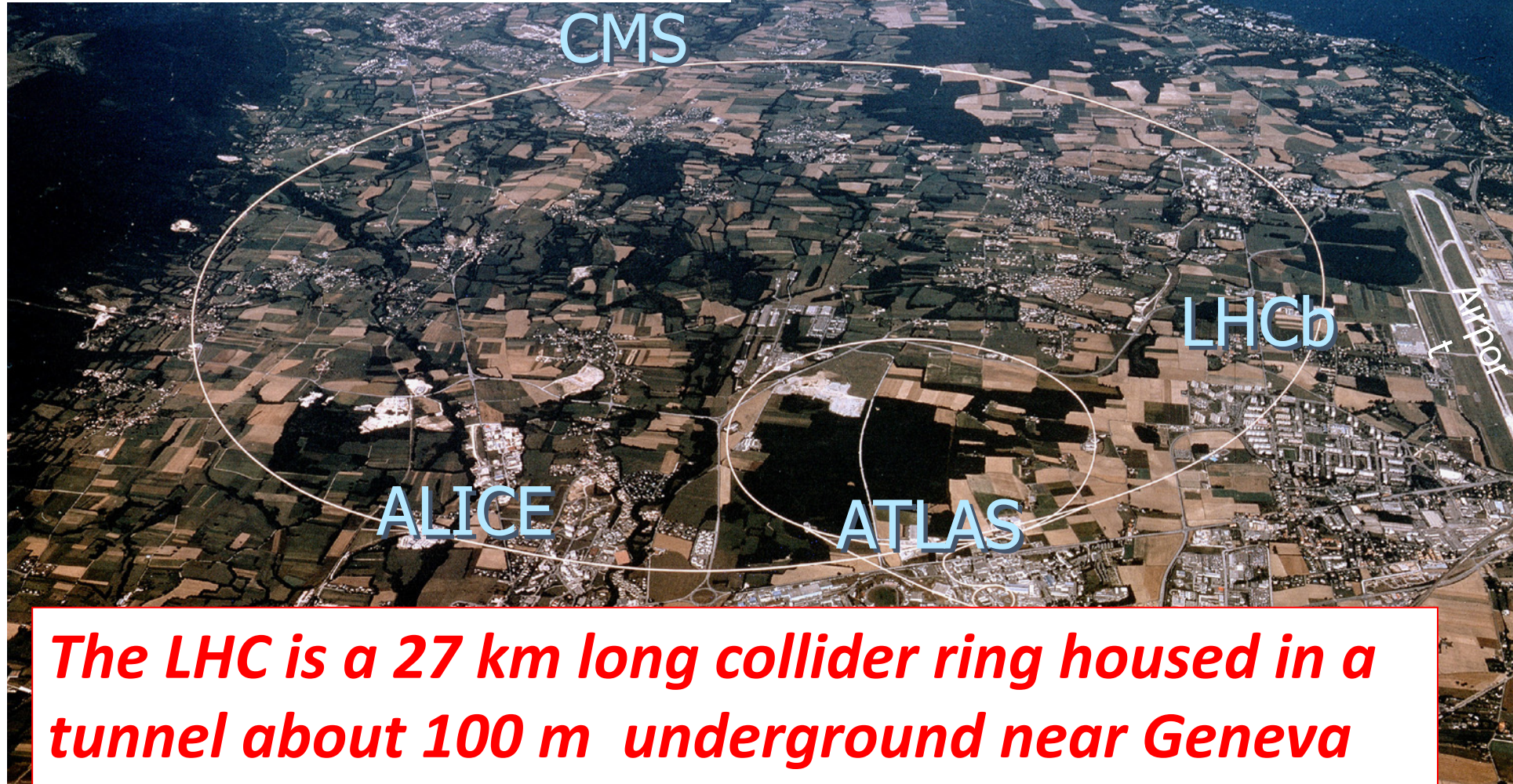
... weak interactions would not be weak

- Life would be impossible: everything would be radioactive

**Its existence is a big deal!**

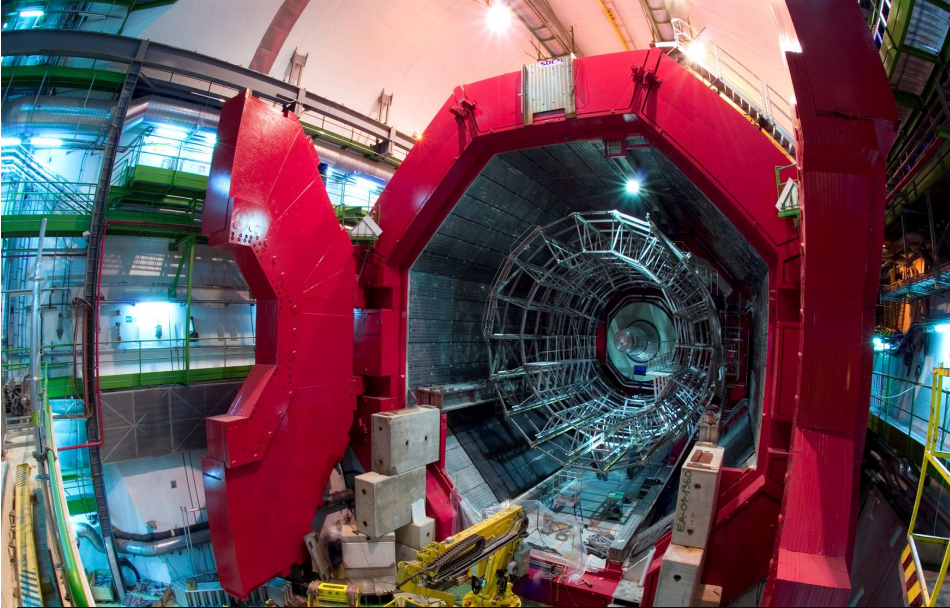


***The LHC machine  
Proton-Proton Collisions  
Heavy Ion Collisions***

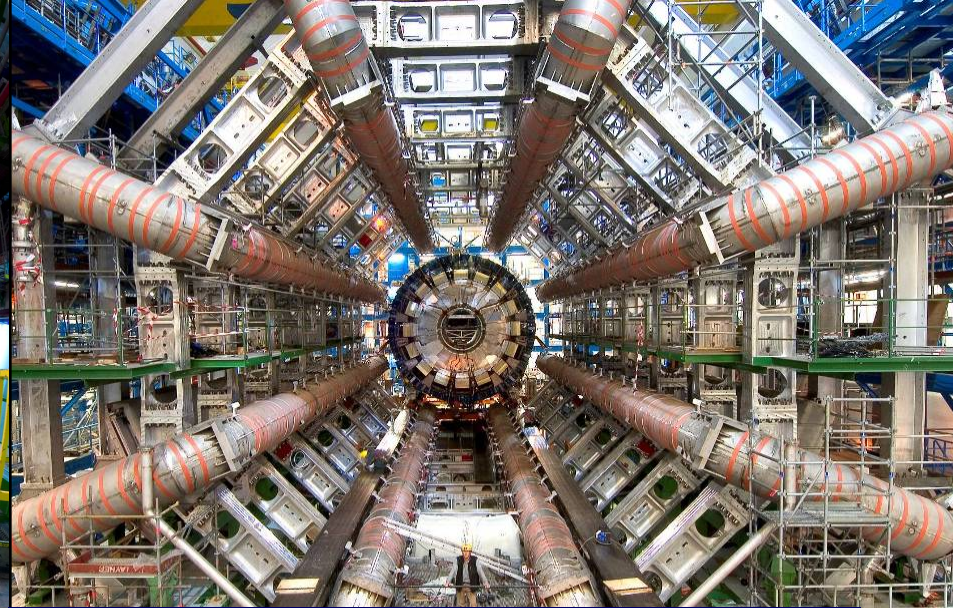


***The LHC is a 27 km long collider ring housed in a tunnel about 100 m underground near Geneva***

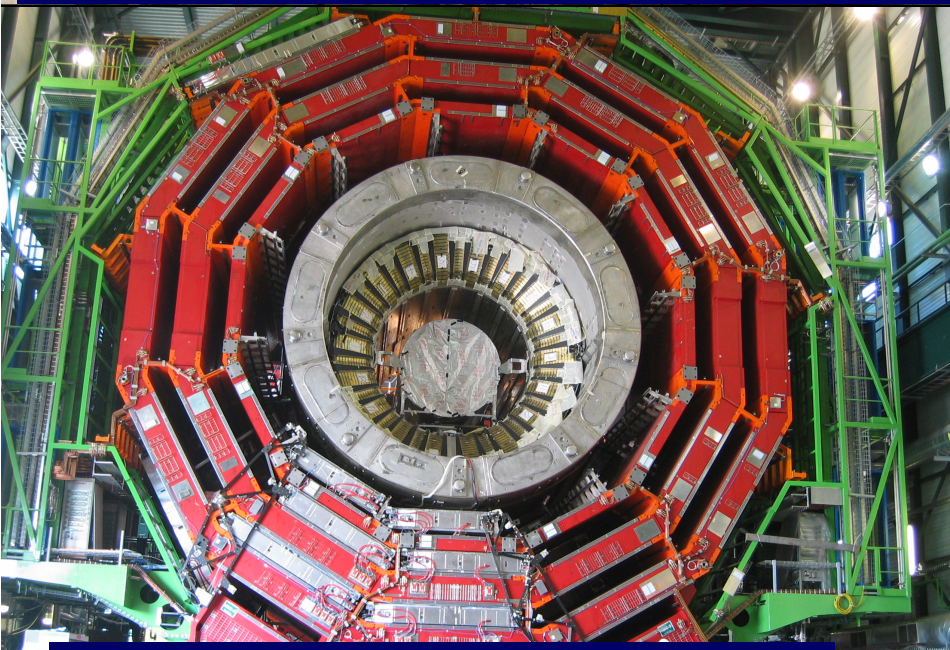




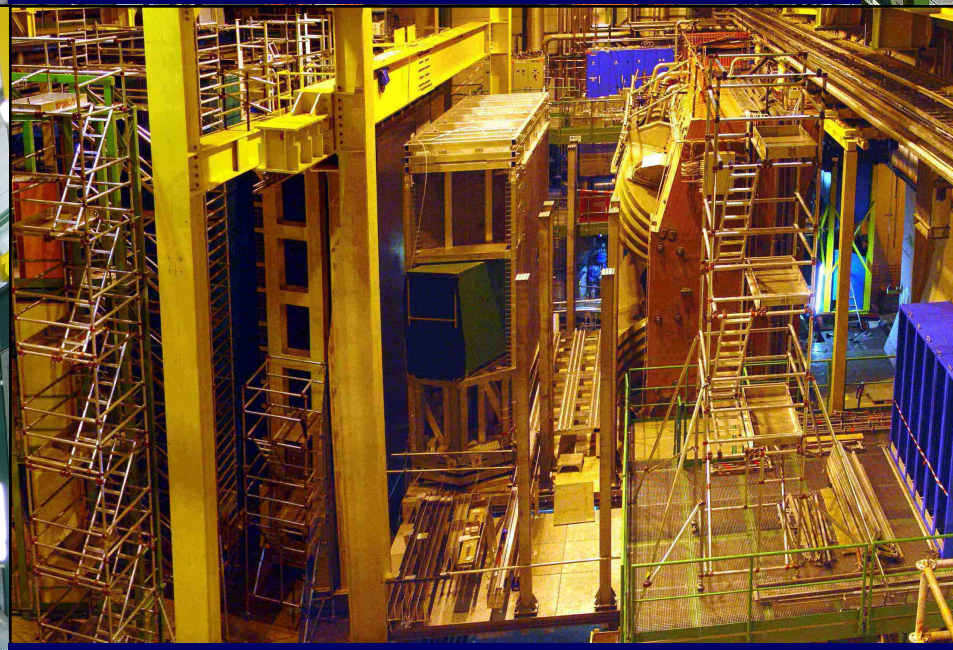
**ALICE: Primordial cosmic plasma**



**ATLAS: Higgs and dark matter**



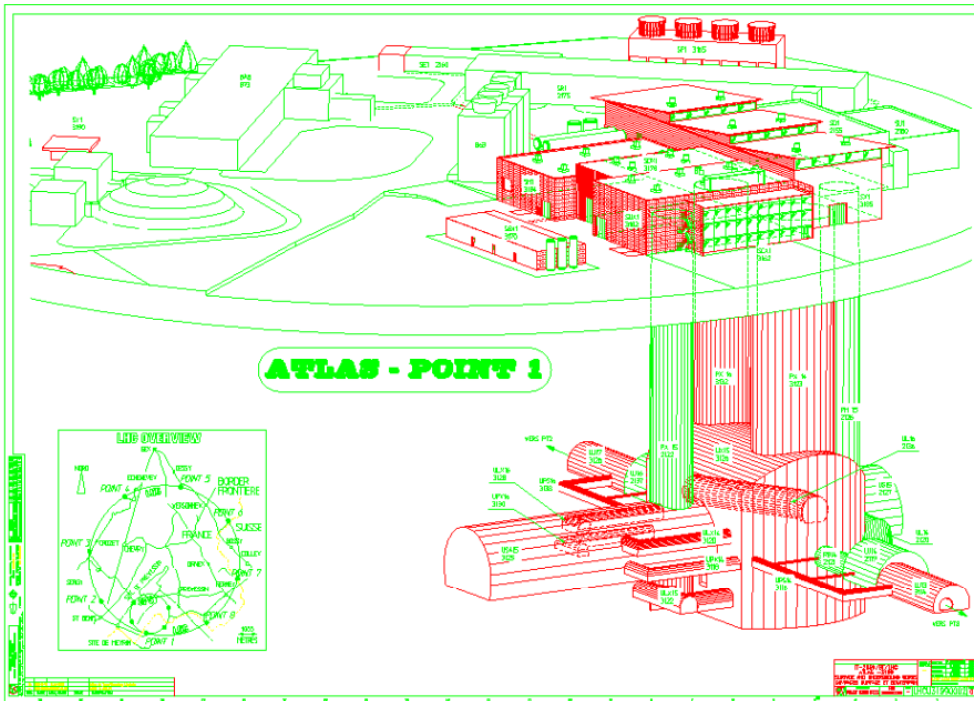
**CMS: Higgs and dark matter**



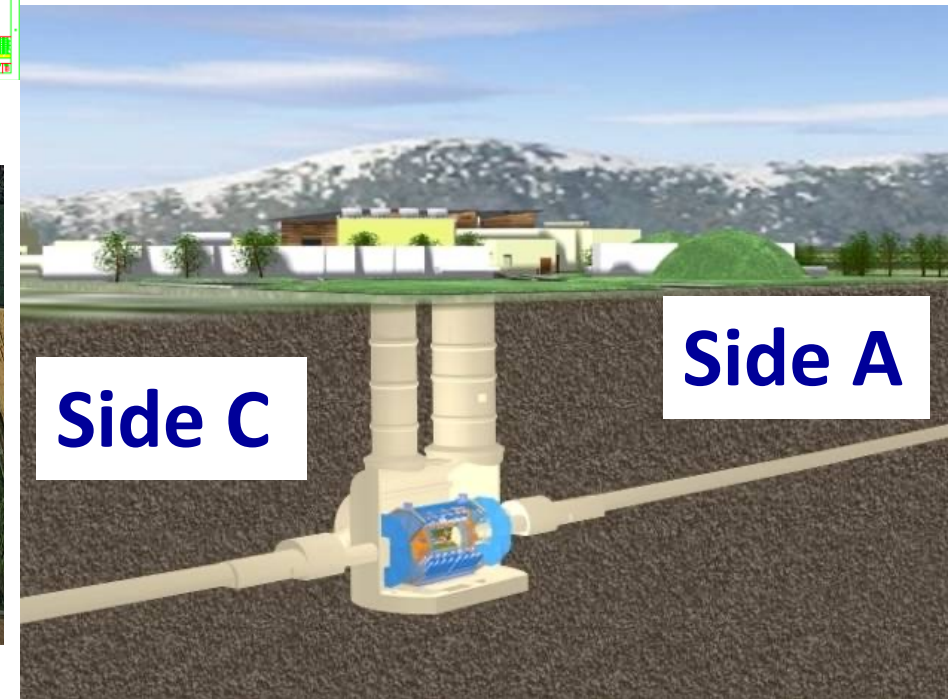
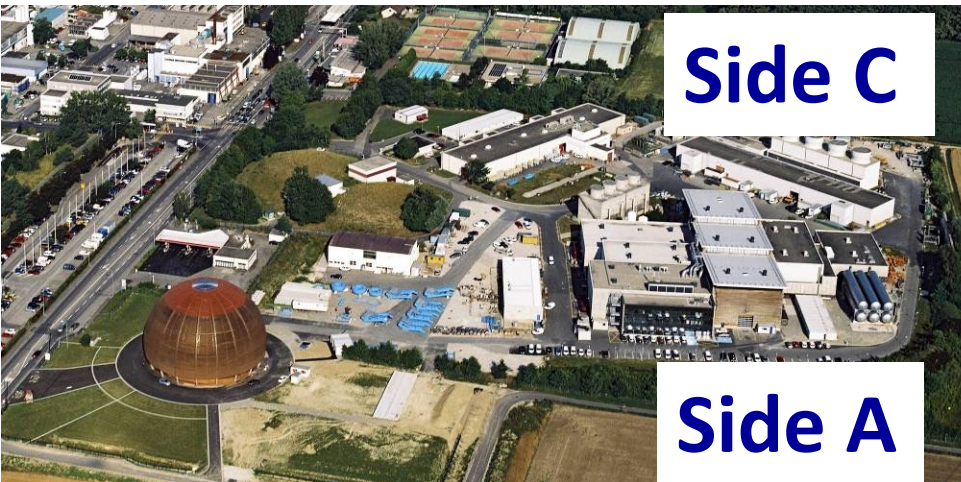
**LHCb: Matter-antimatter difference**



# The Underground Cavern for the ATLAS Detector



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



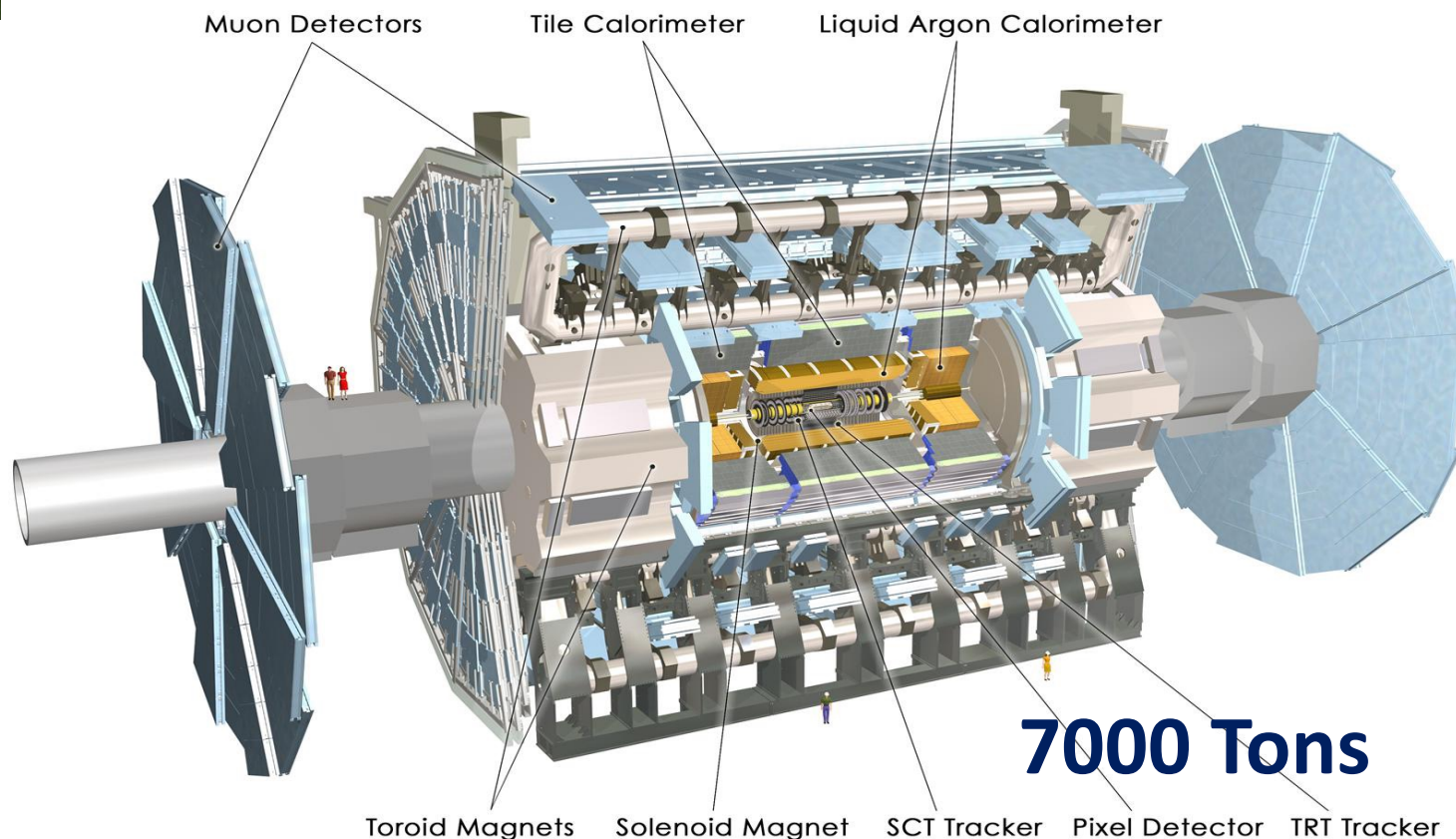


# ***ATLAS Detector at the LHC***

**~3000 Physicists**  
**550M Suisse Franks**

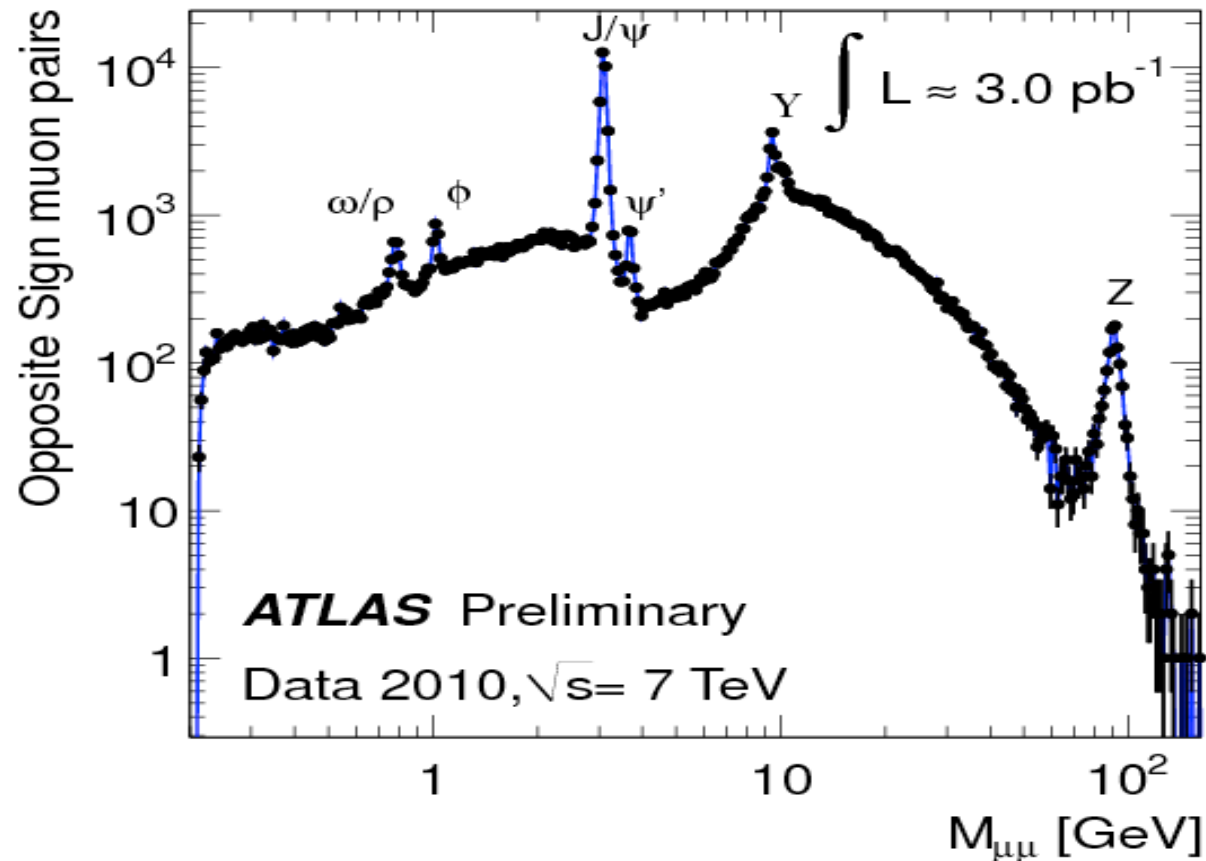
**45 m**

**24 m**



# Confirming previous measurements or discoveries

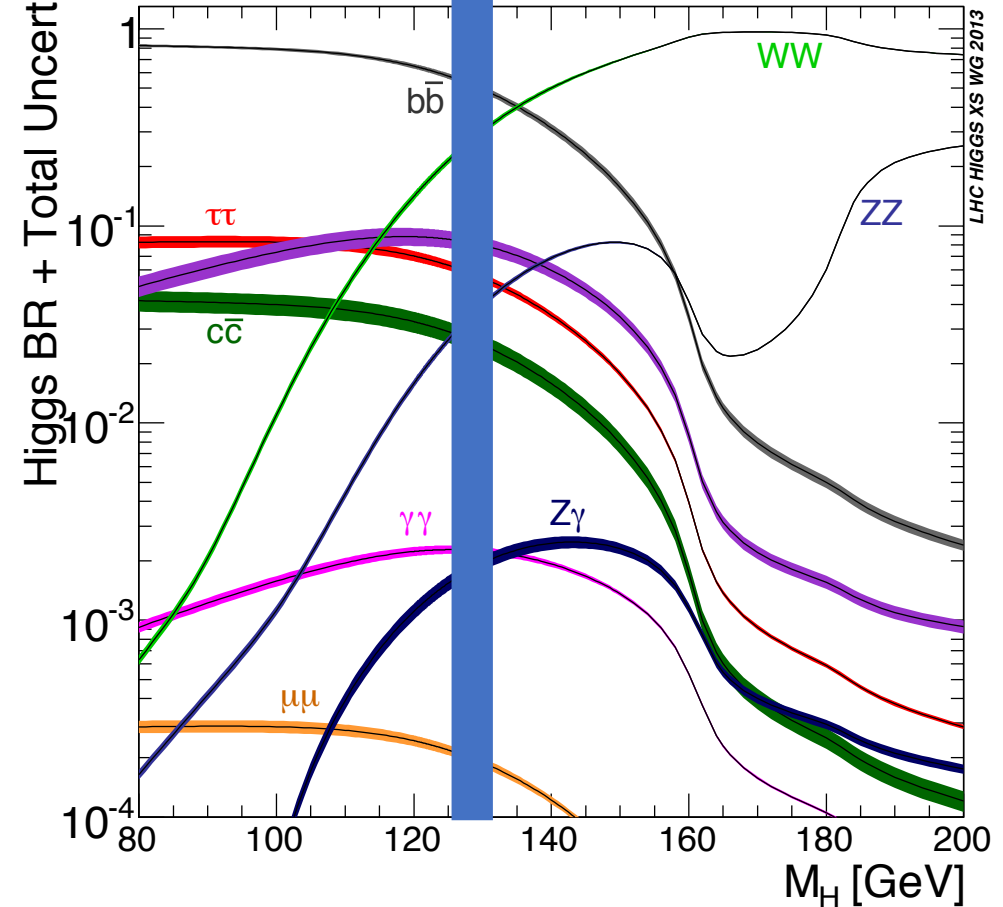
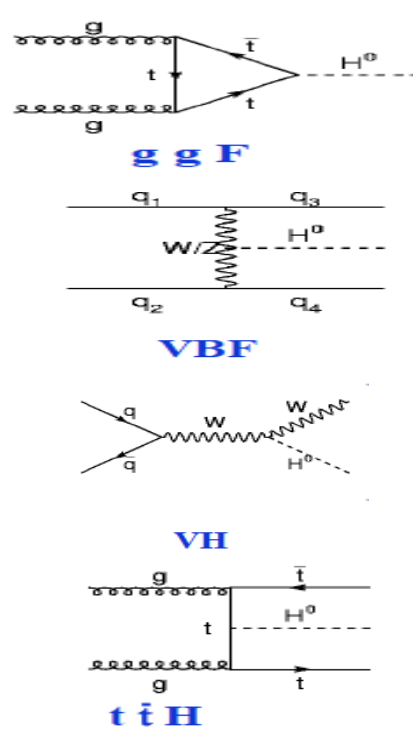
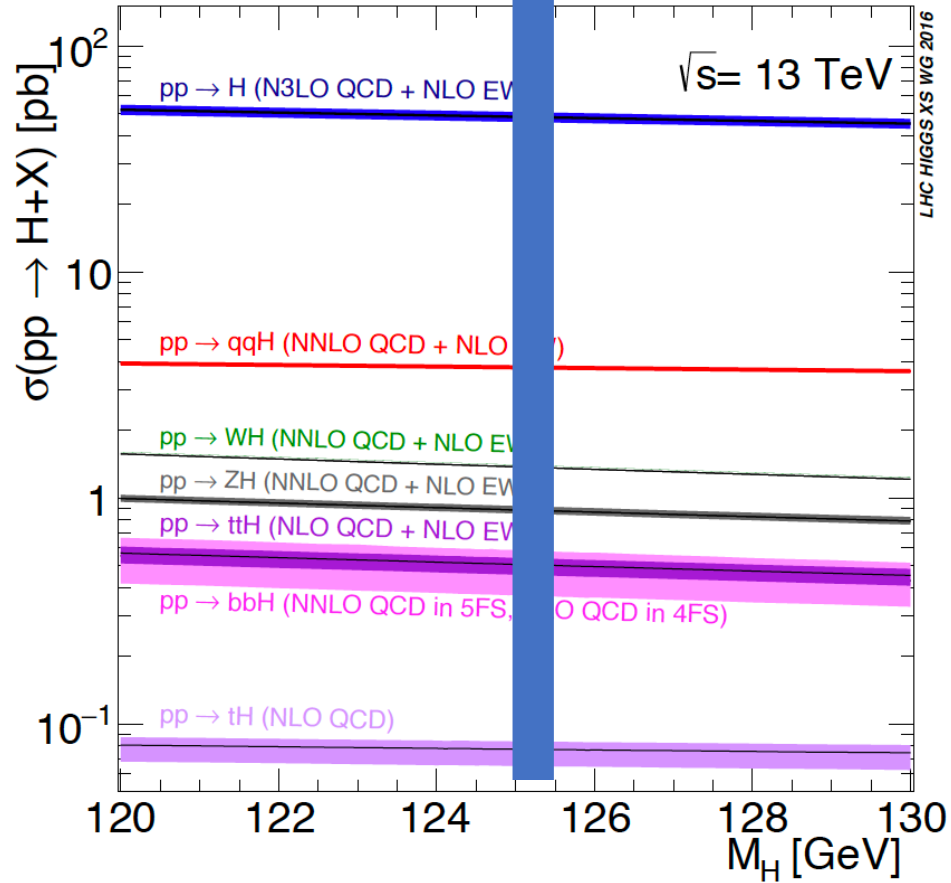
- Before we do new searches, we have to show that we measure accurately what is already known



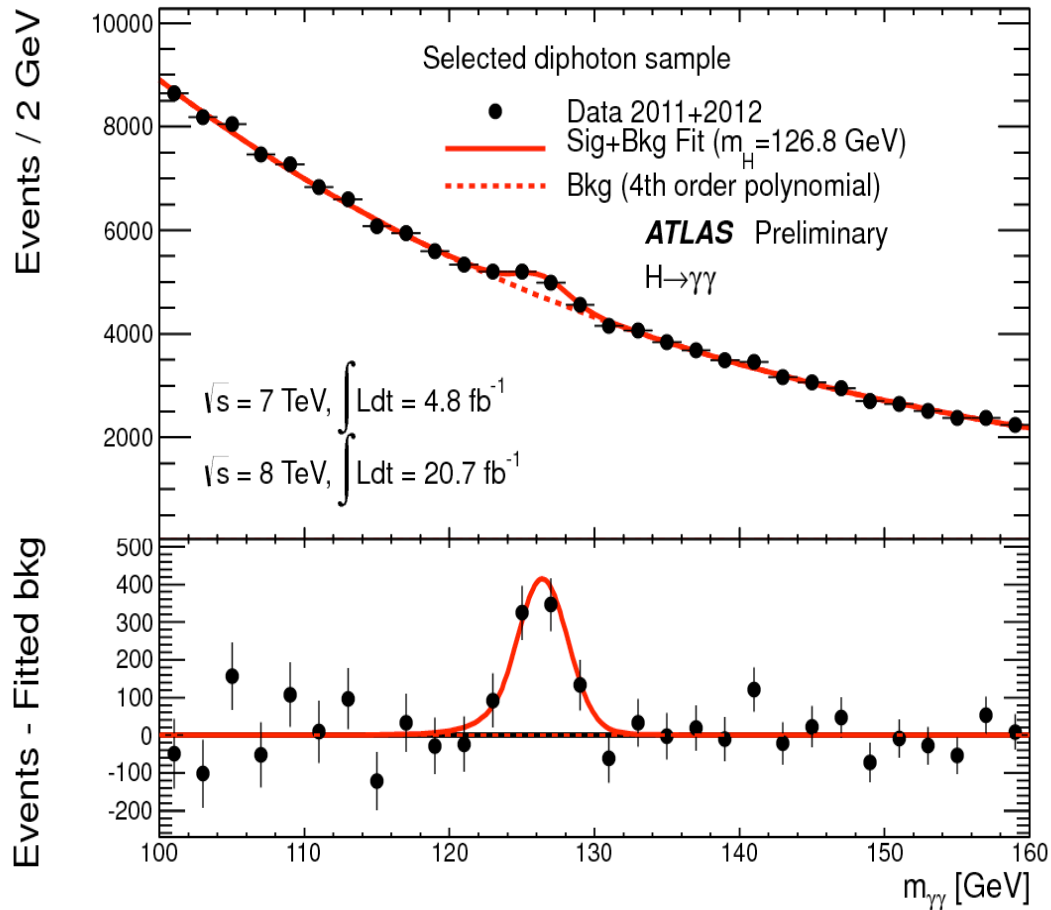


# Higgs boson production and decays

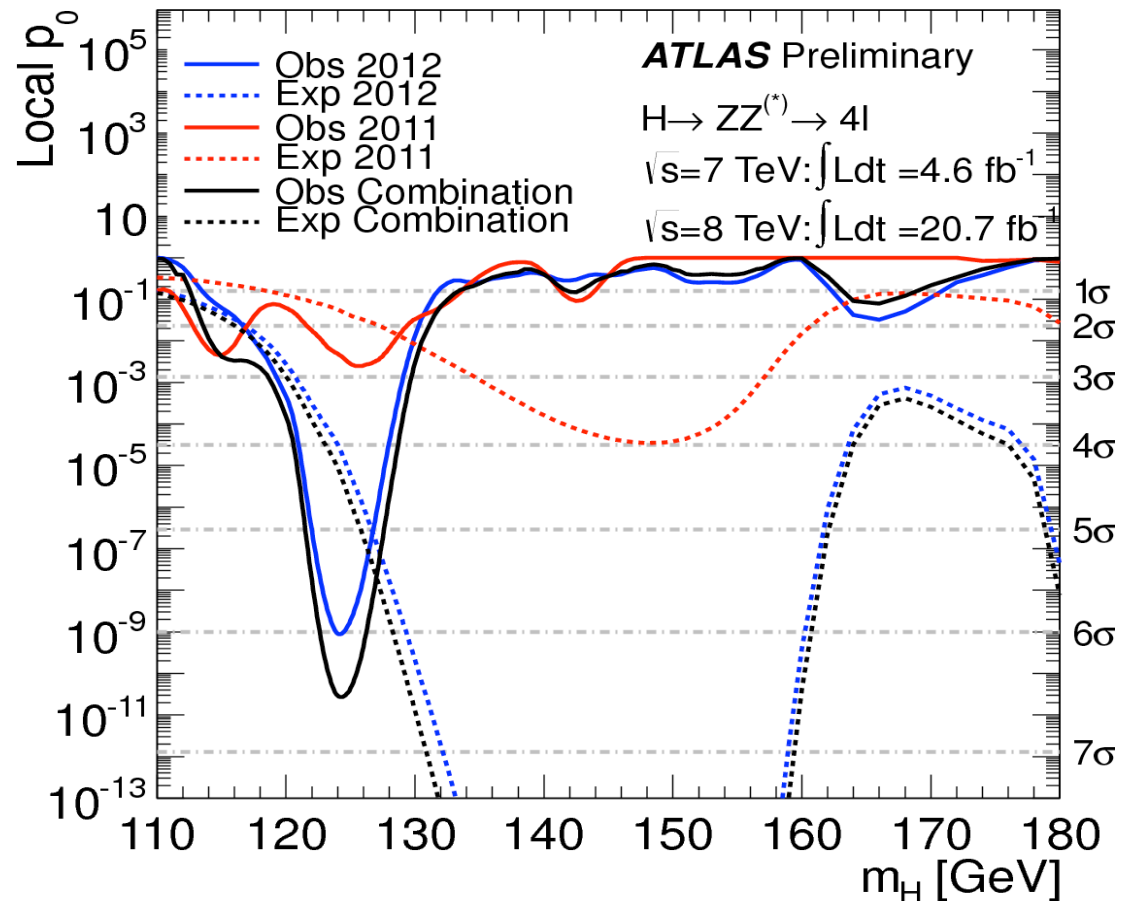
The ATLAS and CMS Experiments at the LHC have discovered, independently, a Higgs boson with mass around 125 GeV using these productions and decay modes



# The Higgs Boson Discovery

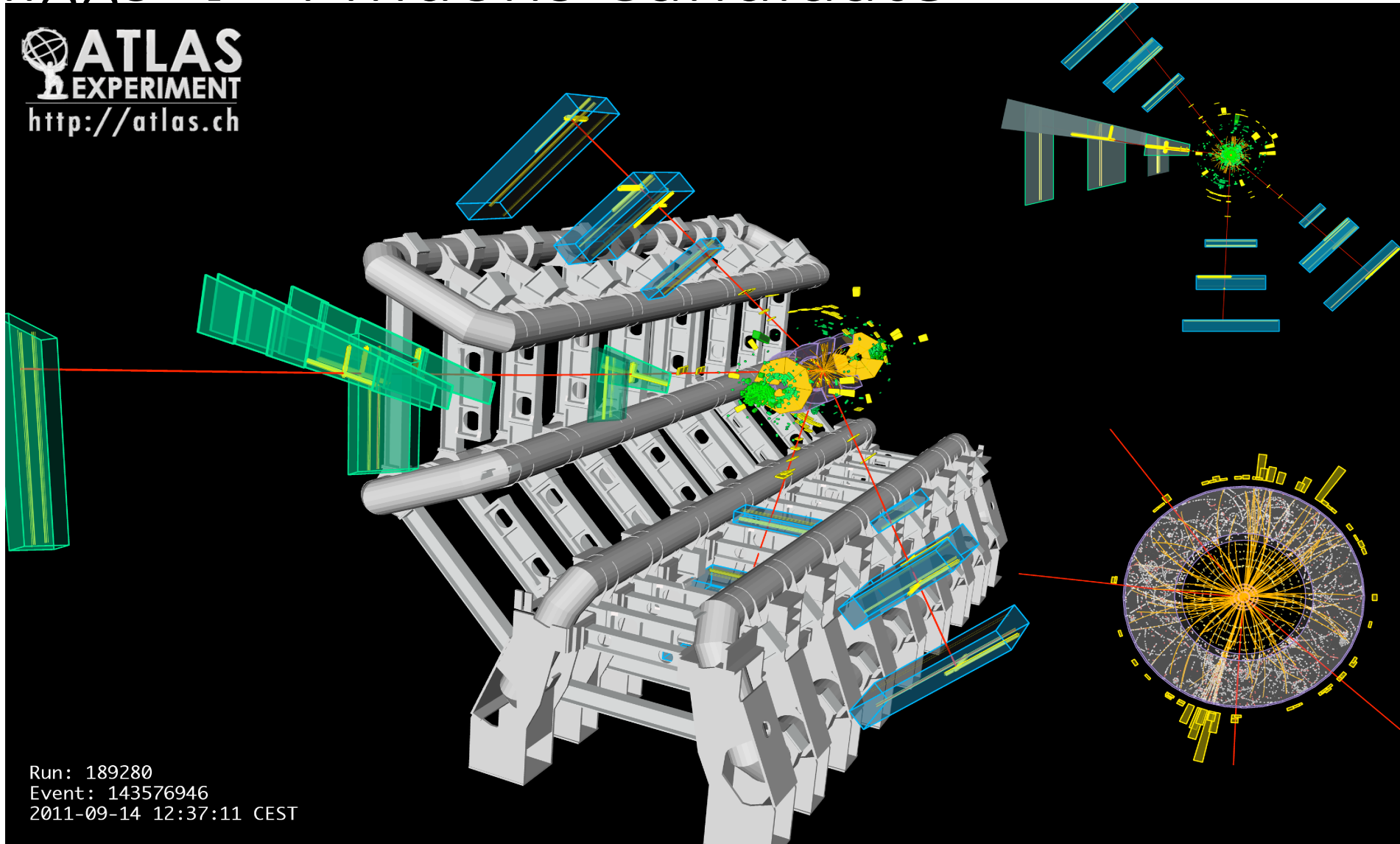


Single channel discovery:  $7.4\sigma$



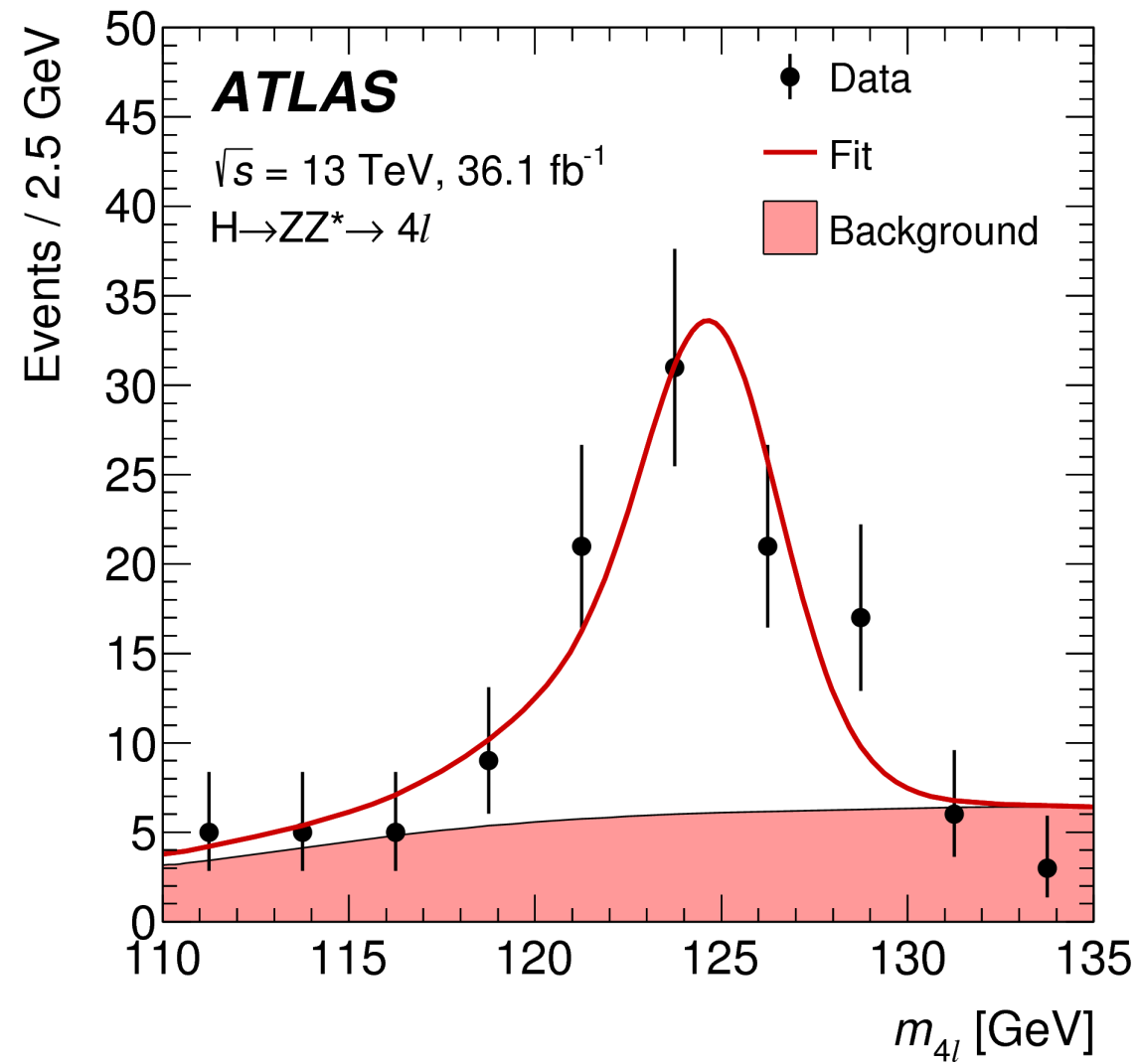
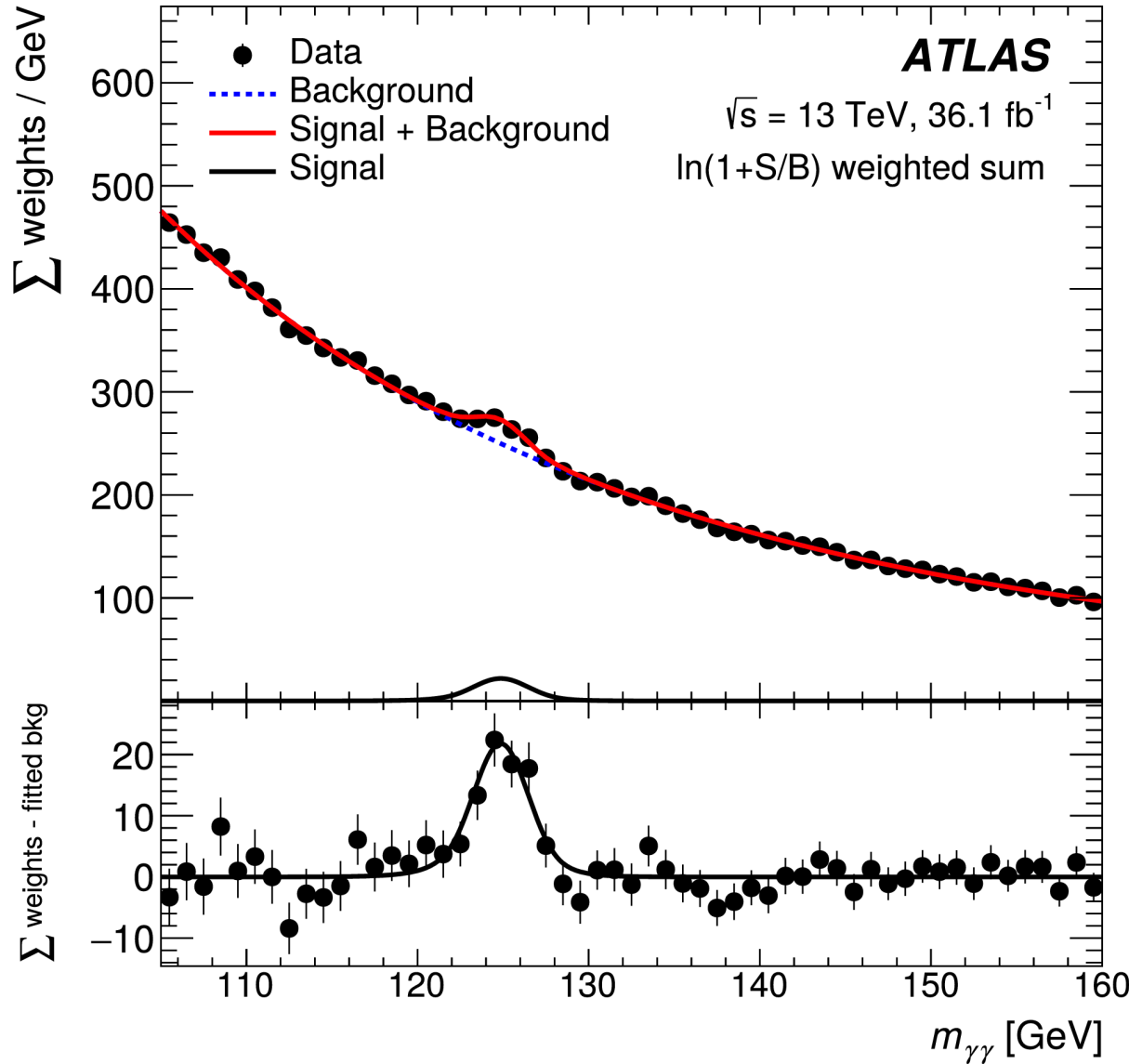
Single channel discovery:  $6.6\sigma$

# Higgs $\rightarrow$ 4 muons Candidate



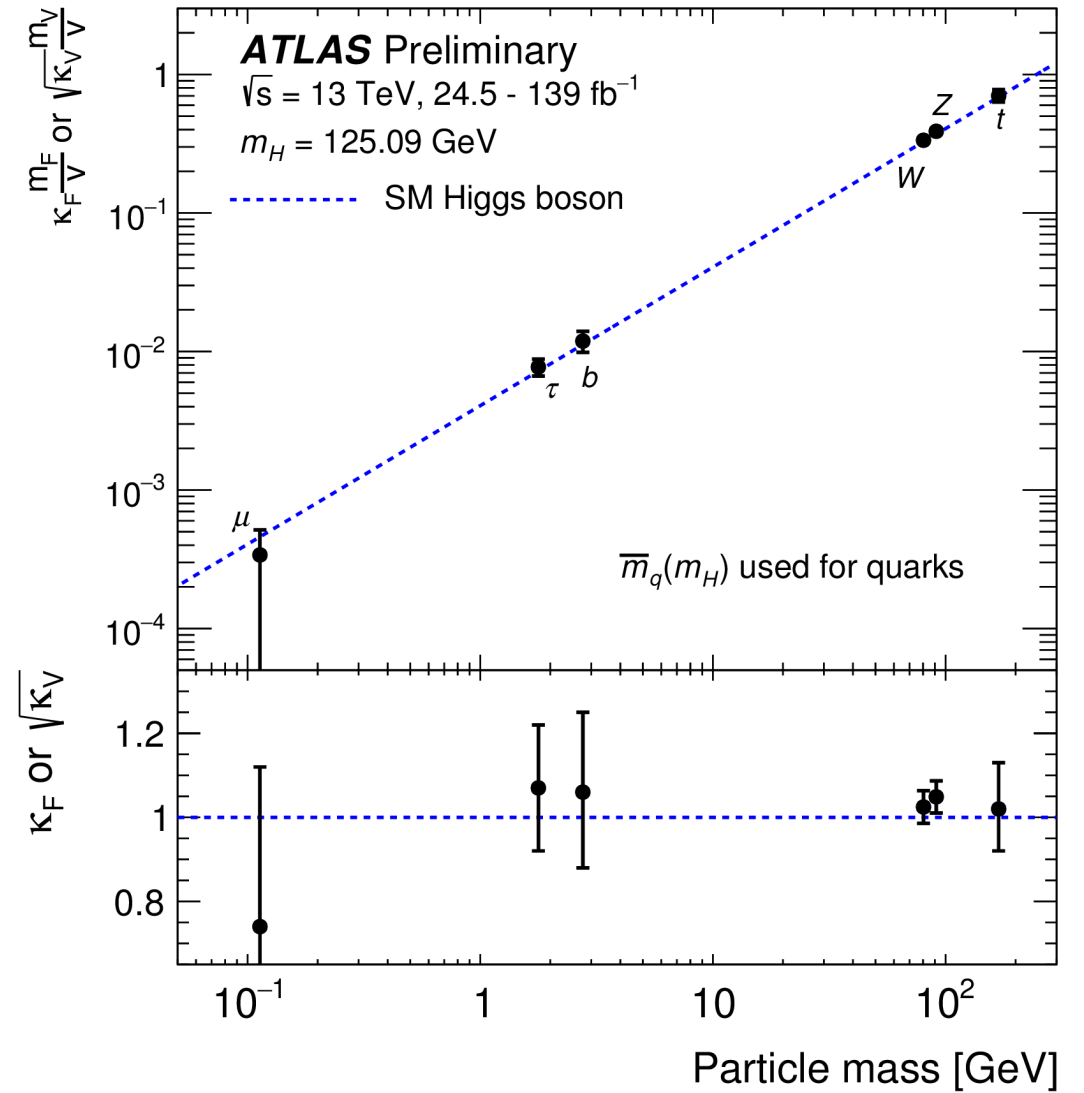


# Higgs $\rightarrow \gamma\gamma, ZZ$



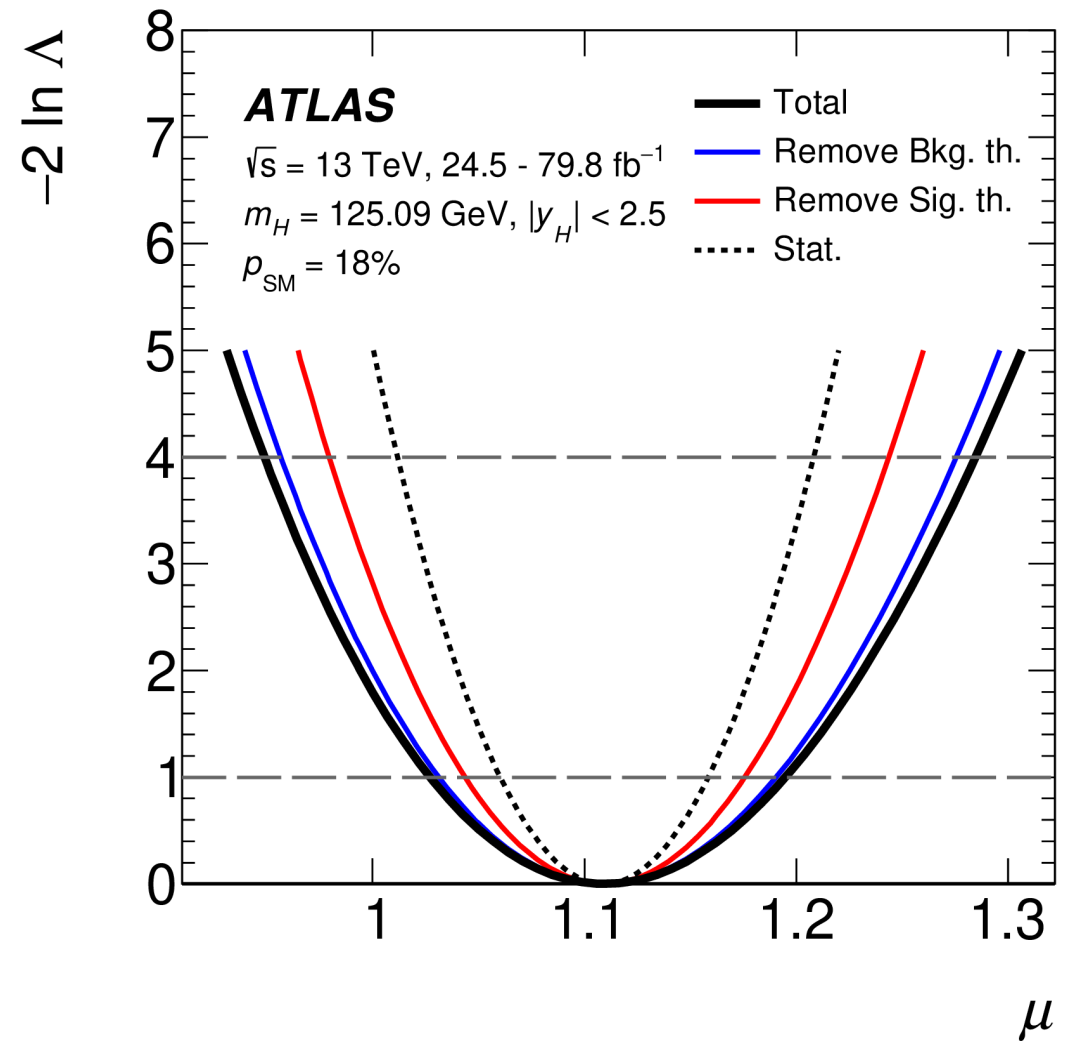
**Discovery confirmed in later measurements**

# Higgs coupling measurements

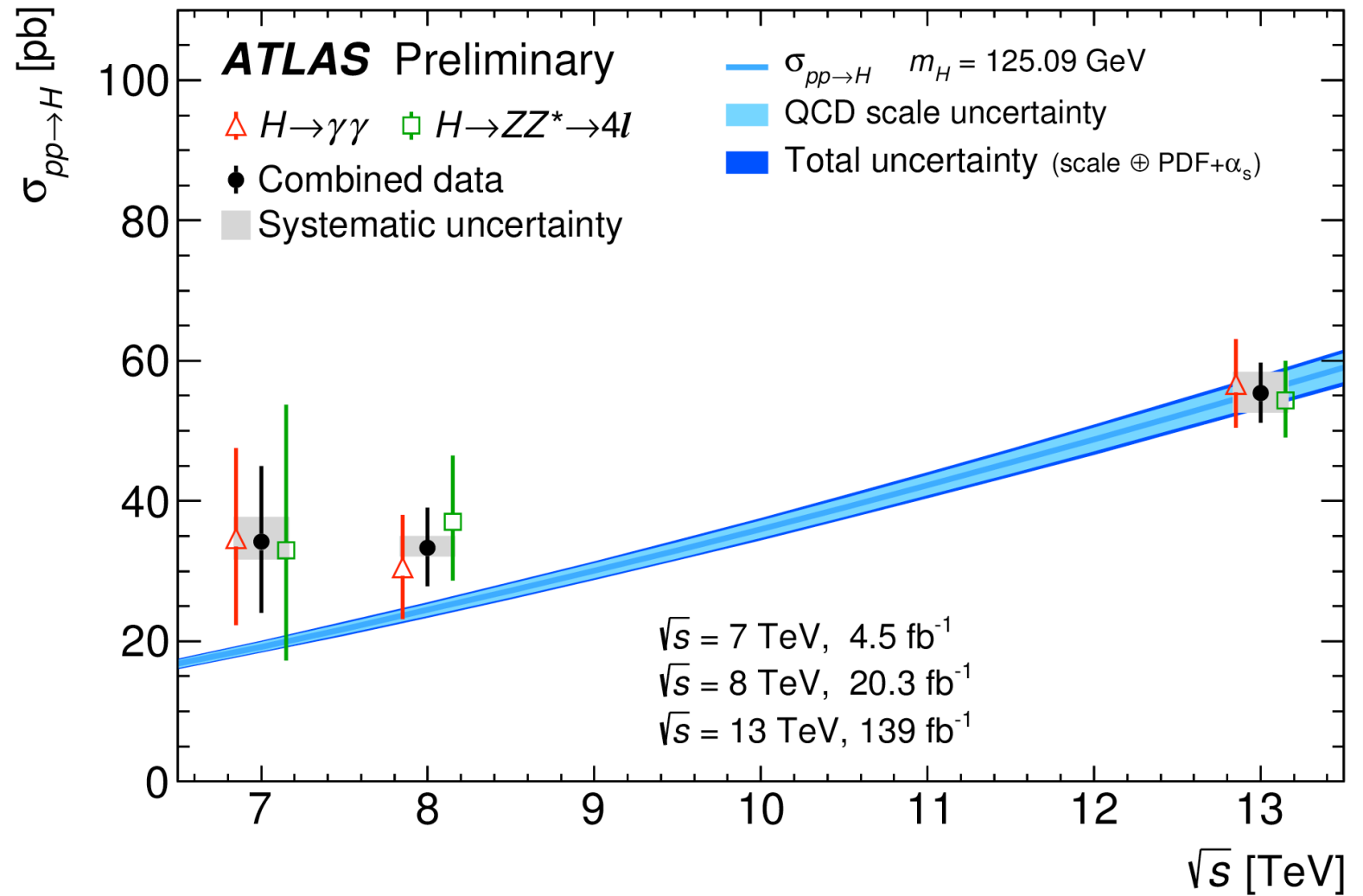
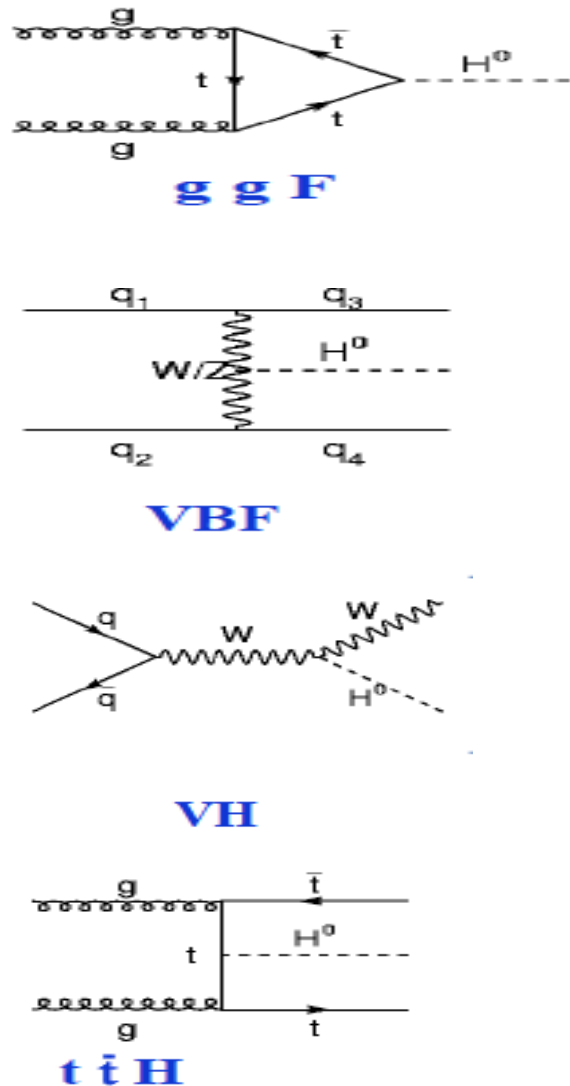


# Signal Strength relative to SM

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

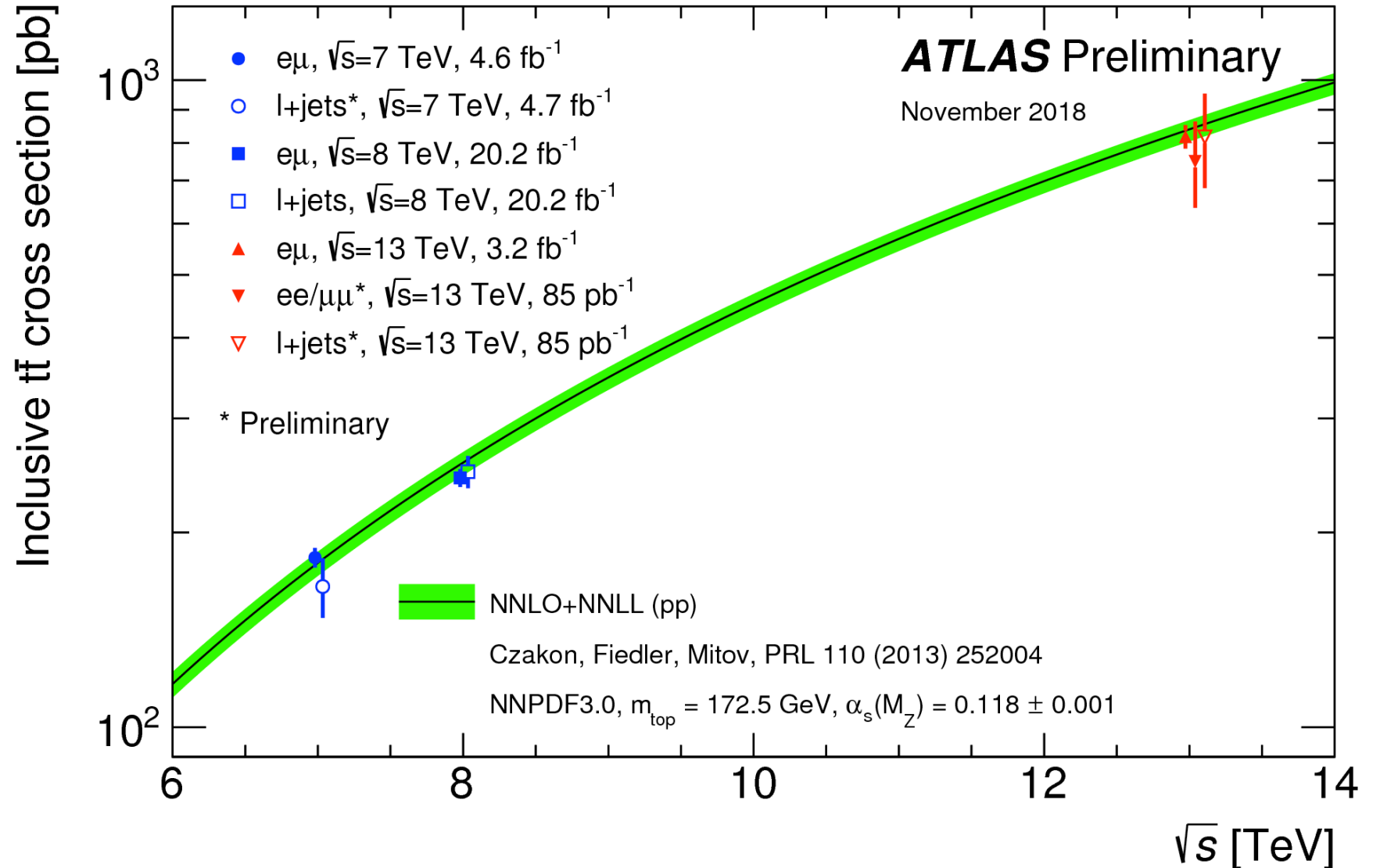


# pp → H + X Cross section measurements



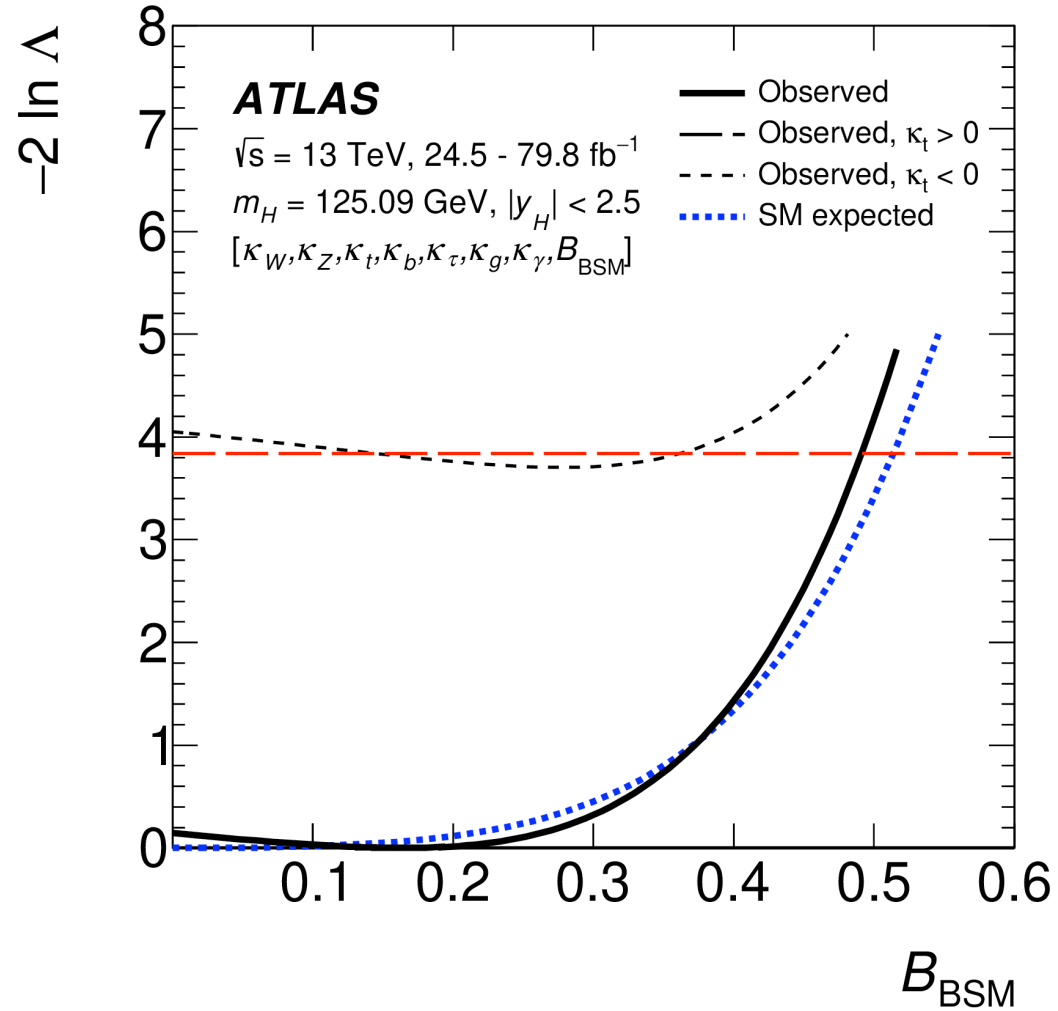
# Top-quark sector

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?**





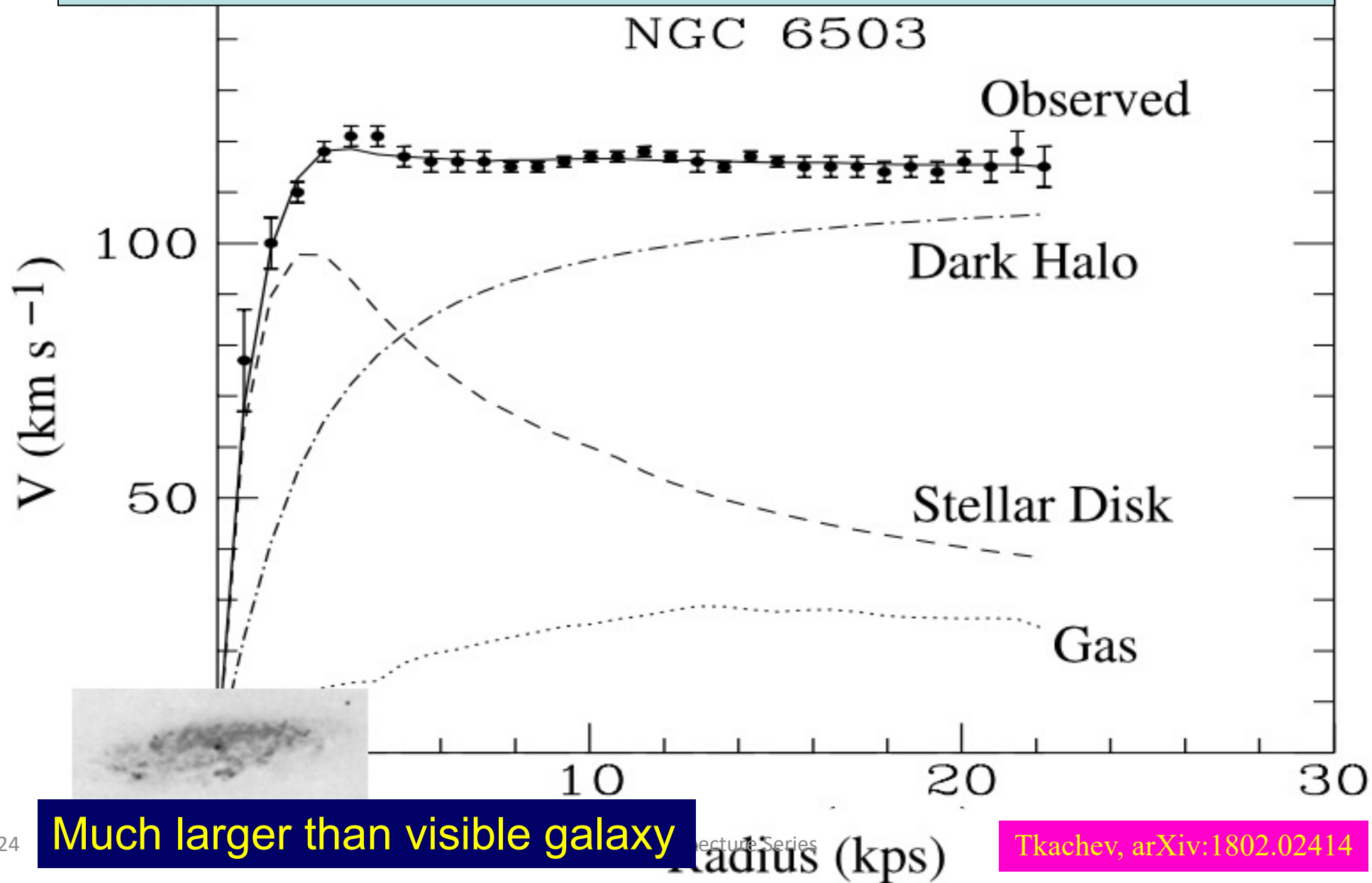
# The Rotation Curves of Galaxies

- 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

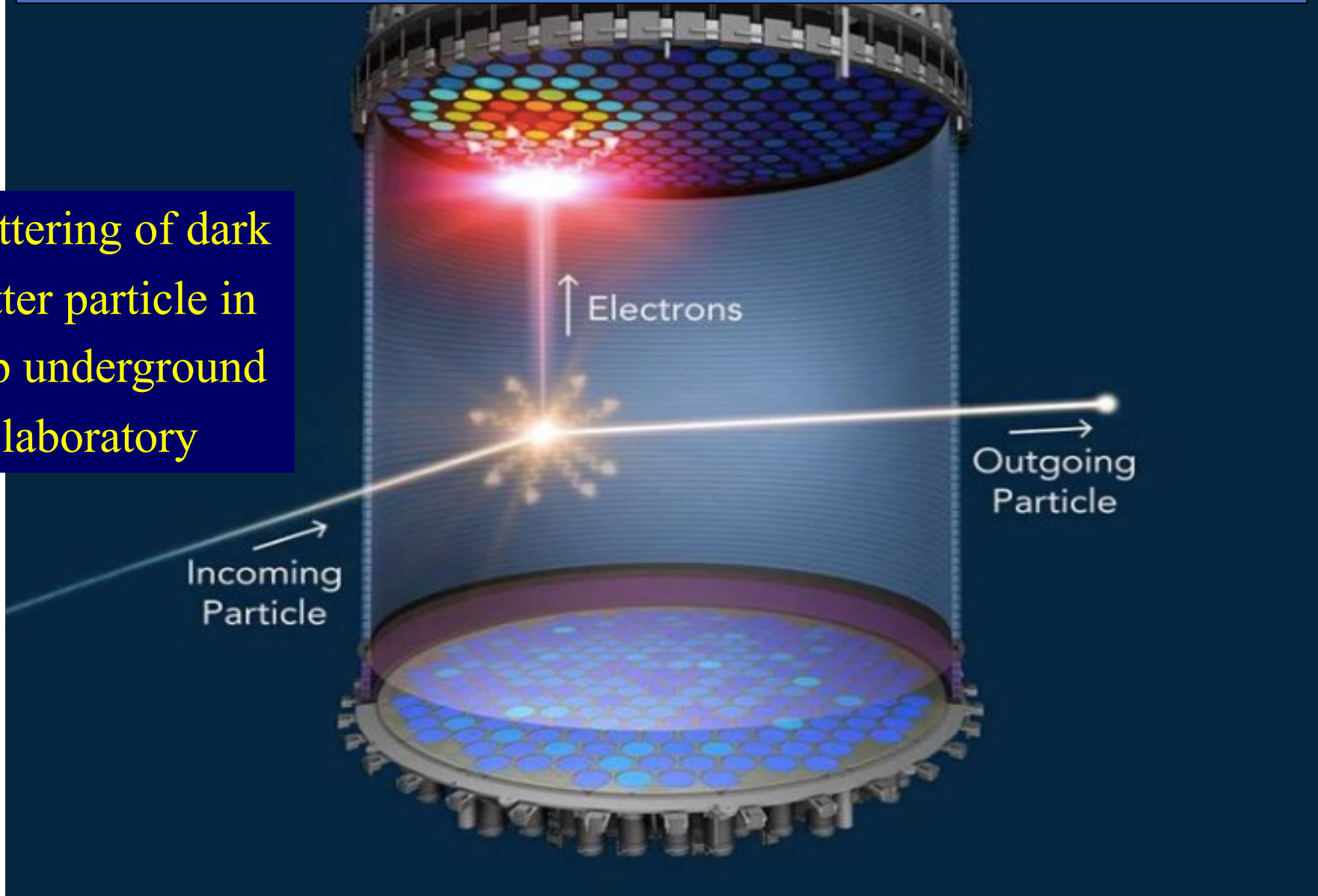
# Sample Rotation Curve: NGC 6503



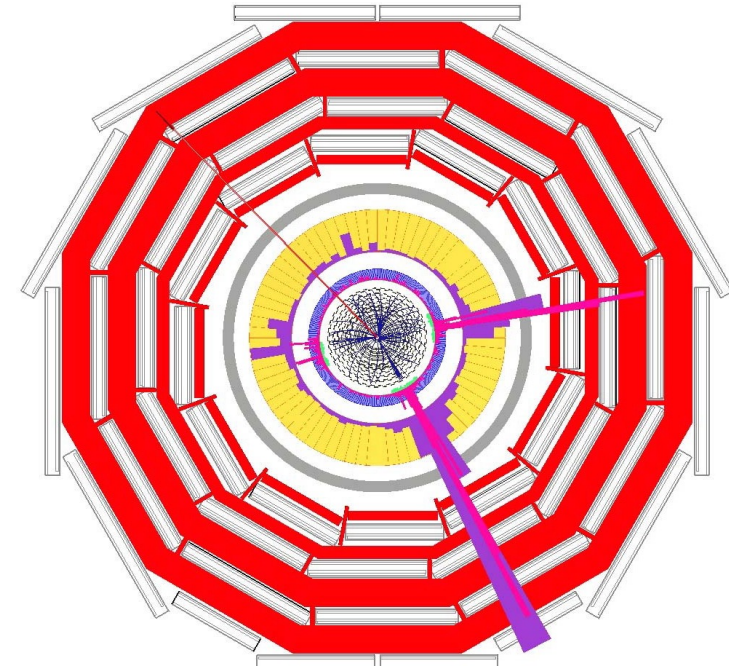
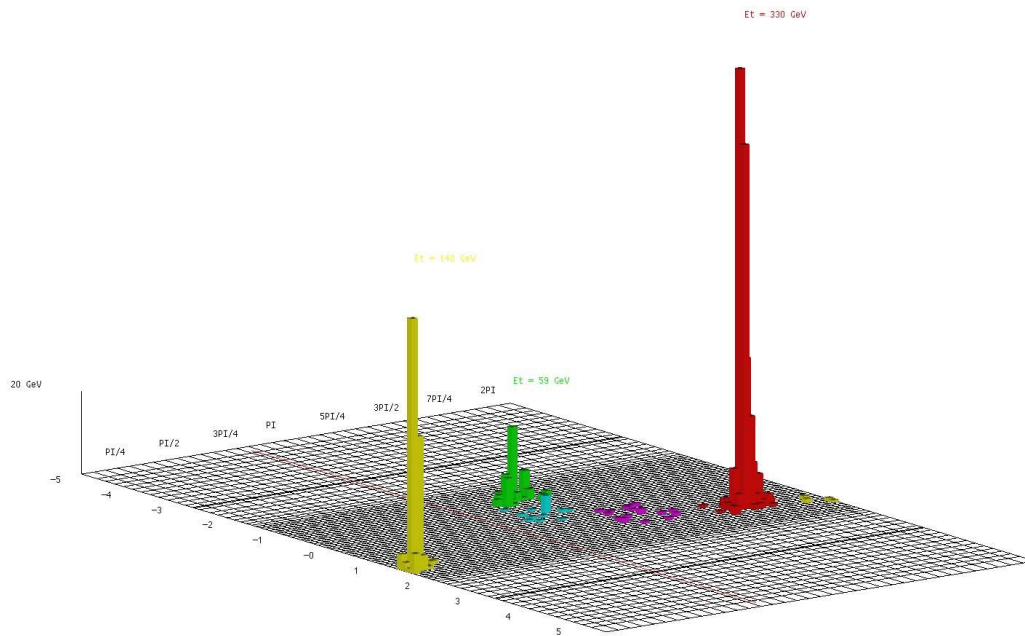
Much larger than visible galaxy

# Direct Dark Matter Detection

Scattering of dark matter particle in deep underground laboratory



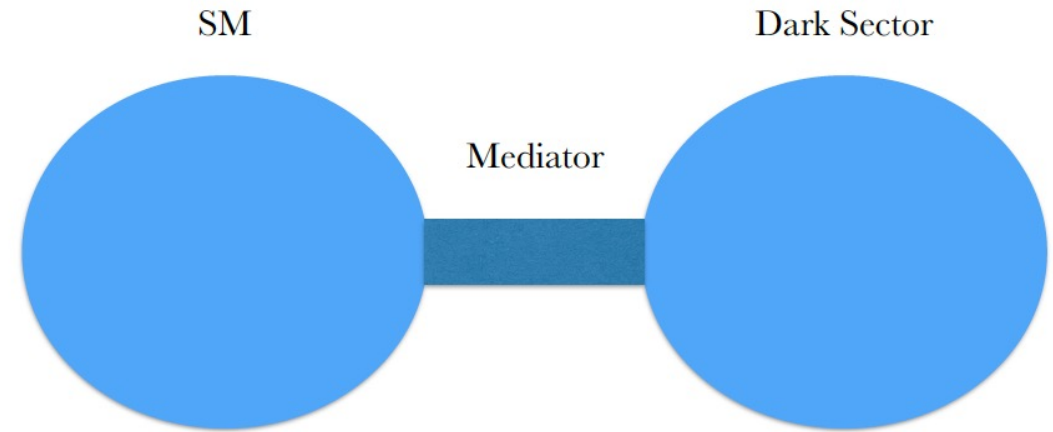
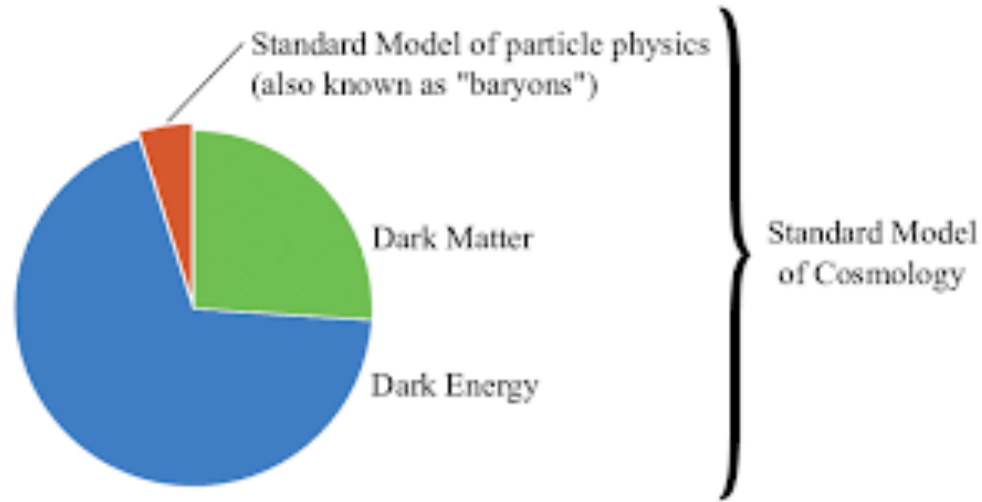
# Classic Dark Matter Signature at LHC



Missing transverse energy  
carried away by dark matter particles

# Dark Sector

- Dark Sector states as "New Physics" beyond the SM



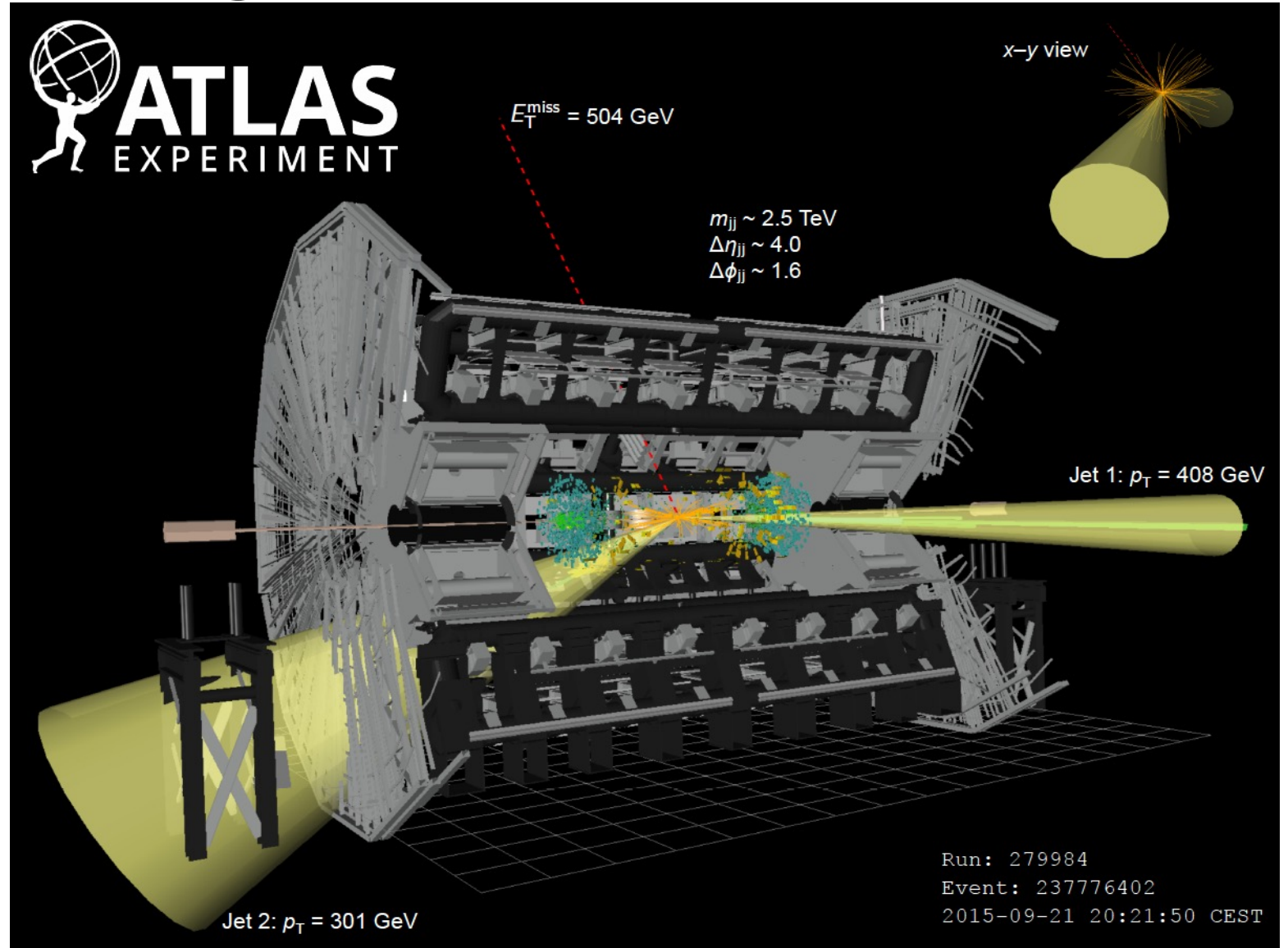
***Need new force / interaction to connect SM to Dark Sector — portals. Weak couplings through kinetic mixing, Higgs or mass mixings***

**Dark Matter could just be one example of Dark Sector States**



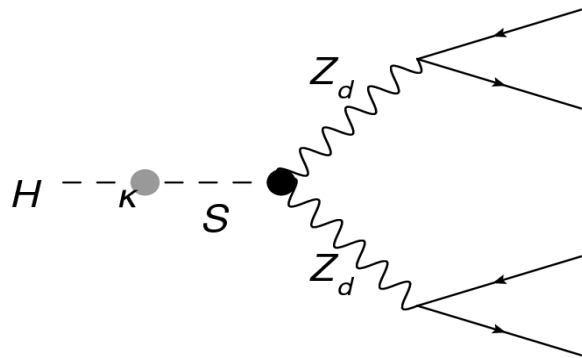
# Some Classic Signatures at LHC

Missing transverse energy carried away by Dark Matter particles



# Some Classic Signatures at LHC

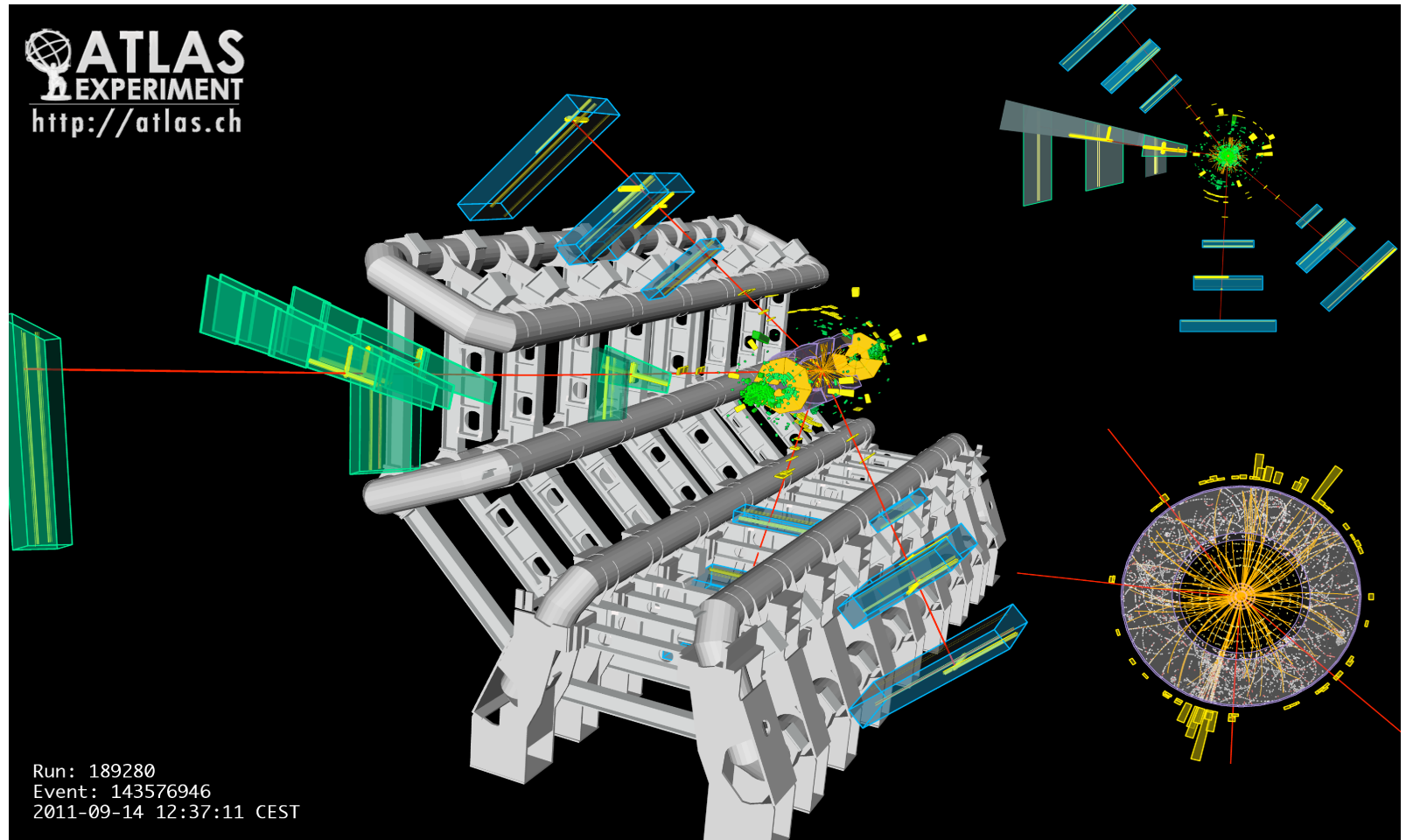
Dark Sector  
States decaying  
to SM particles



$$S / H \rightarrow Z_d Z_d \rightarrow 4l$$

where  $S$  = Dark Scalar

$Z_d$  = Dark Vector Boson

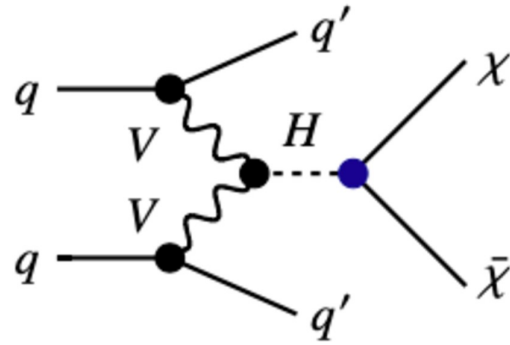


# H $\rightarrow$ invisible

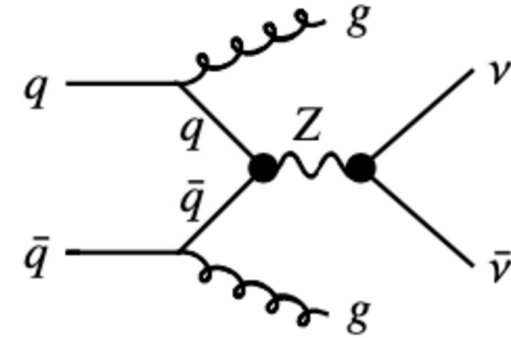
- **Some Dark Sector particle  $\chi$ , neutral and stable over the range of the detector**
  - It is not a neutrino. A BSM-Particle
  - Its mass  $m_\chi < m_H / 2$  such that  $H \rightarrow \chi\chi$ . The detector would be insensitive to such a decay so we call it  $H \rightarrow$  invisibles
- **If it is “invisible”, how do we detect it?**
  - Since the particle  $\chi$  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
  - **$\chi$  could be a candidate for Dark Matter particle**



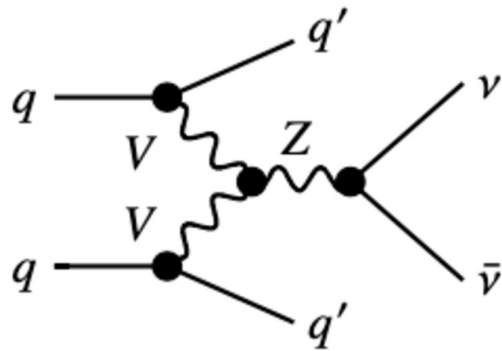
# H $\rightarrow$ invisible



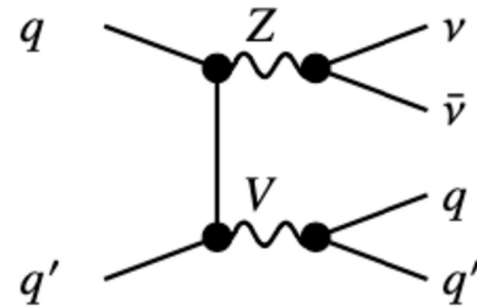
(a) Signal process



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



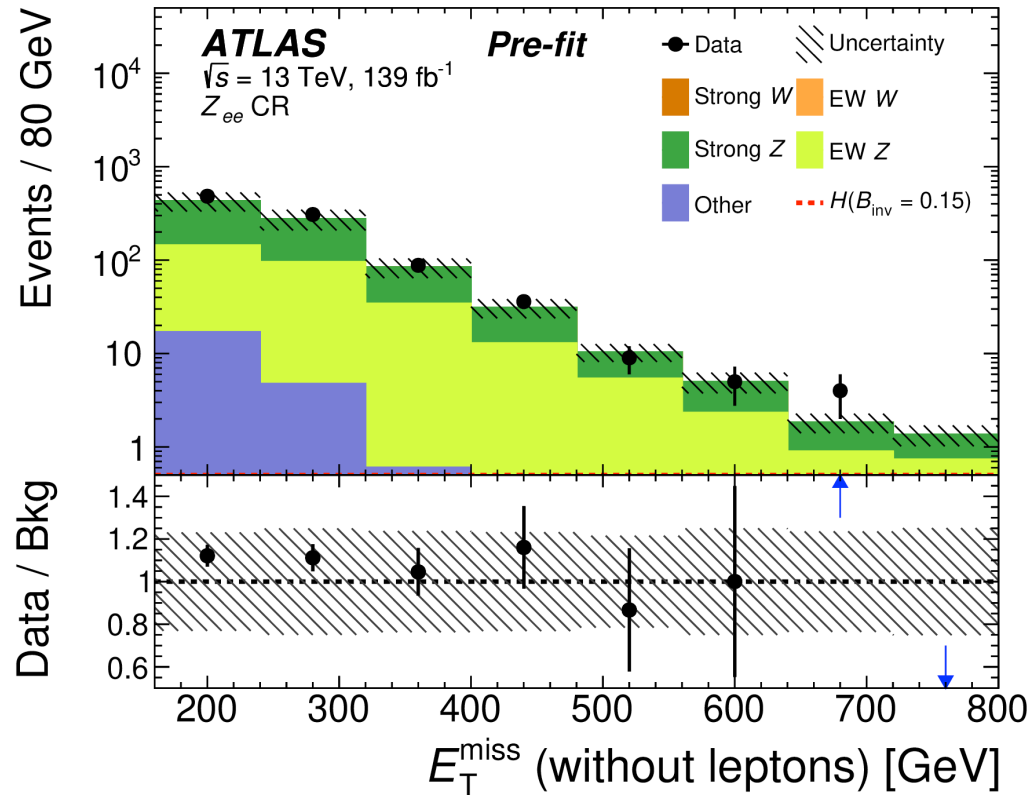
(c) Example diagram for the electroweak VBF Z+jets background process



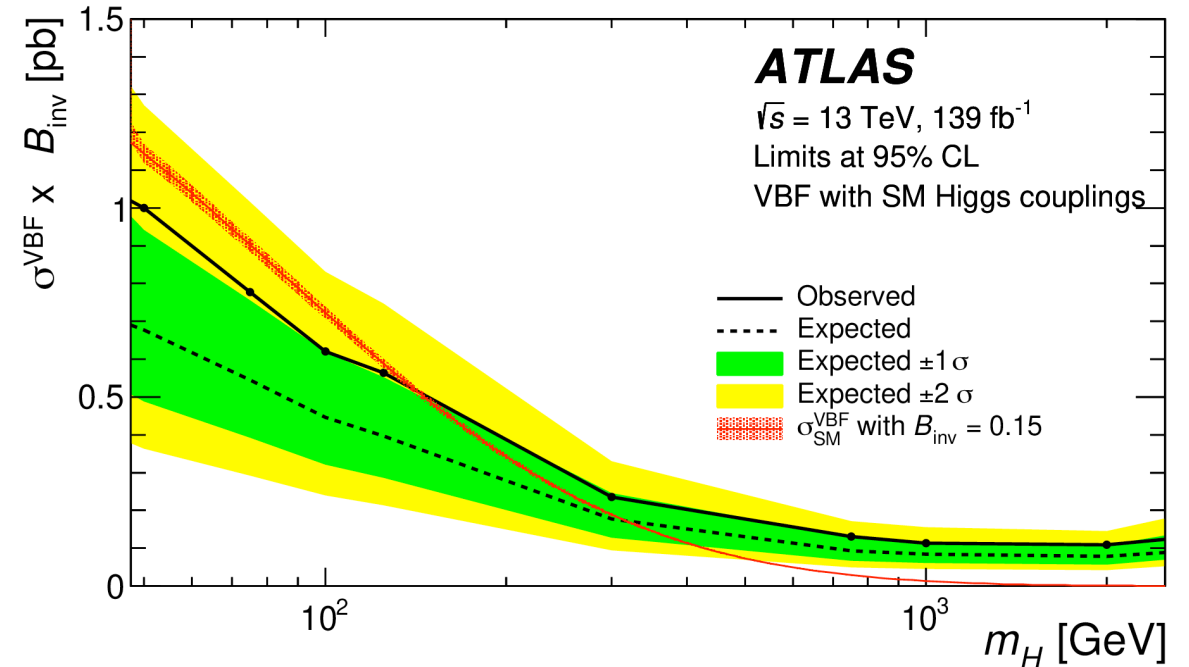
(d) Example diagram for the electroweak diboson process

# H $\rightarrow$ invisible

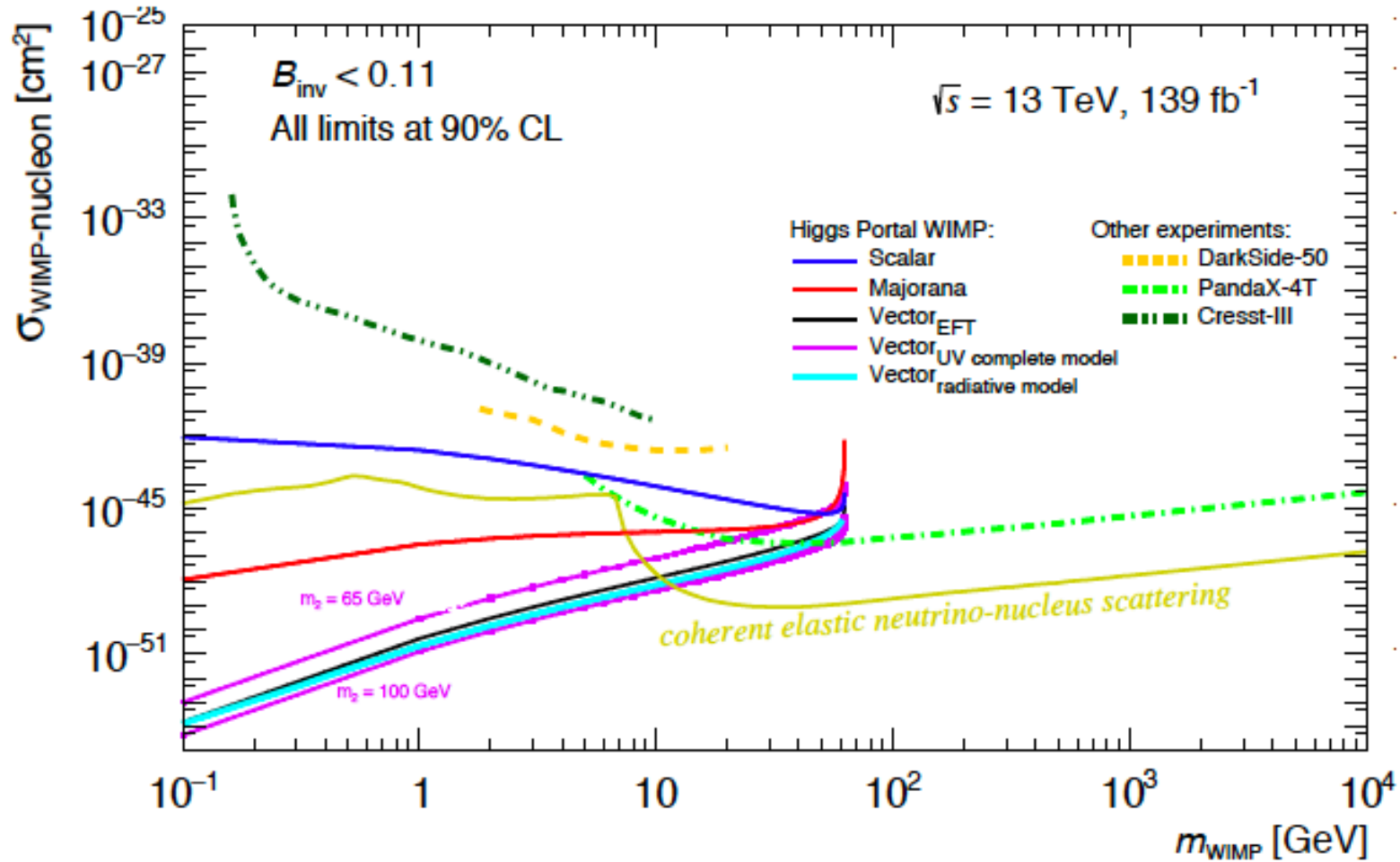
**Branching Ratio Limit < 0.15  
at 95% Confidence Level**



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



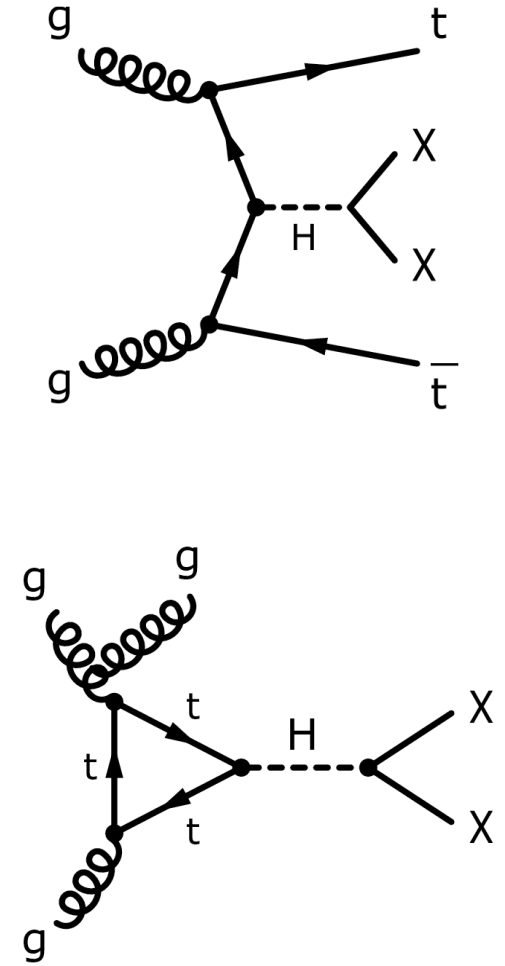
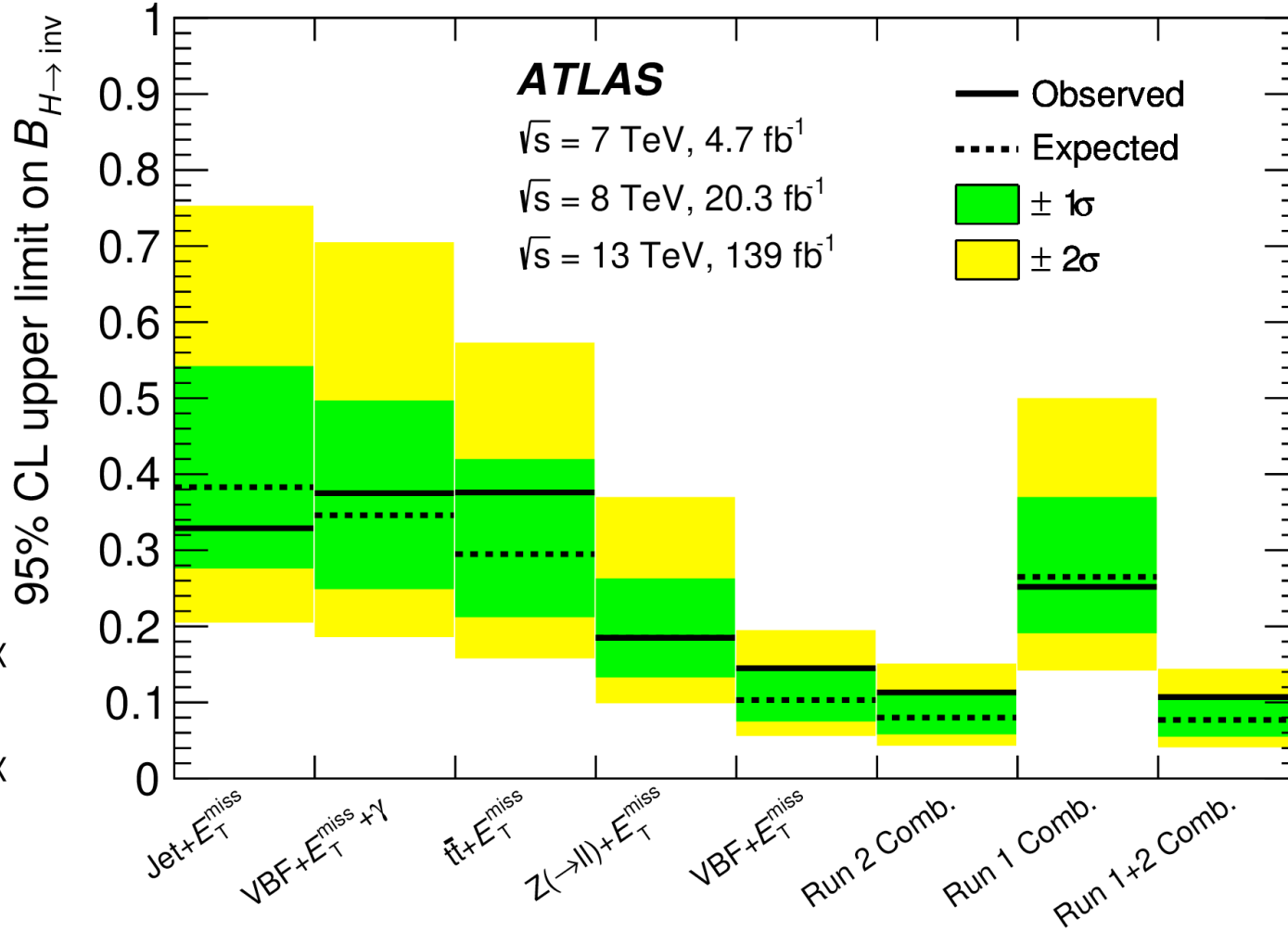
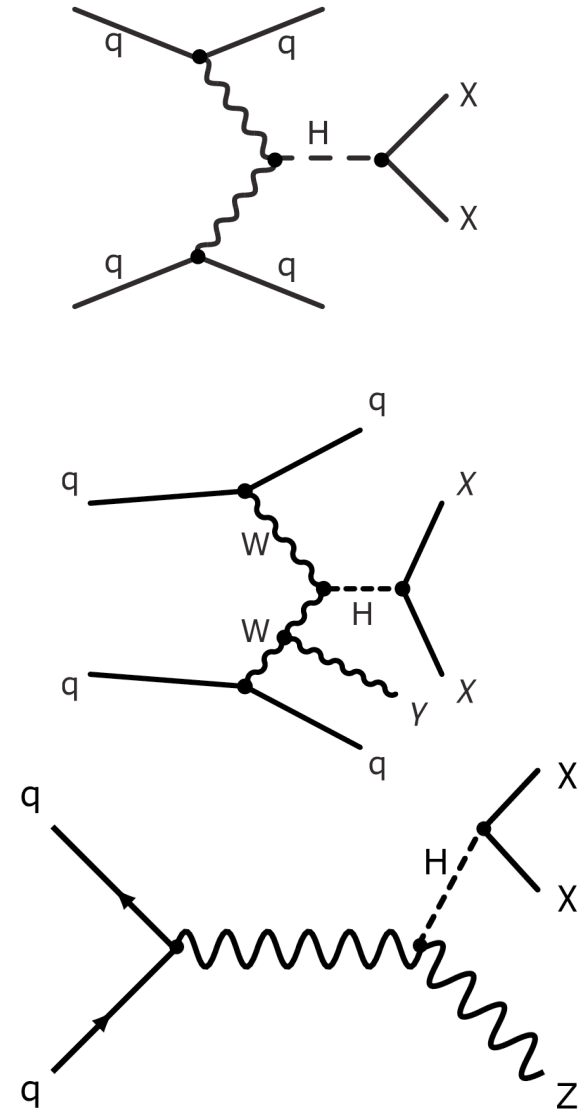
# H $\rightarrow$ invisible — Dark Matter interpretation



Work I did with Mohamed Zaazoua (graduate student from Morocco, alumnus of the African School of Physics 2021), currently a post-doc on ATLAS. Published here <https://doi.org/10.31526/lhep.2022.270>

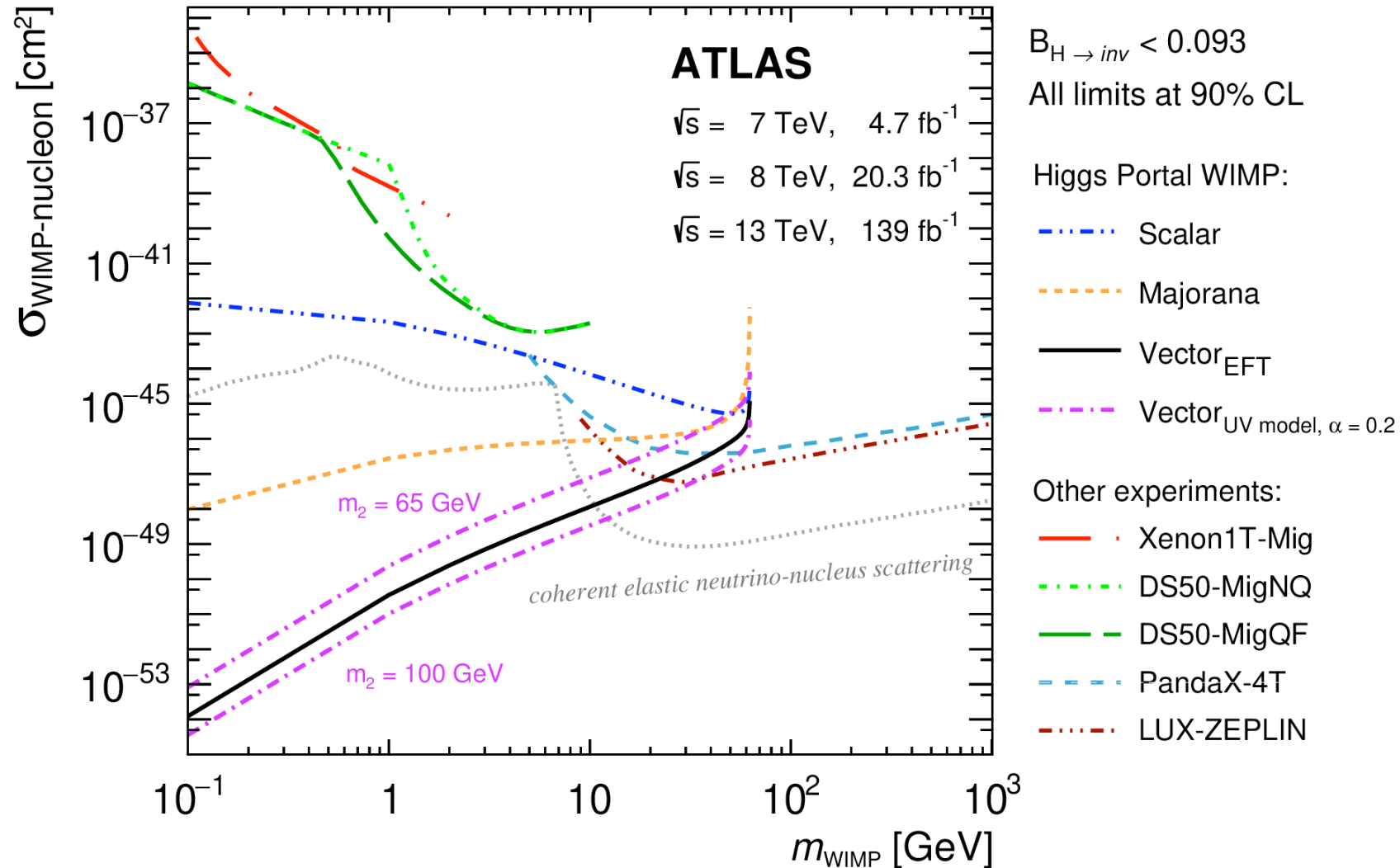
# H $\rightarrow$ invisible combination

BR (H  $\rightarrow$  invisible) < 10% at 95% CL



# H → invisible — Dark Matter interpretation

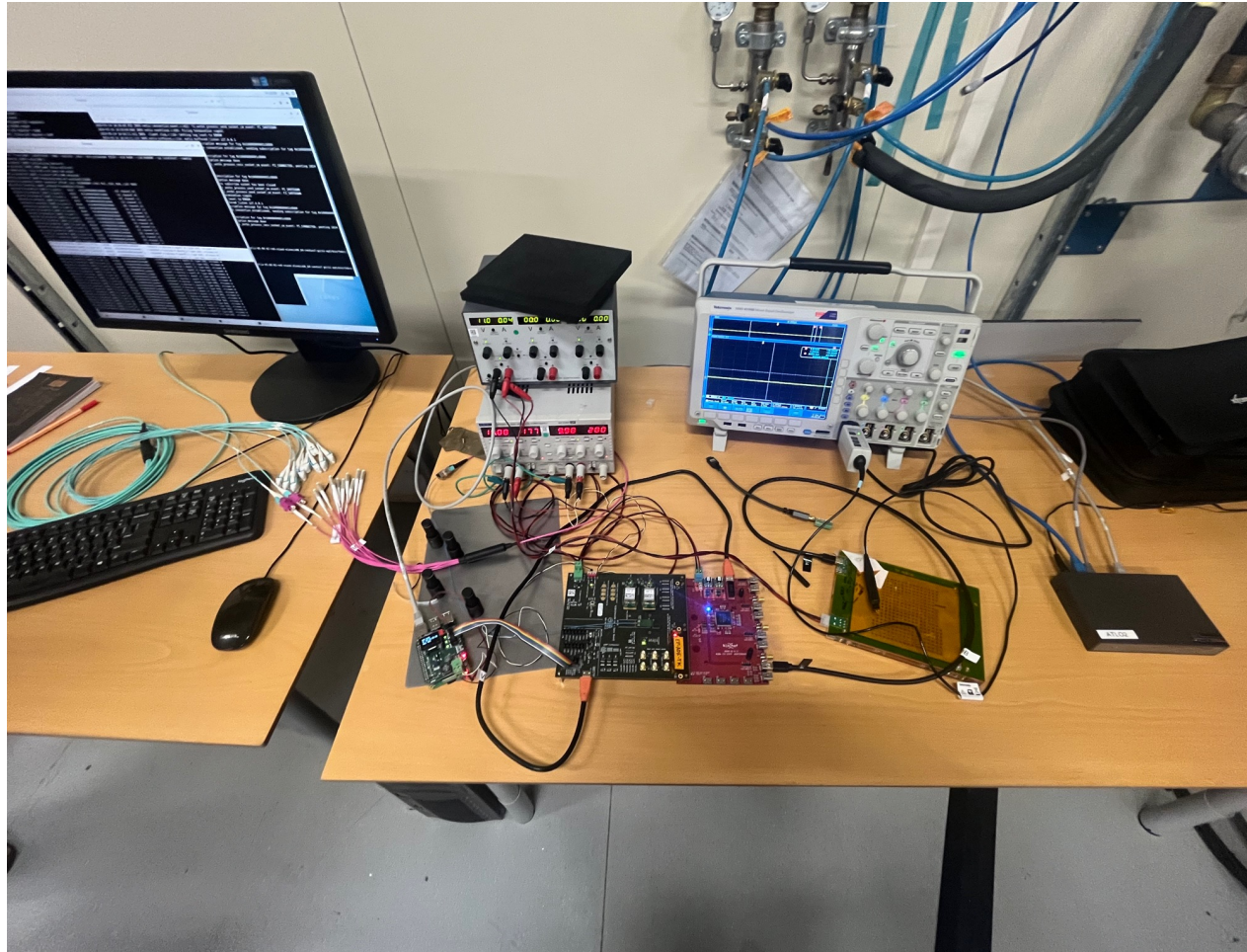
## Upper bound of the DM-Nucleon Scattering Cross Section



# ITk—FELIX readout test stand

@CERN—similar setup, in Lab 1-203, being developed at BNL

**Objective (1):**  
Run stave tests with FELIX



**Objective (3):**  
Develop data readout system further in the framework that will be used for ITk in HL-LHC

**Objective (2):**  
Demonstrate that data path between host and HCC\*/ABC\* works correctly

**The Front-End Link eXchange (FELIX) — interface between the trigger and detector electronics for ATLAS**



# Broader Impact

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



## 3. International Outreach

- ❖ US-ATLAS Outreach: Africa, Asia, Latin America
- ❖ The African School of Physics
- ❖ The African Physics Strategy
- ❖ Research visits
- ❖ Mentorship / coaching



## Morocco, April & July 2024

**THE EIGHTH BIENNIAL AFRICAN SCHOOL OF FUNDAMENTAL PHYSICS AND APPLICATIONS (ASP2024)**

Co-organized by Cadi Ayyad University and Mohammed V University at Faculty of Science Salmalia, Marrakesh, Morocco  
 April 15<sup>th</sup>-19<sup>th</sup> and July 7<sup>th</sup>-21<sup>st</sup>, 2024

**ASP MISSION**  
 To increase capacity development in fundamental physics and related applications in Africa. The ASP has evolved to be much more than a school. It is a program of actions with directed ethos toward physics as an engine for development in Africa.

**SCIENTIFIC PROGRAM**

**TOPICS**

- Nuclear & Particle Physics
- Medical and Radiation Physics
- Applied and Industrial Physics
- Theoretical and Computational Physics
- Space Physics, Astrophysics & Cosmology
- Physics for Sustainable Development
- Condensed and Materials Physics/Biophysics
- Capacity Development and Retention Discussion
- Physics Education, Outreach and Communication

**ACTIVITIES**

- Outreach for Secondary Schools April 15<sup>th</sup>-19<sup>th</sup>, and July 15<sup>th</sup>-19<sup>th</sup>, 2024
- Physics lectures, tutorials and hands-on experimentation for students, July 7<sup>th</sup>-21<sup>st</sup>, 2024
- Workshop for High School Teachers, July 8-12, 2024
- ASP Forum, July 15<sup>th</sup>, 2024

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**CHAIRS**  
 Mohamed Chabat (UCA)  
 Farida Fassi (UMS)

**2019 (9)**  
**2022-2023 (6+)**  
**2023-2024 (6)**  
**2019-2023: 22 alumni**  
**From 10 countries**  
**Areas of concentration:**  
 Astrophysics & cosmology,  
 nuclear physics, particle physics,  
 light sources & materials  
 characterization, nanoscience,  
 nuclear instrumentation,  
 radionuclide production &  
 medical physics, particle  
 accelerators, HEP computing.



**BNL, 2019, 2022-2024**

**ASP alumni visits for research**



Morgan State University, March 2024





# ASP Alumni at BNL 2023-2024



**Dr. Sanae Samsam (Morocco),  
Accelerator Test Facility**



**Gloria Maithya  
(Kenya), DUNE**

6 ASP alumni for the period of June 2023 - April 2024

- From Kenya, Morocco, Senegal and Togo
- 1 arrived on June 18, 2023
- 4 arrived on July 31, 2023
- 1 arrived on January 21, 2024



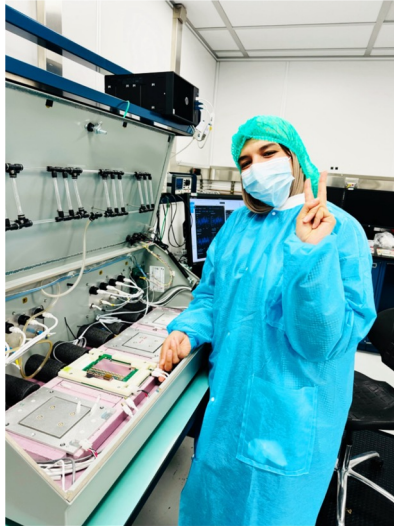
**Aissata Ly  
(Senegal), ITk**

Instrumentation  
Division, CZT



**Dr. Mounia Laassiri  
(Morocco)**

ATLAS ITk



**Fatima Bendebba  
(Morocco),  
ITk & di-Higgs**



**Augustin Sokpor  
(Togo), LGAD**



# Conclusions

- **The Standard Model of particle physics is a very successful theory**
  - Yet, there are 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**