Searches for new phenomena in hadronic final states using the ATLAS detector

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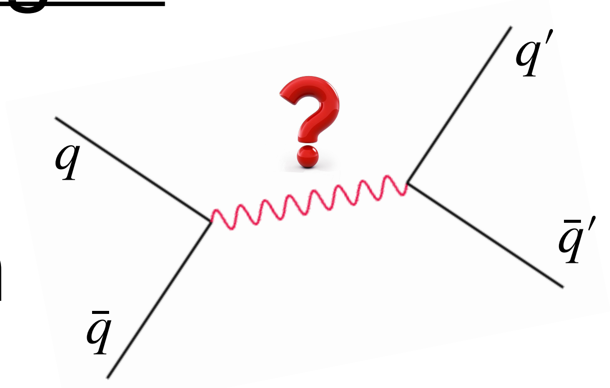
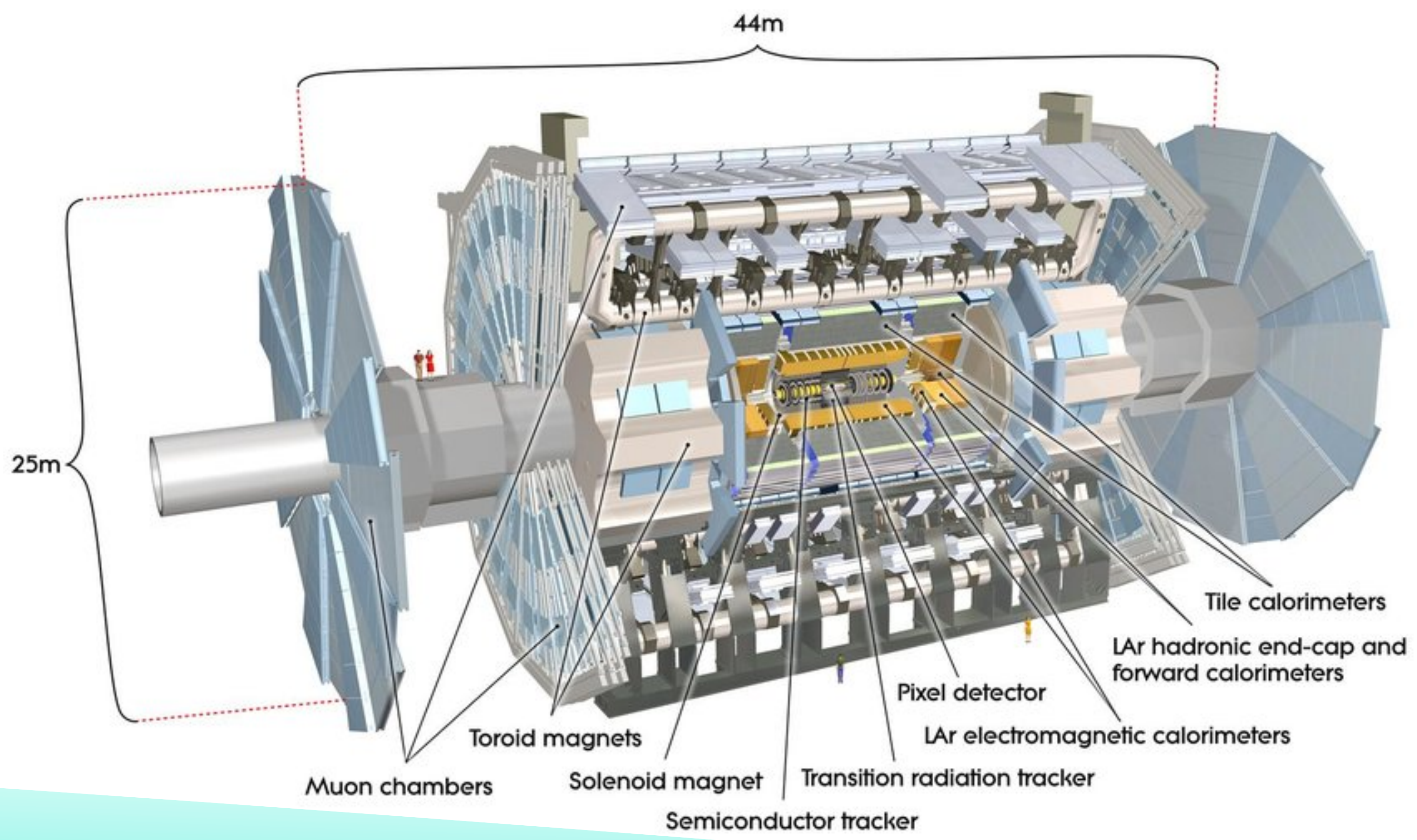
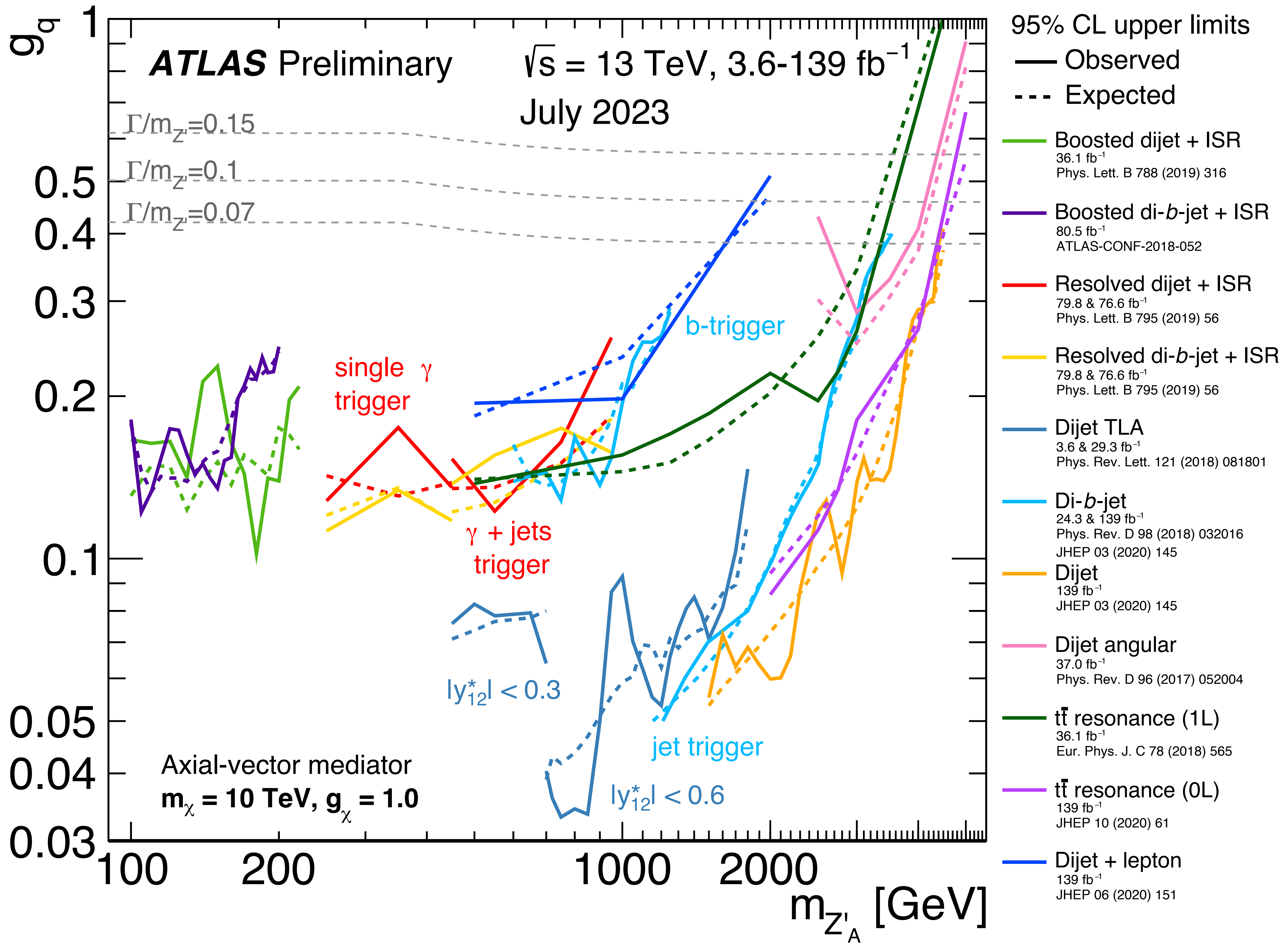
Searching for hadronic resonances

- The search for Beyond the Standard Model (BSM) phenomena is a big part of the ATLAS physics program
- Hadronic final states are both interesting and challenging
    - Lots of promising models with <u>different topologies</u>!



- Multiple searches for resonant dijet production
    - Phase space for Z' mediator largely constrained
    - Improved analyses to increase sensitivity





[ATLAS Exotics Public Results]

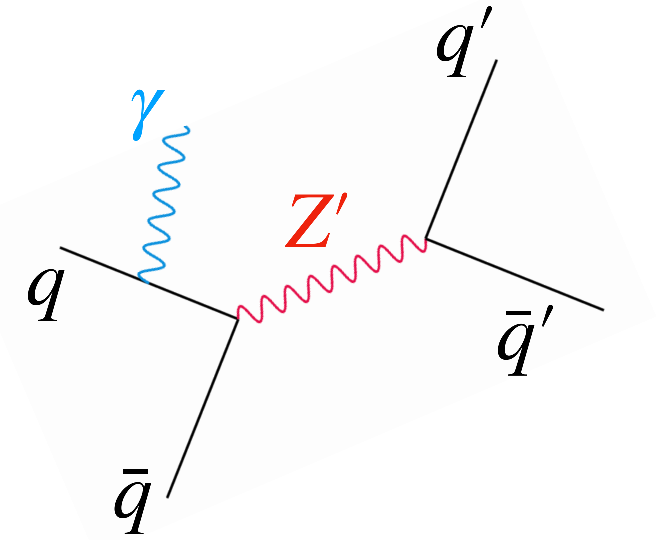
Submitted to PRD - arXiv:2403.08547

Dijet + ISR photon/jet

- Trigger on high-energy Initial State Radiation (ISR) to increase sensitivity to low-mass resonances
  - Two channels: γ—ISR and jet—ISR → each split into flavour-inclusive and b—tagged signal regions (SR)
  - Target scenarios where both decay jets can be reconstructed separately

Photon channel

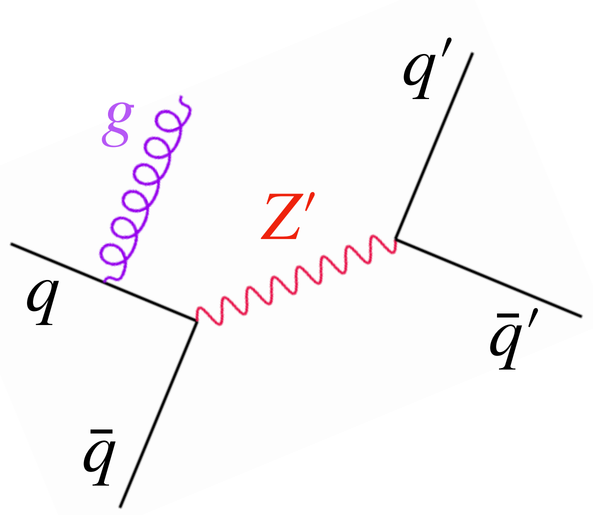
- High-p_T photon at the trigger level, offline $p_T^{\gamma} > 150$ GeV
- At least 2 reconstructed jets with $p_T^{j} > 20$ GeV

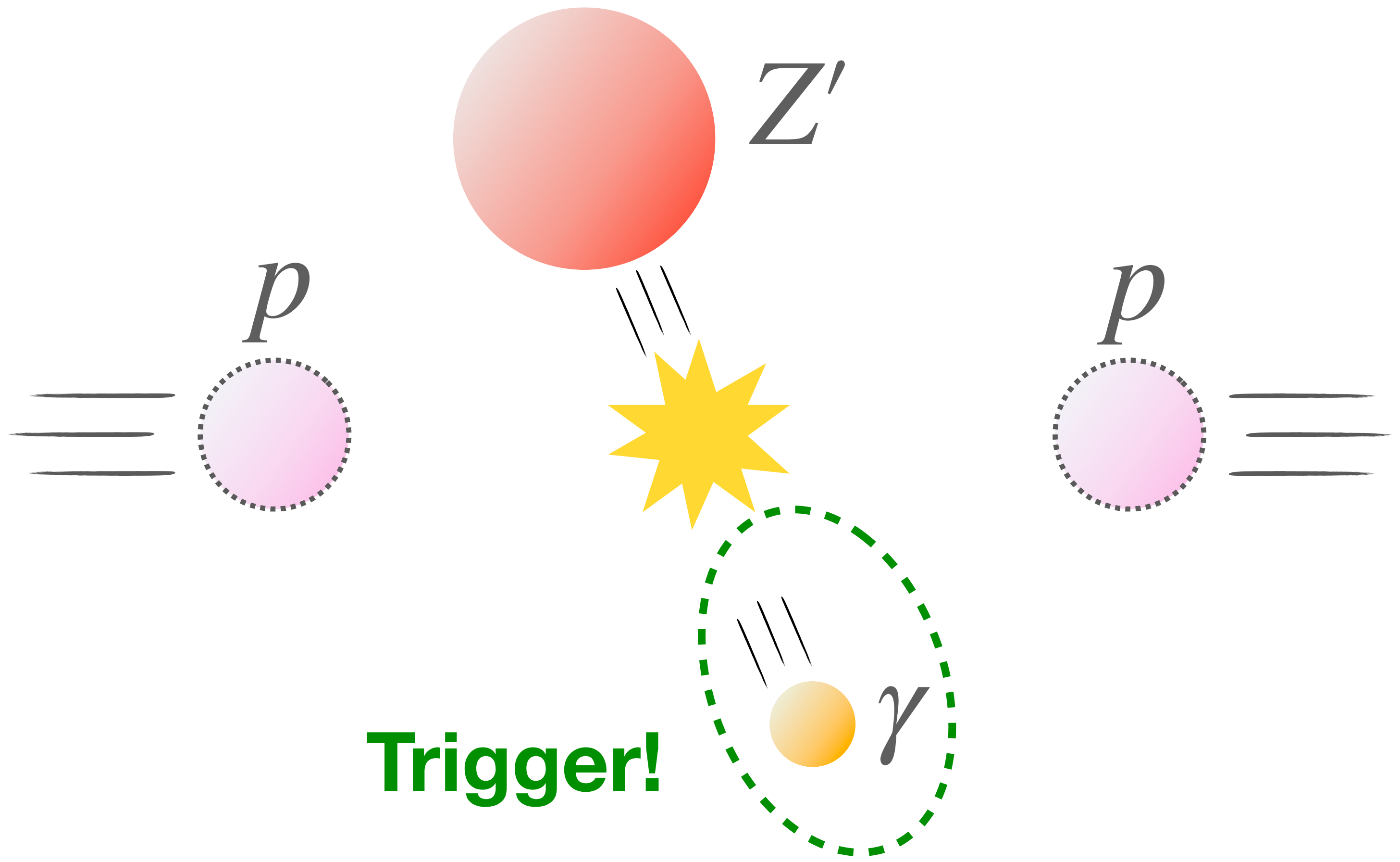


New!

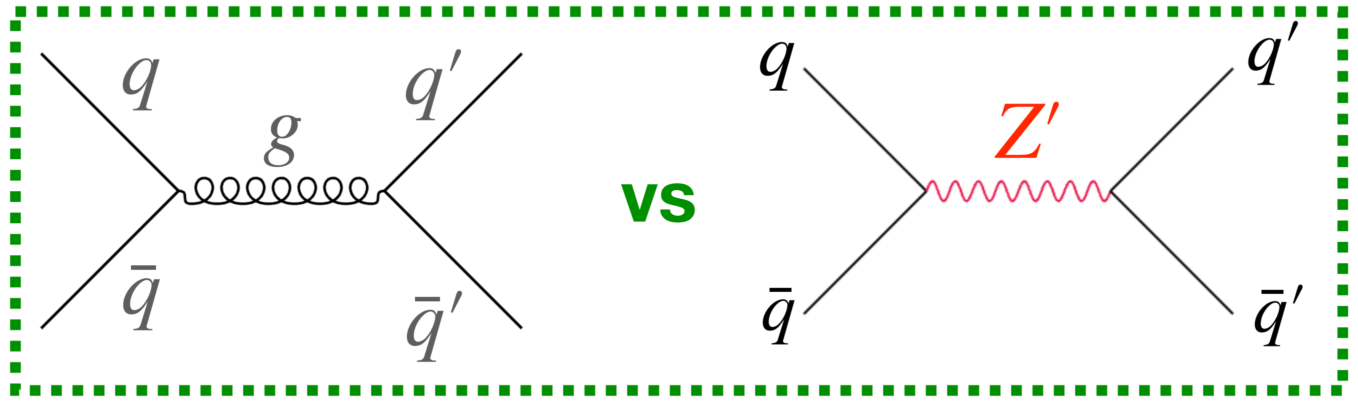
Trijet channel

- High-p_T jet at the trigger level, offline $p_T^{jet} > 475$ GeV
- At least 3 reconstructed jets, combined based on minimum $|\Delta\phi|$

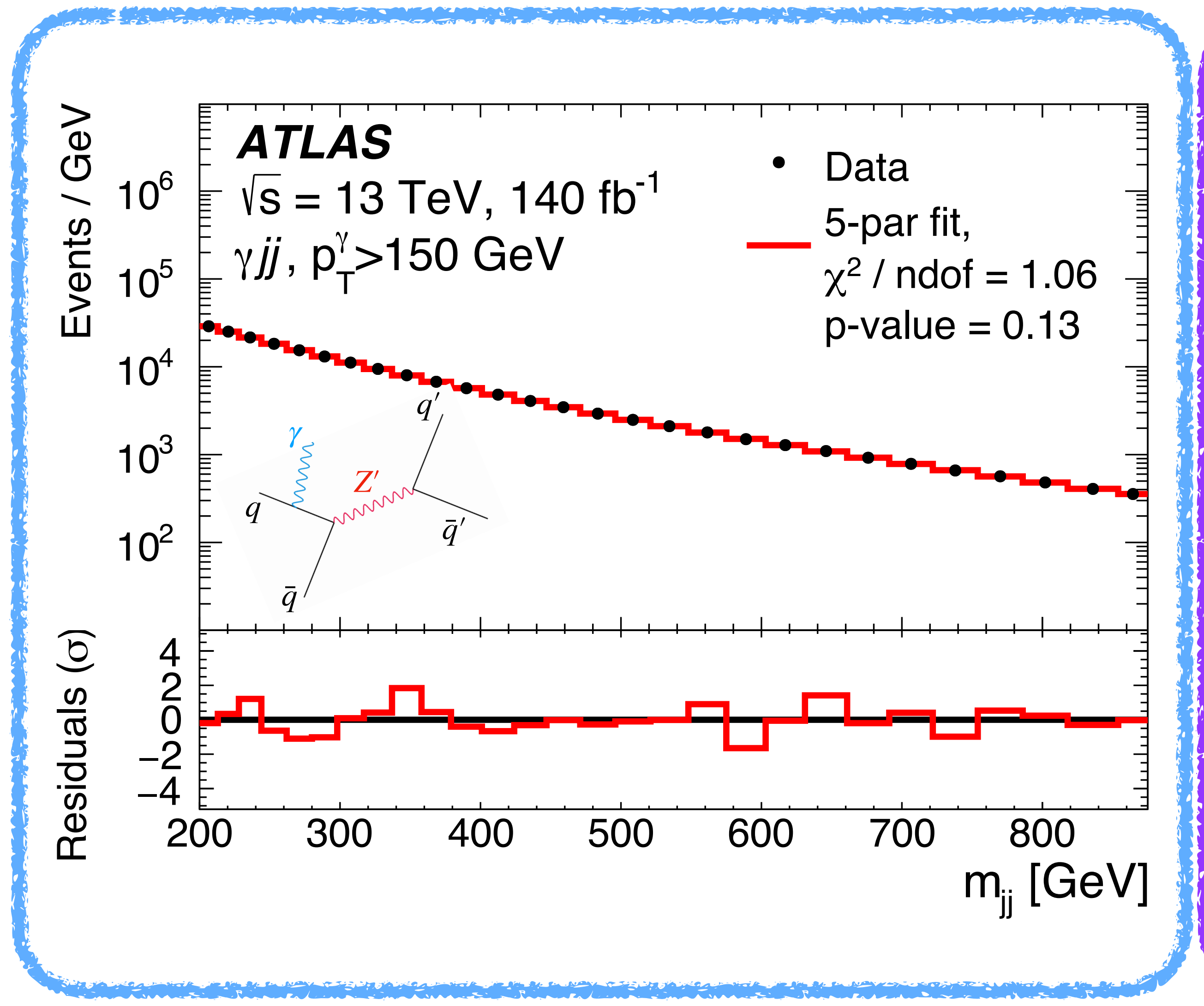


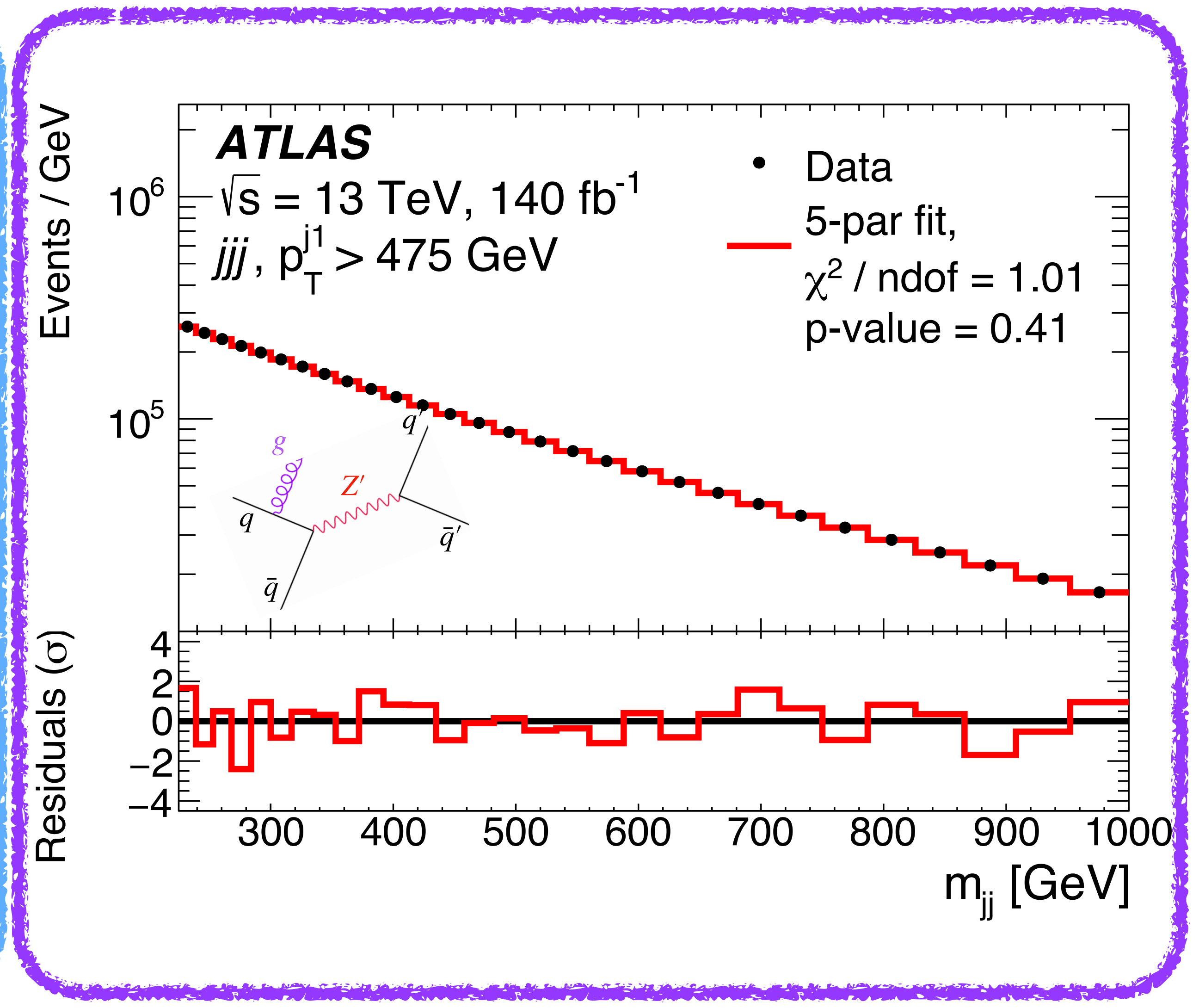


Dijet + ISR photon/jet (II)



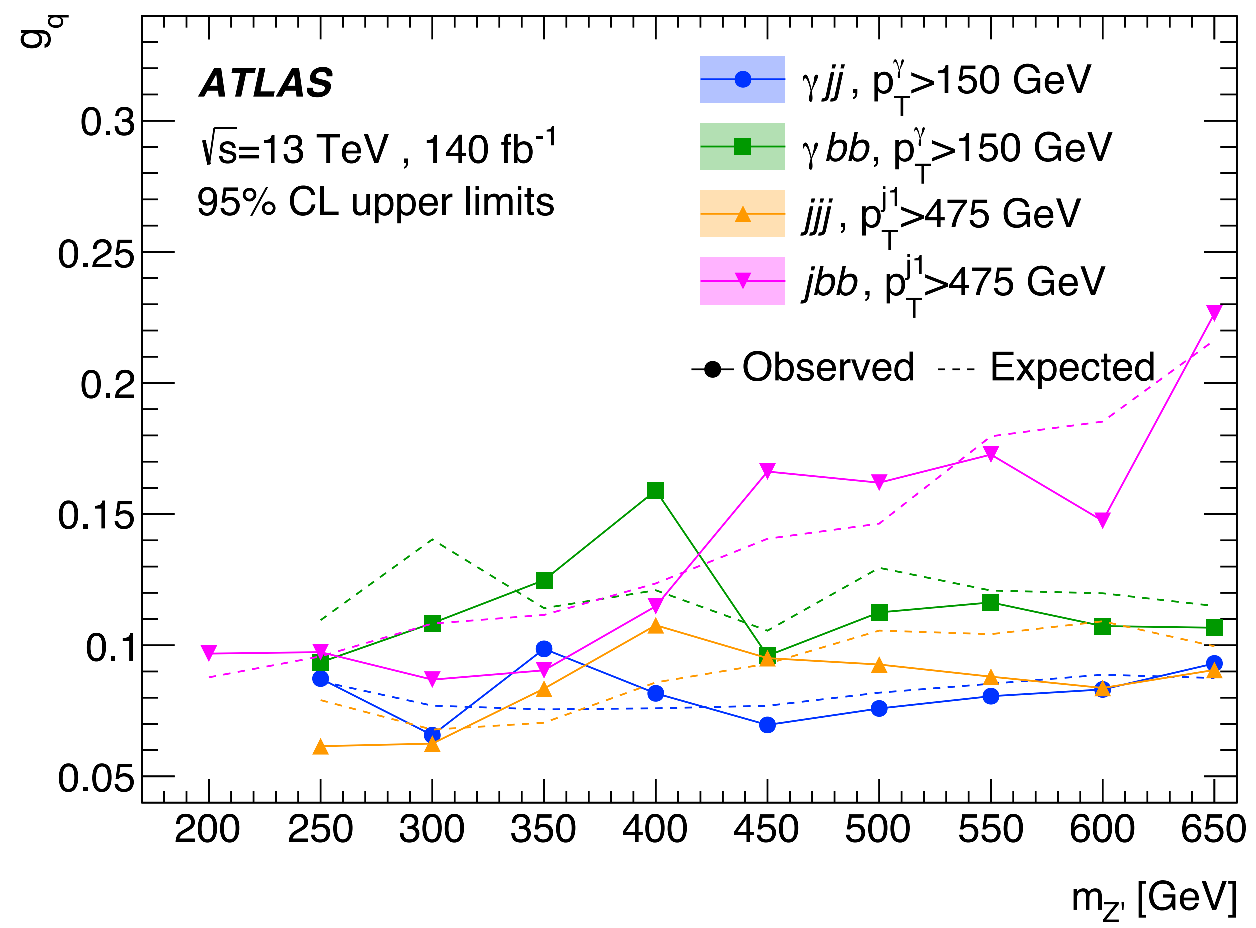
- Dominant background: non-resonant QCD processes
  - Functional fit to data for background estimate
  - Look for signal bump in mass spectrum

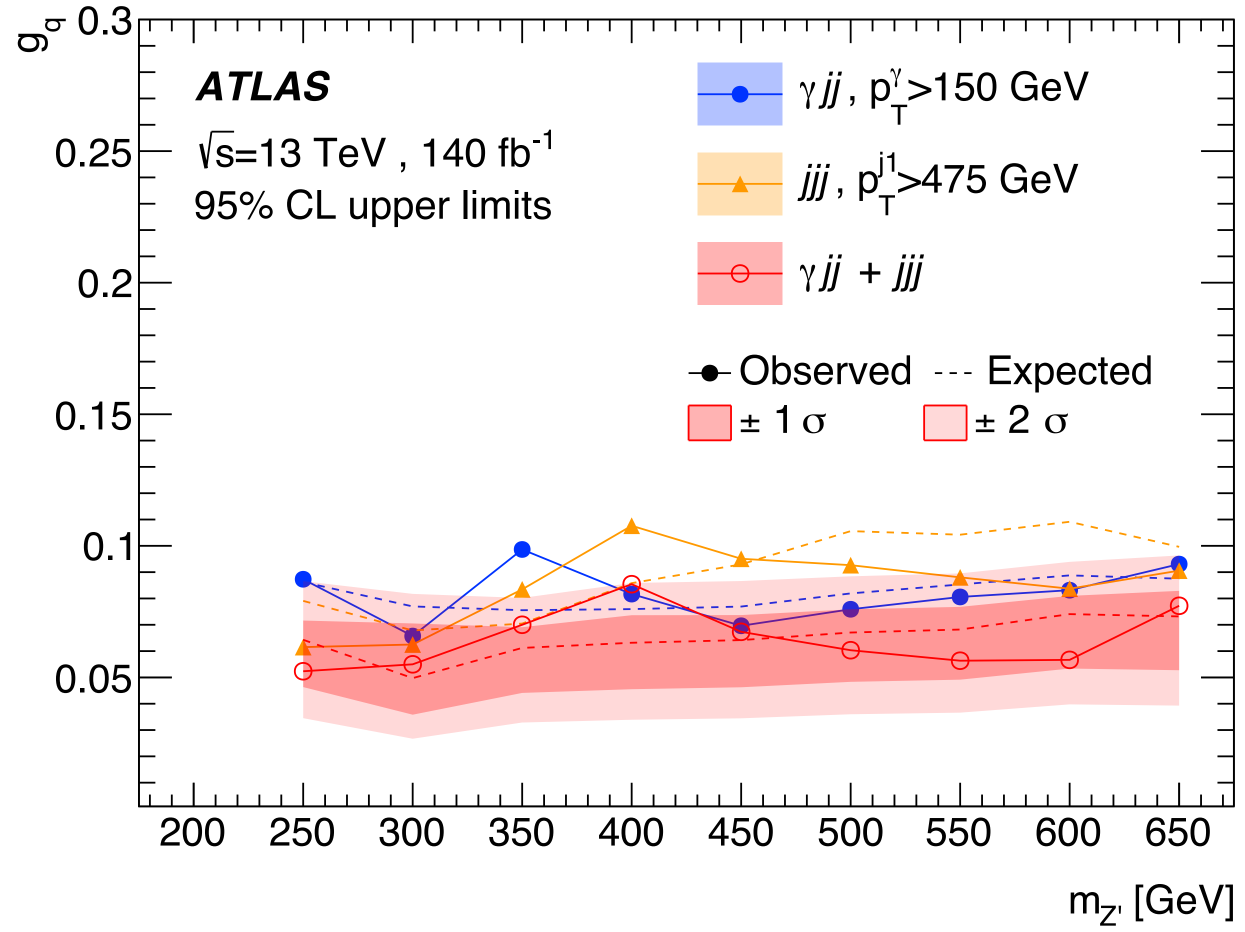


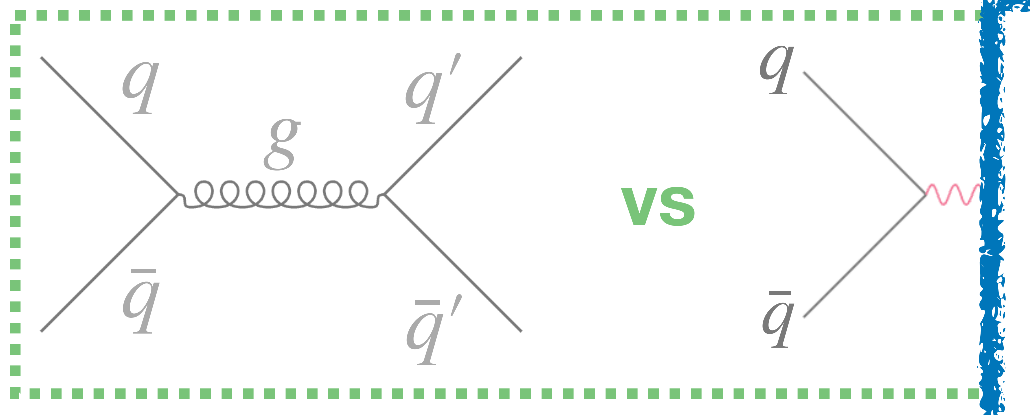


- No significant excess → 95%CL exclusion limits
  - Model-independent limits based on Gaussian templates
  - Interpretation for spin-1 Z' mediator
  - Combine $\gamma jj + jjj$ channels for better exclusion
    - Leading sensitivity in this mass range!

New!







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  - New! Combine $\gamma jj + jjj$
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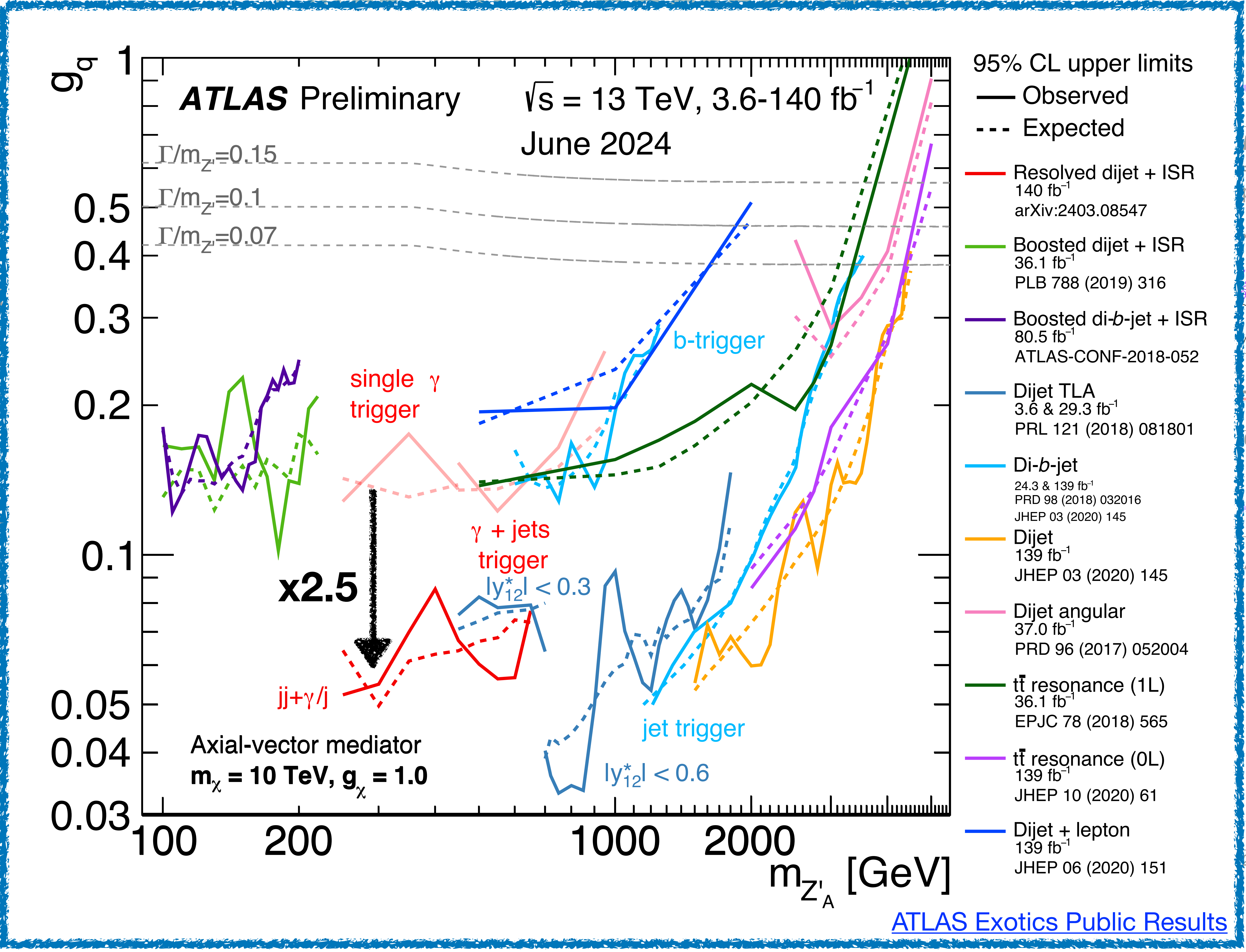
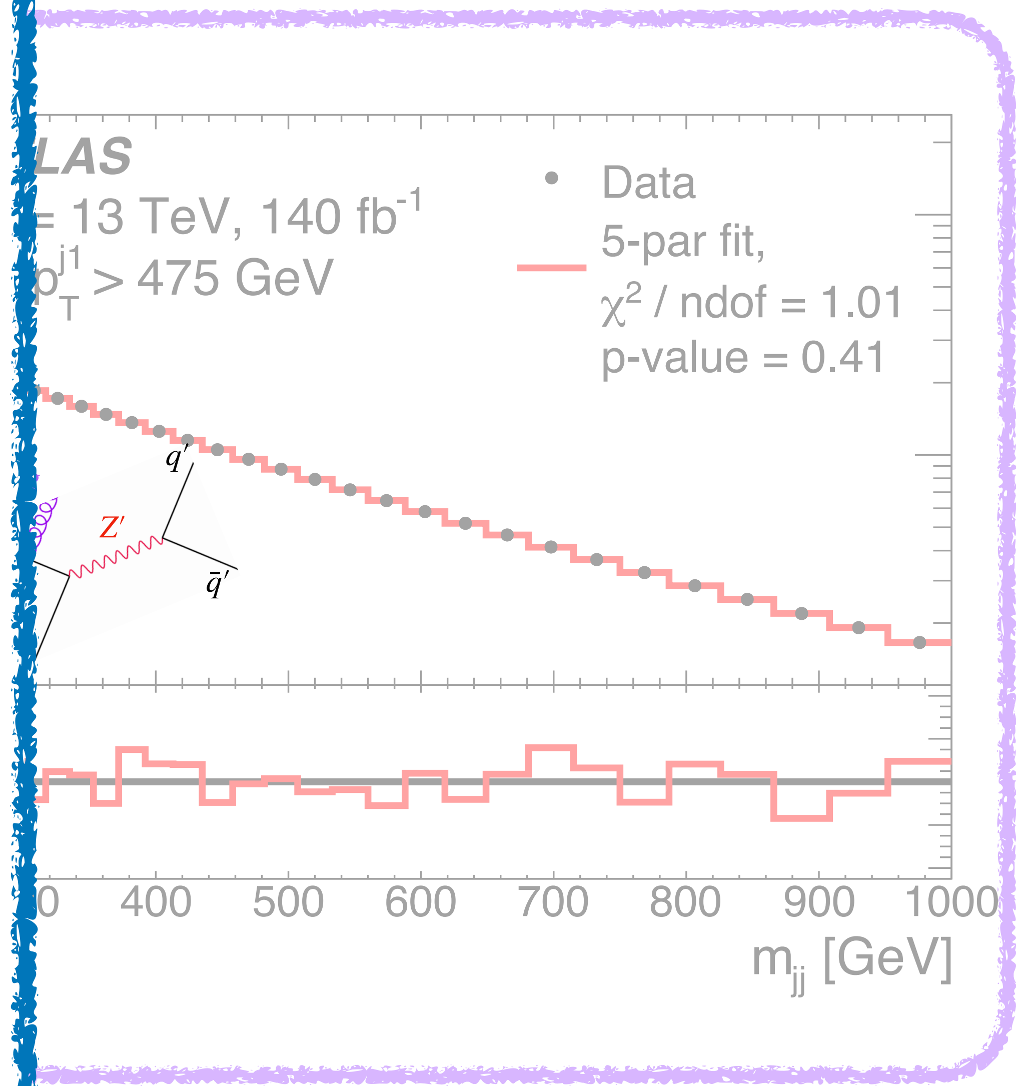
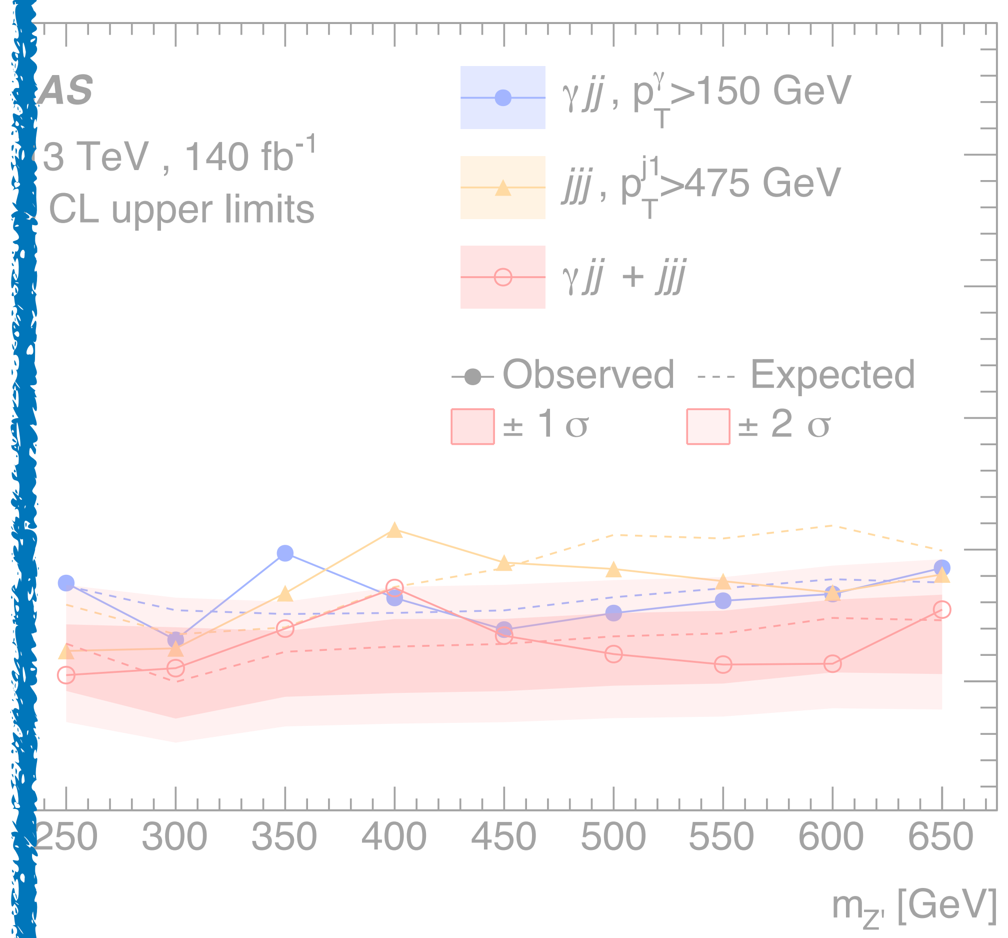
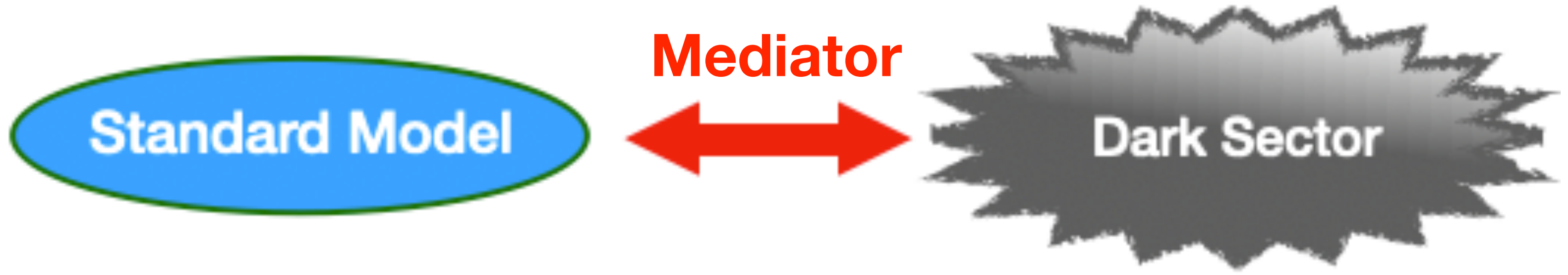






Resonant dark jets

- Other topologies can be explored to test dark matter models with mediator Z'
  - Z' can decay to fermions from the dark sector: $Z' \to f_d \bar{f}_d$
  - Large search program for different f_d properties



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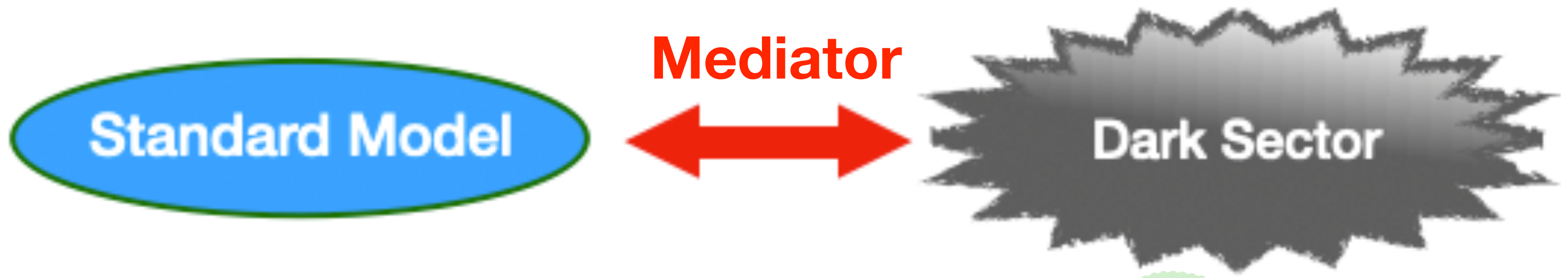
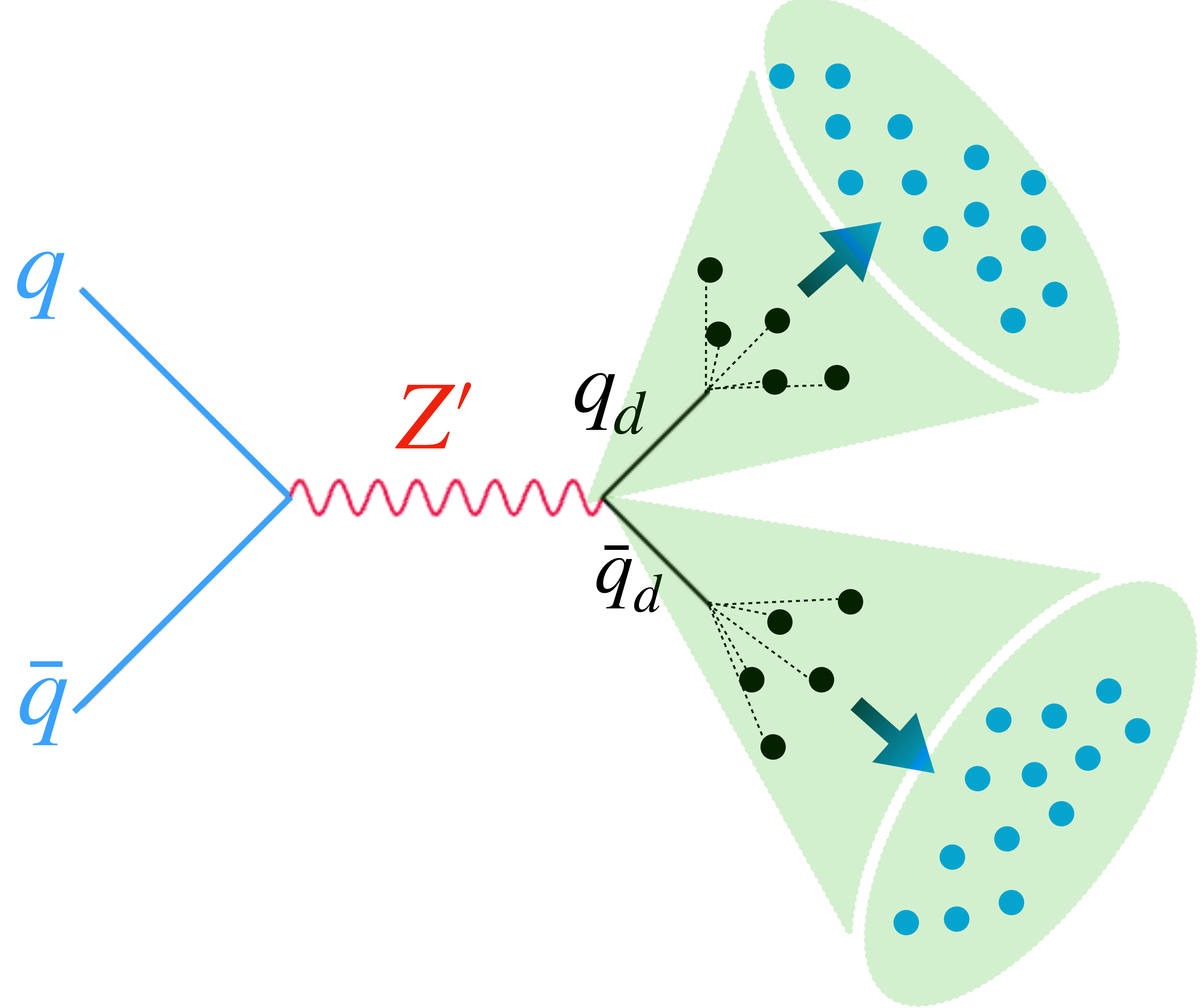


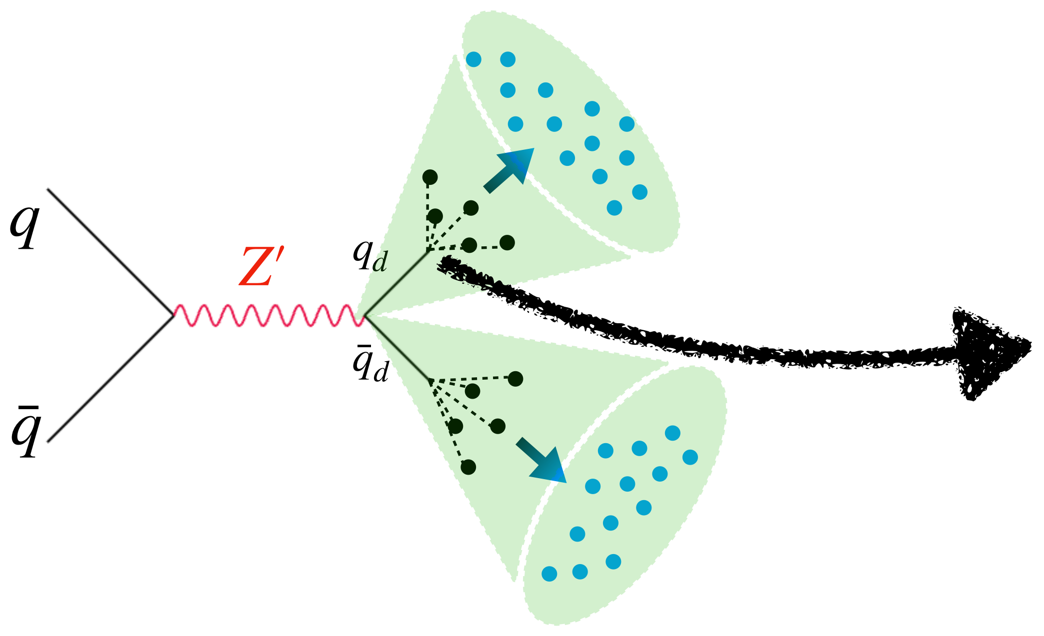
- Search for $Z' \to q_d \bar{q}_d$ with prompt q_d−decays in dijet final states
  - Hadronisation in dark sector before decaying into SM
    - Wider decay activity and large number of tracks
  - Final state: 2 large-R 1.0 jets with high number of tracks



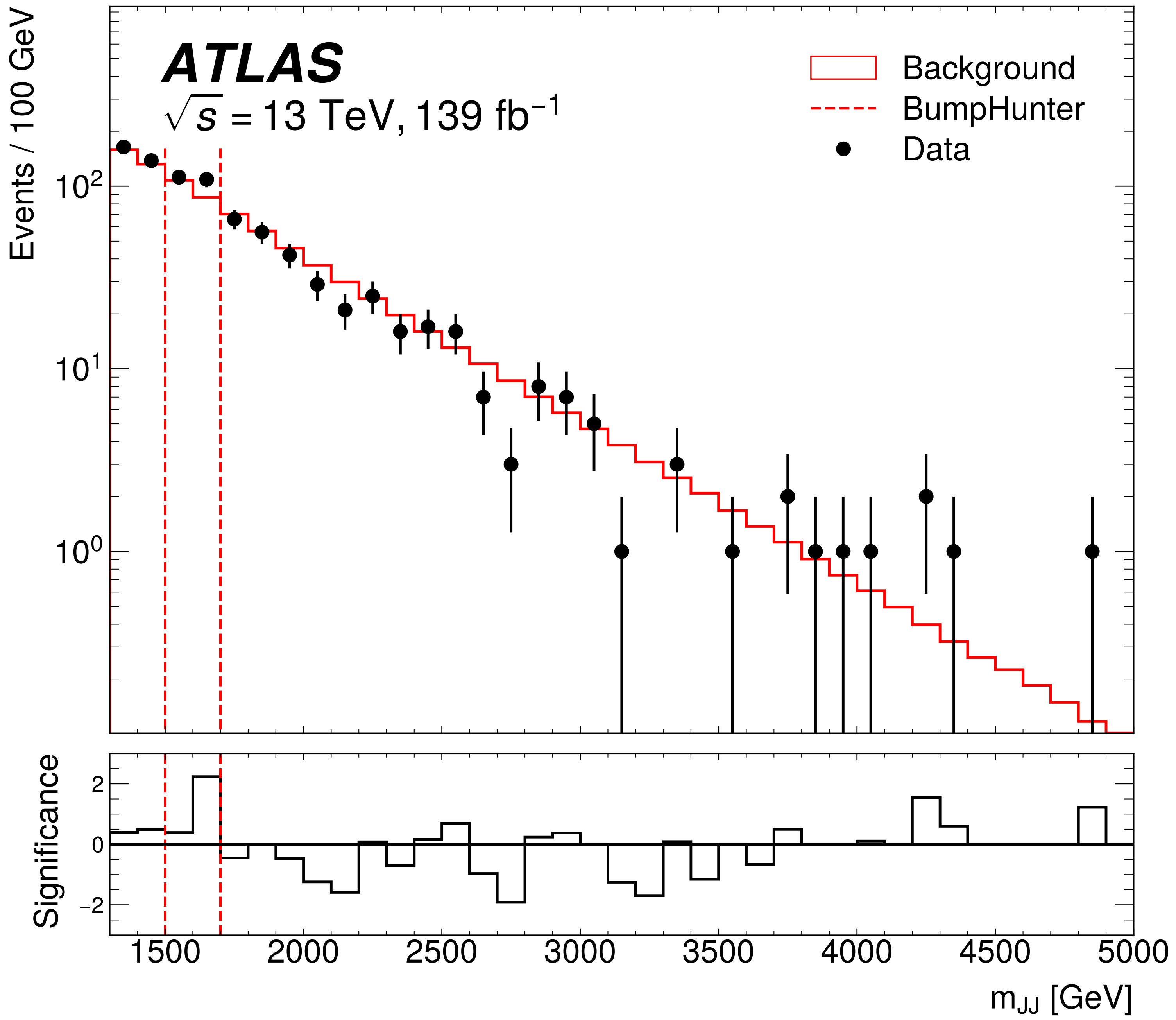
- Define CR, VR and SR according to jet track multiplicity
  - Extract background shape from CR, fit normalisation in SR

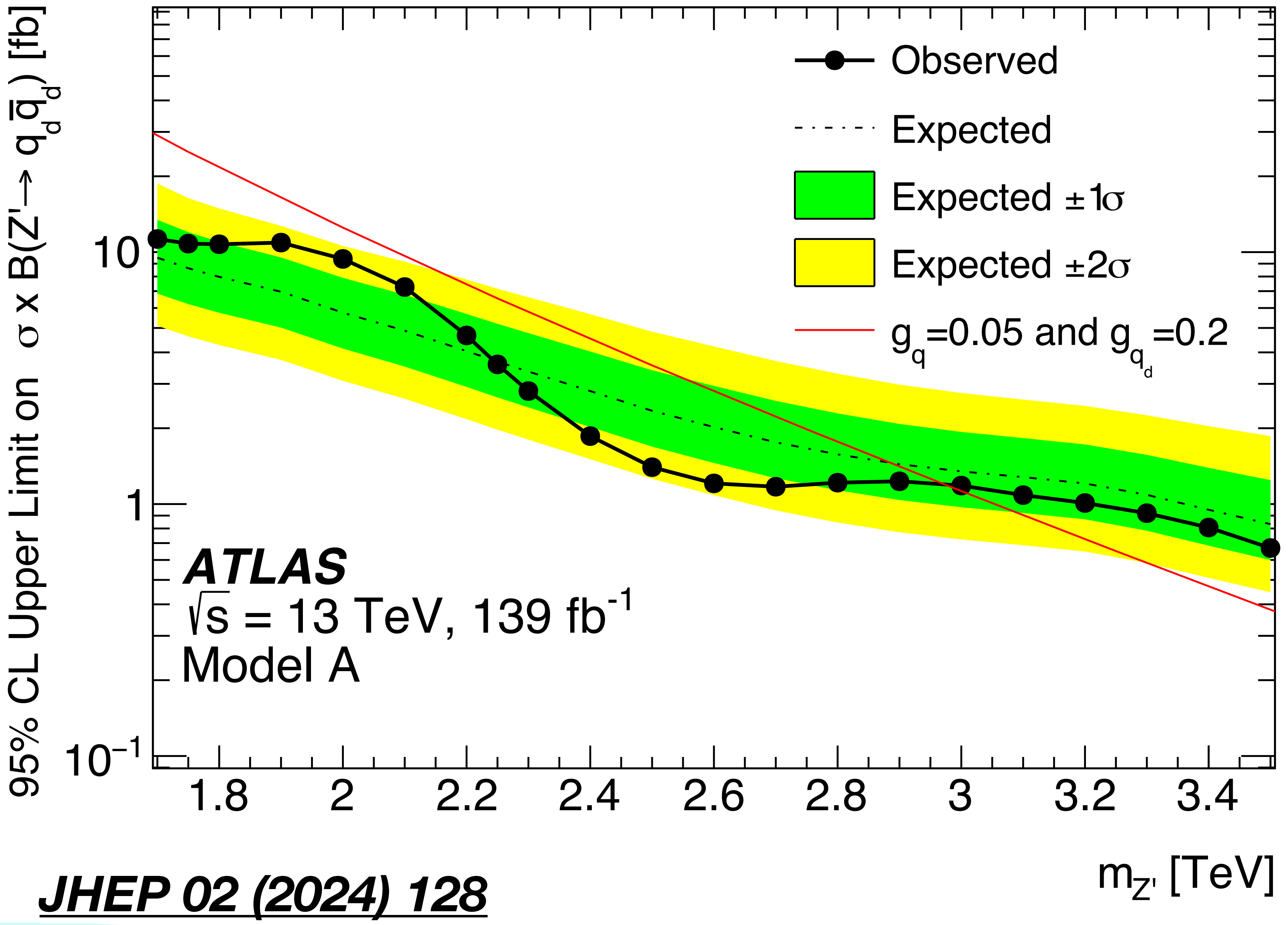
Resonant dark jets (II)

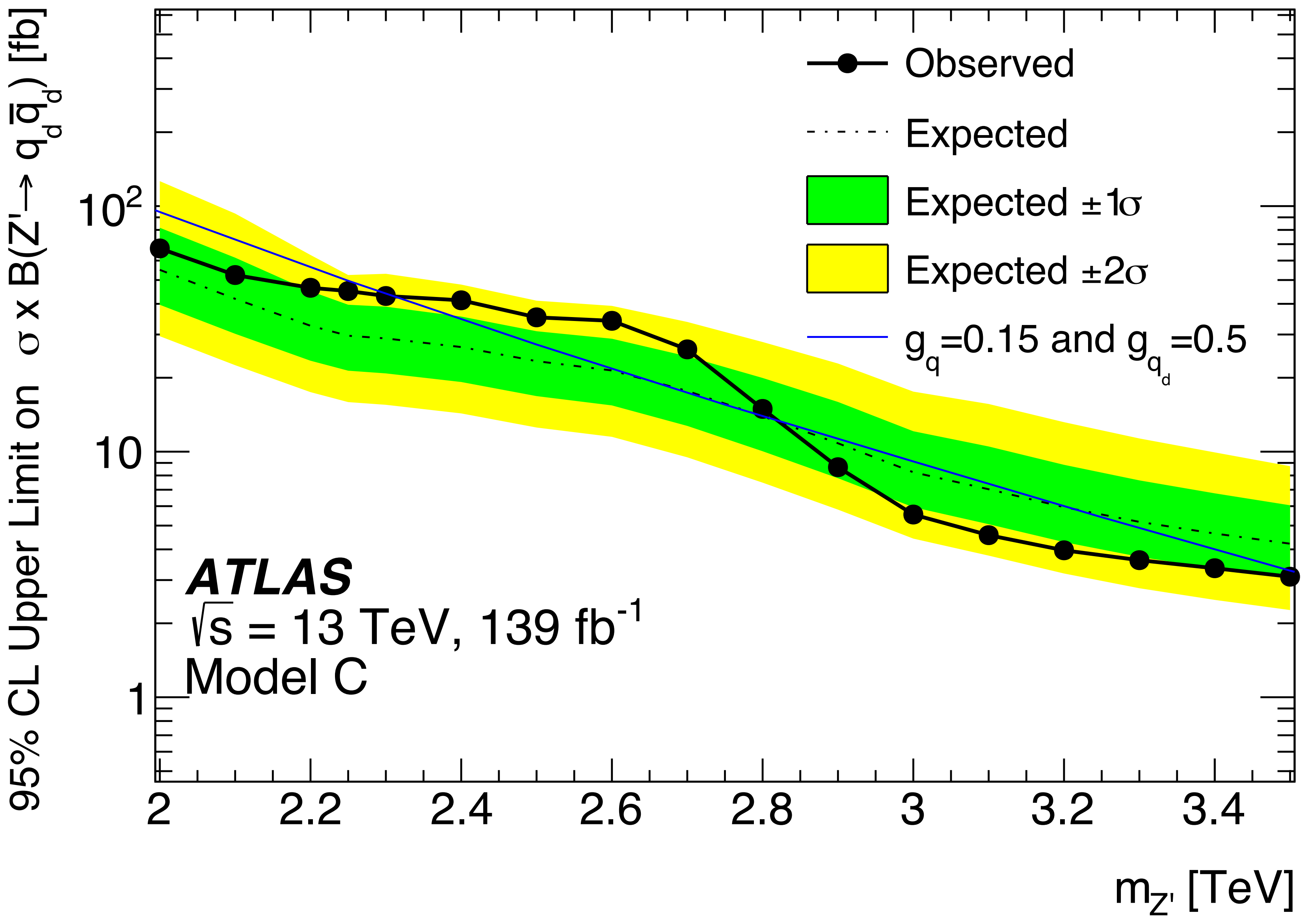
- No significant excess over the background prediction
  - Exclusion limits up to $m(Z') = 3$ GeV, depending on the model

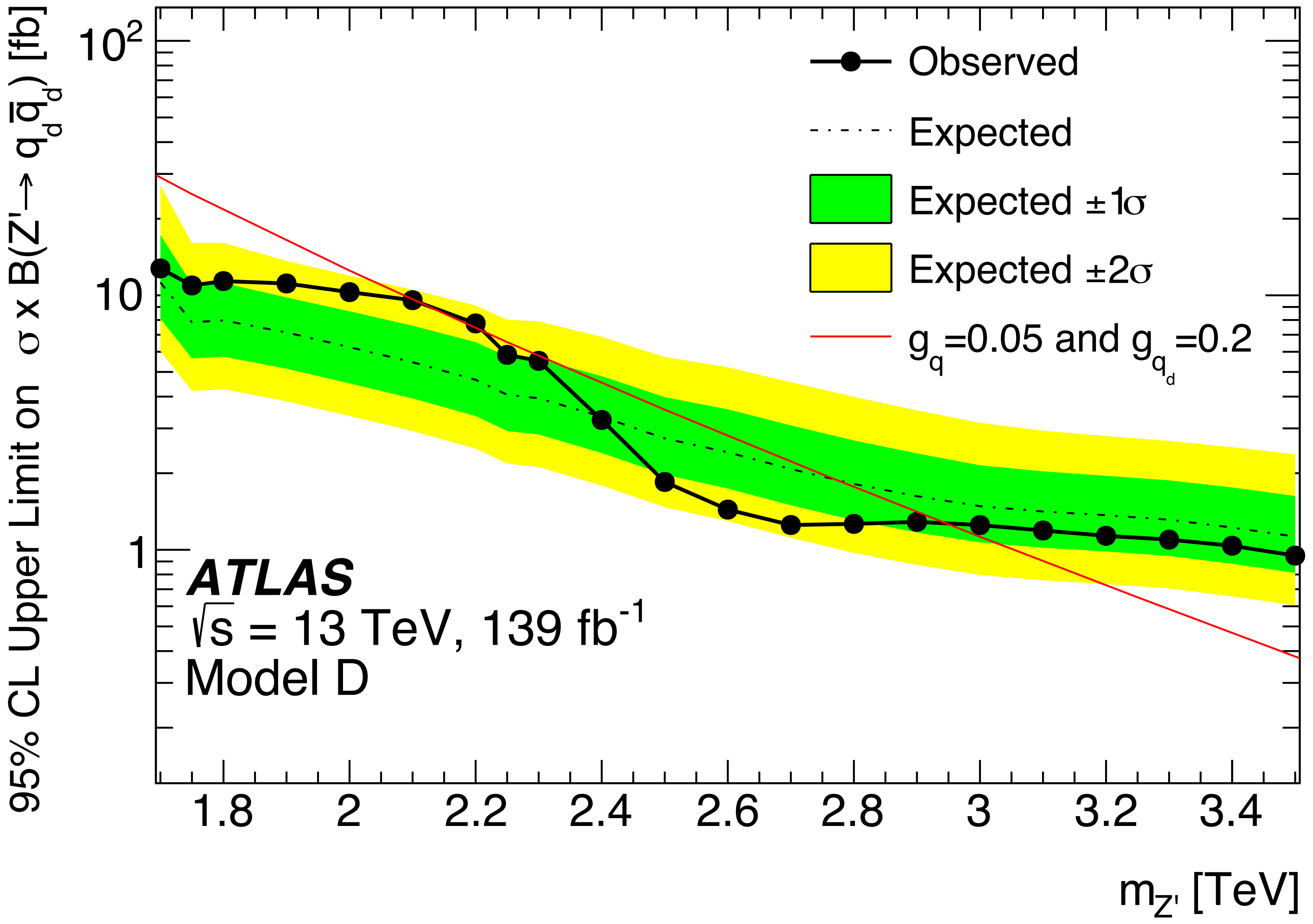


Model	n_f	Λ_d (GeV)	$\tilde{m}_{q'}$ (GeV)	m_{π_d} (GeV)	m_{ρ_d} (GeV)	π_d decay mode
A	2	15	20	10	50	$\pi_d \to c\bar{c}$
B	6	2	2	2	4.67	$\pi_d \to s\bar{s}$
C	2	15	20	10	50	$\pi_d \to \gamma'\gamma'$ with $m_{\gamma'} = 4.0$ GeV
D	6	2	2	2	4.67	$\pi_d \to \gamma'\gamma'$ with $m_{\gamma'} = 0.7$ GeV









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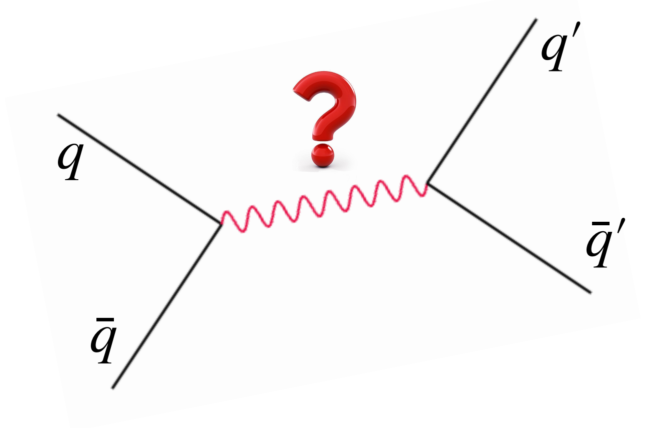
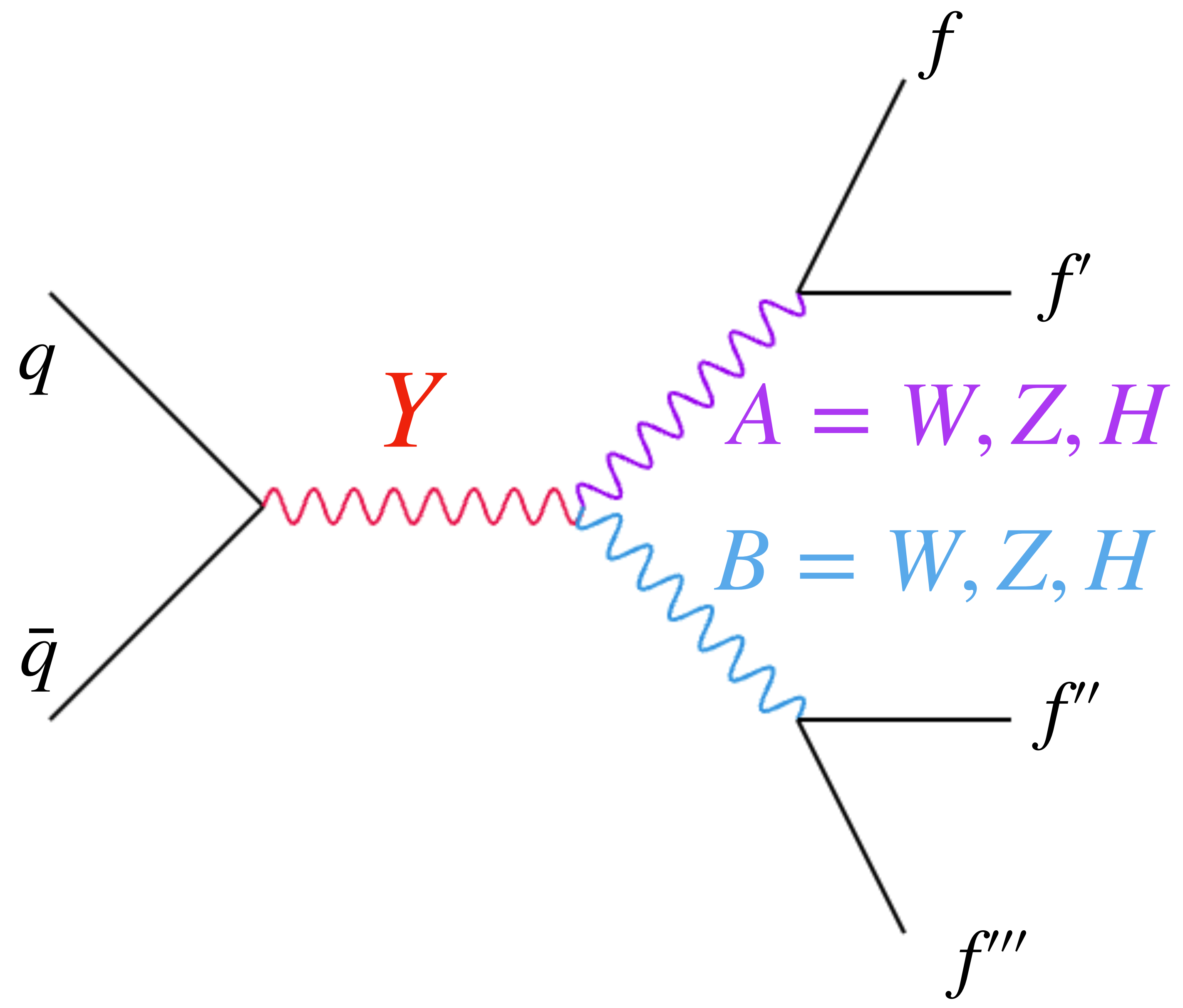
More complex topologies

- Good coverage of the phase space in dijet topologies



- There is good motivation for more complex topologies with intermediate bosons
  - Models with a nearly degenerate Heavy Vector Triplet (HVT) → resonant diboson production



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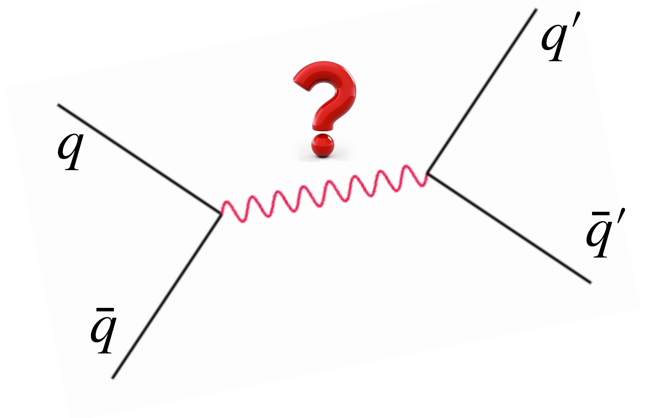

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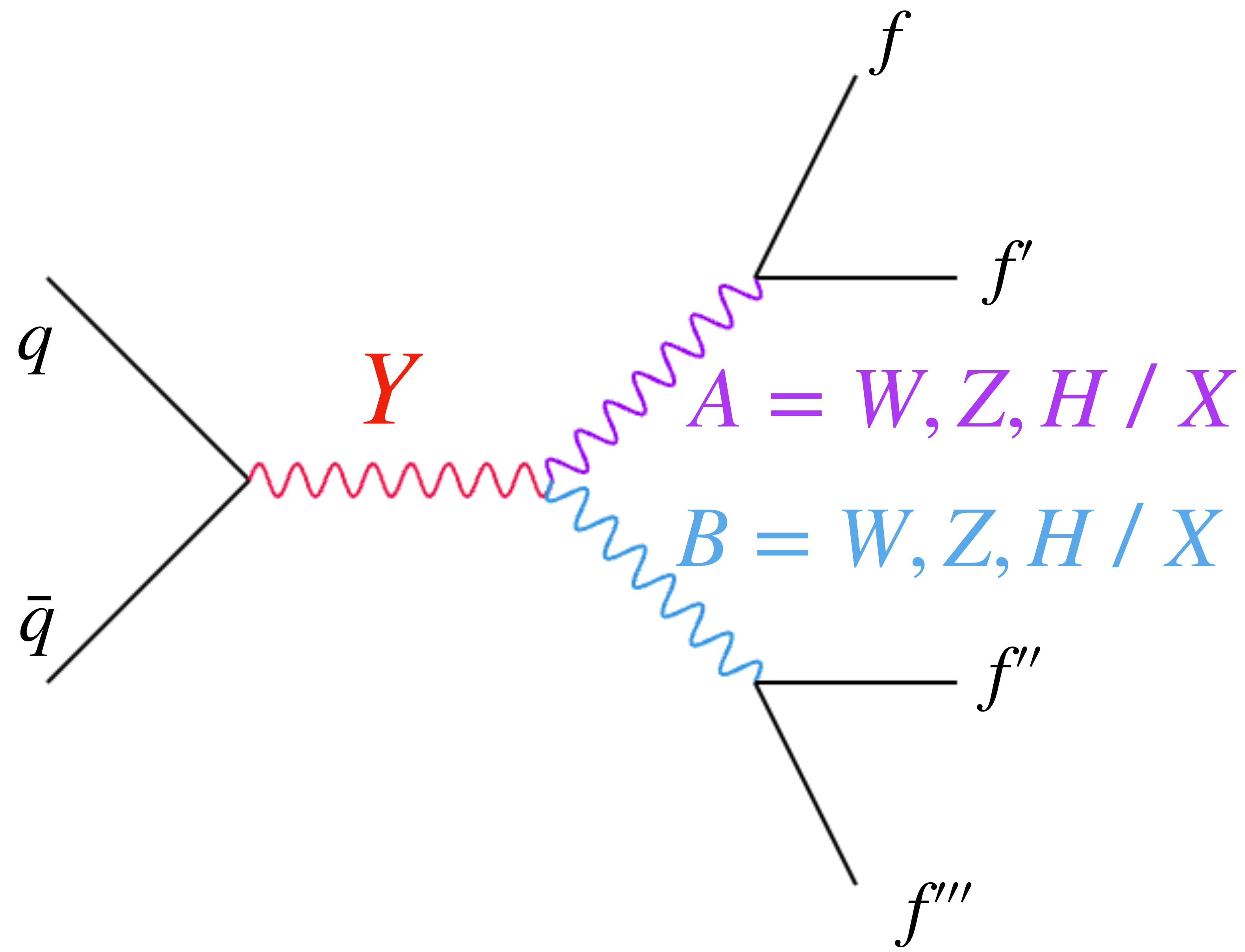
  - Models with a nearly degenerate Heavy Vector Triplet (HVT) → resonant diboson production
  - More exotic theories with $A, B = X$ BSM particle

Lots of channels to explore!

Talks by A. Kvam, A. Lory
and M. Barros



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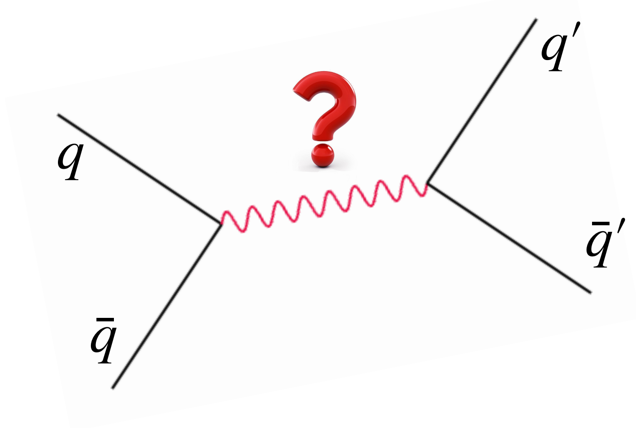

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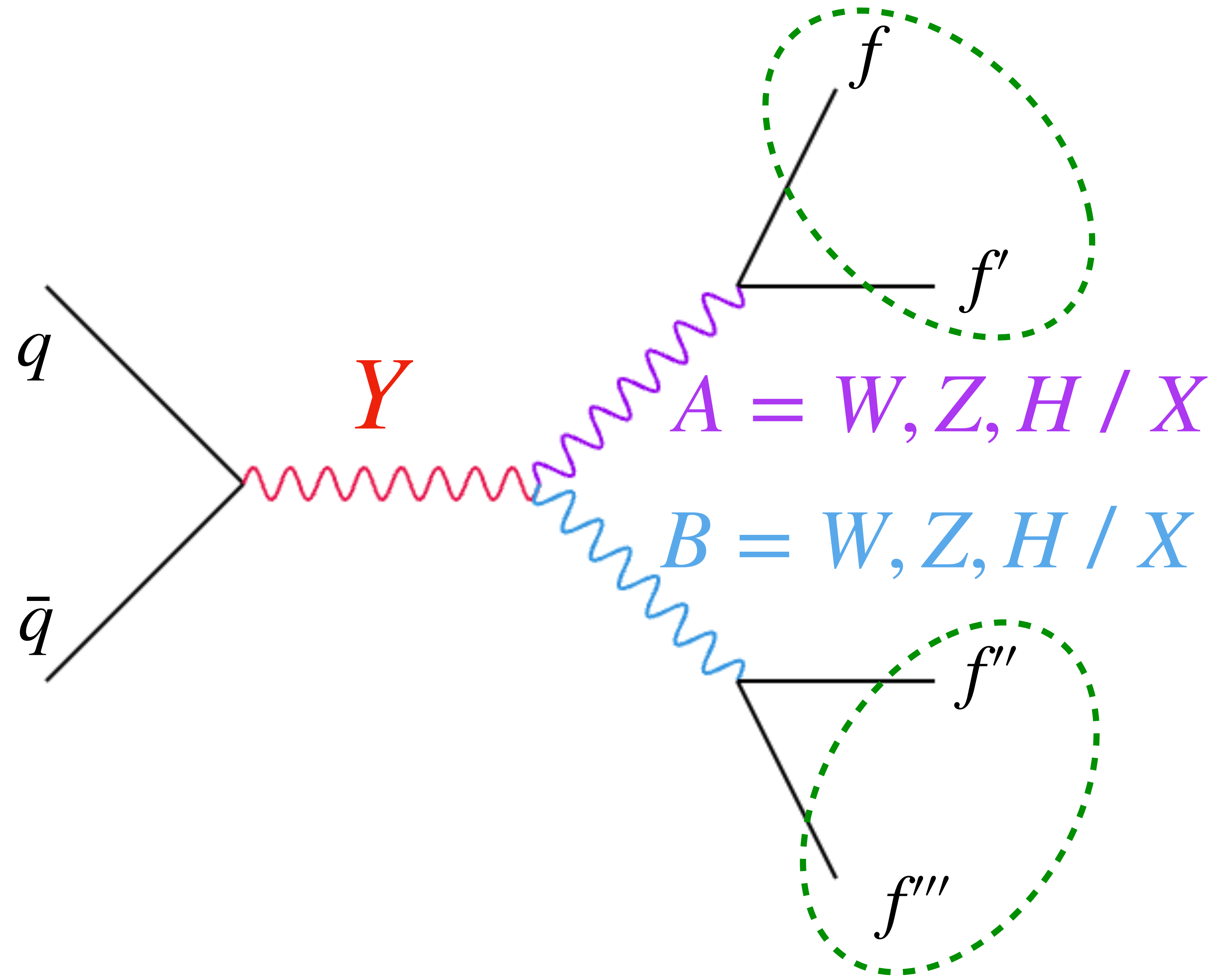


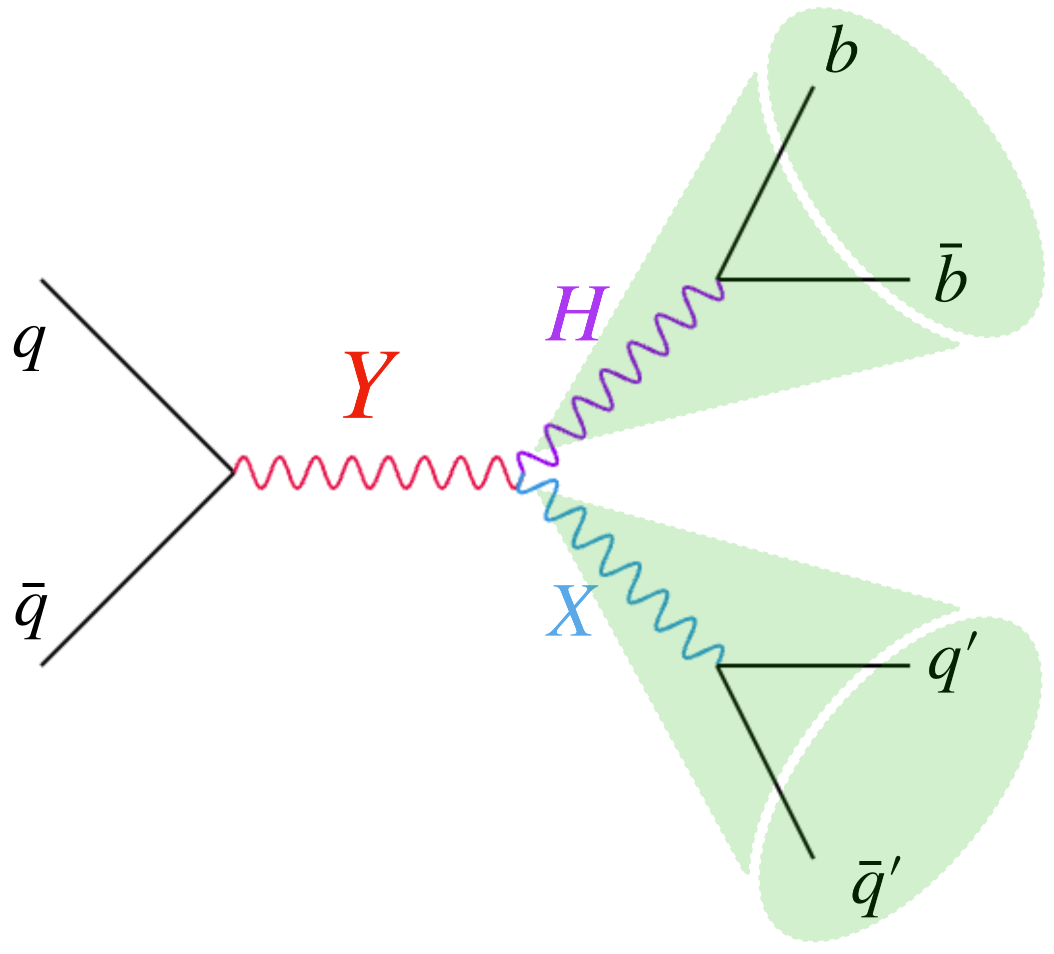
Reconstruct resonance through final decay products

Plenty different final states, focus on jets

Phys. Rev. D 108 (2023) 052009

$Y \to HX$ anomaly search

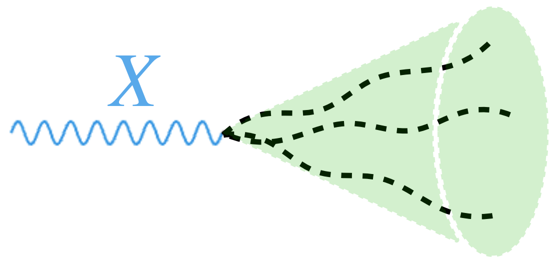
- New search for $Y \to HX$ in hadronic final states
  - Consider generic spin-1 $X \to q\bar{q}$ to maximize sensitivity independent from model!
- Capture hadronic H, X decays with large-R jets
  - High-p_T large-R jet at trigger level, at least 2 offline large-R jets
  - Anomaly tagger for the X decay - separation from QCD jets without assumptions on X!
  - Exploit $H \to b\bar{b}$ branching ratio with a H_{bb} tagger



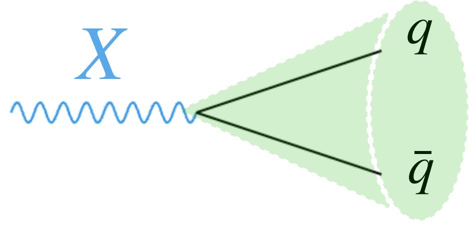
Machine Learning

Machine Learning

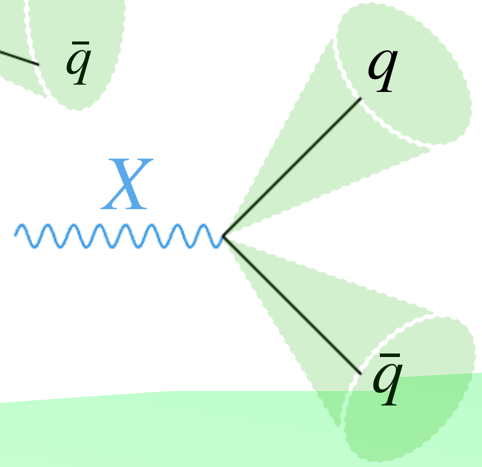
- Define three channels based on the reconstructed X properties
  - Anomalous X: anomaly score > 0.5



    - Merged decay: 2-prong large-R jet



      - Resolved decay: 2 small-R jets

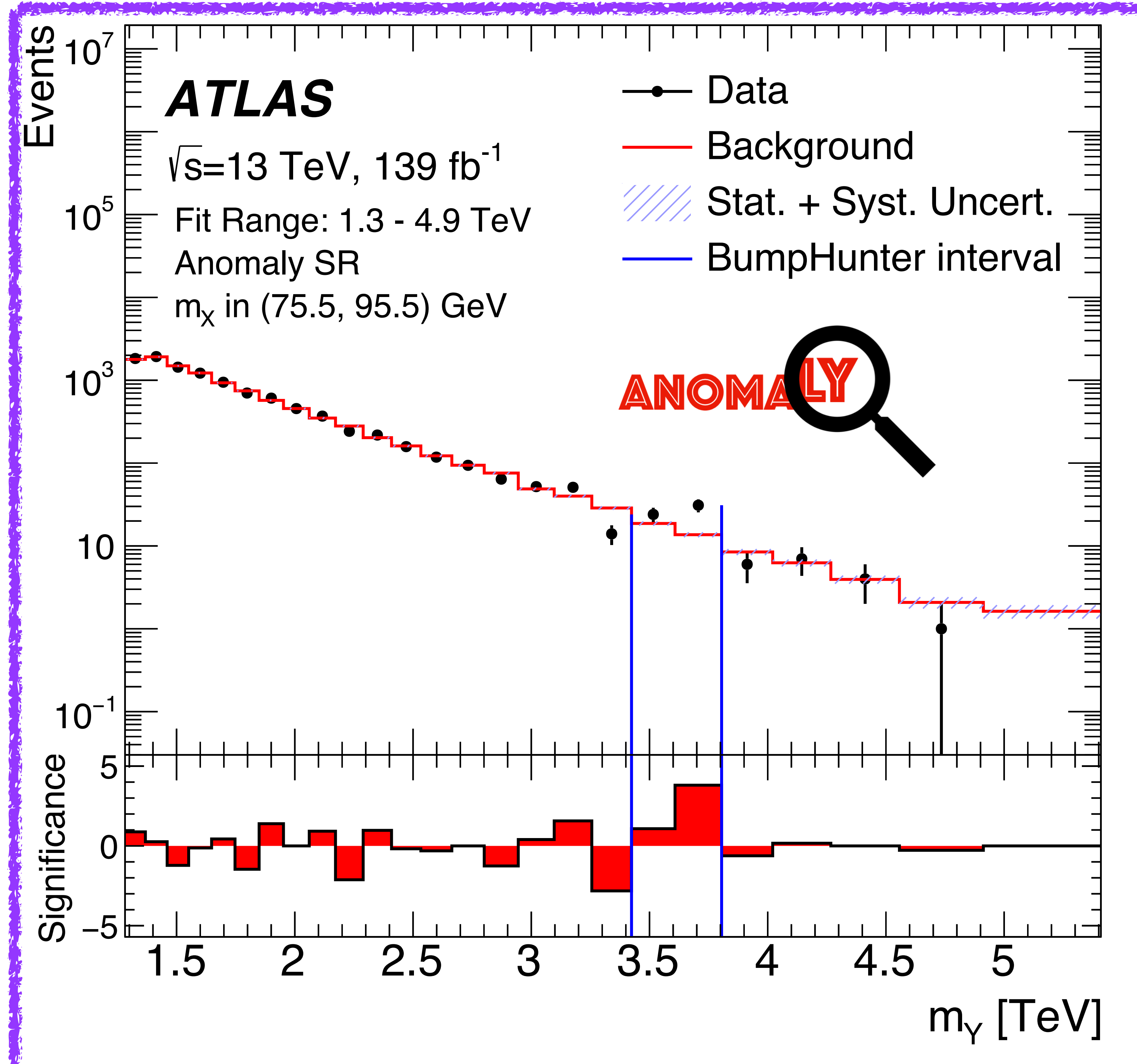


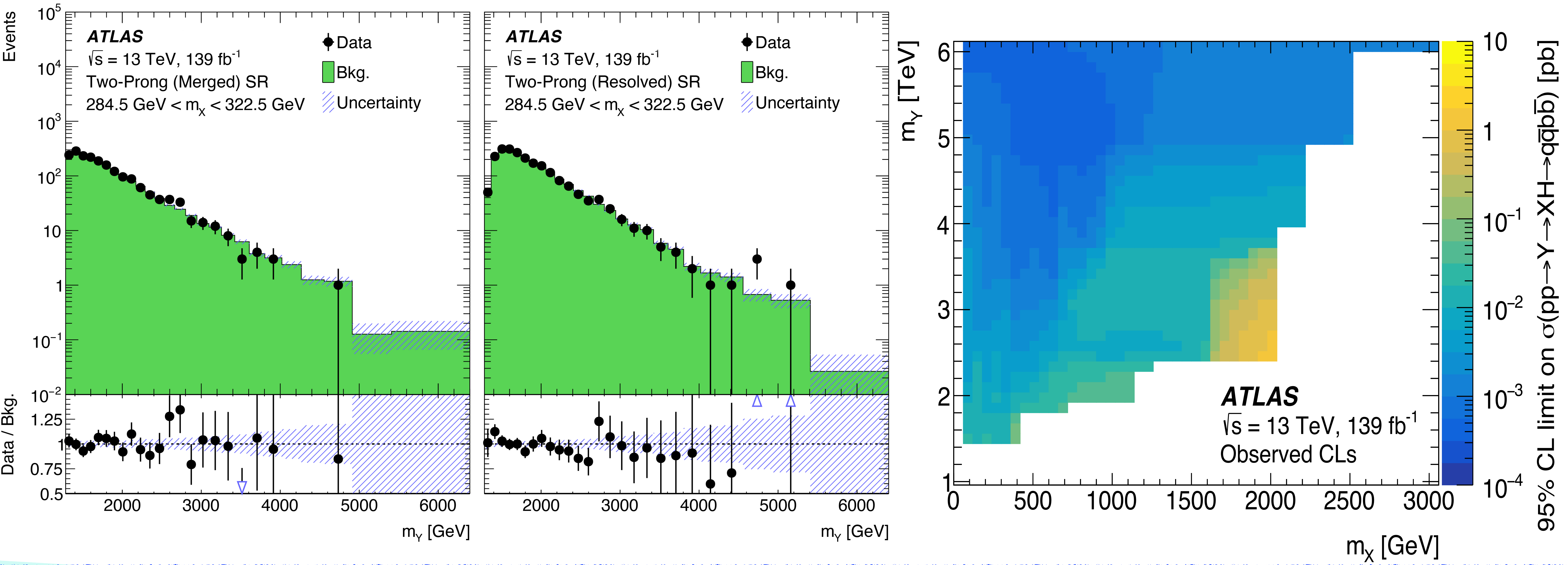
$Y \rightarrow HX$ anomaly search (II)

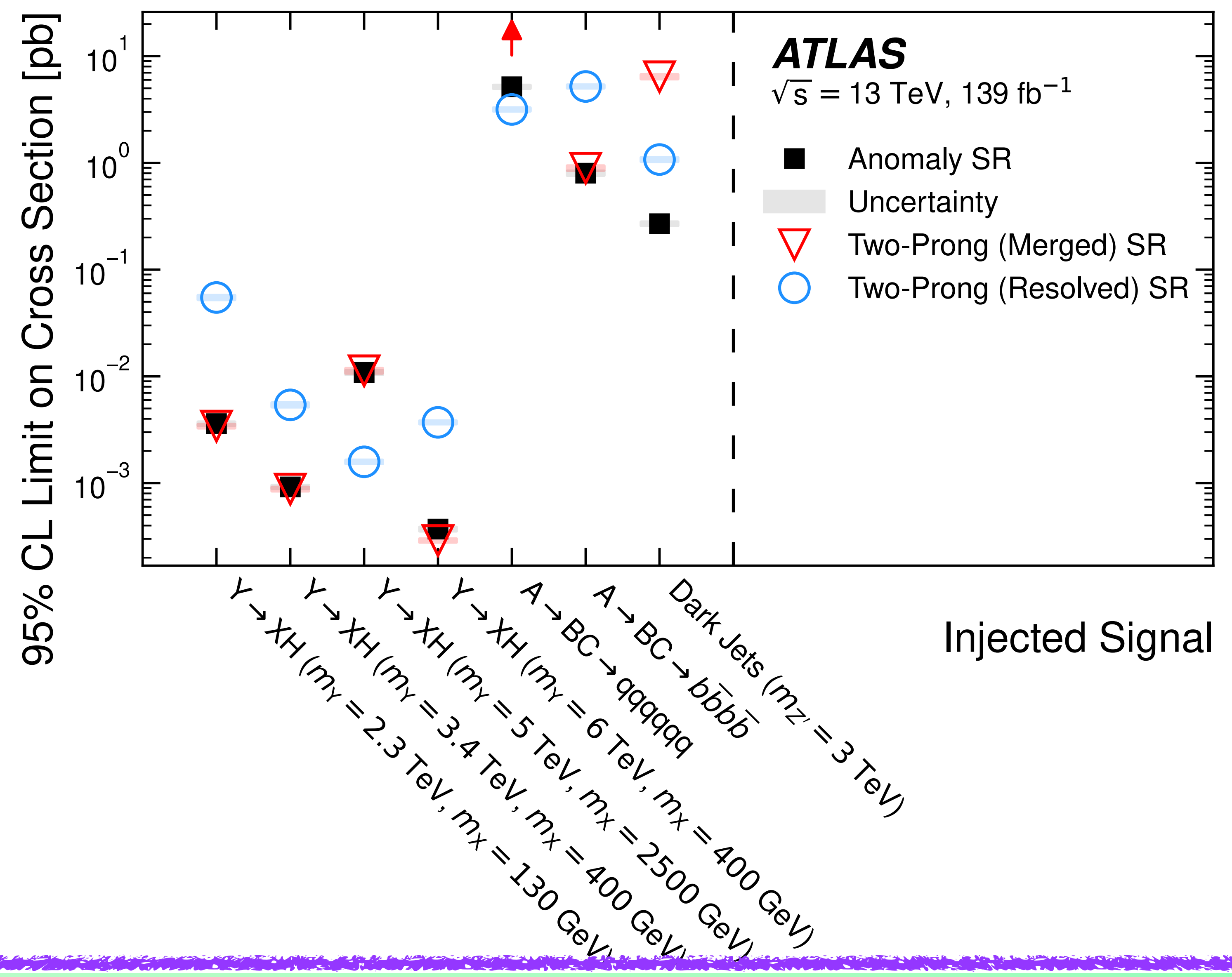
Machine Learning

- Data-driven estimate for QCD multijet background with NN reweighting
- No significant excess found
  - 2-prong channels: exclusion on HVT models
  - Anomaly channel: multiple models

Phys. Rev. D 108 (2023) 052009

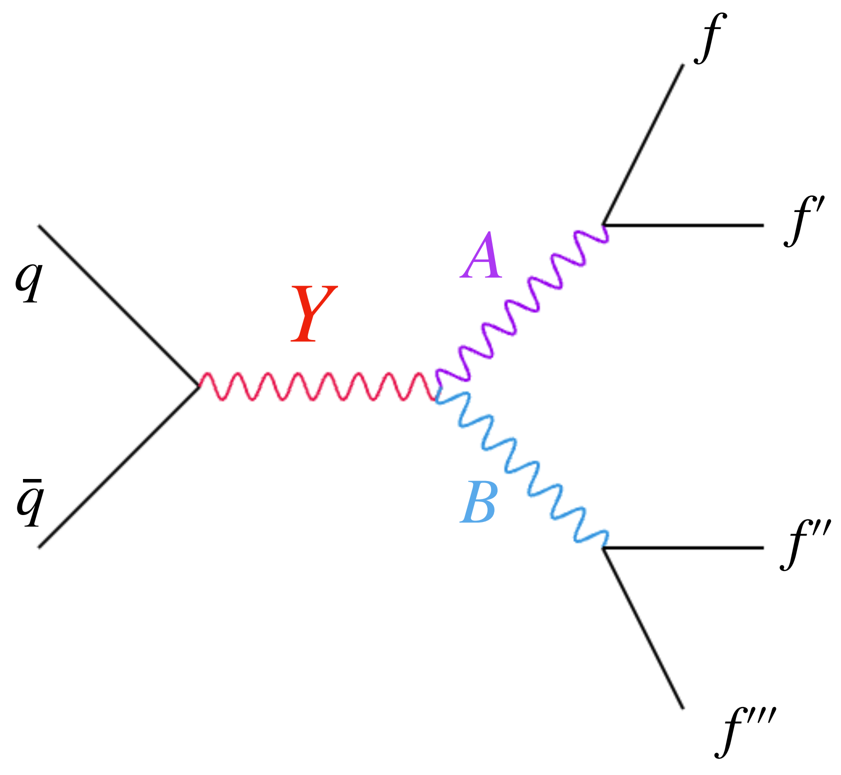


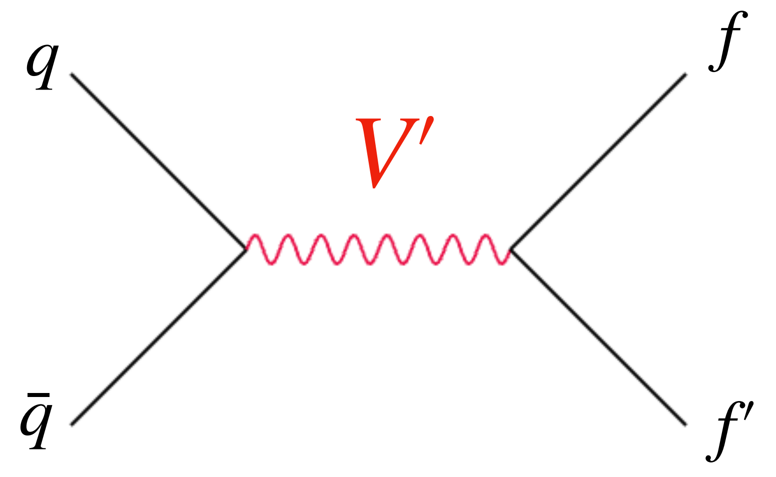




Resonance search combination

- ATLAS counts many independent analyses with sensitivity to these signal scenarios





Analysis	Leptons	$E_{\mathrm{T}}^{\mathrm{miss}}$	Jets	b-tags	Top-tags	VBF	Discr.
$WW/WZ \to qqqq$	0	Veto	$\geq$2J	-	-	-	m_{VV}
$WW/WZ \to \ell\nu qq$	1e, 1μ	Yes	$\geq$2j, $\geq$1J	0, 1, 2	-	Yes	m_{VV}
$WZ \to qq\nu\nu$	0	Yes	$\geq$1J	0	-	Yes	m_{VV}
$WZ \to qq\ell\ell$	2e, 2μ	-	$\geq$2j, $\geq$1J	0	-	Yes	m_{VV}
$WZ \to \ell\nu\ell\ell$	$3 \subset (e, \mu)$	Yes	-	0	-	Yes	m_{VV}
$WH/ZH \to qqbb$	0	Veto	$\geq$2J	1, 2	-	-	m_{VH}
$ZH \to \nu\nu bb$	0	Yes	$\geq$2j, $\geq$1J	1, 2	-	-	m_{VH}
$WH \to \ell\nu bb$	1e, 1μ	Yes	$\geq$2j, $\geq$1J	1, 2	-	-	m_{VH}
$ZH \to \ell\ell bb$	2e, 2μ	Veto	$\geq$2j, $\geq$1J	1, 2	-	-	m_{VH}
$\ell\nu$	1e, 1μ	Yes	-	-	-	-	m_{T}
$\tau\nu$	1τ	Yes	-	-	-	-	m_{T}
$\ell\ell$	$\geq$2e, $\geq$2μ	-	-	-	-	-	$m_{\ell\ell}$
$\tau\tau$	0, 1e, 1μ	Yes	-	0, $\geq$1	-	-	$m_{\tau\tau}$
tt0L	0	-	2J	1, 2	2	-	m_{tt}
tb0L	0	-	$\geq$(1j+1J)	$\geq$1	1	-	m_{tb}
tb1L	1e, 1μ	Yes	2j, 3j	1, 2	-	-	m_{tb}
qq	0	-	2j	0	-	-	m_{jj}
bb	0	-	2j	1, 2	-	-	m_{bb}

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Resonance search combination

- ATLAS counts many independent analyses with sensitivity to these signal scenarios
- Statistical combination of a number of results covering these topologies
  - Individual analyses are studied for orthogonality with slight adjustments
- Interpret results in terms of exclusion for 3 parameter choices in the HVT framework
  - 1D exclusion on production cross section

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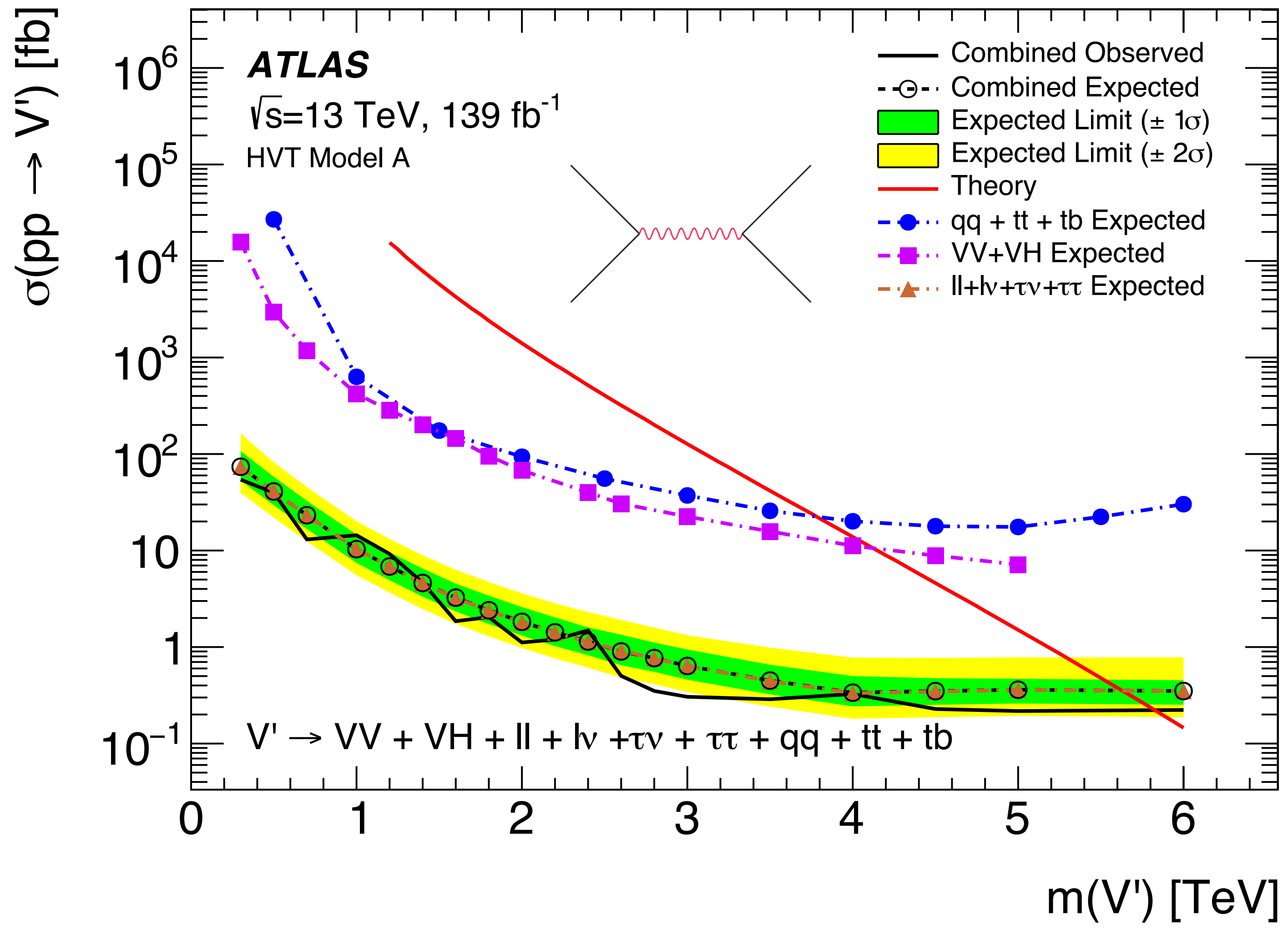

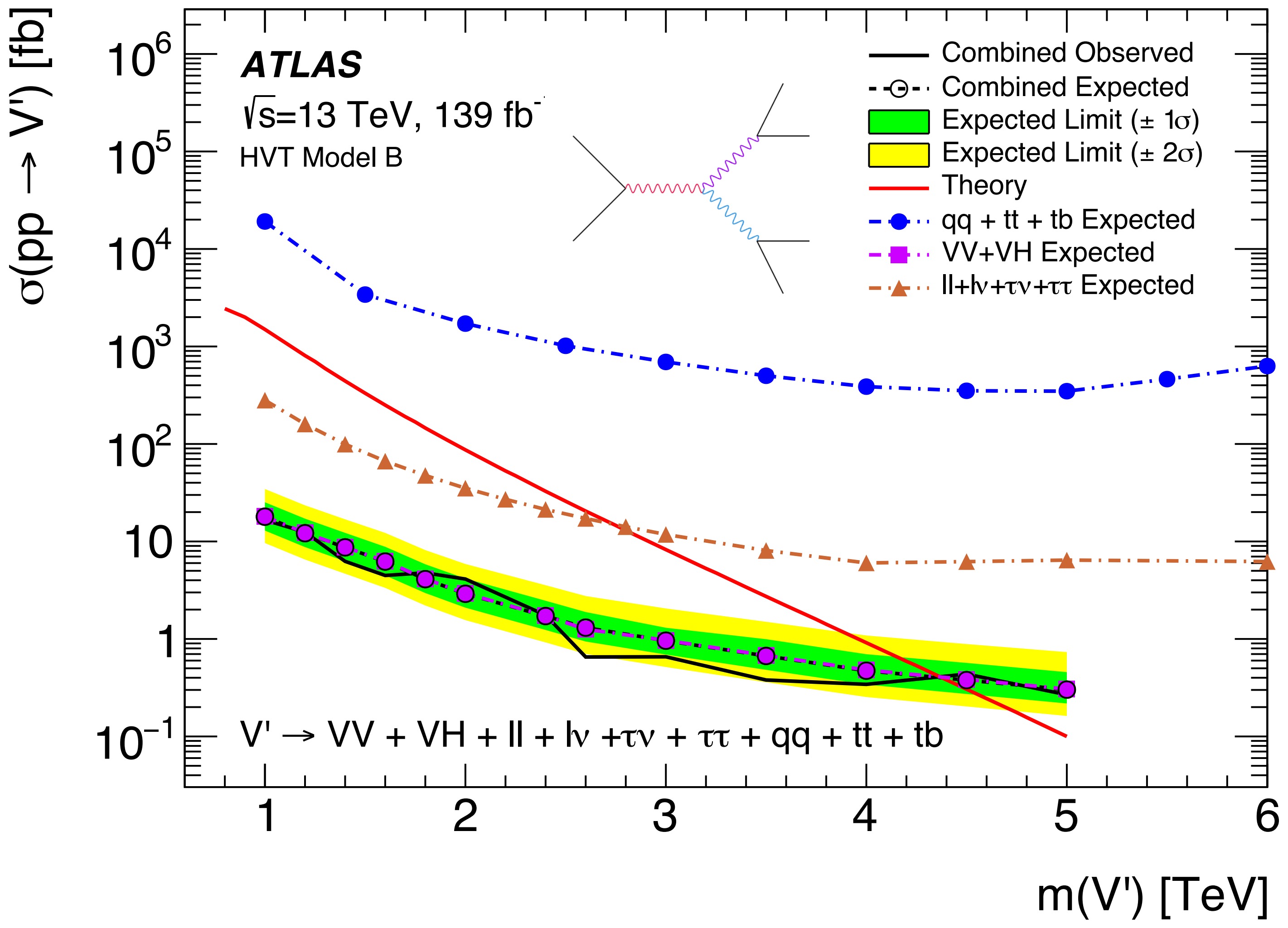

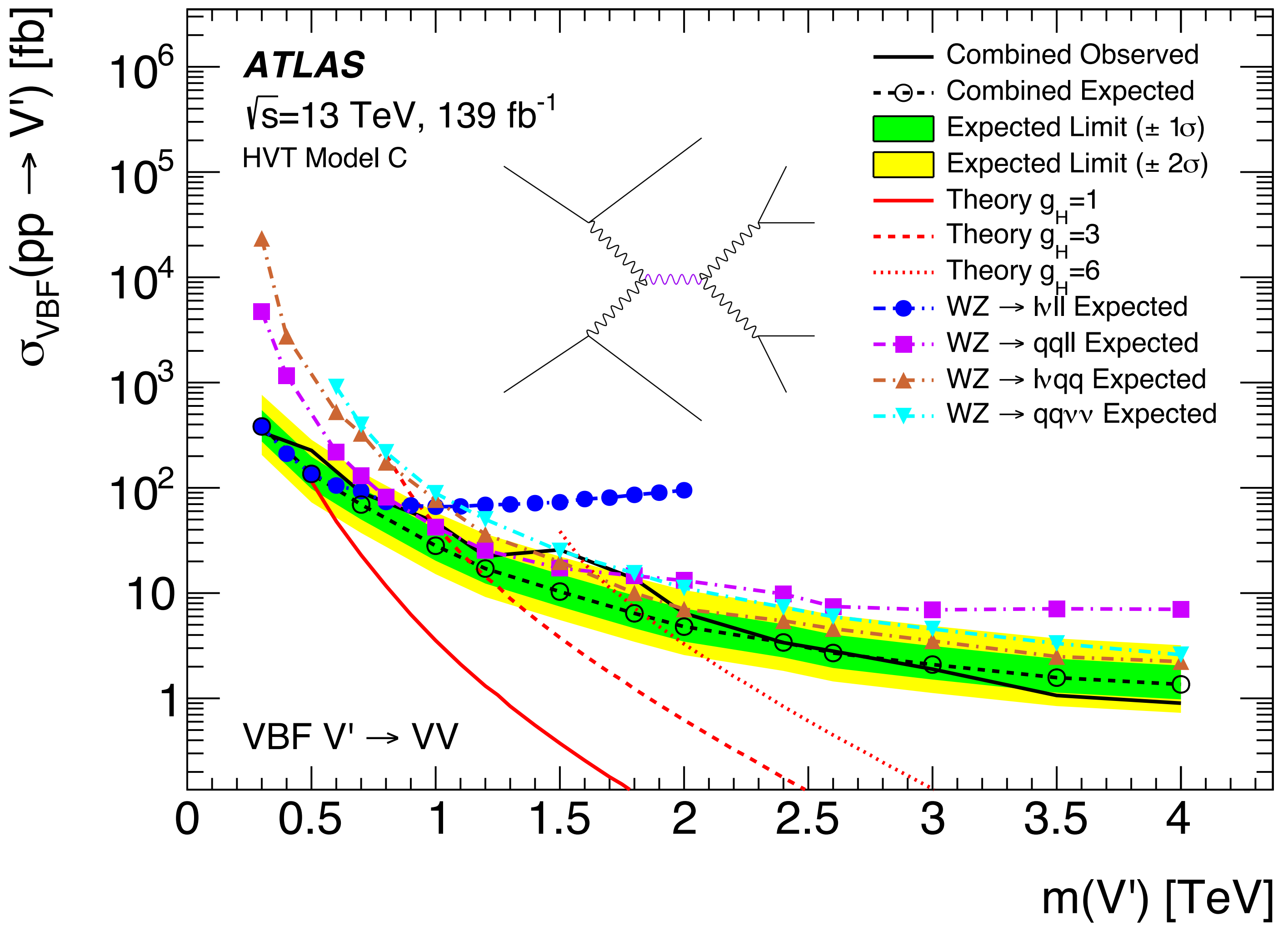

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- ATLAS counts many independent analyses with sensitivity to these signal scenarios
- Statistical combination of a number of results covering these topologies
  - Individual analyses are studied for orthogonality with slight adjustments
- Interpret results in terms of exclusion for 3 parameter choices in the HVT framework
  - 1D exclusion on production cross section
  - 2D exclusion on different possible couplings
  - New! Explored sensitivity to third generation fermions!

$\ell\nu$	$1e$, 1μ	Yes	-	-	-	-	m_{T}	[15]
$\tau\nu$	1τ	Yes	-	-	-	-	m_{T}	[16]
$\ell\ell$	$\geq 2e$, $\geq 2\mu$	-	-	-	-	-	$m_{\ell\ell}$	[14]
$\tau\tau$	0, $1e$, 1μ	Yes	-	0, $\geq$1	-	-	$m_{\tau\tau}$	[17]
tt0L	0	-	2J	1, 2	2	-	m_{tt}	[19]
tb0L	0	-	$\geq$(1j+1J)	$\geq$1	1	-	m_{tb}	[20]
tb1L	$1e$, 1μ	Yes	2j, 3j	1, 2	-	-	m_{tb}	[20]
qq	0	-	2j	0	-	-	m_{jj}	[18]
bb	0	-	2j	1, 2	-	-	m_{bb}	[18]

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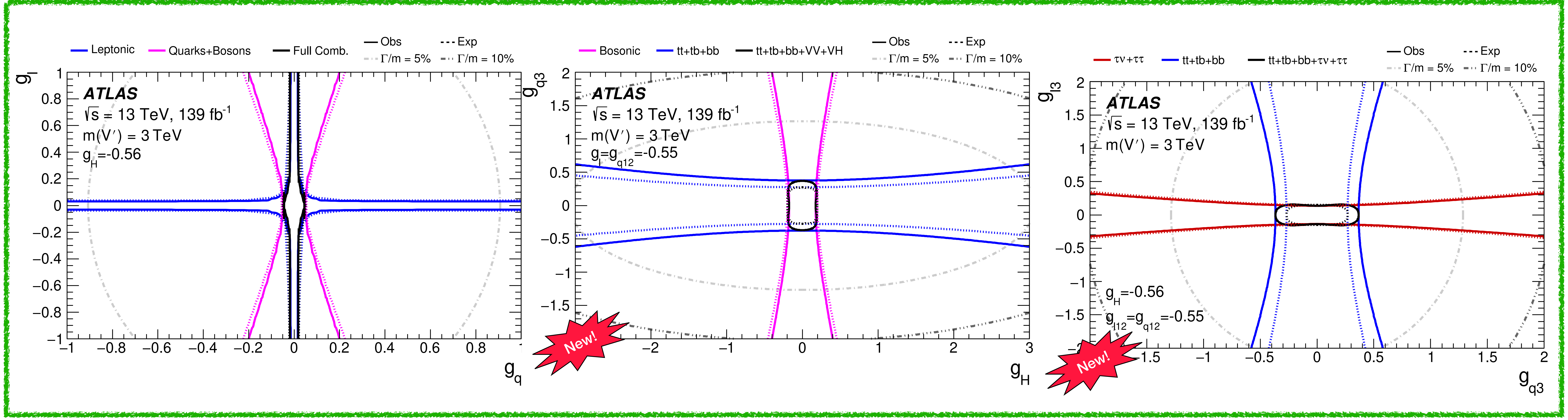
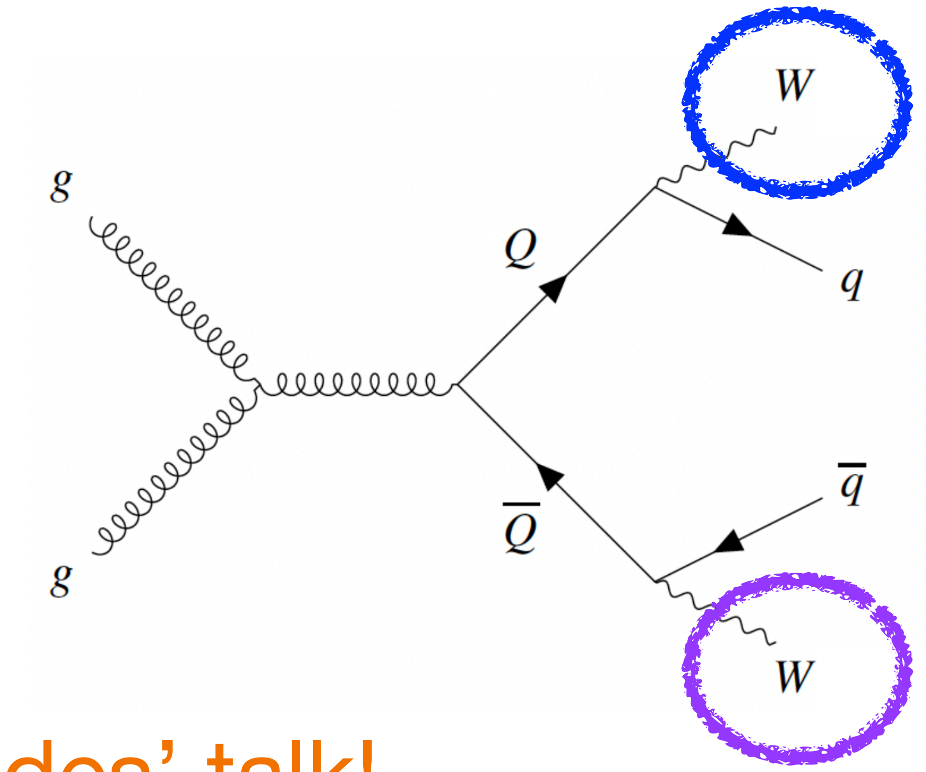


- Improved sensitivity to third generation fermions!

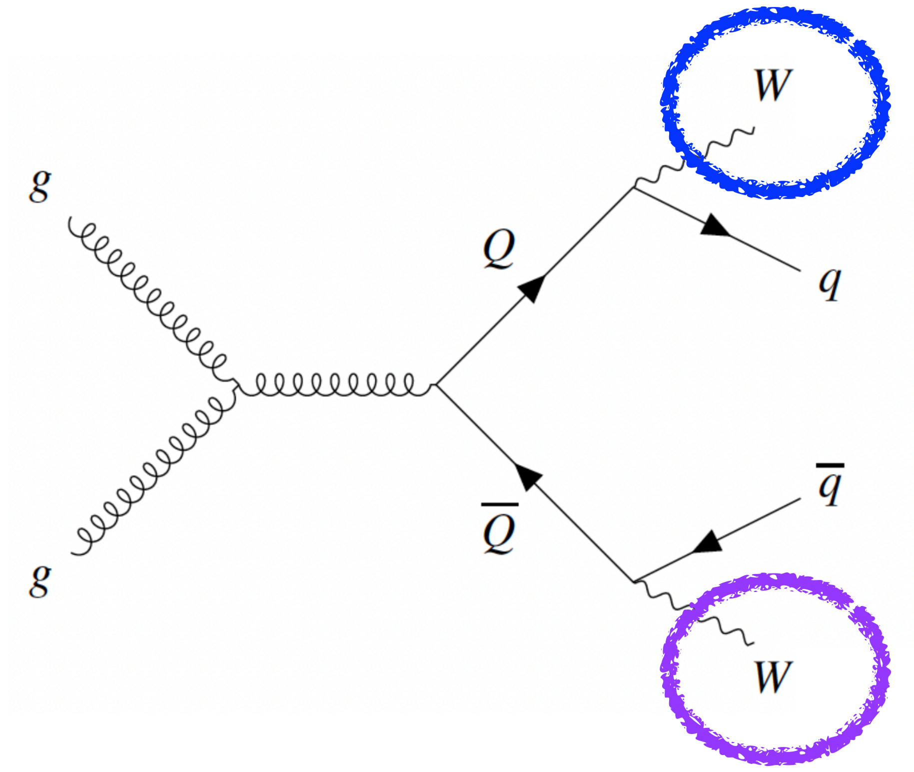
VLQ $\rightarrow$ Wq search



- Mixed topology with heavy resonance decaying to $V + f$ is also possible → VLQ
- Search for pair production of VLQs decaying to W and a light quark — more in D. Paredes' talk!
  - Final state with one $W \rightarrow l\nu$ and one $W \rightarrow qq'$
  - Select events with one high energy lepton, large E_T^{miss}, and jets

Submitted to PRD - arXiv:2405.19862

VLQ → Wq search



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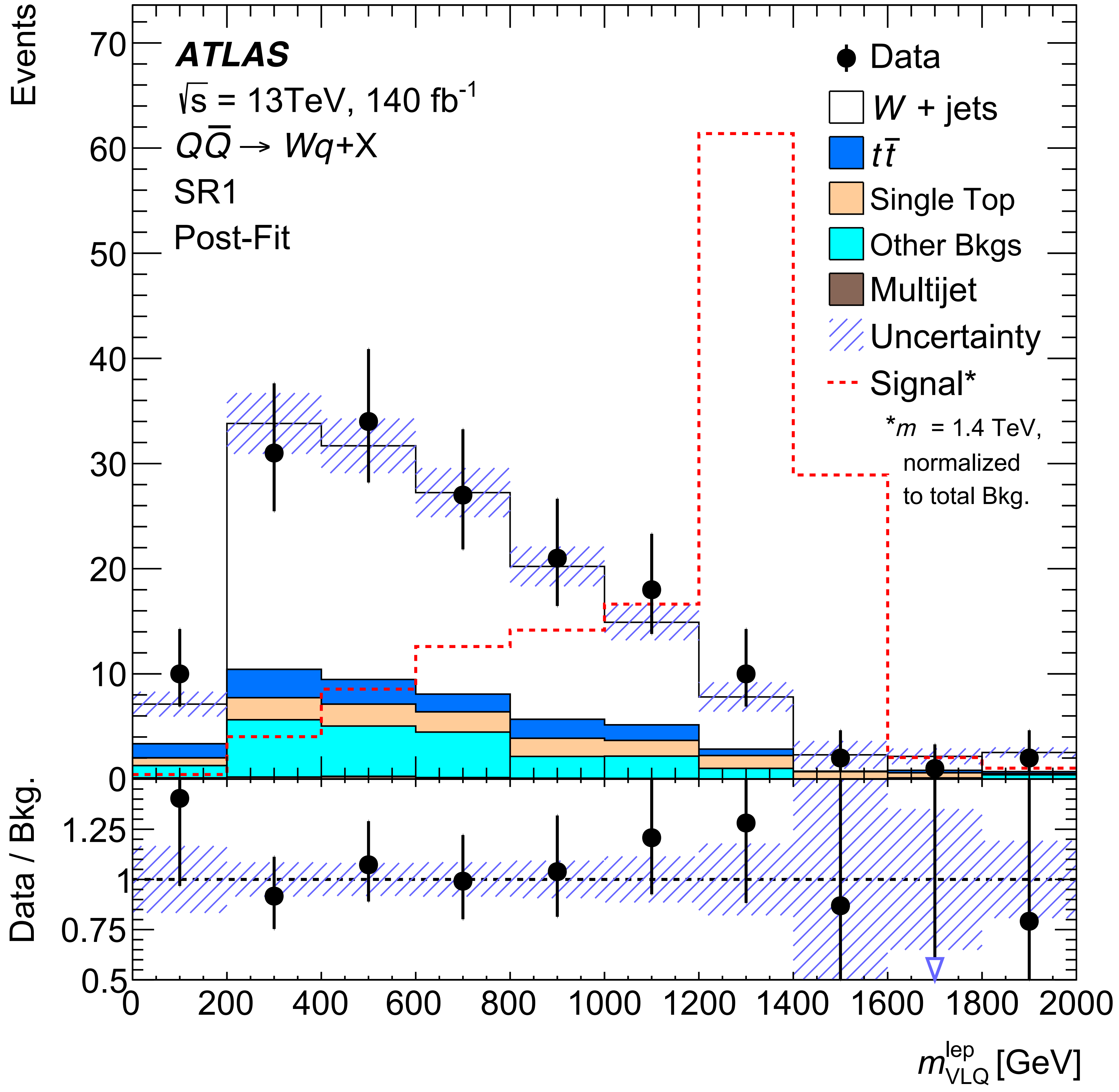
  - Final state with one $W \to l\nu$ and one $W \to qq'$
  - Select events with one high energy lepton, large E_T^{miss}, and jets
- Main backgrounds: W+jets, top quark production
  - Estimated from MC, corrected in dedicated CRs with an iterative reweighting
- Fit to reconstructed mass of leptonic VLQ
  - No significant excess found



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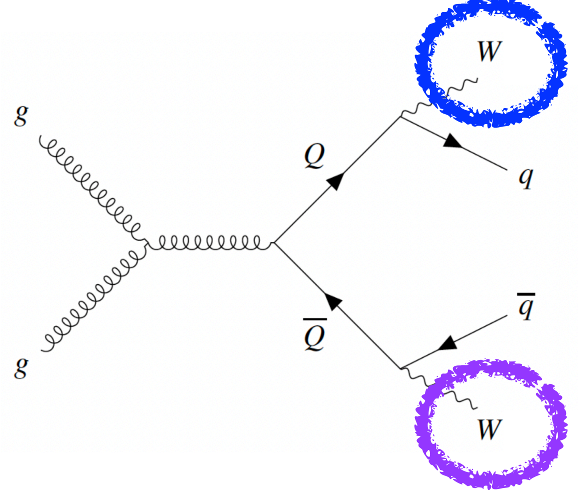
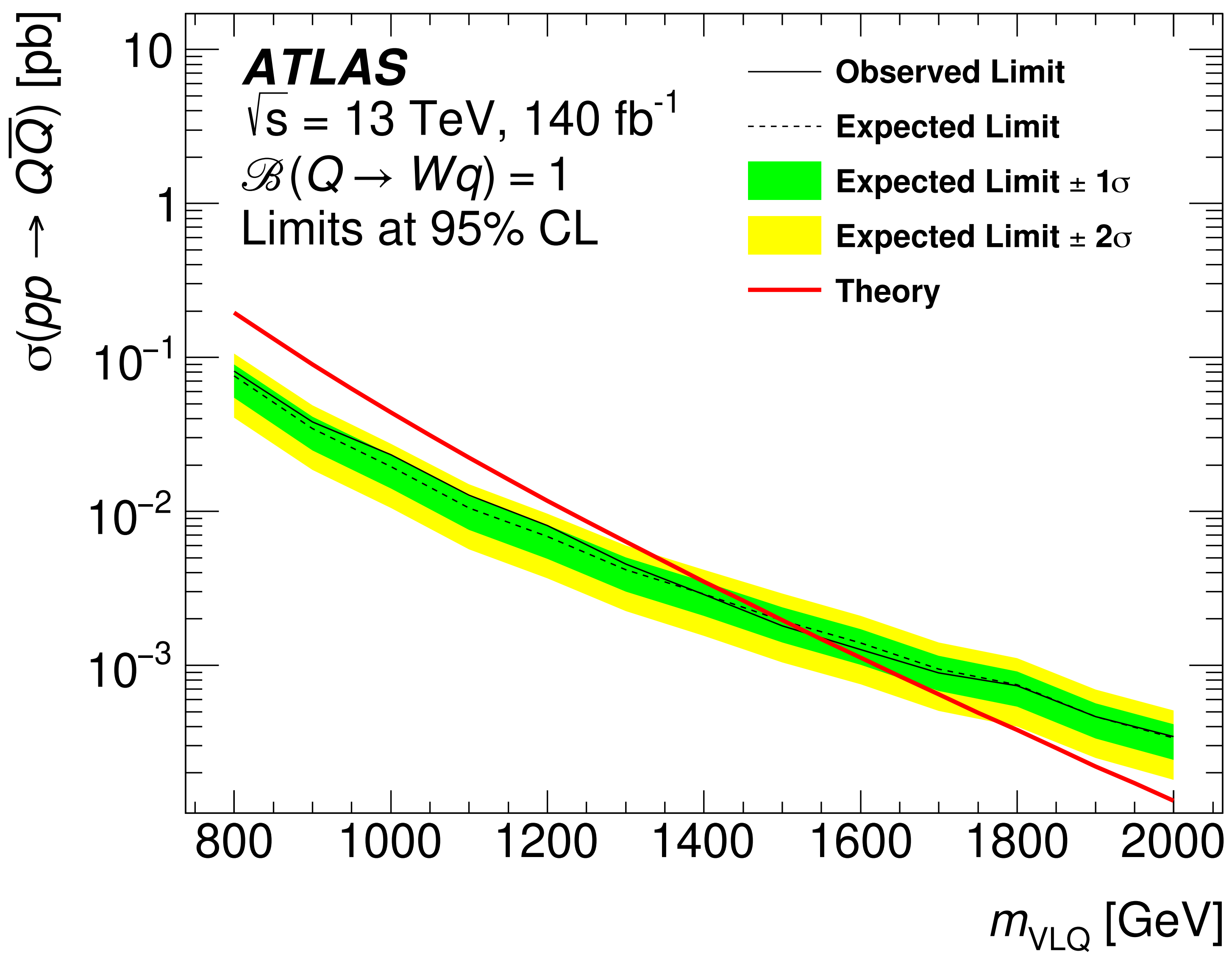
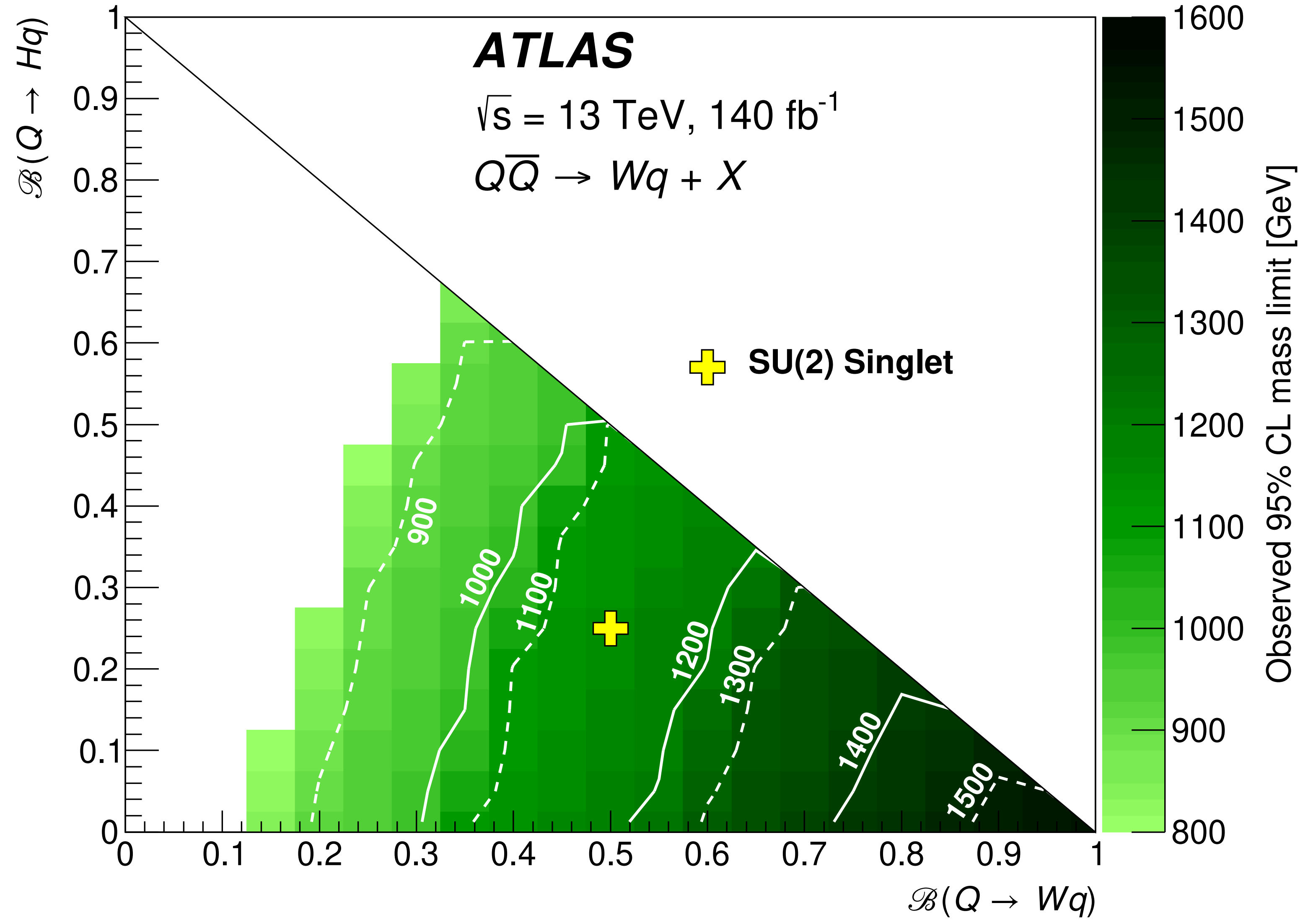


VLQ → Wq search

- Mixed topology with heavy resonance decaying to $V+f$ is also possible
- Search for pair production of VLQs decaying to W and a light quark
  - Final state with one $W \to l\nu$ and one $W \to qq'$
  - Select events with one high energy lepton, large E_T^{miss}, and jets
- Main backgrounds: W+jets, top quark production
  - Estimated from MC, corrected in dedicated CRs with an iterative reweighting
- Fit to reconstructed mass of leptonic VLQ
  - No significant excess found
  - Exclusion limits for different VLQ branching fractions





Submitted to PRD - arXiv:2405.19862

Summary

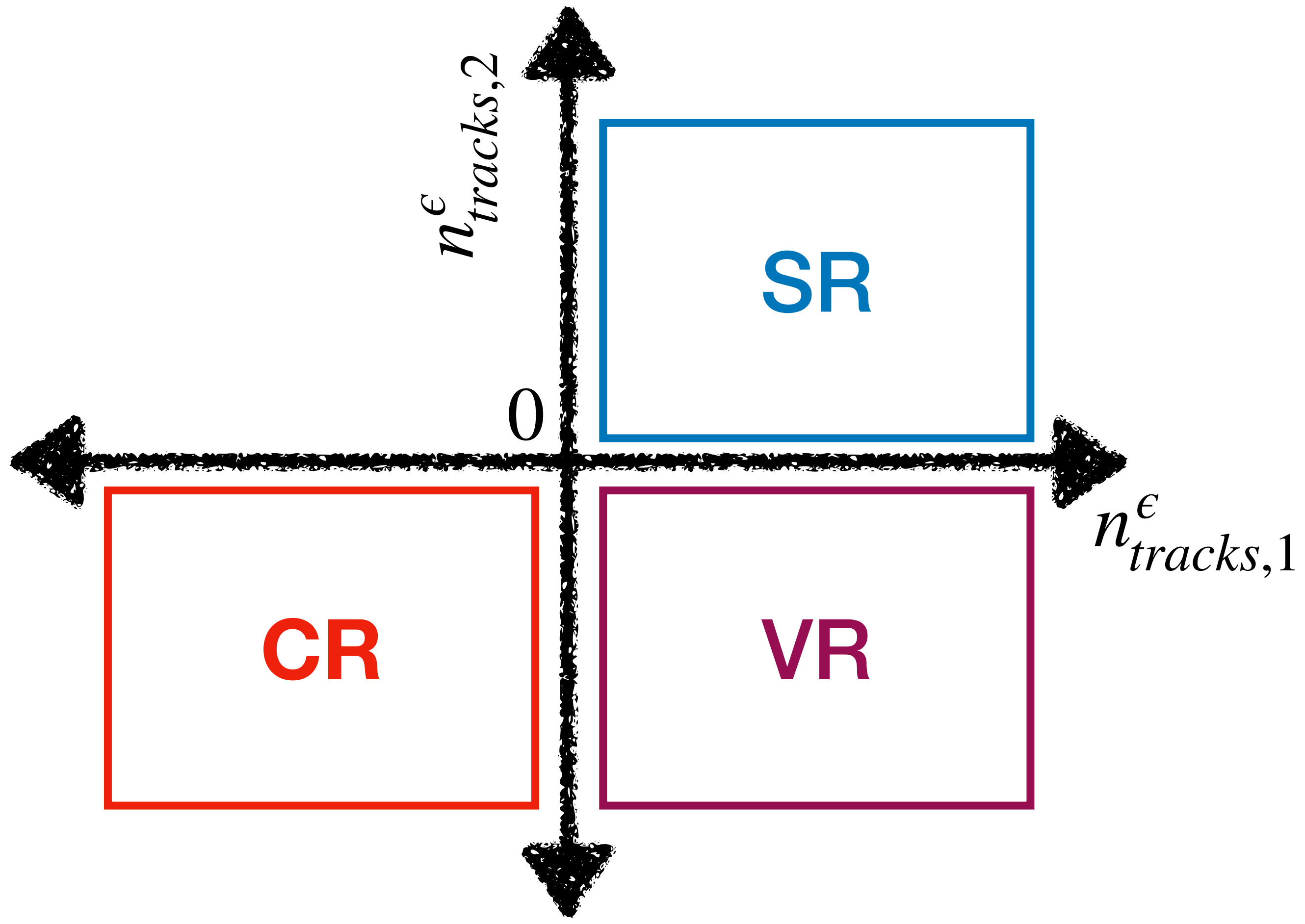
- Large number of ATLAS searches looking for new physics in hadronic final states
  - Improved analysis techniques for leading sensitivity to many different scenarios
  - No BSM physics found (yet) — keep constraining the possible phase space
  - Many ongoing analyses still not published

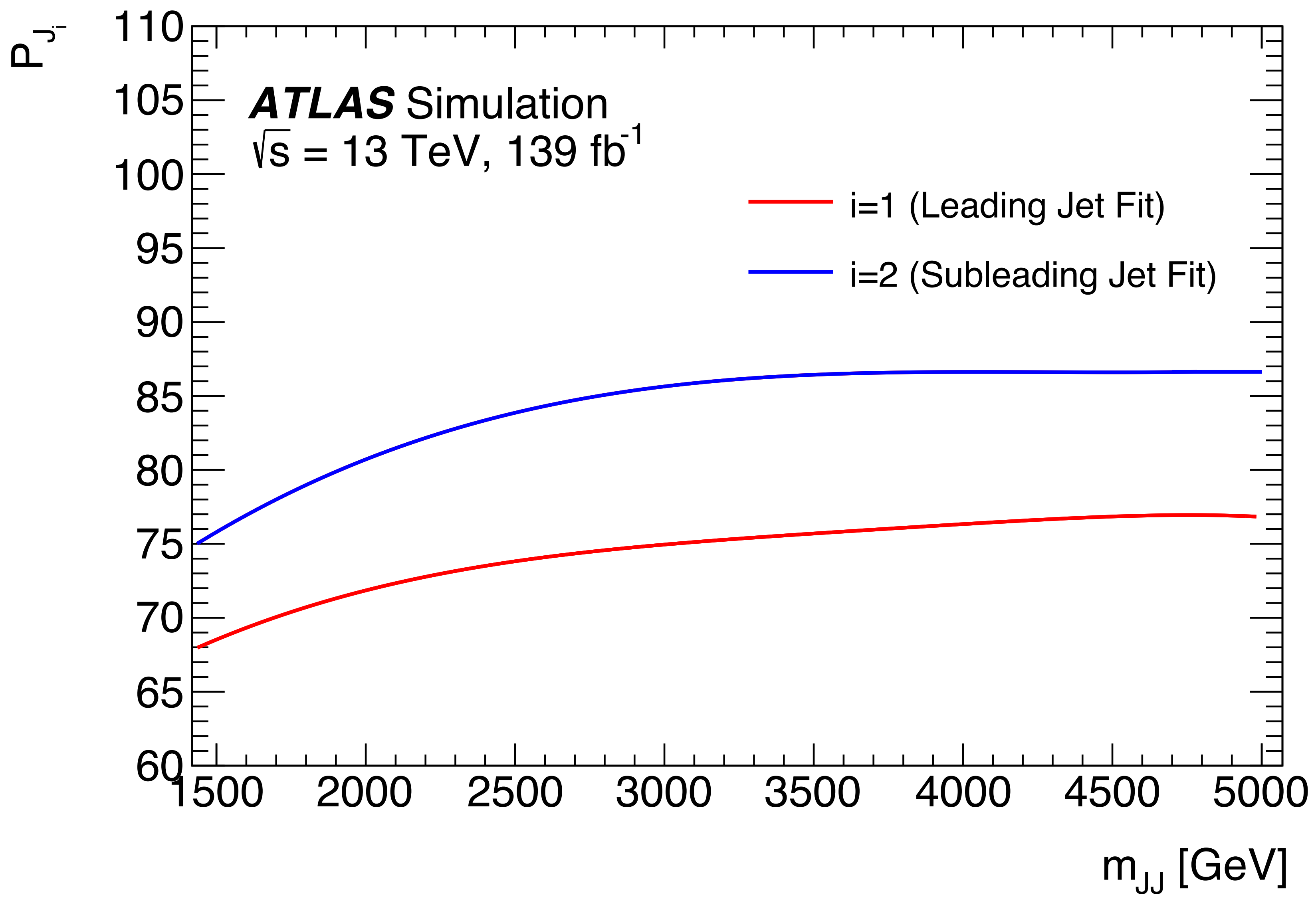
- All results presented so far use LHC Run-2 data
  - More and more Run-3 analyses are starting now, increased luminosity and different approaches
  - <u>**Stay tuned for more ATLAS results soon!**</u>

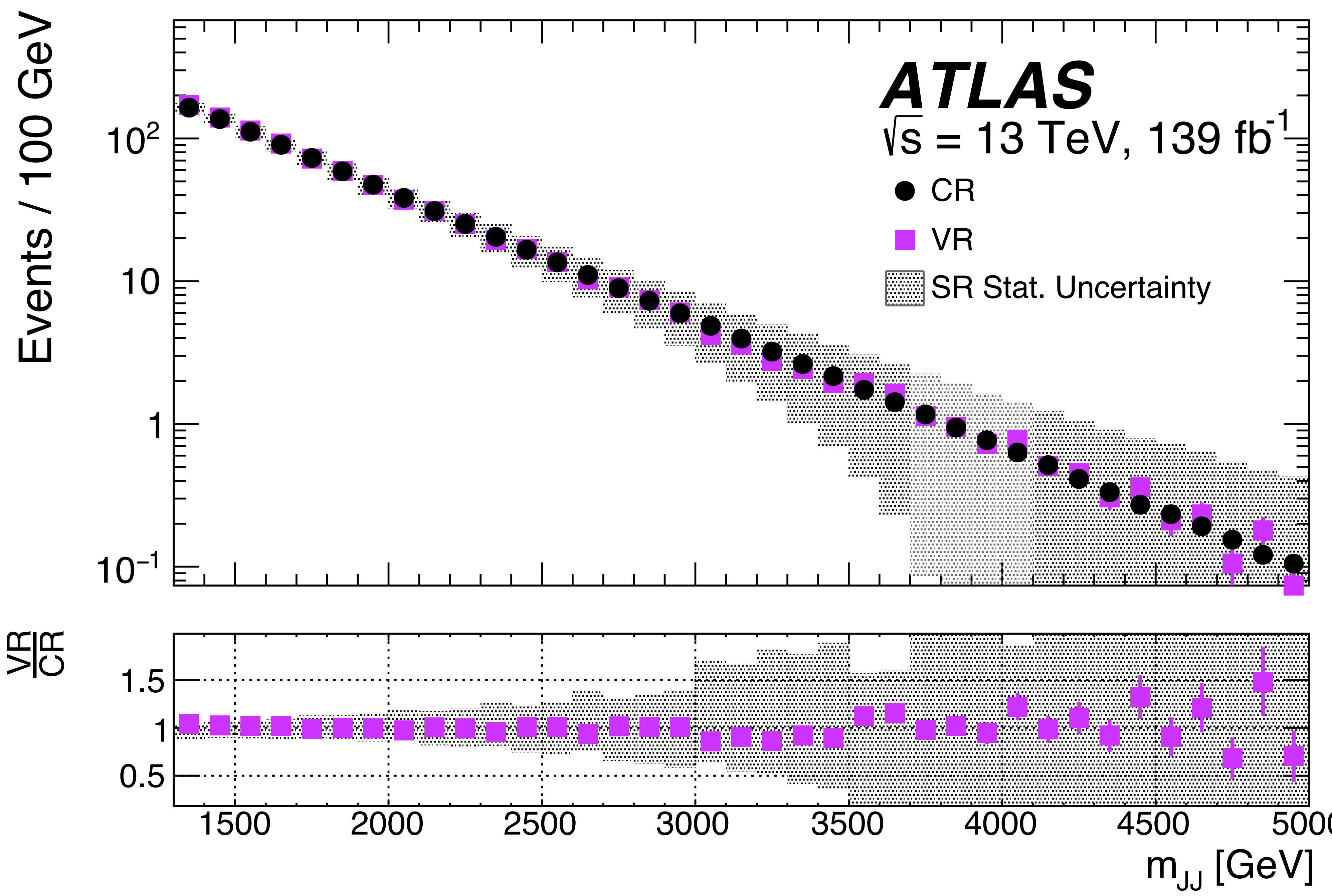
BACKUP

Resonant dark jets

- Selection on jet n_{track} sculpts mass spectrum
  - Find the number of tracks P_J for background efficiency ϵ in each m_{JJ} bin
  - Signal jets will have $n^{\epsilon}_{track} = n_{track} - P_J > 0$
- CR, VR and SR defined with selections on n^{ϵ}_{tracks}
- Data driven background estimate in SR extracted from CR
  - Fit to m_{jj} in CR data for template shape, fit normalization in SR







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$Y \to HX$ anomaly search

- Data-driven estimate for QCD multijet background
- Define CR, VR and SR with Higgs candidate
  - NN-assisted reweighting from Higgs-fail to Higgs-pass regions
  - NN trained inclusively in X candidates → valid for all SR!