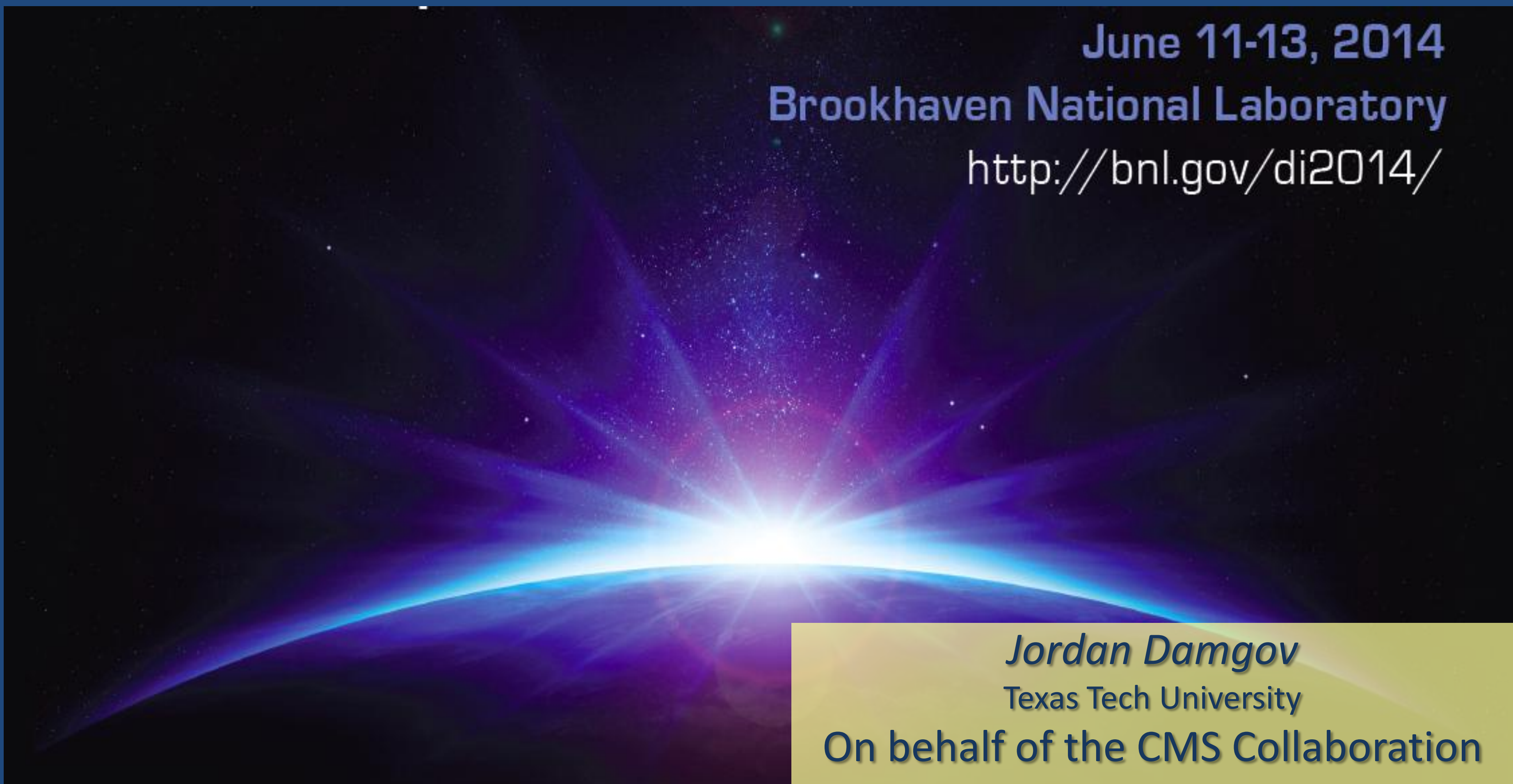
Dark Matter Searches at CMS



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On behalf of the CMS Collaboration

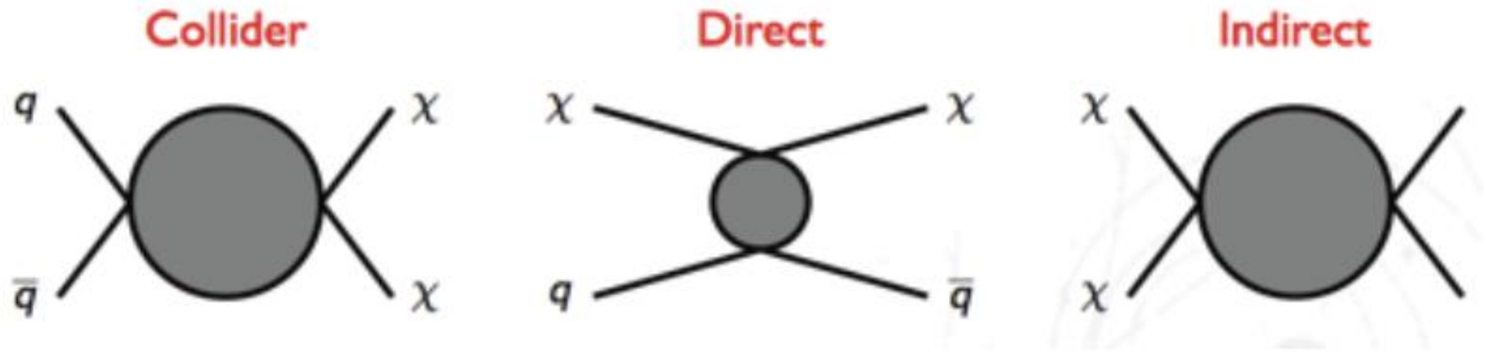
Dark Matter

❖ **There is strong astrophysical evidence for the existence of dark matter**
  ➢ Evidence from bullet cluster, gravitational lensing, rotation curves

❖ **Direct detection experiments**
  ➢ Aim to observe recoil of dark matter off nucleus
  ➢ Excesses observed by several experiments

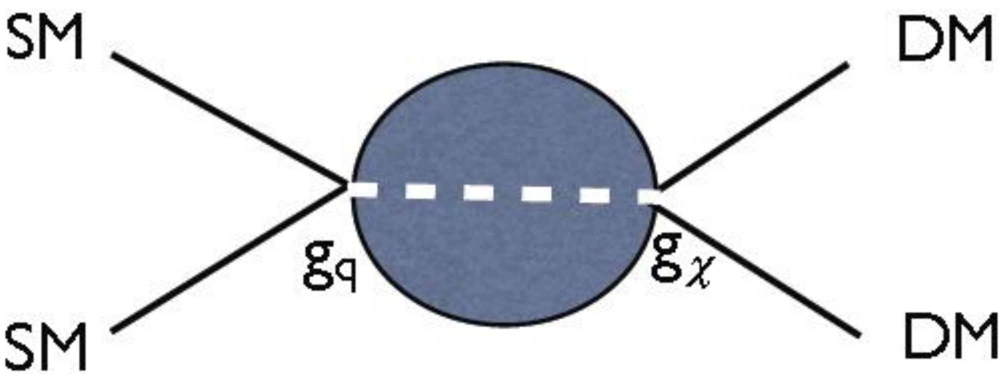
➢ **Need for independent verification from non-astrophysical experiments**
  ✓ Low mass region not accessible to direct detection experiments
  ✓ Limited by threshold effects, energy scale, backgrounds; less sensitive to spin-dependent couplings

Colliders provide alternative, complementary way to search for dark matter



Production of Dark Matter at colliders

- **In framework of effective theory, assume DM(χ) is a Dirac fermion and interaction is characterized by *contact interaction***
  - Set mass of mediator (M) to very high value



✓heavy mediator can be integrated out

$$\Lambda = M/\sqrt{g_\chi g_q}$$

❖ Consider two possibilities:

a) Vector mediator:
   - Spin dependent

b) Axial-Vector mediator:
   - Spin independent

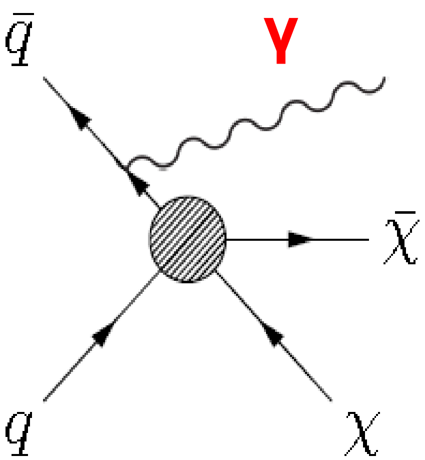
Effective operators

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

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

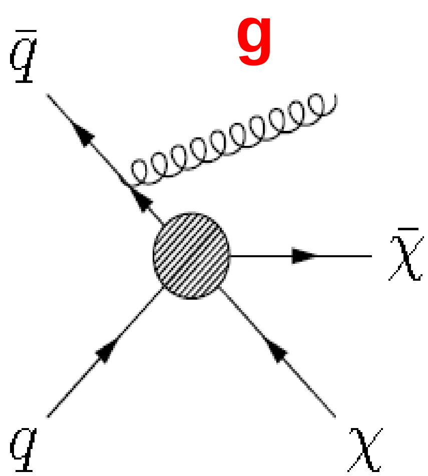
Production of Dark Matter at colliders

- Dark Matter production results in missing transverse energy (MET)
- DM is made experimentally visible trough radiation of jet/photon/W/Z/etc.
  - *Signature mono-X + MET*



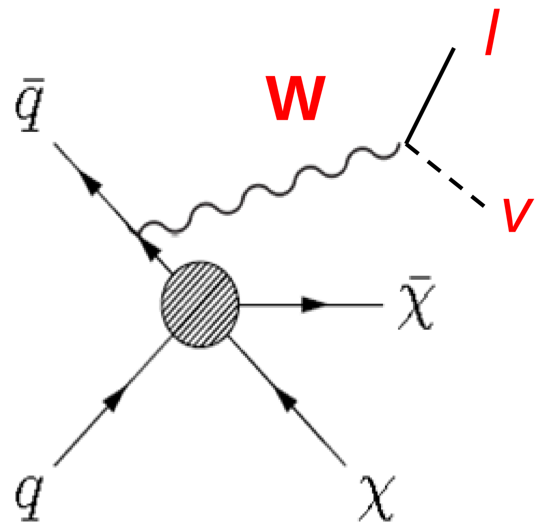
*Mono**photon** + MET*

[CMS-PAS-EXO-12-047](CMS-PAS-EXO-12-047)



*Mono**jet** + MET*

[CMS-PAS-EXO-12-048](CMS-PAS-EXO-12-048)

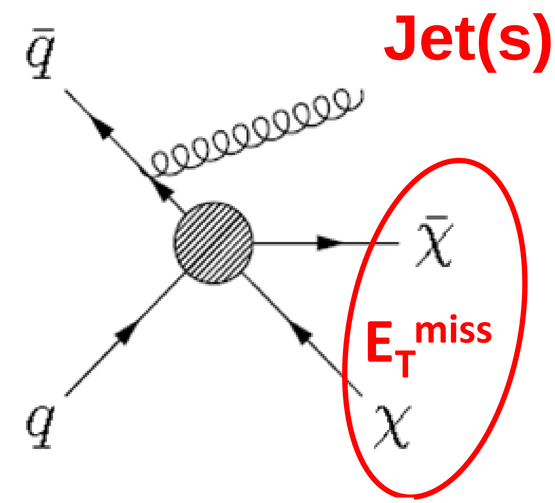


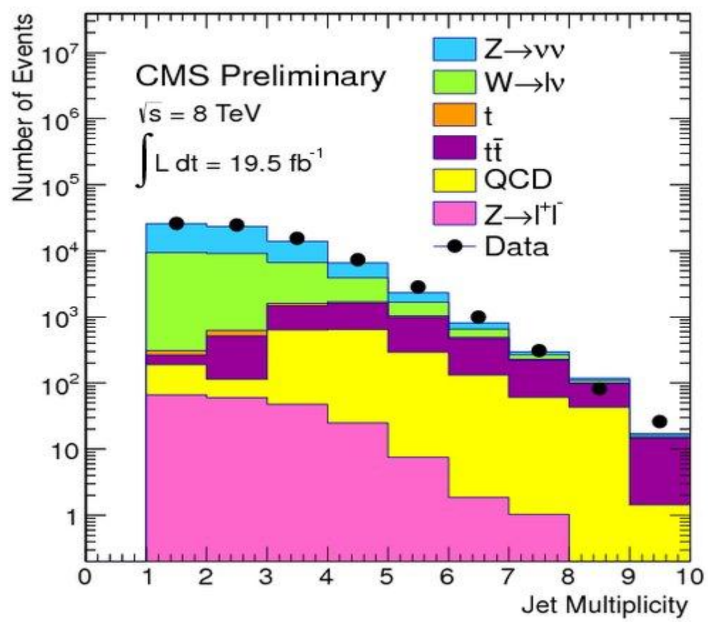
*Mono**lepton**+ MET*

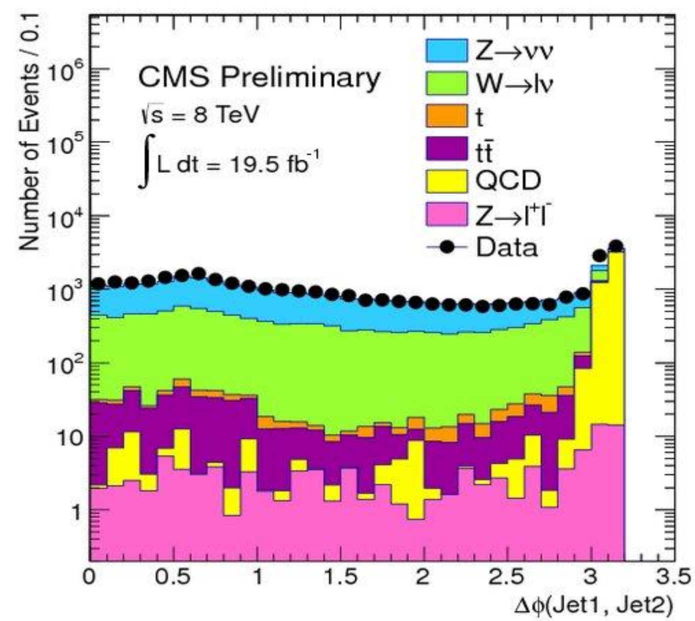
[CMS-PAS-EXO-13-004](CMS-PAS-EXO-13-004)

Monojet- Search Details

- ***Event selection***
  - ✓ Selection based on the jets constituent – removes instrumental background
  - ✓Large missing transverse energy: $\mathbf{E_T^{miss} > 250\ GeV/c}$
  - ✓Energetic jet: $\mathbf{p_T > 110\ GeV}$, $\mathbf{|\eta| < 2.4}$
  - ✓Allow one addition jet, $\mathbf{p_T > 30}$
  - ✓$\Delta\varphi(j1,j2) < 2.5$ – suppresses QCD background
  - ✓ lepton veto(e,μ,τ) – suppresses EWK background







Monojet- Background estimate

❖Dominant backgrounds are **Z(vv)+jets** (~70%) and the **W(lv)+jets**(~30%)

✓ *Z(vv)+jets is irreducible background*

❖ Data-driven estimates with Z(μμ)+jets and W(μv)+jets

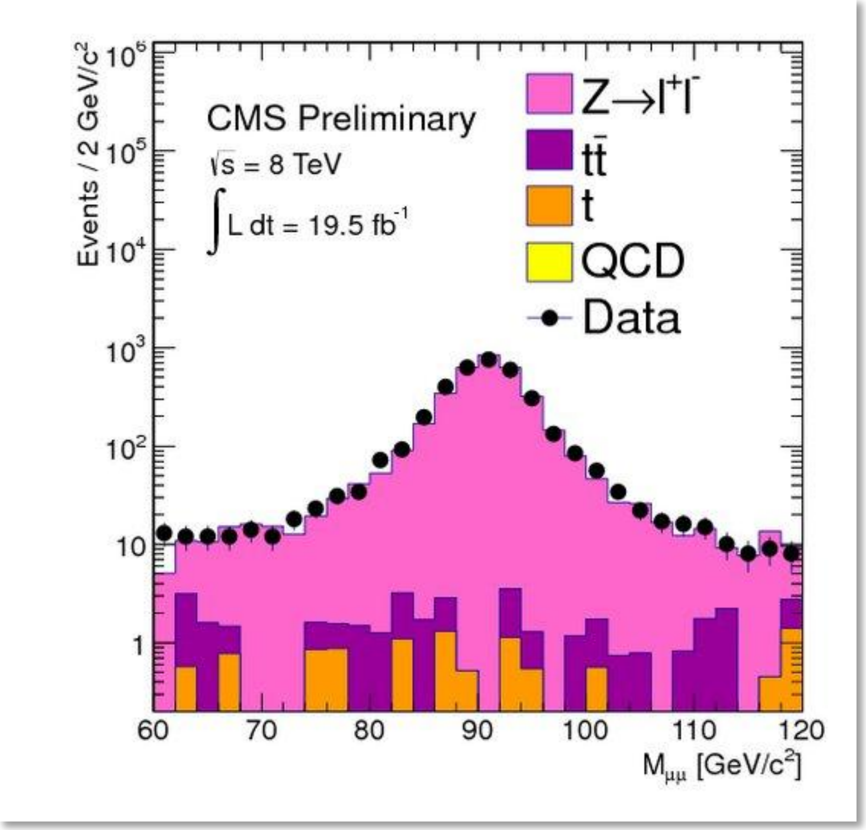
✓ Other backgrounds have negligible contribution(1%) and are taken from MC

➢ *Z(vv)+jets estimates with Z(μμ)+jets*

$$N(Z(\nu\nu)) = \frac{N^{obs} - N^{bgd}}{A \times \epsilon} \cdot R\left(\frac{Z(\nu\nu)}{Z(\mu\mu)}\right)$$

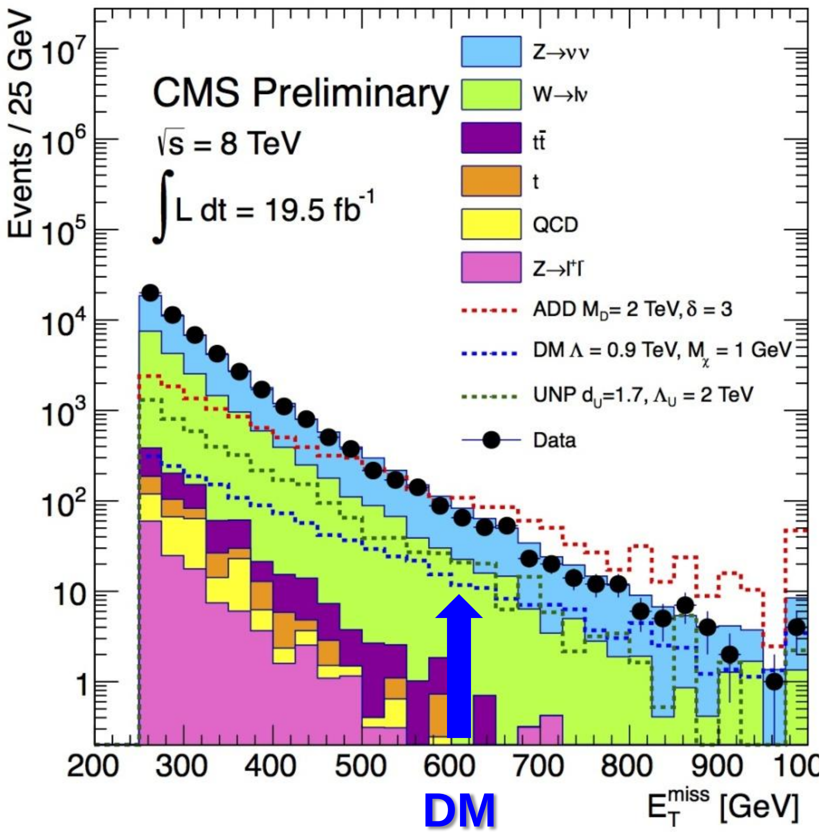
$R\left(\frac{Z(\nu\nu)}{Z(\mu\mu)}\right)$ -Ratio of branching fractions

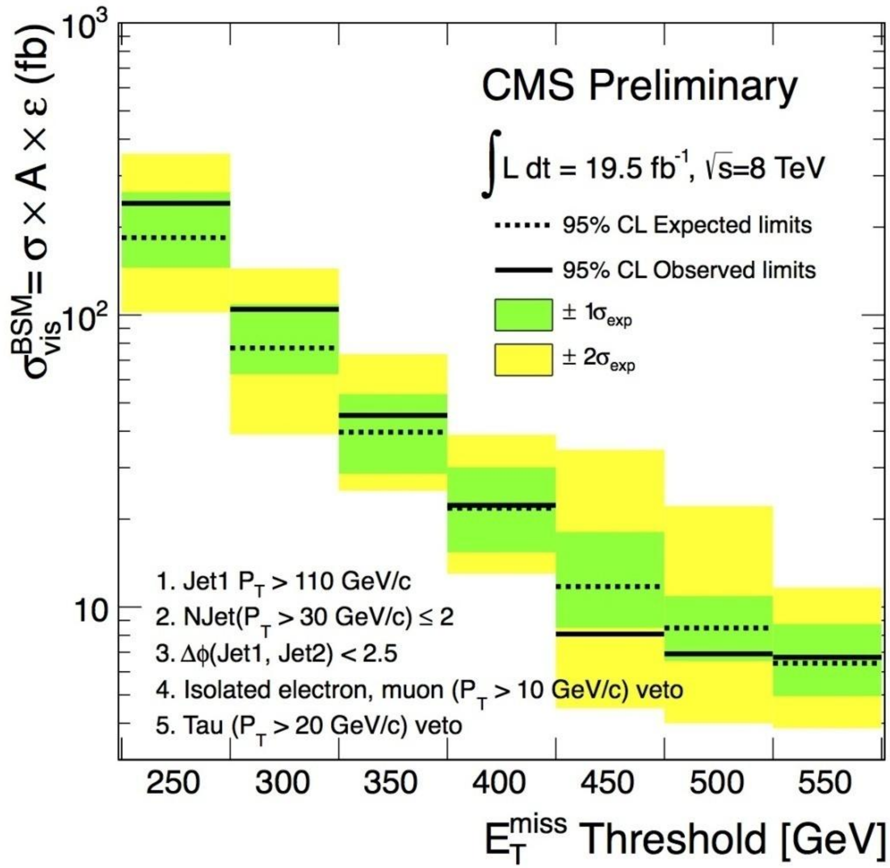
Systematic uncertainty on the Z(vv)+jets normalization is 5%(15%) for E_T^{miss} > 250GeV/c (550 GeV/c)



➢ *W(lv)+jets estimates with W(μv)+jets*

Monojet- Results and interpretation

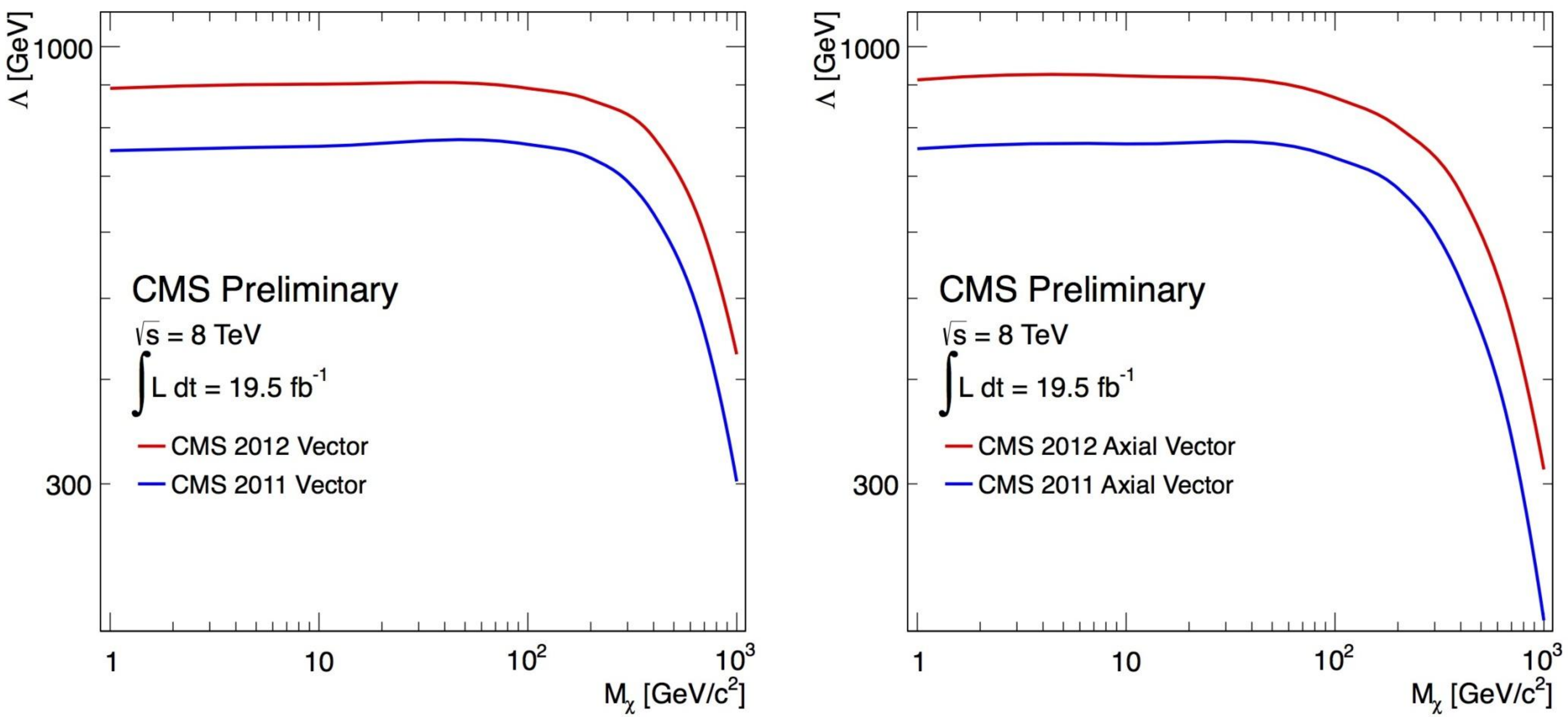




- SM rate in the monojet channel – E_t^{miss}

- Model independent upper cross section limit for BSM. Optimal threshold for DM search is E_t^{miss}>400 GeV

Monojet- Results and interpretation (cont.)



Limits (90% CL) on effective contact interaction scale Λ as a function of DM mass M_X can be translated into **DM – nucleon** cross section limits

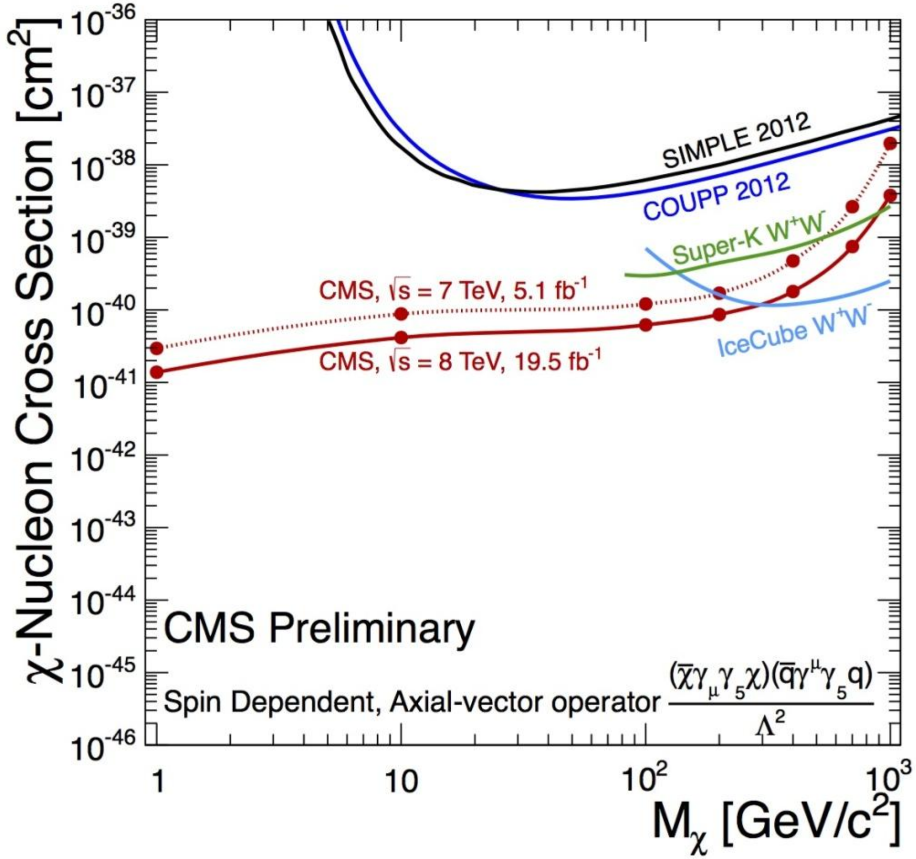
$$\sigma_{SI} = 9\frac{\mu^2}{\pi\Lambda^4} \qquad \sigma_{SD} = 0.33\frac{\mu^2}{\pi\Lambda^4} \qquad \text{where } \mu = \frac{m_\chi m_p}{m_\chi + m_p}$$

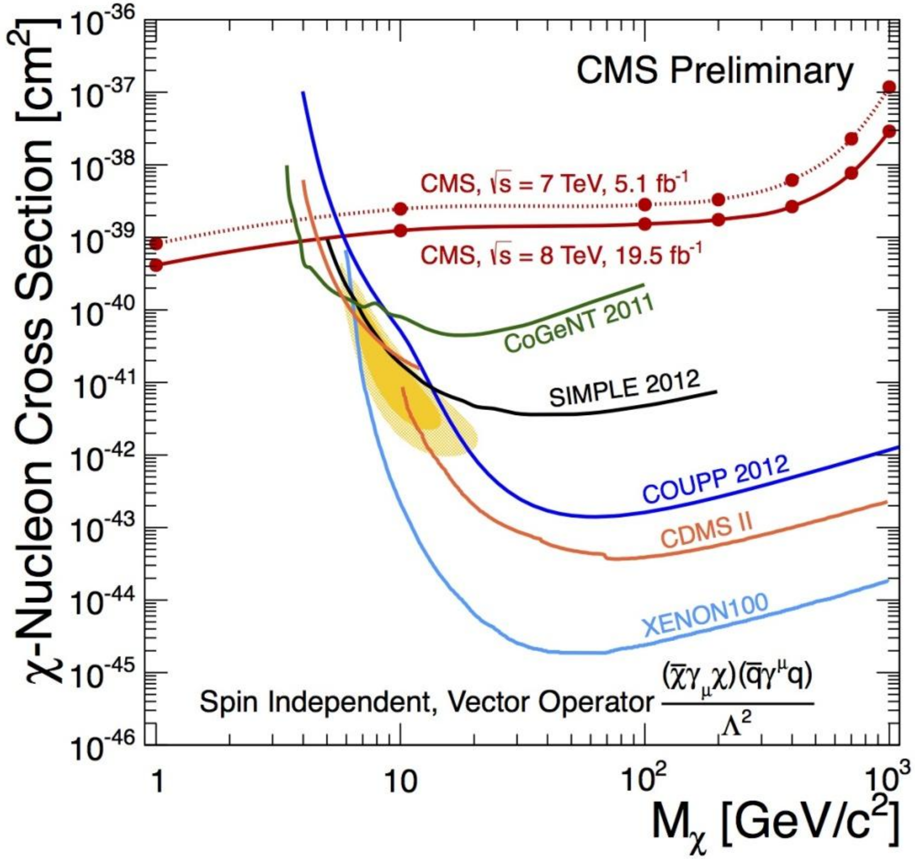
Vector Axial-Vector

Bai, Fox and Harnik, JHEP 1012:048 (2010)

μ = reduced mass of the nucleon (p or n) system

Monojet- DM-Nucleon Limits

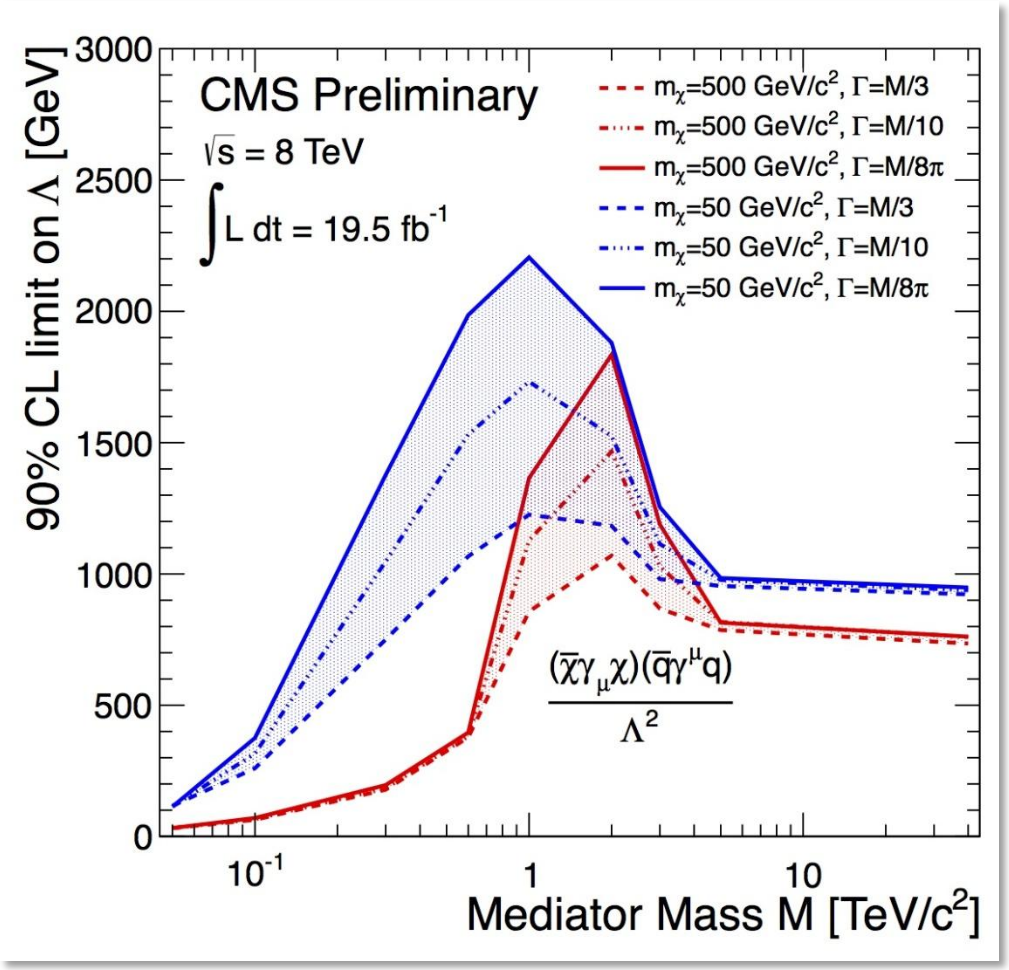




Exclude large cross sections for spin-dependent case

LHC can access very low DM masses

Monojet- Light mediator limits



Considered the case in which the mediator is light enough to be accessible at LHC.

DM mass 50 and 500 GeV/c^2.

The width(Γ) of mediator is also varied between M/3 and M/8π.

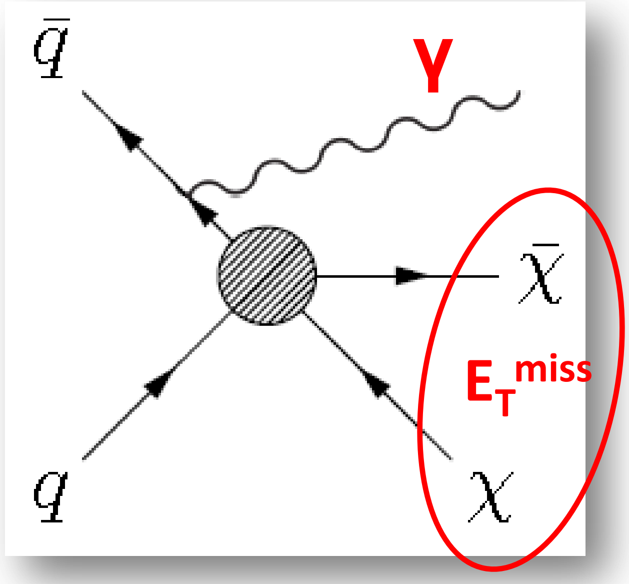
Resonant enhancement in the production cross section is observed once the mass of the mediator is within the kinematic range and can be produced on-shell.

At large mediator mass, the limits on Λ approximate to those obtained in the effective theory framework

Monophoton- Search Details

- Require a **photon** in the event :
  - ✓High energy isolated photon: **$E_T(\gamma) > 145$ GeV/c**
  - ✓In the central part of the detector: **$|\eta| < 1.442$**

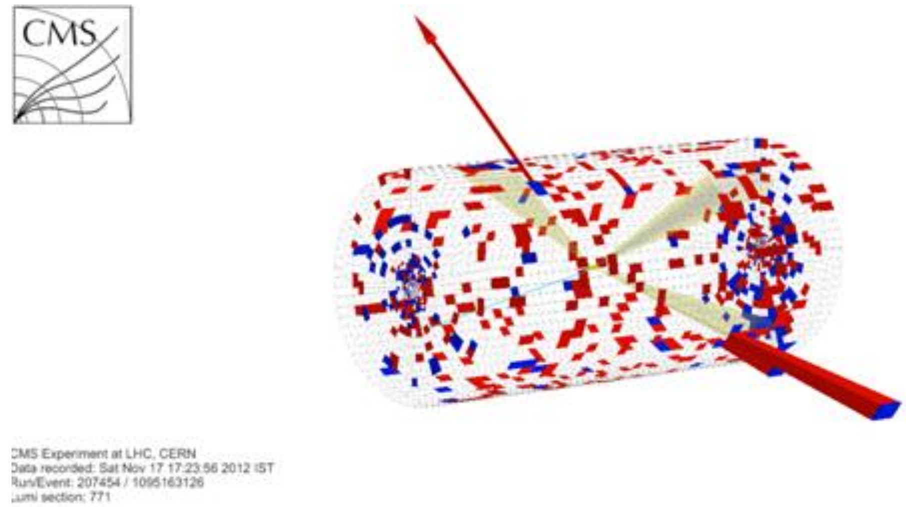
- Large missing transverse energy
  - ✓**E_T^{miss}** > 140 GeV
  - ✓ $\Delta\varphi$ (E_t^{miss}, γ) > 2.0
  - ✓ Additional requirements on E_T^{miss} significance reduces the contribution from events with fake E_T^{miss}



- Remove events with excessive additional activity
  - ✓ No more than one jet with $p_T > 30$ GeV/c
  - ✓No leptons with $p_T > 10$ GeV/c

Monophoton - Backgrounds

❖ *Backgrounds estimated from data-driven(DD) techniques and MC*



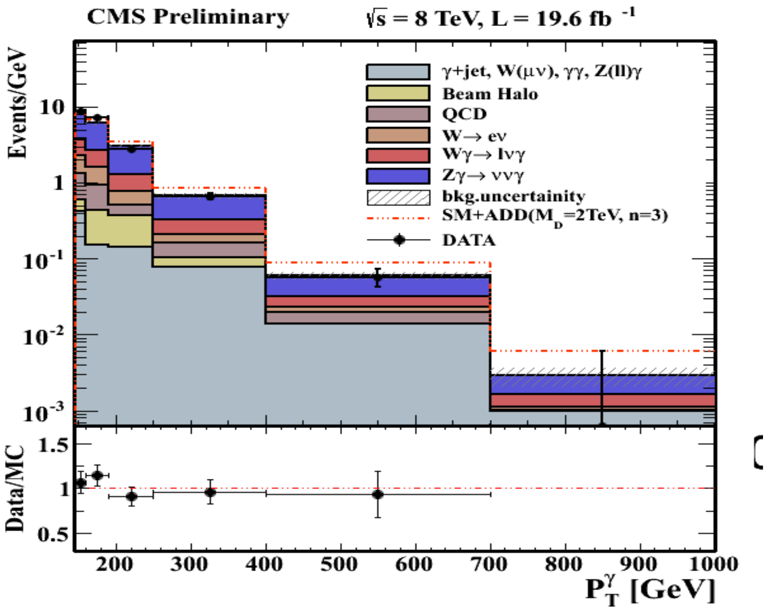
❑ Non-collision backgrounds

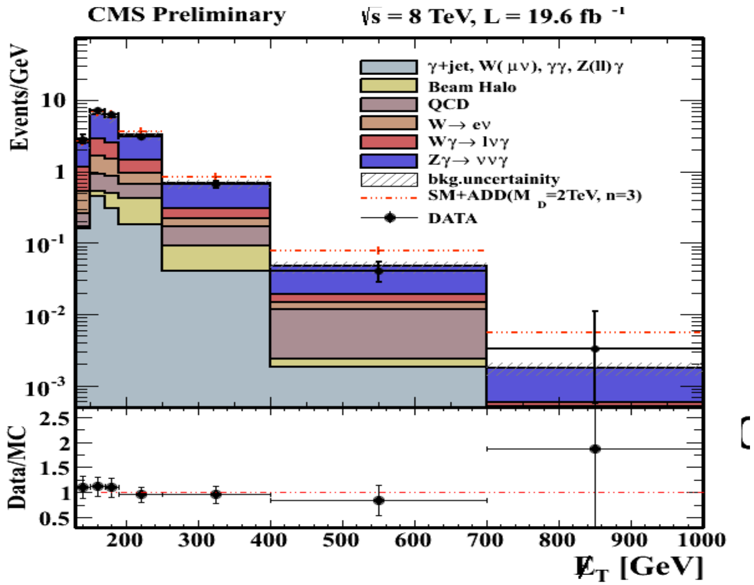
1. ***Beam Halo Muon Induced Showers* - *Mostly removed. Residual estimated.***
2. Cosmic Muon Induced Showers - Identified and removed
3. Neutron Induced Spurious Signals ("Spikes") - Identified and removed

❑ Backgrounds from ***pp collisions***

55%	$Z\gamma \rightarrow \nu\nu\gamma$	***irreducible background*** *(MC, NLO)*
10%	$W \rightarrow e\nu$	electron mis-identified as photon *(DD)*
7%	jets → "γ" + MET	one jet mimics photon, E_T^{miss} from jet mis-measurement *(DD)*
	γ + jet	E_T^{miss} from jet mis-measurement *(MC)*
17%	$W\gamma \rightarrow l\nu\gamma$	charged lepton escapes detection(*MC*)
	$\gamma\gamma$	one photon is mis-measured - gives MET(*MC*)

Monophoton – Search Results



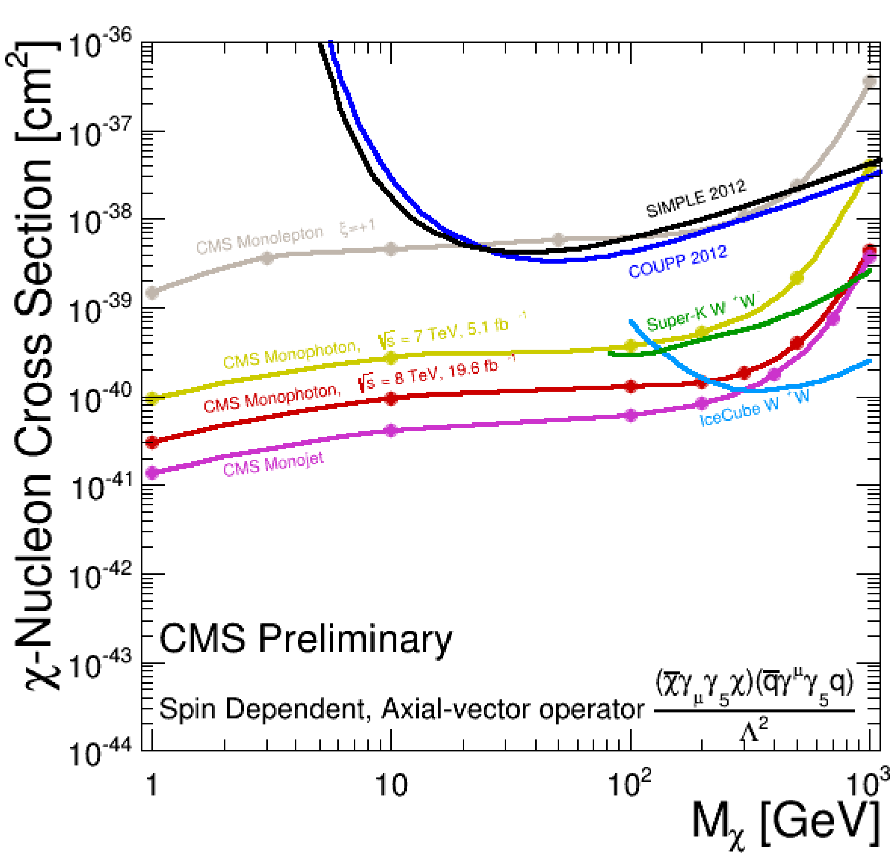


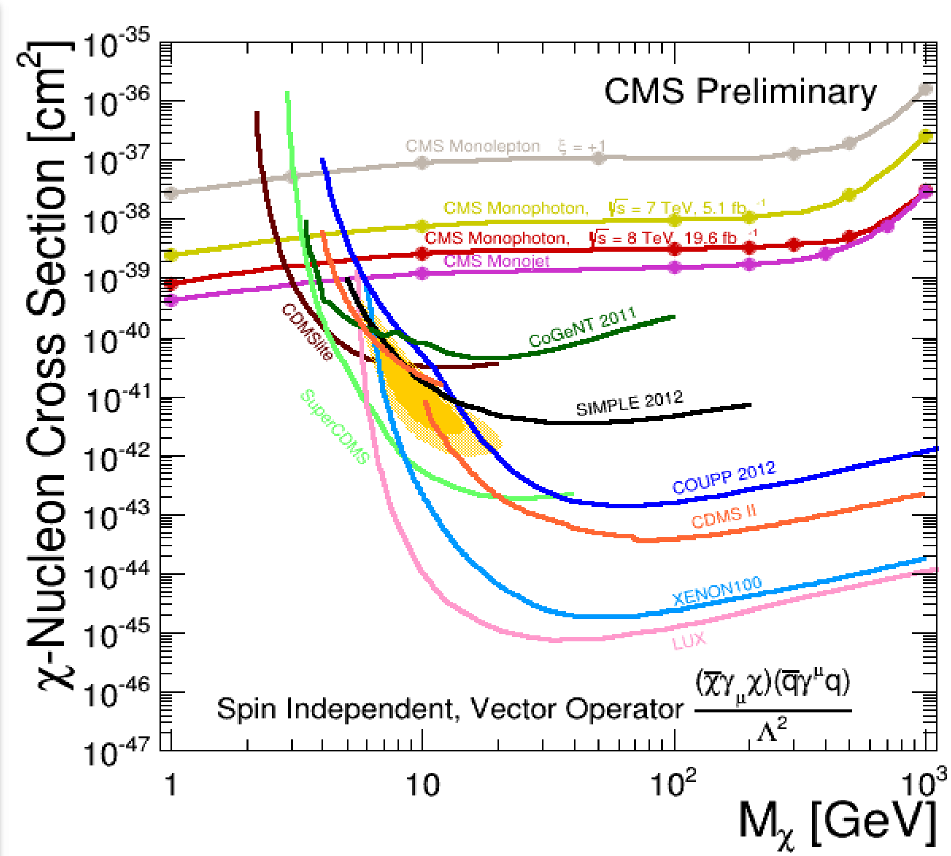
Process	Estimate
$Z(\rightarrow \nu\bar{\nu}) + \gamma$	344.8 ± 42.5
$W(\rightarrow \ell\nu) + \gamma$	102.5 ± 20.6
$W \rightarrow e\nu$	59.5 ± 5.5
jet $\rightarrow \gamma$ fakes	45.4 ± 13.9
Beam halo	24.7 ± 6.2
Others	35.7 ± 3.1
Total background	612.6 ± 63.0
Data	630.0

Background processes describe the data well and no excess is observed.

Interpreted as a limit on DM production cross section

Monophoton- DM-Nucleon Limits





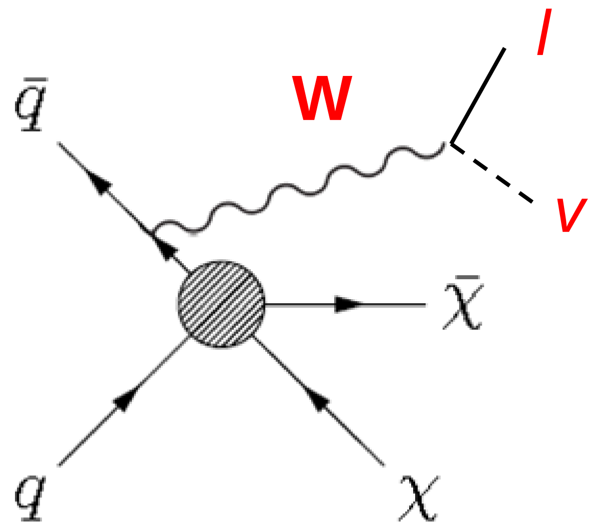
The sensitivity with 8 TeV data is significantly higher than the 7 TeV.

Monolepton- Search Details

Signature W + E_t^{miss}

high p_T electron + E_t^{miss}

high p_T muon + E_t^{miss}



Selection:

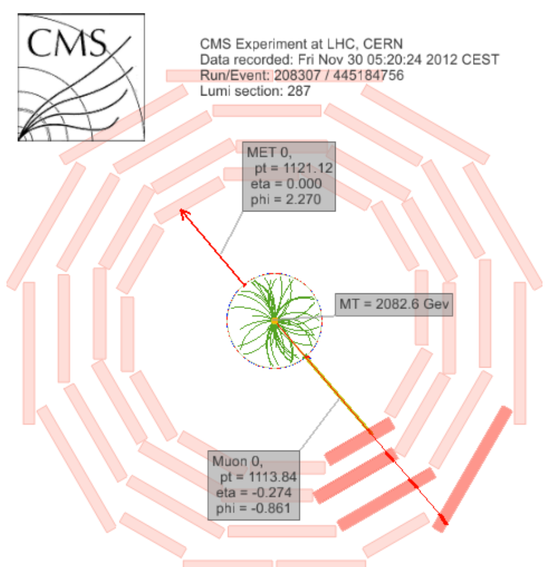
Energetic electron(muon) with p_T> 100(45) GeV

Lepton ID optimized for high p_T leptons

Kinematic selection:

$0.4 < p_T/ E_t^{miss} < 1.5$

$\Delta\varphi$ (l, E_t^{miss}) > 0.8 π



Background:

Derived from simulation

Challenge high M_T tail

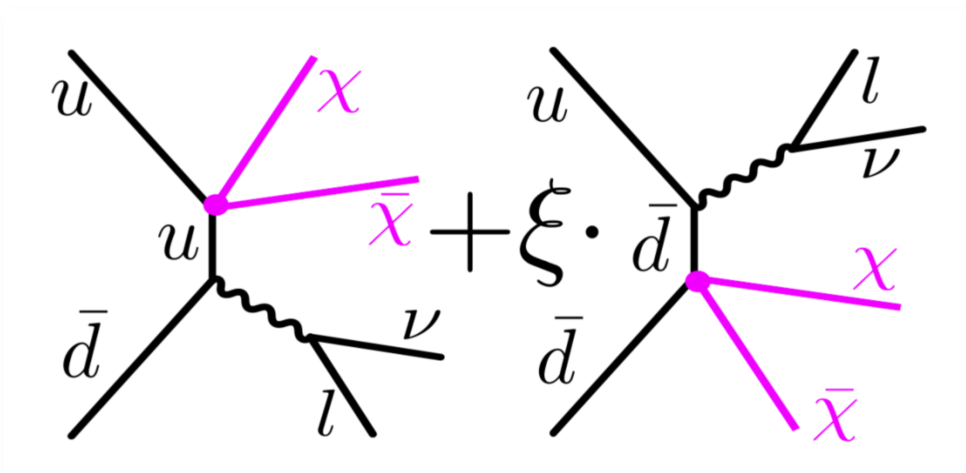
Main background: W→lν with M_T binned k-factor

NLO cross sections

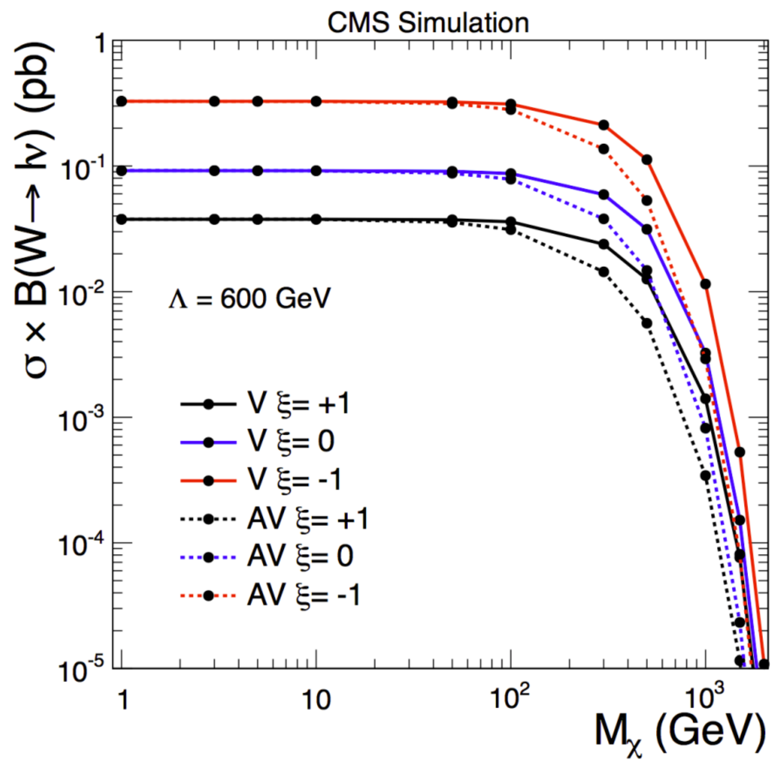
Monolepton- Interference

Relative coupling of DM to different quark flavors *i* is parameterized by ʒ$_{i}$

if [C(u) = C(d)] : destructive interference
if [C(u) = -C(d)] : constructive interference

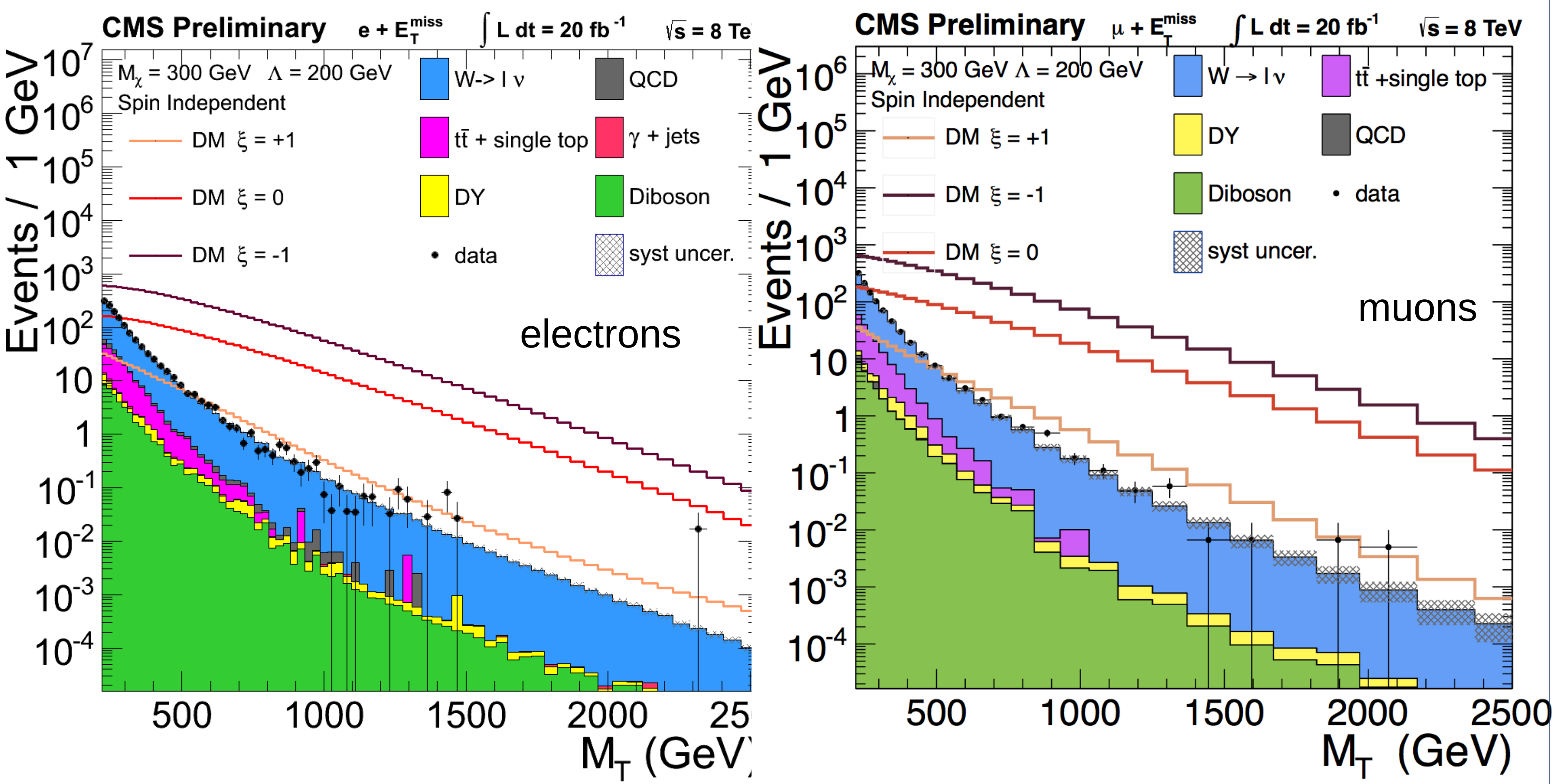


Considered cases: ʒ =-1,0,+1



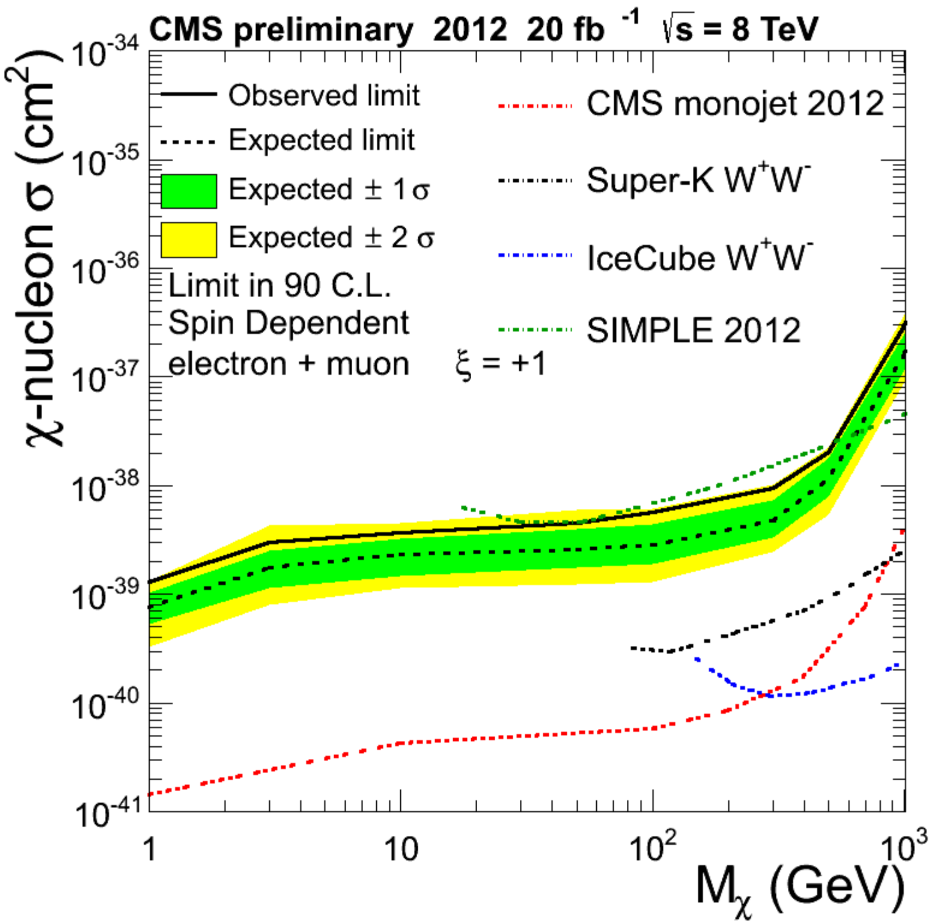
Largest cross section for ʒ = -1
For Mc ≤70 GeV same cross section for V and AV coupling of fixed ʒ

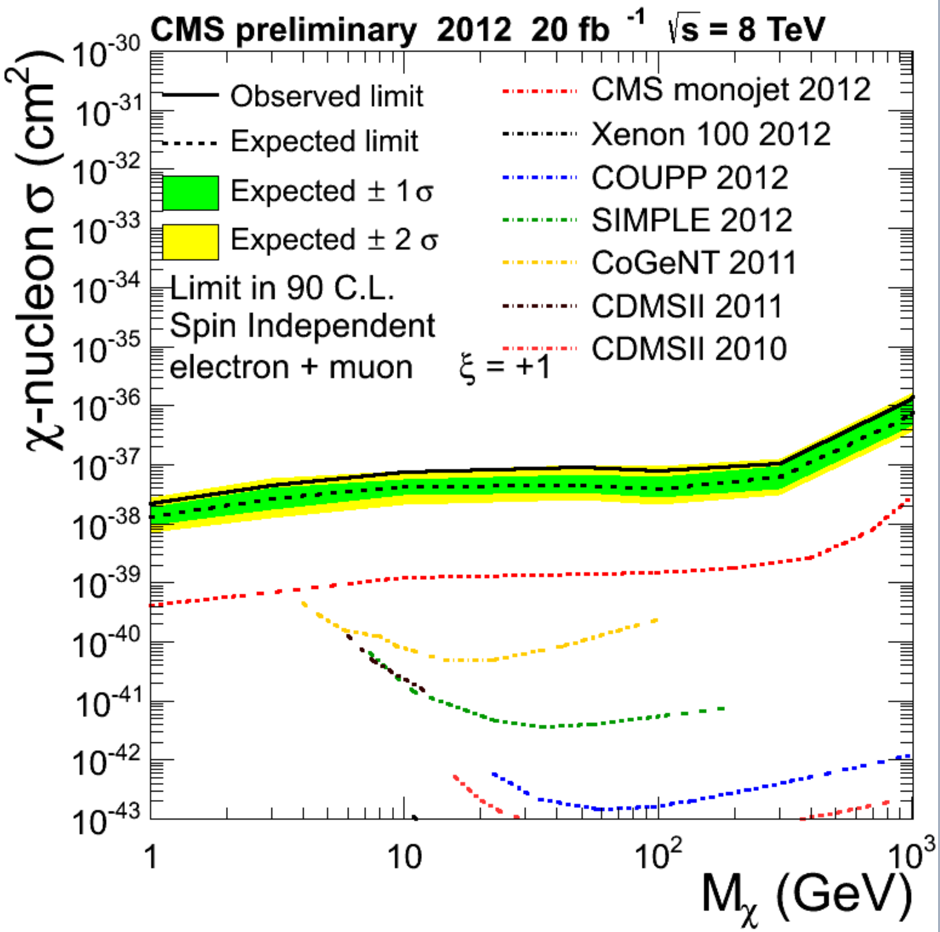
Monolepton- SM and DM signal



Observed event rate in the data agree with the predication by the SM.
Limits on DM production cross section are derived.

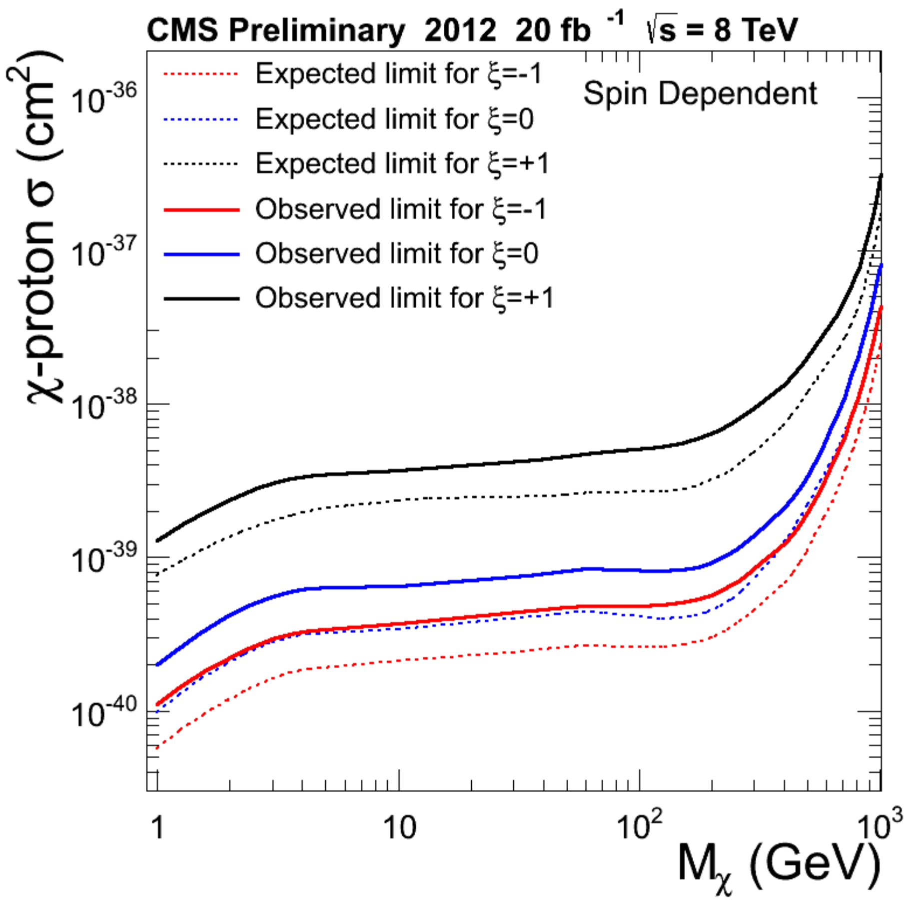
Monolepton- DM-Nucleon Limits

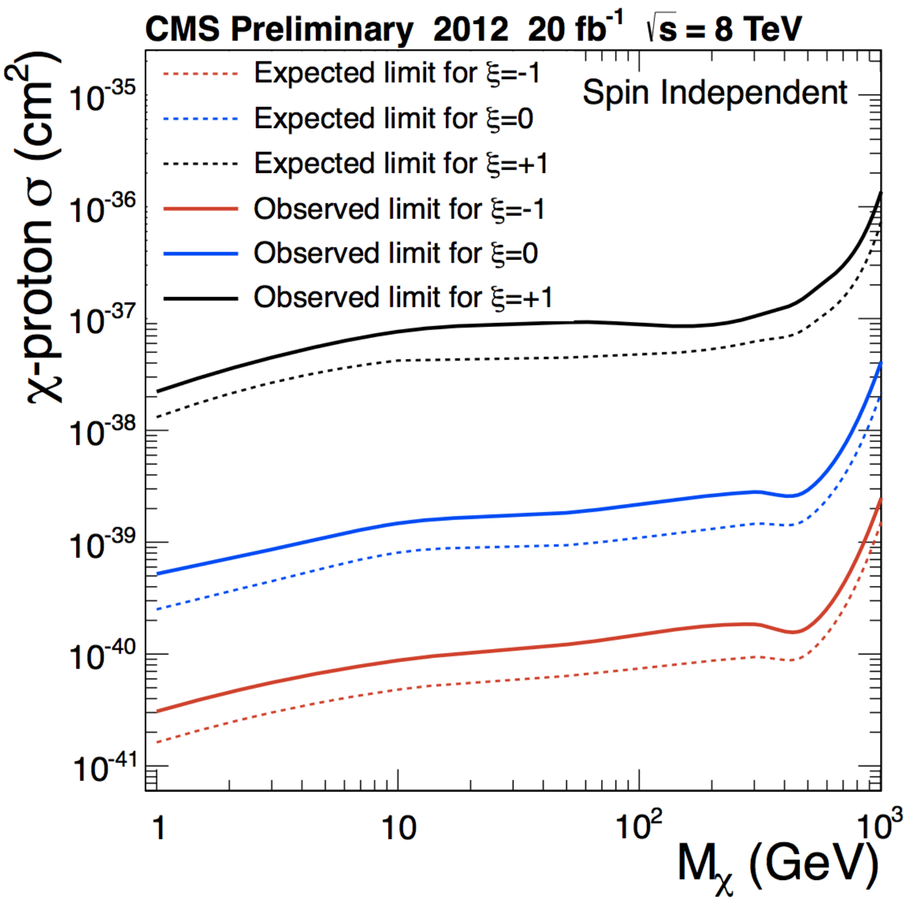




2012 result for =+1 in comparison with monojet and few direct detection, 90% CL

Monolepton- DM-Nucleon Limits (cont)





Excluded nucleon-dark matter cross section for =+1,0,-1

Summary

- Presented searches for Dark Matter in monojet, monophoton and monolepton channels using 20 fb^{-1} of data at 8 TeV.

- Predictions for SM background consistent with observed data, ***no excess is*** found. Limits are set on Dark Matter production, resulting in a significant extension of previously excluded parameter space:

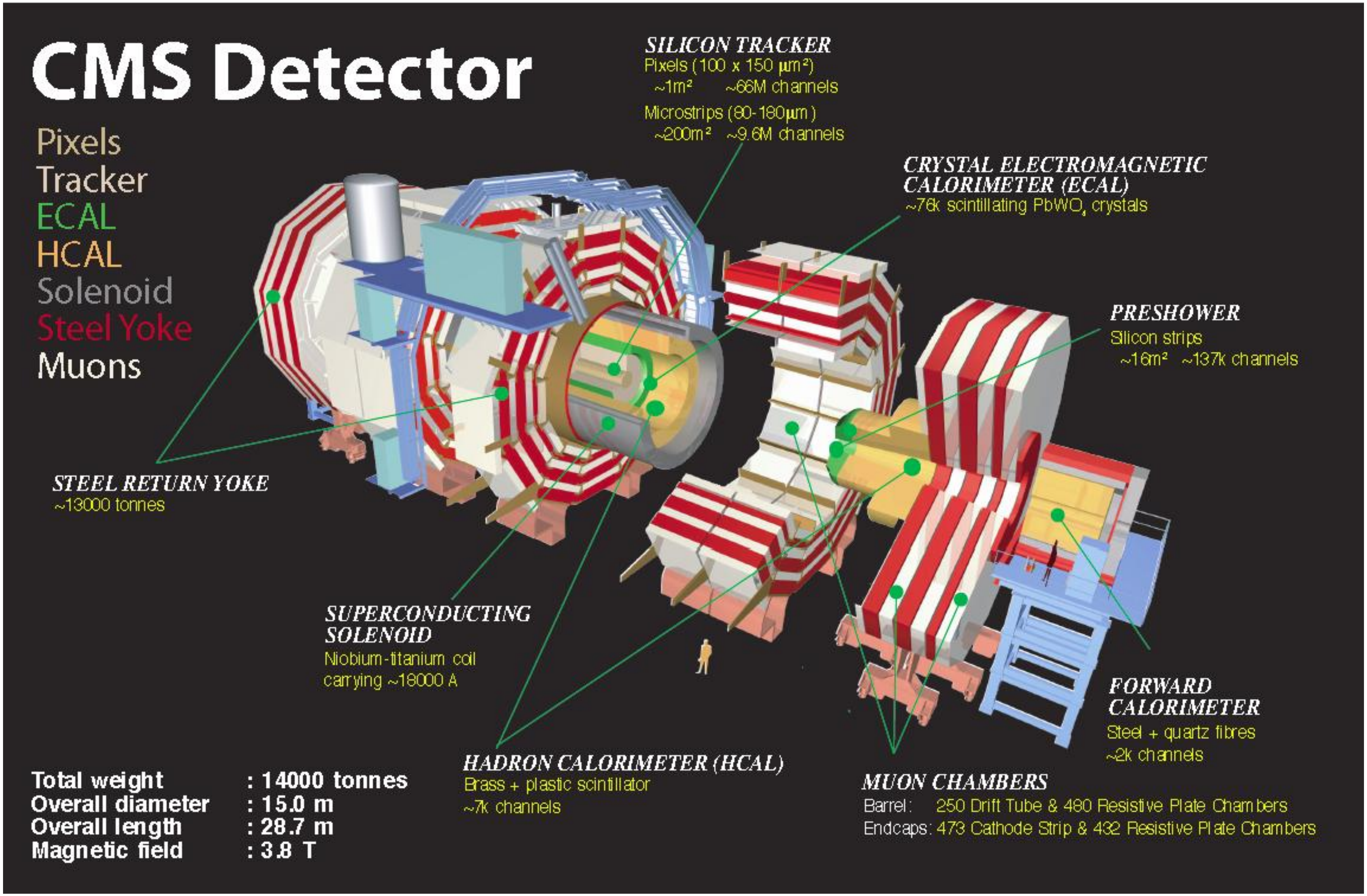
  - ***For spin-independent models, are obtained limits for low mass DM, below 3 GeV, a region as yet unexplored by the direct-detection experiments.***
  - ***For spin-dependent models, limits represent more stringent over entire 1-250 GeV mass, w.r.t. the direct-detection experiments.***

References:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

Thank you !

BACKUP

CMS detector



Monojet- DM-Nucleon Limits-Scalar operator