Recent Results on Dark Sectors in ATLAS

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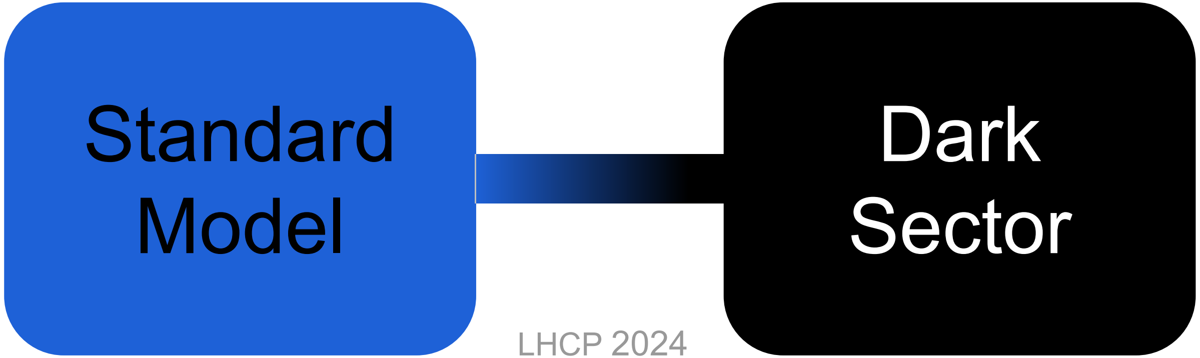
Introduction to Dark Sectors

Evidence of dark matter suggest it interacts through the gravitational force, but interaction via Standard Model gauge forces is yet to be observed.

Hidden sectors contain new particles and forces, which are hidden from us by a weak coupling to the Standard Model.

Dark sector models propose that a feably interacting mediator exists which creates a connection between the Standard Model and dark matter.

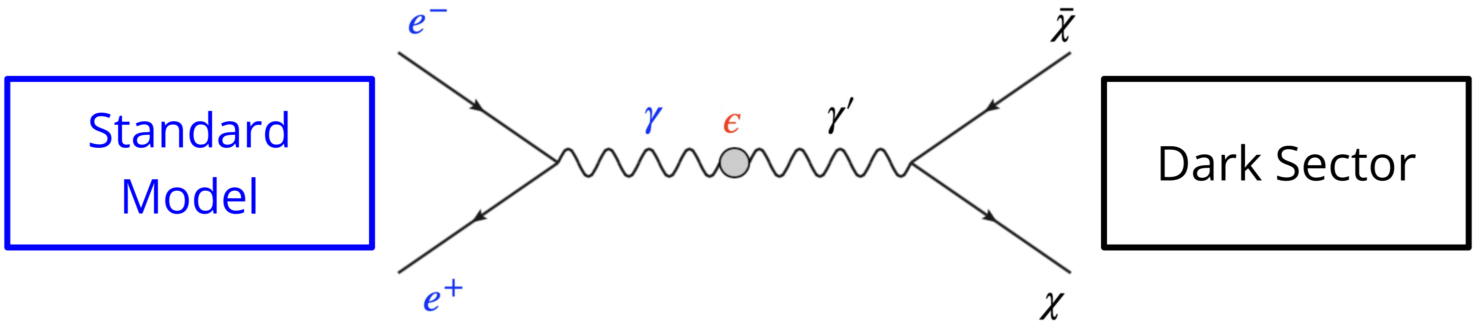


Dark Photons

Dark photon models introduce an additional U(1) gauge boson which kinetically mixes with the SM photon.

$$\mathcal{L} \subset -\frac{1}{4}\hat{B}_{\mu\nu}\hat{B}^{\mu\nu} - \frac{1}{4}\hat{Z}_{D\mu\nu}\hat{Z}_D^{\mu\nu} + \frac{1}{2}\frac{\epsilon}{\cos\theta}\hat{Z}_{D\mu\nu}\hat{B}^{\mu\nu} + \frac{1}{2}m_{D,0}^2\hat{Z}_D^{\mu}\hat{Z}_{D\mu}$$

Such a particle can act as a portal to a hidden sector.



U(1) symmetry can also be broken, introducing a dark Higgs.

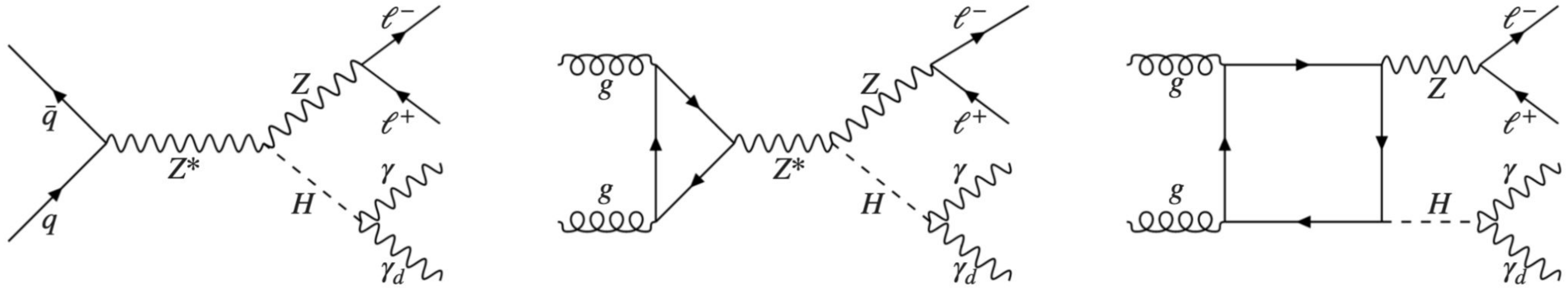
ZH, H→$\gamma\gamma_D$

Search for a Higgs boson decaying into a photon and a dark photon identified as MET.

Clean final state Z→l^+l^- and H→$\gamma\gamma_D$.

Final state includes two light leptons, a single photon and MET.

Current SM measurements constrain BR(H→$\gamma\gamma_D$) < 5%

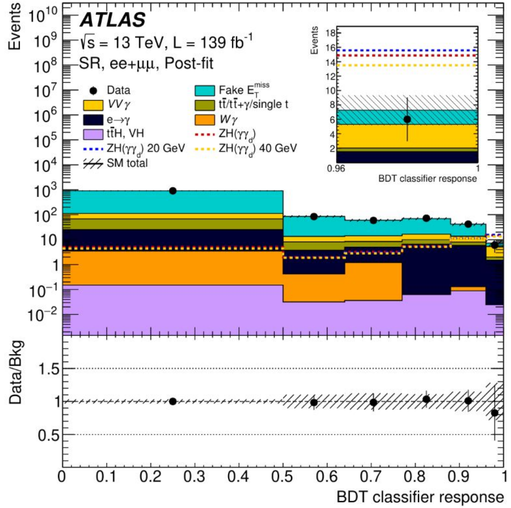


ZH, H→$\gamma\gamma_D$

Multivariate technique used to optimize cuts on SR.

BDT classifier then implemented, trained on:
MET significance, m_T, m_{ll}, p_T^{γ}, $m_{ll\gamma}$ and p_T^{ratio}.

Fit performed in a region where *ee* and *μμ* events are merged.

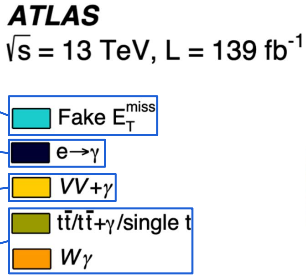


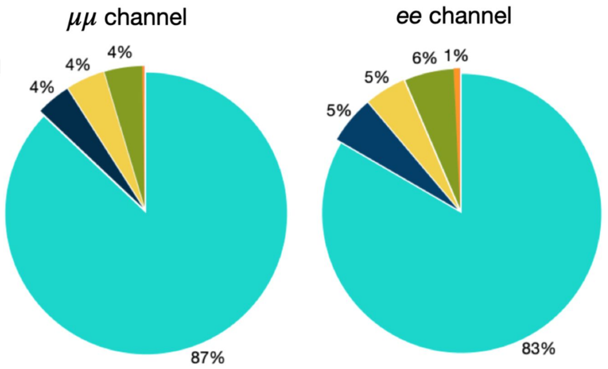
Data driven ABCD estimate

Data driven fake-rate estimate

MC estimate, normalized in CR

Pure MC estimate

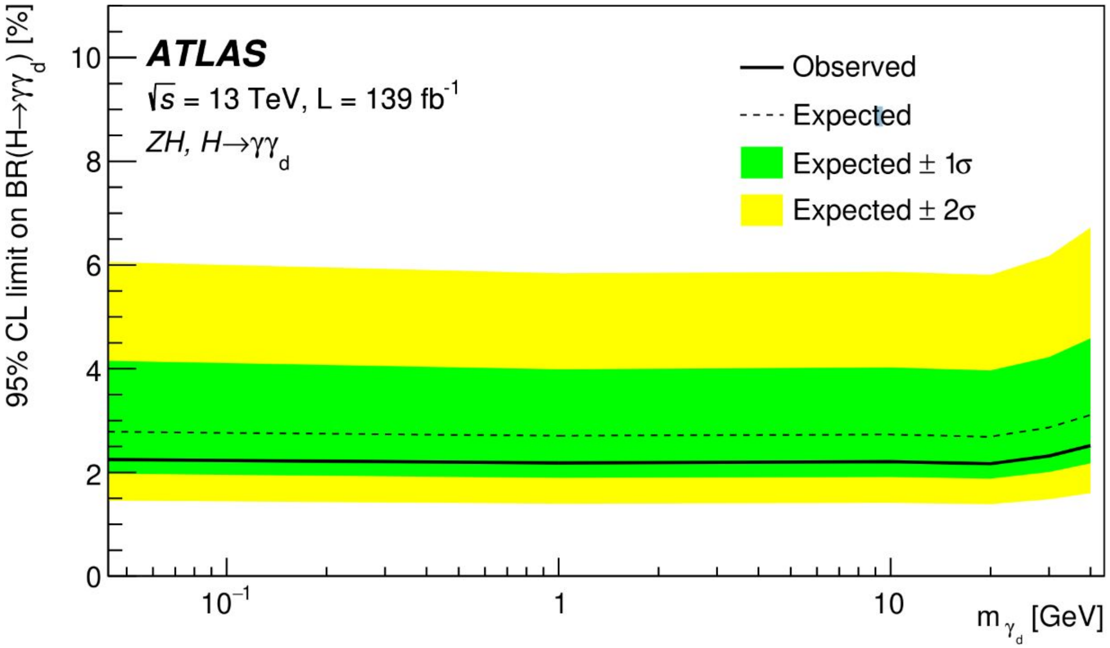




ZH, H→$\gamma\gamma_D$

Limits set on Higgs branching ratio to dark photon with mass from 0 to 40 GeV.

m_{γ_d}	$\mathrm{BR}(H \to \gamma\gamma_d)^{95\%\ \mathrm{CL}}_{\mathrm{obs}}$	$\mathrm{BR}(H \to \gamma\gamma_d)^{95\%\ \mathrm{CL}}_{\mathrm{exp}}$
[GeV]	[%]	[%]
0	2.28	$2.82^{+1.33}_{-0.84}$
1	2.19	$2.71^{+1.28}_{-0.81}$
10	2.21	$2.73^{+1.31}_{-0.82}$
20	2.17	$2.69^{+1.29}_{-0.81}$
30	2.32	$2.87^{+1.36}_{-0.86}$
40	2.52	$3.11^{+1.48}_{-0.93}$

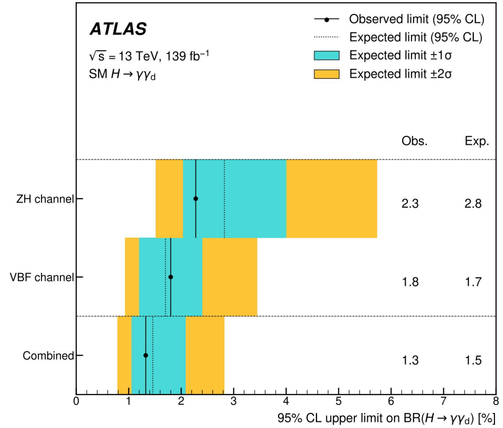


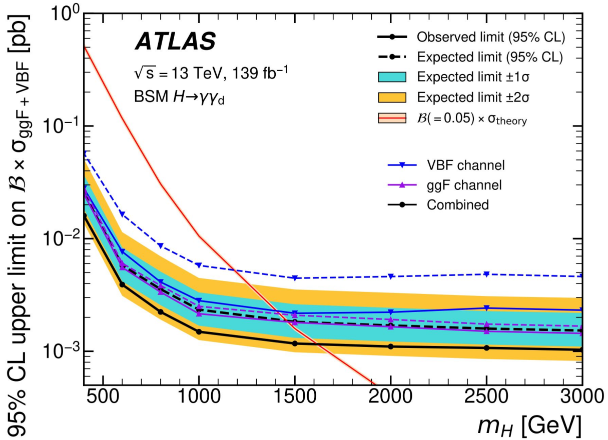
H→$\gamma\gamma_D$ combination

With the now public ZH, VBF and ggF channels, a new combination study was performed for the massless dark photon.

ZH and VBF channels are combined to set the most stringent upper limit on BR($H_{125}\rightarrow\gamma\gamma_D$) of 1.3%.

VBF and ggF channels are combined in the BSM Higgs scenario.





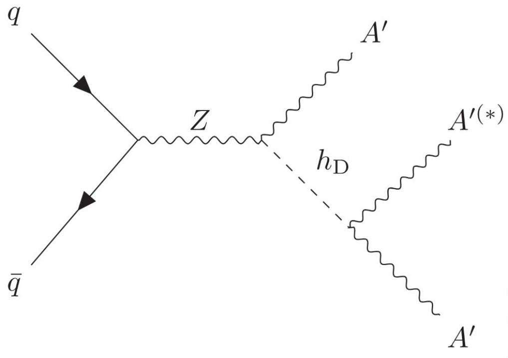
Rare Z decays

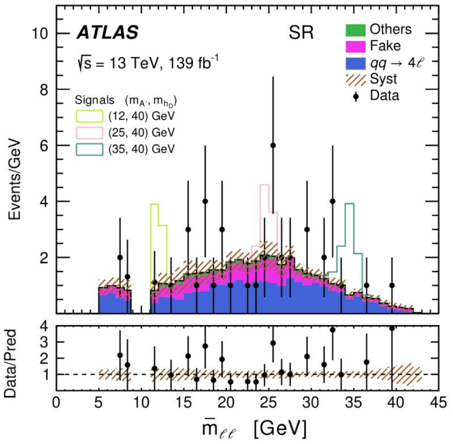
Search for $pp \rightarrow Z \rightarrow A'h_D$, $h_D \rightarrow A'A'^{(*)}$ with $m_{A'} + m_{h_D} < m_Z$, $m_{h_D} > m_{A'}$.

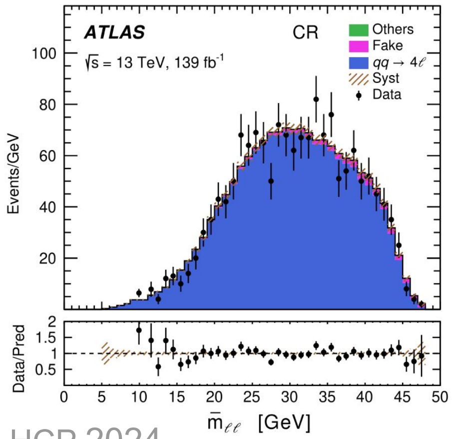
Dark photon is assumed to be the lightest particle in the DS, $BR(A' \rightarrow f\bar{f}) = 100\ \%$

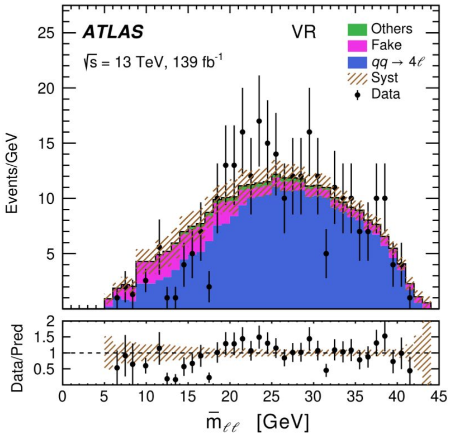
Final state includes at least 2 SFOC lepton pairs.

Dominant background, qqZZ, normalized in CR.



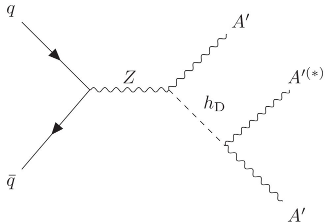




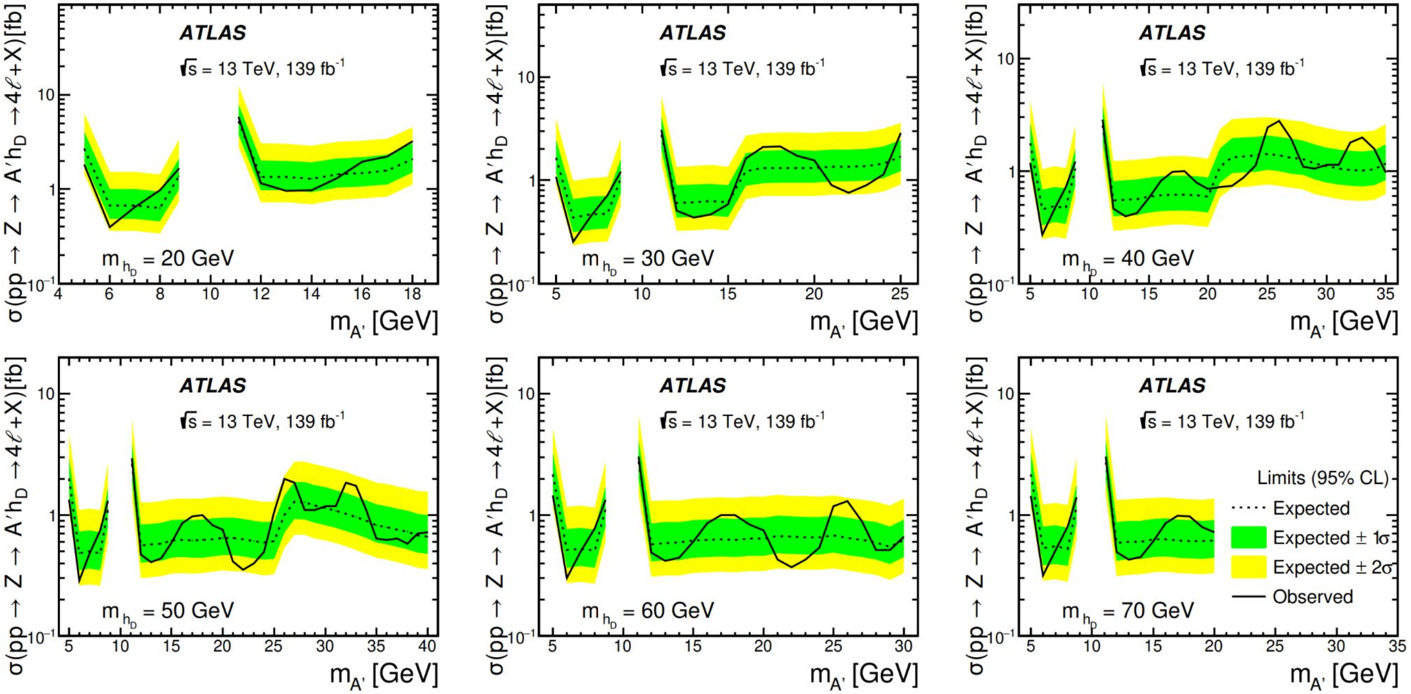


PRL 131, 51801

Rare Z decays

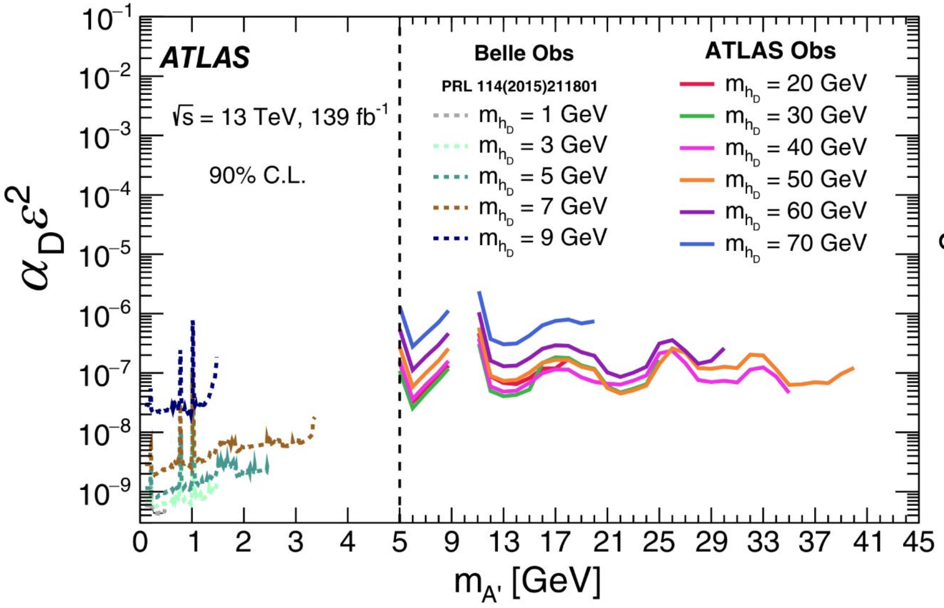


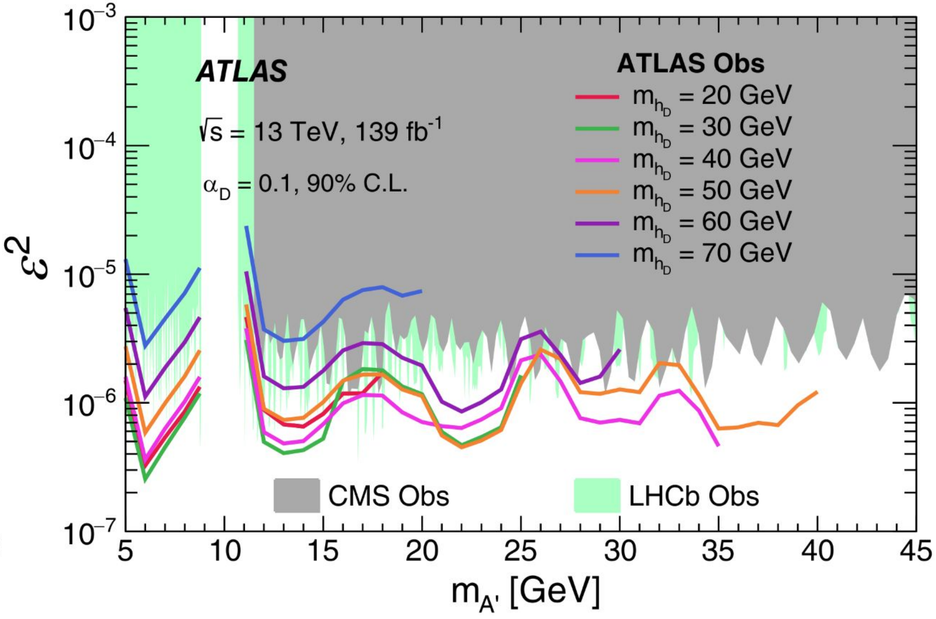
Upper limit set on the σxBR for 20 GeV < m_{h_D} < 70 GeV and 5 GeV < $m_{A'}$ < 40 GeV.



Rare Z decays

Interpreted as upper limit on the dark photon coupling to the dark higgs and the kinetic mixing between the dark photon and the SM photon

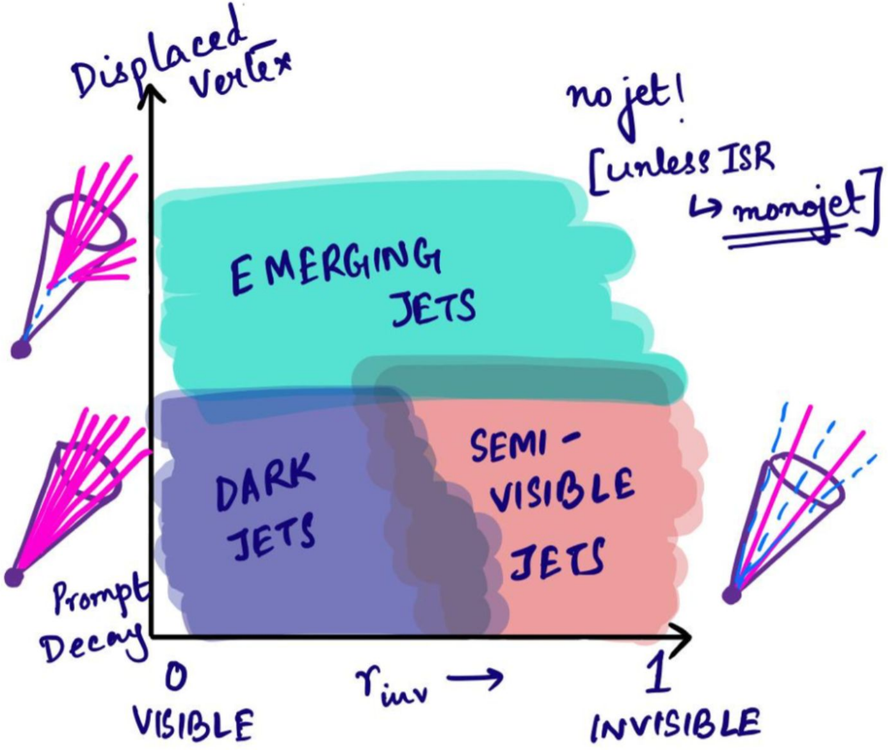




Dark QCD

The dark QCD regime can be divided into four distinct types of signatures.

1. Dark Jets: Dark hadrons decaying to QCD hadrons.
2. Emerging Jets: Displaced jet signatures.
3. Semi-visible jets: Some dark hadrons decay to QCD hadrons.
4. Monojet: One dark jet decays invisible to the detector.

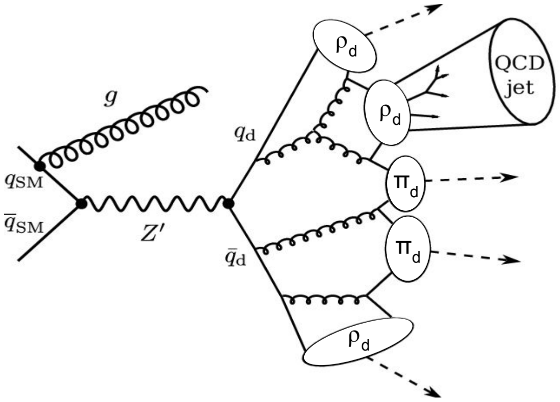


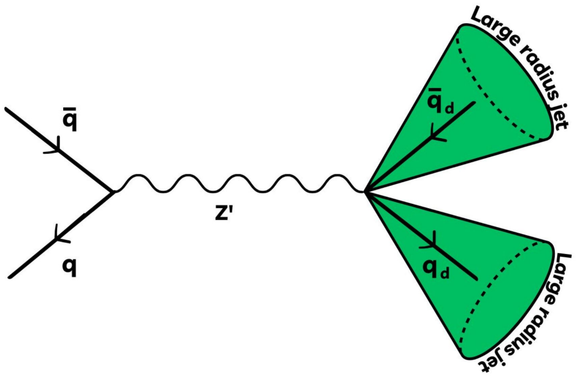
Dark quarks in dijet final states

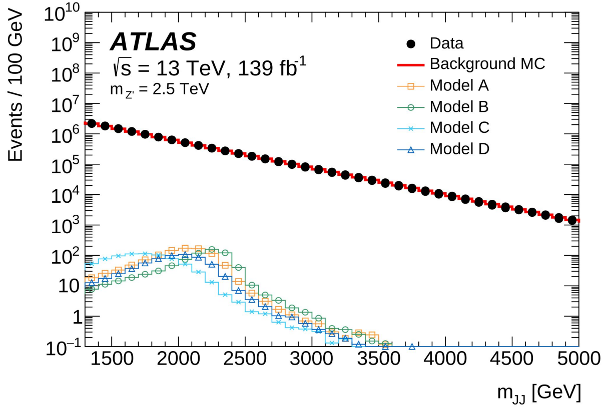
Production of dark quarks via a Z’ mediator resulting in a pair of QCD jets.

Double hadronization of dark quarks leads to two large radius QCD jets.

Search for resonance in dijet invariant mass.



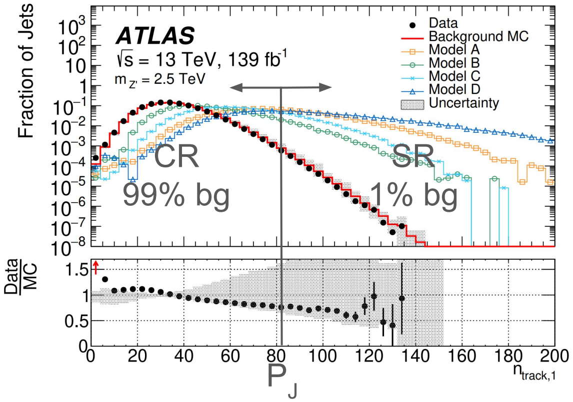




Dark quarks in dijet final states

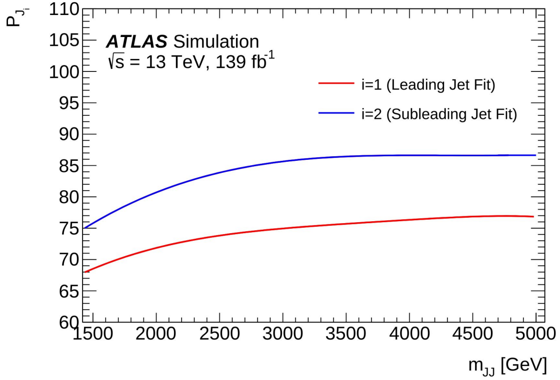
Dark jet selection optimization

- n_{Tracks} optimized in order to not 'sculpt' the background
- Set efficiency, ϵ, is chosen such that for each m_{jj} bin a minimum cut value, P_J, is determined such that $n_{tracks} > P_J$ leads to the target efficiency
- $n^{\epsilon}_{tracks} = n_{tracks} - P_j$, $n^{\epsilon}_{tracks} > 0$ is used to define SR



Modelling multijet background

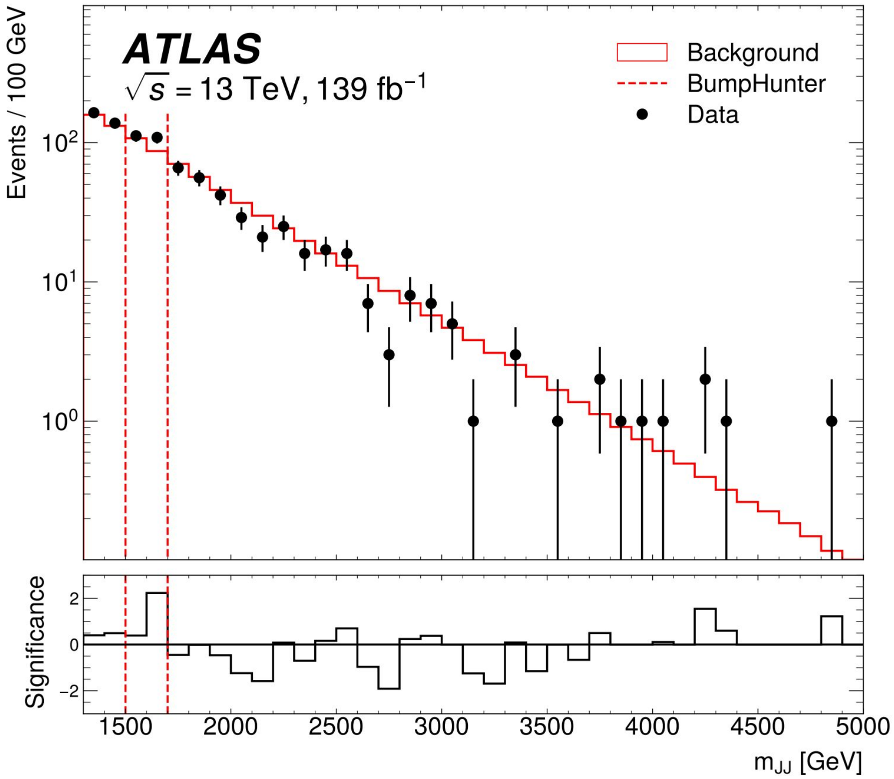
- Shape is extracted from $n^{\epsilon}_{tracks} < 0$ CR
- Normalization floated in SR



Dark quarks in dijet final states

A bumphunt was performed on the M_{jj} distribution in the signal region.

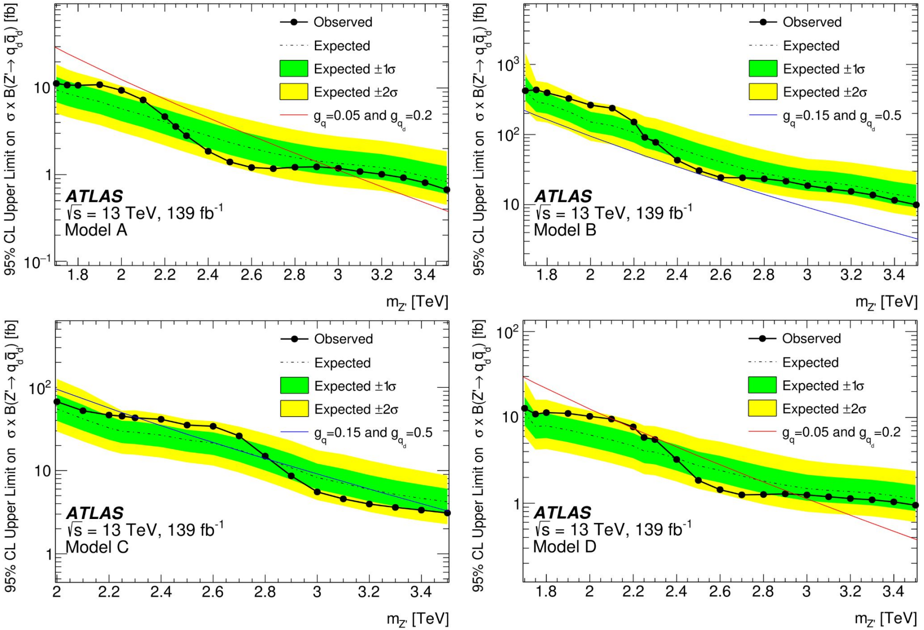
The most discrepant interval is between 1500 and 1700 GeV with a p-value of 0.63.



Dark quarks in dijet final states

Limits set on σxBR with respect to Z' mass for four different benchmark points representing different dark meson decay modes.

Model	n_f	Λ_d (GeV)	$\tilde{m}_{q'}$ (GeV)	m_{π_d} (GeV)	m_{ρ_d} (GeV)	π_d decay mode
A	2	15	20	10	50	$\pi_d \to c\bar{c}$
B	6	2	2	2	4.67	$\pi_d \to s\bar{s}$
C	2	15	20	10	50	$\pi_d \to \gamma'\gamma'$ with $m_{\gamma'} = 4.0$ GeV
D	6	2	2	2	4.67	$\pi_d \to \gamma'\gamma'$ with $m_{\gamma'} = 0.7$ GeV



Dark Mesons

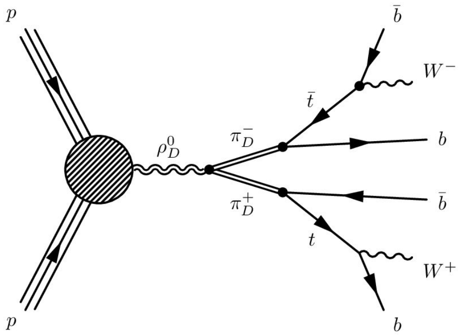
Search for dark mesons originating from a strongly coupled dark sector interacting with the EW part of the SM.

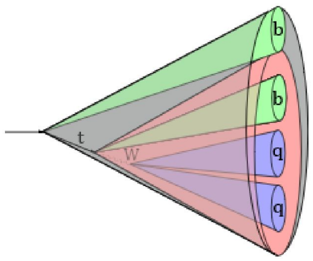
Focus on gaugephobic dark pion decays.

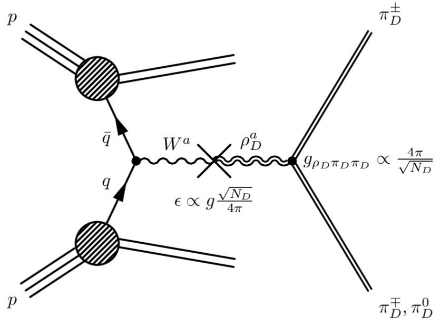
Both all-hadronic and single lepton channel considered.

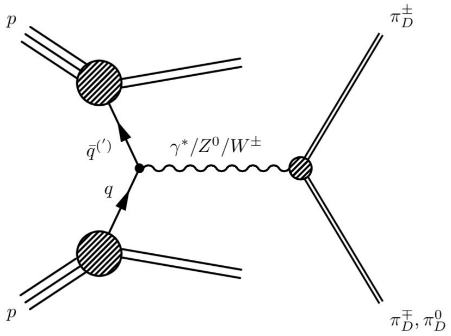
Dark pions are reconstructed with large radius jet, containing two b-jets.

Free parameters include m_π *and* $\eta = m_\pi / m_\rho$.





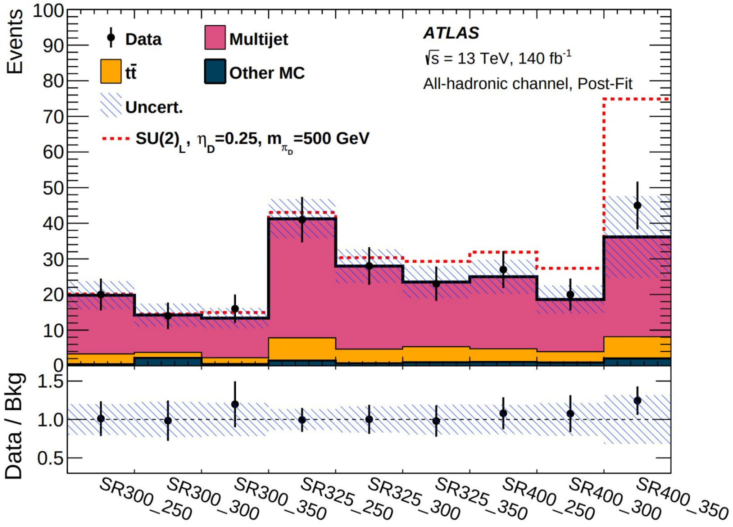


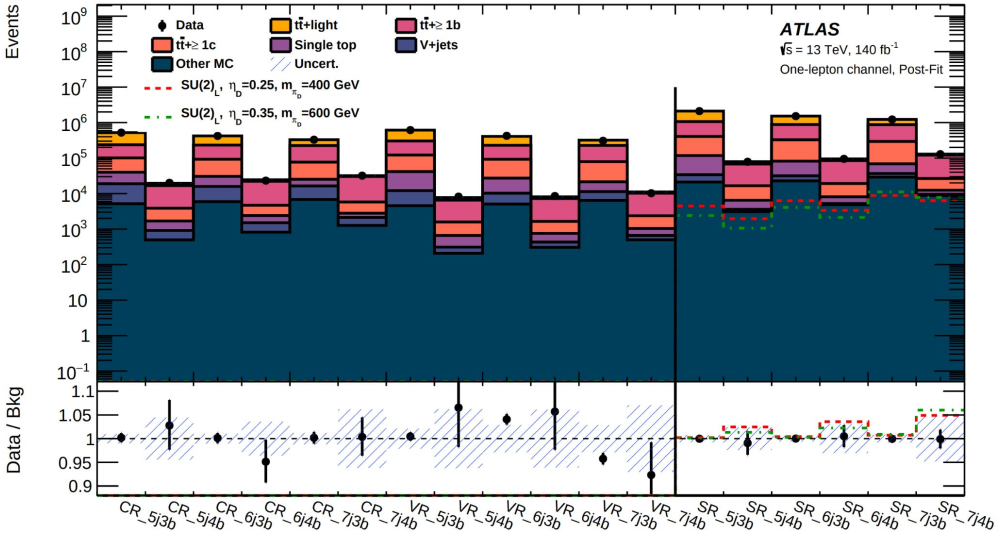


Dark Mesons

Hadronic channel: 9 SRs based on leading and subleading large-R jet mass

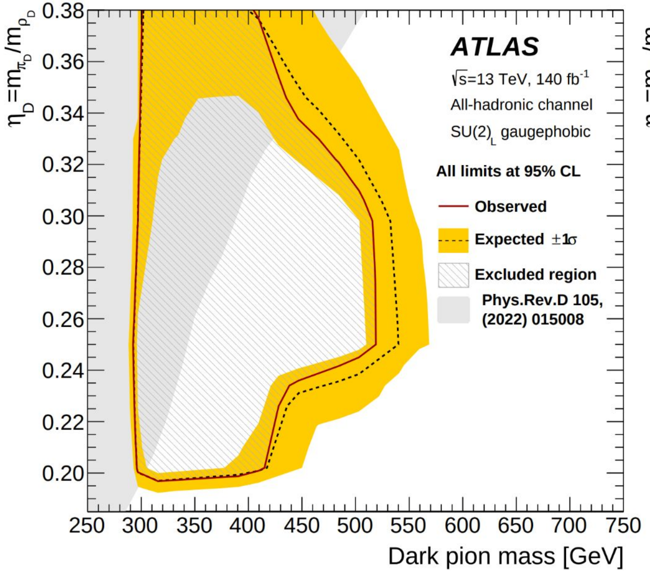
Leptonic channel: 6 SRs and 6 CRs based on jet and b-jet multiplicity

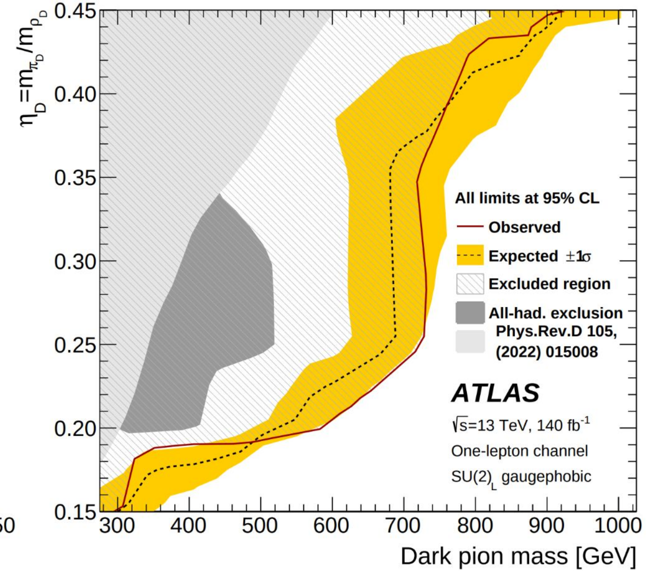




Dark Mesons

Exclusion set for (m_π, η). Most stringent exclusion set by one-lepton channel.





First dedicated LHC search for dark mesons!

Semi-visible jets

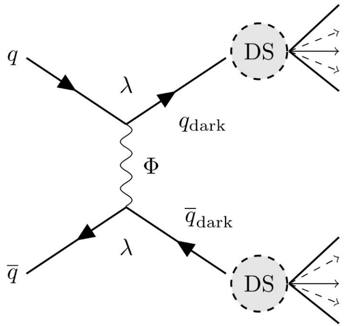
Search for dark quarks produced via t-channel mediator, resulting in semi-visible jets.

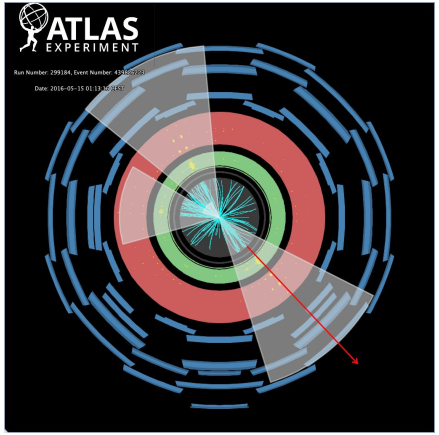
Signature includes back to back jets with MET pointing in the direction of one of the jets.

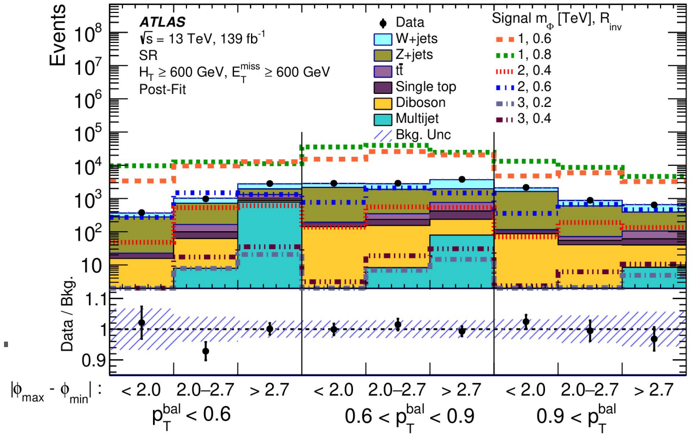
SR is defined with $H_T > 600$ GeV, MET > 600 GeV and $|\phi_{jet} - \phi_{pTmiss}| < 2$.

CR for background estimate constructed using muons.

Fit conducted simultaneously in p_T^{bal} and $|\phi_{max} - \phi_{min}|$.

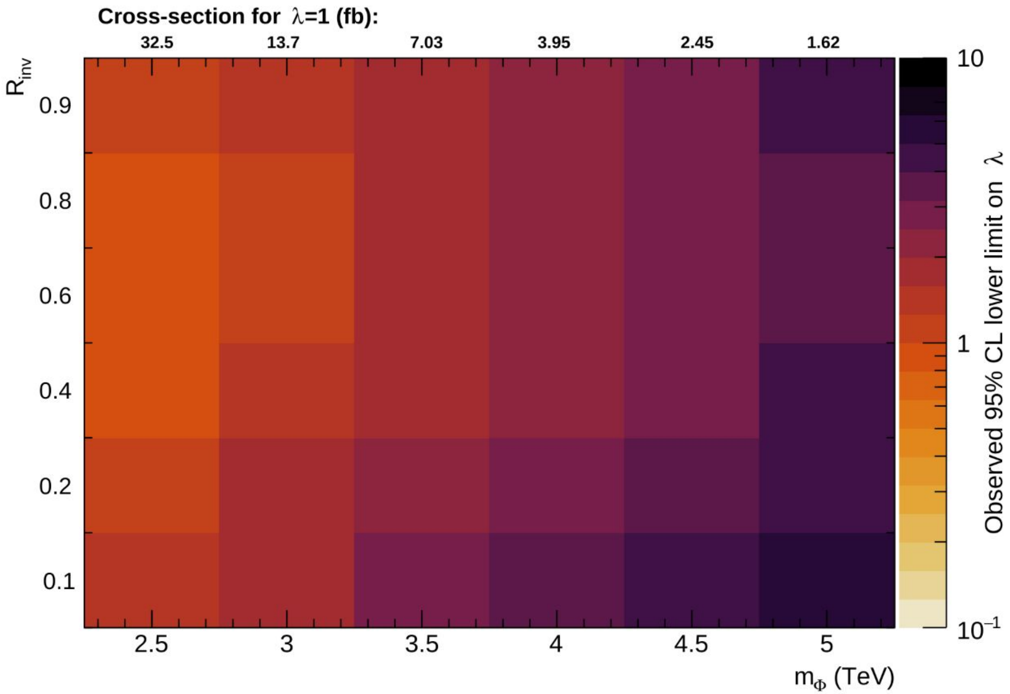


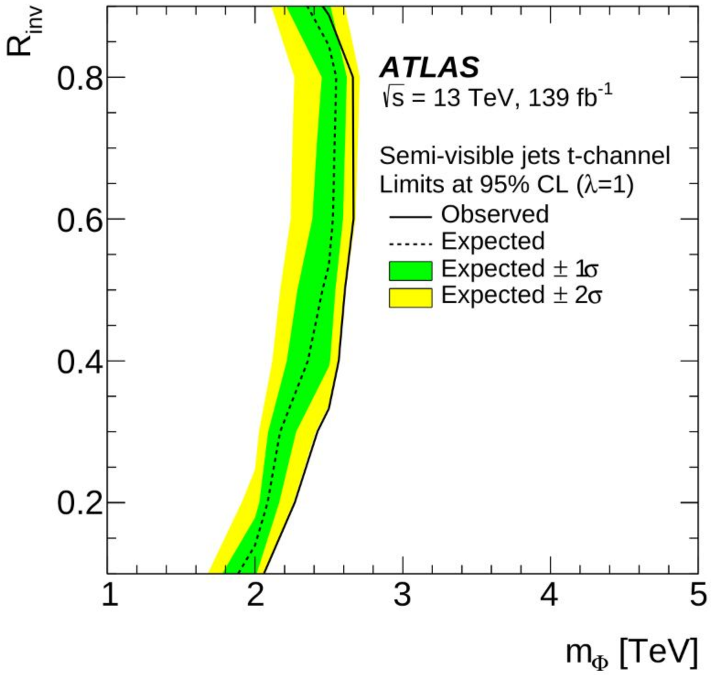




Semi-visible jets

Upper limit set on the mediator mass and fraction of invisible hadrons.





Conclusion

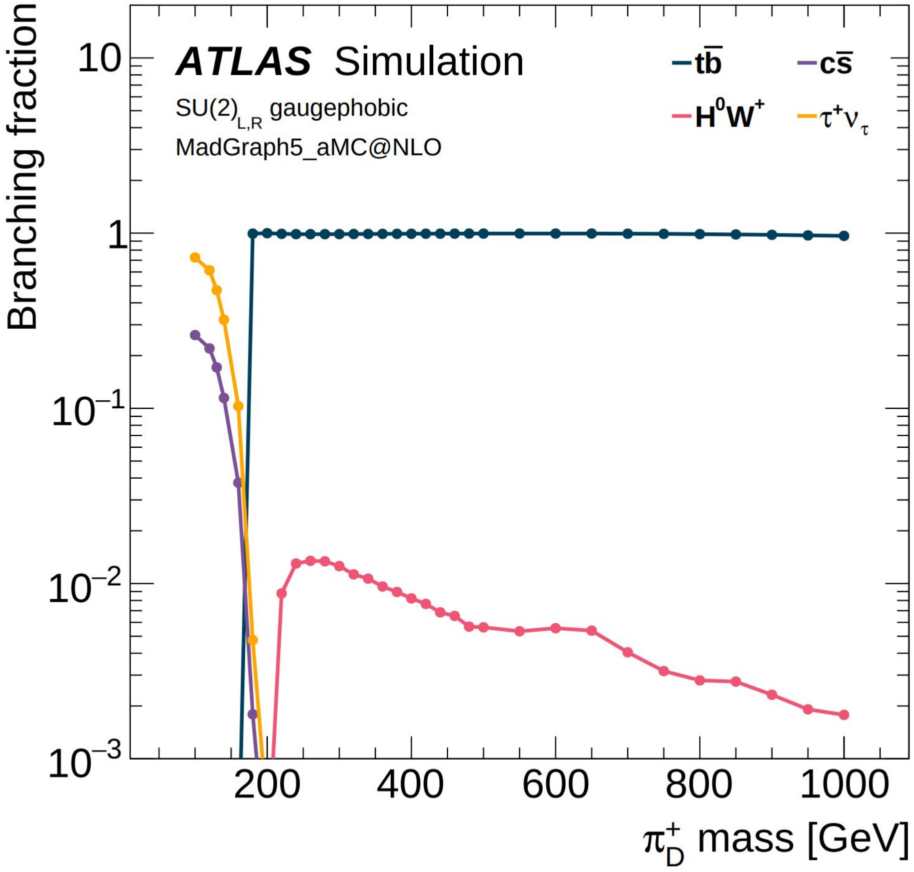
Six analyses were highlighted:

- Search for dark photons in ZH production
- Higgs to dark photon combination
- Search for dark photons in rare Z decays
- Search for dark quarks in dijet events
- Search for dark mesons
- Search for semi-visible jets

No significant excesses above Standard Model prediction were observed.

Backup

Dark Mesons


ATLAS Simulation
SU(2)L,R gaugephobic
MadGraph5_aMC@NLO
tb̄
cs̄
H0W+
τ+ντ
Branching fraction
10
1
10−1
10−2
10−3
200
400
600
800
1000
π+D mass [GeV]