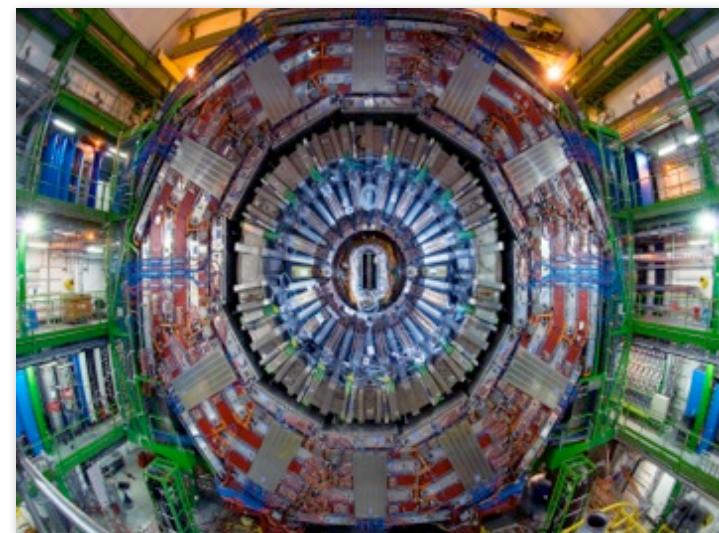
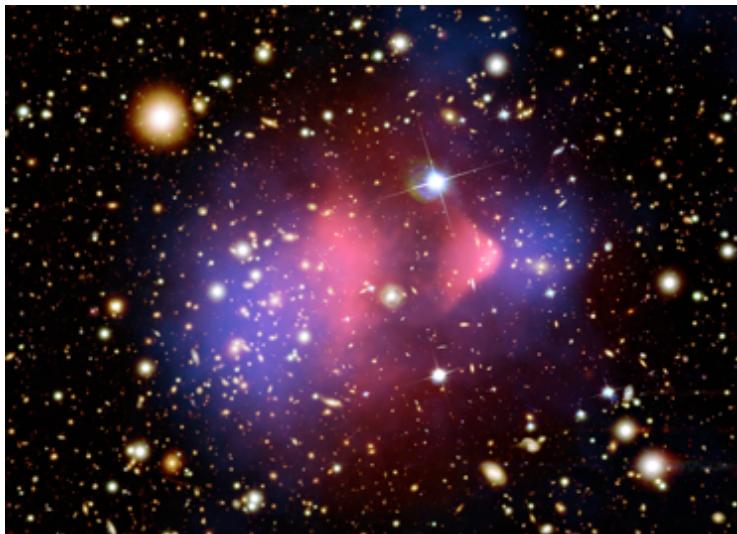


SEARCHES FOR EXTRA DIMENSIONS AND DARK MATTER AT CMS



Steve Worm

*LHCP 2013 - First Large Hadron
Collider Physics Conference*
Barcelona, 16 May 2013



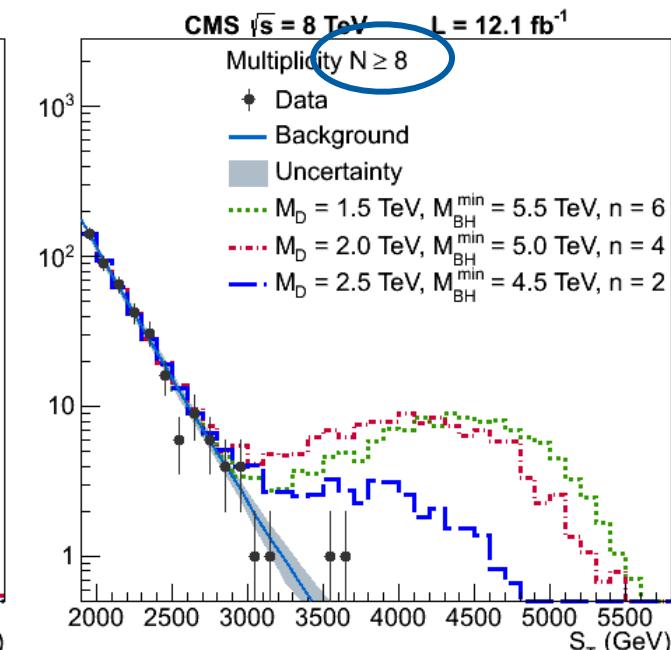
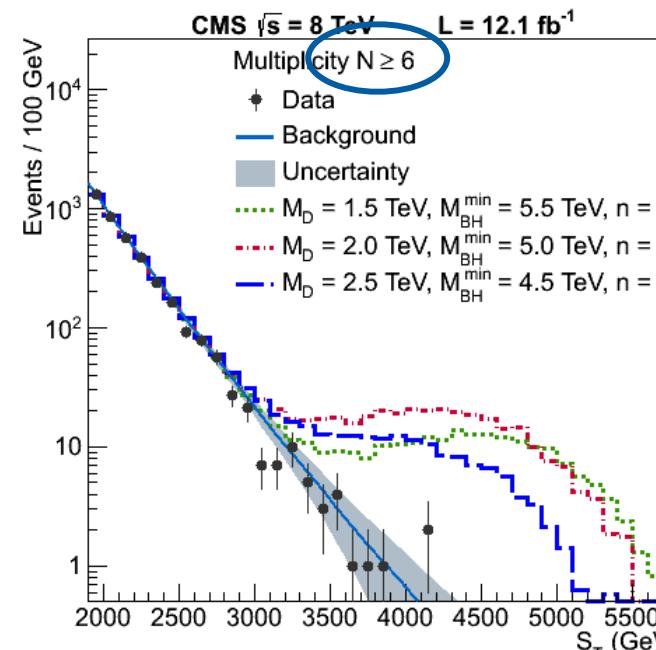
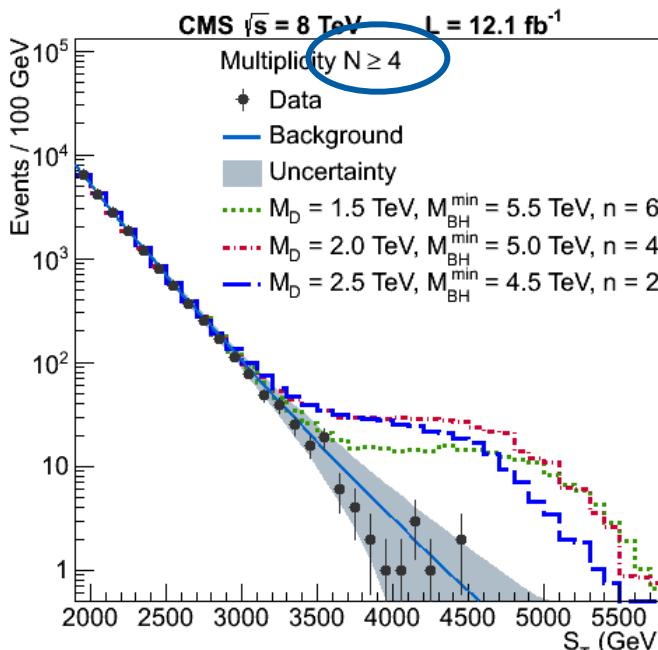
SEARCH FOR BLACK HOLES

[arXiv:1303:5338, EXO-12-009]

- Search for microscopic Black Holes in 12 fb^{-1} of 8 TeV data
 - Hypothetical BH would evaporate into many high- p_T objects
 - Estimate by S_T , the p_T sum of physics objects with $p_T > 50 \text{ GeV}$
- Main background of QCD estimated by fit to $n=2$ distribution
 - Normalised for each multiplicity bin separately at $S_T = 1.8\text{--}2.2 \text{ TeV}$
 - Model-independent limits vs S_T and multiplicity

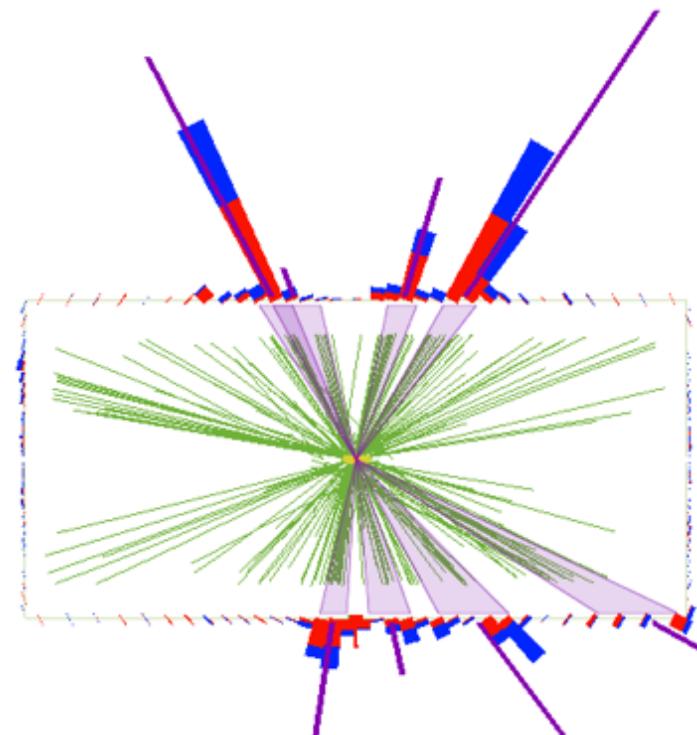
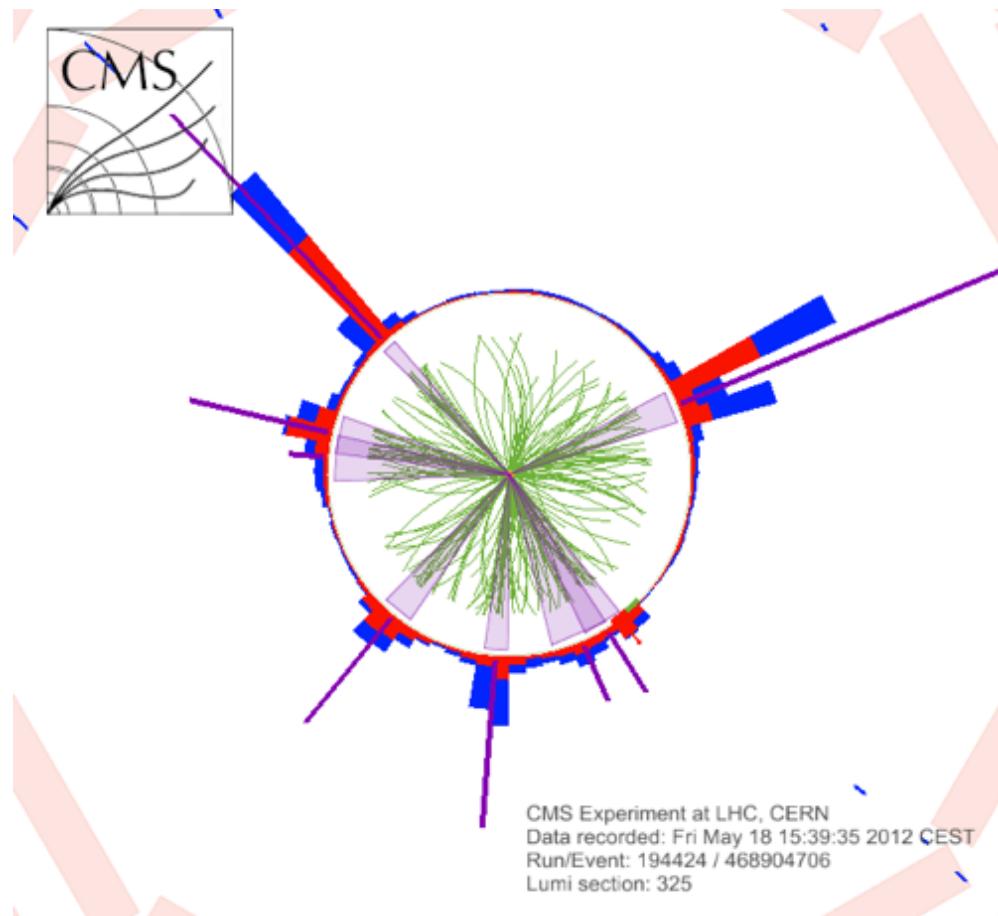
$$S_T = \sum_{j,e,\mu,\gamma,MET}^N p_T$$

Significant improvement in sensitivity ($\sim 15\text{--}20\%$) with respect to 7 TeV data



8-JET EVENT, $S_T = 3$ TeV

[arXiv:1303:5338, EXO-12-009]



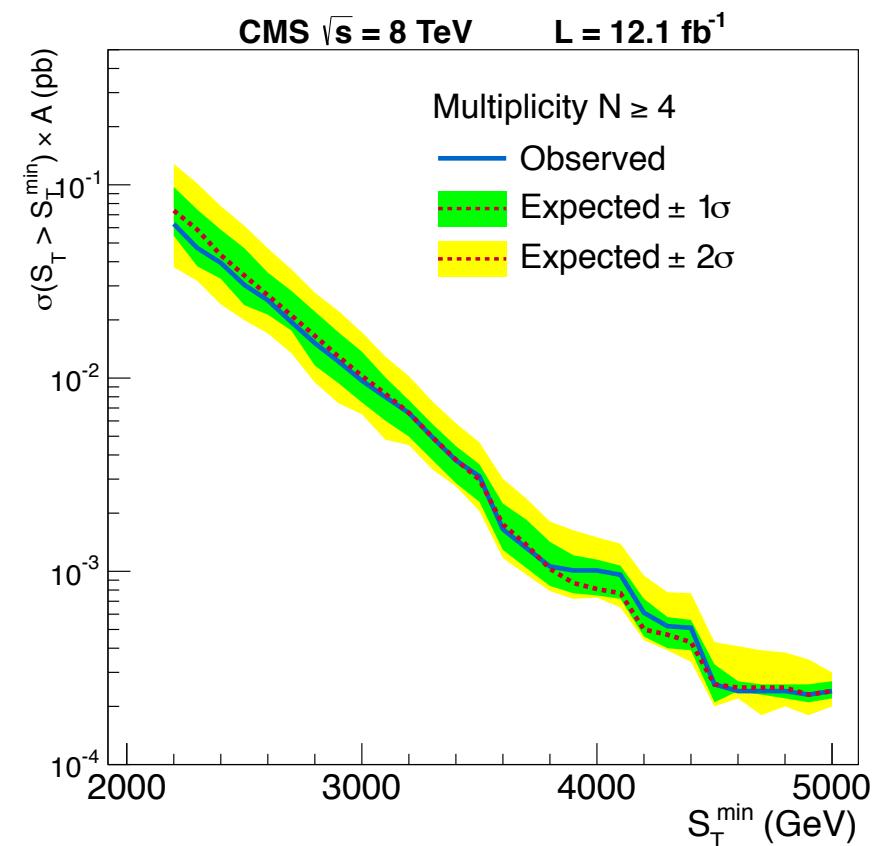
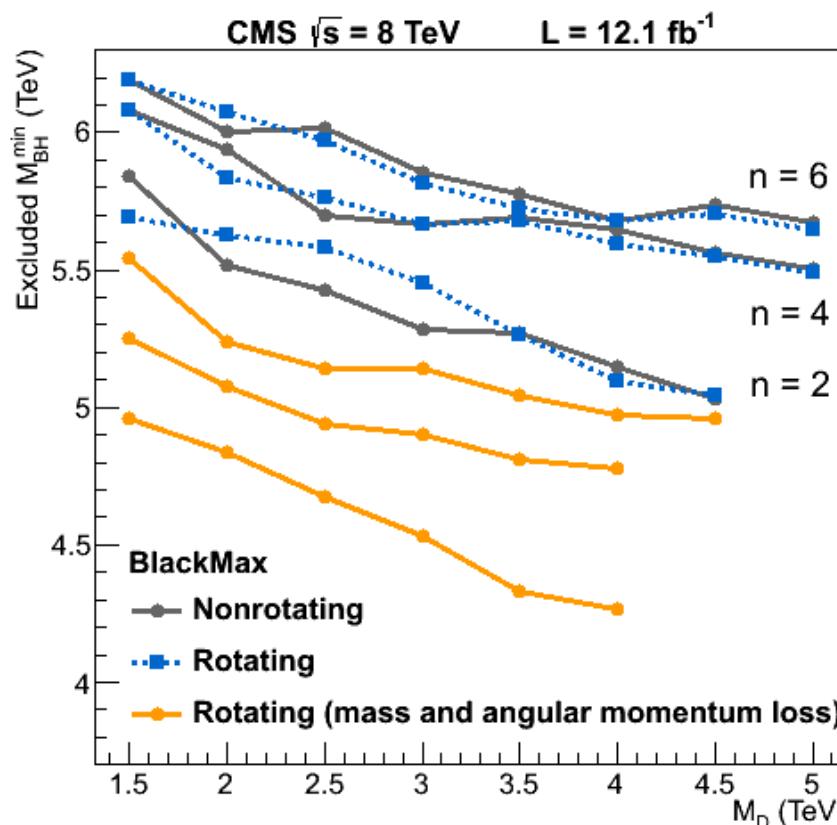
Many interesting events found!

SEARCH FOR BLACK HOLES

[arXiv:1303:5338, EXO-12-009]

- No excess of events above expected backgrounds observed
 - Limits on ADD parameter M_D assuming specific BH models (Charybdis, BlackMax, ...)
 - Model-specific limits on semiclassical BH masses in the 4.3 – 6.2 TeV range

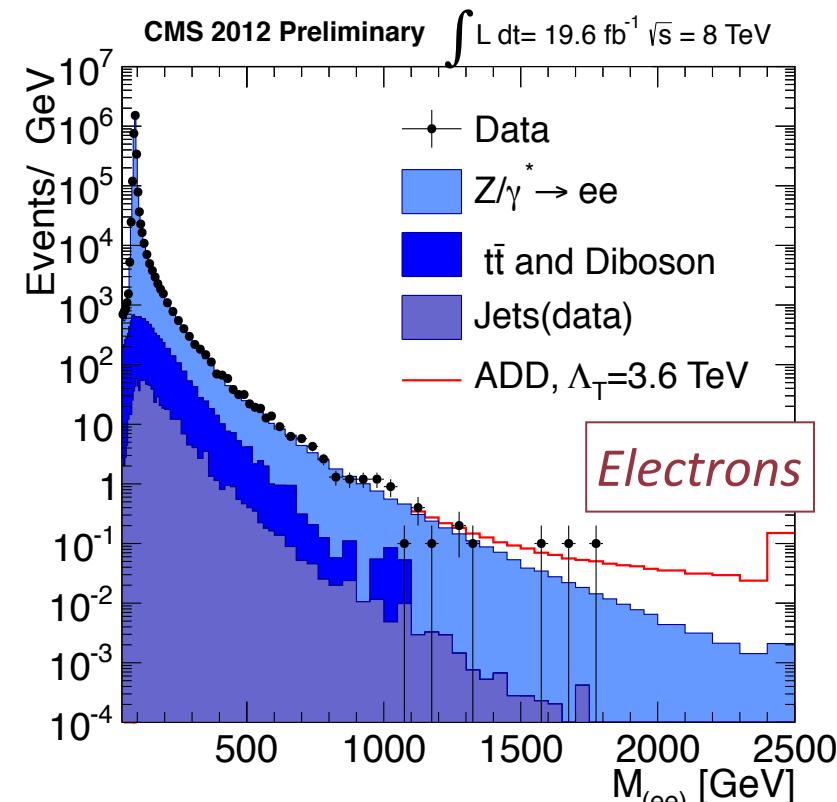
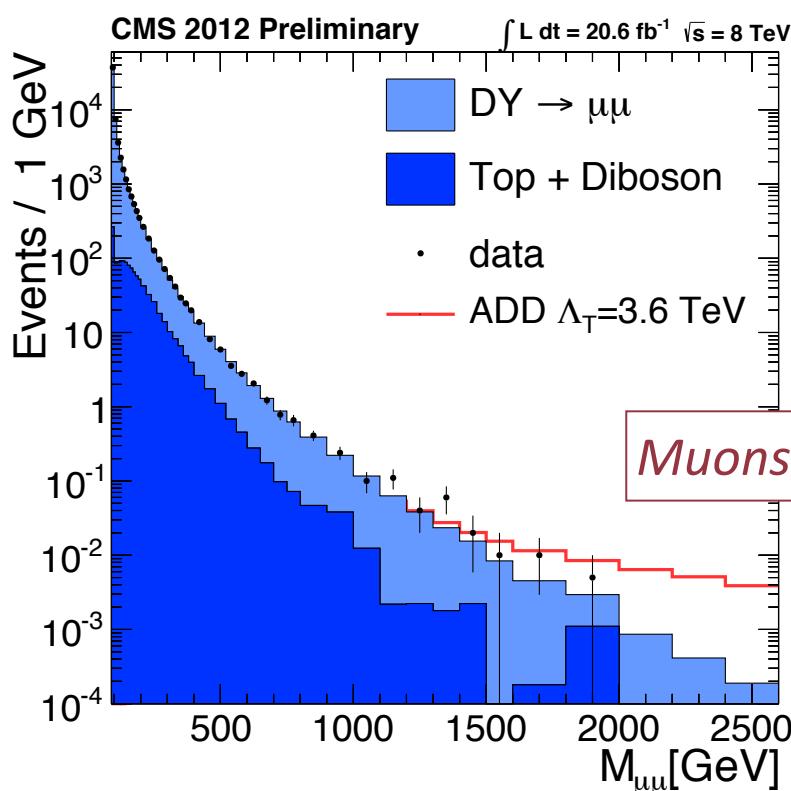
Also interesting as a model-independent search vs S_T and multiplicity



SEARCH FOR EXTRA DIMENSIONS IN DILEPTONS

[EXO-12-027, EXO-12-031]

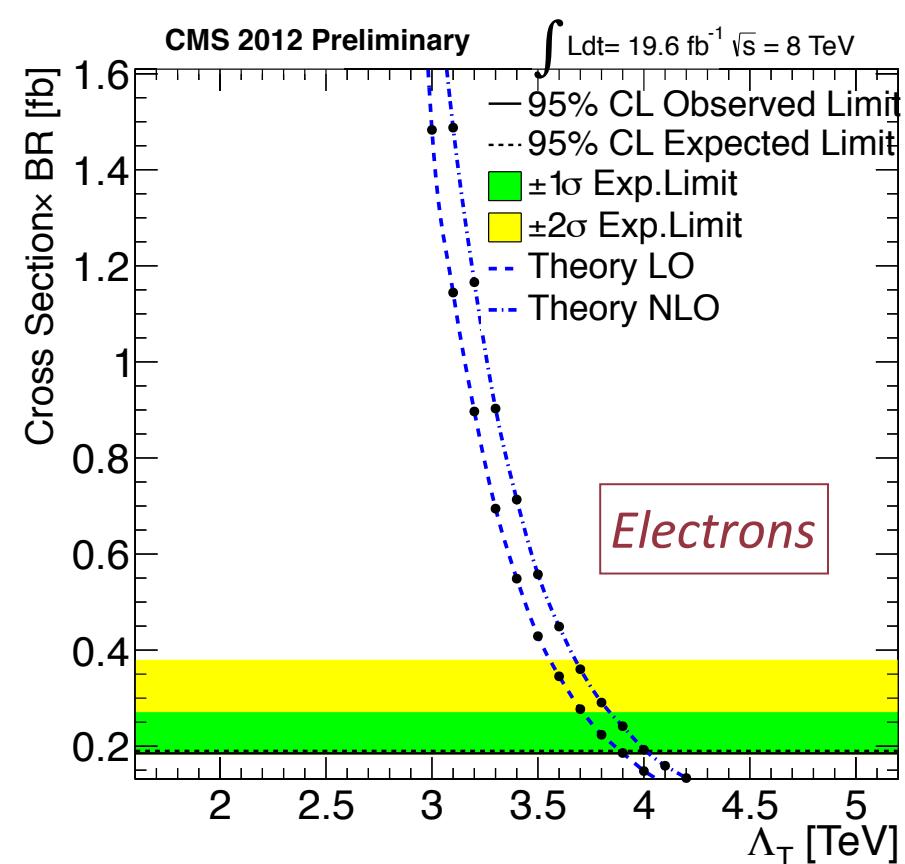
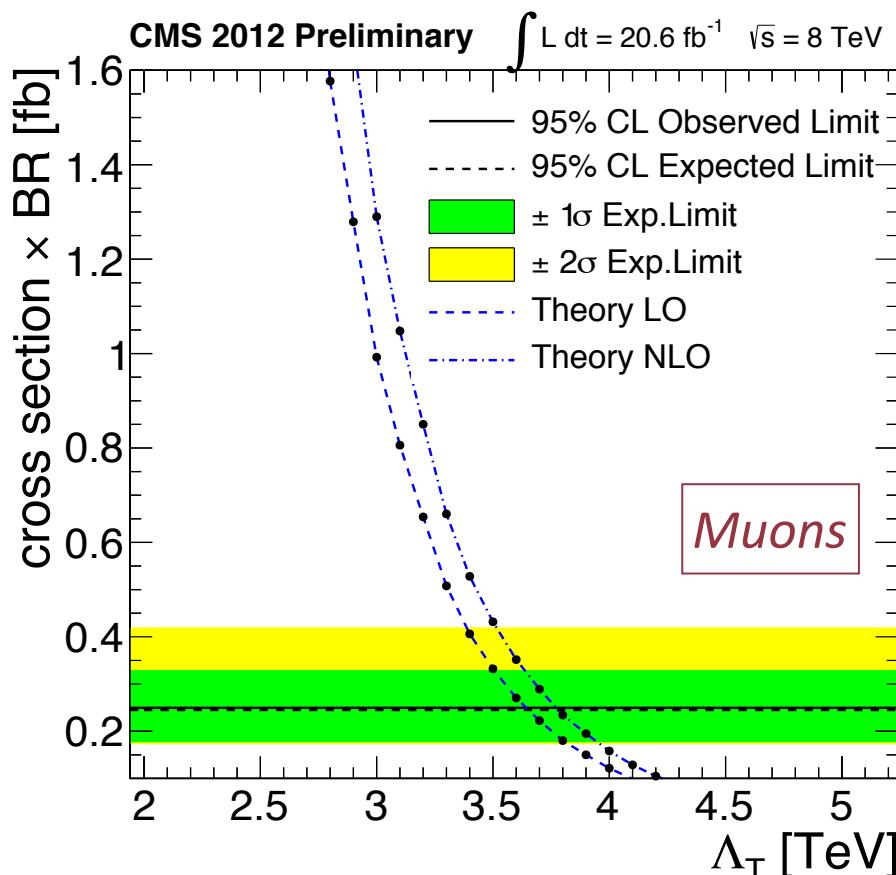
- Extra Dimension search in dilepton invariant mass spectra (same as Z')
- Analysis selection and details
 - Event selection: $E_T(e1, e2) > 35 \text{ GeV}$, $p_T(\mu 1, \mu 2) > 45 \text{ GeV}$, plus isolation criteria
 - Backgrounds: Z/γ^* , $t\bar{t}$, tW , VV , $Z \rightarrow \tau\tau$, multijets with ≥ 1 jet reconstructed as lepton
 - Use functional fit to data for background parameterisation



EXTRA DIMENSIONS IN DILEPTONS

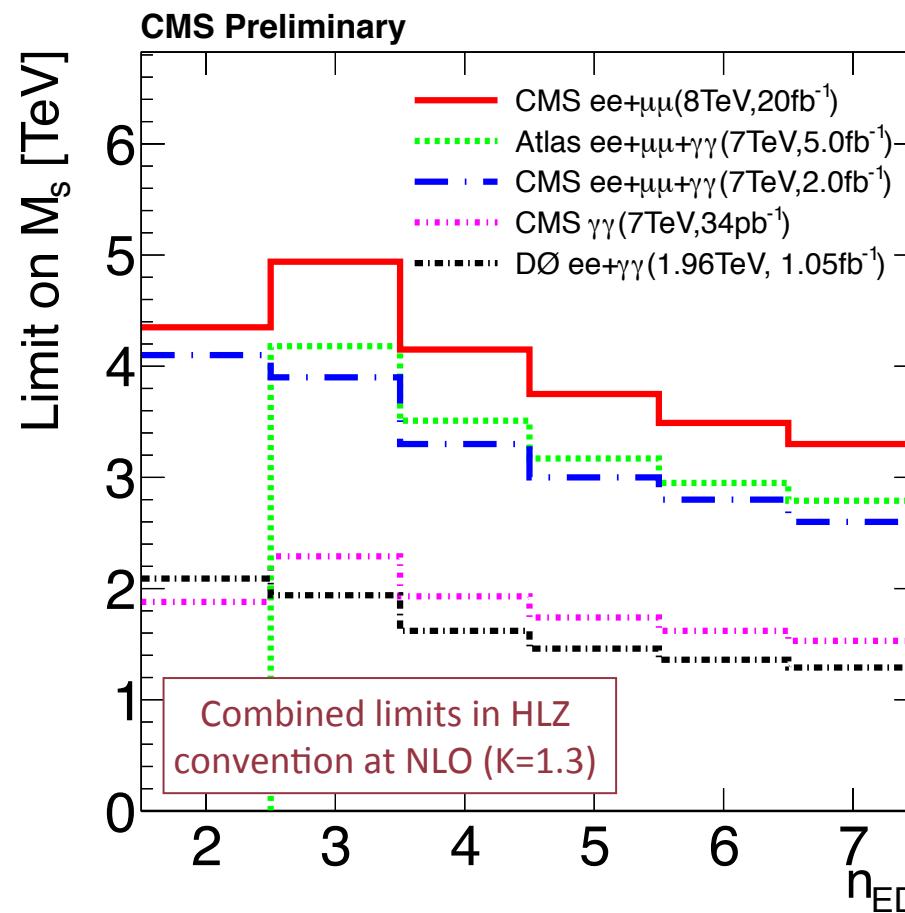
[EXO-12-027, EXO-12-031]

- Simple counting experiment on integral above a mass threshold (Bayesian)
- Leading systematics from momentum scale (muons) and PDF (electrons)



EXTRA DIMENSIONS IN DILEPTONS

[EXO-12-027, EXO-12-031]

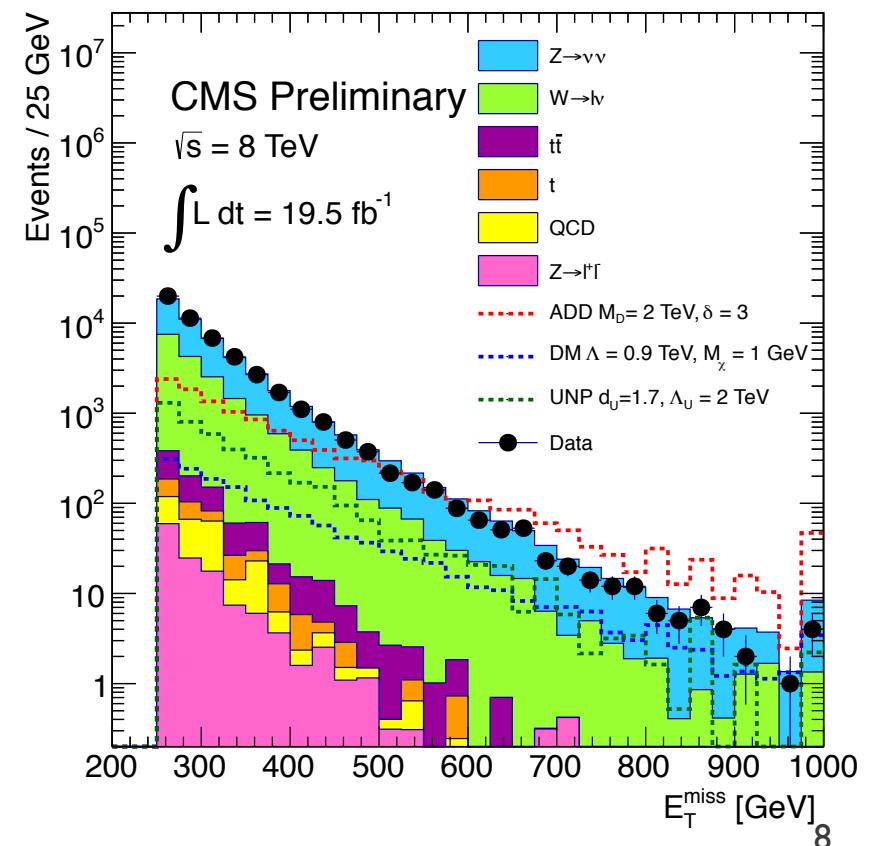
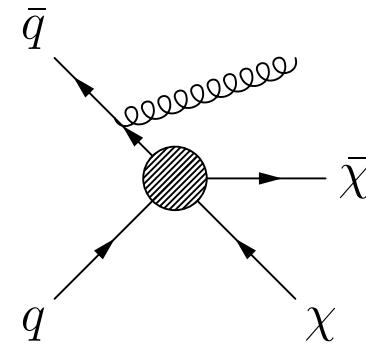


M_s (ADD) at LO	Lumi.	$\delta=3$	$\delta=3$	$\delta=6$	$\delta=6$	Λ_T (GRW)
95% CL limits	[fb^{-1}]	Exp.	Obs.	Exp.	Obs.	[TeV]
CMS dimuon	20.6	4.34	4.33	3.07	3.06	3.64
CMS dielectron	19.6	4.62	4.64	3.27	3.28	3.90
Combined:	20.6+19.6	4.76	4.77	3.37	3.37	4.01

ADD AND DARK MATTER FROM MONOJETS

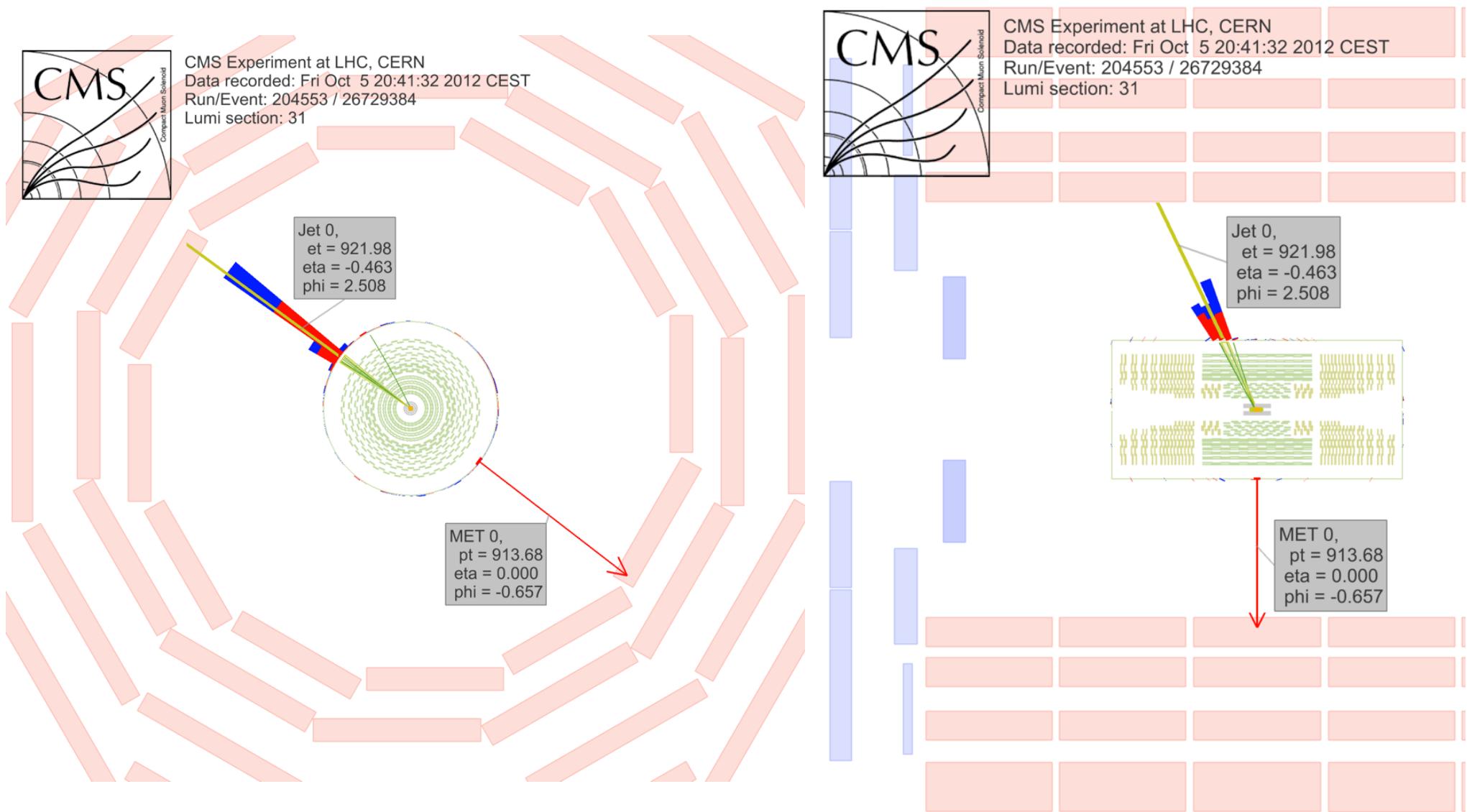
[EXO-12-048]

- Pair-produced Dark Matter or Extra Dimensions
 - Search for missing energy and radiated jet
 - Similar searches in monophoton and other channels
- Monojet Selection:
 - Leading jet $p_T > 110 \text{ GeV}$, $|\eta| < 2.4$
 - allow a second jet if not back-to-back; $\Delta\phi(j_1, j_2) < 2.5$
 - veto isolated leptons
- Backgrounds from Data-Driven and MC
 - Measure $Z(\mu\mu) + \text{jets} \rightarrow Z(vv) + \text{jets}$
 - Measure $W(\mu\mu) + \text{jets} \rightarrow W(lv) + \text{jets}$
 - smaller backgrounds from top, QCD, non-collision
- Missing Energy (E_T^{miss}) to distinguish signal
 - best expected limit at MET $> 400 \text{ GeV}$



A MONOJET EVENT

[EXO-12-048]



LARGE EXTRA DIMENSIONS FROM MONOJETS

[EXO-12-048]

Large Extra Dimensions: Arkani-Hamed, Dimopoulos, Dvali (ADD)

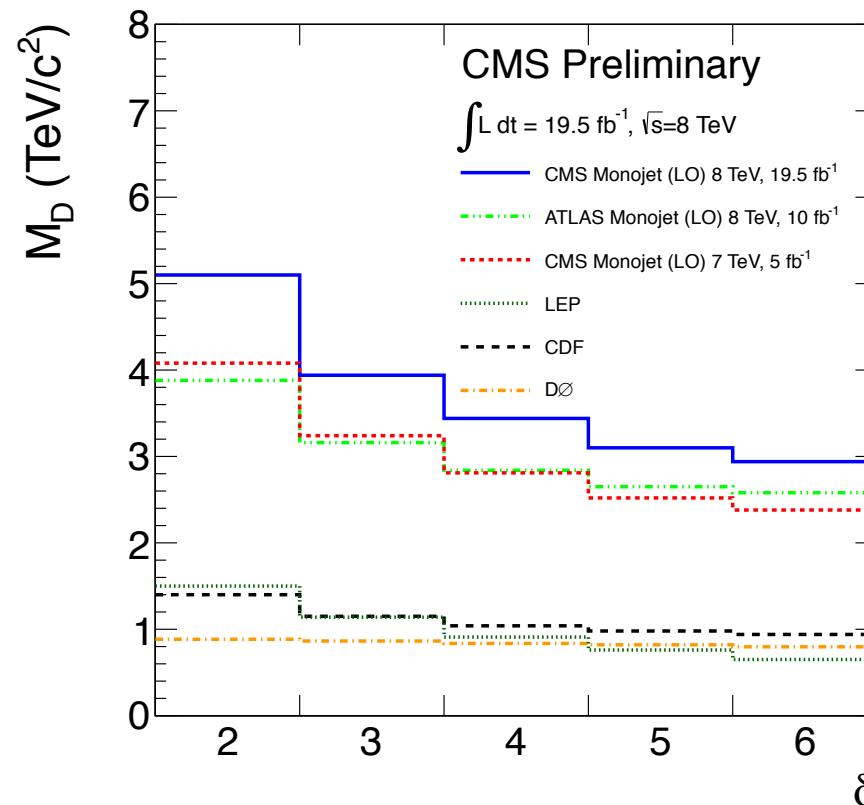
$$M_{Pl}^2 \sim M_D^{2+n} R^n$$

M_{Pl} = 4-dimensional Planck scale

M_D = fundamental $(4+n)$ -dimensional Planck scale

n = number of the extra dimensions

R = size of the extra dimensions

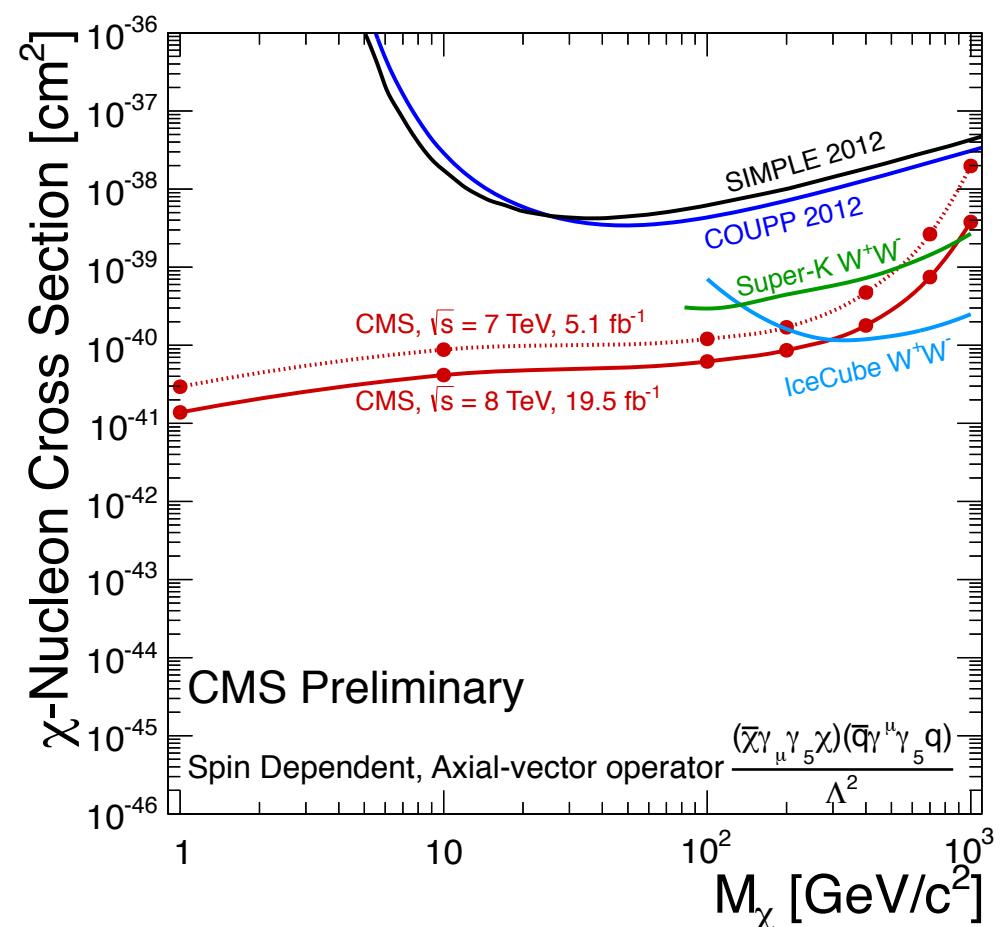
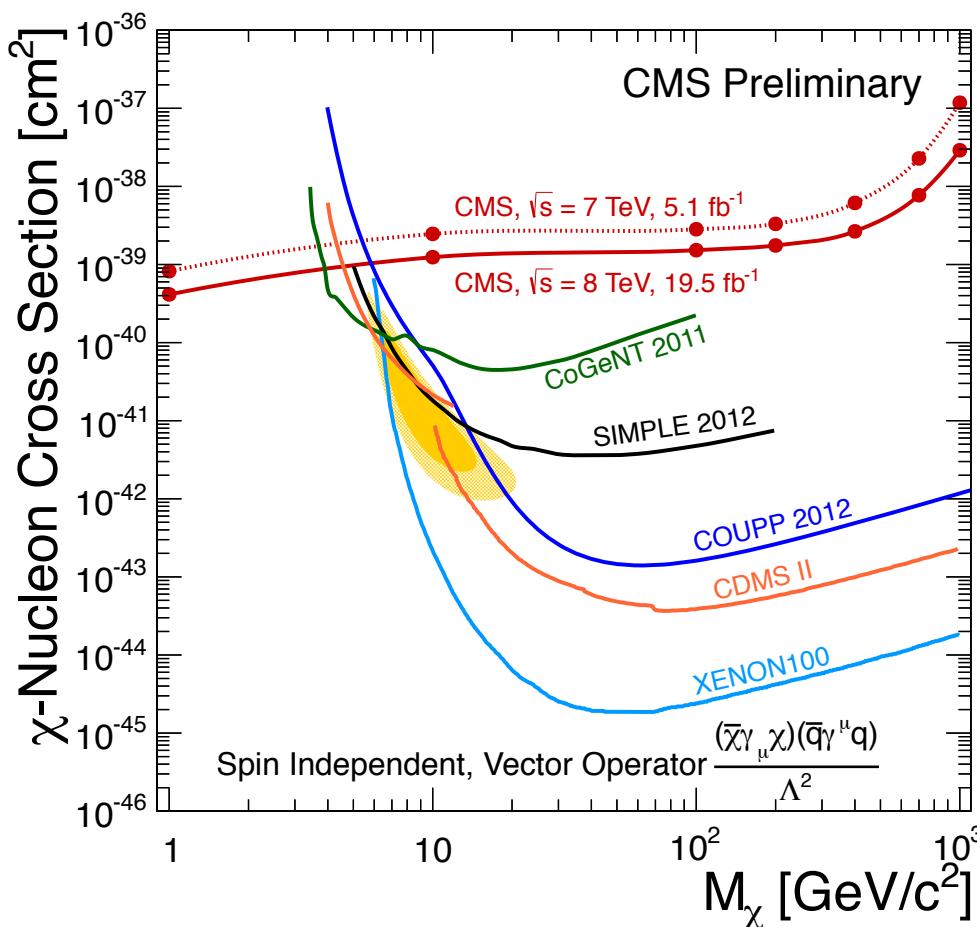


M_D (ADD) at LO	\sqrt{s}	Lumi	$\delta=3$	$\delta=3$	$\delta=6$	$\delta=6$
95% CL limits	[TeV]	[fb^{-1}]	Exp.	Obs.	Exp.	Obs.
CMS Monophoton	7	5.0	1.5	1.6	1.6	1.6
CMS Monojet	8	19.5	3.94	3.96	2.95	2.94

DARK MATTER AND MONOJETS

[EXO-12-048]

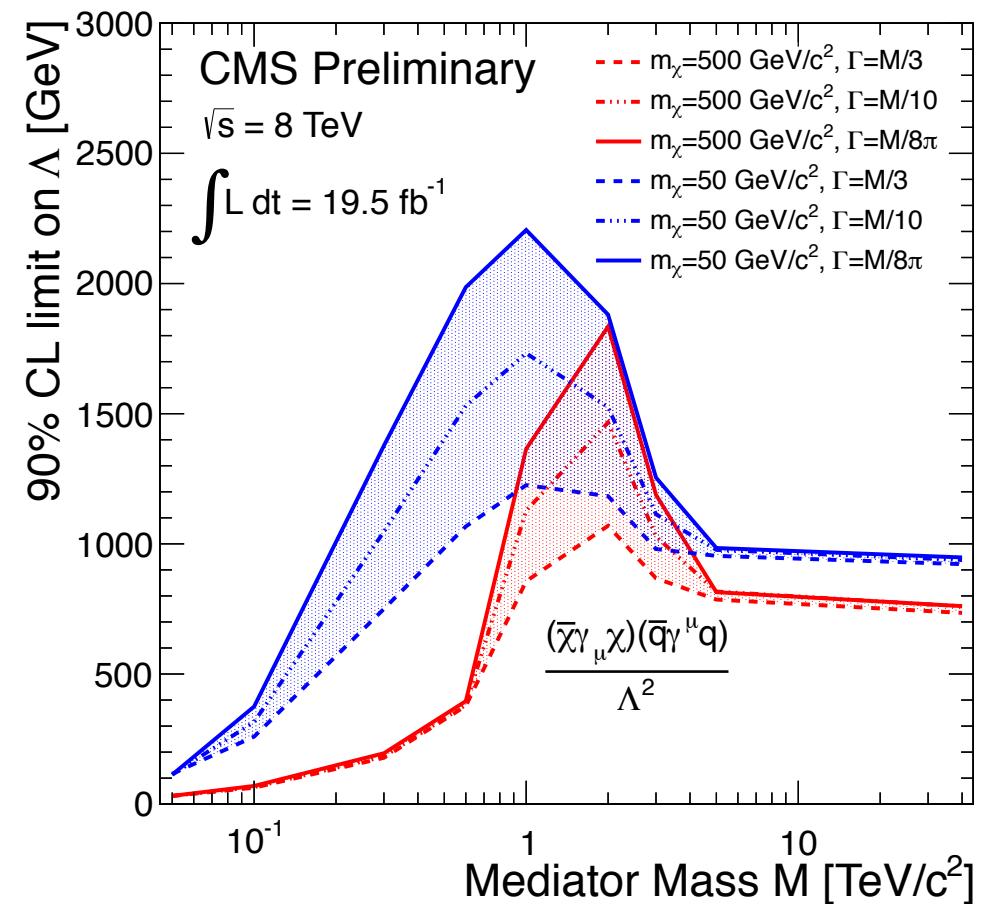
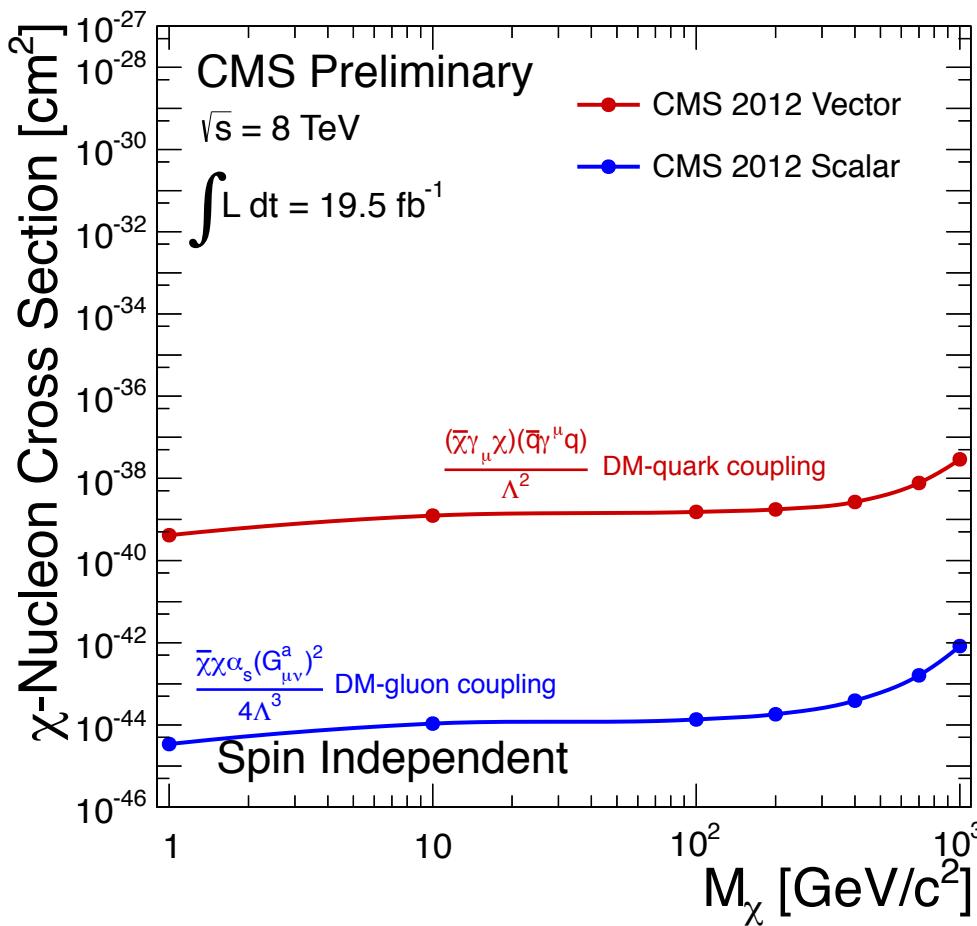
- Pair-production of DM (χ) characterised by a contact interaction effective theory
- Derived limits then compared to direct-detection experiments



DARK MATTER AND MONOJETS

[EXO-12-048]

- Starting to extend simple contact interaction scenario with new operators and a scan over mediator mass



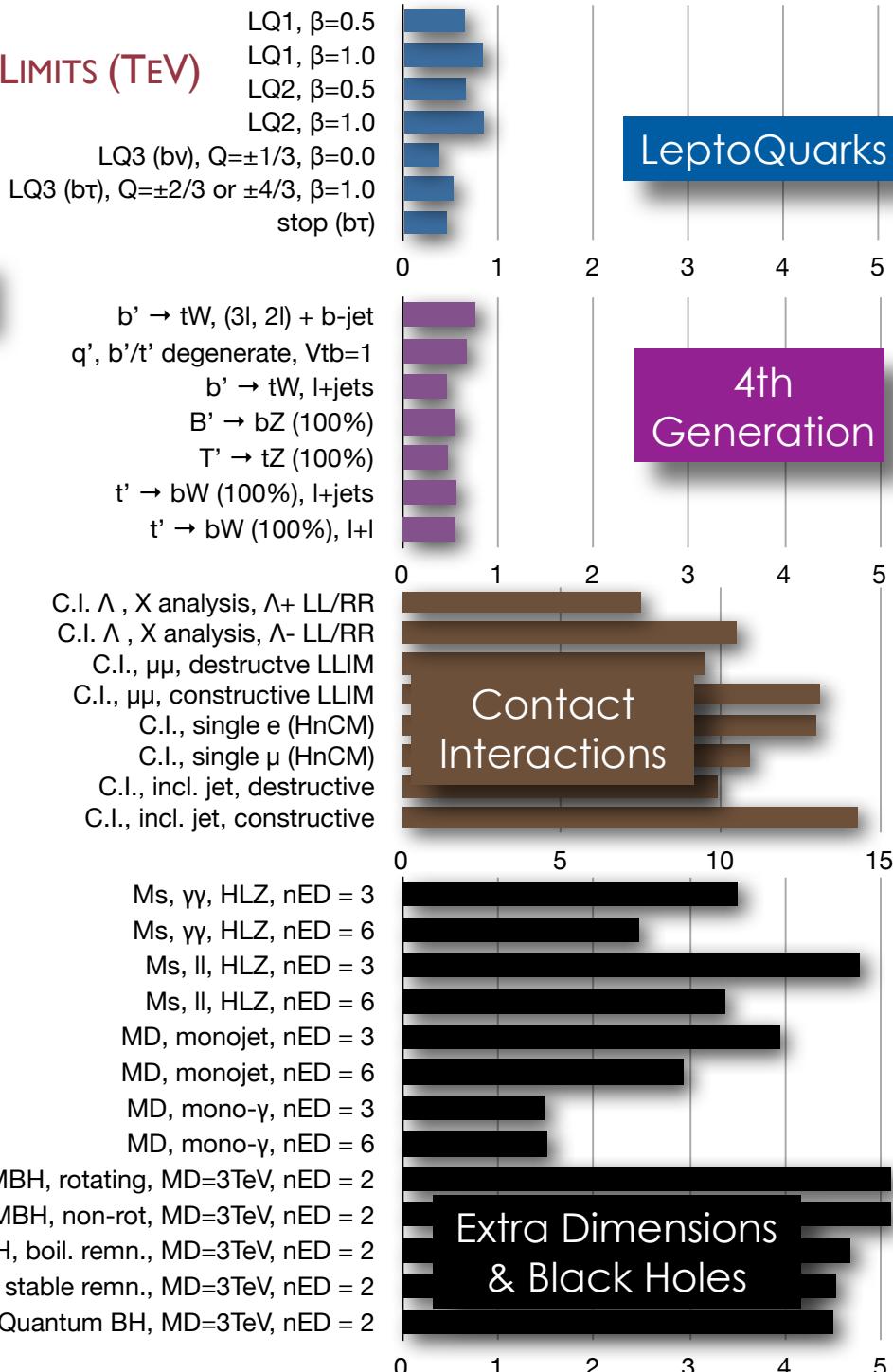
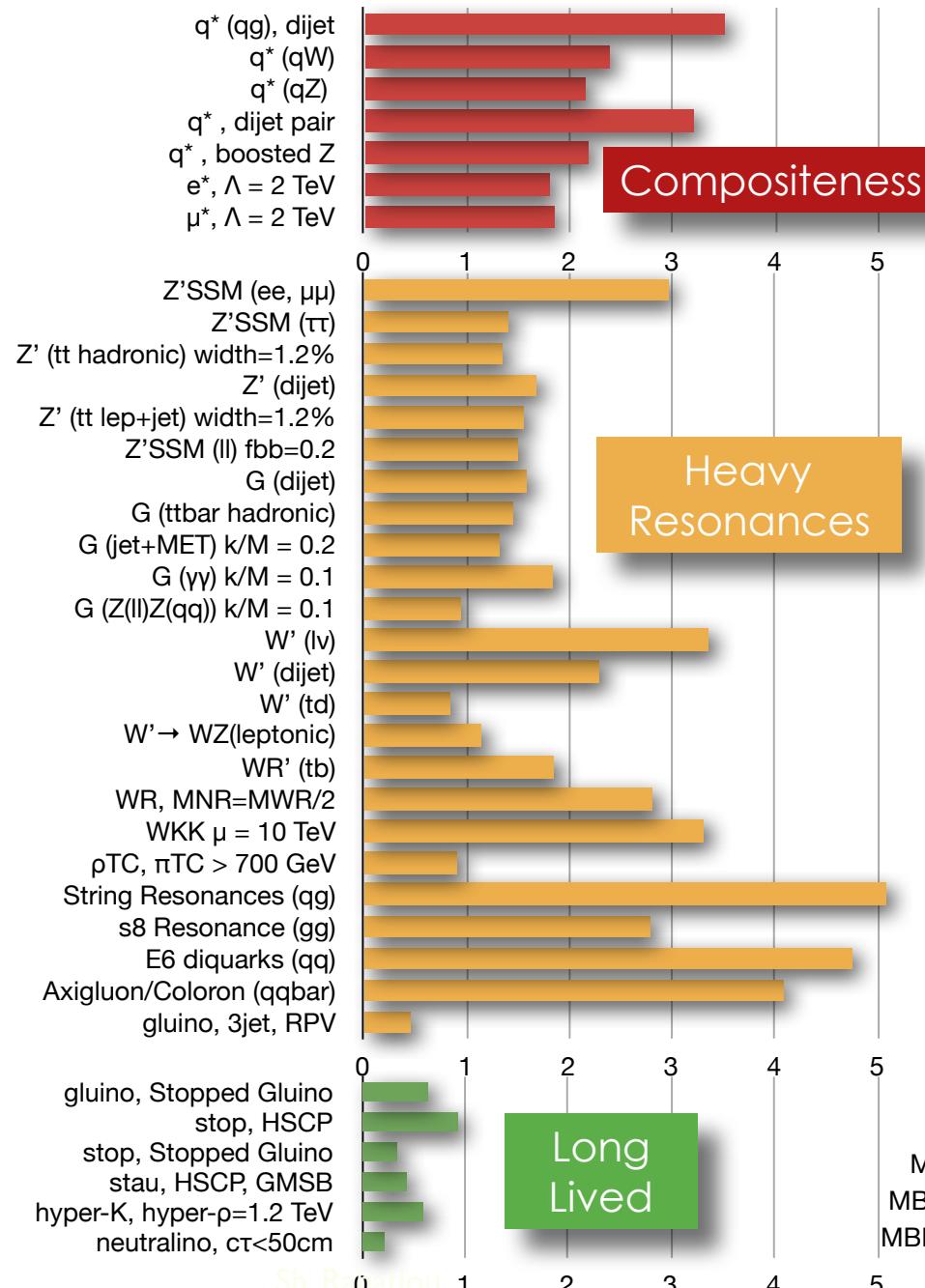
CONCLUSIONS

- CMS has an active programme searching for Extra Dimensions and Dark Matter
- New results presented from the CMS searches for:
 - Black Holes [arXiv:1303:5338, EXO-12-009]
 - Large Extra Dimensions in the dimuon final state [EXO-12-027]
 - Large Extra Dimensions in the dielectron final state [EXO-12-031]
 - Large Extra Dimensions in Monojets EXO-12-048
 - Dark Matter in Monojets [EXO-12-048]

Keep watching-- more results on the way!

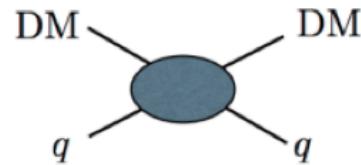


CMS EXOTICA 95% CL EXCLUSION LIMITS (TeV)

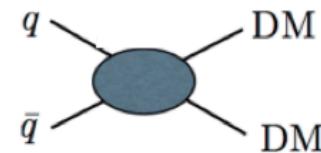


PRODUCTION OF DARK MATTER AT CMS

- Search for evidence of pair-production of Dark Matter particles (χ)

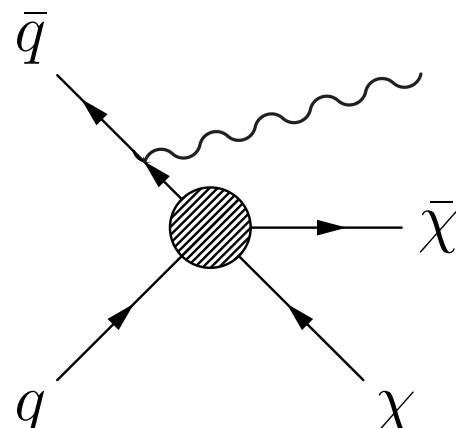


Direct Detection (t-channel)

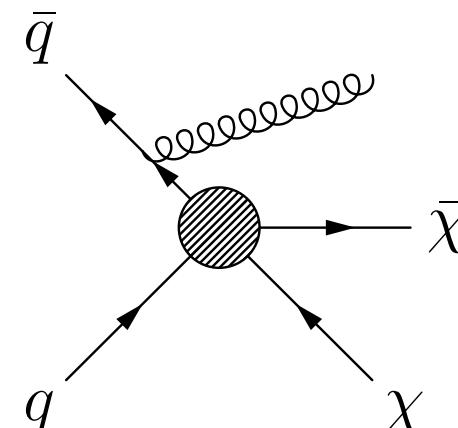


Collider Searches (s-channel)

- Dark Matter production gives missing transverse energy (MET)
- Photons (or jets from a gluon) can be radiated from quarks, giving monophoton (or monojet) plus MET



Monophoton + MET



Monojet + MET

PHENOMENOLOGY

- Pair-production of χ can be characterised by a contact interaction with operators

$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2} \quad \text{vector --> spin independent (SI)}$$

$$\mathcal{O}_{AV} = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2} \quad \text{axial-vector --> spin-dependent (SD)}$$

- Cross section depends on the mass (m_χ) and the scale Λ (for couplings g_χ, g_q)

$$\sigma_{SI} = 9 \frac{\mu^2}{\pi \Lambda^4}$$

$$\sigma_{SD} = 0.33 \frac{\mu^2}{\pi \Lambda^4}$$

*spin-independent
and spin-dependent
cross sections*

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

$$\mu = \frac{m_\chi m_p}{m_\chi + m_p}$$

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

[Goodman, Ibe, Rajaraman, Shepherd, Tait,
Yu, Phys.Rev.D82:116010 (2010)]

MONOJET SELECTION AND BACKGROUNDS

- Data-driven Background Estimation (Lepton Identification)
 - Require isolated muon $> 20 \text{ GeV}/c$; select 1 and 2 muon events
 - Obtain $Z+\text{jet}$ sample from $M(\mu\mu)$, $W+\text{jet}$ sample from $p_T(\mu)+\text{MET}$
- Basic topological selection
 - Reject events with isolated leptons
 - $\text{MET} > 250 \text{ GeV}$, # of Jets = 1 or 2
 - Leading Jet: $p_T > 110 \text{ GeV}$, $|\eta| < 2.4$
 - Second Jet: $p_T > 30 \text{ GeV}$
 - $\Delta\phi(\text{jet1}, \text{jet2}) < 2.5$

