Vector Boson Fusion + Missing Transverse Energy + photon
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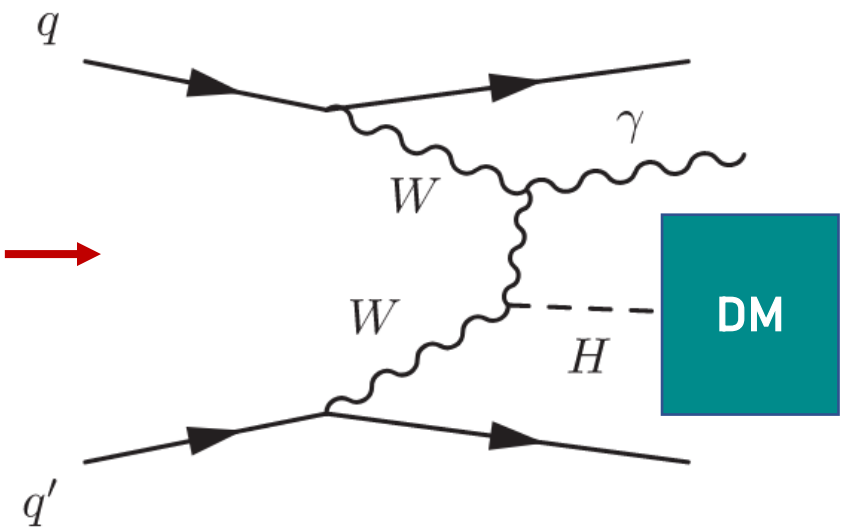
Why VBF + MET + Photon?

Strong astrophysical evidences of Dark Matter.

Coupled with the Higgs boson ?

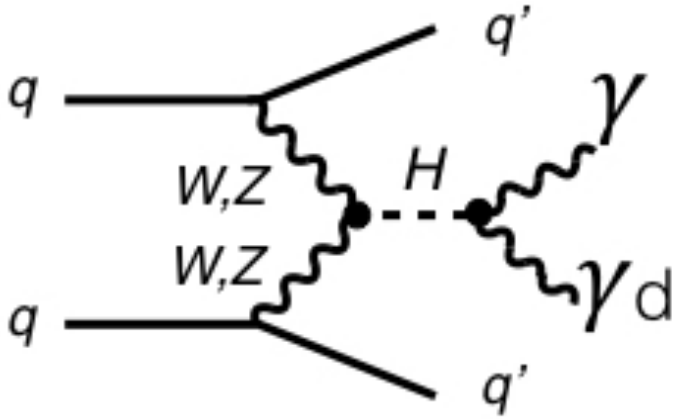
Can be tested at the LHC by searching for an invisible decay mode of the 125 GeV Higgs Boson

VBF + MET + photon



What about the photon?

Requiring a photon strongly suppress various irreducible backgrounds, increasing the significance of the analysis, and..



.. It allows for alternative interpretations like:

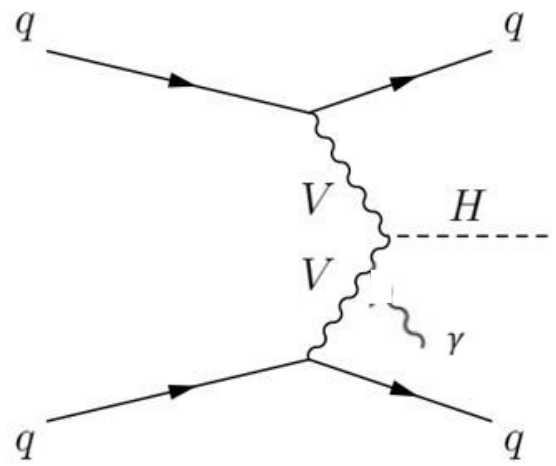
- Higgs decaying to $\gamma + \gamma_d$

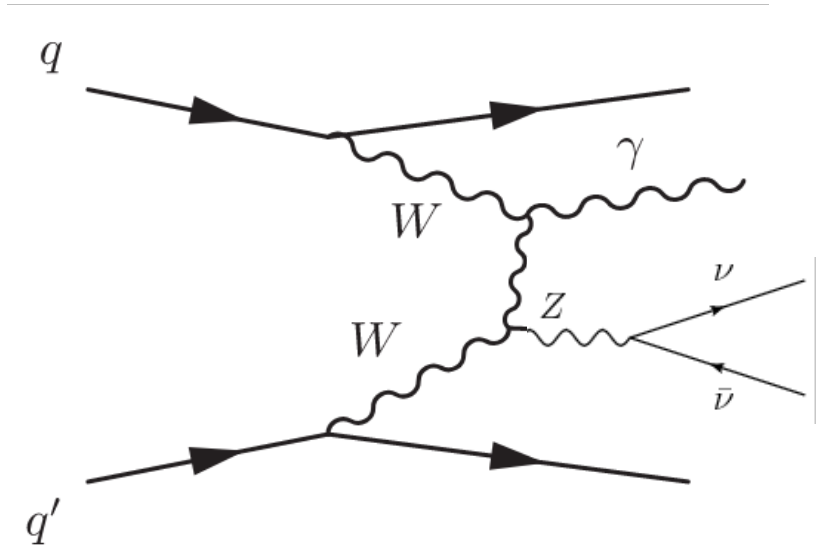
Dark photon paper

Signal and Backgrounds

Signature:

- Two jets
  - High m_{jj}
  - Highly separated in η
  - Not back to back
- One photon
- High MET

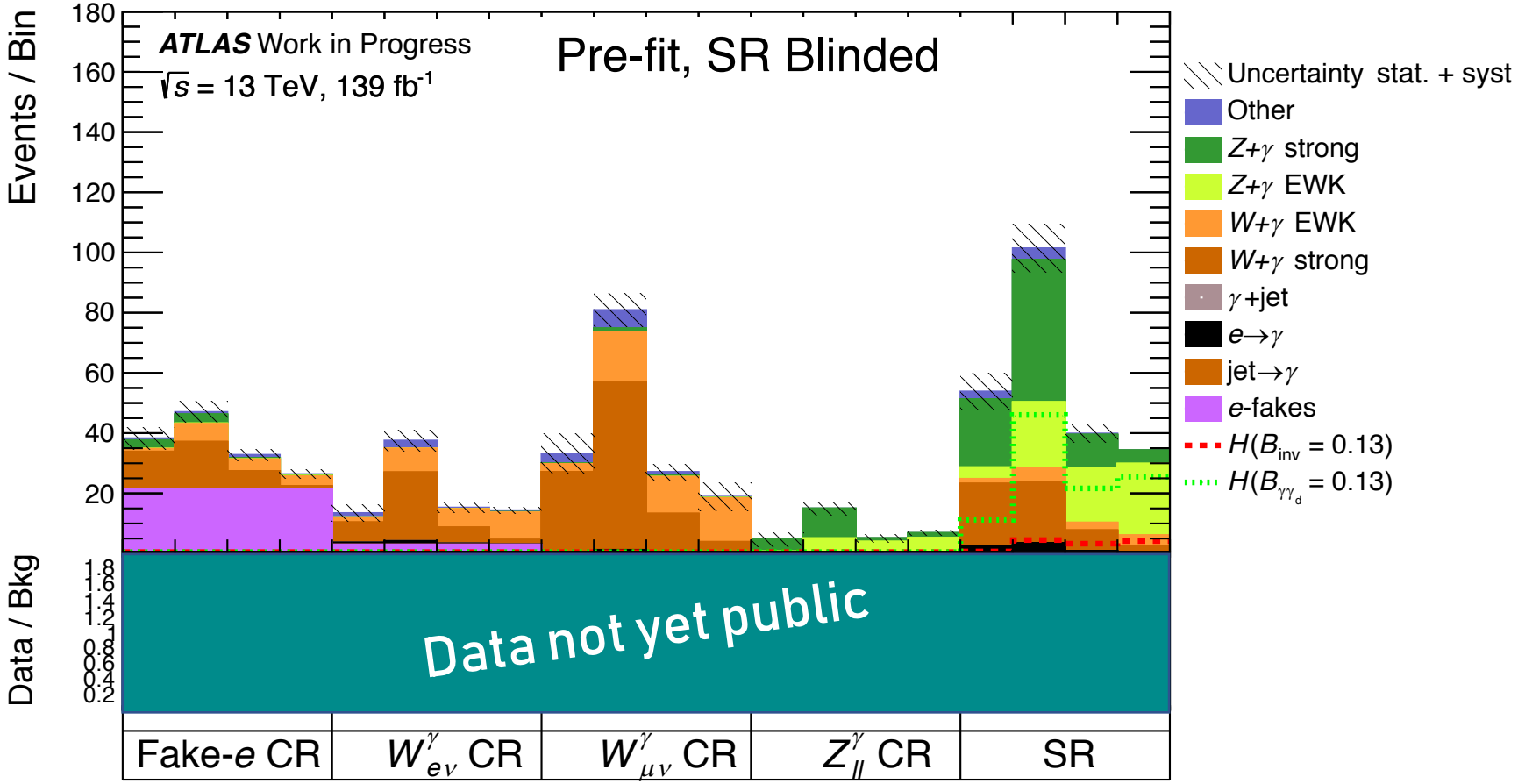




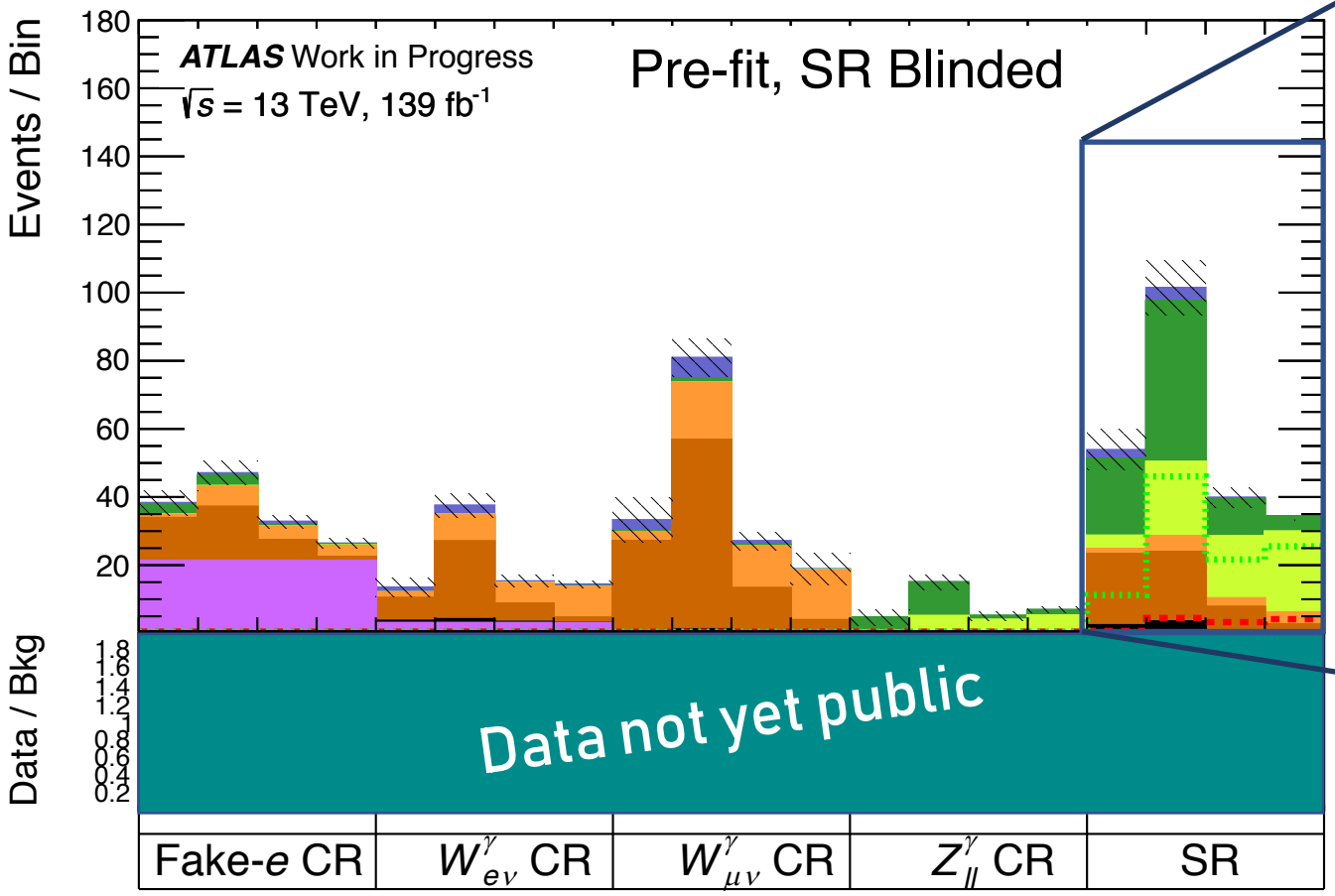
Major backgrounds:

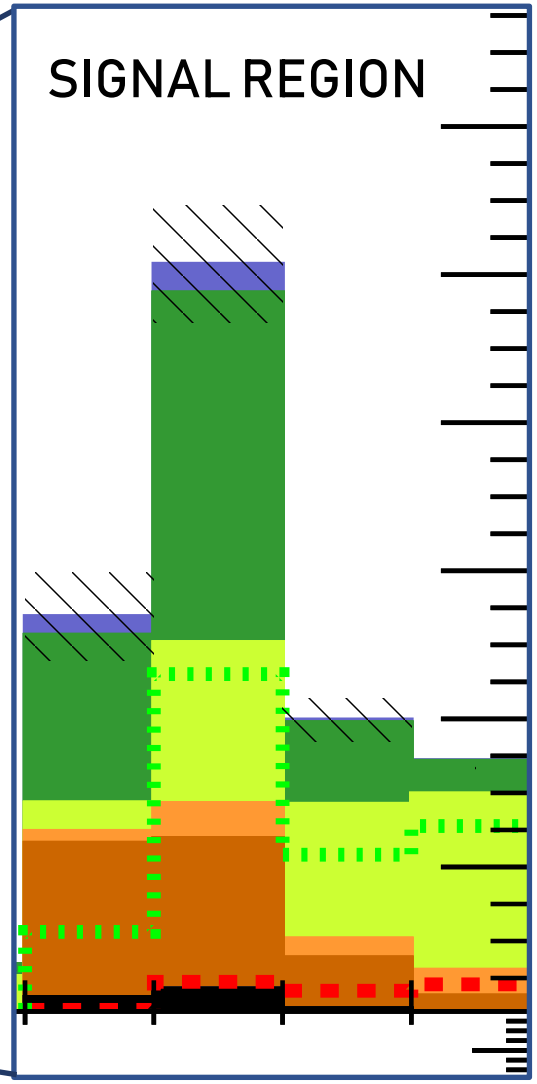
- $Z(\rightarrow \nu\nu)\gamma + jets$
- $W(\rightarrow \nu l_{lost})\gamma + jets$

Yields


ATLAS Work in Progress
√s = 13 TeV, 139 fb-1
Pre-fit, SR Blinded
Events / Bin
Data / Bkg
Data not yet public
Uncertainty stat. + syst
Other
Z+γ strong
Z+γ EWK
W+γ EWK
W+γ strong
γ+jet
e→γ
jet→γ
e-fakes
H(Binv = 0.13)
H(Bγγd = 0.13)
Fake-e CR
W^γ_eν CR
W^γ_μν CR
Z^γ_ll CR
SR

Yields





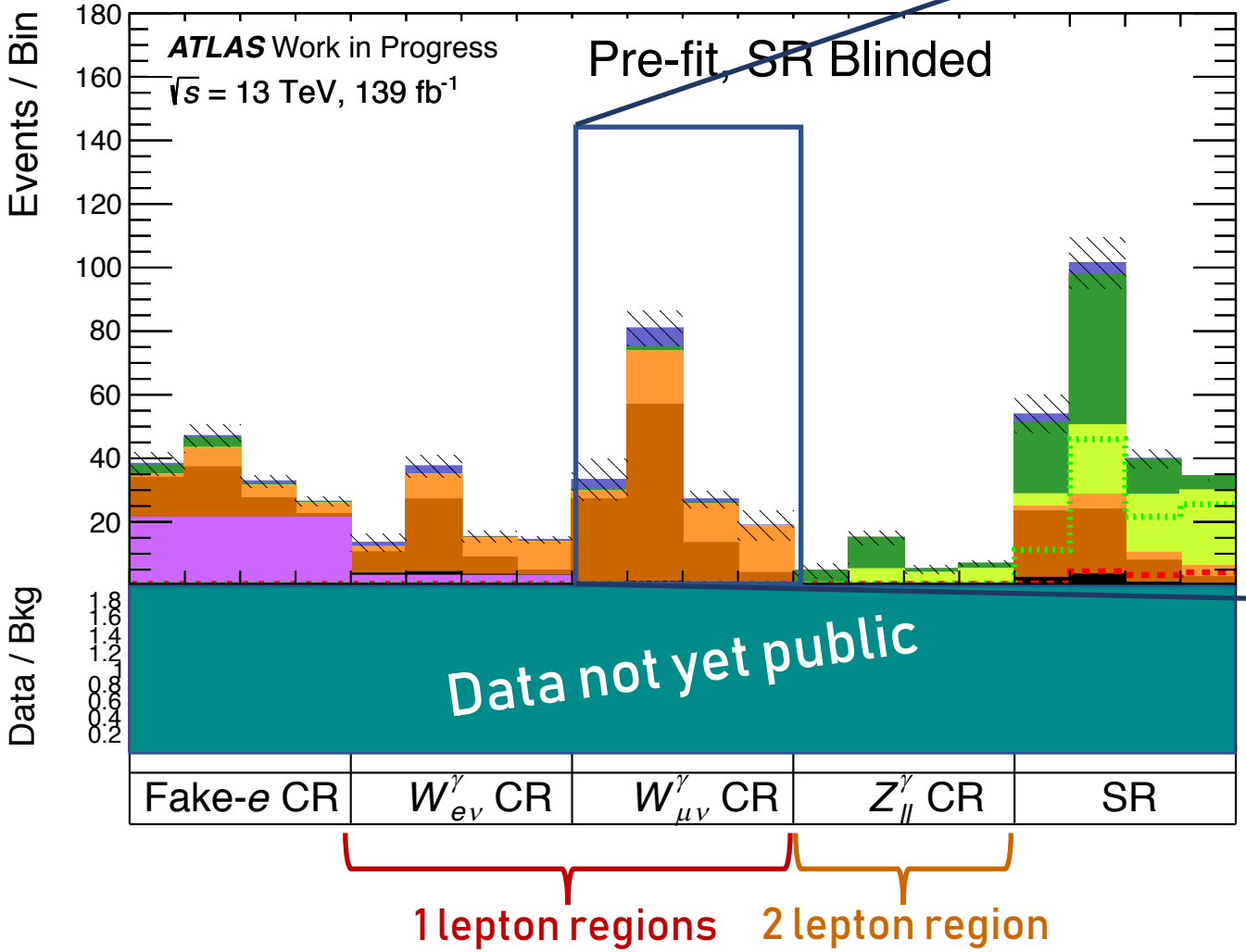
Binning in Mjj → 0.25 0.6 1.0 1.5

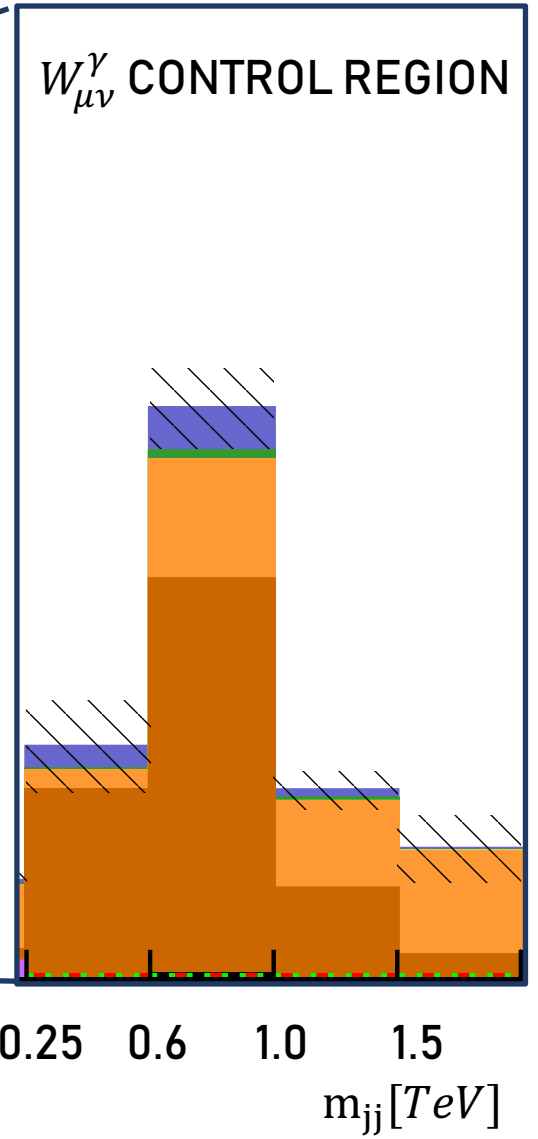
$m_{jj}[TeV]$

2 Jets + one photon + High MET required (leptons vetoed)

Yields

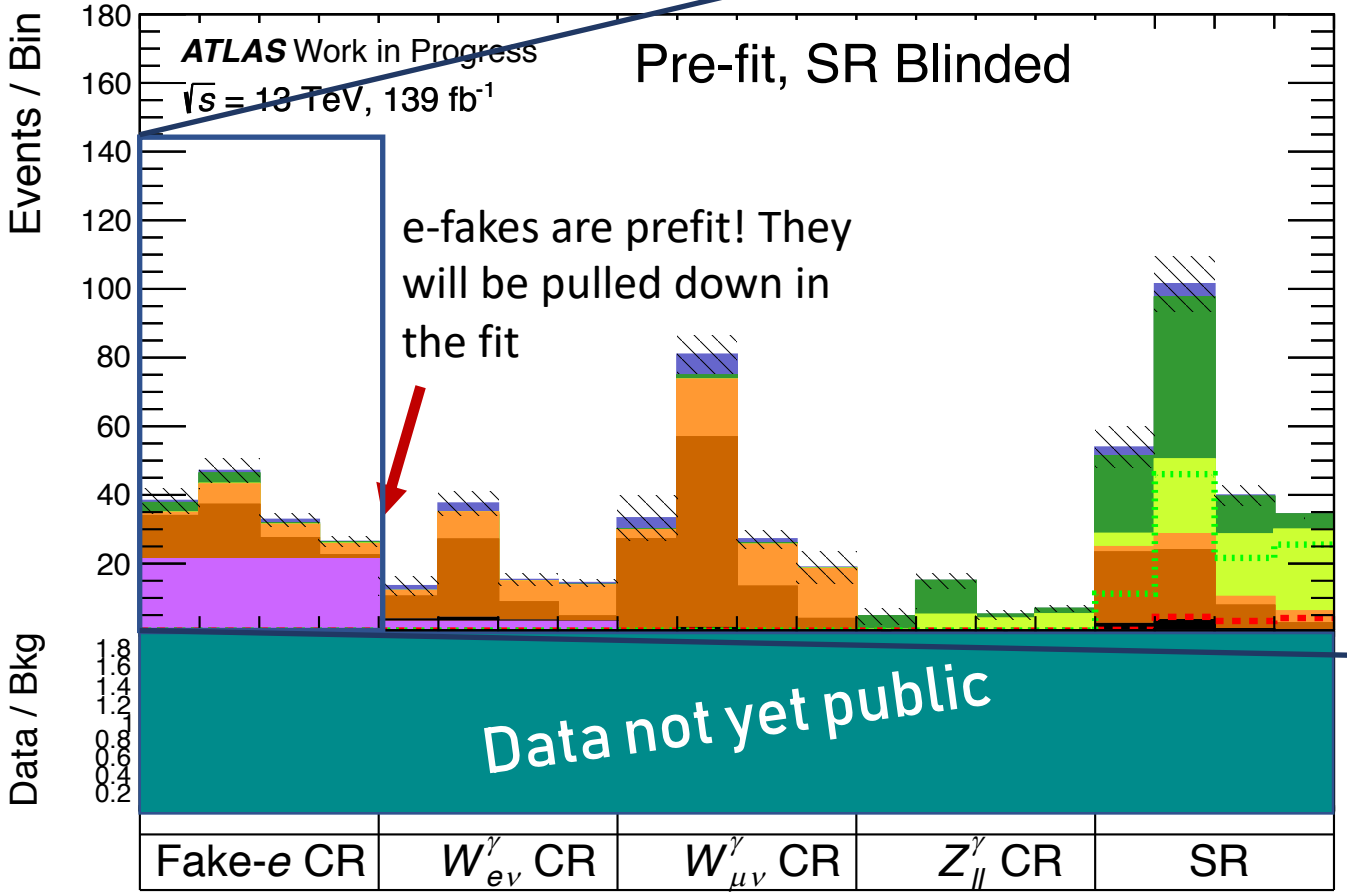
*più a sinistra

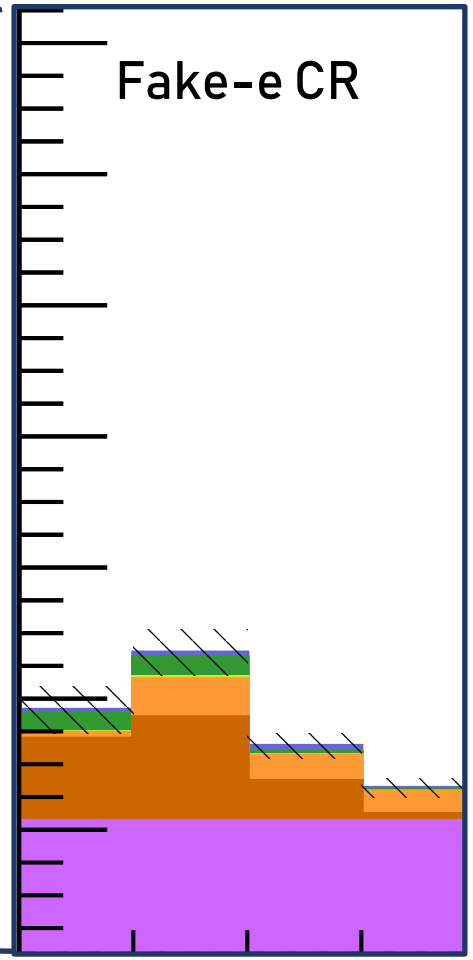




Same SR selections, but a muon is also required
(1 electron for $W^{\gamma}_{e\nu}$ CR, 2 leptons for Z^{γ}_{ll})

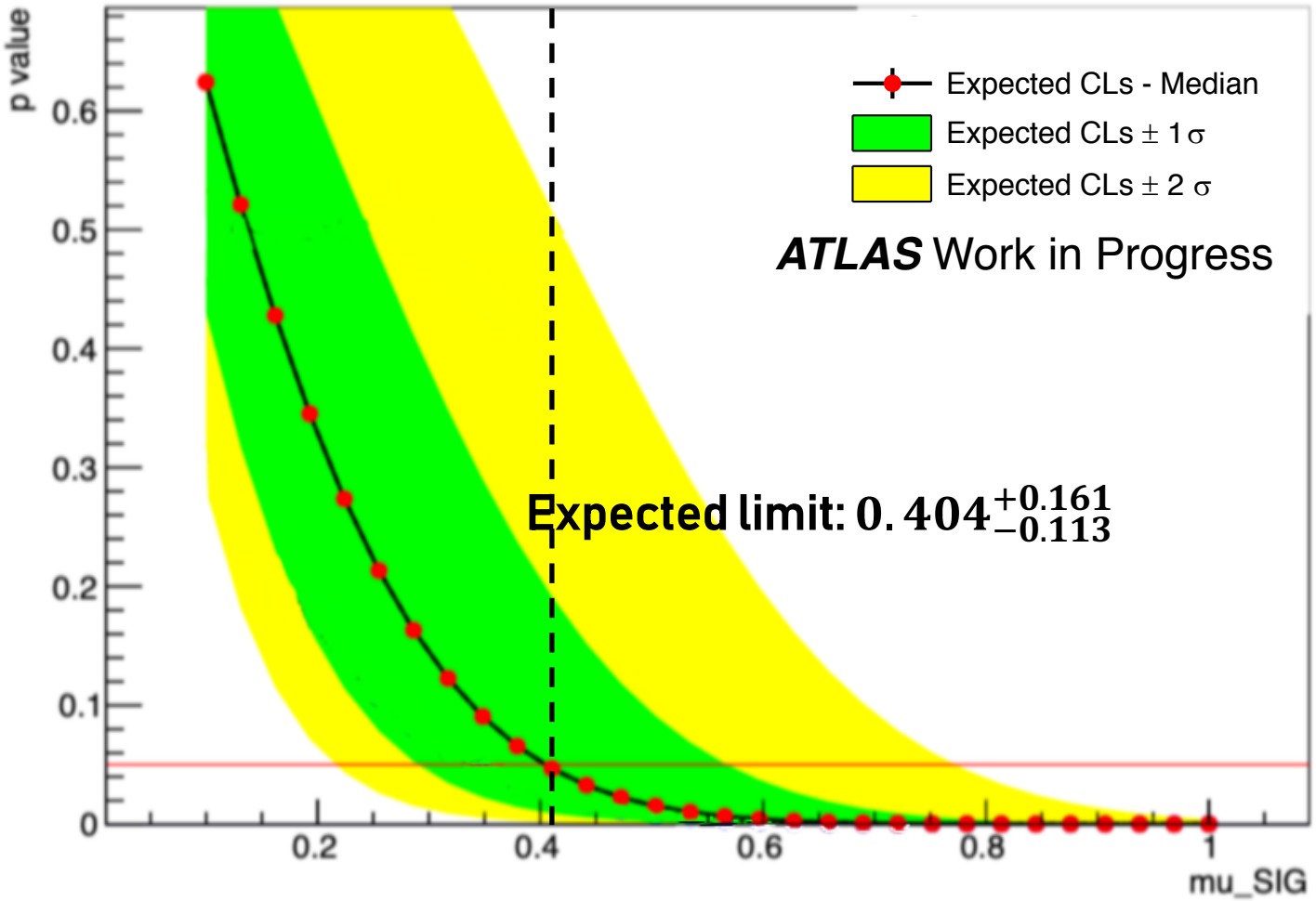
Yields





Same $W^{\gamma}_{e\nu}$ CR but low MET
Used to estimate the number of events in other Regions in which an electron simulates one photon

Limit Extraction



- Profile likelihood fit (HistFitter) on Mjj
- Stat only, no systematics

First limit for this decay channel!

→ mu_SIG = Signal strenght

The mu value where the red line intercept the dotted line represent the max signal allowed at 95% CL, i.e. the Expected Limit

Deep Neural Network (DNN) - Architecture

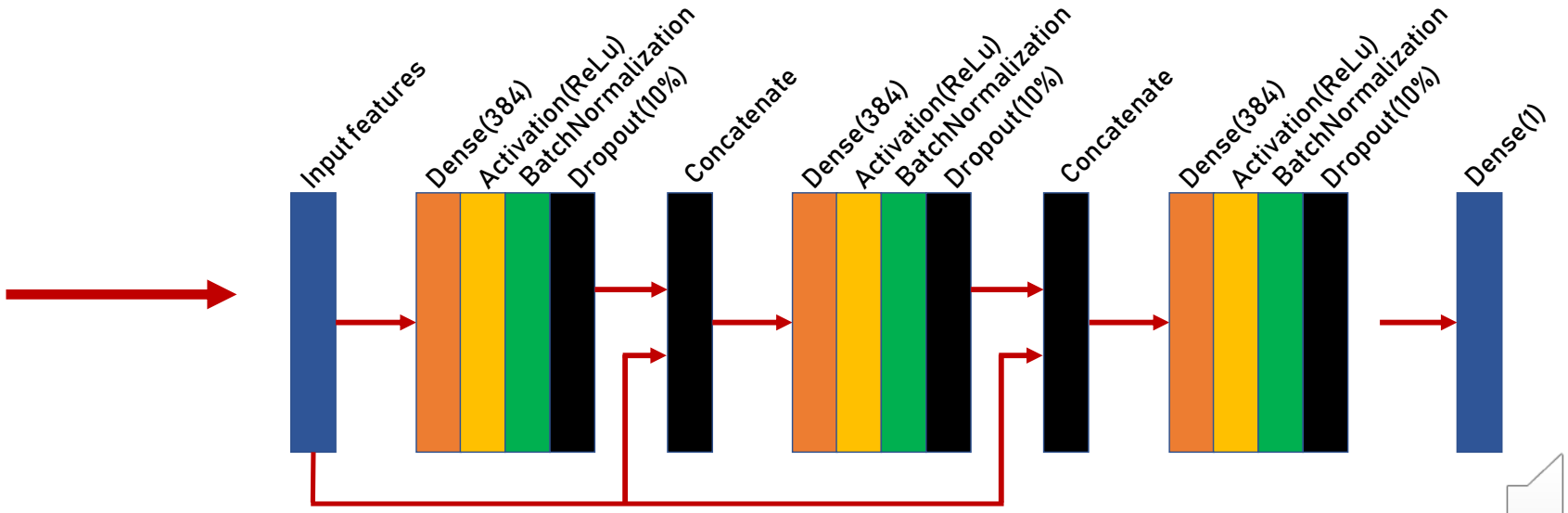
- Alternative approach to the Cutbased only analysis

  Training sample pre-selections:

- n_{ph} =1
- n_{jet} = 2/3
- $E_T^{miss,no-lep}$ > 140 GeV
- No γ+jet

Input features

1. $\Delta\eta_{jj}$
2. $\Delta\varphi_{jj}$
3. m_{jj}
4. $E_T^{miss,no-lep}$
5. $\eta(\gamma)$
6. $p_T(j_1)$
7. $p_T(j_2)$
8. $\eta(j_2)$

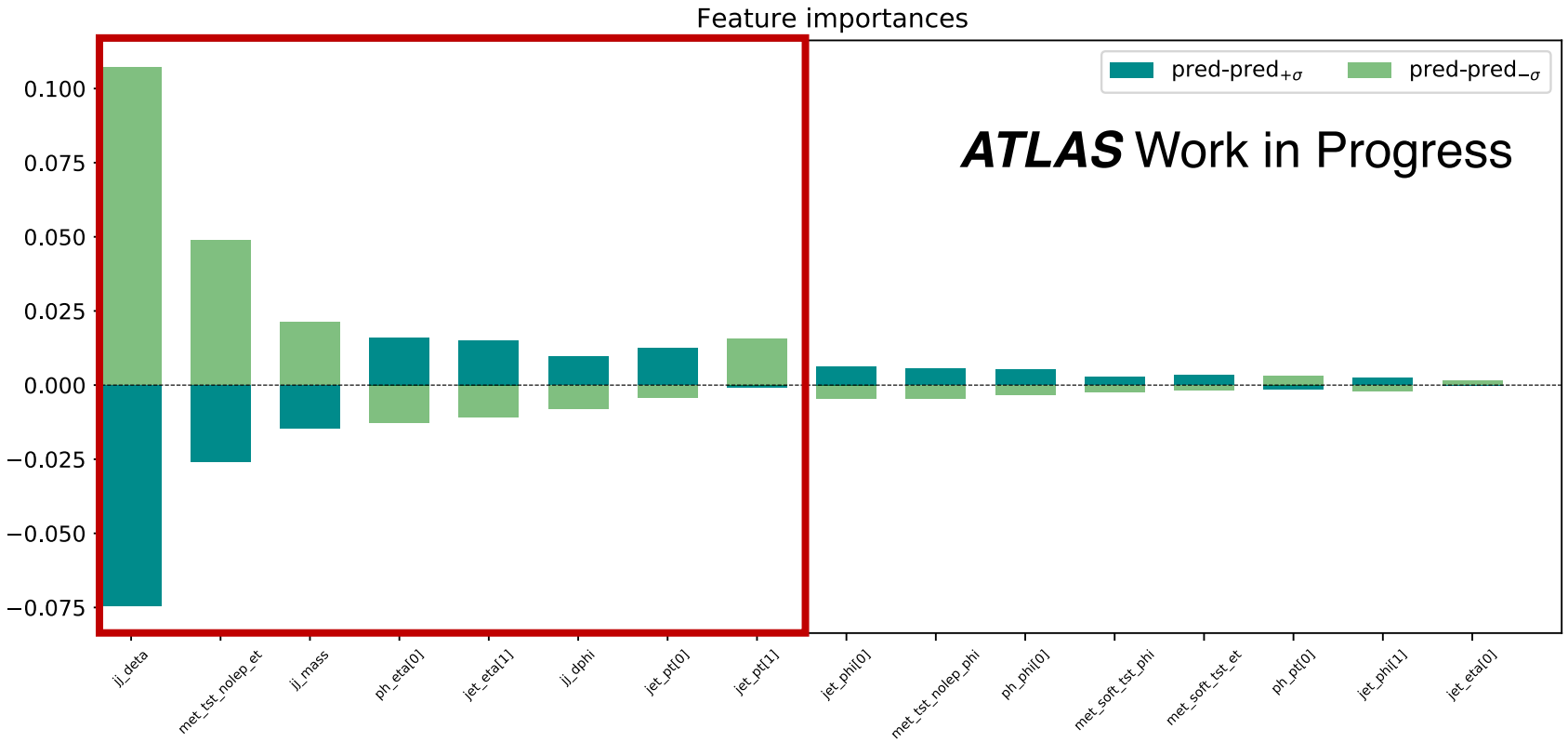


Deep Neural Network (DNN) – Feature selection

Feature chosen via a backward elimination process:

1) Each feature is varied up and down by 10% and the average variation of DNN output interpreted as feature importance

2) The least important feature is removed and the model retrained with the new set of features



Deep Neural Network (DNN) - Training

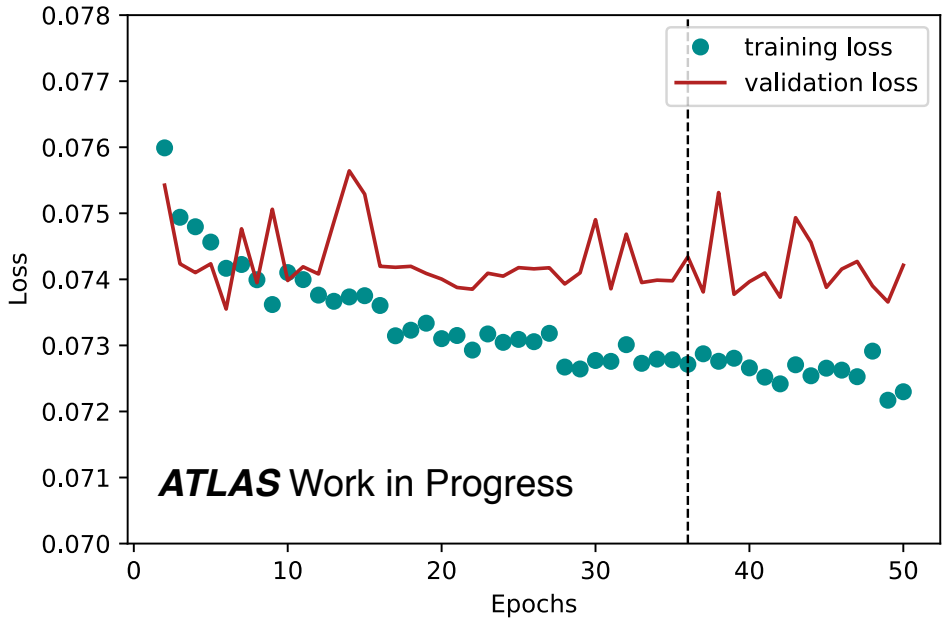
Binary cross-entropy loss, but during training this quantity is monitored

$$Exp.Limit\ Estimation_i = 2\frac{\sqrt{b_i + \left(b_i^{W\&Z}\frac{\sqrt{Data_{iCR}+\sum w_{iCR}^j}}{b_{iCR}^{W\&Z}}\right)^2 + \sum w_j^2}}{s_i}$$

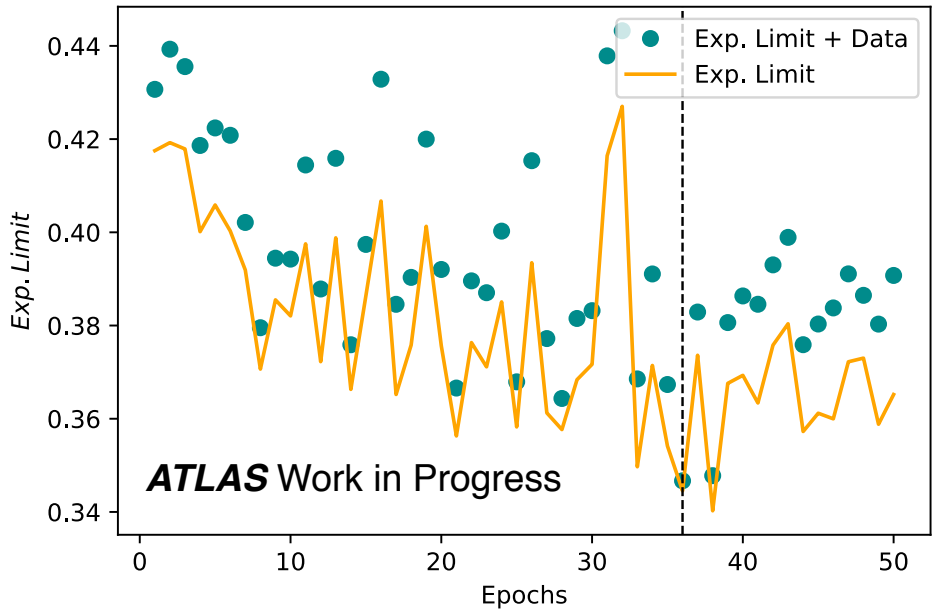
b_i = background events in SR bin i

s_i = signal events in SR bin i

Loss



Expected Limit Estimation (ELE)



Each training epoch, the model is saved only if the ELE improves and the discrepancy between train loss and val loss is small (less than 3%)

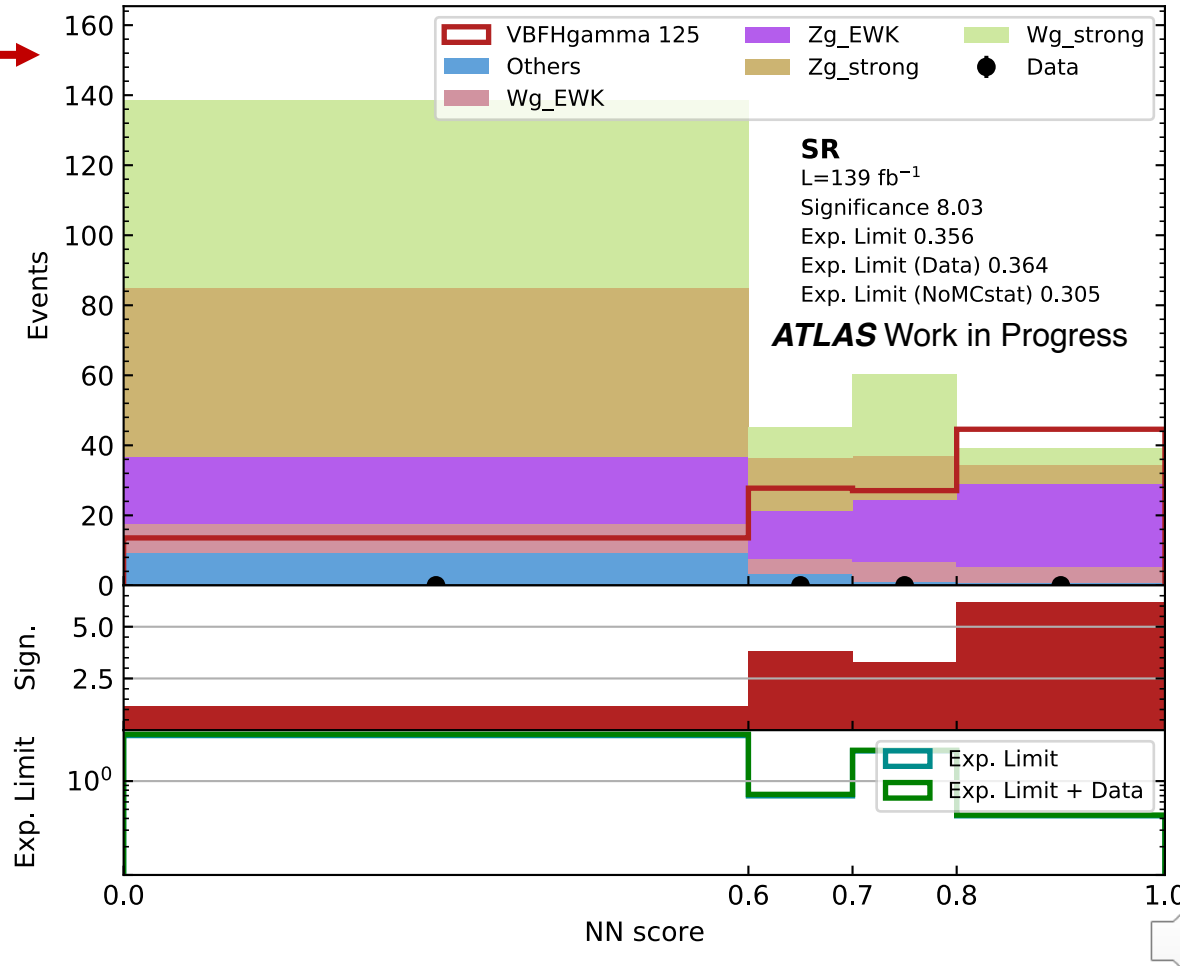
Deep Neural Network (DNN)- performance

SR selections applied →

Binning:

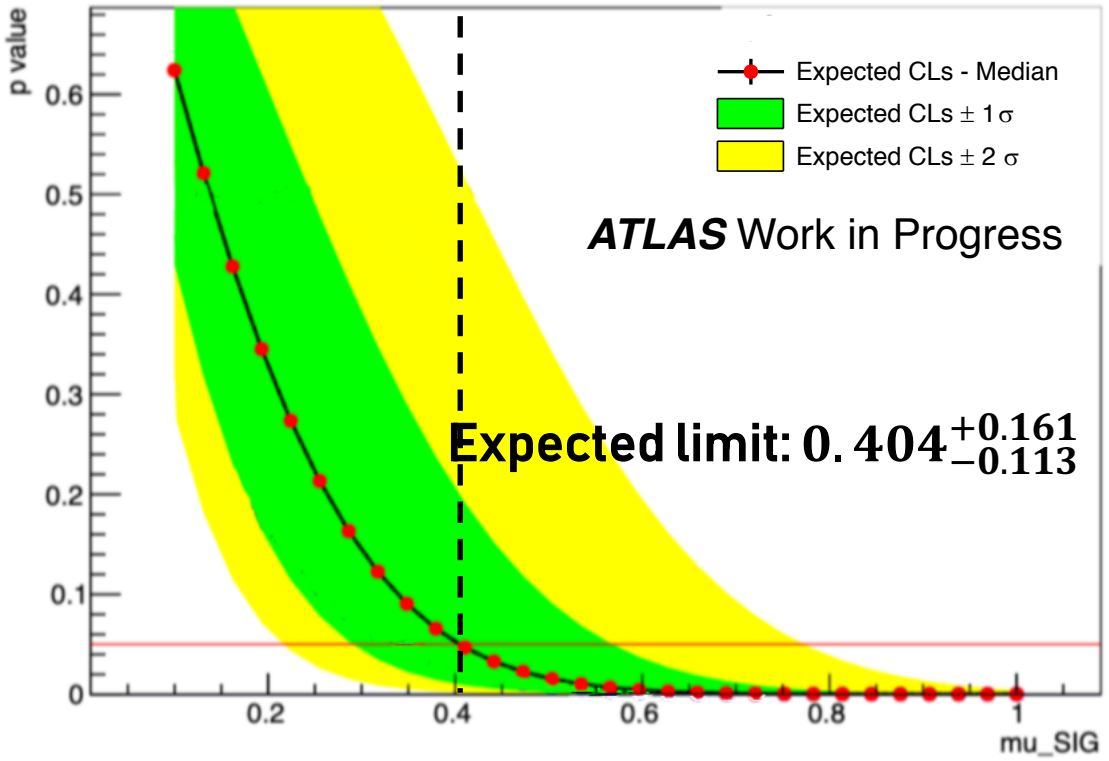
- Number of bins is fixed (4).
- Minimum bin size (0.05)
- Minimum number of events per bin (20),

The ELE is evaluated for all the possible binning choices and the best one is selected

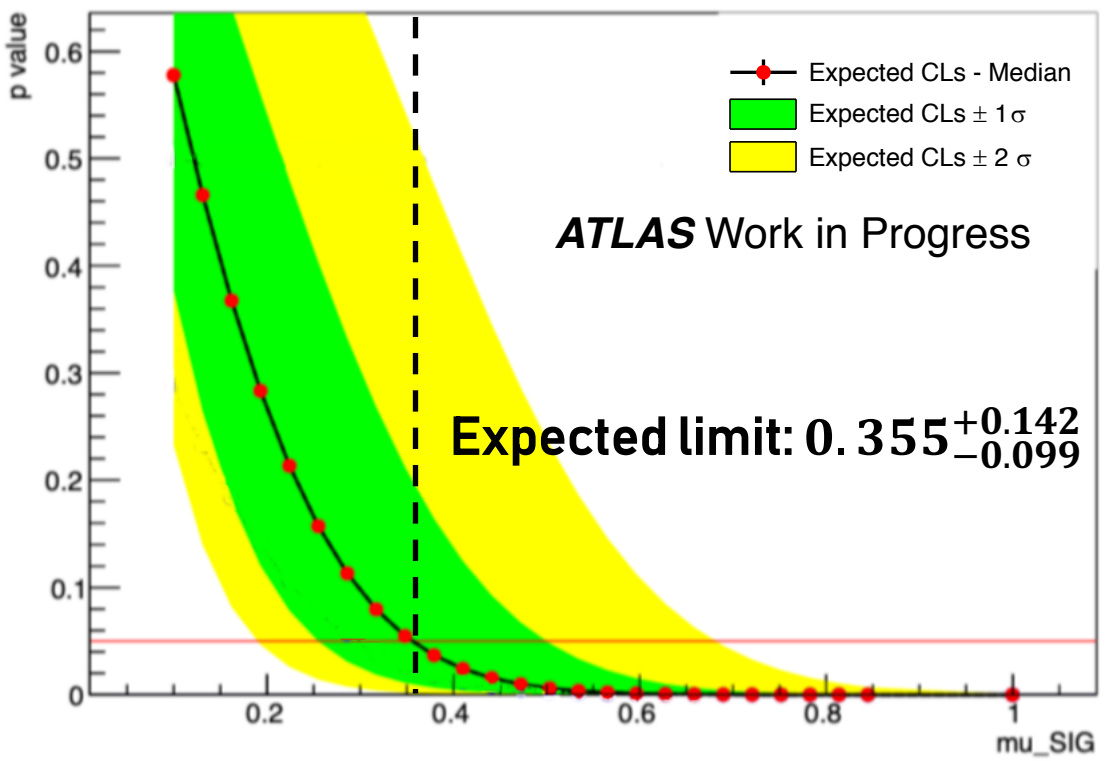


NN-CutBased limit comparison

CutBased



NN



Stat only, profile likelihood fit

~10% improvement

Conclusions

- A search for anomalous Higgs decays to invisible final states in the VBF + photon channel has been presented
- A solid procedure for the training of a DNN for Background vs Signal classification as been set up
- The DNN outperforms the "standard" cutflow analysis:
  - 10% improvement on the expected limit