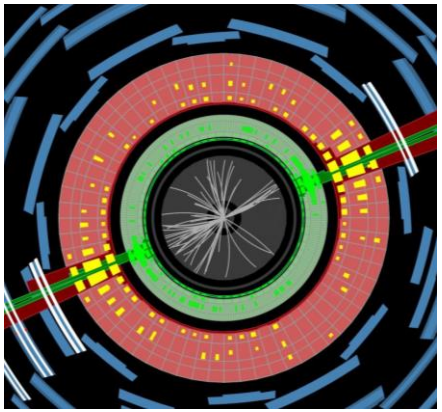
Contur

Constraints On New Theories Using Rivet



a tool for reinterpreting particle-level measurements.

17/5/2024

HSF Workshop Hamburg

Jon Butterworth

UCL

The problem

INSPIRE HEP | literature | find (cn atlas or cn cms) and title "search"

Literature | Authors | Jobs | Seminars | Conferences | More...

1,158 results | cite all | Citation Summary | Most Recent

Date of paper

2003 — 2024

Number of authors

- Single author 1
- 10 authors or less 1

Exclude RPP

- Exclude Review of Particle Physics 1,158

Document Type

- published 1,158
- article 1,157
- note 2
- conference paper 1

A search for R-parity-violating supersymmetry in final states containing many jets in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector #1

ATLAS Collaboration • Georges Aad (Marseille, CPPM) et al. (Jan 29, 2024)

Published in: *JHEP* 05 (2024) 003 • e-Print: 2401.16333 [hep-ex]

pdf | DOI | cite | claim | reference search | 2 citations

Search for new phenomena with top-quark pairs and large missing transverse momentum using 140 fb^{-1} of pp collision data at $\sqrt{s}$ = 13 TeV with the ATLAS detector #2

ATLAS Collaboration • Georges Aad (Marseille, CPPM) et al. (Jan 24, 2024)

Published in: *JHEP* 03 (2024) 139 • e-Print: 2401.13430 [hep-ex]

pdf | DOI | cite | claim | reference search | 2 citations

Search for Long-Lived Heavy Neutral Leptons with Lepton Flavour Conserving or Violating Decays to a Jet and a Charged Lepton #3

CMS Collaboration • Aram Hayrapetyan (Yerevan Phys. Inst.) et al. (Dec 12, 2023)

Published in: *JHEP* 03 (2024) 105 • e-Print: 2312.07484 [hep-ex]

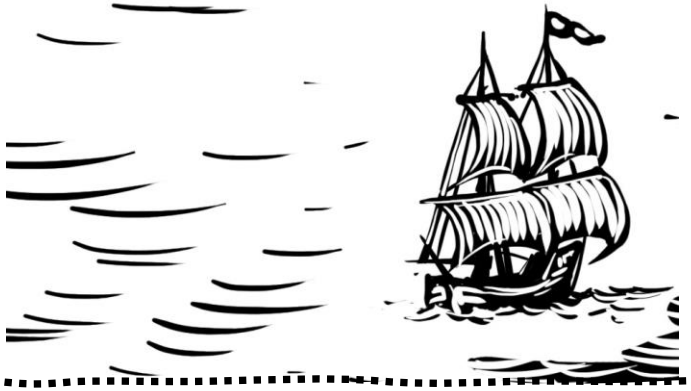
pdf | DOI | cite | datasets | claim | reference search | 6 citations

Search for flavor changing neutral current interactions of the top quark in final states with a photon and additional jets in proton-proton collisions at $\sqrt{s} = 13$ TeV #4

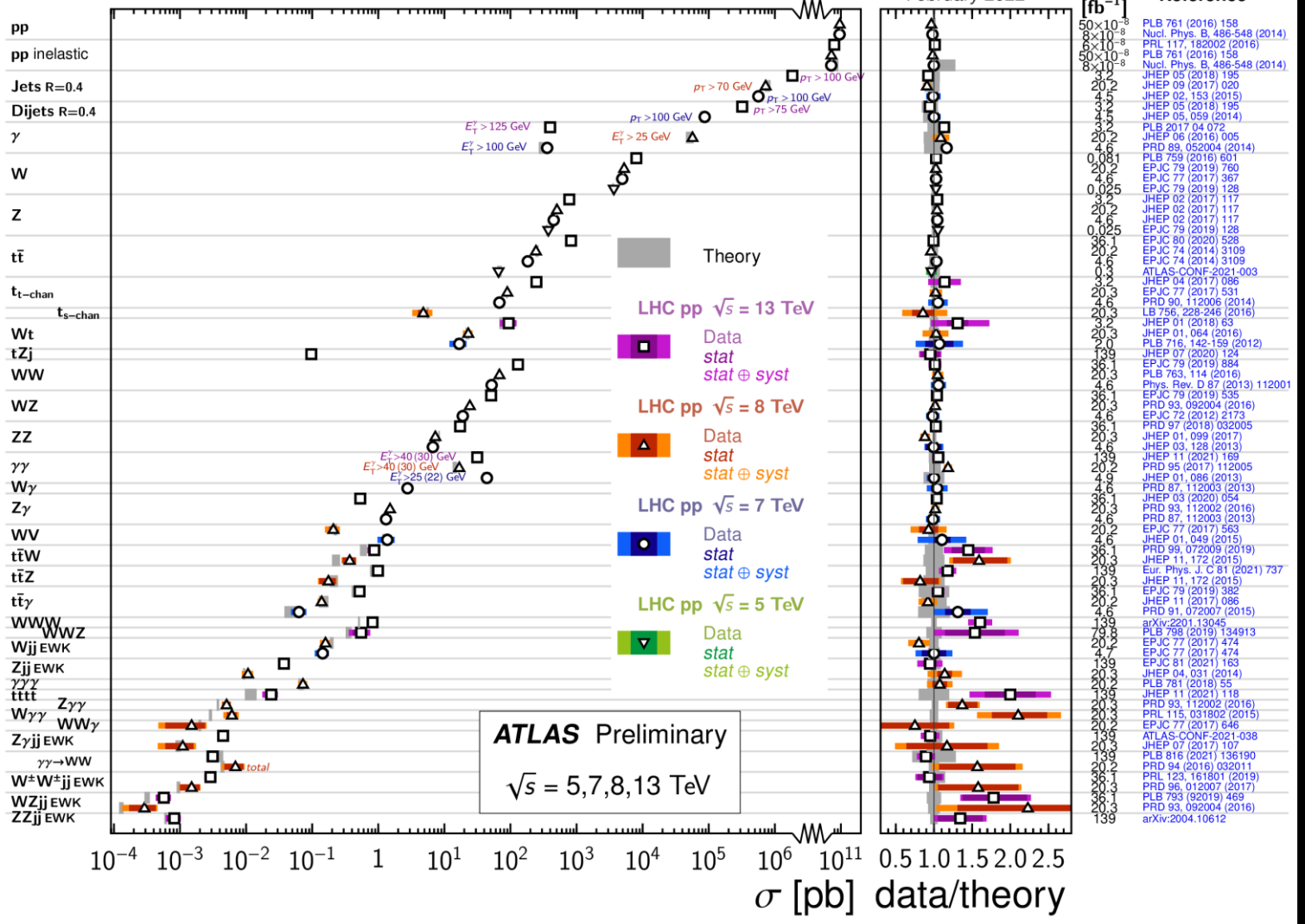
CMS Collaboration • Aram Hayrapetyan (Yerevan Phys. Inst.) et al. (Dec 11, 2023)

Published in: *Phys.Rev.D* 109 (2024) 7, 072004 • e-Print: 2312.08229 [hep-ex]

(Part of) The Solution



The LHC measurement “library”


Standard Model Production Cross Section Measurements
Status: February 2022
pp
pp inelastic
Jets R=0.4
Dijets R=0.4
γ
W
Z
tt̄
t t-chan
t s-chan
Wt
tZj
WW
WZ
ZZ
γγ
Wγ
Zγ
WV
tt̄W
tt̄Z
tt̄γ
WWW
WWZ
Wjj EWK
Zjj EWK
γγγ
tttt
Zγγ
Wγγ
WWγ
Zγjj EWK
γγ→WW
W±W±jj EWK
WZjj EWK
ZZjj EWK
total
Theory
LHC pp √s = 13 TeV
Data
stat
stat ⊕ syst
LHC pp √s = 8 TeV
Data
stat
stat ⊕ syst
LHC pp √s = 7 TeV
Data
stat
stat ⊕ syst
LHC pp √s = 5 TeV
Data
stat
stat ⊕ syst
ATLAS Preliminary
√s = 5,7,8,13 TeV
∫L dt [fb⁻¹]
Reference
σ [pb]
data/theory

Introducing Rivet

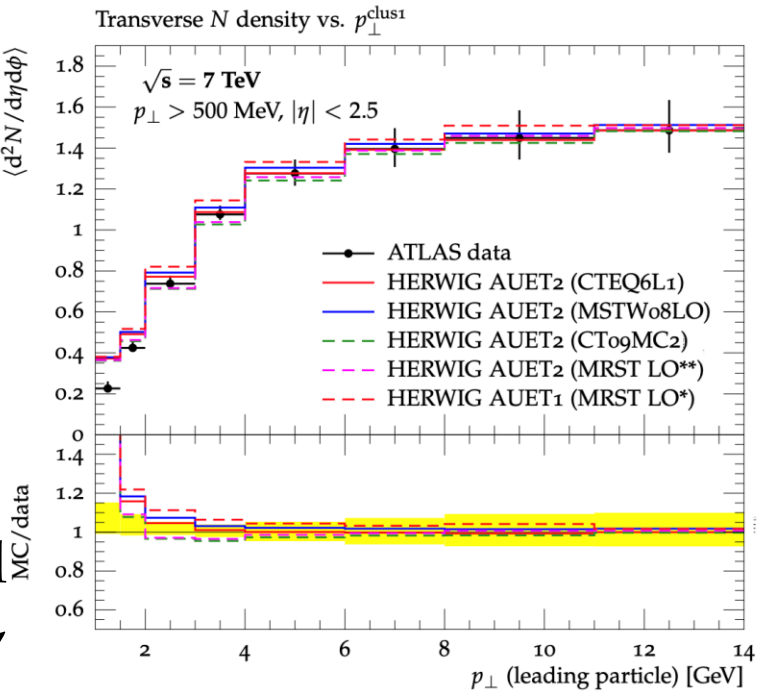
"Robust Independent Validation of Experiment and Theory"

HERA legacy (*1990s, HZTOOL*)

Developed by MCnet for tuning and validation of new MC event generators

- e.g. What does the underlying event look like in 7 TeV pp collisions?

Vast library of measurements of final state particles produced in collisions, and variables derived from them



From ATL-PHYS-PUB-2011-008

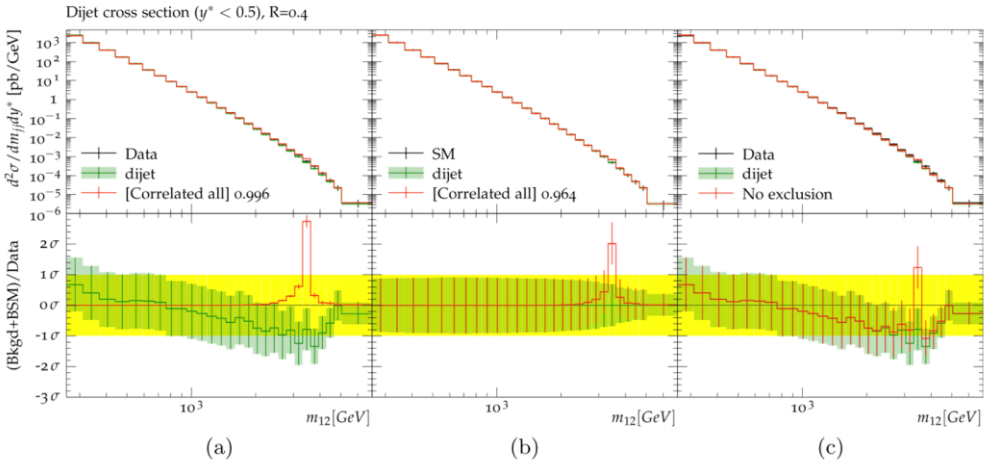
Buckley et al, Bierlich et al arXiv:1003.0694 (CPC), arXiv:1912.05451 (SciPost), arXiv:2404.15984

Introducing Contur

"Constraints On New Theories Using Rivet"

Extend the power of Rivet beyond the Standard Model

Signal-injection of final-state particles from BSM physics events on to measured cross sections in Rivet



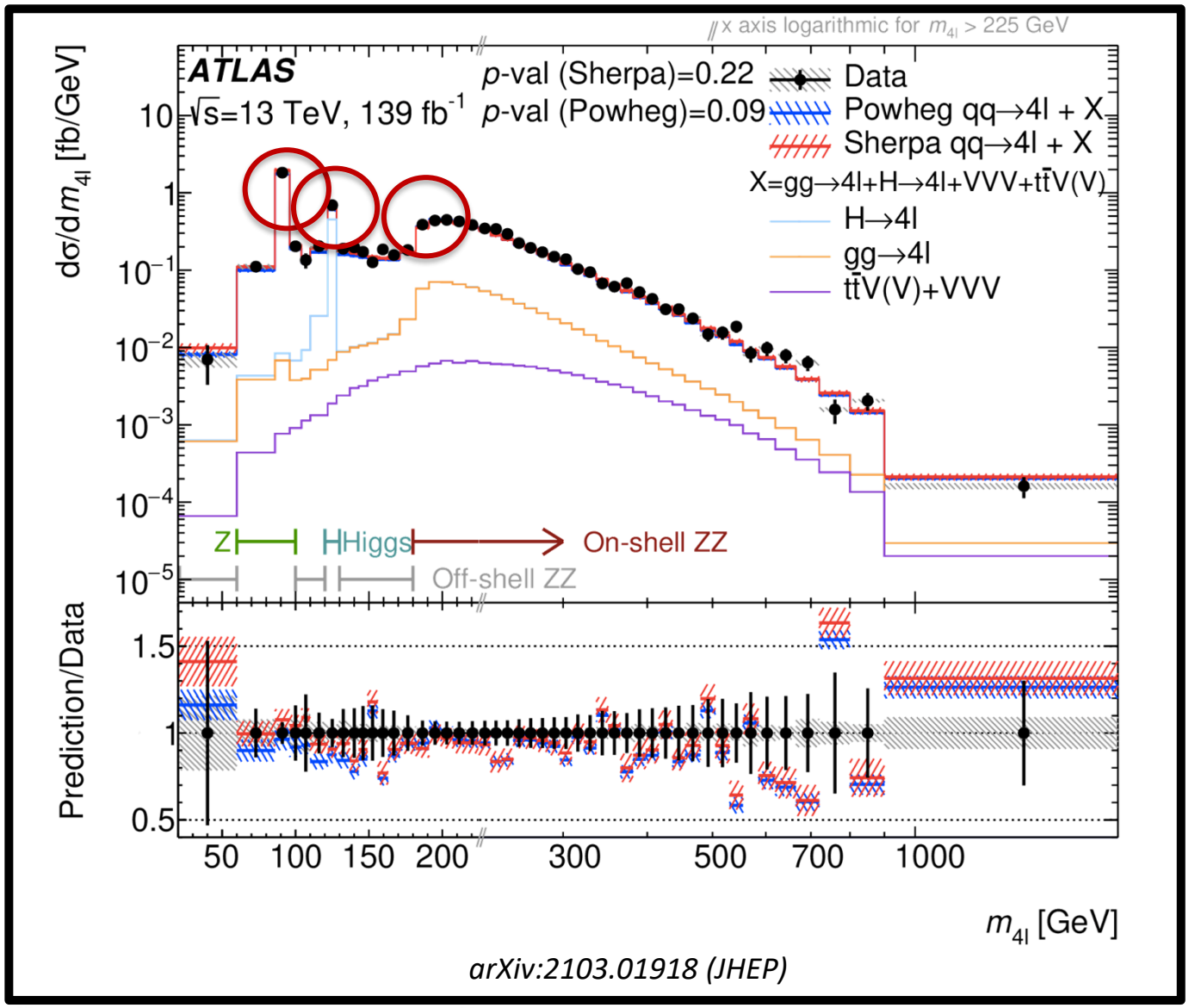
From Altakach, JMB, Ježo, Klasen, Schienbein arXiv:2111.15406 (SciPost Core)

Increasingly precise measurements and SM calculations *together* extend the reach

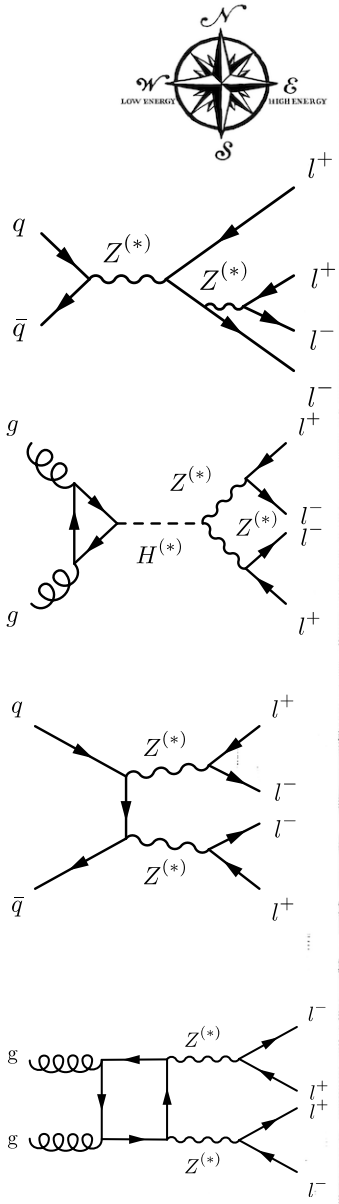
JMB, Grellscheid, Krämer, Sarrazin, Yallup; Buckley et al arXiv:1606.05296 (JHEP), arXiv:2102.04377 (SciPost)

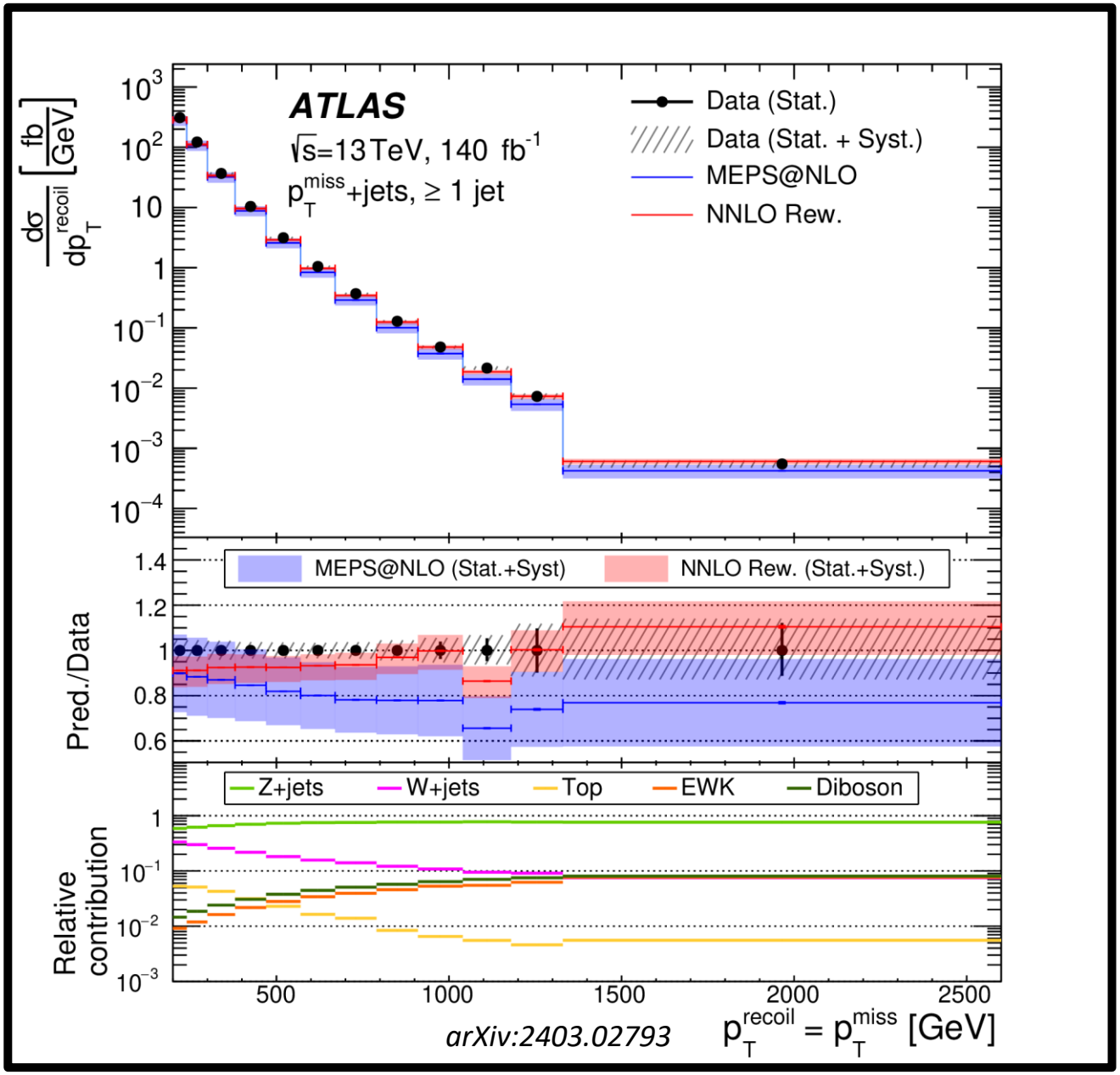
A Contur-friendly measurement

- Is unfolded to particle-level
- Is defined in terms of the final state, not production process
- Has a fiducial phase space which is as inclusive as possible and reflects the actual selection
  - No hidden vetos
  - Minimal extrapolations
- For example:



arXiv:2103.01918 (JHEP)

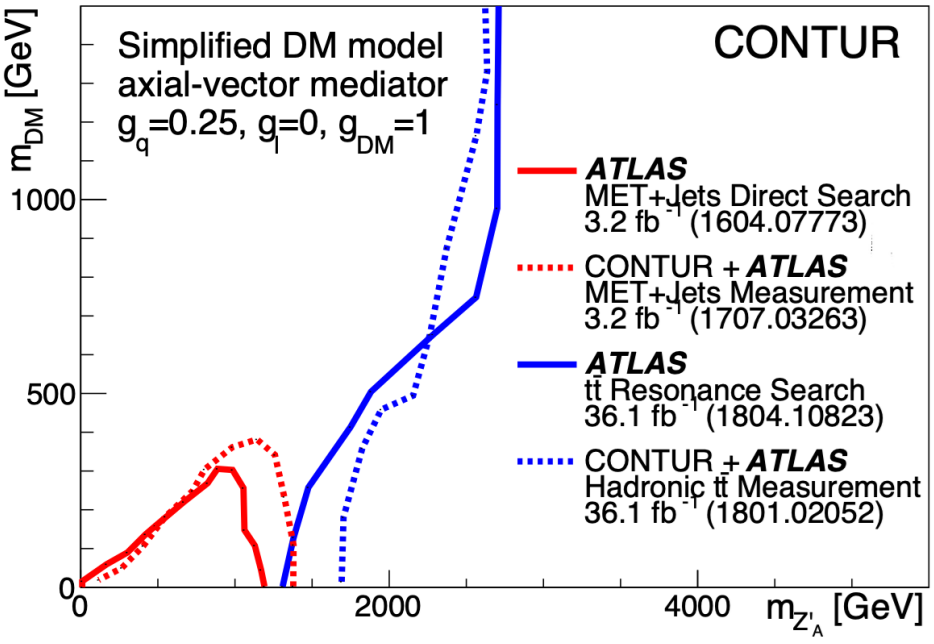



ATLAS
√s=13 TeV, 140 fb-1
pTmiss+jets, ≥ 1 jet
Data (Stat.)
Data (Stat. + Syst.)
MEPS@NLO
NNLO Rew.
dσ/dpTrecoil [fb/GeV]
MEPS@NLO (Stat.+Syst)
NNLO Rew. (Stat.+Syst.)
Pred./Data
Z+jets
W+jets
Top
EWK
Diboson
Relative contribution
arXiv:2403.02793
pTrecoil = pTmiss [GeV]

Unleashing the power of high luminosity LHC data

(selected example case studies)

- Composite Dark Matter
- Dark Matter from Anomaly Cancellation
- Vector-like Quarks



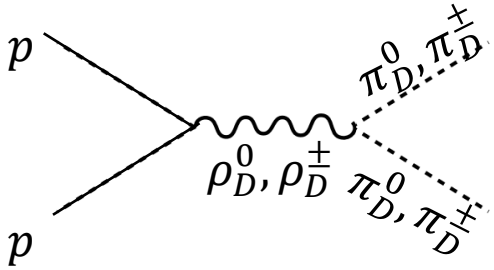
Louie Corpe

Composite Dark Matter Models

- What if Dark Matter is a composite particle arising from e.g. an SU(4) symmetry which confines at some scale Λ_{dark}?
- Leads to bound states ”dark” mesons and baryons.
  - Kribs et al. arXiv:1809.10183 (JHEP)
- Dark fermions transform under electroweak part of the Standard Model: communication with SM
- Dynamics of the theory depend on $\eta = m(\pi_D)/m(\rho_D)$
  - $\eta > 0.5$, ρ_D decays to SM fermions → resonant Drell Yan searches (also in Contur)
  - $\eta < 0.5$, ρ_D decays to π_D → many different decays to SM particles, depending on mass. No searches*, look at the measurements in Contur

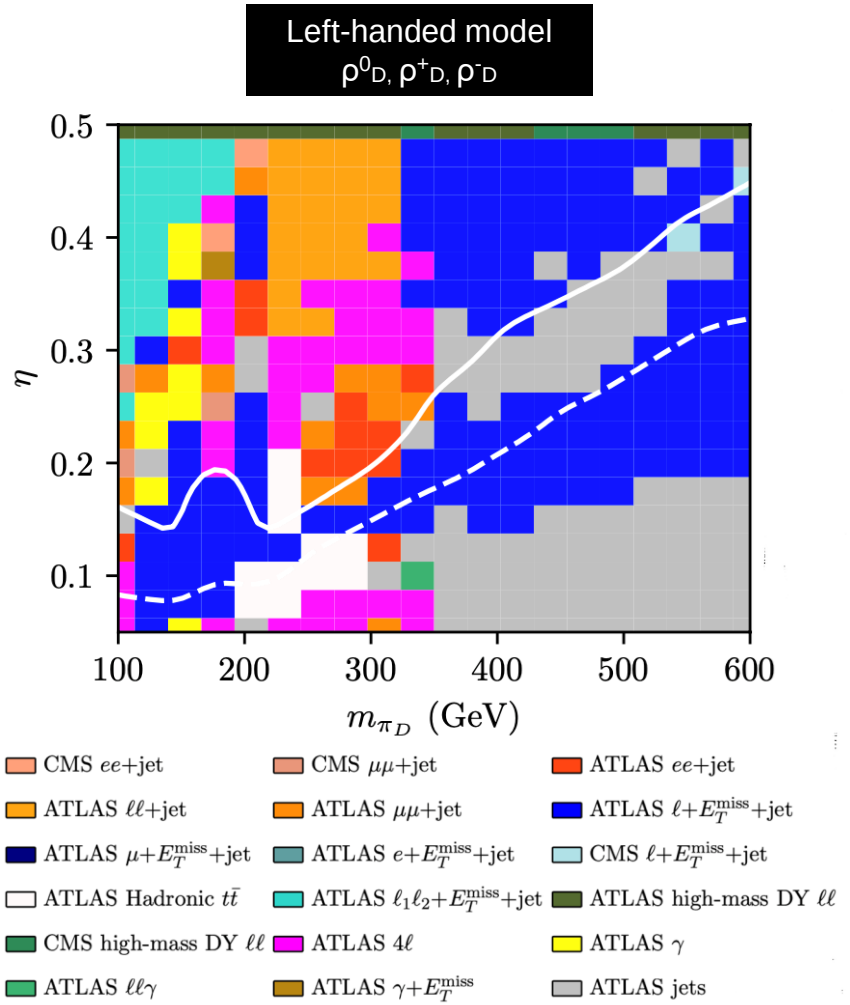
JMB, Corpe, Kong, Kulkarni, Thomas. arXiv:2105.08494 (PRD)

Composite Dark Matter Models



Large areas excluded:

- When pion mass is close to Higgs mass, H→γγ analysis contributes
- Boosted hadron "top" measurements contribute when pion mass ~200 GeV: Pions decay to tb and are boosted from heavy ρ.
- Other sensitivity from Z-pole dileptons, and lepton+missing energy (Z, top, W production in decay chains)

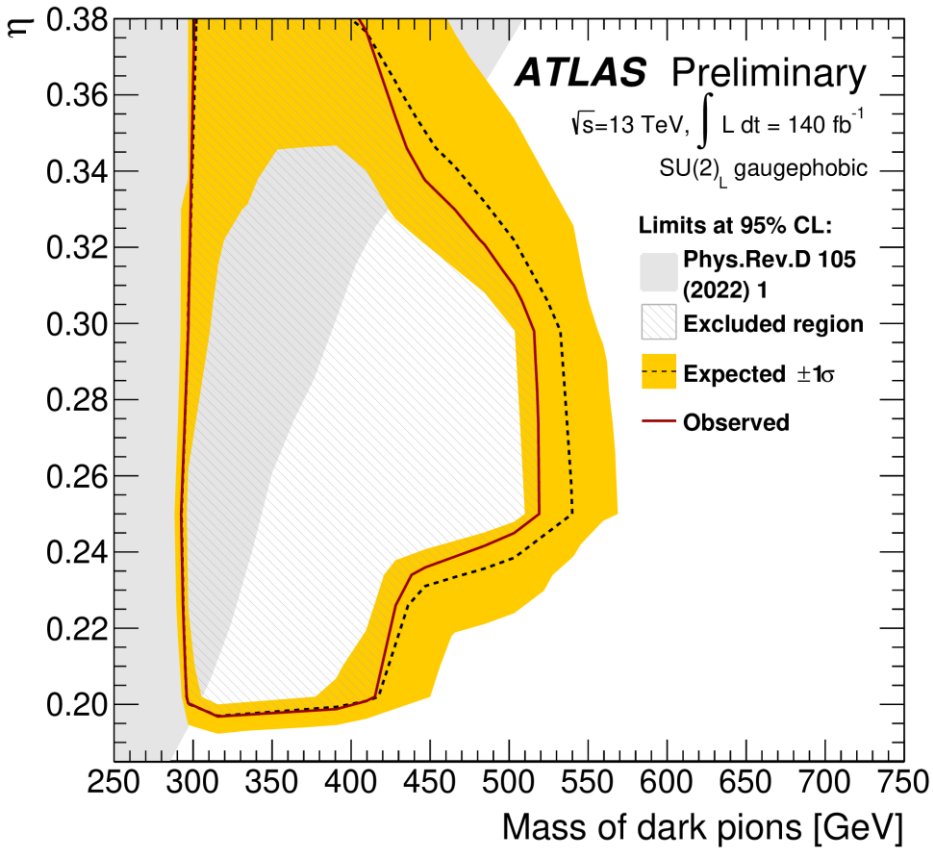


JMB, Corpe, Kong, Kulkarni, Thomas. arXiv:2105.08494 (PRD)

Composite Dark Matter Models

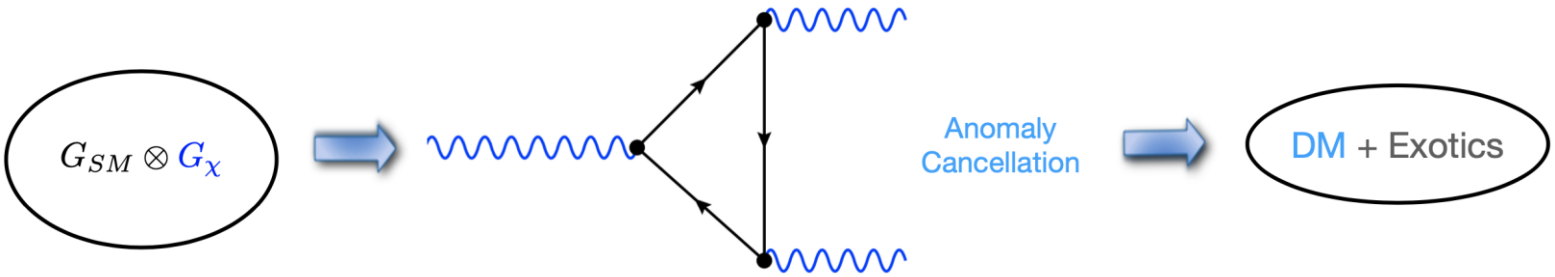
* Dedicated ATLAS search for same model:

- Focused on top and bottom final states
- Extends the region already excluded by measurements, but doesn't (so far) cover it all



ATLAS-CONF-2023-021

Dark Matter from Anomaly Cancellation



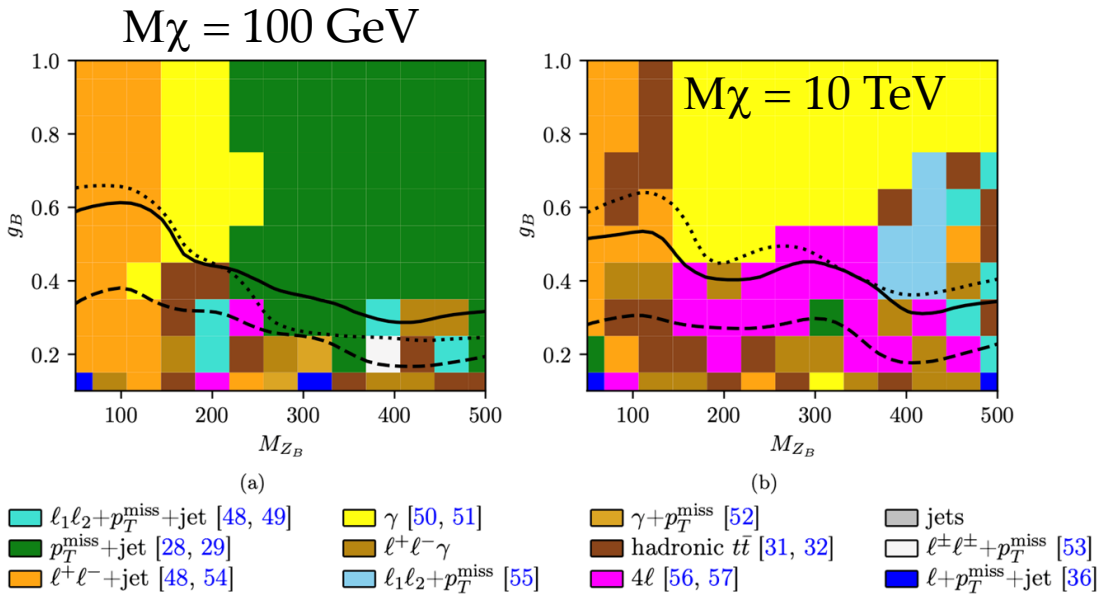


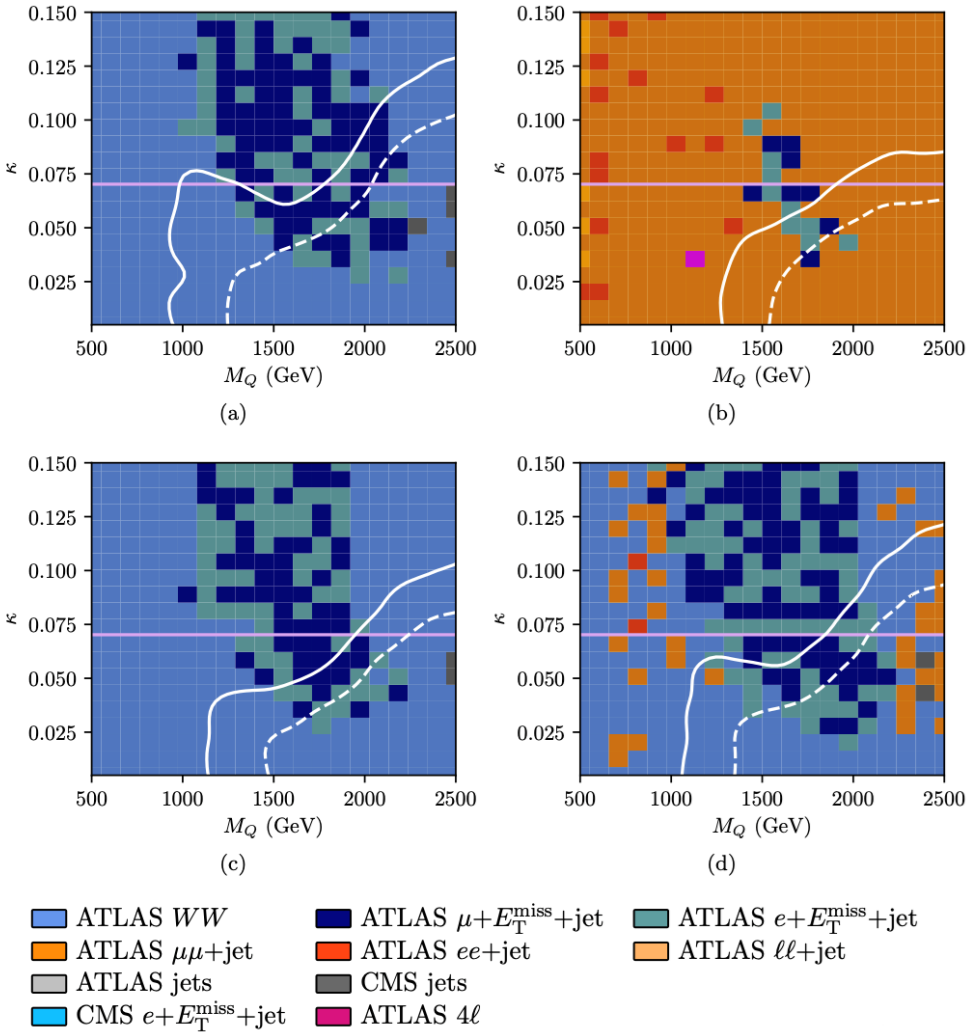
FIG. 6: (a) Results from CONTUR, as in Fig. 5b, but now zooming in on the low M_{Z_B} region. (b) as in (a), but now with $M_\chi = 10$ TeV. Citations are for the most significant measurements giving an exclusion significance of 68% or above anywhere in the plain.

Mass of DM candidate switches on/off $Z_B \rightarrow \chi\chi$
And changes other branchings

JMB, H. Debnath, P. Fileviez Perez, Y. Yeh, axrXiv:2405.03749

Vector-like Quarks

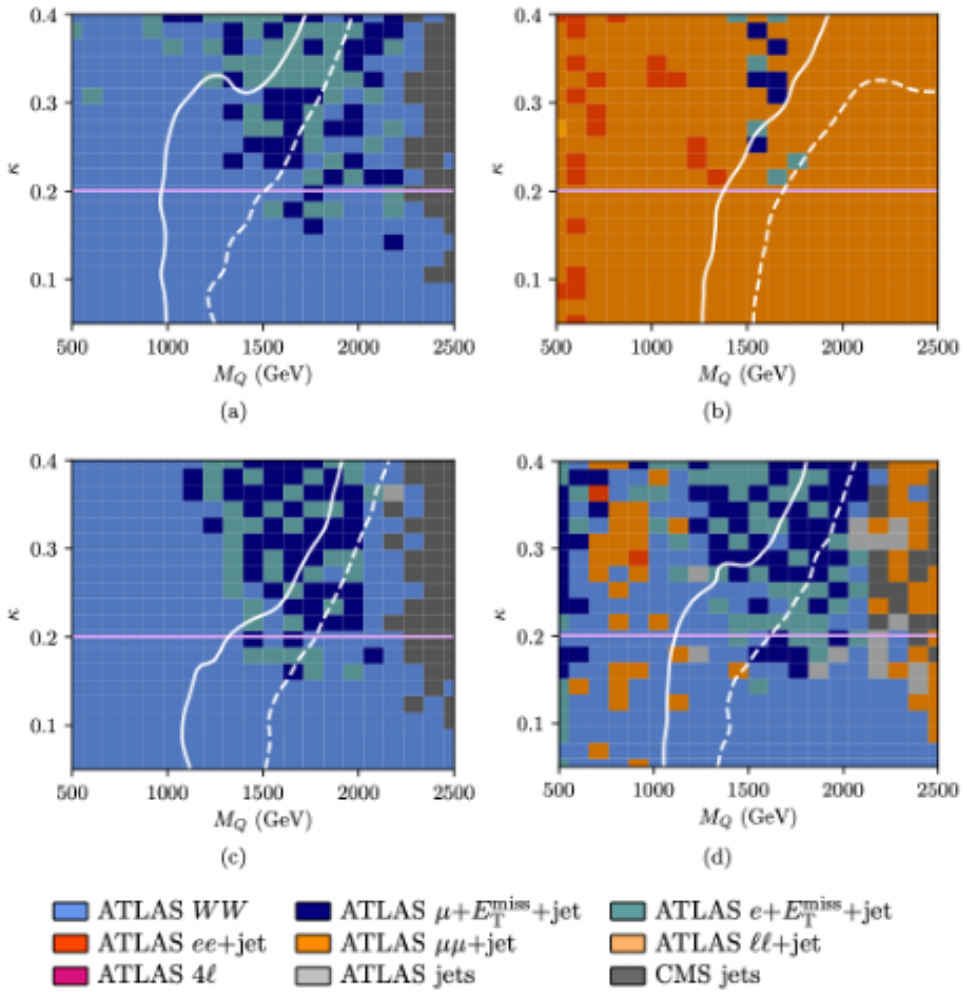
- Experimental searches of have focusses on couplings ot 3rd generation
- Coupling to 1st generation.
- Region above line excluded by non-collider constraints
- No LHC search analyses exist
- Measurements exclude most of the plane.
- Single VLQ production very important at highest masses



Buckley, JMB, Corpe, Huang, Sun arXiv:2006.07172

Vector-like Quarks

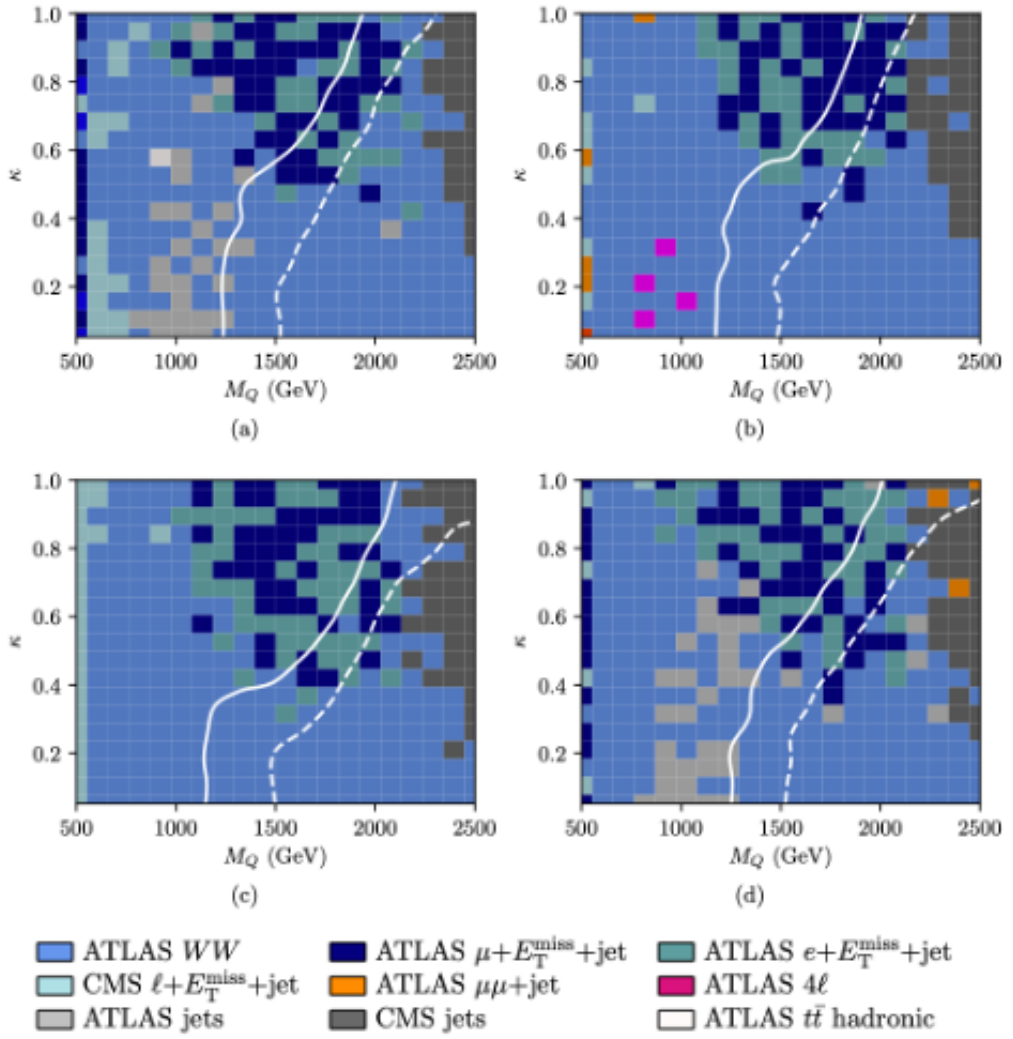
- Coupling to 2nd generation.
- Region above line excluded by non-collider constraints
- No LHC search analyses exist
- Measurements exclude significant part of the plane.
- Single VLQ production again very important at highest masses



Buckley, JMB, Corpe, Huang, Sun arXiv:2006.07172

Vector-like Quarks

- Coupling to 3rd generation.
- No exclusion from non-collider, but there are several LHC searches
- Measurements also exclude significant part of the plane.
- Single VLQ production still significant at highest masses



Buckley, JMB, Corpe, Huang, Sun arXiv:2006.07172

Vector-like Quarks

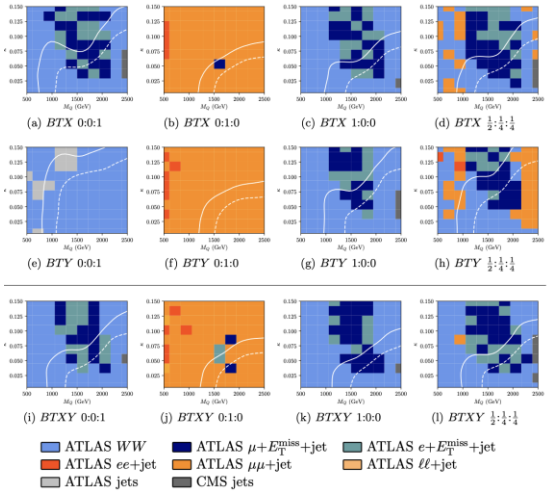
- During journal review, it was pointed out that we'd missed some of the most compelling scenarios, and should instead consider:
  - B, T singlets
  - BT, XT, TY doublets
  - BYX, BTY triplets
- … for each generational coupling scenario and for four different decay branching benchmarks to W, Z, H.
- i.e. 7 x 3 x 4 two dimensional parameter scans
- Hmm. A challenge for Contur?

Buckley, JMB, Corpe, Huang, Sun arXiv:2006.07172

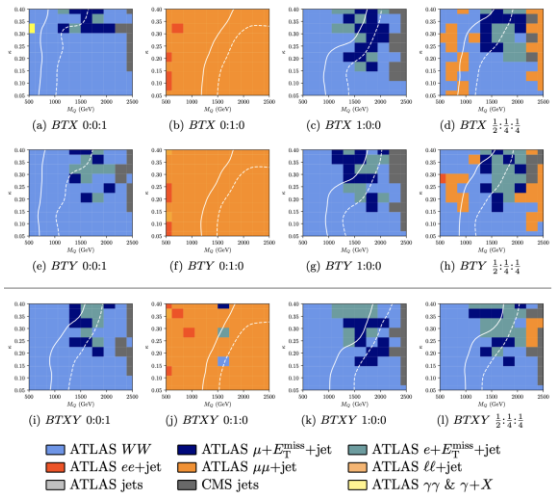
Vector-like Quarks

Vector-like Quarks

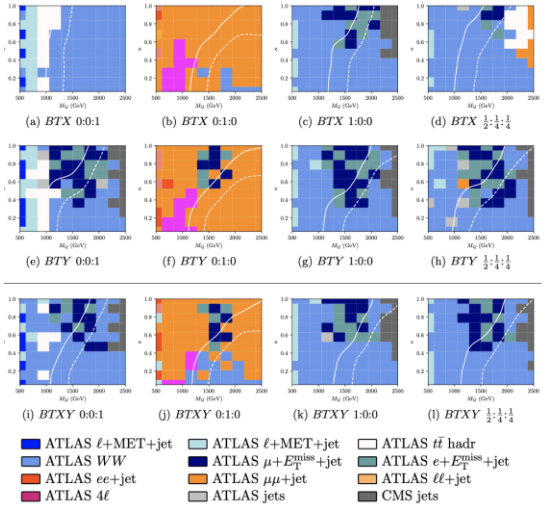
1st Generation



2nd Generation



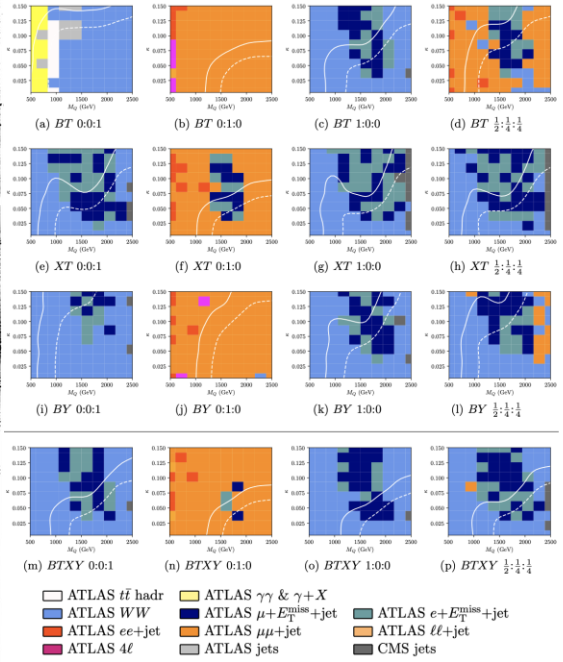
3rd Generation



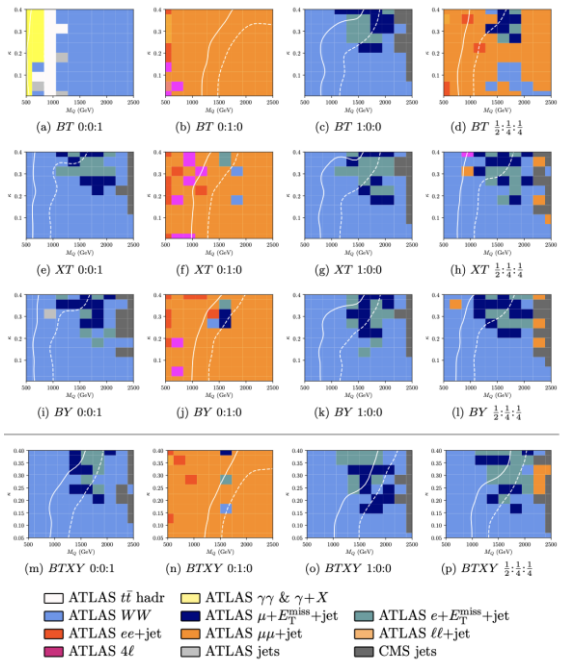
Buckley, JMB, Corpe, Huang, Sun arXiv:2006.07172

Vector-like Quarks

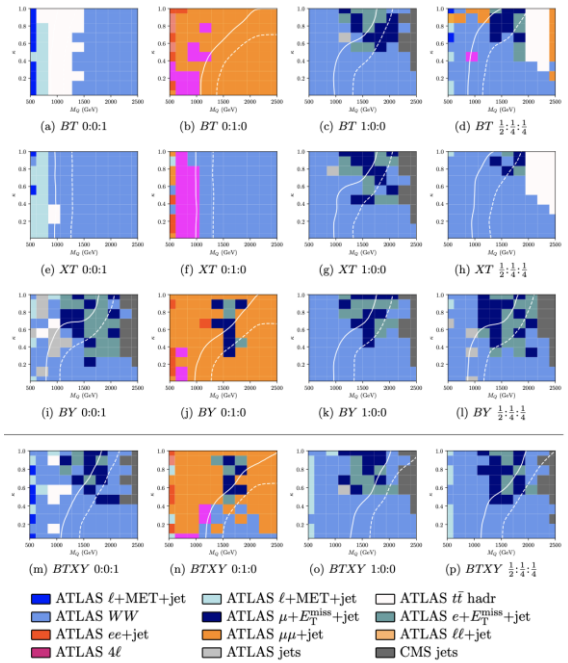
1st Generation



2nd Generation



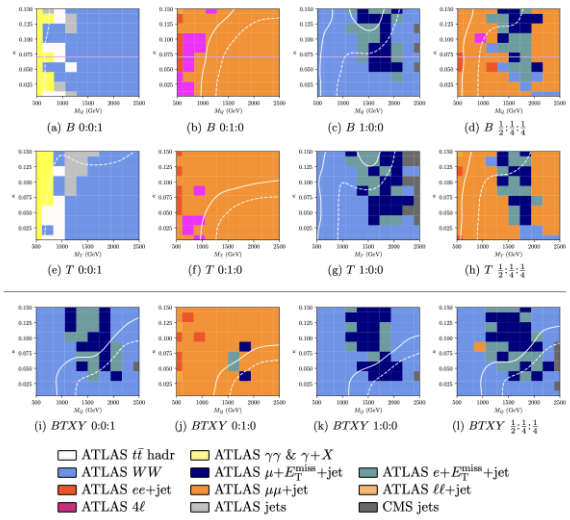
3rd Generation



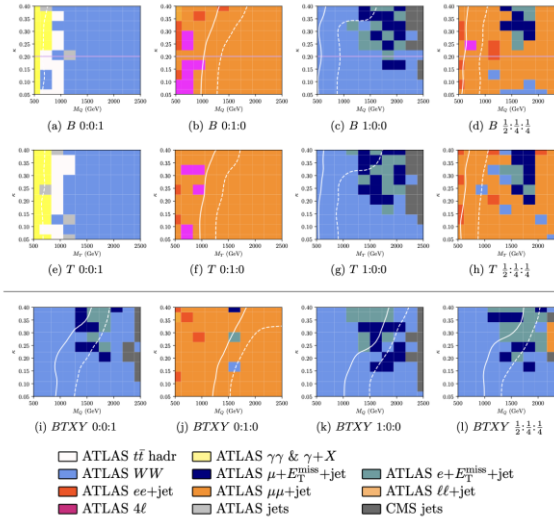
Buckley, JMB, Corpe, Huang, Sun arXiv:2006.07172

Vector-like Quarks

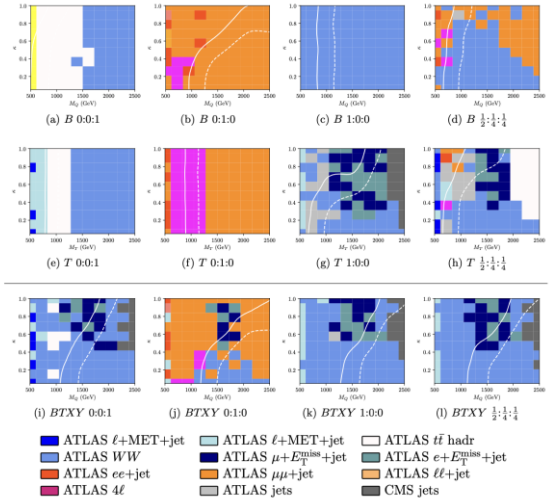
1st Generation



2nd Generation



3rd Generation



Buckley, JMB, Corpe, Huang, Sun arXiv:2006.07172

GAMBIT Interface

TTP23-009, KCL-PH-TH/2023-21, gambit-physics-23, MCnet-23-05, ADP-23-08/T1217, CERN-TH-2023-043

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Received: date / Accepted: date

Abstract Using the GAMBIT global fitting framework, we constrain the MSSM with an eV-scale gravitino as the lightest supersymmetric particle, and the six electroweakinos (neutralinos and charginos) as the only other light new states. We combine 15 ATLAS and 12 CMS searches at 13 TeV, along with a large collection of ATLAS and CMS measurements of Standard Model signatures. This model, which we refer to as the $\tilde{G}$-EWMSSM, exhibits quite varied collider phenomenology due to its many permitted electroweakino production processes and decay modes. Characteristic $\tilde{G}$-EWMSSM signal events have two or more Standard Model bosons and missing energy due to the escaping gravitinos. While much of the $\tilde{G}$-EWMSSM parameter space is excluded, we find several viable parameter regions that predict phenomenologically rich scenarios with multiple neutralinos and charginos within the kinematic reach of the LHC during Run 3, or the High Luminosity LHC. In particular, we identify scenarios with Higgsino-dominated electroweakinos as light as 140 GeV that are consistent with our combined set of collider searches and measurements. The full set of $\tilde{G}$-EWMSSM parameter samples and GAMBIT input files generated for this work is available via Zenodo.

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[b] anders.kvellestad@fys.uio.no

Contents

1 Introduction 2
2 Model 3
3 Collider likelihoods 5
3.1 LHC searches 5

Contur Software

- Written in Python: https://gitlab.com/hepcedar/contur
- Heavy use of python interface to Rivet, Yoda, and of matplotlib, scipy, numpy and more (including pyslha)
- Rivet, Yoda mainly C++ (all on gitlab)
- Can steer event generators (currently Herwig, Madgraph, Pythia) but can also be run on any existing Rivet (Yoda) output (and Rivet can run on any HepMC events)
- Can also be invoked from inside the Madgraph command-line environment (along with Rivet)
- Nascent GUI and ML add-ons