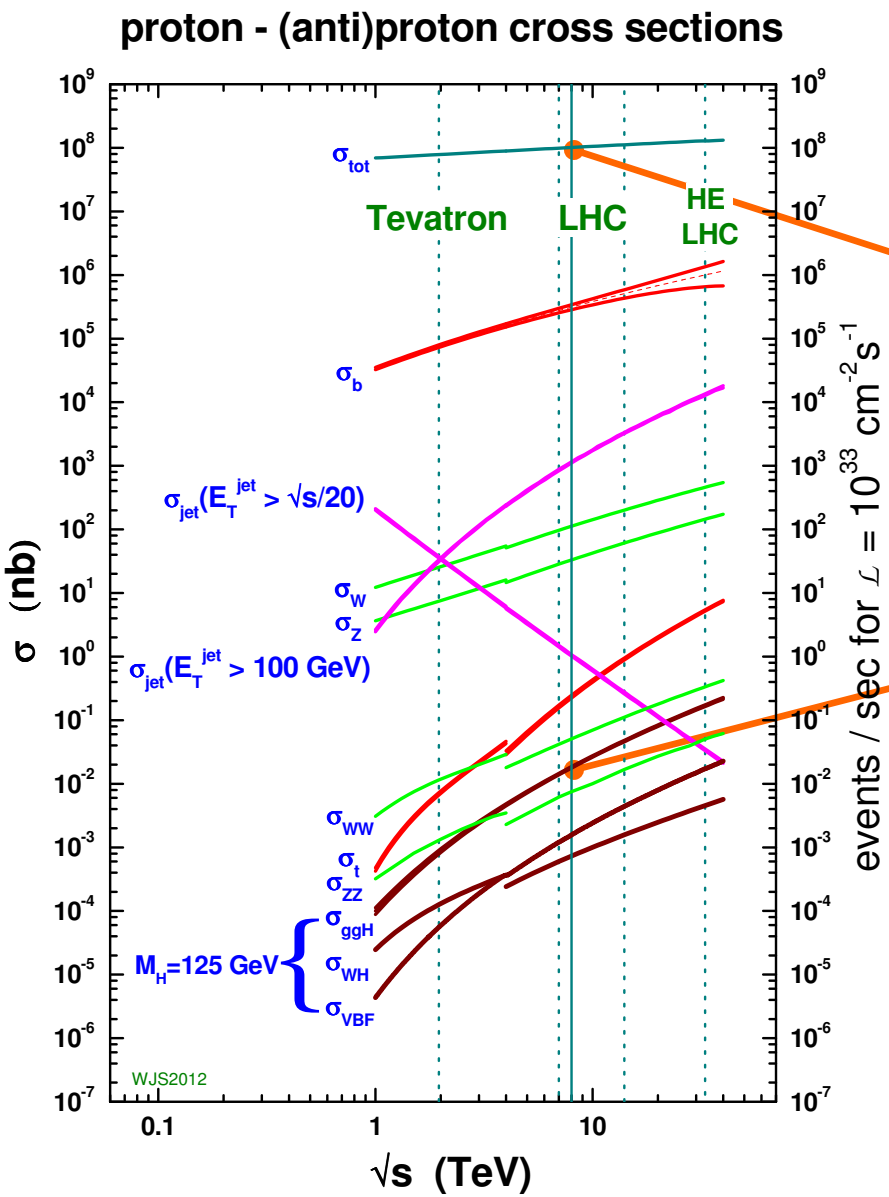
Experimental particle physics

esipap
European School of Instrumentation in Particle & Astroparticle Physics

5. a few words on S/B optimization and data analysis

Interesting processes are rare!



10^8 events/s

$\sim 10^{10}$

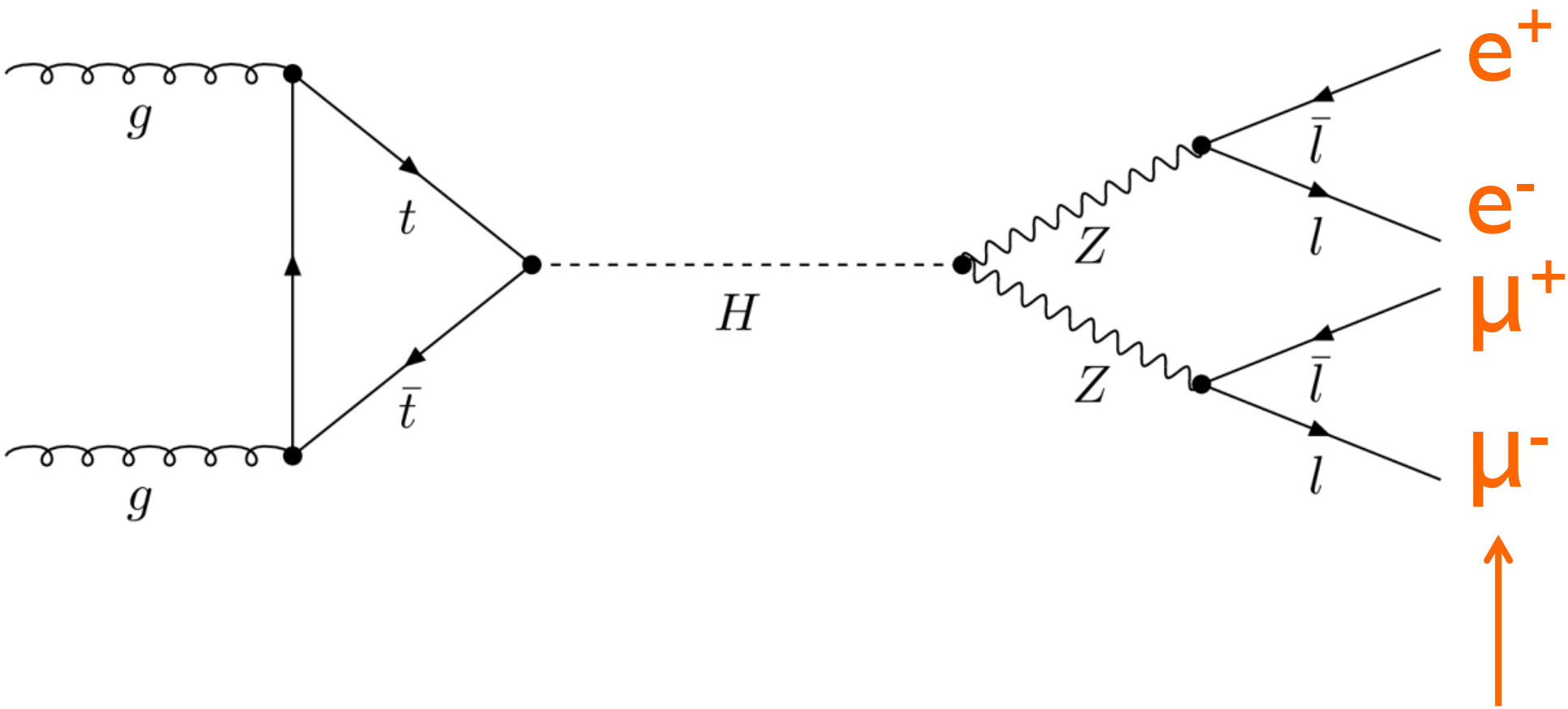
10^{-2} events/s ~

10 events/min

[m_H ~ 125 GeV]

0.2% H → γγ
1.5% H → ZZ

There is no Higgs-boson detector!

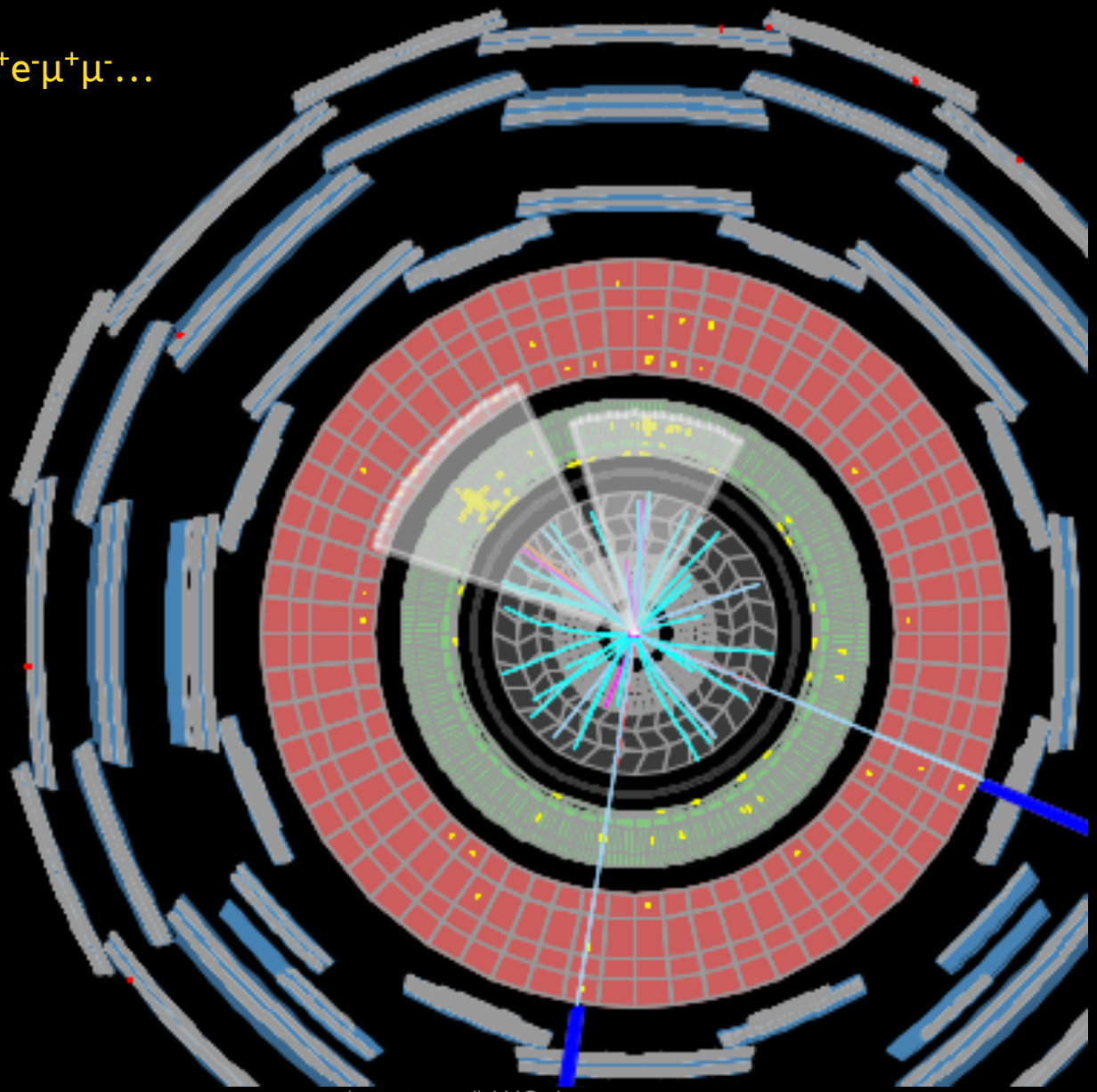


this is what we are looking for…

Step 1: find events with the right ingredients

We are looking for $e^+e^-\mu^+\mu^-$…

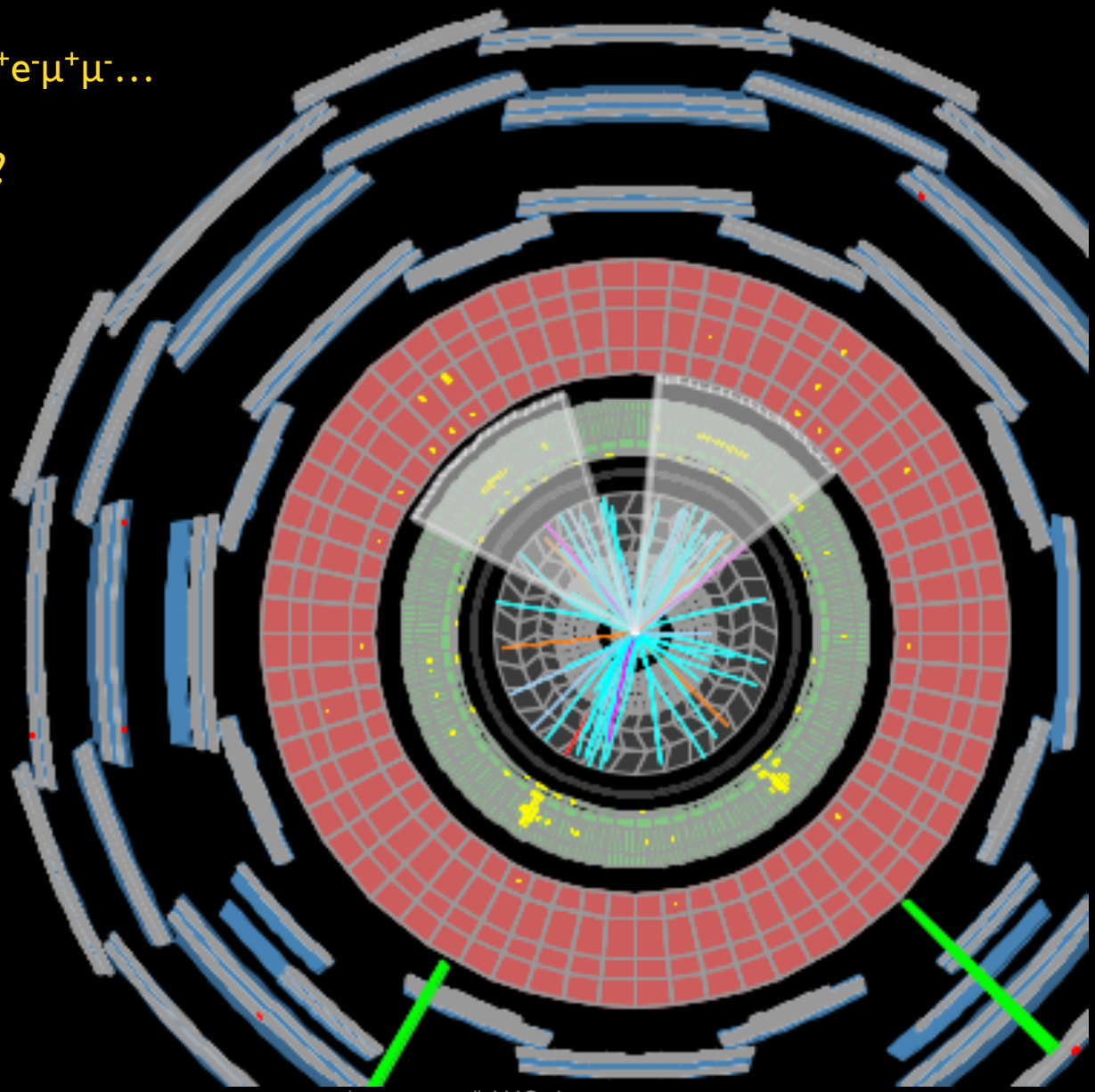
Is this event ok?



Step 1: find events with the right ingredients

We are looking for $e^+e^-\mu^+\mu^-$…

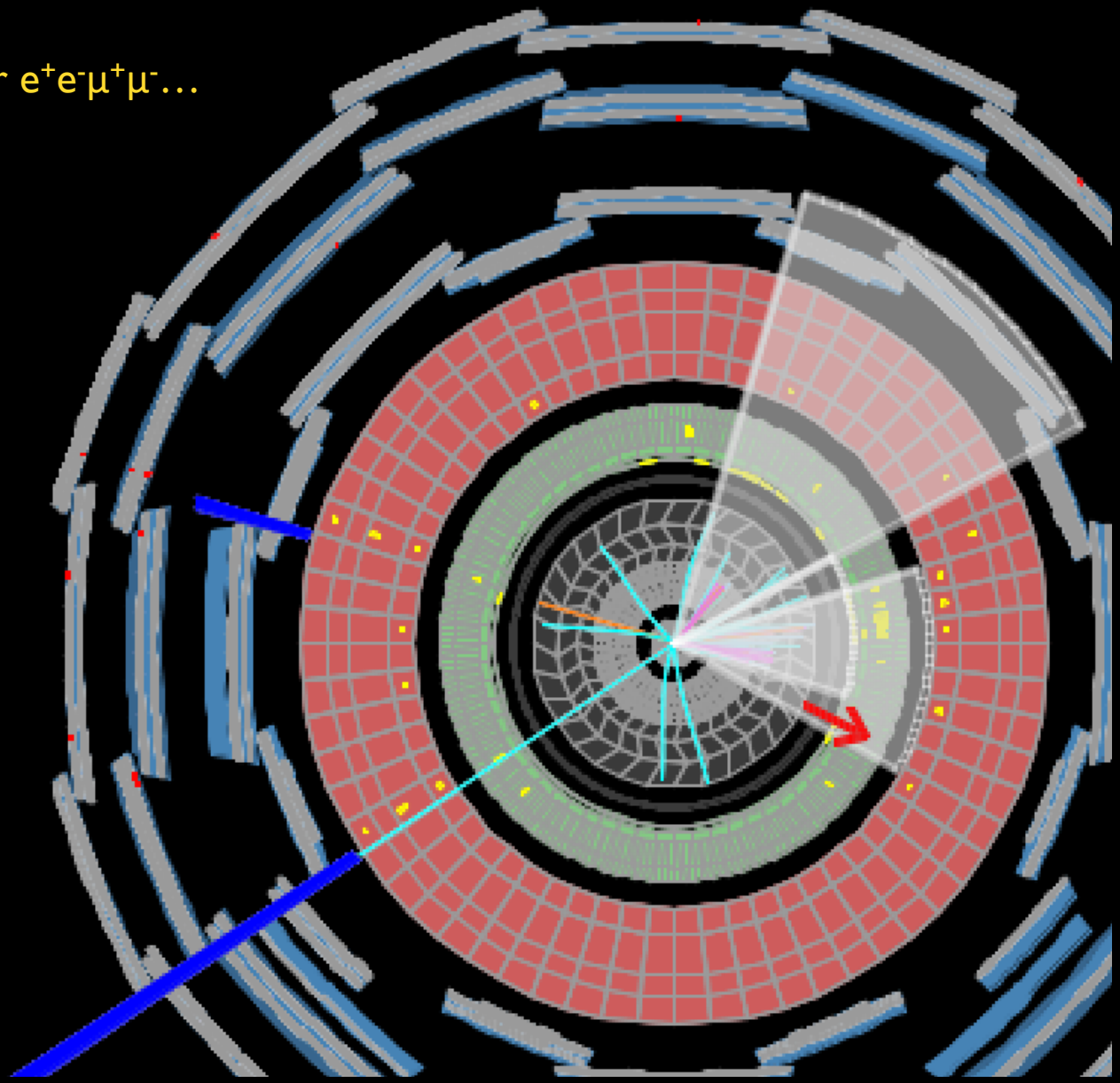
What about this one?



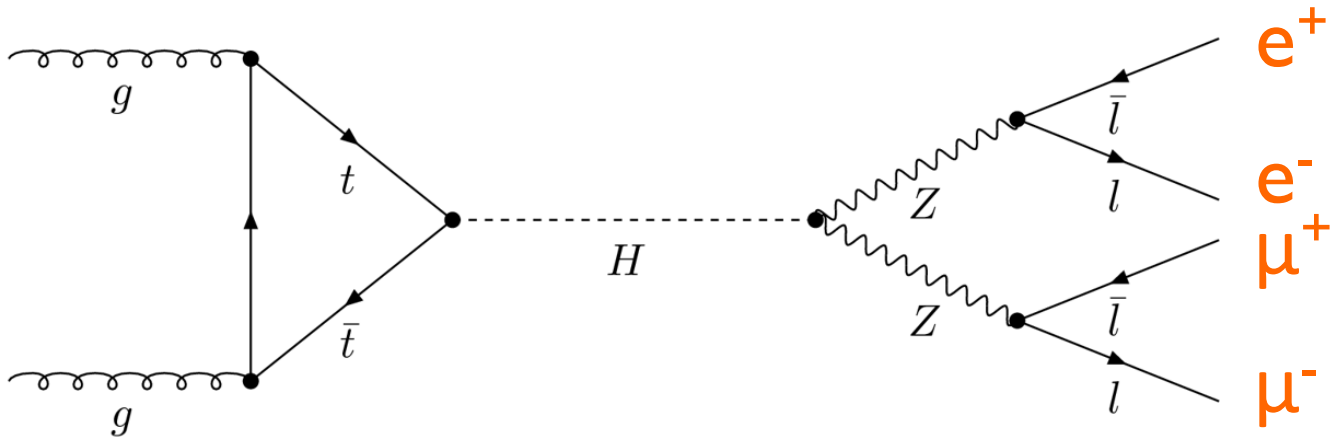
Step 1: find events with the right ingredients

We are looking for $e^+e^-\mu^+\mu^-$…

And this one?



Signal and background

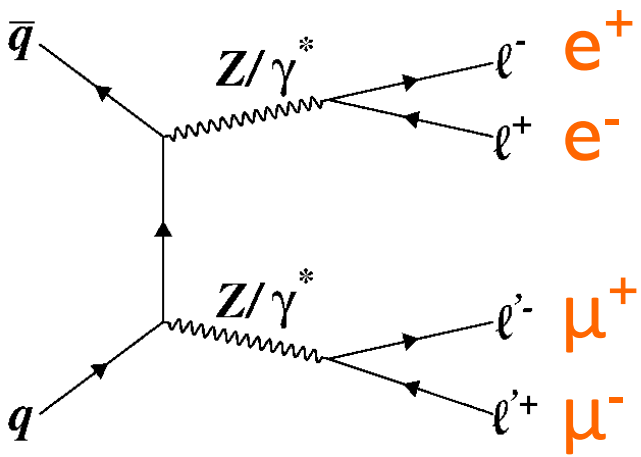


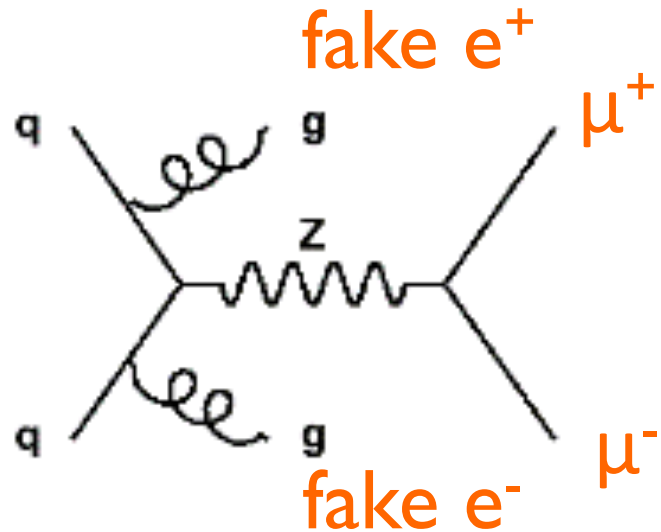
Irreducible background

The final state is exactly the same, but it does not come from the particle you are looking for

Reducible background

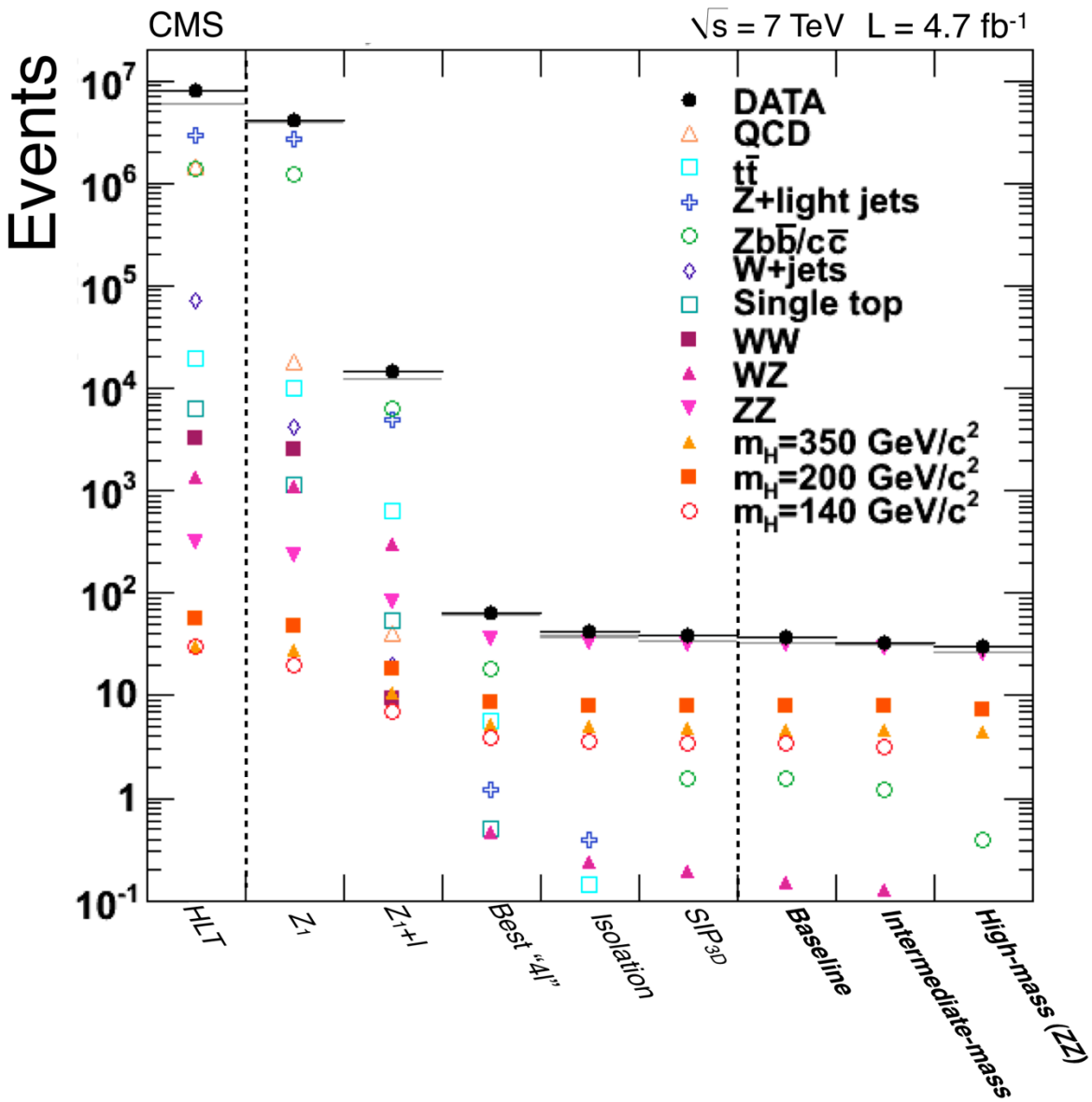
The final state looks like the same, but some f the particle fakes what you are looking for





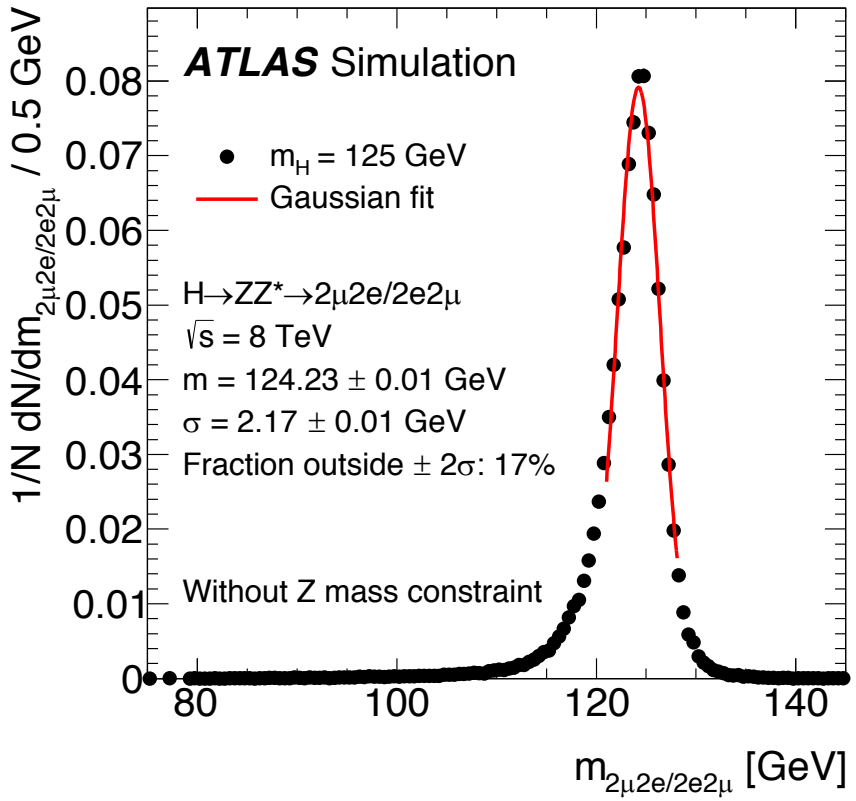
Selections

- Cut on particle properties to reduce reducible background
  - ✓ Shower shapes, track properties, …
- Cut on event properties to distinguish signal from background
  - ✓ Particle kinematics, decay kinematics event shape, …
- Try to keep signal while reducing background!
  - ✓ Increase S/B…



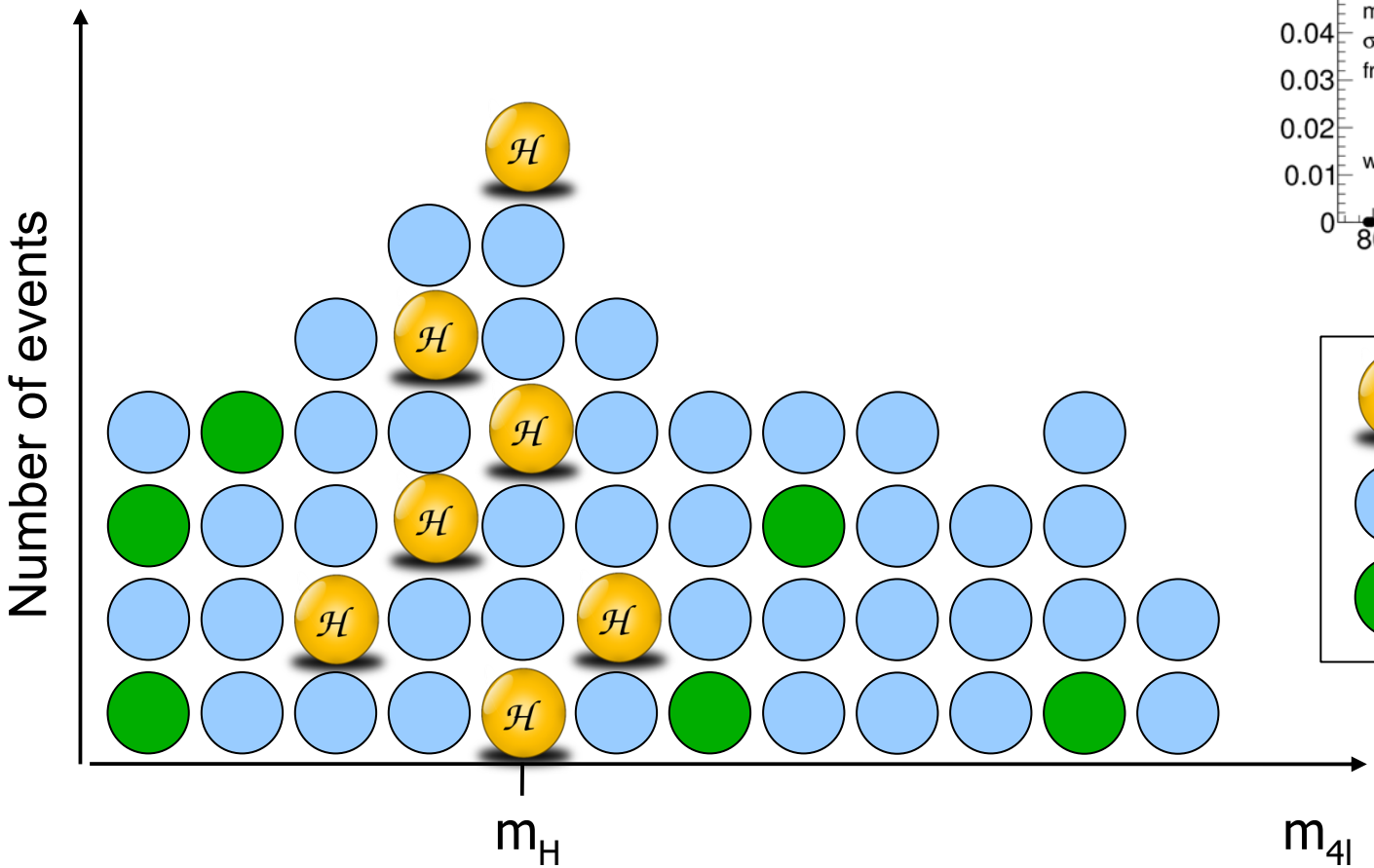
Step 2: reconstruct properties of initial particle

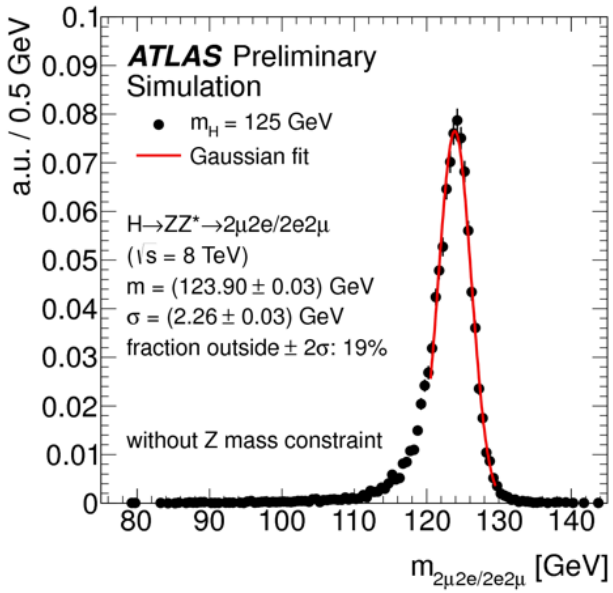
- We have 4 particles…
  - ✓ … with their energy (calorimeters), charge and momentum (tracker)
- Use pairs of opposite sign e^+e^- and $\mu^+\mu^-$
- Reconstruct invariant mass from the 4 particles $M = \sqrt{\left(\sum E_i\right)^2 - \left(\sum \vec{p}_i\right)^2}$

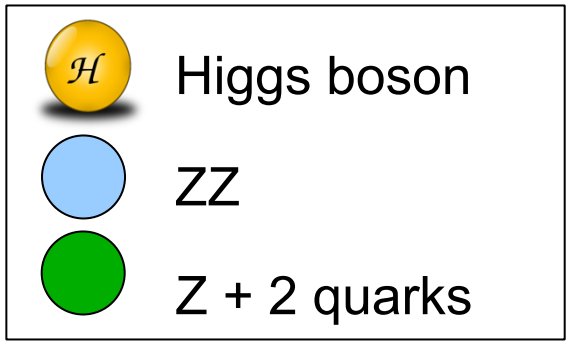


Extract signal from background

$$M = \sqrt{\left(\sum E_i\right)^2 - \left(\sum \vec{p}_i\right)^2}$$

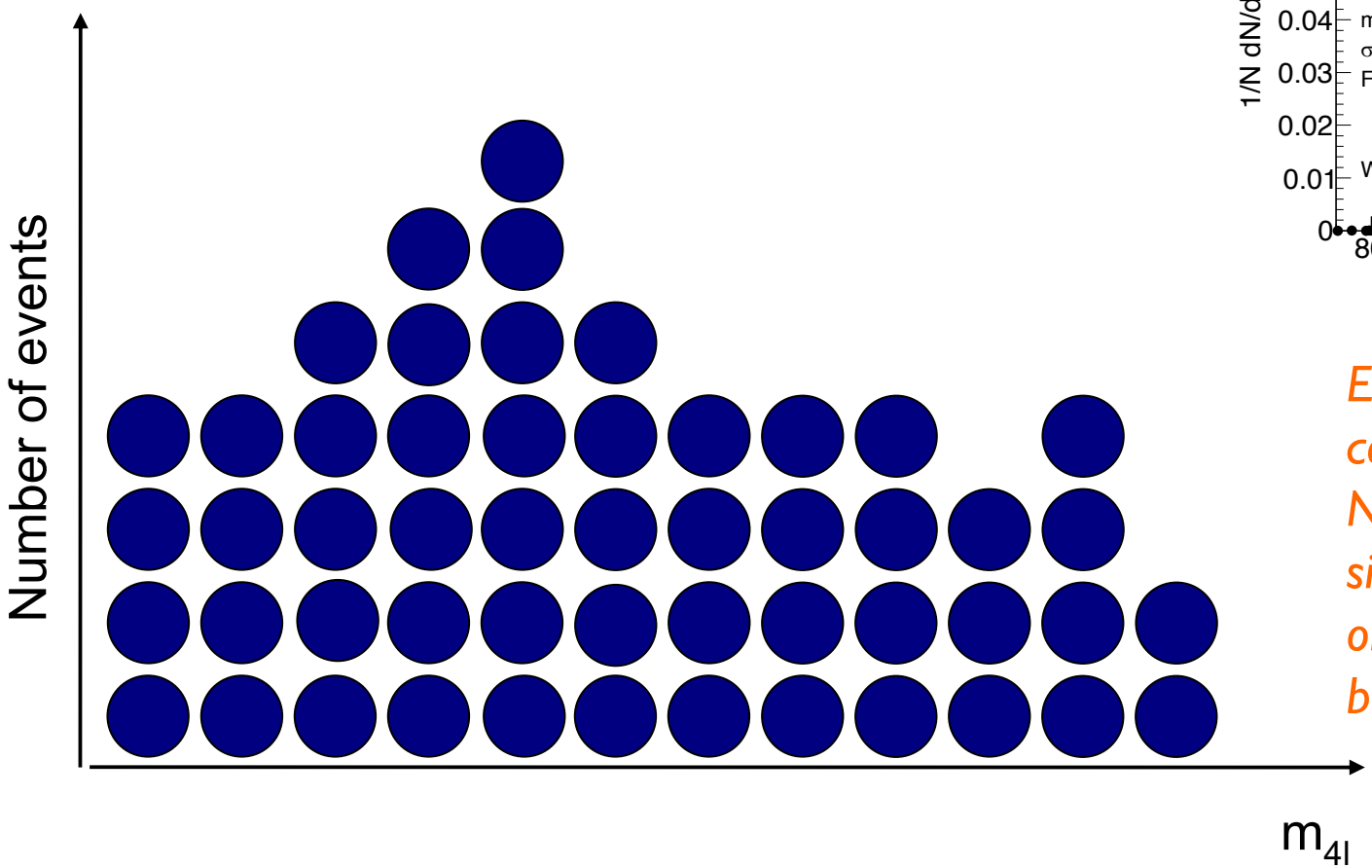


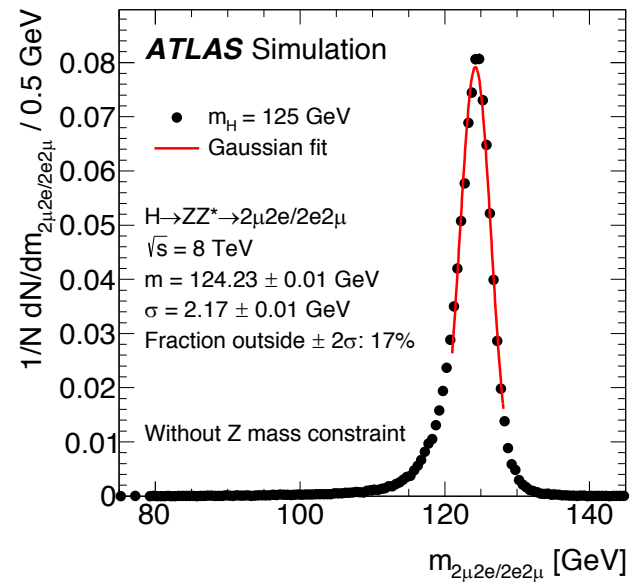




Extract signal from background

$$M = \sqrt{\left(\sum E_i\right)^2 - \left(\sum \vec{p}_i\right)^2}$$

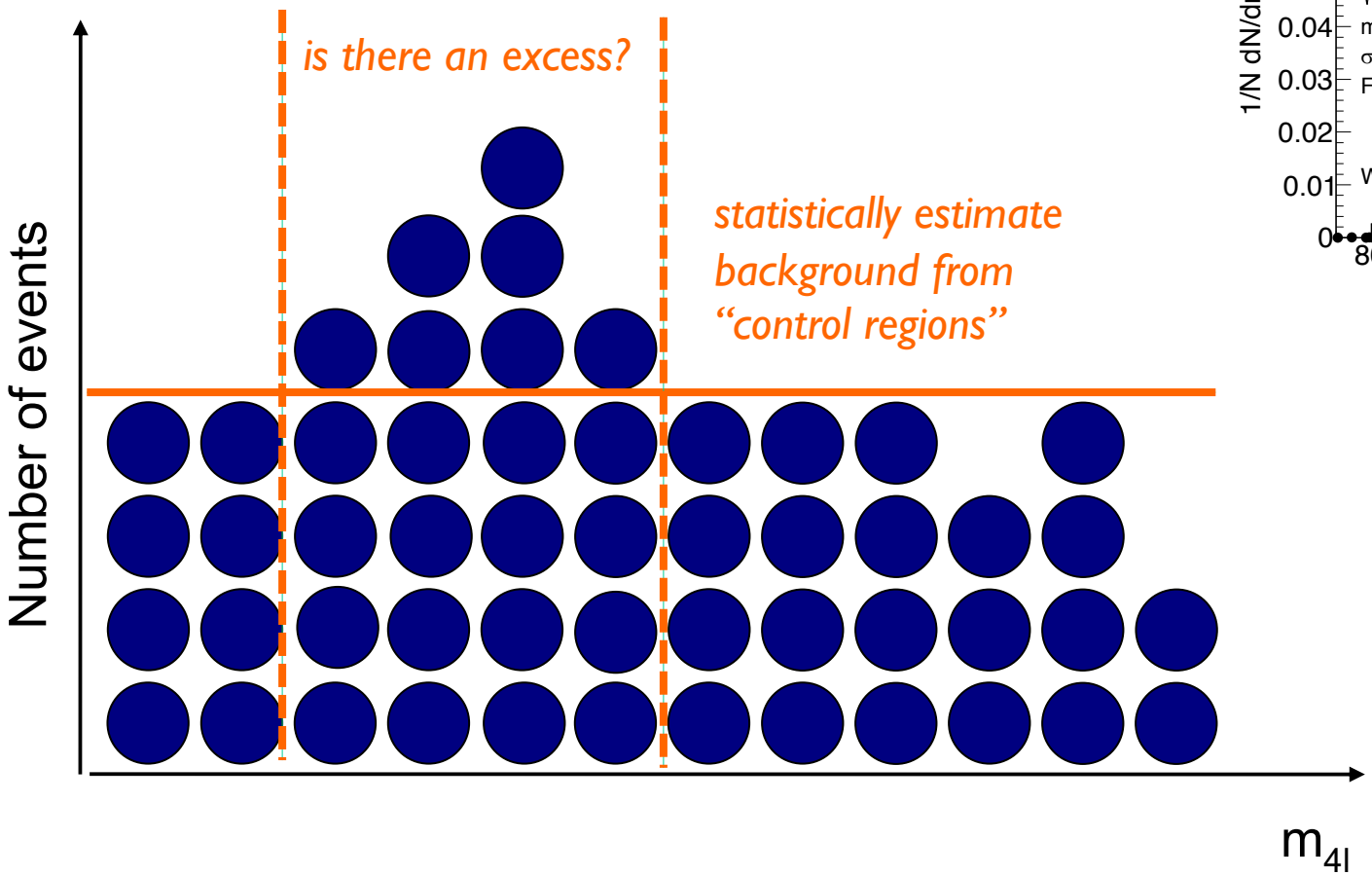


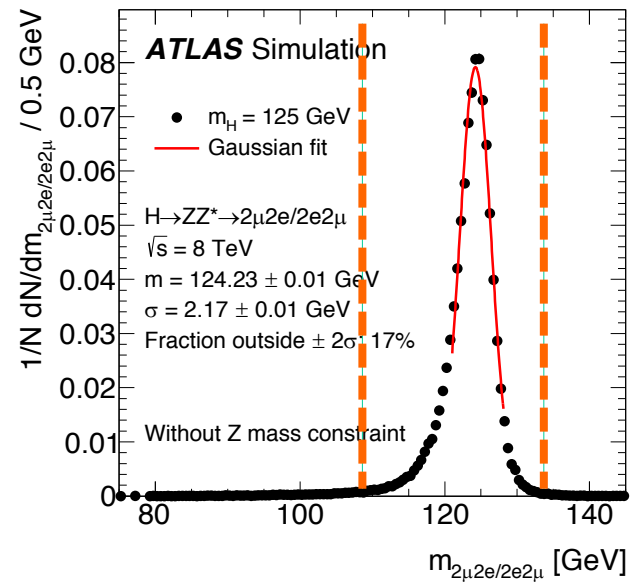


Events in real life do not come with a label!
No way to distinguish signal from background on an event-by-event base…

Extract signal from background

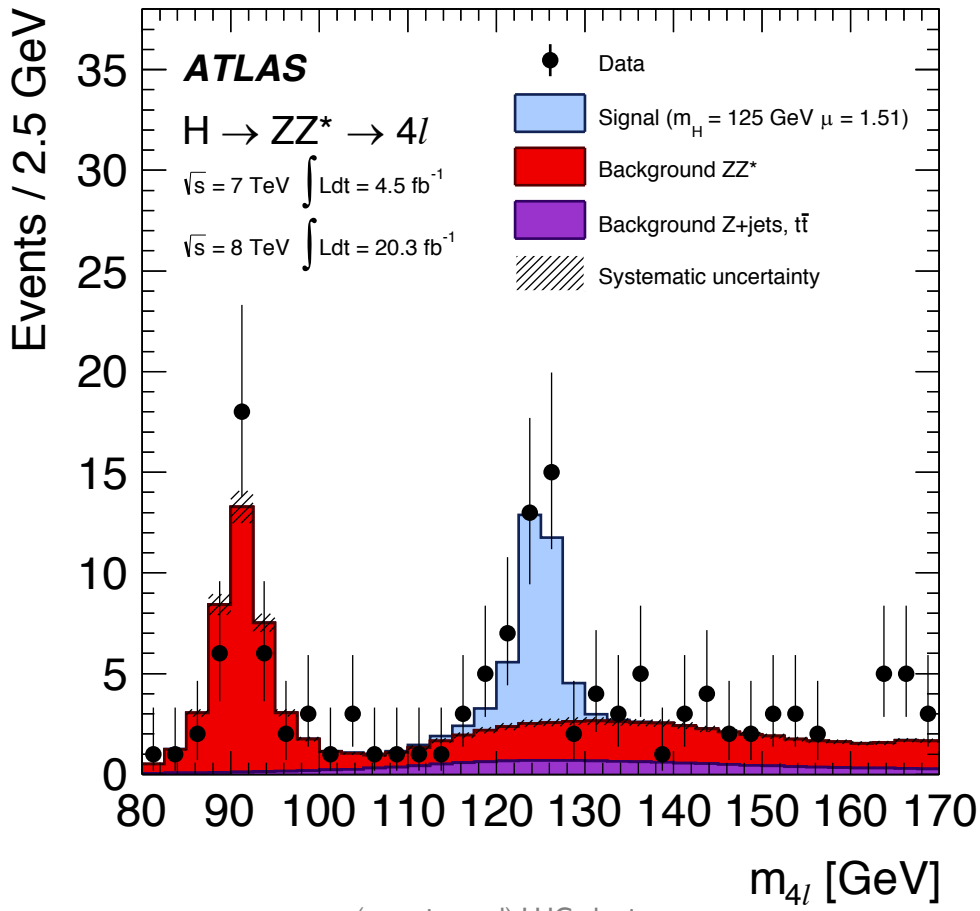
$$M = \sqrt{\left(\sum E_i\right)^2 - \left(\sum \vec{p}_i\right)^2}$$





Extract signal from background

- Background gets estimated…
  - ✓ … from simulation (normalized to data)
  - ✓ … directly from data ("control regions", enriched in background events)



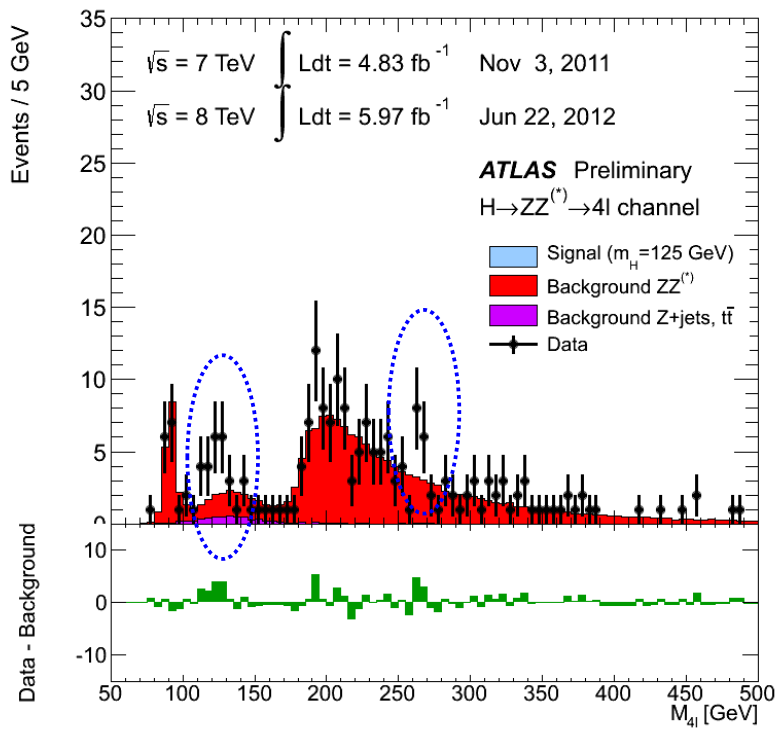
How significant is an excess?

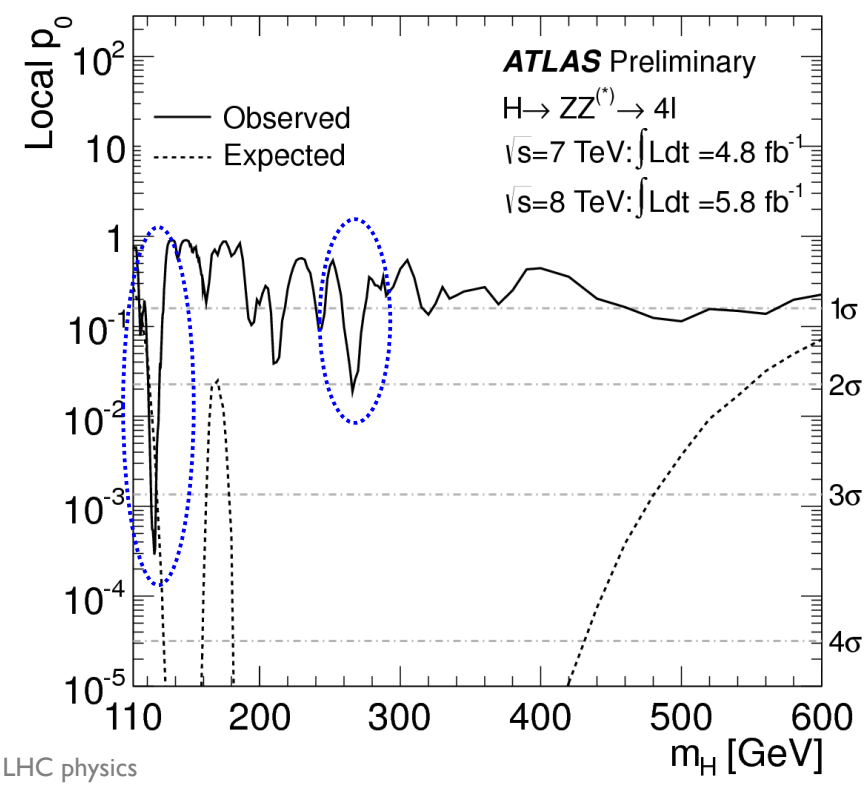
- p0: probability that the excess is due to a fluctuation of background
- Significance:

$$Z \sim \frac{S}{\sqrt{B}} \qquad p_0 = 1 - \mathrm{Erf}\left(\frac{Z}{\sqrt{2}}\right)$$

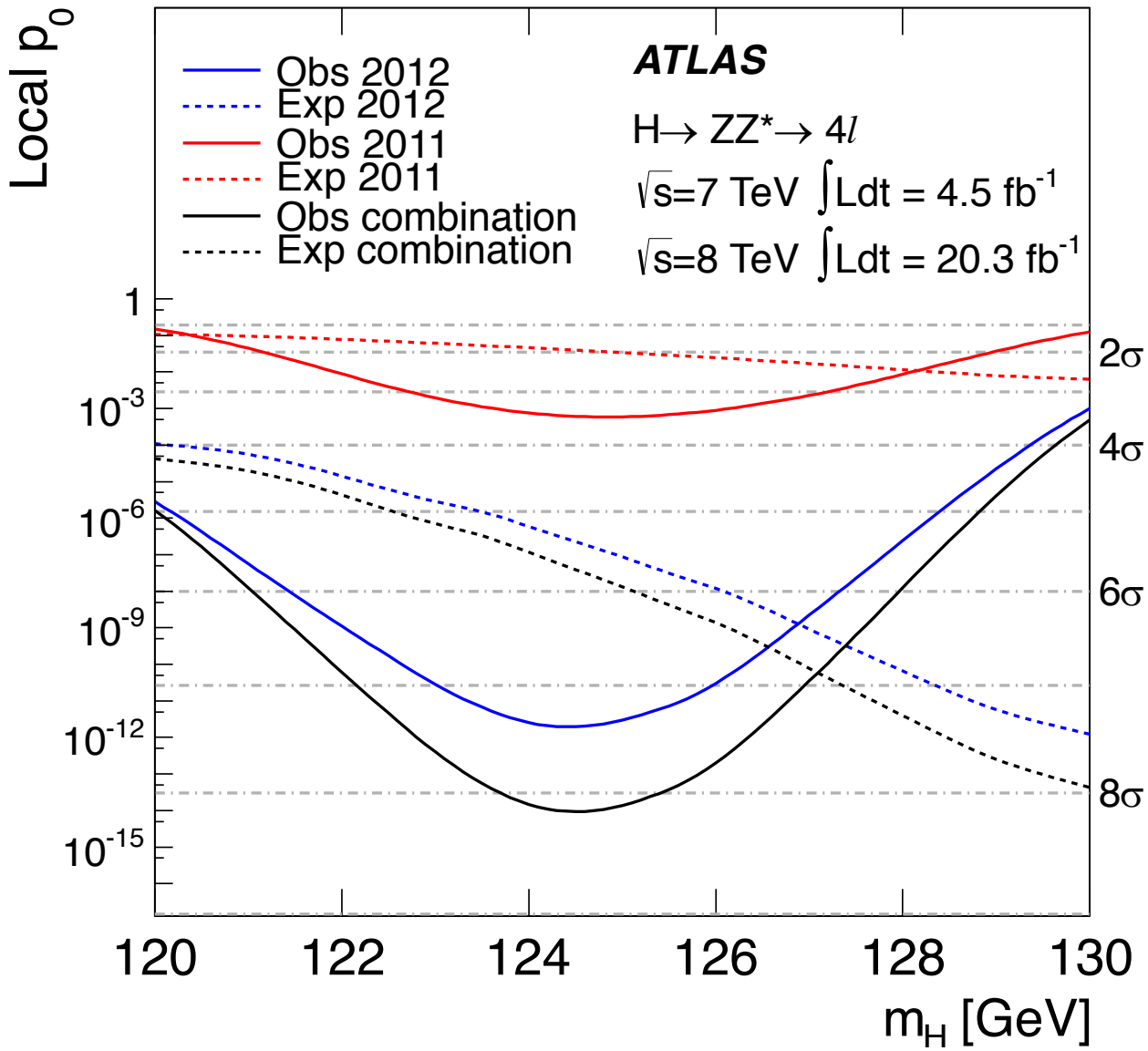
- Convention:
  - 3σ is an evidence (p_0 = 0.27%)
  - 5σ is a discovery (p_0 = $5.7.10^{-7}$)

Erf = Error function

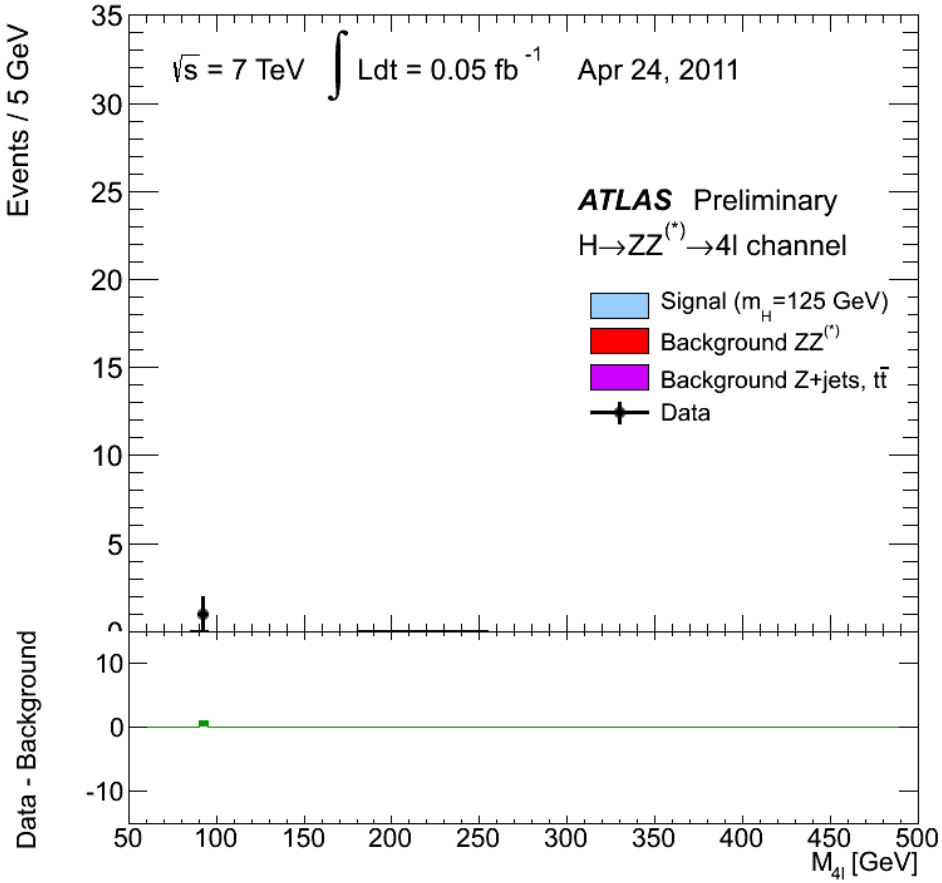


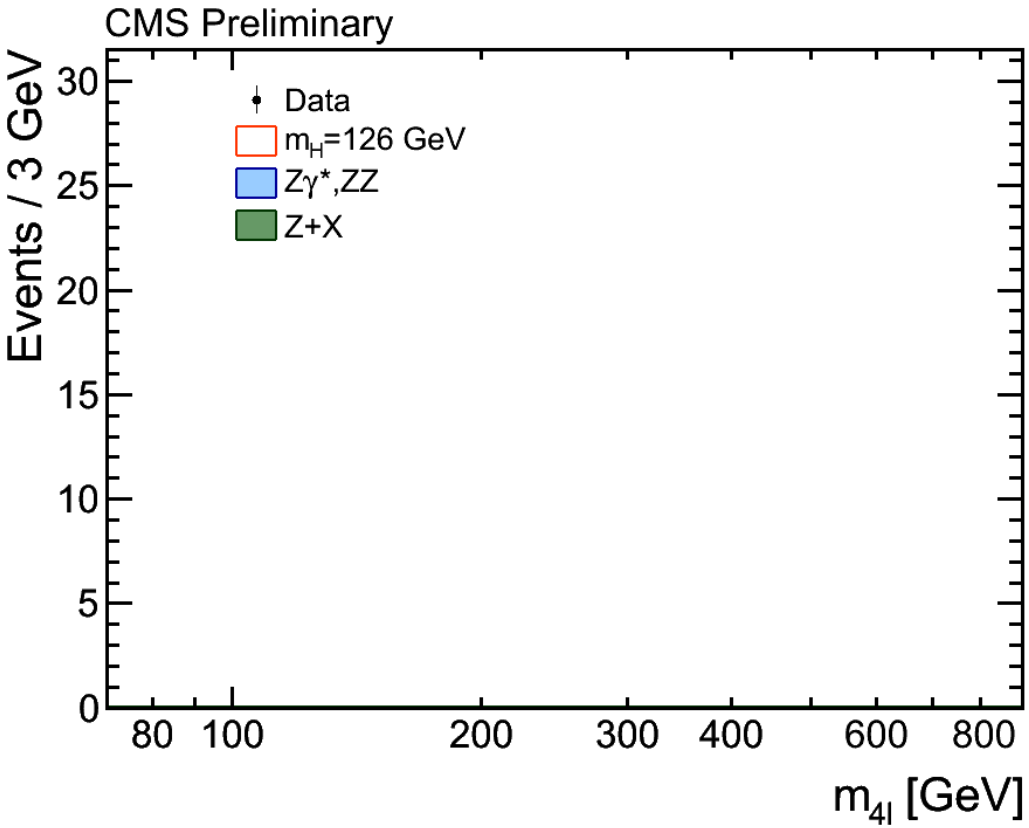


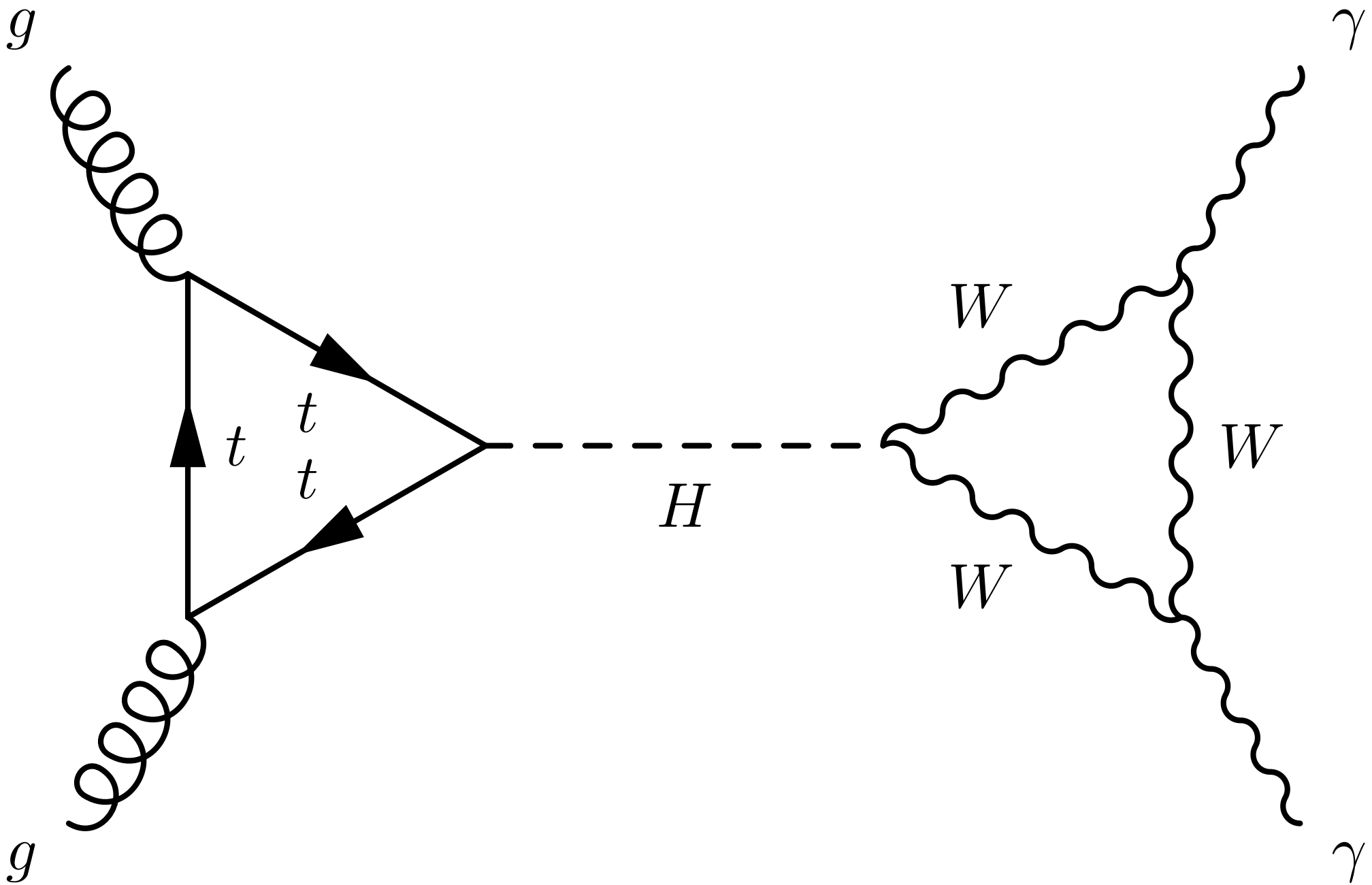
How significant is an excess?



Significance increase with data (and time!)

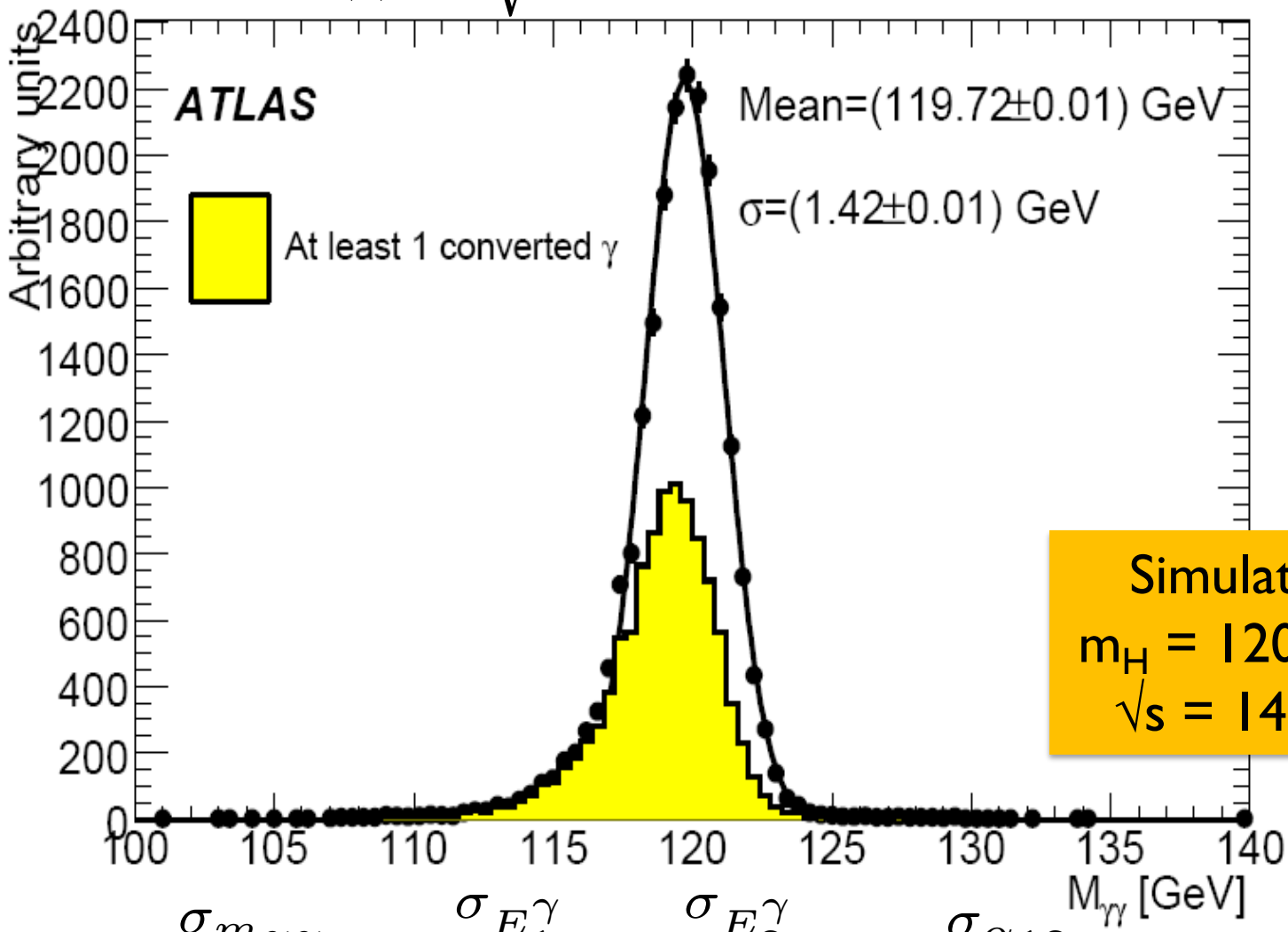





g
g
t
t
t
H
W
W
W
γ
γ

A narrow mass peak…

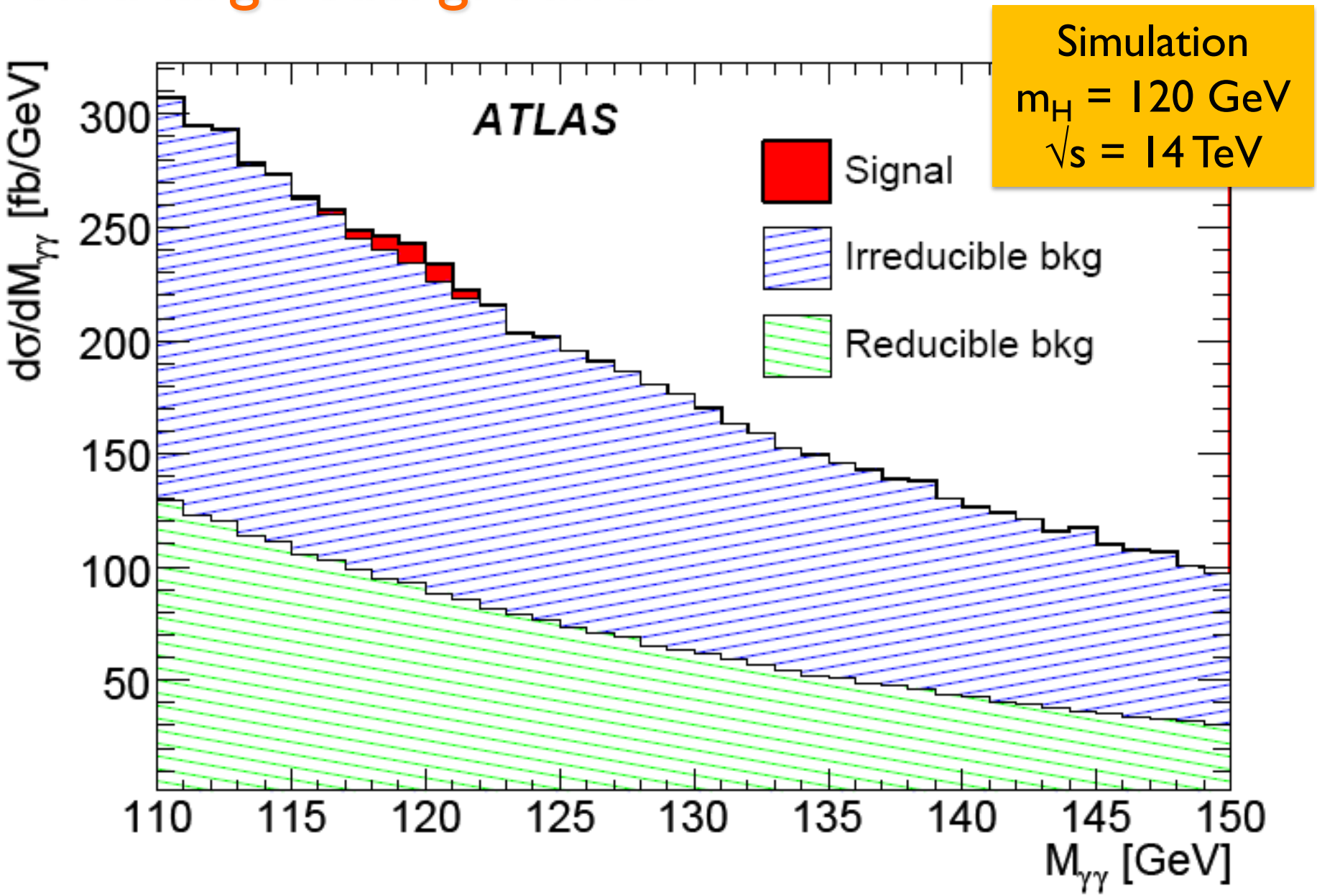
$$m_{\gamma\gamma} = \sqrt{2E_1^\gamma E_2^\gamma (1 - \cos\alpha_{12})}$$



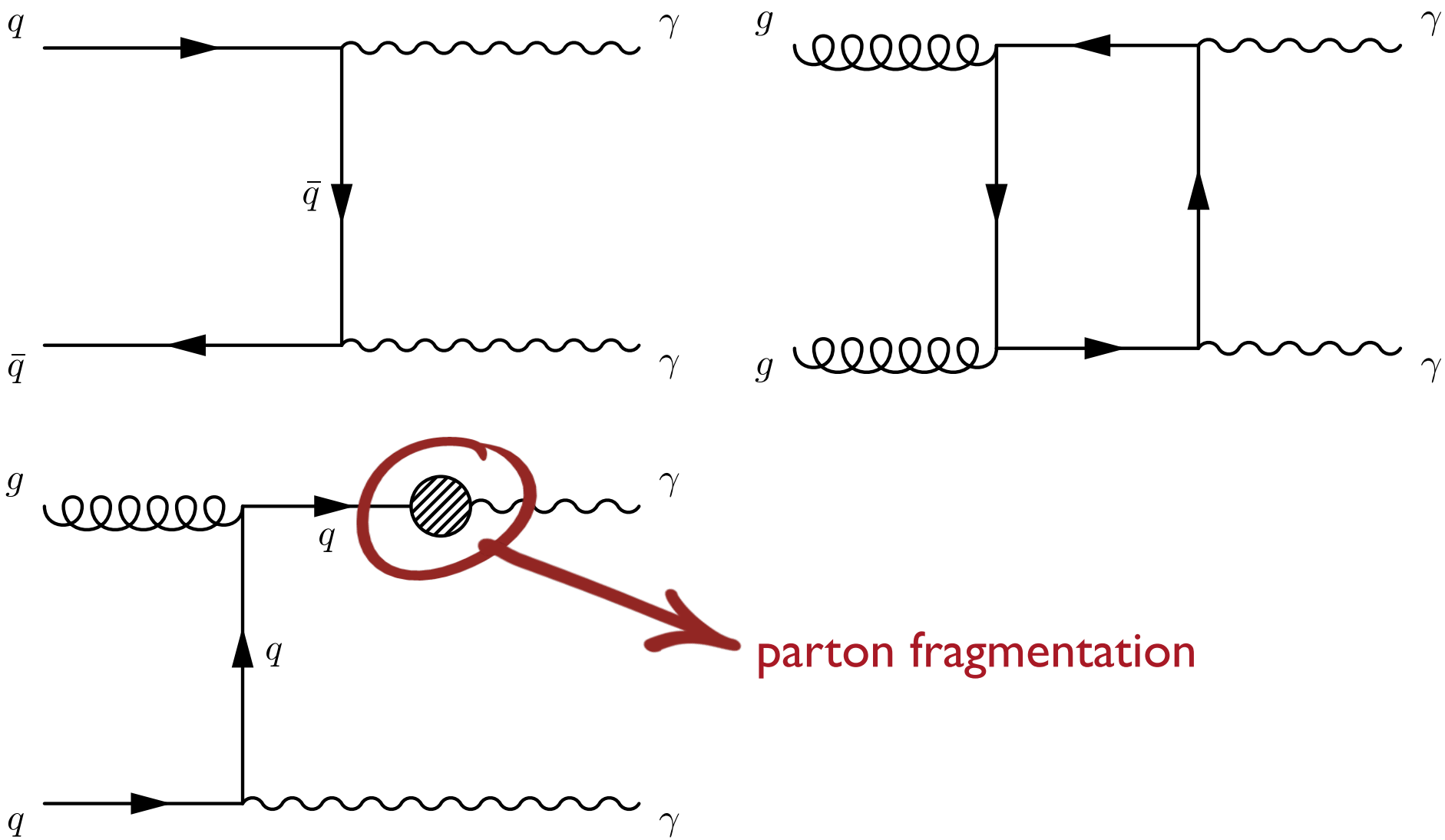
Simulation
m_H = 120 GeV
$\sqrt{s}$ = 14 TeV

$$\frac{\sigma_{m_{\gamma\gamma}}}{m_{\gamma\gamma}} = \frac{\sigma_{E_1^\gamma}}{E_1^\gamma} \oplus \frac{\sigma_{E_2^\gamma}}{E_2^\gamma} \oplus \frac{\sigma_{\alpha_{12}}}{\tan\alpha_{12}}$$

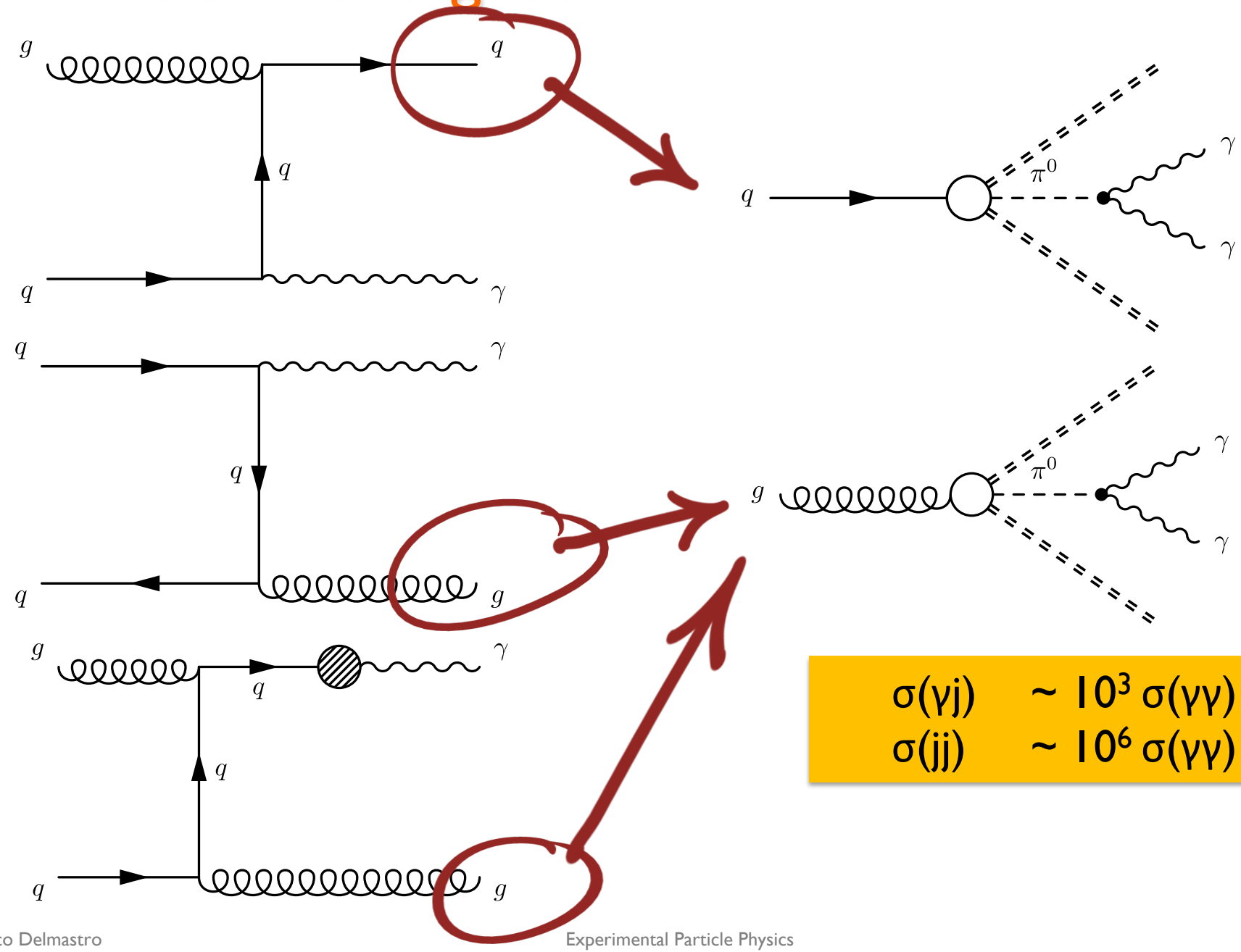
… on a large background!



“Irreducible” background



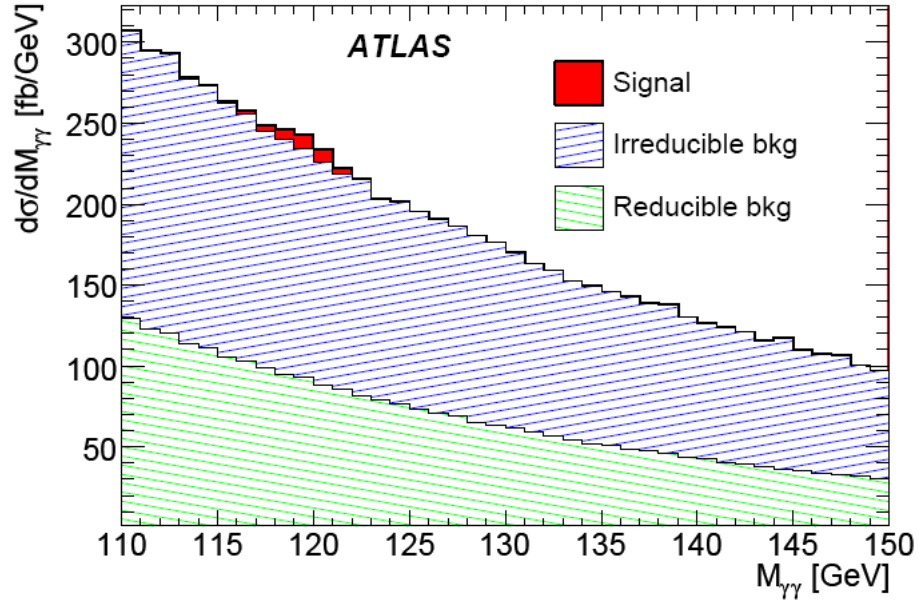
“Reducible” background

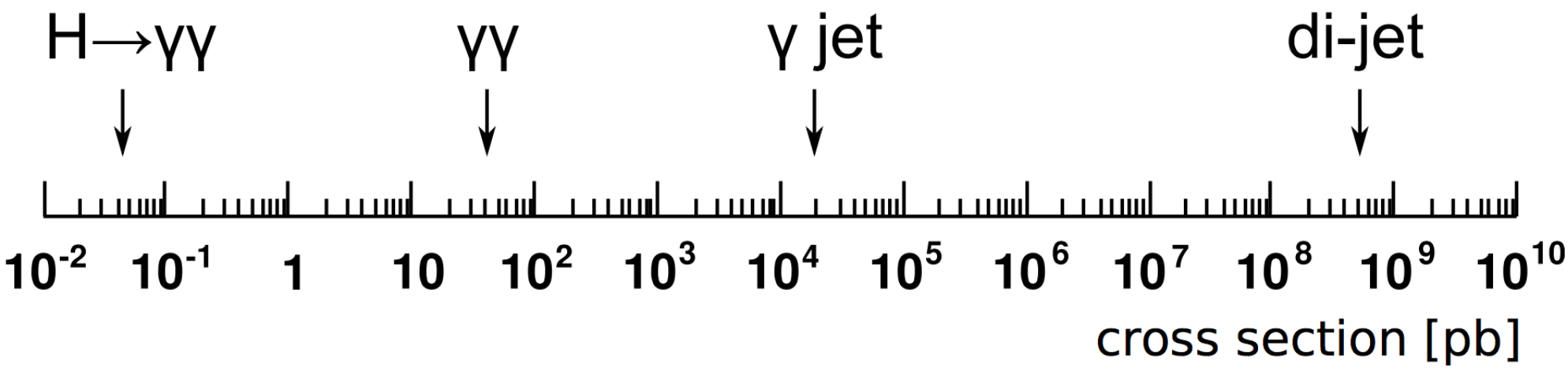


$\sigma(\gamma j) \sim 10^3\, \sigma(\gamma\gamma)$
$\sigma(jj) \sim 10^6\, \sigma(\gamma\gamma)$

Signal vs. background

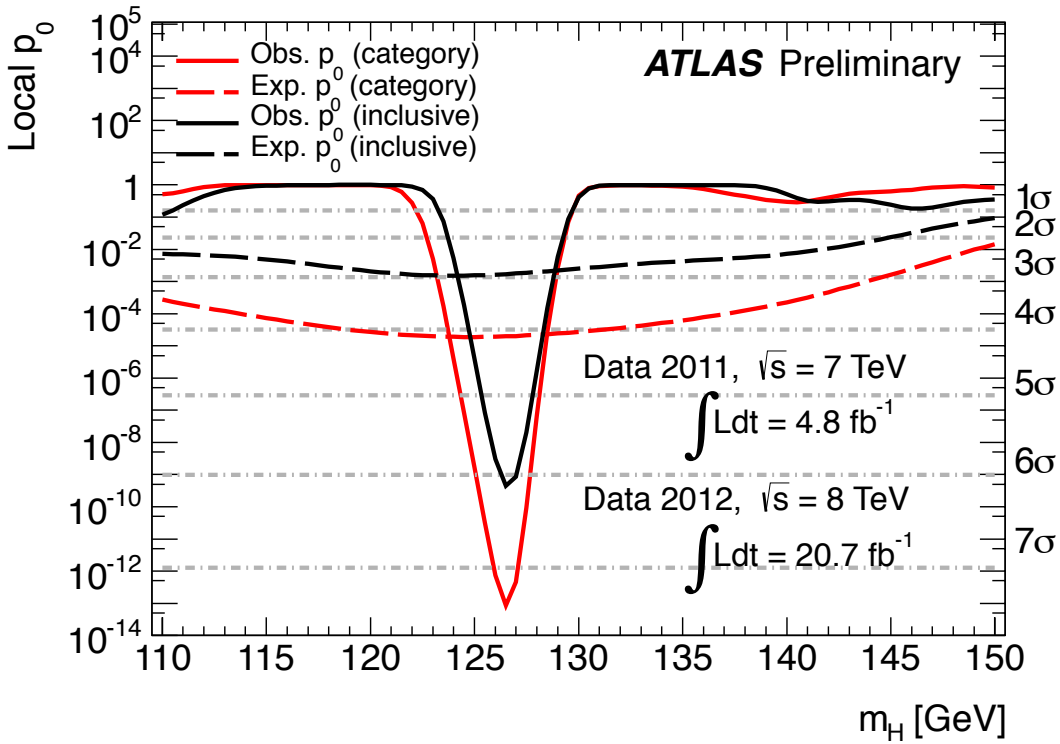
- small branching ratio (~10^{-3})
- huge background
  - ✓ γγ, γj, jj, Drell-Yan
- S/B ~ 3%





H→γγ significance

ATLAS



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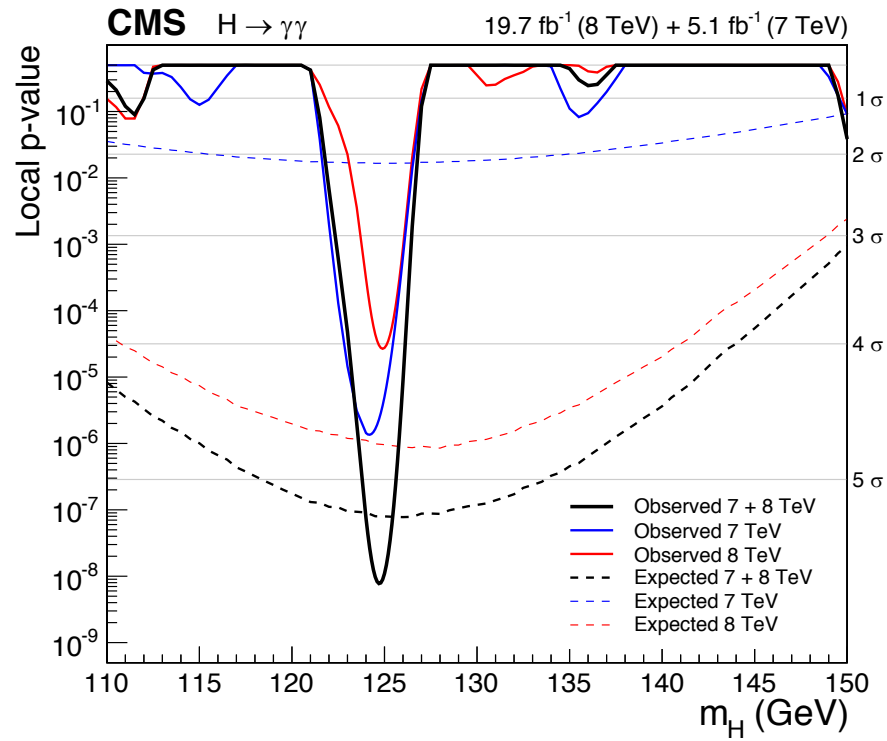

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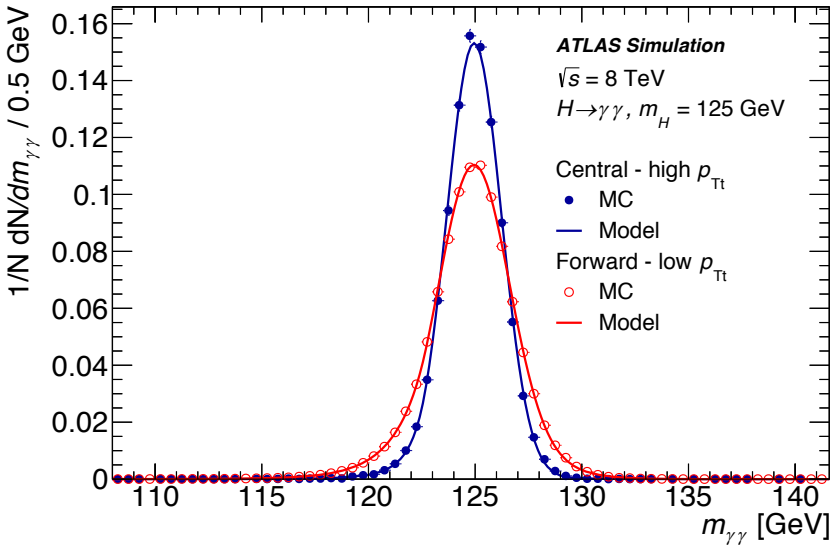
H→γγ invariant mass resolution



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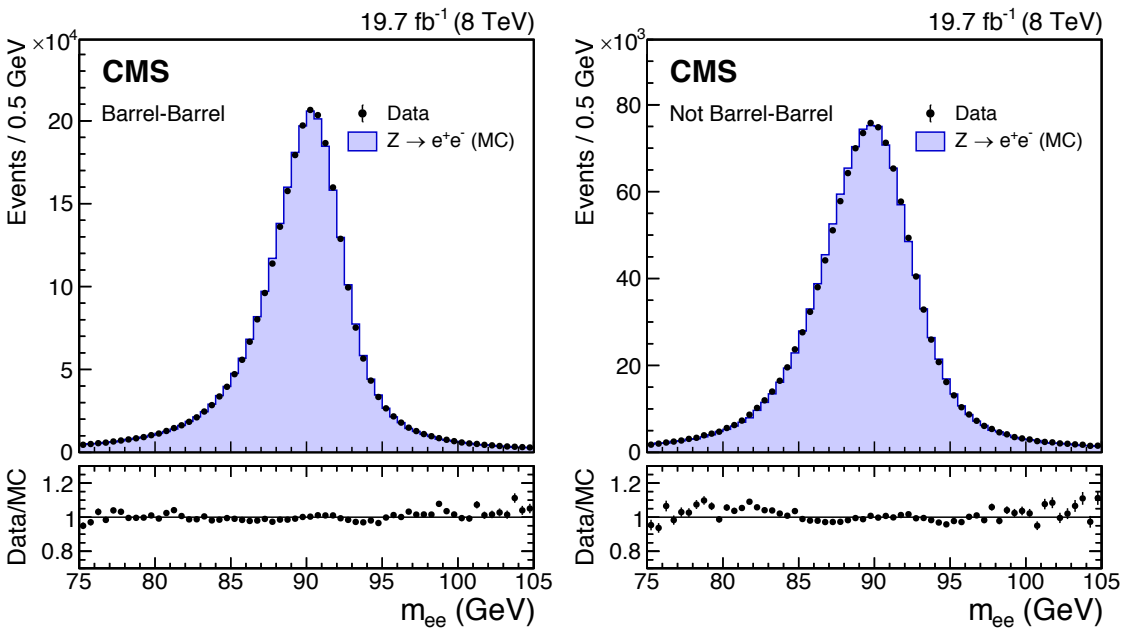
Phys. Rev. D. 90, 112015 (2014)



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H→γγ (weighted) mass spectra

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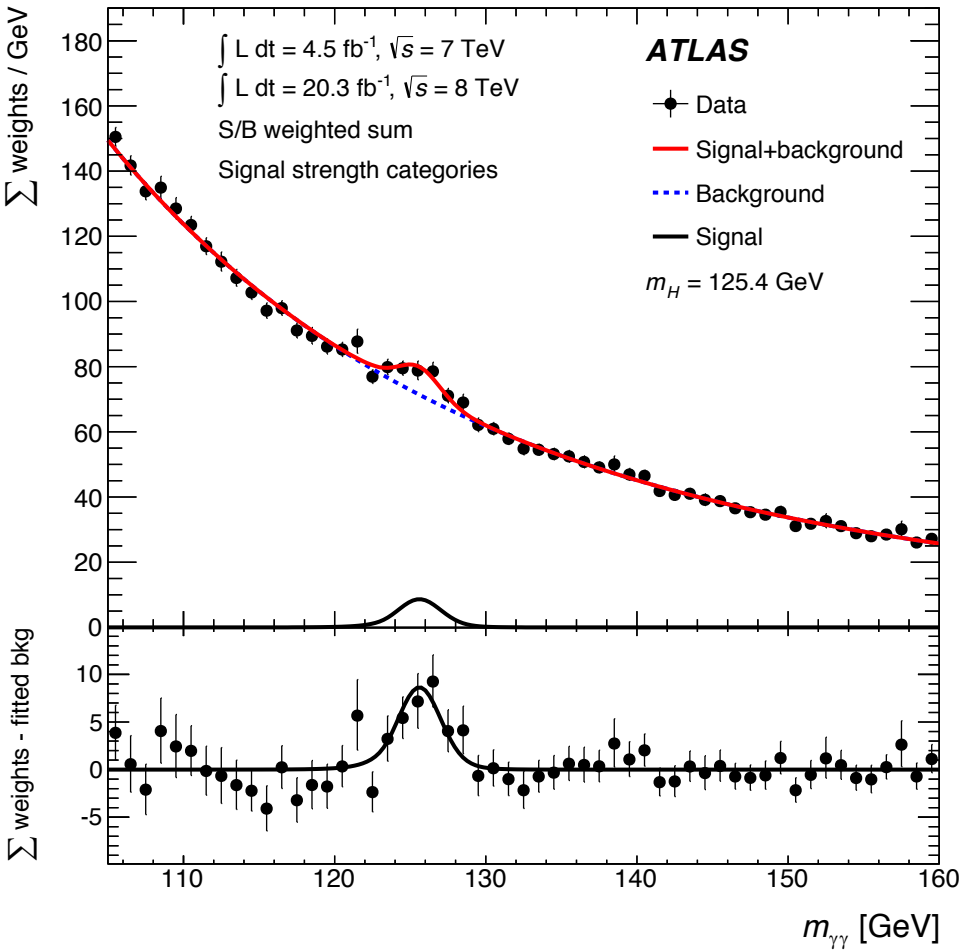

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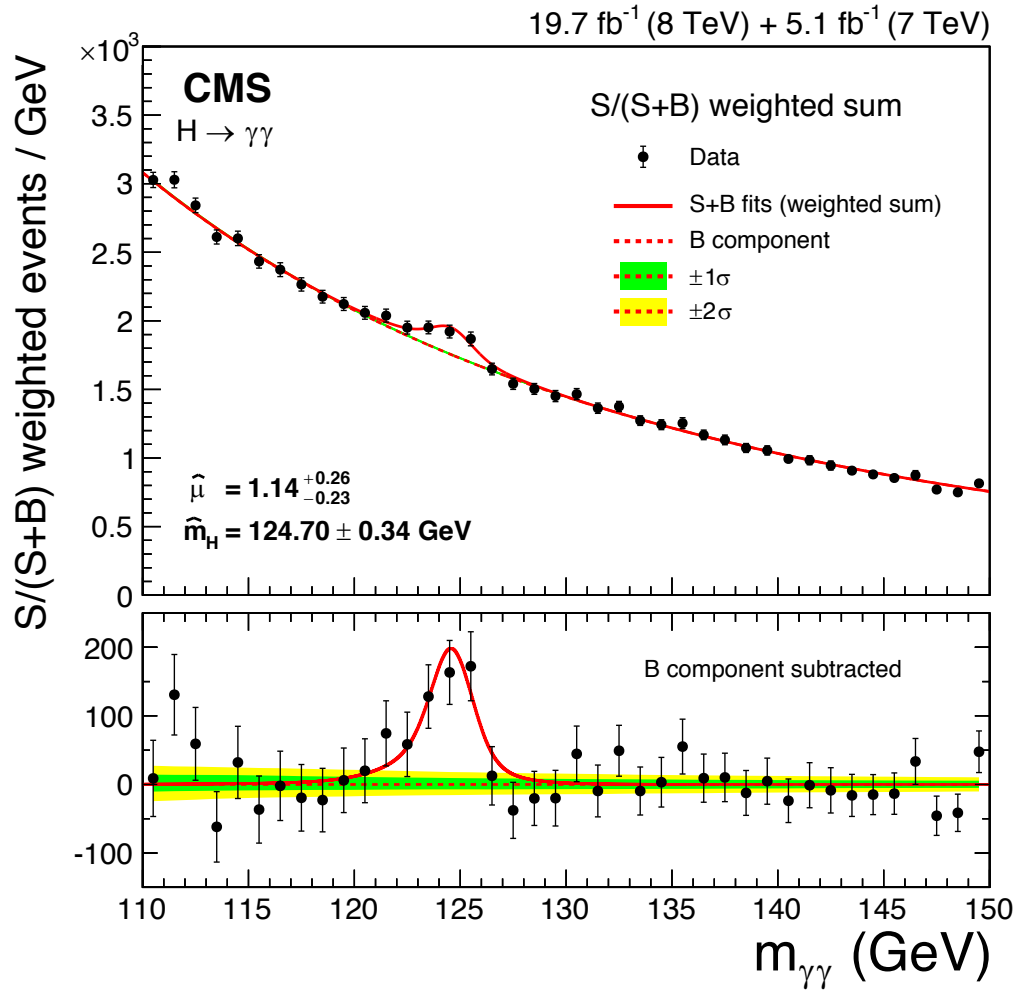

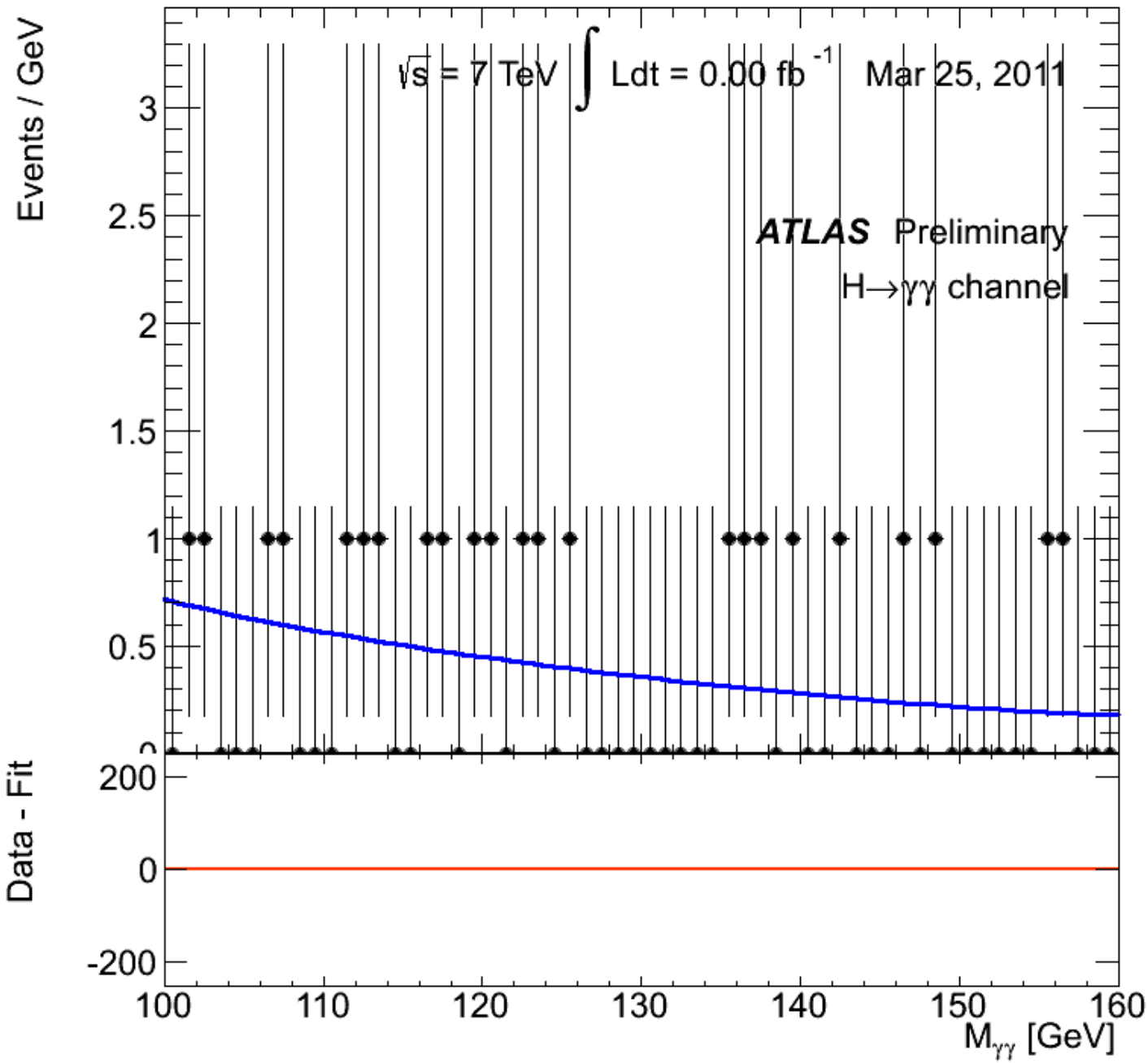
√s = 7 TeV ∫ Ldt = 0.00 fb⁻¹ Mar 25, 2011
ATLAS Preliminary
H→γγ channel
Events / GeV
Data - Fit
M_γγ [GeV]