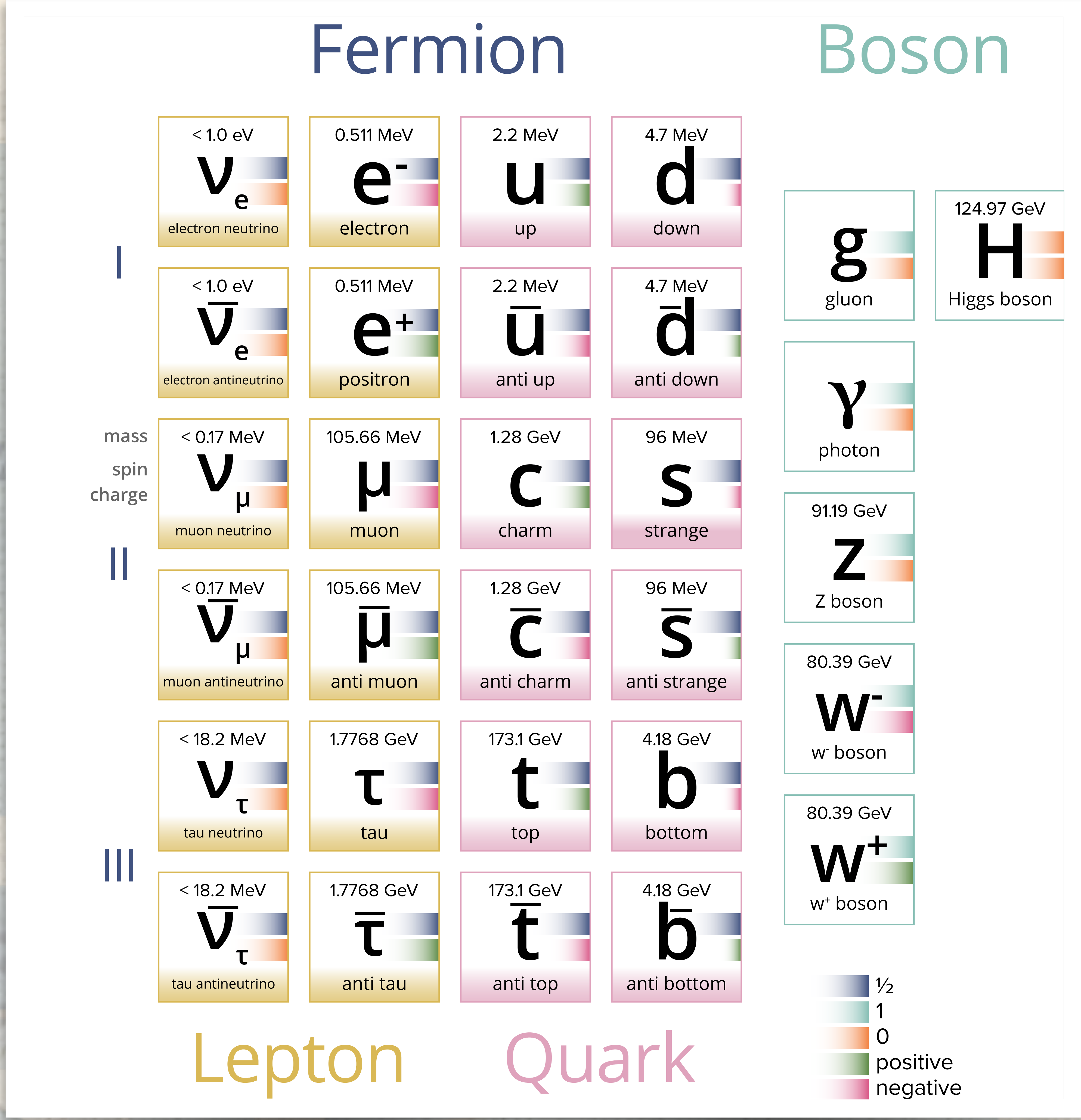
RECENT SEARCHES FOR NEW PHENOMENA WITH THE ATLAS DETECTOR

Ana M. Rodriguez Vera, ON BEHALF OF THE ATLAS COLLABORATION

ATLAS EXPERIMENT

JULY 2023 - ICNFP2023

YORK UNIVERSITÉ UNIVERSITY



Neutrino masses?

Fine-tuning of the Higgs Boson mass?

Pattern of masses?

Origin of dark matter?

Mixing angles in the quark and lepton sectors?

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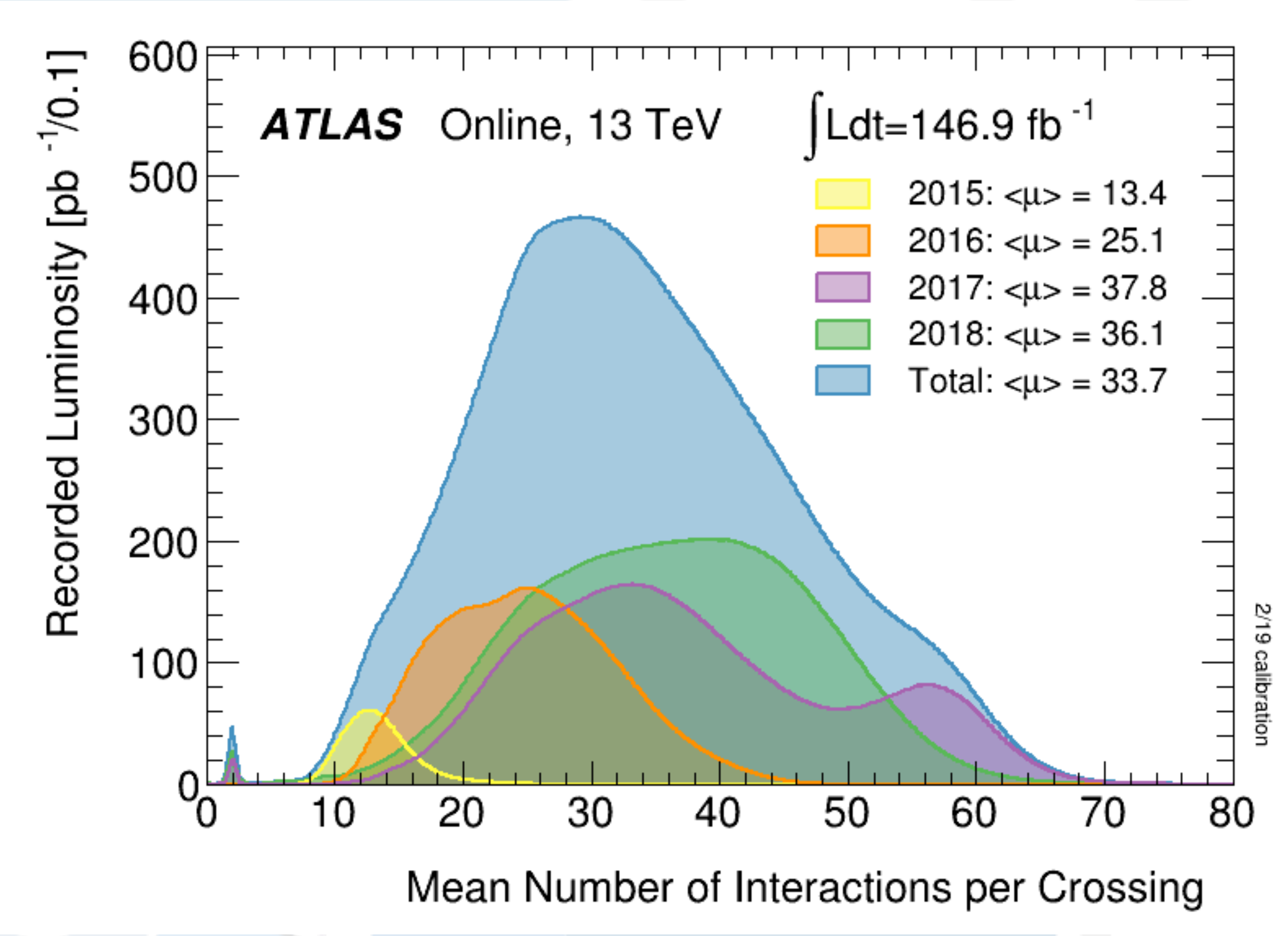
Many BSM extensions predict new particles or interactions directly **accessible at the LHC**



- Leptoquarks and vector-like quarks
- New high mass resonances and lepton flavour-violating decays
- Dark matter searches in final states with large missing transverse momentum
- Dark-sector

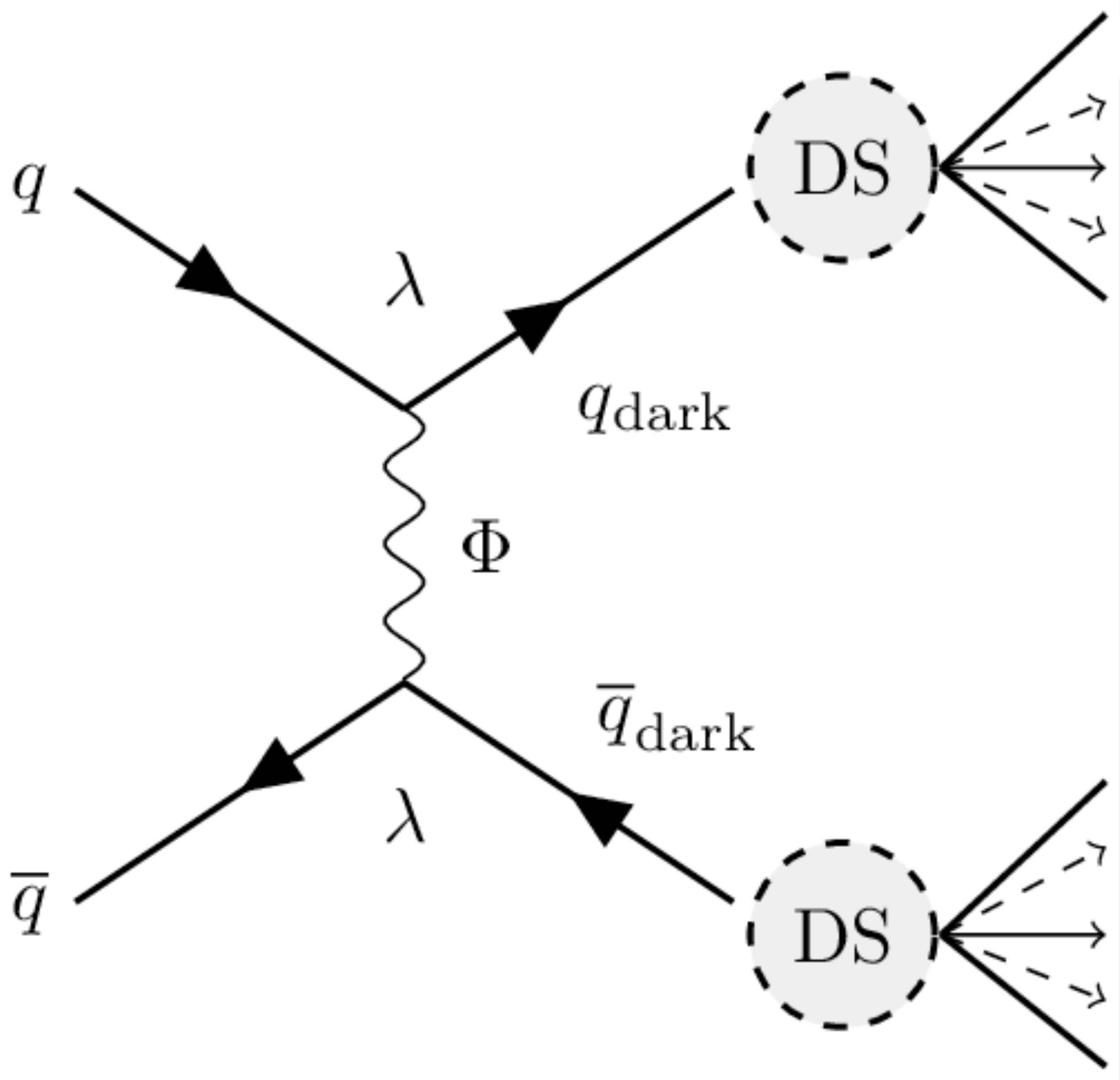
NON-RESONANT PRODUCTION OF SEMI-VISIBLE JETS

MAJORANA NEUTRINOS IN SAME-SIGN WW SCATTERING EVENTS

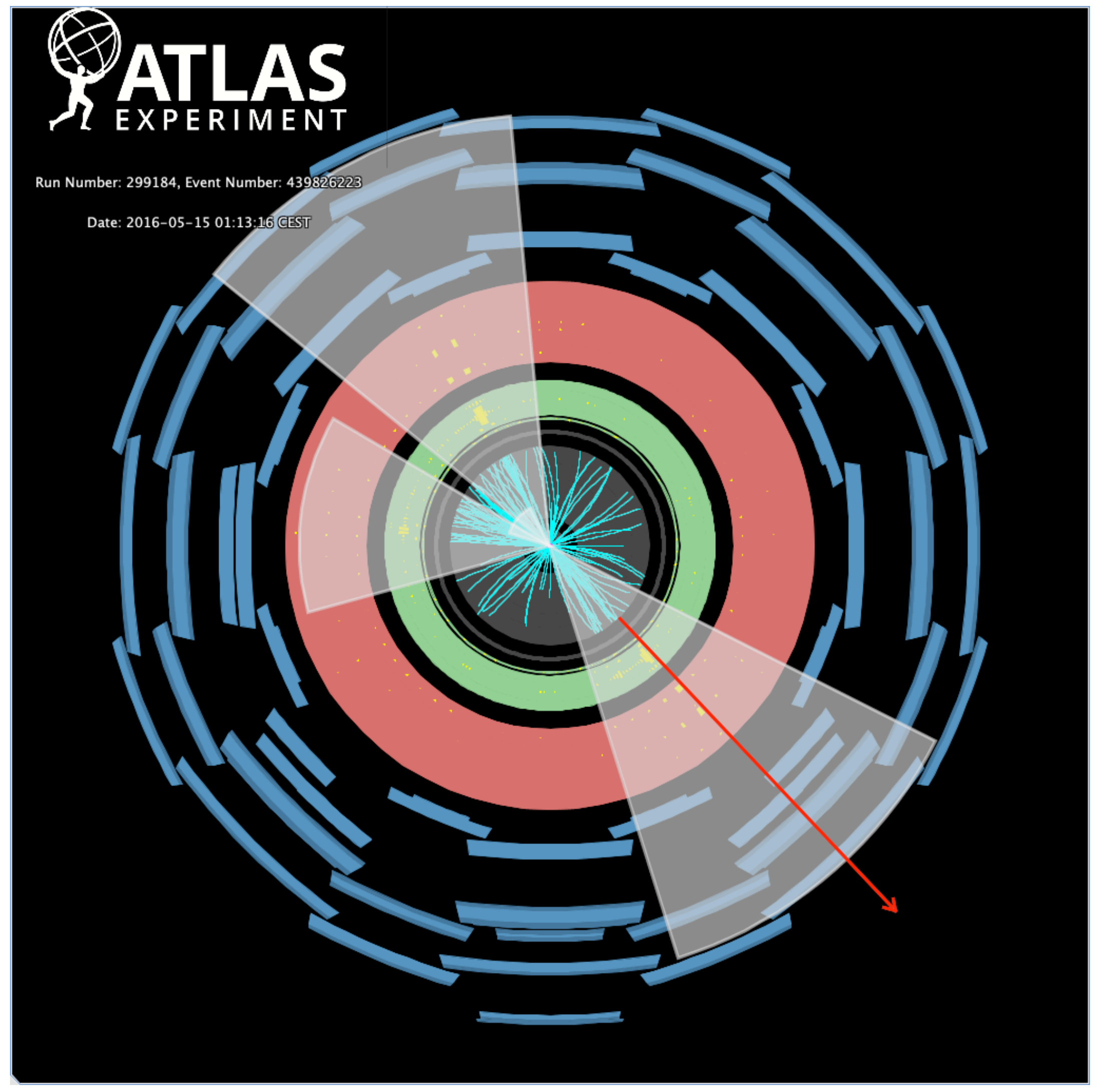
ANOMALY DETECTION

NON-RESONANT PRODUCTION OF SEMI-VISIBLE JETS

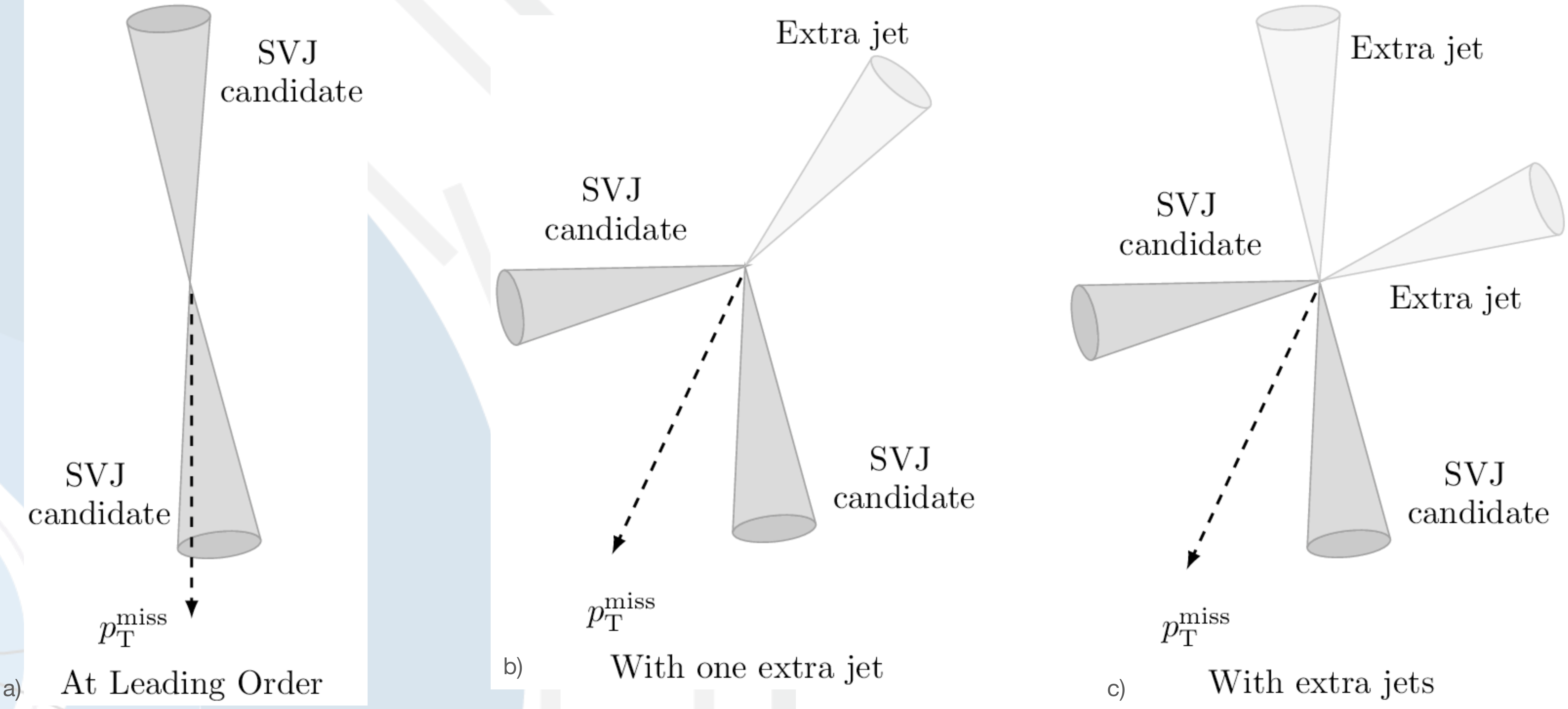
What happens if dark-matter particles are produced inside a jet of Standard-Model particles?



- Semi-visible jets (SVJ), with a significant contribution to the event's **missing pT**, can arise in **strongly interacting dark sectors**
- This results in an event topology where one of the **jets can be aligned** with the direction of the **missing pT**
- Search for semi-visible jets produced via a t-channel **mediator exchange Φ**
- Unknown **coupling λ**



Event display



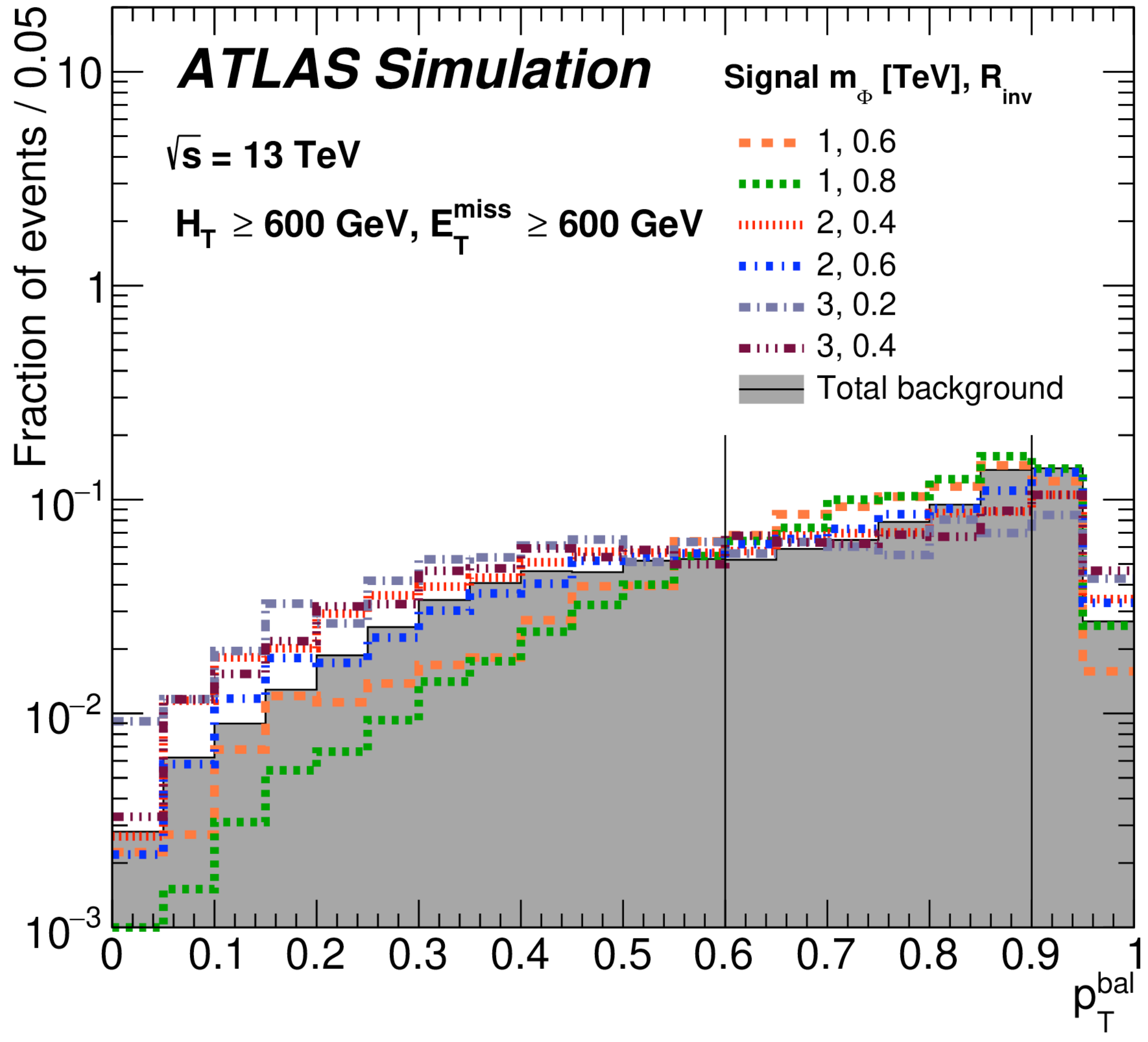
Illustrative sketches of signal event topology, It should be noted that the length of the cones do not represent the visible energy of the particles and that invisible energies are expected in the directions of the two SVJ candidates.

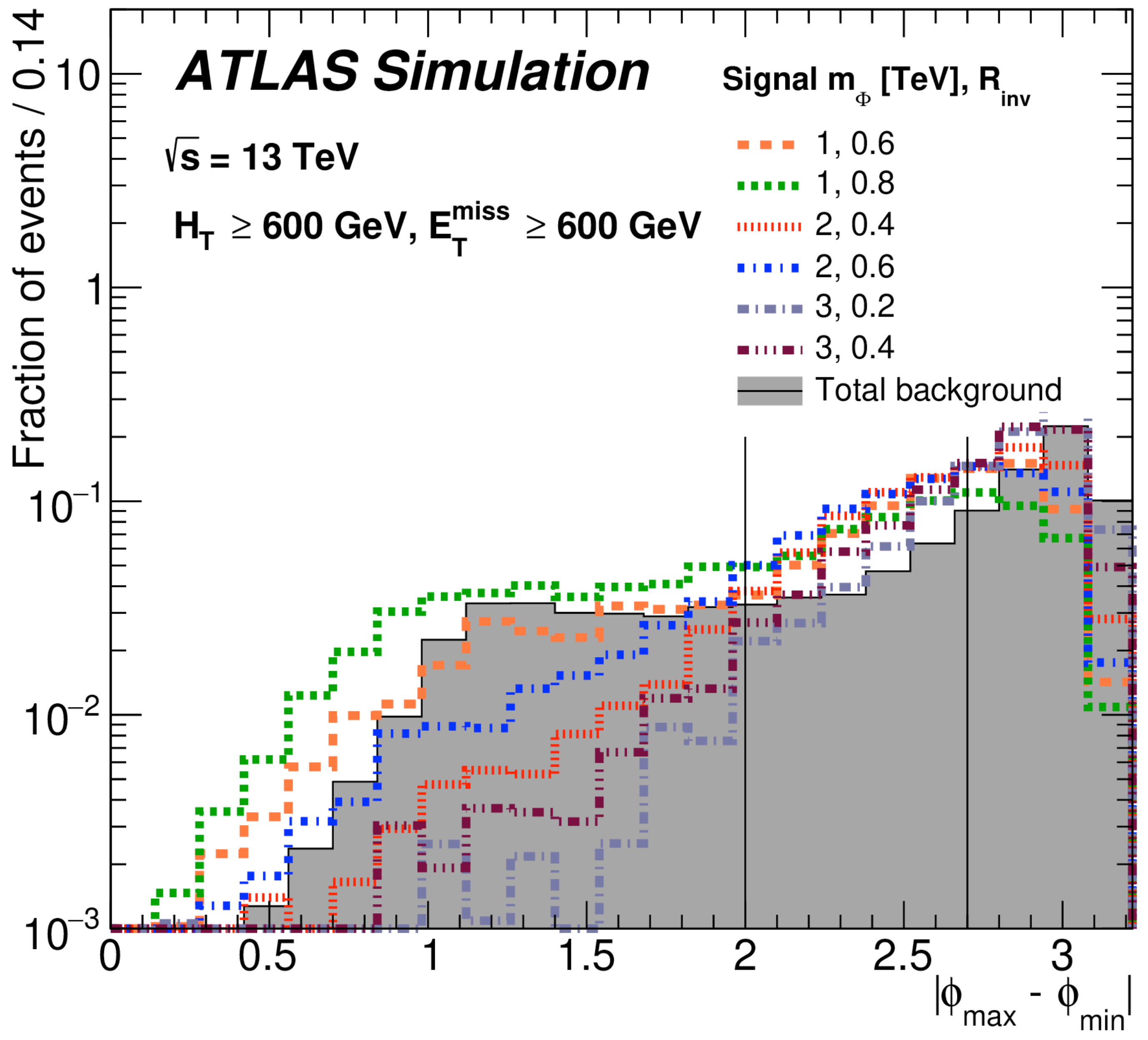
Parameters for the search:

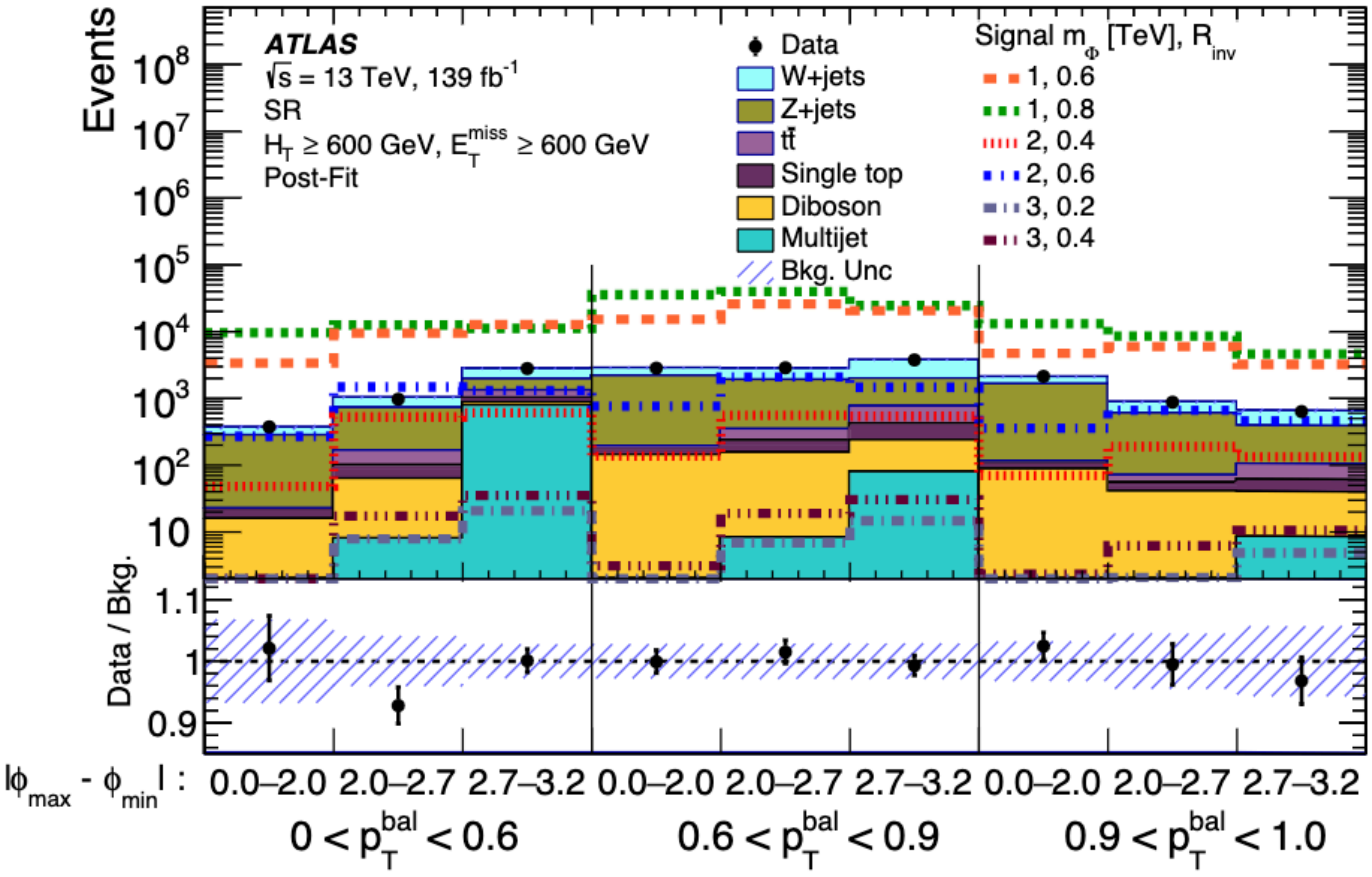
- R_{inv} fraction of stable dark hadrons among all dark hadrons in the event
  - SVJ: intermediate values, resulting in jets geometrically encompassing dark hadrons

- Mediator mass Φ takes values between 1 and 5 TeV
- Unknown **coupling λ**

- SR: $E_T^{miss} > 600$ GeV and $H_T > 600$ GeV,
  - where H_T is the scalar sum of the p_T of jets in the event
- To **estimate the background** two (largely uncorrelated) variables are used
  - pT balance $p_T^{bal} = \frac{|\vec{p}_T(j_1) + \vec{p}_T(j_2)|}{|\vec{p}_T(j_1)| + |\vec{p}_T(j_2)|}$
  - azimuthal separation between jets $|\phi_{max} - \phi_{min}|$
- **Nine bins** are defined as parameters for the background fit



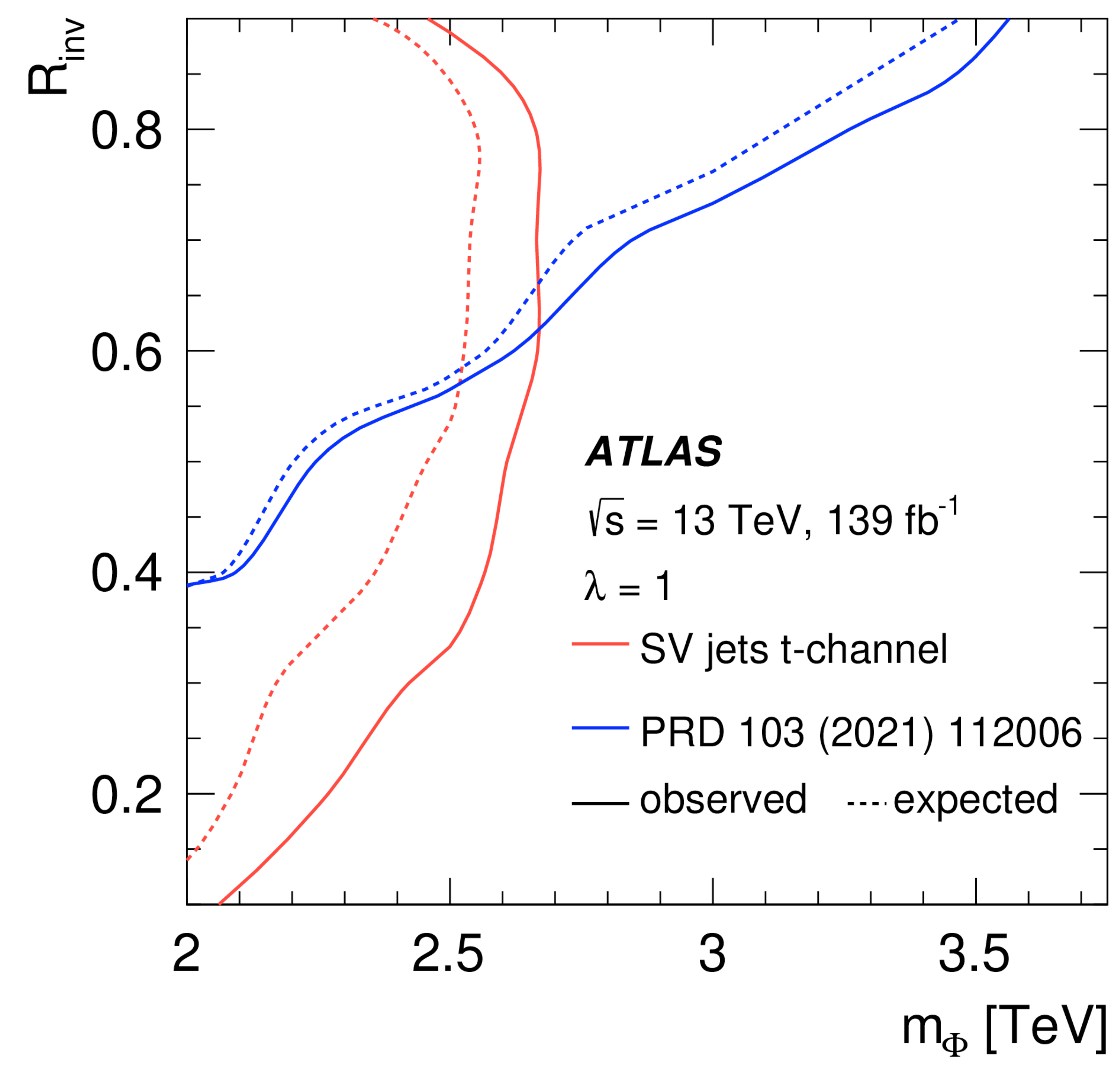


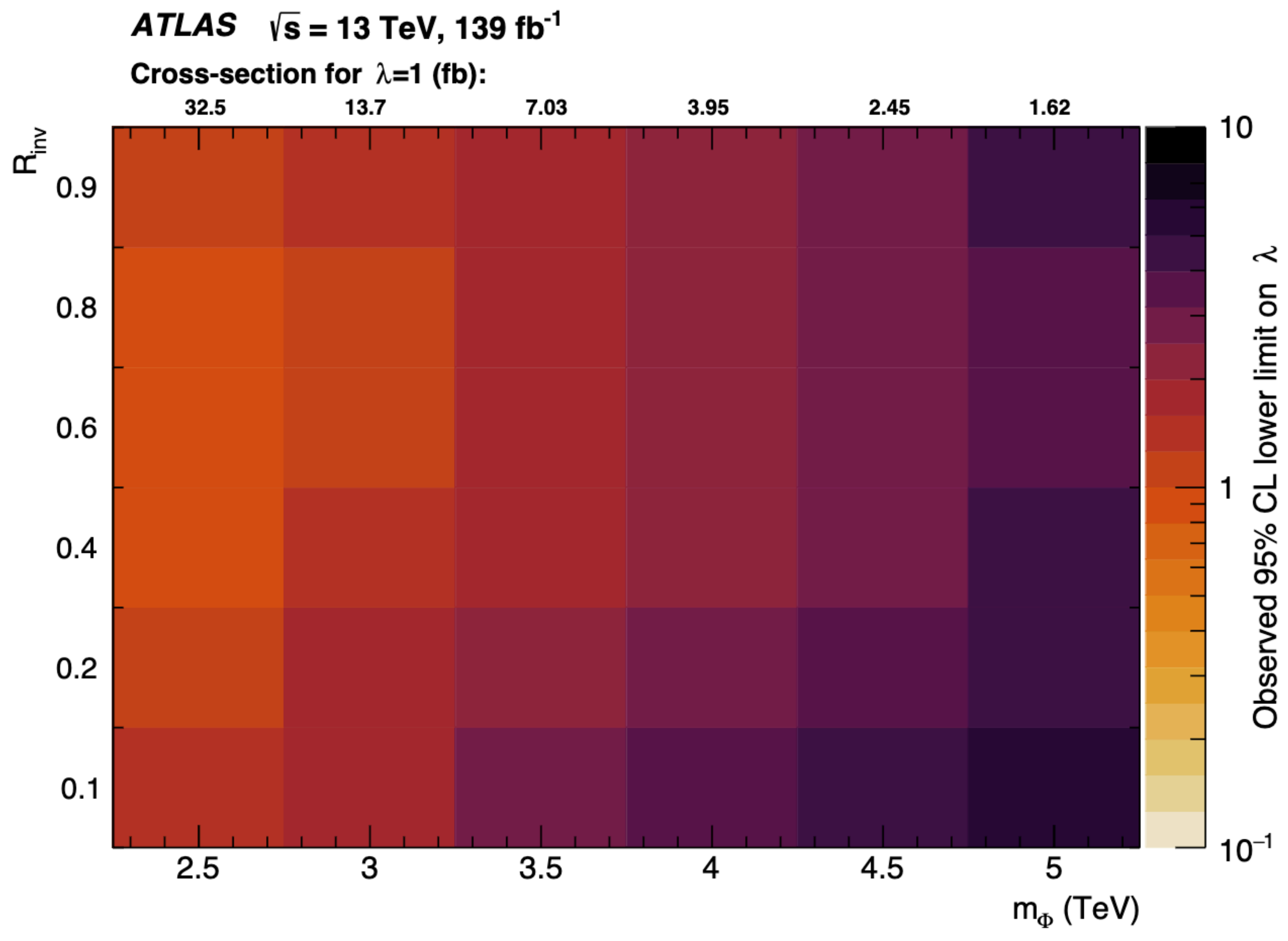


Post fit yields in the SR for all 9 bins

- Post fit, great agreement between background contributions and data
- No excess observed

NON-RESONANT PRODUCTION OF SEMI-VISIBLE JETS



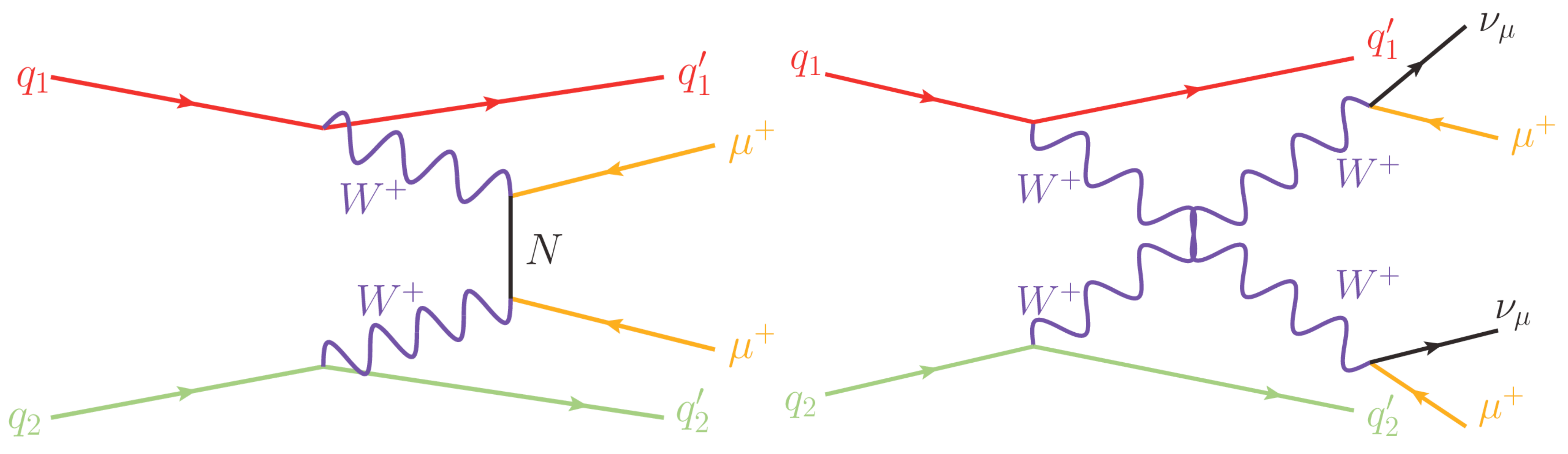


- First search for SVJ
- First limits on this specific semi-visible-jet production scenario
- Excludes mediator masses up to 2.7 TeV.
- The search is **more sensitive at intermediate values** of the invisible fraction $\mathbf{R_{inv}}$
- Limits on the coupling strength of the mediator scalar between the SM and the DS

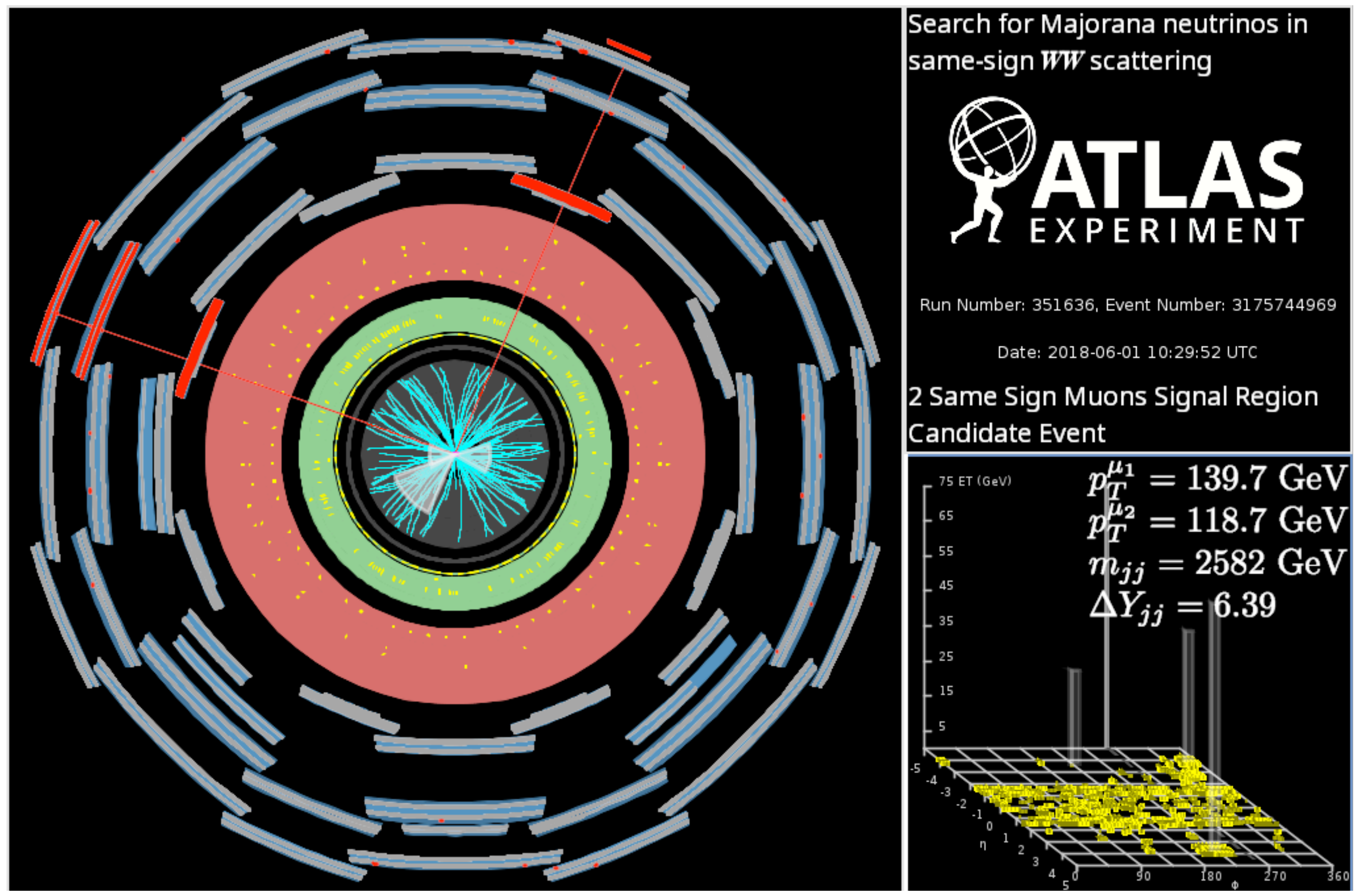
MAJORANA NEUTRINOS IN SAME-SIGN WW SCATTERING EVENTS

- Final states including exactly **two same-sign muons** and at least **two hadronic jets**, well separated in rapidity.
- Benchmark models:
  - Phenomenological Type-I Seesaw model
  - $d = 5$ Weinberg operator model
- Main backgrounds:
  - SM same-sign WW scattering WZ production, is constrained with data in dedicated signal-depleted control regions.
- METHOD: **Distribution of the p_T** of the second-hardest muon is used to search for signals originating from a heavy Majorana neutrino (50 GeV < m < 20 TeV).

https://arxiv.org/abs/2305.14931



Diagrammatic representation of (left) same-sign μ±μ± production in W±W± scattering mediated by a Majorana neutrino N in proton--proton collisions and (right) electroweak same-sign W±W± scattering, which is the main background in this search.



Visualization of one of the candidate events in the signal region.

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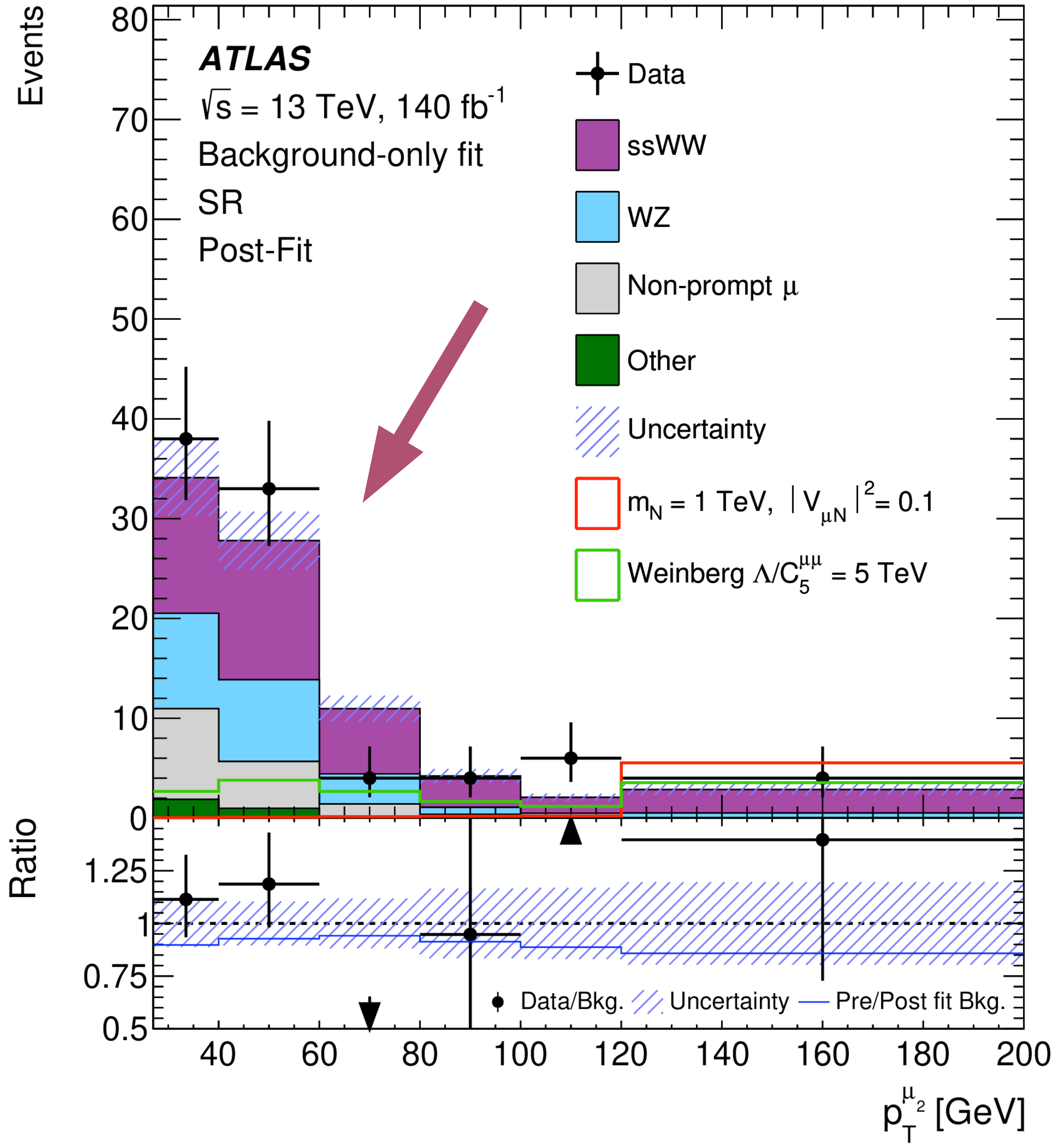
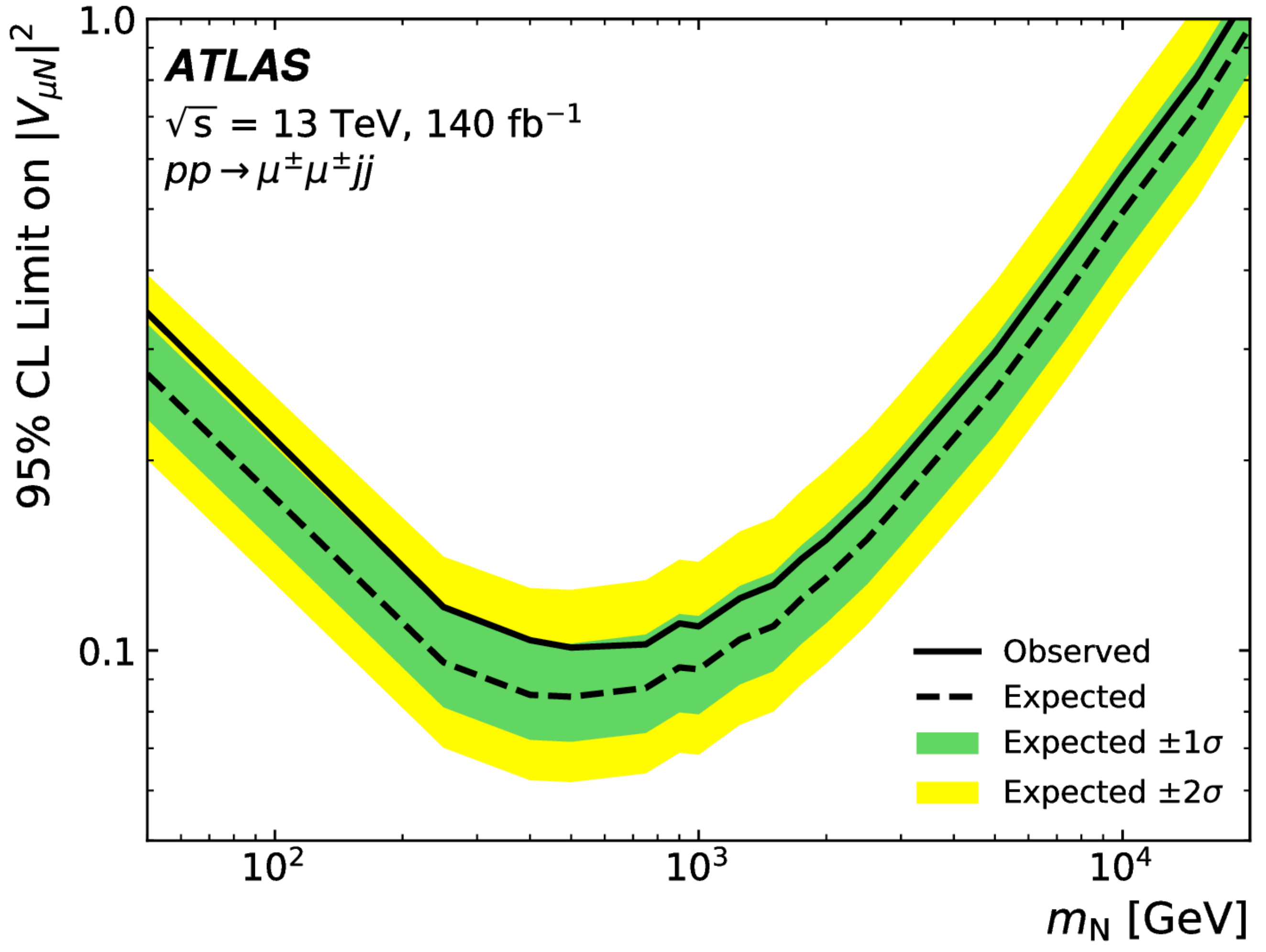


- Signal events typically have a **significantly higher muon p_T** than those arising from SM backgrounds
- Shape of the **p_T distribution of the subleading muon** is used to discriminate
- Suppressed backgrounds by requiring: no third muon/electron, low significance of E_T^{miss}
- Plot show combined profile likelihood fit in the SR for the background

- **No significant excess** is observed over the background expectation
- Results are interpreted in a benchmark scenario of the Phenomenological Type-I Seesaw model
- Sensitivity to the Weinberg operator is investigated
- **Upper limits:**
  - the squared muon-neutrino–heavy-neutrino mass-mixing **matrix element** $|V_{\mu N}|^2$ as a function of the heavy Majorana neutrino's mass m_N
  - on the effective $\mu\mu$ Majorana neutrino mass $|m_{\mu\mu}|$

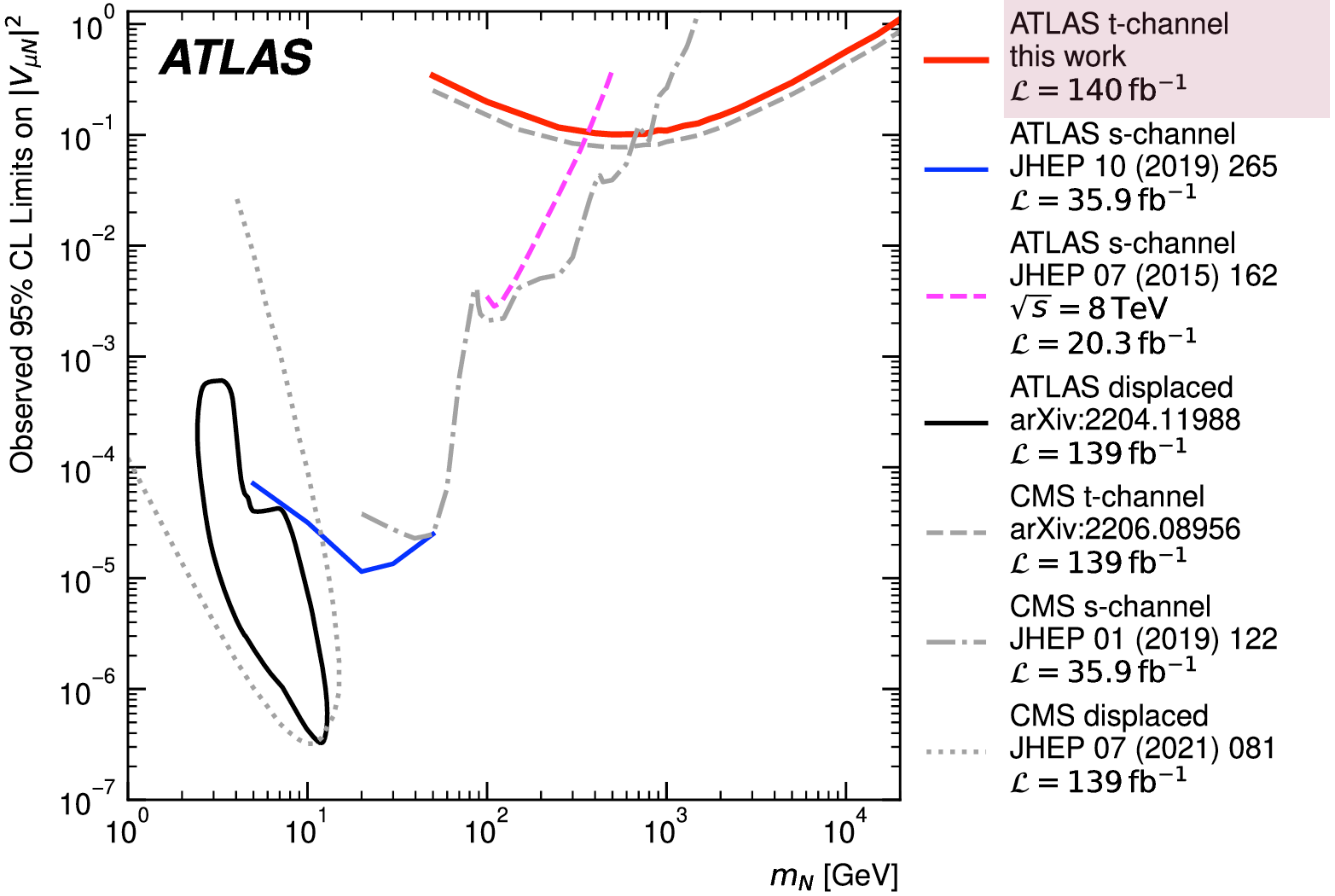
	SR
$W^{\pm}W^{\pm}jj$	41.2 ± 8.0
WZ	22.3 ± 4.4
Non-prompt μ	15.4 ± 4.5
Other	3.1 ± 3.9
Total SM	82.1 ± 7.2
Data	89
$m_N = 1$ TeV, $\lvert V_{\mu N}\rvert^2 = 0.1$	6.2 ± 0.6
Weinberg $\Lambda/\lvert C_5^{\mu\mu}\rvert = 5$ TeV	15.6 ± 2.0

Summary of observed and predicted yields in the signal region (SR),The background prediction is shown after the combined likelihood fit to data under the background-only hypothesis.



Observed and expected 95% CL upper limits on the heavy Majorana neutrino mixing element $|V_{\mu N}|^2$ as a function of m_N in the Phenomenological Type-I Seesaw model

MAJORANA NEUTRINOS IN SAME-SIGN WW SCATTERING EVENTS



Overview of the most stringent ATLAS and CMS observed 95% CL limits set on the heavy Majorana neutrino mixing element $|V_{\mu N}|^2$ as a function of m_N. The t-channel process results extend the kinematic reach in m_N up to 20 TeV and they add valuable sensitivity to the resonant production channels as of a few hundred GeV of m_N.

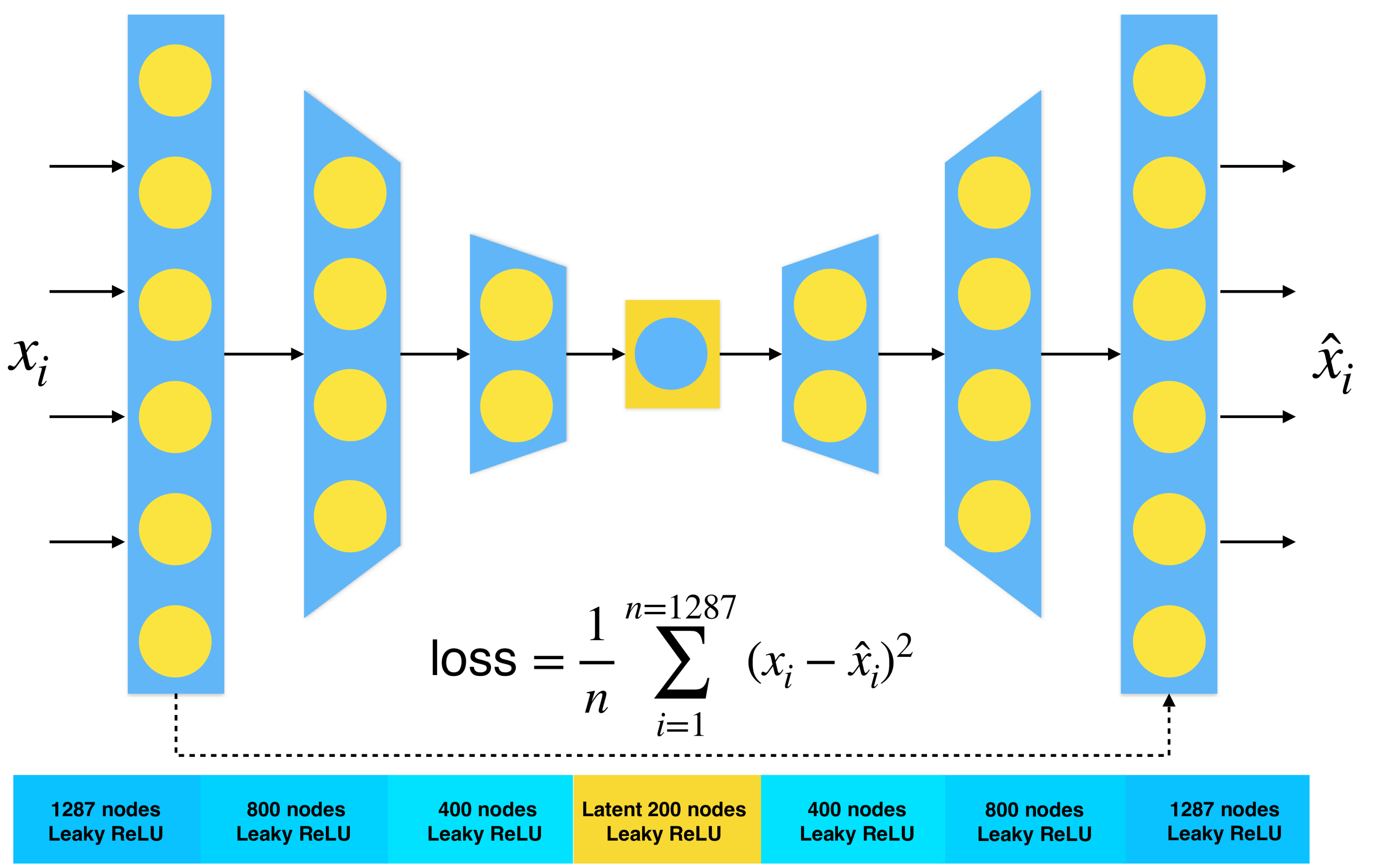
- Improvements in sensitivity of 15-20% in limits w.r.t previous results
- Upper limits are set
  - Muon-neutrino–heavy-neutrino mass-mixing matrix element $|V_{\mu N}|^2$ as a function of the heavy Majorana neutrino's mass m_N
  - observed (expected) upper limit of 16.7 (13.1) GeV on the $\mu\mu$ Majorana neutrino mass $|m_{\mu\mu}|$

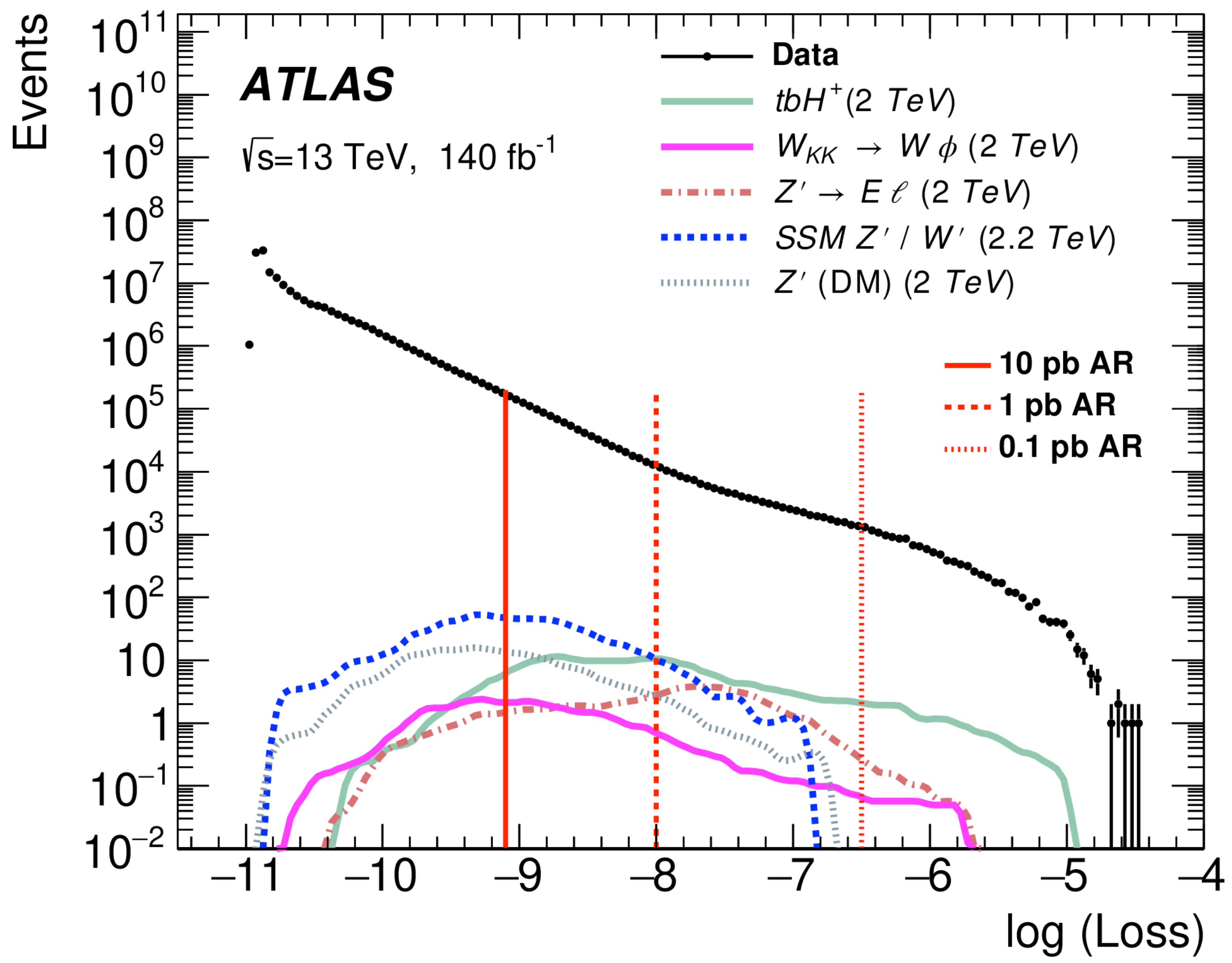
NEW PHENOMENA IN TWO-BODY INVARIANT MASS DISTRIBUTIONS USING UNSUPERVISED MACHINE LEARNING FOR ANOMALY

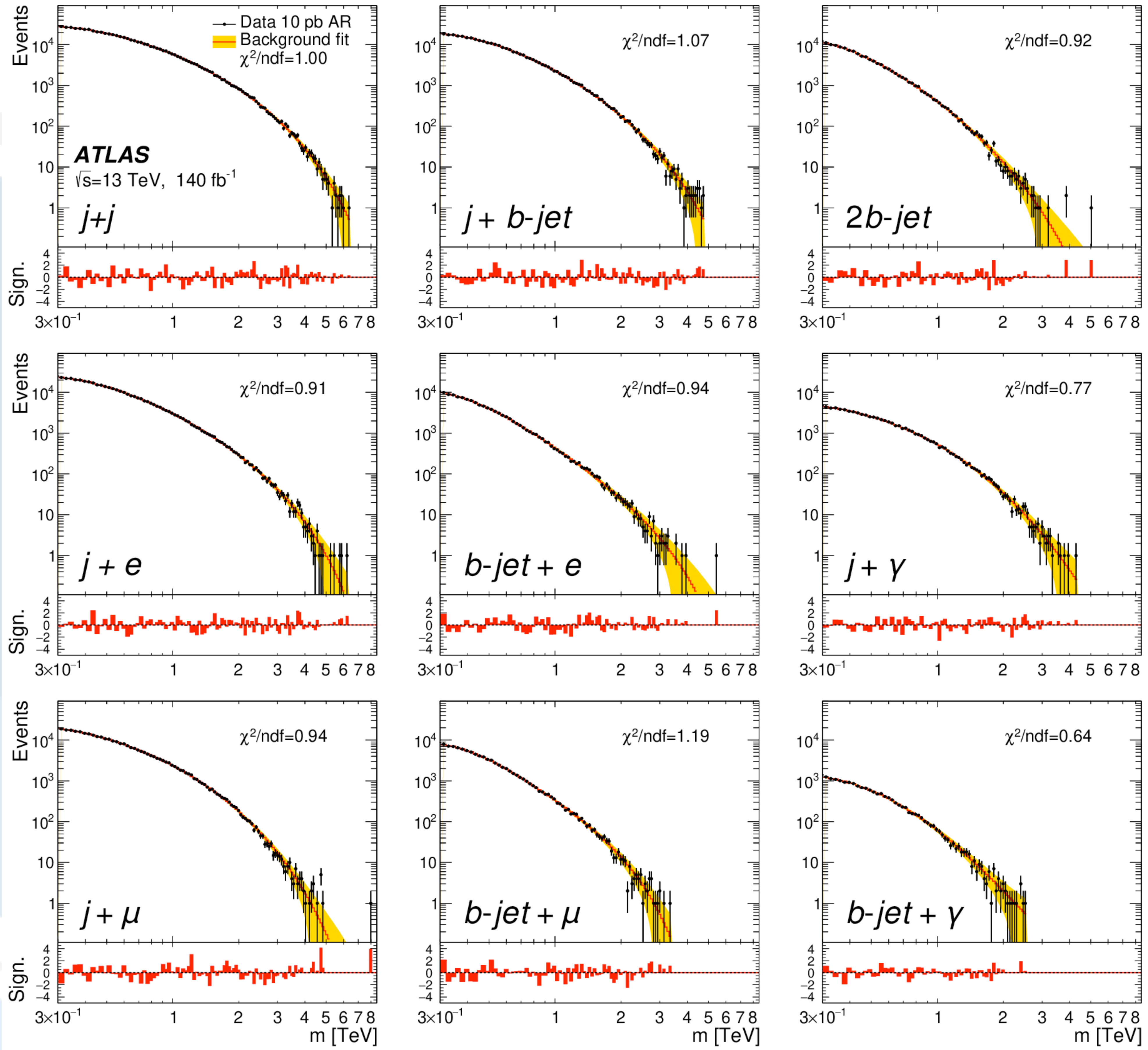
https://arxiv.org/abs/2307.01612

- **Unsupervised** anomaly-detection
- Training an auto-encoder on Run 2 pp collisions
  - Defining **anomalous regions** based on the **reconstruction loss** of the decoder
- Events are triggered containing electron/muon - suppress contamination from QCD multi-jet events
- Focus on **nine invariant mass spectra** that contain:
  - One light jet or b-jet
  - One lepton (e, μ), photon, or second light jet or b-jet in the anomalous region

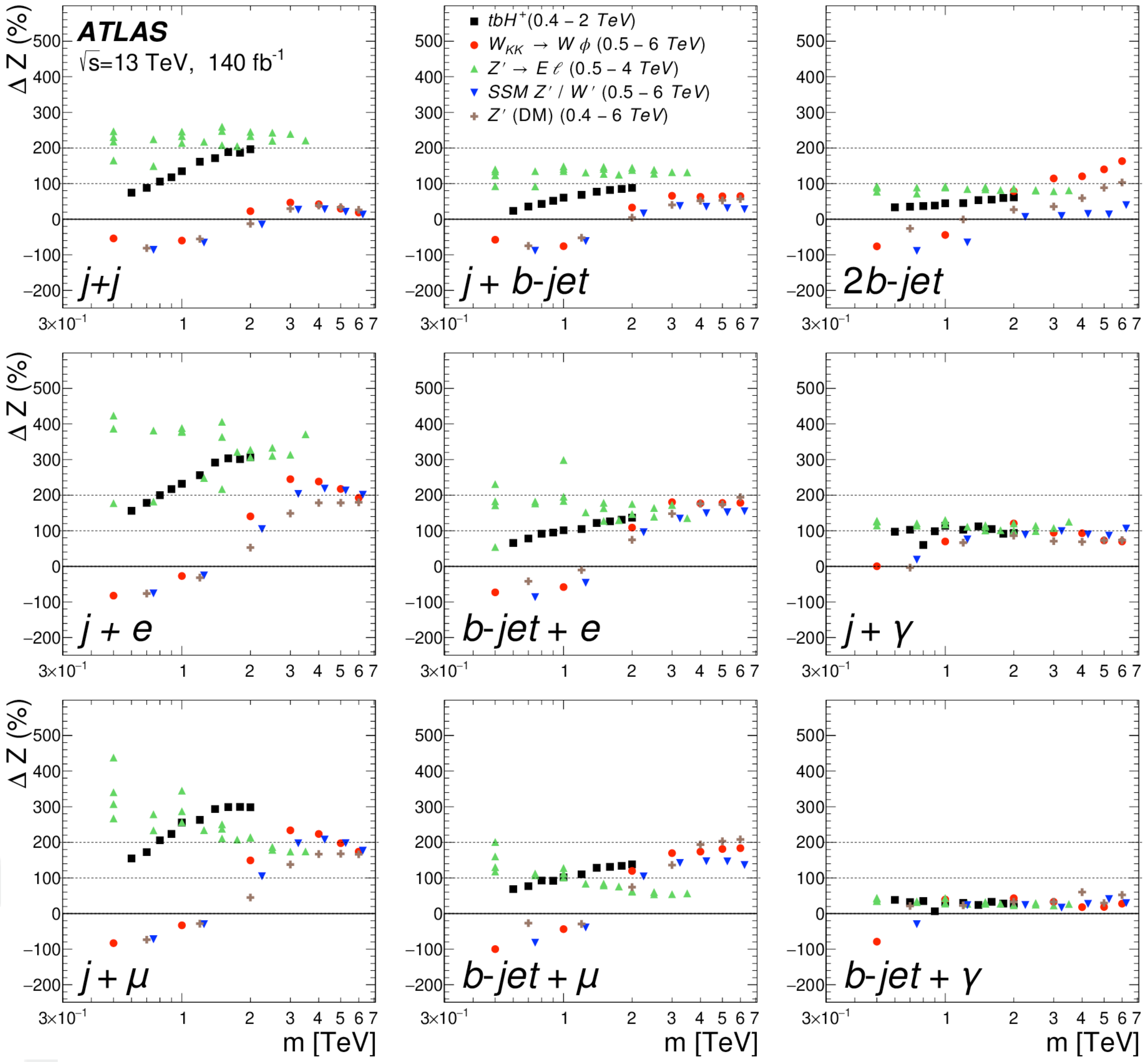
- Unsupervised -> anomalous jets
- Weakly supervised -> massive dijet final states
- **First time in ATLAS** generic search for resonances in various two-body final states that applies an anomaly detection method to the event topology (unsupervised ML: autoencoder (AE))
- **Rapidity-mass matrix (RMM)**: kinematic features of final-state objects in preselected events
- **Log(Loss) = Anomaly score**
- Anomaly score of data vs BSM models
  - scores of BSM processes tend to be larger than those of the collision events
- Three Anomaly Regions (AR) defined starting at 0.1, 1 and 10 pb







Invariant mass distributions for each of the 9 two-body states considered



ΔZ discovery sensitivity improvement

- No bumps observed
- Using the **AE** trained on data **improves the discovery sensitivity** for most of the benchmark BSM models

$$\Delta Z = ((Z_{AE}/Z) - 1) \times 100\%,$$

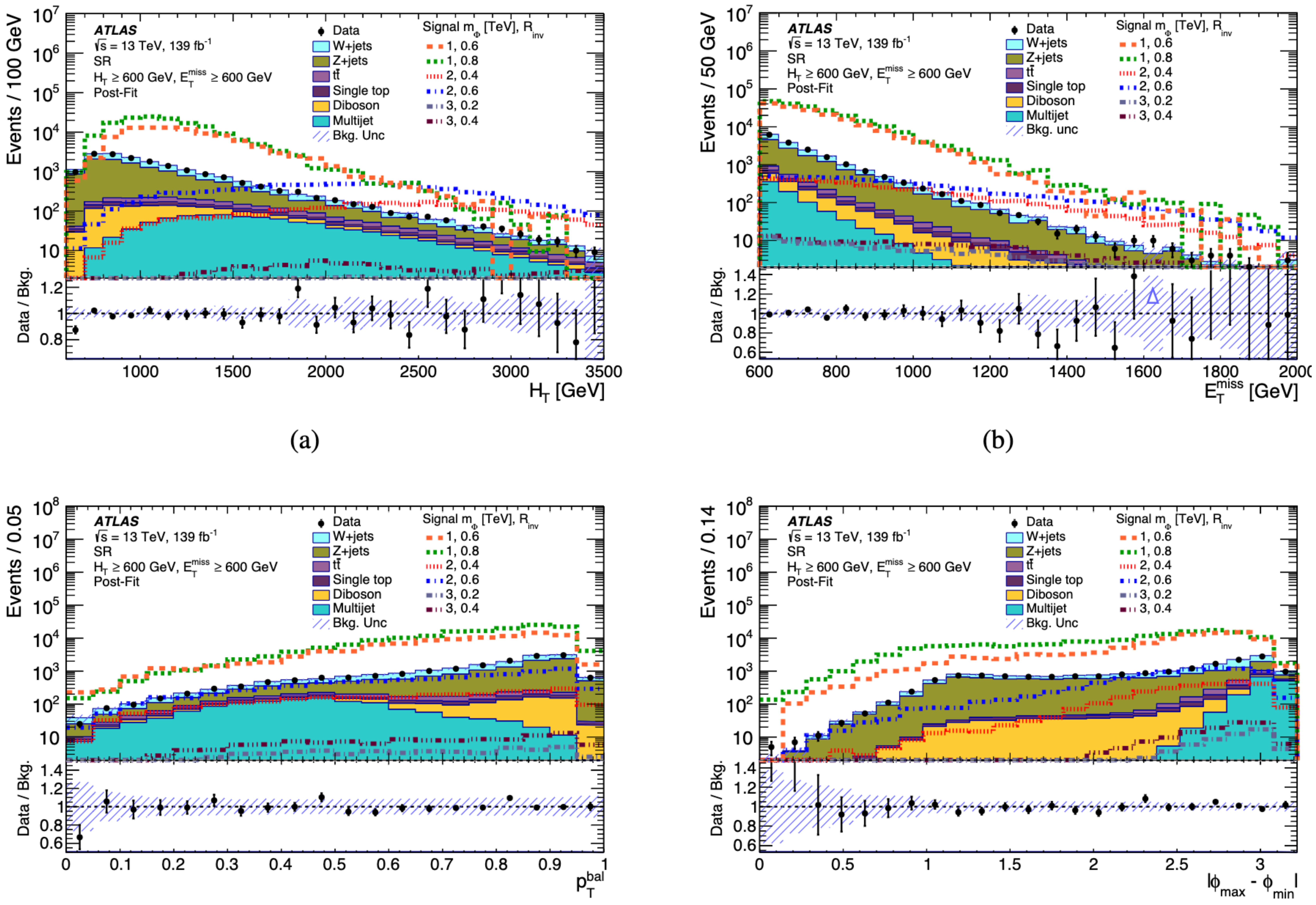
FINAL REMARKS

- No observation of BSM physics yet
- Run 2 exotics analysis in ATLAS continue to search for answers to questions BSM

- ATLAS has a comprehensive BSM physics program:
- OTHER RELEVANT TALKS:
  - Searches for BSM resonances in ATLAS: Monica Verducci
  - Searches for BSM physics using challenging and long-lived signatures with the ATLAS detector: Emma Torro Pastor
  - Combination of ATLAS dark matter searches interpreted in a 2HDM with a pseudo-scalar mediator: (poster) Sanae Ezzarqtouni
  - Search for new physics using unsupervised machine learning for anomaly detection: (poster) Alkaid Cheng
  - Searches for Dark Matter with the ATLAS Experiment at the LHC: Tae Min Hong

THANK YOU!

NON-RESONANT PRODUCTION OF SEMI-VISIBLE JETS



(a) (b)

(c) (d)

Process	k^{SF}
Z+jets	1.18 ± 0.05
W+jets	1.09 ± 0.04
Top processes	0.64 ± 0.04
Multijet	1.10 ± 0.04

Scale factors for each background process obtained from the simultaneous fit using the SR, 1L CR, 1L1B CR and 2L CR.

Process	SR	CR 1L	CR 1L1B	CR 2L
Z+jets	$8\,490 \pm 260$	11.6 ± 1.4	2.2 ± 0.6	$1\,120 \pm 40$
W+jets	$5\,820 \pm 300$	$3\,190 \pm 170$	351 ± 41	-
$t\bar{t}$	920 ± 70	350 ± 29	304 ± 24	-
Single top	533 ± 47	358 ± 29	290 ± 25	-
Multijet	850 ± 100	28 ± 11	7.7 ± 3.1	-
Diboson	757 ± 10	187 ± 9	34.5 ± 2.8	-
Total bkg.	$17\,370 \pm 280$	$4\,120 \pm 100$	990 ± 35	$1\,120 \pm 40$
Data	17 388	4 136	999	1 124
Signal:				
$m_{\Phi} = 1$ TeV, $R_{\text{inv}} = 0.6$	$101\,000 \pm 23\,000$	-	-	-
$m_{\Phi} = 1$ TeV, $R_{\text{inv}} = 0.8$	$160\,000 \pm 40\,000$	-	-	-
$m_{\Phi} = 2$ TeV, $R_{\text{inv}} = 0.4$	$2\,800 \pm 600$	-	-	-
$m_{\Phi} = 2$ TeV, $R_{\text{inv}} = 0.6$	$8\,900 \pm 2\,000$	-	-	-
$m_{\Phi} = 3$ TeV, $R_{\text{inv}} = 0.2$	59 ± 13	-	-	-
$m_{\Phi} = 3$ TeV, $R_{\text{inv}} = 0.4$	126 ± 29	-	-	-

Post-fit yields from the background-only fit, including pre-fit contributions of different signal benchmark points. Dashes refer to components that are negligible or not applicable. The total uncertainties include statistical and systematic uncertainties.

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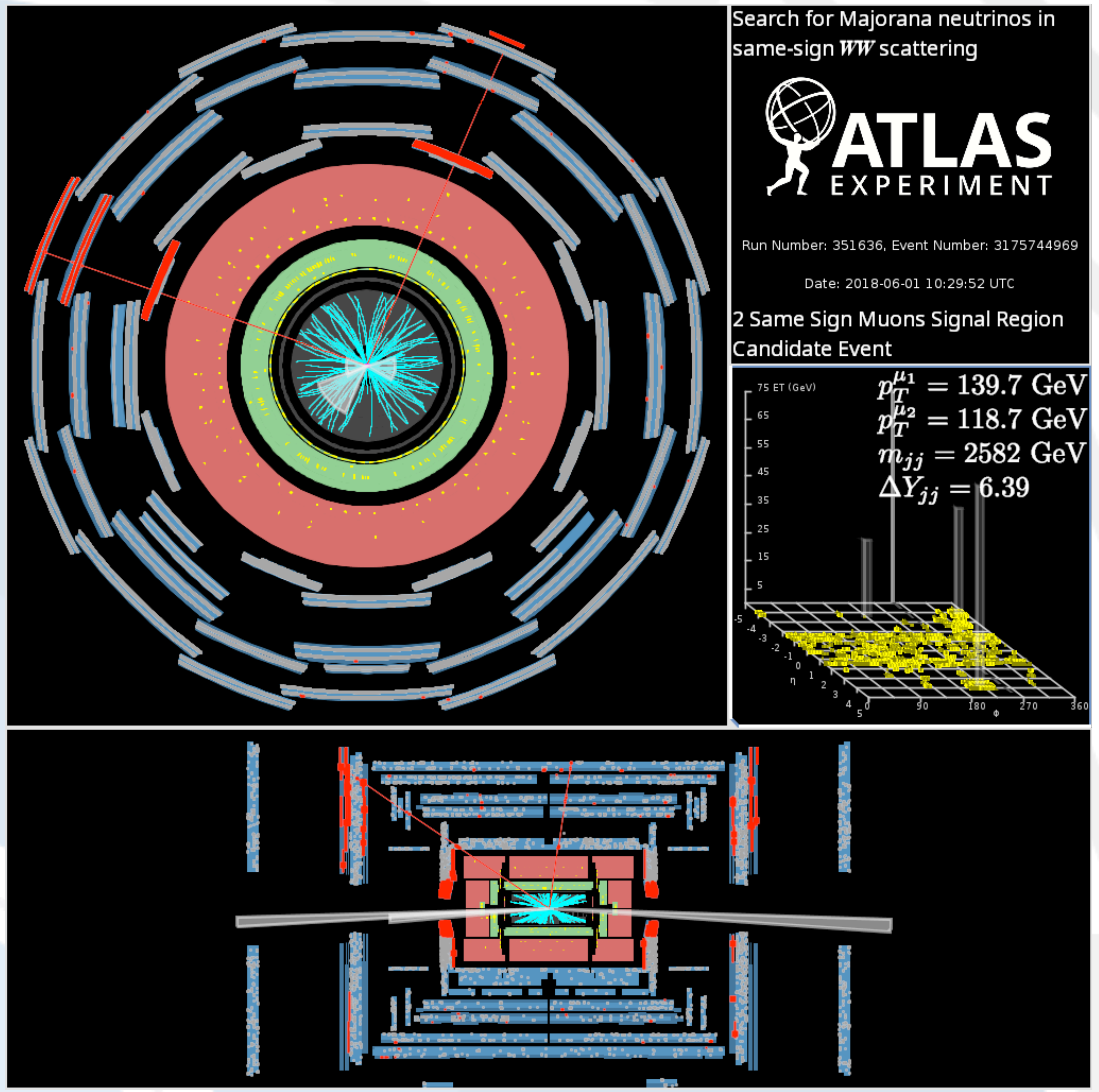
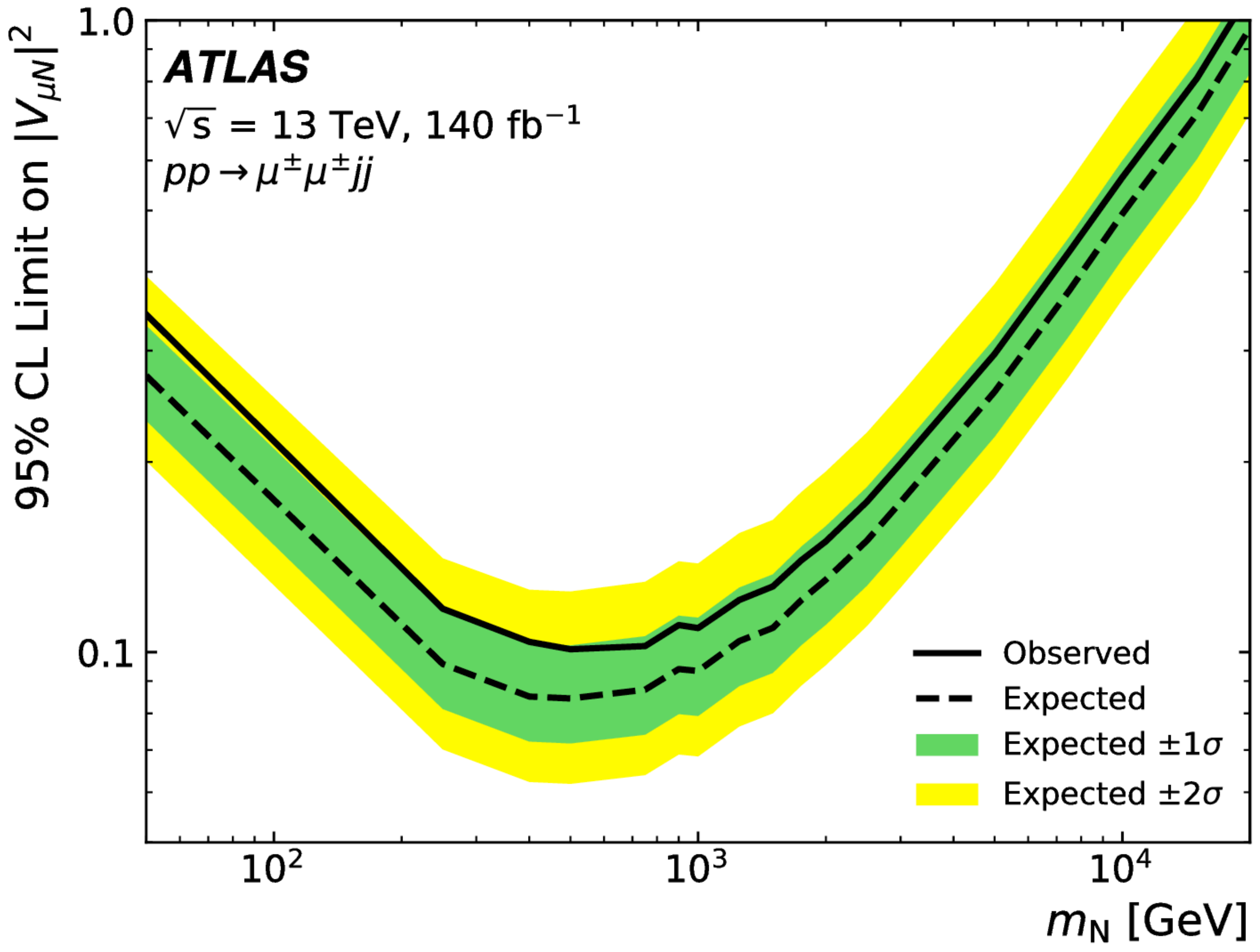


Visualization of one of the candidate events in the signal region.

Observable	SR	ssWW-CR	WZ-CR
Same-sign muons	$= 2$ (signal μ)		
Number of b-jets	$= 0$		
m_{jj}	> 300 GeV		
$\lvert\Delta y_{jj}\rvert$	> 4		
Third lepton (OS)	$= 0$ (baseline)	$= 0$ (baseline)	$= 1$ (signal μ)
E_T^{miss} signif. $\mathcal{S}$	< 4.5	> 5.8	< 4.5
$m_{\ell\ell\ell}$	—	—	> 100 GeV
$p_T^{\mu_2}$	—	< 120 GeV	—

Summary of the main kinematic requirements for the different selection regions.

- No significant excess is observed over the background expectation
- Results are interpreted in a benchmark scenario of the Phenomenological Type-I Seesaw model
- In addition, the sensitivity to the Weinberg operator is investigated.
- Upper limits at the 95% confidence level are placed on the squared muon-neutrino–heavy-neutrino mass-mixing matrix element $|V_{\mu N}|^2$ as a function of the heavy Majorana neutrino's mass m_N , and on the effective $\mu\mu$ Majorana neutrino mass $|m_{\mu\mu}|$



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