Search for Dark Matter in association with a Higgs boson at $\sqrt{s} = 13$ TeV with the ATLAS Detector

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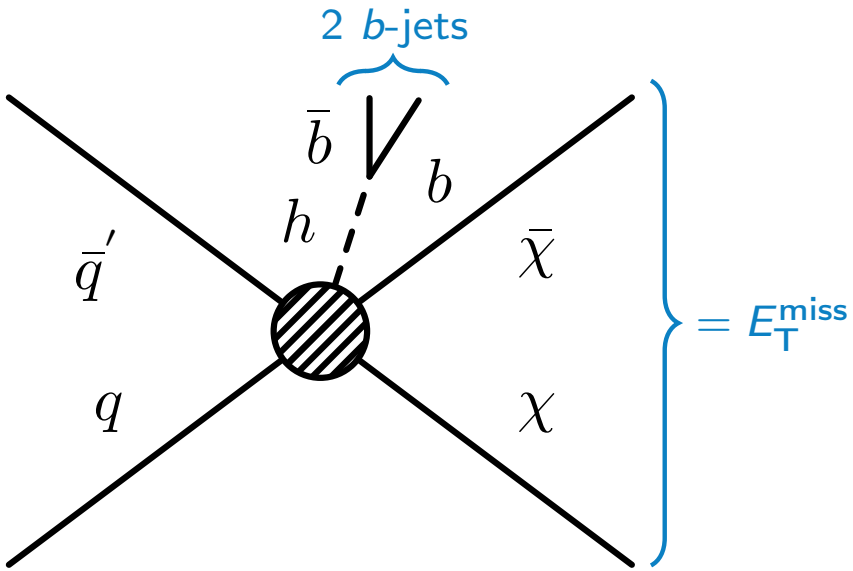
Search for Dark Matter in the Mono-Higgs Channel

- Search for events with a large missing transverse energy ($=E_{\mathrm{T}}^{\mathrm{miss}}$) in association with the Standard Model (SM) Higgs boson, where $h \to b\bar{b}$.



Event signature: 2 b-jets and large $E_{\mathrm{T}}^{\mathrm{miss}}$.

\+ Possible to probe the couplings of the Higgs boson to dark matter (DM).

\+ Channel is sensitive to small and large masses of DM particles.

What are the models to produce such non Standard Model signatures?

Signal Models: Effective Field Theories or Simplified Models

Effective Field Theories (EFT):

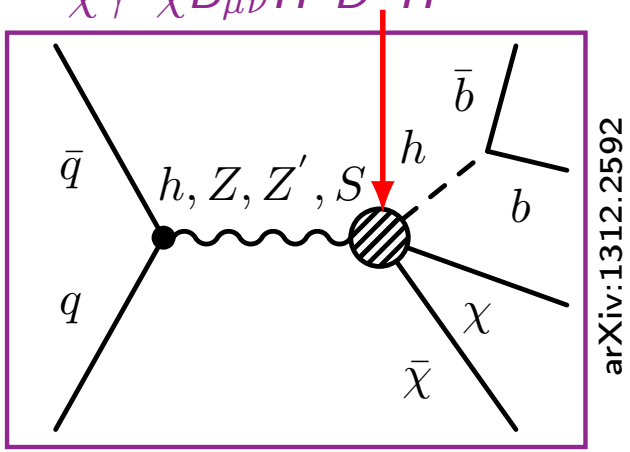
- Contact operators describe the point-like SM-DM interaction.

\+ Minimal model dependence.

\+ Limited number of free parameters: m_χ and Λ (energy scale of interaction).

– $\Lambda >>$ momentum transfer: validity at higher $\sqrt{s}$?

EFT Operator, e.g.
$\bar{\chi}\gamma^\mu\chi B_{\mu\nu}H^\dagger D^\nu H$



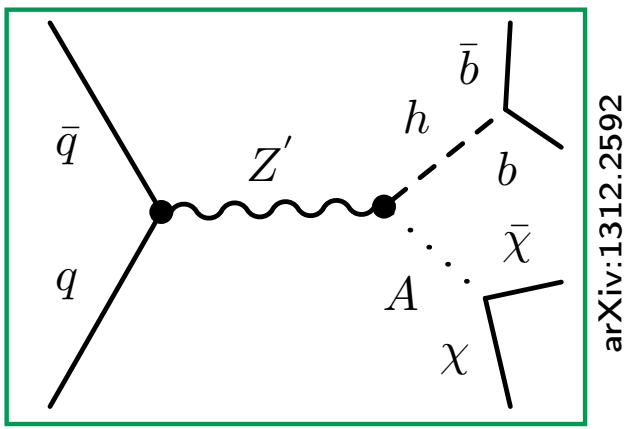
Simplified Models:

- New massive mediator particle which mediates the DM-SM interaction.

\+ Descriptive theory, not limited by momentum transfer.

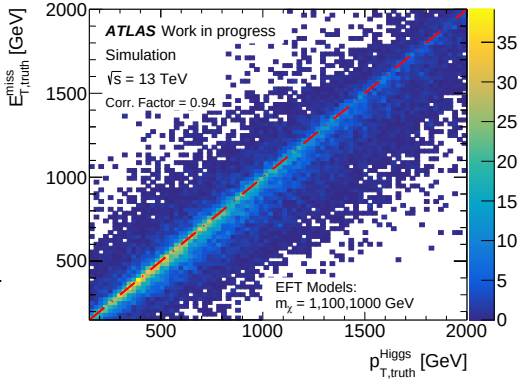
– More free parameters, e.g. $m_A, m_{Z'}, m_\chi, \tan\beta, g_Z$.

Z'- 2 Higgs doublet model



Final State Topology of the Jets from Higgs Decays

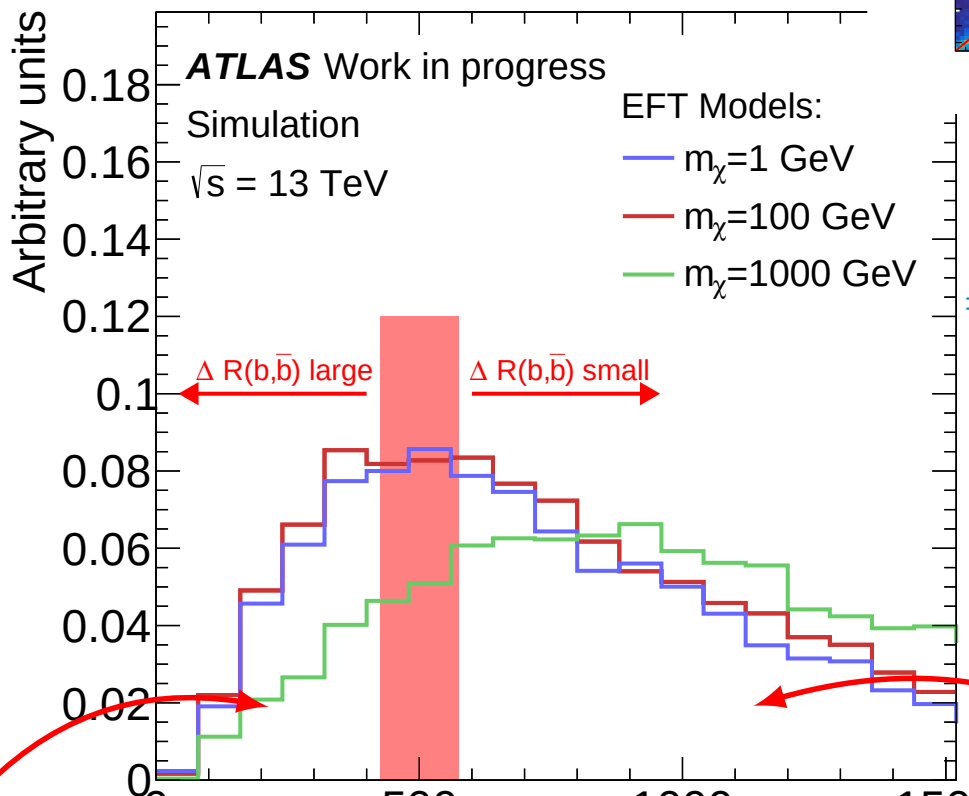
- Transverse momentum of the Higgs boson $p_{\mathrm{T}}^{\mathrm{Higgs}} \approx E_{\mathrm{T}}^{\mathrm{miss}}$.
- b-jet separation: $\Delta R(b,\bar{b}) \approx \frac{2 \cdot m_{\mathrm{H}}}{p_{\mathrm{T}}^{\mathrm{Higgs}}}$.

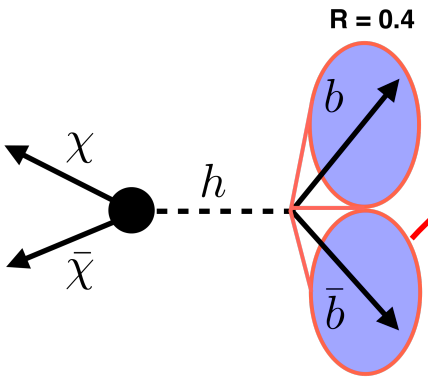


Resolved Regime

- $\Delta R(b,\bar{b})$ is large.

$\Rightarrow$ 2 small-R jets (anti$-k_{\mathrm{T}}$, $R = 0.4$) can be reconstructed.

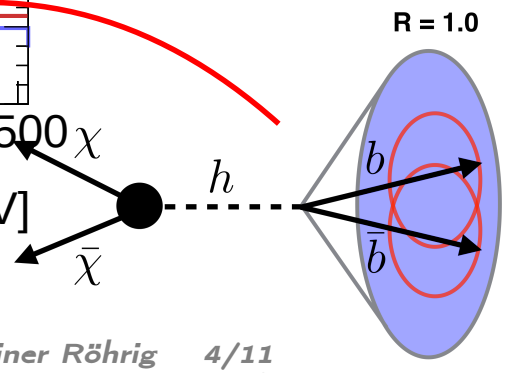




Merged Regime

- $\Delta R(b,\bar{b})$ is small.

$\Rightarrow$ 1 trimmed large-R jet (anti$-k_{\mathrm{T}}$, $R = 1.0$, $R_{sub} = 0.2$, $f_{cut} = 5\%$) can be reconstructed.



Event Selection - 0 Lepton Signal/Control Region

E_T^{miss} trigger: 70 GeV

Veto on electrons and muons

p_T^{miss}(ID) $>$ 30 GeV

E_T^{miss}(Calo) $>$ 150 GeV

Resolved Regime:

$E_T^{miss} < 500$ GeV

$\geq$ 2 small-R jets

Anti-multijet cuts

0 b-jets | 1 b-jet | 2 b-jets

CR | SR

Merged Regime:

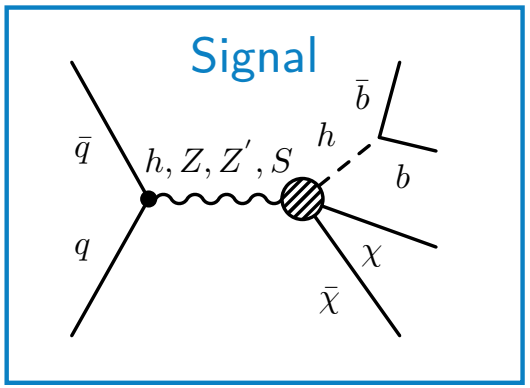
$E_T^{miss} > 500$ GeV

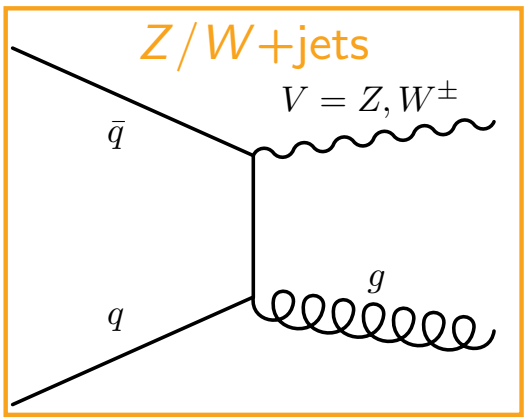
$\geq$ 1 large-R jet

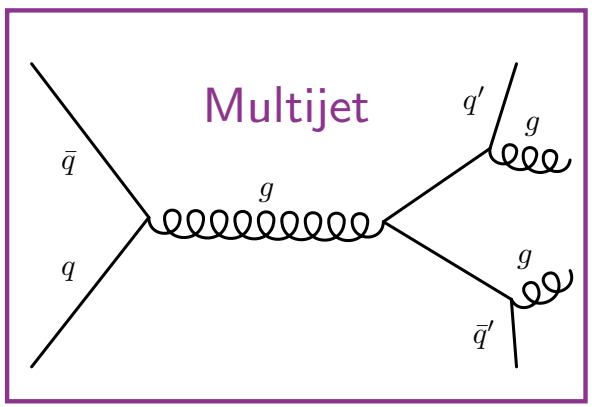
$\geq$ 2 track based jets associated to the leading large-R jet

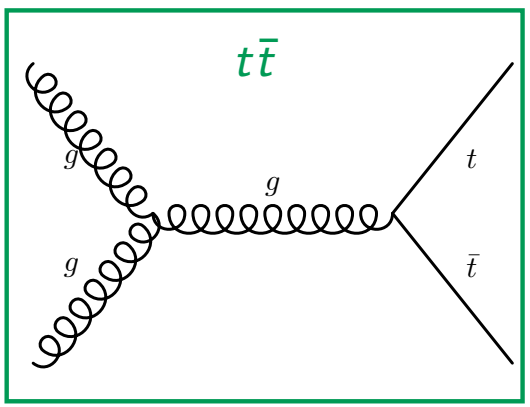
0 b-jets | 1 b-jet | 2 b-jets

CR | SR



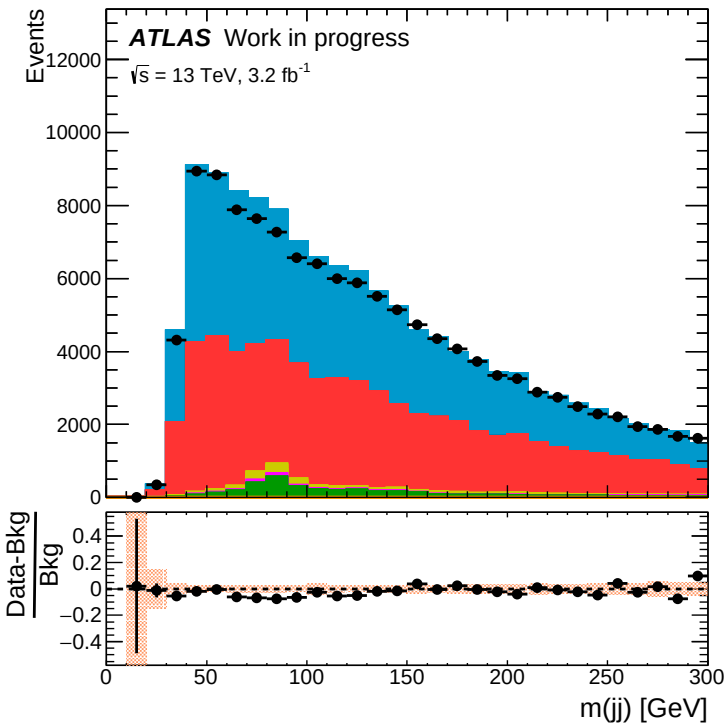




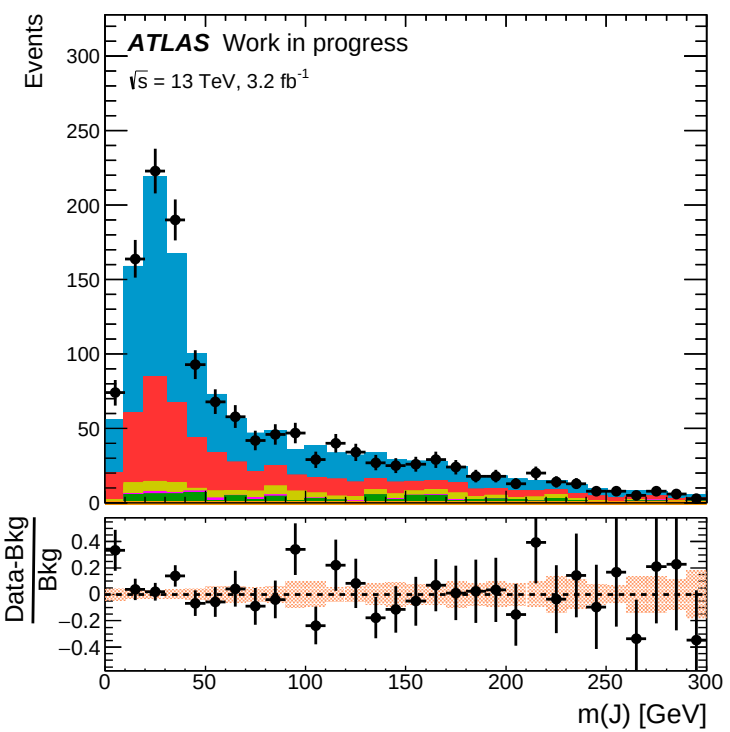


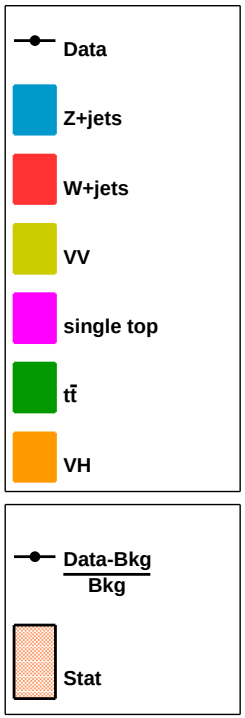
Results in the 0 Lepton and 0 b-Tag Control Region

Resolved regime



Merged regime

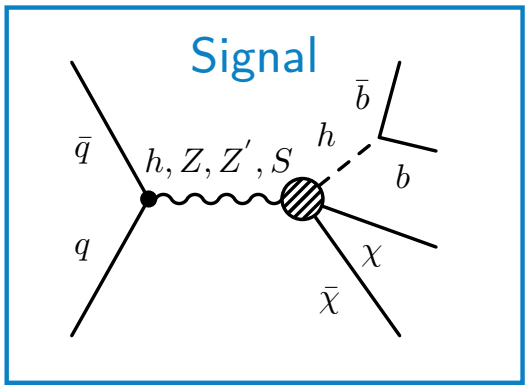


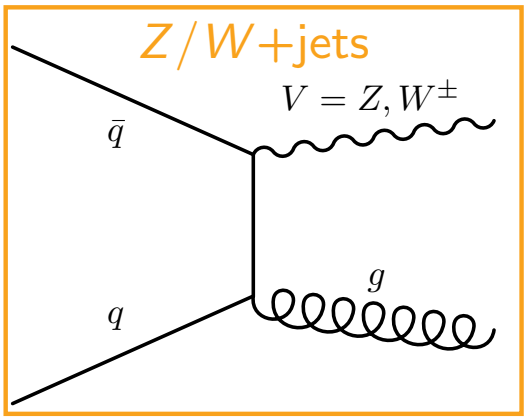


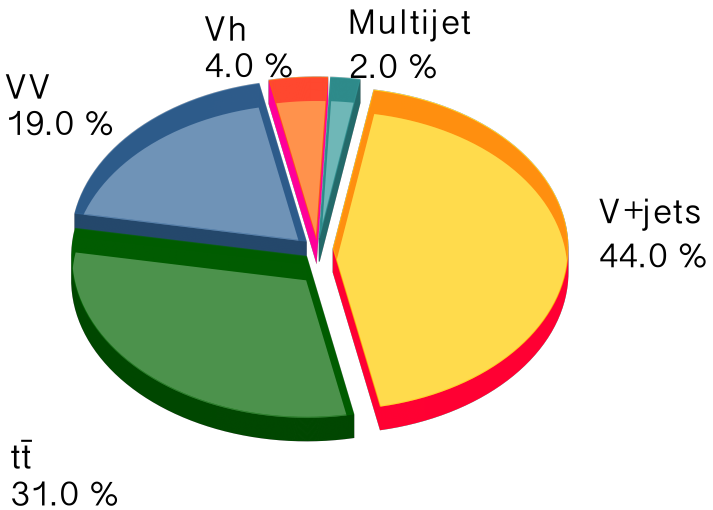
- The final mass distributions $m_{\text{jet}_1\text{jet}_2}$ (left) and m_{Jet} (right).
- Control region dominated by Z+jets and W+jets processes.
- Very good agreement between data and simulation.

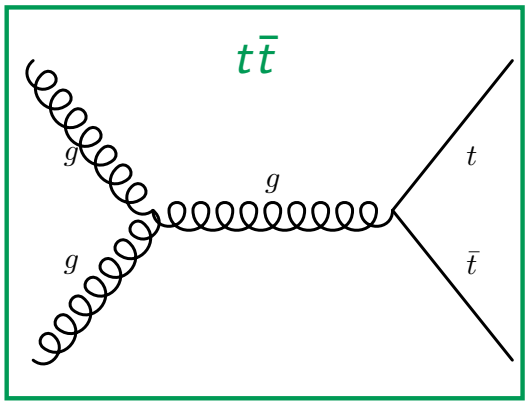
Event Selection - 1/2 Lepton Control Regions

- Control regions are used to estimate the backgrounds: V+jets and $t\bar{t}$.
- Same selection as for the 0 lepton CR/SR, but requiring 1 or 2 leptons.
- 1 lepton control region to estimate W+jets and $t\bar{t}$.
  - $t\bar{t}$ is mainly present in the 1 and 2 b-tag regions.
- 2 lepton control region to estimate $Z(\to \nu\nu)$+jets.





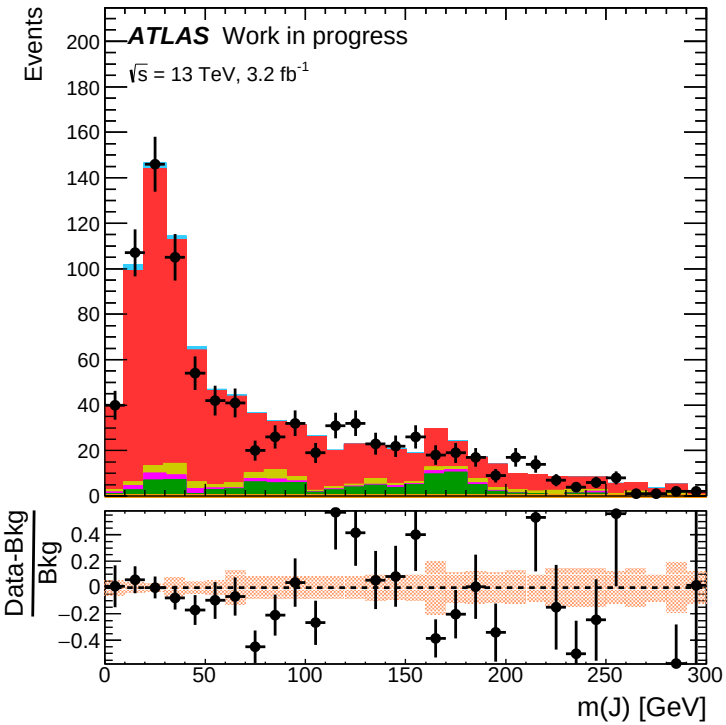




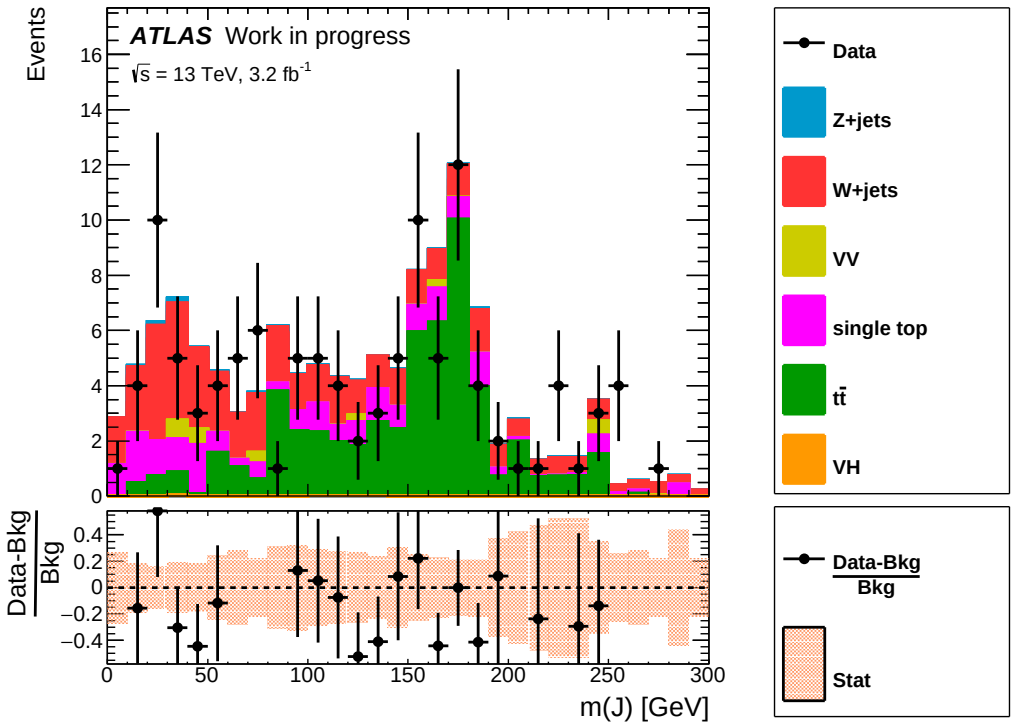
Results in the 1 Lepton Control Region – Merged Regime Only

Control regions are designed to:

estimate the W+jets background



estimate the $t\bar{t}$ background



- Select 1 isolated muon.
- Cut on $E_{\mathrm{T}}^{\mathrm{miss}}$ is modified: $E_{\mathrm{T}}^{\mathrm{miss}} + p_{\mathrm{T}}^{\mathrm{muon}} > 500$ GeV.
  (to emulate processes where a muon is not reconstructed).

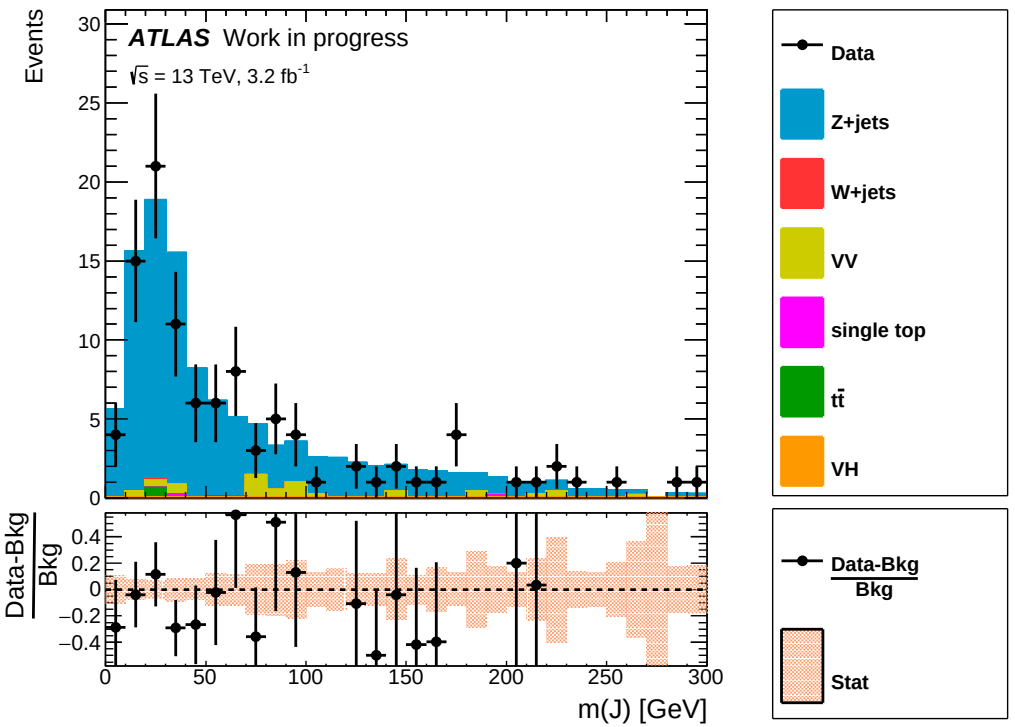
- 0 b-tag region: main contribution is W+jets.
- 1 b-tag region: main contribution is $t\bar{t}$.

Results in the 2 Lepton Control Region – 0 b-Tagged Jets

Control region is designed to estimate the $Z \to \nu\nu$+jets background.

- Use single lepton triggers instead of $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger.
- Select two isolated and oppositely charged leptons (=e or μ).
- Cut on $p_{\mathrm{T}}^{\ell\ell} > 500\mathrm{GeV}$ (emulating $E_{\mathrm{T}}^{\mathrm{miss}}$ in $Z \to \nu\nu$ events.)

Merged regime



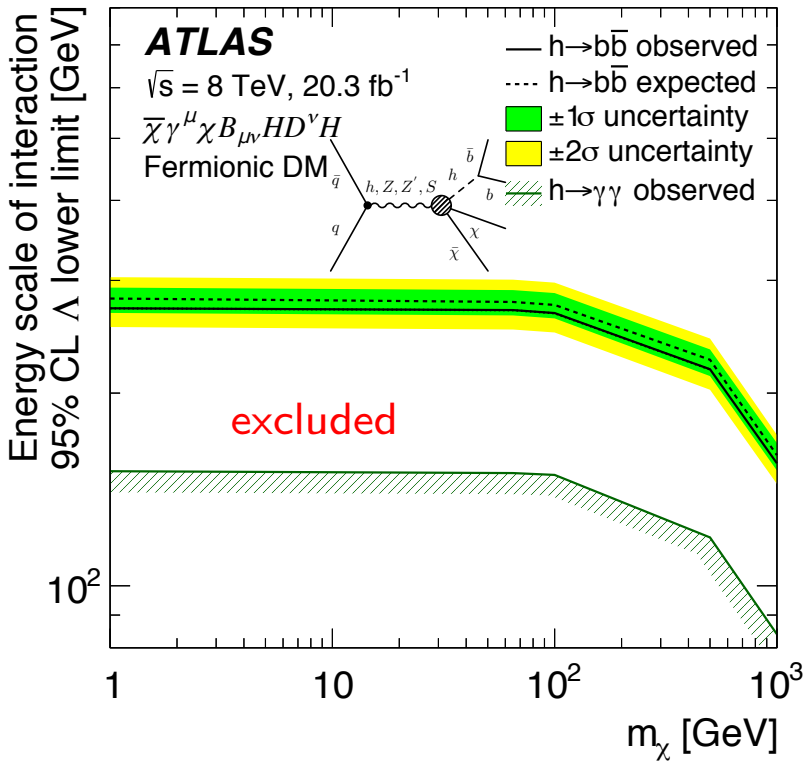
- Good agreement between data and simulation.

Statistical interpretation of data is obtained via simultaneous fits to the mass spectra in all signal and all control regions.

Mono-Higgs Run 1 Cross Section Limits

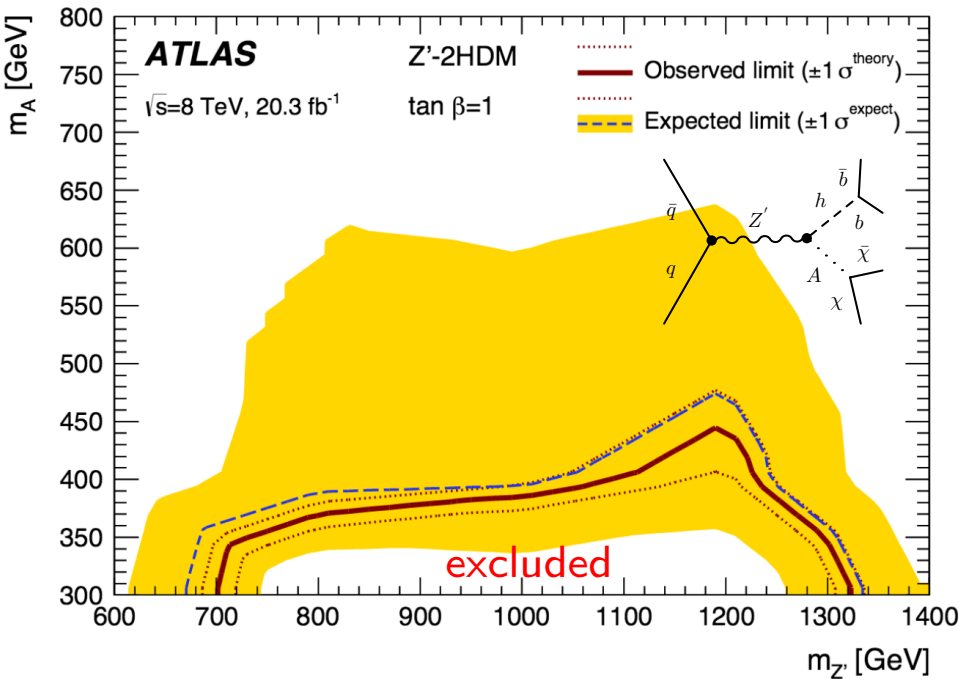
arXiv:1510.06218

EFT Model



- Limits are set in the $\Lambda - m_{\chi}$ plane.
- For small m_{χ}, values up to $\Lambda \approx 270$ GeV are excluded.

Simplified Model



- Limits are set in the $m_A - m_{Z'}$ plane.
- $m_{Z'} = 700 - 1300$ GeV is excluded for m_A up to 350 GeV.

Looking forward to the first run 2 results!

Summary

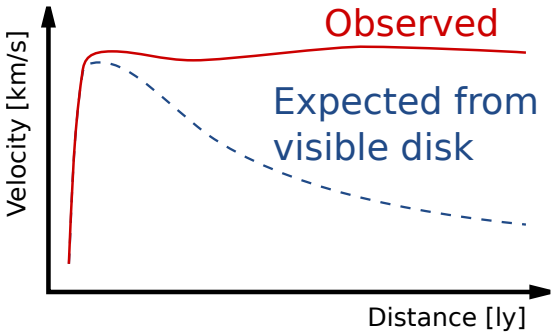
- The LHC searches for dark matter are competitive with and complementary to the direct and indirect detection experiments.
- After the discovery of the Higgs boson in 2012, the search for dark matter in association with the Higgs boson (mono-Higgs) becomes an interesting topic.
- Constraints on various dark matters models possible already with a few fb^{-1}.
- Data taking at $\sqrt{s} = 13$ TeV will restart soon and the discovery of dark matter at the LHC is hopefully around the corner.

Backup

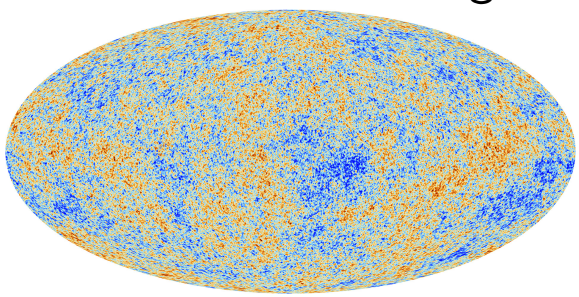
Evidence for Dark Matter

Presence of dark matter inferred from the observation of its gravitational interactions.

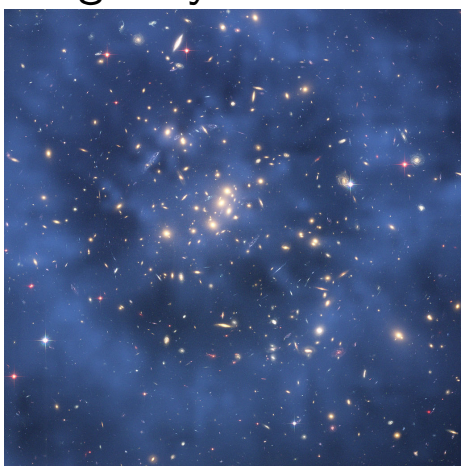
Rotation curves of spiral galaxies and of clusters of galaxies



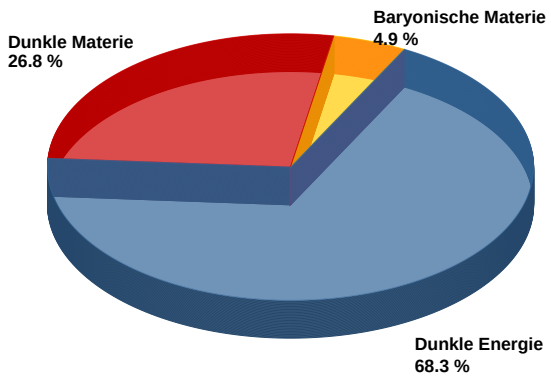
Cosmic microwave background



Gravitational lensing of galaxy clusters



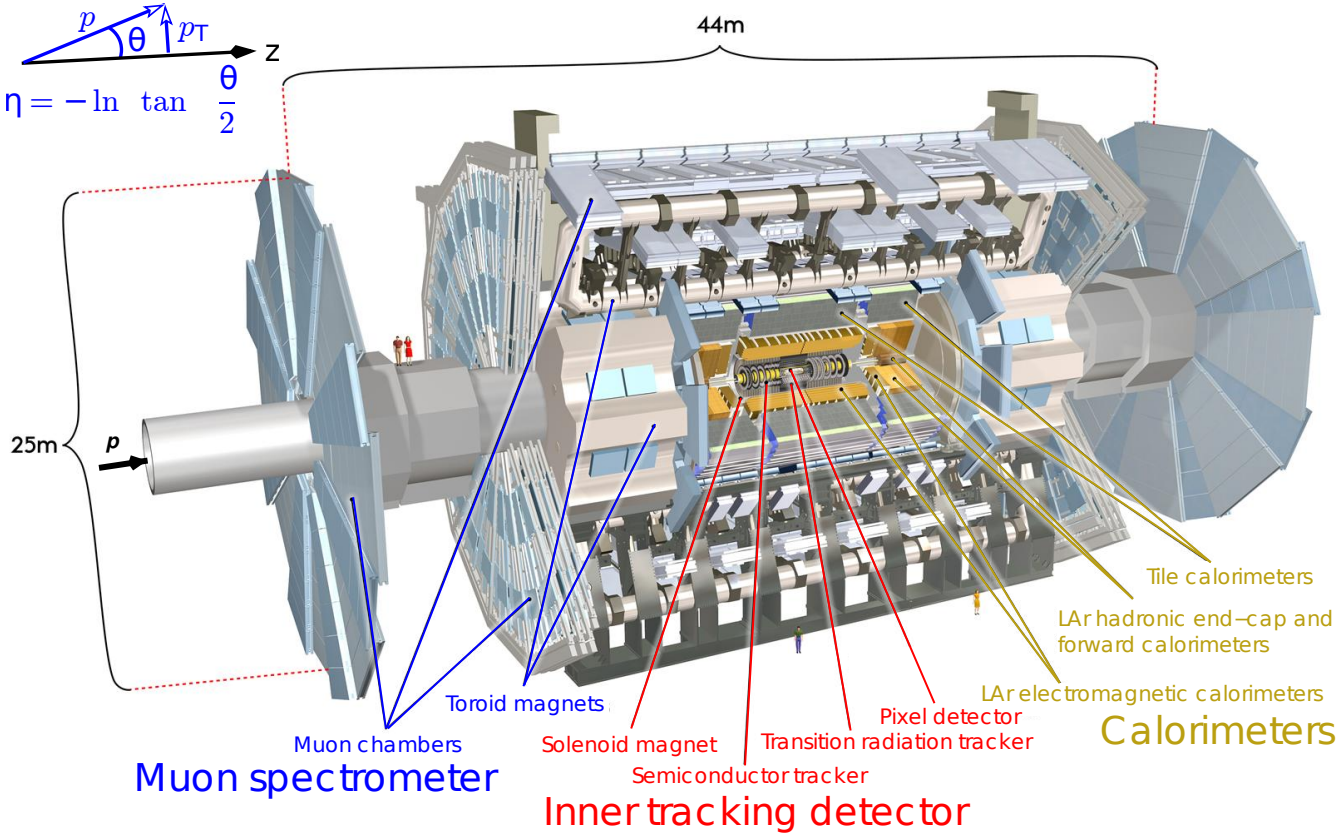
Structure formation in the early universe, $\approx 26.8\%$ of the content of the universe is DM



The ATLAS Detector

Inner Detector:

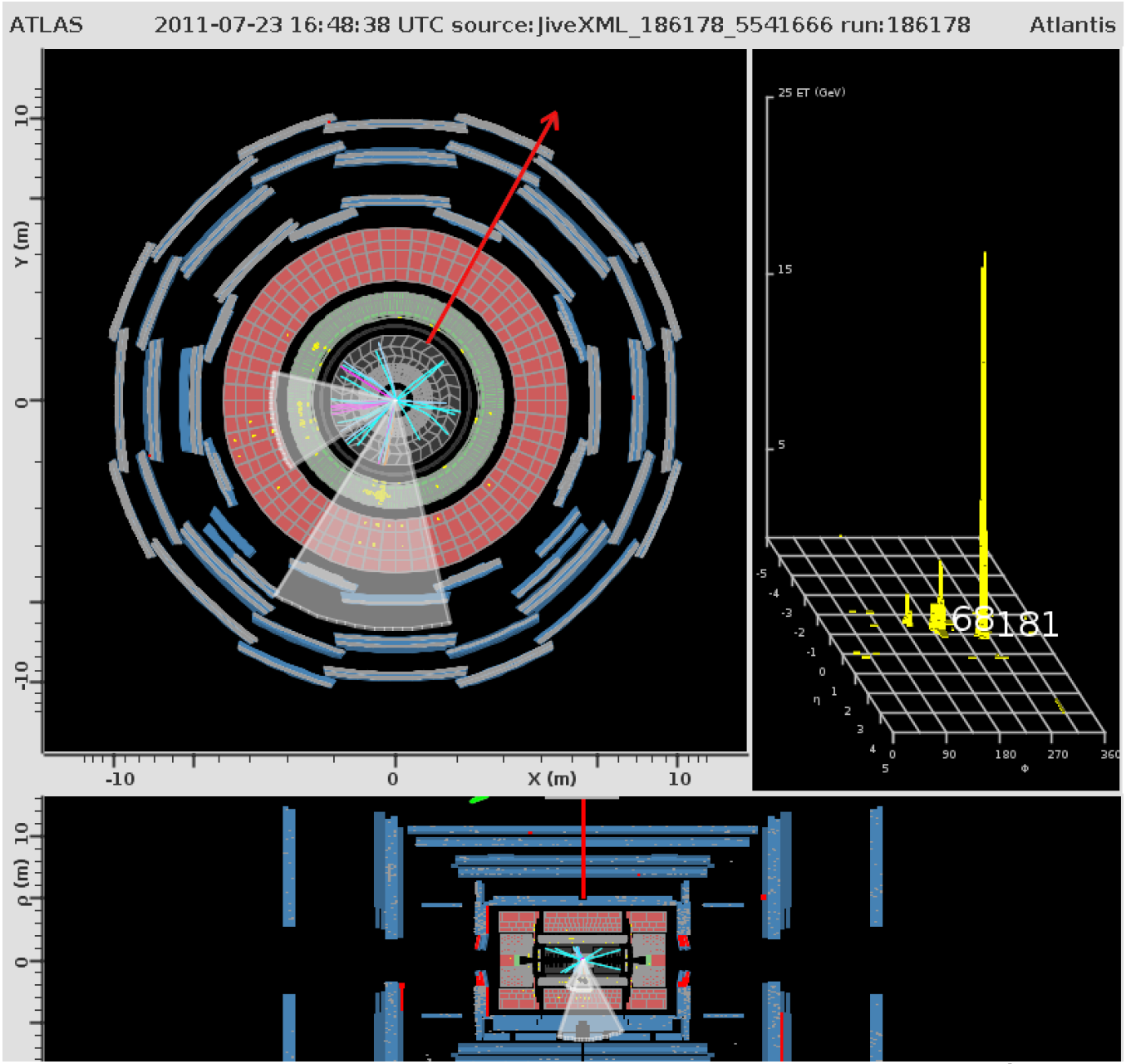
Reconstruction of decay vertices and particle tracks. Important for b-tagging and for the measurement of p_T^{miss}.



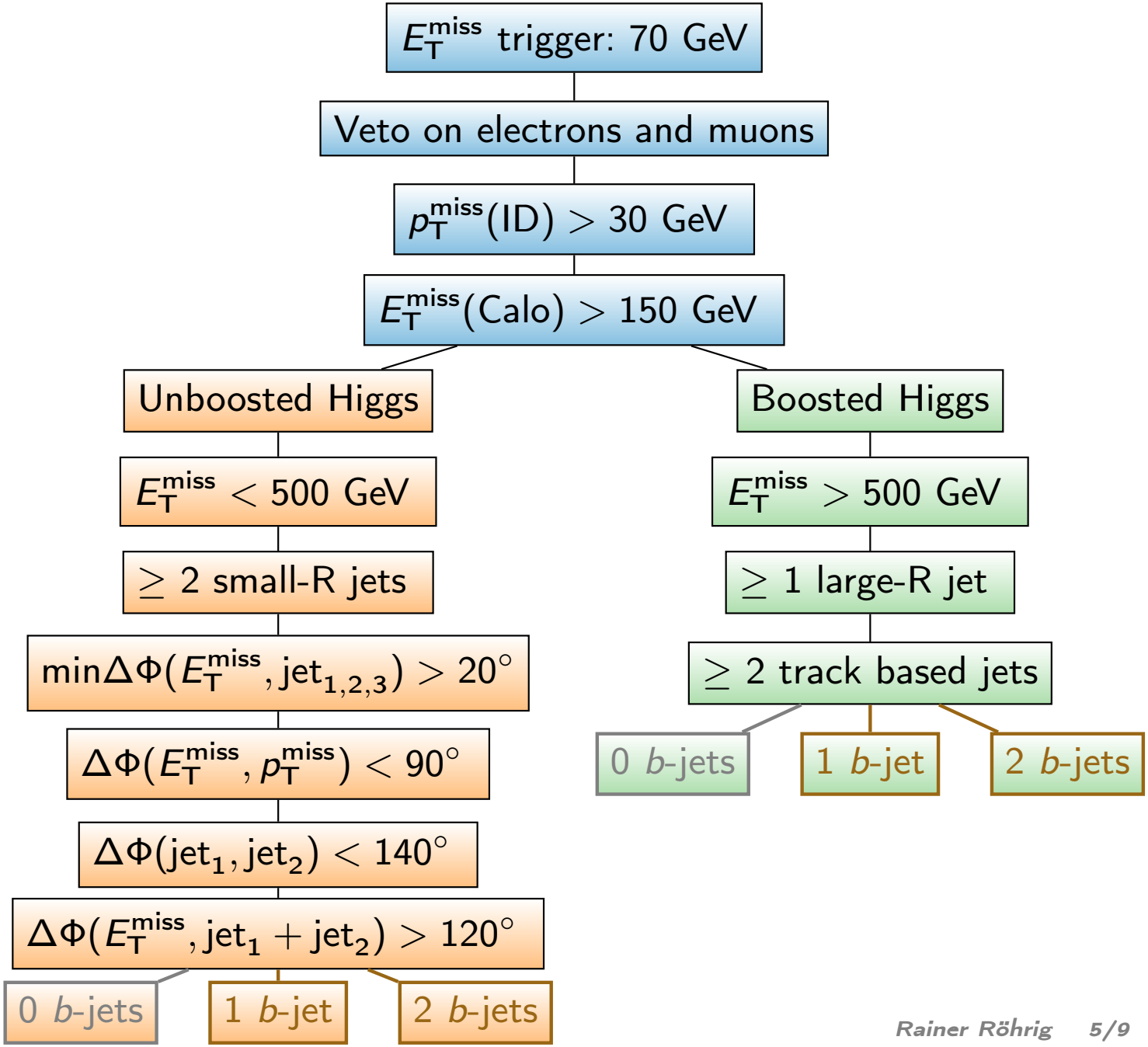
Hadronic Calorimeter:

Reconstruction of jets, and measurement of their energy. Measurement of E_T^{miss}.

Event Display

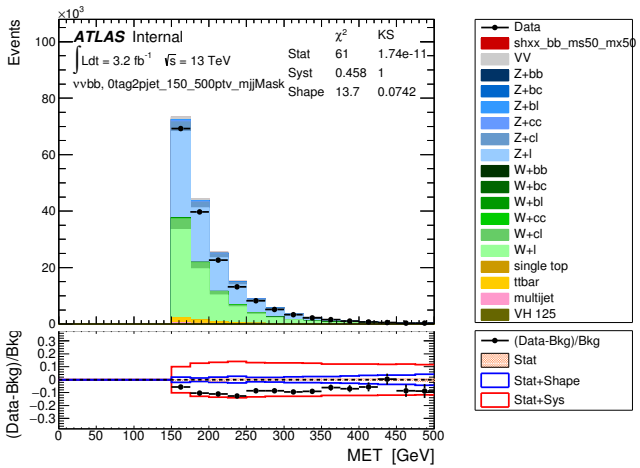


Event Selection

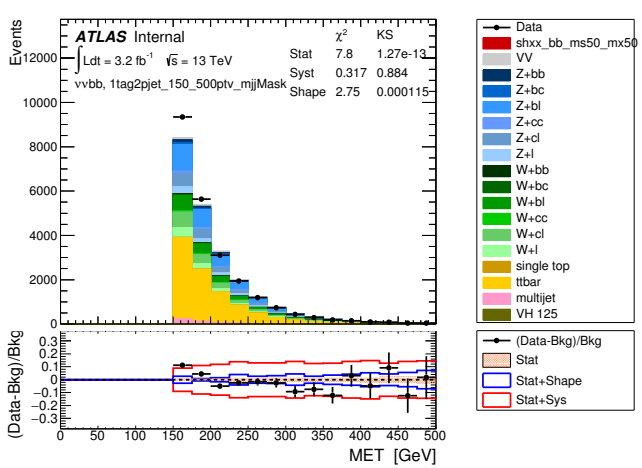


Missing Transverse Energy - 0 Lepton Control Region - Resolved

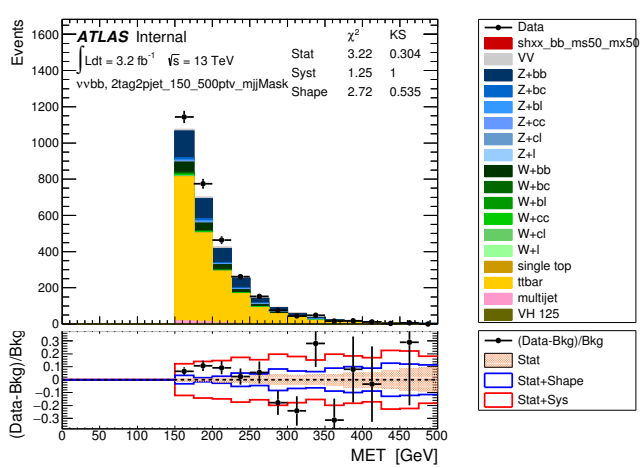
0 btag



1 btag

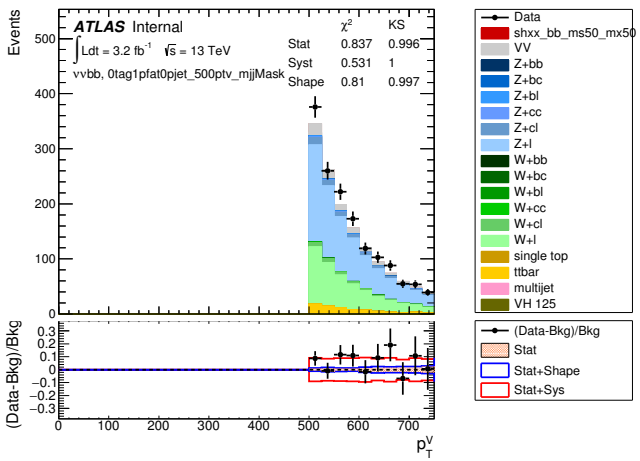


2 btag

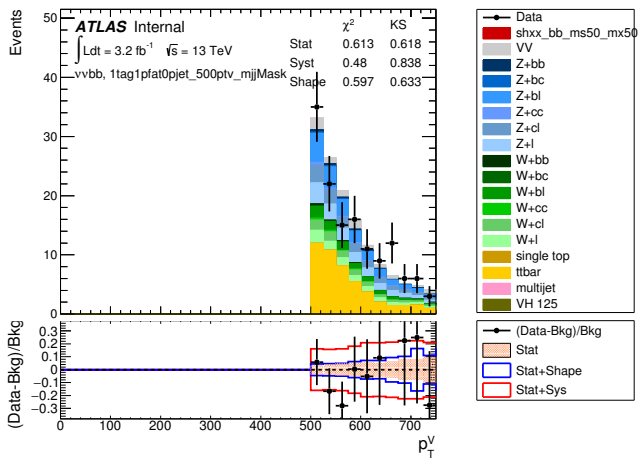


Missing Transverse Energy - 0 Lepton Control Region - Merged

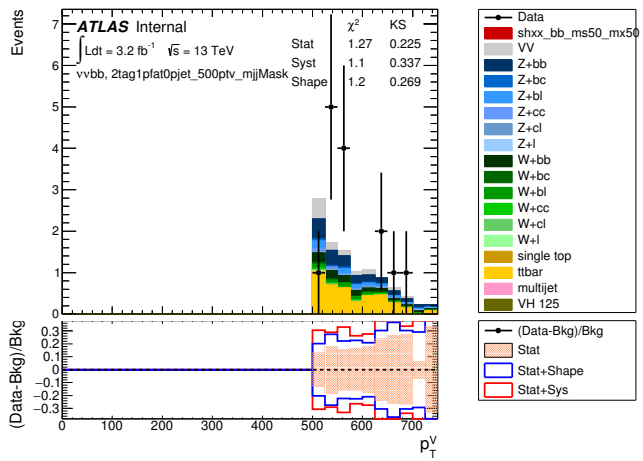
0 btag



1 btag

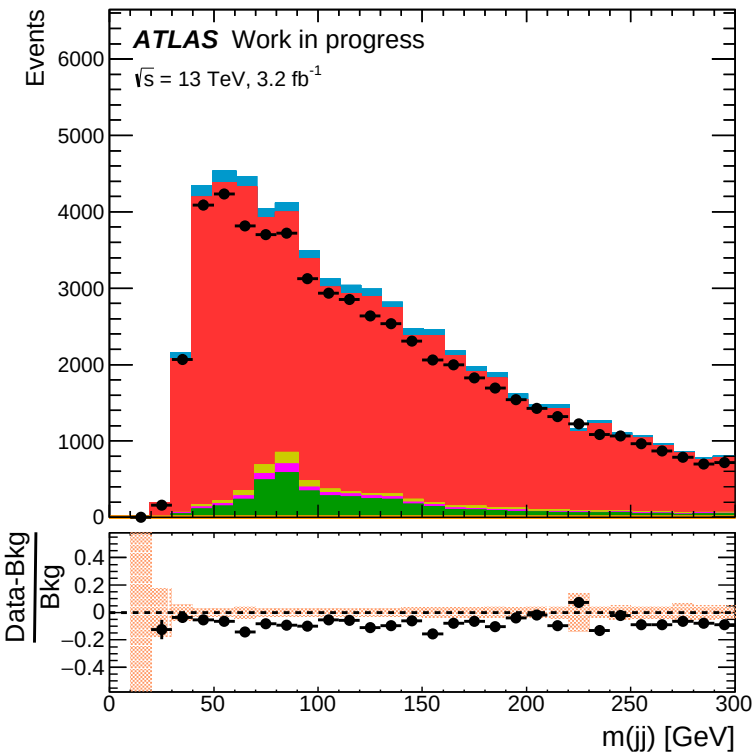


2 btag

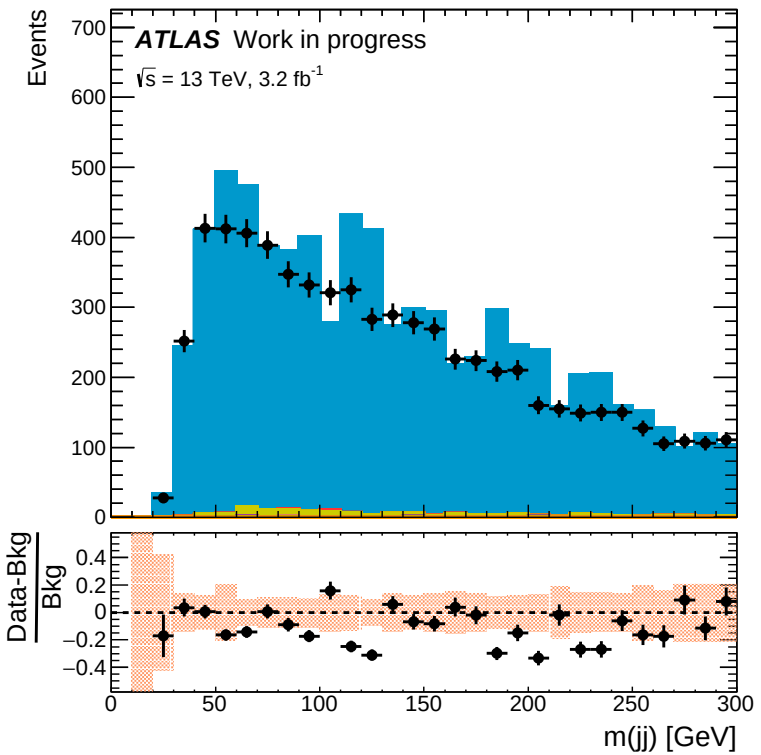


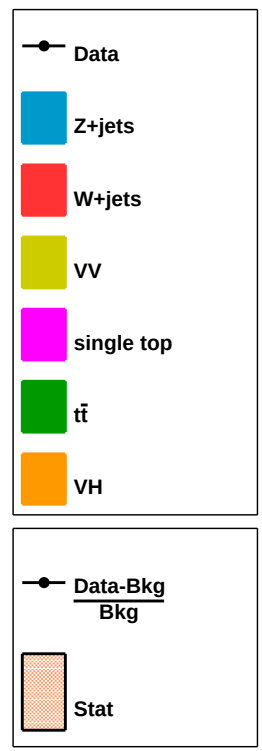
Results of the 1 and 2 Lepton Control Regions – Unboosted Regime

1 Lepton



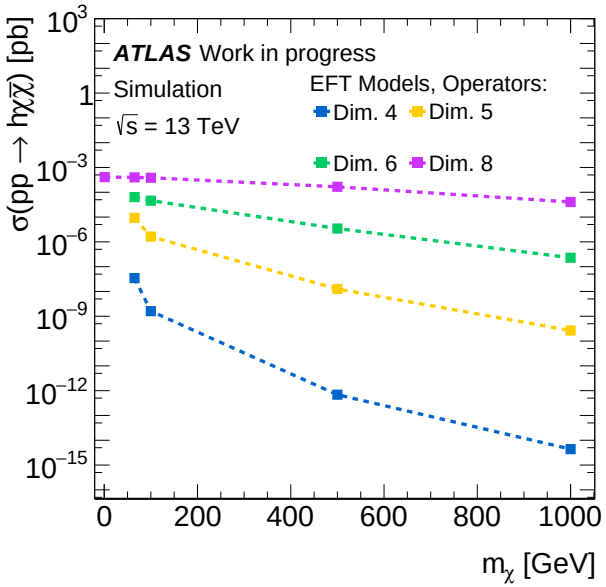
2 Lepton



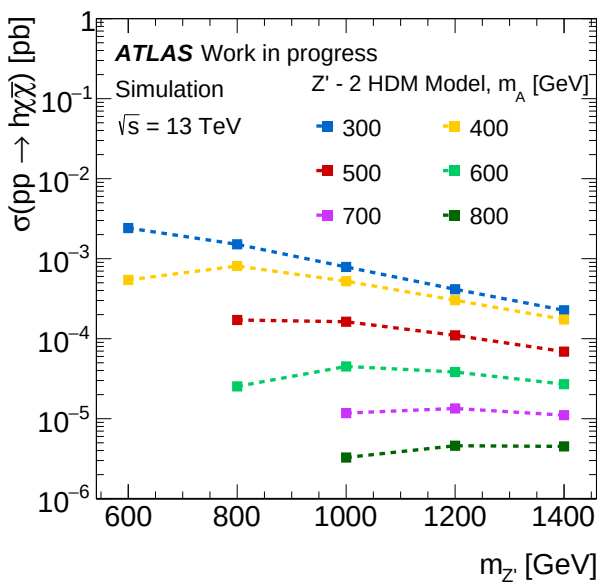


Cross Sections

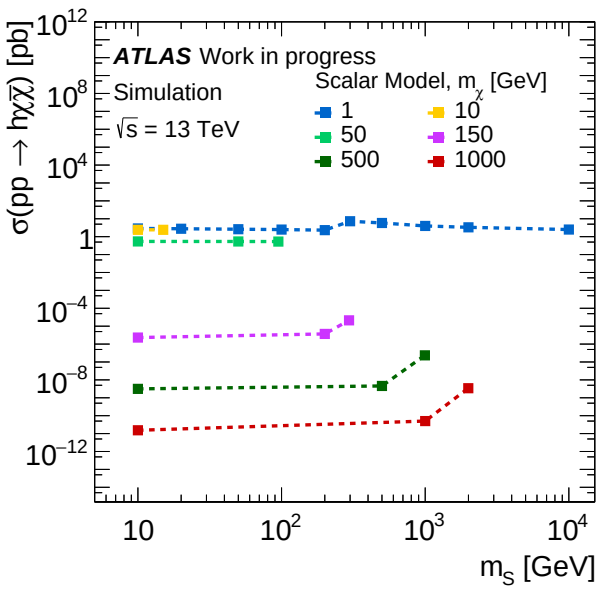
EFT



Z' - 2 HDM



Scalar Mediator



Vector Mediator