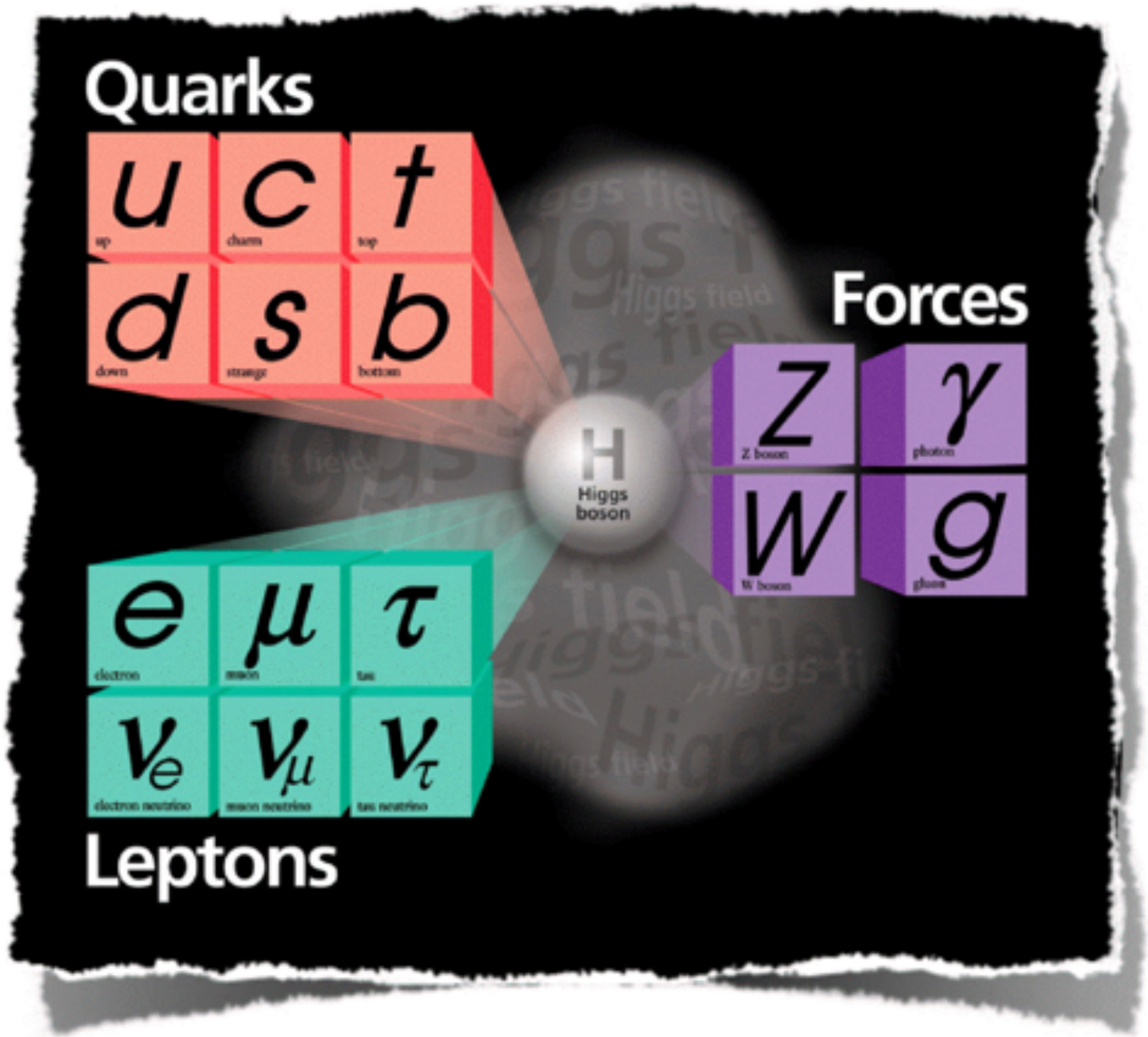
The Higgs boson - a first of its kind?

Liron Barak

CERN

Particle Content

SU(3)×SU(2)×U(1)

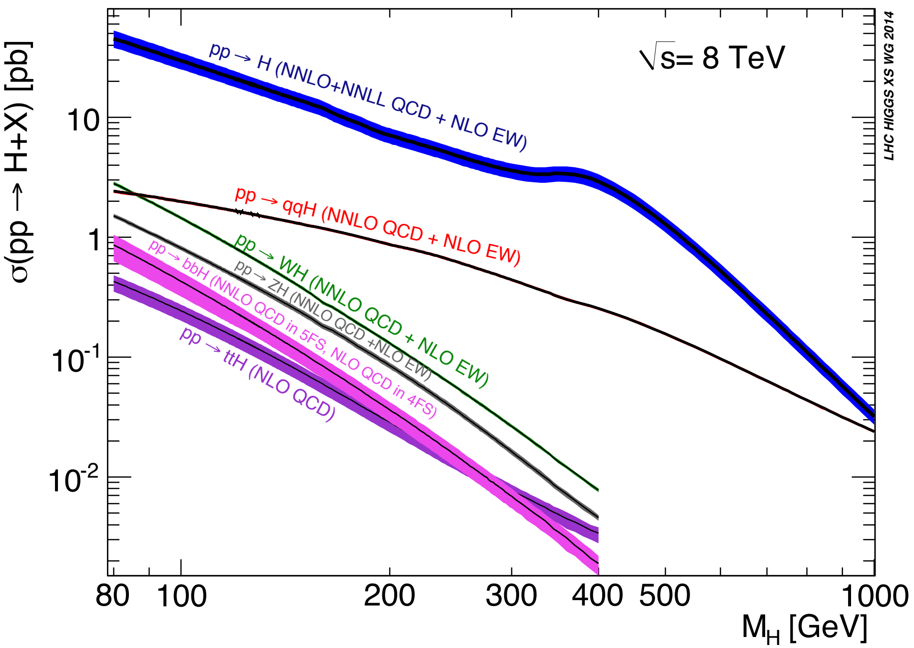


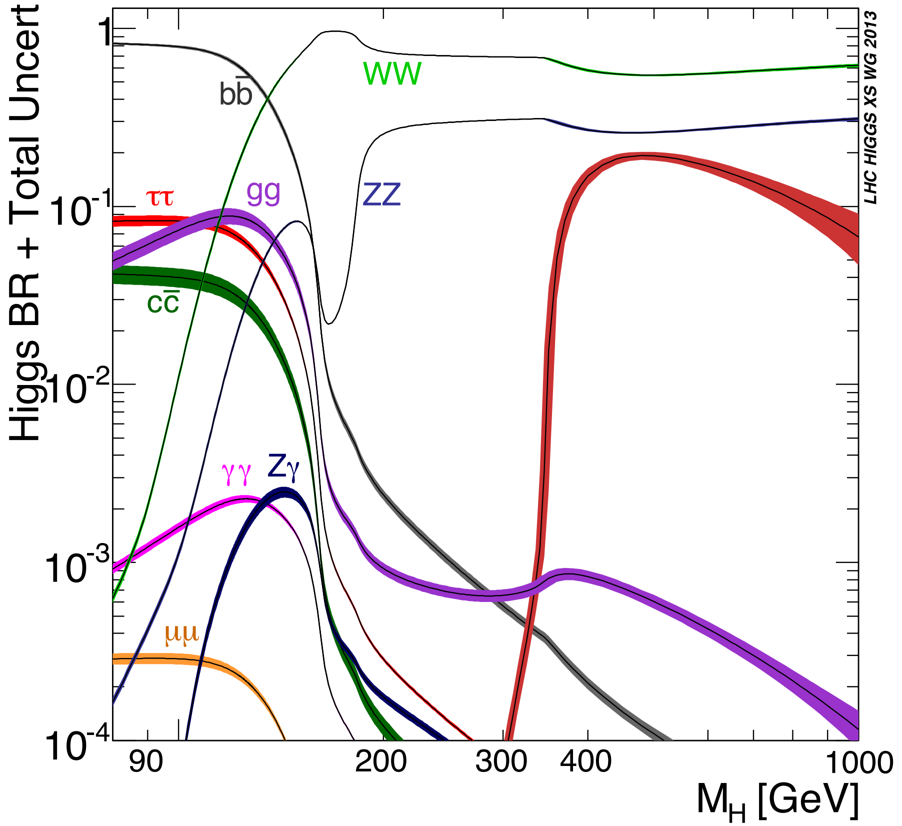
The Higgs Boson

Made by God, 0.0000000001 sec AB ©:

Theory Inputs

- XS and BRs

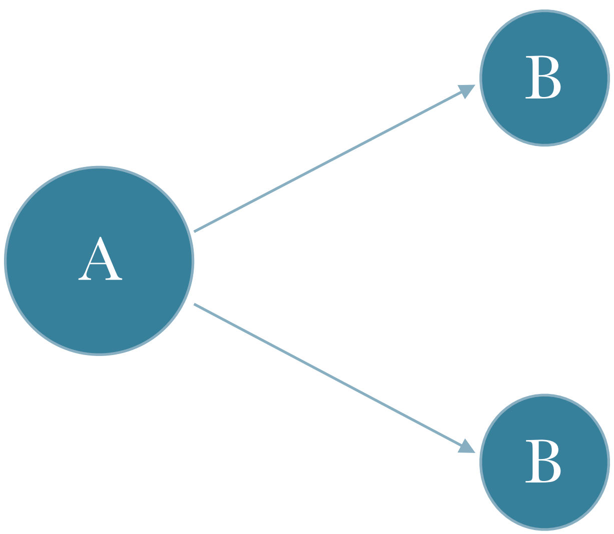




Needle in the Haystack

Bump Hunter (H->γγ)

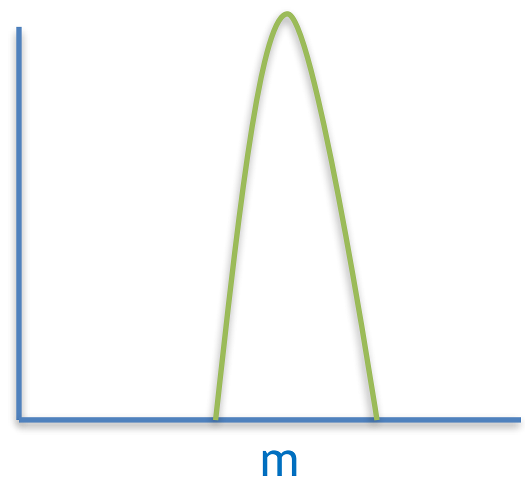
- Hunting a new short lived particle means looking for a bump in the invariant mass ($m_{inv}^2 = (p_1+p_2)^2$) distribution of its decay products.
- The significance of the bump must be high enough to make a statistical fluctuation of the known background highly unlikely.



$$m_A^2 = p_A^2$$

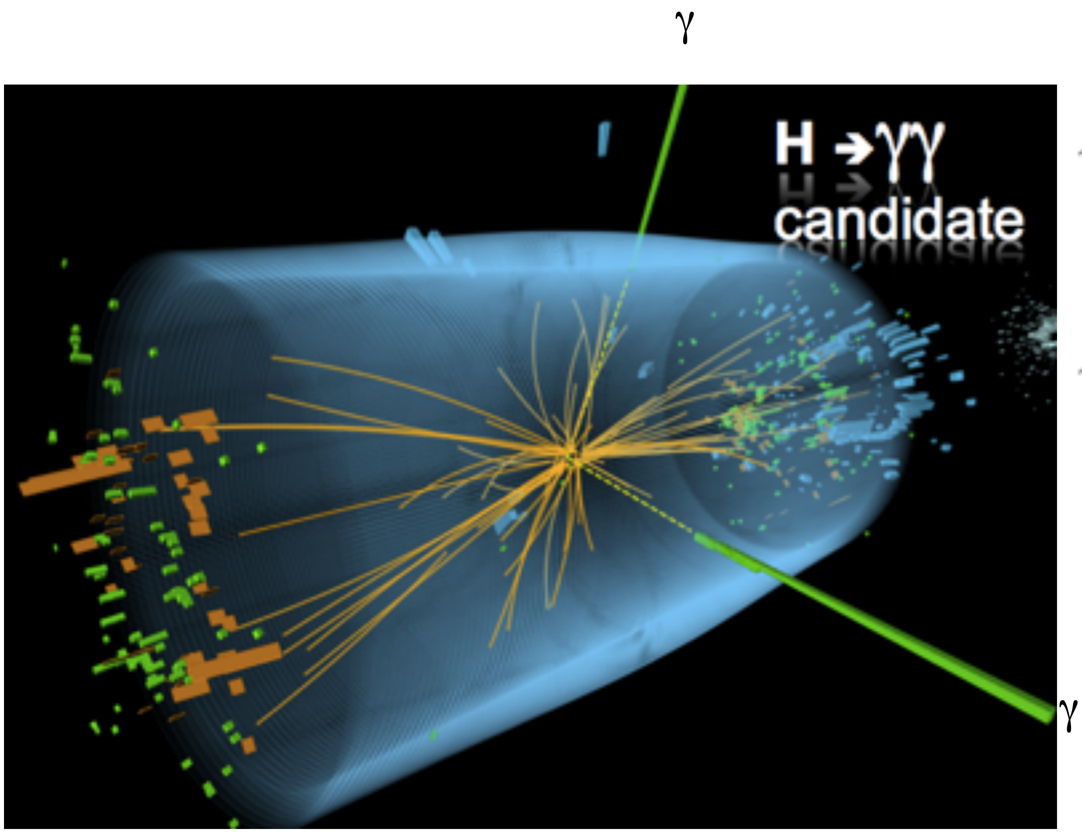
$$p_A = p_B + p_C$$

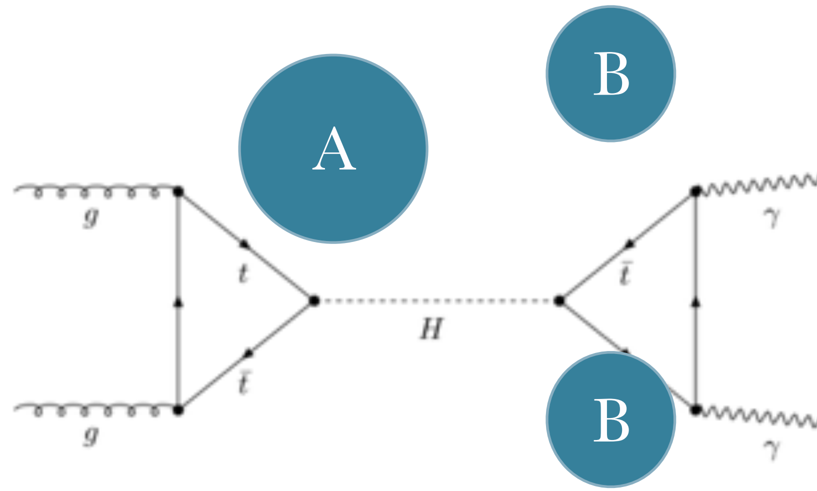
$$m_A^2 = (p_B + P_C)^2$$

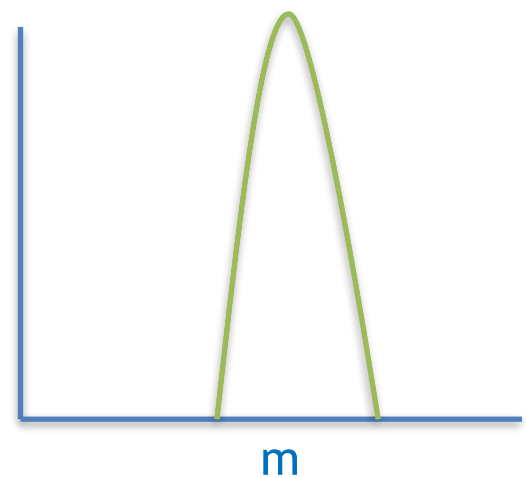


Bump Hunter (H->γγ)

- We have two photons.

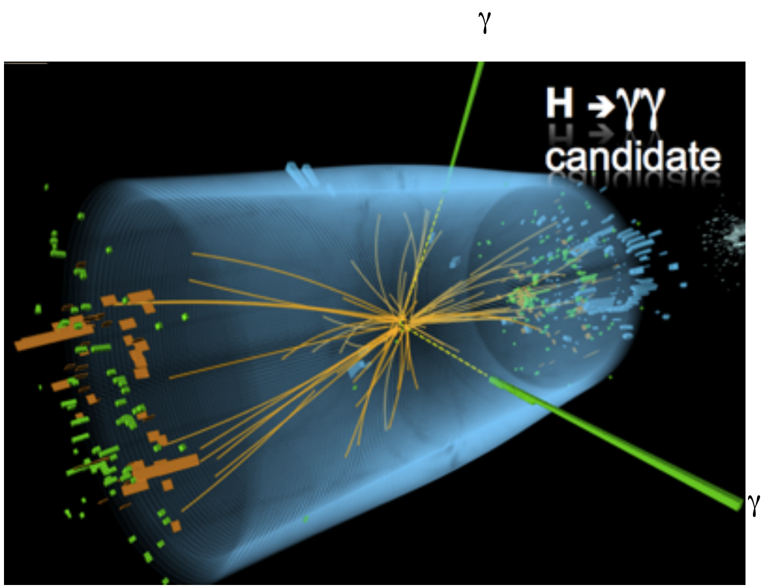


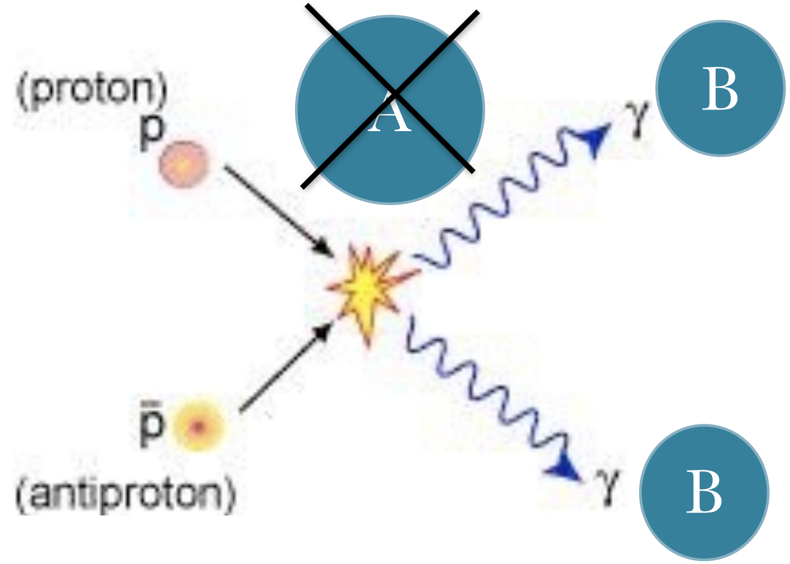


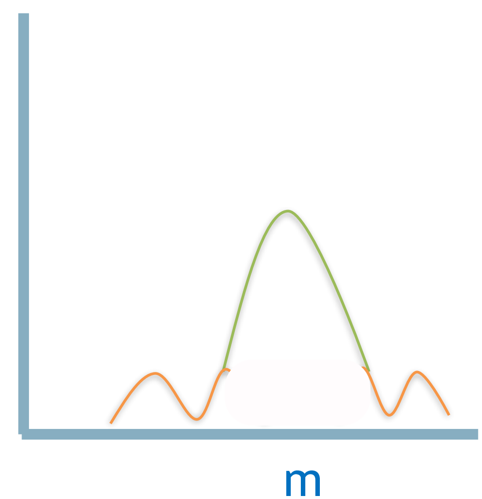


Bump Hunter (H->γγ)

- We have two photons in the background too:

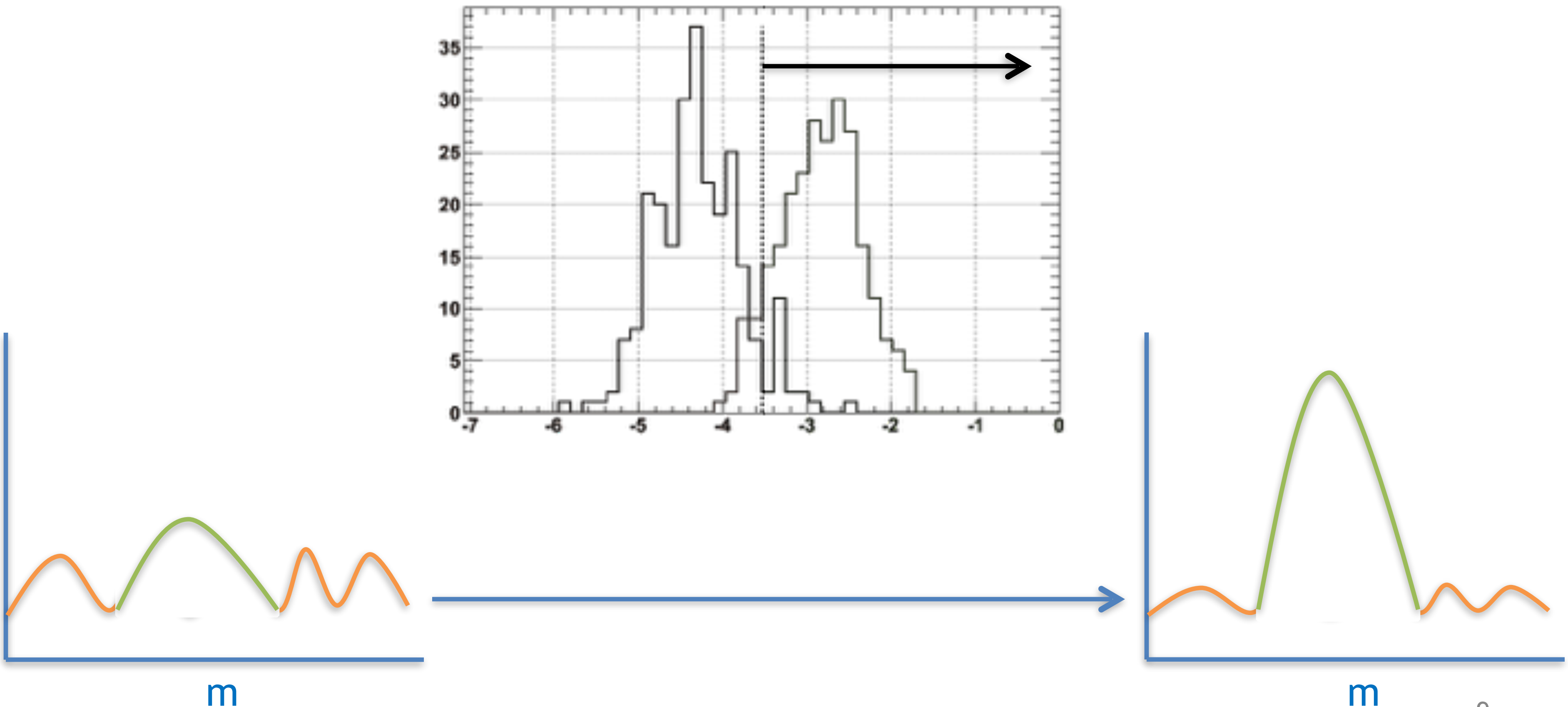






What should we do?

- 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

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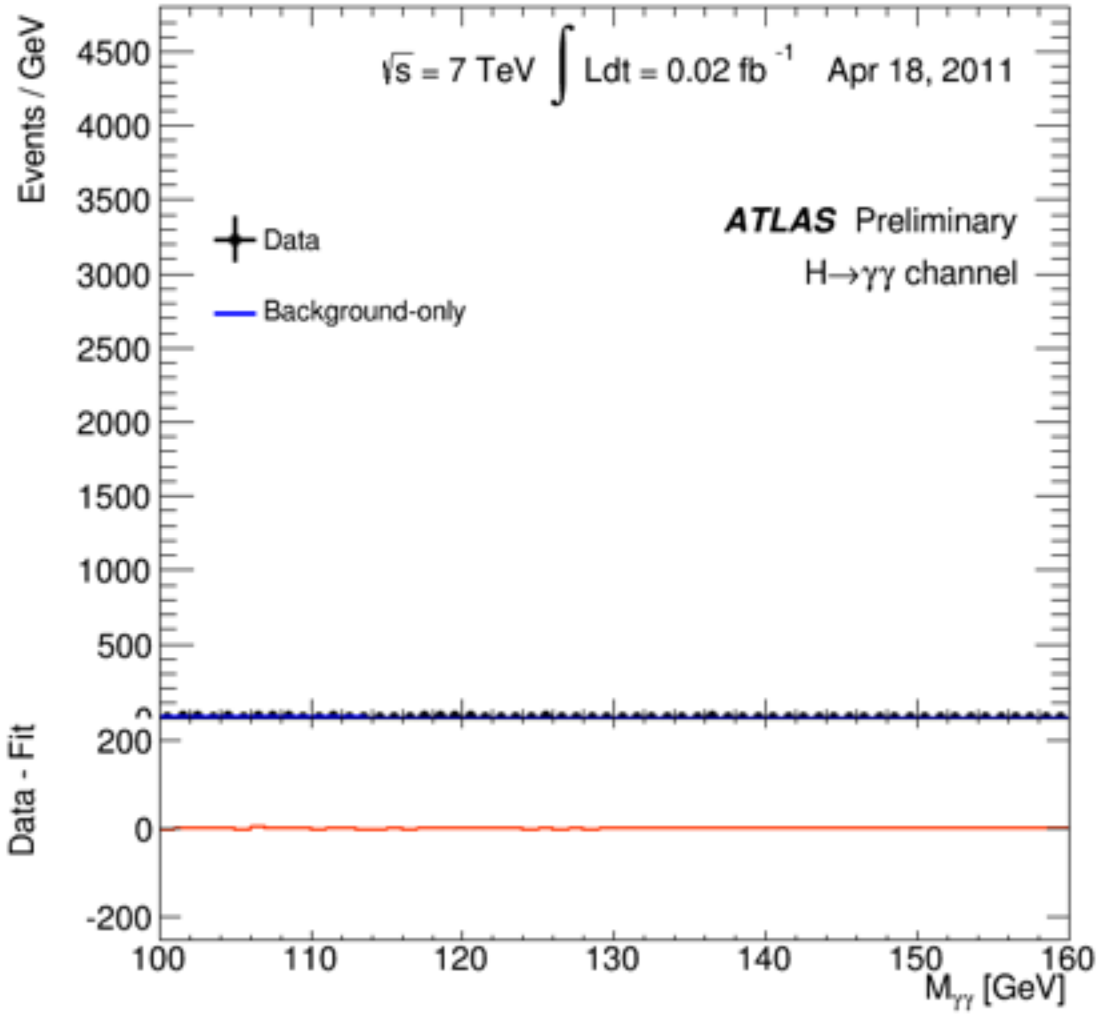
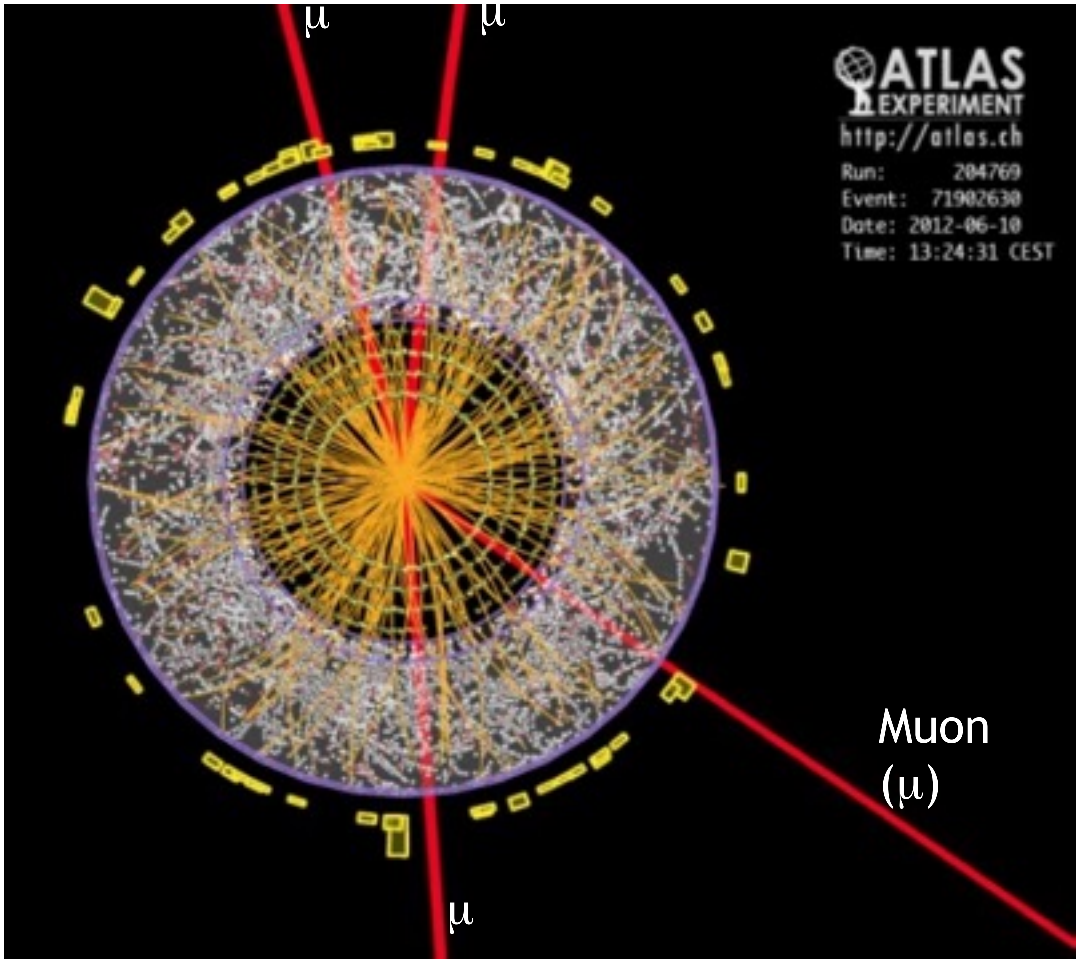
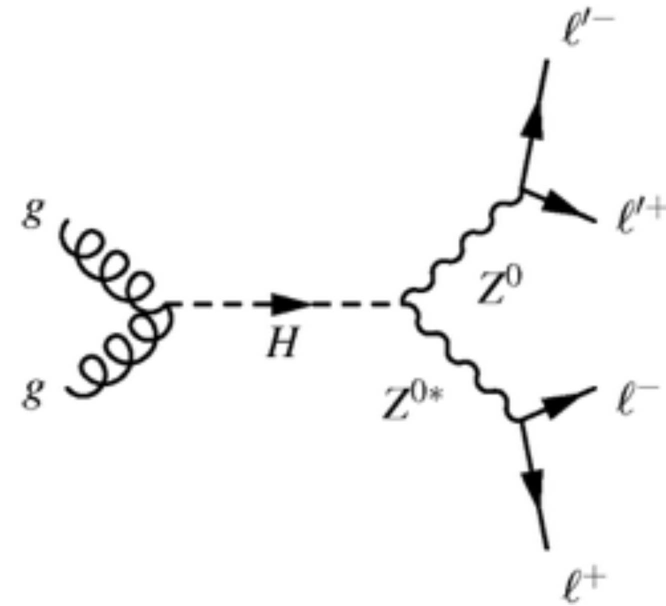


The Golden Channel

- 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

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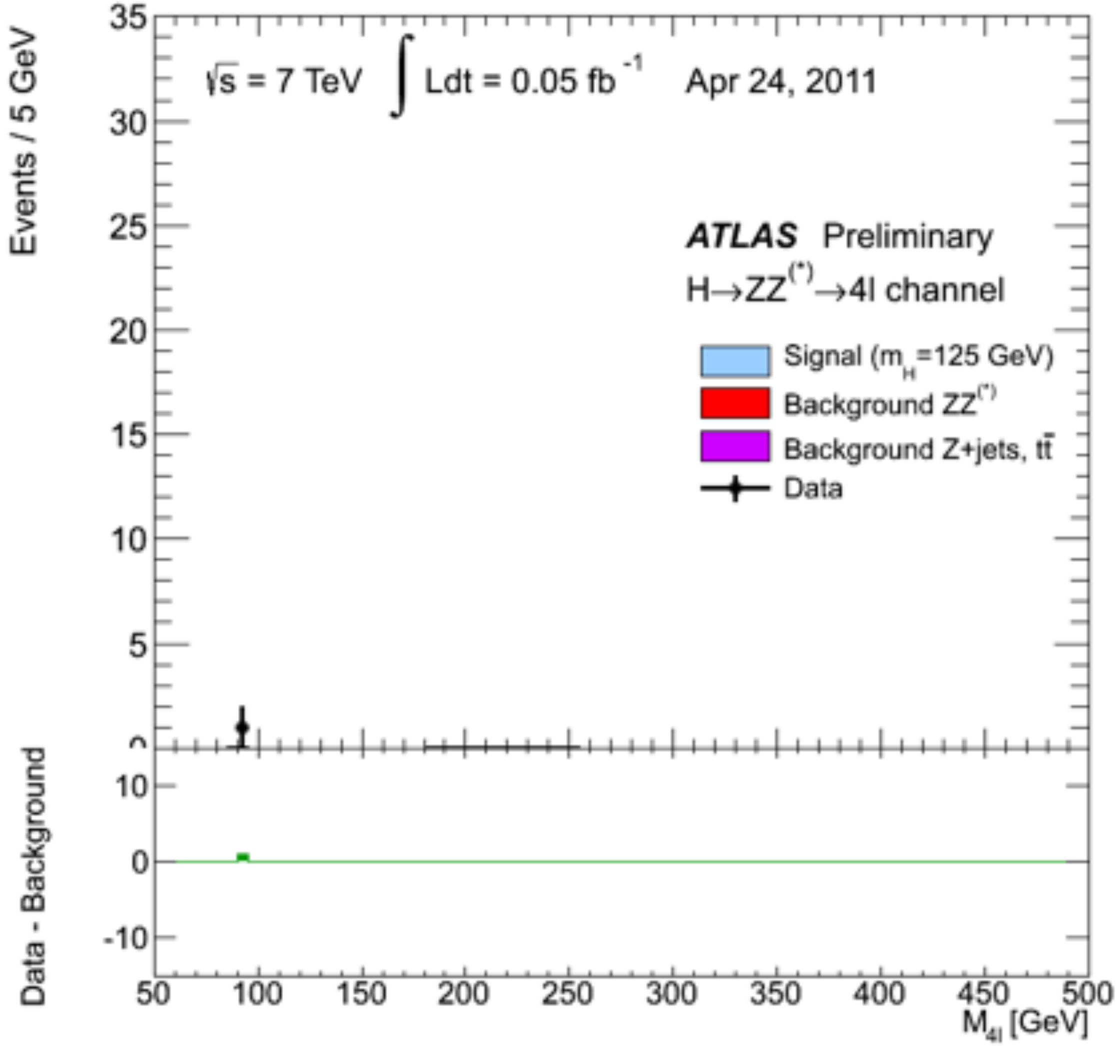
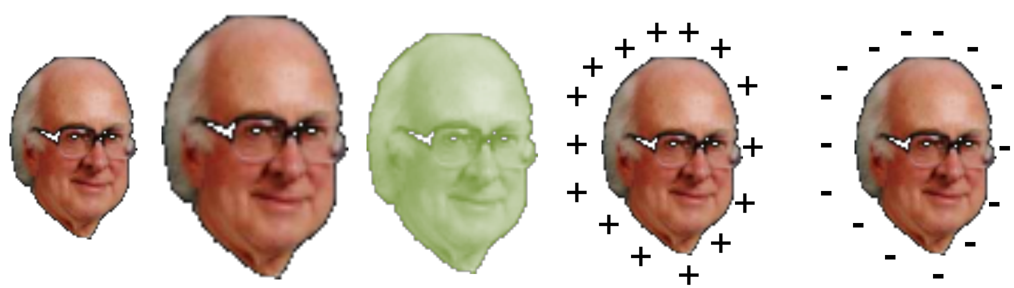


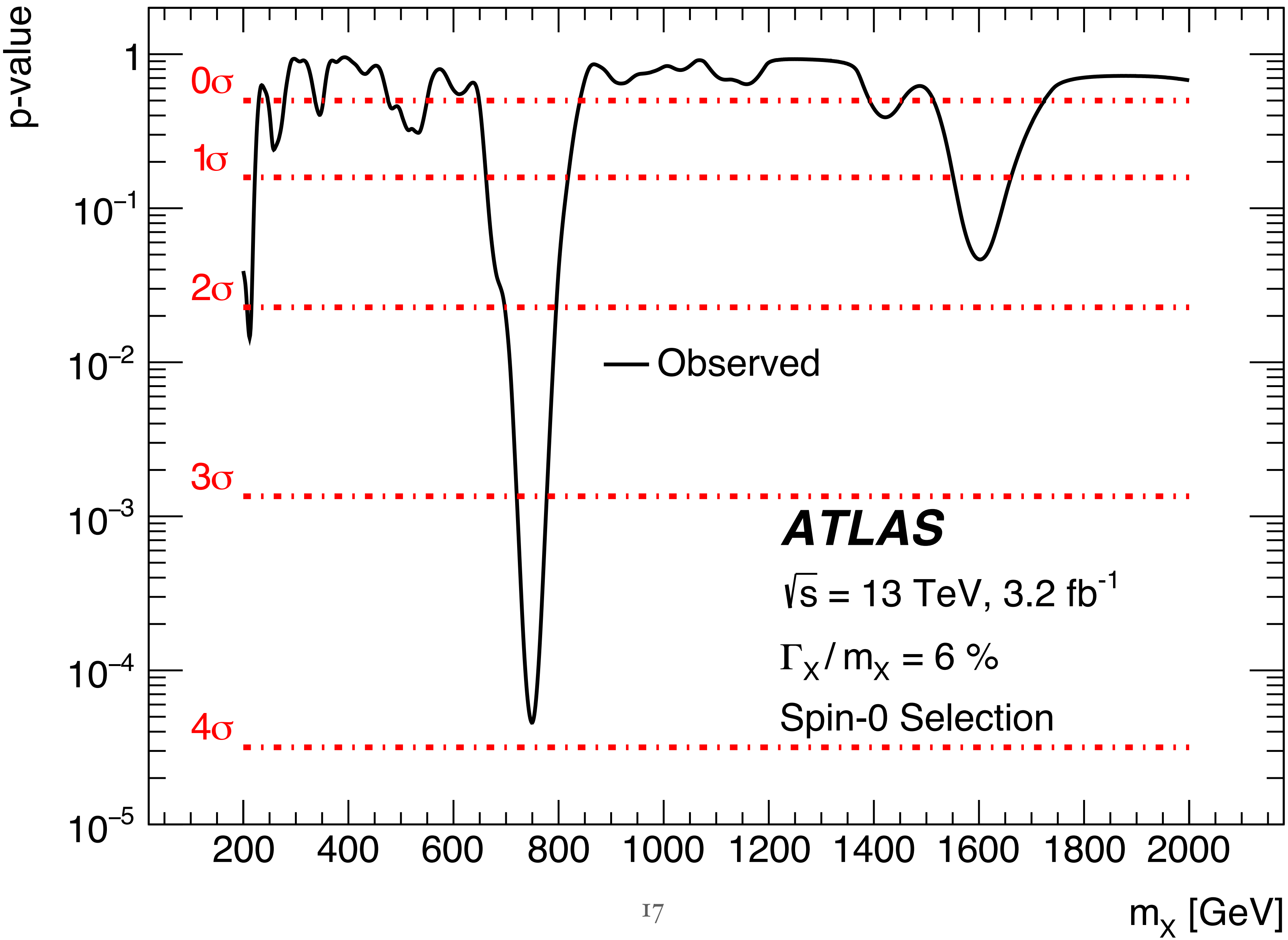
The Glory Day

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

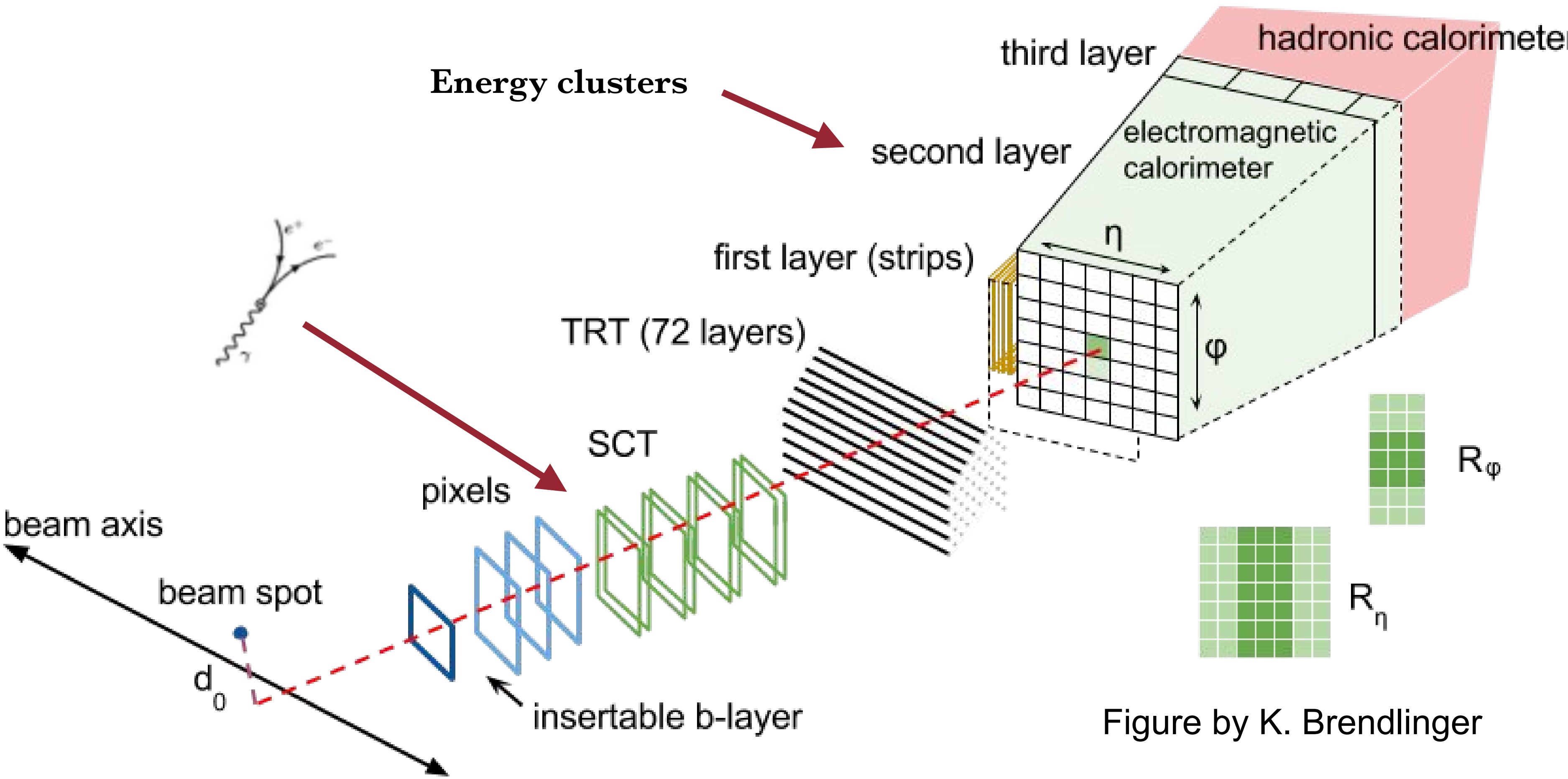
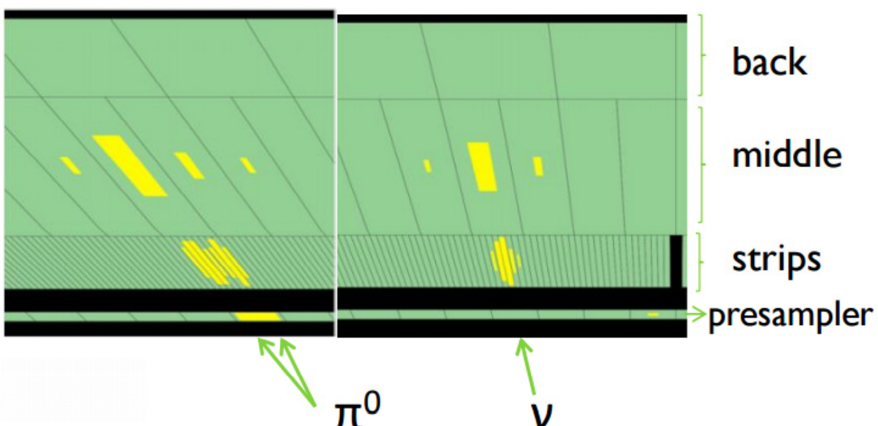


Figure by K. Brendlinger

Photon Reconstruction

Identification

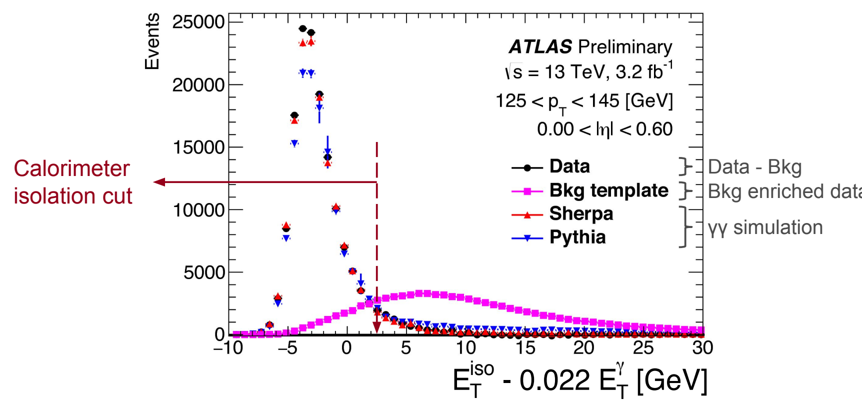
- Applying cuts over discriminating variables (shower shapes) from the calorimeter layers.
- Shower shapes: variables that describe the shape of the electromagnetic shower in the calorimeter, and the fraction of energy deposited in the hadronic calorimeter.
- Cuts are binned in η, and by converted/ unconverted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



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

Isolation

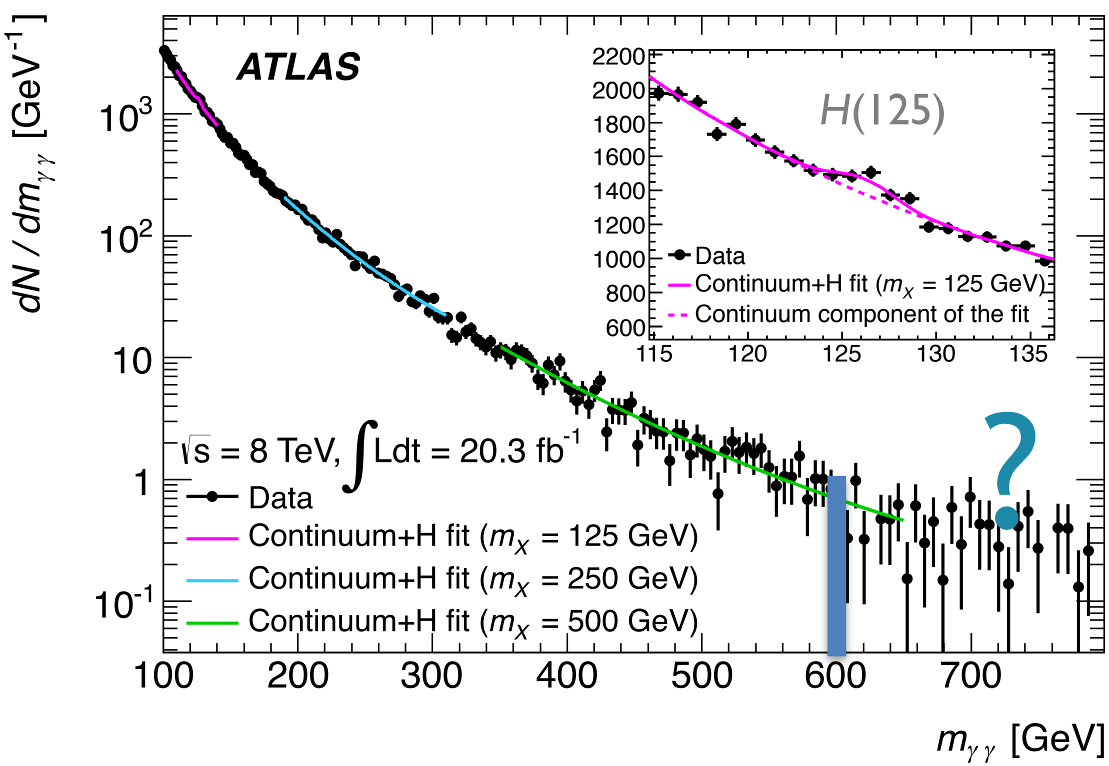
- Important for purity determination, background rejection.
- Both calorimeter and track isolation required.
  - Calo isolation →ΣE_T of energy clusters within ΔR = 0.4:
    $E_T^{iso} < 0.022 E_T + 2.45$ GeV
  - Track isolation →Σp_T of tracks within ΔR = 0.2:
    $p_T^{iso} < 0.05 E_T$



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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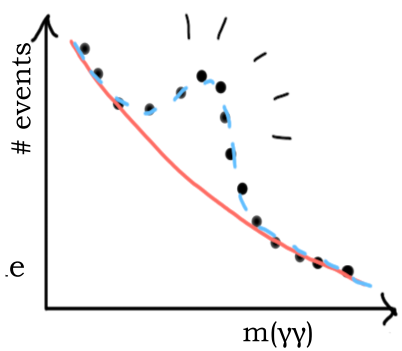

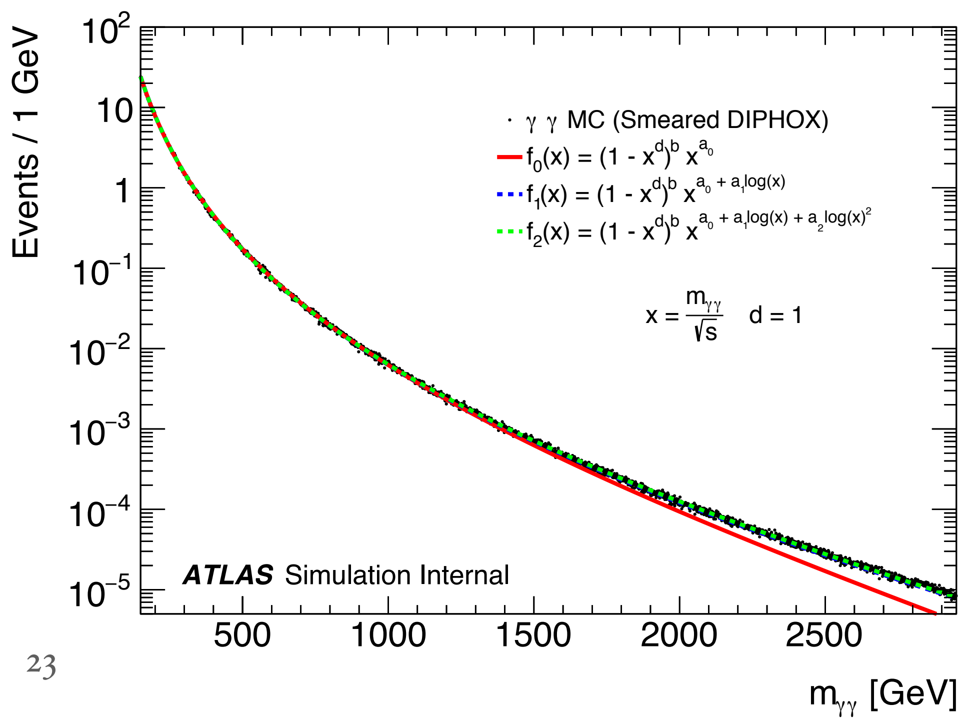

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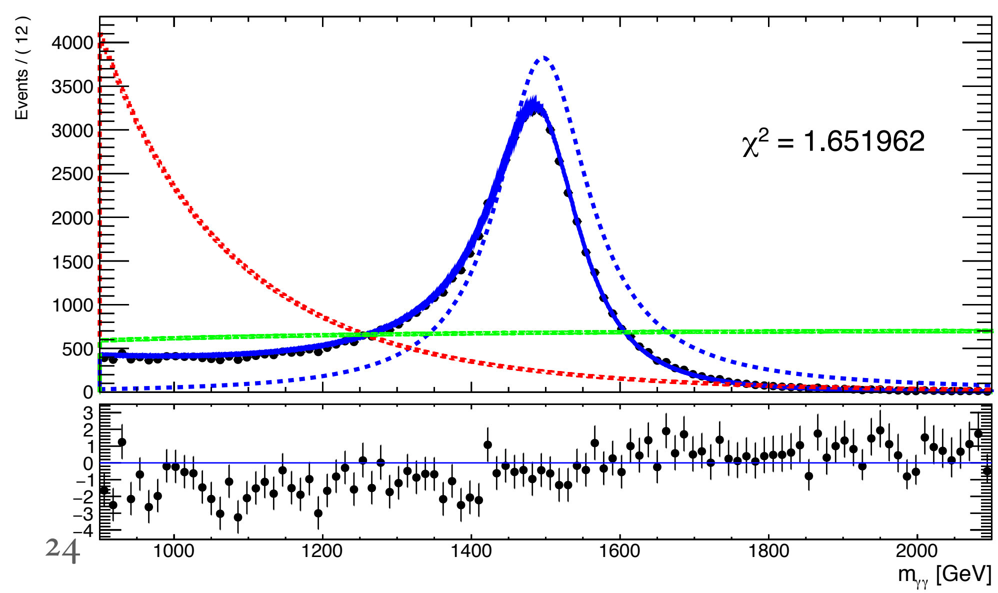
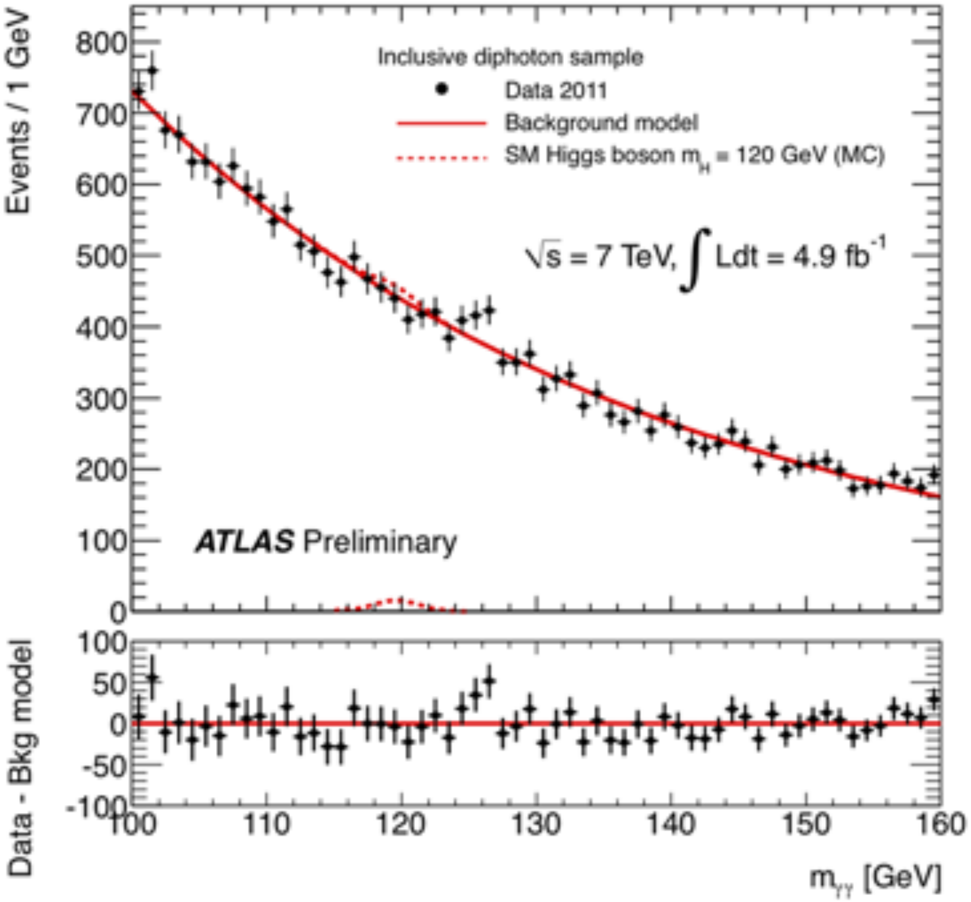
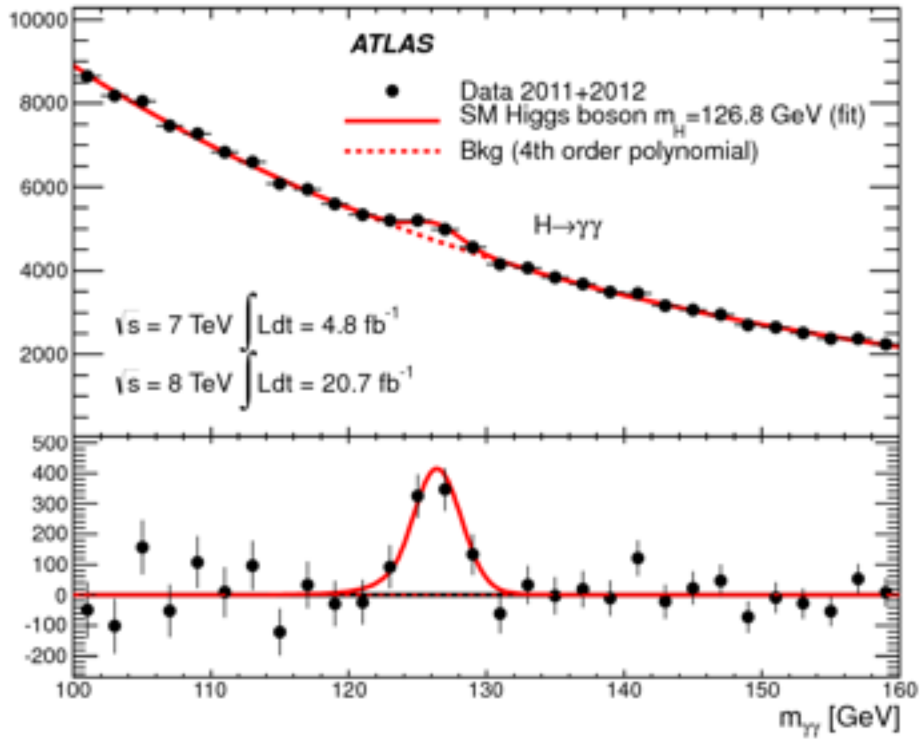
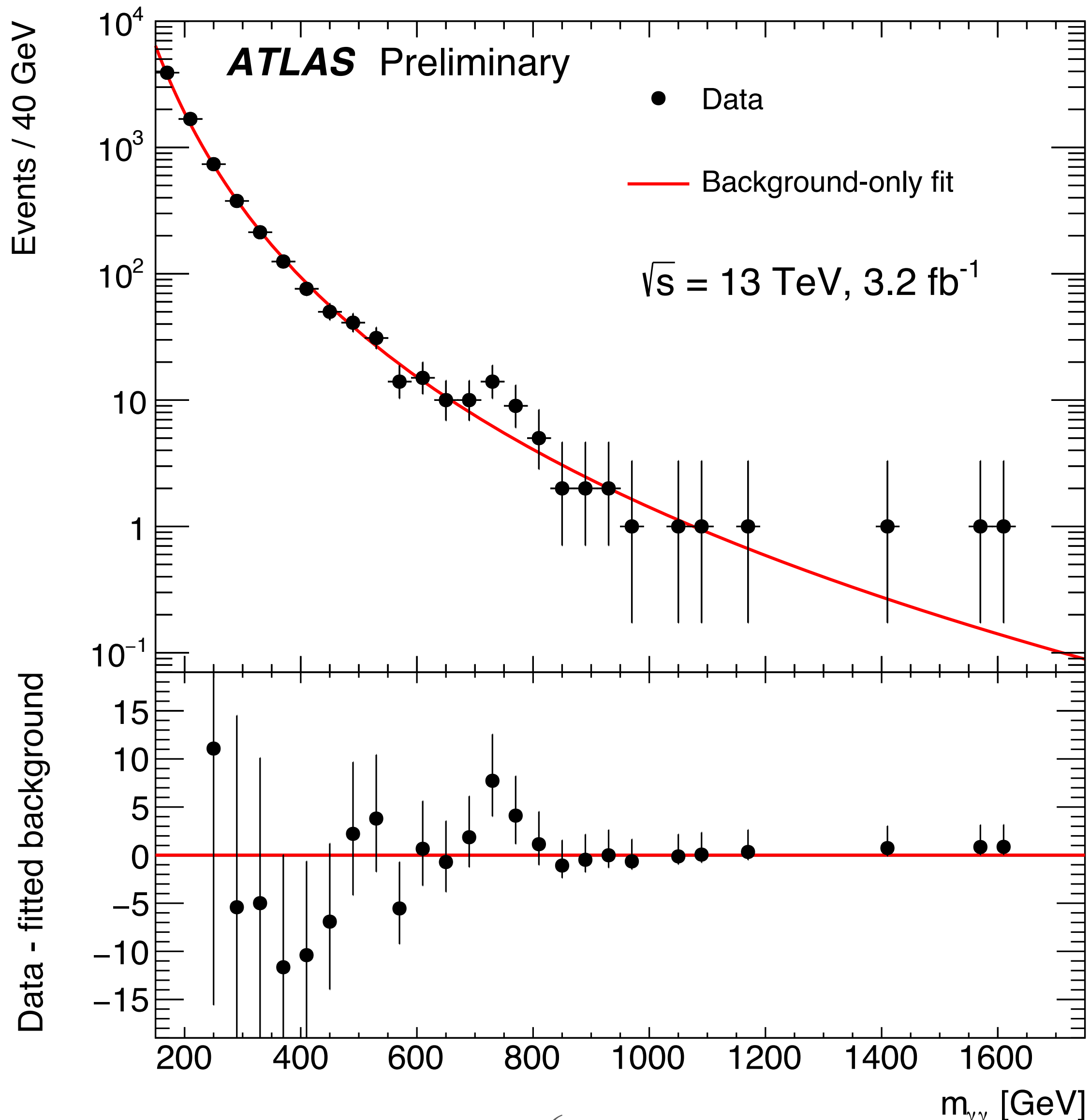


Mass spectrum





Mass spectrum

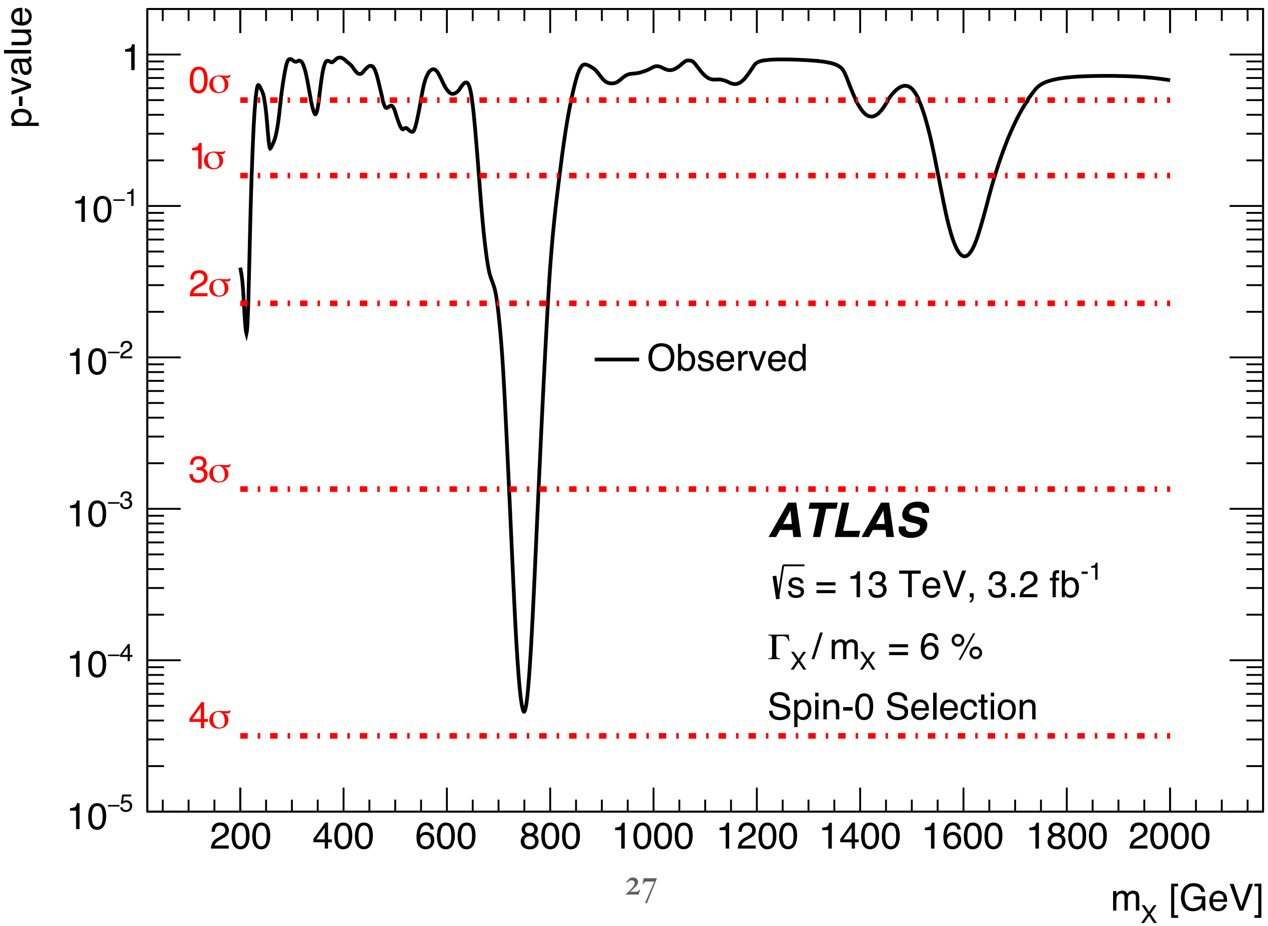


Exciting Result

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

Local Z = **3.9σ**

Global Z = **2.1σ**



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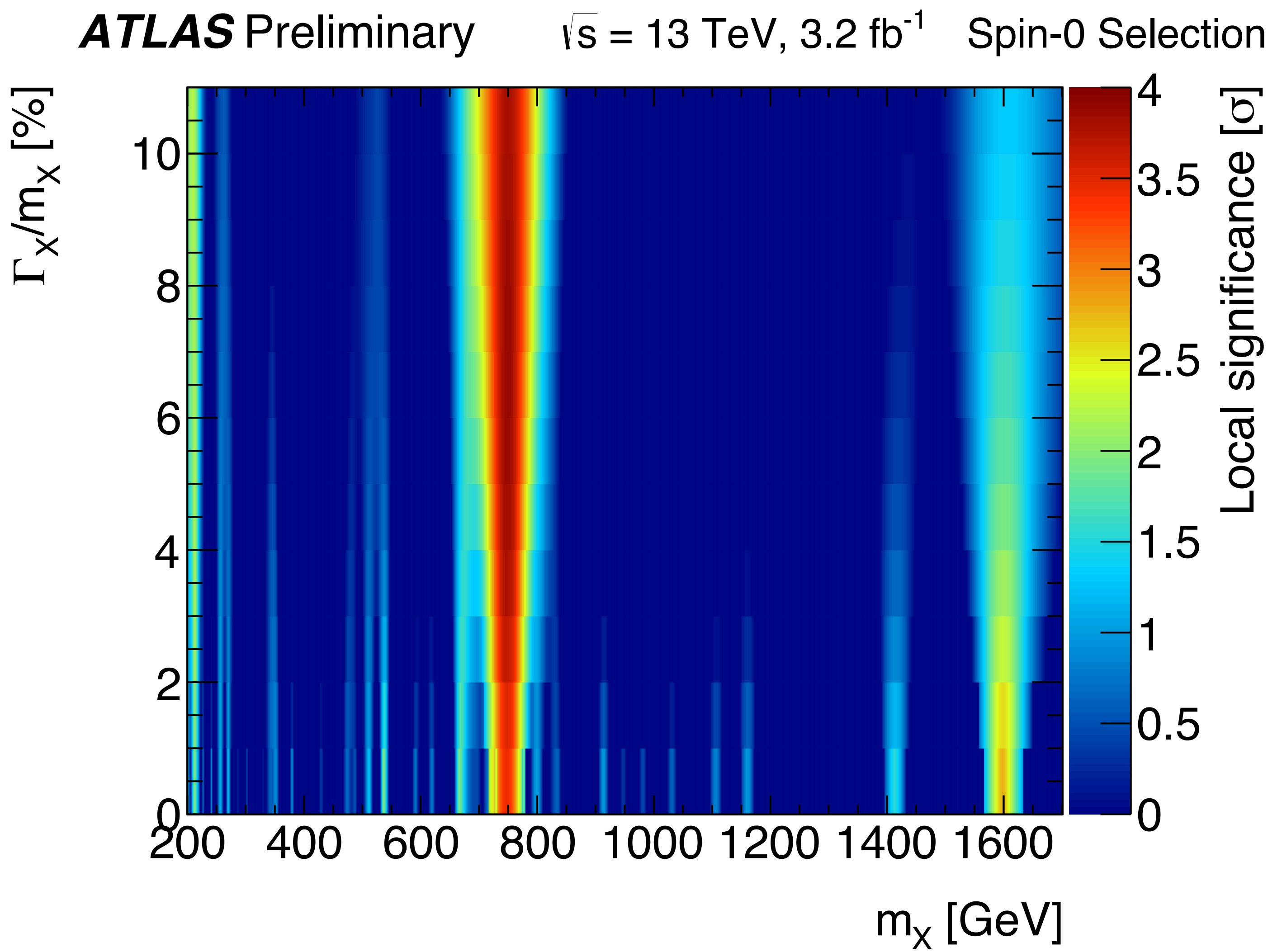


Preparations for 2016

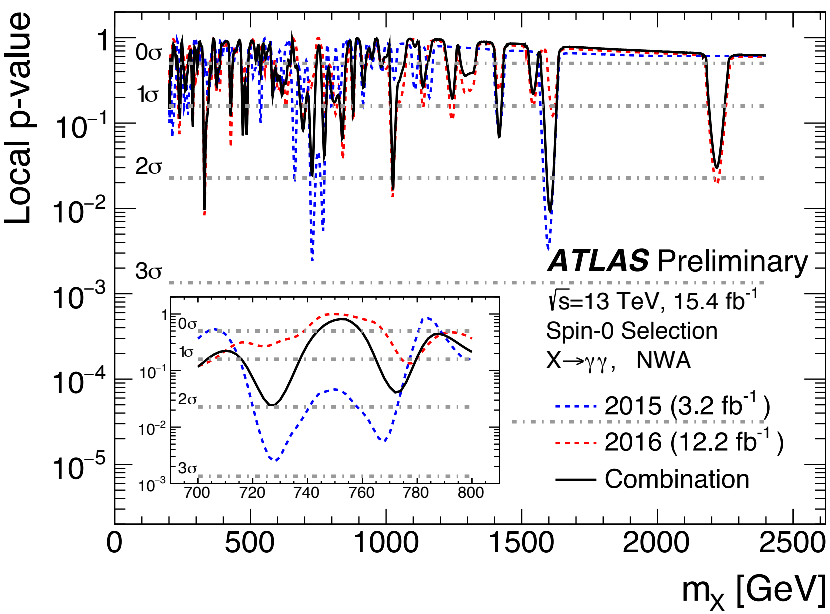
* Changes from 2015 to 2016:
  * Improved photon reconstruction:
    * Higher efficiency of the track isolation.
    * Modified the criteria used to select converted photons to cope with the higher pileup.
    * Energy calibration have been re-trained to account for the small changes in the conversion 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

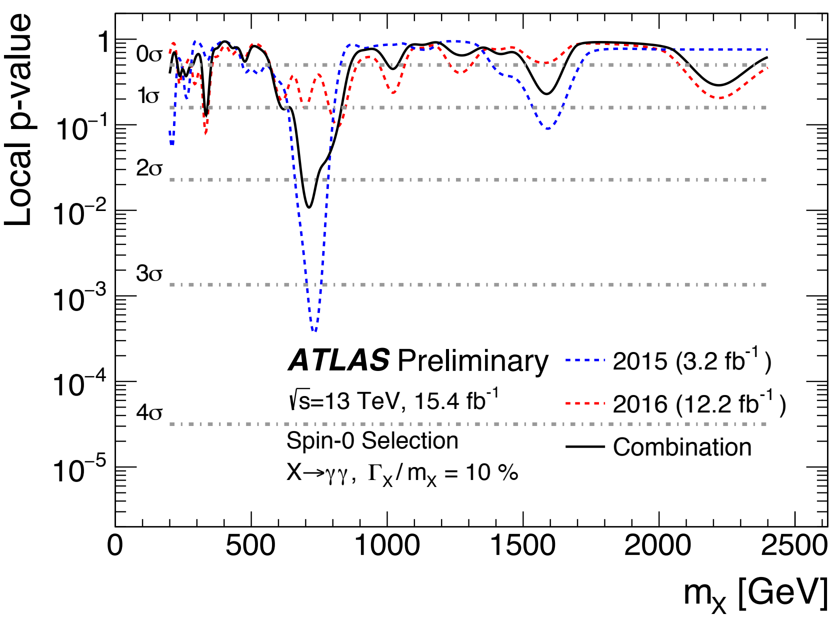
* Changes from 2015 to 2016:
  * Eventually no changes in the analysis… although carefully studied.

Final Results

NWA



Γ_X/m_X = 10%



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

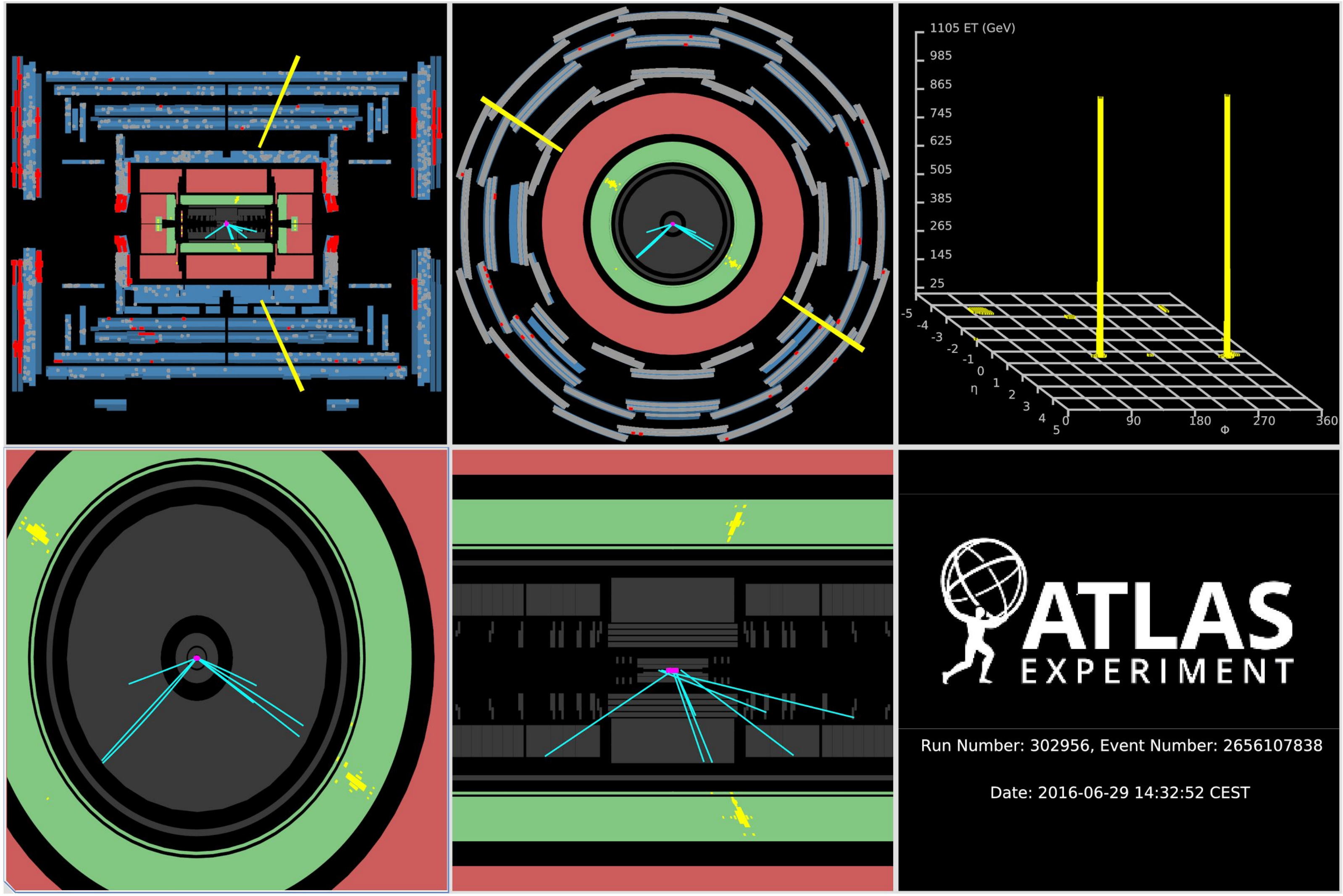
2.4σ local @ 1.6 TeV

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).