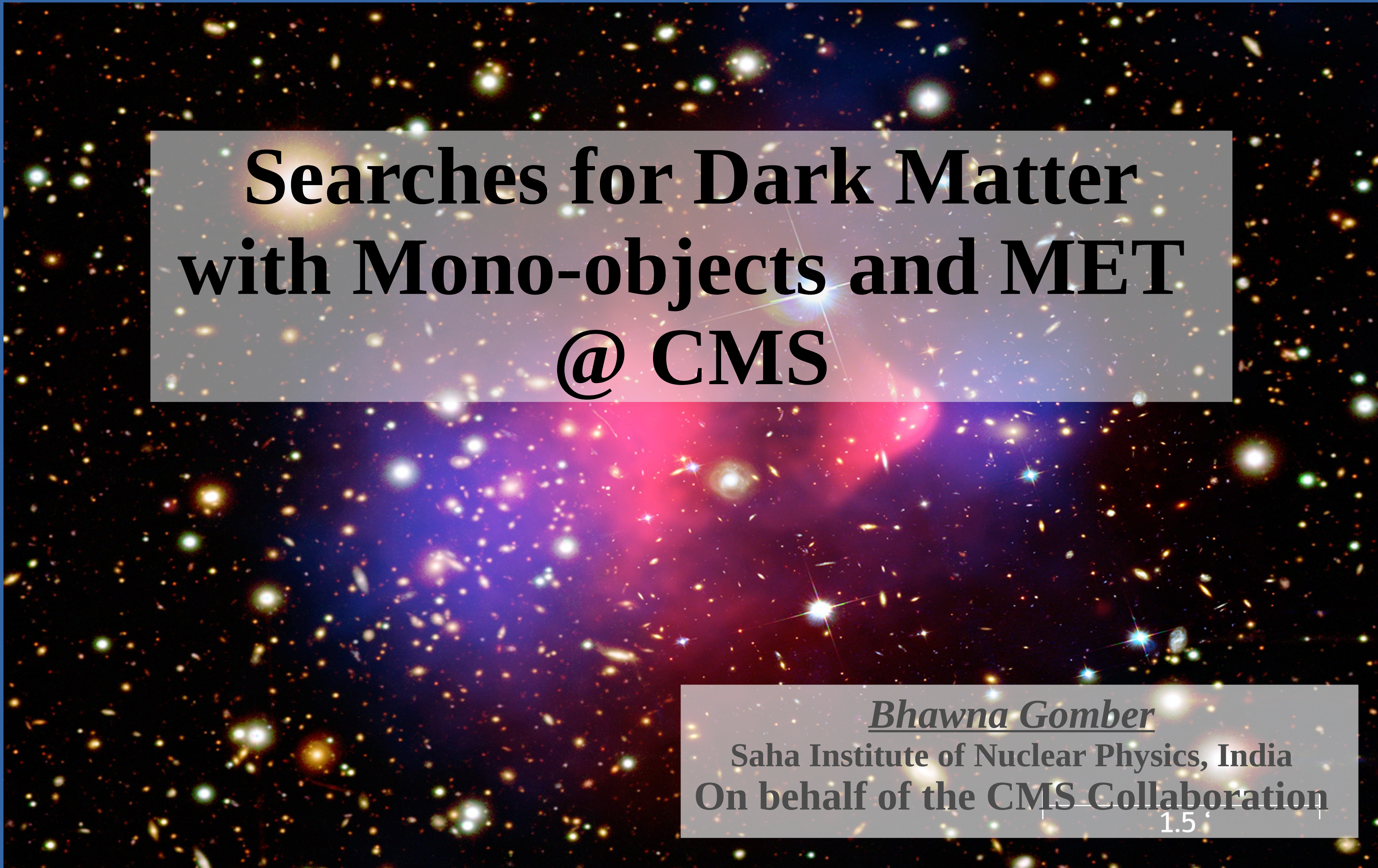


Searches for Dark Matter with Mono-objects and MET @ CMS

Bhawna Gomber

Saha Institute of Nuclear Physics, India

On behalf of the CMS Collaboration

SUSY2014 : 21st – 26th August

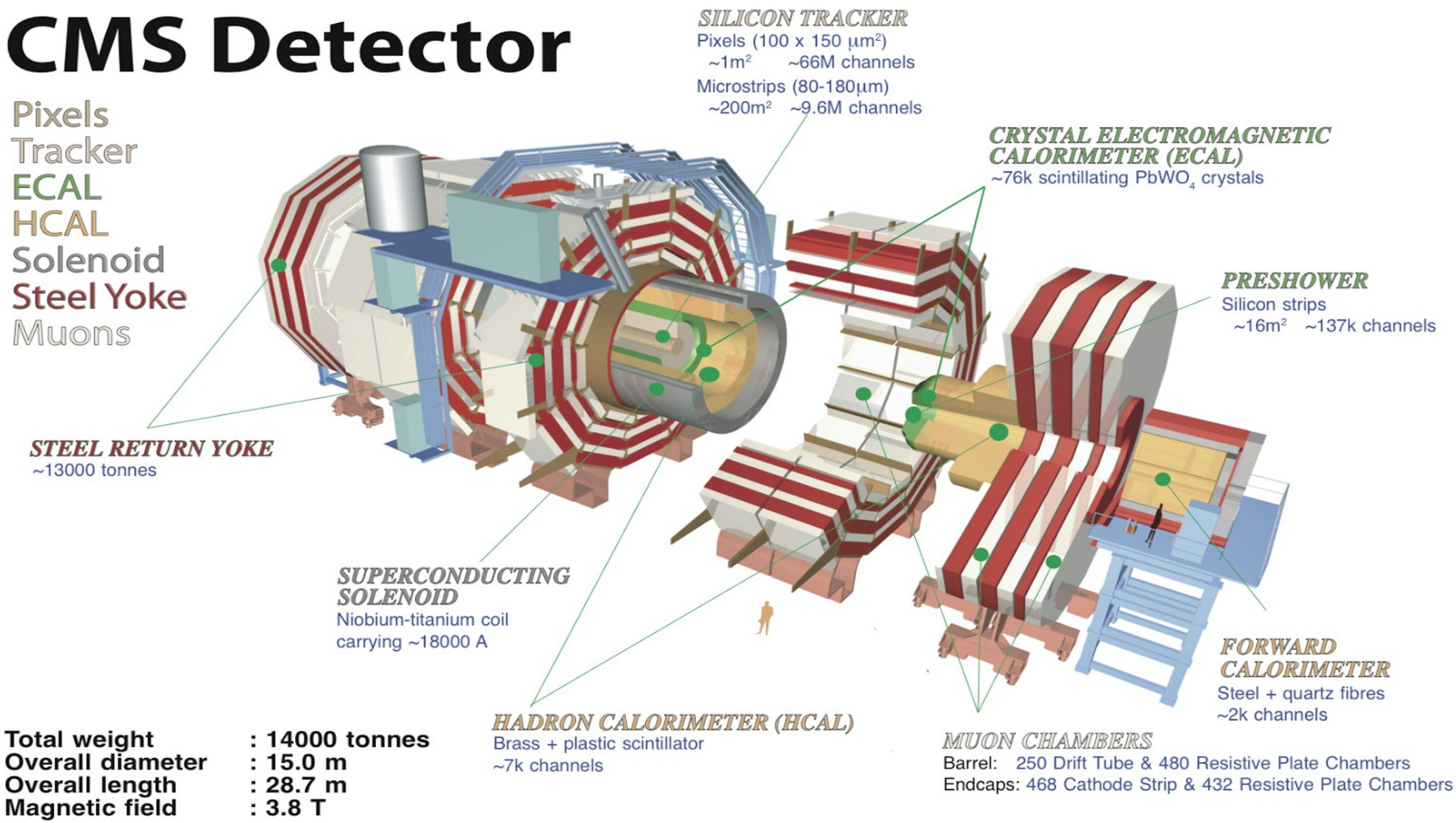
CMS

MANCHESTER 1824

The University of Manchester

CMS Detector

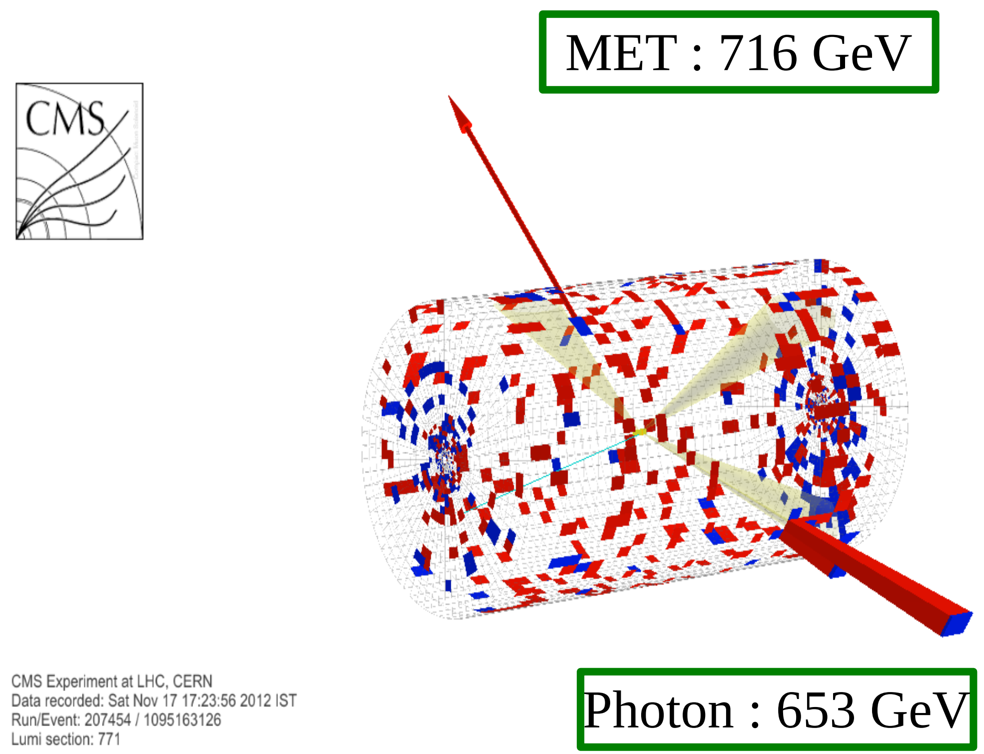
Schematic view



Missing Transverse Energy

The hallmark signature for dark matter ("DM") is a momentum imbalance or missing transverse energy ("MET")

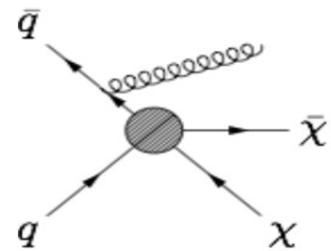
- DM particles escapes the detector without interaction
- Nature still conserves momentum (always!)
- Infer presence of DM by imbalance in momentum



Monophoton Event

DM Effective Field Theory

Exhaustive List of ...



Effective Field Theory (EFT) :
Interaction between DM and SM particles is contact interaction

Dirac fermion, arxiv: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, arxiv: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, arxiv: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, arxiv:1008.1783

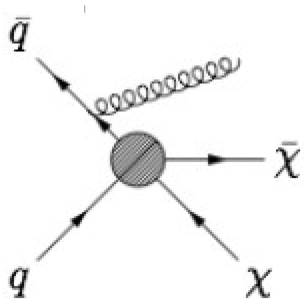
C1	$\chi^\dagger\chi\bar{q}q$	m_q/M_*^2
C2	$\chi^\dagger\chi\bar{q}\gamma^5 q$	im_q/M_*^2
C3	$\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu q$	$1/M_*^2$
C4	$\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu\gamma^5 q$	$1/M_*^2$
C5	$\chi^\dagger\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^2$
C6	$\chi^\dagger\chi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

MET + X Searches

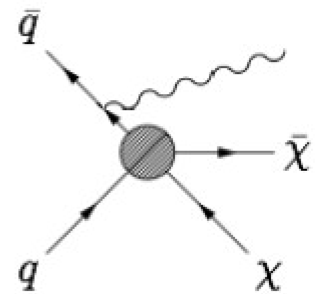
Links

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G

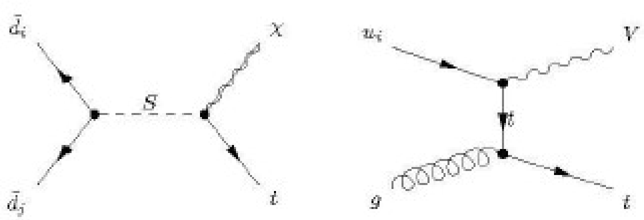
This Talk



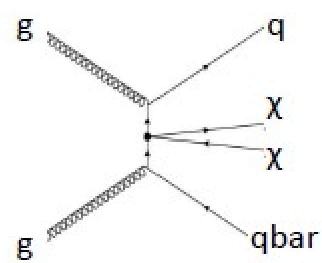
Mono-jet



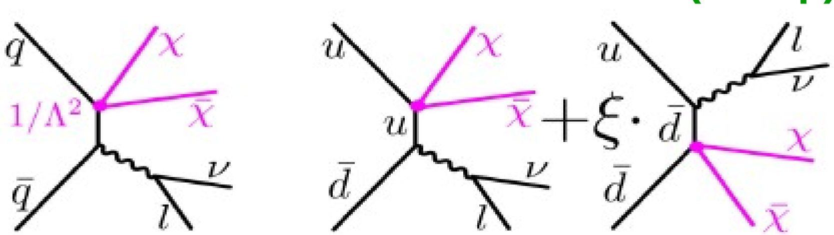
Mono-photon



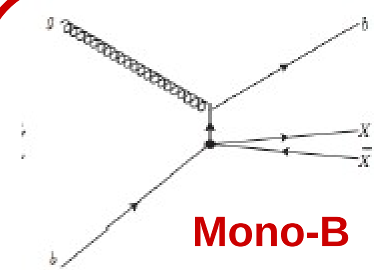
Mono-top



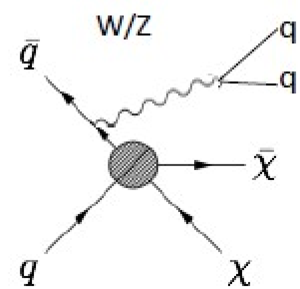
BBbar/TTbar (Di-top)



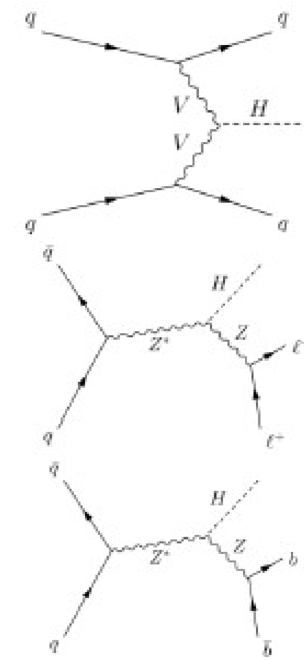
Mono-W (Mono- lepton)



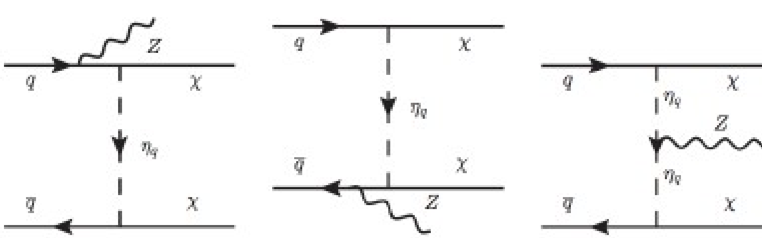
Mono-B



Mono-W/Z (hadronic)



Higgs Portal

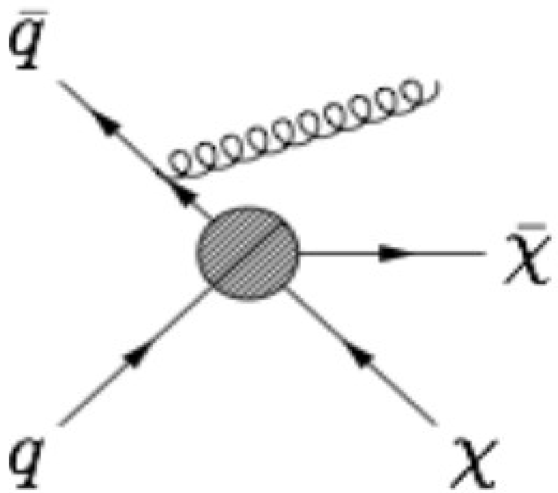


Mono-Z

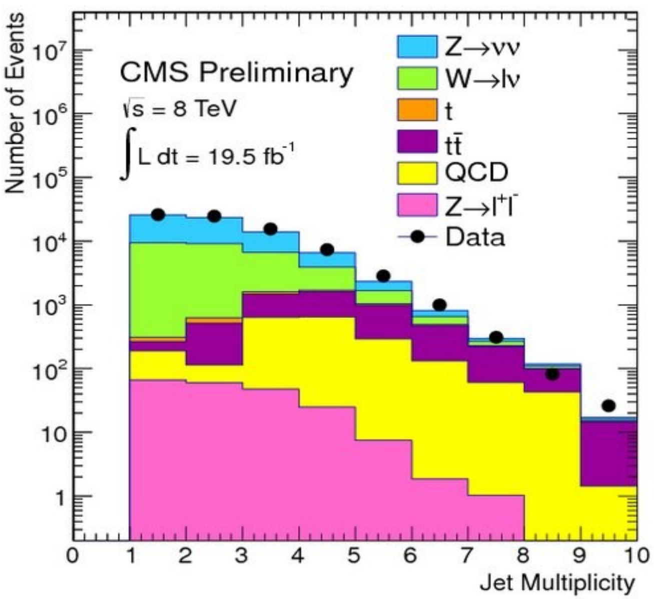
Mono-jet

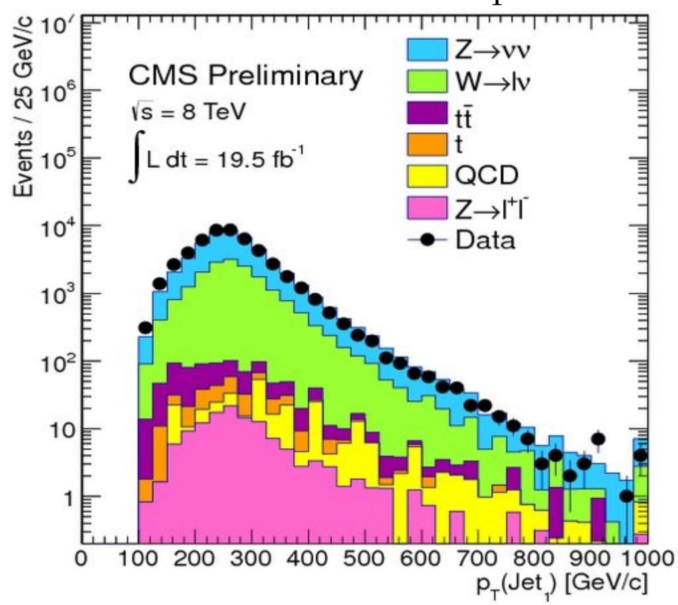
Event Selection

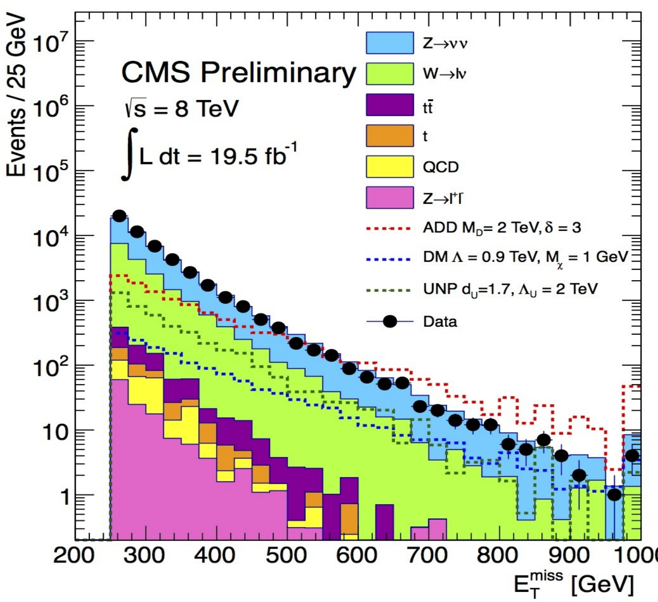
CMS PAS EXO-12-048



- One energetic jet, p_T > 110 GeV, |η| < 2.4, allow an additional jet, p_T>30 GeV
- MET > 400 GeV
- Veto event
  - If j_3 p_T > 30 GeV
  - $\Delta\varphi(j_1, j_2) > 2.5$
  - If isolated electrons, isolated muons or hadronic taus with p_T >10 GeV (20 GeV for tau)



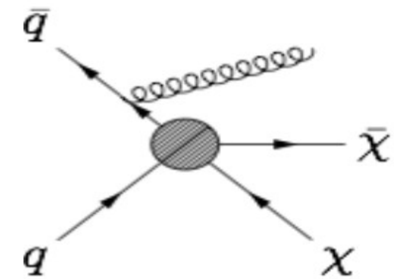


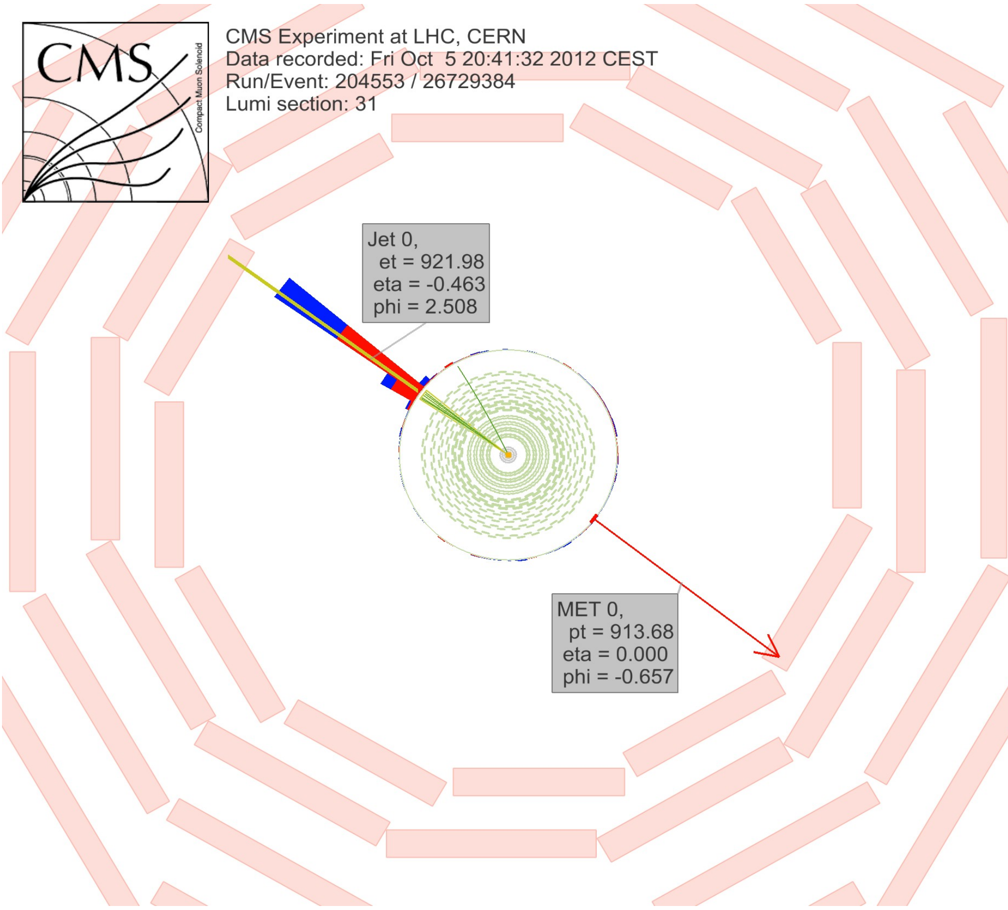


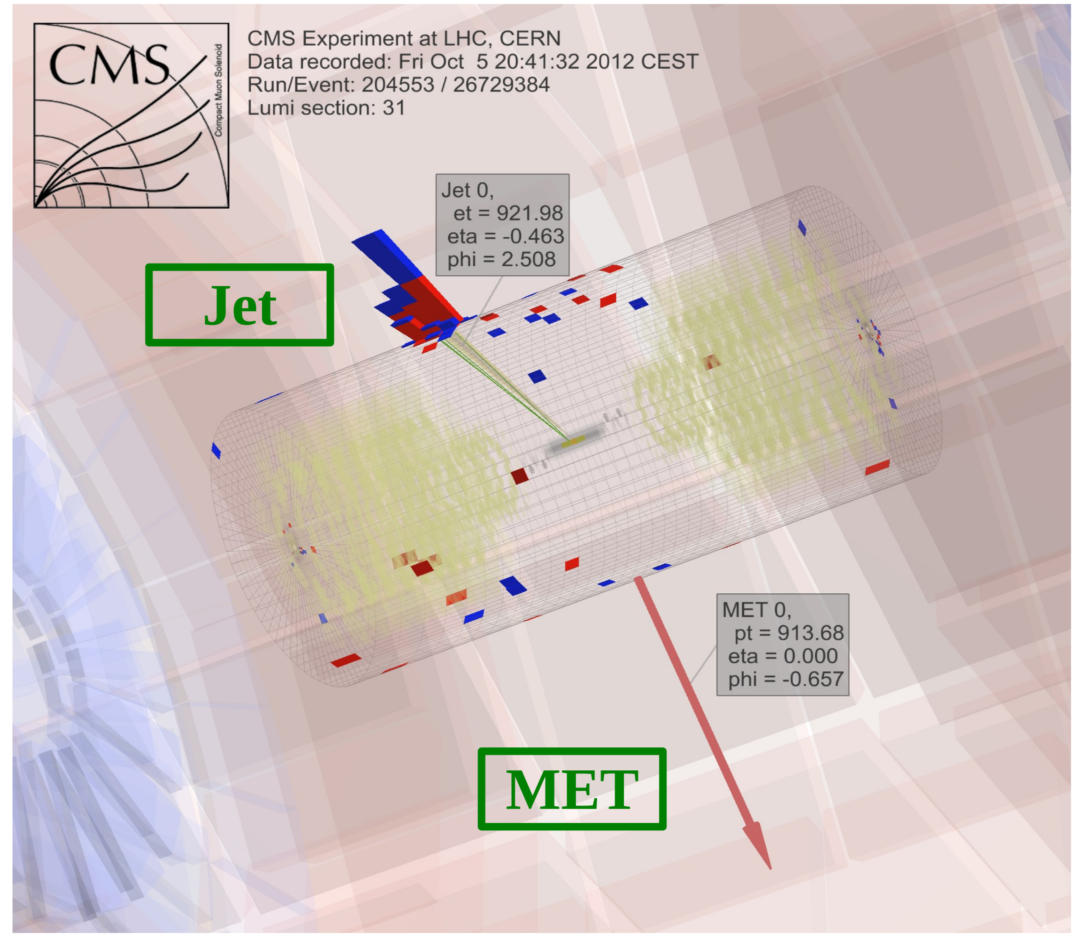
Mono-jet

Event Display

CMS PAS EXO-12-048



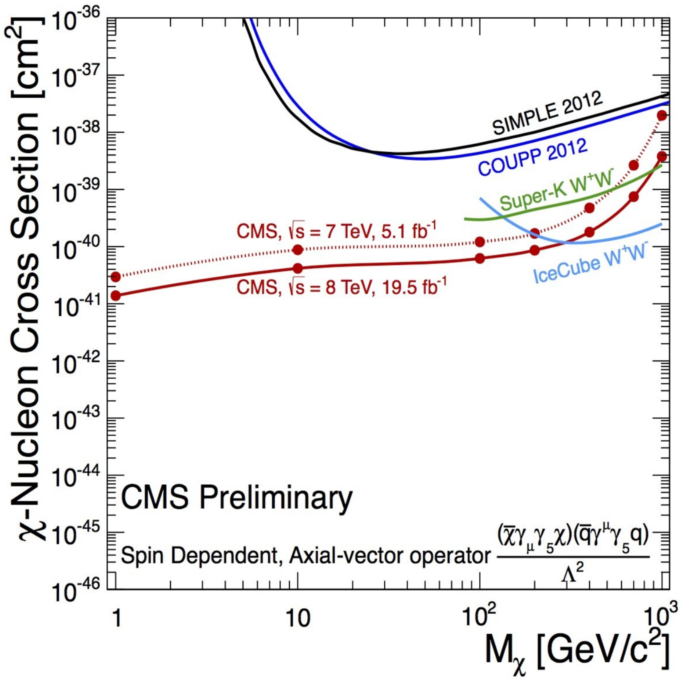


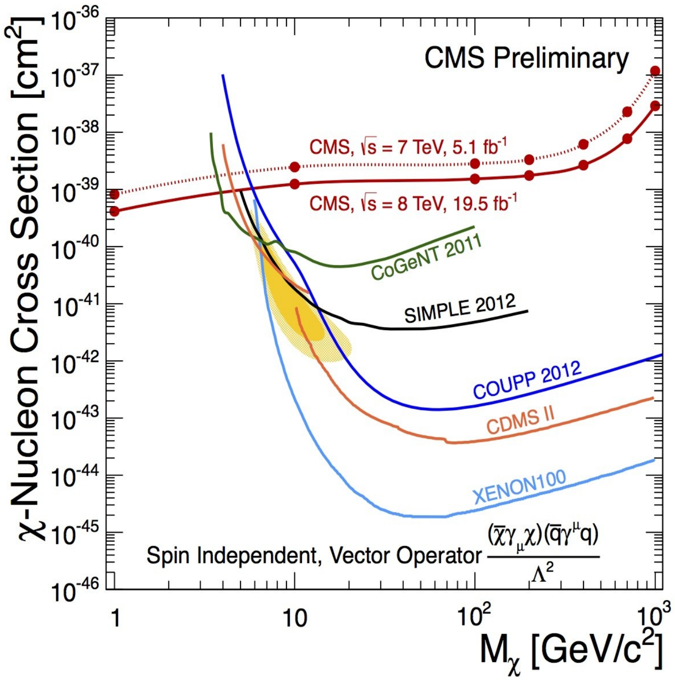


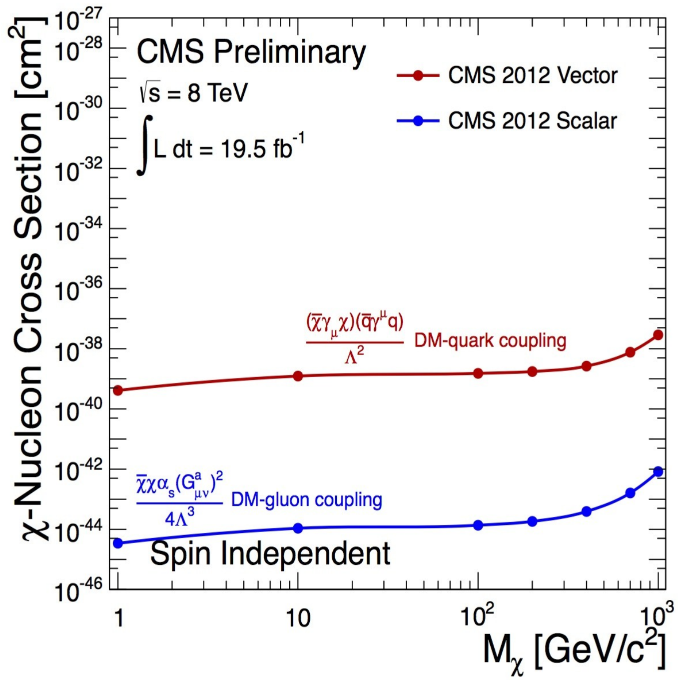
Mono-jet

Results

CMS PAS EXO-12-048







Axial-vector operator spin-dependent (SD)

Vector operator spin-independent (SI)

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

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

Λ : Interaction scale

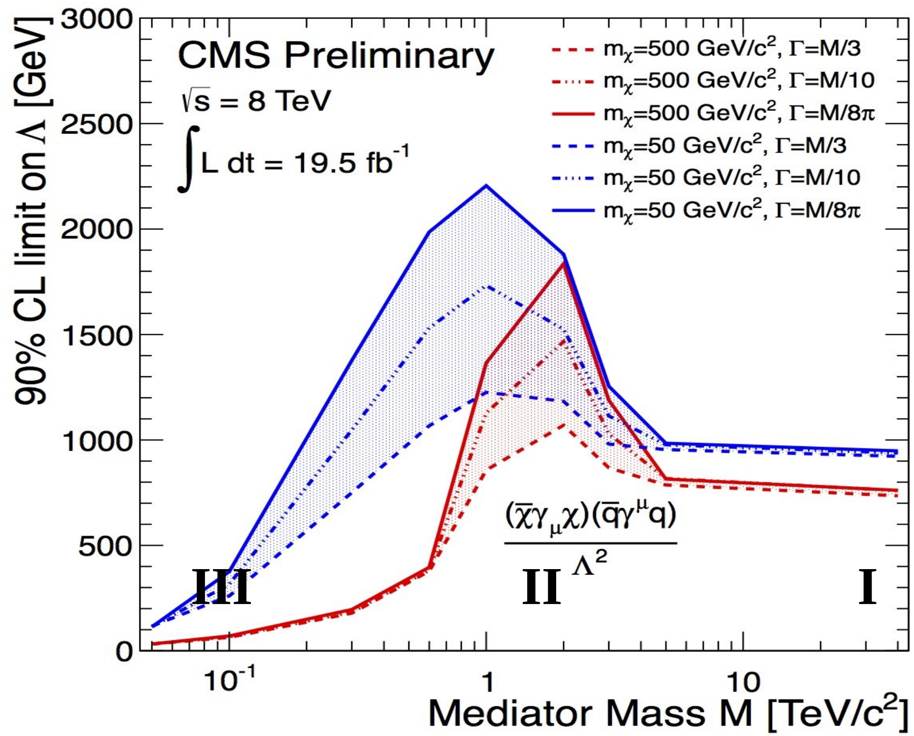
Mono-jet

Remarks

Limitation of EFT → *Simplified Model with M_**

- EFT is valid when mediator mass (M_*) > a few TeV
- The couplings required are large. Comparing this with known couplings :
  - ✗ strong interaction ~ 1.2
  - ✗ weak interaction ~ 0.6
- Theory is non-perturbative if $\sqrt{(g_q\, g_{DM})} > 4\pi$
- Width larger than mass, so unlikely mediator will be identified as a particle.

✔ Region I : EFT limit is good!
✔ Region II : EFT limit is too weak!
✔ Region III : EFT limit is too strong!

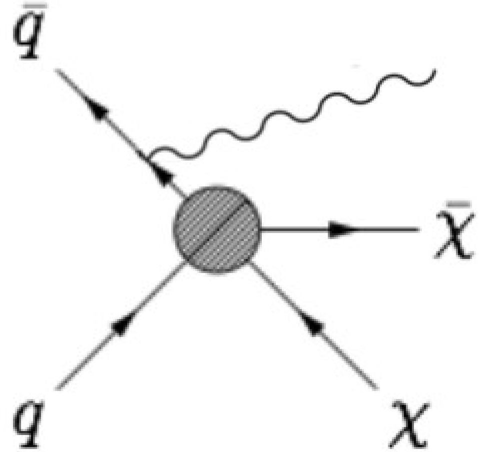


See for example, arXiv:1308.6799 for further reading

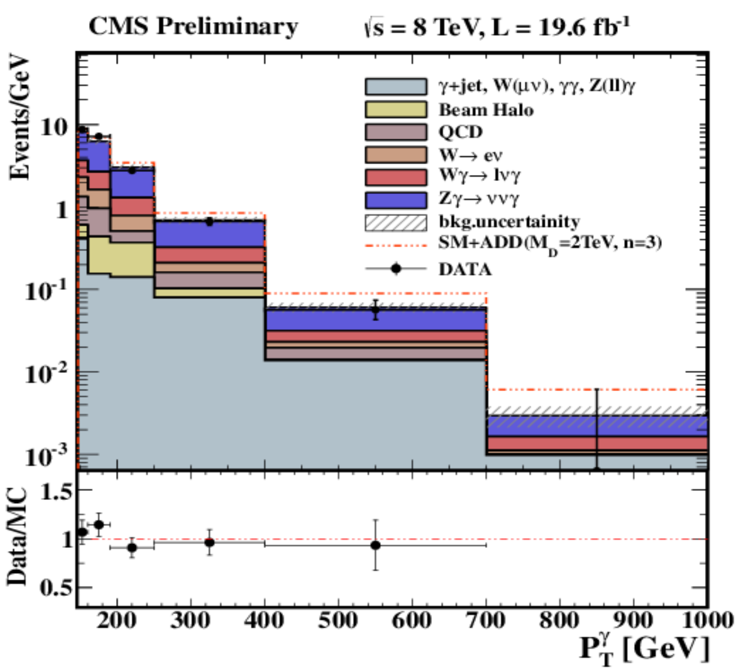
Mono-photon

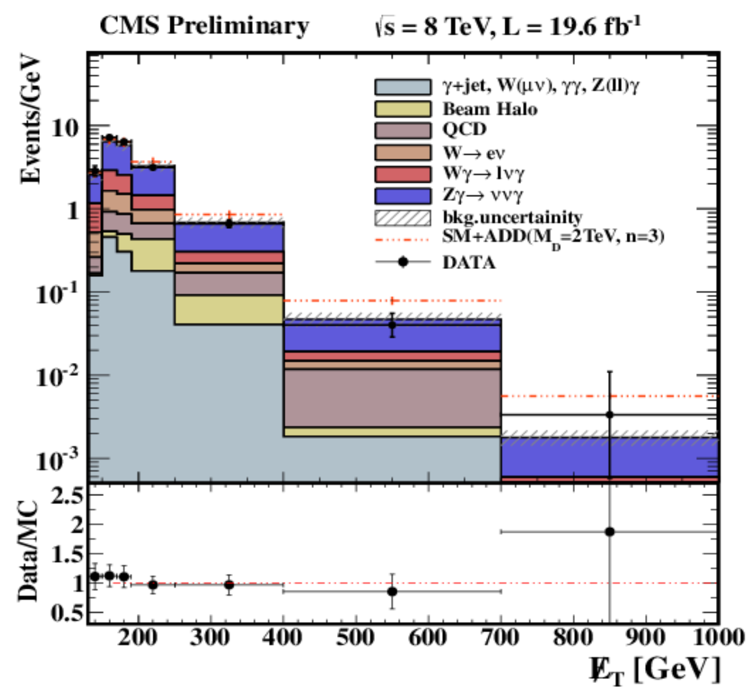
Event Selection

CMS PAS EXO-12-047



- One energetic photon, p_T > 145 GeV, $|\eta|$ < 1.44
- MET > 140 GeV
- Veto events if j_2 p_T > 30 GeV
- Veto on leptons and pixel seed (hit patern in the pixel detector)
- $\Delta\varphi$(photon, MET) > 2
- MinMET >120 GeV, Prob(χ^2) (Reduce fake MET events)

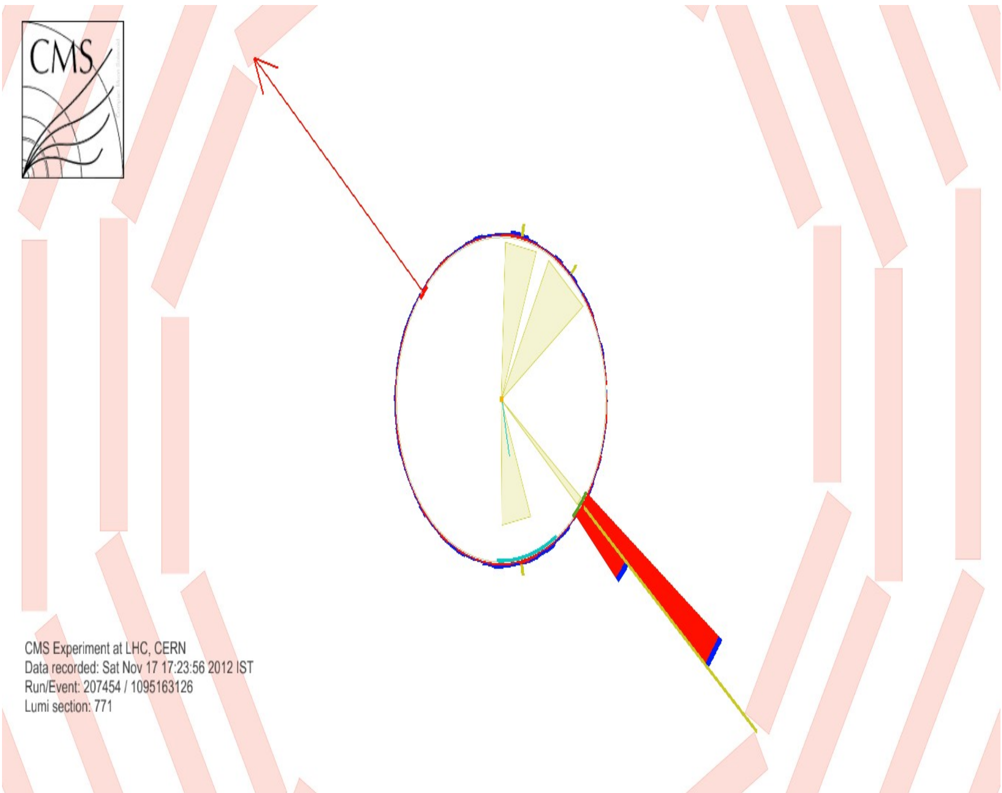


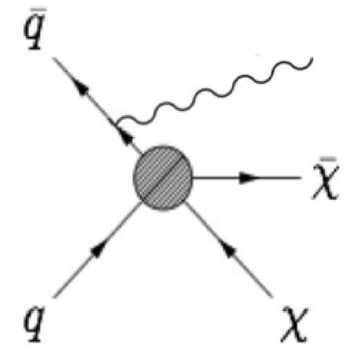


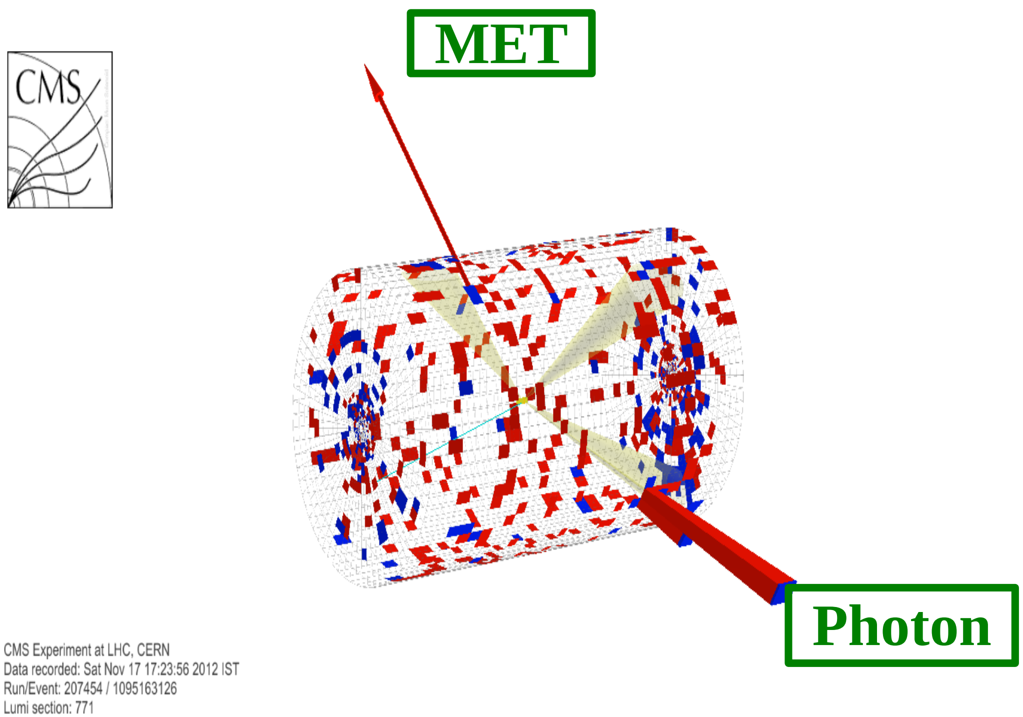
Mono-photon

Event Display

CMS PAS EXO-12-047

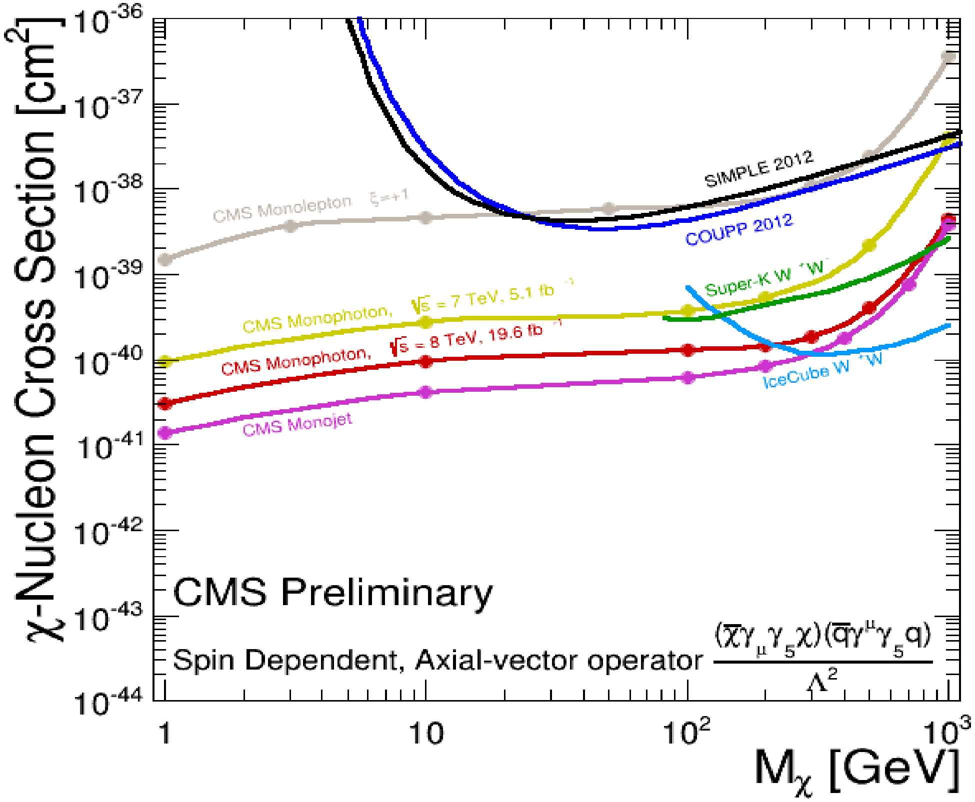


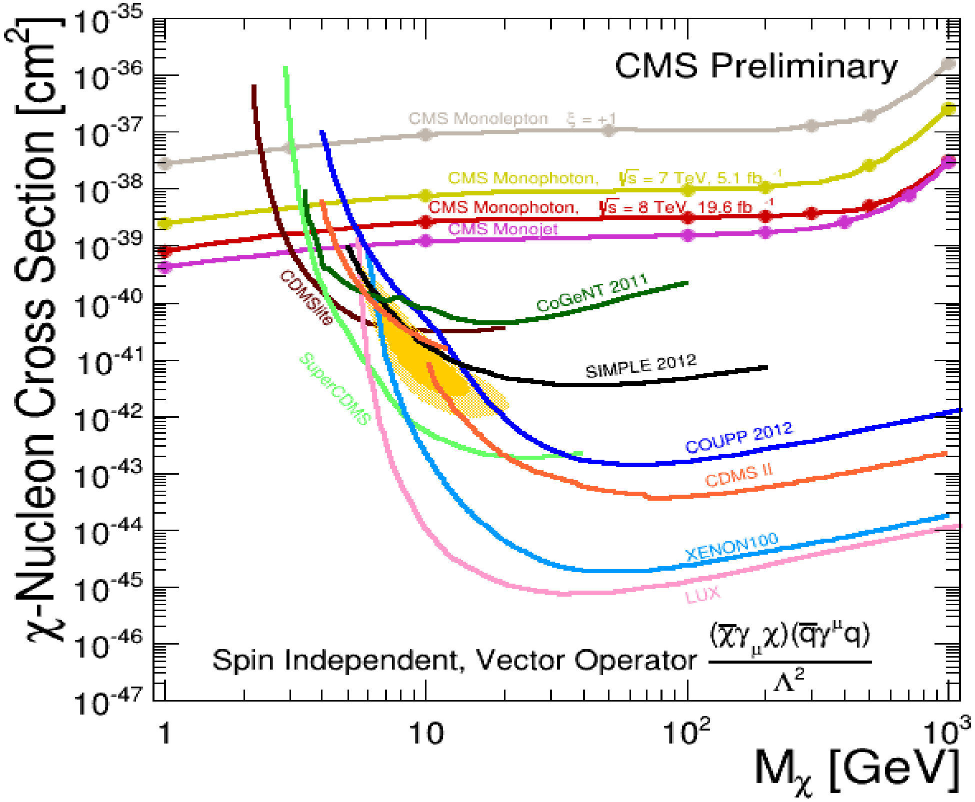




Mono-photon

CMS PAS EXO-12-047





Axial-vector operator spin-dependent (SD)

Vector operator spin-independent (SI)

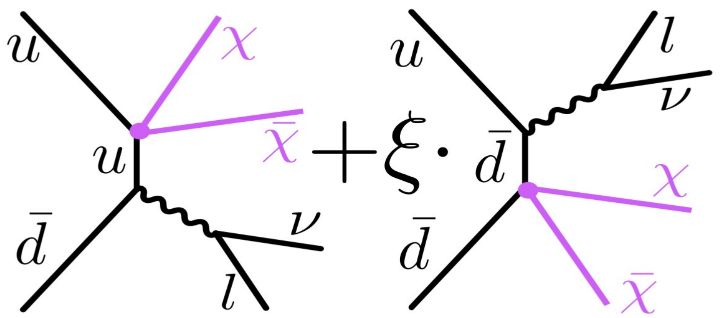
$$\mathcal{O}_{AV} = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2} \qquad \mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

Λ : Interaction scale

Mono-lepton

Event Selection

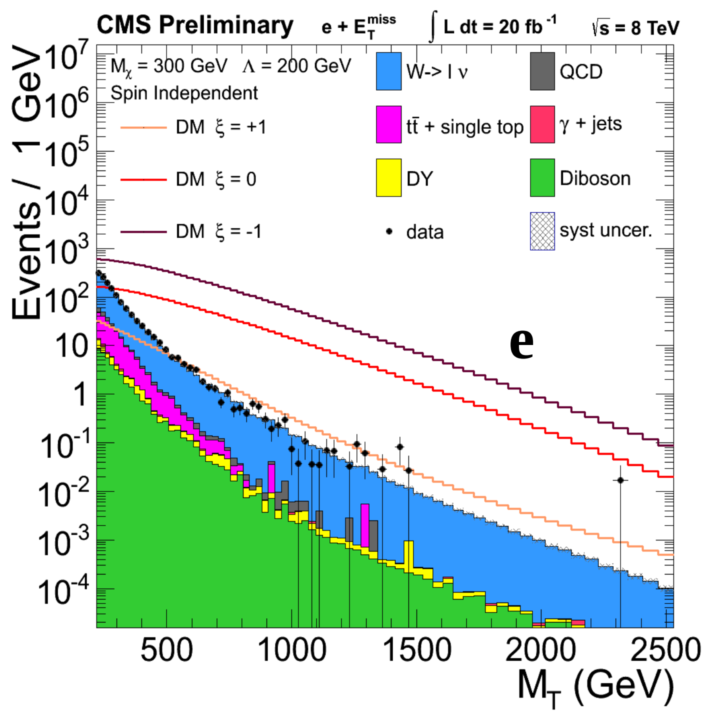
CMS PAS EXO-13-004

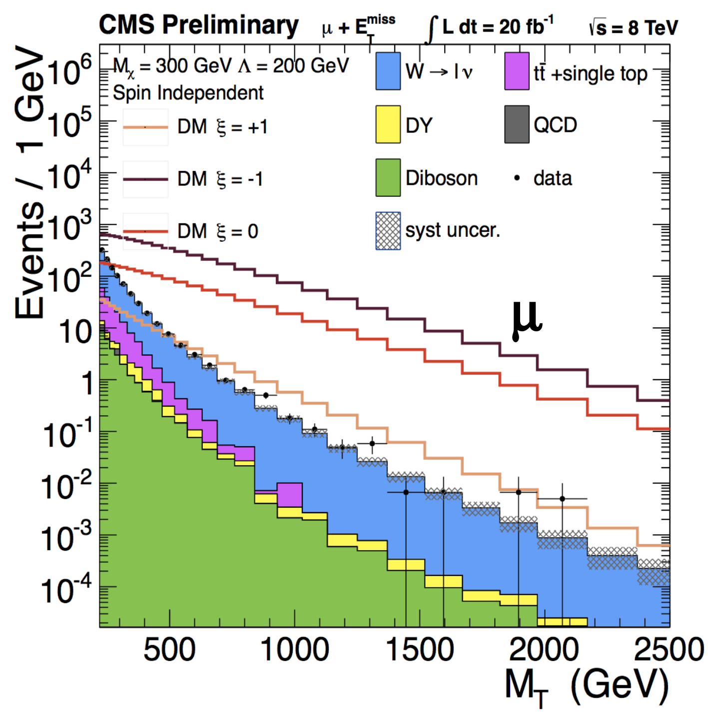


- Dark Matter production with a W
- W recoiling against pair-produced DM
- Vector- and axial-vector couplings considered
- Interference effects parameterized by ξ (W+)

$$M_T = \sqrt{2 \cdot p_T^{\ell} \cdot E_T^{\text{miss}} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}$$

- μ(e) p_T > 45(100) GeV
- 0.4 < p_T/MET < 1.5
- Δφ (lepton, MET) > 0.8*π



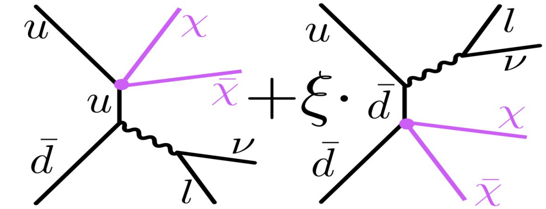


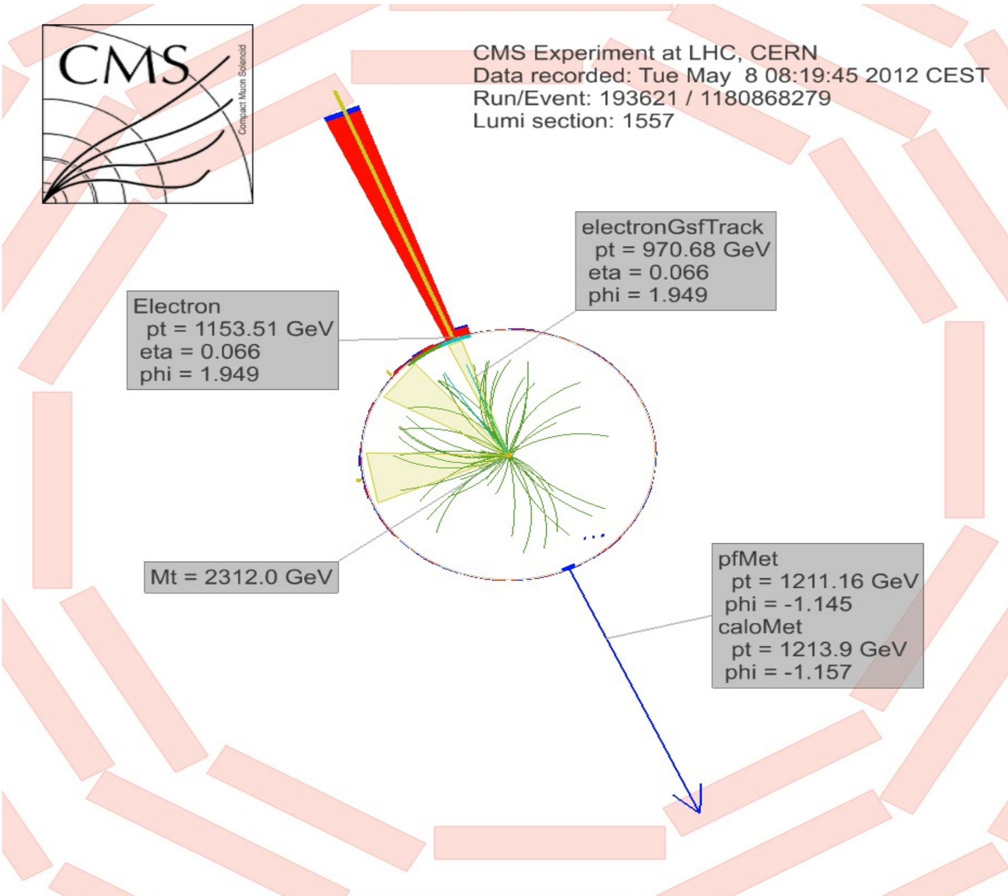
Mono-lepton

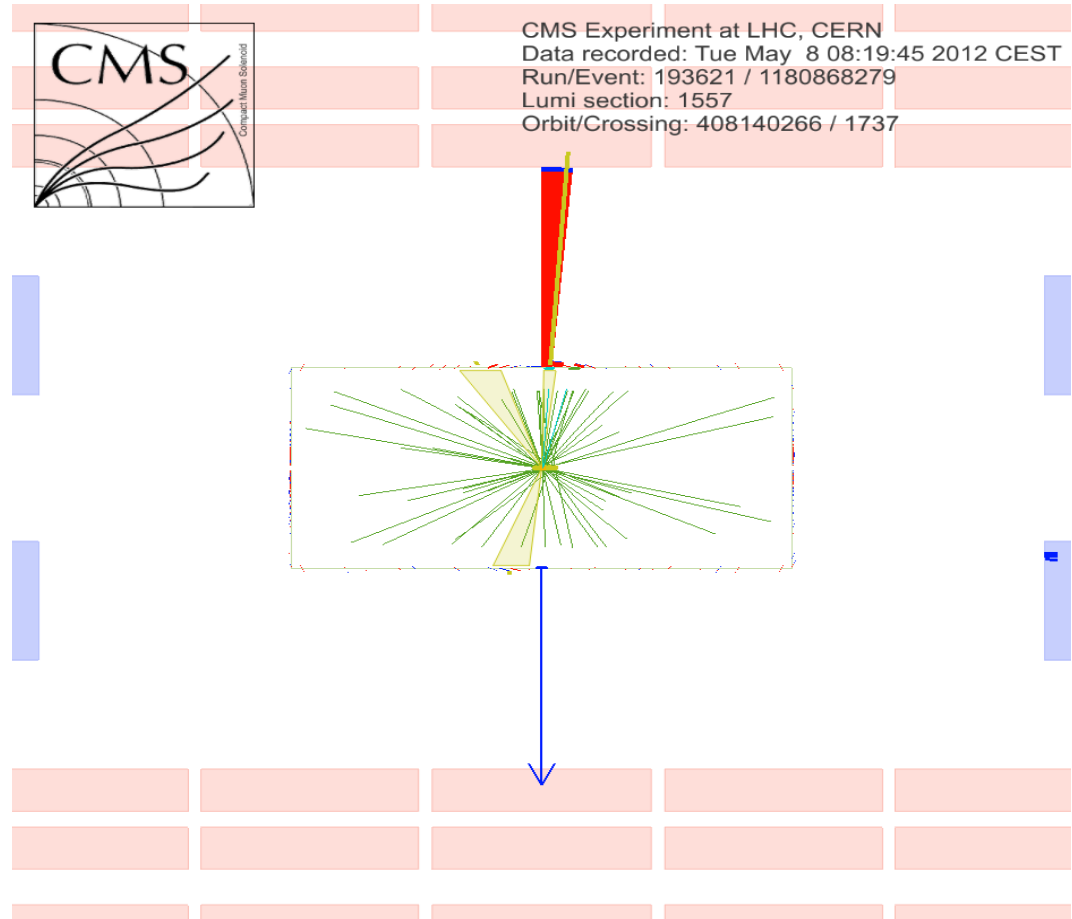
Event Display

CMS PAS EXO-13-004

Electron Channel





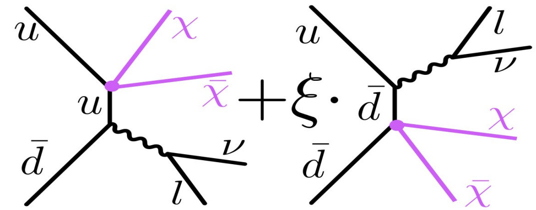


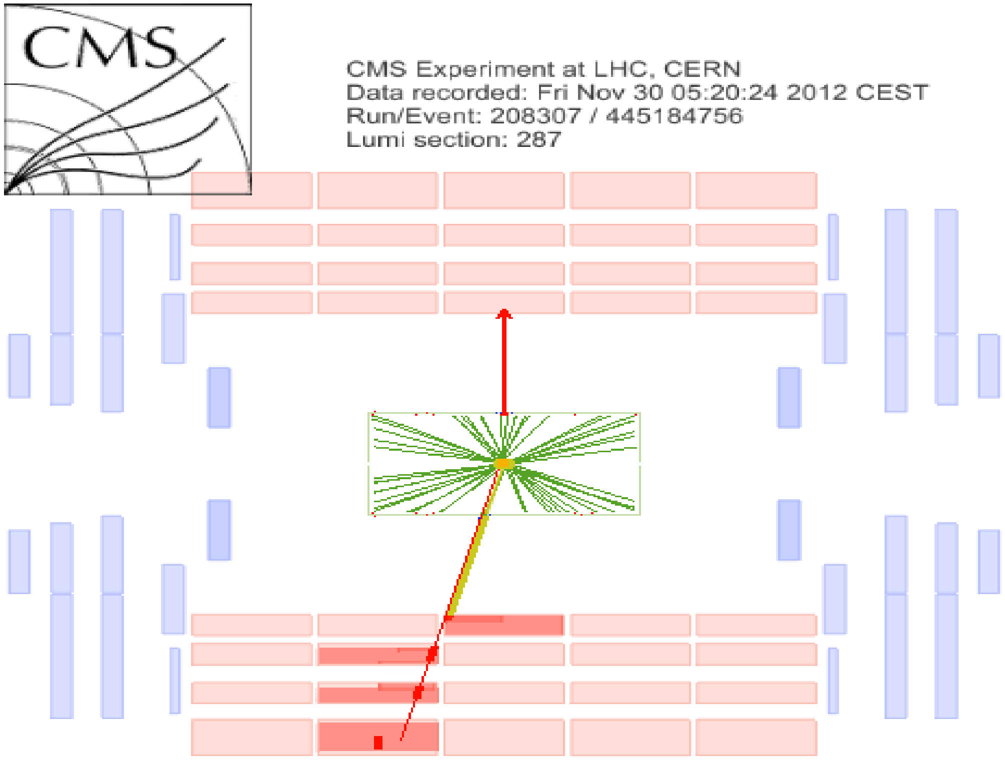
Mono-lepton

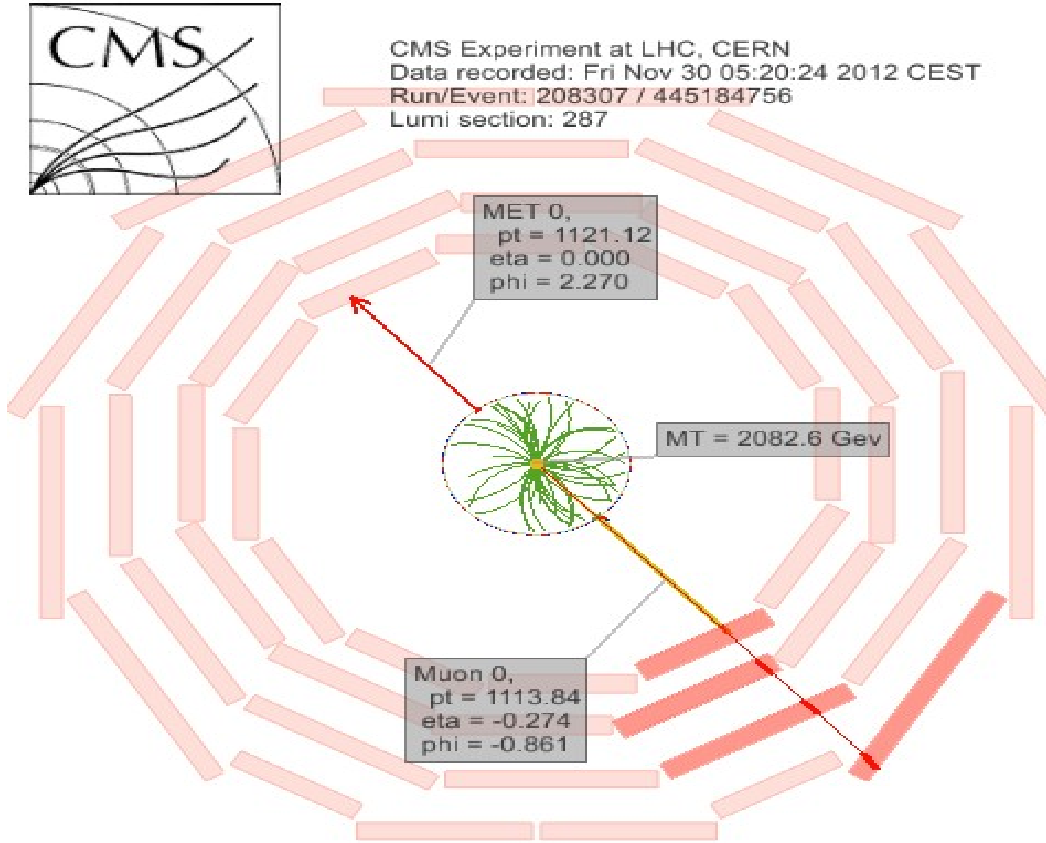
Event Display

CMS PAS EXO-13-004

Muon Channel



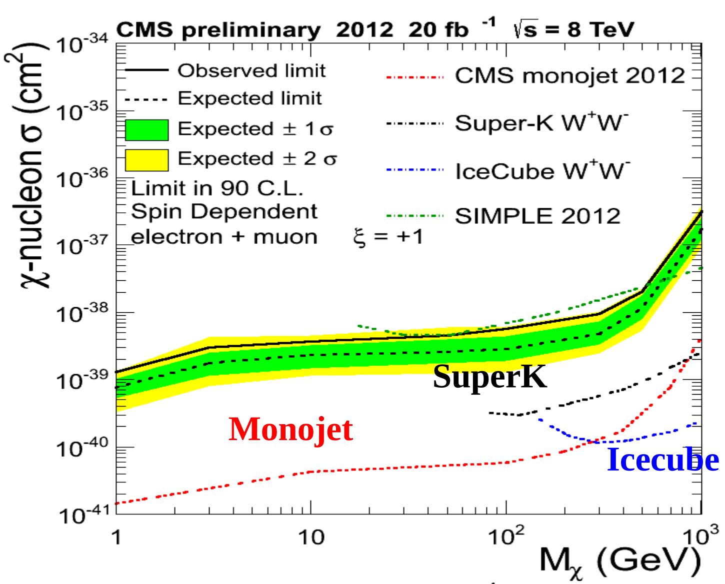


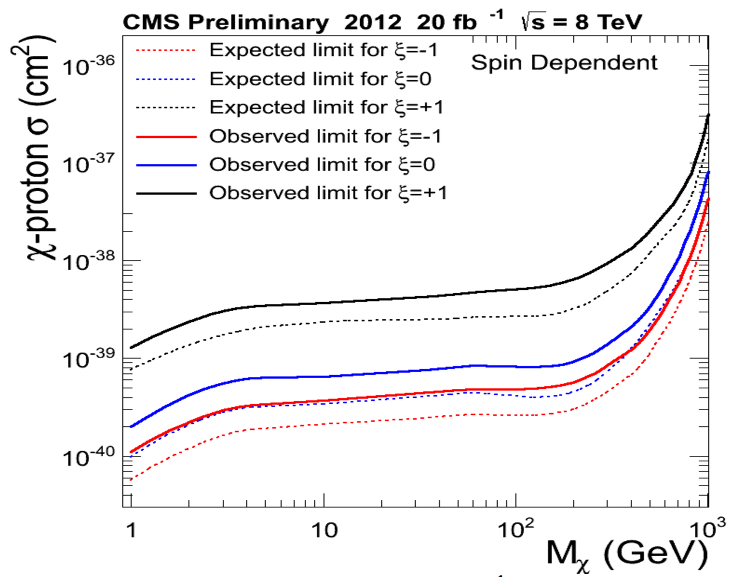


Mono-lepton

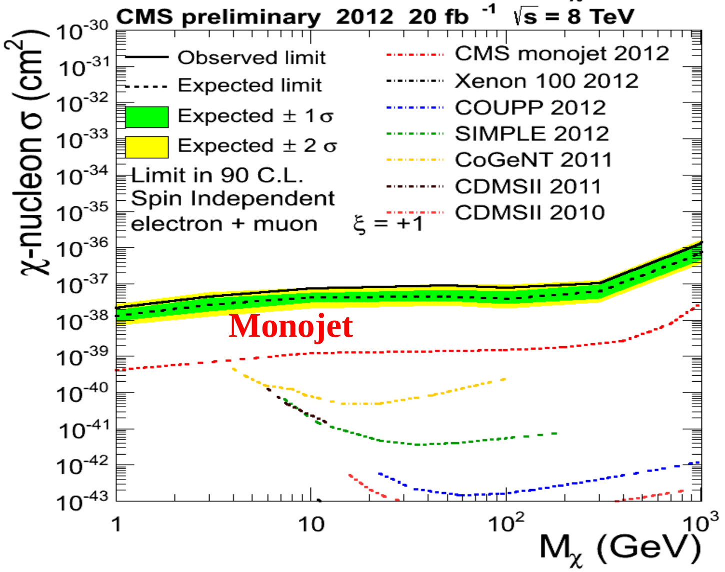
Results

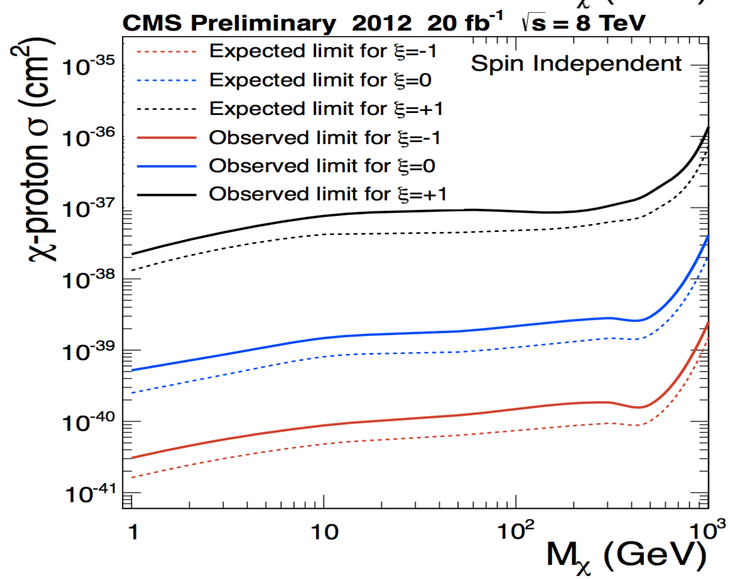
CMS PAS EXO-13-004





Axial-vector operator spin-dependent (SD)





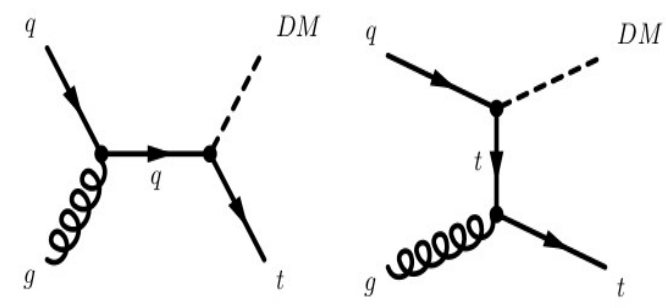
Vector operator spin-independent (SI)

Mono-top ($t \rightarrow jjb$)

Event Selection

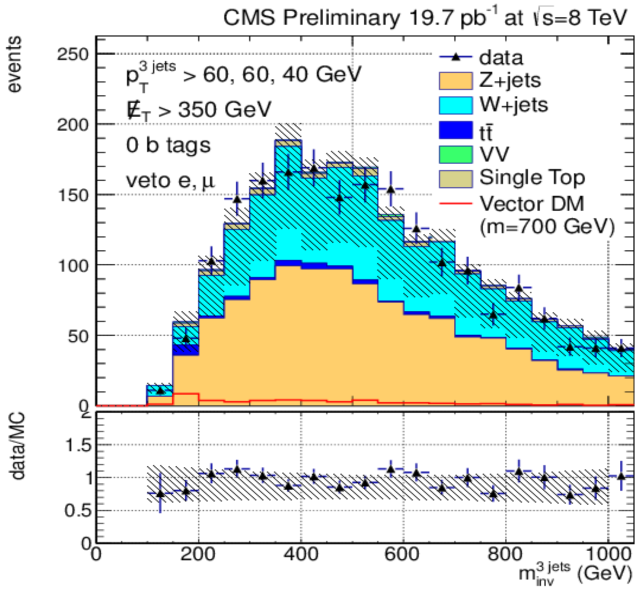
CMS PAS B2G-12-022

- Three jets, with j_1 and j_2 $p_T > 60$ GeV and j_3 $p_T > 40$ GeV
- One jet is tagged b-jet
- MET > 350 GeV
- Veto event with j_4 $p_T > 35$ GeV or isolated $e(\mu)$ $p_T > 20$ (10) GeV
- $M(j_1 j_2 j_3) < 250$ GeV

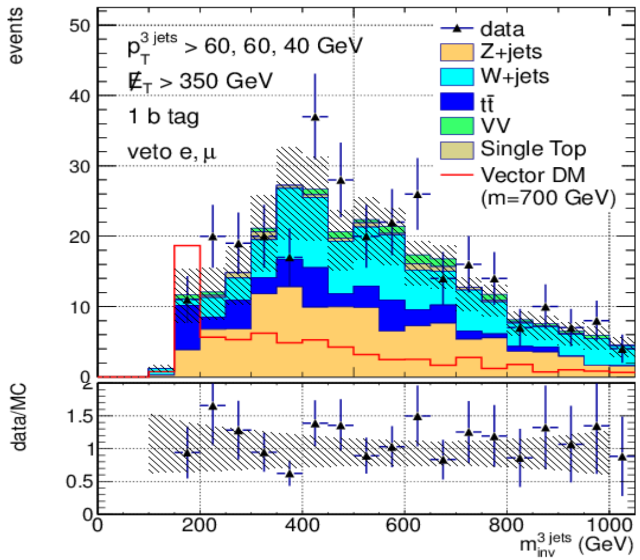


s-channel **t-channel**

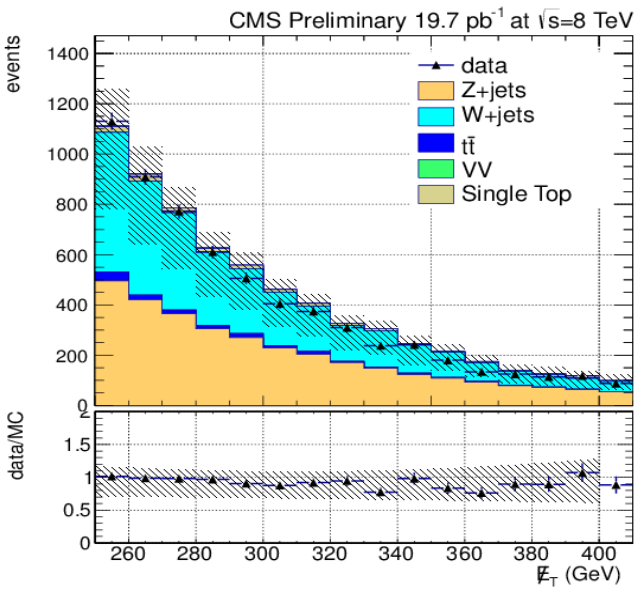
$M(3j)^{0b}$



$M(3j)^{1b}$



MET



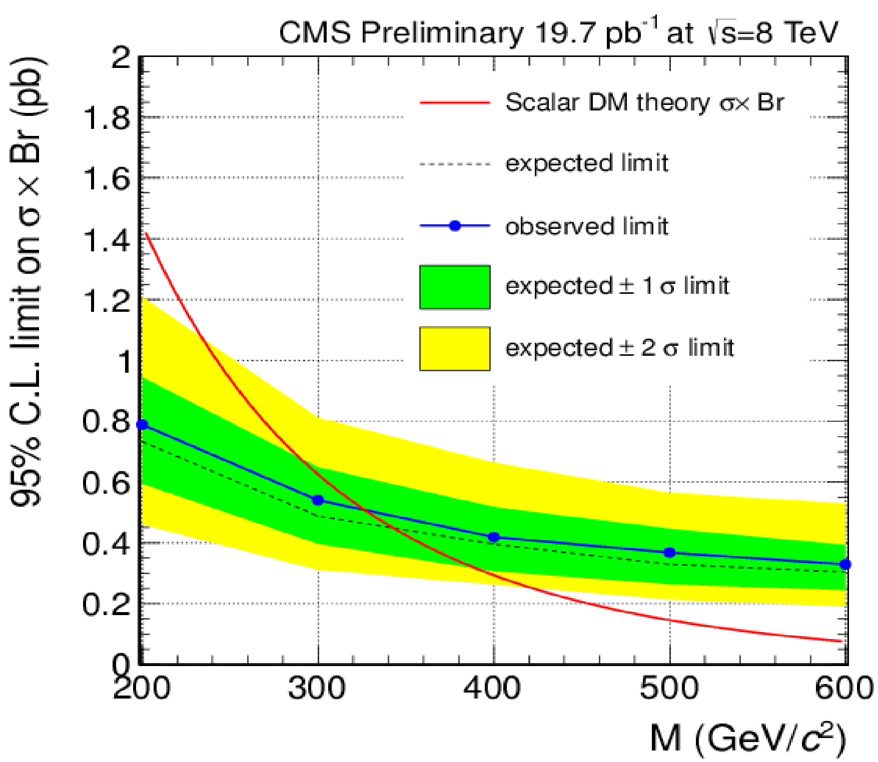
Mono-top

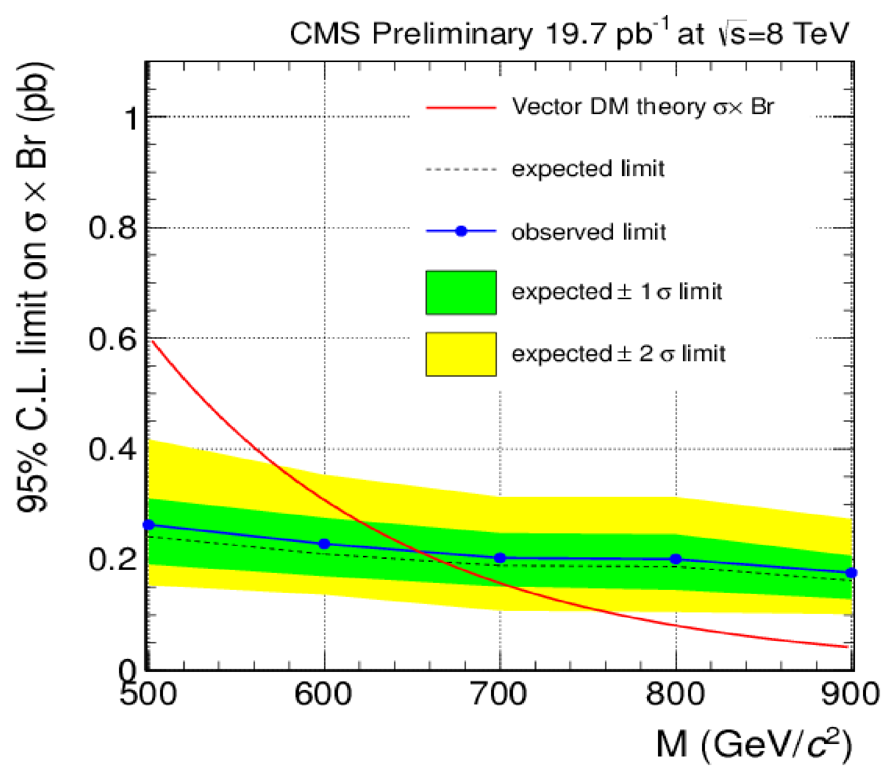
Results

CMS PAS B2G-12-022

- Excellent agreement with data
- DM coupling set to 0.1 for q = u/d [arXiv:1106.6199]
- Exclude scalar (vector) DM masses below 327 (655) GeV

# of b tags	Zero CSVm b tag	One CSVm b tag
$t\bar{t}$	6±0±5	12±0±12
W+jets	18±9±7	3±1±2
Z+jets	103±33±9	11±10±1
Single top	2±1±1	1±1±1
VV	5±0±0	0±0±0
QCD	6	1
sum	140±36	28±16
Data	143	30



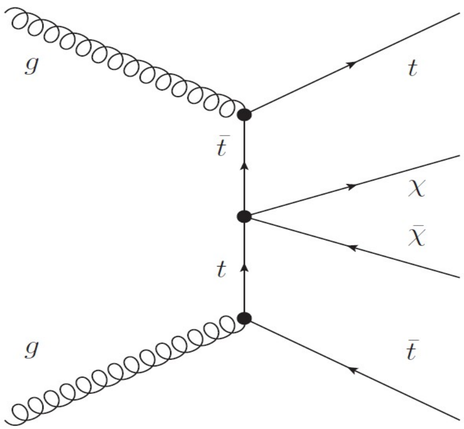


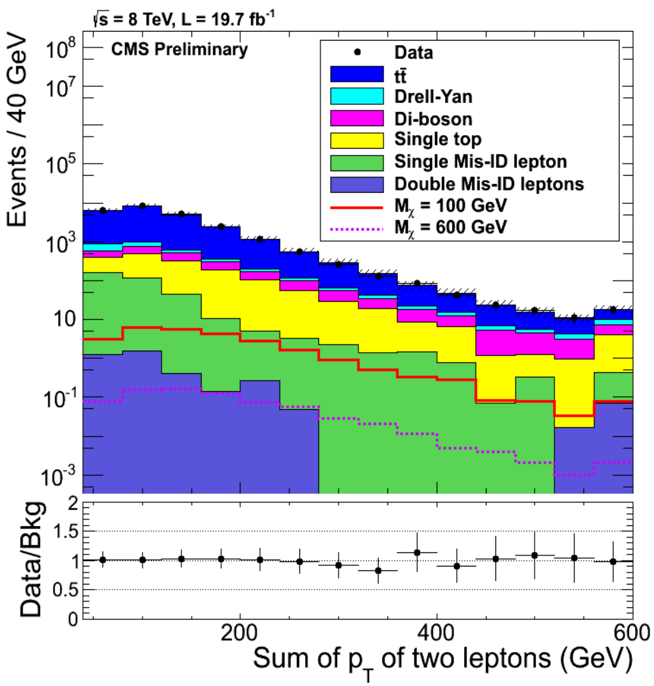
Di-top

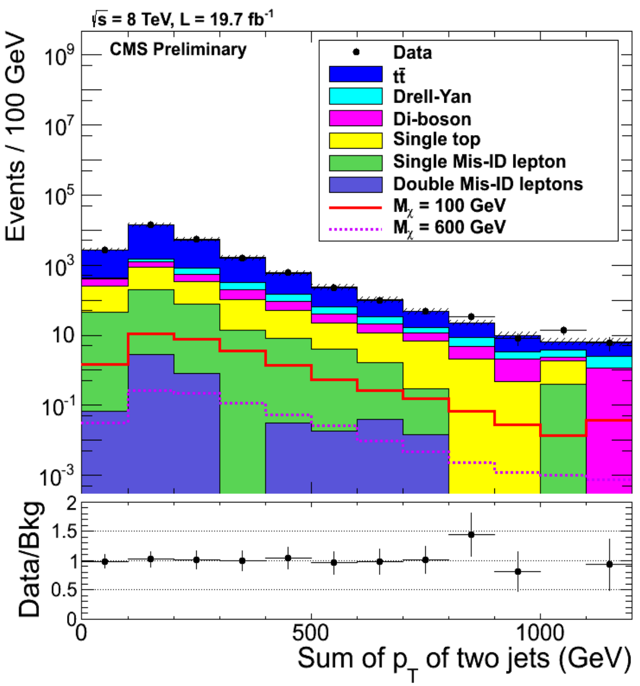
Event Selection

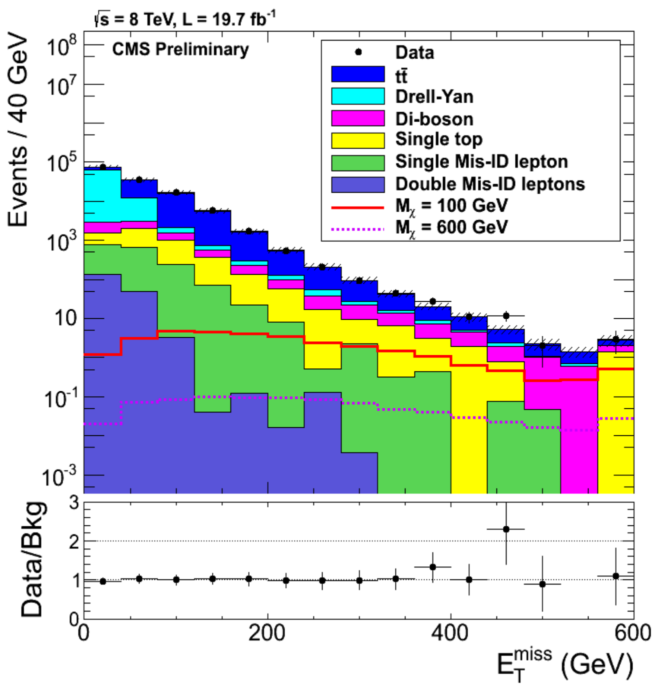
CMS PAS B2G-13-004

- Select pair of top quarks in the di-lepton channel
- Exactly two identified leptons, and at least two jets are selected
- M(ll) > 20 GeV and | M(ll) – 91 GeV| > 15 GeV
- MET > 320 GeV
- $HT(j_1,j_2) < 400$ GeV, $HT(l_1, l_2) > 120$ GeV, $\Delta\varphi(l_1, l_2) < 2$





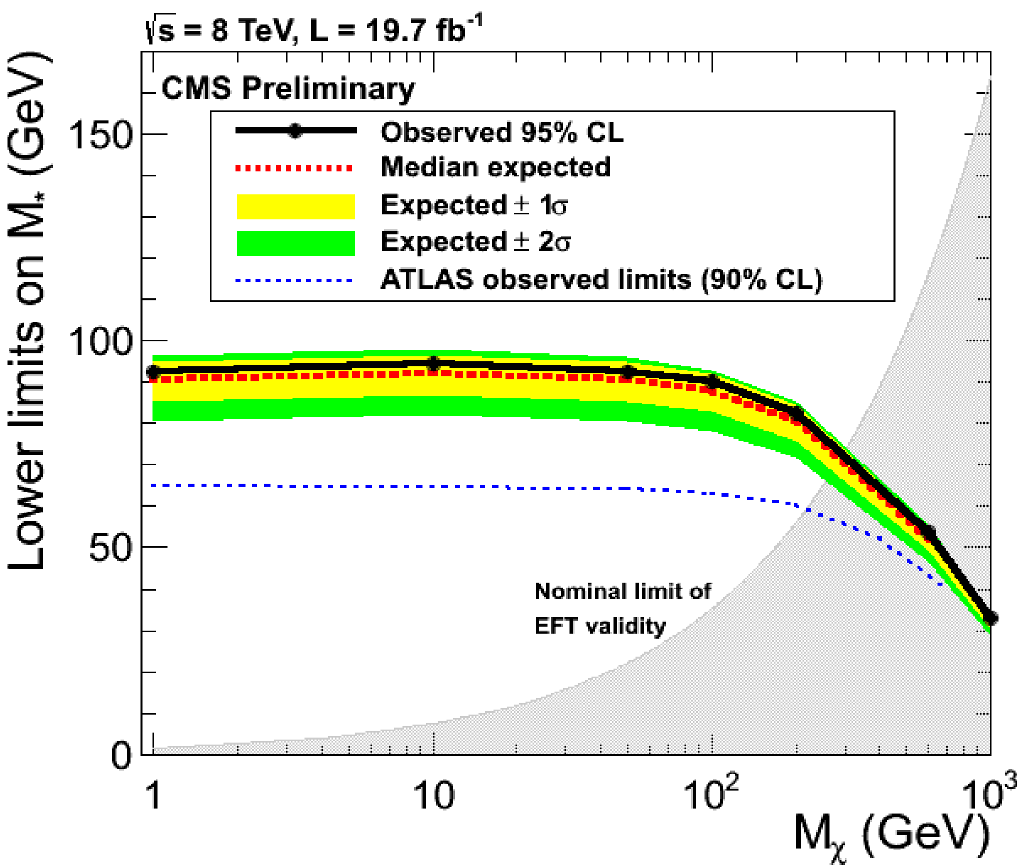




Di-top

Results

CMS PAS B2G-13-004



Background Source	Yield
$t\bar{t}$	$0.87 \pm 0.18 \pm 0.27$
Single top	$0.48 \pm 0.46 \pm 0.09$
Di-boson	$0.32 \pm 0.09 \pm 0.05$
Drell-Yan	$0.19 \pm 0.14 \pm 0.03$
One Mis-ID lepton	$0.02 \pm 0.07 \pm 0.02$
Double Mis-ID leptons	$0.00 \pm 0.00 \pm 0.00$
Total Bkg	$1.89 \pm 0.53 \pm 0.39$
Data	1
Signal	$1.88 \pm 0.11 \pm 0.07$

- For dark particle mass 100 GeV, the interaction scale is excluded at 95% CL below 90 GeV

Summary

- Presented results of dark matter search in CMS with the 8 TeV data, with a number of signatures
  - Mono jet/photon/lepton
  - Mono top (pair)

- Data is consistent with standard model prediction
  - No sign of dark matter signal

- Looking forward to the 13 TeV data

Thank You

BACKUP

MHT Minimization

A way to identify and reduce the fake met contribution, where you minimize the unclustered energy in the event by trying to re-distribute the energy back into the visible objects.

$$\chi^2 = \sum_{i=objects} \left(\frac{(p_T^{reco})_i - (\hat{p_T})_i}{(\sigma_{p_T})_i} \right)^2 + \left(\frac{\hat{\not{E}_T}}{\sigma_{\hat{\not{E}_T}}} \right)^2$$

$$\hat{\not{E}}_{x,y} = \not{E}_{x,y}^{reco} + \sum_{i=objects} (p_{x,y}^{reco})_i - (\hat{p}_{x,y})_i$$

$$\not{E}_T{}^2 = \not{E}_x^2 + \not{E}_y^2$$

- If the MET is intrinsic, balancing the object momenta wouldn't be easy and will result in higher χ^2.
- The variables that give good discrimination are the recalculate minimized MET and Prob(χ^2)