



MARYLAND CENTER FOR  
**FUNDAMENTAL  
PHYSICS**

# REPURPOSING PRECISION SM MEASUREMENTS TO CONSTRAIN NEW PHYSICS

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# Era of Precision Measurements

## High-precision measurement of the $W$ boson mass with the CDF II detector

CDF COLLABORATION, T. AALTONEN, S. AMERIO, D. AMIDEI, A. ANASTASSOV, A. ANNOVI, J. ANTOS, G. APOLLINARI, J. A. APPEL, [...], AND S. ZUCHELLI

+388 authors

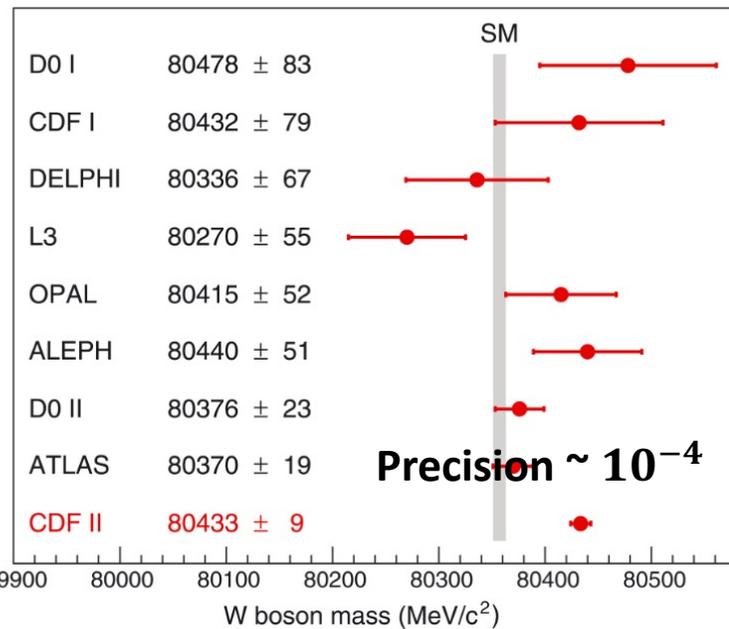
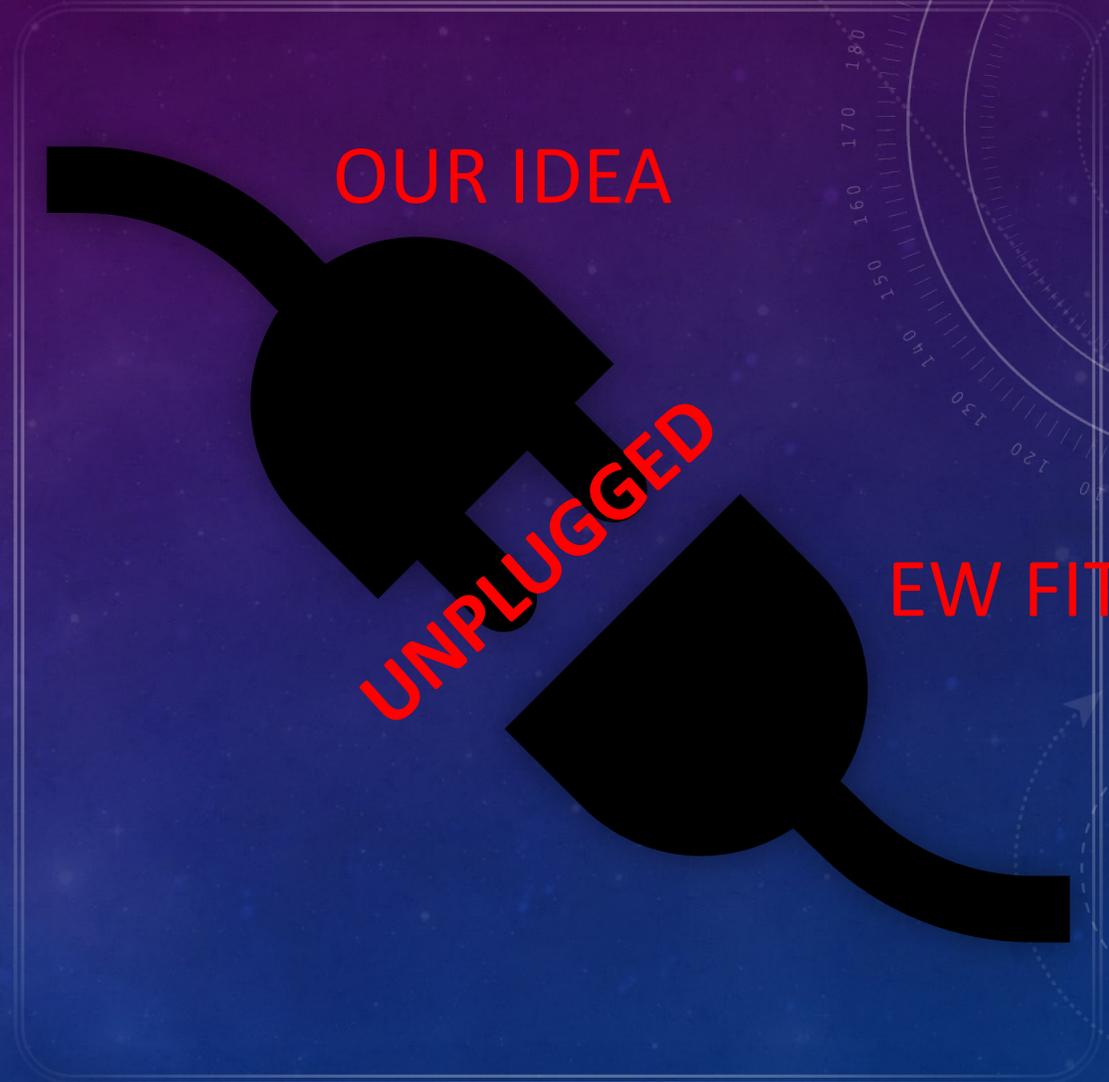


Fig. 5. Comparison of this CDF II measurement and past  $M_W$  measurements with the SM expectation.

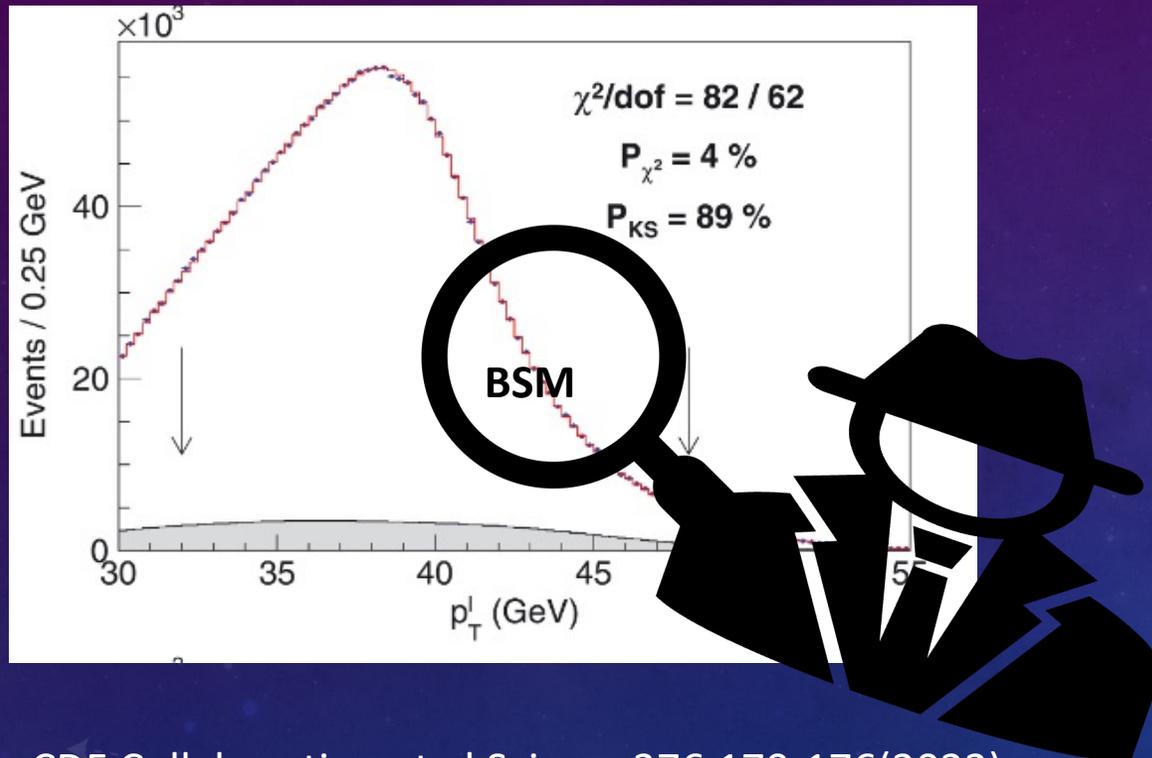
## Improved ATLAS result weighs in on the $W$ boson

An improved ATLAS measurement of the  $W$  boson mass is in line with the Standard Model of particle physics

- Constrain using EW fit is one option
- But NOT US!!



# IRREDUCIBLE NEW PHYSICS BACKGROUND



- $W$  gives a **lepton + MET** final state
- $m_W$  is measured by fitting  $p_T^{\text{lep}}$  and  $p_T^{\text{miss}}$  and  $m_T$  spectra
- Any new physics that can lead to a lepton + MET final state can **contaminate**  $W$  sample
- Agreement with SM == Constraint on NP

CDF Collaboration et al Science376,170-176(2022)

# OUTLINE

- W Mass Measurement
- Ways in which NP can contaminate  $M_W$  data
  - Modify Production
  - Modify Decay
  - Lepton from BSM Particle
- Modified spectra
- Analysis
- Constraints
- Summary

# $M_W$ MEASUREMENT BASICS

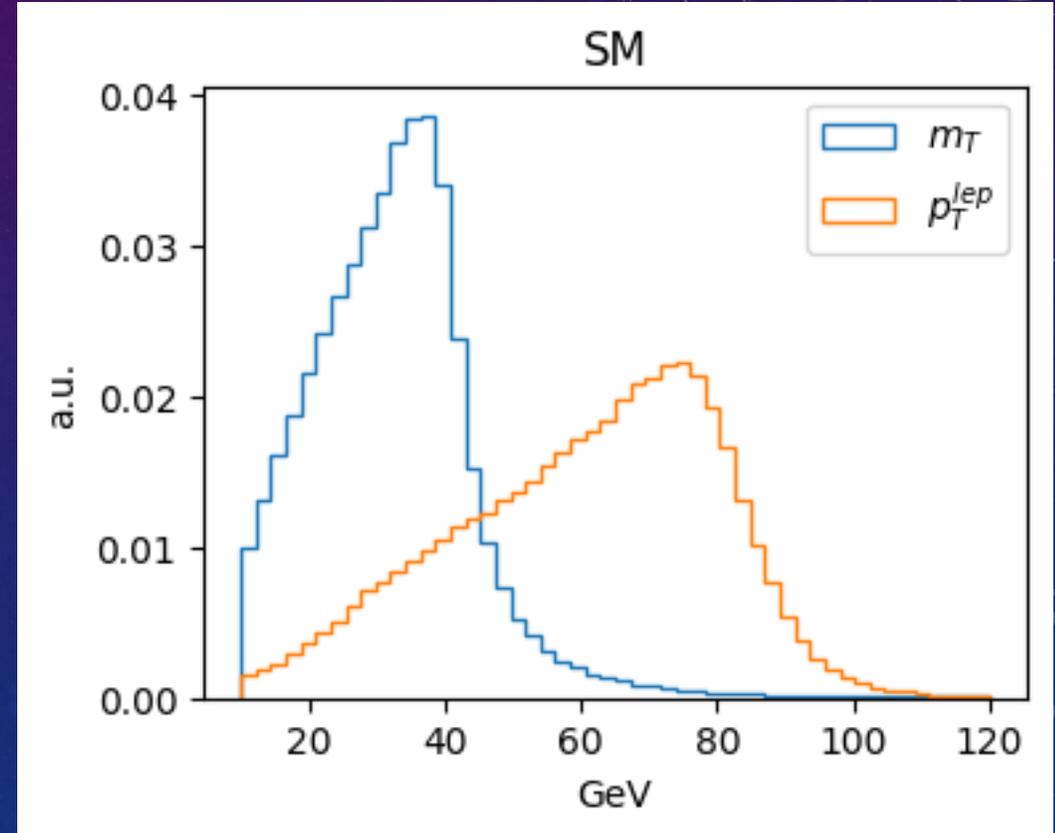
- At tree level  $p_T^{lep}$  has a sharp Jacobian peak at  $M_W/2$ .

- $m_T^2 = (E_T^e + E_T^{miss})^2 - (\vec{p}_T^{lep} + \vec{p}_T^{miss})^2$

- At LO

$$\vec{p}_T^{lep} + \vec{p}_T^{miss} = 0$$

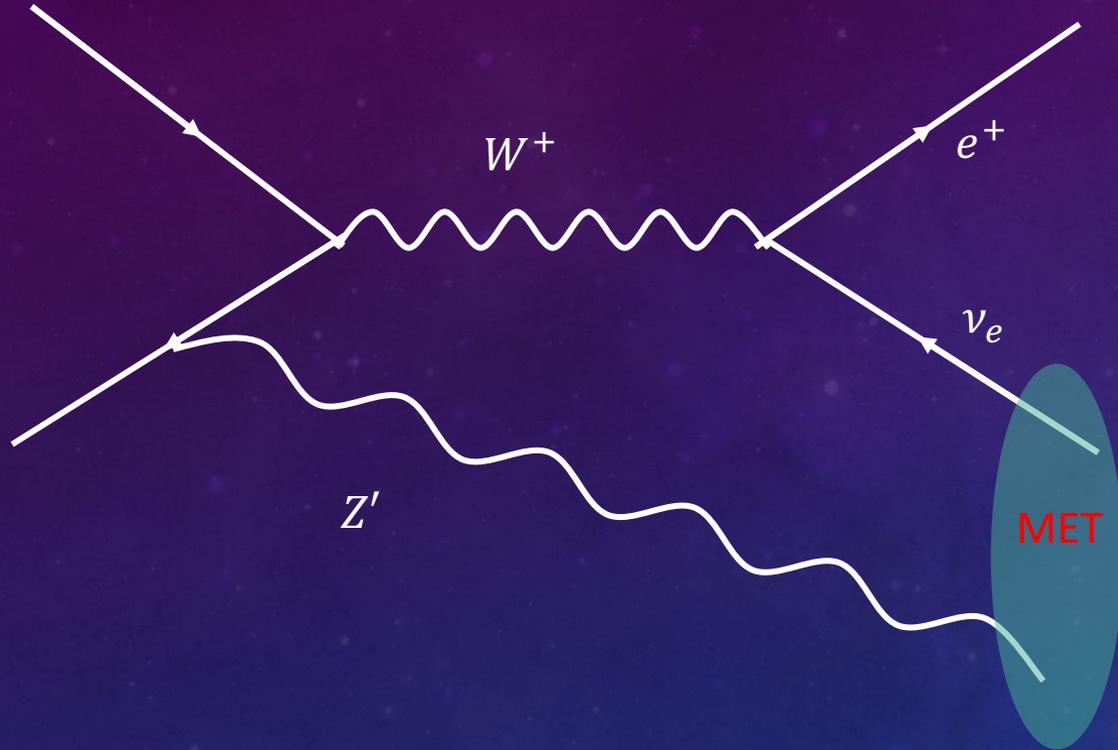
$$\Rightarrow m_T \approx 2 \left| \vec{p}_T^{lep} \right| \approx M_W \text{ (endpoint)}$$



# WHAT KIND OF NP?

- Modify Production
- Modify Decay
- No on-shell W

# WHAT KIND OF NP?

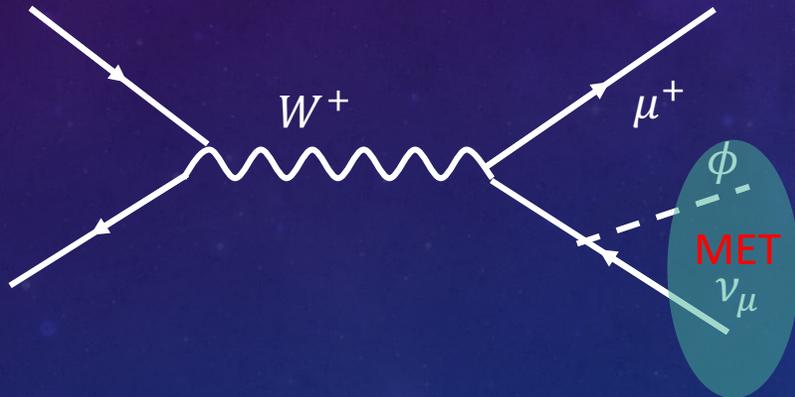
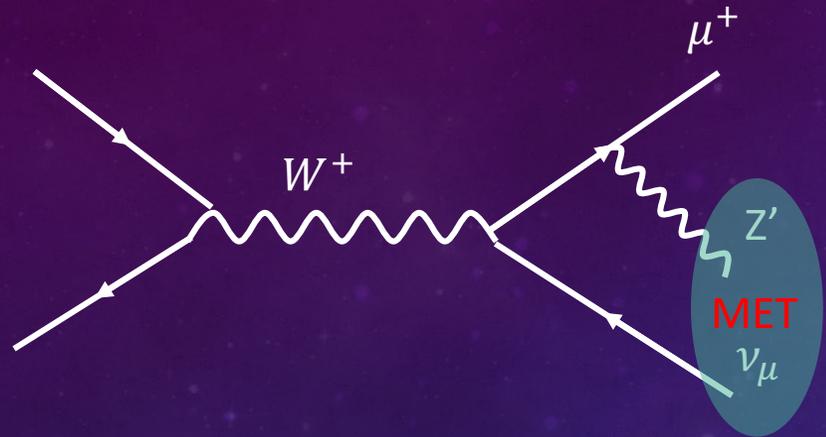


## Modify Production

Invisibly decaying **Quarkphilic**  $Z'$

More involved because Z data is used for calibration and also many other constraints

# WHAT KIND OF NP?



## Modify Decay

Invisibly decaying **leptophilic**  $Z'$  ( $L_\mu - L_\tau$ )

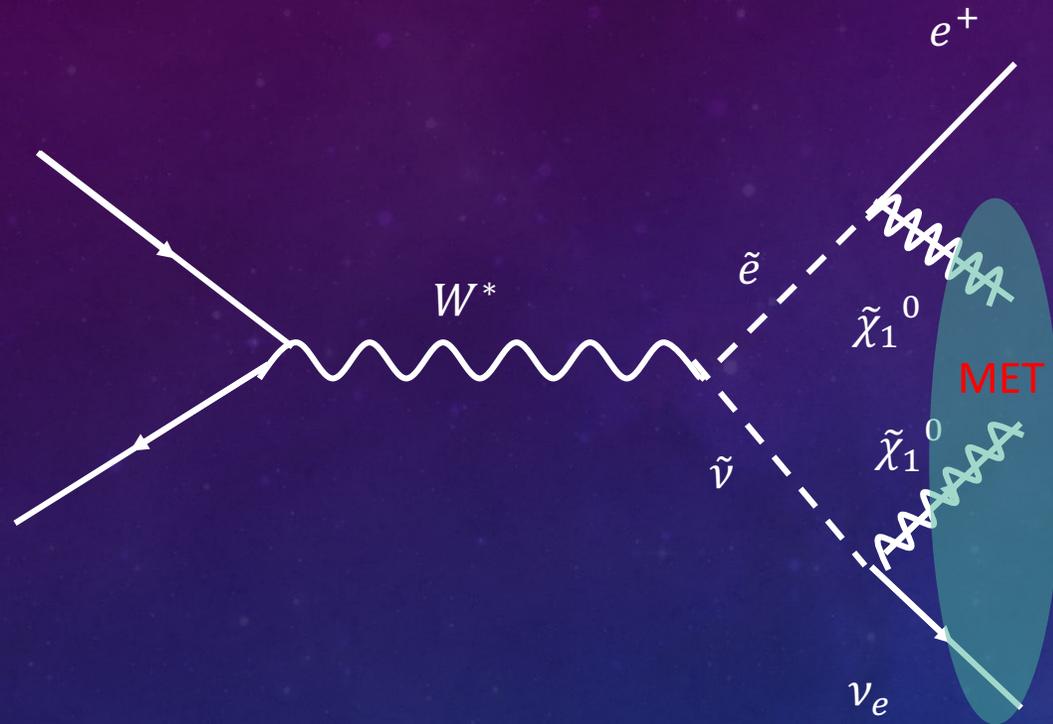
**Neutrino**philic Scalar  $\phi$

$$\frac{\lambda}{2} \phi \bar{\nu} \nu \text{ [4]}$$

Heavy neutrino  $\nu'$

[4] A.de Gou, P.S.B.Dev, B.Dutta, T.Ghosh, T.Han (2019)

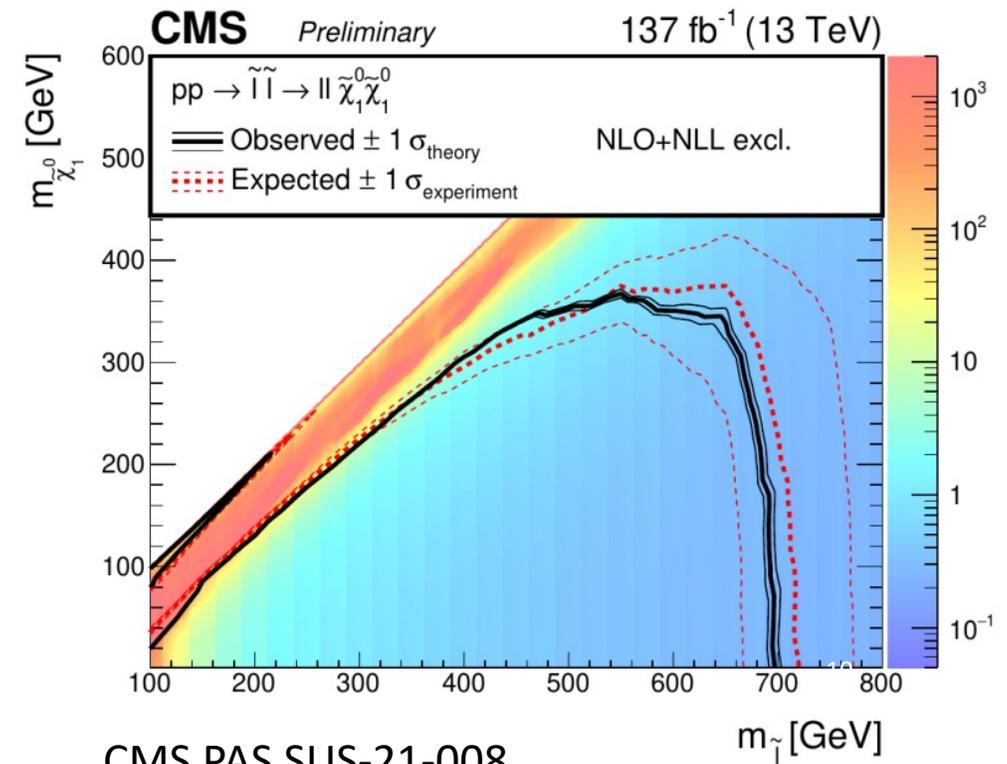
# WHAT KIND OF NP?



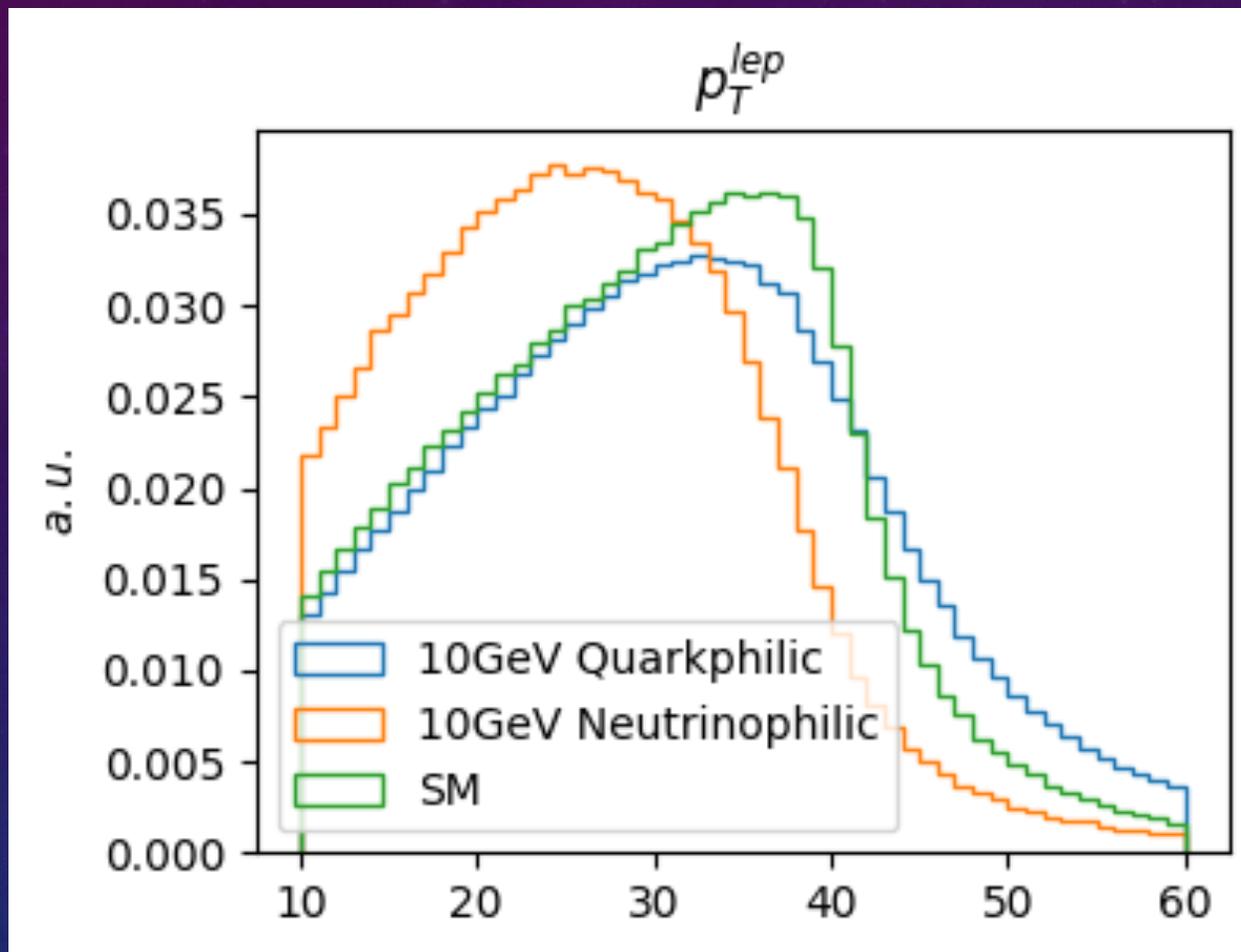
## No on-shell W

SUSY – Slepton production

$$m_{\tilde{l}} - m_{\tilde{\chi}_1^0} \lesssim 80 \text{ GeV}$$



# HOW IS THE SPECTRUM MODIFIED?



# Analysis

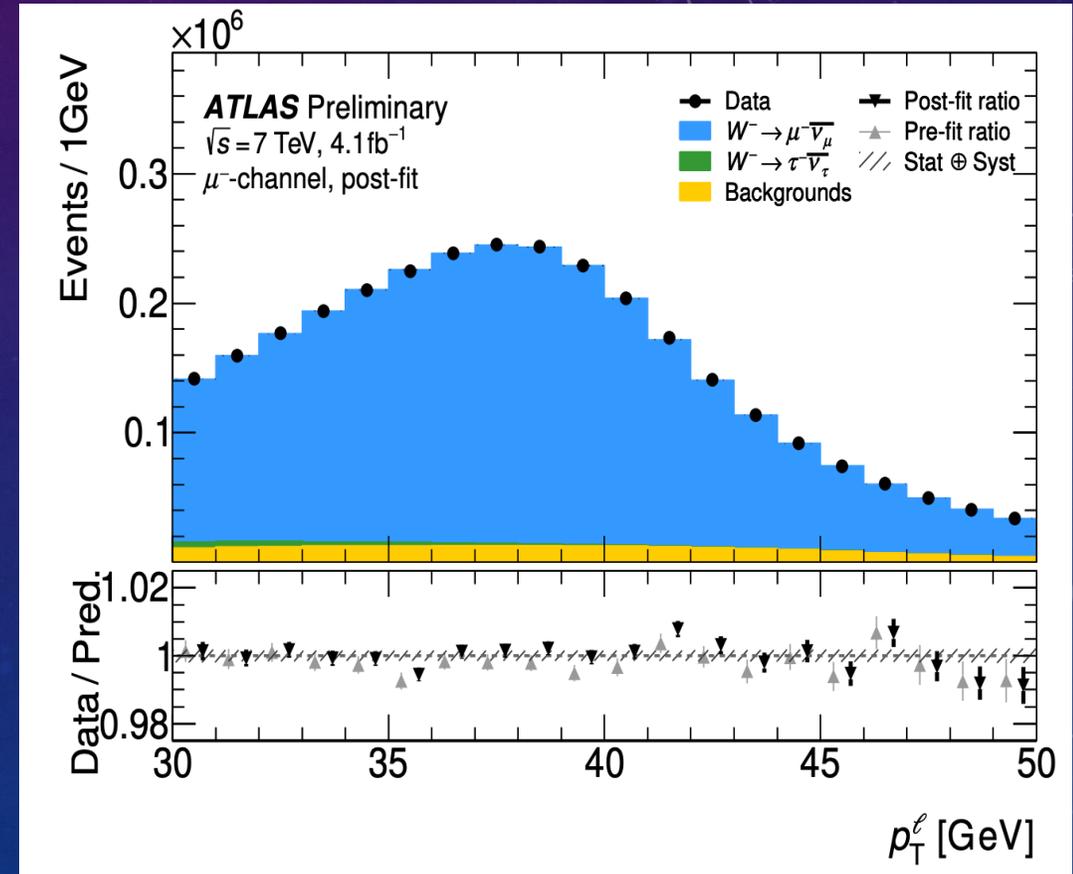
- Data generation MadGraph + Pythia8
- Generate SM + NP templates with  $M_W$  and NP couplings ( $g_{Z'}/\lambda$ ) as parameters
- Normalize SM + NP to data, we only use shapes
- Make exclusion plots by calculating

$$\chi^2 = \sum_i \frac{\left( f_{data}^i - f_{SM}^i(M_W) - f_{NP}^i(g') \right)^2}{\sigma_{fi}^2}$$

$$\sigma_{fi}^2 = f^i + f^{i2} \alpha^2, \quad f^i = L \frac{1}{\sigma} \frac{d\sigma}{dx}$$

$L \rightarrow$  Luminosity,  $x \rightarrow p_T^{lep}, p_T^{miss}, m_T,$   
 $\alpha \rightarrow$  uncorrelated systematic

- $\alpha \sim O(0.5\%)$  at ATLAS



ATLAS-CONF-2023-004

# CONSTRAINTS

(PRELIMINARY)

Leptophilic  $Z'$  ( $L_\mu - L_\tau$ )

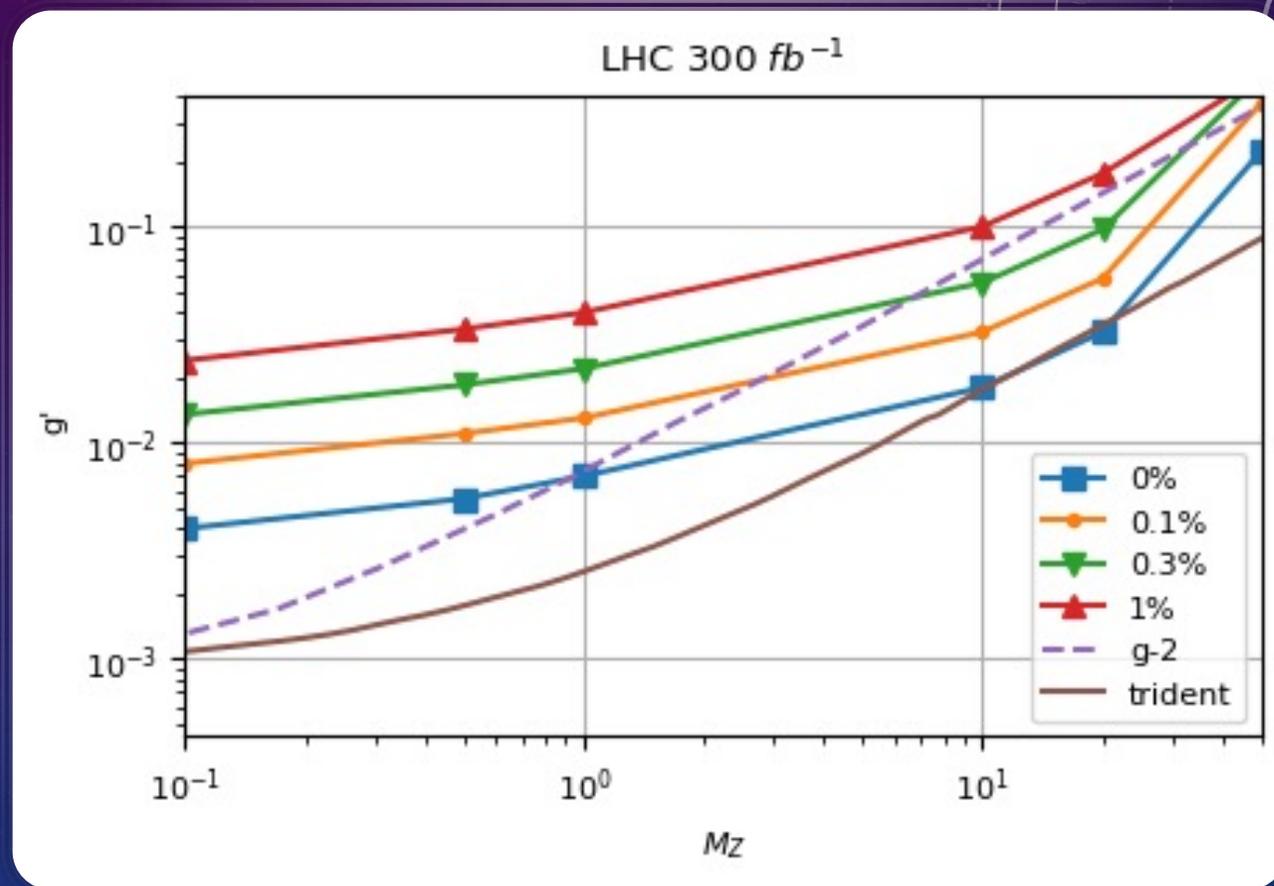
- Constraints from muon  $g-2$  anomaly

$$\Delta a_\mu \approx 10^{-9} \gtrsim \frac{g'^2 m_\mu^2}{16\pi^2 M_{Z'}^2}$$

- Neutrino trident (strongest)

$$\nu + \gamma^* \rightarrow \nu + \mu^+ + \mu^-$$

from beam dump experiments



# CONSTRAINTS (PRELIMINARY)

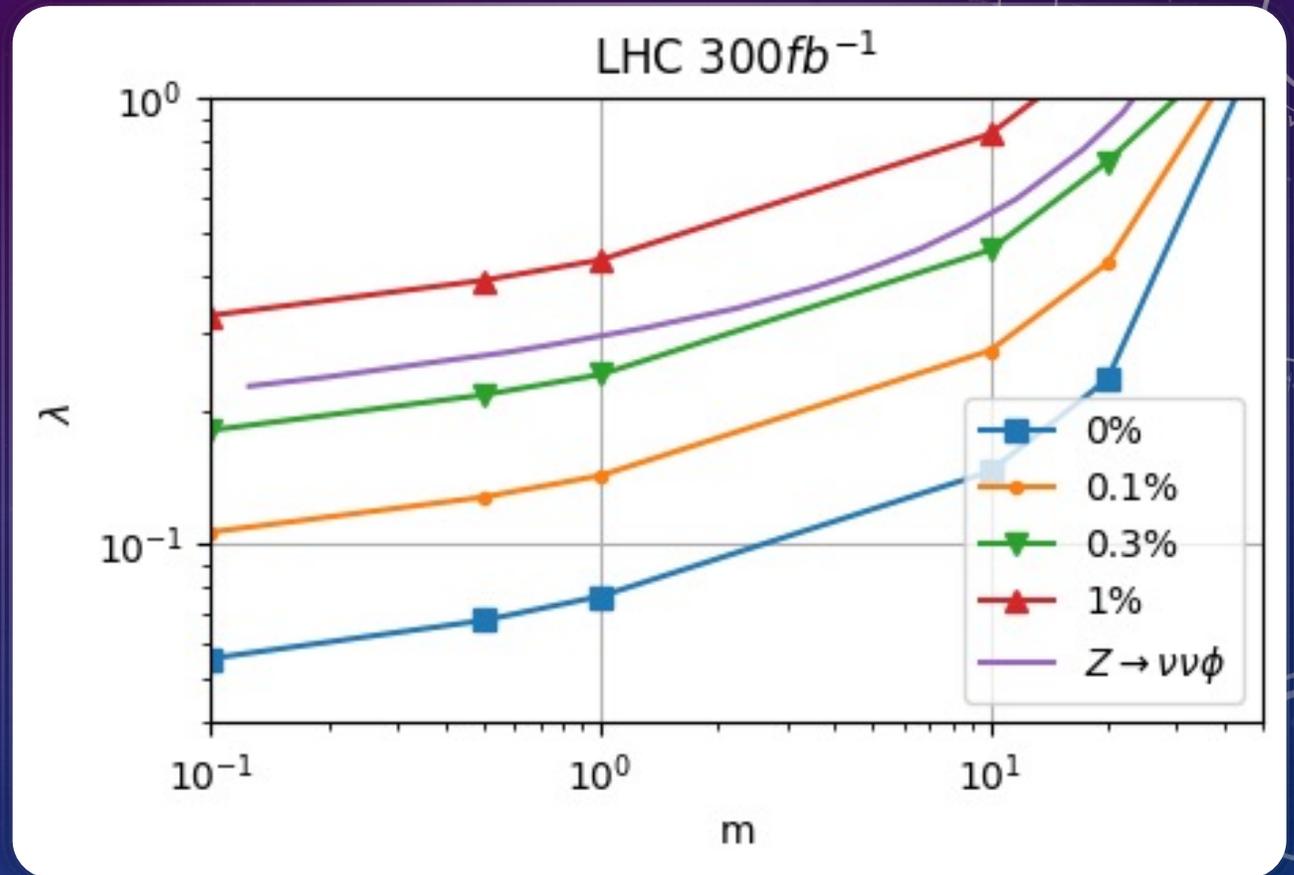
- **Neutrinophilic  $\phi$ -**

- Invisible Z decay

$$Z \rightarrow \nu\nu\phi$$

- Constraints from invisible Higgs decay (less stringent)

$$h \rightarrow \nu\nu\phi$$



# Summary

- We use precision  $W$  data to constrain new physics without invoking Electroweak fit
- Constraints can be competitive with existing best bounds for some types of NP and in certain cases can be the best
- We focused on  $W$  mass measurement, but idea applicable to other precision measurements, e.g., top mass

# Stop pair production contaminating top mass measurement data

