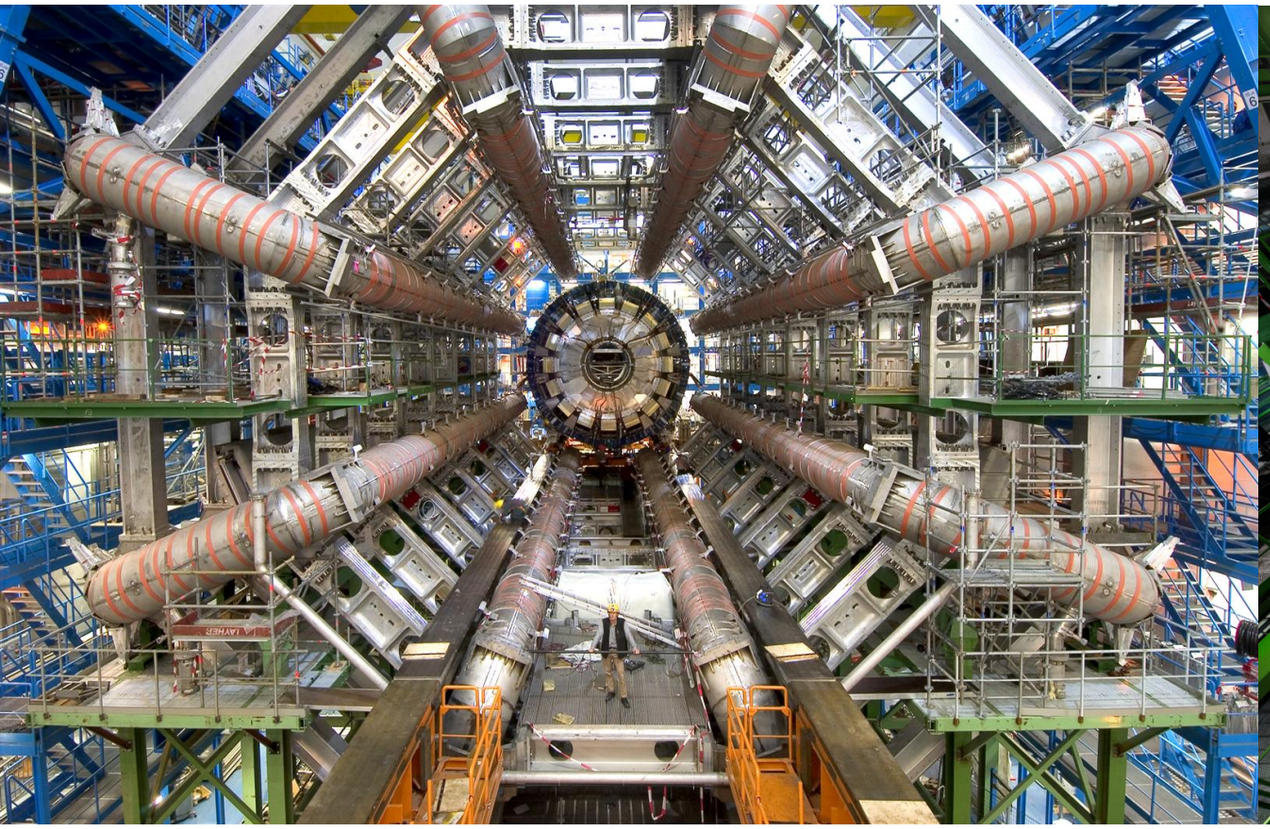
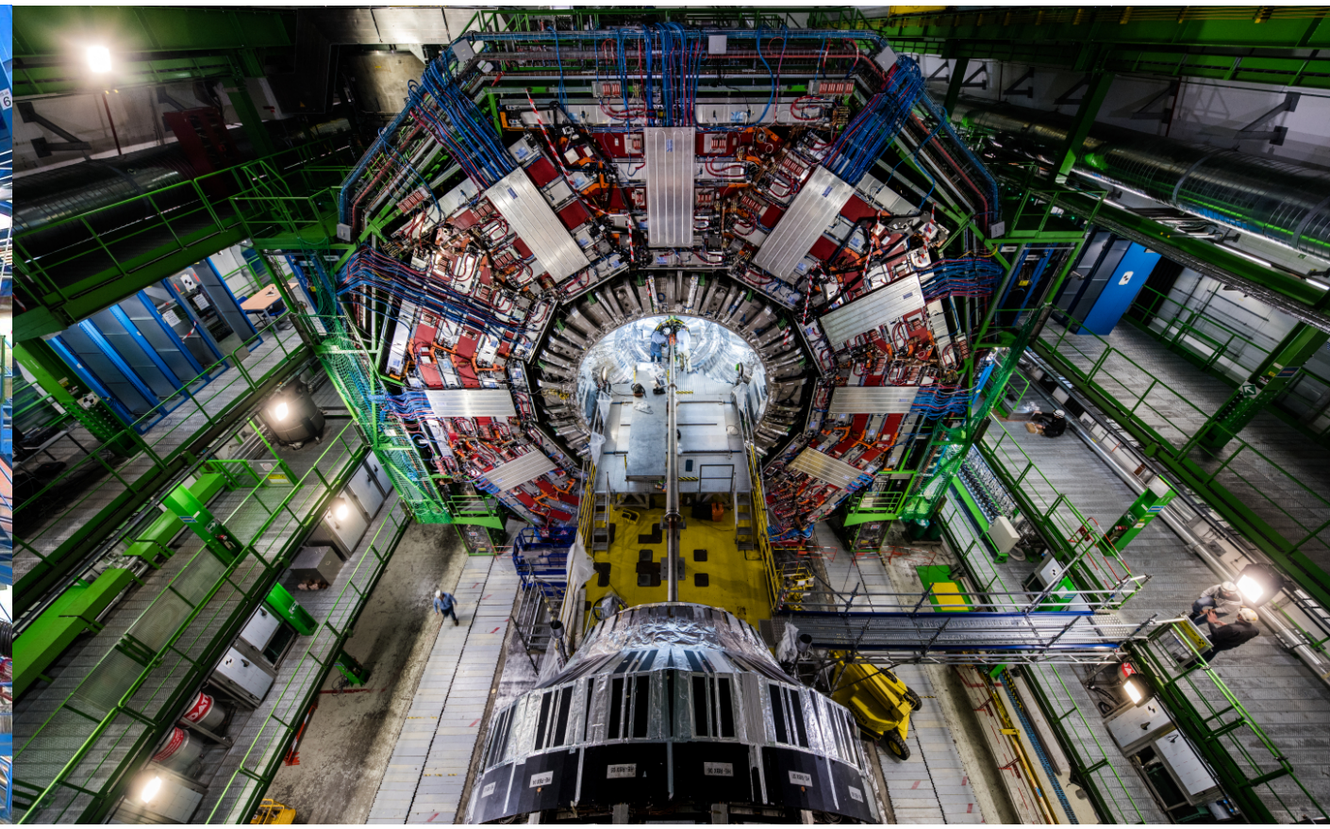



# BSM searches from ATLAS and CMS

Kostas Theofilatos (NKUA)
on behalf of the ATLAS & CMS collaborations

**SUSY2022:** The XXIX International Conference on Supersymmetry and Unification of Fundamental Interactions, 27 Jun-2 Jul 2022, Ioannina (Greece)

ATLAS EXPERIMENT

CMS

HELLENIC REPUBLIC
National and Kapodistrian University of Athens
EST. 1837

# an incredible machine

rate of interesting signals:

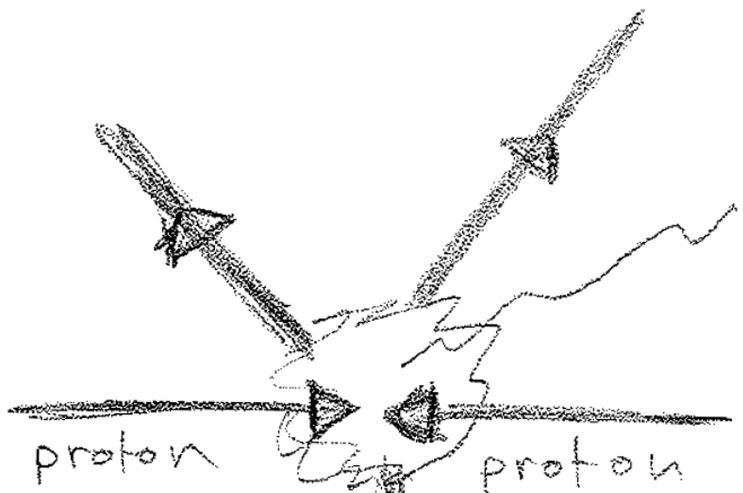
4000 $W^{\pm}$ s / sec

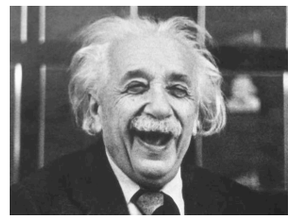
1200 $Z^0$ s / sec

17 $t\bar{t}$ s / sec

1 $h^0$ s / sec

*Run II (20 Hz / nb)



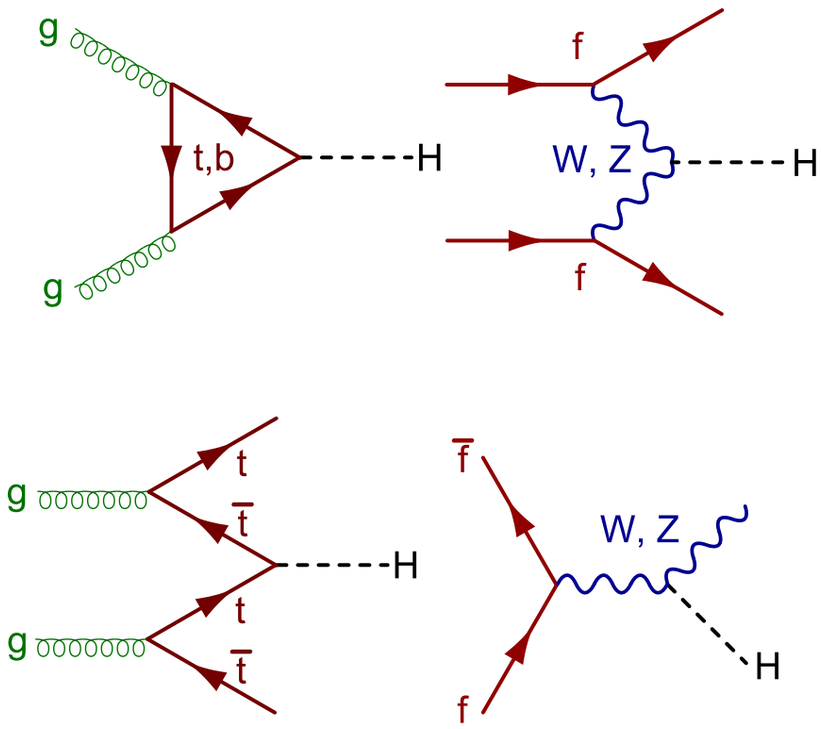

what else ?

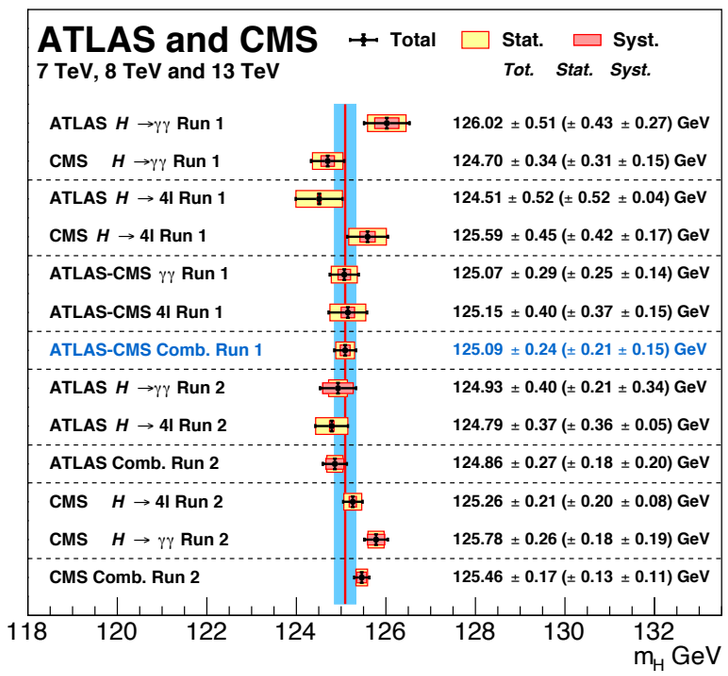
# Higgs, so far

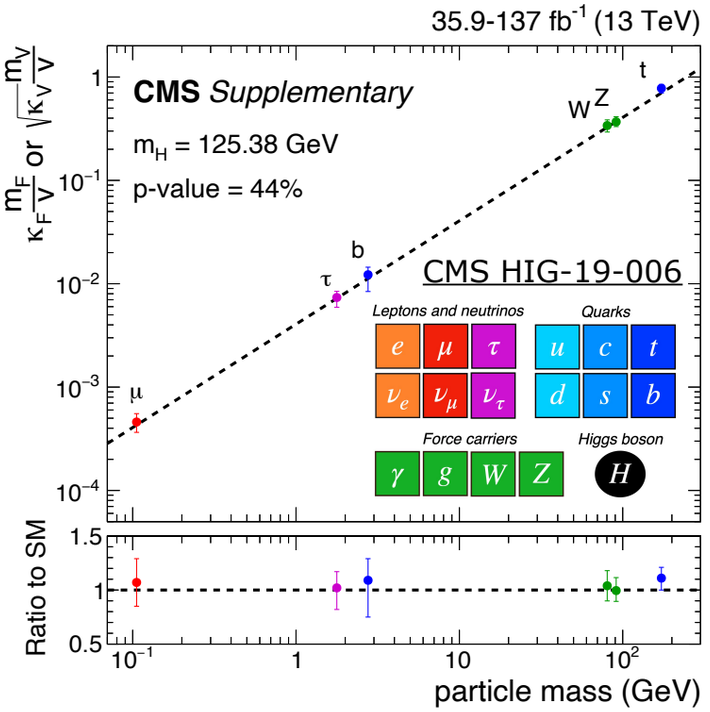
observation of all main:

**production modes** ggF, qqH, VH, ttH

& **decay modes** γγ, ZZ, WW, ττ, bb and evidence for μμ




from all what we know, **H** appears to be a (light) **CP-even fundamental scalar**, just like SUSY predicted (MSSM)

# beyond the SM

There is no doubt that SM is not the final word

it has too many parameters

However, and so far, we haven't found new physics

**ATLAS** and **CMS** routinely experiencing **3-4σ** that come and go, expected given the plethora of SRs (multibin analyses)

**LHCb** and **g-2** experiments report interesting findings

indirectly point to BSM ?

# lepton flavor universality

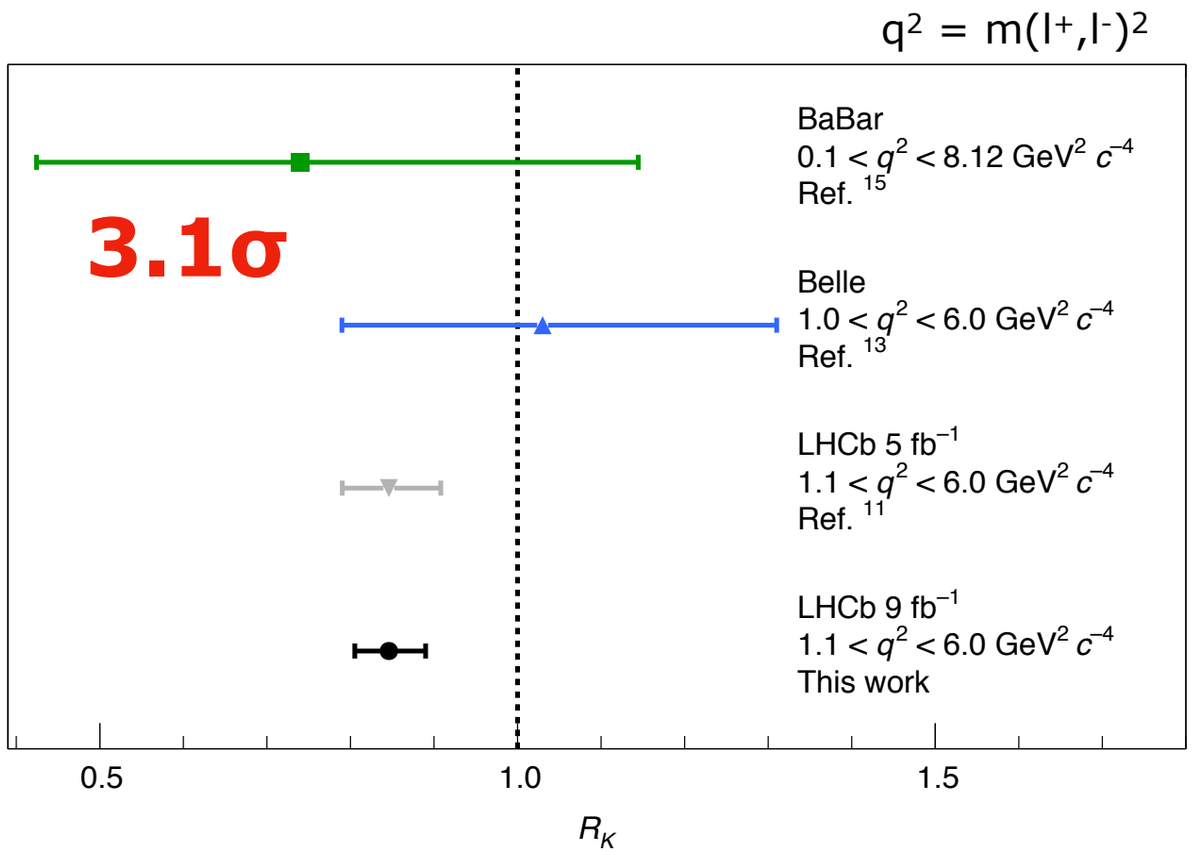
[nature]

# LFU

**e±**, **μ±** and **τ±** have the same interaction strengths in SM, but effects arising from their masses $m_e < m_\mu < m_T$

no charged-lepton-flavor-violating decays have been observed (except of Higgs decays that have interaction strength ~mass of the final state particle)

**or have they ?**

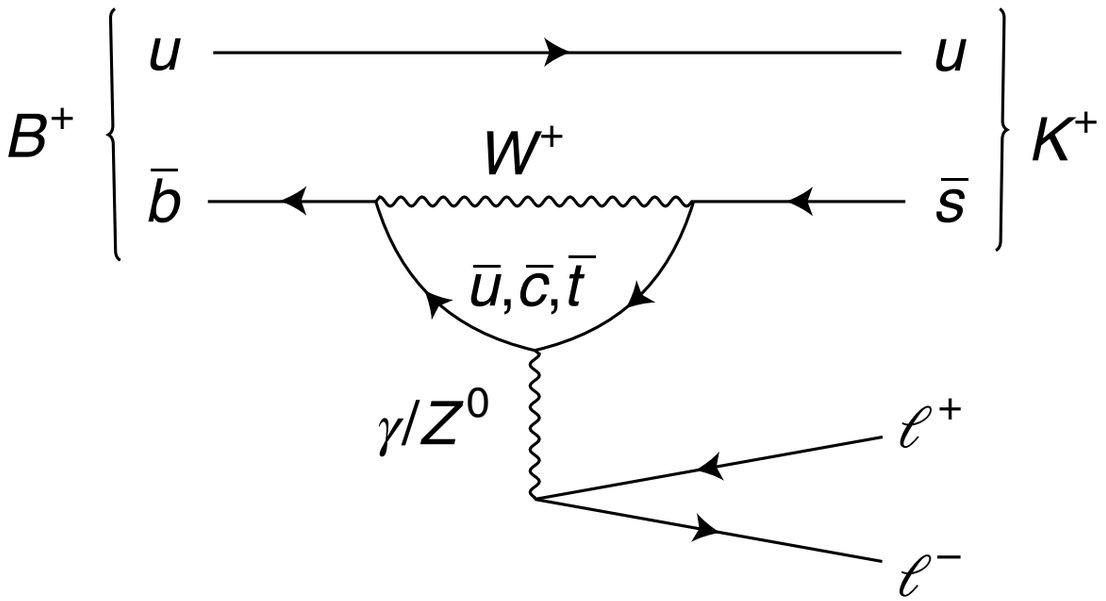


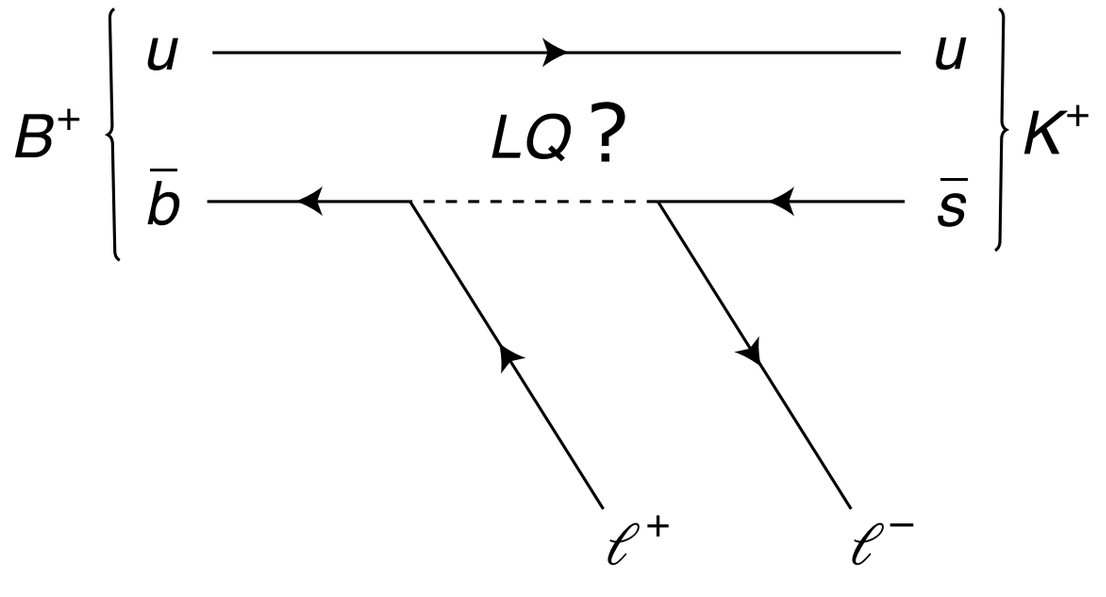

**R(K)** tests **e-μ** universality. Other LHCb analyses testing, **τ-μ** and **τ-e** universality also see **2-3σ** tensions

[nature]

LHCb

# R(K)

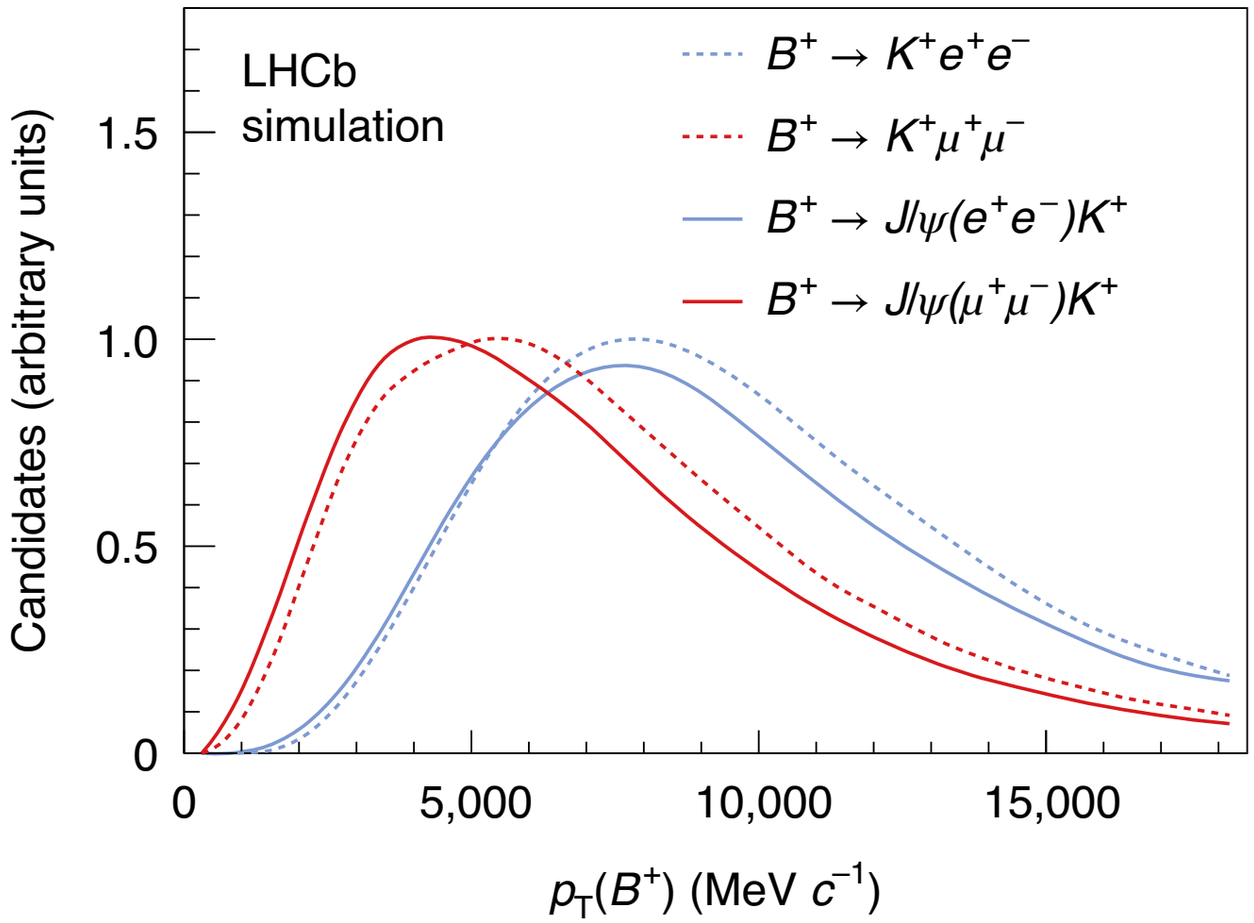



$$R_K = \frac{\mathcal{B}\ (B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}\ (B^+ \to J/\psi(\to \mu^+ \mu^-) K^+)} \Big/ \frac{\mathcal{B}\ (B^+ \to K^+ e^+ e^-)}{\mathcal{B}\ (B^+ \to J/\psi(\to e^+ e^-) K^+)}$$

[nature]

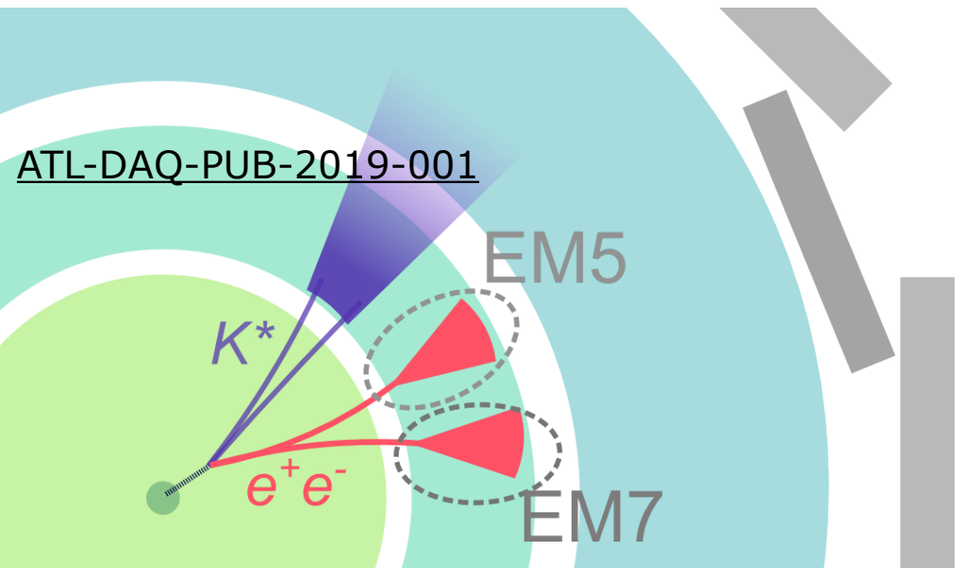
# R(K)




ATLAS + CMS try to provide independent measurements of R(K) but are facing the challenge to trigger low-pt **e**

Special B-physics triggers deployed in 2018 and improved for Run 3

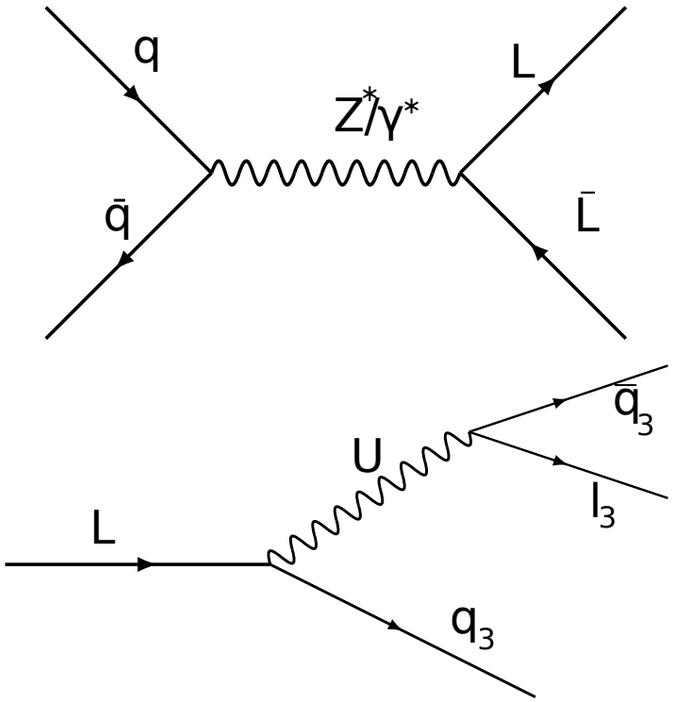
can’t do a competitive measurement with Run-2 data alone



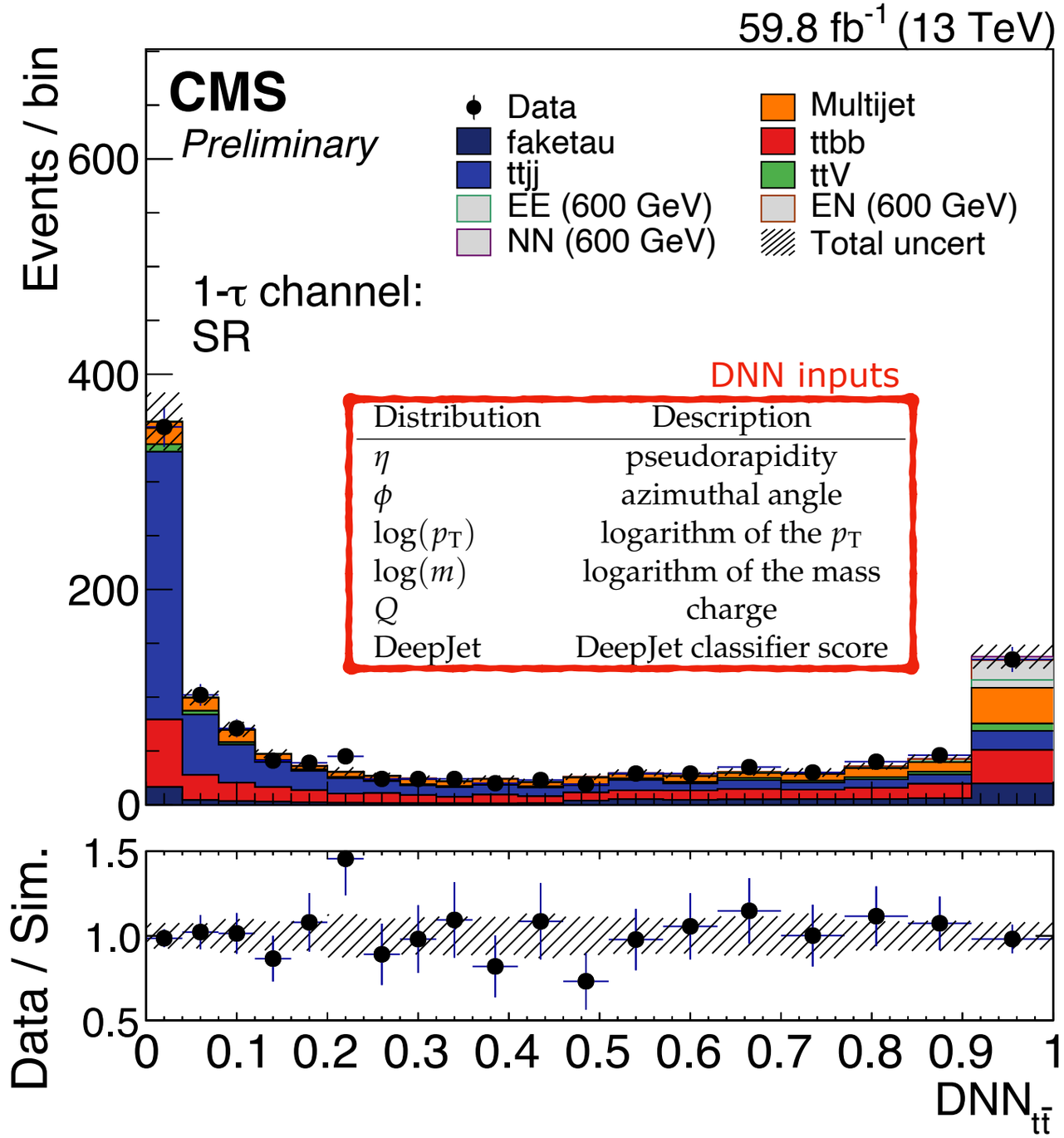
# 3b + Nτ + MET

B2G-21-004 **2.8σ**

[4321 model](#) accommodates
**LHCb flavor anomalies**




L = **vector-like lepton**
U = **leptoquark**
q3, l3= **3rd generation** q & l




2 DNNs trained to discriminate signal against QCD and ttbar

none of the mass ranges tested here for VLL (500–1050 GeV) is excluded

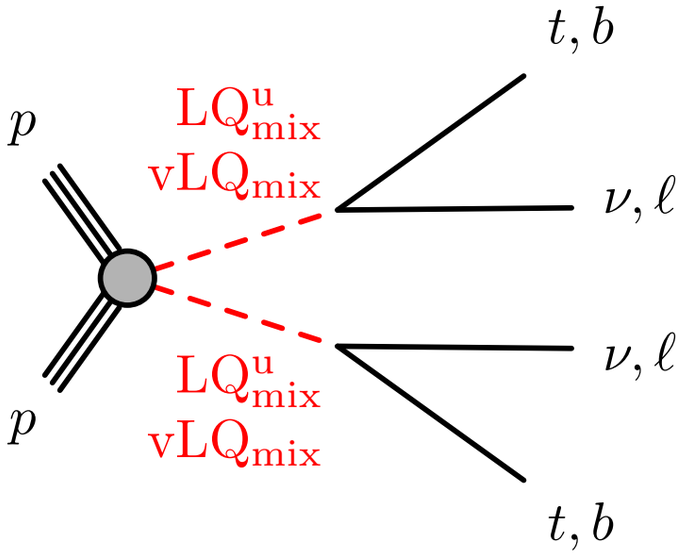
ATLAS-CONF-2022-009 see Patrick's talk

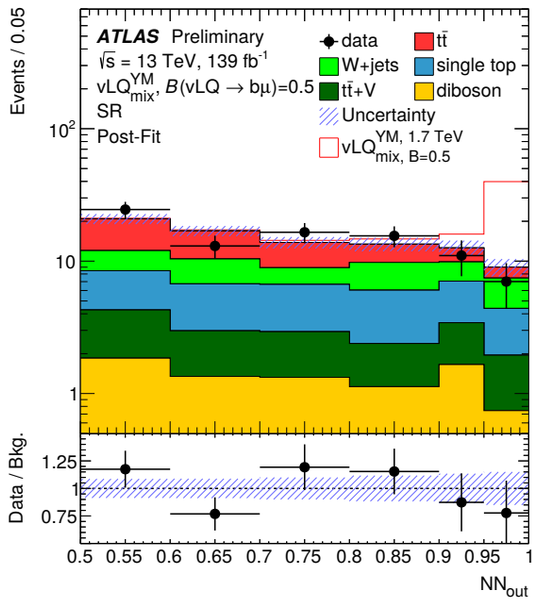
# 1l+4j+MET

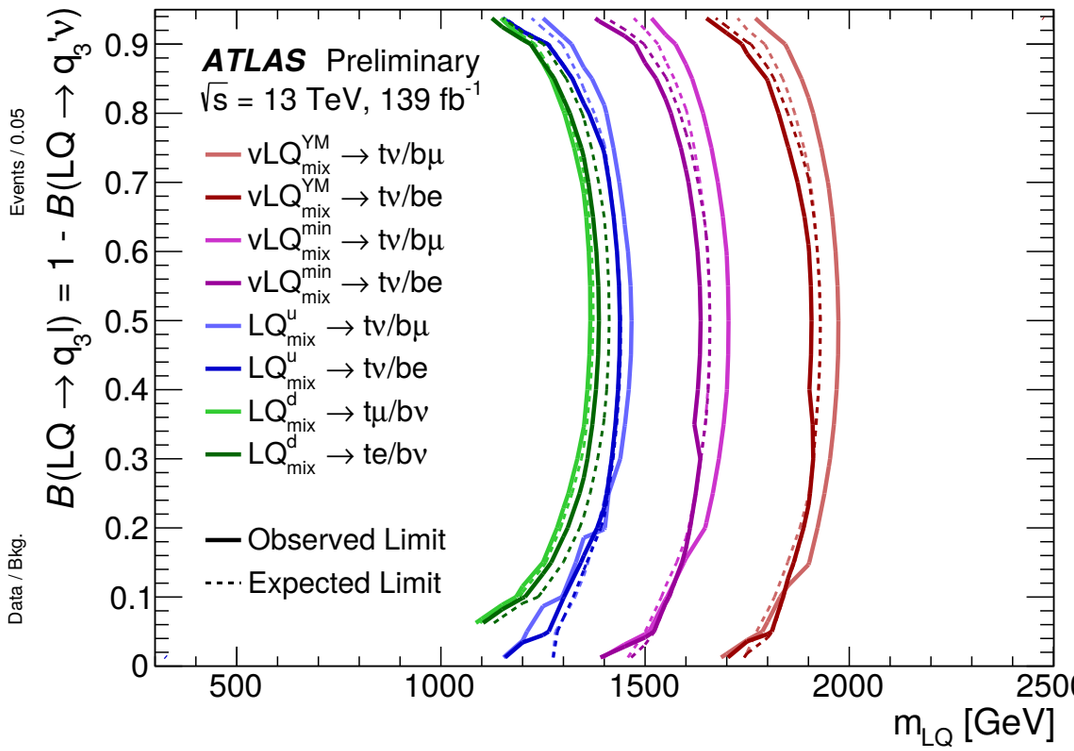
↓

hadronically decaying top

# vLQ aiming to explain LFU tension in B-hadron decays



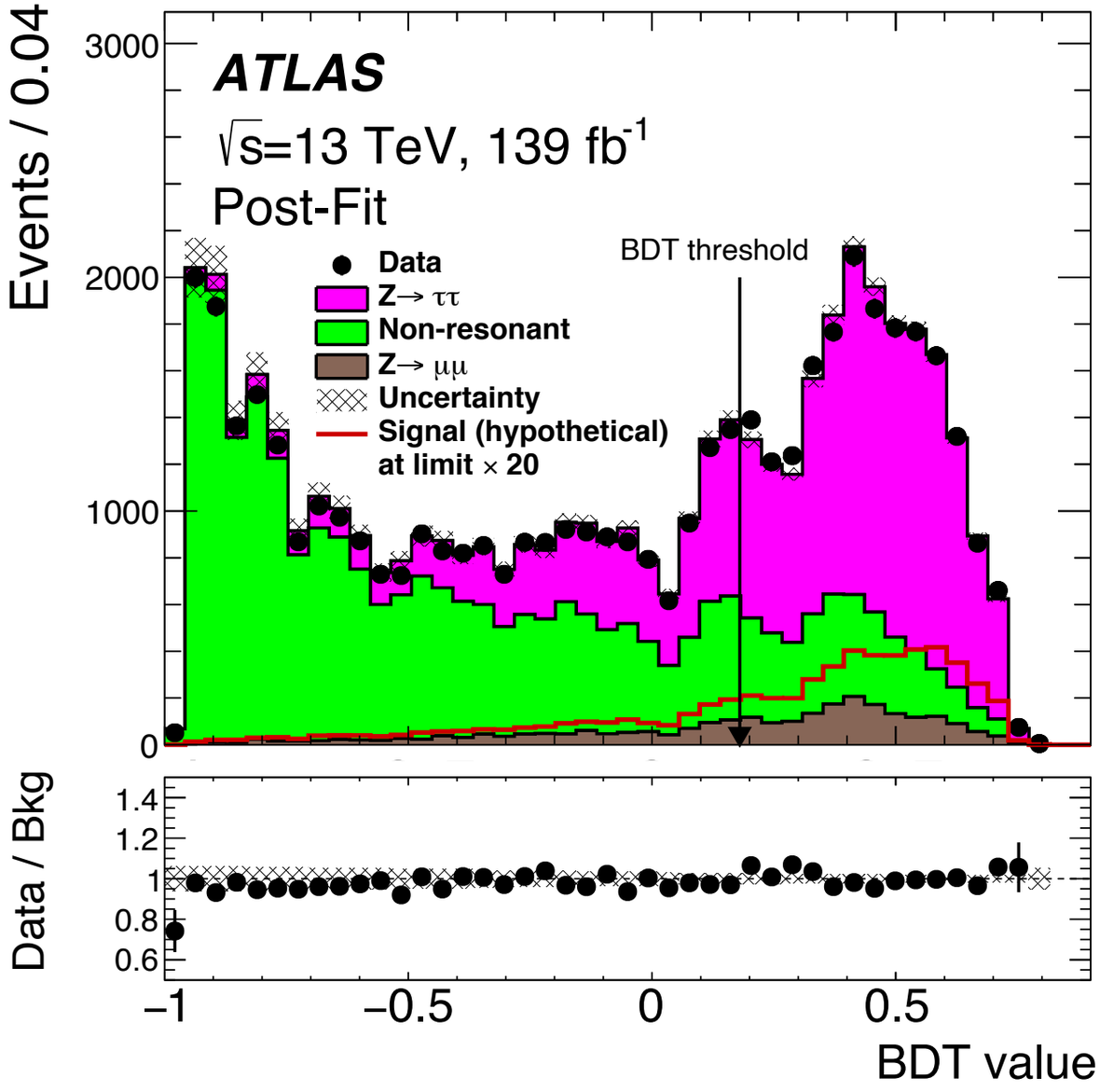

scalar and vector LQs of 3rd generation allowed to decay to quarks and leptons of the 1st and 2nd generation

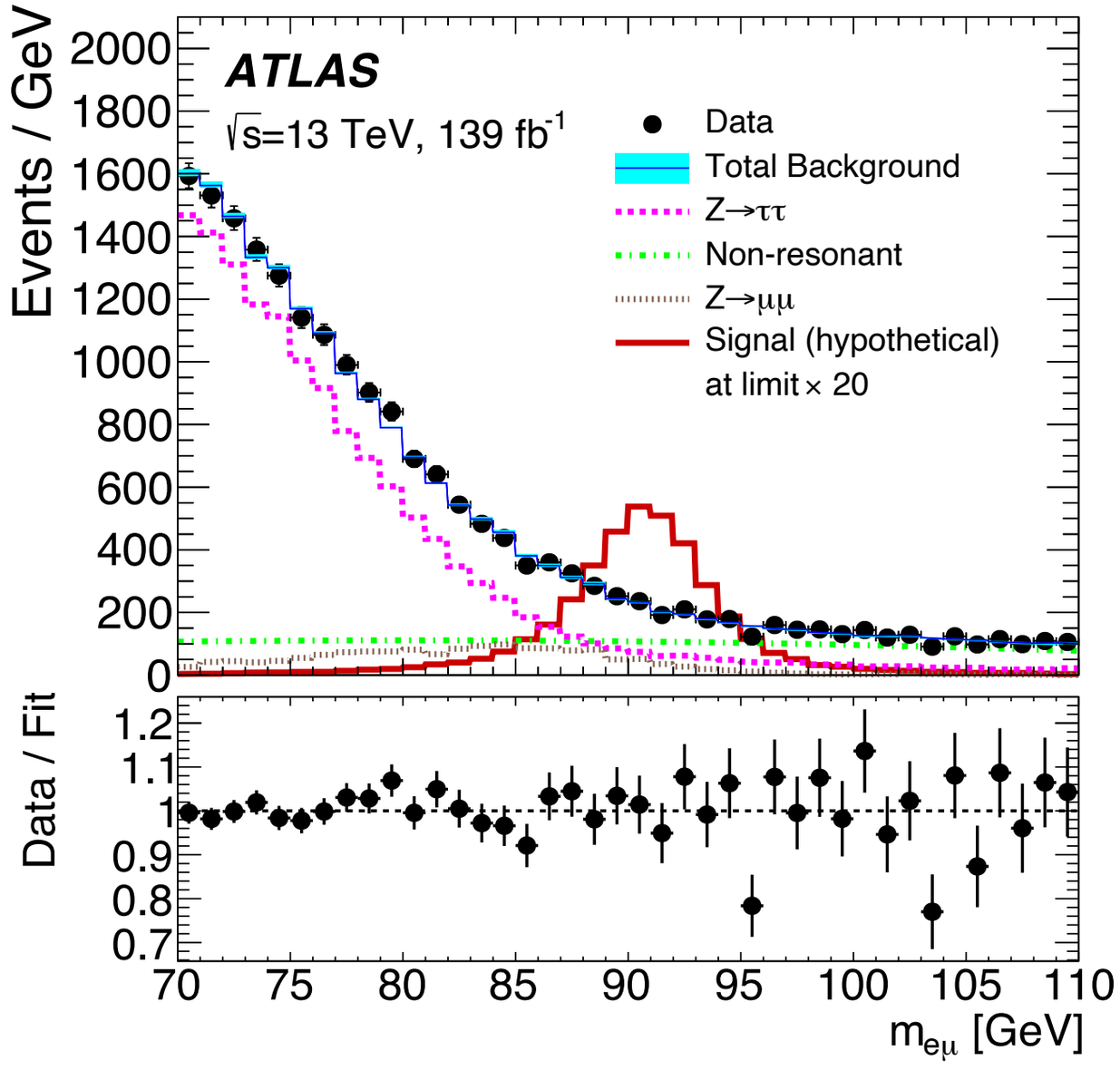
**Several NNs** trained for the **various signal hypothesis** with 15 inputs ($M_T$, $m_{eff}$, $P_T(l)$ …)

**No excess observed in any of the signal models**

EXOT-2018-35

# Z→eμ




BR(Z→eμ) ~ $10^{-60}$ [in SM]

BR(Z→eμ) < 1.7 × $10^{-6}$ [**LEP**]

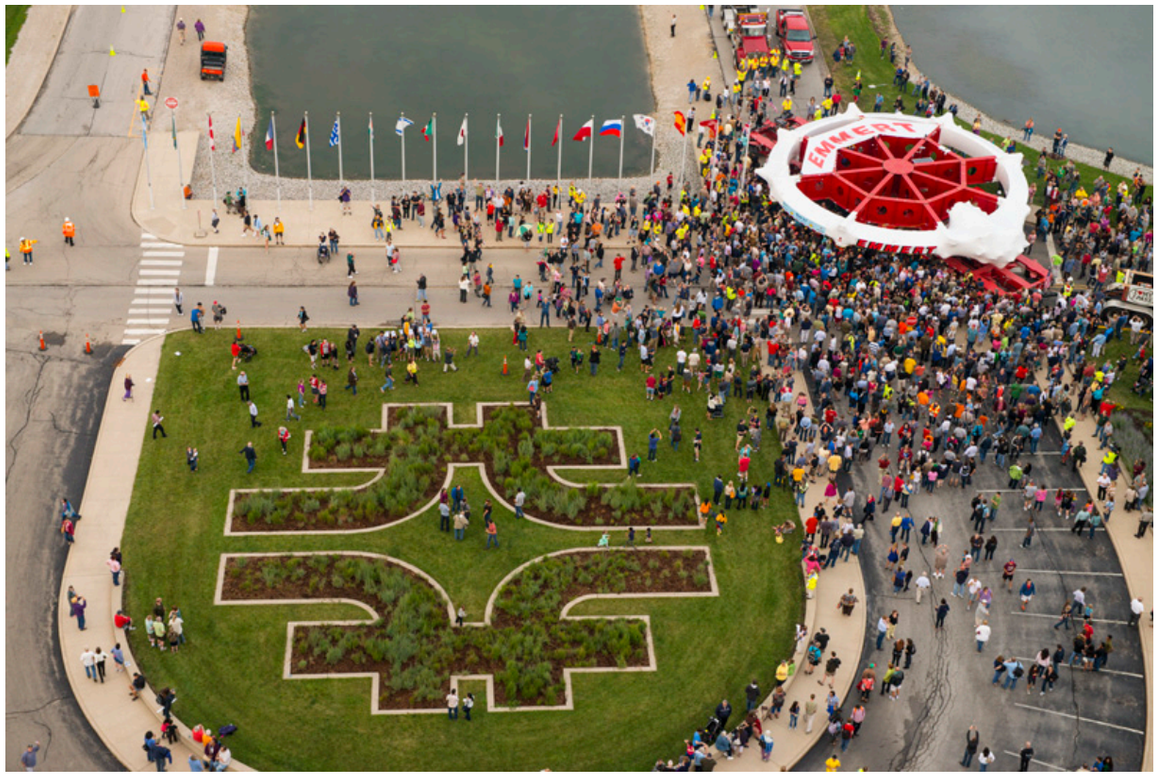
BR(Z→eμ) < 2.62 x $10^{-7}$ [**LHC** ATLAS]

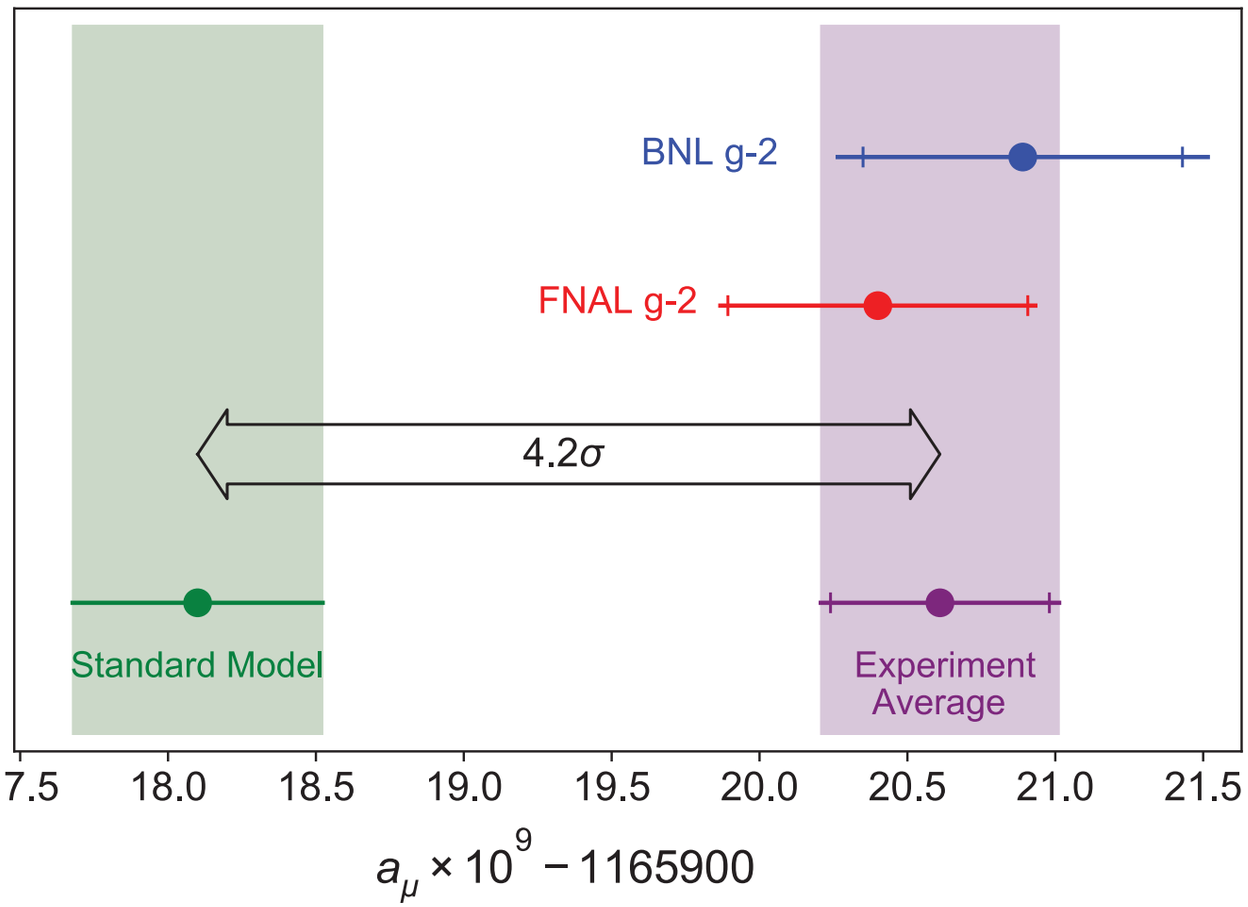
will enter the PDG booklet next year!

# g-2

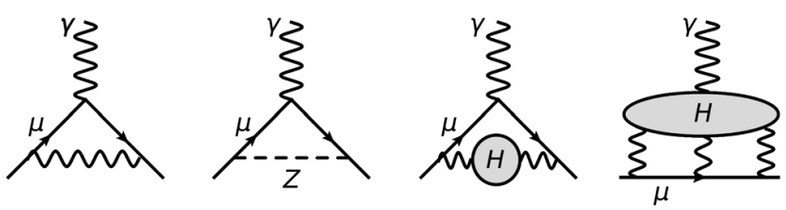
[PRL]

# g-2






$$\vec{\mu}_\ell = g_\ell \left( \frac{q}{2m_\ell} \right) \vec{s} \quad \text{where } g_\ell = 2(1 + a_\ell)$$



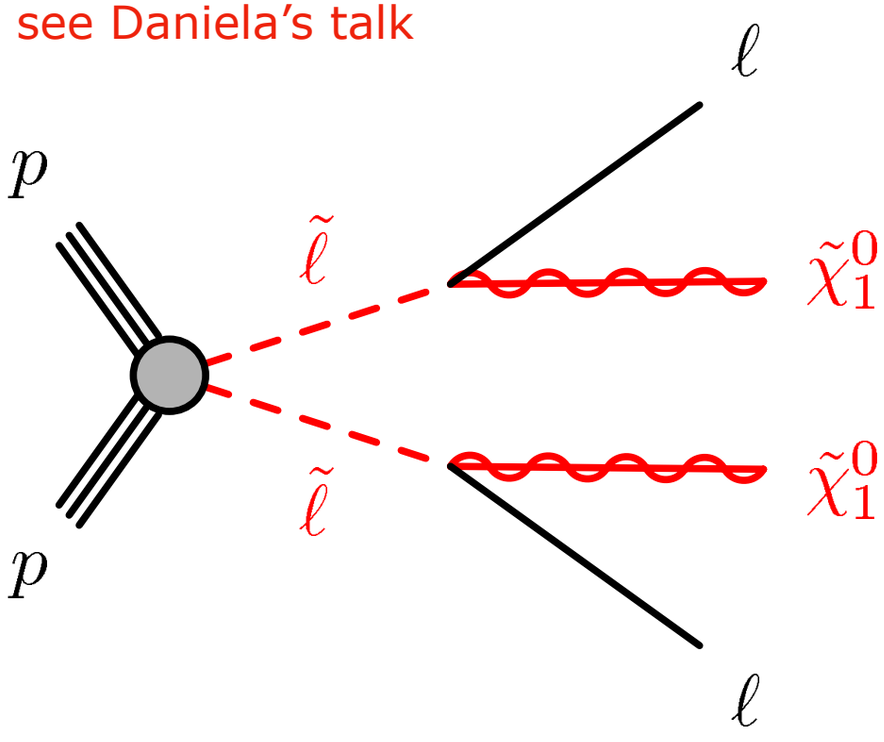

measurement with a precision of 0.46 parts per million, in 4.2σ tension wrt the SM

# smuon (g-2)

ATLAS-CONF-2022-006

see Daniela's talk

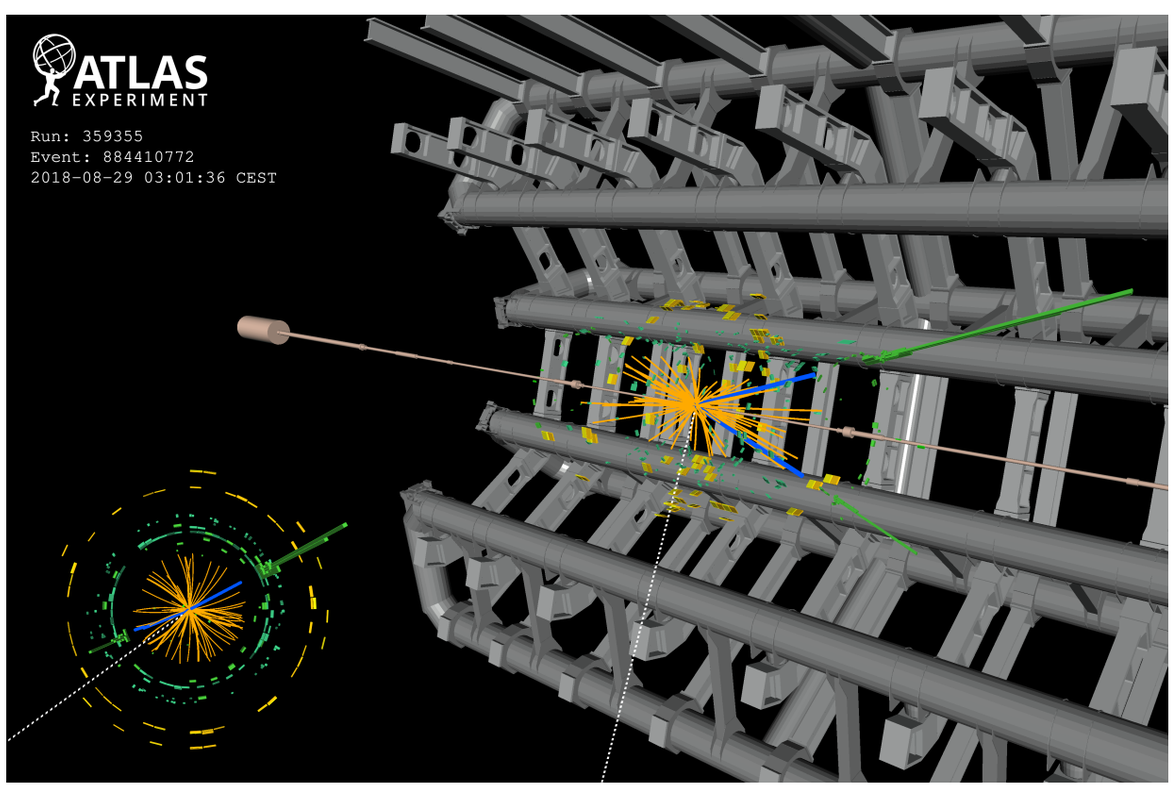
same paper includes also a compressed chargino search with BDT



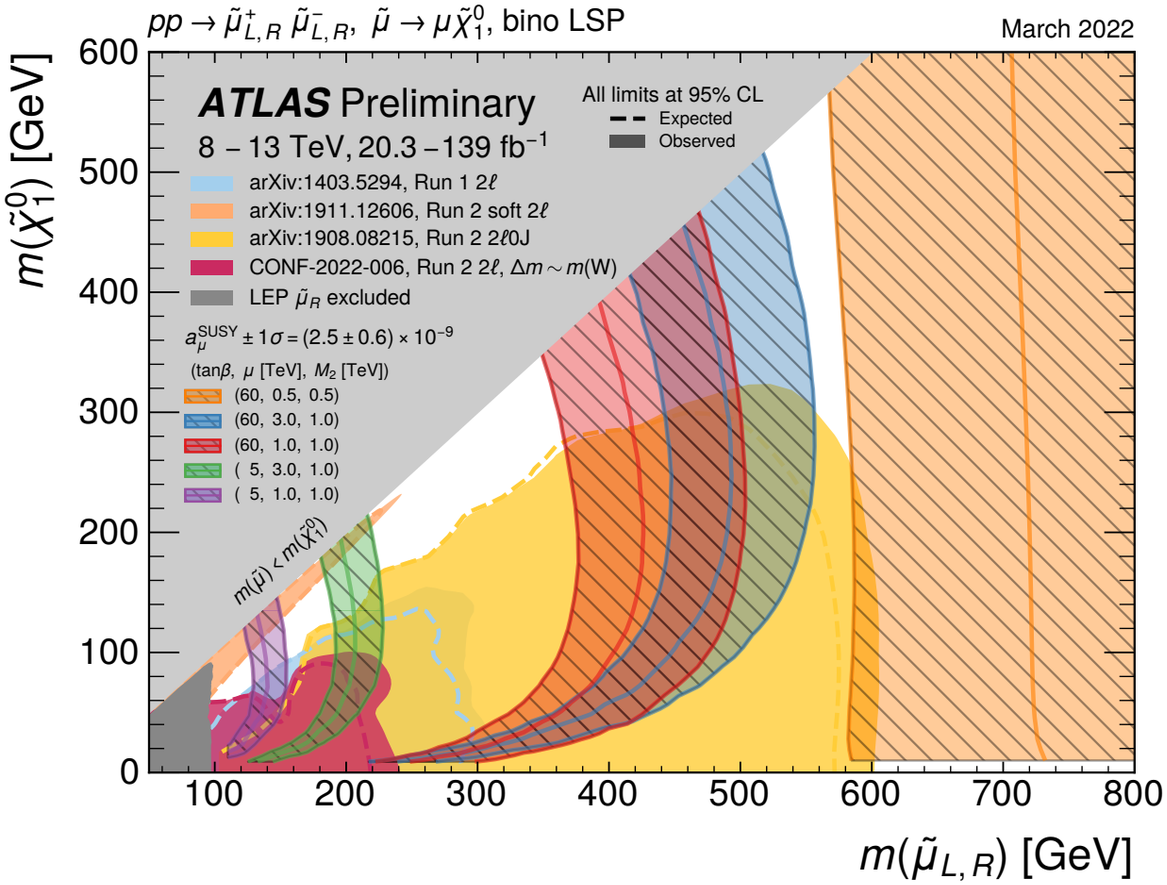

compressed $m(\tilde{\mu}) - m(\tilde{\chi}_1^0) \sim m_W$

with light $m_{LSP}$ mass could **explain g-2**

robust background estimation from from eμ data




$\tilde{e}^+\tilde{e}^-$ candidate



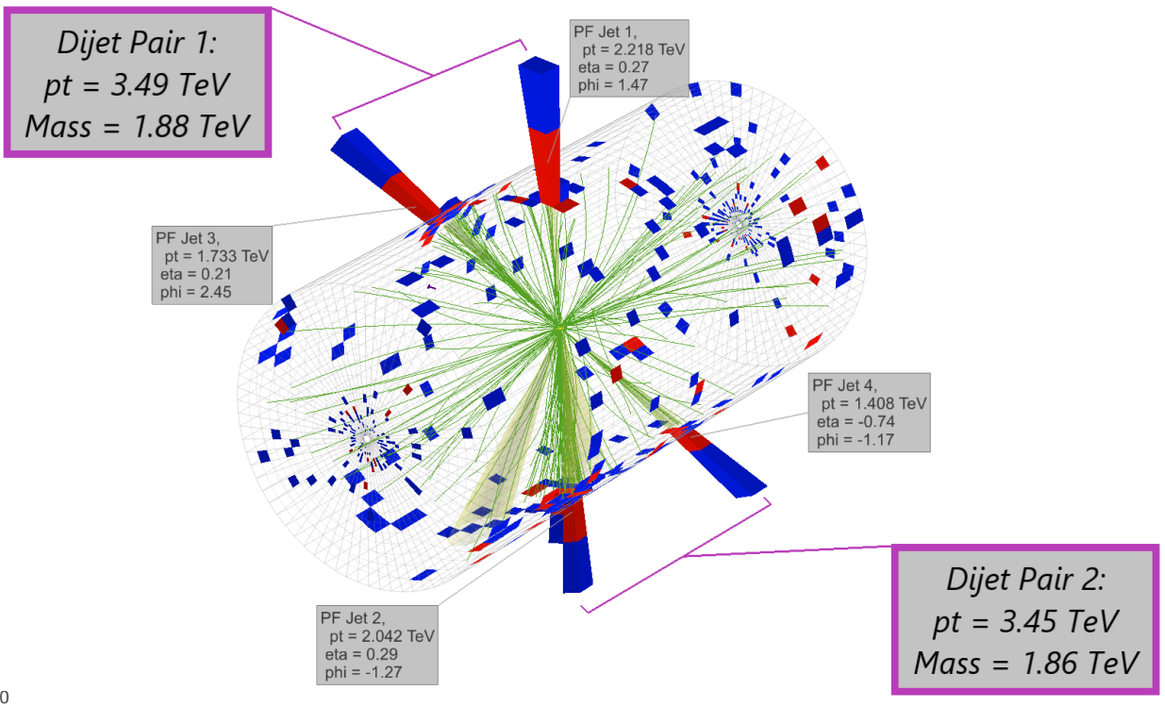

no excess

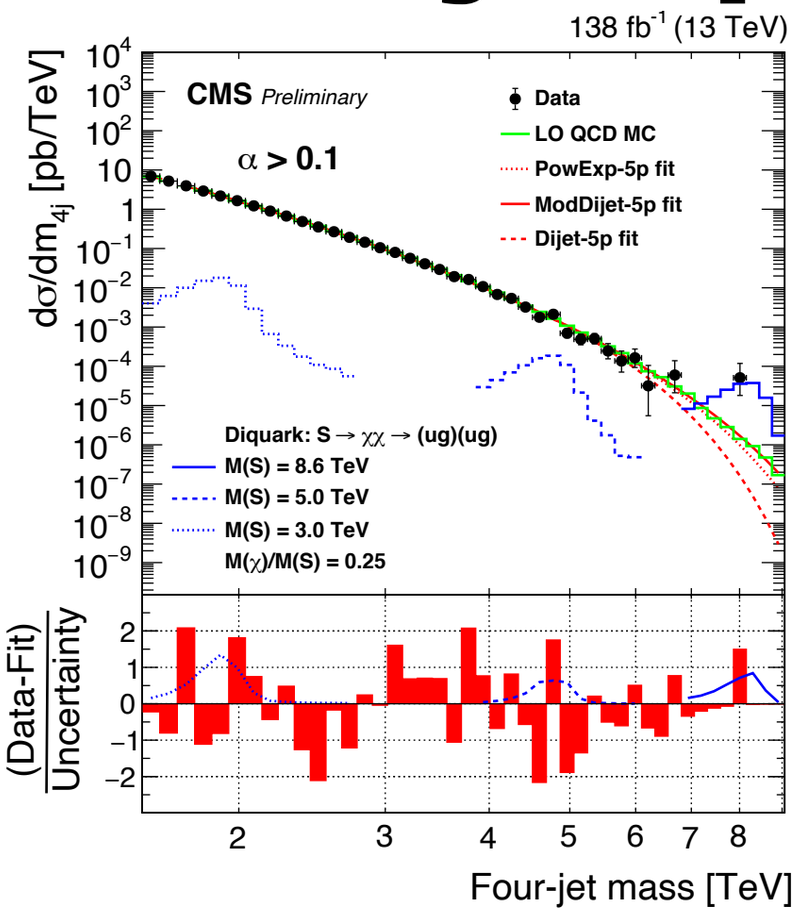
# resonances

EXO-21-010

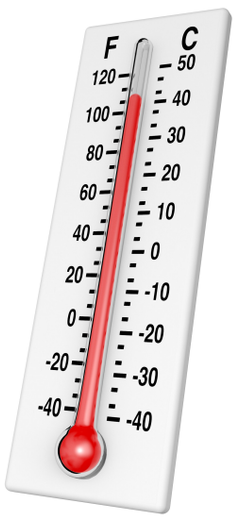
# 3.9σ (local)

# dijet pairs

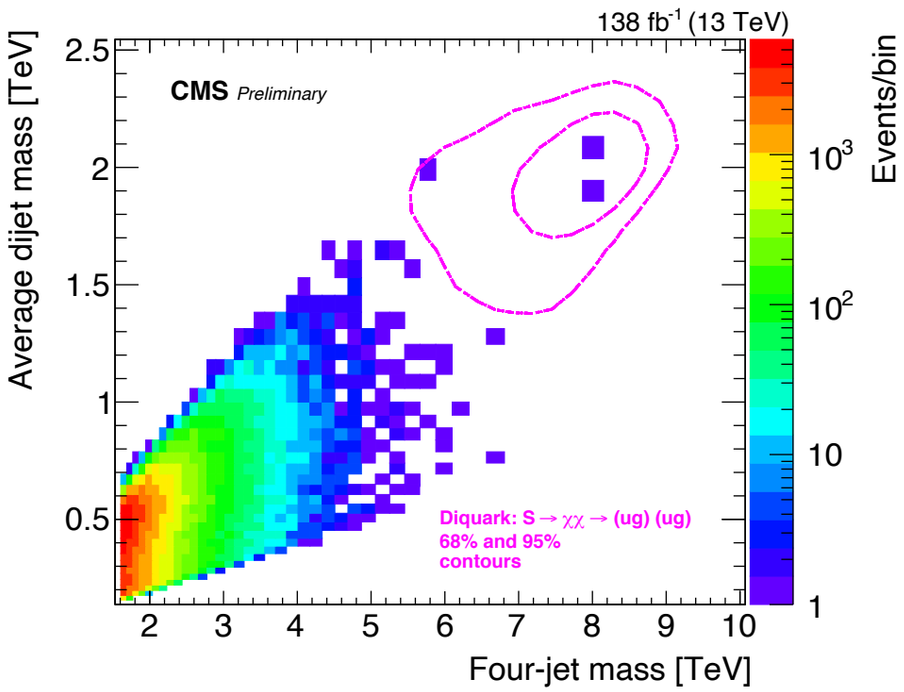



$$pp \rightarrow Y \rightarrow XX \rightarrow (jj)(jj)$$

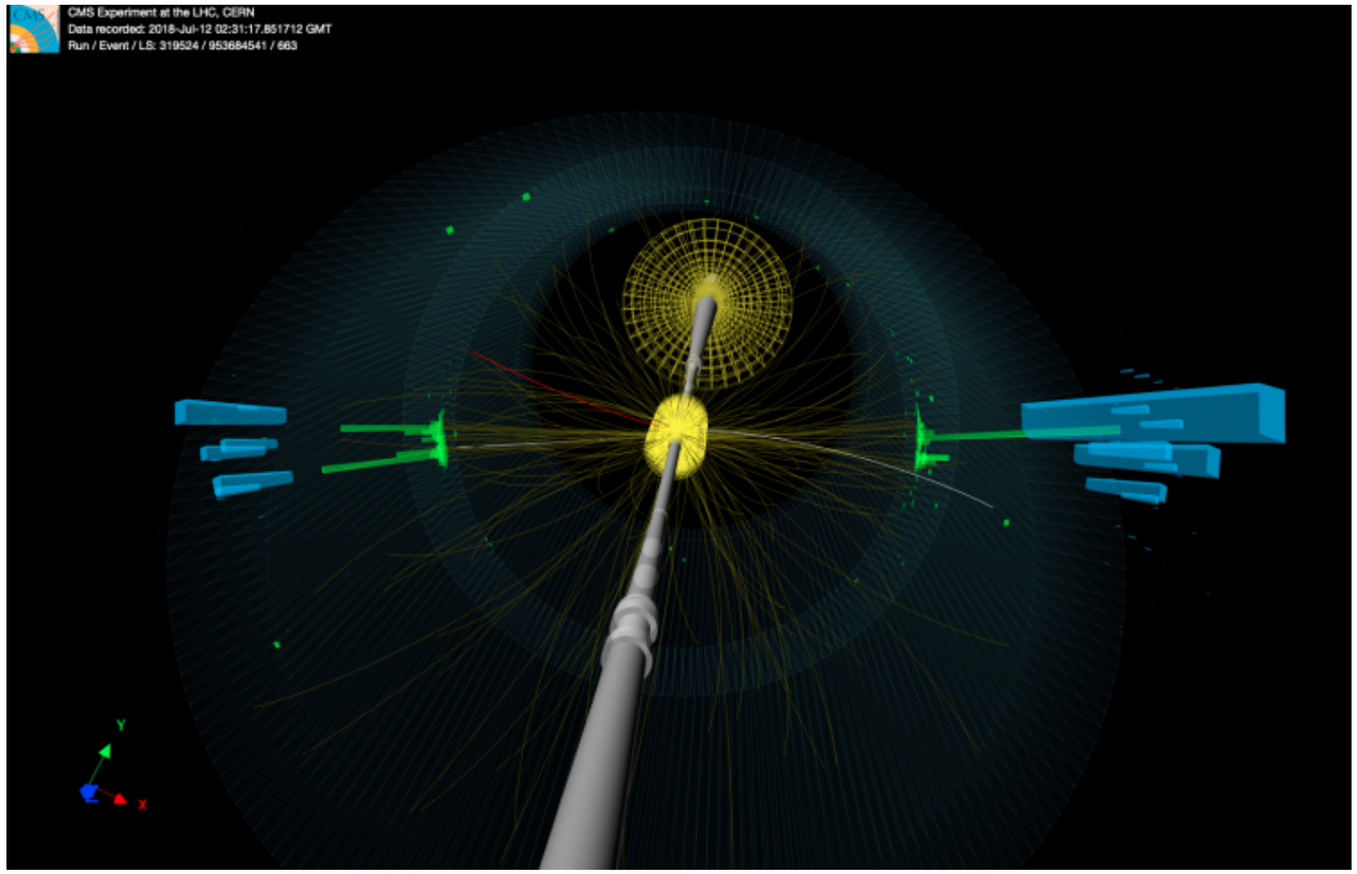


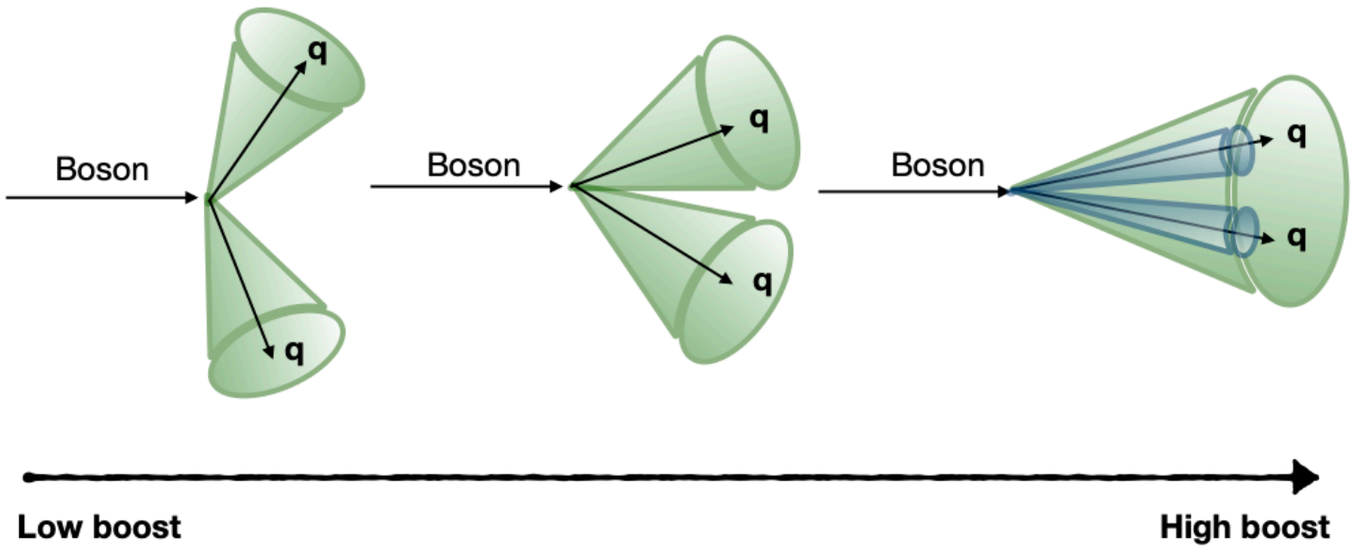

first paired dijet mass search at the LHC

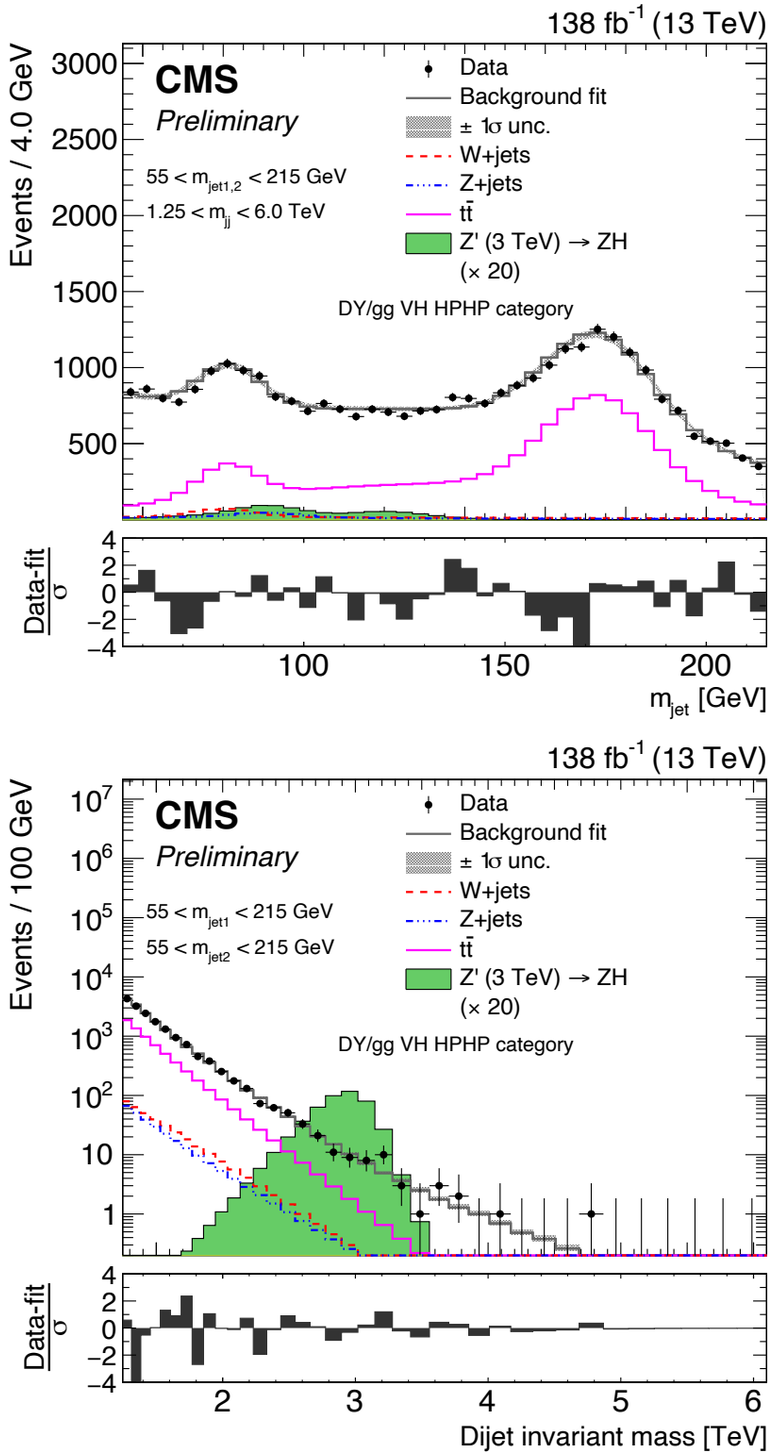


# X → VV or VH

B2G-20-009



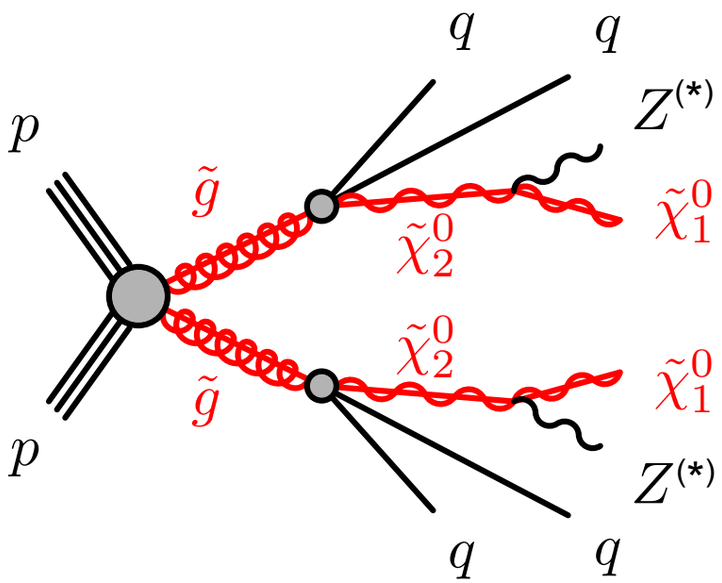



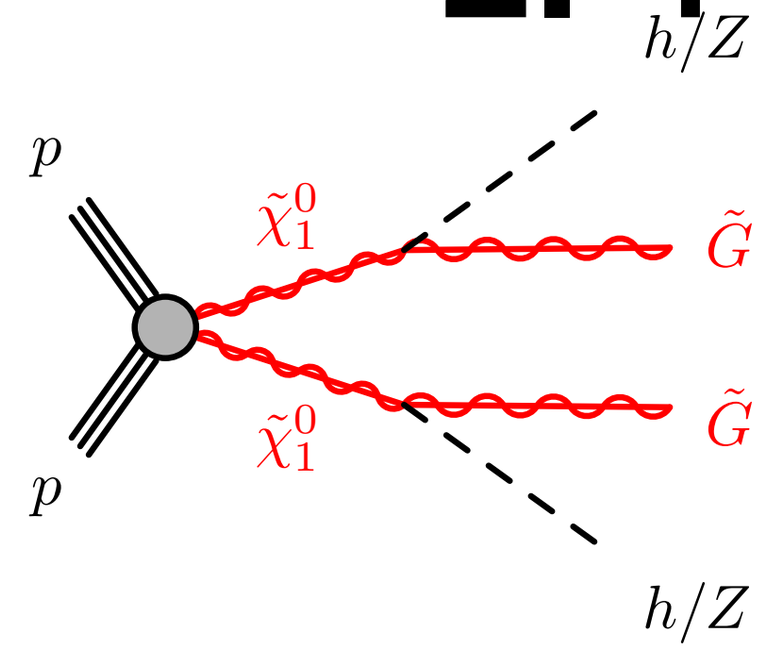

fit of $m_{jj}$, $m_{j1}$, $m_{j2}$ templates and places limits to **masses below 4.8 TeV (1.4 TeV)** for W'/Z' (RS–gravitons)

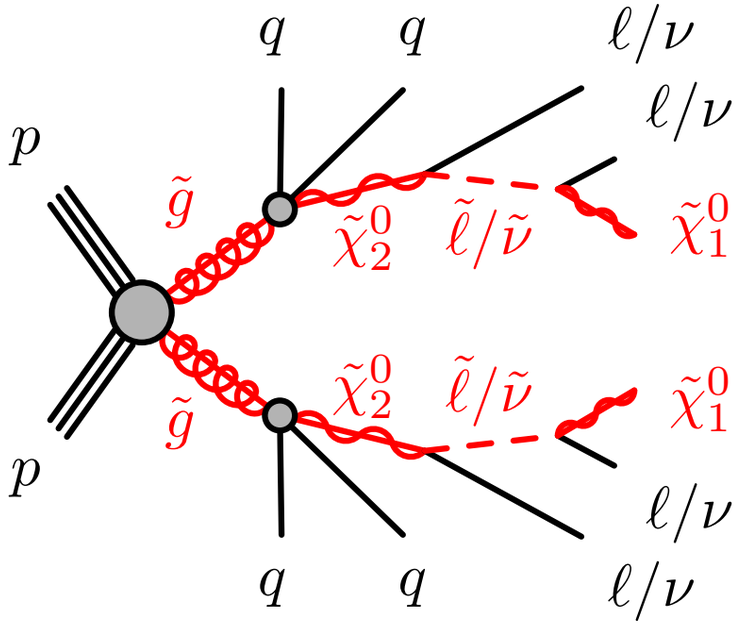
# SUSY

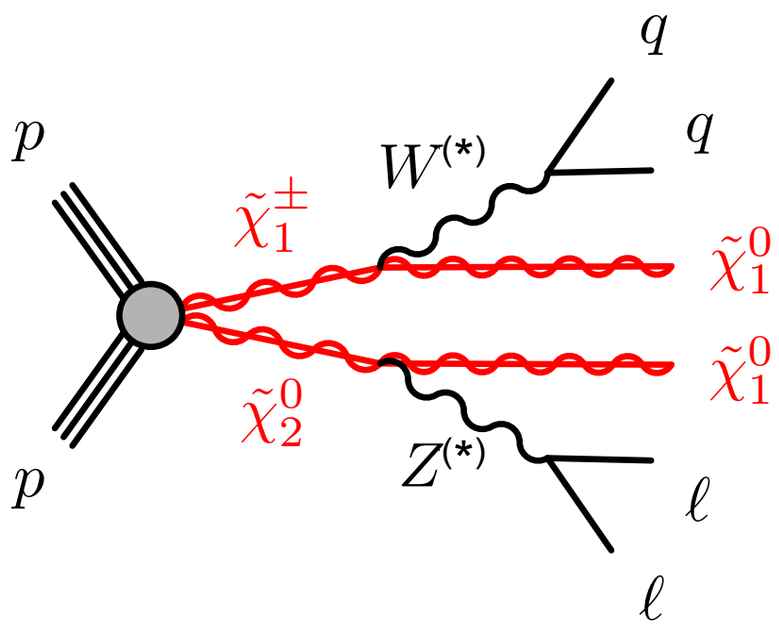
# 2l + jets + MET

SUSY-2018-05 see Yi-Lin's talk



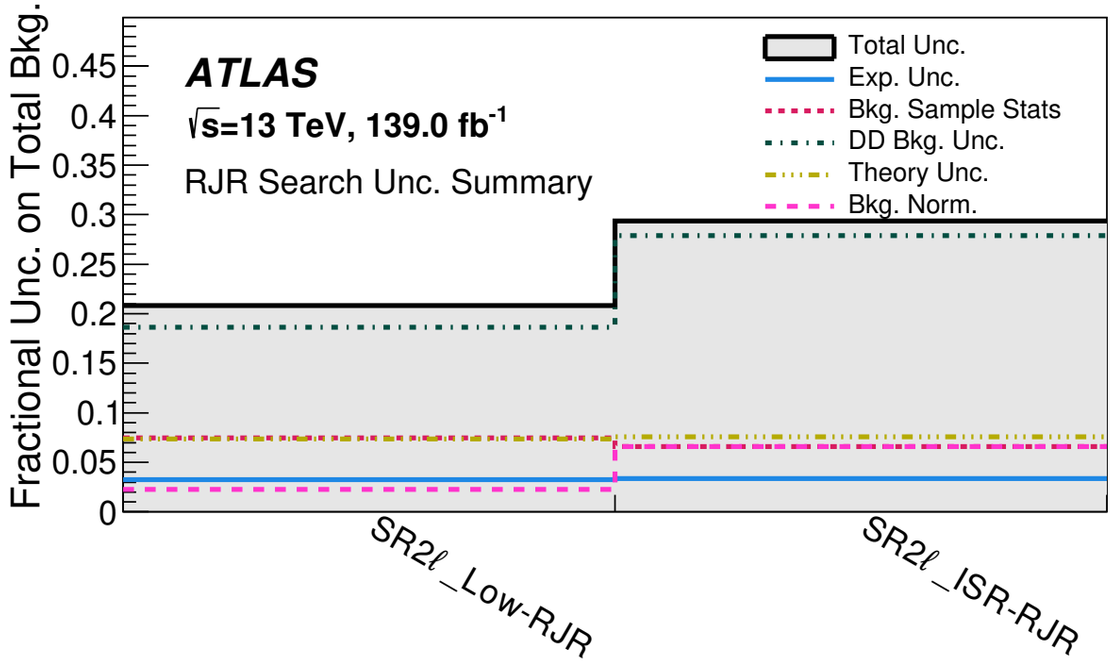

**1** search targeting QCD SUSY ($m_{ll}$ endpoints, $m_Z$)

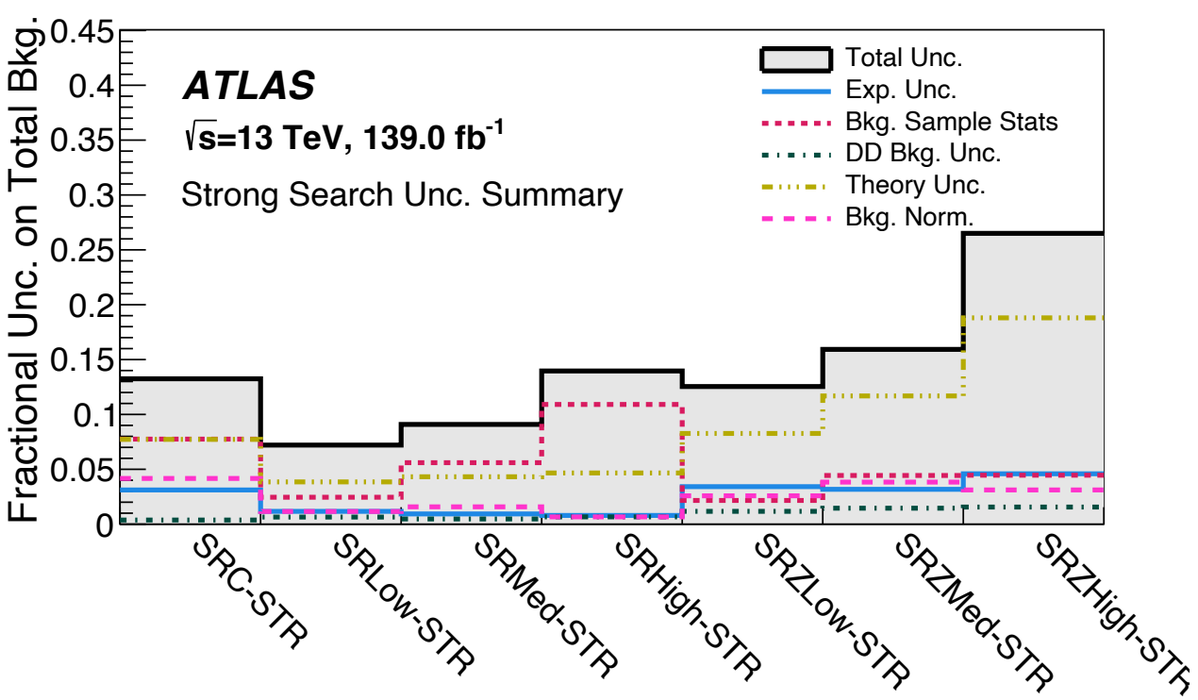
**2** searches targeting EW SUSY, one using recursive jigsaw reconstruction technique to follow up on excesses seen at 36 fb-1

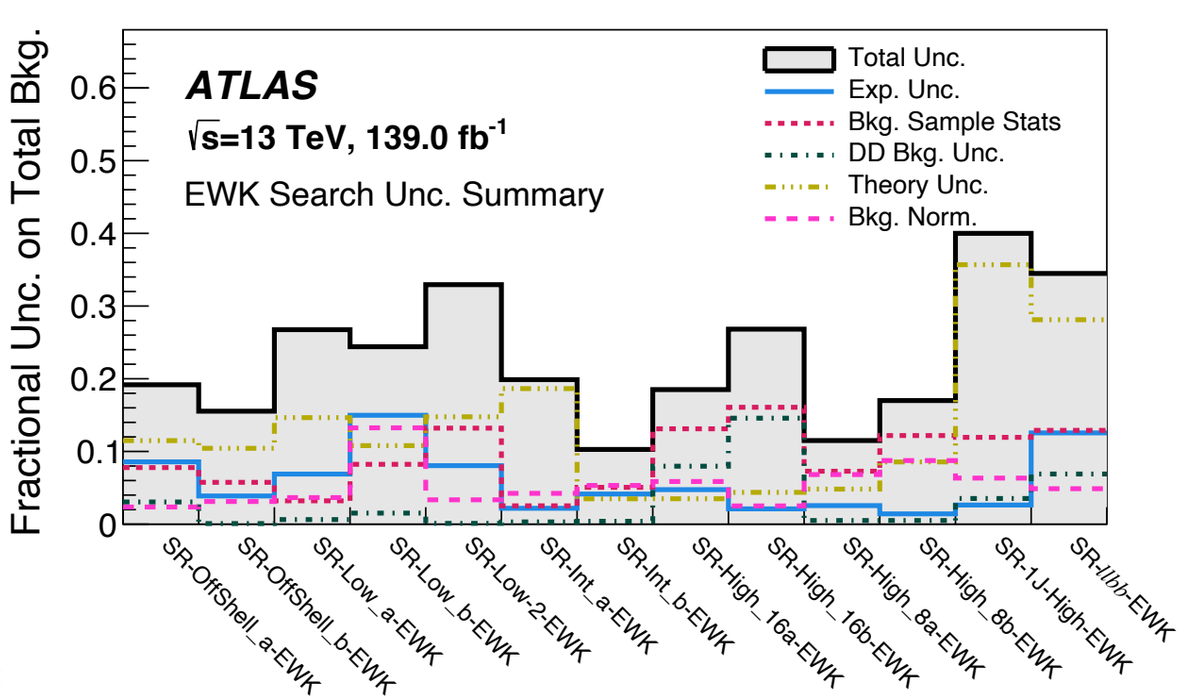
SUSY-2018-05

# 2l + jets + MET

signal regions and uncertainties on the background estimation



# 2l + jets + MET

SUSY-2018-05

| | 1.4σ | 2.0σ |
|---|---|---|
| Signal region | SR2$\ell$_Low | SR2$\ell$_ISR |
| $ee$ | 9 (4.5±3.9) | 3 (1.2±1.2) |
| $\mu\mu$ | 10 (3.9±2.6) | 8 (1.5±1.5) |
| Signal region | SR3$\ell$_Low | SR3$\ell$_ISR |
| $eee$ | 6 (3.5±0.7) | 3 (1.1±0.3) |
| $ee\mu$ | 6 (2.0±0.4) | 3 (0.9±0.3) |
| $\mu\mu\mu$ | 7 (2.7±0.6) | 4 (1.5±0.4) |
| $\mu\mu e$ | 1 (1.9±0.4) | 2 (0.4±0.1) |

**36 fb-1** SUSY-2017-03

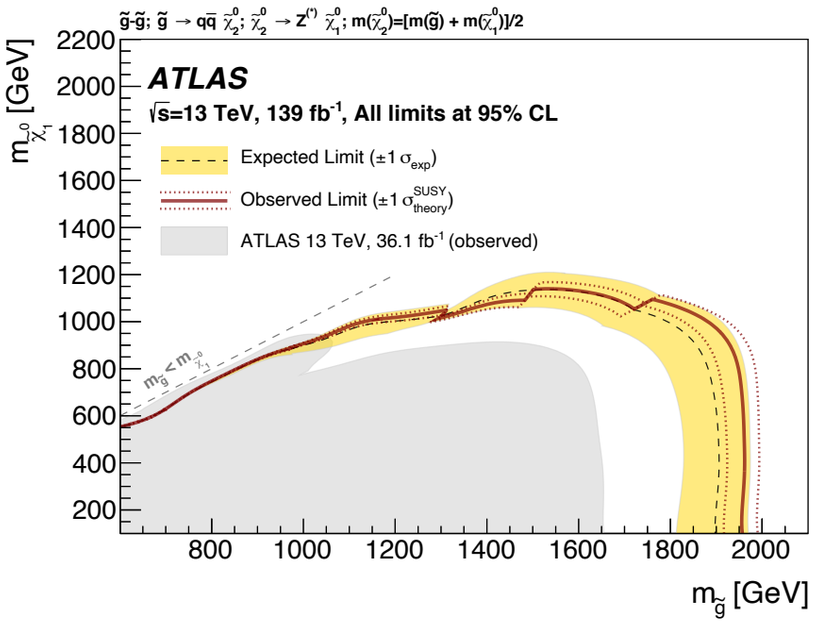
| | SR2$\ell$-Low-RJR | SR2$\ell$-ISR-RJR |
|---|---|---|
| Observed events | 39 | 30 |
| Total expected background events | $42 \pm 9$ | $31 \pm 9$ |
| Diboson events | $10.6 \pm 3.4$ | $8.9 \pm 2.5$ |
| Top events | $3.5 \pm 1.7$ | $8.2 \pm 2.3$ |
| $Z/\gamma^*$ + jets events | $27 \pm 8$ | $12 \pm 9$ |
| Other events | $0.3^{+0.5}_{-0.3}$ | $0.11 \pm 0.04$ |

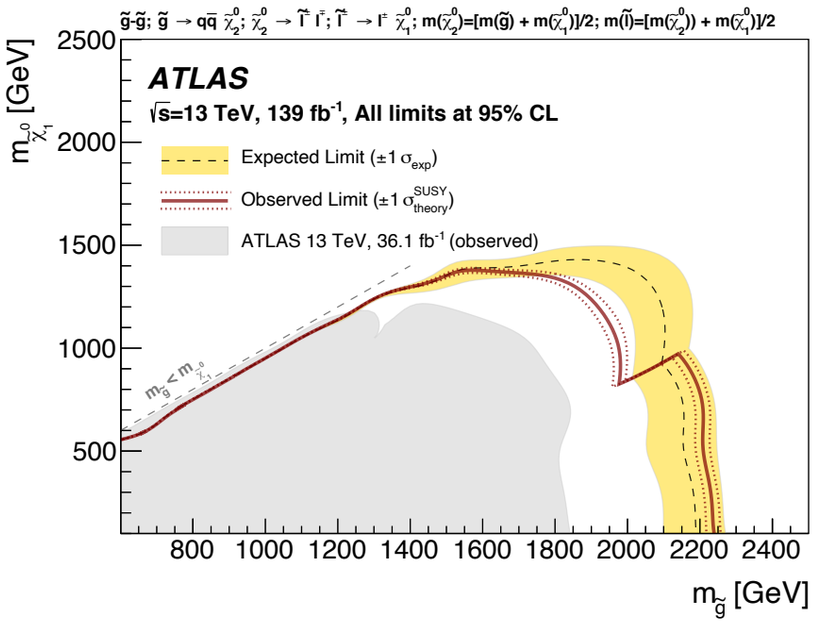
**140 fb-1**

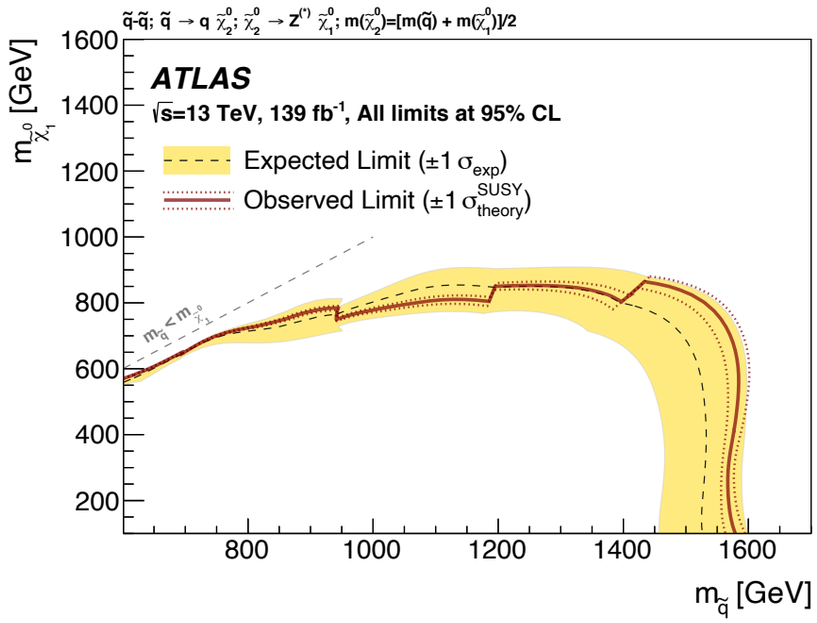
excess gone with more data

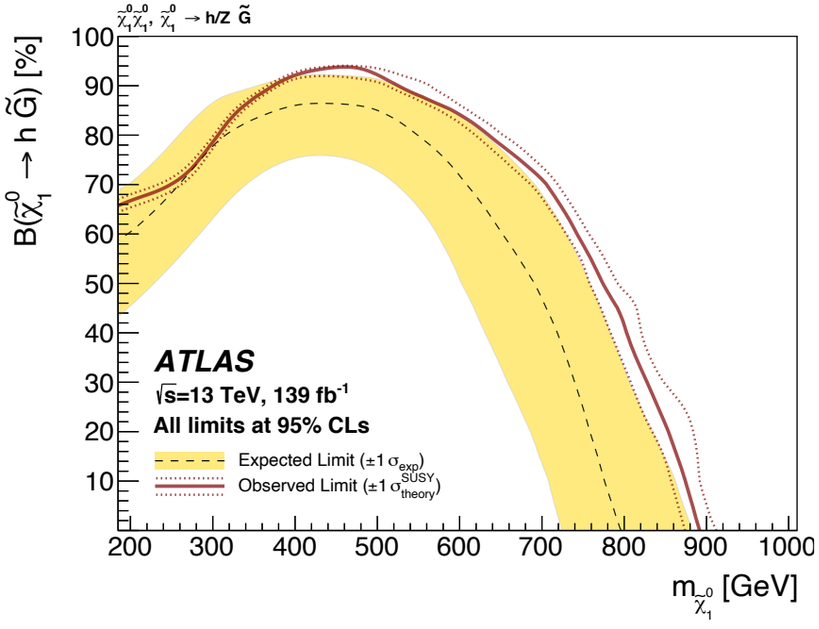
SUSY-2018-05

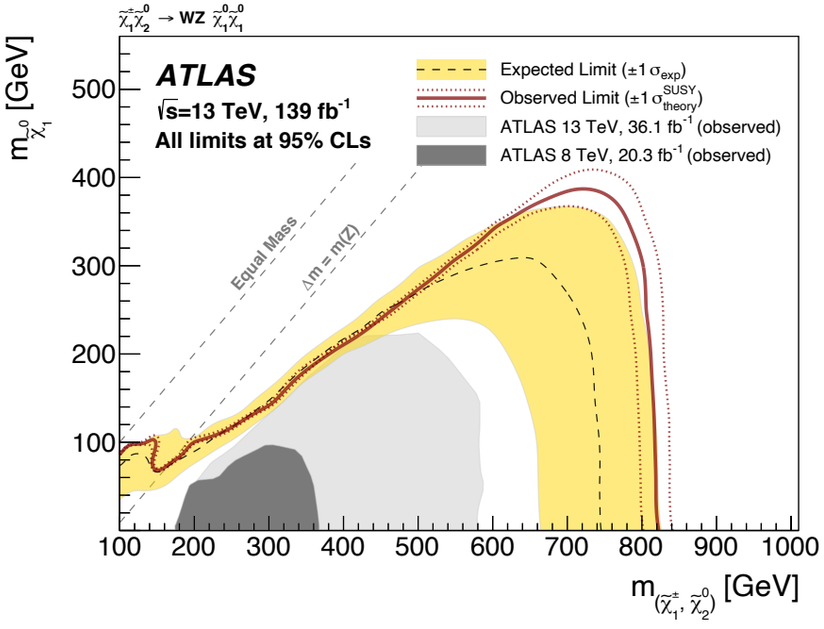
# 2l + jets + MET




**0.9 TeV** for electroweakinos, **1.6 TeV** for squarks, and **2.2 TeV** for gluinos.

SUSY-2018-10

SUS-21-007 see Andrea-Trapote's talk

# 1l + jets + MET

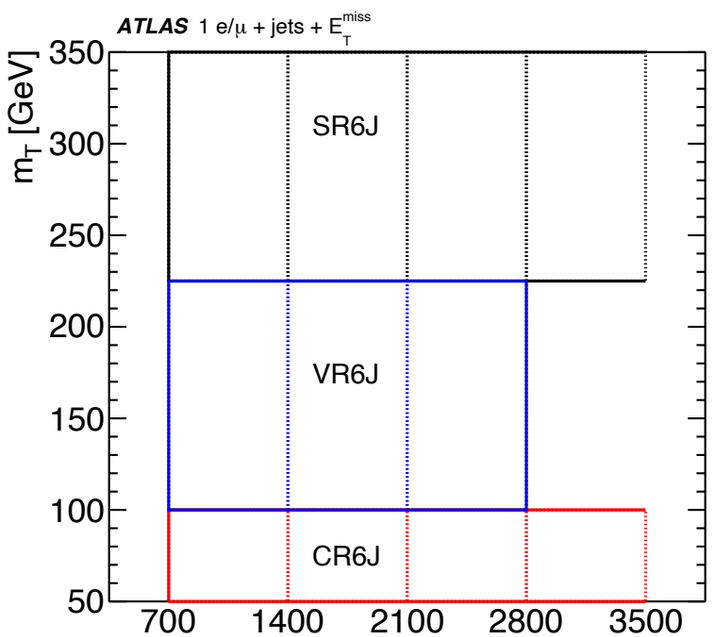
| | ATLAS | CMS |
|---|---|---|
| $N_{Leptons}$ | =1 | =1 |
| $p_{TLepton}$ | >6-7 GeV | >25 GeV |
| $N_{jets}$ | ≥2 | ≥5 |
| MET | >300 GeV | >250 GeV |
| compressed | √ | no |
| top/W/Z-tag | no | √ |
| $N_{SRs}$ | 26 | 44 + 50 |

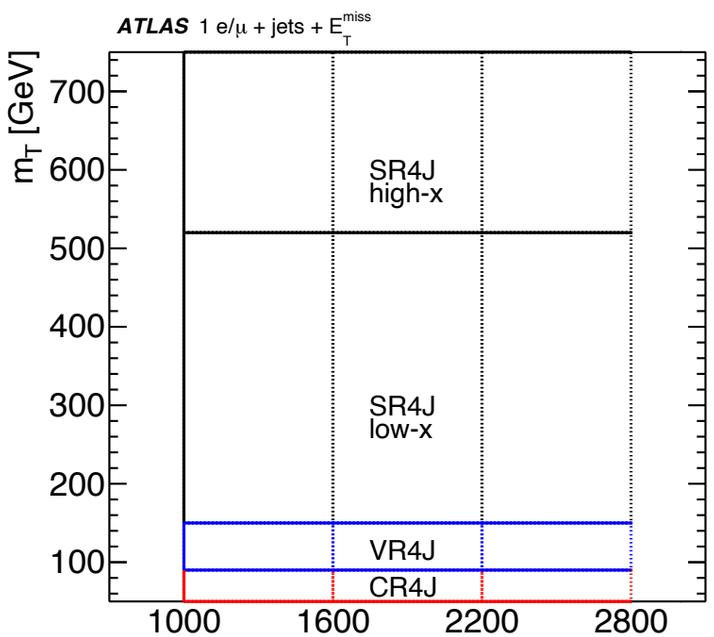
**preselections**

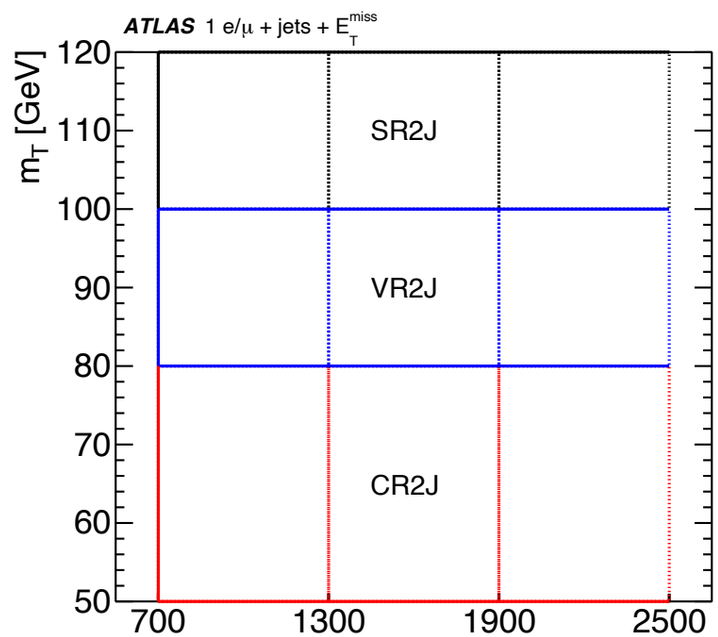
SUSY-2018-10

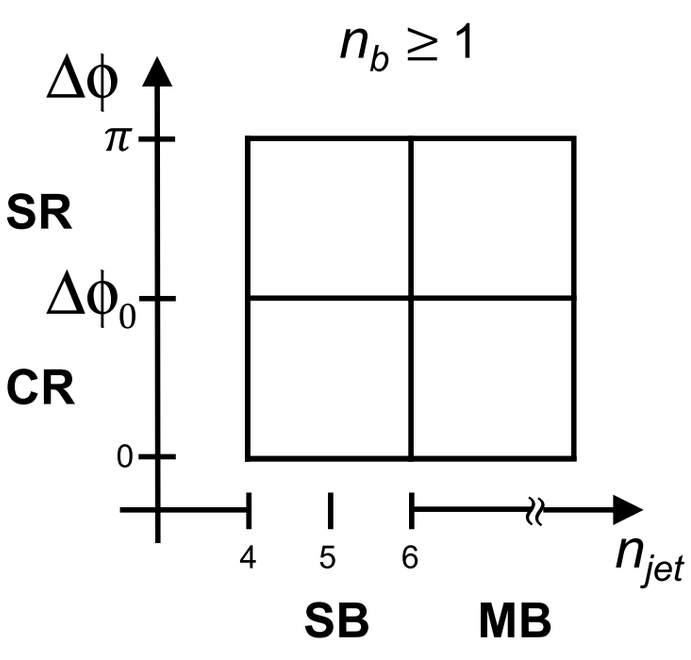
SUS-21-007

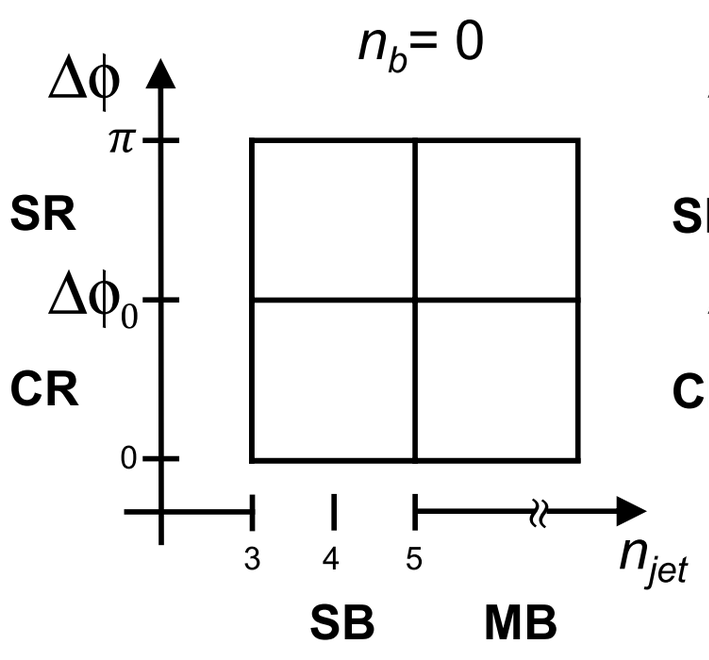
# 1l + jets + MET

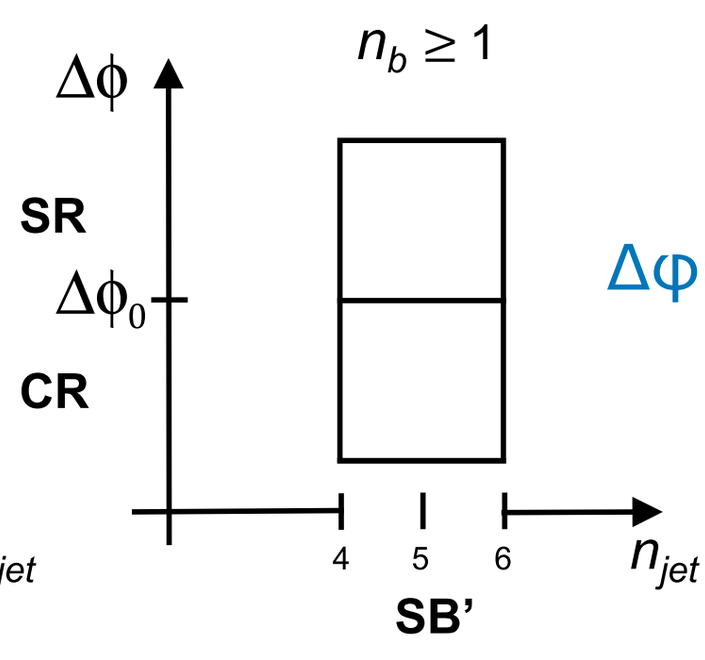



Δφ(W, l)

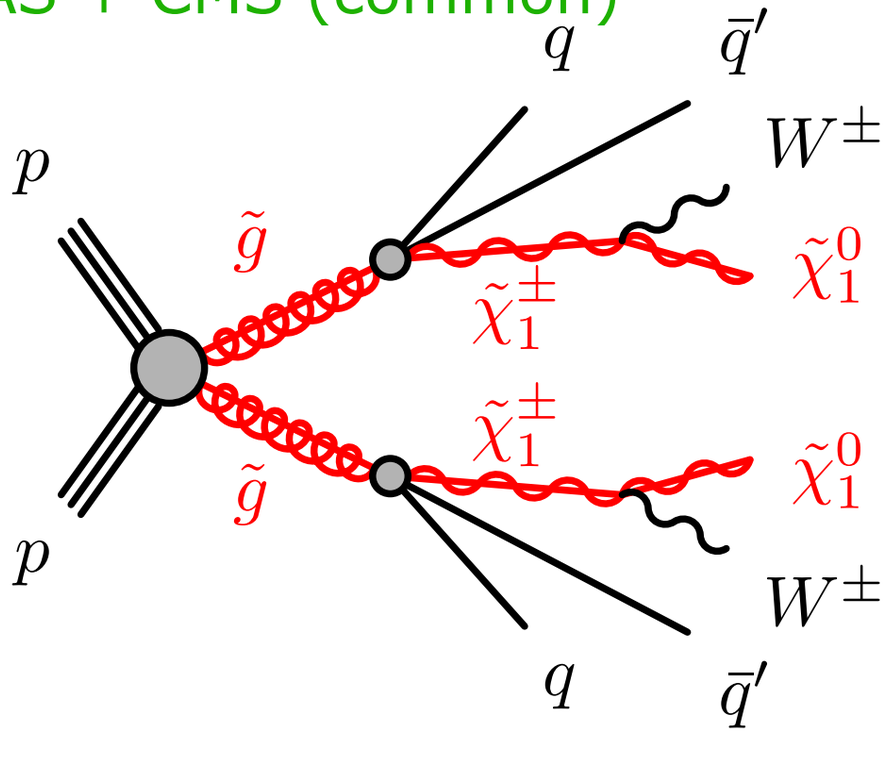
The two analyses use different CRs to estimate the background and define also very different SRs, as a result (also) of assuming different simplified models as signal

SUSY-2018-10

SUS-21-007

# 1l + jets + MET

ATLAS + CMS (common)

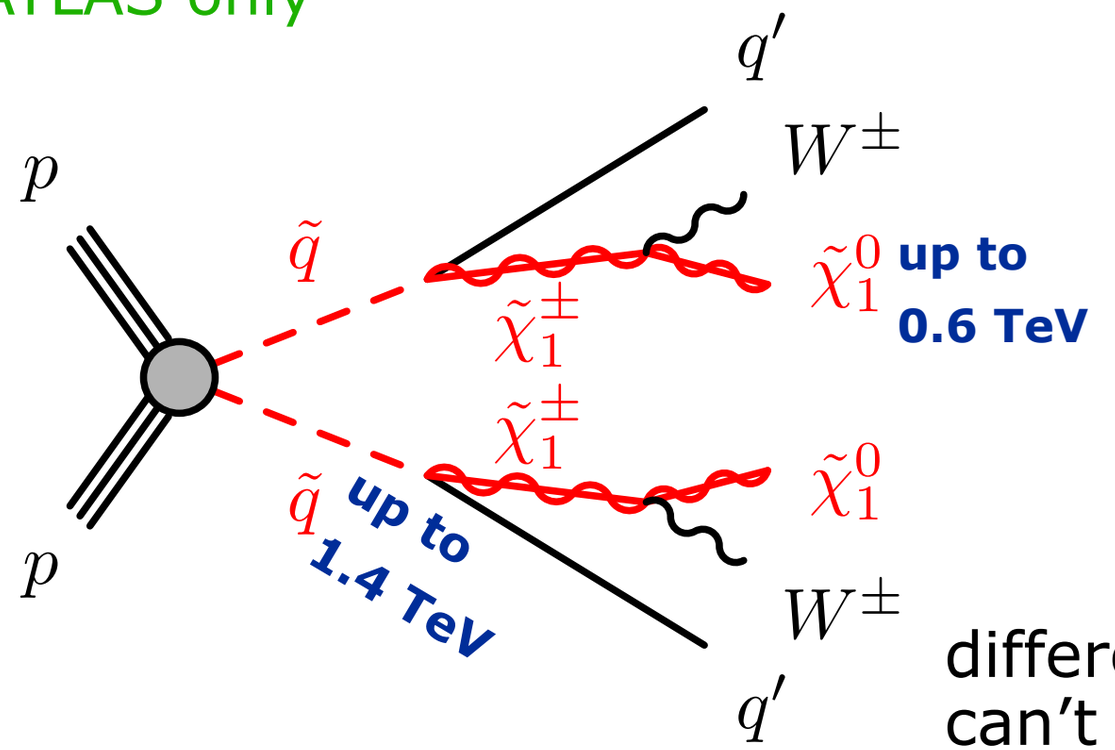



## maximum exclusion reach

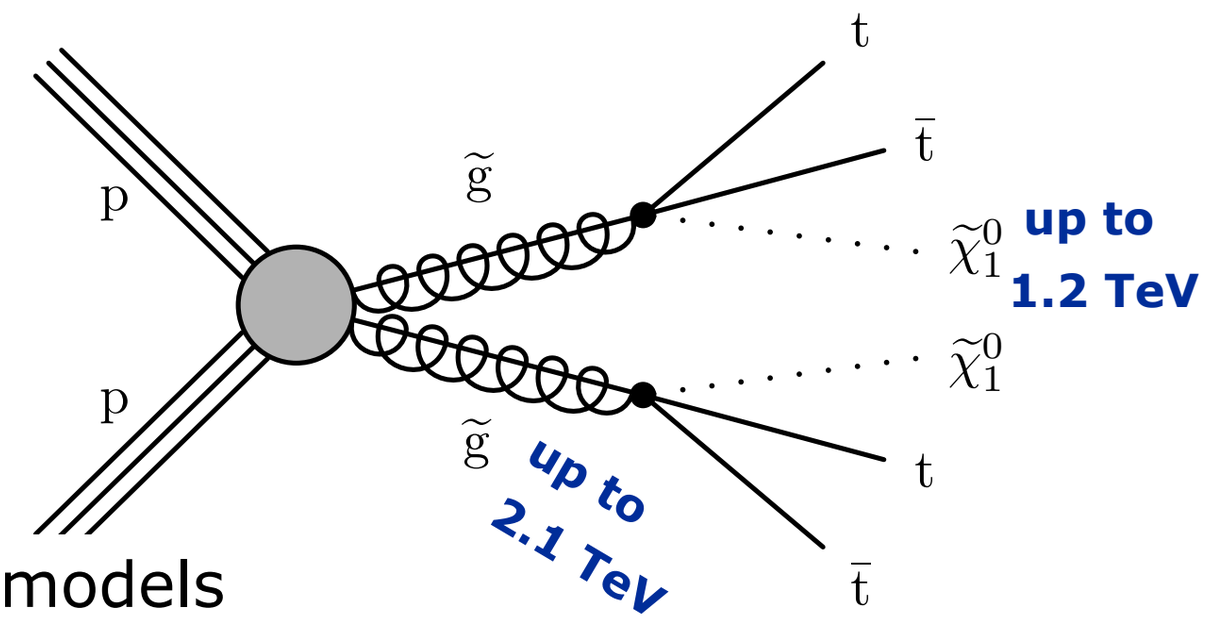
| mass | ATLAS | CMS |
|---|---|---|
| gluino | 2.2 TeV | 2.3 TeV |
| LSP | 1.2 TeV | 1.2 TeV |

similar results → confidence

ATLAS only




CMS only




different models
can't be compared[1]

[1]All other sparticles, which do not explicitly appear in the decay chains, are set to be kinematically inaccessible and decoupled

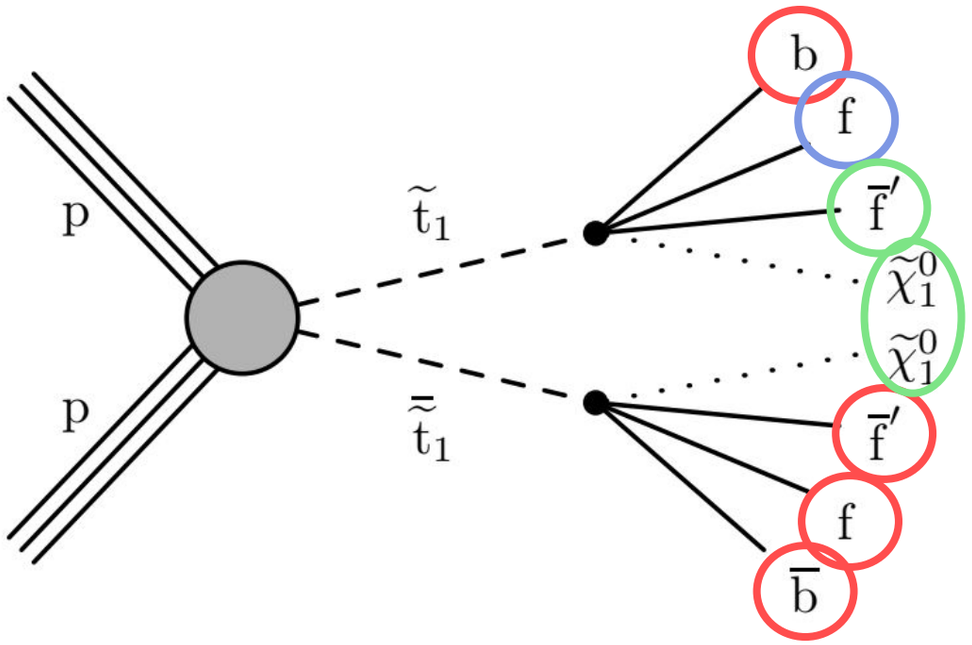
SUS-21-003 see Diego's talk

# more 1l + jets + MET

**compressed scenario**

cosmologically favored

$$\Delta m = m(\tilde{t}_1) - m(\tilde{\chi}_1^0) < m(W)$$




stop pairs

4body decay of stop

soft particles

$P_T$ (μ)> 3.5 GeV

$P_T$ (e) > 5 GeV

Signature:
1 lepton +
jets +
MET

simulated signal grid

$250 \leq m(\tilde{t}1) \leq 800$

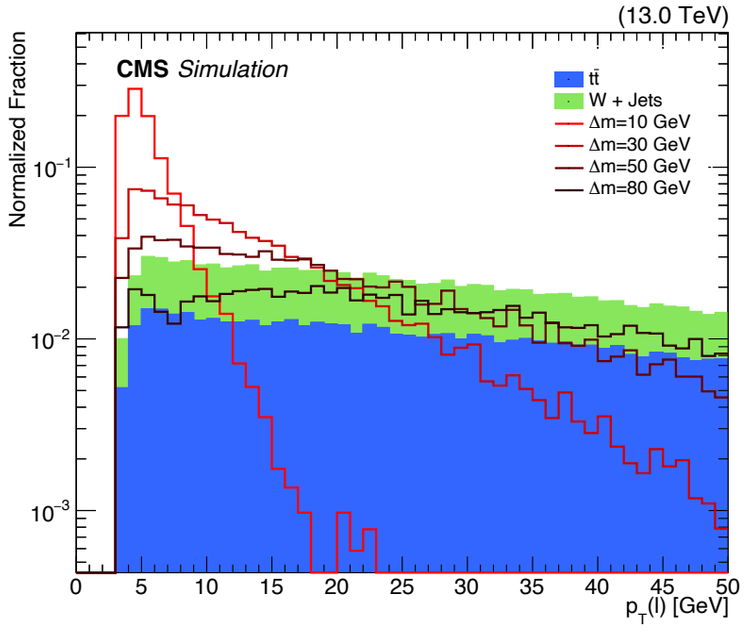
$10 \leq \Delta m < 80$

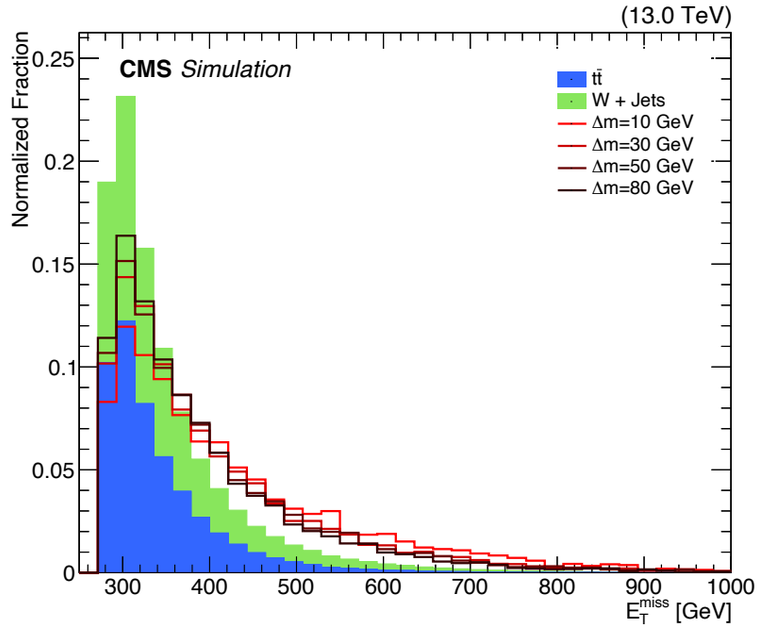
*in steps of 25 or 10, units in GeV*

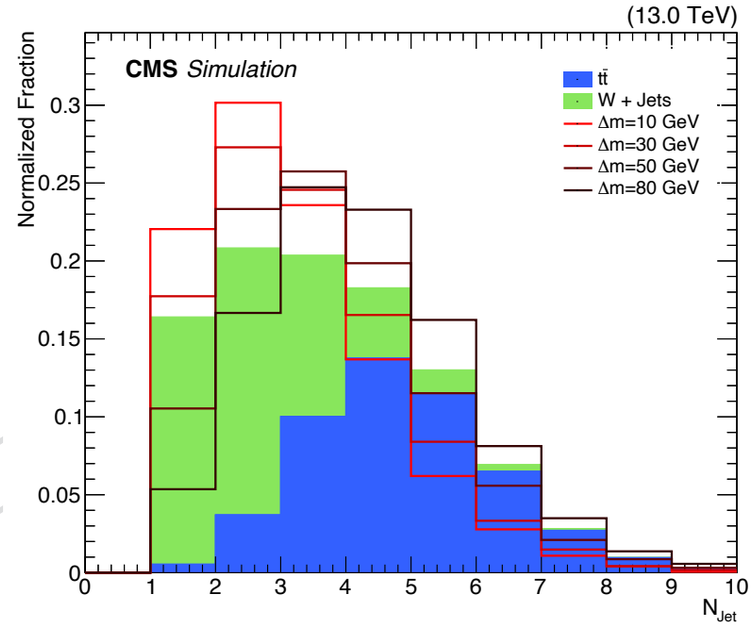
released for SUSY2022

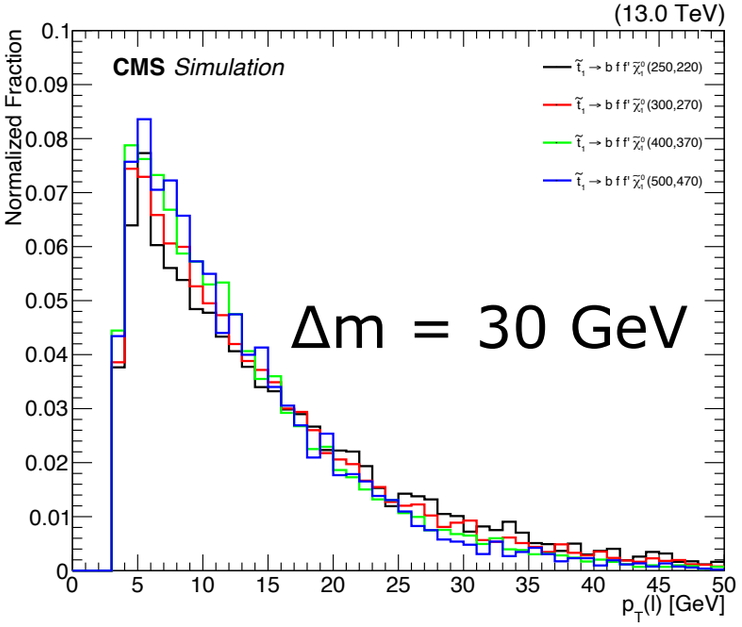
multiple BDTs trained for different signal points and data taking years to maximize sensitivity

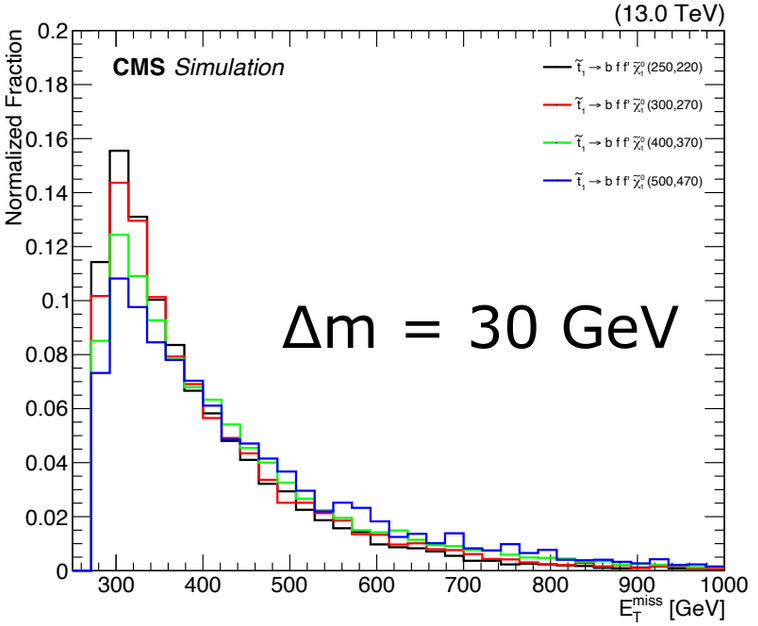
# in order to make this possible, similar SP have to be aggregated **1l + jets + MET**

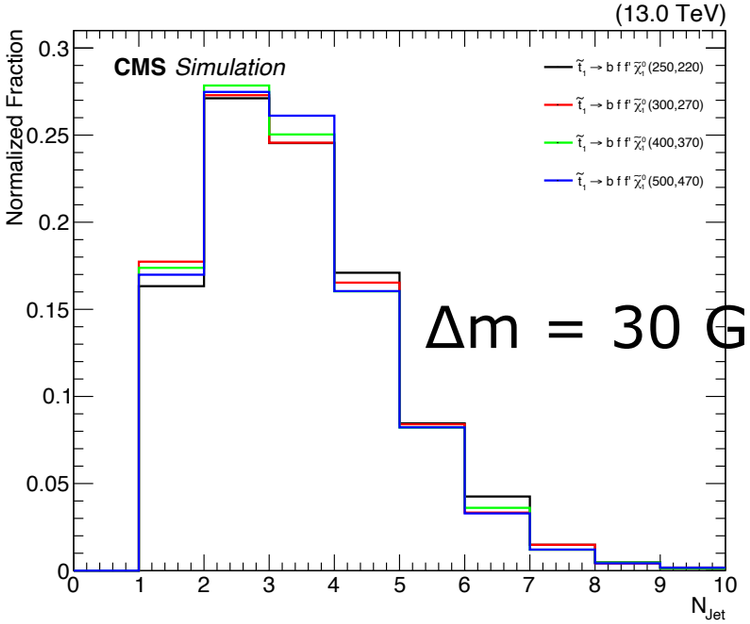



same **Δm**, similar kinematics → BDT training per Δm per year

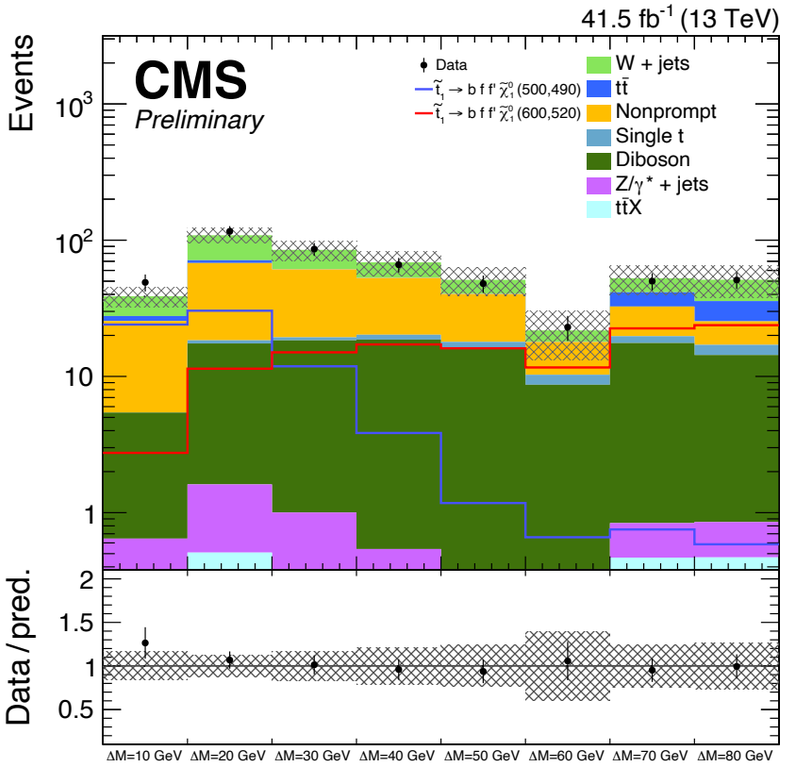
12 inputs: $p_T(l)$, MET, $p_T(j1)$, $H_T$, $M_T$ …

*for **Δm=10**, BDT suppresses **B** by **1/5000** while **S** by **1/20***

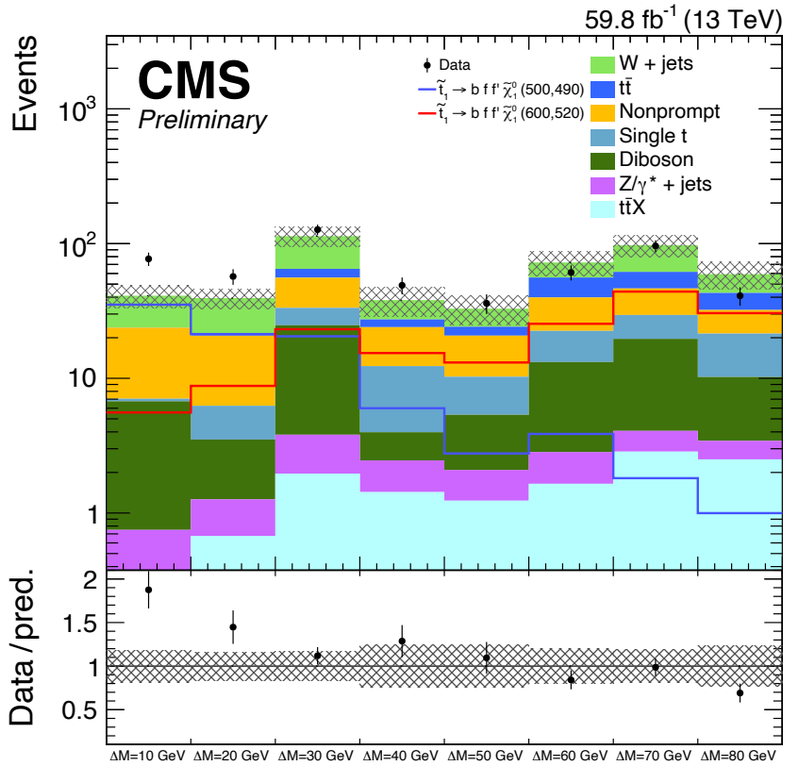
SUS-21-003

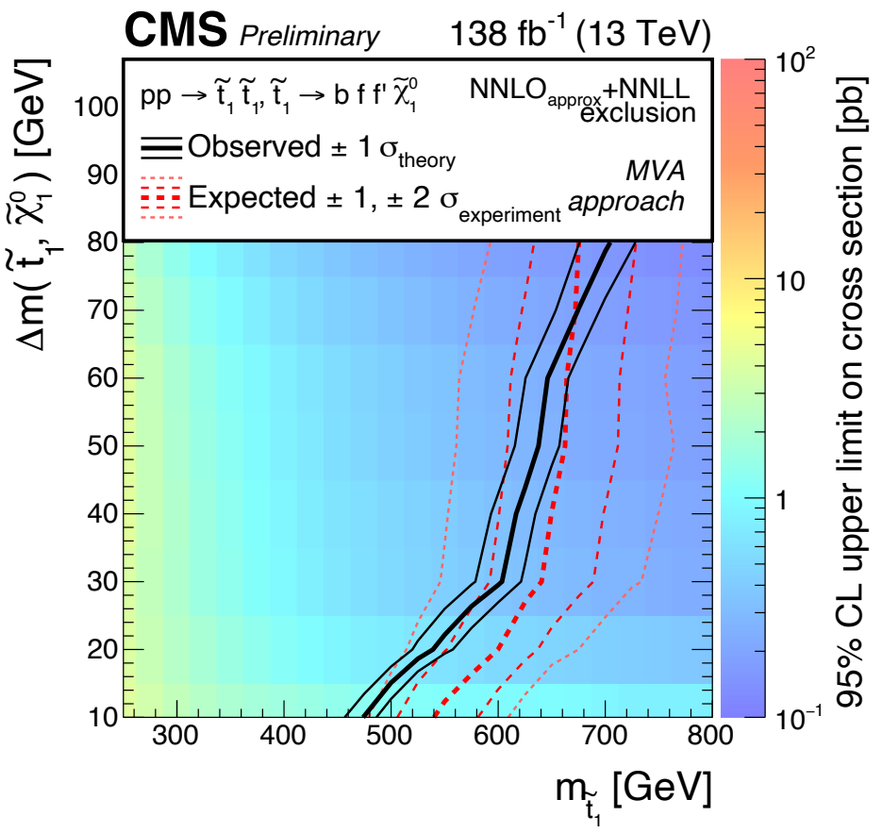
# 1l + jets + MET

## 2017




## 2018




**1.1σ**

**2.9σ**

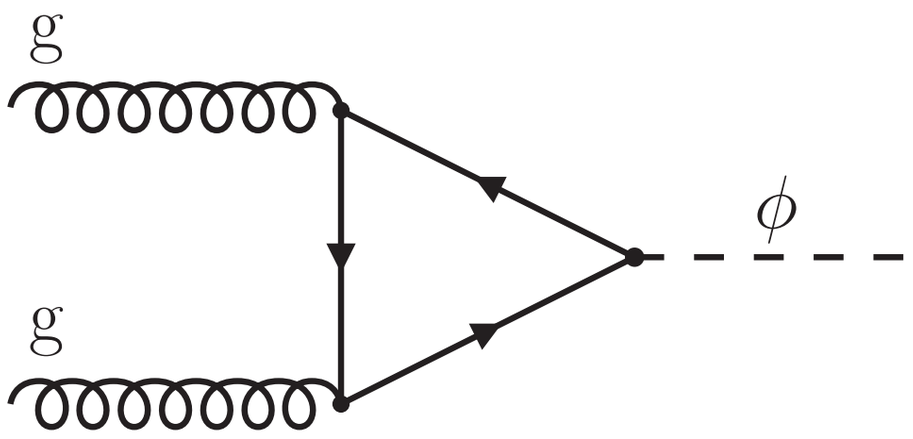
excludes top squark masses up to 480 and 700 GeV at Δm = 10 and 80 GeV respectively

2016 data already published in JHEP09(2018)065

2.9σ (always local) reduces to 2.5σ if 2016 data are included

# $\Phi \rightarrow \tau\tau$

In the MSSM, we expect multiresonance structure with contributions from **h**, **H** and **A**. Here, **h** is **$h_{obs}$@125 GeV**

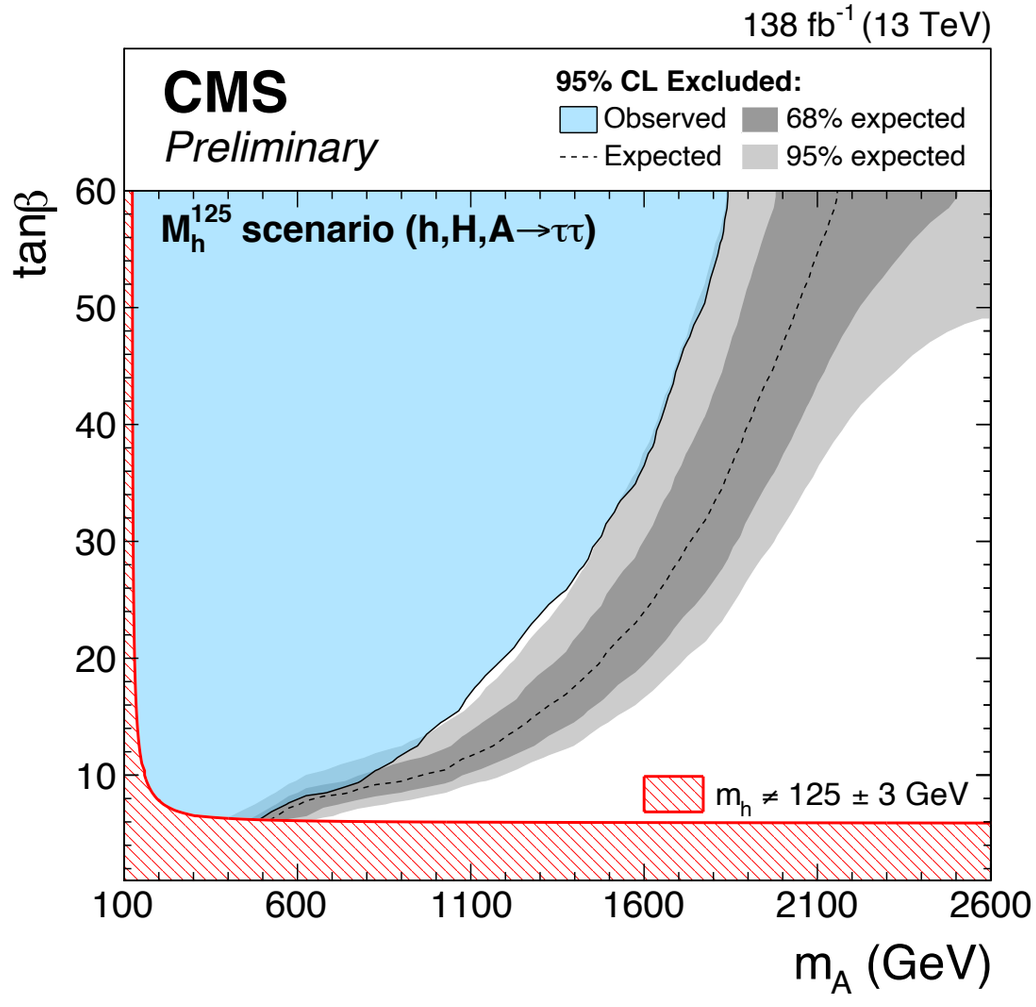



$\tau\tau \rightarrow e\mu$

$\tau\tau \rightarrow e\tau_h$

$\tau\tau \rightarrow \mu\tau_h$

$\tau\tau \rightarrow \tau_h\tau_h$

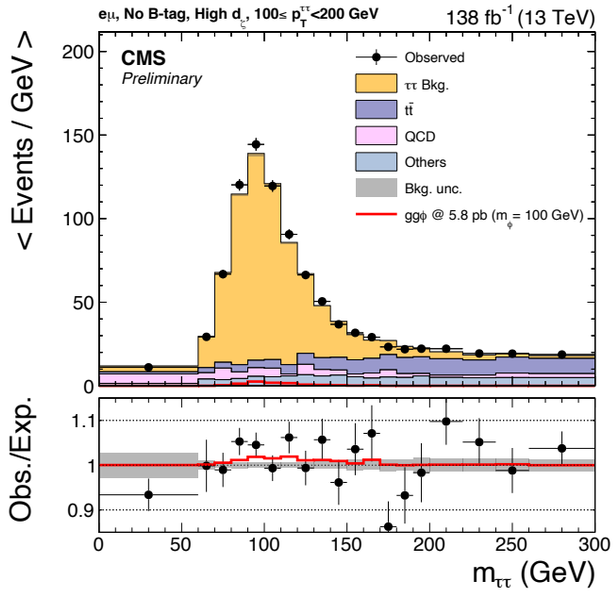


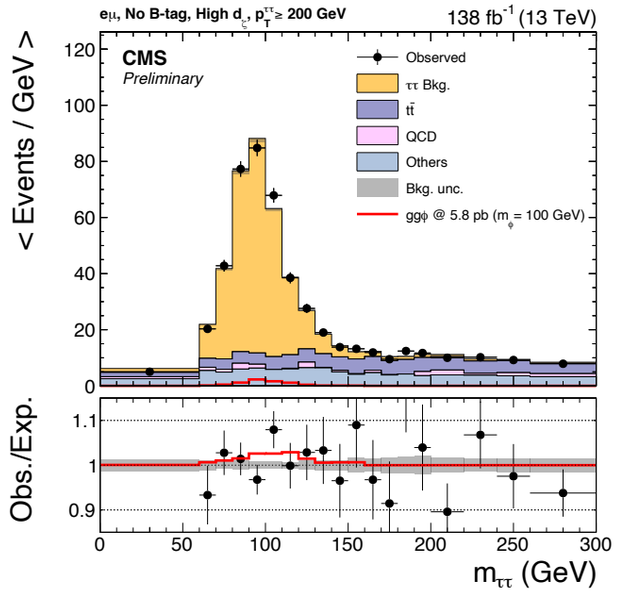

**3 analysis branches**

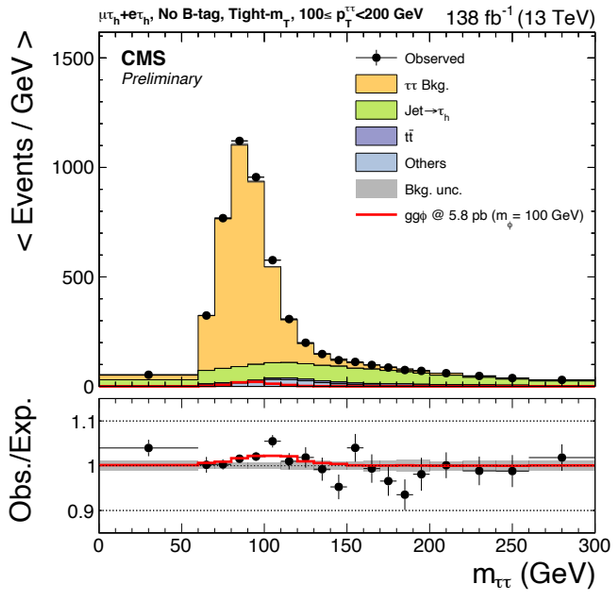
model independent

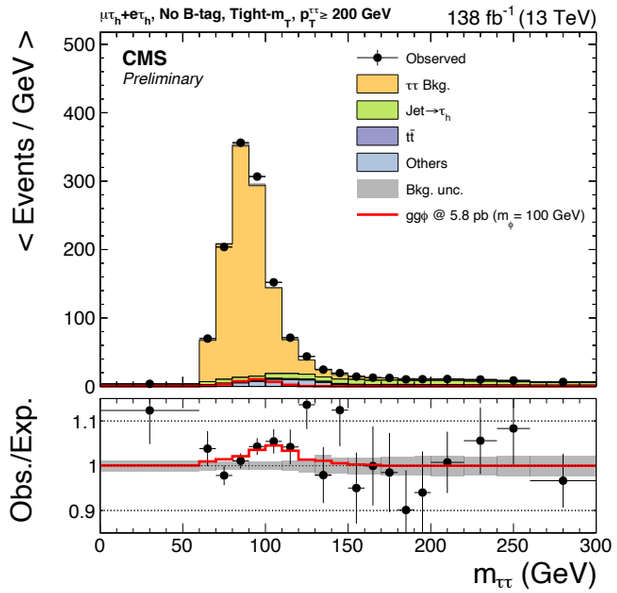
vector leptoquark

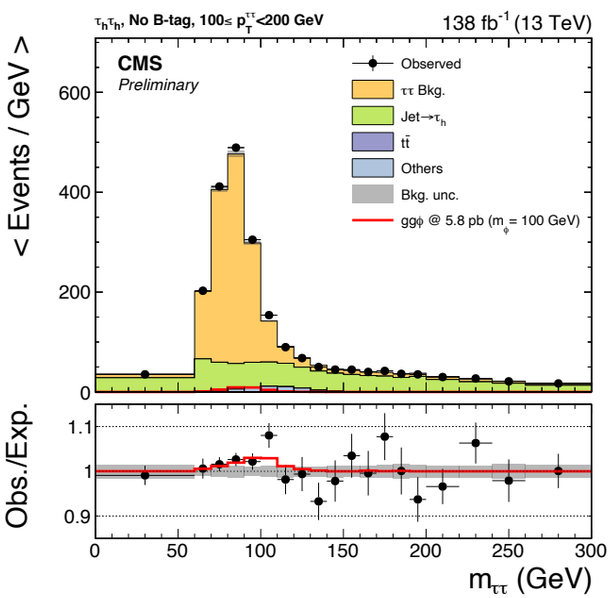
MSSM

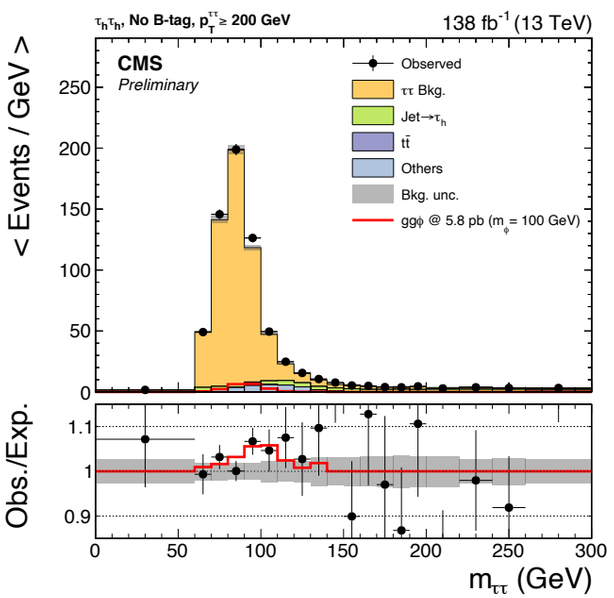


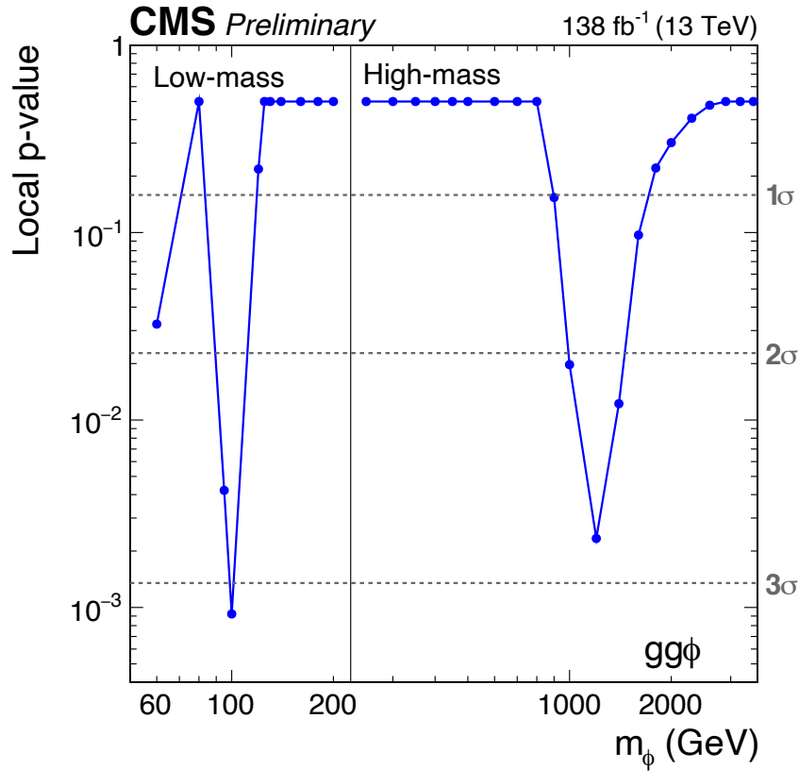




HIG-21-001

# $\varphi \rightarrow 2\tau$

excess for $\mathbf{m_\varphi = 0.1}$ and **1.2 TeV,** consistent across different τ decay modes (eμ,e$\tau_h$, μ$\tau_h$,$\tau_h\tau_h$)



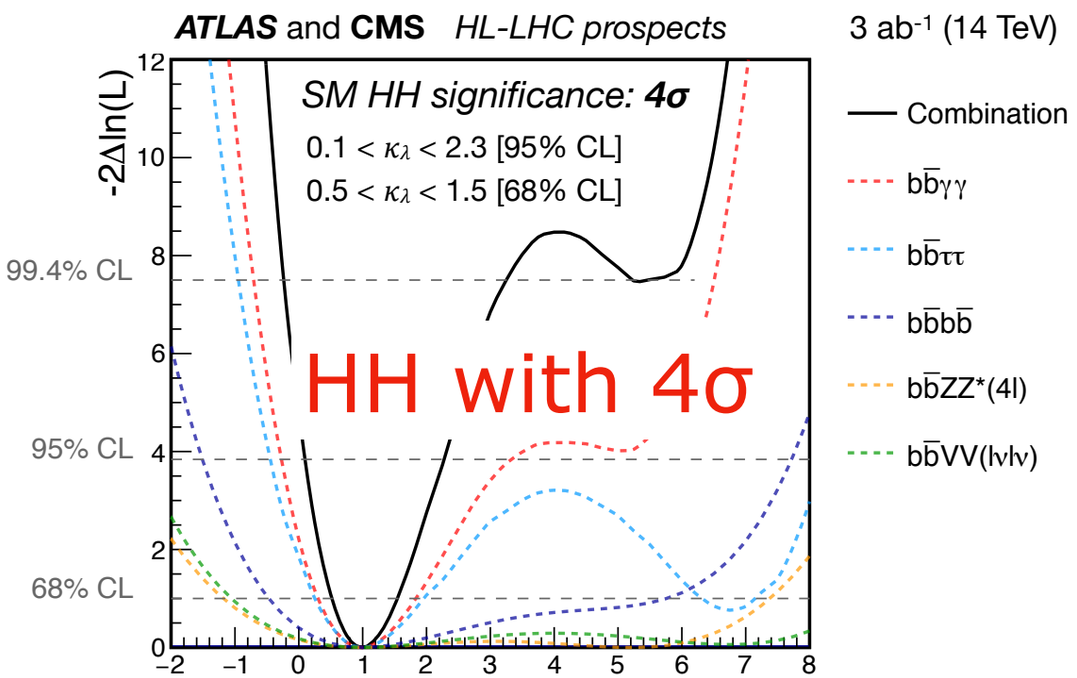

$m_\varphi$>250 GeV uses $m_T^{top}$

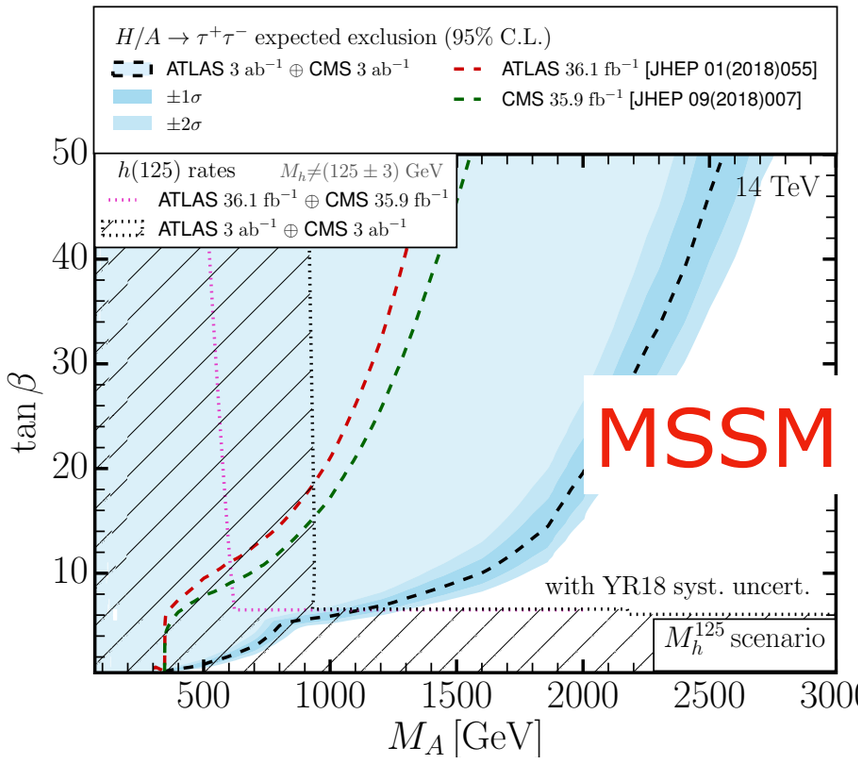
$$m_{\mathrm{T}}^{\mathrm{tot}} = \sqrt{m_{\mathrm{T}}^2(\vec{p}_{\mathrm{T}}^{\,\tau_1}, \vec{p}_{\mathrm{T}}^{\,\tau_2}) + m_{\mathrm{T}}^2(\vec{p}_{\mathrm{T}}^{\,\tau_1}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}) + m_{\mathrm{T}}^2(\vec{p}_{\mathrm{T}}^{\,\tau_2}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})}$$

future

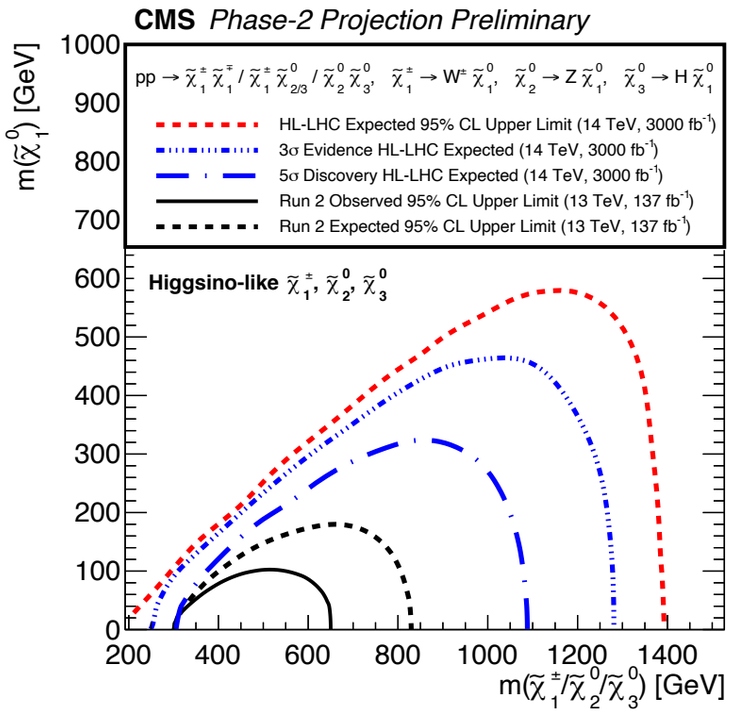
ATL-PHYS-PUB-2022-018
FTR-22-001

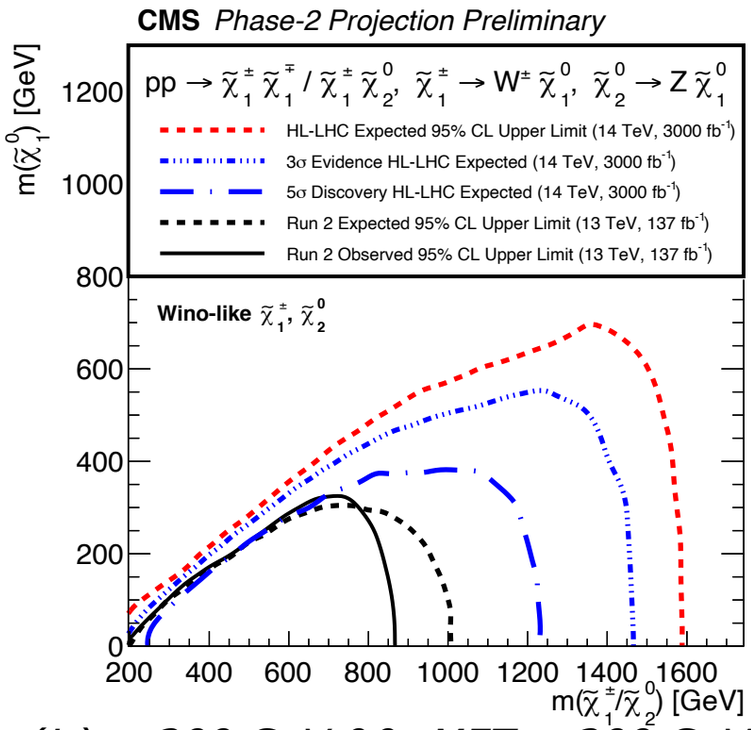
# future prospects



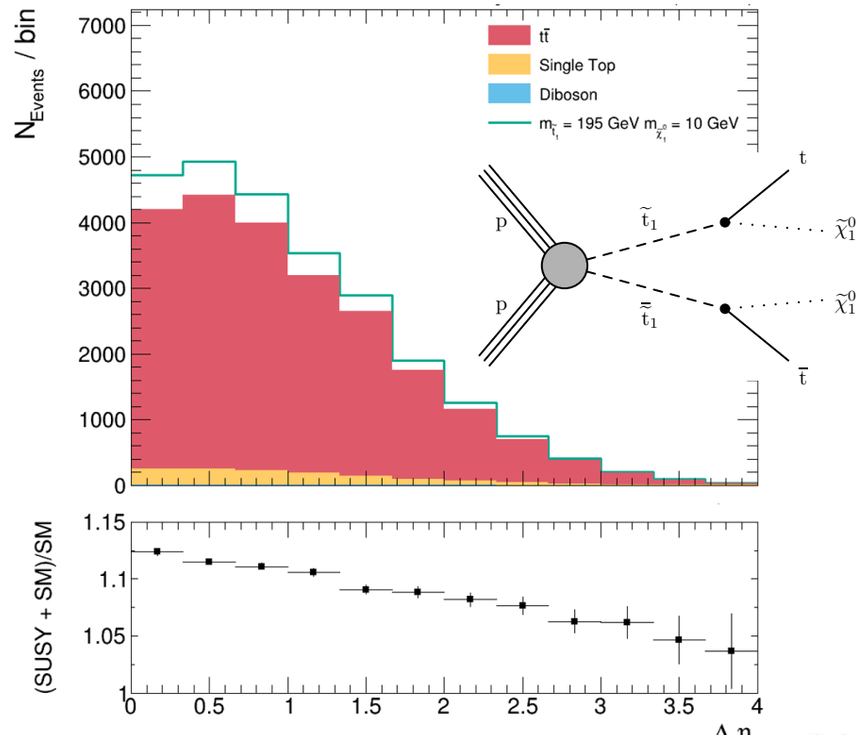




## all-hadronic EW SUSY (for Run2, see Zipper's talk)



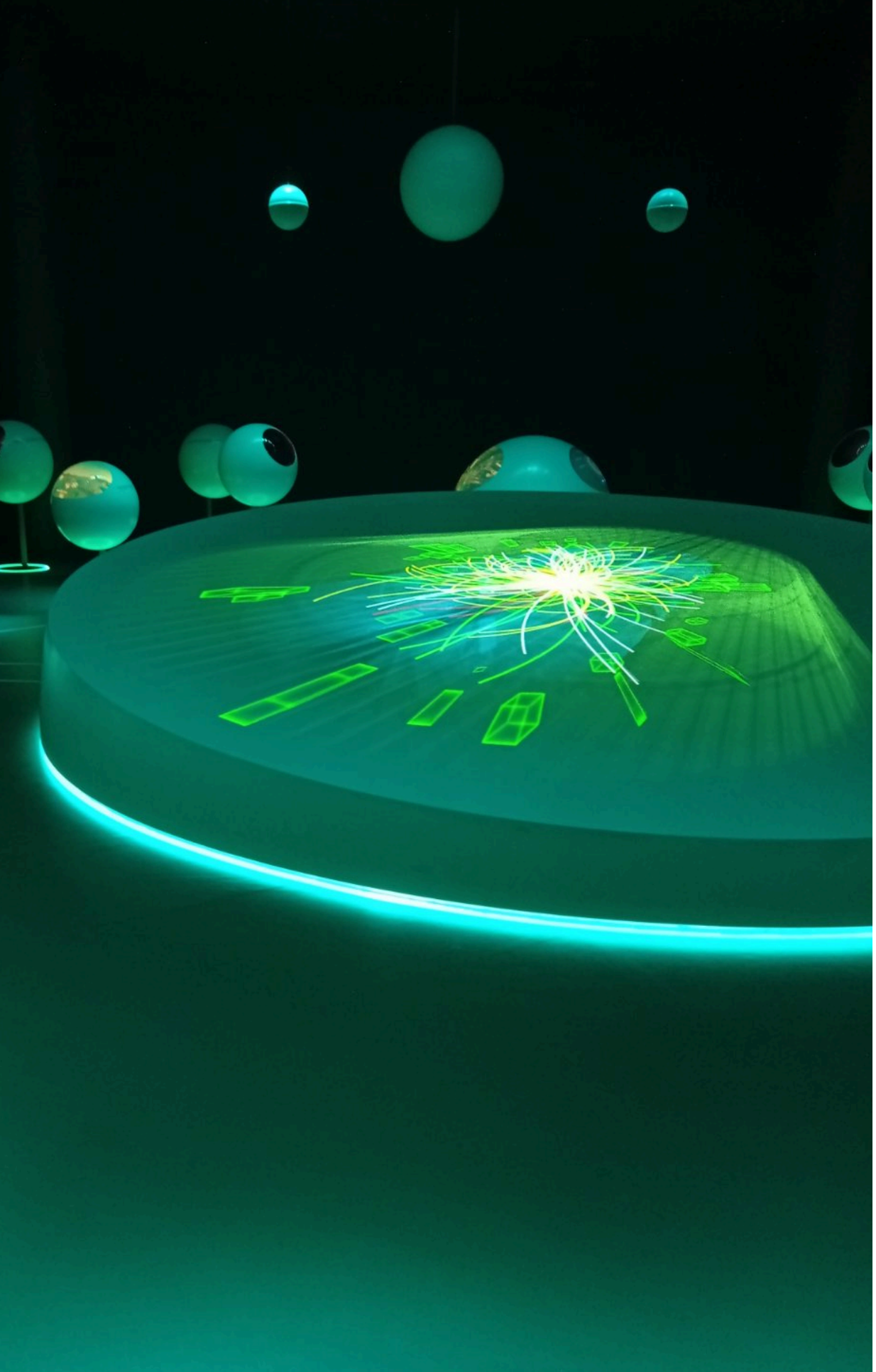




FTR-18-034




*Nj = 2 with W,Z, h tagging (AK08) $p_T(j_2)$ > 200 GeV && MET > 200 GeV*

*exploring top corridor via spin correlations*



# Summary

Tension in the lepton flavors ?
need to wait a bit more to have ATLAS & CMS results

SM stands all experimental tests, despite ATLAS + CMS have many 3σ channels ~routine for large experiments

Exciting days ahead, Run 3 and LHC & detector upgrades

**SUSY possibly still waits** for us, we should not over-interpret the present exclusion limits