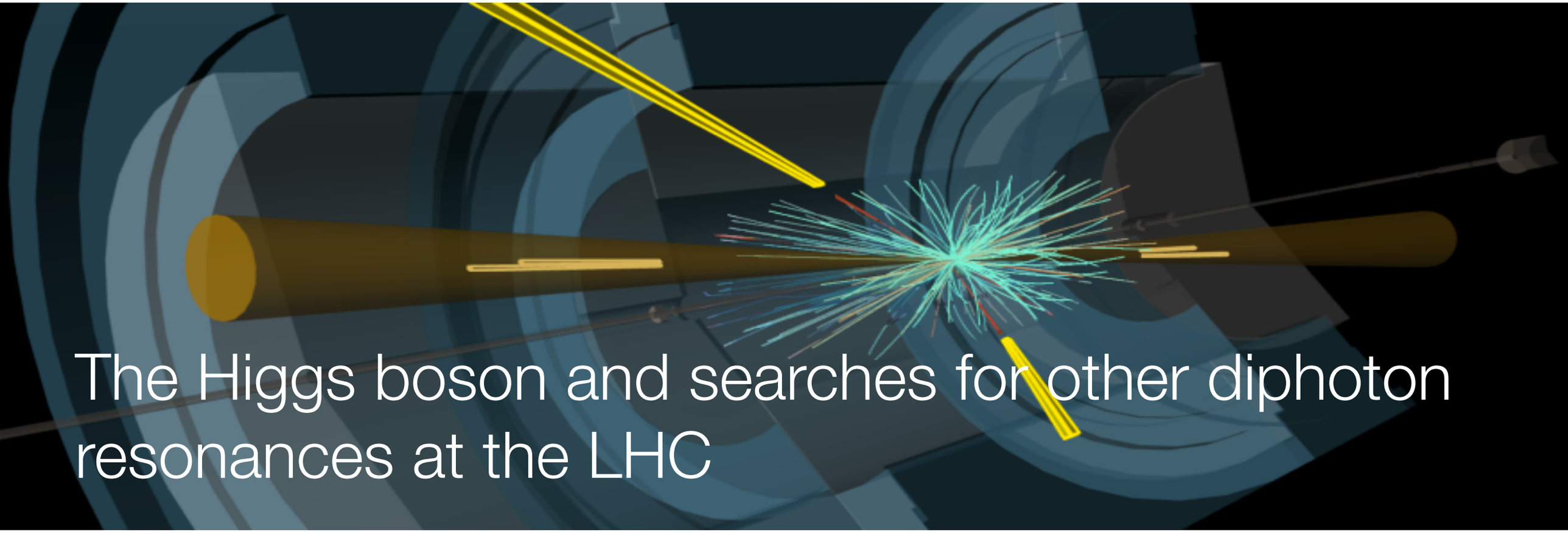


The Higgs boson and searches for other diphoton resonances at the LHC

Bruno Lenzi

22nd ICEPP Symposium
Hakuba, Japan

28/02/2016

July 4 2012 at CERN

After half a century, the discovery!

Press coverage after July 4 2012

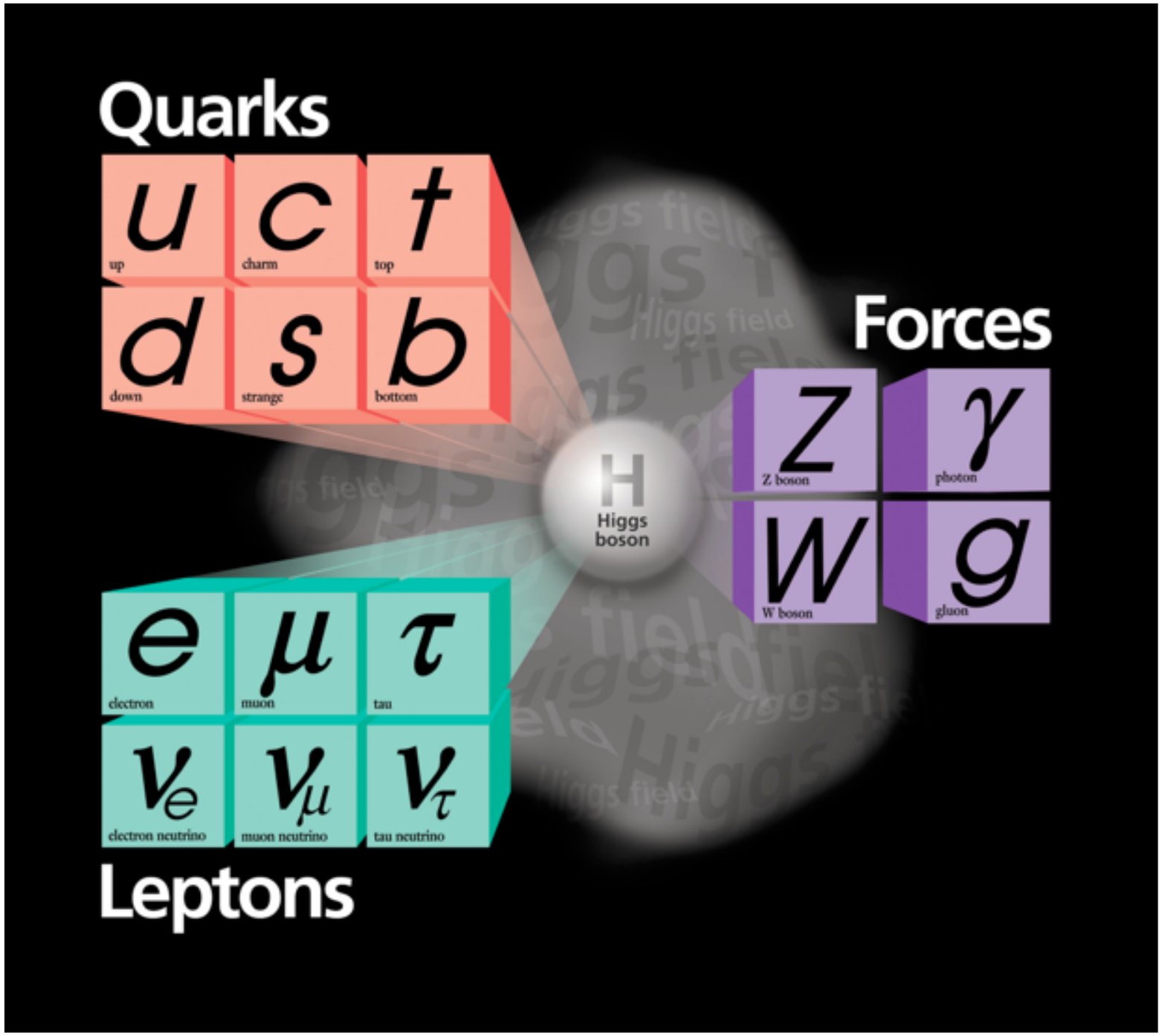
[Andreas Hoecker]

Reactions to the discovery

The top Breakthrough of the Year – the discovery of the Higgs boson – was an unusually easy choice, representing both a triumph of the human intellect and the culmination of decades of work by many thousands of physicists and engineers

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"

The Standard Model (SM) of particle physics



- Unifies special relativity, quantum mechanics and field theory
- Describes electroweak and strong interactions between all known particles
- BEH mechanism gives mass to W,Z bosons (+fermion masses and mixing)
- Survived last decades of experimental verification
  - Higgs boson was (?) the only missing piece

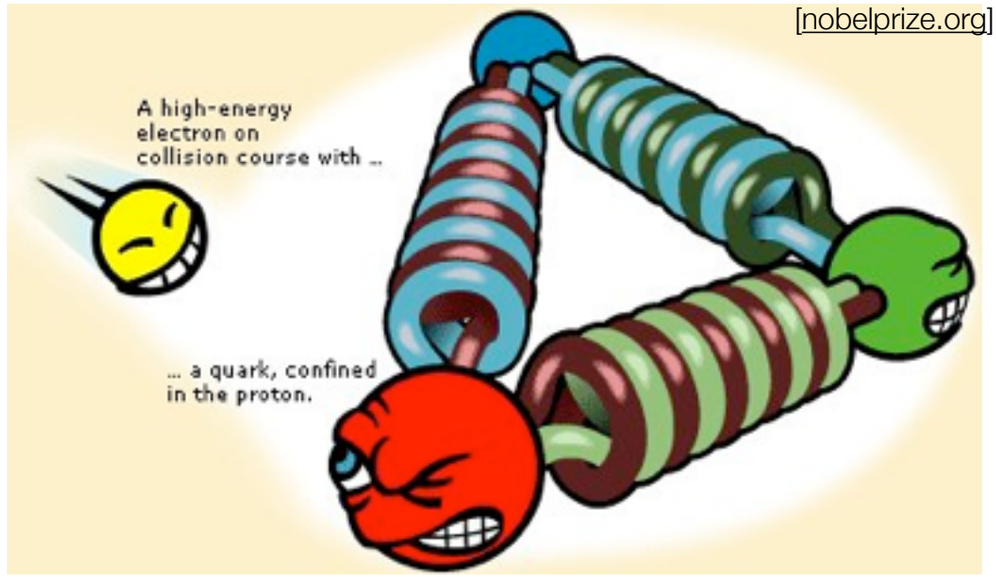
The origin of mass ?

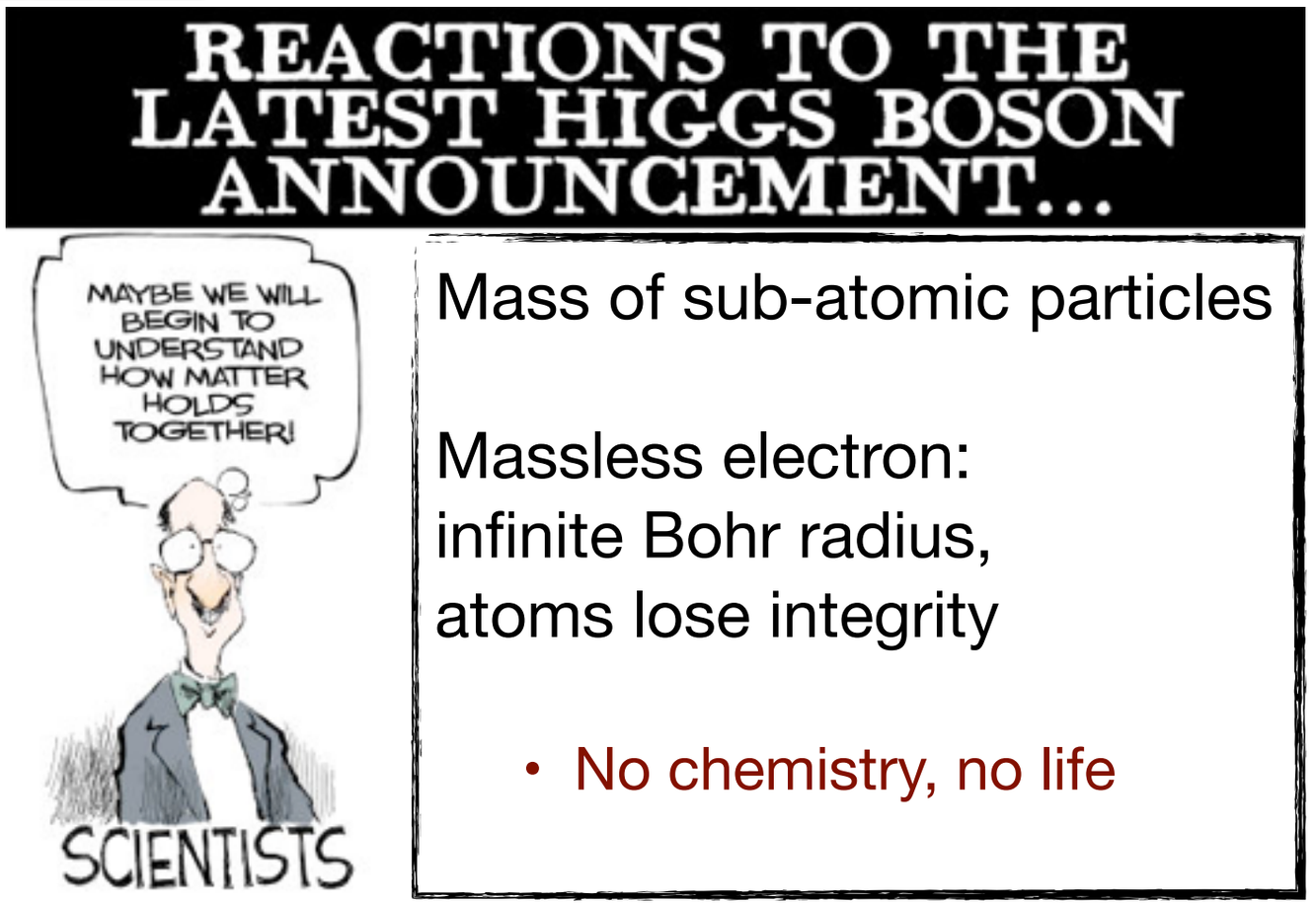
[wikipedia]

Mass of the universe: mostly dark matter

Mass of the proton: 98% binding energy (QCD confinement)

[nobelprize.org]





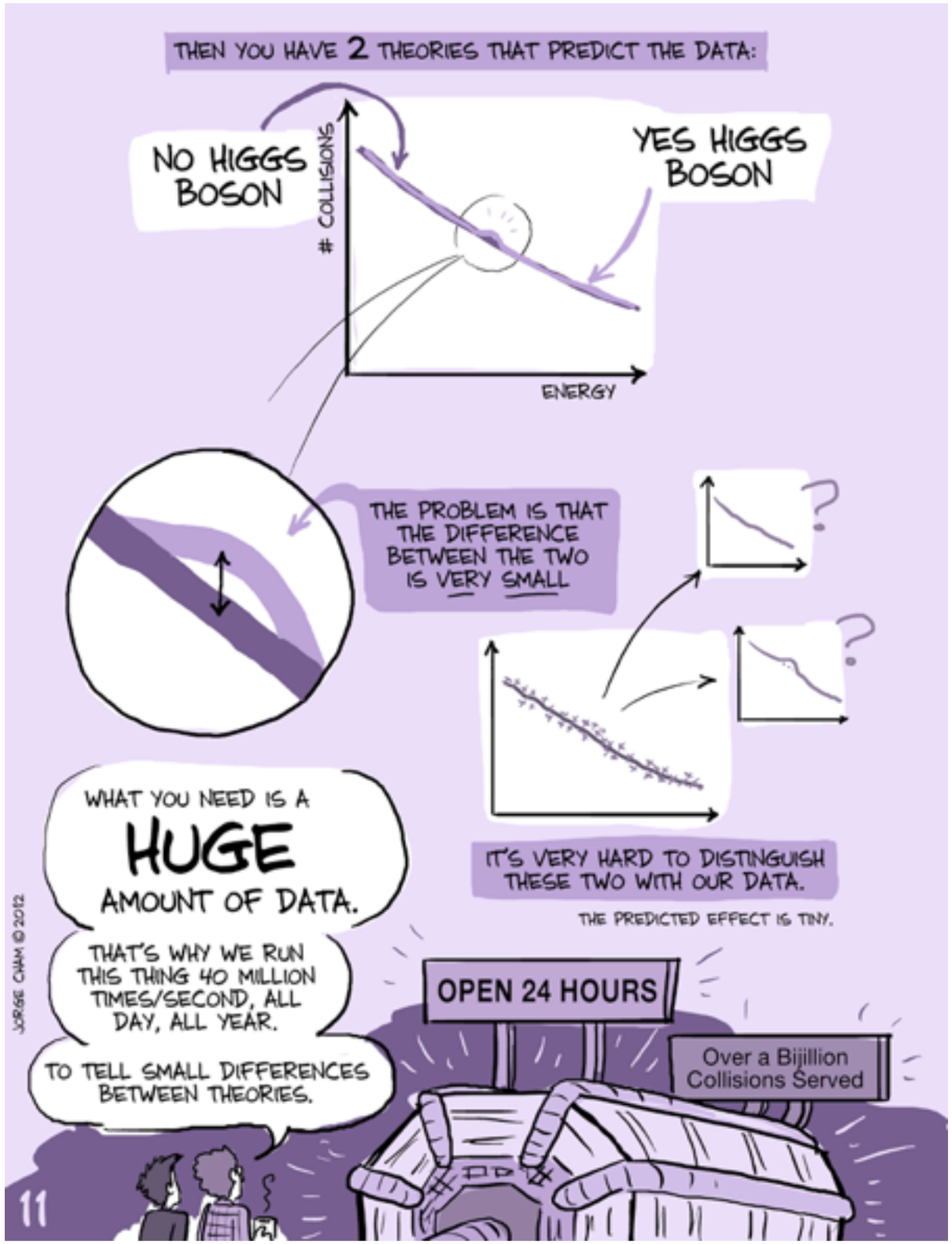
Mass of sub-atomic particles

Massless electron:
infinite Bohr radius,
atoms lose integrity

- No chemistry, no life

Discovering a new particle

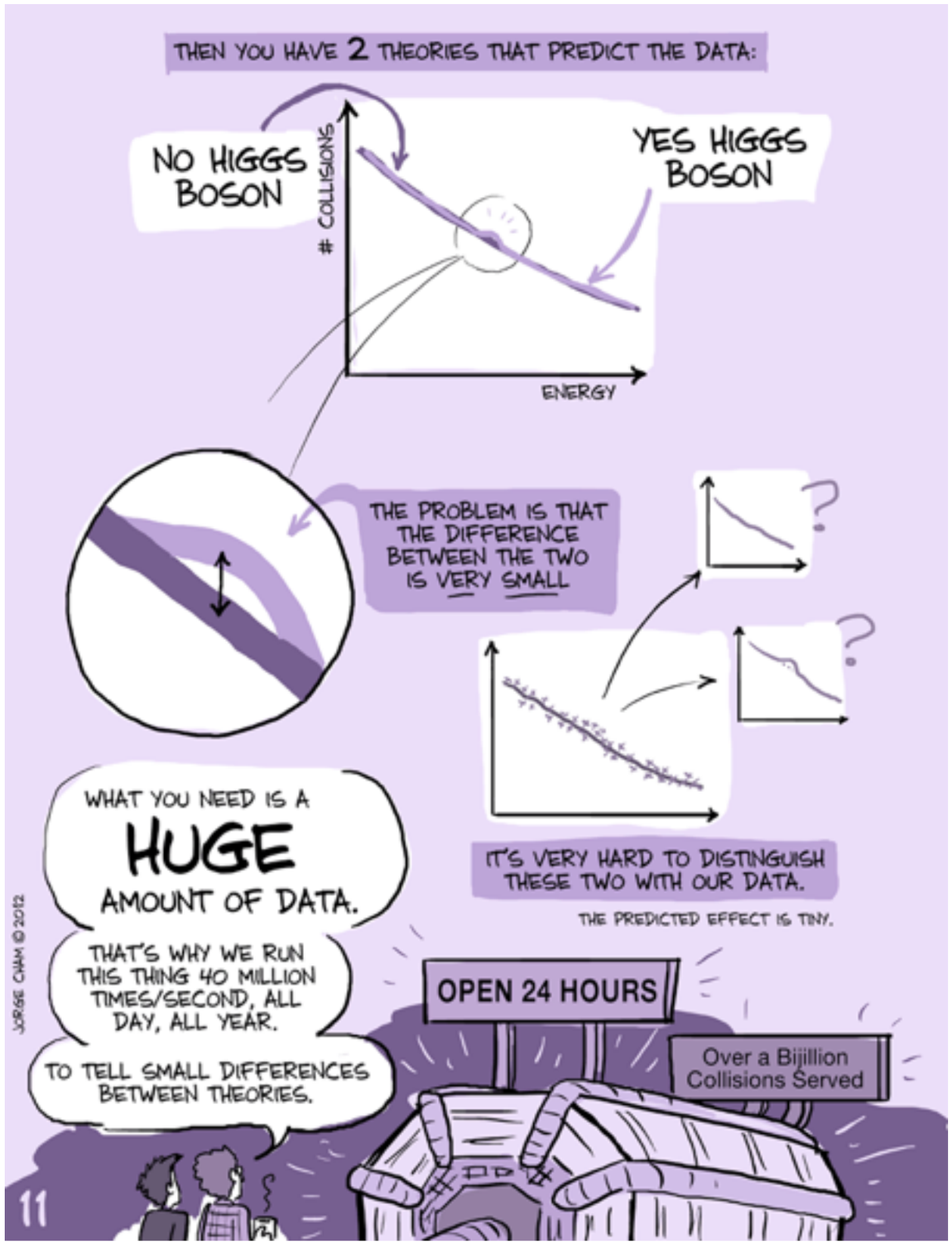
http://www.phdcomics.com/higgs/



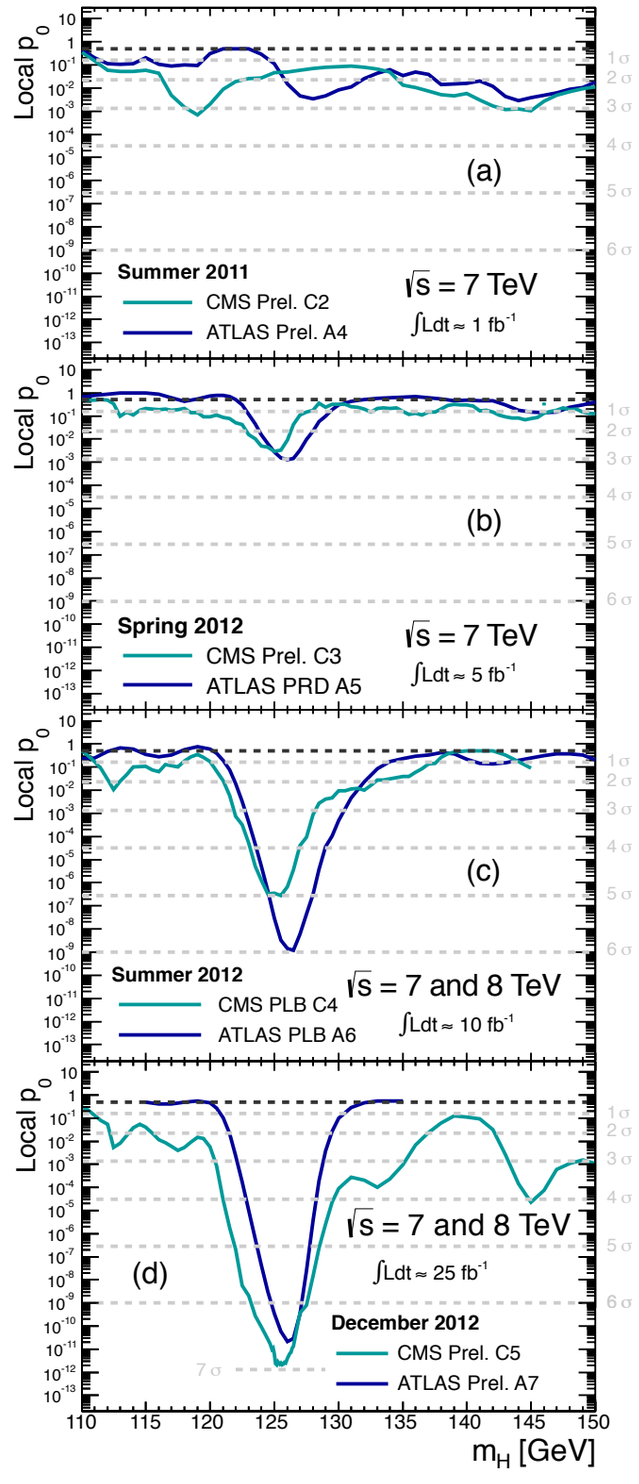
Discovering a new particle

http://pdg.lbl.gov/2015/reviews/rpp2015-rev-higgs-boson.pdf

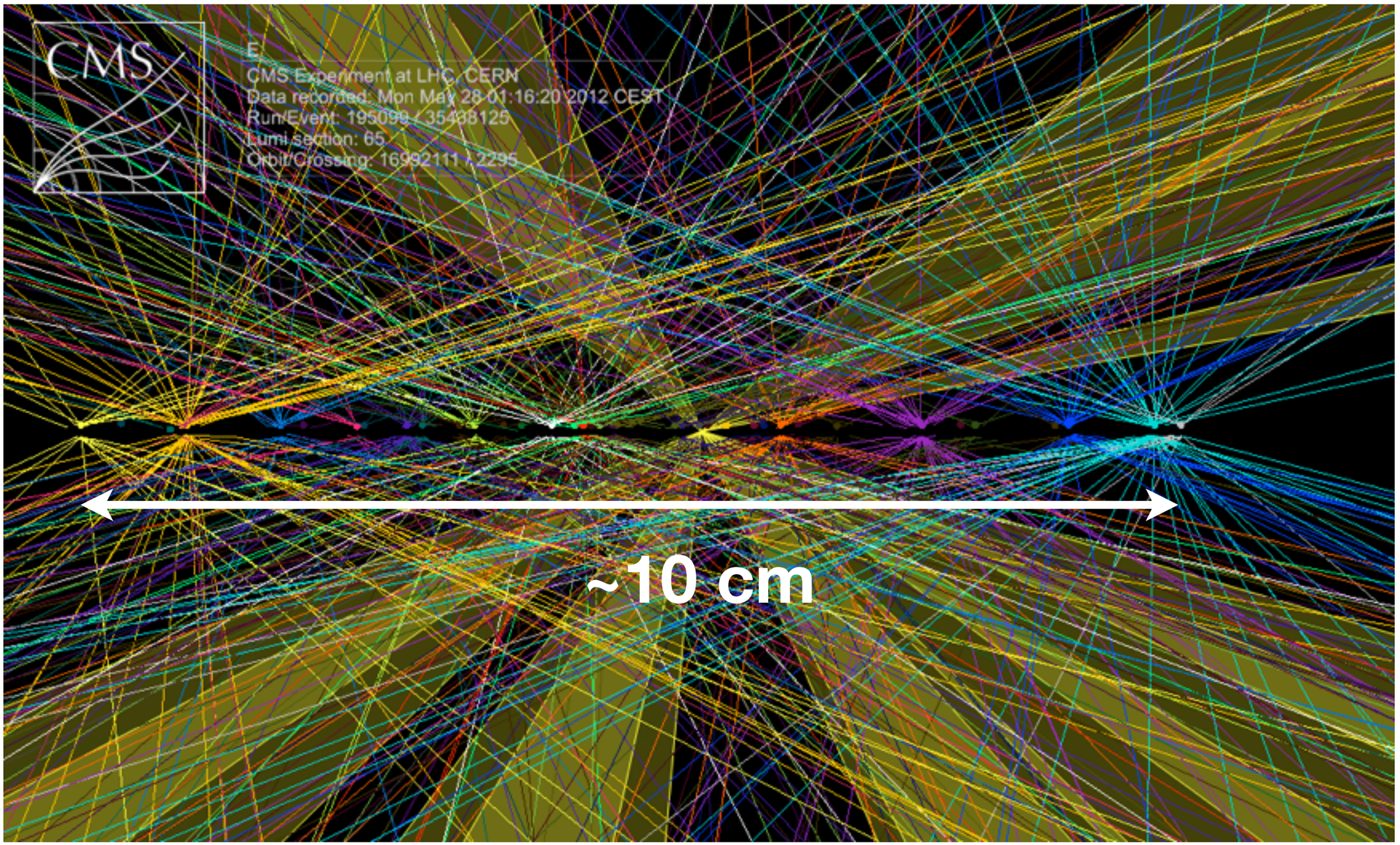
http://www.phdcomics.com/higgs/



Probability of a background fluctuation to look like signal

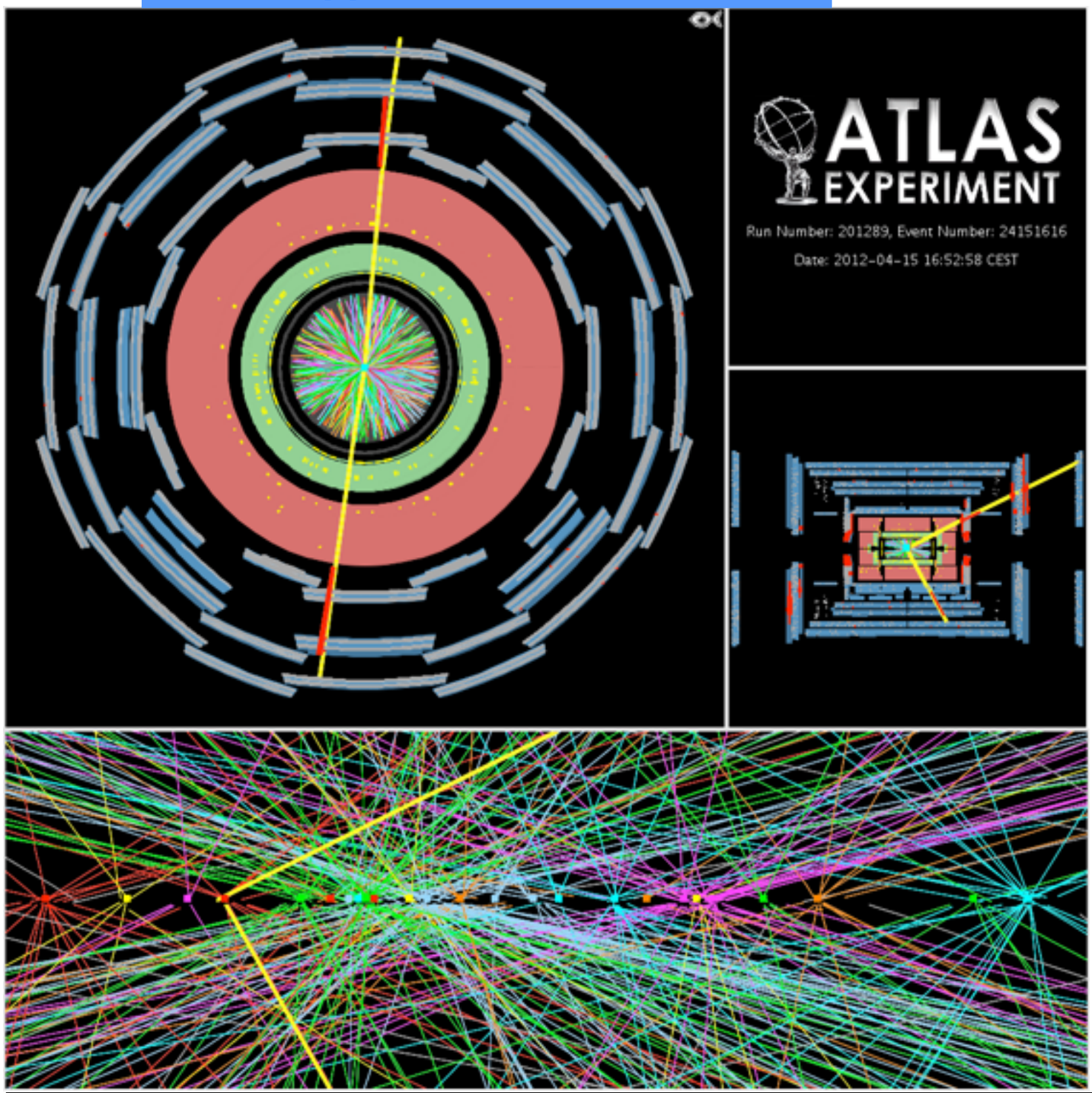


LHC collision, another one coming in 25 ns...



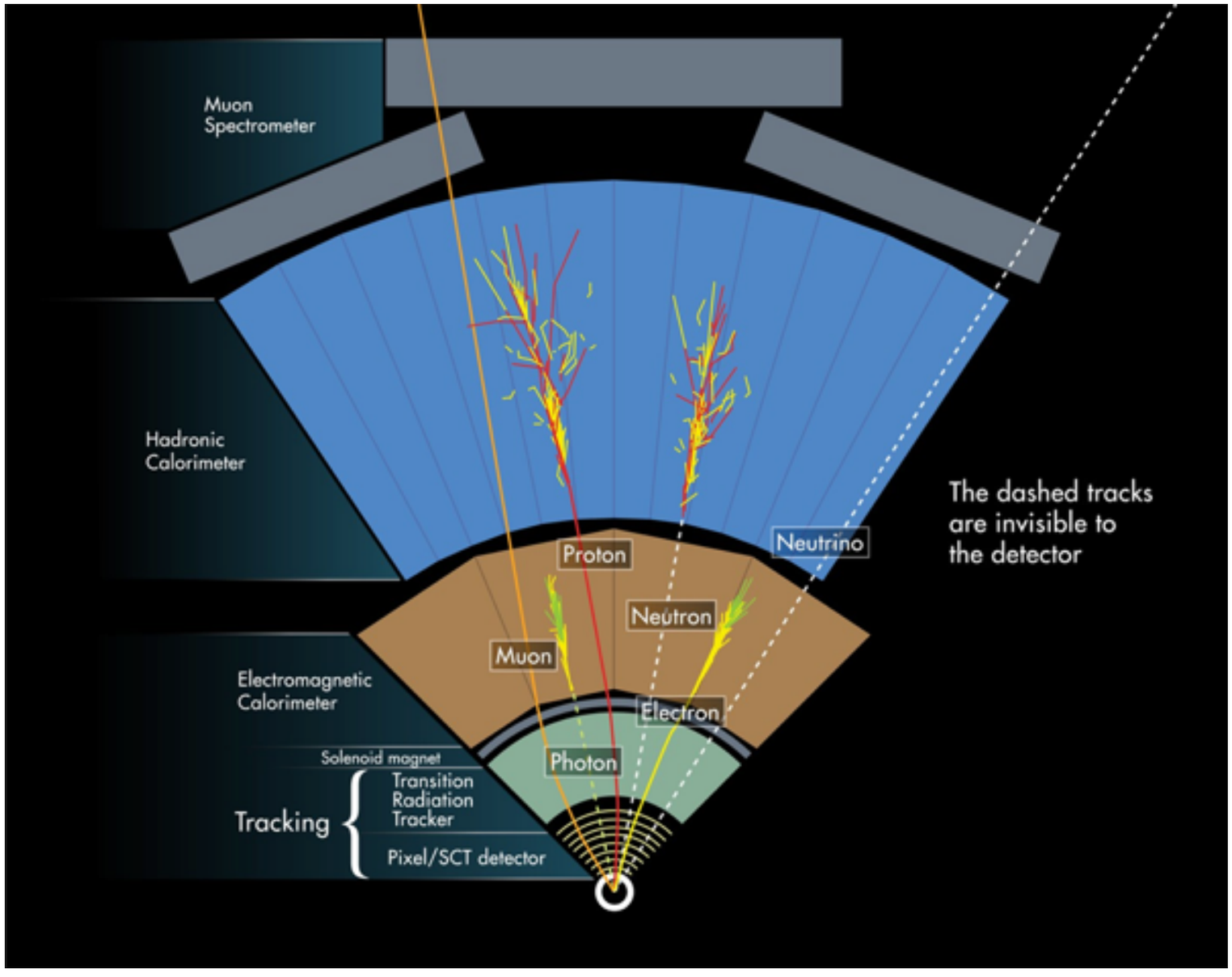
LHC collisions and pile-up

Z → μμ + ~25 interactions



- Collisions at 40 MHz, events recorded @ up to 500 Hz, ~90% used for analyses
- Multiple collisions per LHC bunch crossing (~20 in 2012)
- Experimental conditions beyond detector design capabilities
- Clean signatures: leptons (e,μ) and photons
- Increasingly difficult: (b-)jets, taus, missing transverse energy

LHC collisions and pile-up



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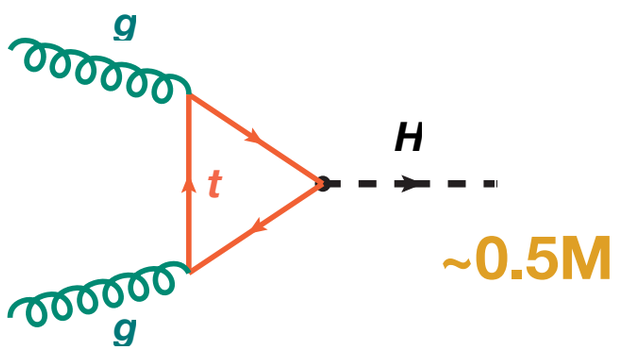
The SM Higgs boson at the LHC run-1

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGCrossSectionsFigures

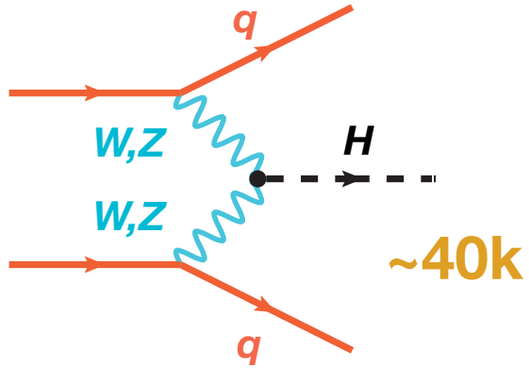
Production mechanisms (events produced)

Gluon-fusion



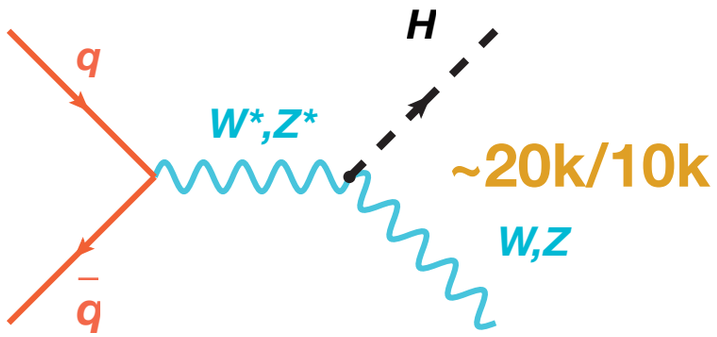
~0.5M

Vector boson fusion (VBF)



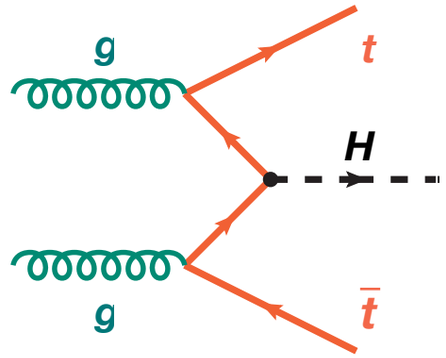
~40k

Associated with W / Z



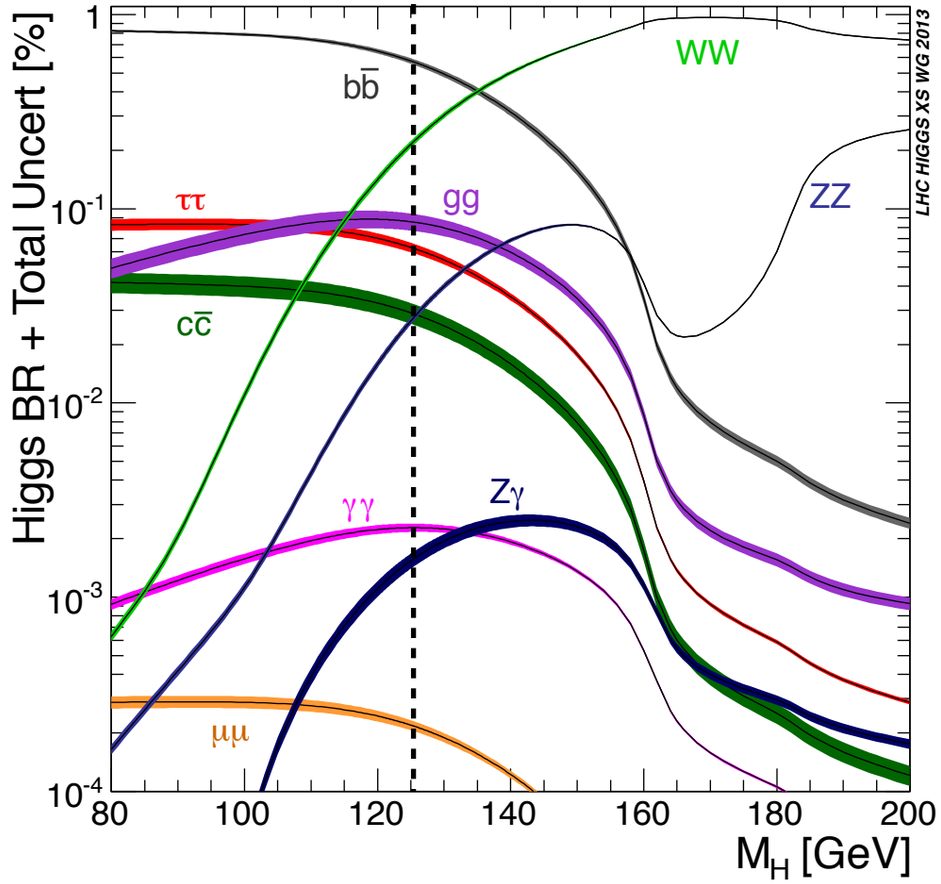
~20k/10k

Associated with tt (or bb)

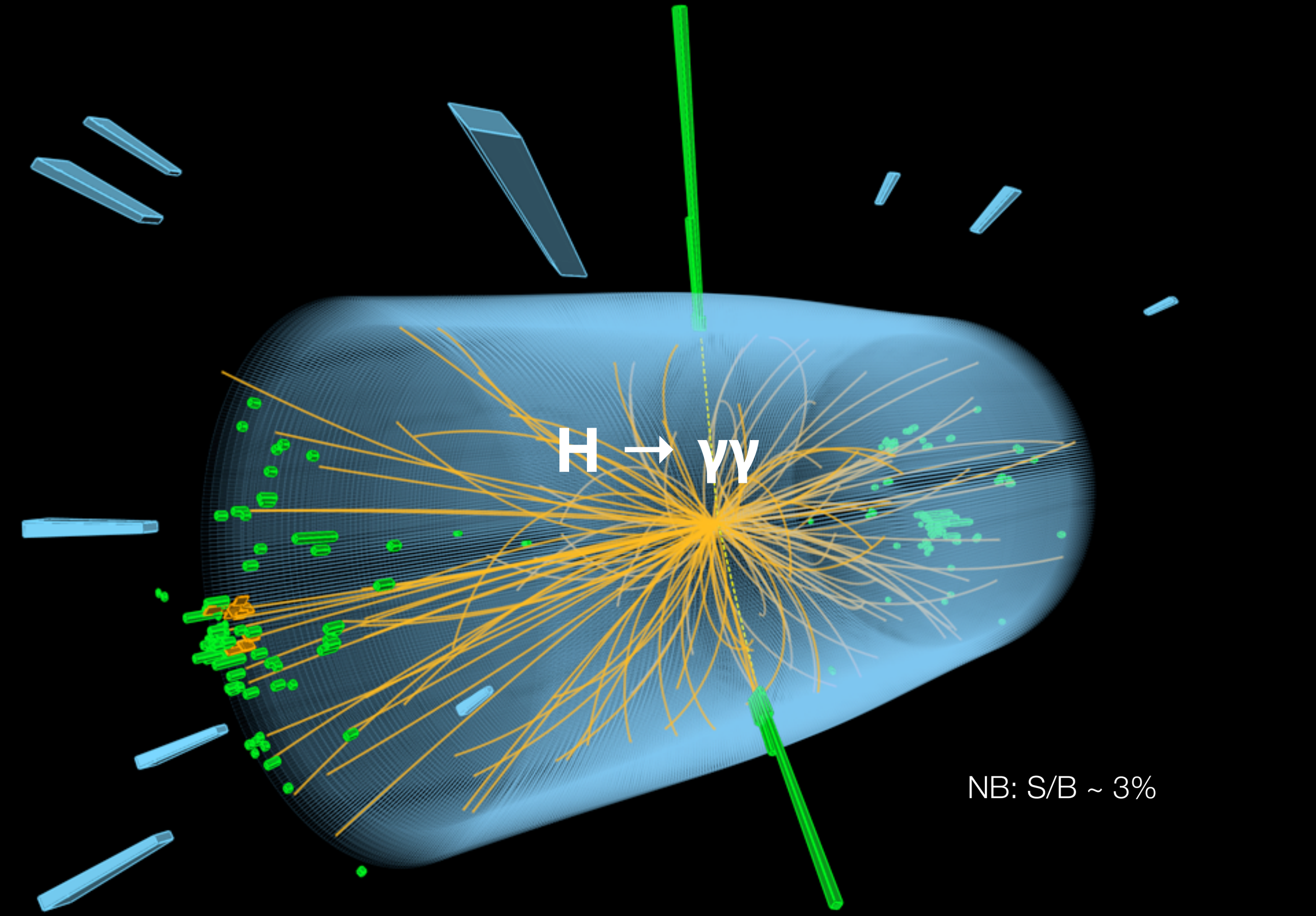


~3k/5k

Decay modes



- Main channels (bosonic): H → γγ, H → ZZ* → 4ℓ, H → WW* → ℓνℓν
- Fermionic modes (associated production): (VBF) H → ττ, (W/Z) H → bb
- Rare decays: H → Zγ, H → μμ

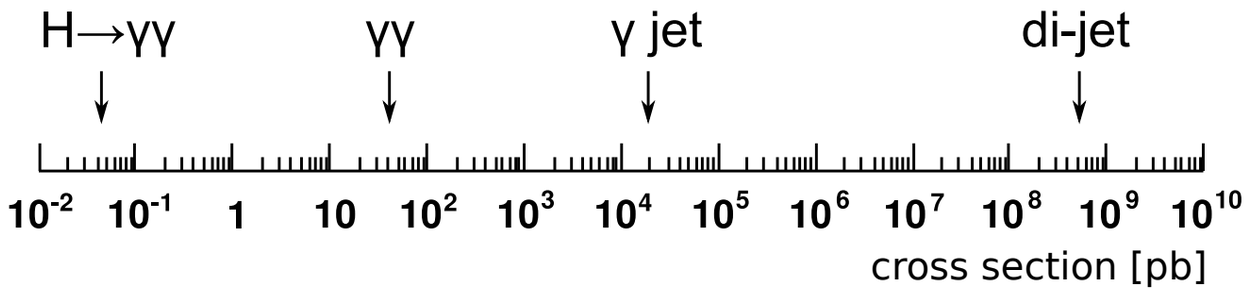


NB: S/B ~ 3%

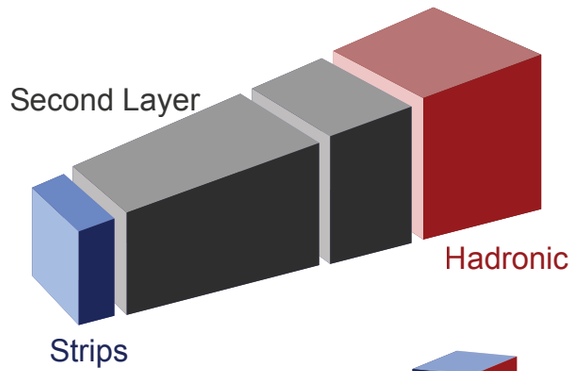
Photon identification

thanks to Jamie Saxon

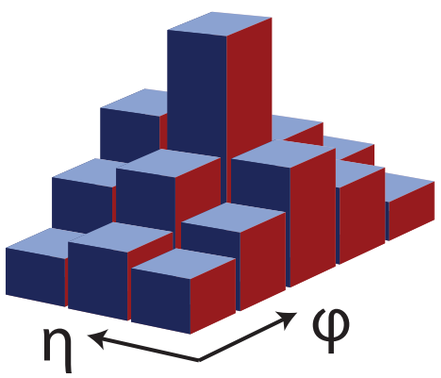
Goal: high γ efficiency, jet ($\pi^0 \rightarrow \gamma\gamma$) rejection factors ~$10^4$



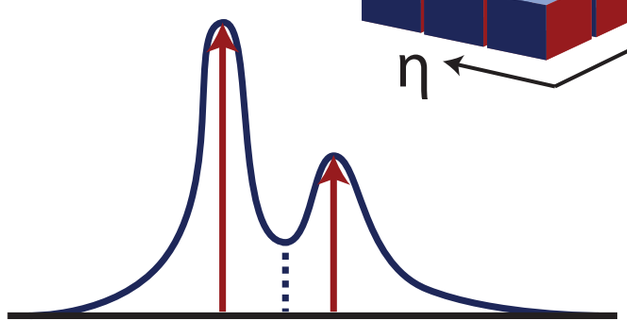
- No hadronic activity

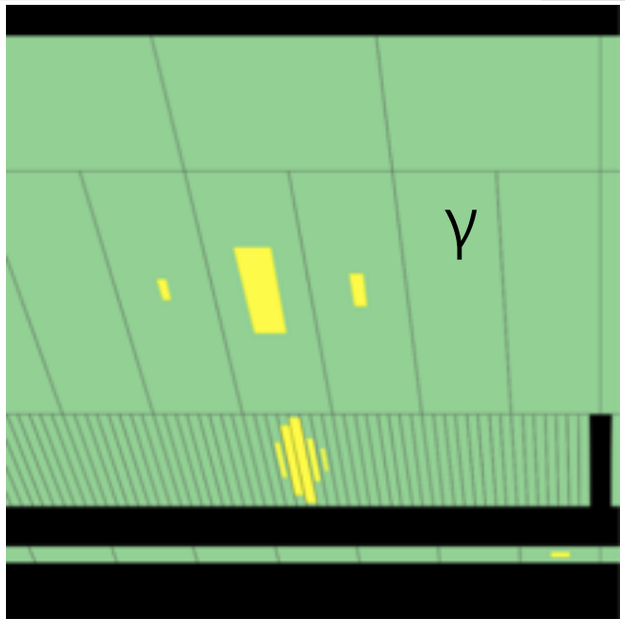


- Narrow showers

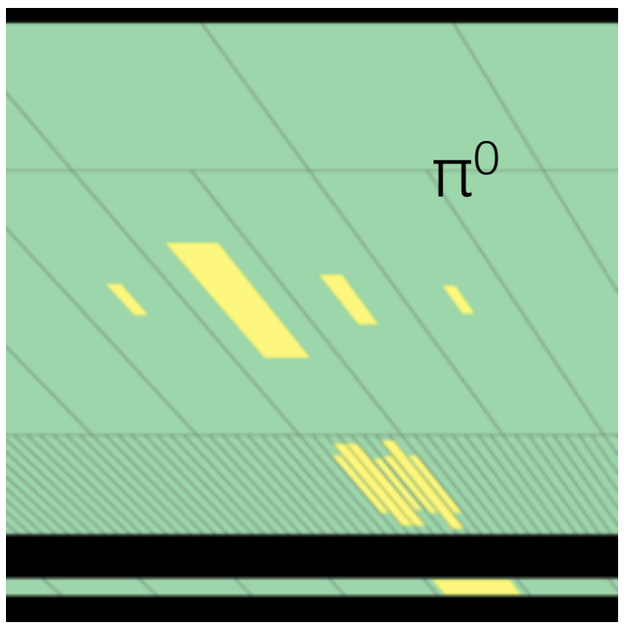


- No second maxima



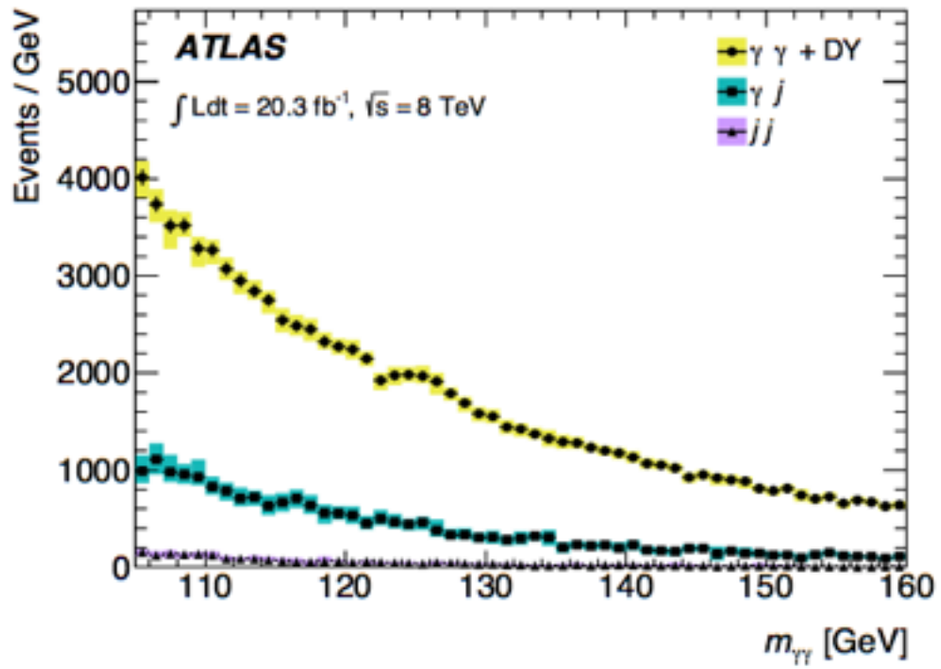


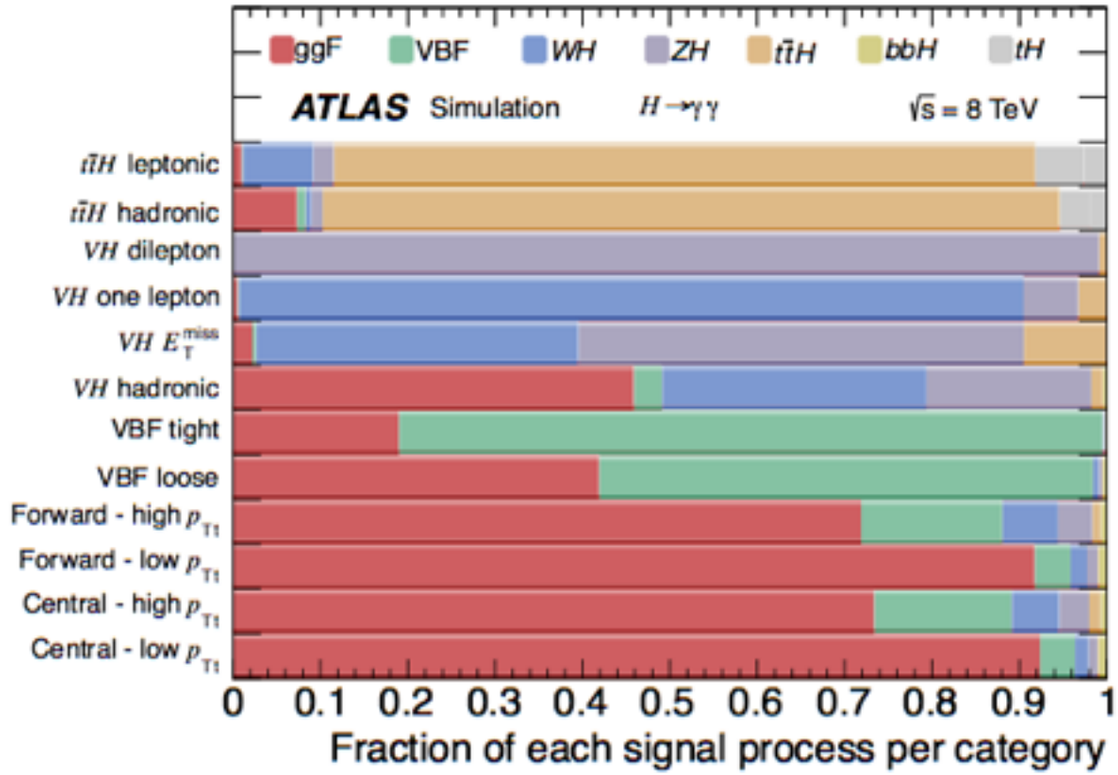
VS



H → γγ: analysis strategy

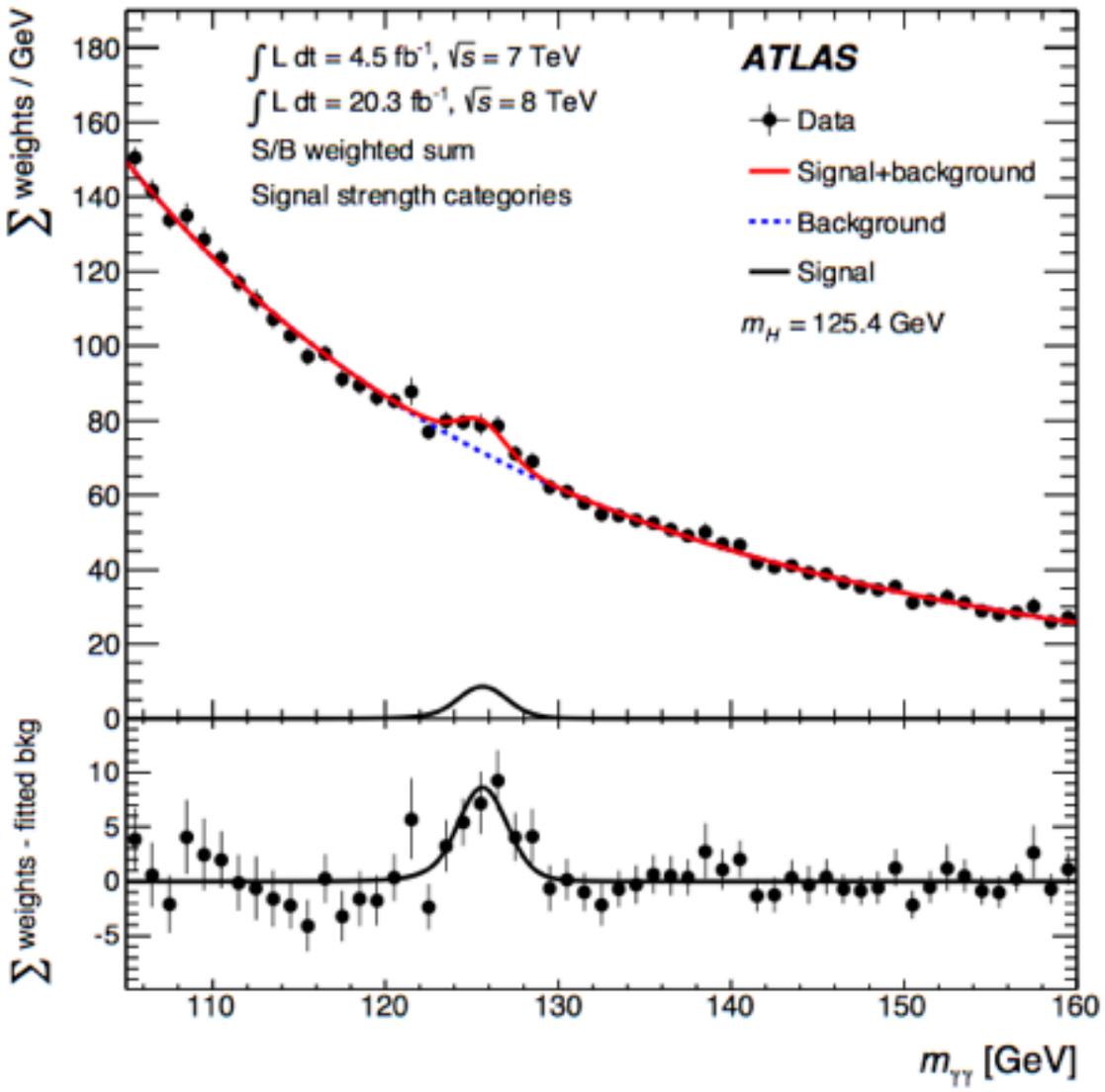
- Select clean γγ sample (purity ~75%)
- Reconstruct $m_{\gamma\gamma}$: ~ 1% resolution
- Split events in categories
  - Improve sensitivity
    - Resolution and S/B vary with e.g. η
  - Access to production modes
    - Leptons and jets for ttH
    - W/Z → ℓ, ν or jets
    - Forward jets to tag VBF

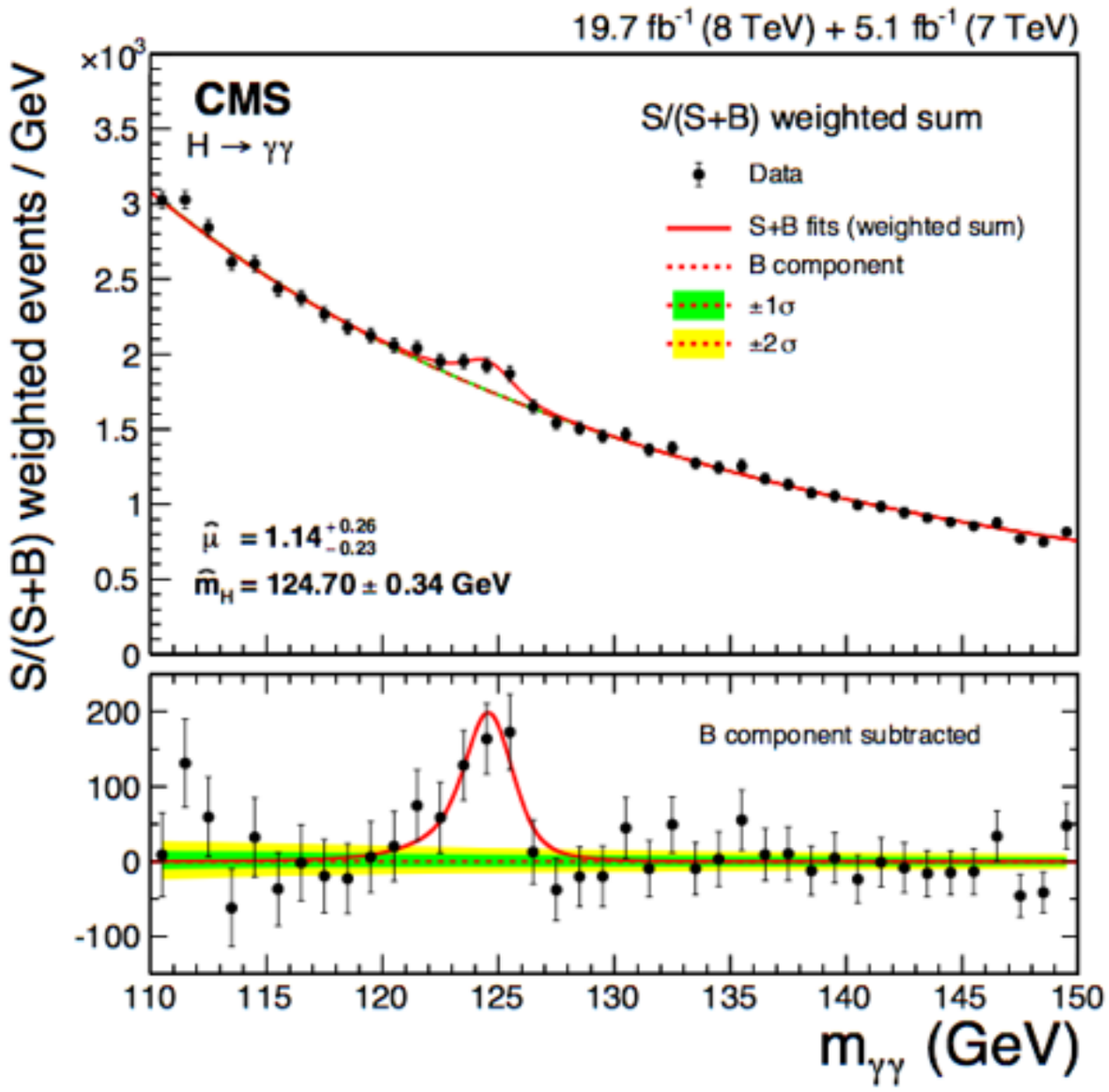




H → γγ: a look at the data

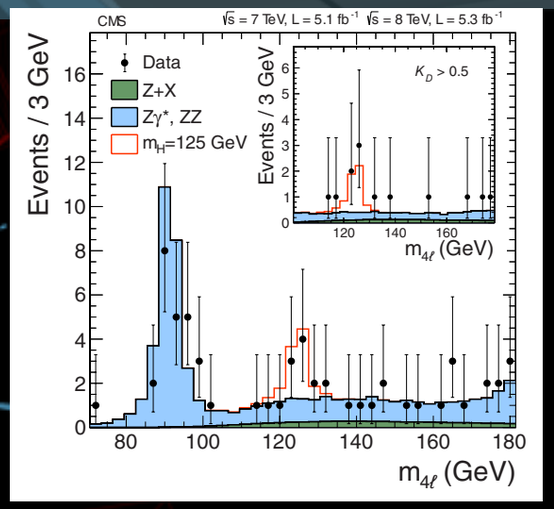
Enhancing the signal with
weights from the categories



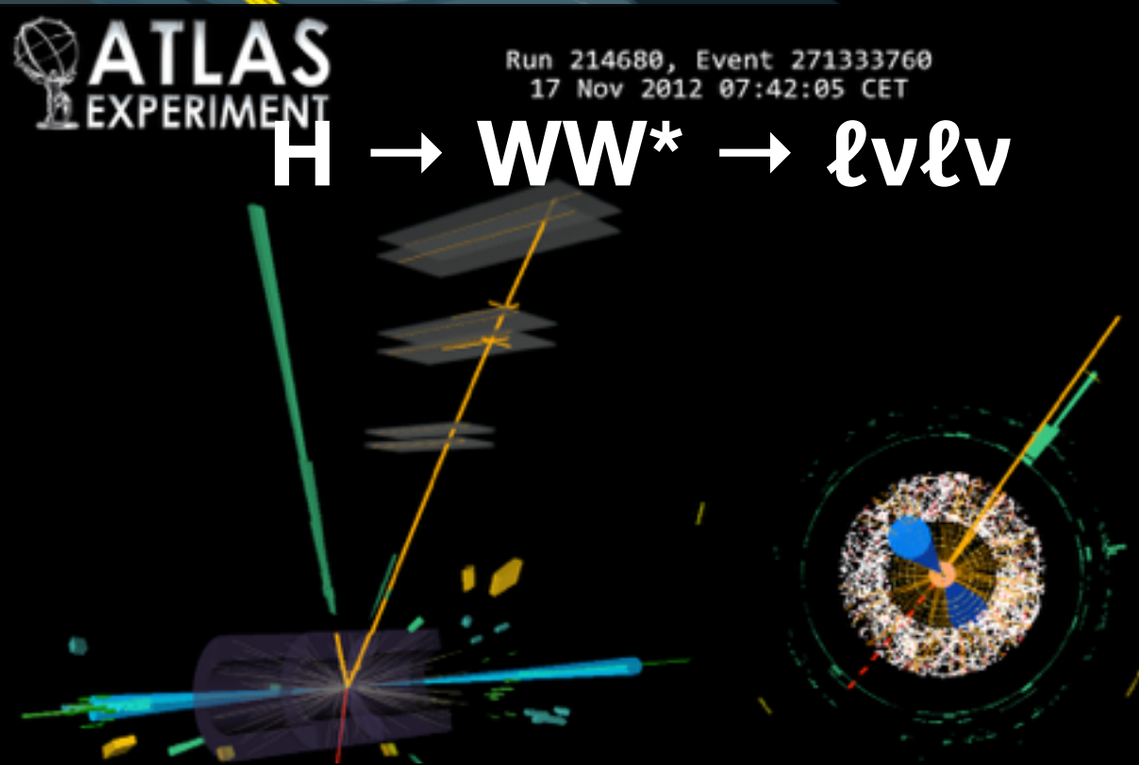


Higgs boson results: other decay modes

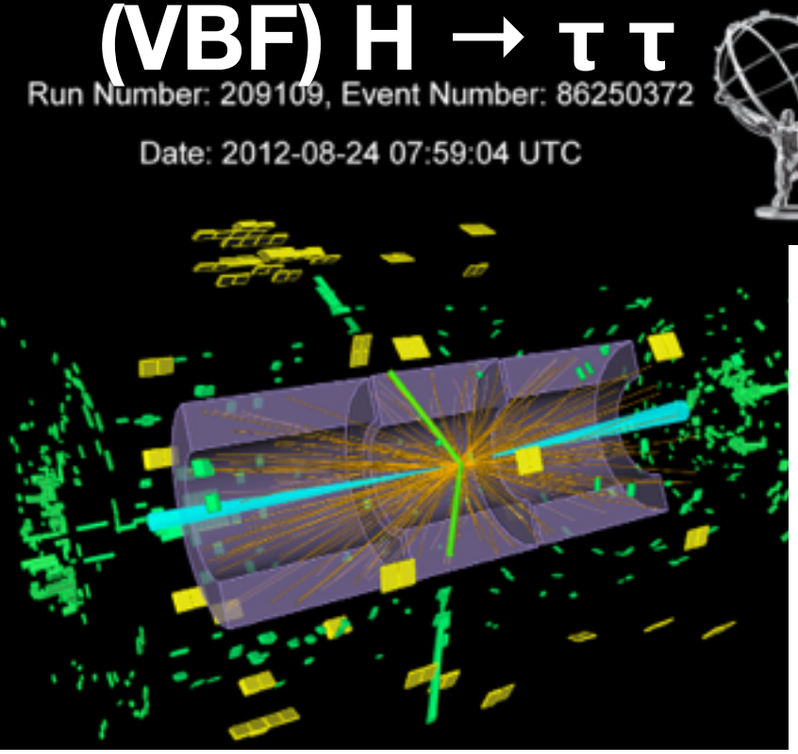
H → ZZ* → 4ℓ

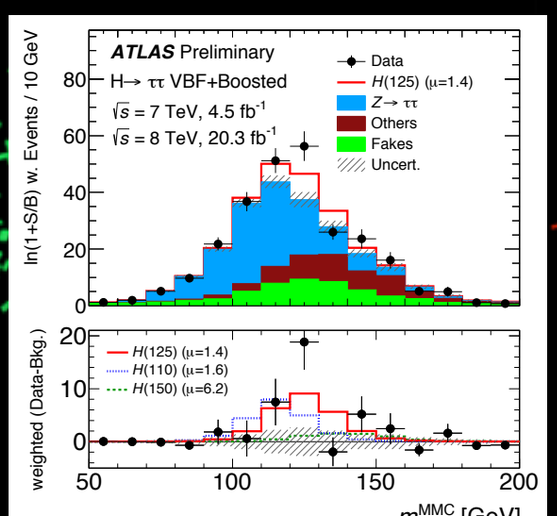


H → WW* → ℓνℓν

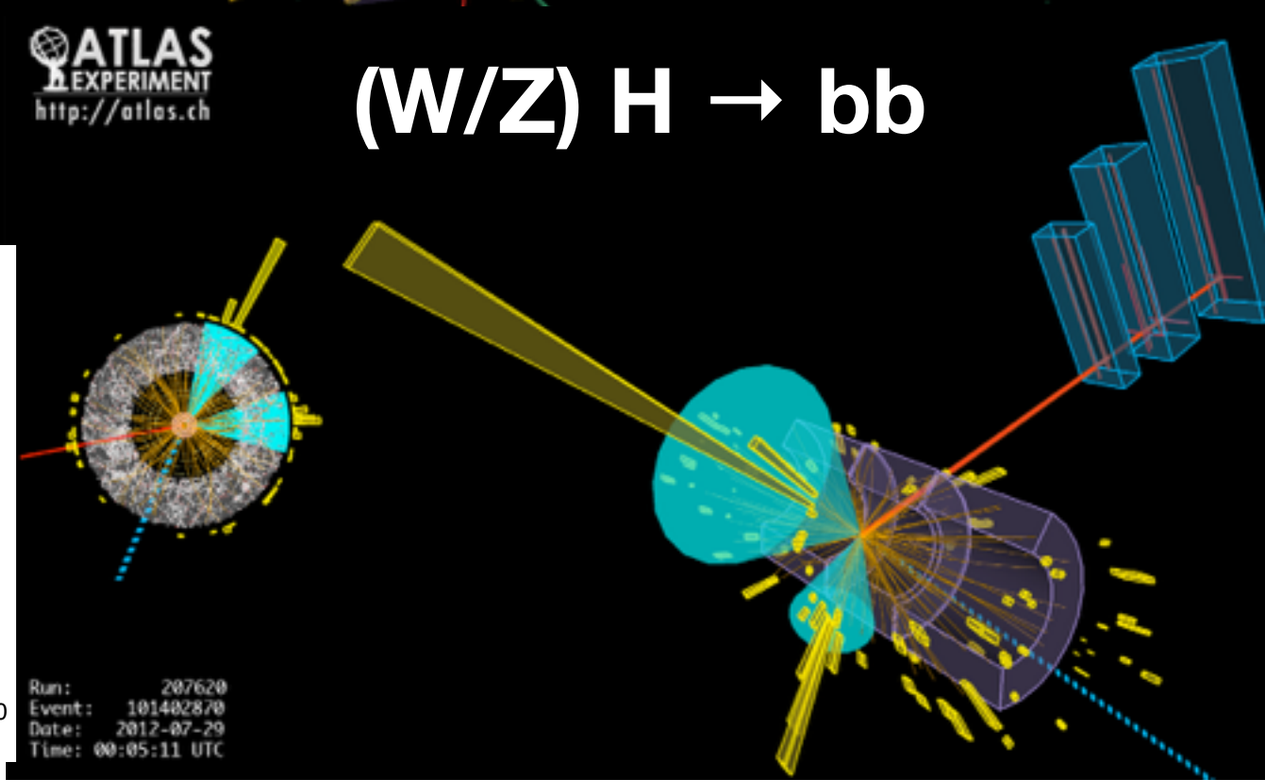


(VBF) H → τ τ



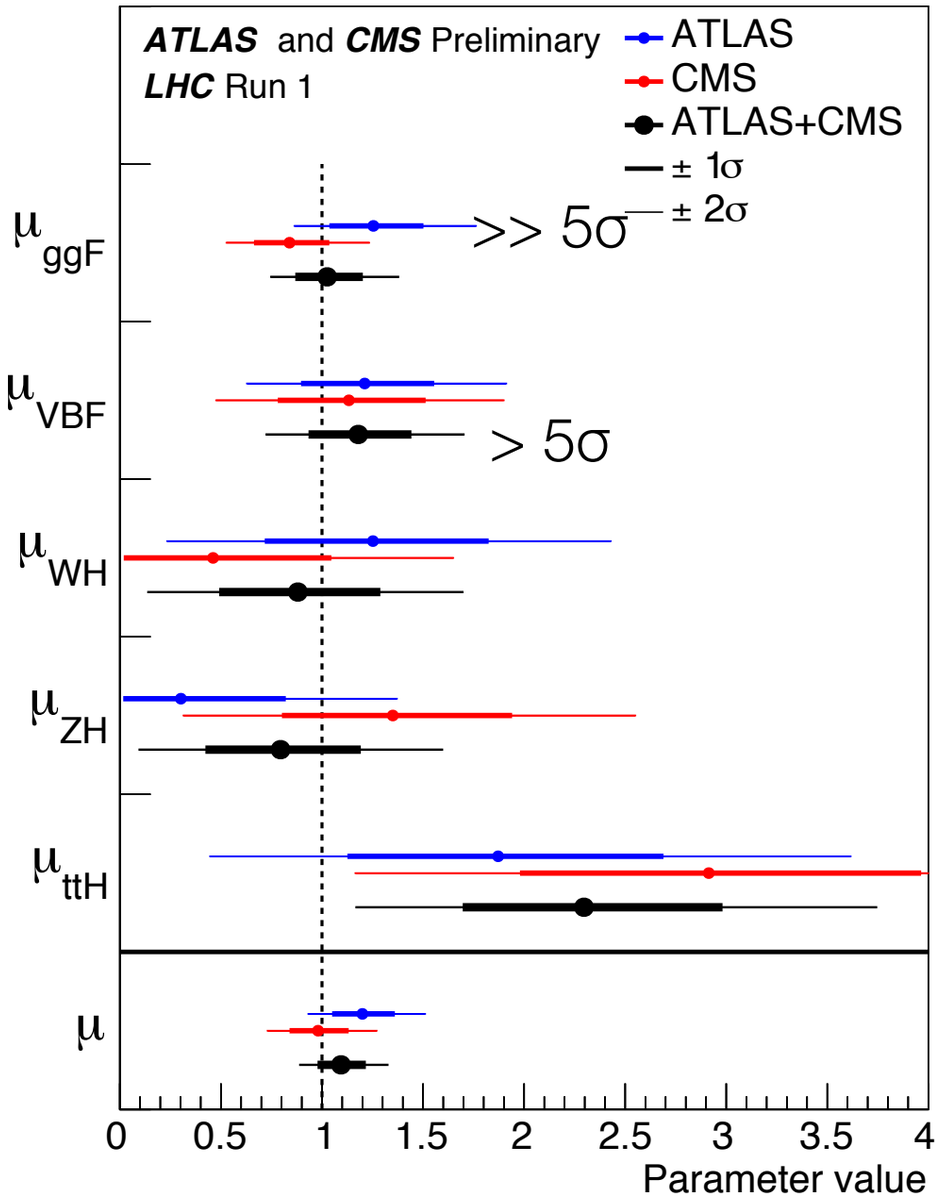


(W/Z) H → bb

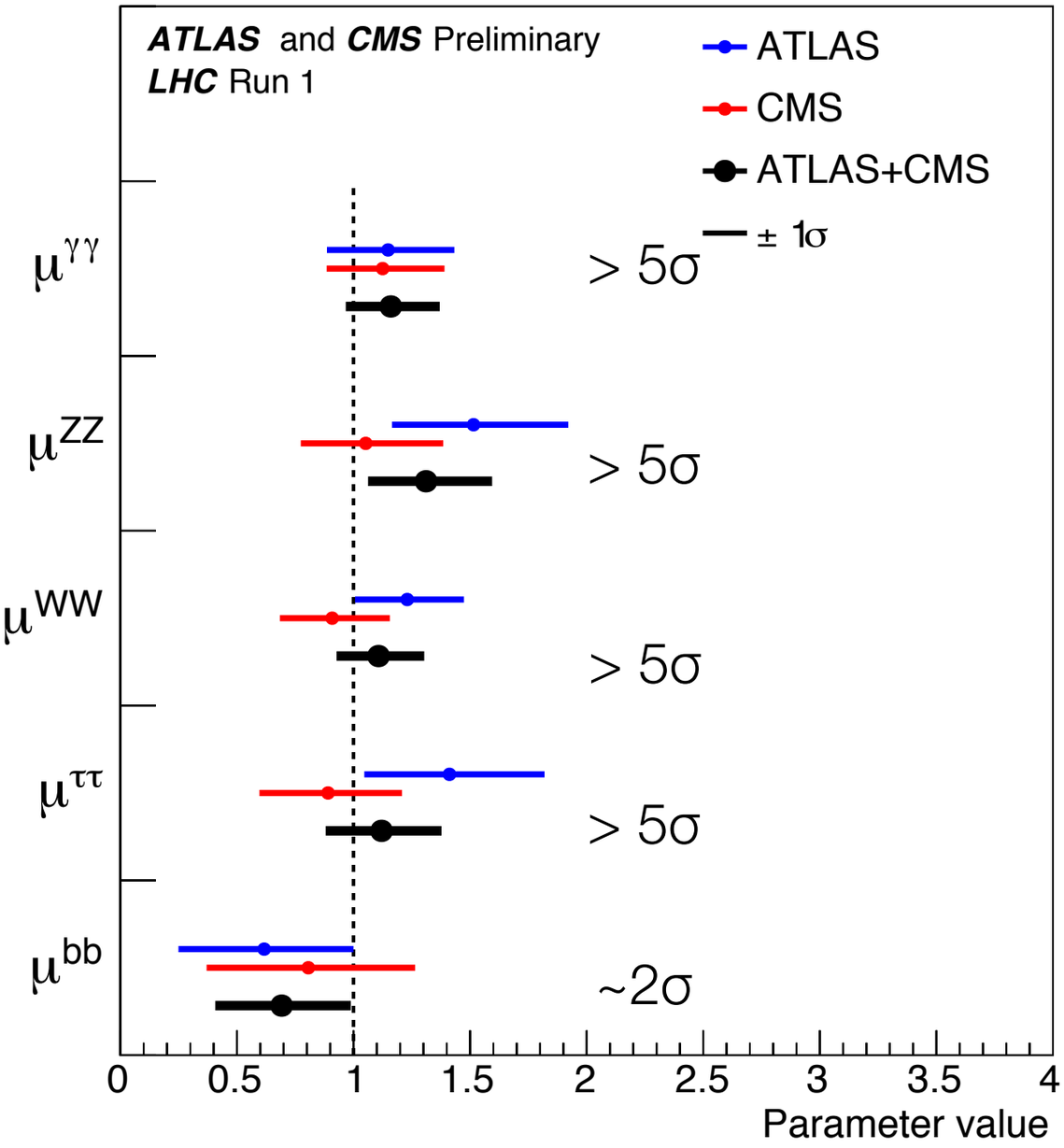


Results: Higgs boson production and decays

γγ + 4ℓ: m_H = 125.09 ± 0.24 GeV (0.2% precision!)

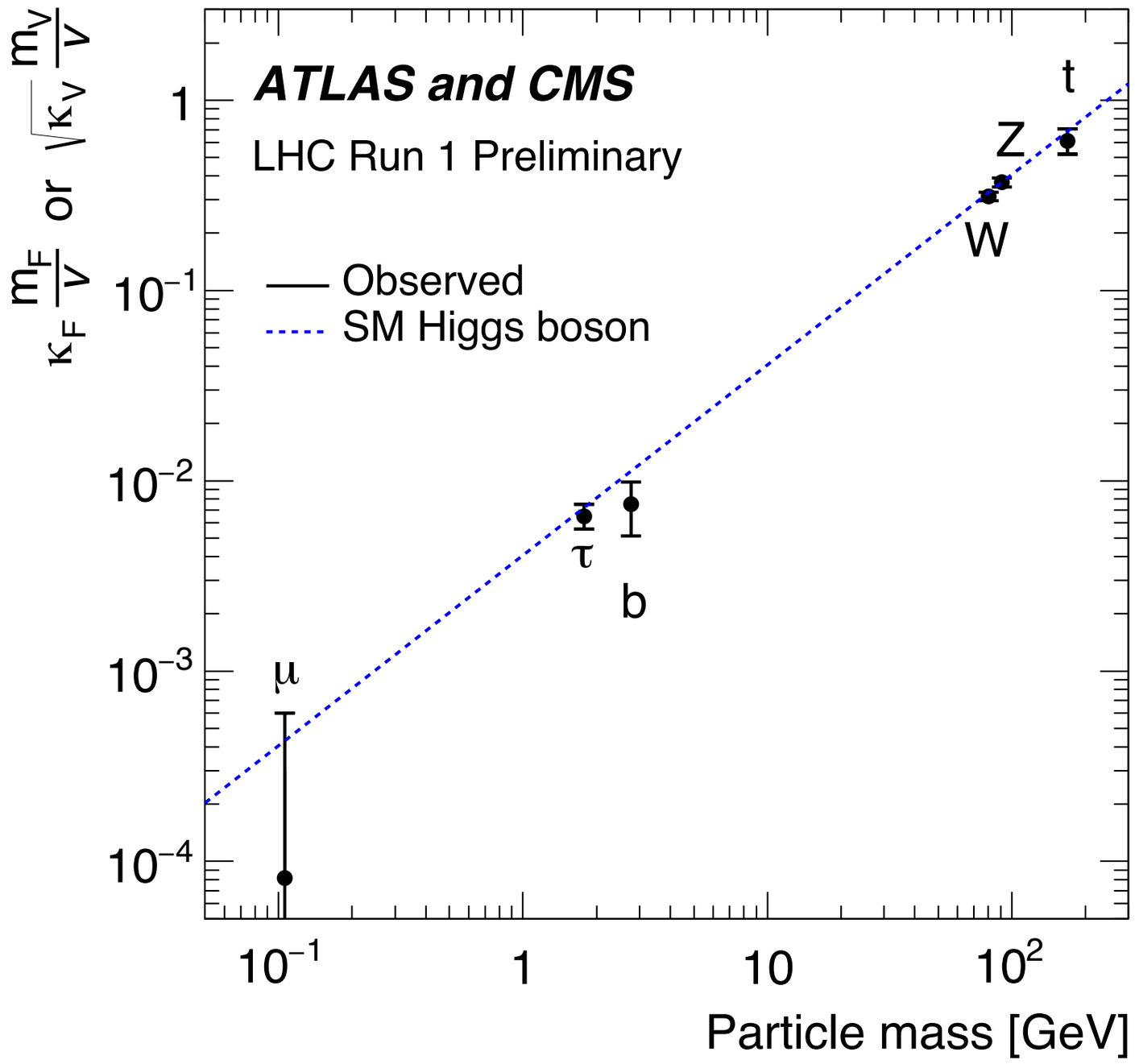


μ = σ/σ$_{SM}$ = 1.09 ± 0.10



Rare decays (μμ, Zγ): 7-10x SM

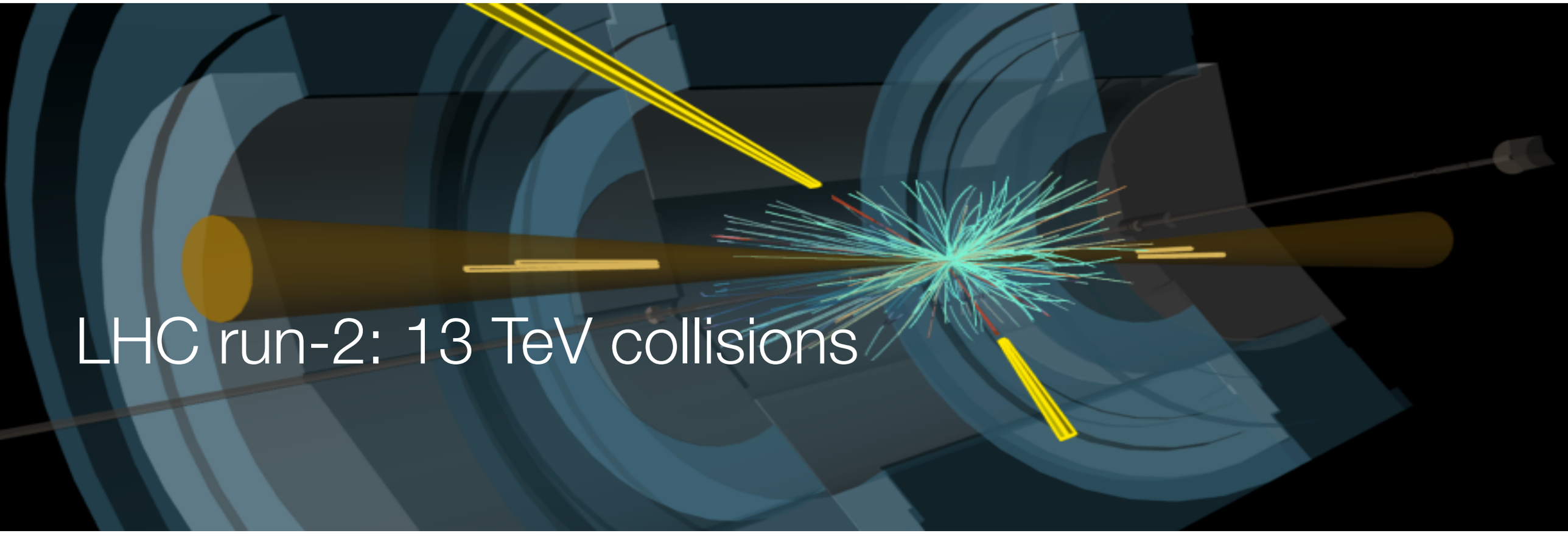
Results: Higgs boson couplings proportional to mass



The new particle

- A boson since it decays to bosons but is it a Higgs boson?
  - Scalar ($J^{PC} = 0^{++}$)
  - Its vacuum expectation value is responsible for EW symmetry breaking
    - Evidence: couplings proportional to mass
- Is it the SM Higgs boson?
  - Elementary particle, associated to the sole mechanism responsible for the masses of gauge bosons and fermions
    - Couplings, width (lifetime), self-interactions (potential) as predicted by the SM

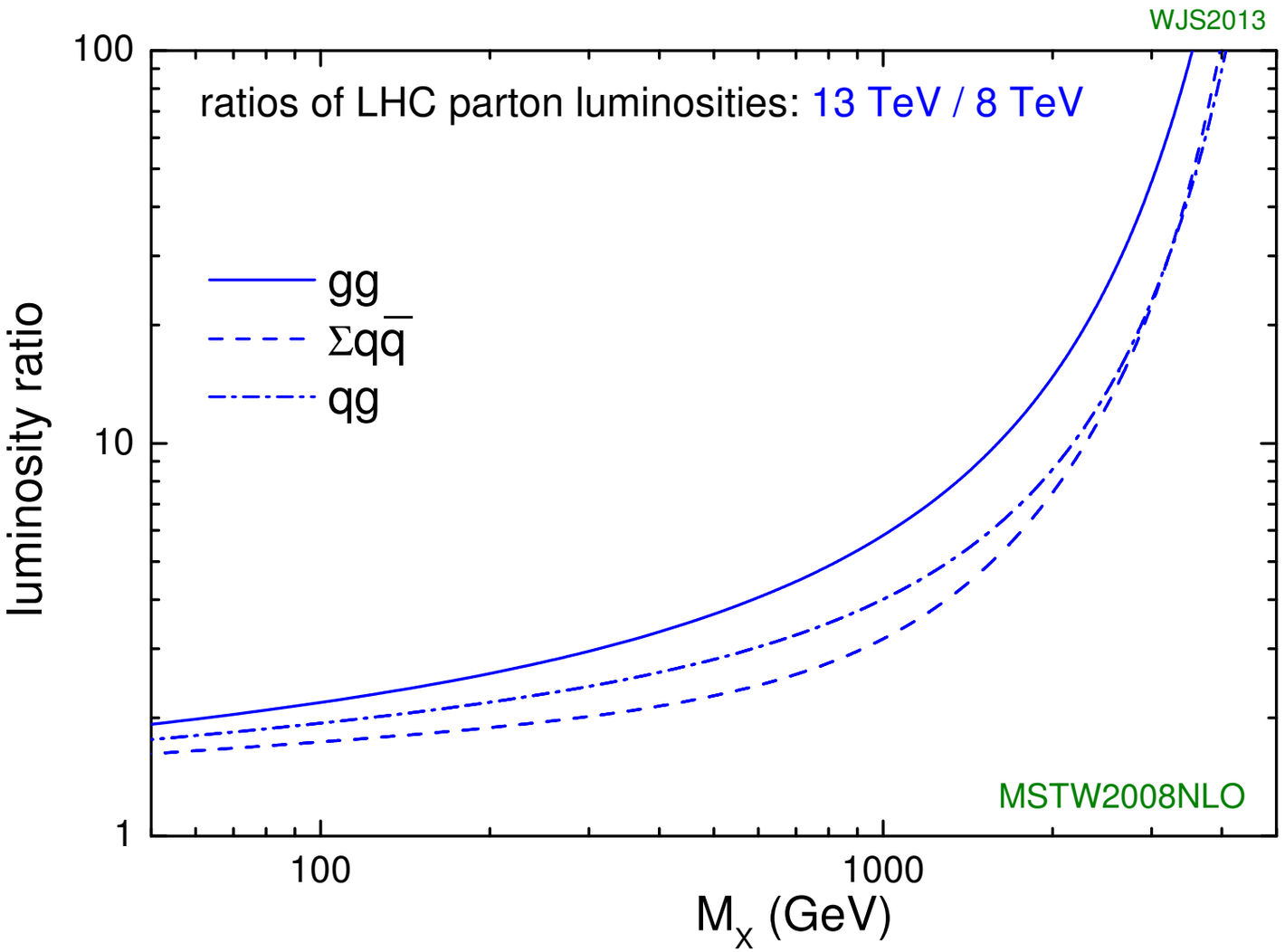
A program for the next decades



LHC run-2: 13 TeV collisions

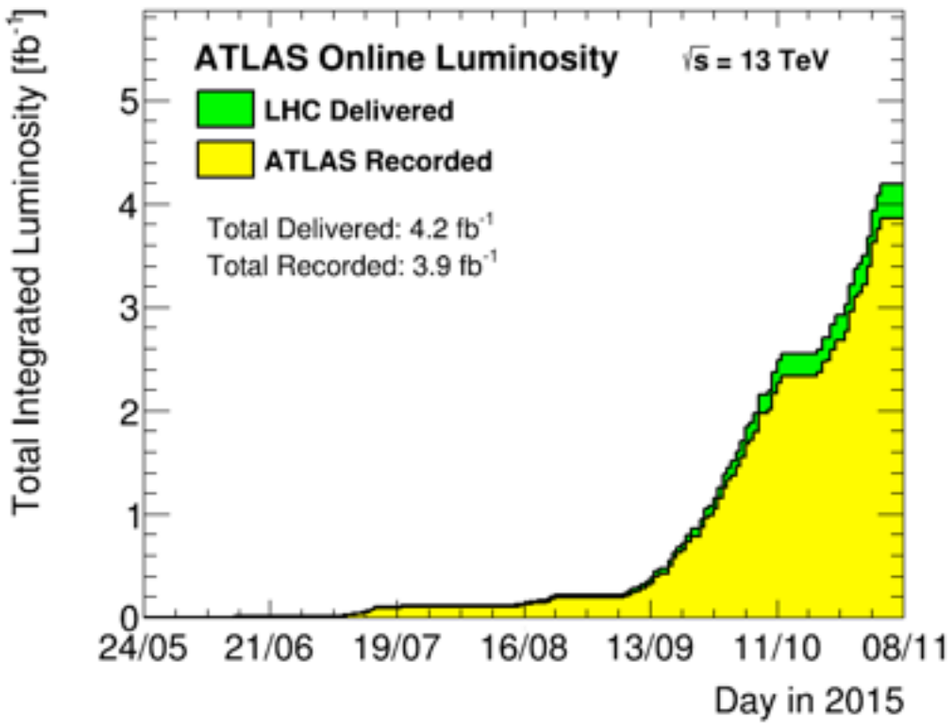
The world at 13 TeV so far

[Stirling]



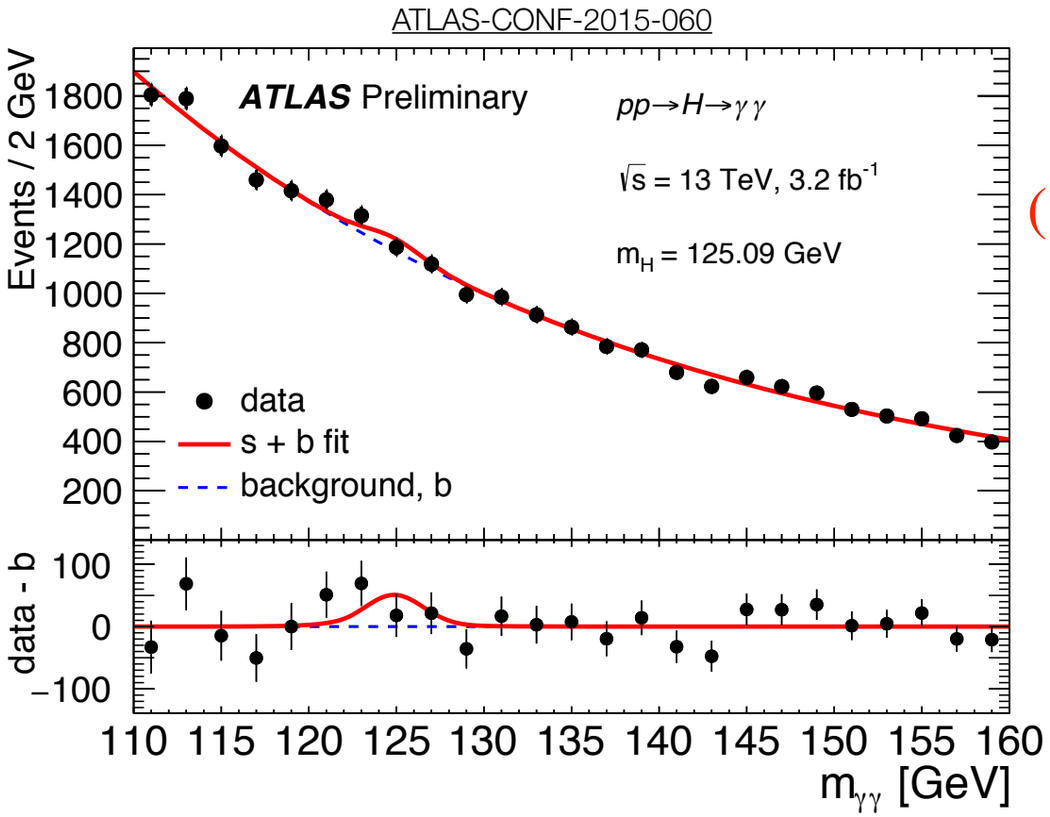
- 2012: 20 fb^{-1} for analyses
- 2015: ~4 fb^{-1} delivered
  ~2-3 fb^{-1} for analyses
- 2016: expect 20-30 fb^{-1}

  Surpass run-1 sensitivity in basically all domains



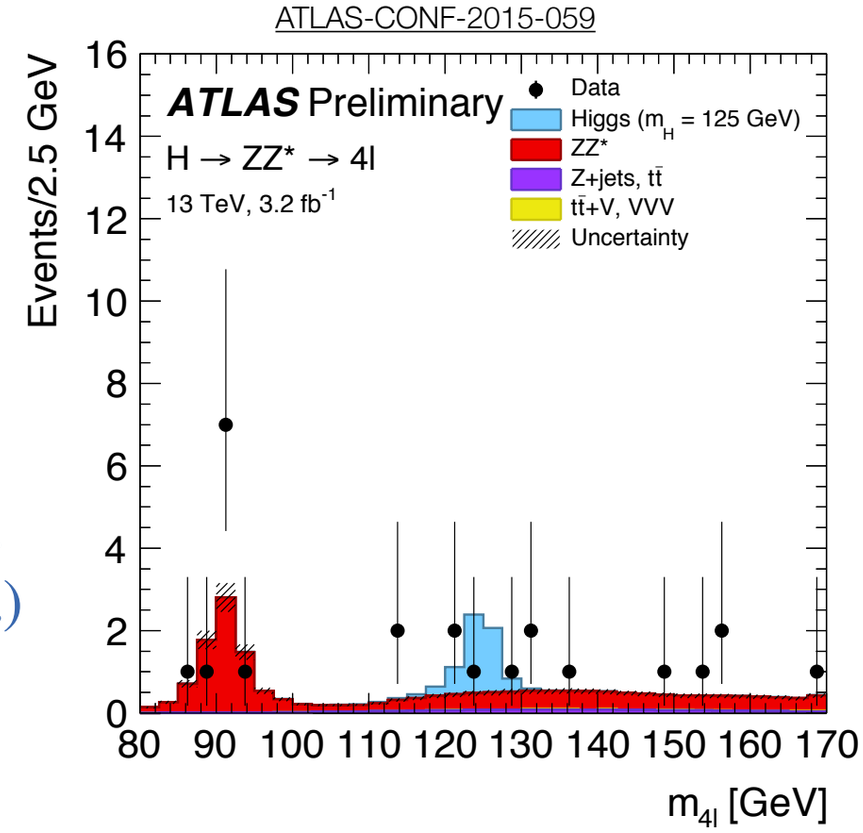
2015 results presented on December

The first Higgs bosons at 13 TeV



1.5σ obs.
(1.9σ exp.)

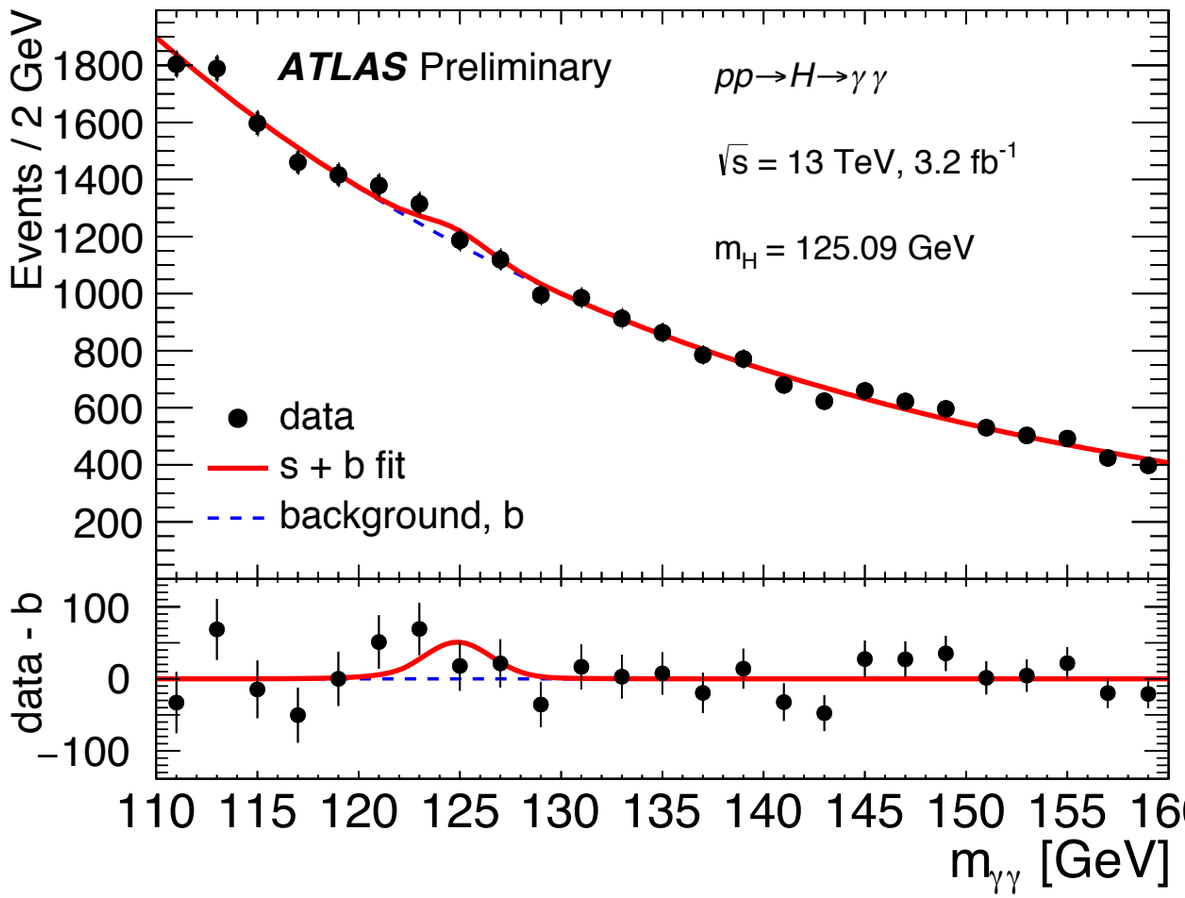
0.7σ obs.
(2.8σ exp.)



CMS analyses still blinded

Searches for (other) diphoton resonances

- Spin-0: Higgs-like (2HDM, NMSSM, …), other decays should be favoured
- Spin-2: Randall-Sundrum graviton, same sensitivity in $\ell^+\ell^-$ decays

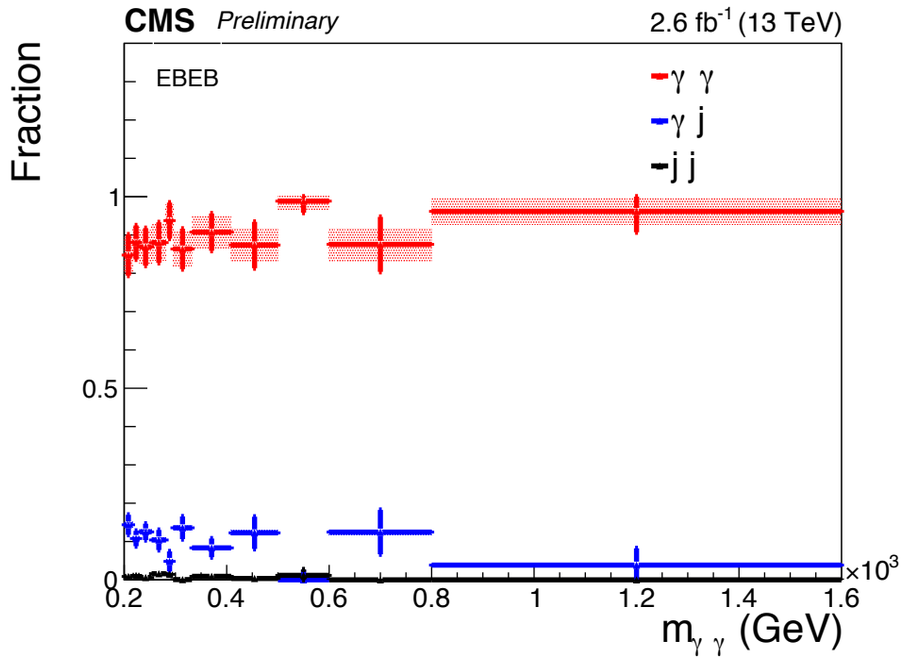


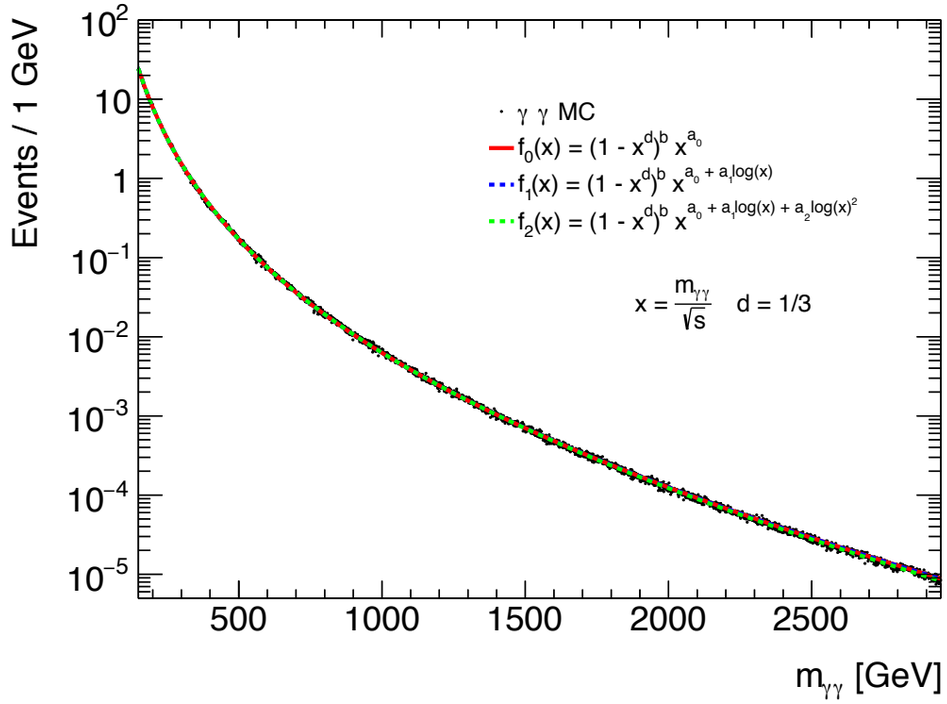
?

Searches for (other) diphoton resonances

CMS-PAS-EXO-15-004

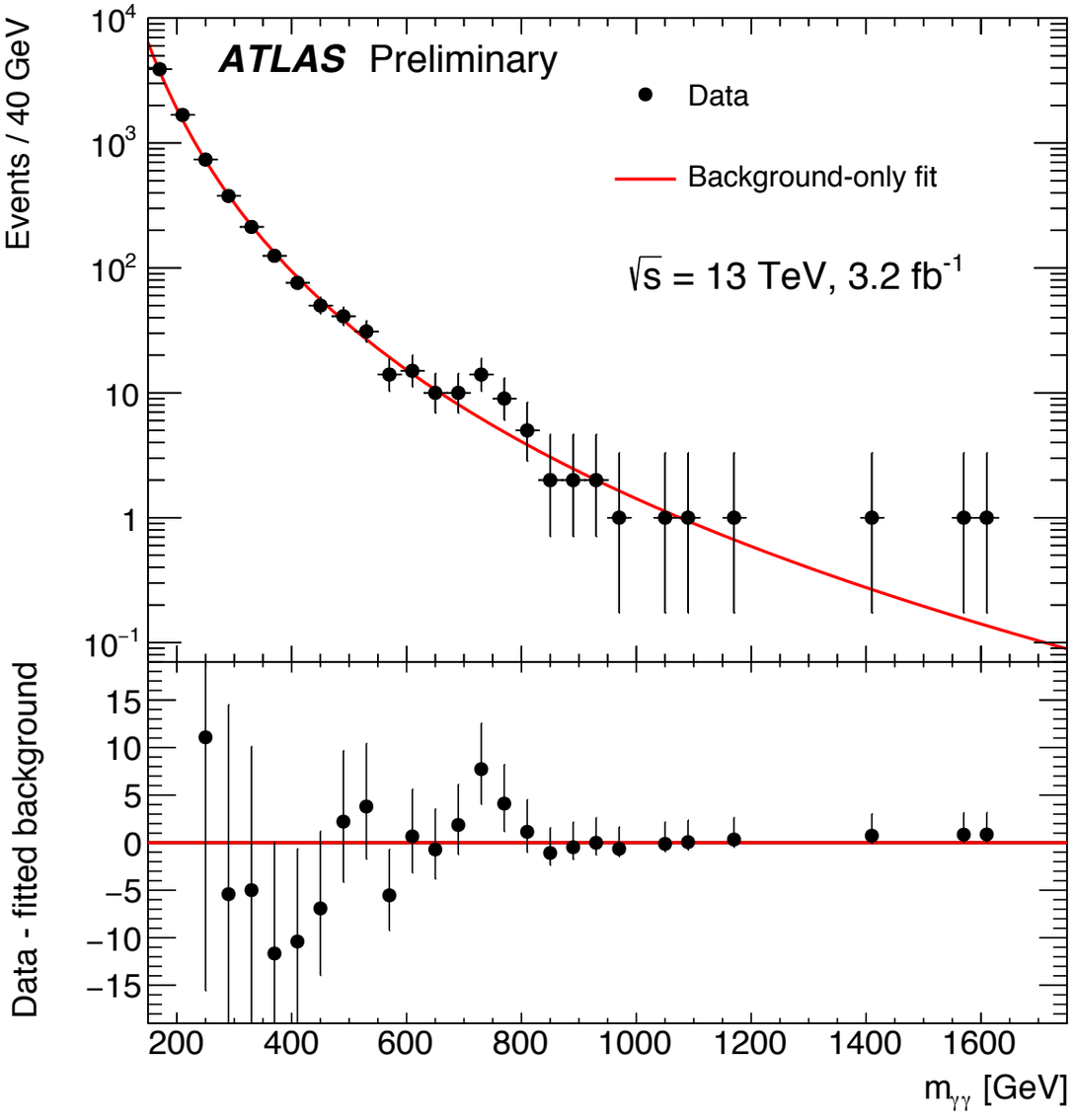
- Pure sample of photons: >90% above 200 GeV
- Selection efficiency increasing with mass
  - Identification and isolation ≳90%
- ATLAS: focus on scalar signal (~30% gain from cuts on E_T / $m_{\gamma\gamma}$)
- CMS: events split between EM barrel (better resolution) and end cap
- Signal + background fit to diphoton invariant mass spectrum
  - Signal from simulation (~1% mass resolution)
  - Background function validated on simulation, fitted on data

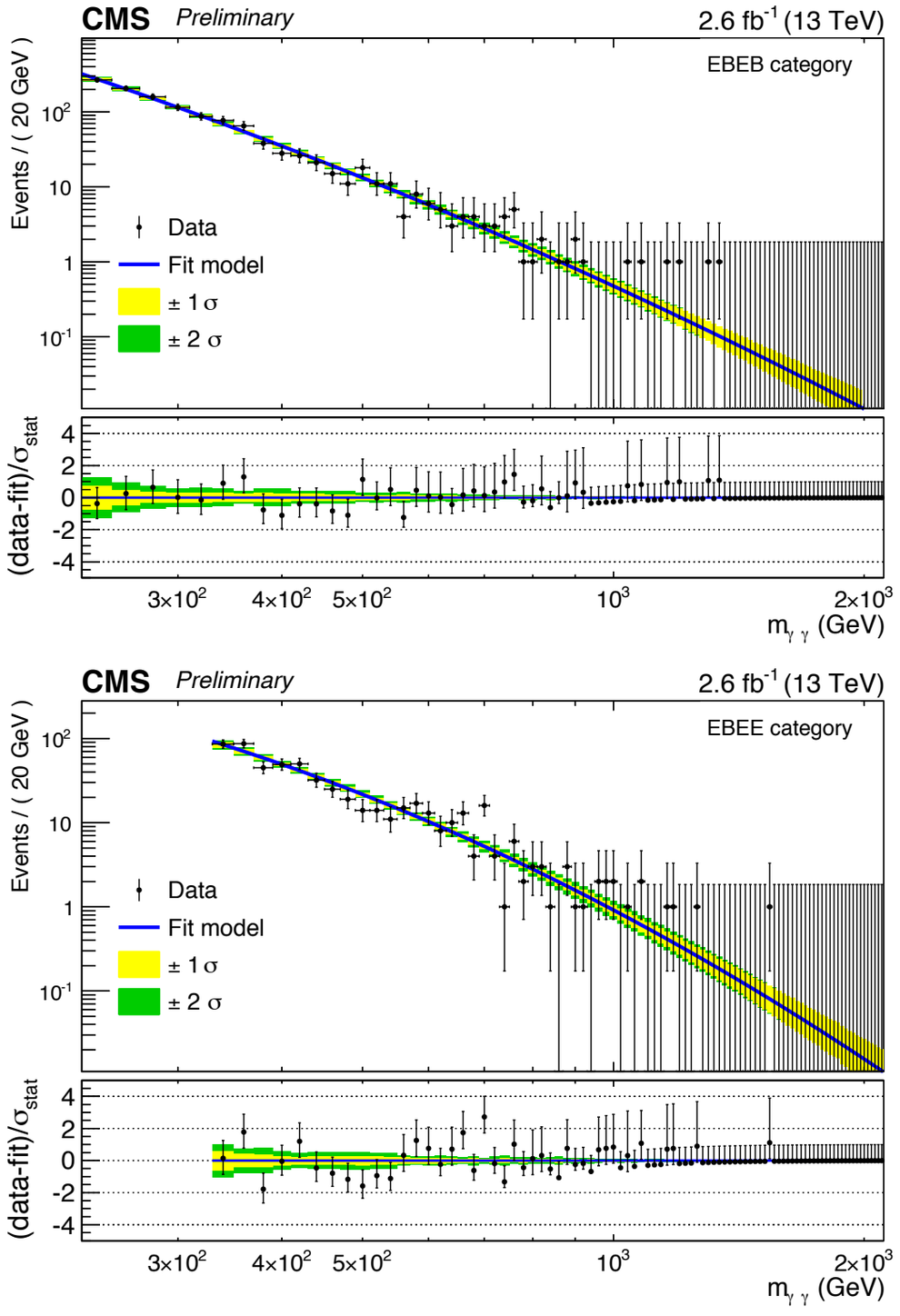




High mass diphoton data

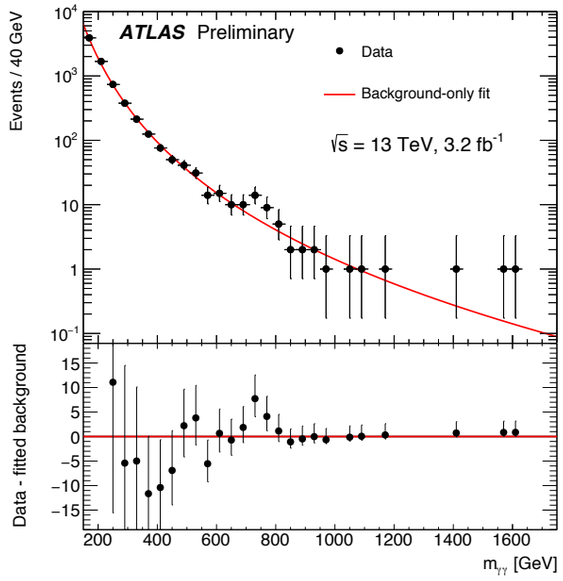
CMS-PAS-EXO-15-004

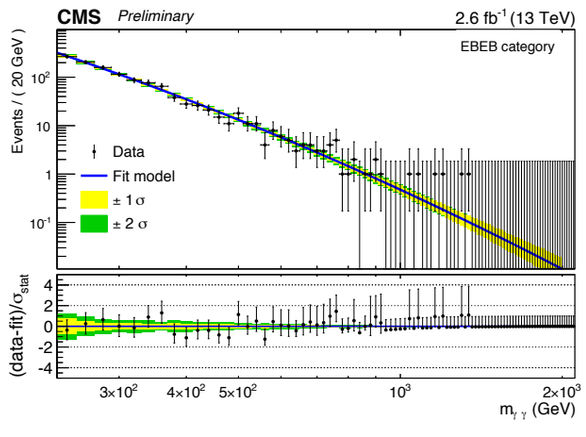


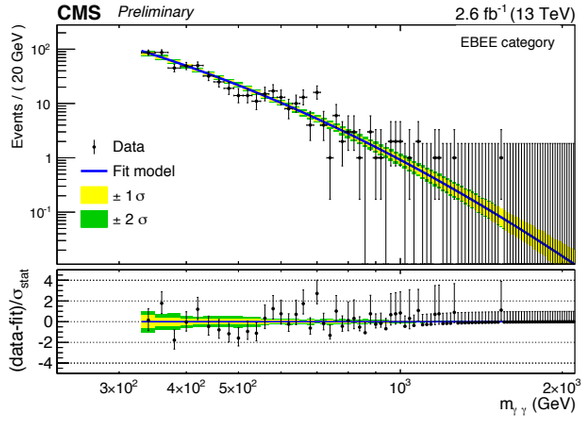


High mass diphoton data

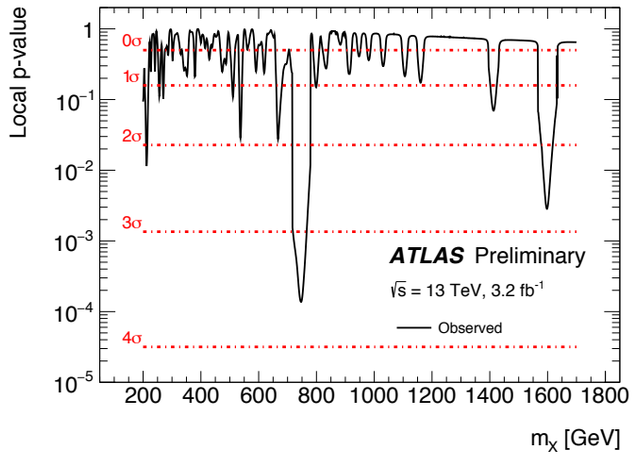
CMS-PAS-EXO-15-004

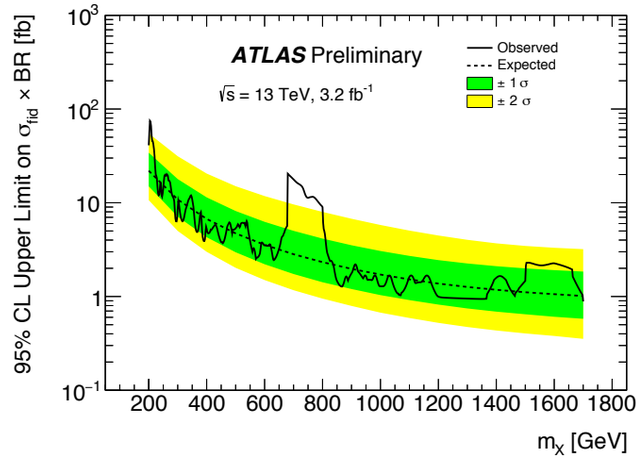






Large width favoured

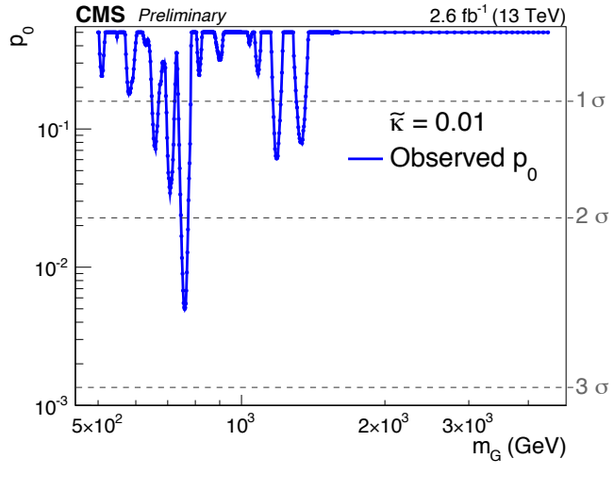


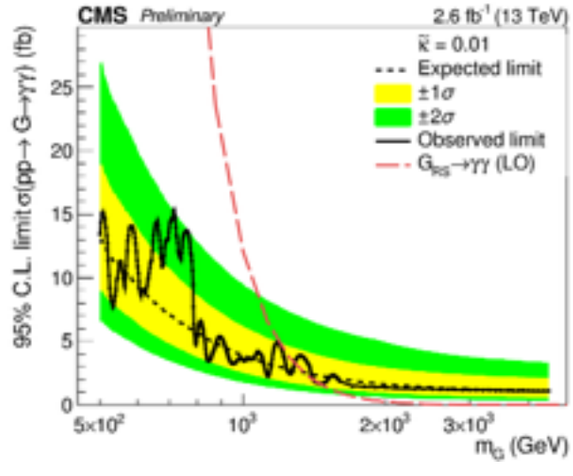


3.6σ @ 750 GeV → 2.0σ after LEE

3.9σ → 2.3σ for Γ/m = 6%

Narrow width favoured

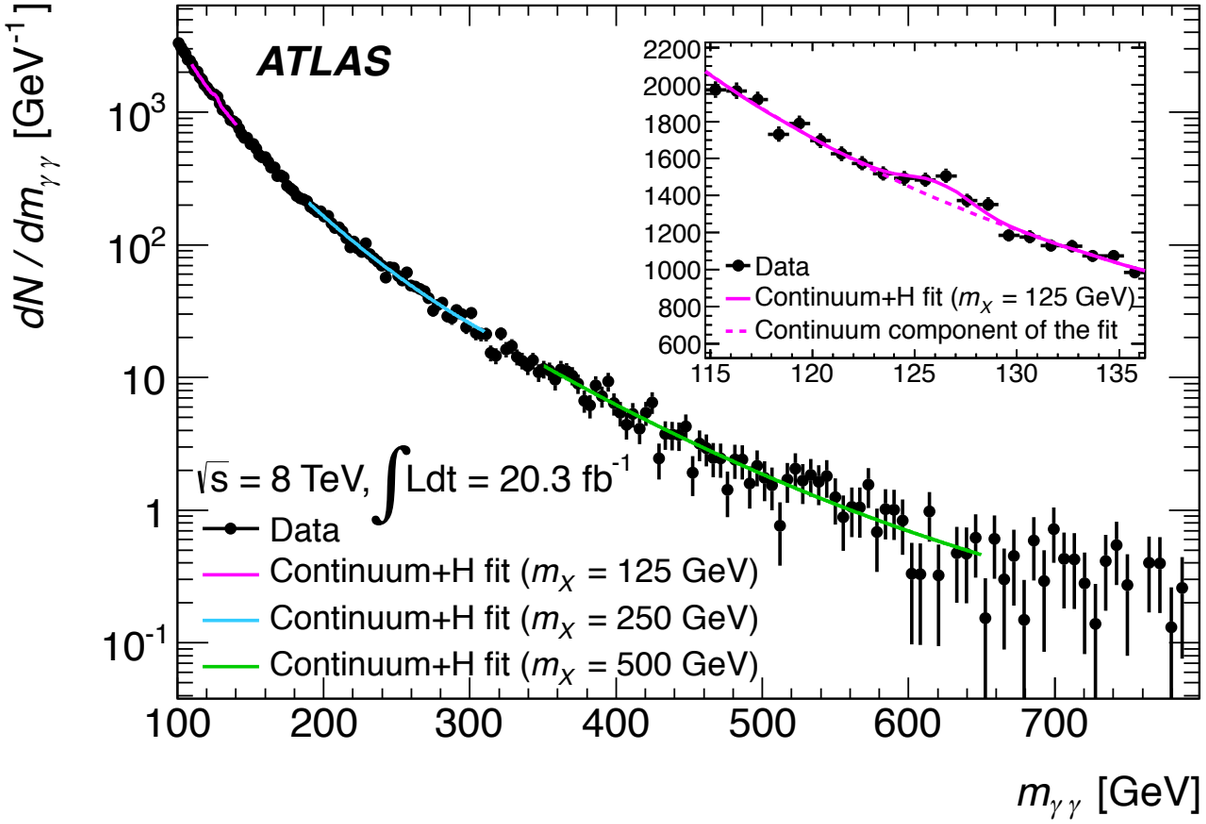


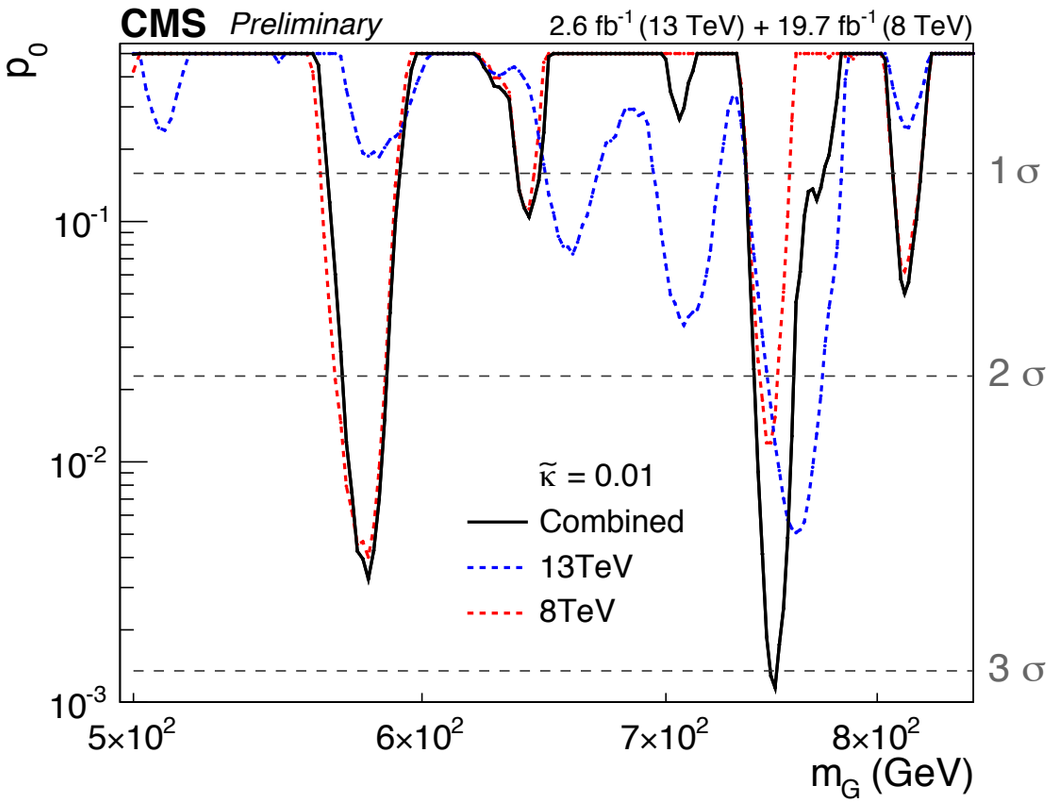


2.6σ @ 760 GeV → 1.2σ after LEE

High mass diphoton results at 8 TeV

- 8 TeV results re-analysed using same method as for 13 TeV data
  - ATLAS: compatibility at 1.4σ (2.2σ) between datasets assuming gg (qq)
  - CMS: 3σ combined significance @ 750 GeV assuming narrow RS signal





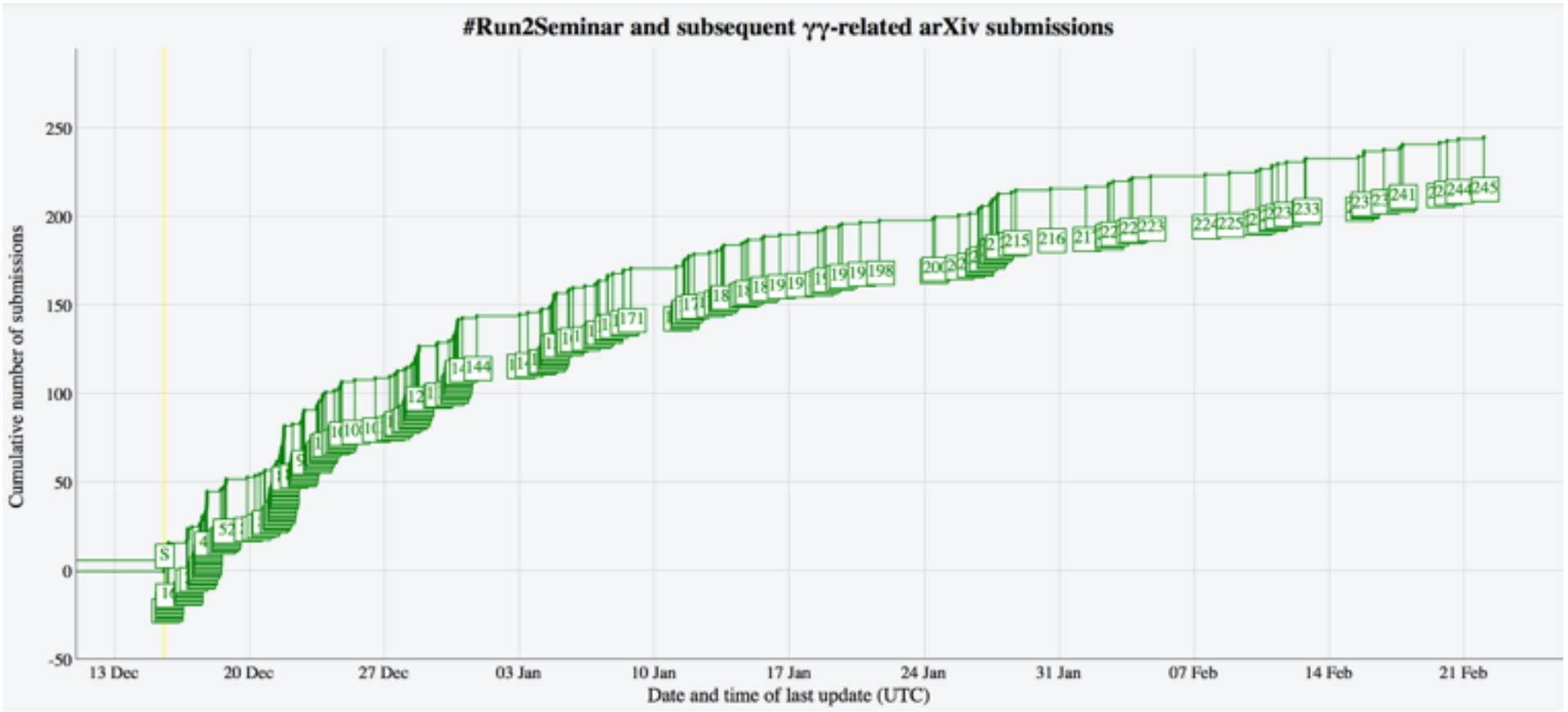
Reactions to the diphoton excess @ 750 GeV

http://jsfiddle.net/adavid/

- Ultra-fast reaction from theory community
- Many possibilities, no obvious explanation
  - No other channels (di-jet, tt, WW, ZZ, Zγ) ?
  - Need more data to confirm / study / exclude

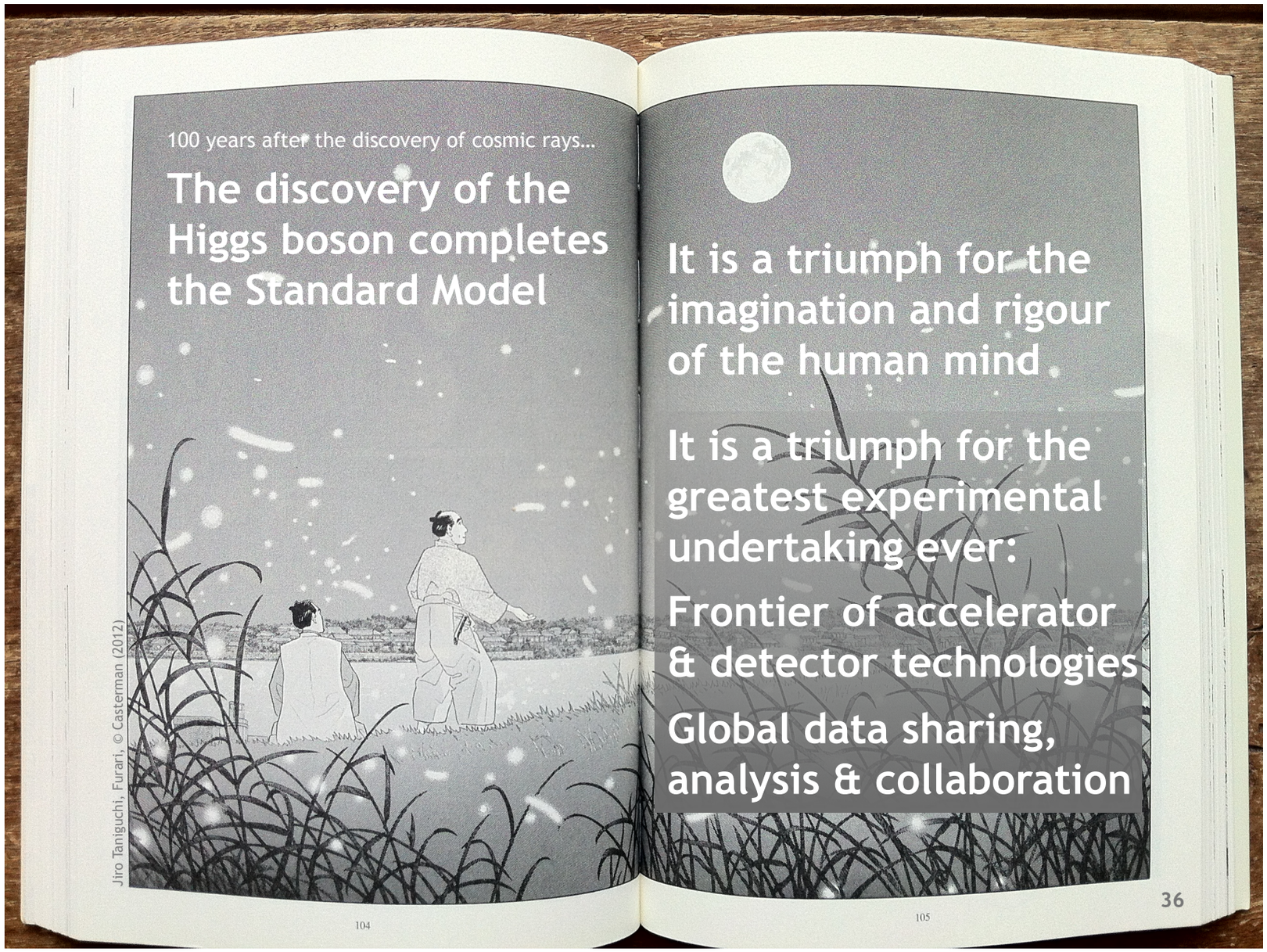
The New York Times

Physicists in Europe Find Tantalizing Hints of a Mysterious New Particle



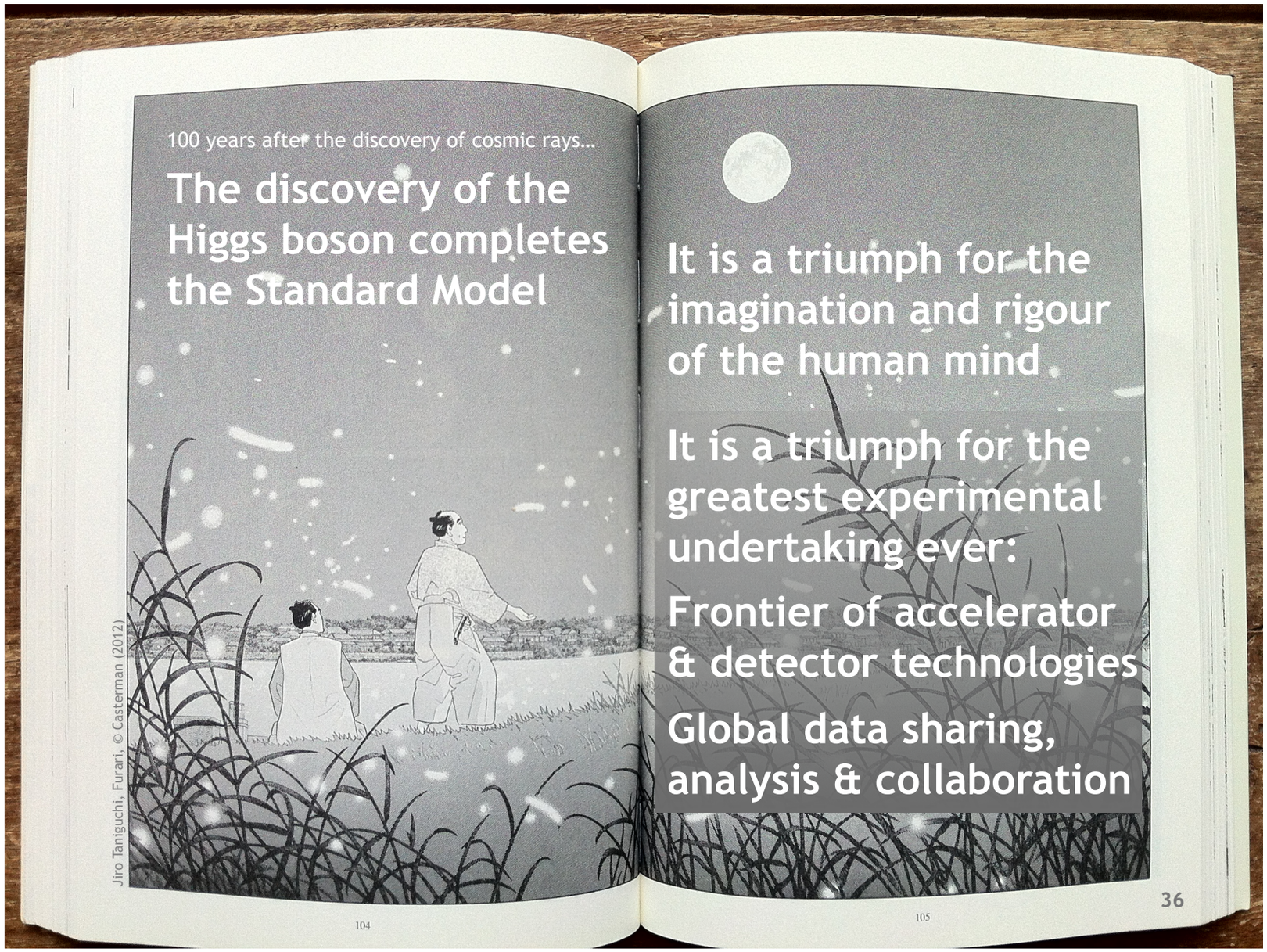
Summary

[Andreas Hoecker]

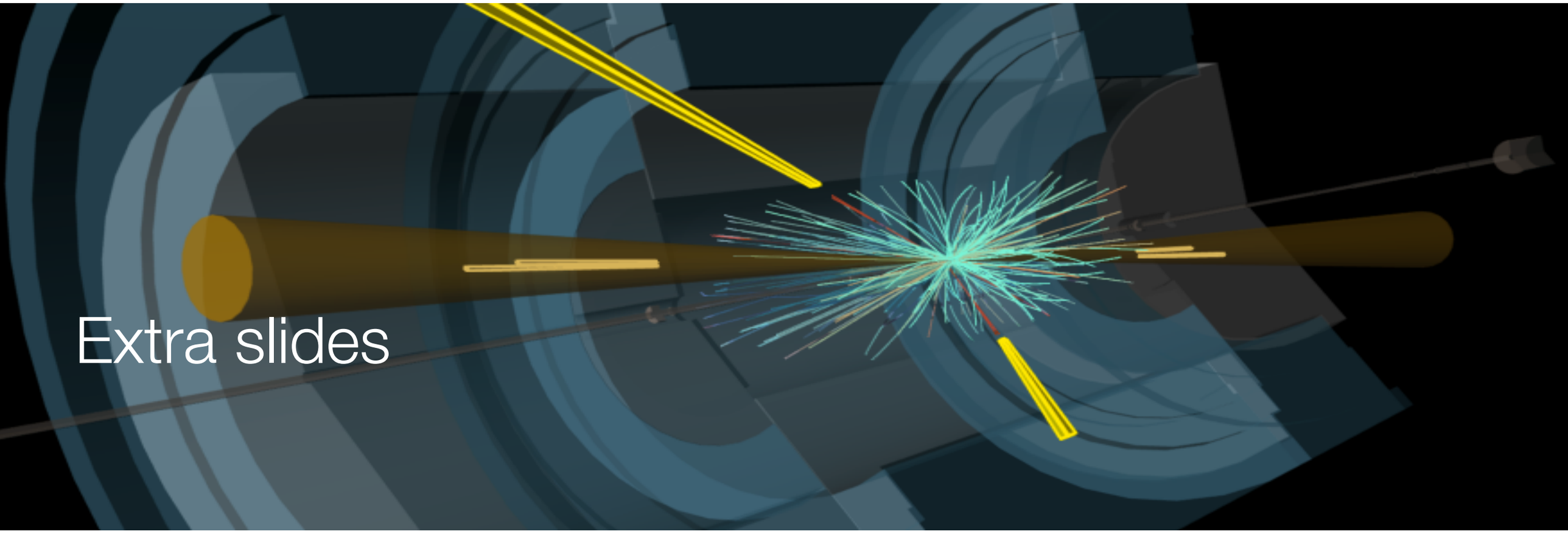


Summary

[Andreas Hoecker]



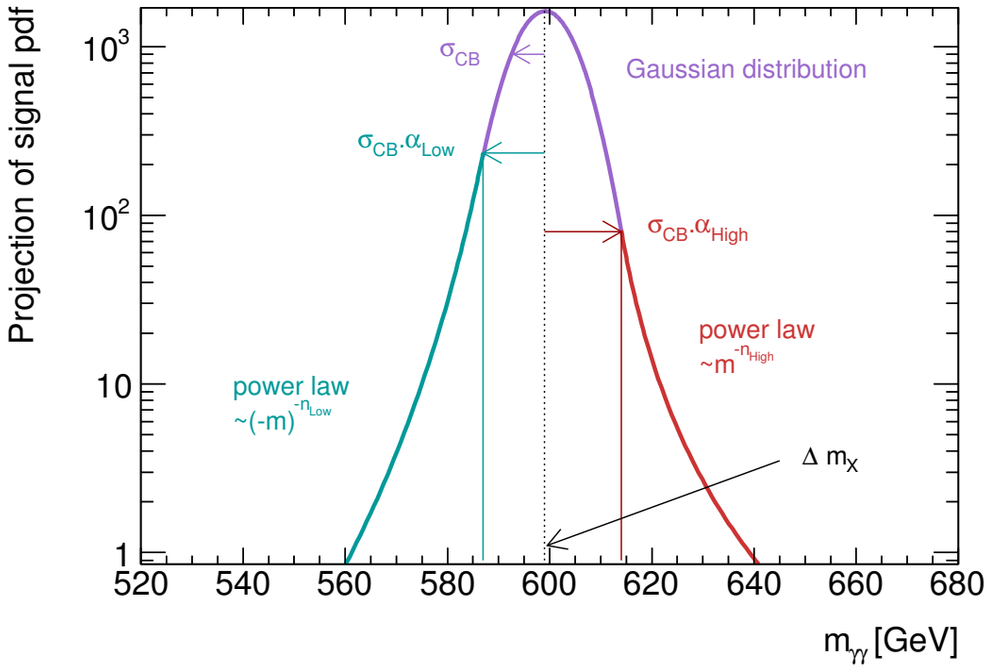
- LHC run-2 just started
- Higher energy, expect larger luminosity
- Great opportunity for new discoveries
  - The next one might be just around the corner

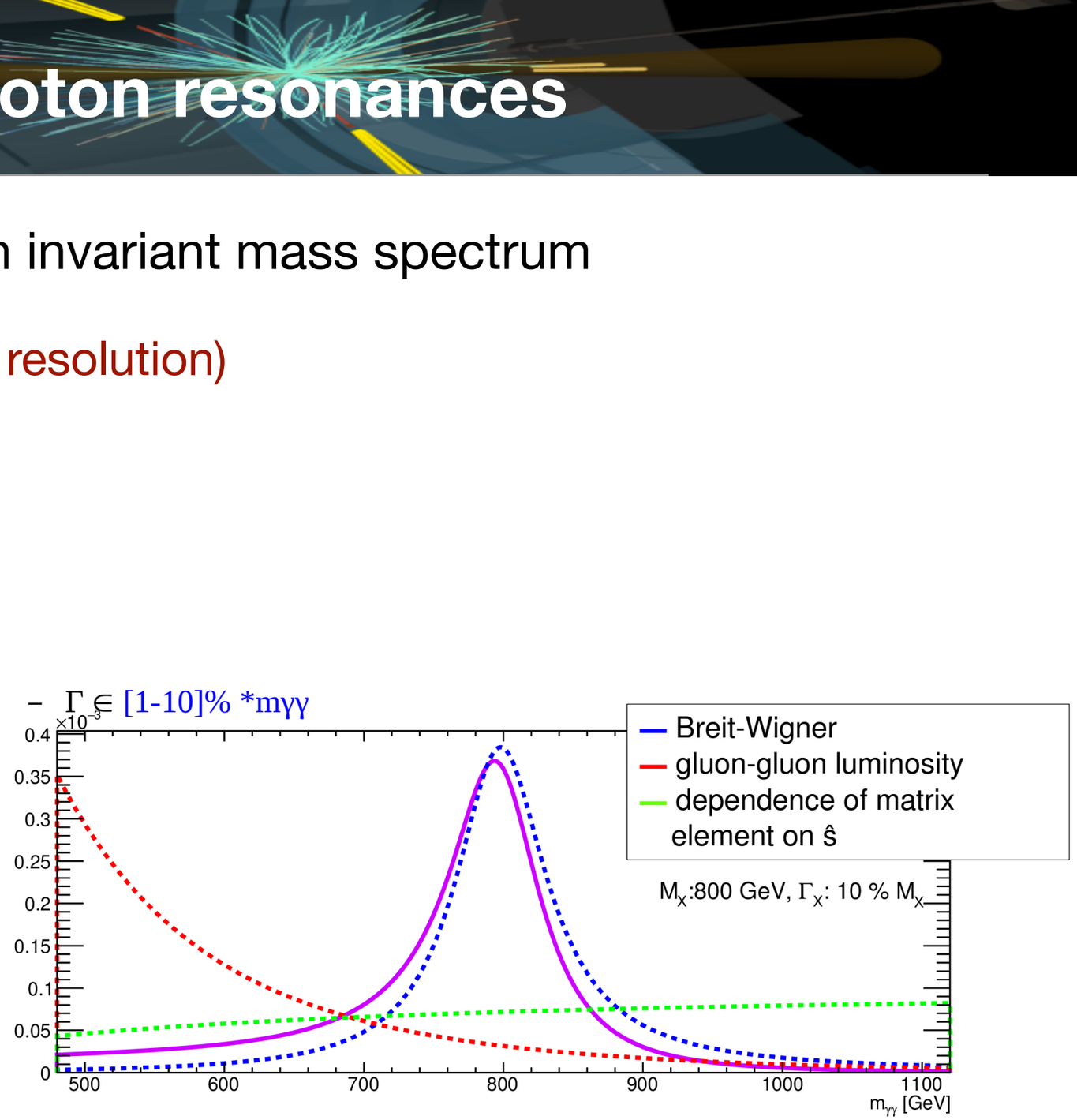


Extra slides

Searches for (other) diphoton resonances

- Signal + background fit to diphoton invariant mass spectrum
  - Signal from simulation (~1% mass resolution)





Searches for (other) diphoton resonances

- Signal + background fit to diphoton invariant mass spectrum
  - Signal from simulation (~1% mass resolution)
  - Background function validated on simulation, fitted on data
    - No needed for additional degrees of freedom