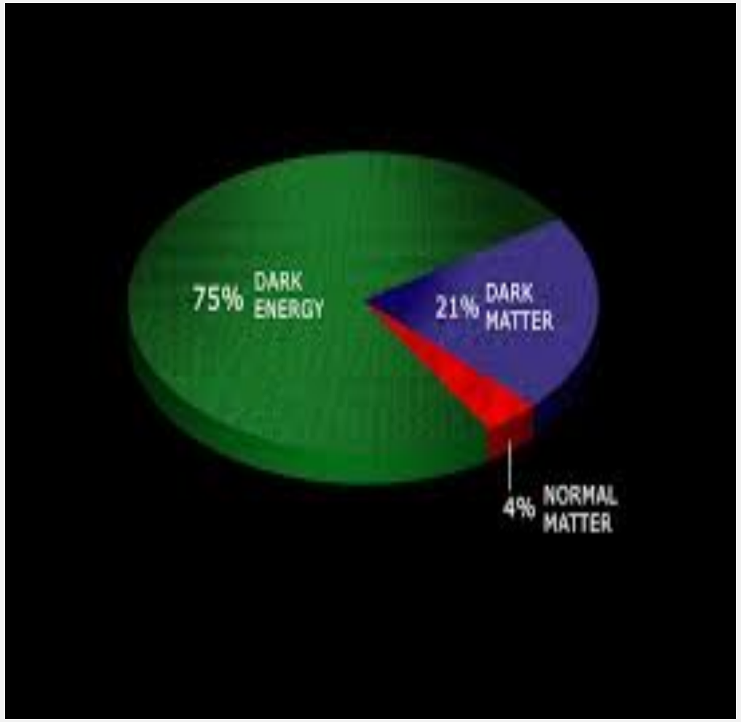
“Search for dark matter produced with an energetic jet or a hadronically decaying W or Z boson at $\sqrt{s}$=13 TeV

Raquel Nunes

1.Introduction



*DM was discovered in 1933 by astrophysicist Fritz Zwicky

*Normal matter interacts with other matter or the electromagnetic force, absorbing, reflecting or emitting light, but DM doesn't interact with anything at all, not even itself, it only reveals to us through gravity.

*85% of all gravity measured in the Universe comes from a source which we know nothing about!

*DM is thought to be the matter that gives the galaxies the extra mass, generating extra gravity they need to stay intact.

*If DM were created at the LHC they would escape through the detectores unnoticed, however, they could carry away energy and momentum, so physicists could infer their existence from the amount of energy and momentum "missing" after a collision.

How to find DM particles?

- p-p collisions
- Energy of collision $\sqrt{s}=13TeV$
- Integrated luminosity: 12.9 fb^(-1)
- Events with large E_T^{miss} (*missing transverse momentum*)
- At least 1 energetic jet (from hadronic decays of W or Z boson)
- No leptons

Where?

- @LHC with the CMS detector to collect the data

Current model of DM

- WIMPS

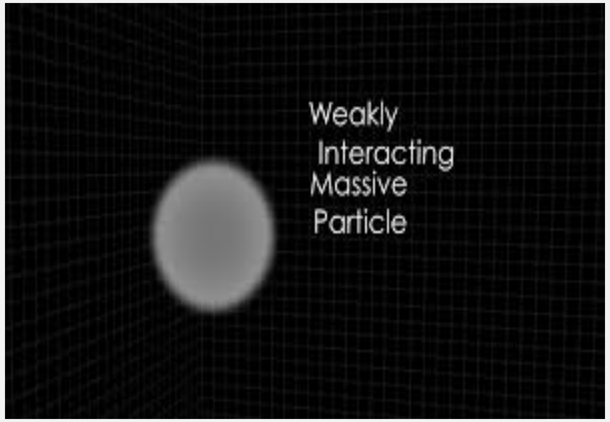
-might be produced through TeV-scale collisions at Cern LHC

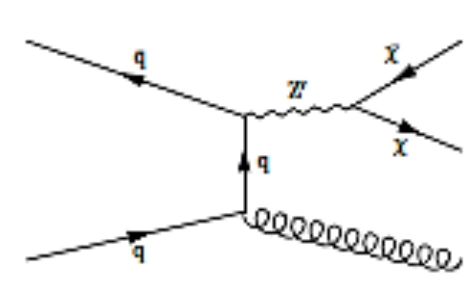
But…

…wouldn't generate directly observable signals in the detector

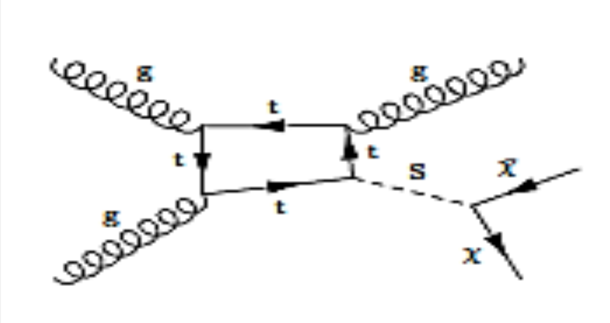
So…

…DM could be detected if found a large transverse momentum imbalance →Monojet channel production

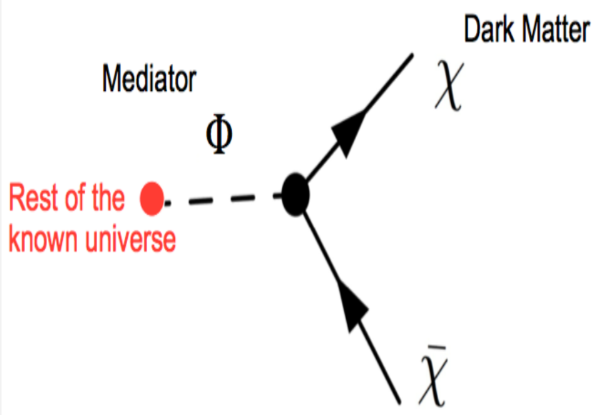




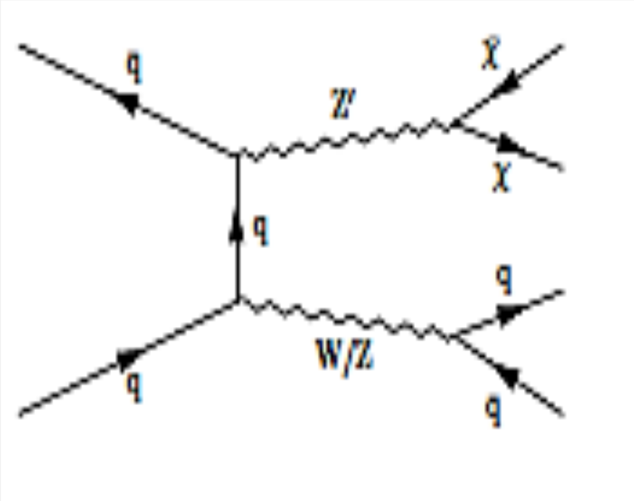
With decay of a spin-1 mediator



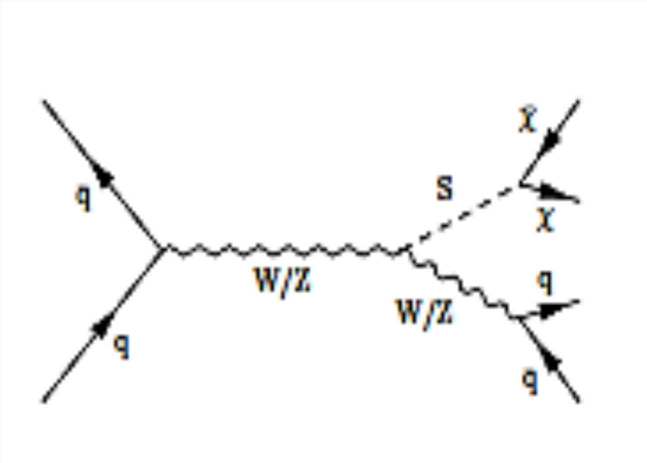
With decay of a spin-0 mediator(S)



Or
…DM might be produced in association with an electroweak boson → Mono-V channel production

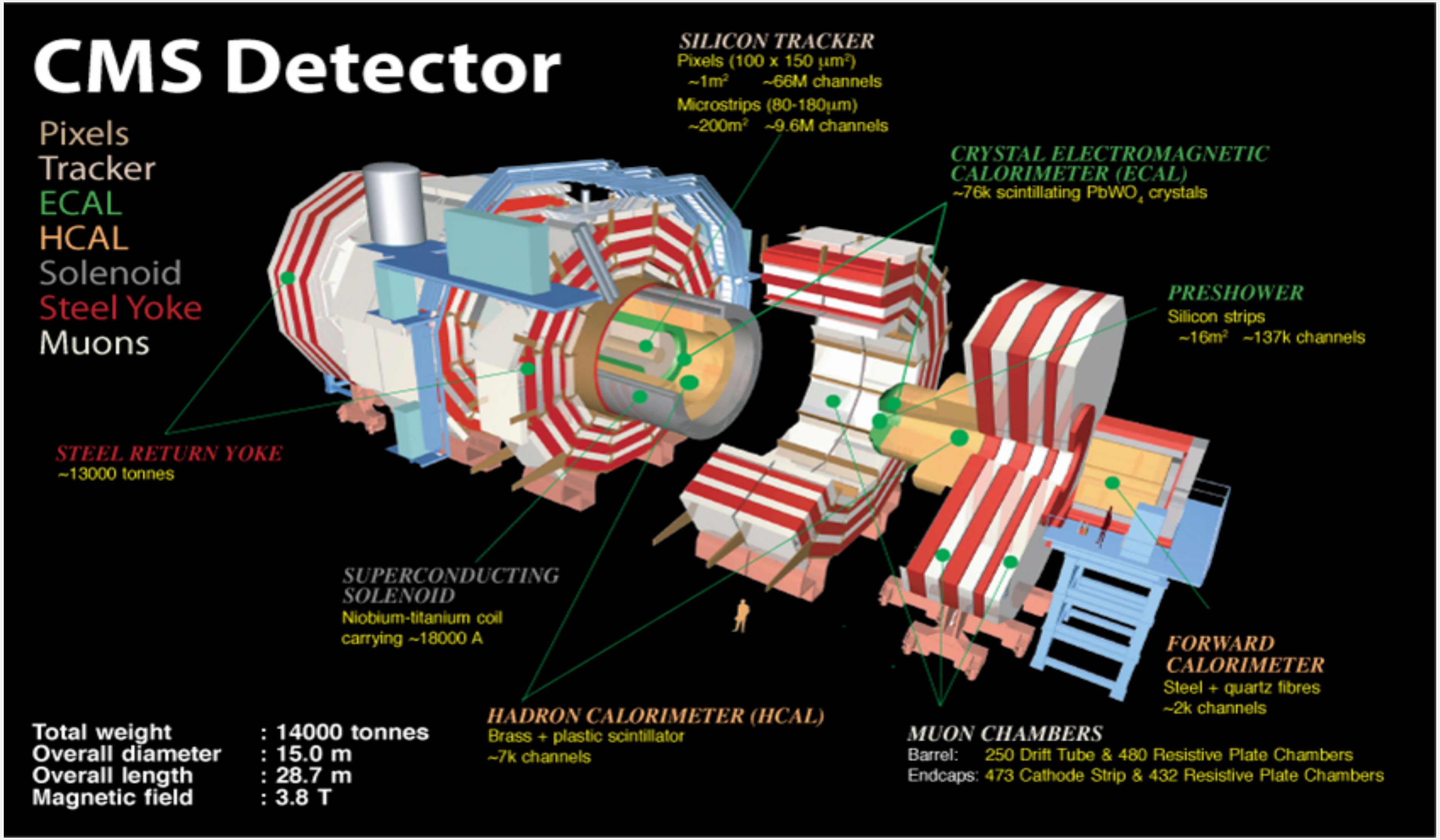


Mediated by a spin-1 particle (Z’ boson)



Mediated by a spin-0 particle (S)

2. The CMS detector



3. Event Simulation

- Monte Carlo generators for simulation of signals and background processes

Process	Monte Carlo generator	Perturbative order in QCD
Z+jets	MadGraph5_aMC@NLO 2.2.3	LO
γ+jets	MadGraph5_aMC@NLO 2.2.3	LO
W+jets	MadGraph5_aMC@NLO 2.2.3	NLO
QCD multijet	MadGraph5_aMC@NLO 2.2.3	LO
$t\bar{t}$	Powheg 2.0	NLO
Single top quark	Powheg 2.0	NLO
Diboson (ZZ, WZ, WW)	Pythia 8.205	LO
Monojet signal (spin-1 mediator)	Powheg 2.0	NLO
Monojet signal (spin-0 mediator)	Powheg 2.0	LO
Mono-V signal (spin-1 mediator)	MadGraph5_aMC@NLO 2.2.3	LO
Mono-V signal (scalar mediator)	JHUGen 5.2.5	LO
$H \to$ inv (gluon fusion)	Powheg 2.0	NLO
$H \to$ inv (vector boson fusion)	Powheg 2.0	NLO
$H \to$ inv (associated production with W or Z)	JHUGen 5.2.5	LO

4. Event Selection

Variable	Mono-V requirement	Monojet requirement
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 250 GeV	> 200 GeV
Leading AK4 jet p_{T}	> 100 GeV	
Leading AK4 jet $\lvert\eta\rvert$	< 2.5	
Charged hadron energy fraction of leading AK4 jet	> 0.1	
Neutral hadron energy fraction of leading AK4 jet	< 0.8	
Number of muons ($p_{\mathrm{T}} > 10$ GeV, $\lvert\eta\rvert < 2.4$)	0	
Number of electrons ($p_{\mathrm{T}} > 10$ GeV, $\lvert\eta\rvert < 2.5$)	0	
Number of τ leptons ($p_{\mathrm{T}} > 18$ GeV, $\lvert\eta\rvert < 2.3$)	0	
Number of photons ($p_{\mathrm{T}} > 15$ GeV, $\lvert\eta\rvert < 2.5$)	0	
Number of b jets ($p_{\mathrm{T}} > 15$ GeV, $\lvert\eta\rvert < 2.4$)	0	
$\Delta\phi$ between four highest p_{T} jets and $E_{\mathrm{T}}^{\mathrm{miss}}$	> 0.5 radians	
Leading AK8 jet p_{T}	> 250 GeV	Fails any of the mono-V AK8 jet requirements
Leading AK8 jet η	< 2.4	
Leading AK8 jet τ_2/τ_1	< 0.6	
Leading AK8 jet mass (m_J)	$65 < m_J < 105$ GeV	

5. Background estimation

- 90% of the search from

$$Z(\nu\overline{\nu})\text{+jets and } W(\ell\nu)\text{+jets}$$

Estimated from the distribution of the p_T hadronic recoil

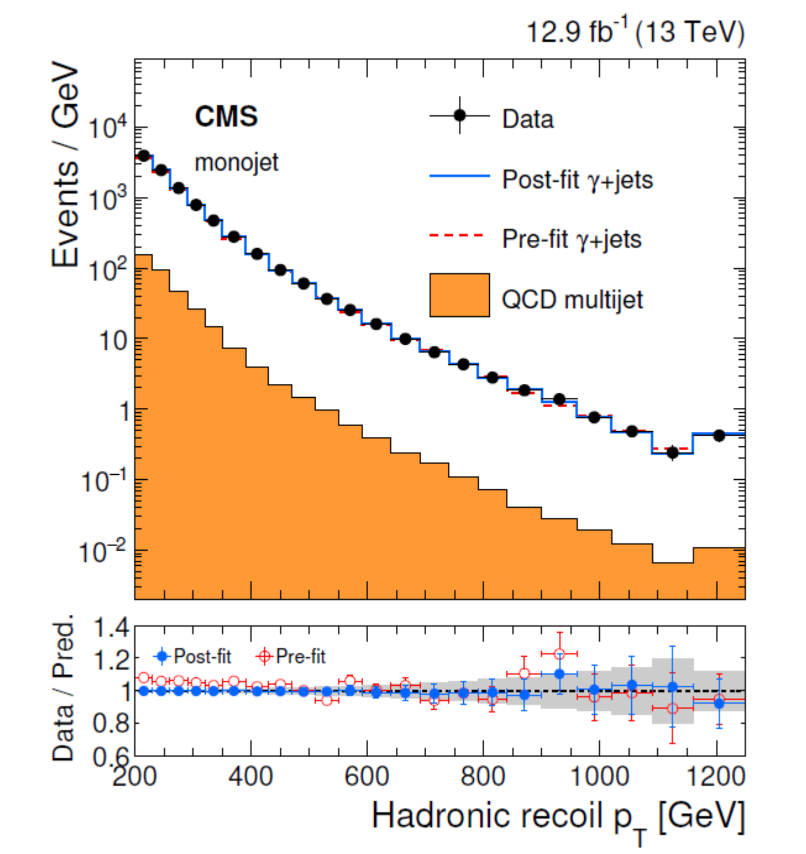
Photon $p_T > 175$ GeV→ $\varepsilon_{trigger} > 98\%$

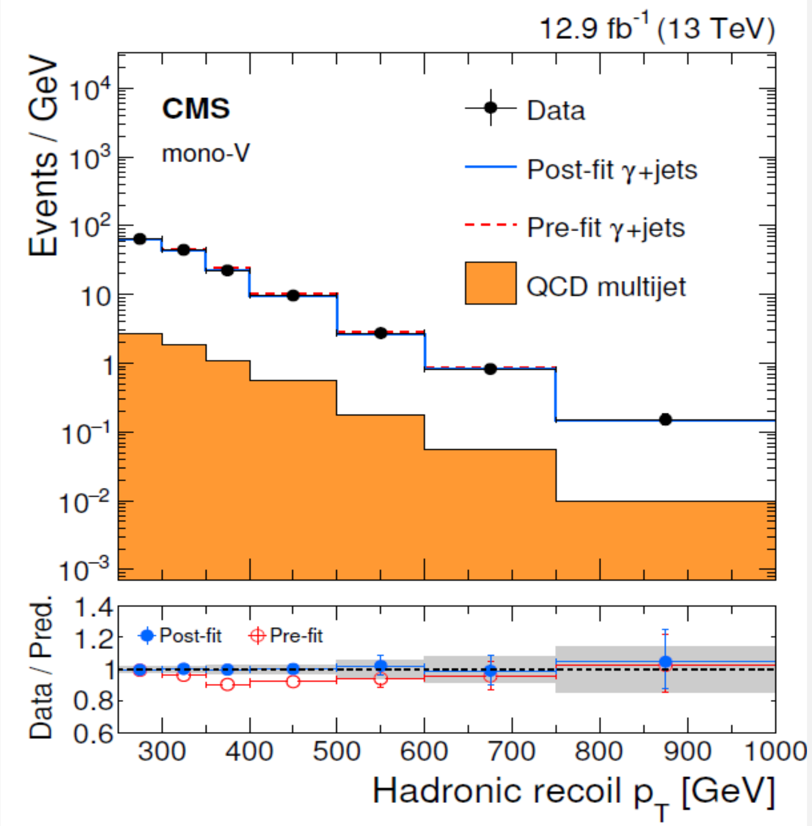
Determined through a maximum likelihood fit, L_k

$$
\begin{aligned}
\mathcal{L}_k(\boldsymbol{\mu}^{\mathrm{Z}(\nu\overline{\nu})}, \boldsymbol{\mu}, \boldsymbol{\theta}) = &\prod_i \mathrm{Poisson}\left(d_i^{\gamma} | B_i^{\gamma}(\boldsymbol{\theta}) + \frac{\boldsymbol{\mu}_i^{\mathrm{Z}(\nu\overline{\nu})}}{R_i^{\gamma}(\boldsymbol{\theta})}\right) \\
&\times \prod_i \mathrm{Poisson}\left(d_i^{\mu\mu} | B_i^{\mu\mu}(\boldsymbol{\theta}) + \frac{\boldsymbol{\mu}_i^{\mathrm{Z}(\nu\overline{\nu})}}{R_i^{\mu\mu}(\boldsymbol{\theta})}\right) \\
&\times \prod_i \mathrm{Poisson}\left(d_i^{\mathrm{ee}} | B_i^{\mathrm{ee}}(\boldsymbol{\theta}) + \frac{\boldsymbol{\mu}_i^{\mathrm{Z}(\nu\overline{\nu})}}{R_i^{\mathrm{ee}}(\boldsymbol{\theta})}\right) \\
&\times \prod_i \mathrm{Poisson}\left(d_i^{\mu} | B_i^{\mu}(\boldsymbol{\theta}) + \frac{f_i(\boldsymbol{\theta})\boldsymbol{\mu}_i^{\mathrm{Z}(\nu\overline{\nu})}}{R_i^{\mu}(\boldsymbol{\theta})}\right) \\
&\times \prod_i \mathrm{Poisson}\left(d_i^{\mathrm{e}} | B_i^{\mathrm{e}}(\boldsymbol{\theta}) + \frac{f_i(\boldsymbol{\theta})\boldsymbol{\mu}_i^{\mathrm{Z}(\nu\overline{\nu})}}{R_i^{\mathrm{e}}(\boldsymbol{\theta})}\right) \\
&\times \prod_i \mathrm{Poisson}\left(d_i | B_i(\boldsymbol{\theta}) + (1 + f_i(\boldsymbol{\theta}))\boldsymbol{\mu}_i^{\mathrm{Z}(\nu\overline{\nu})} + \boldsymbol{\mu} S_i(\boldsymbol{\theta})\right)
\end{aligned}
$$

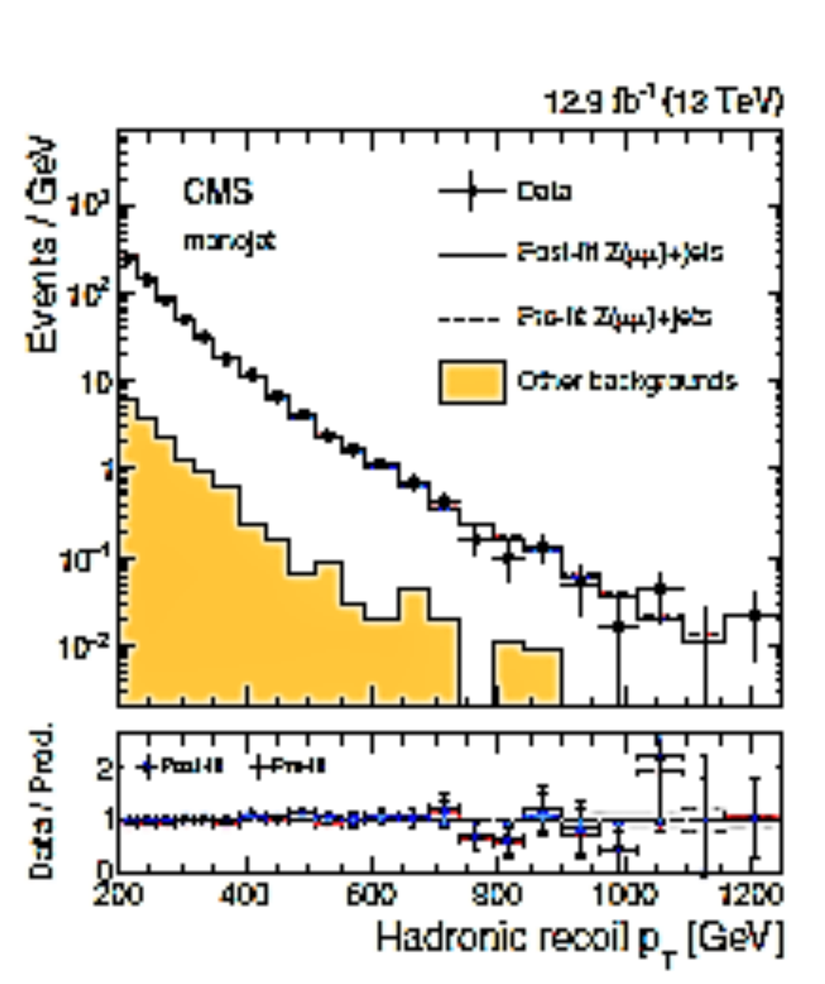
Comparison between data and Monte Carlo simulation before and after performing the simultaneous fit across across all control samples and the signal region, assuming the absence of any signal.

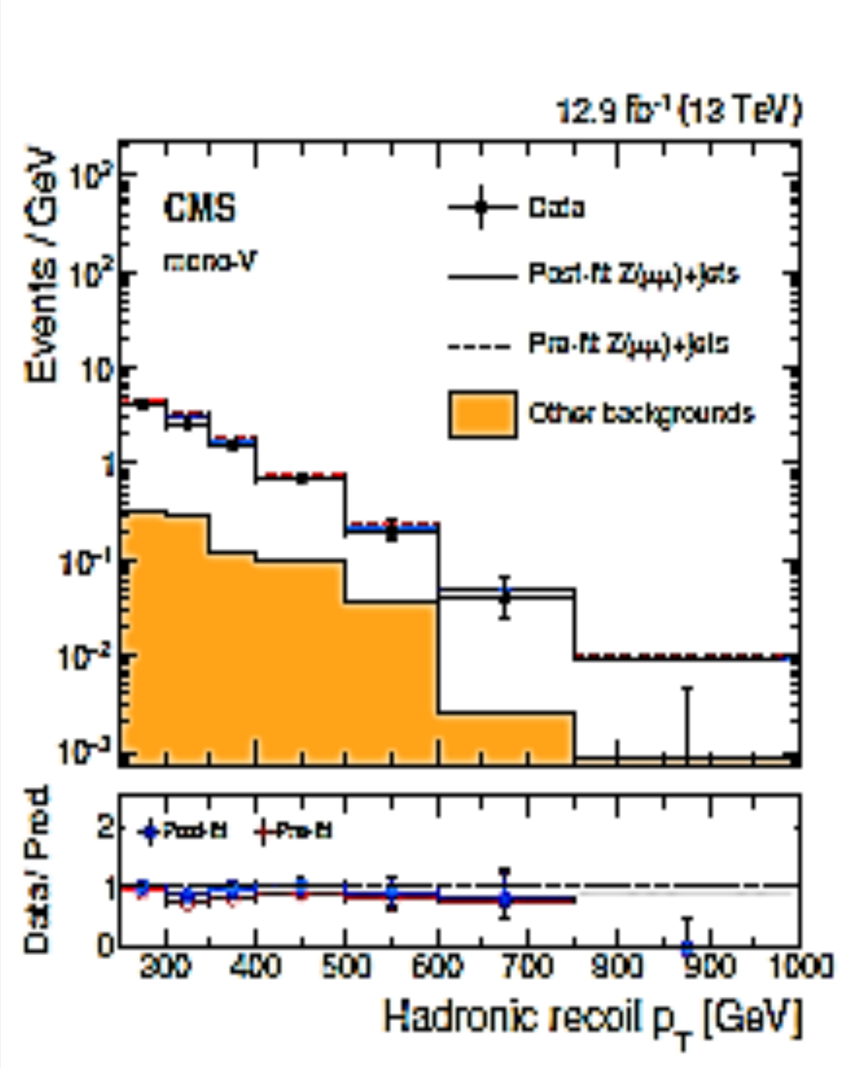
in the γ+jets control sample
hadronic recoil p_T is used as proxy for $E_{\mathrm{T}}^{\mathrm{miss}}$



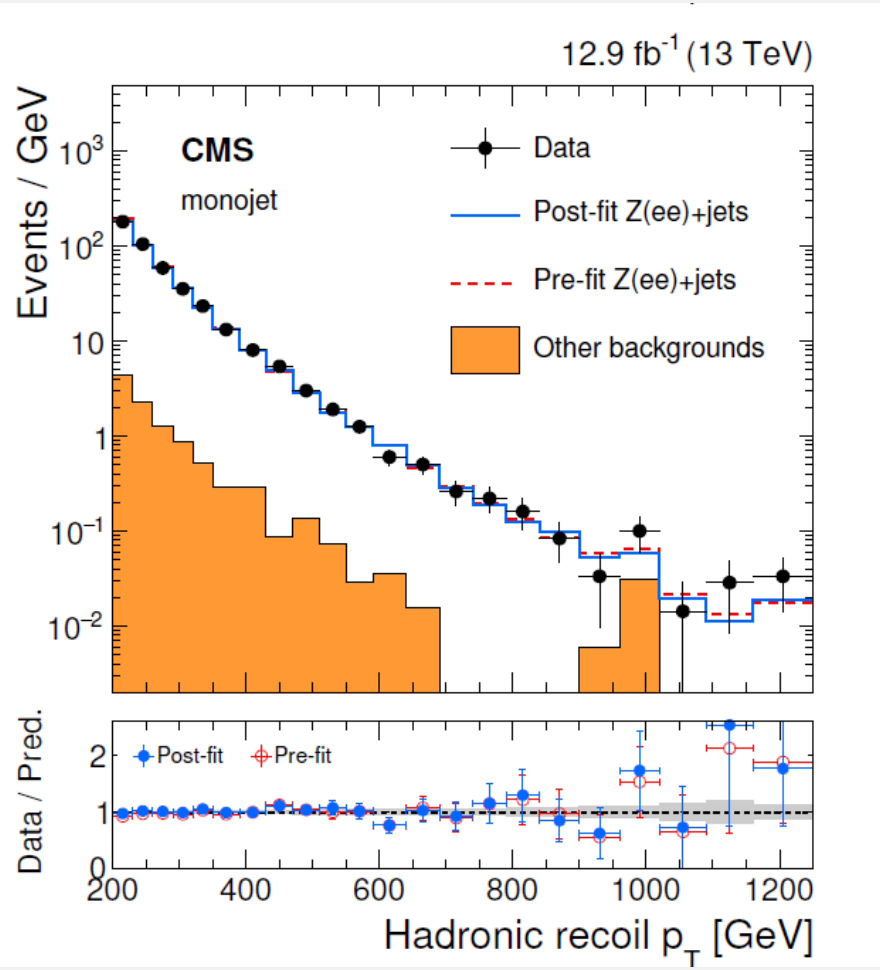


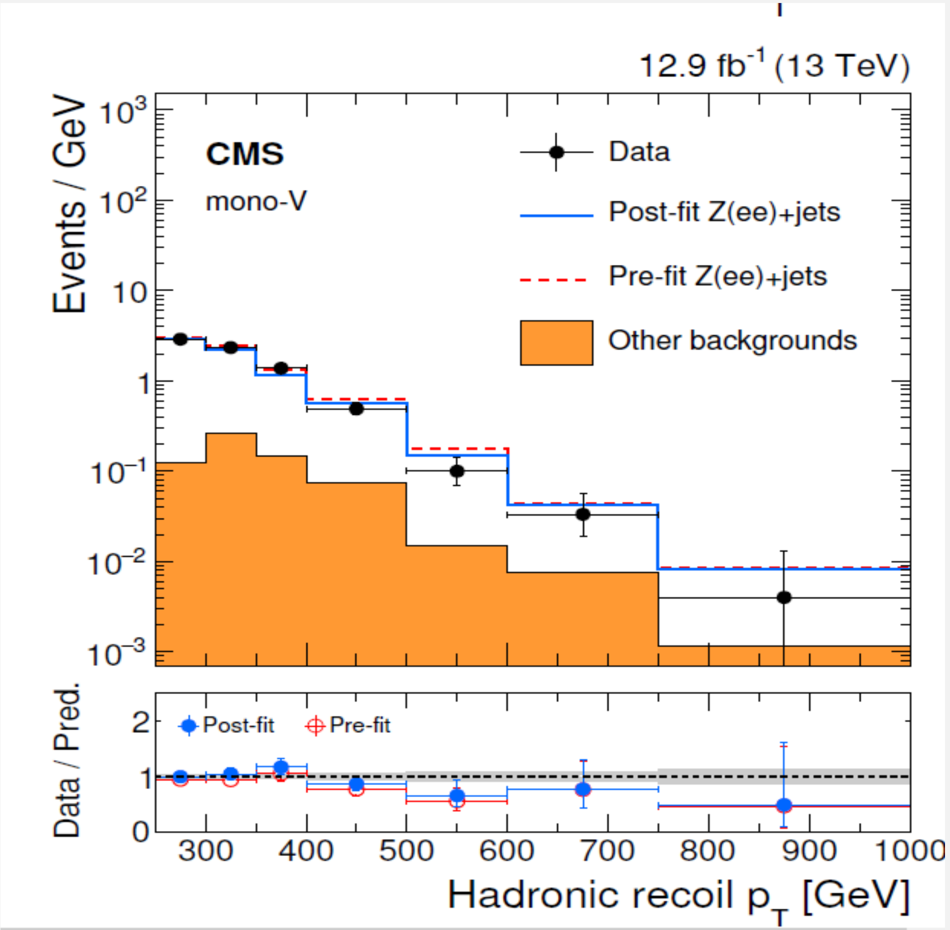
In dimuon control samples





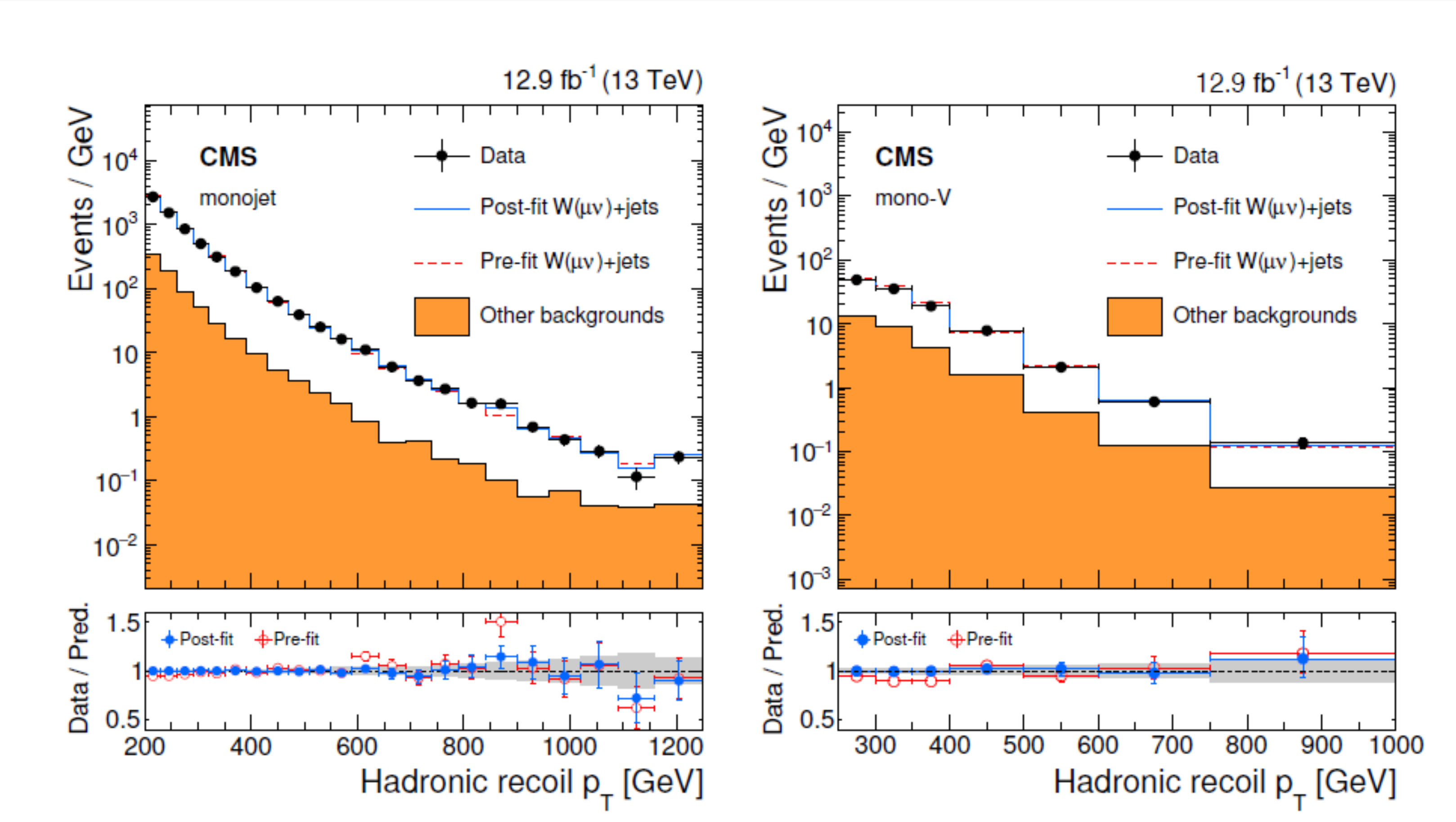
In dielectron control sample



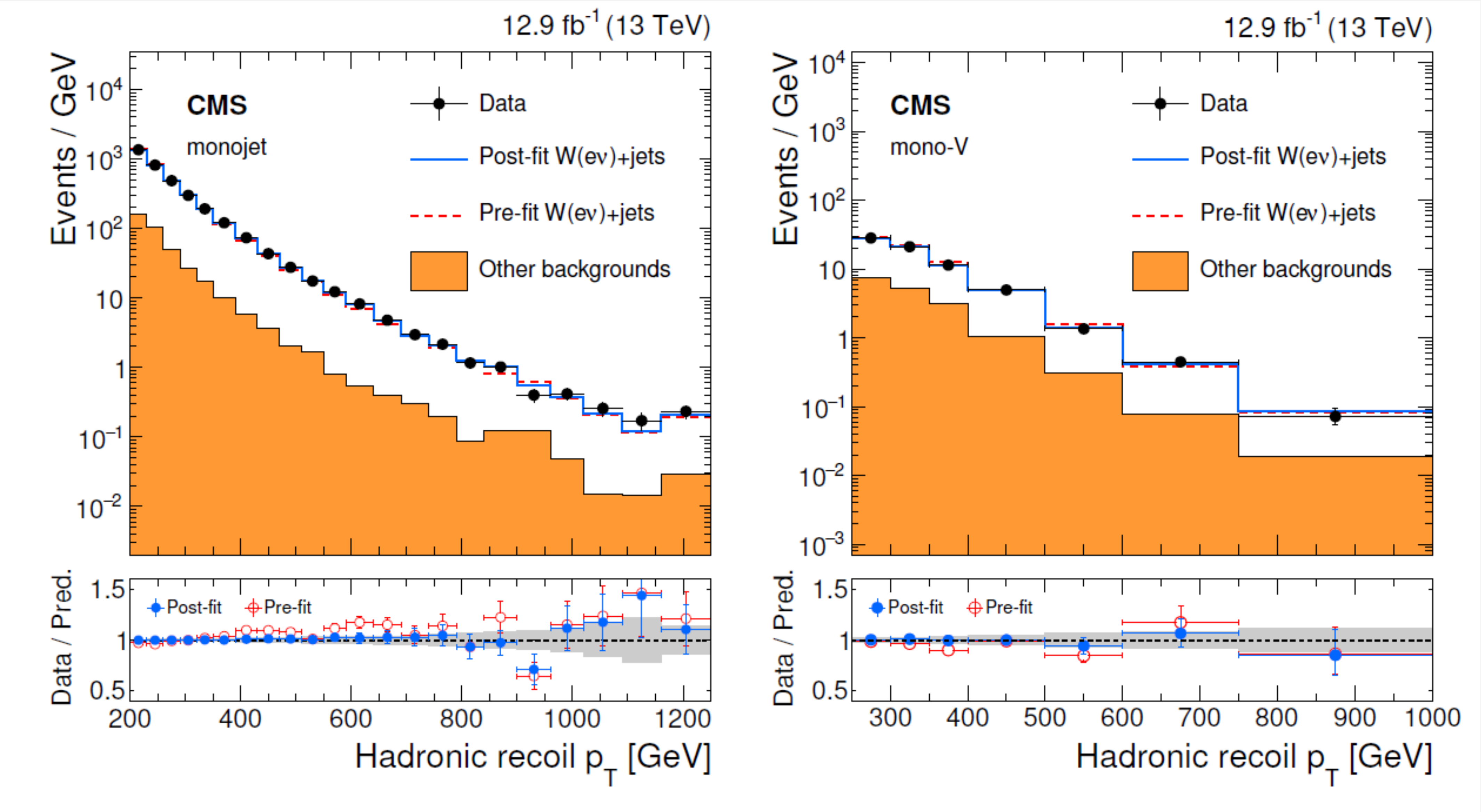


In single-lepton control samples

→ single muon control sample



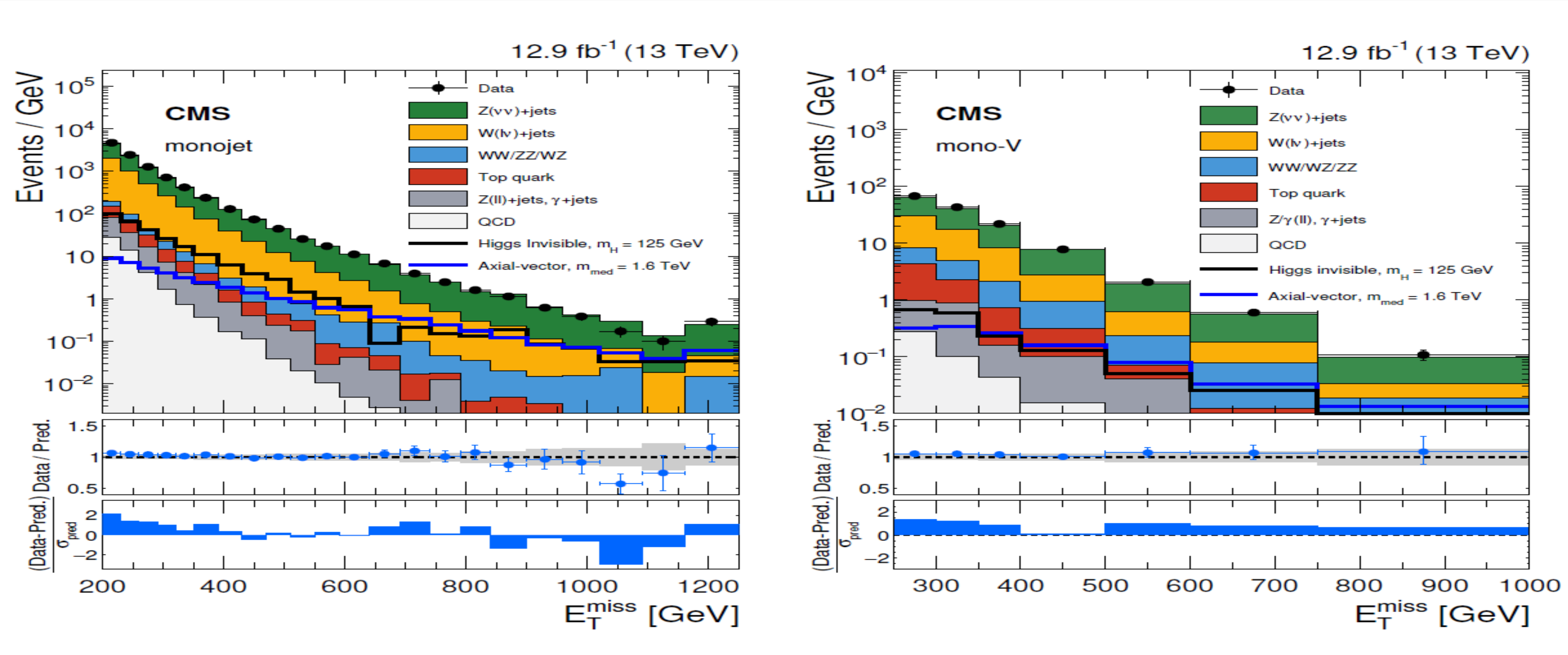
→single electron control sample



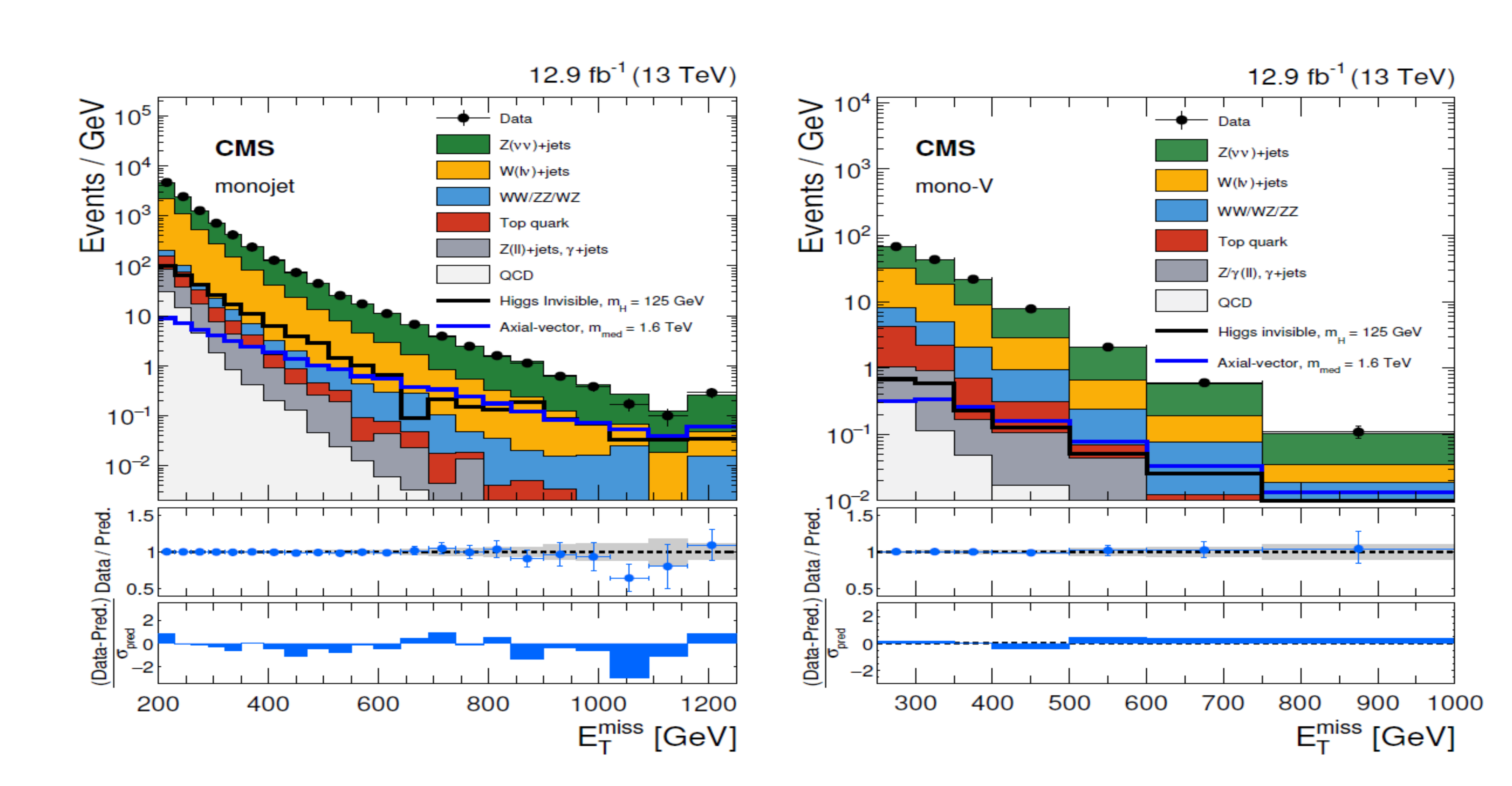
6. Results and interpretations

E_T^{miss} Distributions in the monojet and mono-V signal regions

Excluding the signal region



Including events from the signal region , but assuming the absence of any signal



6.1- Dark matter interpretation

→from the observed cosmological relic density of DM as determined from measures of the cosmic microwave background by the Planck satellite experiment.

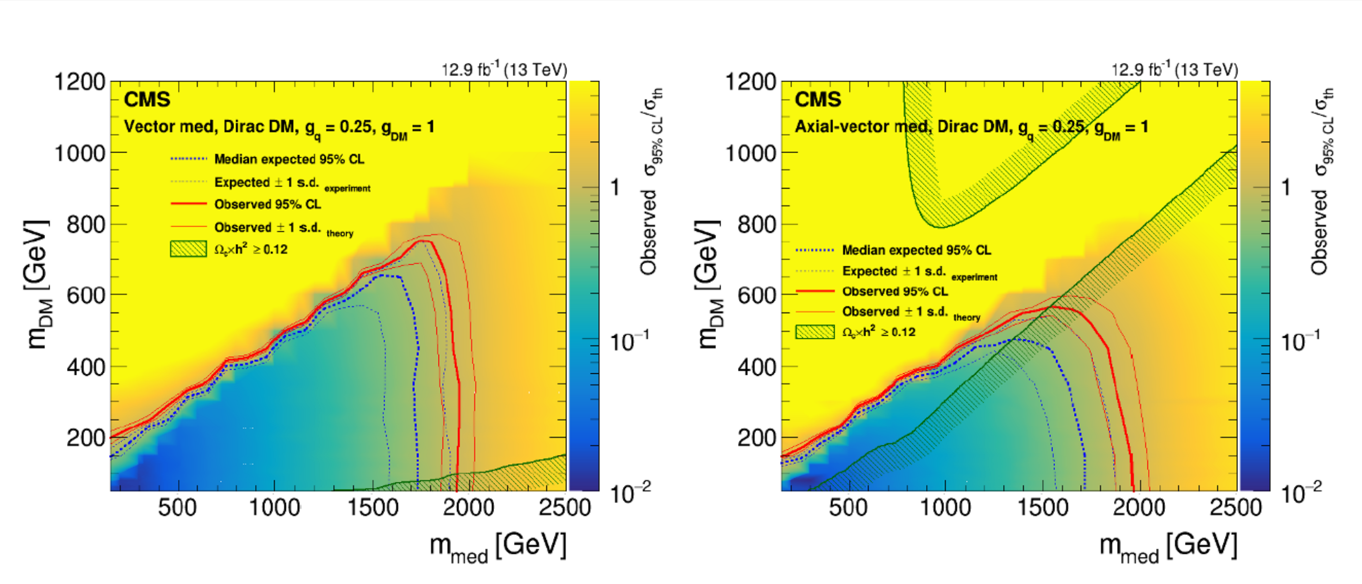
→Observed cold DM density $\Omega ch^2=0.12$

*Ωc=DM relic abundance

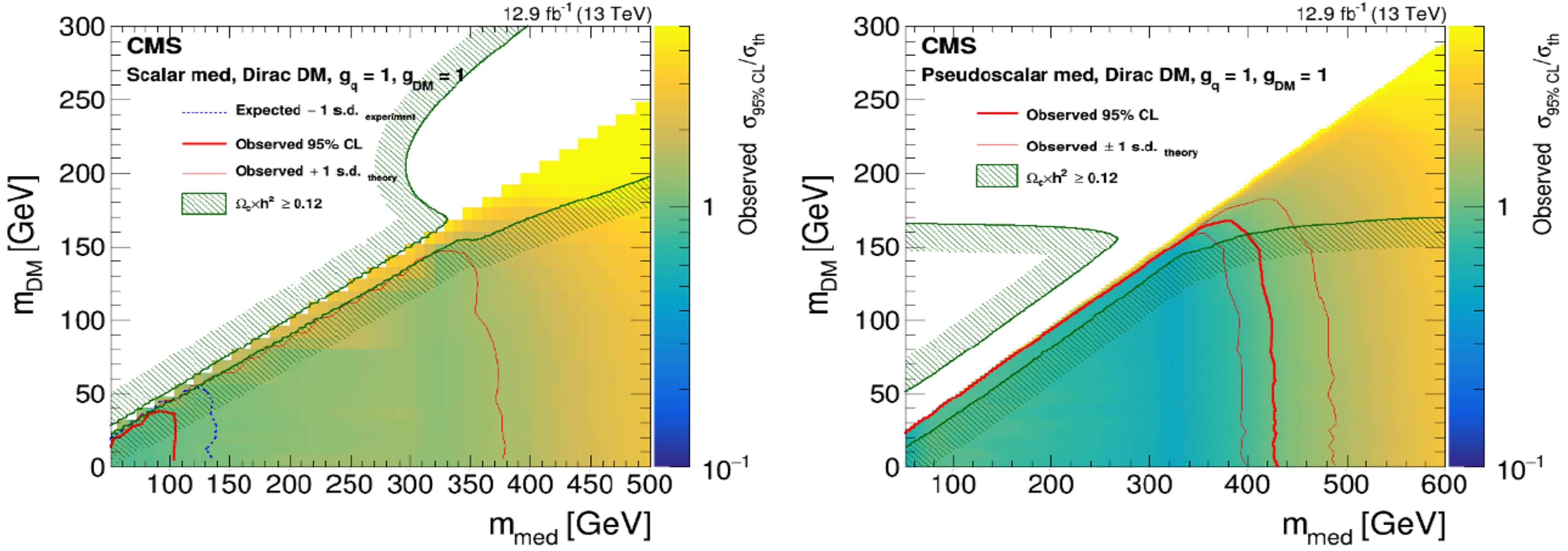
*h=Hubble constant

Exclusion limits at 95% CL on the signal strength $\mu=\sigma/\sigma th$

With vector mediator and axial-vector mediators

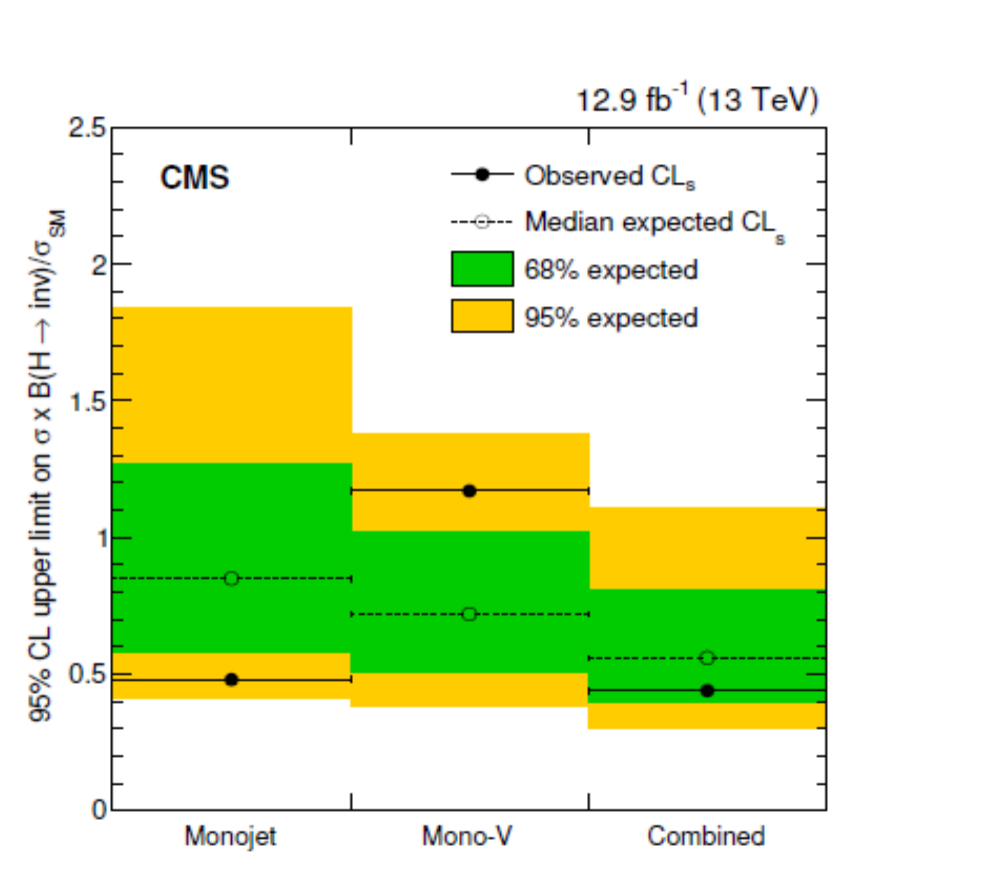


Assuming scalar and pseudoscalar mediators



The hatched green área indicates the region where the DM density exceeds the observed value

Summary



→The results of this search provide the strongest constraints on DM pair production through vector and axial-vector mediators at a particle collider.

→excluded from 95% CL

*scalars mediators with masses up to 100GeV

*pseudoscalars mediators with masses up to 430 GeV

→it is observed (expected) 95% CL upper limit of 0.44 on the invisible branching fraction of a standar model-like 125 GeV Higgs boson, assuming SM production cross section.

Thank you!