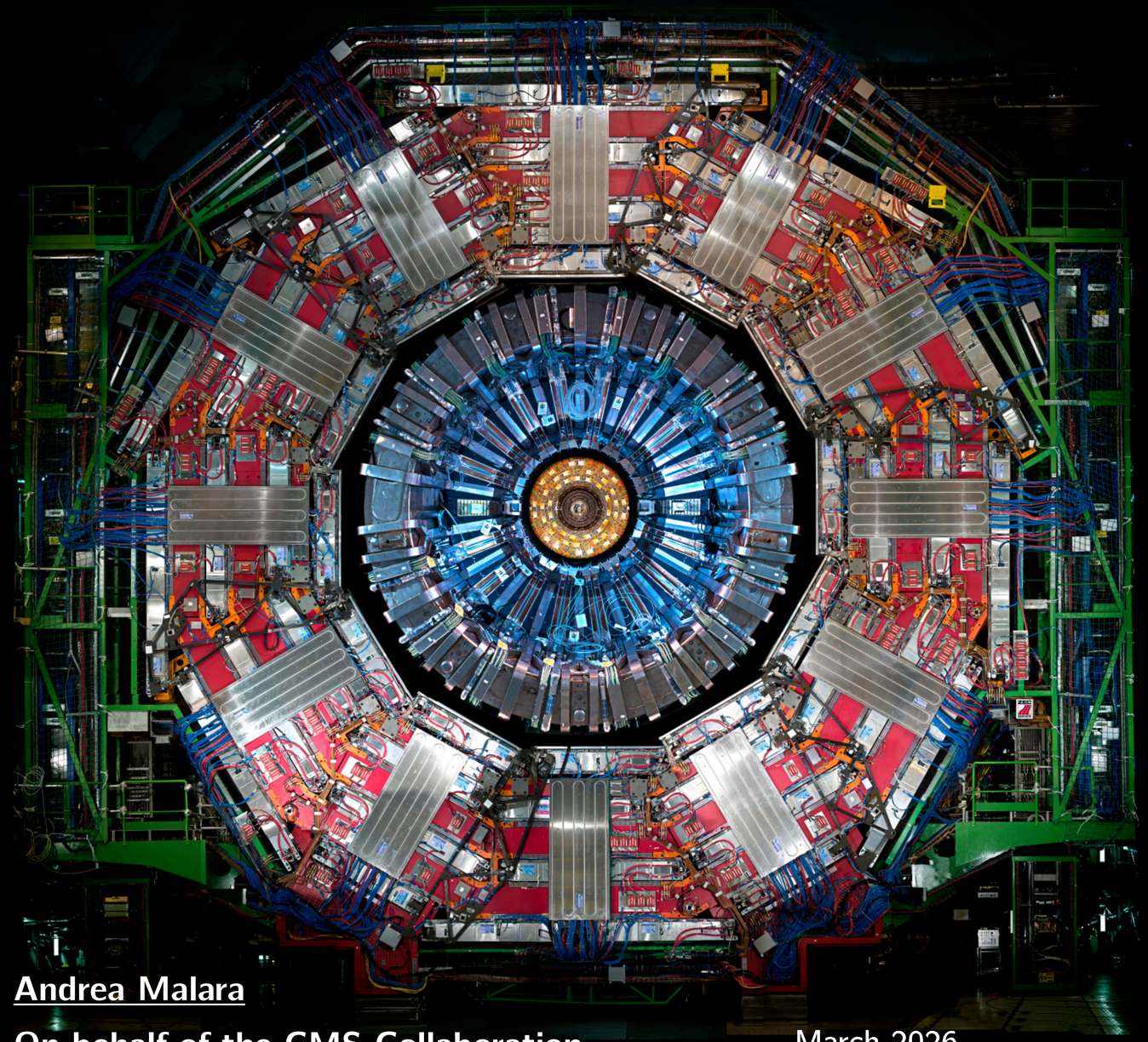
# Searches for new physics at high object masses



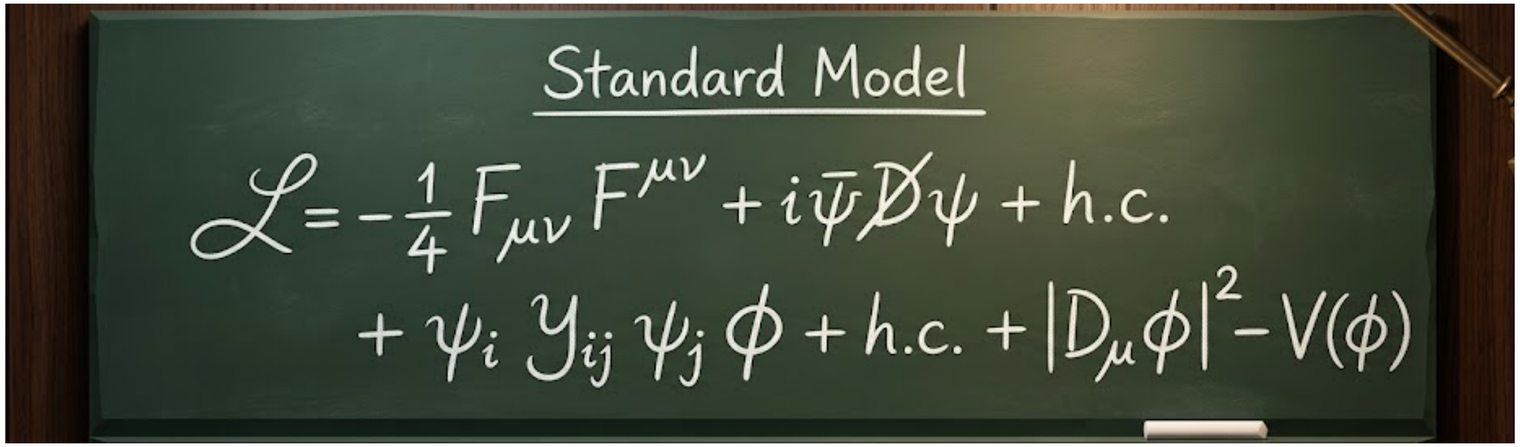
Andrea Malara

On behalf of the CMS Collaboration

March 2026

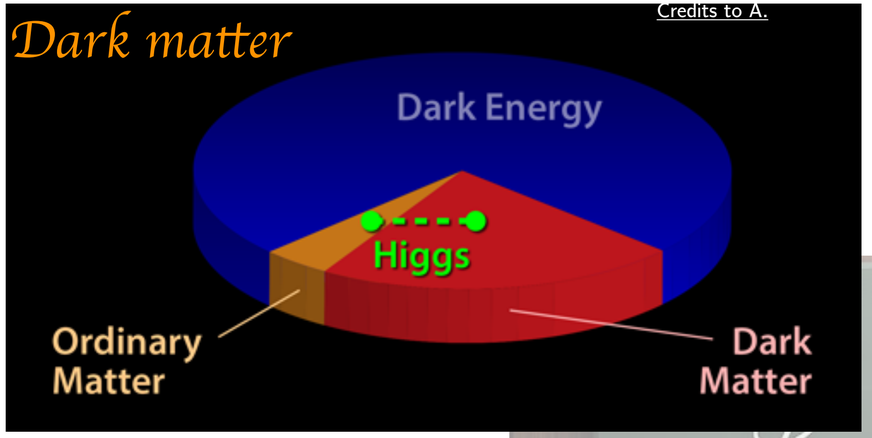
# The Standard Model -- A triumph…

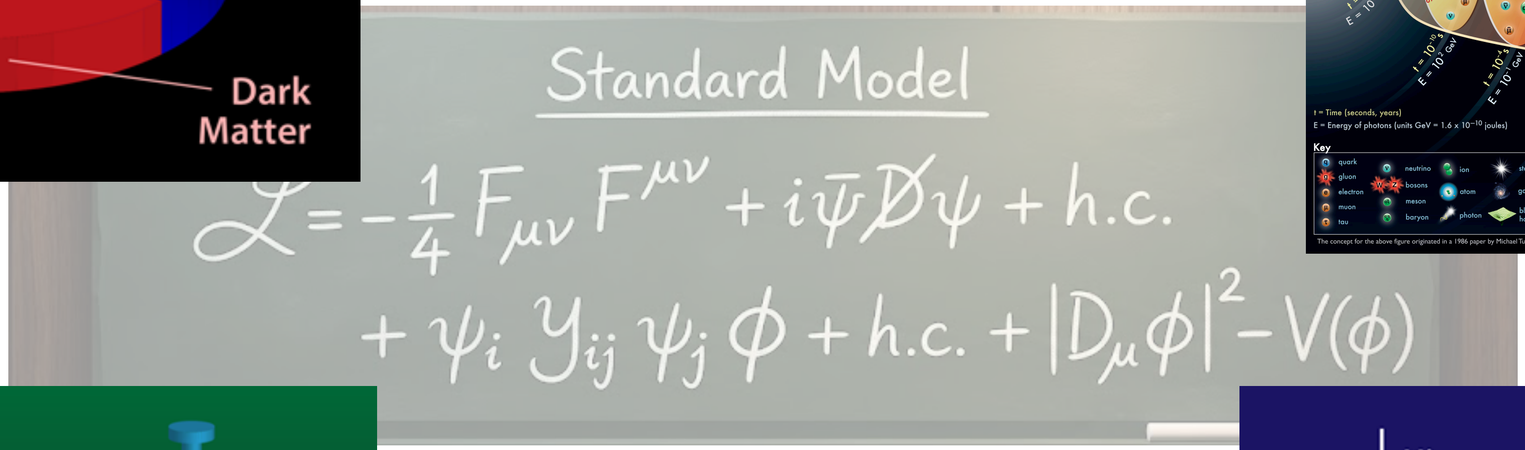
*Precise description of particle interactions up to the electroweak scale!!*

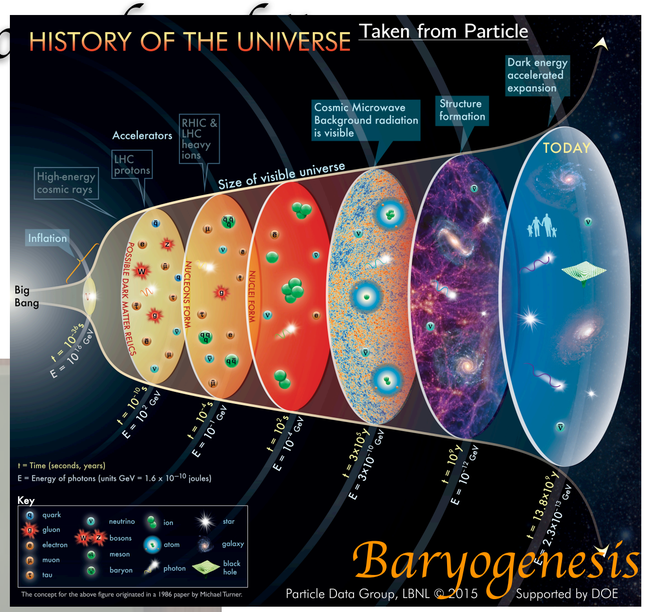


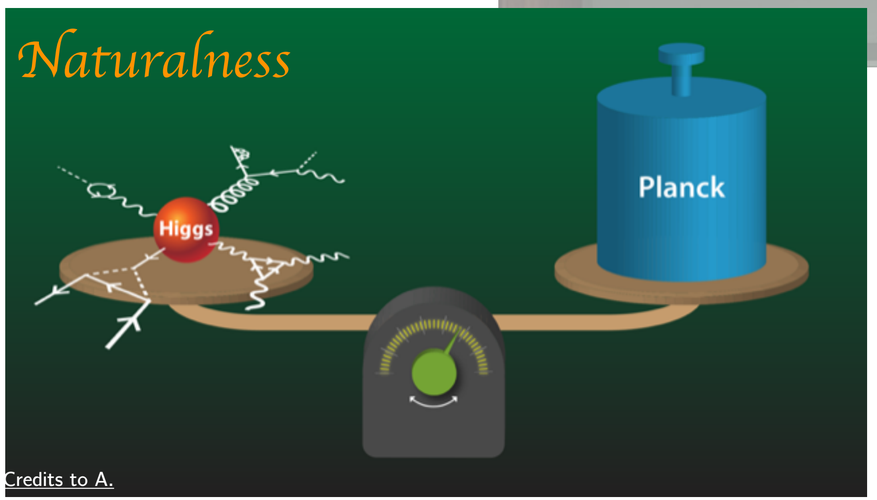
# The Standard Model -- A triumph… with puzzles

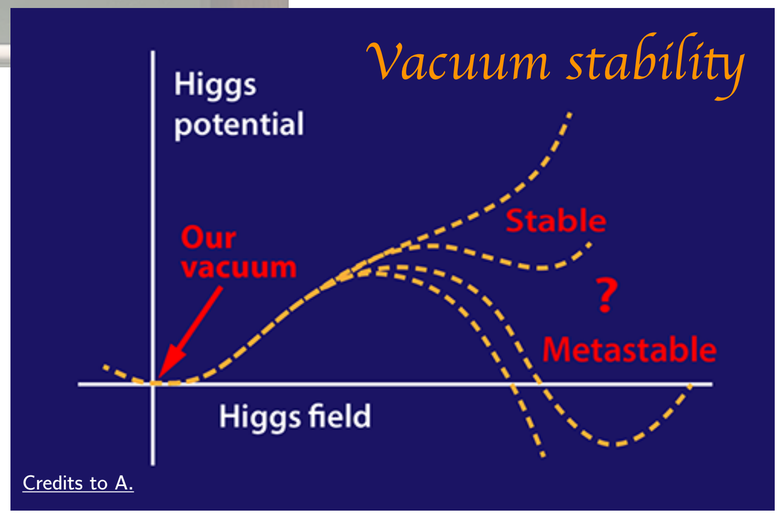
*Precise description of particle interactions up to the electro*



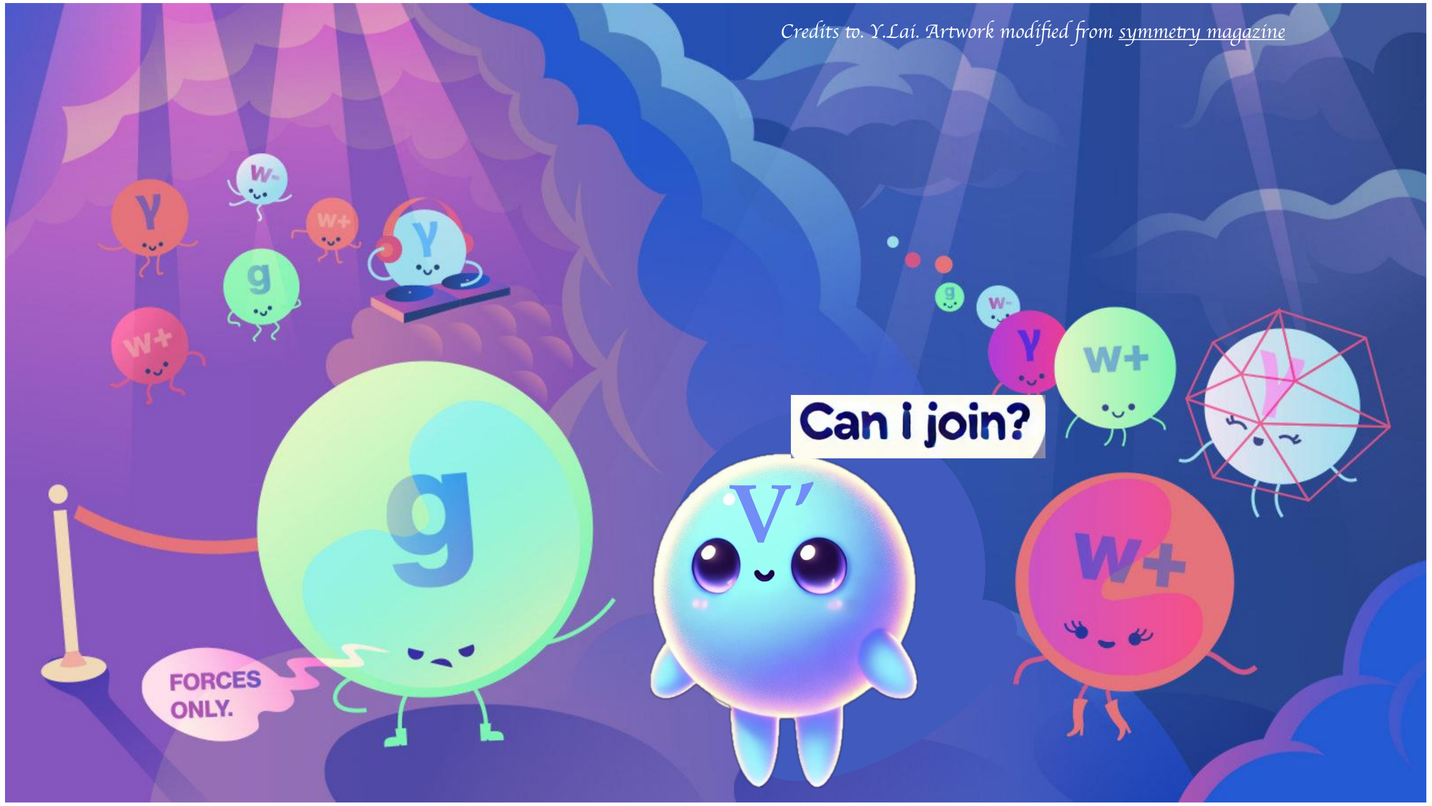



# Hunting for New Physics at the Energy Frontier

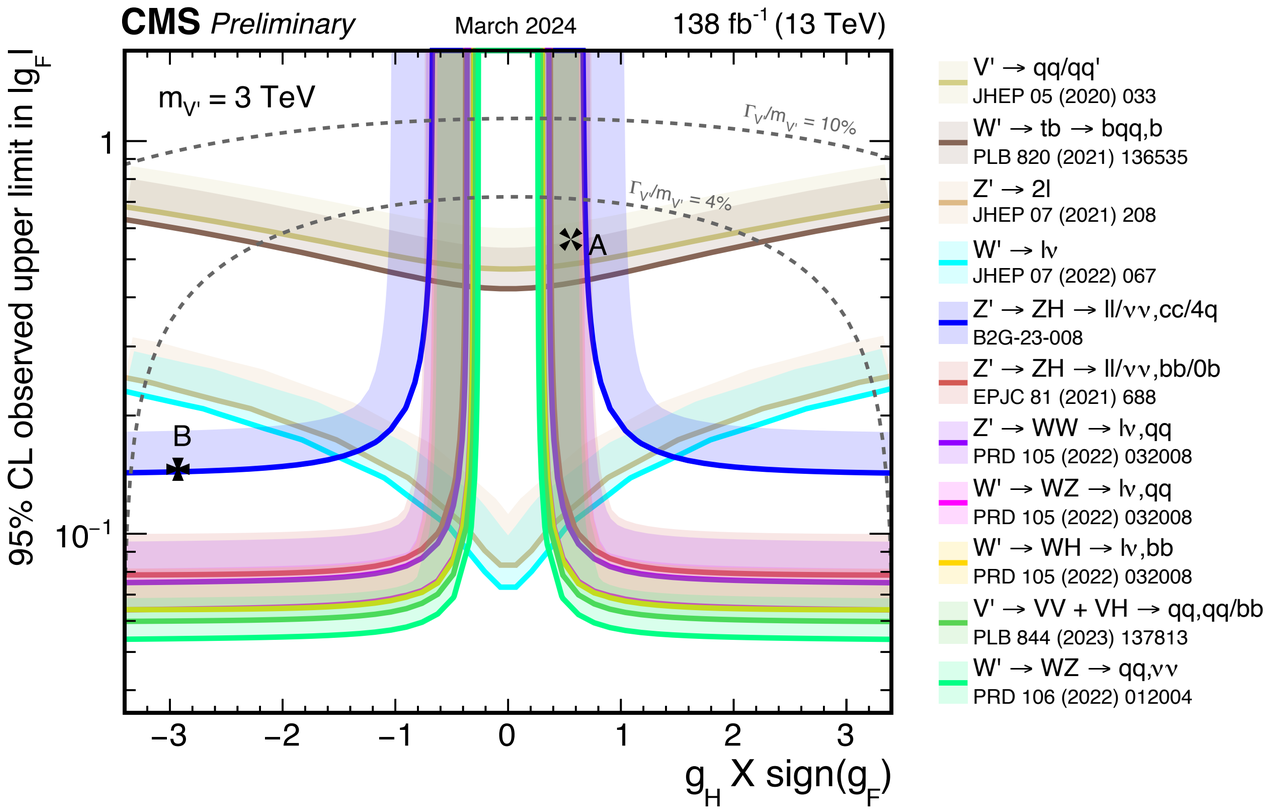
- Beyond the Standard Model (BSM) theory models predict:
  - Additional heavy bosons
  - Dark matter candidates
  - Extra-dimentions
  - ....
  - with properties largely unknown

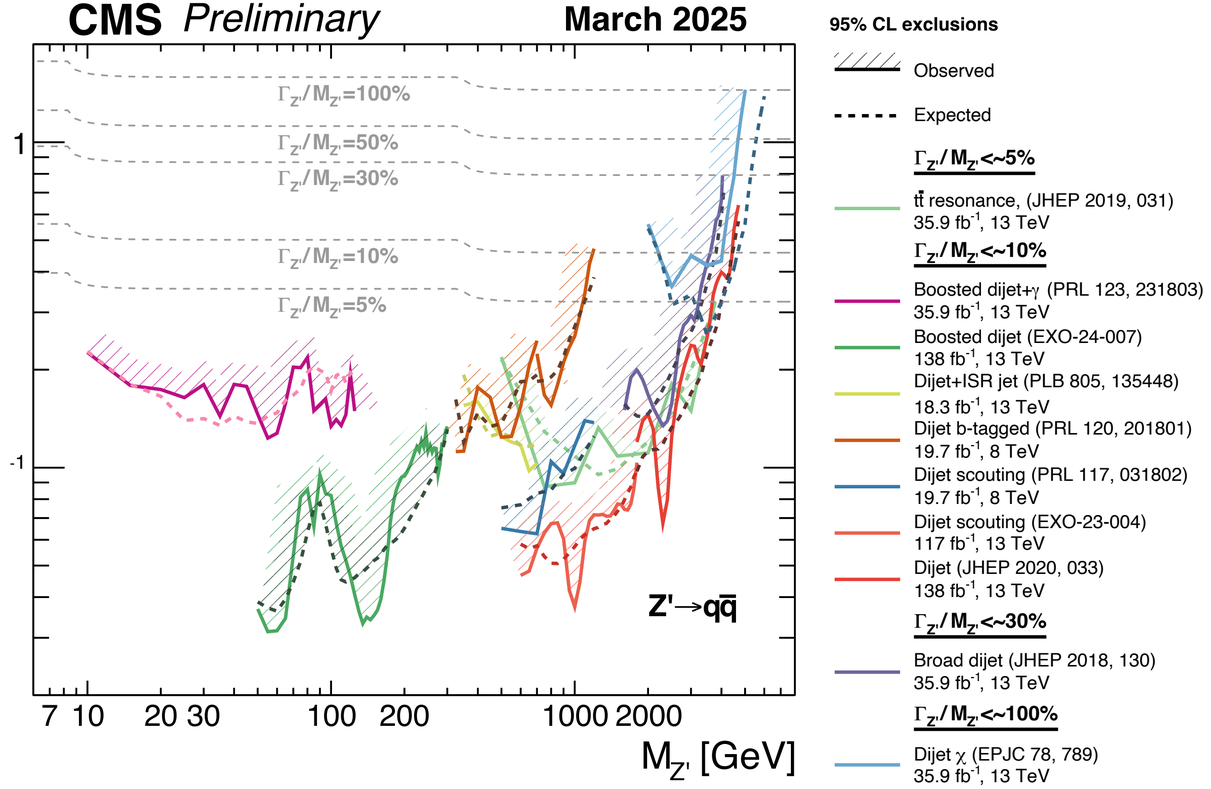



- Broad range of signatures to analyse at the LHC:
  - Hadronic final states
  - Leptons
  - missing transverse momentum

# New Physics searches in CMS

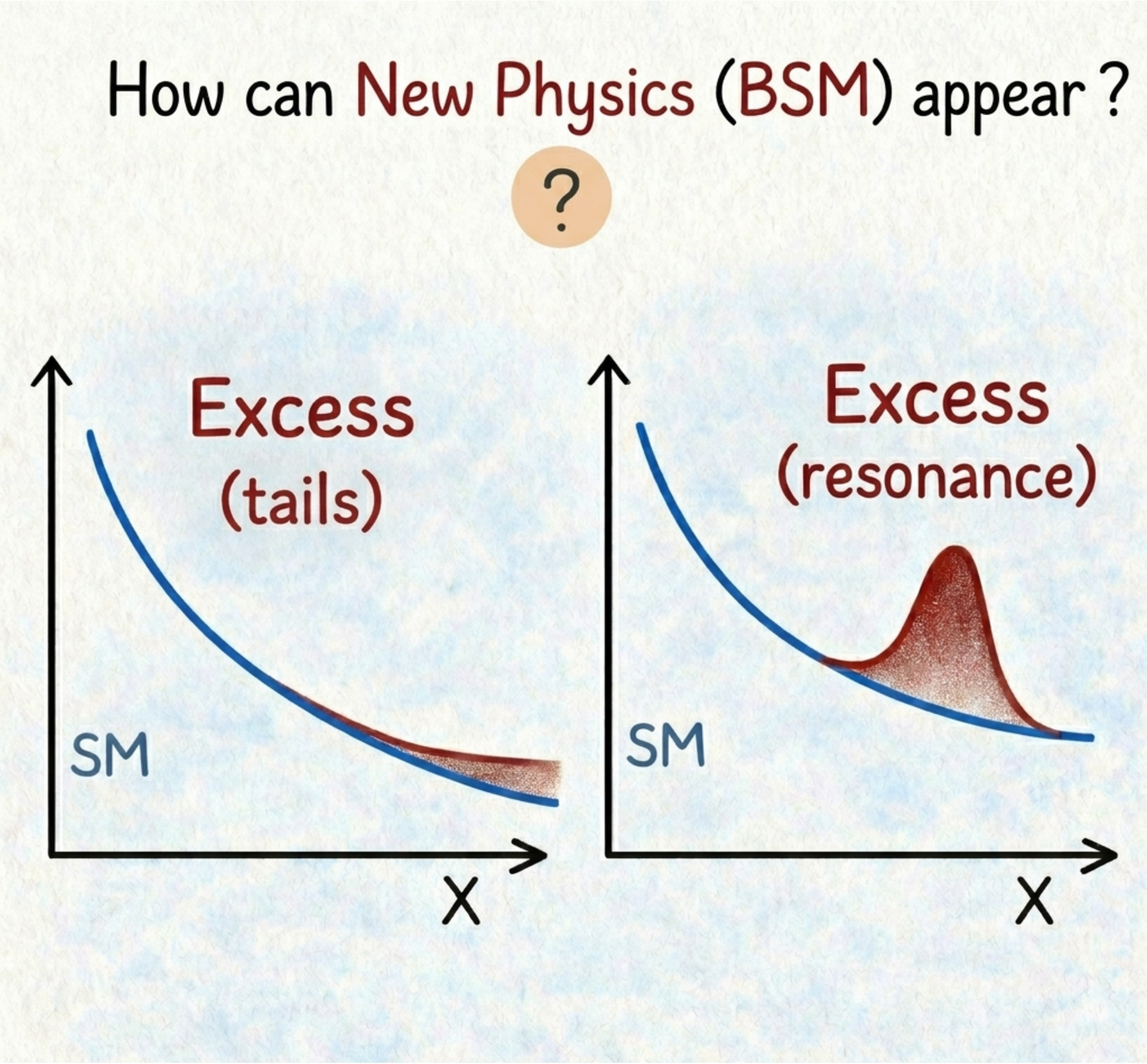
*More public results here and here*

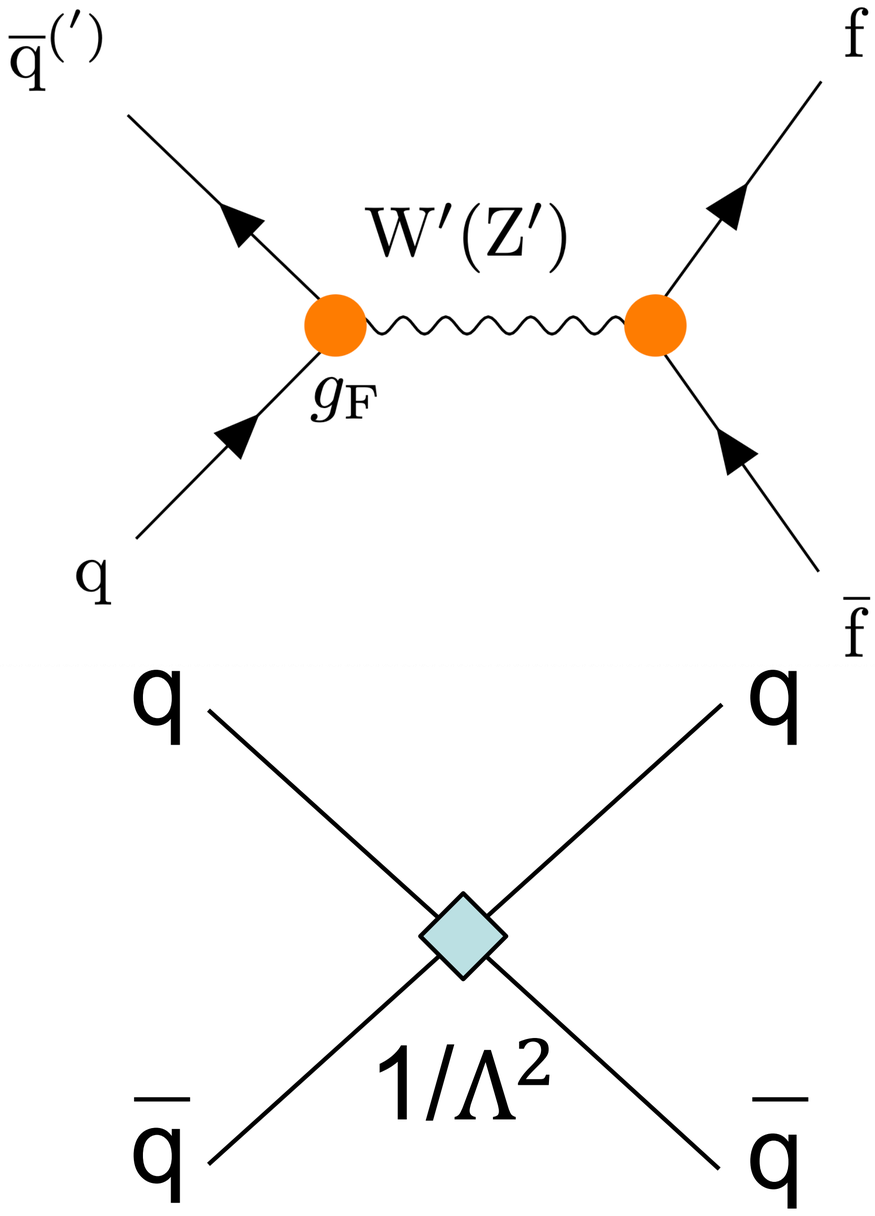



- CMS explores a wide range of models and experimental signatures
- **This talk highlights:**
  - Heavy vector resonances: Spin-1 combination: (Run 2)
  - New Run3 results on $W' \to l\nu$ searches (Run 3)
  - High-mass jet signatures: Dijet and pair of dijet searches (Run 2 & Run 3)

# New Physics at high masses



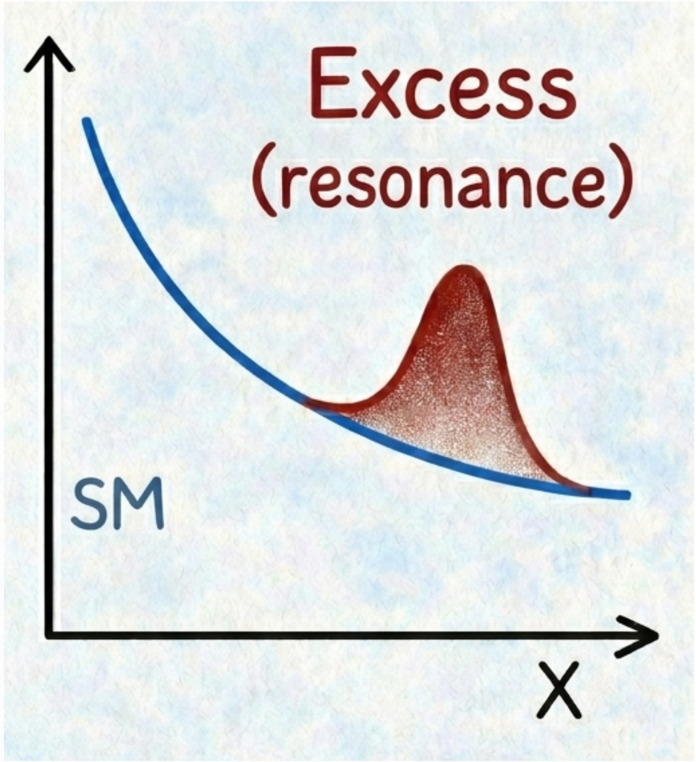



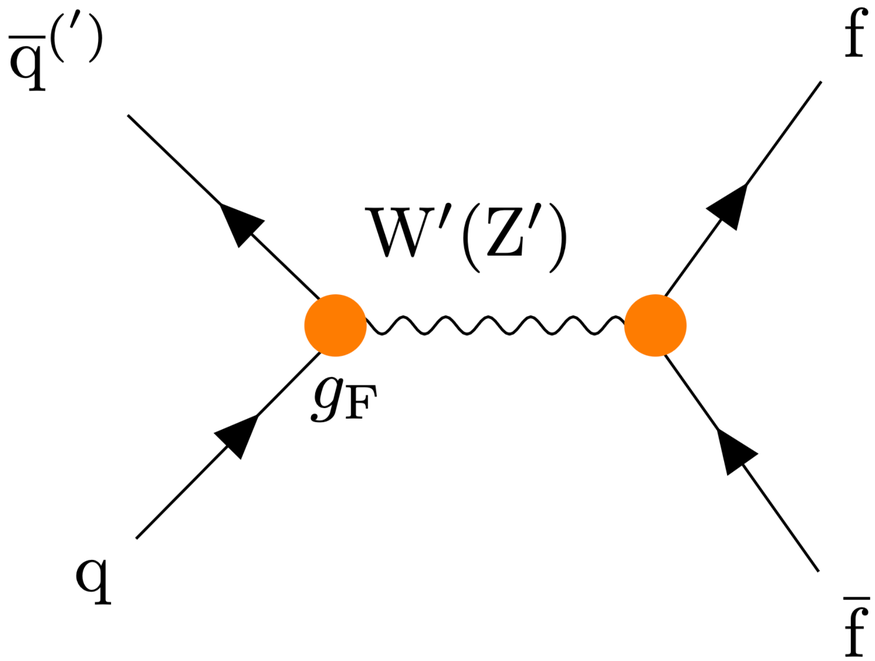
# New Physics at high masses

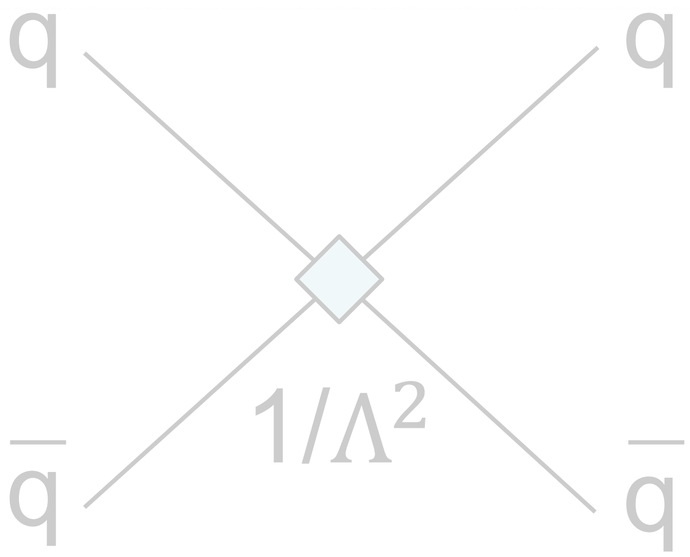
How can New Physics (BSM) appear ?

?



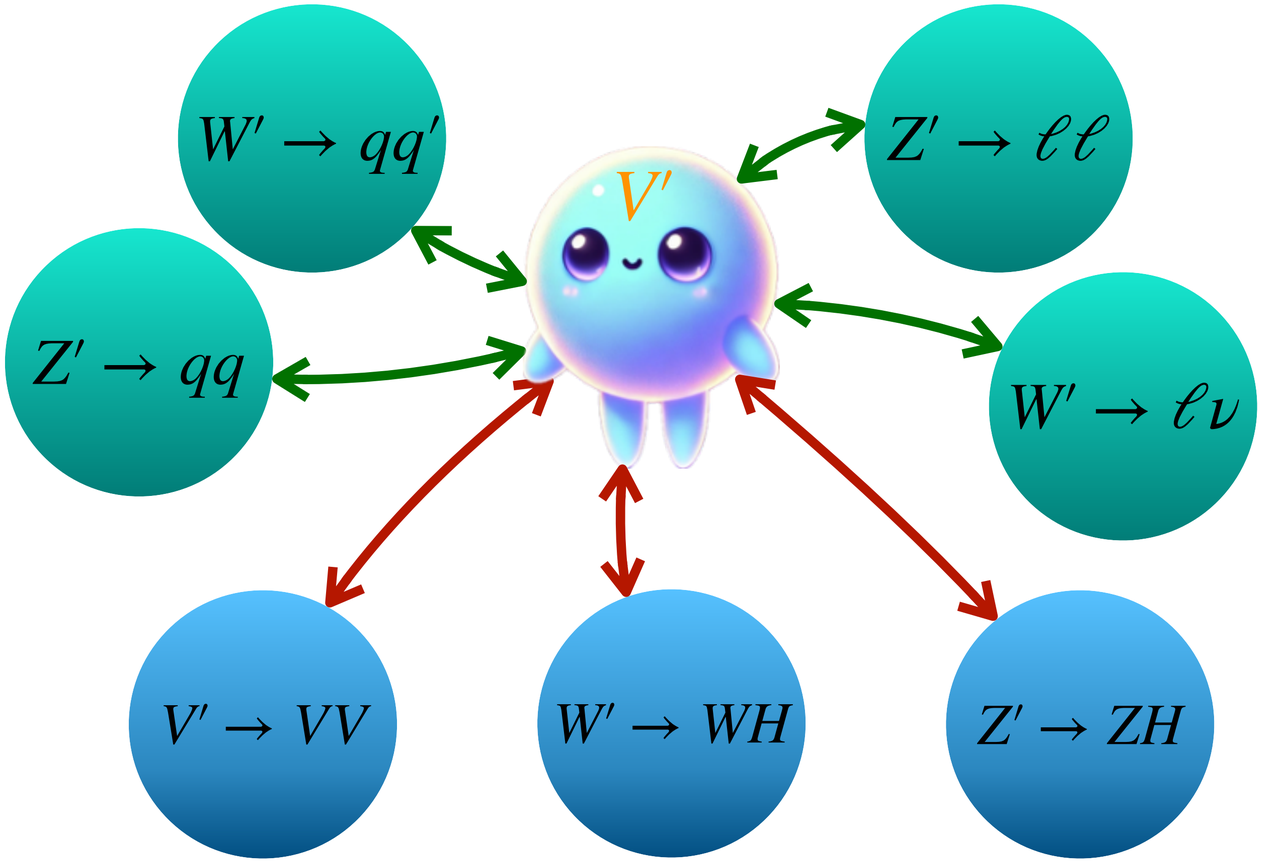



# Heavy vector bosons

Run 2

*Submitted to JHEP:* *arxiv:2601.12583*



# Heavy vector bosons -- Run2 fluctuations

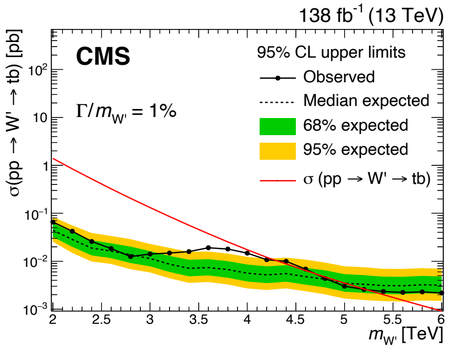
Run 2

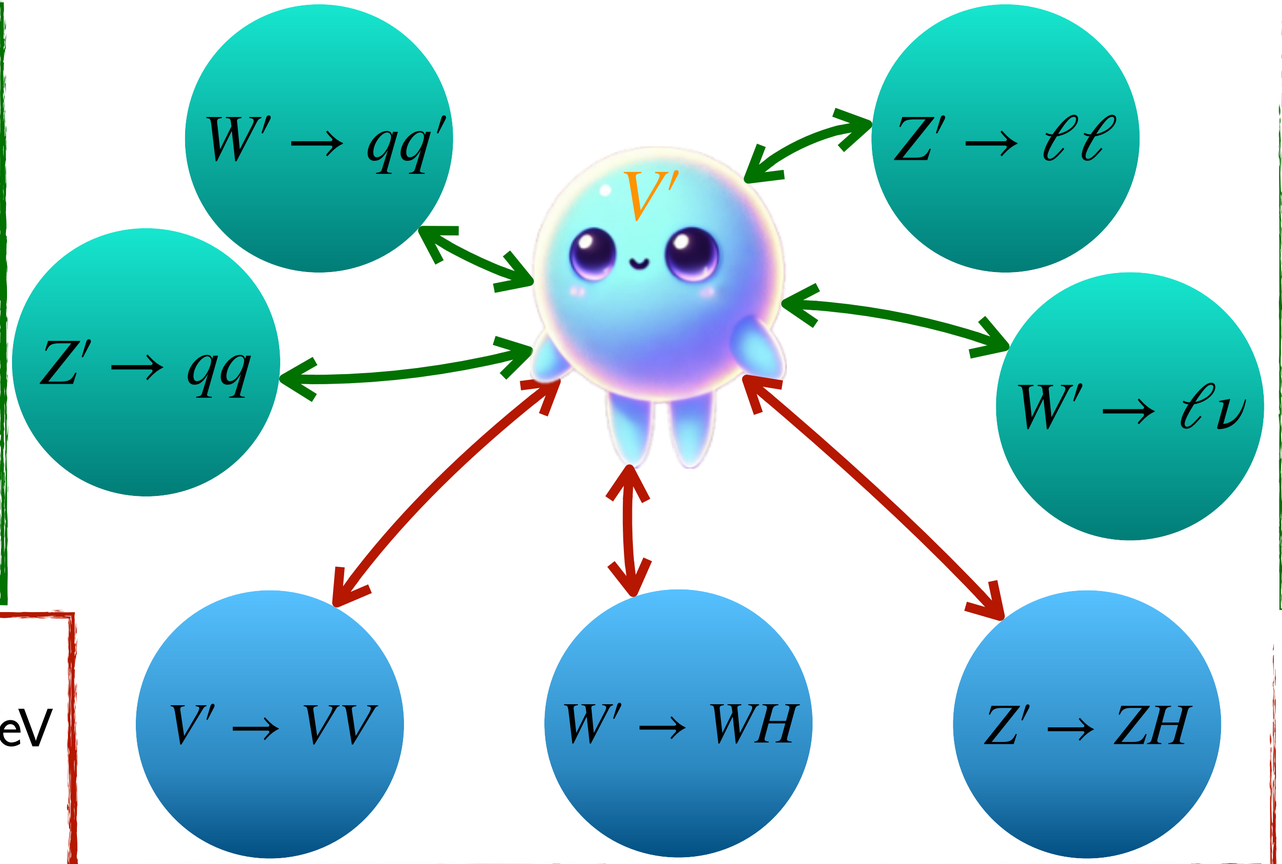
*Submitted to JHEP: arxiv:2601.12583*

$> 2\sigma$ local excess in

$W' \to tb$ at 3.4-4.4 TeV

for CMS-B2G-20-012

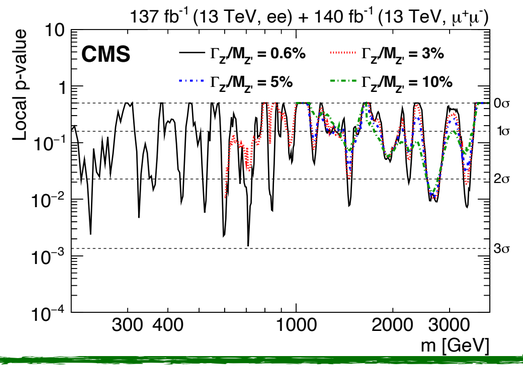



$> 2\sigma$ local excess in

$Z' \to \ell\ell$ at 2.7-3.4 TeV

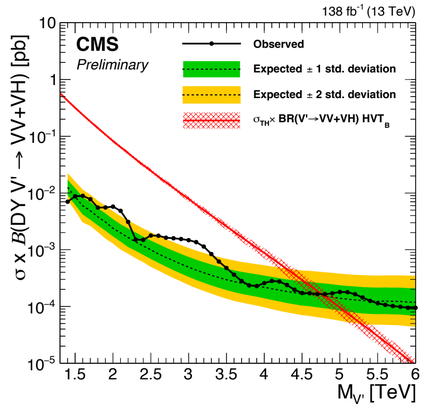
for CMS-EXO-19-019

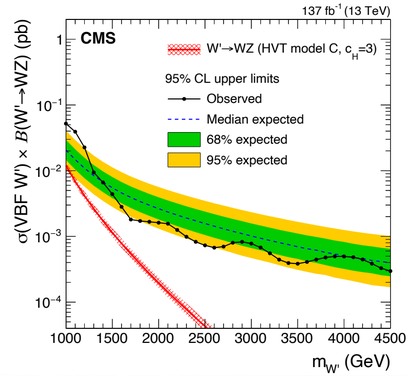



$> 3\sigma$ local excess in

$V' \to VV \to had$ at 2-3 TeV

for CMS-B2G-20-009




$> 2\sigma$ local excess in

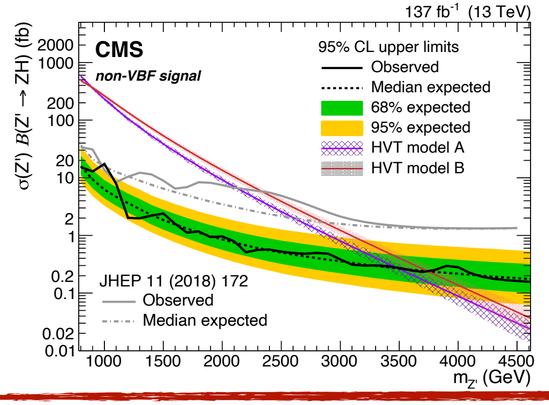
$W' \to W(\ell\nu)V(qq)$ at 1TeV

for CMS-B2G-19-002

$> 2\sigma$ local excess in

$Z' \to Z(\nu\nu)H(bb)$ at 1TeV

for CMS-B2G-19-006

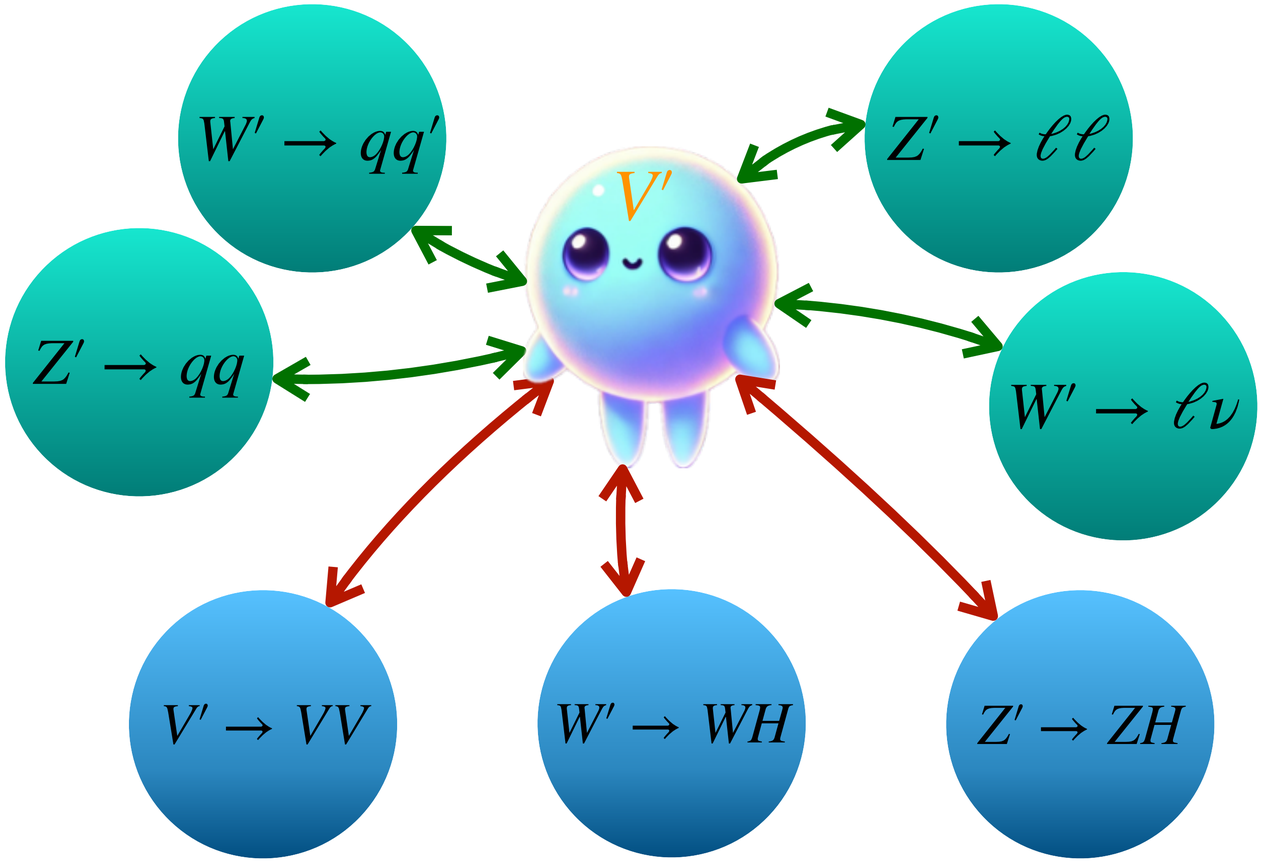


# Heavy vector bosons -- Legacy combination

Run 2

*Submitted to JHEP: arxiv:2601.12583*

- Combination of 16 searches:
  - Maximal coverage of final states
  - Different sensitivity across the parameter space
- Interpretation under the HVT framework
  - Simplified framework for spin-1 resonances
  - Couplings controlled by 2 parameters

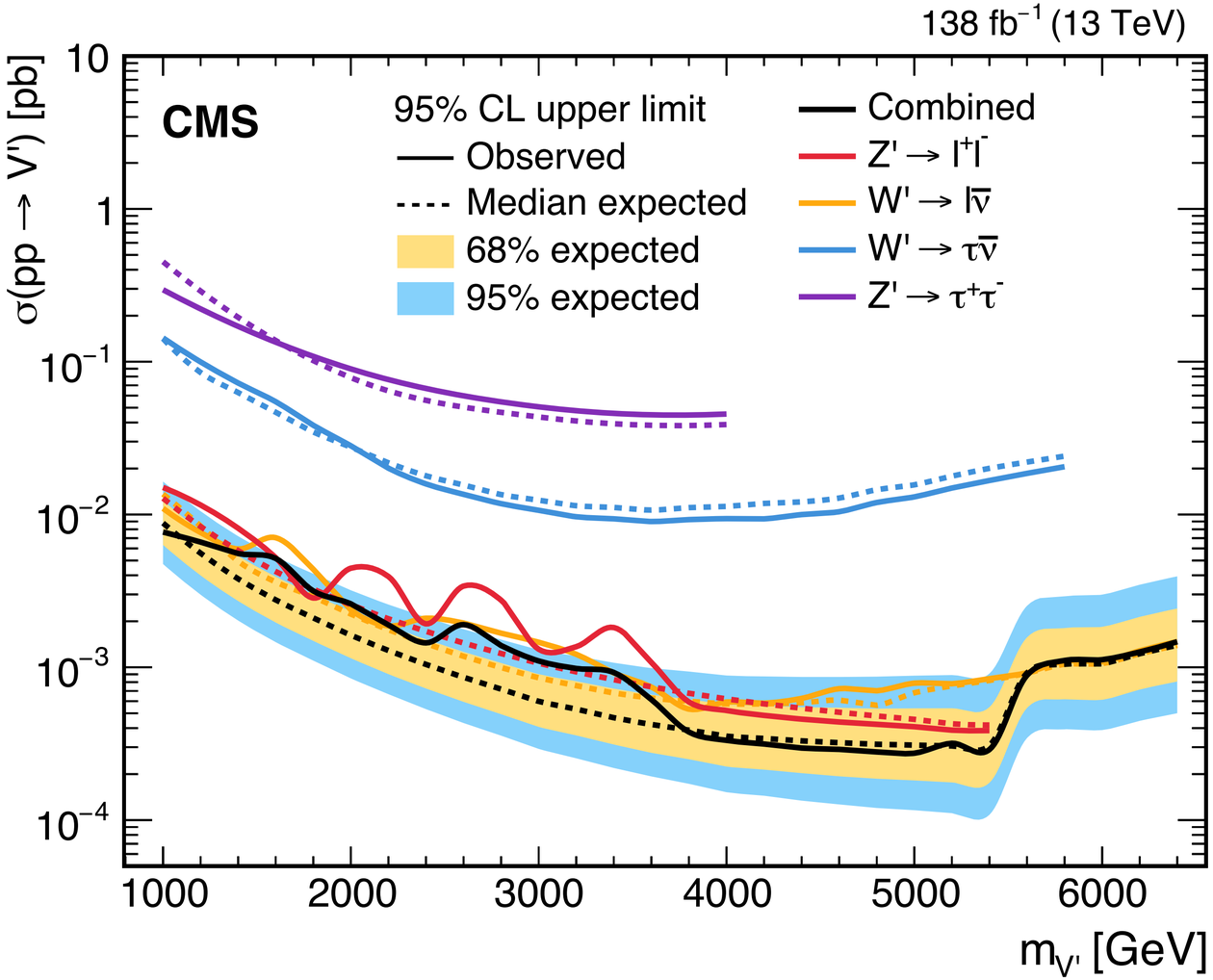


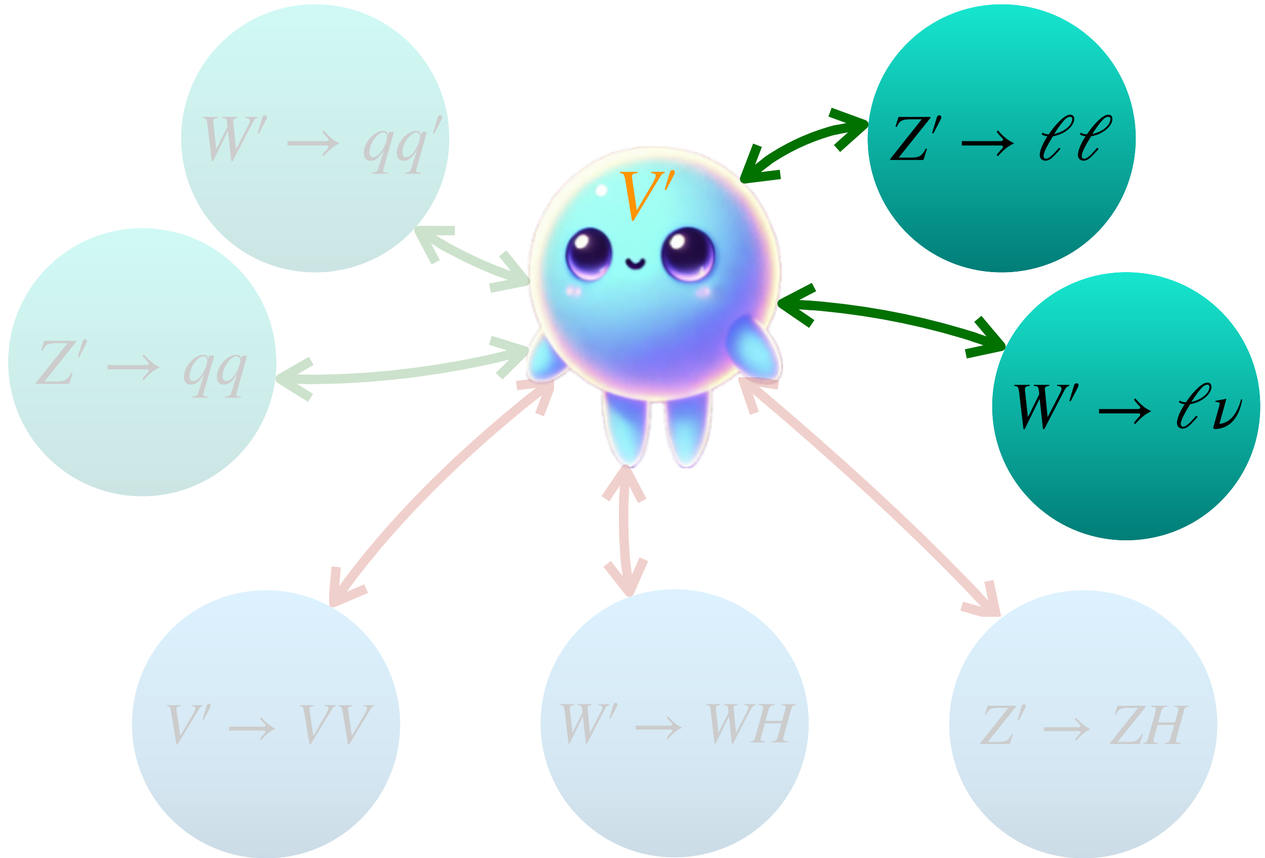

| Channel | Prod. modes | $m_{V'}$ range [TeV] | Leptons | Jets | Reference |
|---|---|---|---|---|---|
| $Z' \to \tau^+\tau^-$ | DY | 0.5–4.0 | $\ell\tau_h$ or $2\tau_h$ | — | [47] |
| $Z' \to \ell^+\ell^-$ | DY | 0.8–5.5 | $2\ell$ | — | [48] |
| $W' \to \ell\overline{\nu}$ | DY | 0.8–6.0 | $1\ell$ | — | [49] |
| $W' \to \tau\overline{\nu}$ | DY | 0.8–6.0 | $1\tau_h$ | — | [50] |
| $V' \to q\overline{q}^{(\prime)}$ | DY | 1.8–8.7 | $0\ell$ | $jj$ | [51] |
| $W' \to t\overline{b}$ $(0\ell)$ | DY | 1.0–4.0 | $0\ell$ | $j^t j^b$ | [52] |
| $W' \to t\overline{b}$ $(1\ell)$ | DY | 2.0–6.0 | $1\ell$ | $j^b j^b$ | [53] |
| $Z' \to t\bar{t}$ $(1\ell)$ | DY | 0.8–5.0 | $1\ell$ | $j^t$ or $jjj^b$ | [54] |
| $Z' \to ZH$ $(2\ell 2b)$ | DY + VBF | 0.8–5.0 | $2\ell$ | $j^{bb}$ | [55] |
| $Z' \to ZH$ $(2\nu 2b)$ | DY + VBF | 0.8–5.0 | $0\ell$ | $j^{bb}$ | [55] |
| $Z' \to ZH$ $(2\ell 2q)$ | DY | 1.2–6.0 | $2\ell$ | $j^H$ | [56] |
| $Z' \to ZH$ $(2\nu 2q)$ | DY | 1.2–6.0 | $0\ell$ | $j^H$ | [56] |
| $W' \to WZ$ $(2q2\ell)$ | DY | 0.6–2.0 | $2\ell$ | $j^V$ or $jj$ | [57] |
| $W' \to WZ$ $(2q2\nu)$ | DY + VBF | 1.0–4.5 | $0\ell$ | $j^V$ | [58] |
| $V' \to WV/WH$ | DY + VBF | 1.0–4.5 | $1\ell$ | $j^V$ | [59] |
| $V' \to VV/VH$ | DY + VBF | 1.3–6.0 | $0\ell$ | $j^V j^V$ | [20] |

# Heavy vector bosons -- Leptonic channels

Run 2

Submitted to JHEP: arxiv:2601.12583



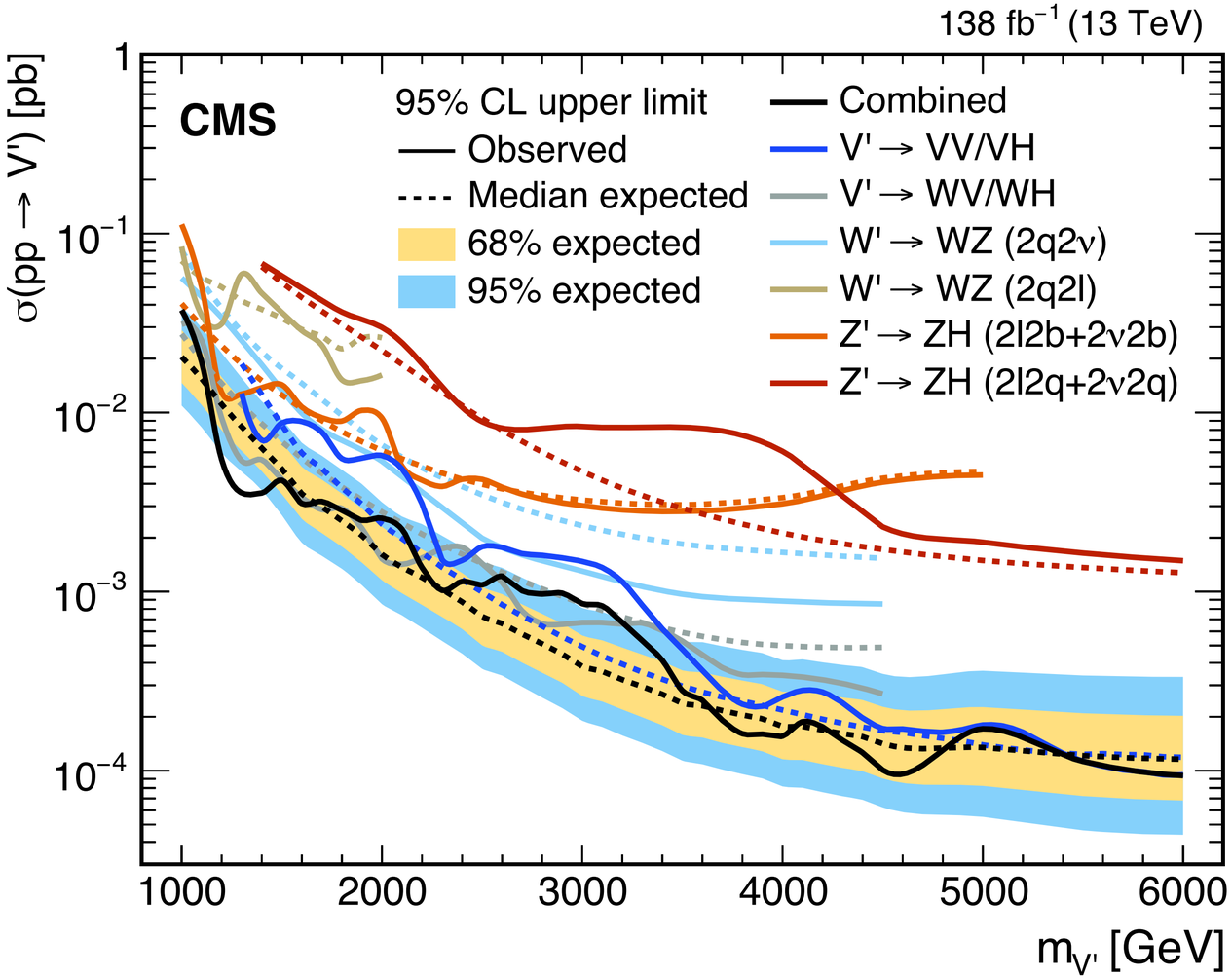

*Mass scan*

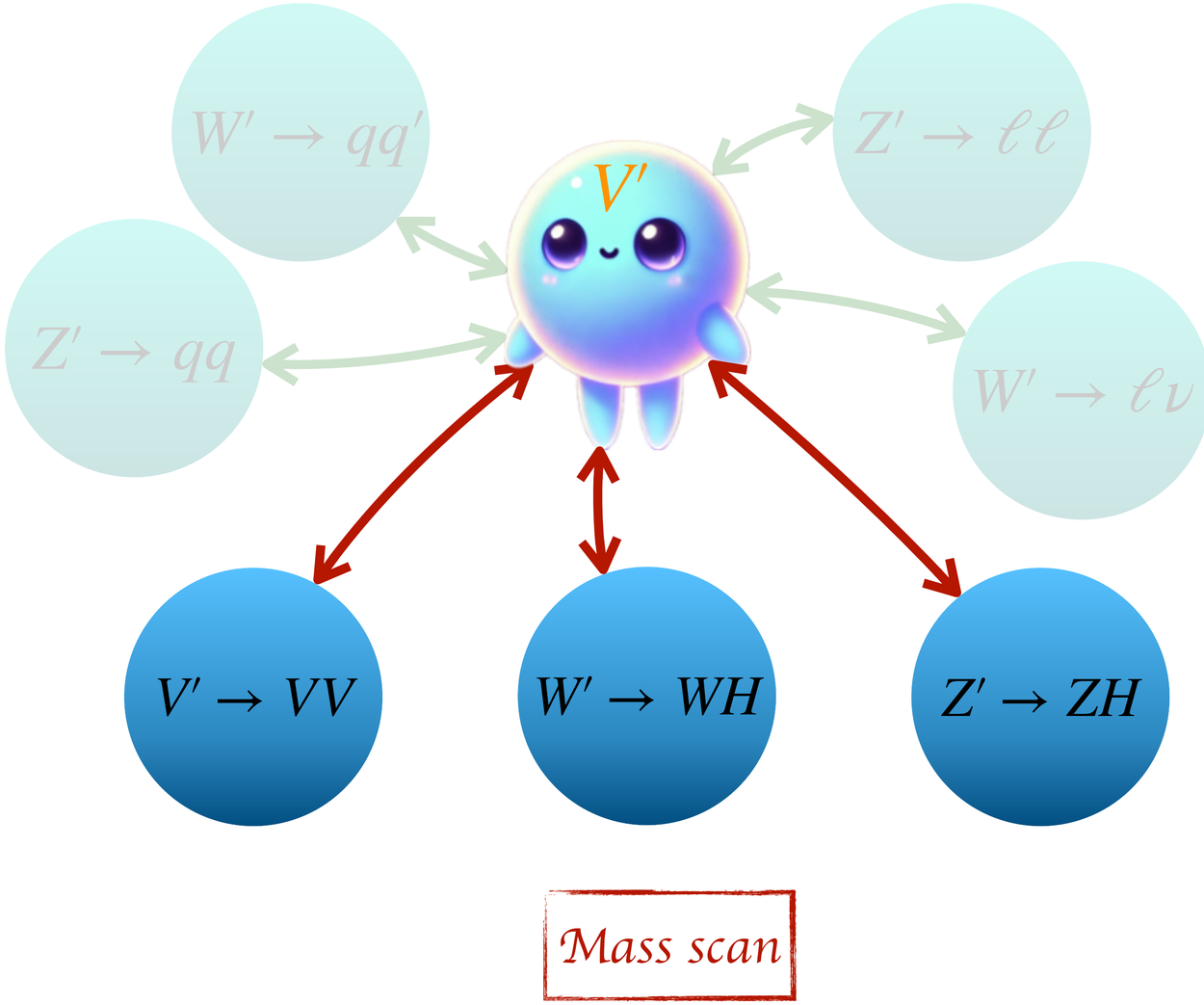
- $Z' \to \ell\ell$ and $W' \to \ell\nu$ as leading channels
- Previous 2.7–3.4 TeV fluctuation in $Z' \to \ell\ell$ reduced
- No significant deviations observed

# Heavy vector bosons -- Bosonic channels

Run 2

Submitted to JHEP: arxiv:2601.12583



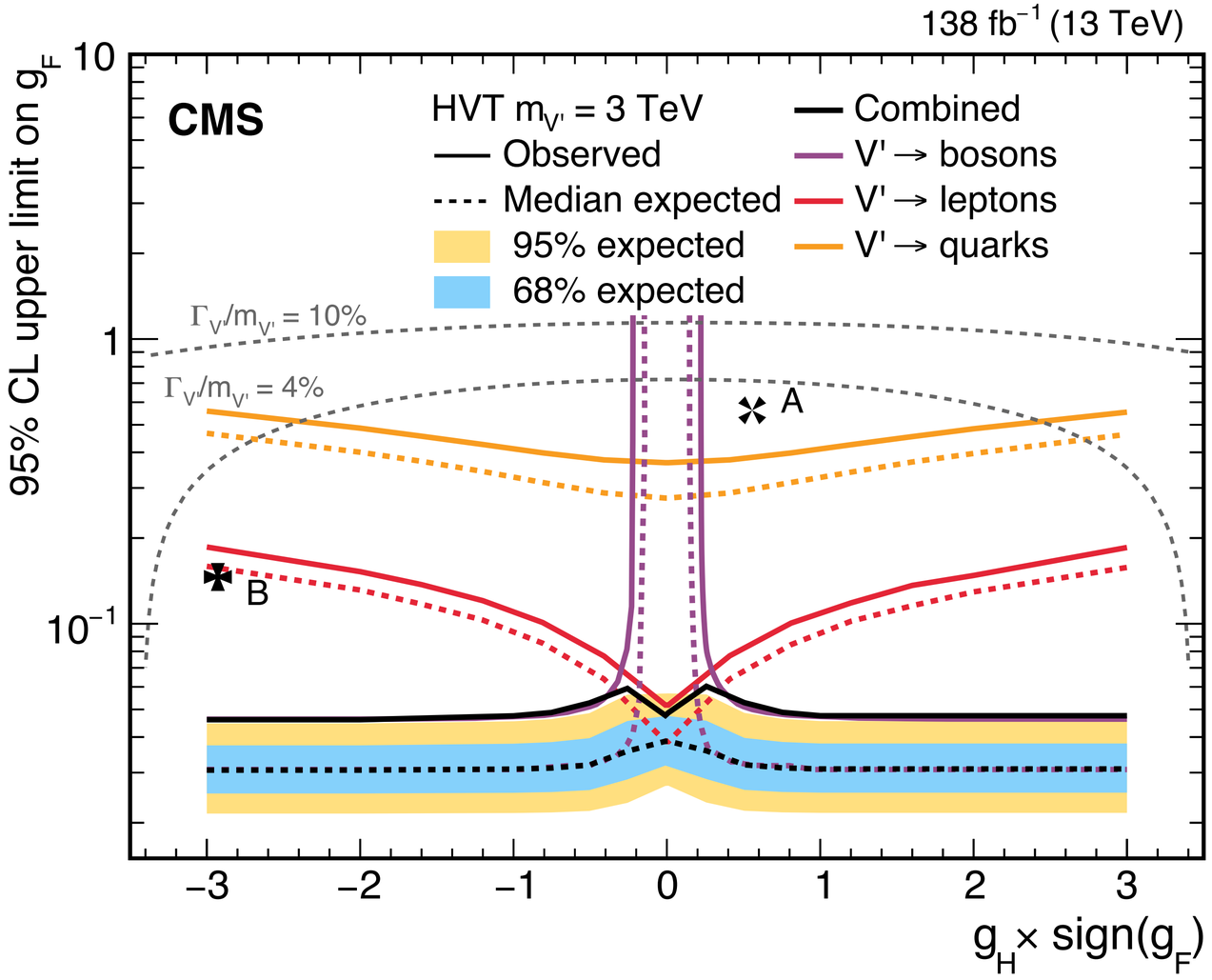

*Mass scan*

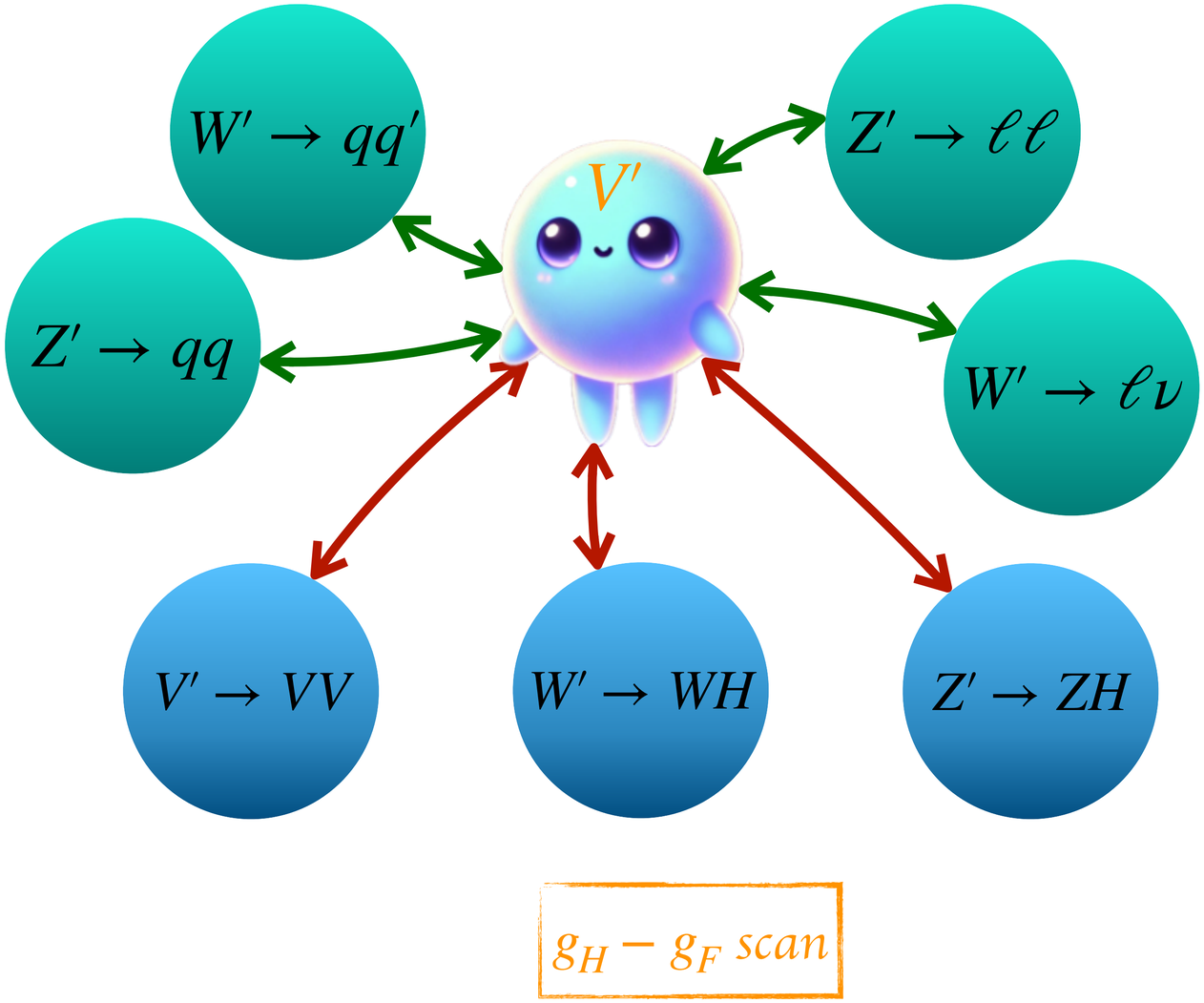
- $V' \to VV/VH \to had$ as leading channel
- Run-2 tensions at 1–3 TeV are reduced
- No significant deviations observed

# Heavy vector bosons -- Coupling scan

Run 2

Submitted to JHEP: arxiv:2601.12583



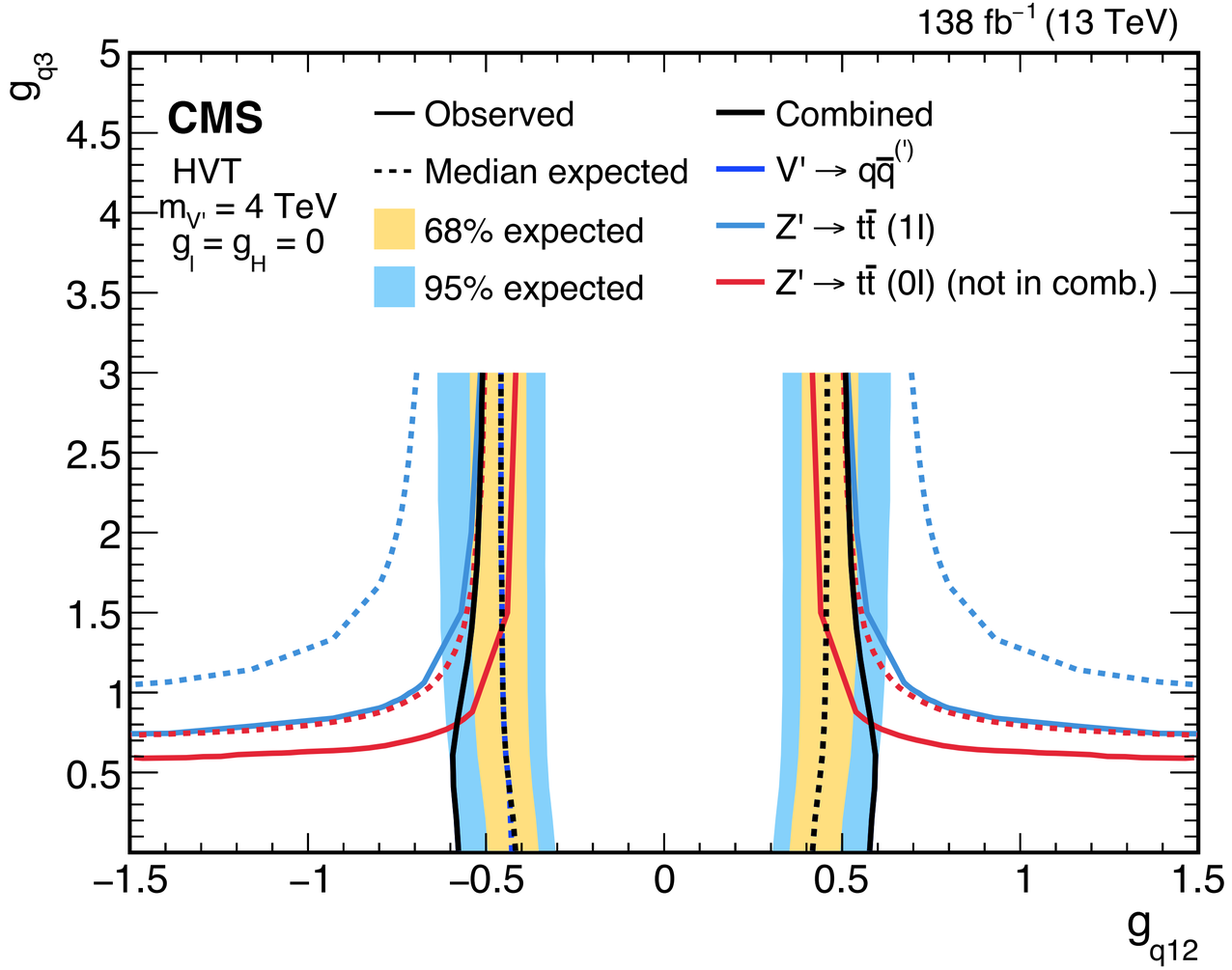

$g_H - g_F$ scan

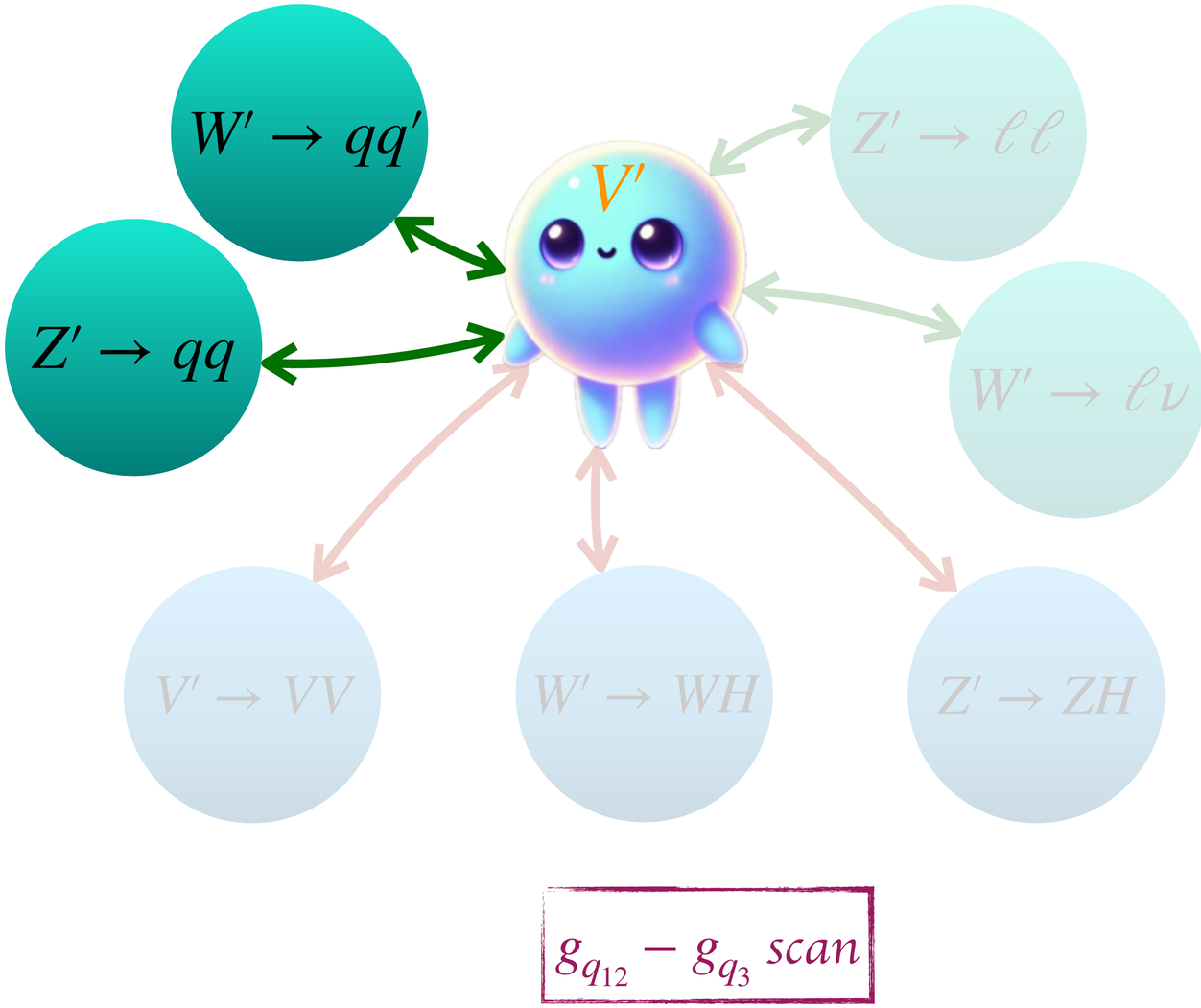
- Sensitivity depends on the relative couplings to fermions and bosons
- No significant deviation observed up to 6 TeV

# Heavy vector bosons -- Coupling scan

Run 2

Submitted to JHEP: arxiv:2601.12583

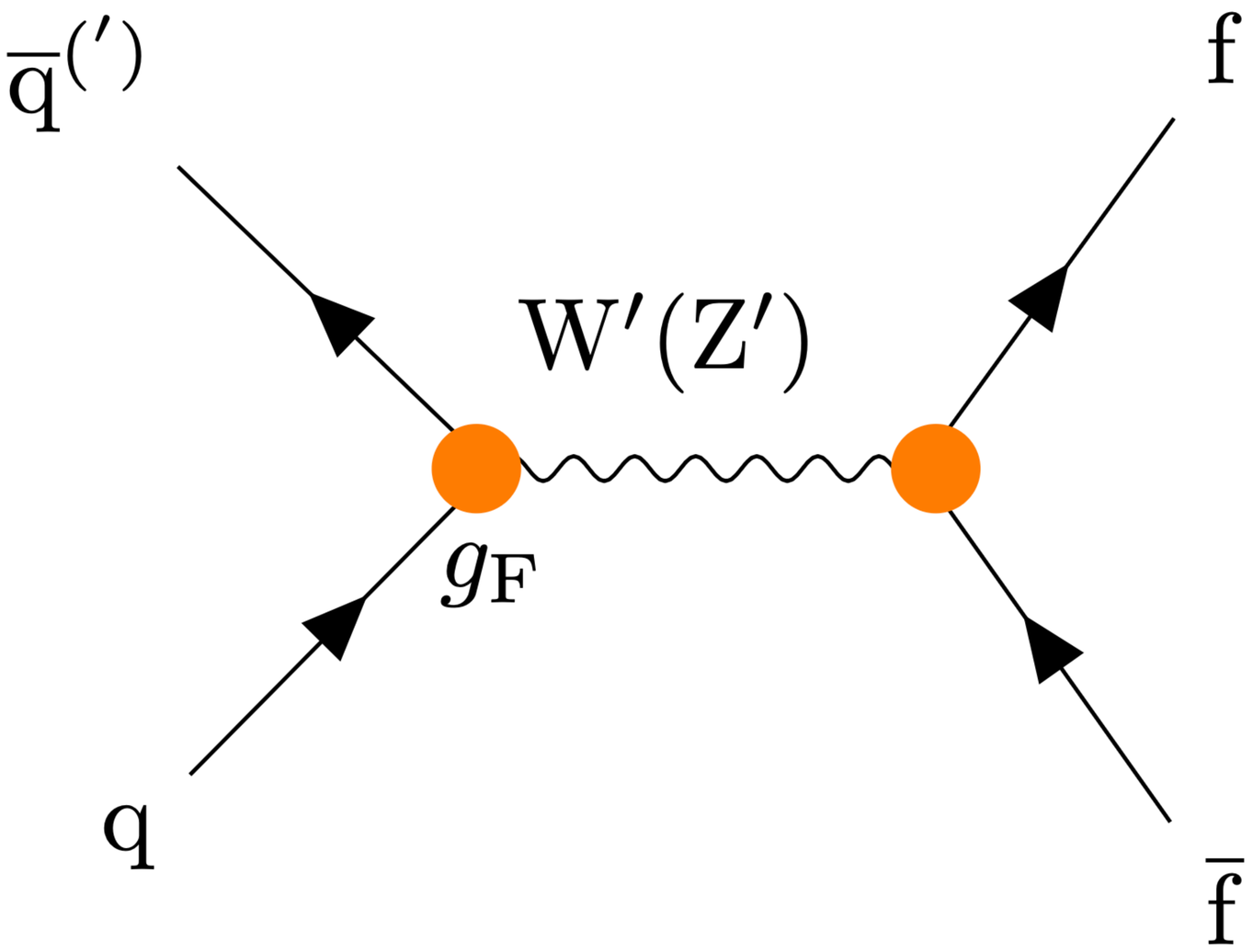



$g_{q_{12}} - g_{q_3}$ *scan*

- Beyond the assumption of fermion universality
- $g_{q_3} - g_H$ and $g_{q_3} - g_{l_3}$ entirely excluded

# Search for $W' \to l\nu$



# Search for $W' \to l\nu$

Run 3

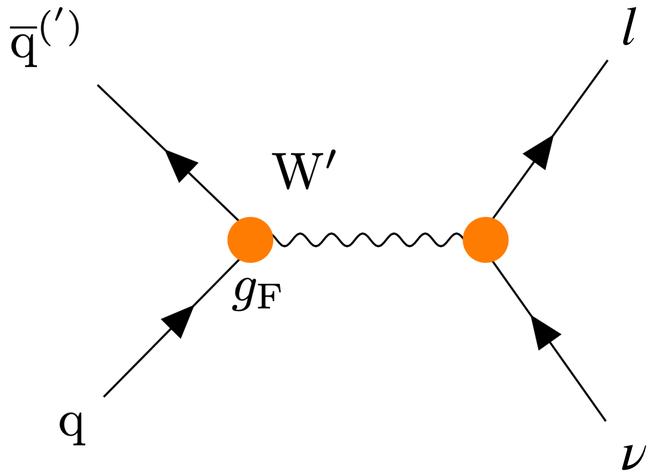
CMS-EXO-24-021

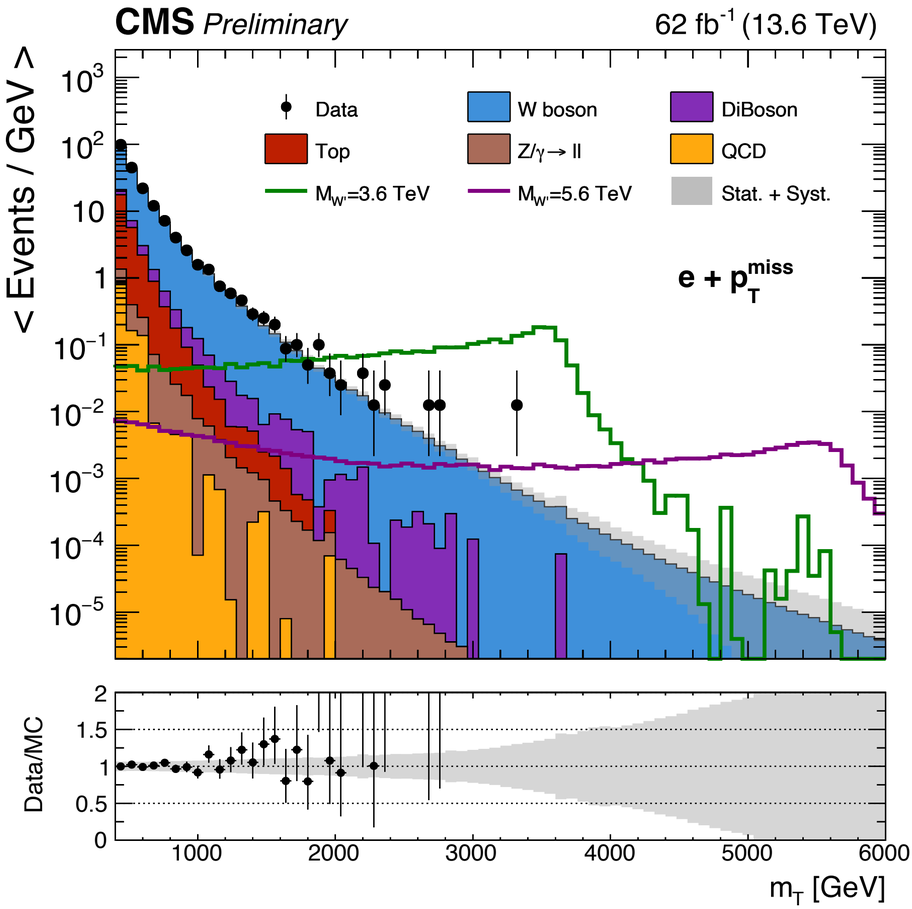
One of the most sensitive probes of heavy vector bosons

- Clean experimental signature
  - High-$p_T$ isolated lepton (e or $\mu$)
  - Large missing transverse momentum

- Transverse mass ($m_T$) used as the sensitive variable
  - $m_T = \sqrt{2 \cdot p_T^l p_T^{miss} \cdot \left(1 - \cos \Delta\phi(p_T^l, p_T^{miss})\right)}$

- Leading uncertainties:
  - Exp: Jet and lepton energy scale
  - Theo: PDF and high-$m_T$ cross section



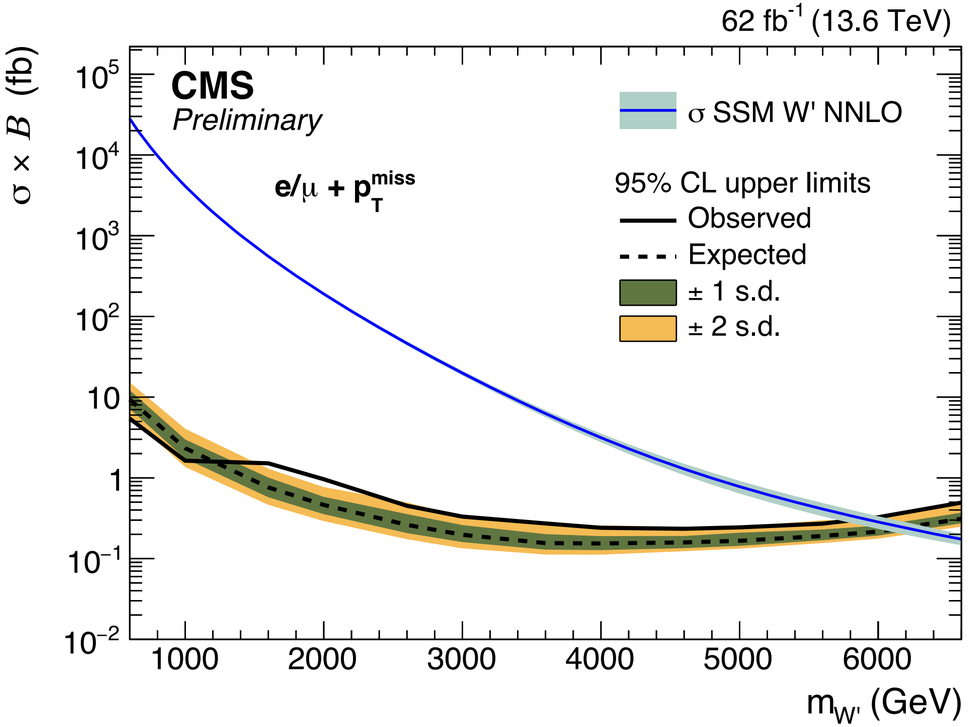



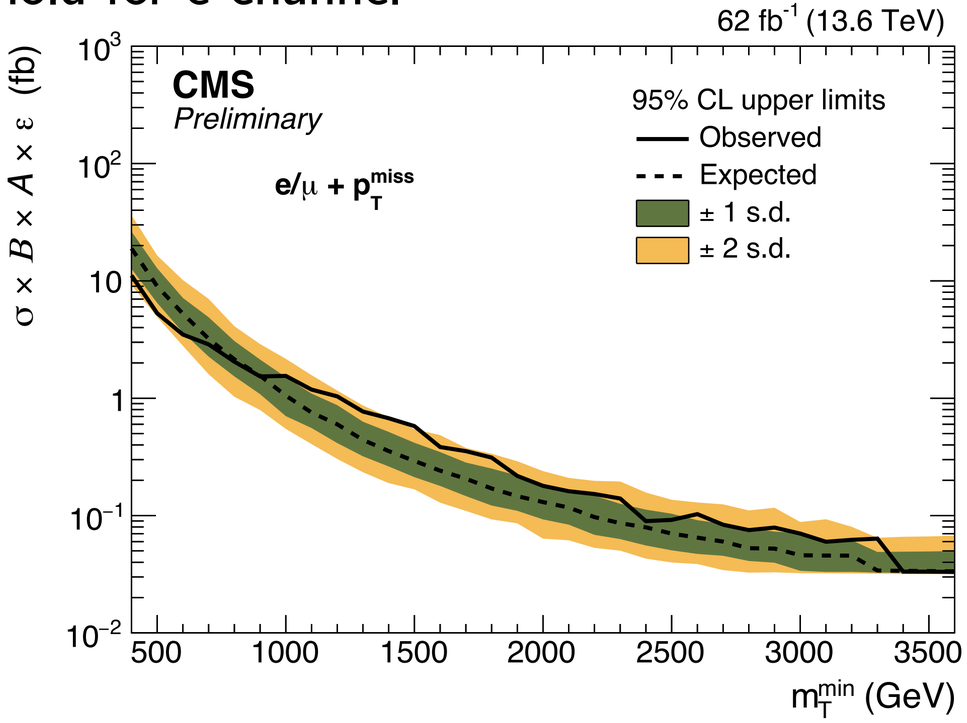
# Search for $W' \to l\nu$ -- Results

Run 3

CMS-EXO-24-021

- **No significant deviation from the SM**
  - SSM W' mass excluded up to $\sim 6\ TeV$
  - Model-independent interpretation
- Improved sensitivity compared to Run2
  - Higher center-of-mass energy
  - Lower trigger threshold for e-channel



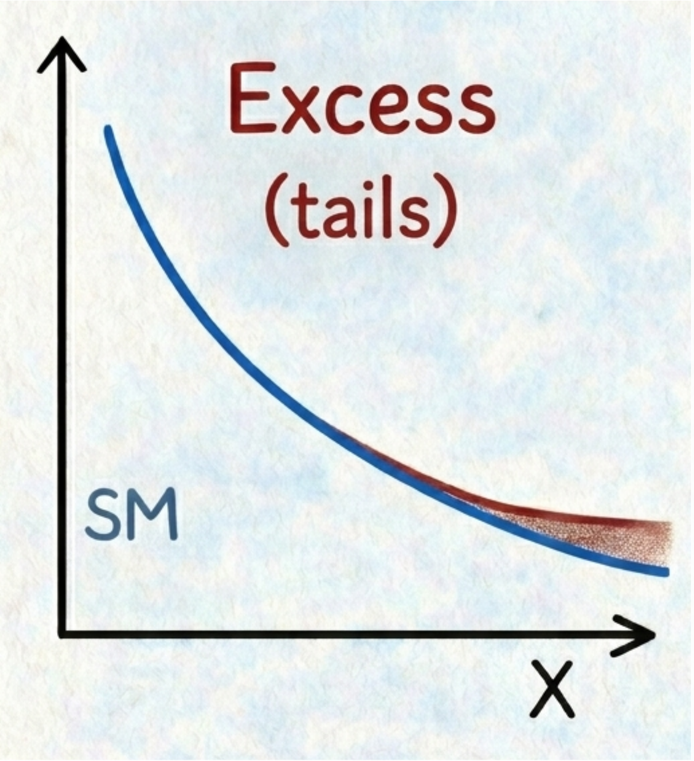




| Dataset | e channel Obs (exp) TeV | μ channel Obs (exp) TeV | e+μ channel Obs (exp) TeV |
|---|---|---|---|
| Run2 | 5.4 (5.3) | 5.6 (5.5) | 5.7 (5.6) |
| 2022+2023 | 5.7 (5.9) | 5.6 (6.0) | 5.9 (6.2) |

# New Physics at high masses

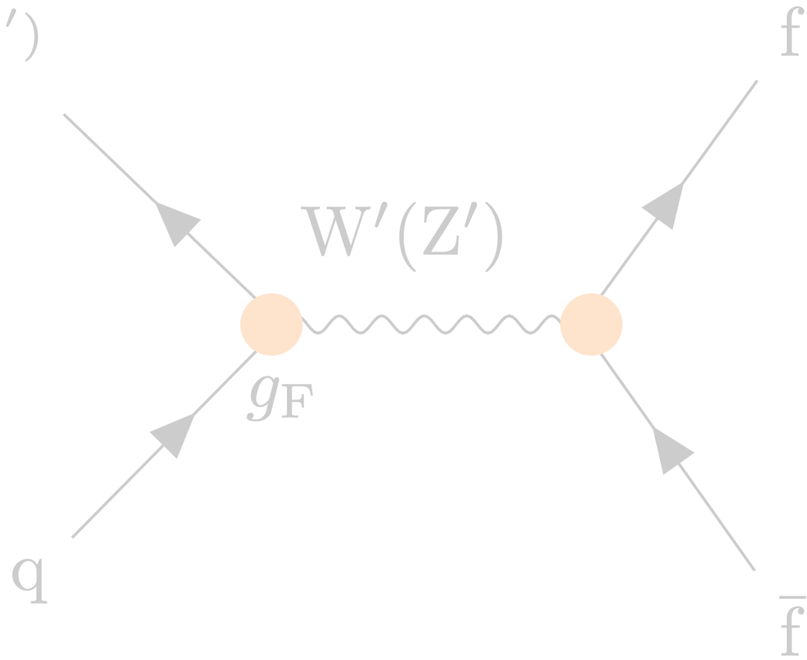
How can New Physics (BSM) appear ?

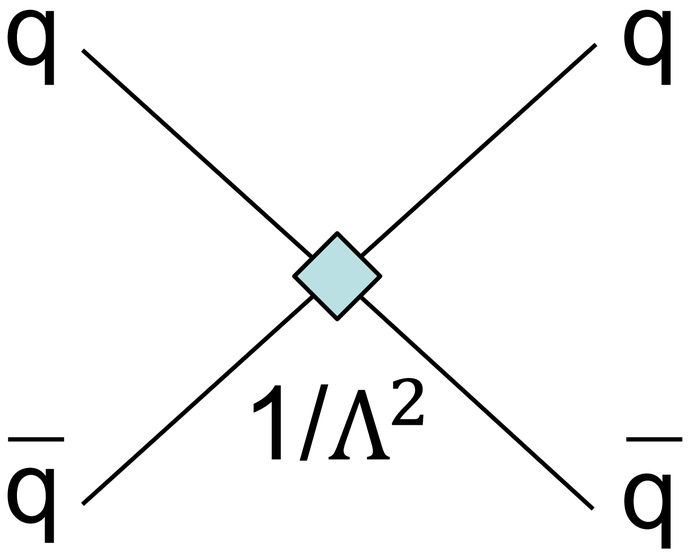
?









# Dijet angular analysis

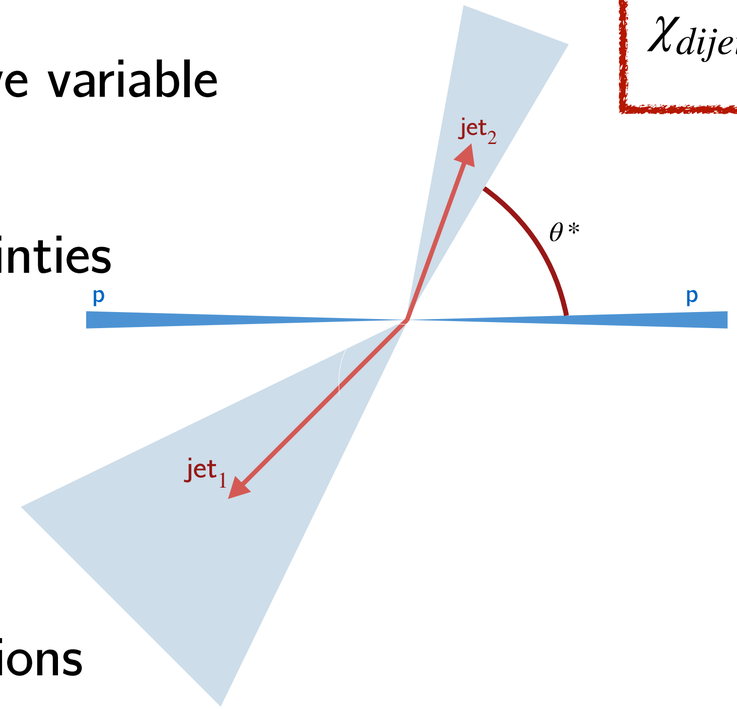
Run 2

CMS-EXO-24-011: paper to be submitted

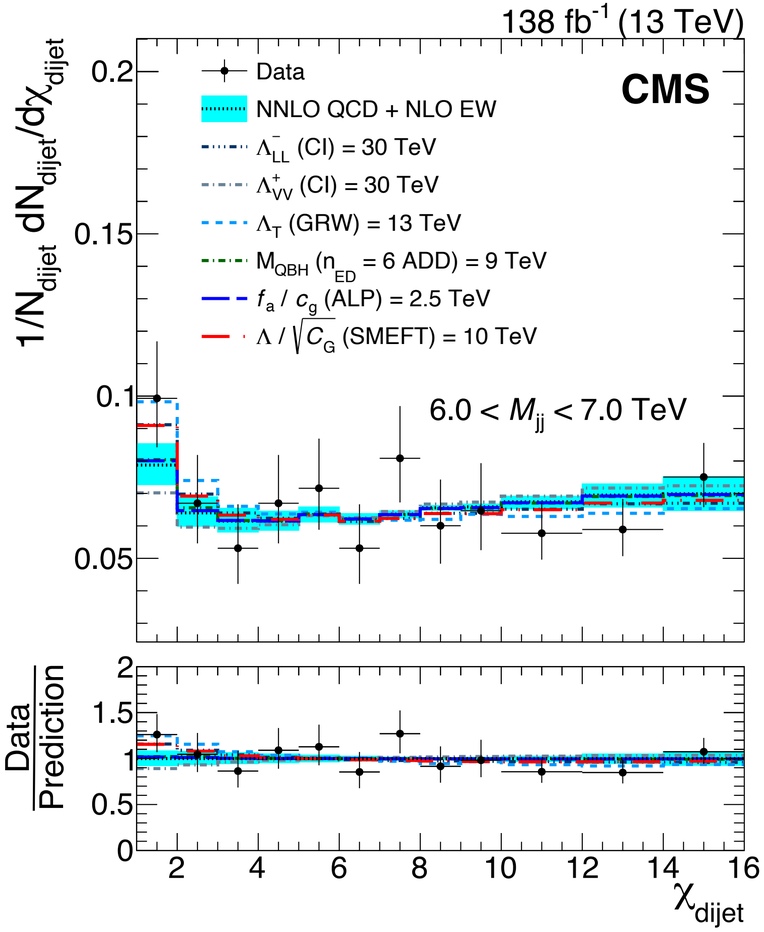
## Nonresonant effects in dijet production

$$\chi_{dijet} = exp(|y_1 - y_2|) \sim \frac{1+\cos(\theta^*)}{1-\cos(\theta^*)}$$

- Angular distribution ($\chi_{dijet}$) as the sensitive variable
  - Scattering angle of the dijet system
  - Small dependence on theoretical uncertainties




- Normalised differential cross sections:
  - Compared to NNLO QCD + EW predictions
  - Detector response accounted for via response smearing




- Leading uncertainties:
  - Exp: Jet energy scale and resolution
  - Theo: Scale choice of $\mu_R/\mu_F$ (updated wrt. previous results)

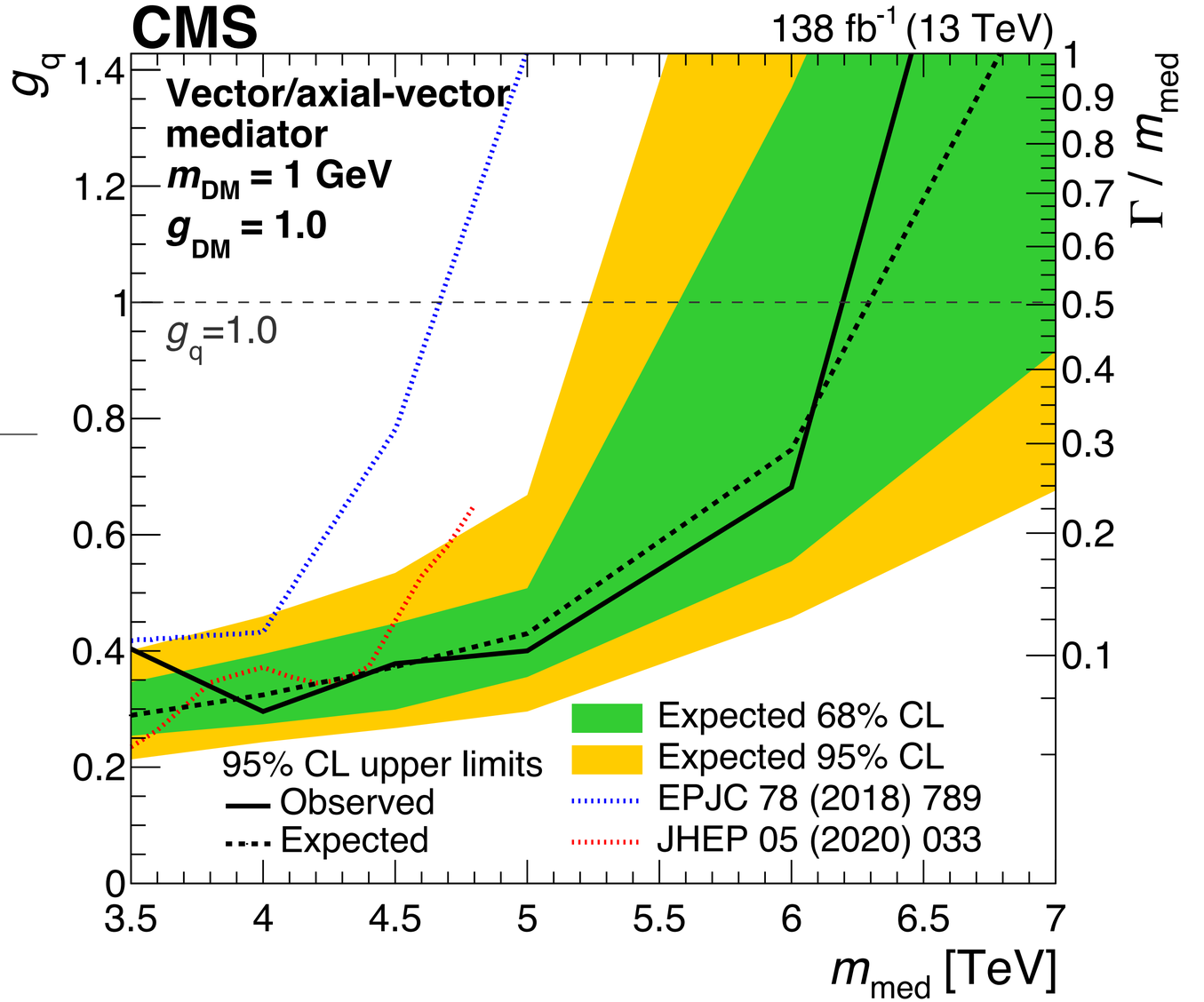
# Dijet angular analysis -- Results

Run 2

CMS-EXO-24-011: paper to be submitted

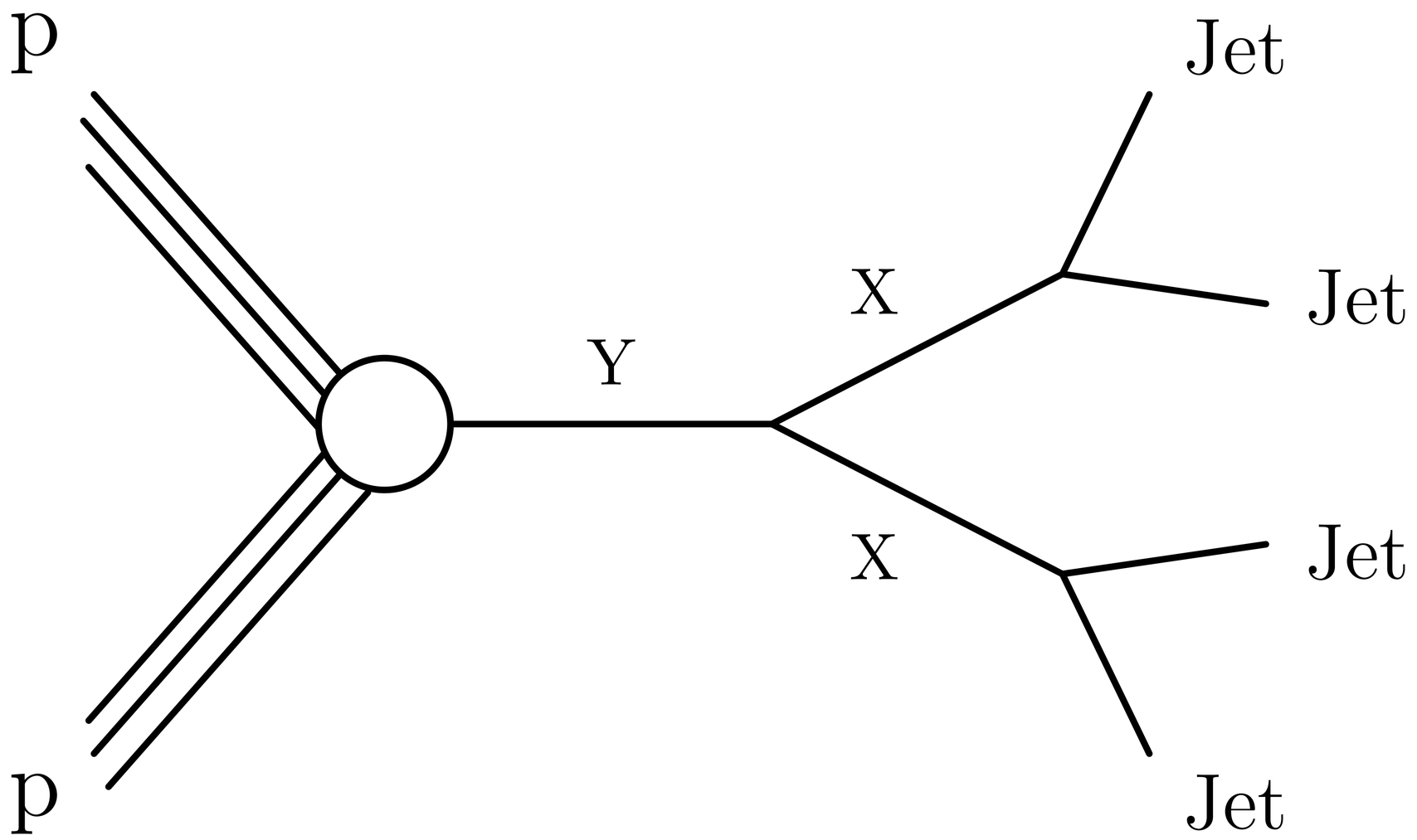
- No significant excess observed
- Several interpretations provided
  - Quark compositeness
  - DM models
  - Extra-dimensions
  - SMEFT

| Model | Observed limit | Expected limit |
|---|---|---|
| CI $\Lambda^{+}_{\mathrm{LL/RR}}$ (NLO) | 17 TeV | $18^{+20}_{-2}$ TeV |
| CI $\Lambda^{-}_{\mathrm{LL/RR}}$ (NLO) | 37 TeV | $34^{+8}_{-5}$ TeV |
| CI $\Lambda^{+}_{\mathrm{VV}}$ (NLO) | <19 and 27–31 TeV | $41^{+17}_{-22}$ TeV |
| CI $\Lambda^{-}_{\mathrm{VV}}$ (NLO) | 50 TeV | $45^{+11}_{-7}$ TeV |
| CI $\Lambda^{+}_{\mathrm{AA}}$ (NLO) | 19 TeV | $39^{+16}_{-21}$ TeV |
| CI $\Lambda^{-}_{\mathrm{AA}}$ (NLO) | 49 TeV | $44^{+11}_{-7}$ TeV |
| CI $\Lambda^{+}_{\mathrm{(V-A)}}$ (NLO) | 14.9 TeV | $14.0^{+1.8}_{-1.4}$ TeV |
| CI $\Lambda^{-}_{\mathrm{(V-A)}}$ (NLO) | 15.7 TeV | $14.6^{+2.2}_{-1.6}$ TeV |
| ADD $\Lambda_{\mathrm{T}}$ (GRW) | 13.4 TeV | $14.2 \pm 1.0$ TeV |
| ADD $M_{\mathrm{S}}$ (HLZ) $n_{\mathrm{ED}} = 2$ | 15.0 TeV | $16.0 \pm 1.1$ TeV |
| ADD $M_{\mathrm{S}}$ (HLZ) $n_{\mathrm{ED}} = 3$ | 15.9 TeV | $16.9 \pm 1.2$ TeV |
| ADD $M_{\mathrm{S}}$ (HLZ) $n_{\mathrm{ED}} = 4$ | 13.4 TeV | $14.2 \pm 1.0$ TeV |
| ADD $M_{\mathrm{S}}$ (HLZ) $n_{\mathrm{ED}} = 5$ | 12.1 TeV | $12.8 \pm 0.9$ TeV |
| ADD $M_{\mathrm{S}}$ (HLZ) $n_{\mathrm{ED}} = 6$ | 11.3 TeV | $11.9 \pm 0.8$ TeV |
| QBH $M_{\mathrm{QBH}}$ (ADD, $n_{\mathrm{ED}} = 6$) | 8.5 TeV | $9.1 \pm 0.3$ TeV |
| QBH $M_{\mathrm{QBH}}$ (RS1) | 6.3 TeV | $6.8 \pm 0.4$ TeV |
| DM mediator $m_{\mathrm{med}}$ | 6.2 TeV | $6.2 \pm 0.8$ TeV |
| ALP $c_{\mathrm{g}}/f_{\mathrm{a}}$ | $0.42\ \mathrm{TeV}^{-1}$ | $0.38 \pm 0.03\ \mathrm{TeV}^{-1}$ |
| SMEFT $C_{\mathrm{G}}/\Lambda^2$ | $0.0076\ \mathrm{TeV}^{-2}$ | $0.0081 \pm 0.0012\ \mathrm{TeV}^{-2}$ |



# Pair-produced dijet resonances

CMS-EXO-25-004




Pair production of new particles X decaying to dijets

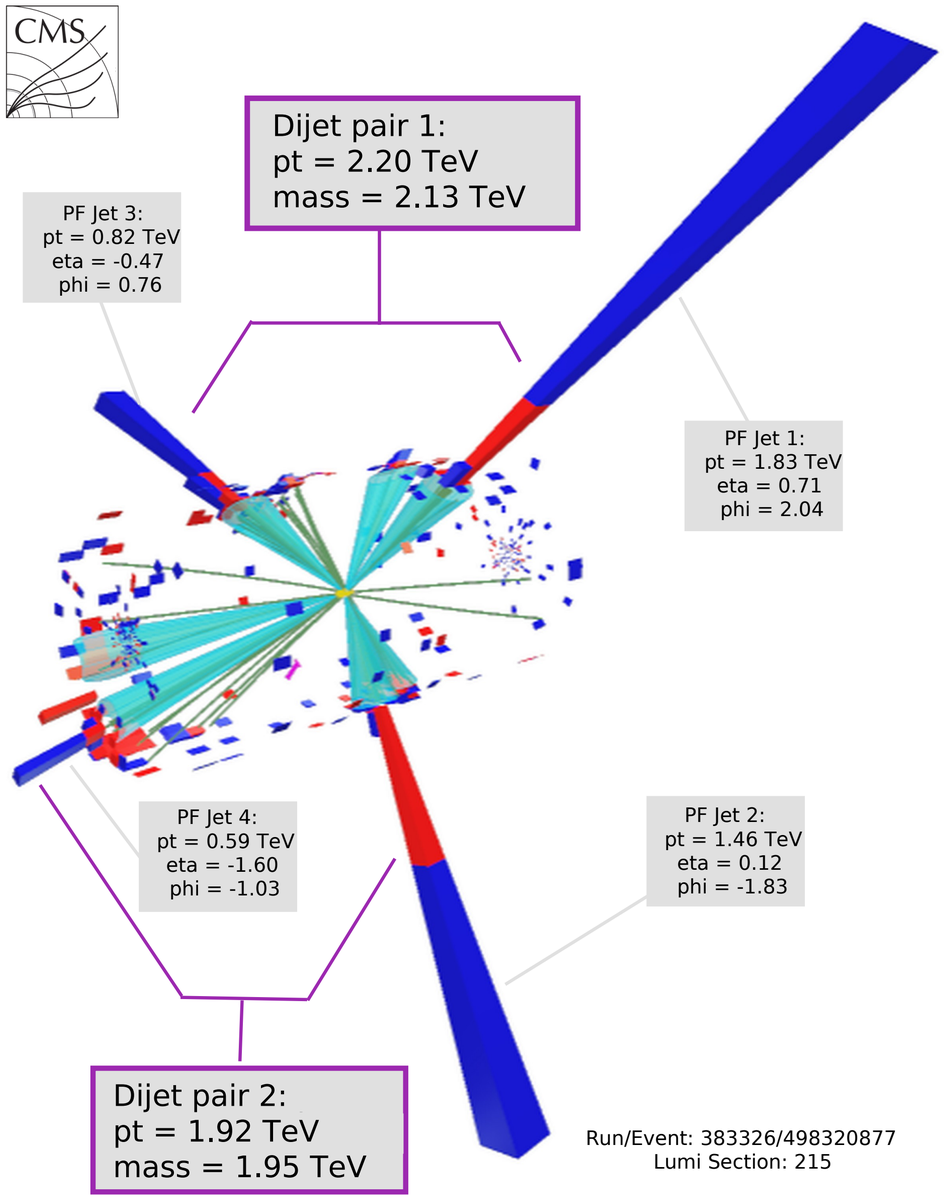
# Pair-produced dijet resonances

Run 3

CMS-EXO-25-004

## Resonant dijet pair production

- Two dijet resonances reconstructed with 4 jets
- Sensitive observables:
  - Four-jet mass $m_{4j}$
  - Average dijet mass $\overline{m_{2j}}$




- Highest mass events previously observed with Run2 data:
  - CMS: $m_{4j} = 8\ TeV$; $\overline{m_{2j}} = 2\ TeV$
- Current highest mass events with Run3 data:
  - CMS: $m_{4j} = 6.2\ TeV$; $\overline{m_{2j}} = 2\ TeV$

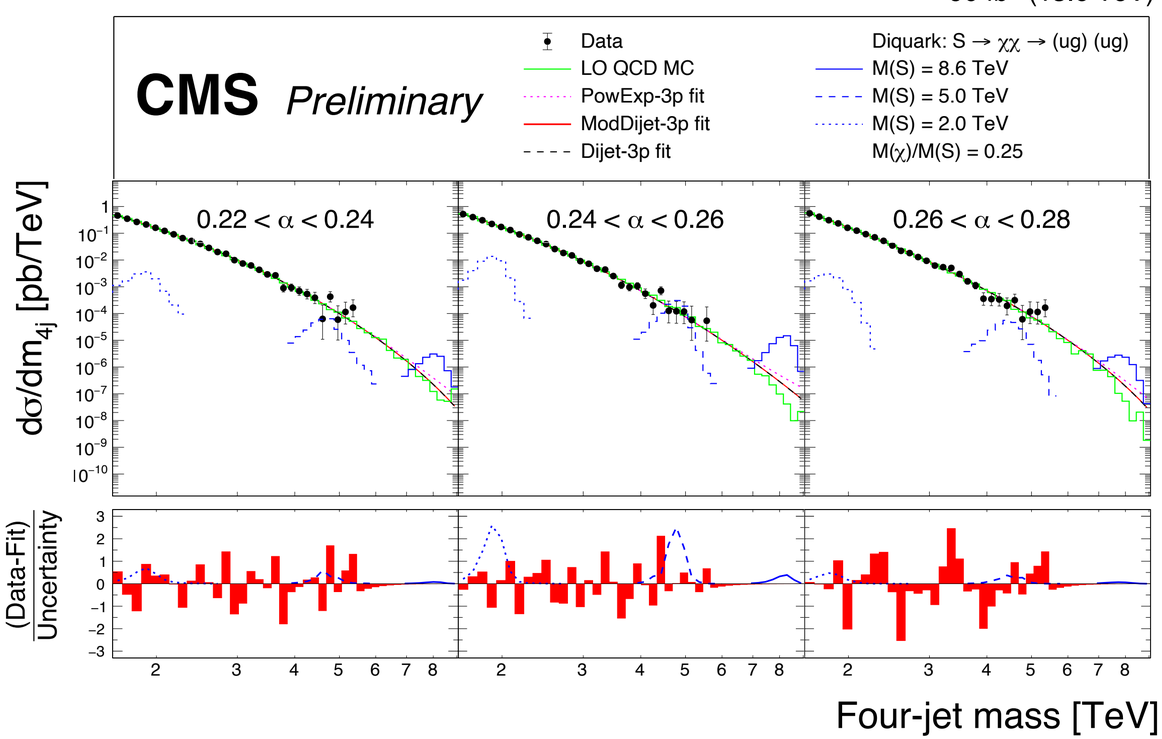
# Pair-produced dijet resonances -- Results

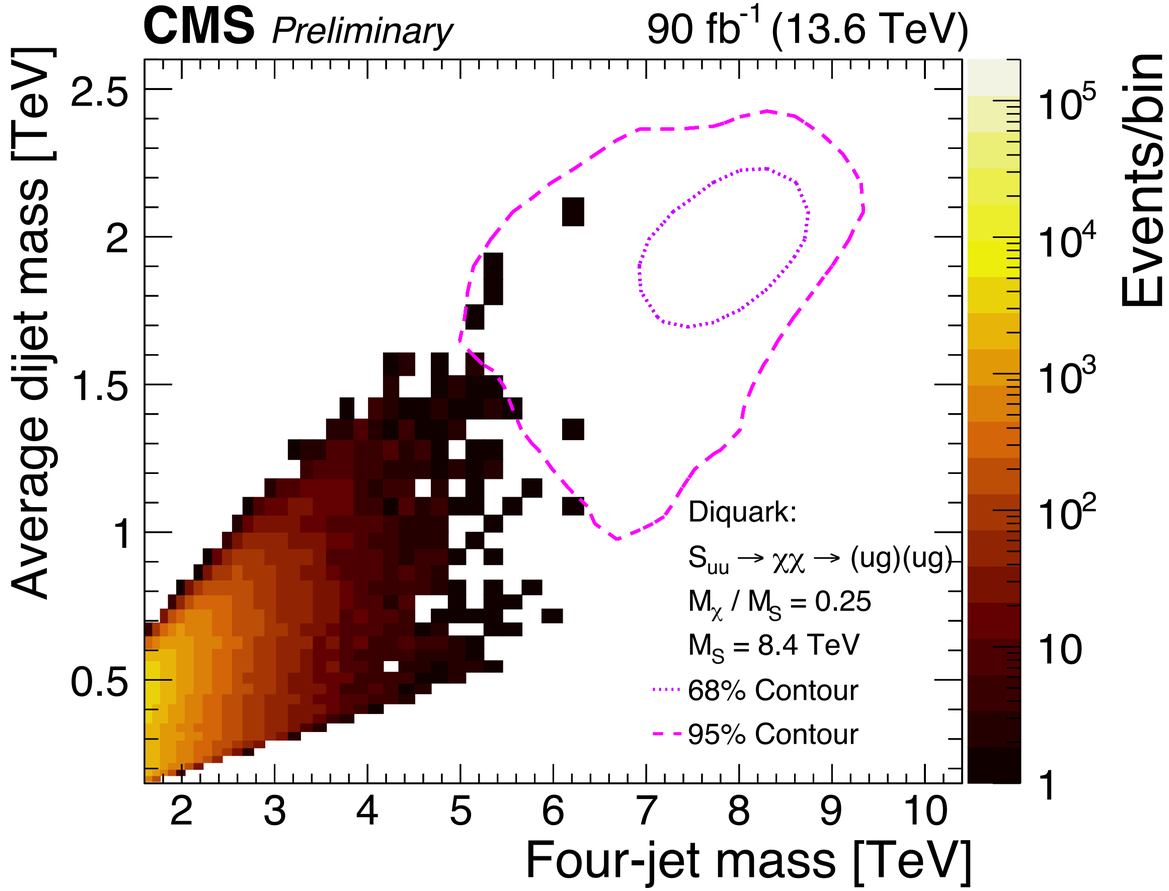
Run 3

CMS-EXO-25-004

- Fit of the falling spectrum of $m_{4j}$
  - Performed in $\overline{m_{2j}}/m_{4j}$ bins→ to minimise background sculpting
  - Discrete profiling is used for background modelling

- **No significant excess observed**
  - Interpretation in diquark models (D2D)

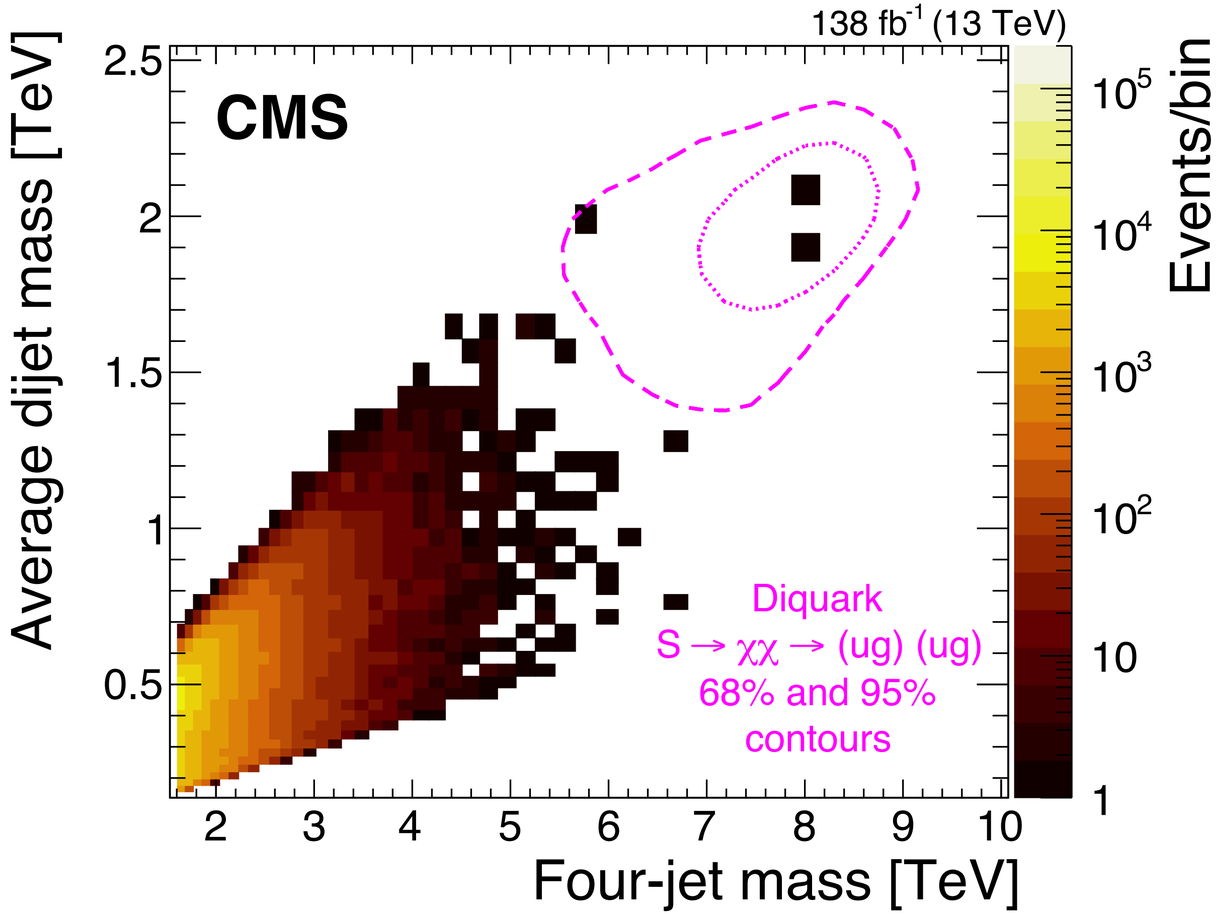


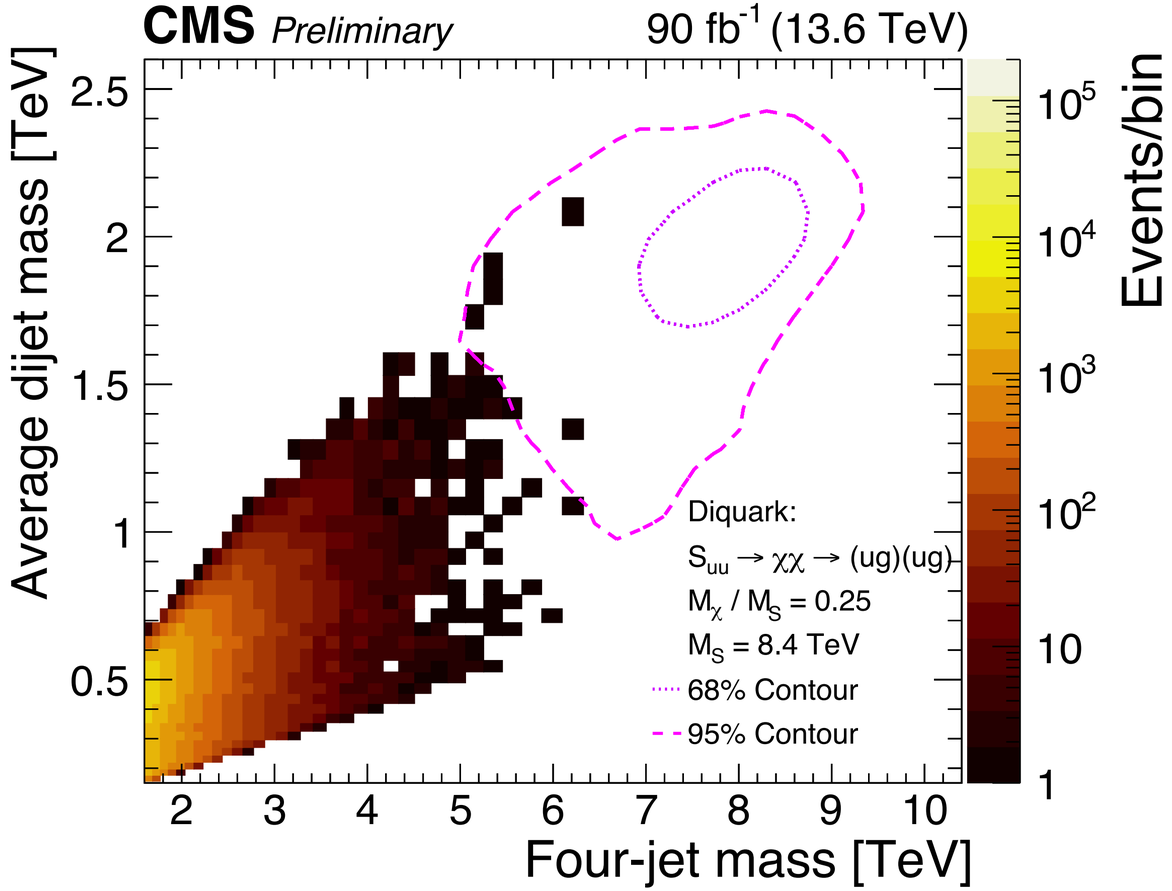



# Pair-produced dijet resonances -- Comparison Run 3

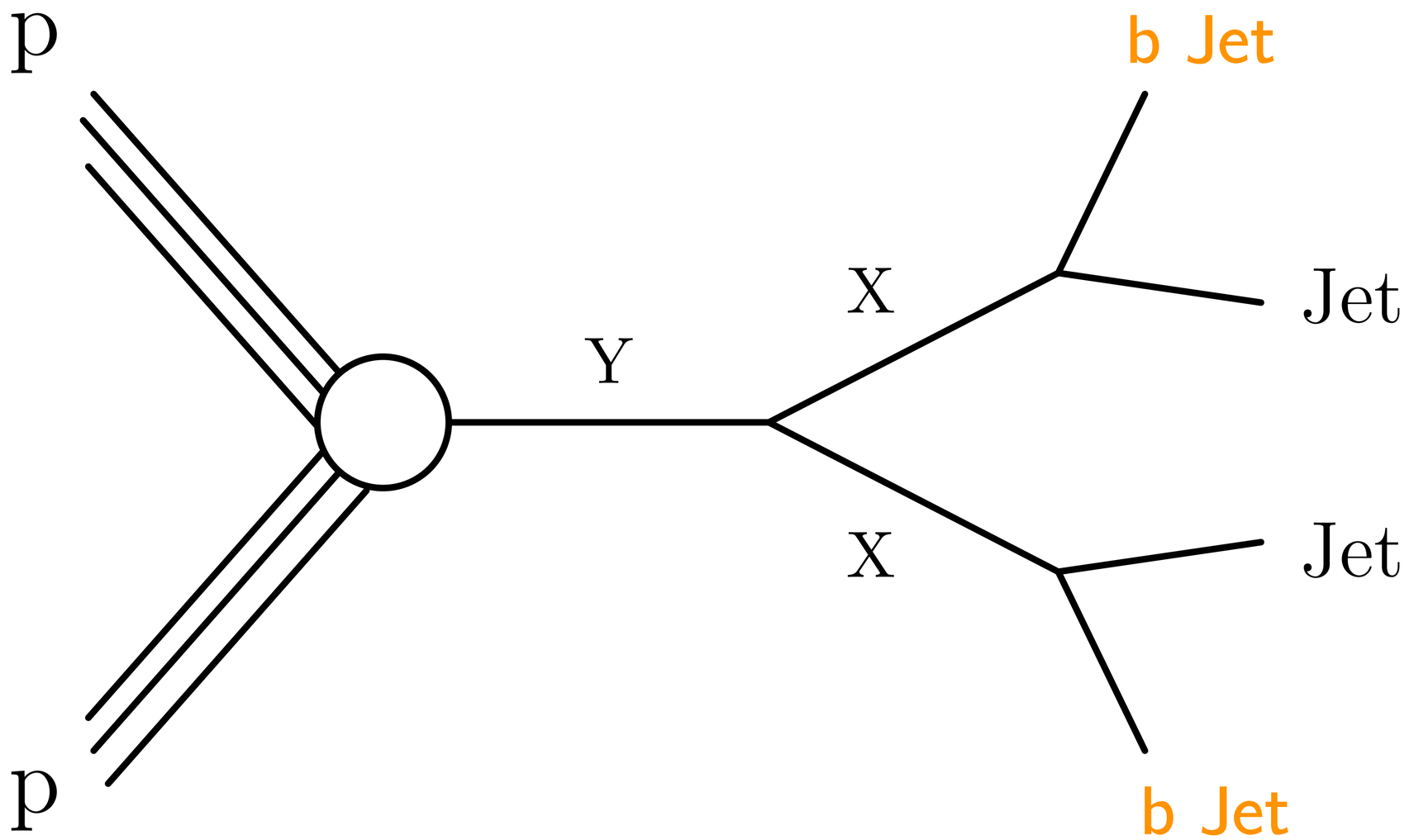
CMS-EXO-25-004

- Intriguing excess from Run2 analysis not confirmed
  - But more data still to be analysed



# Pair-produced dijet resonances with b-jets




Pair production of new particles X decaying to dijets with 2 b-jets

# Pair-produced dijet resonances with b-jets

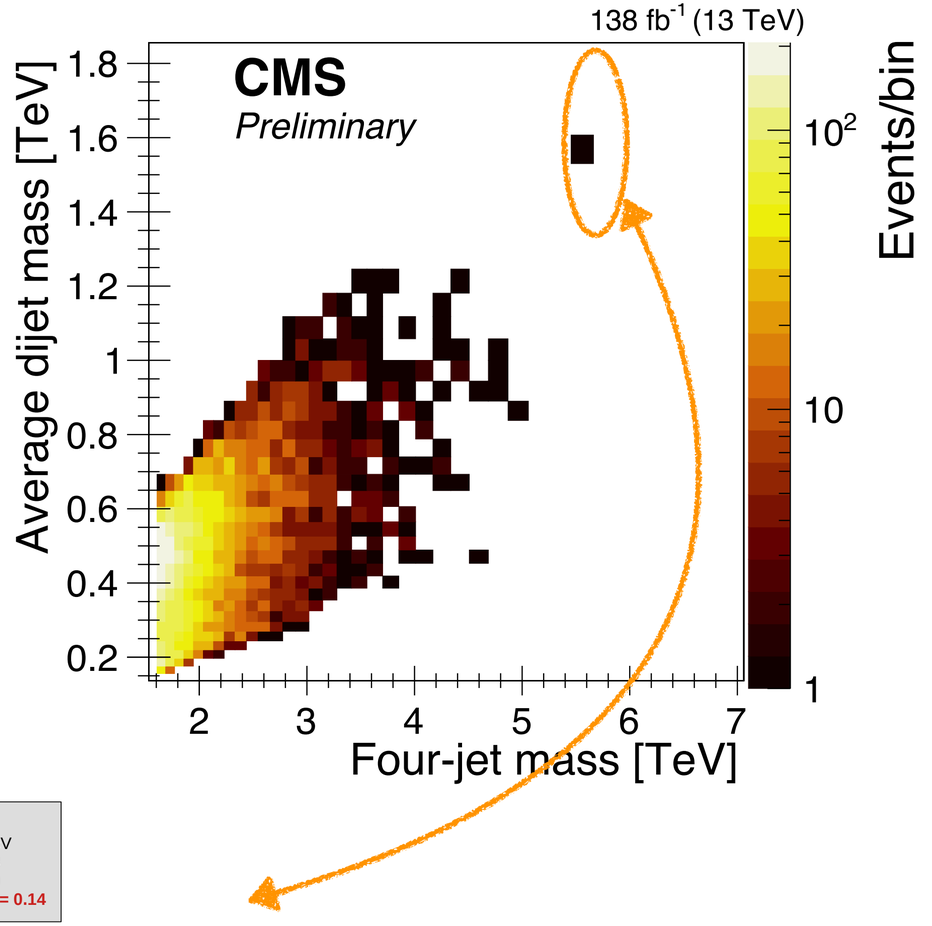
Run 2

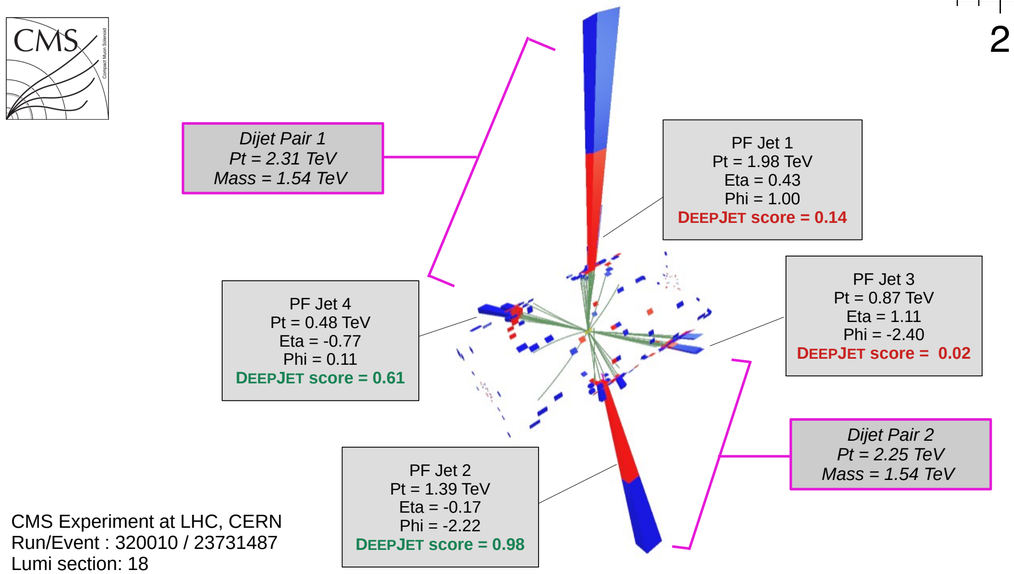
CMS-EXO-24-039

## Dijet pair production with 2 b jets

- Resonant:
  - $m_{4j}$ and $\overline{m_{2j}}$ as the sensitive variables
- Non-resonant:
  - $\overline{m_{2j}}$ as the sensitive variable

- Current highest mass events with Run2 data:
  - CMS: $m_{4j} = 5.5\ TeV$; $\overline{m_{2j}} = 1.5\ TeV$

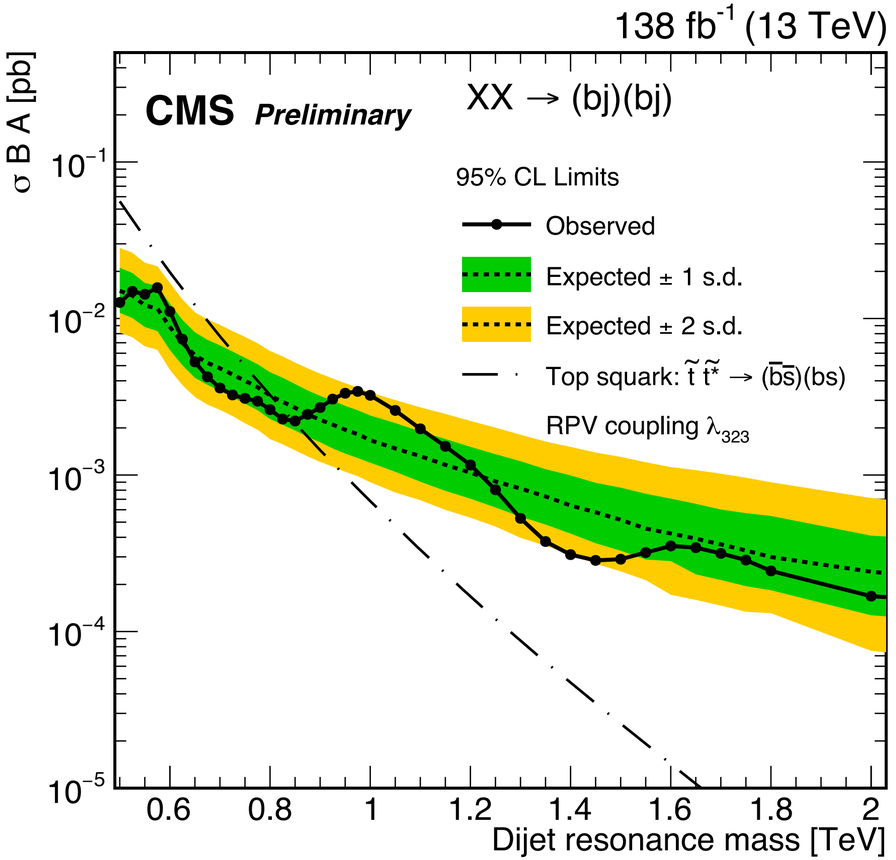


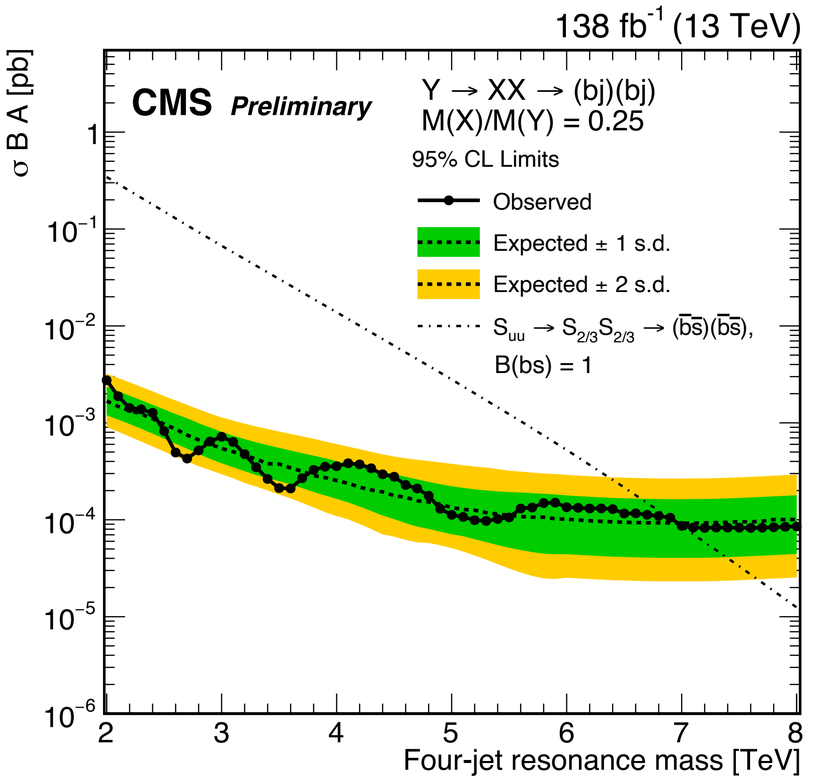



# Pair-produced dijet resonances with b-jets -- Results Run 2

CMS-EXO-24-039

- Fit of the falling spectrum of $m_{4j}$
  - $\overline{m_{2j}}$ for the non-resonant interpretation
- No significant excess observed
- Limits set on:
  - pair-produced diquarks (D2D)
  - Top squark (RPV)



# Conclusions

CMS continues to probe new physics at the highest accessible energies

- Heavy vector resonances
  - Run2 legacy combination of 16 channels
  - Sensitivity up to 6 TeV
  - W' search showcases improved sensitivity using Run3 data
- High-mass searches
  - Dijet angular analysis probing non-resonant BSM effects
  - Pair-produced dijet resonances
- No significant deviation observed from the SM observed (yet)
  - Constantly improving techniques for high-mass signatures
  - Large Run3 dataset to be explored
  - Sensitivity will continue to grow

Thank you for your attention!

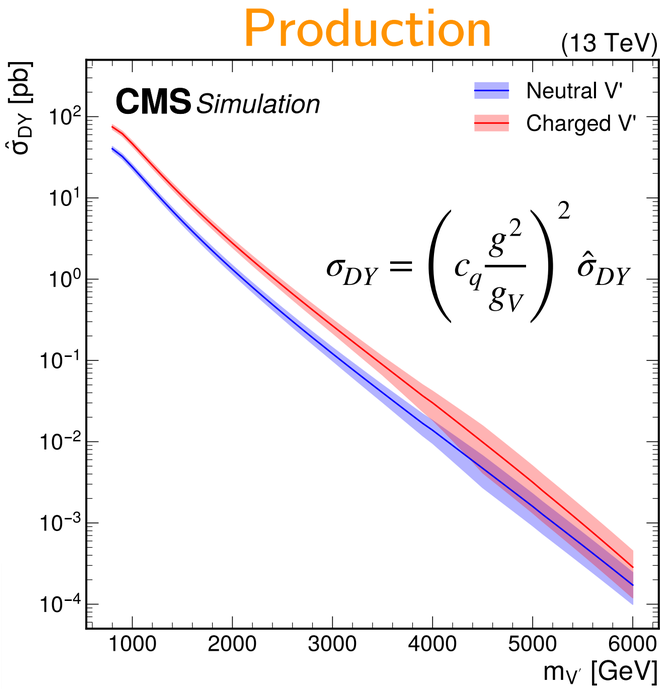
# ~~~ Additional Material ~~~

# HVT framework

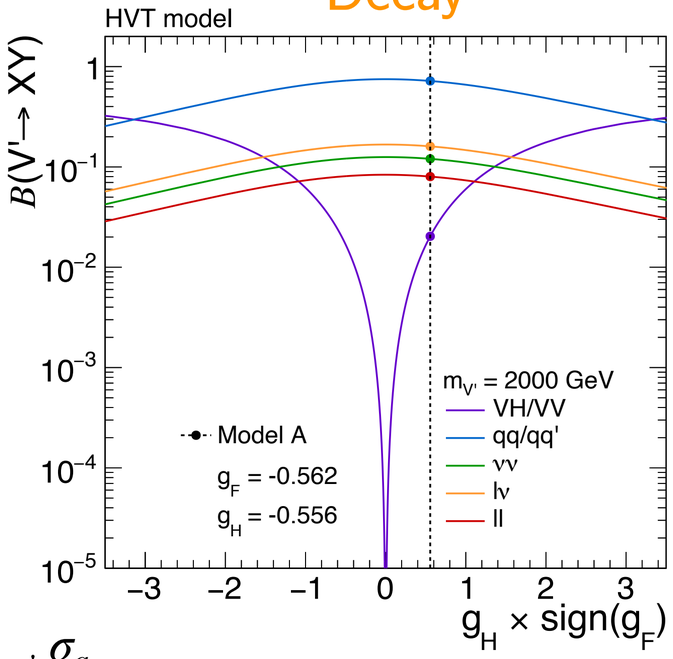
Submitted to JHEP: arxiv:2601.12583

- Heavy Vector Triplet (HVT):
  - Simplified framework for heavy spin-1 resonances
  - Massive charged and neutral bosons (Z' and W')
  - Similarities with the SM EW sector
  - Couplings to fermions and bosons controlled by $g_F$ and $g_H$

Production



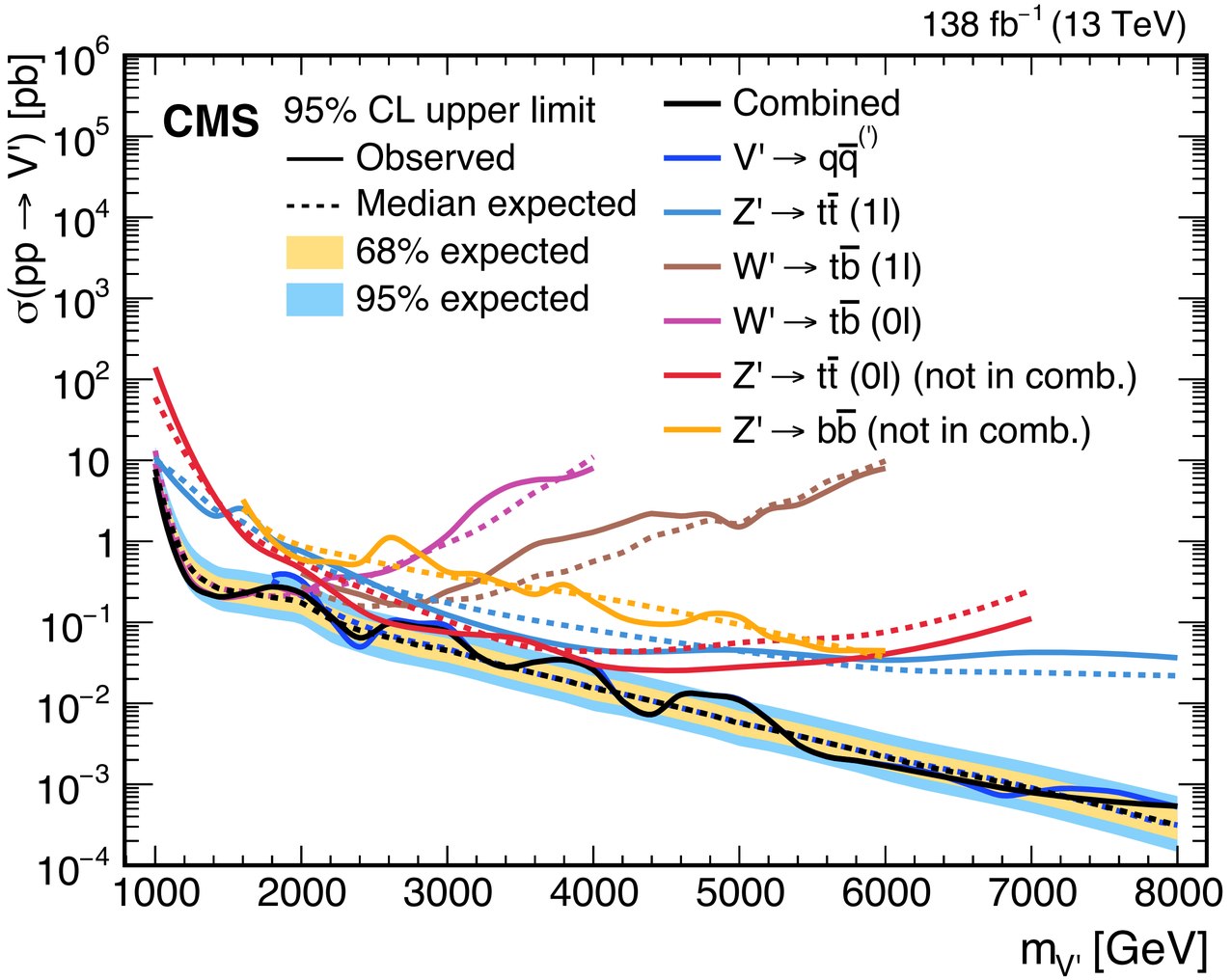

Decay

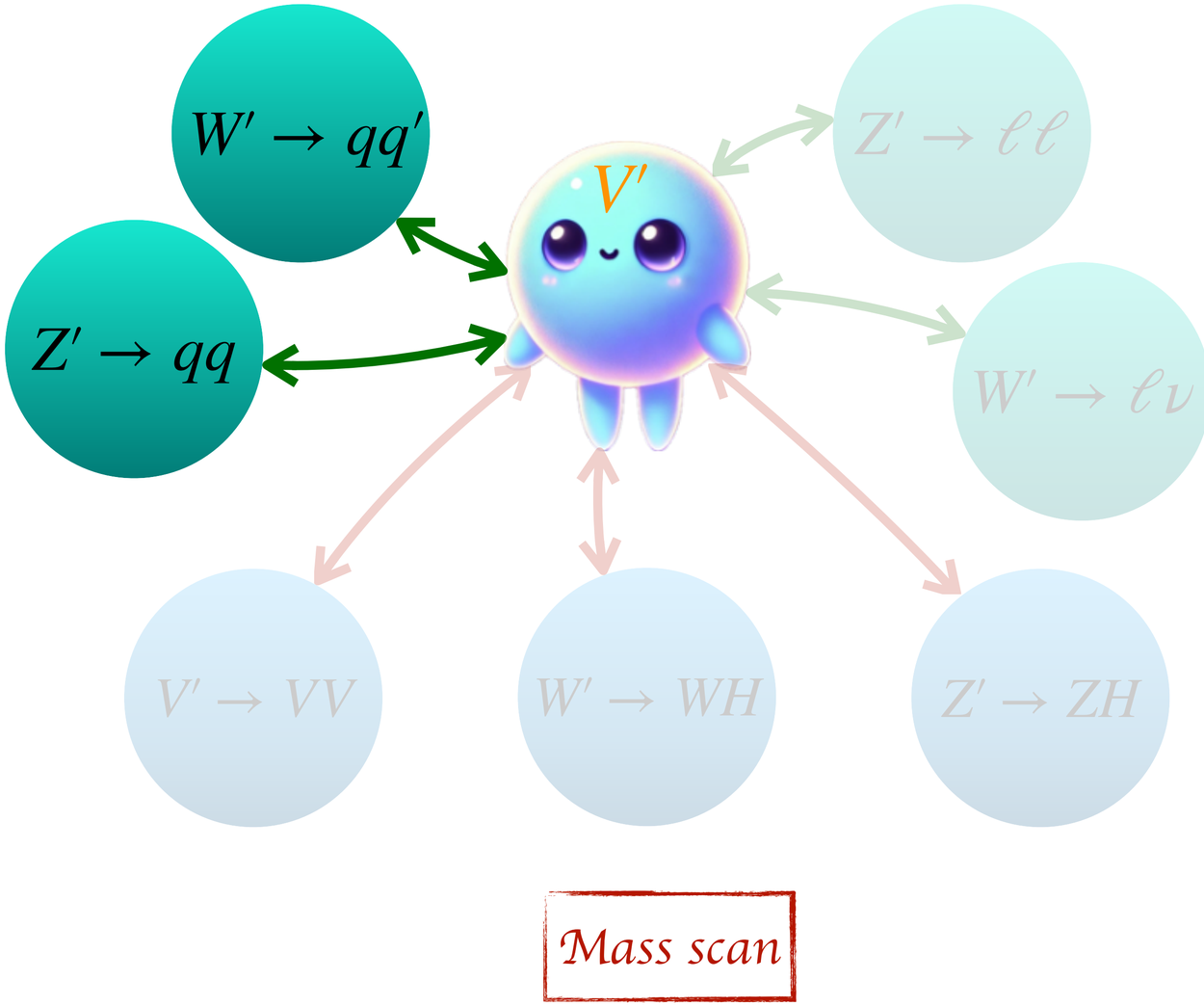



$$\mathscr{L}^{\mathrm{int}}_{\mathscr{W}} = -c_q \frac{g^2}{g_V} \mathscr{W}^a_\mu \bar{q}_k \gamma^\mu \frac{\sigma_a}{2} q_k - c_l \frac{g^2}{g_V} \mathscr{W}^a_\mu \bar{l}_k \gamma^\mu \frac{\sigma_a}{2} l_k - c_H g_V (\mathscr{W}^a_\mu H^\dagger \frac{\sigma_a}{2} i D^\mu H + \mathrm{h.c.})$$

# Combination's results

Submitted to JHEP: arxiv:2601.12583



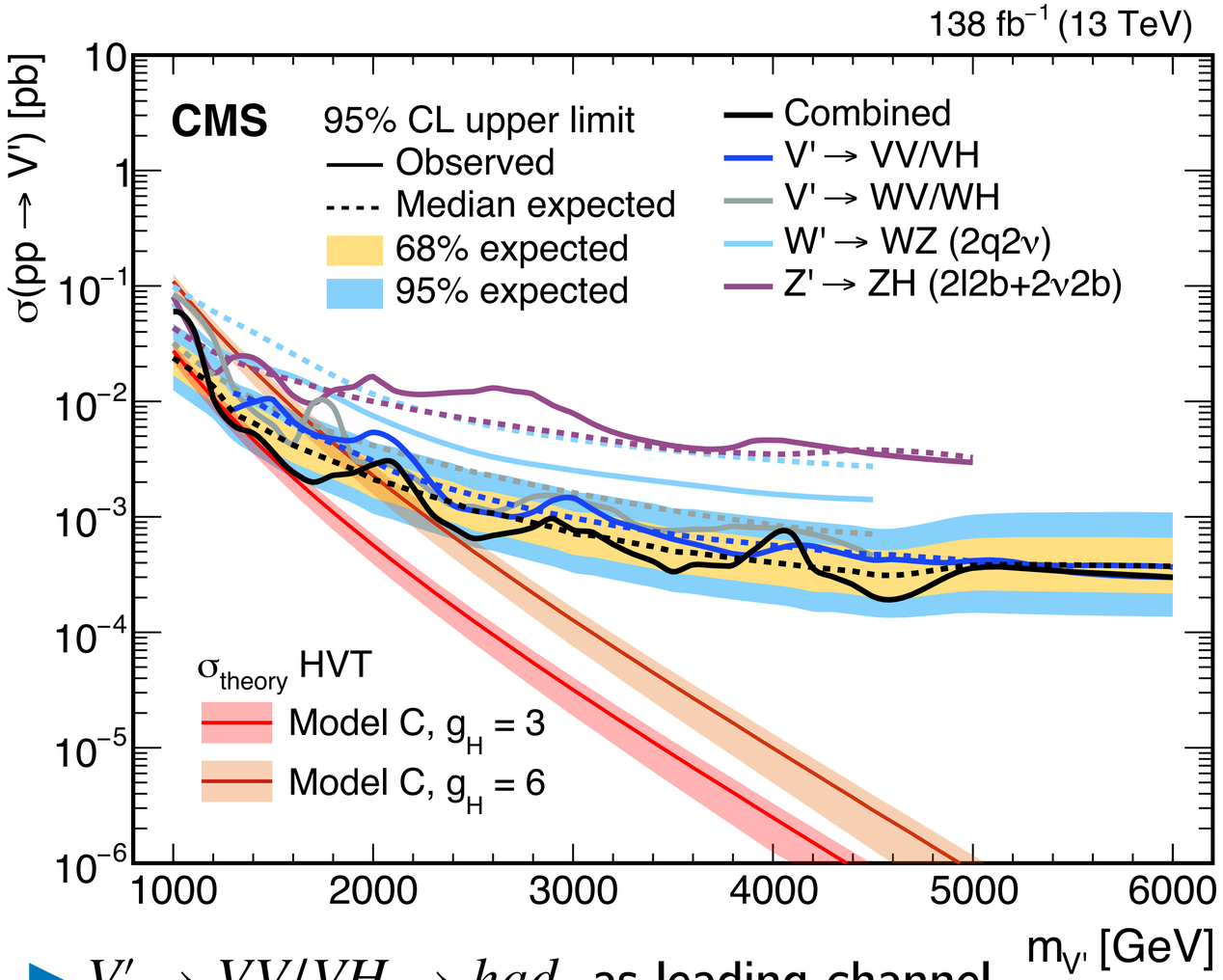



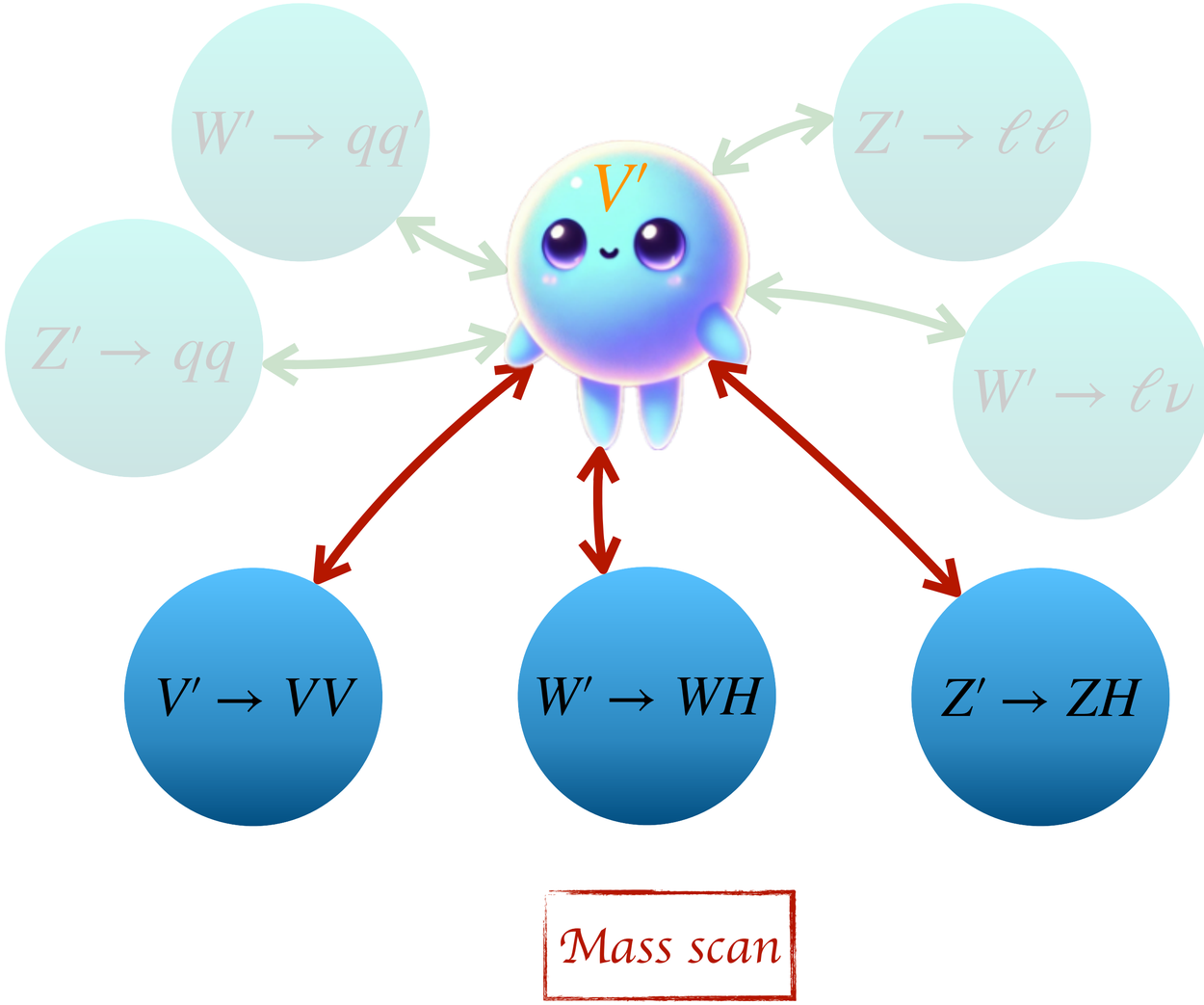

*Mass scan*

- $V' \to qq$ as leading channel
- Tension at 3.4-4.4 TeV from $W' \to tb$ not confirmed
- No other significant deviations

# Combination's results

Submitted to JHEP: arxiv:2601.12583




Mass scan

- $V' \to VV/VH \to had$ as leading channel
- Tensions at 1 TeV in $W' \to W(\ell\nu)V(qq)$ and $Z' \to Z(\nu\nu)H(bb)$ reduced
- Tensions at 2-3 TeV in $V' \to VV \to had$ reduced
- No other significant deviations
- Mixing of DY and VBF signals, when available!!

# Combination's results

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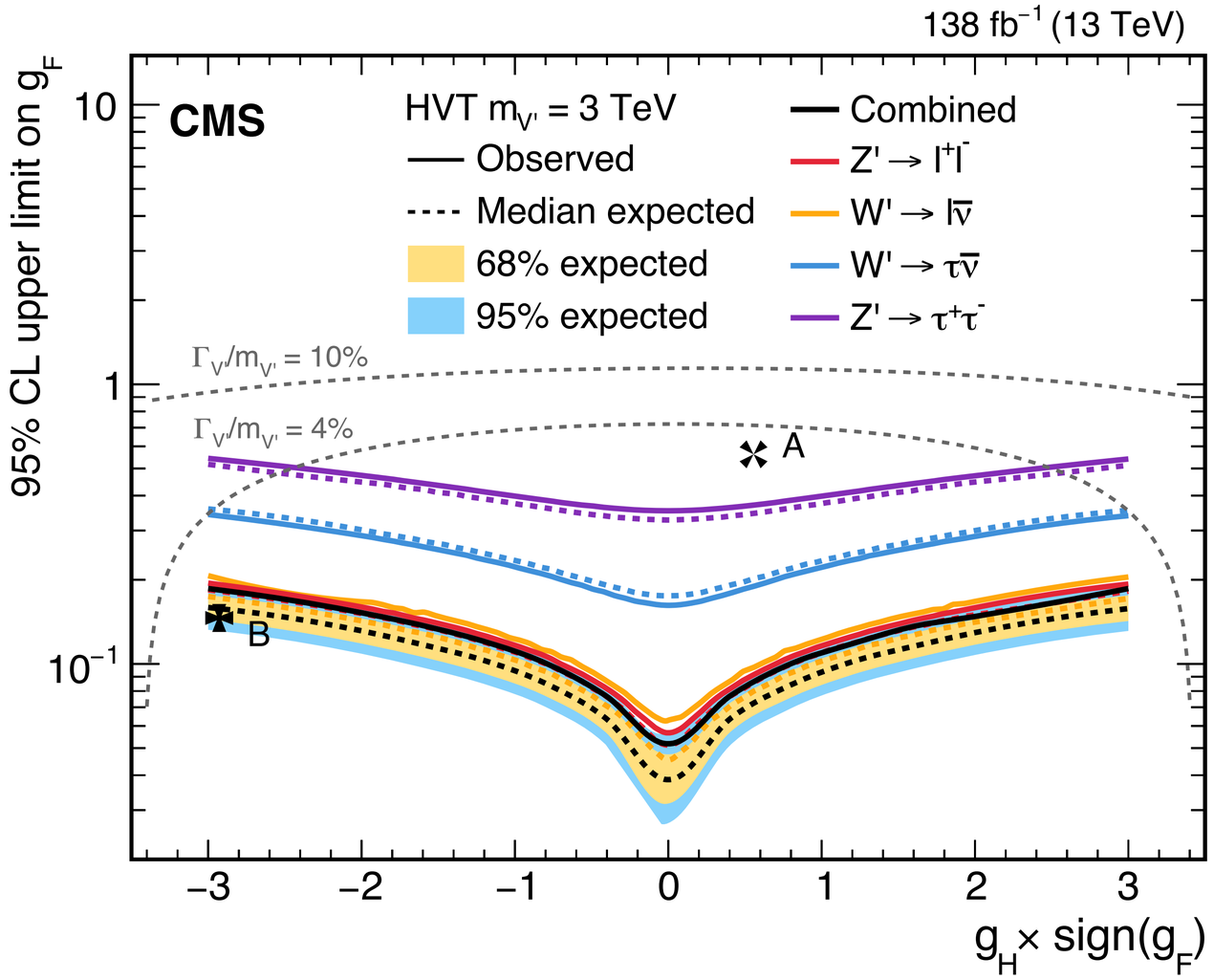


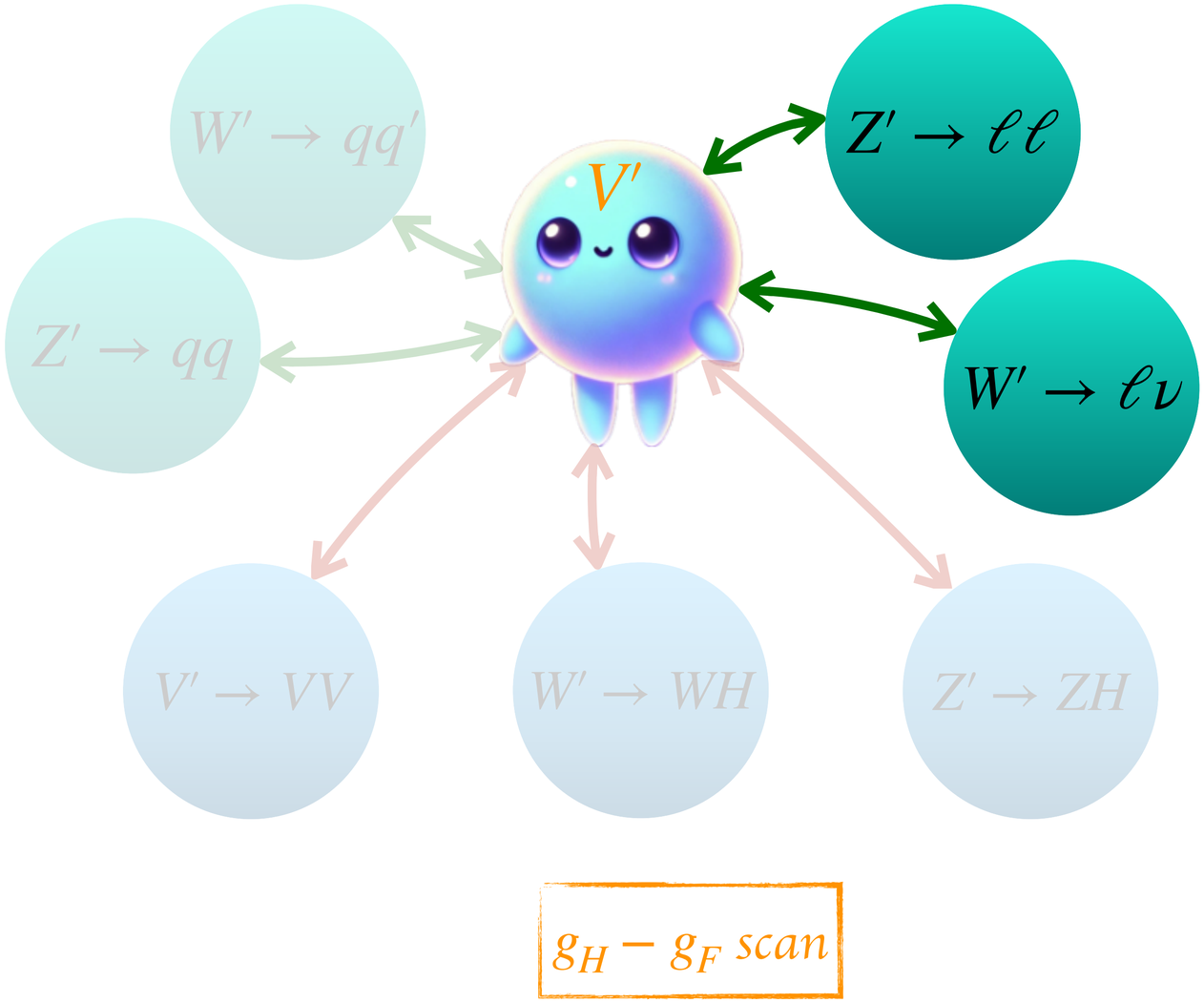


- $Z' \to \ell\ell$ and $W' \to \ell\nu$ as leading channels
- Tension at 2.7-3.4 TeV from $Z' \to \ell\ell$ reduced
- No other significant deviations

# Combination's results

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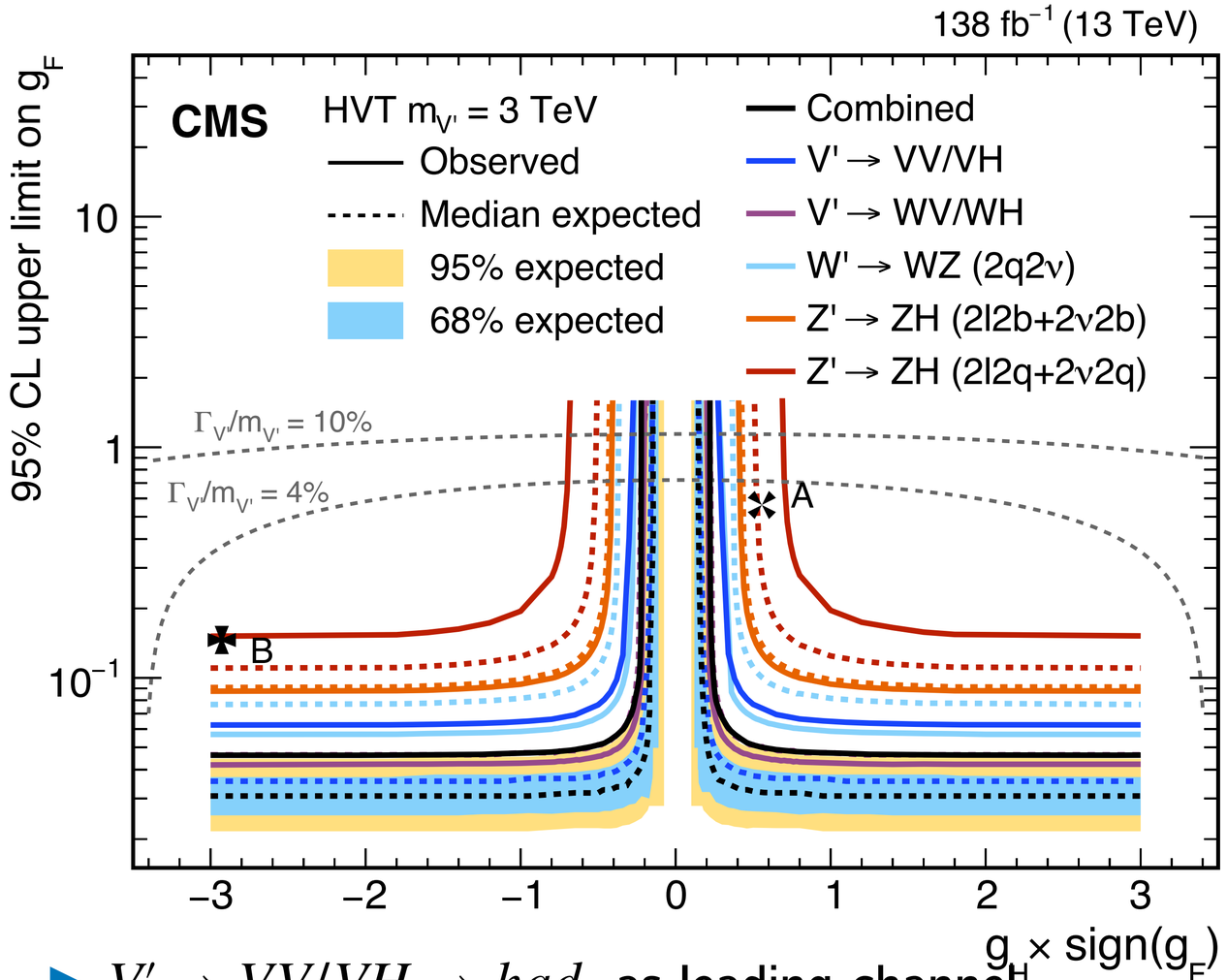
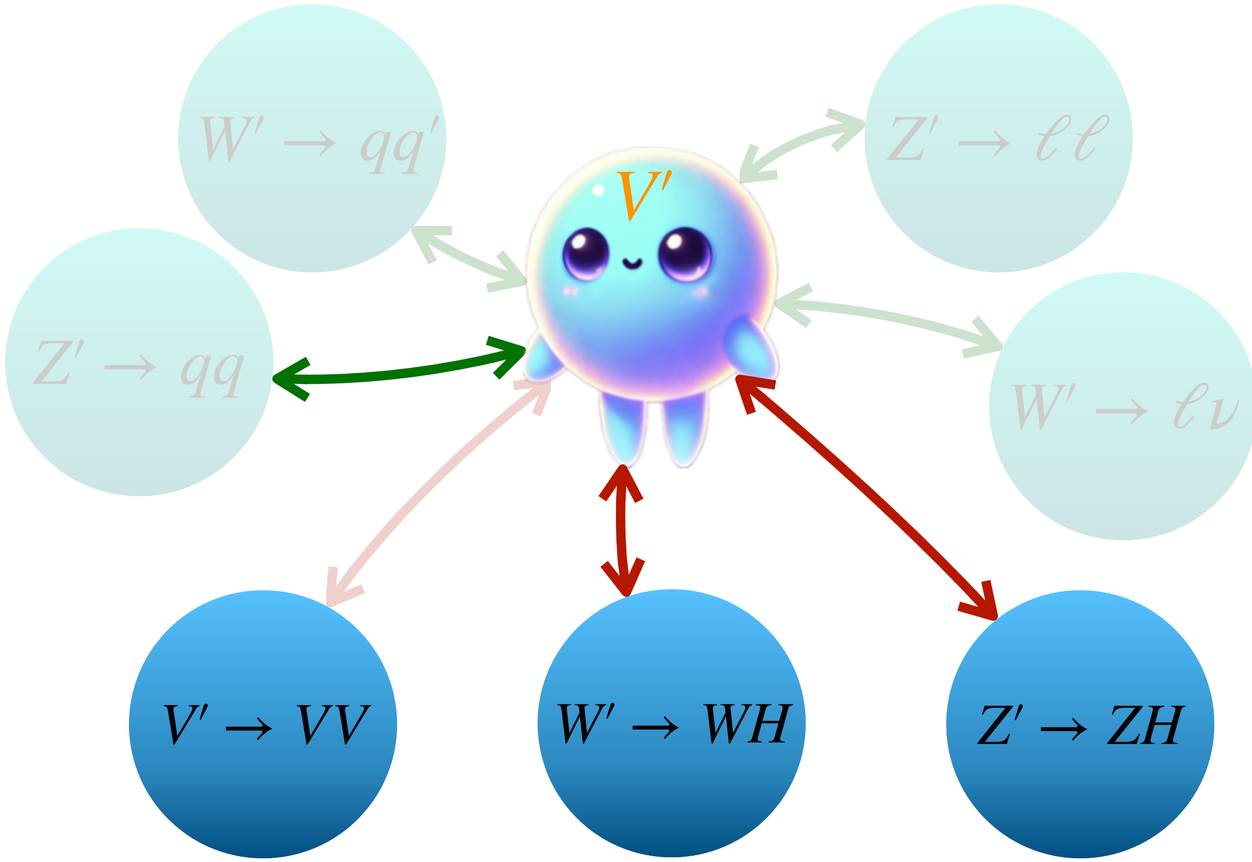


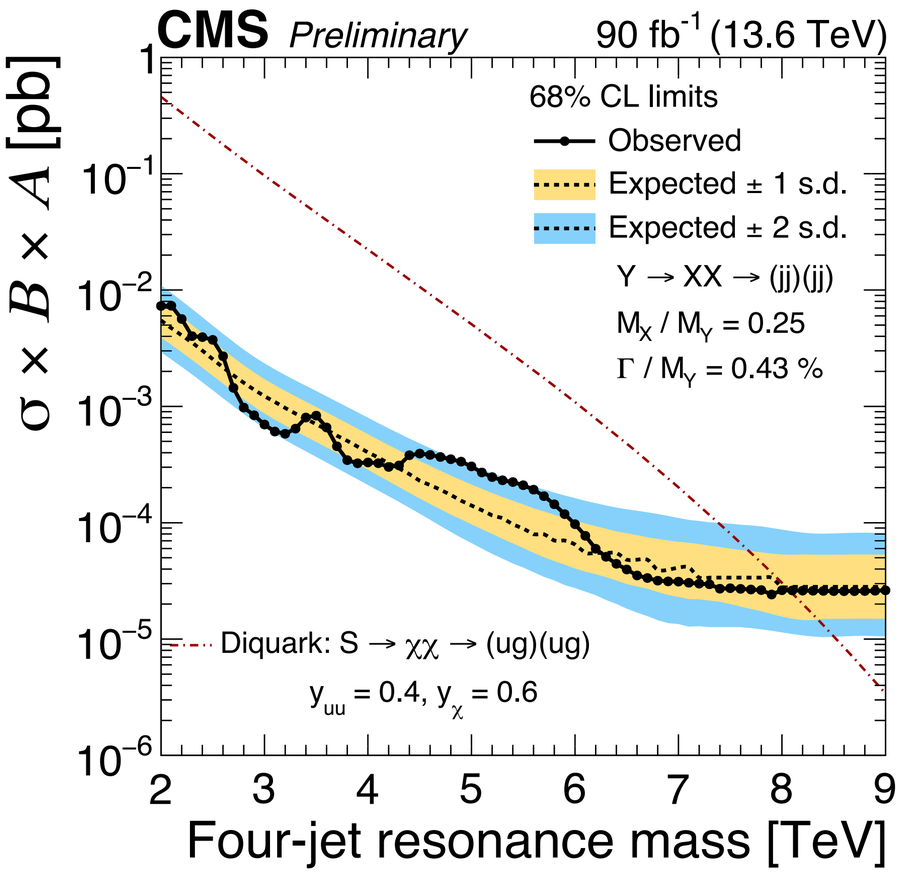



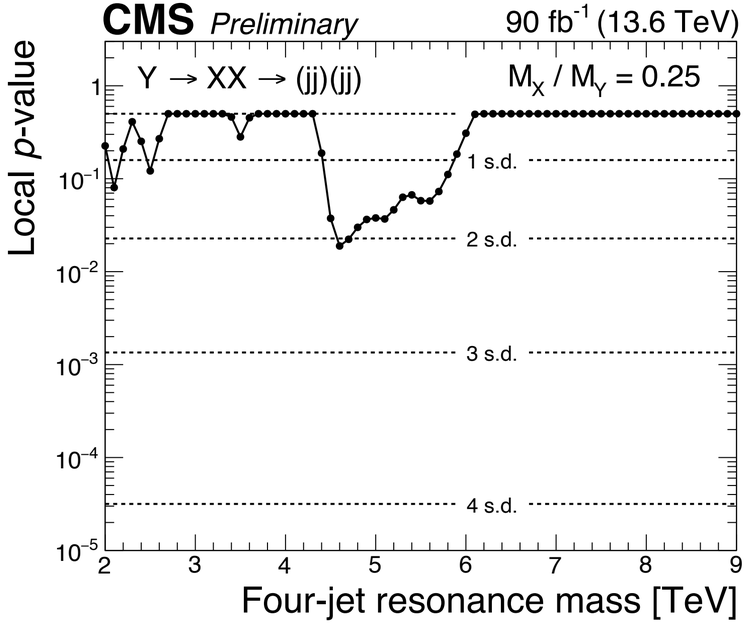

$g_H - g_F$ scan

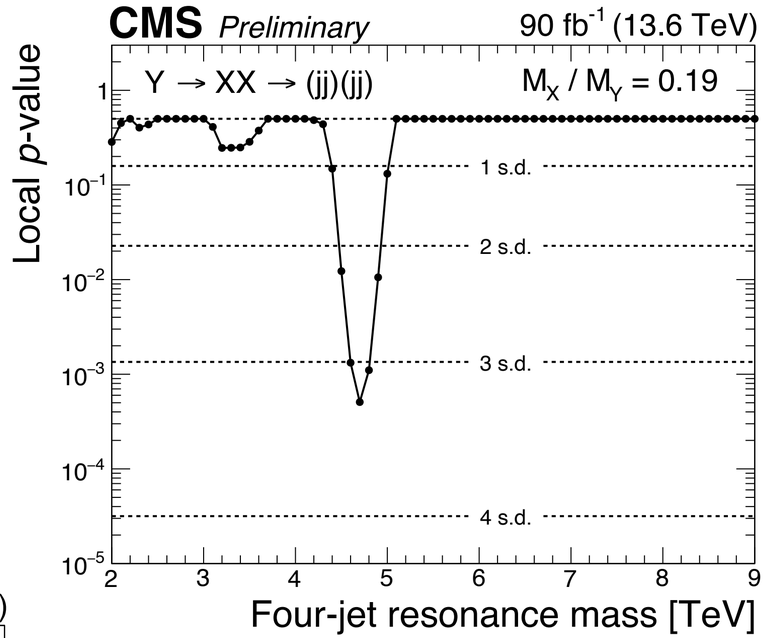
- $V' \to VV/VH \to had$ as leading channel
- Tensions at 1 TeV in $W' \to W(\ell\nu)V(qq)$ and $Z' \to Z(\nu\nu)H(bb)$ reduced
- Tensions at 2-3 TeV in $V' \to VV \to had$ reduced
- No other significant deviations

# Dijet searches

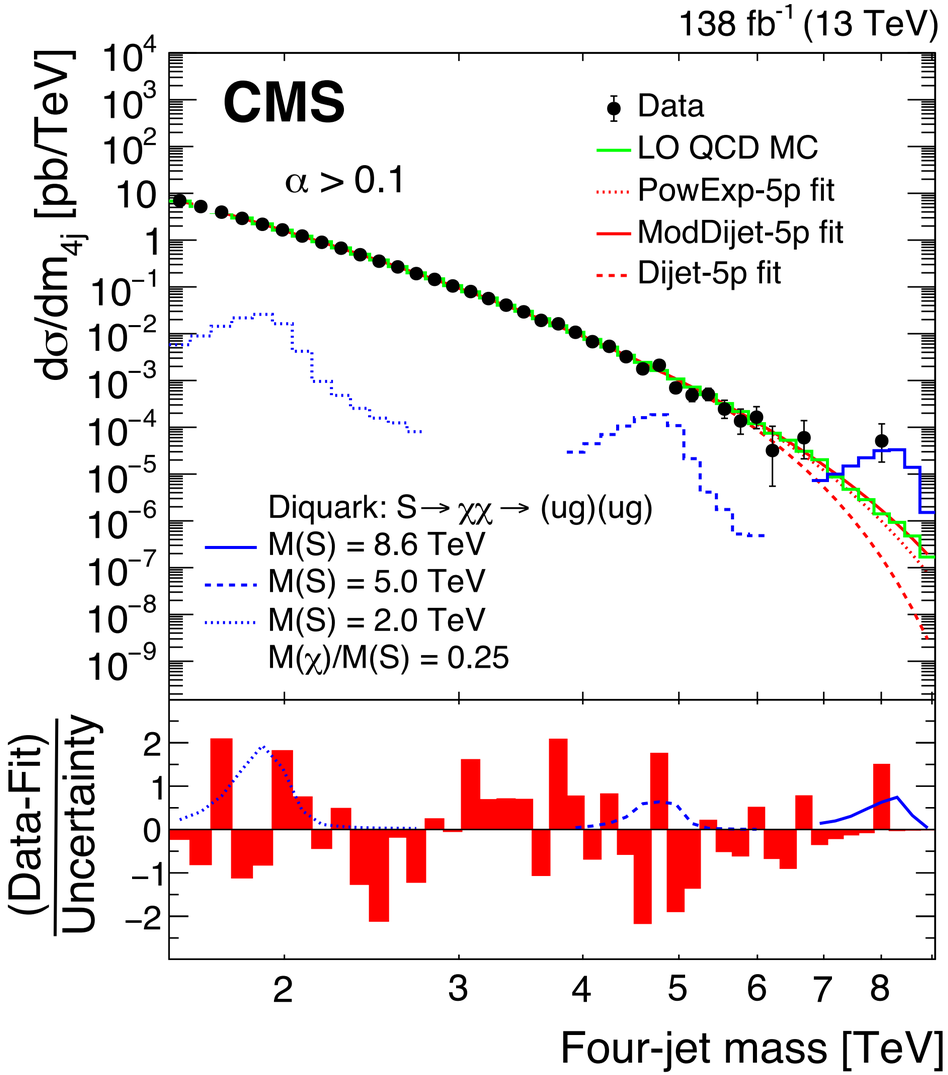
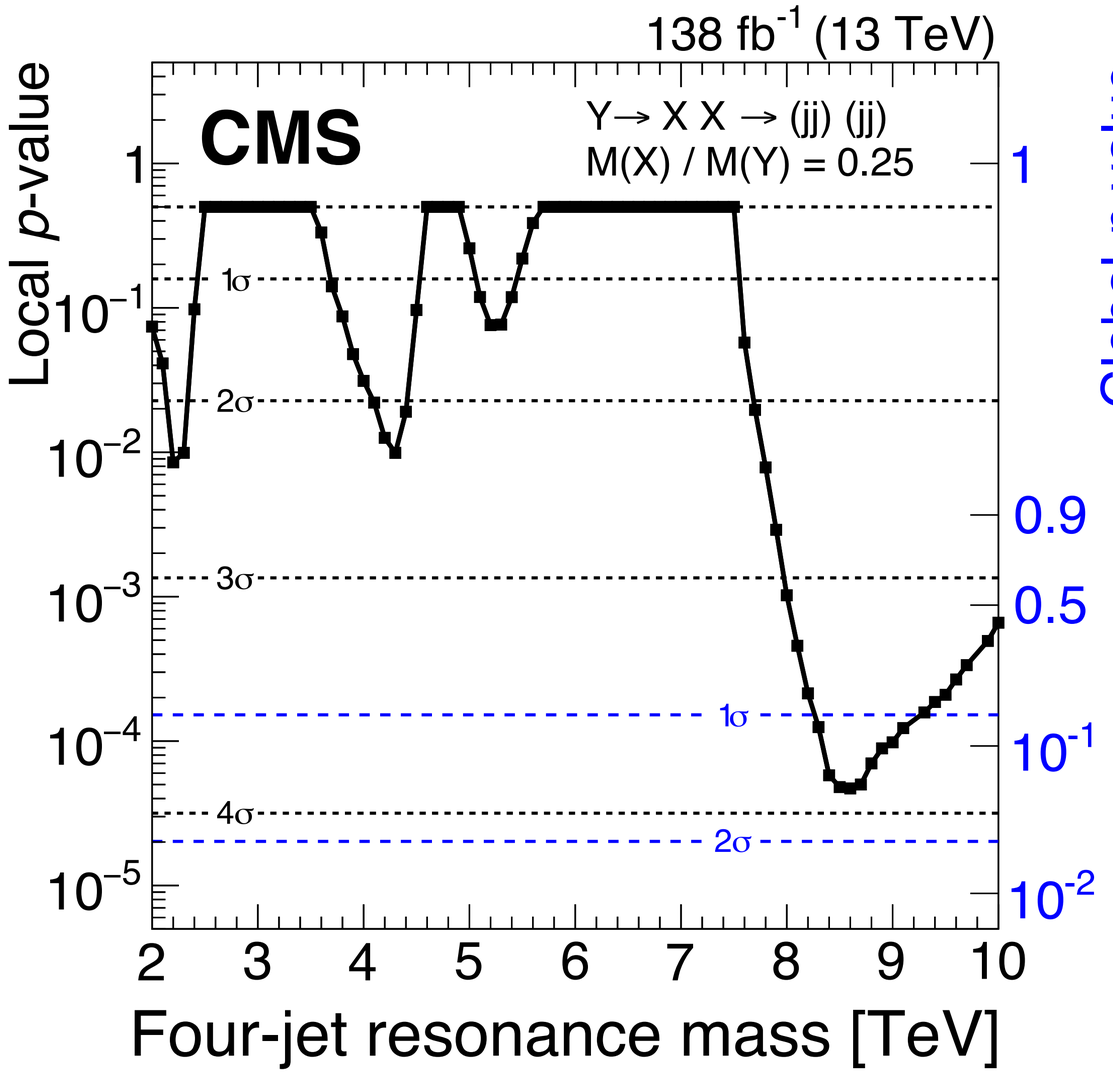
Run 3



# Pair-produced dijet resonances -- Results

Run 3

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