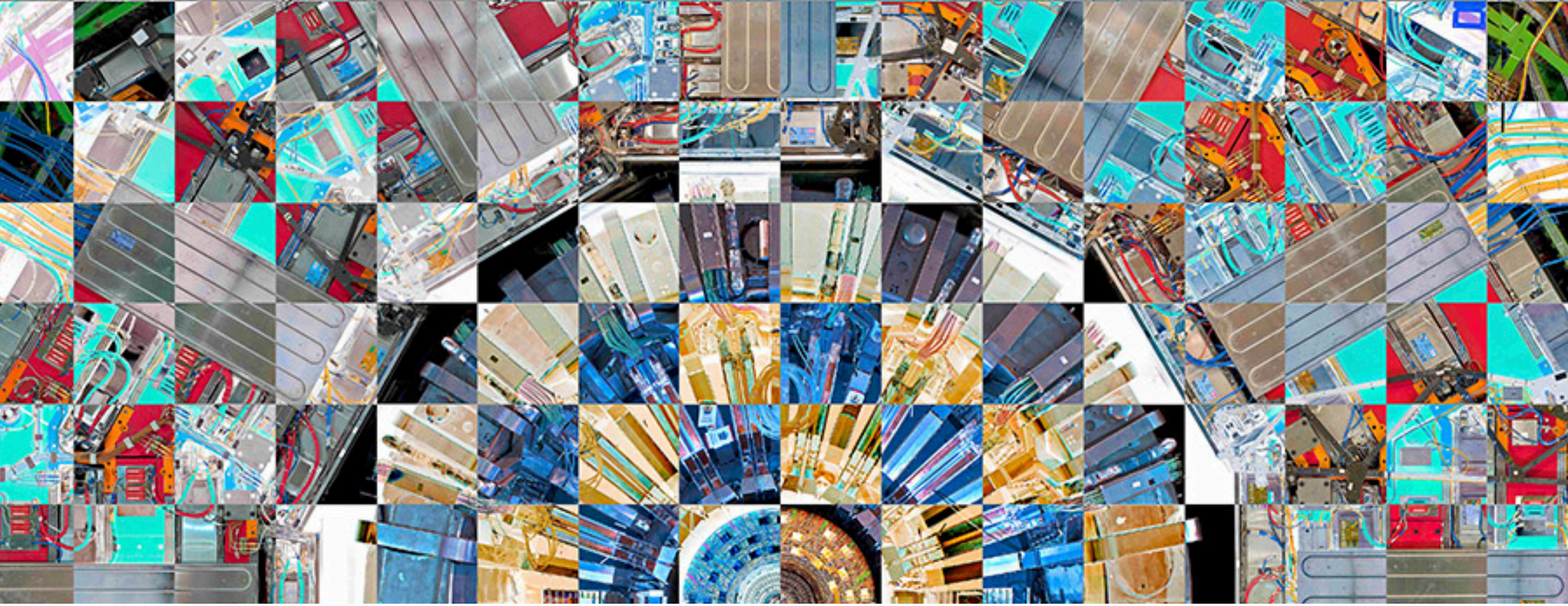


LHC Dark Matter WG public meeting

CMS Summary

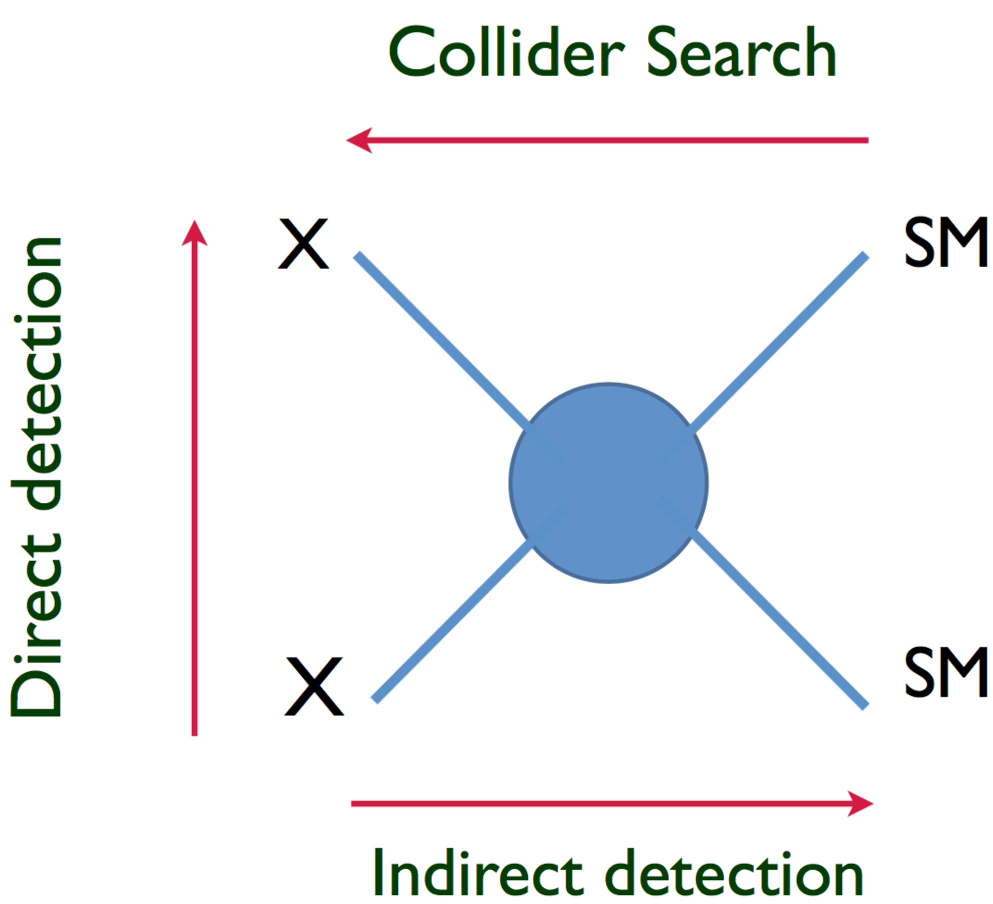
Cornell University

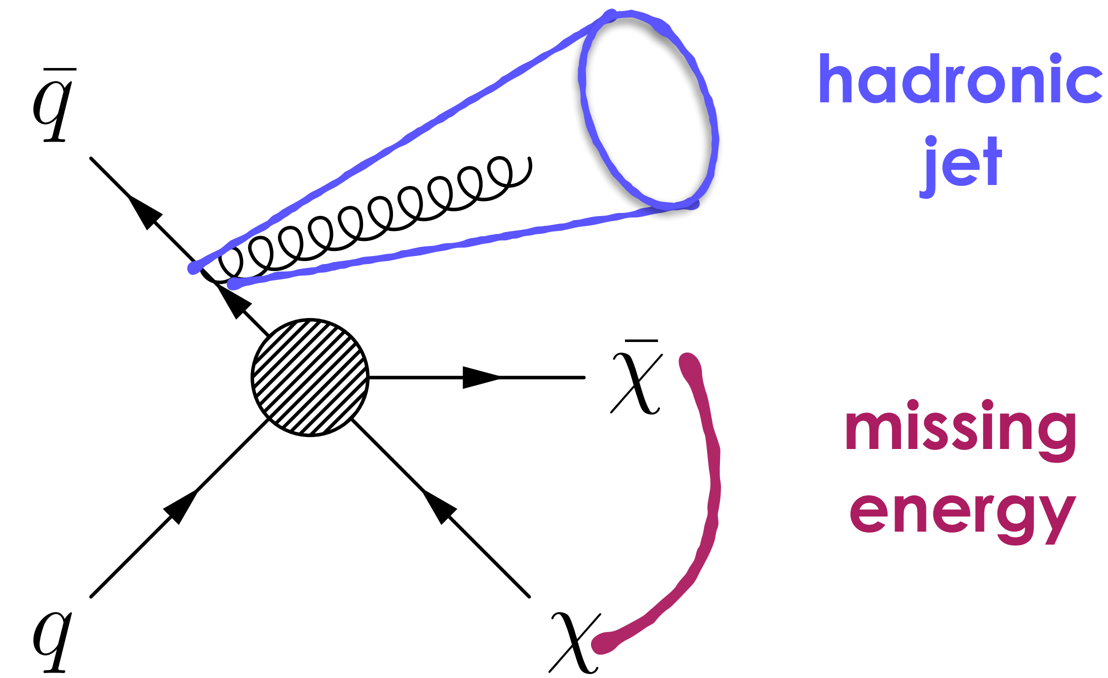
Livia Soffi

CERN, 12/18/2017

Dark Matter Quest at Colliders

- Existence of a DM particle hypothesized to explain a range of **astrophysical measurements**
- **DM particles pair-produced** in pp collisions at sufficiently high energy



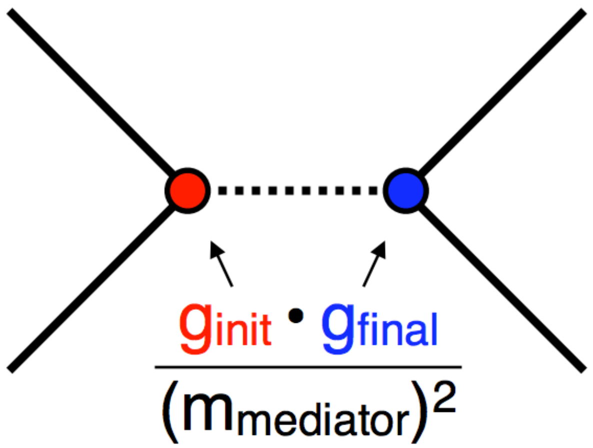


- At Collider: $pp \rightarrow E_T^{miss} +$ ***gluon***

- **Visible object radiated by initial partons** necessary to **"see" the event**

What Fermi Taught Us

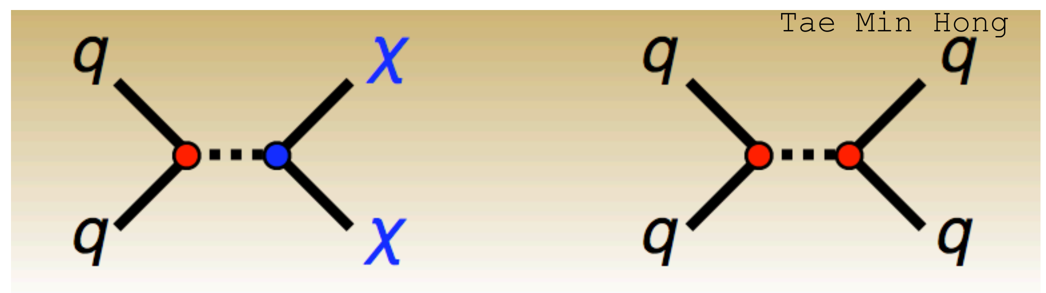
- **Simplified Model:** Explicit nature of the **Mediator**



- At least 4 parameters (**M_{med}, M_{DM}, g_{SM}, g_{DM}**)
- Valid at **all energies**
- If mediator couples to quarks, it can also decay to **SM particles**

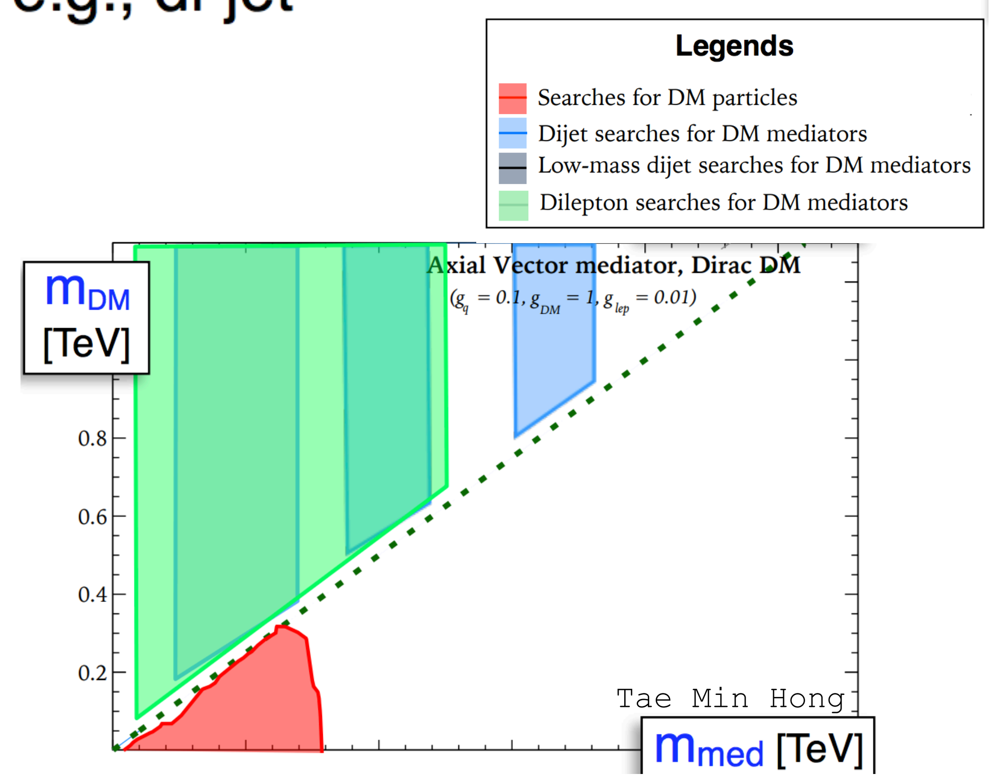
Mediator

Vector	Axial-Vector
Scalar	Pseudoscalar



e.g., Z', ϕ e.g., di-jet

- Results depending on **coupling assumptions**
- Alternate (g_{DM} , g_q , g_{lep}) alters conclusions
- **Overlapping coverages** important for robustness

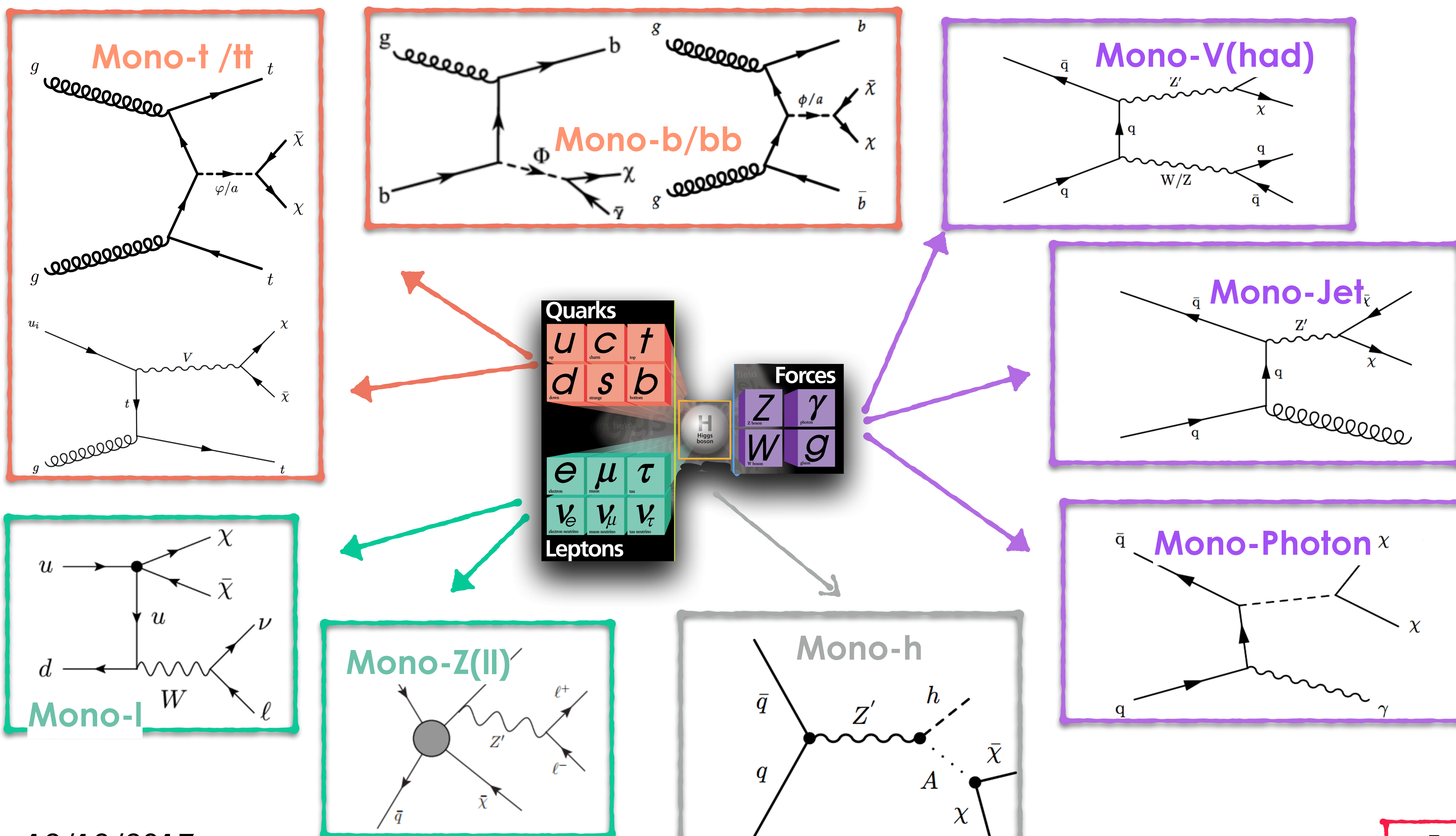


A Wide Spectrum of final states

$pp \rightarrow E_T^{miss} + \textbf{gluon}$ —extended to→ $pp \rightarrow E_T^{miss} + \textbf{X}$

X = Any SM particle

- Probe different nature of mediators and couplings



A Wide Spectrum of final states

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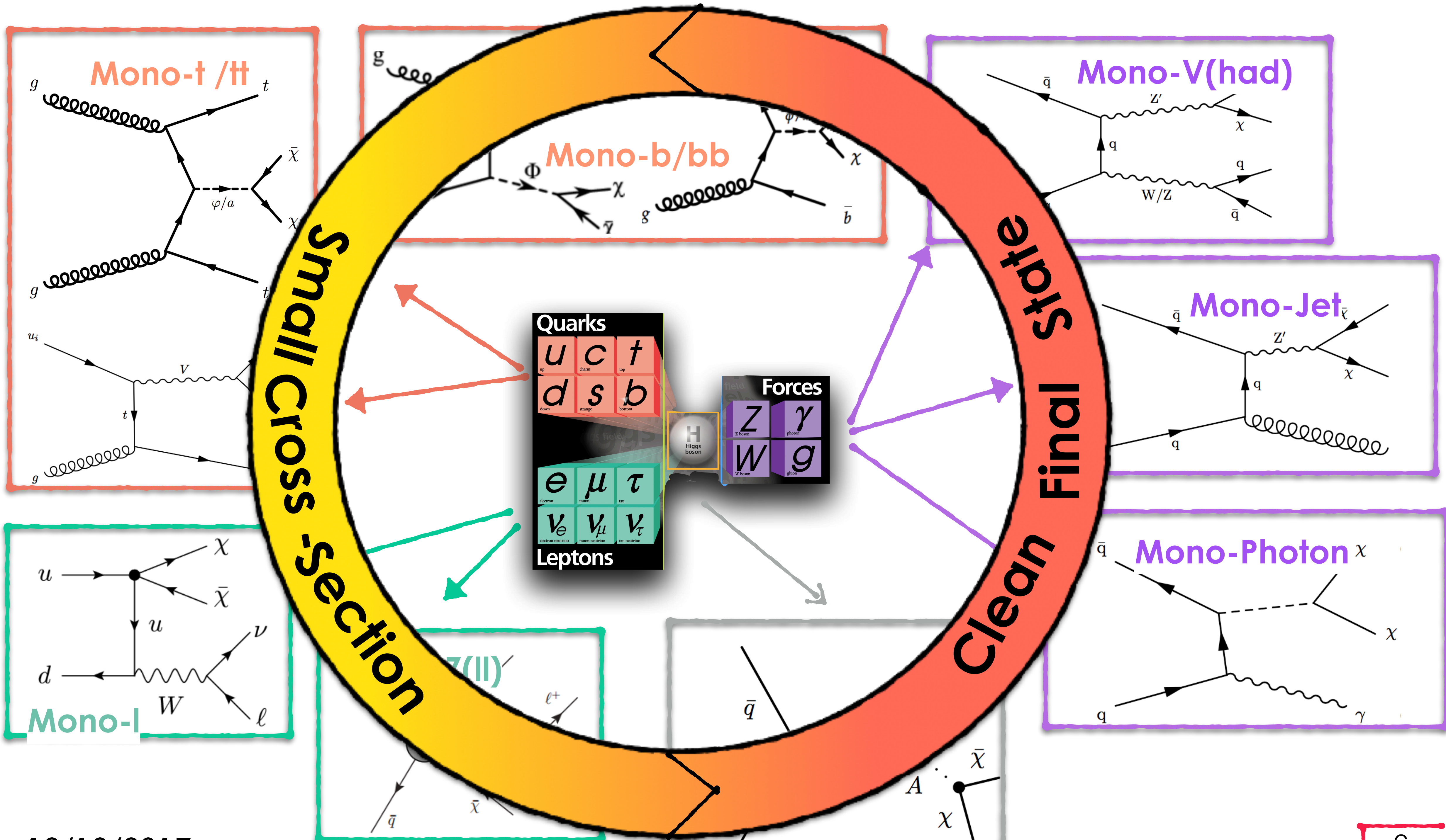


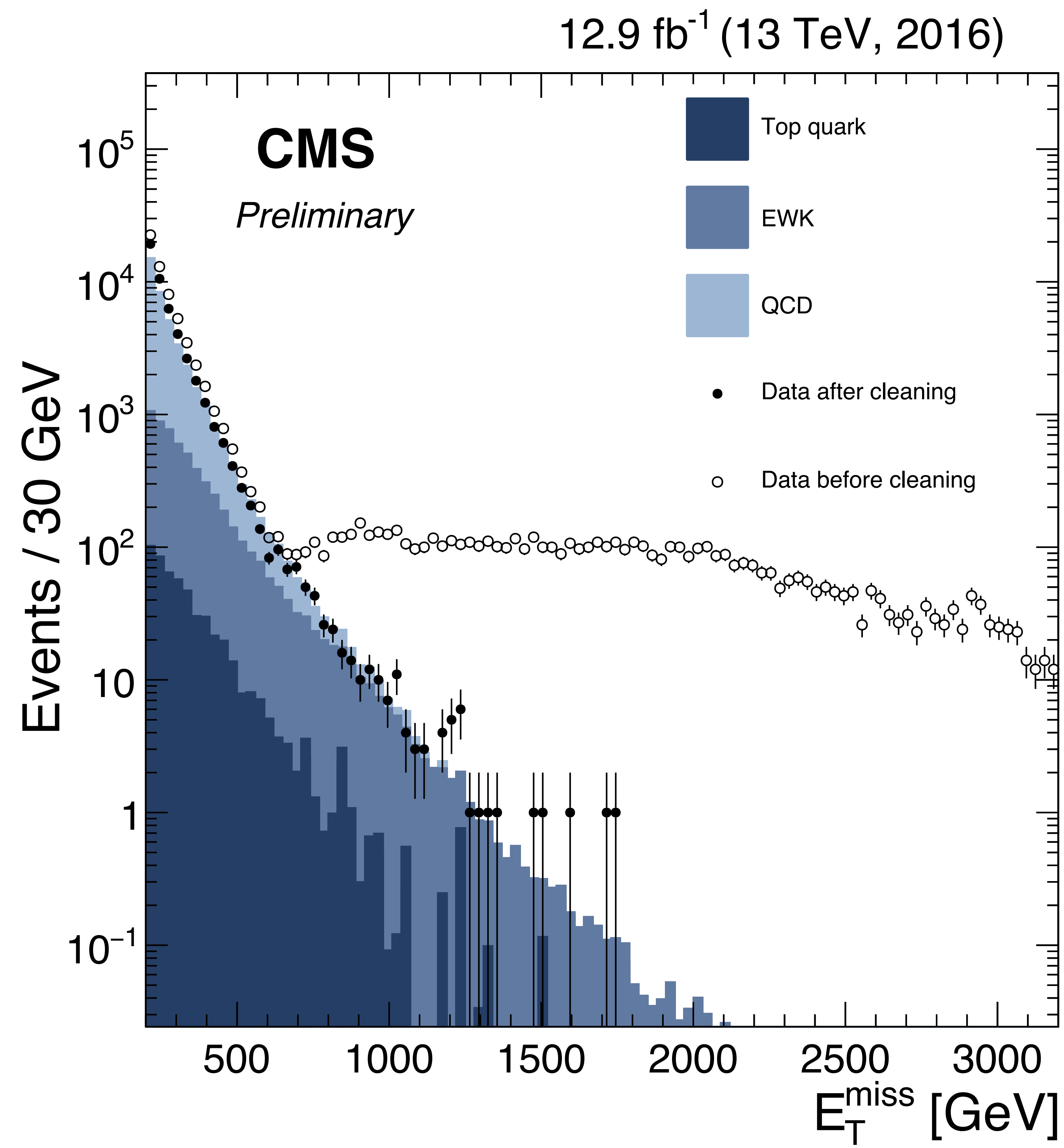
MET @ CMS

- Key Variable: **Missing Transverse energy (MET)**
- Precise measurement of all reconstructed physics objects

$$\vec{E}_{\mathrm{T}}^{\mathrm{miss\,corr}} = \vec{E}_{\mathrm{T}}^{\mathrm{miss}} - \sum_{\mathrm{jets}} (\vec{p}_{\mathrm{T,jet}}^{\mathrm{\,corr}} - \vec{p}_{\mathrm{T,jet}}),$$

- MET measurement improved by **correcting the pT of the jets and propagating the jet energy corrections**

- **Spurious detector signals causing fake MET suppressed.**

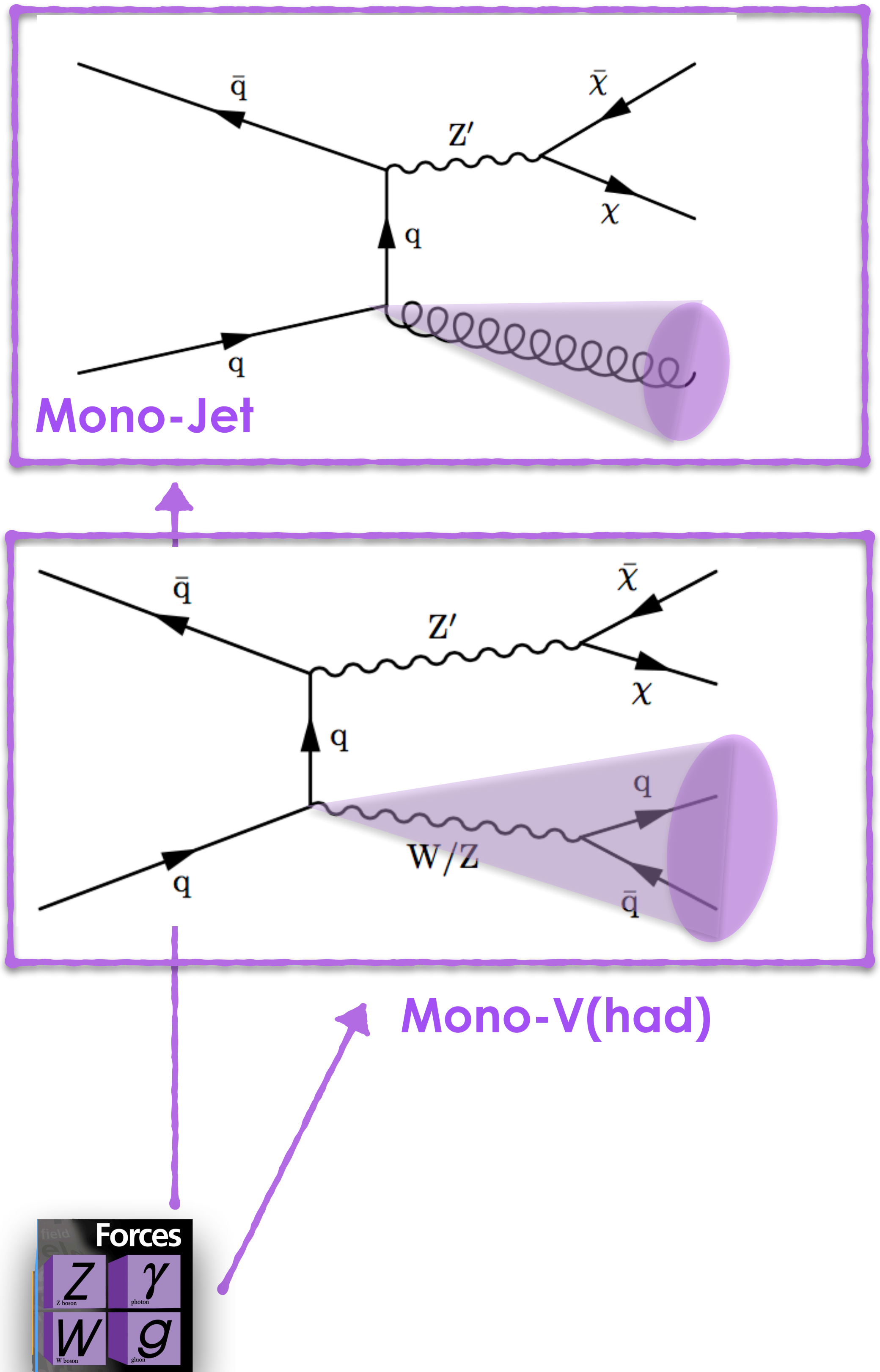


Dark Matter Searches at CMS

Final State	Dataset	CMS Documents
H(γγ)+MET	2016, 35.9 fb^{-1}	EXO-16-054
Z(ll)+MET	2016, 35.9 fb^{-1}	EXO-16-052
top+MET	2016, 35.8 fb^{-1}	EXO-16-051
Photon+MET	2016, 12.9 fb^{-1}	EXO-16-039
Jet or V (hadronic)+MET	2016, 35.9 fb^{-1}	EXO-16-048
top pair+MET	2015, 2.2 fb^{-1}	EXO-16-005
Re-Interpretations in terms of DM Simplified Model		
Dijet Search(Boost)	2016, 35.9 fb^{-1}	EXO-17-001
Dijet Search	2016, 35.9 fb^{-1}	EXO-16-056
Dijet Angular Distribution	2016, 35.9 fb^{-1}	EXO-16-046
Dilepton Search	2016, 35.9 fb^{-1}	EXO-16-047
tt(ll)+MET	2016, 35.9 fb^{-1}	SUS-17-001

- Reach menu of **results with full 2016 data**
- Many other under review process : mono-Photon, mono-H,mono-tt
- **Analyses working also on 2017 data** -> 2018 Conferences

Dark Matter + Jets



Channel highly sensitive to DM production

- High gluon production cross-section

Mono-jet

- MET > 200 GeV
- P_T AK4-jet > 100 GeV
- HT or MET trigger

Mono-V

High V p_T: V→jj decay products merged in one *fat* jet

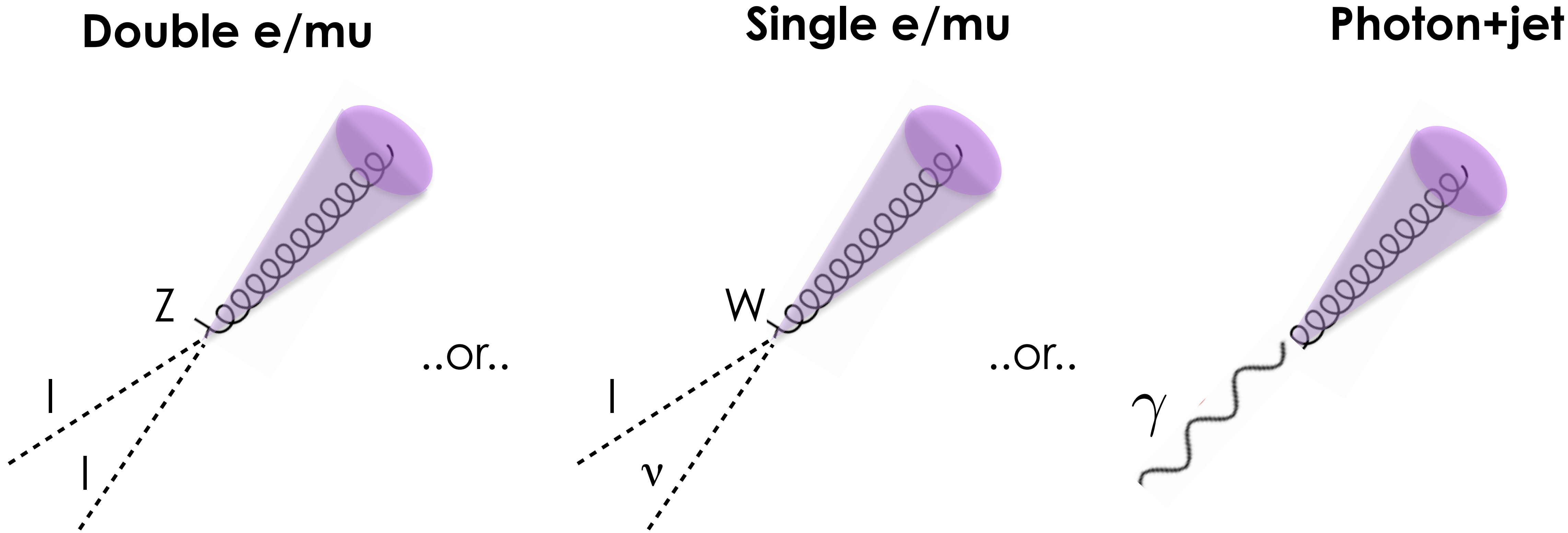
- MET > 250 GeV
- P_T AK8-jet > 250 GeV
- N-subjetiness < 0.6
- Mass: 65-105 GeV

- Veto on leptons/photons
- No veto on additional jets targeting also multijet+MET signature

arXiv:1712.02345

Dark Matter + Jets: Backgrounds

- Major background from **Z(→νν) + jets (60%) and W(lν) + jets (30%)** estimated in **data** in several **control regions (CR)**



arXiv:1712.02345

Dark Matter + Jets: Backgrounds

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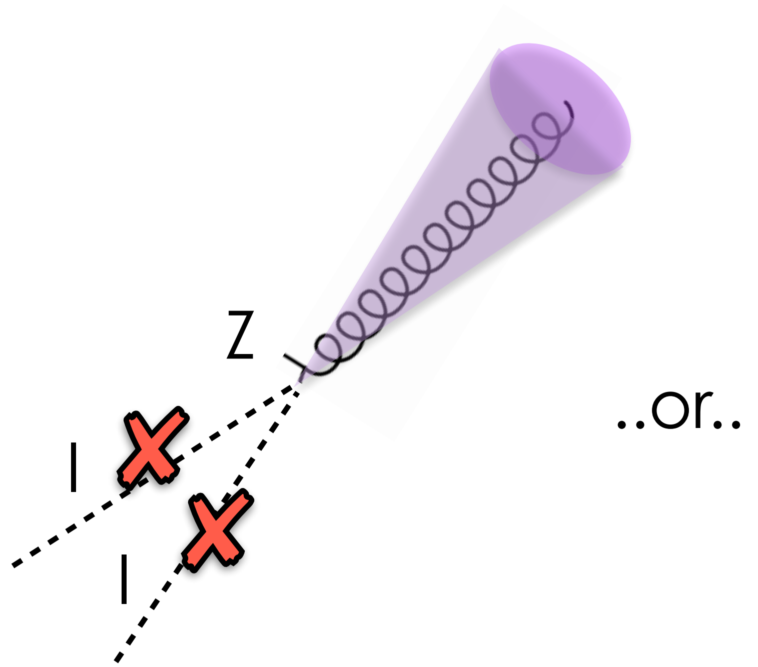
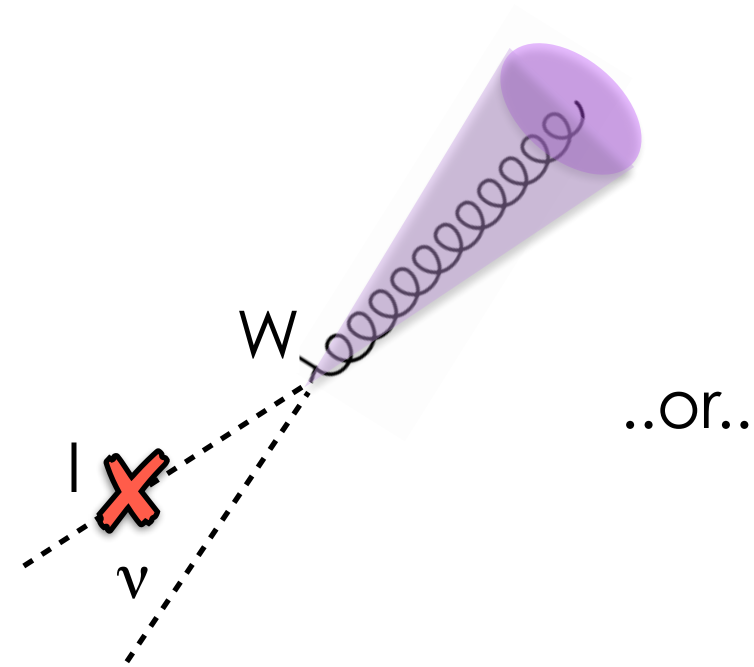
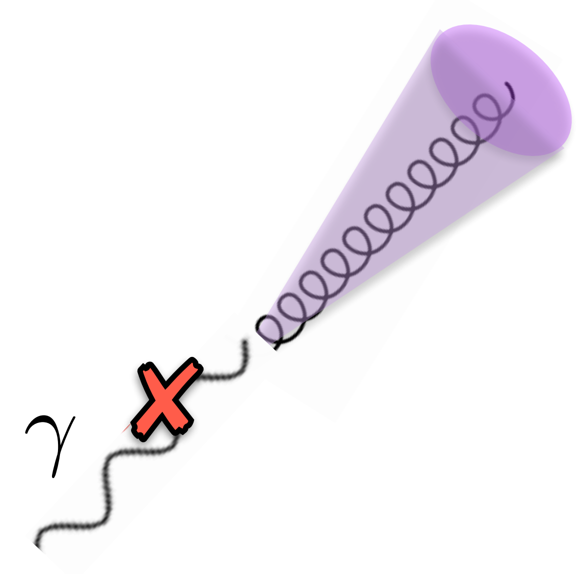
Double e/mu

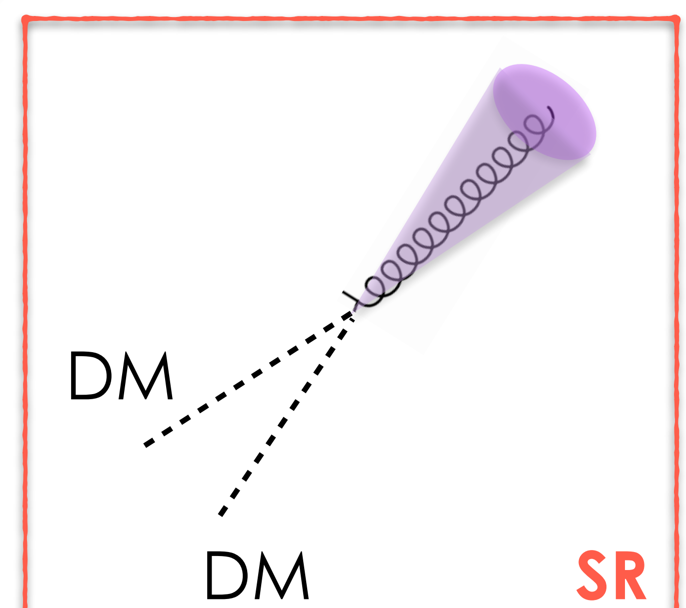


Single e/mu



Photon+jet



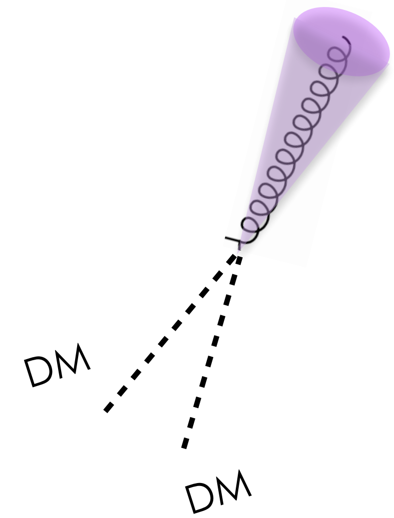


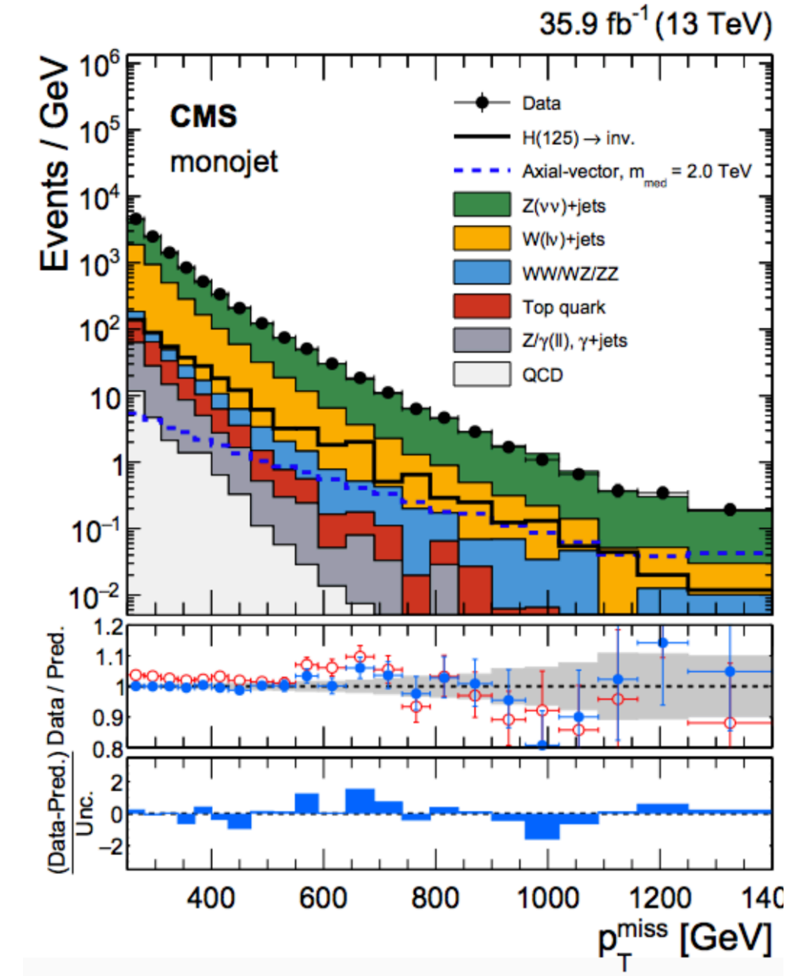
- **Boson recoil (W/Z/γ pT) used to mimic E_T^{miss} in SR**
- Simultaneous likelihood fit to E_T^{miss} in SR and CRs

Dark Matter + Jets: Signal Region

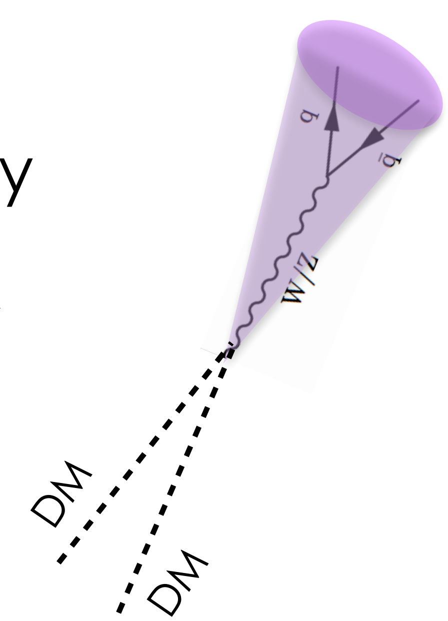
- Relate CR and SR using bin-by-bin **transfer factors "R" from simulation**

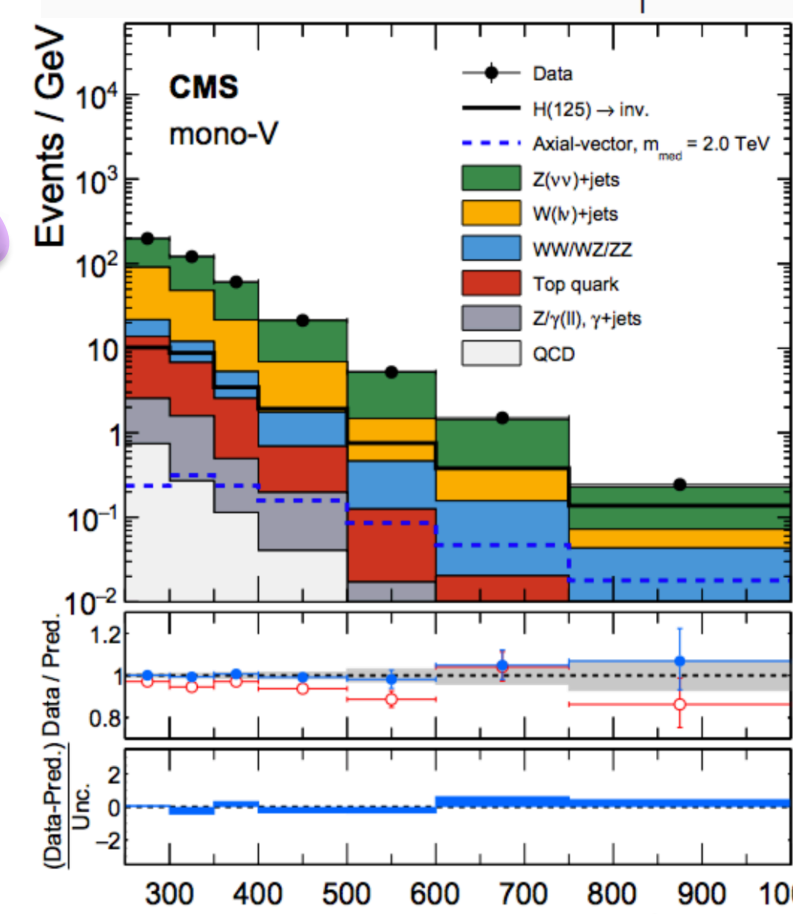
  - $N_i^{Z(SR)} = N_i^{Z(ll)} \times \mathbf{R^{Z(ll)}}$
  - $N_i^{Z(SR)} = N_i^{Y} \times \mathbf{R^{Y}}$
  - $N_i^{W(SR)} = N_i^{W(l\nu)} \times \mathbf{R^{W(l\nu)}}$





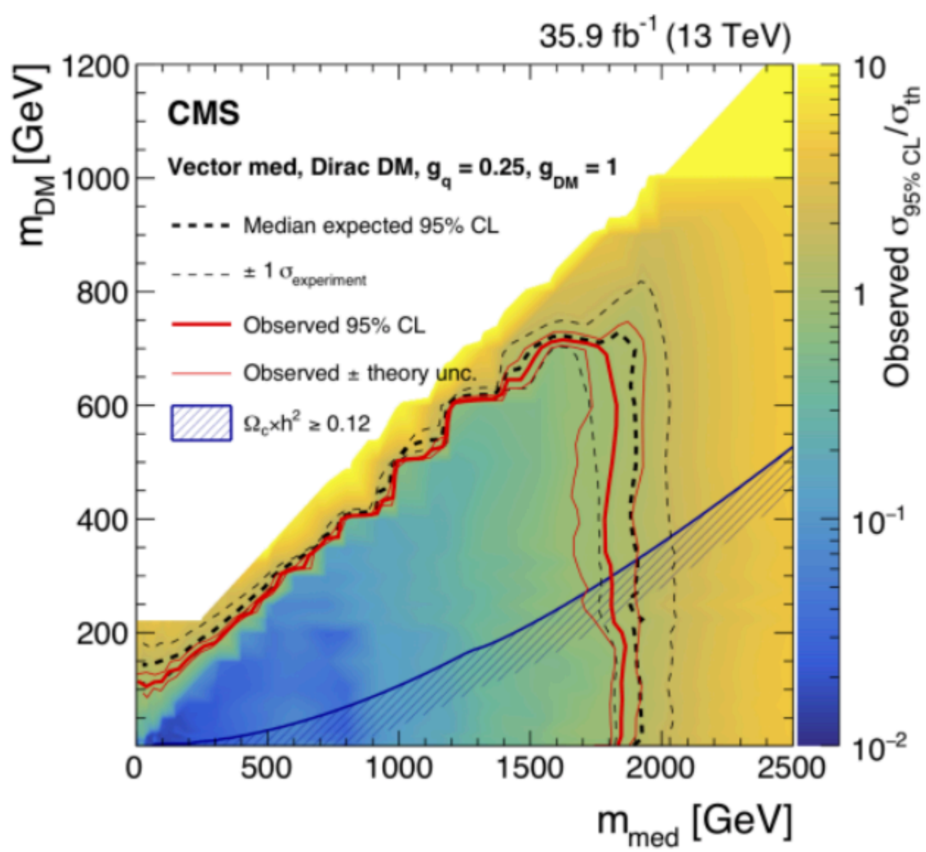
- Rely on **theory prediction** of the ratio of V+jet cross sections
- Recent work of the theory community [**arXiv:1705.04664**]: Uncertainty on R reduced by ~40% to ~20%
- Now dominated by experimental uncertainty

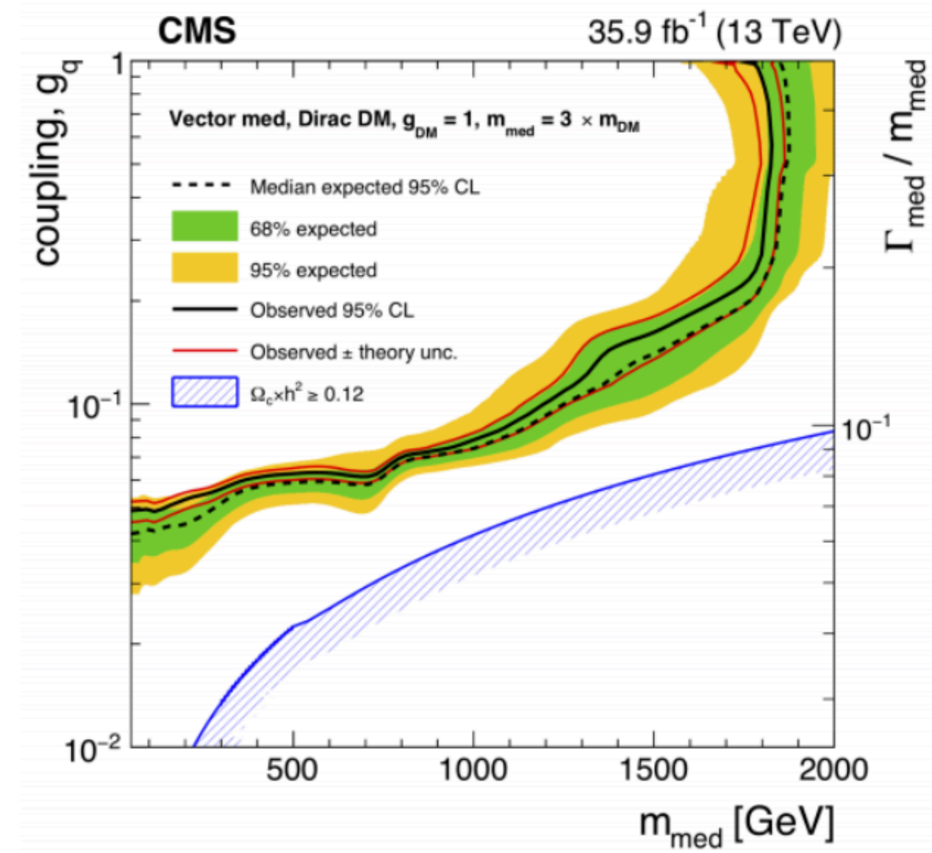




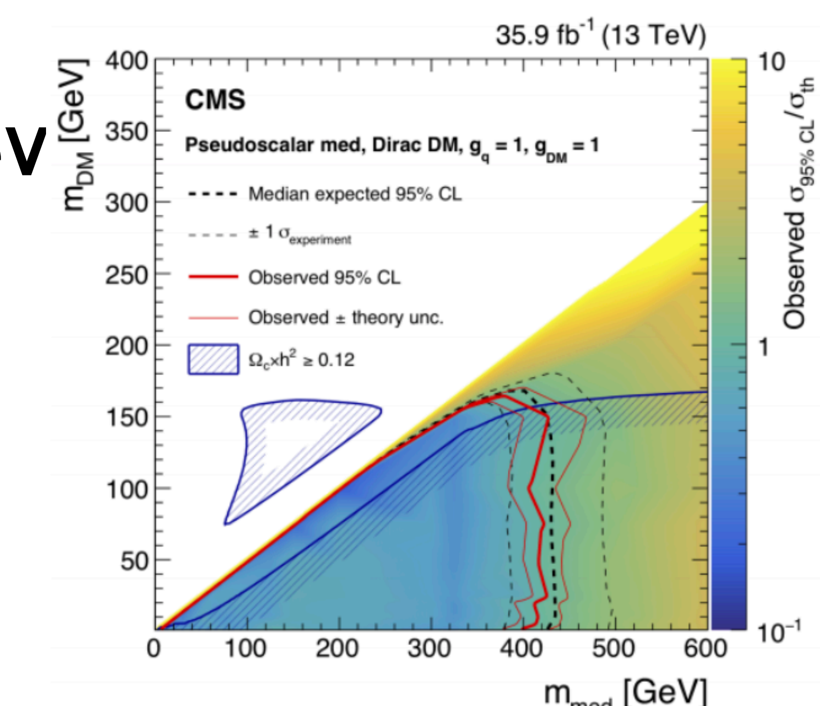
Dark Matter + Jets: Results

- Given the observed lack of excess, upper limits are set on σ_{DM} assuming **simplified models for signal as a function of M_{med} and m_{DM}**





- **Exclude Mediator (vector, axial-vector) of m < 1.8 TeV**
- **Pseudo-scalar of mass up to 400 GeV is excluded**
- Fermion portal DM model: exclusion up to 1.4 TeV
- BR(h->invisible)<0.4 @95% CL

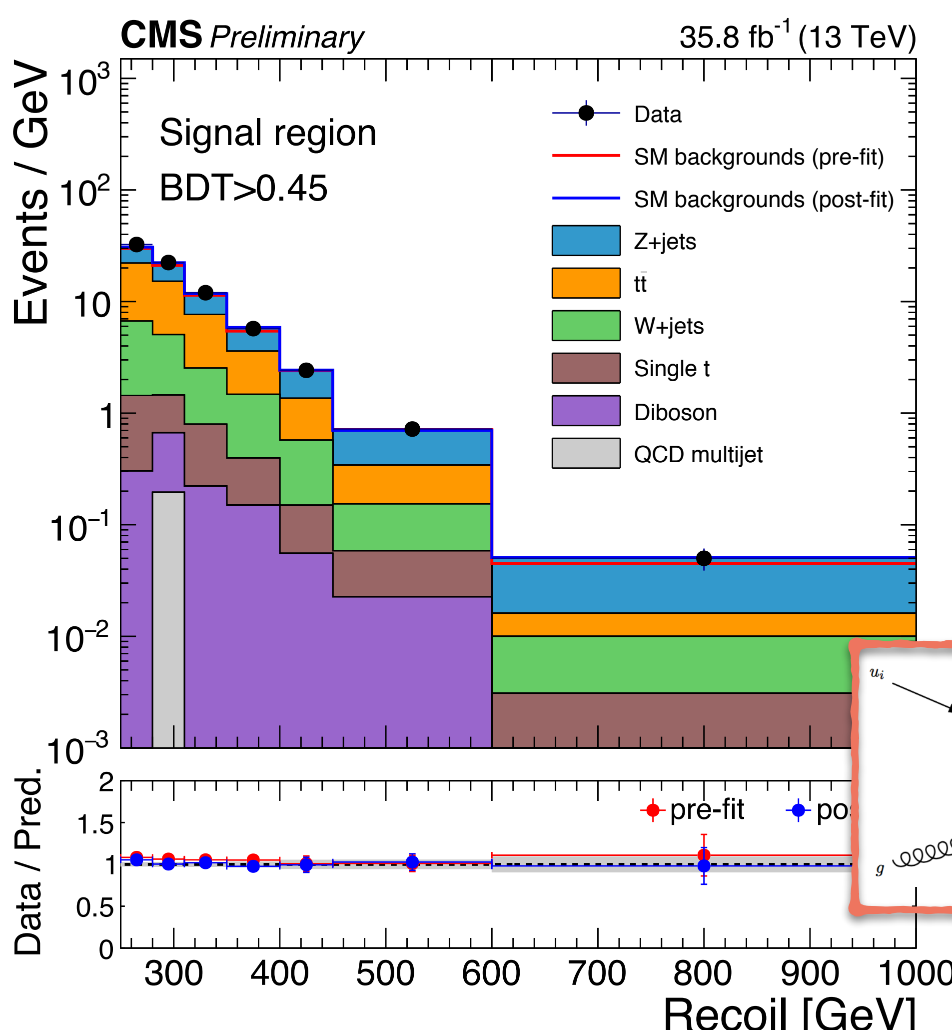


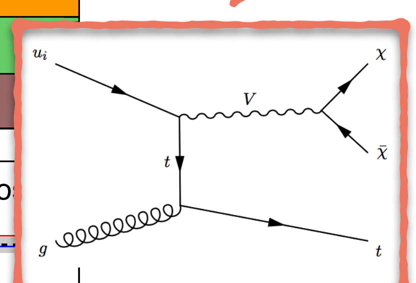
arXiv:1712.02345

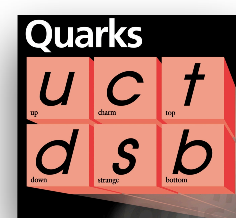
Dark Matter + Heavy Flavors

Mono-t(had)

- One fat jet P_T> 250 GeV with ΔR=1.5
- MET > 250 GeV
- b-tagging: loose WP
- Top-tagging: soft drop mass and BDT cuts
- CRs and SRs based on final topology for background estimation

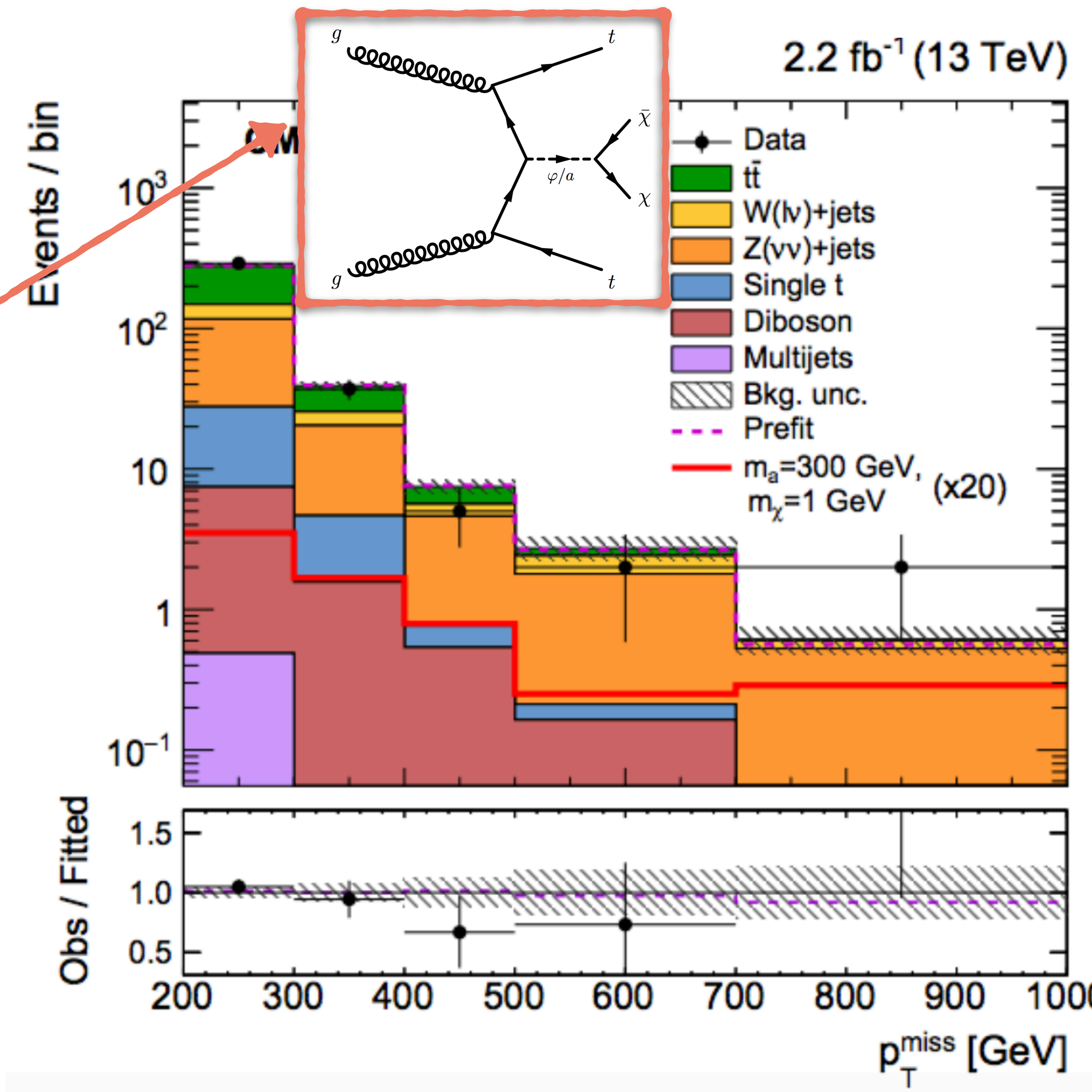






Mono-tt (bb)

- $P_T(l_1)$ > 30 GeV, $P_T(l_2)$ > 10 GeV
- MET > 50 GeV
- Veto event with third lepton
- Njets ≥ 2, N b-jets ≥ 1

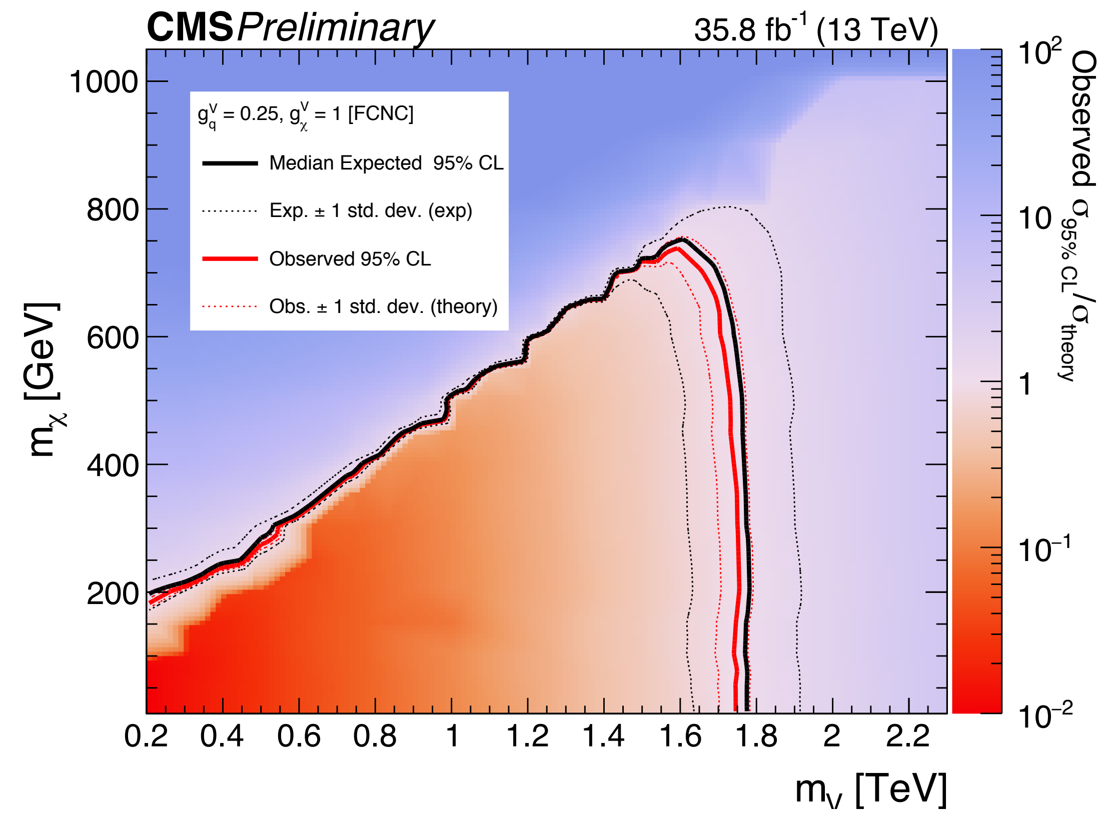


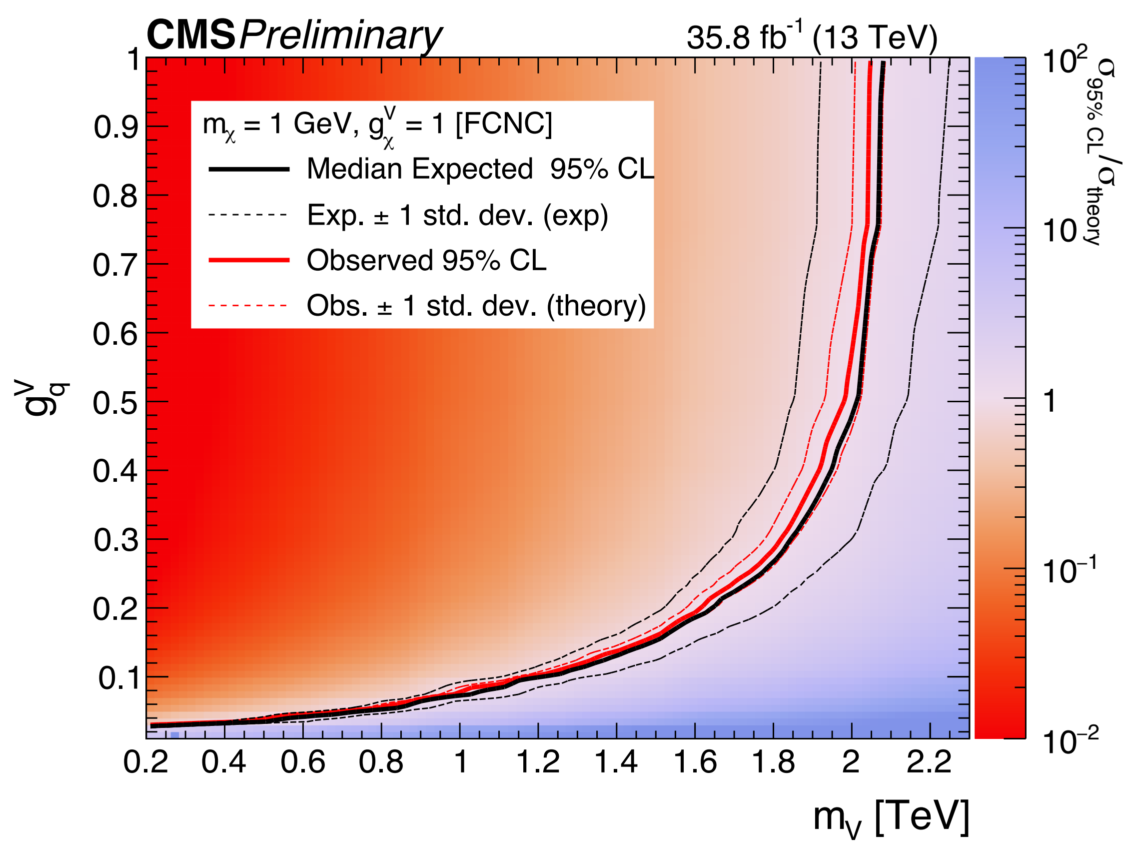
CMS-PAS-EXO-16-051

arXiv:1706.02581

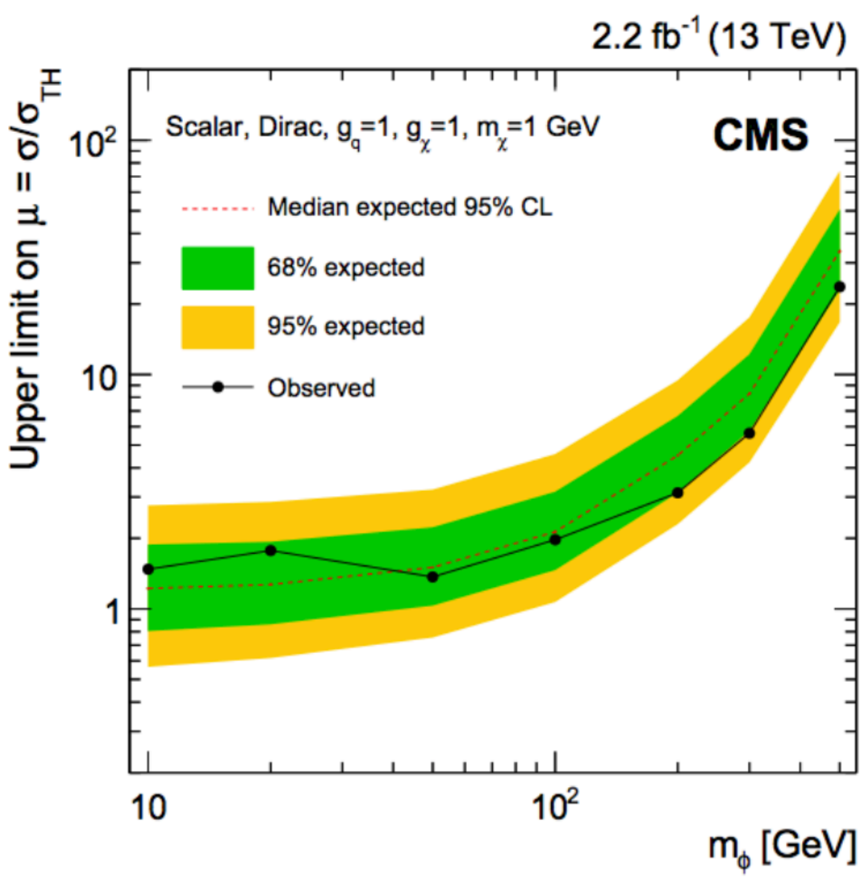
Dark Matter + Heavy Flavors: Results

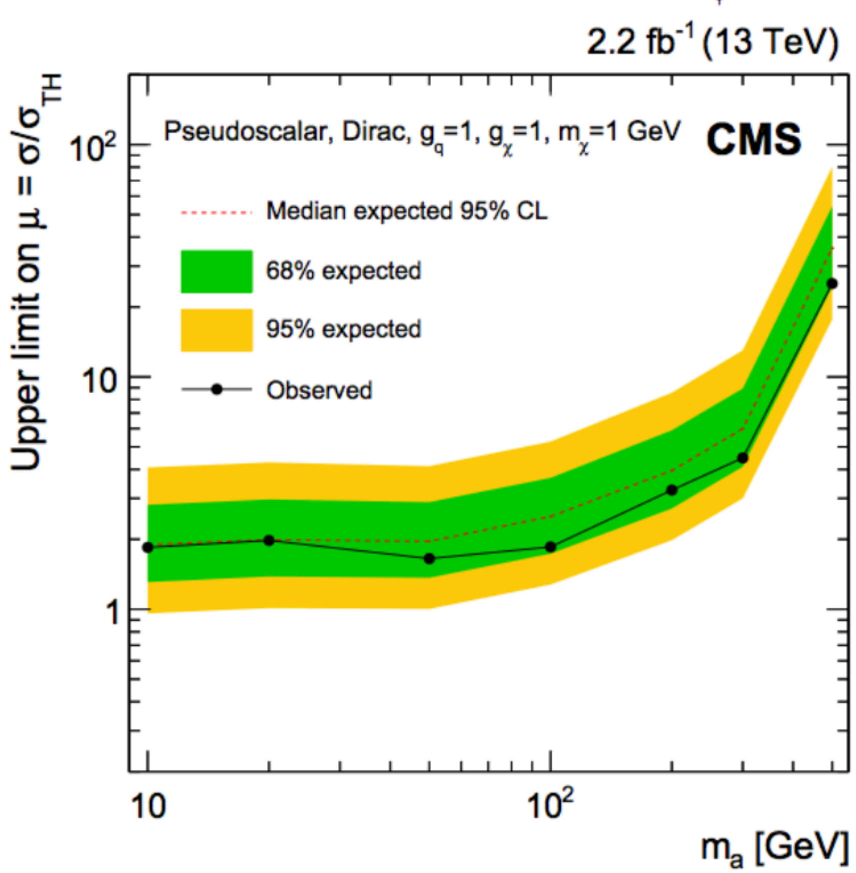
Mono-t(had)





Mono-tt (bb)



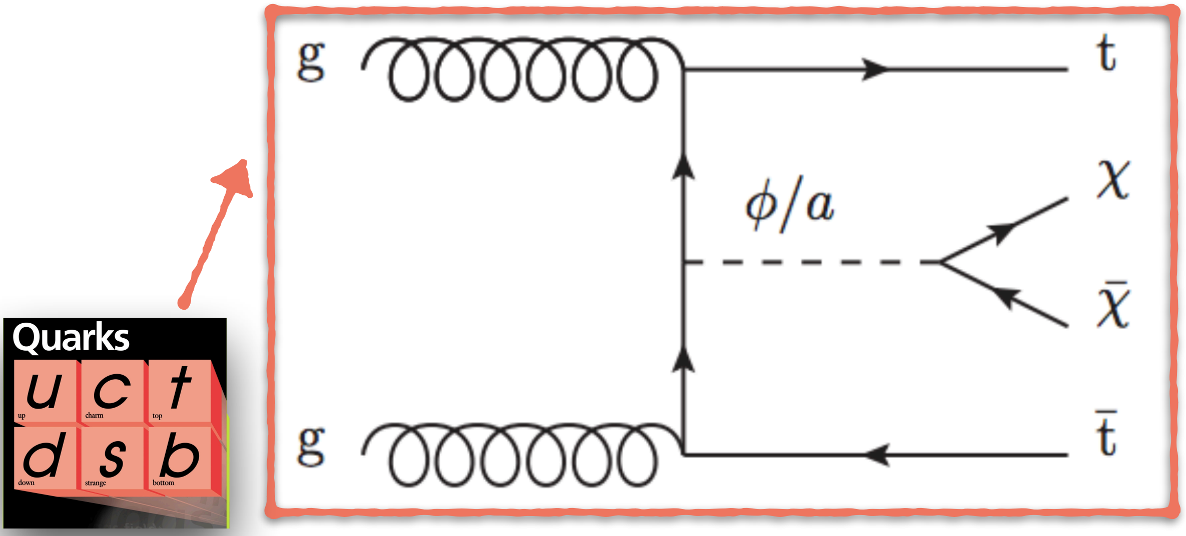


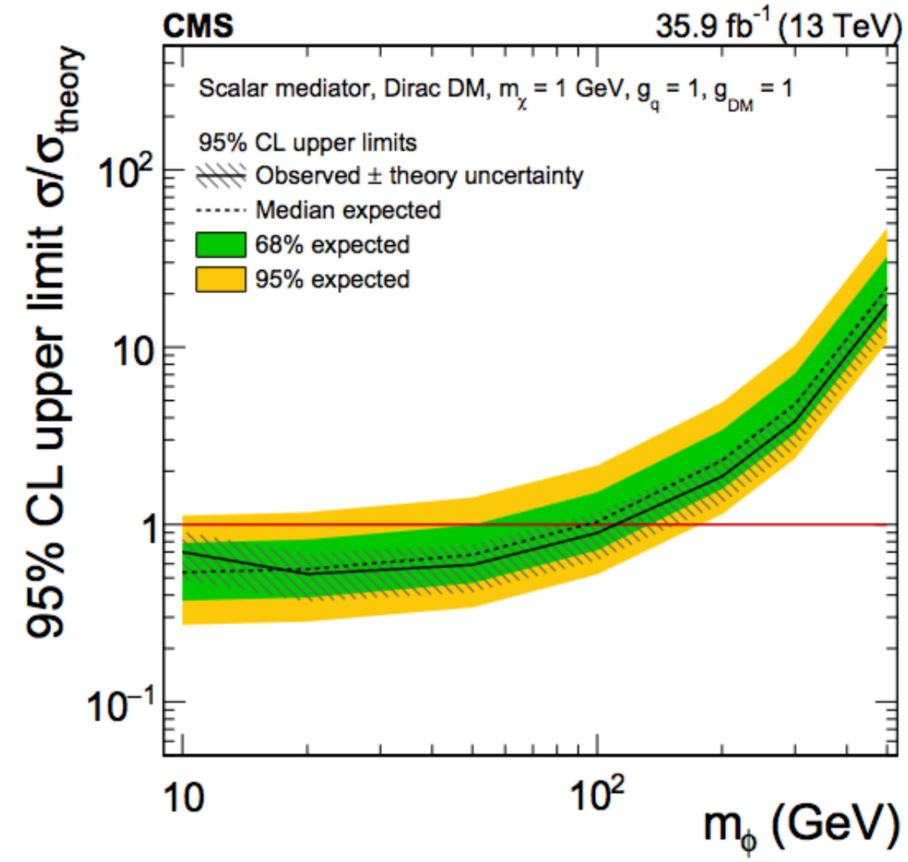
 CMS-PAS-EXO-16-051

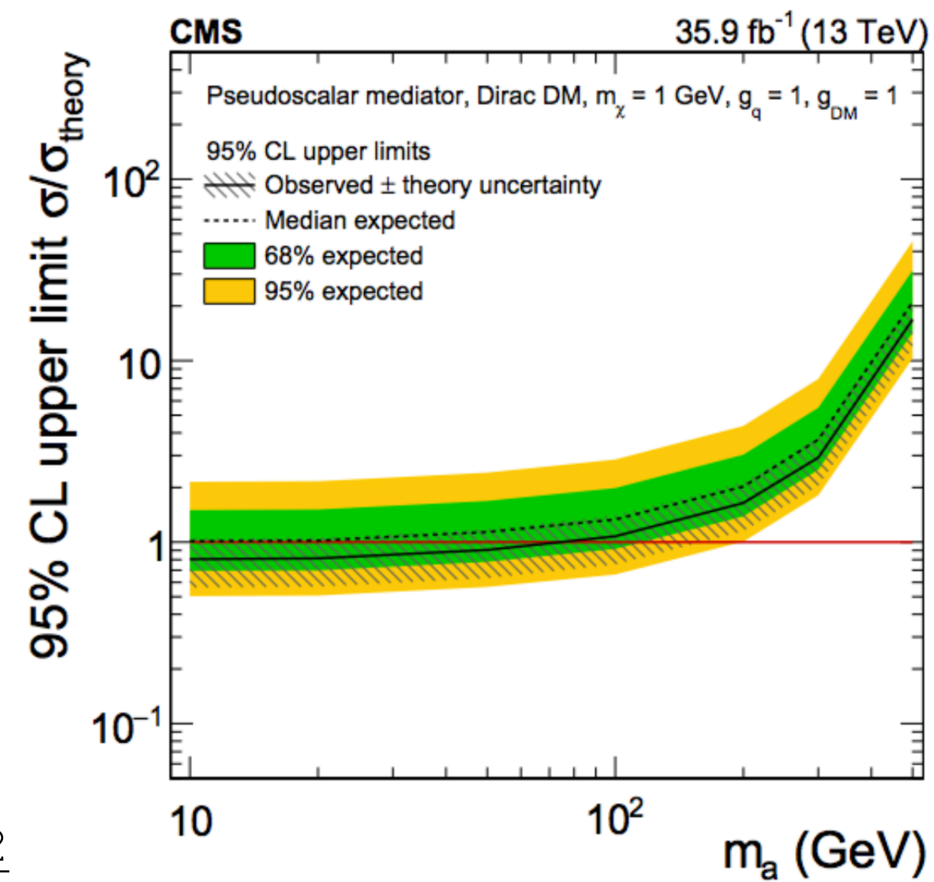
arXiv:1706.02581

Dark Matter + tt(ll)

- DM Interpretation of a **SUSY search for top pair production with large MET**



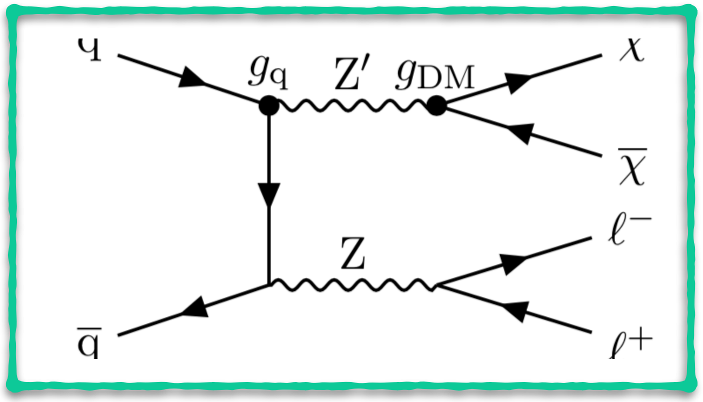




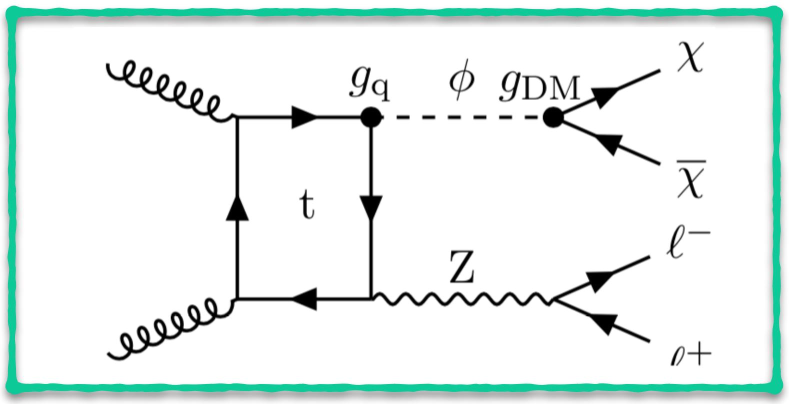
- Two opposite sign leptons
- $M(ll) > 20$ GeV, $|M_Z - M(ll)| < 15$ GeV
- MET > 80 GeV
- Njets ≥ 2, N b-jets ≥ 1
- (Pseudo) Scalar mass up to (50 GeV) 100 GeV excluded for M_{DM}=1 GeV

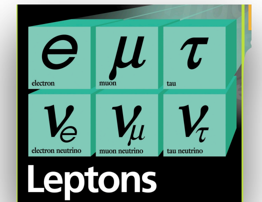
arXiv:1711.00752

Dark Matter + Z(ll)

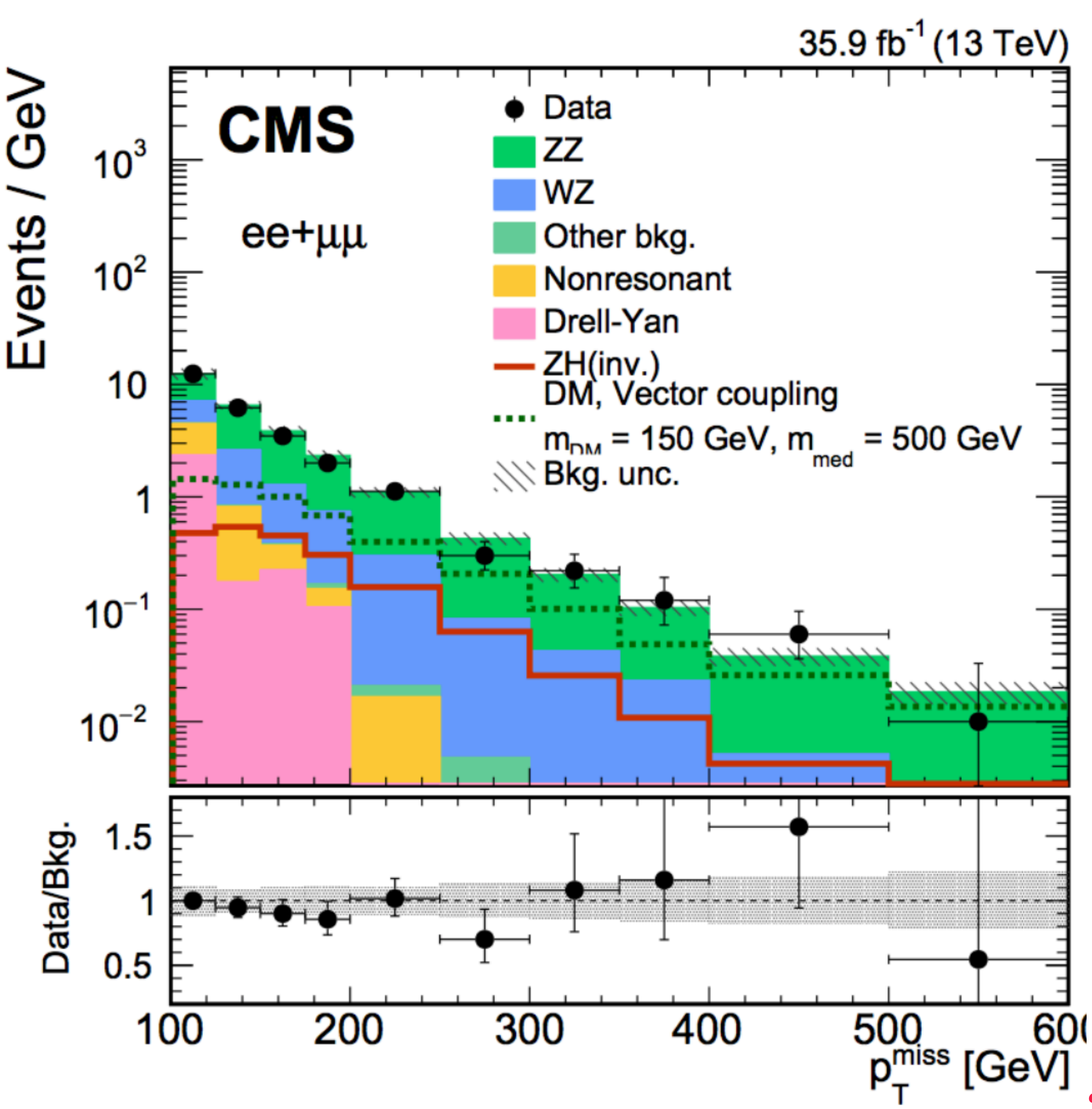


Mono-Z(ll)





- $P_T(ll)$ > 60 GeV
- MET > 100 GeV
- Veto event with extra e, μ, τ, >1 jet and b-jet

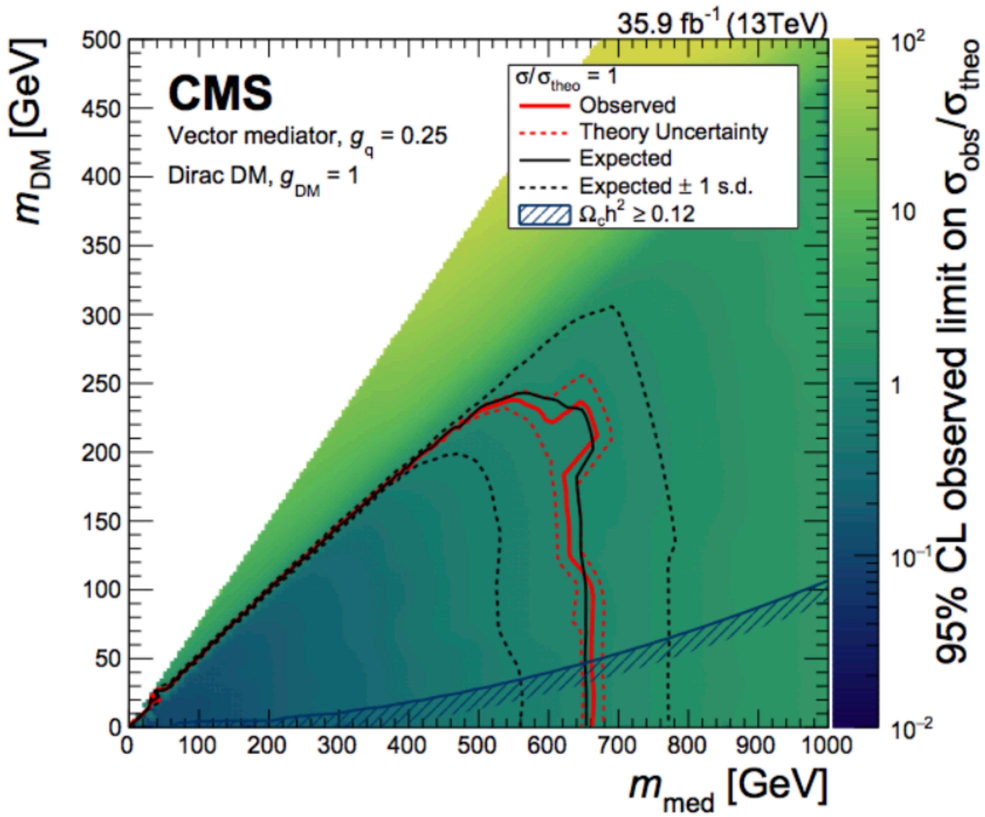


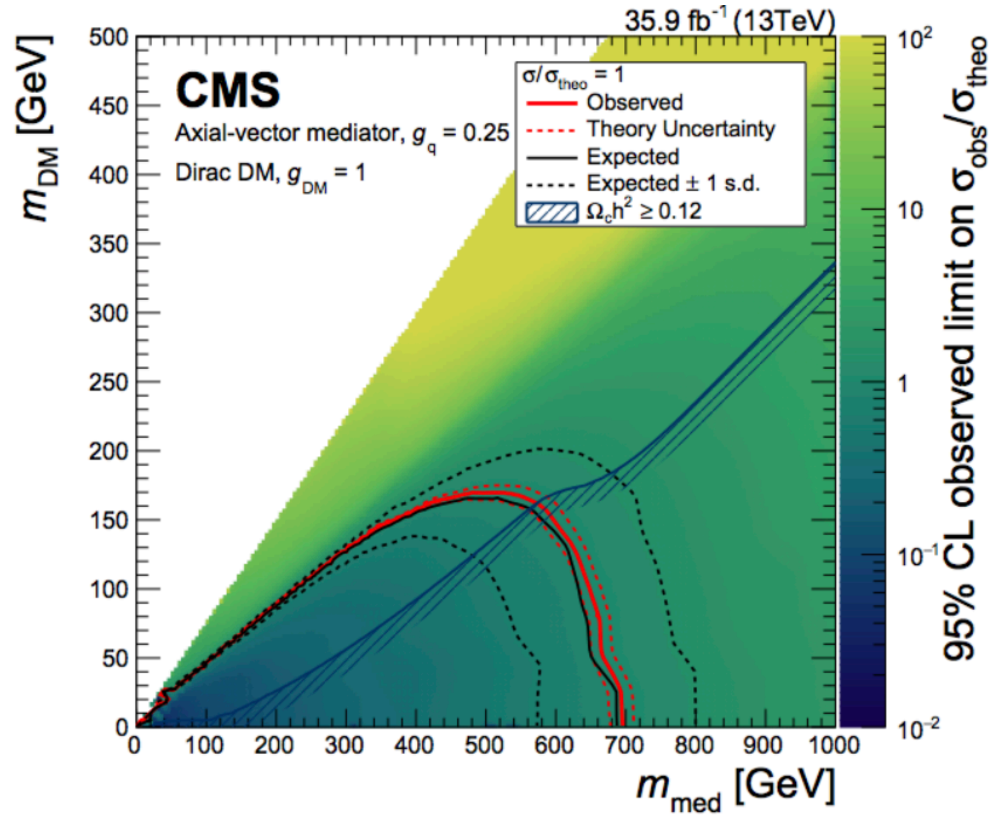
- Main backgrounds WZ,ZZ from CR in data for three and four leptons
- Non resonance Background from e- μ enriched data sample

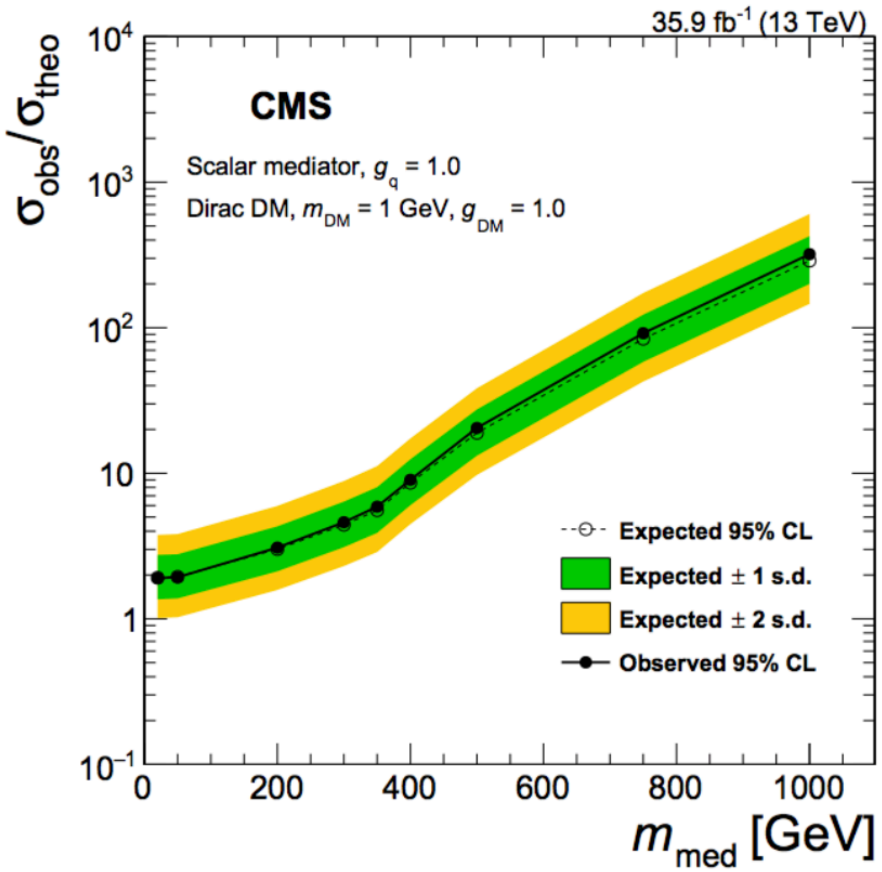
arXiv:1711.00431

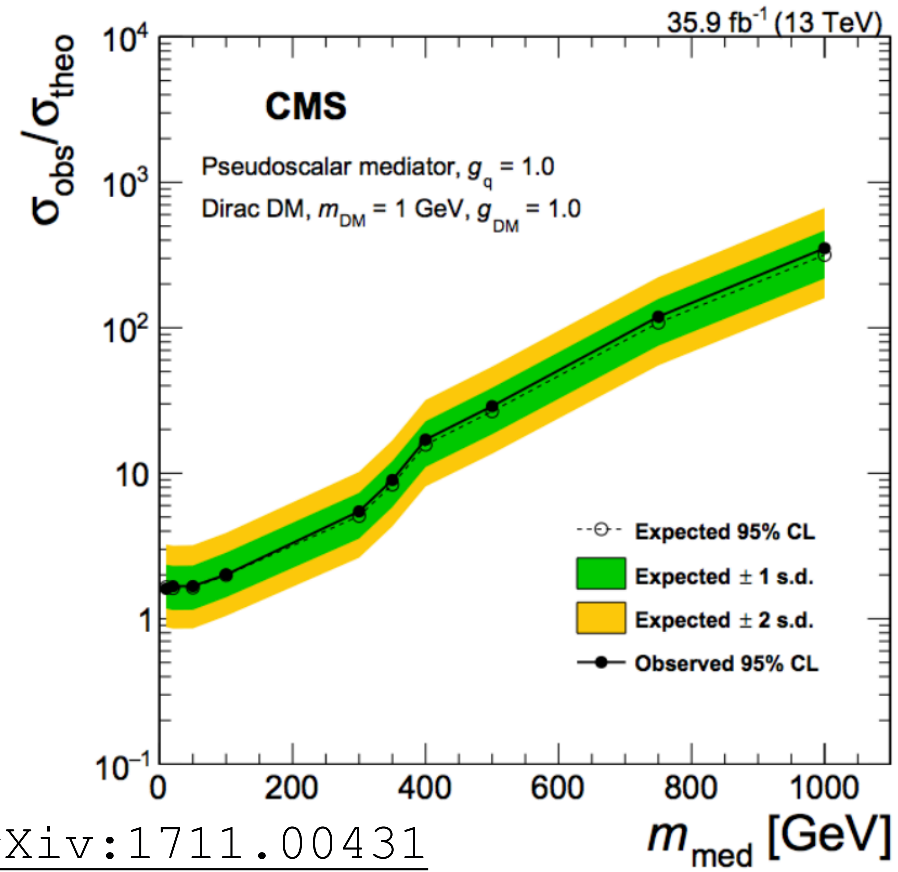
Dark Matter + Z(ll): Results

- Limits evaluated for **vector, axial vector, scalar and pseudo-scalar mediators**



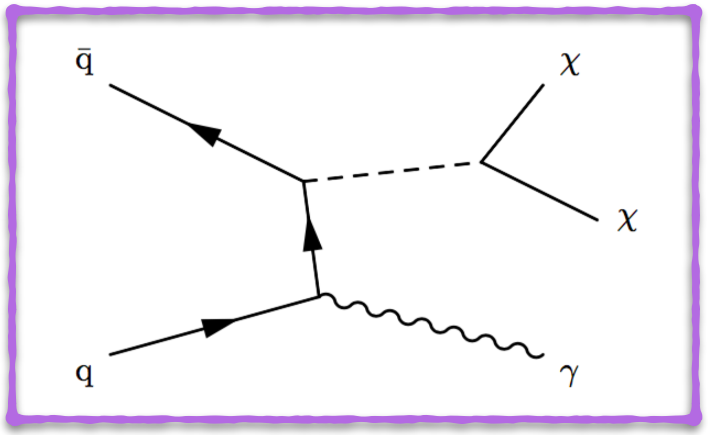




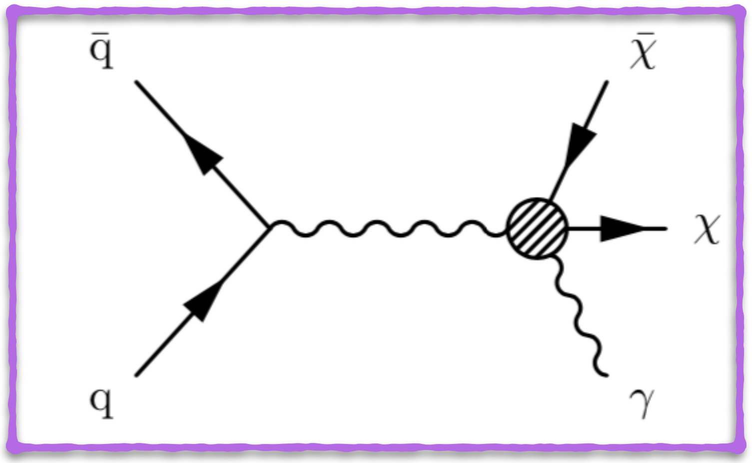


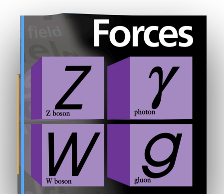
arXiv:1711.00431

Dark Matter + Photon

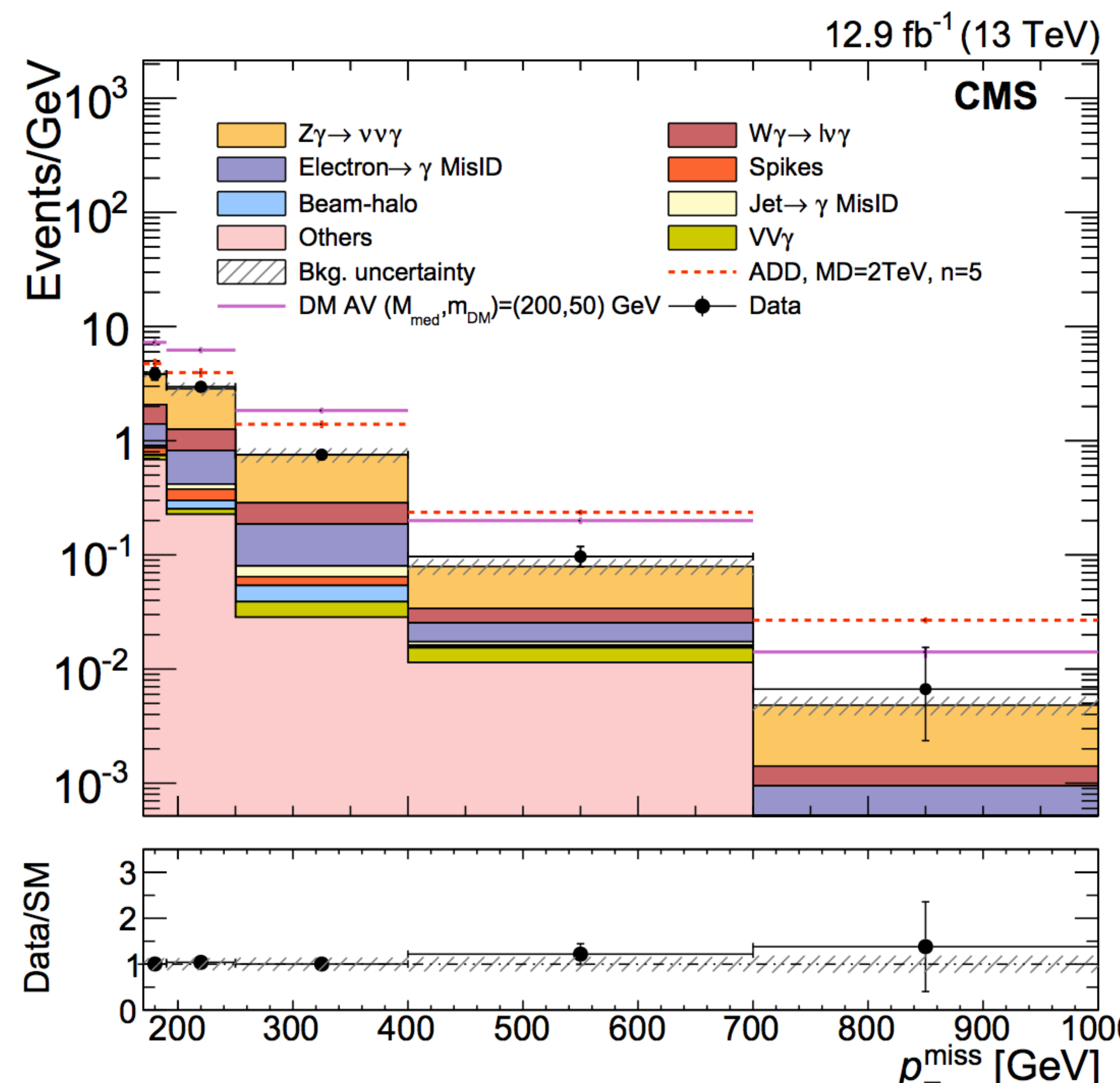


Mono-Photon





- Well identified γ $p_T > 175$ GeV
- $E_T^{miss} > 170$ GeV
- $\Delta\phi(\gamma, E_T^{miss}) > 0.4$
- Lepton veto



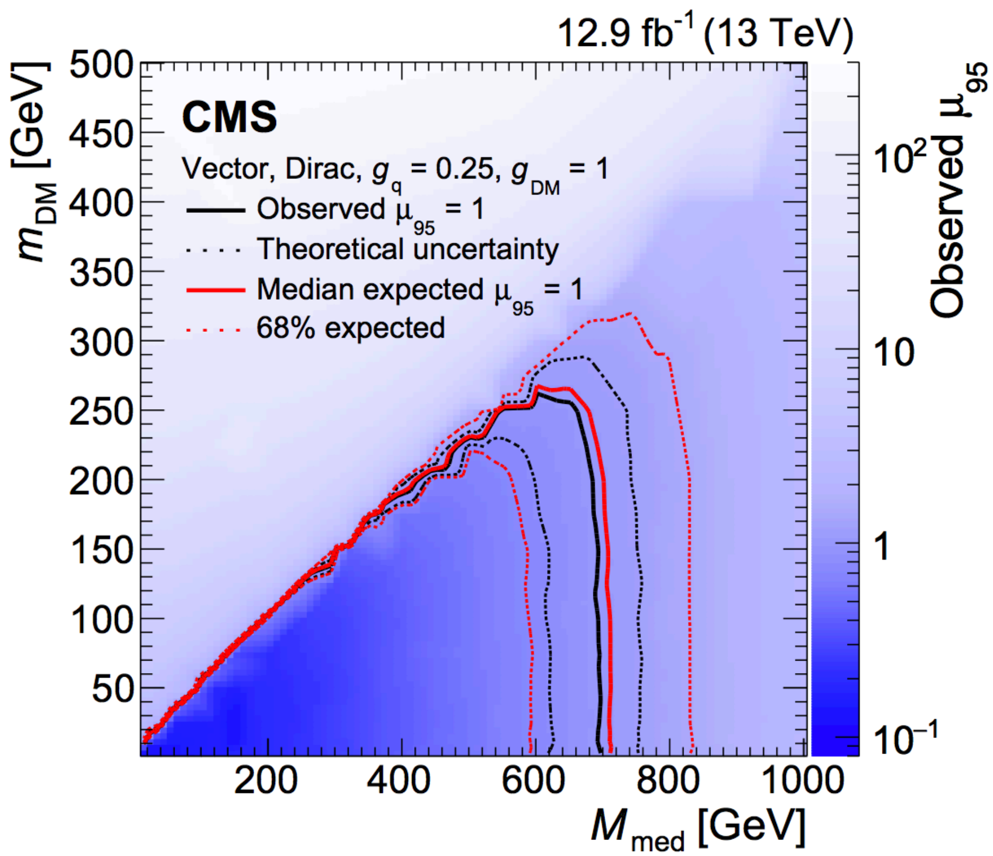
- Major background $Z(\to\nu\nu) + \gamma$ (55%) **and** $W(l\nu) + \gamma$ (15%) from **CR**

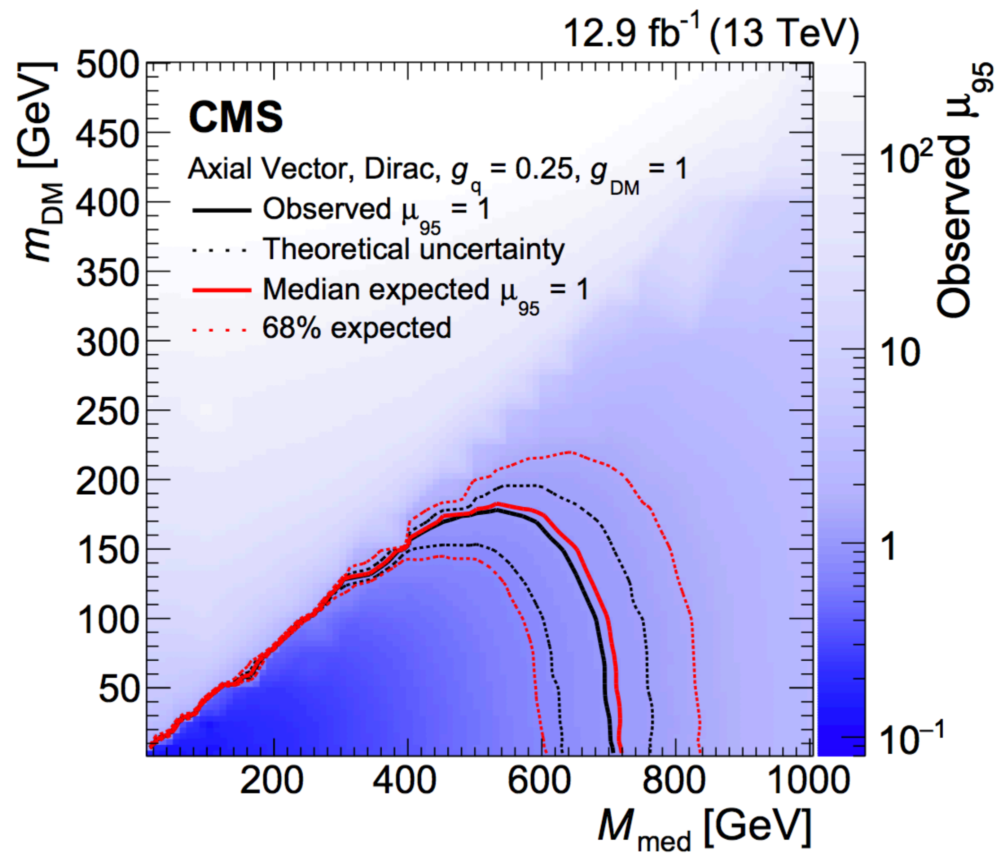
- Data driven background estimation for QCD multijet, electron-photon fake rate and non collision background: beam halo & spikes

arXiv:1706.03794

Dark Matter + Photon:Results

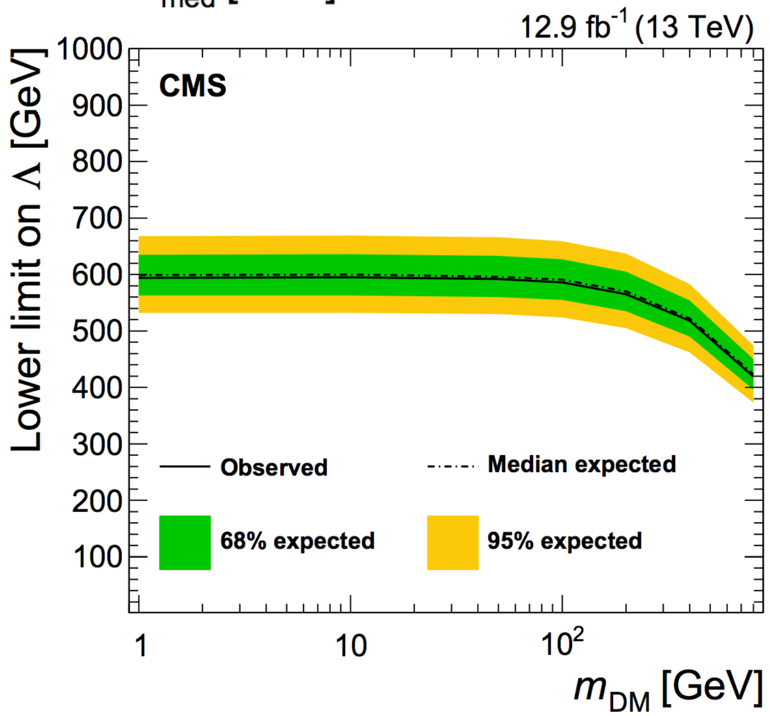
- No excess is observed in this final state
- **Mediator mass up to 700 GeV** excluded for vector, axial vector mediators





- **A dimension 7 EFT benchmark** with direct couplings between DM and electroweak bosons

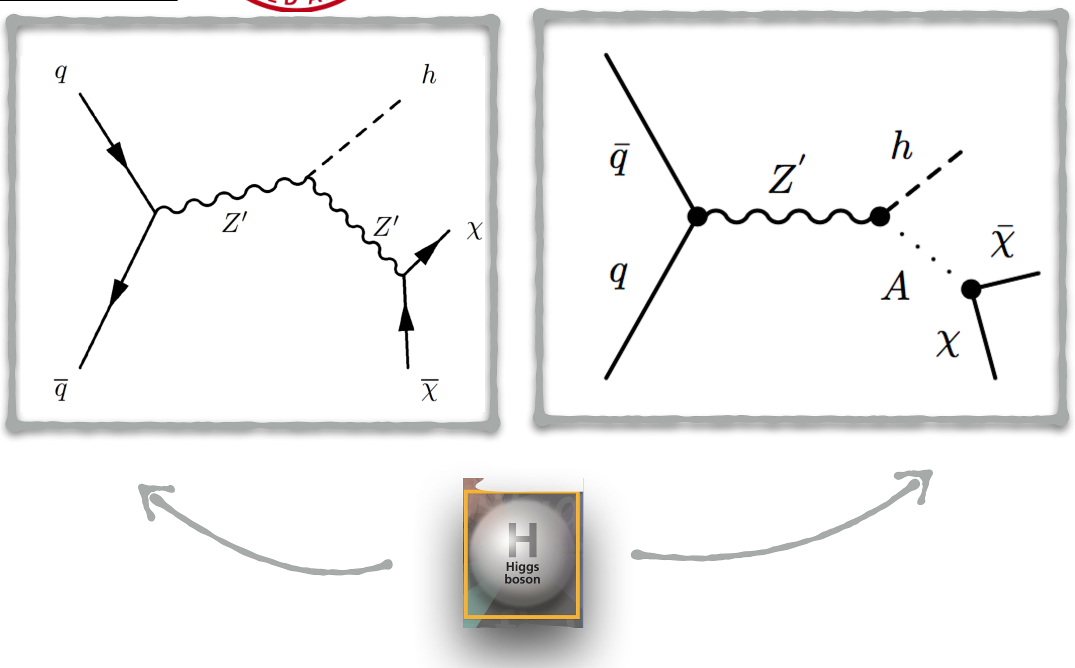
- **ADD model of LED**:stable gravitons invisible to the detector in association with a photon:excluded **M_D< 2.44 TeV for n=3**



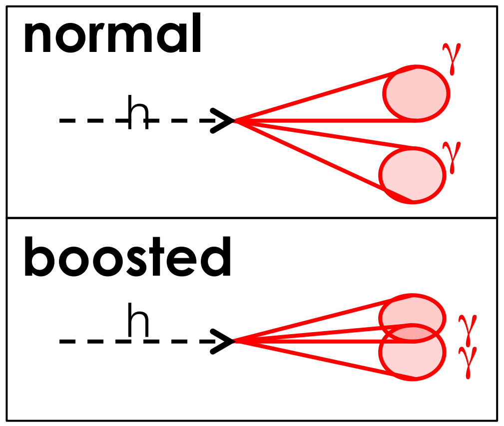
Livia Soffi - 12/18/2017

arXiv:1706.03794

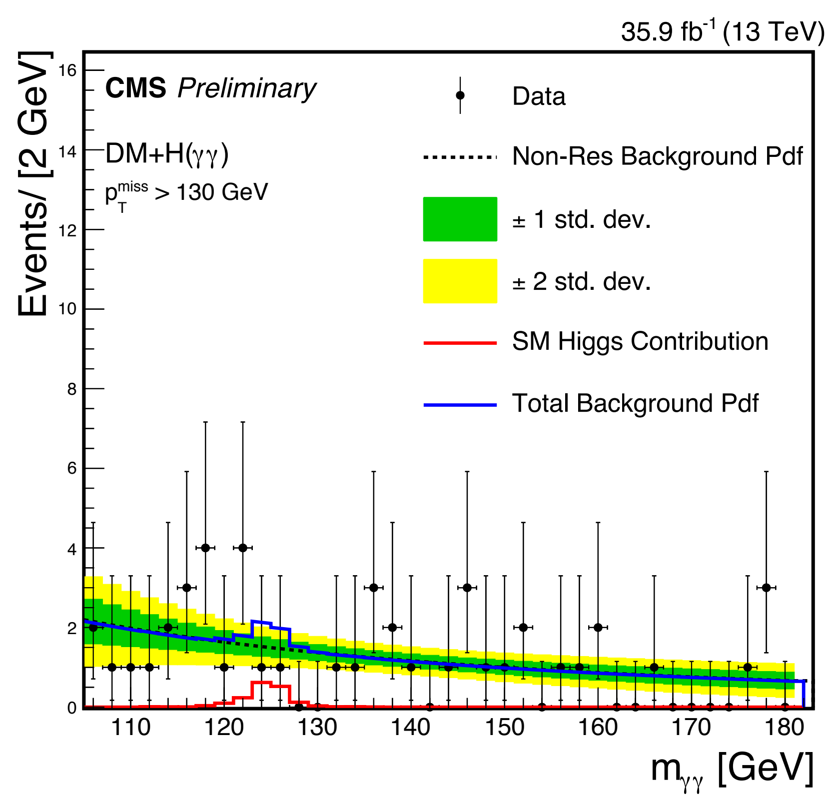
Dark Matter + Higgs(γγ)

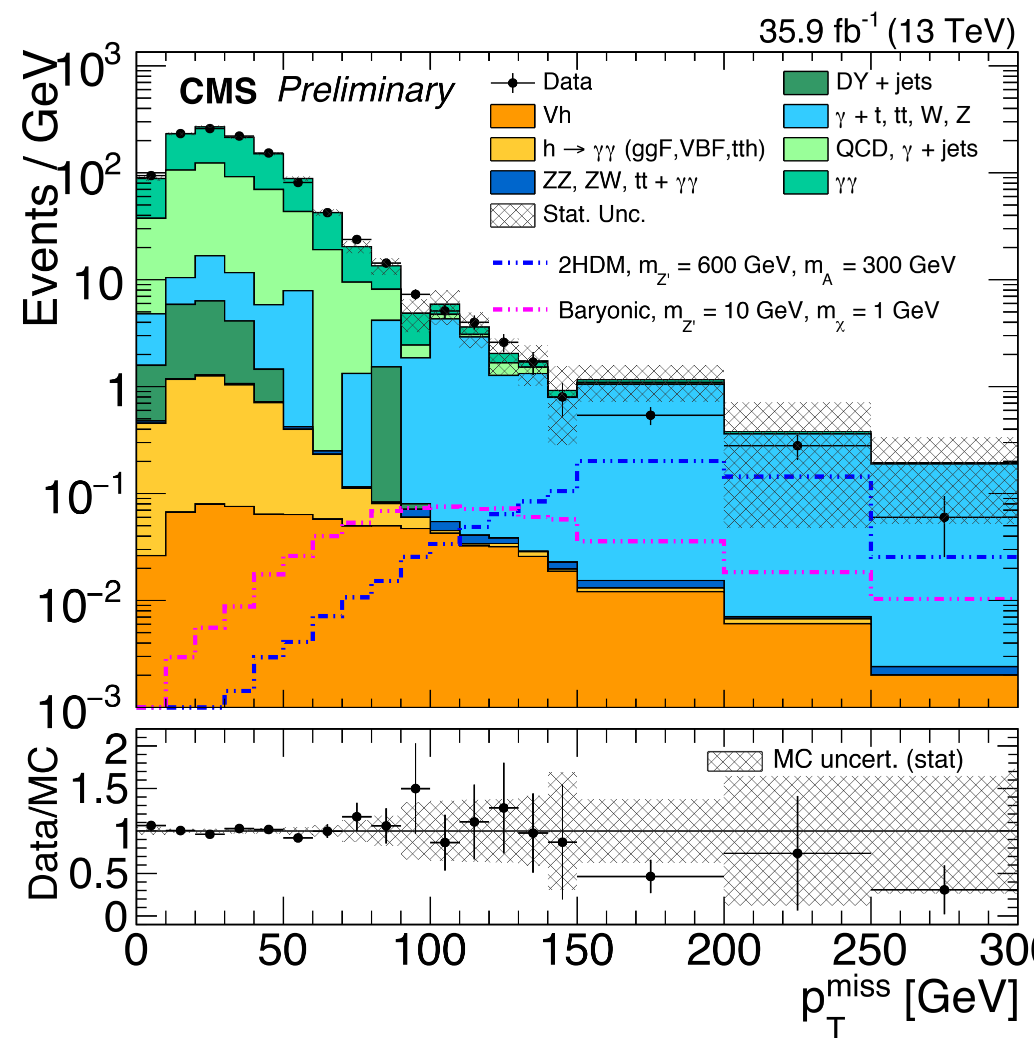


- Similar analysis as SM H→γγ bump hunt search
  - **Improved photon-id for high Z' mass**



- Background estimated using **fit to data**
- Simultaneous fit in two MET categories: 50-130 GeV, >130 GeV

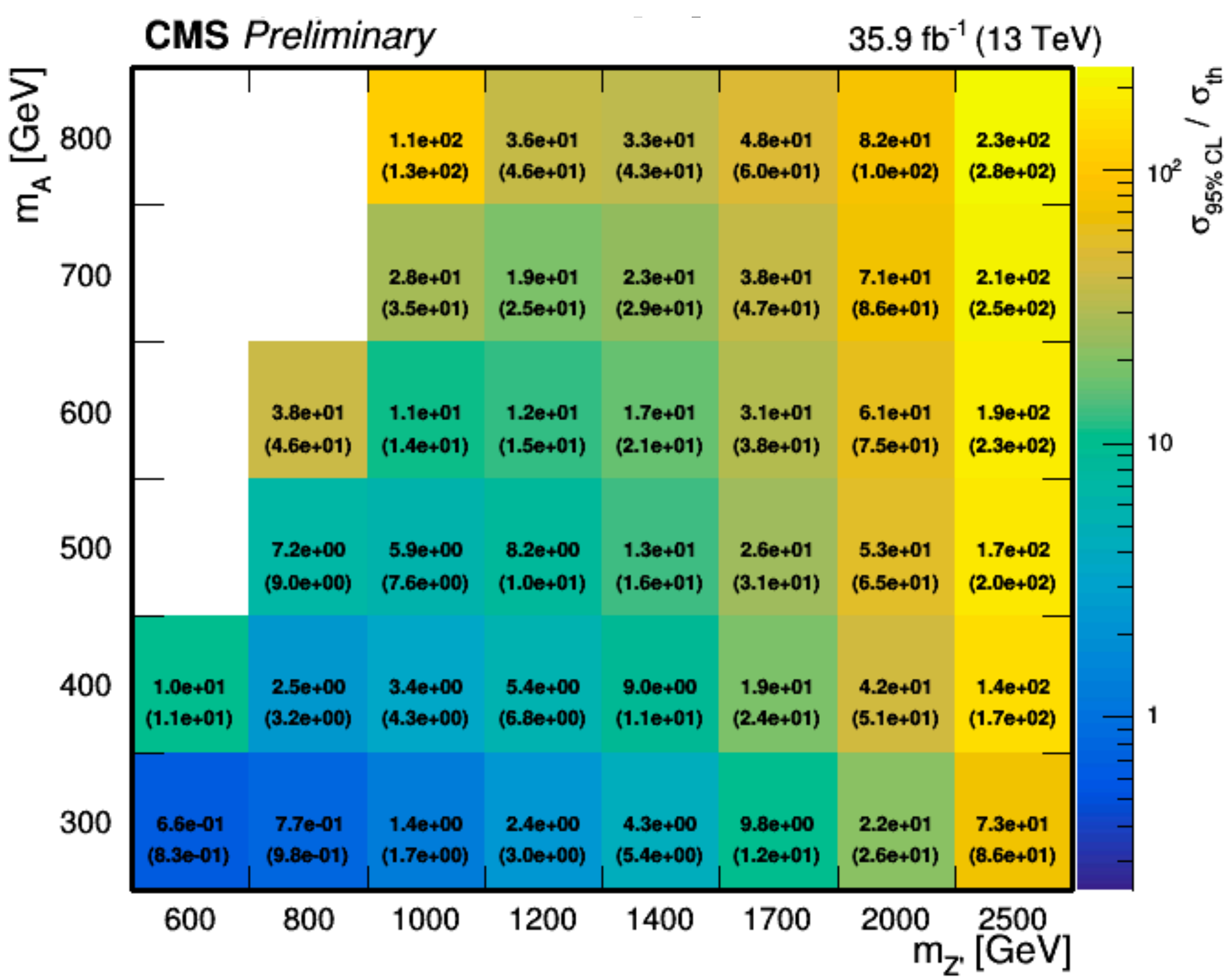




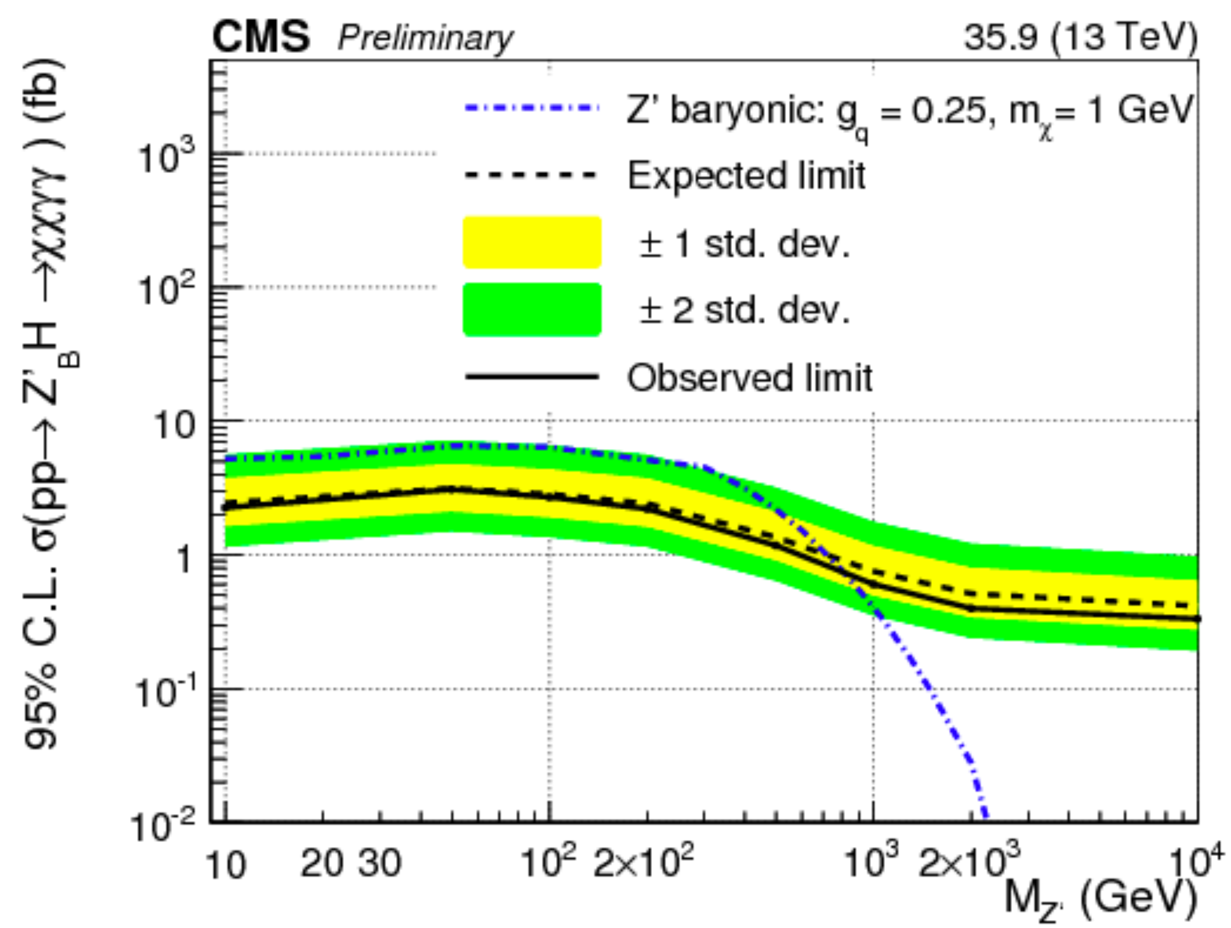
- **SM Higgs production** irreducible **background**

Dark Matter + Higgs: Results

- Results interpreted in term of two simplified models:



Z' baryonic model



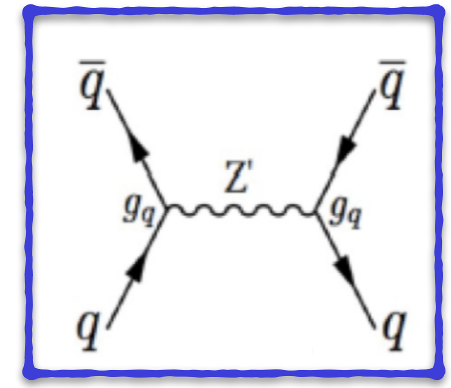
- Excluded $M_{Z'}$ **<900GeV** when m_{DM} = 100 GeV, g_Z =0.8 and m_A = 300 GeV
- Excluded $M_{Z'}$ **< 800 GeV** when m_{DM} = 1 GeV, g_q = 0.25

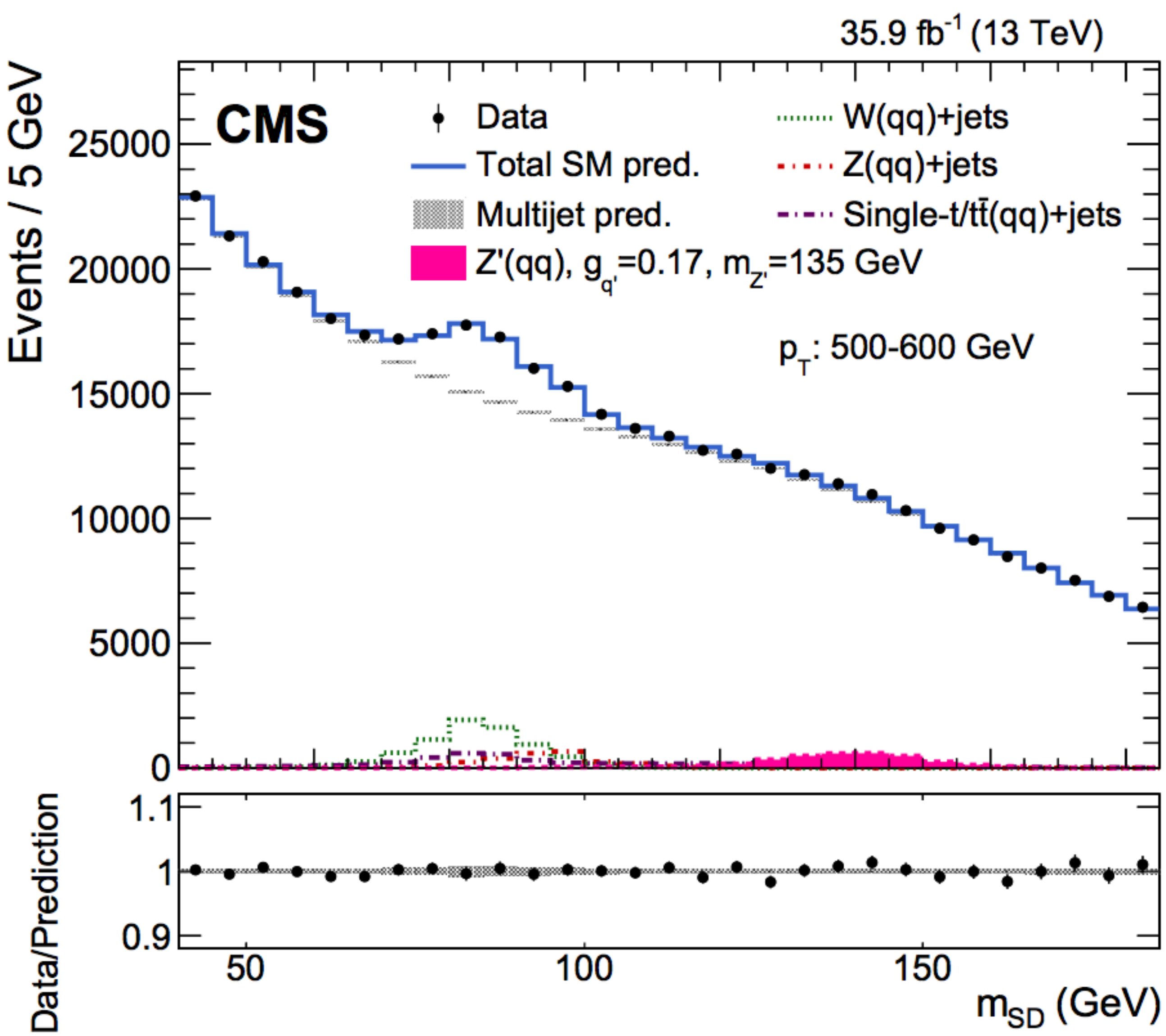
Early Paper on combined DM +Higgs (gg+bb) w/ 2015

JHEP 10 (2017) 180

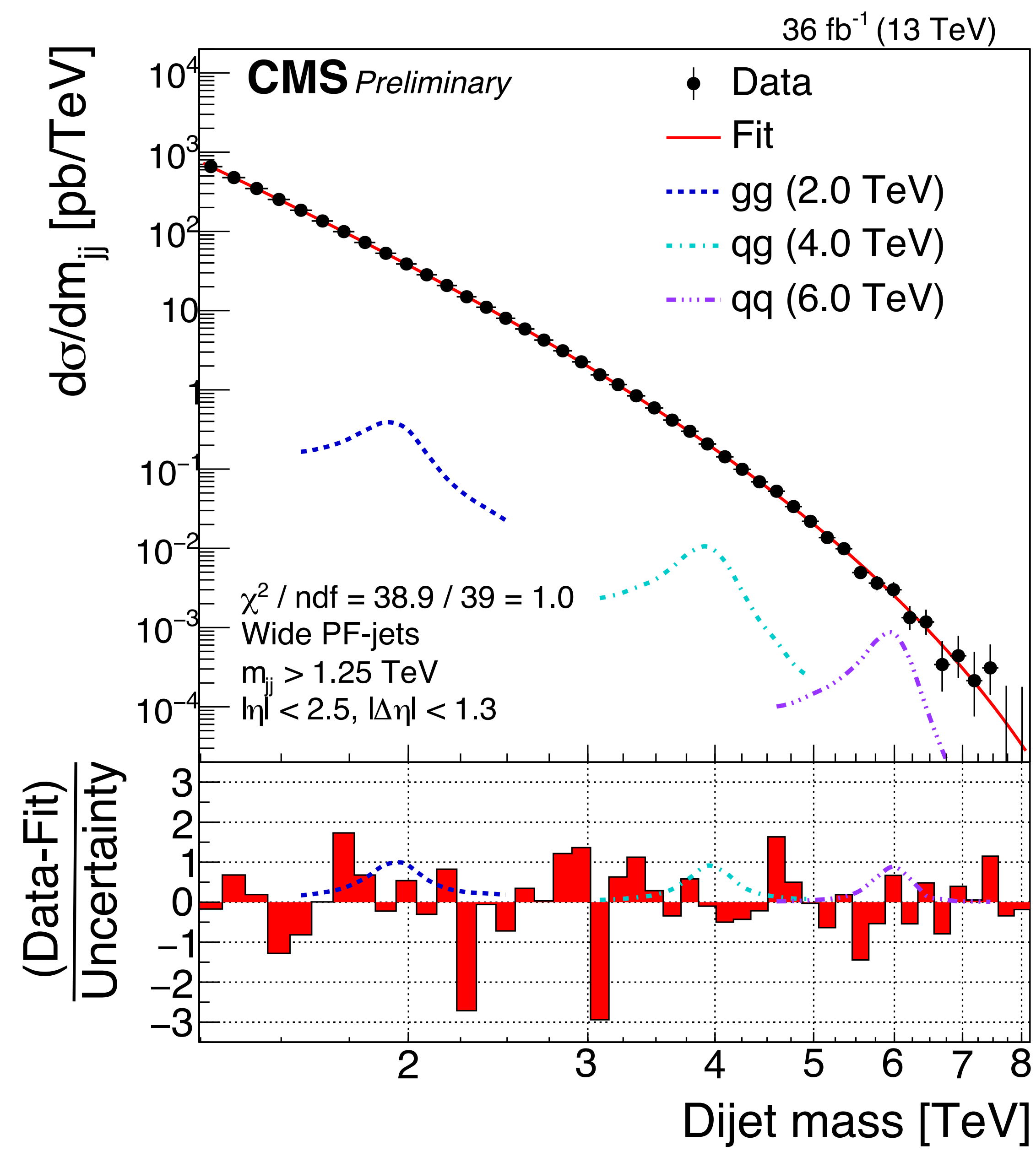
MET-less Dark Matter Searches: Dijet

- **Complementary information** from visible decays of the mediator
- Look for a bump in **dijet invariant mass spectrum**





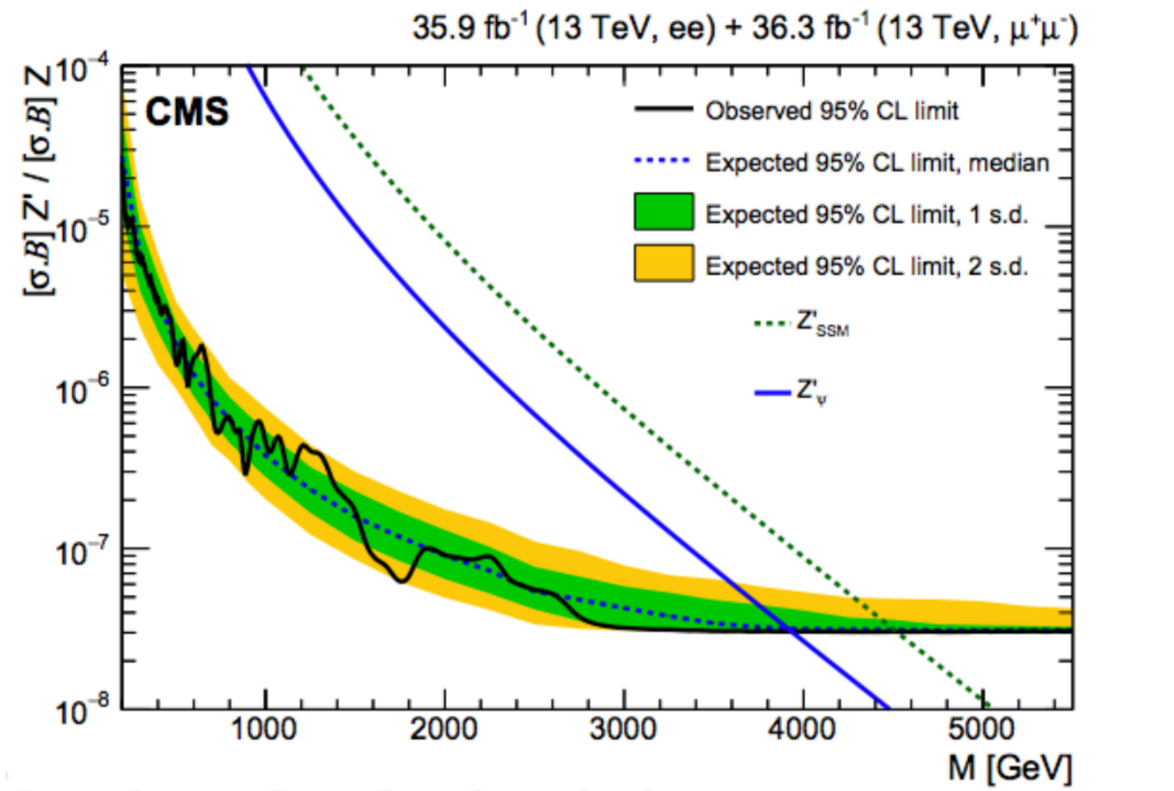
Boosted DiJet + ISR jet

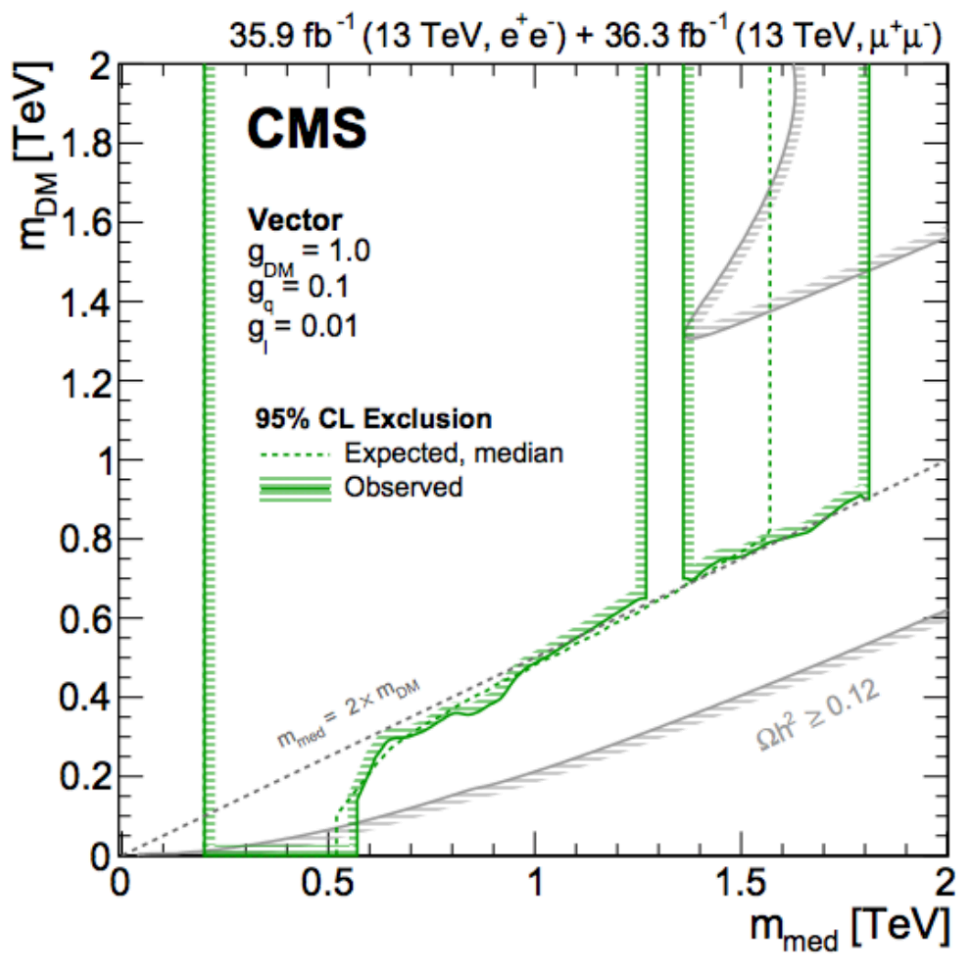


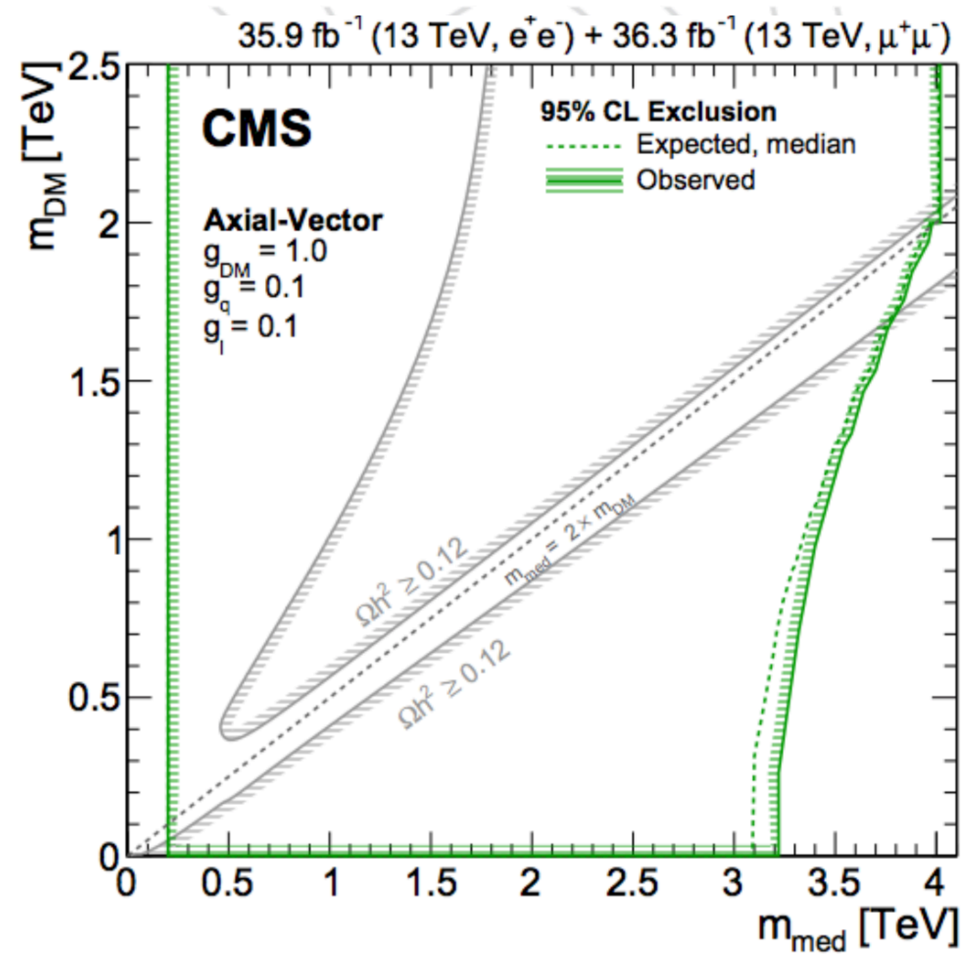
Data Scouting

MET-less DM Searches: Dilepton

- Dark sector particles w/ **sizable interactions with SM fermions**
- Probe phase space regions where mediator cannot decay to the dark sector and the **leptonic BR becomes sizable.**

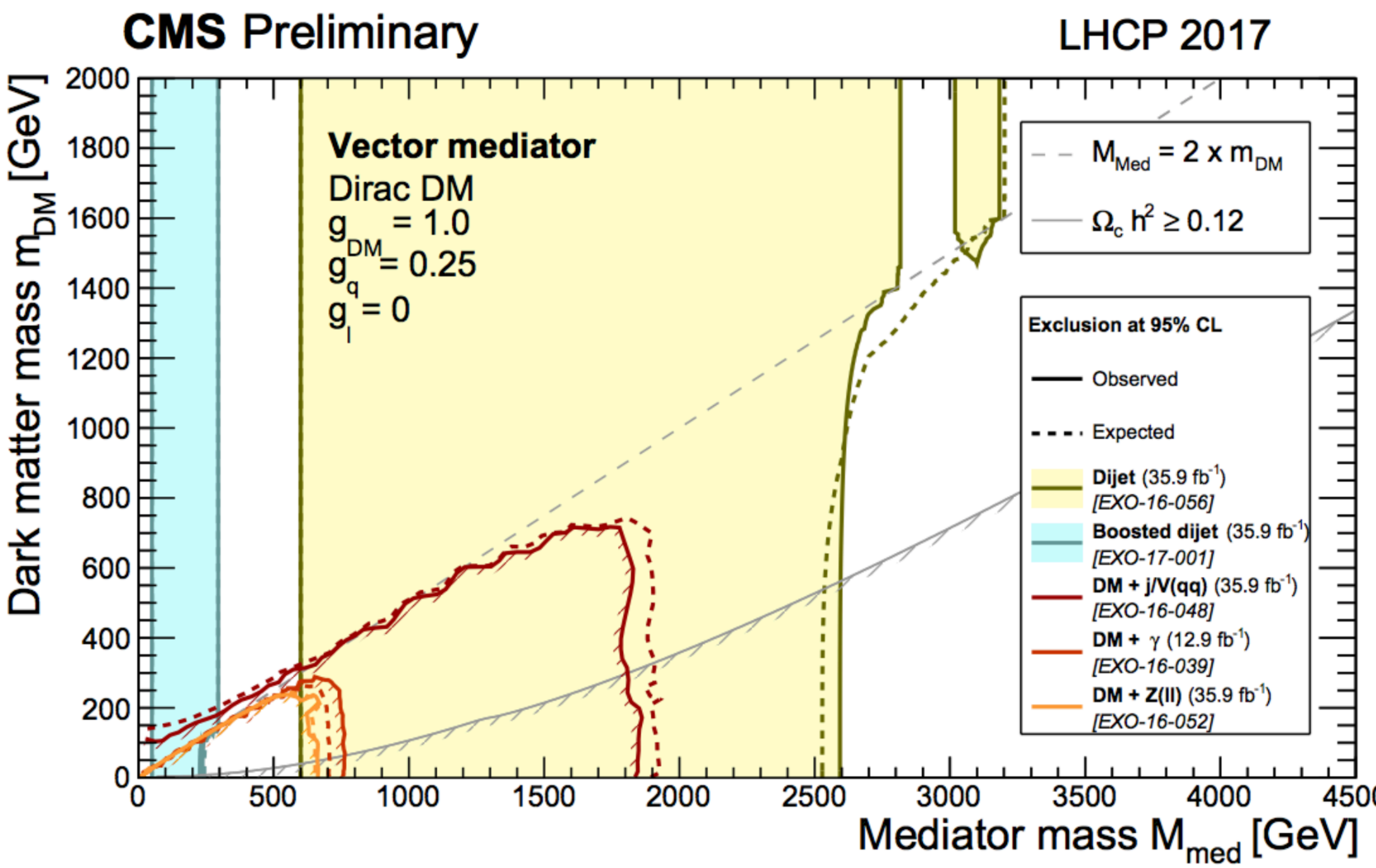




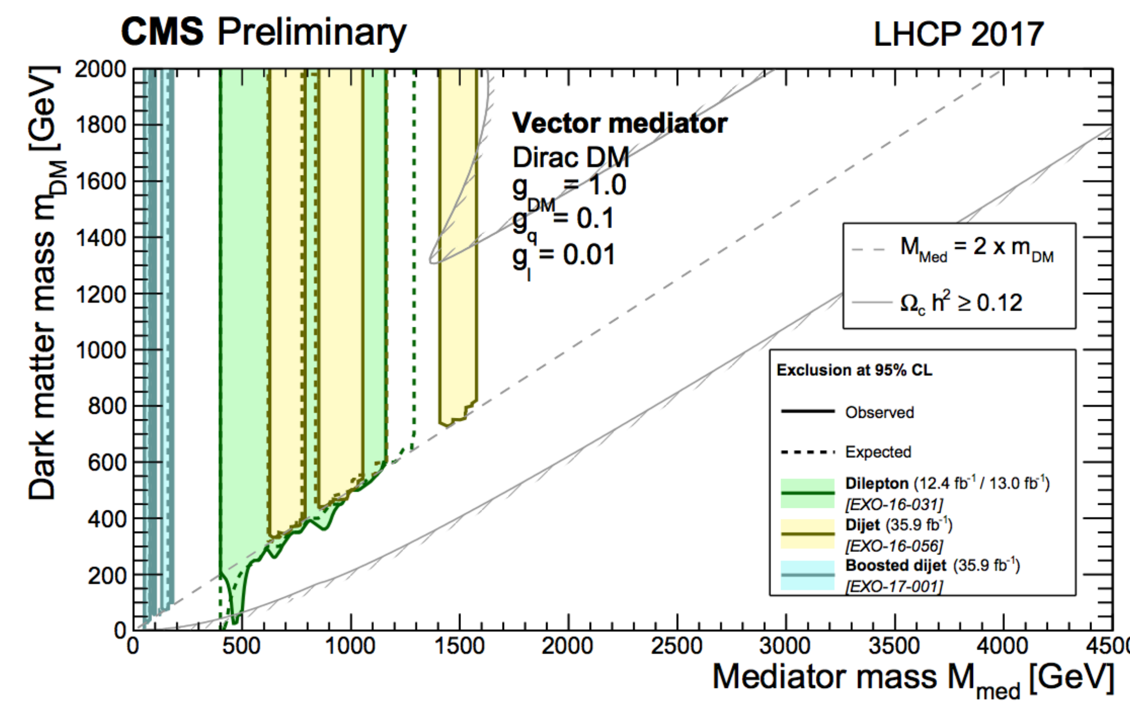


The Full Picture

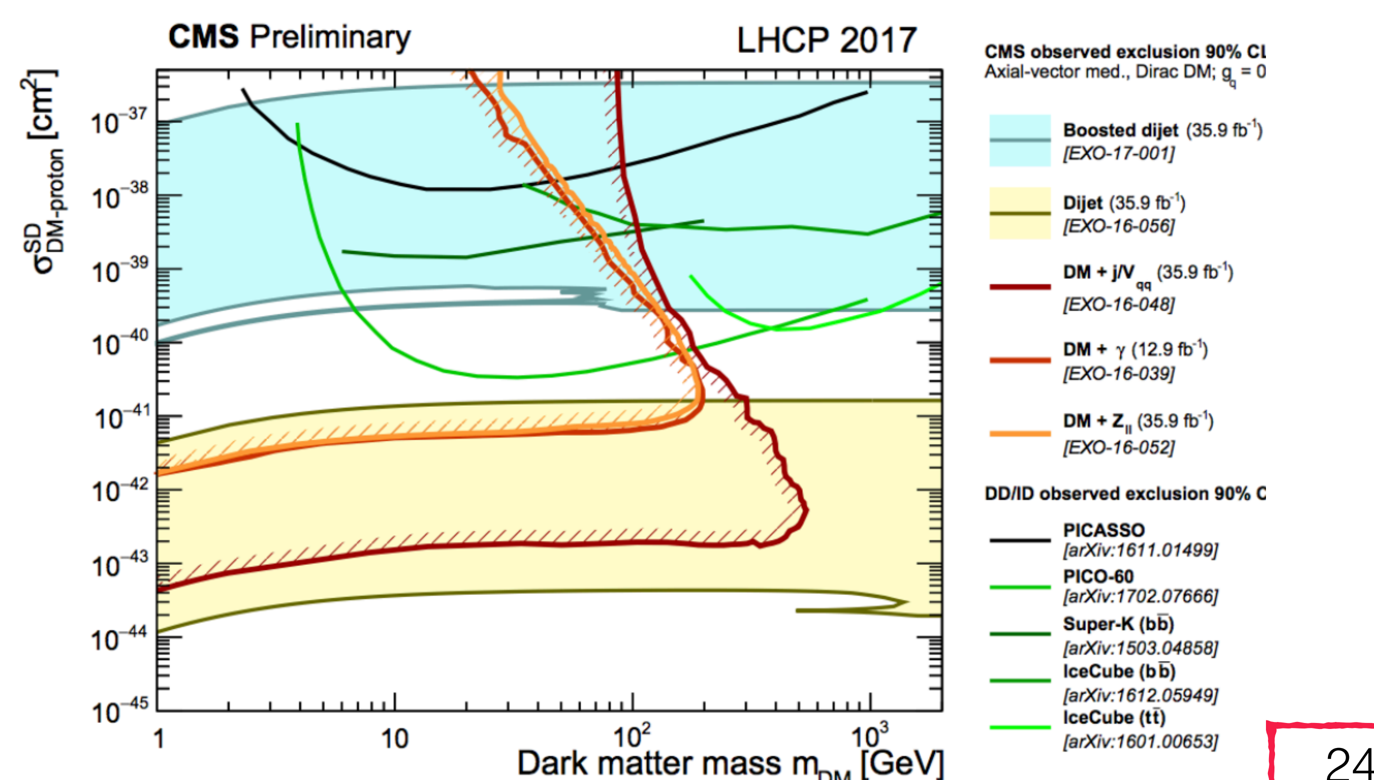
- 95% CL exclusion region on **DM mass -Mediator mass plane**



Excluded region strongly depend on couplings

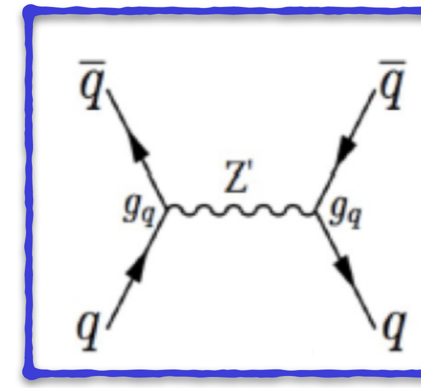


- Limit on Mediator - DM mass plane converted to **DM- nucleon cross section**
- **LHC limits are more stringent in lower DM masses and for spin dependent cross sections**



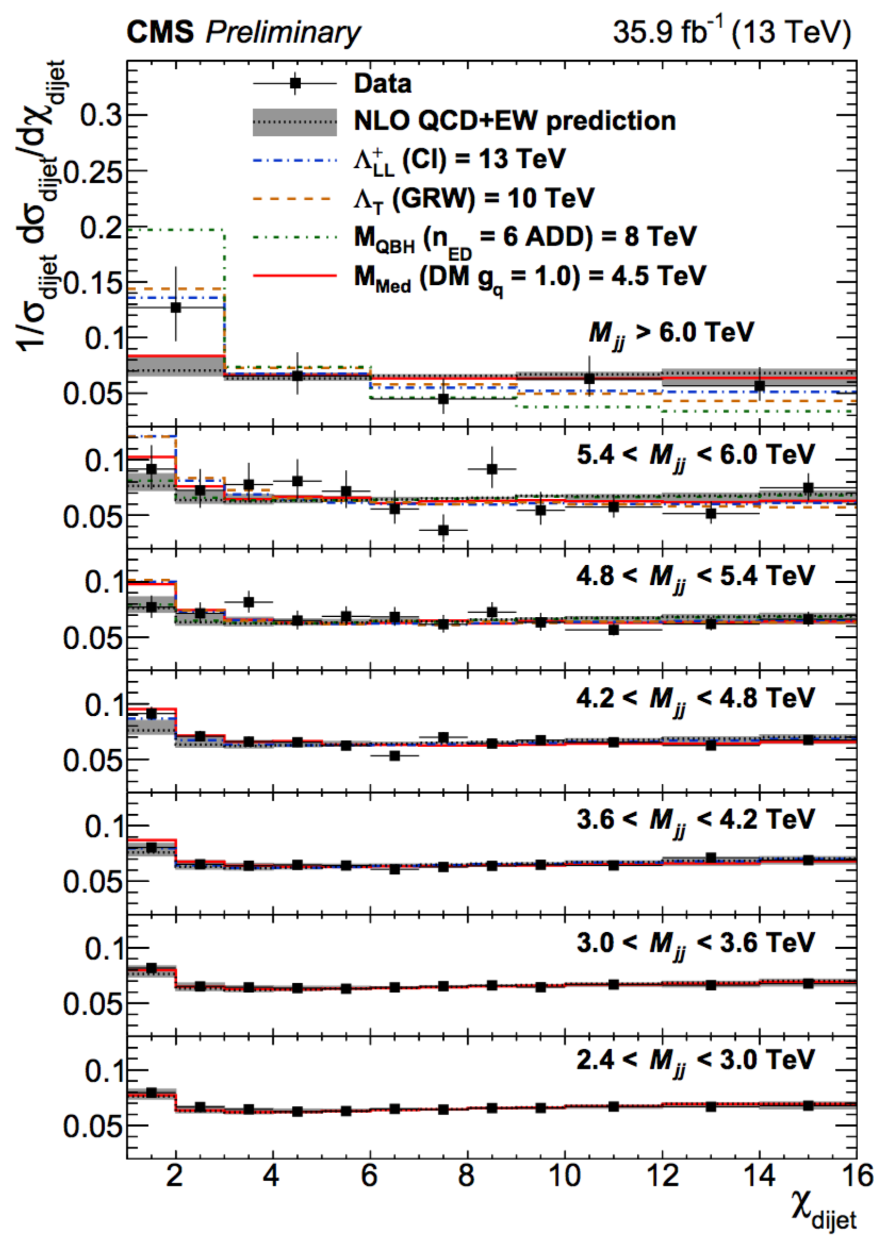
MET-less DM Searches: Angular Dijet

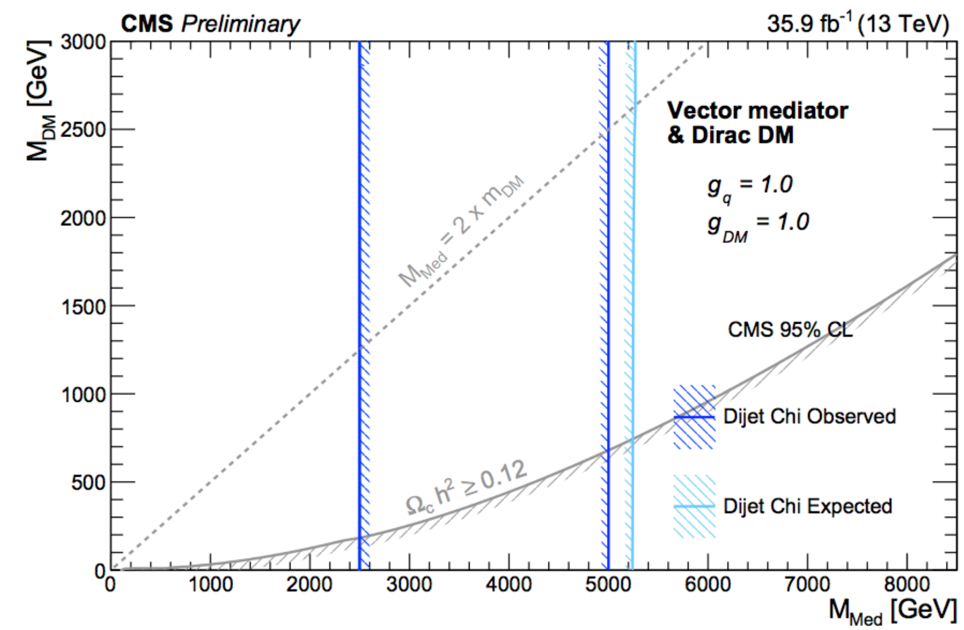
- Measurements of dijet angular distributions
- Promising strategy to constrain **wide mediators or non-resonant signatures**

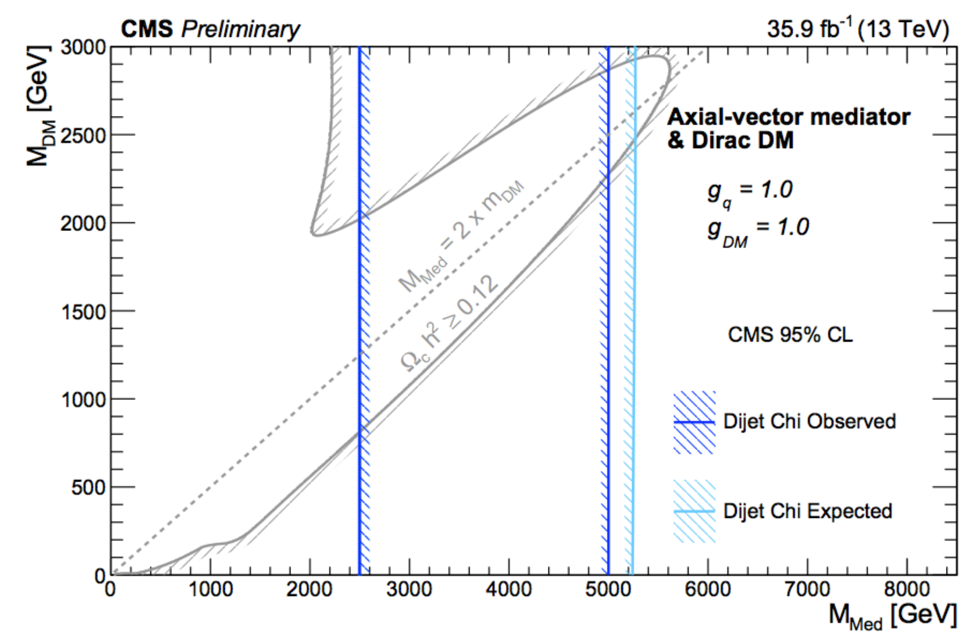


- $\chi_{dijet} = \exp(|(y1 - y2)|)$

- NP have a different angular distribution and can produce an **excess at small values of χ_{dijet}**





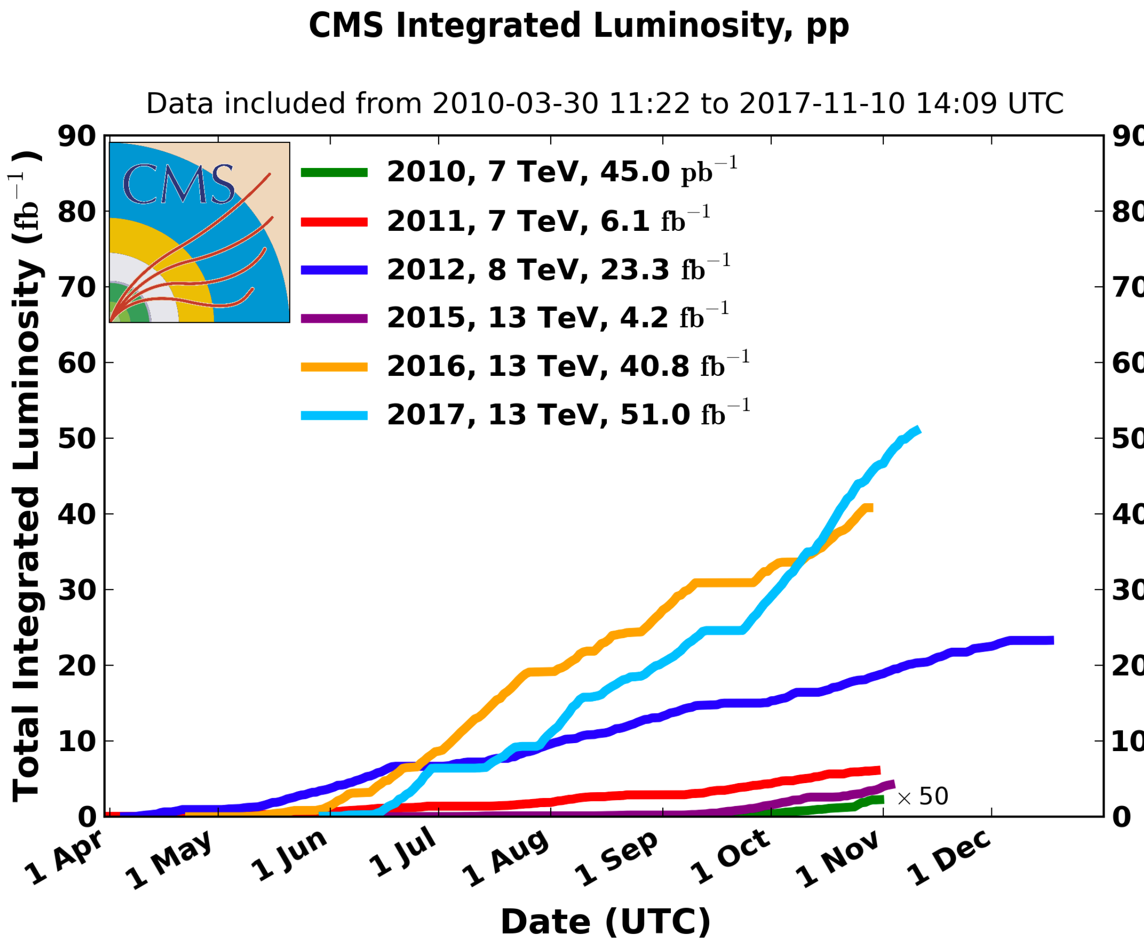


- Predictions of QCD at NLO (NLOJET++ 4.1.3) in FASTNLO 2.1 w/ EW corrections (1% -5% at small and large values of M_{jj})
- μ_f and μ_r set to the average p_T of the two jets

Conclusions

- **Very successful 2015-2016 DM search program at CMS**
- Exploiting advanced **analysis techniques** and **background estimation** methods:
  - Stringent bounds are put on **parameter space using simplified models for DM**
  - **Di-jet/Di-lepton/tt+MET BSM** results re-interpretation

- Working closely with theorists to develop new models: **LHC DM working group**
- No evidence of DM yet but parameter space not fully explored
  - e.g., **long lived signatures**
- **Great expectations for 2017**: +45 fb^{-1} of data ready to be analyzed

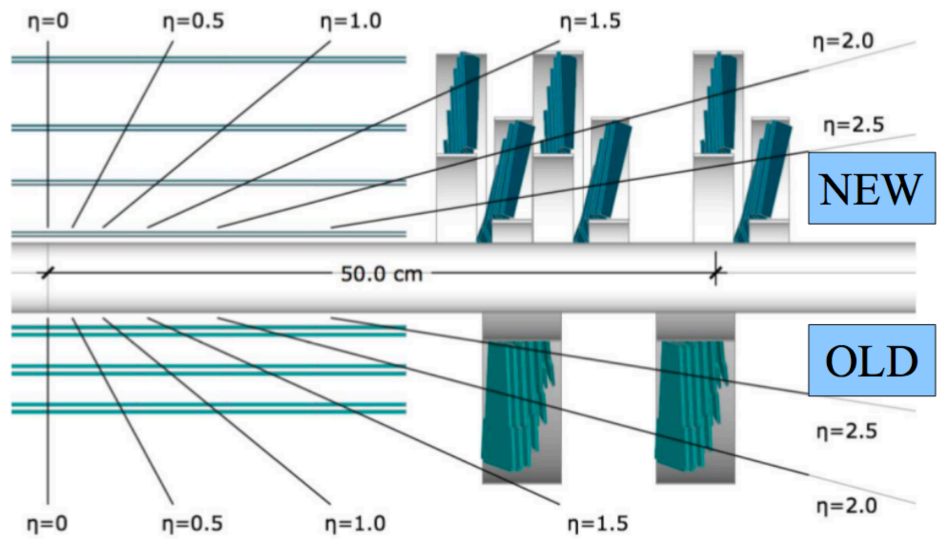


Backup

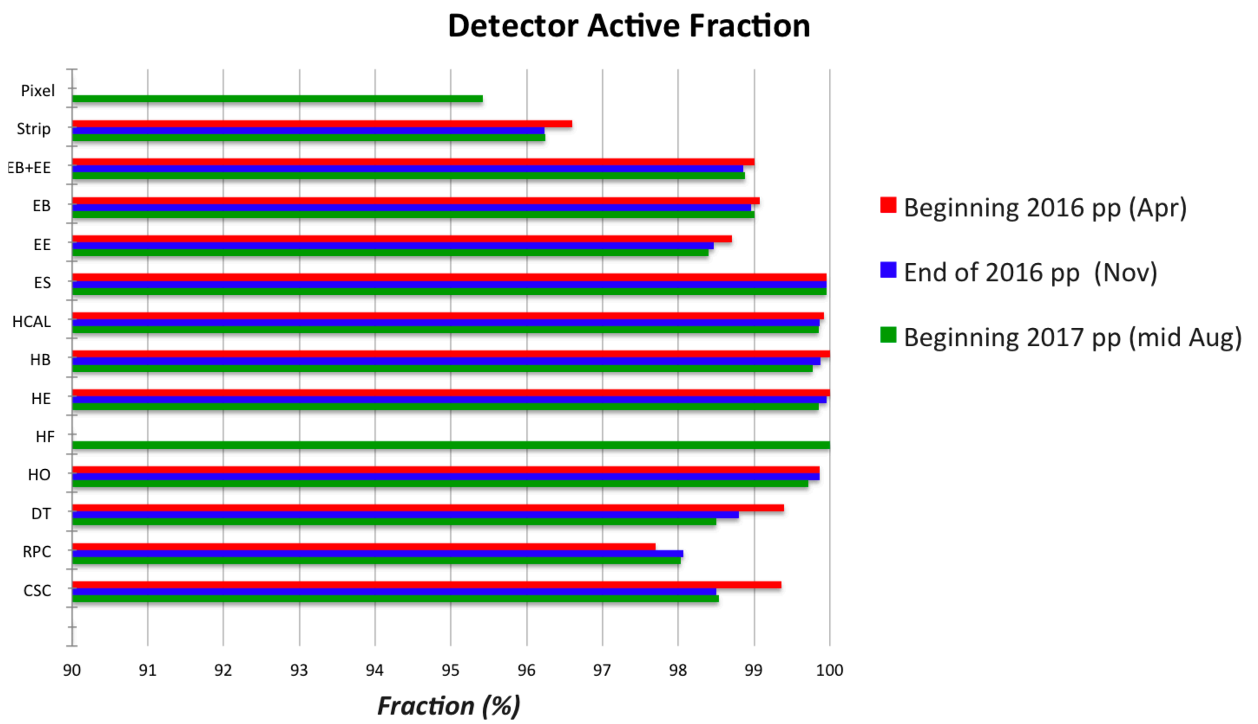
CMS Performances in Run2

- Good performance and data taking in 2016 and 2017.

- 2017: **New Pixel Detector:**
- **4 hit coverage**; 3 layers/2 disks to **4 layers / 3 disks**



- **New material budget**
- **Commissioning** work ongoing with **2017** data



CMS Detector

High sensitivity to a wide spectrum of final states

Silicon Tracker

Pixel (100 x 150 μm) - 66M channels

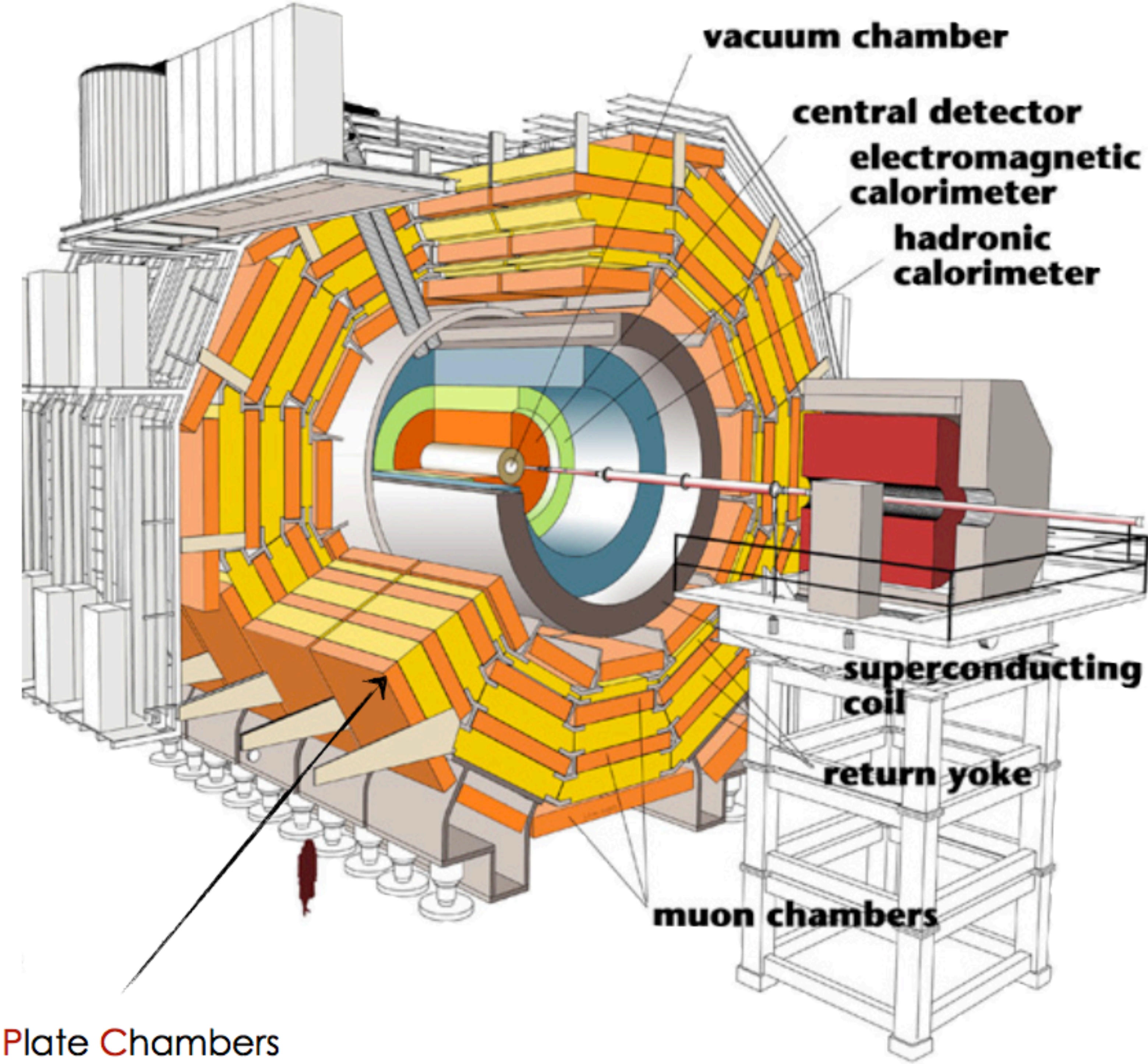
MicroStrips (80 x 180 μm) - 9.6M channels

- ✓ P_T resolution ~ 1.5% @100 GeV
- ✓ dE/dx measurement

Electromagnetic CALorimeter

76K PbWO4 crystals

- ✓ Designed energy resolution ~0.5% for E(γ) > 100 GeV
- ✓ Fast scintillation scale: > 80% of the light emitted in ~ 25 ns



Brass/Scintillator Hadron Calorimeter

Muon Chambers

Drift Tube - Cathode Strips Chambers - Resistive Plate Chambers

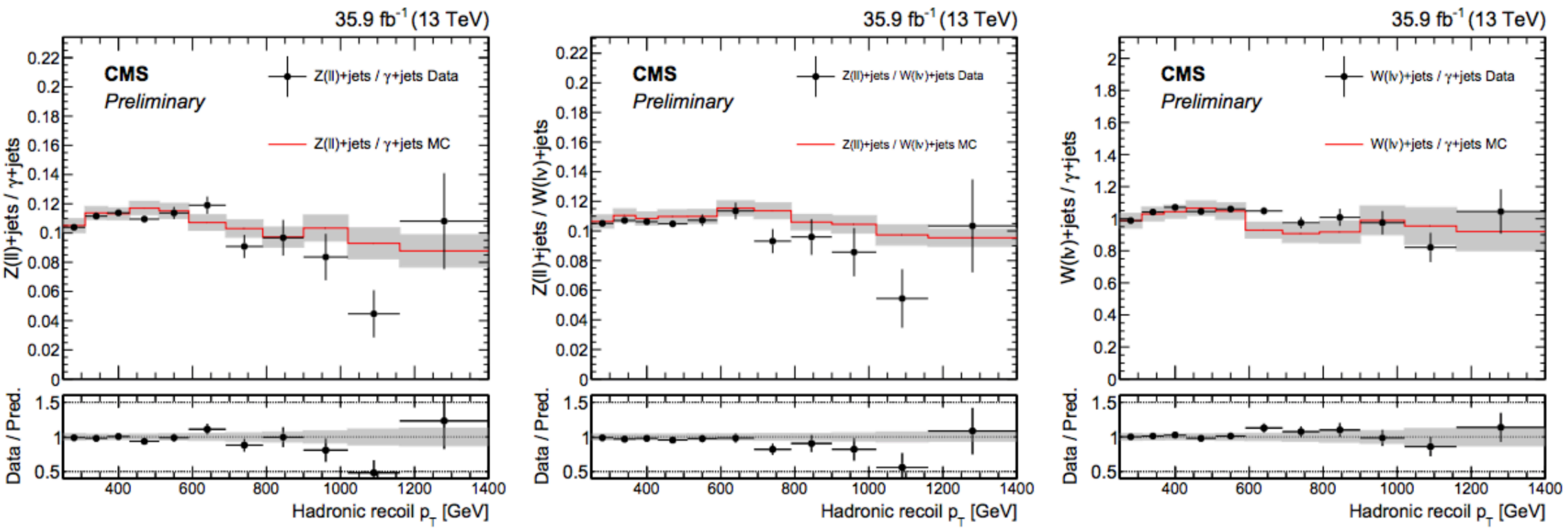
- ✓ Single-point resolution ~ 200 μm
- ✓ σ_{DT} ~ 3ns
- ✓ σ_{CSC} ~ 7ns

- MET also sensitive to overlapping detector signals from additional interactions, particle misidentification, detector malfunctions.

- Detailed understanding of these effects is important for maintaining an optimal MET performance-> studied in data
  - **spurious deposits** due to particles striking **sensors in the ECAL** photodetectors,
  - **real showers with non-collision origins** caused by beam halo particles
  - **ECAL dead cells**
  - **direct particle interactions with the light guides and photomultiplier** tubes of the forward calorimeter.
  - **Minimum energy thresholds in the calorimeters, inefficiencies in the tracker**
  - **Nonlinearity** of the response of the calorimeter for hadronic particles
  - **Machine-induced backgrounds**, especially the production of muons when beam protons undergo collisions upstream
  - **interactions in the cathode strip chambers (CSCs)**, a subdetector with good reconstruction performance for both collision and non-collision muons, will often line up with the deposit.

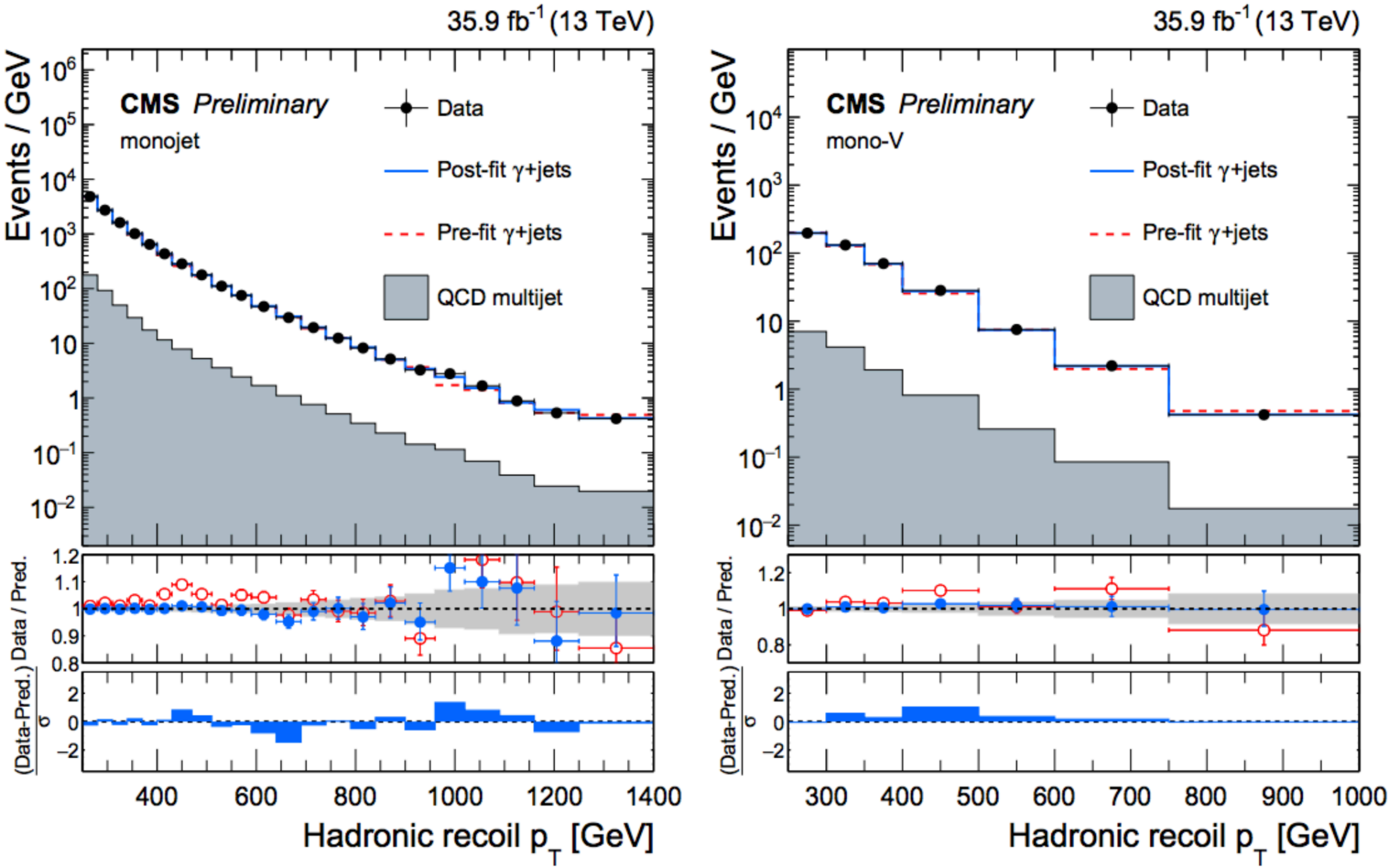
Mono-Jet @ CMS

Mono-Jet @ CMS

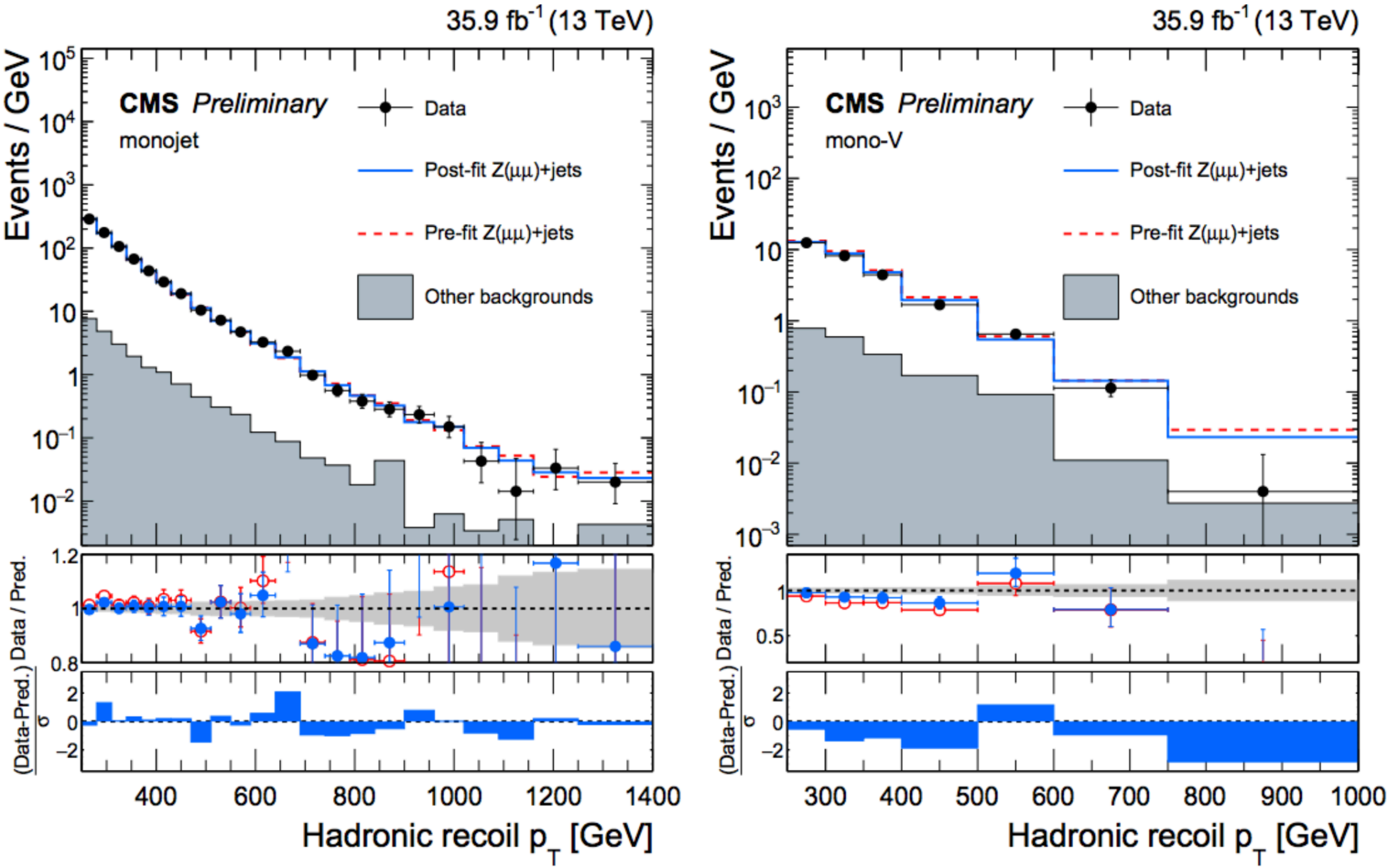


35.9 fb^{-1} (13 TeV)
CMS
Preliminary
Z(ll)+jets / γ+jets Data
Z(ll)+jets / γ+jets MC
Z(ll)+jets / γ+jets
Data / Pred.
Hadronic recoil p_T [GeV]
35.9 fb^{-1} (13 TeV)
CMS
Preliminary
Z(ll)+jets / W(lν)+jets Data
Z(ll)+jets / W(lν)+jets MC
Z(ll)+jets / W(lν)+jets
Data / Pred.
Hadronic recoil p_T [GeV]
35.9 fb^{-1} (13 TeV)
CMS
Preliminary
W(lν)+jets / γ+jets Data
W(lν)+jets / γ+jets MC
W(lν)+jets / γ+jets
Data / Pred.
Hadronic recoil p_T [GeV]

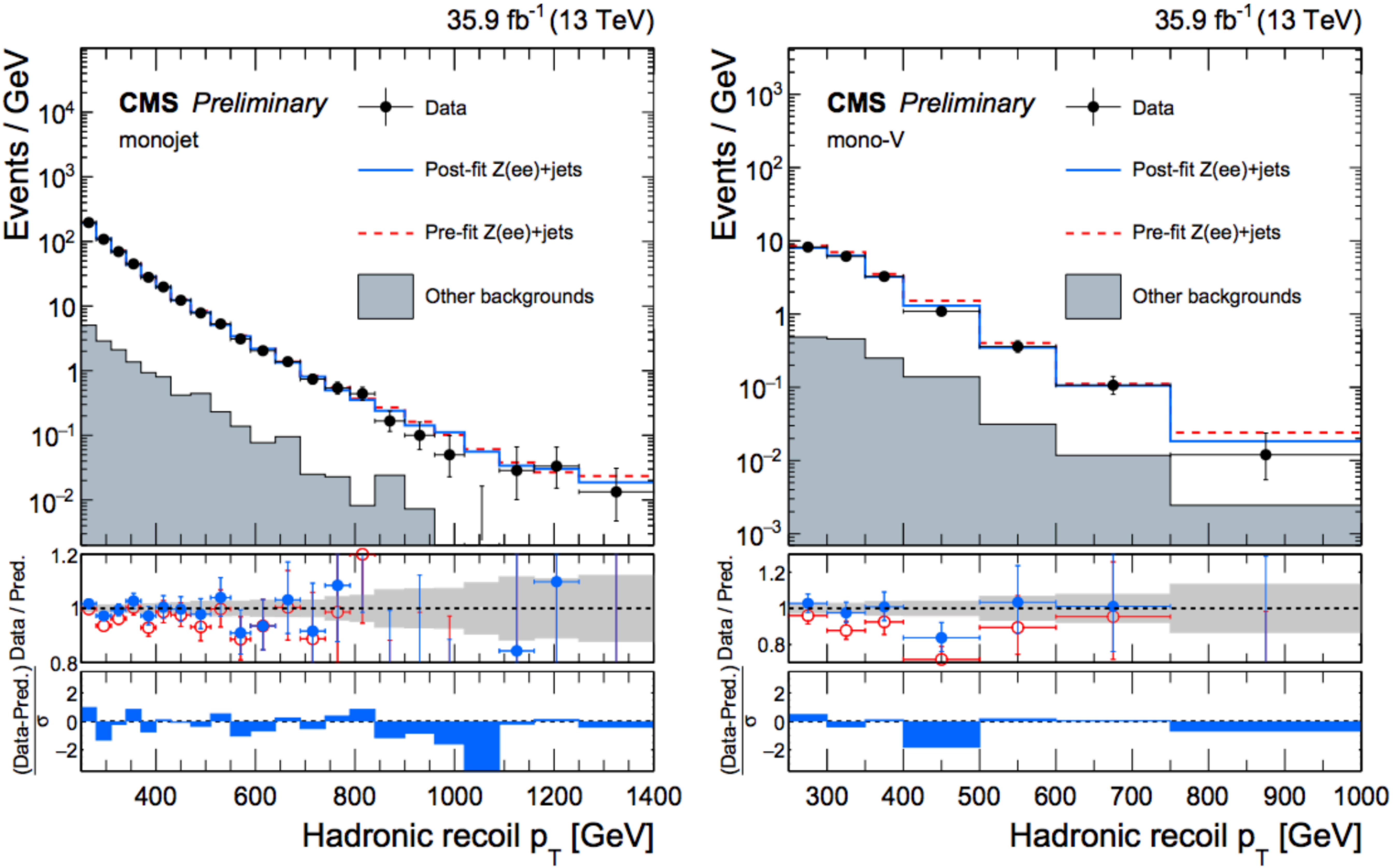
Mono-Jet @ CMS


35.9 fb^{-1} (13 TeV)
CMS Preliminary
monojet
Data
Post-fit γ+jets
Pre-fit γ+jets
QCD multijet
Events / GeV
Data / Pred.
(Data-Pred.)/σ
Hadronic recoil p_T [GeV]
35.9 fb^{-1} (13 TeV)
CMS Preliminary
mono-V
Data
Post-fit γ+jets
Pre-fit γ+jets
QCD multijet
Events / GeV
Data / Pred.
(Data-Pred.)/σ
Hadronic recoil p_T [GeV]

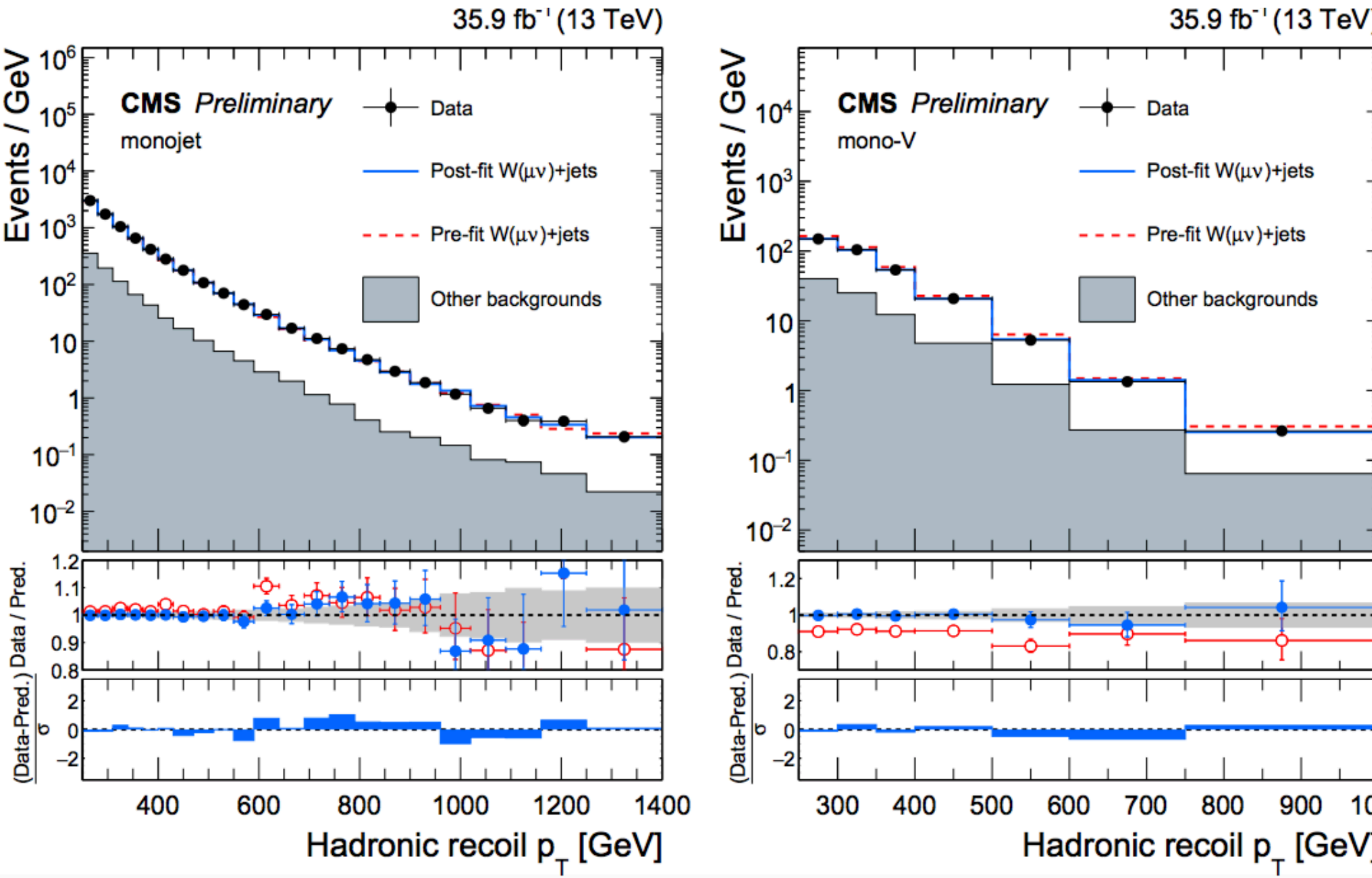
Mono-Jet @ CMS


35.9 fb^{-1} (13 TeV)
CMS Preliminary
monojet
Data
Post-fit Z(μμ)+jets
Pre-fit Z(μμ)+jets
Other backgrounds
Events / GeV
Data / Pred.
(Data-Pred.)/σ
Hadronic recoil p$_T$ [GeV]
35.9 fb^{-1} (13 TeV)
CMS Preliminary
mono-V
Data
Post-fit Z(μμ)+jets
Pre-fit Z(μμ)+jets
Other backgrounds
Events / GeV
Data / Pred.
(Data-Pred.)/σ
Hadronic recoil p$_T$ [GeV]

Mono-Jet @ CMS

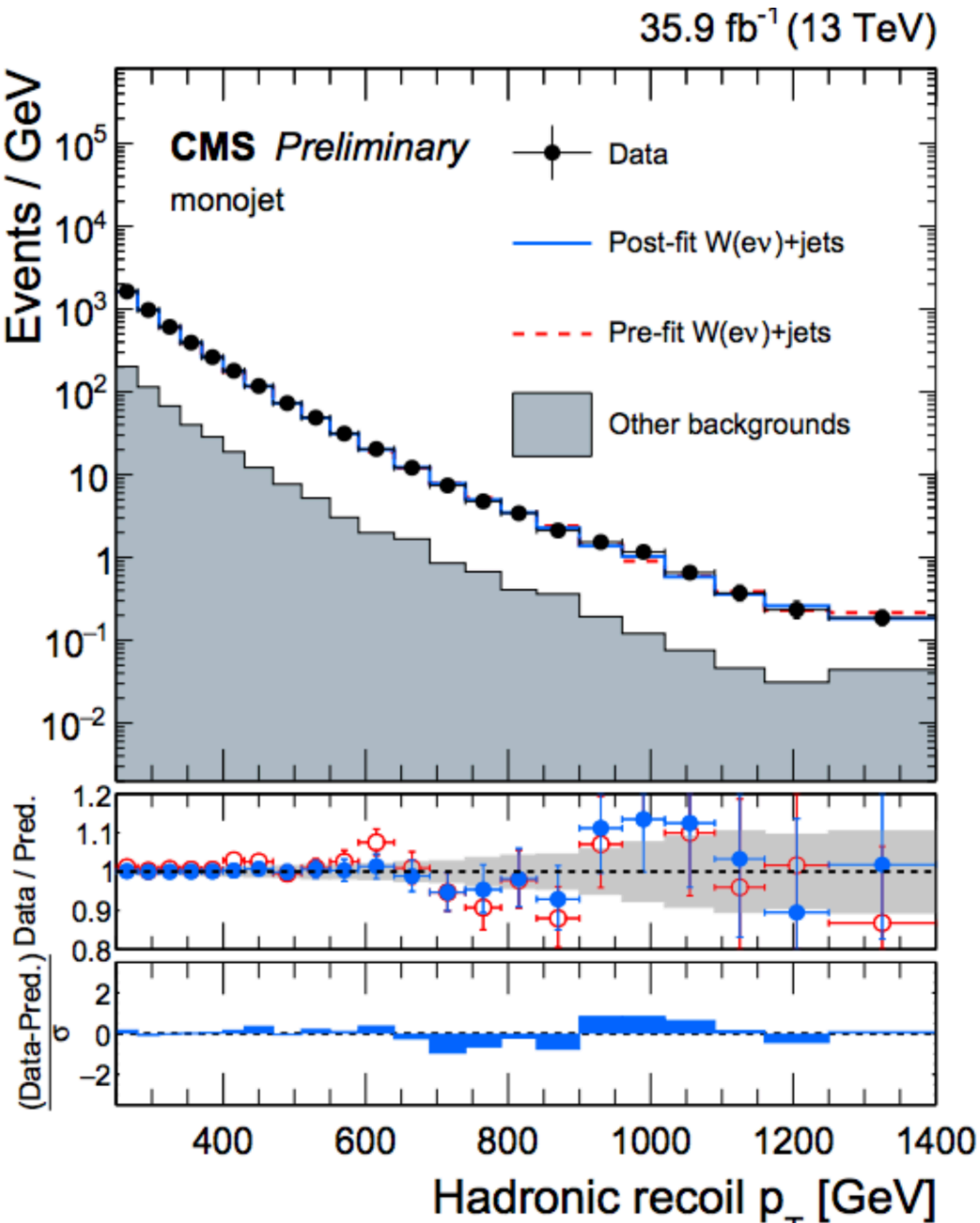

35.9 fb^{-1} (13 TeV)
CMS Preliminary
monojet
Data
Post-fit Z(ee)+jets
Pre-fit Z(ee)+jets
Other backgrounds
Events / GeV
Data / Pred.
(Data-Pred.) / σ
Hadronic recoil p$_T$ [GeV]
35.9 fb^{-1} (13 TeV)
CMS Preliminary
mono-V
Data
Post-fit Z(ee)+jets
Pre-fit Z(ee)+jets
Other backgrounds
Events / GeV
Data / Pred.
(Data-Pred.) / σ
Hadronic recoil p$_T$ [GeV]

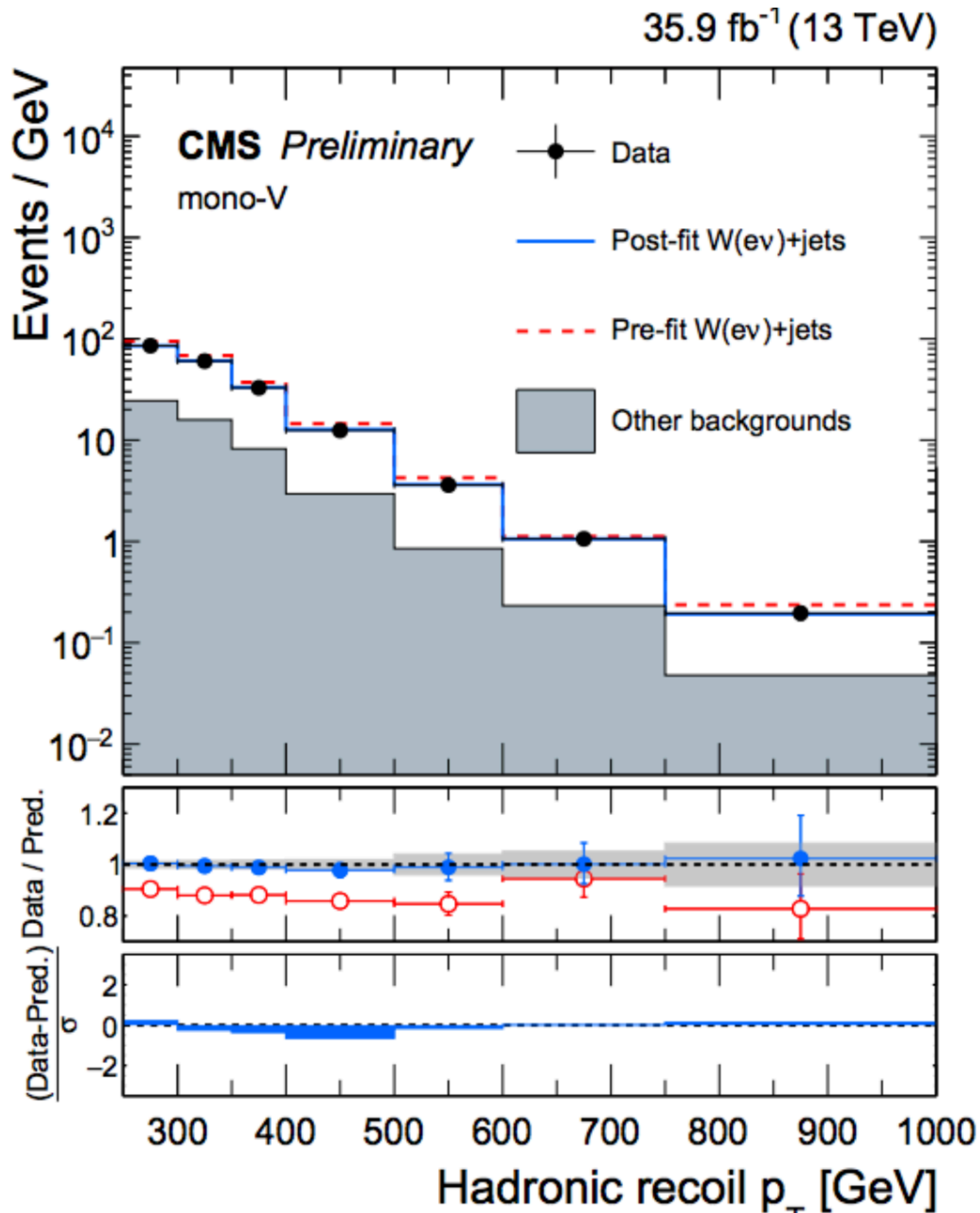
Mono-Jet @ CMS



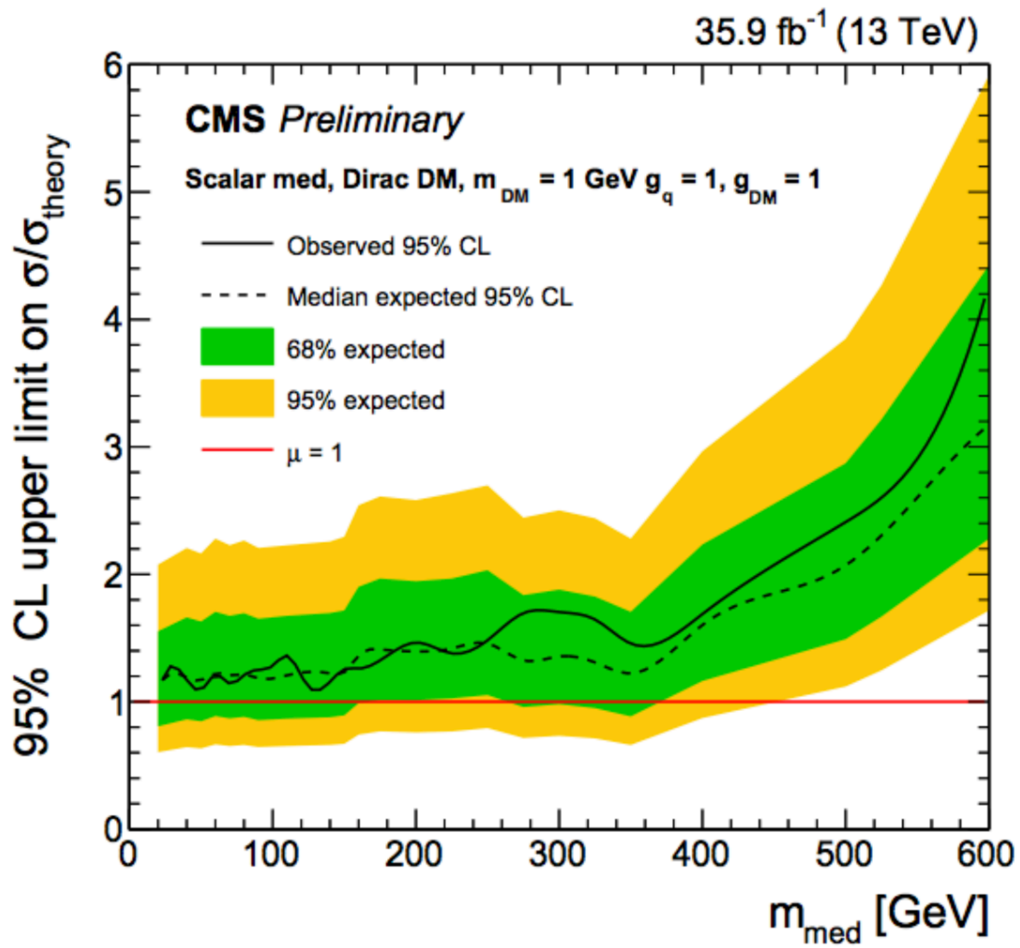
35.9 fb⁻¹ (13 TeV)
CMS Preliminary
monojet
Data
Post-fit W(μν)+jets
Pre-fit W(μν)+jets
Other backgrounds
Events / GeV
Data / Pred.
(Data-Pred.) / σ
Hadronic recoil pT [GeV]
35.9 fb⁻¹ (13 TeV)
CMS Preliminary
mono-V
Data
Post-fit W(μν)+jets
Pre-fit W(μν)+jets
Other backgrounds
Events / GeV
Data / Pred.
(Data-Pred.) / σ
Hadronic recoil pT [GeV]

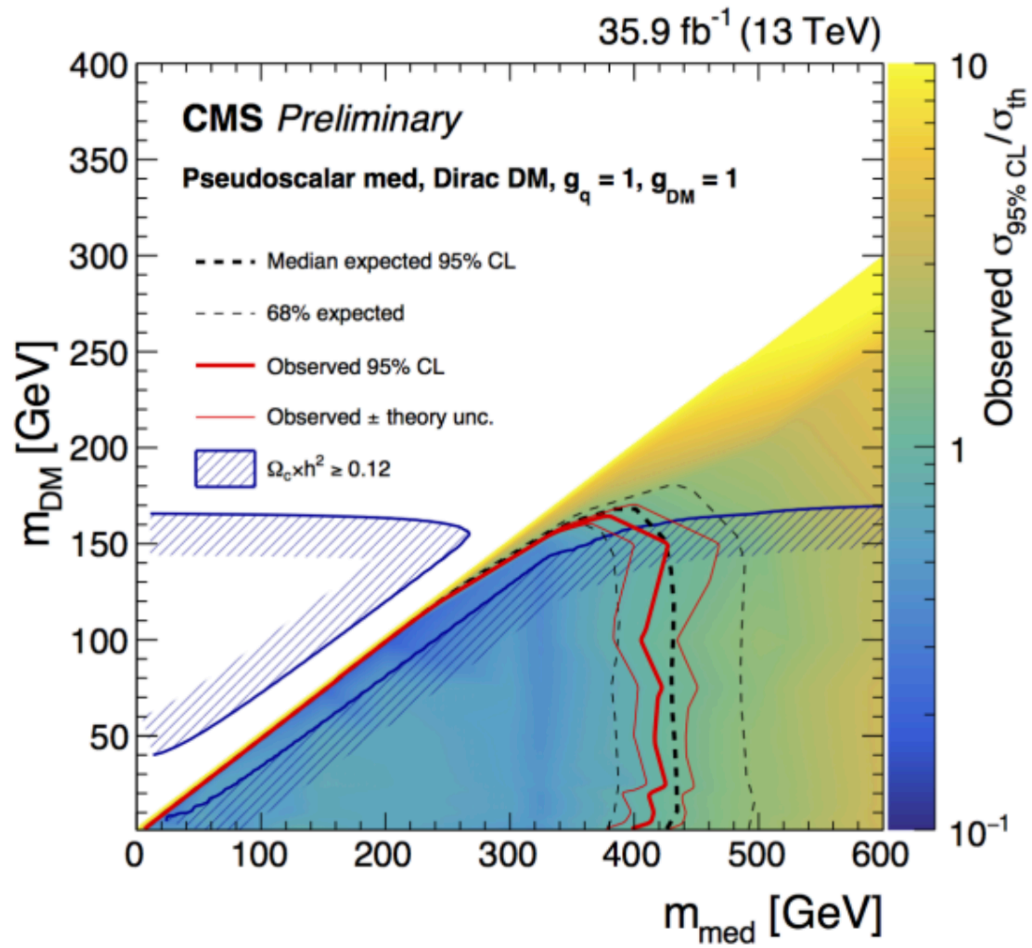
Mono-Jet @ CMS

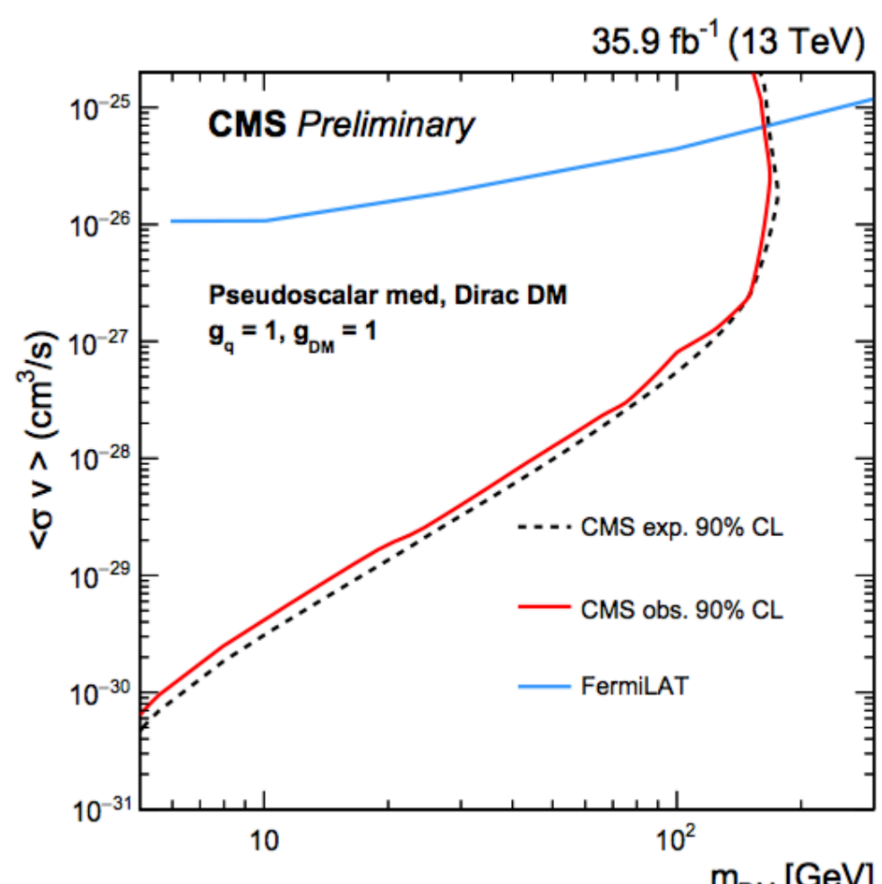

35.9 fb^{-1} (13 TeV)
CMS Preliminary
monojet
Data
Post-fit W(eν)+jets
Pre-fit W(eν)+jets
Other backgrounds
Events / GeV
Data / Pred.
(Data-Pred.) / σ
Hadronic recoil p_T [GeV]


35.9 fb^{-1} (13 TeV)
CMS Preliminary
mono-V
Data
Post-fit W(eν)+jets
Pre-fit W(eν)+jets
Other backgrounds
Events / GeV
Data / Pred.
(Data-Pred.) / σ
Hadronic recoil p_T [GeV]

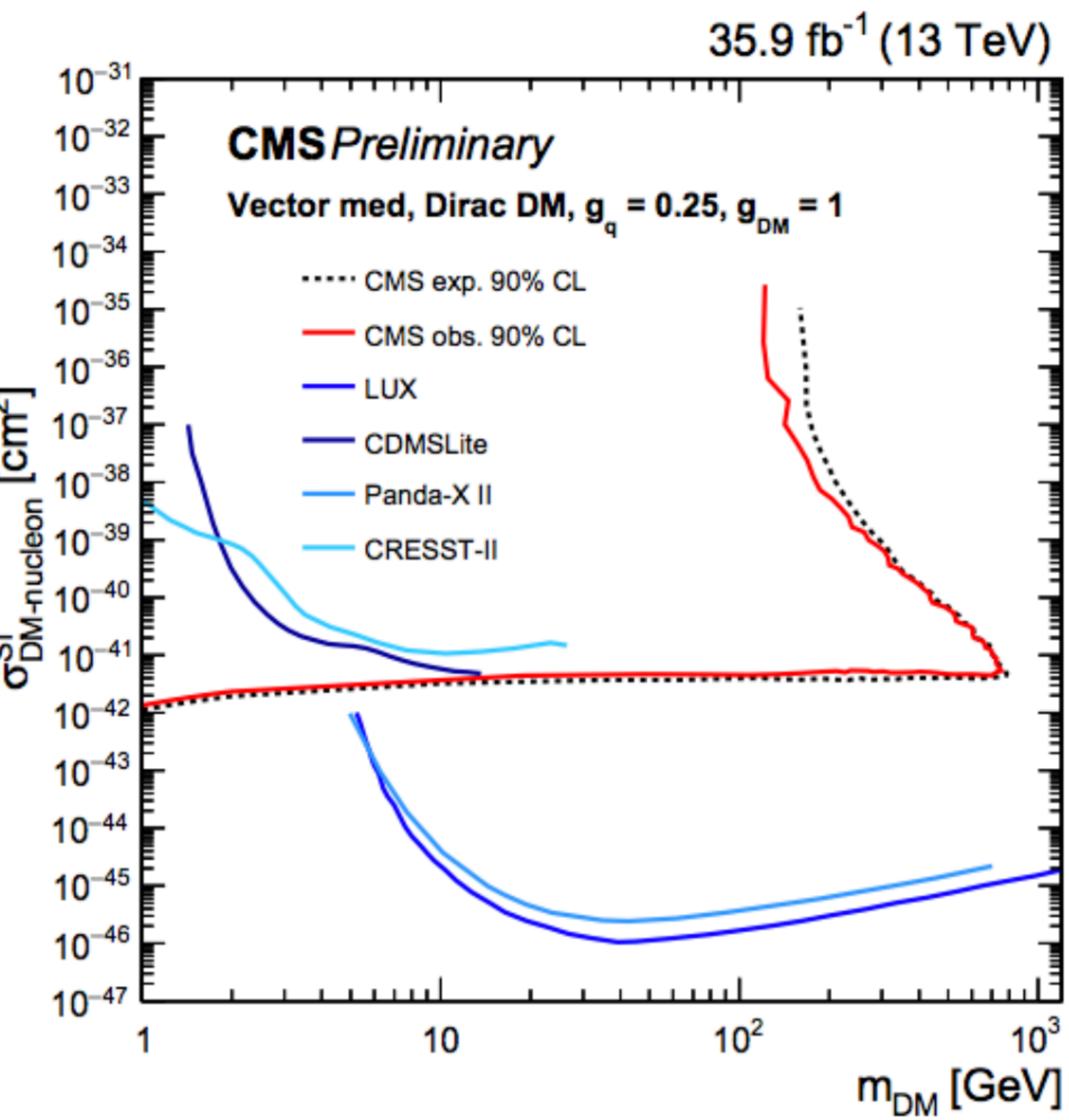
Mono-Jet @ CMS

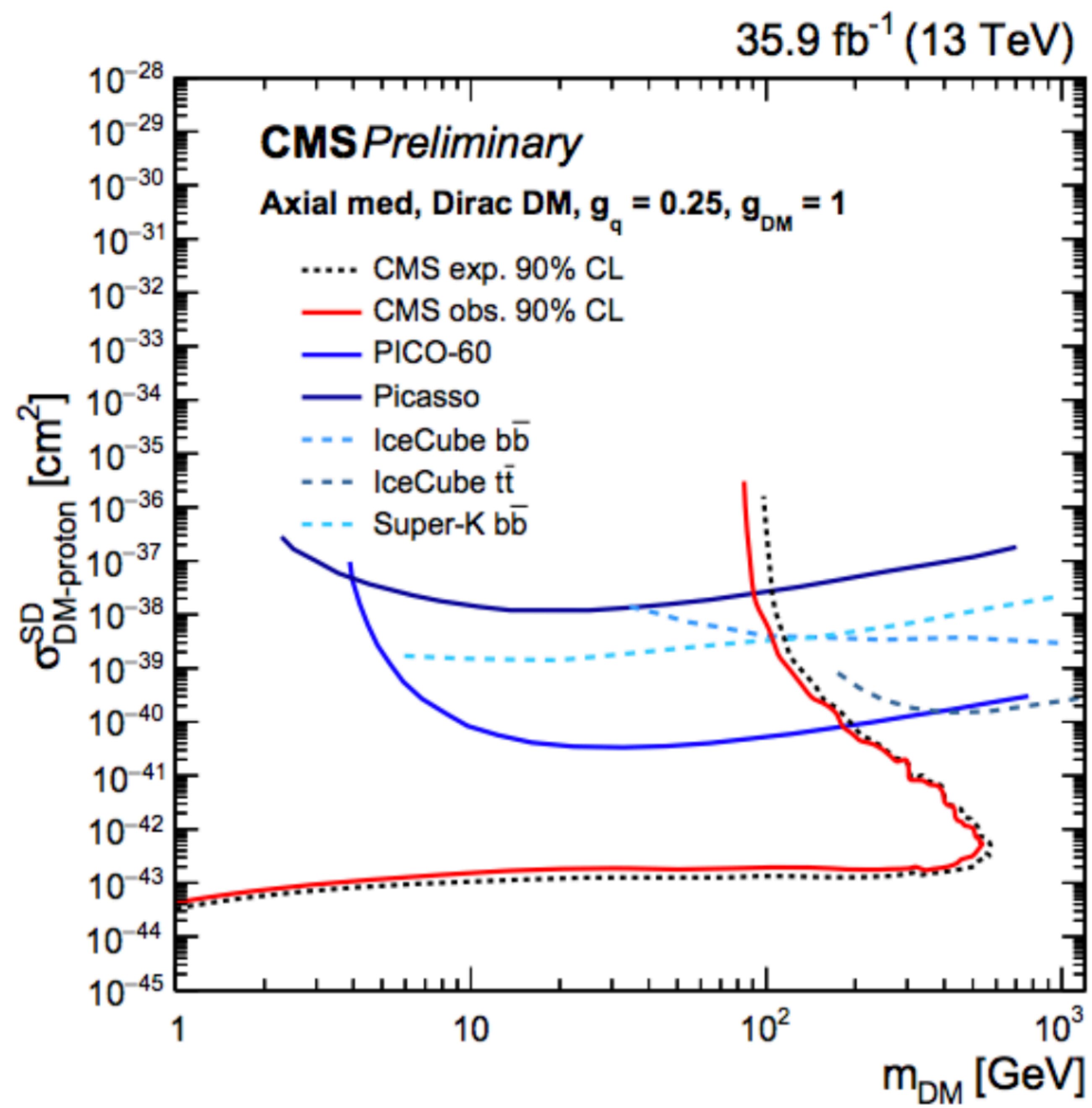

35.9 fb-1 (13 TeV)
CMS Preliminary
Scalar med, Dirac DM, m DM = 1 GeV g q = 1, g DM = 1
Observed 95% CL
Median expected 95% CL
68% expected
95% expected
μ = 1
95% CL upper limit on σ/σtheory
mmed [GeV]


35.9 fb-1 (13 TeV)
CMS Preliminary
Pseudoscalar med, Dirac DM, g q = 1, g DM = 1
Median expected 95% CL
68% expected
Observed 95% CL
Observed ± theory unc.
Ωcxh2 ≥ 0.12
mDM [GeV]
mmed [GeV]
Observed σ95% CL/σth

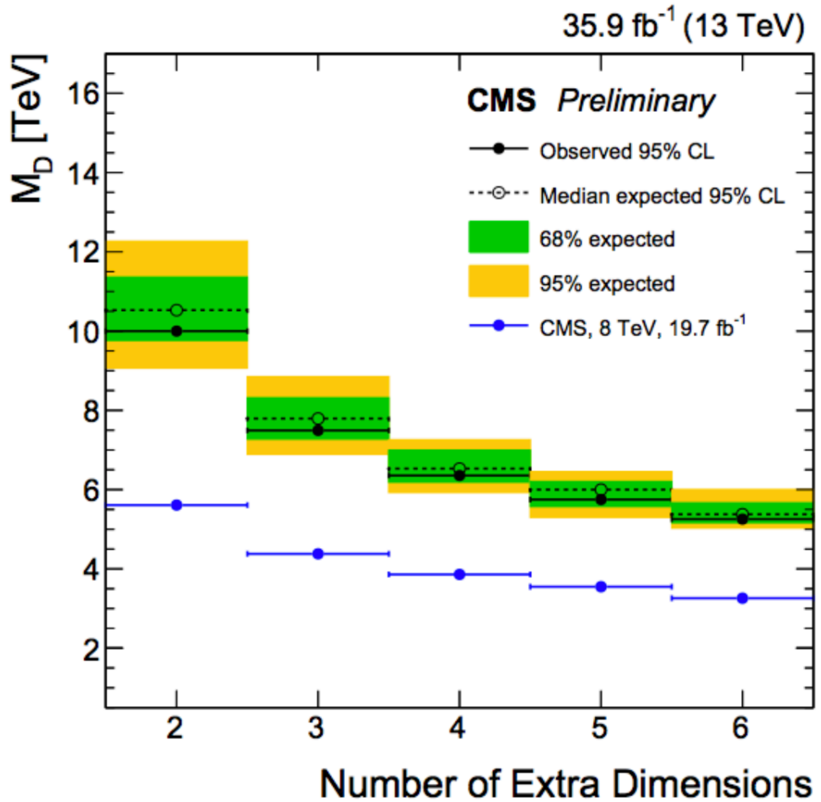

35.9 fb-1 (13 TeV)
CMS Preliminary
Pseudoscalar med, Dirac DM
g q = 1, g DM = 1
CMS exp. 90% CL
CMS obs. 90% CL
FermiLAT
<σ v > (cm3/s)
mDM [GeV]

Mono-Jet @ CMS

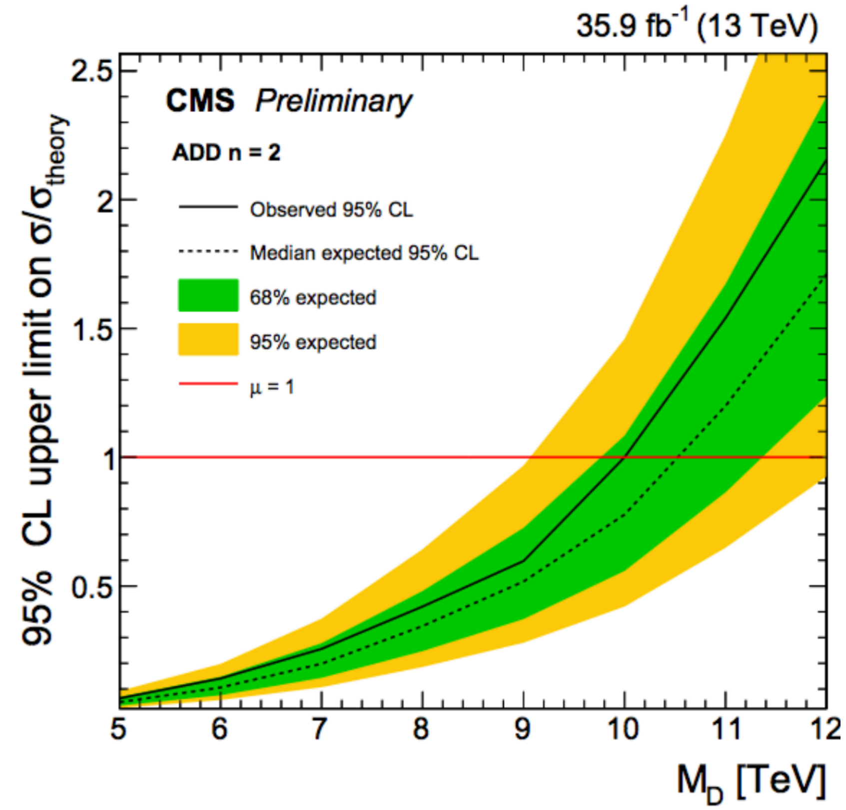

35.9 fb^{-1} (13 TeV)
CMS Preliminary
Vector med, Dirac DM, g_q = 0.25, g_{DM} = 1
CMS exp. 90% CL
CMS obs. 90% CL
LUX
CDMSLite
Panda-X II
CRESST-II
$\sigma^{SI}_{DM\text{-nucleon}}$ [cm^2]
m_{DM} [GeV]


35.9 fb^{-1} (13 TeV)
CMS Preliminary
Axial med, Dirac DM, g_q = 0.25, g_{DM} = 1
CMS exp. 90% CL
CMS obs. 90% CL
PICO-60
Picasso
IceCube $b\bar{b}$
IceCube $t\bar{t}$
Super-K $b\bar{b}$
$\sigma^{SD}_{DM\text{-proton}}$ [cm^2]
m_{DM} [GeV]

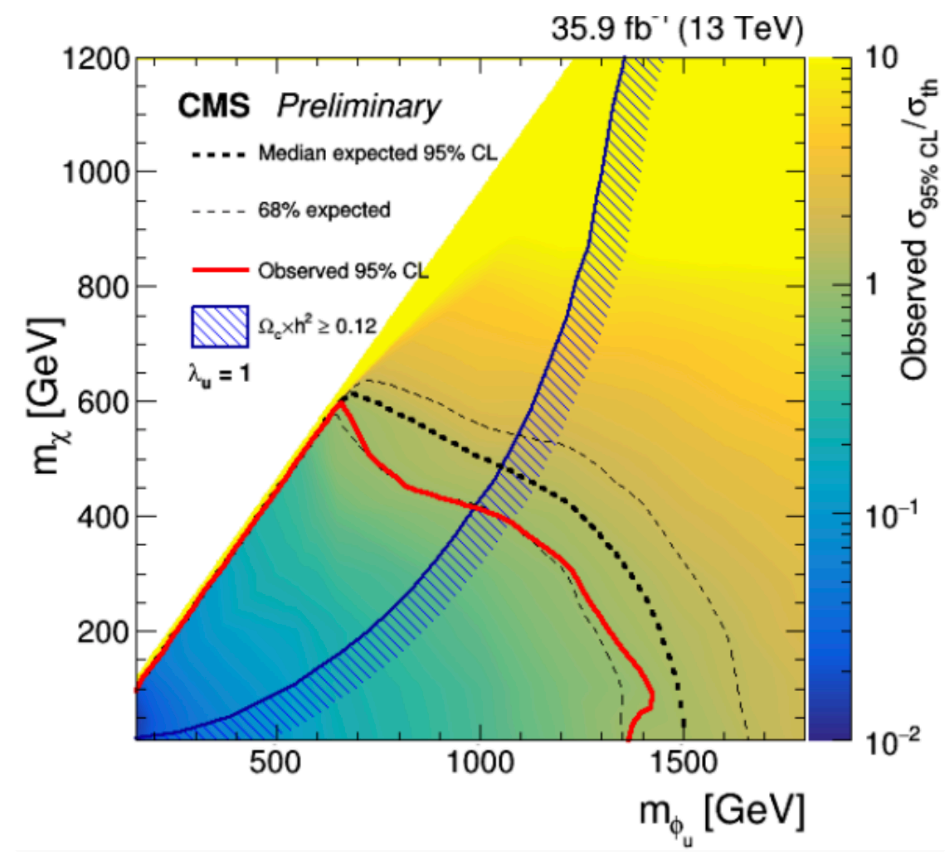
Mono-Jet @ CMS



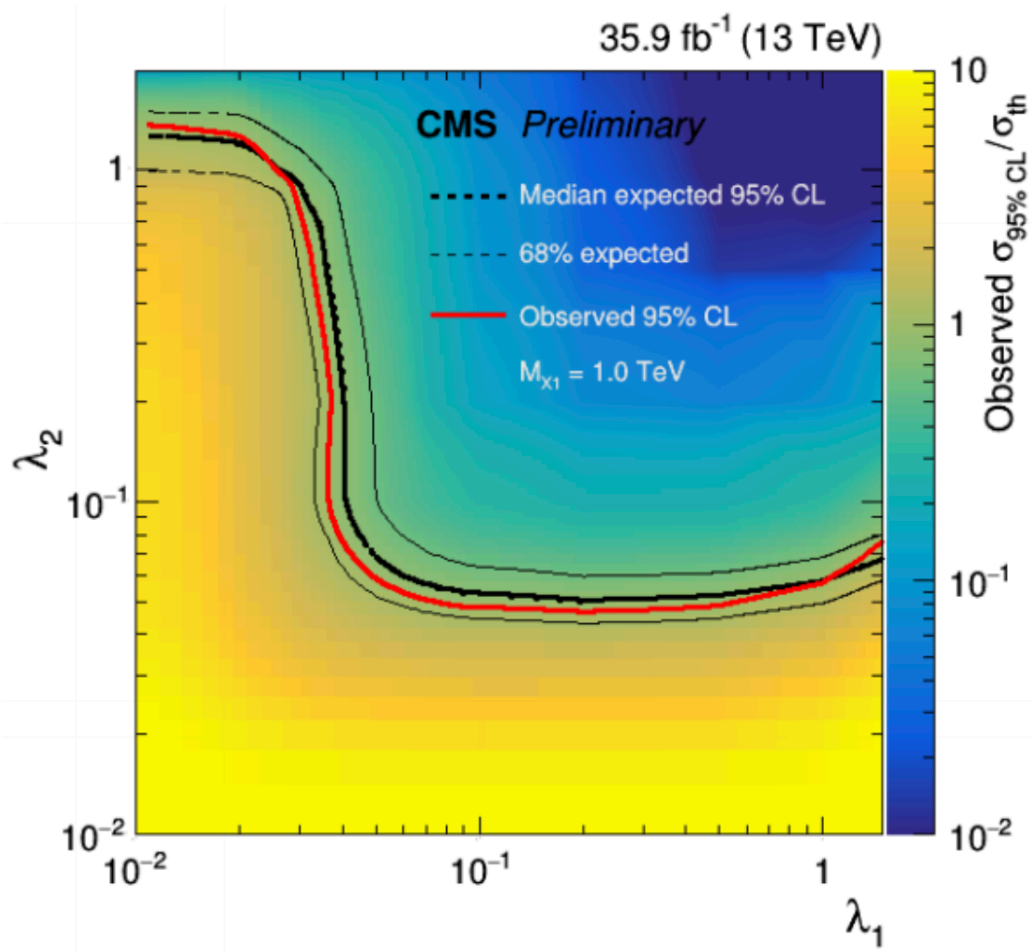
35.9 fb⁻¹ (13 TeV)
CMS Preliminary
Observed 95% CL
Median expected 95% CL
68% expected
95% expected
CMS, 8 TeV, 19.7 fb⁻¹
M_D [TeV]
Number of Extra Dimensions



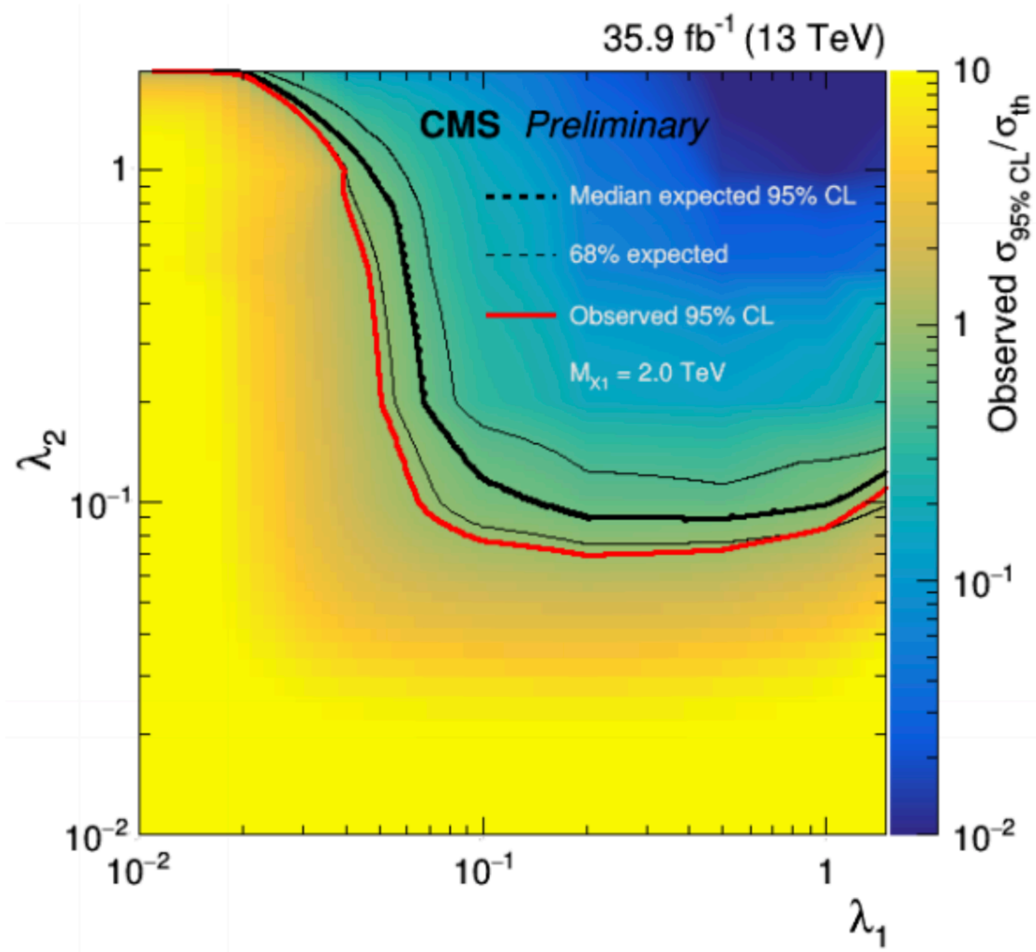
35.9 fb⁻¹ (13 TeV)
CMS Preliminary
ADD n = 2
Observed 95% CL
Median expected 95% CL
68% expected
95% expected
μ = 1
95% CL upper limit on σ/σ_theory
M_D [TeV]



35.9 fb⁻¹ (13 TeV)
CMS Preliminary
Median expected 95% CL
68% expected
Observed 95% CL
Ω_c×h² ≥ 0.12
λ_u = 1
m_χ [GeV]
m_φu [GeV]
Observed σ_95% CL/σ_th



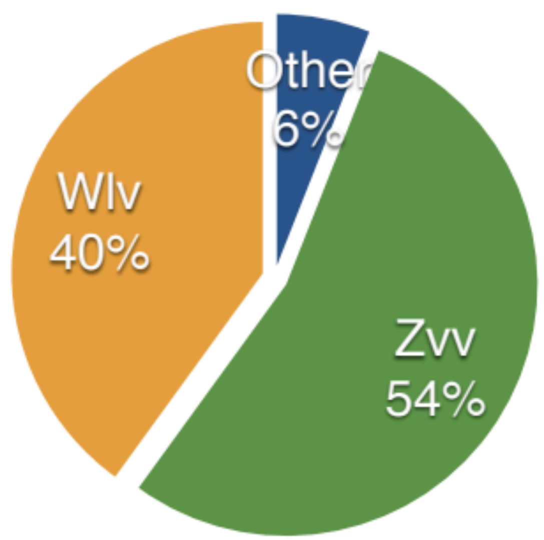
35.9 fb⁻¹ (13 TeV)
CMS Preliminary
Median expected 95% CL
68% expected
Observed 95% CL
M_X1 = 1.0 TeV
λ_2
λ_1
Observed σ_95% CL/σ_th



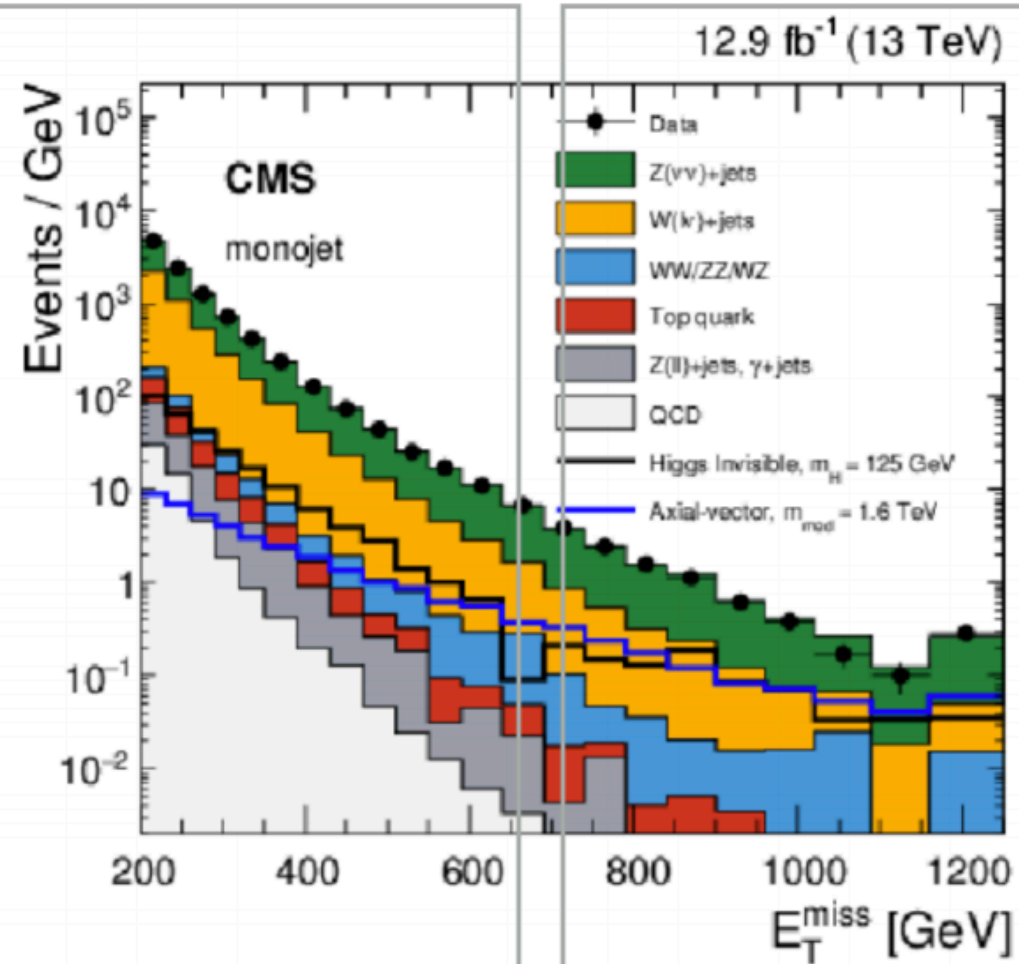
35.9 fb⁻¹ (13 TeV)
CMS Preliminary
Median expected 95% CL
68% expected
Observed 95% CL
M_X1 = 2.0 TeV
λ_2
λ_1
Observed σ_95% CL/σ_th

Background composition and analysis overview

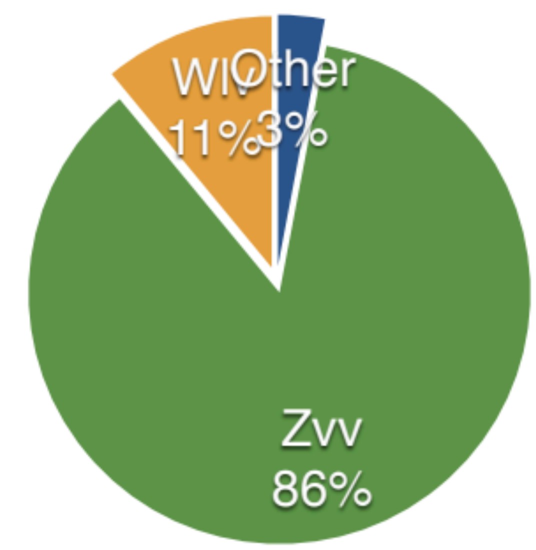
Low MET



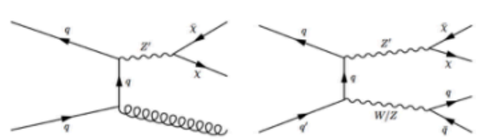
qual parts of Zvv and Wlv



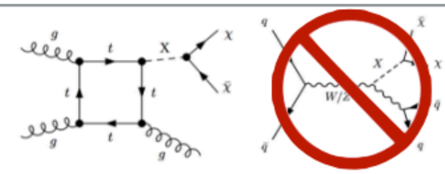
High MET



Dominated by Zvv



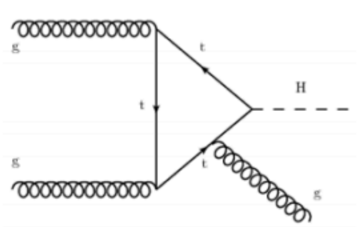
σ(mono-jet) ≥ 100 x σ (mono-W)



σ(mono-jet) ~ 30 x σ (mono-W)

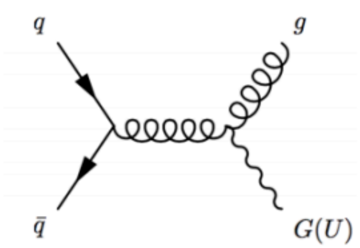
All samples are now produced in NLO in QCD

Higgs Invisible



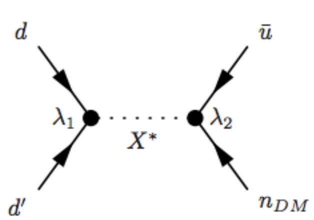
SM like Higgs boson, decaying into BSM invisible particles

ADD EDs



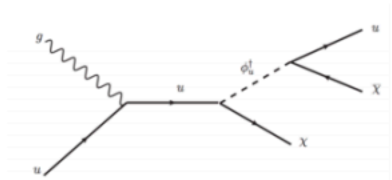
ADD Model of EDs, producing gravitons that interact weakly with the detector

Nonthermal DM



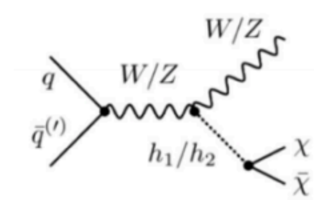
minimal extension to SM with ~ TeV scalar color triplet mediator with non thermal DM decay products

Fermion Portal DM



It is a simplified DM model in which DM particle couples with a scalar mediator (ϕ) and a SM fermion.

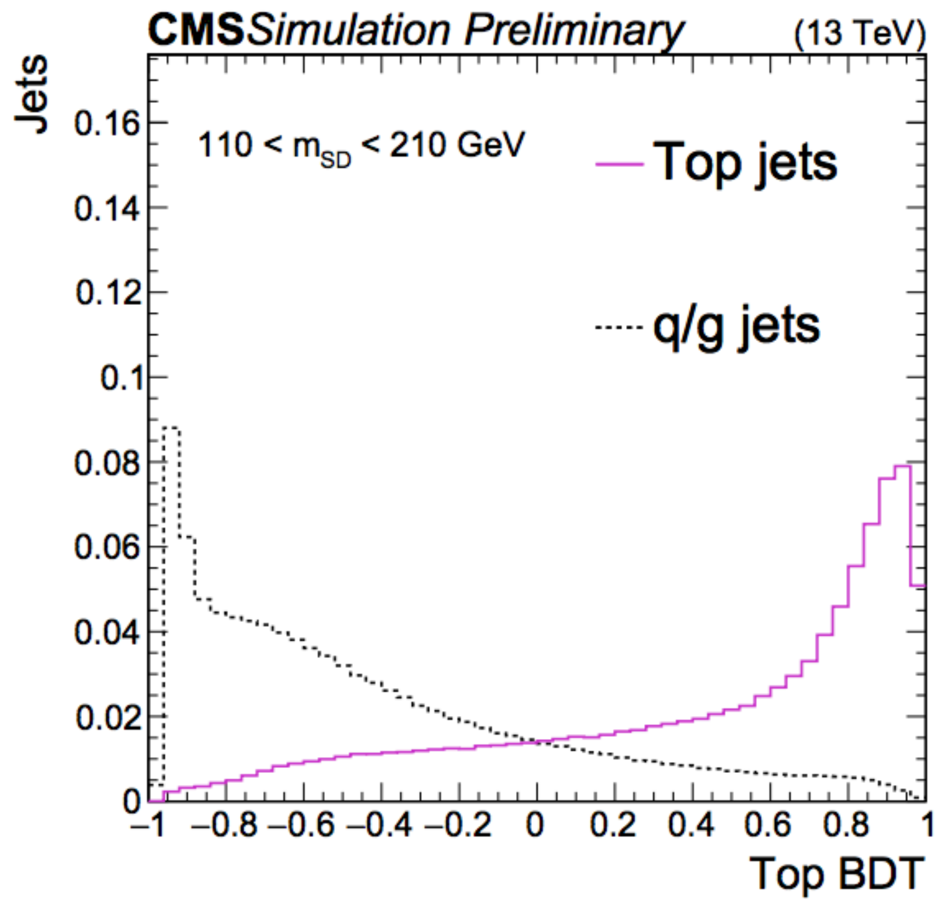
SMM Model

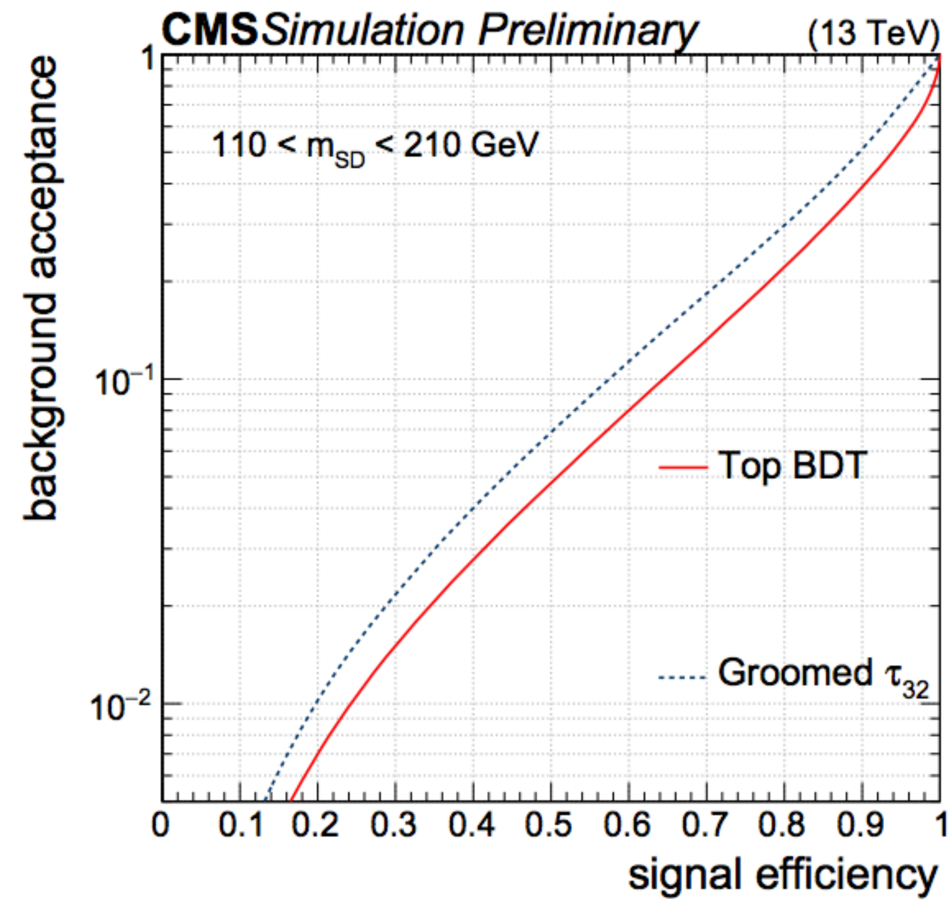


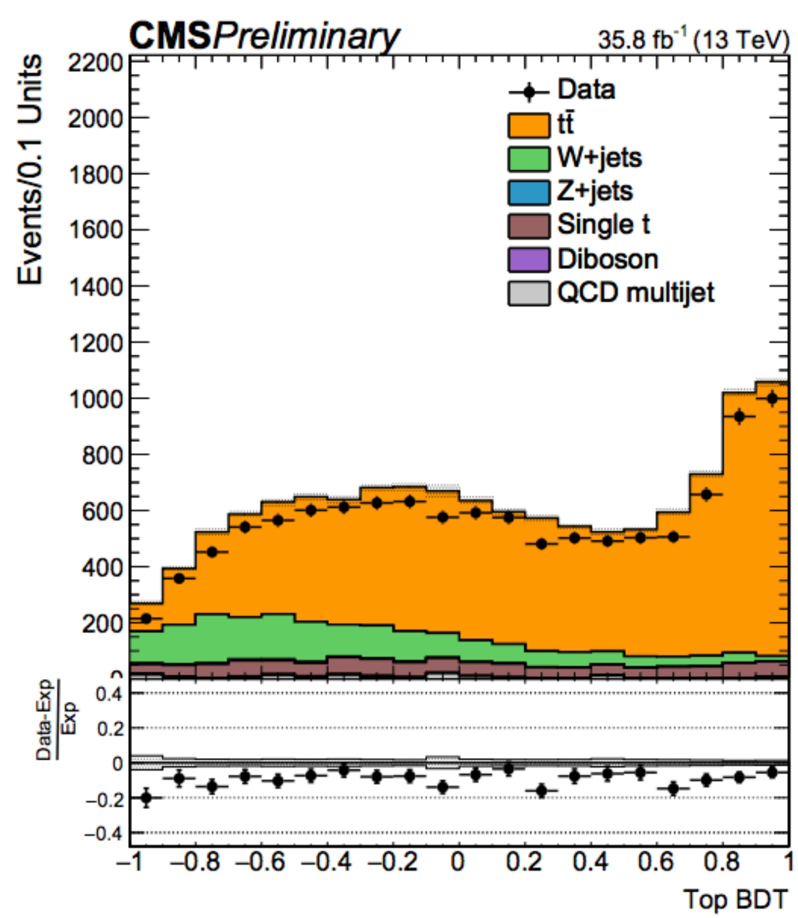
Extension of the scalar DM model, with additional scalar and mixing

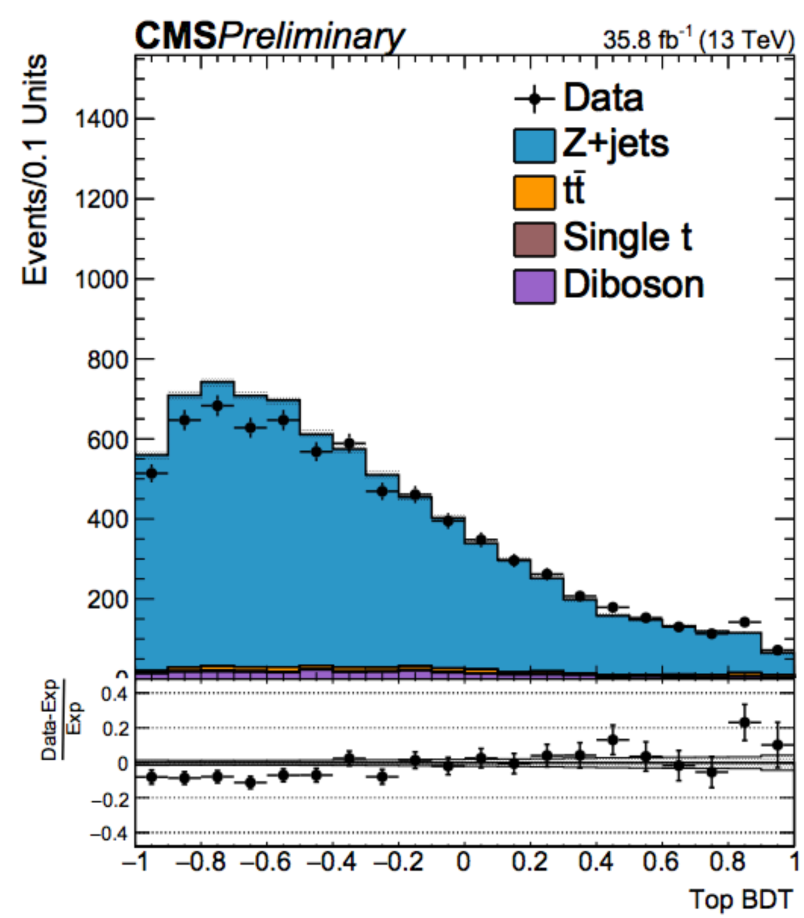
Mono-Top @ CMS

Mono-Top @ CMS

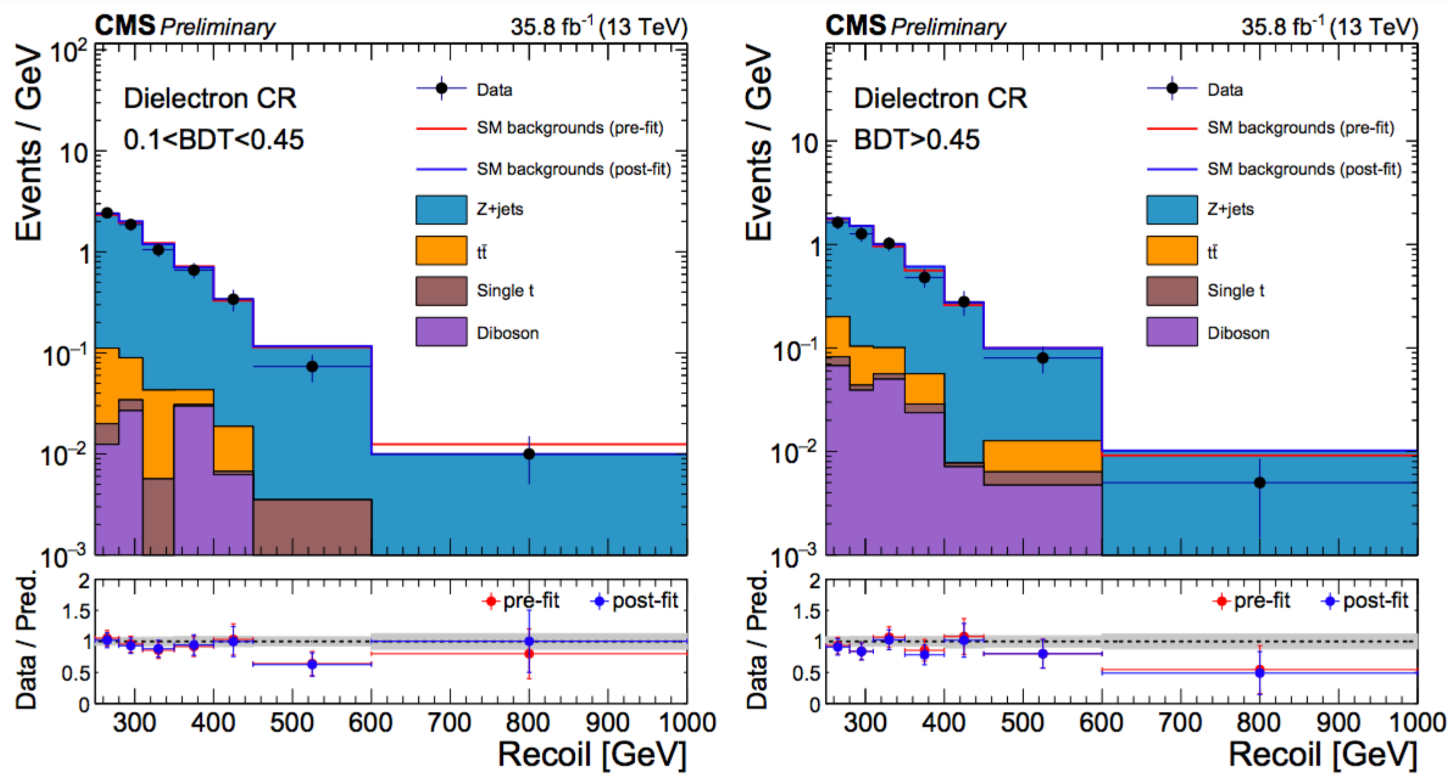

CMS Simulation Preliminary
(13 TeV)
110 < m_SD < 210 GeV
Top jets
q/g jets
Jets
Top BDT


CMS Simulation Preliminary
(13 TeV)
110 < m_SD < 210 GeV
Top BDT
Groomed τ32
background acceptance
signal efficiency

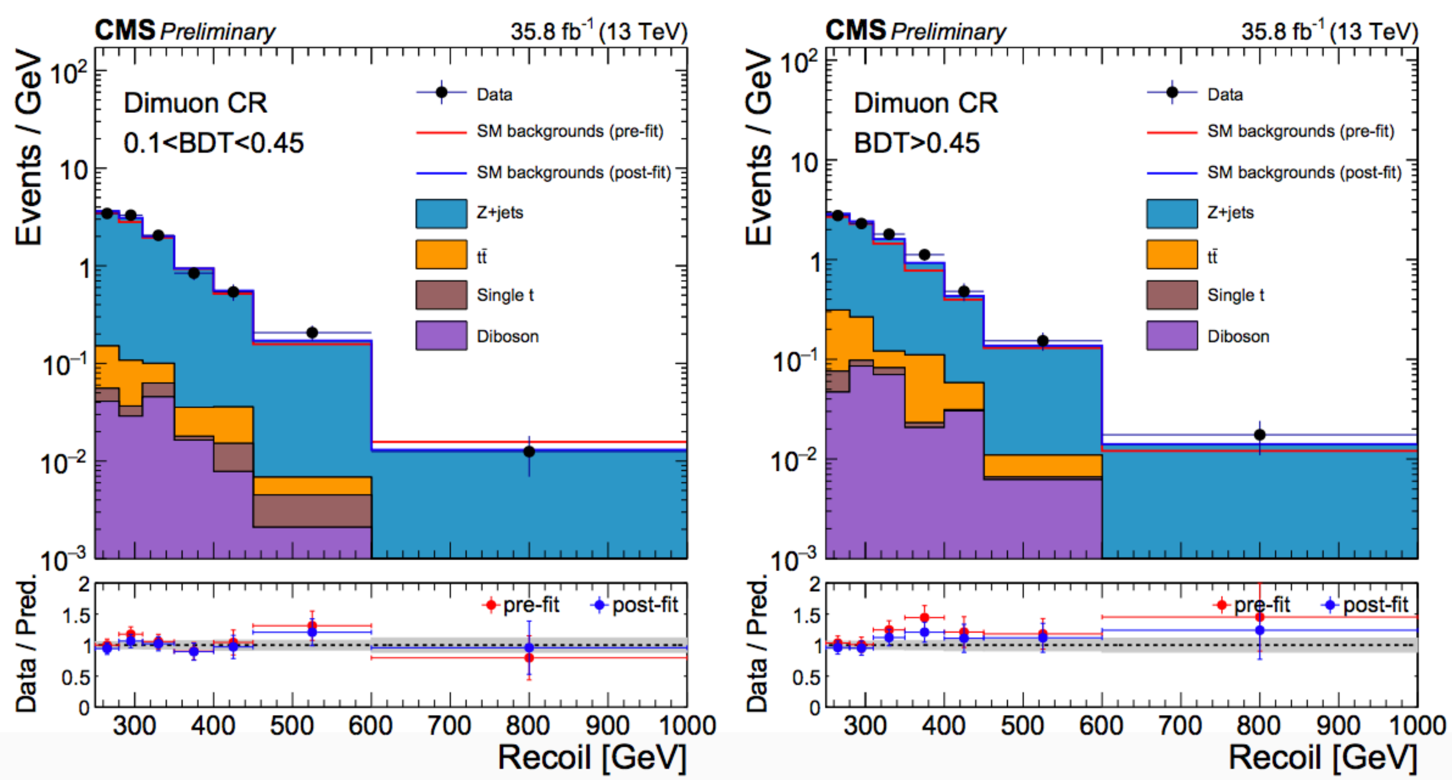

CMS Preliminary
35.8 fb-1 (13 TeV)
Data
tt̄
W+jets
Z+jets
Single t
Diboson
QCD multijet
Events/0.1 Units
Data-Exp / Exp
Top BDT

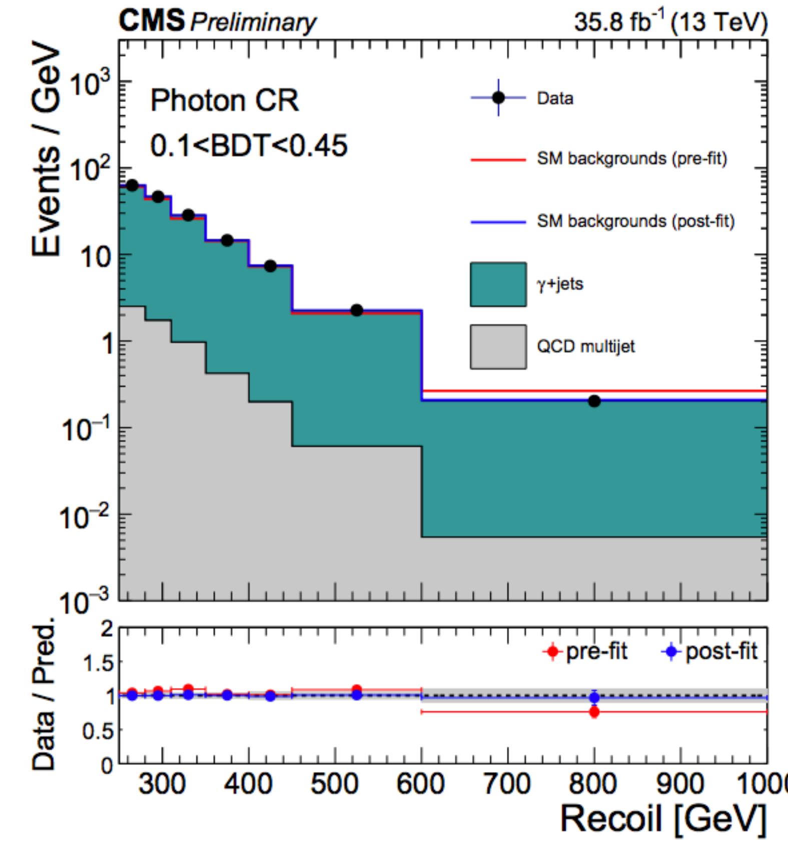

CMS Preliminary
35.8 fb-1 (13 TeV)
Data
Z+jets
tt̄
Single t
Diboson
Events/0.1 Units
Data-Exp / Exp
Top BDT

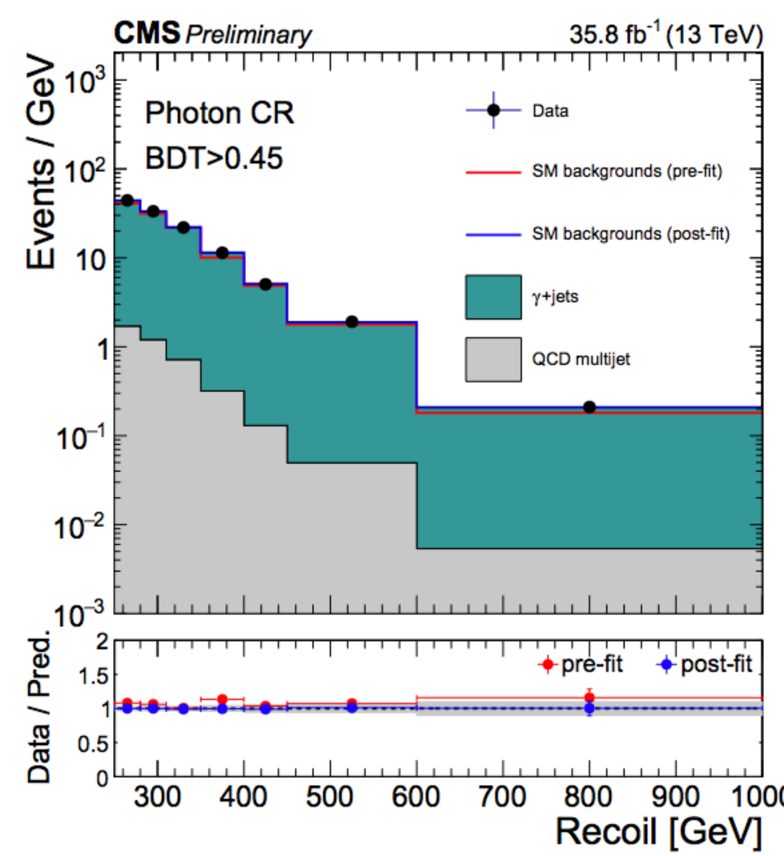
Mono-Top @ CMS



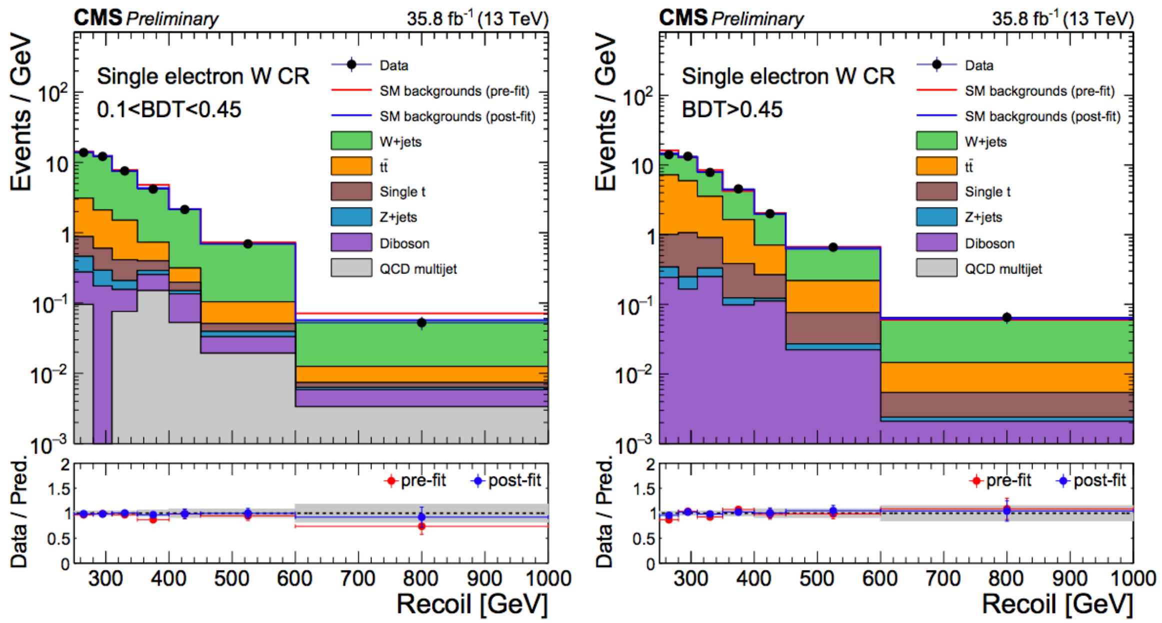
(a)



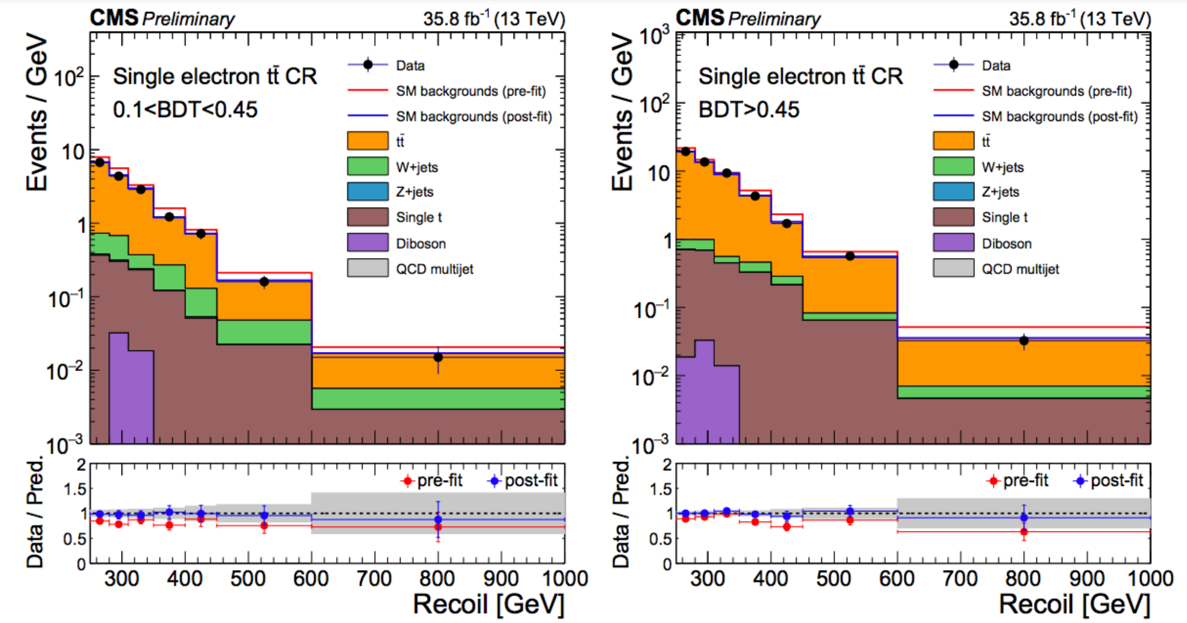




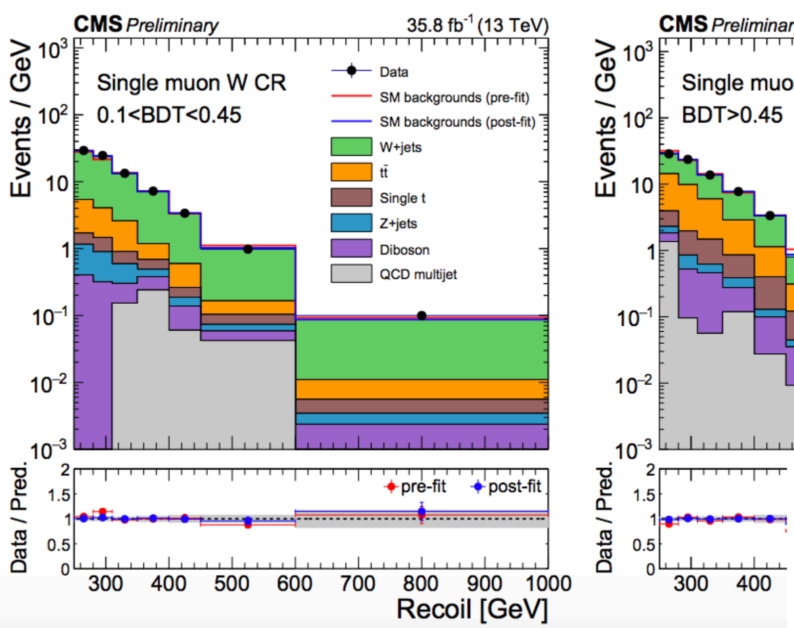
Mono-Top @ CMS

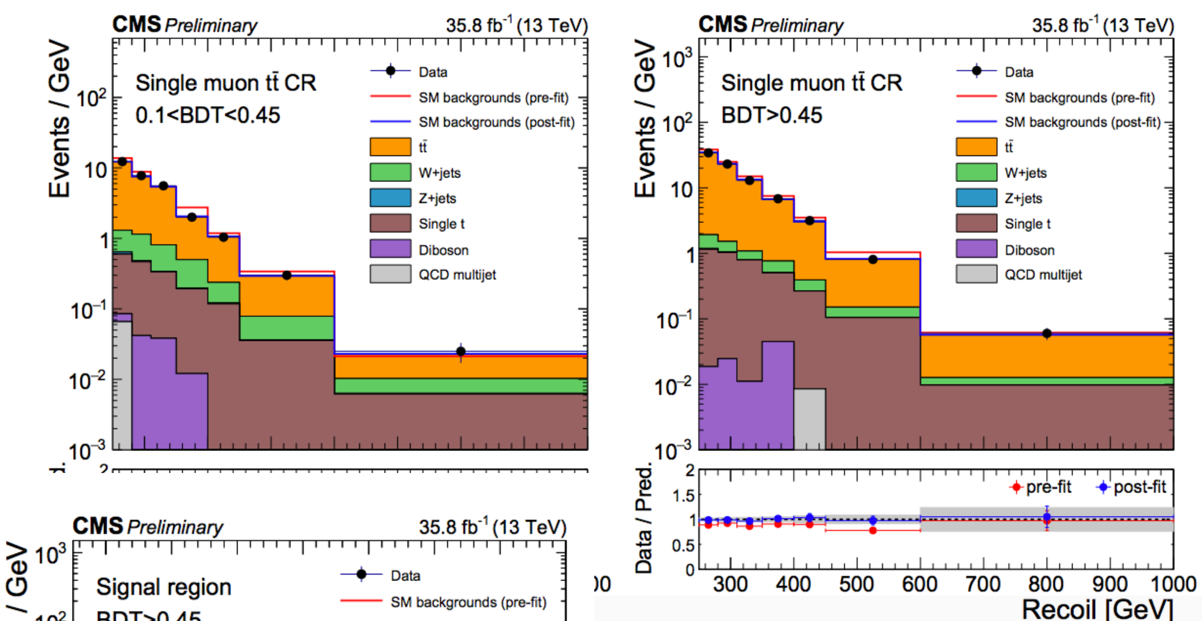


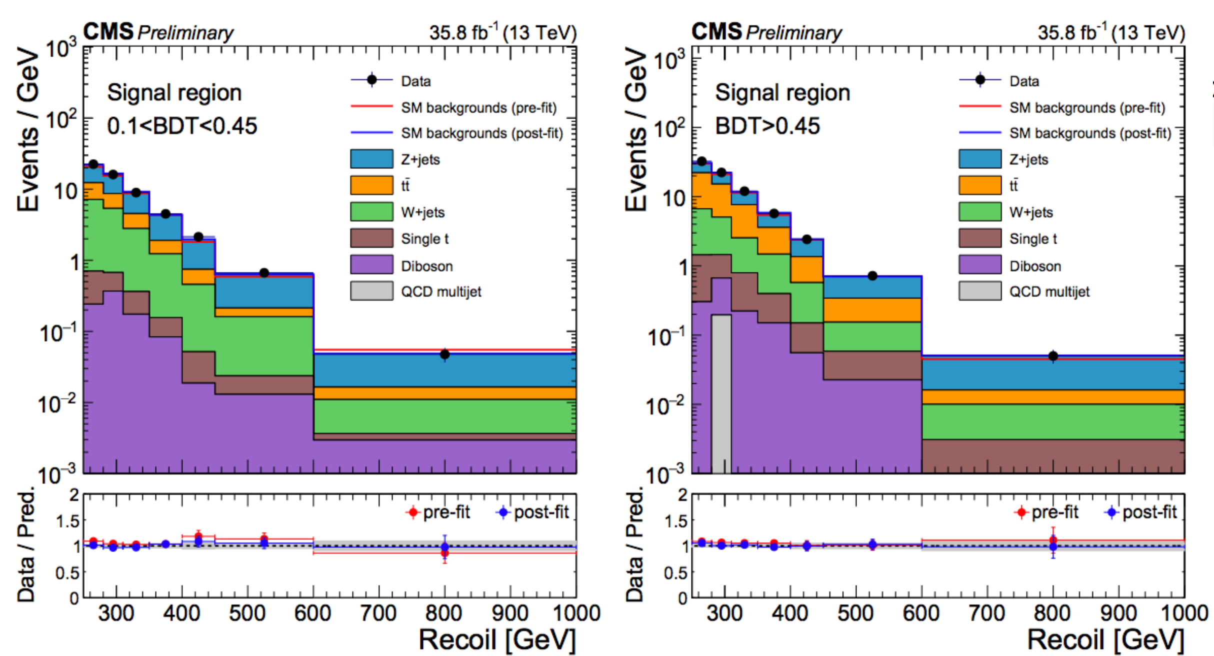
(a)



(a)

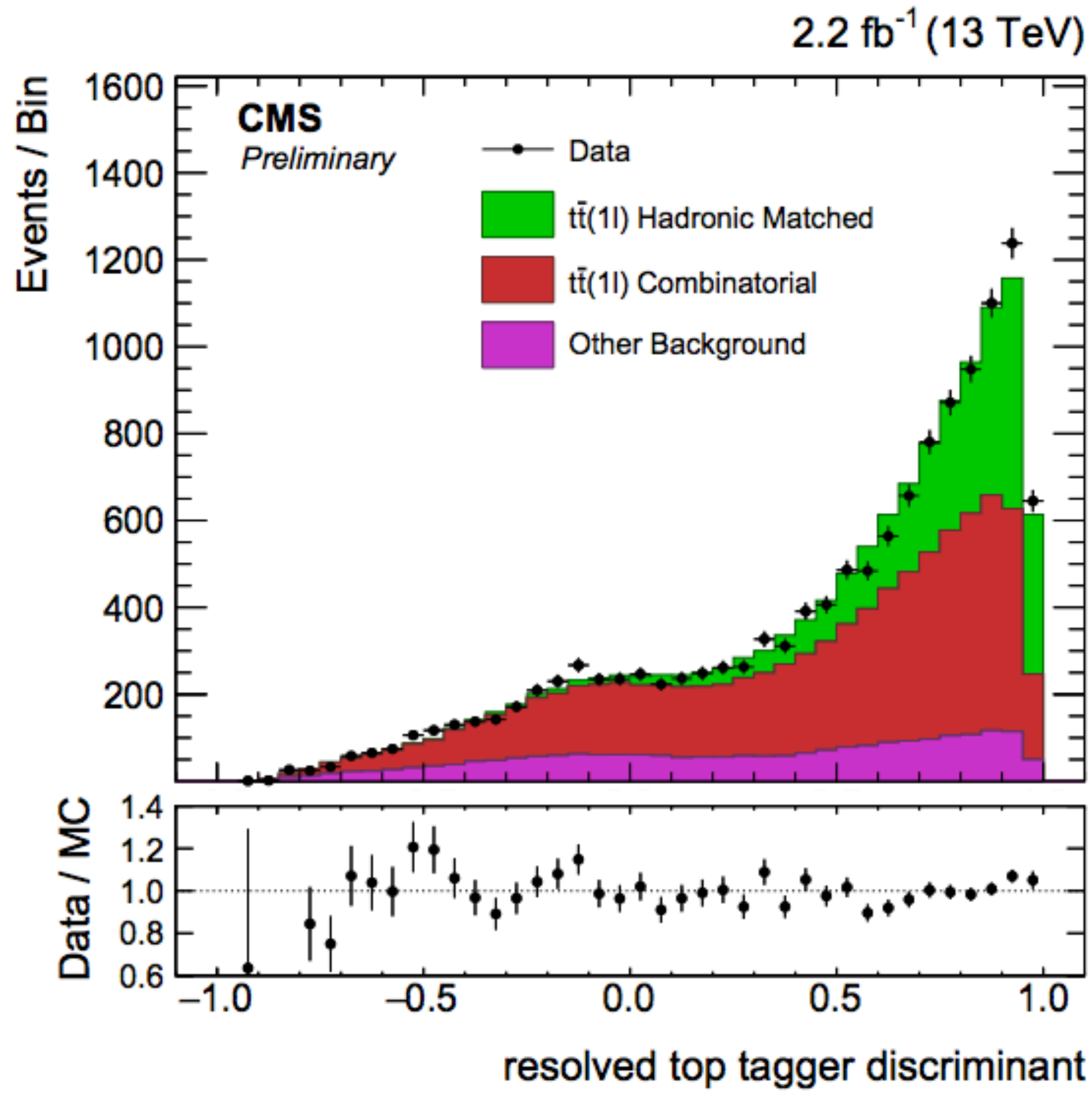




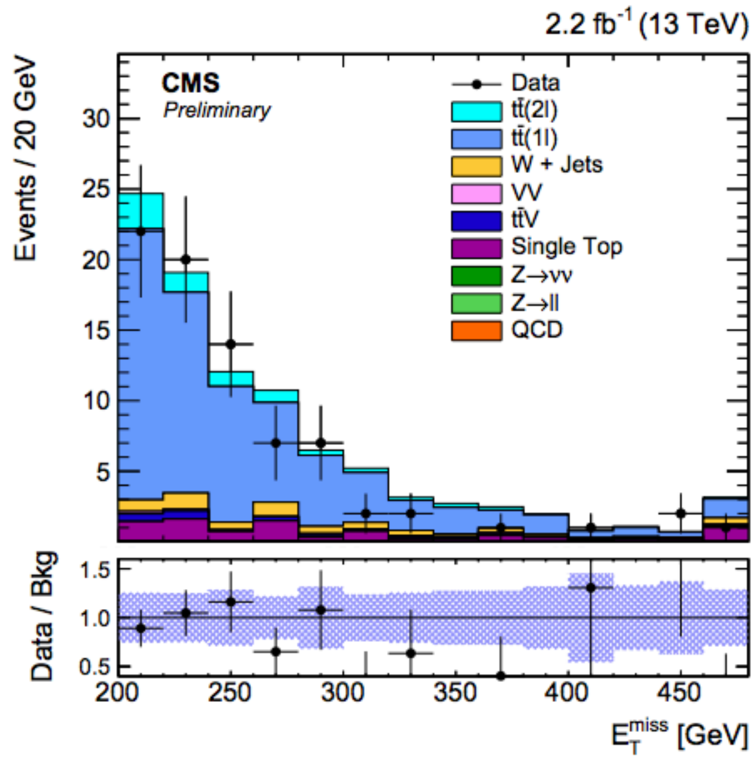


Mono-tt(bb) @ CMS

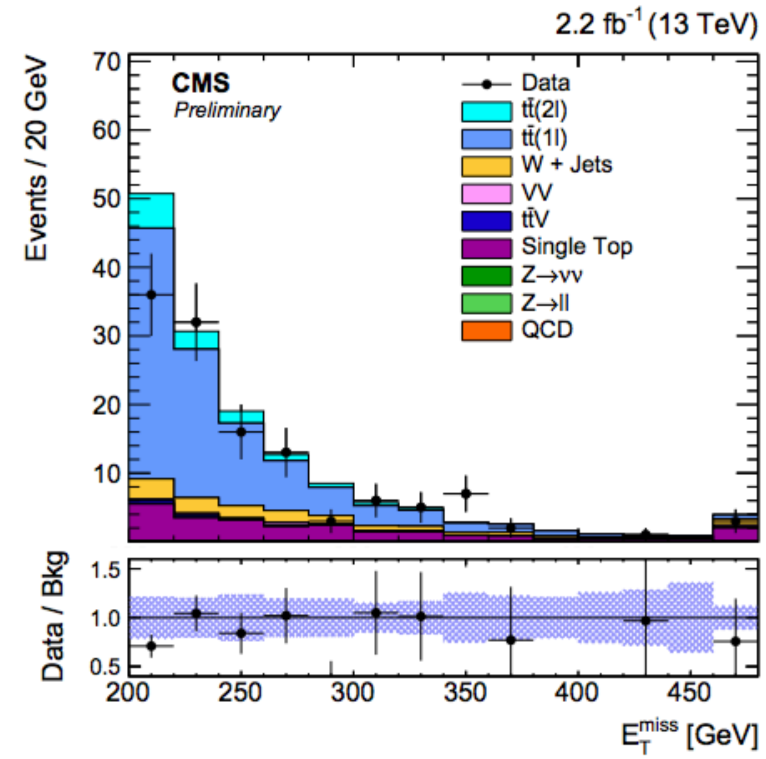
Mono-tt(bb) @ CMS



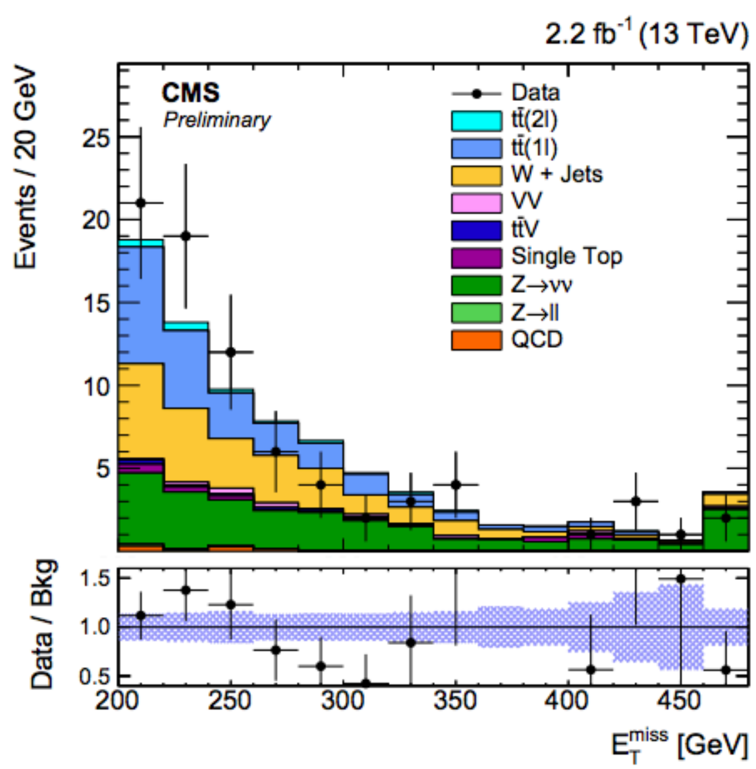
Mono-tt(bb) @ CMS



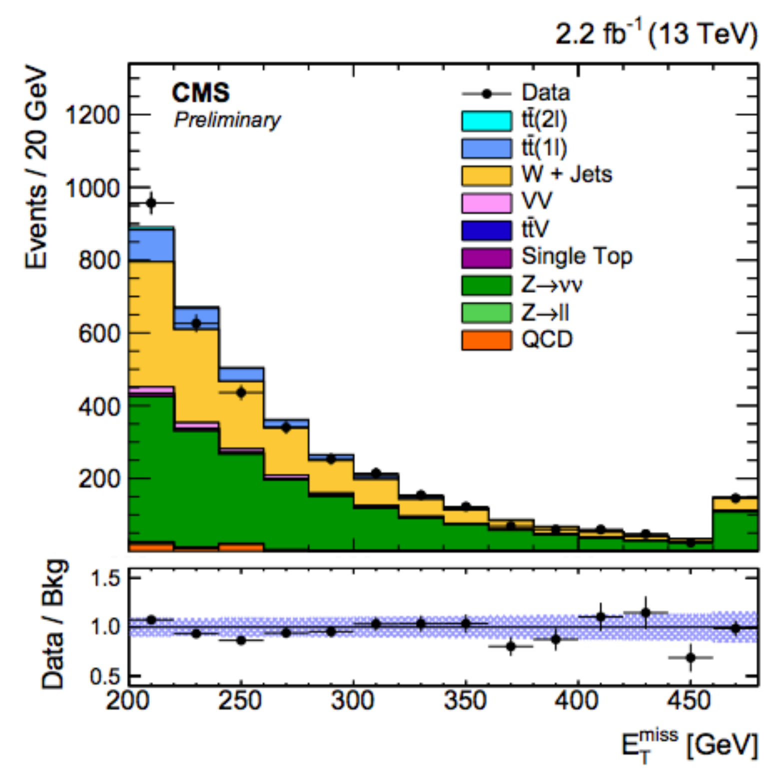
(a) semileptonic $t\bar{t}$: two top tags



(b) semileptonic $t\bar{t}$: less than two top tags



(c) $W/Z+$jets: two top tags



(d) $W/Z+$jets: less than two top tags

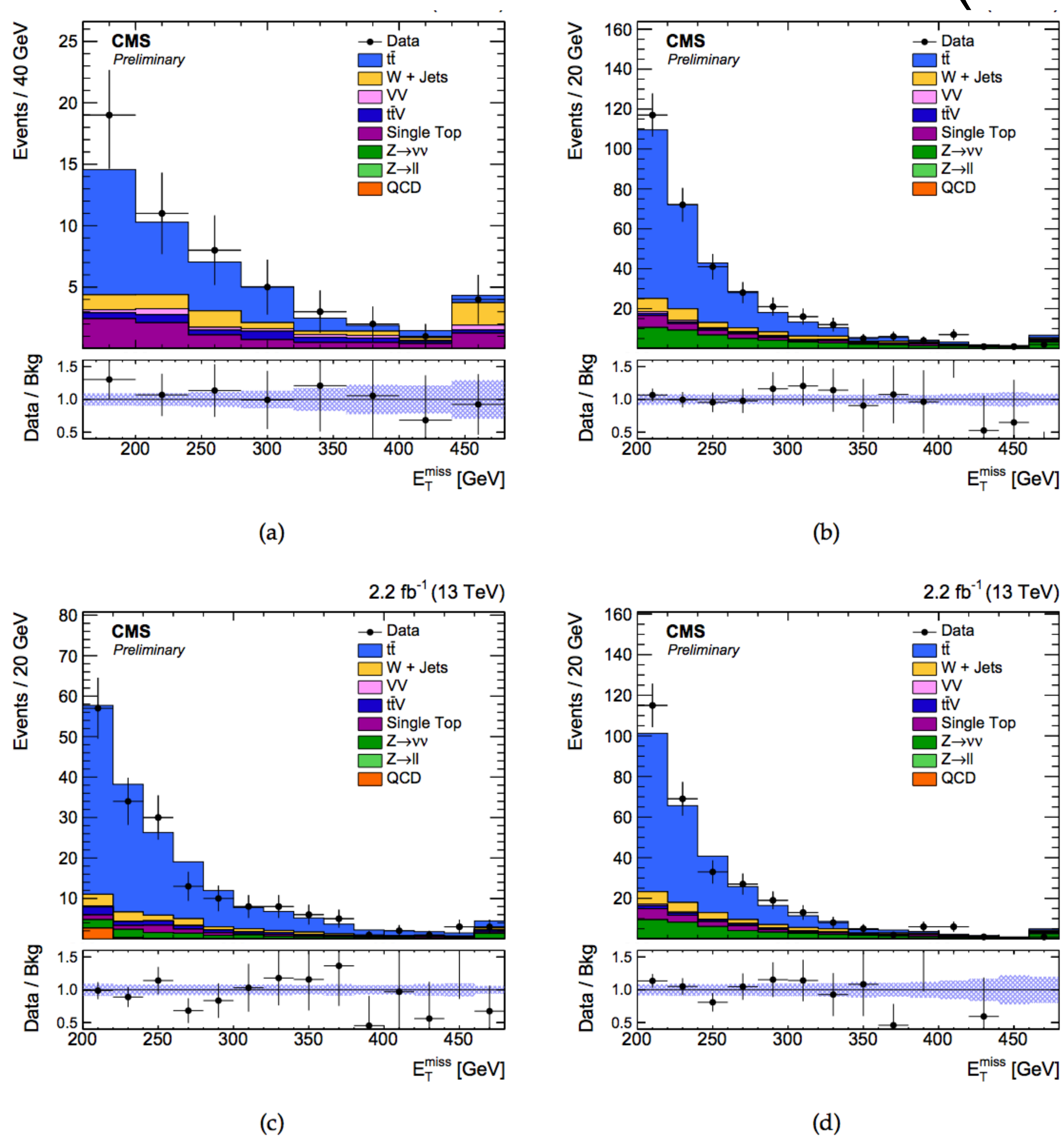


Figure 8: Post-fit distributions of E_T^{miss} expected from SM backgrounds and observed in data in the signal regions for the (a) semileptonic, (b) inclusive hadronic, (c) two top tags hadronic category and (c) less than two top tags hadronic category. The expected distributions are shown after fitting to the observed data simultaneously across signal and control regions with an assumption of zero signal contribution. The overall post-fit uncertainties are shown in the blue band on the lower panel.

Mono-H Theory Motivation

A model where a vector mediator (Z 0 B) is exchanged in the s-channel, radiates a Higgs boson, and decays into two DM particles.

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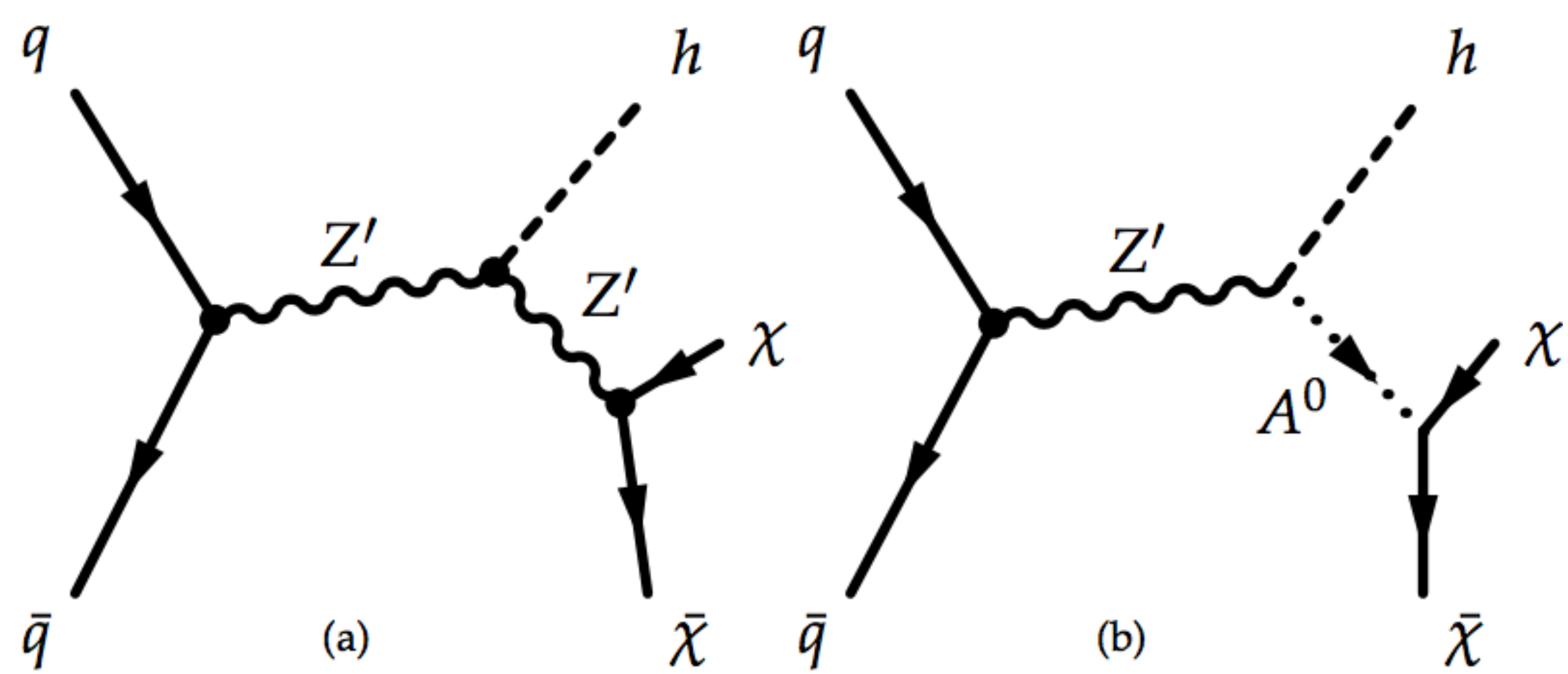
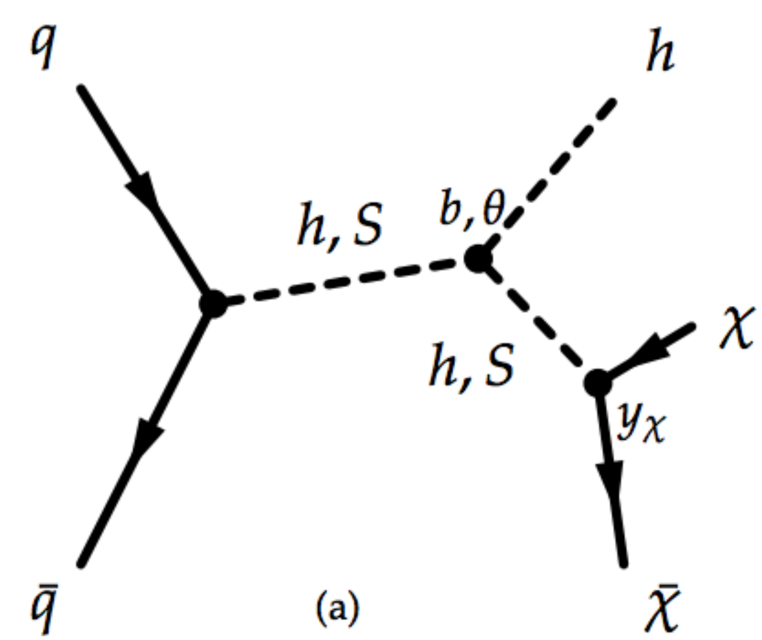
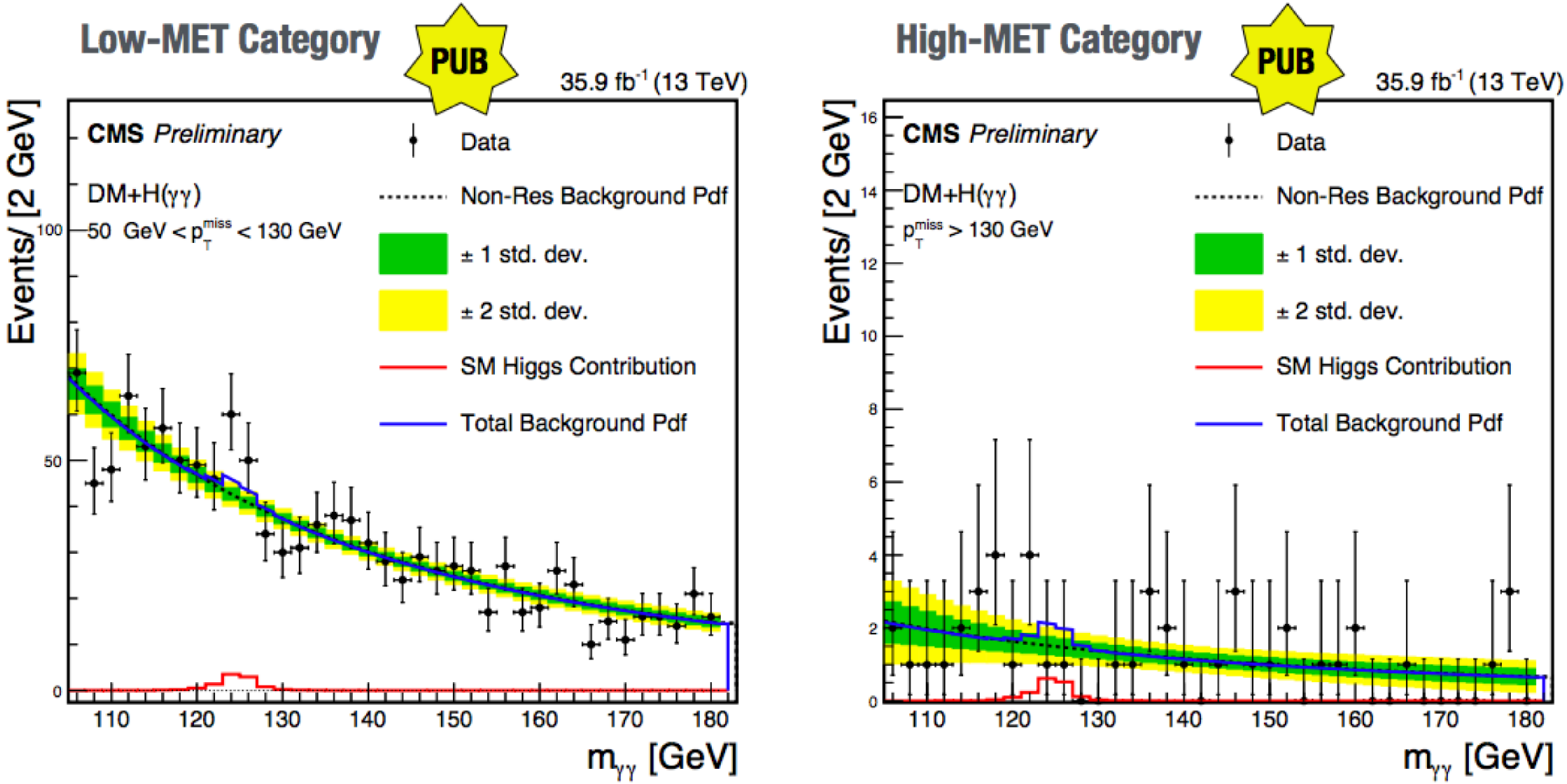




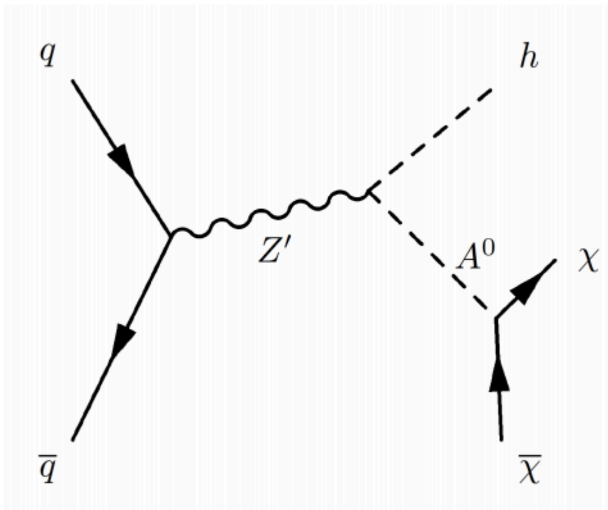
Final Fits

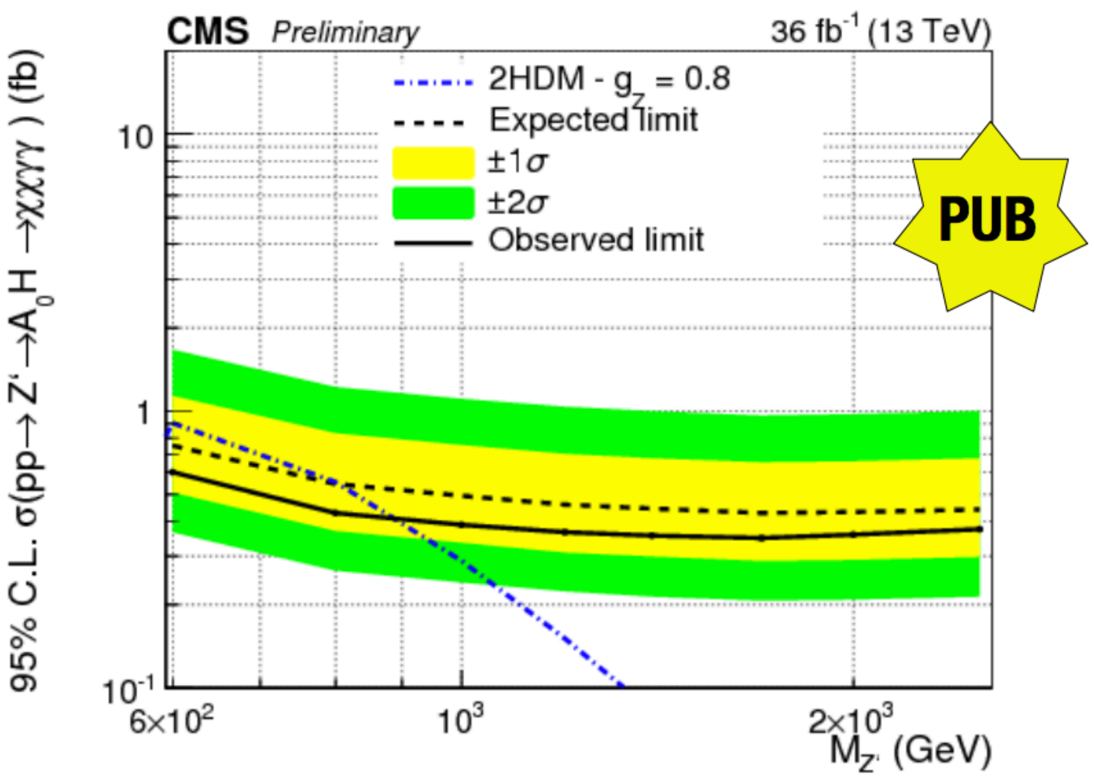
Final fit preformed with power law



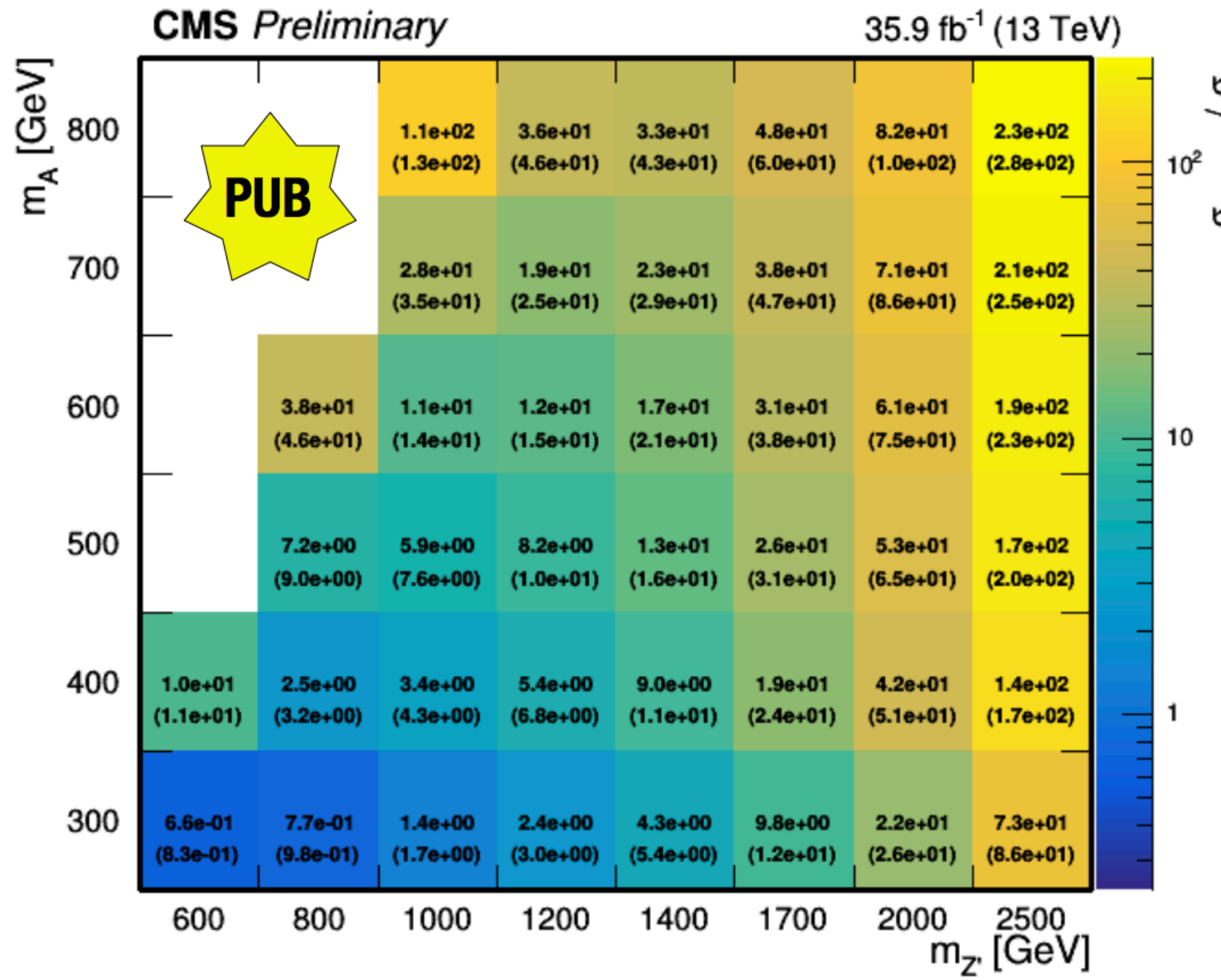
Results for 2HDM

2HDM signals with m_{A0} = 300 GeV are excluded for Z' masses below 900 GeV.





Upper limits with m_A = 300 GeV in the High-MET Category



Observed (expected) 95% CL limits on the signal strength as a function of m_A and $m_{Z'}$.

Displaced Dark Matter Signatures

- No backgrounds from SM processes: excellent **target for the HL-LHC**

- Softer-MET spectrum expected: χ_1 gets ~20% of the χ_2 momentum

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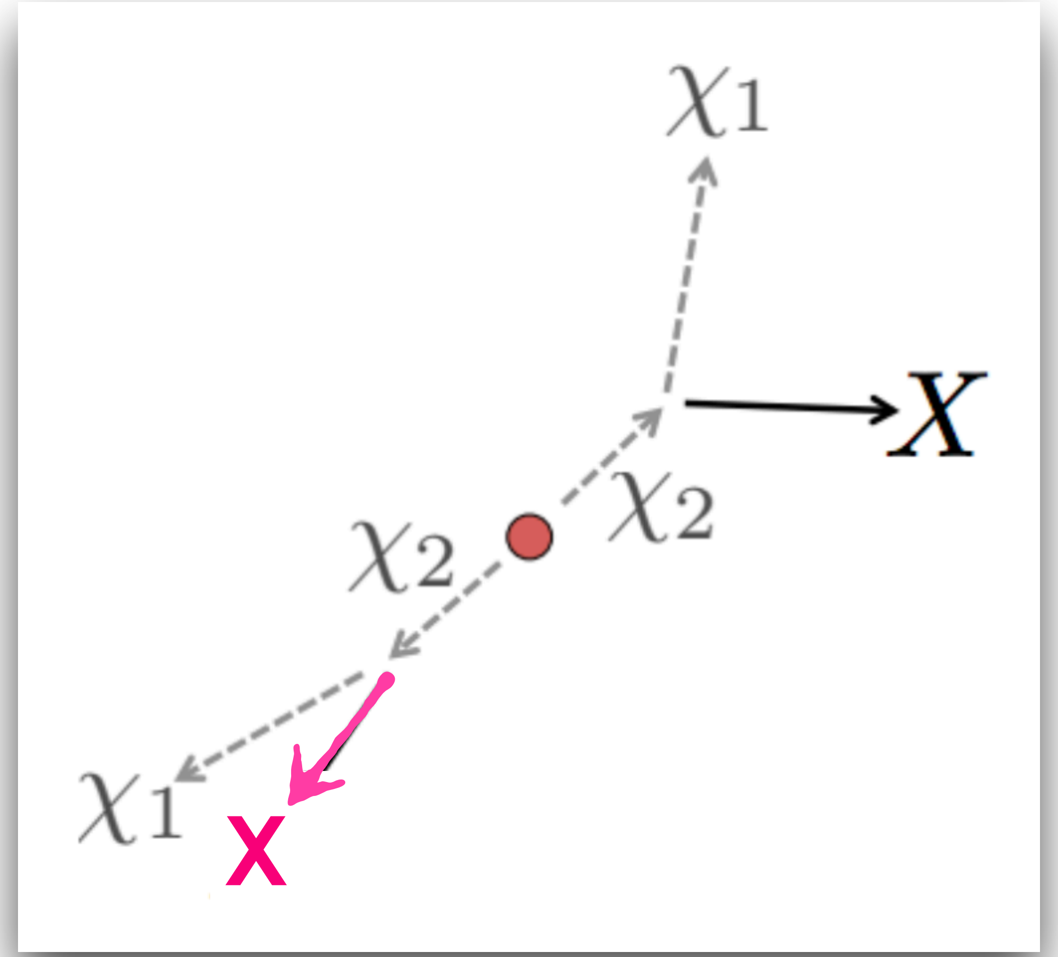
  - Plan to include this interpretation in **2017 Mono-Jet and Mono-Higgs analyses**



https://arxiv.org/pdf/1704.06515.pdf

Mono-tt(ll) @ CMS

Mono-Z(ll) @ CMS

Mono-Z(ll) @ CMS

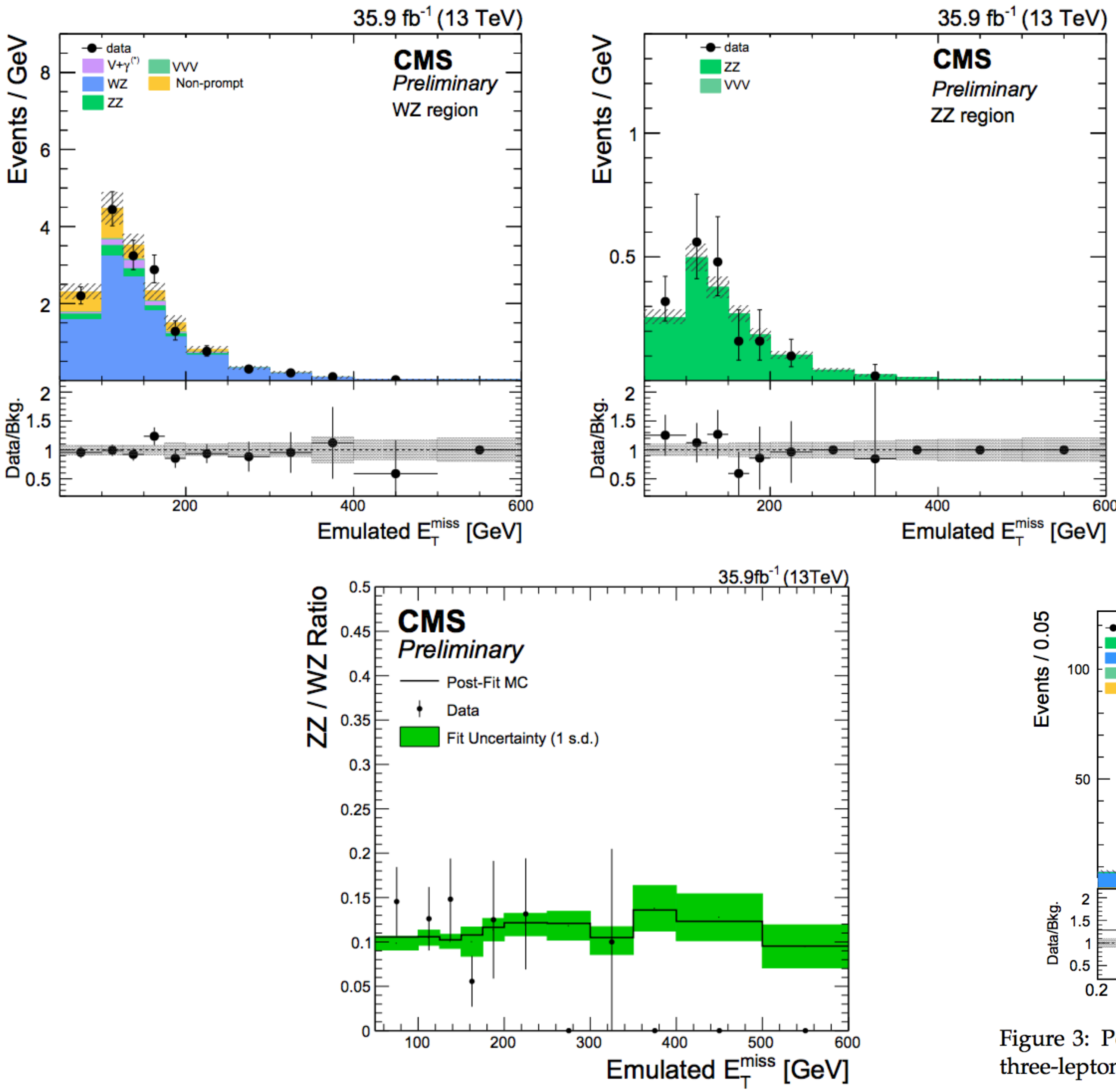


Figure 2: Emulated E_T^{miss} distribution for the WZ $\to 3\ell\nu$ (top left) and ZZ $\to 4\ell$ (top right) control regions, and the ratio between both distributions in data and simulation (bottom). Uncertainty bands correspond to the combined statistical and systematic components.

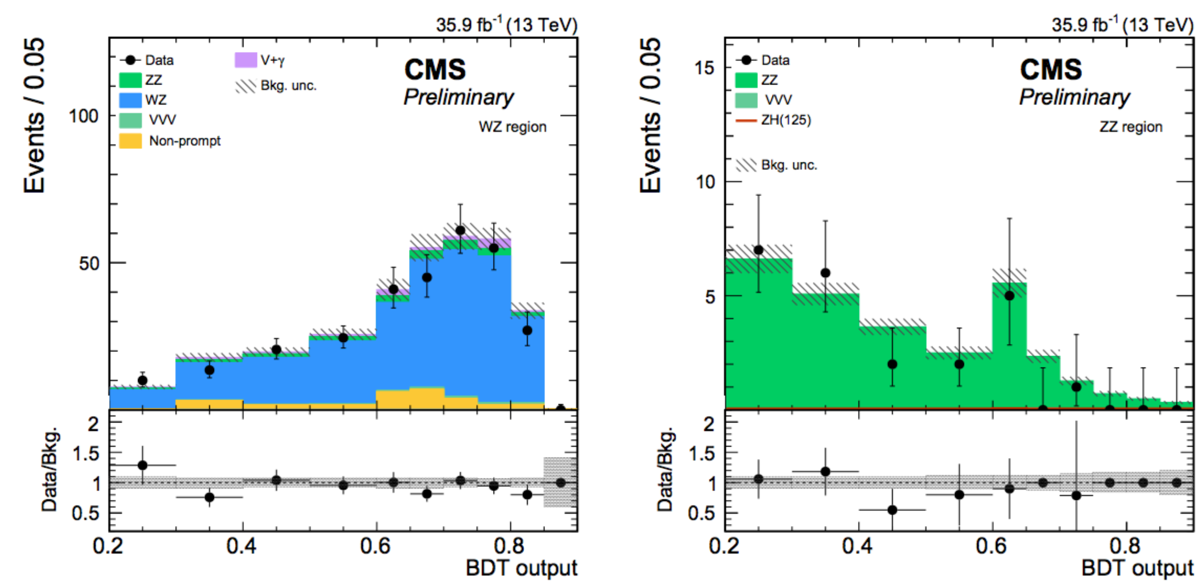
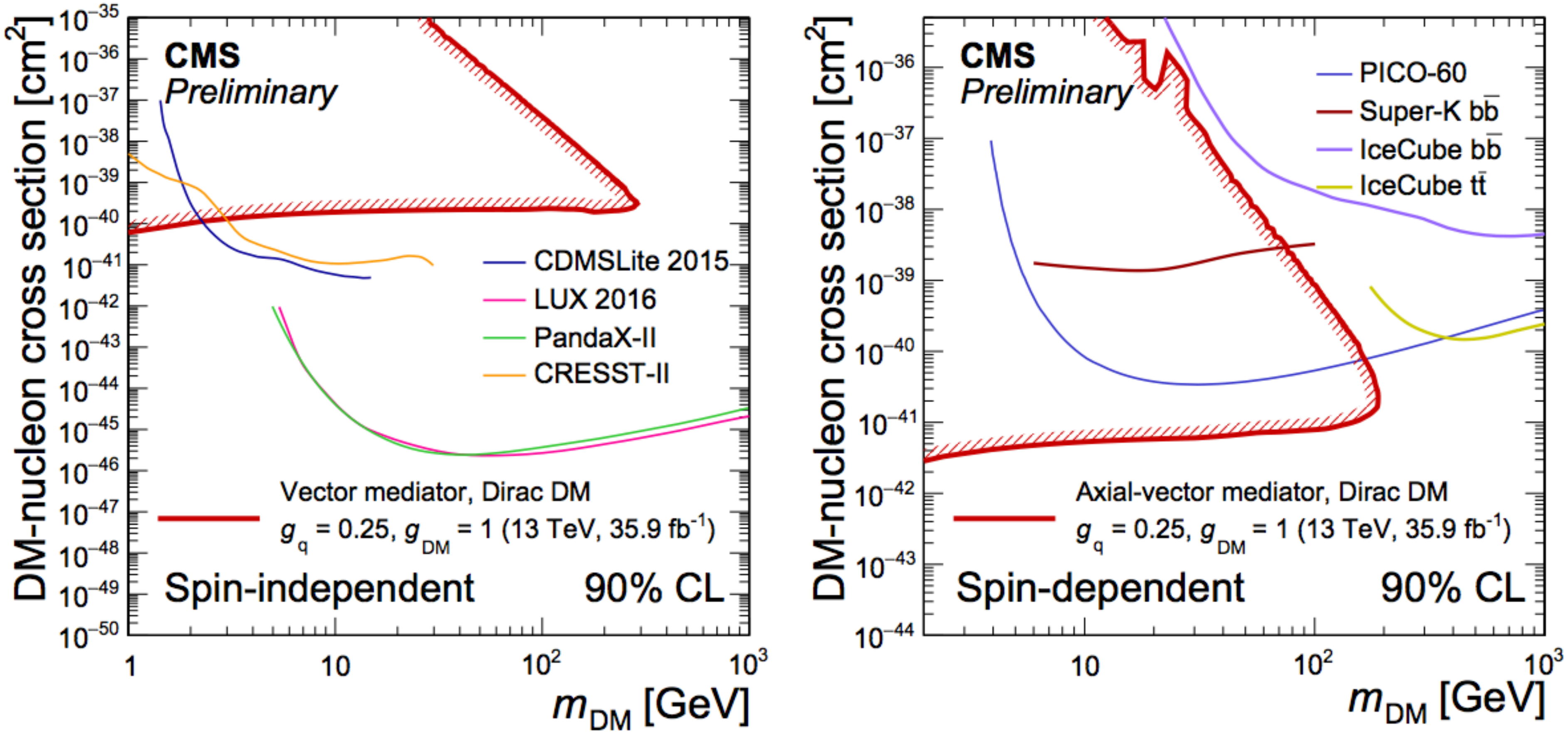
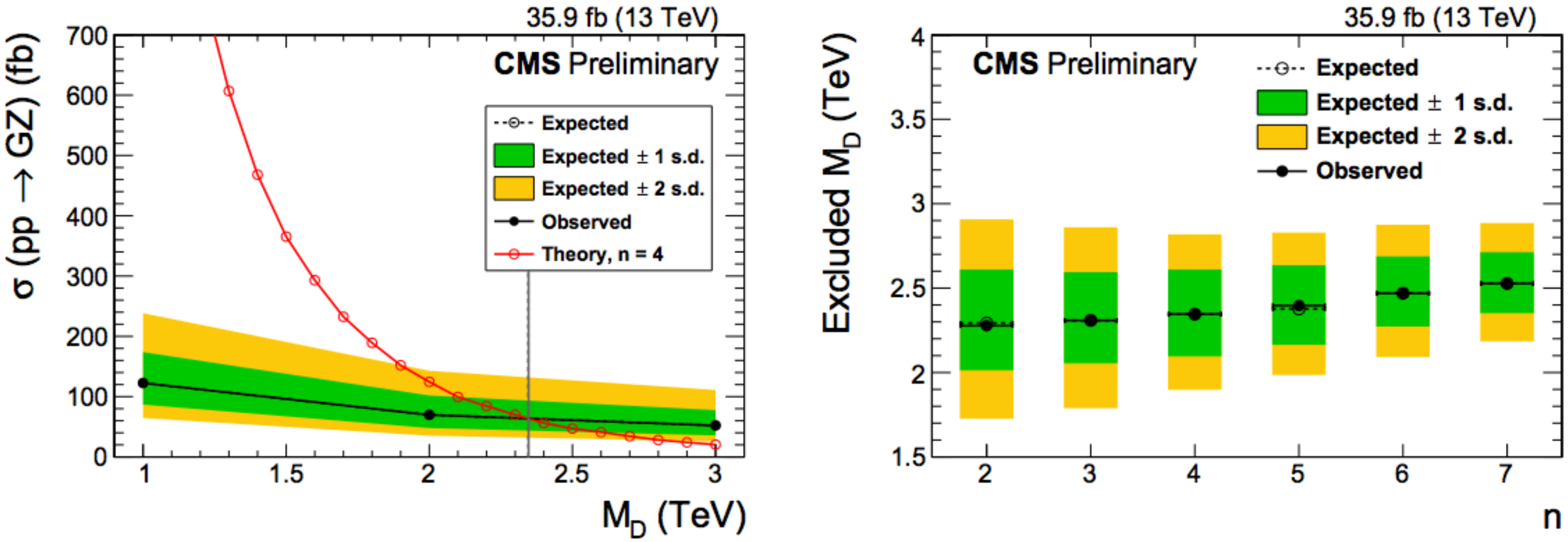


Figure 3: Post-fit distribution of the BDT classifier in the diboson control regions: (left) WZ three-lepton region; (right) ZZ four-lepton region.

Mono-Z(ll) @ CMS



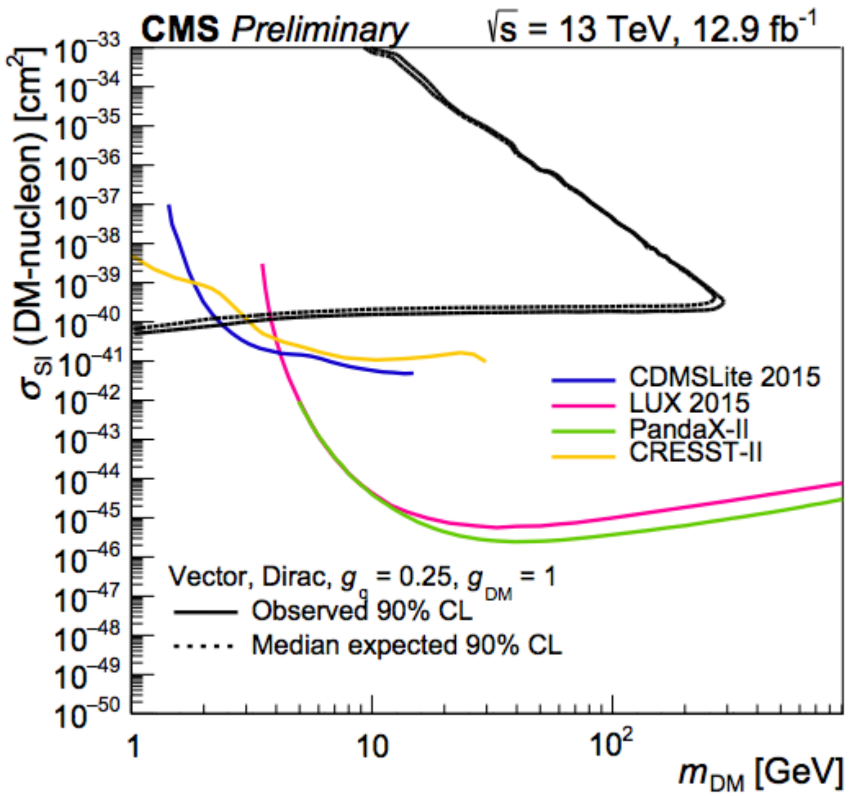
CMS
Preliminary
CDMSLite 2015
LUX 2016
PandaX-II
CRESST-II
Vector mediator, Dirac DM
g_q = 0.25, g_DM = 1 (13 TeV, 35.9 fb^-1)
Spin-independent
90% CL
DM-nucleon cross section [cm^2]
m_DM [GeV]
PICO-60
Super-K bb̄
IceCube bb̄
IceCube tt̄
Axial-vector mediator, Dirac DM
Spin-dependent

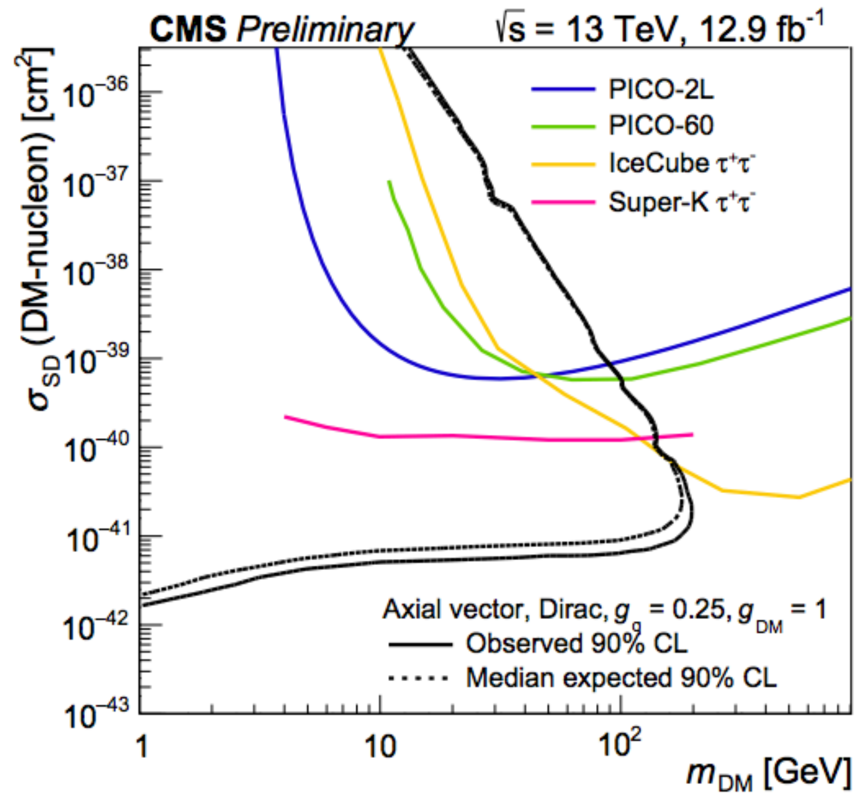


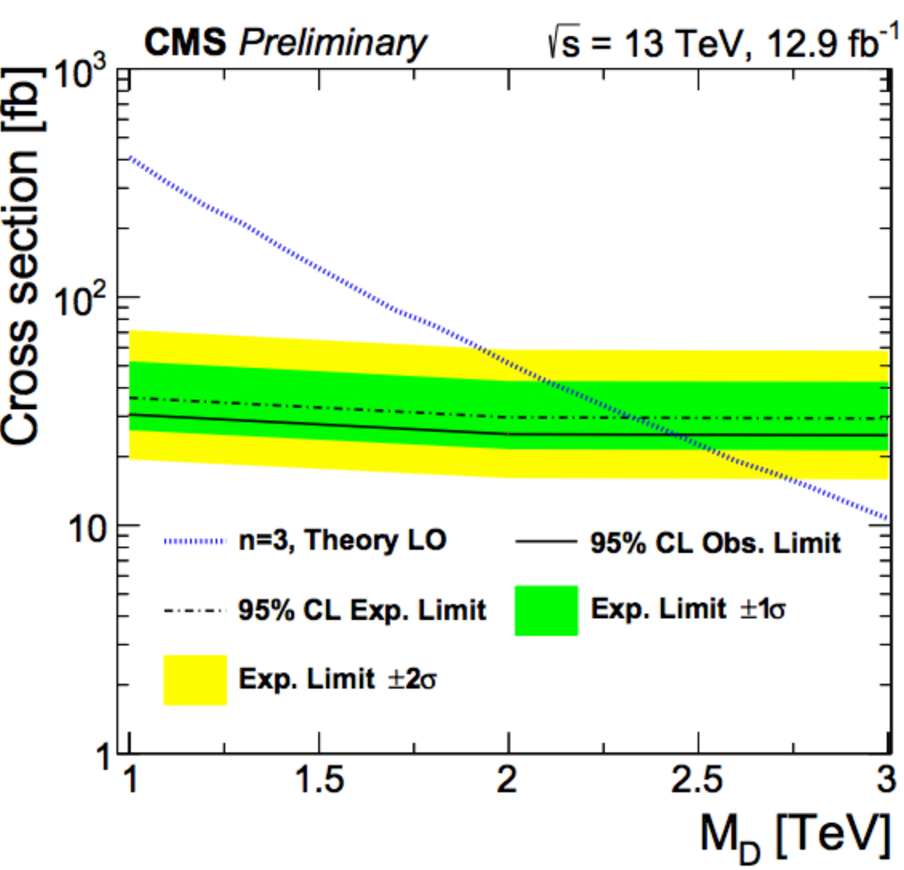
35.9 fb (13 TeV)
CMS Preliminary
Expected
Expected ± 1 s.d.
Expected ± 2 s.d.
Observed
Theory, n = 4
σ (pp → GZ) (fb)
M_D (TeV)
Excluded M_D (TeV)
n

Mono-Photon @ CMS

Mono-Photon @ CMS







n	Obs. limit (TeV)	Exp. limit (TeV)
3	2.44	2.33
4	2.48	2.38
5	2.54	2.45
6	2.60	2.50

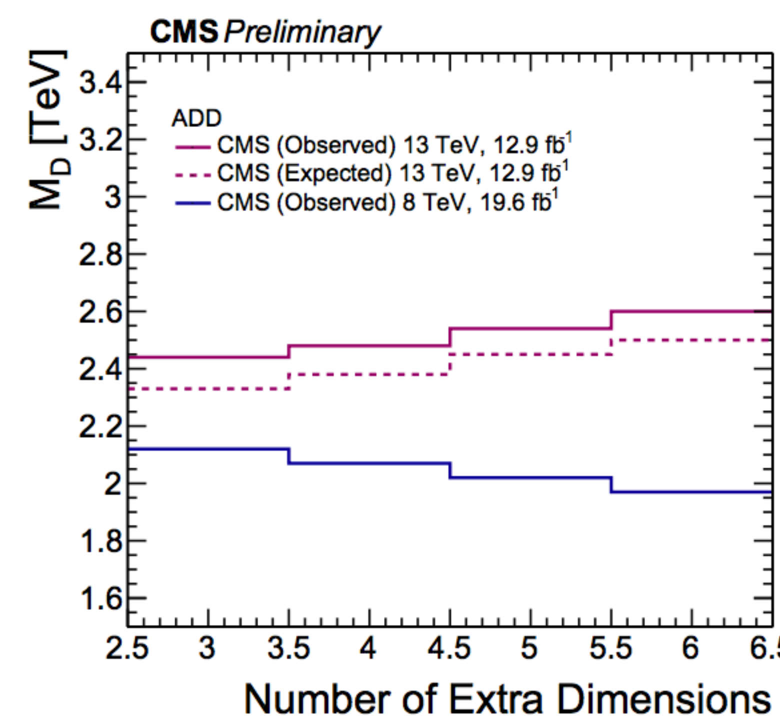


Figure 7: Lower limit on M_D as a function of n.

Mono-H(gg) @ CMS

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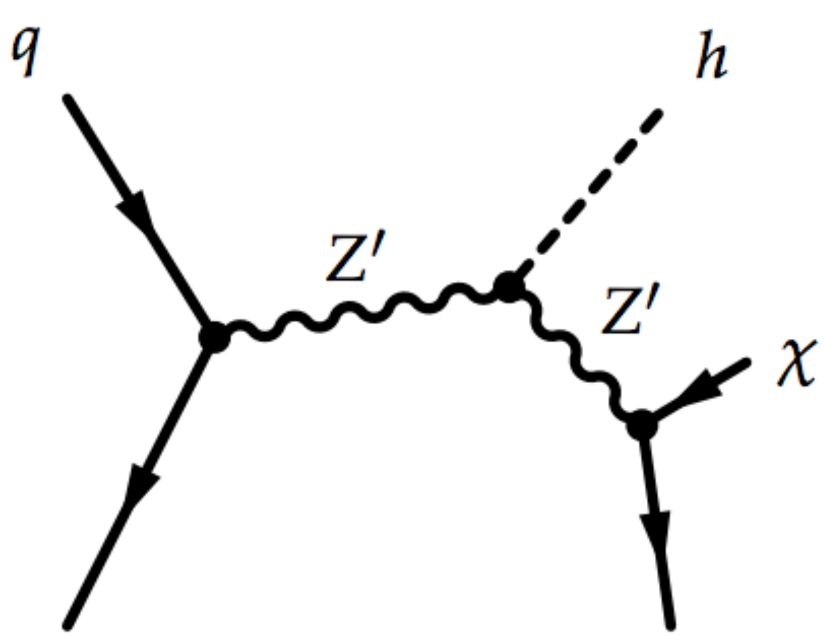
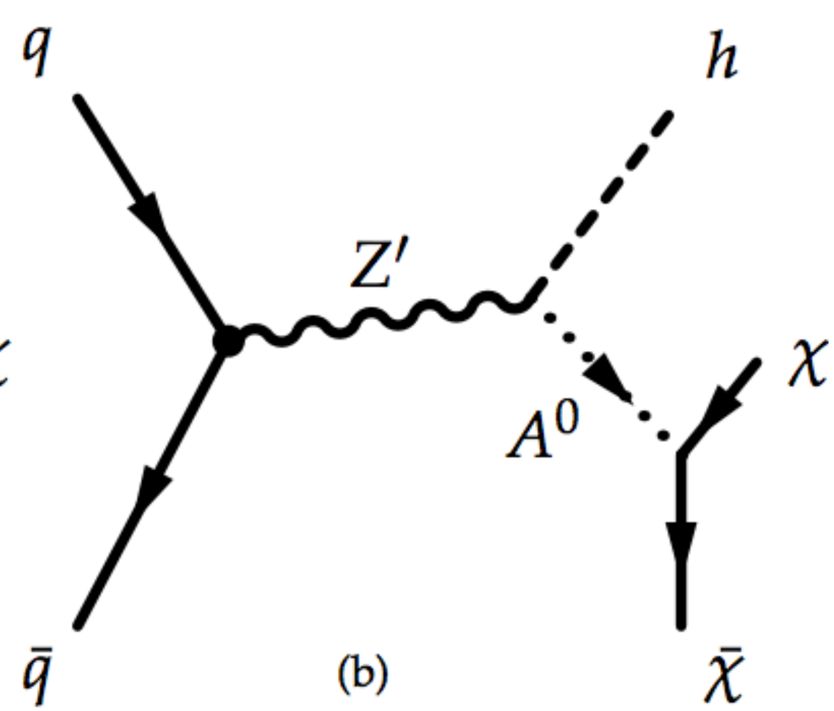
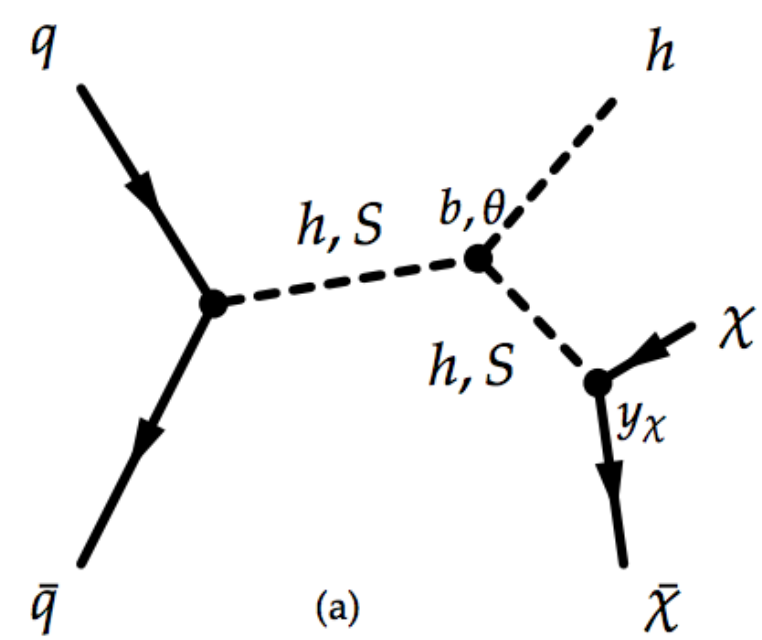


(a)



(b)



(a)

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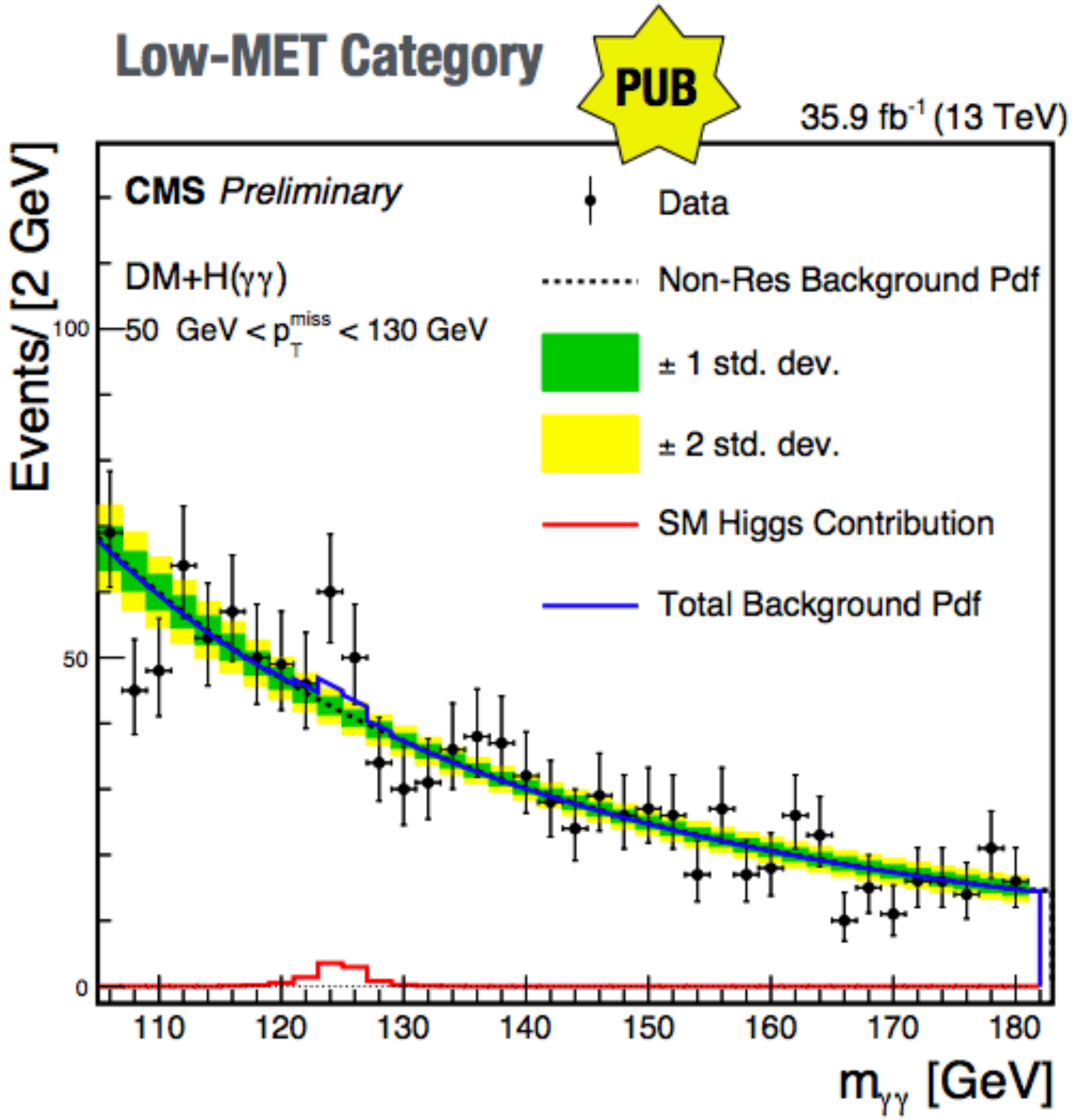
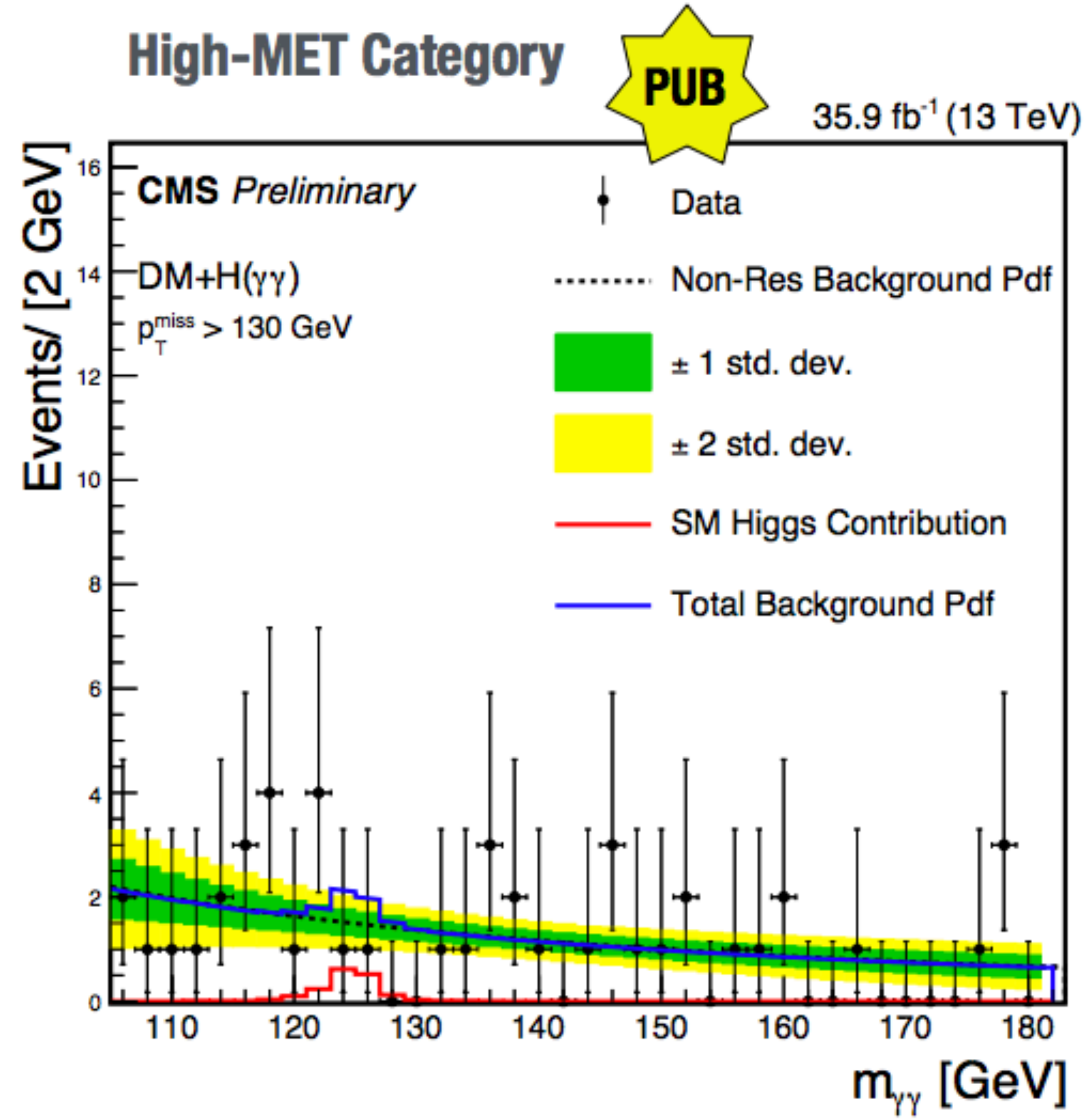
Final fit preformed with power law

Low-MET Category



High-MET Category



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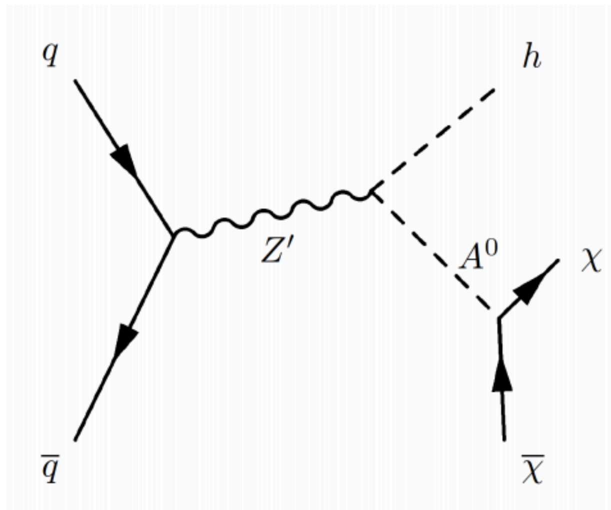

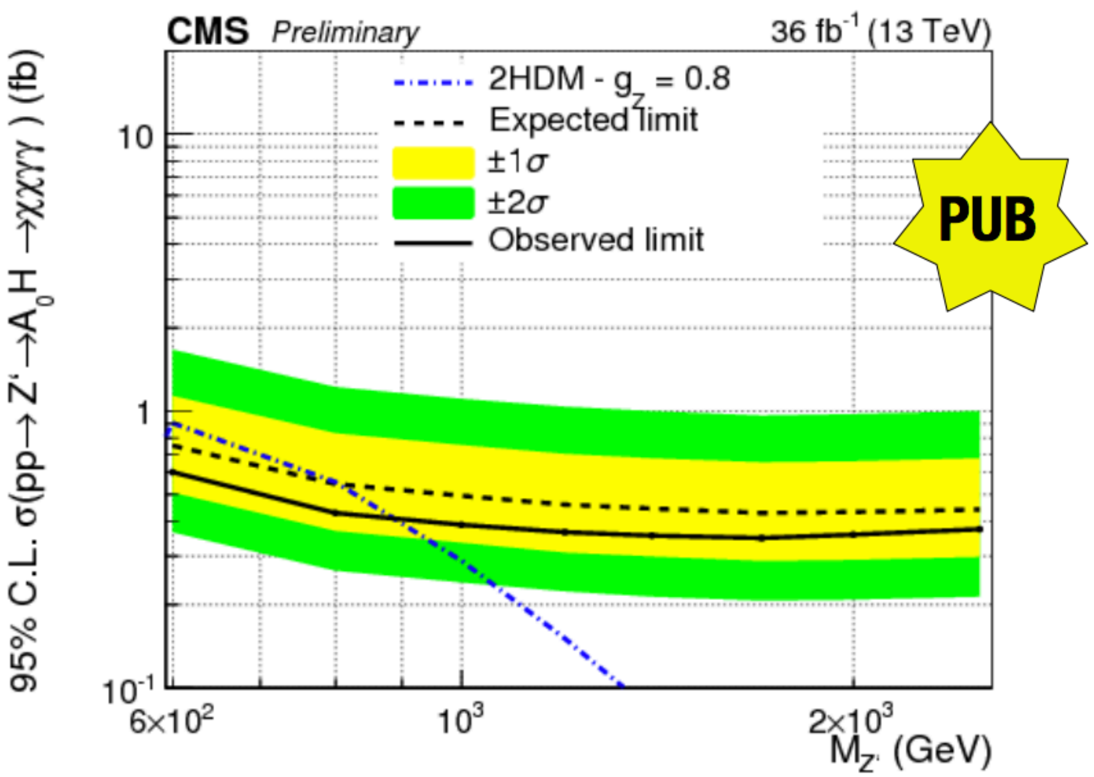

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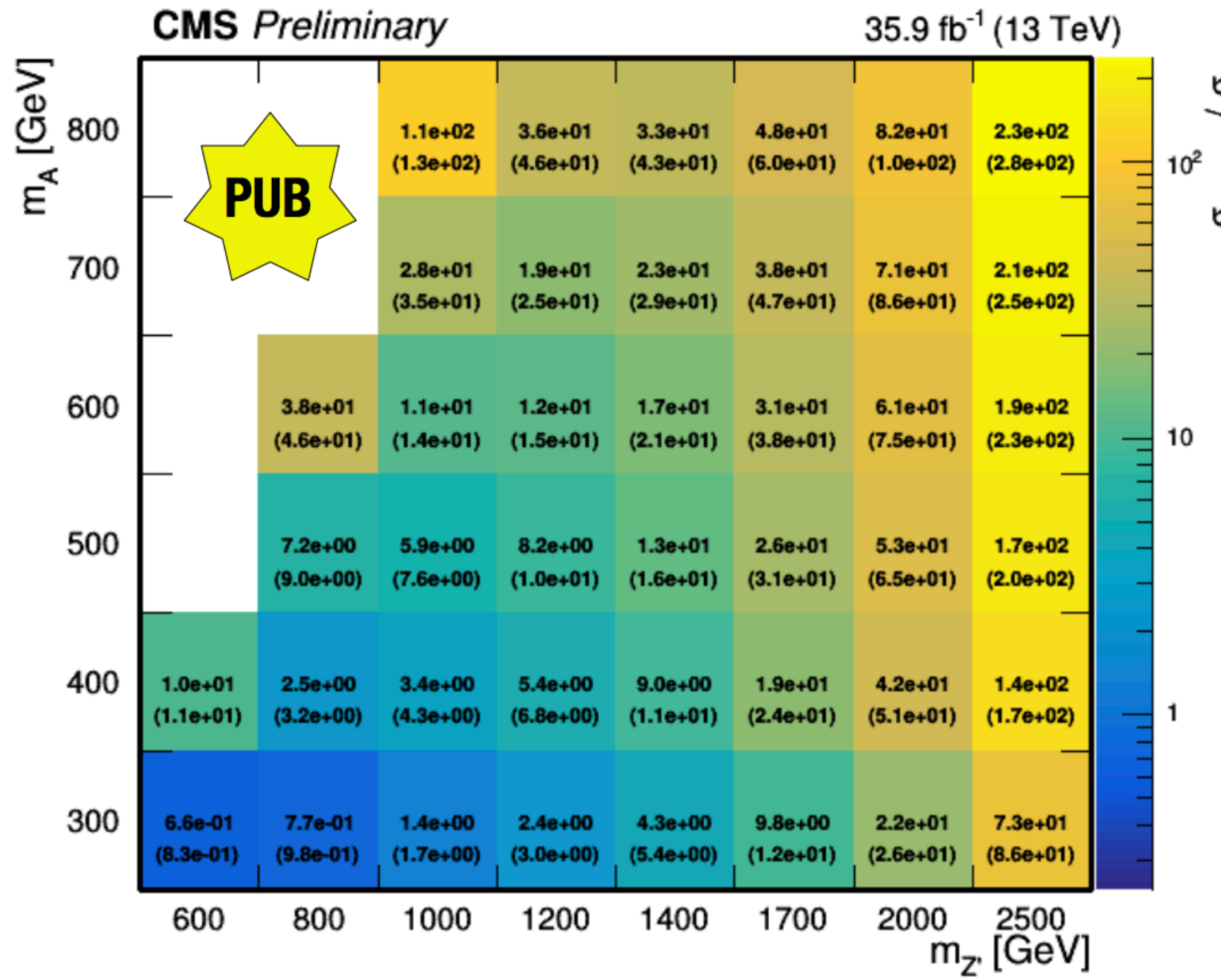

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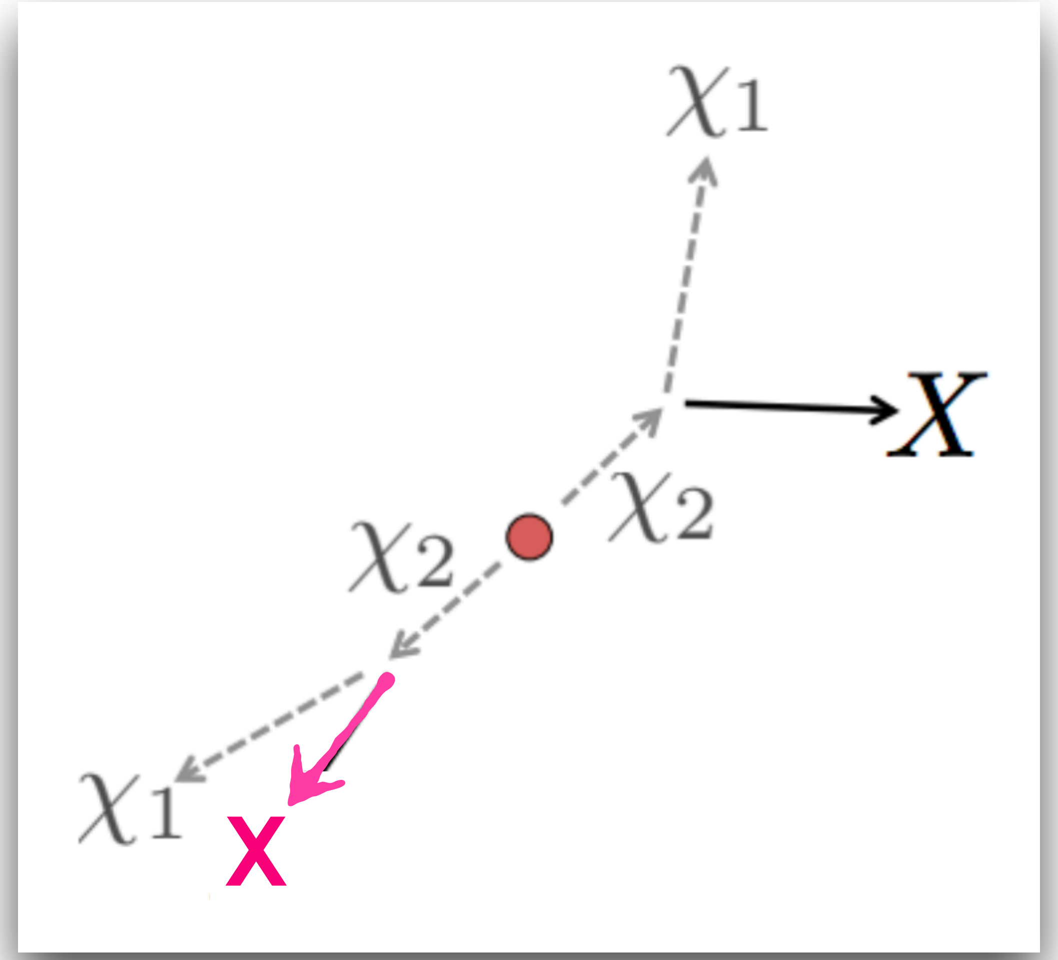

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