Search for Heavy Higgs in Higgs→ZZ→4l with ATLAS detector at LHC

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Supervisors: Samira Hassani
Philippe Schune

July 7 2016

Introduction

- **The work is done in scope of ATLAS experiment at CERN using Large Hadron Collider proton proton collisions**

In context of NSW

- Qualification task: cavern background simulation for NSW - finished
- Software development for ATLAS Muon Spectrometer - in progress
- Cosmic bench for Micromegas commissioning at Saclay - in progress

In context of Physics analysis

- ZZ cross section measurement at 13 TeV - finished
  http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.116.101801
- H→4l analysis at 13 TeV: - in progress
  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2015-059/
  - SM Higgs measurements
    (background estimation & mass measurements)
  - Heavy Higgs search

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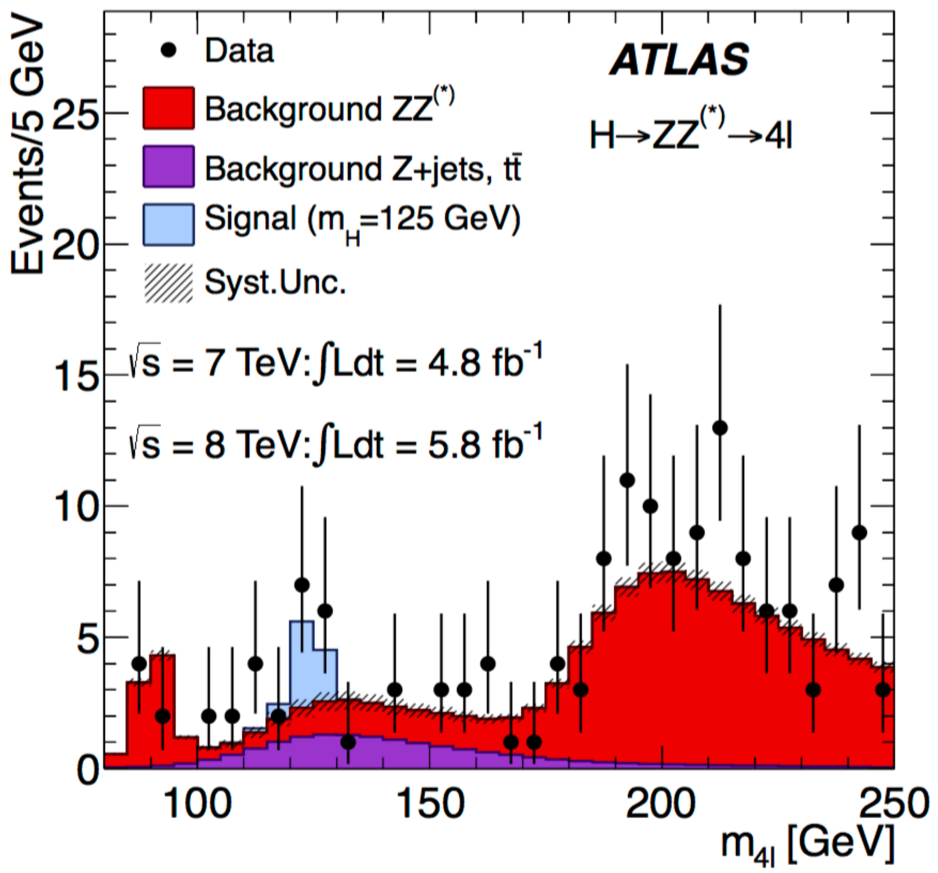
Higgs Boson

Higgs discovery in Run 1



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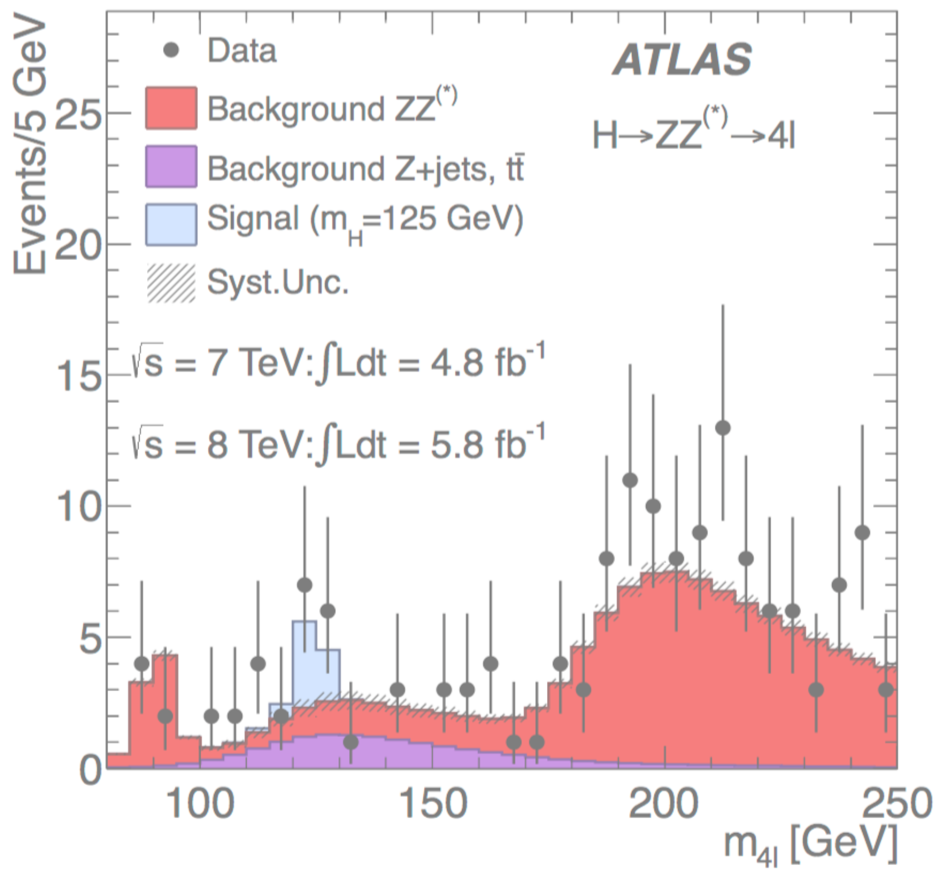
Higgs Boson

Higgs discovery in Run 1



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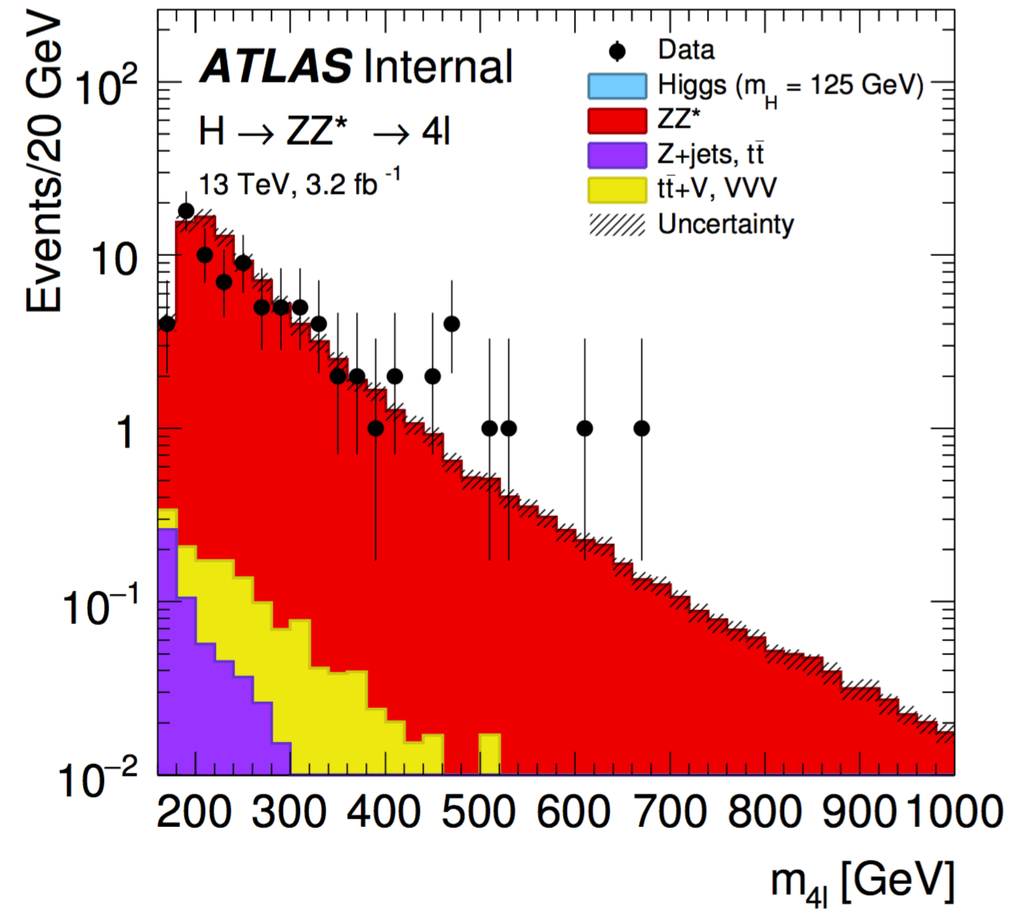
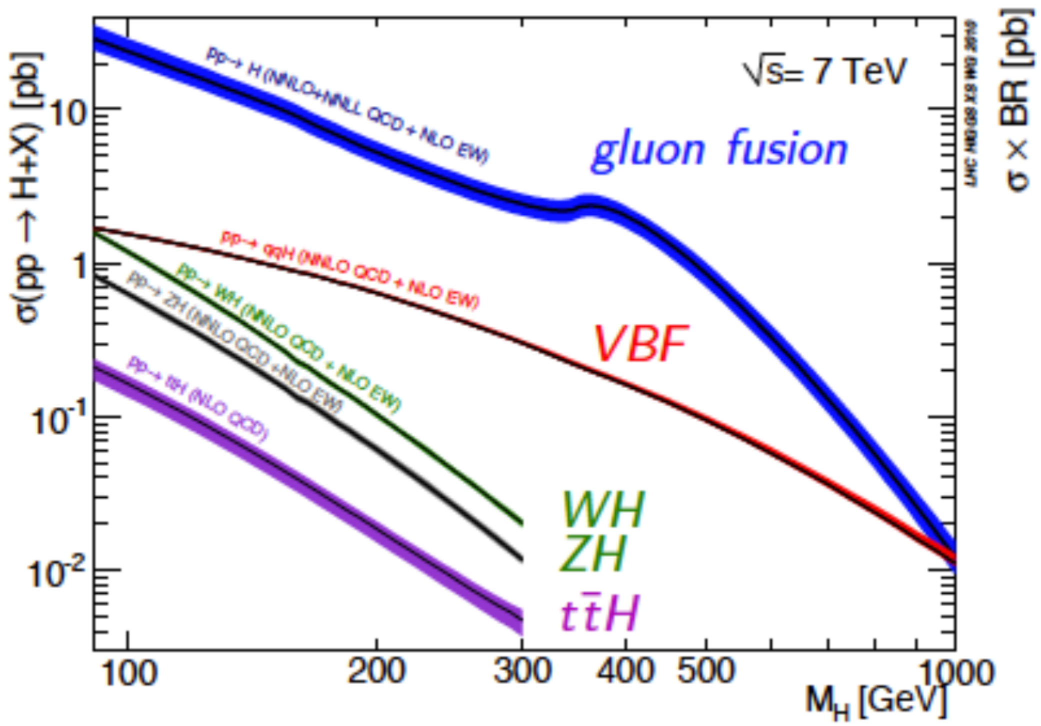
Heavy Higgs search in Run 2



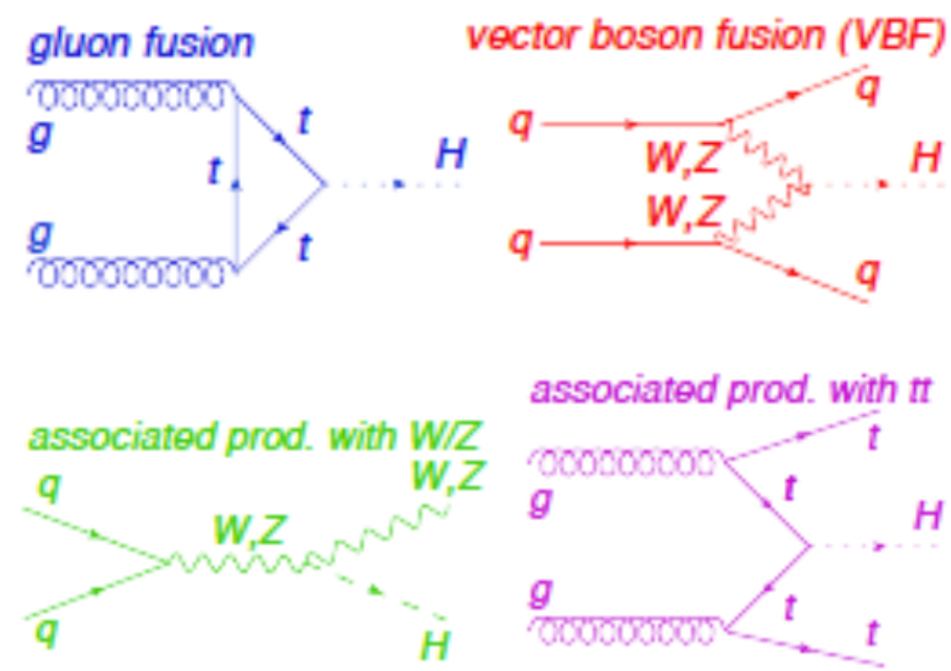
- But some models (EWS, 2HDM, hMSSM …) predict other Higgs bosons at higher masses
- We are currently doing a search for the Heavy Higgs boson
  - if we find it, we have to study its properties
  - if we do not, we have to put an upper limit

Heavy Higgs-like boson search

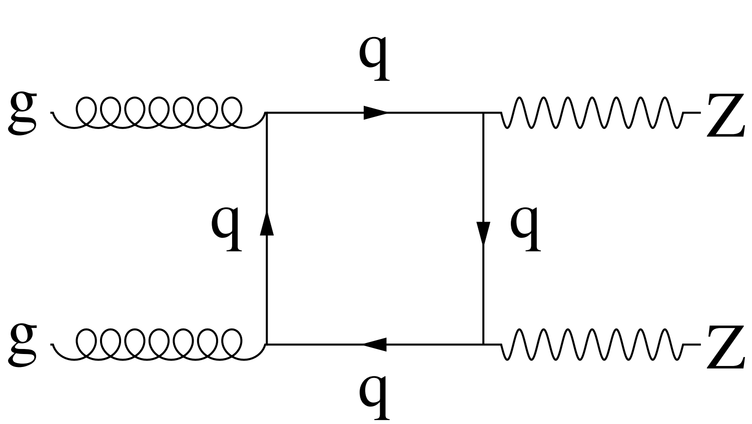
- **Search for additional heavy Higgs-like scalar boson in H→ZZ→4l decay channel**

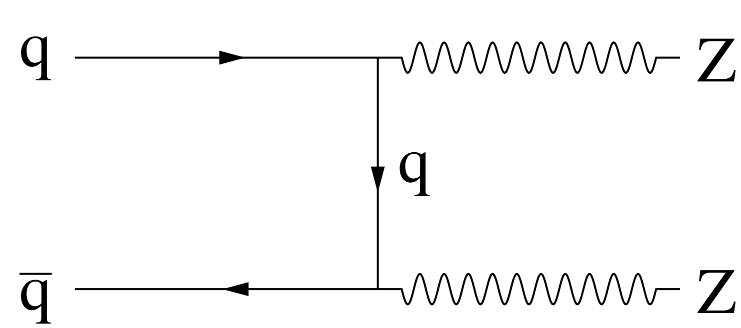


Signal



Background





and other minor processes

Heavy Higgs-like boson search

- **Contributions to two different analyses on search for additional heavy Higgs-like scalar boson in H→ZZ→4l decay channel**

  Preliminary results: Conf note
  (Winter Conference 2015)

- Mass range:
  200 GeV < m_{4l} < 1000 GeV

- Based on Run 2 13 TeV data
  (3.2 fb^{-1})

- Use simplified model as model independent as possible:
  - Inclusive production mode is chosen due to limited statistics
  - Narrow Width Approximation
  - Signal-Background interference can be neglected

Heavy Higgs-like boson search

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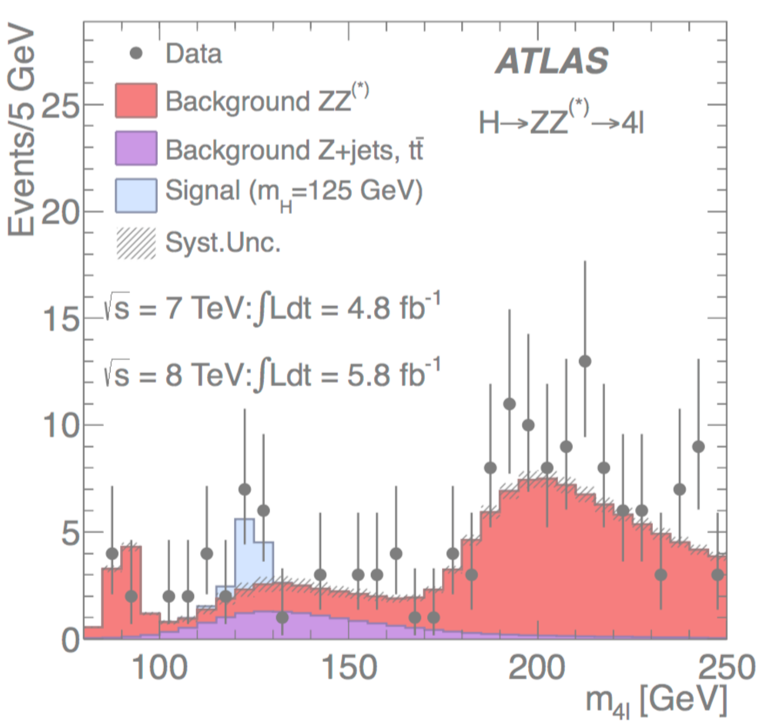
Next results:
(Summer Conference 2016)

- Mass range:
200 GeV < m_{4l} < 1000 GeV
- Based on 2015 & early 2016 13 TeV data
($3.2 + \sim 10\ fb^{-1}$ expected)
- Use more sophisticated model:
  - Add categories for ggF and VBF production modes
  - Large Width Approximation
  - Treatment of interference will be common within the Higgs high mass analysis

Components

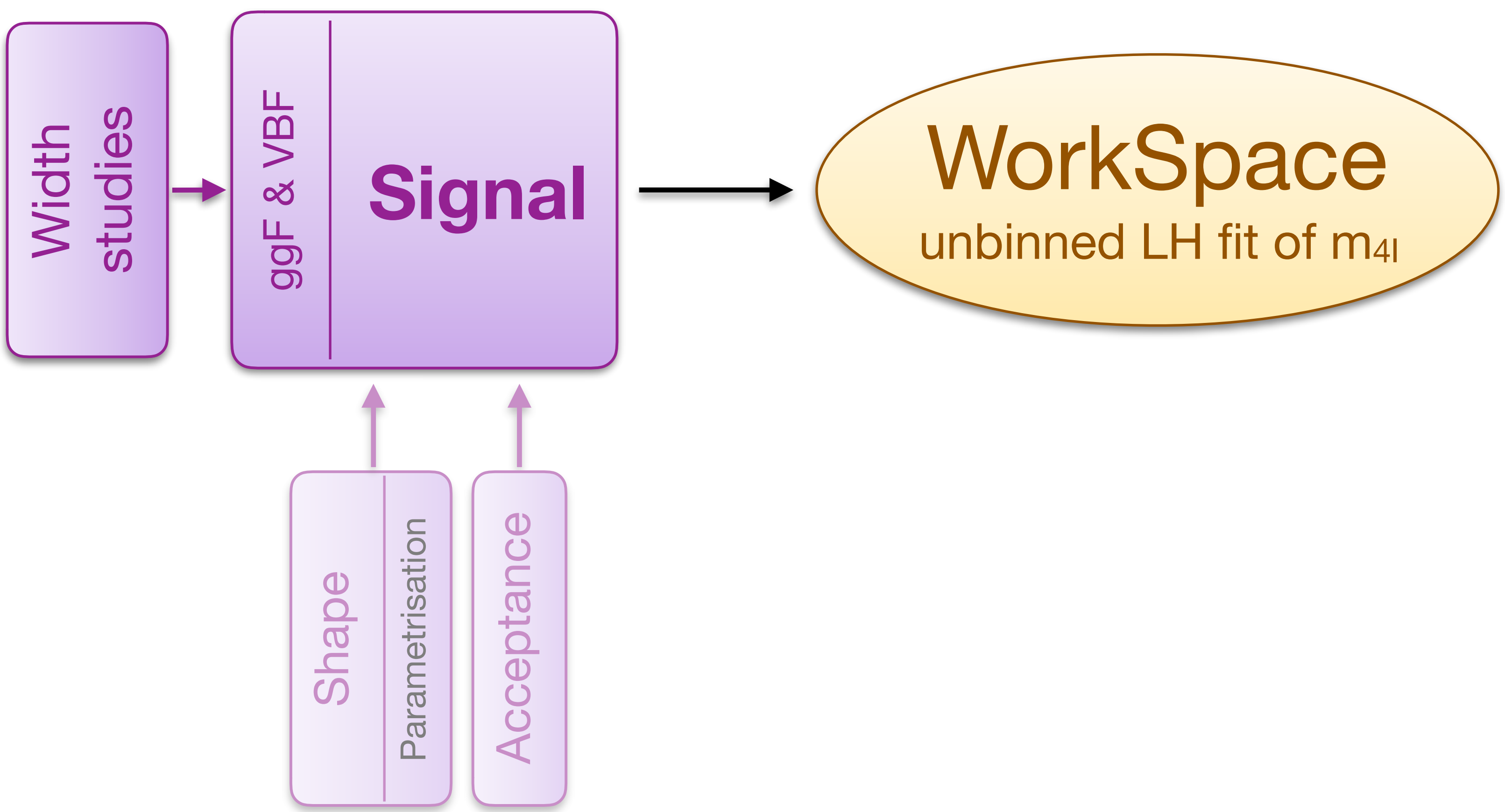
WorkSpace

unbinned LH fit of m_{4l}



Use sophisticated statistical tools for unbinned maximum likelihood fit of data

Components


Width studies
ggF & VBF
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unbinned LH fit of m_{4l}
Shape
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Acceptance

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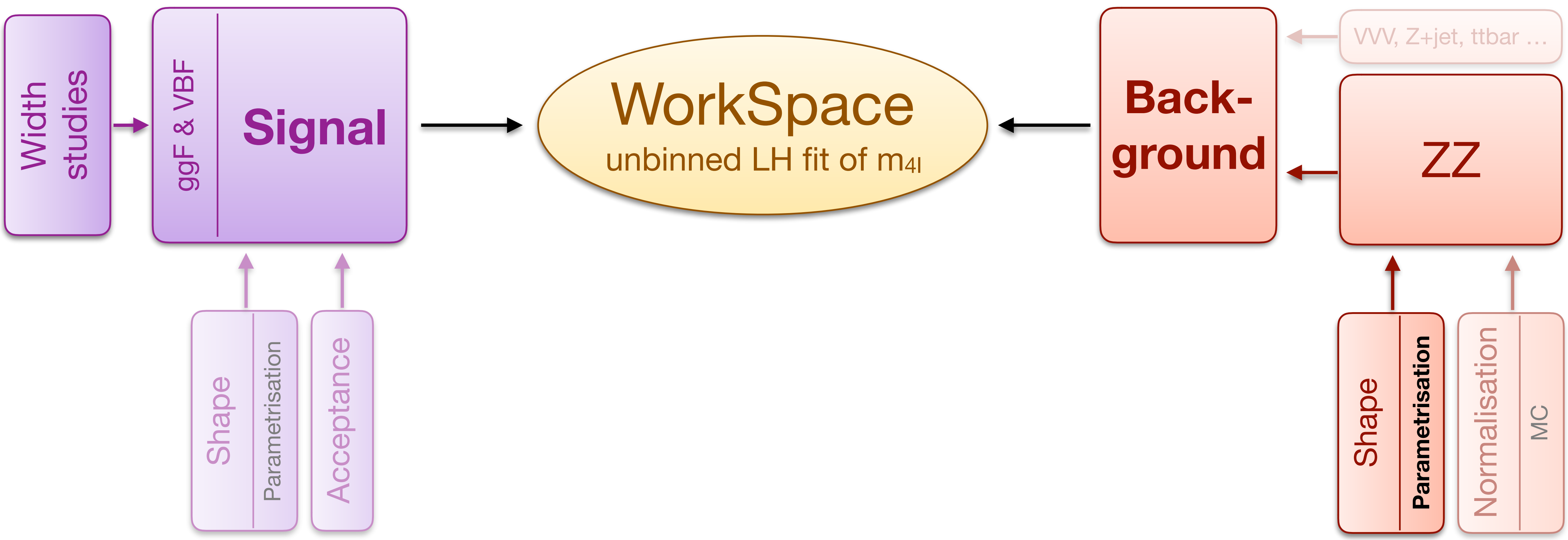

Width studies
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Back-ground
VVV, Z+jet, ttbar …
ZZ
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Normalisation
MC

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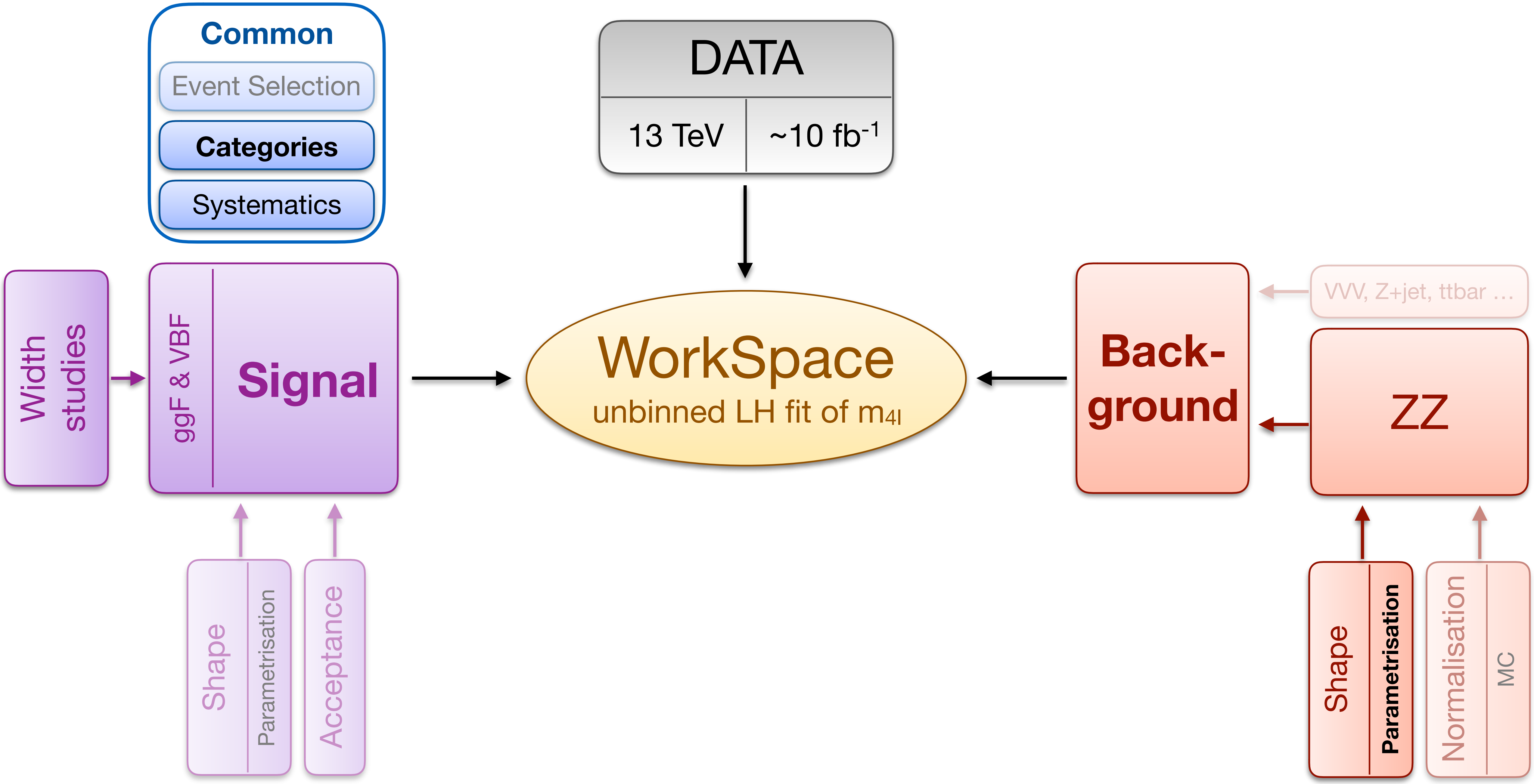

Common
Event Selection
Categories
Systematics
DATA
13 TeV
~10 fb-1
Width studies
ggF & VBF
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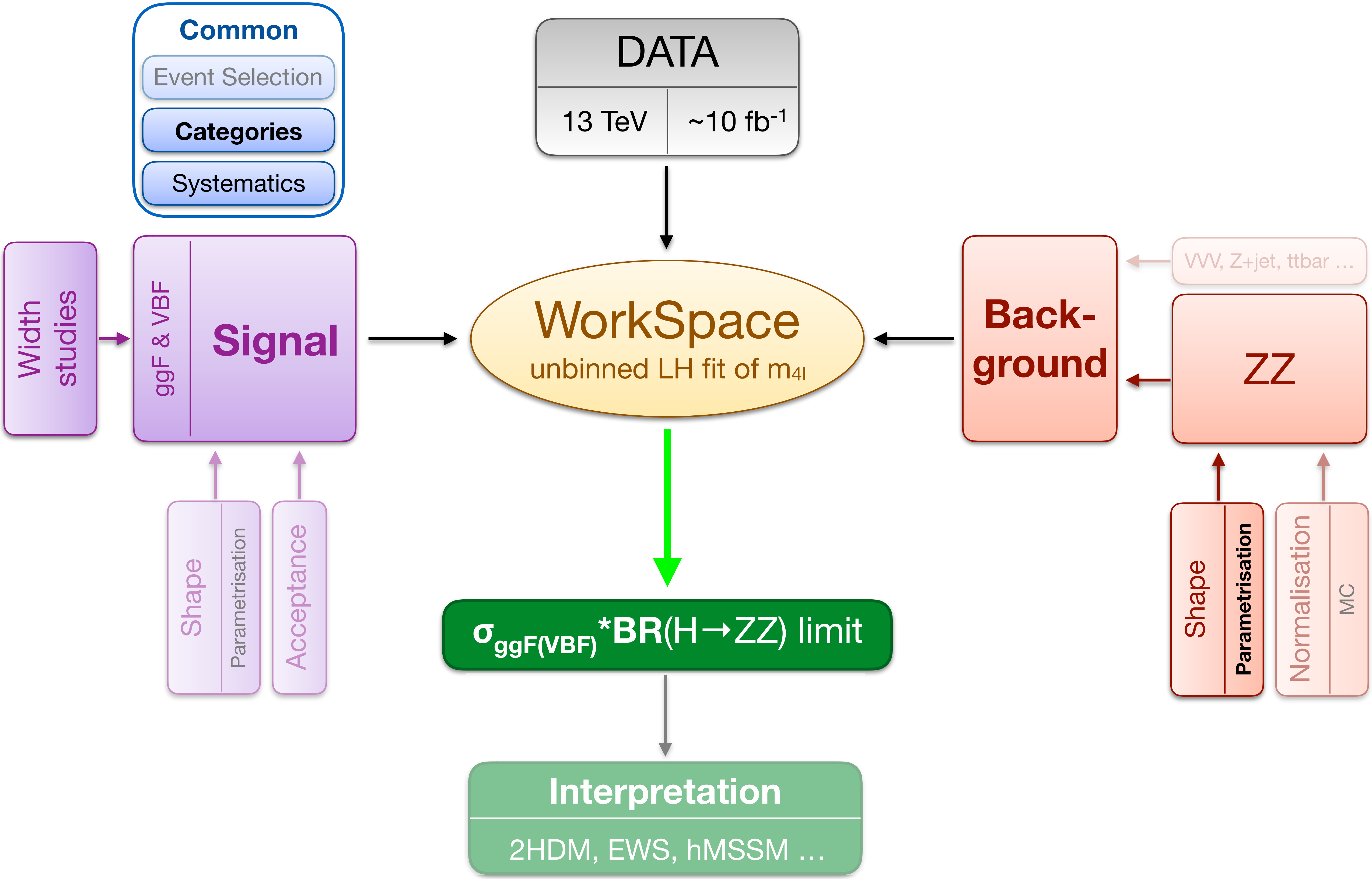

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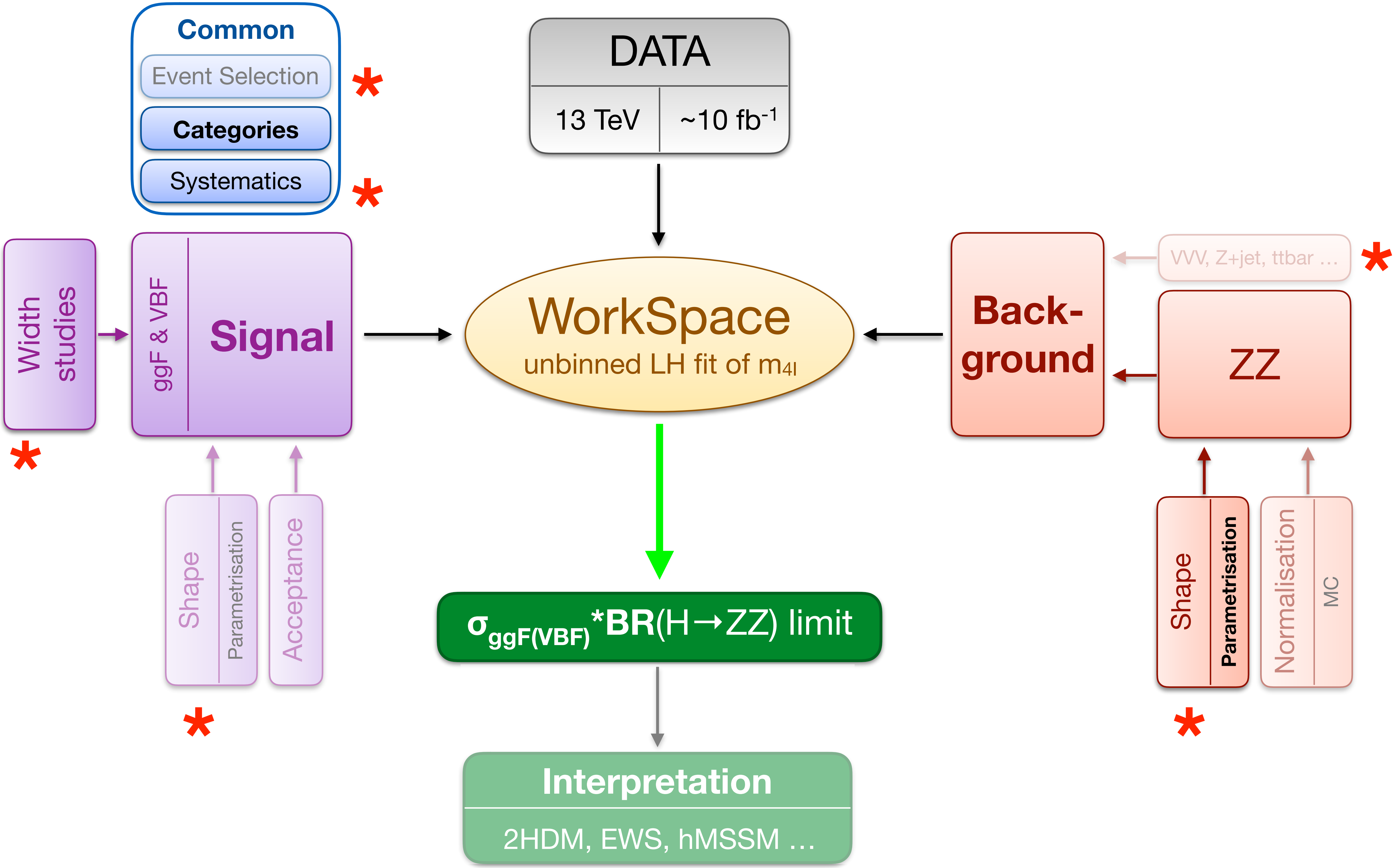
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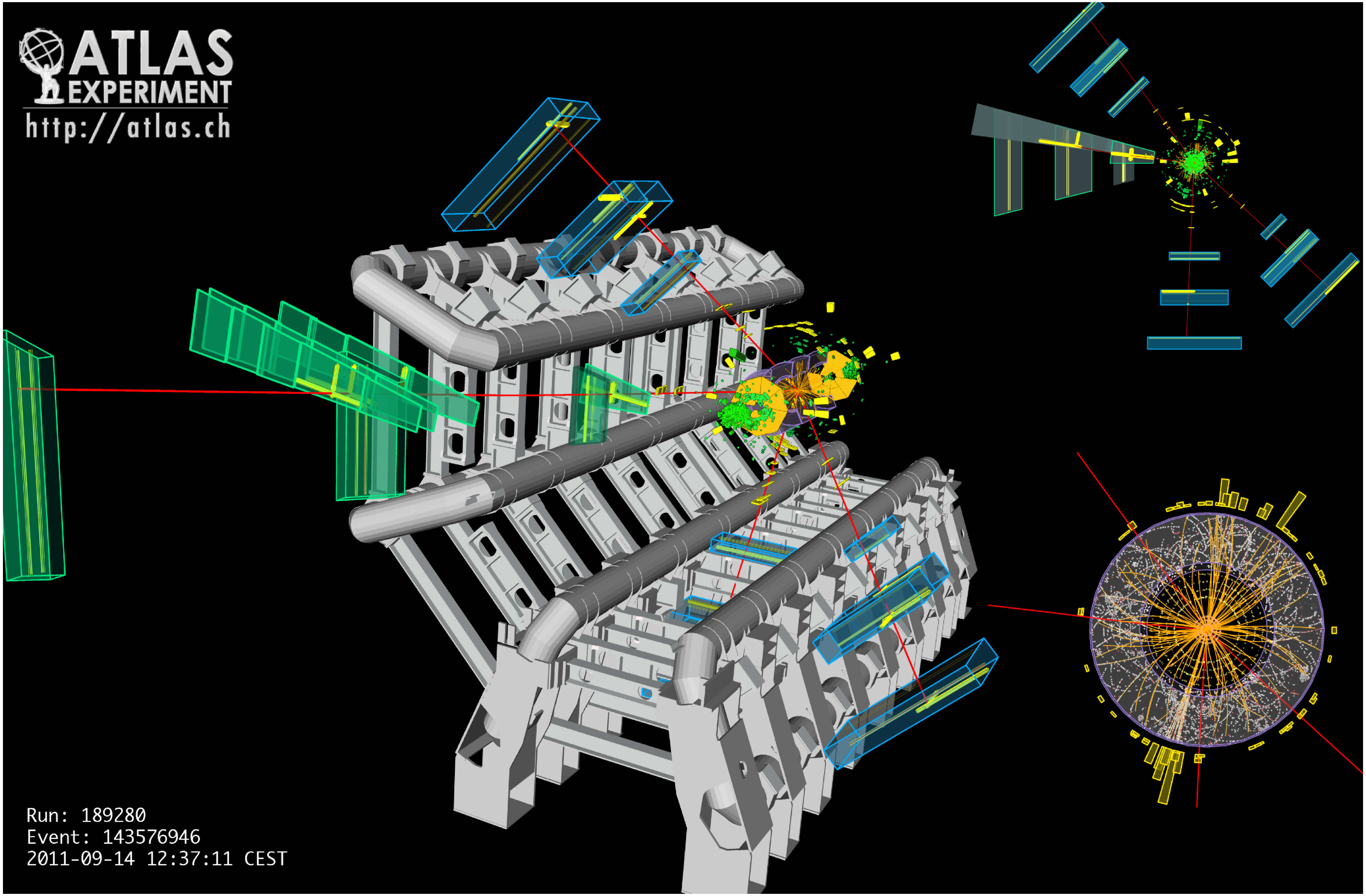

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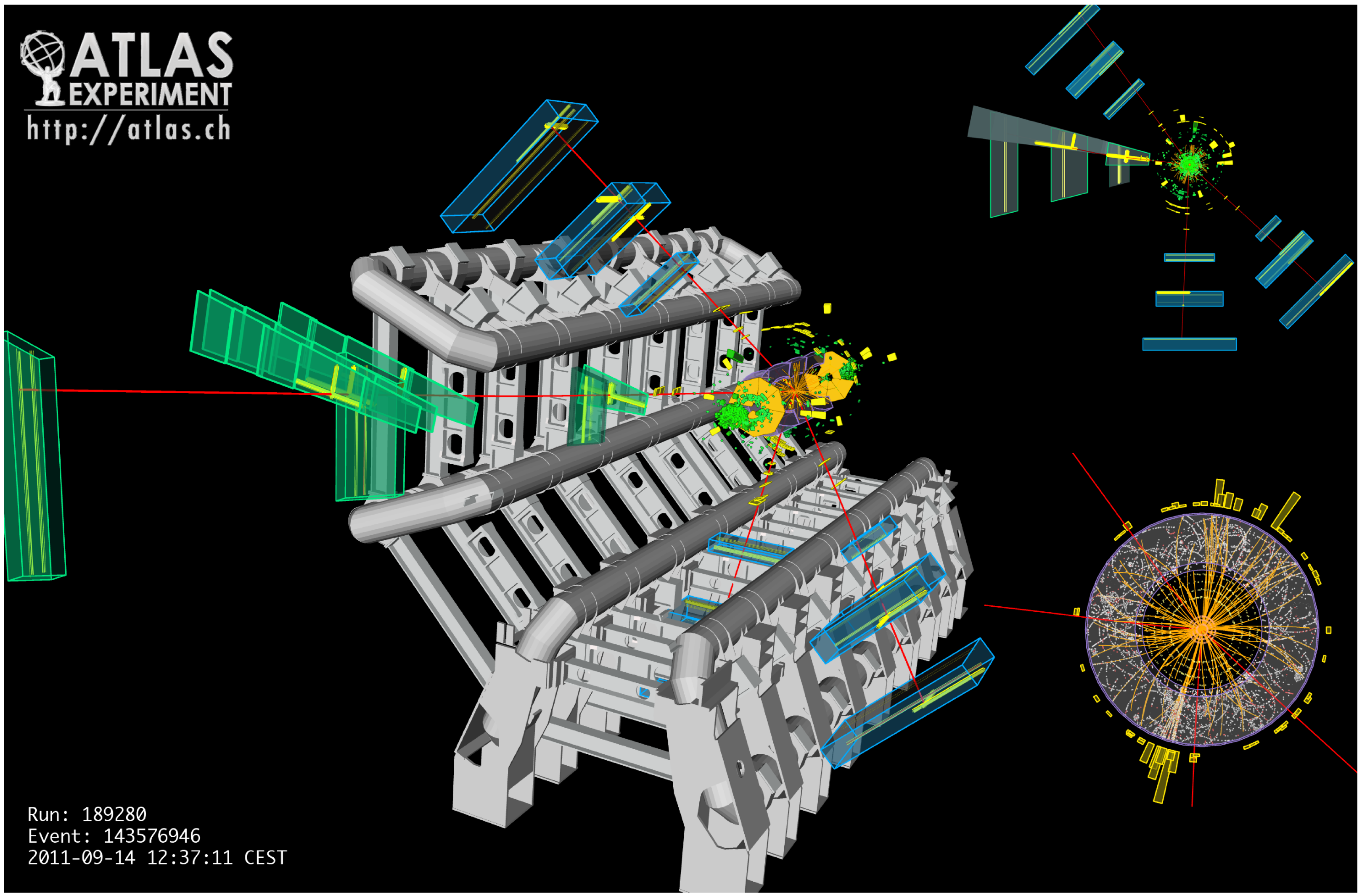


Event selection:

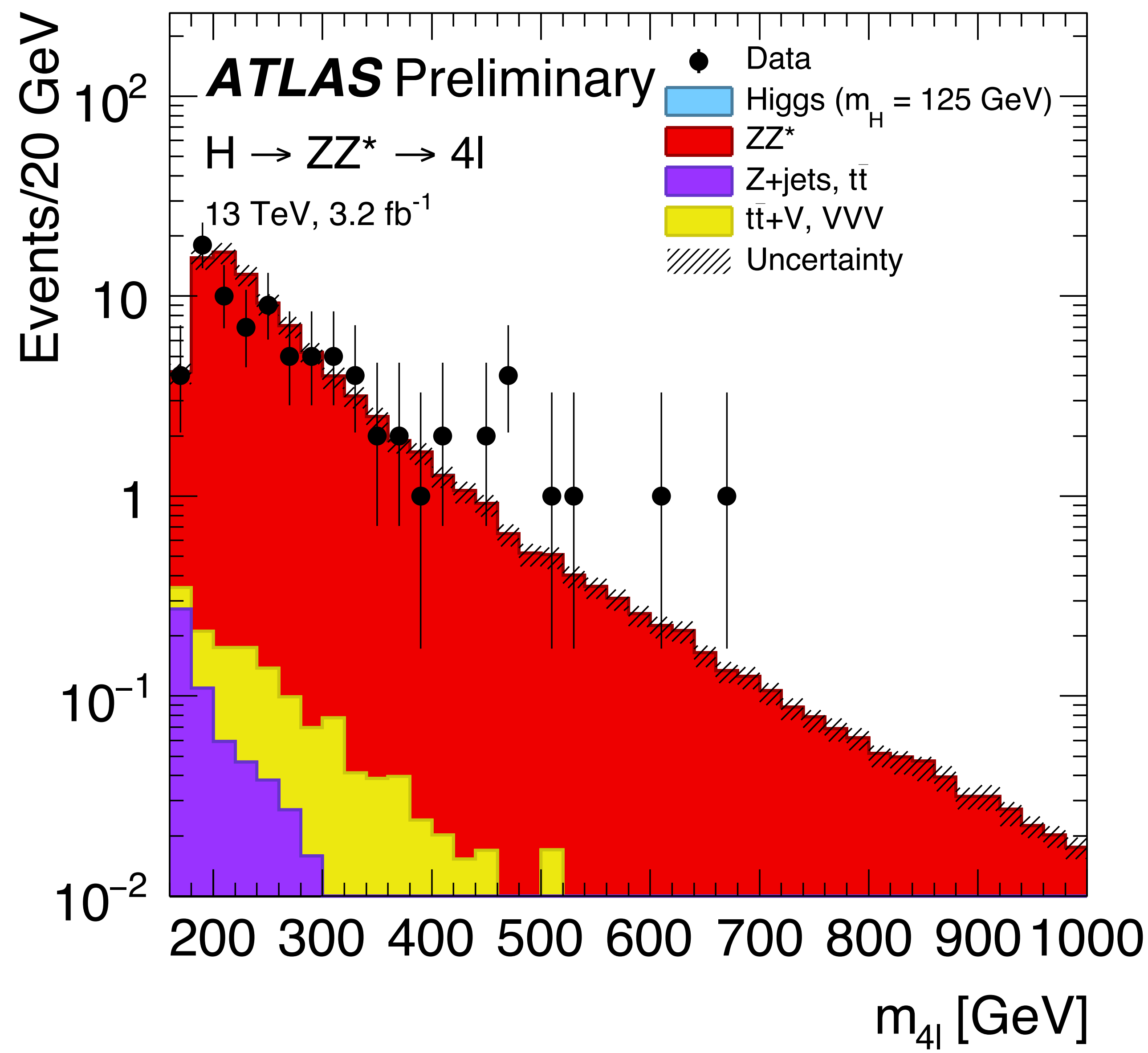
- At least 4 leptons in the event that have p_T above the threshold (20,15,10,5(6) GeV)
- All leptons should be reasonably isolated from other particles (lepton is not coming from jet)
- All leptons have small impact parameter (point to a primary vertex)
- Two opposite sign same flavour lepton pairs are required (ZZ like lepton quadruplet)
- Invariant masses of both leptons pairs are close to Z boson mass
- J/Psi veto

Background

See next slide

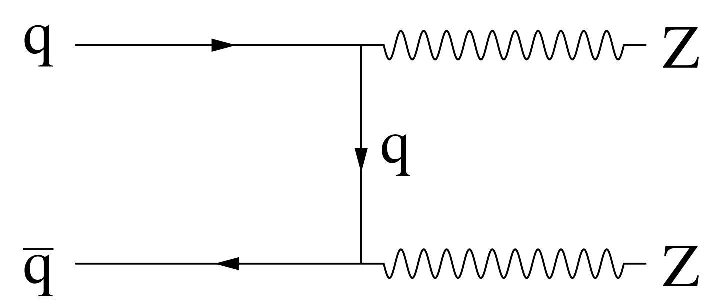
- **Dominant irreducible background:**
  - **SM ZZ** production
  - important within whole mass range
  - estimated from MC
- **Other irreducible background:**
  - **VVV**, **ttbar+V**
  - contributing at intermediate mass
  - estimated from MC
- **Reducible background:**
  - **Z+jet**, **ttbar**
  - fake leptons are mainly originated by jets
  - important only at low mass
  - * estimated with Data Driven methods

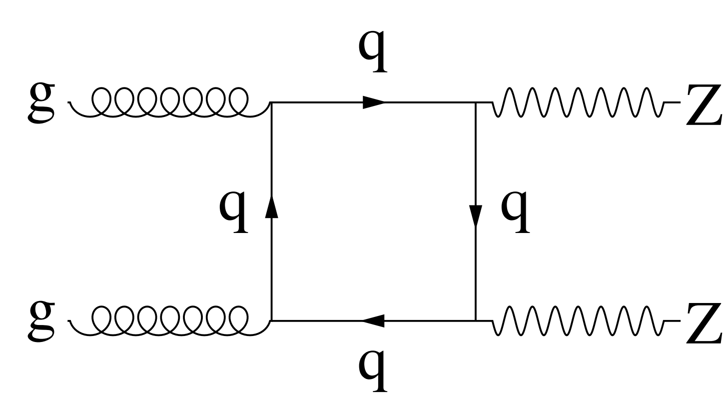
More details in the back up



ZZ Background

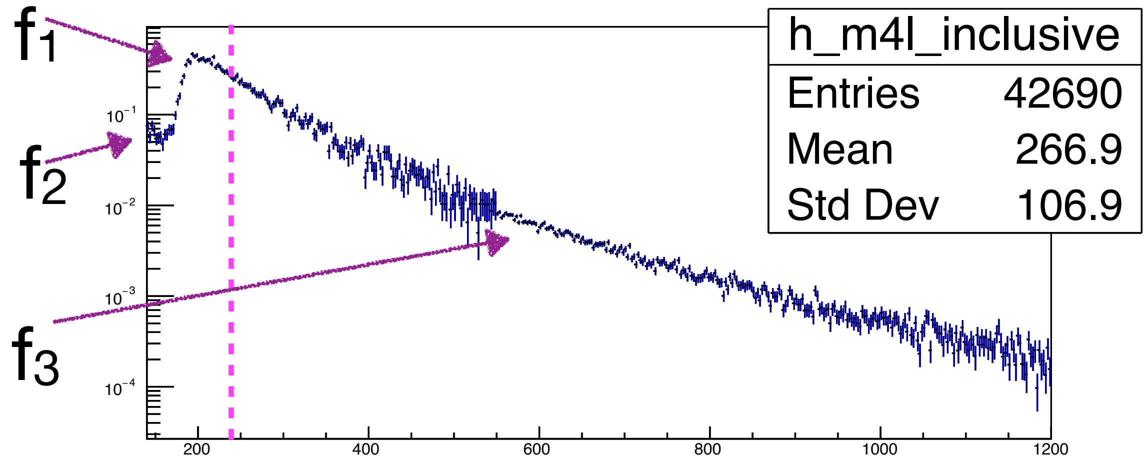
- Event topology is exactly as a signal one
- **Both shape and normalisation are taken from MC**
- Two production modes: qq→ZZ & gg→ZZ

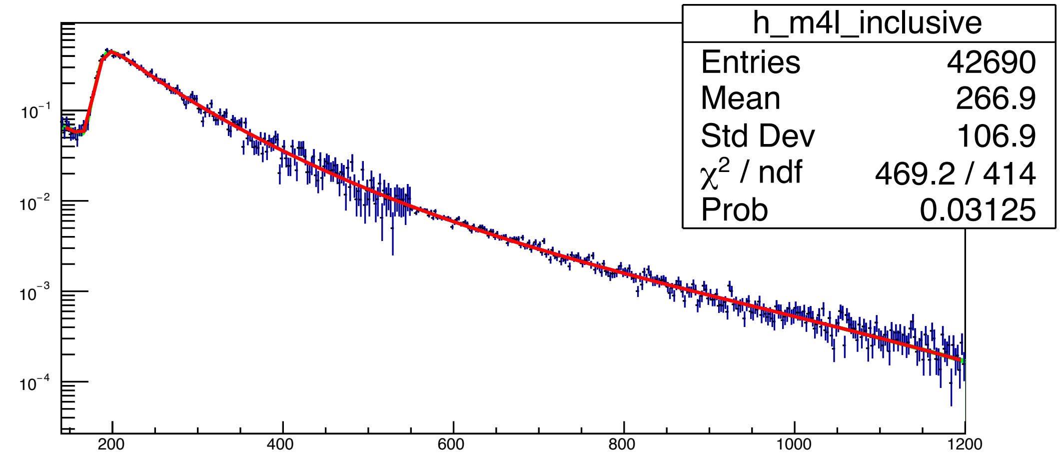




ZZ Background

- Event topology is exactly as a signal one
- **Both shape and normalisation are taken from MC**
- Two production modes: qq→ZZ & gg→ZZ
- * **Shape is described by parametric function with 9 parameters**
  - smother background shape
  - better treatment of statistical uncertainty in the tail





$$f_1(x) = (\frac{1}{2} + \frac{1}{2} * erf(\frac{x - a_1}{a_2})) \times \frac{a_4}{1 + exp(\frac{x-a_1}{a_3}))}$$

$$f_2(x) = exp(b_1 + b_2 * x)$$

$$f_3(x) = exp(c_1 + c_2 * x + c_3 * x^2 + c_4 * x^{2.7})$$

$$f(x) = (f_1(x) + f_2(x)) * (x < x_0) + f_3(x) * (x > x_0) * C_{norm}$$

Signal Hypothesis

- Sensitive mass region: **200 < m_H <1000 GeV**

- Two Higgs production modes are considered:
  - **ggF** (gluon gluon fusion)
  - **VBF** (vector boson fusion)

- **Width hypothesis:**

  previously used approach

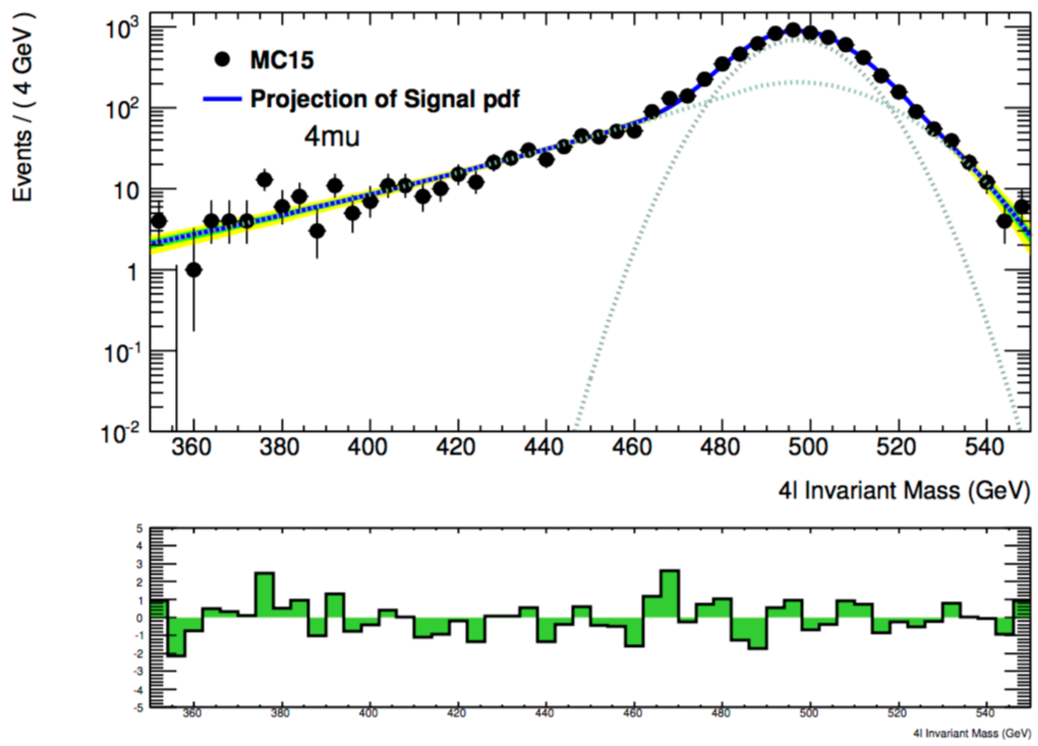
  - **NWA** (narrow width) - the resonance is assumed to have a width of 4 MeV (for masses >200 GeV)
  - **LWA** (large width) - the resonance is assumed to have a width up to 15% of its mass

  motivated by numerous theoretical models, but newer tested before in H4l

Signal Modelling in Narrow Width

$$f_{signal}(m_{4\ell}) = f_{CB} \cdot CB(m_{4\ell}; \mu, \sigma_{CB}, \alpha_{CB}, n_{CB}) + (1 - f_{CB}) \cdot Gauss(m_{4\ell}; \mu, \sigma_{Gauss})$$

- **Signal shape is parametrised by the sum of Gauss and CB**
  - Gauss and CB shearing the same mean mass
  - 5 free parameters



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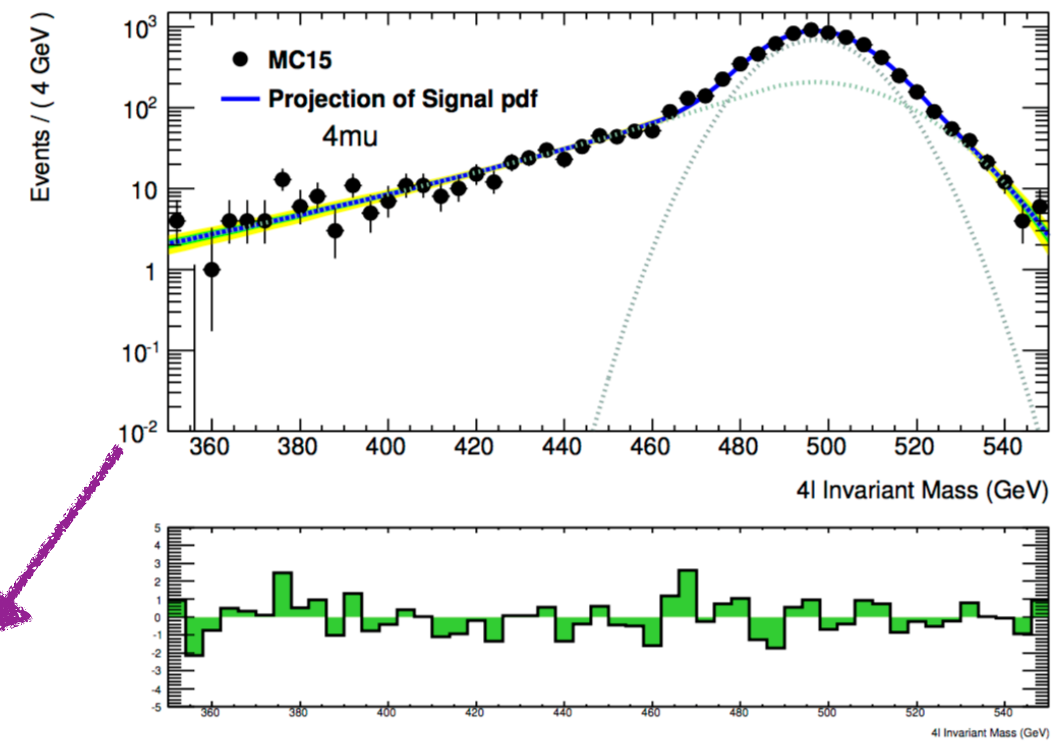
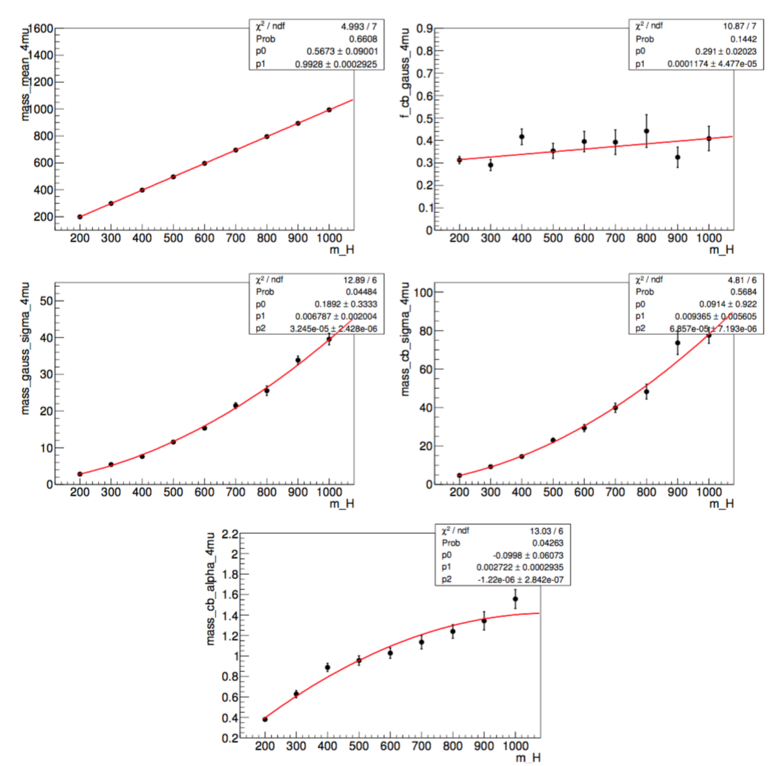
- Shape fit is done for all available mass points
- Shape parameters are interpolated between available mass points by polynomial function





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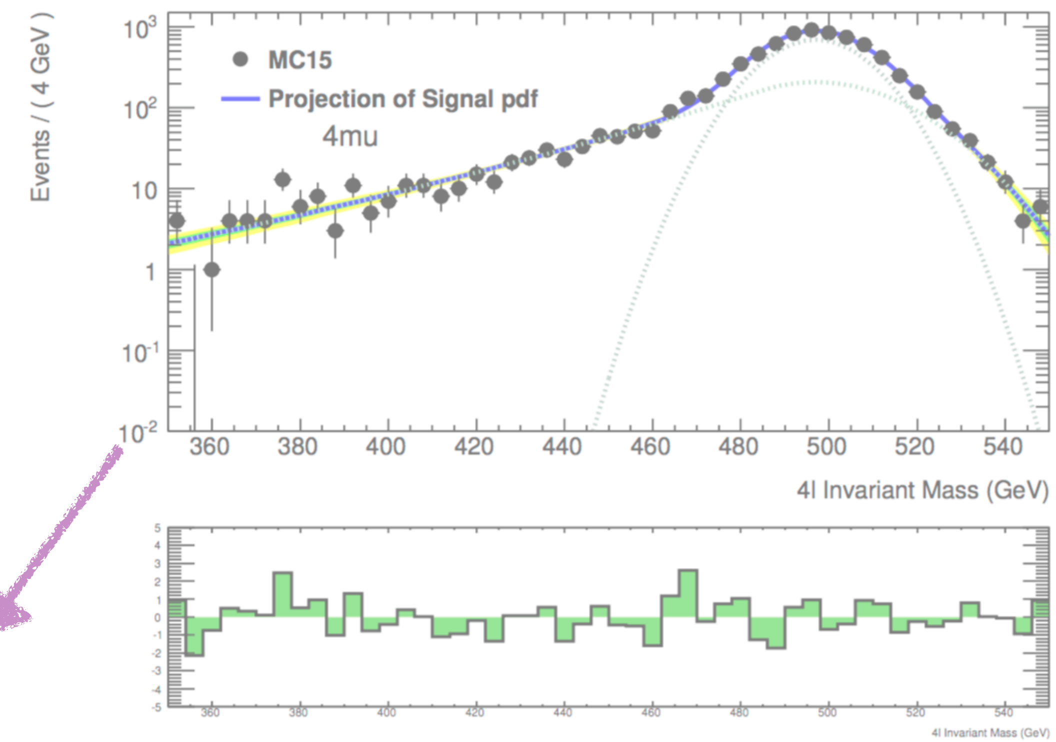

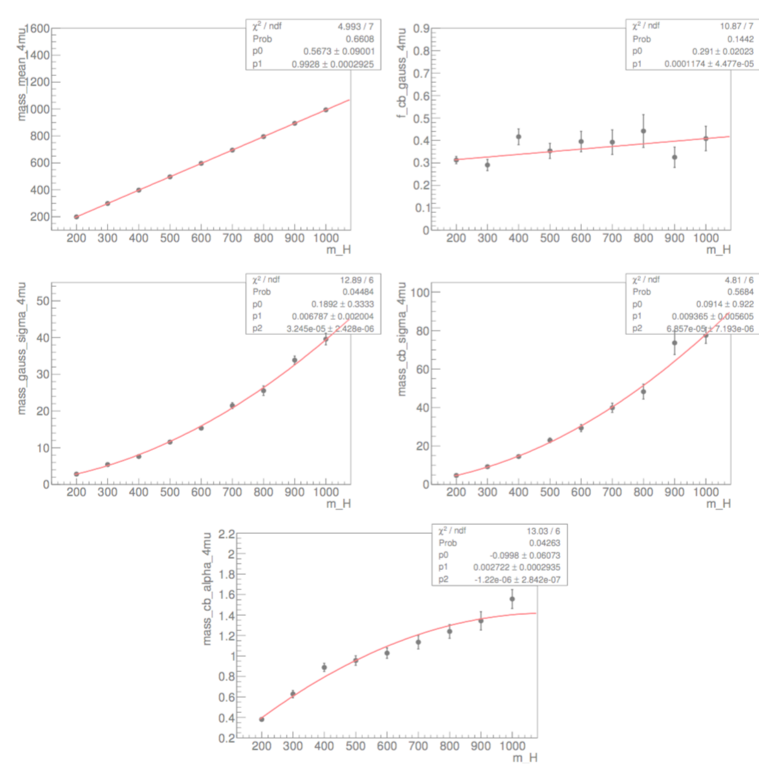

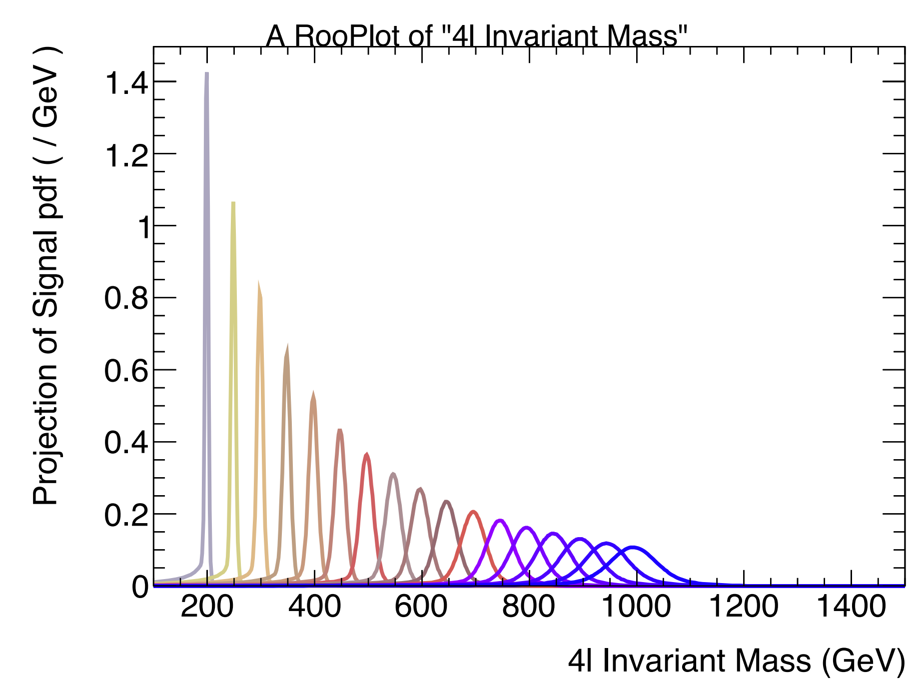

* Signal vs Background Kinematic Discriminant

- **Signal can be discriminated wrt background** with some kinematic variables assuming spin 0 model

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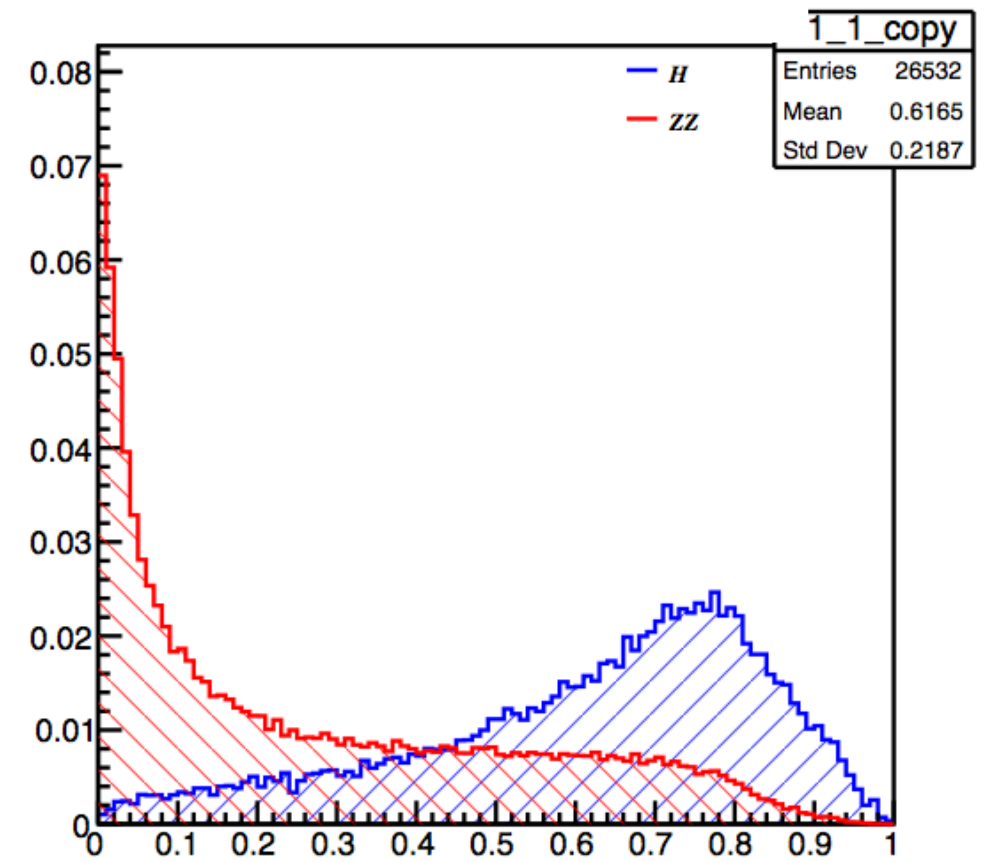
- **Matrix Element based Kinematic Discriminant (MELA)** is easy to use for the mass scan
  - Input: 4 lepton system kinematic in CM system
  - Matrix elements are calculated by Madgraph
  - By construction the discriminant is confined within [0,1] and slightly changing with m_{4l}

$$MELA = \frac{ME_{sign}}{ME_{sign} + c * ME_{bkg}}$$

MELA for 600 GeV



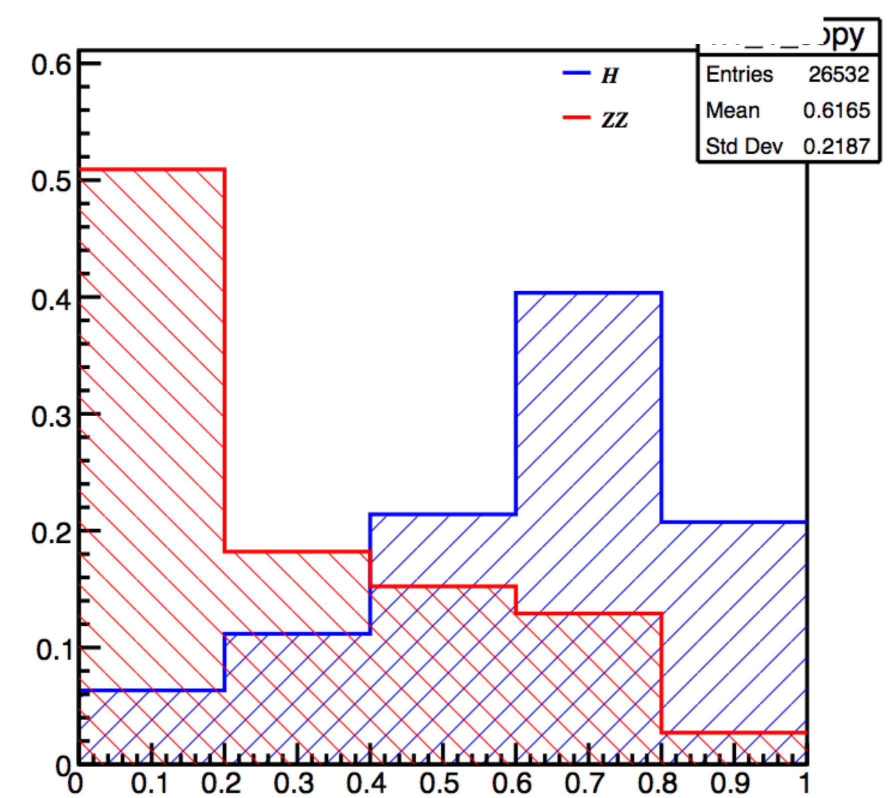
Signal vs Background Kinematic Discriminant

- **Signal can be discriminated wrt background** with some kinematic variables assuming spin 0 model

- **Matrix Element based Kinematic Discriminant (MELA)** is easy to use for the mass scan

- It was shown that by **adding MELA information it is possible to gain 5-20%** on the limit for different mass regions
  - Test was done for inclusive production mode
  - Implemented through m_{4l} fit in MELA bins

MELA for 600 GeV



Mass points [GeV]	*300*	*400*	*500*	*600*	*700*	*800*	*900*	*1000*
Limit Improvement [%]	**26**	**25**	**22**	**20**	**16**	**12**	**10**	**8**

Signal Modelling in Large Width

- **Signal shape in LWA is modelled as a truth resonance line shape convoluted with detector effects**

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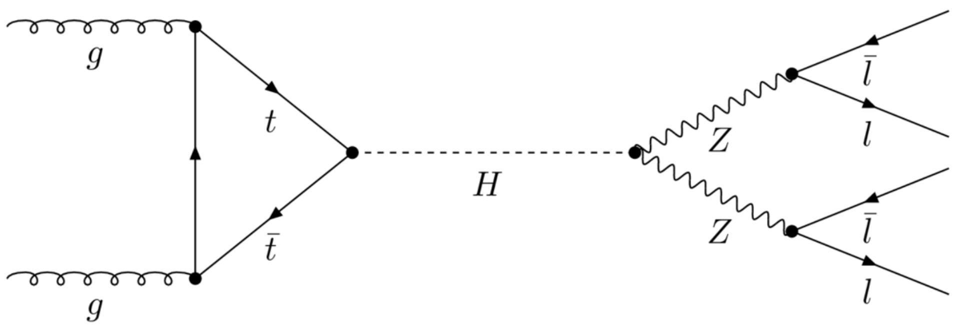
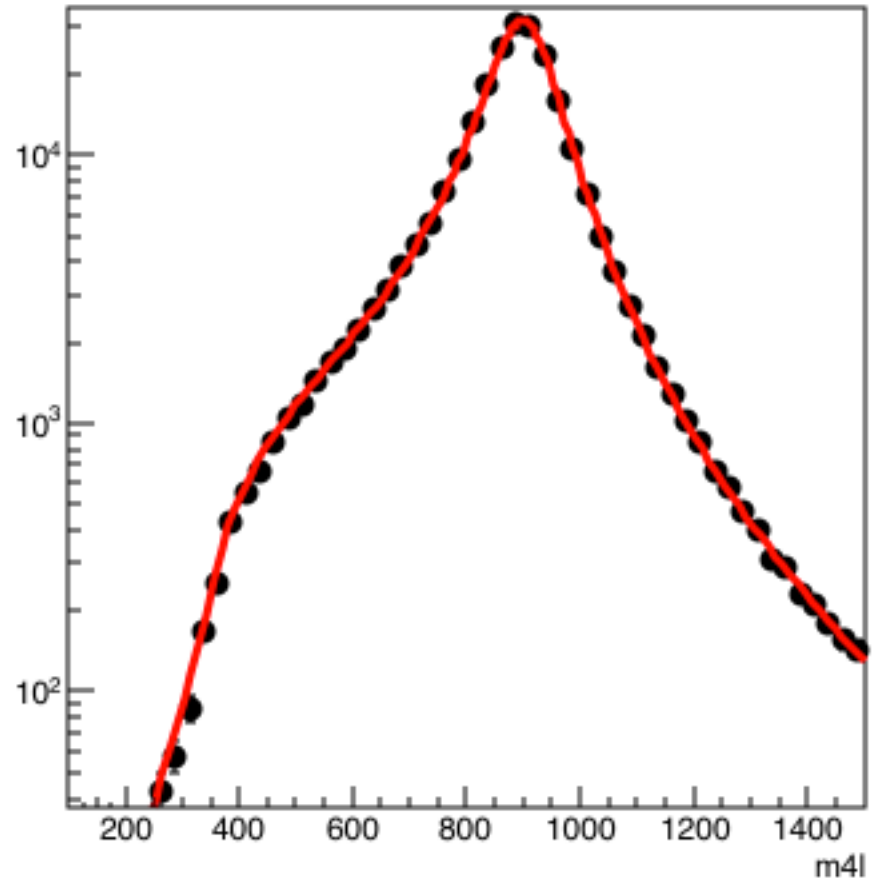
- Signal shape in LWA is modelled as a truth resonance line shape convoluted with detector effects

- **Truth line shape can be computed from tree level Feynman diagram of the process**



$$\sigma_{pp\to H\to ZZ}(m_{4\ell}) = 2m_{4\ell}\cdot\mathcal{L}_{gg}\cdot\frac{1}{|s-s_H|^2}\cdot\Gamma_{H\to gg}(m_{4\ell}^2)\cdot\Gamma_{H\to ZZ}(m_{4\ell}^2)$$

Truth line shape for 900 GeV mass and 15% width

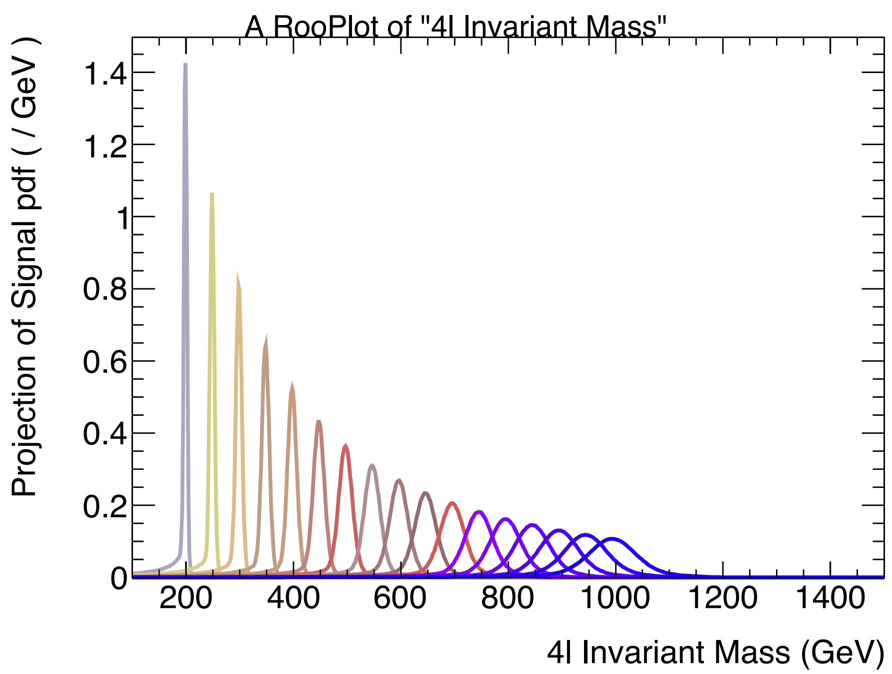


* Signal Modelling in LWA

- **Signal shape in LWA is modelled as a truth resonance line shape convoluted with detector effects**

- **Truth line shape can be computed from tree level Feynman diagram of the process**

- **And finally convoluted with detector resolution**
  - detector resolution is already modelled by NWA parametrisation



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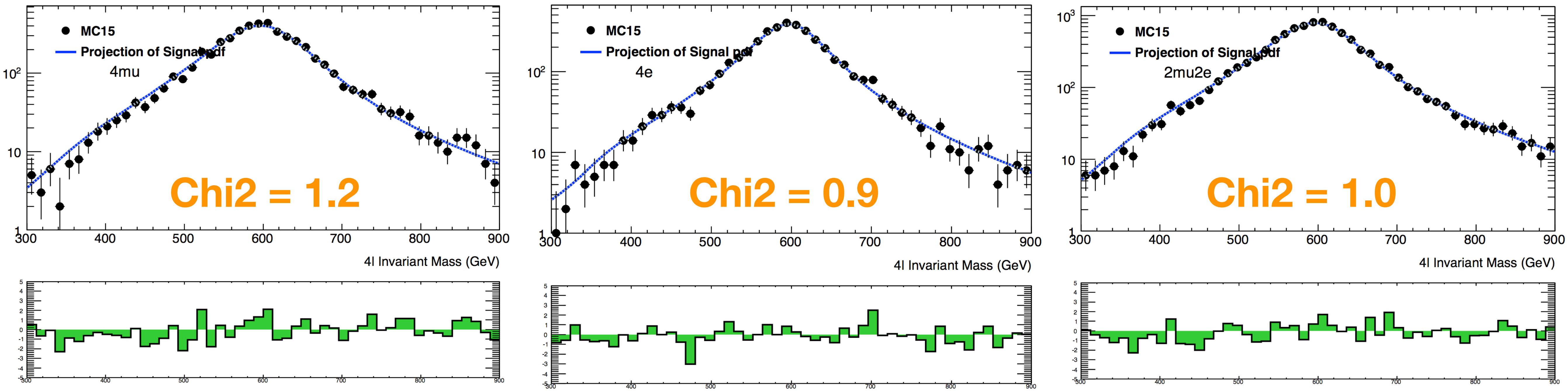
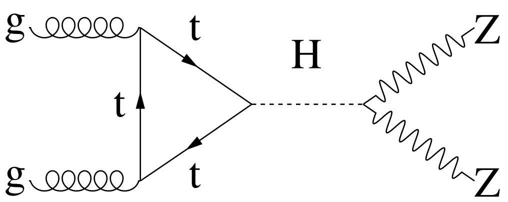
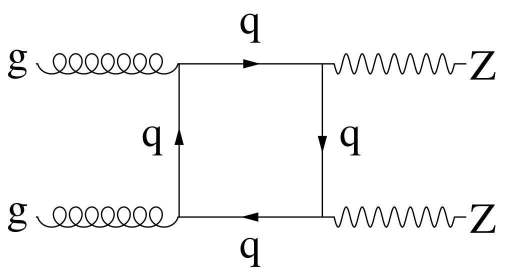
Comparison of the model to the MC distribution for 600 GeV mass and 15% width hypothesis

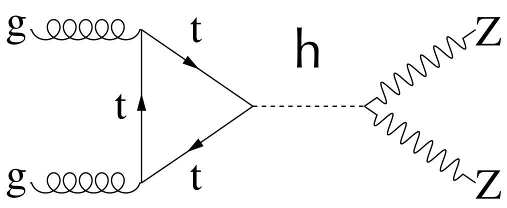


Interference in LWA

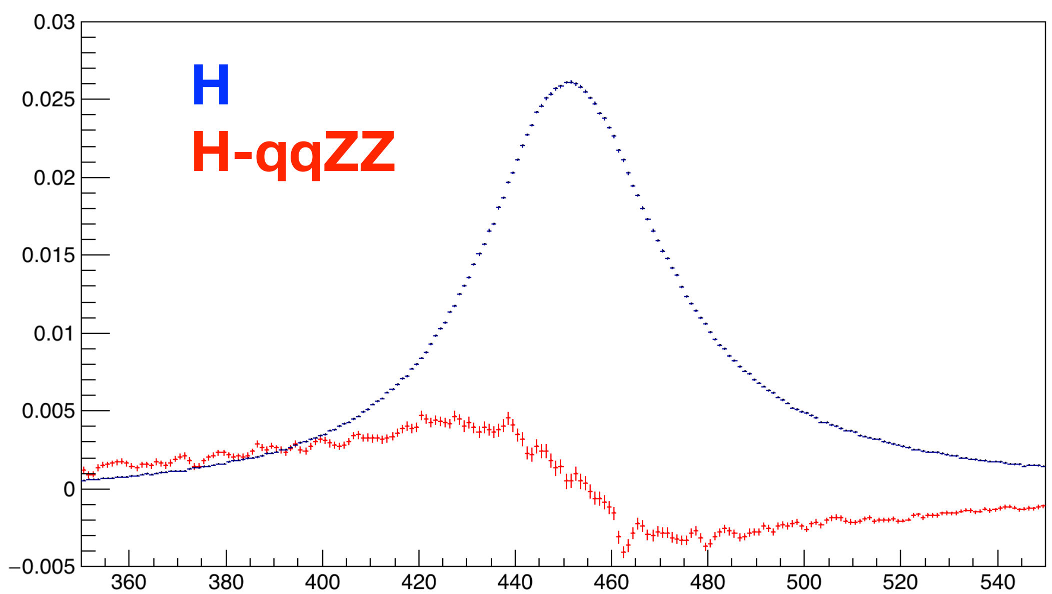
- **In LWA signal interference with the SM background becomes important:**
  - interference of the signal with SM qqZZ (H-qqZZ)
  - interference of the signal with SM Higgs boson (H-h)



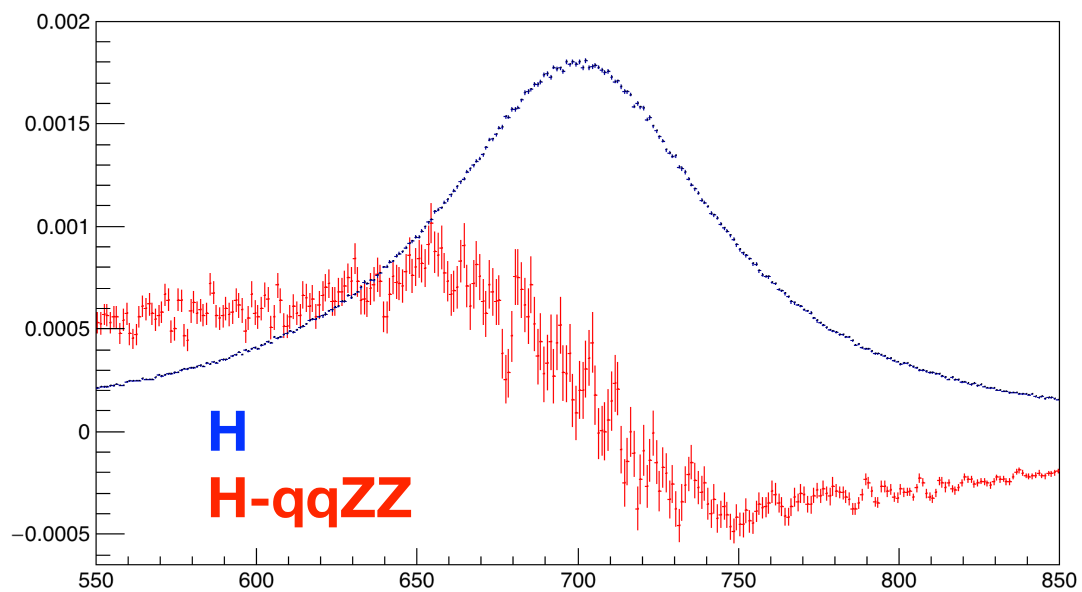




450 GeV 10%



700 GeV 15%



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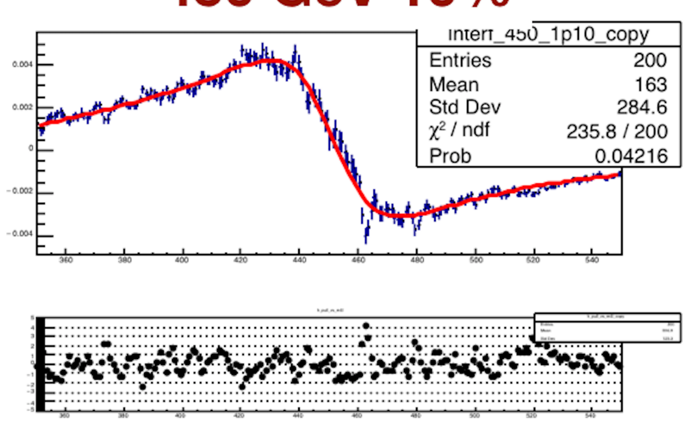
- **H-qqZZ interference can be computed from Feynman diagram, while non analytical part of the function can be replaced with polynomial and fitted to MC simulation**

$$\sigma_{pp}(m_{4\ell}) = \mathcal{L}_{gg} \cdot \frac{1}{m_{4\ell}} \cdot Re\left[\frac{1}{s - s_H} \cdot ((a_0 + a_1 \cdot m_{4\ell} + ...) + i \cdot (b_0 + b_1 \cdot m_{4\ell} + ...))\right]$$

450 GeV 10%



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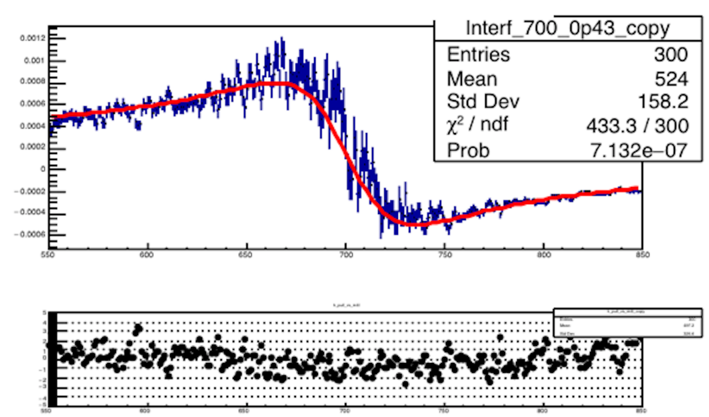

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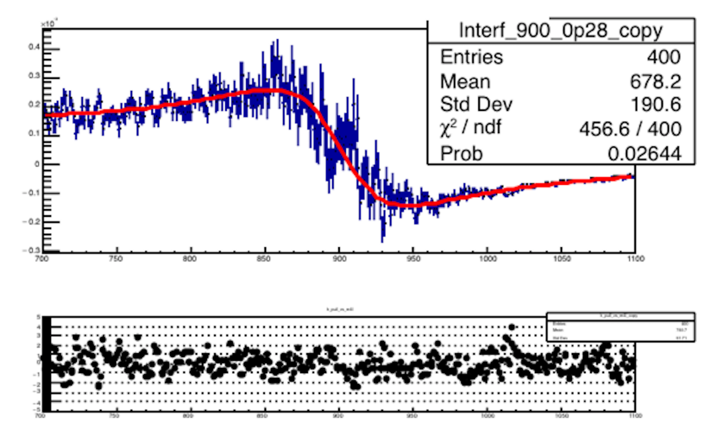

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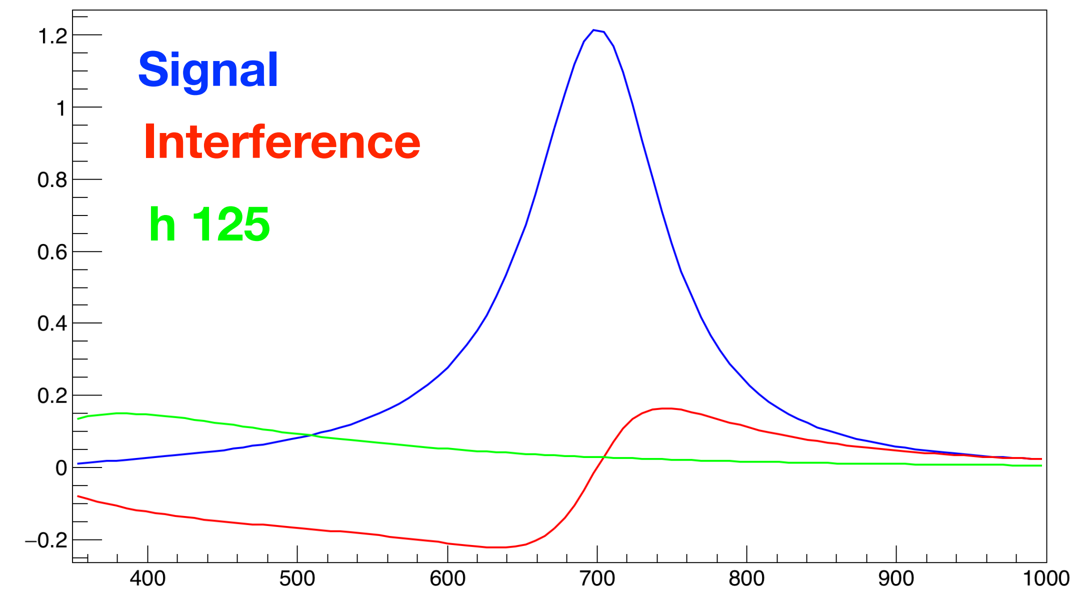
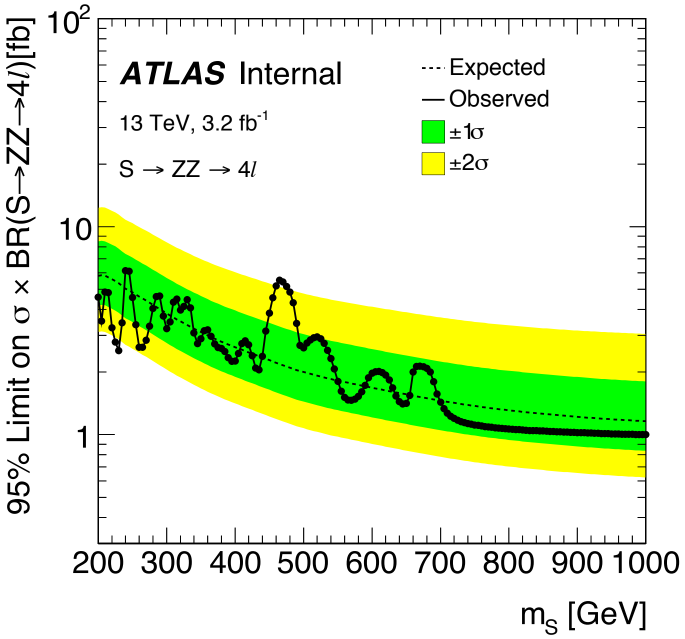
- **H-h interference can be fully analytically computed at tree level as it was done for LWA signal shape**

700 GeV W = 15%



(Expected) Results

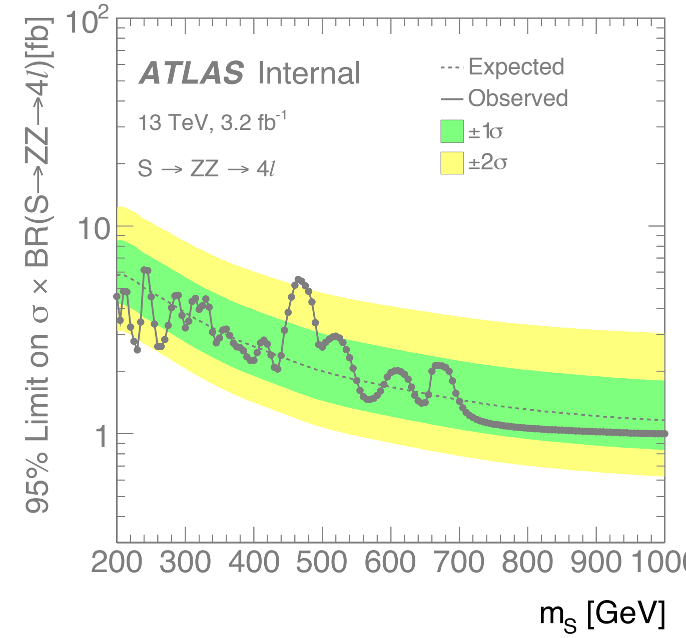
- At **Winter 2015** we have already shown the limits on inclusive cross section of a Heavy Higgs boson
- And …



Winter 2105

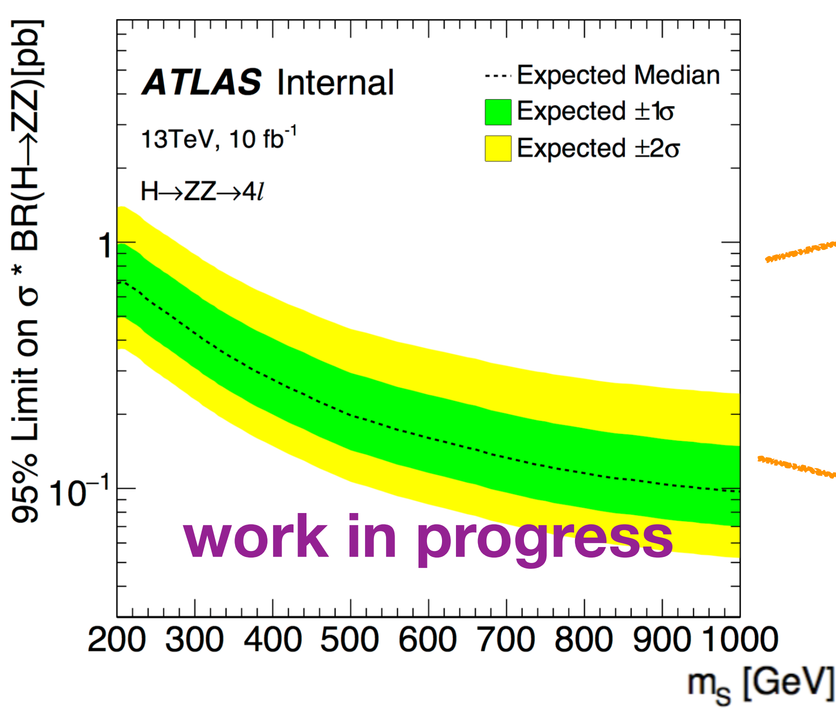
(Expected) Results

- At **Winter 2015** we have already shown the limits on inclusive cross section of a Heavy Higgs boson
- And we expect to show much more for **Summer 2016**:
  (approved by ATLAS Higgs group just yesterday!)
  - ggF limits in NWA
  - VBF limits in NWA
  - MELA improved inclusive limits in NWA
  - Inclusive limit in LWA



Winter 2105

Expected for **Summer 2016**



NWA

- **σ_{ggF}*BR(H→ZZ) limits**
- **σ_{VBF}*BR(H→ZZ) limits**
- **σ*BR(H→ZZ) limits with MELA**

σ*BR(H→ZZ) limits LWA

Summary

- Heavy Higgs search was released with 3.2 fb^{-1} at 13 TeV

- The results will be updated with more data (10 fb^{-1}) will be updated soon for summer conferences

- Now starting another interesting hardware activity on the tests of the Micromegas M0 module for NSW project

Thank You for Attention!

And stay tuned for ICHEP !
(August 3)

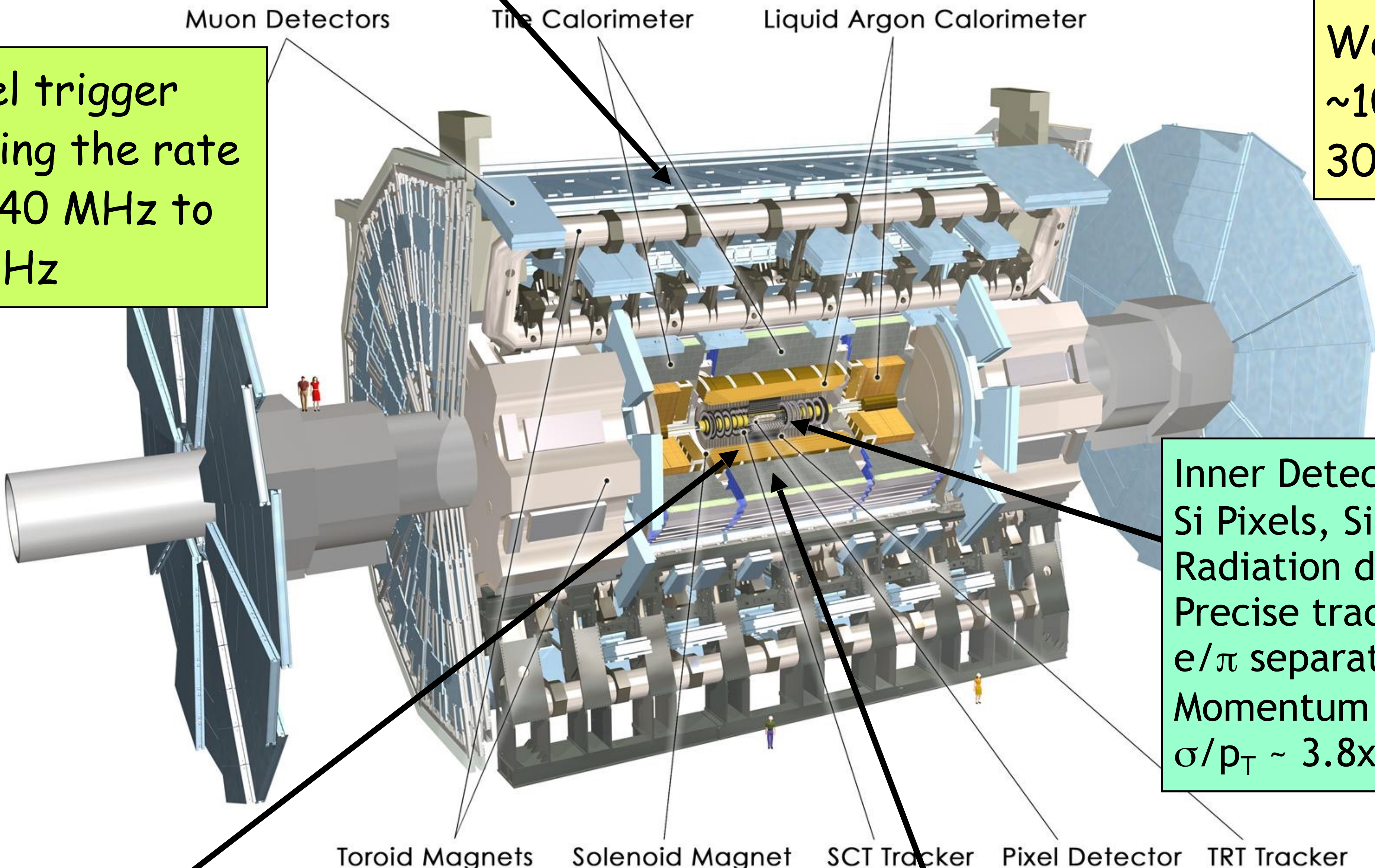
Back Up

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to E_μ ~ 1 TeV

ATLAS

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

3-level trigger reducing the rate from 40 MHz to ~200 Hz



Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing, e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T\,(\mathrm{GeV}) \oplus 0.015$

EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

Background

- **Dominant irreducible background:**
  - **SM ZZ** production
  - important within whole mass range
  - estimated from MC
- **Other irreducible background:**
  - **VVV**, **ttbar+V**
  - contributing at intermediate mass
  - estimated from MC
- **Reducible background:**
  - **Z+jet**, **ttbar**
  - fake leptons are mainly originated by jets
  - important only at low mass
  - estimated with Data Driven methods

DataDriven **ll+$\mu\mu$**

- Z+heavyJet and ttbar are estimated by simultaneous fit of m_{12} in 2 CRs: Inv-d_0 & $e\mu$+$\mu\mu$ (similar to Run1)
- Z+lightJet is deduced from Inv-Iso CR
- Data to MC difference in cut efficiencies is taken as systematics
- Background shape is taken from MC and smoothed with RoKeysPDF
- the same shape is used for all decay channels

DataDriven **ll+ee**

- Estimated from 3l+X CR; where X is a “loose lepton” with lowest p_T, no Iso. or d_0 or LH
- ZZ is suppressed by requiring Same Sign Z2 pair
- n_{BL} and $p^e{}_{TRT}$ are fitted simultaneously to extract normalisation of three bkg components
- efficiency of X passing tight selection is deduced from Z+X CR