

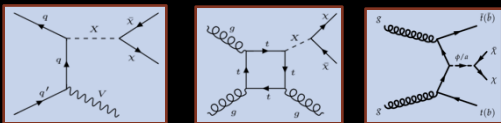
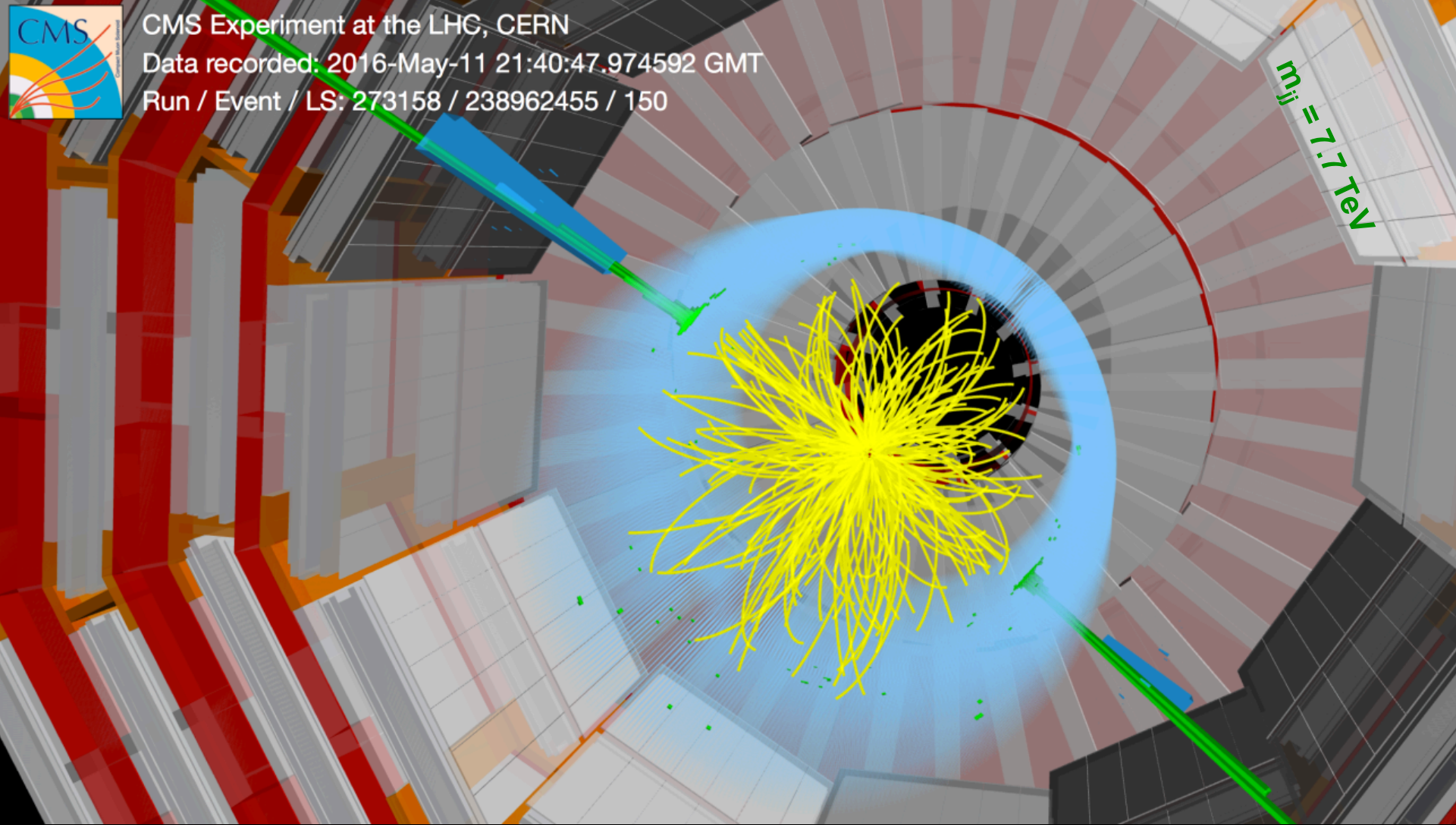
“SEARCHES FOR EXOTICS AT CMS”

Tristan du Pree (CERN) *on behalf of the CMS Collaboration*



CMS Experiment at the LHC, CERN
Data recorded: 2016-May-11 21:40:47.974592 GMT
Run / Event / LS: 273158 / 238962455 / 150

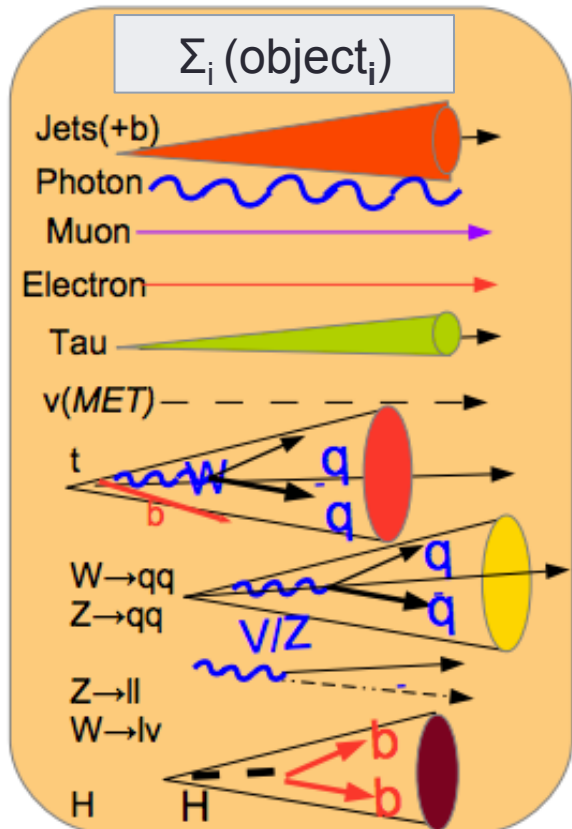
$m_{ij} = 7.7 \text{ TeV}$



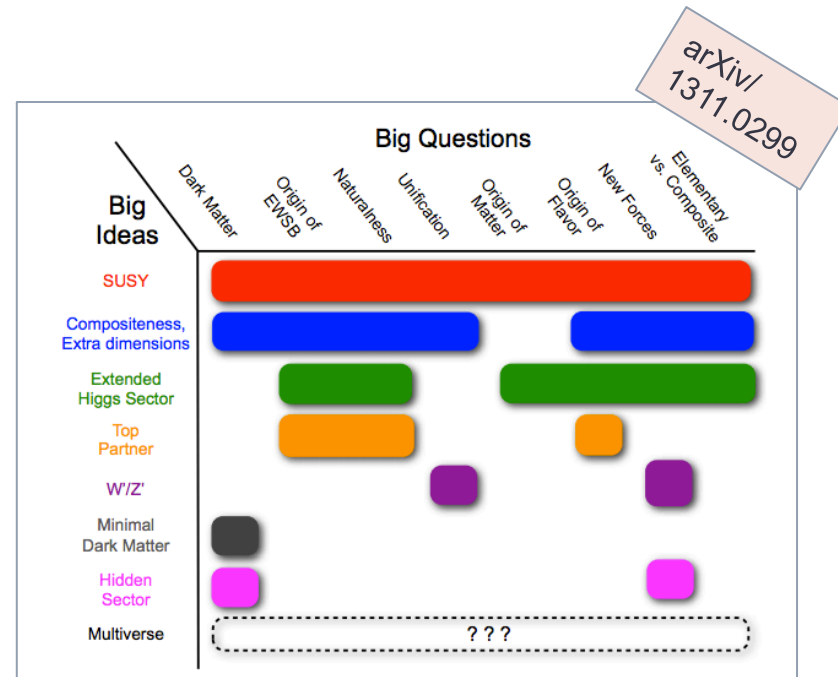
LHC interpretations workshop
CERN, 12-14 December 2016

This workshop

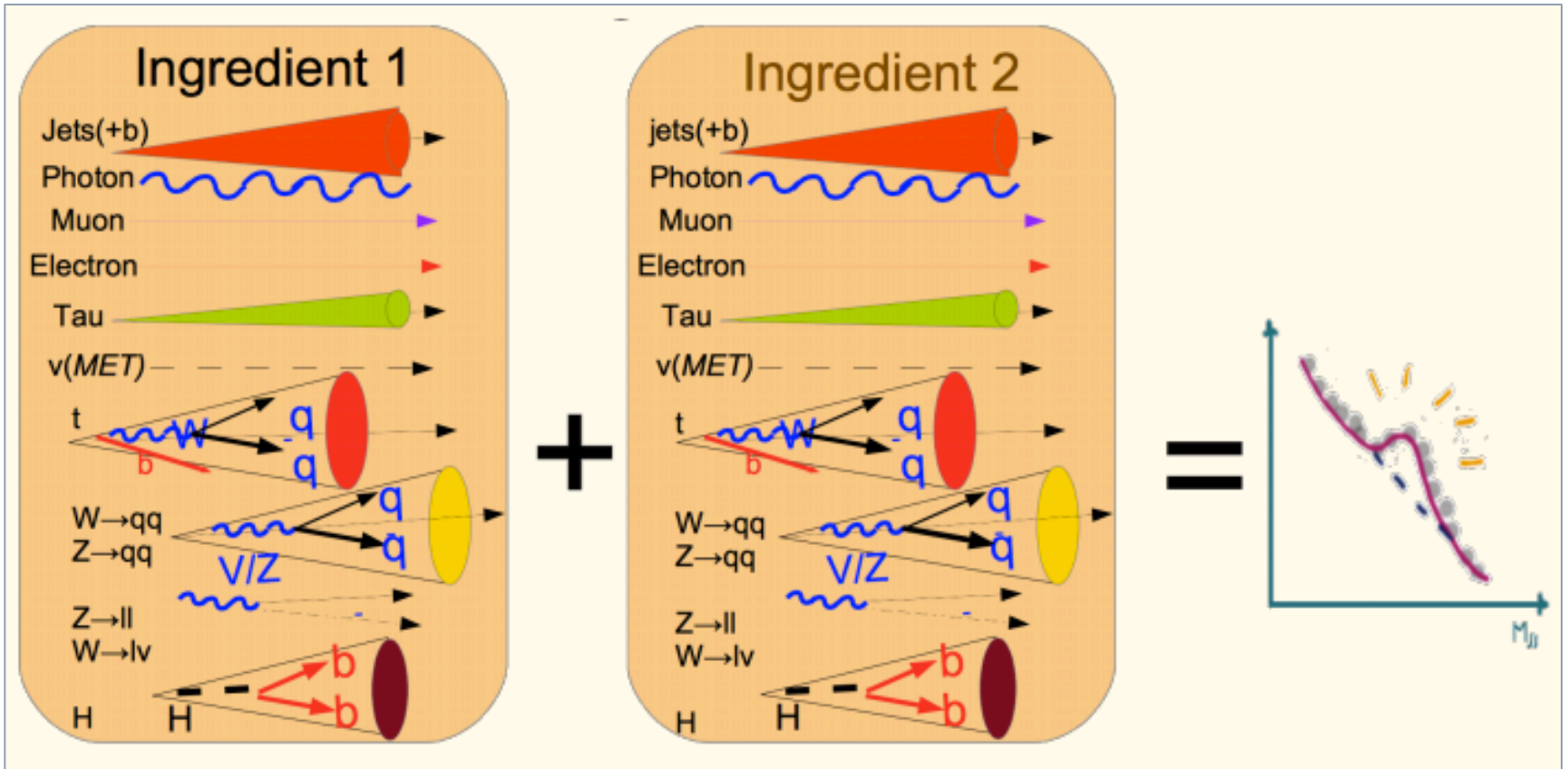
Detector



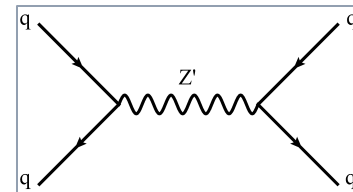
Interpretations



I) Resonances

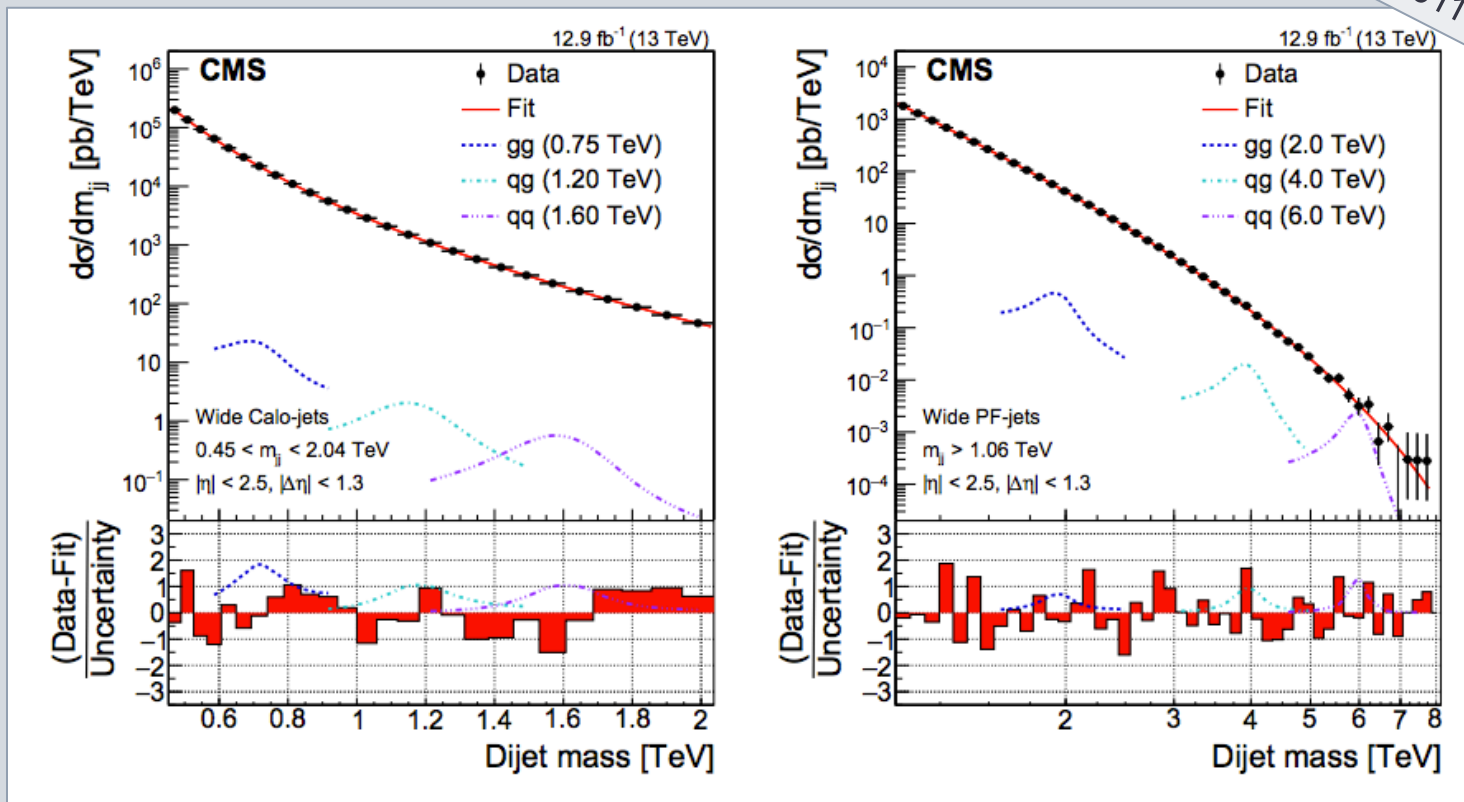


j+j



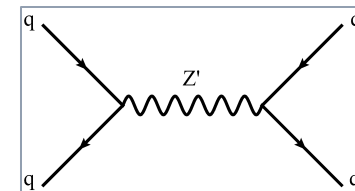
- **Dijet search: $p p \rightarrow X \rightarrow j j$**

arXiv/1611.03568



- **High mass & Low mass (scouting)**

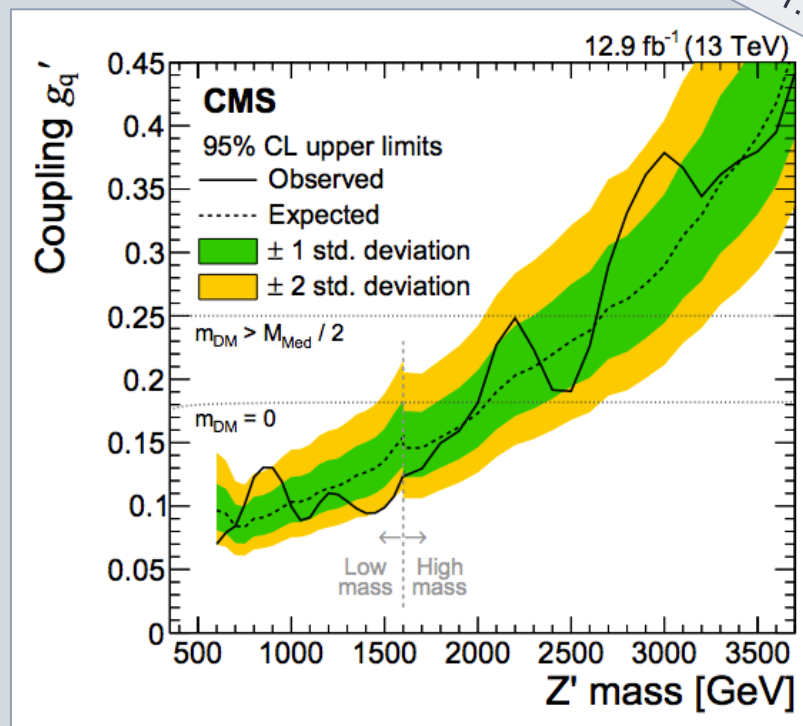
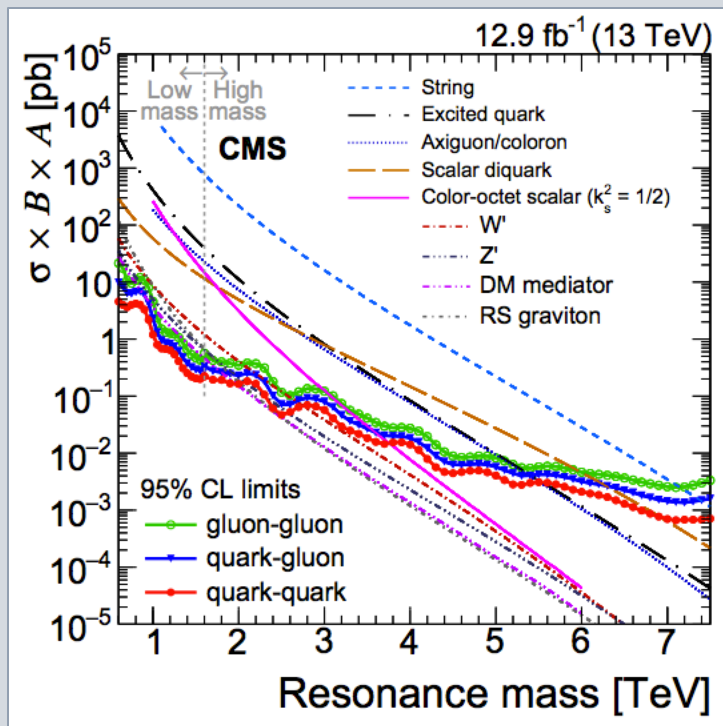
j+j



• Sensitive to various models (gg / qq / qg)

➤ New interpretation: Dark Matter mediator

arXiv/1611.03568

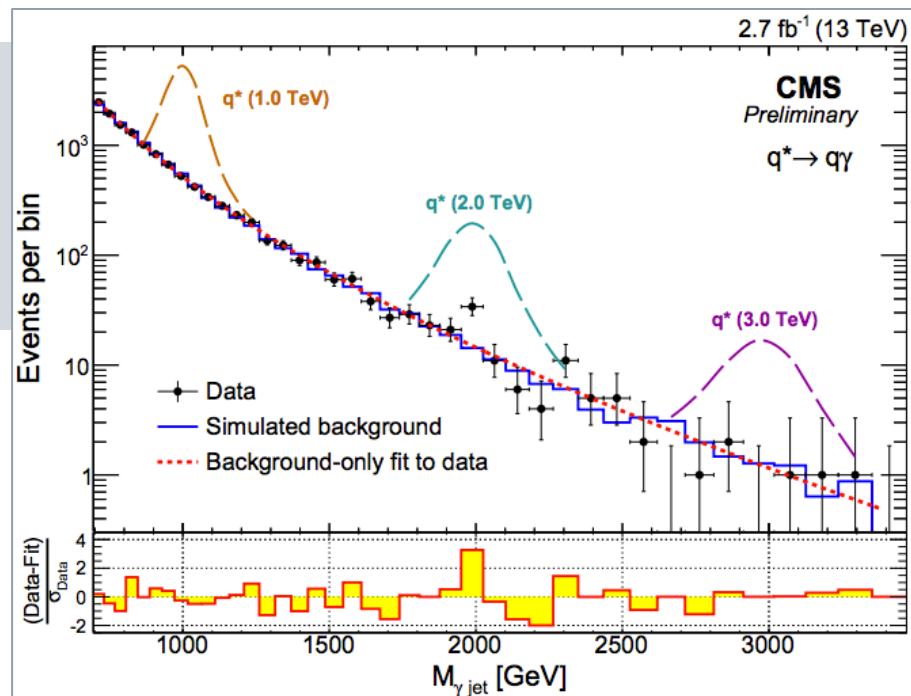
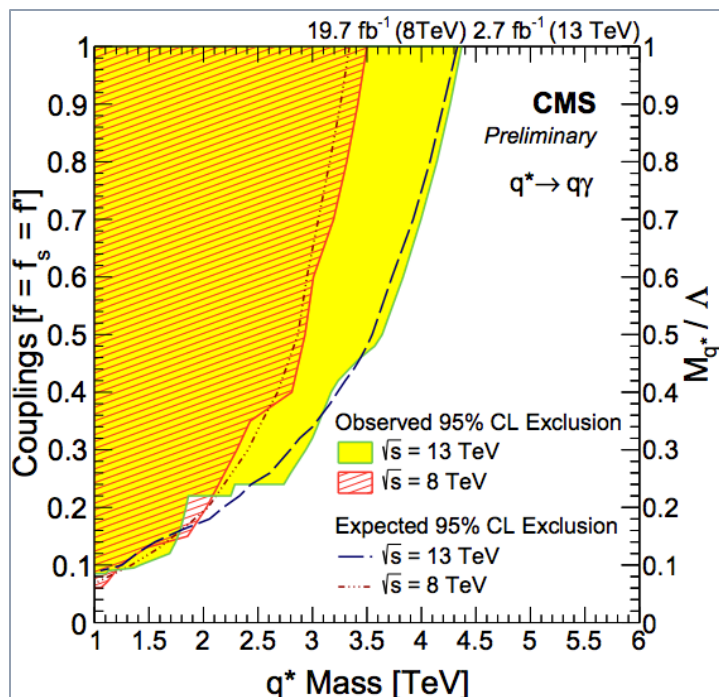
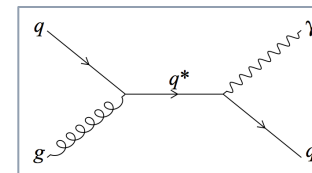


➤ Limits on cross-section & coupling

j+γ

• Search for excited quarks

- Excess **~2 TeV**
- Dataset **2.7/fb**



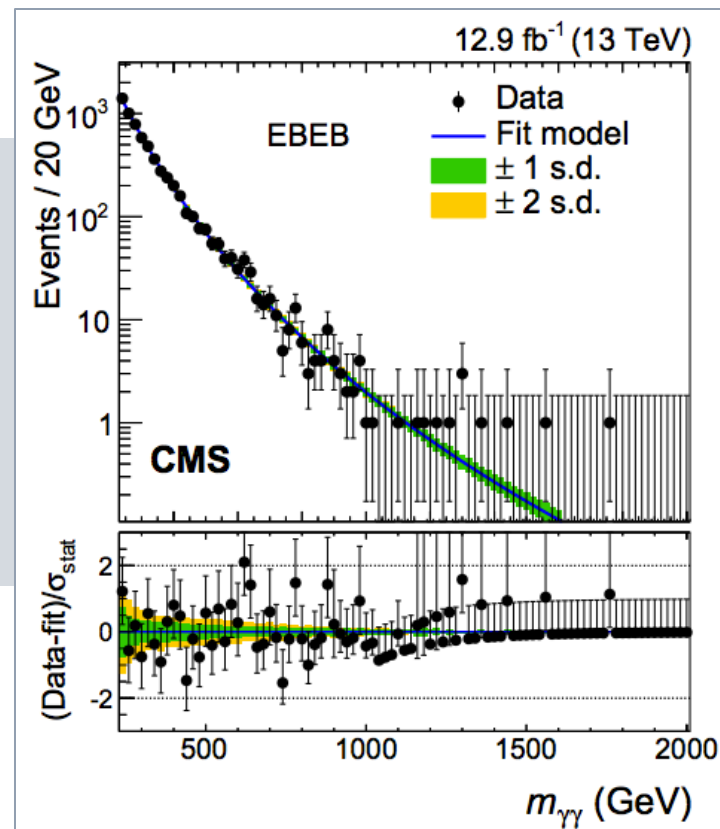
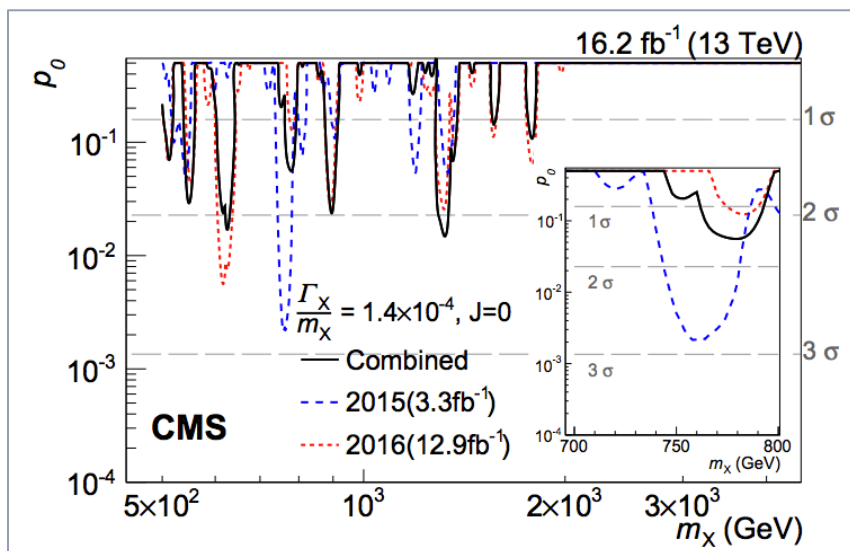
• Interpretations

- Usual (M,σ) limits
- Also coupling: **(M,f)**

arXiv/1609.02507

$\Upsilon + \gamma$

- **Search for diphoton**
 - Spin-0 & spin-2
- **Combined interpretations**
 - **2012**: 19.7/fb @ 8TeV
 - **2015**: 3.3/fb @ 13 TeV
 - **2016**: 12.9/fb @ 13 TeV

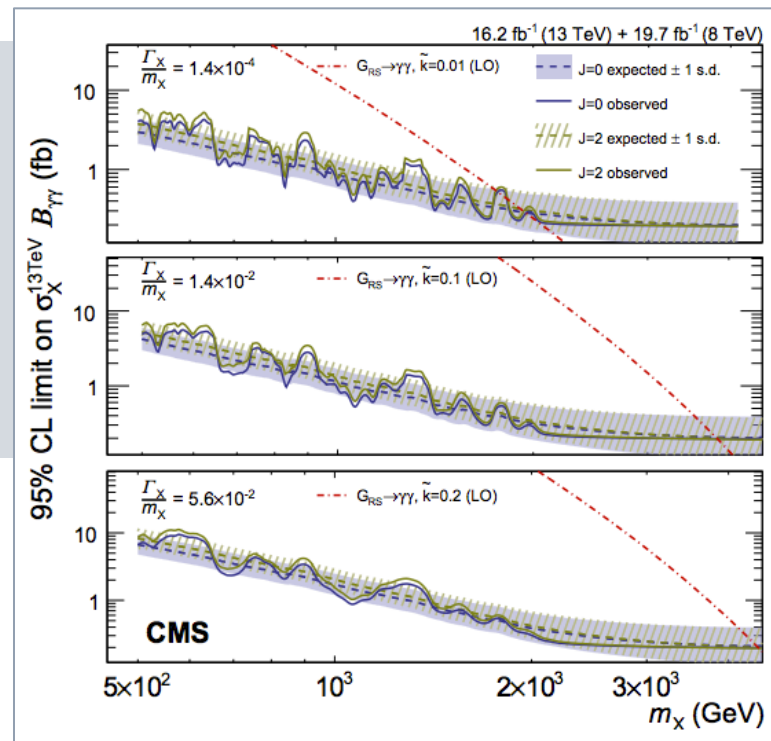


- **Widths:**
 $1.4 \times 10^{-4} - 5.6 \times 10^{-2}$
 - Local p-value at most $\sim 2\sigma$

$\Upsilon + \Upsilon$

- **Search for diphoton**
 - Spin-0 & spin-2
- **Exclude mass M_G up to 1.95 – 4.45 TeV**
 - **Coupling $k = 0.01 - 0.2$**

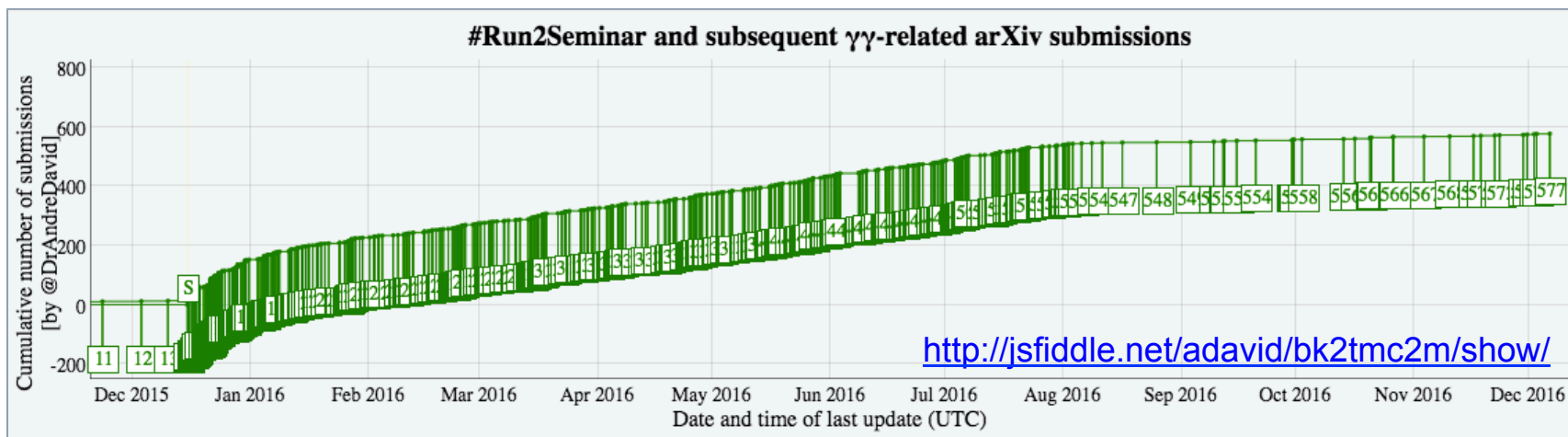
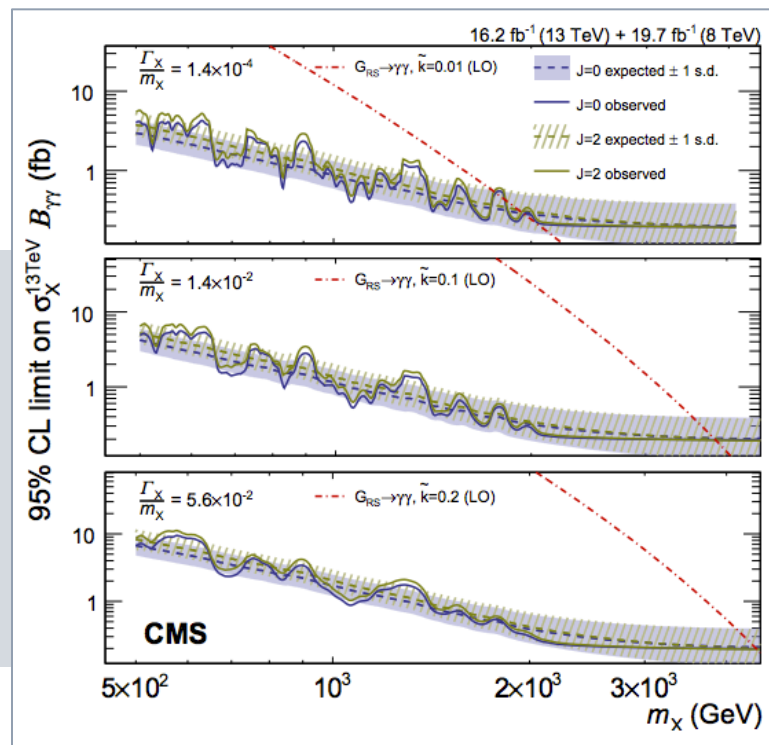
arXiv/
1609.02507

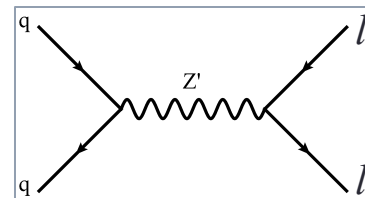


$\gamma+\gamma$

- **Search for diphoton**
 - Spin-0 & spin-2
- **Exclude mass M_G up to 1.95 – 4.45 TeV**
 - **Coupling $k = 0.01 – 0.2$**

arXiv/
1609.02507

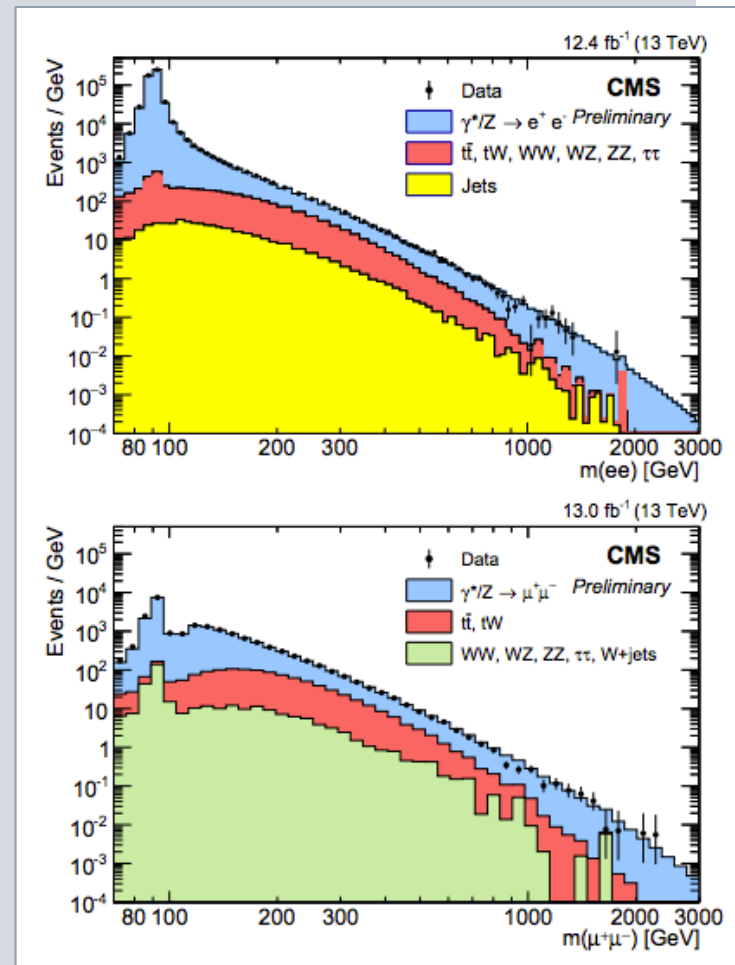
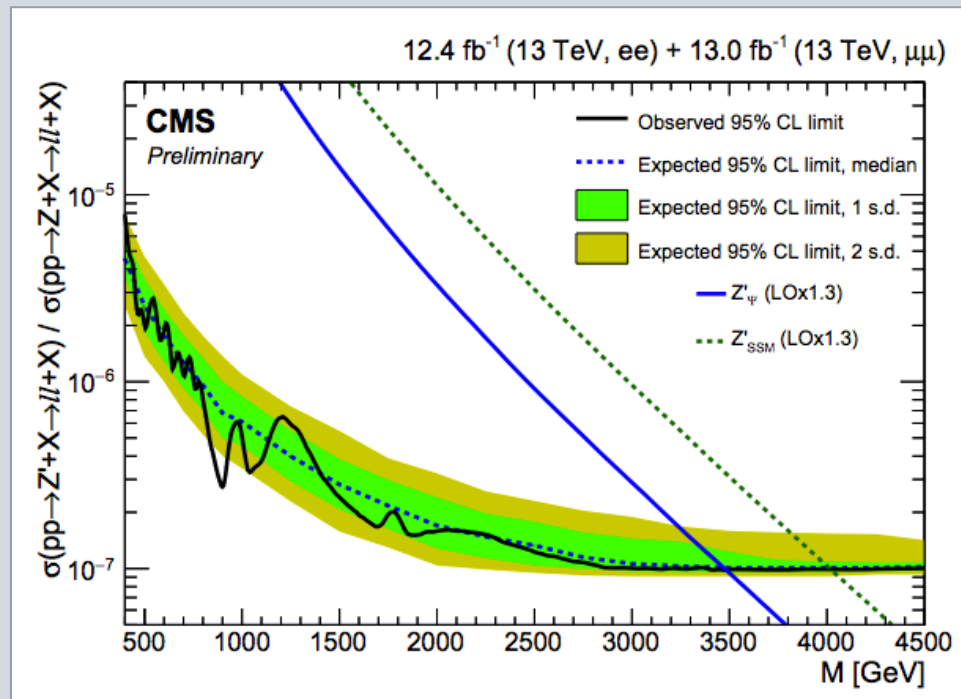




• Exclusions by ee & $\mu\mu$:

- $M(Z'_\psi) < 3.5 \text{ TeV}$
- $M(Z'_{SSM}) < 4.0 \text{ TeV}$

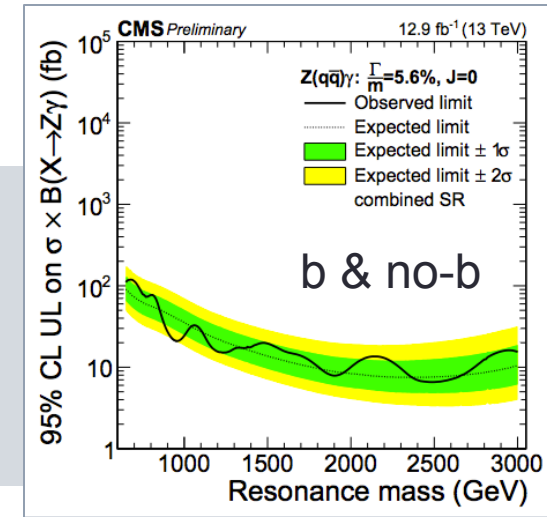
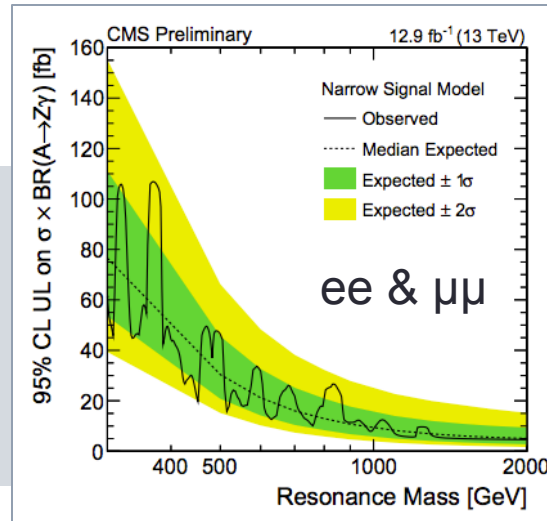
**CMS PAS
EXO-16-031**



$X_i + X_j$

- $\gamma + Z$

- Connected to $\gamma\gamma$
- **Leptonic** (low mass)
- **Hadronic** (high mass)



- I+MET (charged)**

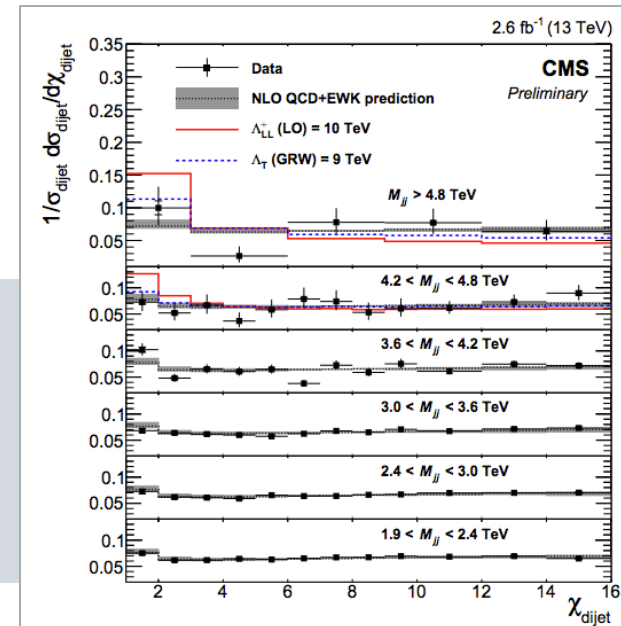
- Exclude $M_{W'}$ \rightarrow 5 TeV

CMS PAS EXO-16-006

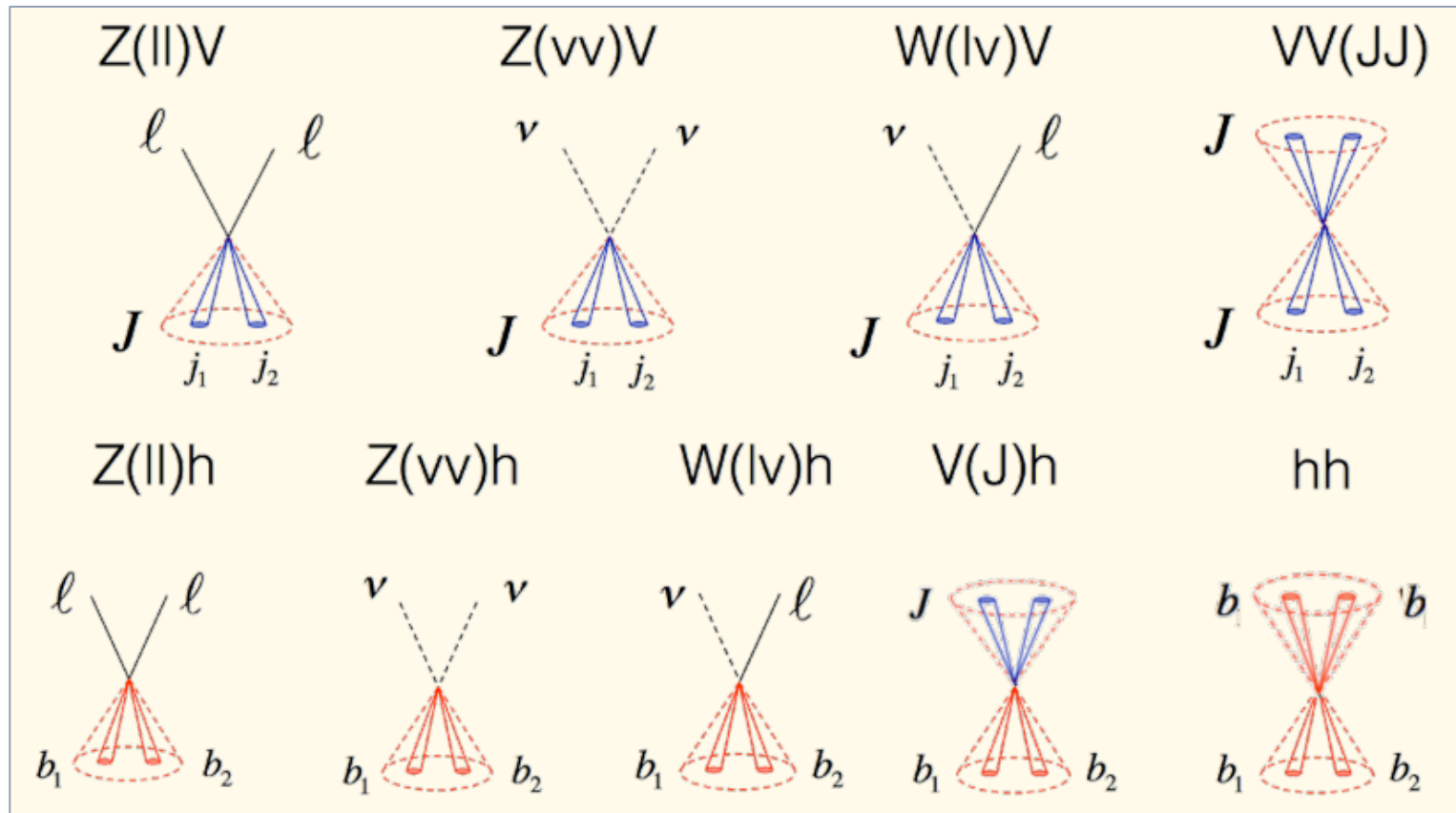
- χ : dijet angles**

- Compositeness
- Wide resonances
 - Probe also large couplings

CMS PAS EXO-15-009



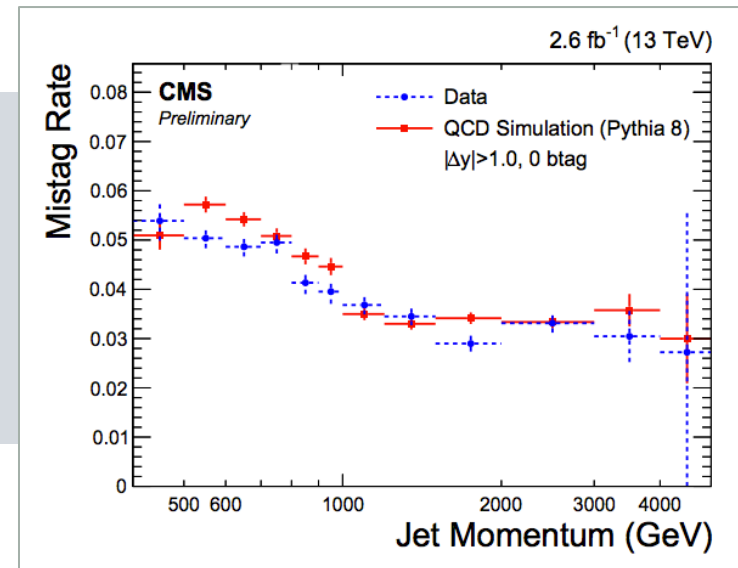
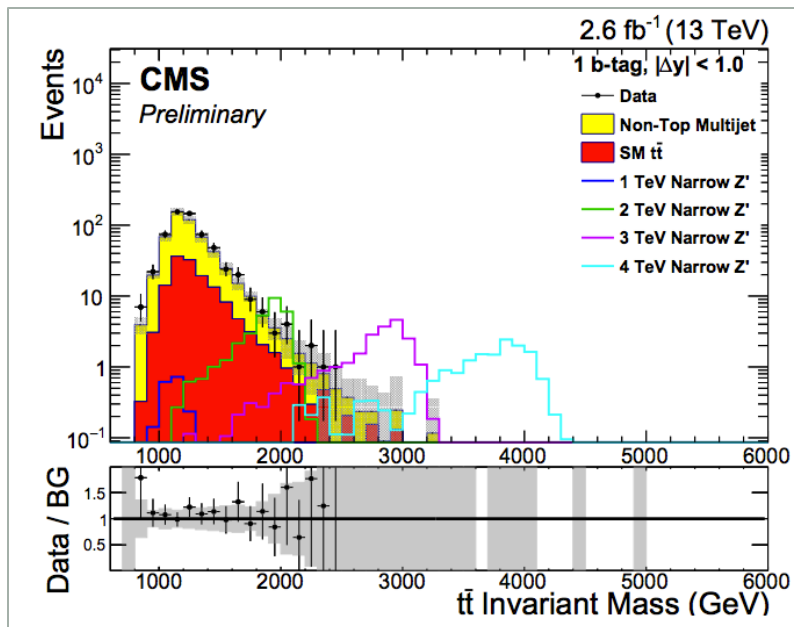
II) Tagging



t+t

• Z' → tt

1. Semi-leptonic CMS PAS B2G-15-002
2. All-hadronic CMS PAS B2G-15-003
 - Boosted tops
 - Substructure $t \rightarrow bW \rightarrow bqj$



• Interpret as Z' & KK gluon

➤ Width 1 / 10 / 30%

• Leptonic

➤ Exclude $M_{Z'}$, < 2.3 / 3.4 / 4.0 TeV

• Hadronic

➤ Exclude $M_{Z'}$, < 1.6 / 3.3 / 3.8 TeV

t+b

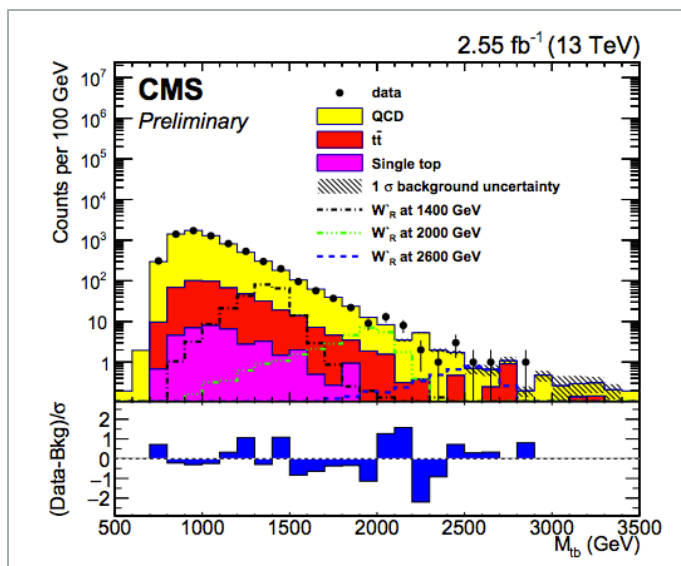
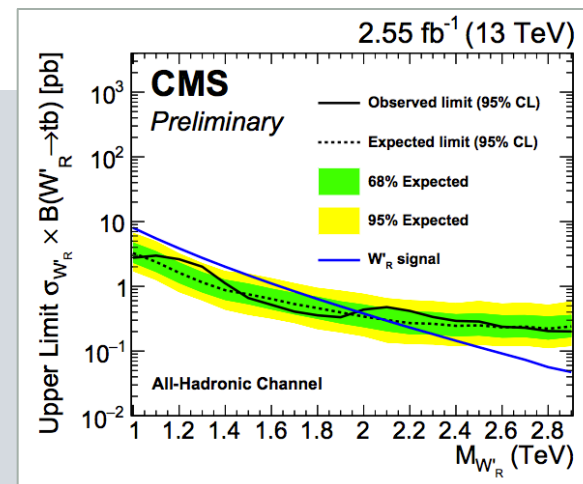
• $W' \rightarrow tb$

1. Semi-leptonic
2. All-hadronic

CMS PAS B2G-16-017

CMS PAS B2G-16-009

- Jet mass
- N-subjettiness
- Subjet b-tagging



• Interpret as right-handed W'

• Leptonic

- Exclude $M_{W'} < 2.7$ TeV

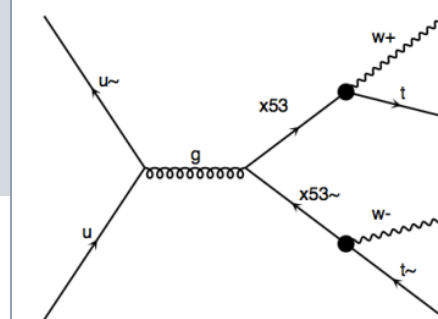
• Hadronic

- Exclude $M_{Z'} < 2.0$ TeV

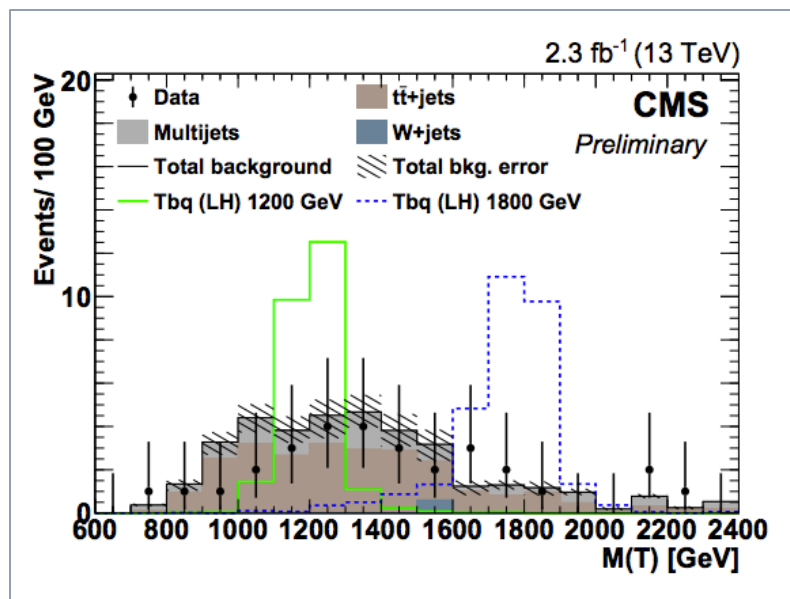
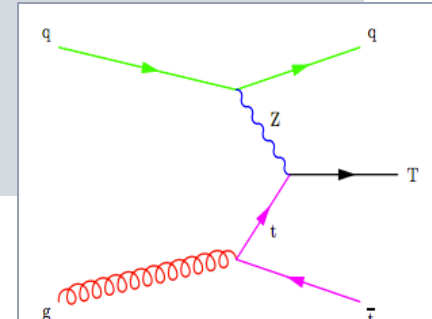
V+q

- **VLQ: extension of quark sector**
 - Production: **pairs** and **single** (EWK)
 - Search for V+q

CMS PAS B2G-15-006



CMS PAS B2G-16-005



- **Run-1 limits**
600 – 900 GeV
- **Run-2: already**
up to 1500 GeV
 - Coupling dependent

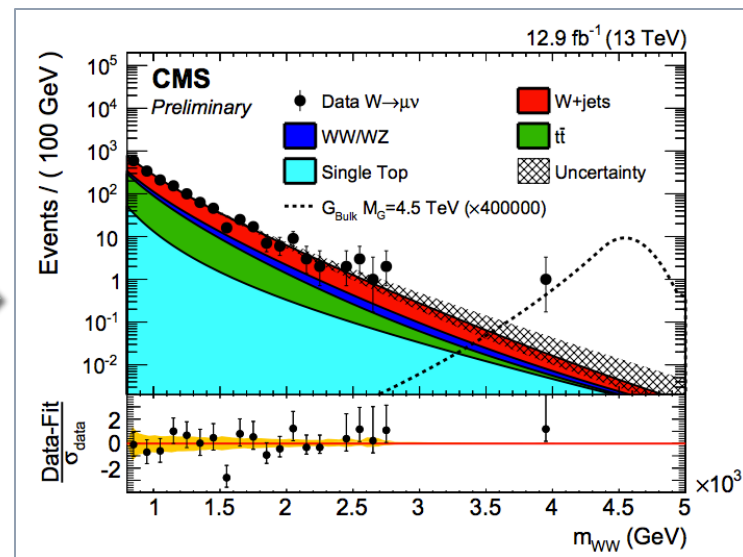
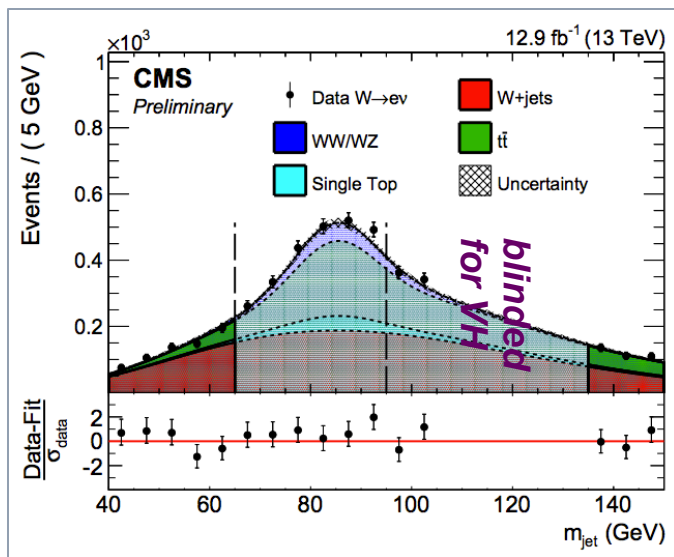
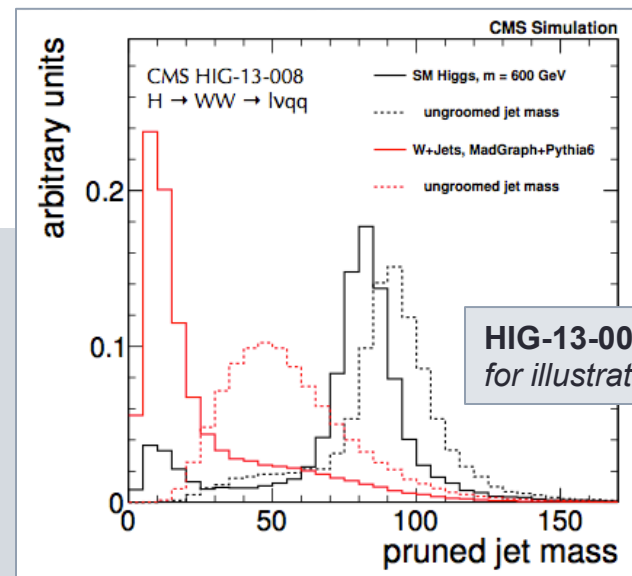
V+V

- **W/Z masses**

- Grooming
- Jet mass
- N-subjettiness

CMS PAS
B2G-16-020

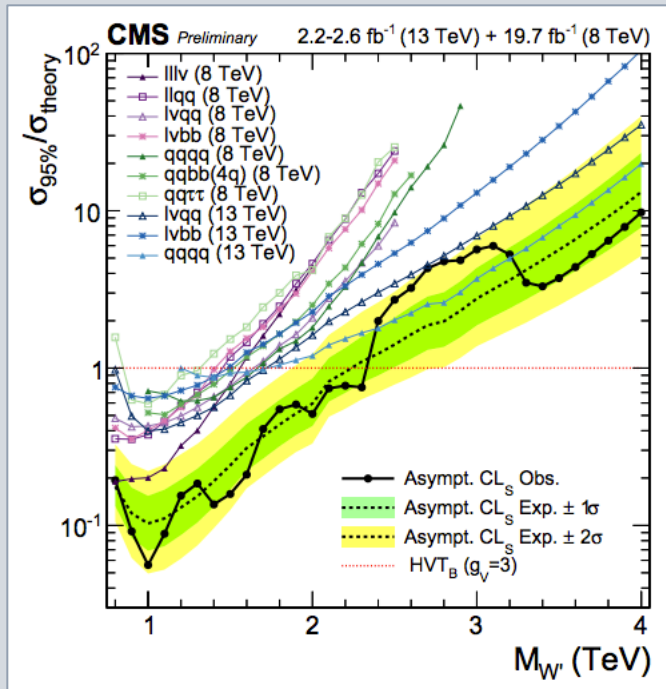
- **Control in $t\bar{t}$ and search for $X \rightarrow VV$**



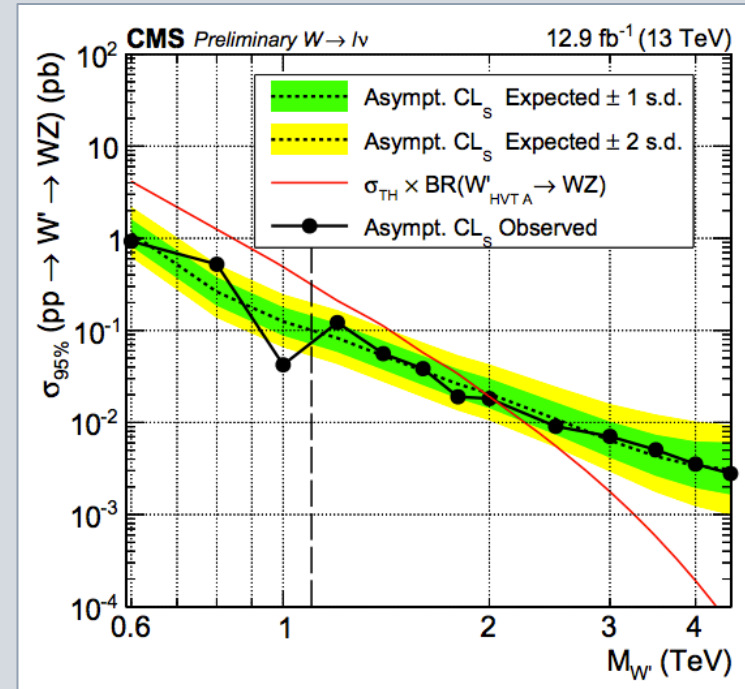
V+V

- Run-1 excess (2 TeV) not confirmed
 - 2012+2015 combination. 2016: $X \rightarrow W(l\nu)V(qq)$

2012+2015: B2G-16-007



2016: B2G-16-020



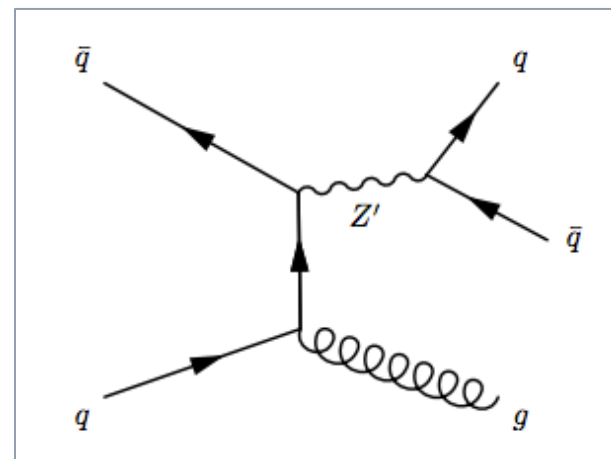
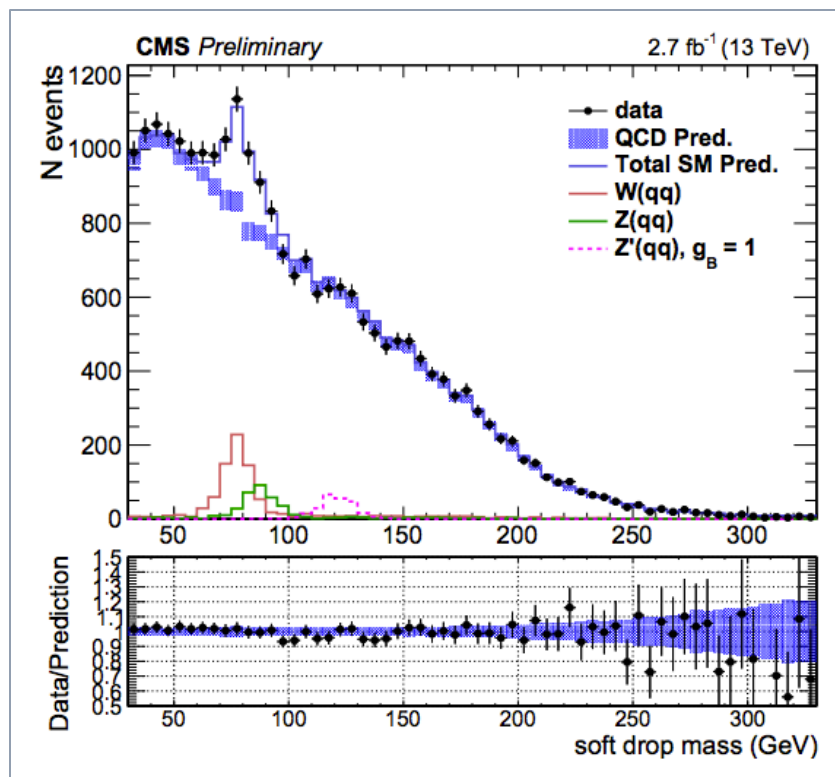
- Interpret as HVT W' , Z' , G_{bulk}

(j+j)+j

- **Low-mass search**

- Use **dijet + ISR** !
- Jet substructure

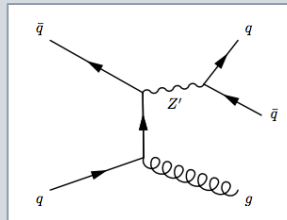
CMS PAS EXO-16-030



(j+j)+j

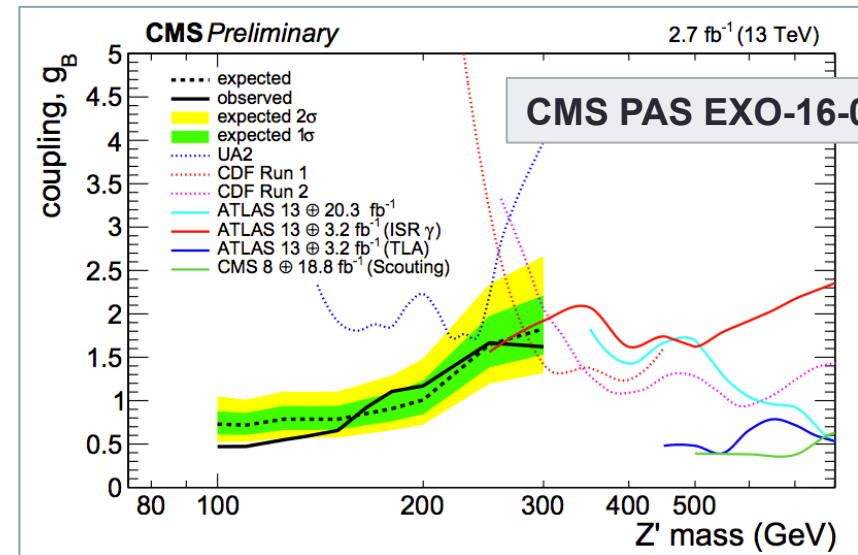
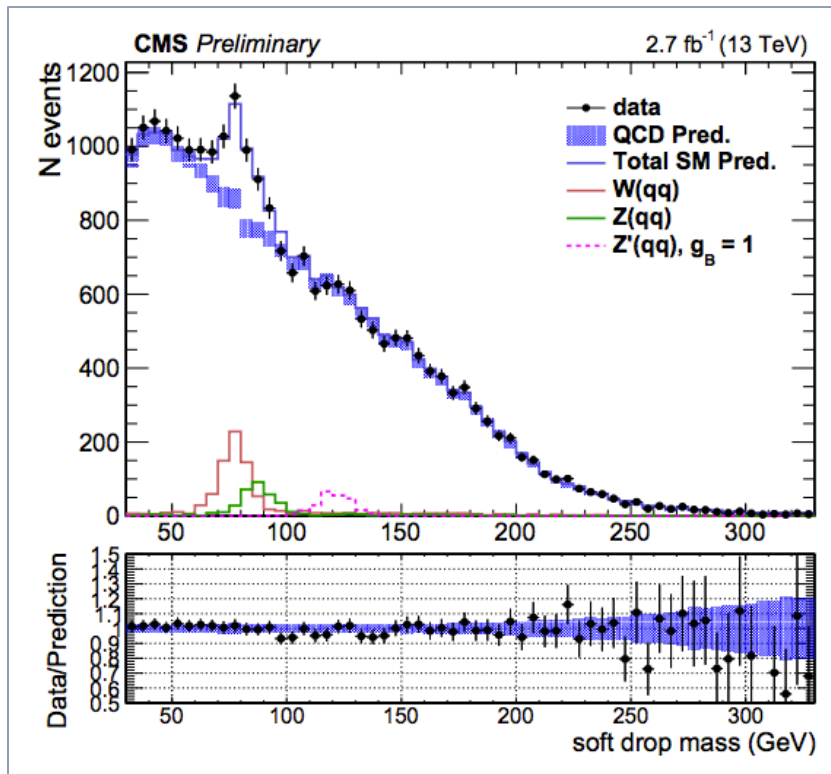
- **Low-mass search**

- Use dijet + ISR
- Jet substructure

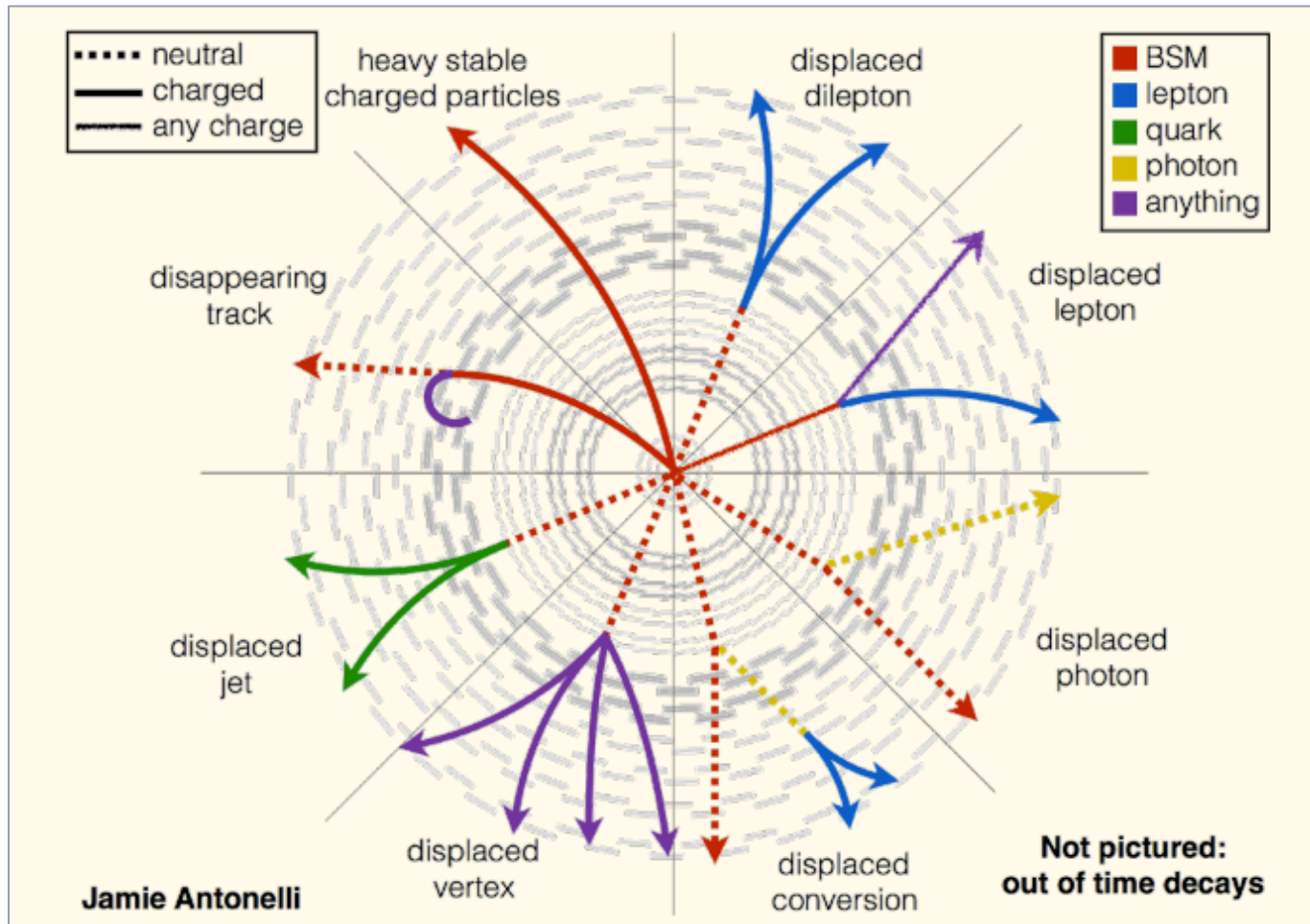


- **New constraints**

- Sensitivity down to **100 GeV**



III) Displaced

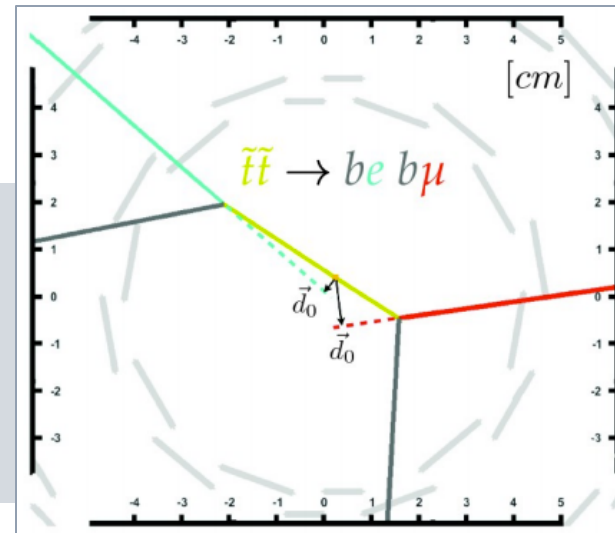
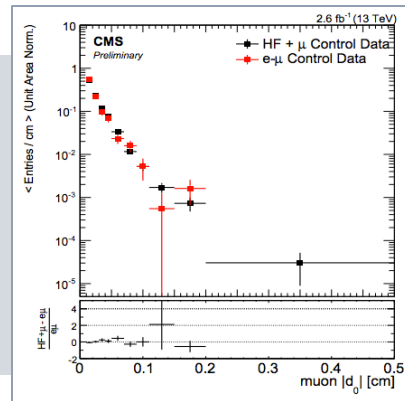


LL

- **Long lived: $e\mu$**
 - Displaced tracks

CMS PAS EXO-16-022

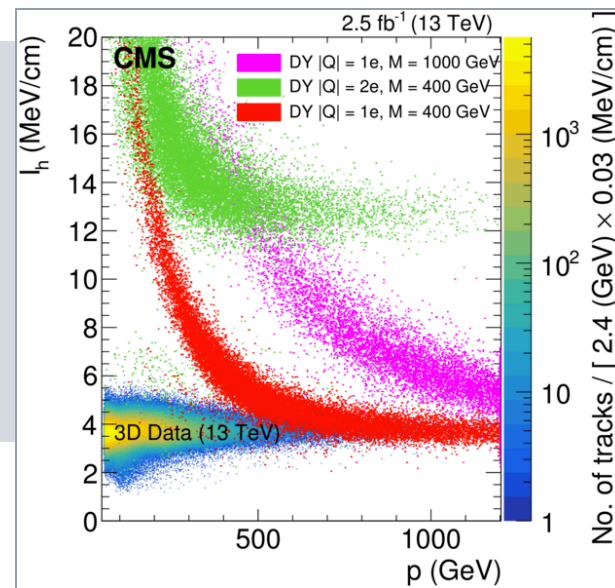
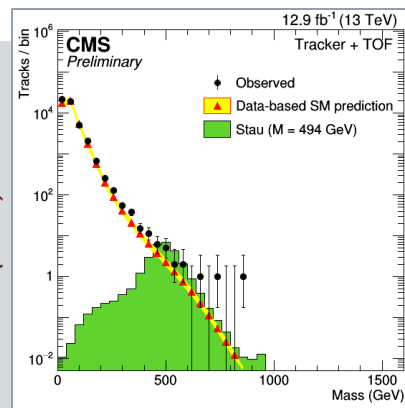
$T \sim 0.1 \text{ mm} - 1 \text{ m}$



- **Long lived: HSCP**
 - Tracker dE/dX
 - Muon TOF

CMS PAS EXO-15-010
CMS PAS EXO-16-036

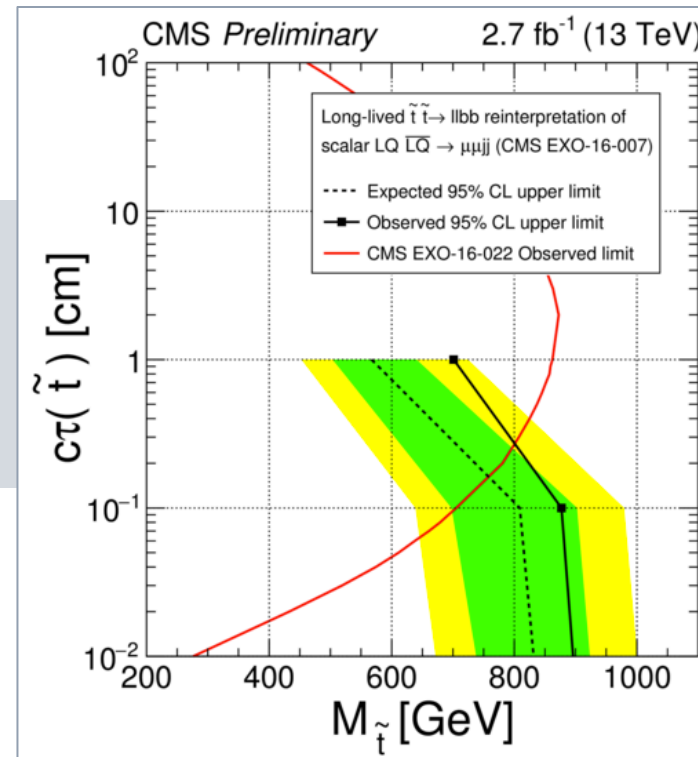
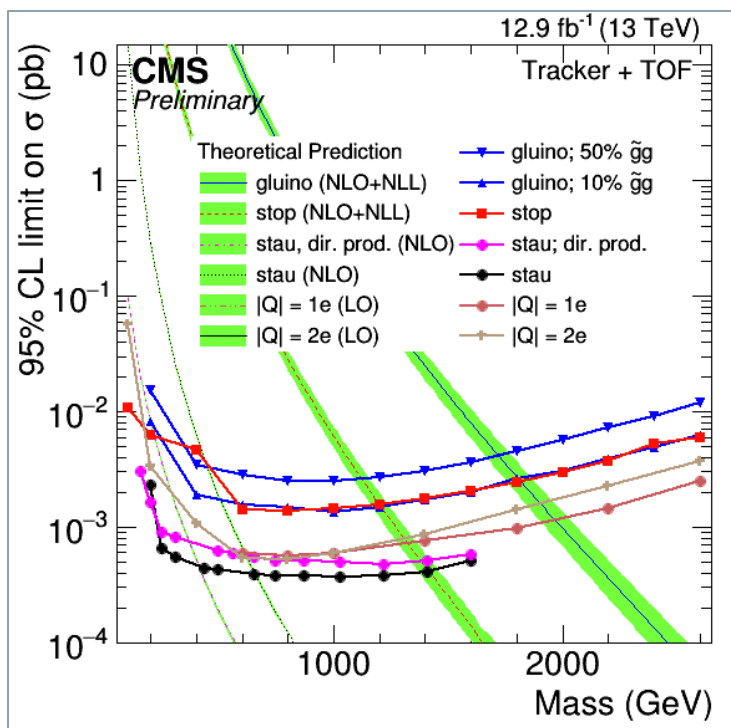
$T \sim O(1 \text{ m})$



LL

- $e\mu$
 - LL RPV **stop** + **LQ** reinterpretation
 - Short-living analog!

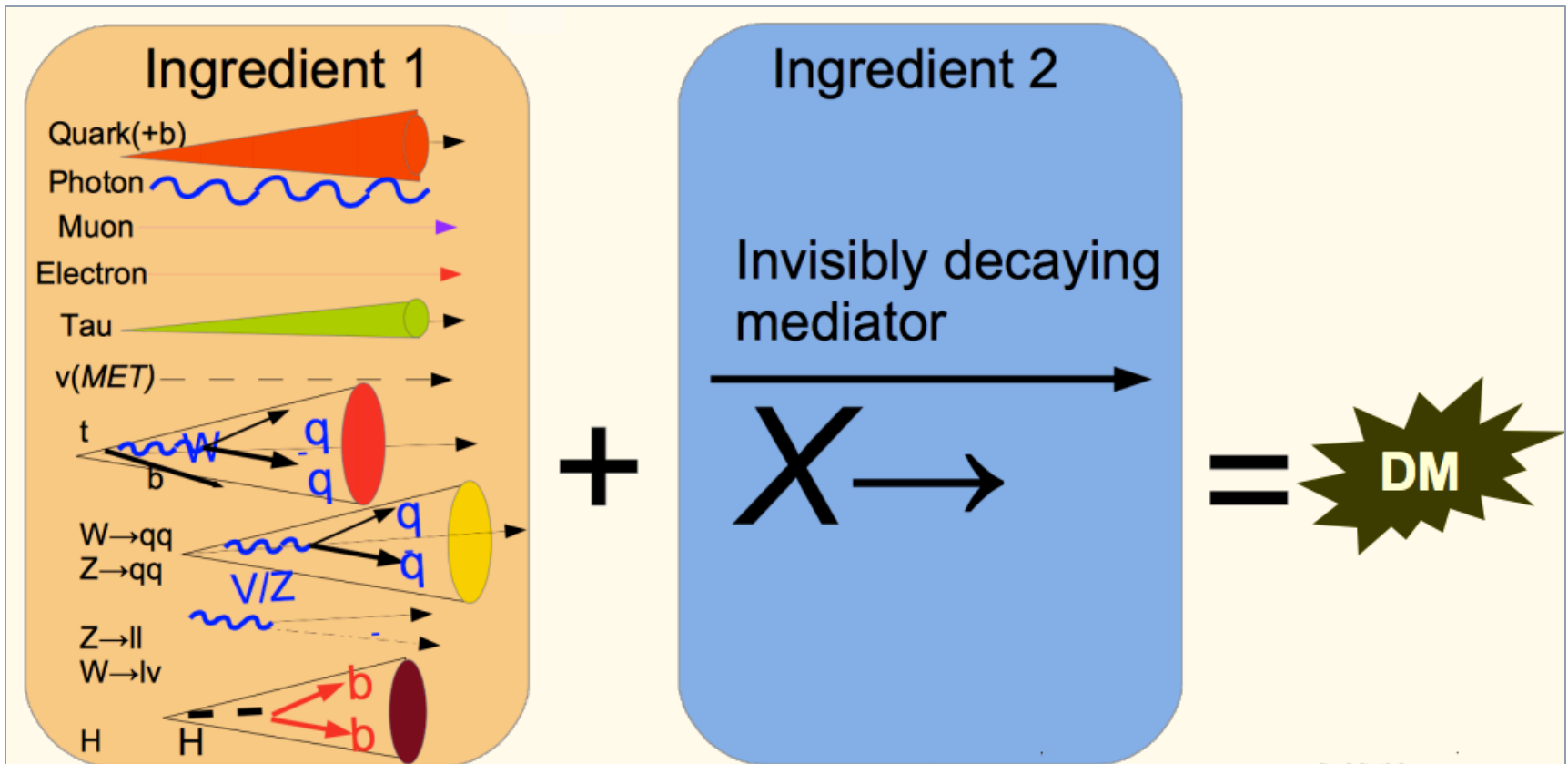
CMS PAS EXO-16-022
+
CMS PAS EXO-16-007



- **HSCP**
 - Stau / stop / gluino

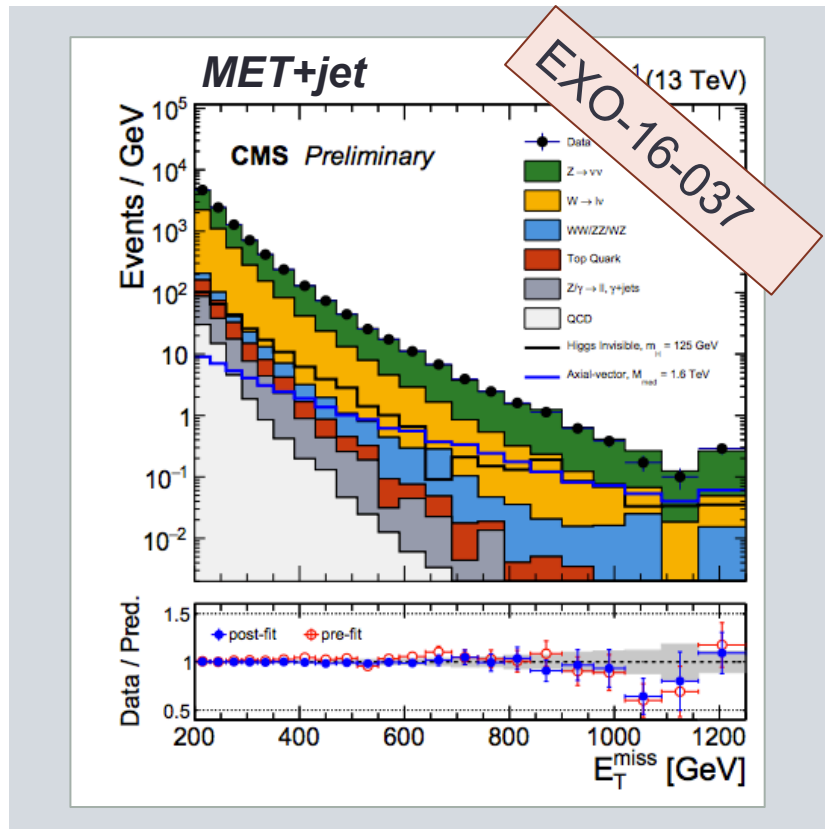
CMS PAS EXO-16-036

IV) DM & Mediators



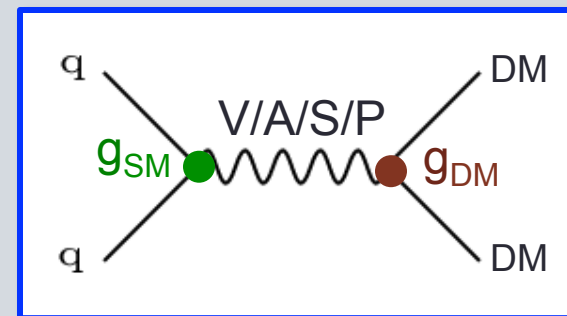
MET+X

Reconstruction



Interpretation

- **Model:** DM-SM mediator
 - **Axial / Vector** ($X = j/V/Z/\gamma$)
 - **Pseudo / Scalar** ($X = j/V/Z/bb/tt$)

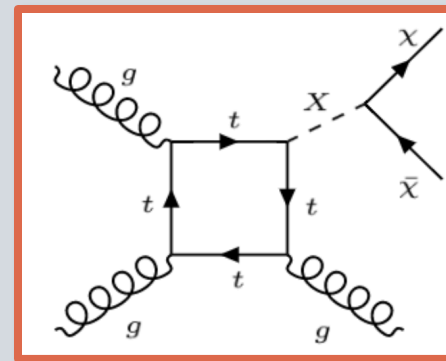
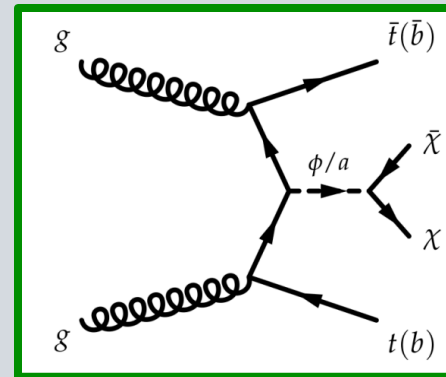
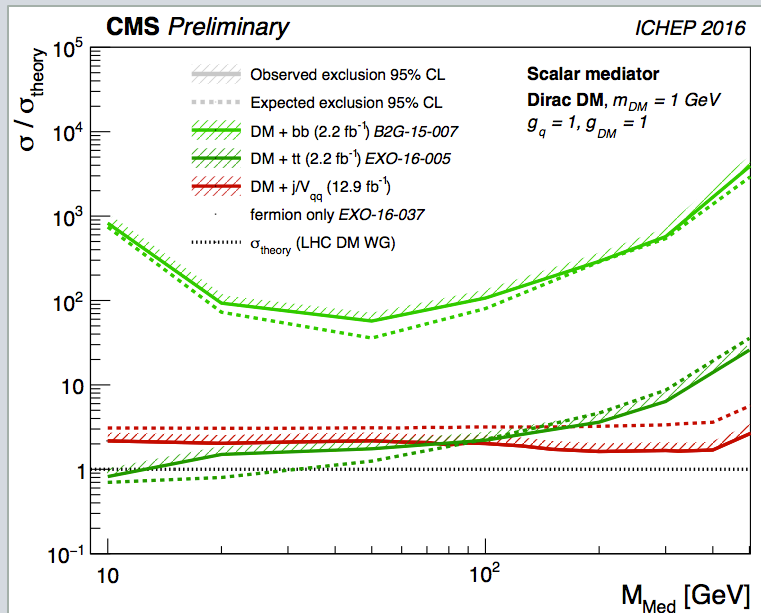


- **LHC DM WG**
 - [arXiv/1507.00966](https://arxiv.org/abs/1507.00966)
 - [arXiv/1603.04156](https://arxiv.org/abs/1603.04156)

CERN-CMS-DP-2016-057
<https://cds.cern.ch/record/2208044>

S & P

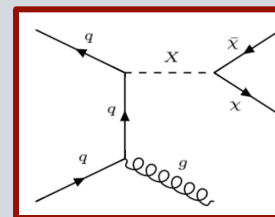
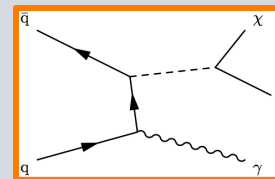
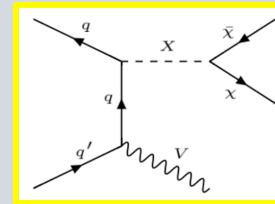
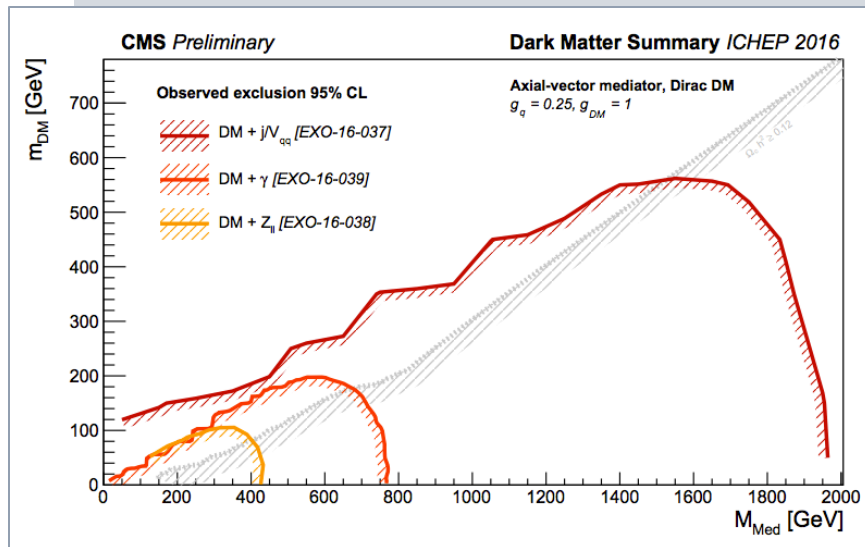
- DM+bb & DM+tt & DM-jet (*f-only*)



- Low M_{Med} : sensitivities similar and close to $\sigma/\sigma_{\text{theory}} \sim 1$
 - Case for combined interpretation, especially for $M_{\text{Med}} \sim (10, 200)$ GeV

V & A

- DM+Z / DM+ γ / DM+j/V

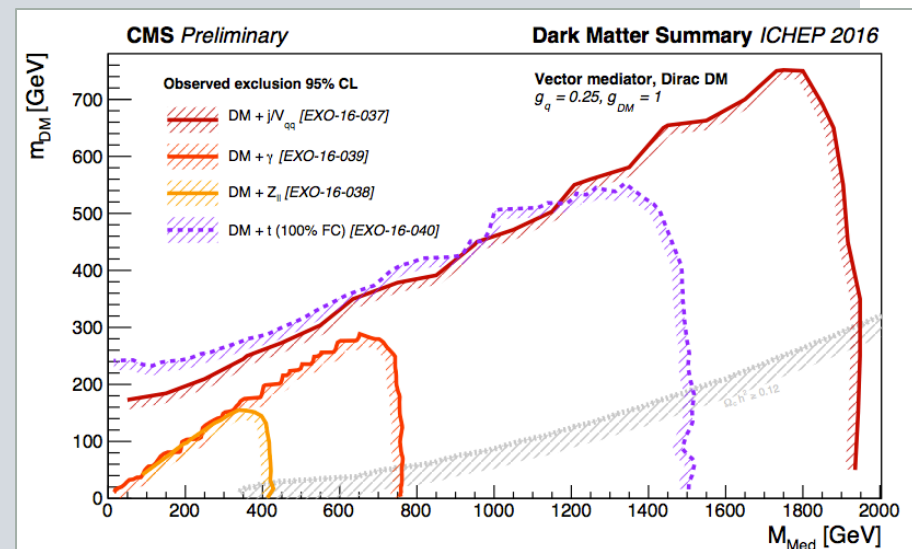
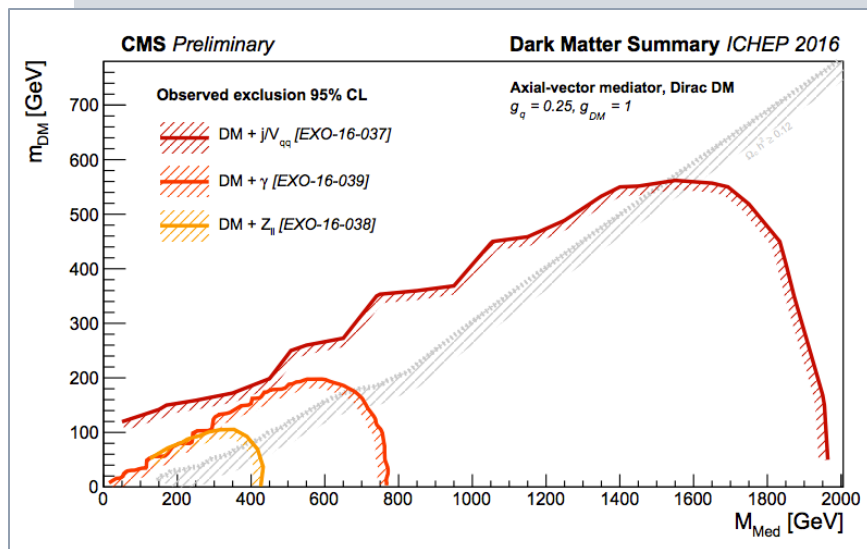


- Limits up to $M_{Med} \sim 2 \text{ TeV}$, $m_{DM} \sim 600 \text{ GeV}$ ($g_q = 0.25, g_{DM} = 1$)

V & A

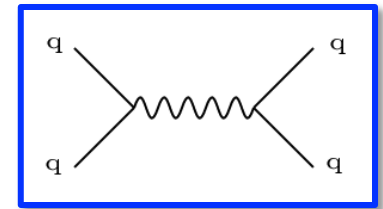
- DM+Z / DM+ γ / DM+j/V / DM+t

CERN-CMS-DP-2016-057
<https://cds.cern.ch/record/2208044>



➤ Limits up to $M_{Med} \sim 2 \text{ TeV}$, $m_{DM} \sim 750 \text{ GeV}$ ($g_q = 0.25, g_{DM} = 1$)

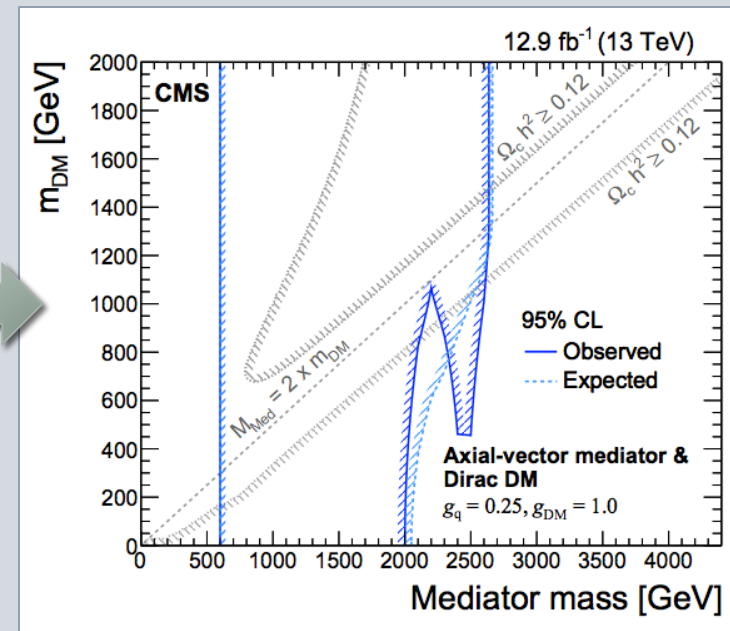
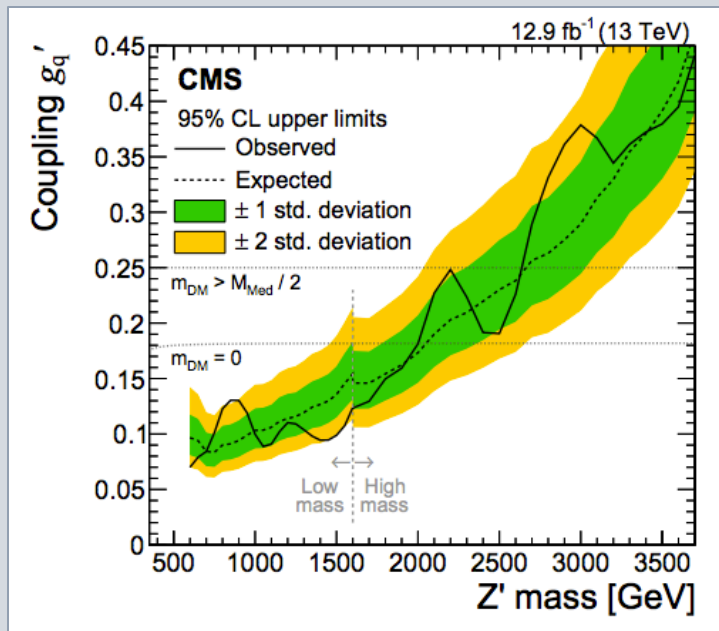
V & A: dijet



• Dijet DM reinterpretation

➤ Limits: $\sigma \rightarrow g \rightarrow m$

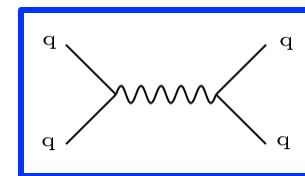
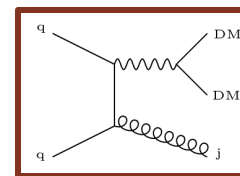
EXO-16-032
arXiv:1611.03568



• Interpret as constraint on DM Mediator

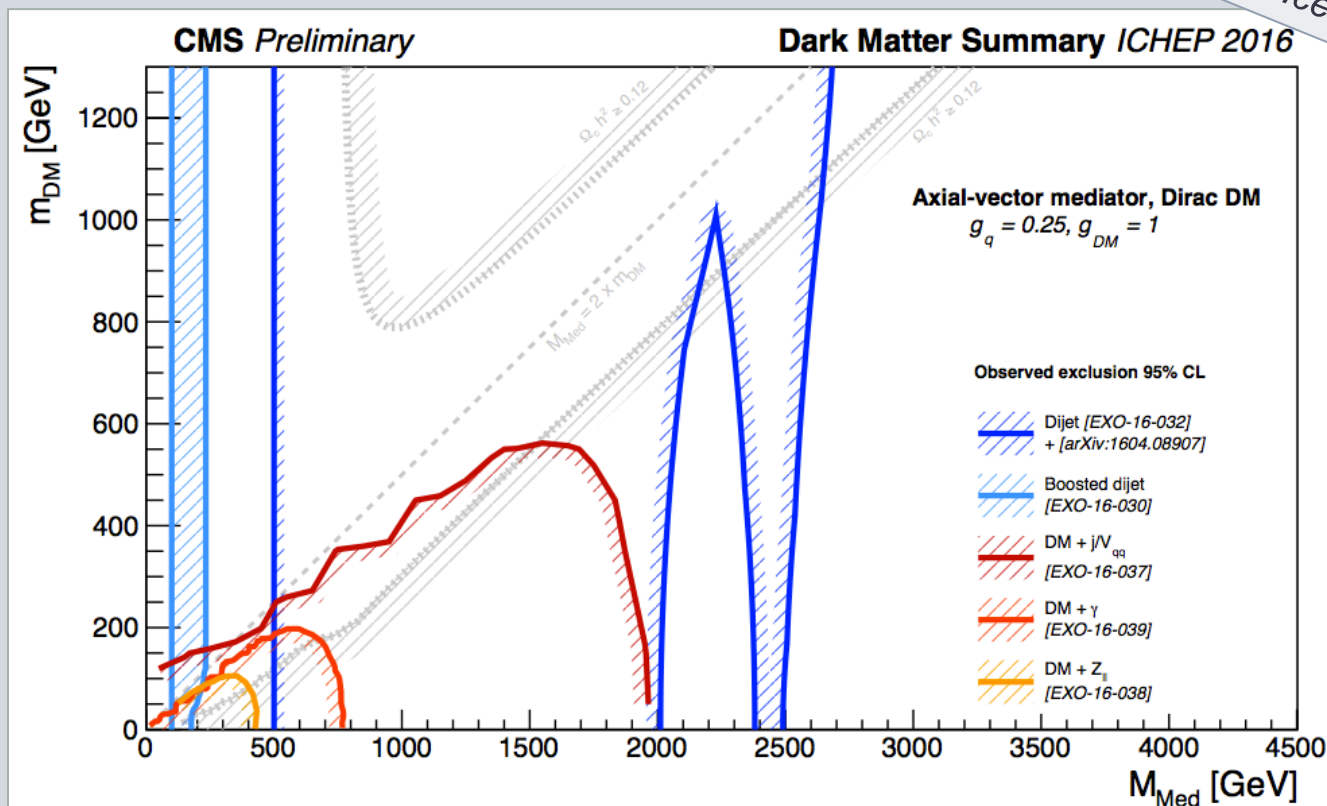
➤ Include width for Z' coupling to SM & DM

V & A summary



- MET+X** vs **Dijet**

CERN-CMS-DP-2016-057
<https://cds.cern.ch/record/2208044>

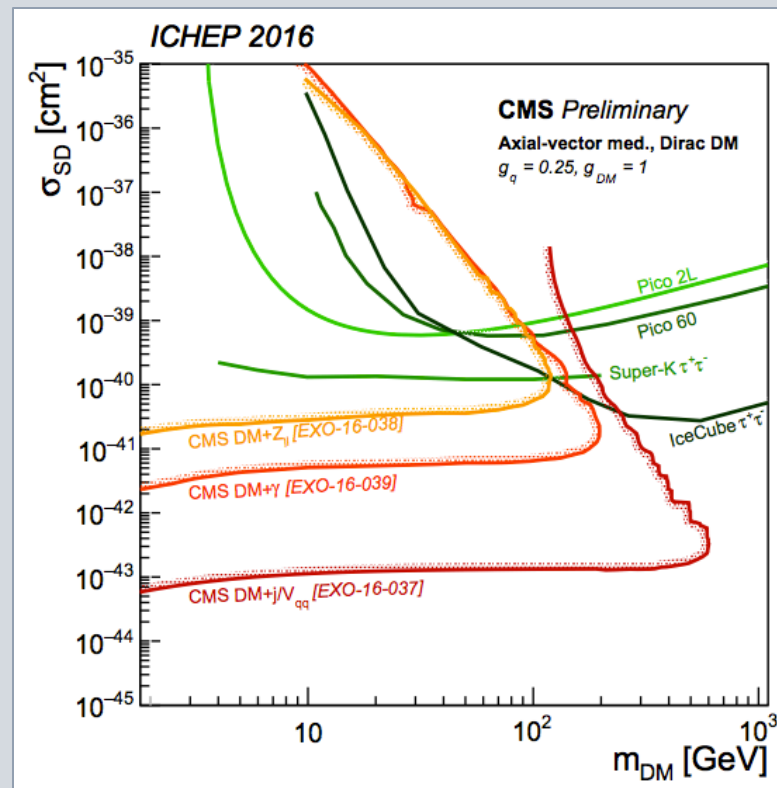
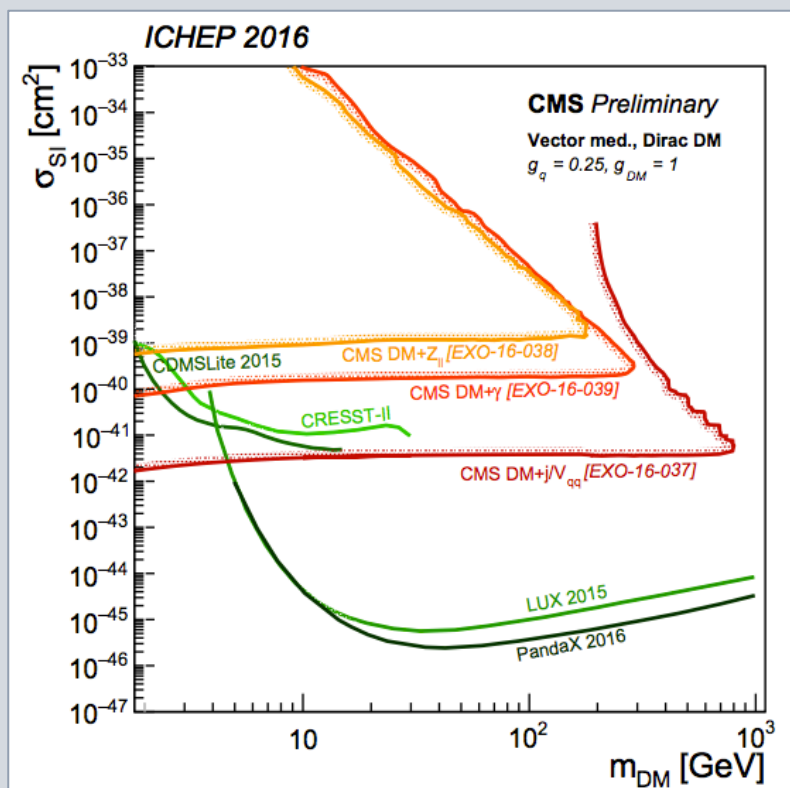


- DM+Z** / **DM+ γ** / **DM+j/V** / **Dijet+ISR** / **Dijet**

CERN-CMS-DP-2016-057
<https://cds.cern.ch/record/2208044>

DD: MET+X

- Translate (M,m) constraints to DD (m,σ) plane

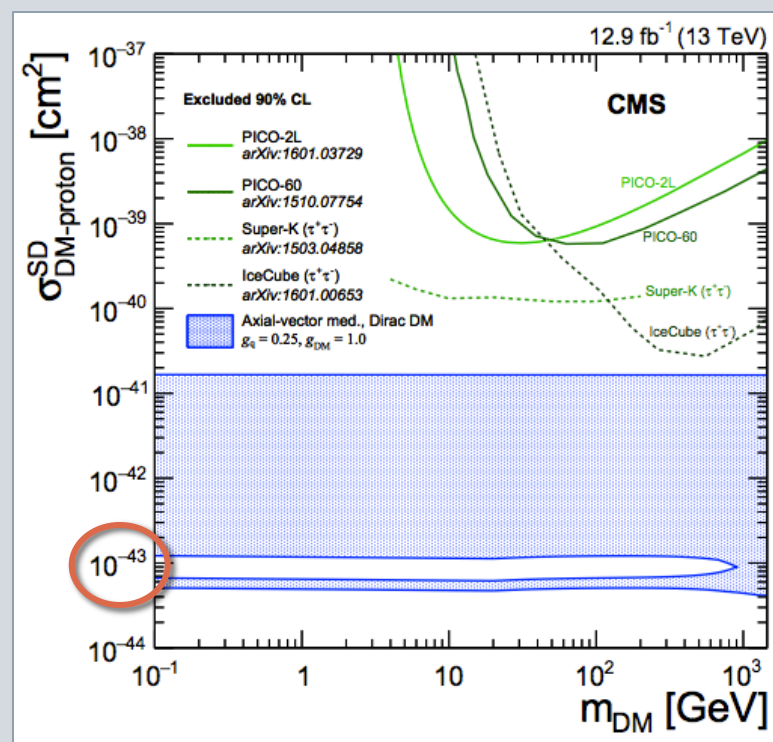
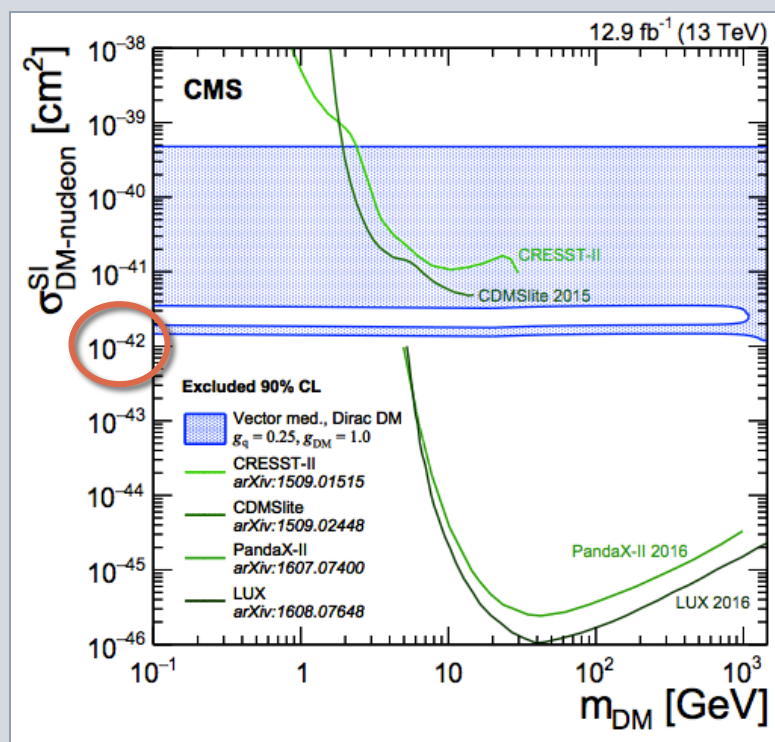


- LHC very competitive for **low mass** and **Spin Dependent**

DD: dijet

EXO-16-032
arXiv:1611.03568

- MET-less, but **same DM reinterpretation**



- Powerful **DM constraints** from **MET-less** mediator searches

Conclusions

- **Large variety of CMS searches**

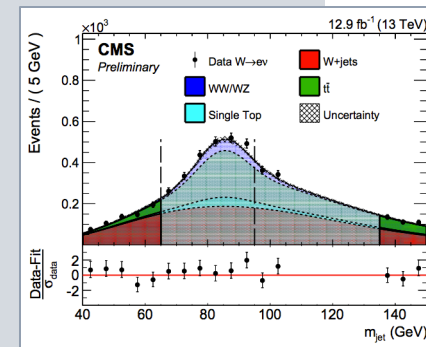
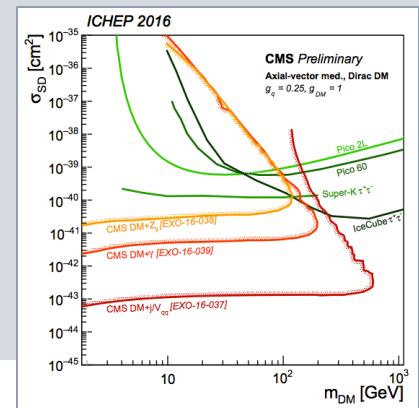
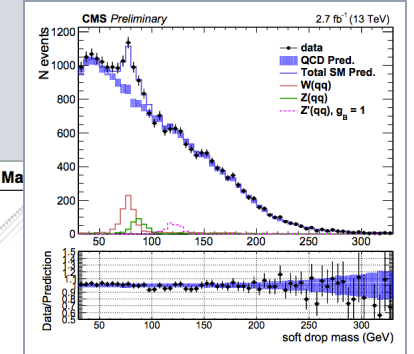
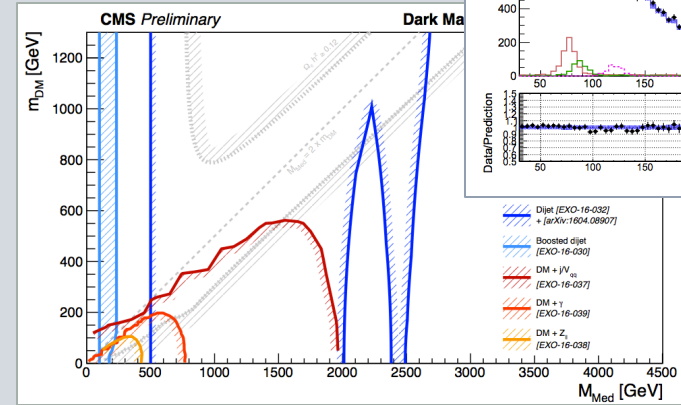
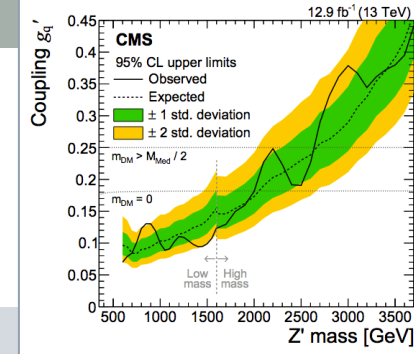
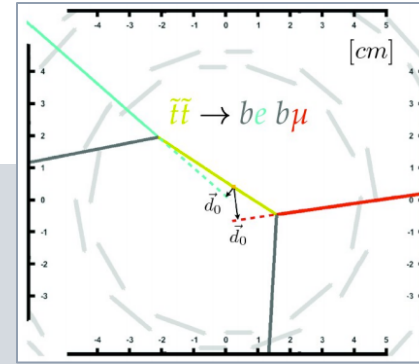
- Nothing new found yet
- Constraining various models

- **Expanding program**

- Boosted reconstruction
- Low-mass
- Long-lived
- Combined interpretation

- **CMS keeps searching**

- Higher & lower mass
- Smaller couplings
- Complexer final states



2 more slides for discussion (next pages)

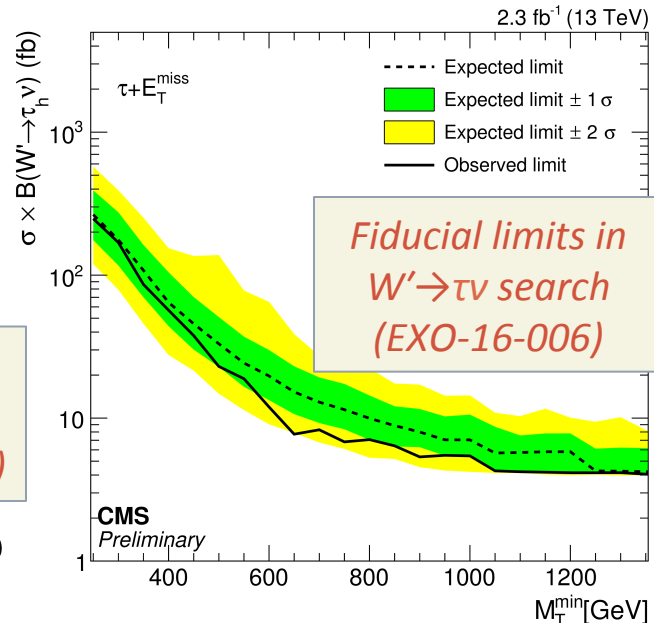
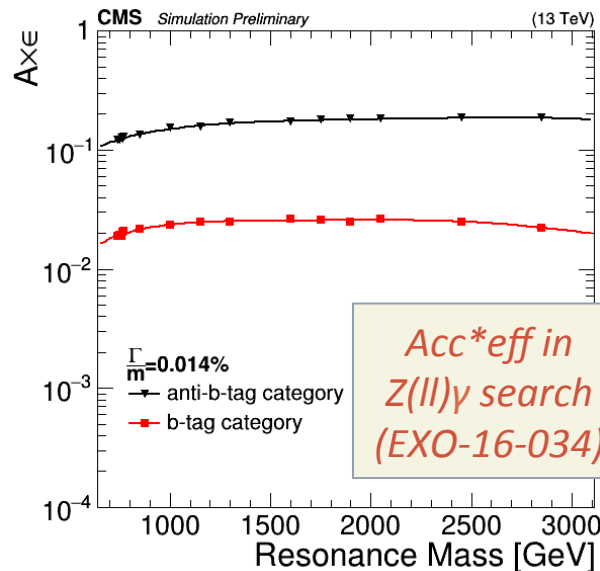


Public information for reinterpretation of CMS results

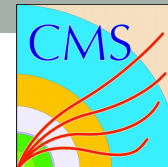
Common examples

- Number of observed **events** in the **signal** region (or regions)
- Total expected **background** (plus uncertainty) in the signal region(s)
- Signal **acceptance** and **efficiency** vs key kinematic variables
- **Limits** on cross section times branching ratio (fiducial or «model-independent» limits)

Process	E_T^{miss}	E_T^{miss}	E_T^{miss}	E_T^{miss}	E_T^{miss}	N_{obs} and N_{exp} in monojet DM search (EXO-16-037)		
	[250 - 300] GeV	[300 - 350] GeV	[350 - 400] GeV	[400 - 500] GeV	[500 - 600] GeV	N_{obs}	N_{exp}	Upper limit
Z($\nu\nu$)+jets	1784 ± 50	1232 ± 40	652 ± 22	507 ± 20	13	13	0.057 ± 0.009	< 0.005
W($\ell\nu$)+jets	1195 ± 49	677 ± 31	337 ± 17	190 ± 12	42	42	0.99 ± 0.144	< 0.1
Z($\ell\ell$)+jets	16 ± 4	8.86 ± 2.11	2.31 ± 0.55	1.11 ± 0.27	0.048 ± 0.011	0.048 ± 0.011	0.133 ± 0.09	0.018 ± 0.013
Top quark	163 ± 23	65 ± 9	27 ± 4	20 ± 3(22)	2.7 ± 0.39	2.7 ± 0.39	0.66 ± 0.13	< 0.08
Dibosons	193 ± 35	134 ± 25	68 ± 12	62 ± 11(66)	16.7 ± 3	16.7 ± 3	0.66 ± 0.13	4.69 ± 0.85
QCD	14.3 ± 9	5.65 ± 3.57	2.42 ± 1.55	1.73 ± 1.11	0.312 ± 0.21	0.312 ± 0.21	0.66 ± 0.13	0.018 ± 0.013
γ +jets	21 ± 4	32 ± 6	3.7 ± 0.73	7.72 ± 1.52	3.95 ± 0.77	3.95 ± 0.77	0.66 ± 0.13	< 0.08
Total Prefit	3373 ± 185	2281 ± 107	1174 ± 59	824 ± 37	221 ± 10	221 ± 10	84 ± 4	26 ± 3
Total Postfit	3386 ± 54	2155 ± 40	1093 ± 26	789 ± 23	203 ± 10	203 ± 10	88 ± 5.6	26 ± 3
Observed	3395	2162	1093	780	207	90	27	



*This information is usually released as **supplementary material** on the **public web page** of the analysis*



Foreseen developments

- Provide **information** that was already provided in the past
 - E.g. N_{obs} , N_{exp} , $\text{Acc} \cdot \text{eff}$

- 1. Provide it in a more **systematic** and **consistent** way
 - For a **larger number** of analyses
 - In a more **user-friendly** form
 - E.g. tables and functional parameterizations in HEPDATA

- 2. In addition, provide **correlation matrices** between bins of total expected background
 - For non-resonant searches (using signal and background **shapes**)
 - See talk by N.Wardle on simplified likelihoods

*Thank
you!*



<http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html>
<http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G/index.html>

#DMatLHC