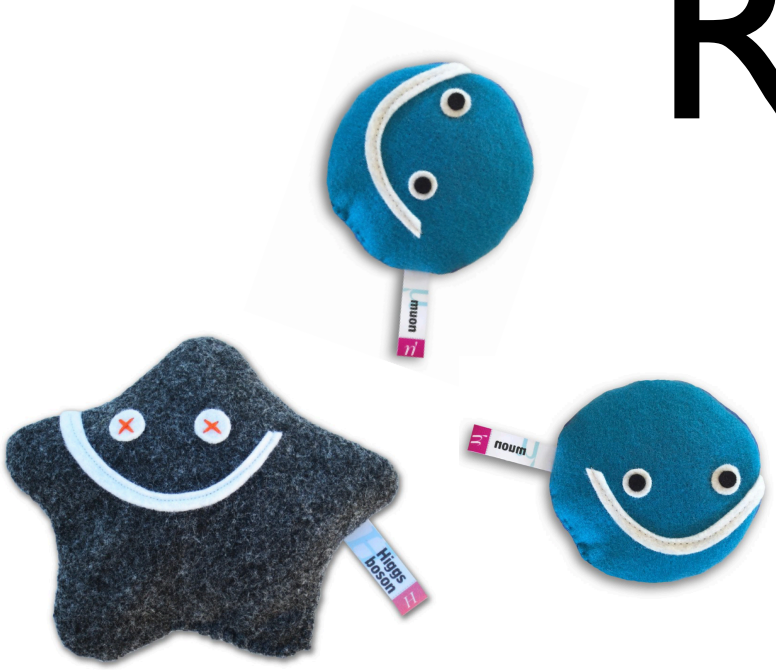
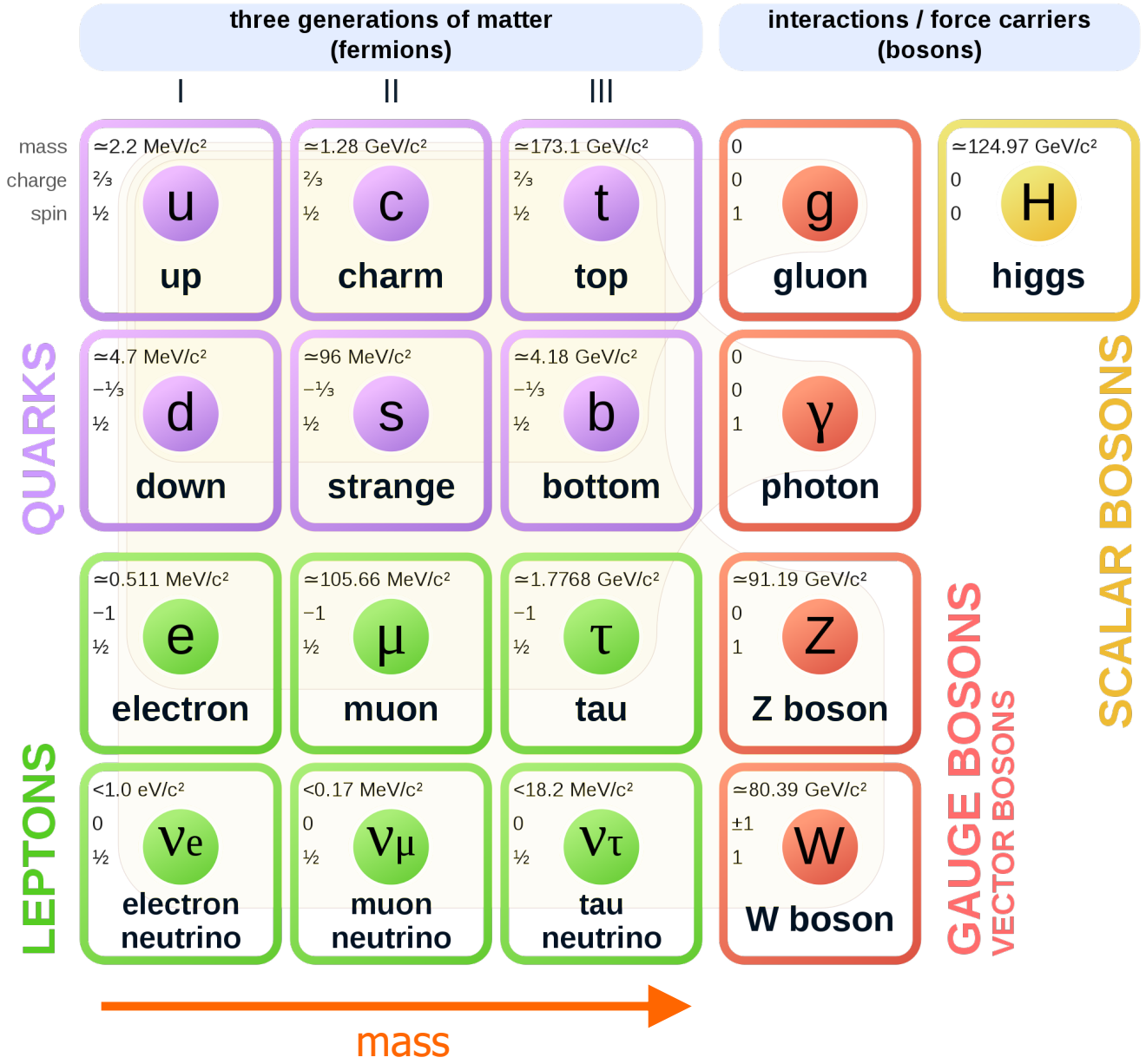
Higgs boson
Rare decays

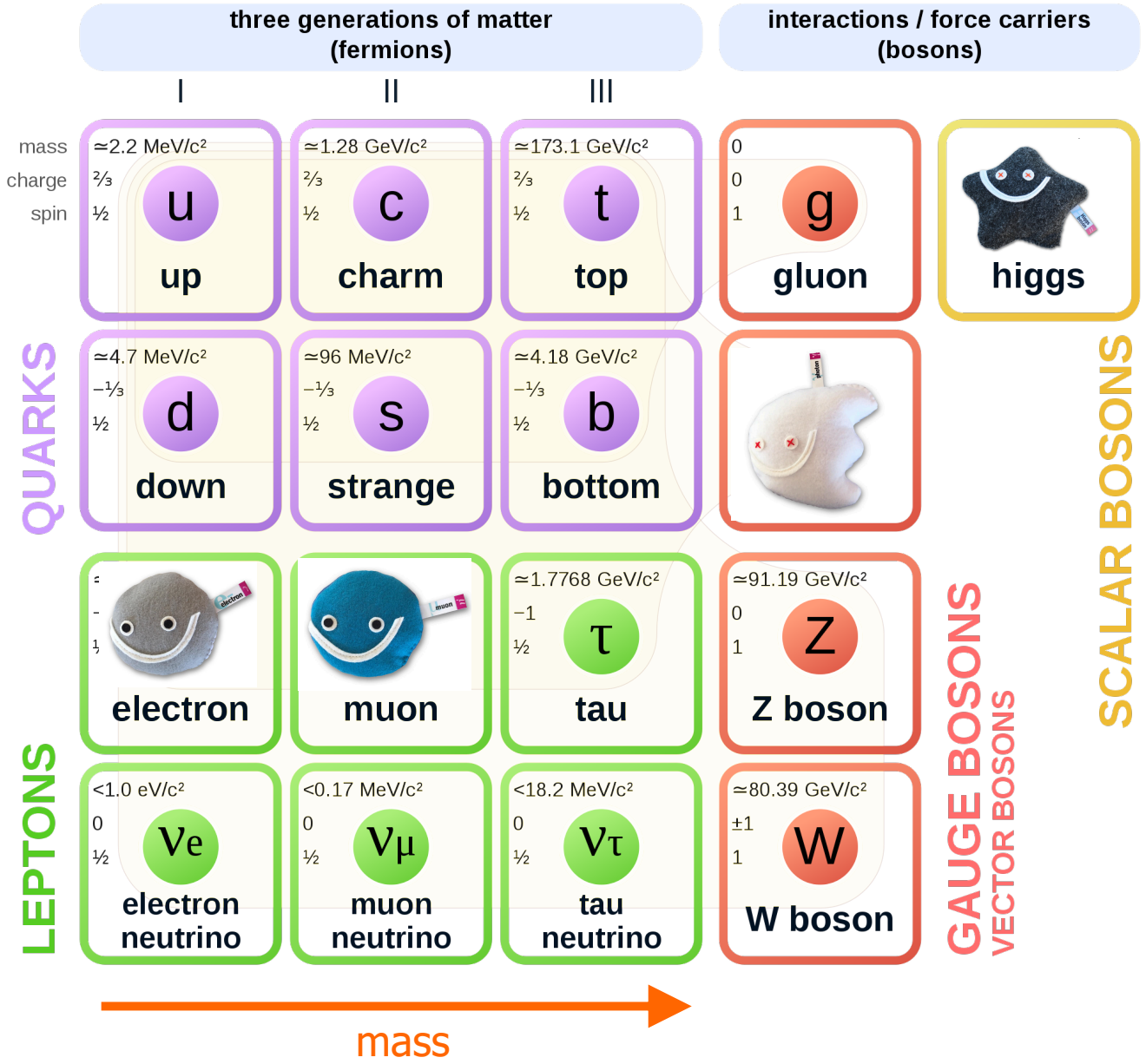


Marco Delmastro
AnimaScience LAPP
5/2/2021

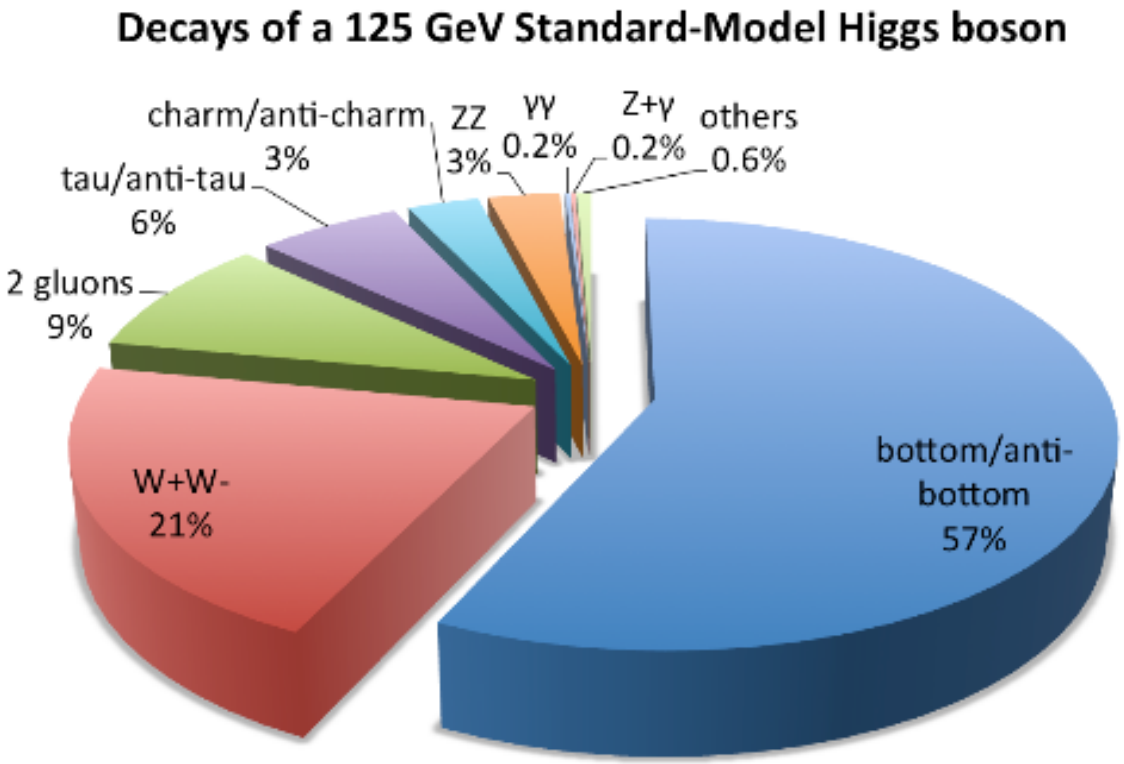
The Standard Model

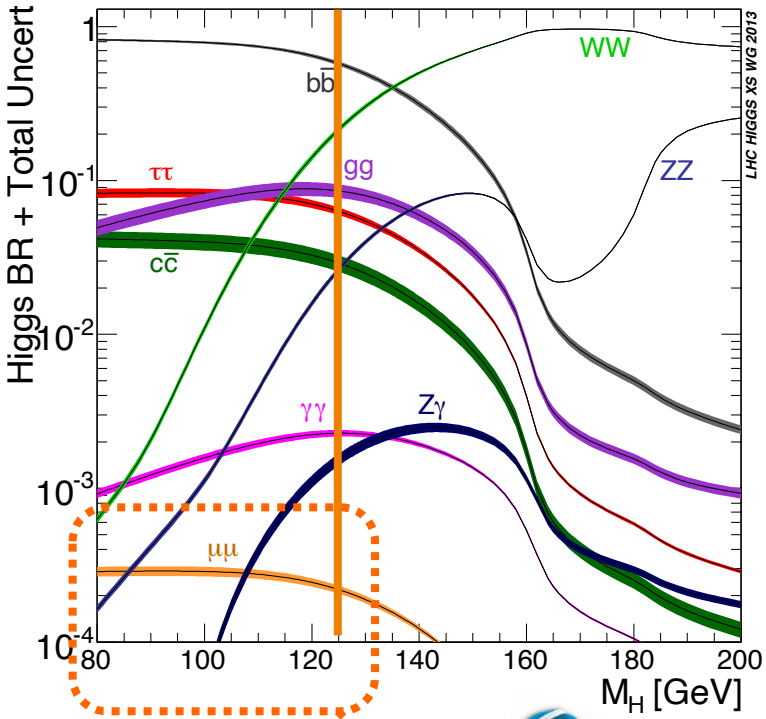


The Standard Model



Higgs decays





Higgs coupling strength depends to particle mass!

H → μμ

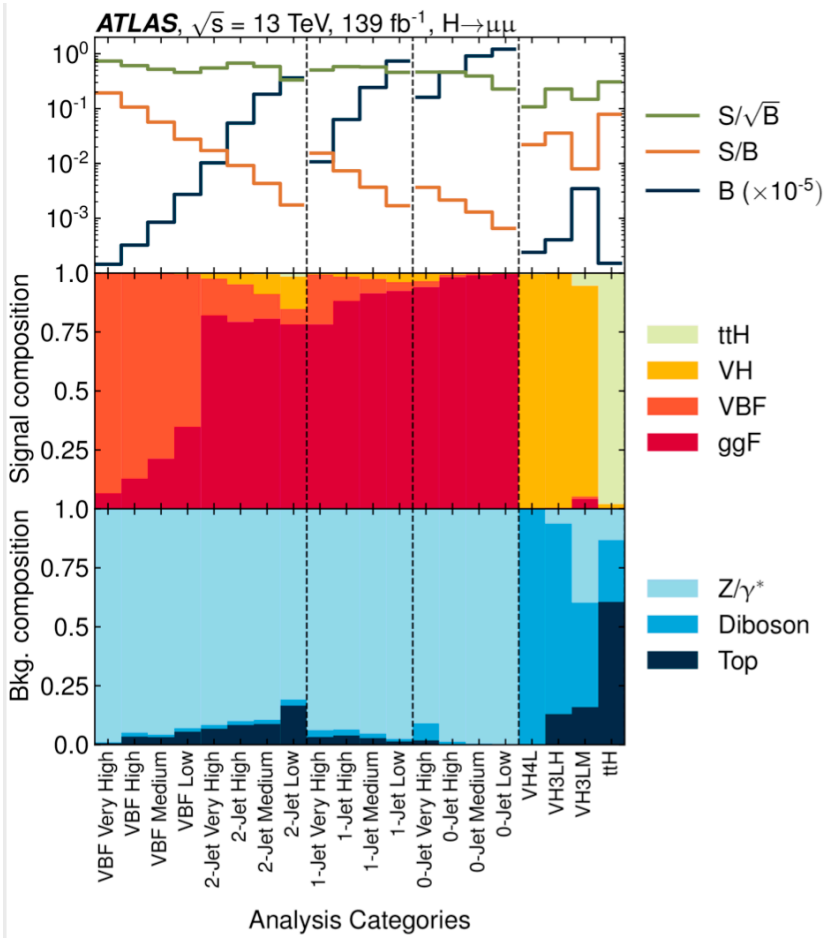
- **Challenging…**
  - ✓ Very rare!
    - BR(H→μμ) = **(2.17±0.04)×10^{-4}**
  - ✓ A lot of background!
    - S/B ~ **0.1%** level
      - S/B H→γγ ~5-10%
- **… but very interesting!**
  - ✓ Coupling to second generation fermions!
- **Results announced in Summer 2020**
  - ✓ ATLAS arXiv:2007.07830
  - ✓ CMS CMS-PAS-19-006

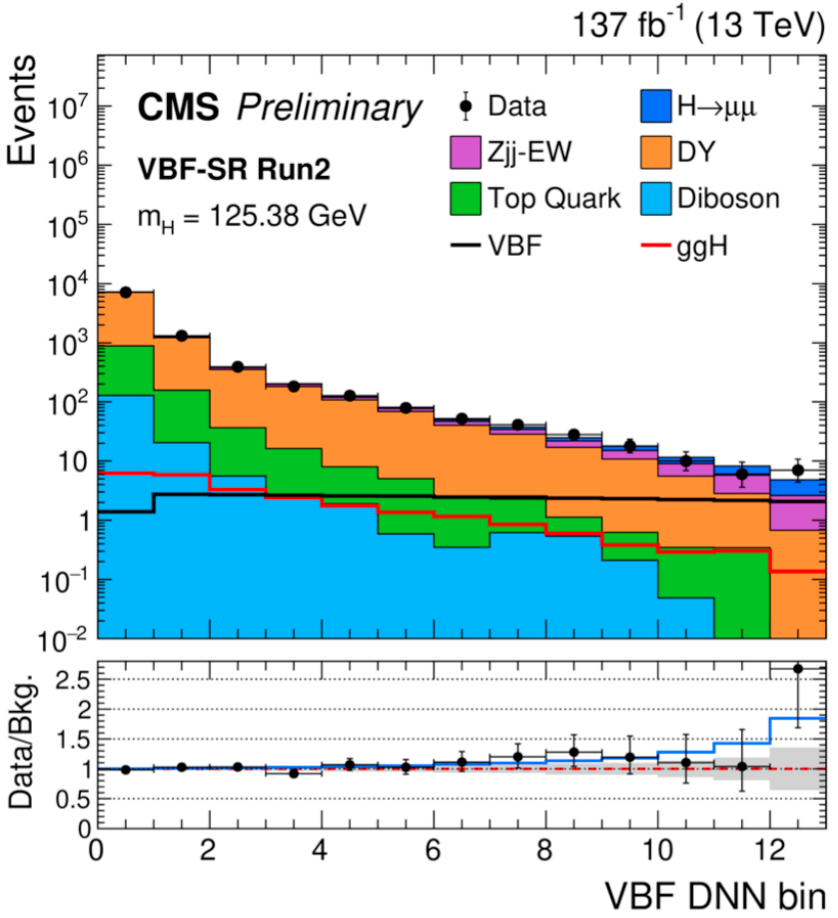
II

≃1.28 GeV/c²		
⅔	c	charm
½		
≃96 MeV/c²		
−⅓	s	strange
½		
≃105.66 MeV/c²		
−1	μ	muon
½		
<0.17 MeV/c²		
0	νμ	muon neutrino
½		

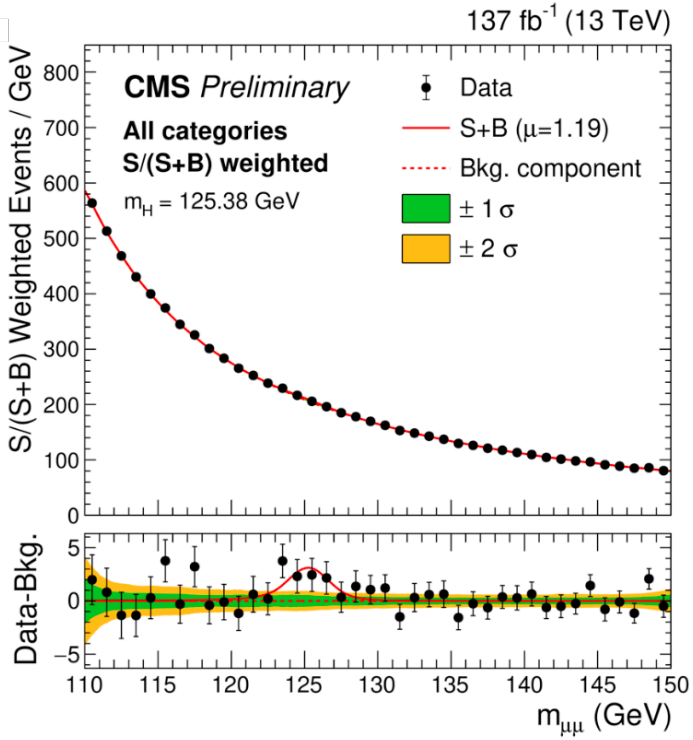
H → μμ: a couple of experimental details…

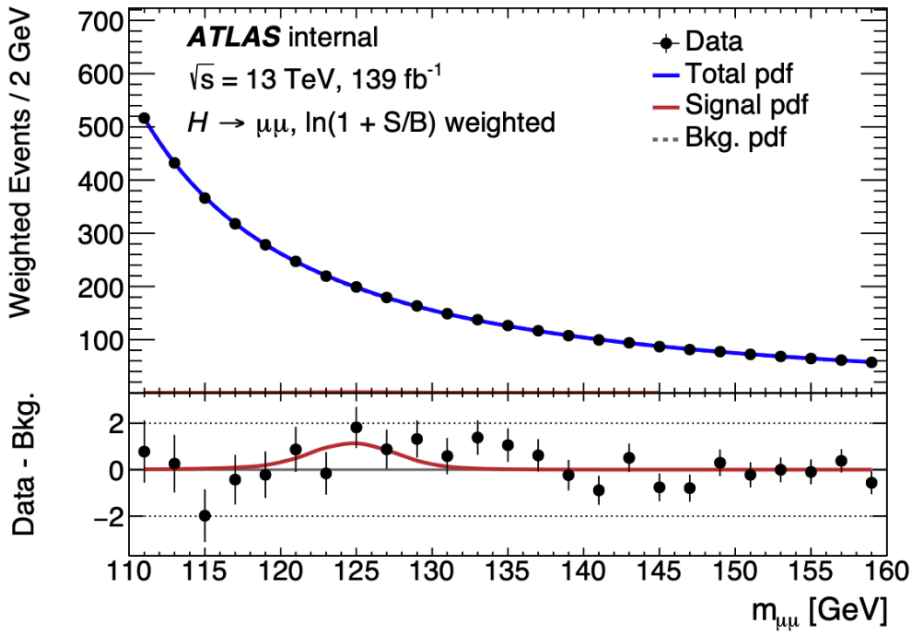
- Data separated in production mode enriched categories…
- "Typical" S+B fits both by ATLAS and CMS ("bump hunting"), but CMS introduced **DNN score template fit in VBF category**!



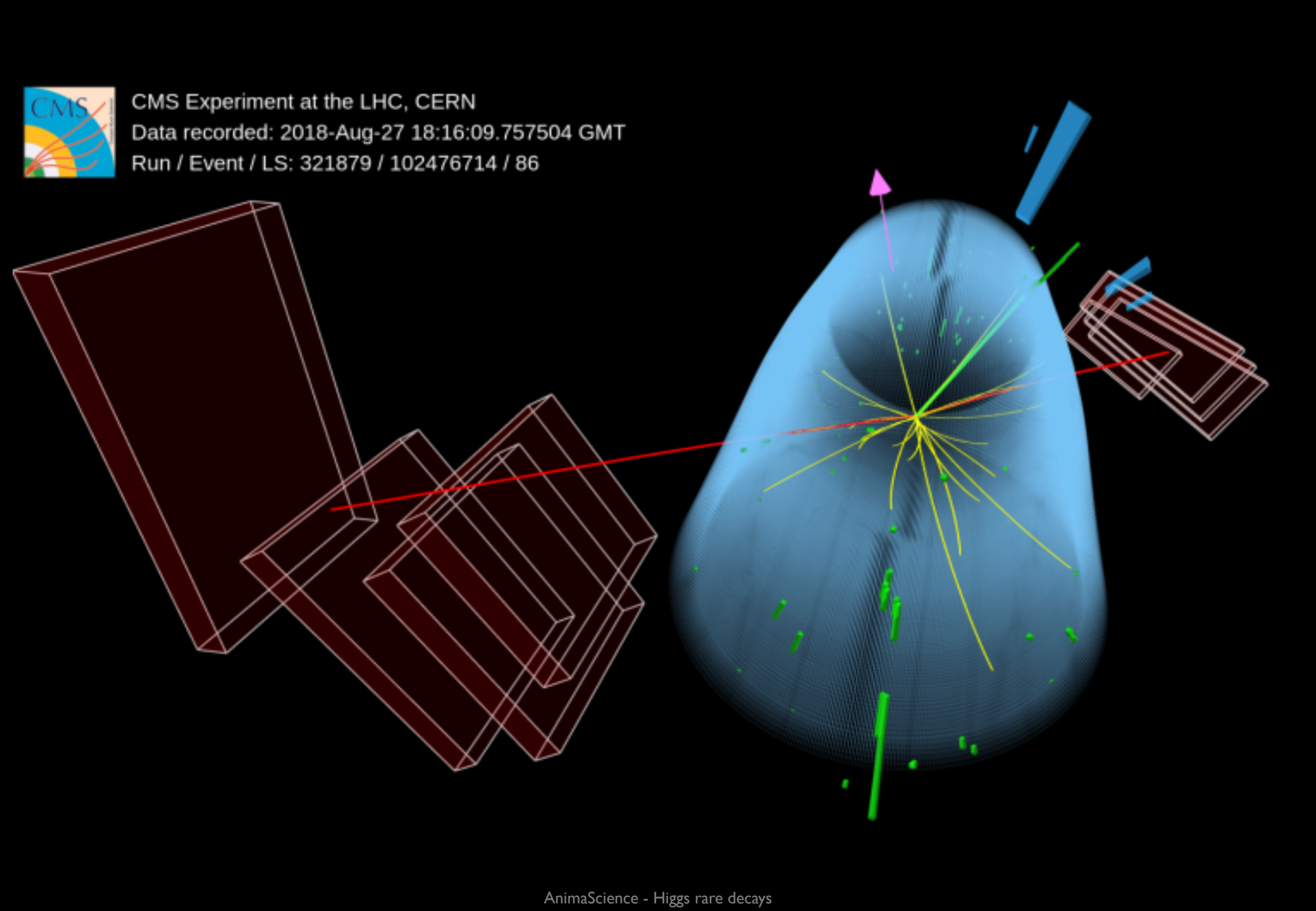


H → μμ: an evidence and a quasi-evidence…





- CMS:
  - Compatibility with B-only hypothesis **2.95σ** (2.46σ)
  - Signal strength $\mu = 1.19^{+0.44}_{-0.42} = 1.19^{+0.41}_{-0.39}(stat)\,^{+0.17}_{-0.16}(syst)$
- ATLAS:
  - Compatibility with B-only hypothesis **2.0σ** (1.7σ)
  - Signal strength $\mu = 1.17^{+0.61}_{-0.58} = 1.17^{+0.58}_{-0.57}(stat) \pm 0.10(spurious)^{+0.07}_{-0.03}(exp)^{+0.13}_{-0.08}(theory)$

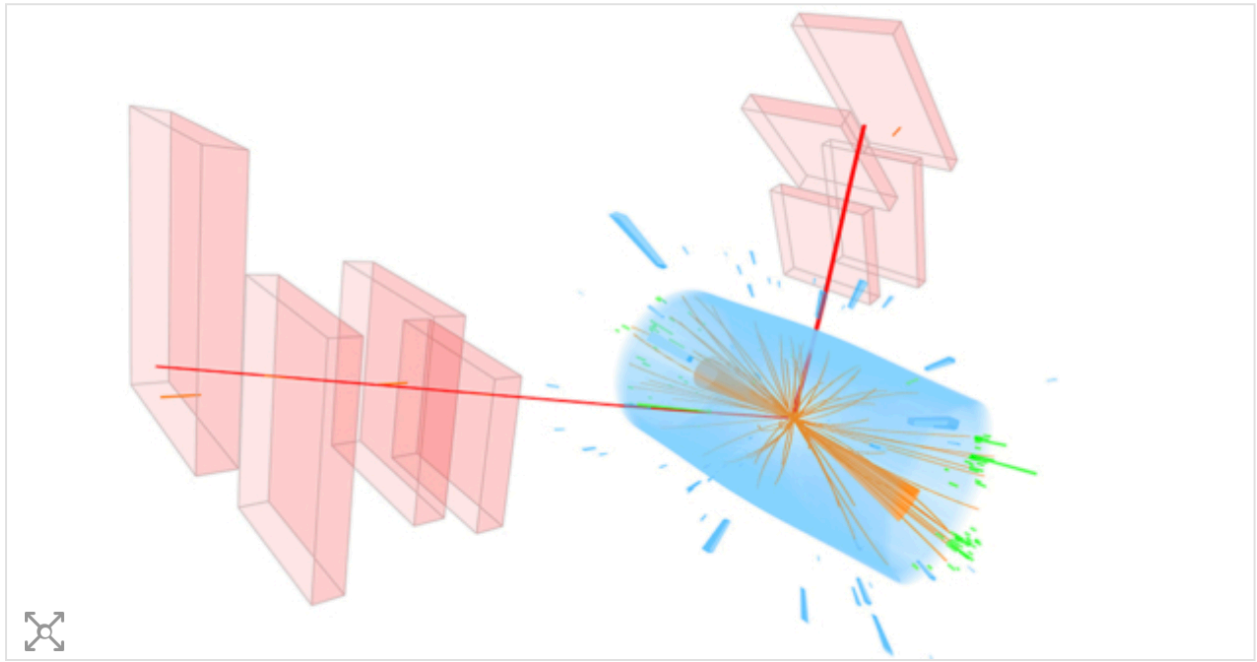

CMS Experiment at the LHC, CERN
Data recorded: 2018-Aug-27 18:16:09.757504 GMT
Run / Event / LS: 321879 / 102476714 / 86

CERNCOURIER | Reporting on international high-energy physics

HIGGS AND ELECTROWEAK | NEWS

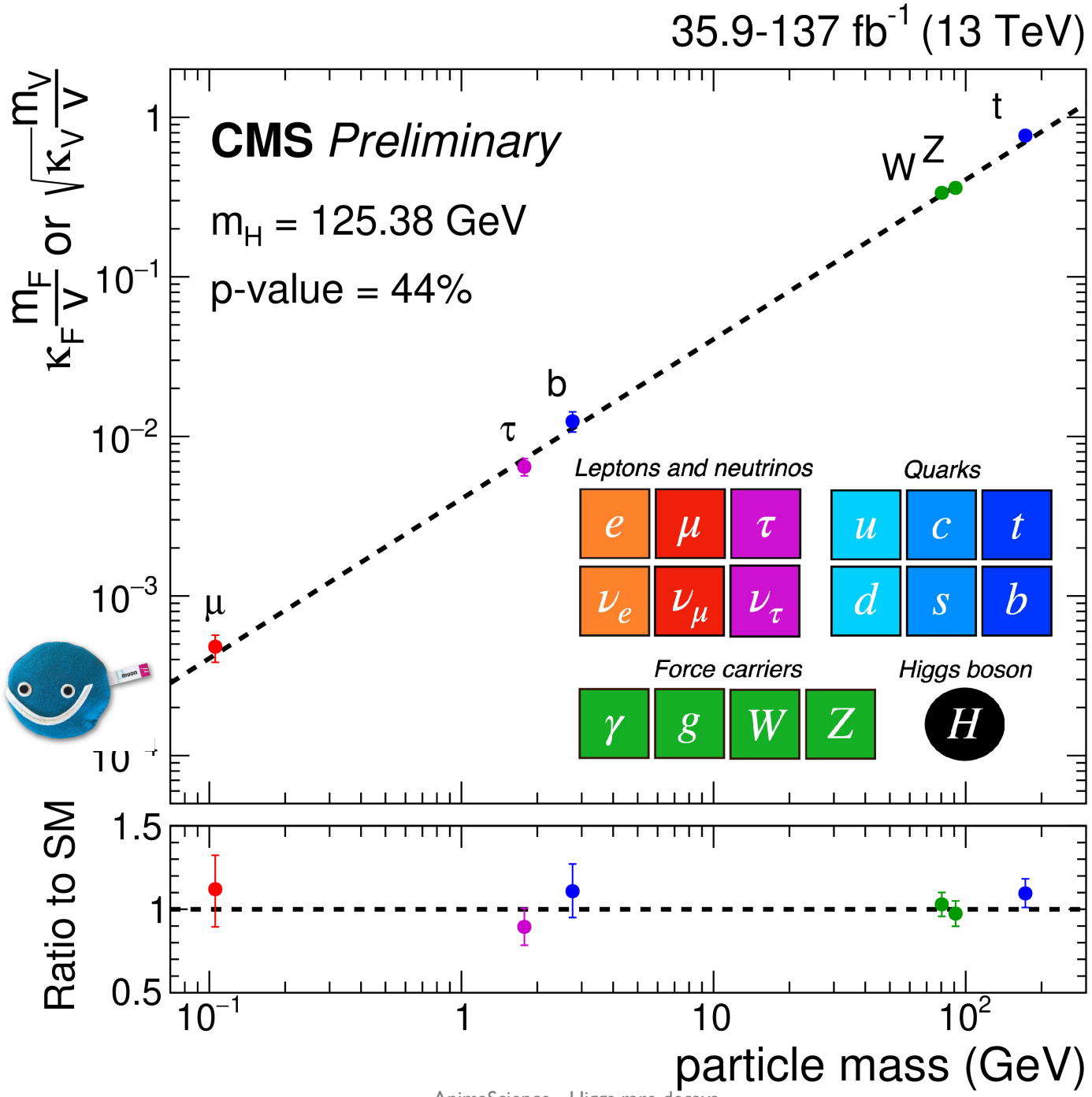
Turning the screw on H → μμ

9 September 2020



New topology A CMS candidate for Higgs-boson production via vector-boson fusion and its decay into two muons (red lines). Credit: CMS-PHO-EVENTS-2020-017-1

AnimaScience - Higgs rare decays

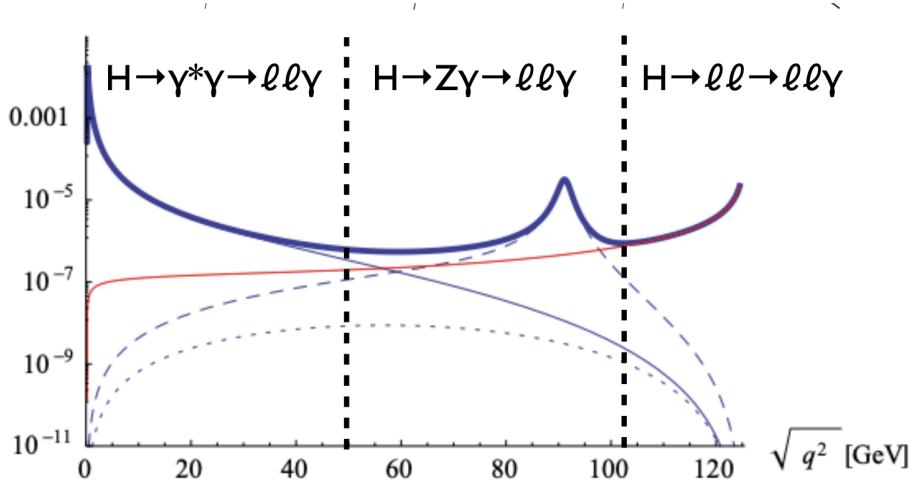

35.9-137 fb^{-1} (13 TeV)
CMS Preliminary
m_H = 125.38 GeV
p-value = 44%
$\frac{m_F}{\kappa_F v}$ or $\sqrt{\frac{m_V}{\kappa_V v}}$
Ratio to SM
particle mass (GeV)
μ
τ
b
W
Z
t
Leptons and neutrinos
Quarks
Force carriers
Higgs boson

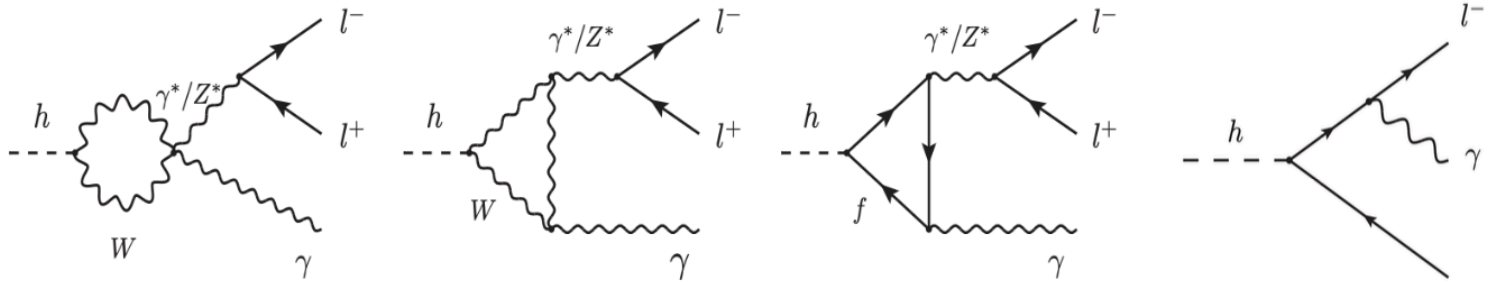
$H \to \ell\ell\gamma$

- **Challenging…**
  - ✓ Even rarer! (m_{ll} < 30 GeV)

$$\mathcal{B}(H \to ee\gamma) = 7.20 \times 10^{-5}$$
$$\mathcal{B}(H \to \mu\mu\gamma) = 3.42 \times 10^{-5}$$

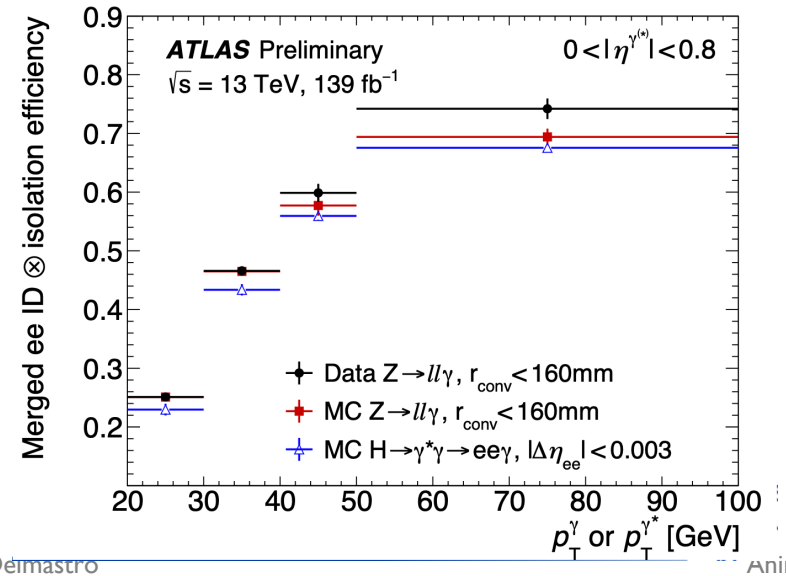
- **… but very interesting!**
  - ✓ 3-body decay!
  - ✓ Can study Higgs CP property
- **Results announced on 2/2/21!**
  - ✓ ATLAS: ATLAS-CONF-2021-002

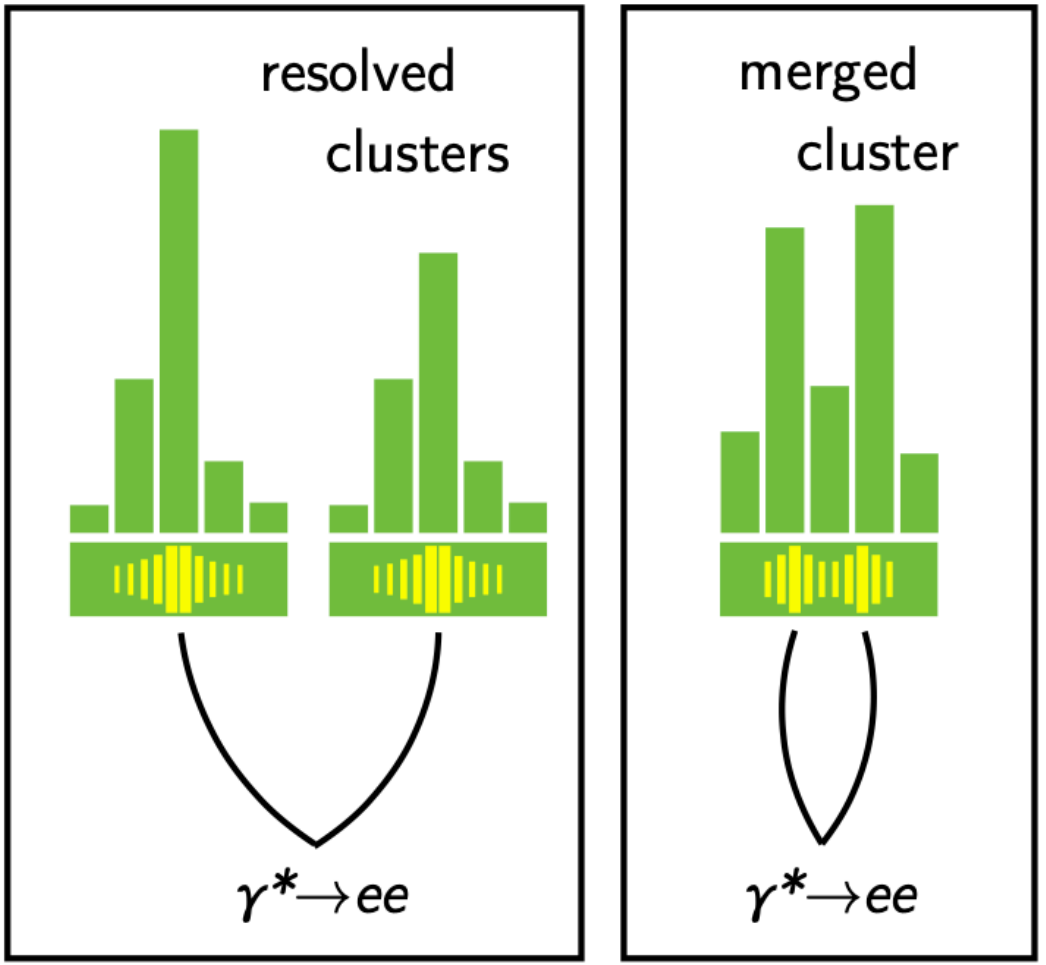


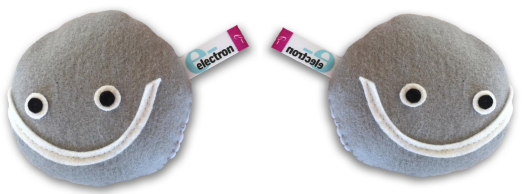


H → $\ell\ell\gamma$: a couple of experimental details…

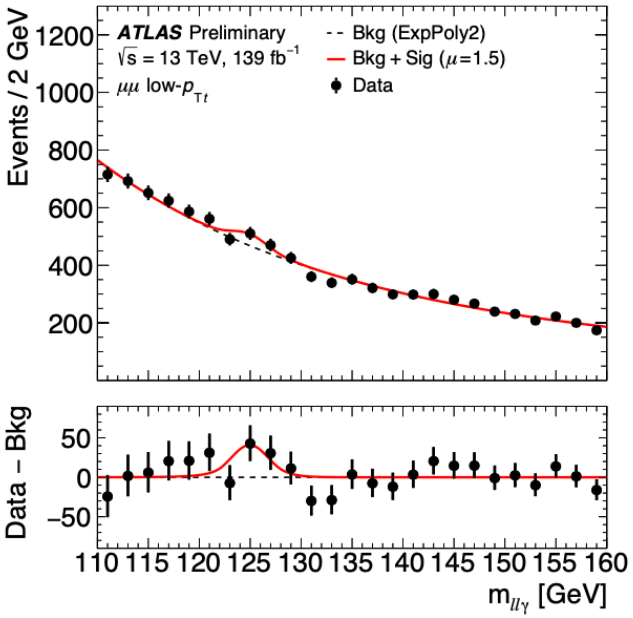
- Due to low mass of dilepton pair leptons often very collimated
  - ✓ Not a problem for muons
  - ✓ Electromagnetic clusters from electron can overlap in calorimeter
- Dedicated trigger and ID!

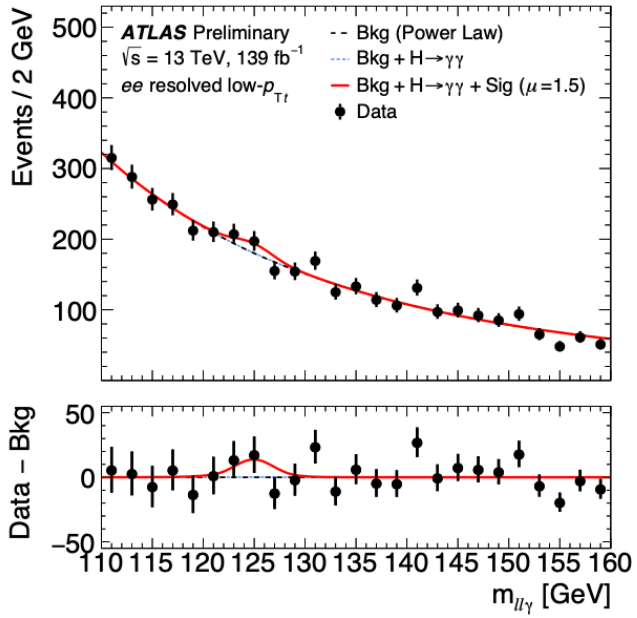


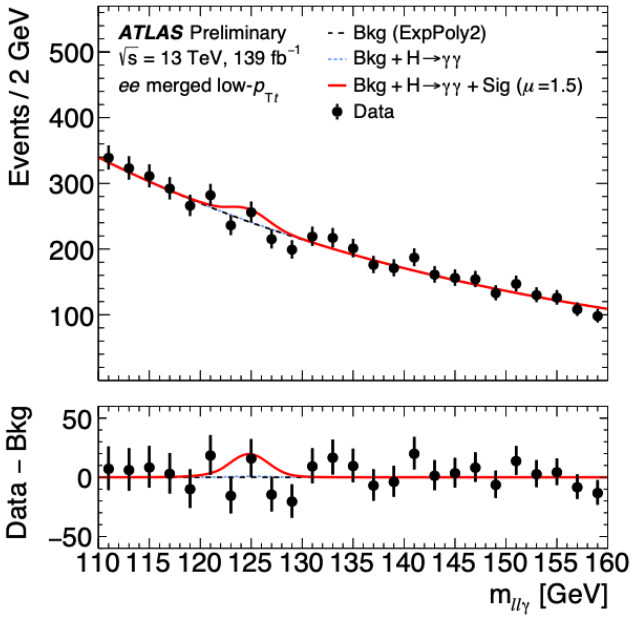




H → $\ell\ell\gamma$: evidence!







- Observed:

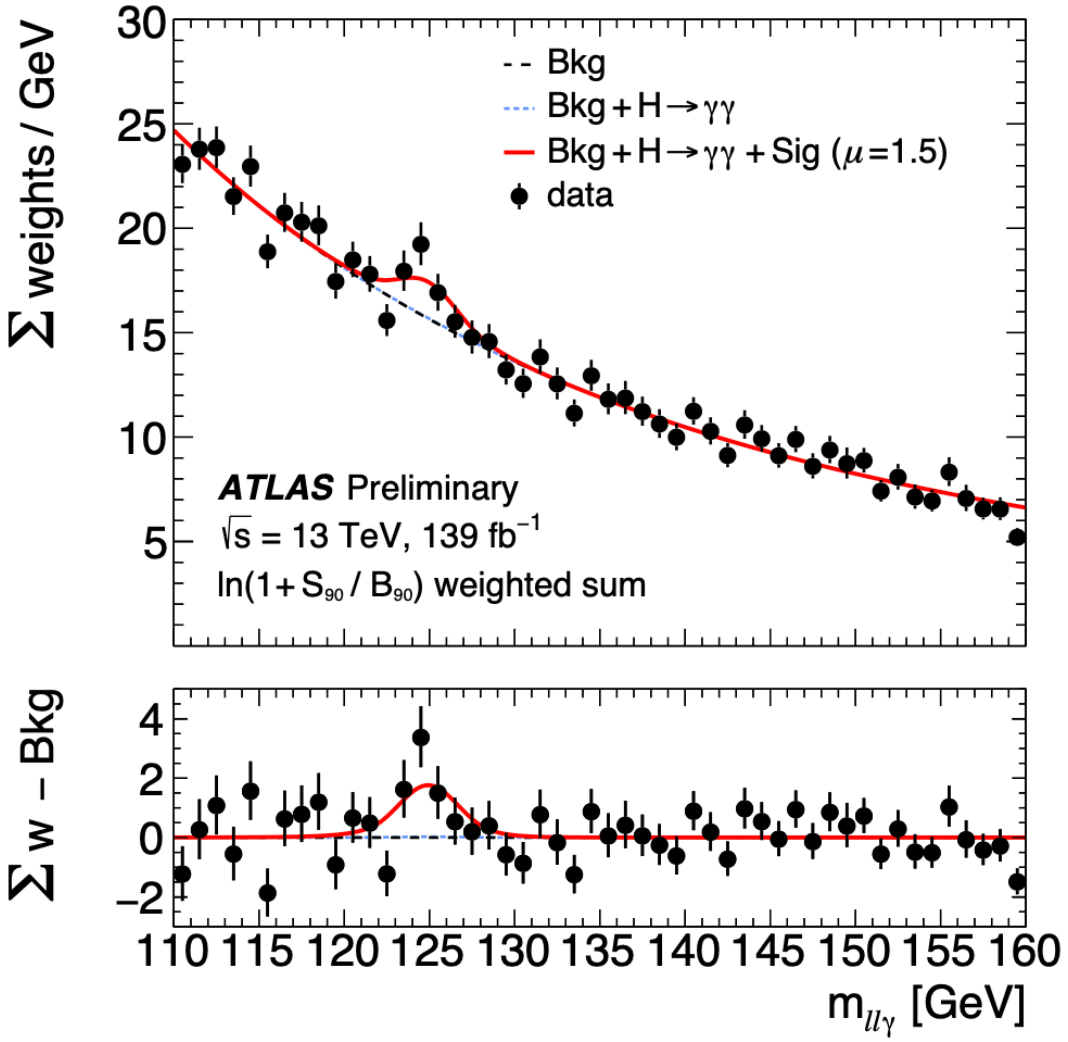
$$\mu = 1.5 \pm 0.5 = 1.5 \pm 0.5\ (\text{stat.})\ ^{+0.2}_{-0.1}\ (\text{syst.})$$

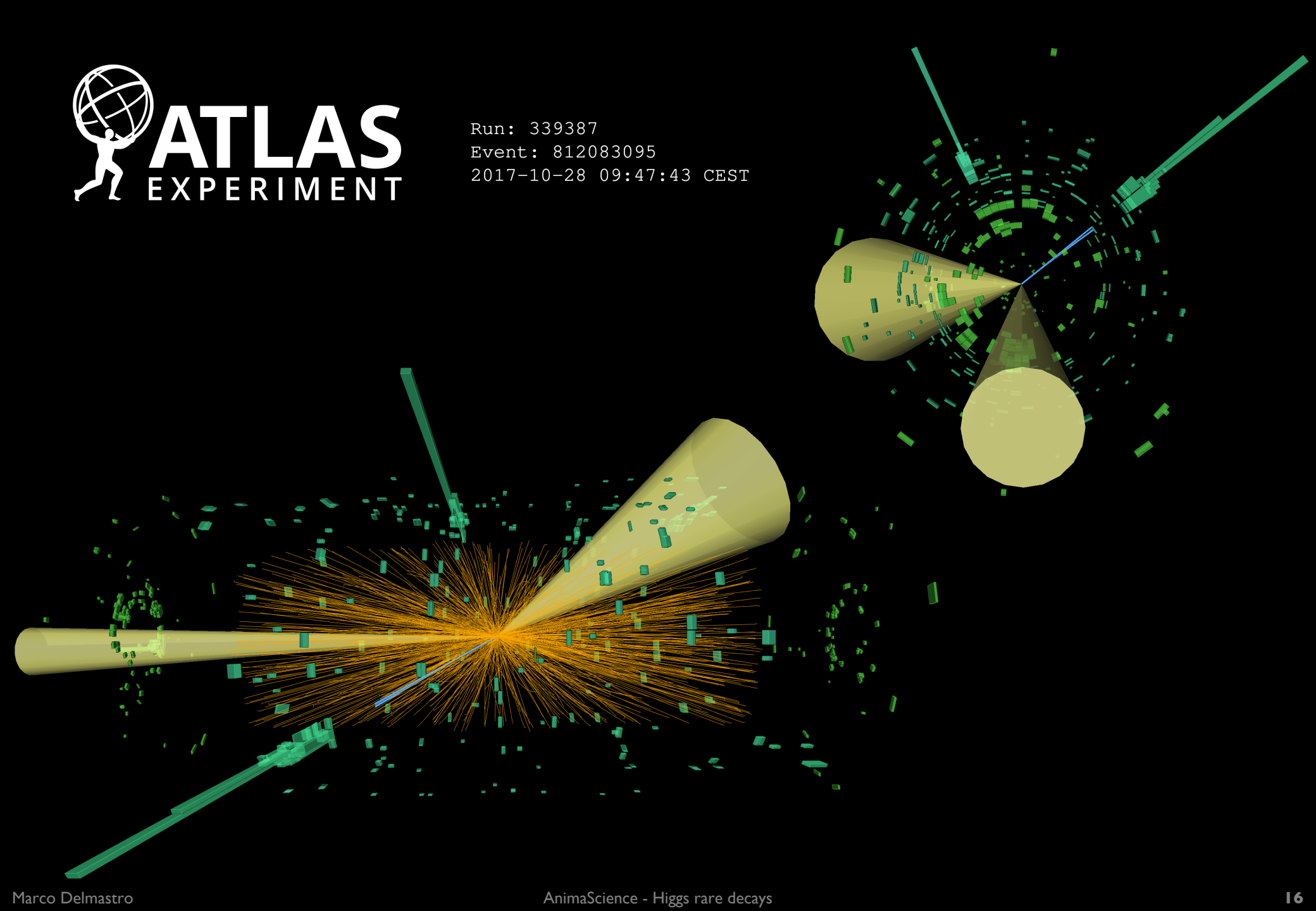
$\sigma \times BR(\ell\ell\gamma)|_{m\ell\ell<30\ GeV}$:

$$8.7\ ^{+2.8}_{-2.7}\ \text{fb} = 8.7\ ^{+2.7}_{-2.7}\ (\text{stat.})\ ^{+0.7}_{-0.6}\ (\text{syst.})\ \text{fb}$$

H → $\ell\ell\gamma$: evidence!

- Significance above background-only hypothesis: 3.2σ (expected 2.1σ)
- First evidence for H→ℓℓγ

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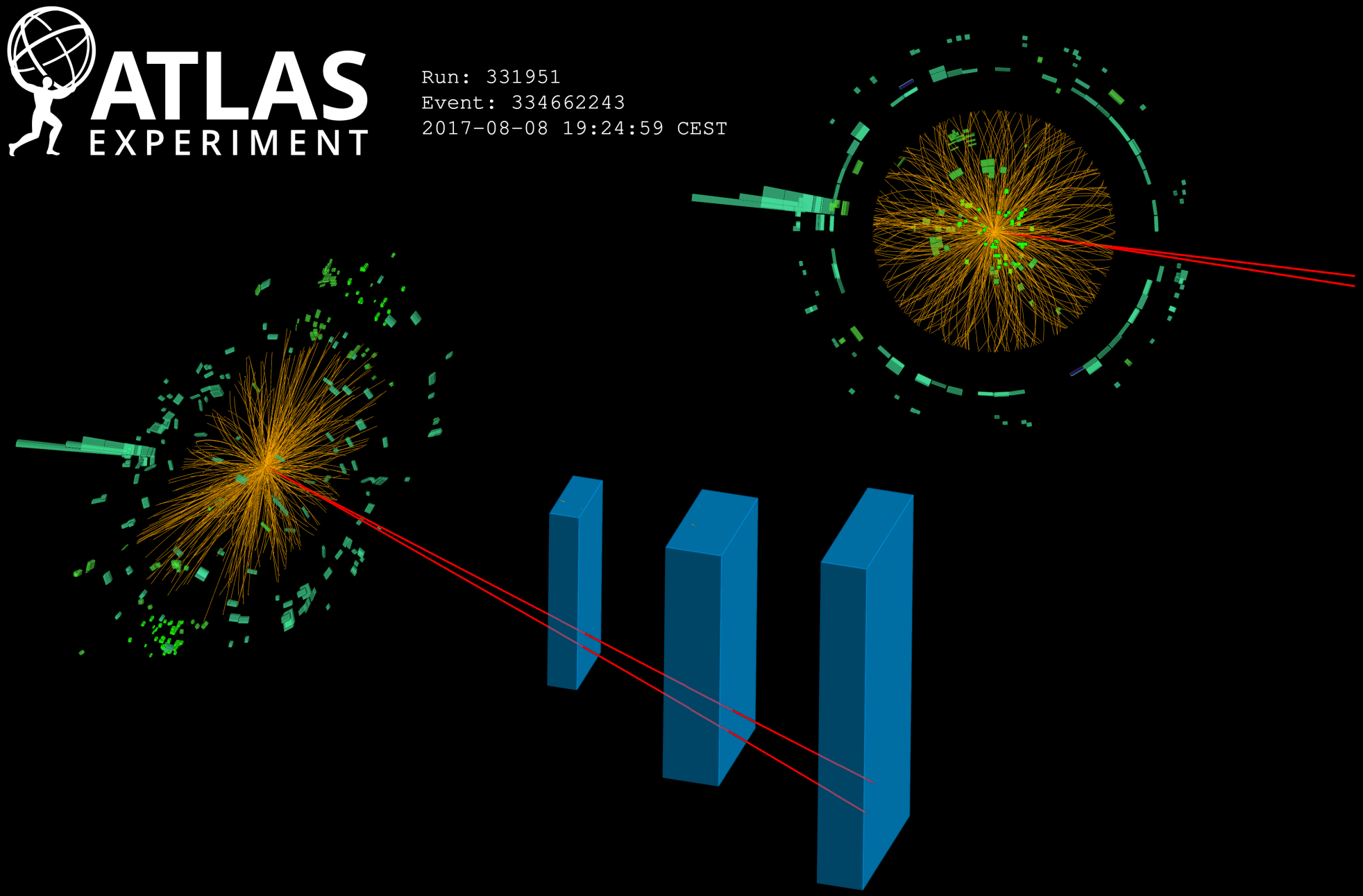
2017-10-28 09:47:43 CEST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EXPERIMENT
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2017-08-08 19:24:59 CEST

ENERGY FRONTIERS

Reports from the Large Hadron Collider experiments

ATLAS

First evidence for rare Higgs-boson decay

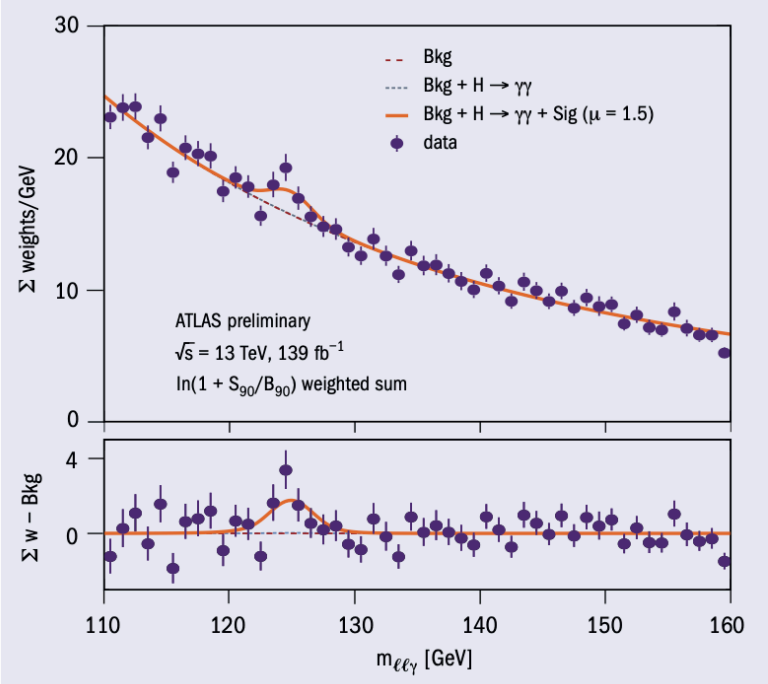
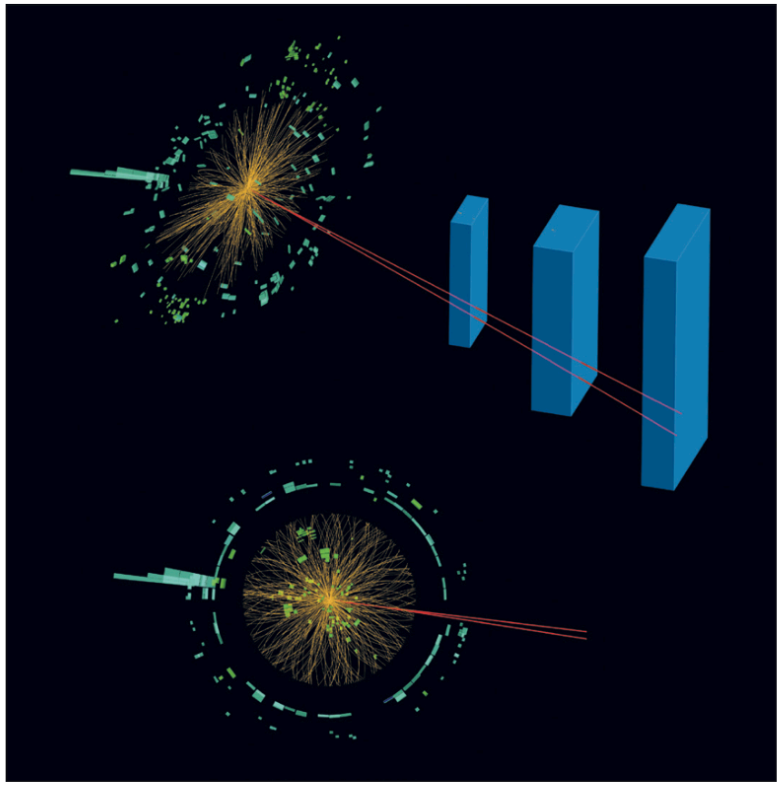


Fig. 1. *Invariant mass of the ℓℓγ system, with every data event contributing a category-dependent weight representing the expected sensitivity of the H → ℓℓγ signal. The data are shown as purple dots, while the lines show the signal and background functions as obtained by a fit.*



Rare decay *A candidate H → μ⁺μ⁻γ decay in the ATLAS detector.*