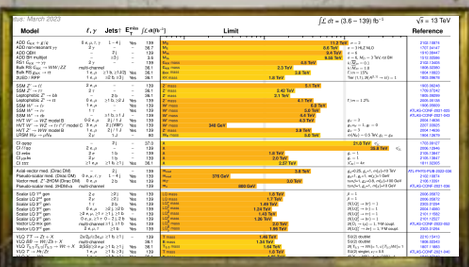
Recent searches for new phenomena with the ATLAS detector



Lorenzo Feligioni on behalf of the ATLAS collaboration

TeVPA 2023

CPPM Centre de Physique des Particules de Marseille

cnrs IN2P3 Les deux infinis

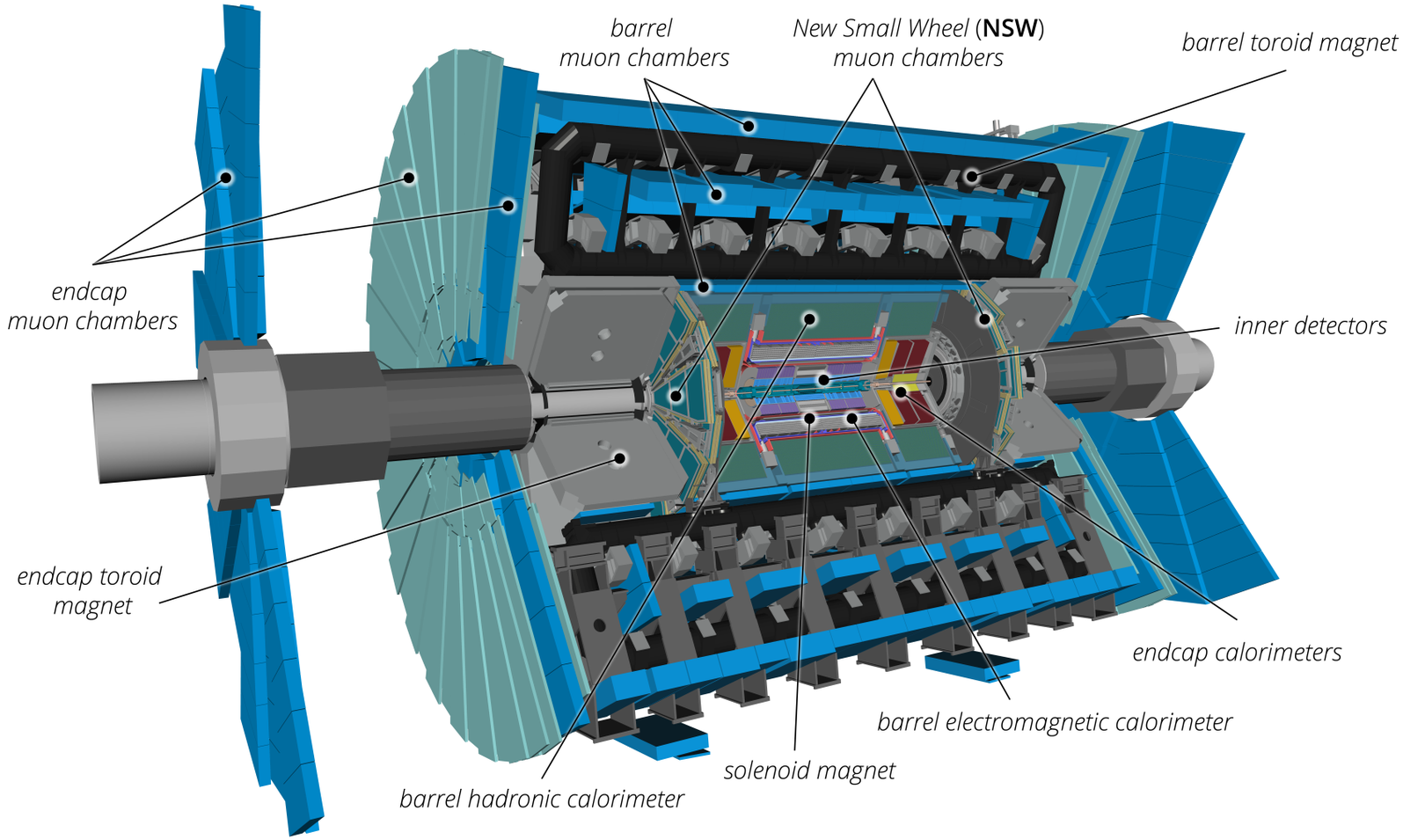
Aix*Marseille université

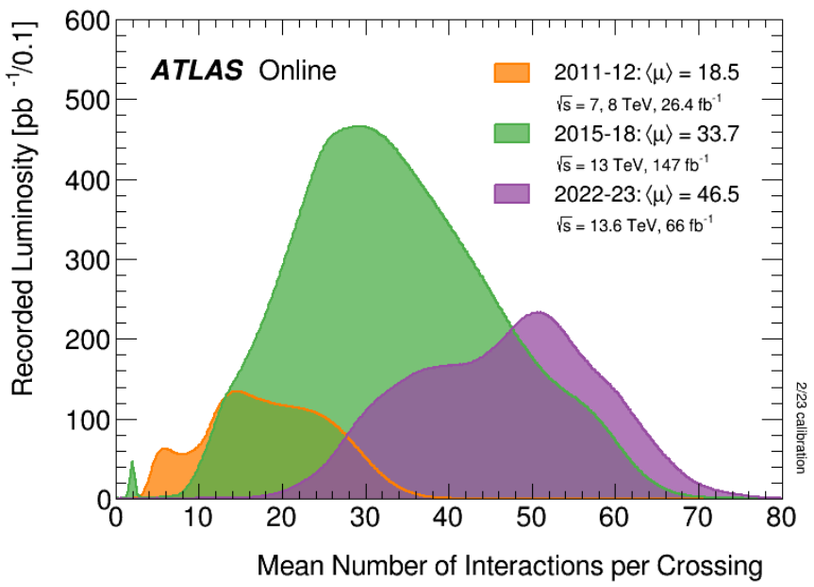
ATLAS EXPERIMENT

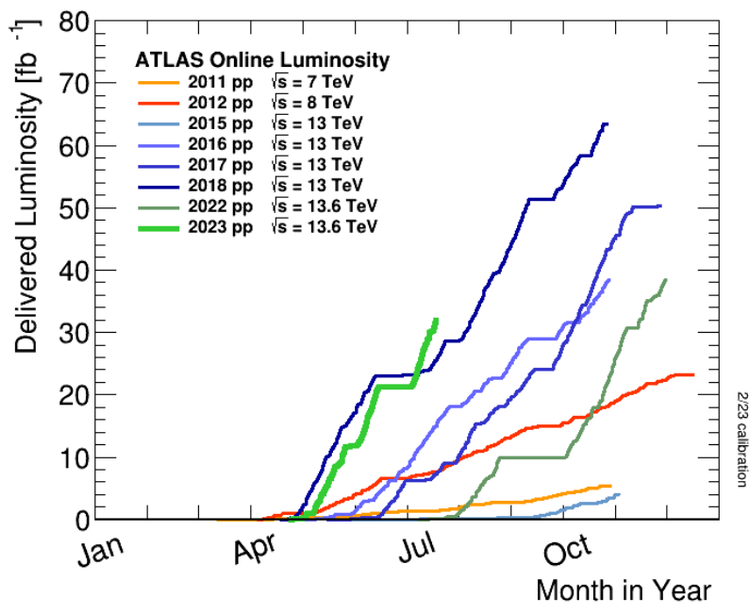
BSM Physics at the LHC

The ATLAS Experiment at the LHC

- Evolution for Run 3 :
  - New LAr Calorimeter digital trigger electronic boards
  - Improved muon Level 1 trigger thanks to NSW
  - Upgraded TDAQ
- Excellent performance of the detector
  - ~66 fb-1 of data recorded by ATLAS in Run 3
- Large effort on analyzing data
  - ~40 new results this summer





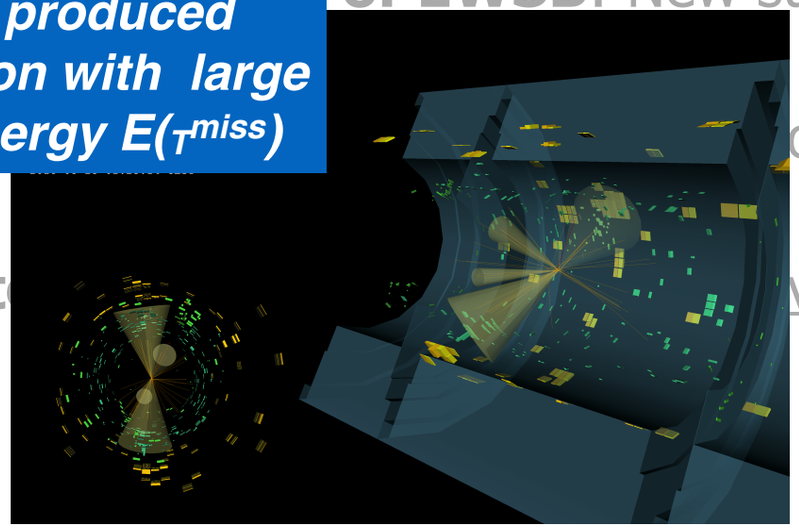


CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM

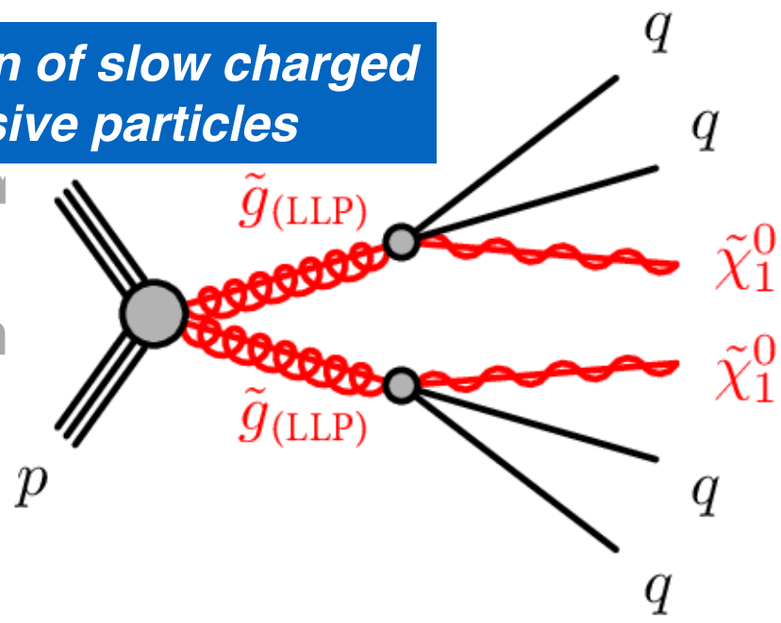
BSM Physics at the LHC

- Many new models addressing the shortcoming of the SM make predictions that can be tested at the LHC:
  - **Natural EWSB**: Supersymmetry (SUSY), large/warped extra dimensions (ADD/RS)
  - **Neutrino masses/mixing, flavor anomalies**: RPV SUSY, scalar di-quarks
  - **Dynamic production of EWSB**: New stro
  - opoles, SUSY
  - **Dark matt** vera's talk th

Di-Higgs produced In association with large Missing energy $E(_T^{miss})$



Production of slow charged massive particles

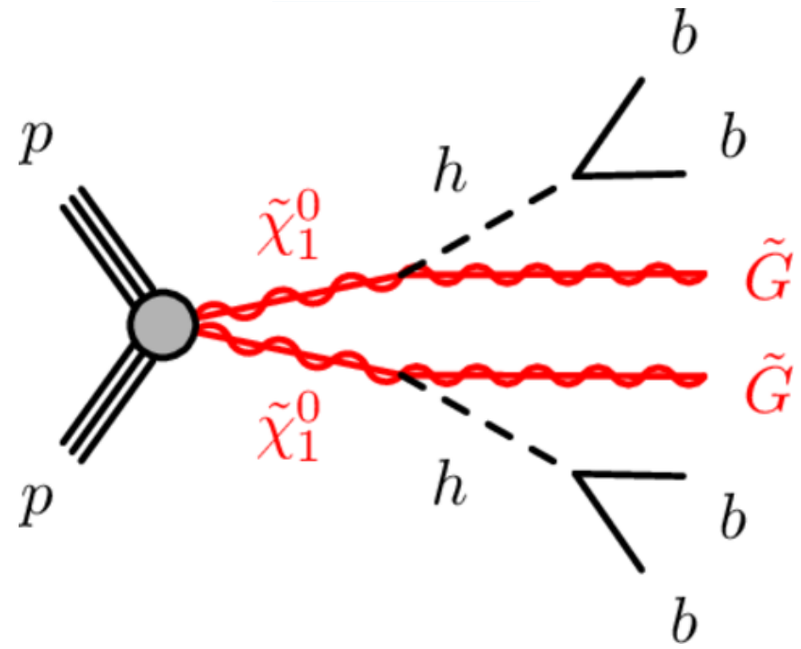


SUSY EWK 4b + E_T^{miss}

Search for pair production of higgsinos in events with two Higgs bosons and missing transverse momentum in $\sqrt{s}$ = 13 TeV pp collisions at the ATLAS experiment ATLAS-CONF-2023-048

- Gauge Mediated Symmetry Breaking Models (GMSB)
  - LSP ➔ particle associated to the spontaneous breaking of the global supersymmetry
- High Mass Channel:
  - **significant E_T^{miss}**
  - background estimated with MC simulation
  - BDT used to discriminate signal and background
- Low mass Channel
  - **≥4 b-jets to reconstruct higgs bosons**
  - QCD background estimated with ABCD method

$\tilde{\chi}_0^1$ NLSP



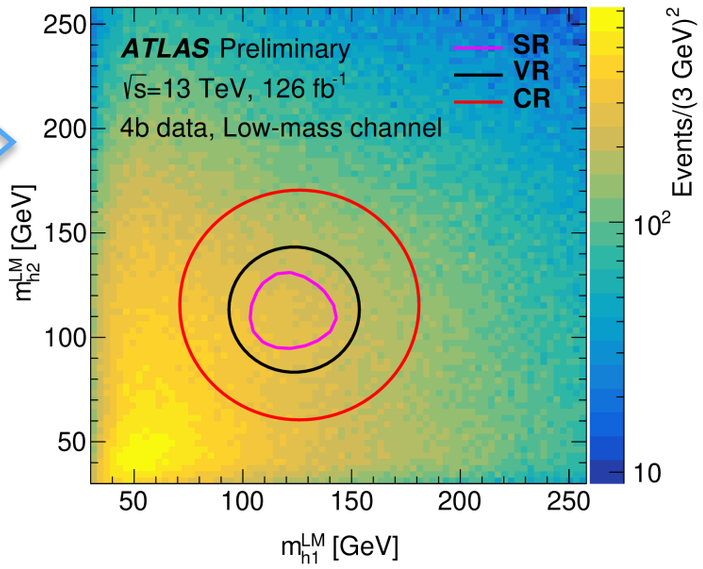
h_1^{LM} and h_2^{LM} Higgs candidates

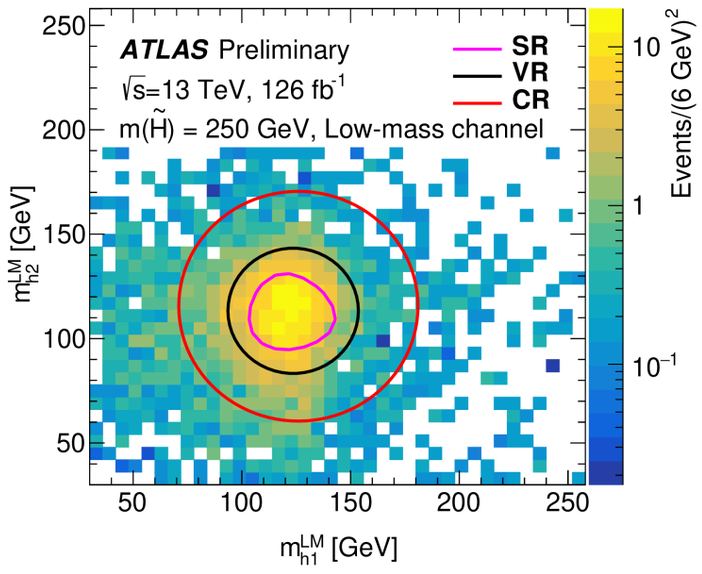
$$X_{hh}^{SR} = \sqrt{\left(\frac{m(h_1^{LM}) - 120\,\text{GeV}}{0.1 \cdot m(h_1^{LM})}\right)^2 + \left(\frac{m(h_2^{LM}) - 110\,\text{GeV}}{0.1 \cdot m(h_2^{LM})}\right)^2}$$

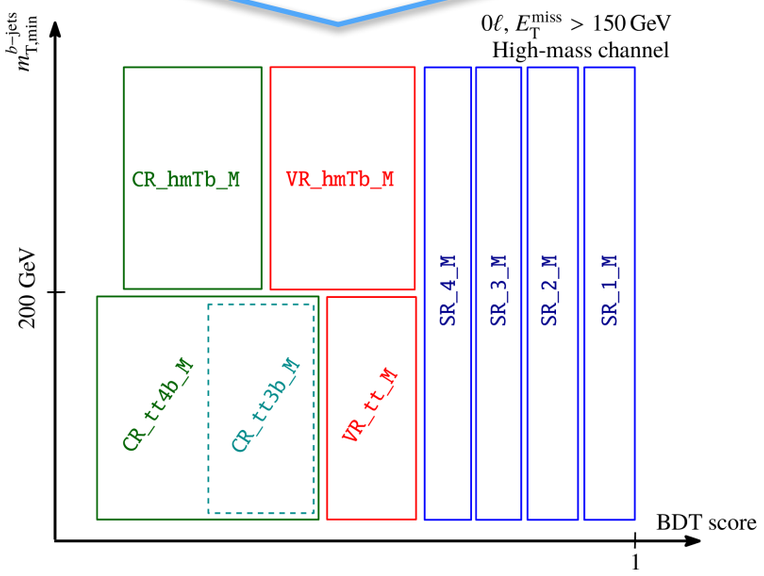
SUSY EWK 4b + E_T^{miss}

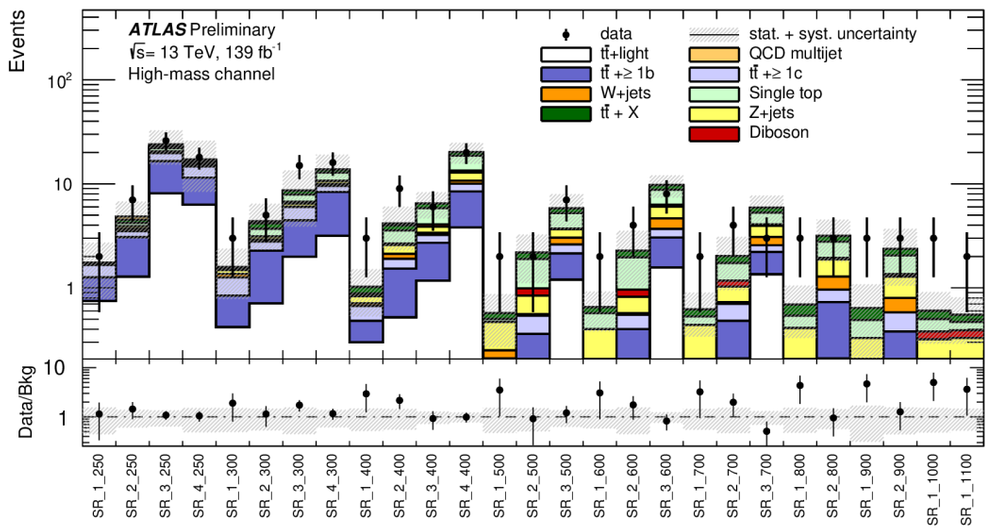
Search for pair production of higgsinos in events with two Higgs bosons and missing transverse momentum in √s = 13 TeV pp collisions at the ATLAS experiment ATLAS-CONF-2023-048

- Low mass:
  - reconstruction of higgs boson masses
- High mass:
  - Mass dependent SR and CR function of BDT score





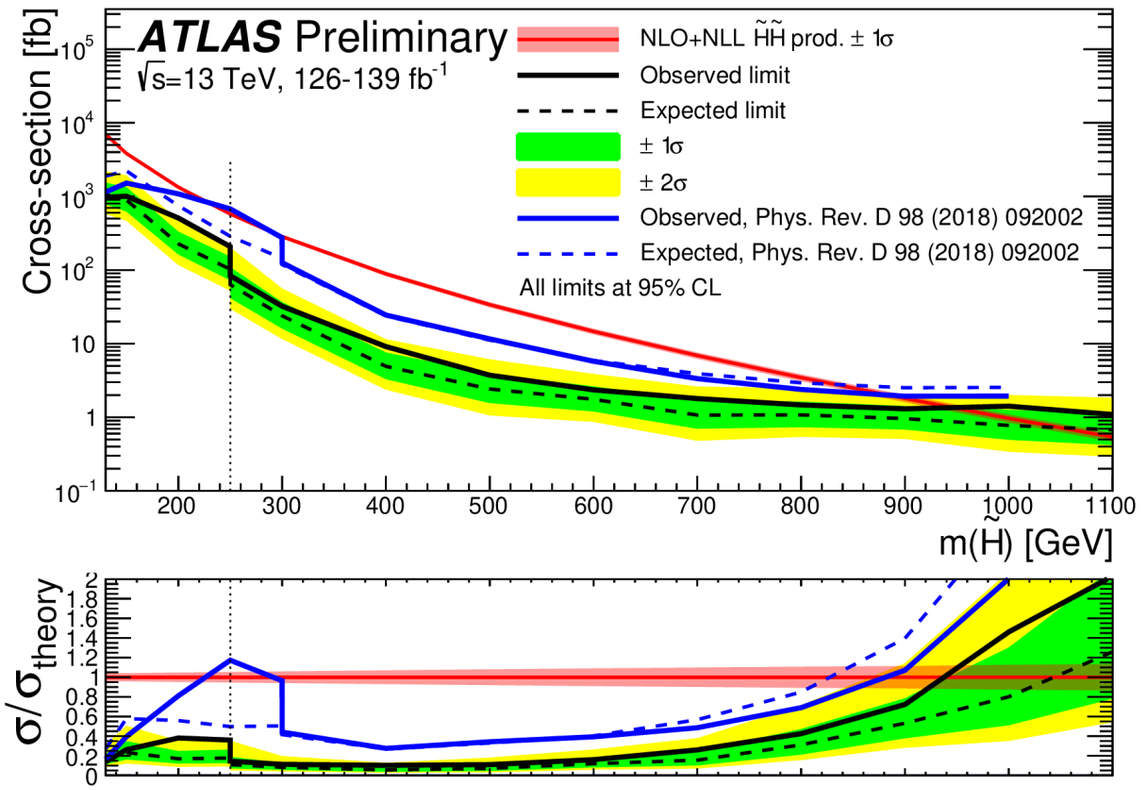


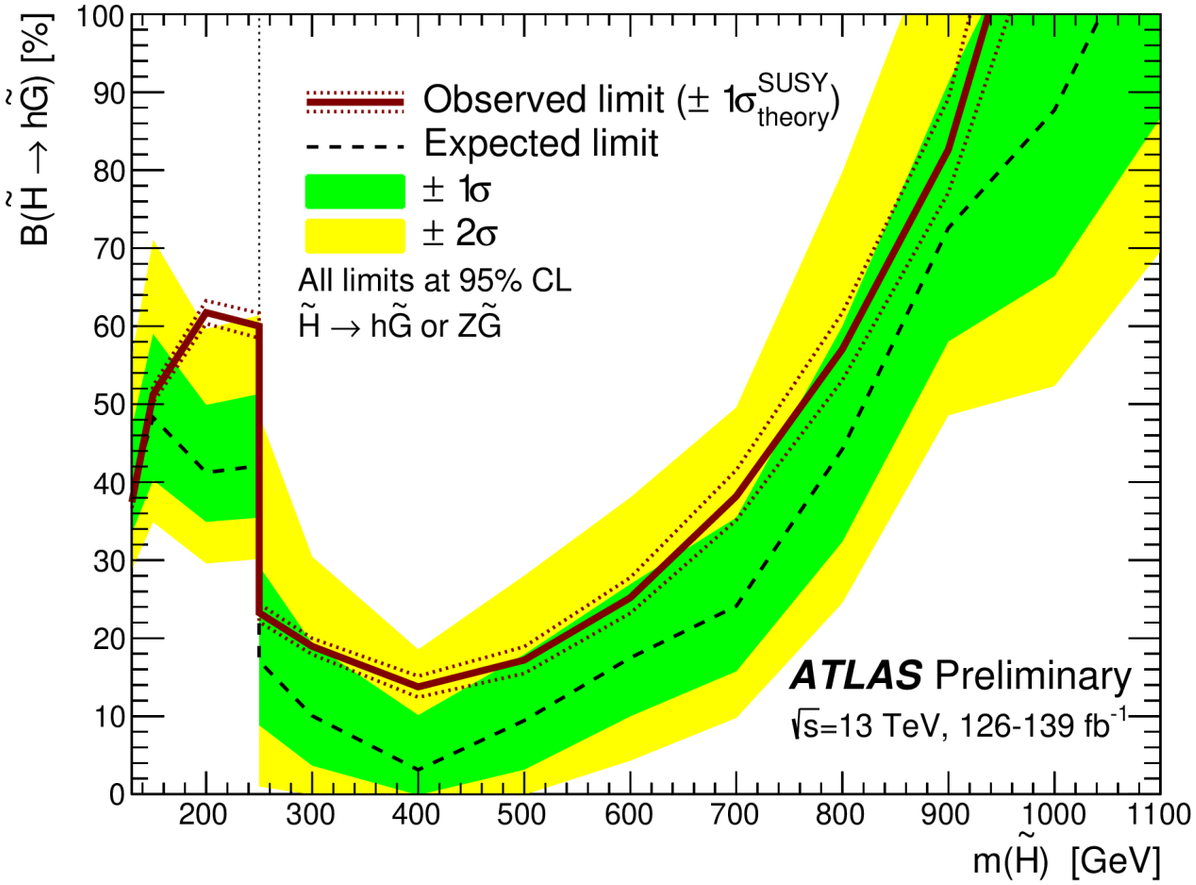


SUSY EWK 4b + E_T^{miss}

Search for pair production of higgsinos in events with two Higgs bosons and missing transverse momentum in √s = 13 TeV pp collisions at the ATLAS experiment ATLAS-CONF-2023-048

- Highest mass reach of all analyses targeting GMSB models, reaching TeV scale





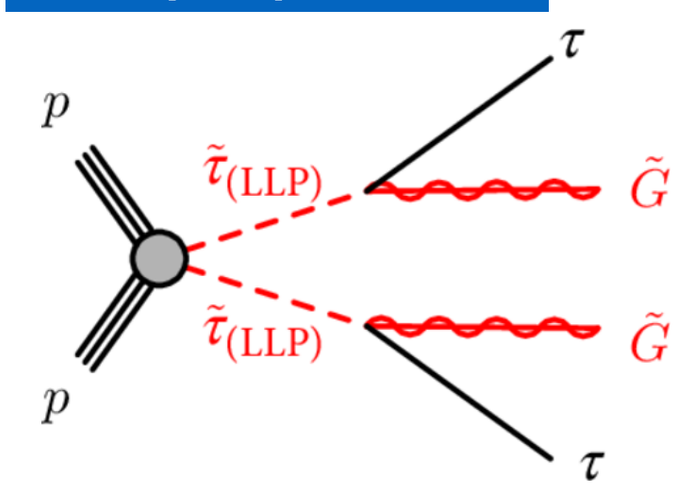
More EWK SUSY results in Francesco's presentation

Slow, charged and heavy LLP

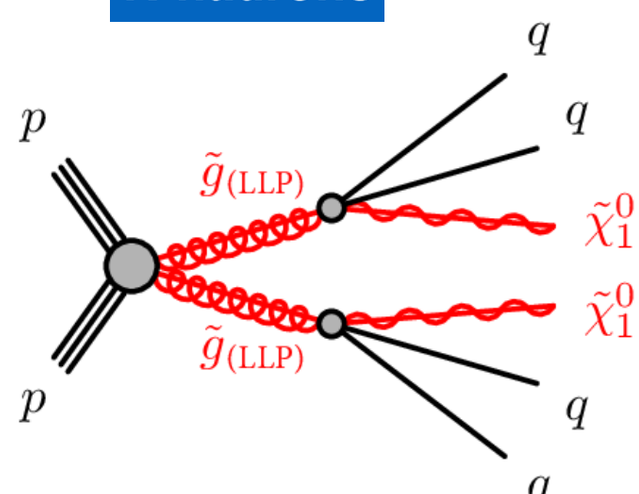
Search for massive, long-lived charged particles with large specific ionisation and low-beta in 140 fb−1 of pp collisions at √s=13 TeV using the ATLAS experiment ATLAS-CONF-2023-044

- Searching for heavy (m>100 GeV) charged particles with $\tau > 3$ ns*
- Results interpreted for pair-production of different LL sparticles
- In Run 2 a 3.3σ excess for m~1.4 TeV was observed
- **Main idea**: m≡$p/\beta\gamma$ from two independent determinations of $\beta\gamma$:
  - $\beta_{dE/dx}$: Bethe-Bloch to go from dE/dx measured by the pixel detector to $\beta\gamma$
  - β_{ToF} : using the time of flight (ToF) measured by the hadronic calorimeter

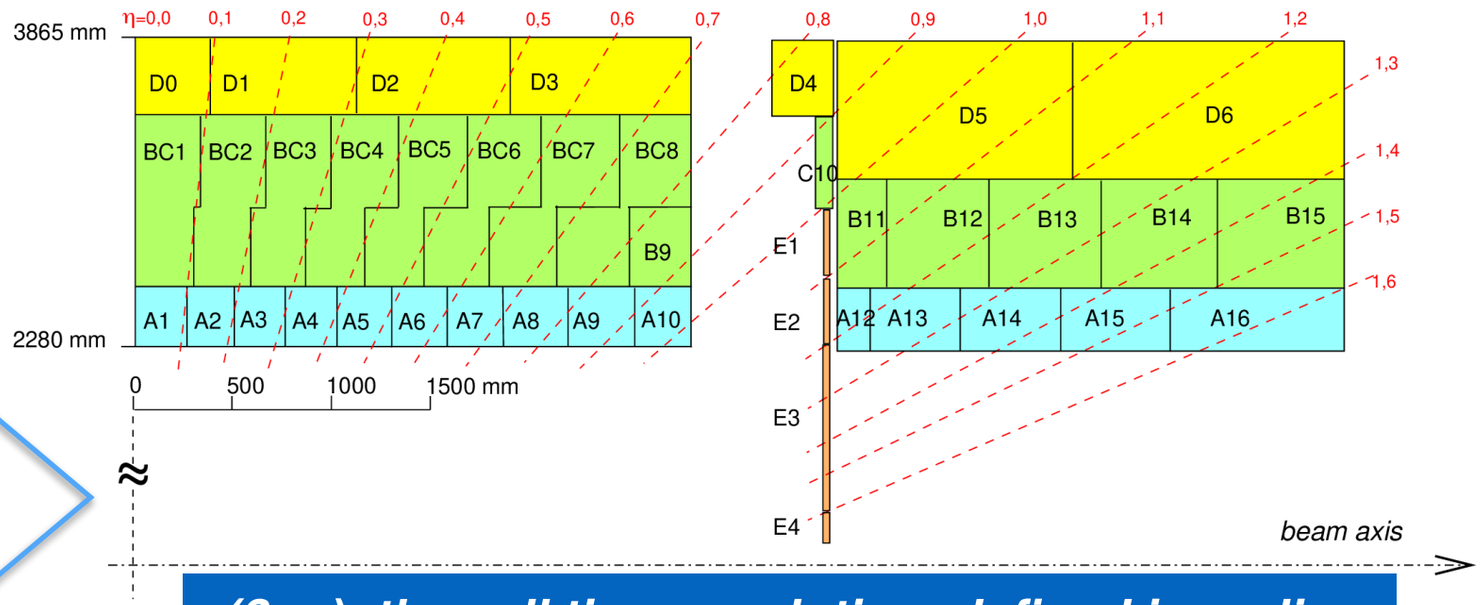
Staus pair production



R-hadrons



TileCal cell layout and |η| acceptance



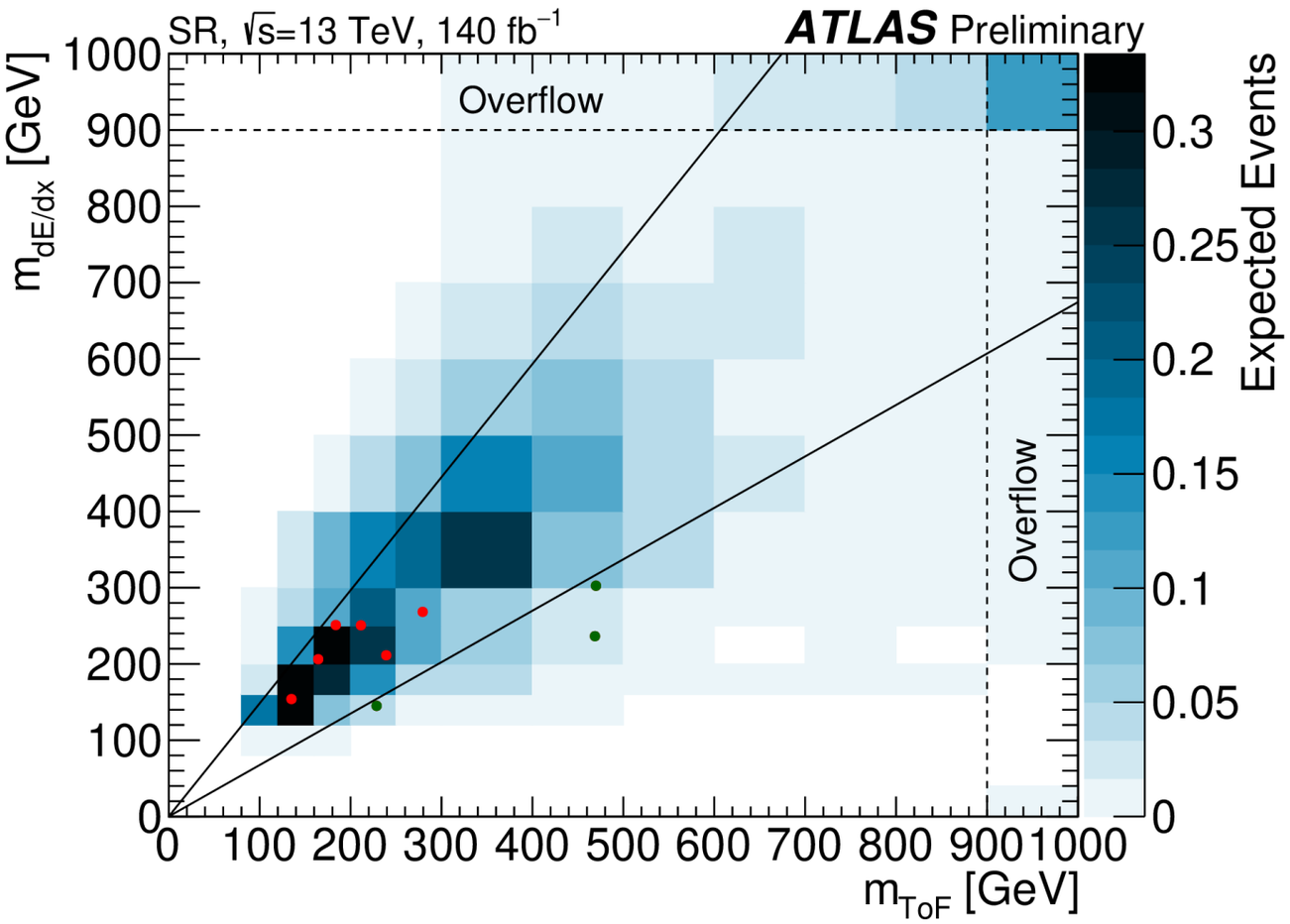
$\sigma(\beta_{ToF})$≡ the cell time resolution, defined in η slices

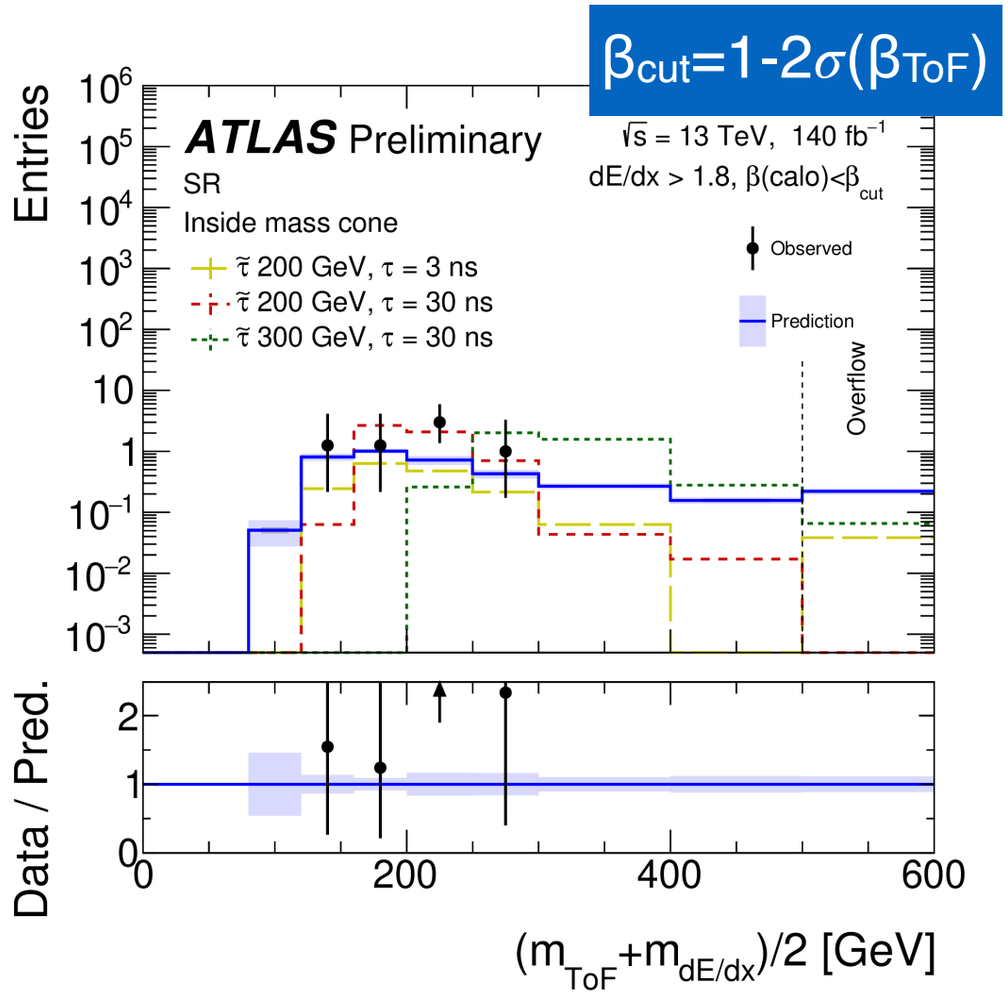
* to allow the particle to reach the calorimeter

Slow, charged and heavy LLP

Search for massive, long-lived charged particles with large specific ionisation and low-beta in 140 fb−1 of pp collisions at √s=13 TeV using the ATLAS experiment ATLAS-CONF-2023-044

- The search is performed in the ($m_{dE/dx}$, m_{ToF}) plane with trapezoidal mass windows
- 9 events (5.1 ± 0.5) observed (exp) 5.1 ± 0.5) in SR
  - 6 in the compatibility cone (expected 3.7 ± 0.4)





BSM Physics at the LHC

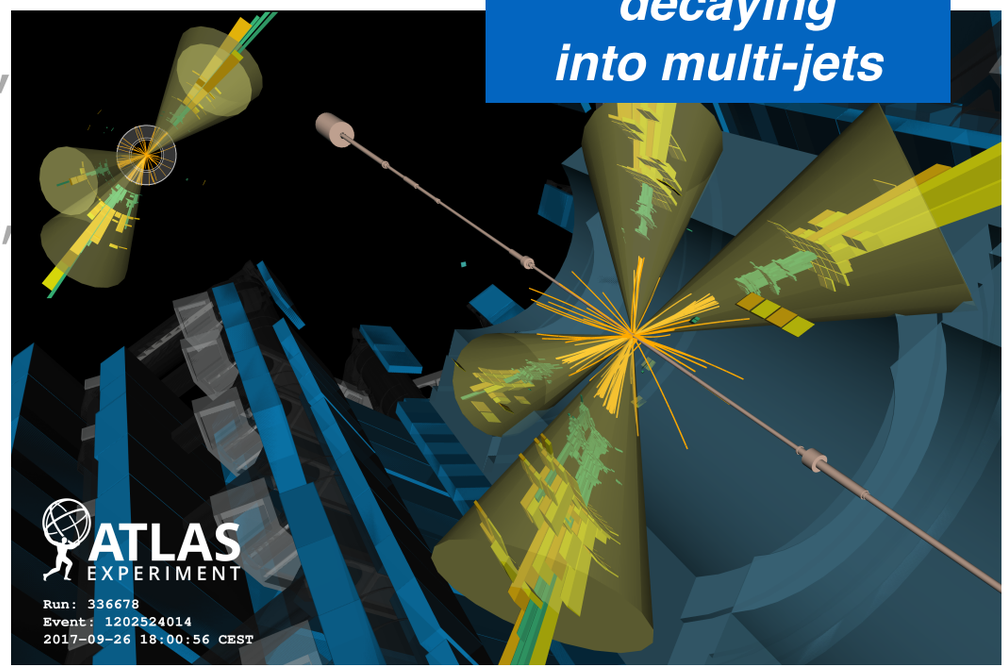
- Many new models addressing the shortcoming of the SM make predictions that can be tested at the LHC:

Massive new resonances decaying into lepton + quark

$$uu \to d\bar{l}^{+}$$
$$u\bar{d} \to u\bar{l}^{+}$$
$$d\bar{d} \to dl^{+}$$

  - **Natura**SUSY), large/warped extra dimensions (ADD/RS)
  - **Neutrino masses/mixing, flavor anomalies**: RPV SUSY, scalar di-quarks
  - **Dynamic explanation of EWSB**: New strong dynamics
- **Unification of all forces:** magnetic monopoles,
- **Dark matter:** Axion-Like particles, Dark Sectors,

Heavy resonances decaying into multi-jets



Quantum Black Holes

Search for quantum black hole production in lepton+jet final states using proton-proton collisions at $\sqrt{s}$=13 TeV with the ATLAS detector arXiv:2307.14967

- QBHs are produced near the scale of quantum gravity M_D.

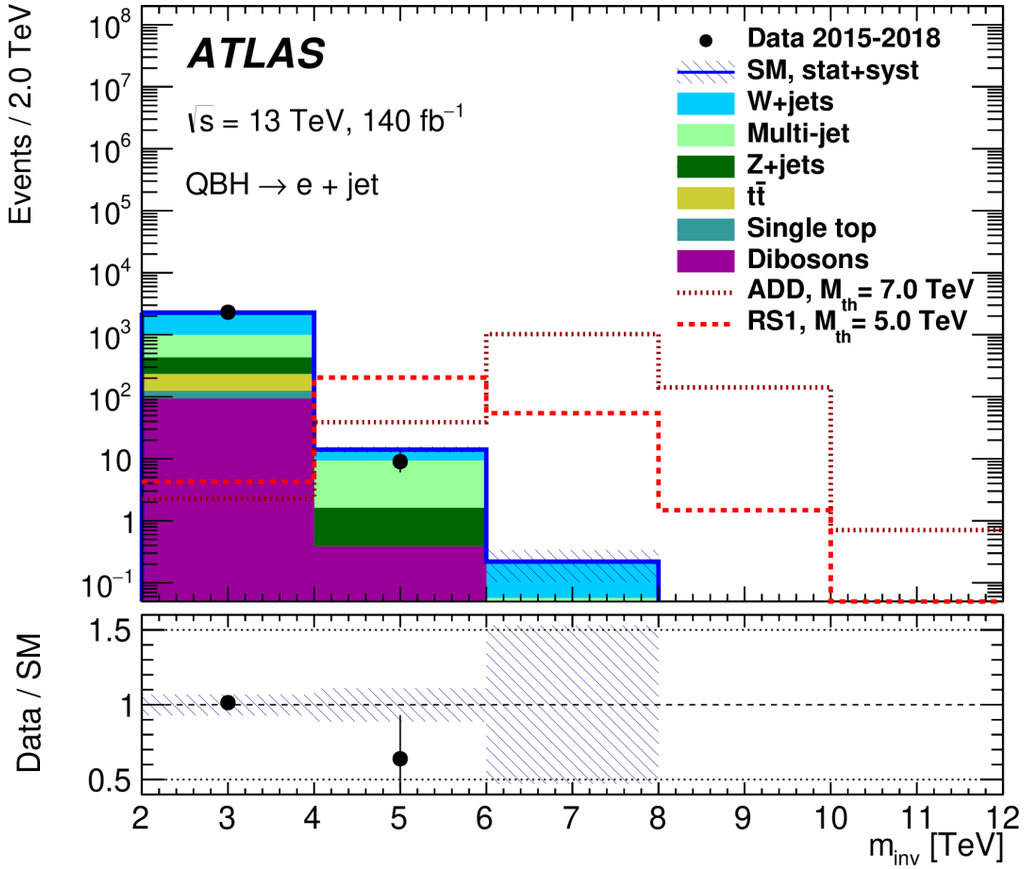
$$uu \to \bar{d}l^+$$

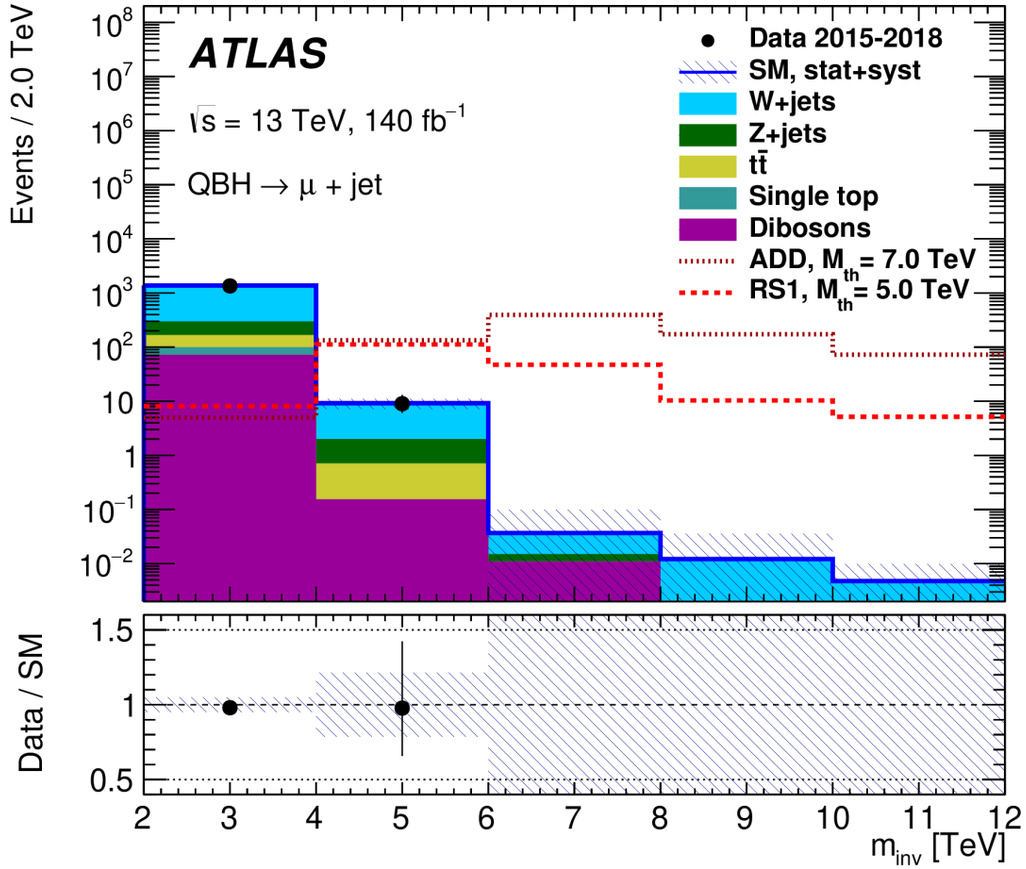
- Global symmetries (B and L) not necessarily conserved in strong-gravity interactions ➔ striking lepton + jet resonances

$$u\bar{d} \to \bar{u}l^+$$

$$\bar{d}\bar{d} \to dl^+$$

  - New particles should be visible on the reconstructed lepton+jet invariant mass

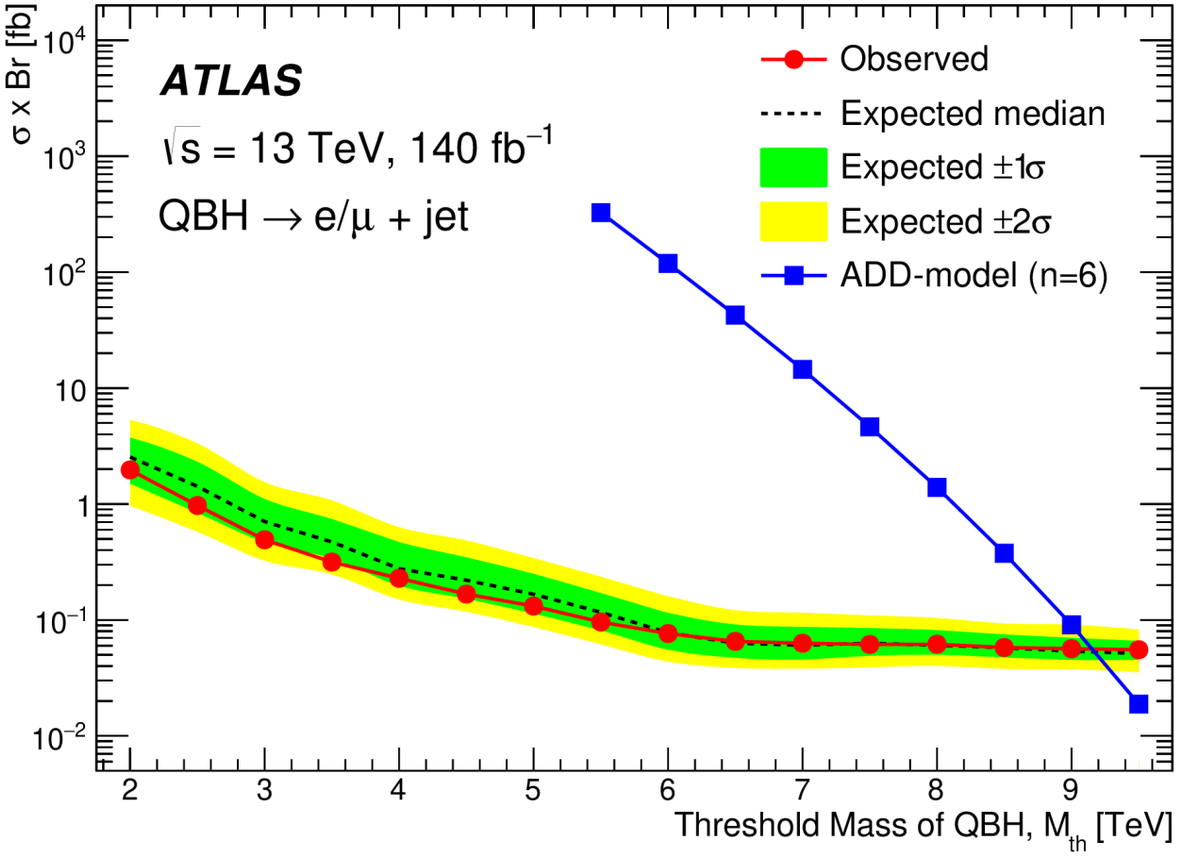


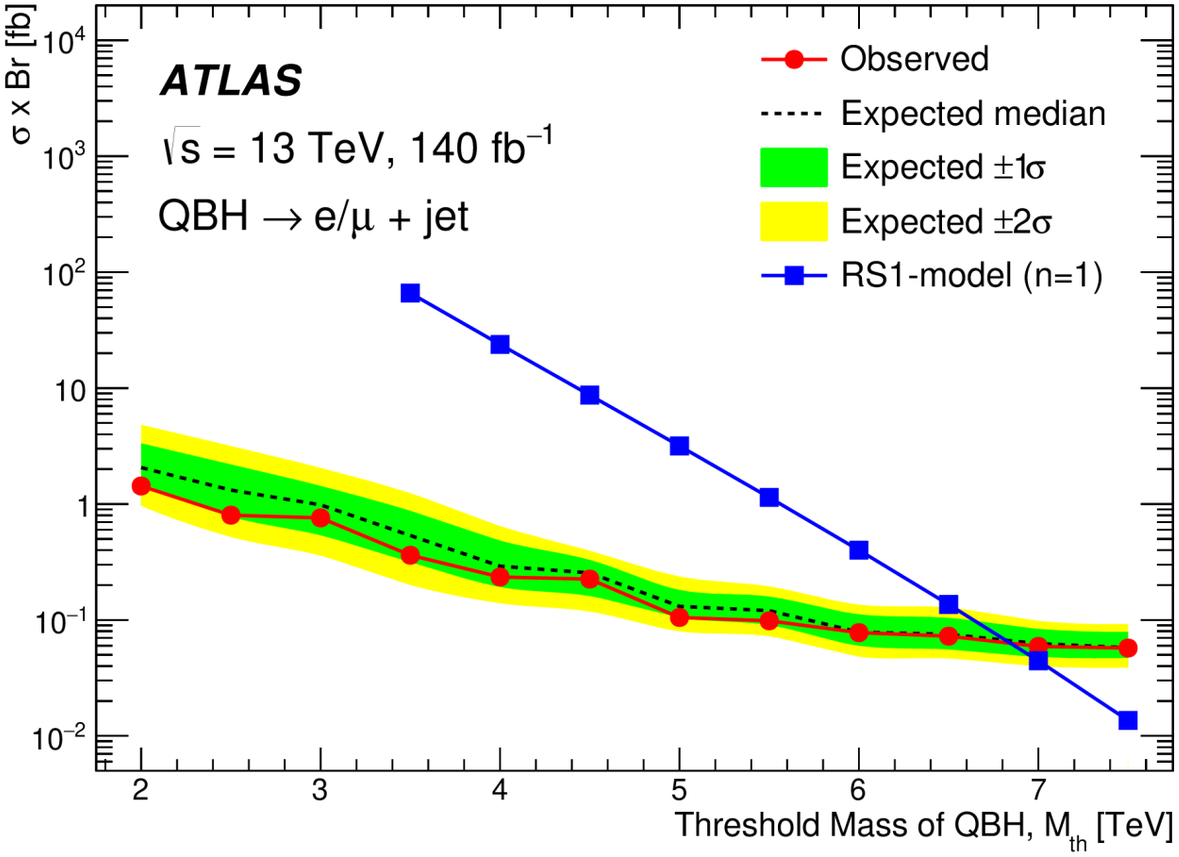


Quantum Black Holes

Search for quantum black hole production in lepton+jet final states using proton-proton collisions at √s=13 TeV with the ATLAS detector arXiv:2307.14967

- No evidence found, limits are set quantum black holes decaying to a lepton and a quark
- The resulting lower mass threshold limits in the **ADD (RS1)** models with **six (one)** extra dimensions are **9.2 (6.8) TeV**

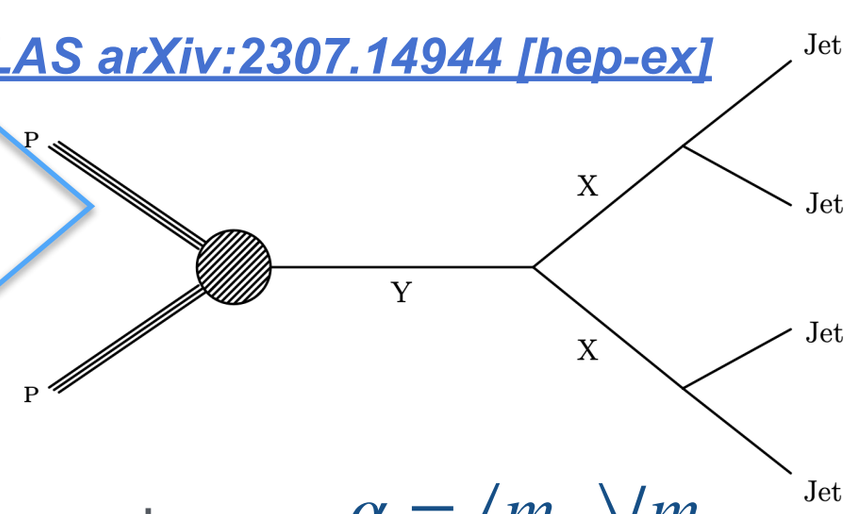




Multijet resonances

Pursuit of paired dijet resonances in the Run 2 dataset with ATLAS arXiv:2307.14944 [hep-ex]

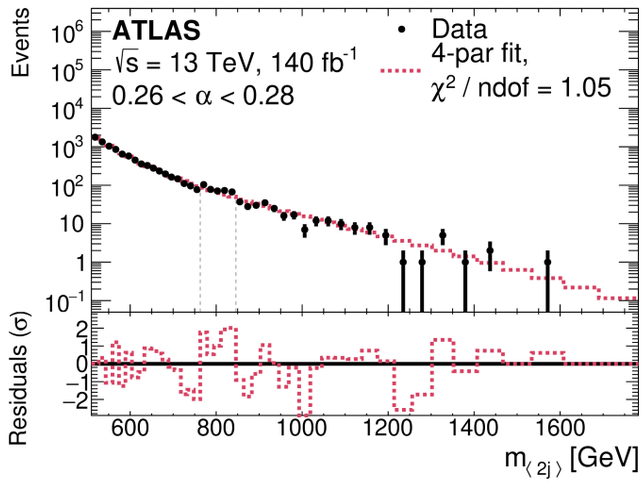
- Search for a generic massive resonance Y decaying into pairs of intermediate resonance X
  - **Paired minimizing** $\Delta R = |\Delta R_{AB} - 0.8| + |\Delta R_{cd} - 0.8|$



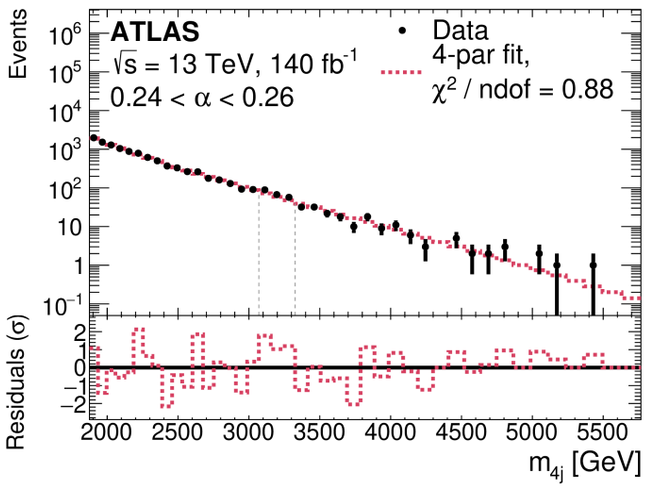
- No deviations observed ➔ limits set for different $\mathbf{m_{Y/X}}$ scenarios

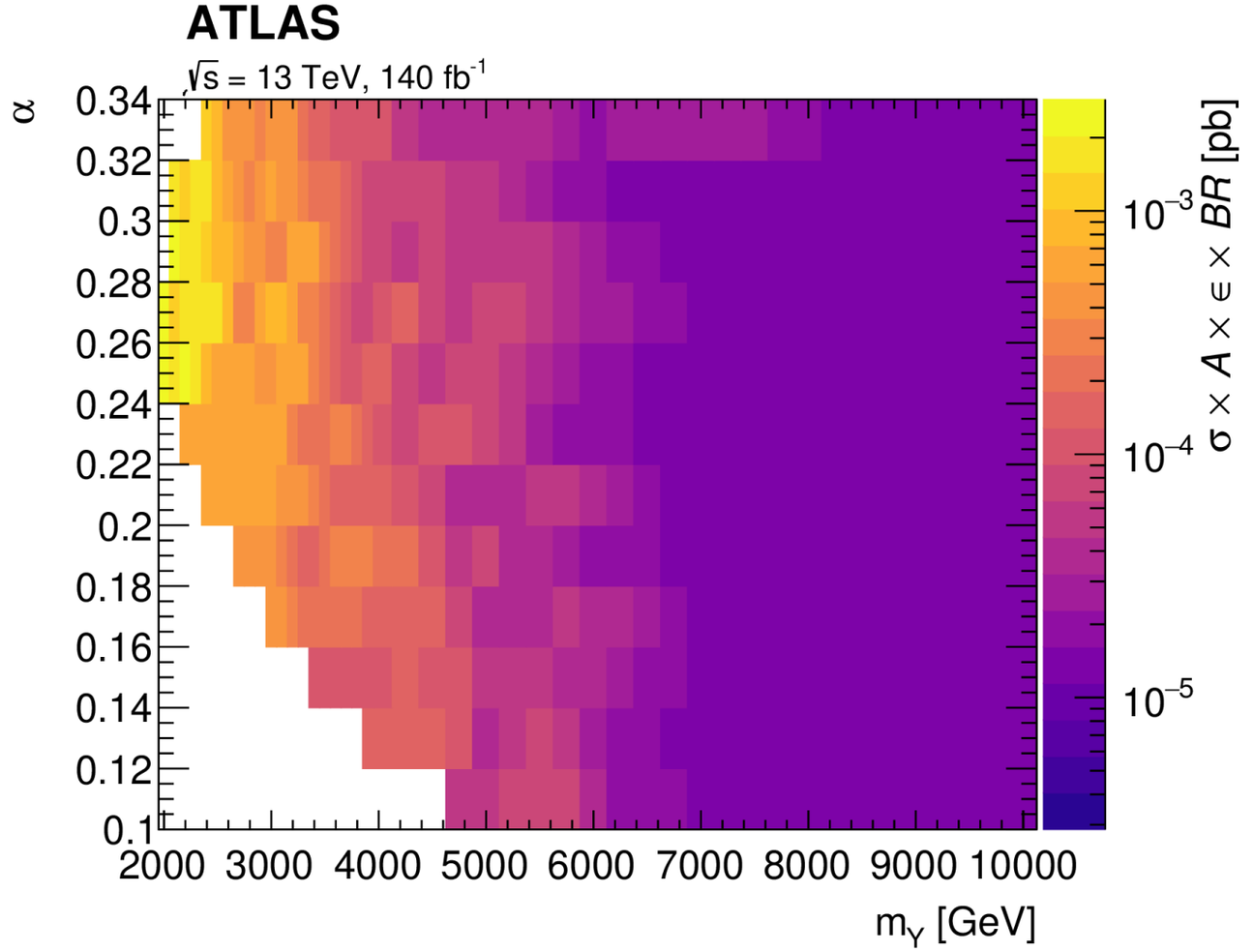
$\alpha = \langle m_{2j} \rangle / m_{4j}$

1.98 σ



0.53 σ





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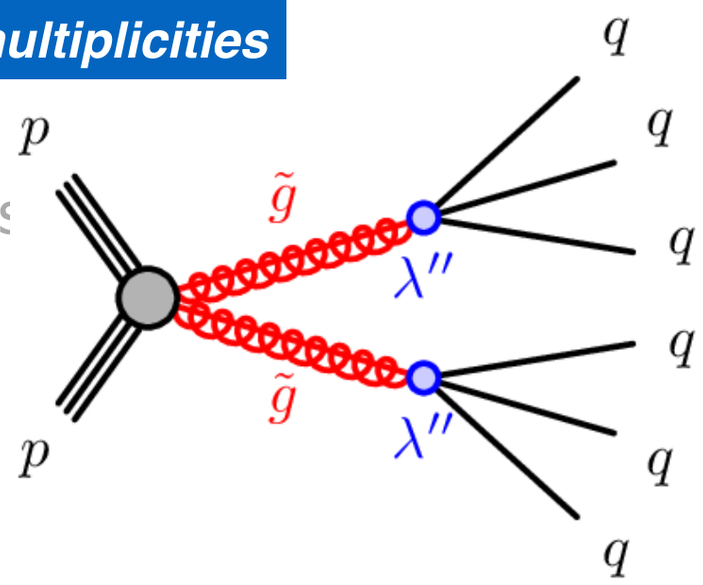
  - **Unification of all forces:** magnetic monopoles, SUSY
  - **Dark matter:** Axion-Like particles, Dark Sectors, SUSY, s

Resonances with large jet multiplicities



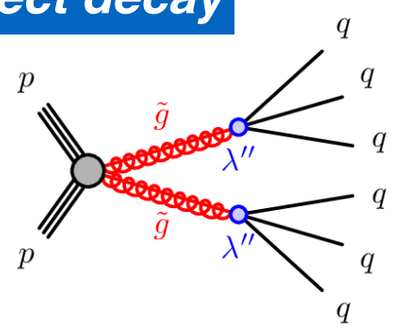
RPV multijet

A search for R-parity-violating supersymmetry in final states containing many jets in $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector ATLAS-CONF-2023-049

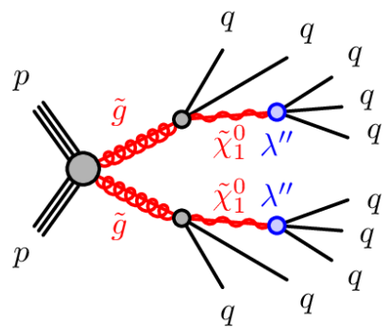
- **R-parity violation:** UDD RPV coupling leads SUSY particles to decay to quarks
- Jet counting analysis: define single-bin signal regions (SR) requiring high jet multiplicity
- Mass resonance analysis: NN based on attention mechanism to predict probability for jet to be assigned to each $\tilde{g}$

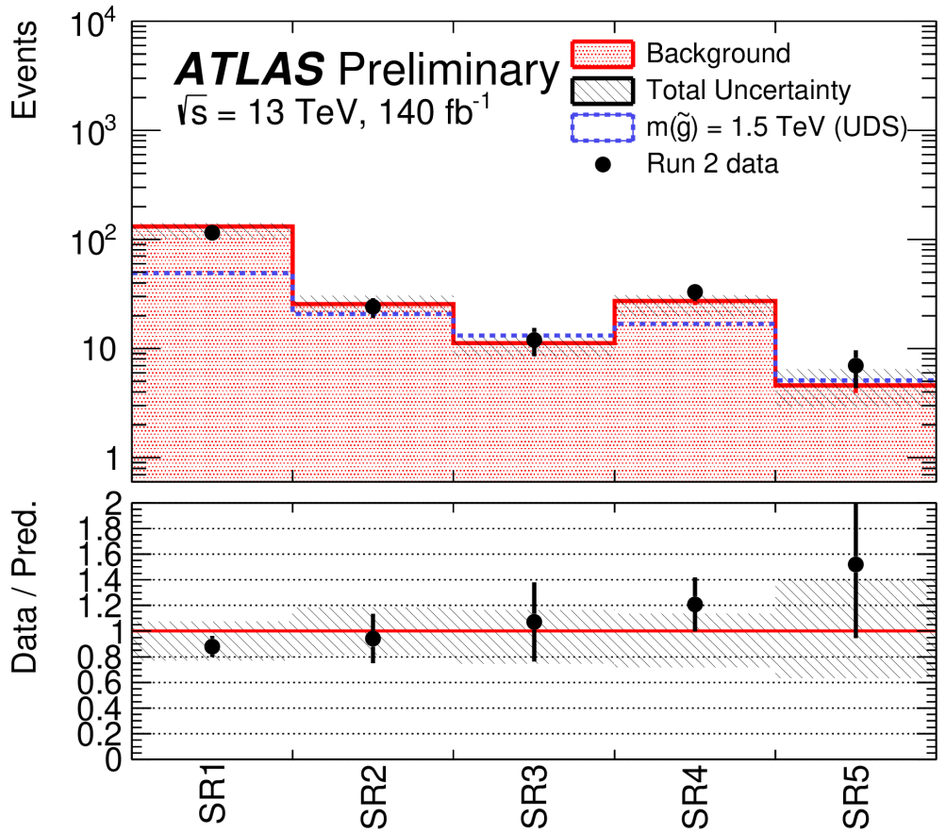
	n_{jets}	$p_{\text{T}}(j)$ [GeV]	C	$n_{b-\text{jets}}$
SR1	≥ 7	180	≥ 0.90	-
SR2	≥ 7	220	≥ 0.90	-
SR3	≥ 7	240	≥ 0.90	-
SR4	≥ 8	180	≥ 0.85	-
SR5	≥ 8	210	≥ 0.85	-
SR1bj	≥ 7	180	≥ 0.85	≥ 2
SR2bj	≥ 8	180	≥ 0.85	≥ 2

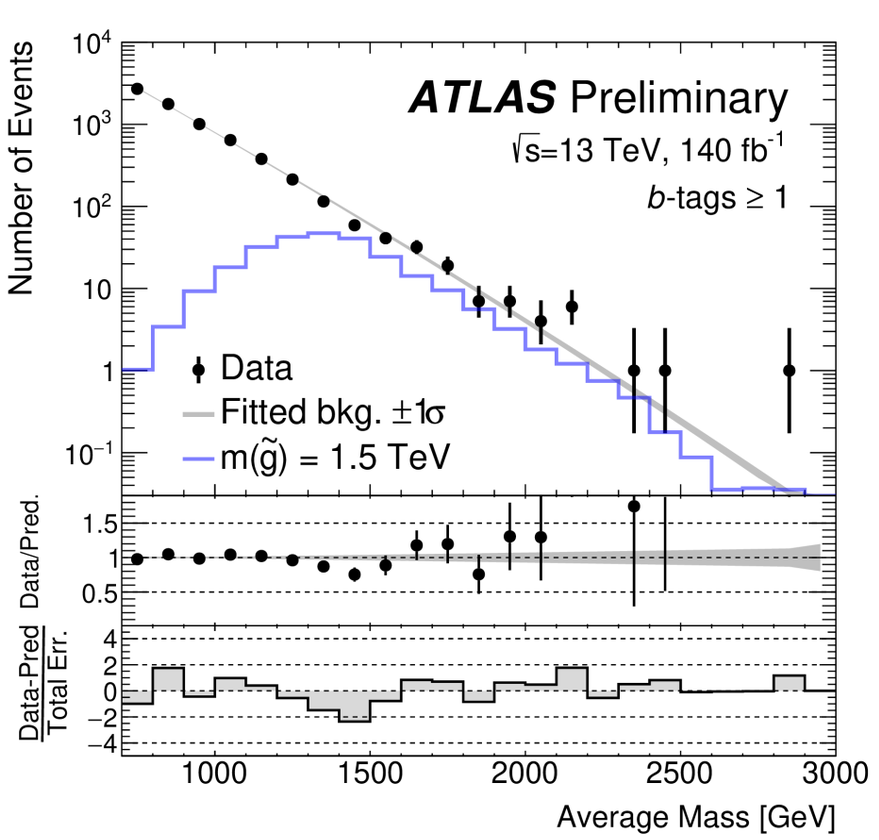
direct decay



cascade decay



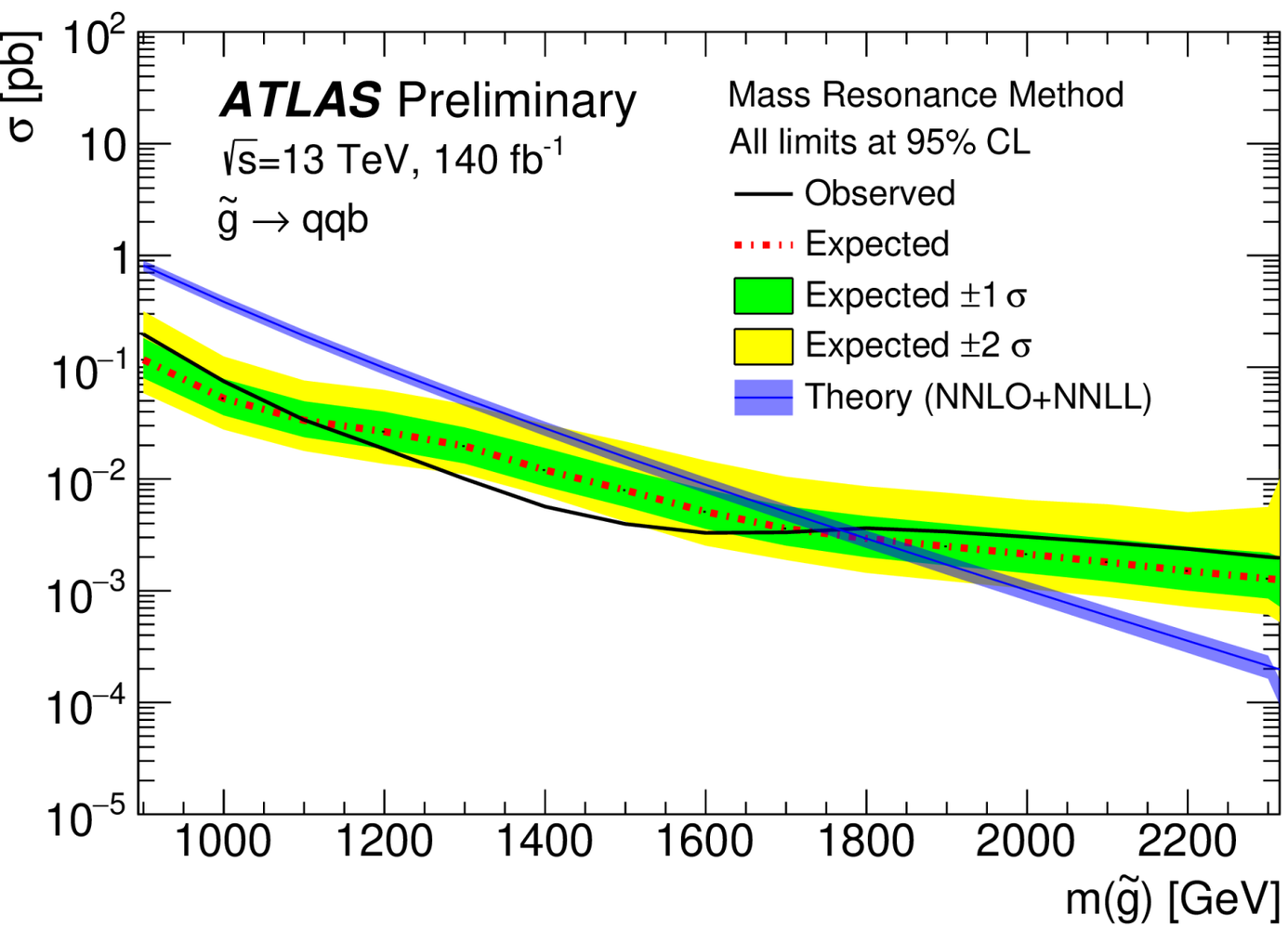


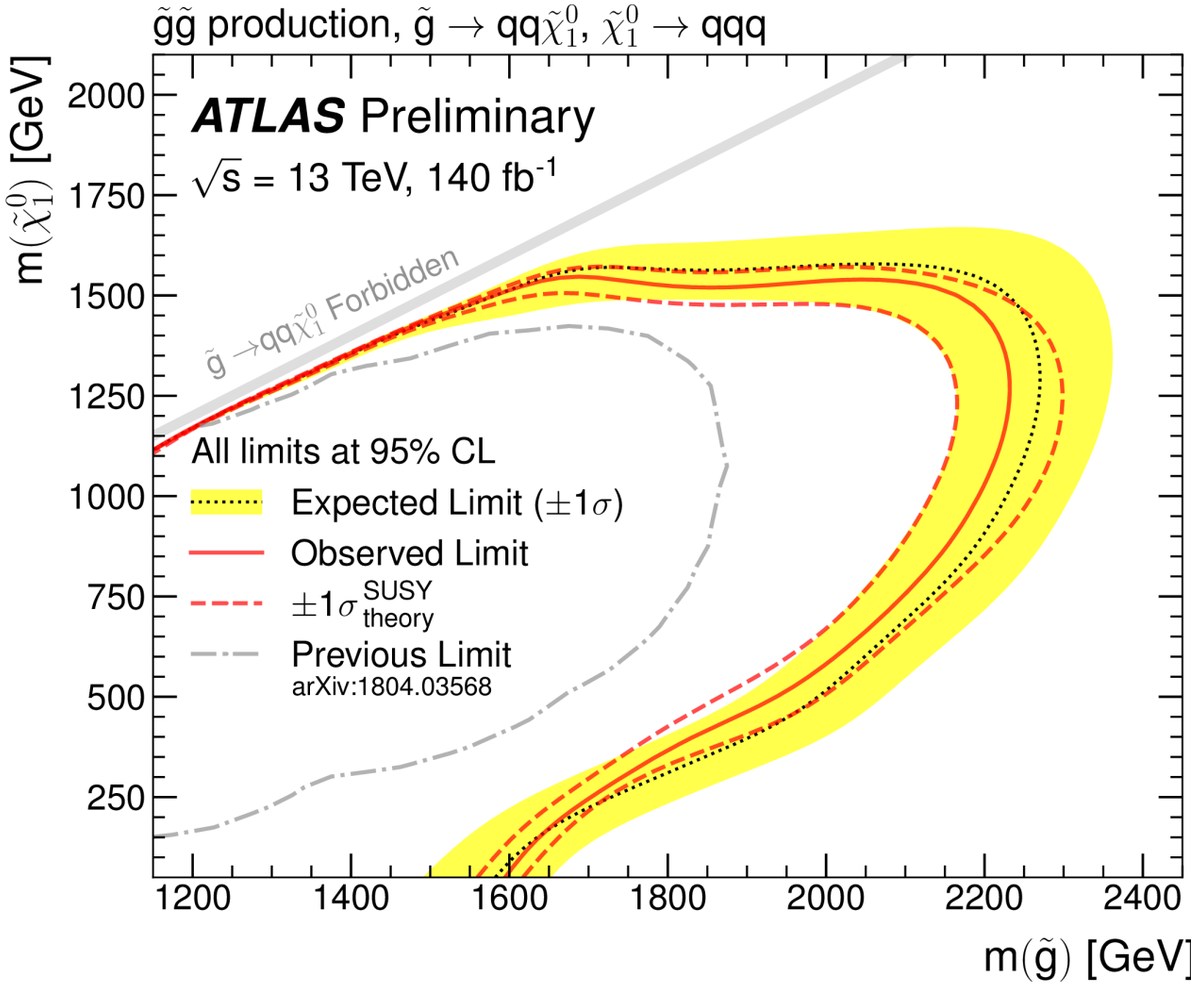


RPV multijet

A search for R-parity-violating supersymmetry in final states containing many jets in $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector ATLAS-CONF-2023-049

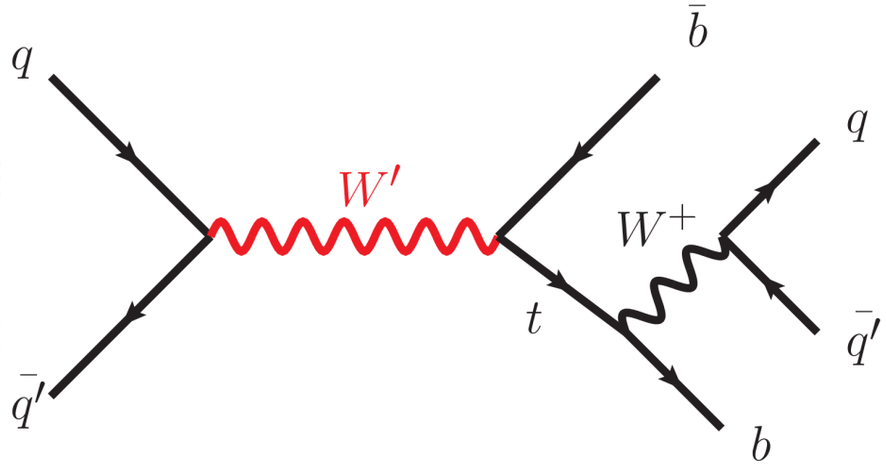
- Limits greatly improved by current analysis: event shape, ML, luminosity
  - **direct decay model** $m(\tilde{g})$ <1800 GeV excluded at 95% CL.
  - In the **cascade decay model**, $m(\tilde{g})$<2340 GeV excluded for $m(\tilde{\chi}_0^1)$ =1250 GeV.



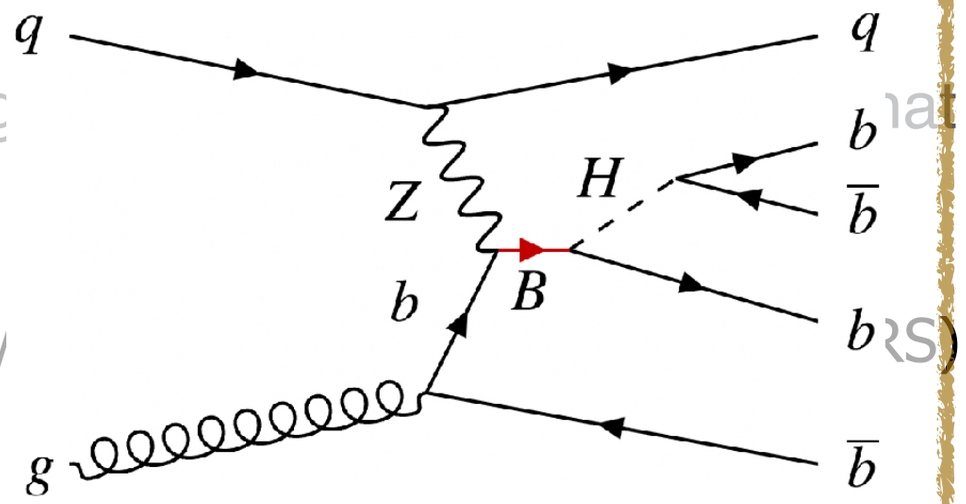


BSM Physics at the LHC

Heavy resonances decaying to top quarks



..and to b-jets



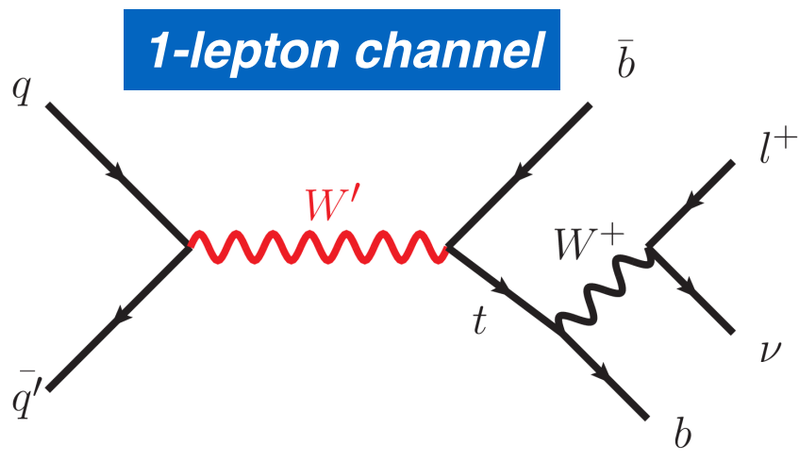
- Many … rtcoming … hat can be …
- **Nat** … Y), large/ … RS)
- **Neu** … **malies**: …

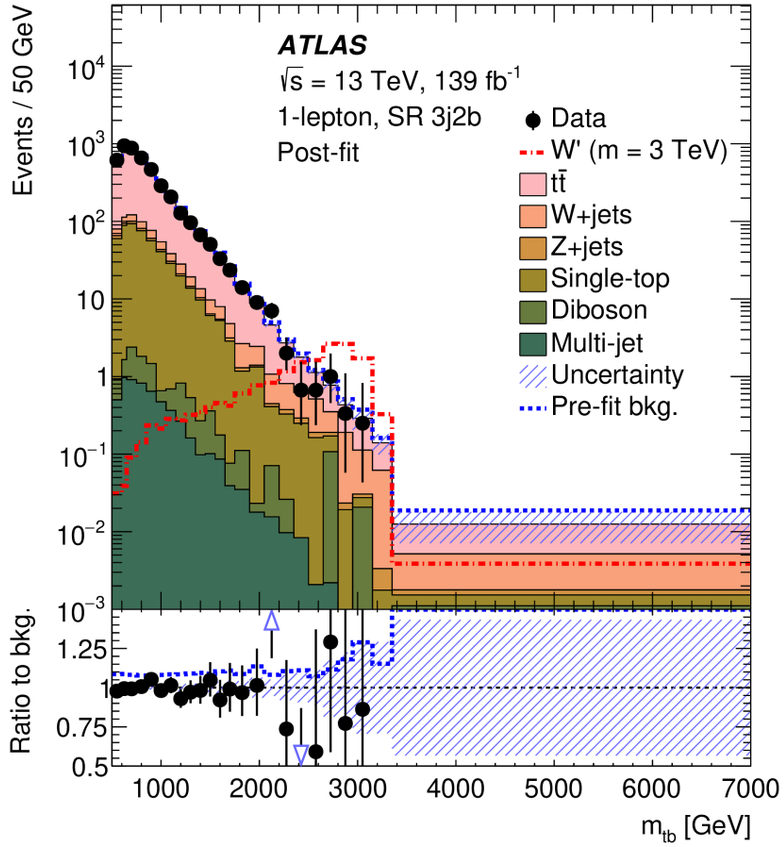
- **Dynamic explanation of EWSB**: New strong dynamics
- **Unification of all forces:** magnetic monopoles, SUSY
- **Dark matter:** Axion-Like particles, Dark Sectors, SUSY, scalar mediators

Vector Boson Resonances

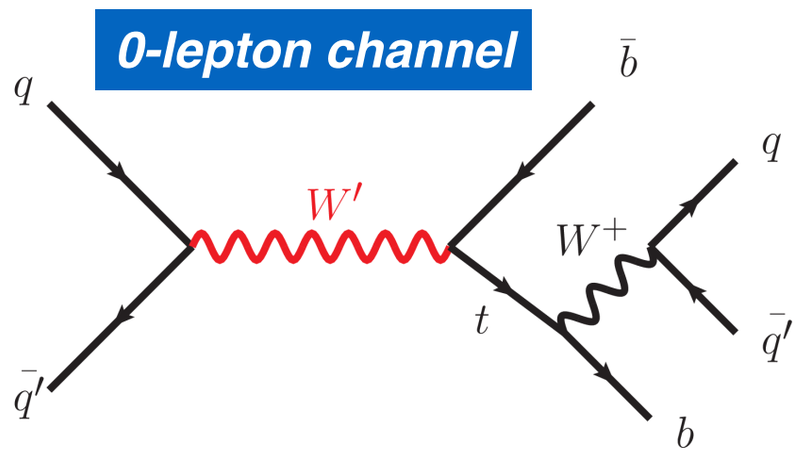
Search for vector-boson resonances decaying into a top quark and a bottom quark using pp collisions at √s=13 TeV with the ATLAS detector arXiv:2308.08521

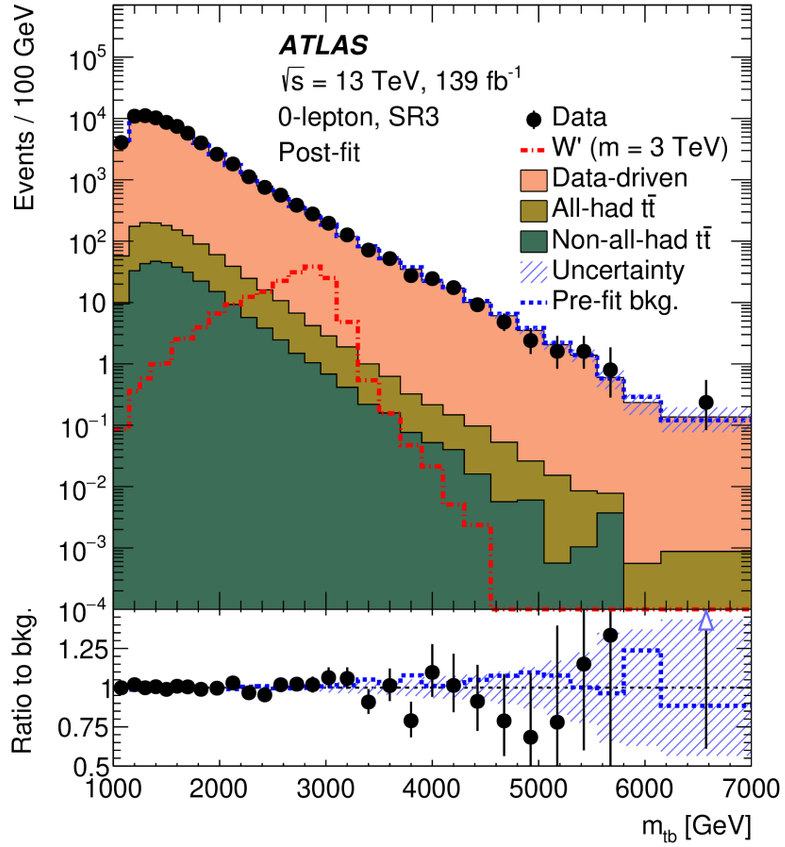
1-lepton channel





0-lepton channel

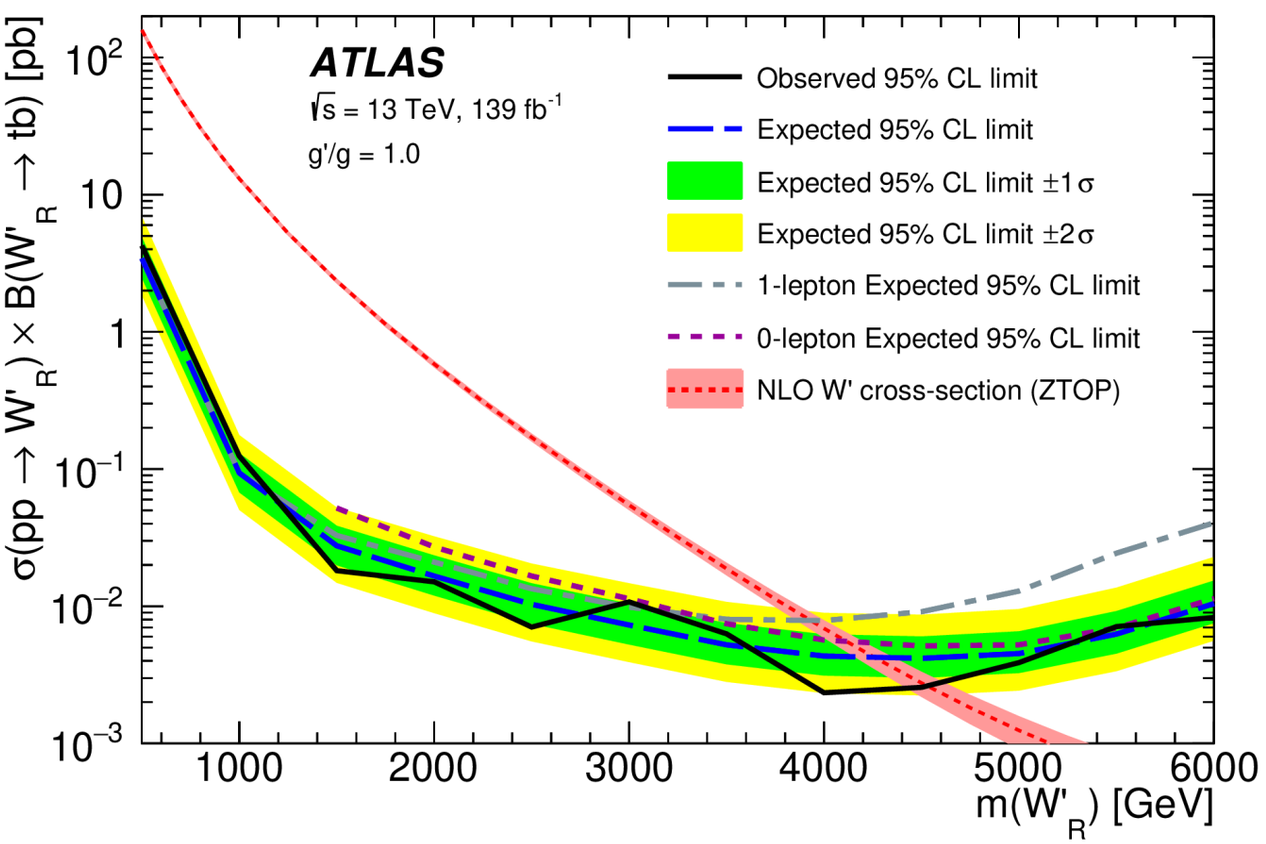


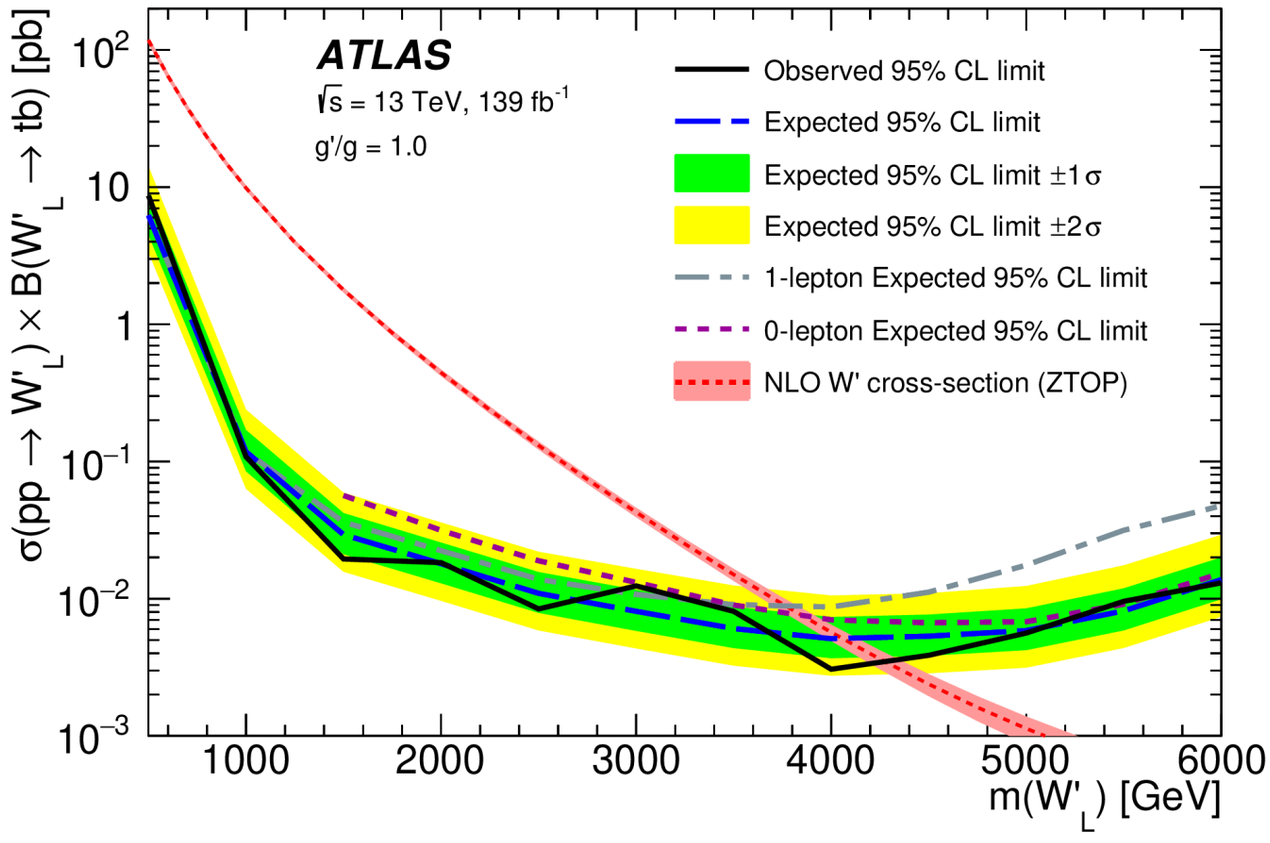


Vector Boson Resonances

Search for vector-boson resonances decaying into a top quark and a bottom quark using pp collisions at √s=13 TeV with the ATLAS detector arXiv:2308.08521

- *m(W')* > 4.6 (4.2) TeV excluded for right-(left-)handed W' and coupling value of g'/g = 1.0

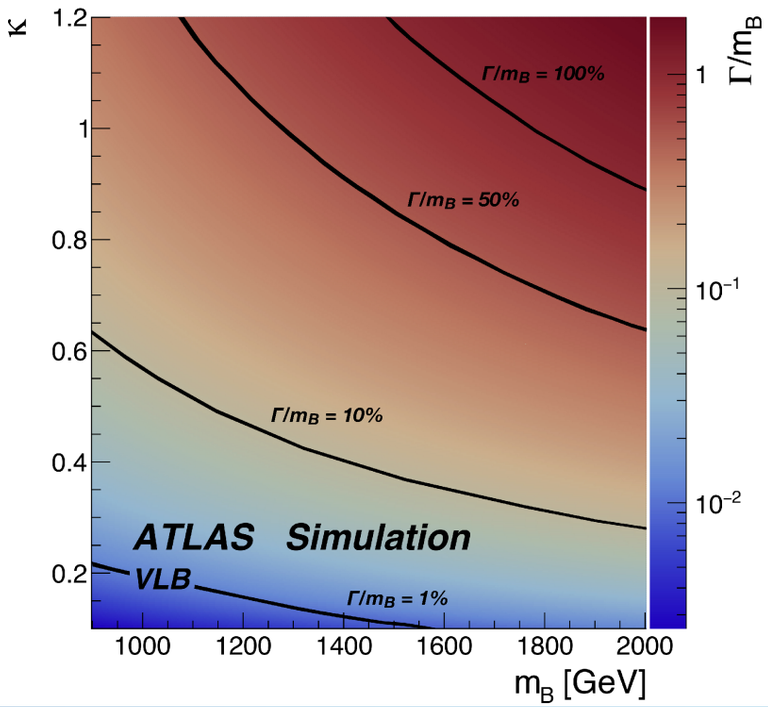


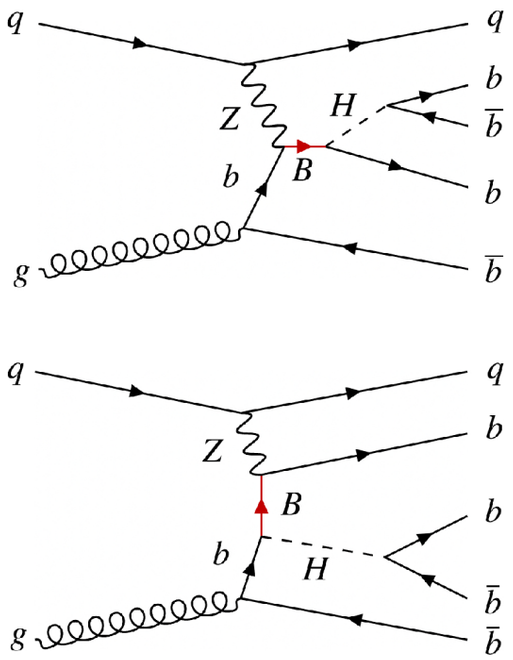


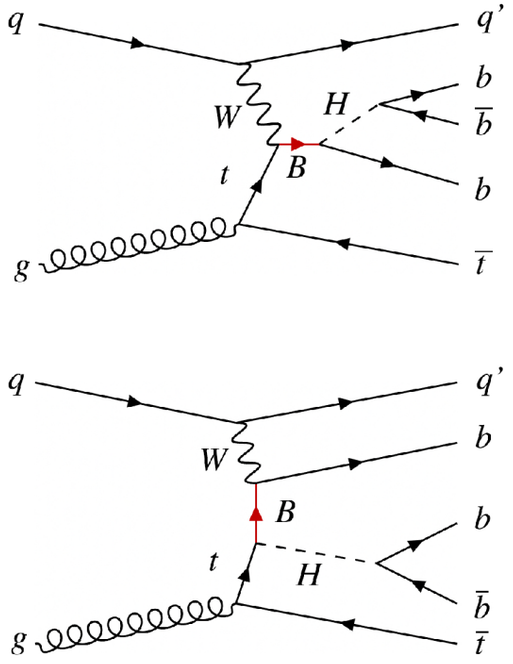
VLQ: bH(H→bb)

Search for single vector-like B quark production and decay via B→bH(bb) in pp collisions at √s=13 TeV with the ATLAS detector arXiv:2308.02595

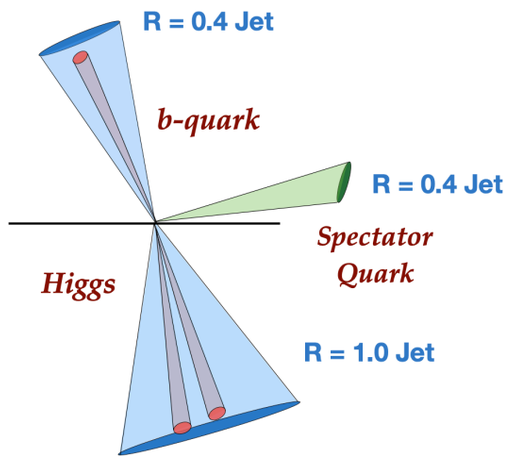
- New strong interaction predicts VLQs, new spin-1/2 bound states
- Extensively searched at the LHC in pair production
- Single VLQ production may overtake at high masses depending on the strengths of couplings (κ)







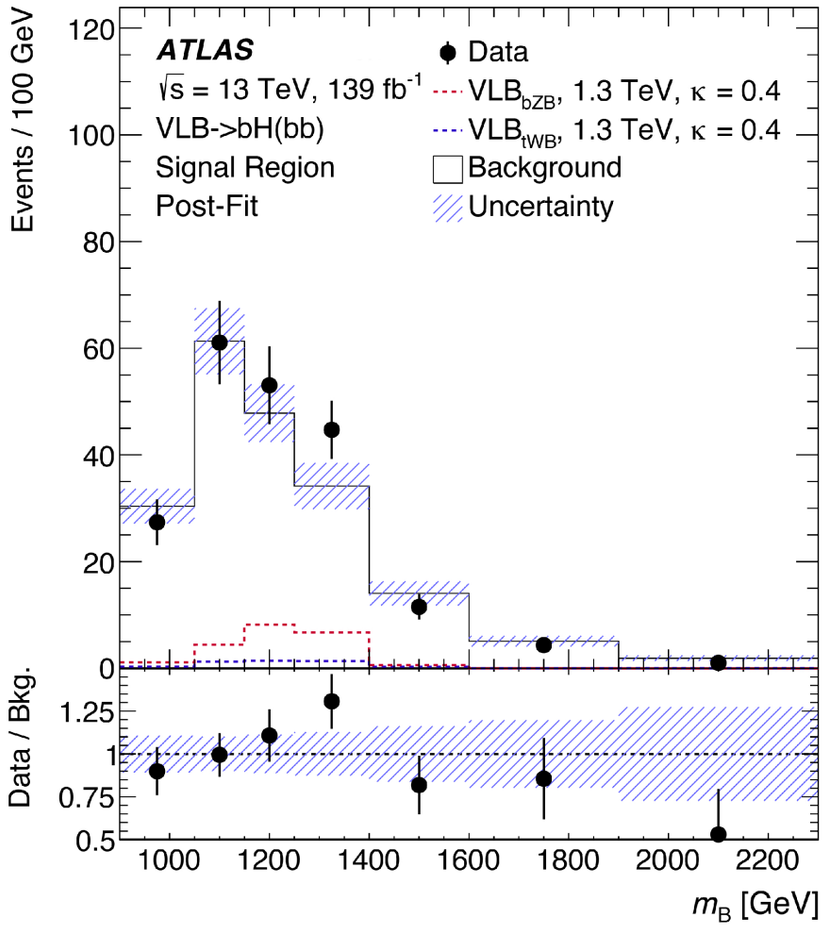
- Experimental signature:
  - 3 high-pT b-quarks
  - Boosted Higgs system

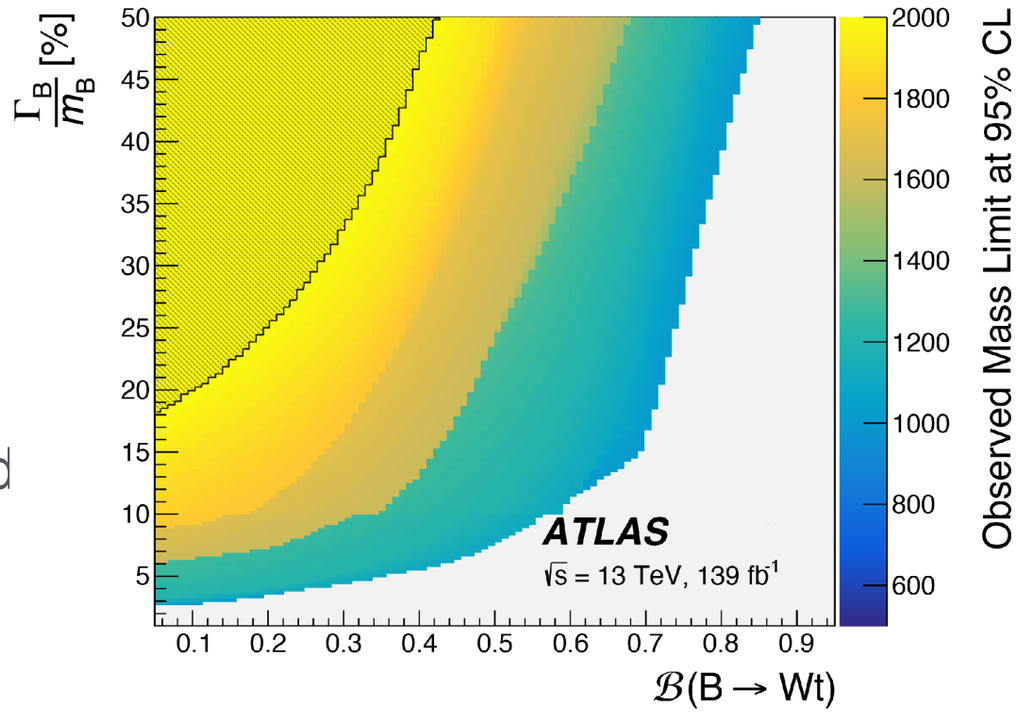


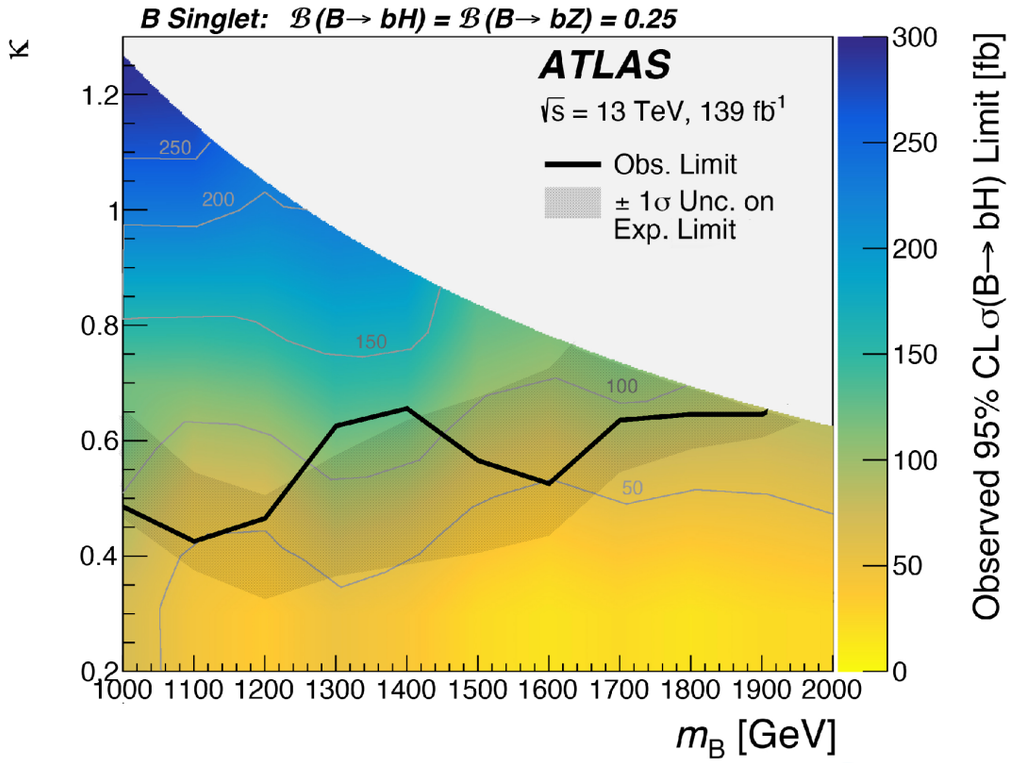
VLQ: bH(H→bb)

Search for single vector-like B quark production and decay via B→bH(bb) in pp collisions at √s=13 TeV with the ATLAS detector arXiv:2308.02595

- No excess found, results interpreted in terms of upper limits on the B production cross-section
- Different values of the coupling strength κ and the mass in either the singlet or doublet state excluded



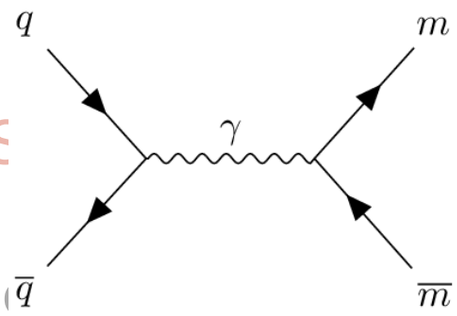


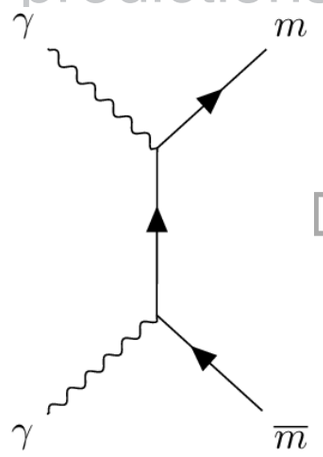


BSM Physics at the LHC

- Many new models addressing the shortcoming of the SM make predictions that can be te

Detection of High Electric Charged Objects (HECO) compatible in the detector





  - **Natural EWSB**: Supersymmetry (SUS D/RS)
  - **Neutrino masses/mixing, flavor an**
  - **Dynamic explanation of EWSB**: New strong dynamics
- **Unification of all forces:** magnetic monopoles, SUSY
- **Dark matter:** Axion-Like particles, Dark Sectors, SUSY, scalar mediators

Magnetic monopoles and HECOs

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM

Aix*Marseille université
cnrs IN2P3 Les deux infinis

Search for magnetic monopoles and stable particles with high electric charges in 13 TeV proton–proton collisions with the ATLAS detector arXiv:2308.04835

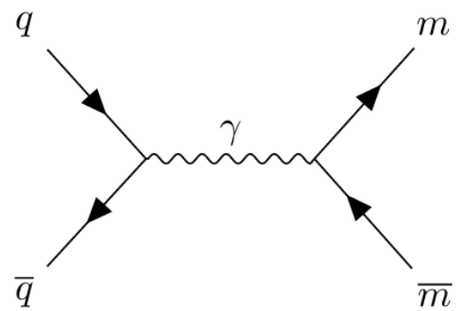
- Magnetic monopole: isolated magnetic charge, restores the broken electric–magnetic dual symmetry in Maxwell's equations

Dirac's quantization condition

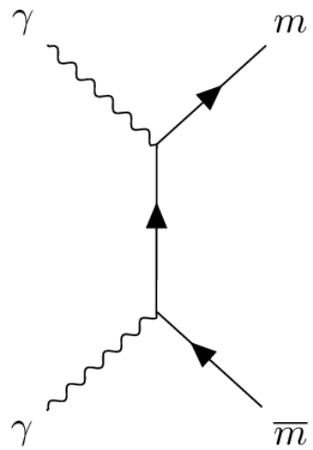
$$g_D = \frac{2}{2\alpha} \approx 68.5e$$

- Highly Ionizing Particles (HIP):
  - **Large number of TRT hits** in a region aligned with a **narrow high-energy deposit in the EM calorimeter**.

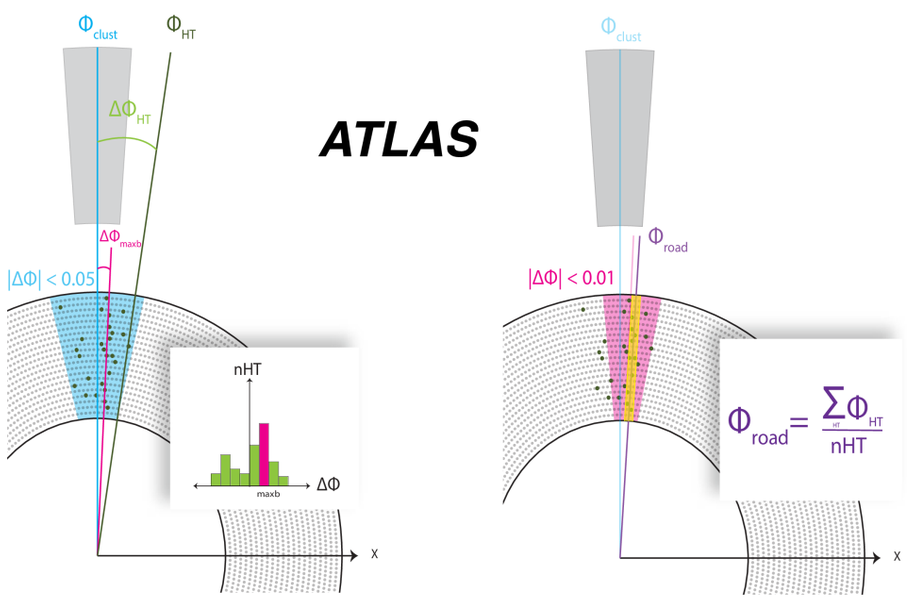
Drell-Yan

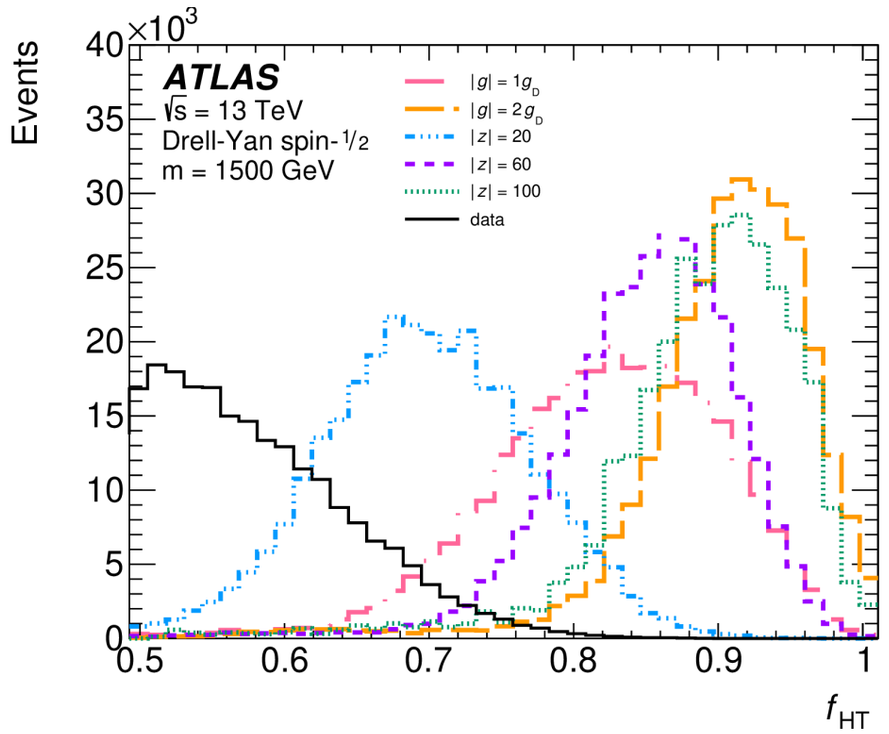


Photon Fusion



f_{HT} = fraction of all the TRT hits in the road exceed the high threshold





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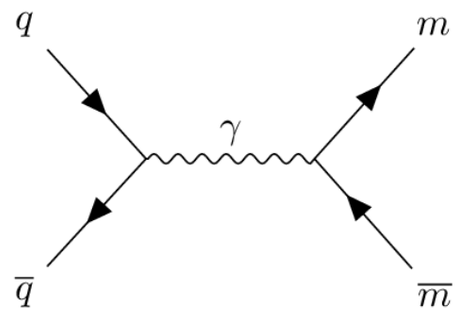

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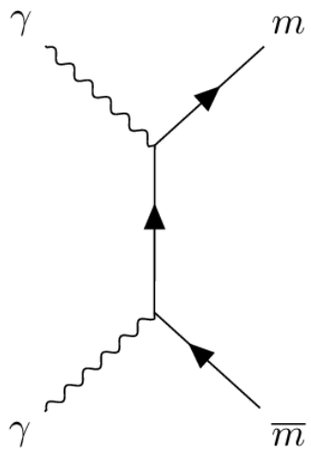
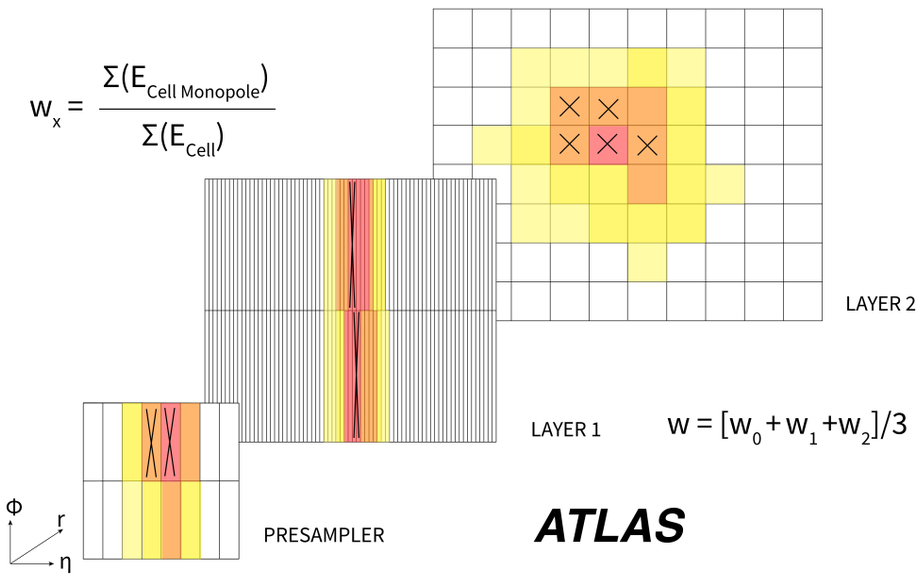
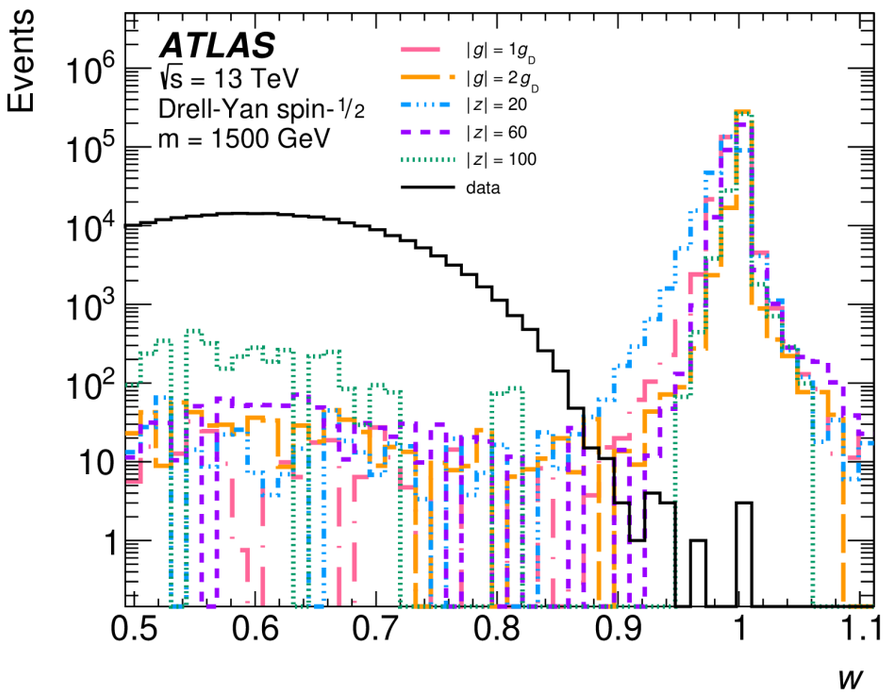


w_0, w_1 and w_2:fractions of EM cluster energy (E_i) contained in the most energetic cells

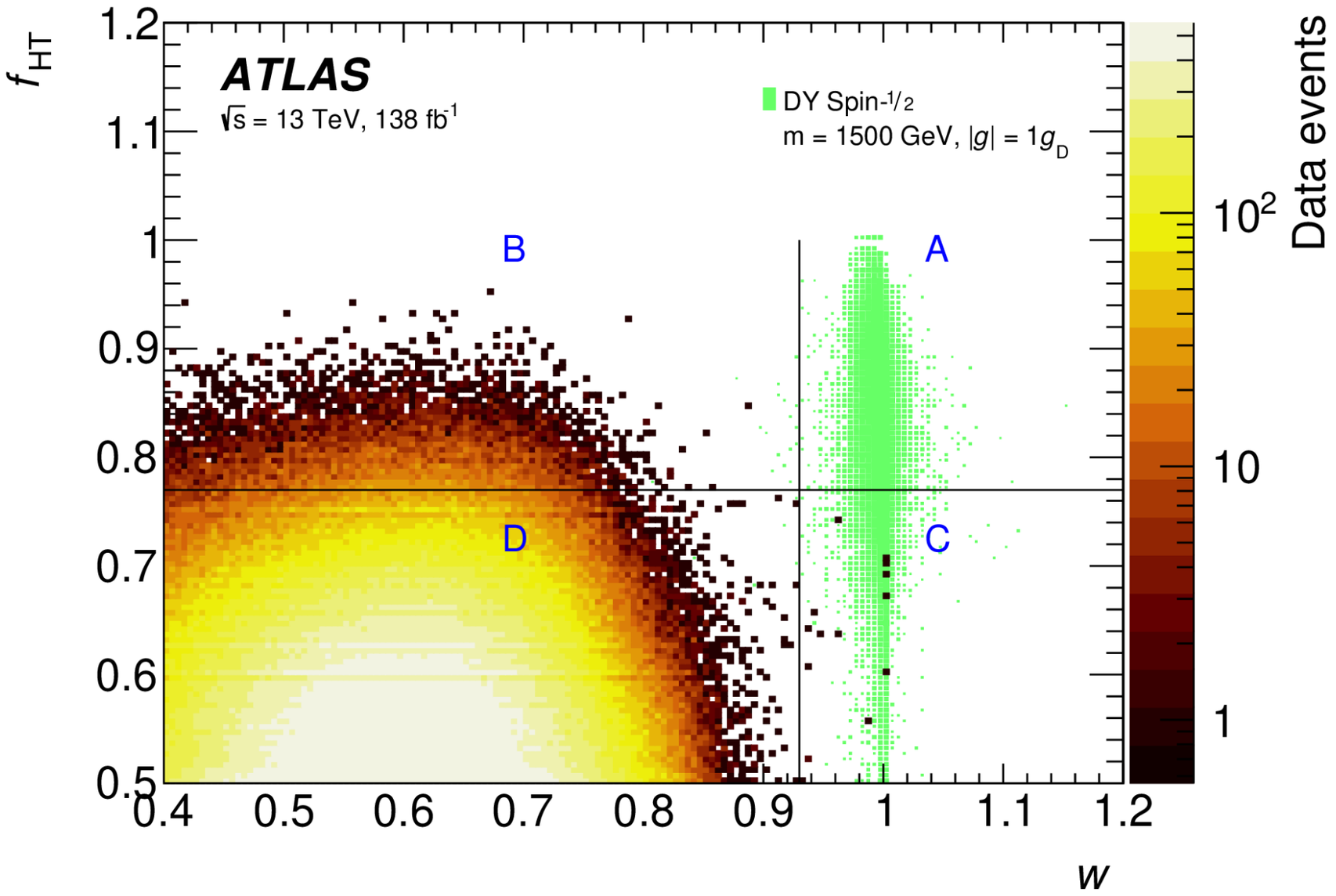




Magnetic monopoles and HECOs

Search for magnetic monopoles and stable particles with high electric charges in 13 TeV proton–proton collisions with the ATLAS detector arXiv:2308.04835

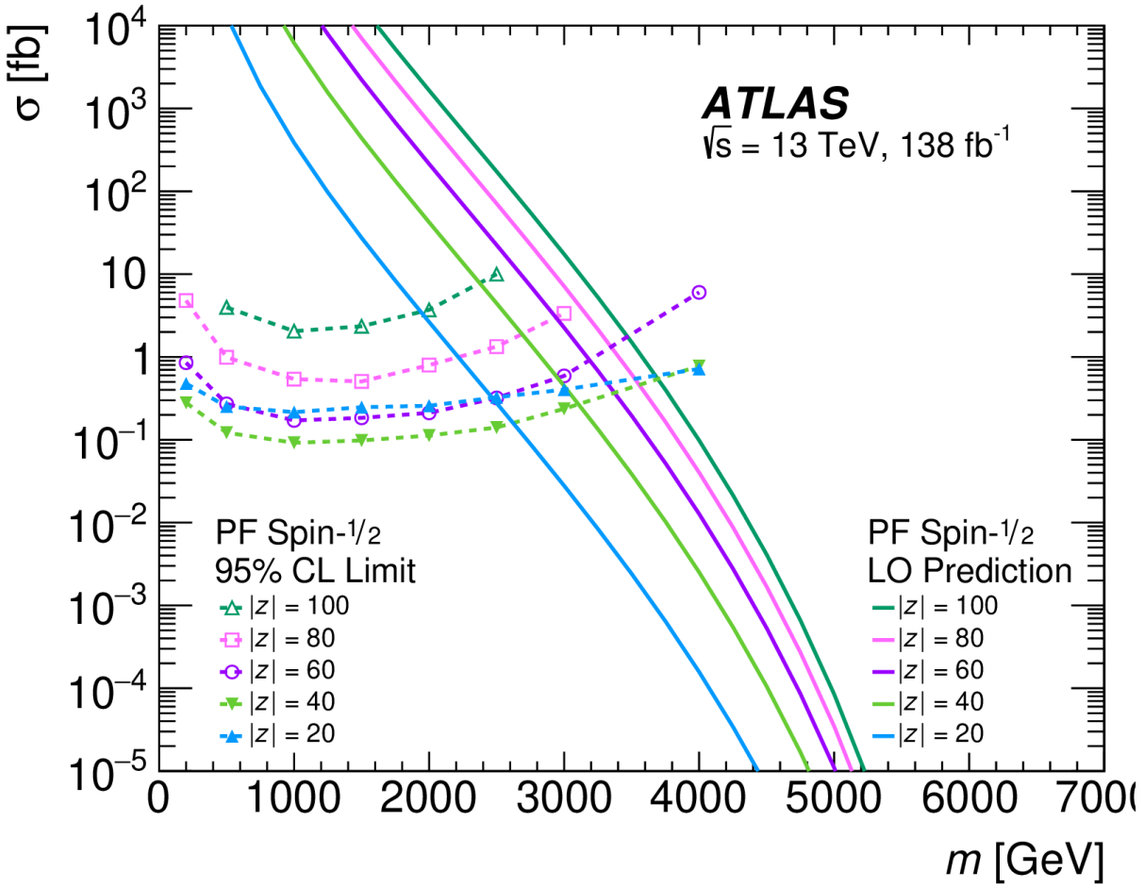
- Background estimated using ABCD method: two-dimensional distribution of f_{HT} and W

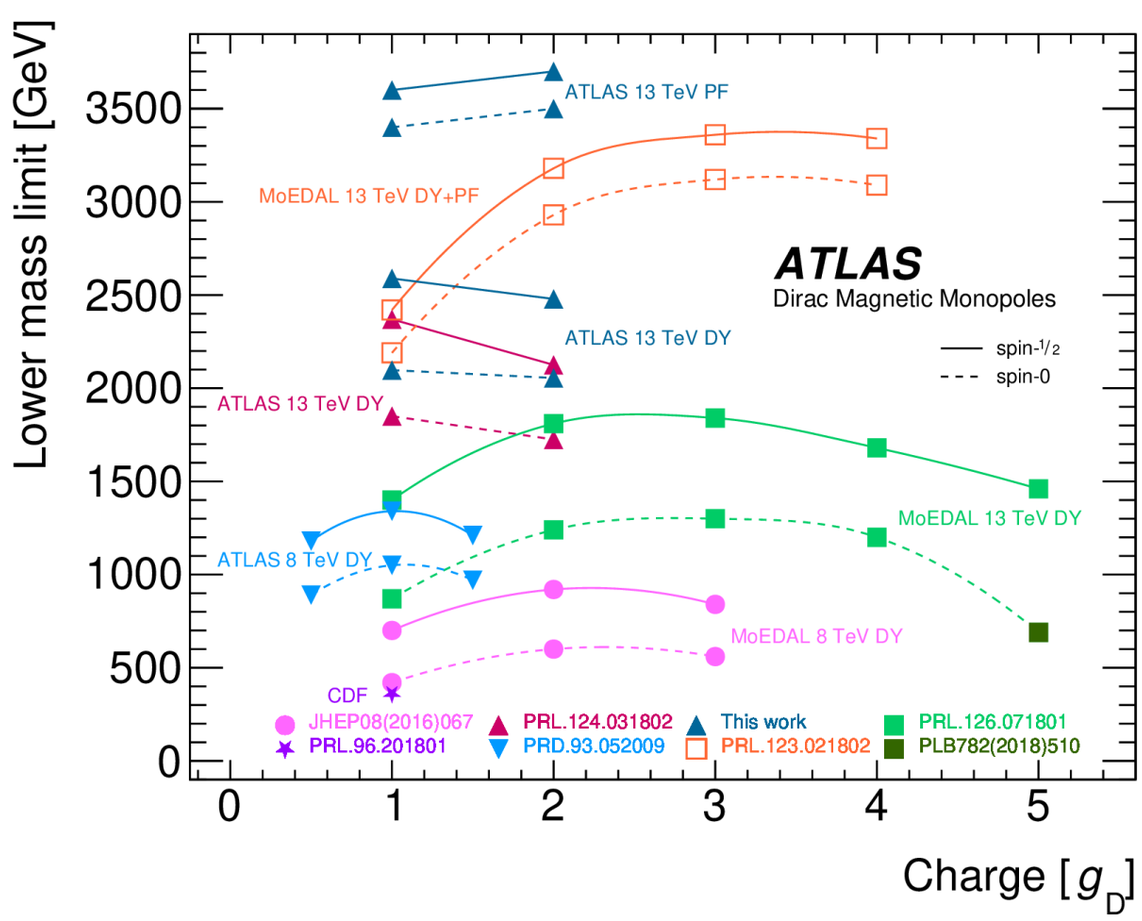


Magnetic monopoles and HECOs

Search for magnetic monopoles and stable particles with high electric charges in 13 TeV proton–proton collisions with the ATLAS detector arXiv:2308.04835

- Consistent with the bkg expectation, **no event observed in SR**
  - exclusion limits set on spin 0 and 1/2 for DY and PF signal models
  - A factor of ~3 improvement from added luminosity an improved background estimate uncertainties





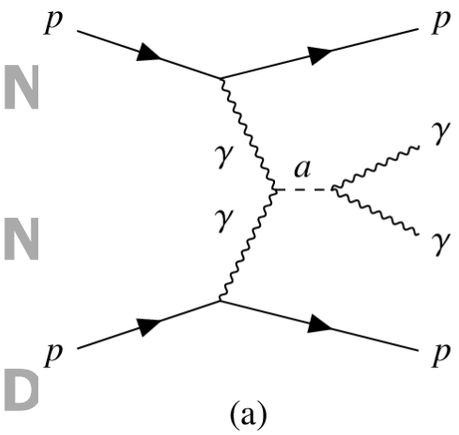
BSM Physics at the LHC

Photon pairs produced in association with forward protons
more on Olivera's talk

Multi-lepton production from the decay of dark photons
more on Olivera's talk

$t\bar{t}$ production with large missing energy
more on Francesco's talk

- N ress he SM make predictions that can be tested at the LHC:



- N upersymm arped extra d S)
- N /mixing, f V SUSY, scala
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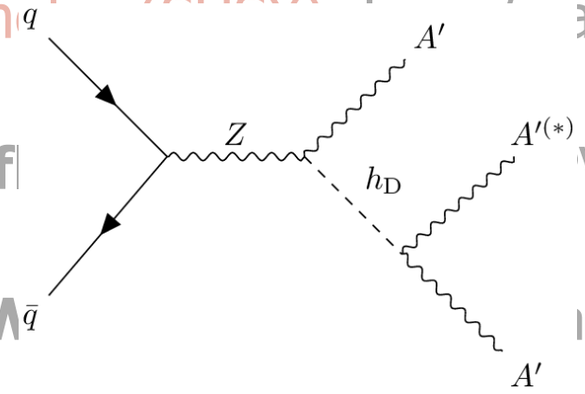
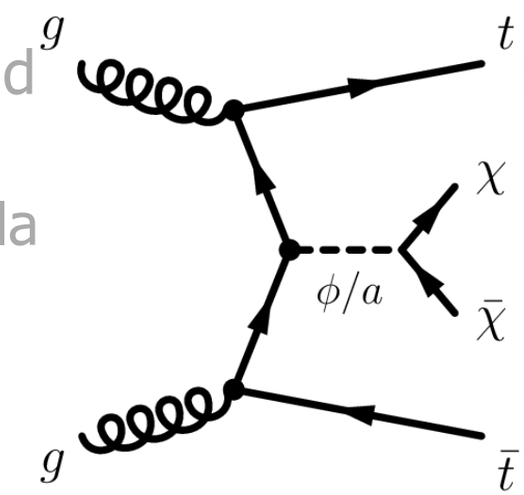




- **Unification of all forces:** magnetic monopoles, SUSY
- **Dark matter:** Axion-Like particles, Dark Sectors, SUSY, scalar mediators

Conclusions

ATLAS carried out a thorough search for BSM signatures in covering many interesting final states and produced many new results

Presented here

- A search for R-parity-violating supersymmetry in final states containing many jets in √s = 13 TeV pp collisions with the ATLAS detector ATLAS-CONF-2023-049
- Pursuit of paired dijet resonances in the Run 2 dataset with ATLAS arXiv:2307.14944 [hep-ex]
- Search for massive, long-lived charged particles with large specific ionisation and low-beta in 140 fb−1 of pp collisions at √s=13 TeV using the ATLAS experiment ATLAS-CONF-2023-044
- Search for magnetic monopoles and stable particles with high electric charges in 13 TeV proton–proton collisions with the ATLAS detector arXiv:2308.04835
- Search for quantum black hole production in lepton+jet final states using proton-proton collisions at √s=13 TeV with the ATLAS detector arXiv:2307.14967
- Search for single vector-like B quark production and decay via B→bH(bb) in pp collisions at √s=13 TeV with the ATLAS detector arXiv:2308.02595
- Search for vector-boson resonances decaying into a top quark and a bottom quark using pp collisions at √s=13 TeV with the ATLAS detector arXiv:2308.08521
- Search for pair production of higgsinos in events with two Higgs bosons and missing transverse momentum in √s = 13 TeV pp collisions at the ATLAS experiment ATLAS-CONF-2023-048
- Search for singly produced vector-like top partners in multilepton final states with 139 fb−1 of pp collision data at √s=13 TeV with the ATLAS detector arXiv:2307.07584
- Search for electroweak SUSY production in final states with tau-leptons in √s=13 TeV pp collisions with the ATLAS detector ATLAS-CONF-2023-029
- Run 2 results of searches for charginos and neutralinos at the ATLAS experiment using statistical combination ATLAS-CONF-2023-046
- Search for top-squark pair production, in minimal flavour violating supersymmetry, in final states containing t-quark, c-quark and missing transverse momentum using the full Run 2 dataset collected by the ATLAS detector ATLAS-CONF-2023-058
- Search for new phenomena with top-quark pairs in final states with one lepton, jets and missing transverse momentum using 140 b−1 of data at √s=13 TeV with the ATLAS detector ATLAS-CONF-2023-043
- Search for lepton-flavour violation in high-mass dilepton final states using 139 fb−1 of pp collisions at √s=13 TeV with the ATLAS detector arXiv:2307.08567

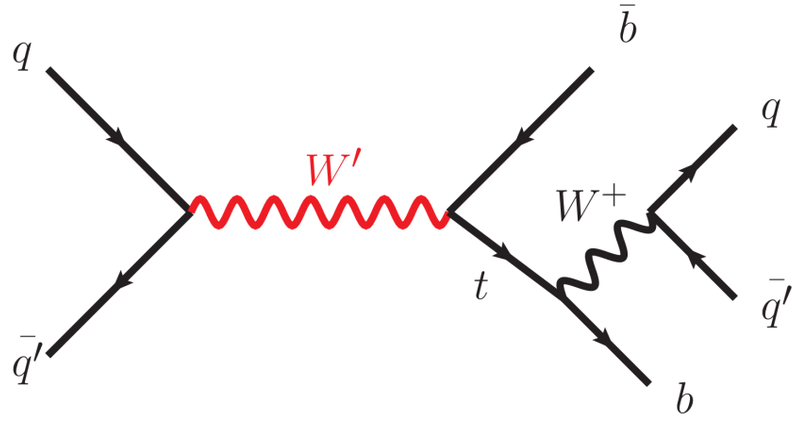
More on Dark Matter on Francesco and Olivera's talk this afternoon

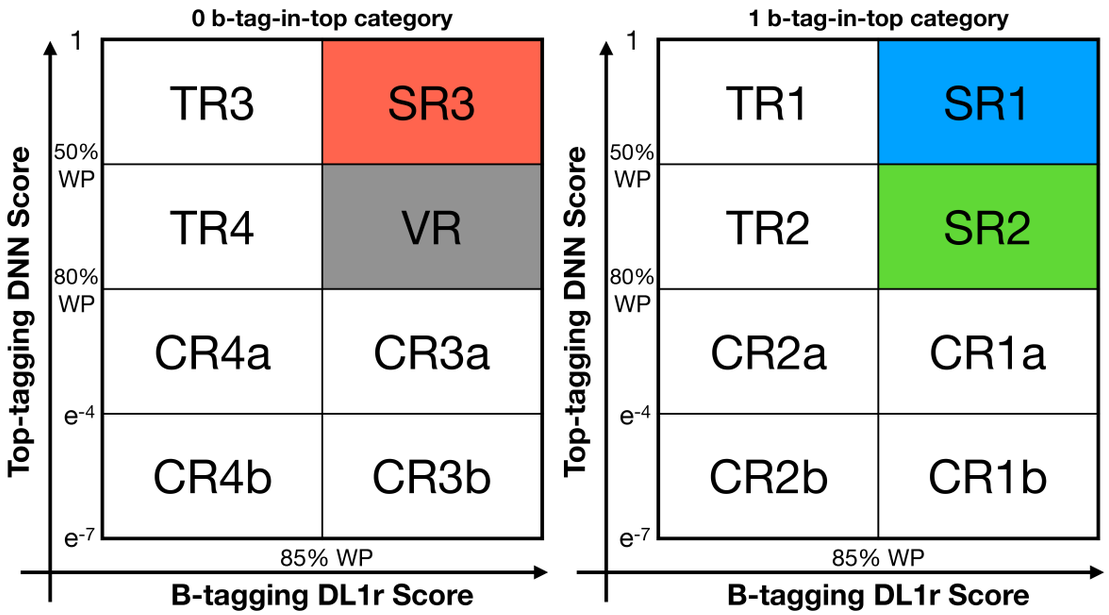
Vector Boson Resonances

Search for vector-boson resonances decaying into a top quark and a bottom quark using pp collisions at √s=13 TeV with the ATLAS detector arXiv:2308.08521

- Search for new heavy W' gauge bosons
- Search for resonance in the ***tb*** invariant mass spectrum (m_{tb})

0-lepton channel





- 1 top-tagged large-R jet formed by 0/1 b-tagged small-R jets
- top candidate with b-quark form W' candidate
- Signal, control and validation regions function of top- and b-tagging NN scores

Vector Boson Resonances

Search for vector-boson resonances decaying into a top quark and a bottom quark using pp collisions at √s=13 TeV with the ATLAS detector arXiv:2308.08521

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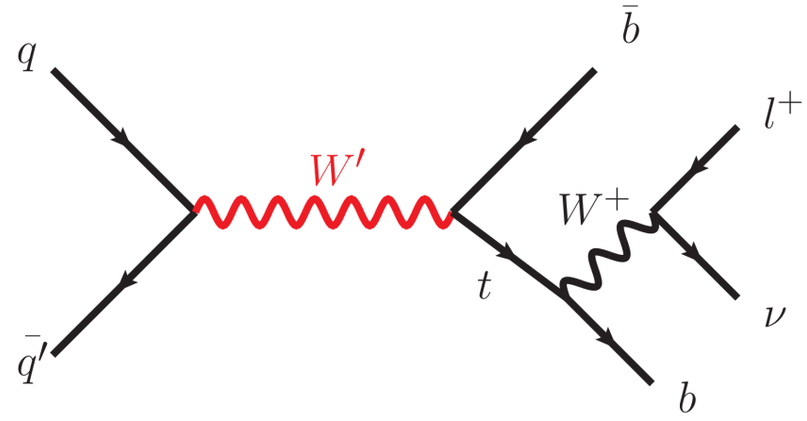

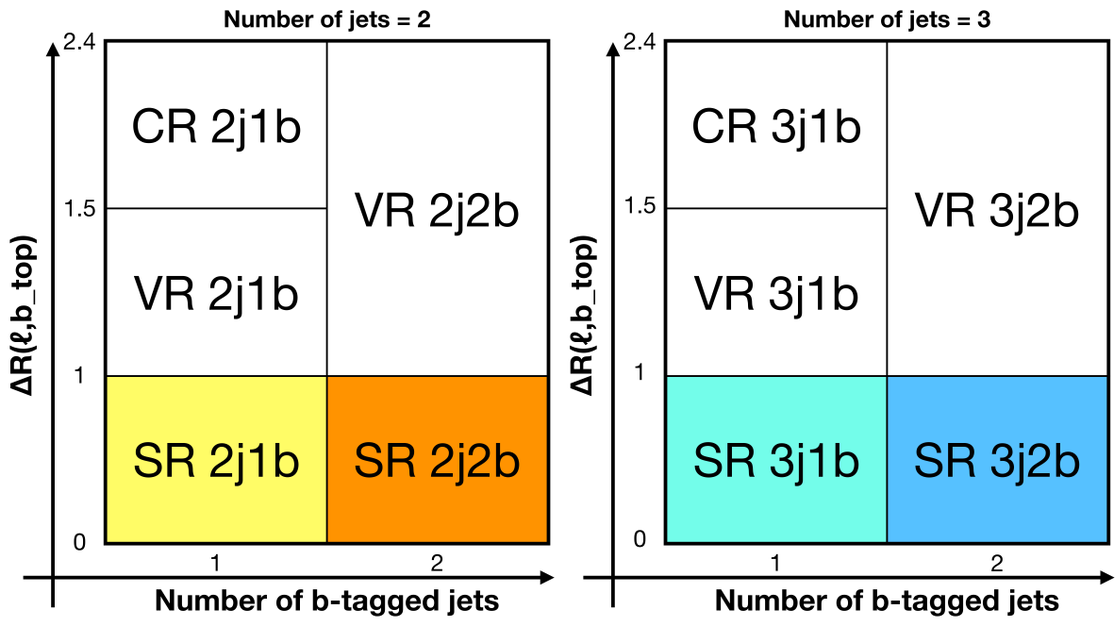

- 1 isolated lepton, ≥2 jets and large E_T^{miss}
- W' mass from reconstruction of $p_z(\nu)$
- Events categorized based on number of jets, b-tagged jets, and other kinematic variables.

Vector Boson Resonances

Search for vector-boson resonances decaying into a top quark and a bottom quark using pp collisions at √s=13 TeV with the ATLAS detector arXiv:2308.08521

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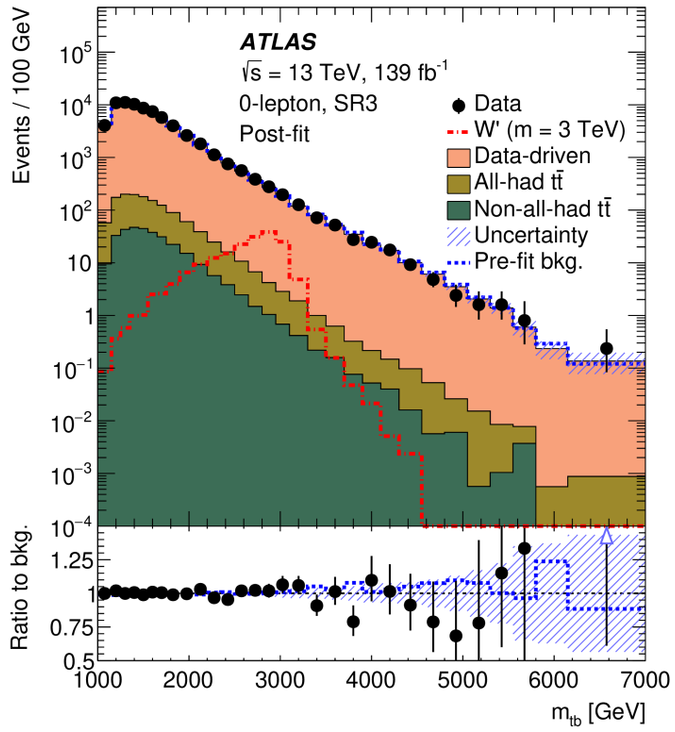
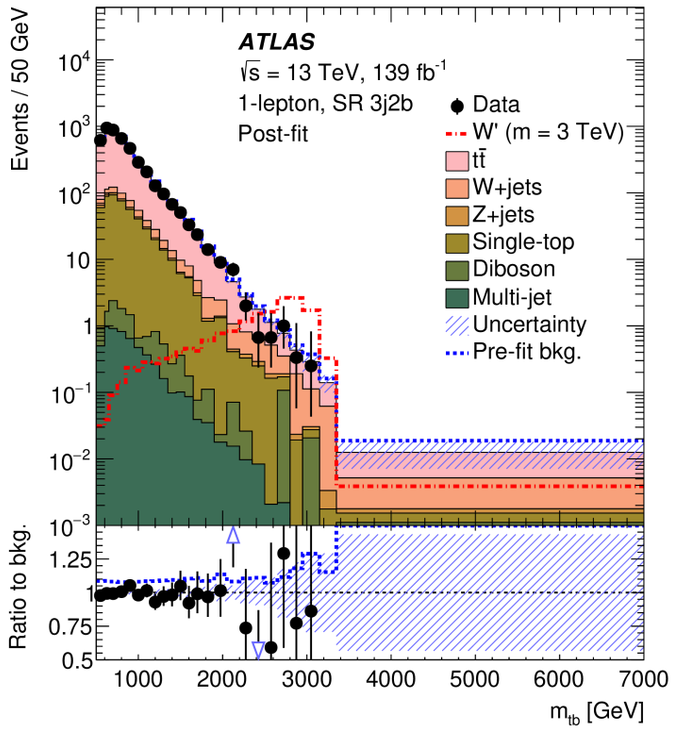
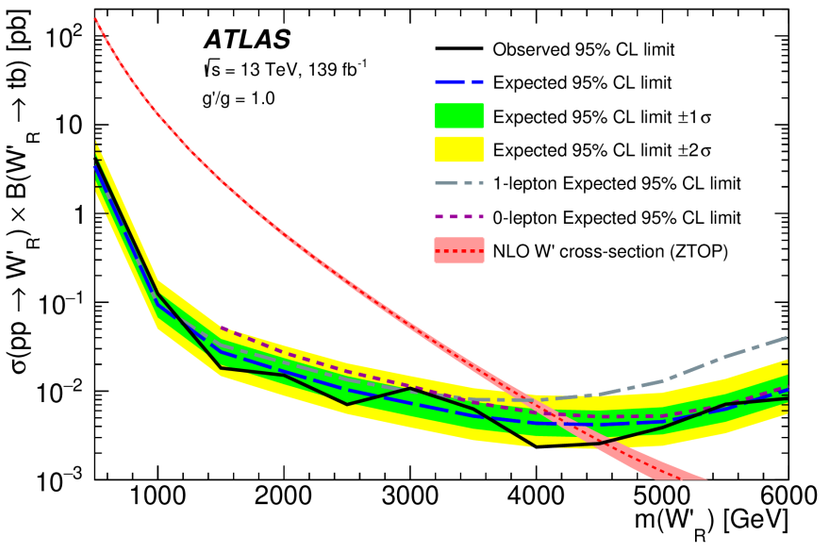
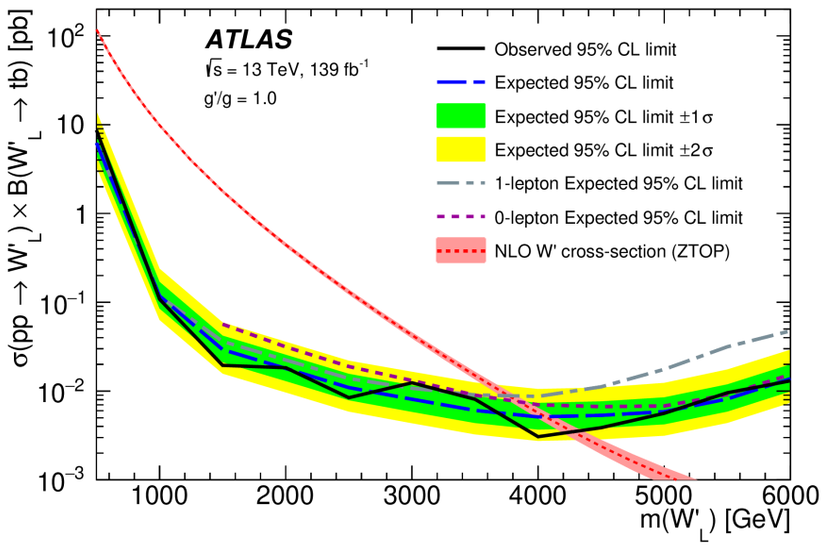






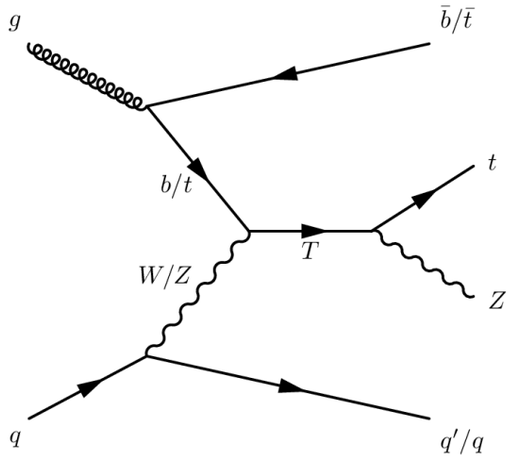


VLQ: Single T to multi-lepton

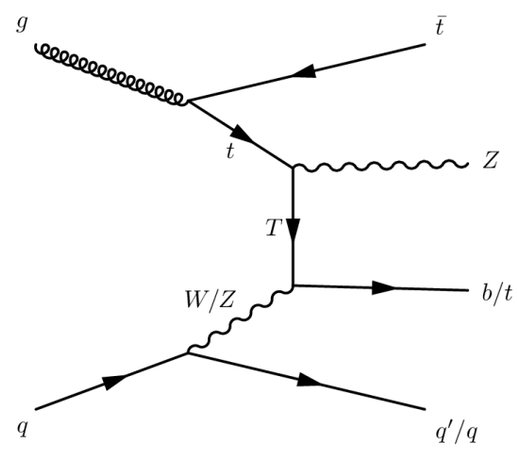
Search for singly produced vector-like top partners in multilepton final states with 139 fb−1 of pp collision data at √s=13 TeV with the ATLAS detector arXiv:2307.07584

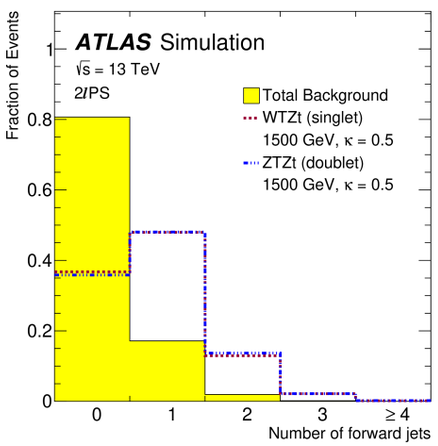
- Single T are produced the s- and t-channel topologies: WTZt (singlet) and ZTZt (doublet)
- Analysis performed in 2l opposite-sign and 3 lepton final states
- 2L analysis:
  - Invariant mass of leptons compatible with Z
  - Large hadronic "top-jet"

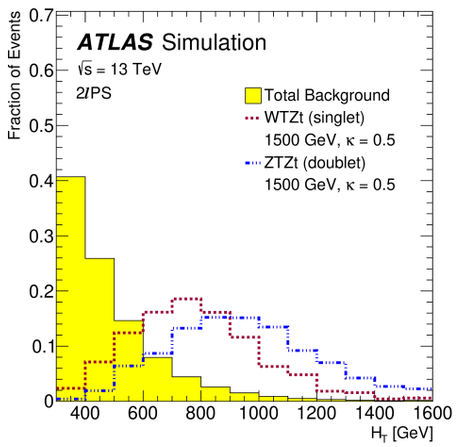
WTZt

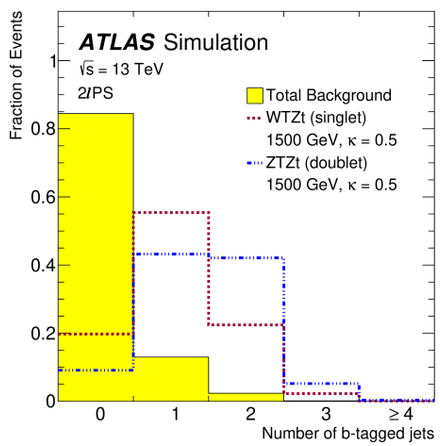


ZTZt









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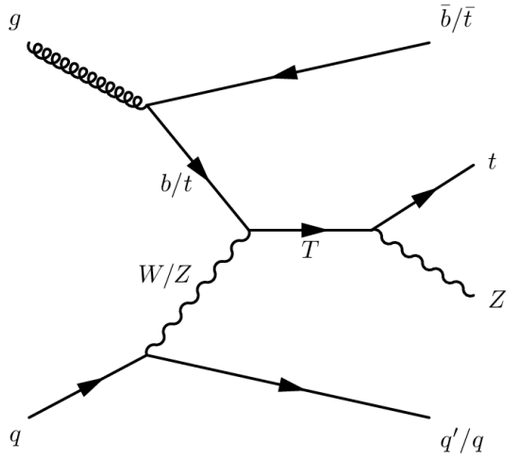
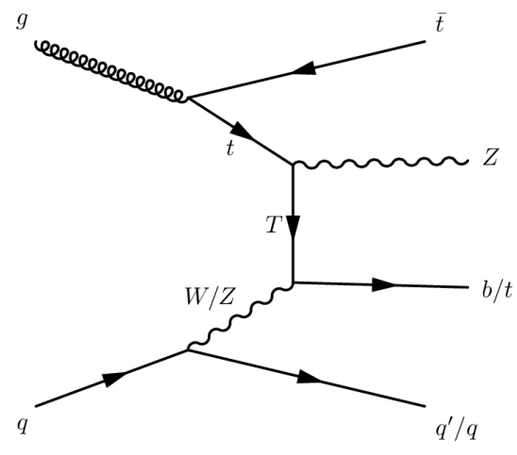
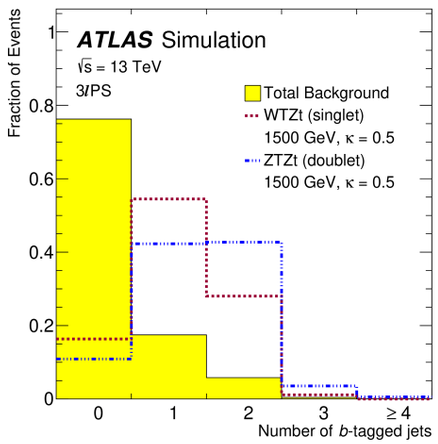
WTZt

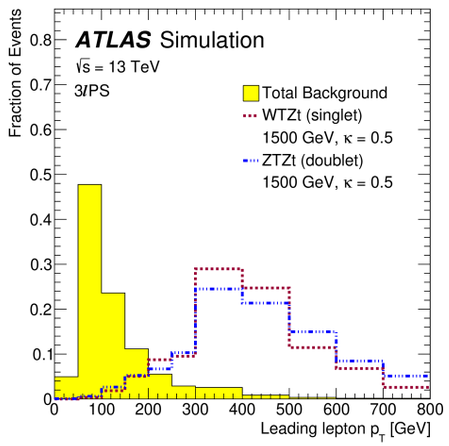


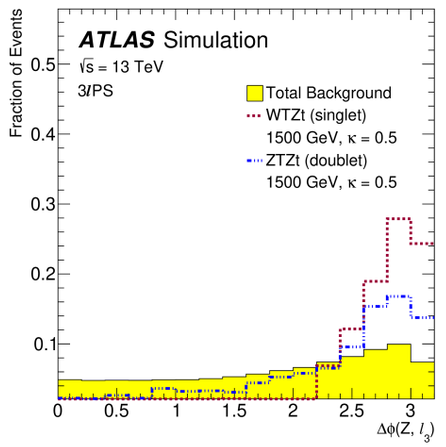
ZTZt



- Analysis performed in 2l opposite-sign and 3 lepton final states
- 3L analysis:
  - Invariant mass of leptons compatible with Z
  - Large angular separation between T, the Z boson decay products



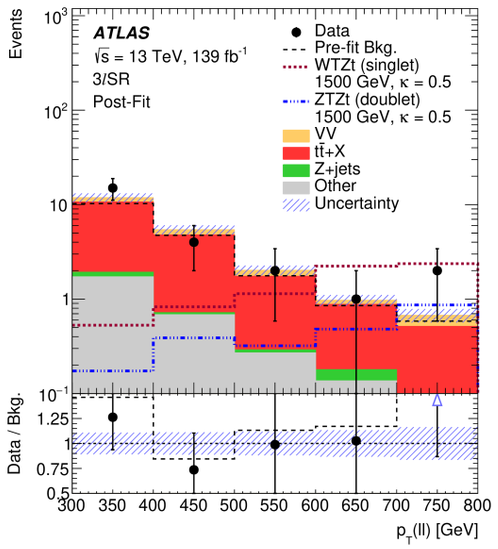


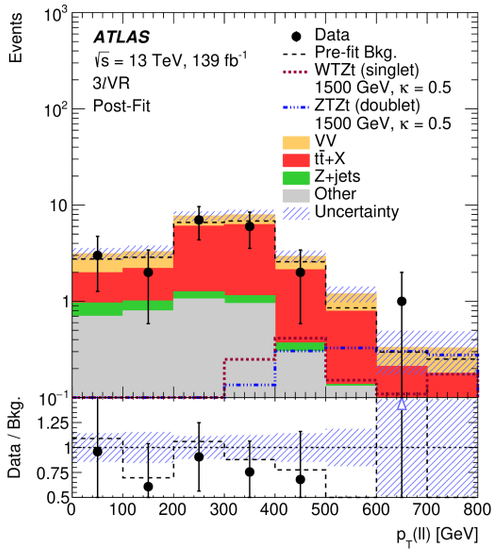


VLQ: Single T to multi-lepton

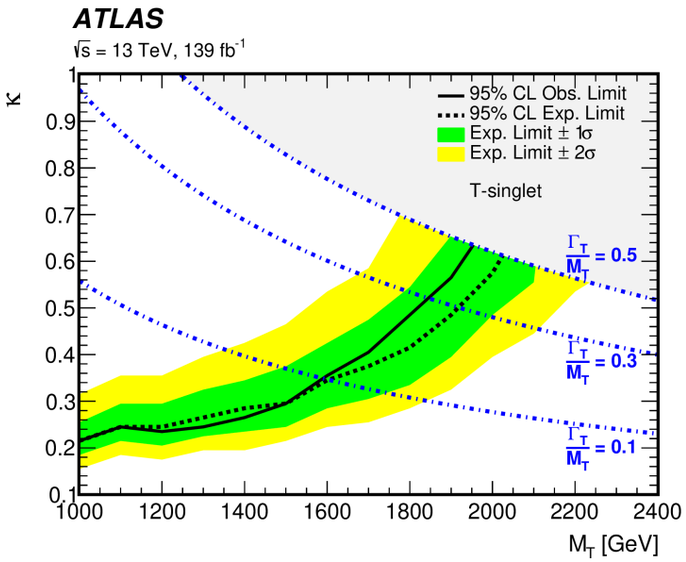
Search for singly produced vector-like top partners in multilepton final states with 139 fb−1 of pp collision data at √s=13 TeV with the ATLAS detector arXiv:2307.07584

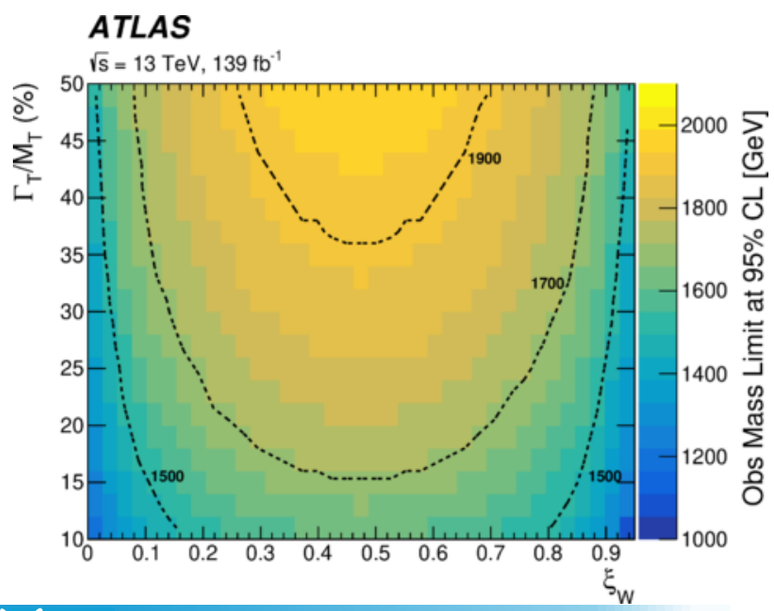
- pT(ll) used as a final discriminant





- Results are interpreted in terms of limits on the T mass and coupling for different electroweak representations and branching ratio scenarios.





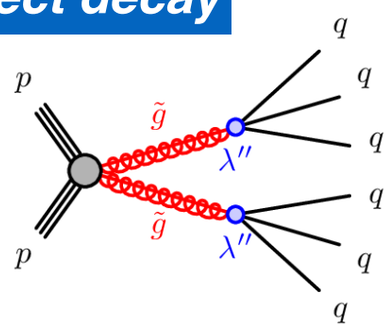
RPV multijet

A search for R-parity-violating supersymmetry in final states containing many jets in $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector ATLAS-CONF-2023-049

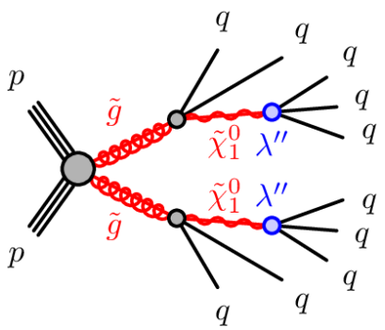
B: Barion number, L: Lepton number, S: Spin

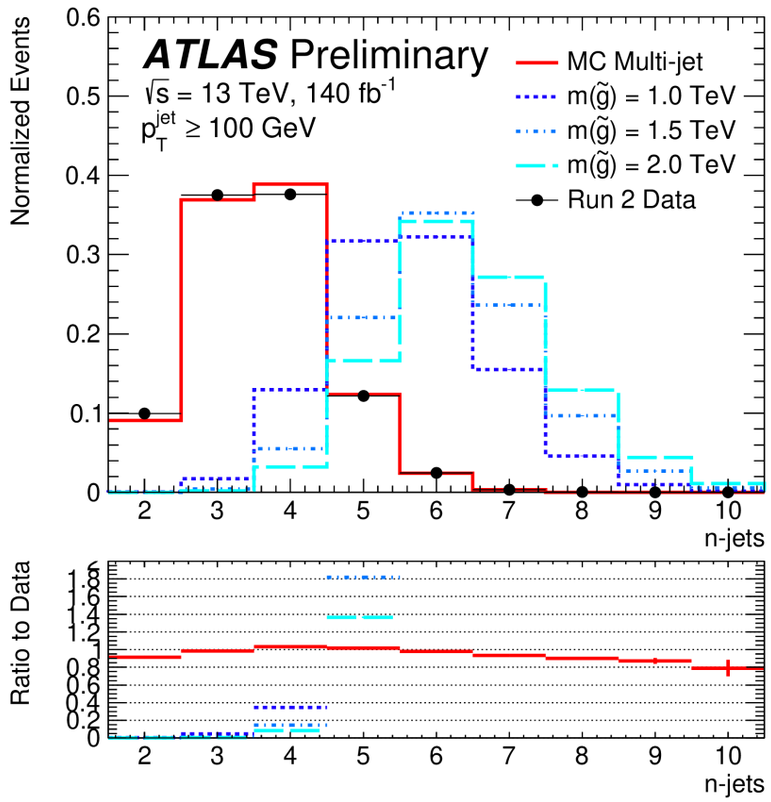
- **R-parity:** $R = (-1)^{3(B-L)+2s}$ ➔ R = **+(-)1** for **SM particles (superpartners)**
- SUSY allows for B and L violation if R-parity violation (RPV) is admitted
  - LSP possibly not stable ➔ signals with large number of SM particles in the final state
  - UDD RPV coupling leads SUSY particles to decay to quarks

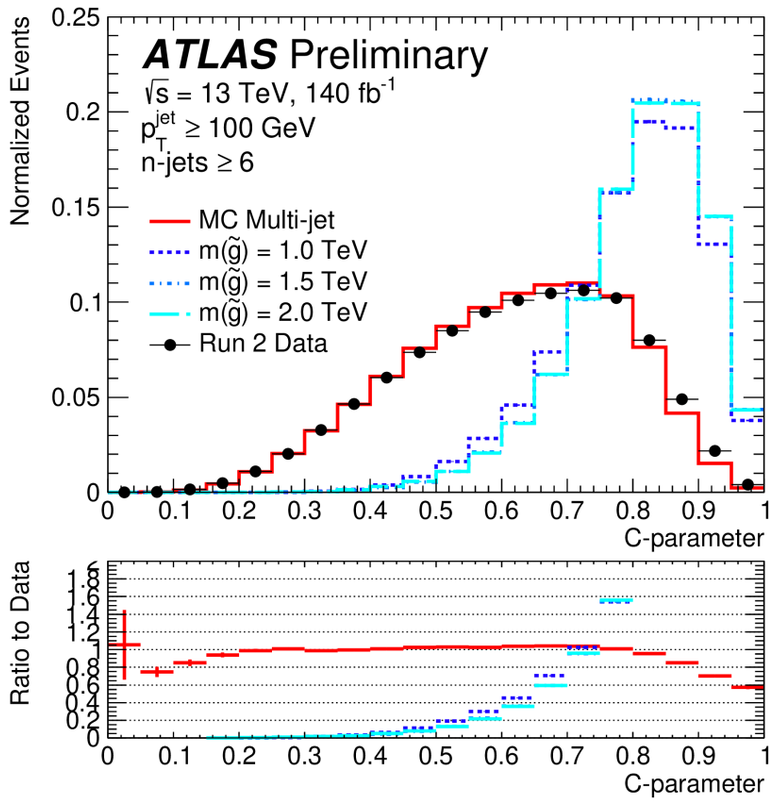
direct decay



cascade decay



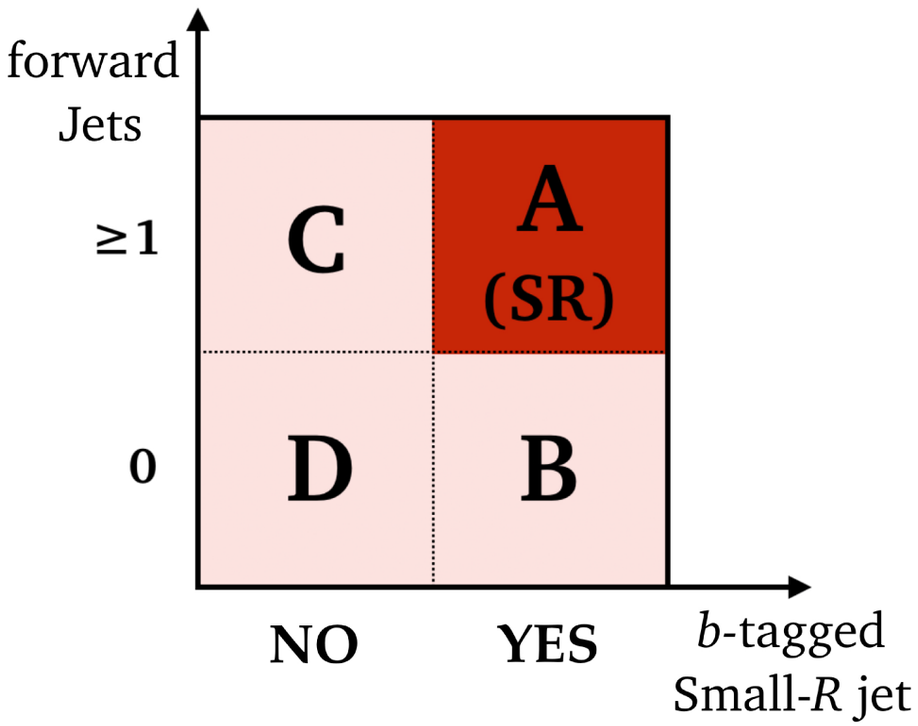




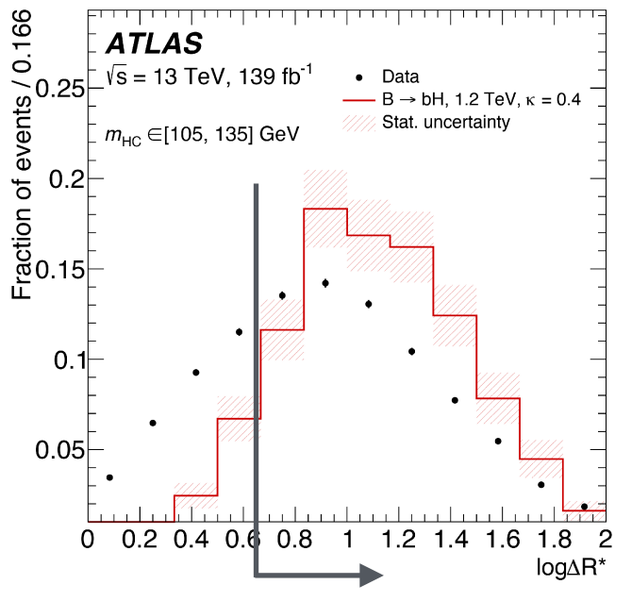
VLQ: bH(H→bb)

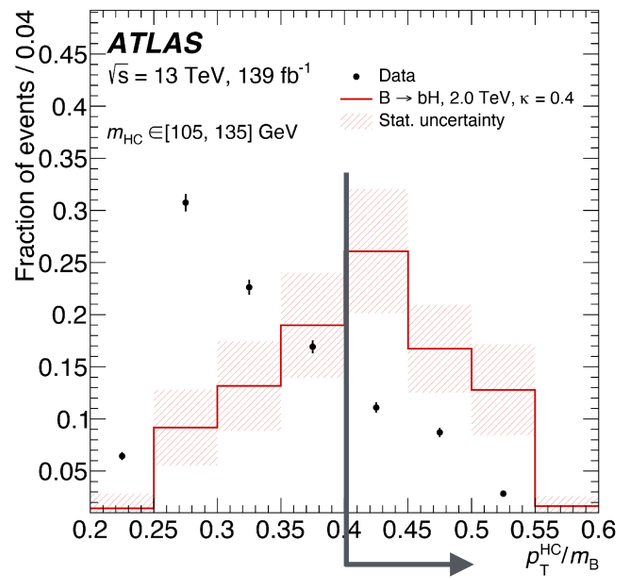
Search for single vector-like B quark production and decay via B→bH(bb) in pp collisions at √s=13 TeV with the ATLAS detector arXiv:2308.02595

- ABCD data driven background estimation



- Kinematic variables used to discriminated against background
  - ΔR* = ratio ΔR between track jets and effective radii
  - p_T^{HC}/m_B : reject events where jets have large distance between large radius and small radius jets





RPV multijet

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
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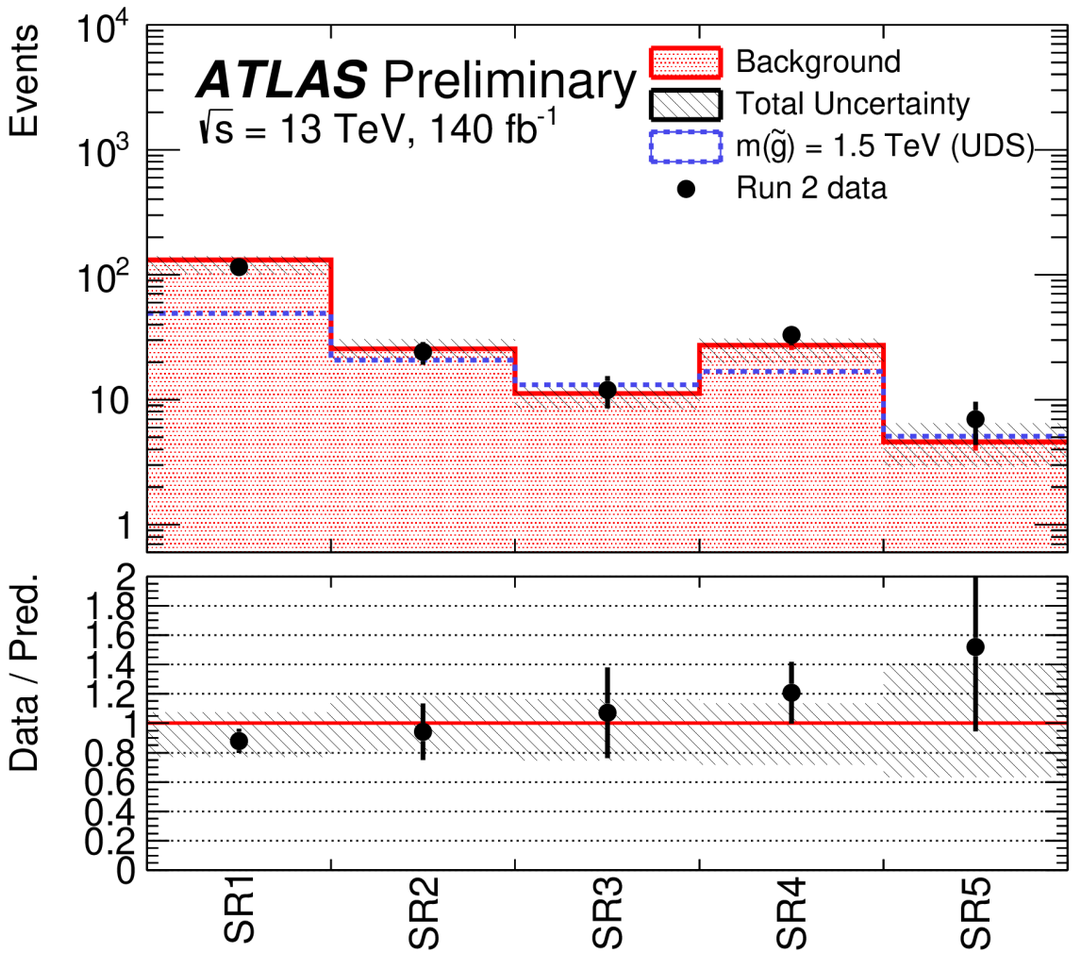
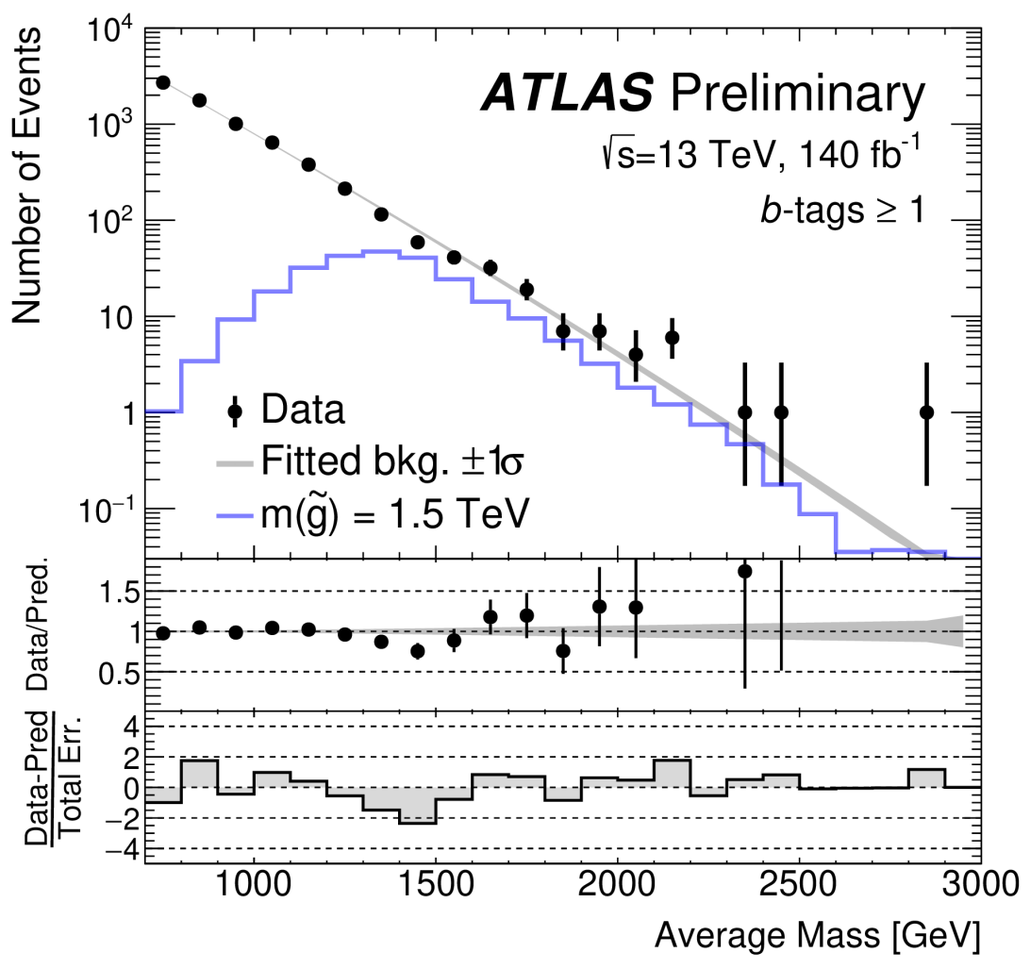
A search for R-parity-violating supersymmetry in final states containing many jets in $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector ATLAS-CONF-2023-049

- **Jet counting analysis**: define single-bin signal regions (SR) requiring high jet multiplicity

	n_{jets}	$p_{\text{T}}(j)$ [GeV]	C	$n_{b-\text{jets}}$
SR1	≥ 7	180	≥ 0.90	-
SR2	≥ 7	220	≥ 0.90	-
SR3	≥ 7	240	≥ 0.90	-
SR4	≥ 8	180	≥ 0.85	-
SR5	≥ 8	210	≥ 0.85	-
SR1bj	≥ 7	180	≥ 0.85	≥ 2
SR2bj	≥ 8	180	≥ 0.85	≥ 2

- **Mass resonance analysis**: *NN* based on attention mechanism to predict probability for jet to be assigned to each $\tilde{g}$

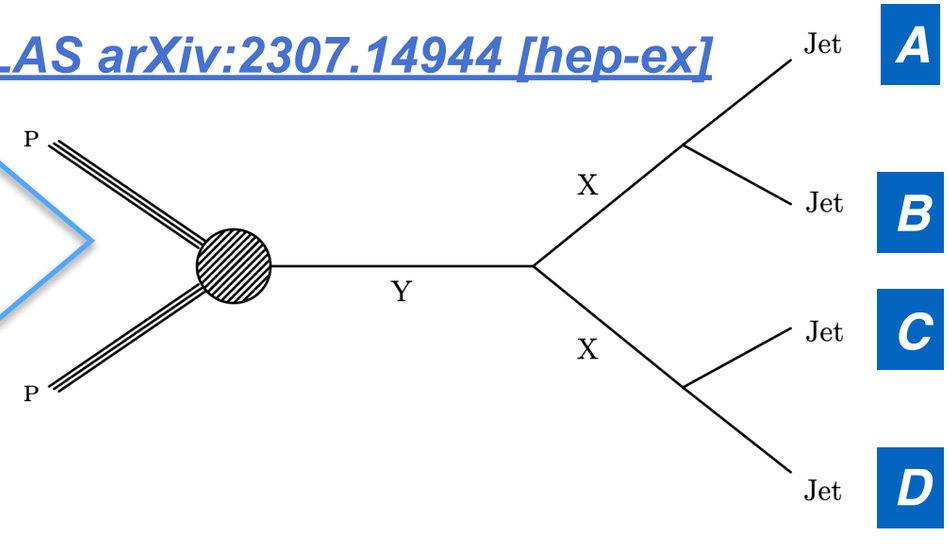




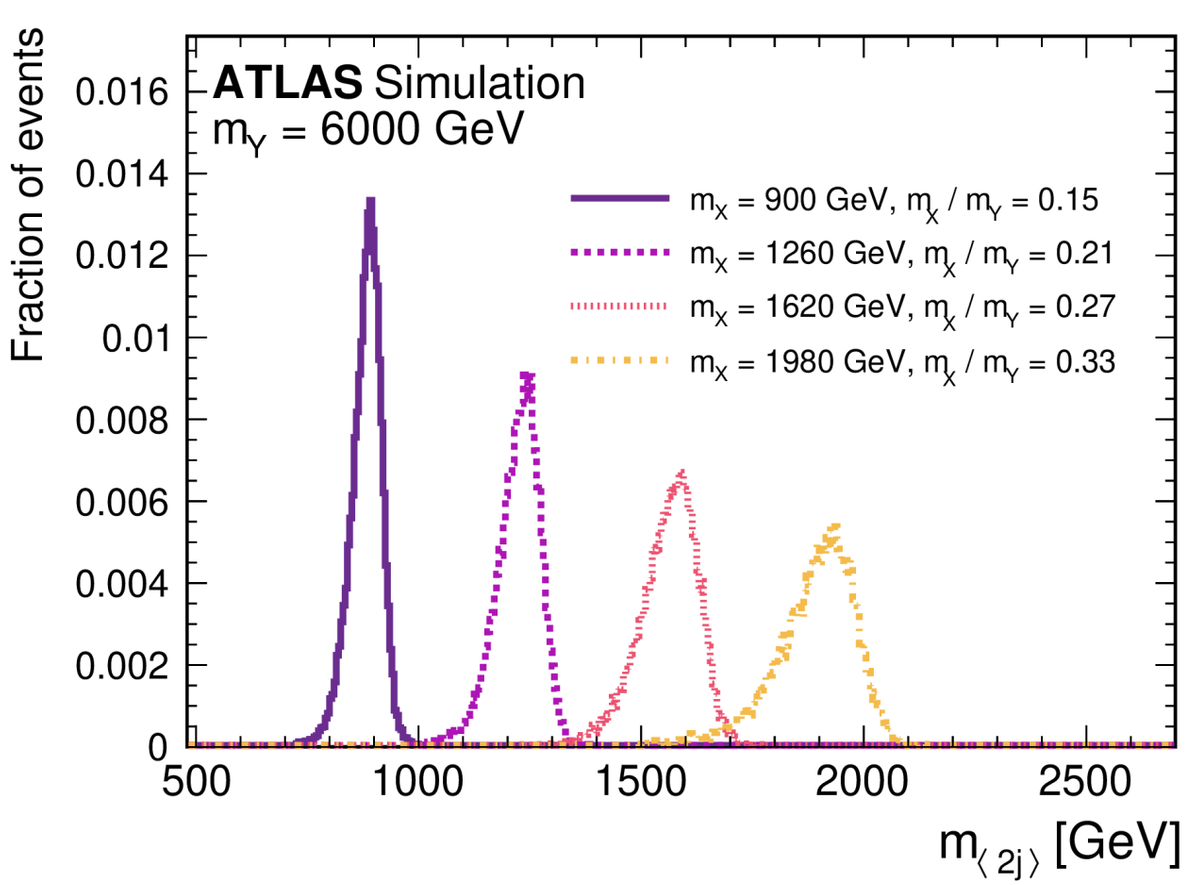
Multijet resonances

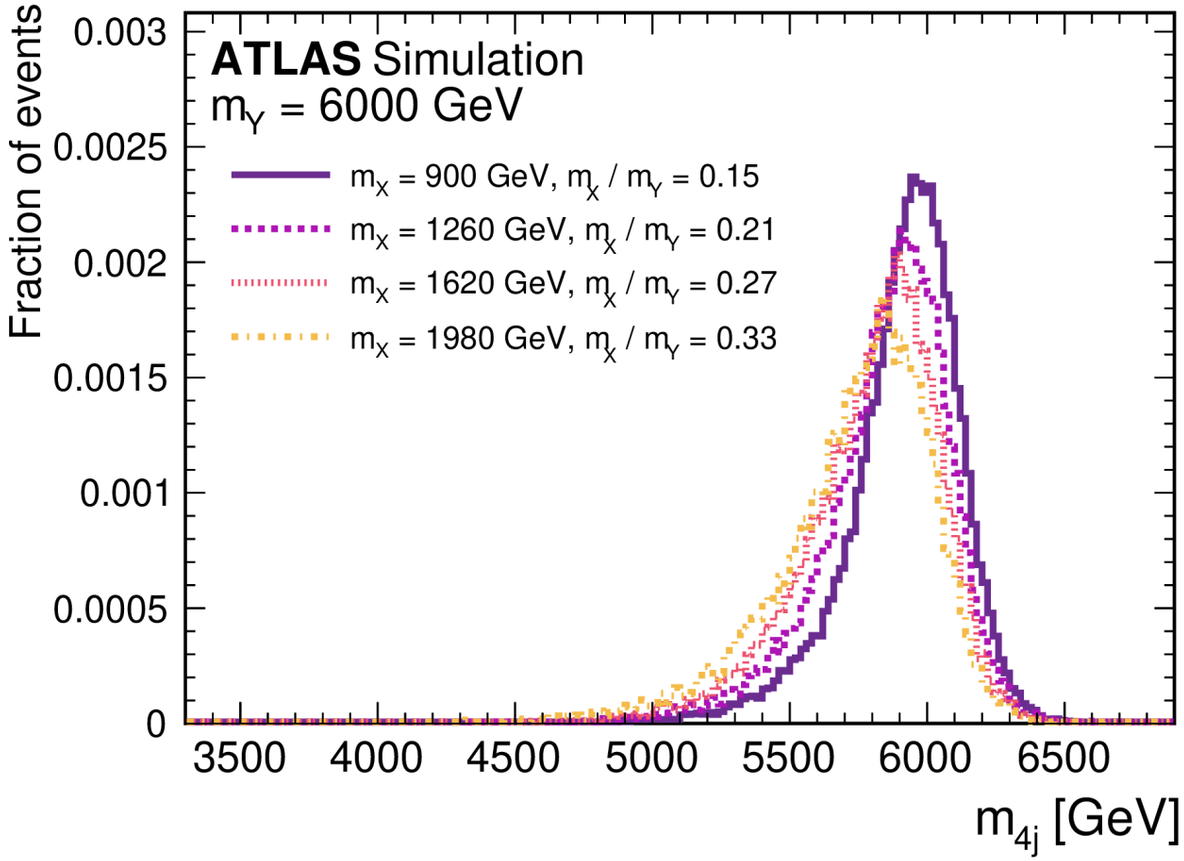
Pursuit of paired dijet resonances in the Run 2 dataset with ATLAS arXiv:2307.14944 [hep-ex]

- Search for a generic massive resonance Y decaying into pairs of intermediate resonance X



- Scalar di-quarks and colorons possible candidates
- **CMS observed excess** 2.5σ at m_{4j}~8 TeV

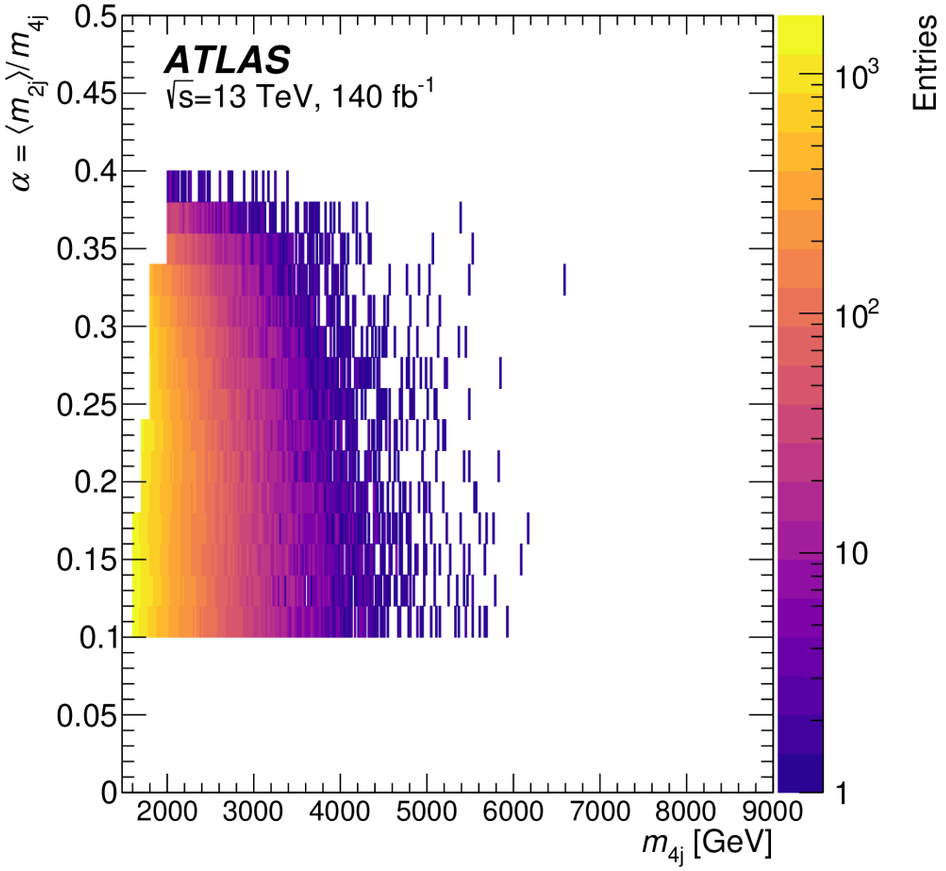


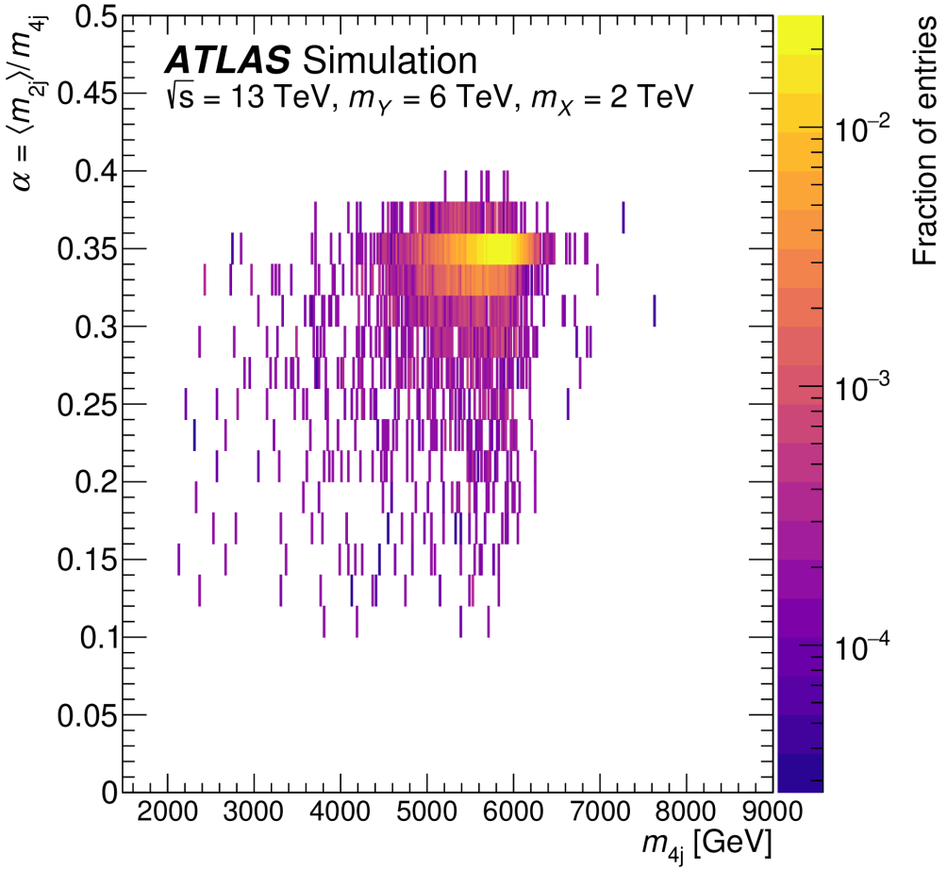


Multijet resonances

Pursuit of paired dijet resonances in the Run 2 dataset with ATLAS arXiv:2307.14944 [hep-ex]

- Event reconstruction exploits production of **same mass** resonances
- Hadronic jets collimated but still forming four anti-k_t *R=0.4* jets
  - Paired minimizing $\Delta R = |\Delta R_{AB} - 0.8| + |\Delta R_{cd} - 0.8|$
- Reconstructed resonance mass ratio $\alpha = \langle m_{2j} \rangle / m_{4j}$ used to de-correlate m_{4j} and m_{2j}

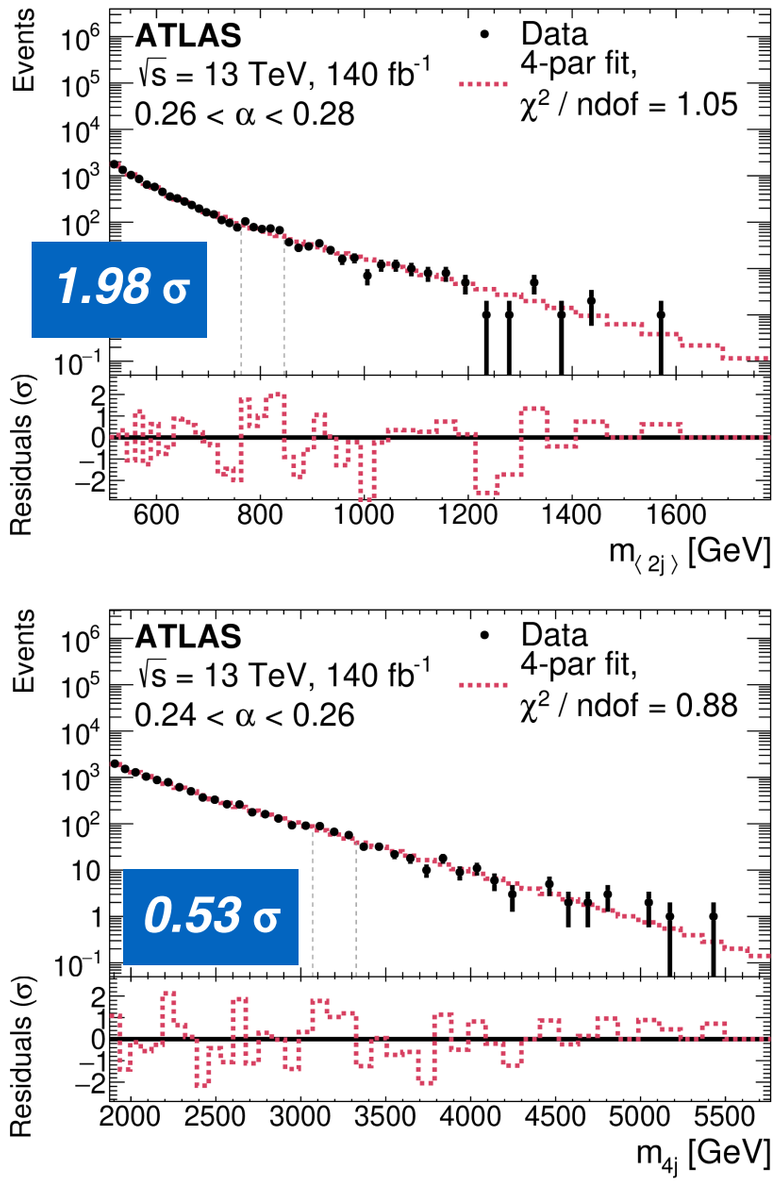


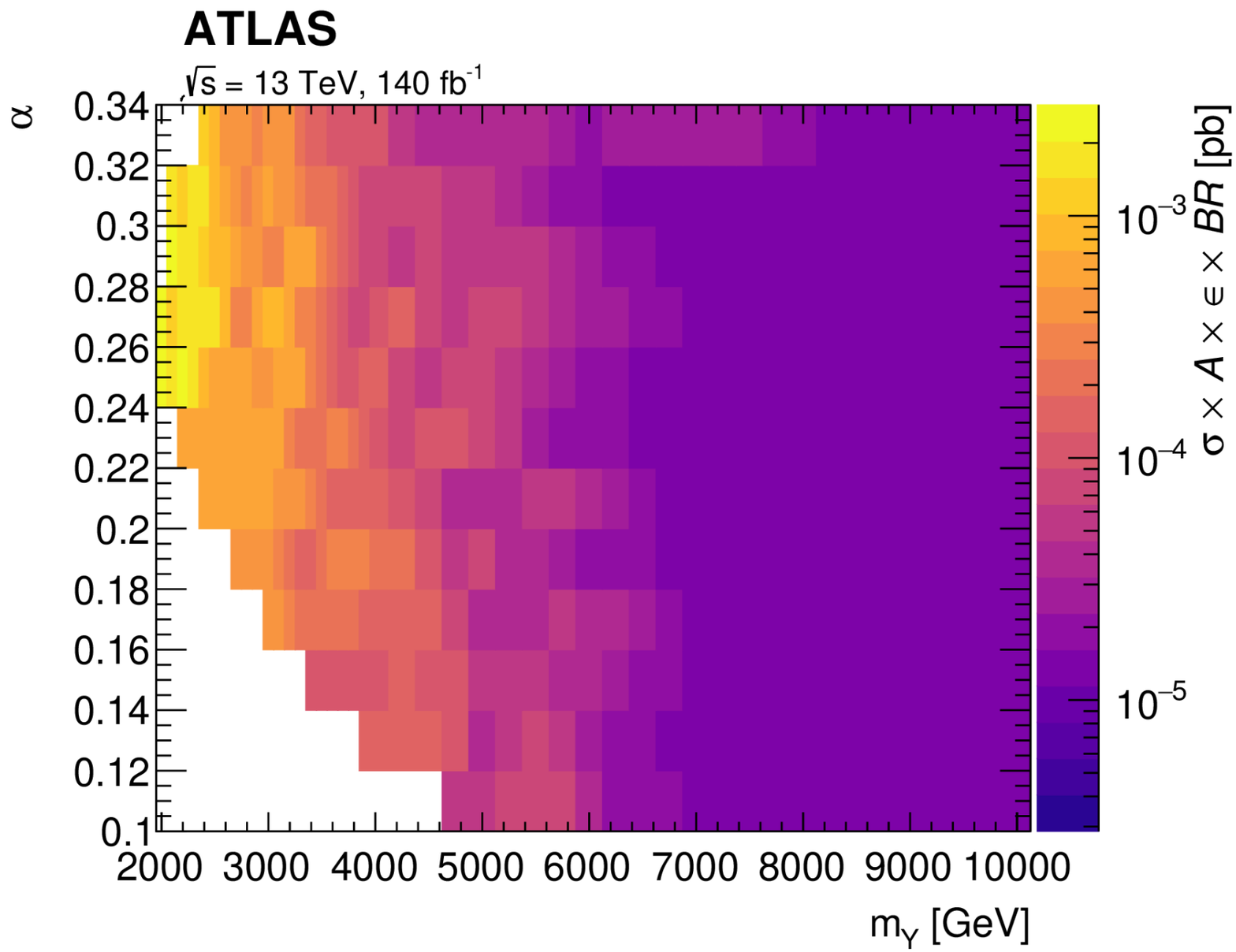


Multijet resonances

Pursuit of paired dijet resonances in the Run 2 dataset with ATLAS arXiv:2307.14944 [hep-ex]

- Multijet background fitted with 4 parameter function: $f(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln(x) + p_5 \ln(x)^2}$
- No deviations observed ➔ model dependent and independent limits set for different $\mathbf{m_{Y/X}}$ scenarios

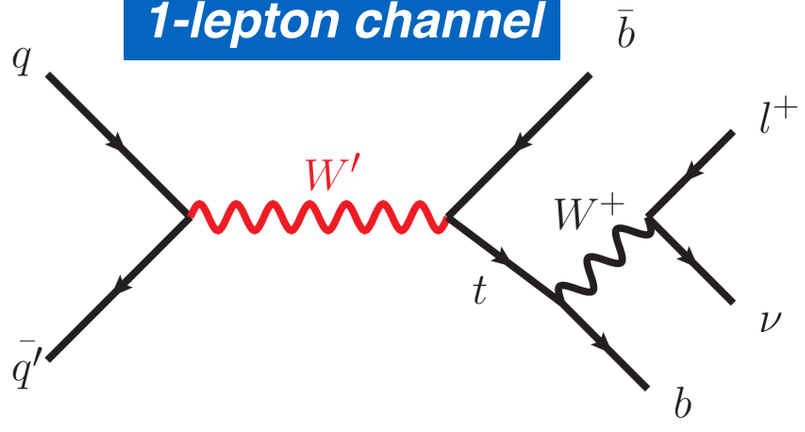




Vector Boson Resonances

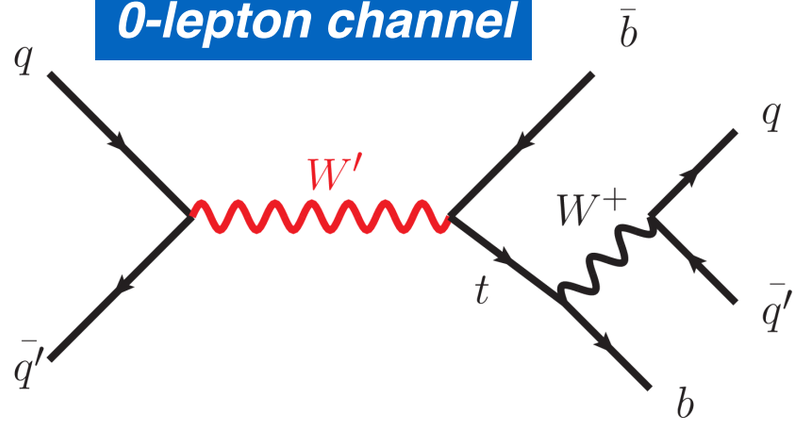
Search for vector-boson resonances decaying into a top quark and a bottom quark using pp collisions at √s=13 TeV with the ATLAS detector arXiv:2308.08521

1-lepton channel



- 1 isolated lepton, ≥2 jets and large E_T^{miss}
- W' mass from reconstruction of $p_z(\nu)$
- Events categorized based on number of jets, b-tagged jets, and other kinematic variables.

0-lepton channel



- 1 top-tagged large-R jet formed by 0/1 b-tagged small-R jets
- top candidate with b-quark form W' candidate
- Signal, control and validation regions function of top- and b-tagging NN scores

Slow, charged and heavy LLP

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
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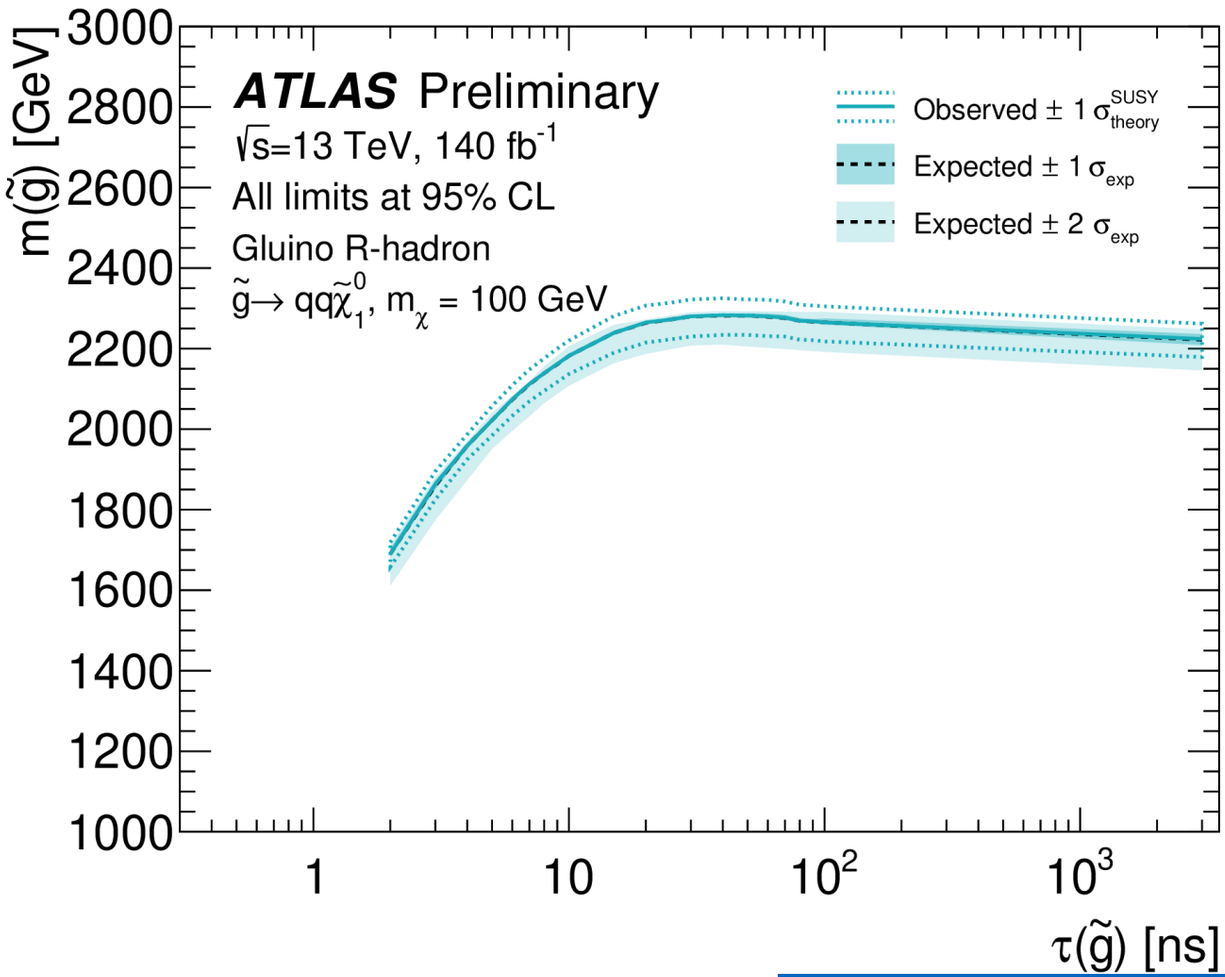
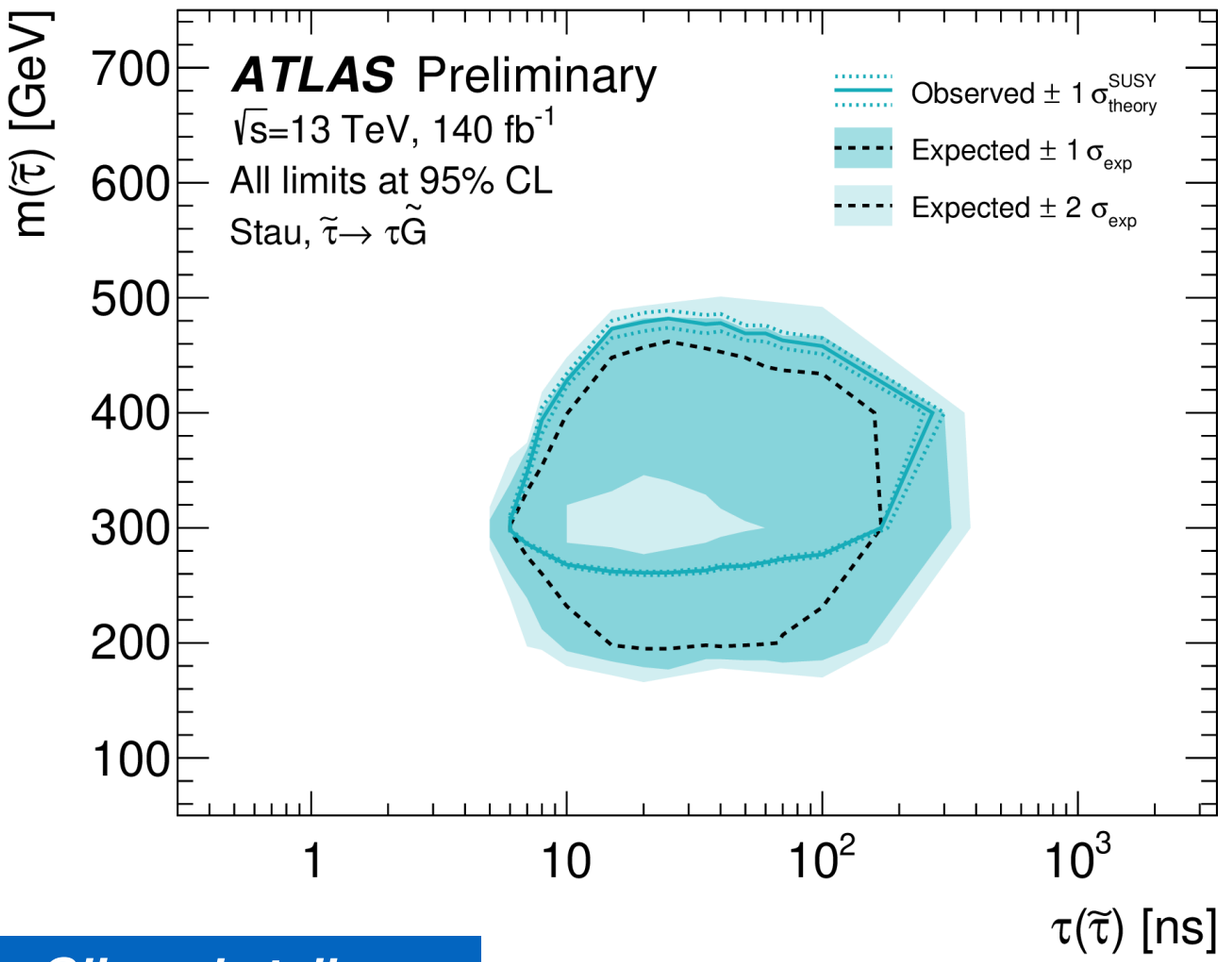
cnrs IN2P3 Les deux infinis

Search for massive, long-lived charged particles with large specific ionisation and low-beta in 140 fb−1 of pp collisions at $\sqrt{s}$=13 TeV using the ATLAS experiment ATLAS-CONF-2023-044

- $m(\tilde{g})$< 2.3 TeV excluded for τ=30 ns and $m(\tilde{\chi}_0^1)$=100 GeV.
- 280< $m(\tilde{\tau})$<420 GeV excluded for lifetimes of 10 ns.
  - Mass limits for $\tilde{\tau}$ extend up to 100 ns, lower mass limit constant in 10–100 ns range





more on LLP on Olivera's talk

BSM Physics at the LHC

- Many new models addressing the shortcoming of the SM make predictions that can be tested at the LHC:
  - **Natural EWSB**: Supersymmetry (SUSY), large/warped extra dimensions (ADD/RS)
  - **Neutrino masses/mixing, flavor anomalies**: RPV SUSY, scalar di-quarks
  - **Dynamic explanation of EWSB**: New strong dynamics
  - **Unification of all forces:** magnetic monopoles, SUSY
  - **Dark matter:** Axion-Like particles, Dark Sectors, SUSY, scalar mediators