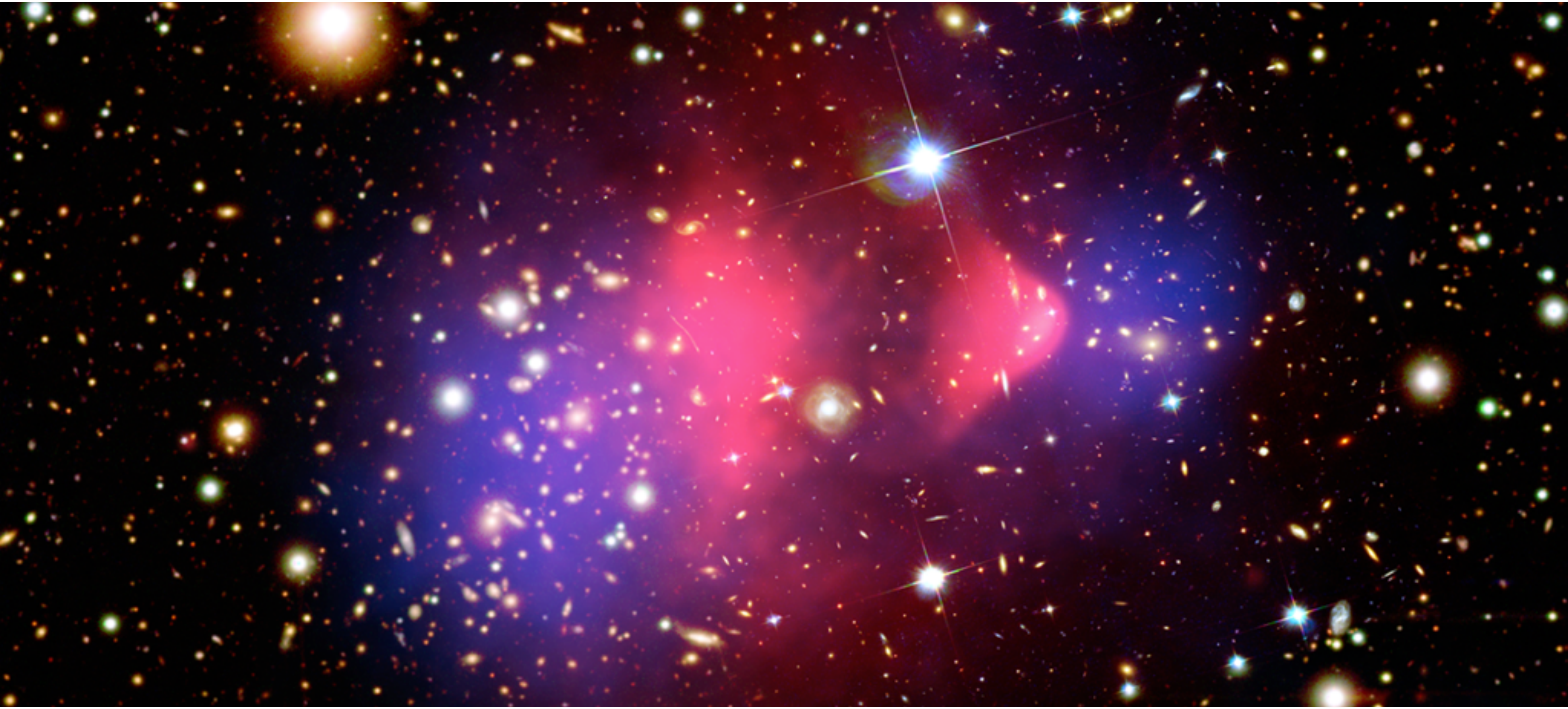
Search for dark matter in multijet events at CMS



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on behalf of the CMS Collaboration

23rd International Conference on Supersymmetry and Unification of Fundamental Interactions,
Aug. 23-29, 2015
Granlibakken Conference Center and Lodge, Tahoe, CA, USA

Dark Matter models

Dirac fermion, 1008.1783

D1 ★	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
D2	$\bar{\chi}\gamma^5\chi\bar{q}q$	im_q/M_*^3
D3	$\bar{\chi}\chi\bar{q}\gamma^5 q$	im_q/M_*^3
D4	$\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	m_q/M_*^3
D5 ★	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D6	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D7	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D8 ★	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D9	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	$1/M_*^2$
D10	$\bar{\chi}\sigma_{\mu\nu}\gamma^5\chi\bar{q}\sigma_{\alpha\beta}q$	i/M_*^2
D11	$\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^3$
D12	$\bar{\chi}\gamma^5\chi G_{\mu\nu}G^{\mu\nu}$	$i\alpha_s/4M_*^3$
D13	$\bar{\chi}\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^3$
D14	$\bar{\chi}\gamma^5\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$\alpha_s/4M_*^3$

Majorana fermion, 1005.1286

M1	qq	$m_q/2M_*^3$
M2	qq	$im_q/2M_*^3$
M3	qq	$im_q/2M_*^3$
M4	qq	$m_q/2M_*^3$
M5	qq	$1/2M_*^2$
M6	qq	$1/2M_*^2$
M7	GG	$\alpha_s/8M_*^3$
M8	GG	$i\alpha_s/8M_*^3$
M9	$G\tilde{G}$	$\alpha_s/8M_*^3$
M10	$G\tilde{G}$	$i\alpha_s/8M_*^3$

Real scalar, 1008.1783

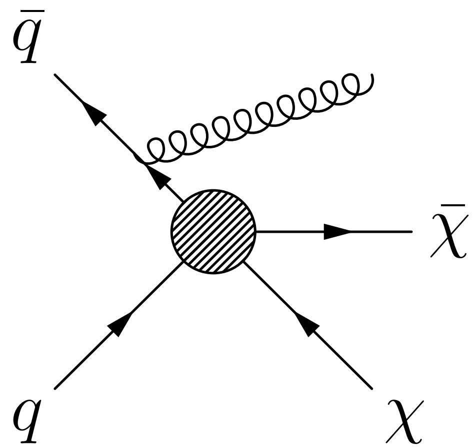
R1	$\chi^2\bar{q}q$	$m_q/2M_*^2$
R2	$\chi^2\bar{q}\gamma^5 q$	$im_q/2M_*^2$
R3	$\chi^2 G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/8M_*^2$
R4	$\chi^2 G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/8M_*^2$

Complex scalar, 1008.1783

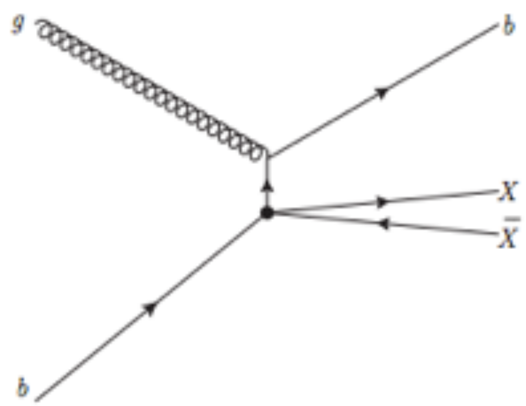
C1	$\chi^\dagger\chi\bar{q}q$	m_q/M_*^2
C2	$\chi^\dagger\chi\bar{q}\gamma^5 q$	im_q/M_*^2
C3	$\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu q$	$1/M_*^2$
C4	$\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu\gamma^5 q$	$1/M_*^2$
C5	$\chi^\dagger\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^2$
C6	$\chi^\dagger\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^2$

★ Used in this razor analysis

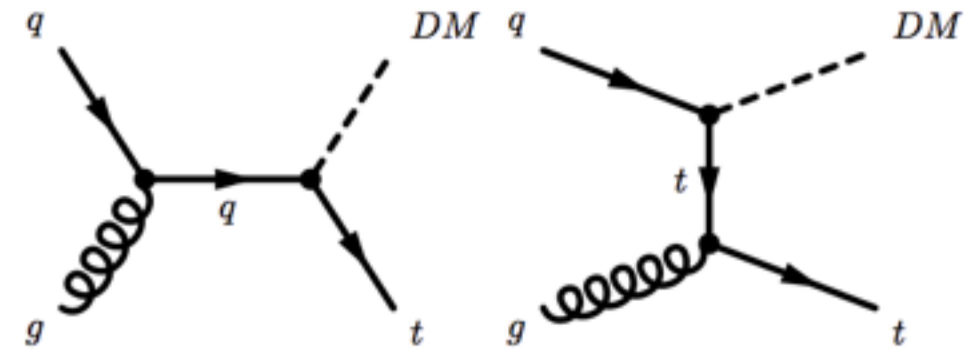
X + Missing Transverse Energy



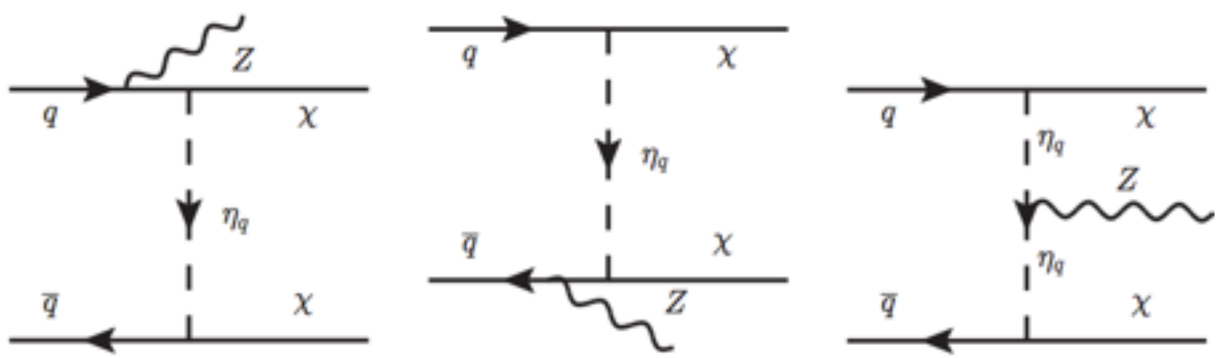
Monojet



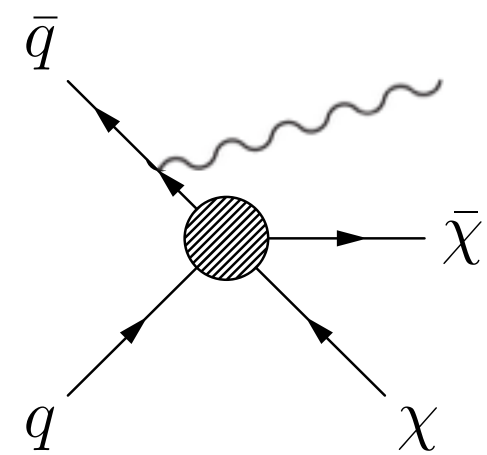
MonoB



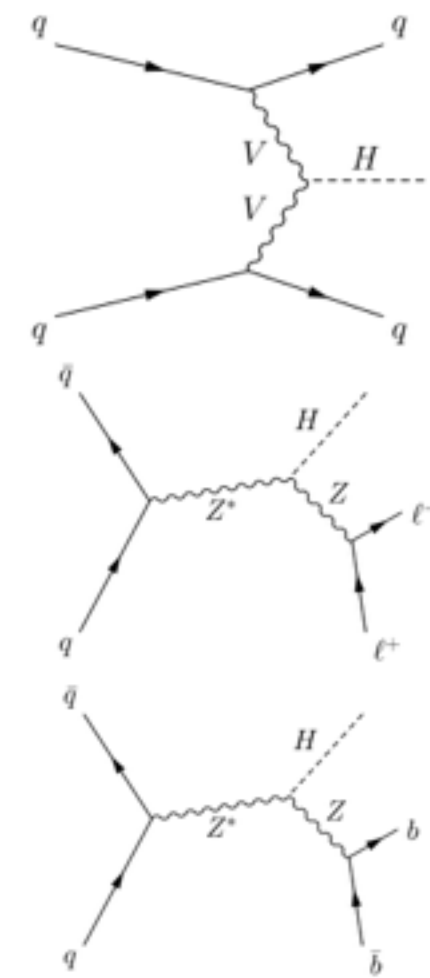
MonoTop



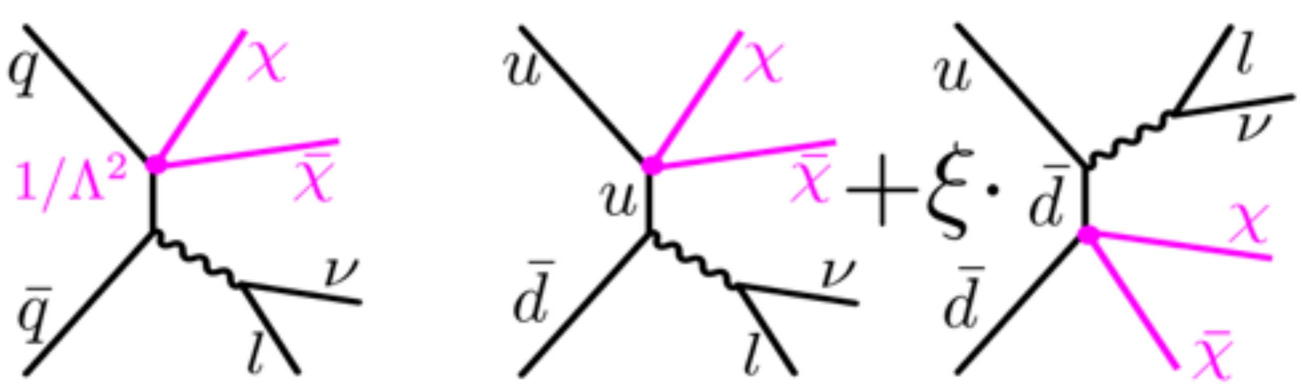
MonoZ



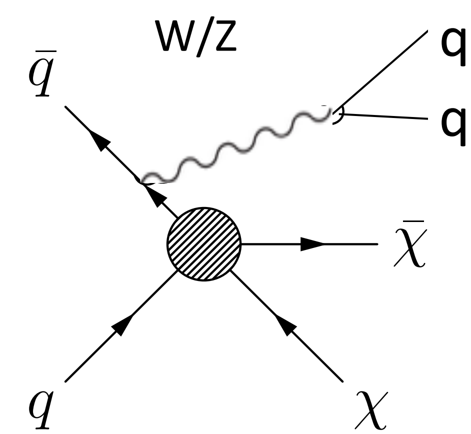
MonoPhoton



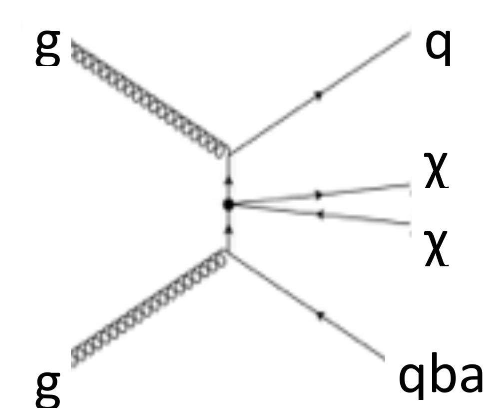
Higgs Portal



MonoW (monoLepton)

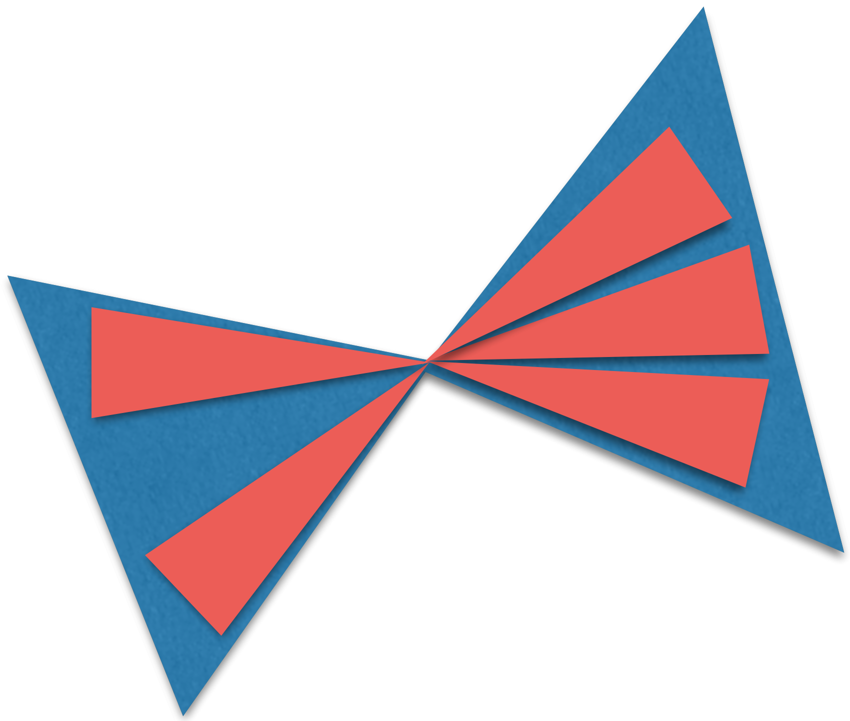


MonoW/Z (Hadronic)



BBbar /TTbar

Jets and Razor variables



- At least 2 AK5 jets with P_T > 80 GeV and |eta| < 2.4.
- Force events to be dijet+MET topology, two megajets are formed from reconstructed jets with P_T > 40 GeV and |eta| < 2.4.
- Reject if |deltaPhi| between 2 megajets > 2.5.
- Use momenta of two megajets to compute razor variables,

$$M_R \equiv \sqrt{(|\vec{p}_{J_1}| + |\vec{p}_{J_2}|)^2 - (p_z^{J_1} + p_z^{J_2})^2}\,,$$

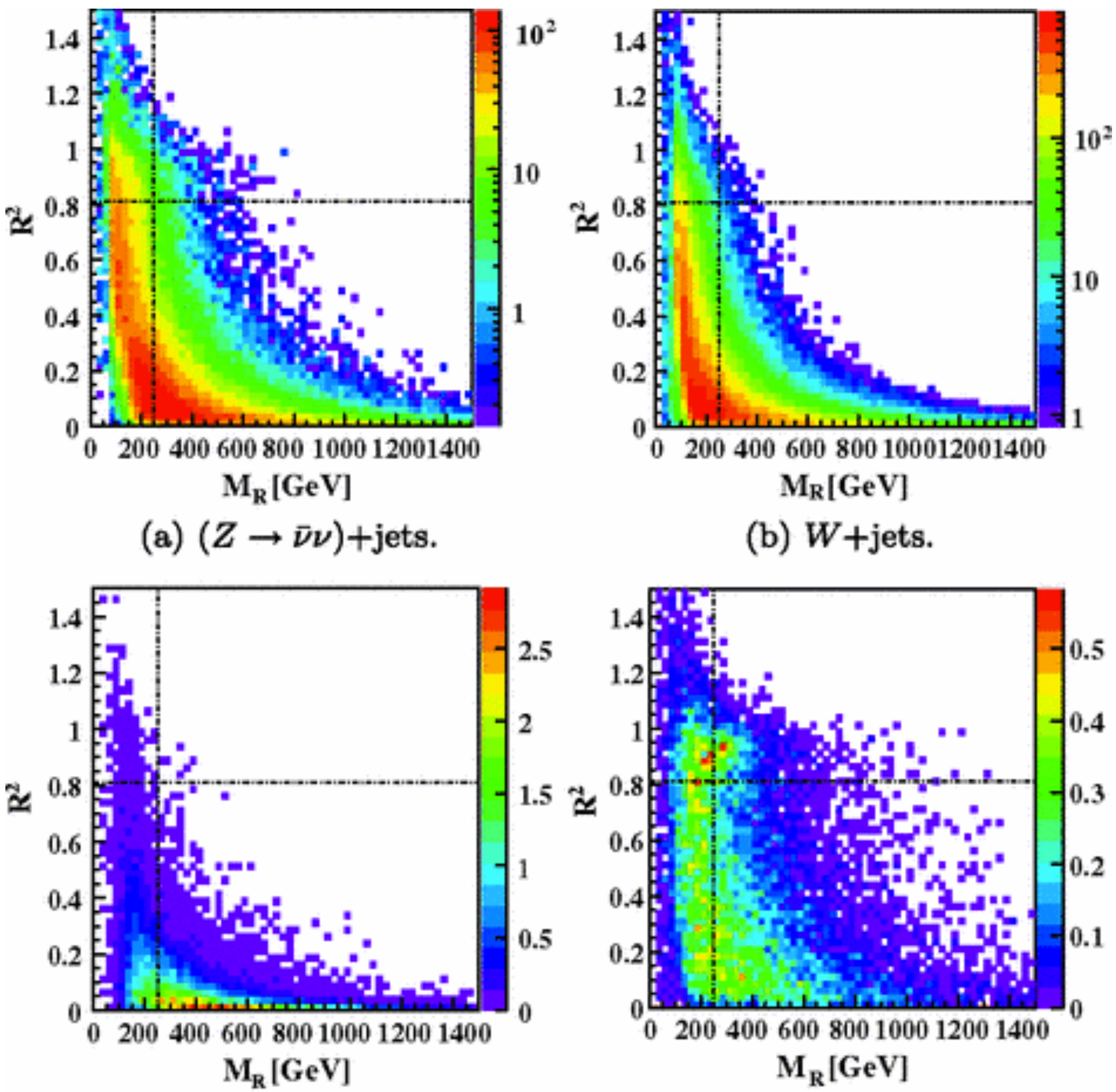
$$R \equiv \frac{M_T^R}{M_R}\,,$$

with

$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{J_1} + p_T^{J_2}) - \vec{E}_T^{miss}\cdot(\vec{p}_T^{J_1} + \vec{p}_T^{J_2})}{2}}\,.$$

- Events with M_R >200 GeV, and R^2 > 0.5 are retained for the analysis.

Razor: motivations



(a) $(Z \rightarrow \bar{\nu}\nu)$+jets. (b) W+jets. (c) $t\bar{t}$. (d) Signal ($M_\chi = 100$ GeV, $\Lambda = 644$ GeV).

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Event selection at trigger levels

- Parked data was used with corresponding integrated luminosity 18.8 fb^{-1}.
- Two jets are reconstructed at L1 in the central path.
- At the HLT, at least two jets with $P_T > 64$ GeV are considered.
  - $R^2 > 0.09$ and $R^2 \times M_R > 45$ GeV are considered.

M_R Range (GeV)	200 – 300	300 – 400	400 – 3500
Trigger Efficiency	$91.1\pm^{1.5}_{1.7}$	$90.7\pm^{2.3}_{2.9}$	$94.4\pm^{2.4}_{3.6}$

Trigger efficiencies for different M_R regions

Event categories

Sample	b-tagging selection	$\mathrm{M_R}$ selection
0μ, 1μ, and 2μ	no CSV loose jet	$200 < \mathrm{M_R} \leq 300$ GeV (VL) $300 < \mathrm{M_R} \leq 400$ GeV (L) $400 < \mathrm{M_R} \leq 600$ GeV (H) $\mathrm{M_R} > 600$ GeV (VH)
0μbb	≥ 2 CSV tight jets	$\mathrm{M_R} > 200$ GeV
0μb	$=1$ CSV tight jets	
1μb	≥ 1 CSV tight jets	
2μb		
$\mathrm{Z}(\mu\mu)$b	≥ 1 CSV loose jets	

0-Tag: Background estimation

$$n_i^{0\mu} = \left(n_i^{1\mu} - N_i^{t\bar{t},1\mu} - N_i^{Z(\ell\ell)+jets,1\mu}\right)\frac{N_i^{W+jets,0\mu} + N_i^{Z(\nu\bar{\nu})+jets,0\mu}}{N_i^{W+jets,1\mu}} + \left(n_i^{2\mu} - N_i^{t\bar{t},2\mu}\right)\frac{N_i^{Z(\ell\ell)+jets,0\mu}}{N_i^{Z(\ell\ell)+jets,2\mu}}$$

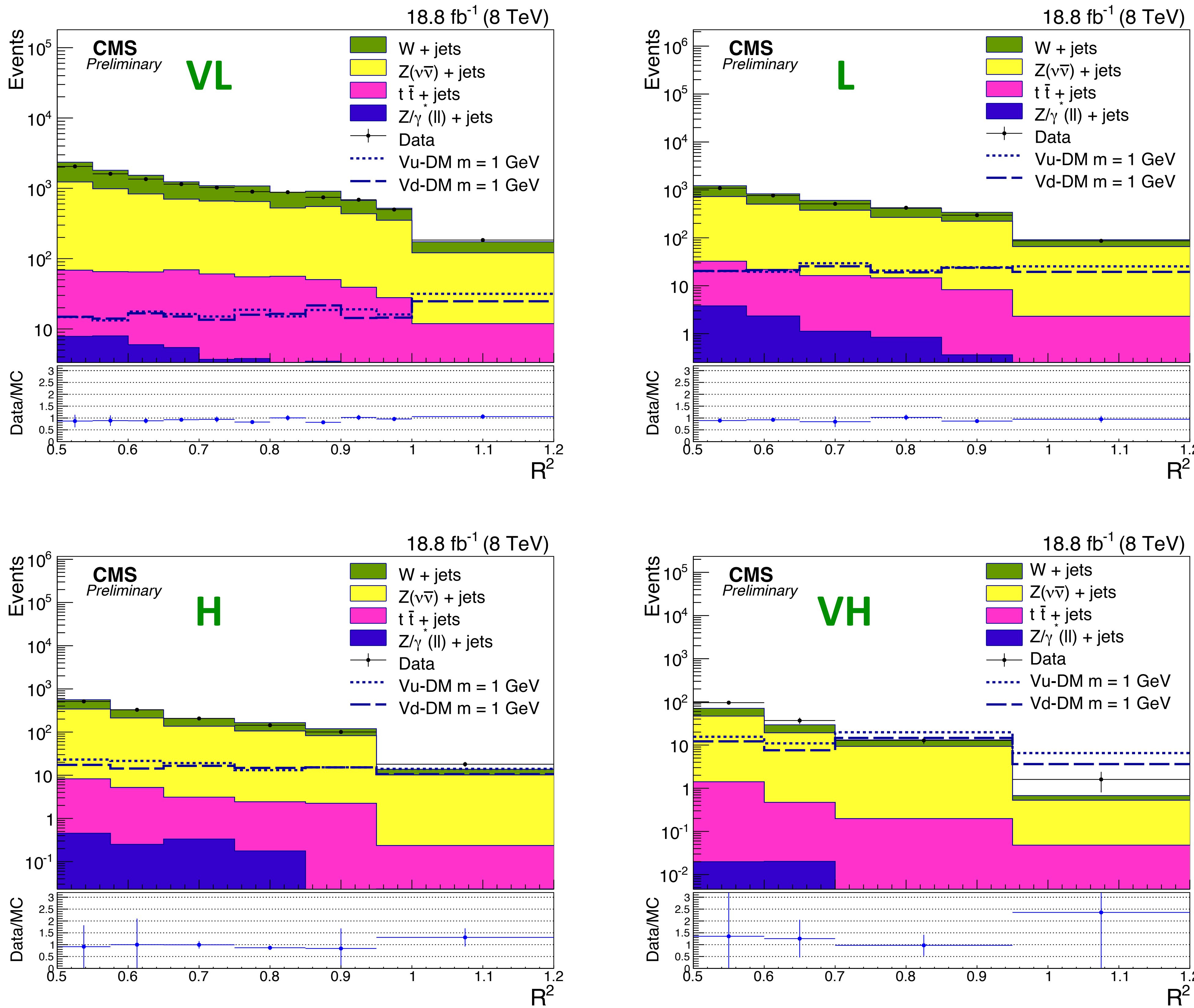
SIGNAL REGION

1 muon events to predict
- remaining W(lv)+jets
- Z(vv)+Jets

2 muon events
to predict
- remaining Z(ll)+jets

- bin-by-bin prediction.
- Independent M_R categories

0-Tag: Data-vs-SM predictions



0-Tag: Interpretation in EFT framework

- To translate upper limit to lower limit of the cutoff scale, and DM-Nucleon cross section,

Axial-vector operator spin-dependent (SD)

$$\mathcal{O}_{AV} = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2}$$

Vector operator spin independent (SI)

$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

$$\Lambda_{LL} = \Lambda_{GEN}\left(\frac{\sigma_{GEN}}{\sigma_{UL}}\right)^{1/4}$$

$$\sigma^{SD}_{N-\chi} = 0.33\frac{\mu^2}{\pi\Lambda^4_{LL}}$$

$$\sigma^{SI}_{N-\chi} = 9\frac{\mu^2}{\pi\Lambda^4}$$

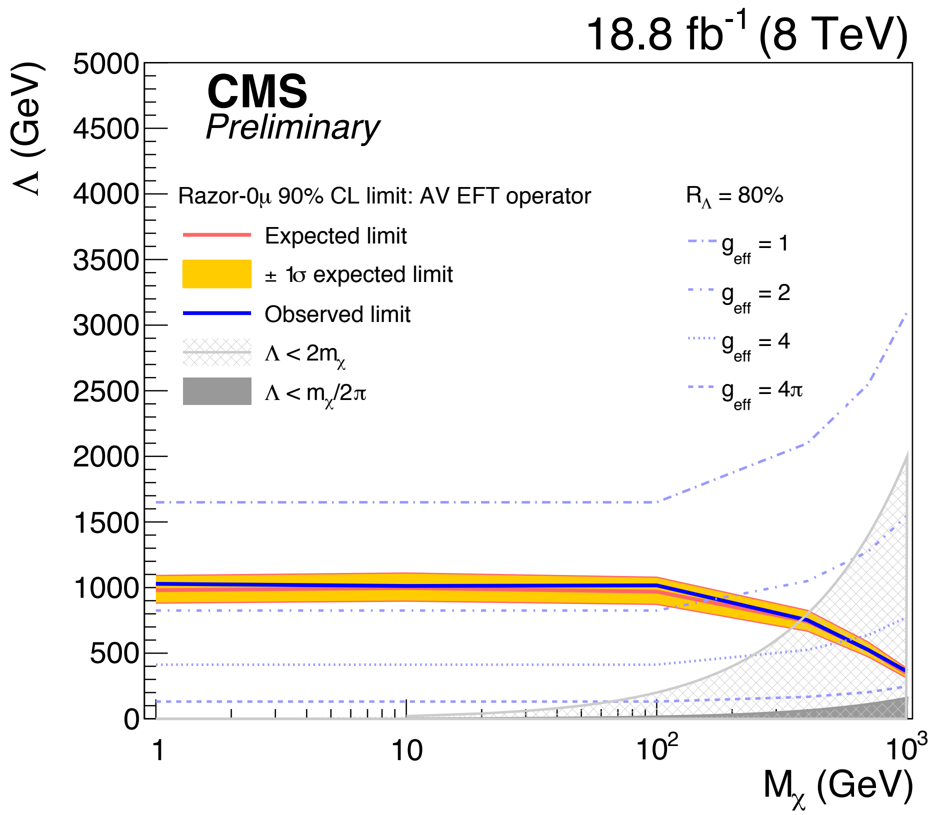
- Validity of the EFT approach
  - Kinematics for s-Channel

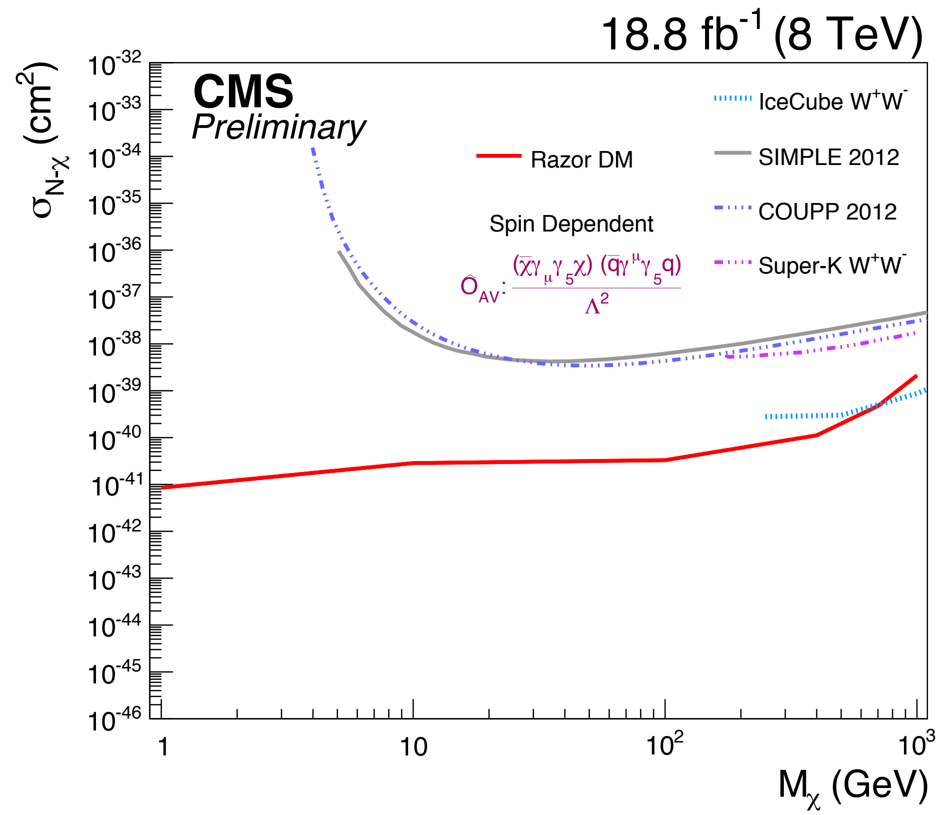
$$Q_{tr} < M$$
$$g_q, g_\chi < 4\pi$$
$$Q_{tr} < \sqrt{g_q g_\chi}\Lambda < 4\pi\Lambda$$

  - Effect of the EFT cutoff, 1307.2253

$$R_\Lambda = \frac{\int dR^2 \int dM_R \left.\frac{d^2\sigma}{dR^2 dM_R}\right|_{Q_{tr}<g_{\rm eff}\Lambda}}{\int dR^2 \int dM_R \frac{d^2\sigma}{dR^2 dM_R}}$$

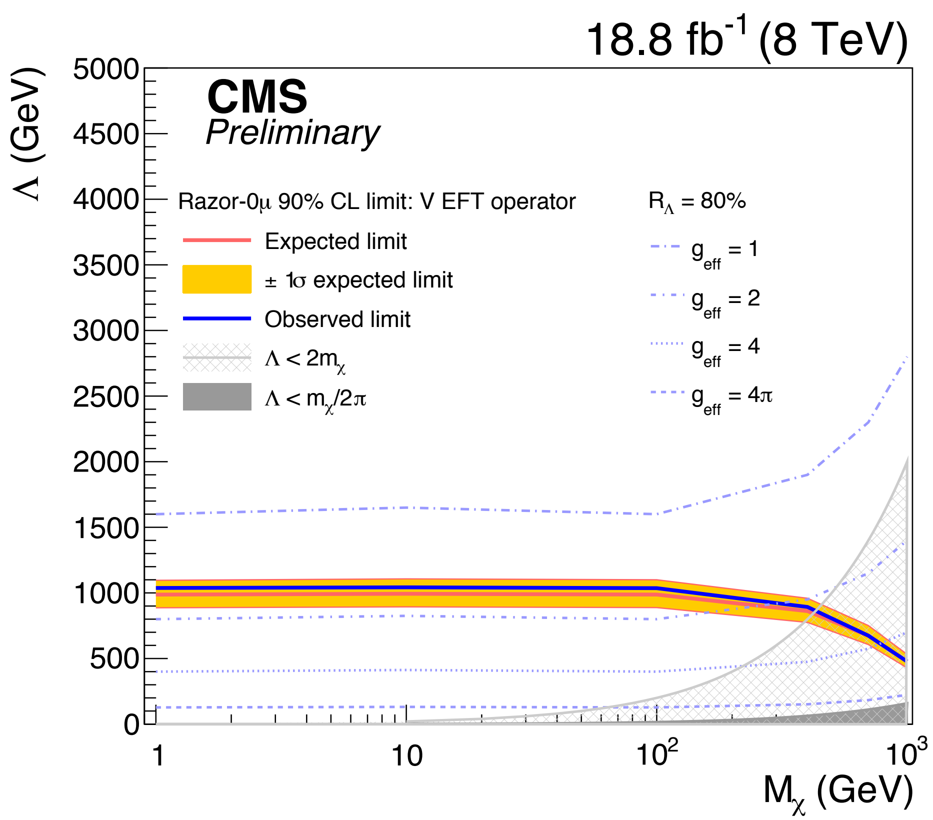
0-Tag: Interpretation in EFT framework

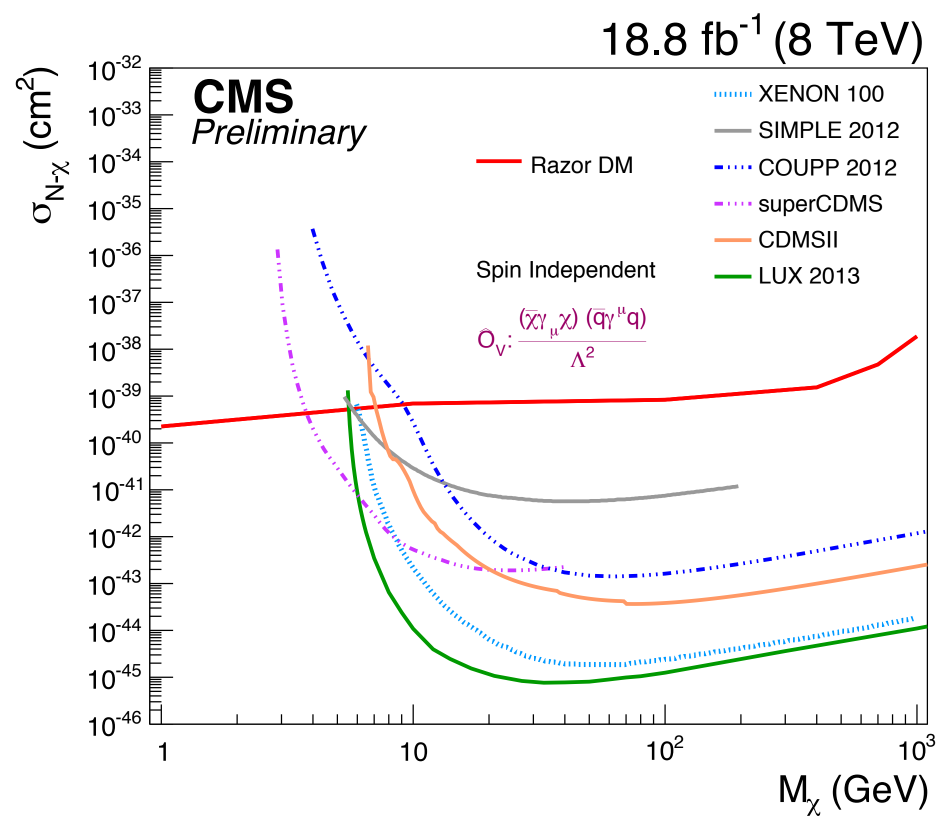




Axial-vector operator spin-dependent (SD)

$$\mathcal{O}_{AV} = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2}$$





Vector operator spin independent (SI)

$$\mathcal{O}_{V} = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO14004

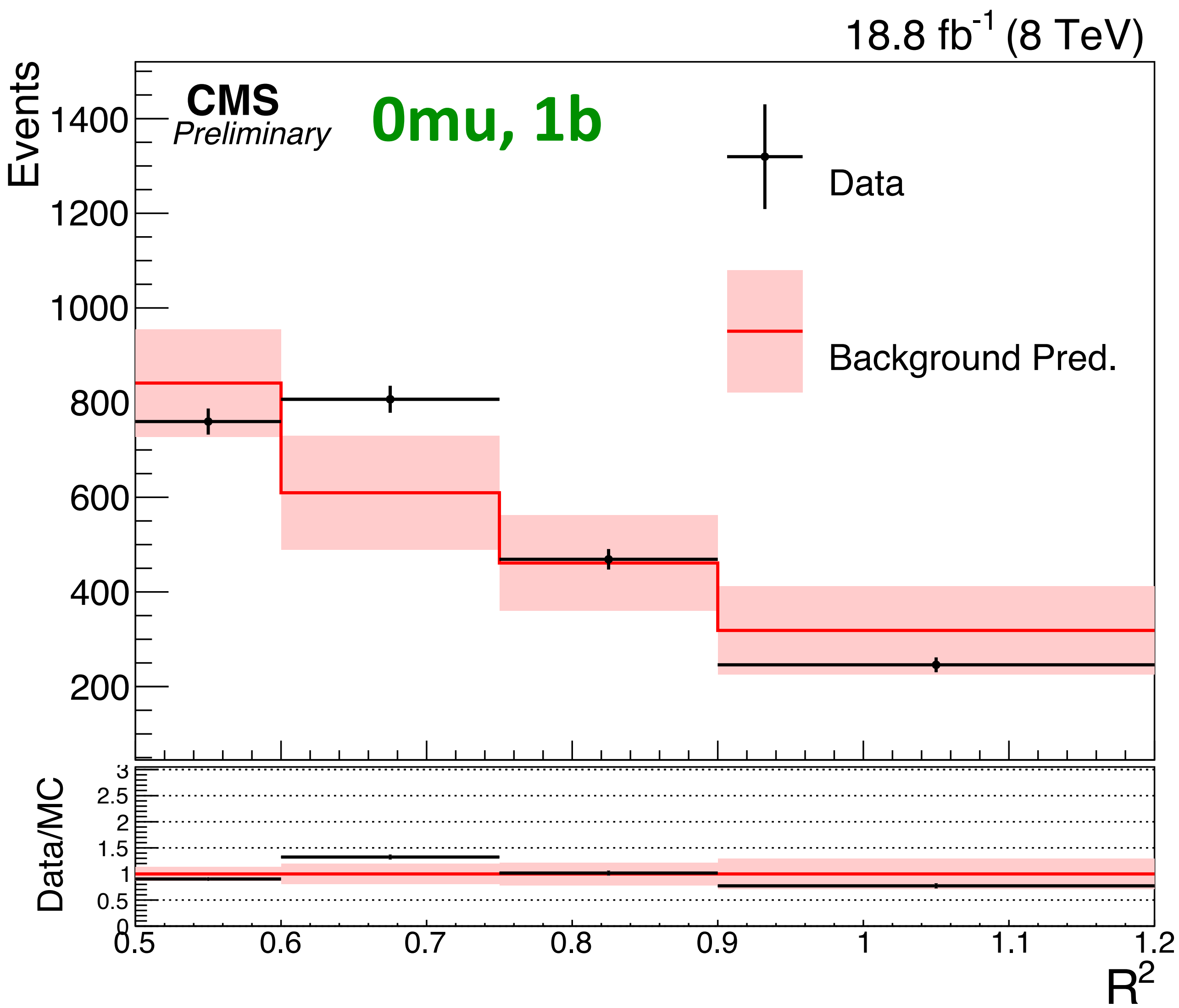
b-Tag: Background estimation

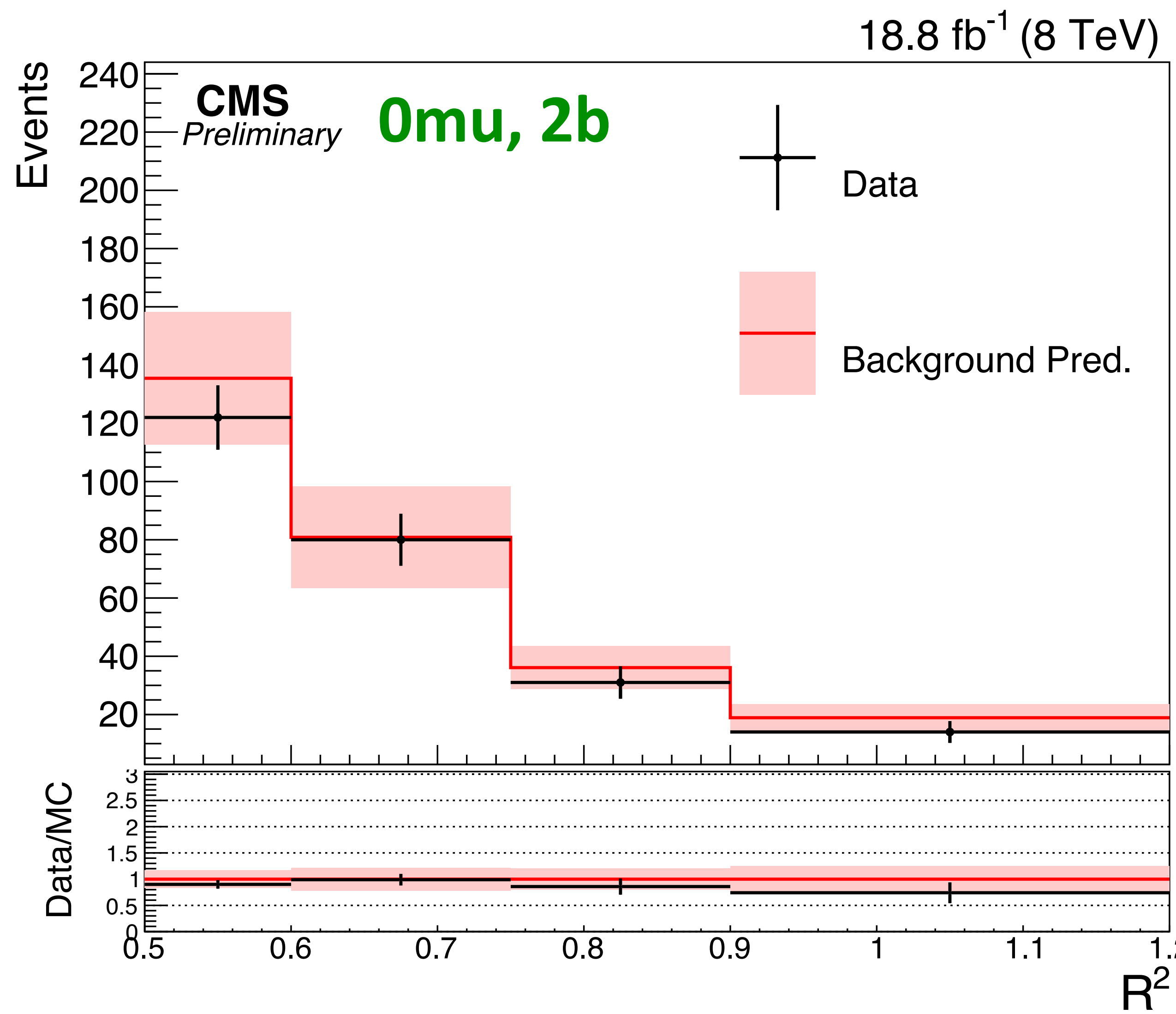
- A method is similar to the no b-Tag.
- Background is dominated by ttbar events, and V+Jets is subleading.
- ttbar events in the 0-muon+b-Tag sample can be computed as

$$n(t\bar{t})_i^{0\mu b} = (n(t\bar{t})_i^{2\mu b} - N_i^{Z(\ell\ell)+jets,2\mu b} - N_i^{W+jets,2\mu b})\frac{N(t\bar{t})_i^{0\mu b}}{N(t\bar{t})_i^{2\mu b}}$$

- W(lv)+Jets and Z(vv)+Jets are predicted using the Z(mumu)b

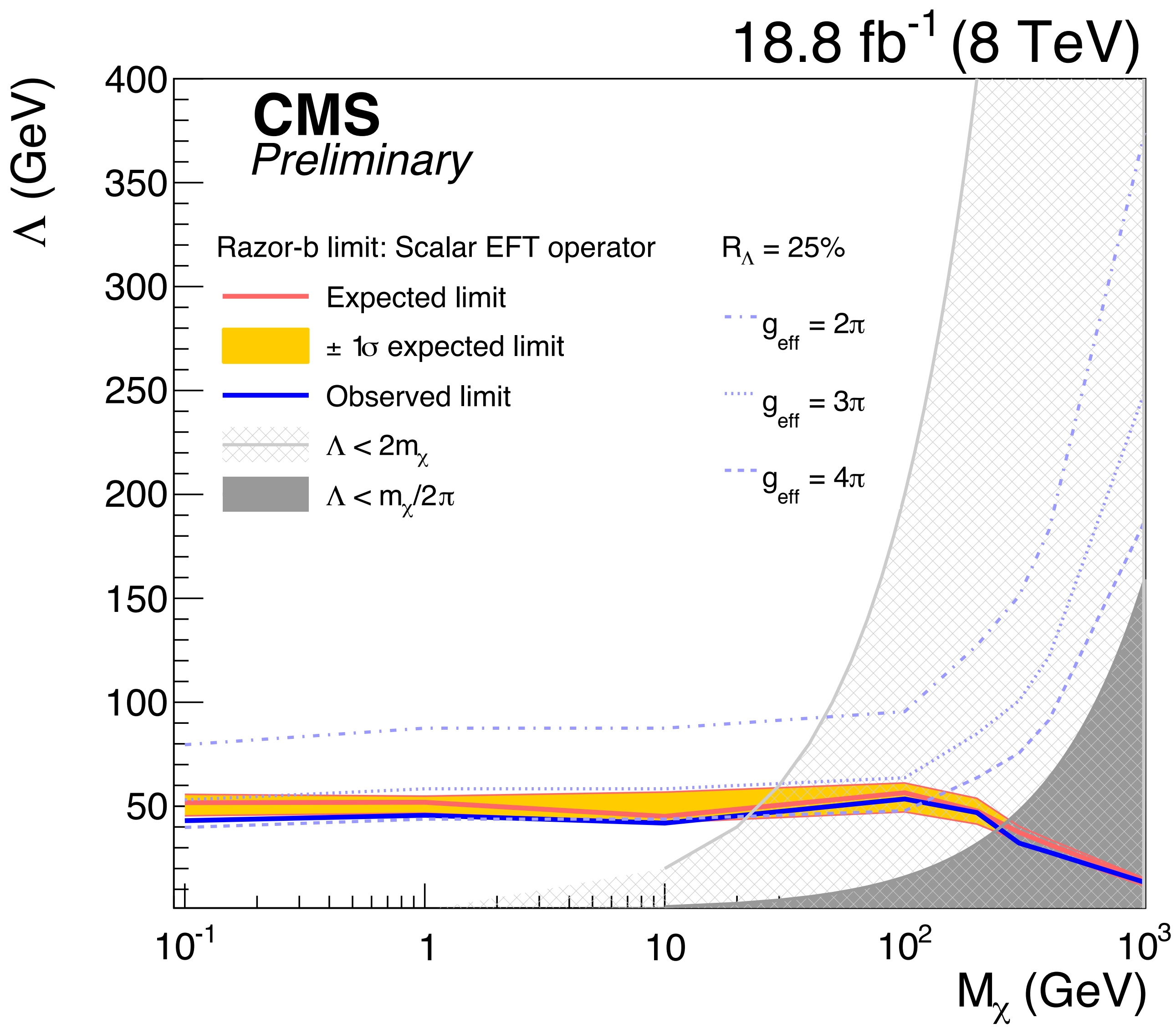
b-Tag: Data-vs-SM predictions

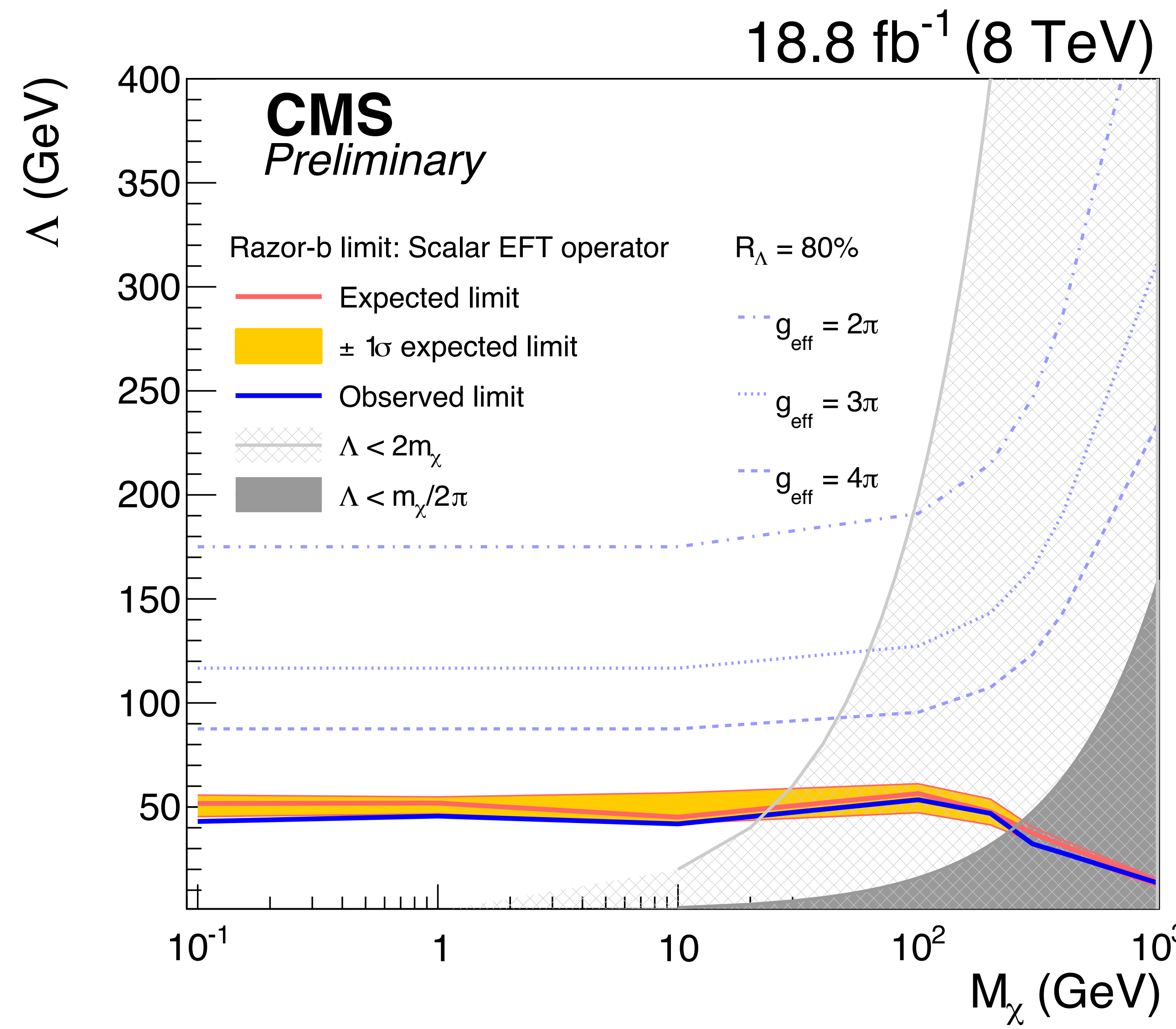




Sample	$Z(\nu\bar{\nu})$+jets	$W(\ell\nu)$+jets	$Z(\ell\ell)$+jets	$t\bar{t}$	Predicted (simulation)	Predicted (data driven)	Observed
$0\mu bb$	44 ± 3	14 ± 2	0.2 ± 0.1	204 ± 4	262 ± 5	271 ± 37	247
$0\mu b$	417 ± 8	216 ± 7	2.4 ± 0.4	1480 ± 12	2116 ± 16	2231 ± 281	2282

b-Tag: Interpretation in EFT framework





$$\hat{\mathcal{O}}_S = \frac{m_q}{\Lambda^3}\bar{\chi}\chi\bar{q}q, \quad \Lambda_{LL} = \Lambda_{GEN}\left(\frac{\sigma_{GEN}}{\sigma_{UL}}\right)^{1/6}$$

Summary

- Presented the multijet+MET analysis with/without b-tagged jets at the CMS.
- No excess of events over the estimated SM background.
- Limits to EFT DM models have been obtained, and translate into dark matter-nucleon cross section.
- Looking forward for 13 TeV results.