The Higgs boson - a first of its kind?

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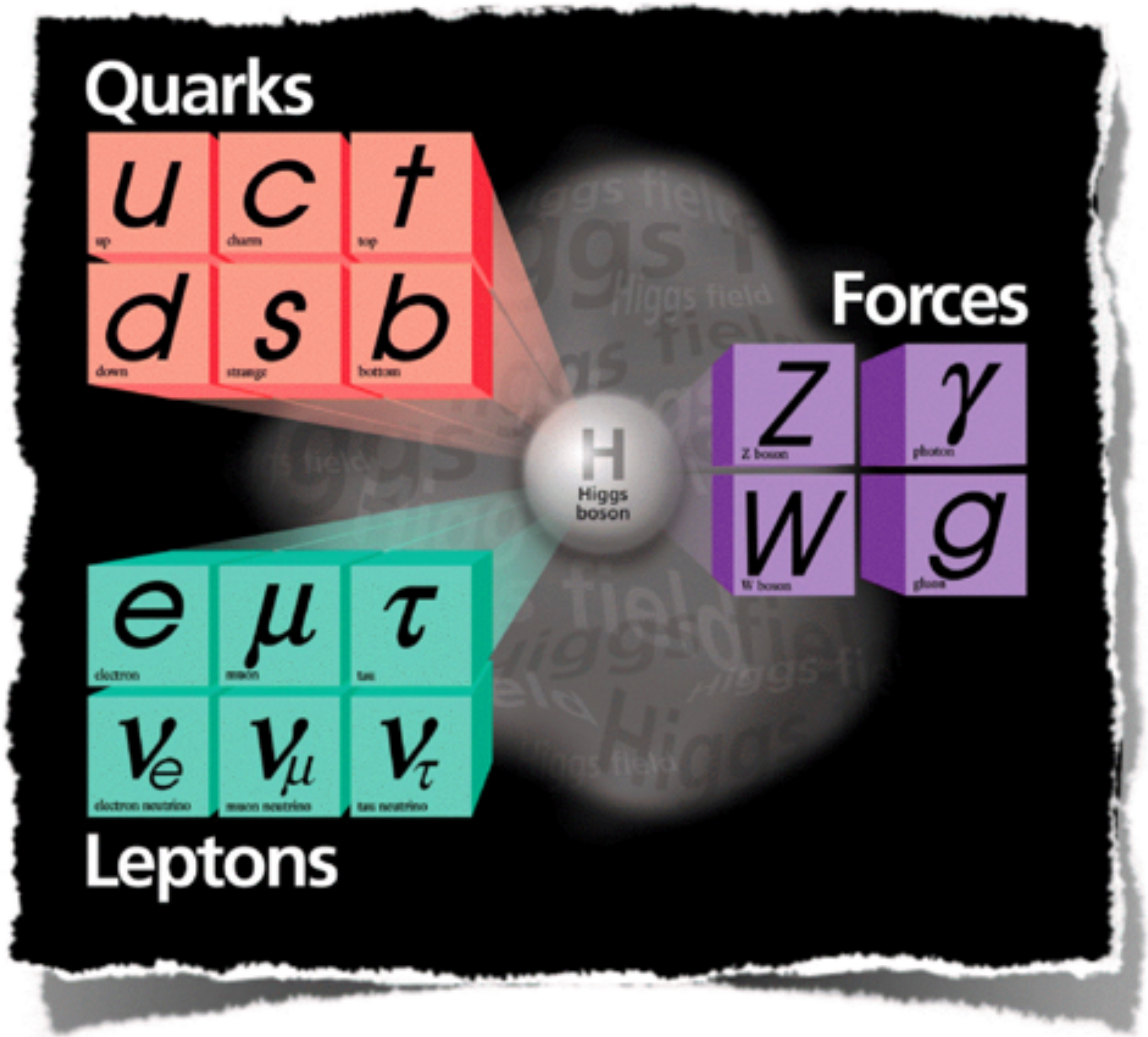
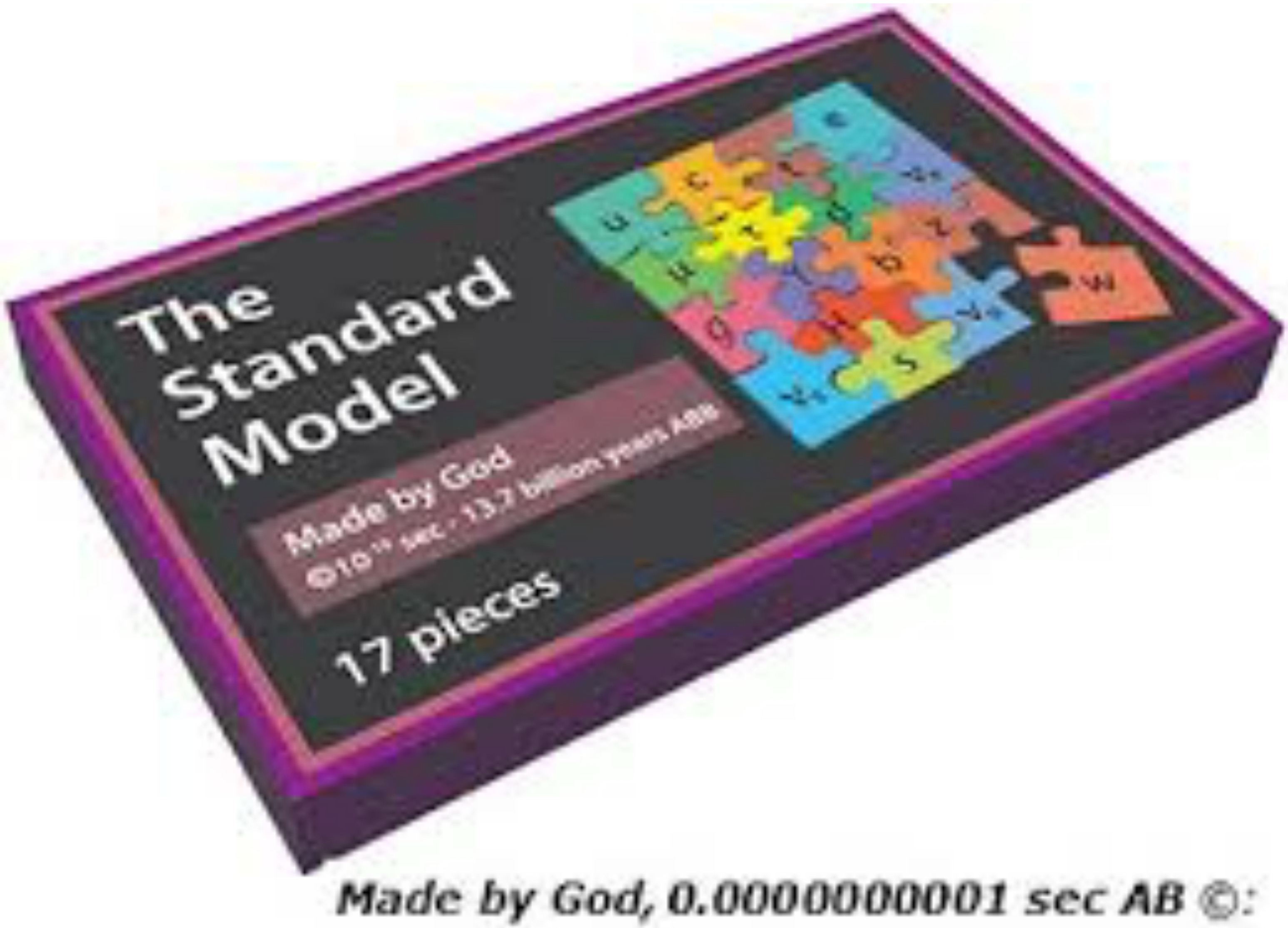
Particle Content

SU(3)×SU(2)×U(1)

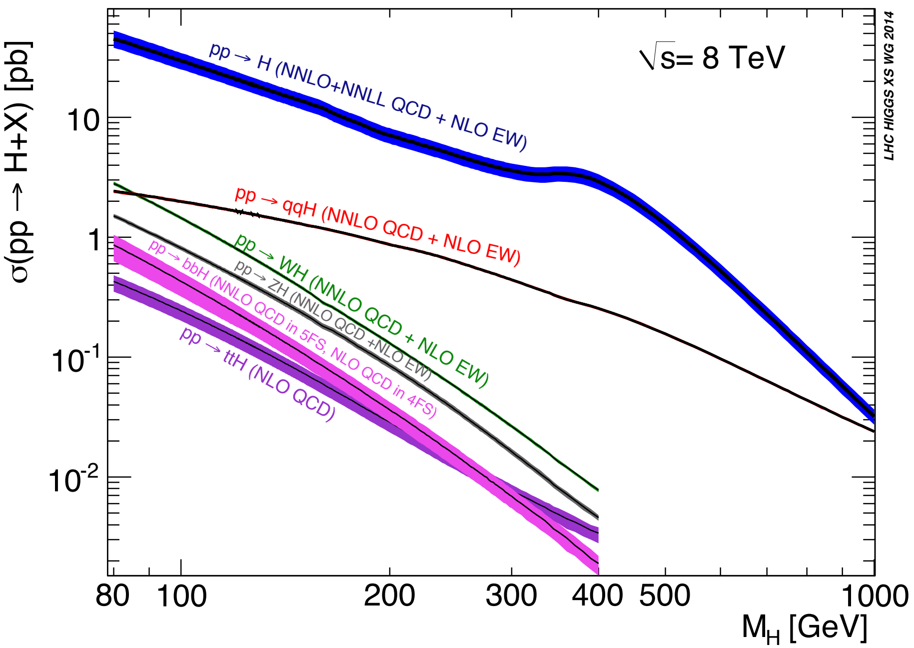


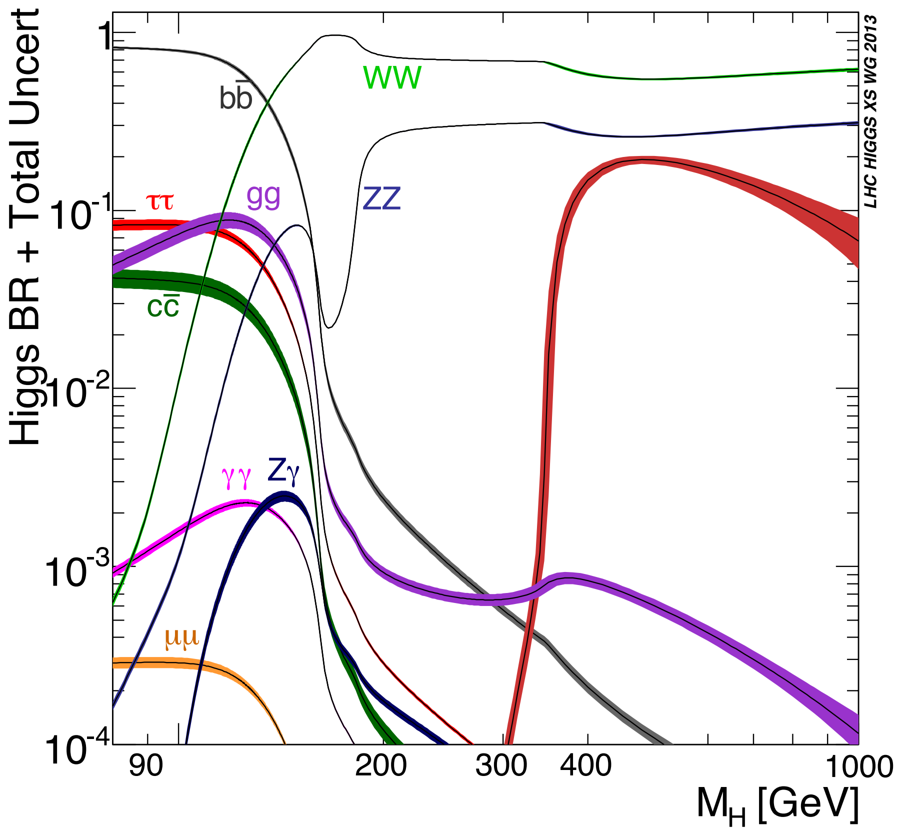
The Higgs Boson



Theory Inputs

- XS and BRs

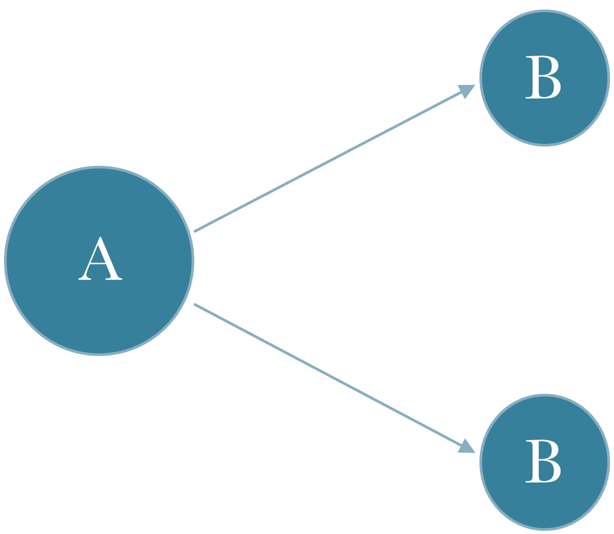




Needle in the Haystack

Bump Hunter (H->γγ)

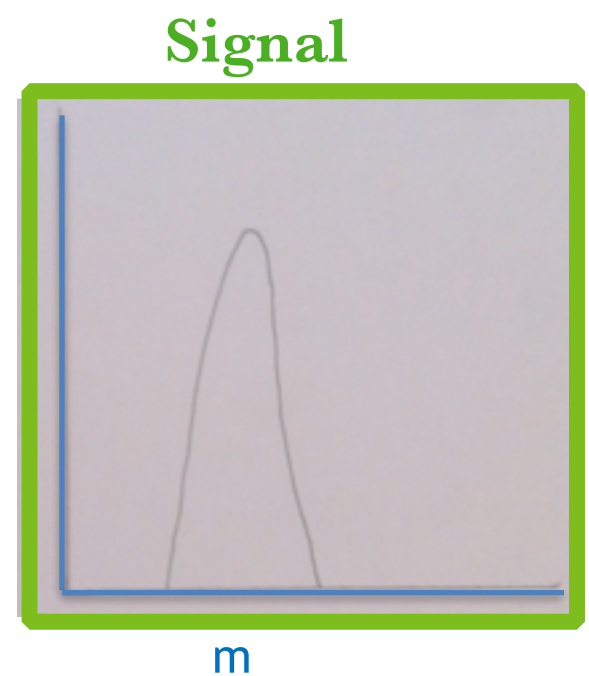
- When a heavy particle (A) decays into two lighter particles (B and C) -> we can calculate the mass of the mother particle (m_A) from the speed and direction of the two daughters (B and C).



$$m_A^2 = p_A^2$$

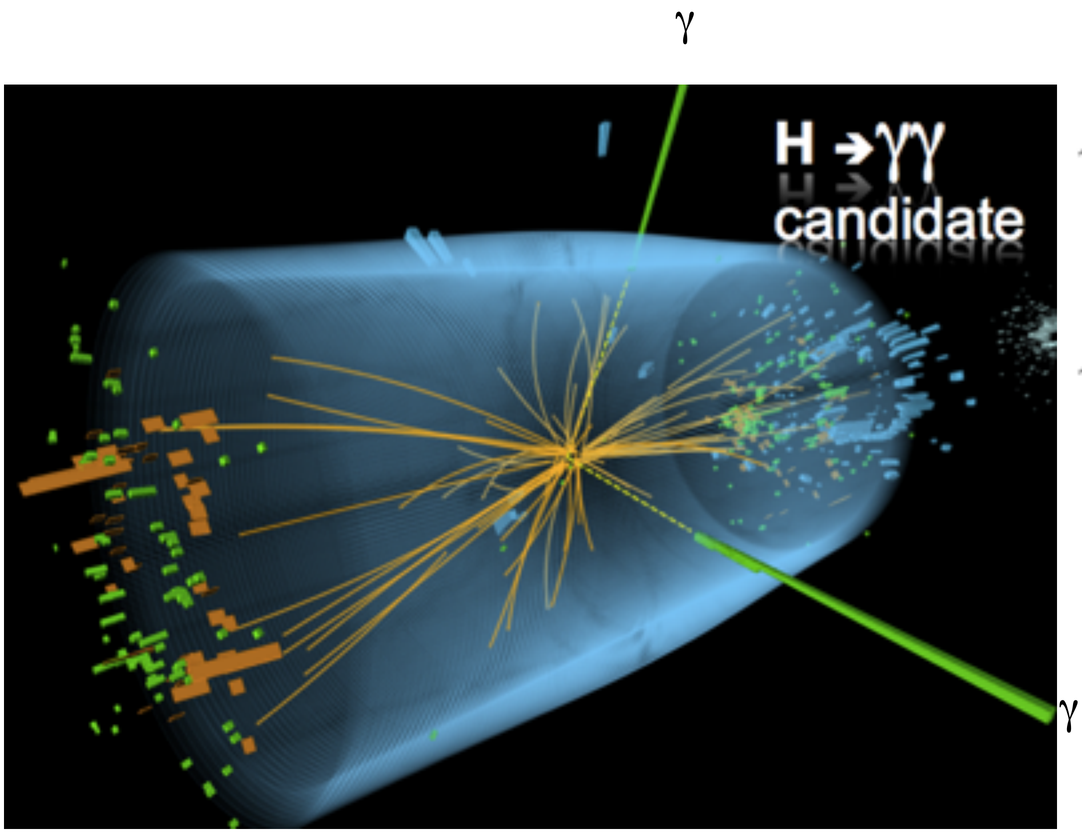
$$p_A = p_B + p_C$$

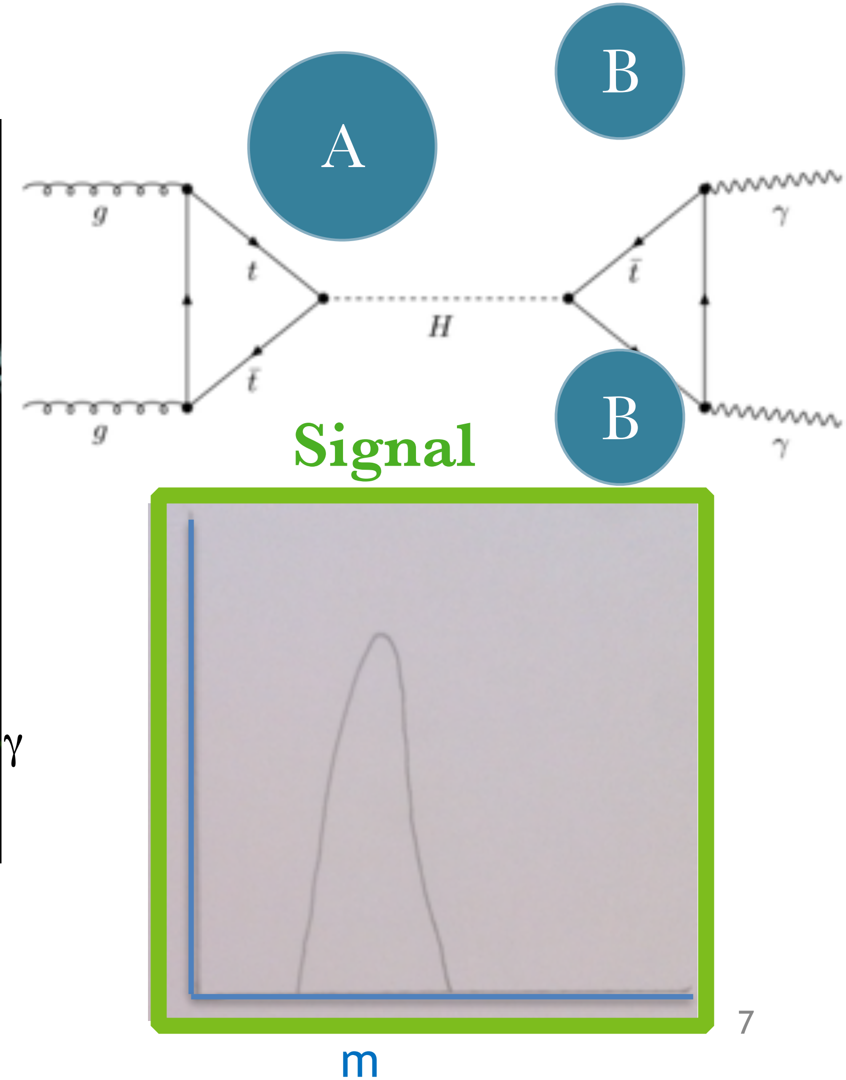
$$m_A^2 = (p_B + P_C)^2$$



Bump Hunter (H->γγ)

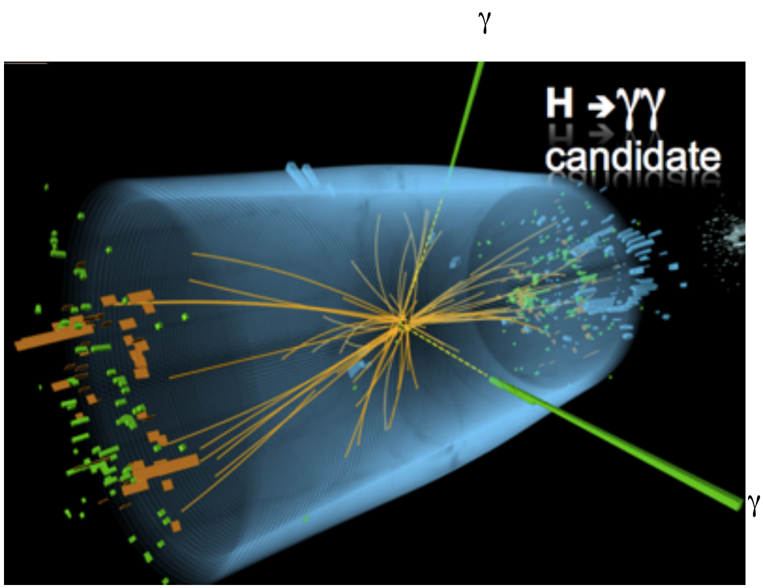
- We have two photons.

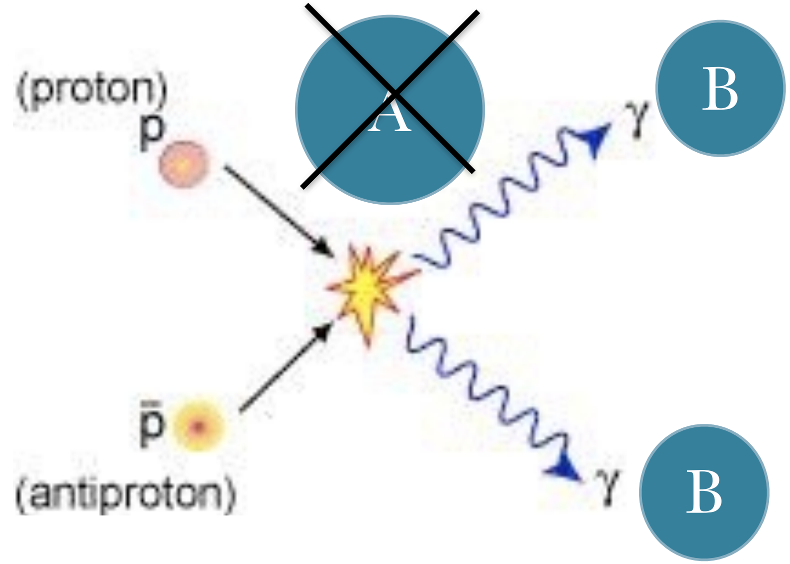


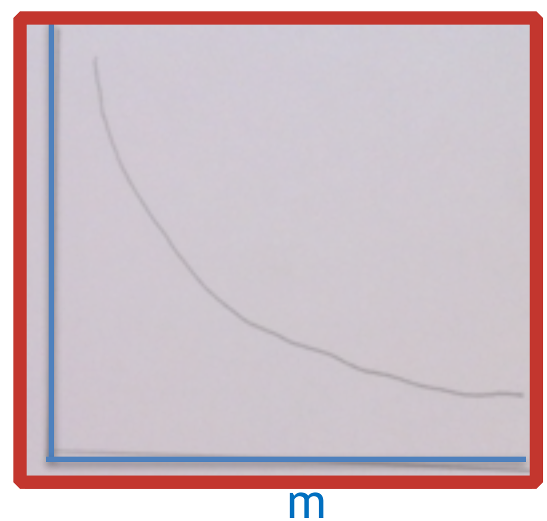


Bump Hunter (H->γγ)

- We have two photons in the background too:

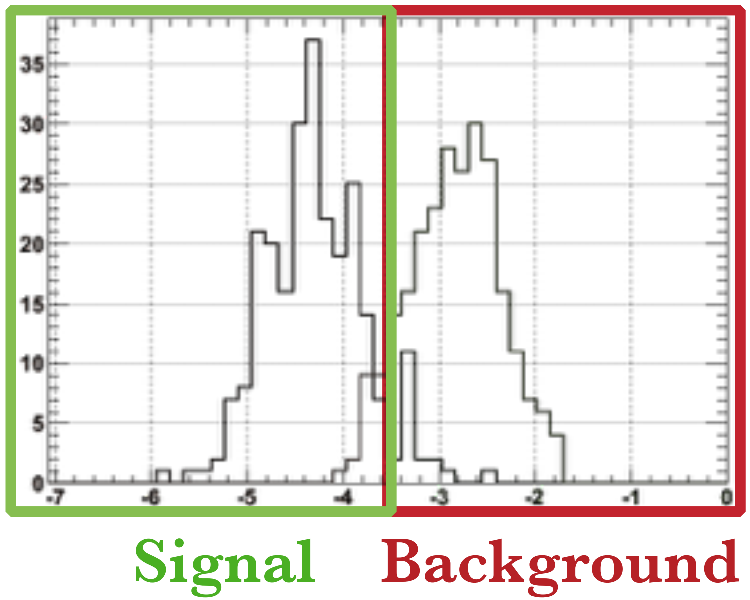


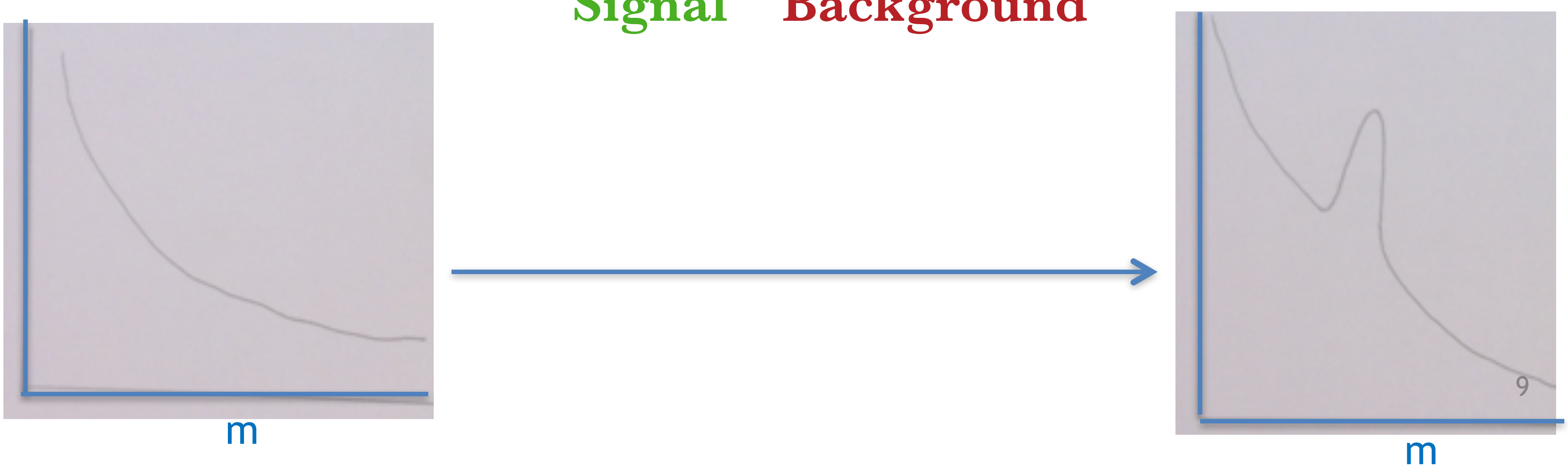




What should we do?

- Identify discriminating variables to suppress our backgrounds.





H->$\gamma\gamma$

- How did we do it? https://twiki.cern.ch/twiki/pub/AtlasPublic/HiggsPublicResults//Hgg-FixedScale-Short2.gif

H->γγ

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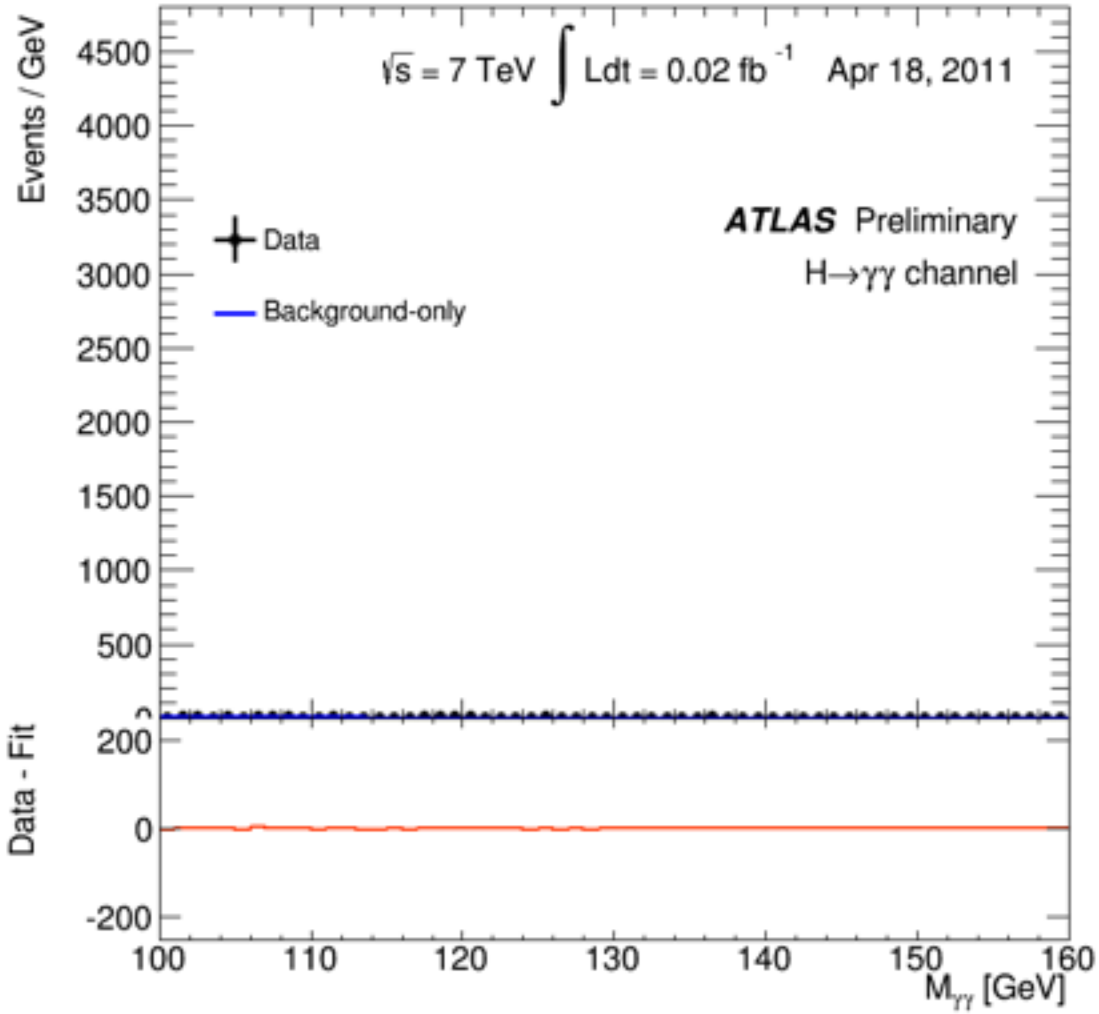
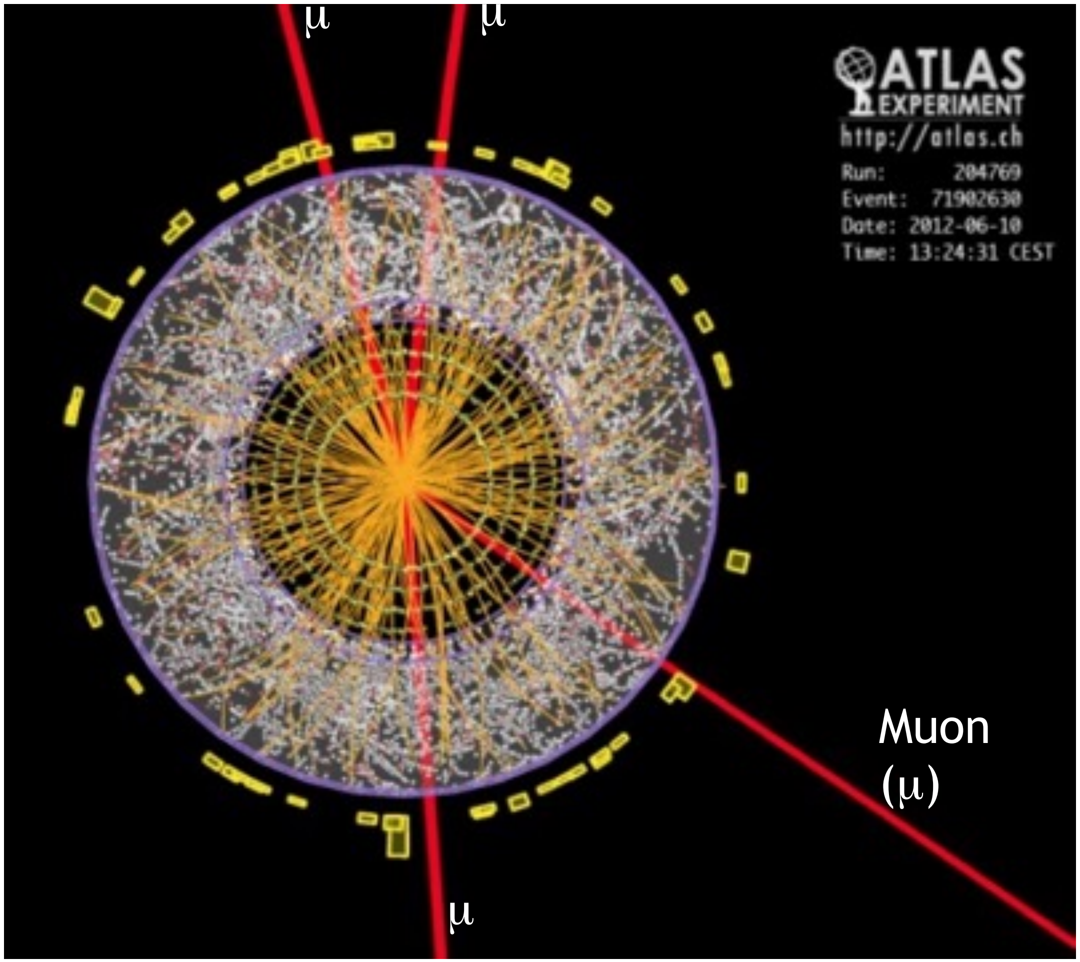
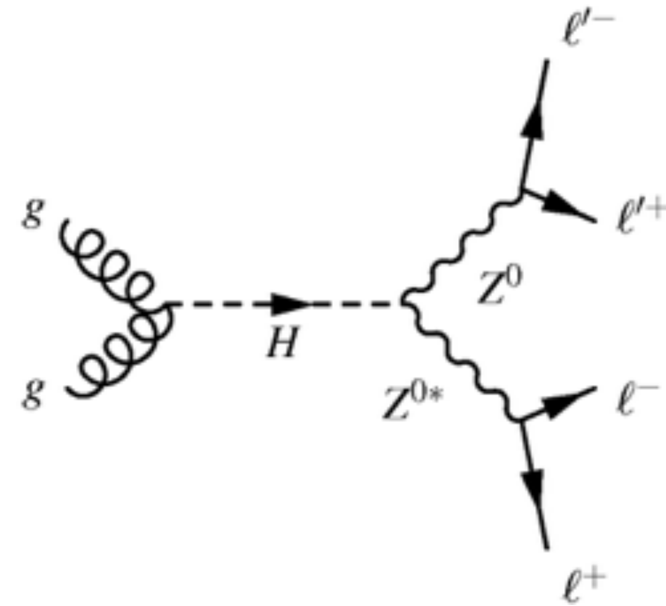


The Golden Channel

- H->ZZ events in ATLAS



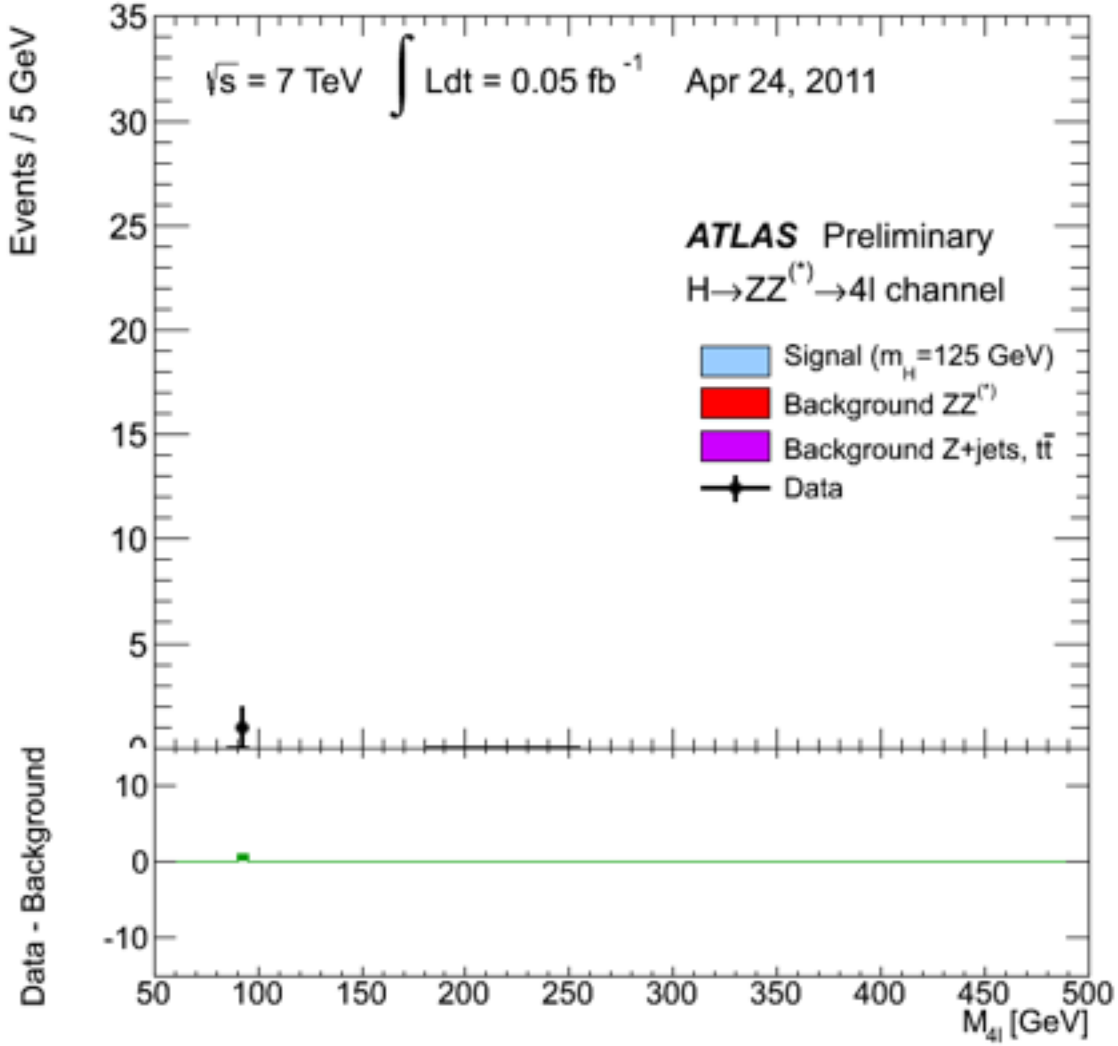


The Golden Channel

- How did we do it? https://twiki.cern.ch/twiki/pub/AtlasPublic/HiggsPublicResults//4l-FixedScale-NoMuProf2.gif

The Golden Channel

- How did we do it?

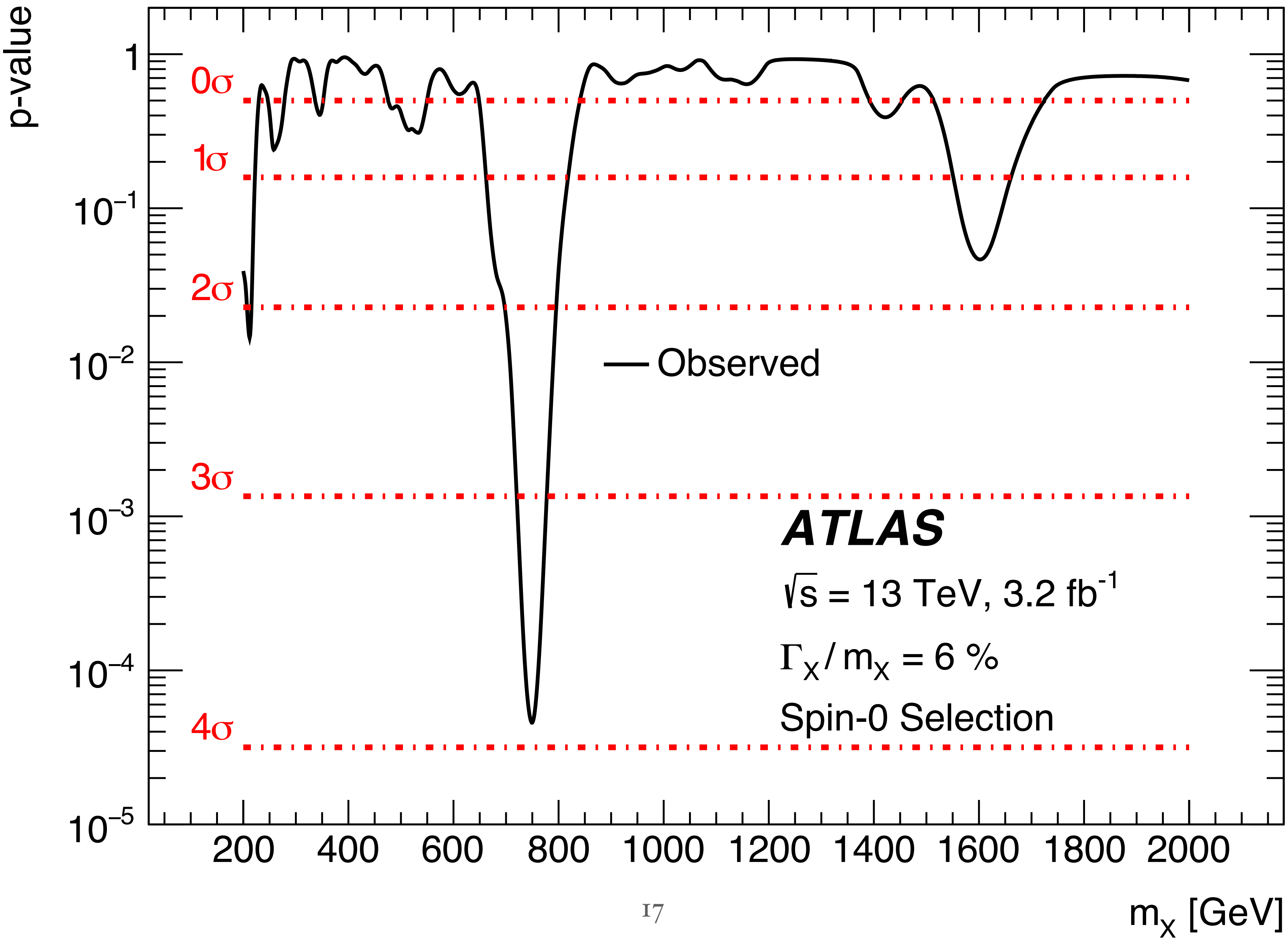


The Glory Day

Beyond the Standard Model

- Problems in the Standard Model (Neutrino mass, dark matter…).
- Fermions come in three families, why only one Higgs family?
- With two Higgs families, five states; Charged Higgs – the smoking gun.

Getting there....




THE BEGINNING

Photon Reconstruction

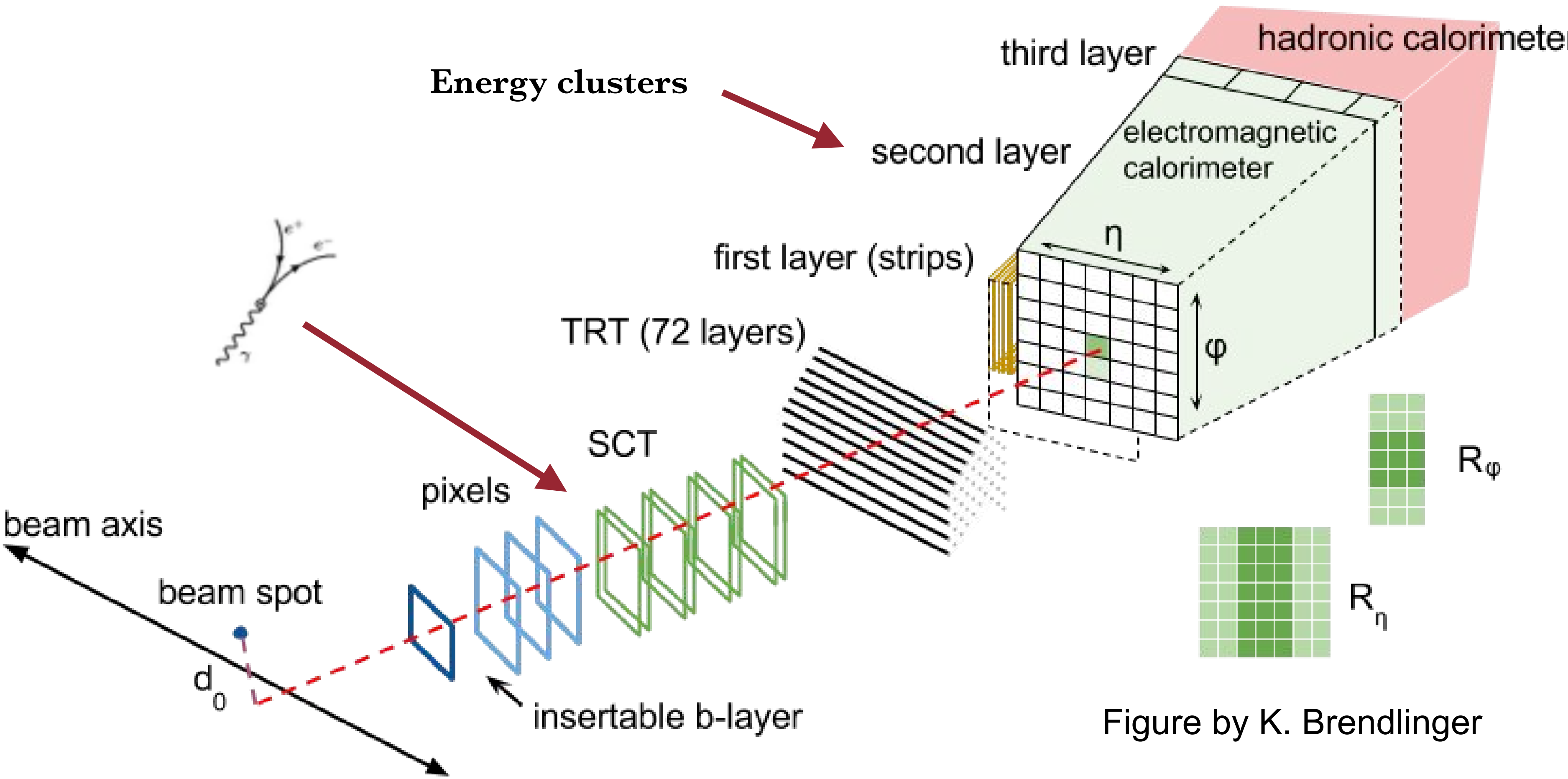
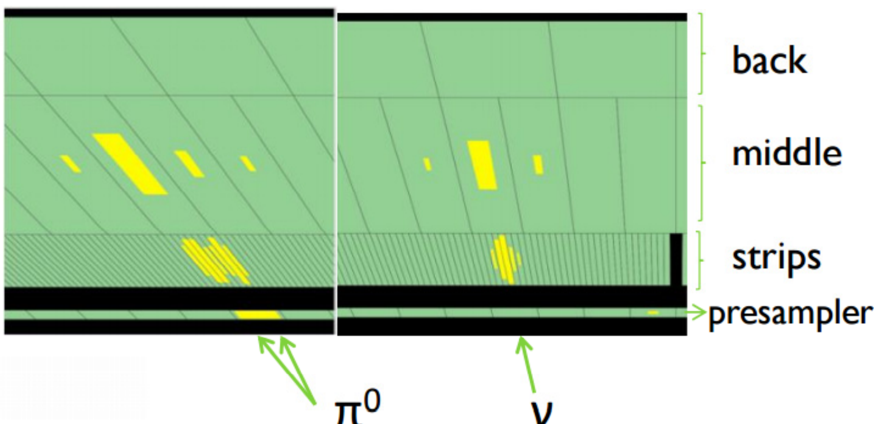


Figure by K. Brendlinger

Photon Reconstruction

Identification

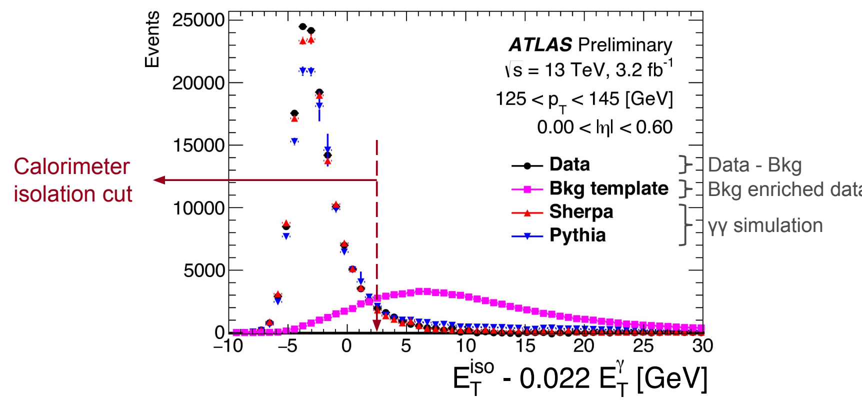
- Applying cuts over discriminating variables (shower shapes) from the calorimeter layers.
- Shower shapes: variables that describe the shape of the electromagnetic shower in the calorimeter, and the fraction of energy deposited in the hadronic calorimeter.
- Cuts are binned in η, and by converted/ unconverted photons and Pileup robust.



Efficiency:
85% (E_T=50GeV)-95%(E_T=200GeV)
Uncertainty:
±2% - ±5% for E_T >50GeV
η dependent

Isolation

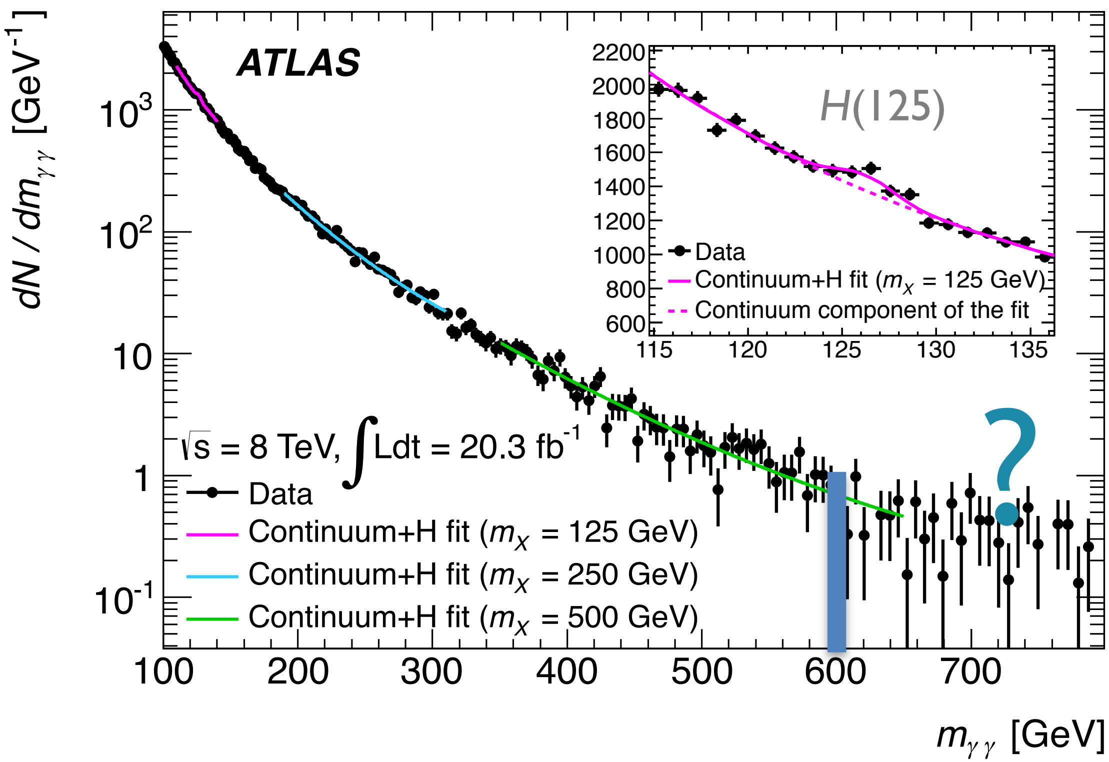
- Important for purity determination, background rejection.
- Both calorimeter and track isolation required.
  - Calo isolation →ΣE_T of energy clusters within ΔR = 0.4:
    $$E_T^{iso} < 0.022 E_T + 2.45 \text{ GeV}$$
  - Track isolation →Σp_T of tracks within ΔR = 0.2:
    $$p_T^{iso} < 0.05 E_T$$



Isolation efficiency:
88 - 97%
Isolation uncertainty:
1-2%

Recap

- Run1 (65-600GeV):
  - Two regions: low mass (65-110GeV) and high (110-600GeV). Extending the SM Higgs search that was done form 100-160GeV.



Run 2

* Changes from run1 to run2:
  * New energy, upgraded detector ->
    Re-optimization of the cuts (pT, isolation -> BG reduction).
  * Improving analysis:
    * Background modelling.
    * Signal parametrization.

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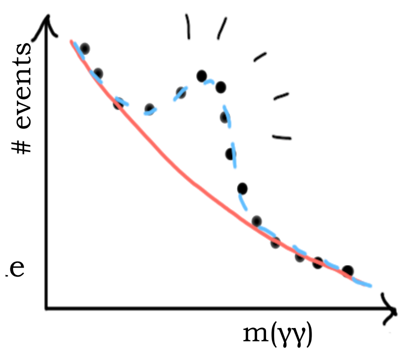

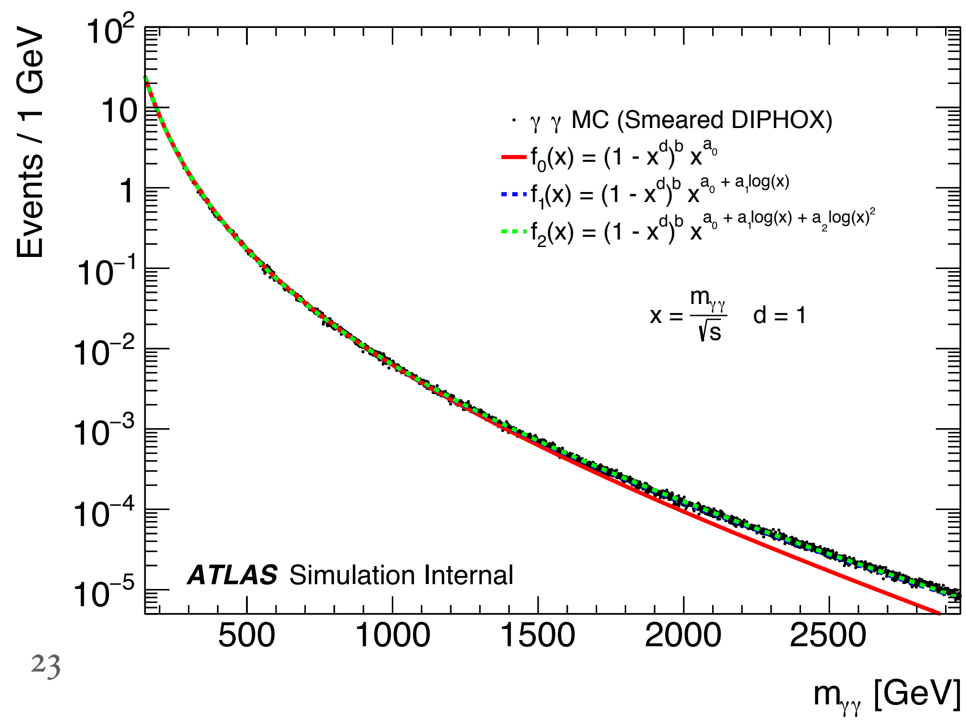

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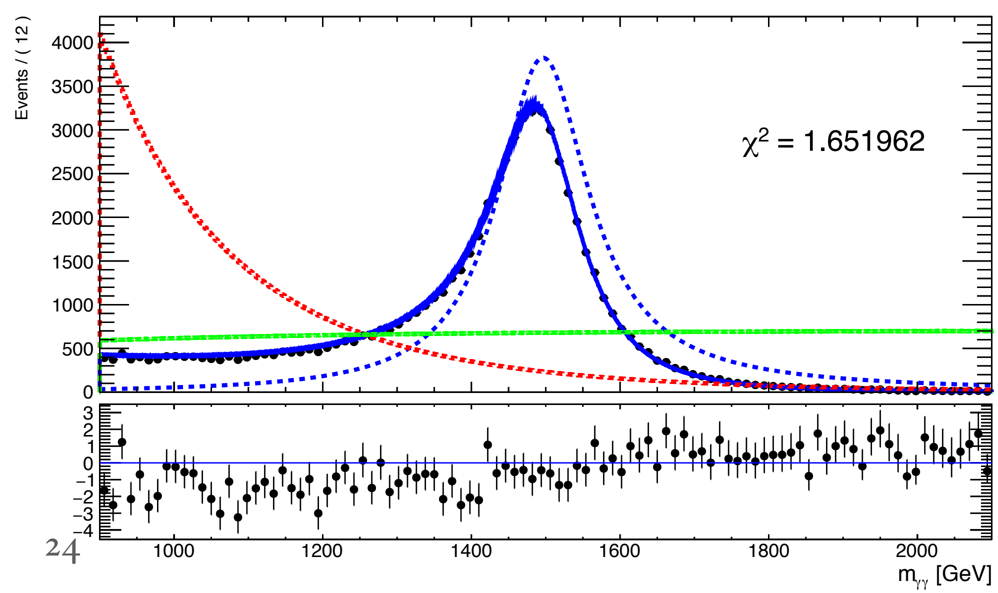
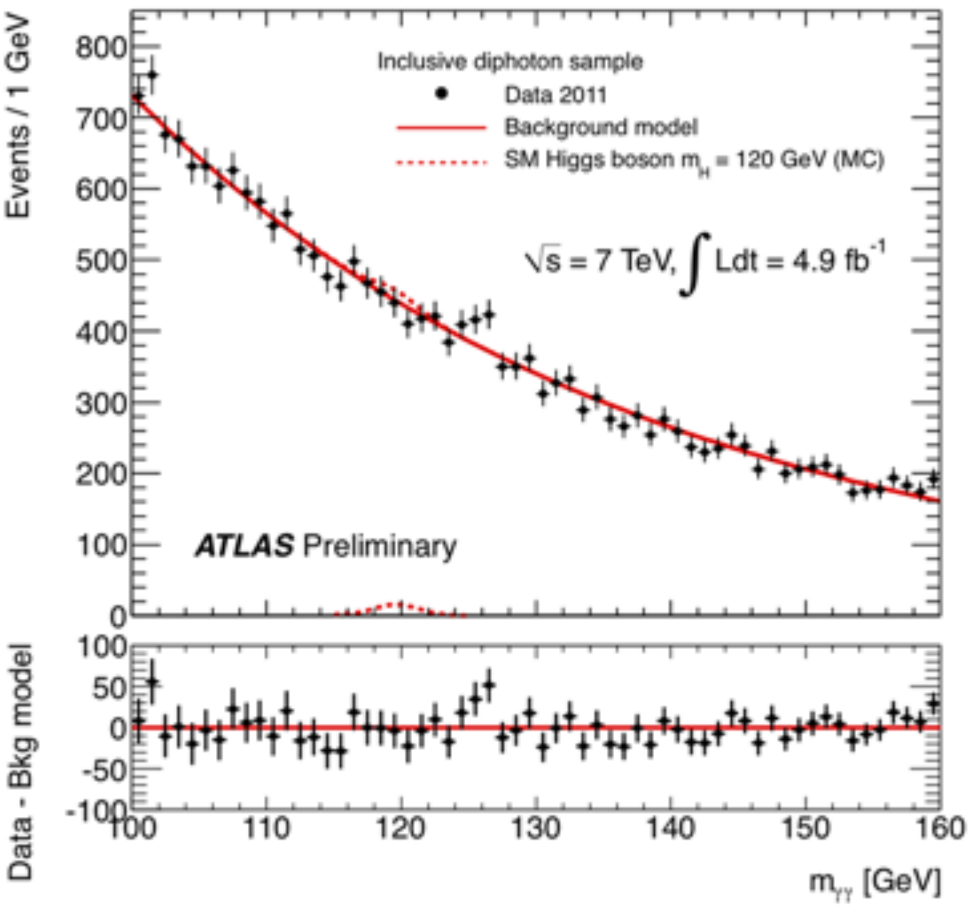
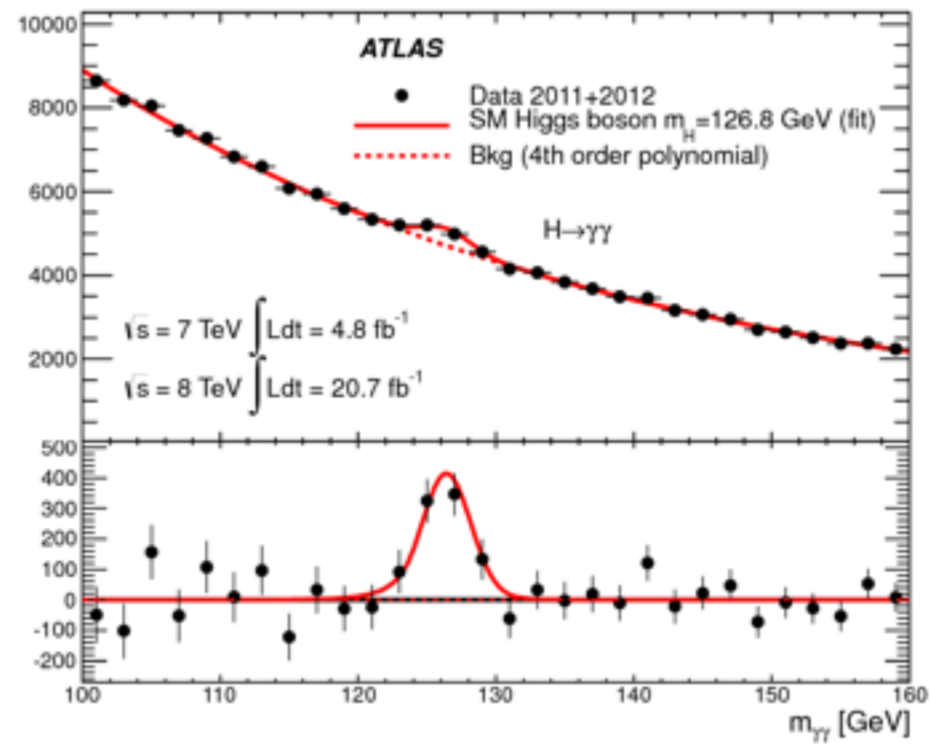
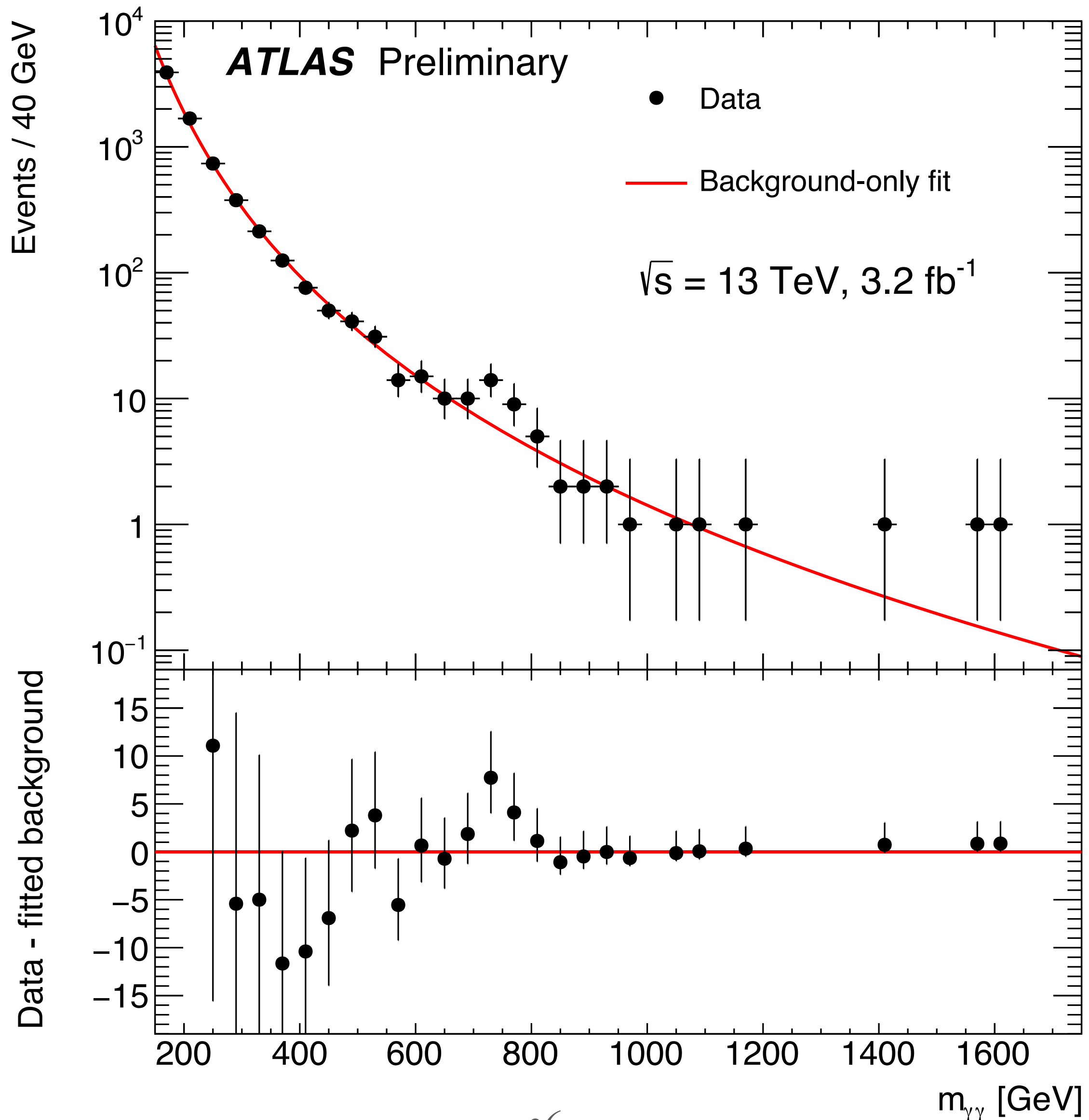


Mass spectrum





Mass spectrum

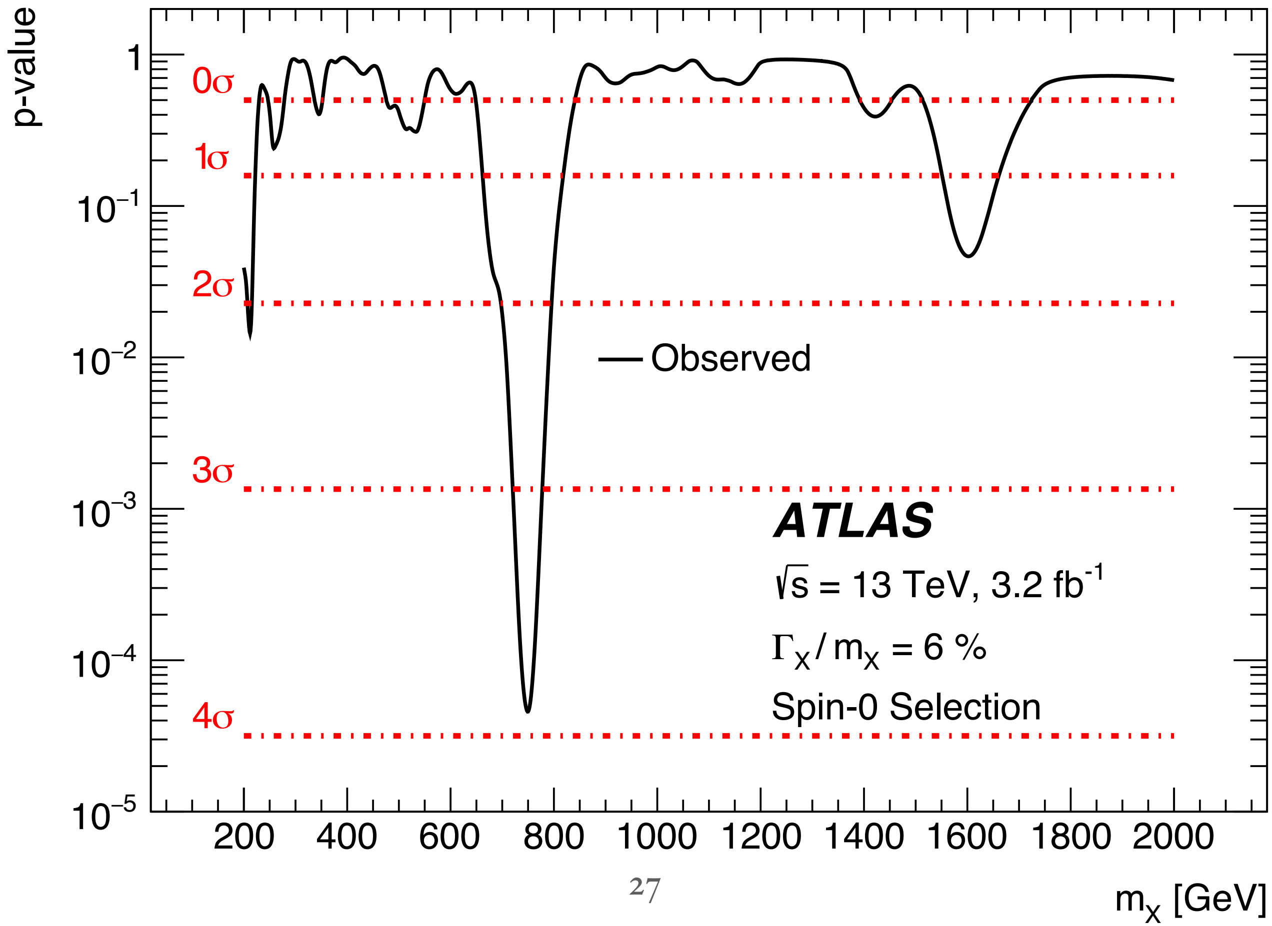


Exciting Result

$m_X \sim 750\text{GeV}, \Gamma_X \sim 45\text{GeV}(6\%)$

Local Z = **3.9σ**

Global Z = **2.1σ**



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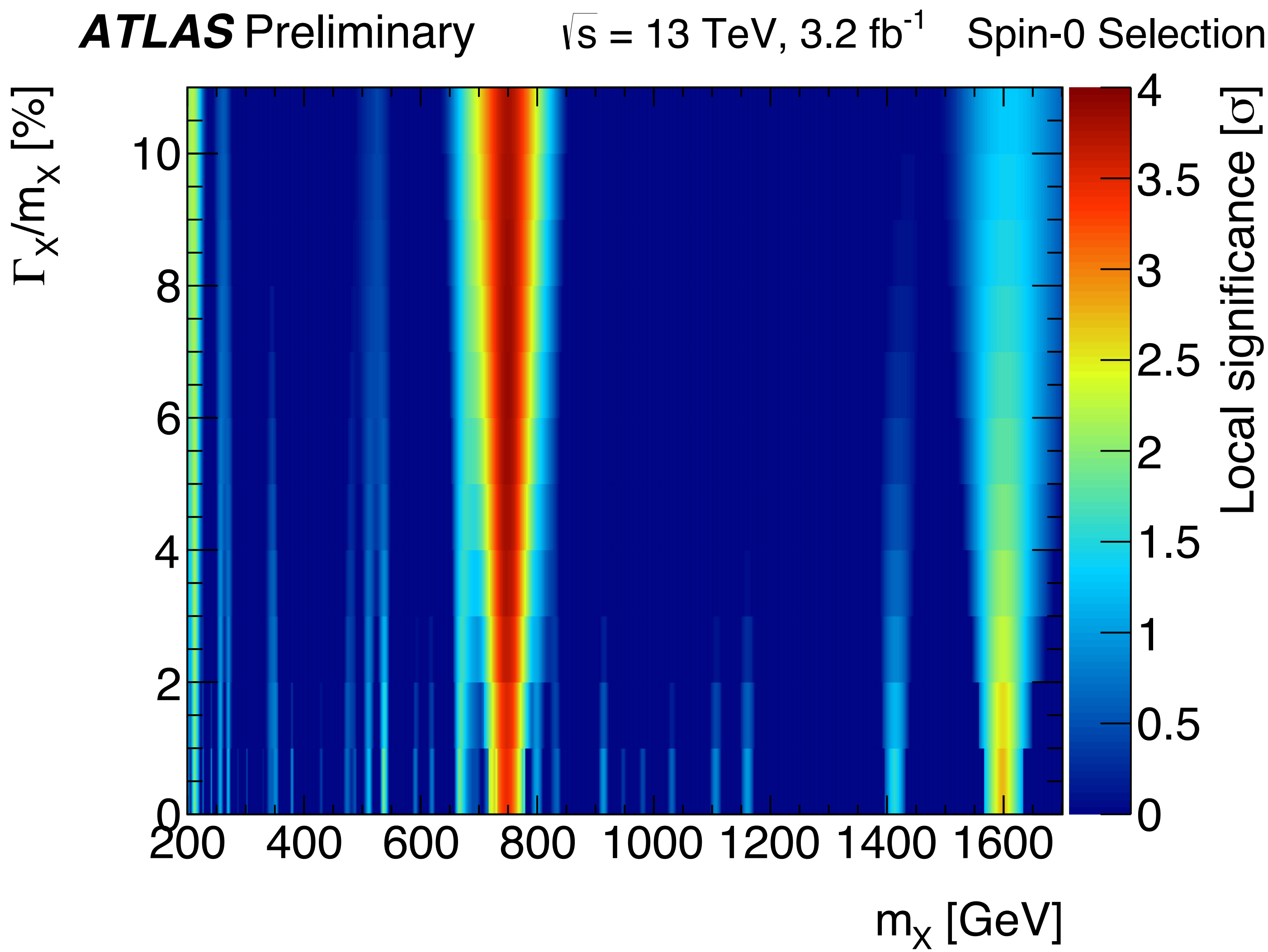
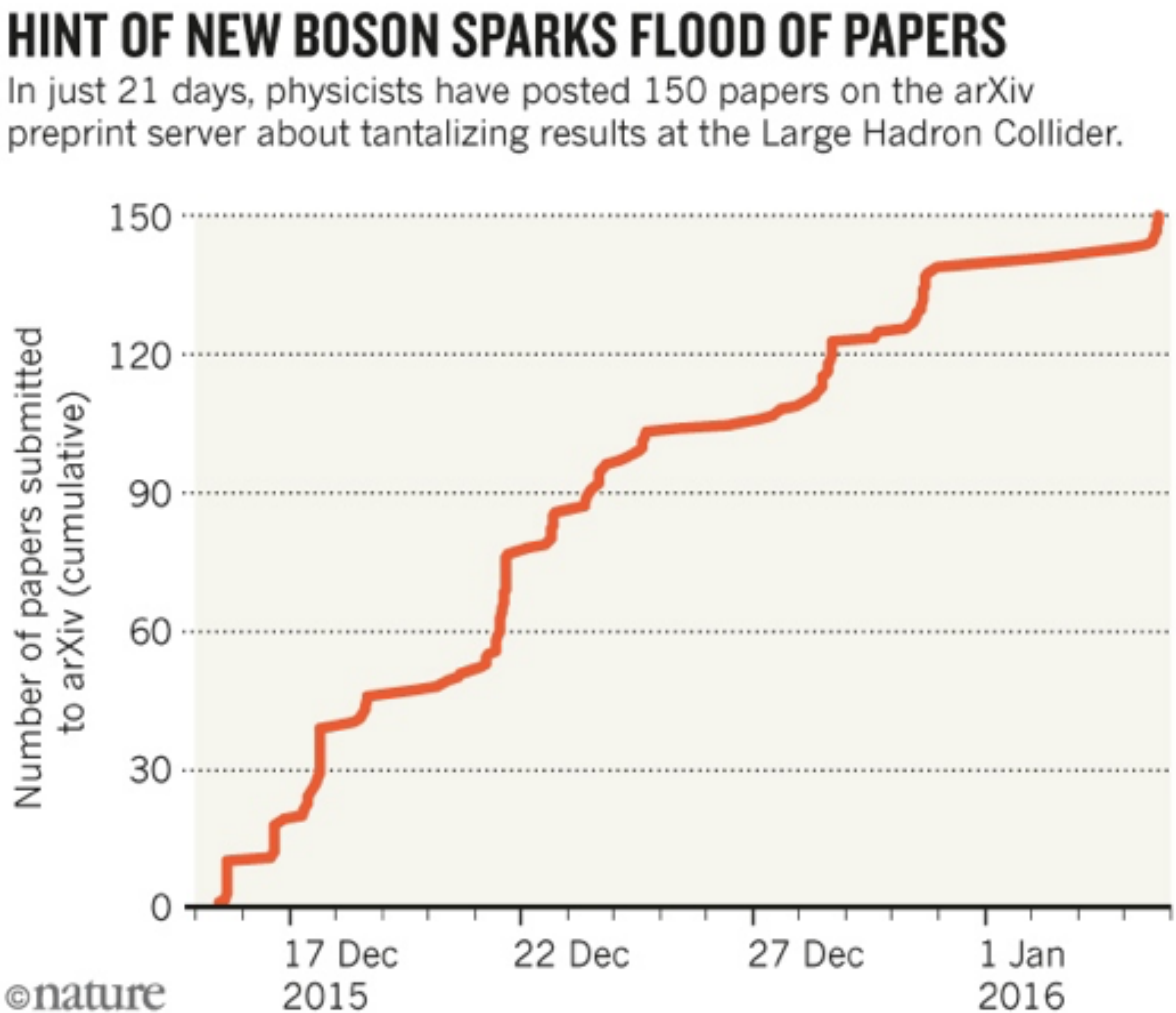


The Buzz



HINT OF NEW BOSON SPARKS FLOOD OF PAPERS
In just 21 days, physicists have posted 150 papers on the arXiv preprint server about tantalizing results at the Large Hadron Collider.
Number of papers submitted to arXiv (cumulative)
150
120
90
60
30
0
17 Dec 2015
22 Dec
27 Dec
1 Jan 2016
©nature

Preparations for 2016

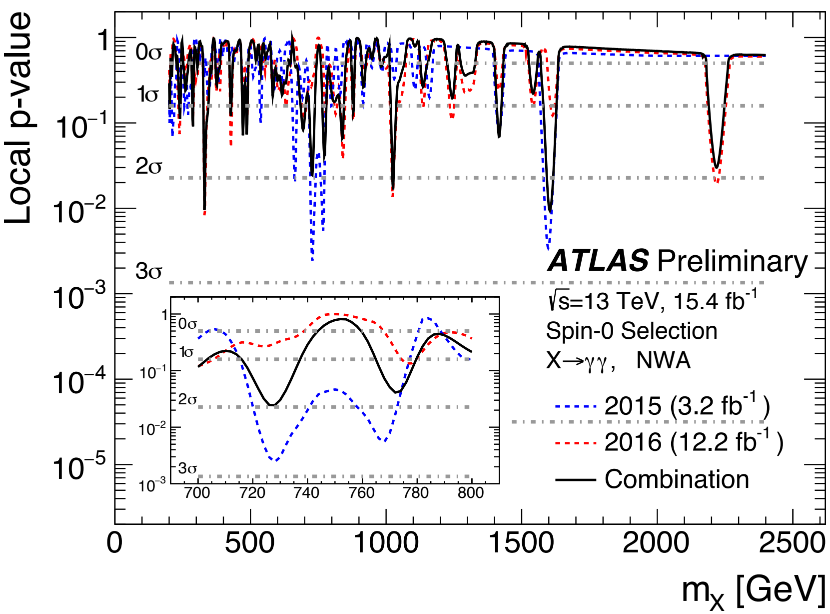
* Changes from 2015 to 2016:
  * Improved photon reconstruction:
    * Higher efficiency of the track isolation.
    * Modified the criteria used to select converted photons to cope with the higher pileup.
    * Energy calibration have been re-trained to account for the small changes in the conversion reconstruction and improved near $|\eta|$ =[1.37-1.52].
  * The 2015 data and simulated samples, have been reprocessed with the same reconstruction software as used for the 2016 data.

Preparations for 2016

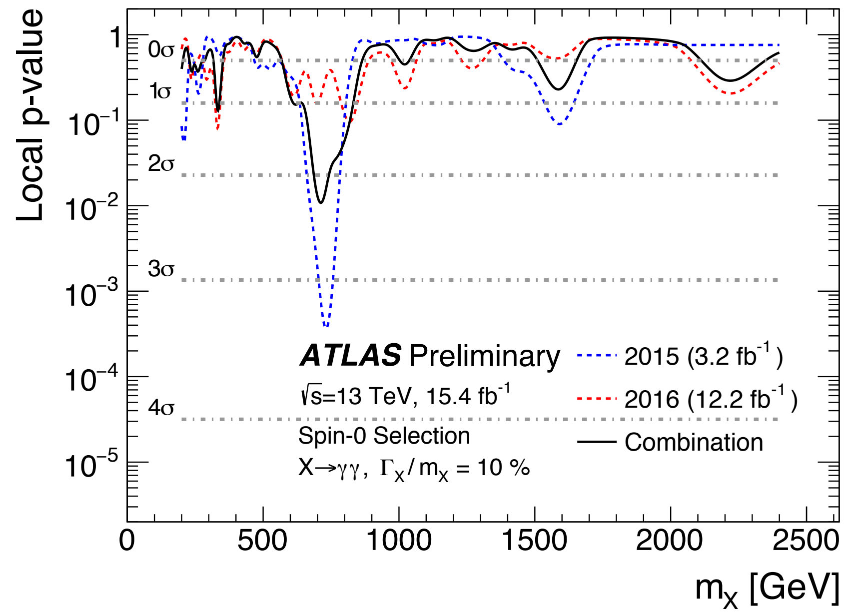
- Changes from 2015 to 2016:
  - Eventually no changes in the analysis… although carefully studied.

Final Results

NWA



Γ_X/m_X = 10%



Largest significance observed for combined dataset 15.4 fb^{-1}

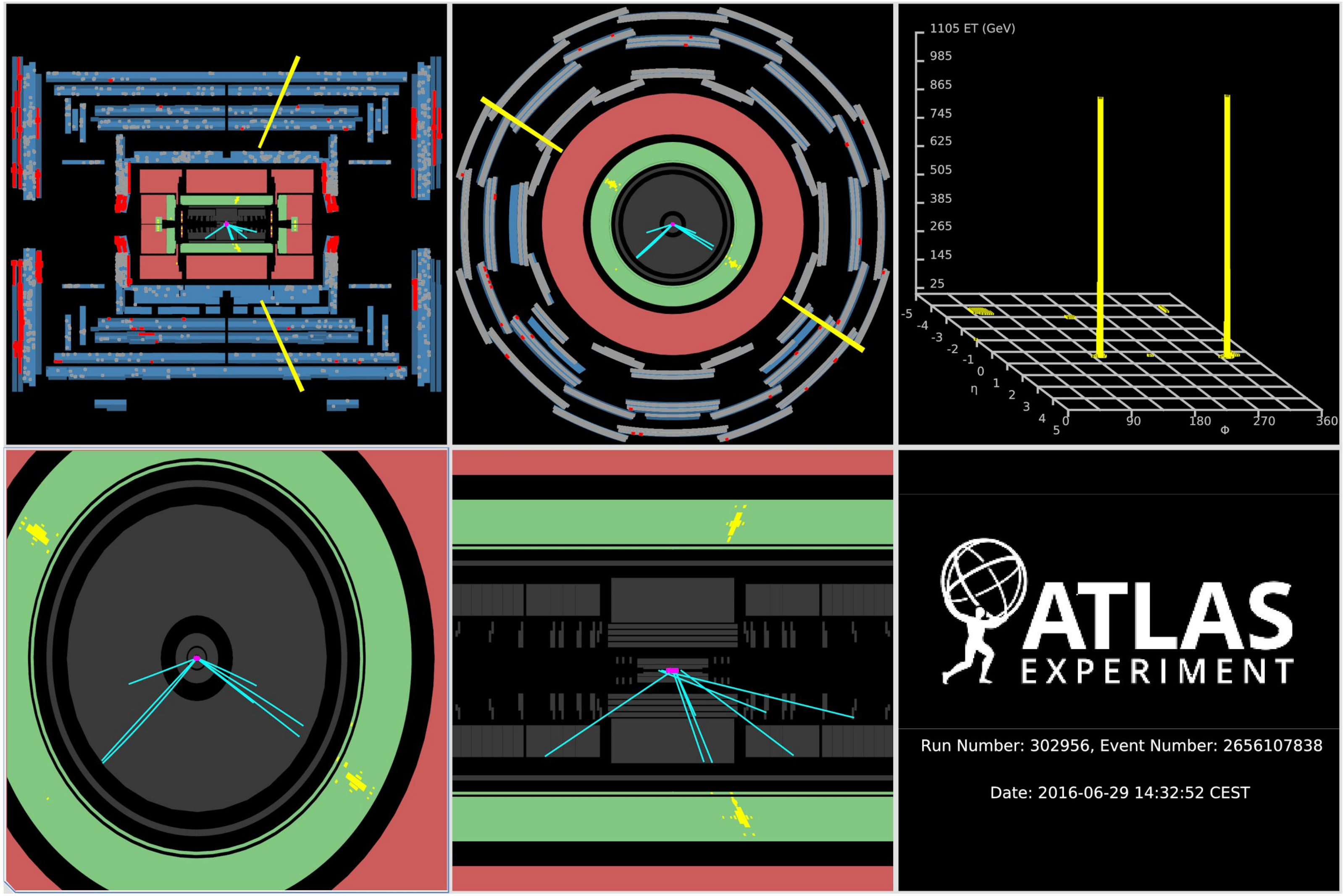
2.4σ local @ 1.6 TeV

Global significance below 1σ

2.3σ local @ 710 GeV

Global significance below 1σ

Event with highest invariant mass $m_{\gamma\gamma}$ = 2.2 TeV



Leading photon: unconverted, E_T = 1.1 TeV, η = 0.45, φ = −0.58, E_T^{iso} = 5.2 GeV
Subleading photon: converted, E_T = 1.1 TeV, η = 0.41, φ = 2.56, E_T^{iso} = -1.0 GeV

What's happened?

- What went wrong?
  - NOTHING!!!! That is how statistical fluctuation looks like… google it!
- Could we anticipate it? Were there any hints?
  - Was it really that significant? Next talk!
  - Was it really seen by the two independent experiments?
    - CMS had
      - 2015 alone: **2.6σ local @ 760 GeV** assuming **narrow kappa**
        adding the 0T data: 2.9σ local @ 760 GeV
      - Combined with 8TeV: 3.4σ local @ 750 GeV
  - Some hints:
    - Kinematically the events looked like the side bands.
    - The best fitted width was quite large (6-8%).
    - After improving the uncertainty on the resolution ->
      the NWA significance went down to 2.9σ local @ 750 GeV!
    - Haven't seen in run1 ATLAS spin 2 analysis.
    - Wasn't observed in any other channel….dijet, ttbar, ZGamma
  - Are those really hints? Not really!

Win win situation

* In hebrew we says: “יצא שכרו בהפסדו”....
* Loose:
  * ATLAS:
    * Many people diverged from other activities.... other channels paid the price!
  * HEP:
    * Funding agencies might be more sceptic now.....
* Gain:
  * ATLAS:
    * We learnt a lot during the process of understanding and scrutinizing!
    * We advanced the photon performance, the statistical treatment etc.
  * HEP:
    * Enjoy the excitement! We need it sometimes ;)
    * New models/ideas to explain such anomaly.

What's next?

- Extending the mass range:
    - Low mass.
    - Closing the gap - 150-200GeV.
    - High mass - >3TeV.
- Looking for non resonant signals in diphoton final states.
- Adding interference effects.... always ignored ;(

THANK YOU
FOR YOUR ATTENTION

High Energy Physics

- Probing matter with very high energy in order to study the particles that made the universe.
- In the LHC, we can probe for the first time the highest energy ever (100GeV-1TeV) and the smallest distance ever (10^{-18}-10^{-19}m).