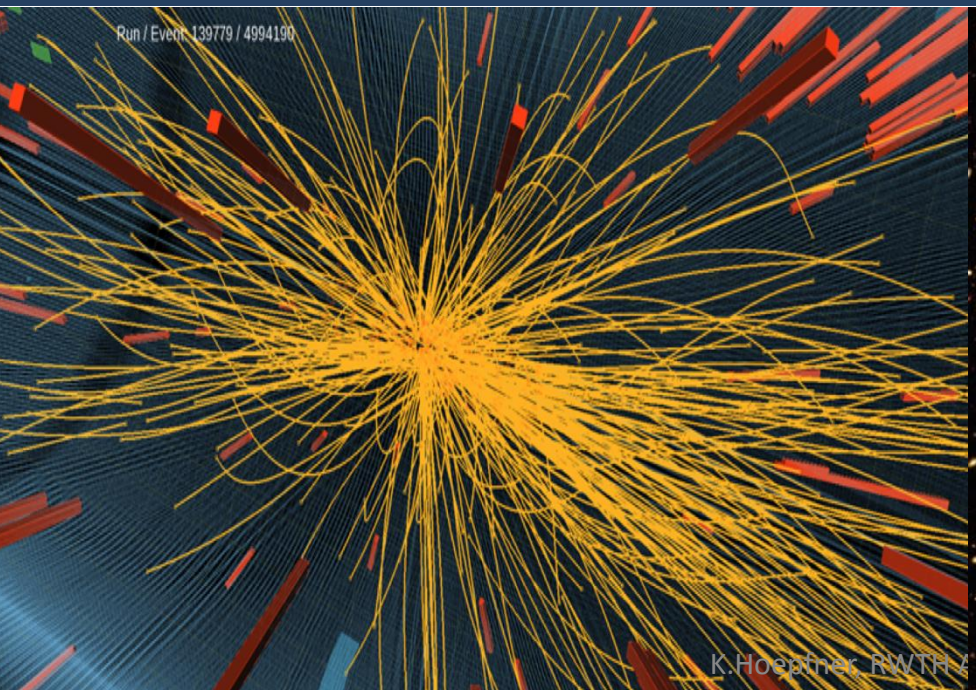
GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung
PHYSICS AT THE TERA SCALE
Helmholtz Alliance

Search for Dark Matter at CMS

Kerstin Hoepfner, RWTH Aachen, III. Phys. Inst. A
On behalf of the CMS collaboration

EPS Conference 2013, Stockholm

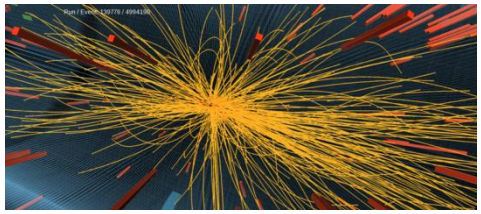


Phenomenology

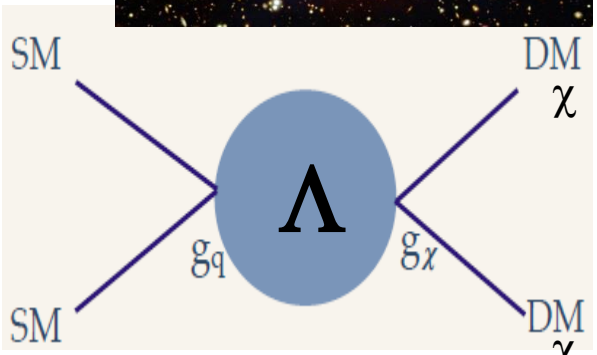
Dark matter = part of cosmological SM

Fermionic weakly interacting massive particle

Searches at the LHC



- DM χ produced in pairs
- Effective field theory → contact interaction between DM and SM particles
- Characterizing parameters: scale of eff. interaction $\Lambda = M/\sqrt{g_\chi g_q}$ and mass Mχ



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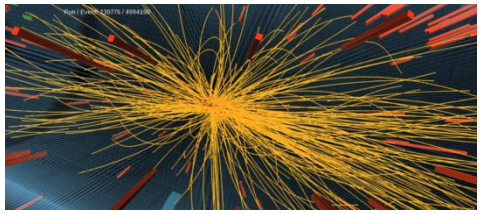

- DM χ produced in pairs
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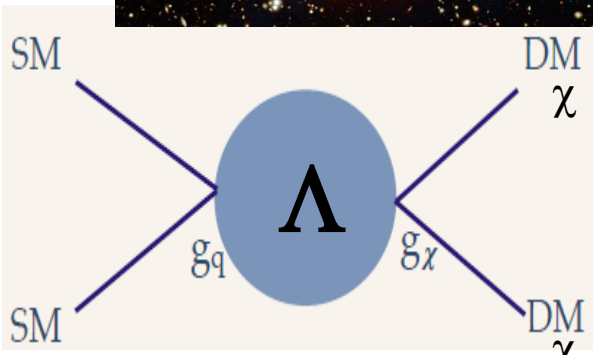


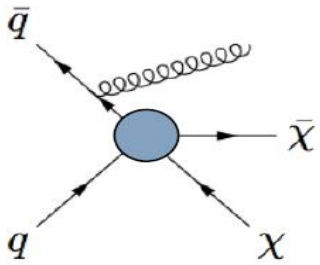
Most prominent couplings

Spin-**in**dependent vector coupling (**V**) $\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\chi \quad \xi_i\bar{q}_i\gamma_\mu q_i$

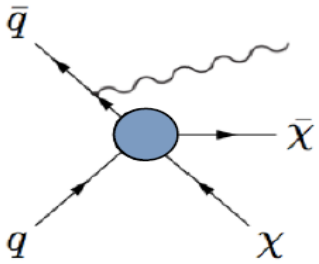
Spin-**dependent** axial-vector coupling (**AV**) $\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\gamma^5\chi \quad \xi_i\bar{q}_i\gamma_\mu\gamma^5 q_i$

How to make DM visible at the LHC?

Signatures – simple and striking

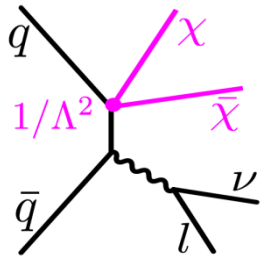


monojet +MET



monophoton +MET

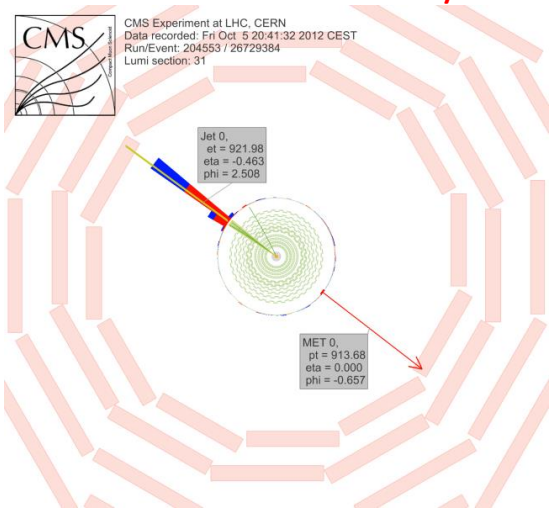
Radiation of a jet / photon from initial state



Recoil of a W-boson
W→lν with l=e,μ

CMS-PAS-EXO-12-048

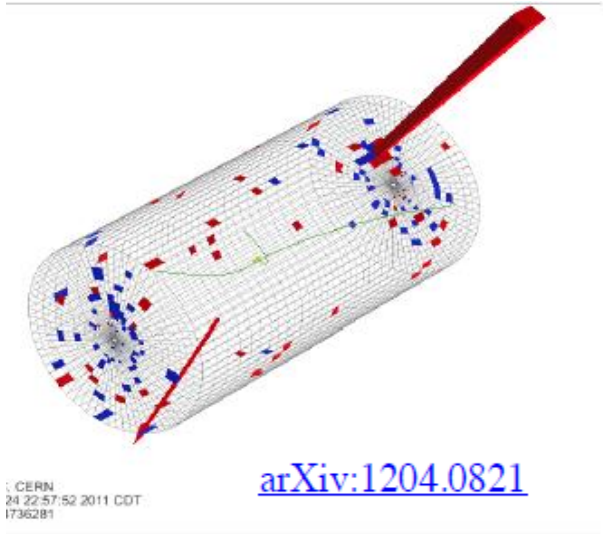
Full 2012 dataset 20/fb



arXiv:1206.5663

CMS-PAS-EXO-11-096

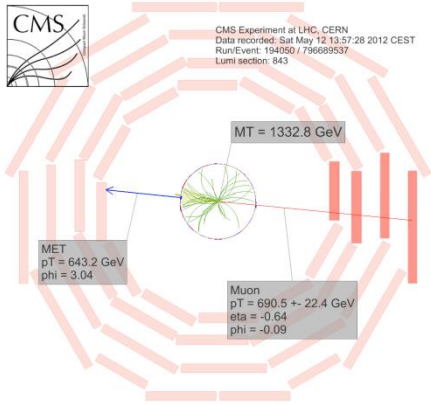
Full 2011 dataset 5/fb



arXiv:1204.0821

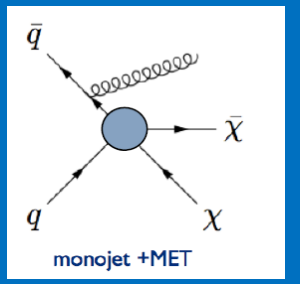
CMS-PAS-EXO-13-004

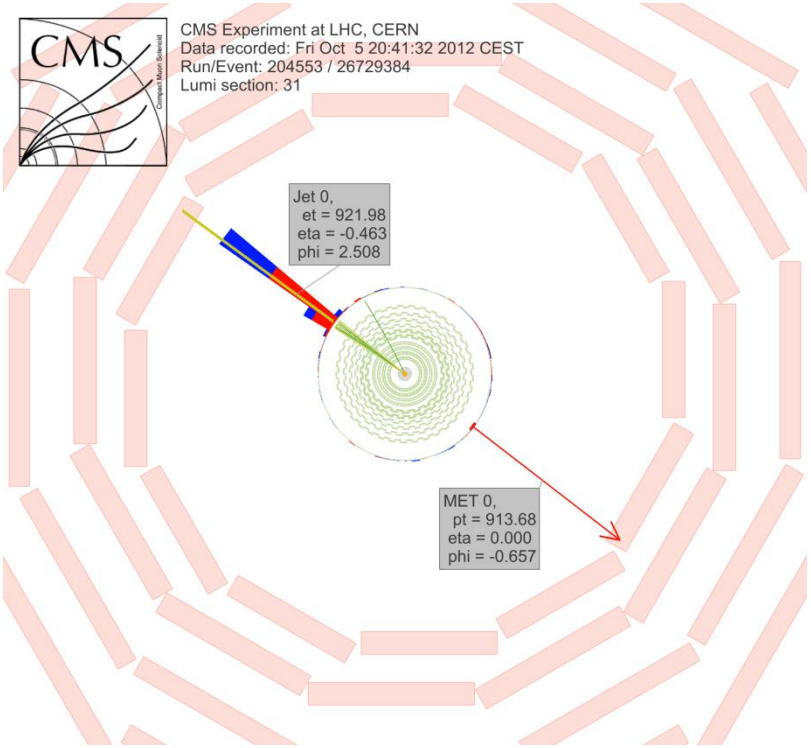
Full 2012 dataset 20/fb



All results for combination of electron + muon channels

Search for Pair Produced Dark Matter in Monojet Channel





Signature: high p_T jet + MET

CMS-PAS-EXO-12-048

20/fb of 2012 pp data at sqrt(s) = 8 TeV

Event Selection

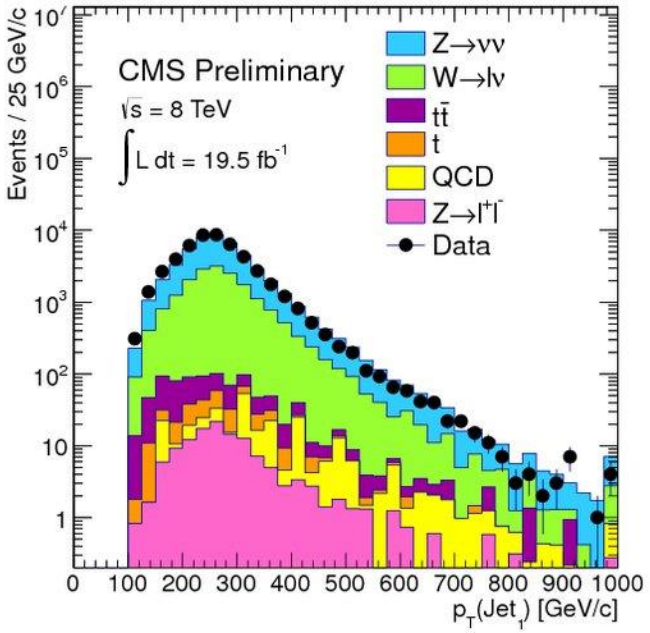
CMS-PAS-EXO-12-048

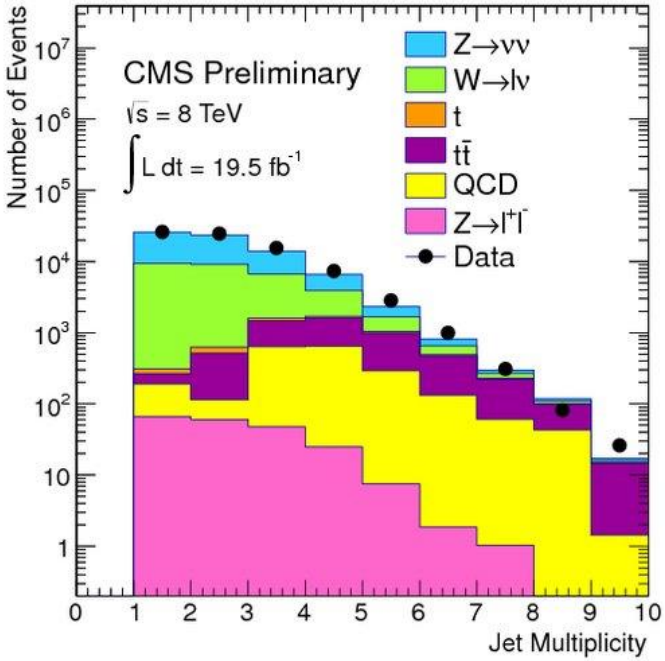
Search for single jet recoiling against MET>250 GeV

- Leading jet p_T>110 GeV ($|\eta|$<2.0)
- Allow for second jet with p_T>30 GeV if $\Delta\phi$ (j1, j2) <2.5
- Jet quality: >20% carried by charged hadrons, <70% carried by neutral hadron or photon
- Reject events with isolated lepton (e,mu,tau)
- Good primary vertex

Triggers

- MET>120 GeV
- jet p_T>80 GeV (η<2.6) + MET>105 GeV



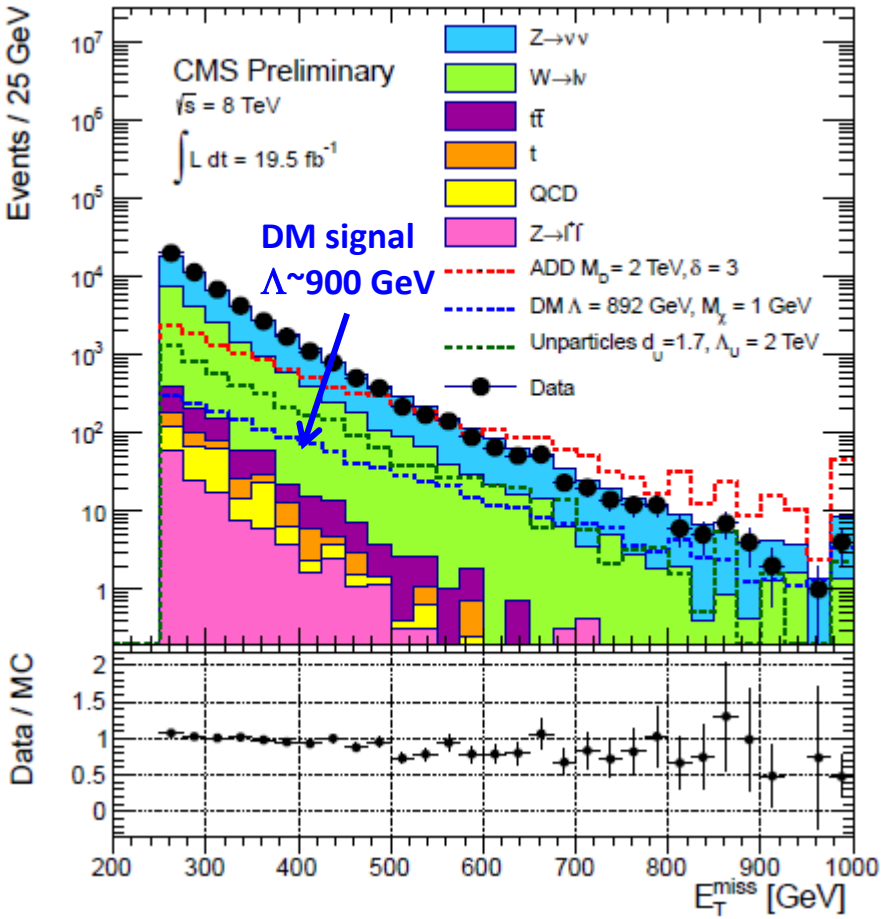


Background

CMS-PAS-EXO-12-048

- Dominant background (~70%) is $Z \rightarrow \nu\nu + j \rightarrow$ Data driven estimate from $Z \rightarrow \mu\mu + j$
- W+jets (~30%) also from data driven
- QCD : rejected by $\Delta\phi$ cut
- EWK : veto events with isolated tracks and isolated leptons
- Other backgrounds are negligible (~1%) and taken from MC

Possible signal and backgrounds in **MET** distribution after all cuts



Search performed in 7 bins of MET

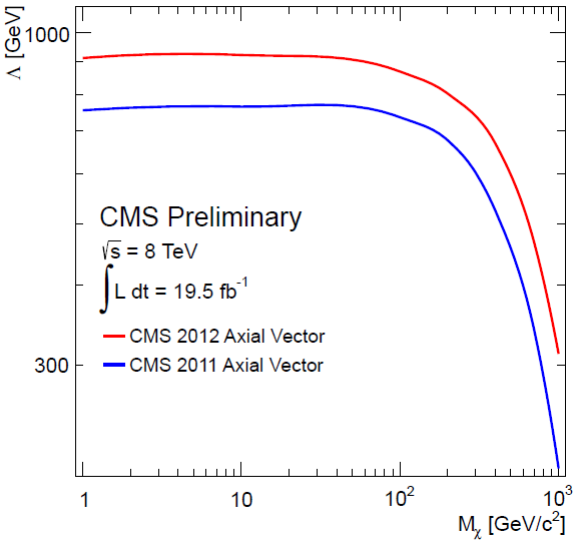
95% C.L. limits on σ × A × ε

CMS-PAS-EXO-12-048

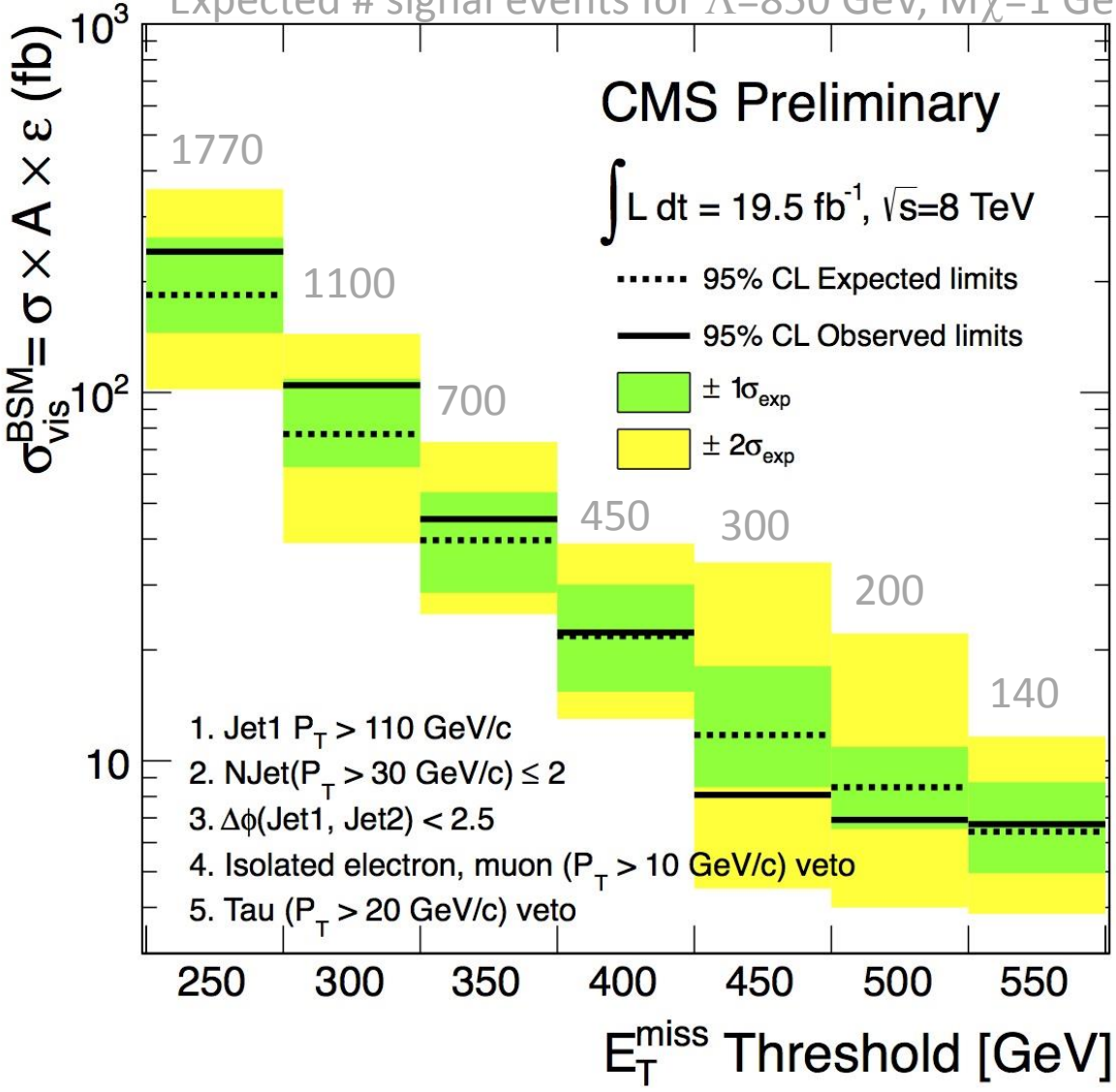
Search performed in 7 bins of MET

Lambda limit ~900 GeV

AV & V for Mχ < 100 GeV

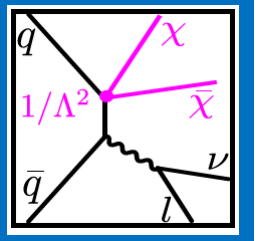


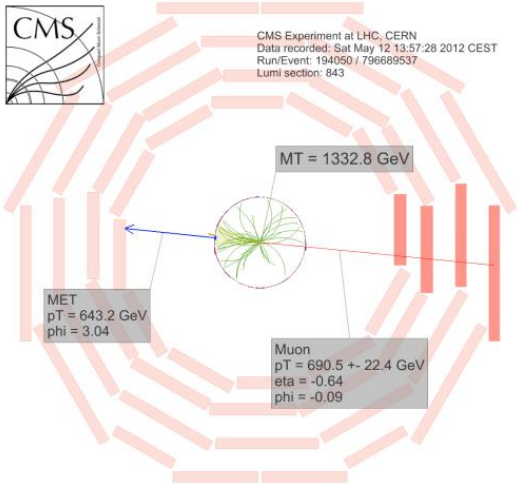
Expected # signal events for Λ=850 GeV, Mχ=1 GeV

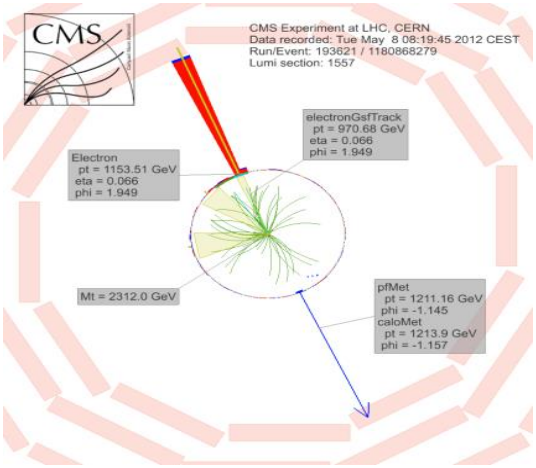


Brand new result

Search for Pair Produced Dark Matter in Monolepton Channel







Signature W + MET:

high p_T electron + MET

High p_T muon + MET

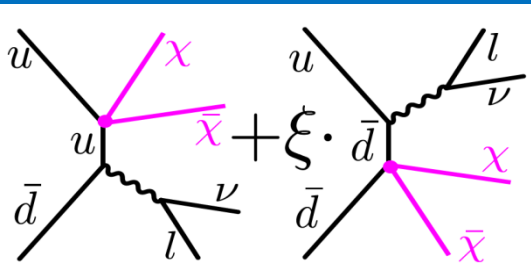
CMS-PAS-EXO-12-060

CMS –PAS-EXO-13-004

20/fb of 2012 pp data at sqrt(s) = 8 TeV

Search strategy following arXiv:1208.4861v2

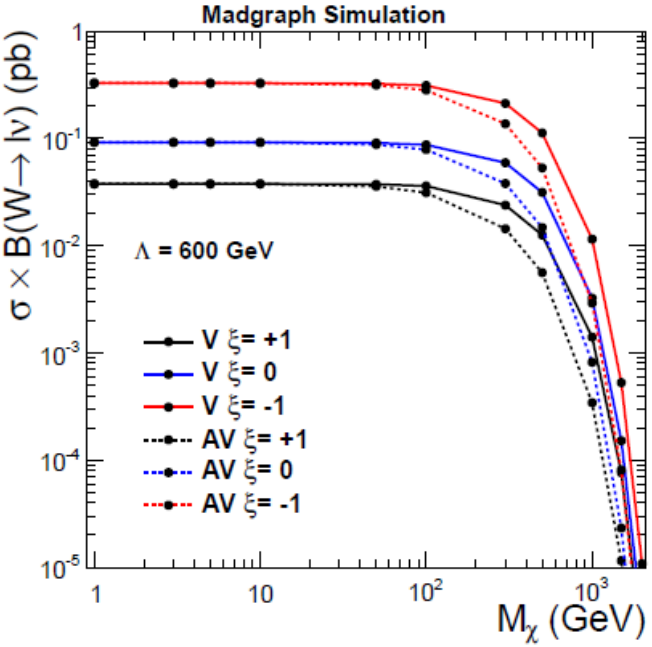
Interference



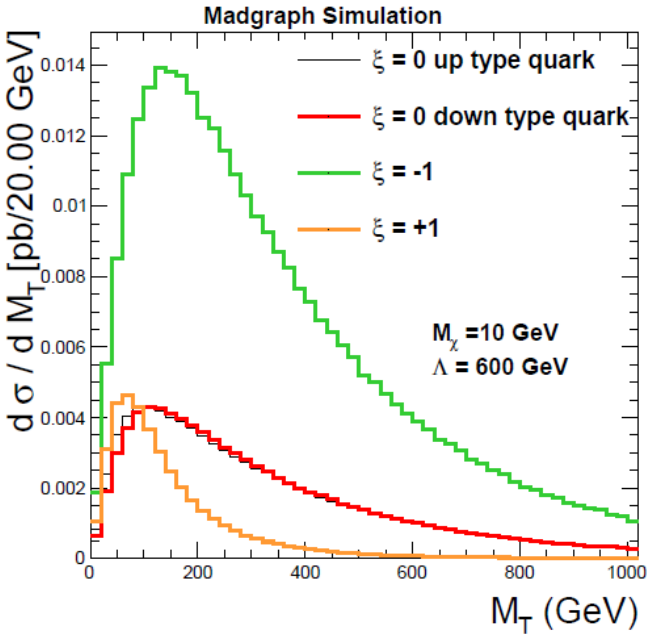
Monolepton channel sensitive to interference.
Possibly different coupling to u- and d-type quarks

Parametrized by $\xi = -1, 0, +1$

$$\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\chi \quad \xi_i\bar{q}_i\gamma_\mu q_i$$



Largest cross section for χ = -1
For Mχ <~70 GeV same cross section for V and AV coupling of fixed ξ



Interference type influences M_T shape
→ impact on sensitivity

Selecting Monolepton Events

CMS-PAS-EXO-13-004

Event selection

- Single electron(muon) trigger with p_T>85(40) GeV
- Lepton ID optimized for high p_T
- Kinematical selections:

  $0.4 < p_T / \text{MET} < 2$

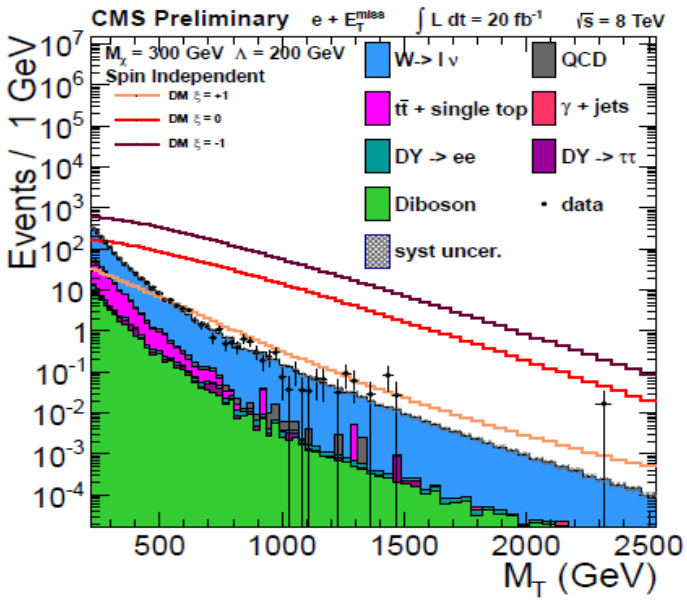
  $\Delta\phi < 0.8$

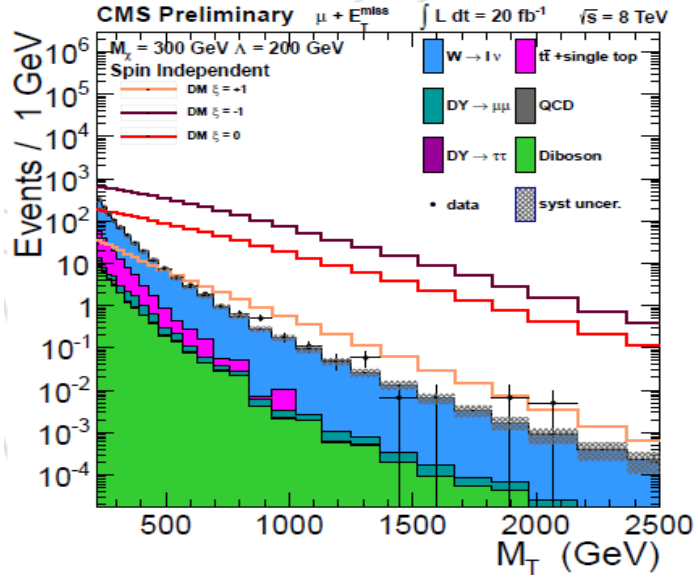
Transverse mass distribution

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

Background

- Derived from simulation
- Main bkgr: W→lv with MT binned k-factor
- NLO xsec's



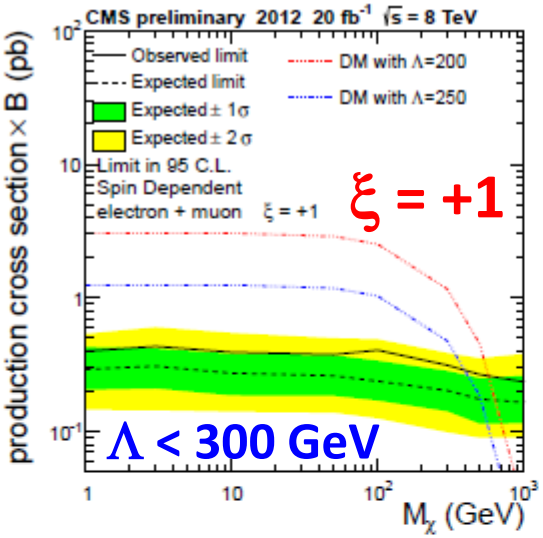


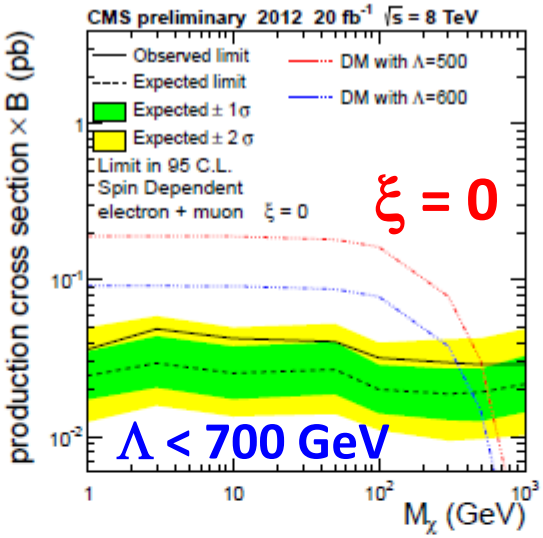
Limits on production cross section + λ

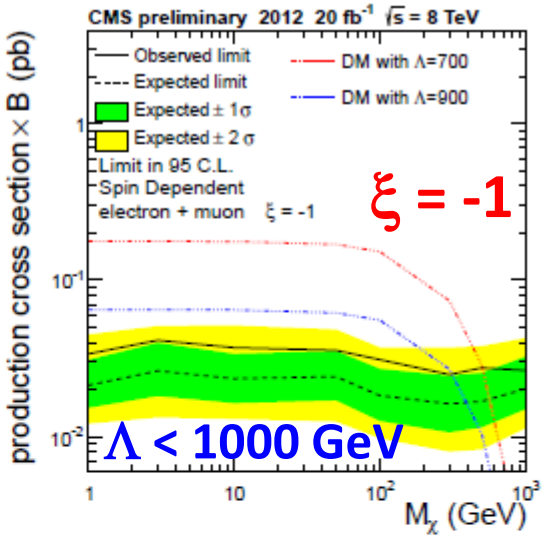
CMS-PAS-EXO-13-004

V

Spin In-depen dent

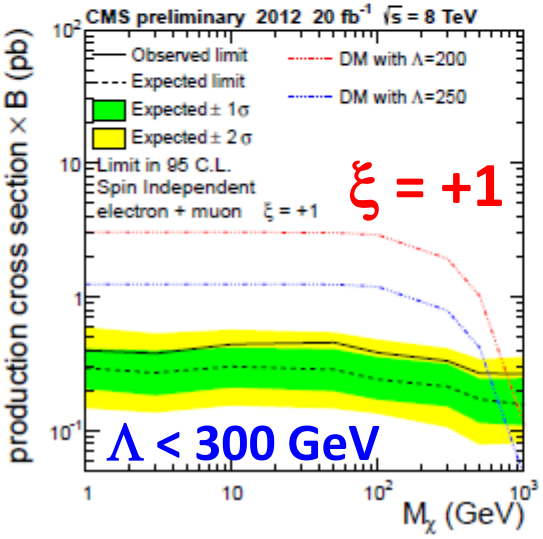


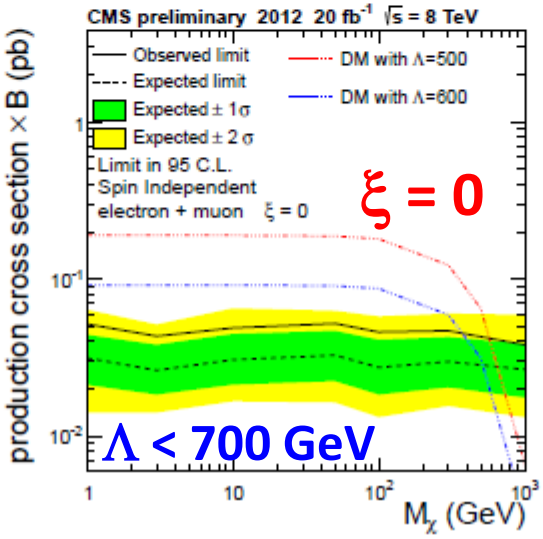


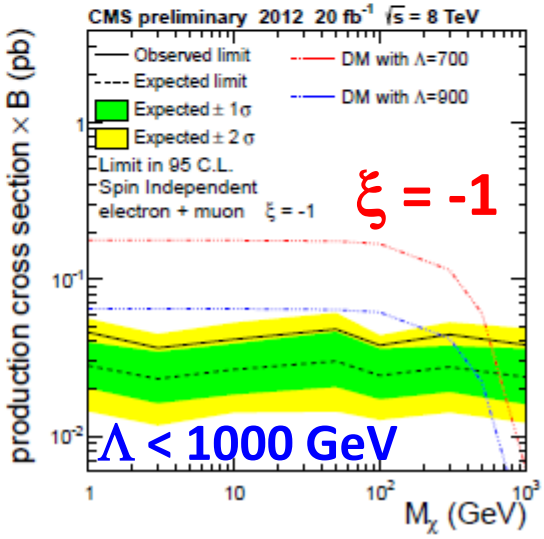


AV

Spin depen dent

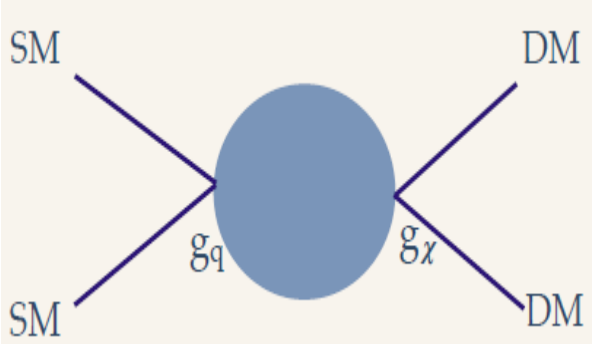


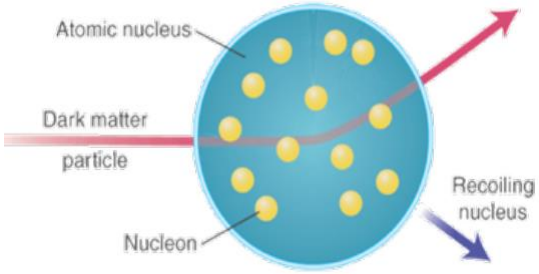




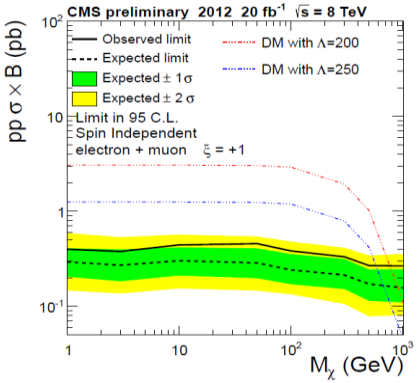
Translate production cross section limit into DM – nucleon limits

Purpose: to compare to direct detection experiments



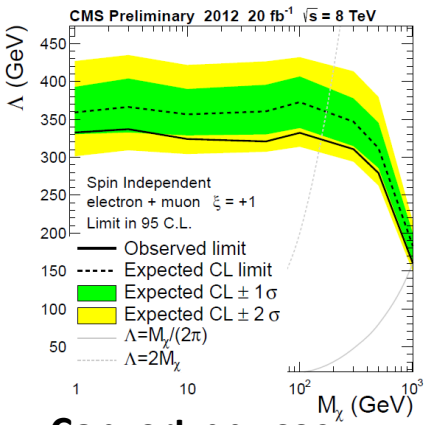


Translate limits to same plane as direct detection experiments

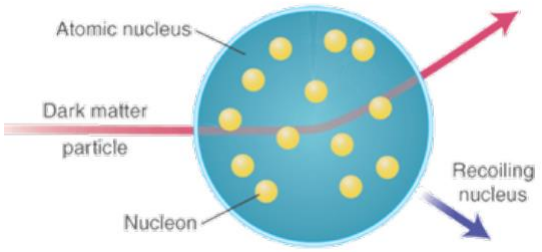


Vector operator

$$\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\chi \quad \xi_i\bar{q}_i\gamma_\mu q_i$$



Convert pp xsec limit into Λ–limit



Spin-Independent

$$\mathcal{O}^N = f_q^N \frac{(\bar{N}\gamma^\mu N)\,(\bar{\chi}\gamma_\mu\chi)}{\Lambda^2}$$

Coefficient relating nucleon and quark operator

Channel	Lambda limit for Mchi < 200 GeV
l+MET ξ = +1	300 GeV
l+MET ξ = 0	700 GeV
l+MET ξ = -1	1000 GeV
Jet + MET	900 GeV

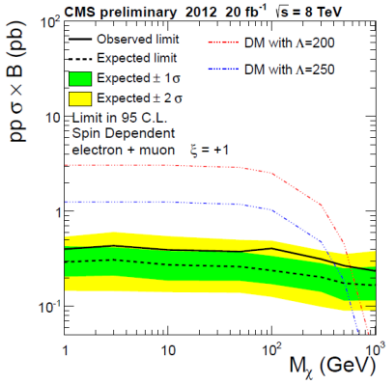
μ = reduced mass of the nucleon (p or n) system

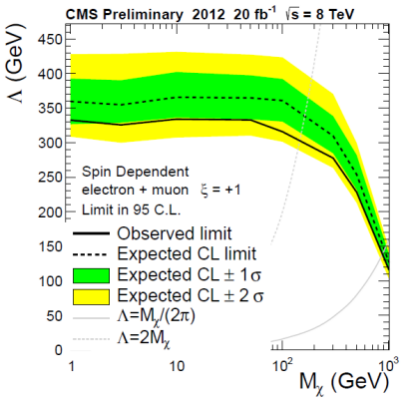
$$\sigma_{SI} = \frac{\mu^2}{\pi\,\Lambda^4}\left(\sum_q f_q^N\right)^2$$

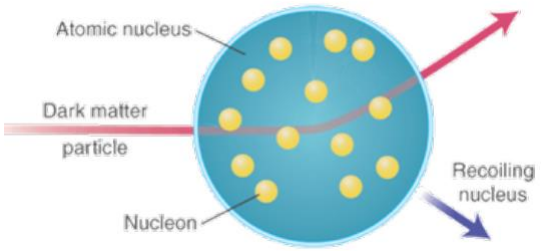
with $f_u^p = f_d^n = 2, f_d^p = f_u^n = 1$
$f = 0$ for other quarks

arXiv:0803.2360.

Translate limits to same plane as direct detection experiments







Axial-Vector operator

$$\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\gamma^5\chi \quad \xi_i\bar{q}_i\gamma_\mu\gamma^5 q_i$$

Convert pp xsec limit into Λ–limit

Spin-Dependent

$$\mathcal{O}^{Nq} = \Delta_q^N \frac{(N\gamma^\mu\gamma_5 N)\,(\bar{\chi}\gamma_\mu\gamma_5\chi)}{\Lambda^2}$$

Sum of quark helicities

Channel	Lambda limit for Mchi < 200 GeV
l+MET ξ = +1	300 GeV
l+MET ξ = 0	700 GeV
l+MET ξ = -1	1000 GeV
Jet + MET	900 GeV

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

$$\Delta_u^p = \Delta_d^n = 0.842 \pm 0.012$$
$$\Delta_d^p = \Delta_u^n = -0.427 \pm 0.013$$
$$\Delta_s^p = \Delta_s^n = -0.085 \pm 0.018$$

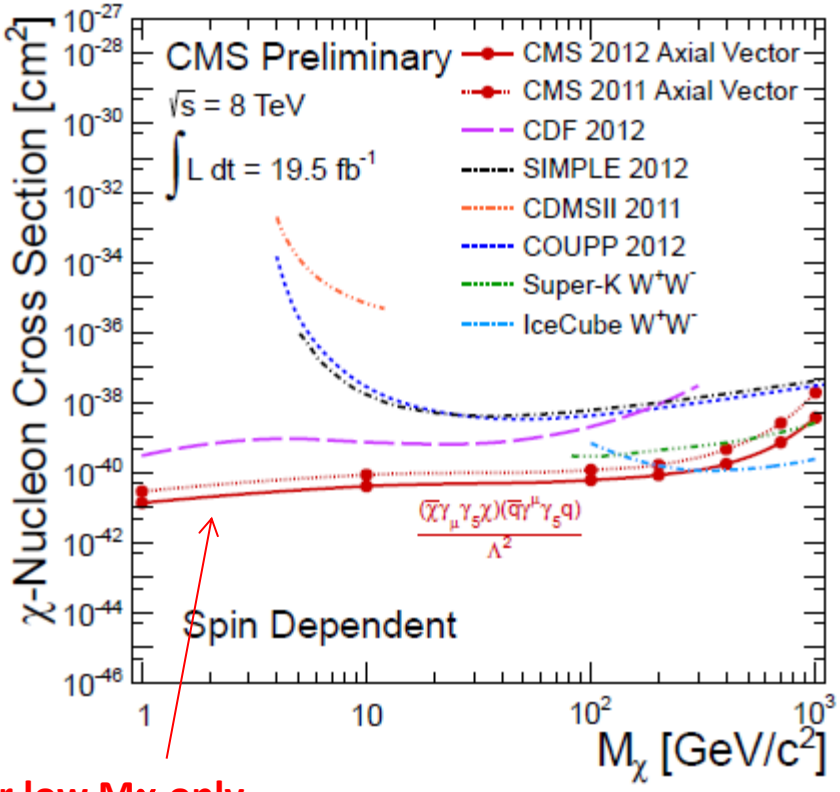
arXiv:0803.2360.

$$\sigma_{SI} = \frac{3\mu^2}{\pi\,\Lambda^4}\left(\sum_q \Delta_q^N\right)^2$$

Monojet

CMS-PAS-EXO-12-048

Not sensitive to interference, 90% C.L.
Comparison 2011 – 2012 result

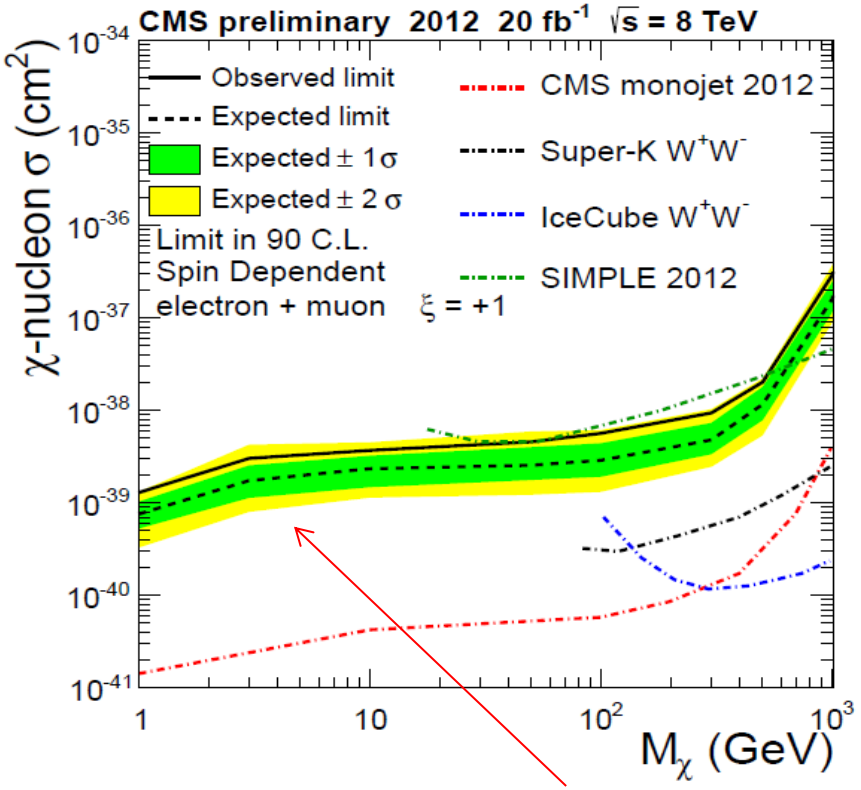


For low Mχ only LHC sets limits

Monolepton ξ = +1

2012 results in comparison to monojet and some direct detection experiments, 90% C.L.

CMS-PAS-EXO-13-004

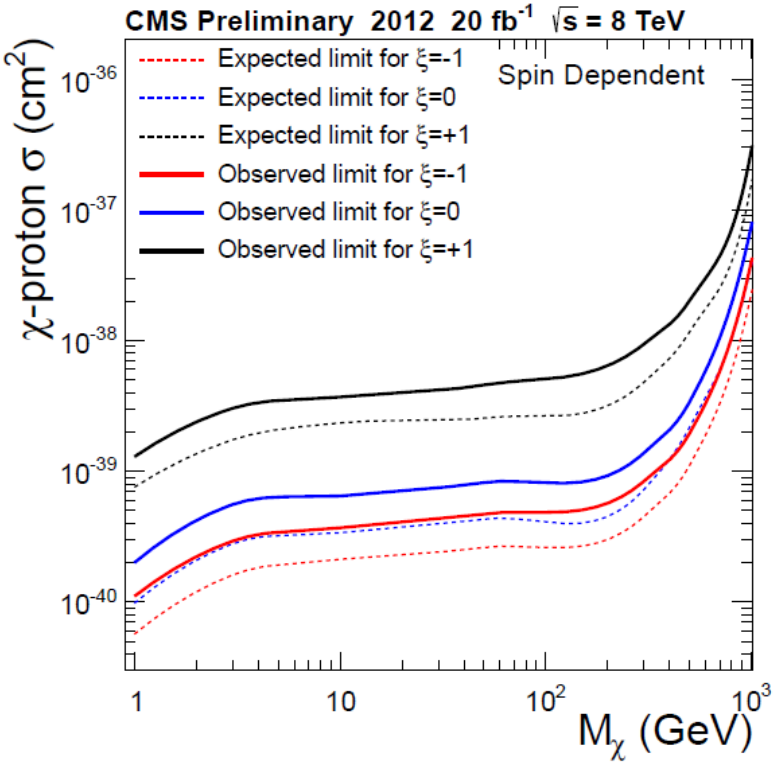


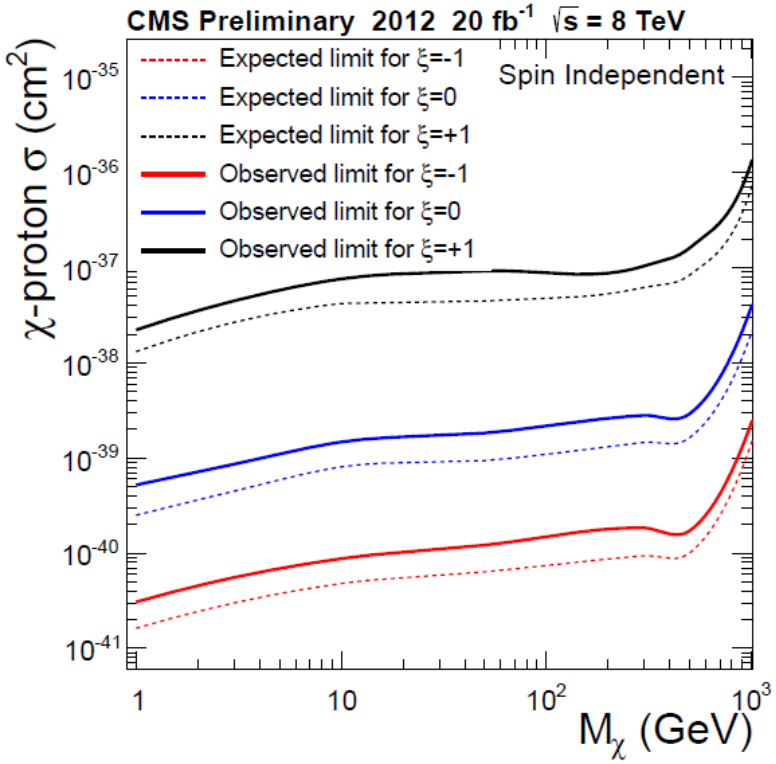
For low Mχ only LHC sets limits

Channel	DM-nucleon cross section [cm^2]	
Coupling	AV (SD)	V (SI)
Monojet	10^{-41}	10^{-39}
Monolepton ξ = +1	10^{-39}	10^{-38}

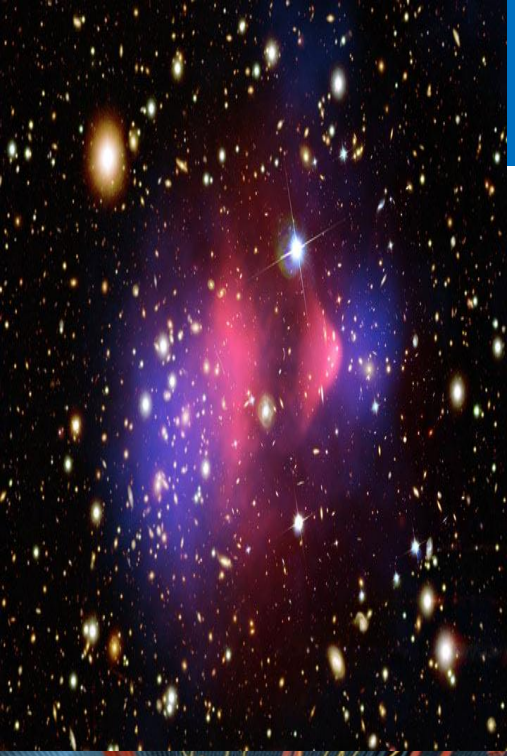
Monolepton DM-nucleon Limits for interference cases ξ = -1, 0, +1

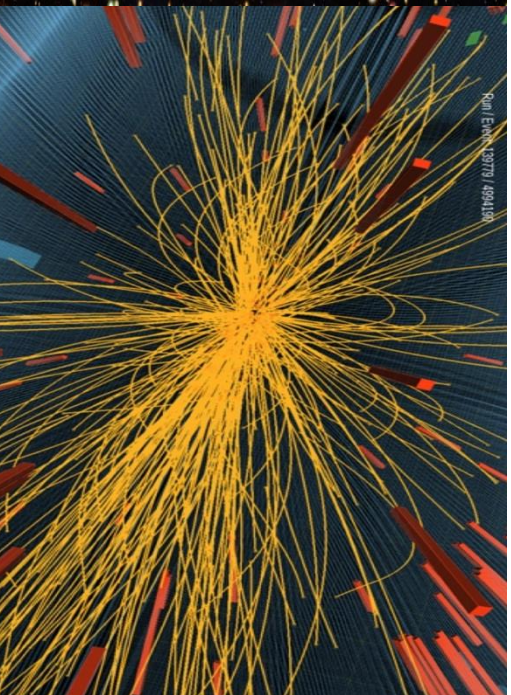
CMS-PAS-EXO-13-004





Channel	DM-nucleon cross section [cm^2]	
Coupling	AV	V
Monojet	10^{-41}	10^{-39}
Monolepton ξ = +1	5 x 10^{-39}	10^{-38}
Monolepton ξ = 0	7 x 10^{-40}	10^{-39}
Monolepton ξ = -1	4 x 10^{-40}	3 x 10^{-41}





Summary

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

- Search for pair produced dark matter candidates with CMS
- Results **with full 2012** dataset at sqrt(s)=8 TeV
- Channels:
  - jet + MET
  - Electron + MET
  - Muon + MET

- No indication of a signal observed
- Exclude production cross section of 10^{-1}…10^{-2} pb
- Translate these limits into χ-nucleon limits for comparison with direct detection experiments
- For $M\chi < 10$ GeV only collider limits
- Exclude χ-nucleon cross sections from 10^{-38}…10^{-41} cm^2

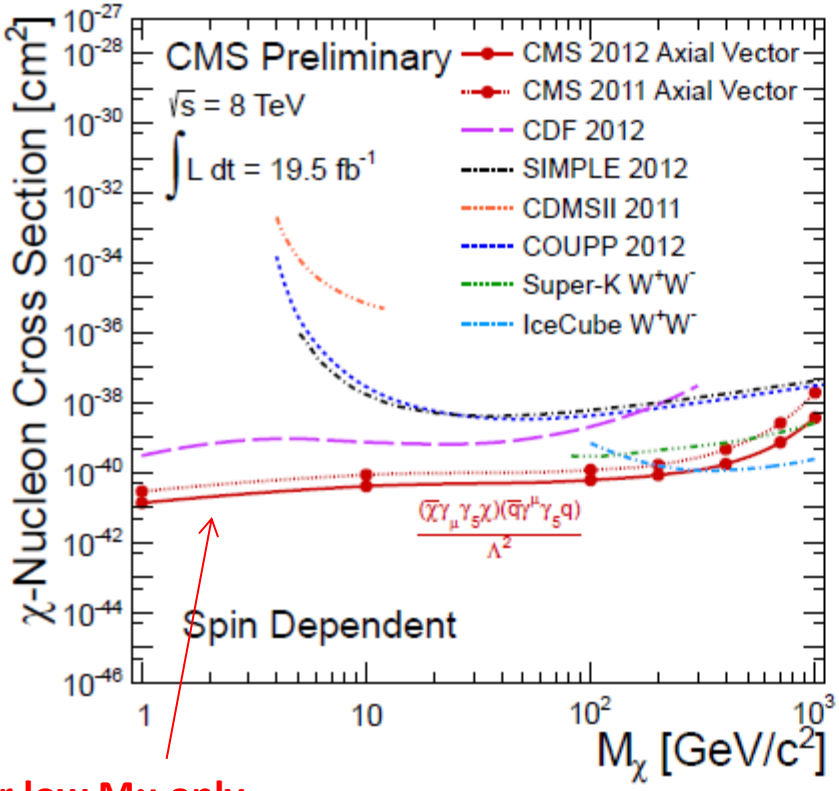
Additional Material

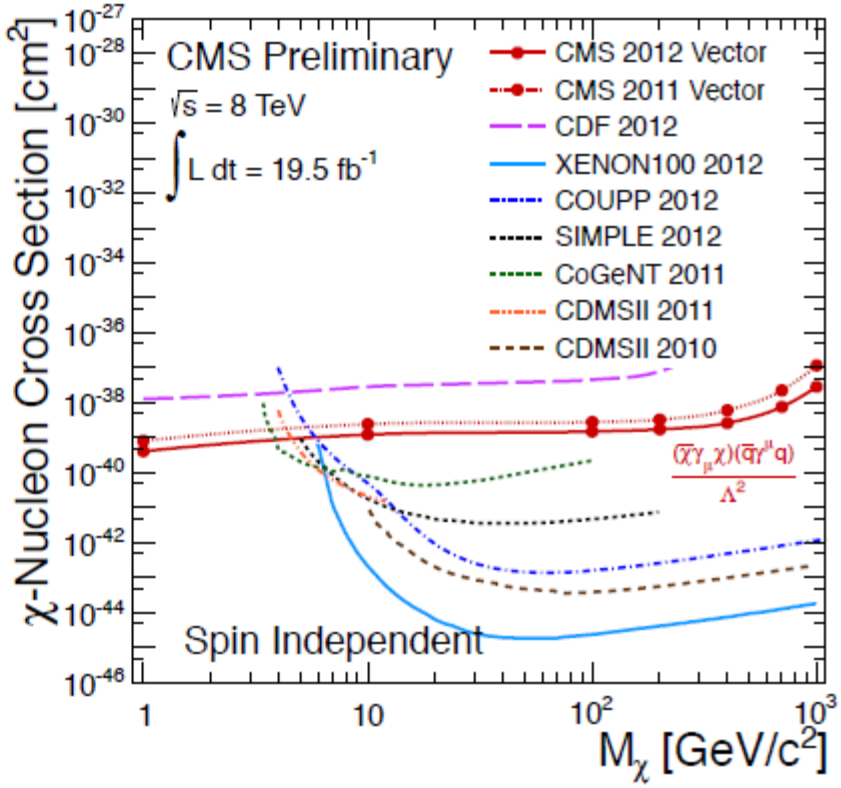
Monojet Result

CMS-PAS-EXO-12-048

Not sensitive to interference, 90% C.L.

Comparison 2011 – 2012 results plus monophoton





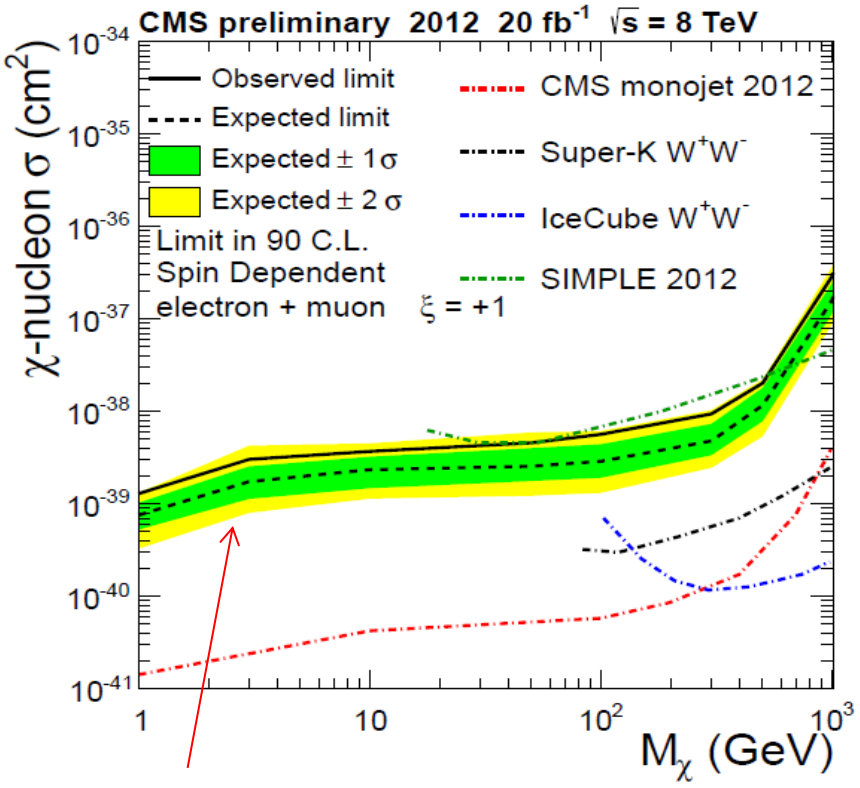
For low Mχ only LHC sets limits

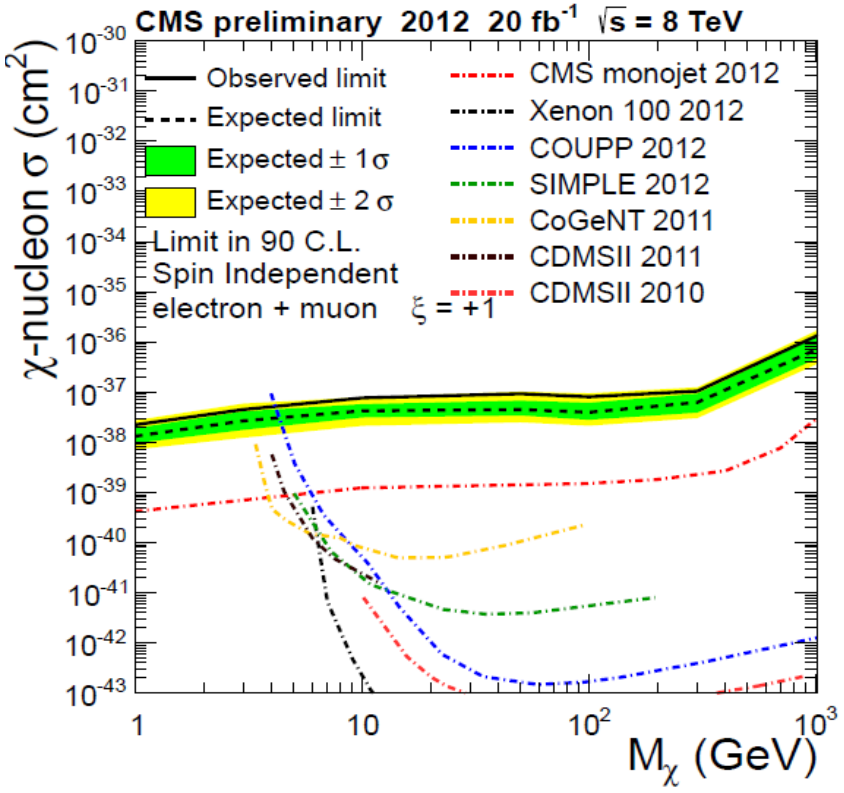
Channel	DM-nucleon cross section [cm²]	
Coupling	AV	V
Monojet	10^{-41}	10^{-39}

Monolepton Result ξ = +1

CMS-PAS-EXO-13-004

2012 results in comparison to monojet and some direct detection experiments, 90% C.L.





For low Mχ only LHC sets limits

Channel	DM-nucleon cross section [cm²]	
Coupling	AV	V
Monolepton	10^{-39}	10^{-38}

Lambda limits monolepton

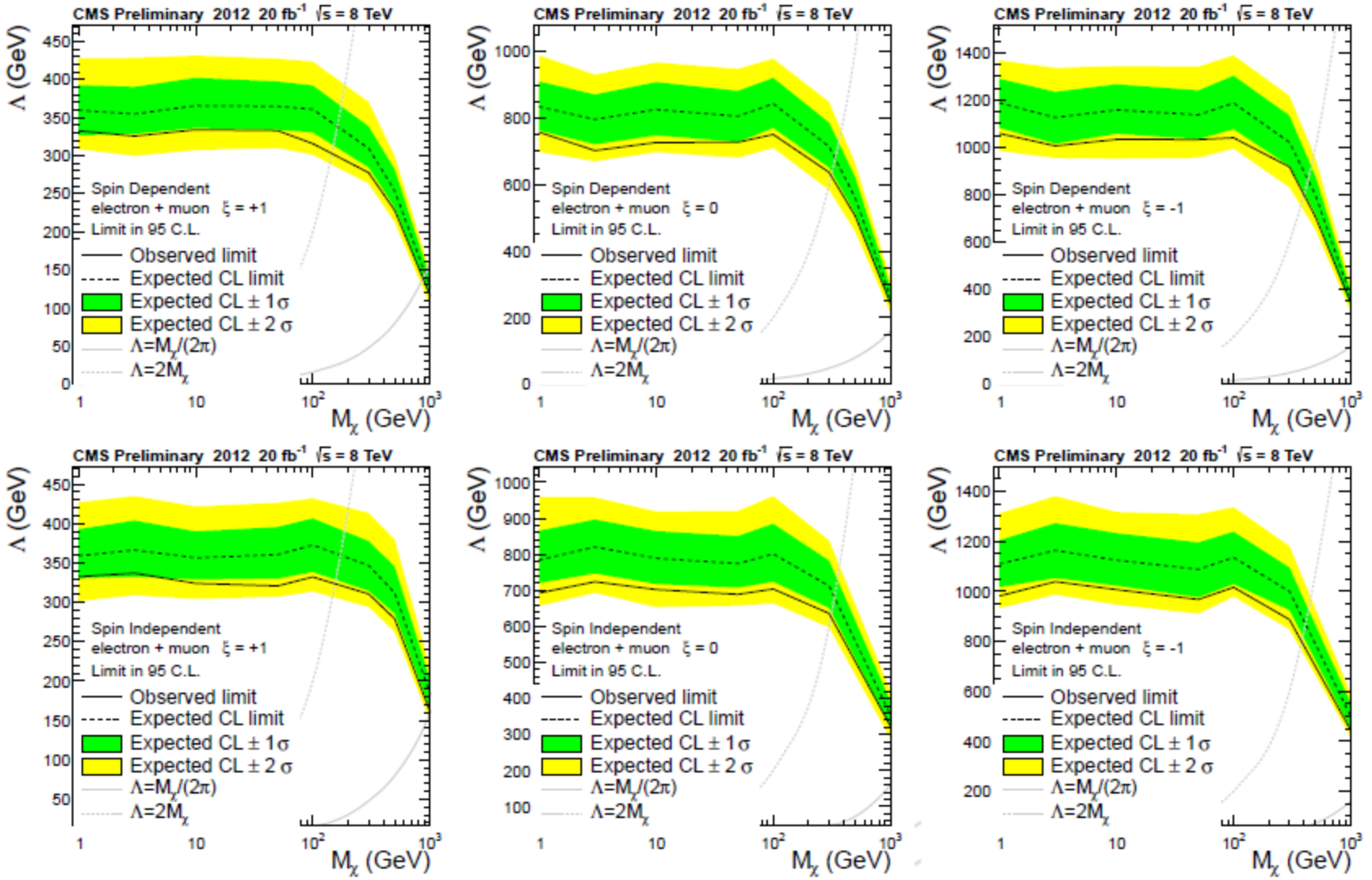
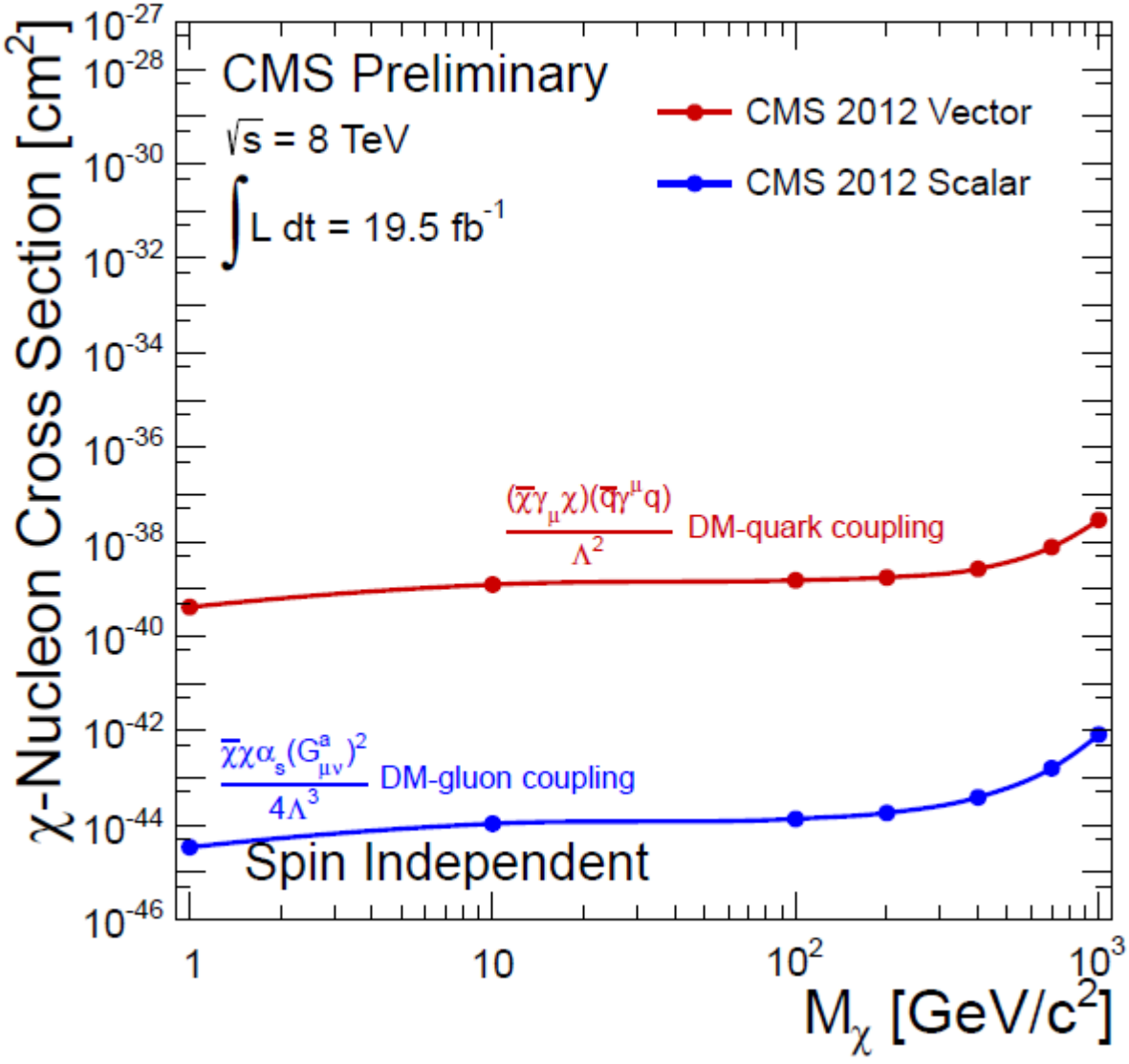


Figure 8: Exclusion plane in Λ-M_χ, for the combination of the electron and muon channel, where all parameter points below the observed limit are excluded with 95% confidence. The validity of the theory is shown in the grey lines for $M_\chi/(2\pi)$ and $2M_\chi$.

Monojet Scalar model



Monojet Λ as fct of mediator mass

Observed limits on Λ as a function of the mass of the mediator (M), assuming vector interactions and a dark matter mass of 50 GeV (blue) and 500 GeV (red). The width of the mediator was varied between M/3, M/10 and M/8Pi.