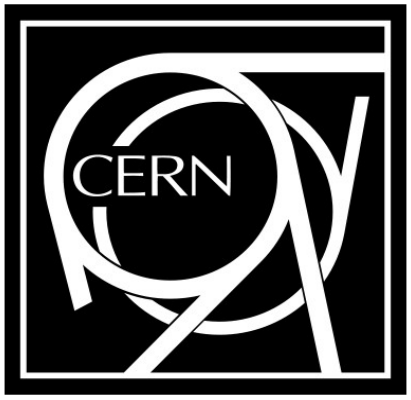
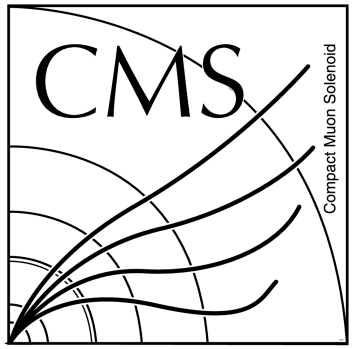
Dark matter searches:

MET+X

에너지를 누락



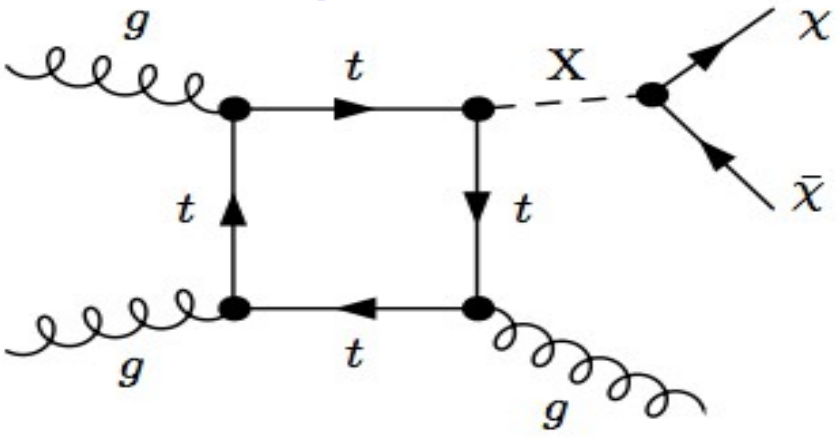
Phil Harris



Search for Dark Matter at LHC

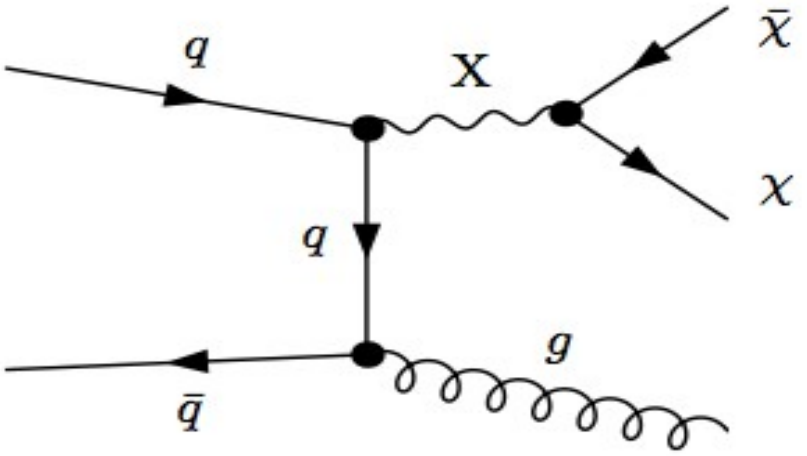
- Can split dark matter into two classes of searches

Spin 0



Yukawa coupling to quarks
(At the moment no mixing)

Spin 1



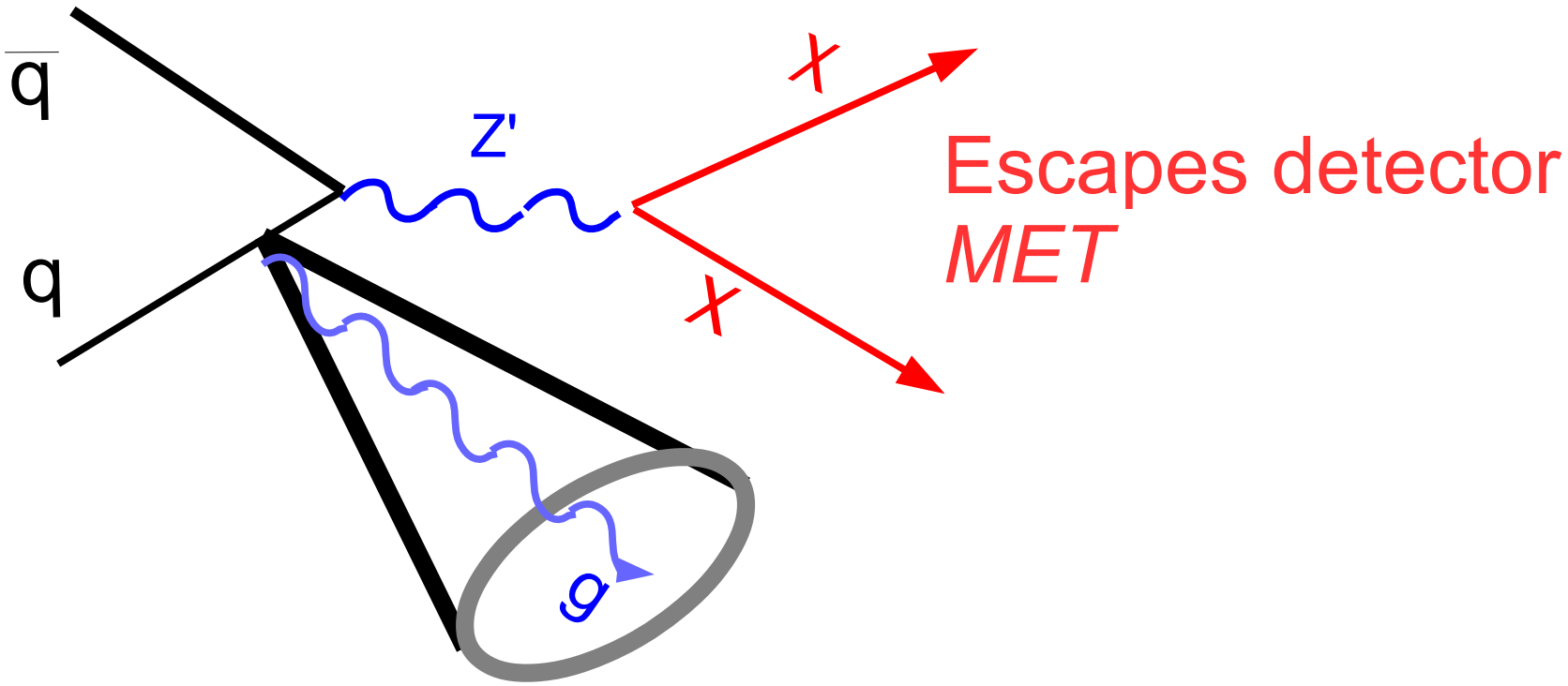
Flavor universal to quarks
(At the moment no mixing)

All dark matter searches are really
a search for Dark Matter + A mediator

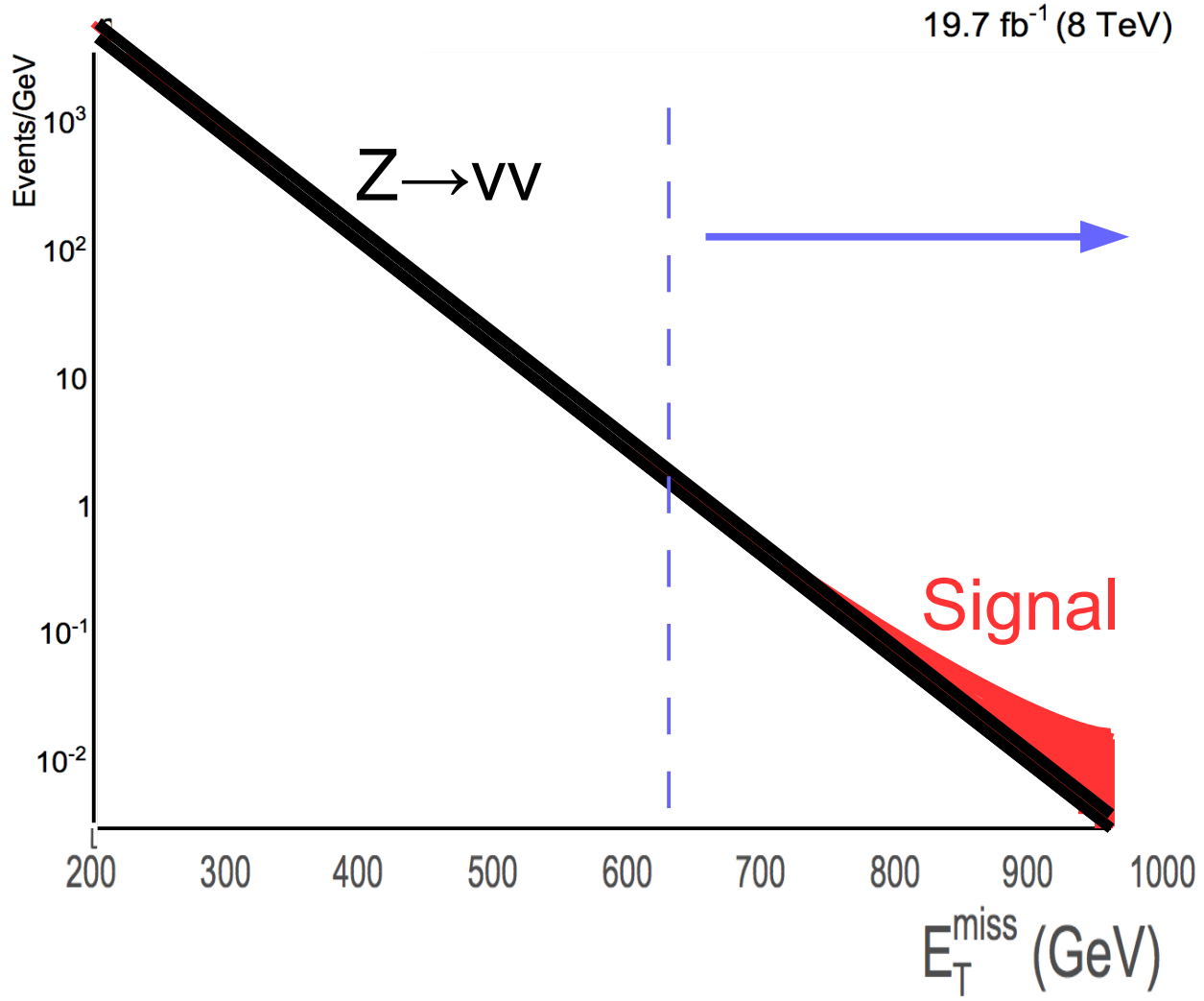
Experimental Strategy

The Basic Monojet Search

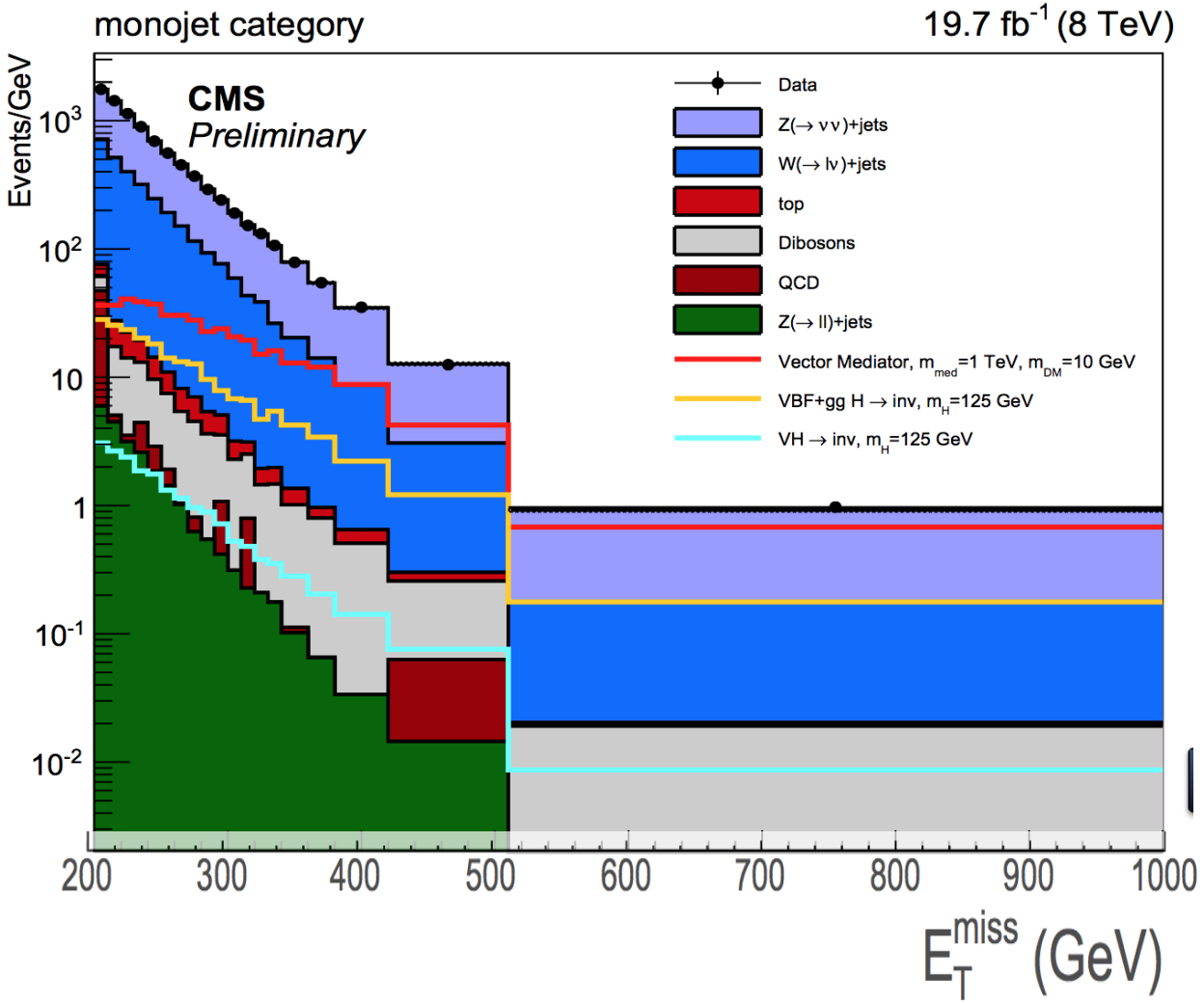
Escaping detector gives us signatures of *MET*



How do we search?



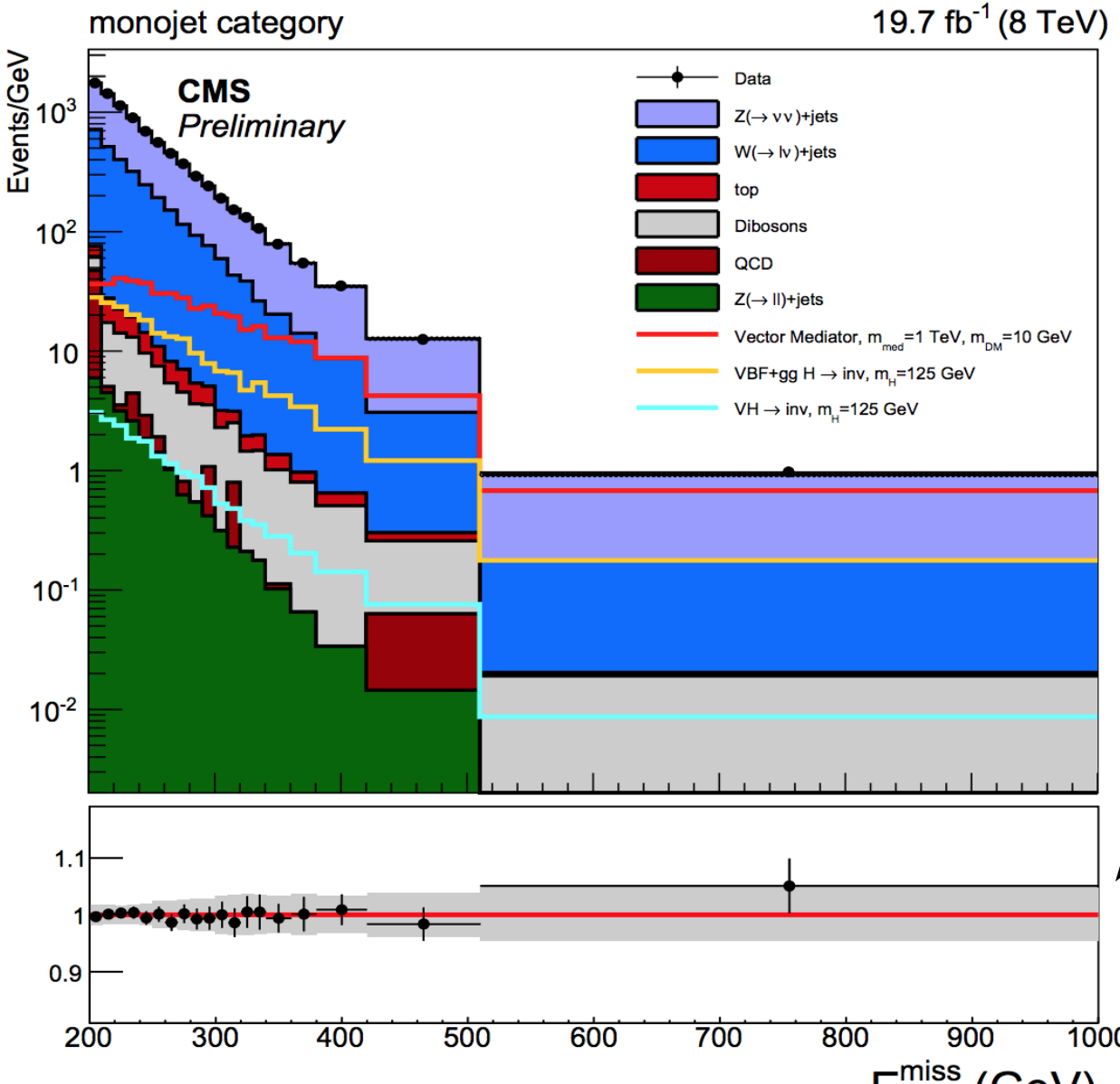
How do we search(data)?



MonoJet Selection

CMS-EXO-12-055

How do we search(data)?

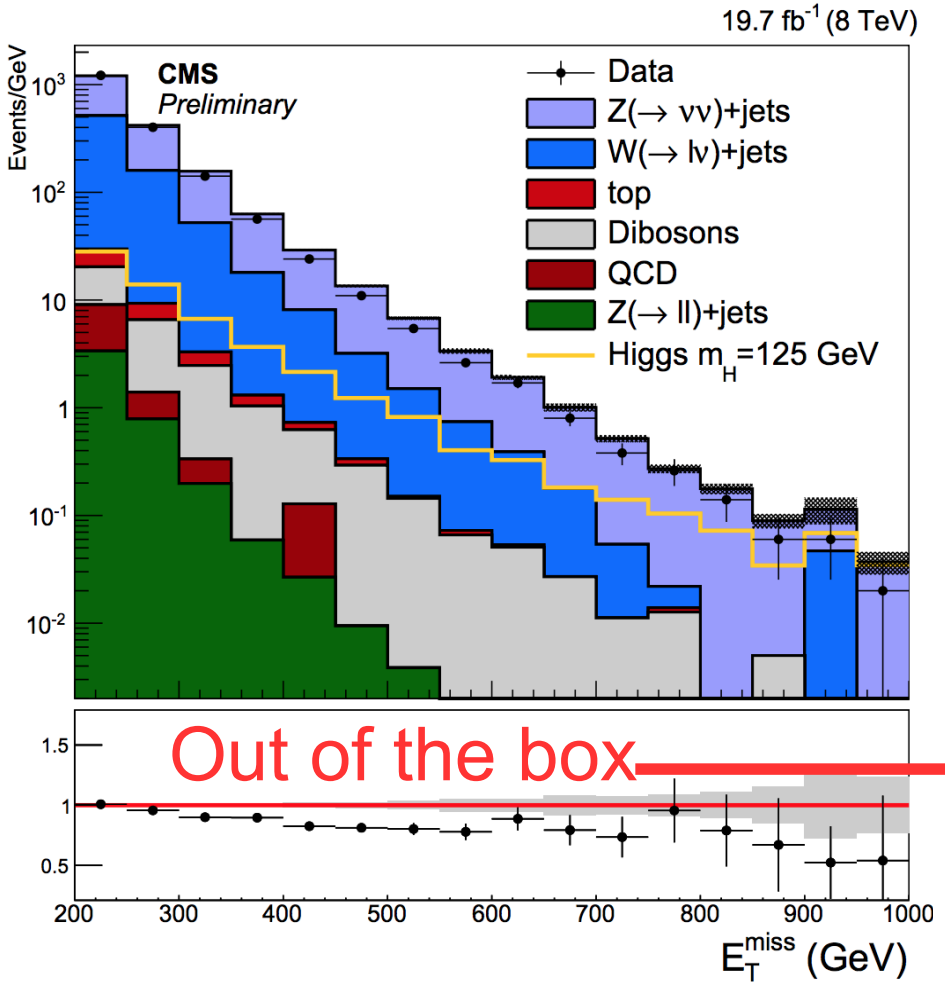


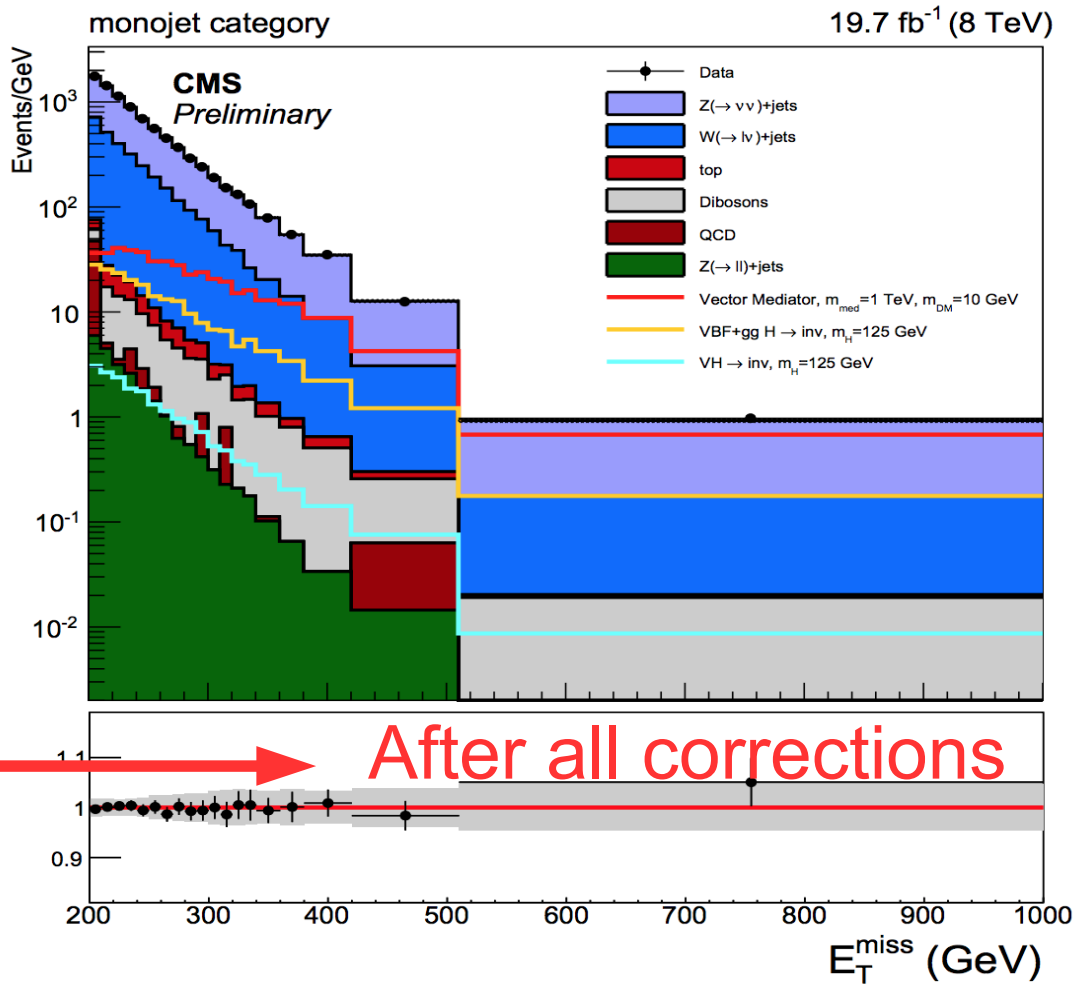
MonoJet Selection

Its a precision analysis

CMS-EXO-12-055

How do we get to this precision?

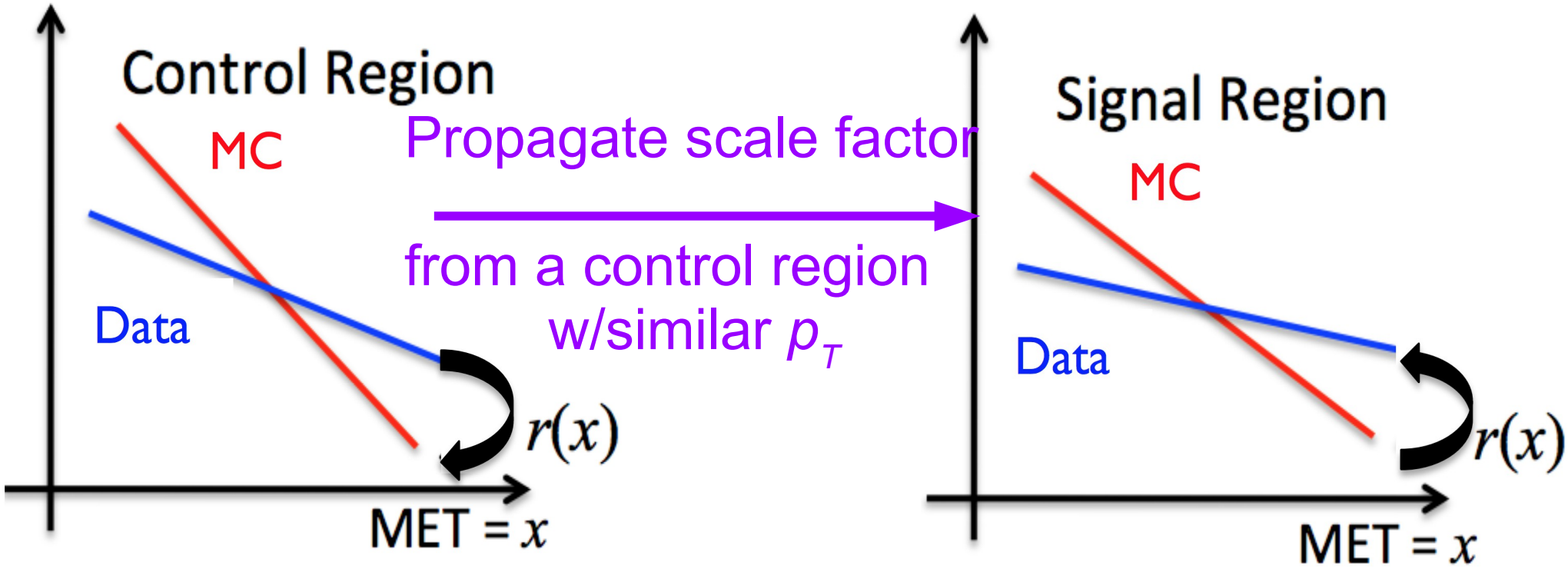




Rely on a series of control regions to correct for the data/MC agreement

CMS-EXO-16-010
CMS-EXO-12-055

Strategy to fix agreement



Control: another decay of a Z boson

$Z \rightarrow \mu\mu$ ~~$Z \rightarrow \mu\mu$~~ $\rightarrow Z \rightarrow \nu\nu$

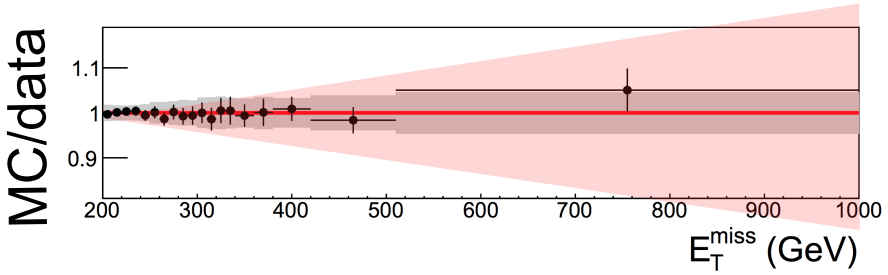
Remove

Problem is control regions have less events than signal

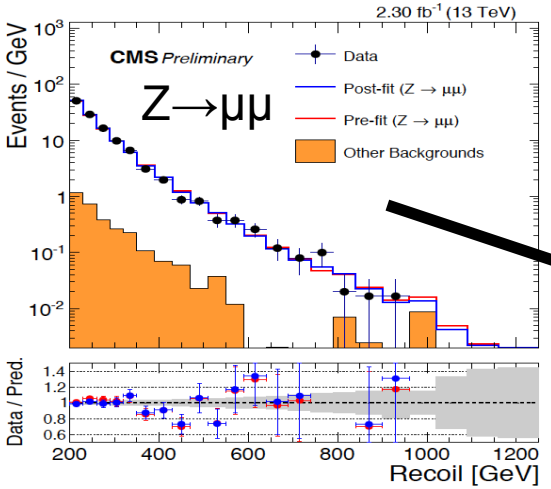
$\sigma_{\mu\mu} = 0.1\ \sigma_{\nu\nu}$ → Statistical precision is 4x worse

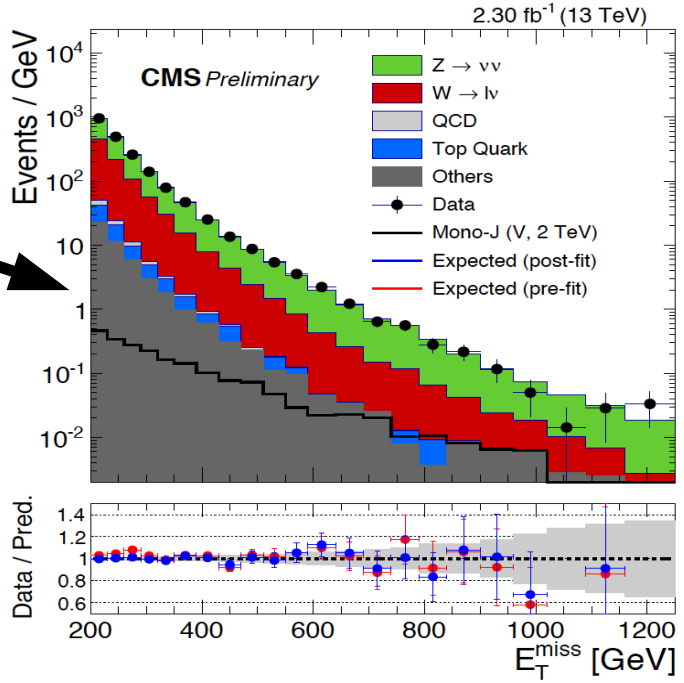
Not good enough!

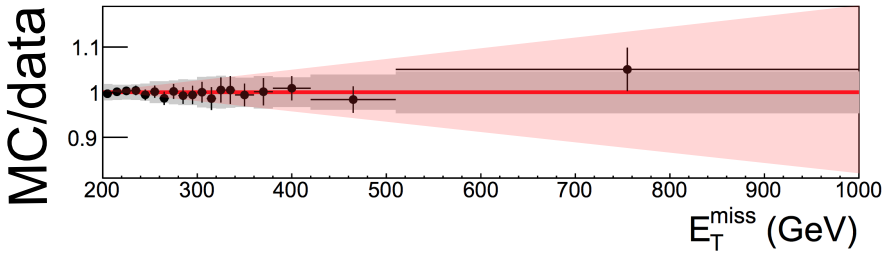
CMS-EXO-16-010
CMS-EXO-12-055



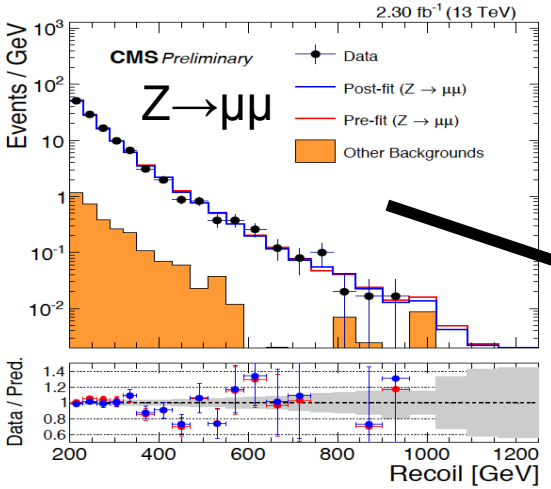
1 Control region
100% uncertainty @ 1 TeV

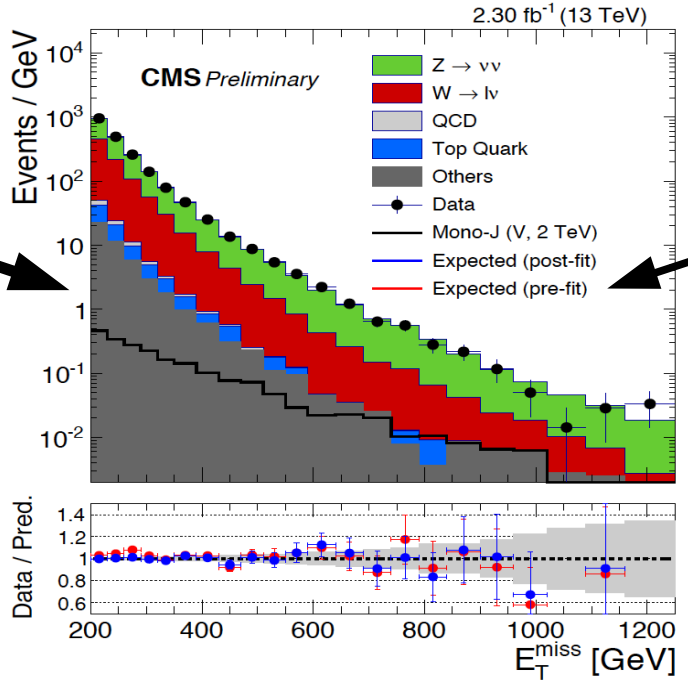


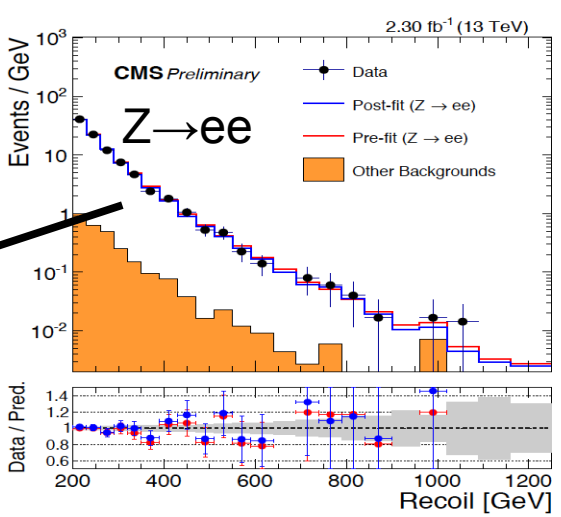


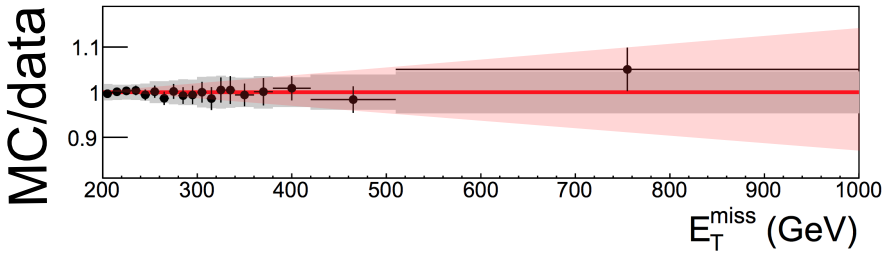


2 Control regions
60% uncertainty @ 1 TeV

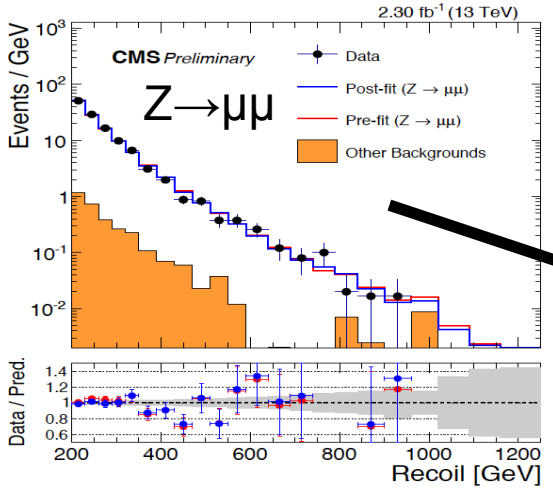


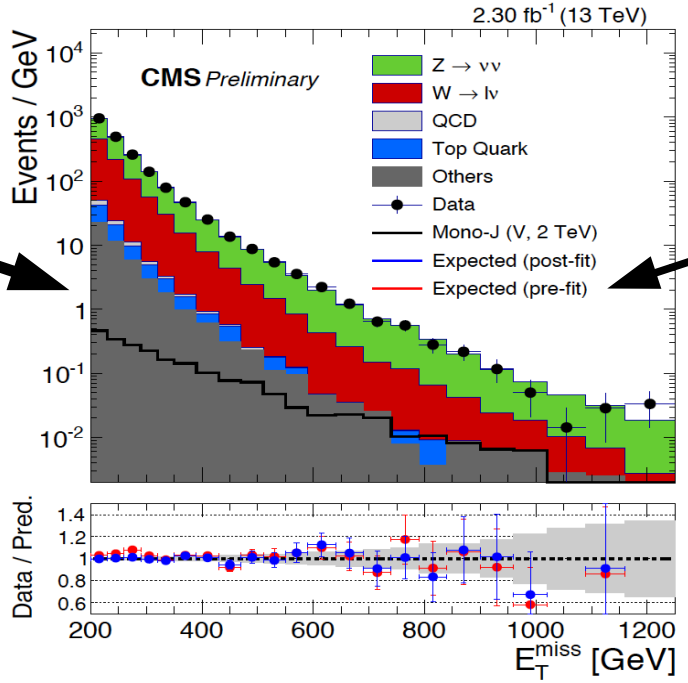


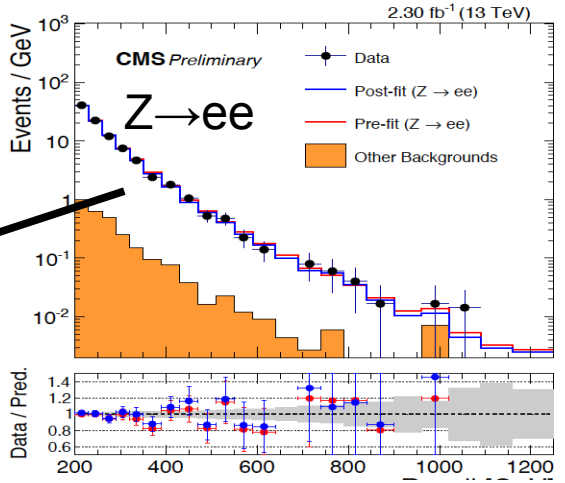


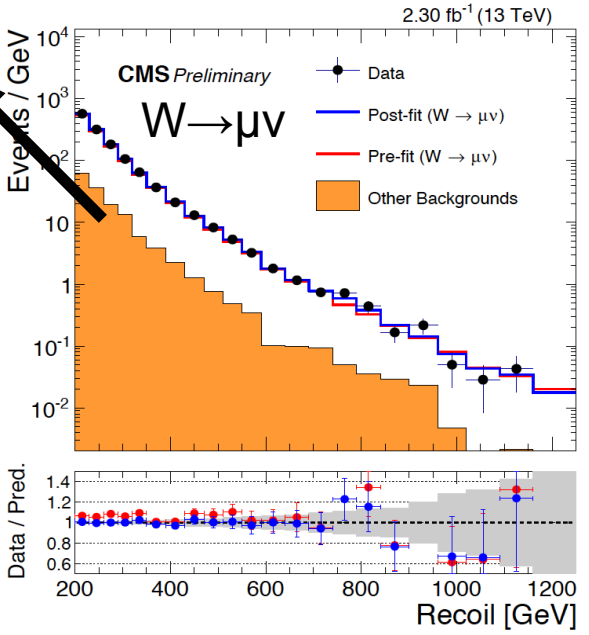


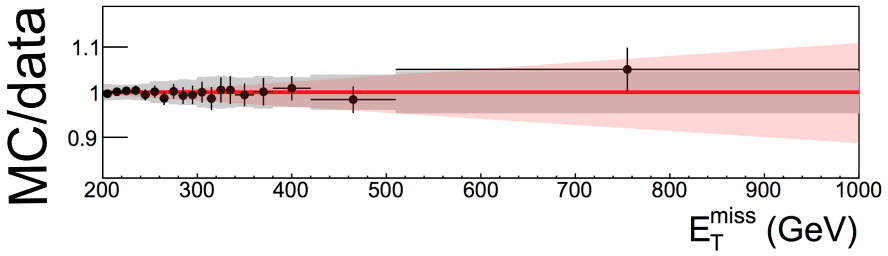
3 Control regions
40% uncertainty @ 1 TeV



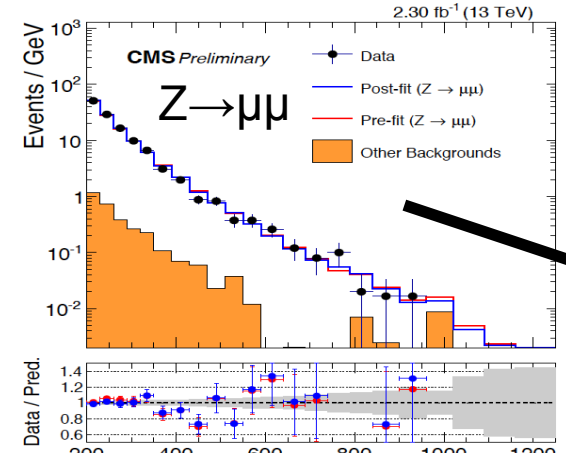


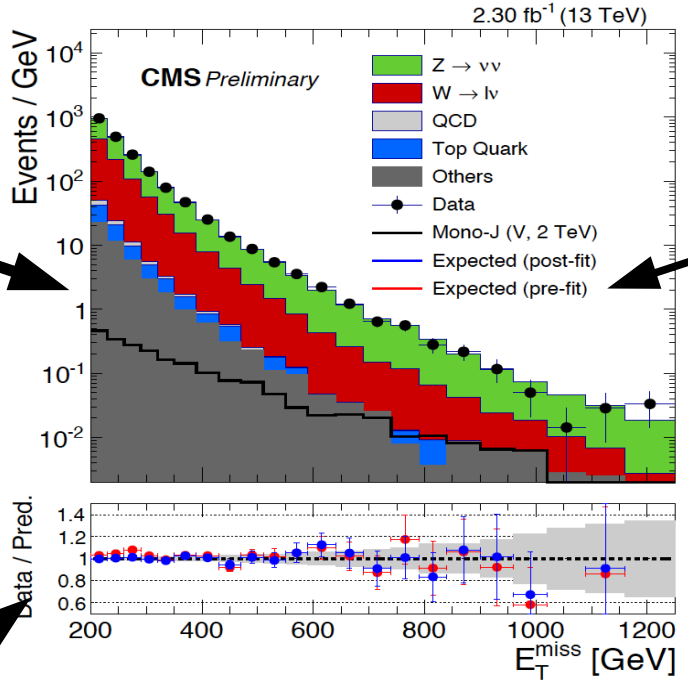


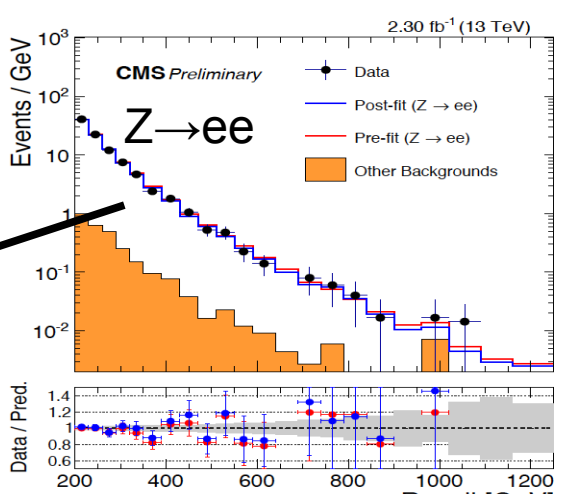


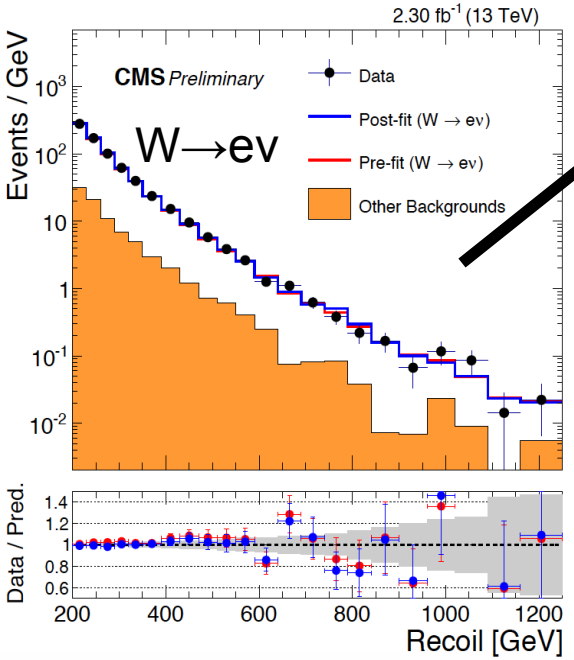


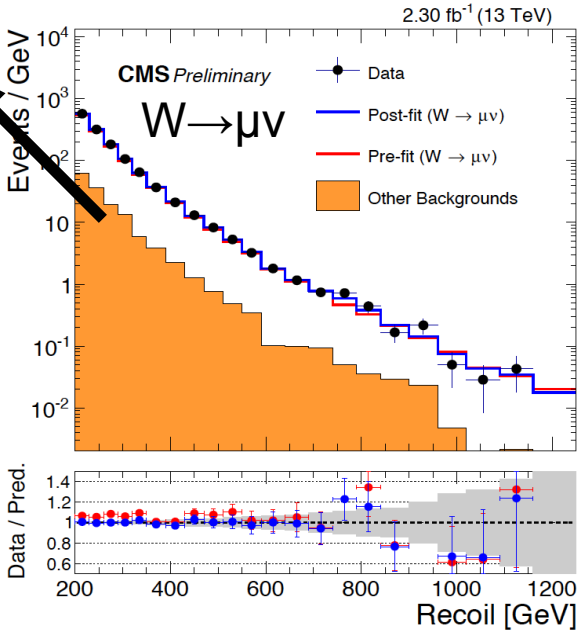
4 Control regions
30% uncertainty @ 1 TeV

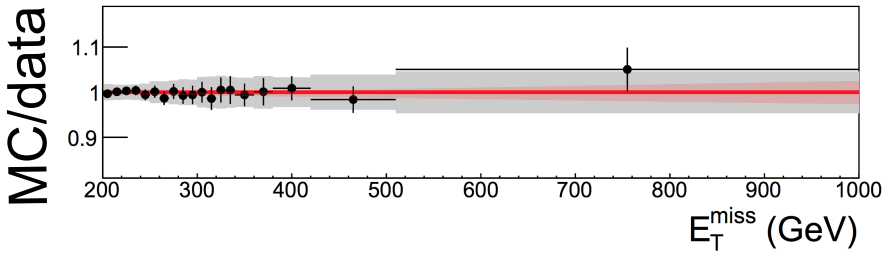




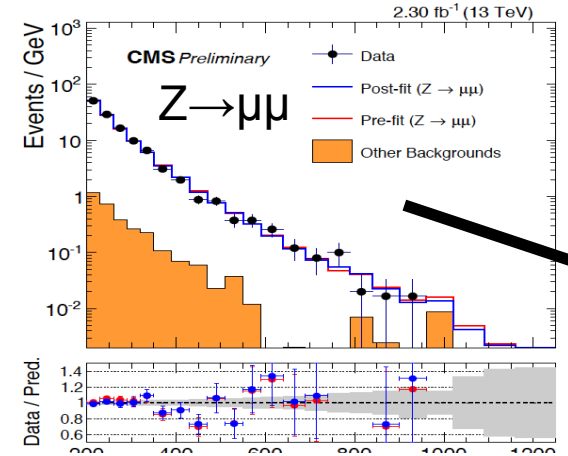


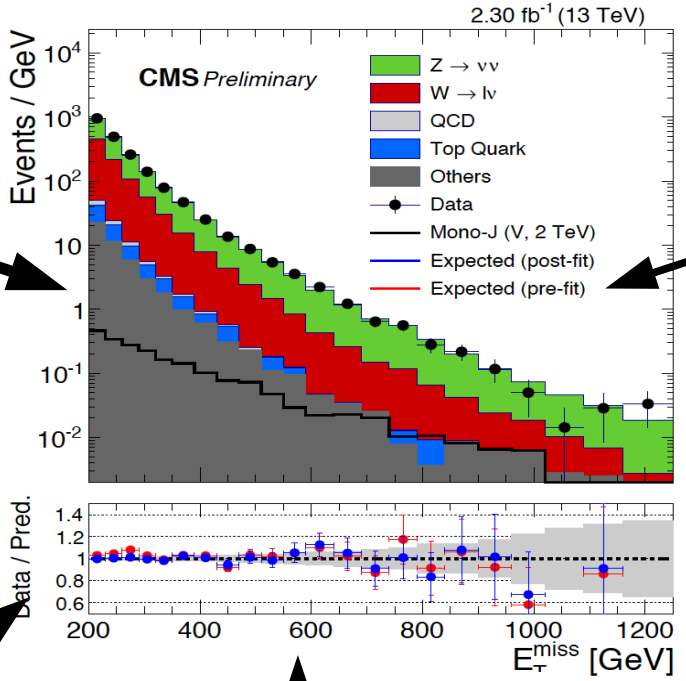


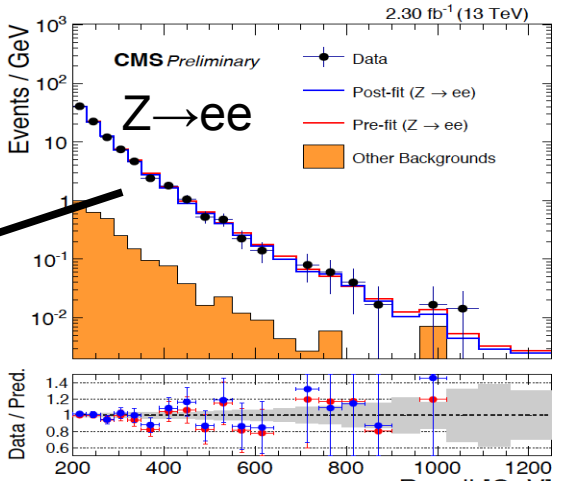


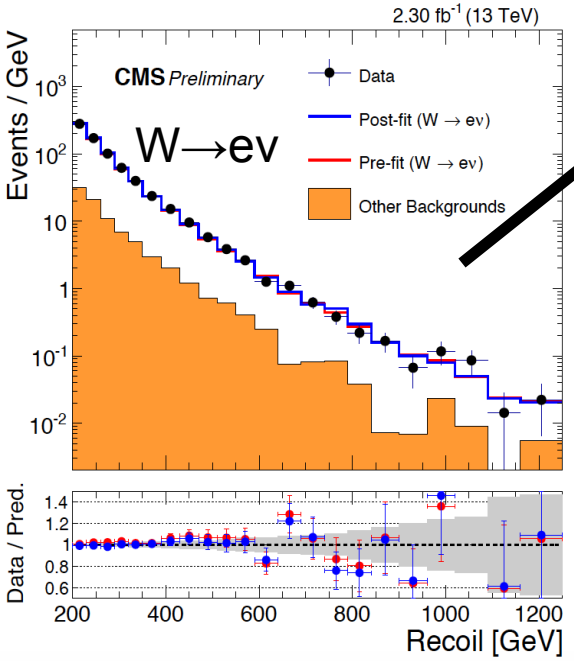


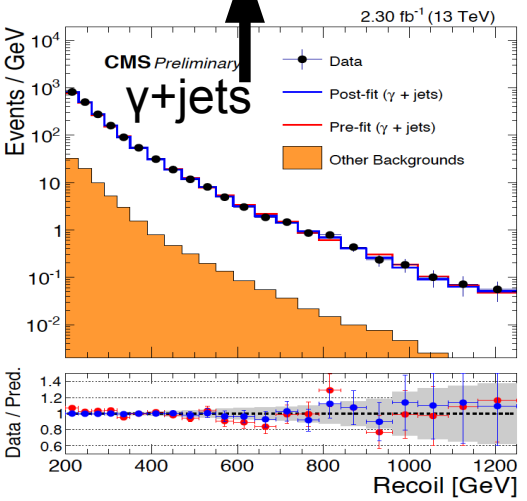
5 Control regions
15% uncertainty @ 1 TeV

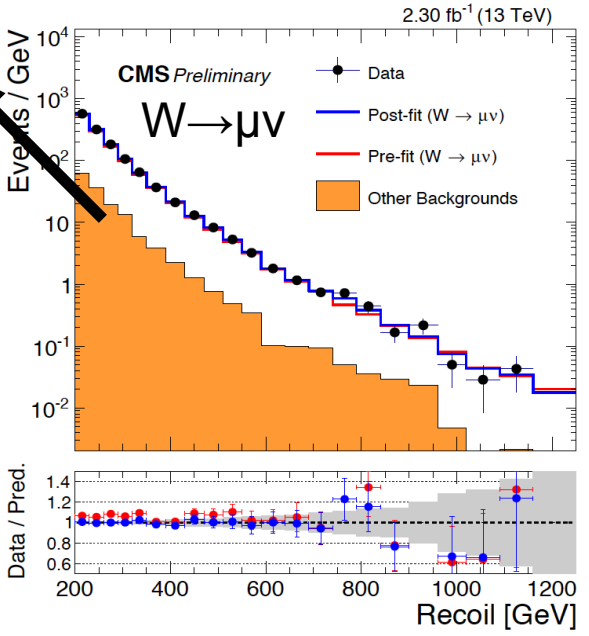


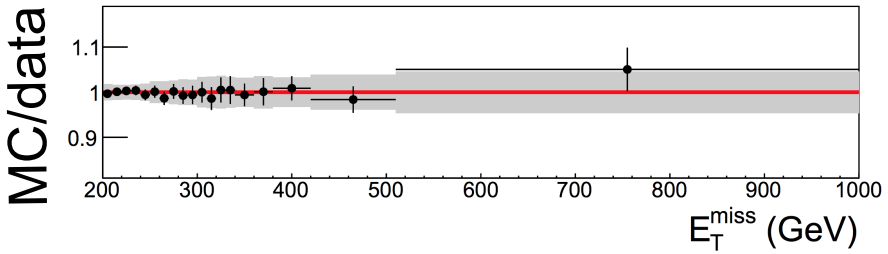




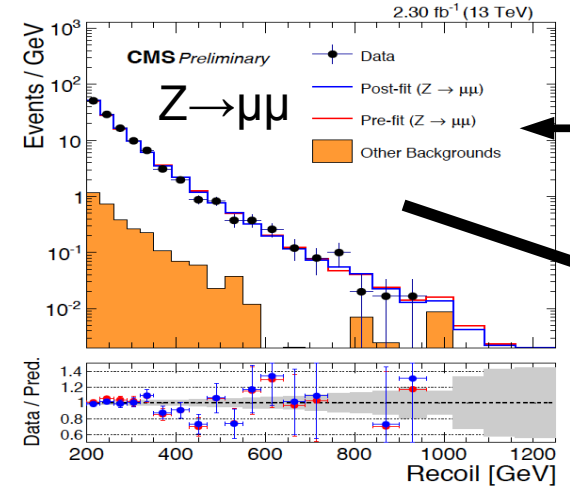


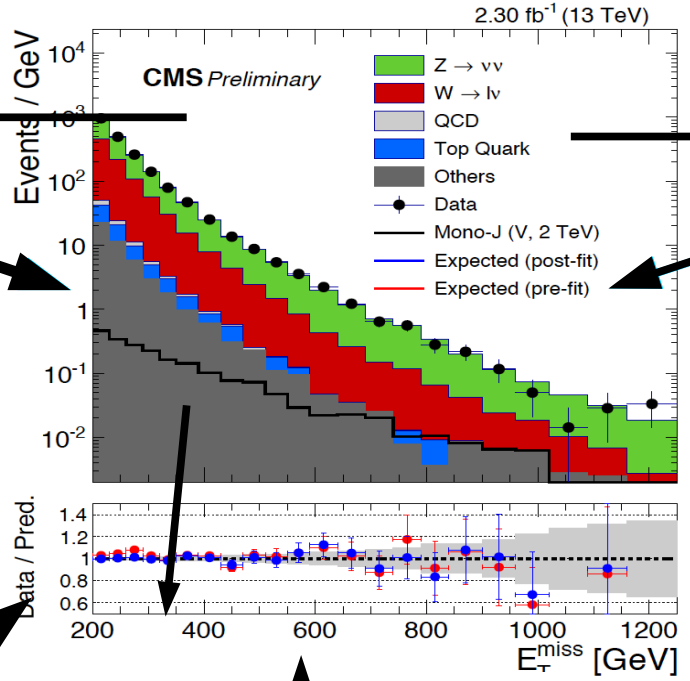


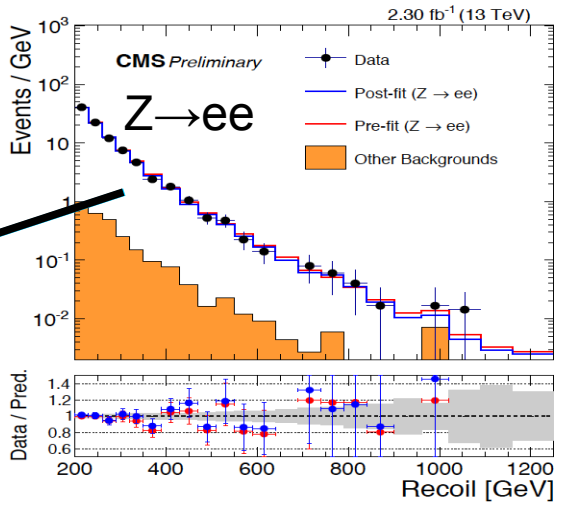


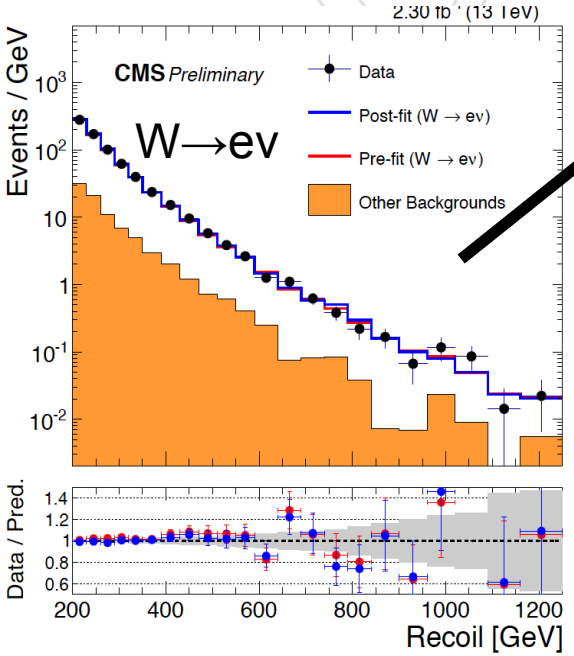


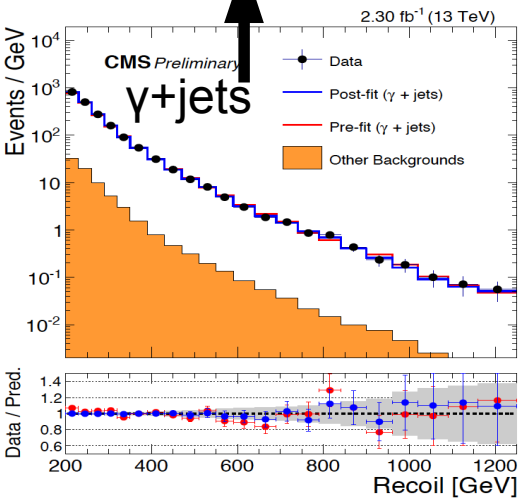
5 Control regions+Signal
15% uncertainty @ 1 TeV
All in one big Simultaneous fit

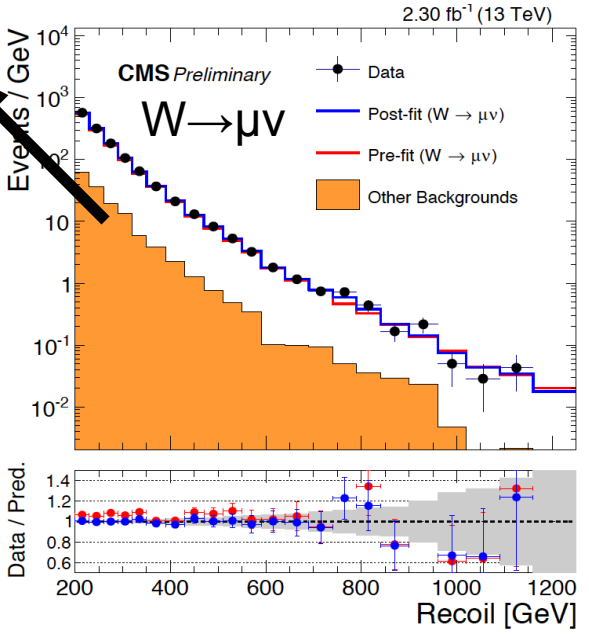




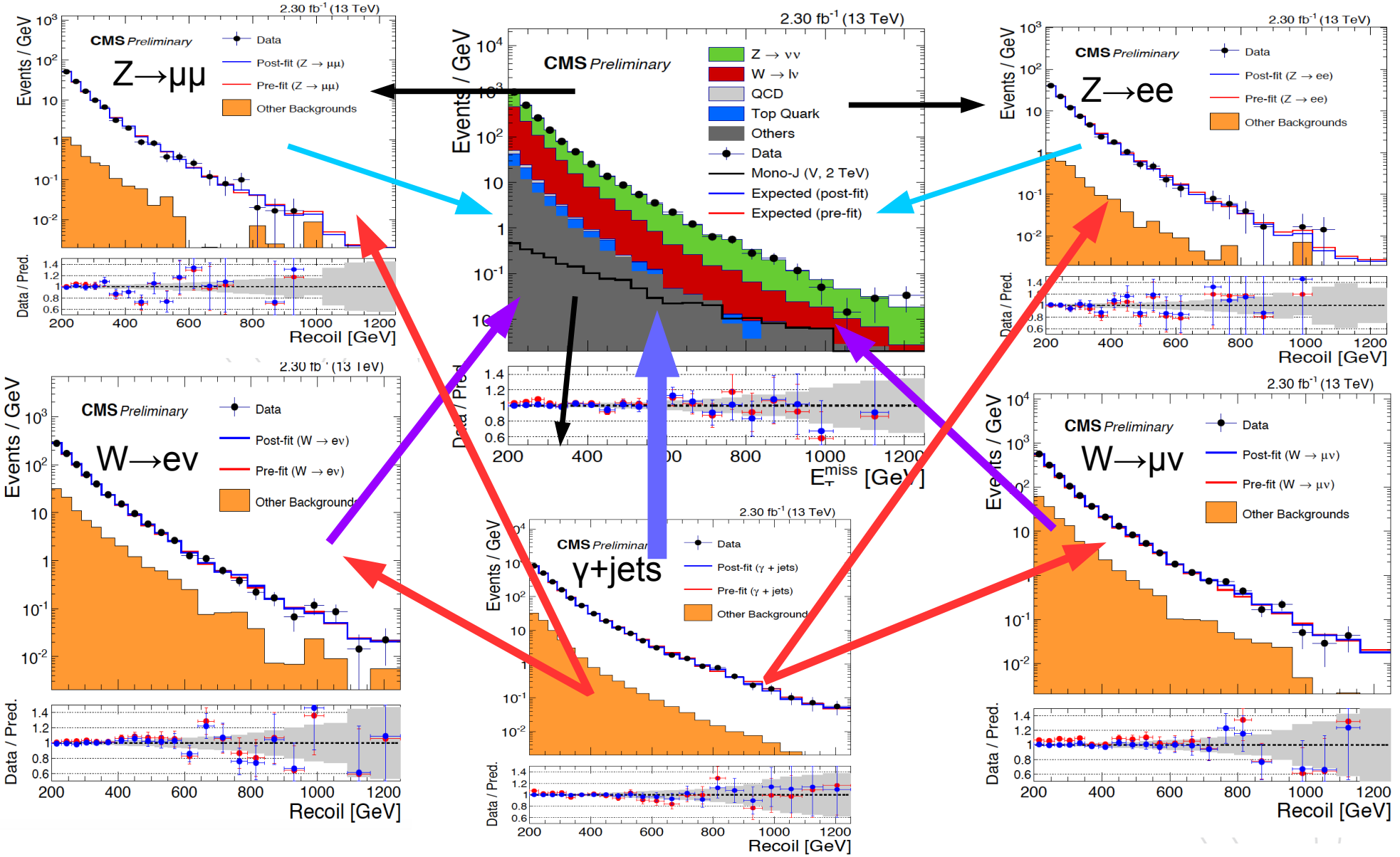






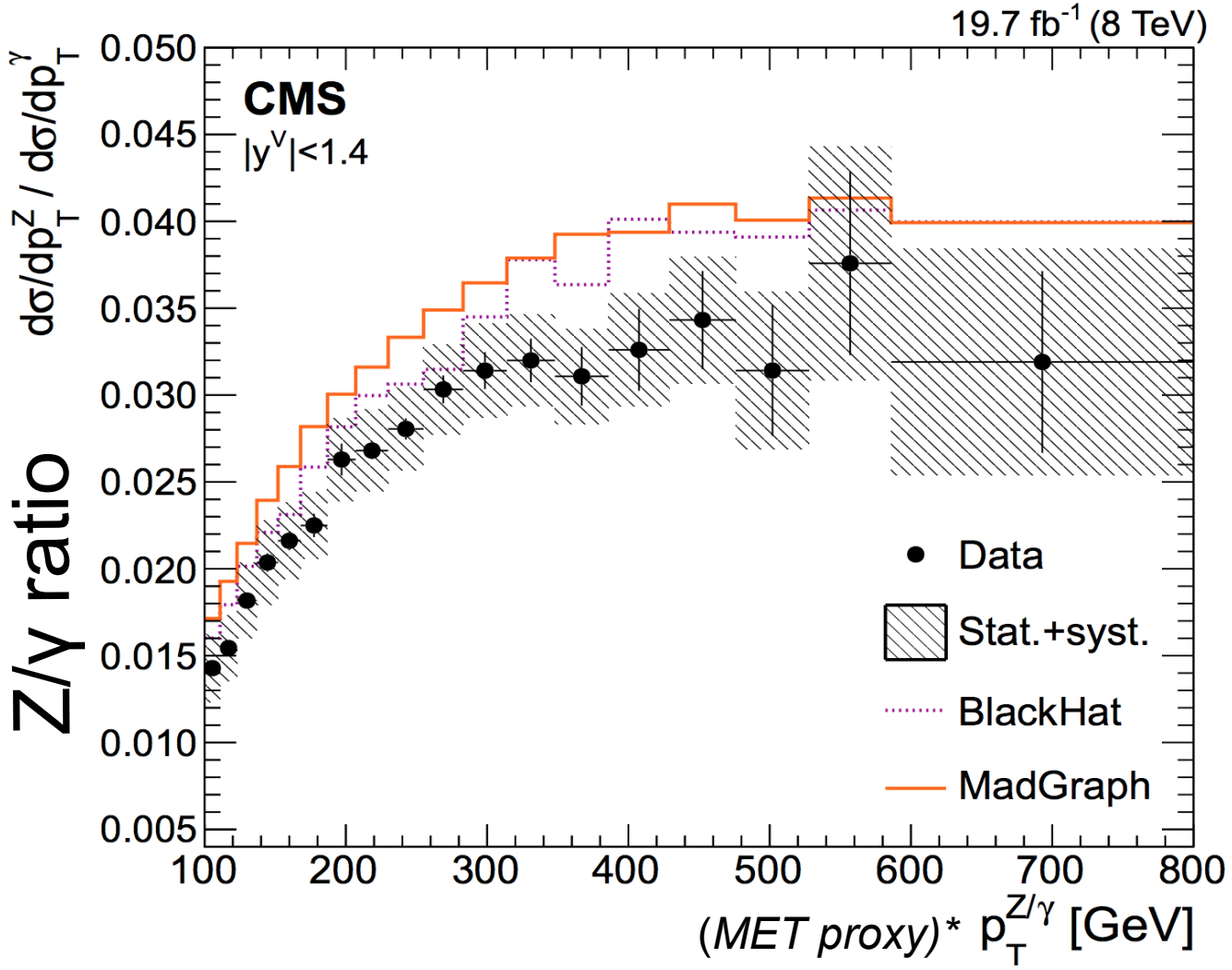


- To large extent the γ+jets drives the constraint
  - However we need need Z→ll to constraint γ



A mystery? Understanding Z/γ p_T

Can we really use Photons to model Zs ?

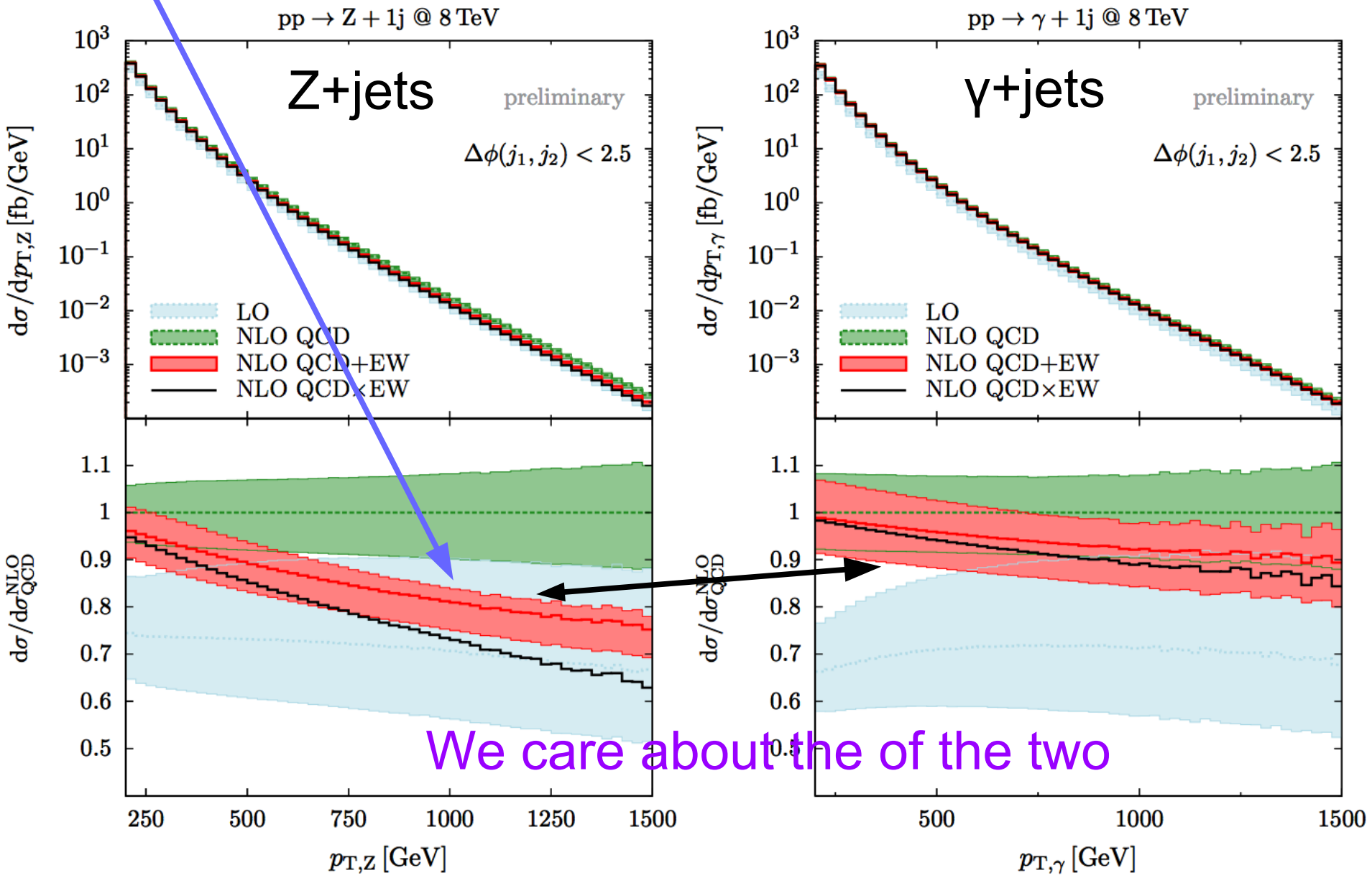


*See backup

CMS-SMP-14-005

How do we fix this?

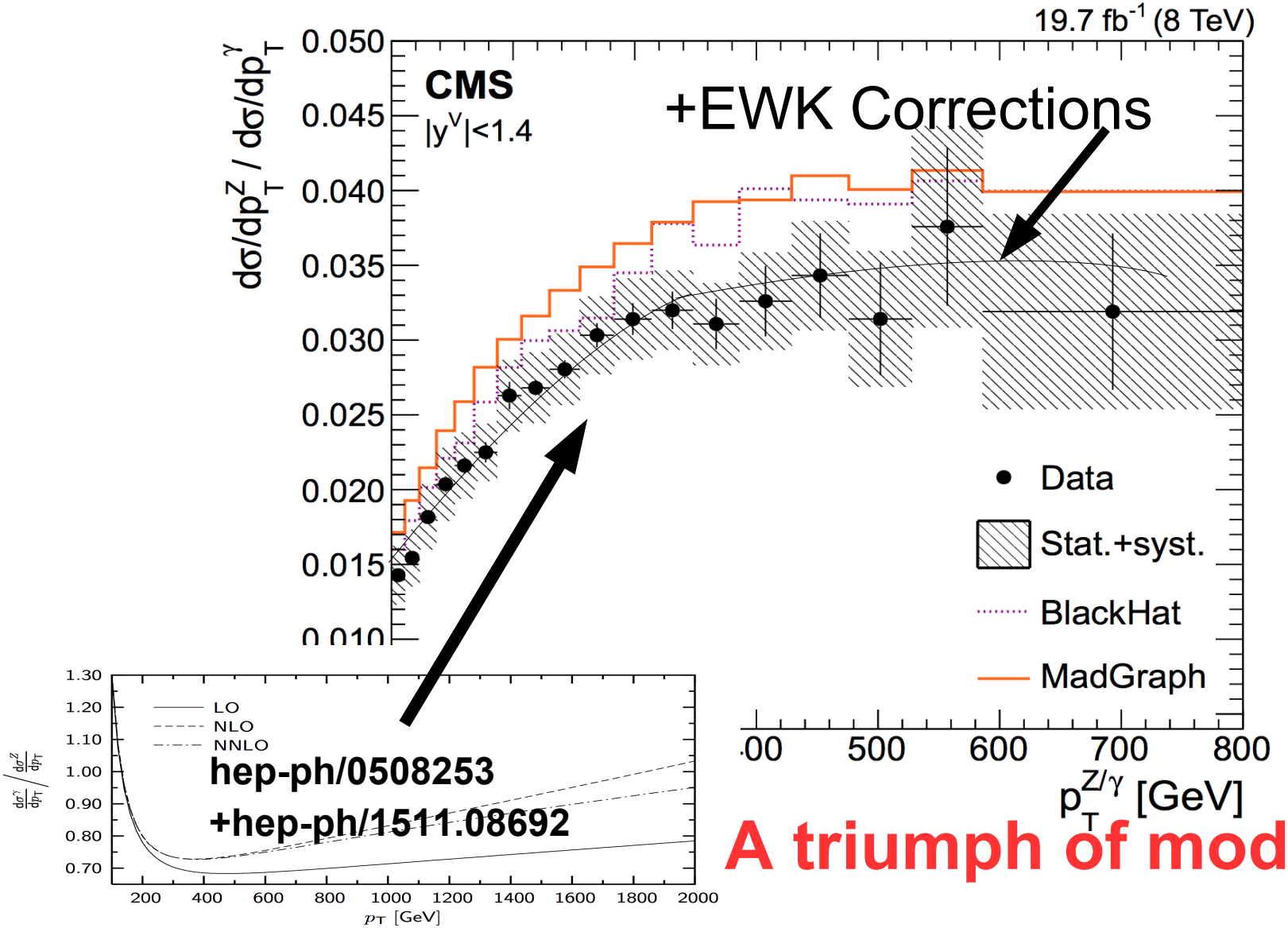
Impact of the electroweak corrections



We care about the of the two

A mystery? The Z p_T spectrum

- These results are missing NLO EWK corrections!

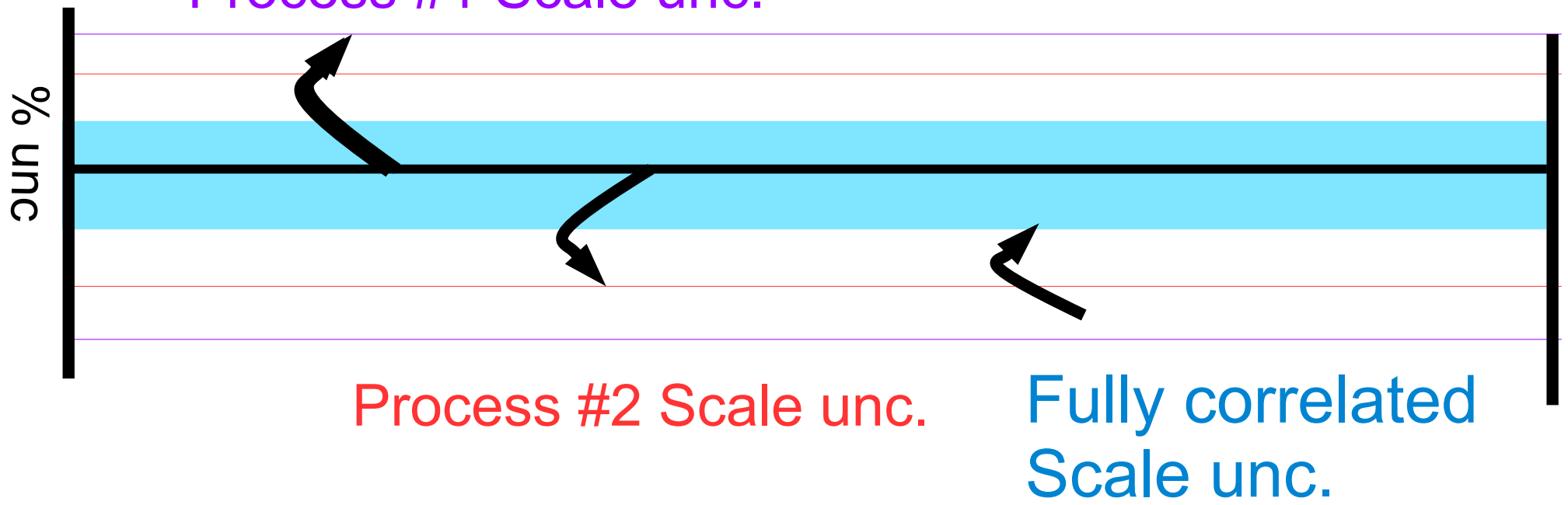


A triumph of modern QCD

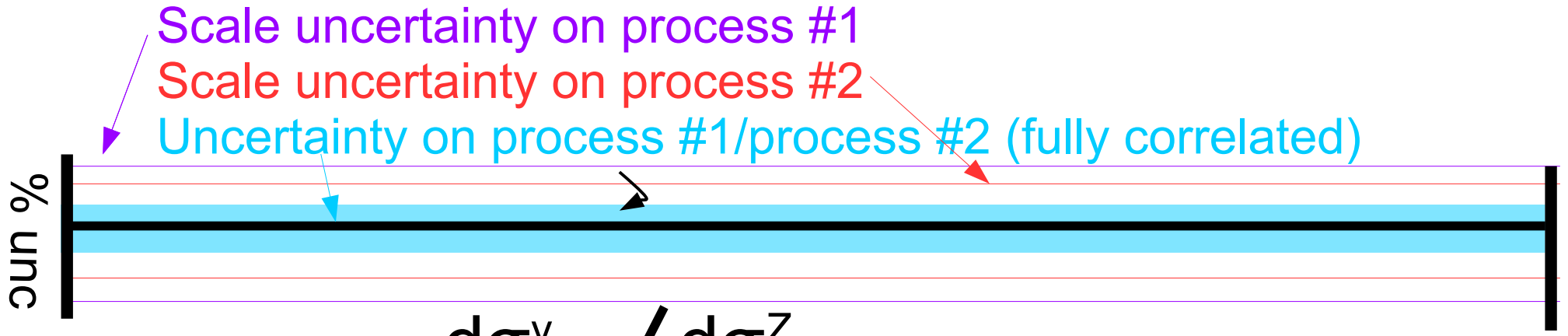
CMS-SMP-14-055

However we still have a problem!

Unc. $\longrightarrow \dfrac{d\sigma^{\gamma}}{dp_T} \Big/ \dfrac{d\sigma^{Z}}{dp_T} = d\sigma^{\gamma}/d\sigma^{Z}(\mu)$



Uncertainty on ratio? How is it done?



$$\text{Unc.} \longrightarrow \frac{d\sigma^{Y}}{dp_T} \Big/ \frac{d\sigma^{Z}}{dp_T} = d\sigma^{Y}/d\sigma^{Z}(\mu)$$

$$\begin{pmatrix} d\sigma^{Y}(+\sigma) \\ d\sigma^{Z}(+\sigma) \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} d\sigma^{Y}(\mu^{up})/d\sigma^{i}(\mu_0) \\ d\sigma^{Z}(\mu^{up})/d\sigma^{i}(\mu_0) \end{pmatrix}$$

Uncertainty on ratio? How is it done?

Scale uncertainty on process #1

Scale uncertainty on process #2

Uncertainty on process #1/process #2 (fully correlated)

Unc. $\longrightarrow \dfrac{d\sigma^{Y}}{dp_T} \Big/ \dfrac{d\sigma^{Z}}{dp_T} = d\sigma^{Y}/d\sigma^{Z}(\mu)$

$$\begin{pmatrix} d\sigma^{Y}(+\sigma) \\ d\sigma^{Z}(+\sigma) \end{pmatrix} = \begin{pmatrix} 1 & C \\ C & 1 \end{pmatrix} \begin{pmatrix} d\sigma^{Y}(\mu^{up})/d\sigma^{i}(\mu_0) \\ d\sigma^{Z}(\mu^{up})/d\sigma^{i}(\mu_0) \end{pmatrix}$$

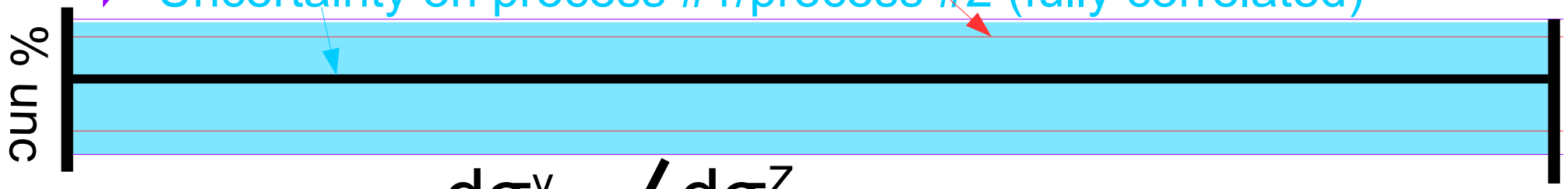
Adjust C until uncertainty is

Uncertainty on ratio? How is it done?

Scale uncertainty on process #1

Scale uncertainty on process #2

Uncertainty on process #1/process #2 (fully correlated)



$$\text{Unc.} \longrightarrow \frac{d\sigma^{Y}}{dp_T} \Big/ \frac{d\sigma^{Z}}{dp_T} = d\sigma^{Y}/d\sigma^{Z}(\mu)$$

$$\begin{pmatrix} d\sigma^{Y}(+\sigma) \\ d\sigma^{Z}(+\sigma) \end{pmatrix} = \begin{pmatrix} 1 & C \\ C & 1 \end{pmatrix} \begin{pmatrix} d\sigma^{Y}(\mu^{up})/d\sigma^{i}(\mu_0) \\ d\sigma^{Z}(\mu^{up})/d\sigma^{i}(\mu_0) \end{pmatrix}$$

Decorrelate scale unc. until its max of either process

$$\mathbf{d\sigma^{Y}/d\sigma^{Z}(+\sigma) < \max_i (d\sigma^{i}(\mu^{up})/d\sigma^{i}(\mu_0))}$$

What is the previous unc?

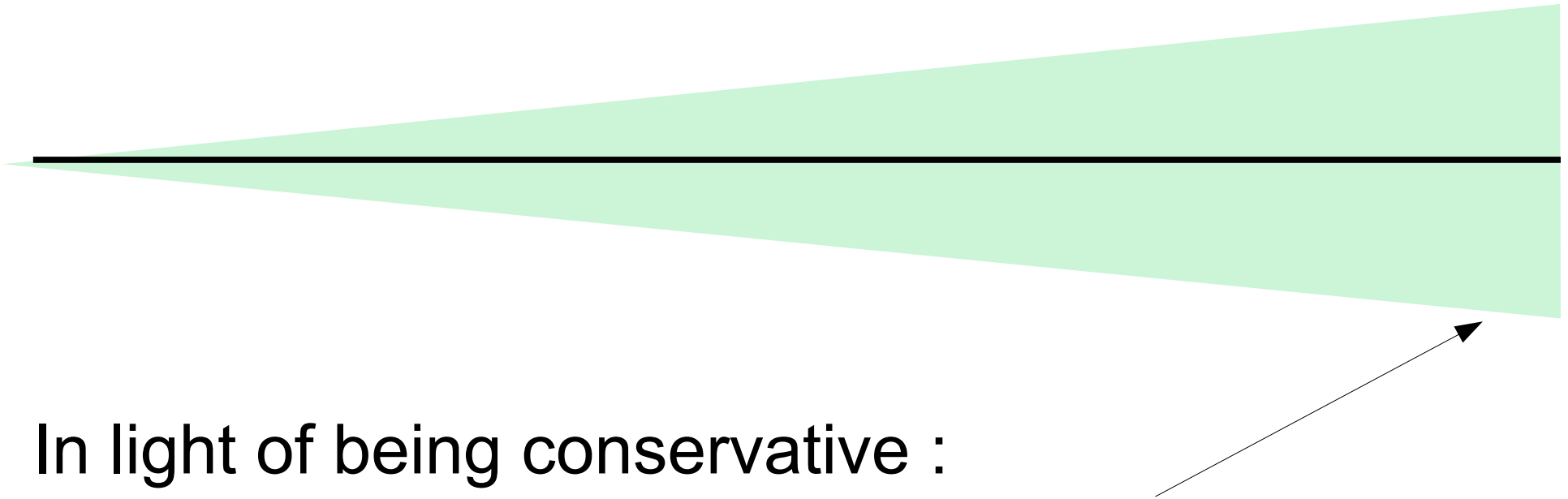
Can we motivate this?

Unc. $\longrightarrow \dfrac{d\sigma^{\gamma}}{dp_T} \Big/ \dfrac{d\sigma^{Z}}{dp_T} = d\sigma^{\gamma}/d\sigma^{Z}(\mu)$

$$\begin{pmatrix} d\sigma^{\gamma}(+\sigma) \\ d\sigma^{Z}(+\sigma) \end{pmatrix} = \begin{pmatrix} 1 & C \\ C & 1 \end{pmatrix} \begin{pmatrix} d\sigma^{\gamma}(\mu^{up})/d\sigma^{i}(\mu_0) \\ d\sigma^{Z}(\mu^{up})/d\sigma^{i}(\mu_0) \end{pmatrix}$$

Makes Little Sense

What about the EWK uncertainty?

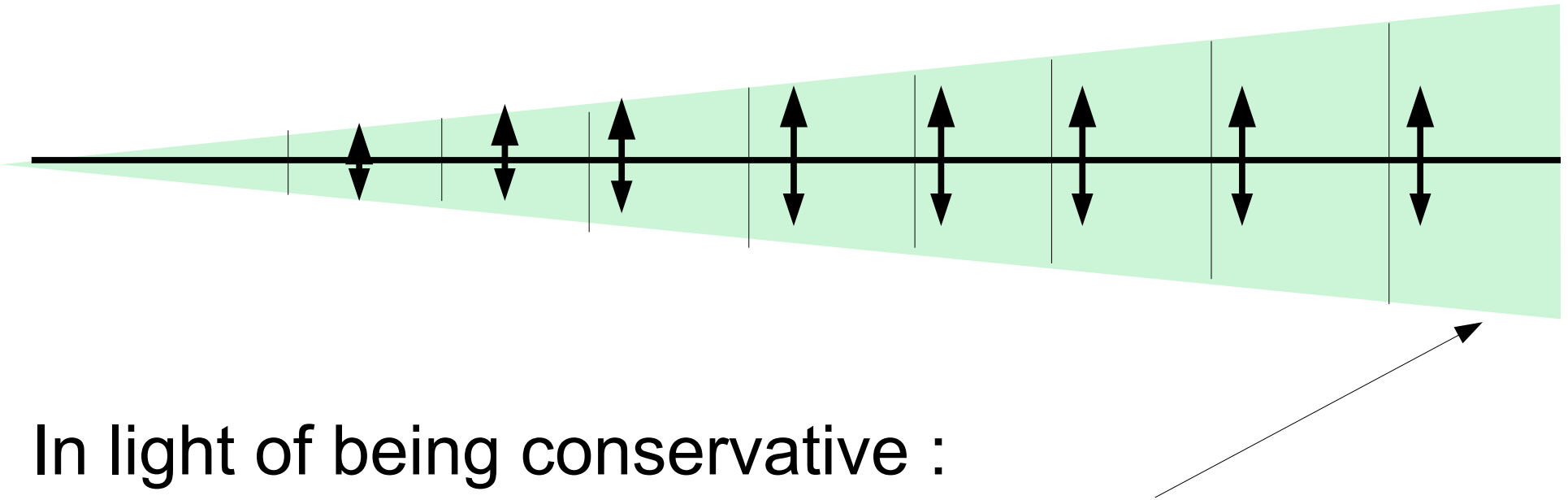


In light of being conservative :

Treated full correction as an uncertainty

More formal way could be with scale

What about the EWK uncertainty?



In light of being conservative :

Treated full correction as an uncertainty

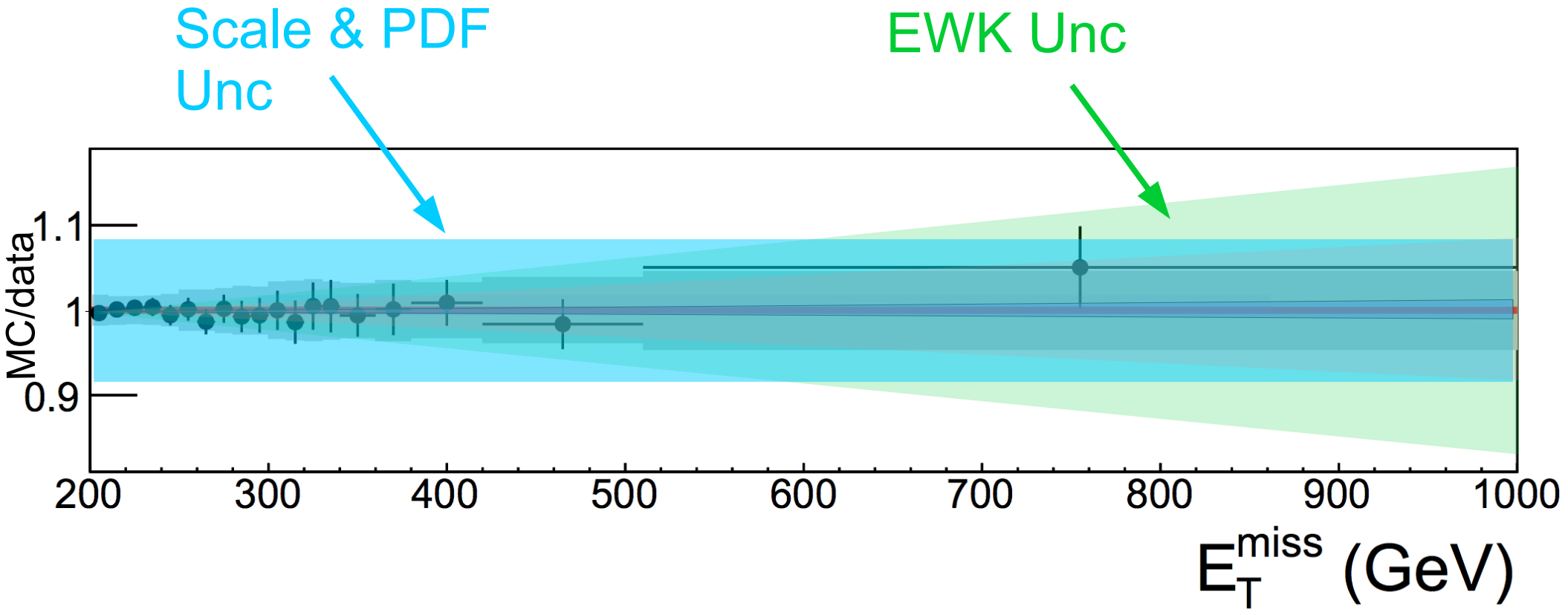
Additionally de-correlated this per bin

Avoids low *MET* to high *MET* constraints

Not very logical

Other (better) schemes exist

What do the uncertainties look like?

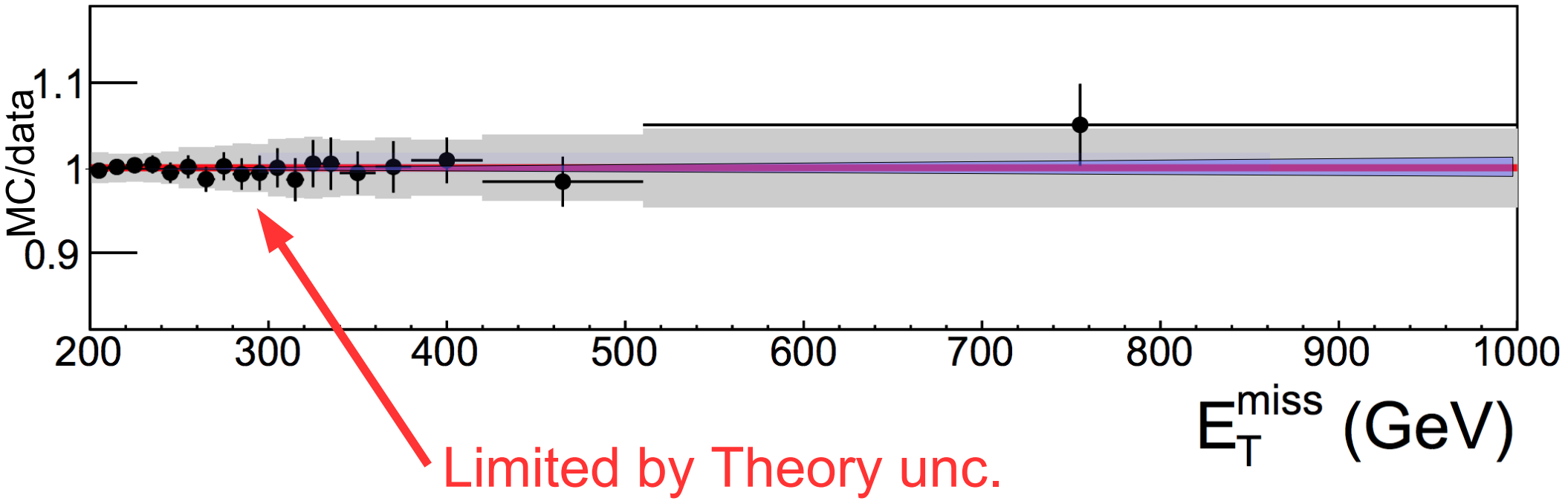


Updated unc still too large

CMS-EXO-12-055

Profiling them in the fit

Constraints after the fit



Still systematics limited @low *MET*

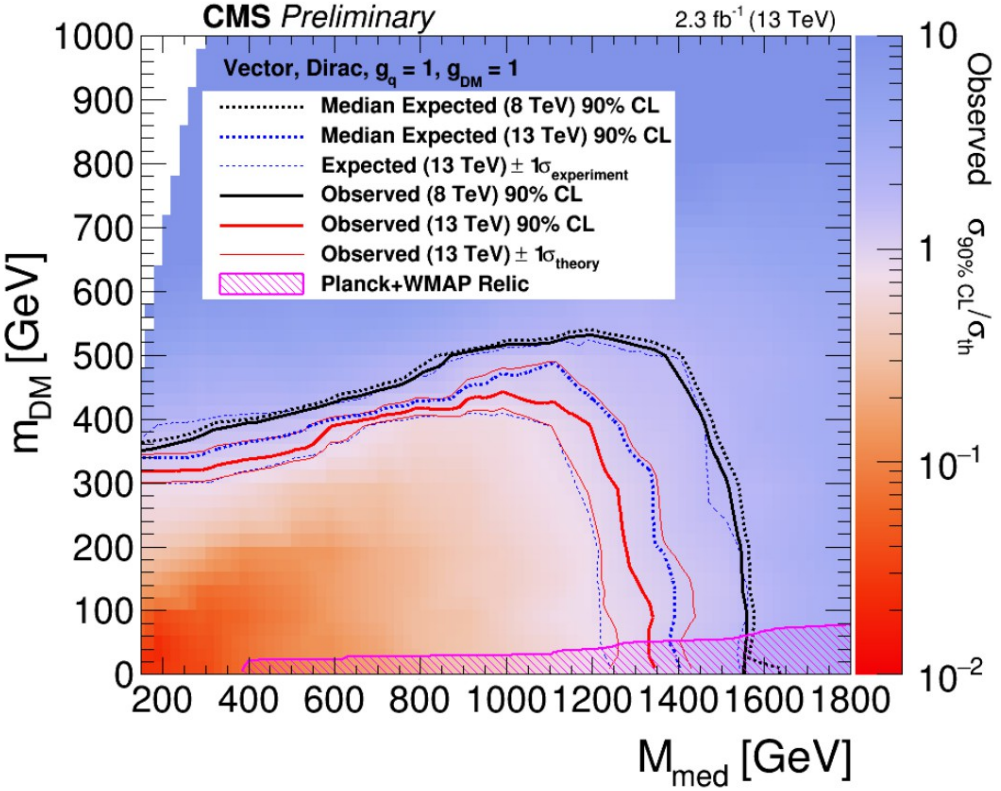
Not systematics limited @ high *MET*

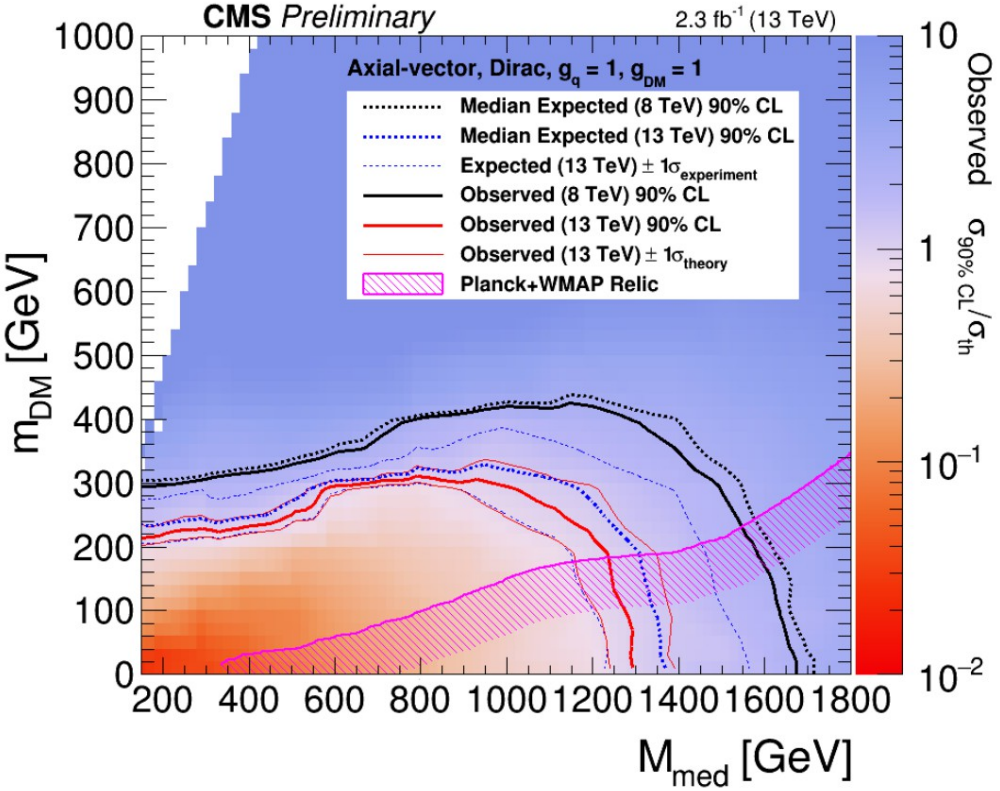
→ Likely will *never* be

CMS-EXO-12-055

Spin 1

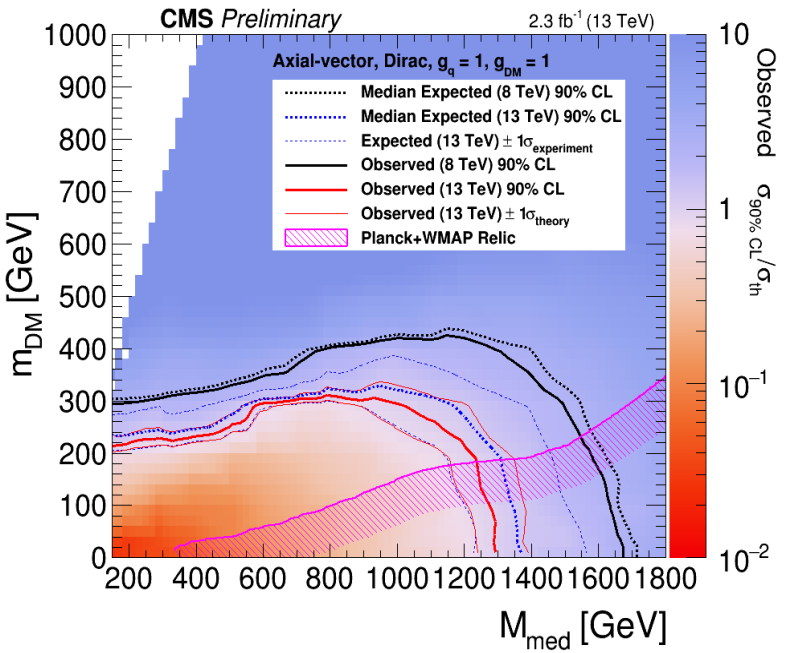
Results



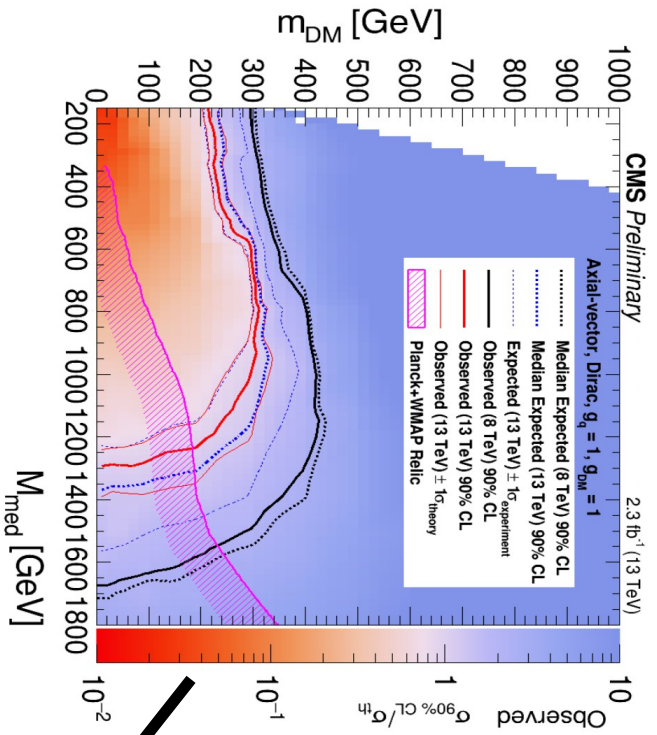


Both 13 TeV and 8 TeV analysis treat:
mono-V and monojet on equal footing

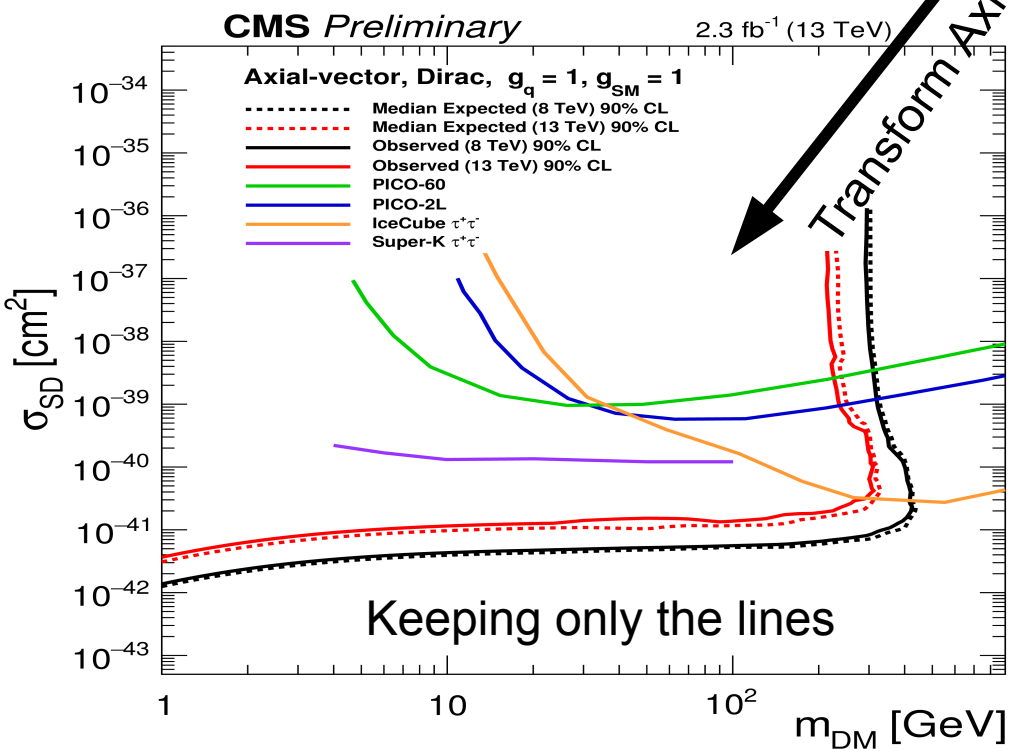
An 1-2σ excess is present in both data sets in tail



Rotate Plot



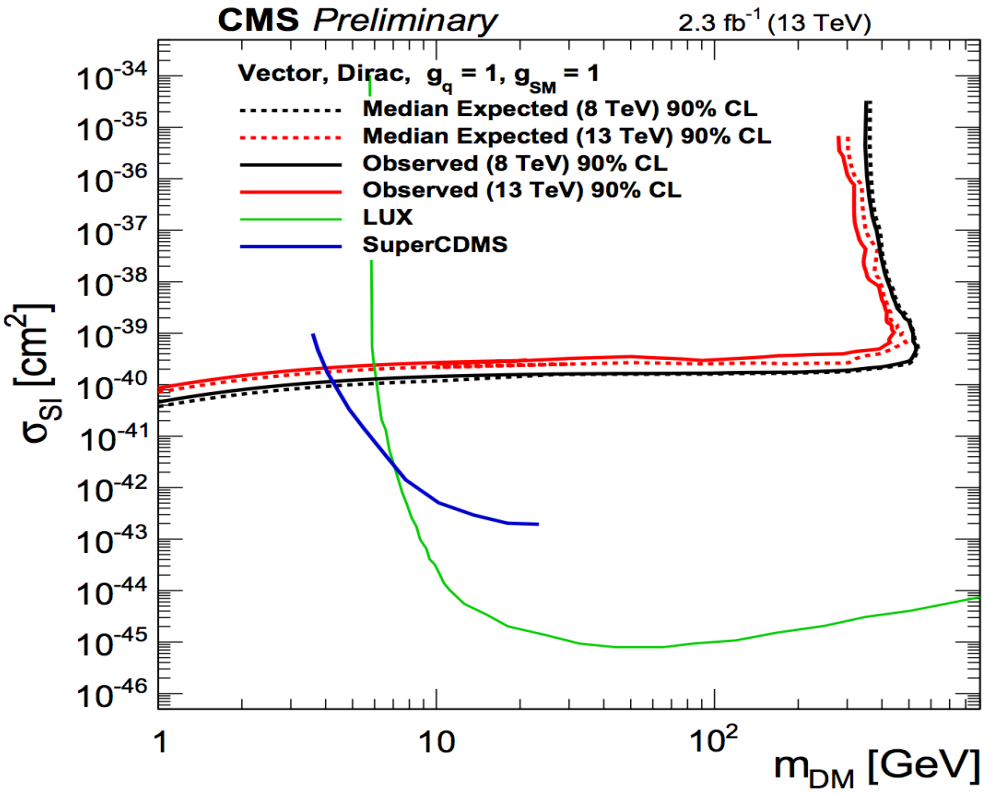
Transform Axis

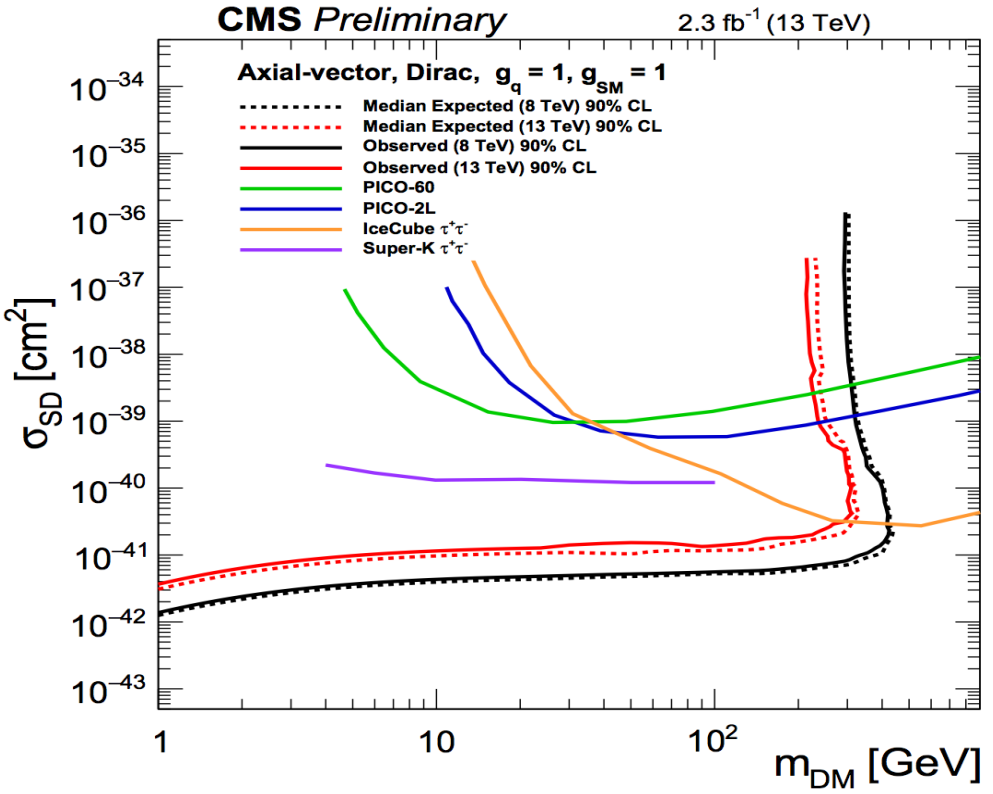


Now that search is cast in terms of mediator

No concerns in the translation

Our Current Public Results



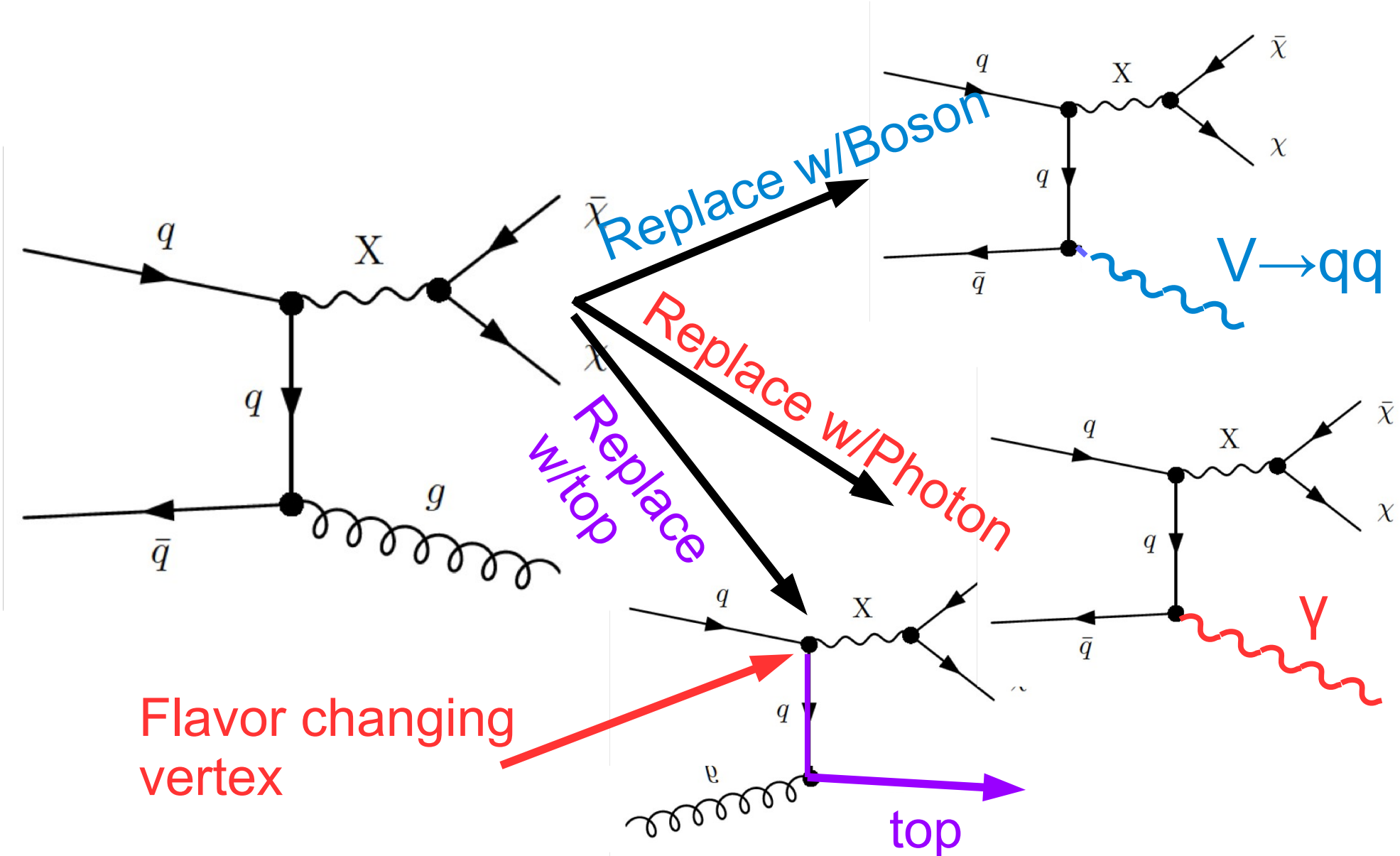


Translation to direct detection now standardized

An 1-2σ excess is present in both data sets in tail

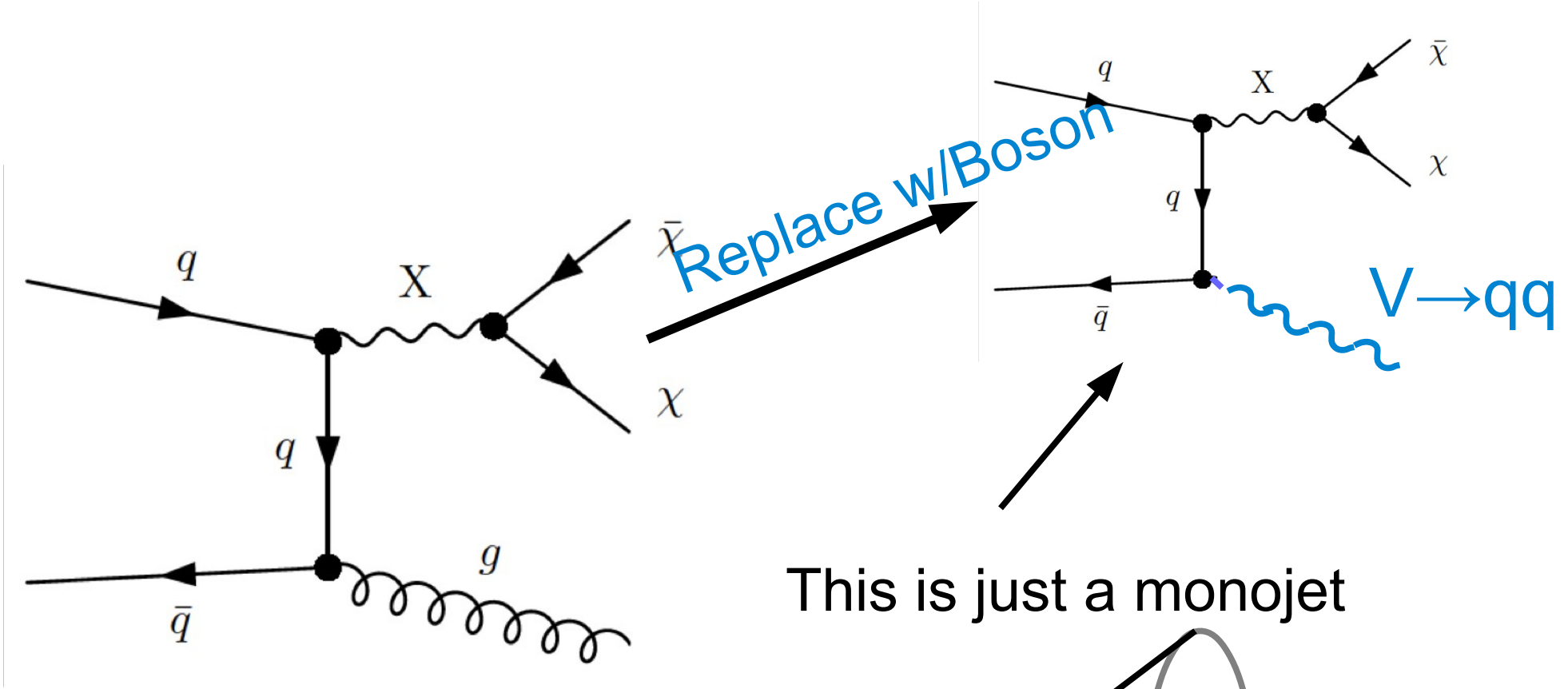
The split in simplified model terms

- With spin 1 can generate other final states :

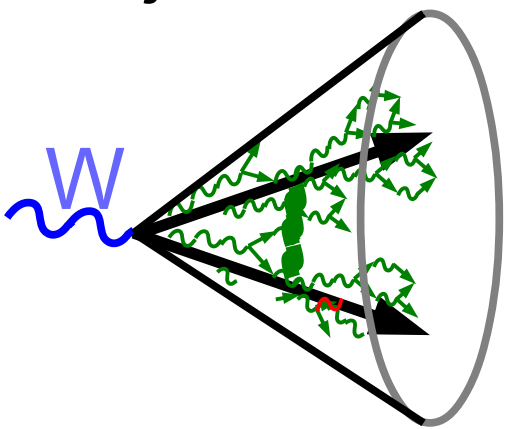


The split in simplified model terms

- With spin 1 can generate other final states :

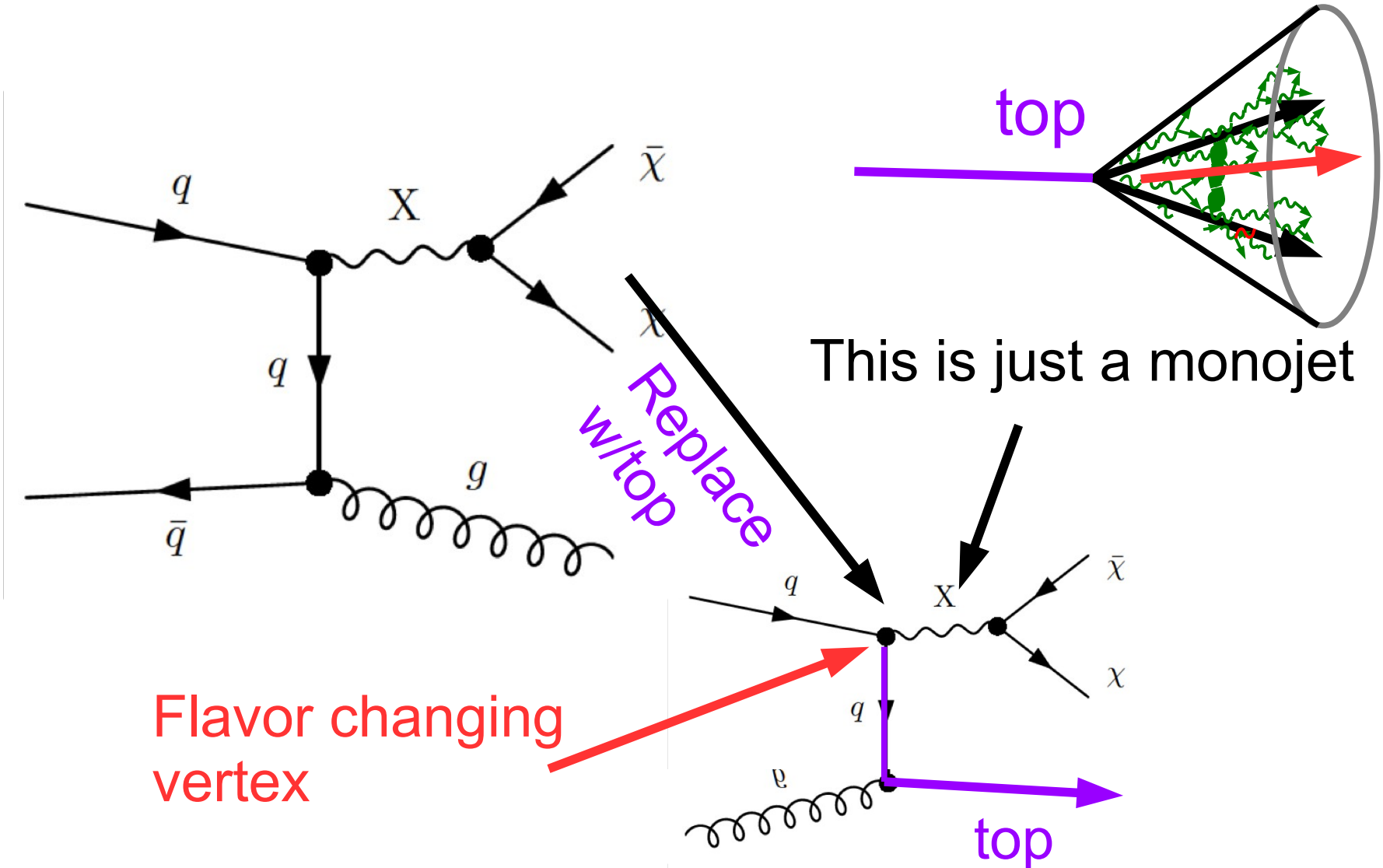


This is just a monojet



The split in simplified model terms

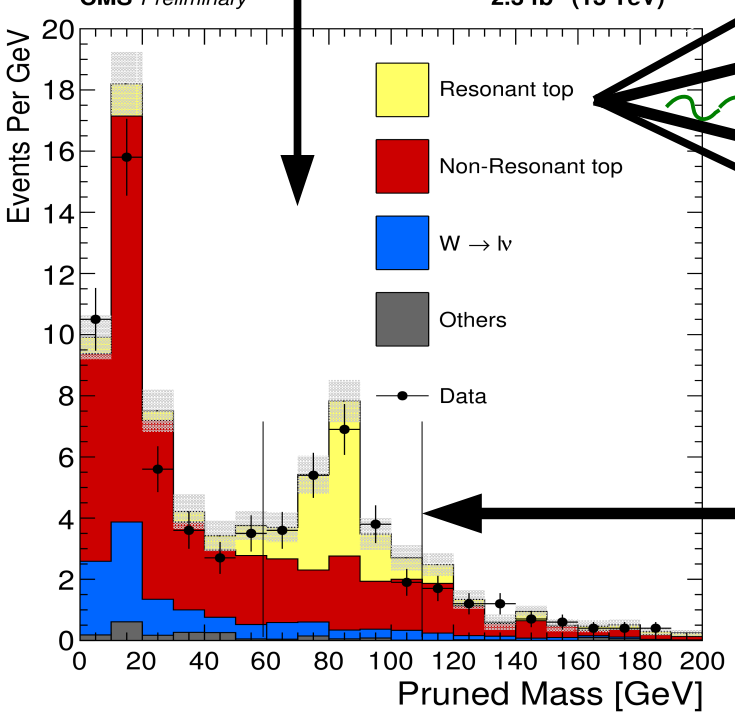
- With spin 1 can generate other final states :

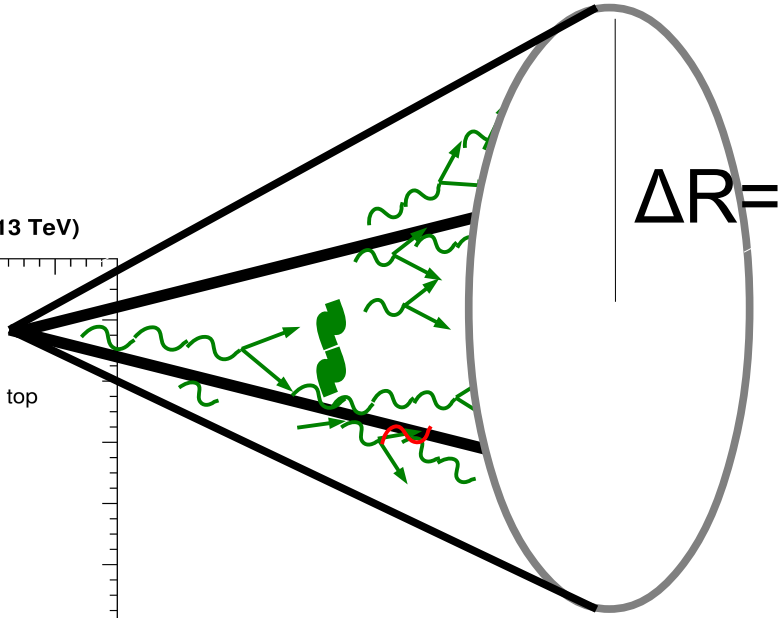


What differentiates them?

- For both the mono-top and mono-V we tag

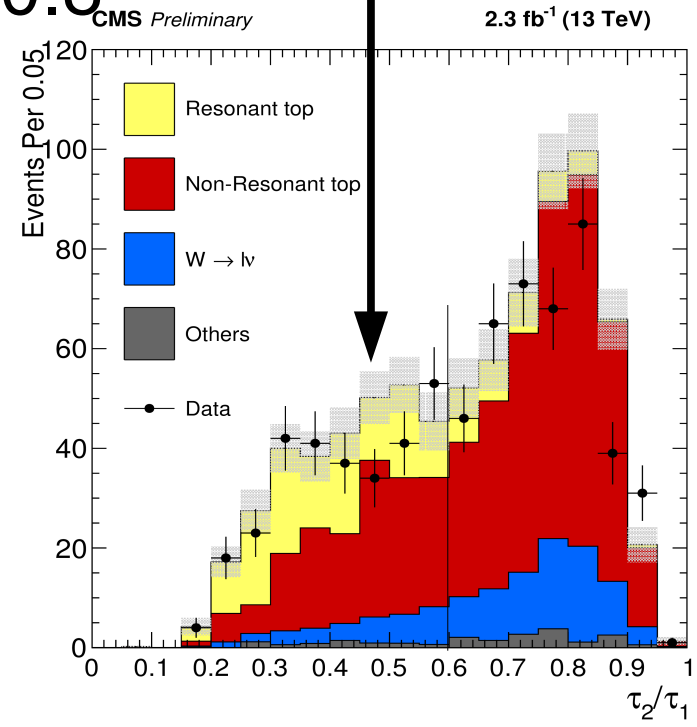
Cut on mass





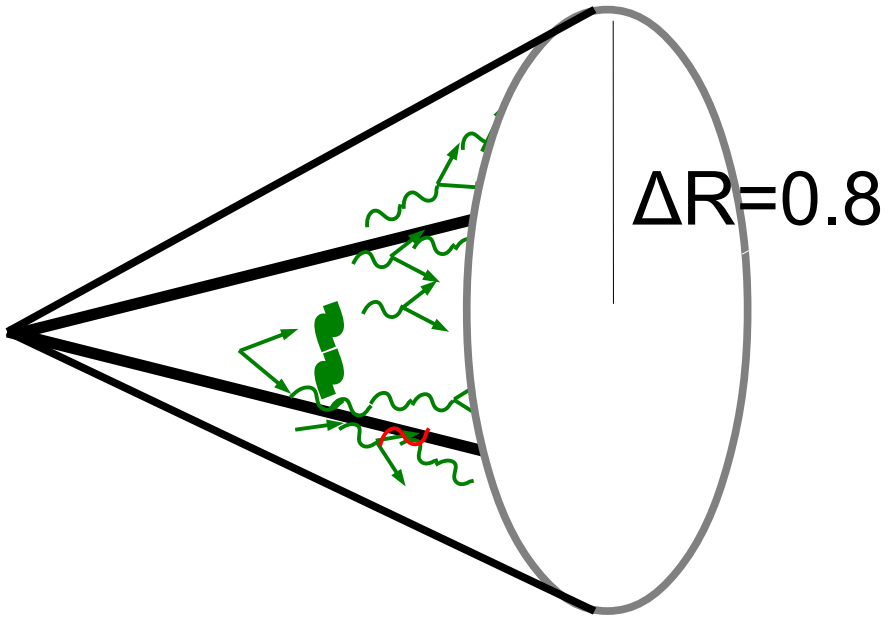
Tag & Probe on this peak
To get efficiency

Cut on
Likelihood of
2 prongs (τ_2/τ_1)



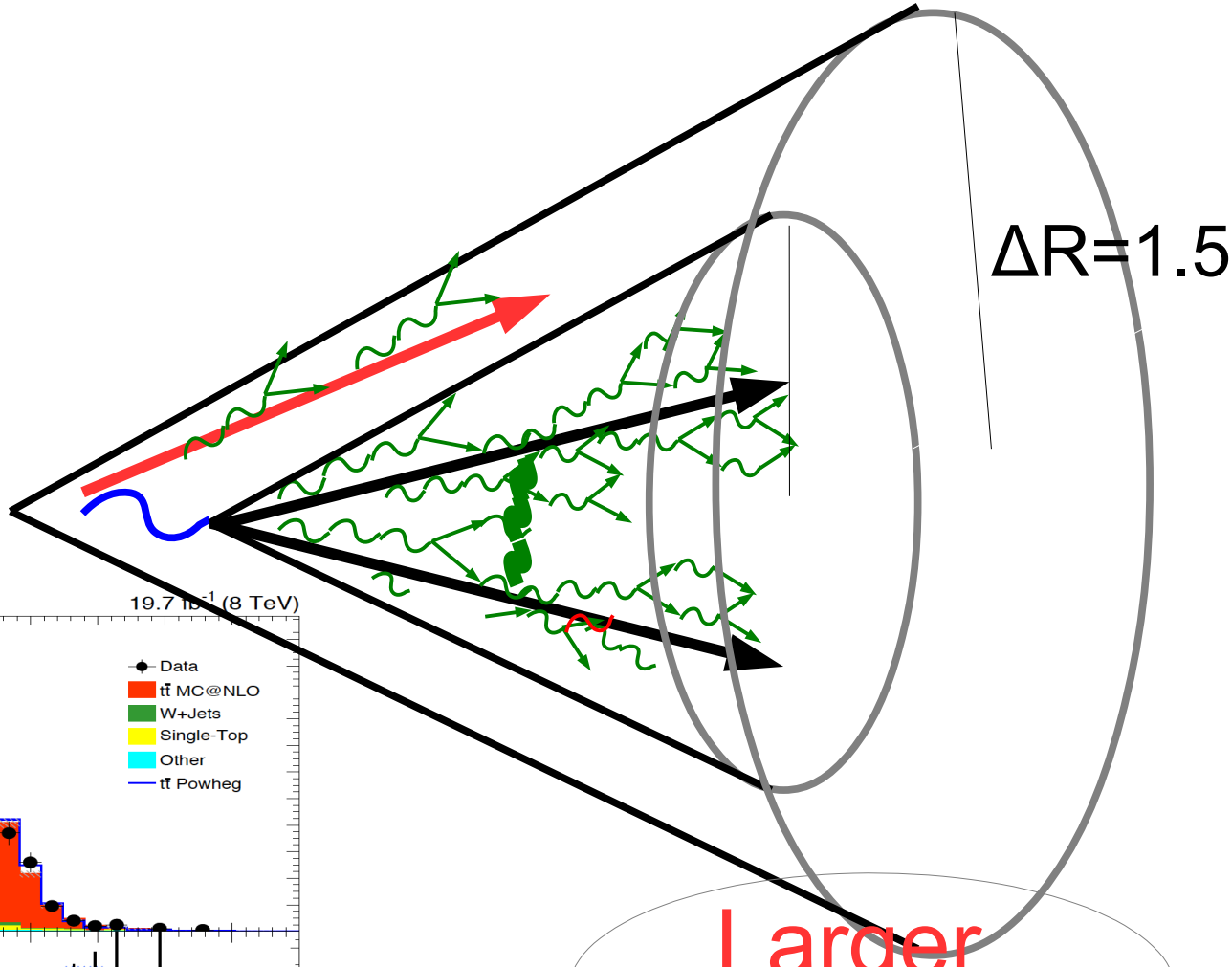
What differentiates them?

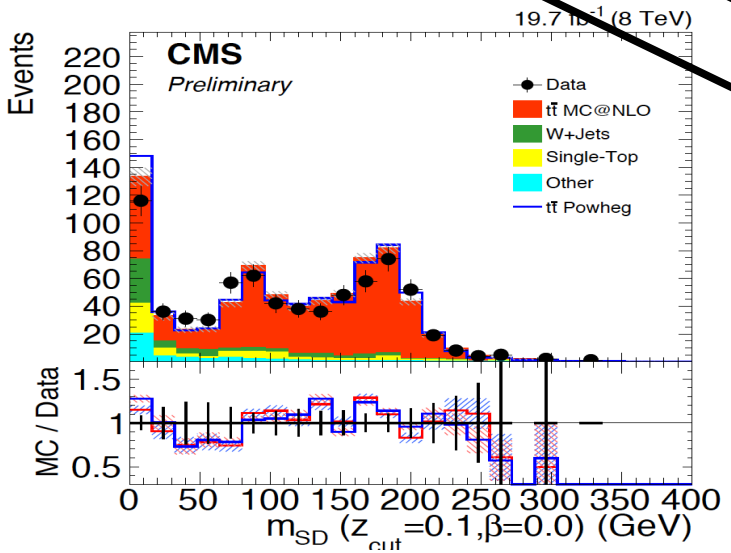
- For both the mono-top and mono-V we tag



What differentiates them?

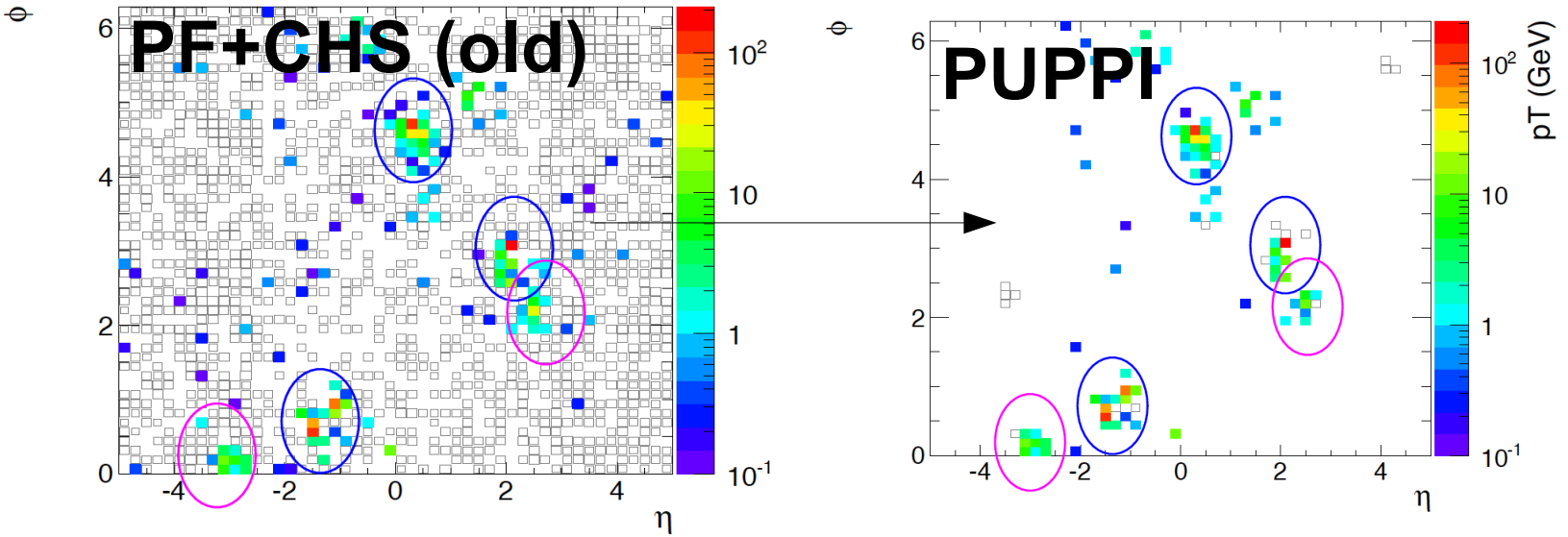
- For both the mono-top and mono-V we tag

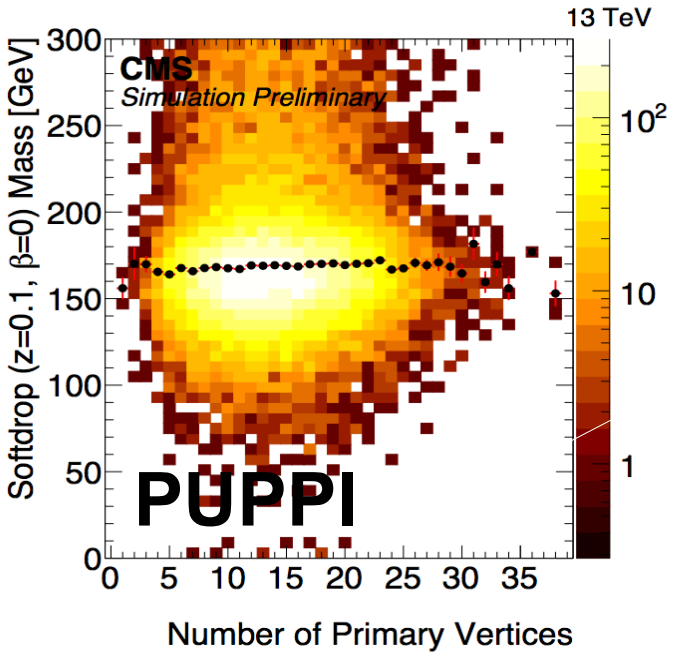


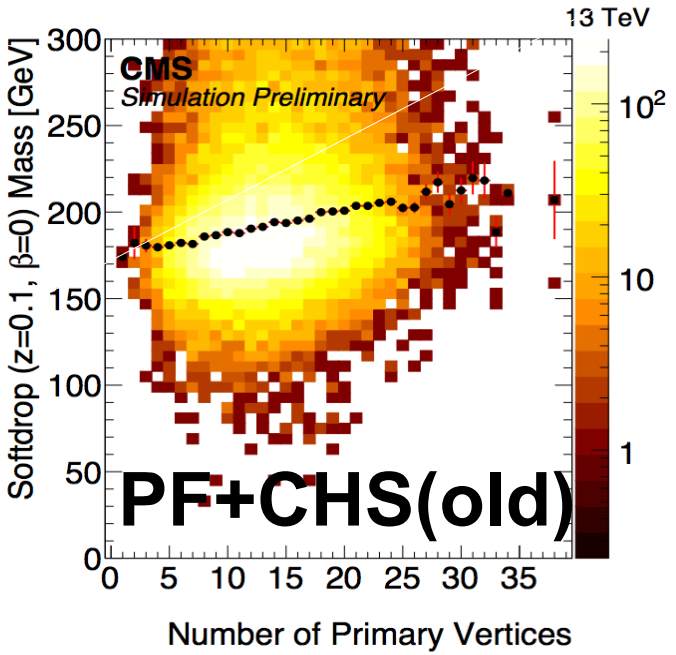


PUPPI-ganda

- Key to Large Cones is PUPPI







γ+jets

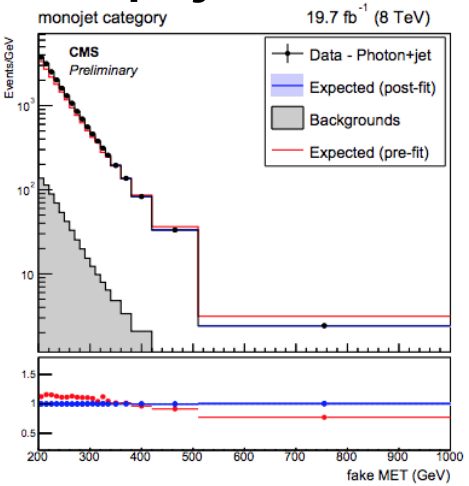
Zμμ+jets

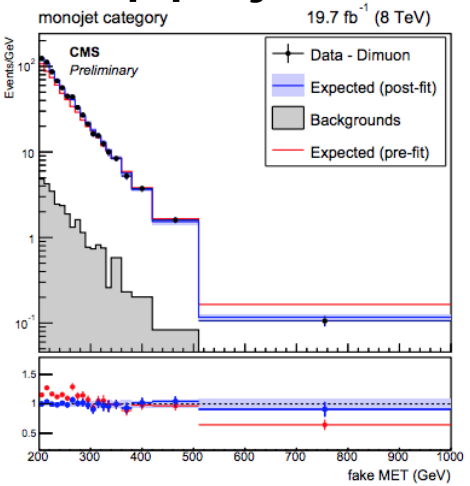
Wlν+jets

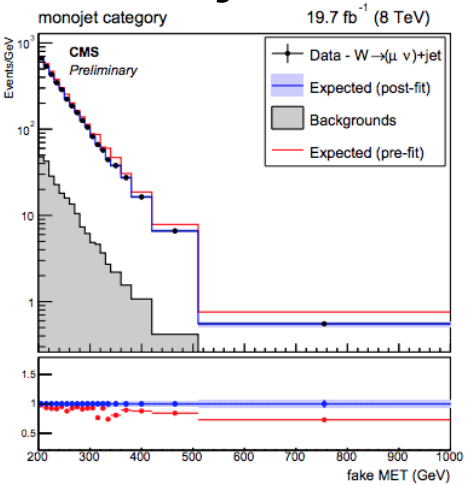
Monojet category

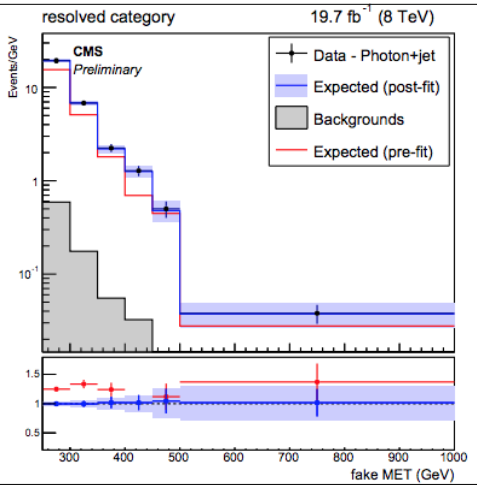
Di-jet category

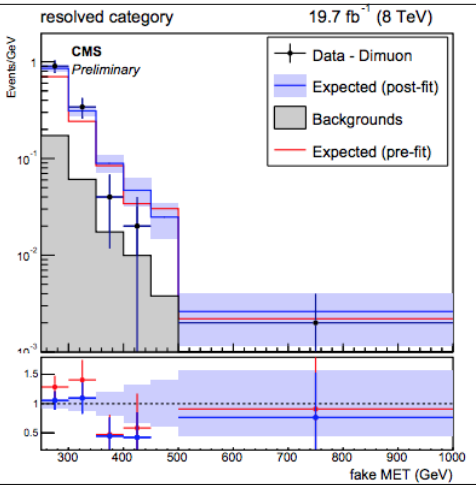
Single jet category

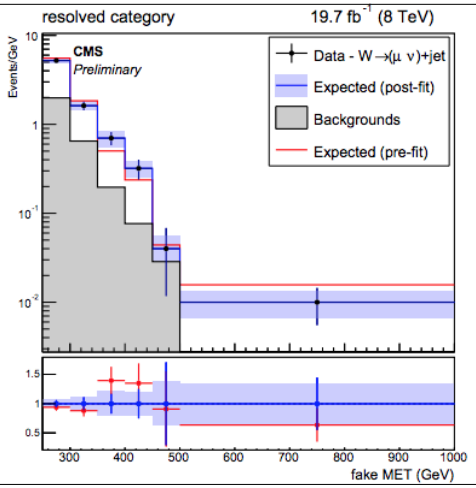


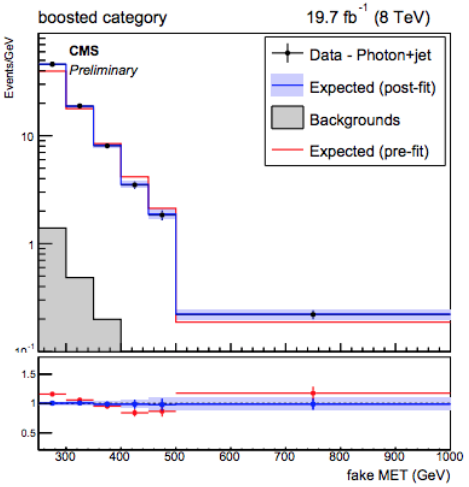


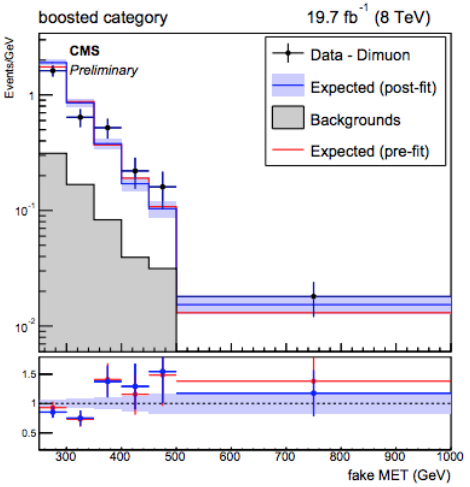


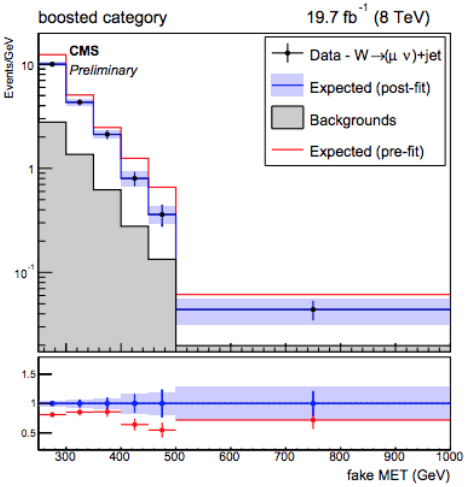












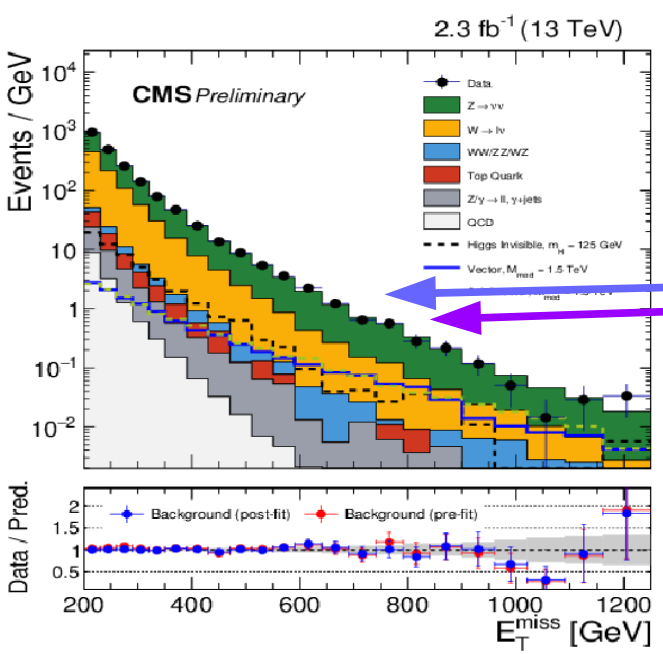
CMS-EXO-12-055

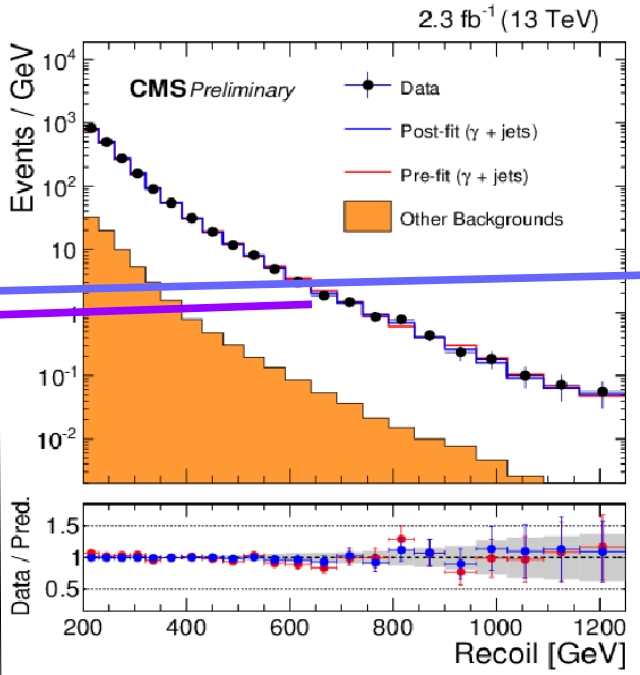
Signal

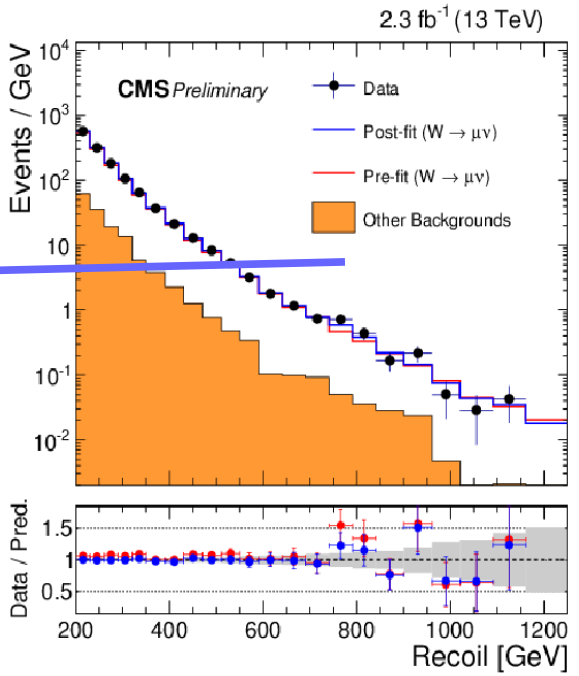
CRs: γ+jets

+ W + ….

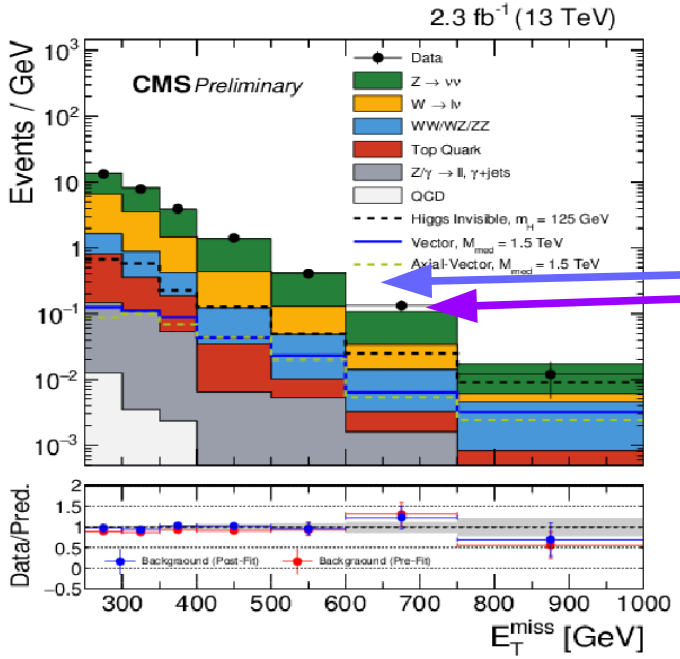
Monojet

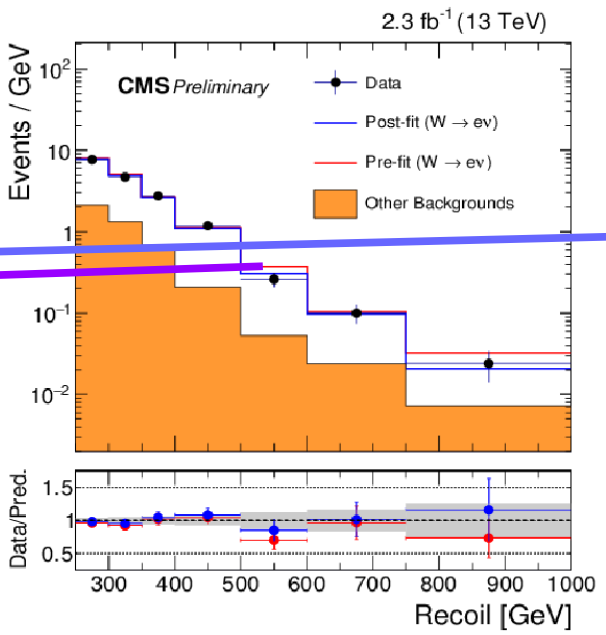


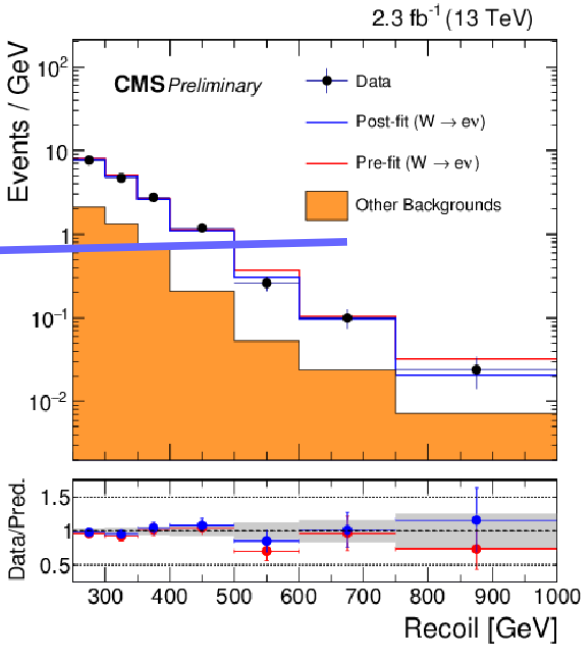




Mono-V

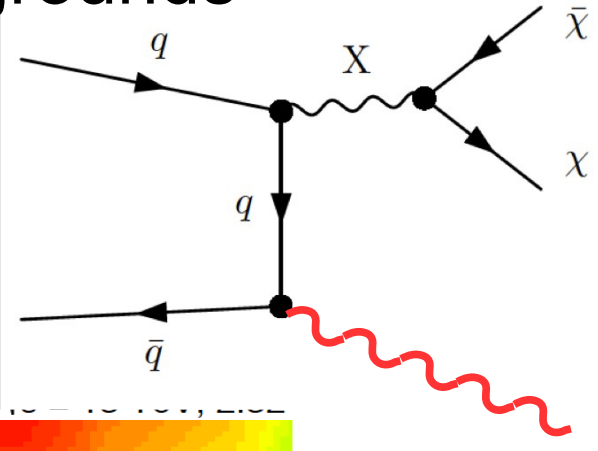


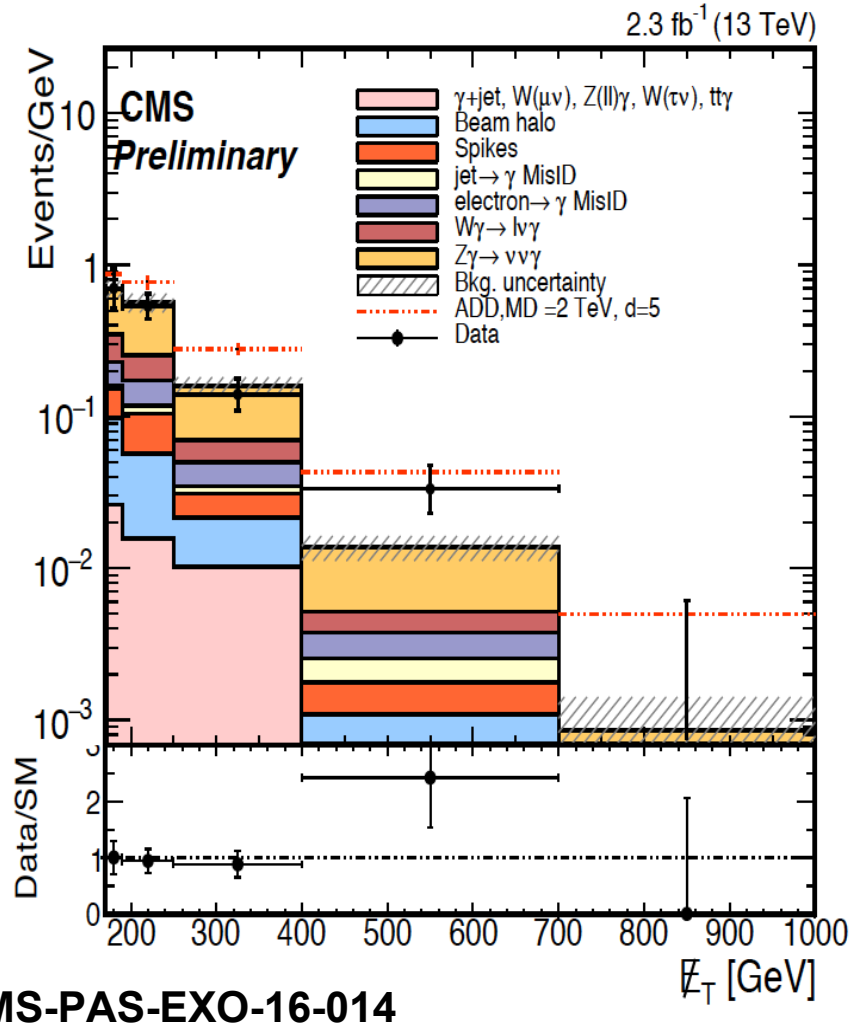


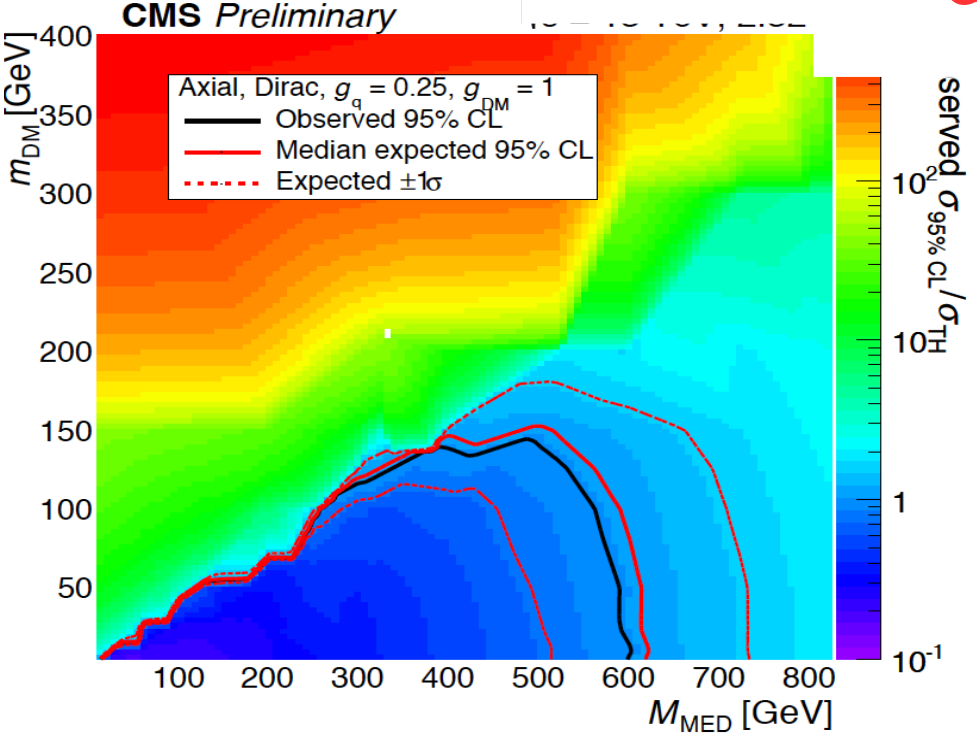


Monophoton

- Tag a photon and look for *MET*
  - Many challenging experimental backgrounds







CMS-PAS-EXO-16-014

Monotop

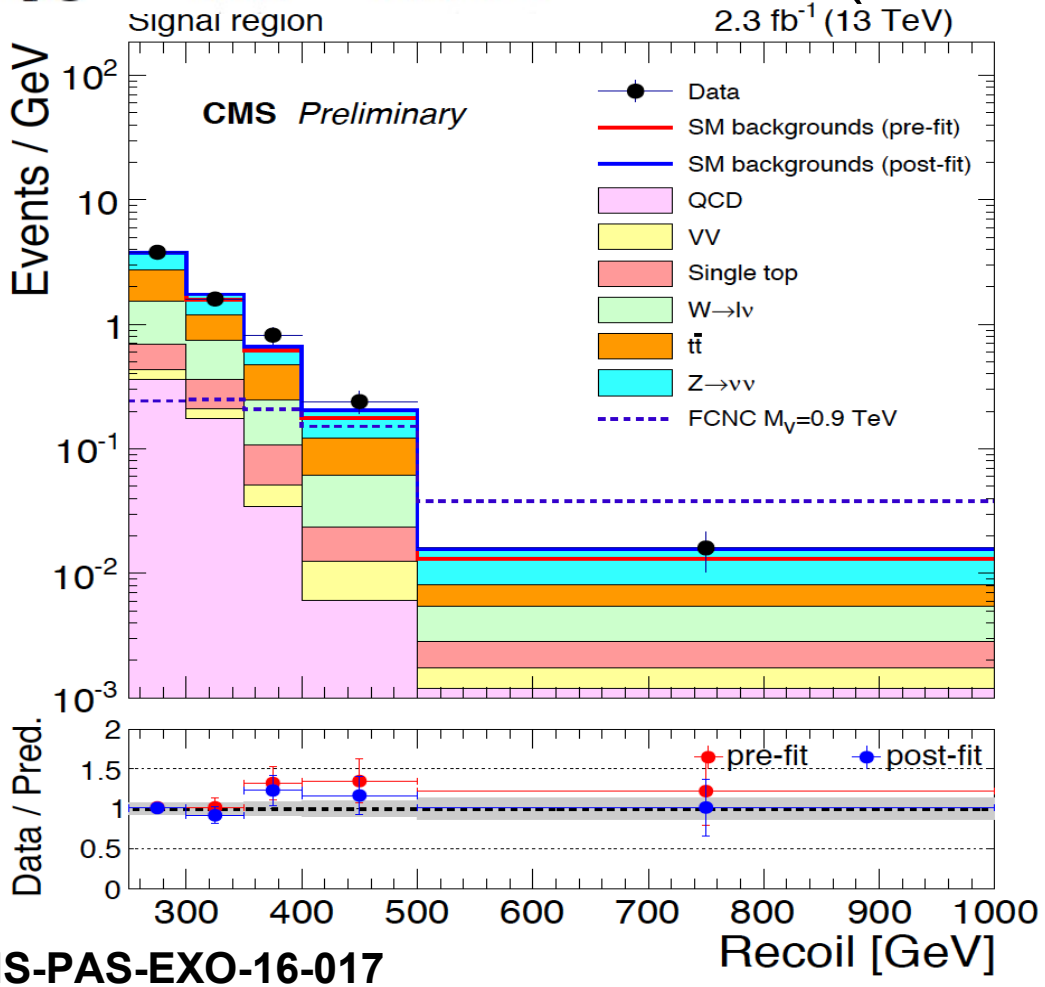
$$V_\mu \bar{u}_i [(a^1_{FC})^{ij}\gamma^\mu + (b^1_{FC})^{ij}\gamma^\mu\gamma^5] u_j$$

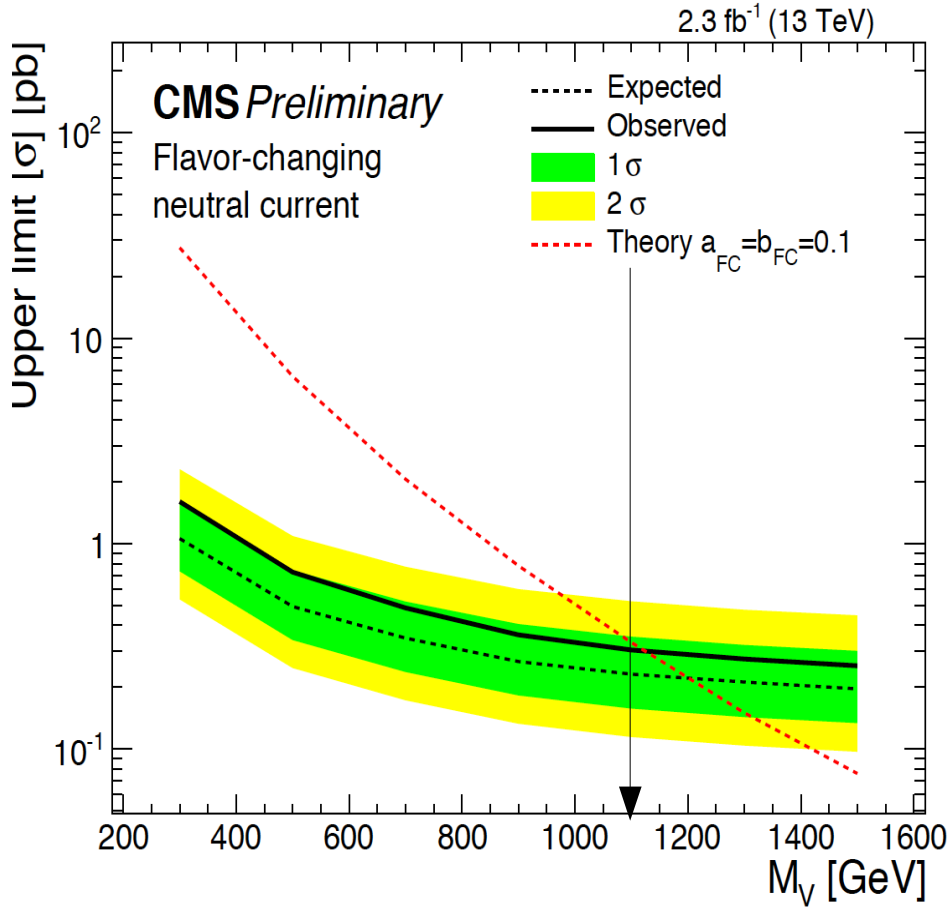
$$a^1_{FC} = (a_R + a_L)/2$$

$$b^1_{FC} = (a_R - a_L)/2$$

Taking a_i=0.1

(DM forum choice 0.25→x10)

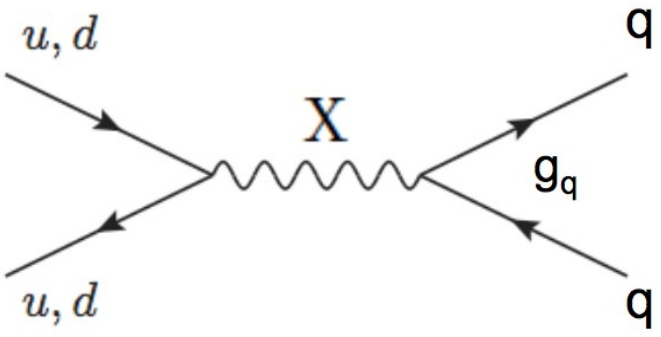


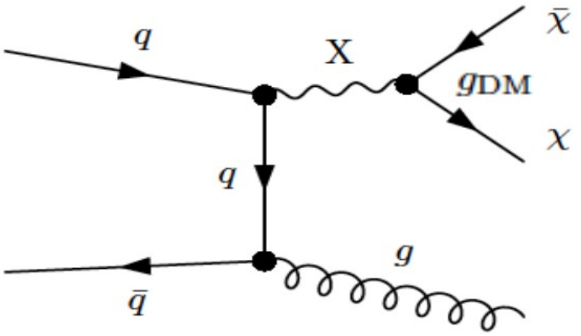


CMS-PAS-EXO-16-017

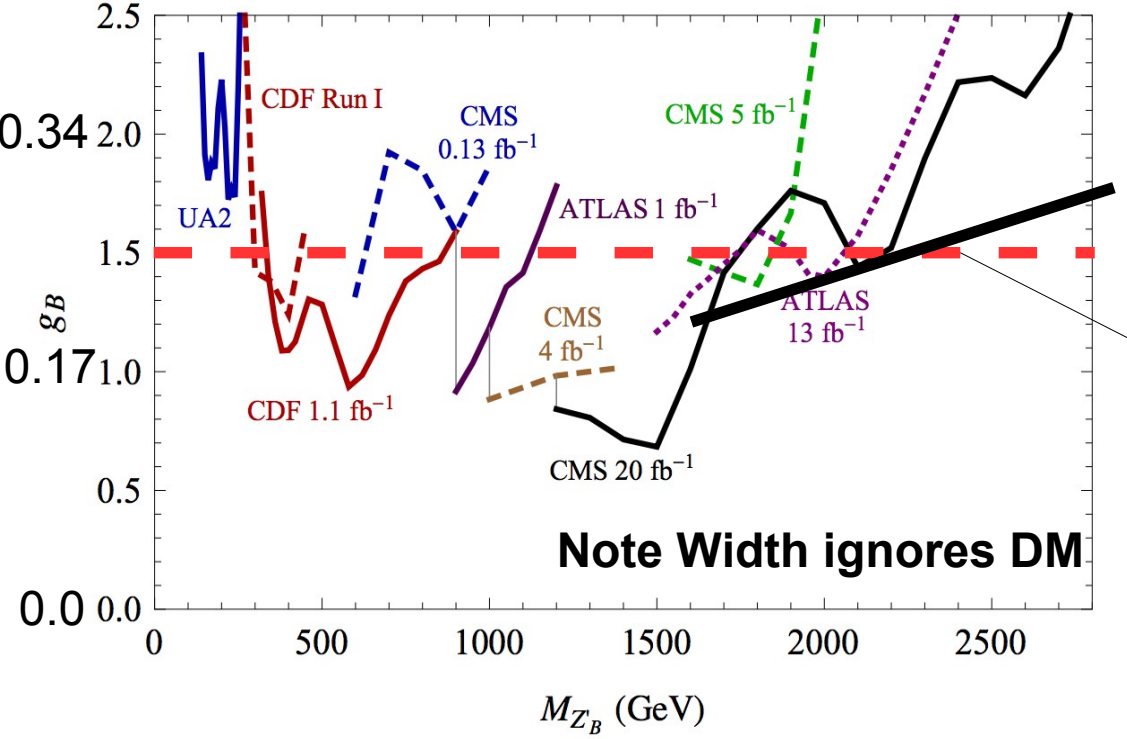
Mediator Search

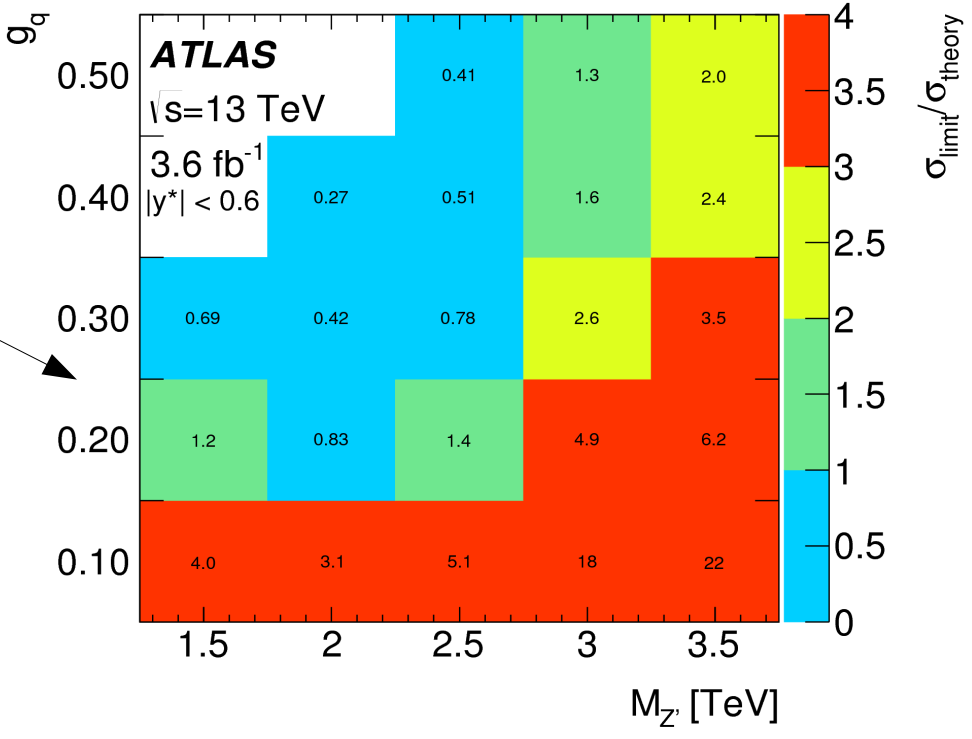
- In addition we can just look for the mediator



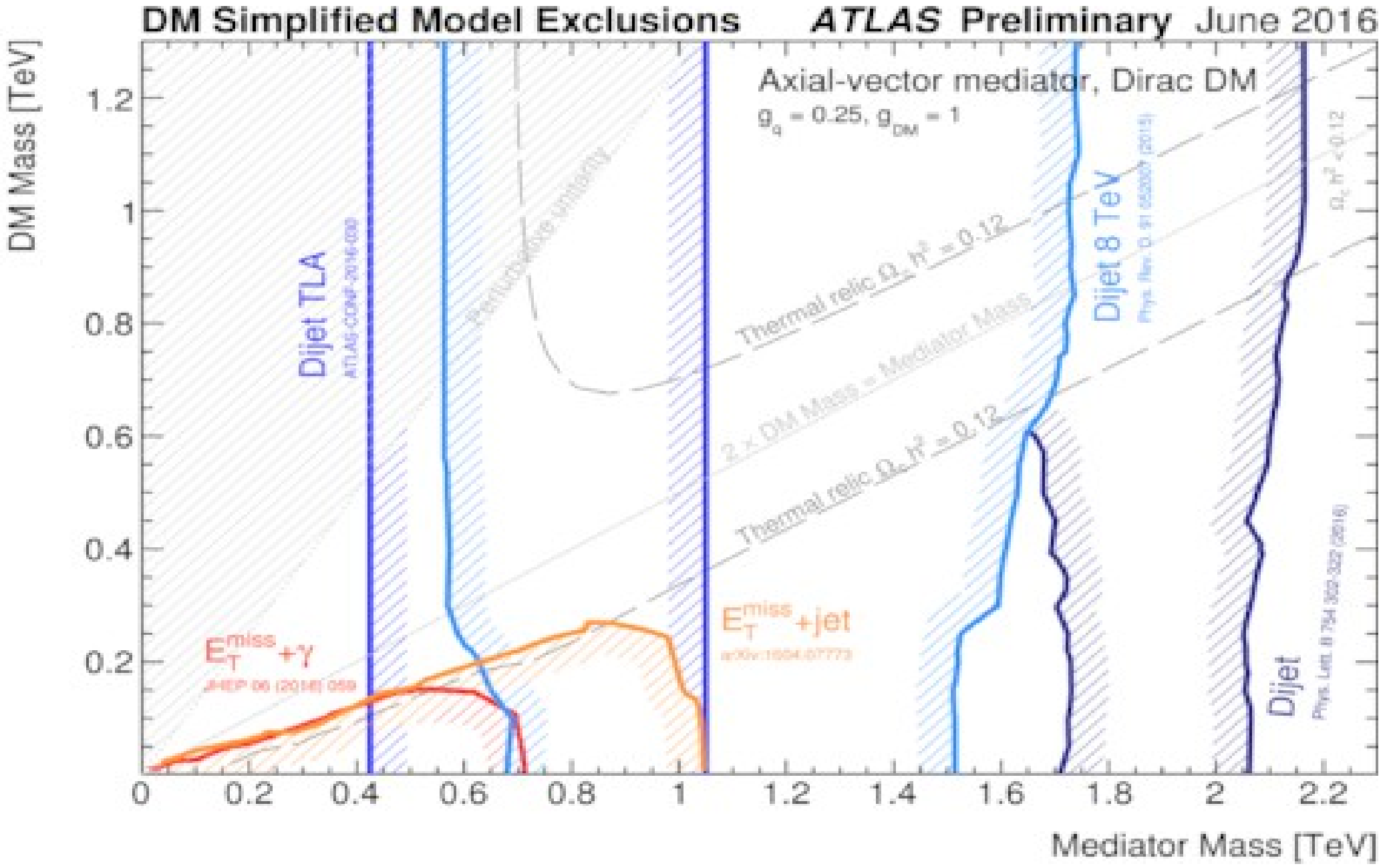


See Krisztian Peters' talk for more

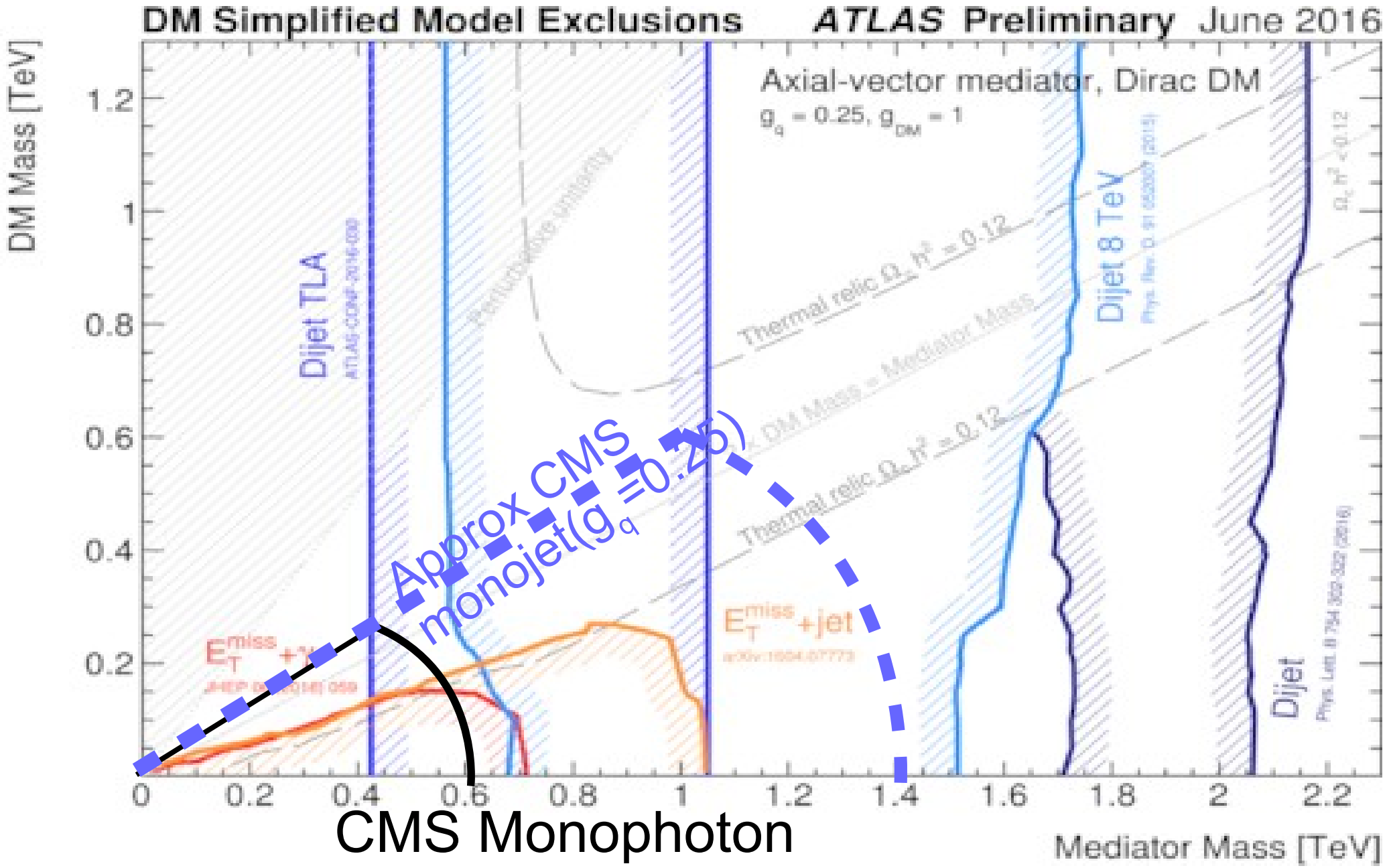




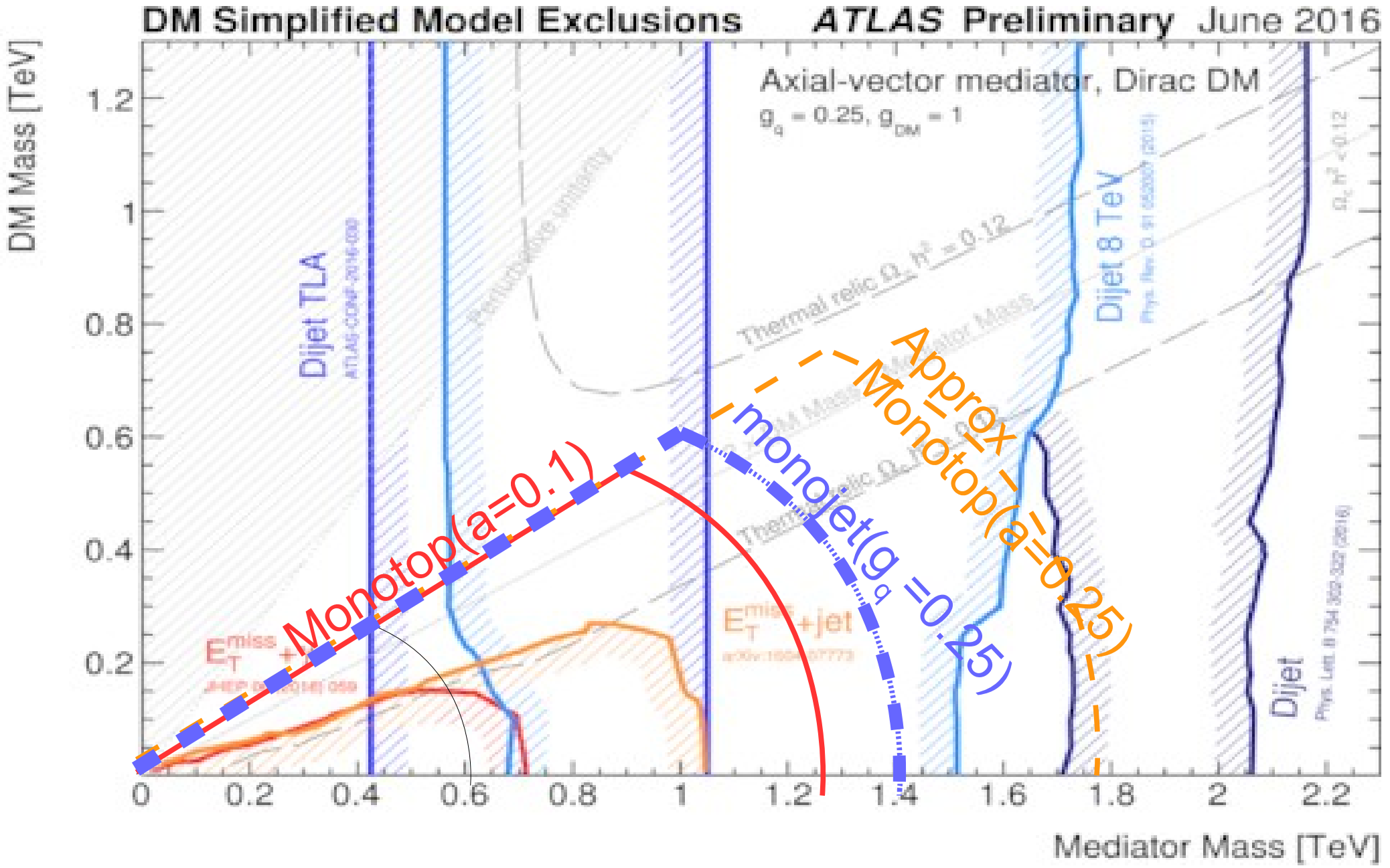
Putting it all together



Putting it all together



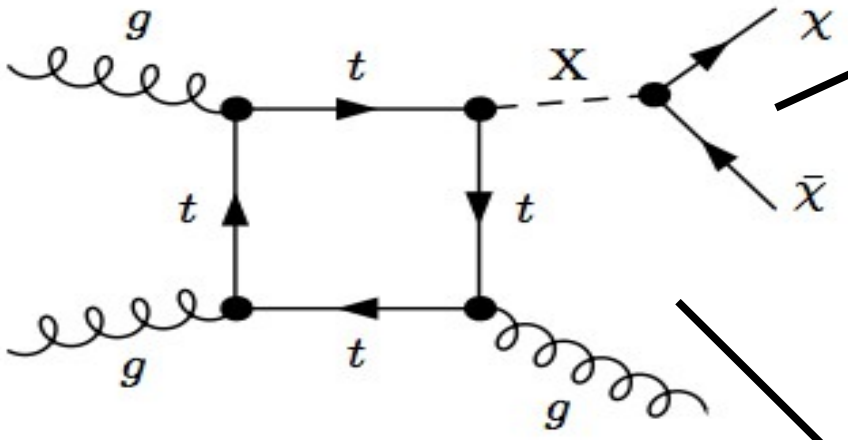
Putting it all together

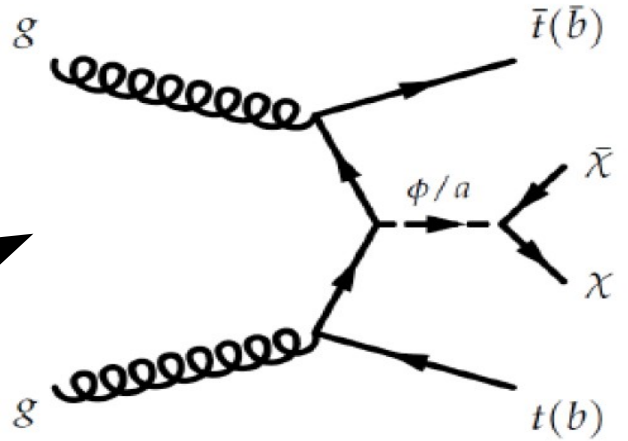


Spin 0

What can you do with Spin 0?

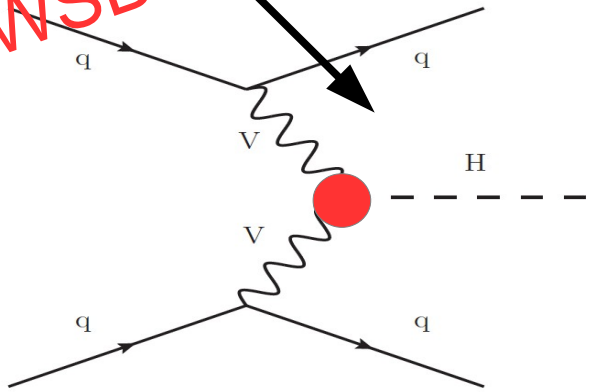
Big Assumption :
No mixing w/Higgs

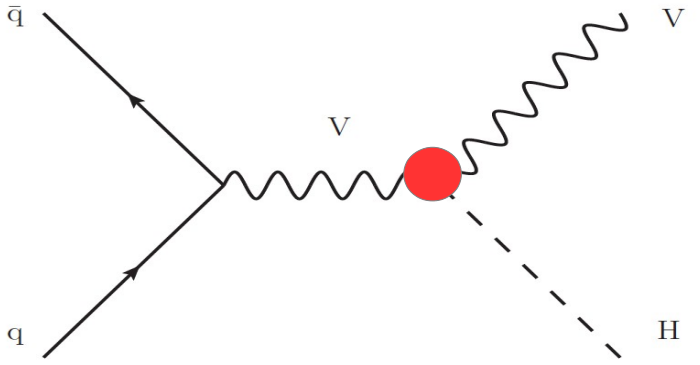




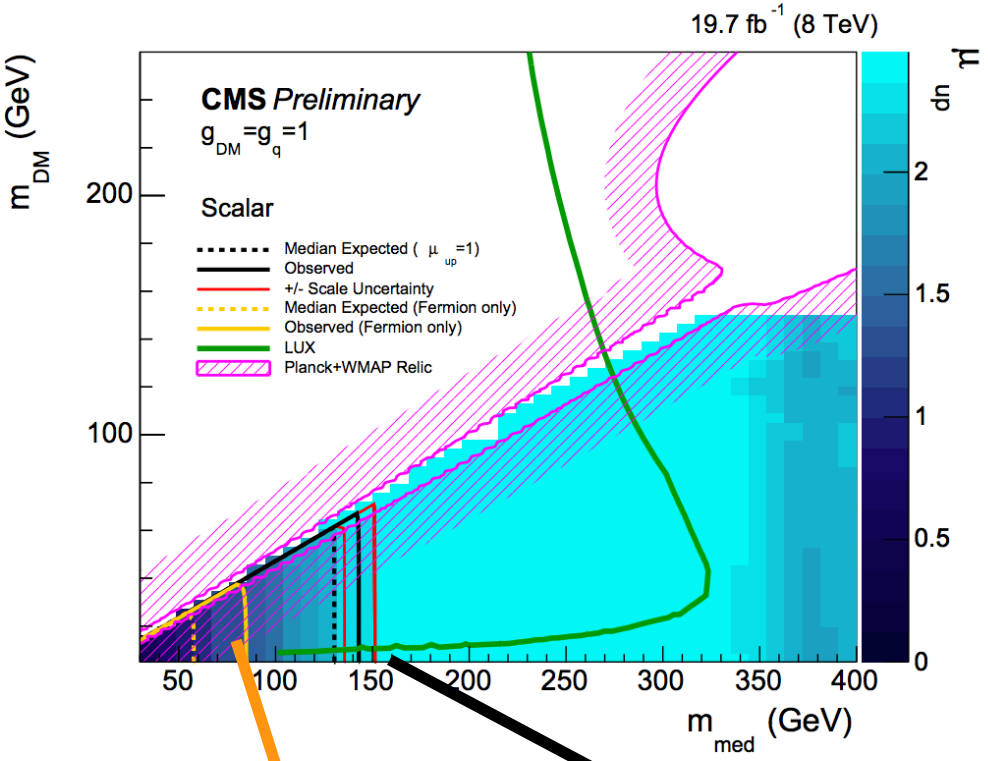
Applying EWSB!

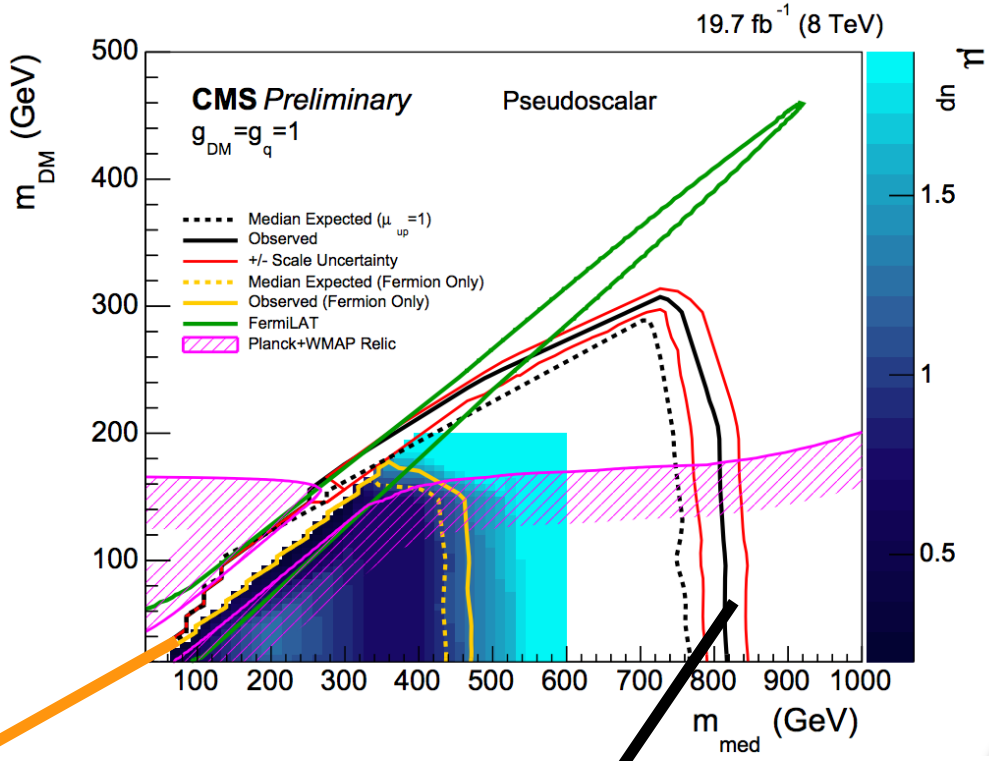
Higgs invisible or
Scalar w/EWSB





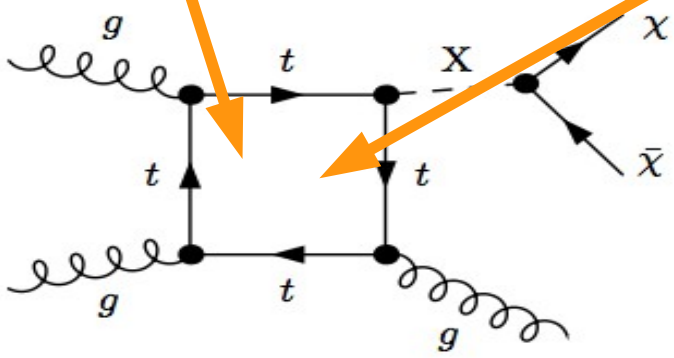
Our Current Scalar & Psuedo results





- Currently driven by 8TeV exclusion

Clear that there are issues



+

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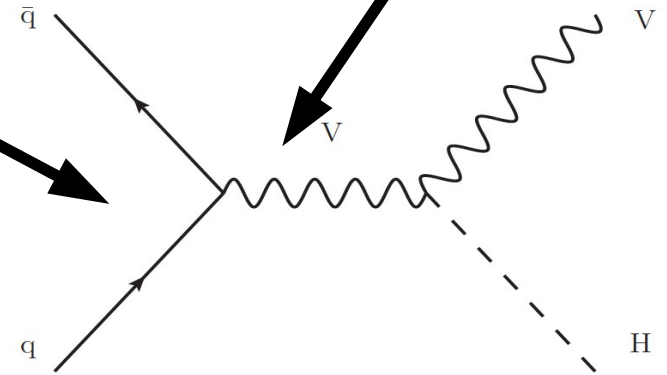
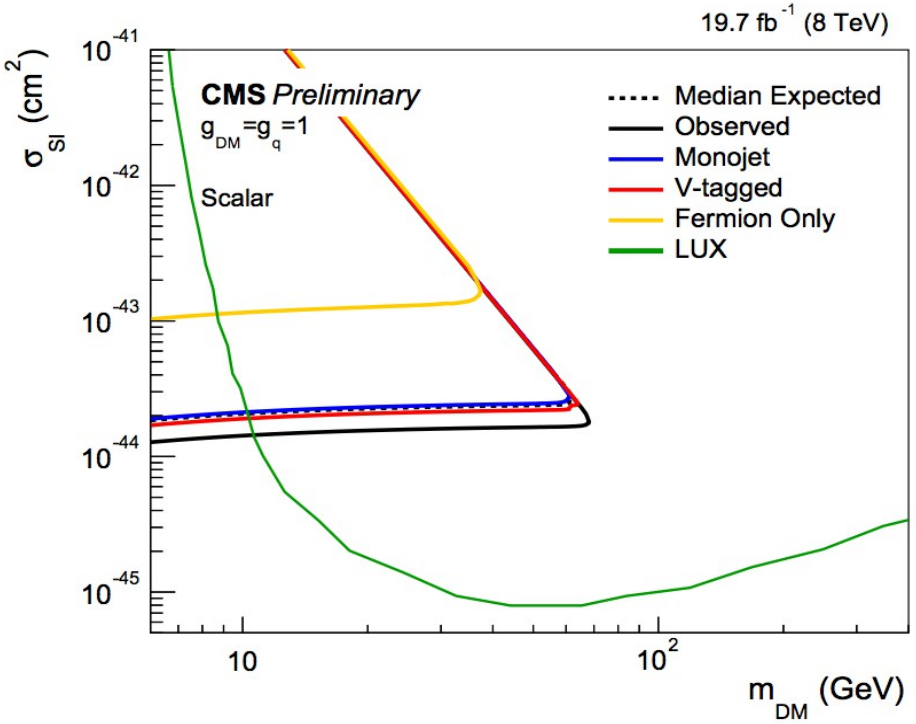
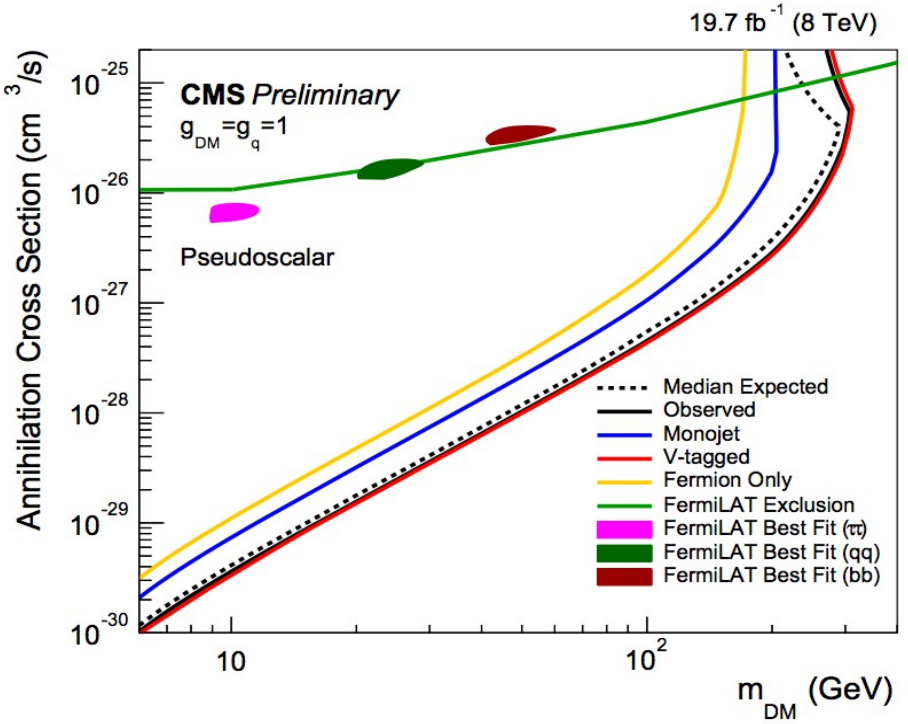


CMS-PAS-EXO-12-055

Our Current Scalar & Psuedo results



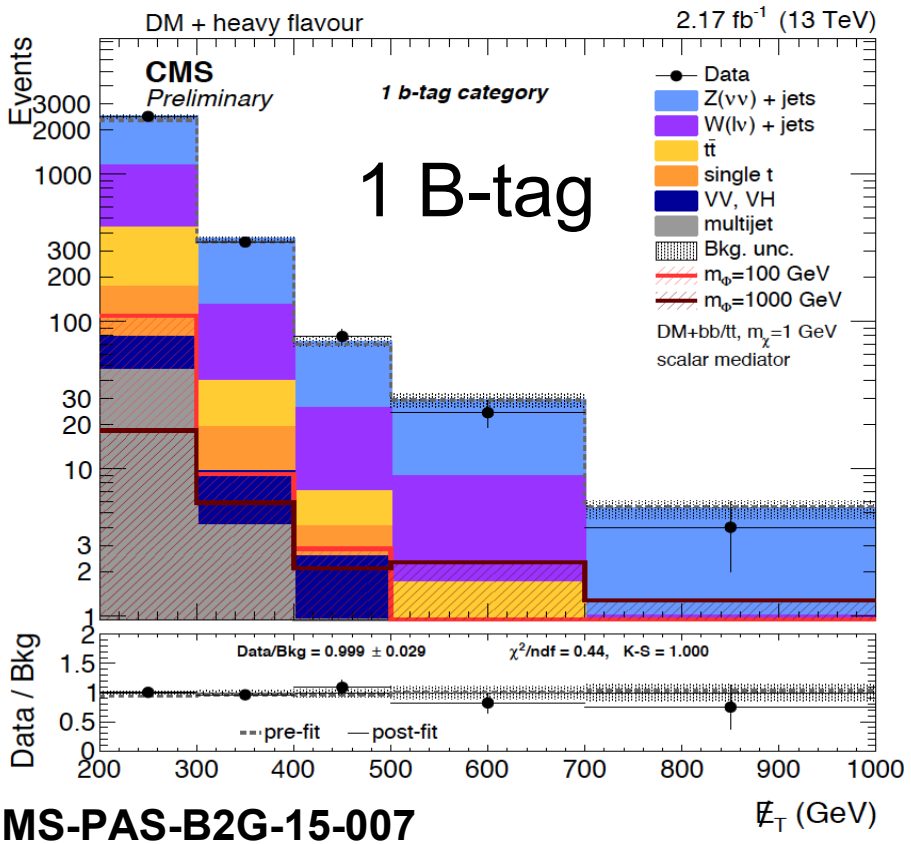


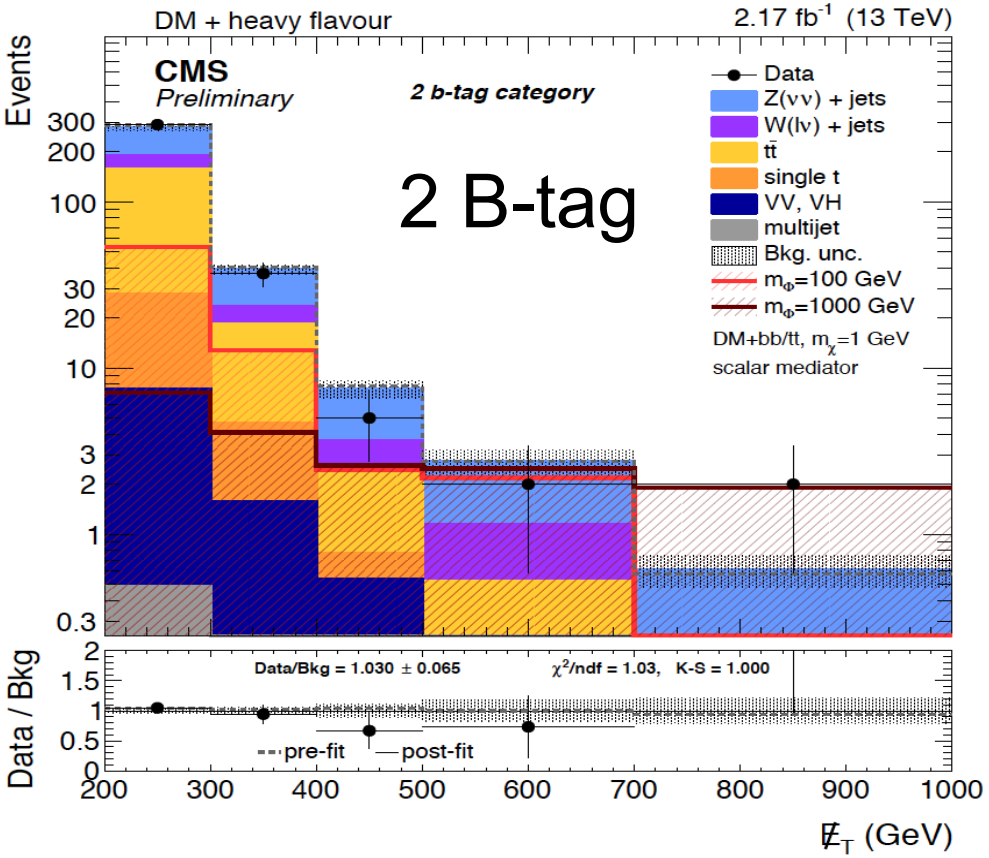
- When the dark matter is not onshell
  - Strong exclusion of pseudoscalar interpreation of LAT
  - Scalar and Direct detection are in close comopetition
    - Expect LHC to pass LUX this summer

CMS-PAS-EXO-12-055

Heavy Flavor

- Mono-B or B(s)
  - Require less than 4 jets
  - Basically the monojet analysis with either 1 or 2 bs
  - Inject both tt+DM and bb+DM into the analysis

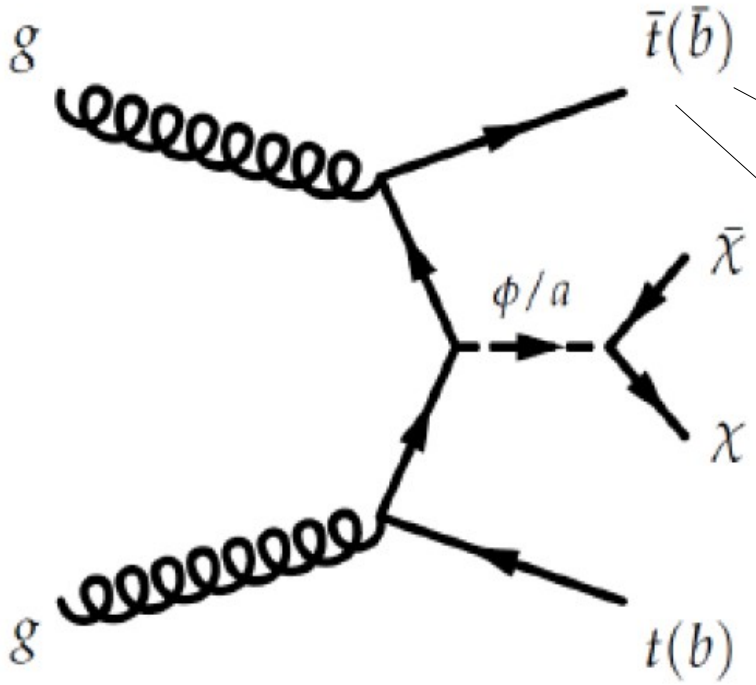


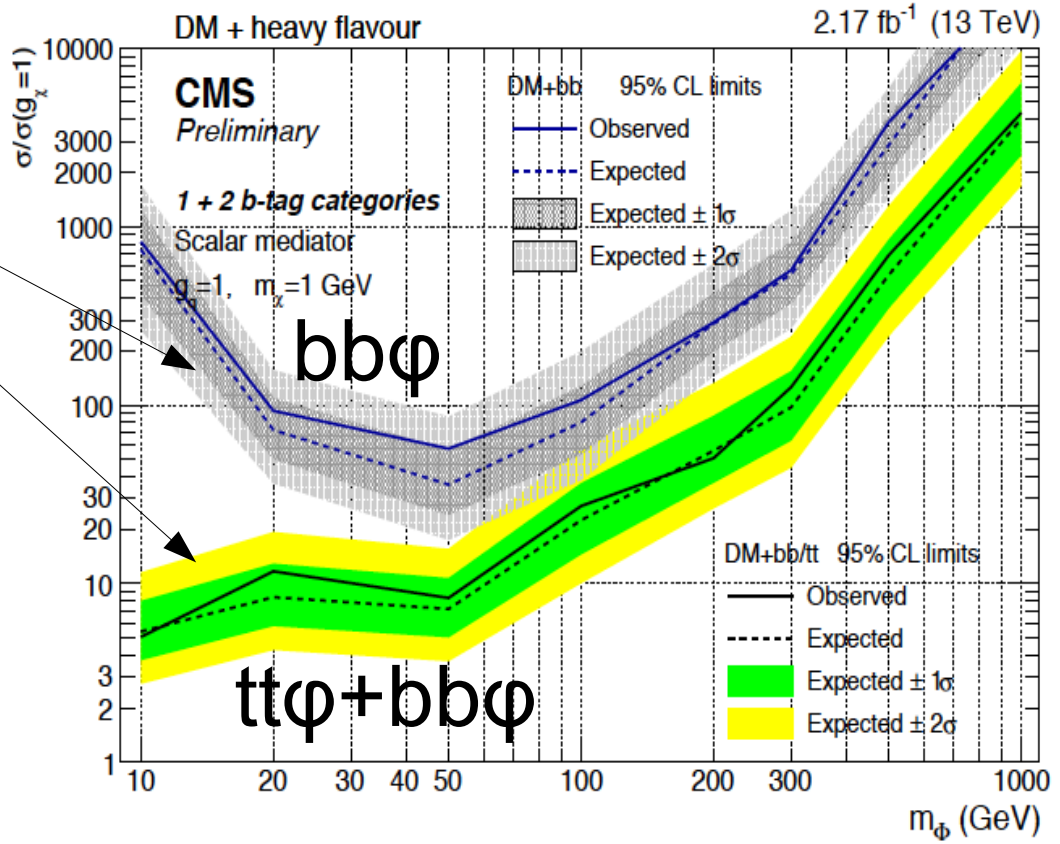


CMS-PAS-B2G-15-007

Heavy Flavor Results

- Mono-B or B(s)
  - Note that this is only < 4 jets
  - Inject both tt+DM and bb+DM into the analysis

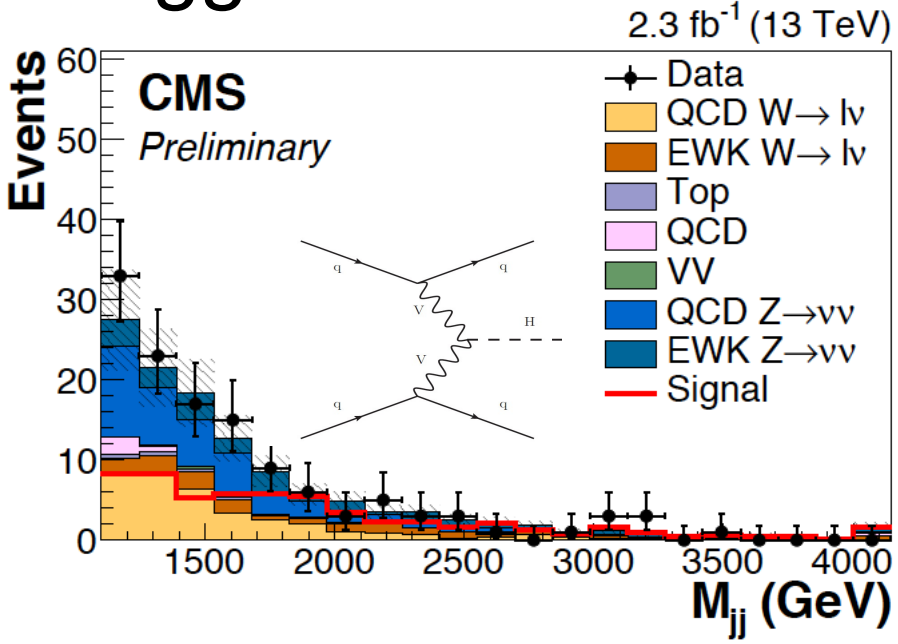


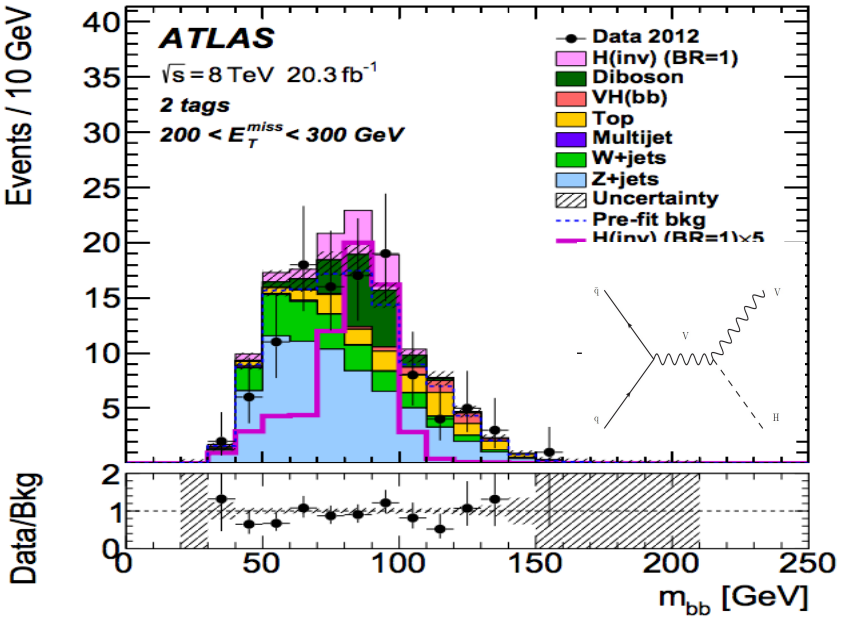


CMS-PAS-B2G-15-007

Higgs Invisible Interpretation

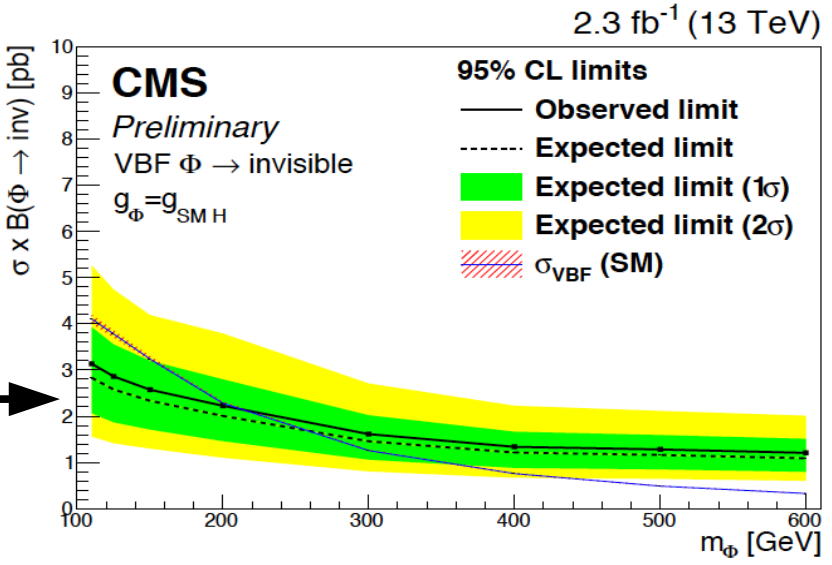
- Higgs Invisible is scalar model with EWSB





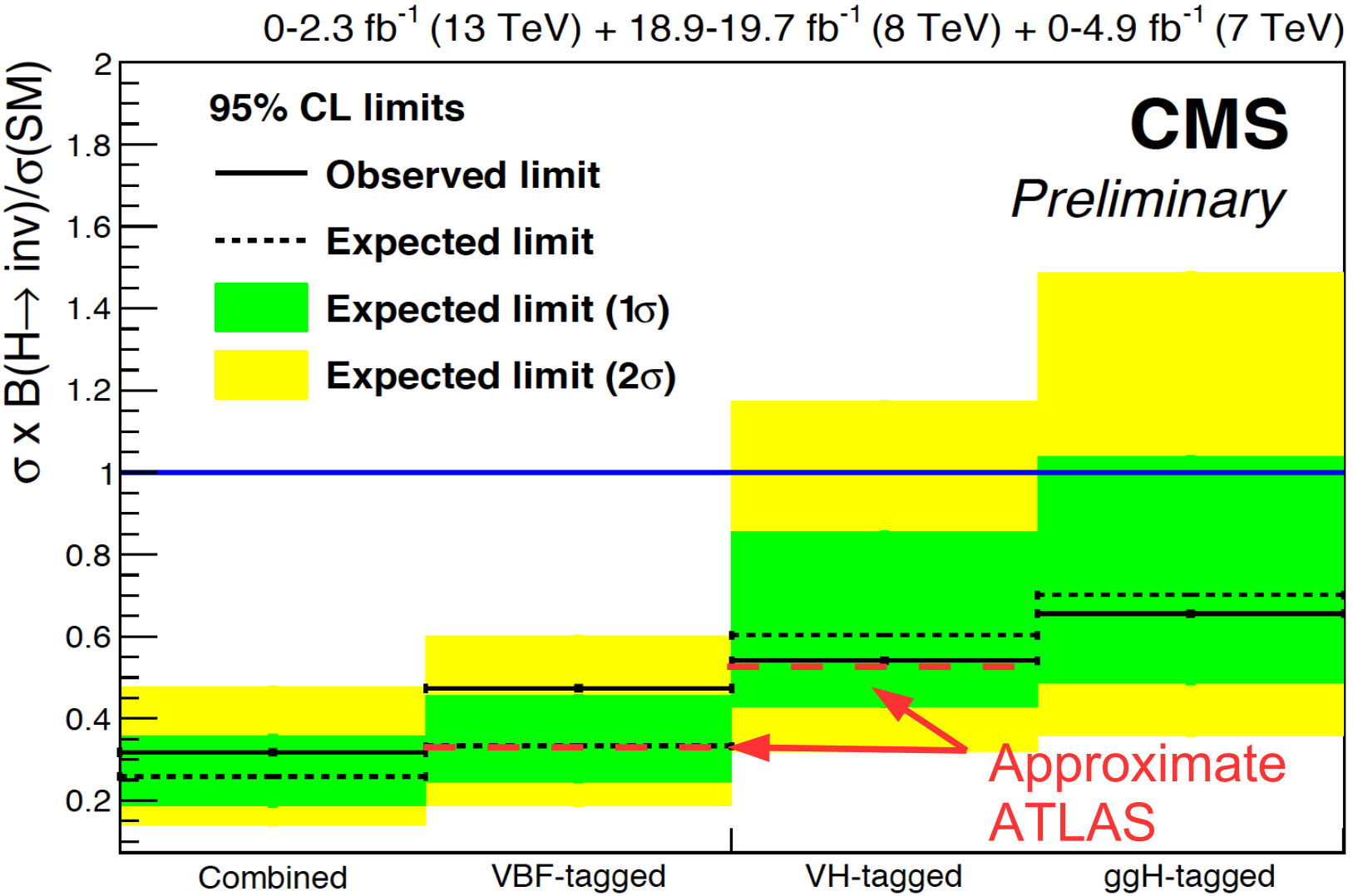
30% improvement in VBF from tying the W→Z constraints together in control regions

Starting to scan mass →



CMS-PAS-HIG-16-009/ATLAS-HIGG-2015-03

Results



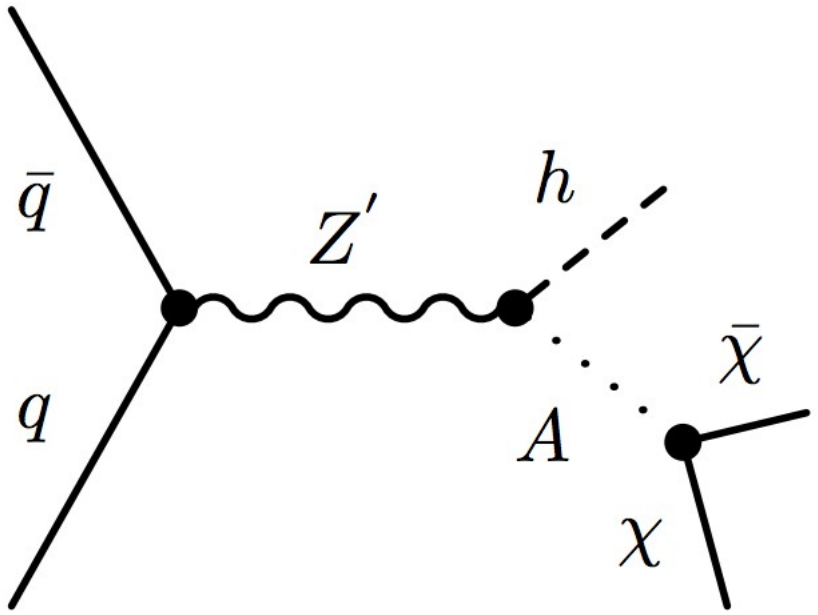
CMS : BR(H→Inv) < 0.32 (0.26 expected)

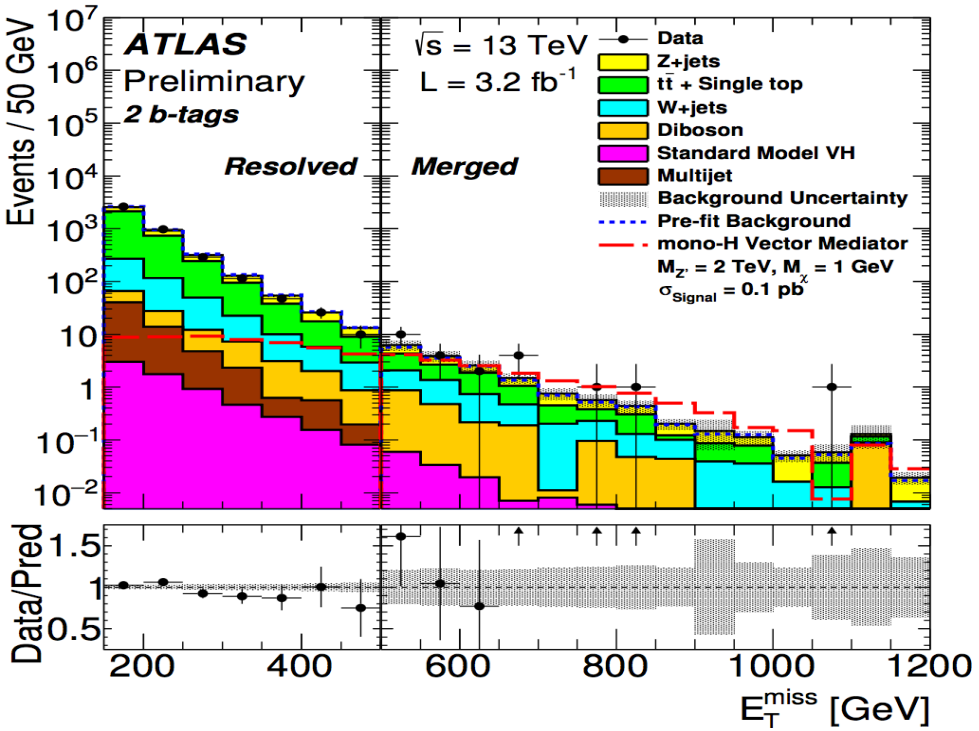
ATLAS : BR(H→Inv) < 0.25 (0.27 expected)

CMS-PAS-HIG-16-009/ATLAS-HIGG-2015-03

Mono-Higgs

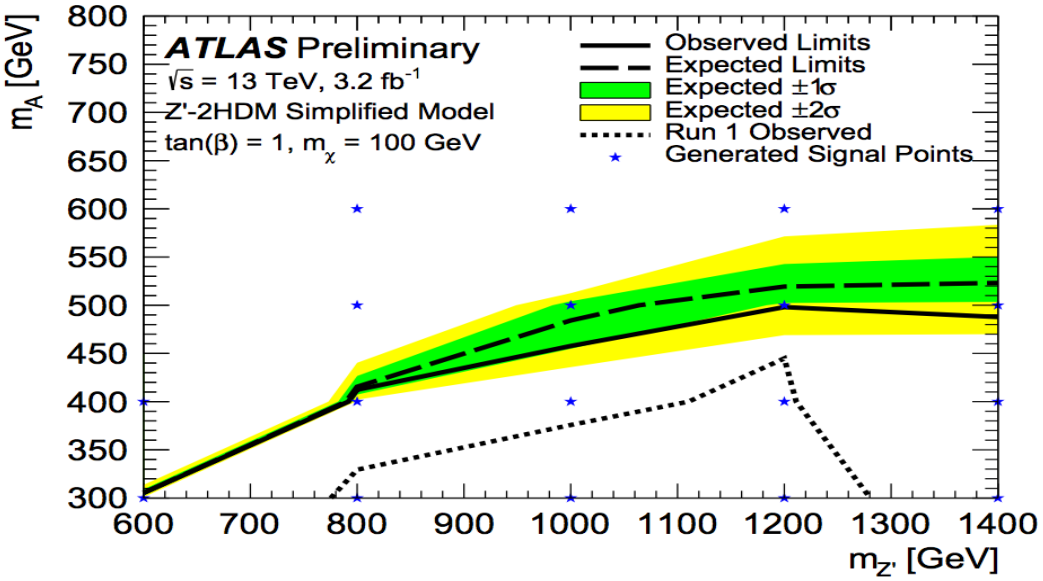
Adding Spin 1 and Spin 0 mediators





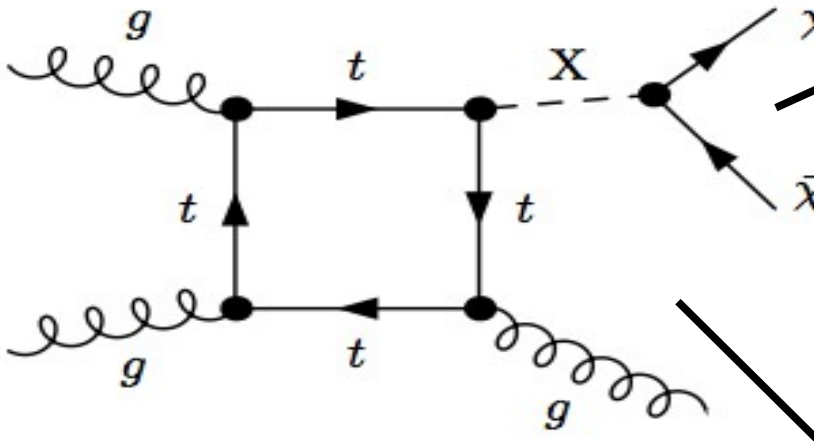
h→bb bounds drive mono-Higgs

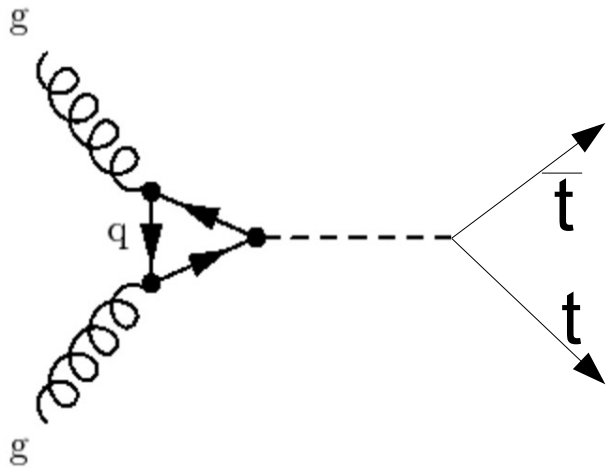
B-tagging forces ttbar background to drive analysis



ATLAS-CONF-2016-019

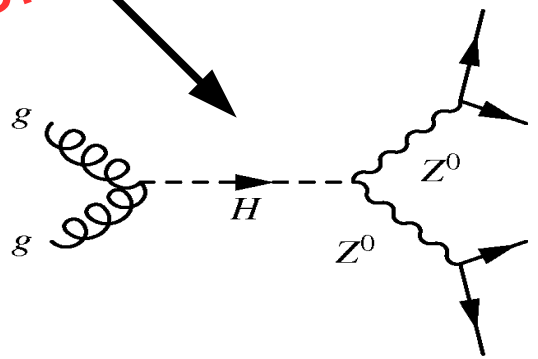
What about the visible?

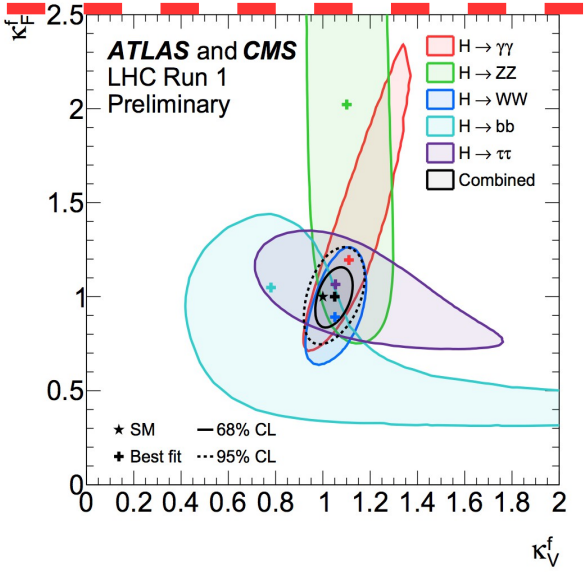




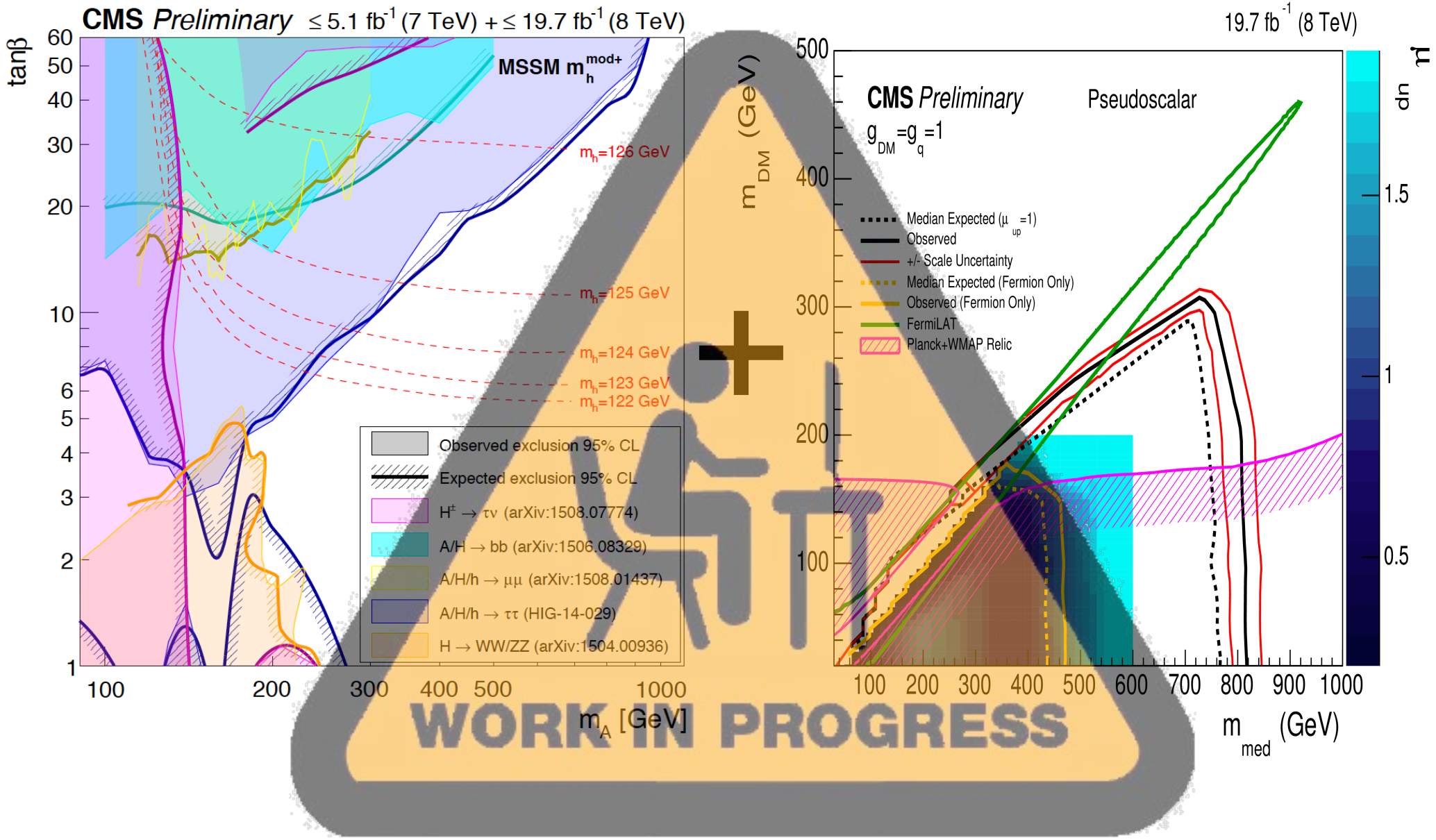
Higgs couplings

Applying EWSB!





Not yet available



Spin 0
Di-photon
(미안 해요)

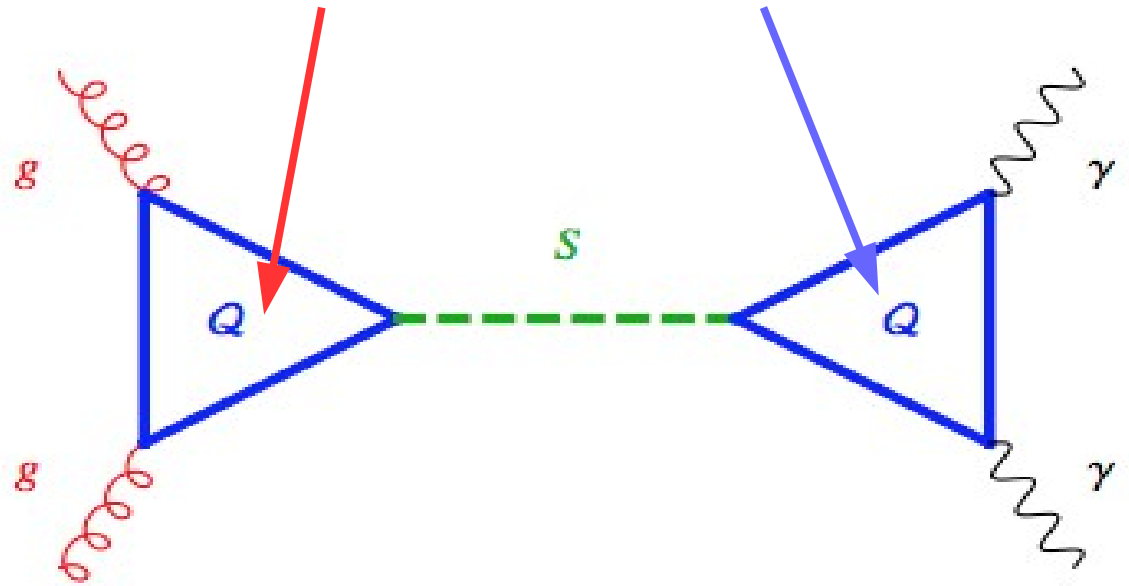
Preliminary
Work with U. Haish,O. Buchmuller,K. Hahn,N. Wardle, T. Du Pree

The simplest DM model

- Lets try to make something super basic
  - Basic model

$$\mathcal{L}_S = g_\chi S \bar{\chi}\chi + \frac{\alpha_s}{4\pi}\frac{c_g}{\Lambda} S G^a_{\mu\nu} G^{a\,\mu\nu} + \frac{\alpha}{4\pi}\frac{c_\gamma}{\Lambda} S F_{\mu\nu} F^{\mu\nu}$$

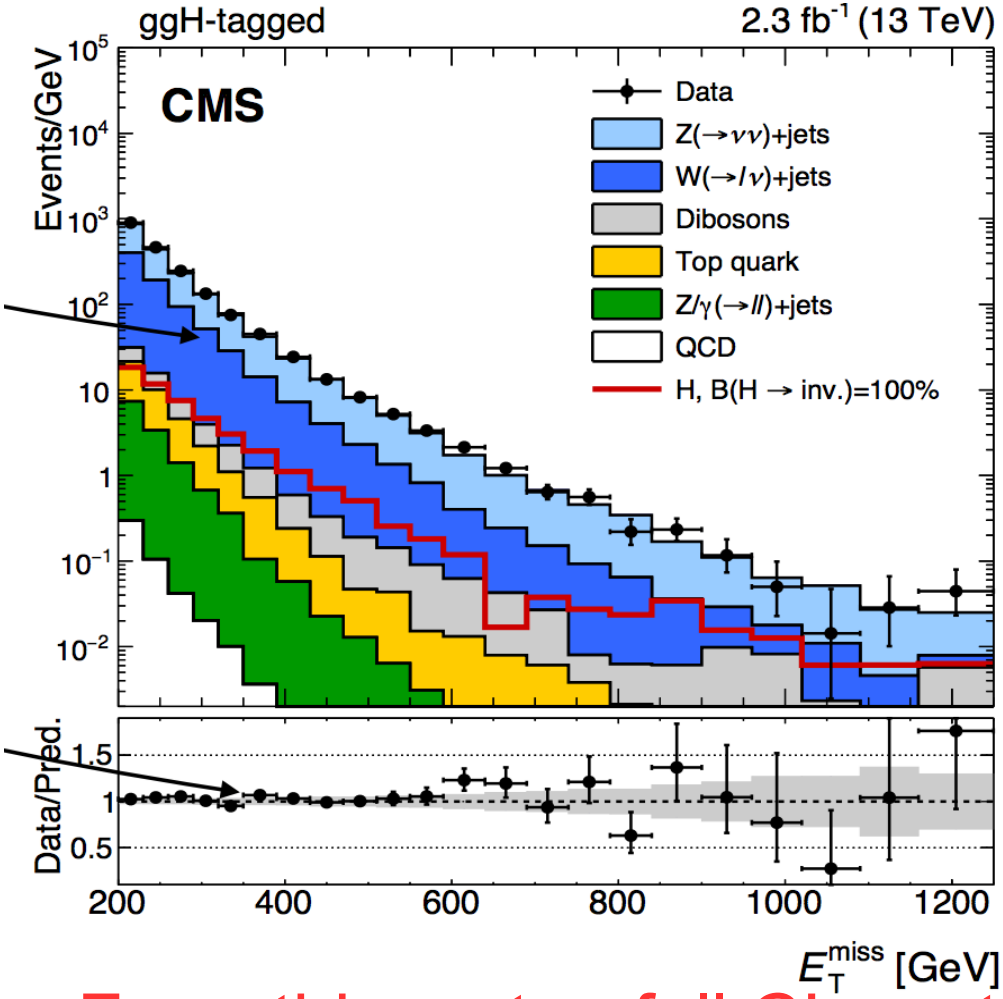
??



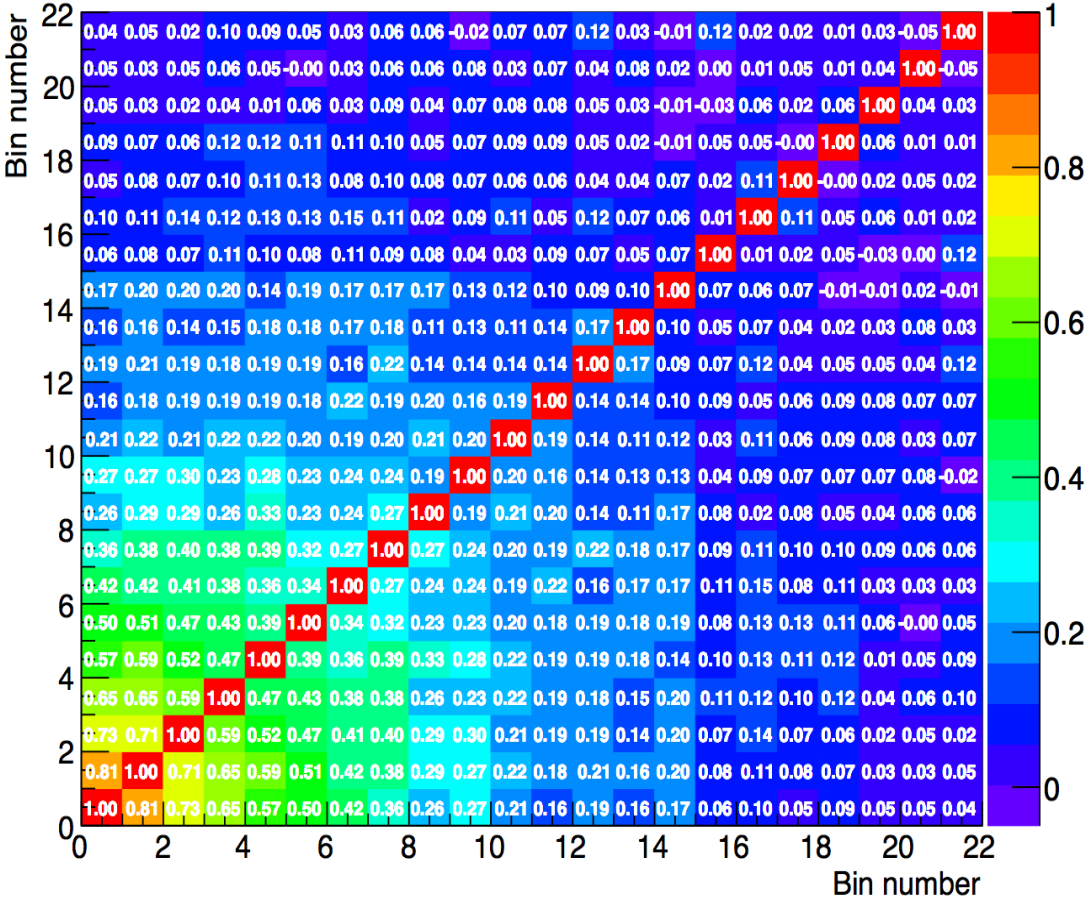
Re-interpreting the Analysis

- Future plans from LHC→simplified likelihoods
  - What is it? => Reduced control fit to 2 objects

MET distribution



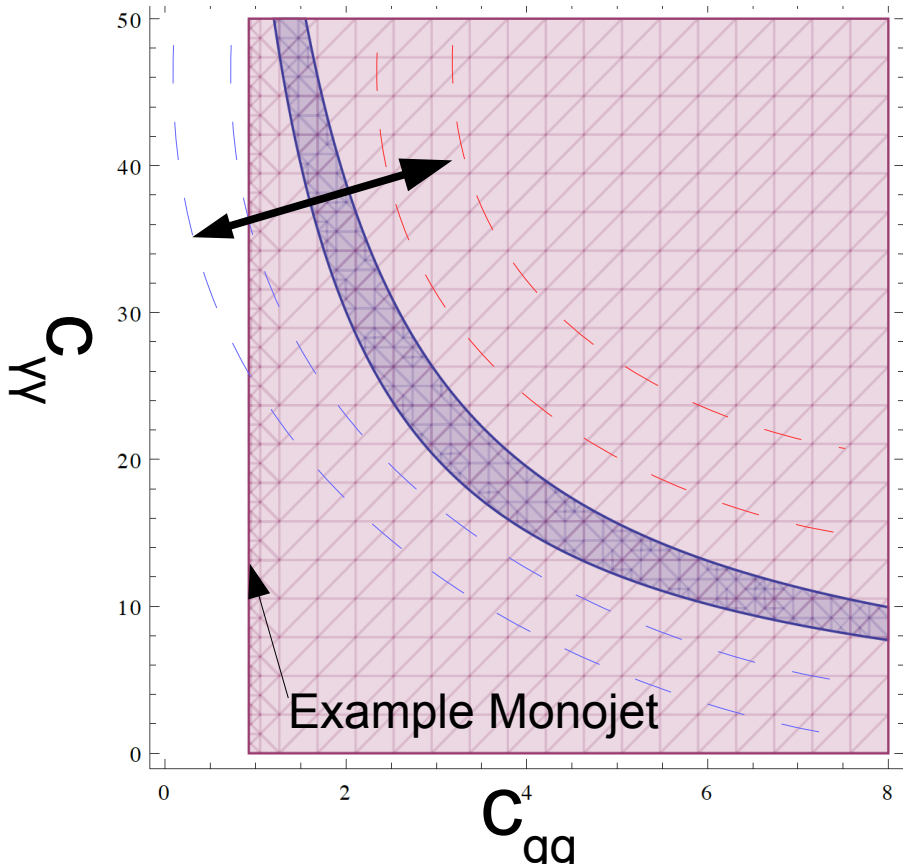
Toy Bin by bin covariance

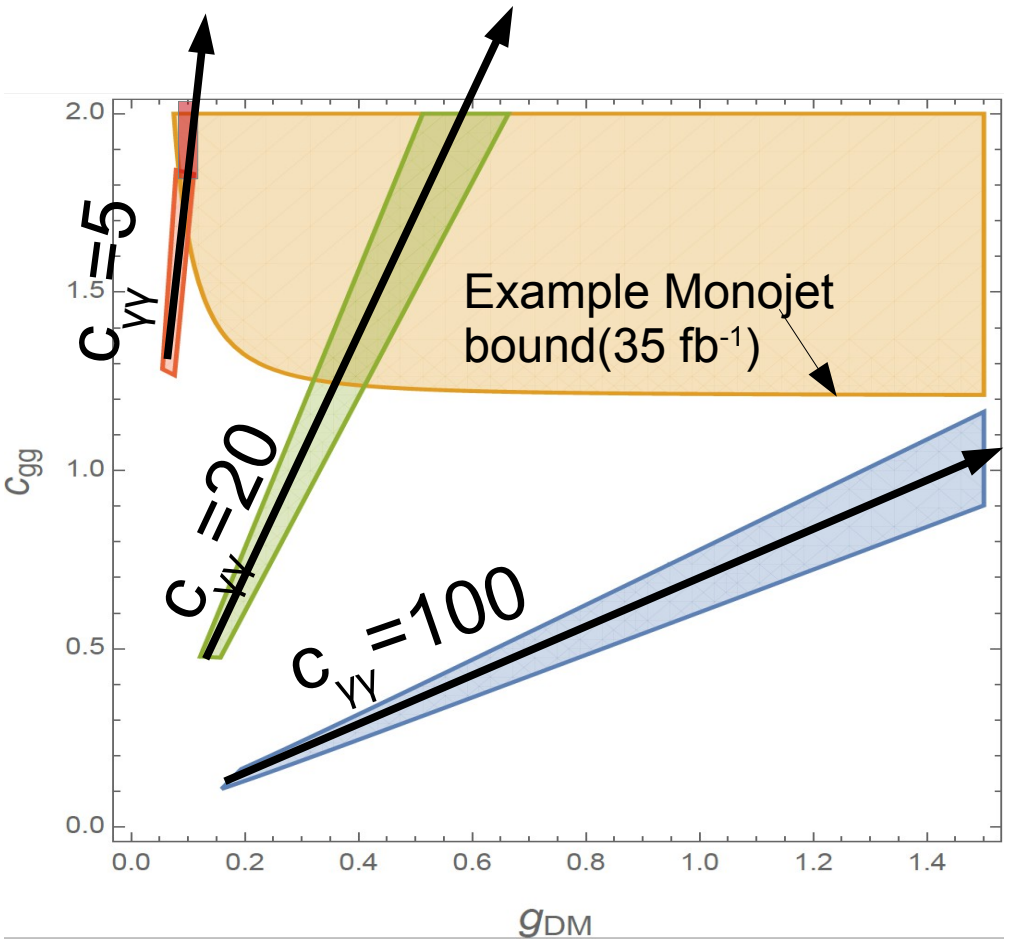


From this: setup full CL_s get both expected and observed

Using the best fit cross section

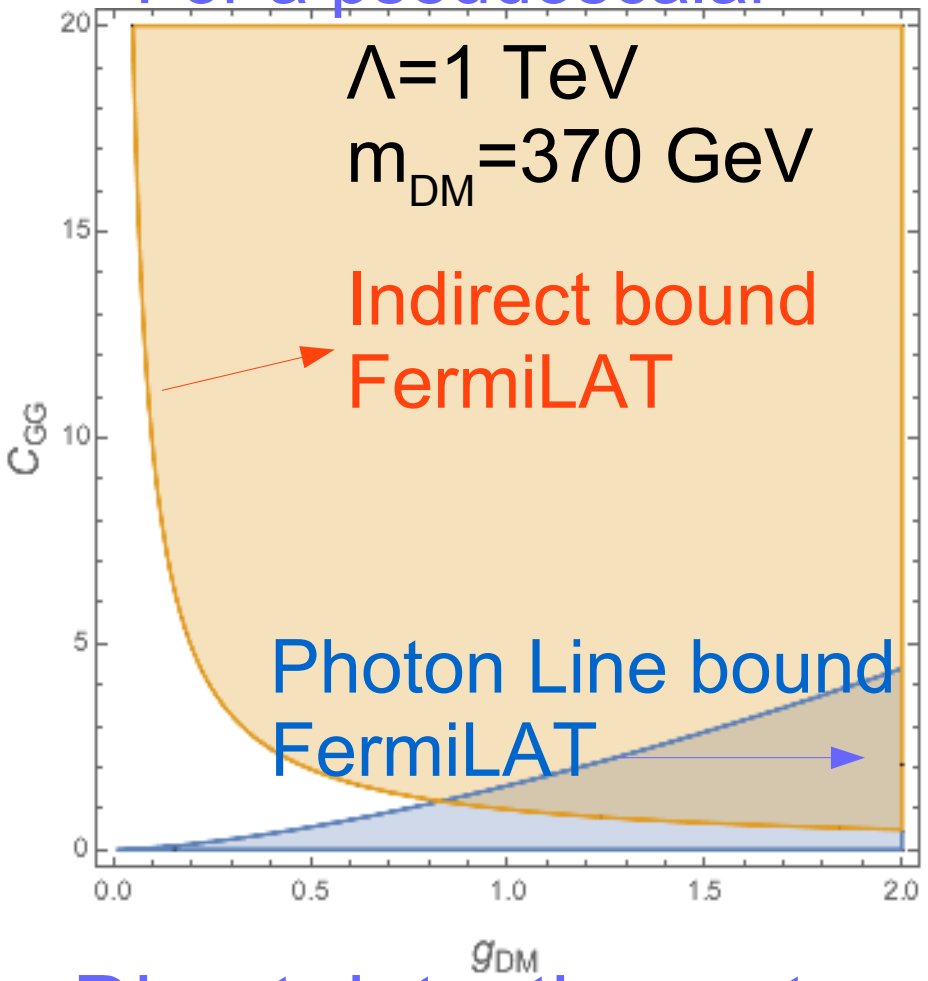
- We have 3 free couplings :
  - $g_{DM}, c_{GG}, c_{\gamma\gamma}$
- Taking the photon best fit can constrain one

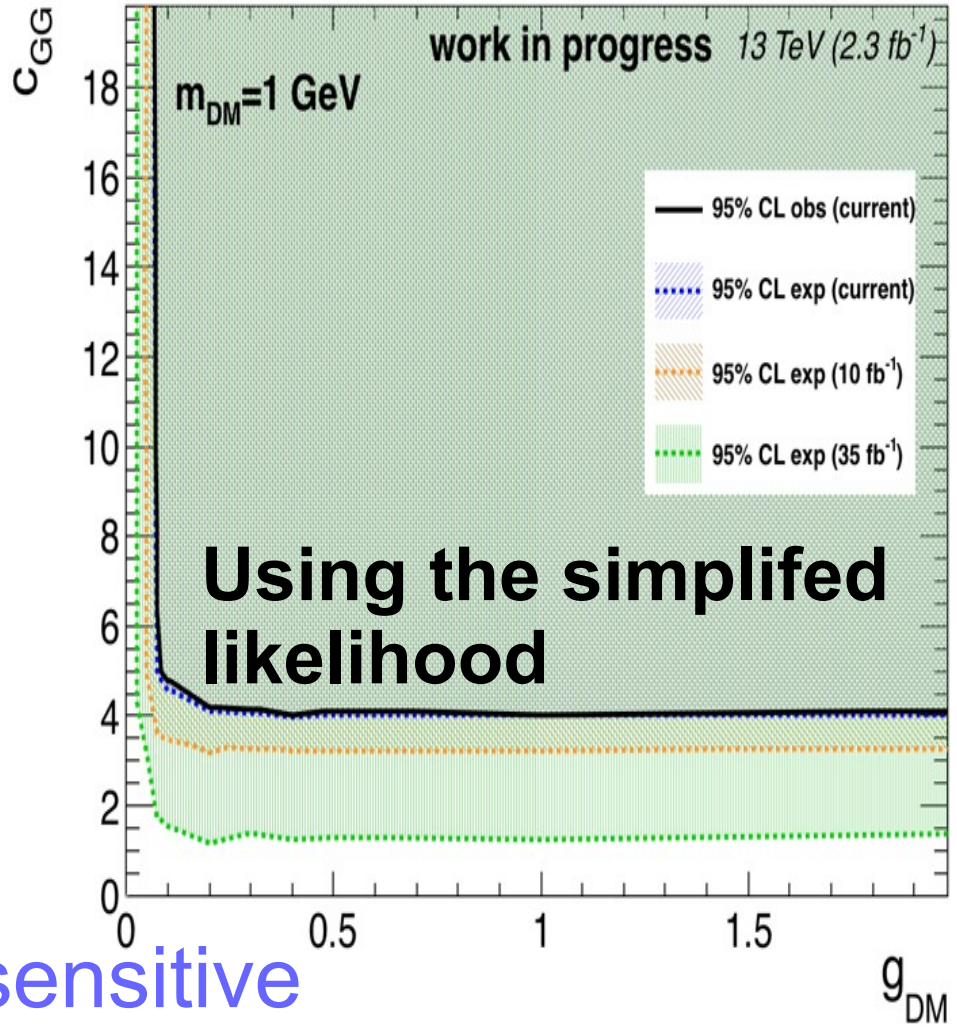




Considering All Constraints

For a pseudoscalar

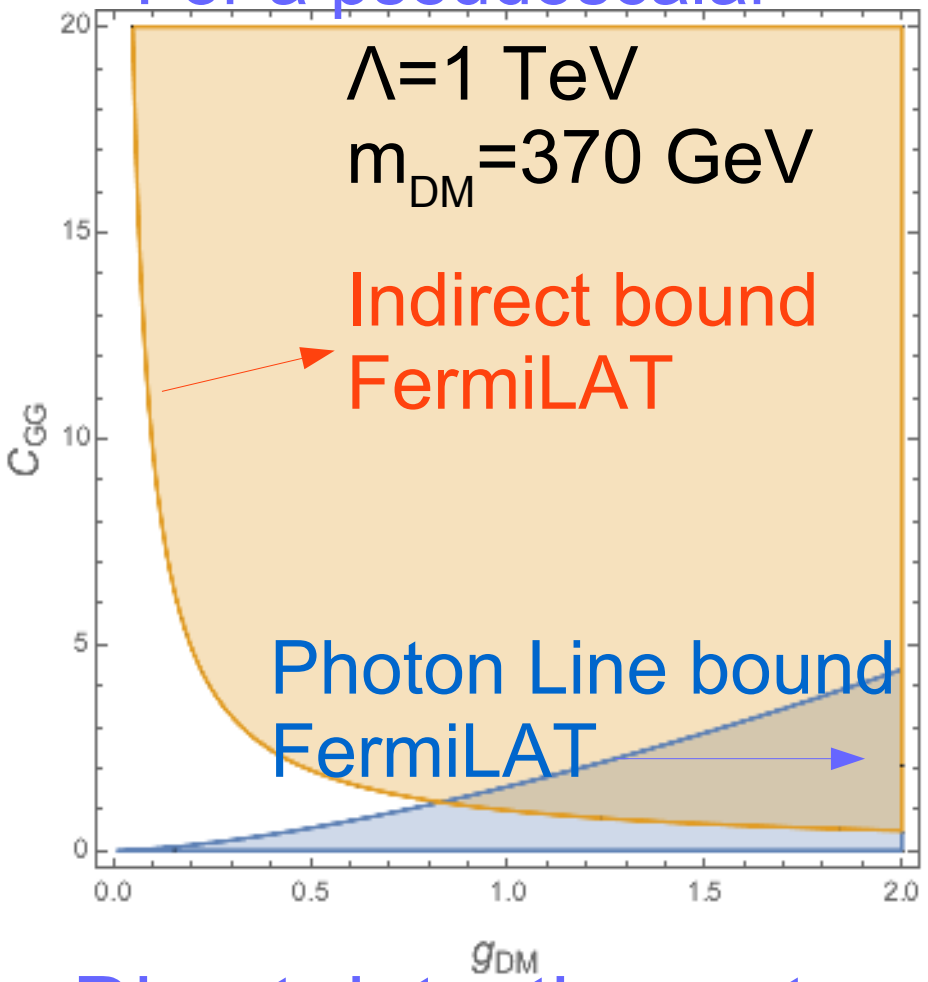


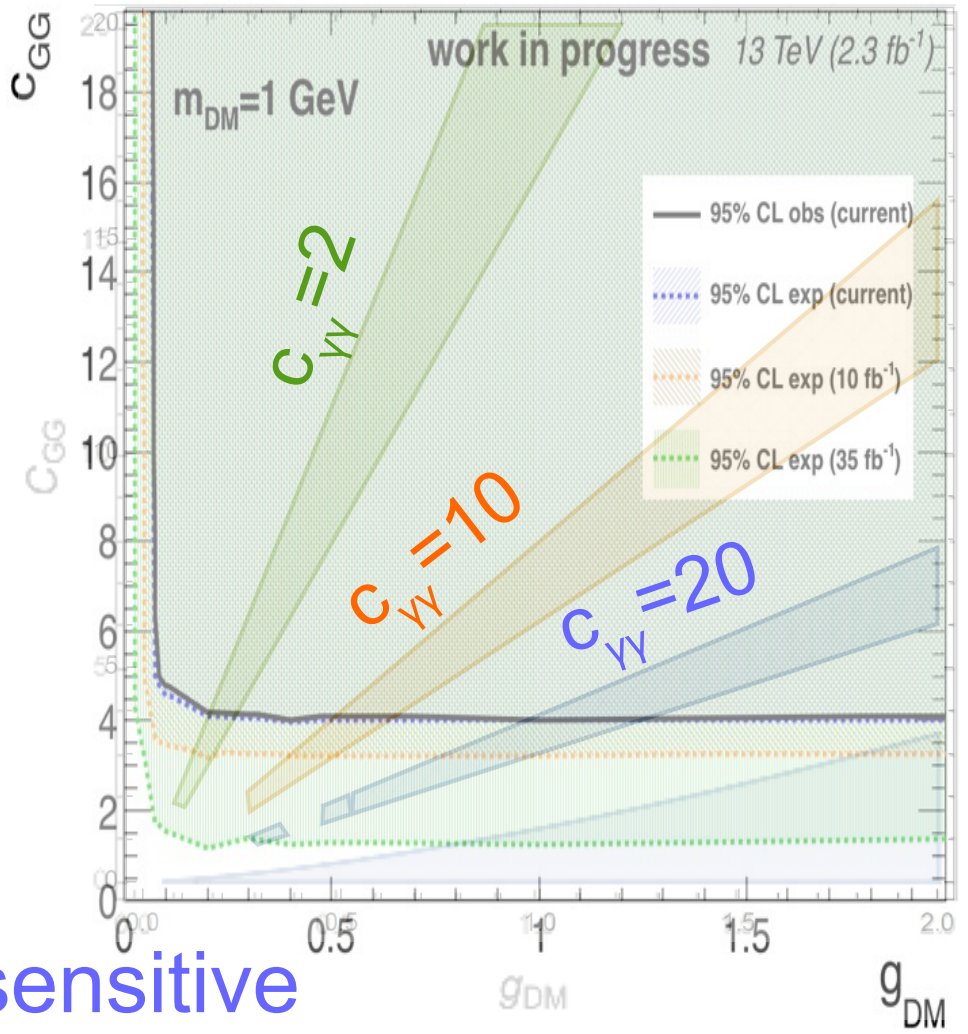


- Direct detection not yet sensitive
- Indirect detection limits on-shell production
- Photon Line bounds limit photon coupling < 100

Considering All Constraints

For a pseudoscalar





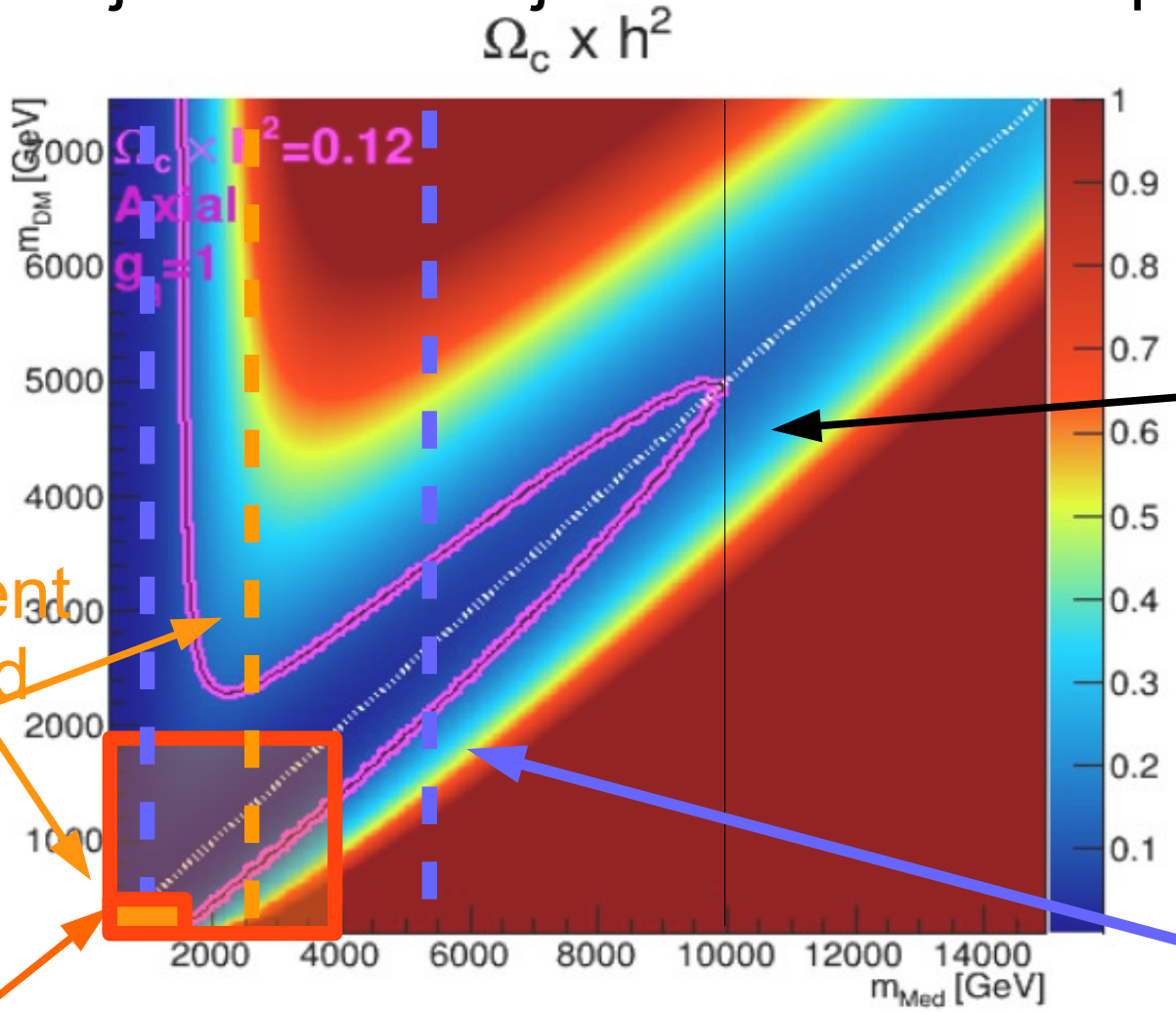
- Direct detection not yet sensitive
- Indirect detection limits on-shell production
- Photon Line bounds limit photon coupling < 100

Outlook

Hep-ph/1603.08525
Hep-ph/1509.02904
ATL-PHYS-PUB-2015-004

Outlook

- Spin 1 :
  - Dijet and monojet will continue to push out the bounds



Mediator mass Maxes out around 8-9 TeV

Smaller for coupling g_q<1

Current bound

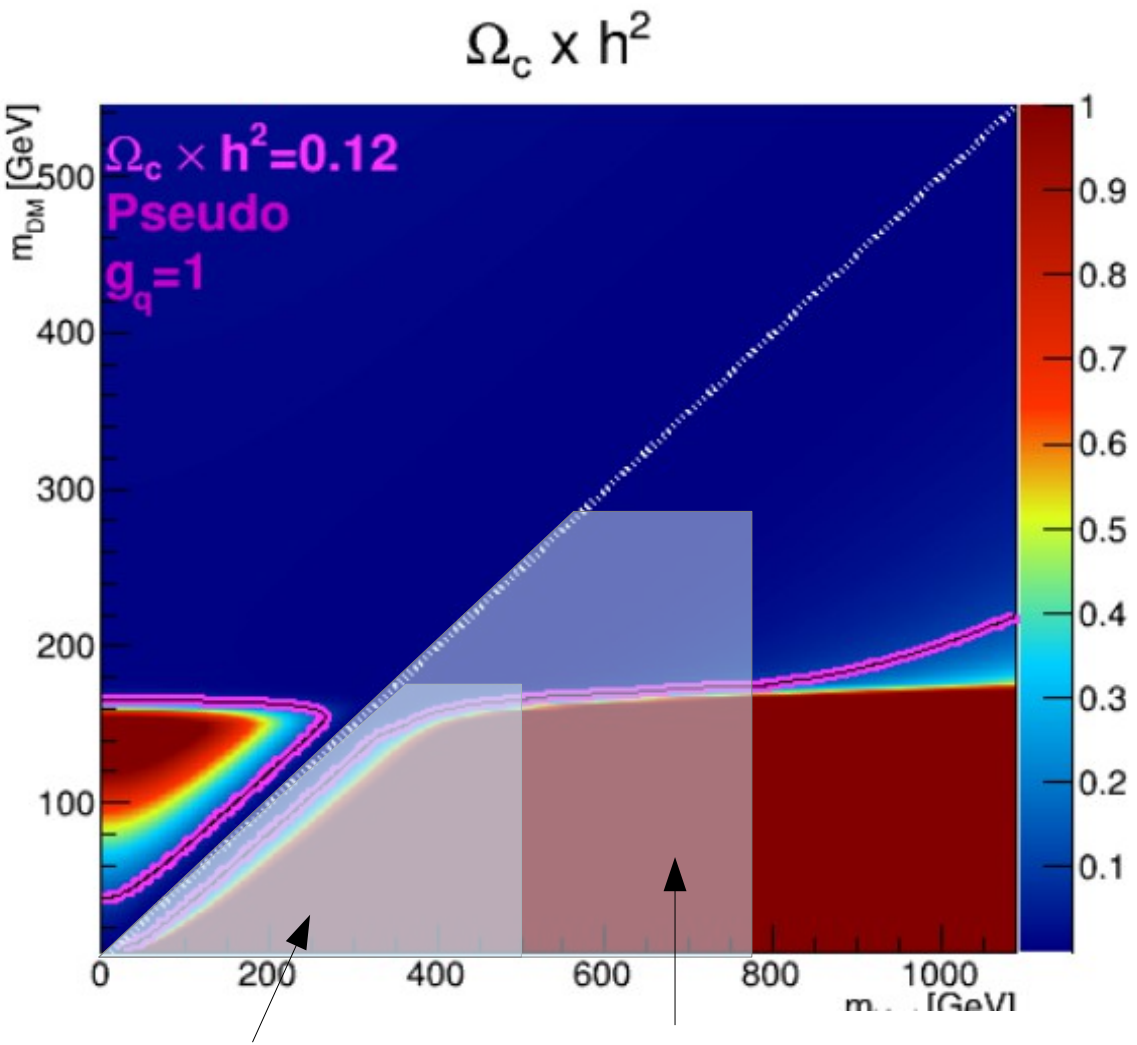
Approximate region monojet can probe

Approximate dijet reach

Hep-ph/1603.08525
Hep-ph/1509.02904
EXO-12-055
HIG-16-012

Outlook

- Spin 0 :
  - Yet to truly coalesce in 13 TeV



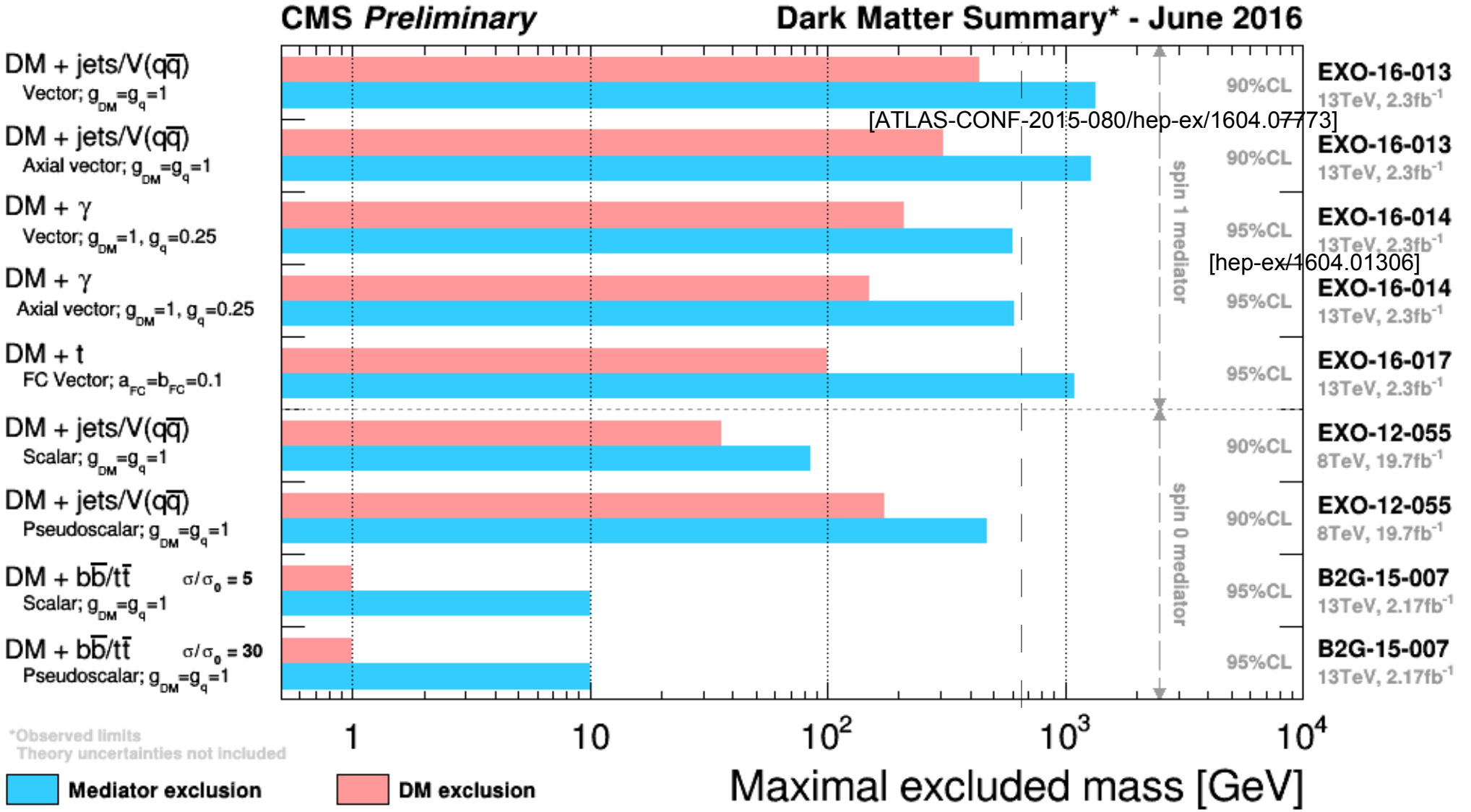
Current monojet Approx future

Current reach for Higgs-like Scalar w/EWSB + no mixing

Mono-Z : 130 GeV
VBF : 250 GeV
Mono-V/j : 150 GeV

Heavy Flavor :
1st bb/tt+φ result
No exlcusion yet

Summary



DM+A (by Z')
Pseudoscalar ($g_{DM}=g_q=1$)

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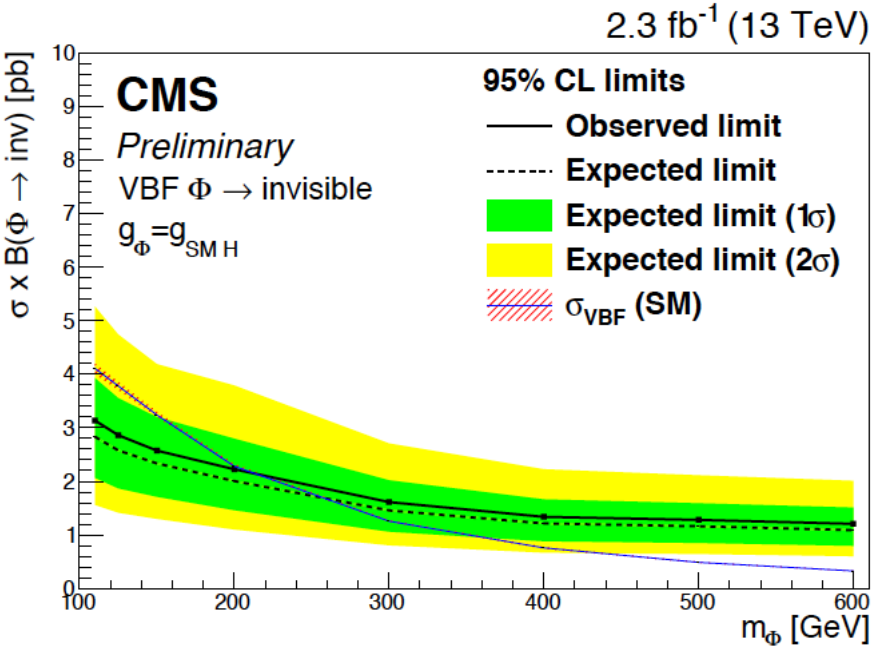
ATLAS-CONF-2016-011

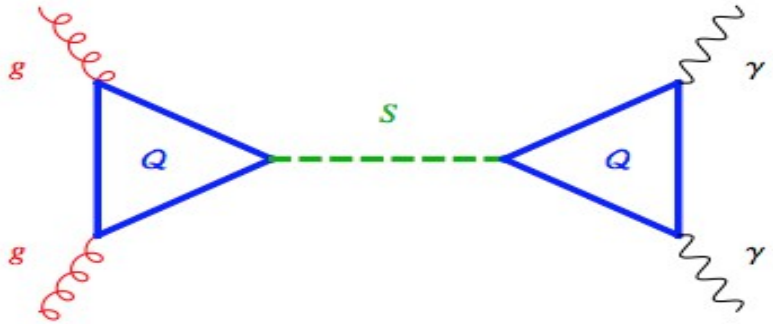
Thanks

감사합니다

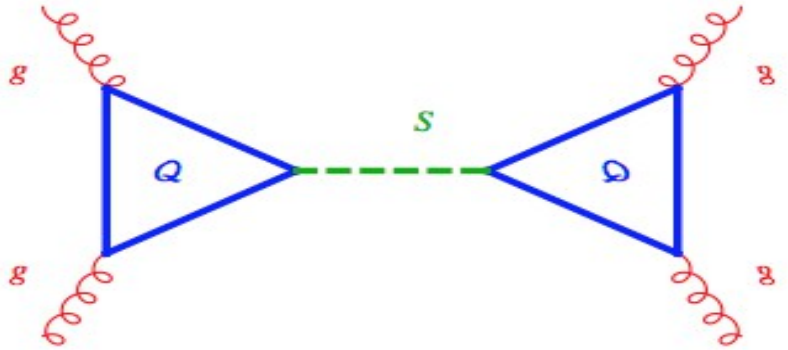

2.3 fb-1 (13 TeV)
CMS
Preliminary
VBF Φ → invisible
gΦ=gSM H
95% CL limits
Observed limit
Expected limit
Expected limit (1σ)
Expected limit (2σ)
σVBF (SM)
σ x B(Φ → inv) [pb]
mΦ [GeV]
0
1
2
3
4
5
6
7
8
9
10
100
200
300
400
500
600

What are the decays

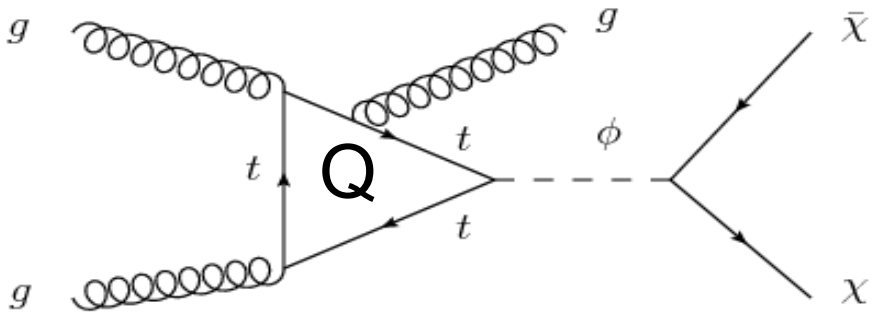
- We only really have a few decays:



Diphoton decays



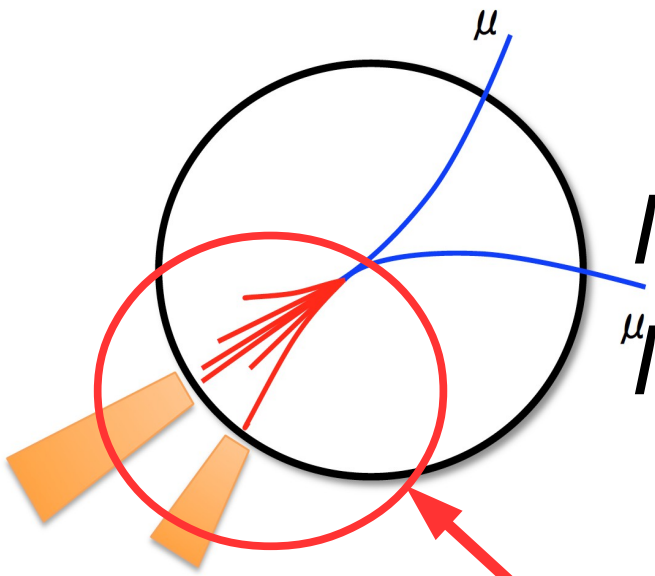
Dijet decays



Monojet decays

What goes into this?

- To find a signal we look for high *MET* :



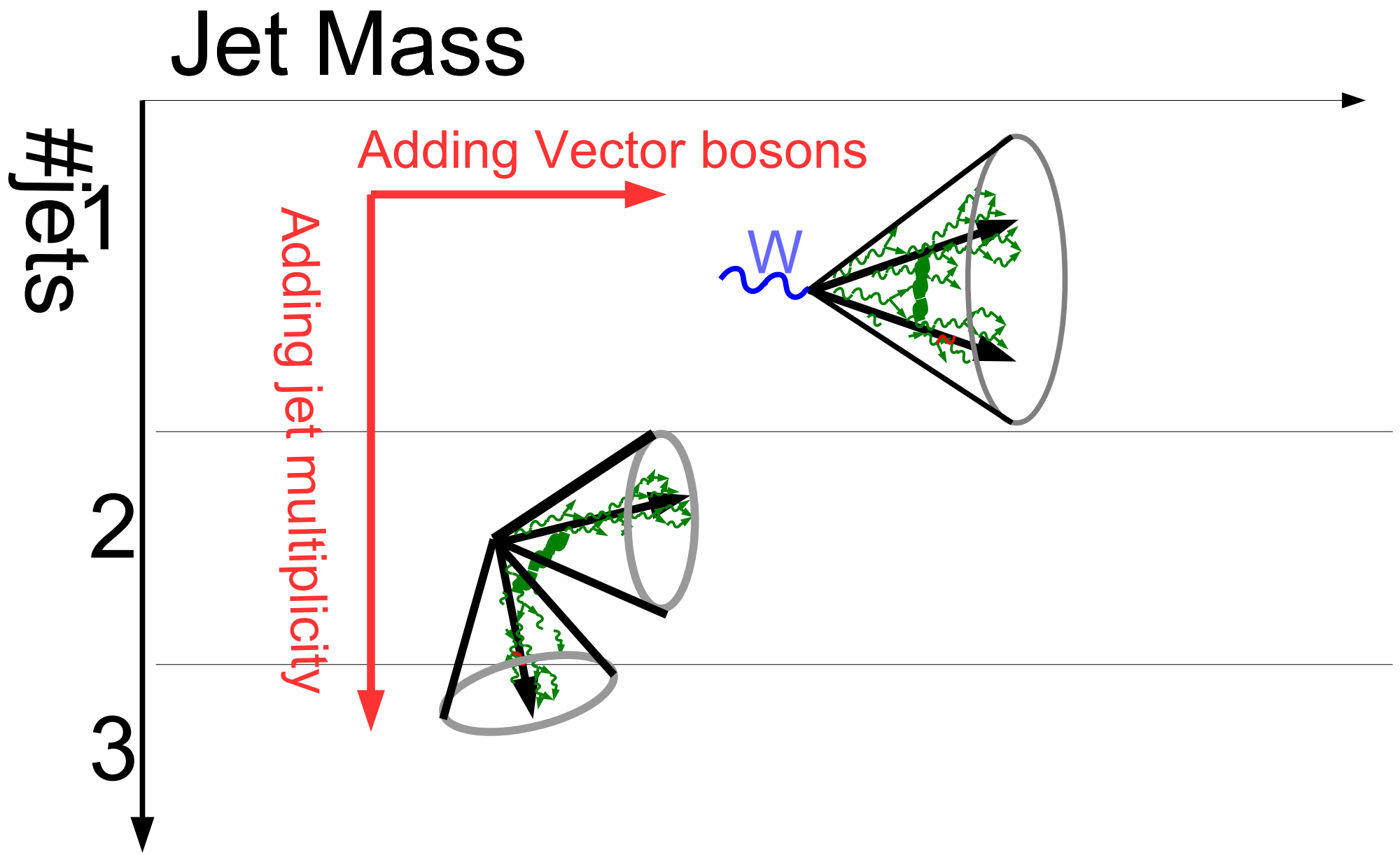
$$MET = -\Sigma_{All\ particles}\ p_T$$

$$^{\mu}MET(Z\rightarrow\nu\nu) = -\ Z\ recoil\ +\ p_T(\nu\nu)$$

Modeling of production mode is needed (HO corrections)

Modelling of the calorimeter response and resoltuion

Monojet Extenstion Plane



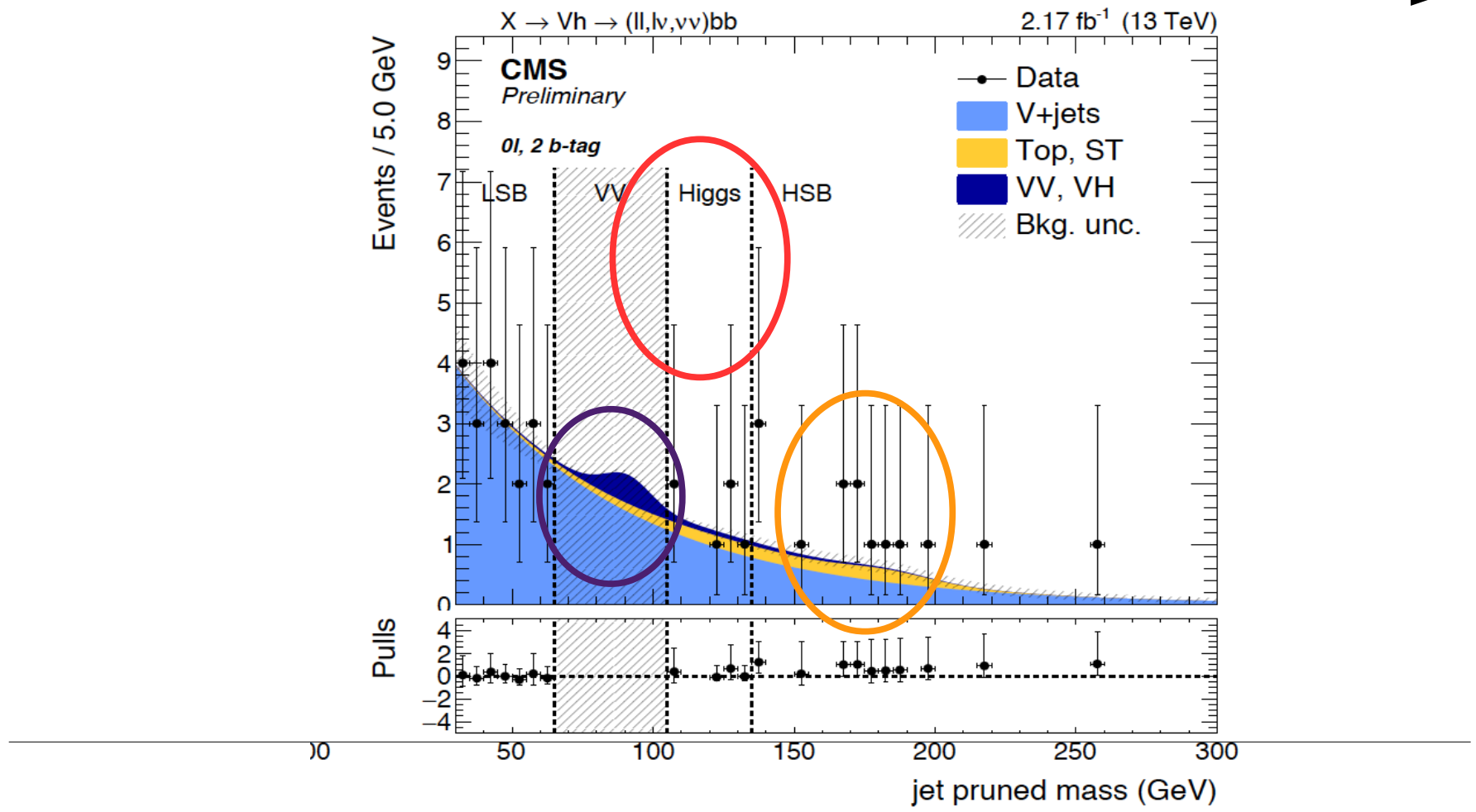
Monojet Extenstion #1 (V→qq)

Jet Mass

#jets

1

2



MET+V(qq),*MET*+H(bb),*MET*+t(qqb)

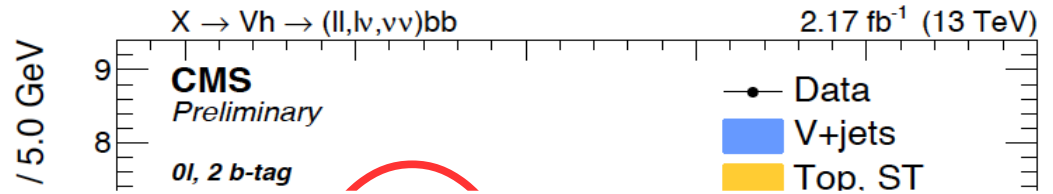
Beyond Monojet

Jet Mass

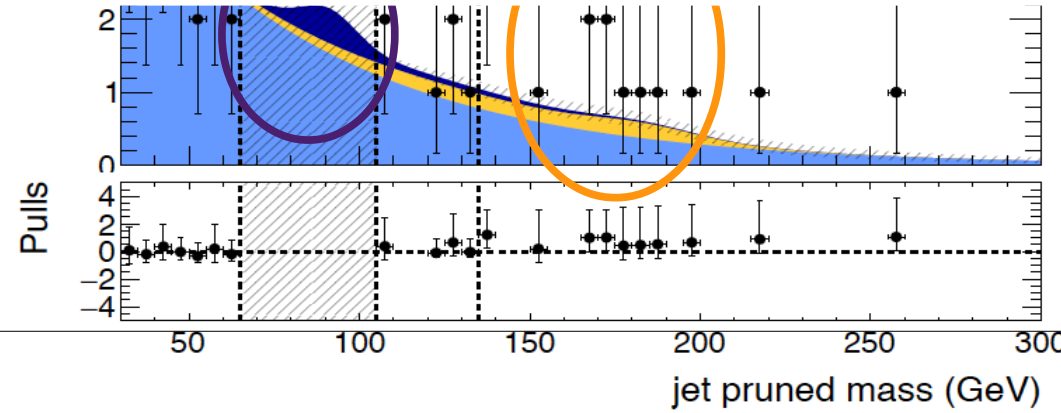
#jets

1

2



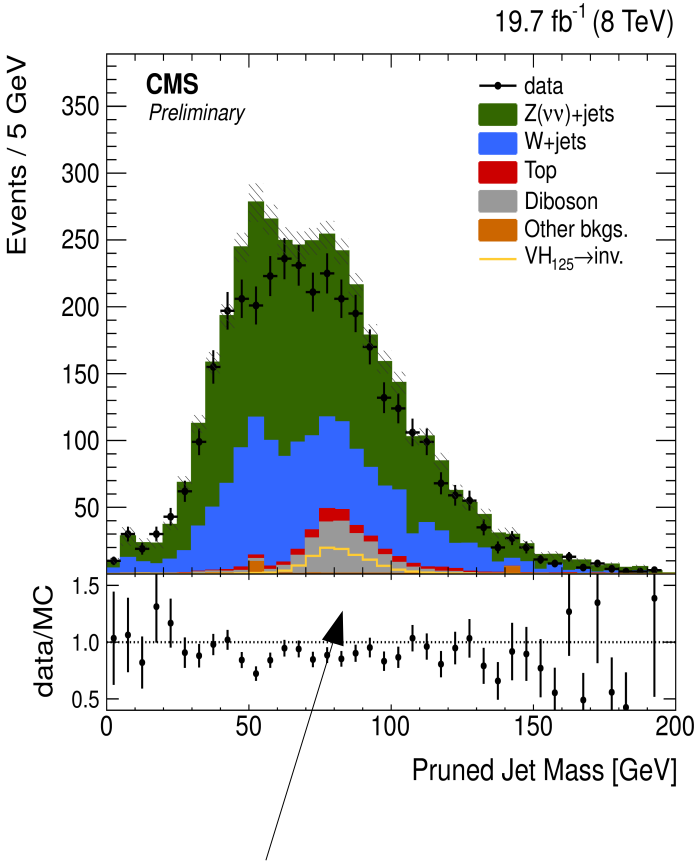
MET+fat jet is still a monojet



MET+V(qq),*MET*+H(bb),*MET*+t(qqb)

MET + fat jet

- There is no clean way to separate fat jets form jets



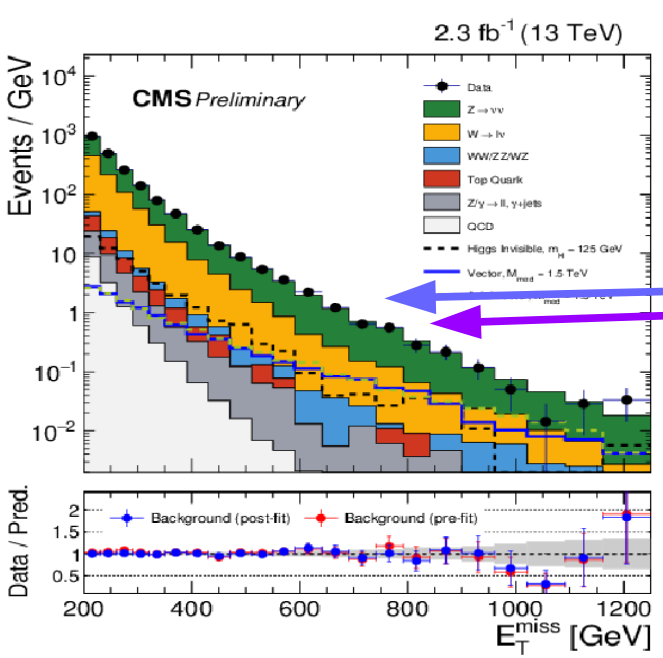
Is there room for improvement?

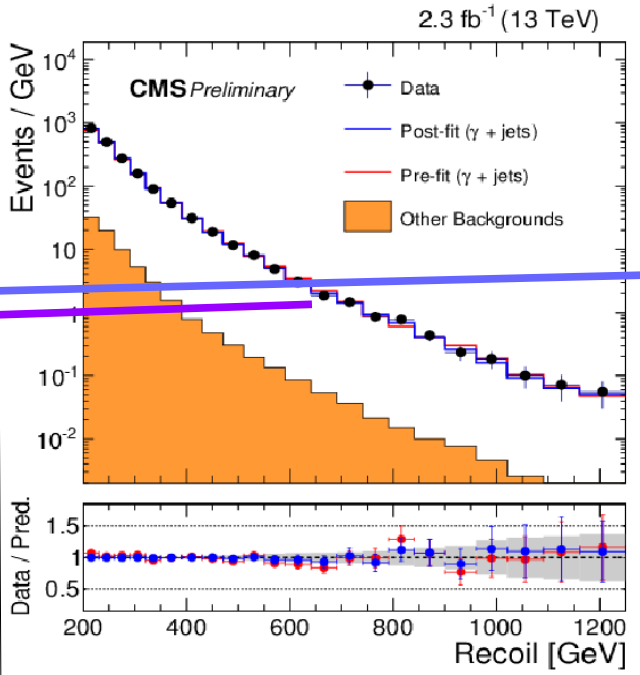
Yes

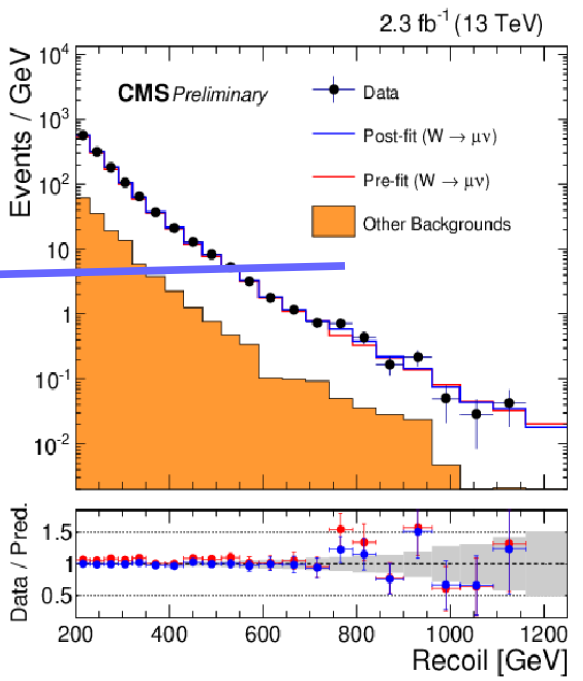
Currently require a simple :
jet mass cut + τ2/τ1

Signal | CRs: γ+jets | + W + ….

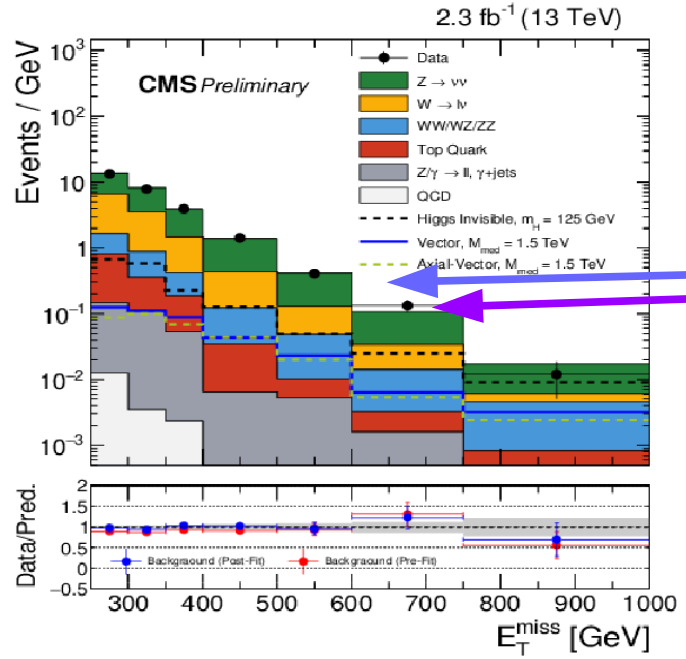
Monojet

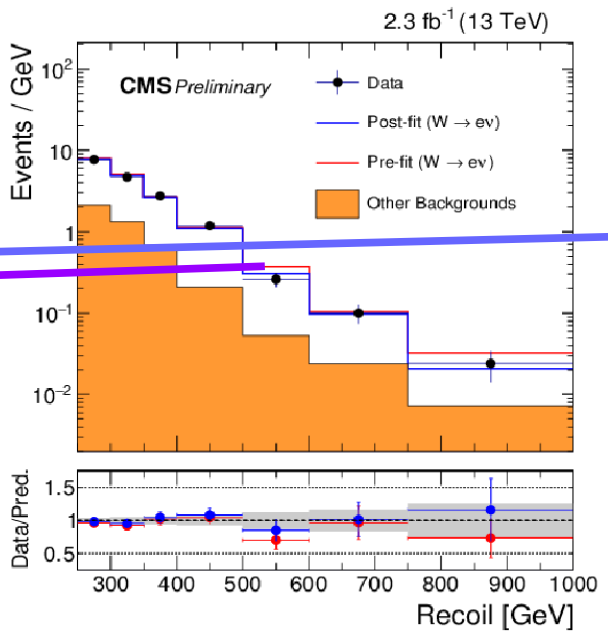


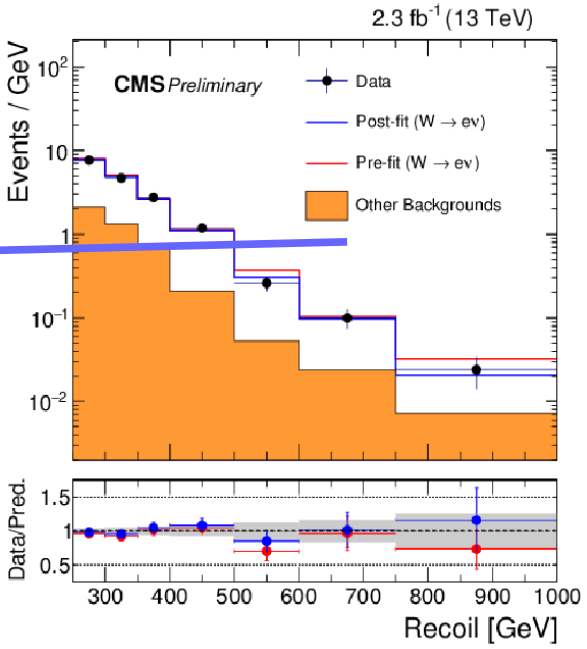




Mono-V





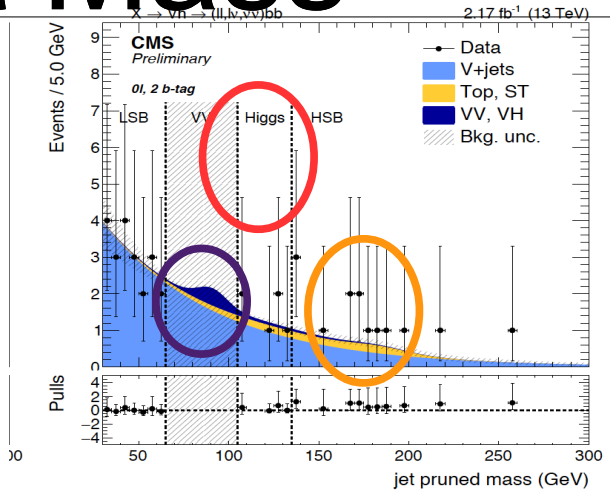


Beyond Monojet

Jet Mass

#jets

1

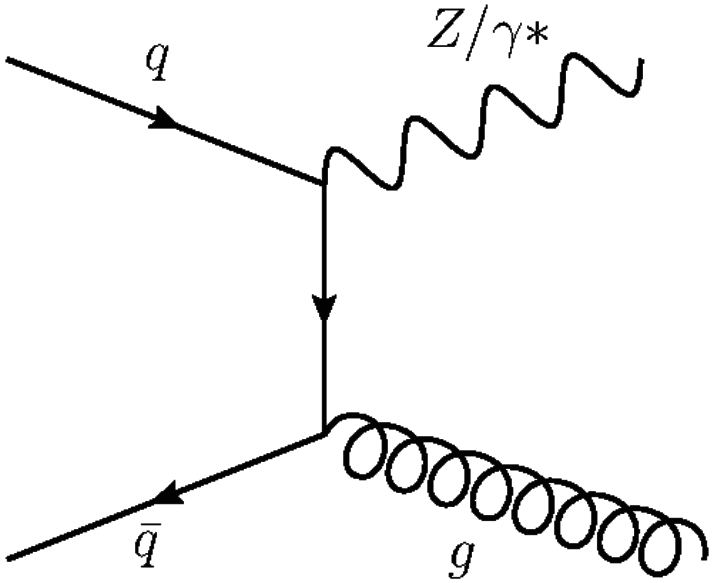


2

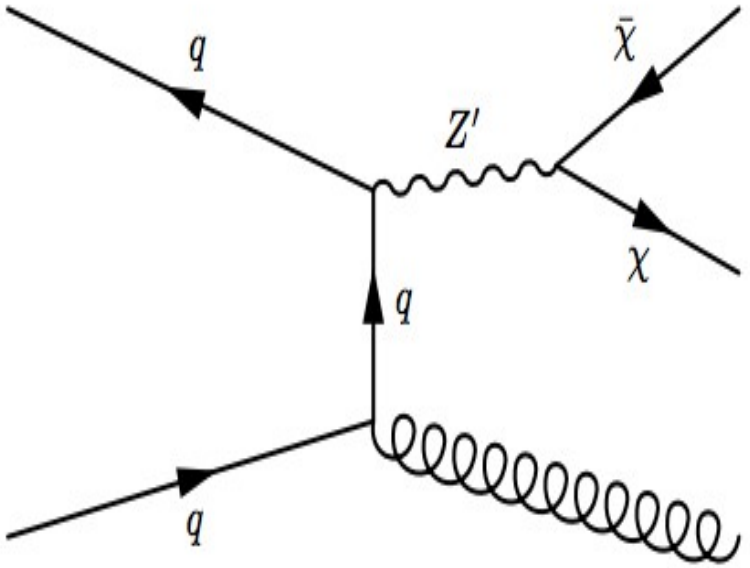
Using the 2nd jet or more can add to discrimination

3

Where do we gain from 2nd Jet?



VS



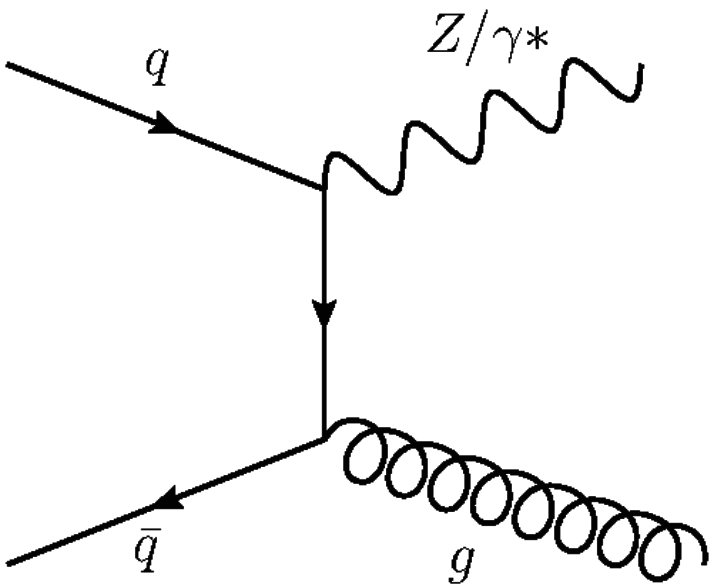
Background

Signal

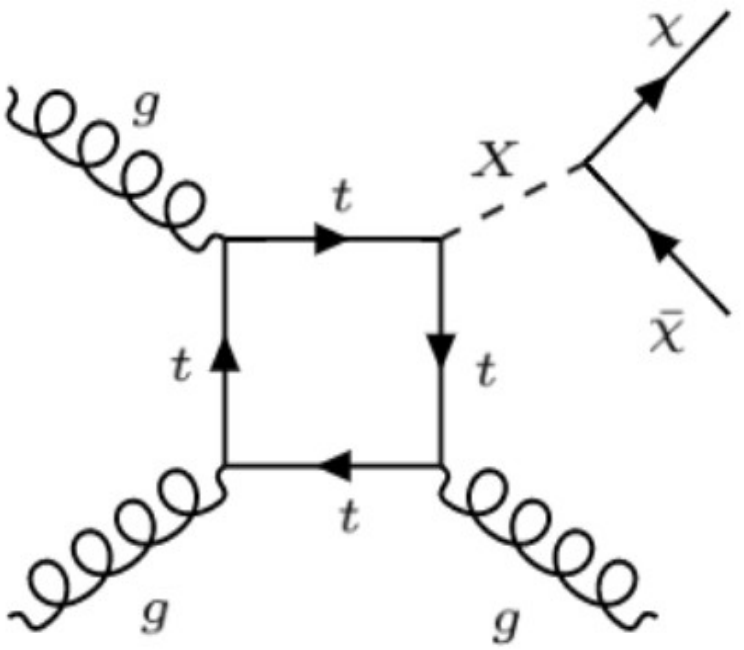
For Vector and Axial mediators not much

Only real difference is mediator mass

Where do we gain from 2nd Jet?



VS



Background

Signal

For Scalar and Pseudoscalar mediators more
Now the production modes are different

In addition to 2nd jet can consider a quarkgluon discriminator

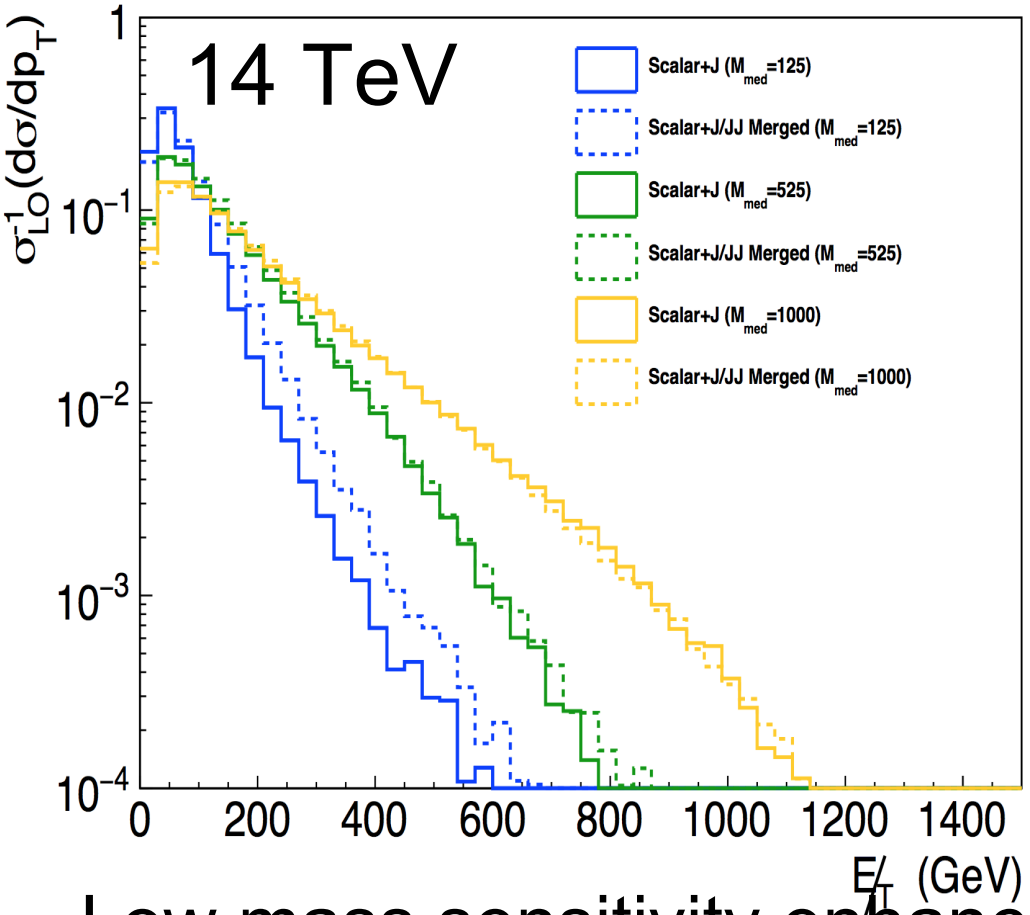
Spectrum of Signal MCs

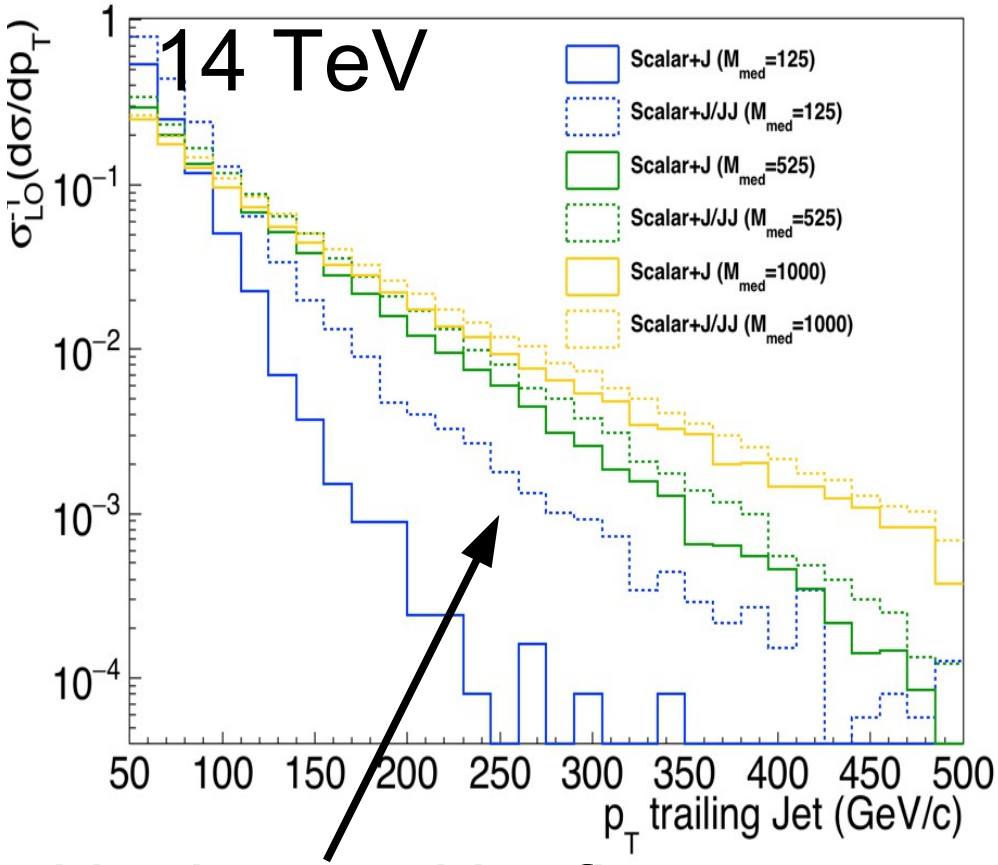
Sample	LO/ Leading Loop	LO in 2j	NLO,1,2j
Vector/ Axial	Madgraph MCFM	Powheg	aMC@NLO
Scalar/ Pseudoscalar	Powheg MCFM aMC@NLO	VBF@NLO aMC@NLO	

aMC@NLO+MG get highest order 1/2 jets merged

Advantage of merged MC

- Taking advantage of the new technology
  - Can consider exploring new regions of phase space

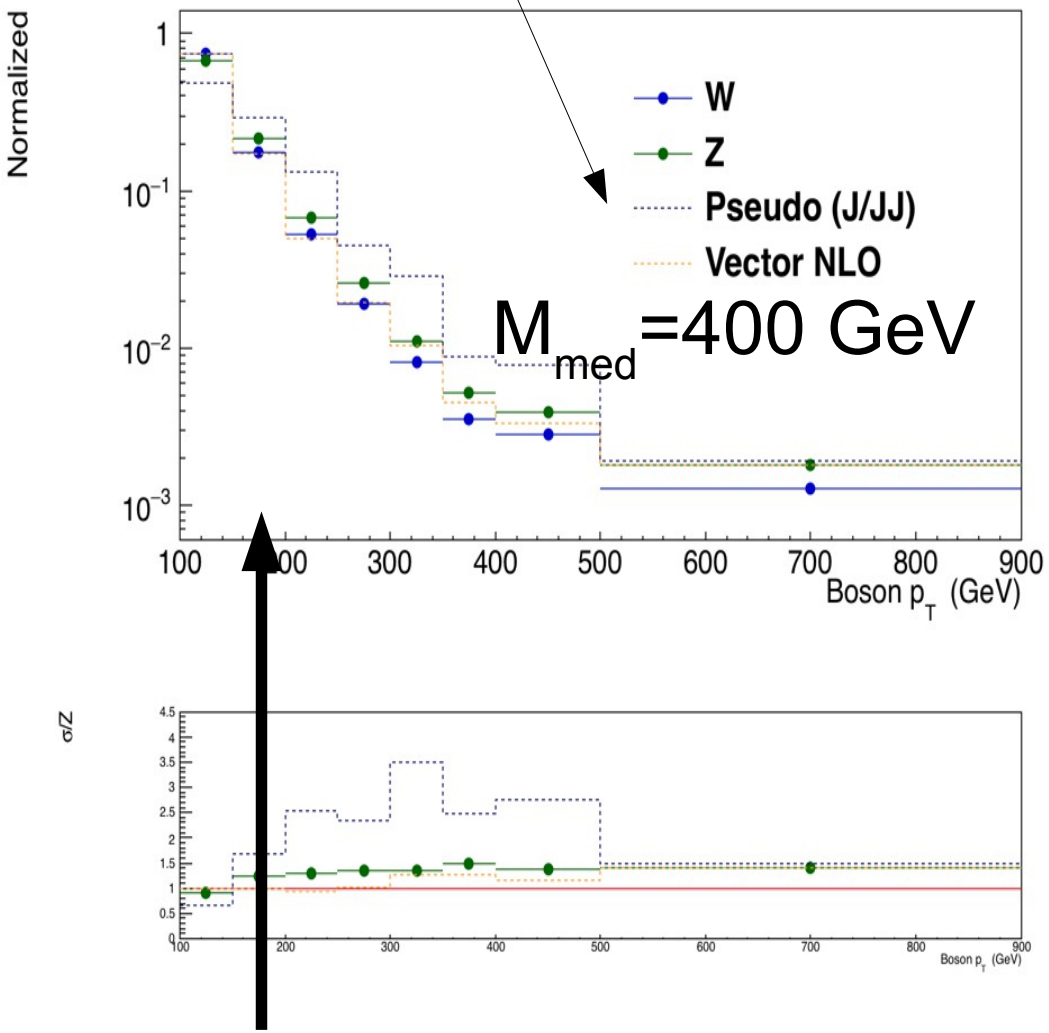


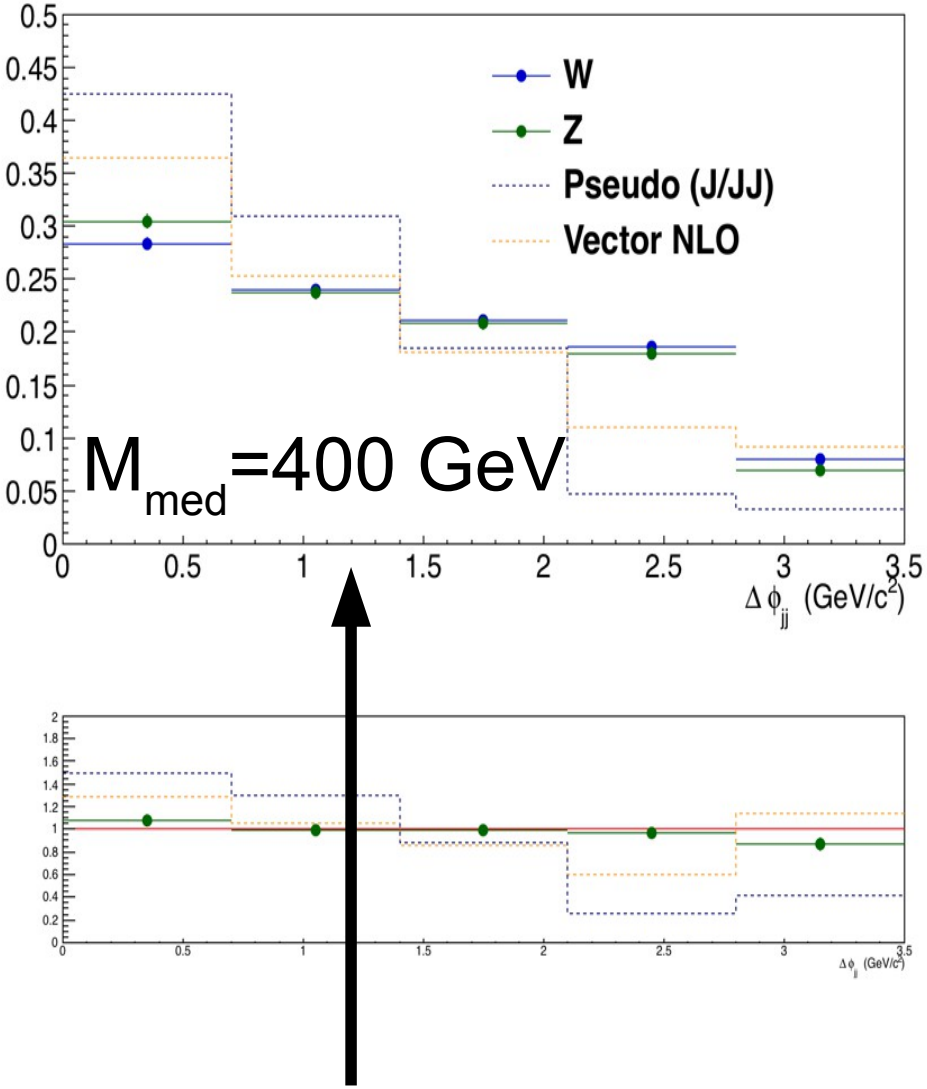


Low mass sensitivity enhanced in the multi jet final state

FYI aMC@NLO
merged 0,1,2jet
pseudoscalar

Basic Concept of Gains



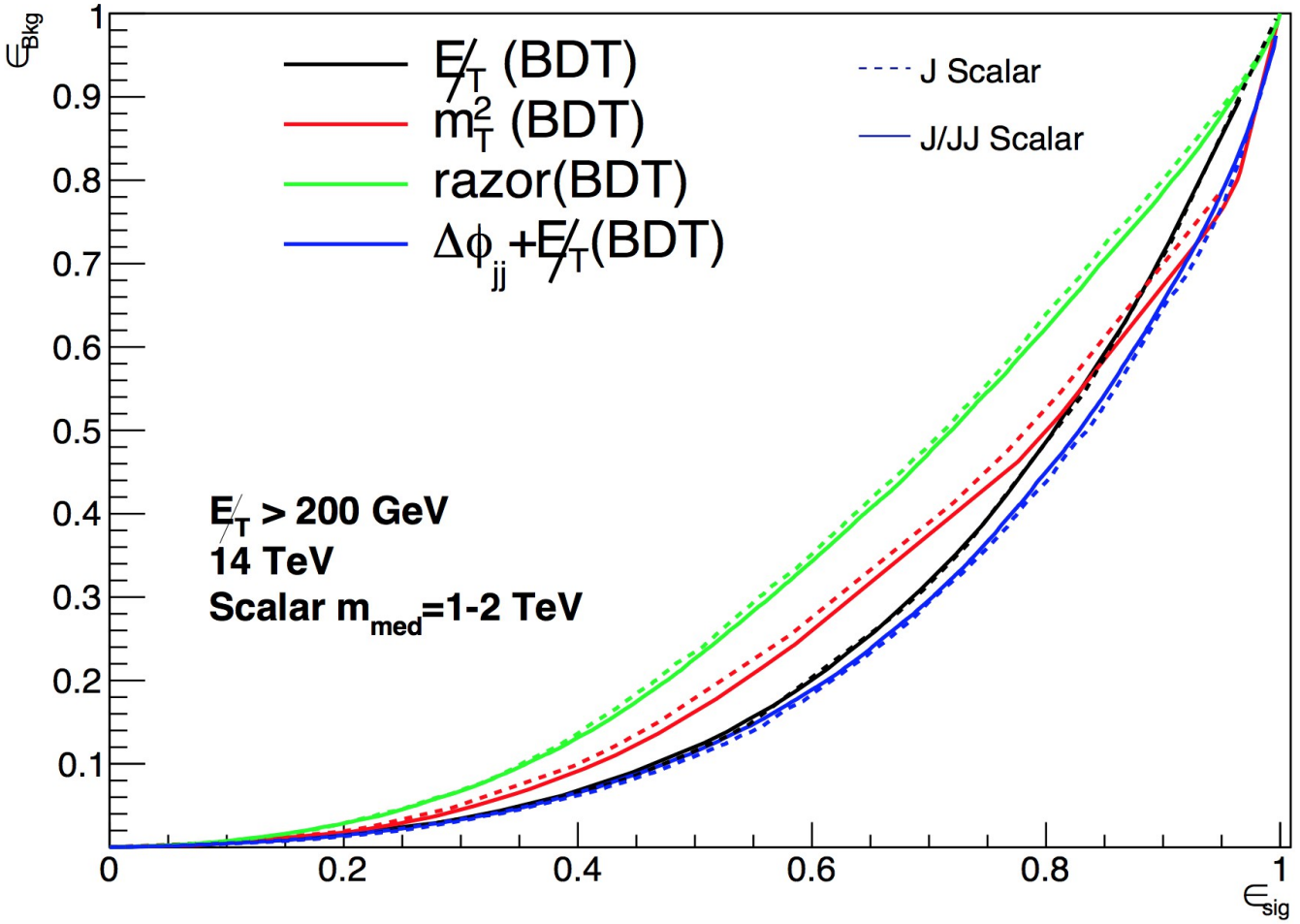


Gluon fusion induces
Higher pT spectrum

Heavier mediator forces
jets to be closer

How do the single variables perform?

- Comparison of single variables

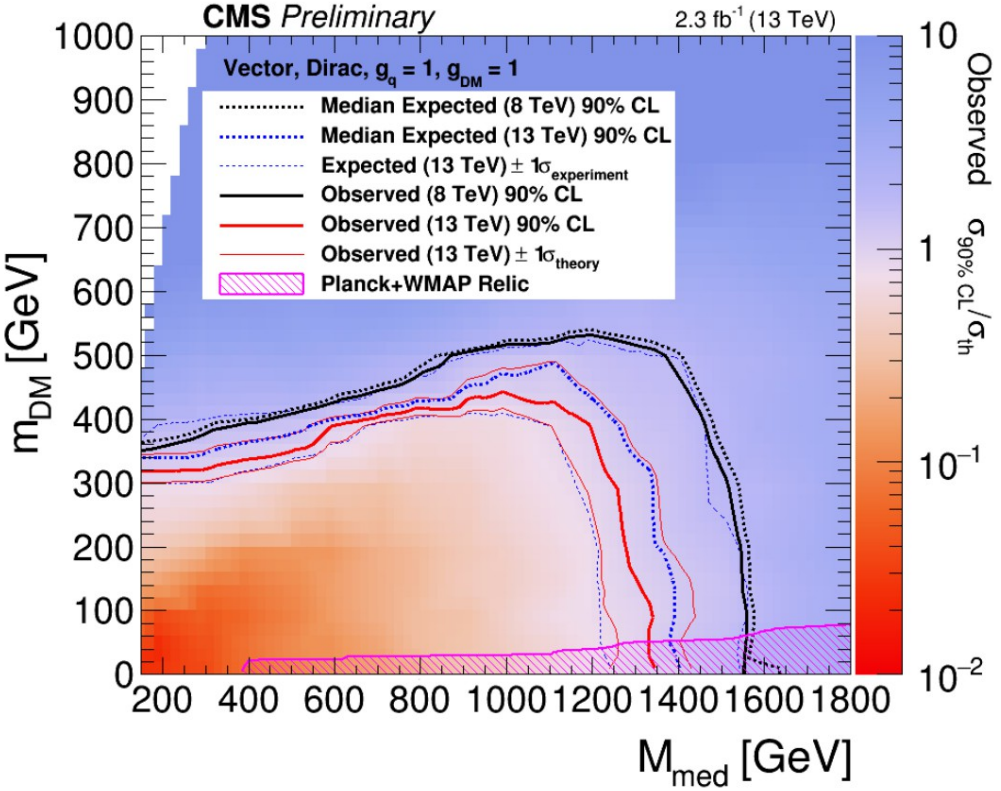


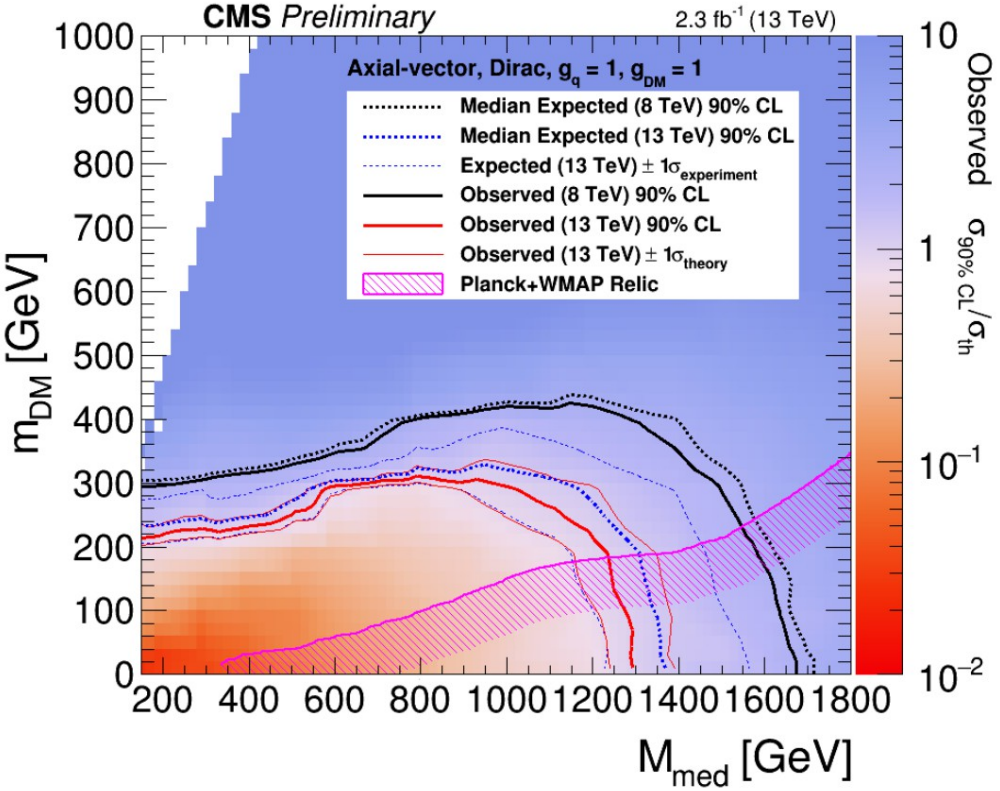
Gain comes from fact that light mass objects have collinear jets

Using $\Delta\varphi_{jj}$ can bring as much as 20% gain

Results

Our Current Public Results

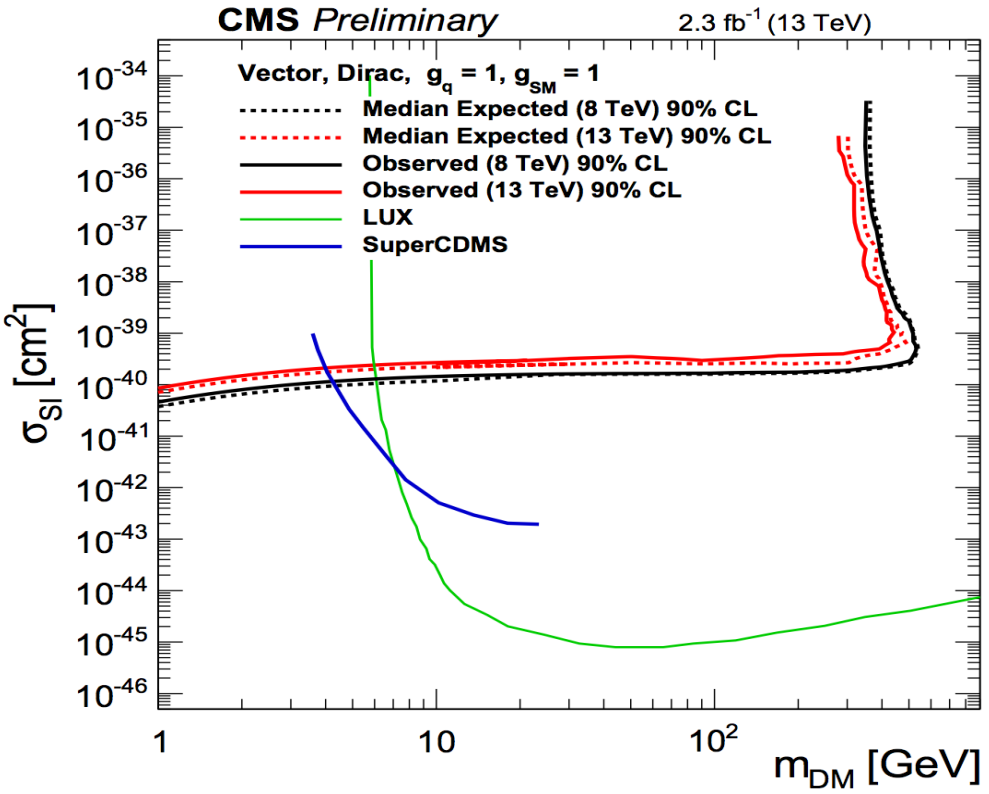


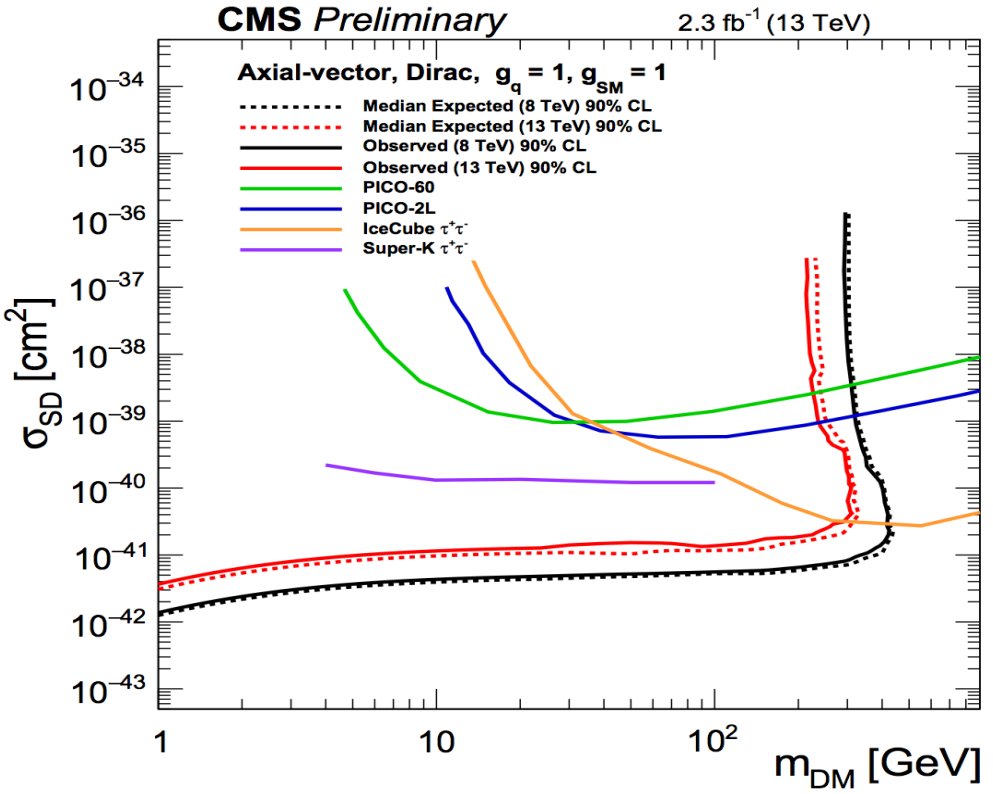


Both 13 TeV and 8 TeV analysis treat:
mono-V and monojet on equal footing

An 1-2σ excess is present in both data sets in tail

Our Current Public Results

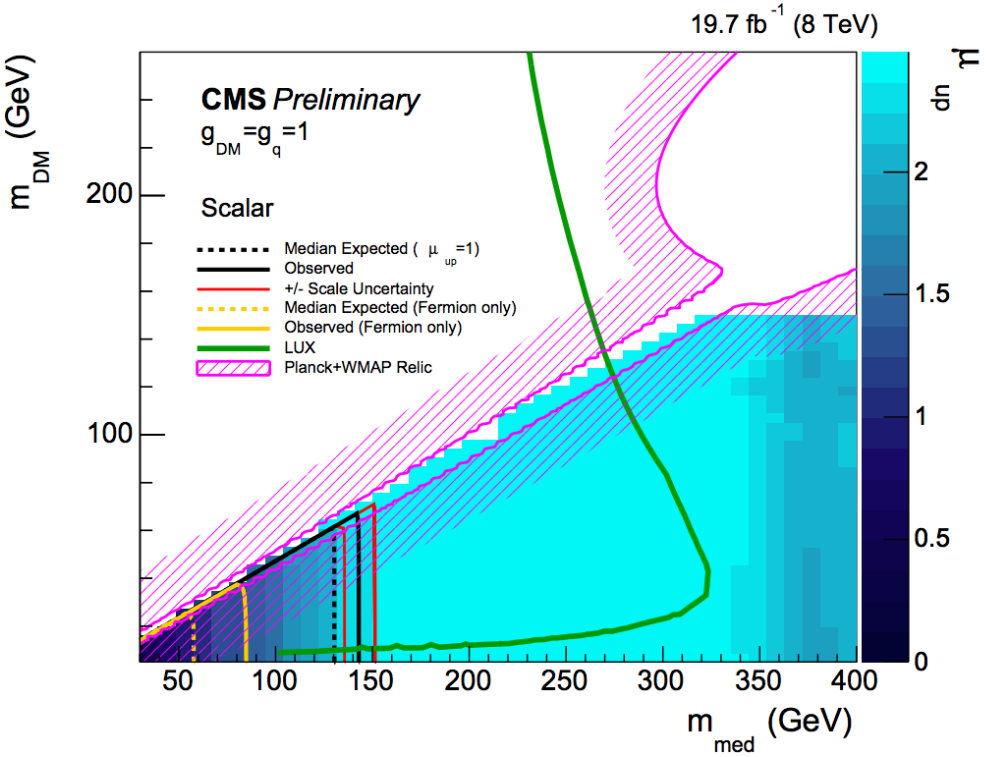


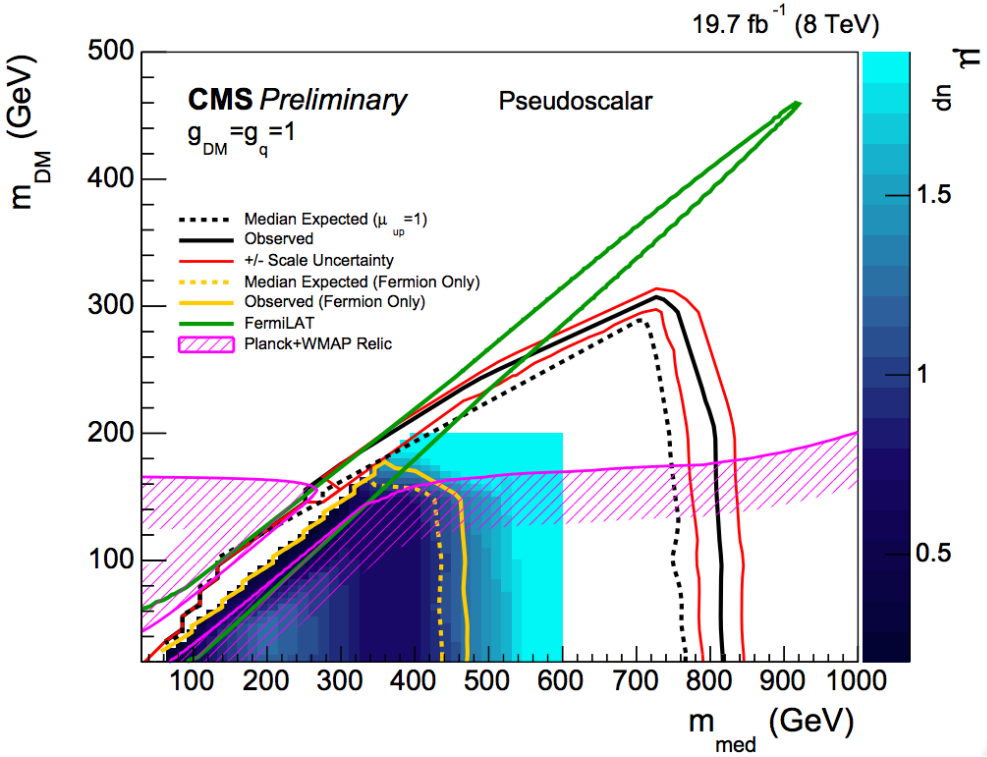


Translation to direct detection now standardized

An 1-2σ excess is present in both data sets in tail

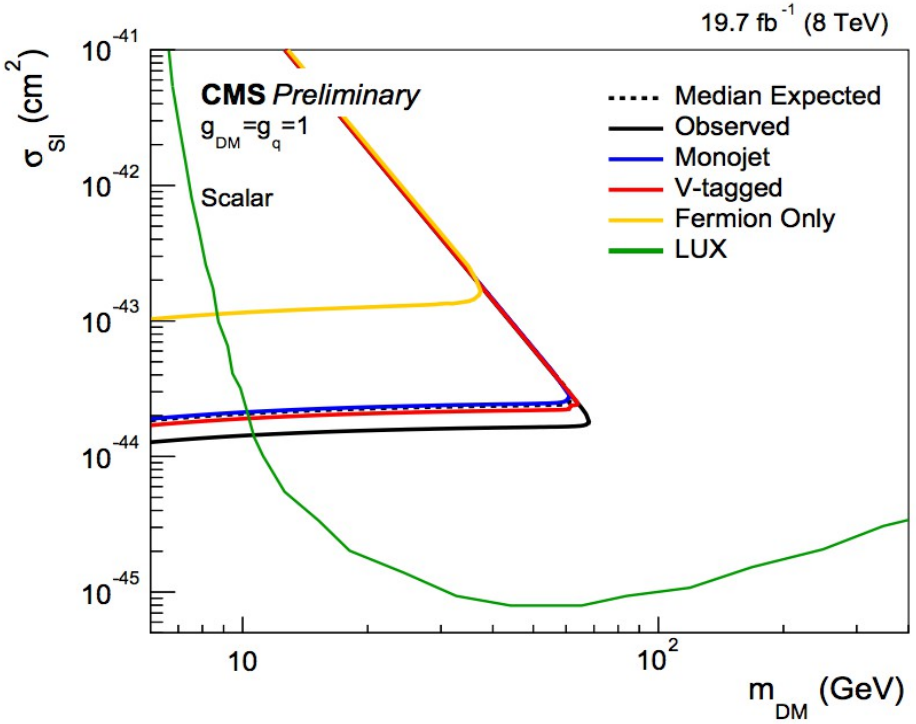
Our Current Scalar & Psuedo results

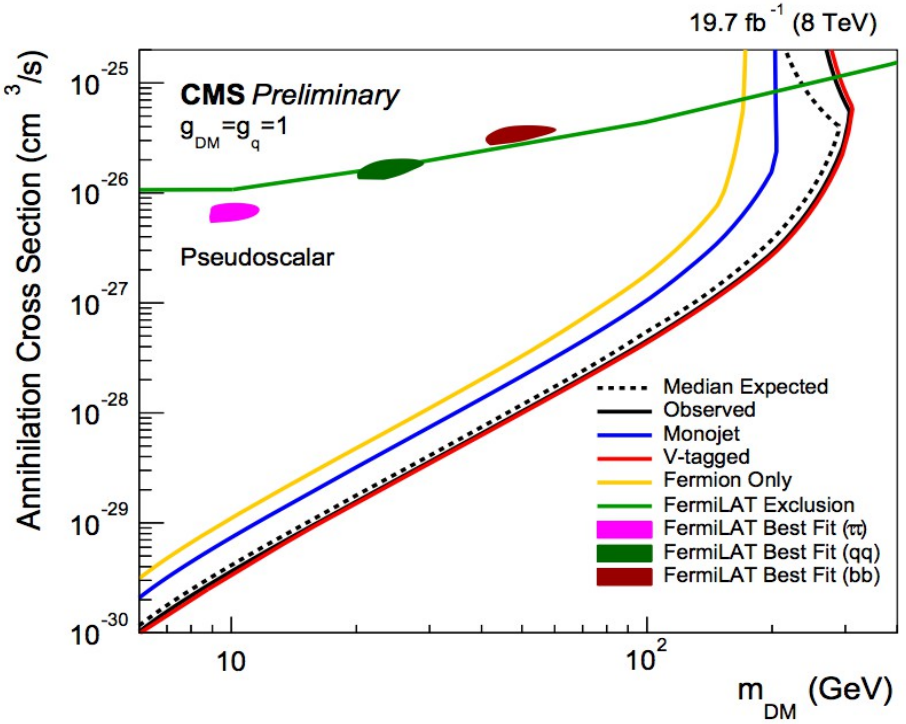




- Currently only have 8TeV exclusion
  - Yellow line : Official simplified models
  - Black/Red (controversial) : Simplified + EWSB
    - Allows us to add Higgsstrahlung

Our Current Scalar & Psuedo results

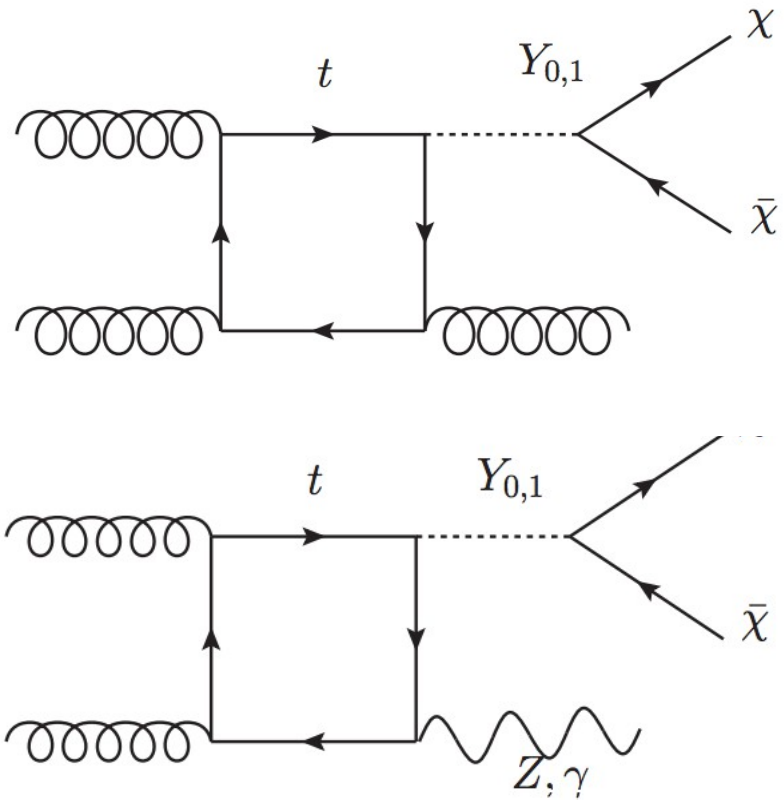




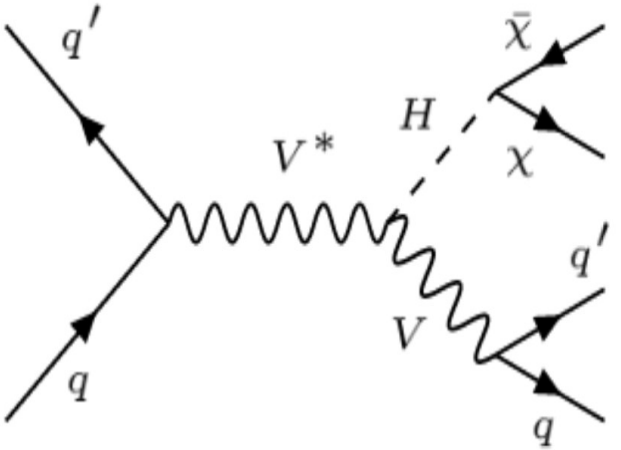
- When the dark matter is not onshell
  - Strong exclusion of pseudoscalar interpreation of LAT
  - Scalar and Direct detection are in close comopetition
    - Expect LHC to pass LUX this ~~summer~~ winter!

To break or not to break?

- EWK symmetry breaking adds lots of mono-V
  - Contribution can be very significant if pseudoscalar
- There are models that do that (e.g. 2HDM...)
  - Need physics at a higher scale (dim-7 operator)

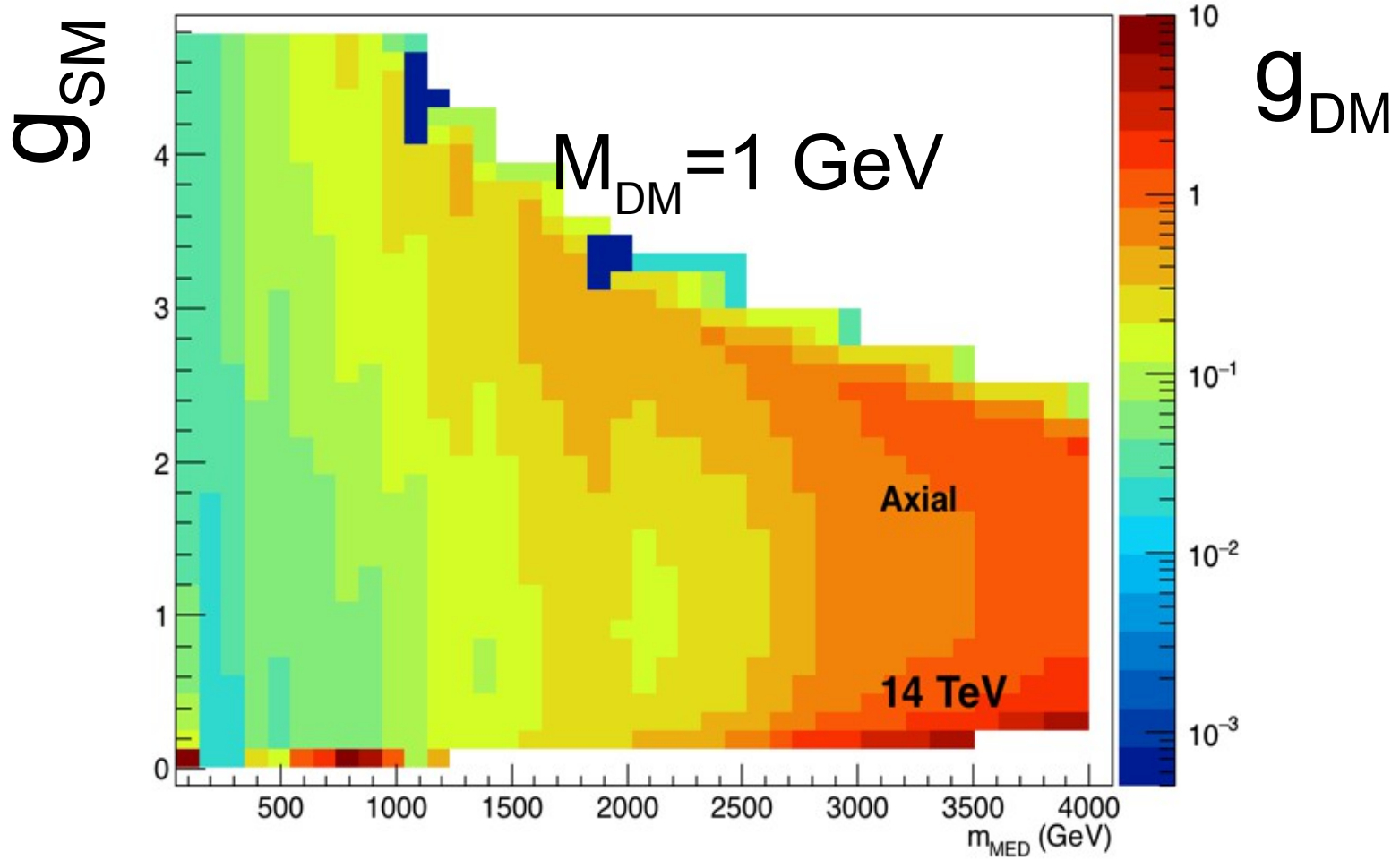


+?



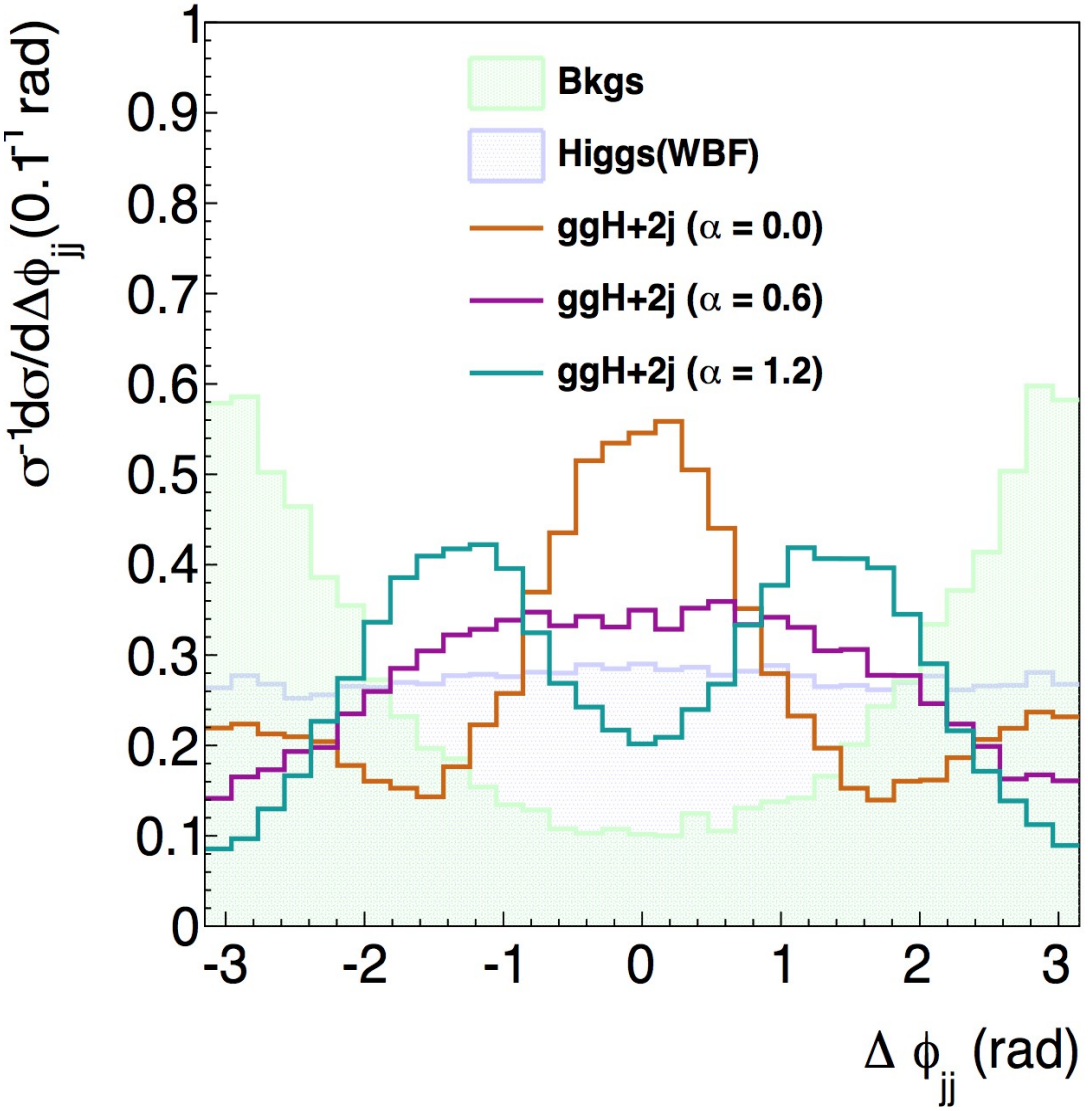
MIXING!?

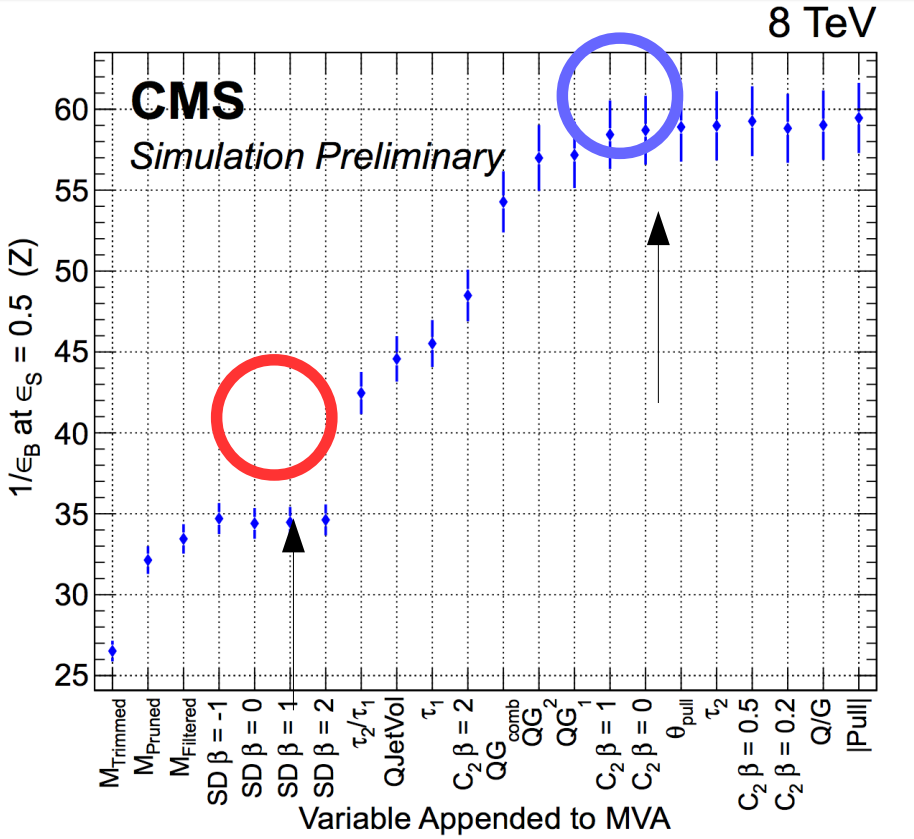
Extending Our results



Is it time to consider varying the couplings?

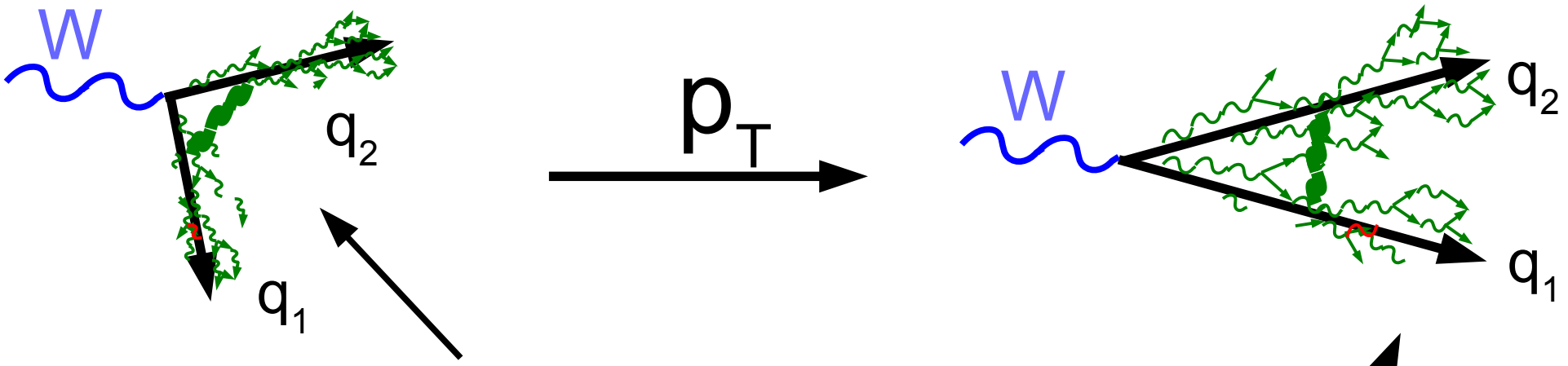
$$\mathcal{L}_{\text{axial}} \supset \frac{1}{2} m_{\text{MED}}^2 Z''_\mu Z''^\mu - g_{\text{DM}} Z''_\mu \bar{\chi} \gamma^\mu \gamma^5 \chi - \sum_q g_{SM}^q Z''_\mu \bar{q} \gamma^\mu \gamma^5 q \,.$$


Bkgs
Higgs(WBF)
ggH+2j (α = 0.0)
ggH+2j (α = 0.6)
ggH+2j (α = 1.2)
σ⁻¹dσ/dΔφ_jj (0.1⁻¹ rad)
Δ φ_jj (rad)


8 TeV
CMS
Simulation Preliminary
1/ε_B at ε_S = 0.5 (Z)
M_Trimmed
M_Pruned
M_Filtered
SD β = -1
SD β = 0
SD β = 1
SD β = 2
τ2/τ1
QJetVol
τ1
C2 β = 2
QG_comb
QG^2
QG^1
C2 β = 1
C2 β = 0
θ_pull
τ2
C2 β = 0.5
C2 β = 0.2
Q/G
|Pull|
Variable Appended to MVA

Building a V-tagger

- Evolution of effects



At low p_T "resolve" two jets : resolved tag

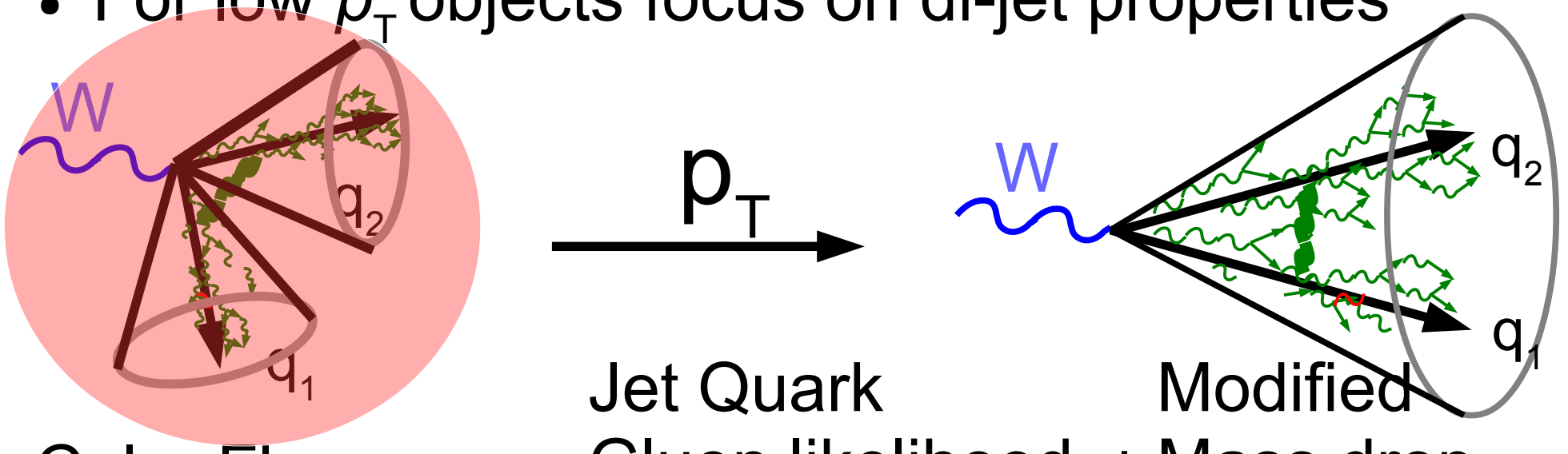
Focus on identifying <u>two</u> jets like a W

At high p_T we obtain one big jet

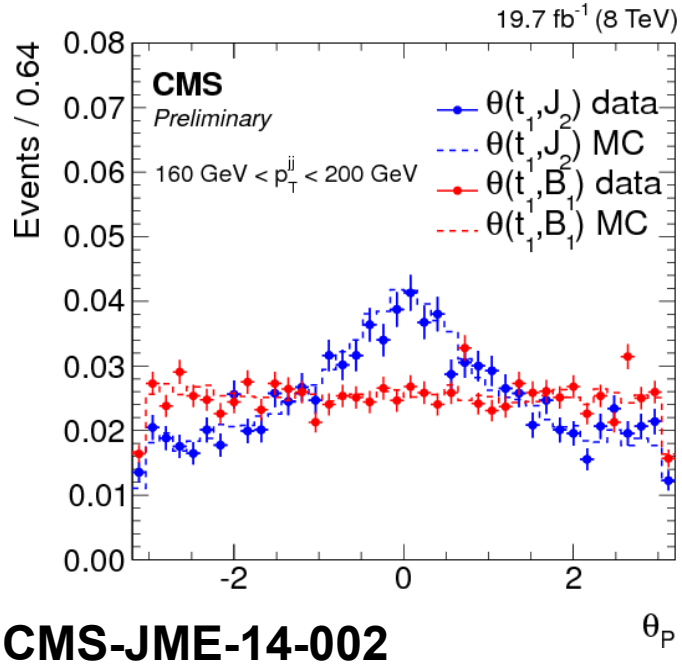
Focus on identifying <u>one</u> jet like a W

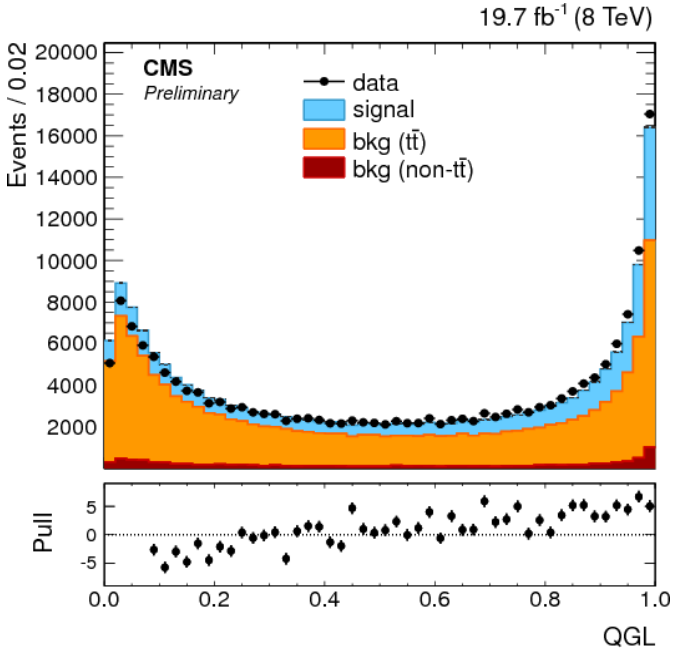
Resolved Tagger

- For low p_T objects focus on di-jet properties



Color Flow + Jet Quark Gluon likelihood + Modified Mass drop





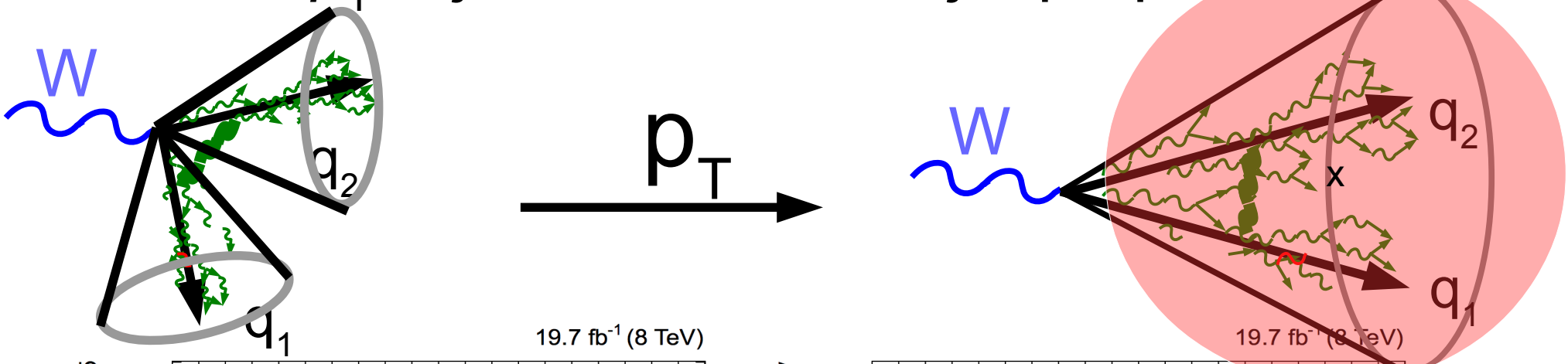
$\zeta = \Delta R_{12} \cdot \max(m_{j1}, m_{j2})/m_{jj}$

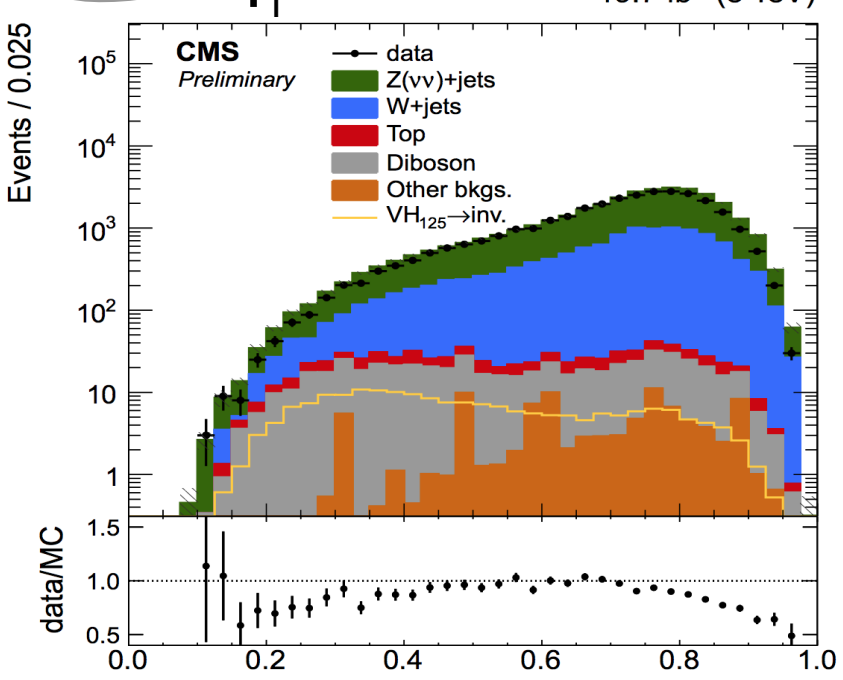
CMS-JME-14-002

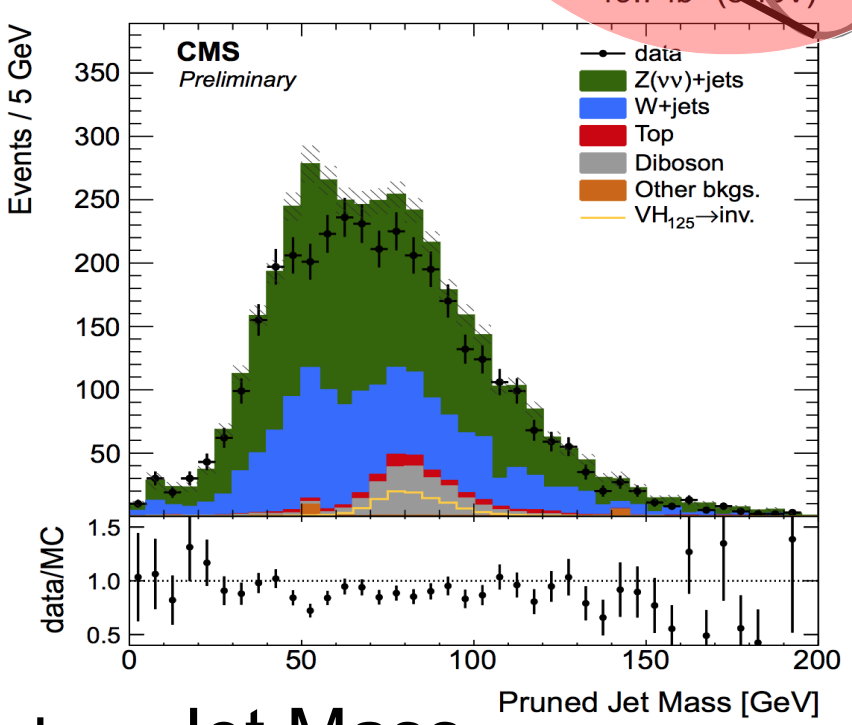
arXiv:1407.7037

Boosted Tagger

- For low p_T objects focus on di-jet properties







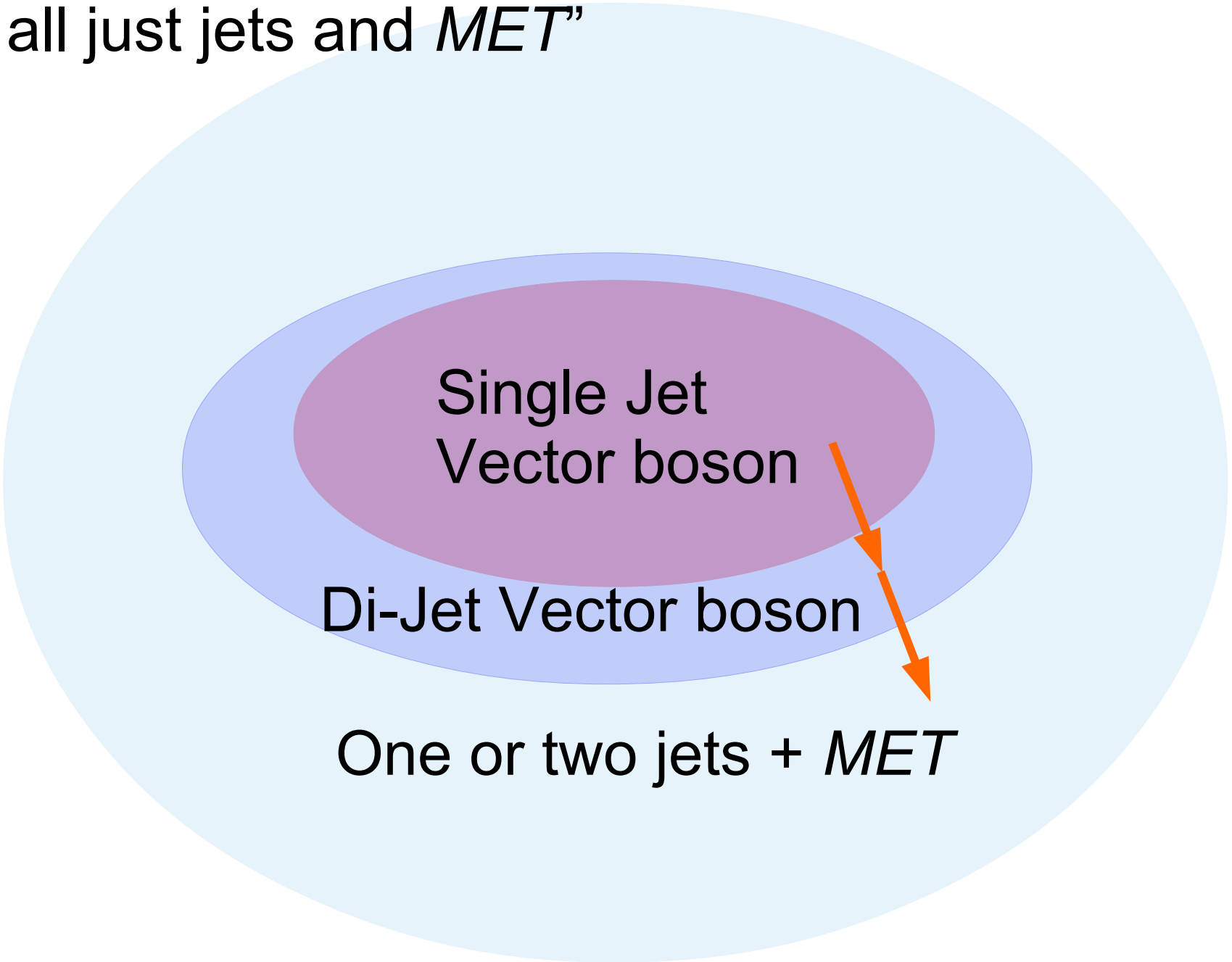
Likelihood for 2 prongs + Jet Mass

CMS-JME-13-006

arXiv:1407.7037

One Big Analysis

"Its all just jets and *MET*"



γ+jets

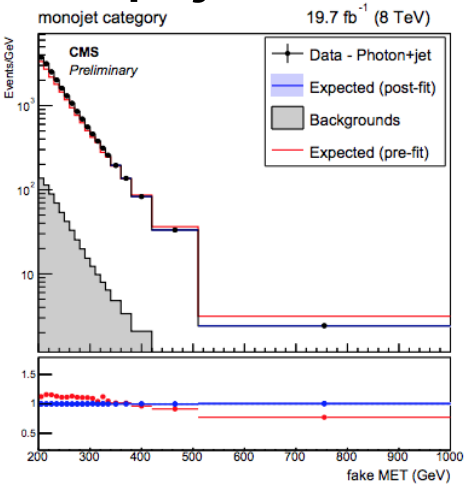
Zμμ+jets

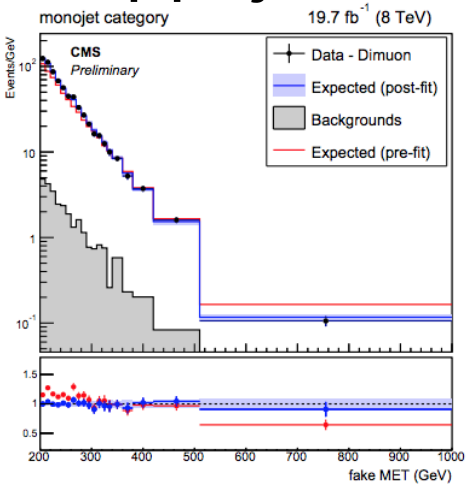
Wlν+jets

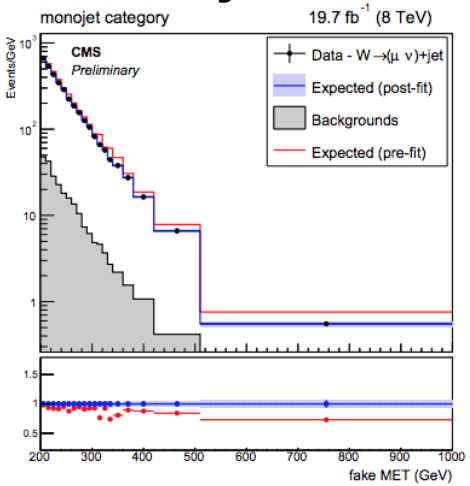
Monojet category

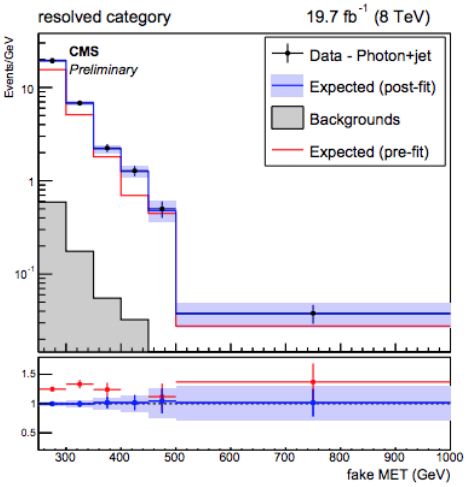
Di-jet category

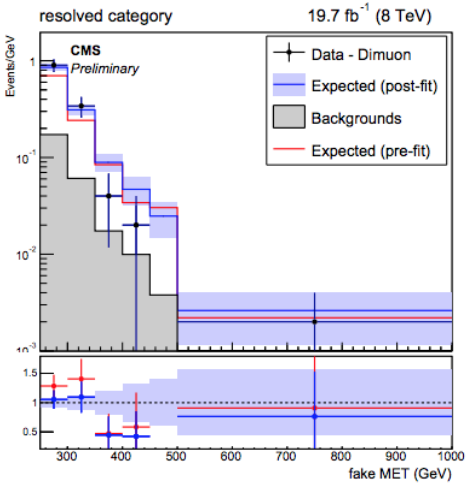
Single jet category

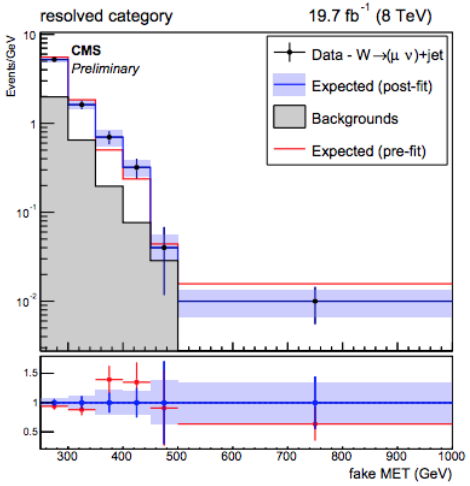


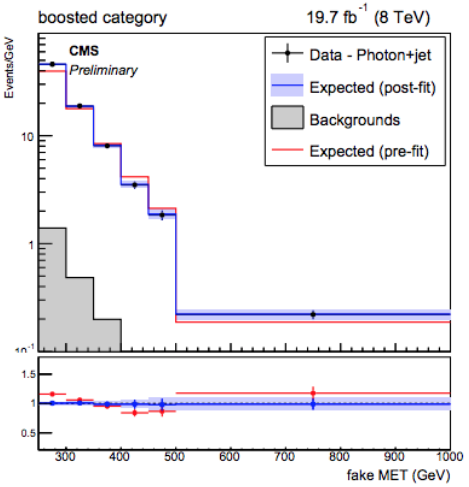


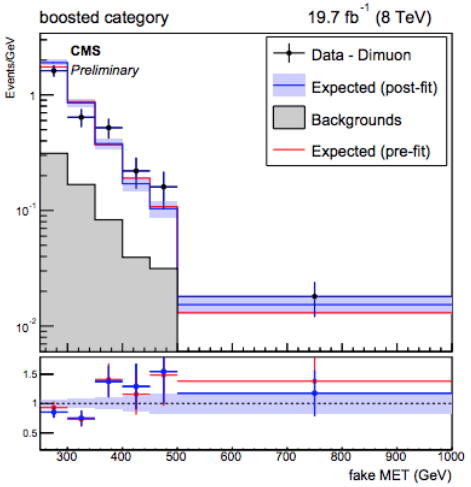


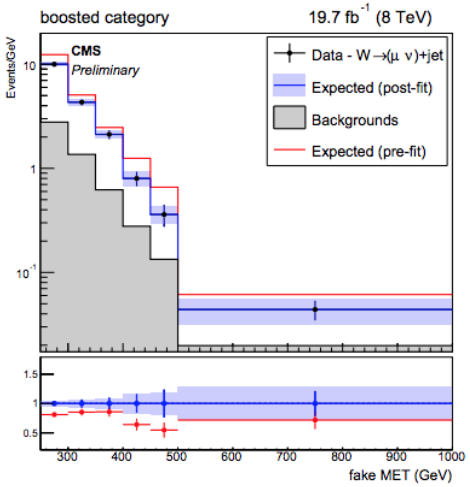






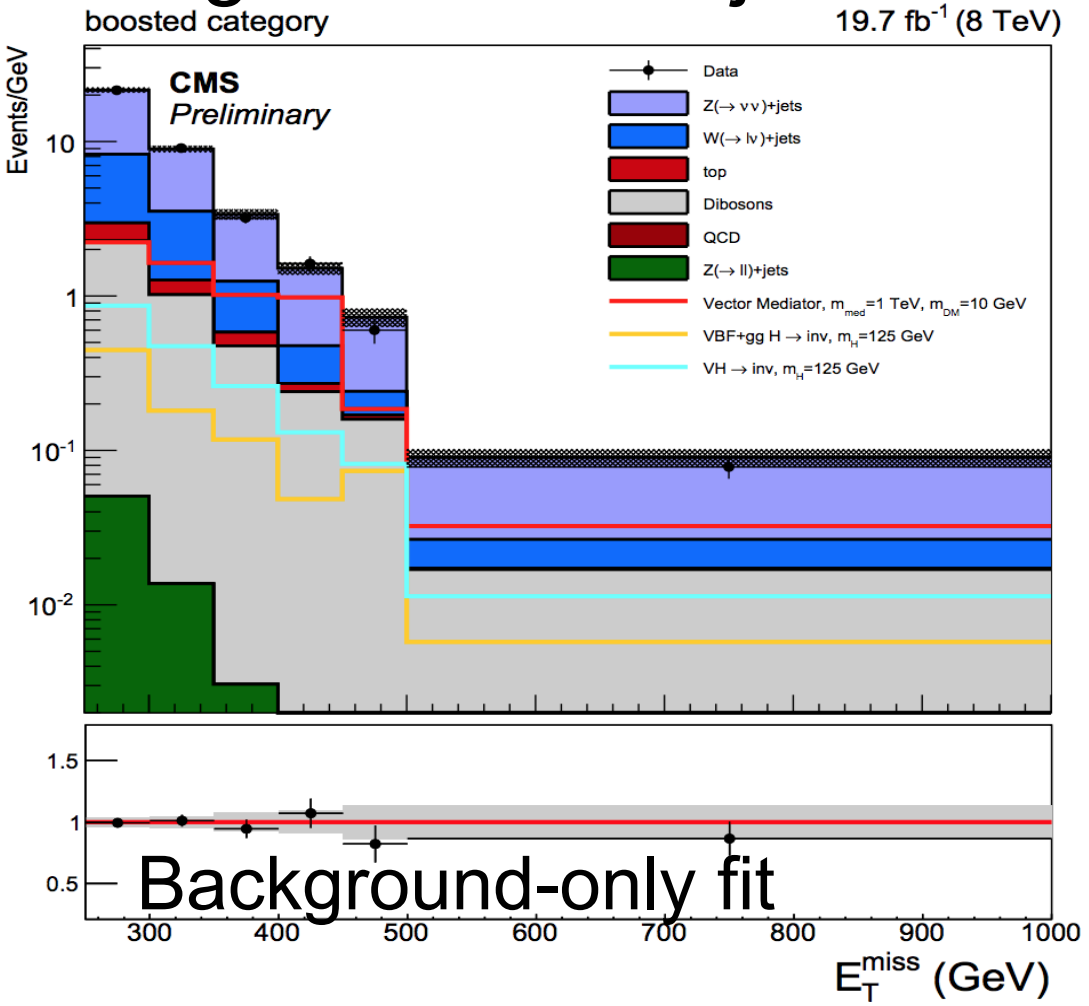




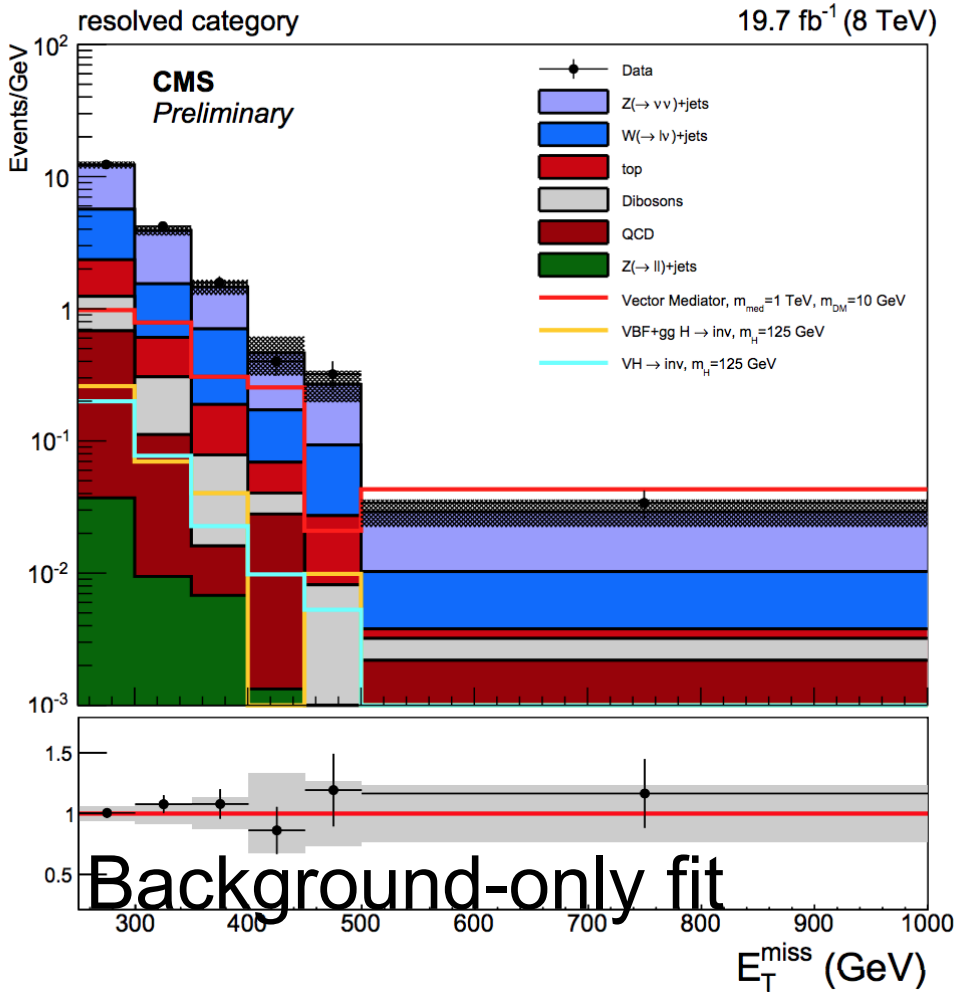


CMS-EXO-12-055

Single “Boosted” jet



Two “Resolved” jets



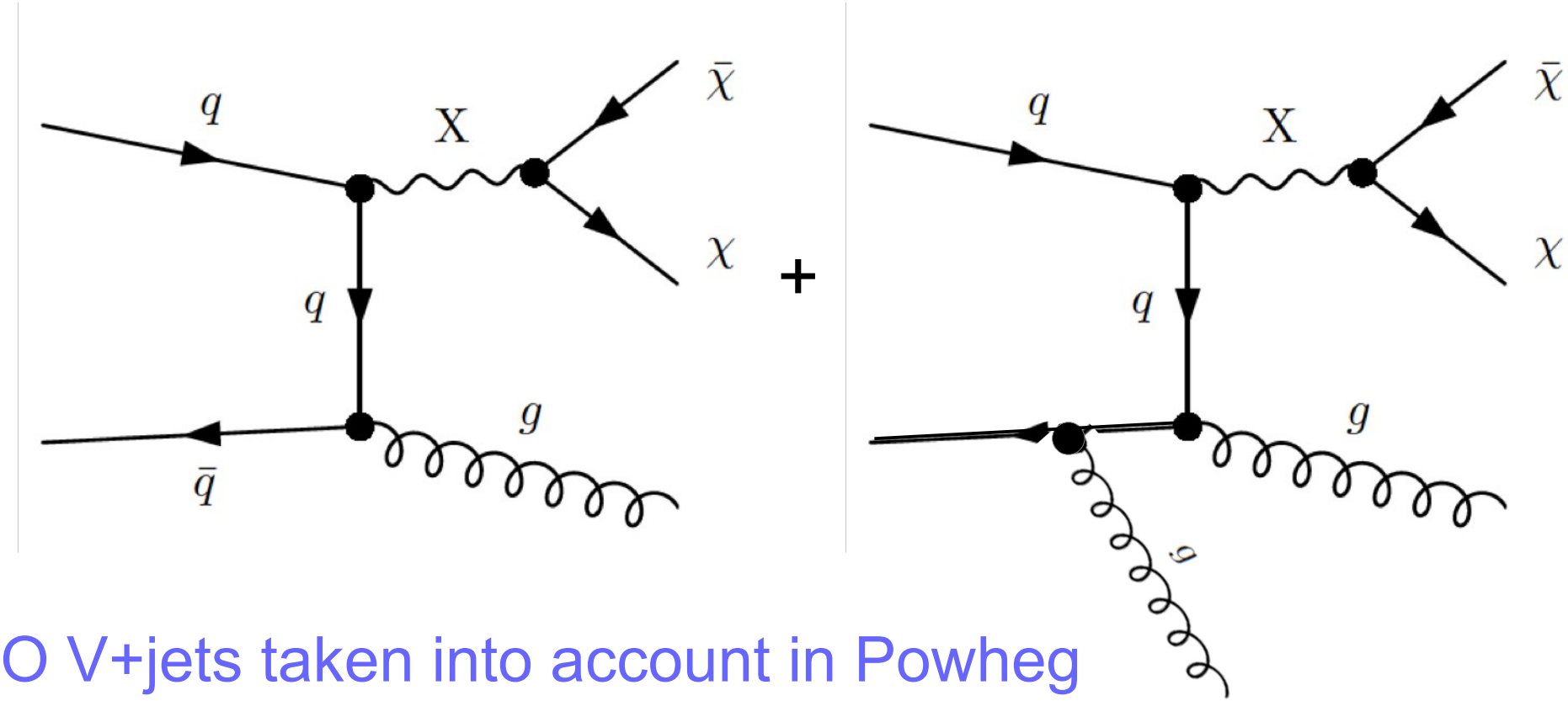
Observe a small excess in resolved *MET* tail (1σ)

Observe a small deficit in the mono-V *MET* tail (1.5σ)

CMS-EXO-12-055

2 Jets @ Vector/Axial Simplified Model

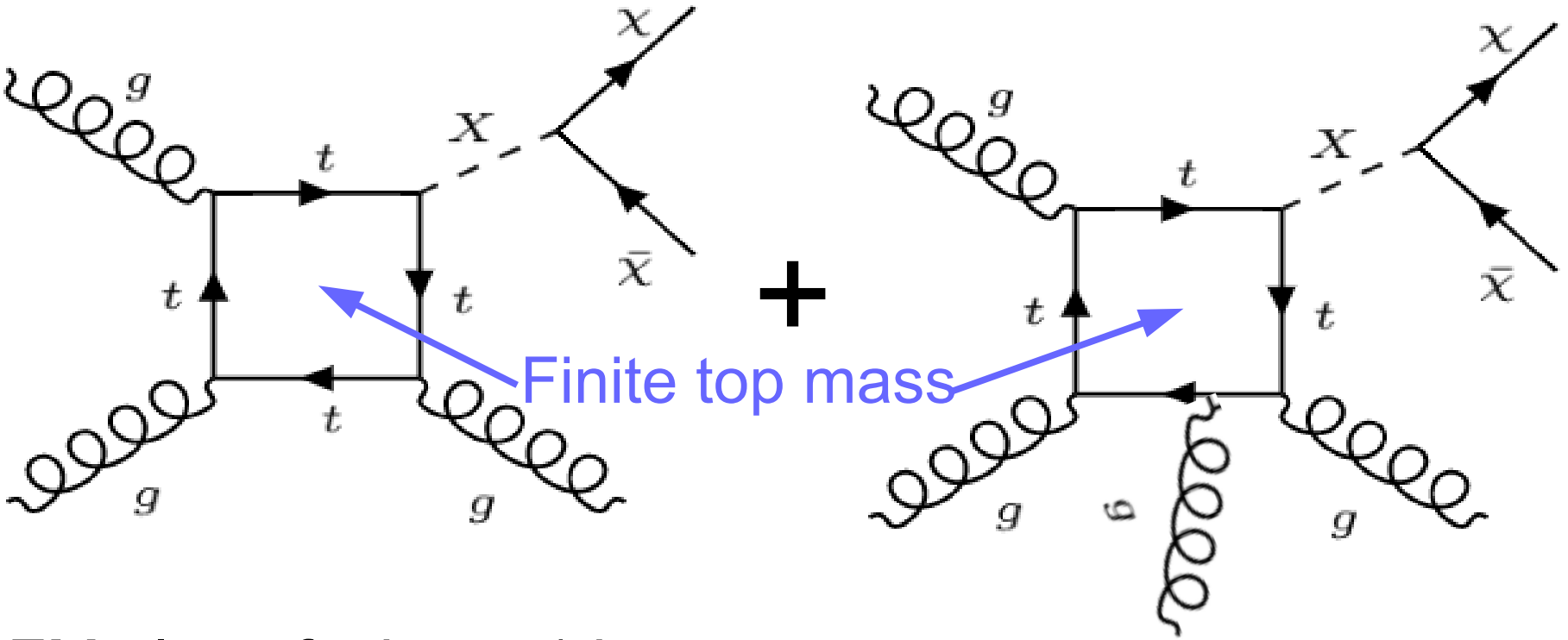
- At higher $\sqrt{s}$ multi-jet final states predominant
- In light of building on new ideas



NLO V+jets taken into account in Powheg
Now available in Madgraph as well

(Pseudo)Scalar Simplified Model

- Requires finite top mass at 2 jets order
  - Available now in now with Madgraph
  - Also can do some hacky procedure



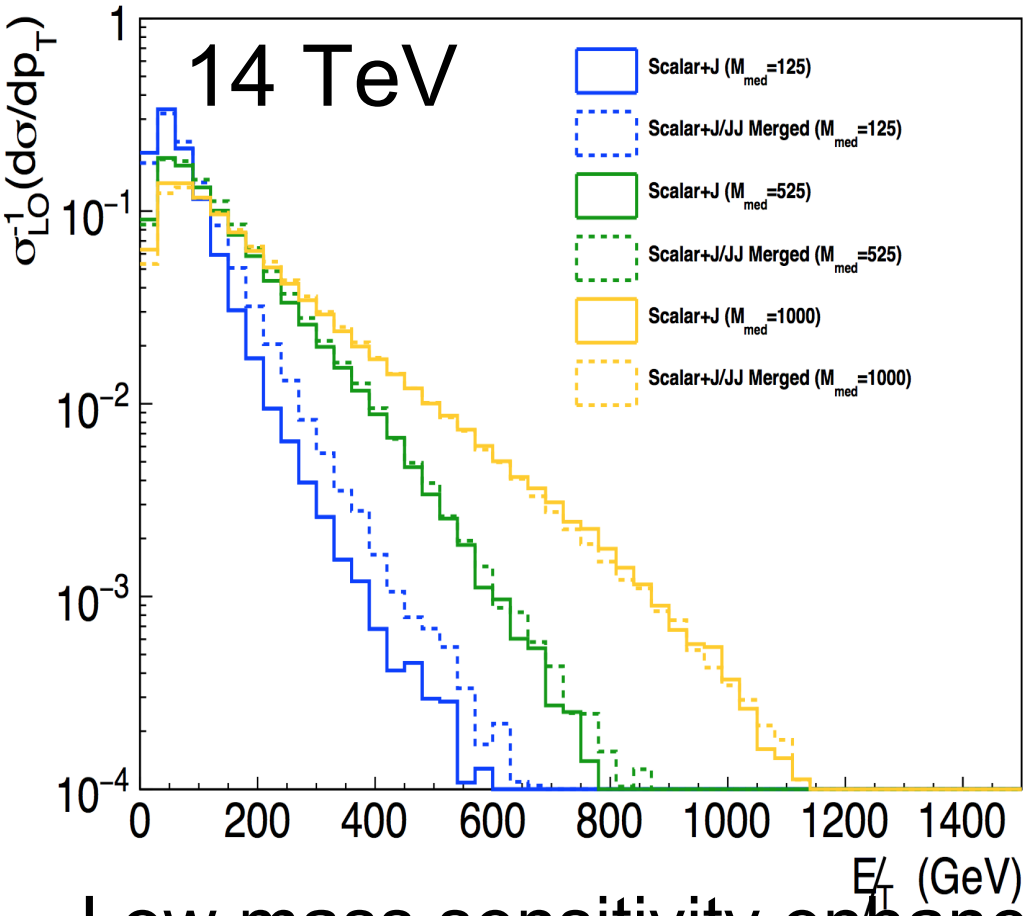
MCFM gluon fusion + 1 jet

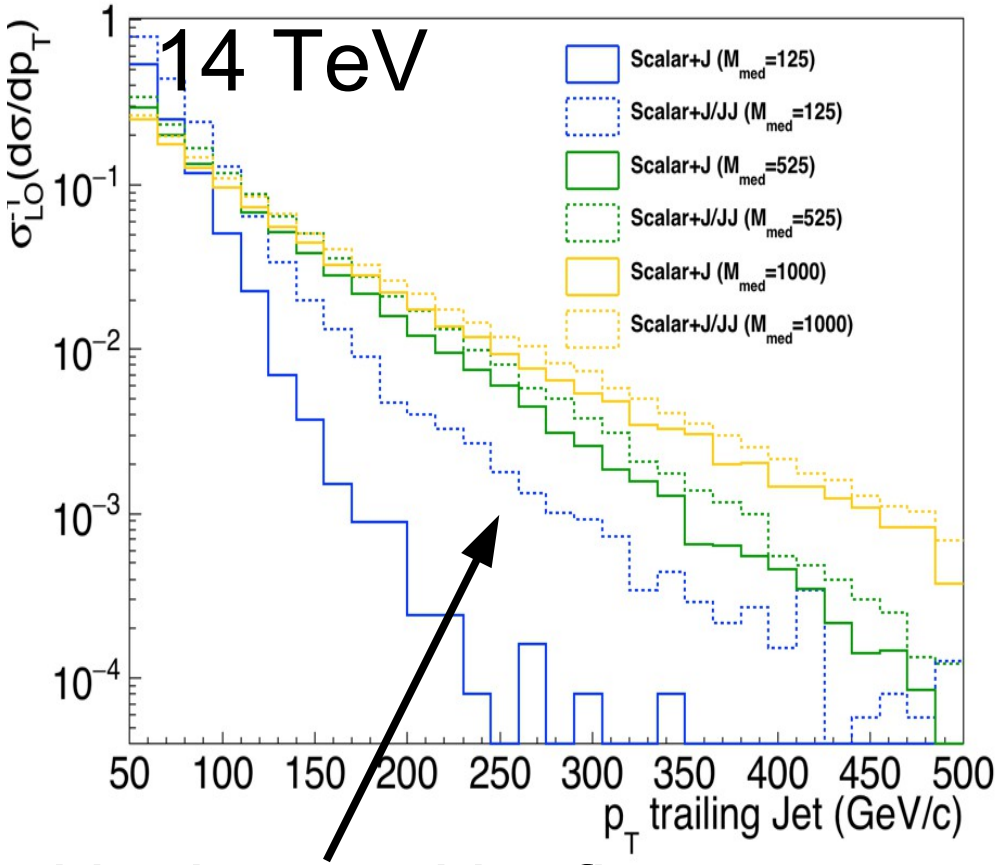
VBF@NLO gluon fusion + 2 jet

One caveat : On-shell production is only available for 2 jet final state

Advantage of merged MC

- Taking advantage of the new technology
  - Can consider exploring new regions of phase space





Low mass sensitivity enhanced in the multi jet final state

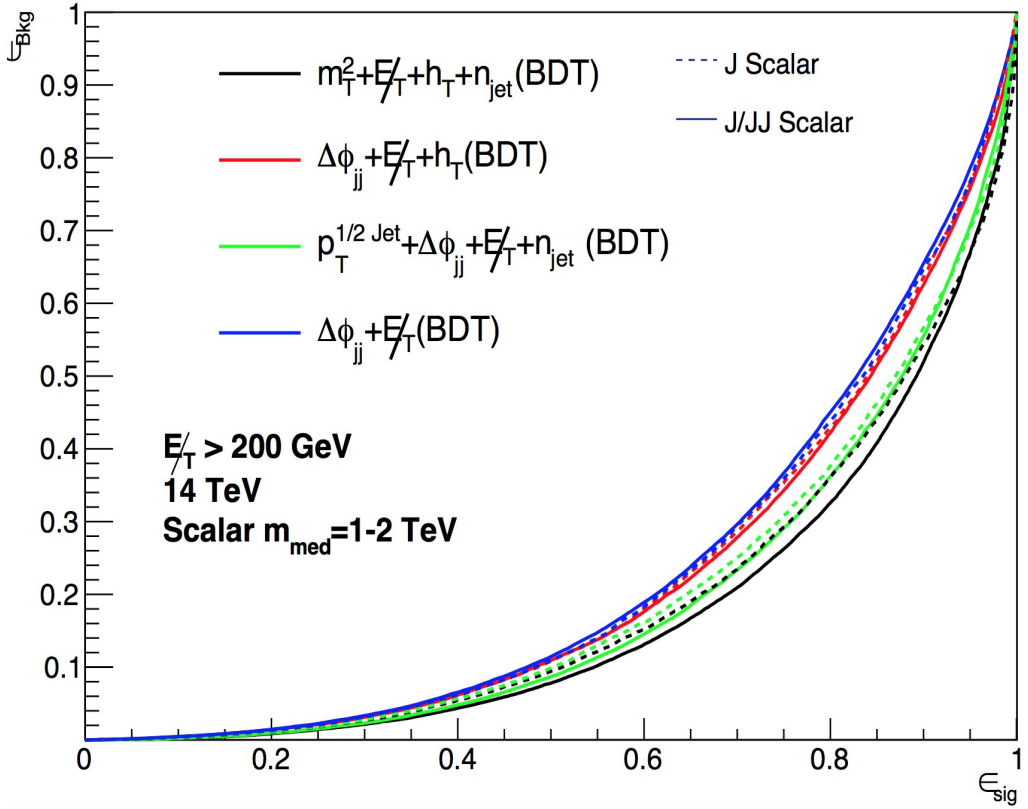
Question #2 : Advantage of MC

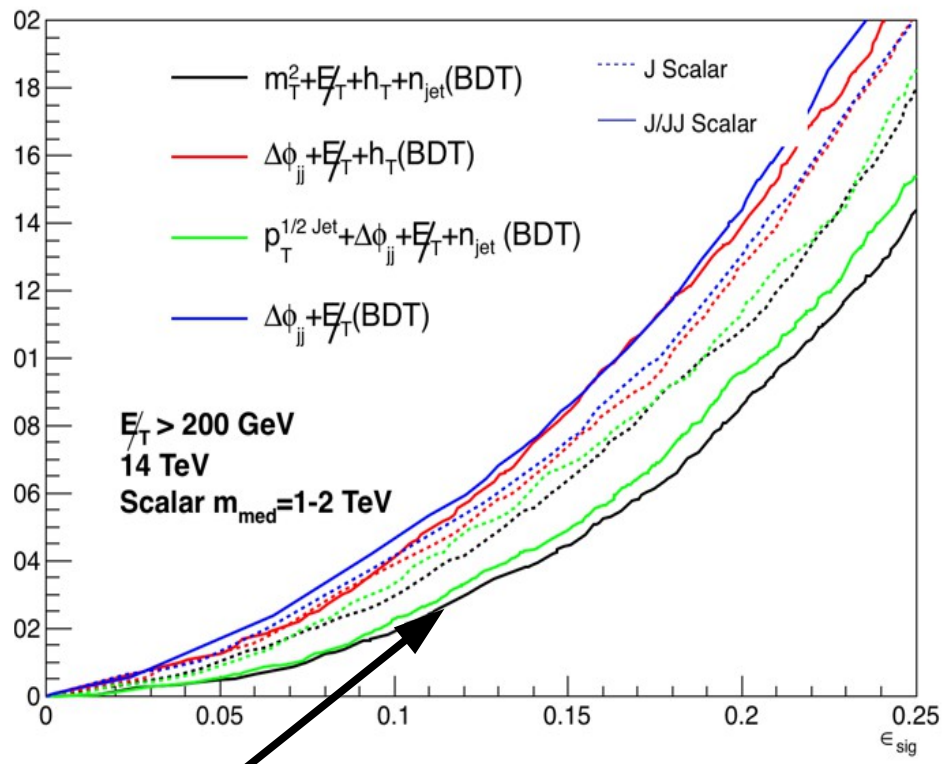
- With 2 jet MC : can now probe multijet final states
- Two questions can be answered :
  - Which variables are most sensitive with 2 jet MC?
  - Which variables are sensitive at 100 TeV?

- Considered a number of multi-jet variables :
  - M_T^2 : SUSY like variable obtained for pairwise sparticles
  - Razor variables : M_R , R : Related SUSY variables
  - *MET* : standard
  - $\Delta\varphi_{jj}$: angle between the two jets

Whats the maximum gain?

- Making an MVA combining all information





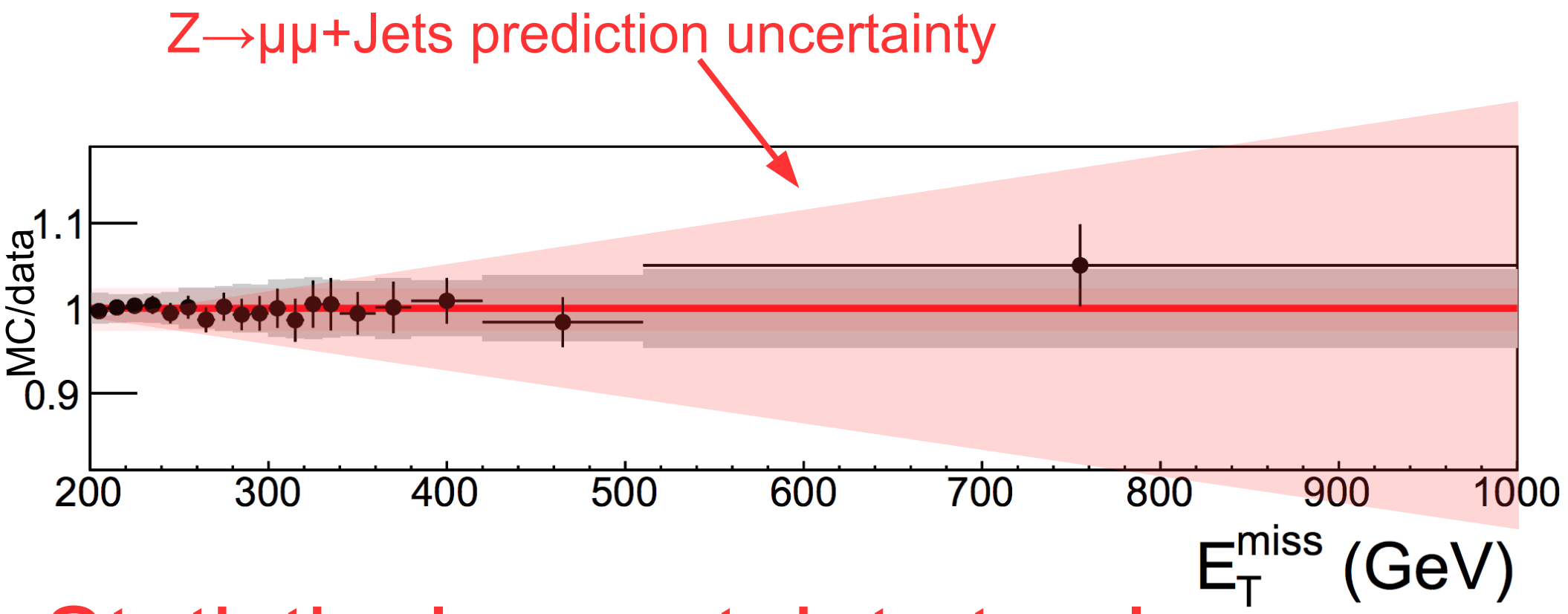
Background drops by a factor of 2

Can maximize sensitivity by an additional sqrt(2)

The only other way to gain is to reduce the systematics

Strategy to fix agreement

10x less Z→μμ than Z→νν

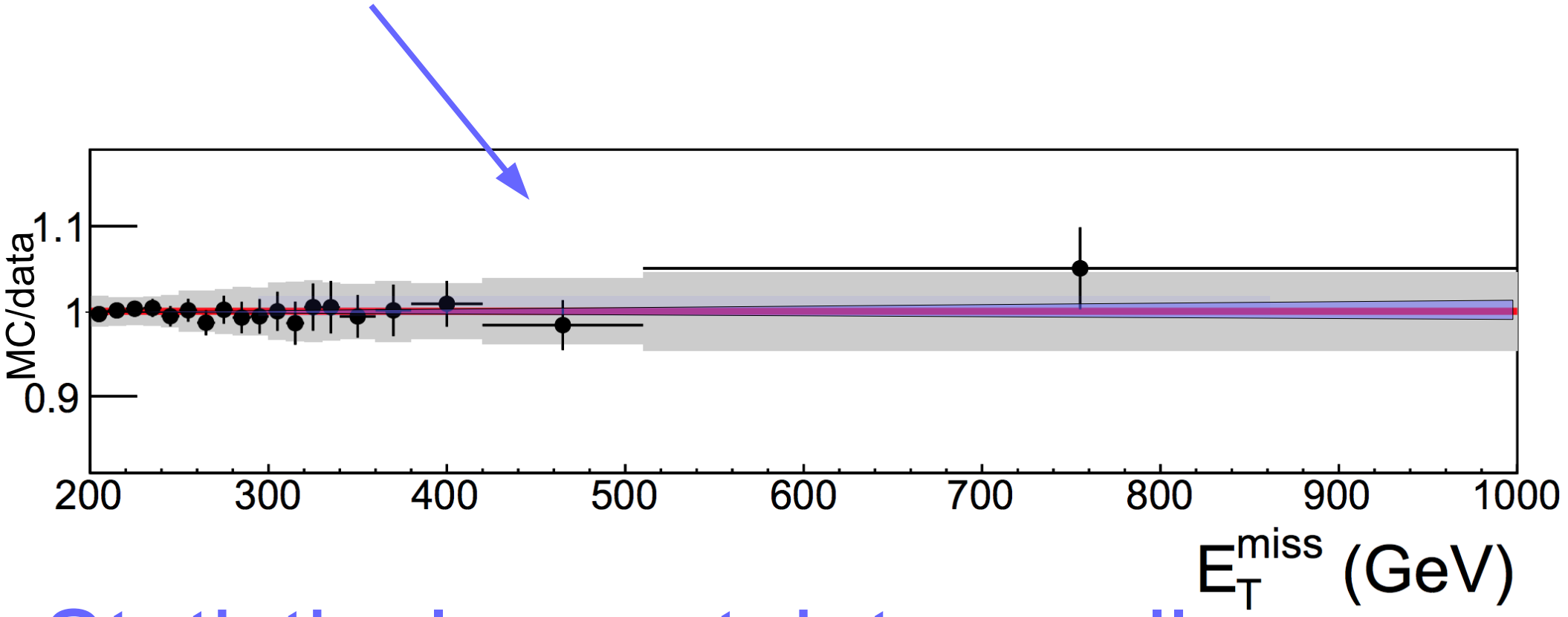


Statistical uncertainty too large

CMS-EXO-12-055

Strategy to fix agreement

5x More γ+Jets than Z→νν



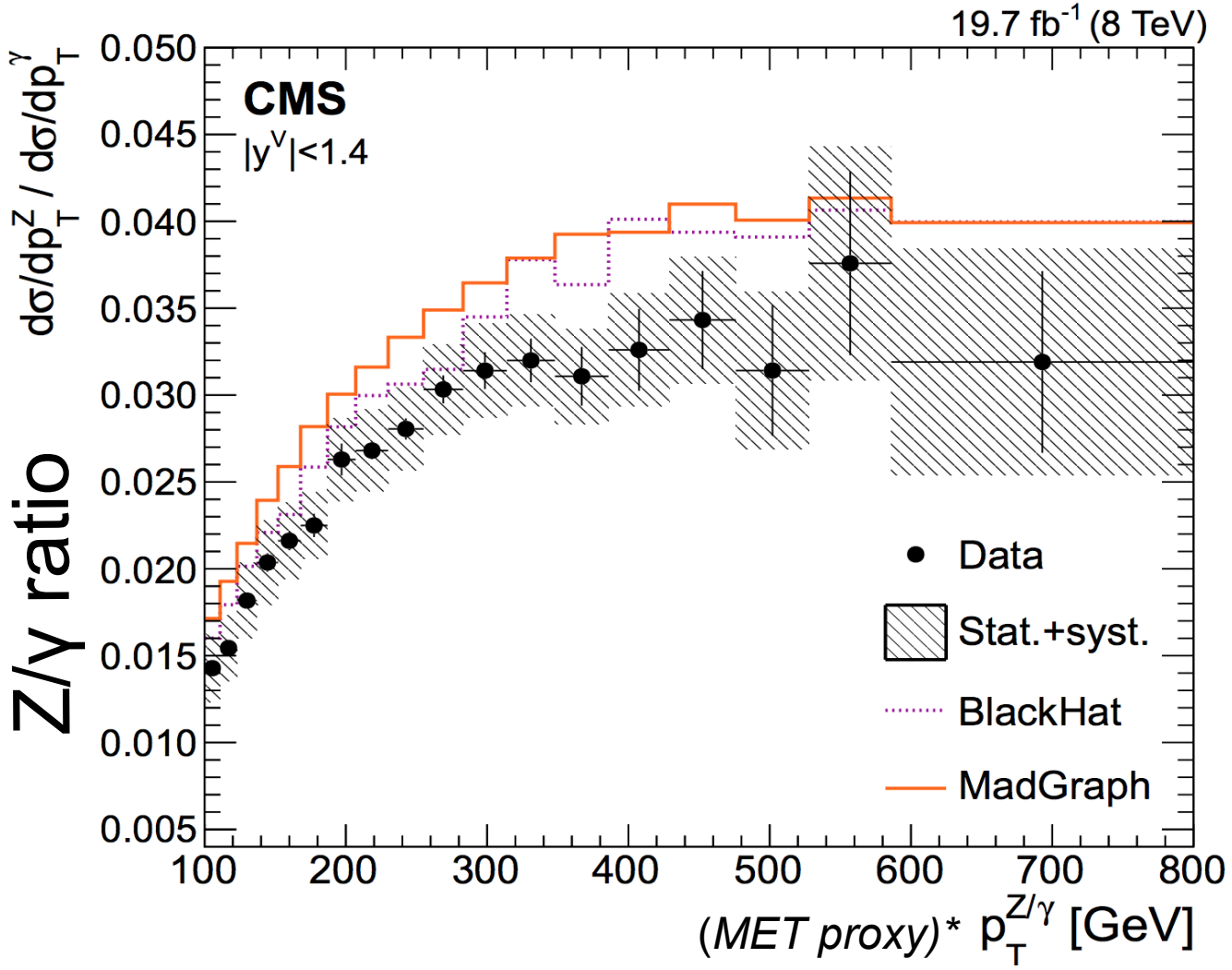
Statistical uncertainty small

….However

CMS-EXO-12-055

A mystery? Understanding Z/γ p_T

Can we really use Photons to model Zs ?

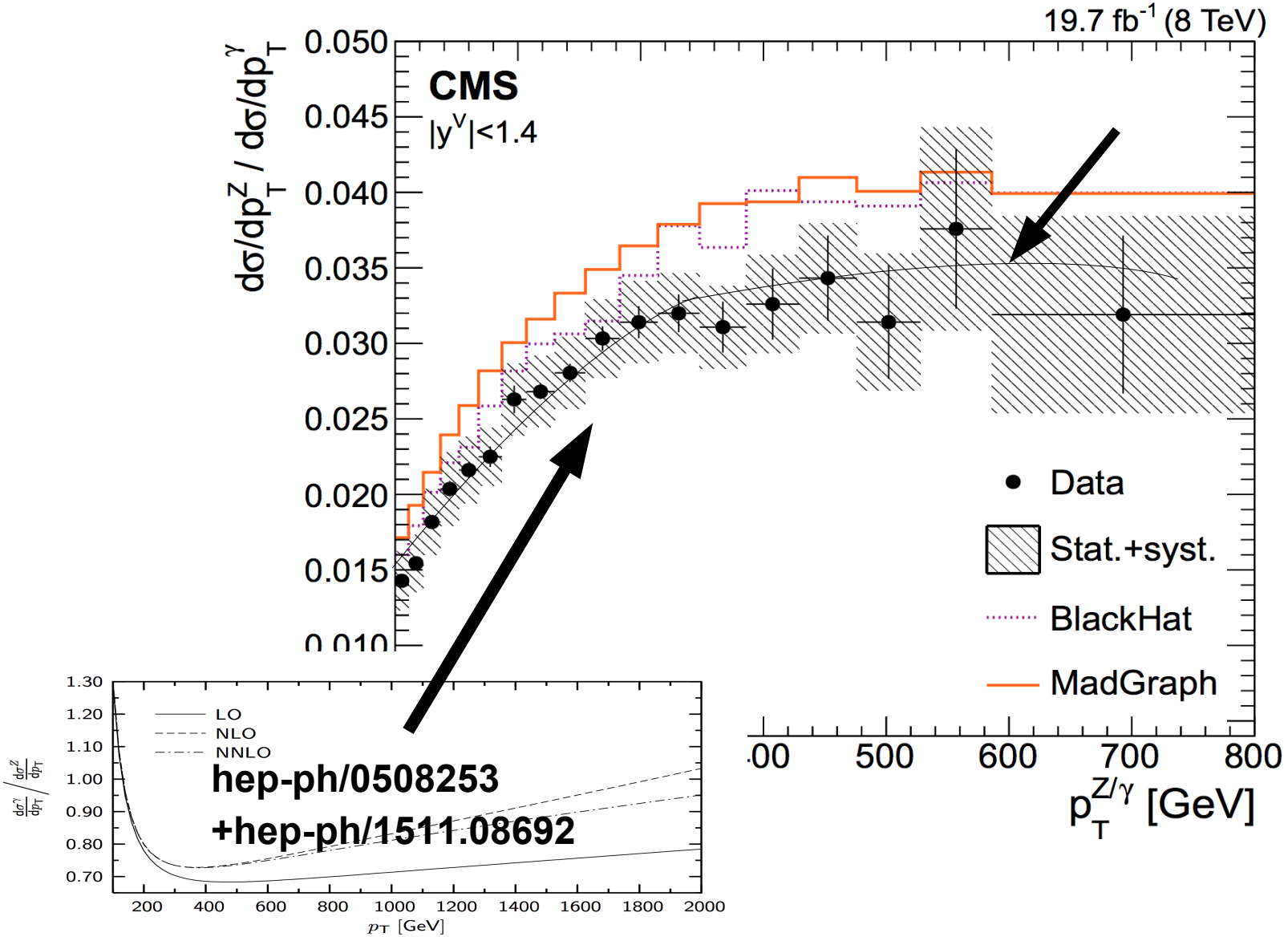


*See backup

CMS-SMP-14-005

A mystery? The Z p_T spectrum

- These results are missing NLO EWK corrections!



CMS-SMP-14-055

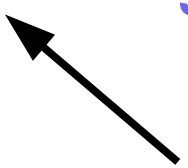
How do we fix this?

$$\frac{d\sigma^{\gamma}}{dp_T} \quad \text{and} \quad \frac{d\sigma^{Z}}{dp_T}$$

Before : $\sigma_{tot}=\sigma_{NLO}(0,1jet)$

After : $\sigma_{tot}=\sigma_{NLO}(0,1,2j)(1+\sigma_{EWK})$ (added)

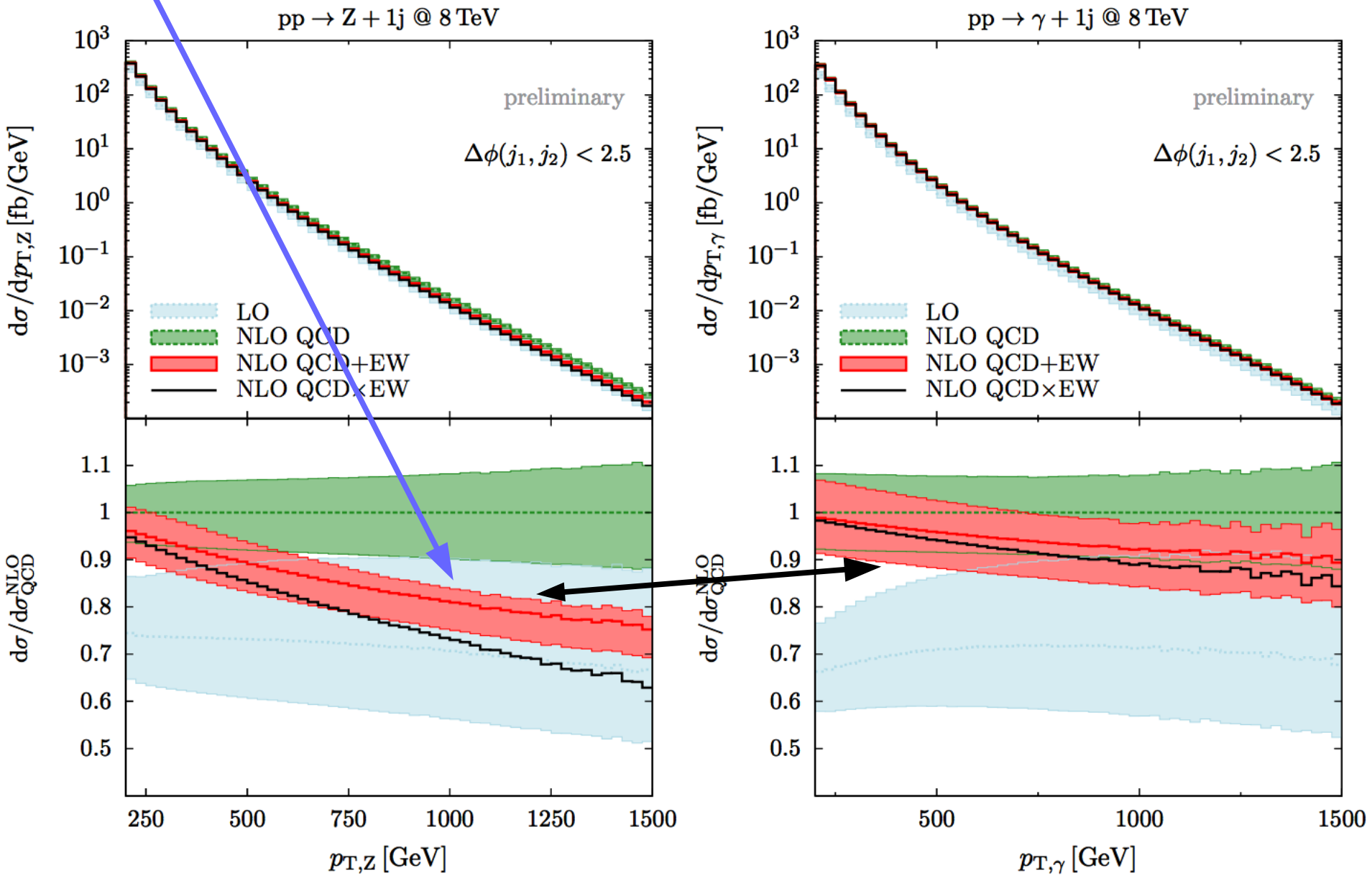
Energy leakage outside of photon which biases *MET*



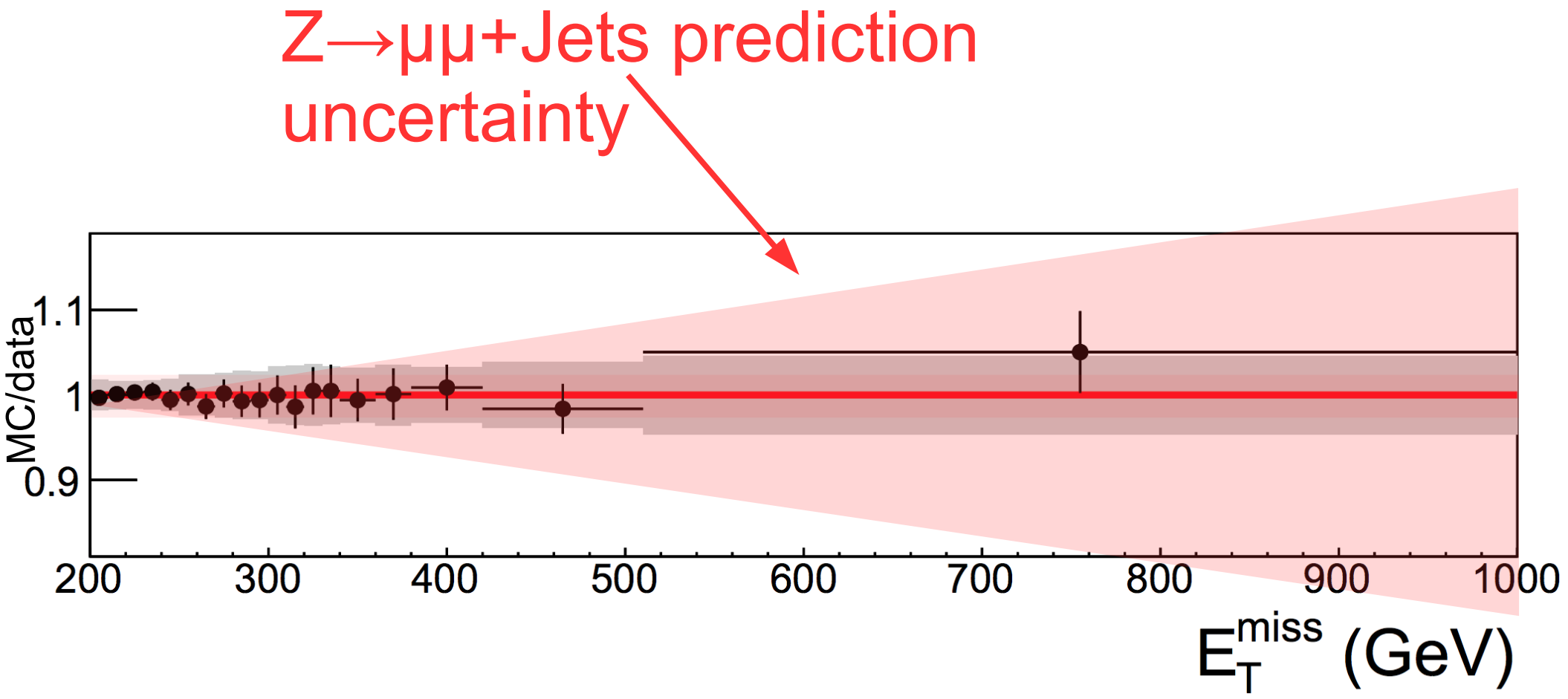
This was the harder one

How do we fix this?

Impact of the electroweak corrections

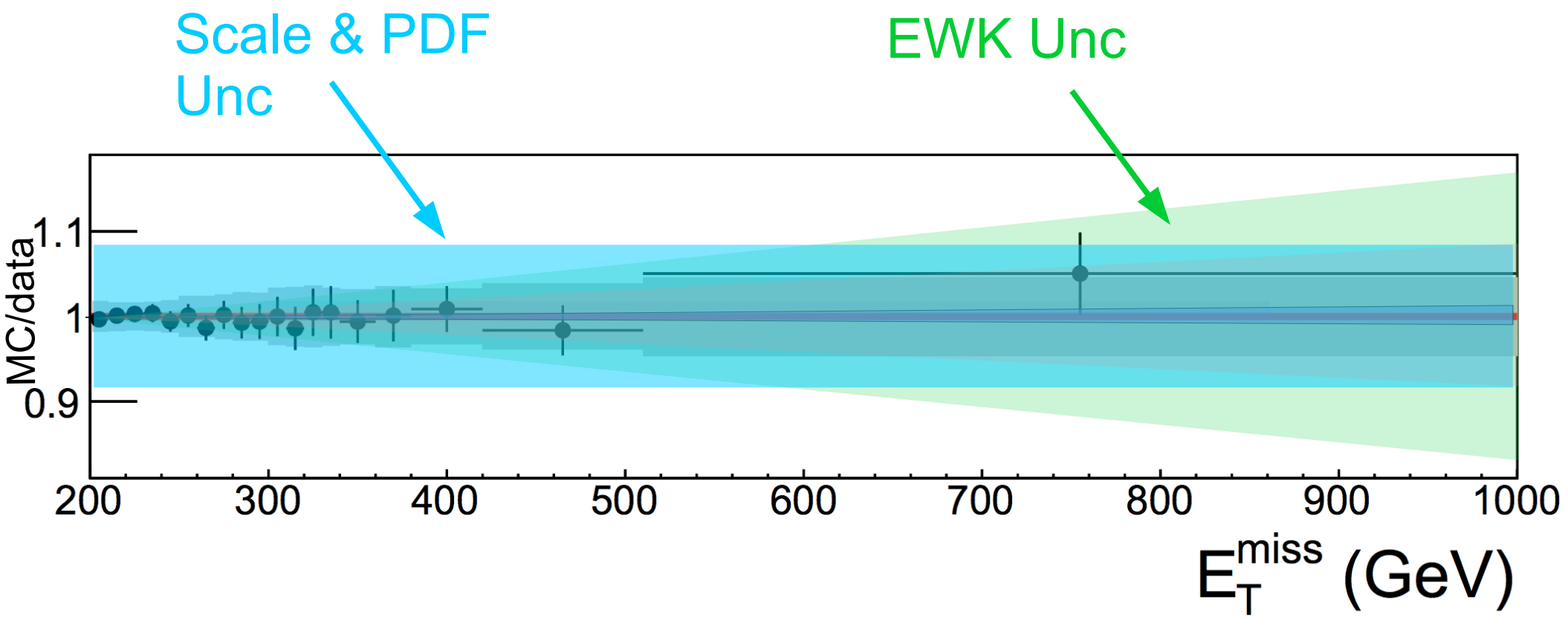


Strategy to fix agreement



CMS-EXO-12-055

Strategy to fix agreement



Updated unc still too large

CMS-EXO-12-055

What is the previous unc?

Scale & PDF Unc

Unc. $\rightarrow \dfrac{d\sigma^{\gamma}}{dp_T} \Big/ \dfrac{d\sigma^{Z}}{dp_T} = d\sigma^{\gamma}/d\sigma^{Z}(\mu)$ ↑ On the ratio

$$\begin{pmatrix} d\sigma^{\gamma}(+\sigma) \\ d\sigma^{Z}(+\sigma) \end{pmatrix} = \begin{pmatrix} 1 & C \\ C & 1 \end{pmatrix} \begin{pmatrix} d\sigma^{\gamma}(\mu^{up})/d\sigma^{i}(\mu_0) \\ d\sigma^{Z}(\mu^{up})/d\sigma^{i}(\mu_0) \end{pmatrix}$$

Adjust C until uncertainty is

$$\mathbf{d\sigma^{\gamma}/d\sigma^{Z}(+\sigma) < max_i\,(d\sigma^{i}(\mu^{up})/d\sigma^{i}(\mu_0))}$$

What is the previous unc?

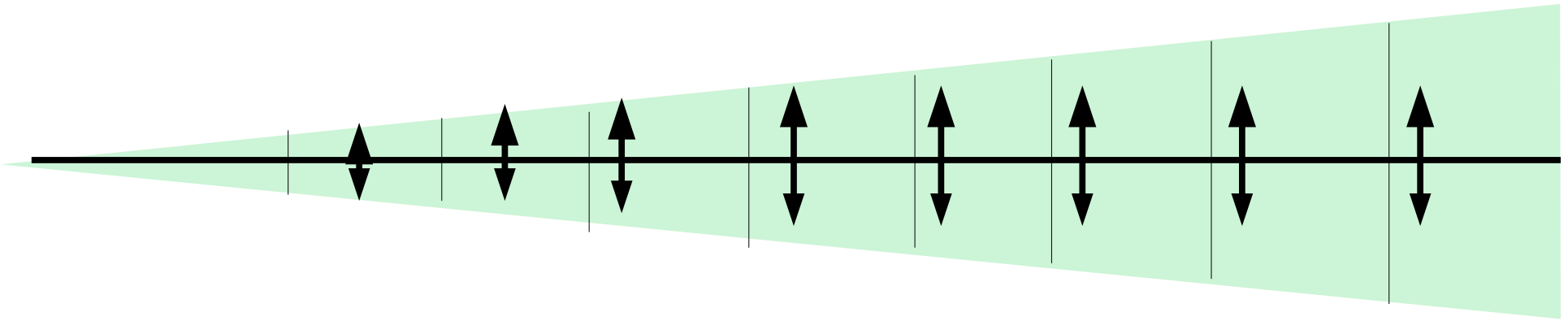
Scale & PDF Unc

Unc. $\longrightarrow \dfrac{d\sigma^{\gamma}}{dp_T} \Big/ \dfrac{d\sigma^{Z}}{dp_T} = d\sigma^{\gamma}/d\sigma^{Z}(\mu)$ ↑ On the ratio

$$\begin{pmatrix} d\sigma^{\gamma}(+\sigma) \\ d\sigma^{Z}(+\sigma) \end{pmatrix} = \begin{pmatrix} 1 & C \\ C & 1 \end{pmatrix} \begin{pmatrix} d\sigma^{\gamma}(\mu^{up})/d\sigma^{i}(\mu_0) \\ d\sigma^{Z}(\mu^{up})/d\sigma^{i}(\mu_0) \end{pmatrix}$$

Makes No Sense

What about the EWK uncertainty?



In light of being conservative :

Treated full correction as an uncertainty

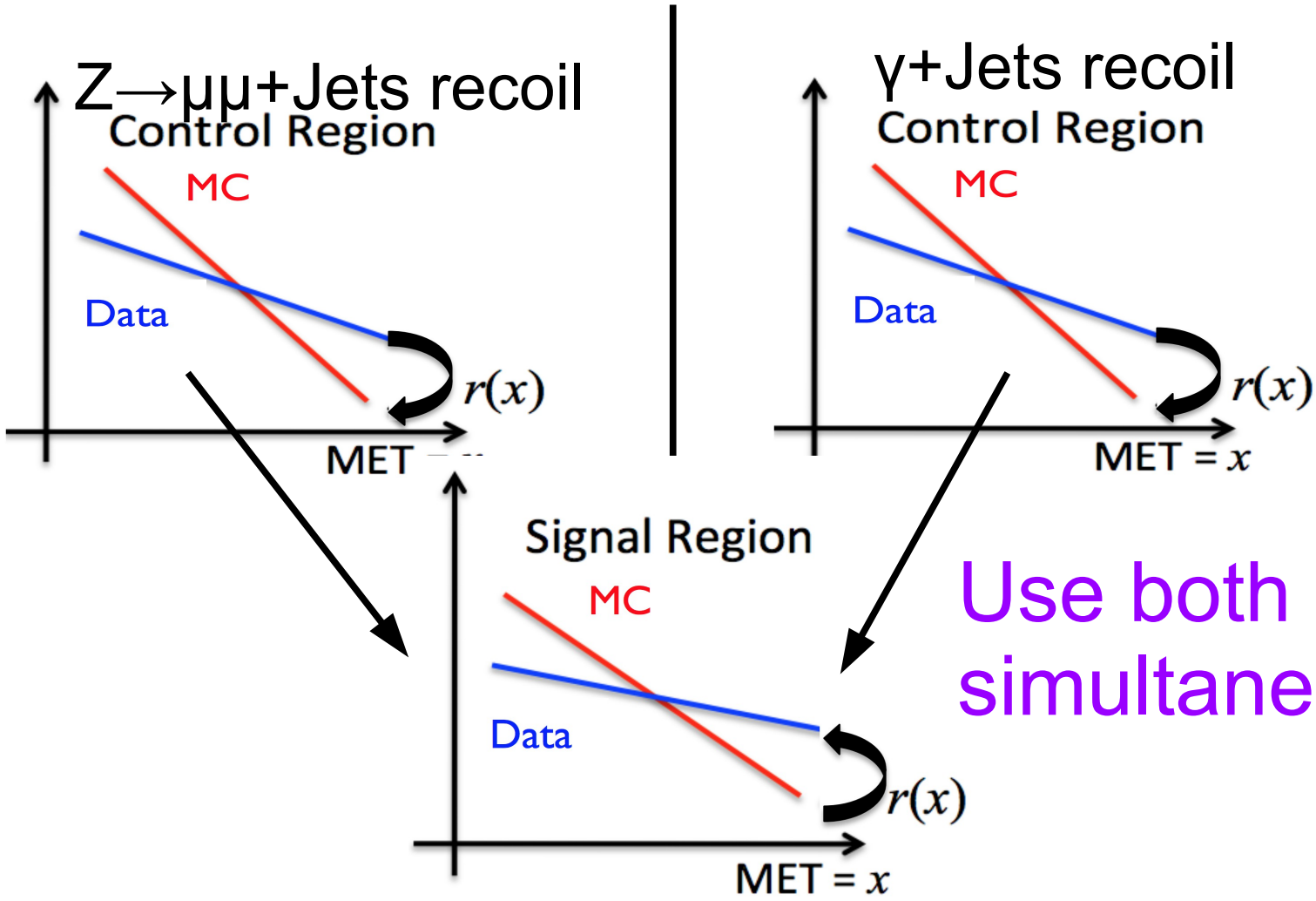
Additionally de-correlated this per bin

Avoids low *MET* to high *MET* constraints

Not very logical

Other (better) schemes exist

Strategy to fix agreement



Use both regions simultaneously

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Strategy to fix agreement

Coffee ?  or Tea? 

Answer : Yes Please

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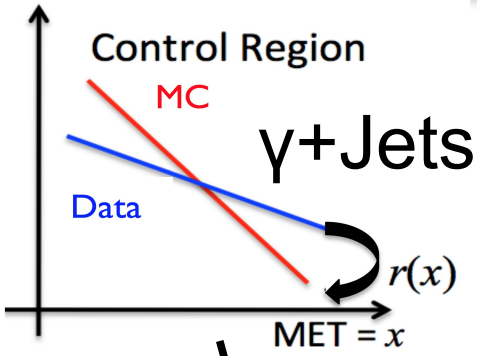
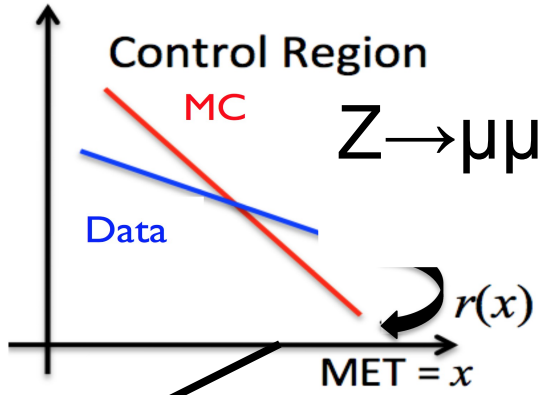
Strategy to fix agreement

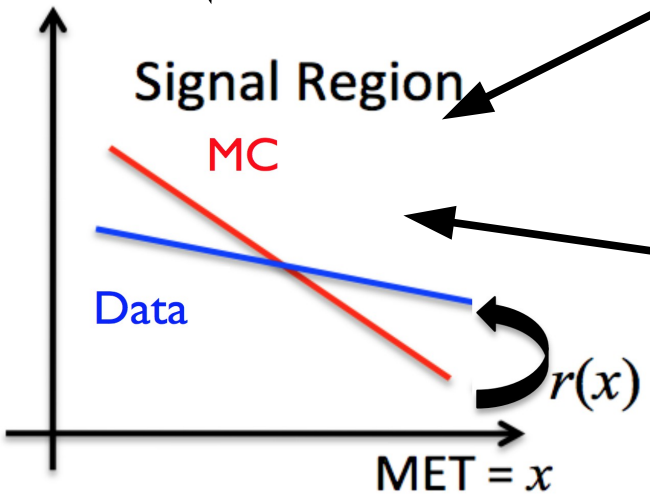
Coffee ?  or Tea? 



γ+Jets recoil

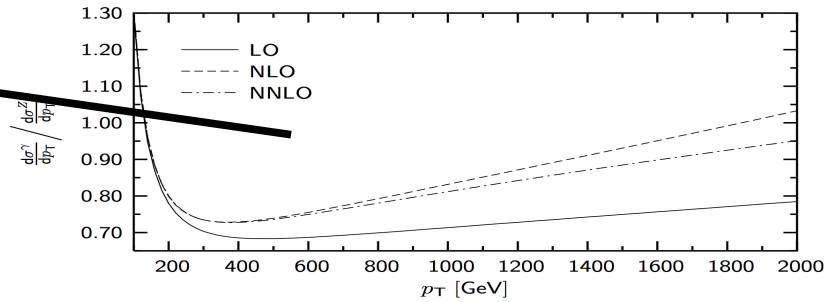


Z→μμ+Jets recoil



and Donuts

Not enough LO

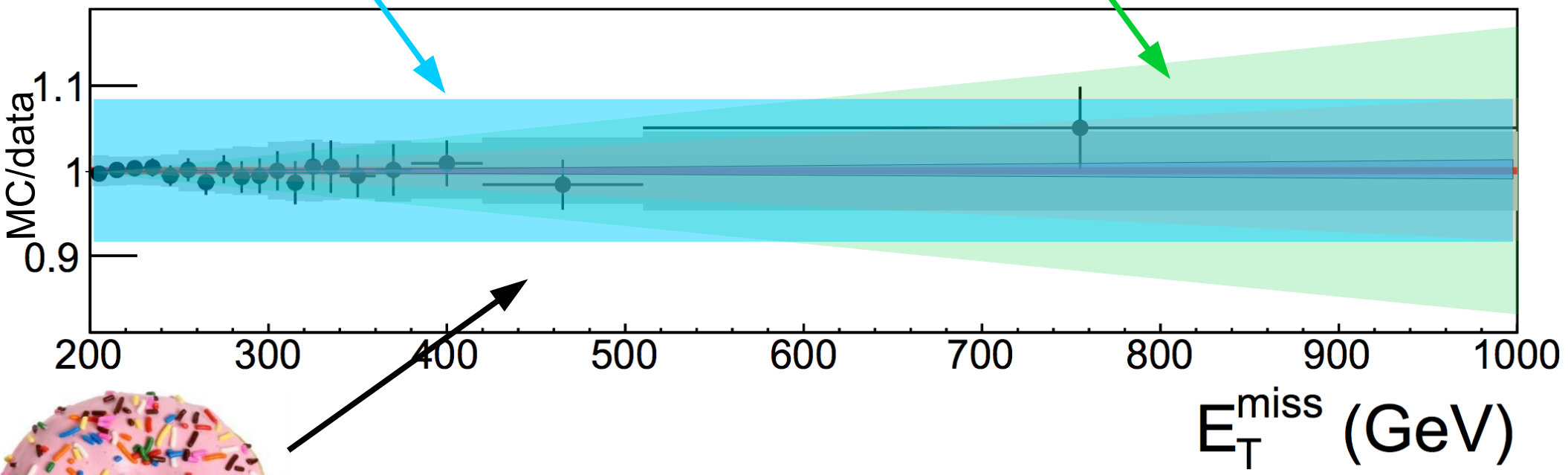


Strategy to fix agreement

Coffee ?  or Tea? 

Scale & PDF Unc

EWK Unc



Donuts? Constraint

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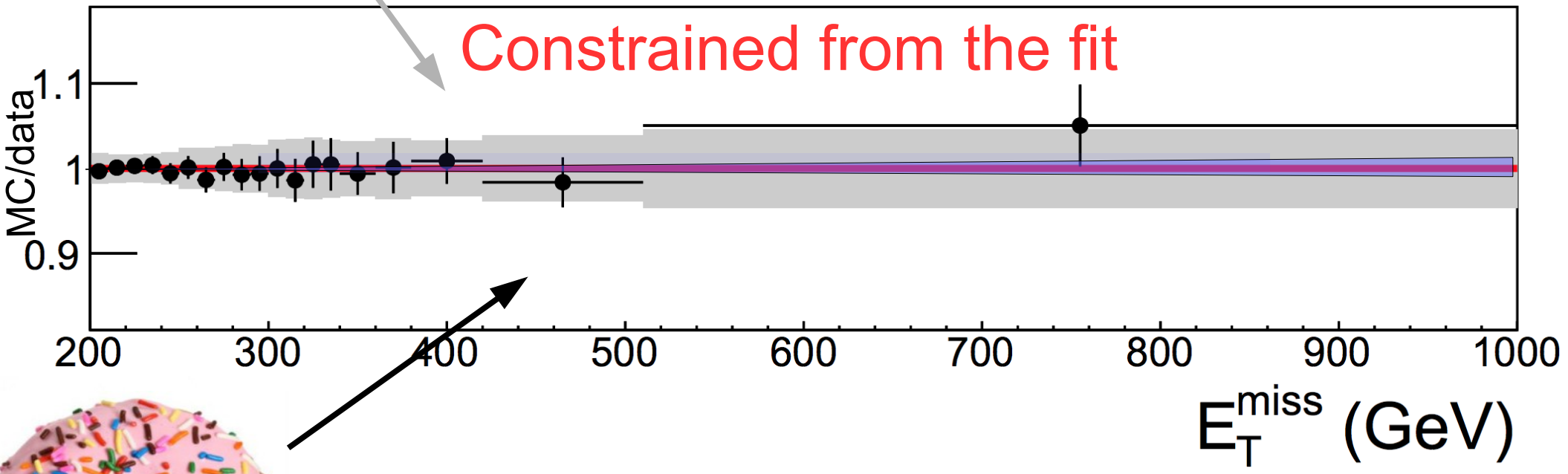
Strategy to fix agreement

Coffee ?  or Tea? 

Actual Uncertainty we use

Constrained from the fit



Donuts

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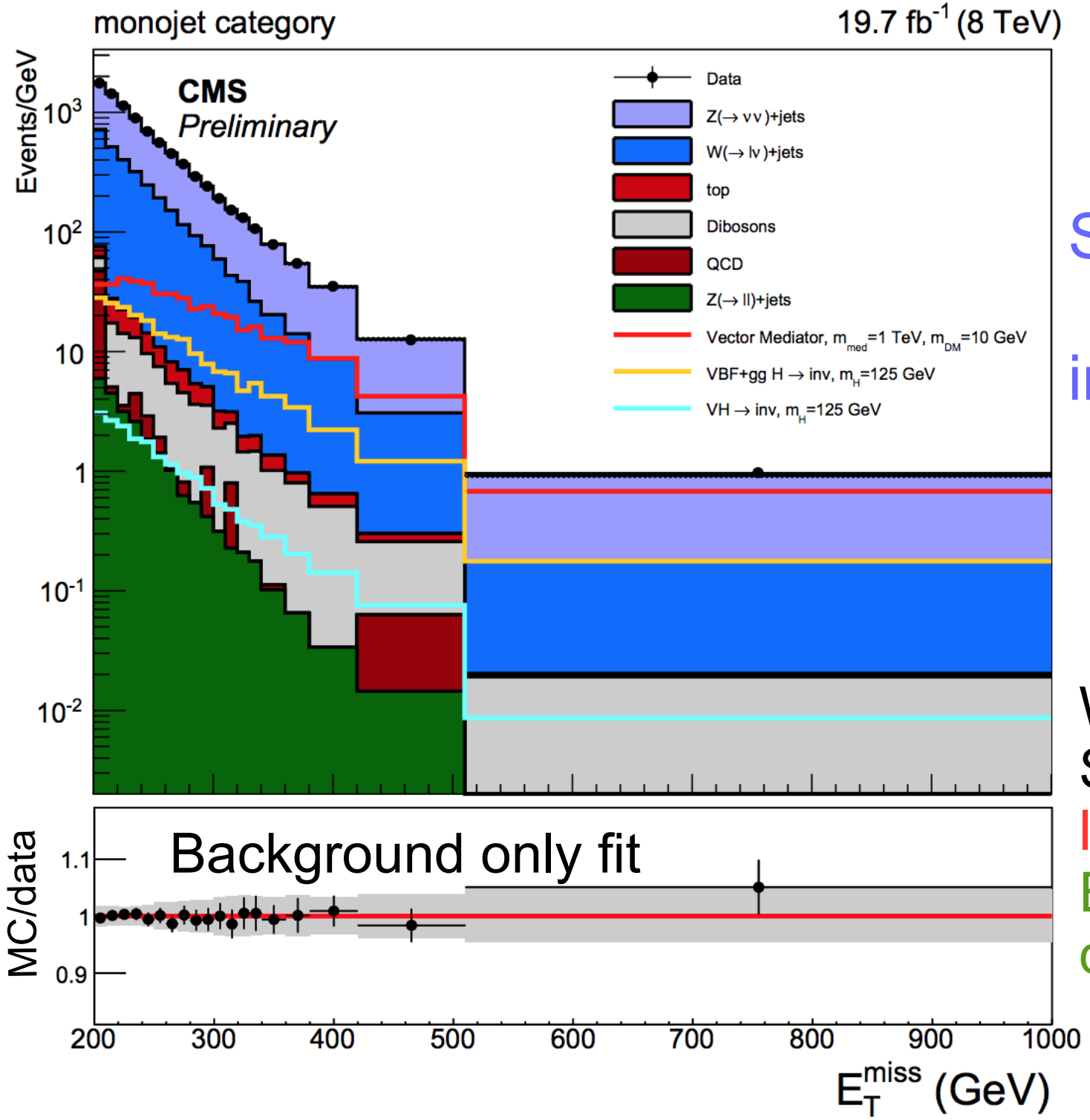
The Result



Small excess
(1-2σ)
in *MET* tail

With new method
Still systematics limited
EWK uncertainty dominates

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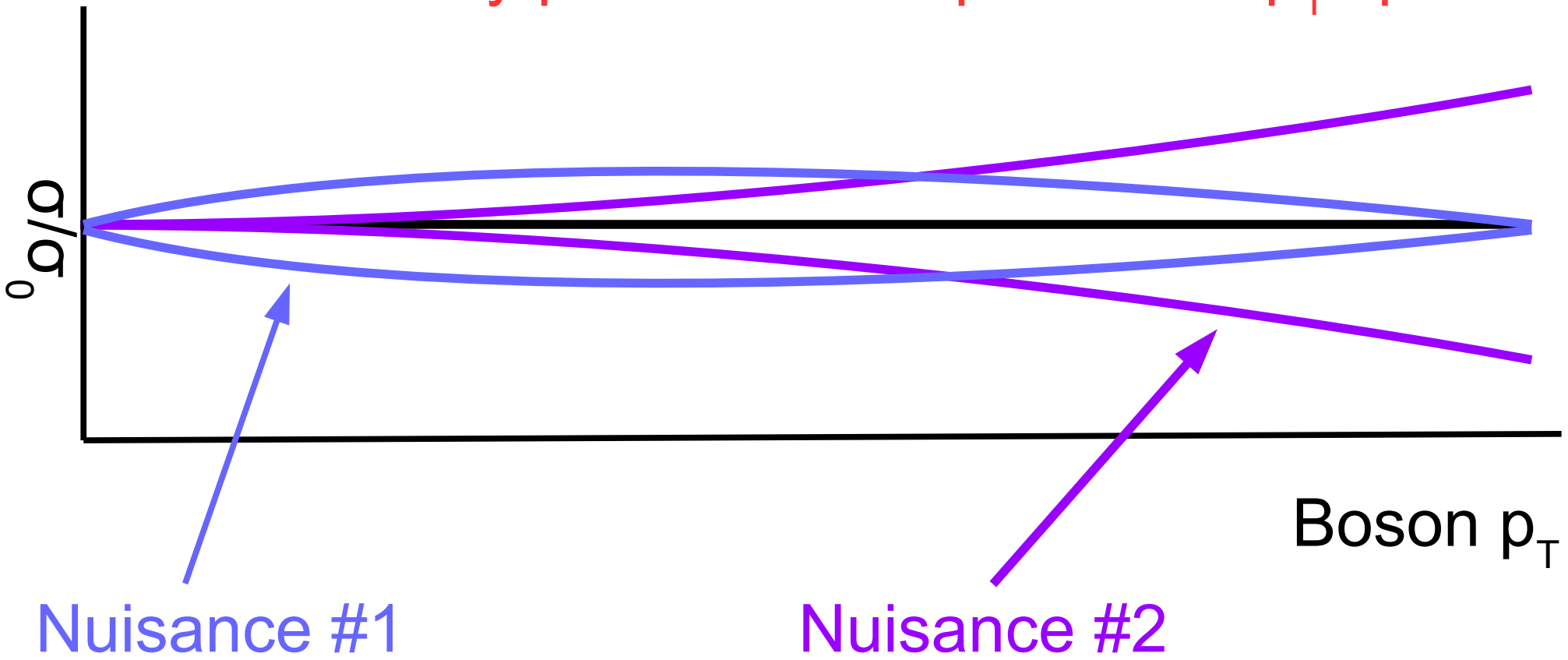
How do we do the fit?

The updated version of this search fits the W,Z,γ p_T simultaneously

Simultaneously profile the shapes of the p_T spectra



Can we bound our uncertainties into a class of shapes?

We are Stuck!

We are relying on

$$d\sigma^{\gamma}/d\sigma^{Z}(+\sigma) < \max_i (d\sigma^i(\mu^{up})/d\sigma^i(\mu_0))$$

For the uncertainty on

$$\frac{d\sigma^{\gamma}}{dp_T} \Big/ \frac{d\sigma^{Z}}{dp_T}$$

We need a better a approach

Ideally one that we can embed to the likelihood(L)

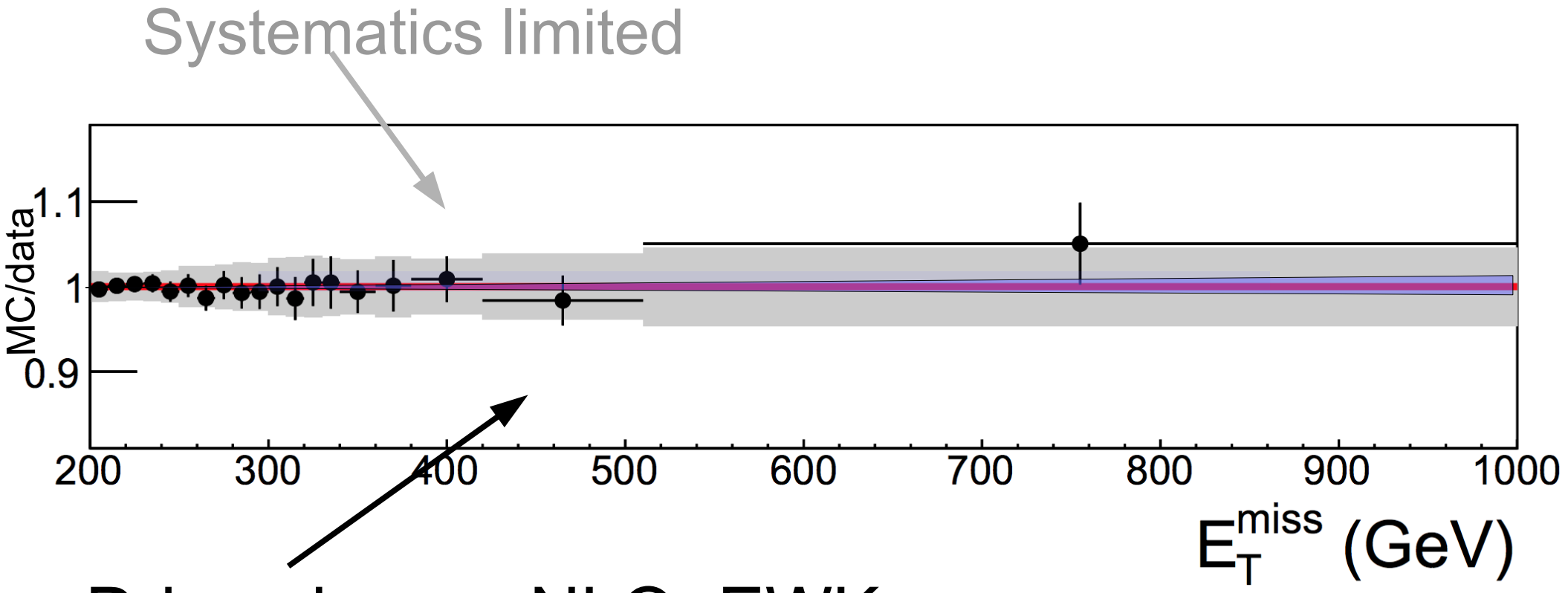
$$\mathrm{Log}(L)=\mathrm{Log}(L_0)+(d\sigma^{\gamma}/d\sigma^{Z}(\theta)-d\sigma^{\gamma}/d\sigma^{Z}(\mu_0))/\sigma^2$$

Profiled nuisance

Improved knowledge of high p_T spectrum drives search

Can we improve?

Monojet search will not improve quickly in the future



Driven by our NLO+EWK uncertainties

CMS-EXO-12-055

Towards a complete statement on Dark Matter

Analyses presented

- Mono Jet:

Scalar Axial Higgs modified vector modified scalar mixture

Jets	Inclusive	V tag	Top	b tag	Higgs
1					
2					
3					
n					
leptons					
Y					
X→YY					

- Mono Everything: Extending to improve scalar at 100 TeV

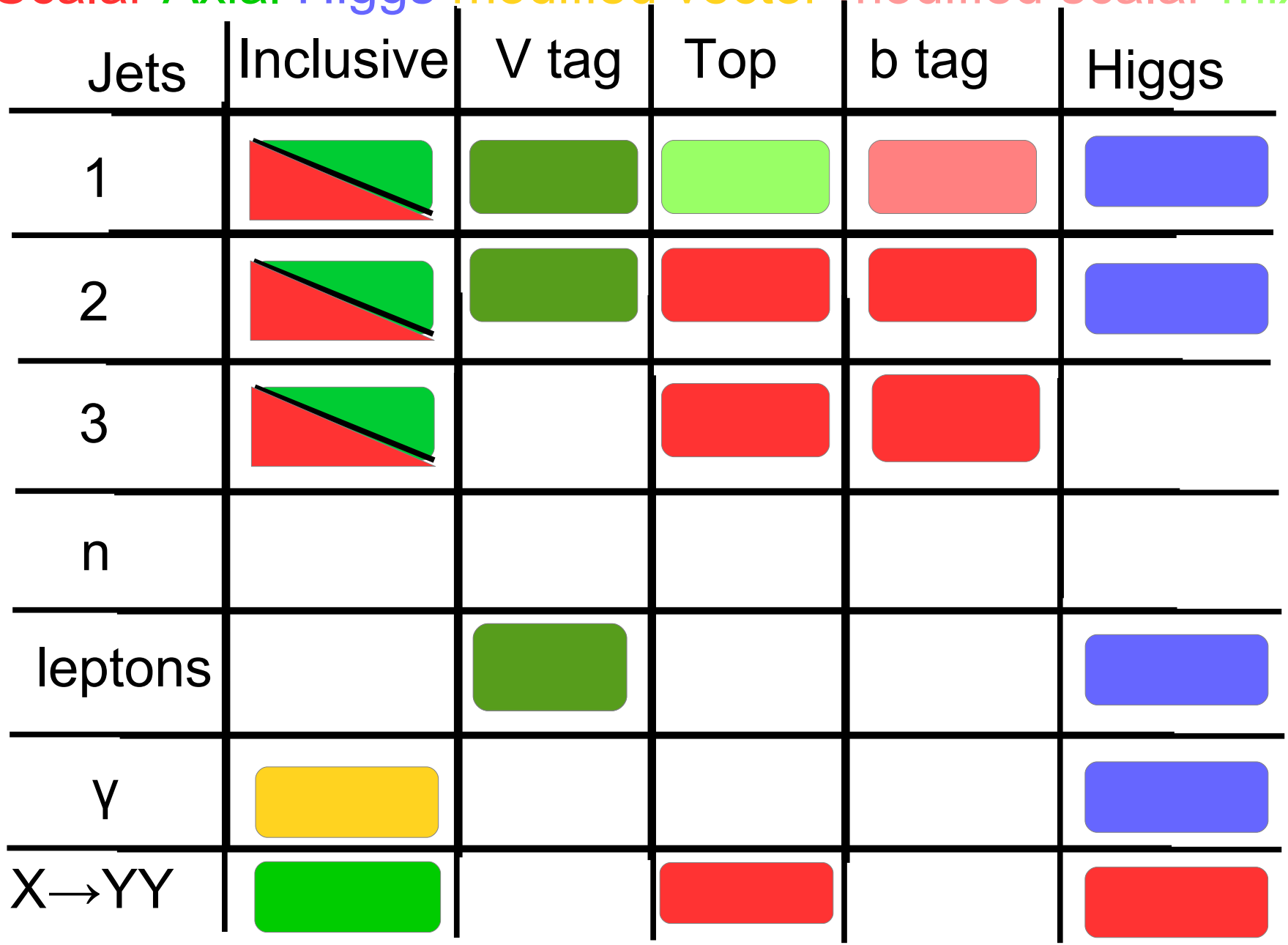
Scalar Axial Higgs modified vector modified scalar mixture

Jets	Inclusive	V tag	Top	b tag	Higgs
1					
2					
3					
n					
leptons					
Y					
X→YY					

- Mono Everything:

Extending models to cover modified simplified models

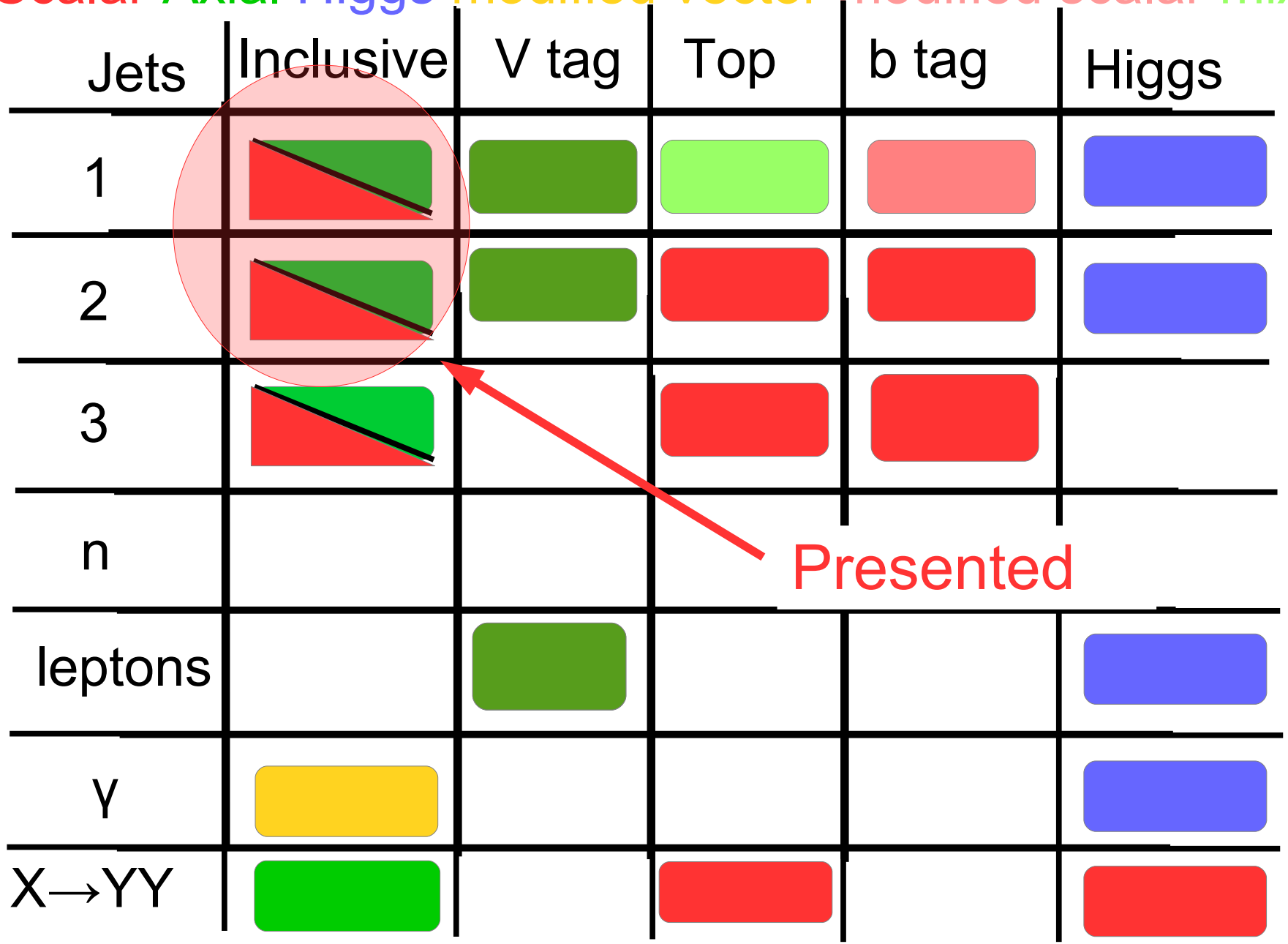
Scalar Axial Higgs modified vector modified scalar mixture



- Mono Everything:

Extending models to cover modified simplified models

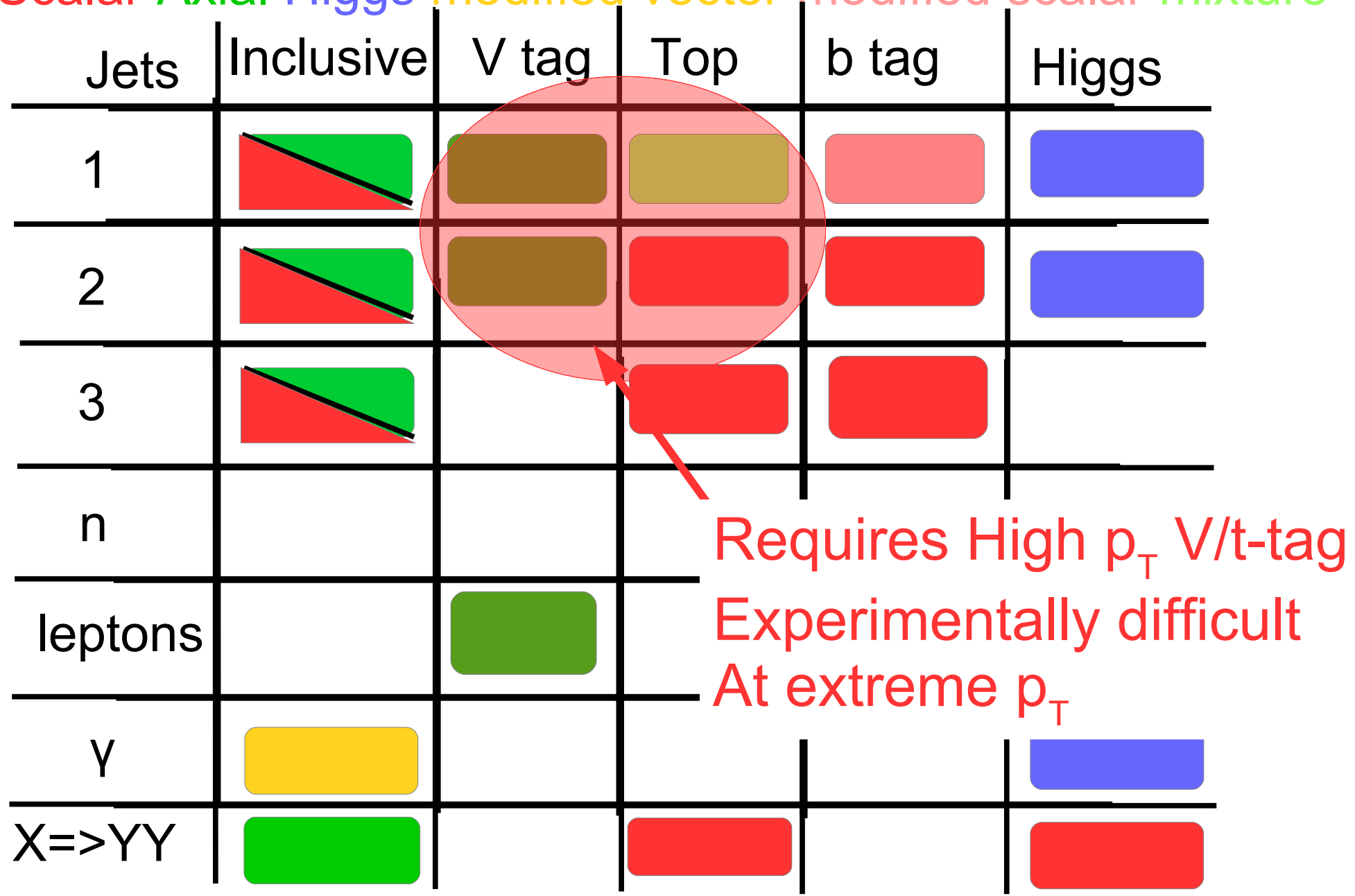
Scalar Axial Higgs modified vector modified scalar mixture



- Mono Everything:

Extending models to cover modified simplified models

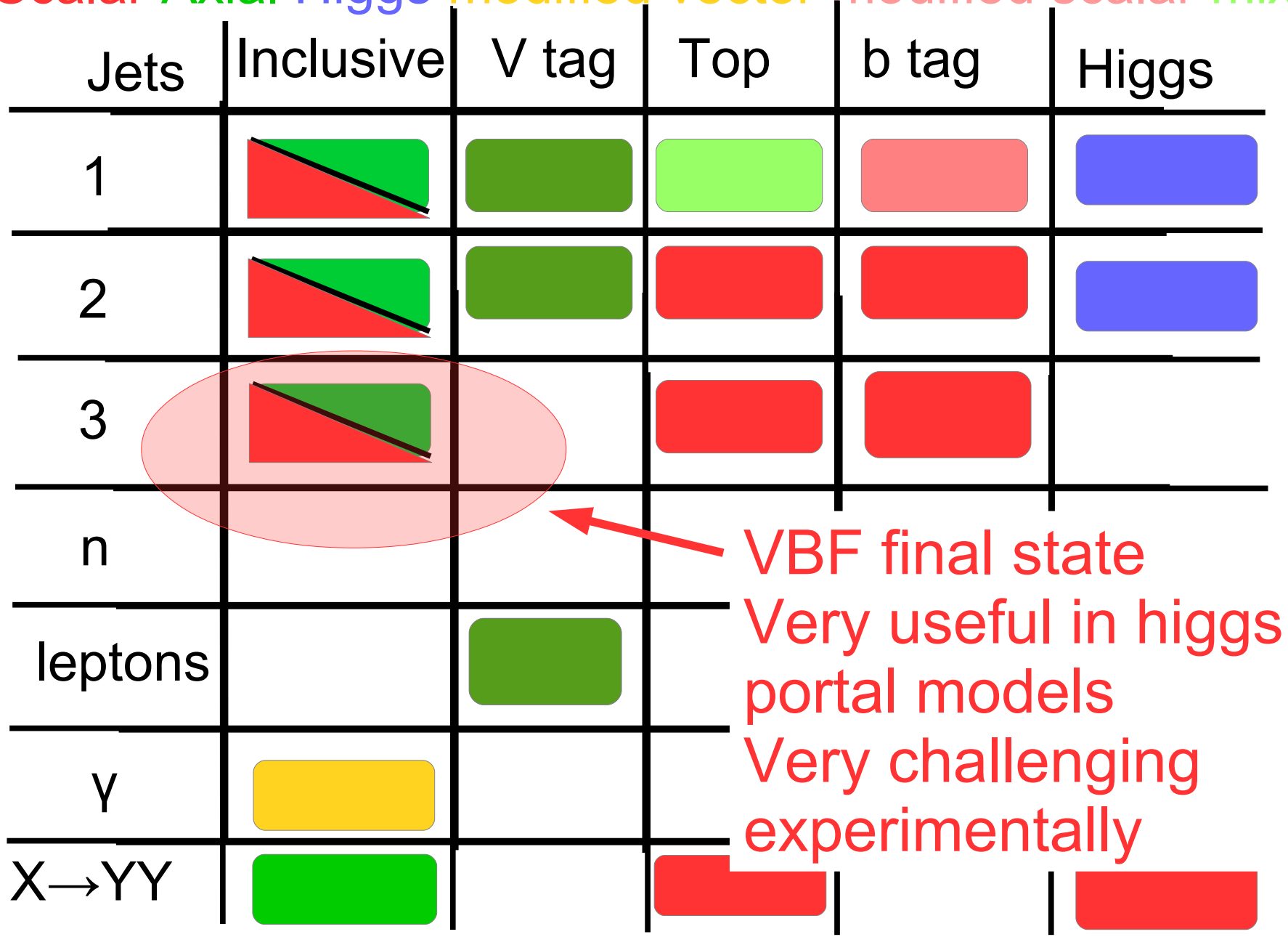
Scalar Axial Higgs modified vector modified scalar mixture



- Mono Everything:

Extending models to cover modified simplified models

Scalar Axial Higgs modified vector modified scalar mixture



- Mono Everything:

Extending models to cover modified simplified models

Scalar Axial Higgs modified vector modified scalar mixture