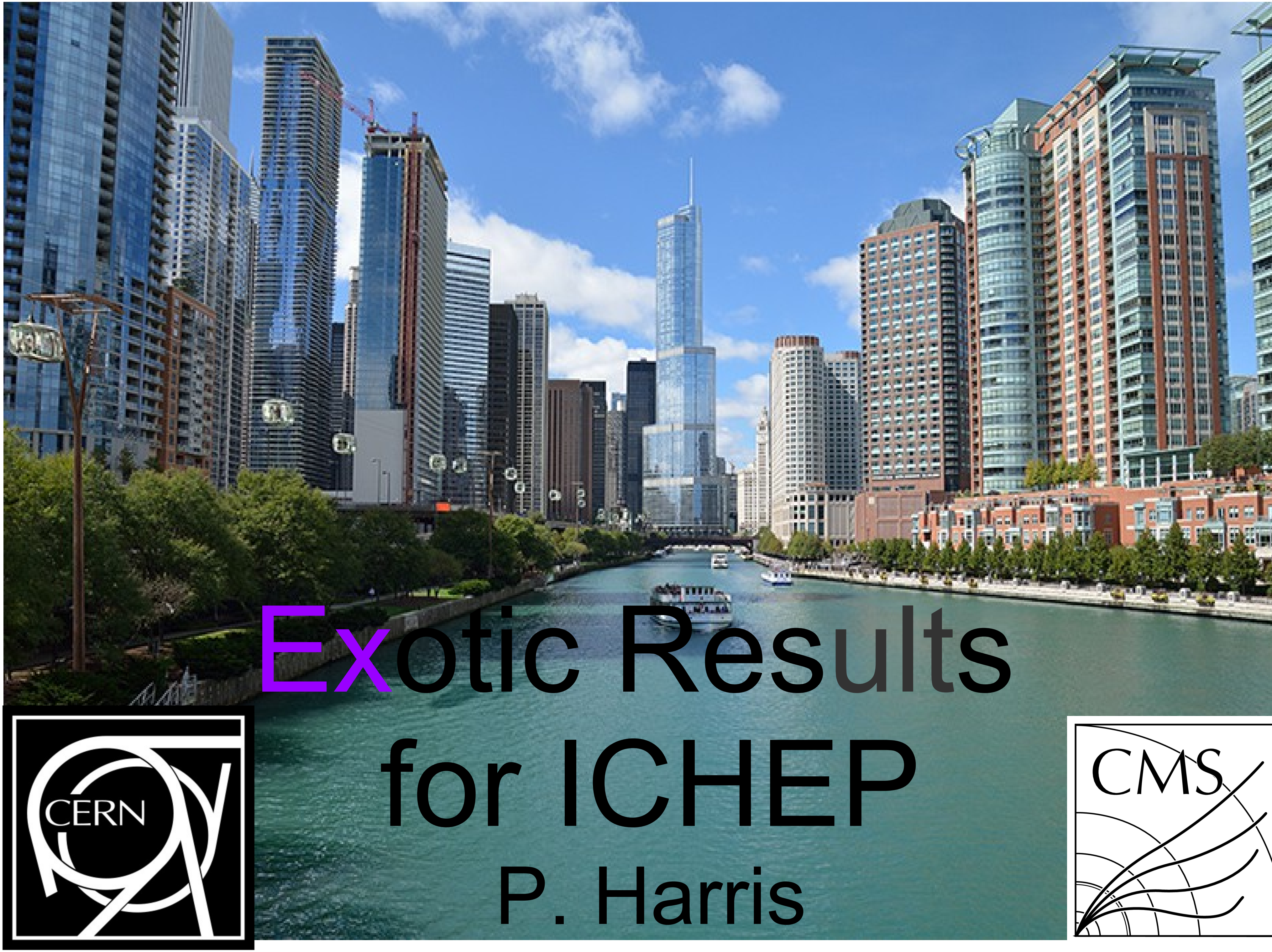


Exotic Results for ICHEP

P. Harris

Whats new?

- EXO-16-005 ttbar+MET 2015
- EXO-16-010 Z(ll)+MET 2015
- EXO-16-011 monoH(γγ) 2015
- EXO-16-012 monoH(bb) 2015
- EXO-16-037 monojet 2016
- EXO-16-038 Z(ll)+MET 2016
- EXO-16-039 mono-γ 2016
- EXO-16-040 monotop 2016

Analyses/minute=1.05

1 8TeV result :19.6 fb^{-1}

9 2015 results: 2.7 fb^{-1}

11 2016 results: 12.9 fb^{-1}

- EXO-16-032 dijets 2016
- EXO-16-030 low-mass dijets 2015
- EXO-16-032 Z'→ee/μμ 2016
- EXO-16-043 LQ(ee) 2016
- EXO-16-034 Z(ll)gamma 2016
- EXO-16-035 Z(qq)gamma 2016
- EXO-16-025 Z(qq)gamma 8 TeV
- EXO-16-022 displaced e-mu 2015
- EXO-16-036 HSCP 2016
- B2G-16-020 VW(W→lv) 2016
- B2G-16-010 VZ (Z→ll) 2015
- B2G-16-017 W'→tb(→lvbb) 2016
- B2G-16-009 W'→tb(→qqbb) 2015

Whats new?

- EXO-16-005 ttbar+MET 2015
- EXO-16-010 Z(ll)+MET 2015
- EXO-16-011 monoH(γγ) 2015
- EXO-16-012 monoH(bb) 2015
- EXO-16-037 monojet 2016
- EXO-16-038 Z(ll)+MET 2016
- EXO-16-039 mono-γ 2016
- EXO-16-040 monotop 2016

Heavy Mediators

- EXO-16-032 dijets 2016
- EXO-16-030 low-mass dijets 2015
- EXO-16-032 Z'→ee/μμ 2016
- EXO-16-043 LQ(ee) 2016
- EXO-16-034 Z(ll)gamma 2016
- EXO-16-035 Z(qq)gamma 2016
- EXO-16-025 Z(qq)gamma 8 TeV
- EXO-16-022 displaced e-mu 2015
- EXO-16-036 HSCP 2016
- B2G-16-020 VW(W→lv) 2016
- B2G-16-010 VZ (Z→ll) 2015
- B2G-16-017 W'→tb(→lvbb) 2016
- B2G-16-009 W'→tb(→qqbb) 2015

Whats new?

- EXO-16-005 ttbar+MET 2015
- EXO-16-010 Z(ll)+MET 2015
- EXO-16-011 monoH(γγ) 2015
- EXO-16-012 monoH(bb) 2015
- EXO-16-037 monojet 2016
- EXO-16-038 Z(ll)+MET 2016
- EXO-16-039 mono-γ 2016
- EXO-16-040 monotop 2016

Diphoton stuff

- EXO-16-032 dijets 2016
- EXO-16-030 low-mass dijets 2015
- EXO-16-032 Z'→ee/μμ 2016
- EXO-16-043 LQ(ee) 2016
- EXO-16-034 Z(ll)gamma 2016
- EXO-16-035 Z(qq)gamma 2016
- EXO-16-025 Z(qq)gamma 8 TeV
- EXO-16-022 displaced e-mu 2015
- EXO-16-036 HSCP 2016
- B2G-16-020 VW(W→lv) 2016
- B2G-16-010 VZ (Z→ll) 2015
- B2G-16-017 W'→tb(→lvbb) 2016
- B2G-16-009 W'→tb(→qqbb) 2015

Whats new?

- EXO-16-005 ttbar+MET 2015
- EXO-16-010 Z(ll)+MET 2015
- EXO-16-011 monoH(γγ) 2015
- EXO-16-012 monoH(bb) 2015
- EXO-16-037 monojet 2016
- EXO-16-038 Z(ll)+MET 2016
- EXO-16-039 mono-γ 2016
- EXO-16-040 monotop 2016

Lifetime Frontier

- EXO-16-032 dijets 2016
- EXO-16-030 low-mass dijets 2015
- EXO-16-032 Z'→ee/μμ 2016
- EXO-16-043 LQ(ee) 2016
- EXO-16-034 Z(ll)gamma 2016
- EXO-16-035 Z(qq)gamma 2016
- EXO-16-025 Z(qq)gamma 8 TeV
- EXO-16-022 displaced e-mu 2015
- EXO-16-036 HSCP 2016
- B2G-16-020 VW(W→lν) 2016
- B2G-16-010 VZ (Z→ll) 2015
- B2G-16-017 W'→tb(→lνbb) 2016
- B2G-16-009 W'→tb(→qqbb) 2015

Whats new?

- EXO-16-005 ttbar+MET 2015
- EXO-16-010 Z(ll)+MET 2015
- EXO-16-011 monoH(γγ) 2015
- EXO-16-012 monoH(bb) 2015
- EXO-16-037 monojet 2016
- EXO-16-038 Z(ll)+MET 2016
- EXO-16-039 mono-γ 2016
- EXO-16-040 monotop 2016

Boosted Jet Searches

- EXO-16-032 dijets 2016
- EXO-16-030 low-mass dijets 2015
- EXO-16-032 Z'→ee/μμ 2016
- EXO-16-043 LQ(ee) 2016
- EXO-16-034 Z(ll)gamma 2016
- EXO-16-035 Z(qq)gamma 2016
- EXO-16-025 Z(qq)gamma 8 TeV
- EXO-16-022 displaced e-mu 2015
- EXO-16-036 HSCP 2016
- B2G-16-020 VW(W→lv) 2016
- B2G-16-010 VZ (Z→ll) 2015
- B2G-16-017 W'→tb(→lvbb) 2016
- B2G-16-009 W'→tb(→qqbb) 2015

Whats new?

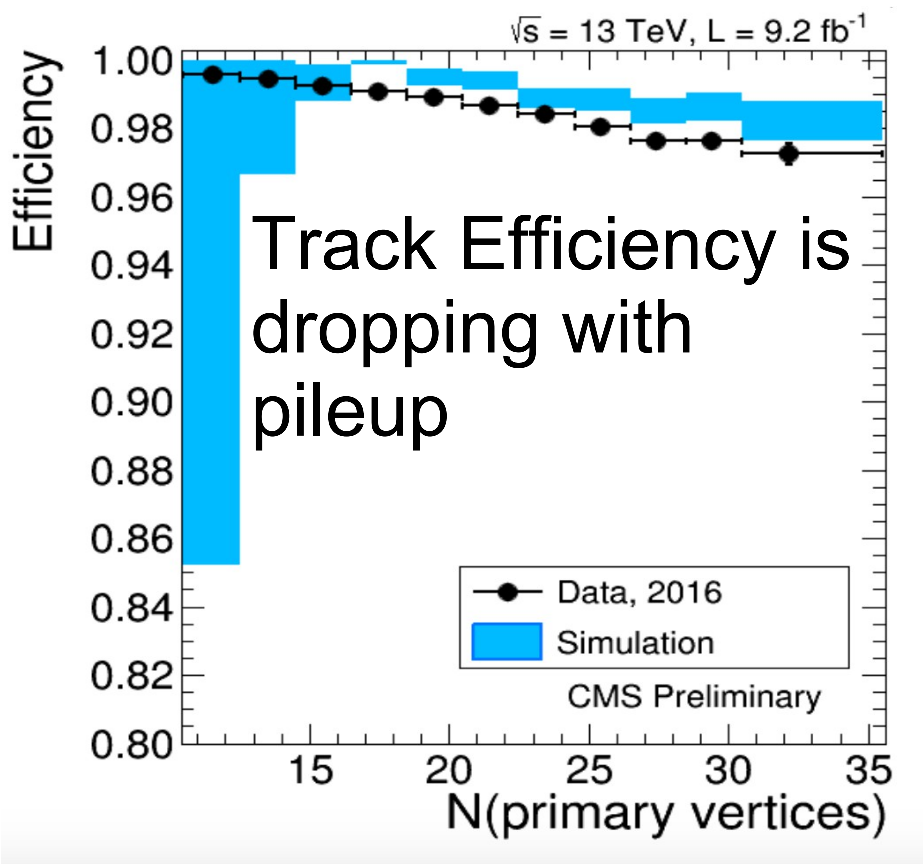
- EXO-16-005 ttbar+MET 2015
- EXO-16-010 Z(ll)+MET 2015
- EXO-16-011 monoH(γγ) 2015
- EXO-16-012 monoH(bb) 2015
- EXO-16-037 monojet 2016
- EXO-16-038 Z(ll)+MET 2016
- EXO-16-039 mono-γ 2016
- EXO-16-040 monotop 2016

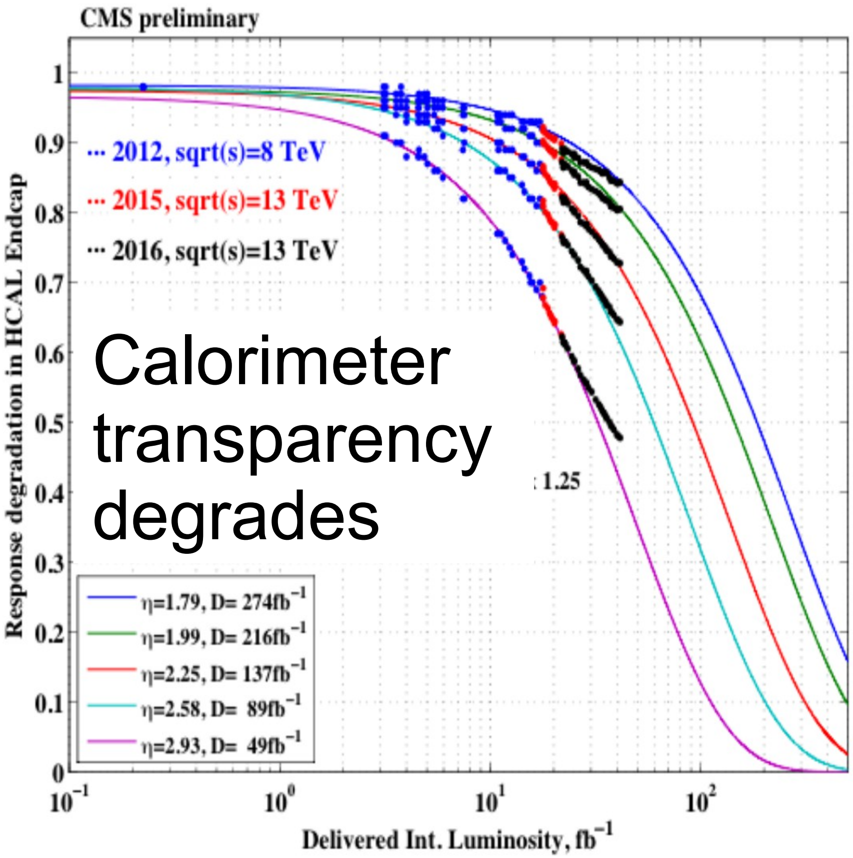
Dark Matter

- EXO-16-032 dijets 2016
- EXO-16-030 low-mass dijets 2015
- EXO-16-032 Z'→ee/μμ 2016
- EXO-16-043 LQ(ee) 2016
- EXO-16-034 Z(ll)gamma 2016
- EXO-16-035 Z(qq)gamma 2016
- EXO-16-025 Z(qq)gamma 8 TeV
- EXO-16-022 displaced e-mu 2015
- EXO-16-036 HSCP 2016
- B2G-16-020 VW(W→lv) 2016
- B2G-16-010 VZ (Z→ll) 2015
- B2G-16-017 W'→tb(→lvbb) 2016
- B2G-16-009 W'→tb(→qqbb) 2015

Common Themes

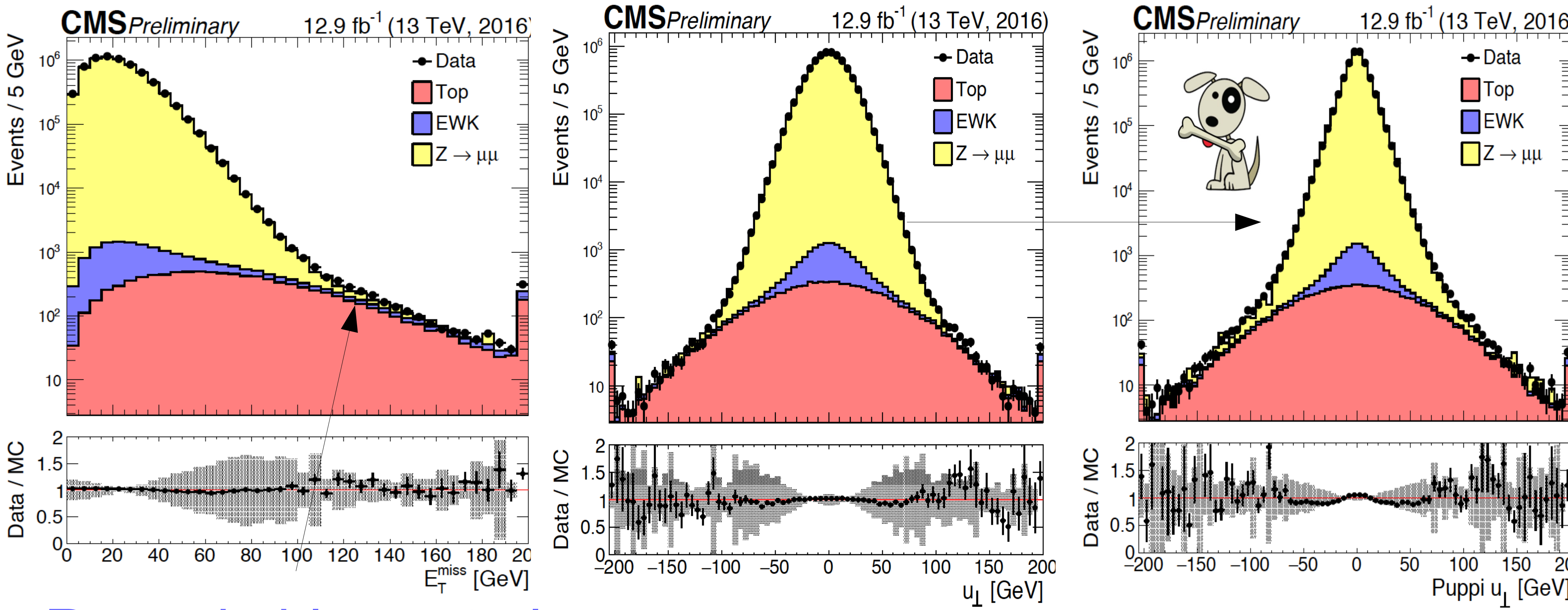
- Running at such high luminosity is tough!





- While drops like this are not long term issues
- Challenge of quality results in short time hard

Control of Data



Remarkable control of the *MET*

Plot is 1 week old

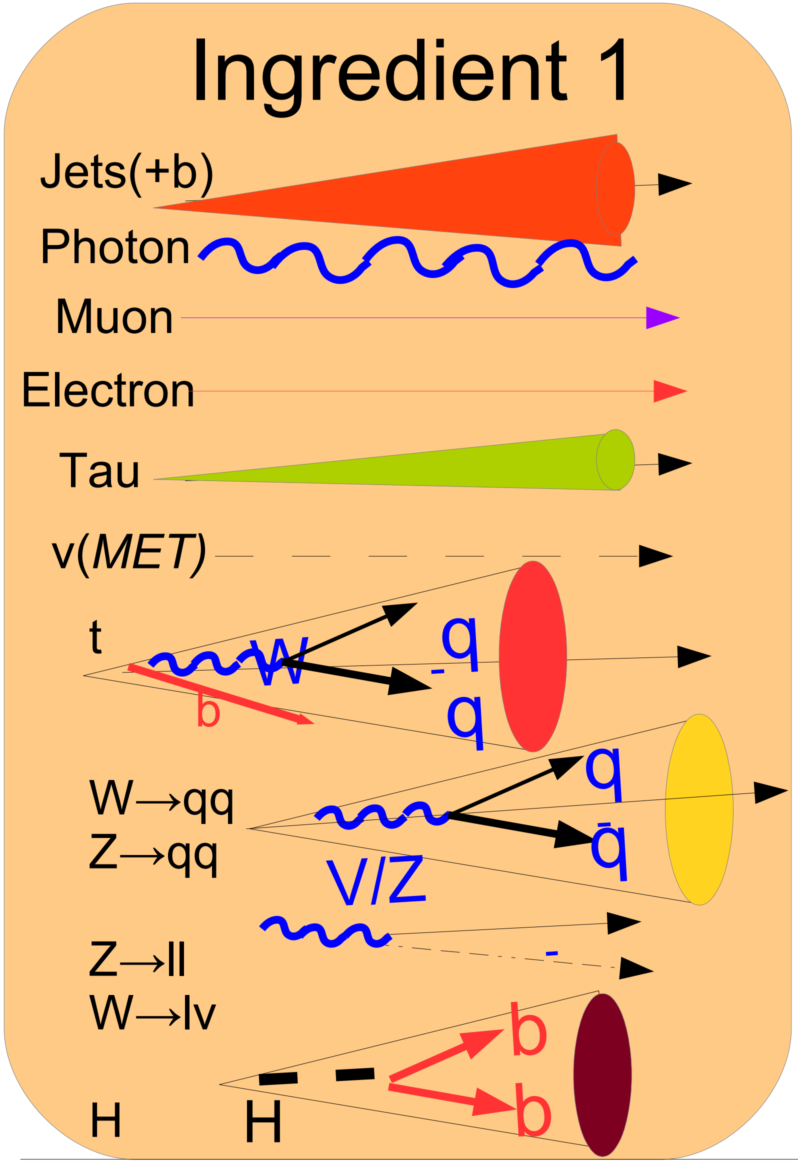
Same events (less PU sensitivity)

- However we have it mostly under control
  - We still have time to push out new techniques (#PUPPI)

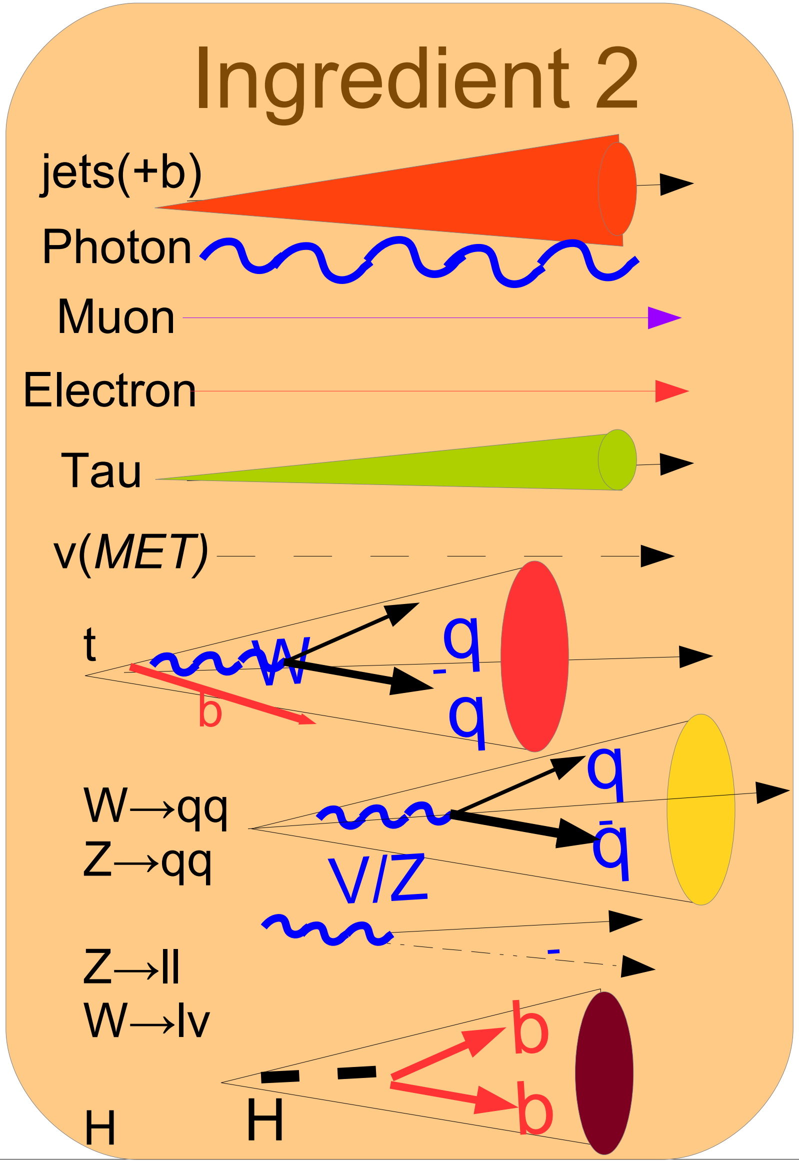
JME-16-004

The Searches

Making a “Mass” out of of It



+



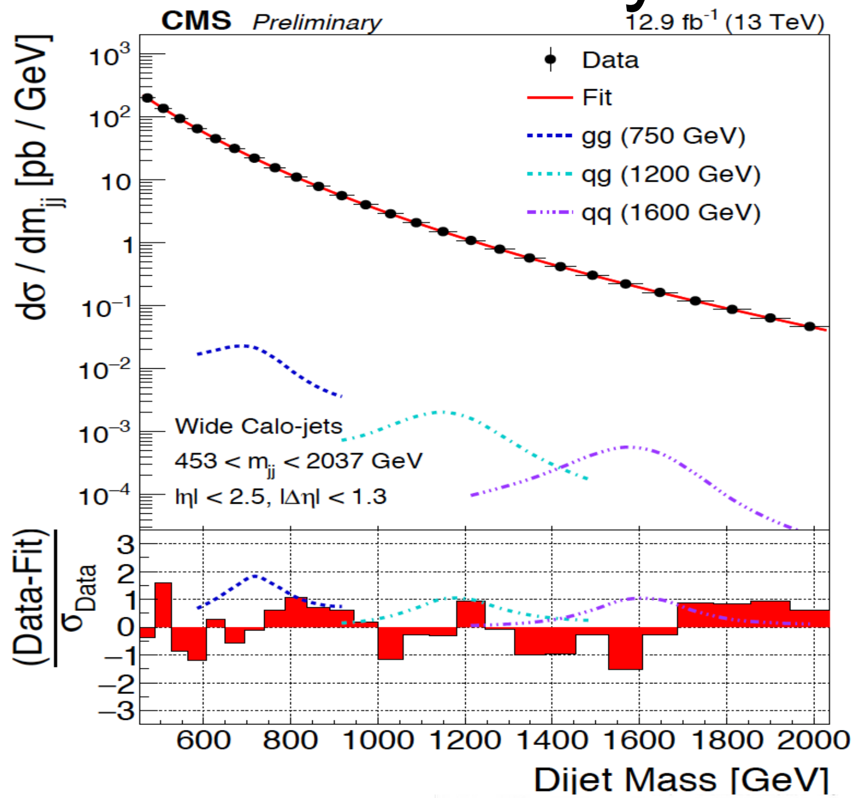
=

Mass (169 ways)

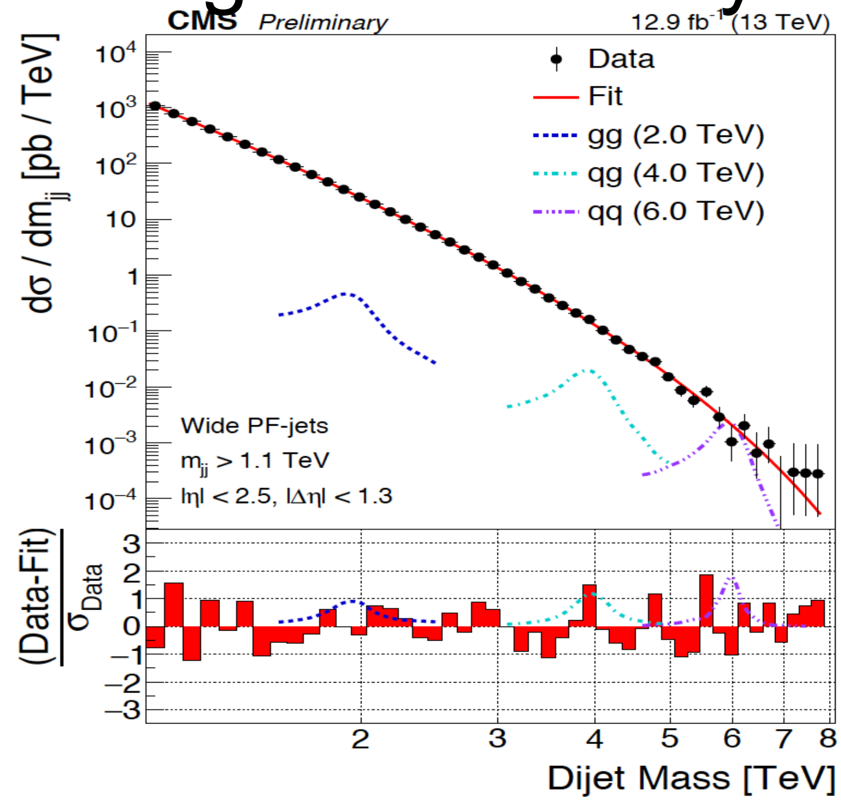
Total Luminosity : 12.9 fb^{-1} (2016)
Final State : jj

Dijet Search

Low mass Analysis



HIgh mass Analysis



Data scouted analysis

Analysis at trigger
Not all events on tape

FSR recovered jets

Dijet selection

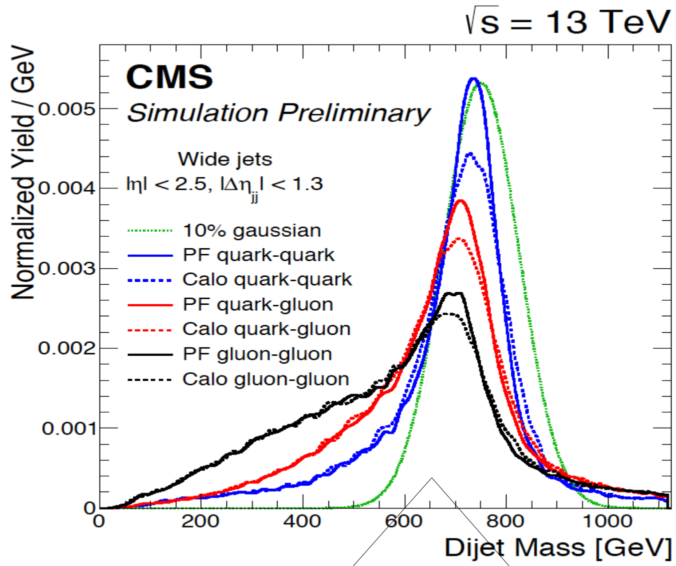
EXO-16-032

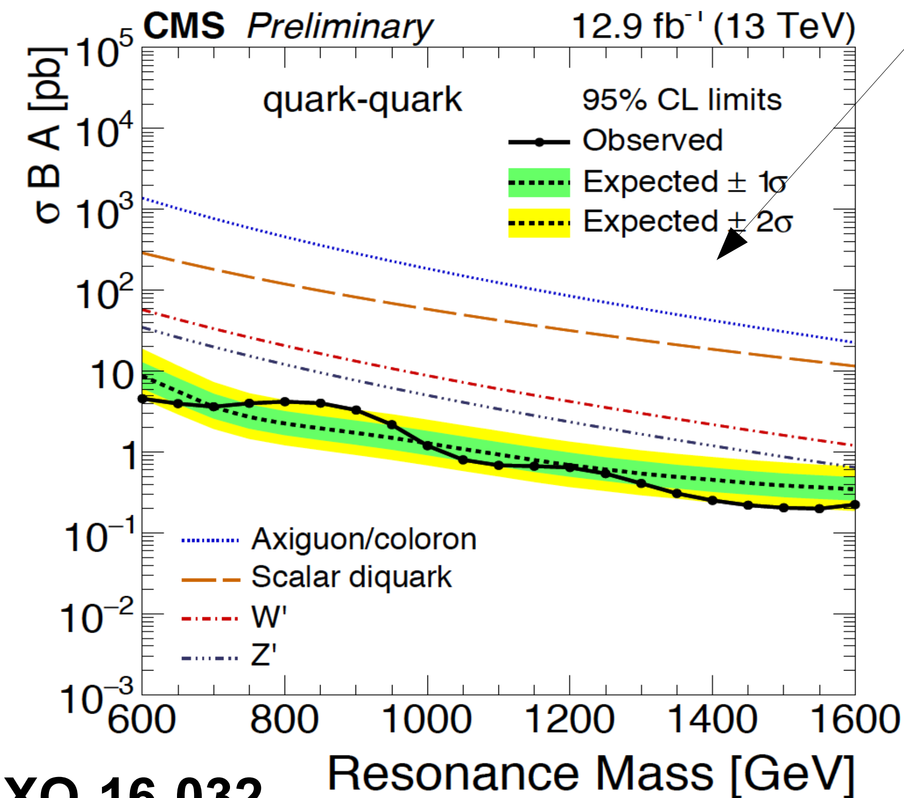
Total Luminosity : 12.9 fb^{-1} (2016)

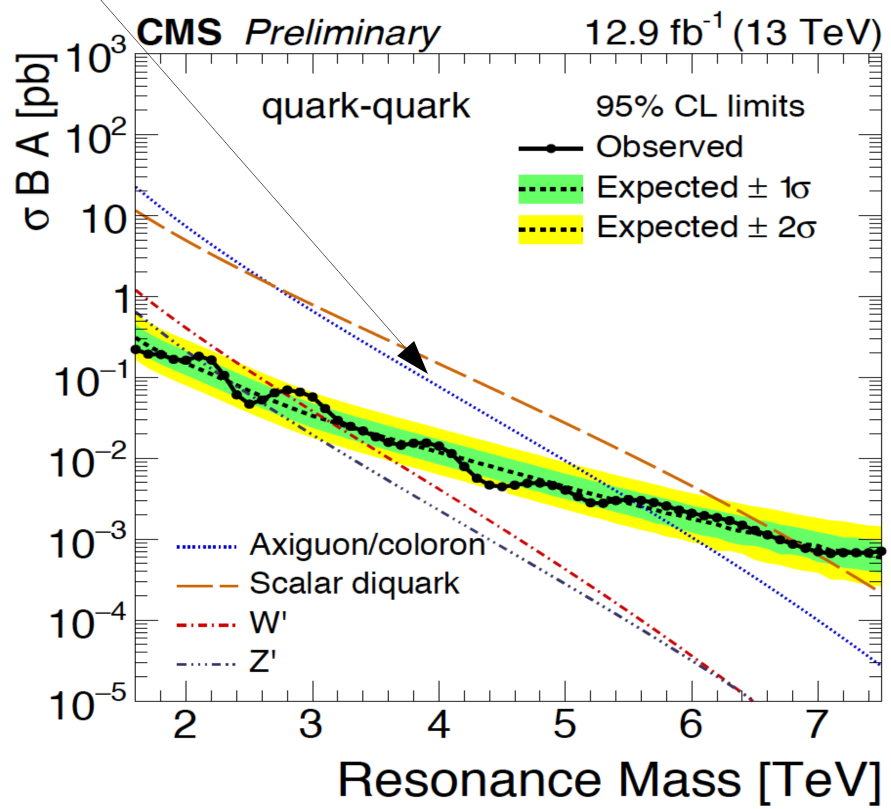
Final State : jj

Dijet Search

Data+ (Signal)

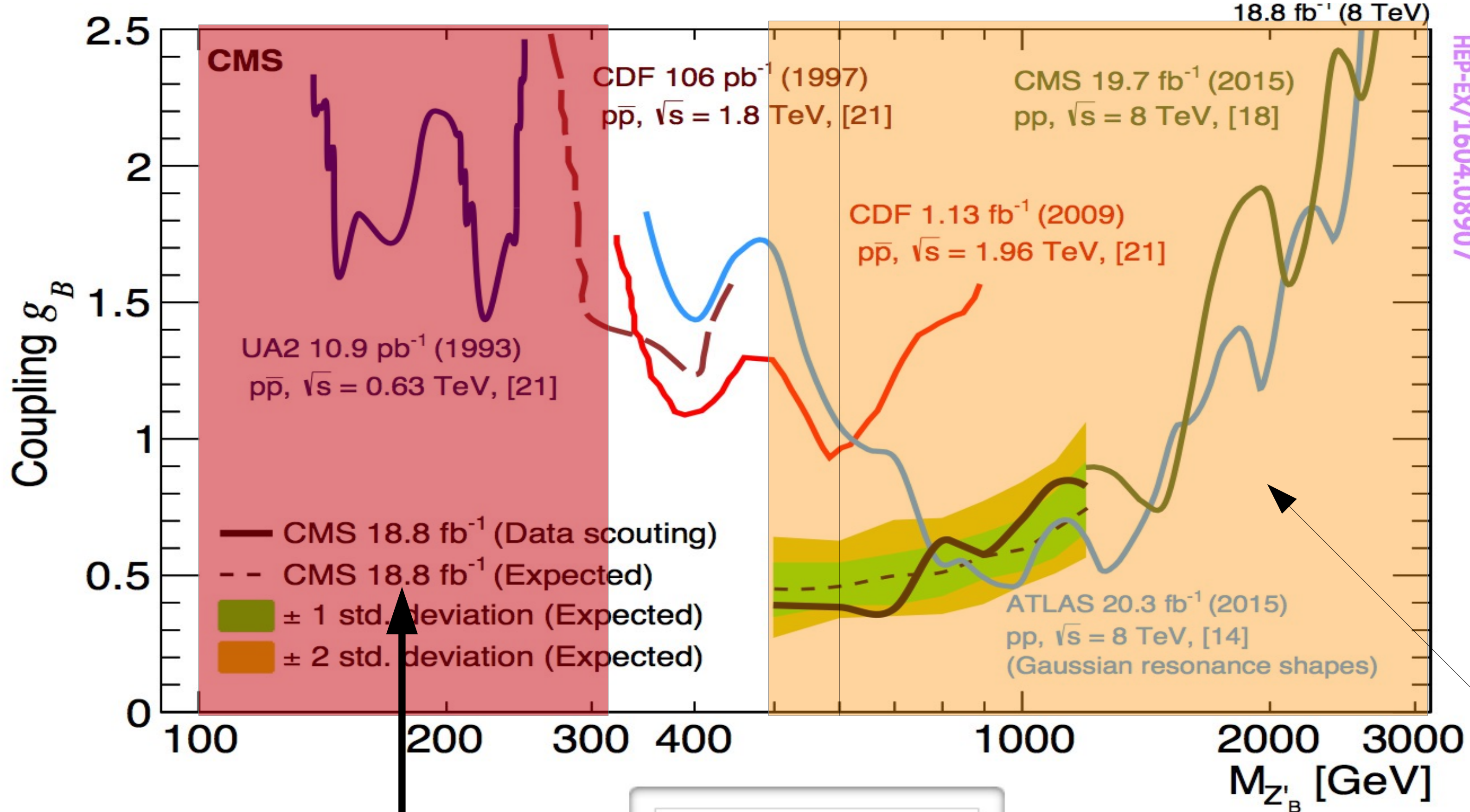






EXO-16-032

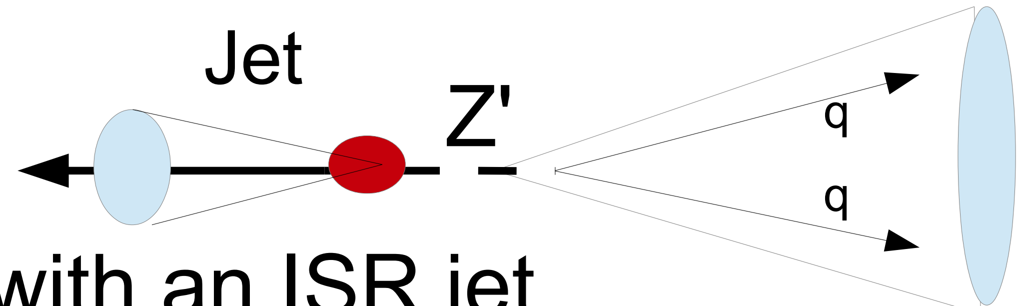
Z'+jet



$$\mathcal{L} \sim \frac{g_B}{6} Z'_{B,\mu}\bar{q}\gamma^{\mu}q$$

Covered by Dijet analysis

Can we go lower?
(UA2 is our compeition)

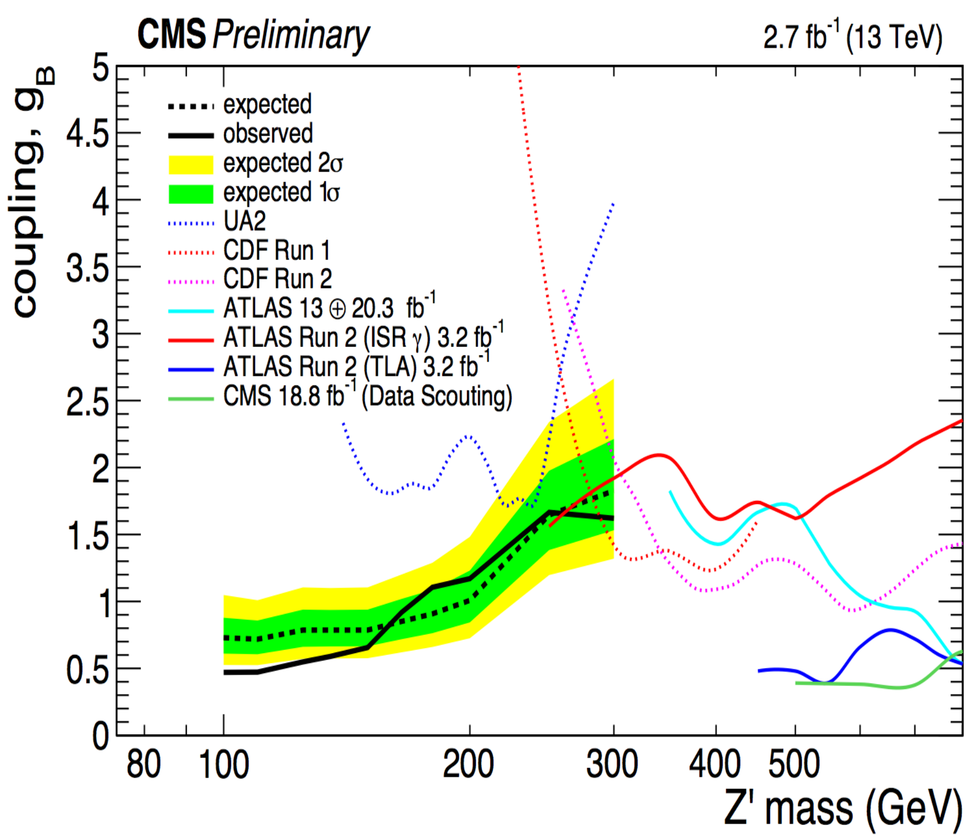


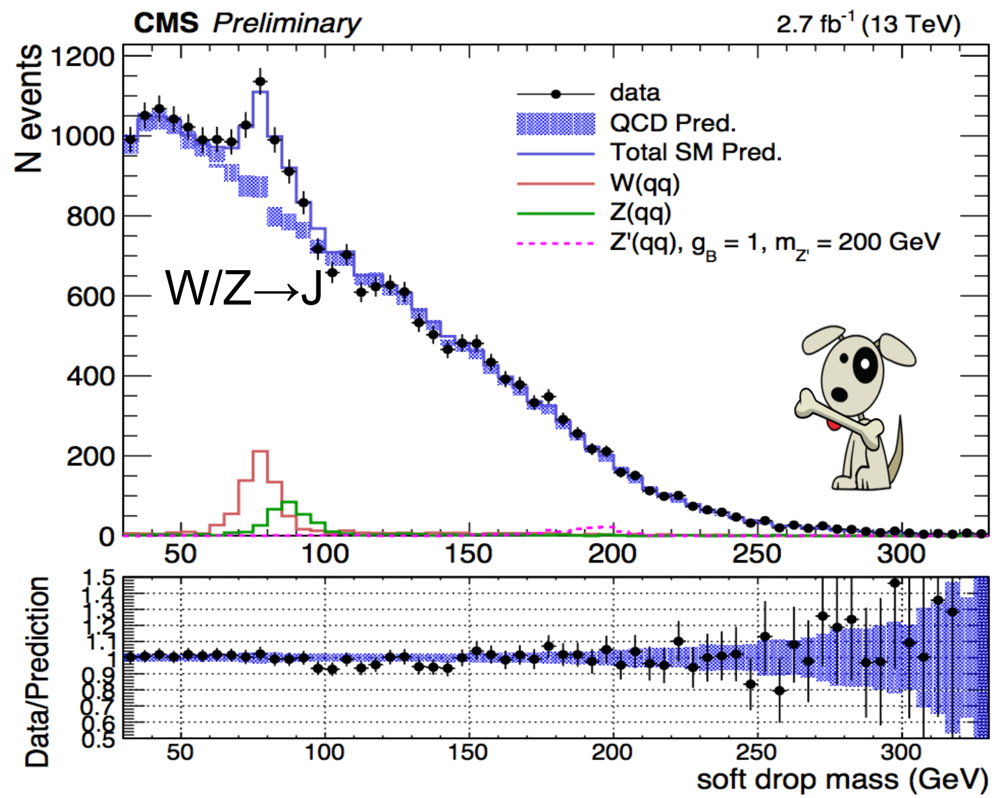
Select Z' with an ISR jet

EXO-16-030

Total Luminosity : 2.7 fb^{-1} (2015)
Final State : (qq)+j

Z'+jet





Beats UA2 (1988)

Goes to new phase space Z' mass < 140 GeV

EXO-16-030

GAMES OF THE XXIVTH OLYMPIAD SEOUL 1988

Total Luminosity : 2.7 fb^{-1} (2015)
Final State : jj+j

Z'+jet

*** Discussion title: Review of EXO-16-030

Dear Authors

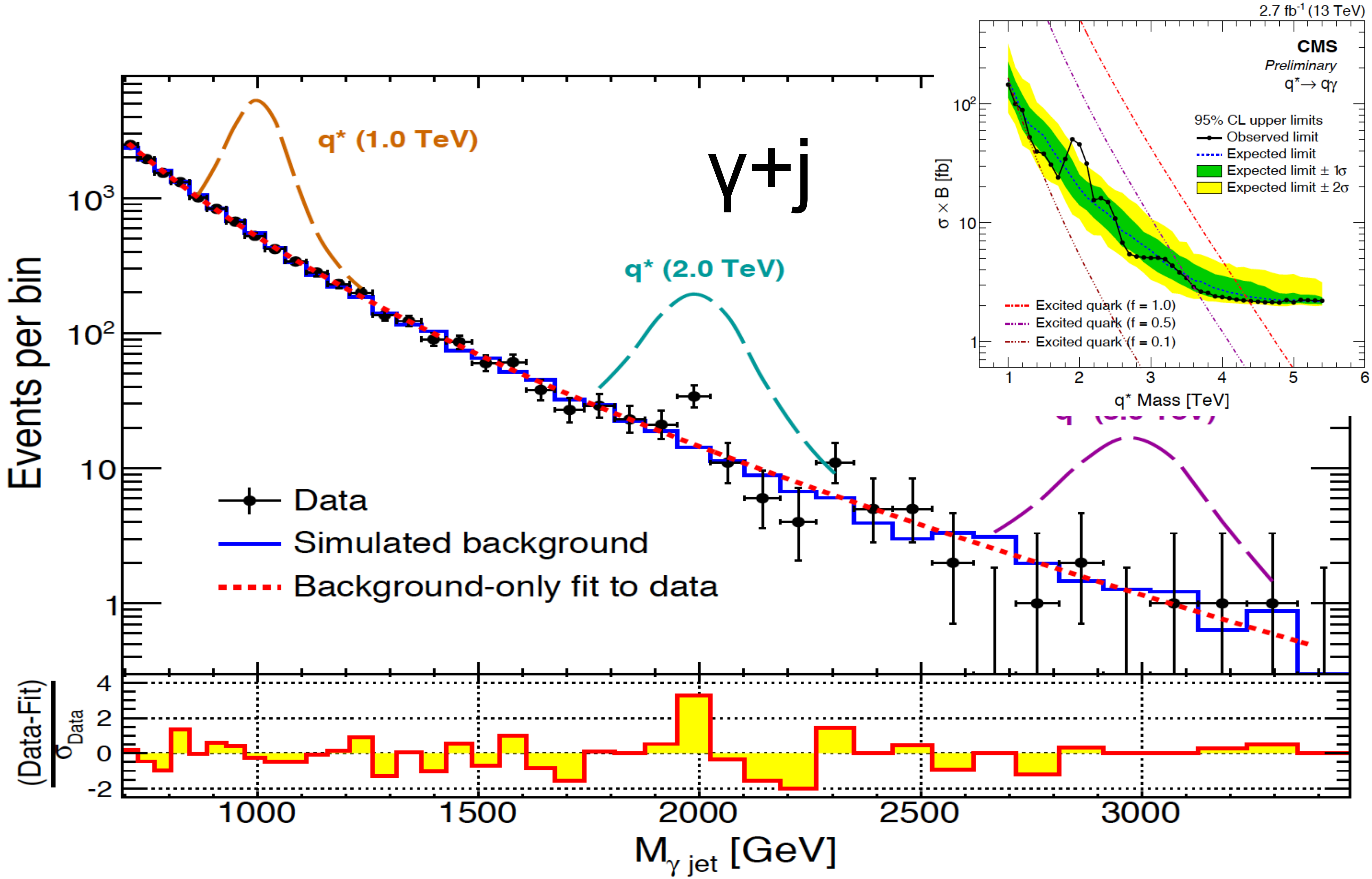
I noticed that in your PAS the introduction refers to UA1 and UA2 results at sqrt(s)=300 GeV. These results came out when I was on UA2 in fact, and the SppS ran at sqrt(s)=630 GeV.

Best regards Joe[Incandela]

EXO-16-030

Total Luminosity : 2.7 fb^{-1} (2016)
Final State : γ j

γ+j search

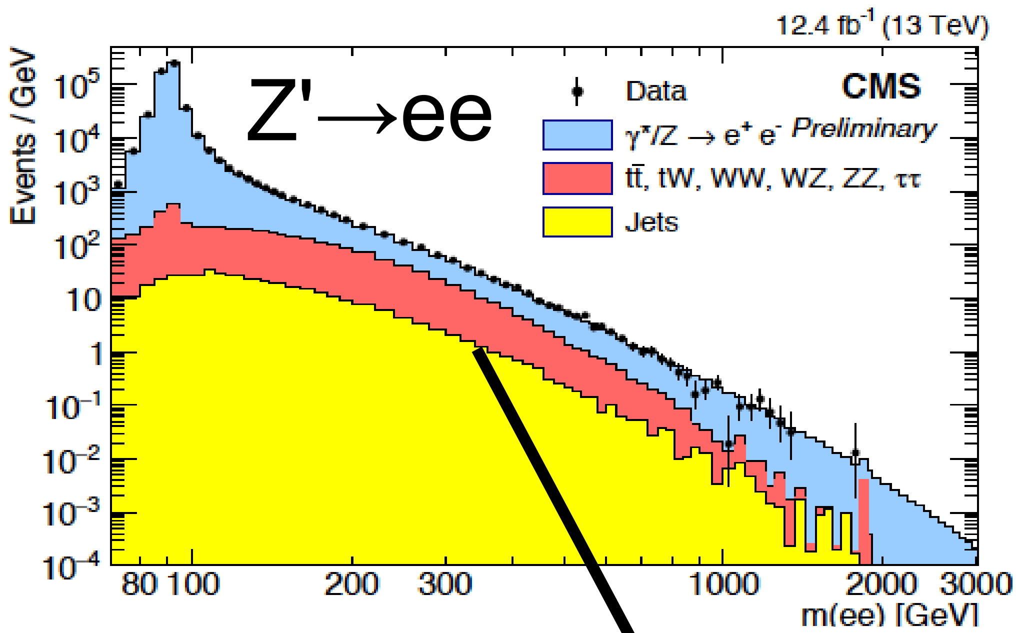


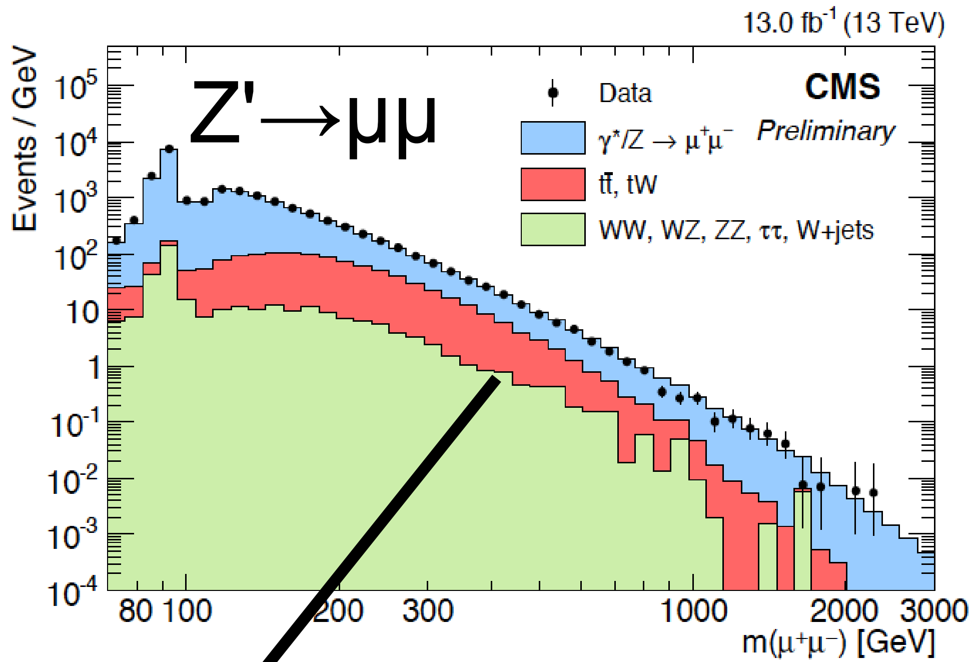
EXO-16-015

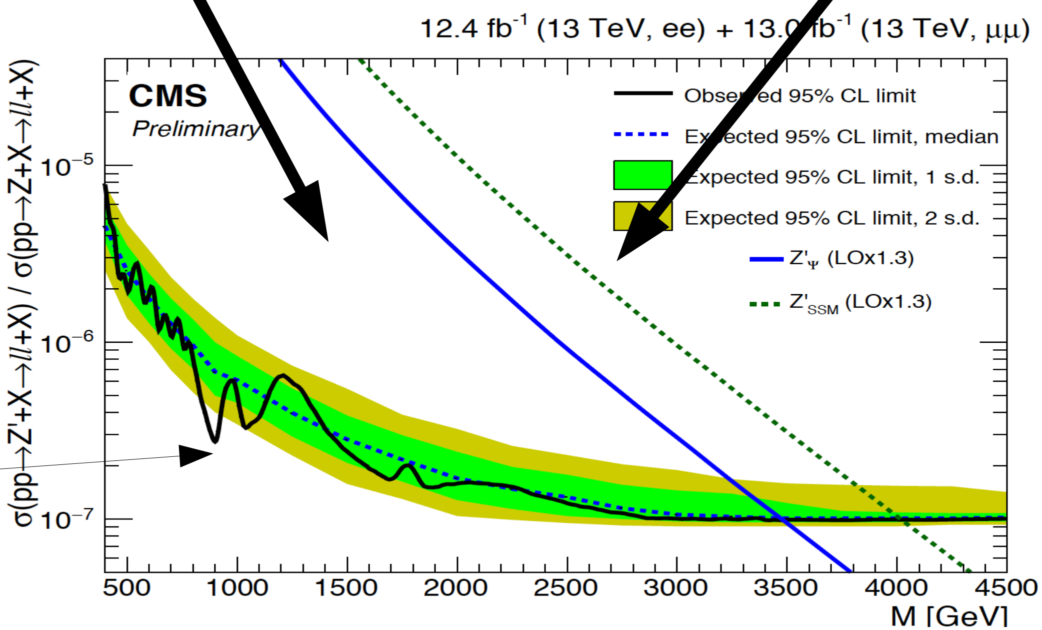
Total Luminosity : 12.9 fb^{-1} (2016)

Final State : ee/μμ

Dilepton Search







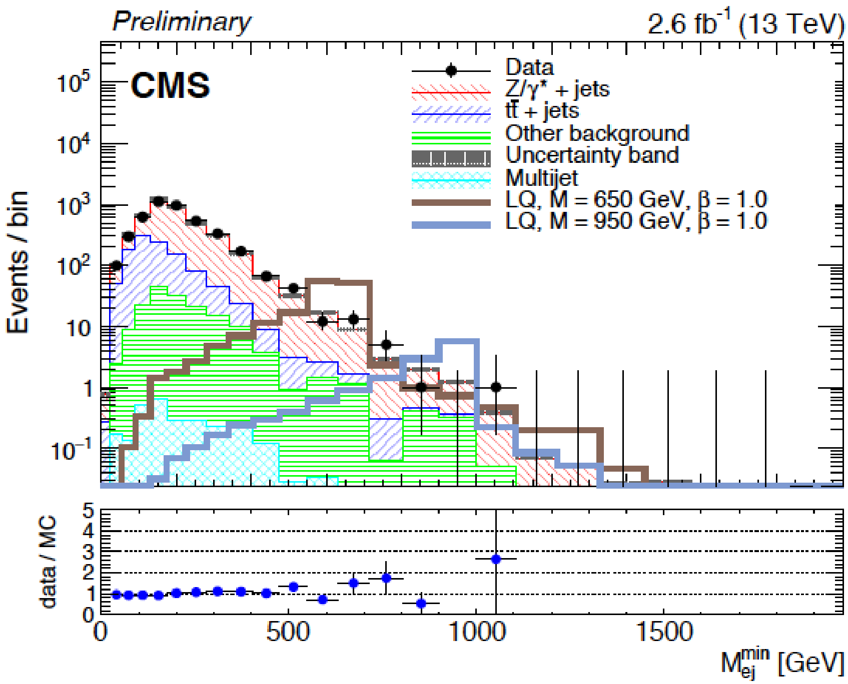
Small Deficit
No excess

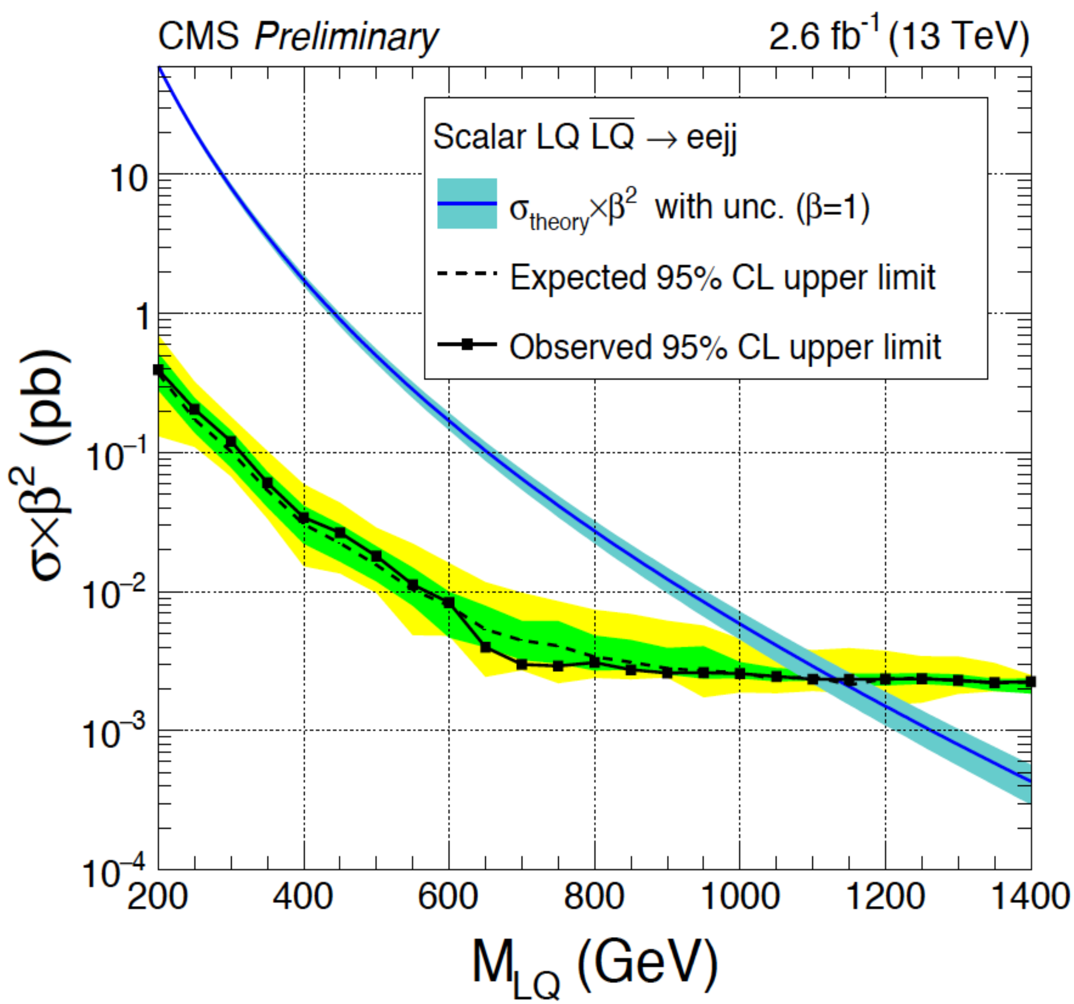
EXO-16-031

Total Luminosity : 2.6 fb^{-1} (2015)
Final State : ee+2j

Leptoquark(LQ→e+j)

- Leptoquark decaying in electron final state





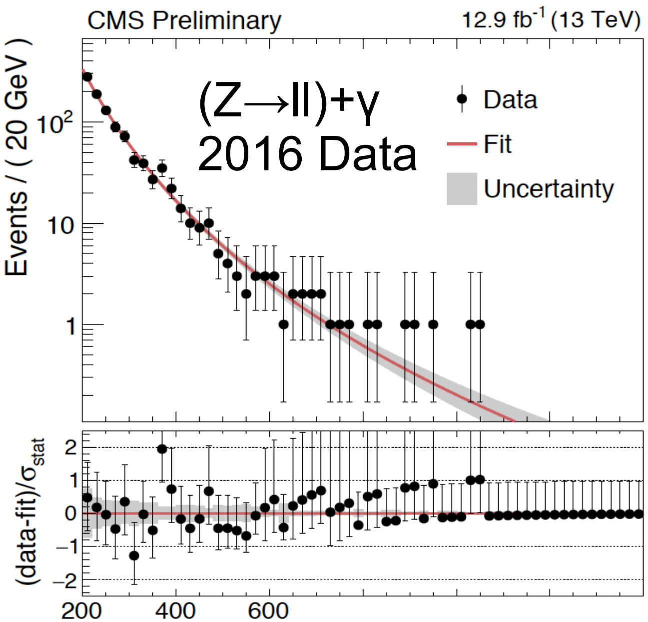
Search in tail of mass/H_T
No excess and no deficit

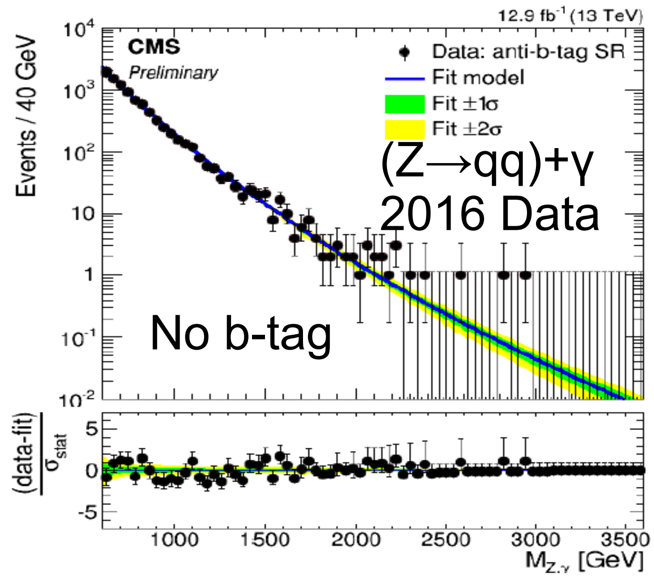
8TeV leptoquark search excess is now gone

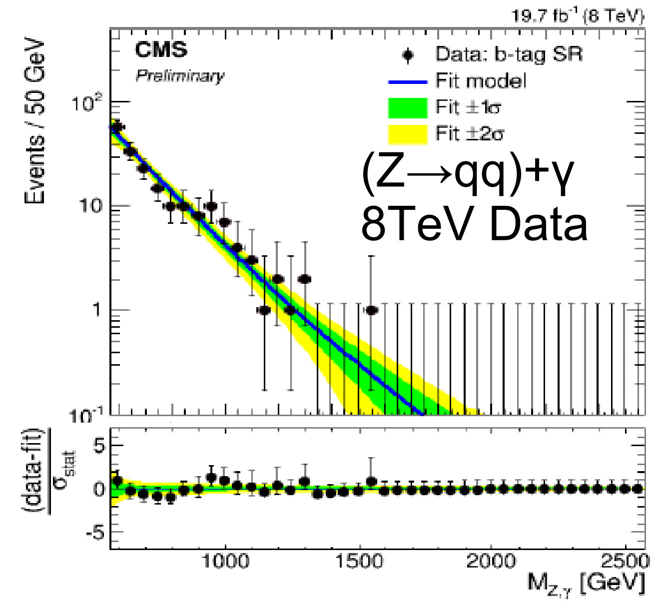
EXO-16-043

Total Luminosity : 19.6/12.9 fb^{-1} (8TeV/2016)
Final State : Z+γ(Z→qq/Z→ll)

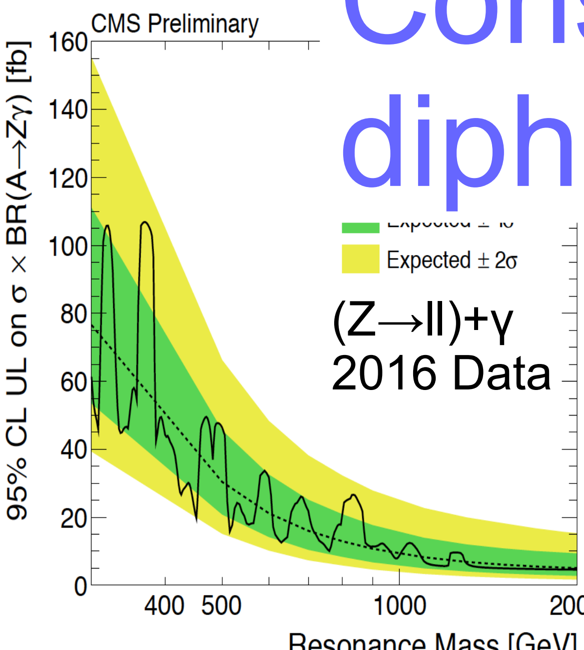
Z+γ

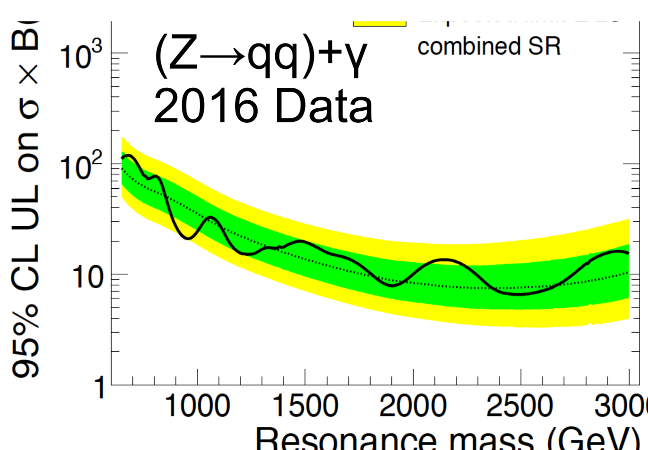


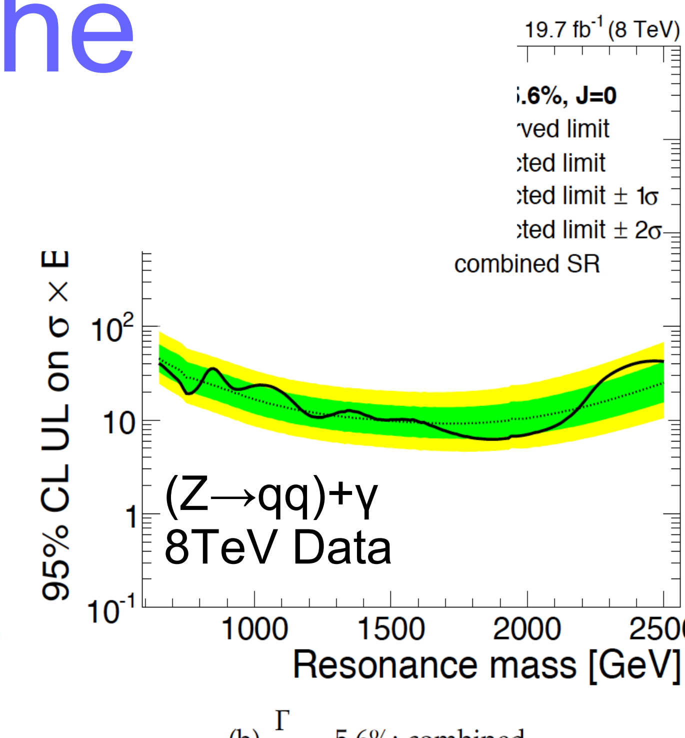




Consistent with the diphoton results

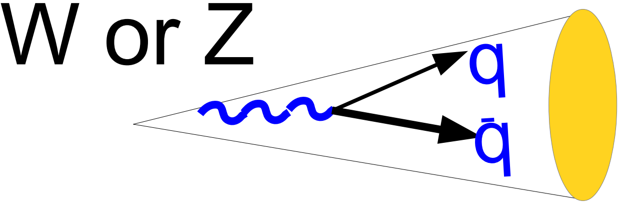




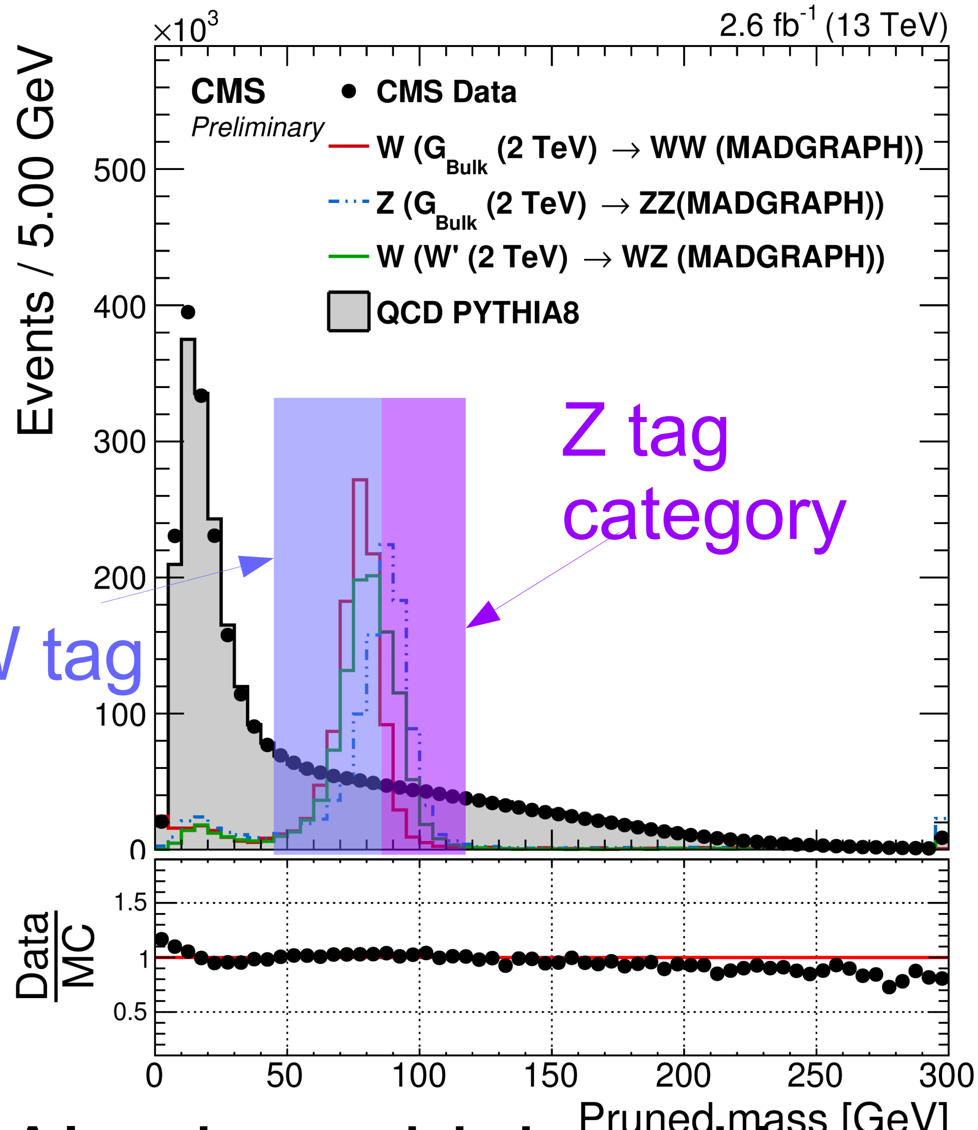


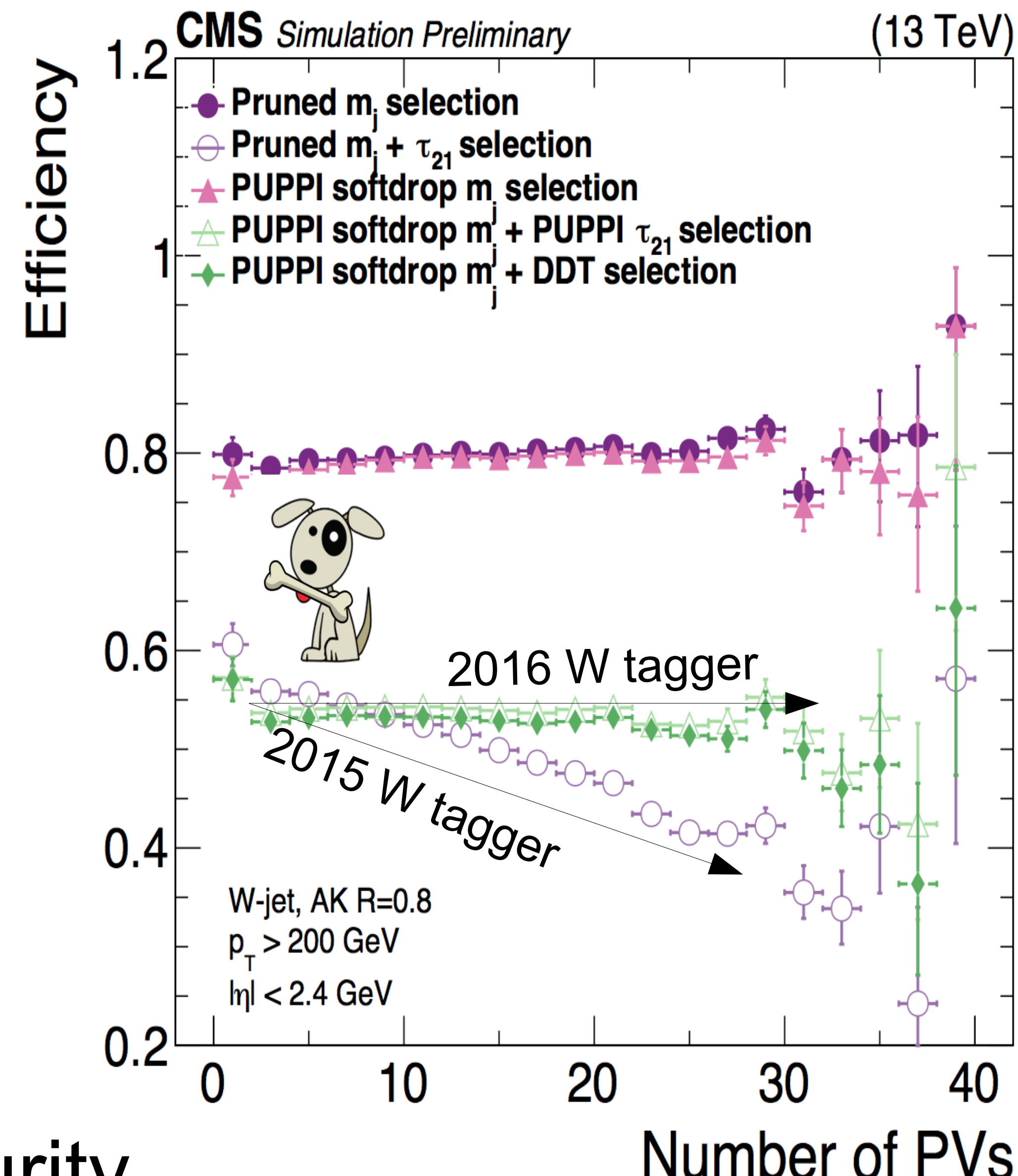
EXO-16-034/EXO-16-035/EXO-16-025

V/top-tagged Searches



Tagging Vector bosons



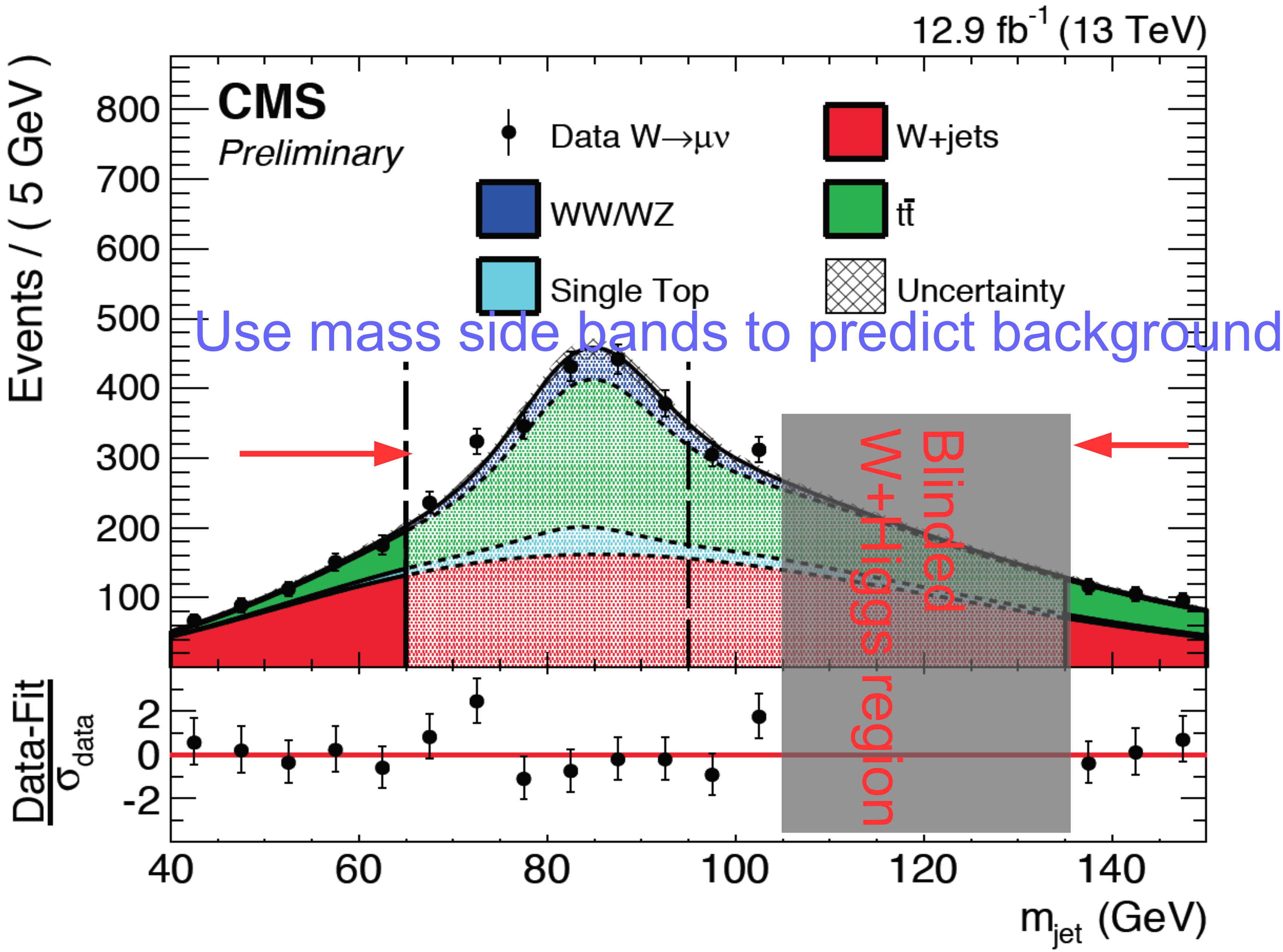


Also have high and low purity

Vector boson taggers are a regular part of LHC life

Total Luminosity : 12.9 fb^{-1} (2016)
Final State : VW($V \rightarrow qq + W \rightarrow l\nu$)

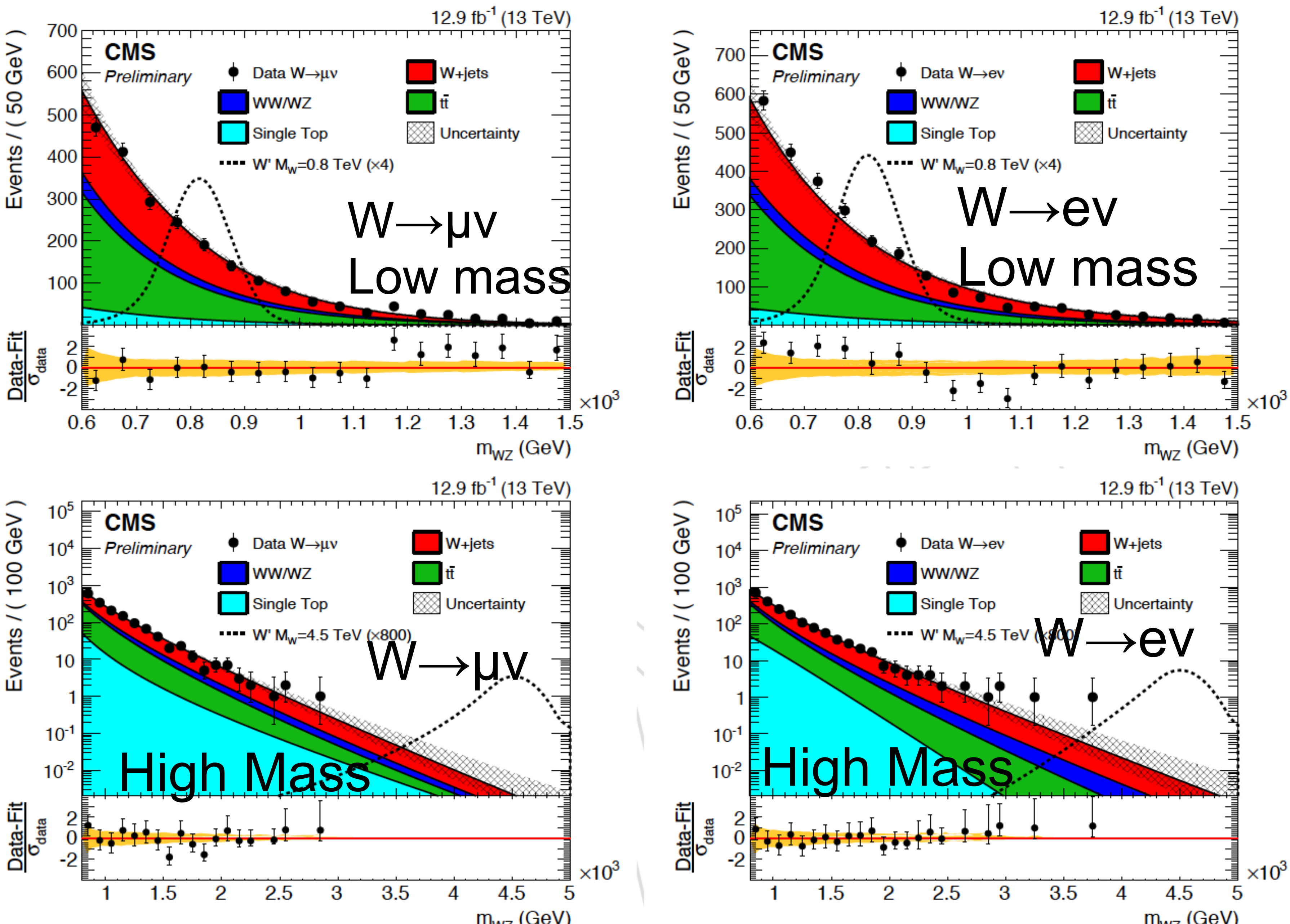
VW Search



B2G-16-020

Total Luminosity : 12.9 fb^{-1} (2016)
Final State : VW($V \to qq + W \to l\nu$)

VW Search

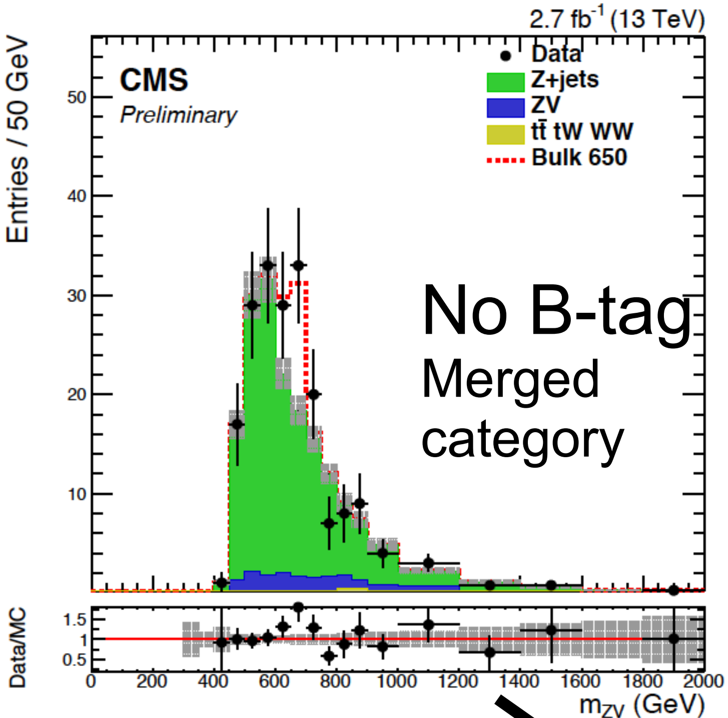


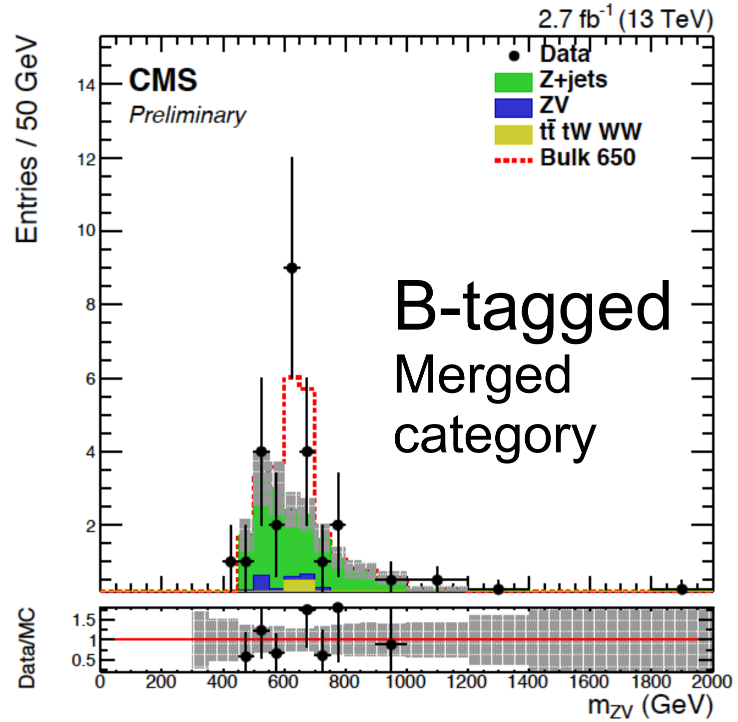
B2G-16-020

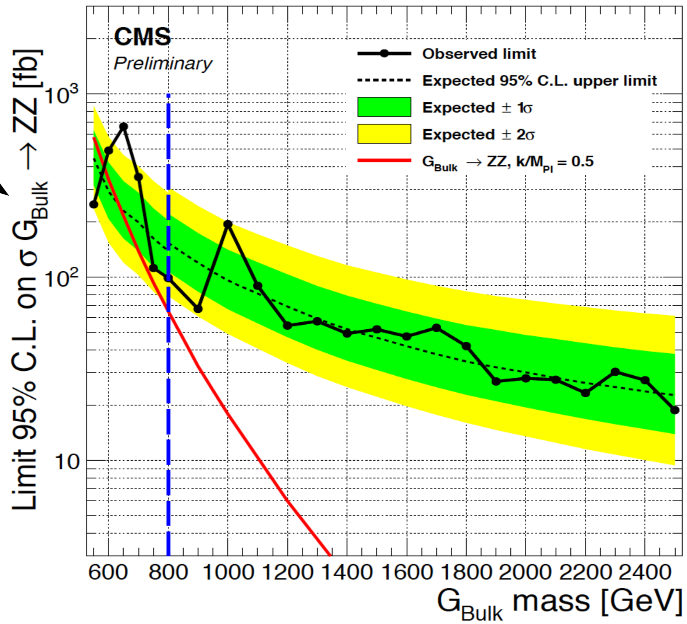
Total Luminosity : 2.7 fb^{-1} (2015)

Final State : ZZ(Z→qq+Z→ll)

ZZ searches







An excess is present in ZZ

3.9σ/3.5σ Local Global

#650isthenew750

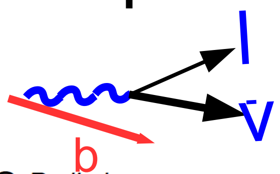
B2G-16-010

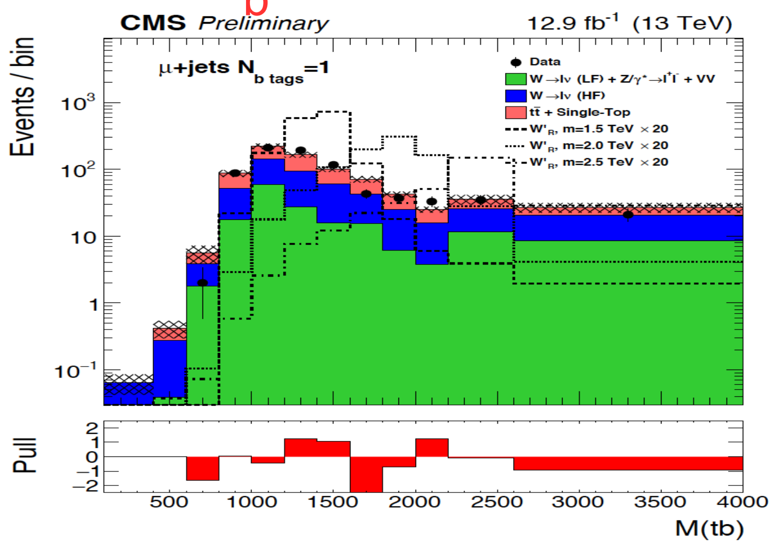
Total Luminosity : 12.9/2.6 fb^{-1} (2016/2015)
Final State : $t+b(t\rightarrow l\nu b/t\rightarrow qqb+b)$

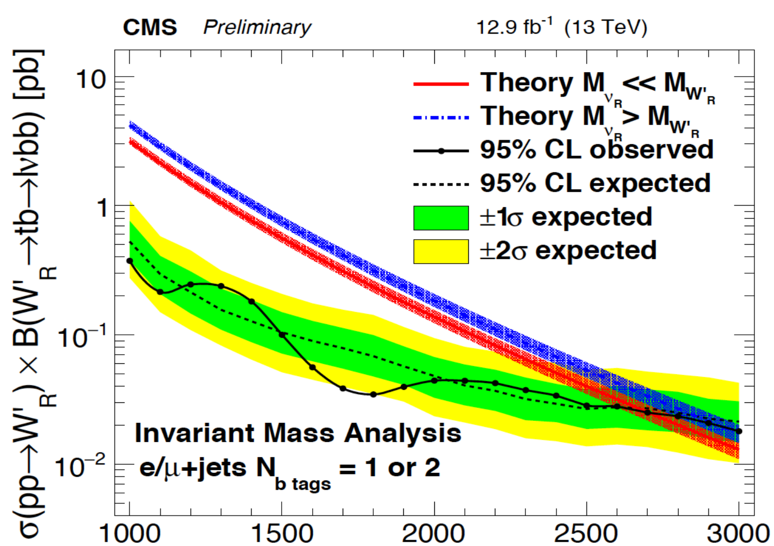
$W'\rightarrow tb$

Mass Reach up to 2 TeV

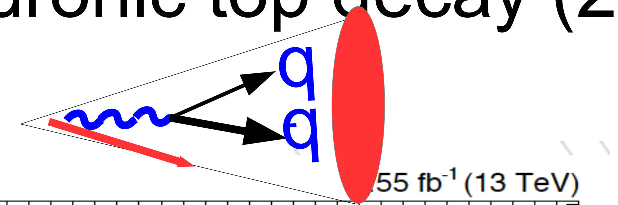
Leptonic top decay(2016)

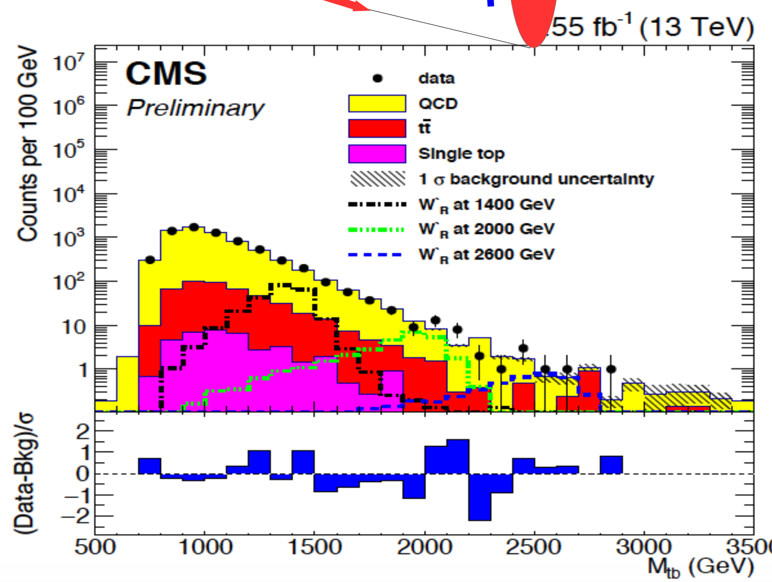


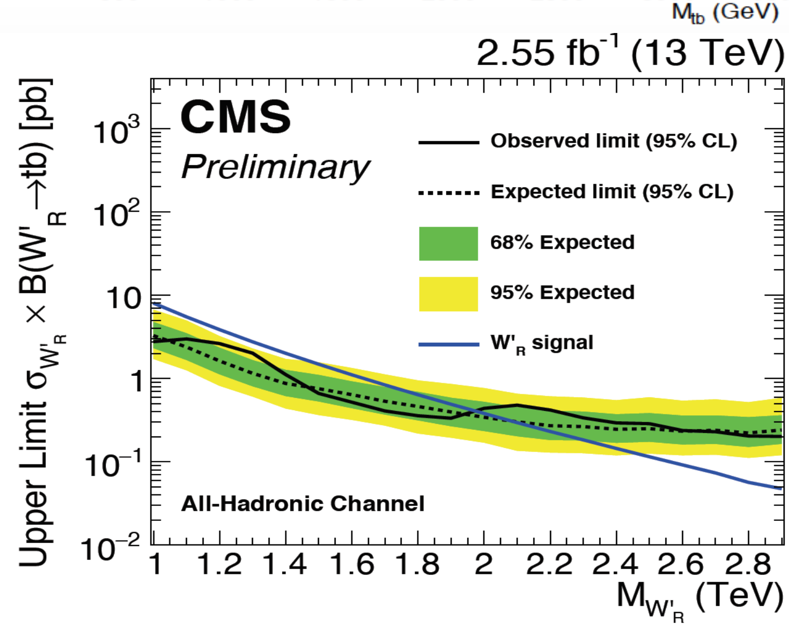




Hadronic top decay (2015)







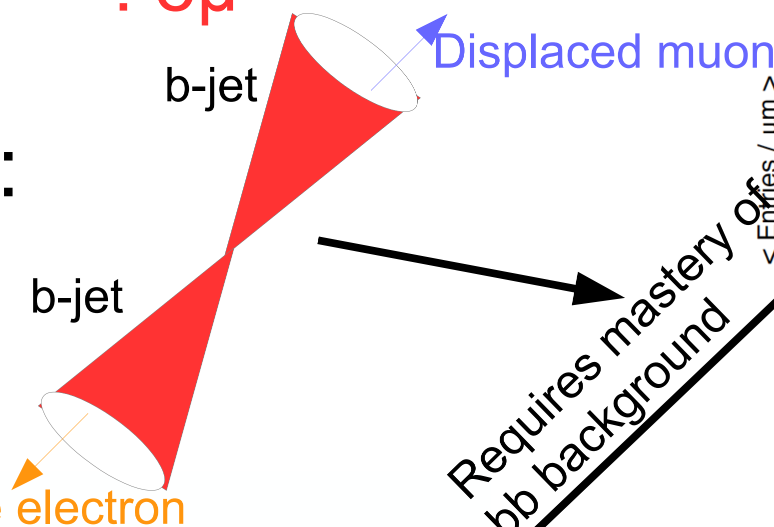
B2G-16-017/B2G-16-009

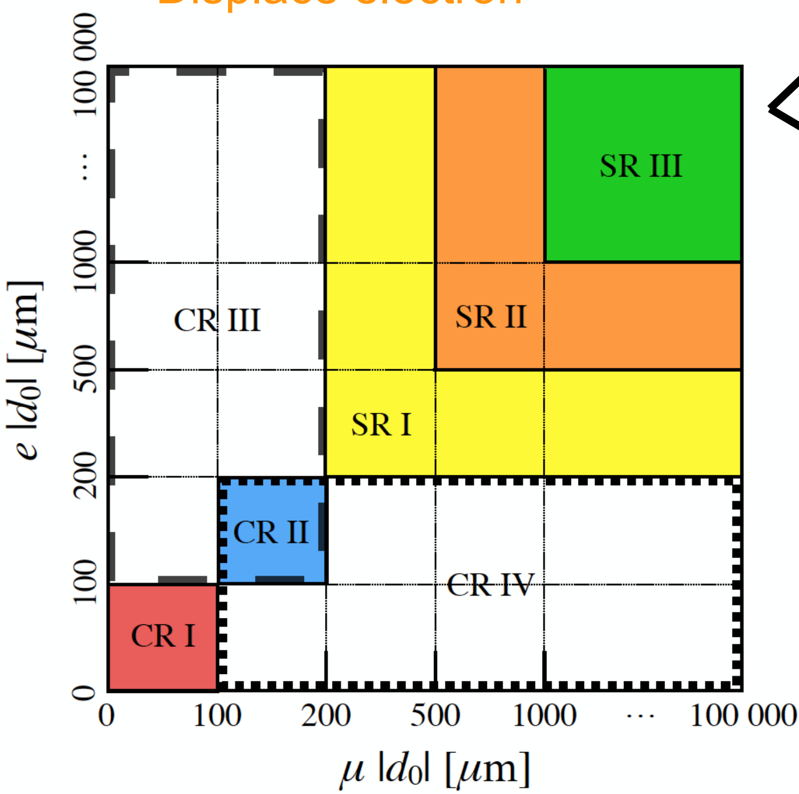
Lifetime
Frontier

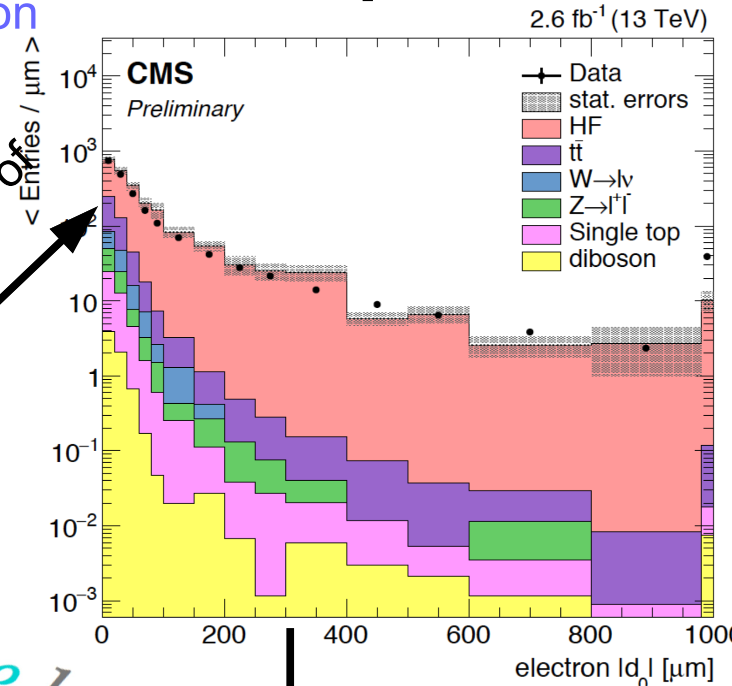
Total Luminosity : 2.6 fb^{-1} (2015)
Final State : eμ

Displaced eμ

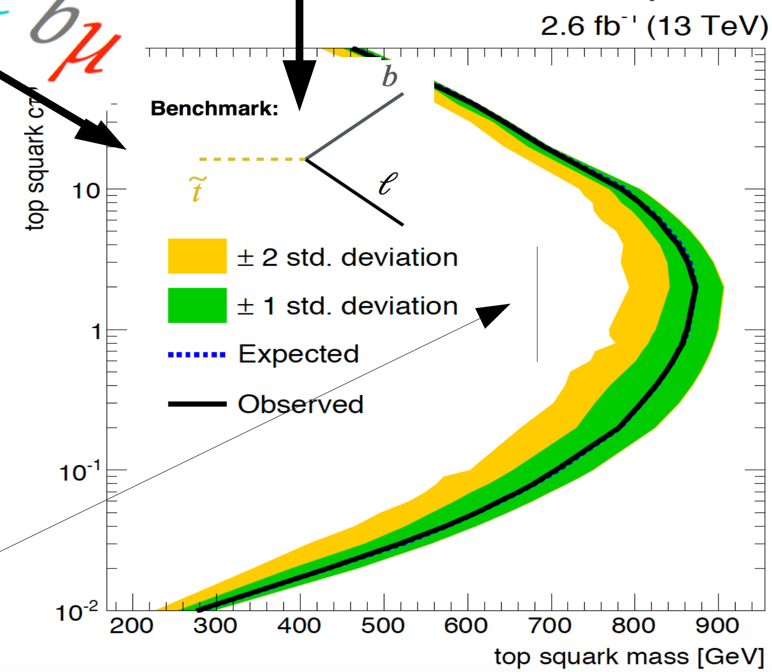
- Concept:







$\tilde{t}\tilde{t} \rightarrow be\, b\mu$



8TeV result

EXO-16-022

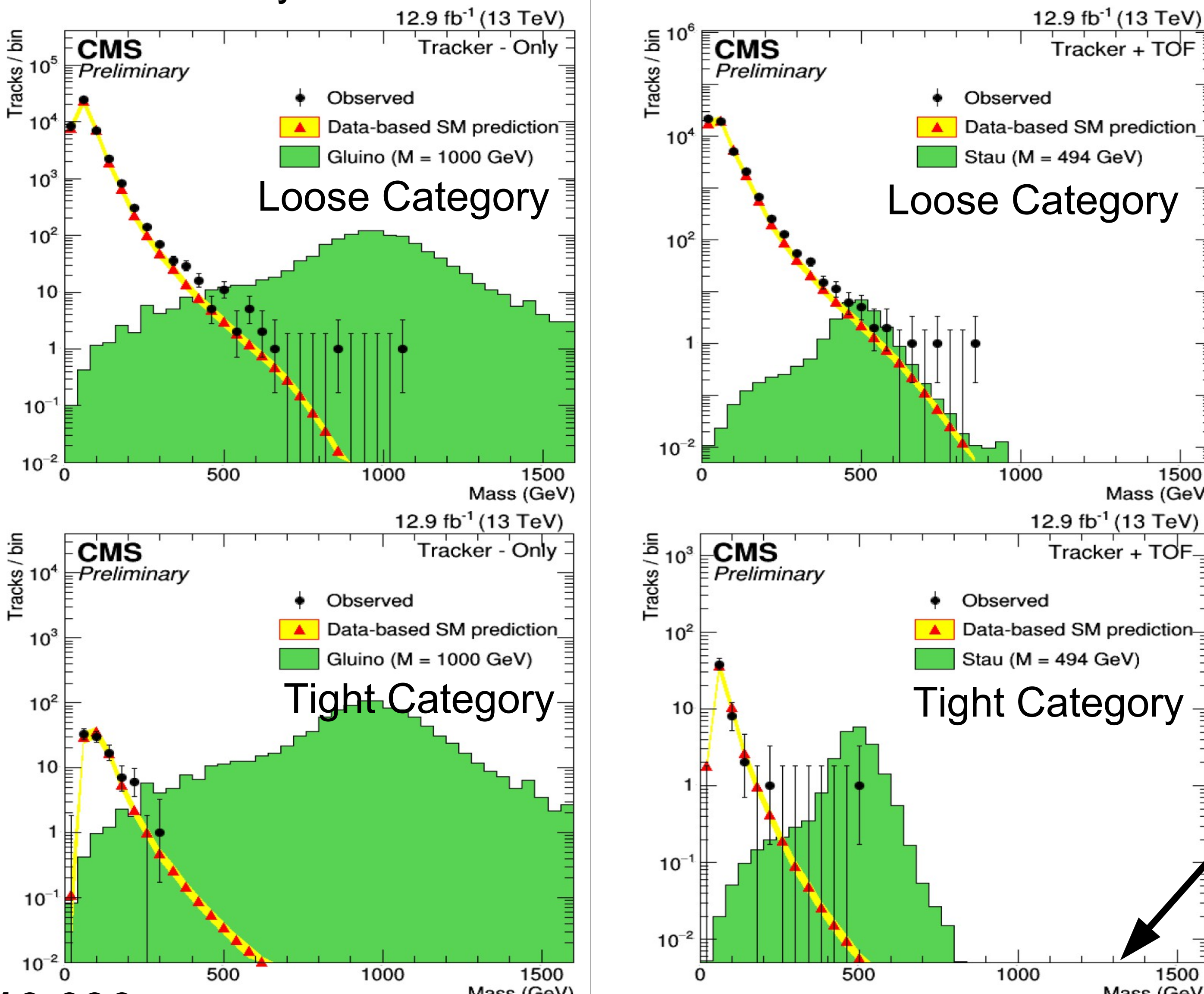
Total Luminosity : 12.9 fb^{-1} (2016)
Final State : Long lived track

Heavy & Stable

- Two approaches: dE/dX & Time of Flight

Tracker Only info

Muon TOF info



$$dE/dx =$$

$$I_h = K\frac{m^2}{p^2} + C,$$

Solve for mass

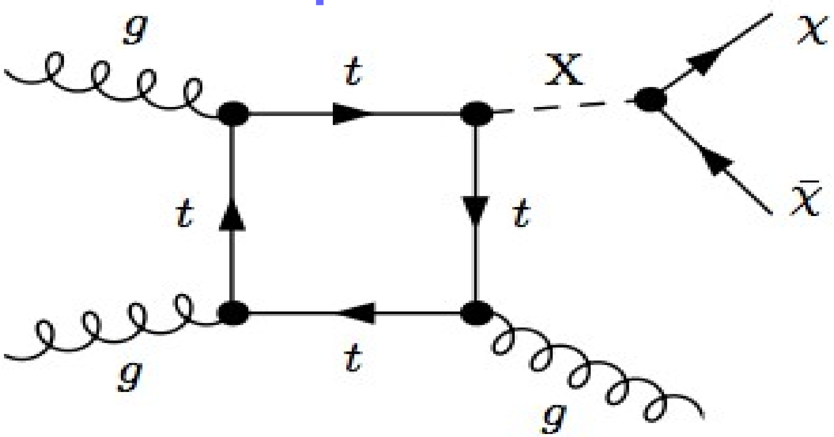
EXO-16-036

Dark Matter Searches

Search for Dark Matter at LHC

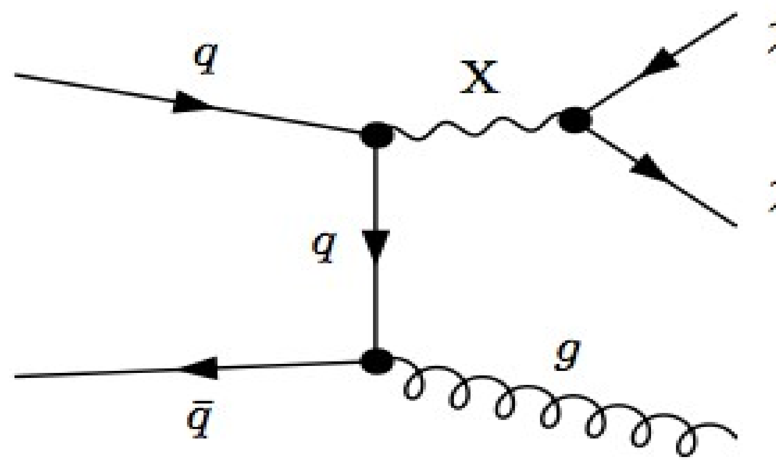
- Can split dark matter into two classes of searches

Spin 0



Yukawa coupling to quarks
(At the moment no mixing)

Spin 1

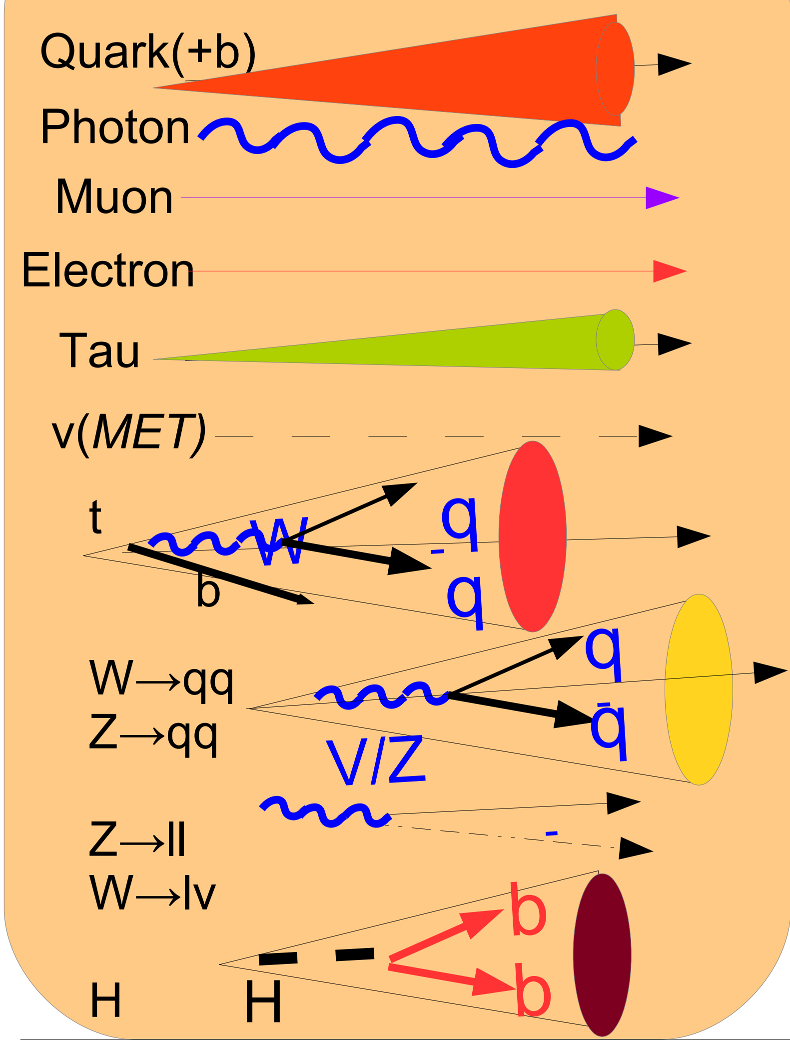


Flavor universal to quarks
(At the moment no mixing)

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

Making a “Mediator” out of of It

Ingredient 1



+

Ingredient 2

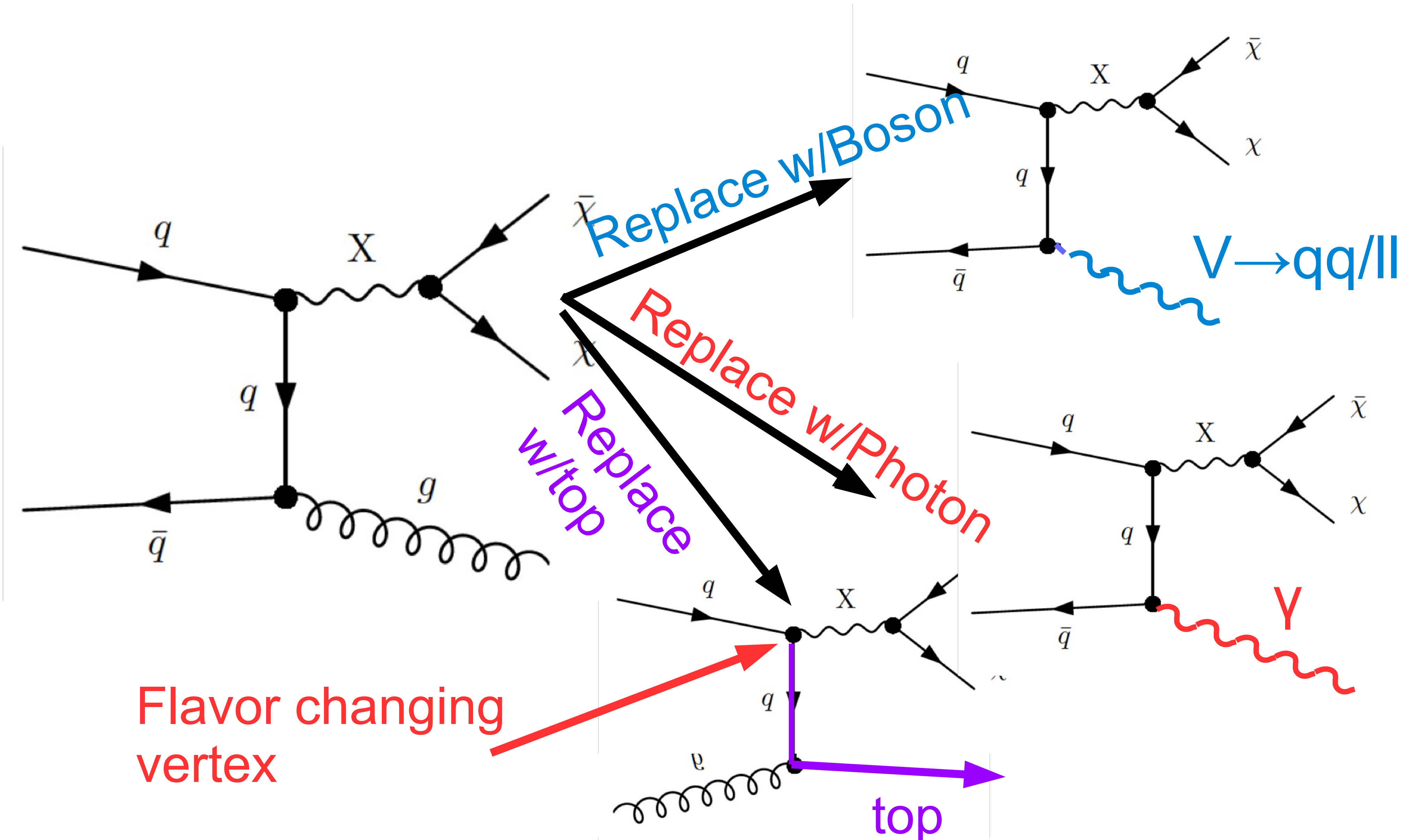
Invisibly decaying mediator

$X \rightarrow$

=

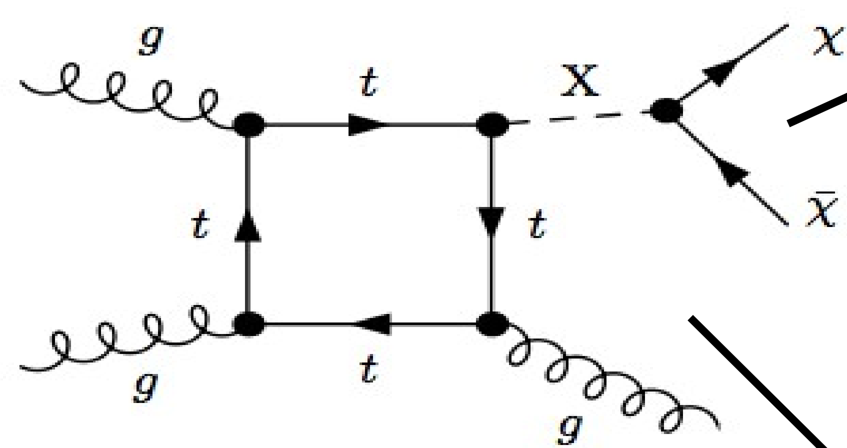
Mediator X p_T (13 ways)

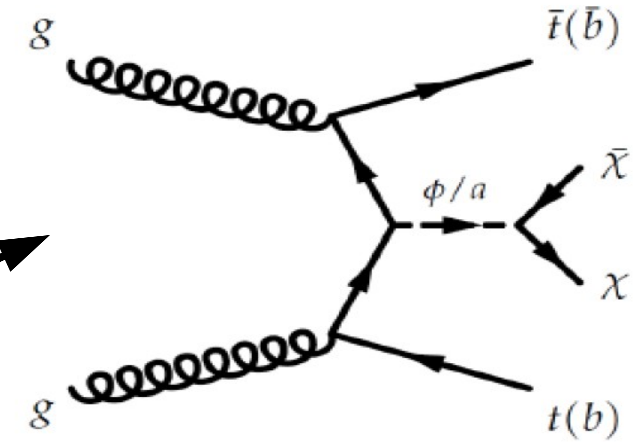
Spin 1 DM Searches



Spin 0 DM Searches

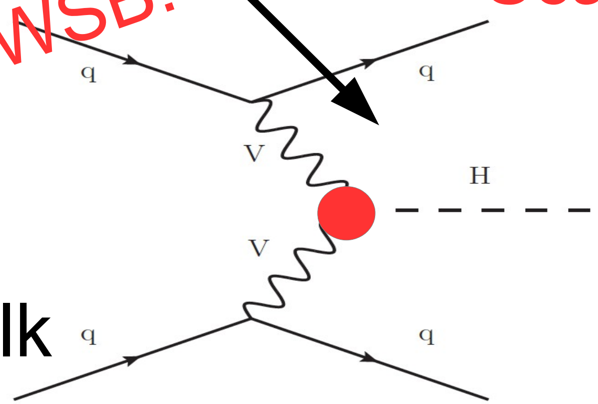
Big Assumption :
No mixing w/Higgs

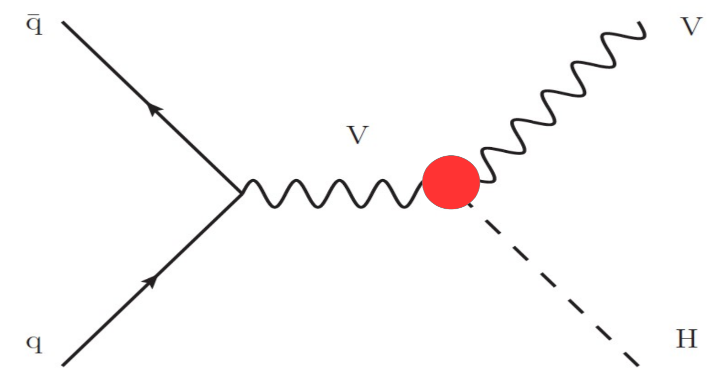




Higgs invisible or
Scalar w/EWSB

Applying EWSB!



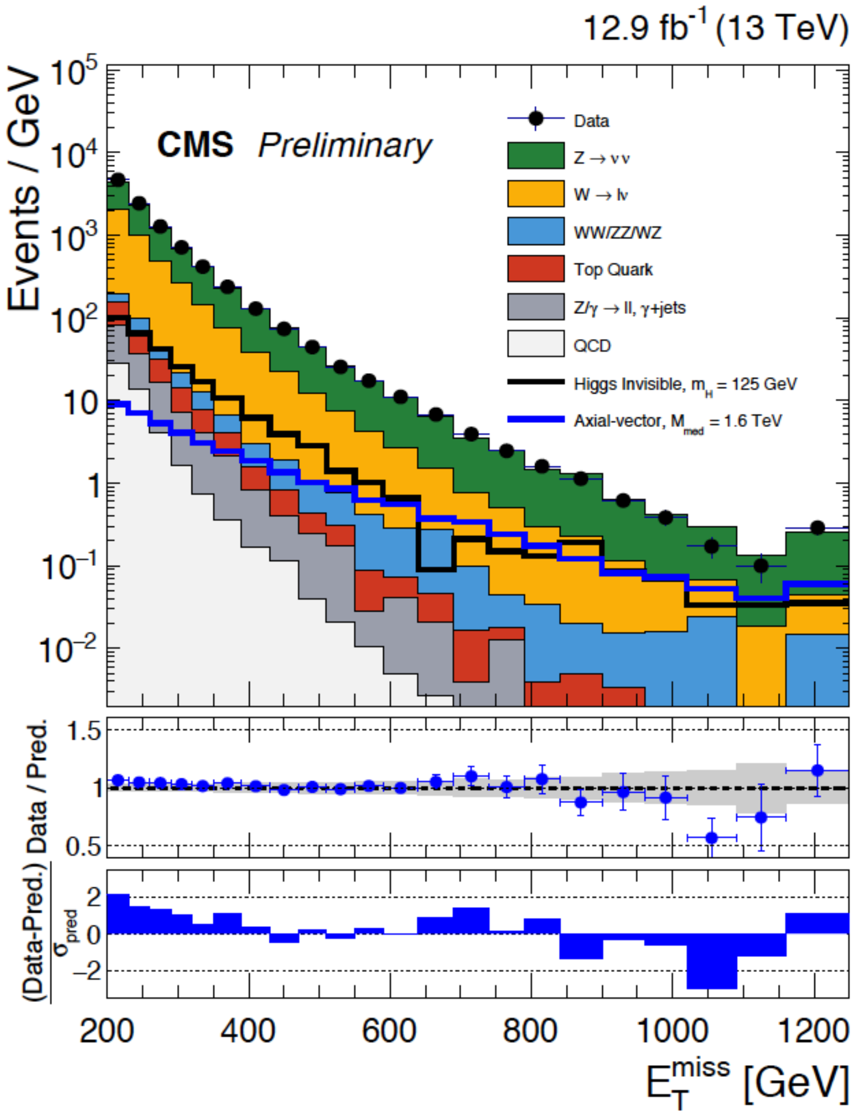


See Guillelmo's talk

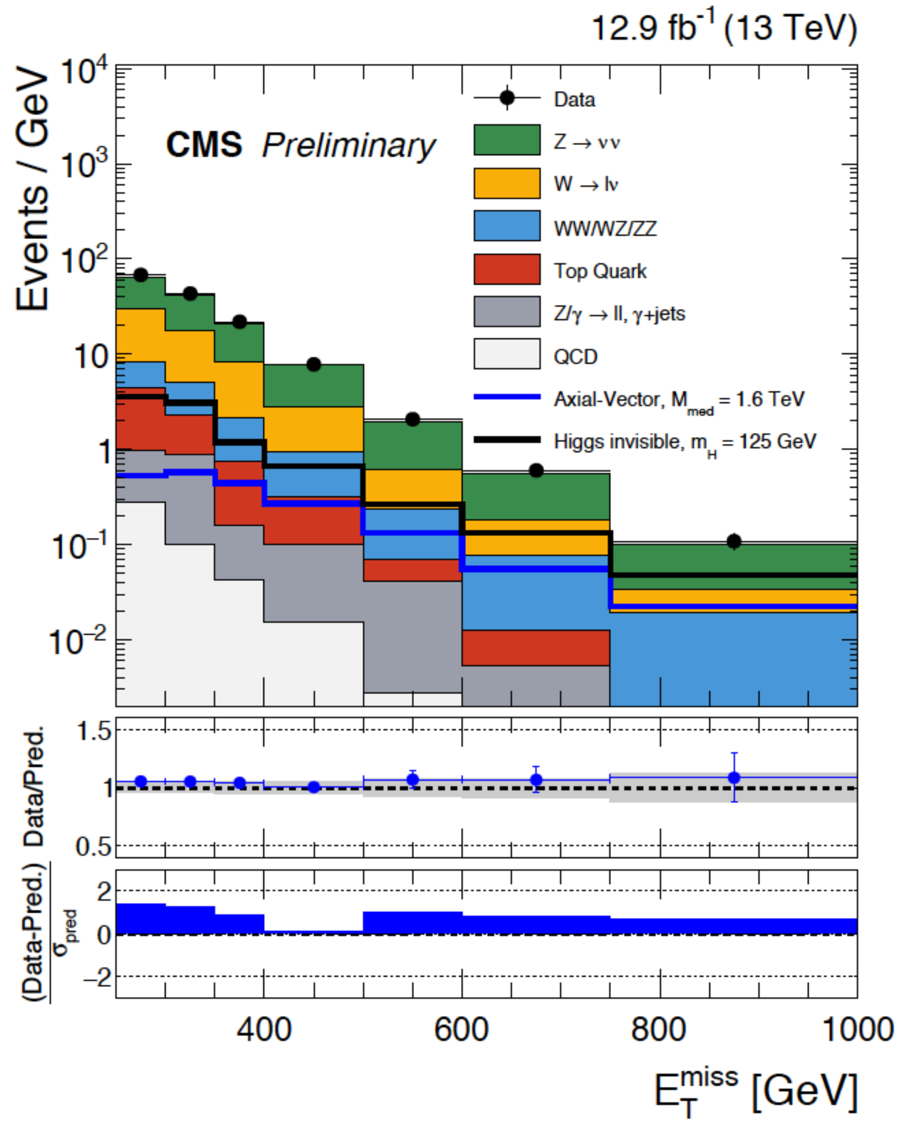
Total Luminosity : 12.9 fb^{-1} (2016)
Final State : J/V→qq+*MET*

Monojet/V

Monojet Category



V-tagged Category



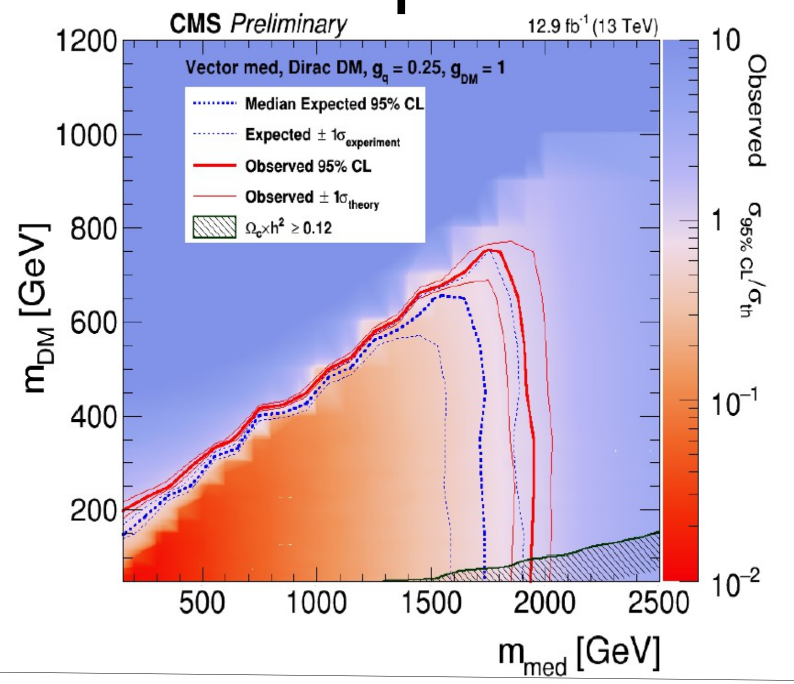
EXO-16-037

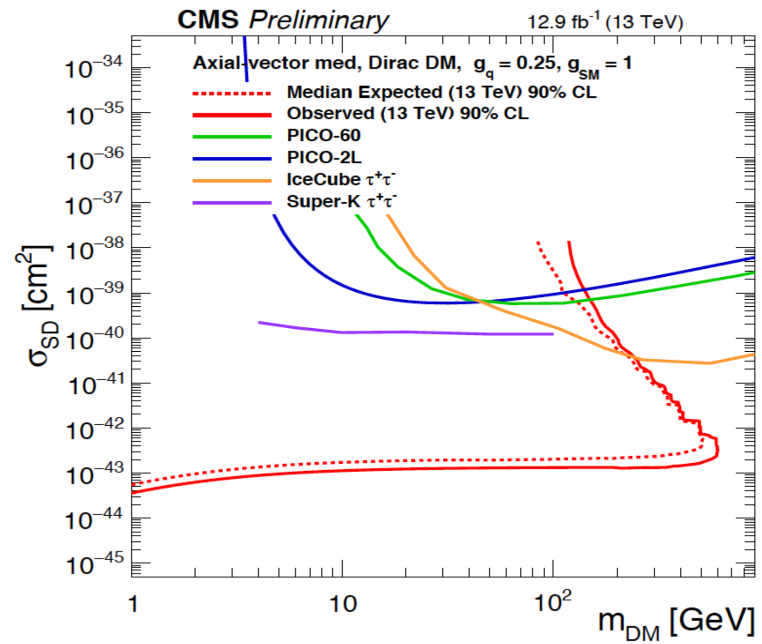
Total Luminosity : 12.9 fb^{-1} (2016)
Final State : J/V→qq+*MET*

Monojet/V

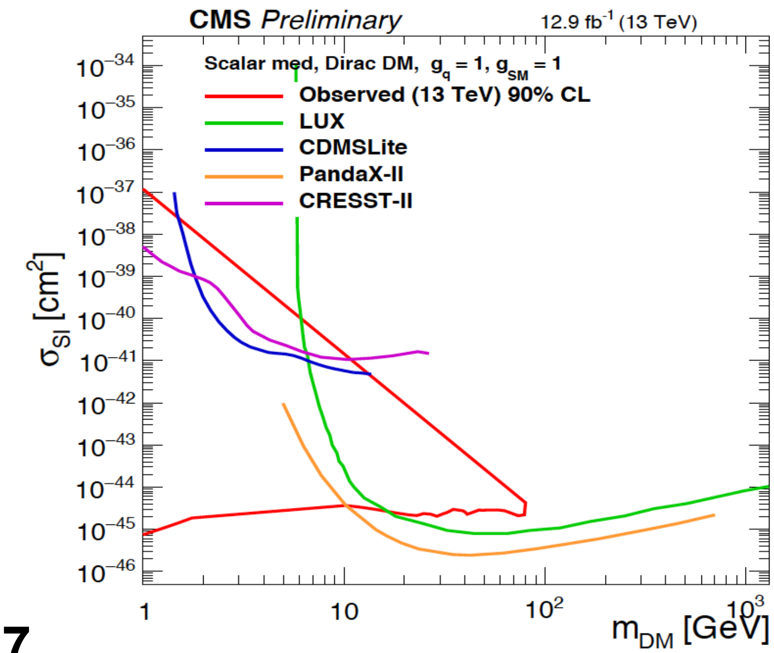
$u\gamma^{\mu}u$ $u\gamma^{5}u$

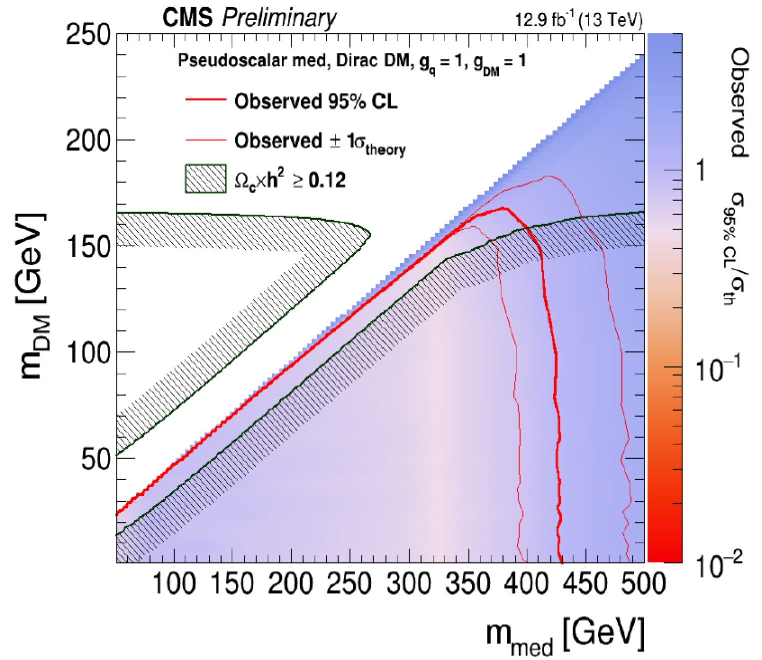
Spin 1





Spin 0

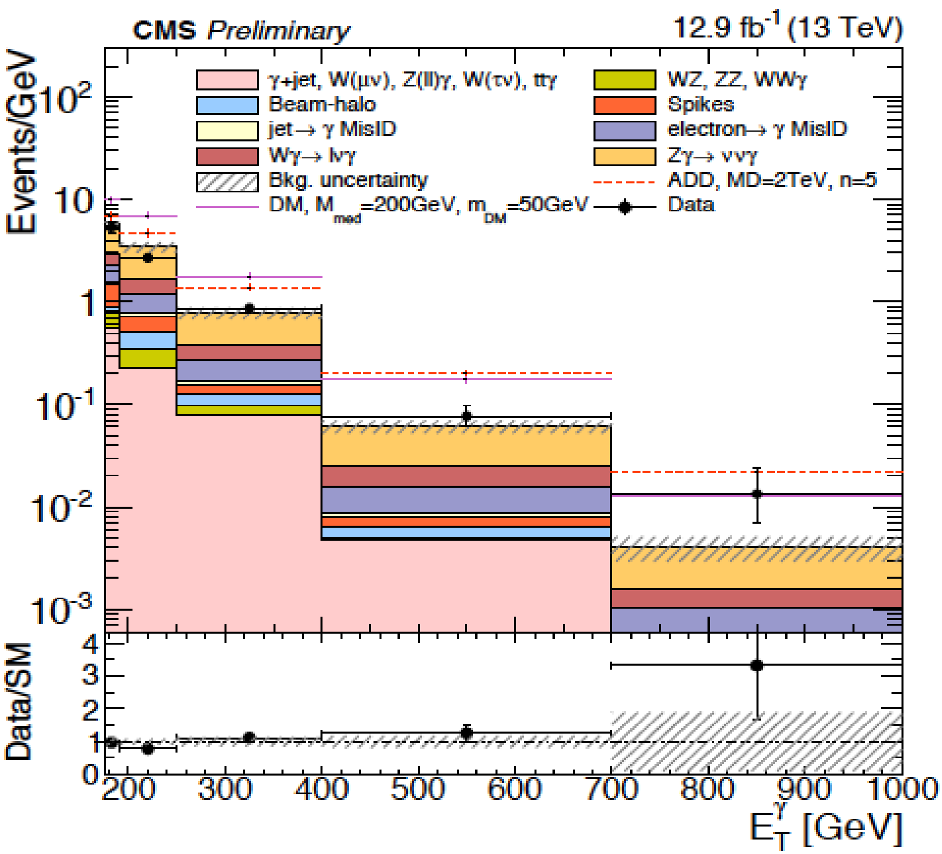


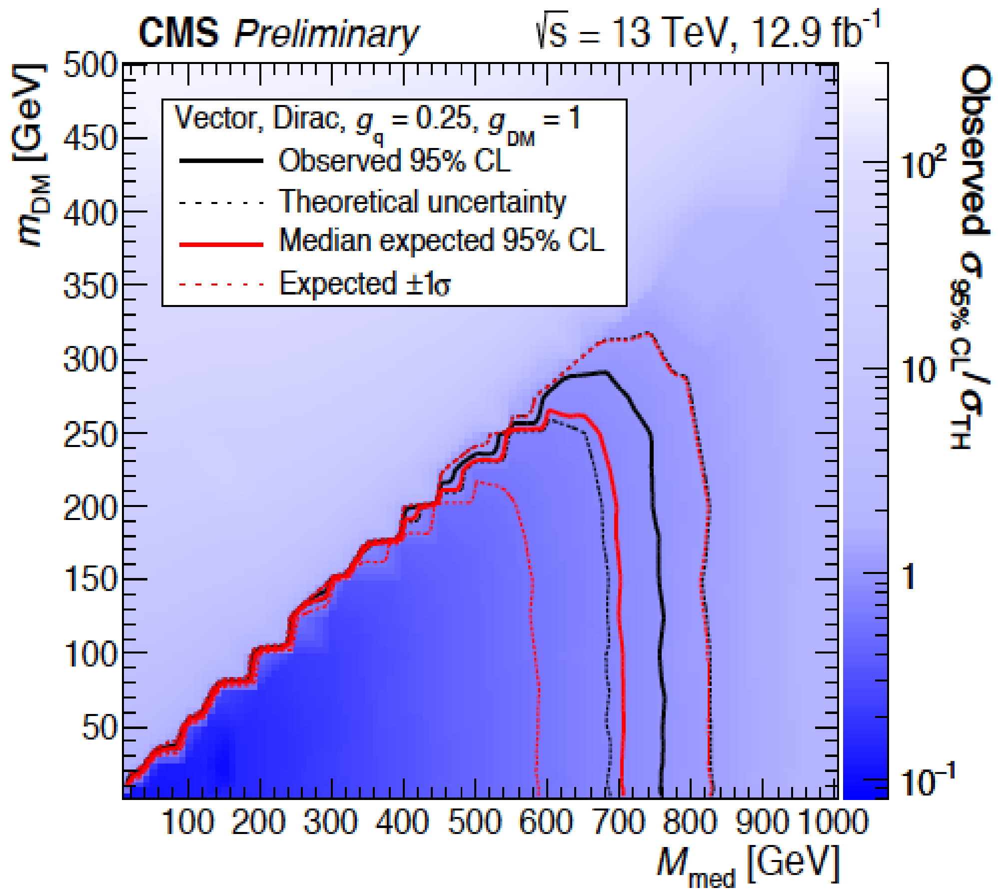


EXO-16-037

Total Luminosity : 12.9 fb^{-1} (2016)
Final State : γ+*MET*

Mono-γ



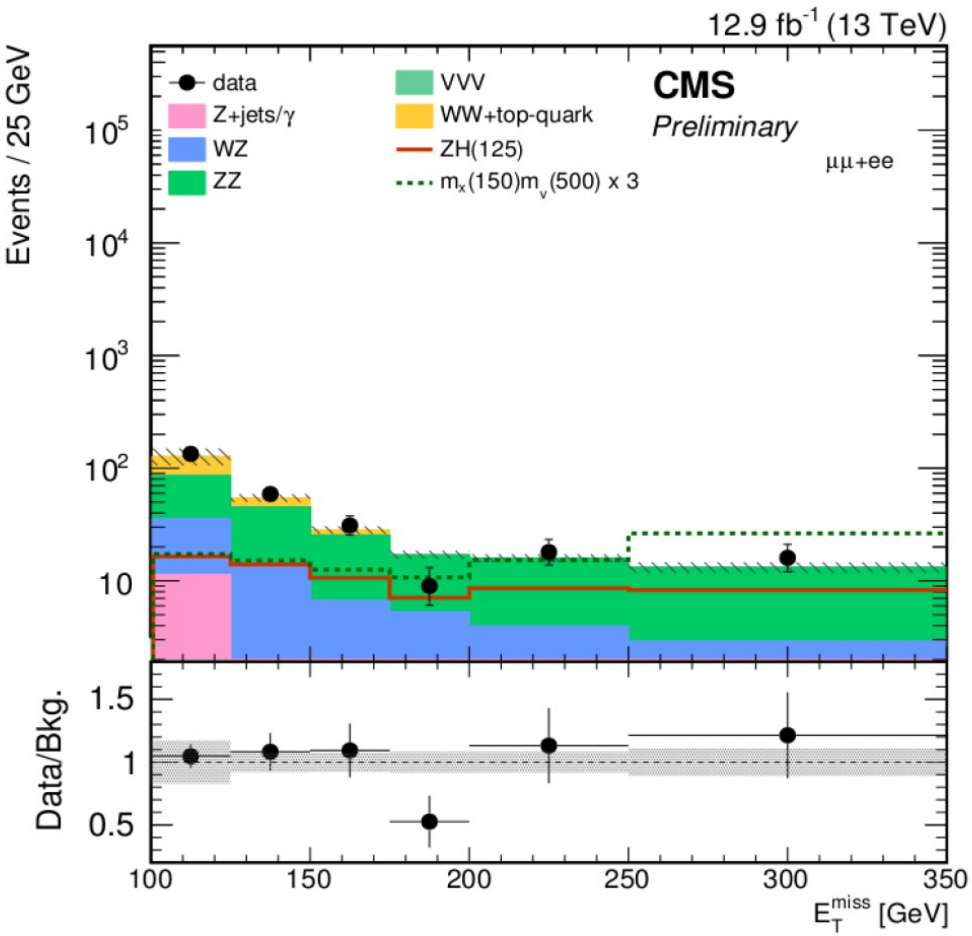


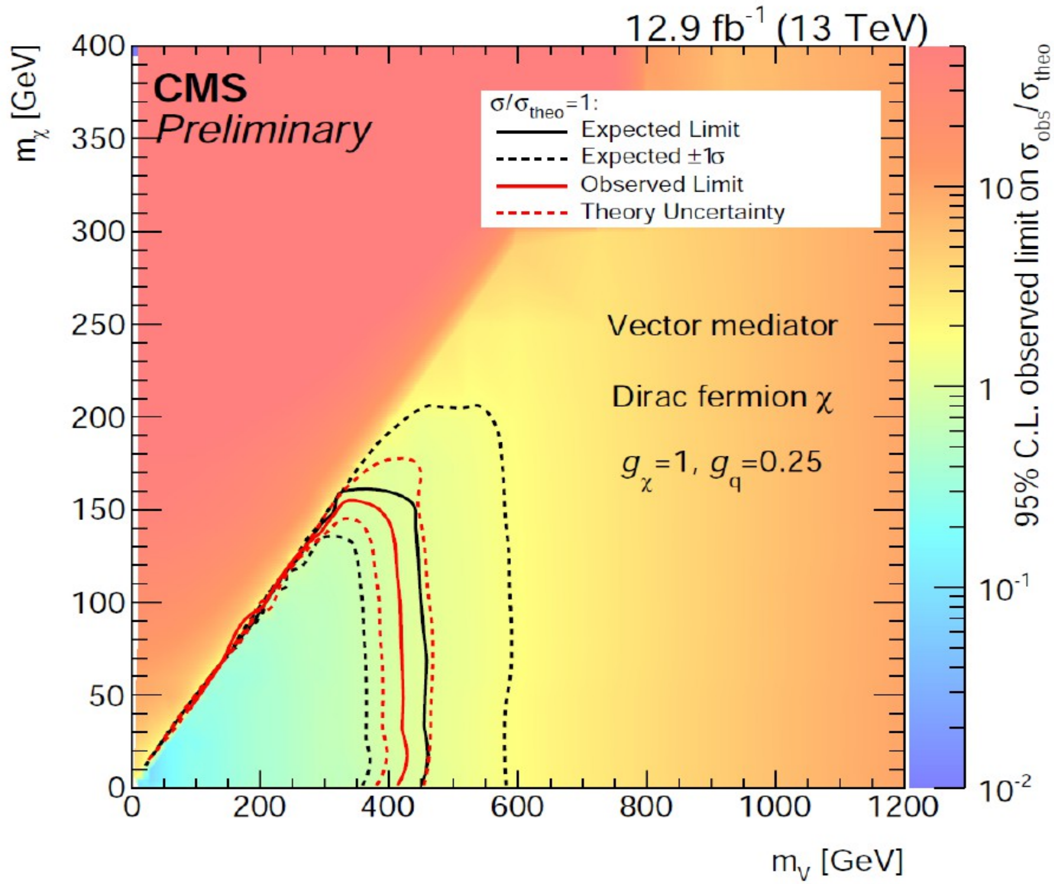
Small integrated deficit over whole region
Mass exclusion out to 750 GeV (2 TeV for monojet/V)

EXO-16-039

Total Luminosity : 12.9 fb^{-1} (2016)
Final State : Z→ll+*MET*

Mono-Z



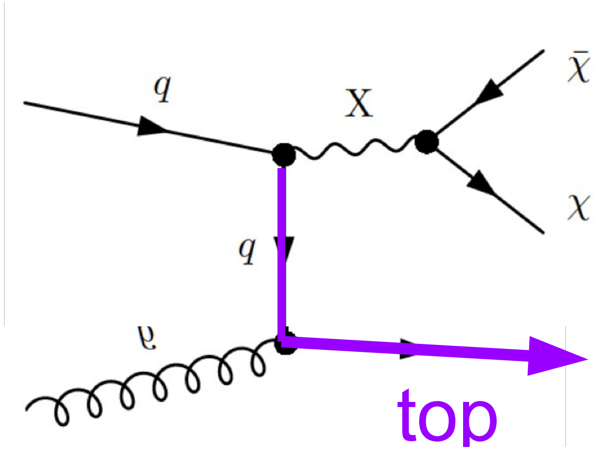


Small excess(1σ) over whole region
Mass exclusion out to 400 GeV for vector mediator
Scalar model BR(Higgs) <0.86 (Guillelmo's talk)

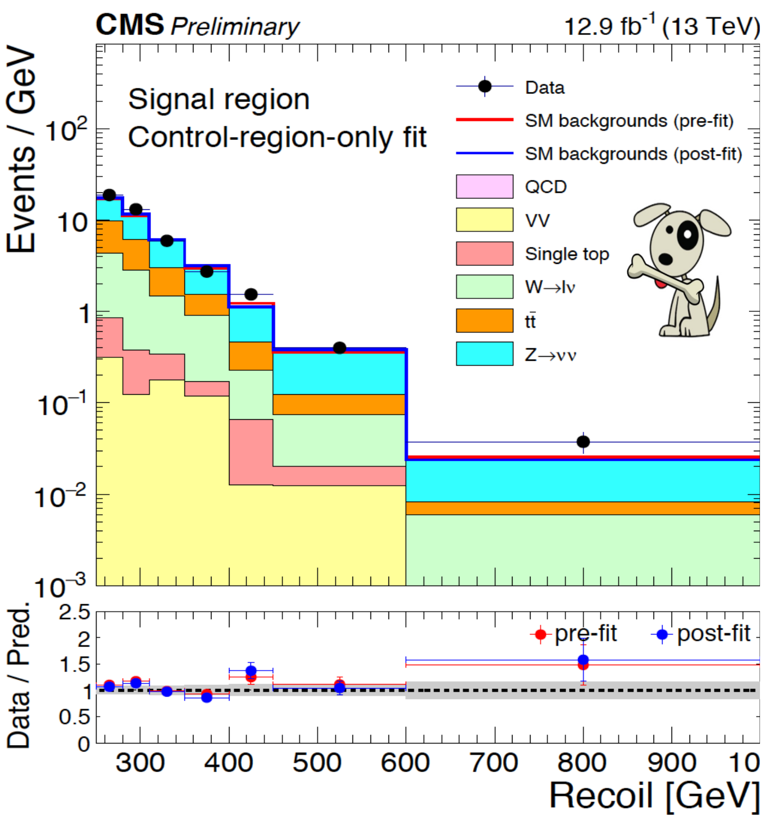
EXO-16-038

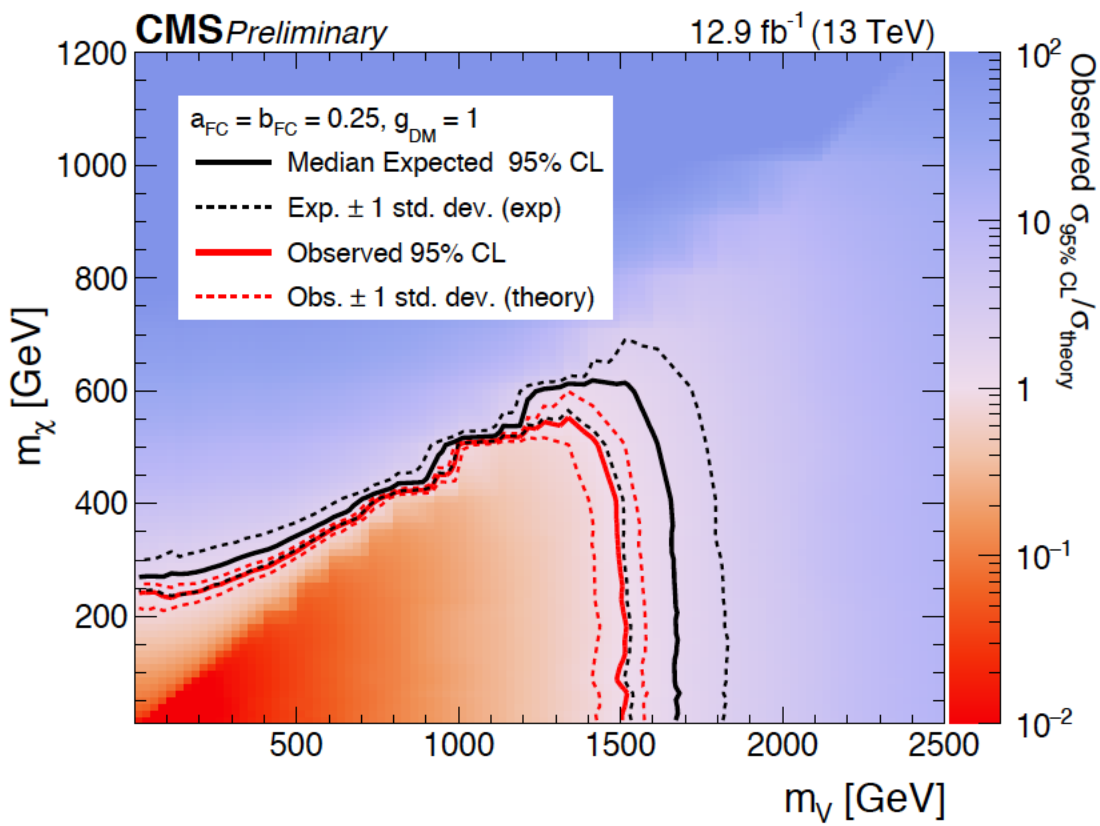
Total Luminosity : 12.9 fb^{-1} (2016)
Final State : top+*MET*

Mono-Top



Require top tag and *MET*
Small excess (1σ)



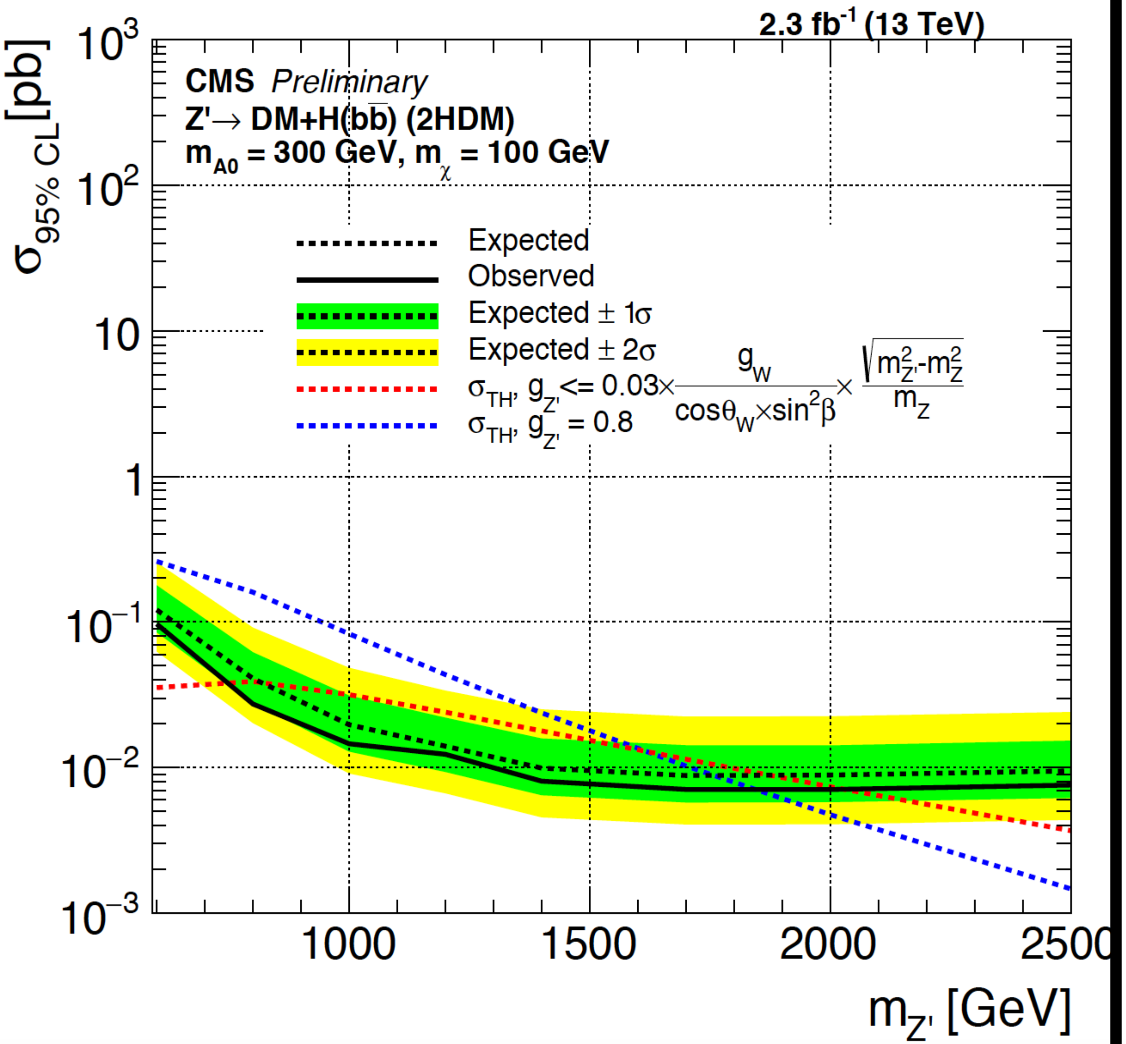


EXO-16-040

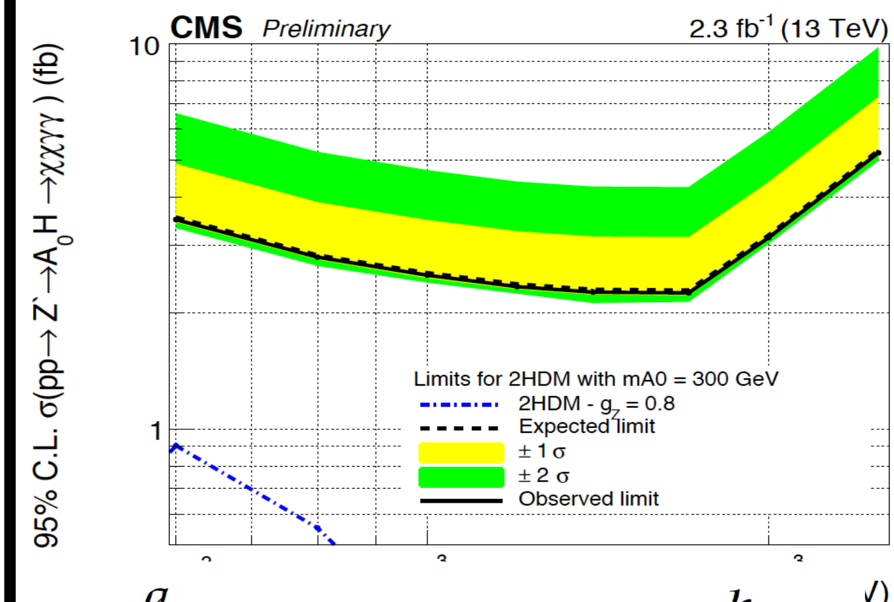
Total Luminosity : 2.3 fb^{-1} (2015)
Final State : Higgs(bb/γγ)+*MET*

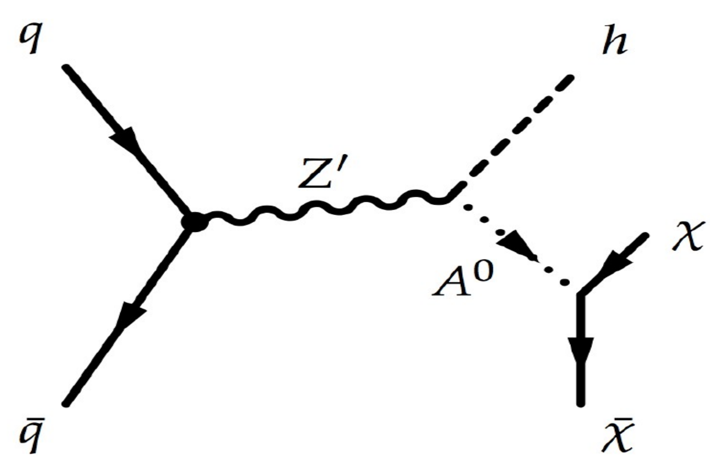
Mono-Higgs

MET+H→bb



MET+H→γγ



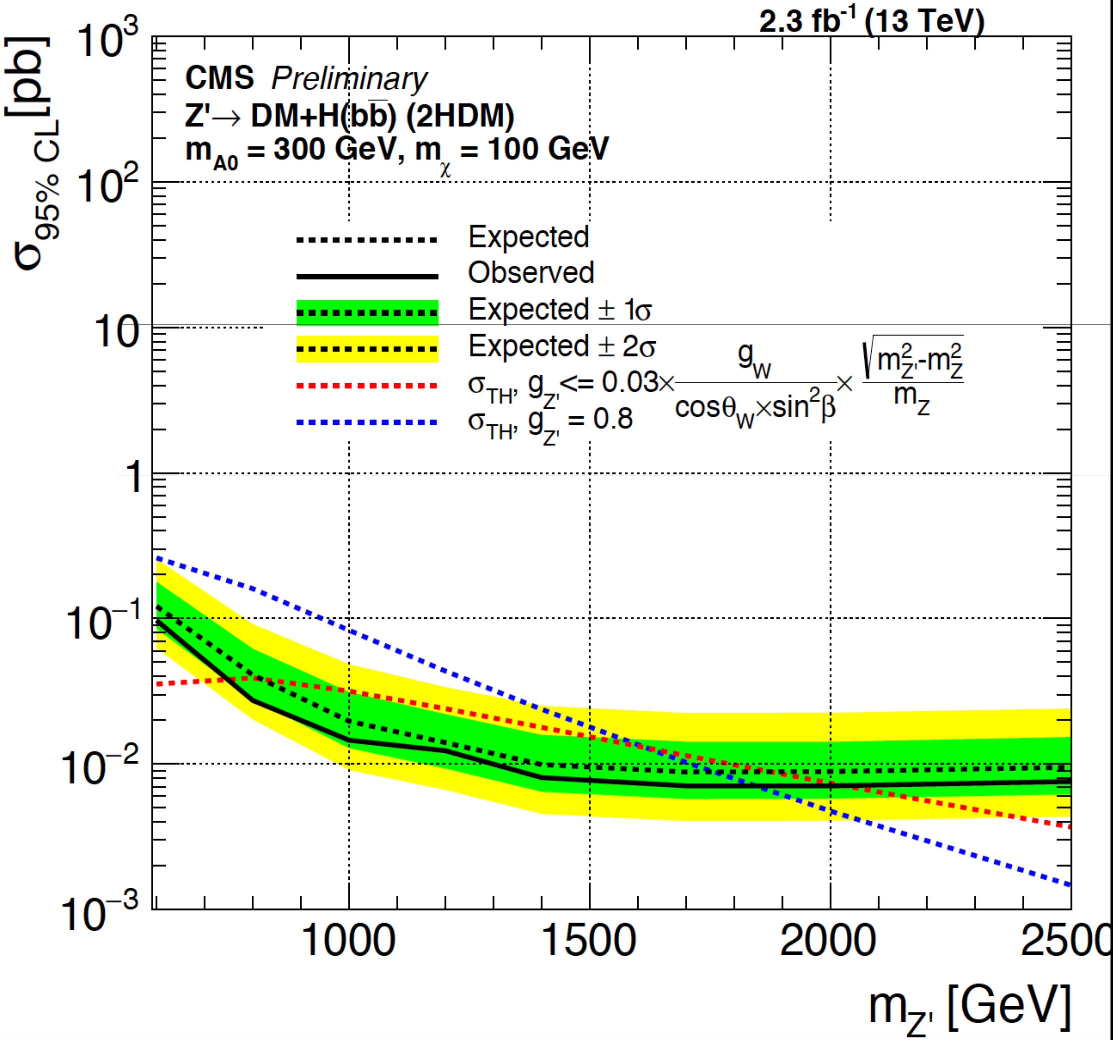


EXO-16-011/EXO-16-012

Total Luminosity : 2.3 fb^{-1} (2015)
Final State : Higgs(bb/γγ)+*MET*

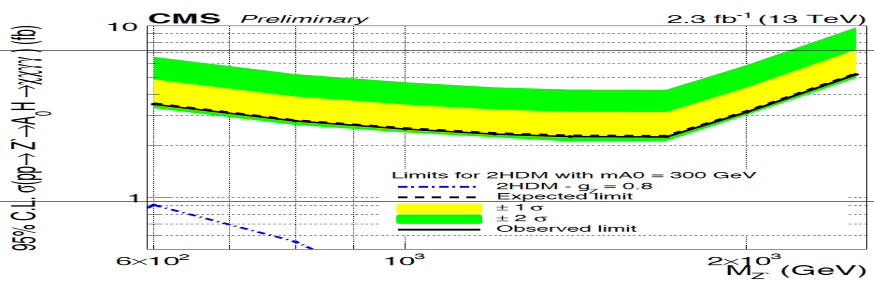
Mono-Higgs

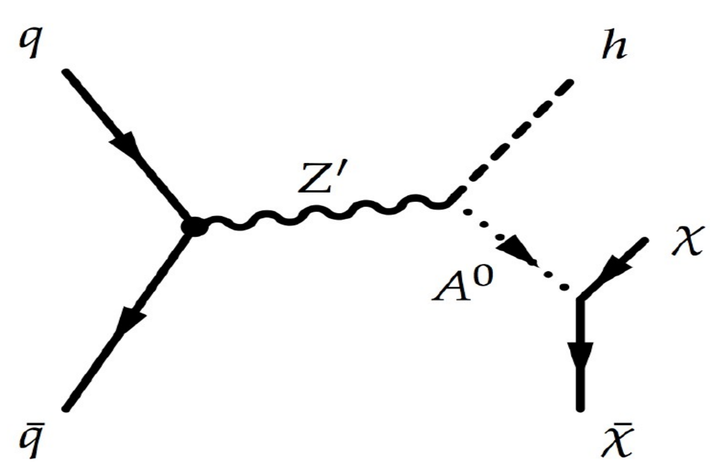
MET+H→bb



MET+H→γγ

bb final state dominates final state



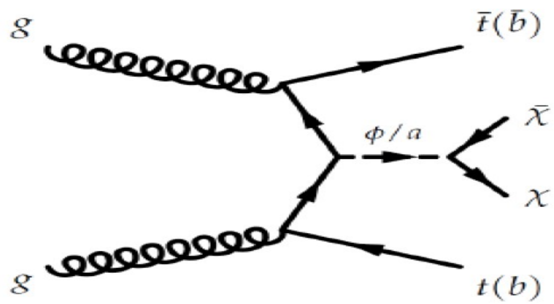


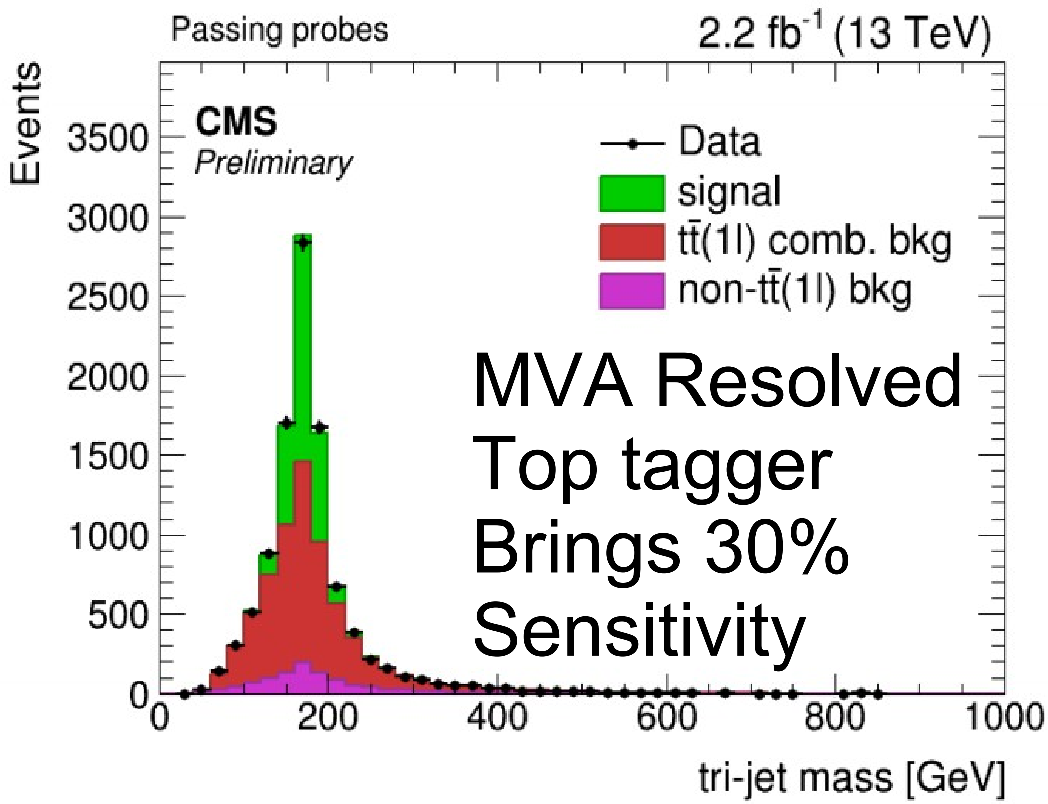
EXO-16-011/EXO-16-012

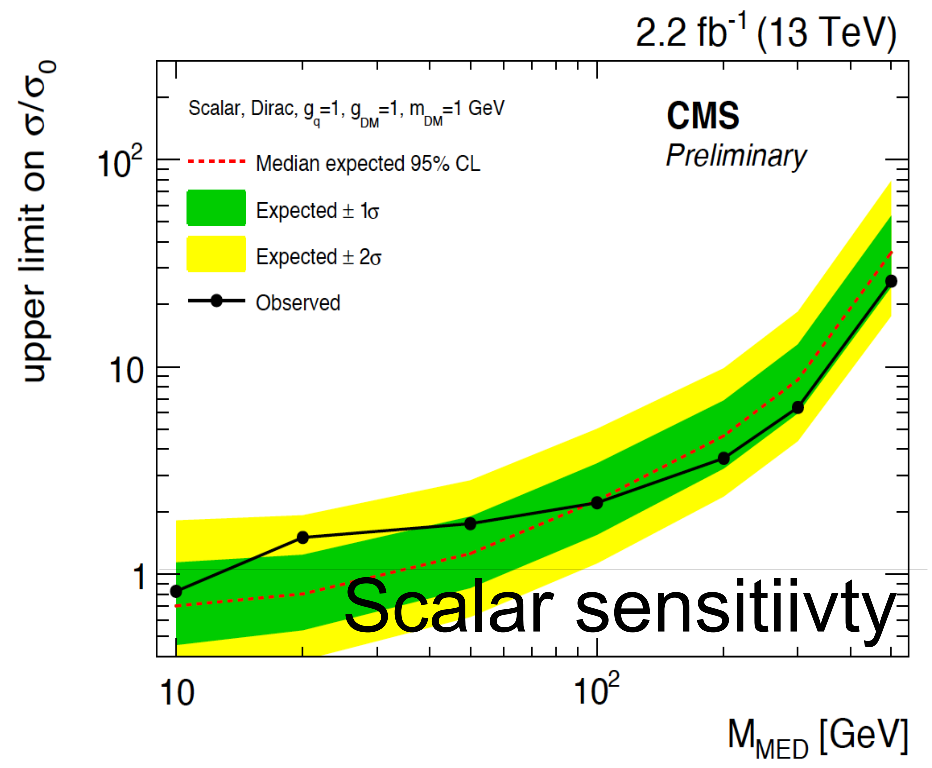
Total Luminosity : 2.3 fb^{-1} (2015)

Final State : tt+*MET*

tt+DM







Sensitivity pushed to exclude Scalar mediator models

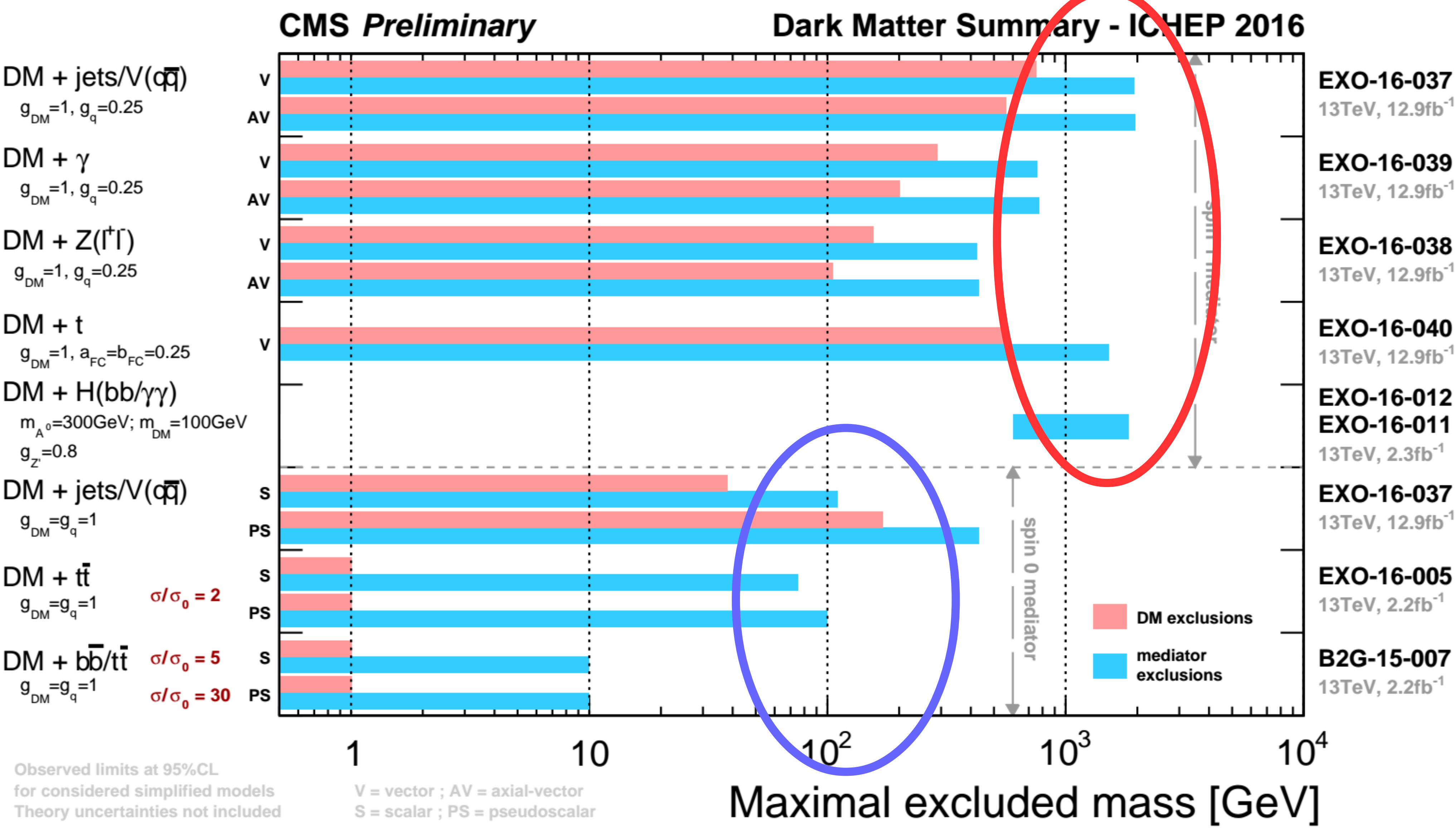
EXO-16-005

Mediator Arms Race

CMS ATLAS

Who can cover the territory first?

Dark Matter Summary

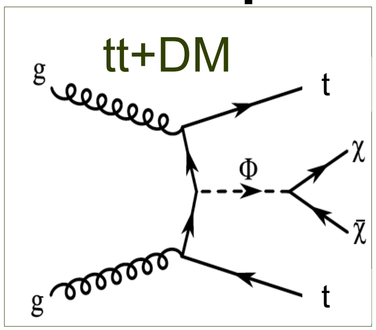


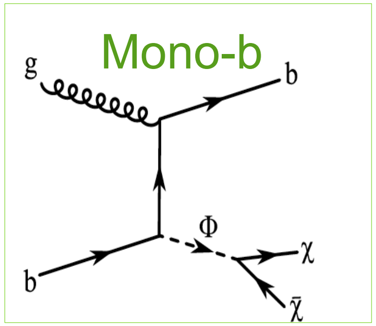
Spin 0 exclusion is at the 100-200 GeV level

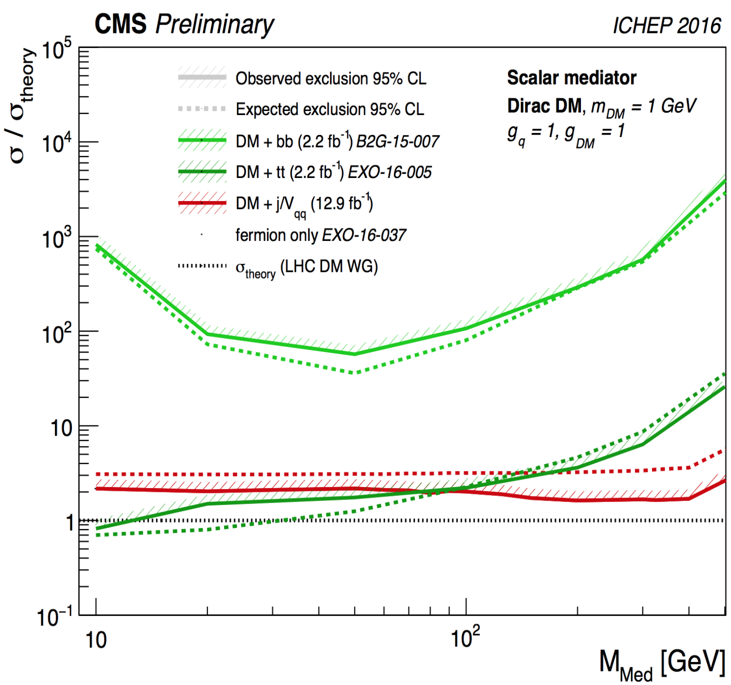
Spin 1 exclusion is at the 2 TeV

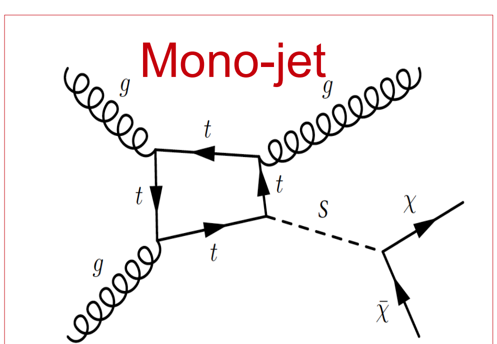
Impact of Mediator Searches

Spin 0

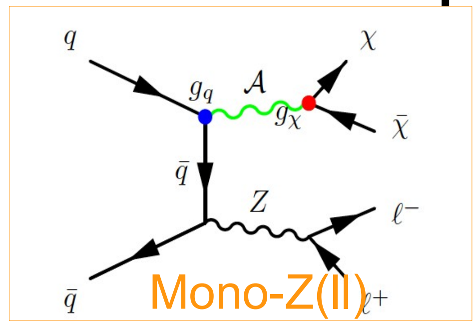


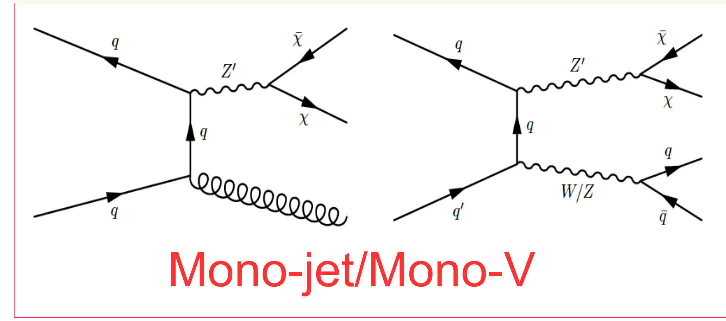


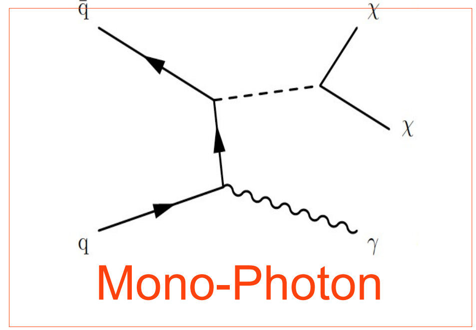


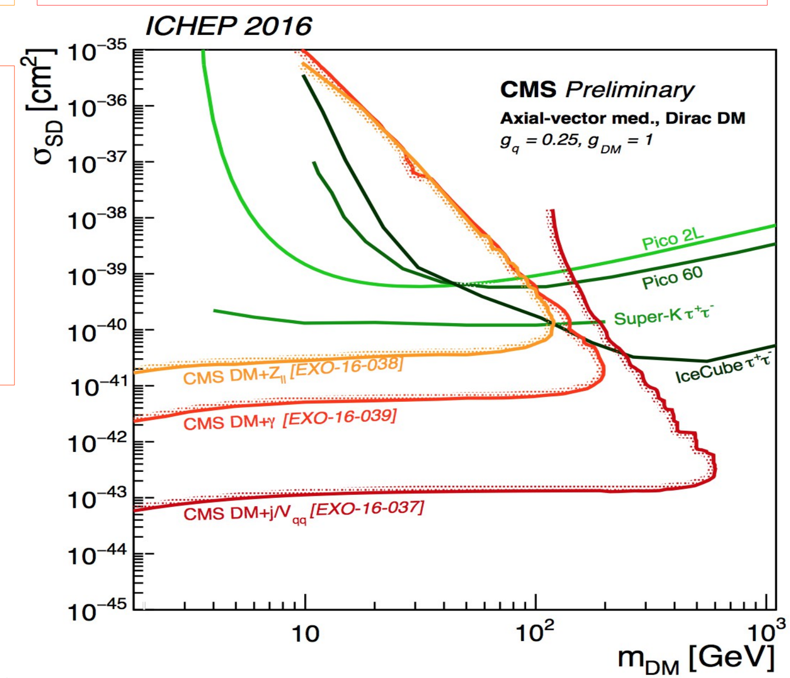


Spin 1

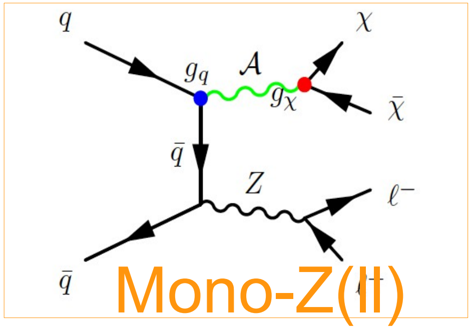


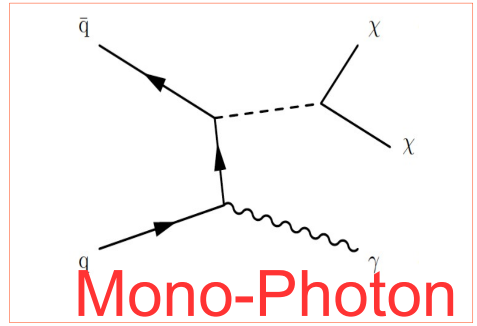


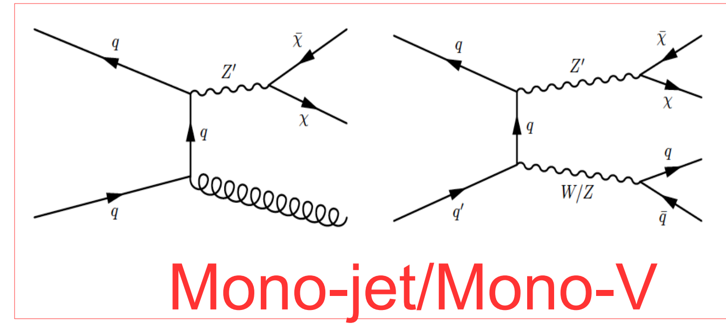


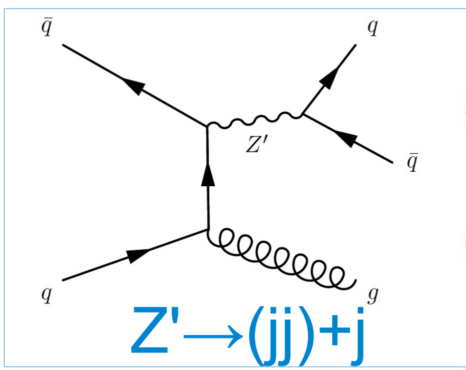


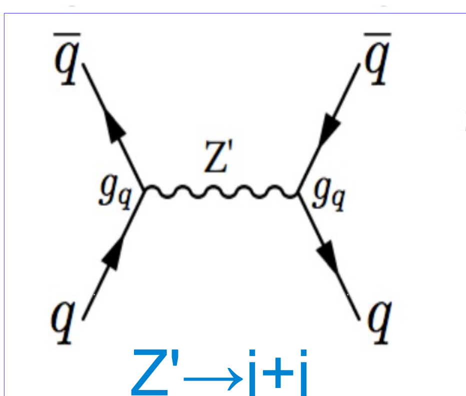
Impact of the mediator searches stand to effect our global view of Dark Matter

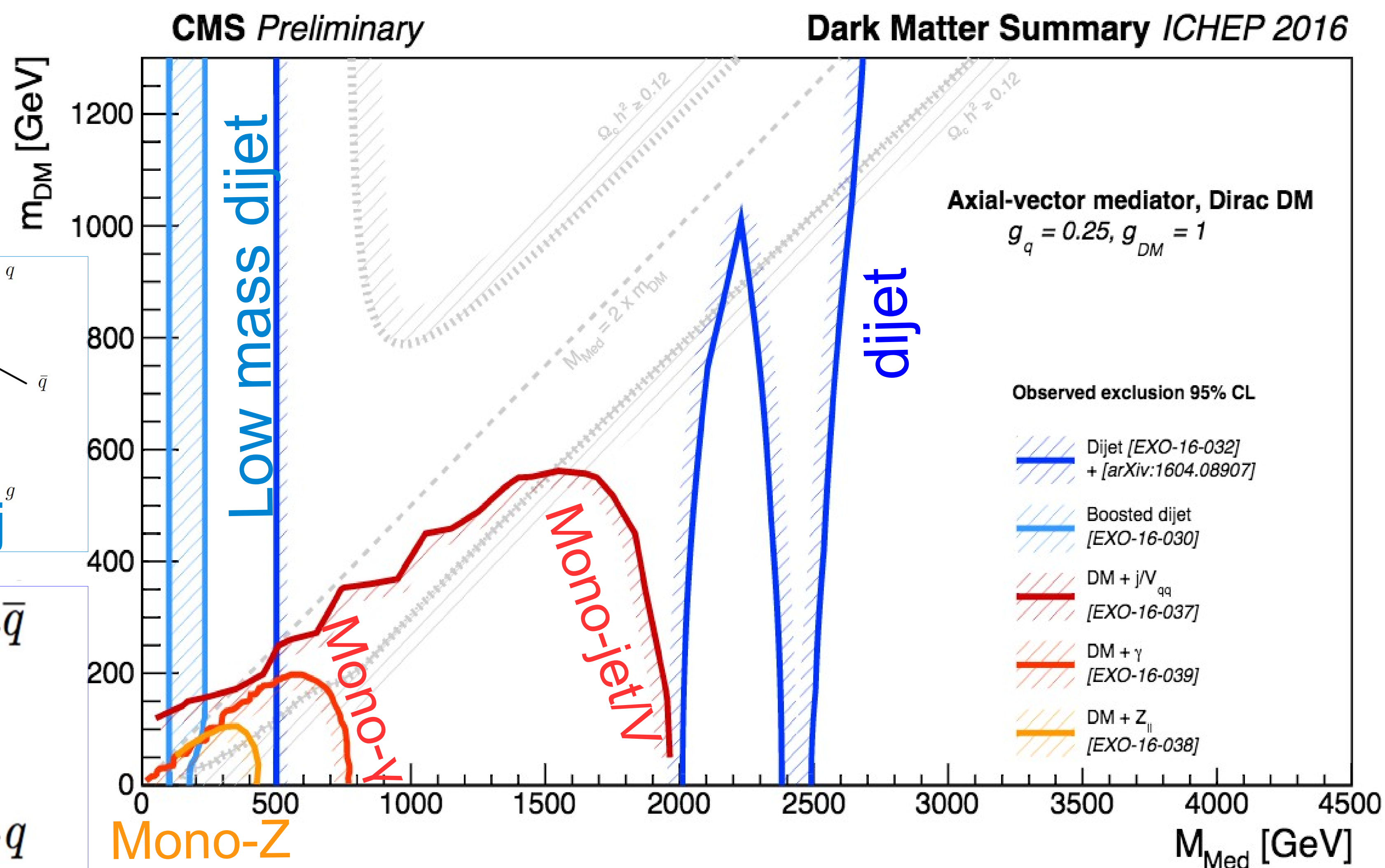

Mono-Z(ll)


Mono-Photon


Mono-jet/Mono-V


Z'→(jj)+j


Z'→j+j


CMS Preliminary
Dark Matter Summary ICHEP 2016
Axial-vector mediator, Dirac DM
$g_q = 0.25$, $g_{DM} = 1$
Observed exclusion 95% CL
Dijet [EXO-16-032] + [arXiv:1604.08907]
Boosted dijet [EXO-16-030]
DM + j/V$_{qq}$ [EXO-16-037]
DM + γ [EXO-16-039]
DM + Z$_{ll}$ [EXO-16-038]
m_{DM} [GeV]
M_{Med} [GeV]
Low mass dijet
dijet
Mono-jet/V
Mono-γ
Mono-Z

In Summary

- No New Physics
  - A plethora of new an interesting results
  - Excess in ZZ(ll+j)@650 GeV and γ+j @ 2TeV
- LHC Run II has warmed up
  - Just getting into the interesting part
- Now probing :
  - Spin 1 mediators in the 2-3 TeV range
  - Spin 0 mediators in the hundreds of GeV range
  - Long lived 100 GeV particles in the few cm range

Thanks
(750) 에 의해 낙심 하지 않습니다

*Bonus Heavy Ion QCD talk in back

Backup

My Favorite Heavy Ion Result

Softdrop condition

Softdrop = Jet grooming technique
removes large-angle soft radiation + remaining background

Soft Drop condition

$$z > z_{\mathrm{cut}}\,\theta^{\beta}$$

energy threshold

angular exponent

We use $\beta = 0$ and $z_{cut} = 0.1$
All soft emissions are removed
Equivalent to modified Mass Drop

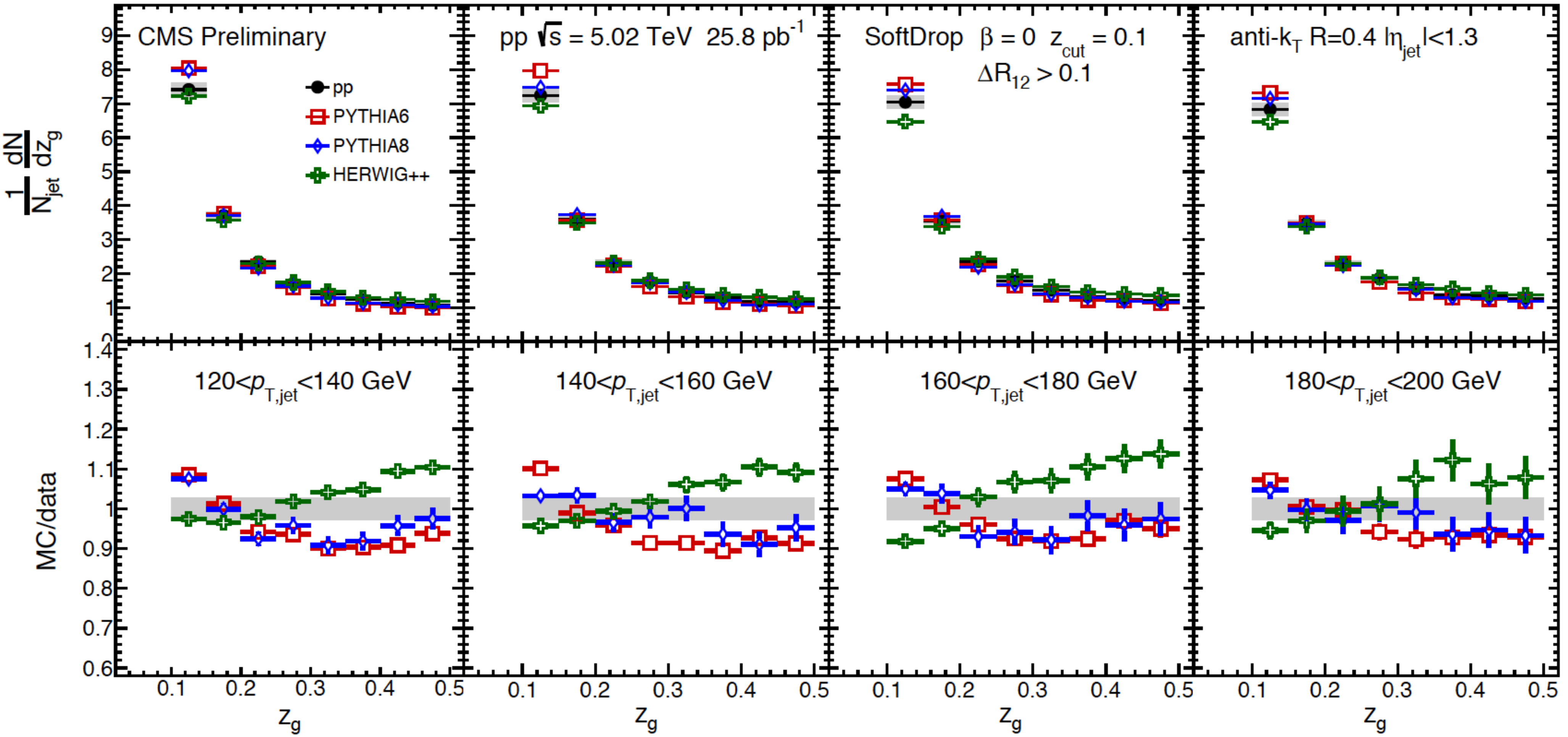
$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}}$$

Momentum fraction carried by the subleading branch of first splitting

[1] Larkoski, Marzani, Thaler
Phys. Rev. D91:111501 (2015)
Soft Drop: JHEP 1405 (2014) 146

Measurement in pp

Note: For detector resolution reasons require $\Delta R_{12(\text{subjet})} > 0.1$

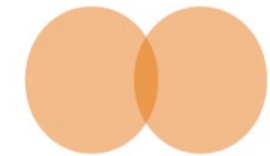


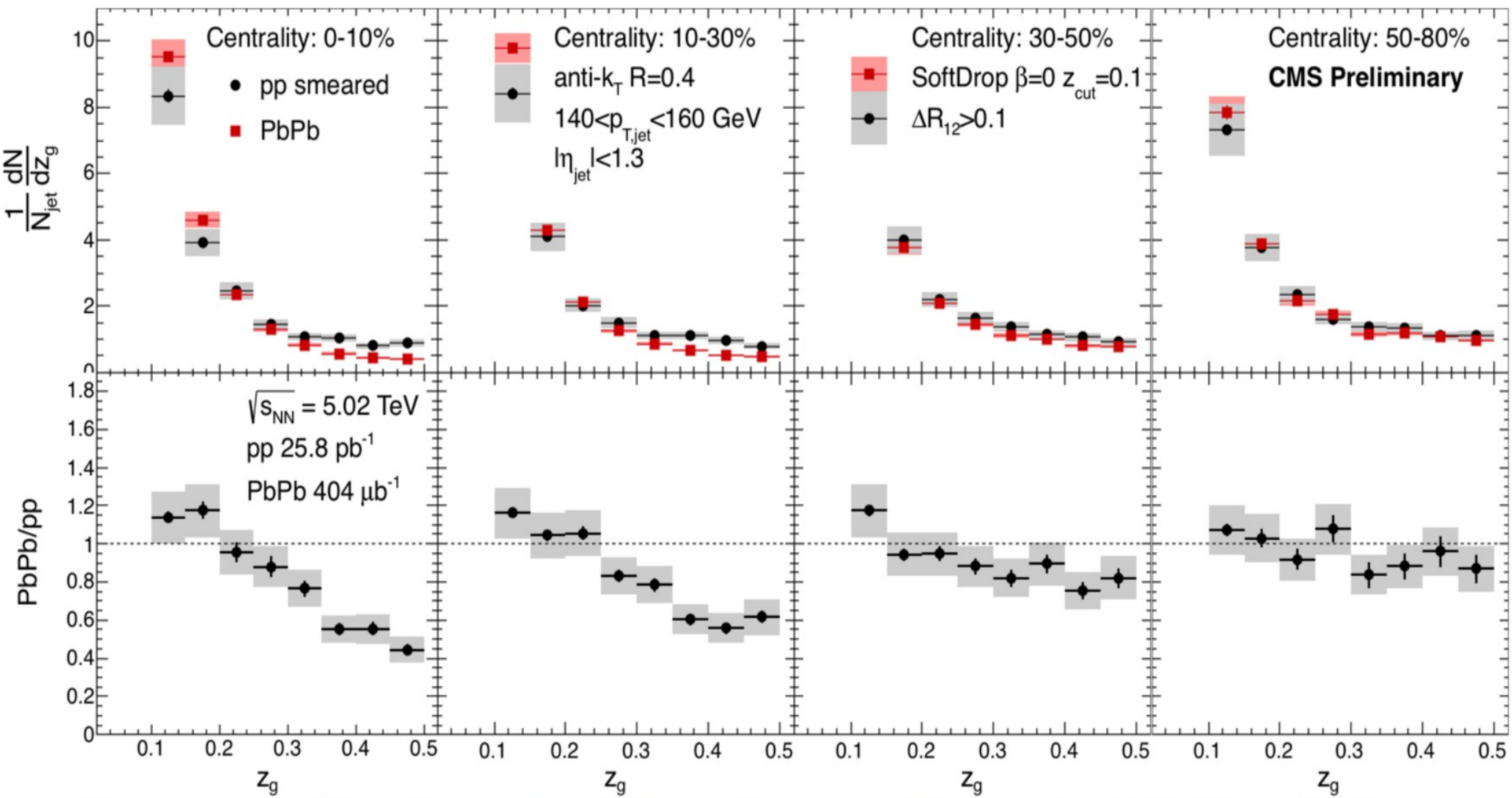
Pythia and Herwig predictions straddle the pp result

$p_{T,jet}$: 140-160 GeV

Central collisions

Peripheral collisions



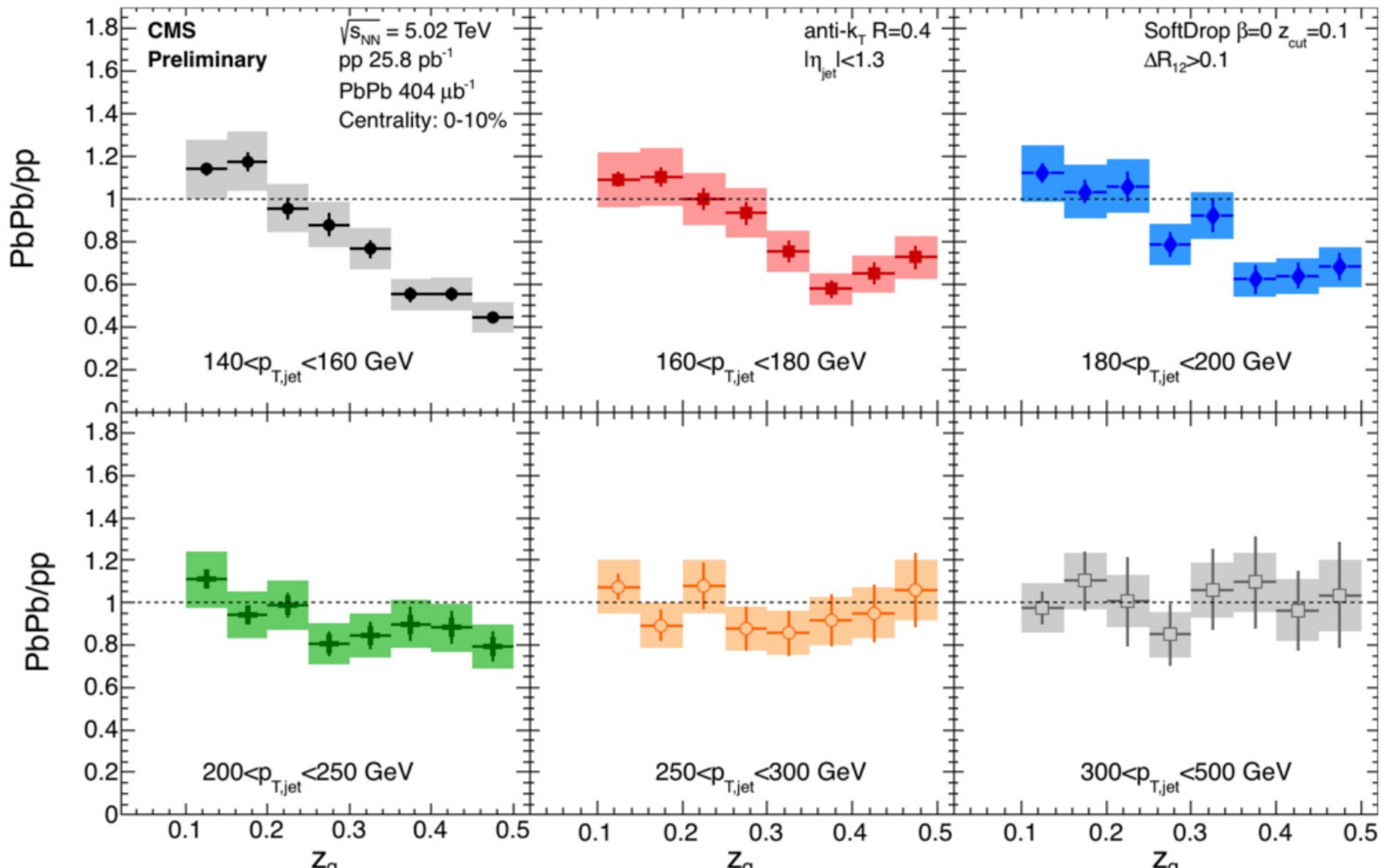


Strong modification of splitting observed in central PbPb collisions

Branching more imbalanced in central PbPb

Jet p_T dependence

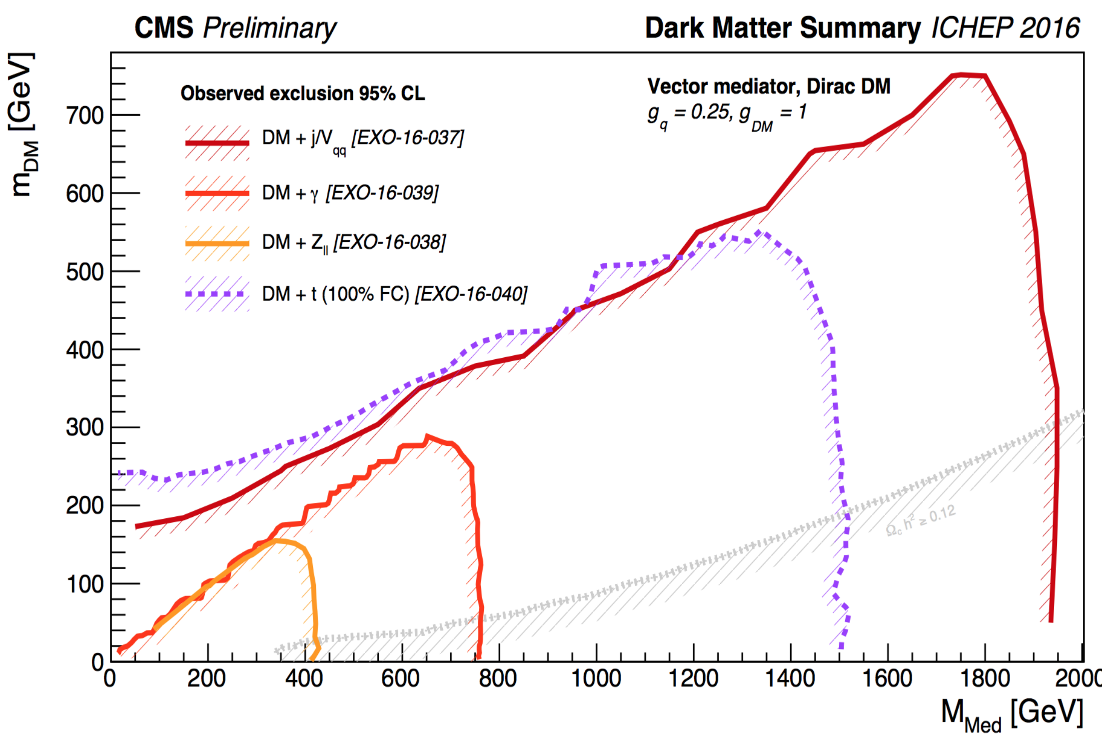
Modification gets weaker when increasing jet p_T

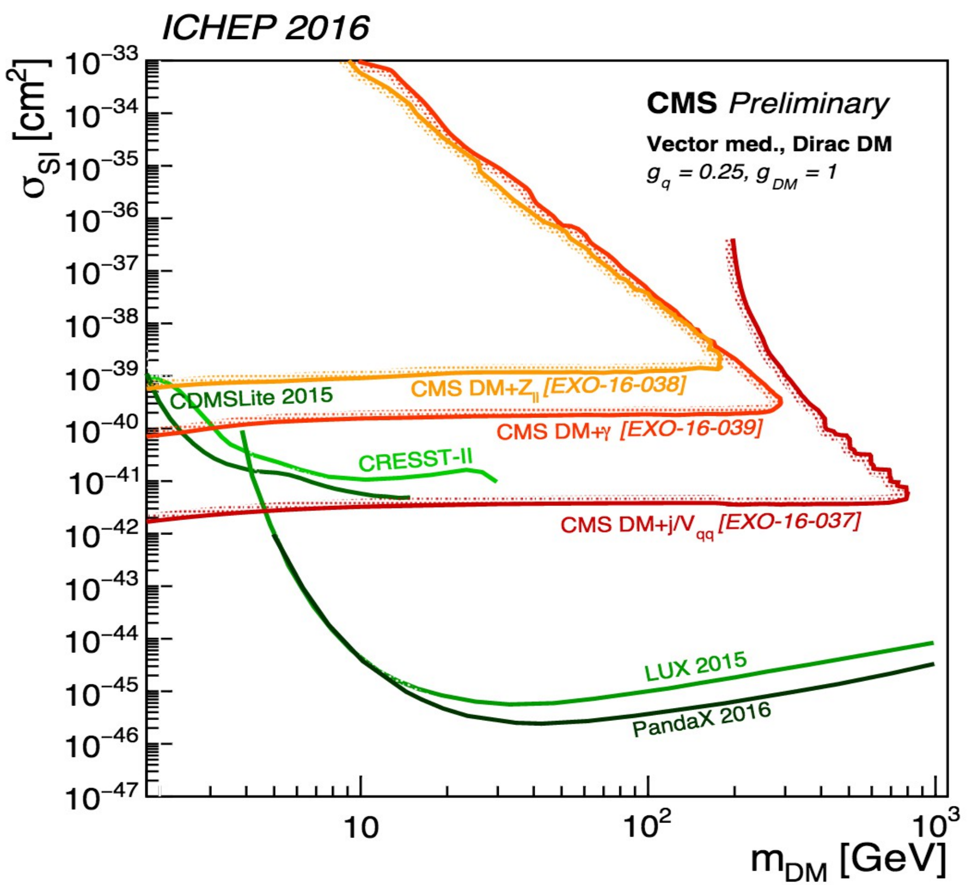


Due to normalization, cannot distinguish between increase at low z_g or suppression at high z_g

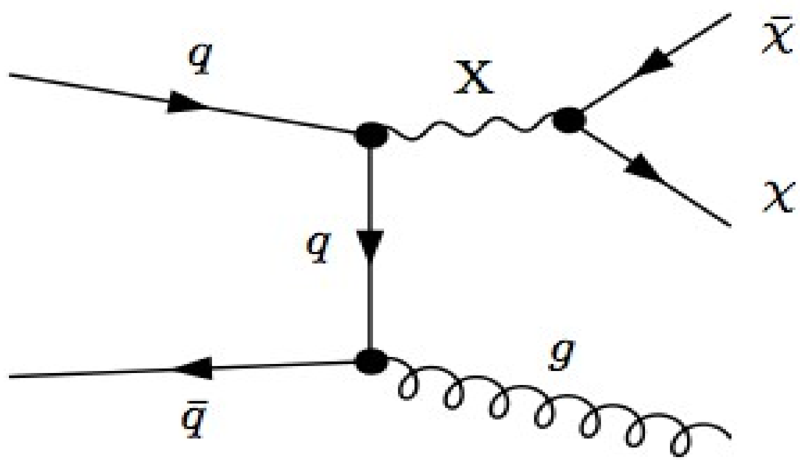
CMS-PAS-HIN-16-006

Dark Matter Searches

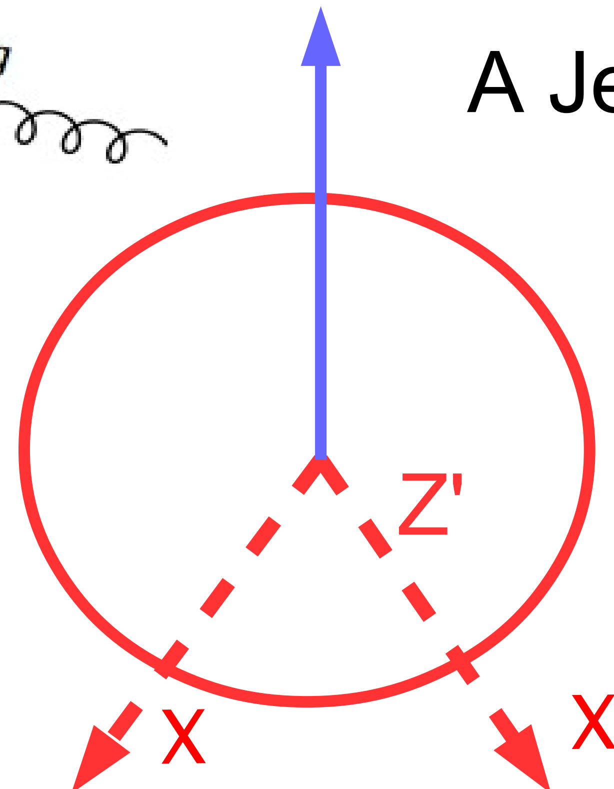




DM Signature



A Jet (+other particles)



Dark matter

$\text{Mediator } \vec{p}_T = \overrightarrow{MET}_{(E_T^{Miss})}$

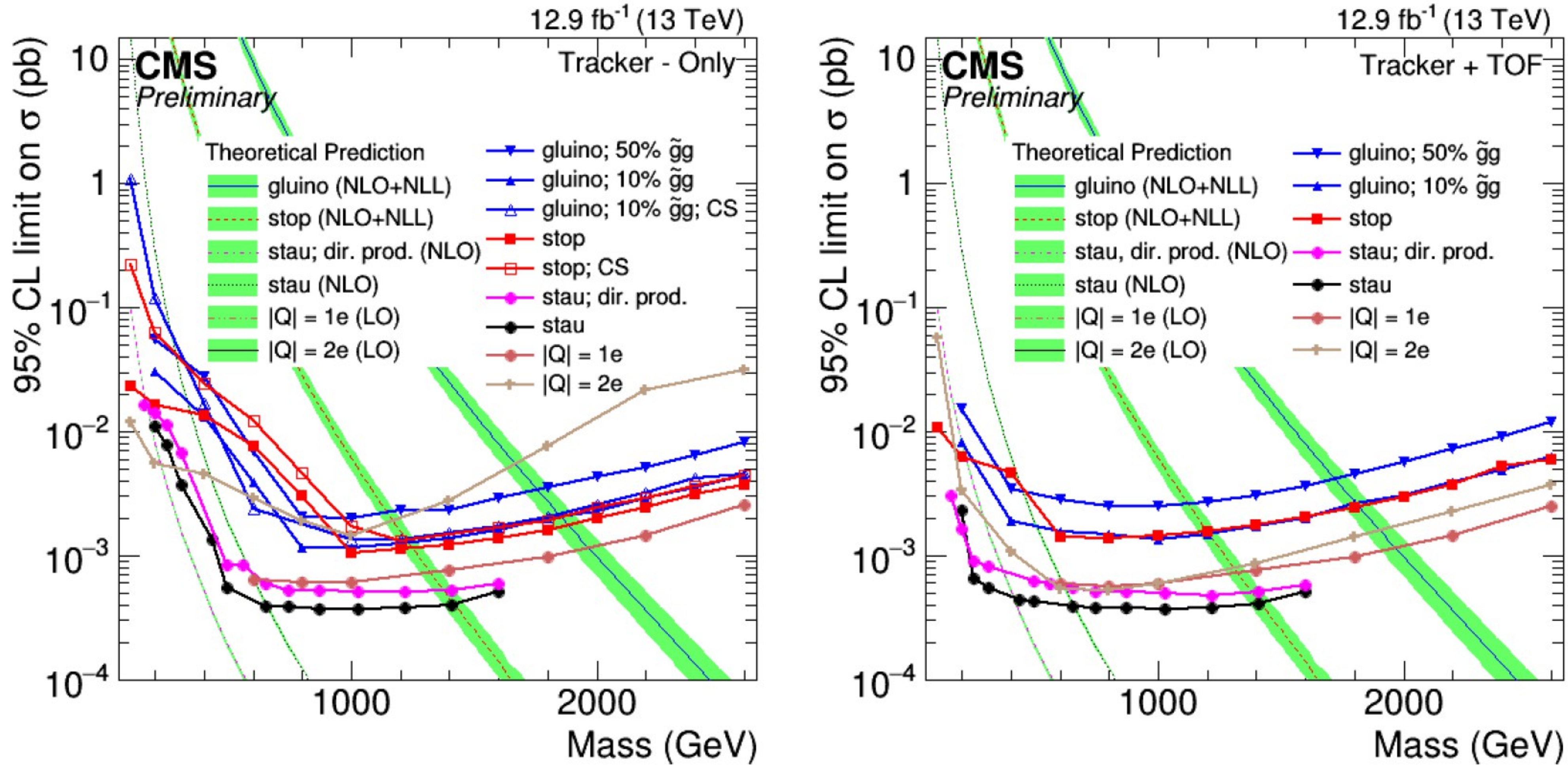
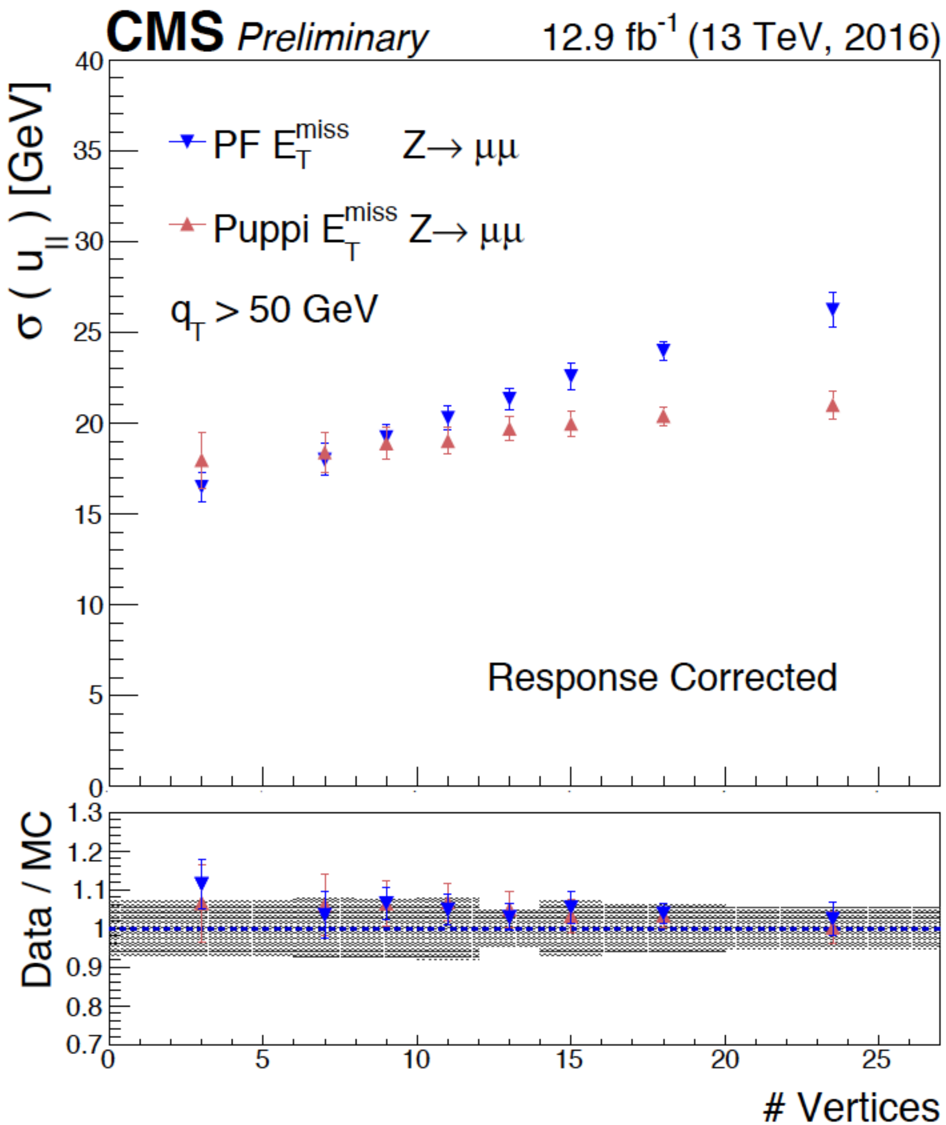
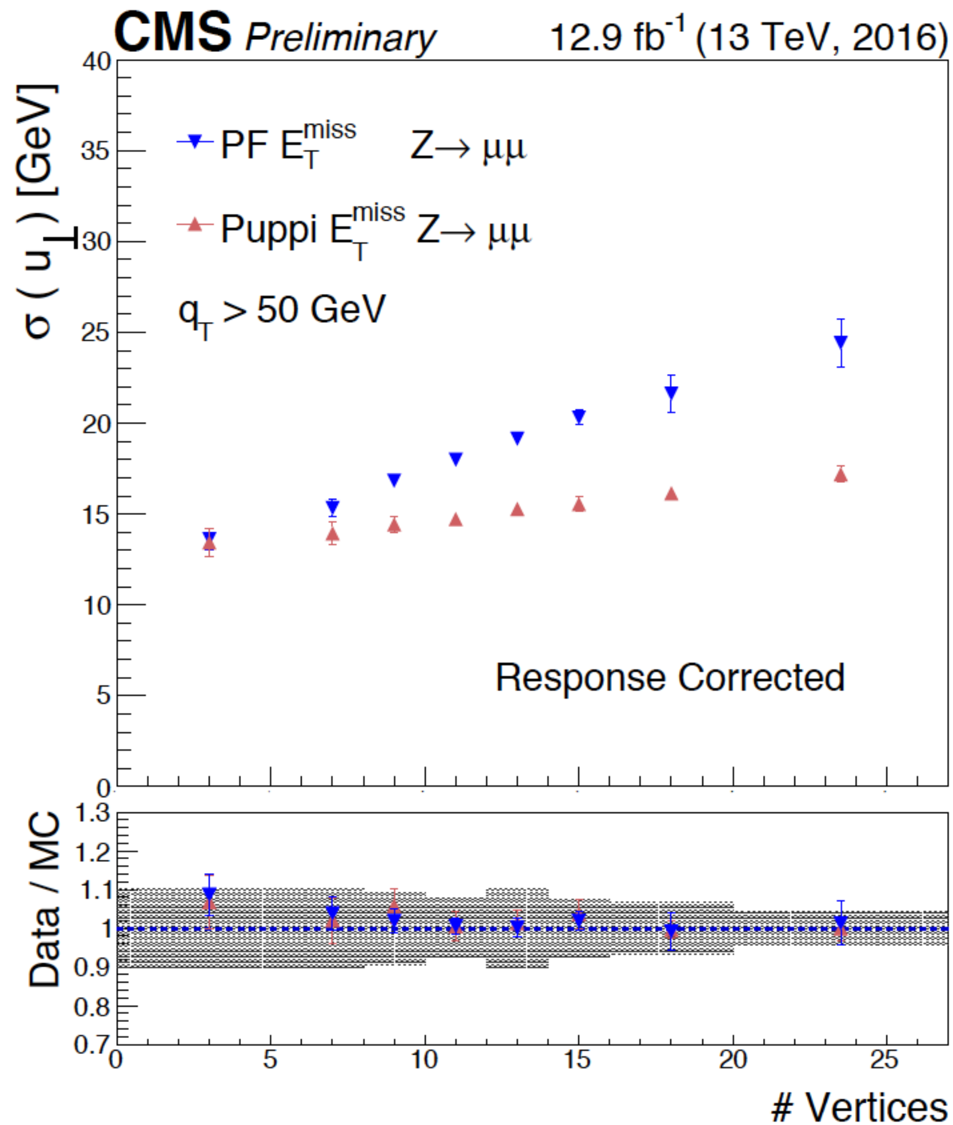
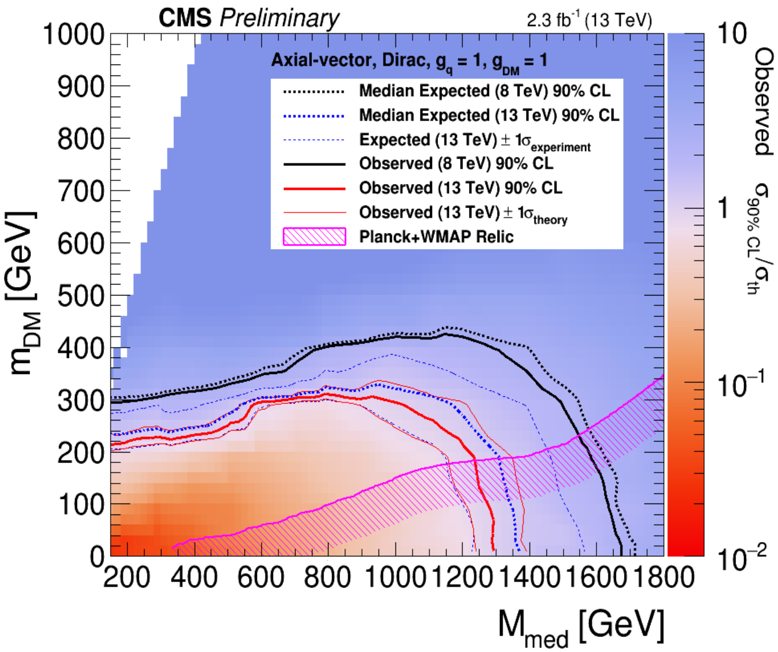


Figure 3: Cross section upper limits at 95% CL on various signal models for the tracker-only analysis (left column) and tracker+TOF analysis (right column) at $\sqrt{s} = 13\,\text{TeV}$. In the legend, 'CS' stands for charged suppressed interaction model.

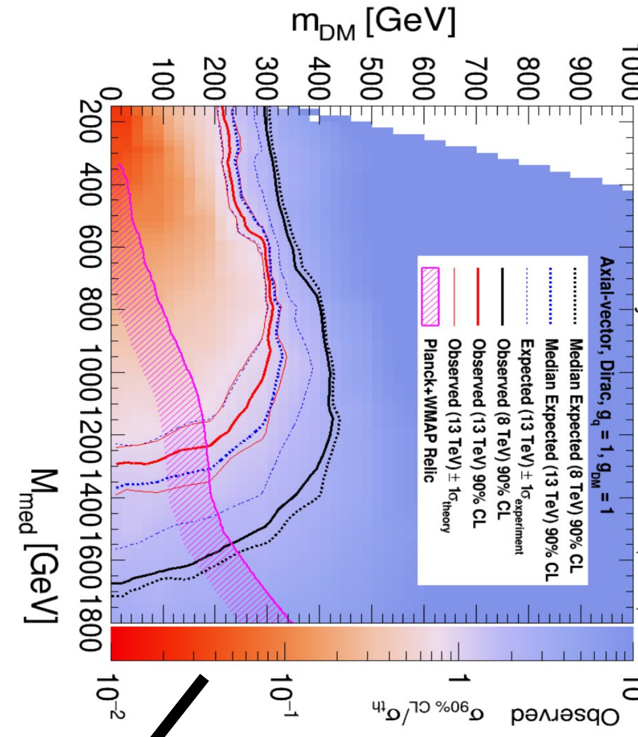
PUPPE$_T$ Performance in Data



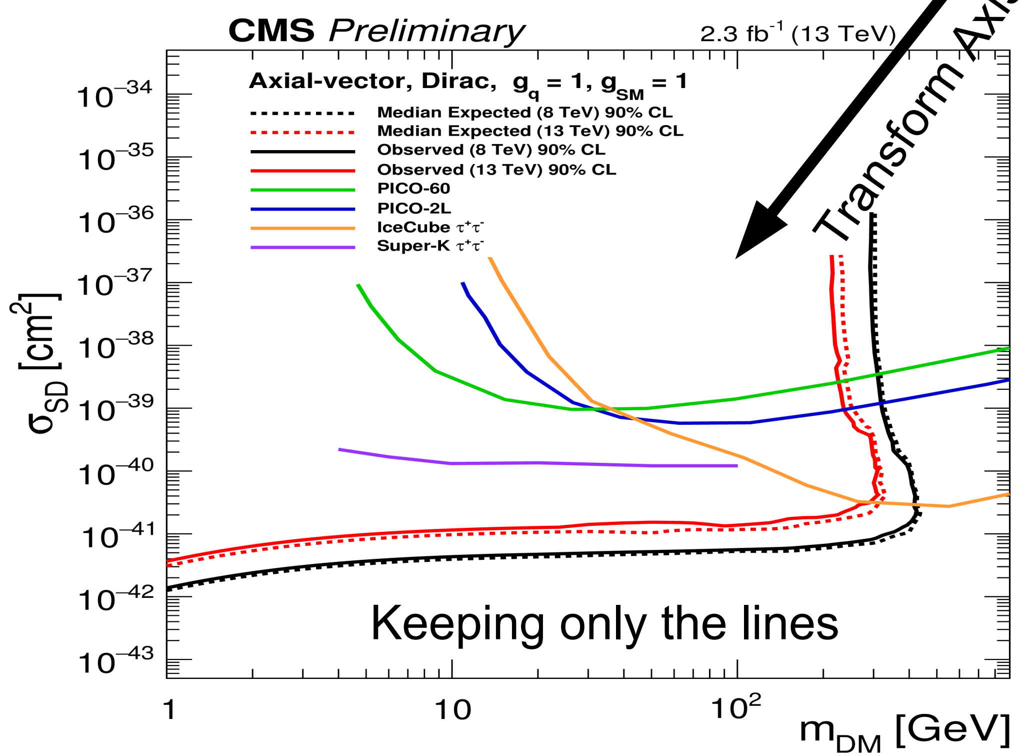




Rotate Plot



Transform Axis



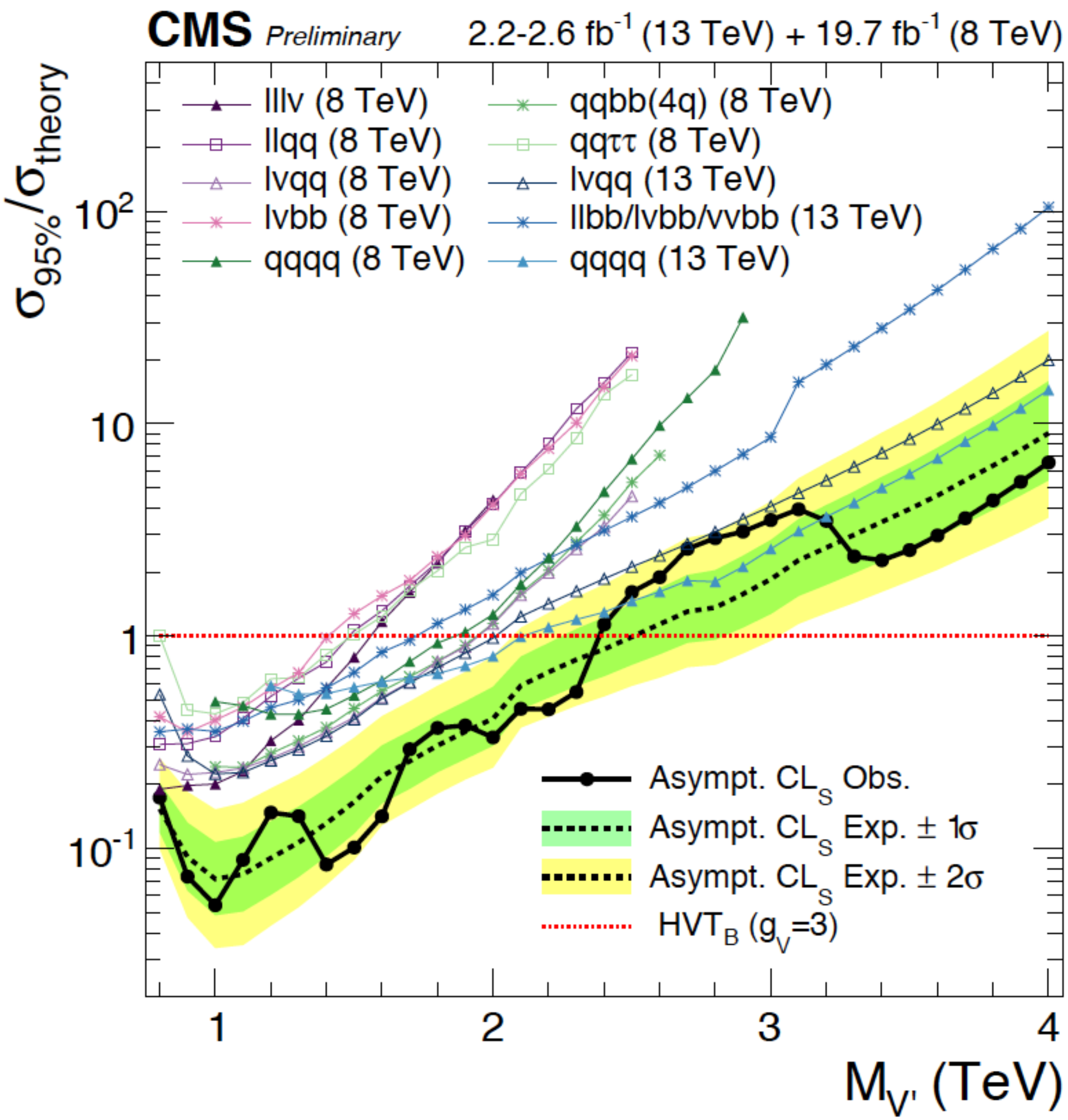
Now that search is cast in terms of mediator

No concerns in the translation

Total Luminosity : 2.6 fb^{-1} (8TeV/2015)

Final State : VV

VV Combination

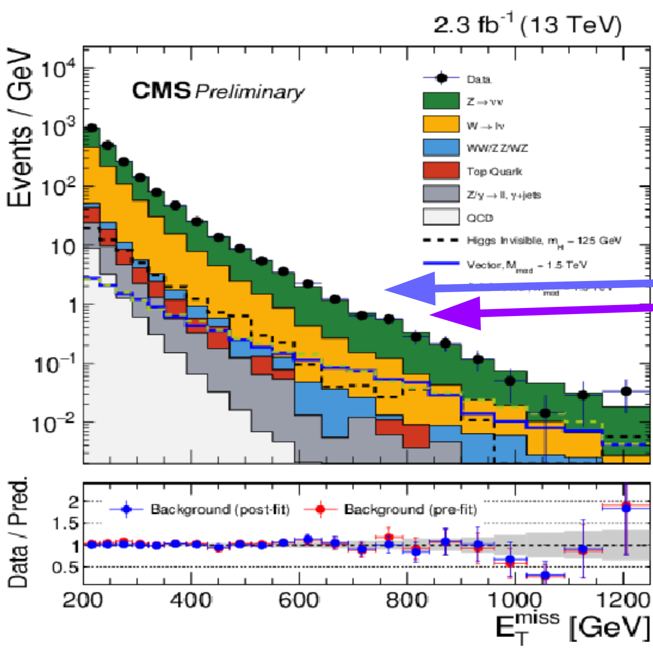


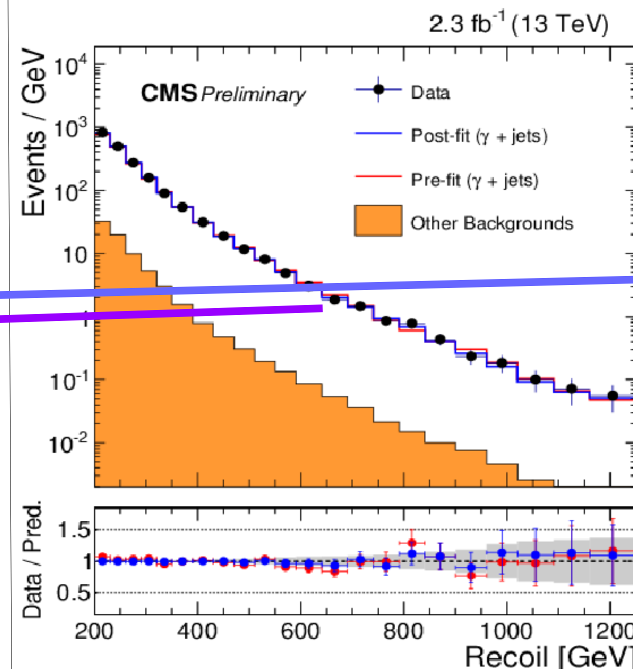
Diboson search now has many different final states

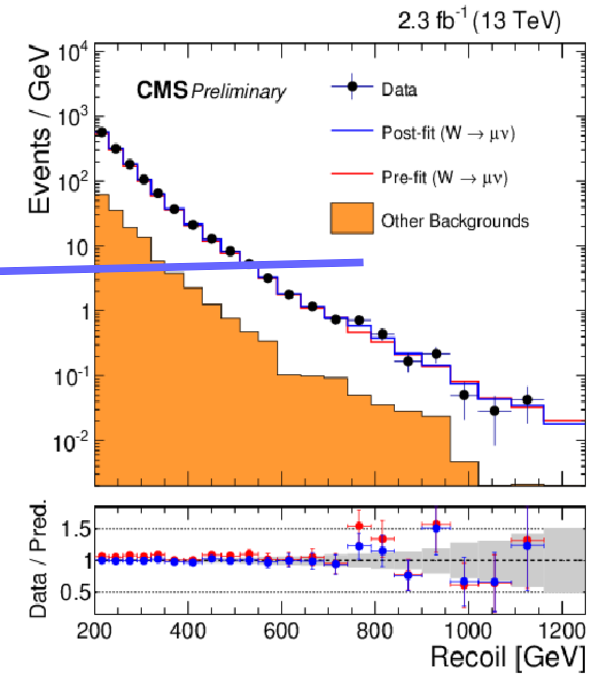
Many different combinations possible

Signal | CRs: γ+jets | + W + ...

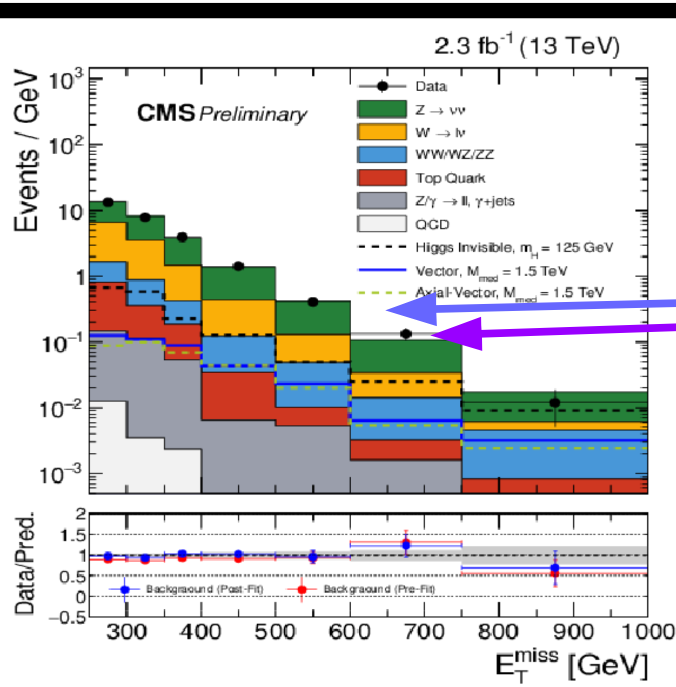
Monojet

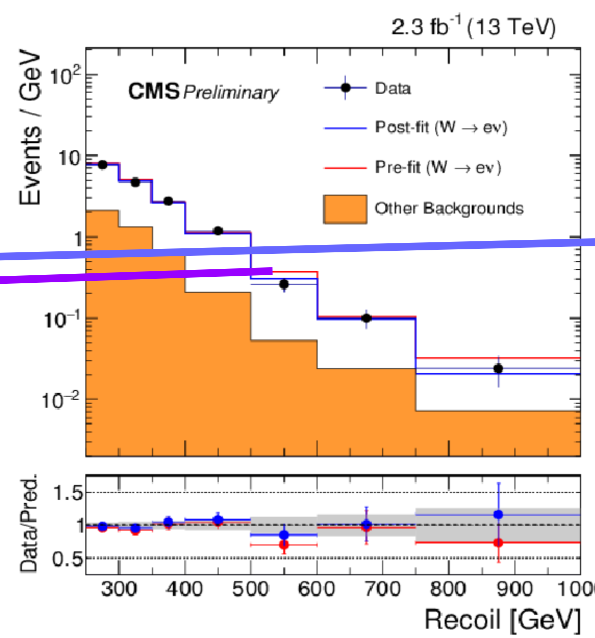


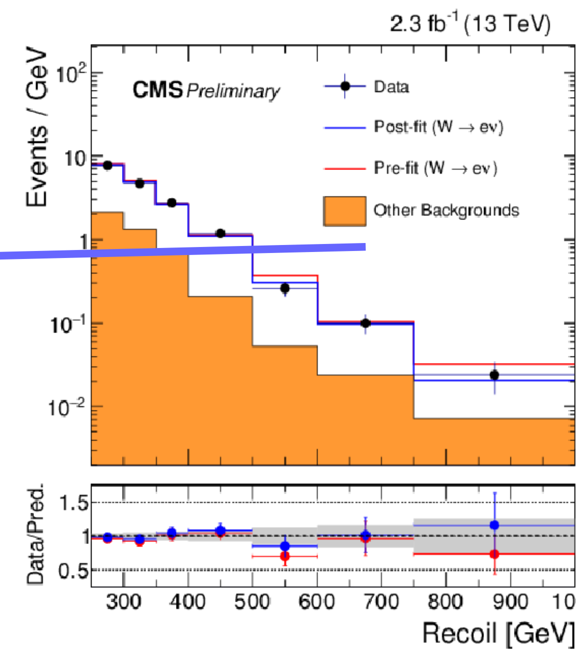




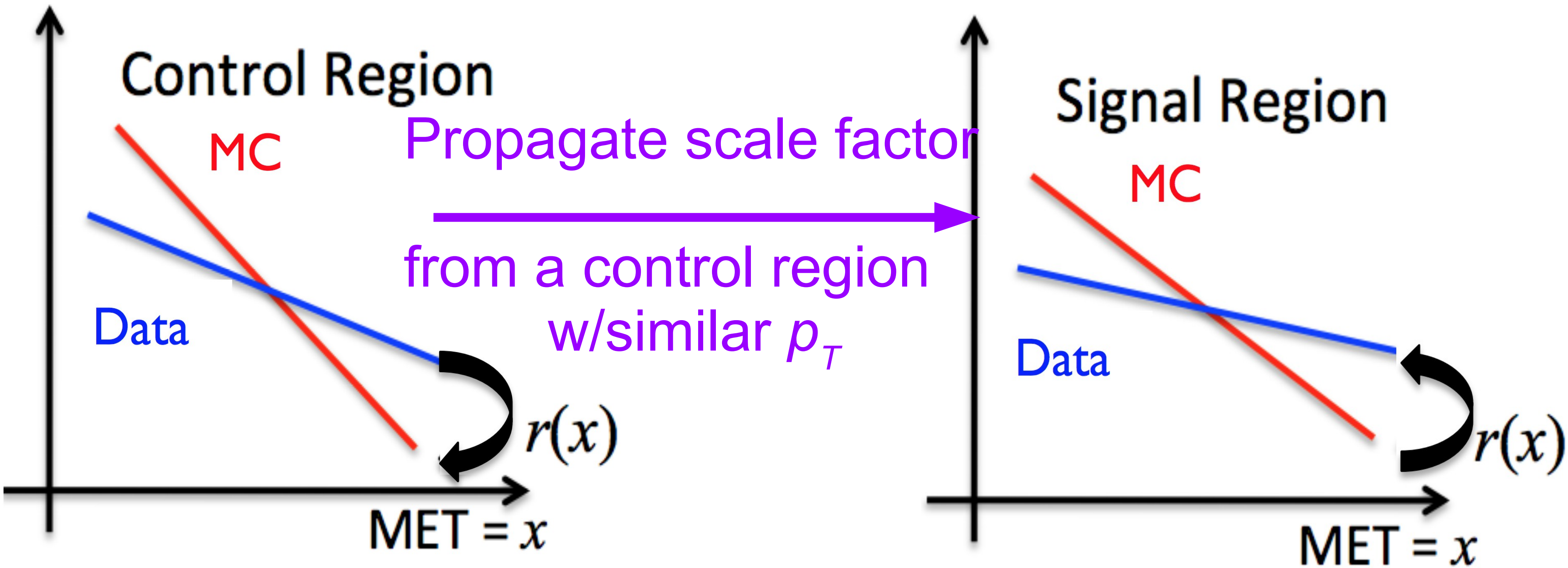
Mono-V







Strategy to fix agreement



Control: another decay of a Z boson

$Z \rightarrow \cancel{\mu\mu}$ $\longrightarrow$ $Z \rightarrow \nu\nu$

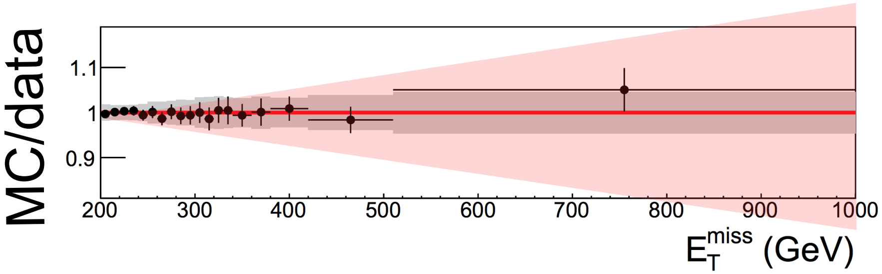
Remove

Problem is control regions have less events than signal

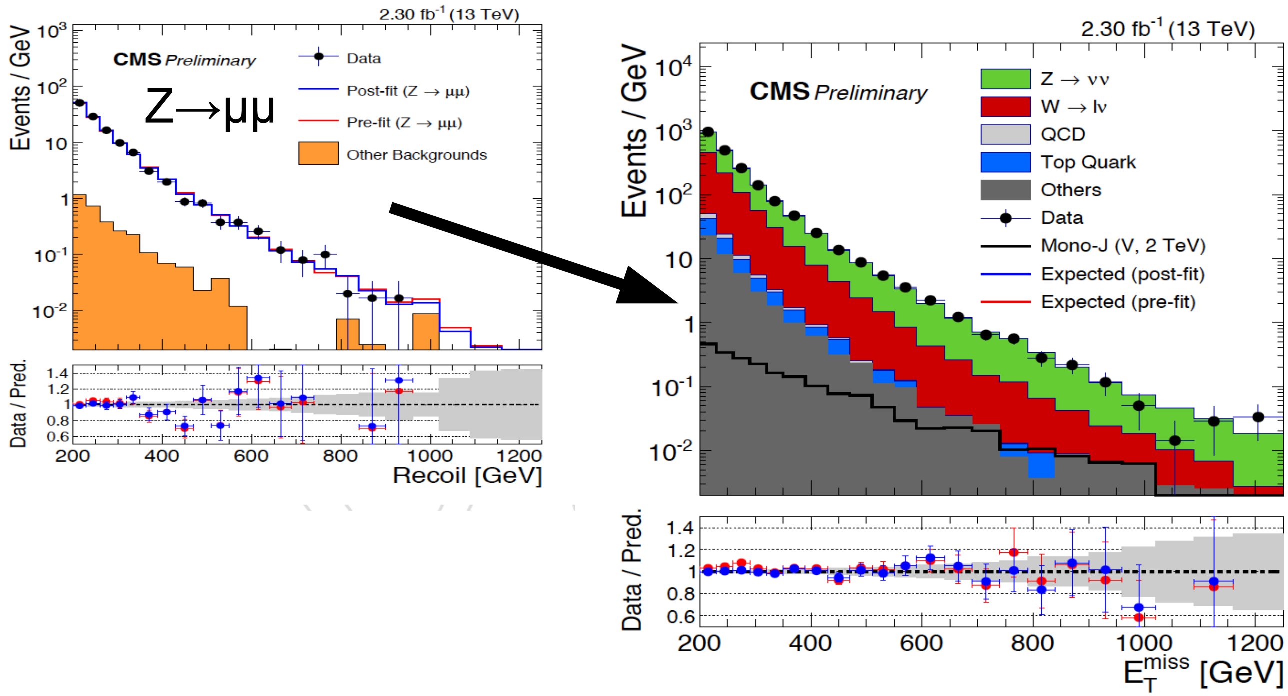
$\sigma_{\mu\mu} = 0.1\ \sigma_{\nu\nu}$ $\longrightarrow$ Statistical precision is 4x worse

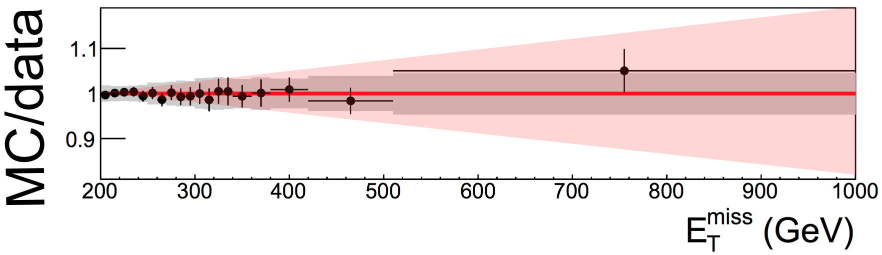
Not good enough!

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

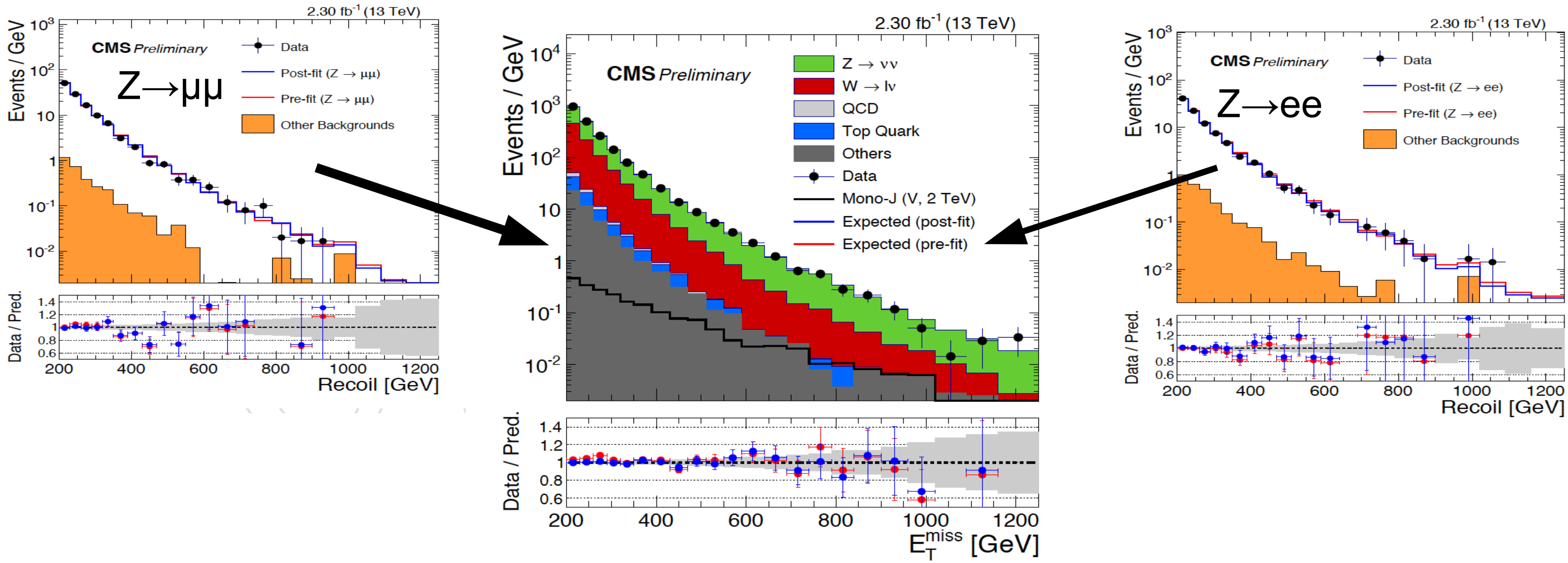


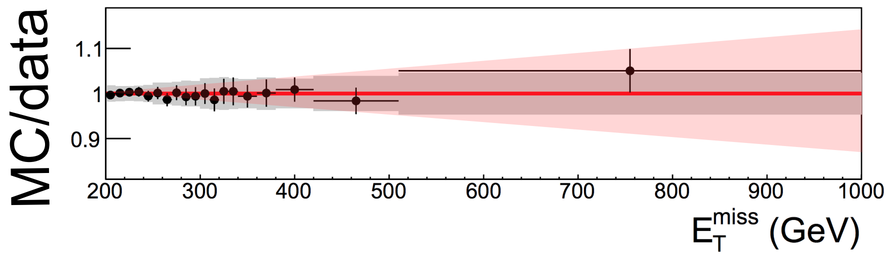
1 Control region
100% uncertainty @ 1 TeV



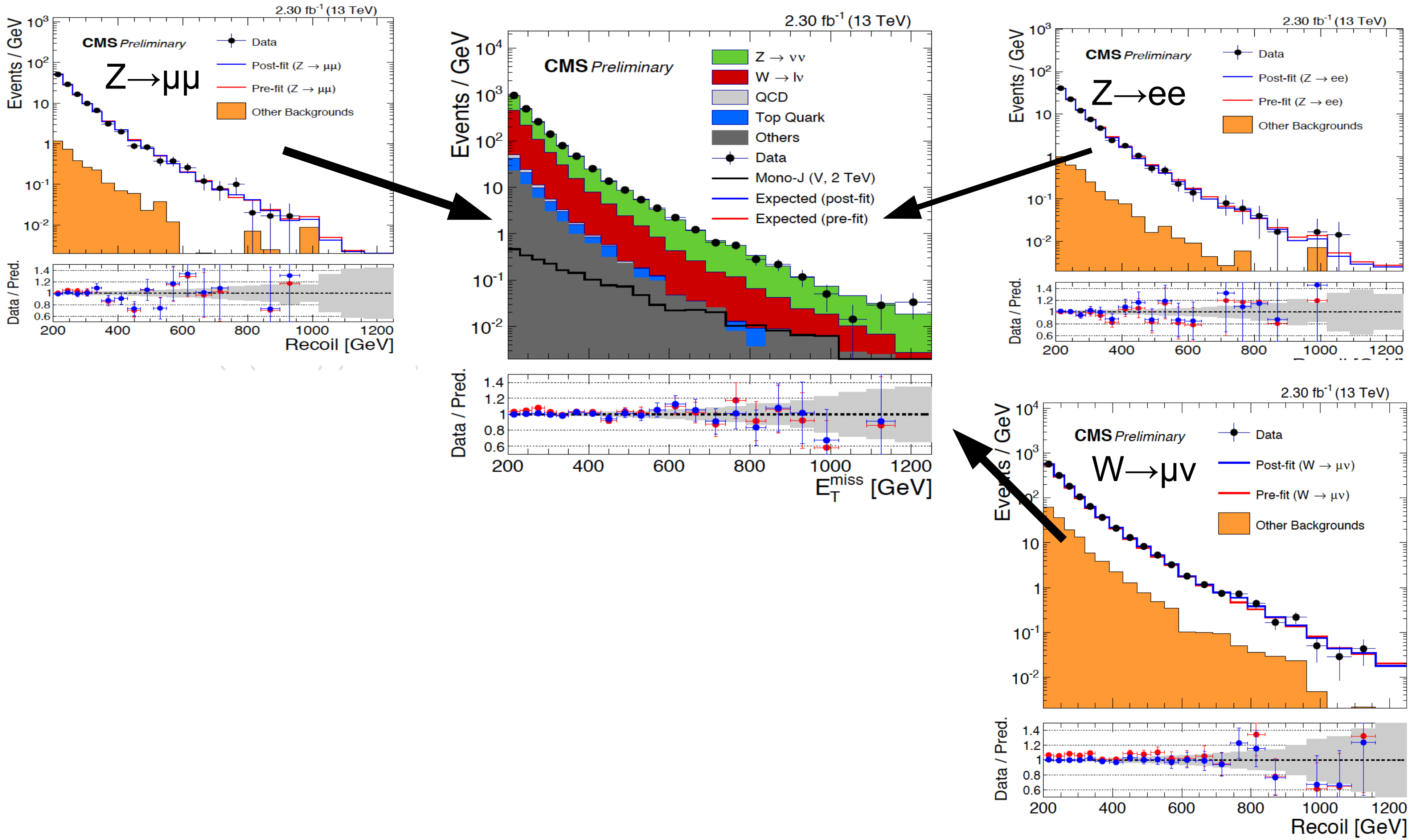


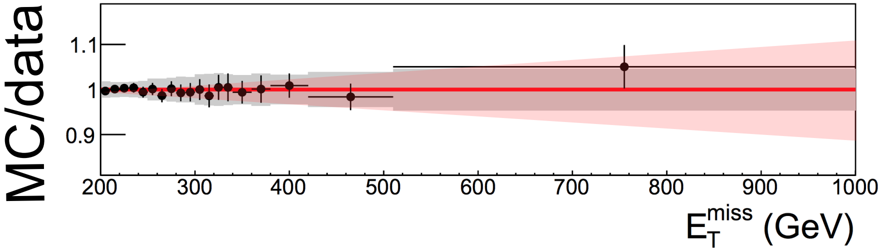
2 Control regions
60% uncertainty @ 1 TeV



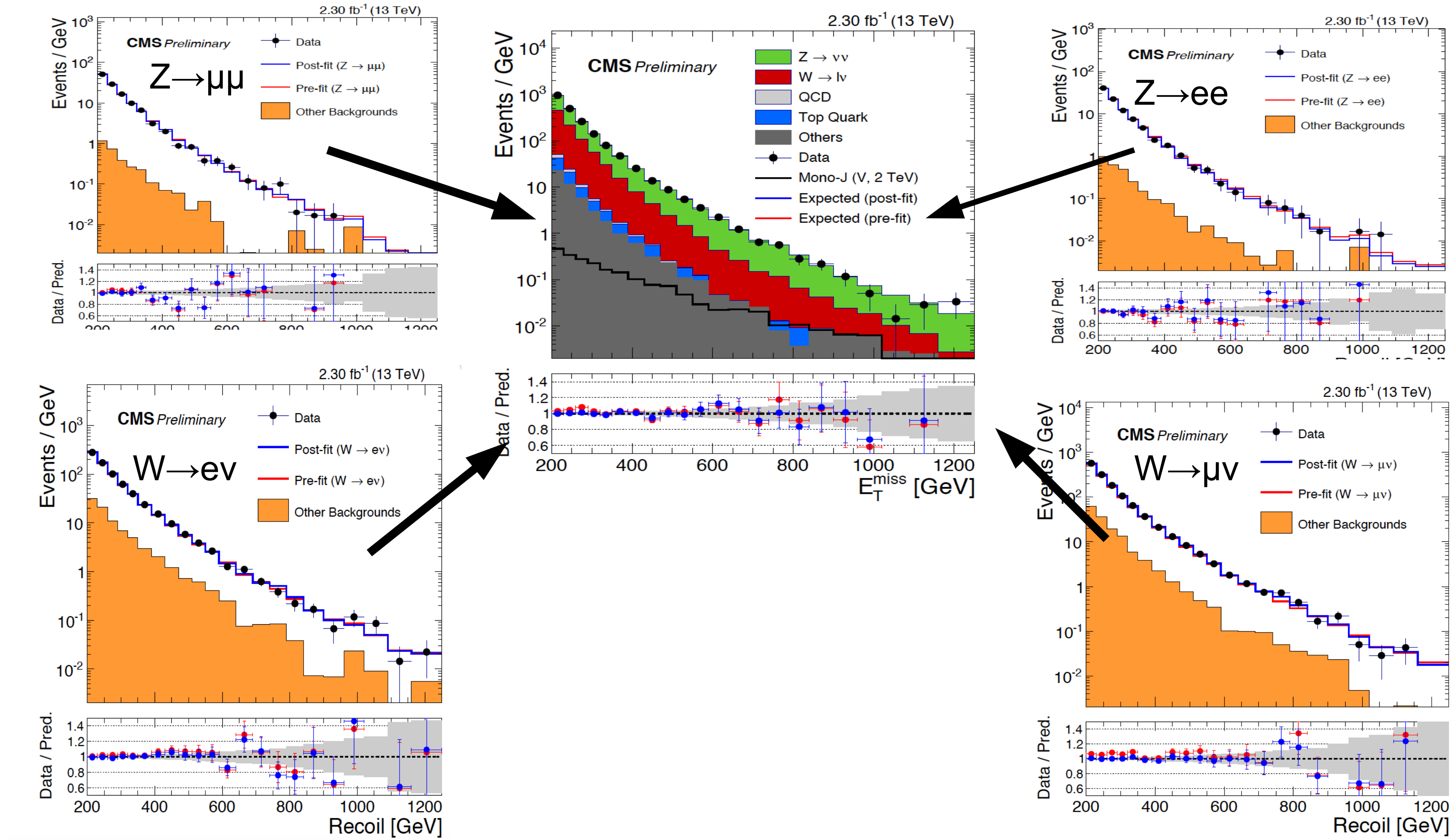


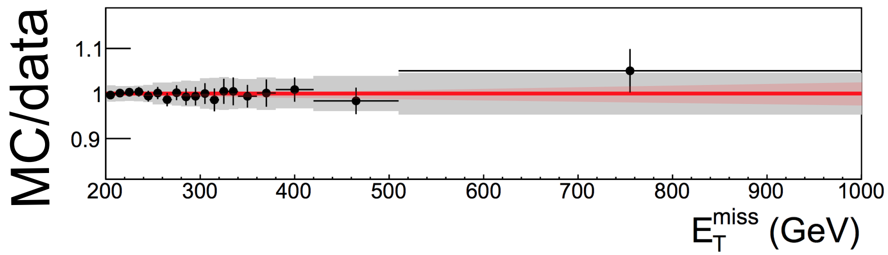
3 Control regions
40% uncertainty @ 1 TeV



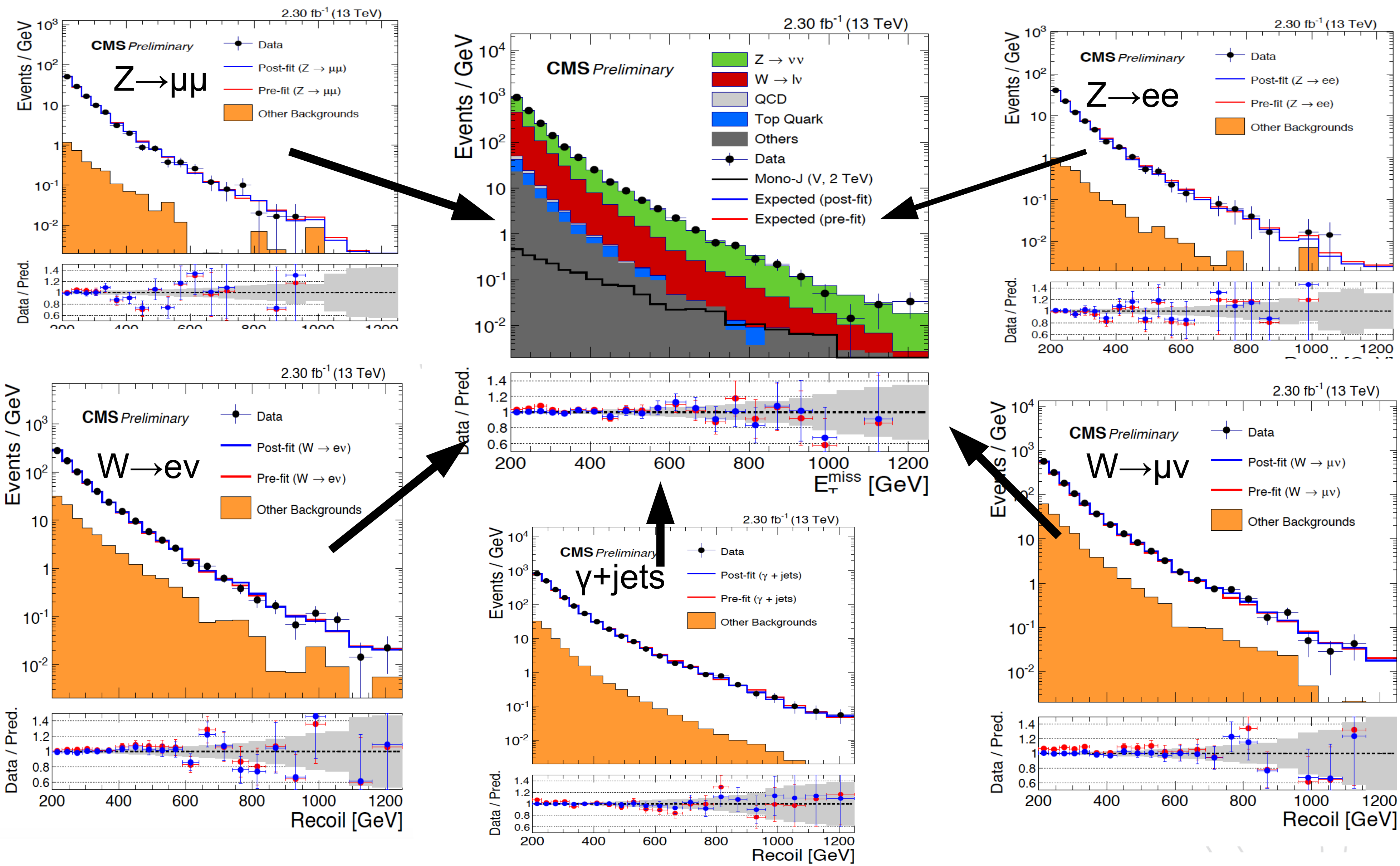


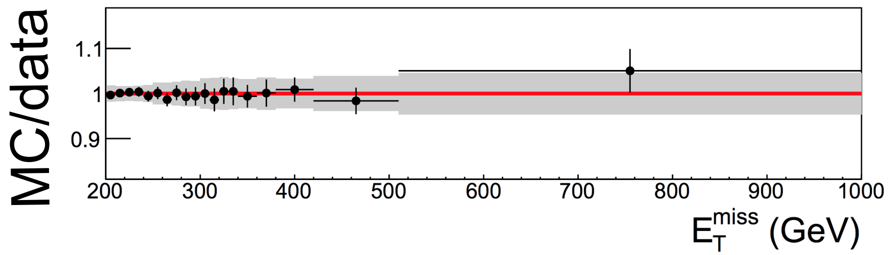
4 Control regions
30% uncertainty @ 1 TeV





5 Control regions
15% uncertainty @ 1 TeV

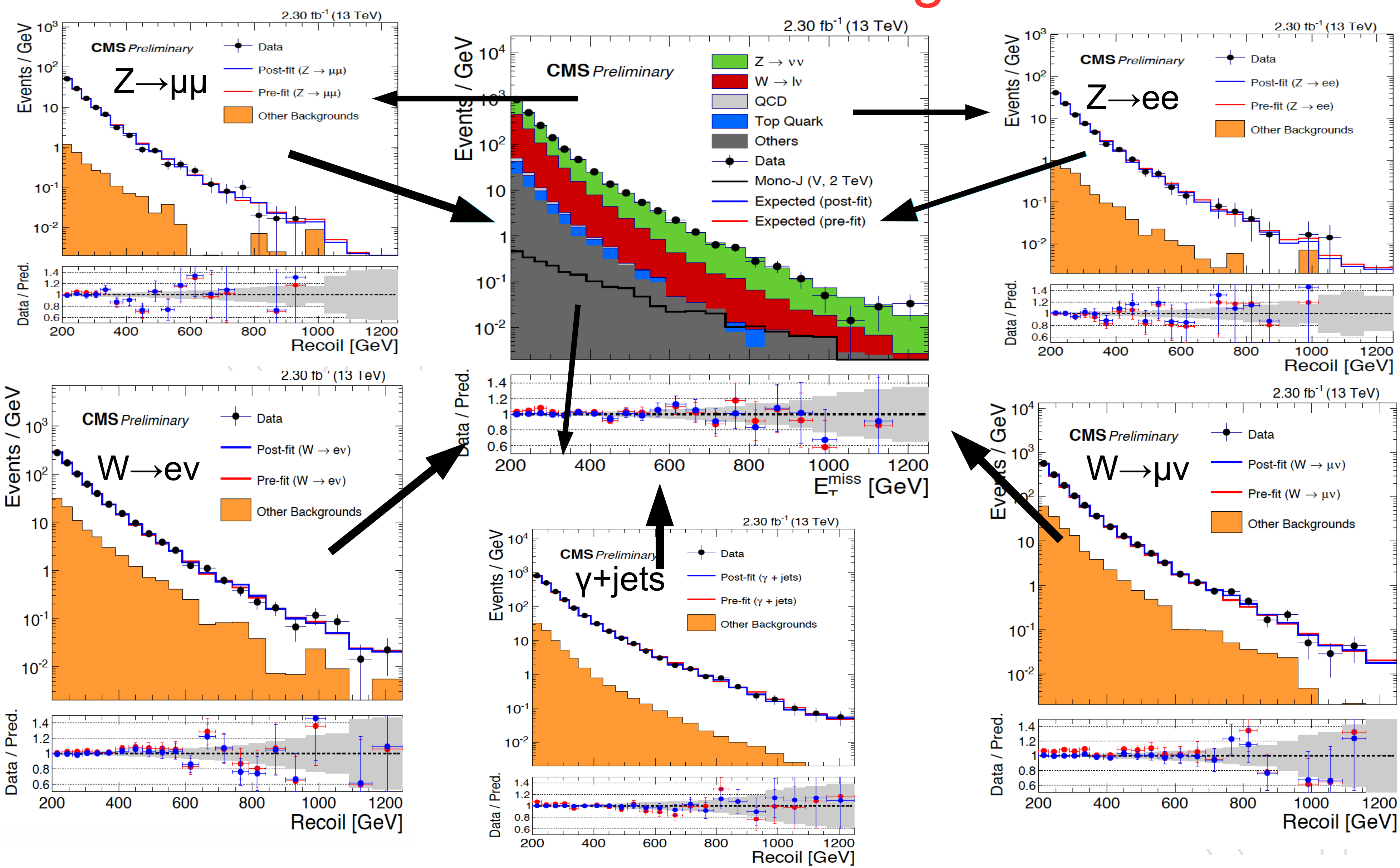




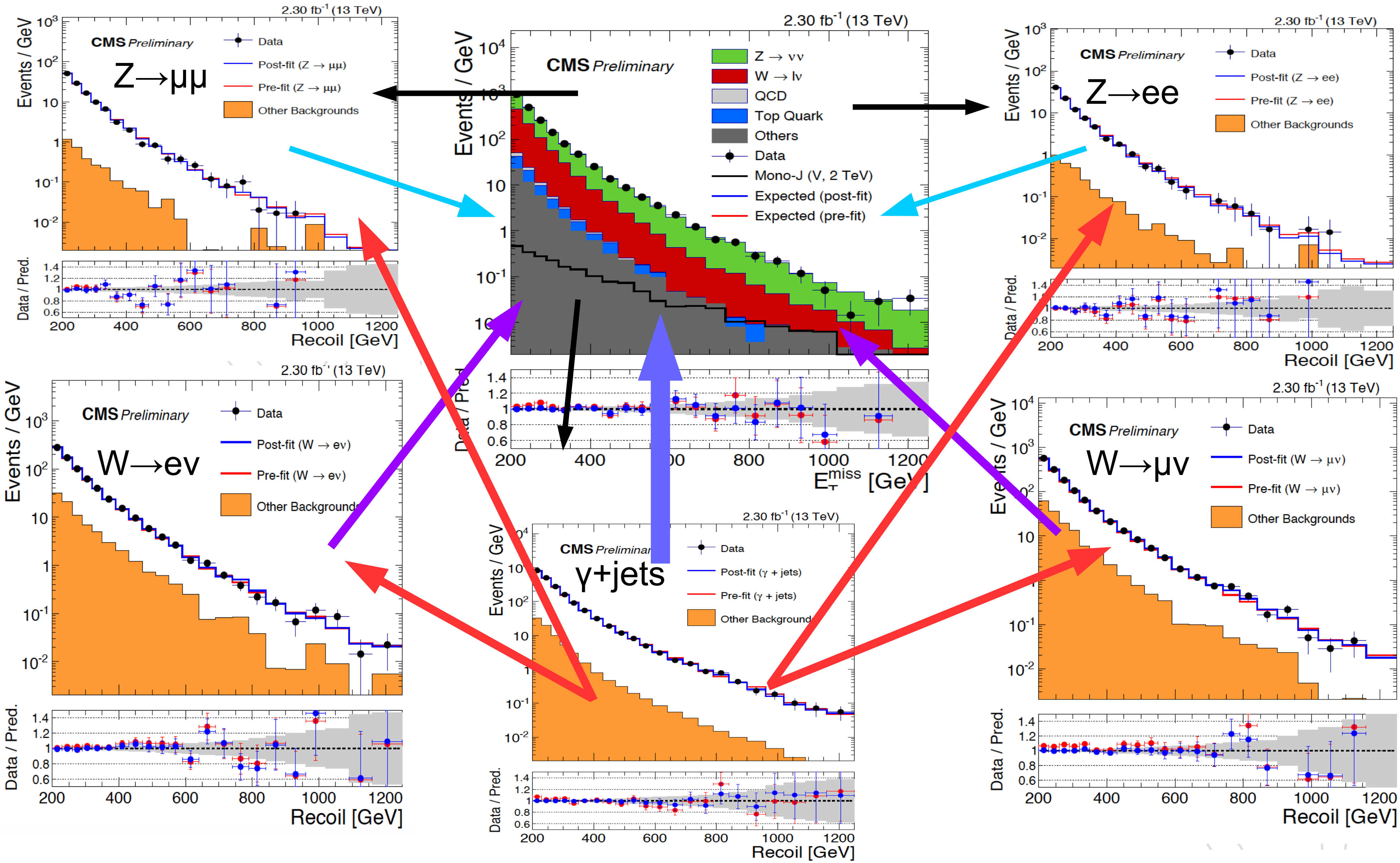
5 Control regions+Signal

15% uncertainty @ 1 TeV

All in one big Simultaneous fit

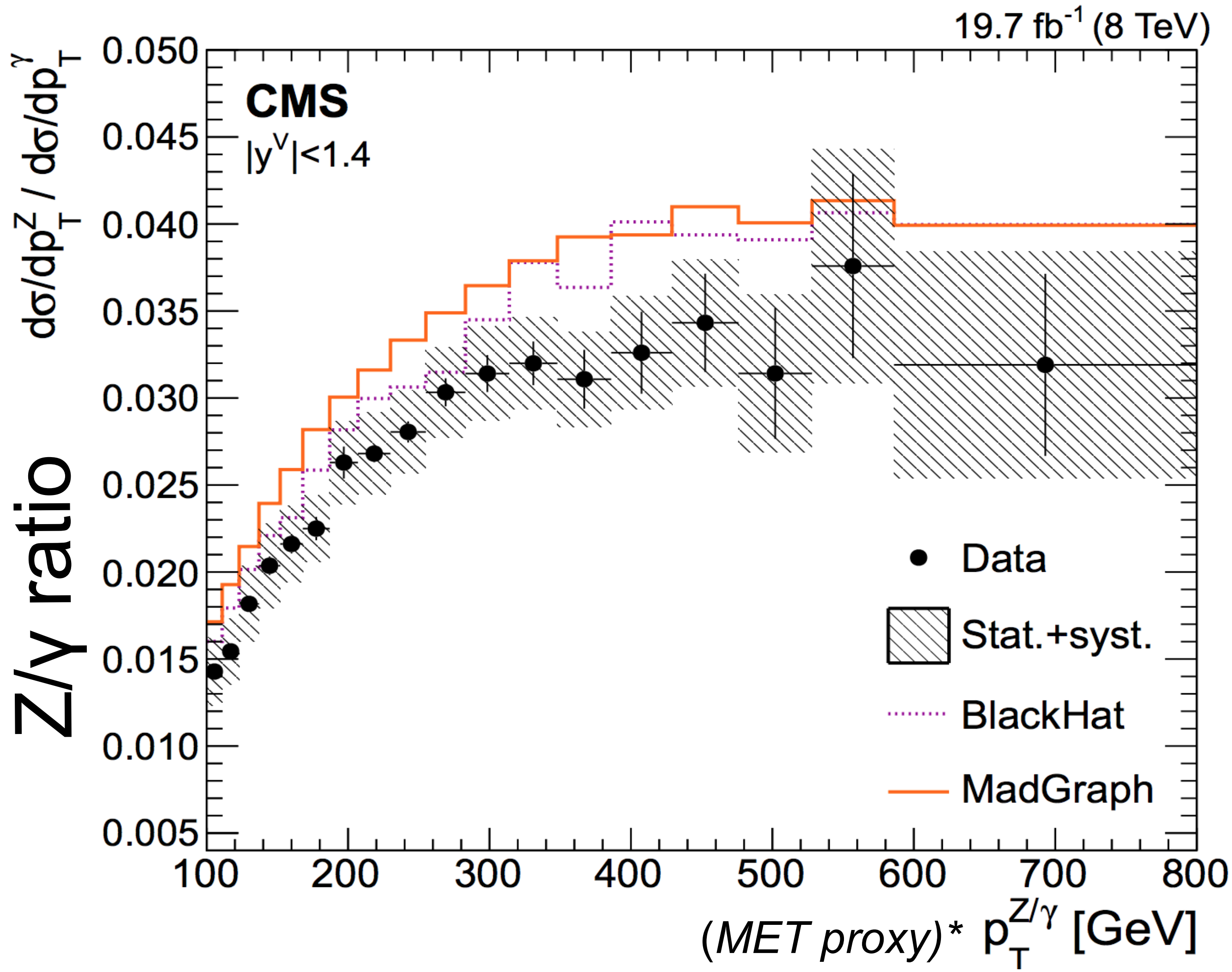


- To large extent the γ+jets drives the constraint
  - However we need need Z→ll to constraint γ



A mystery? Understanding Z/γ p_T

Can we really use Photons to model Zs ?

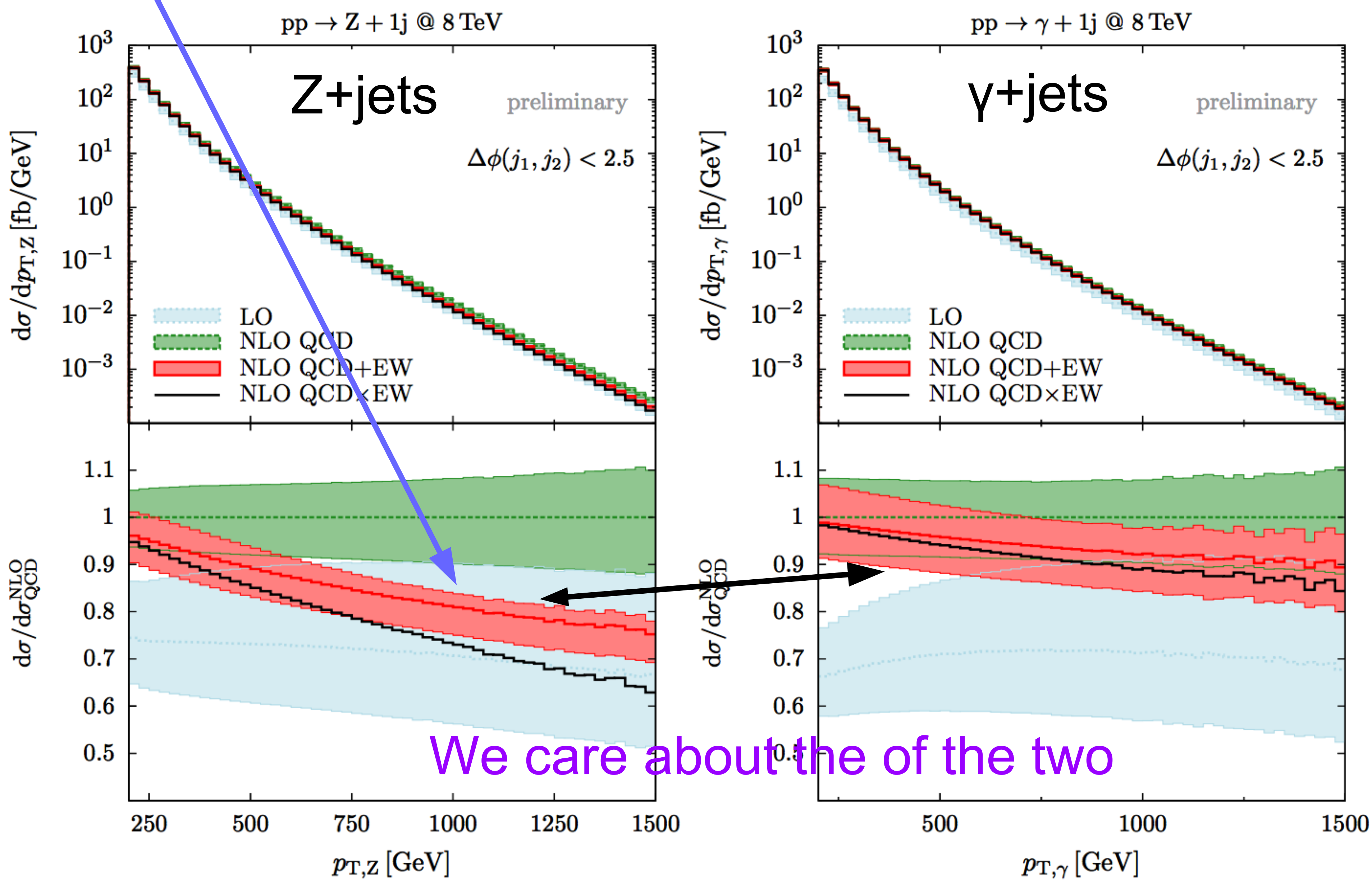


*See backup

CMS-SMP-14-005

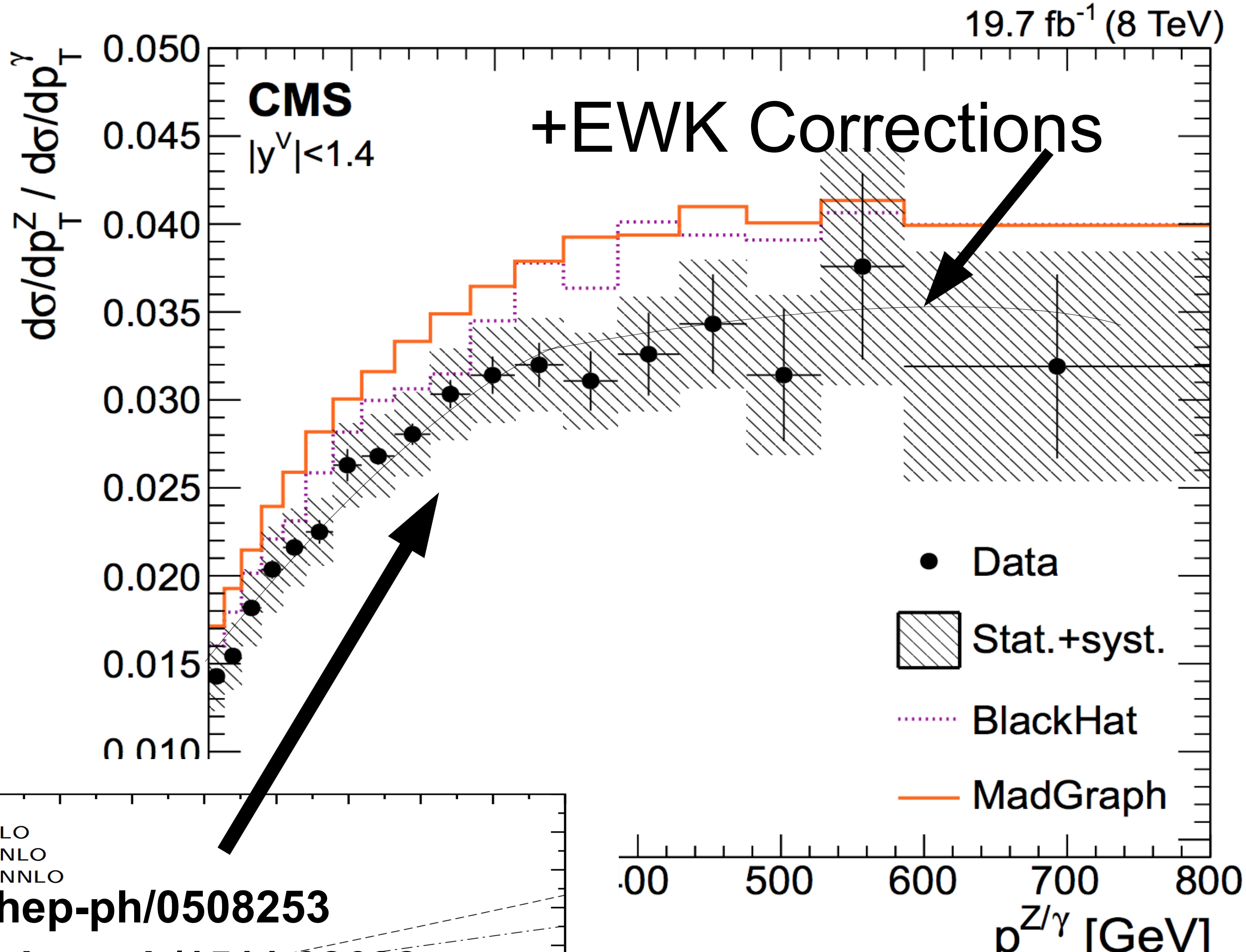
How do we fix this?

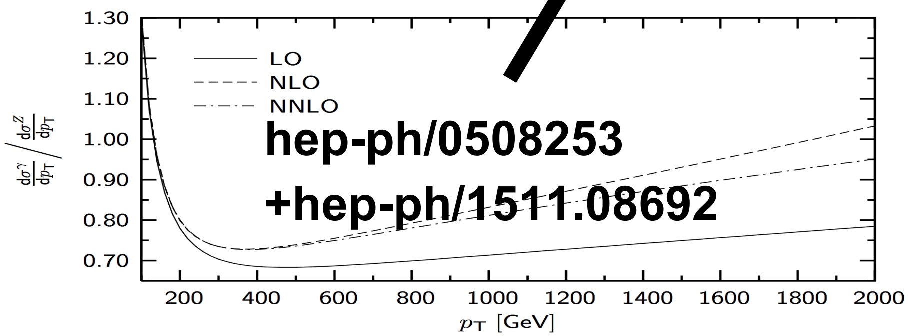
Impact of the electroweak corrections



A mystery? The Z p_T spectrum

- These results are missing NLO EWK corrections!





hep-ph/0508253

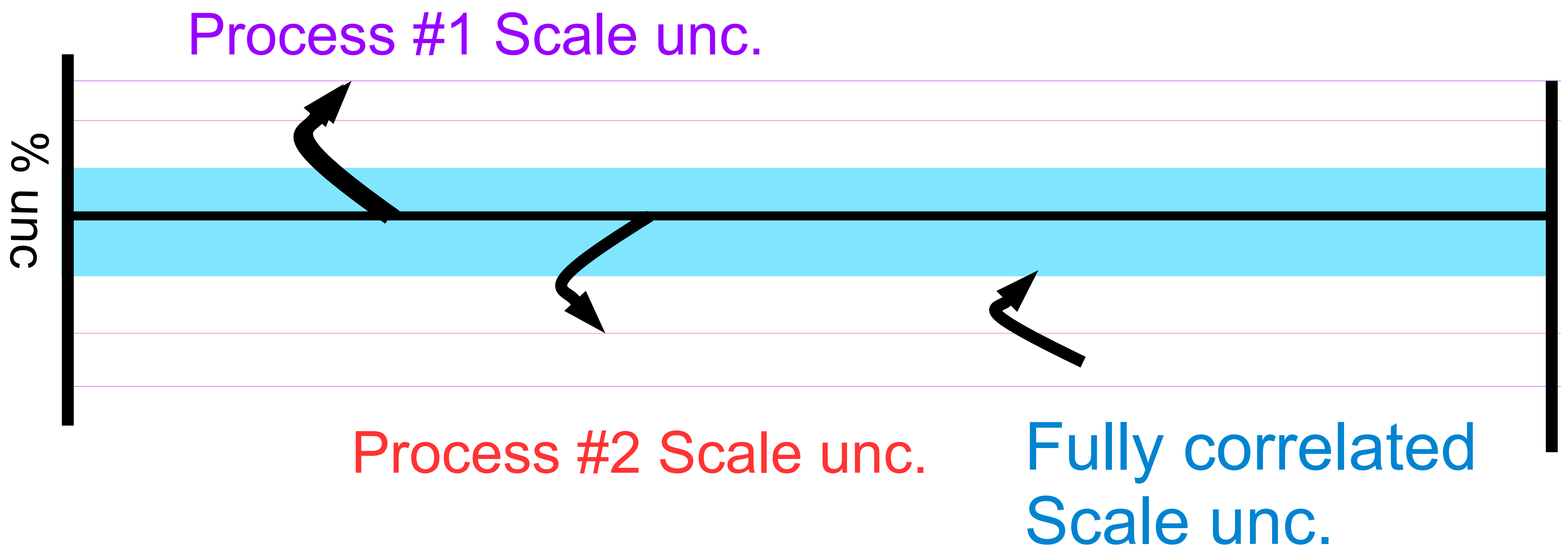
+hep-ph/1511.08692

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?

Scale uncertainty on process #1

Scale uncertainty on process #2

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

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

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

Uncertainty on ratio? How is it done?

Scale uncertainty on process #1

Scale uncertainty on process #2

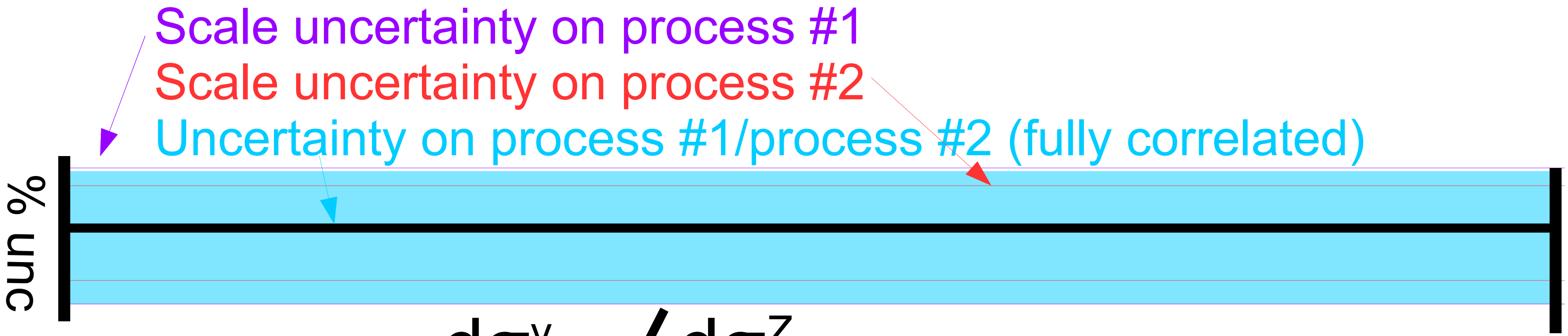
Uncertainty on process #1/process #2 (fully correlated)

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

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

Adjust C until uncertainty is

Uncertainty on ratio? How is it done?



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

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

Decorrelate scale unc. until its max of either process

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

What is the previous unc?

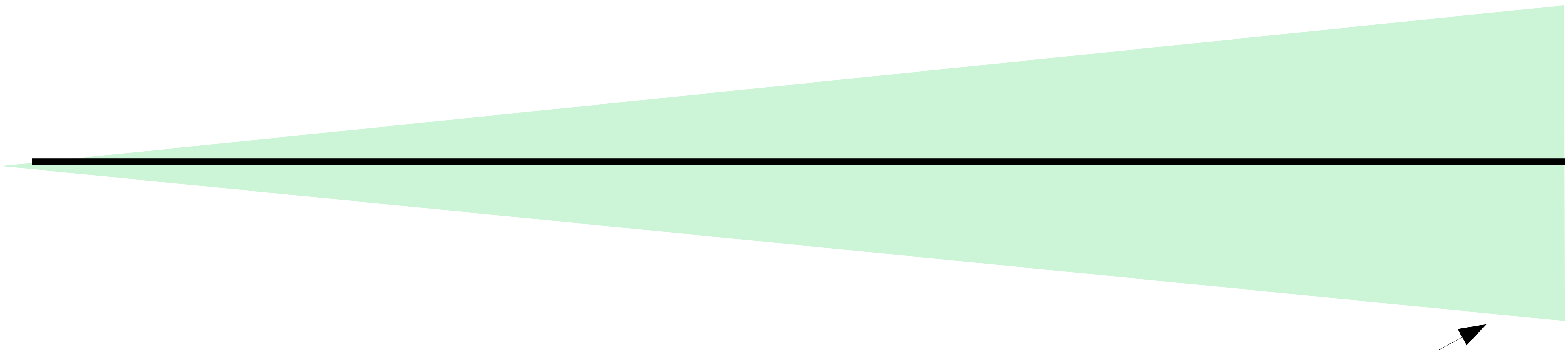
Can we motivate this?

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

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

Makes Little Sense

What about the EWK uncertainty?

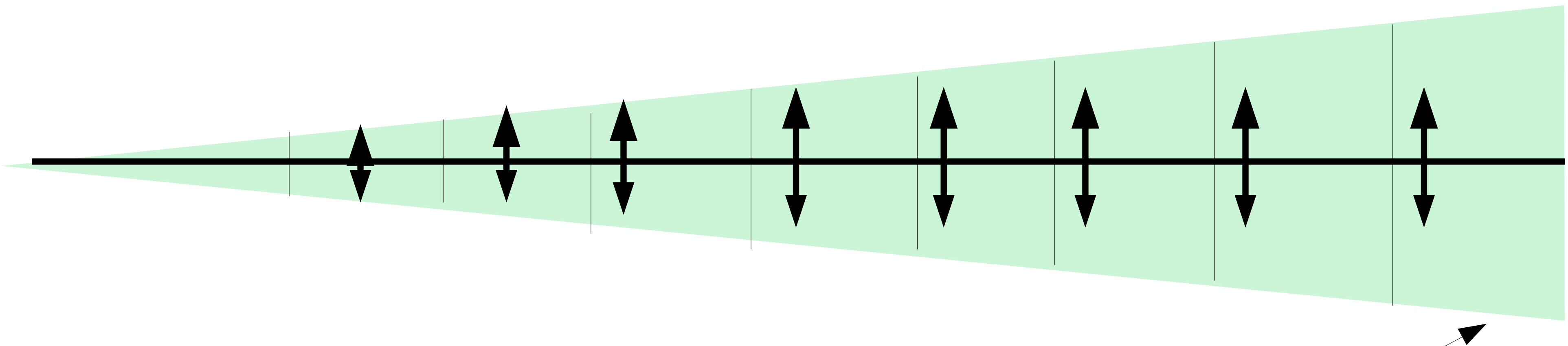


In light of being conservative :

Treated full correction as an uncertainty

More formal way could be with scale

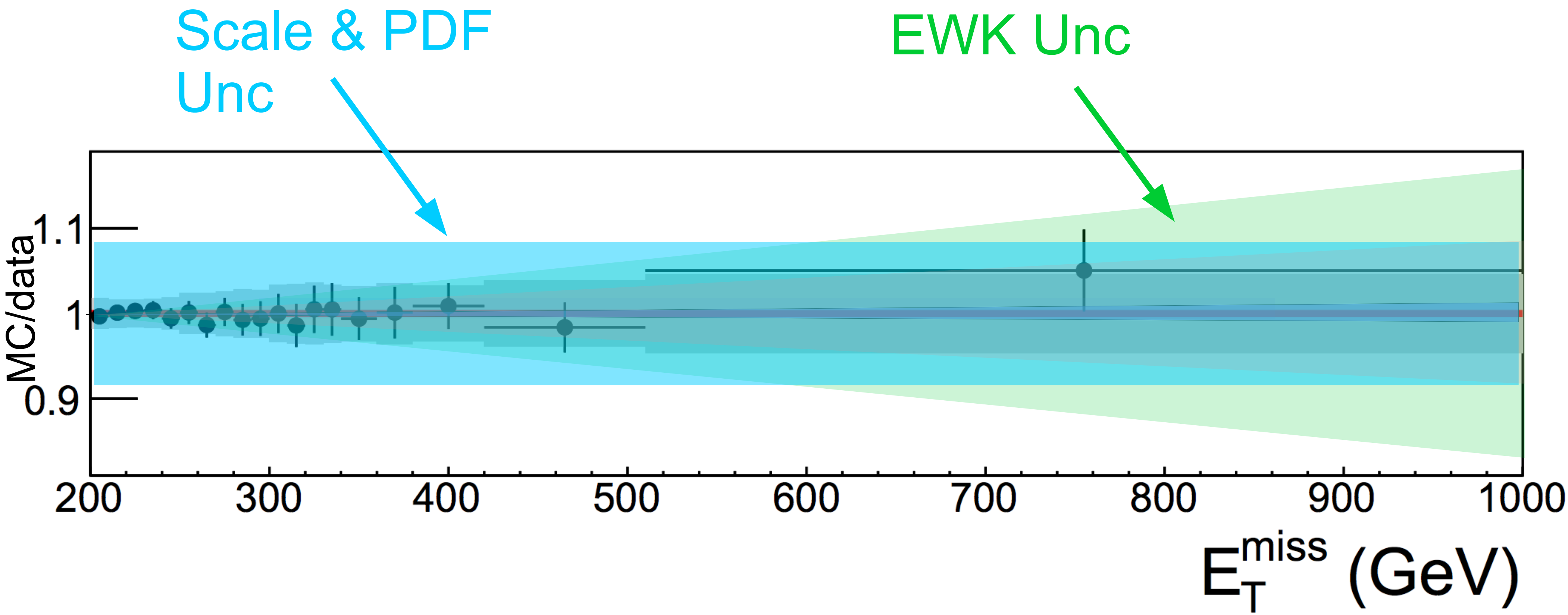
What about the EWK uncertainty?



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?

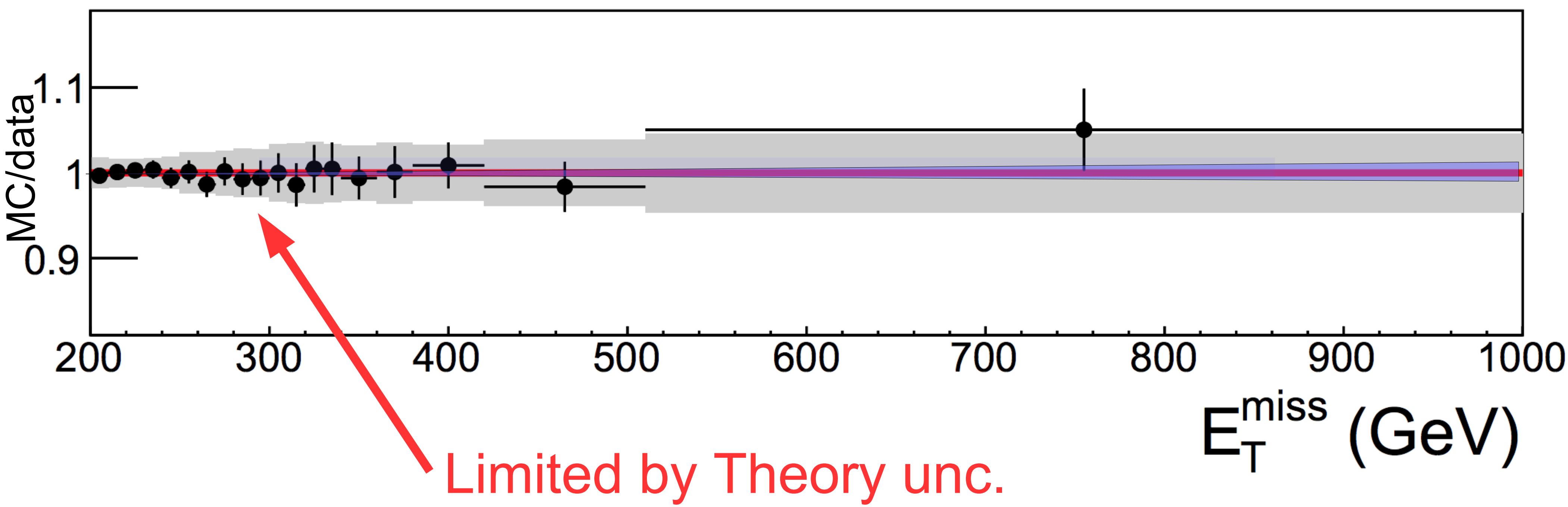


Updated unc still too large

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