Searches for dark matter at the CMS experiment

EXO-13-004, EXO-12-048, EXO-11-096

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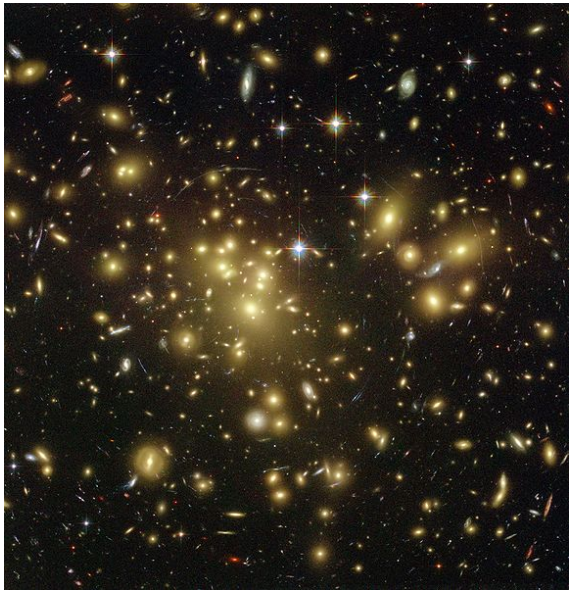
RWTH AACHEN UNIVERSITY

Bundesministerium
für Bildung
und Forschung

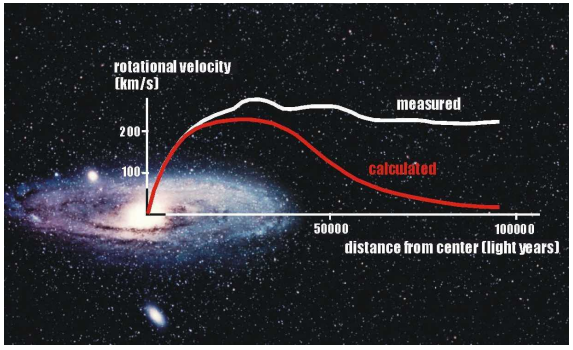
Introduction

Gravitational lenses



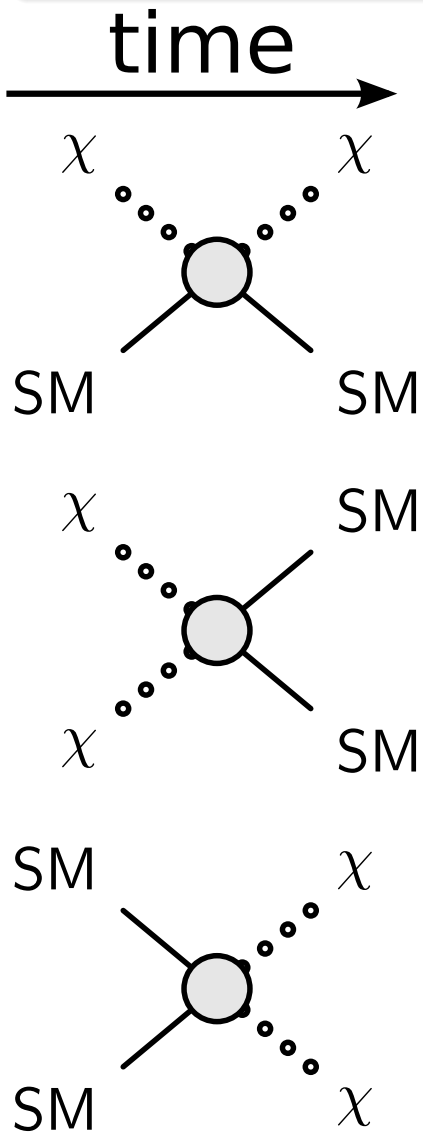
NASA
http://hubblesite.org/newscenter/newsdesk/archive/releases/2003/01/image/a

Galaxy rotation curves



Queens Uni. / arXiv:1111.5793
http://www.universetoday.com/91520/

Fermionic dark matter searches



Direct detection experiments

Dark matter – nucleus scattering.
SIMPLE, LUX, XENON, etc.

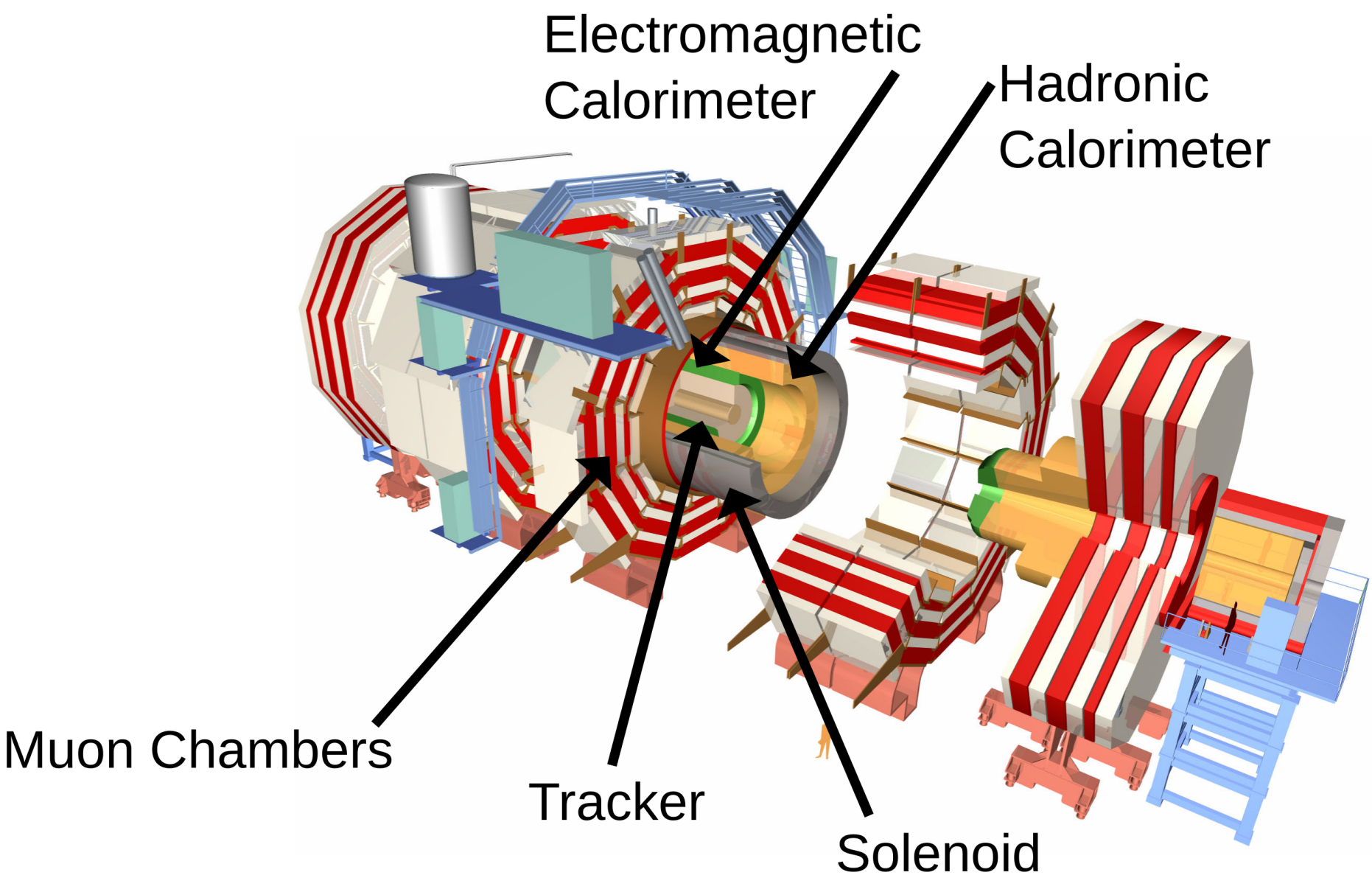
Indirect detection experiments

Dark matter annihilation or decay.
IceCube, Super-K, etc.

Collider experiments

Dark matter production.
CMS, ATLAS, etc.

CMS detector

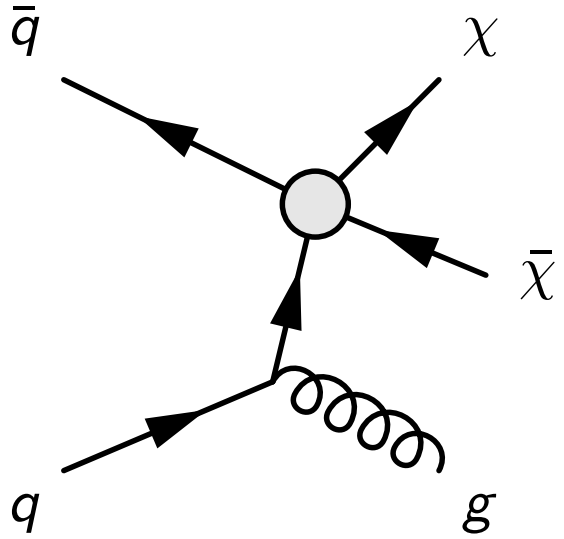


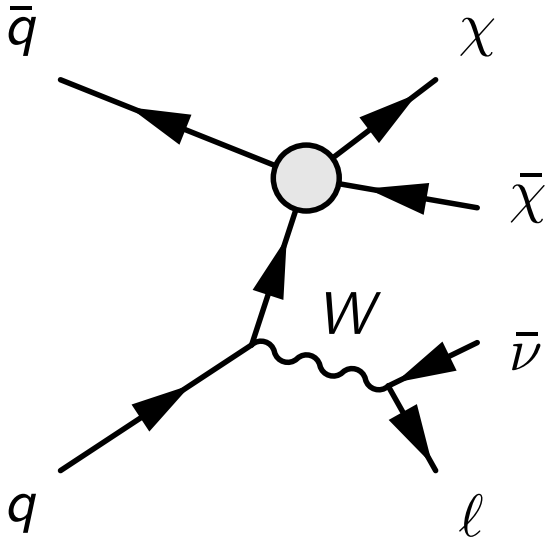
Model and couplings

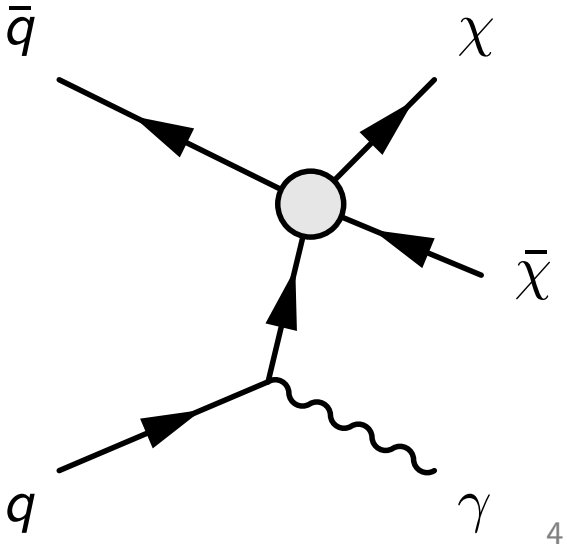
Effective field theory.
Covers multiple scenarios, limited validity.
Parameters: M_χ, $\Lambda = \frac{M_{\text{mediator}}}{\sqrt{g_\chi \cdot g_q}}$.

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

jet + E_T^{miss}	$\ell + E_T^{\text{miss}}$	$\gamma + E_T^{\text{miss}}$
$20\,\text{fb}^{-1}$ @ 8 TeV	$20\,\text{fb}^{-1}$ @ 8 TeV	$5\,\text{fb}^{-1}$ @ 7 TeV
CMS-PAS-EXO-12-048	CMS-PAS-EXO-13-004	CMS-PAS-EXO-11-096



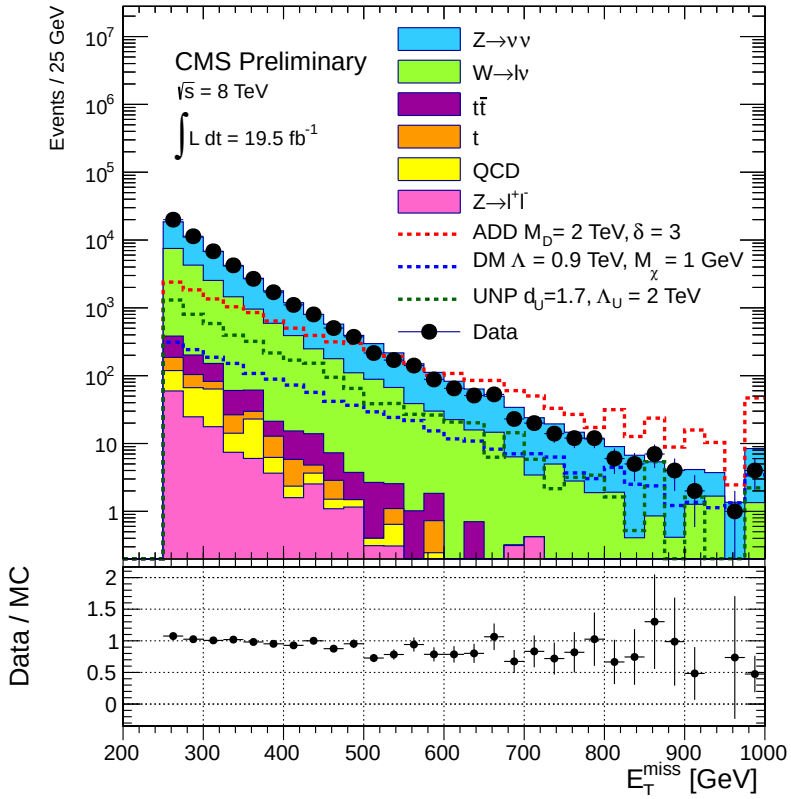




Monojet – Selection

Selection

- Trigger: $E_T^{\text{miss}} > 120\,\text{GeV}$
- Trigger: $p_T(\text{jet}) > 80\,\text{GeV}$, $E_T^{\text{miss}} > 105\,\text{GeV}$
- $p_T(\text{jet}) > 110\,\text{GeV}$
- $E_T^{\text{miss}} > 250\,\text{GeV}$
- Allow for second jet, if $\Delta\phi(j_1, j_2) < 2.5$ (ISR, FSR).
- Calorimetric criteria.
- Veto events with isolated leptons.

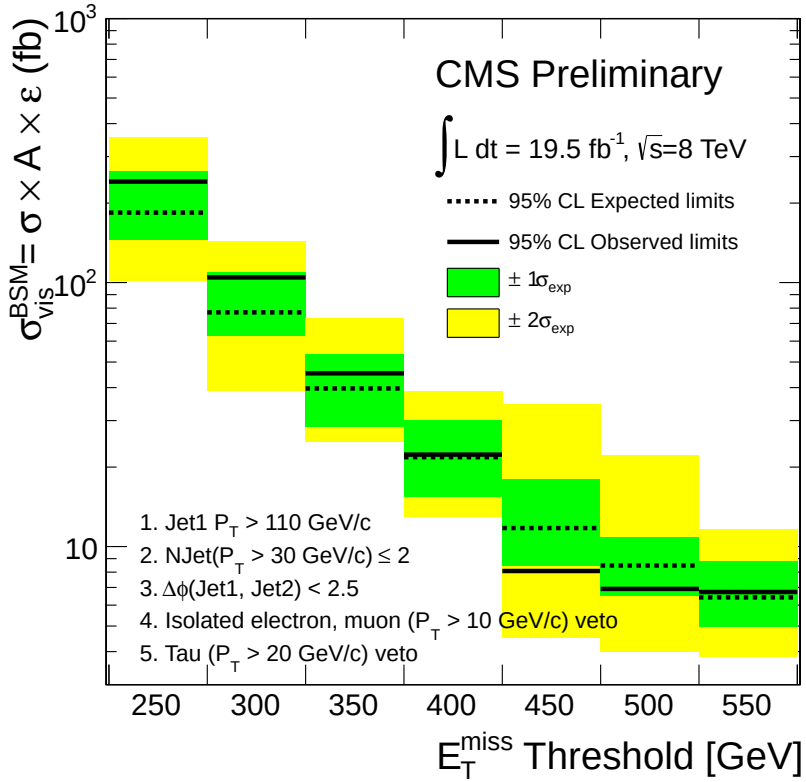


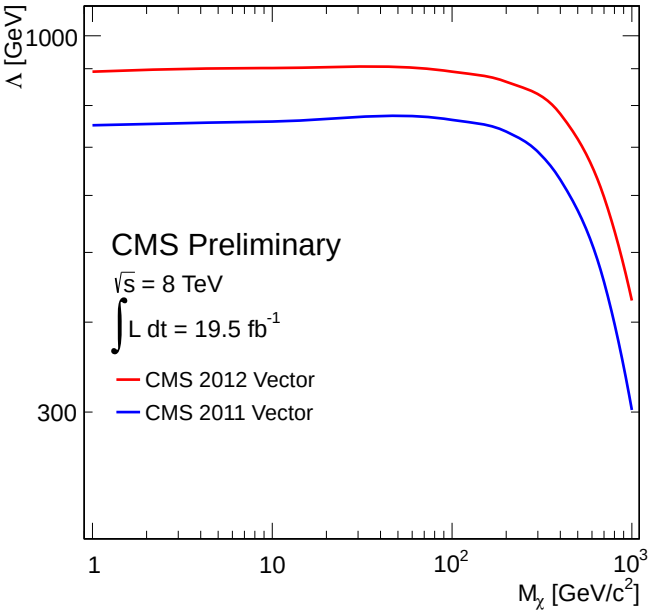
Backgrounds

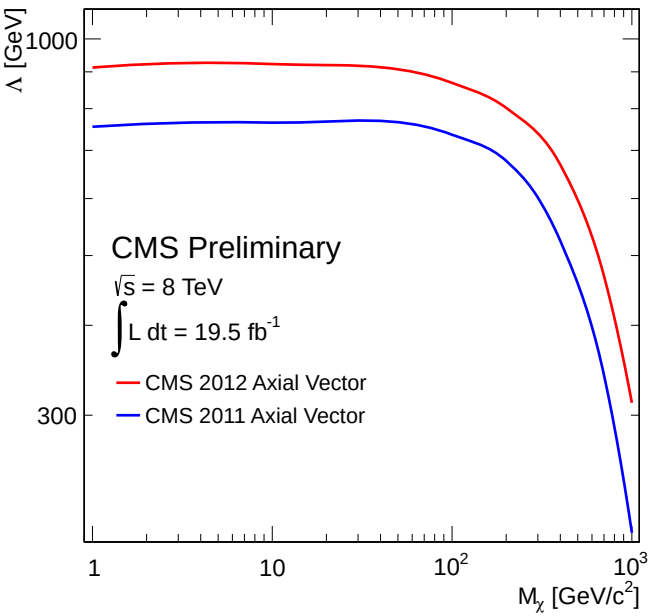
- Data-driven: $Z(\nu\nu) + \text{jets}$ (from $Z \to \mu\mu$).
- Data-driven: $W + \text{jets}$ (from $W \to \mu\nu$).
- $t\bar{t}$, $Z(\ell\ell) + \text{jets}$, single-top, multijets.

Monojet – Limits

Analyze 7 different regions of E_T^{miss} (different lower thresholds).





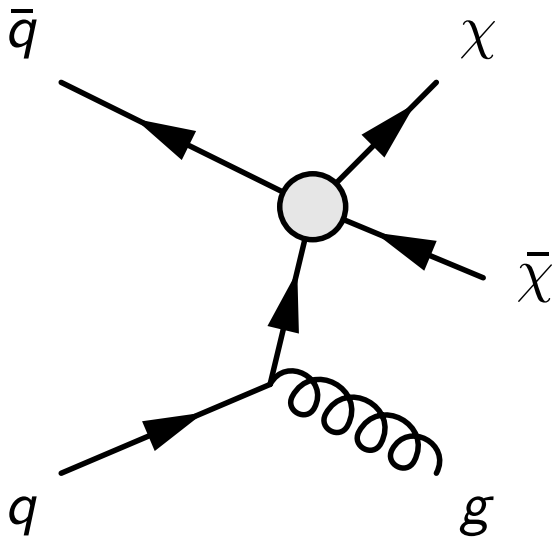


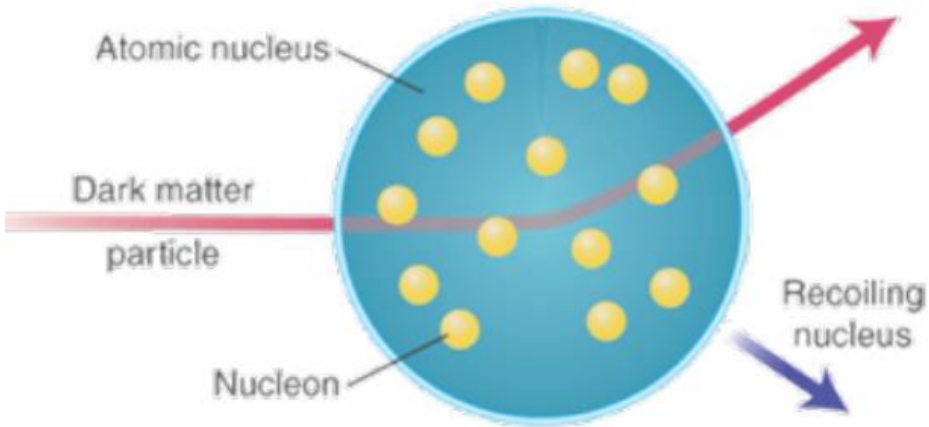
$\sigma \propto \Lambda^{-4}$

Limit: $\Lambda \approx 900\,\text{GeV}$

Limits – conversion to DM nucleon cross section

Non-collider experiments: dark matter nucleon cross section limits.





Spin independent

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

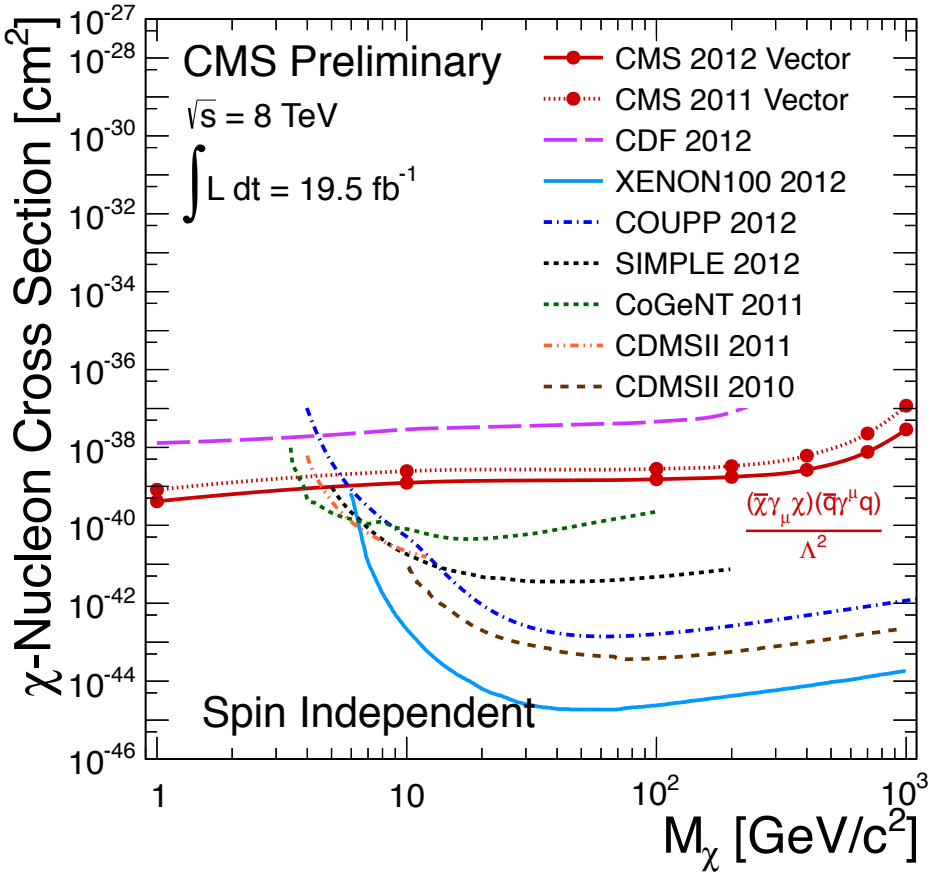
$$f_u^p = f_d^n = 2,\ f_d^p = f_u^n = 1$$

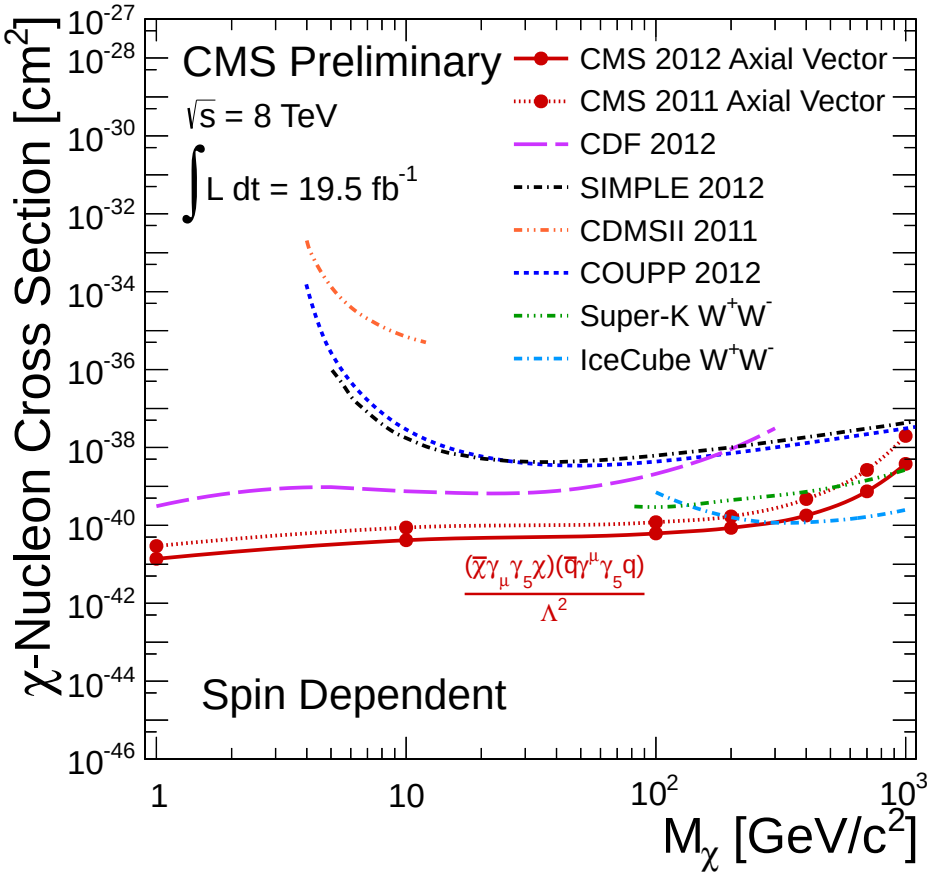
Spin dependent

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

$$\Delta_u^p = \Delta_d^n = 0.842,\ \Delta_d^p = \Delta_u^n = -0.427$$

Monojet – Limits on DM nucleon cross section





- Interpretation in effective field theory.
- Collider experiments particullary sensitive to low M_χ.
- S.D.: $\sigma^N < 10^{-40}\,\mathrm{cm}^2$ better than non-collider experiments.

Monolepton – Selection

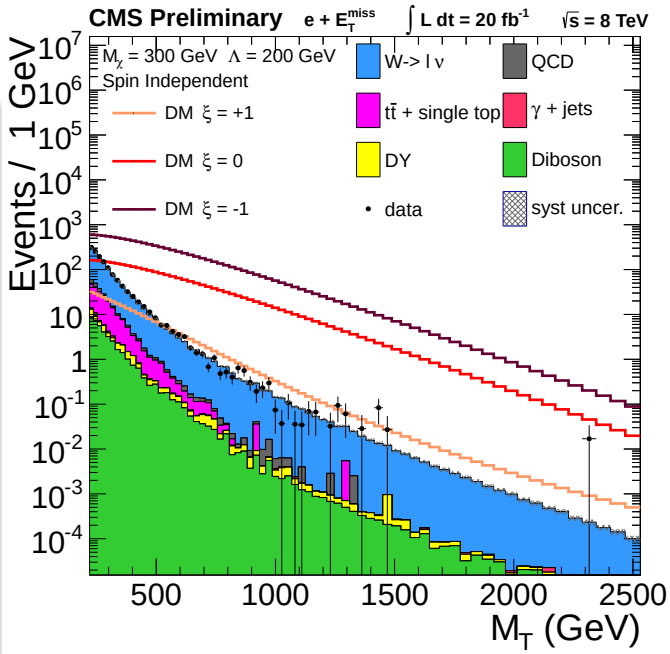
Selection

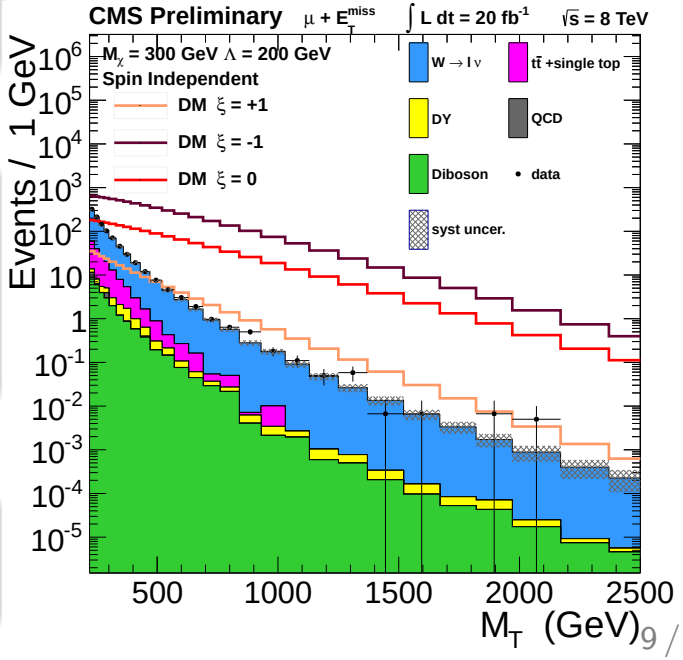
- Single electron or muon trigger.
- One good electron with $E_T > 100\,\text{GeV}$ or muon with $p_T > 45\,\text{GeV}$.
- Looking for a balanced back-to-back event:
  $0.4 < p_T / E_T^{\text{miss}} < 1.5$
  $\Delta\phi(\ell, E_T^{\text{miss}}) > 0.8\pi$

Monte Carlo backgrounds

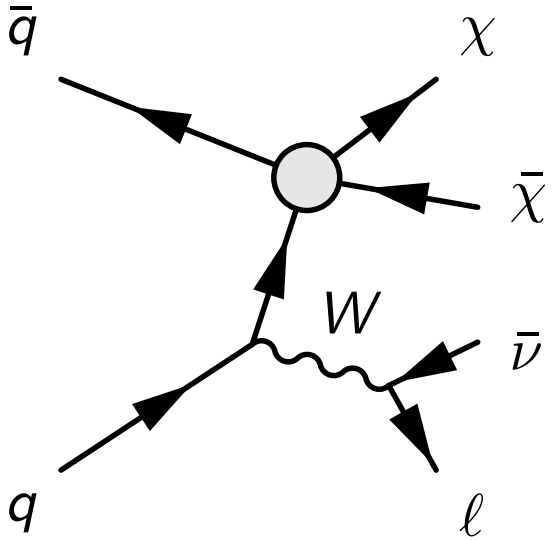
$W \to \ell\nu$, Drell-Yan, Diboson, $t\bar{t}$, single-top, multijet

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

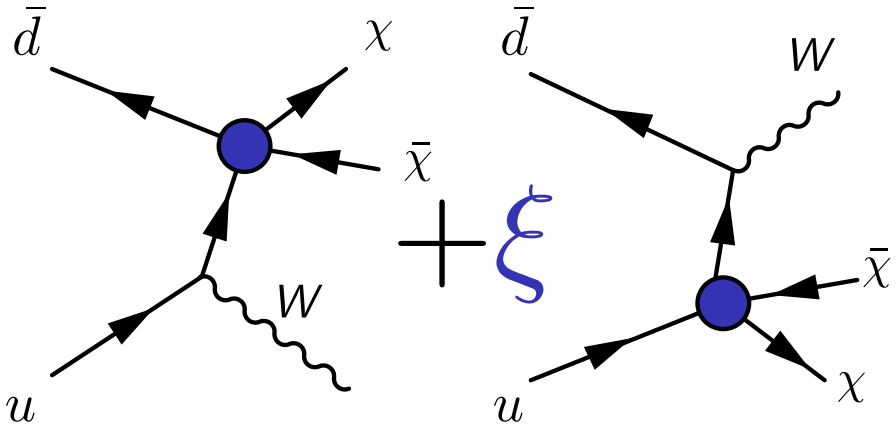




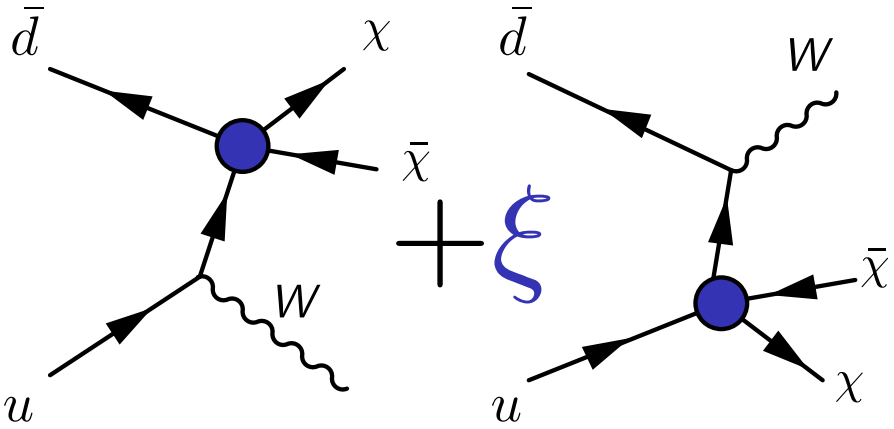
Monolepton – Signal with interference



Monolepton – Signal with interference

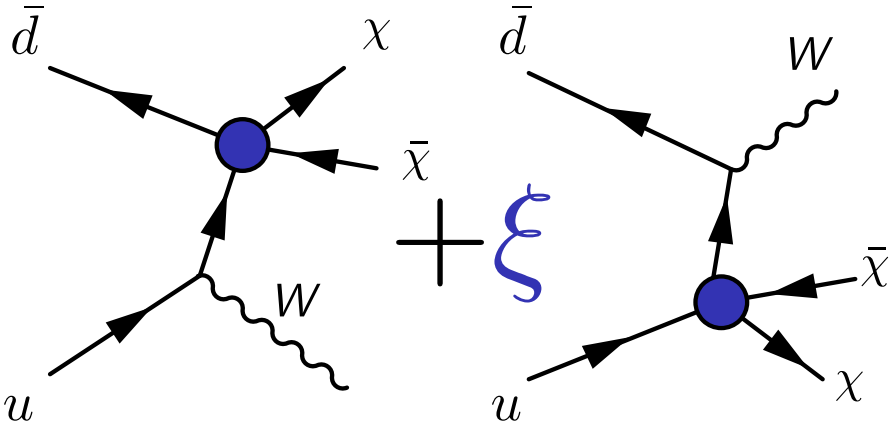


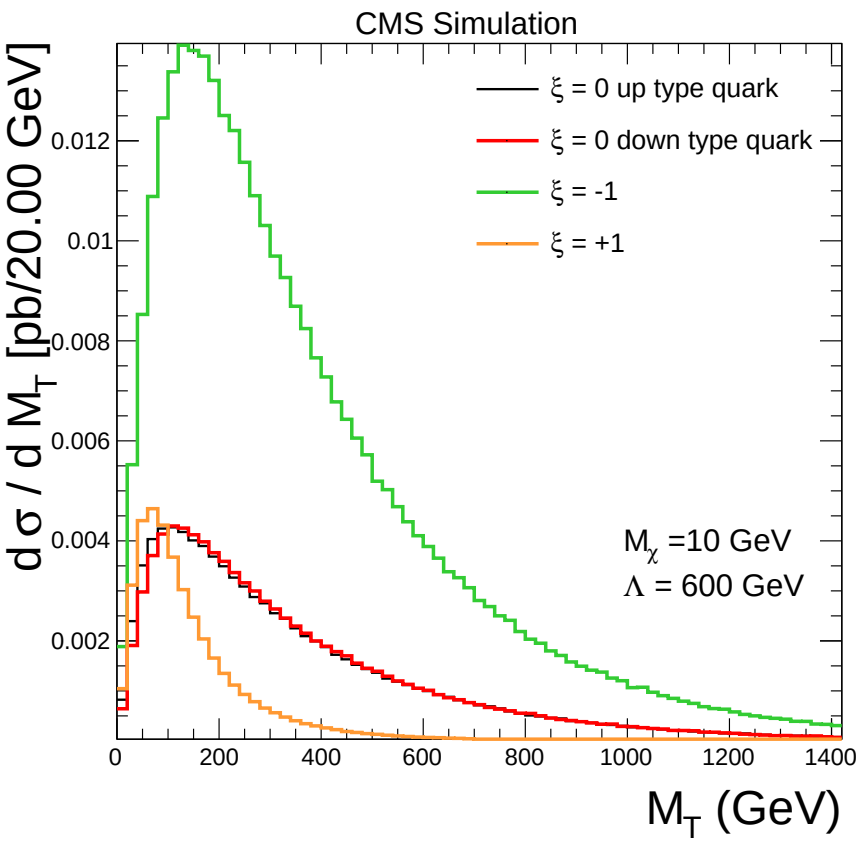
Monolepton – Signal with interference



Interference $\rightarrow$ Sensitivity to quark couplings.
Consider: $\xi = -1,\ 0,\ +1$.

Monolepton – Signal with interference





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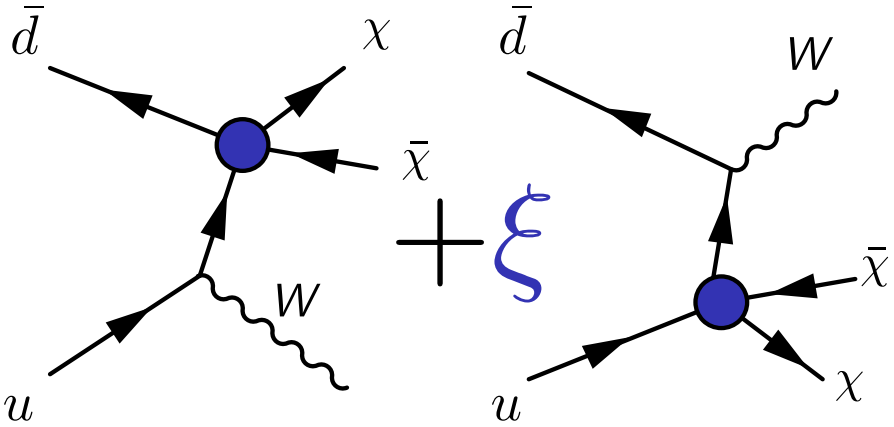
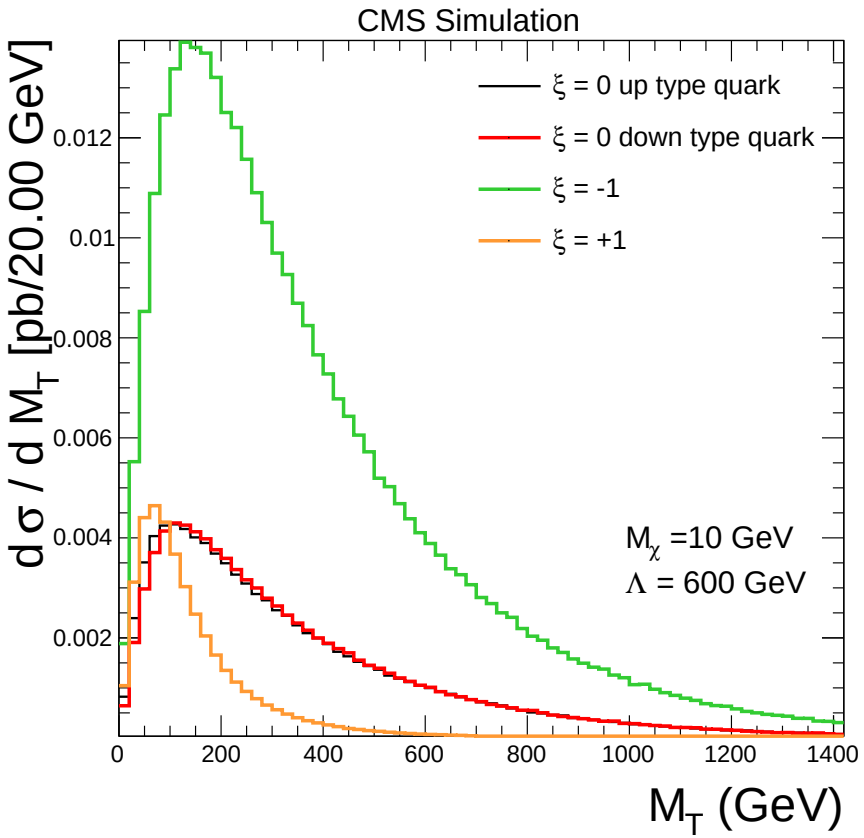
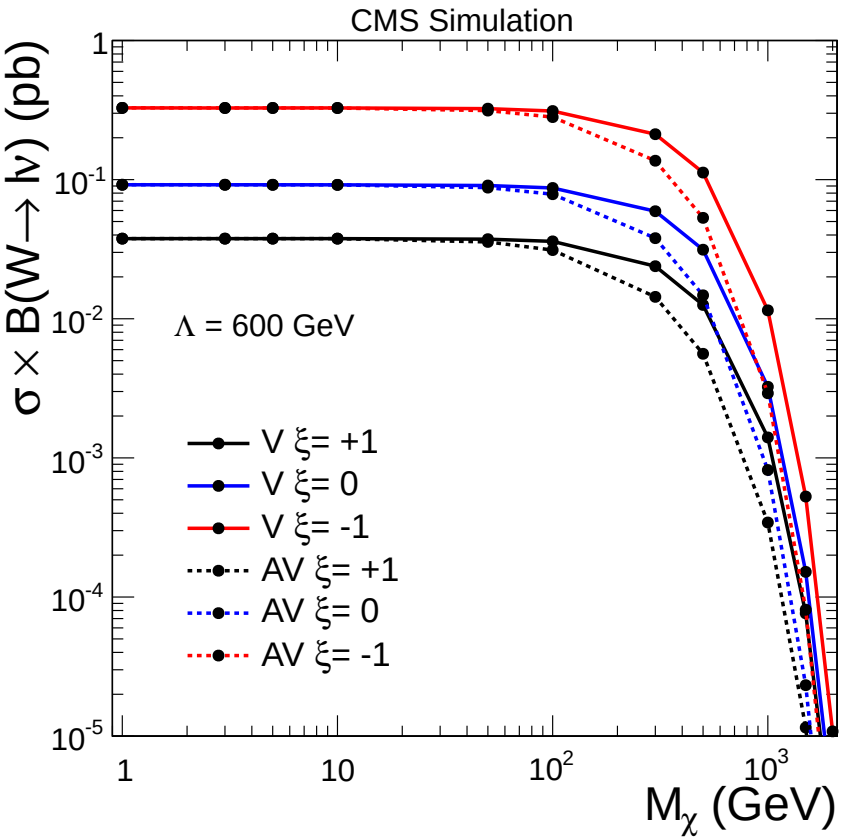
Monolepton – Signal with interference

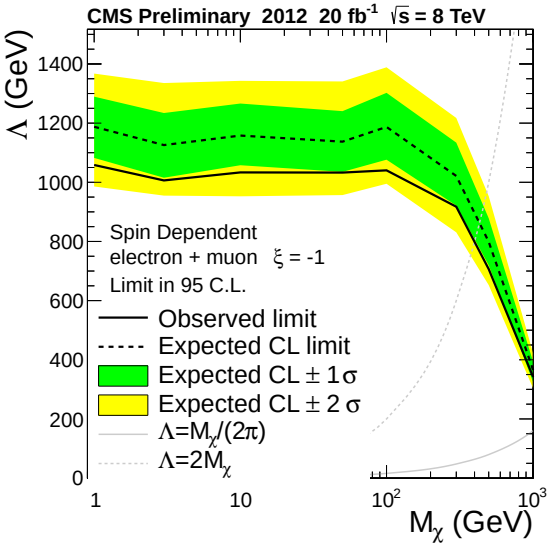
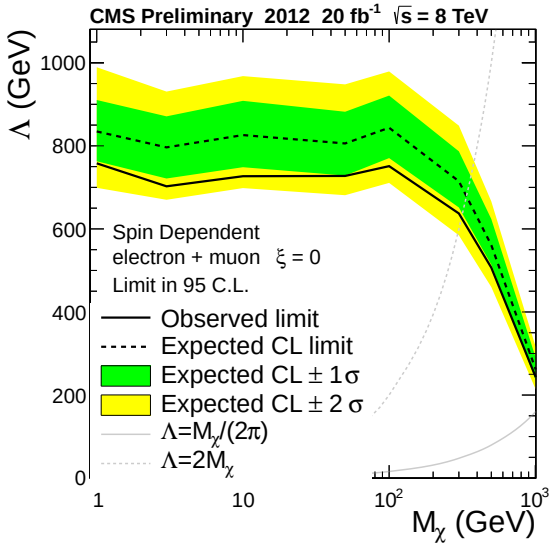
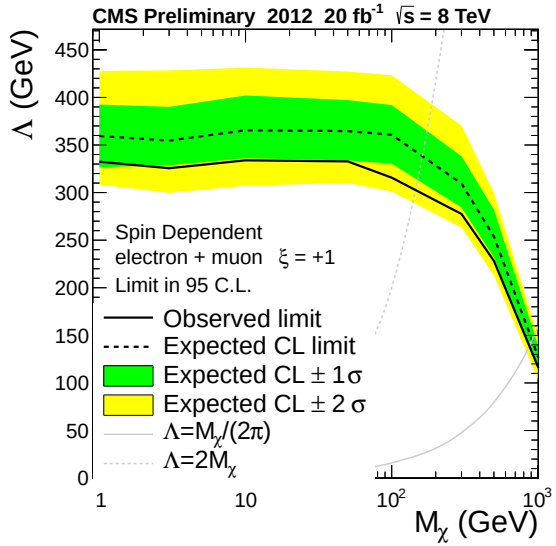
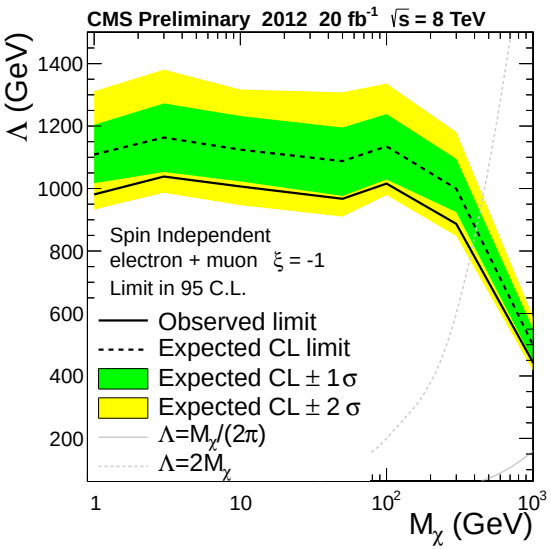
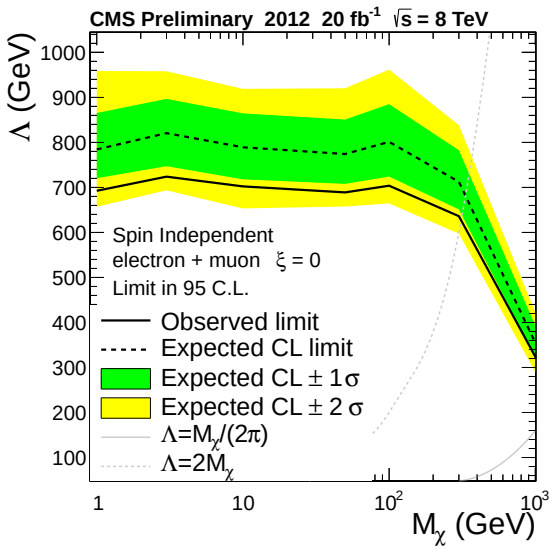
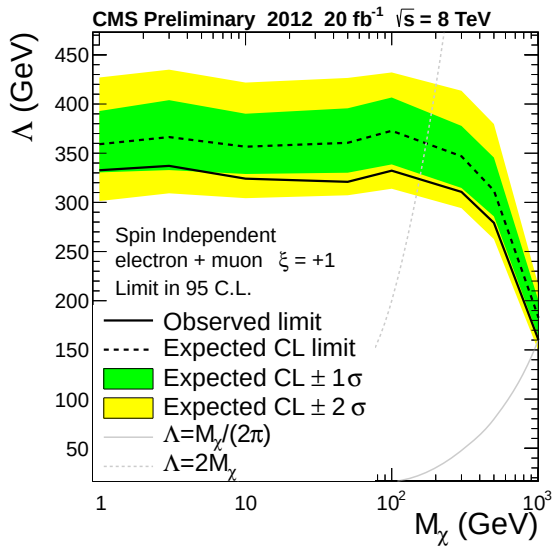


Interference → Sensitivity to quark couplings.
Consider: $\xi = -1, 0, +1$.



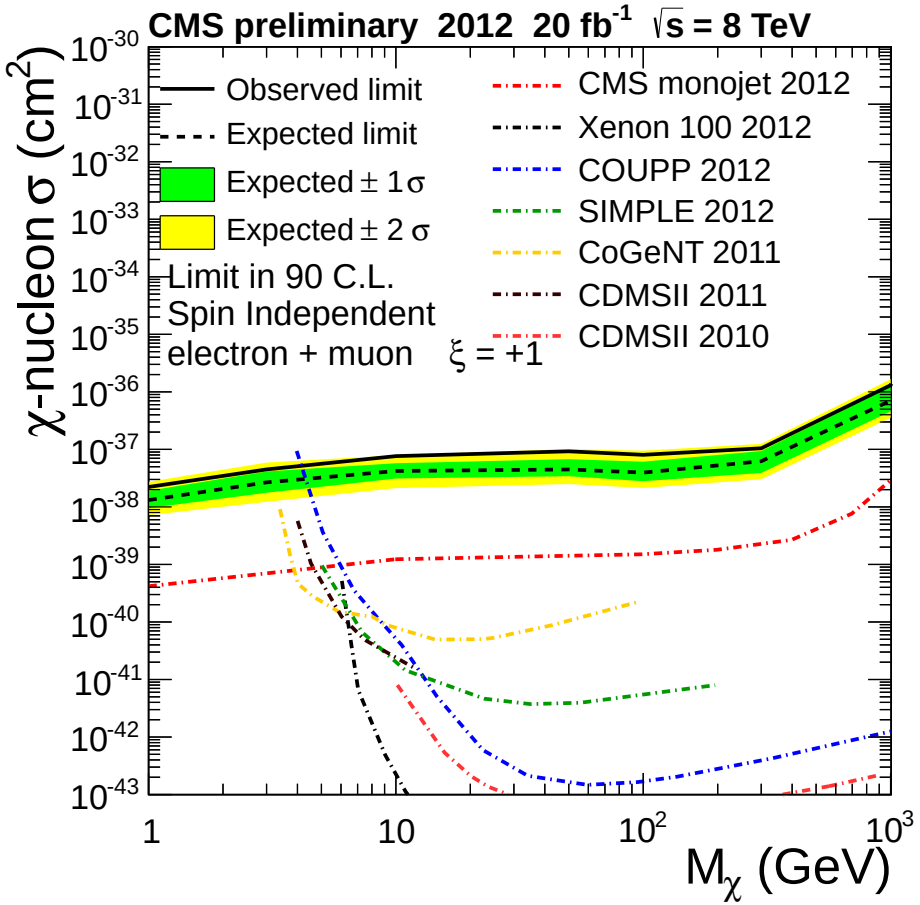


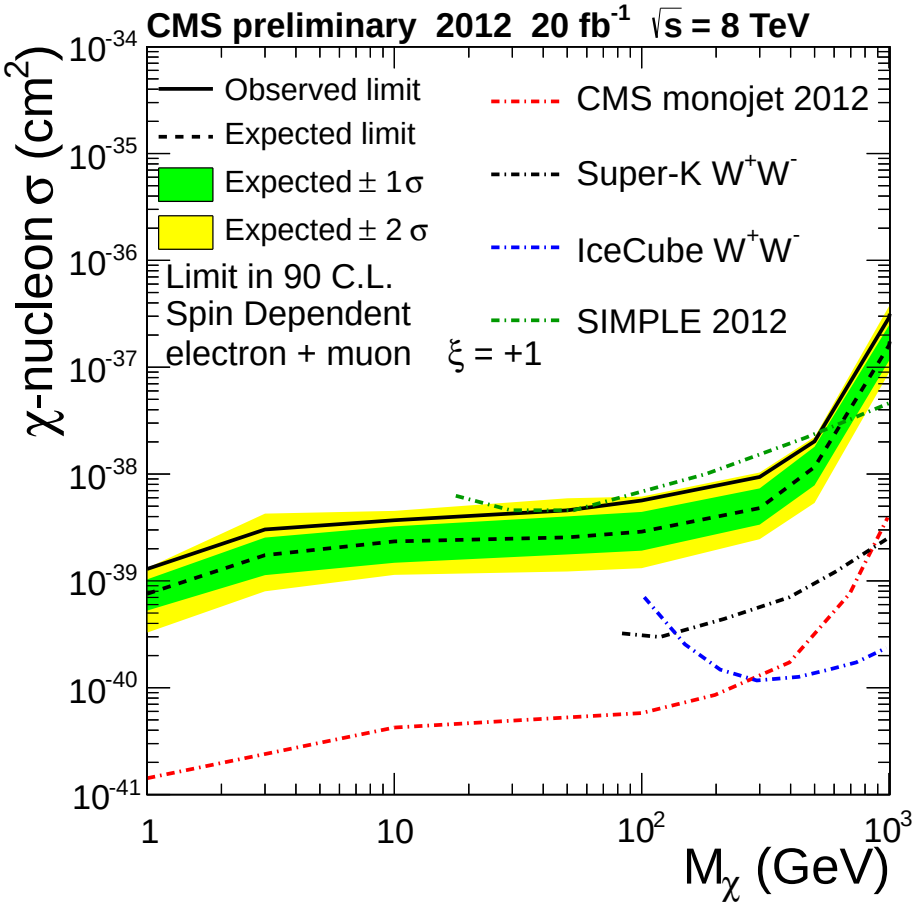
Monolepton – limit

	$\xi = -1$	$\xi = 0$	$\xi = +1$
AV			
V			

Monolepton – Limits on DM nucleon cross section

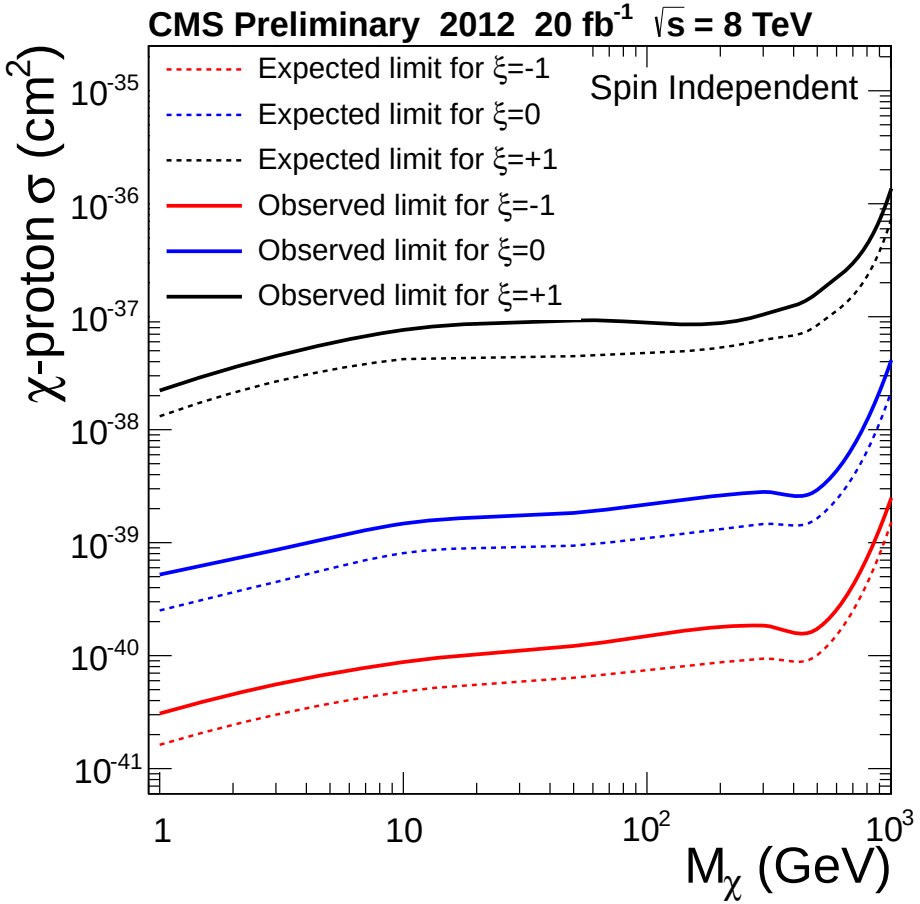
- $\xi = +1$ – destructive interference case.
- Small branching fraction.

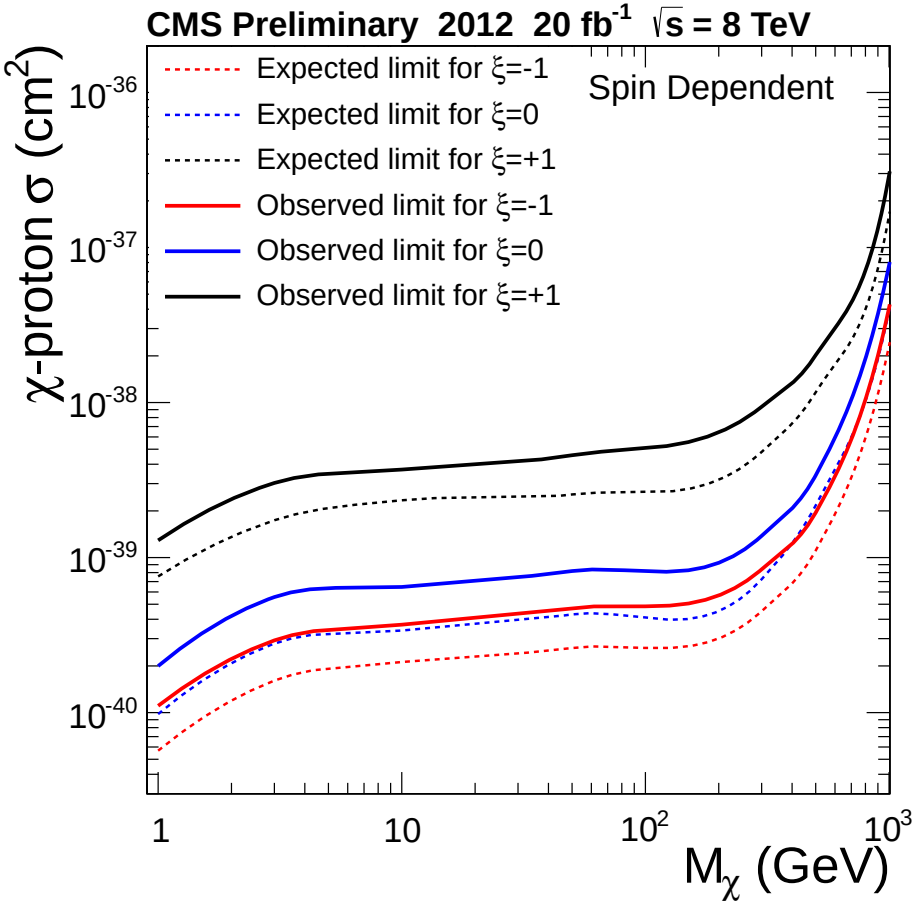




Monolepton – Limits on DM nucleon cross section (ξ)

- Limits for different interference scenarios.
  Sensitivity to quark couplings.





Monophoton – Introduction

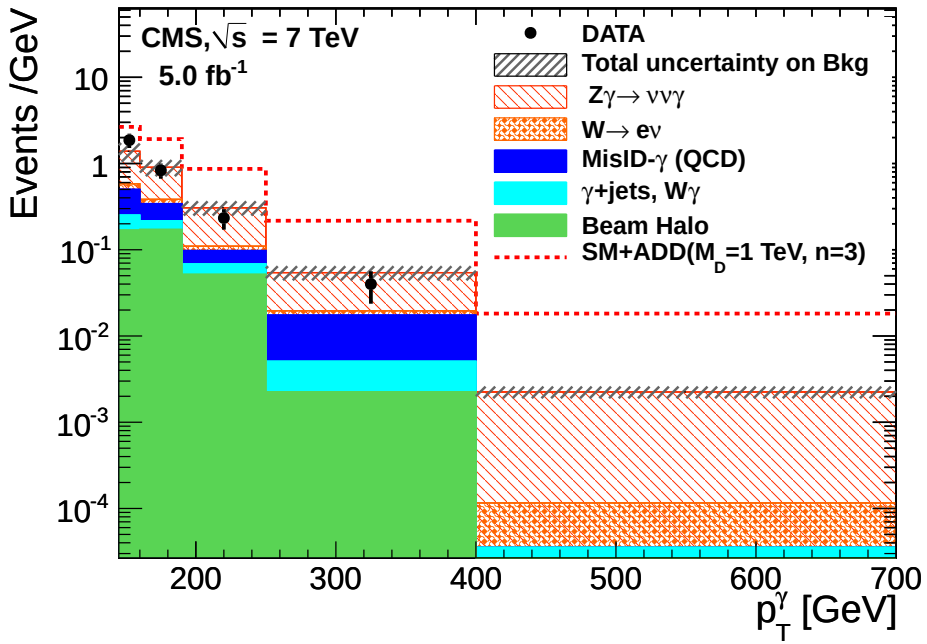
Selection

- Single photon trigger
- $p_T > 145\,\text{GeV}$
- Barrel only
- Calorimetric criteria
- Isolation criteria
- $E_T^{\text{miss}} > 130\,\text{GeV}$
- Reject events with muon, track($> 20\,\text{GeV}$), or jet($> 40\,\text{GeV}$)

Backgrounds

$Z\gamma \to \nu\bar{\nu}\gamma$, $W\gamma$, $W \to e\nu$, $\gamma +$ jet, multijet, diphoton, beam halo, cosmics.

$\sqrt{s} = 7\,\text{TeV}$
(8 TeV analysis ongoing)

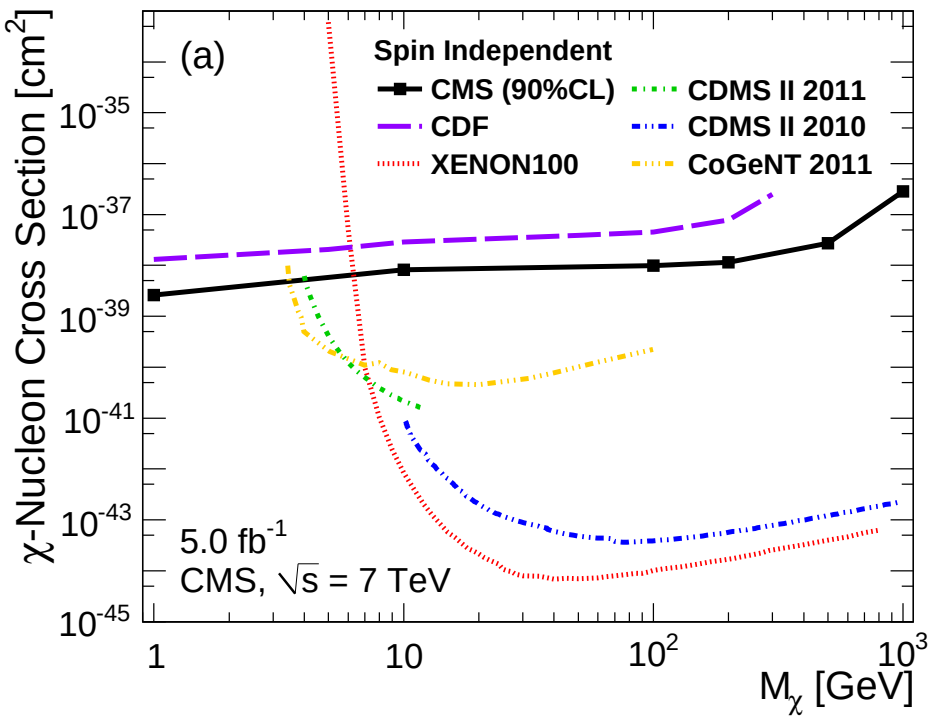


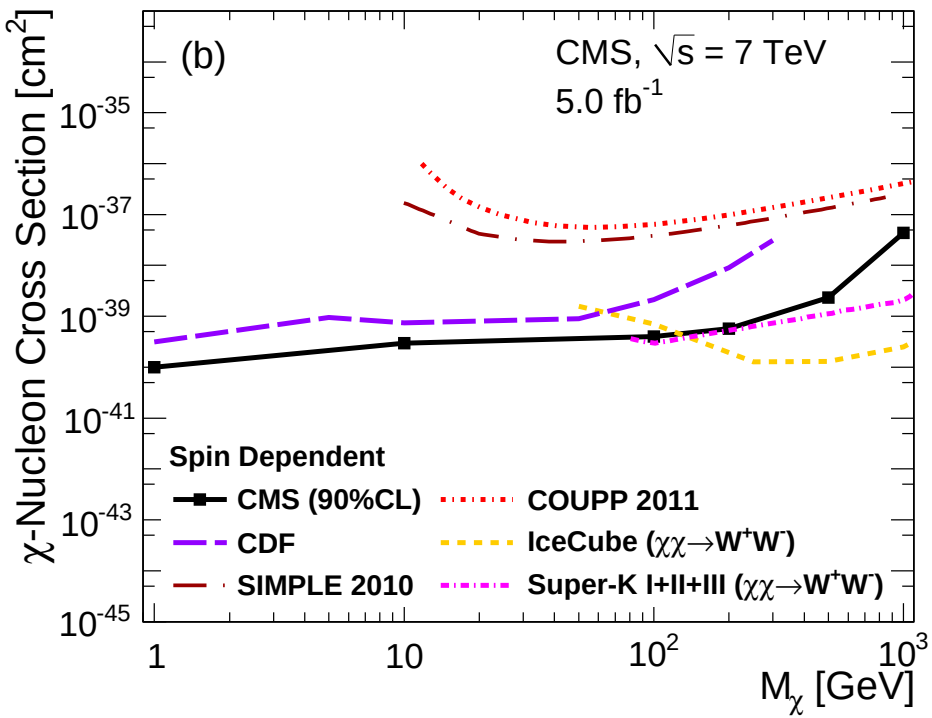
Observed: 73 events.
Expected: 75.1 ± 9.4 events.

Monophoton – Limits

90% CL limits on dark matter.

M_χ [GeV]	Vector		Axial-Vector	
	σ [fb]	Λ [GeV]	σ [fb]	Λ [GeV]
1	14.3 (14.7)	572 (568)	14.9 (15.4)	565 (561)
10	14.3 (14.7)	571 (567)	14.1 (14.5)	573 (569)
100	15.4 (15.3)	558 (558)	13.9 (14.3)	554 (550)
200	14.3 (14.7)	549 (545)	14.0 (14.5)	508 (504)
500	13.6 (14.0)	442 (439)	13.7 (14.1)	358 (356)
1000	14.1 (14.5)	246 (244)	13.9 (14.3)	172 (171)





Summary

- Searches for pair-produced dark matter in CMS with monojet, monolepton and monophoton.

- No strong indication for dark matter at CMS found.

- Limits set for $M_\chi < 10\,\text{GeV}$, not reached by direct detection experiments.

$M_\chi = 1\,\text{GeV}$	vector Λ_{obs} (TeV)	axial-vector Λ_{obs} (TeV)
monolepton $\xi = -1$	0.95	1.02
monojet	0.89	0.91
monophoton (7 TeV)	0.57	0.57
monolepton $\xi = +1$	0.31	0.32
monolepton $\xi = 0$	0.68	0.72