Search for Dark Matter Production at the LHC

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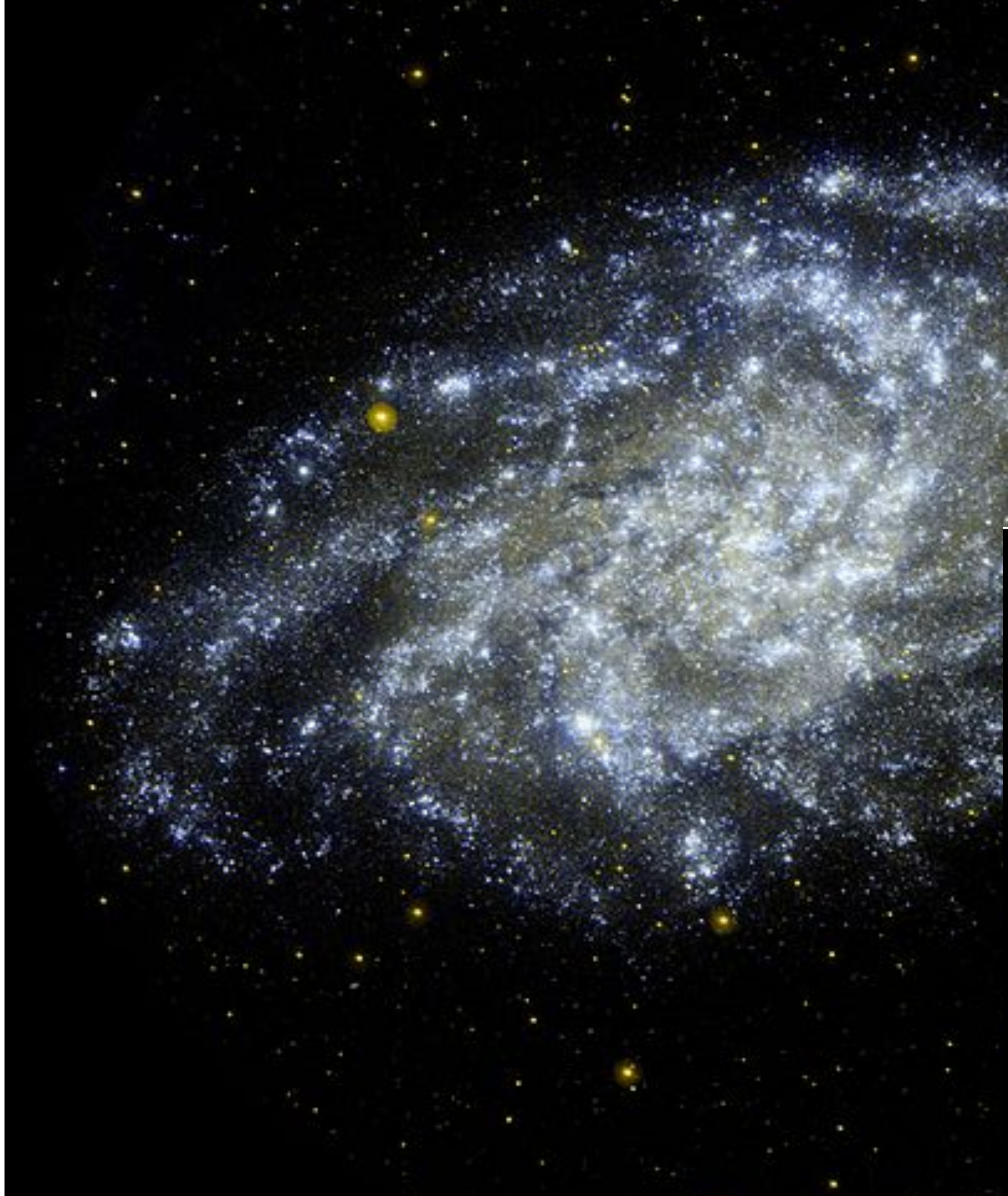
Outline

- Introduction/Motivation
- LHC and ATLAS/CMS
- SUSY DM
- Search for WIMPS

- Final notes

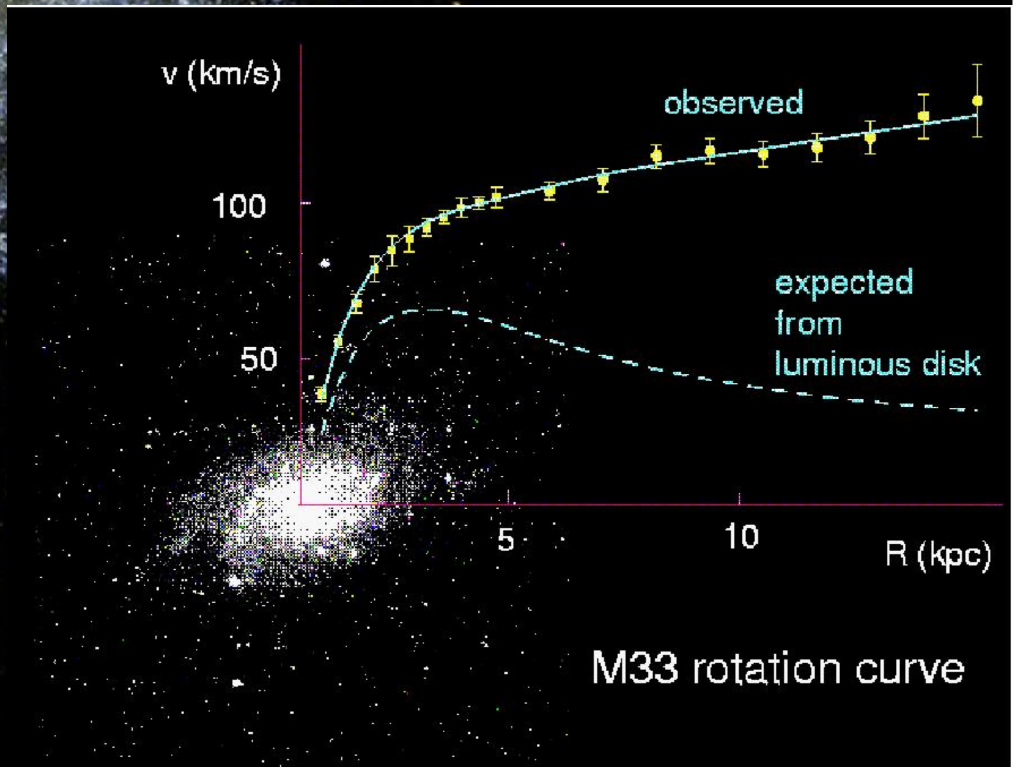
"Particles, particles, particles."

Galaxia M33

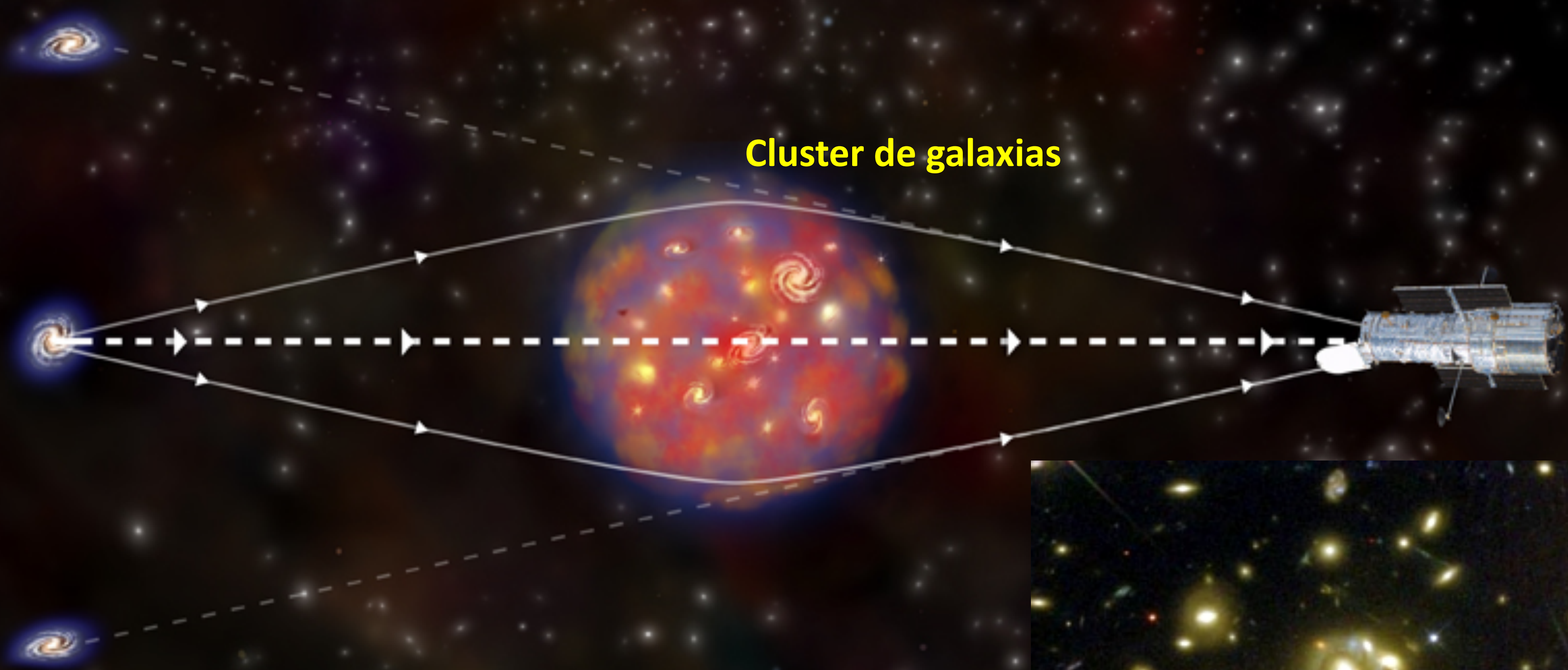


The rotation of the starts around the center of the galaxies are not consistent with the amount of mass observed (L/M ratio)$_{SUN}$

Spherical dark matter halo

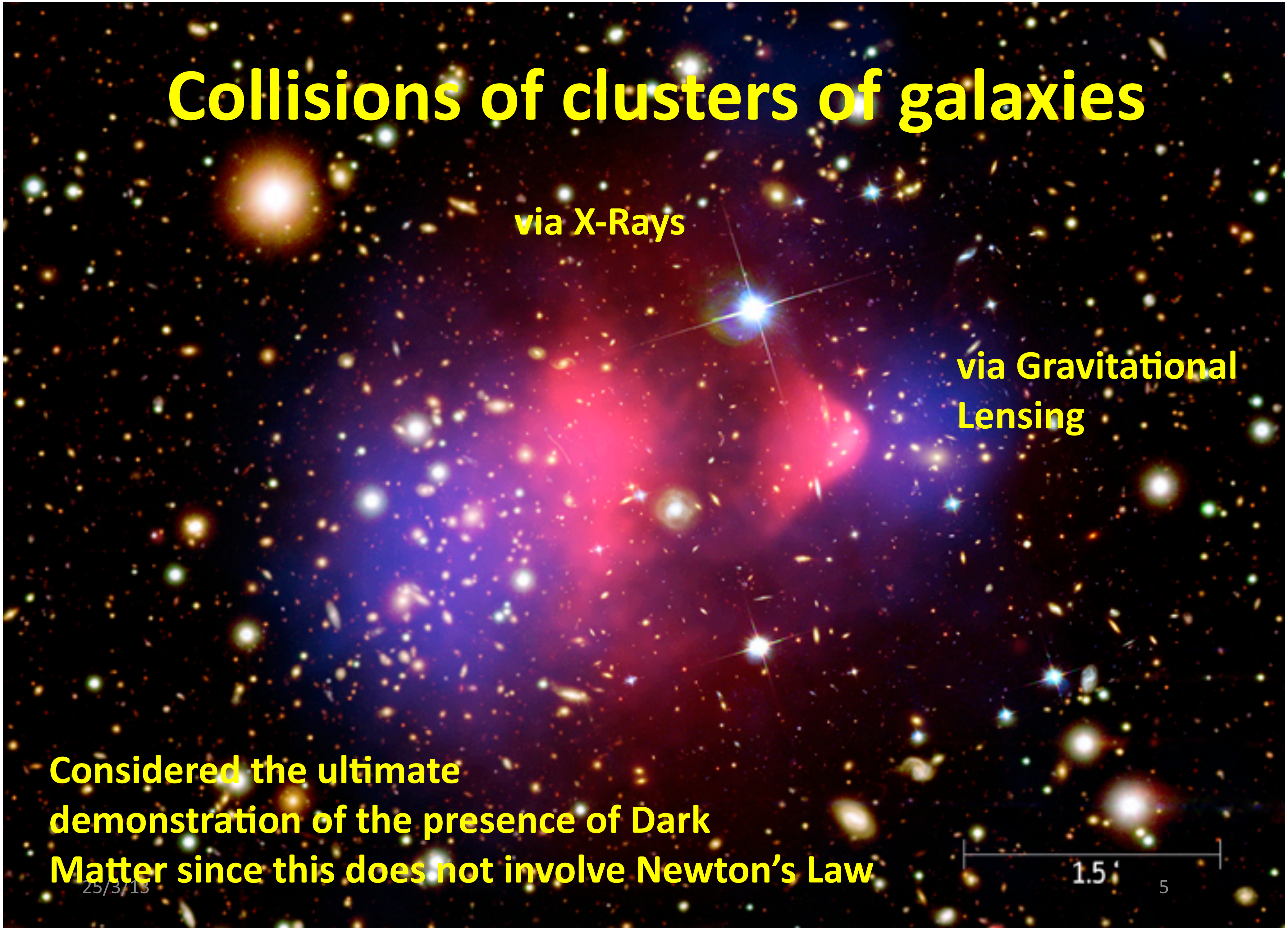


Gravitational Lensing

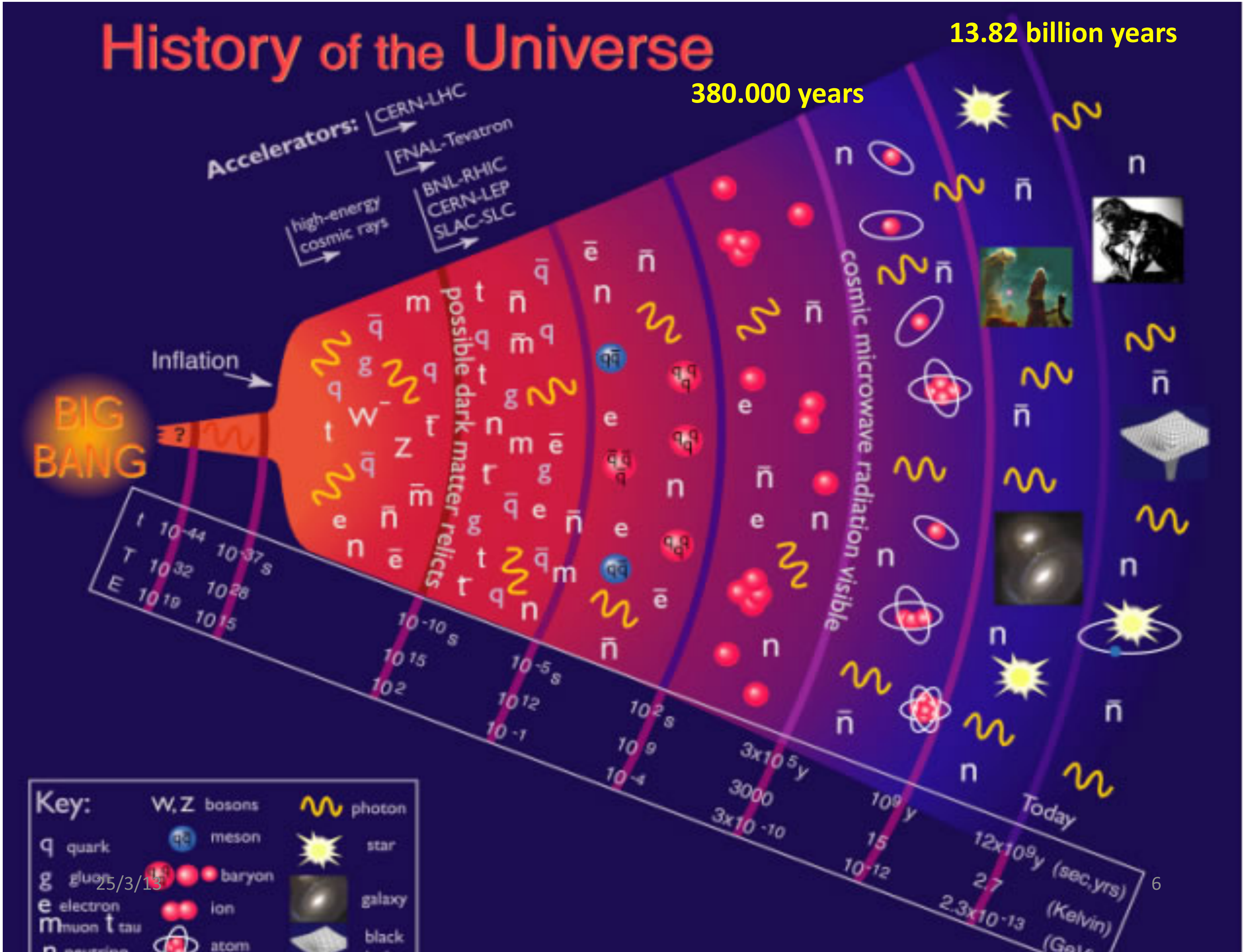


Large distortion of the imagines of distant galaxies due to gravitation lensing
→ indication of DM in galaxy clusters

Collisions of clusters of galaxies



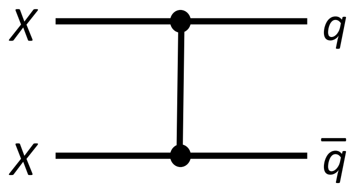
Considered the ultimate demonstration of the presence of Dark Matter since this does not involve Newton's Law



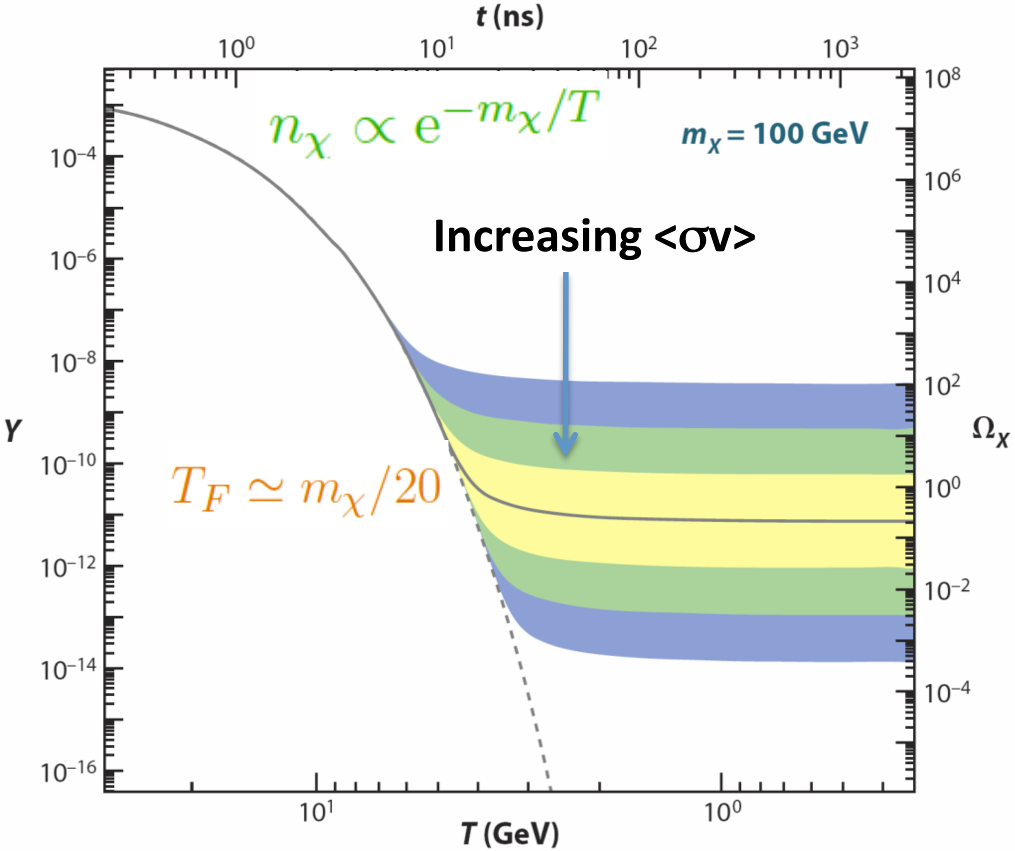
History of the Universe
13.82 billion years
380.000 years
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10-44 10-37s
T 1032 1028
E 1019 1015
10-10 s
1015
102
10-5 s
1012
10-1
102 s
109
10-4
3x105 y
3000
3x10-10
109 y
15
10-12
Today
12x109y (sec,yrs)
2.7 (Kelvin)
2.3x10-13
Key:
W, Z bosons
photon
q quark
meson
star
g gluon
baryon
e electron
ion
galaxy
m muon
t tau
atom
black

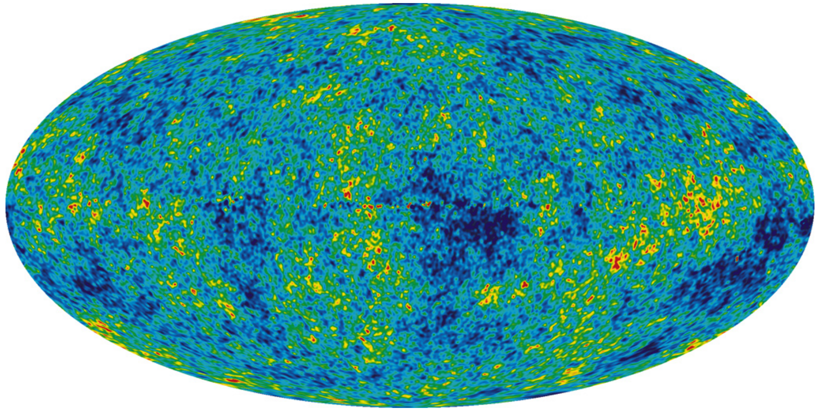
WMAP results

arXiv:1212.5226v2 (January 30th 2013)

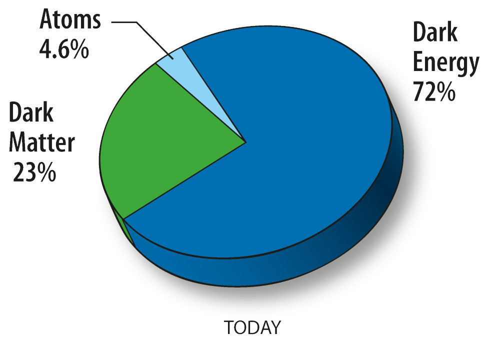


$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$





$$\Omega_\chi h^2 \simeq \frac{0.1\ \mathrm{pb}\cdot c}{\langle \sigma(\chi\chi \to \mathrm{SM}) v \rangle}$$

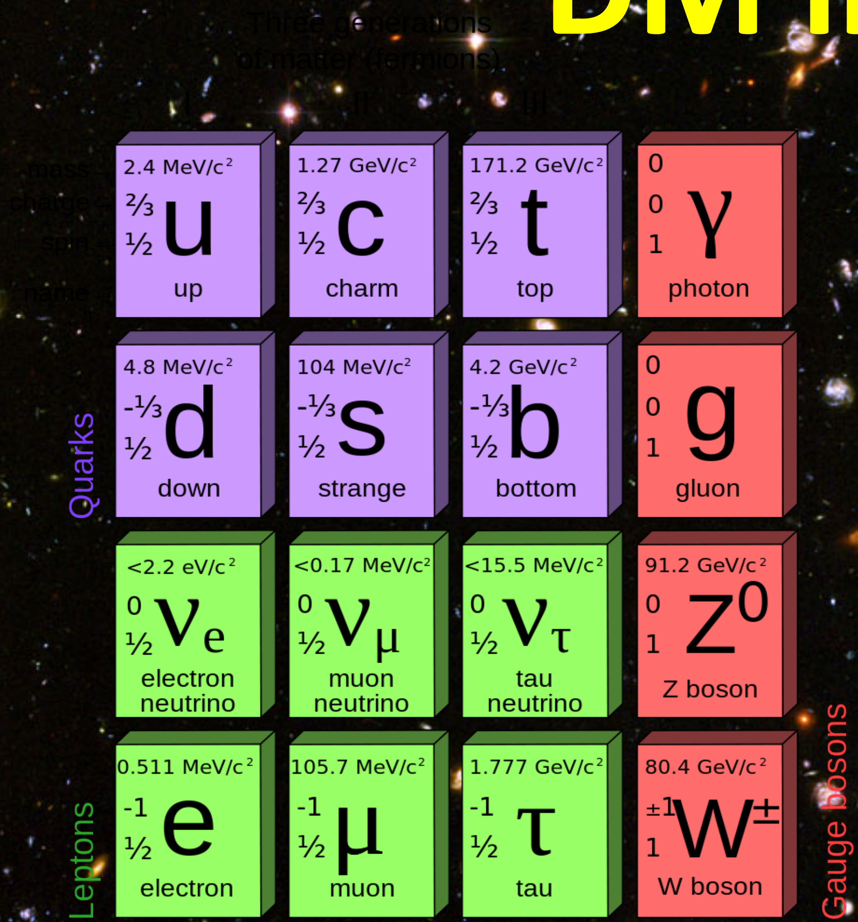


$$\langle \sigma(\chi\chi \to \mathrm{any}) v \rangle \simeq 3 \cdot 10^{-26} \mathrm{cm}^3 \mathrm{s}^{-1}$$

WMAP : $\Omega_{CMD} h^2 \sim 0.1$

Weak scale for $\chi\chi$ annihilation cross section

DM in the SM ?



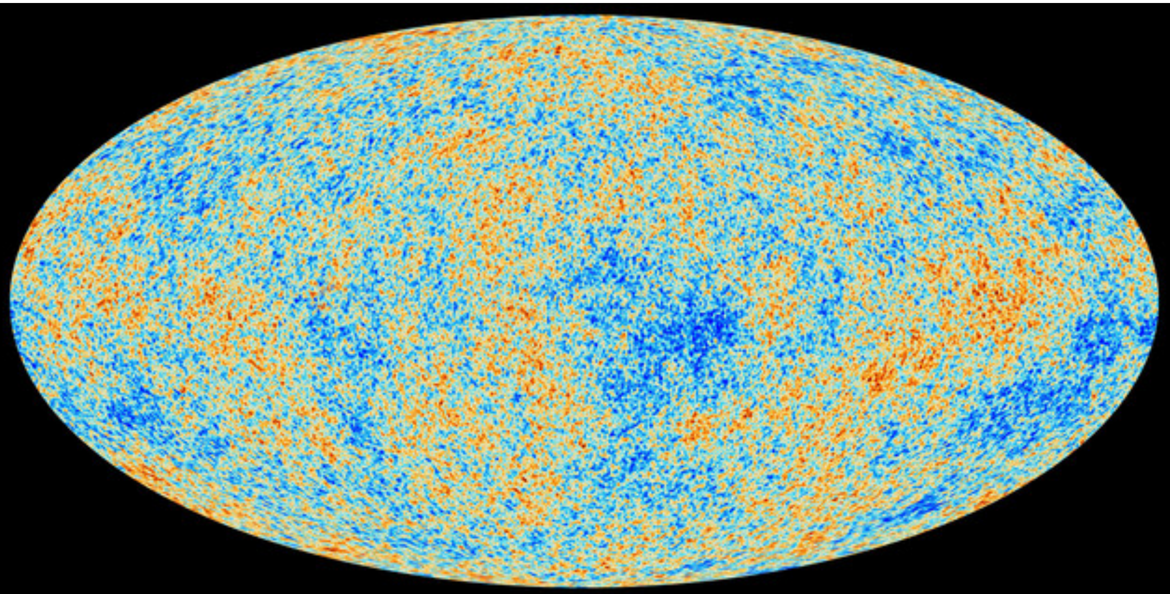
Neutrino ?

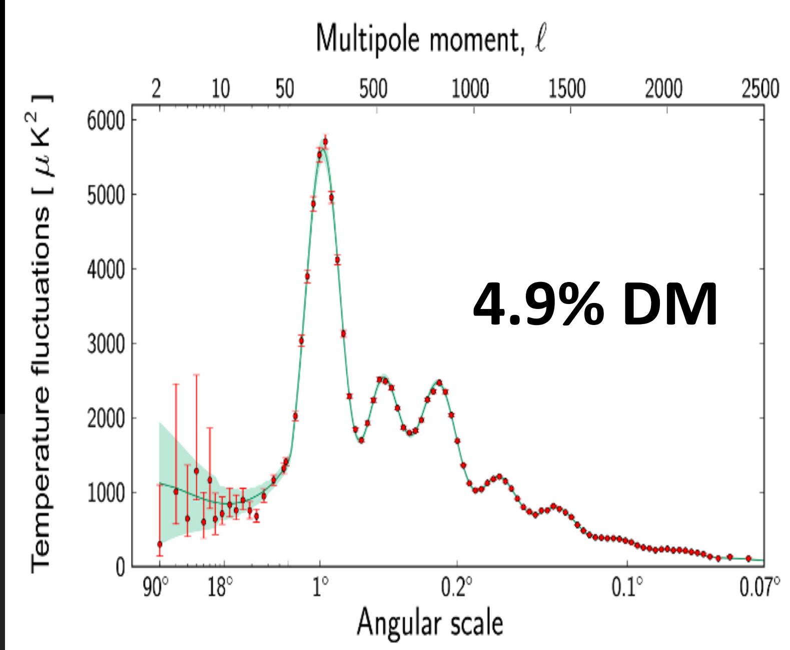
Insufficient

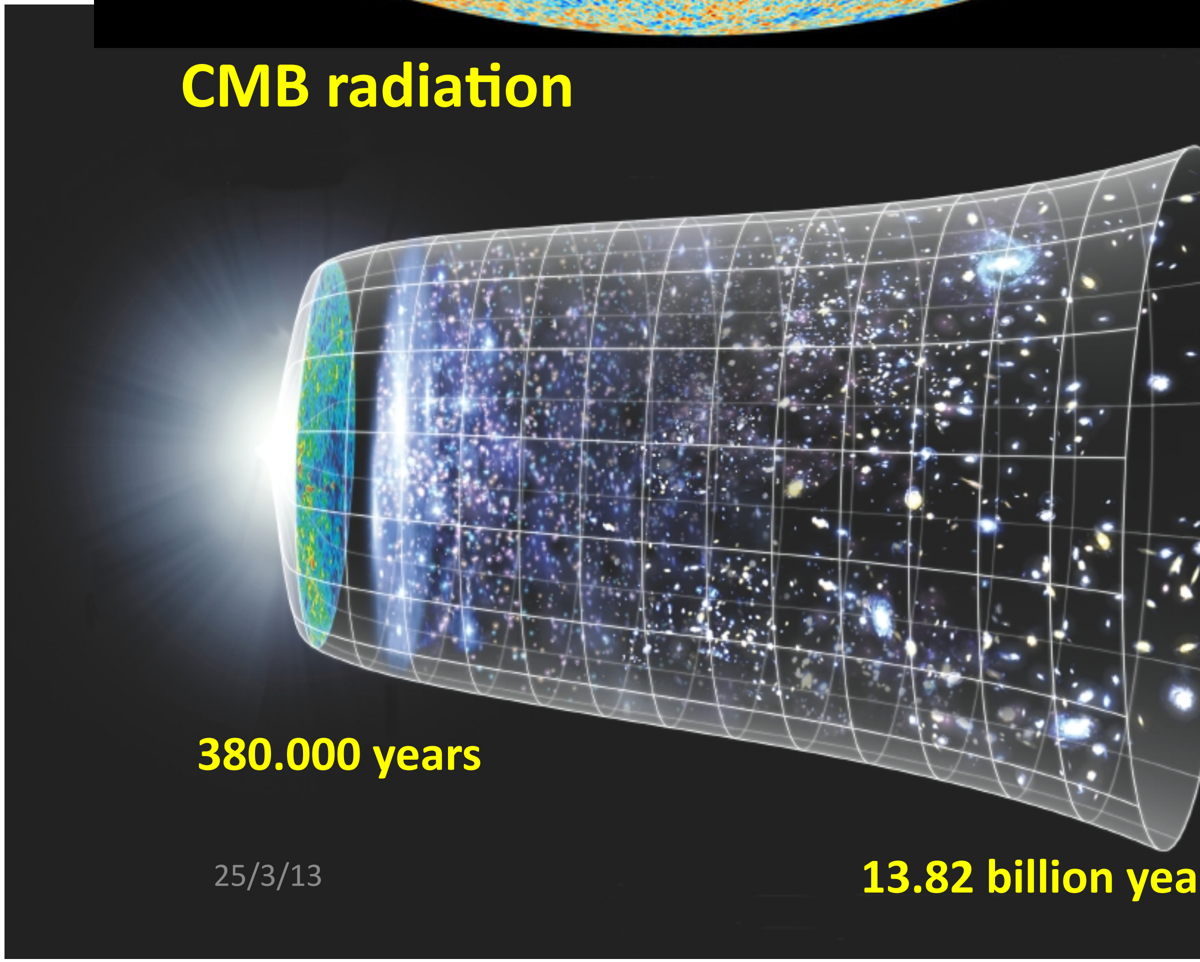
($\Omega_\nu h^2 < 0.0067$ @ 95%CL)

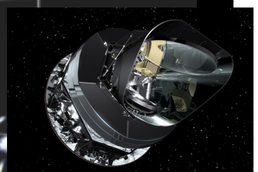
SO, …. we do not really have an explanation…..

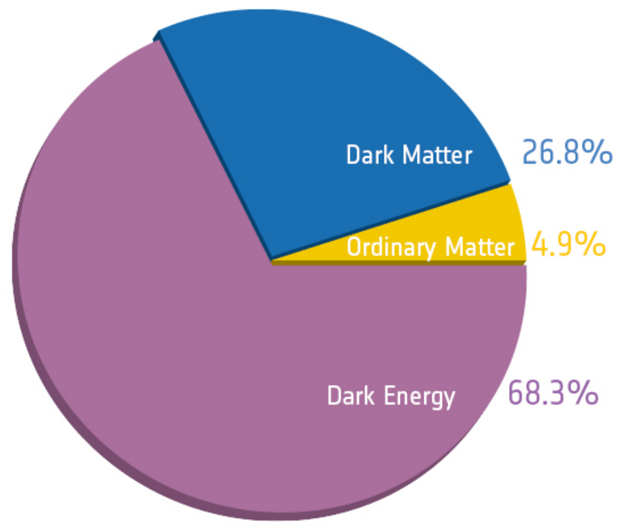
Planck (20 March 2013)
arXiv:1303.5062v1











After Planck

Dark Matter Candidates

- Neutrinos ? ($\Omega_\nu h^2 < 0.0067$ @ 95%CL)
- Sterile Neutrinos
- Axions
- SUSY particles
  - Lightest neutralino
  - Sneutrinos
  - Gravitinos
  - Axinos
- KK states (UED)
- Wimpzillas
- ………
- ………

General requirements

- Electrically Neutral ("dark")
- Stable (lifetime larger than age of the Universe)
- Massive and Weakly interacting ($\Omega_{CDM} h^2 \sim 0.1$)

→WIMPS

Note: No reason DM should be made out of a single component (neutrinos exist)

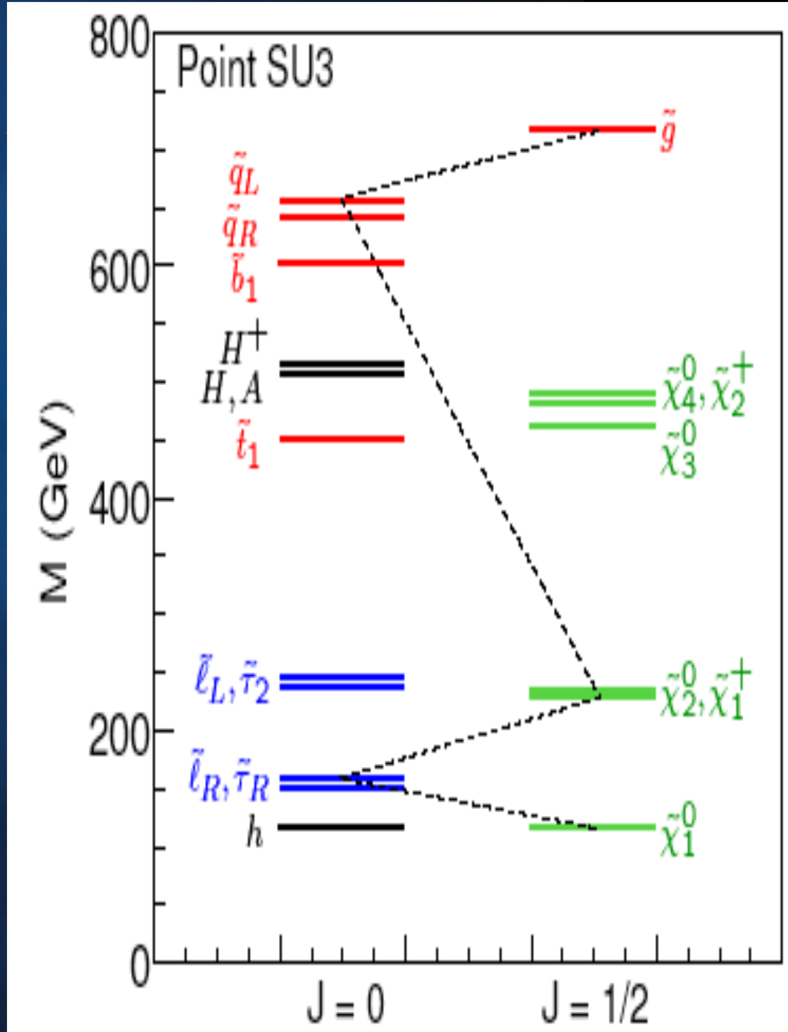
SUSY

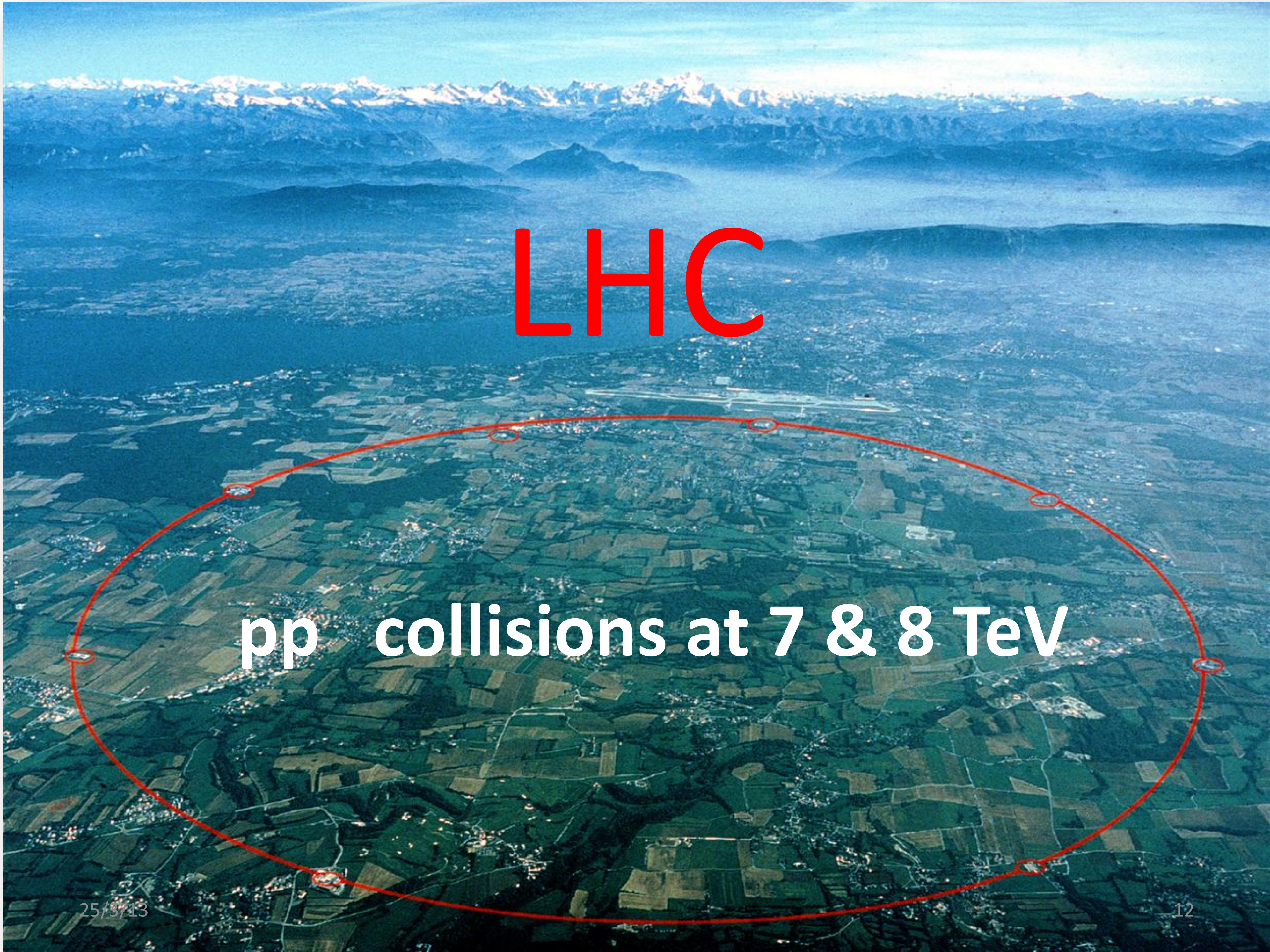
- Addresses the Hierarchy Problem
- Unification of forces & GUT scale
- Natural candidate for DM

neutralino

$$\overline{\chi}_1^0$$

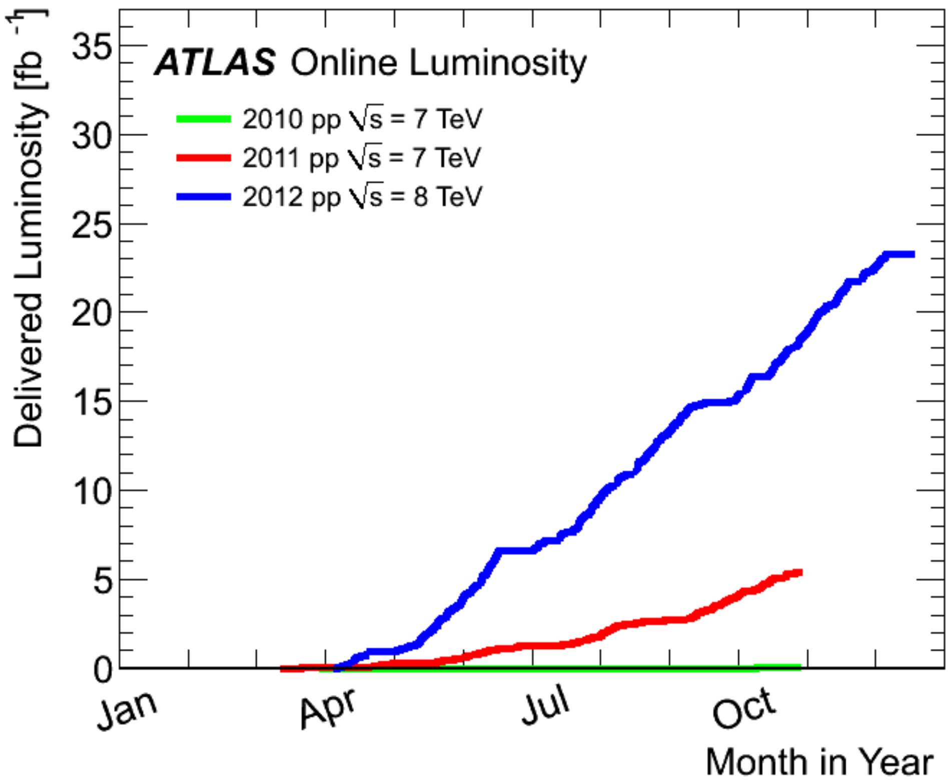
Picture taken before the LHC era

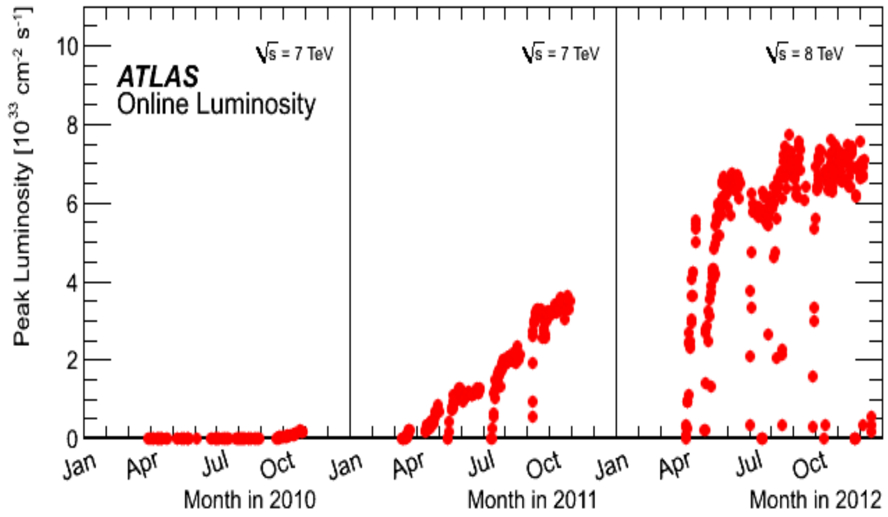



LHC
pp collisions at 7 & 8 TeV

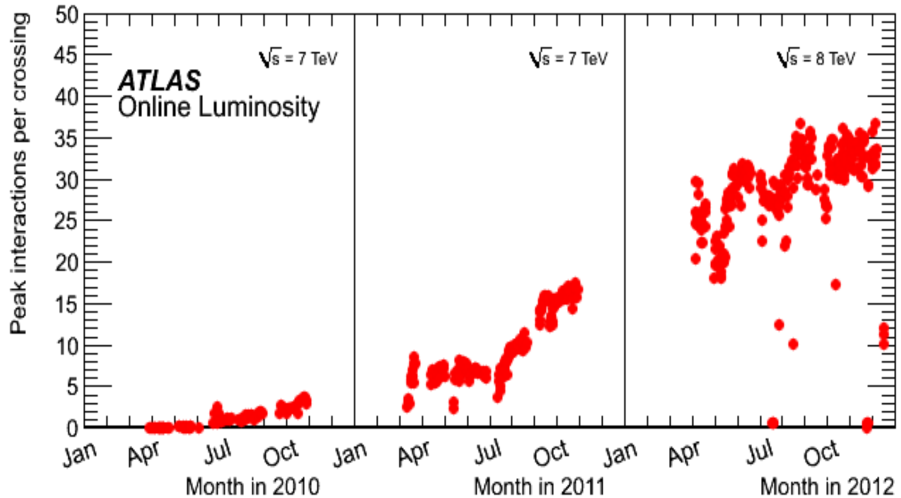
LHC Performance (2010-2012)

Spectacular LHC performance
(rapid increase of data samples)



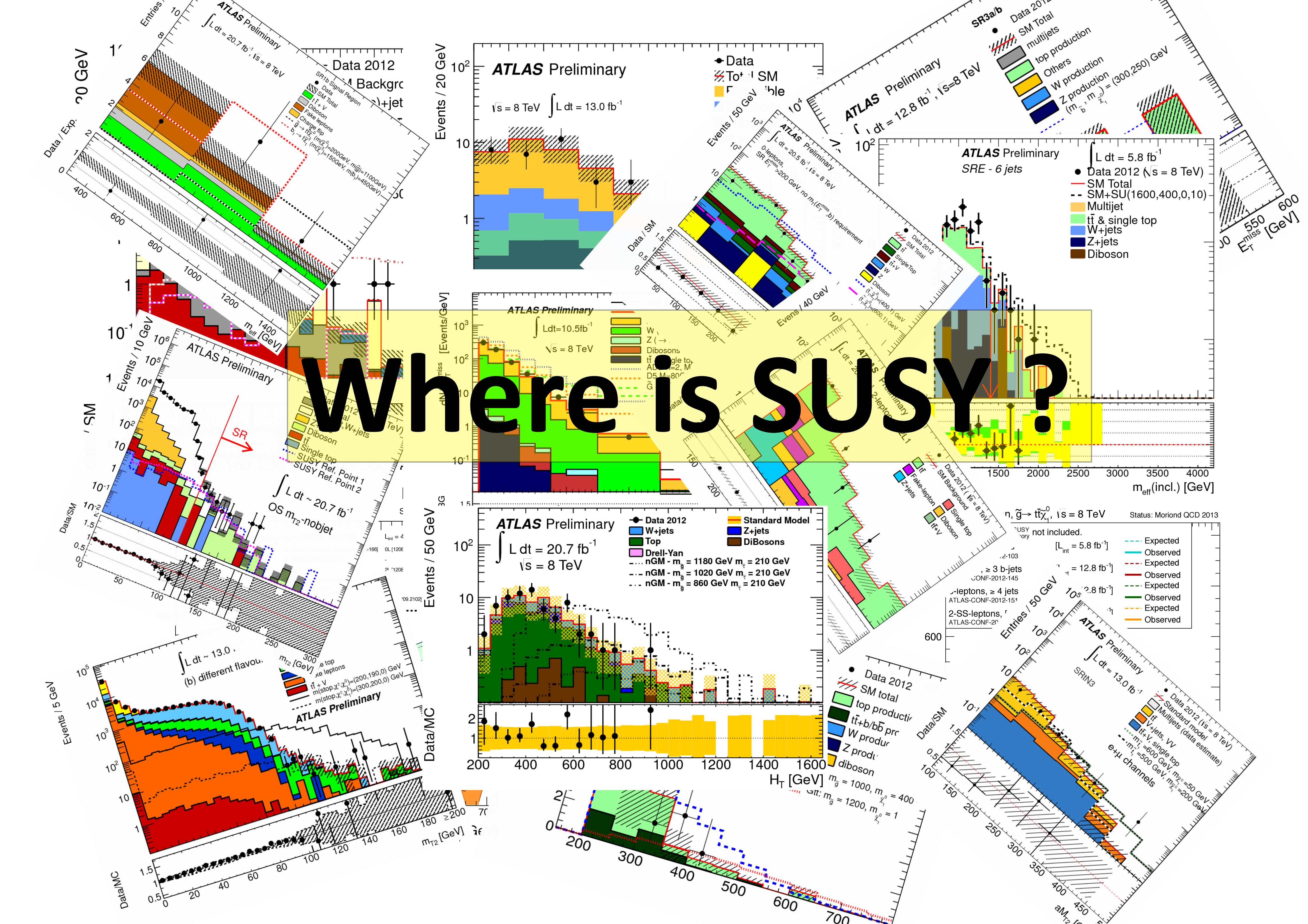


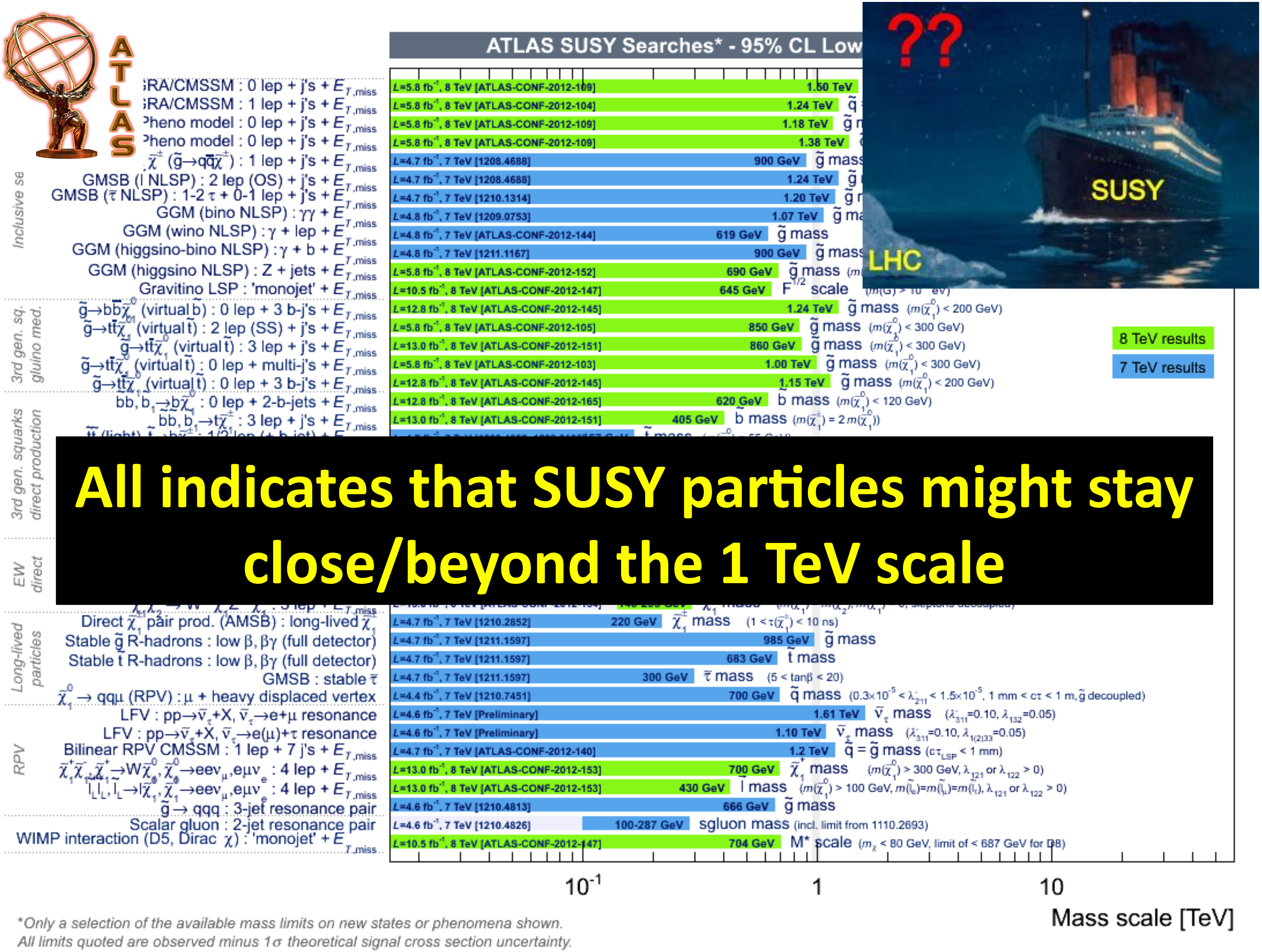
o a rapid increase of pile-up conditions



LHC ended pp run at 8 TeV
after delivering more than 23 fb^{-1}

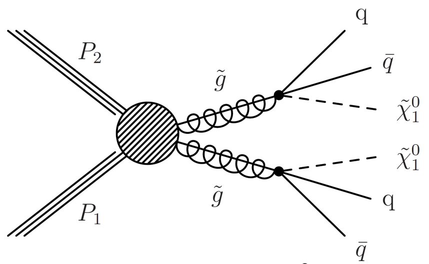
…will come back in 2015 with 13-14 TeV collisions


Where is SUSY?



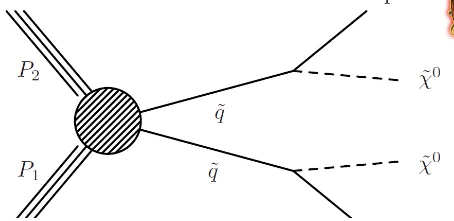
All indicates that SUSY particles might stay close/beyond the 1 TeV scale

What about SUSY DM ?

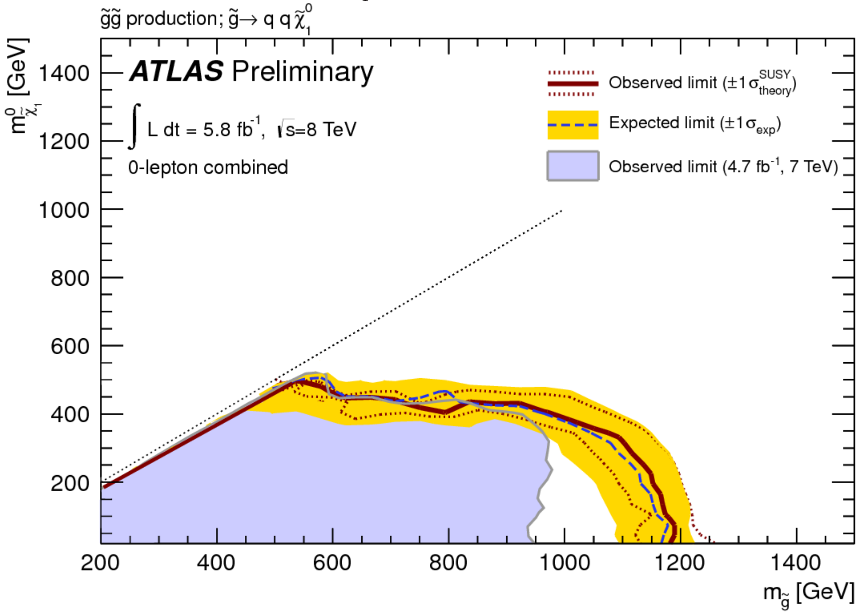


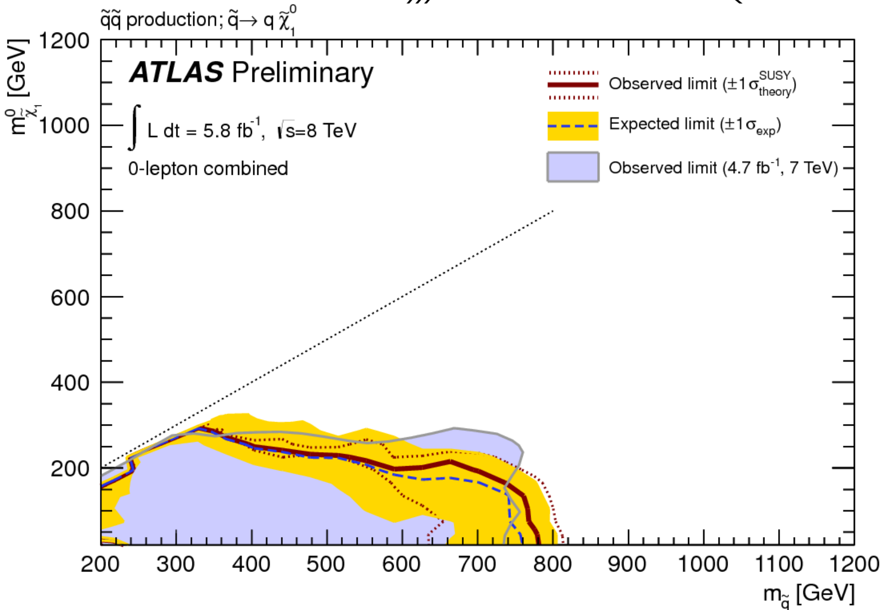
Inclusive SUSY

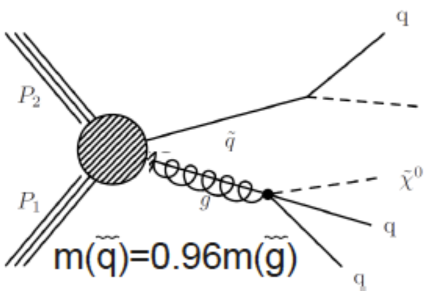
ATLAS-CONF-2012-109

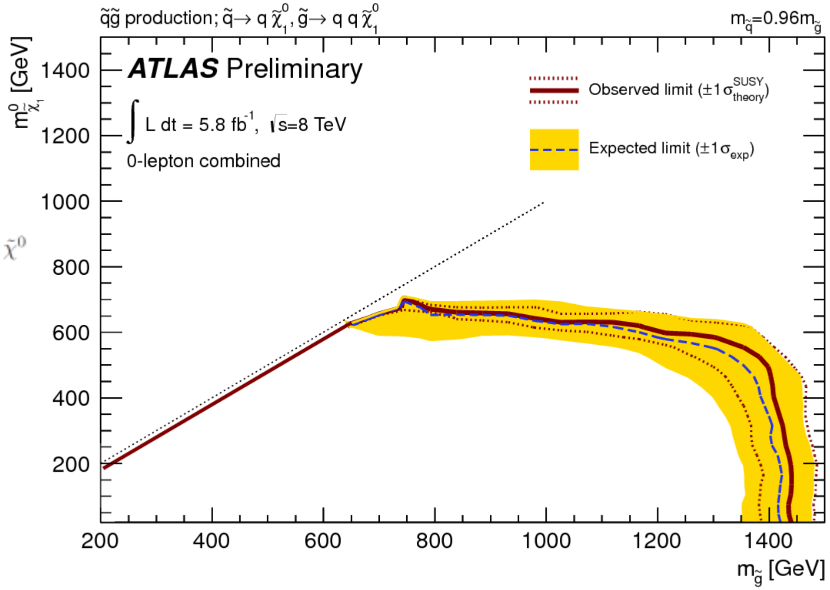


Multiple-jets and large E_T^{miss}





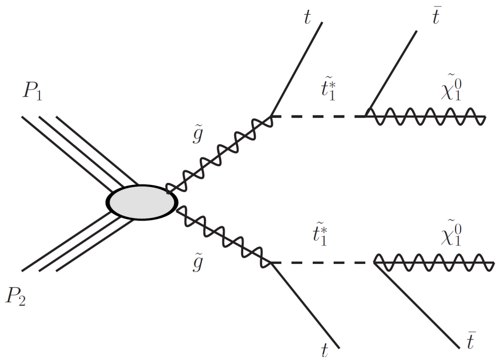


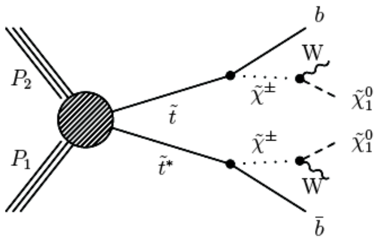


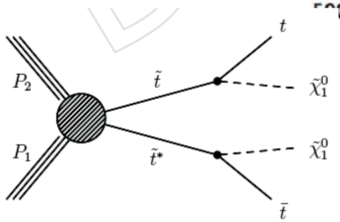
Considering only few sparticles and final state with 100% branching Fraction

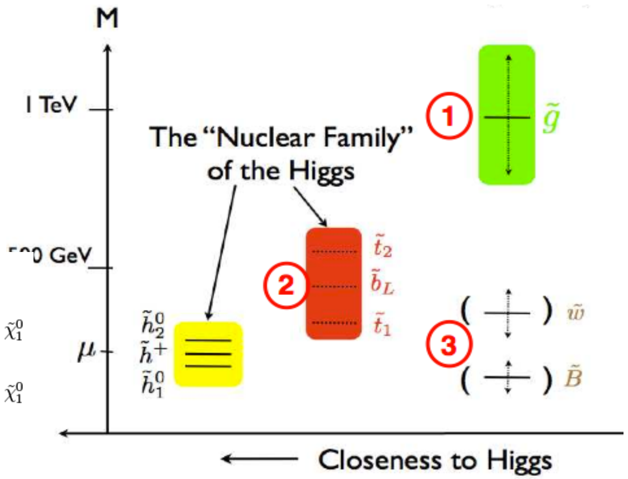
Exclusions for the neutralino mass 200 – 600 GeV

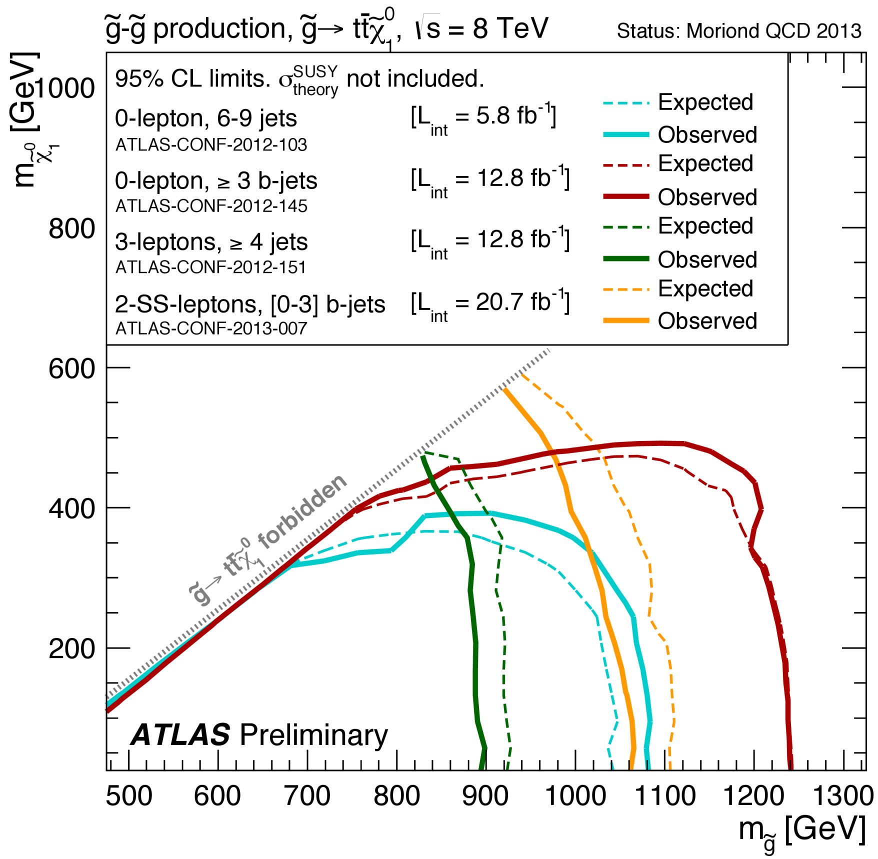
Stop Searches

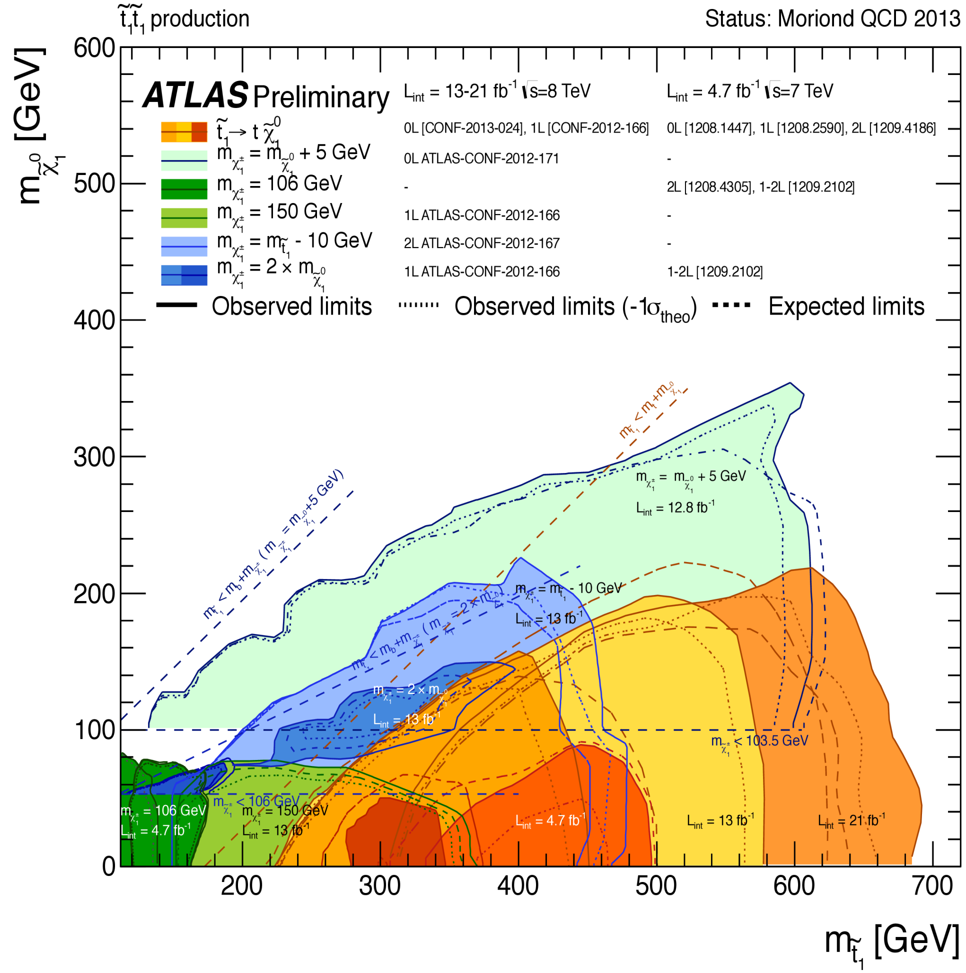








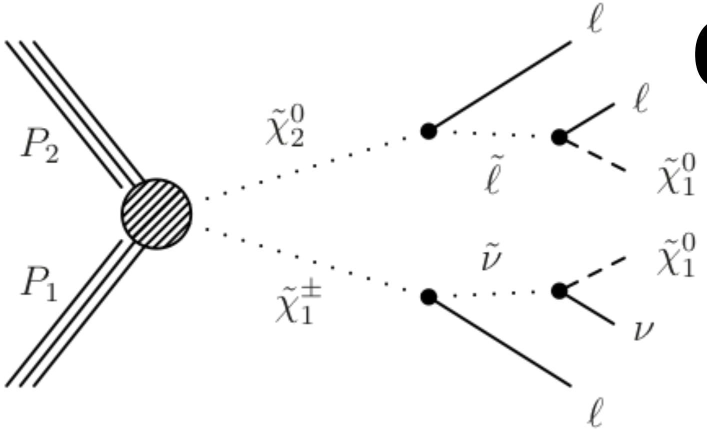




Sensitivity up to 700 GeV stops

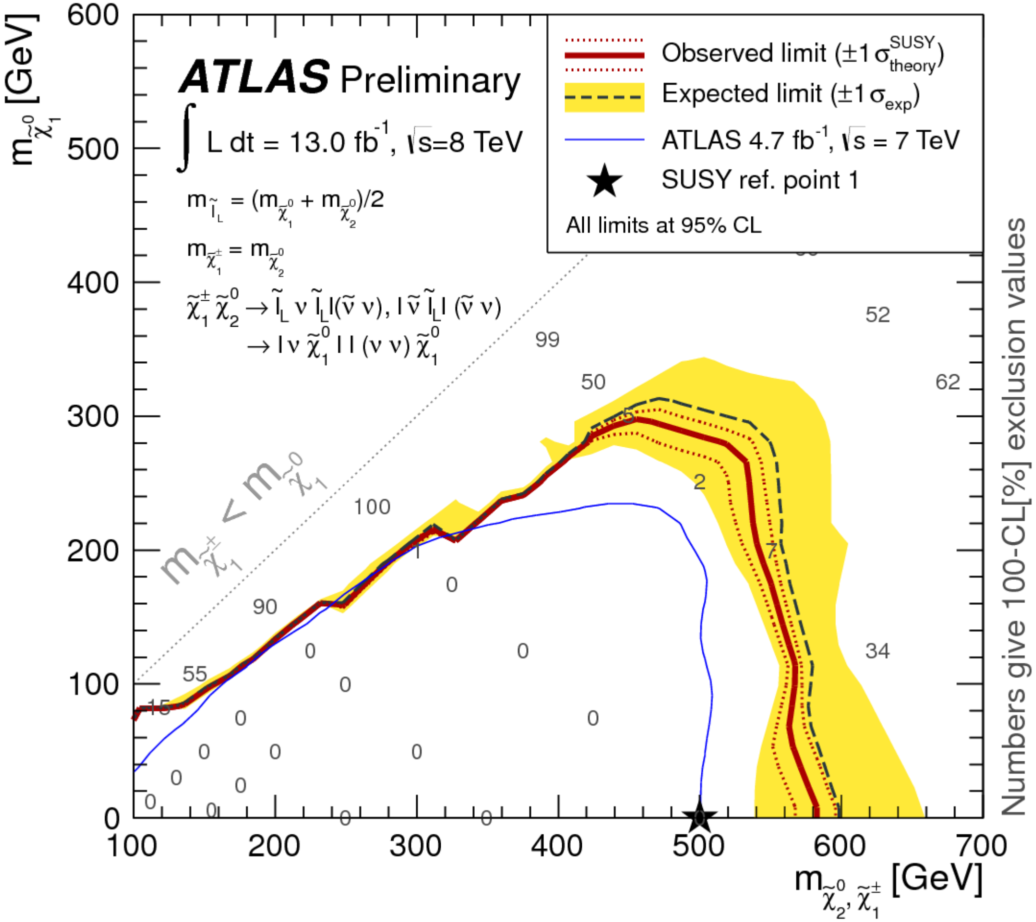
Exploring neutralino masses up to 300 – 500 GeV

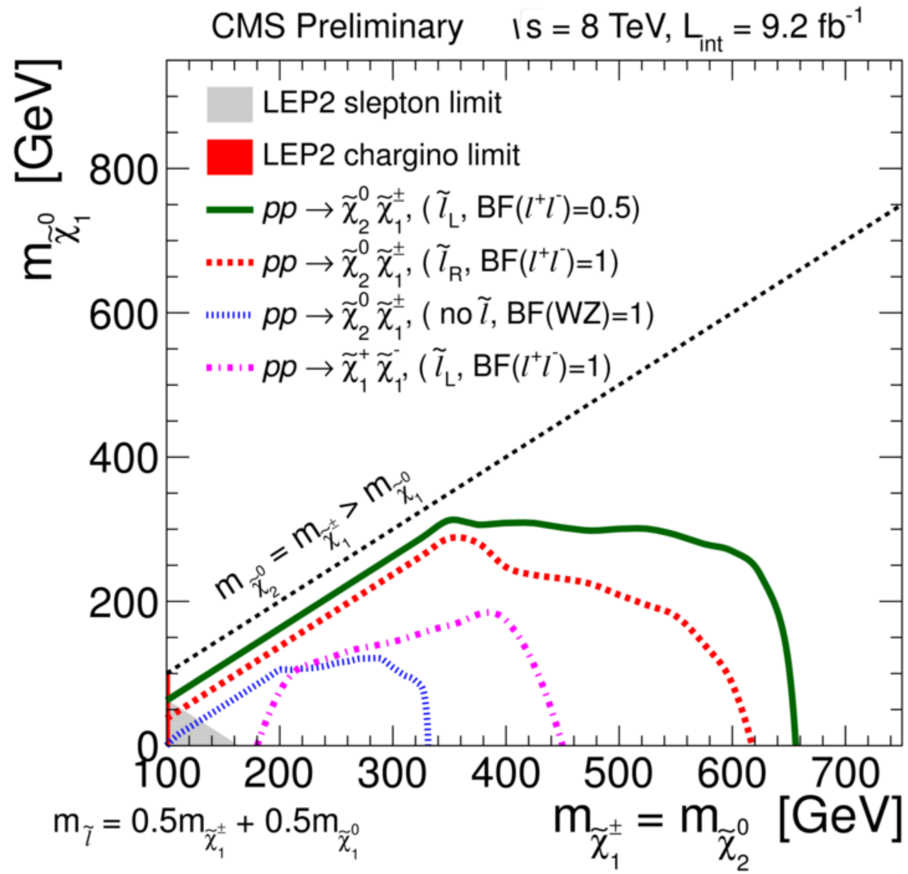
Chargino/Neutralino



3 leptons + E_T^{miss}

ATLAS-CONF-2012-154
CMS-PAS-SUS-12-022

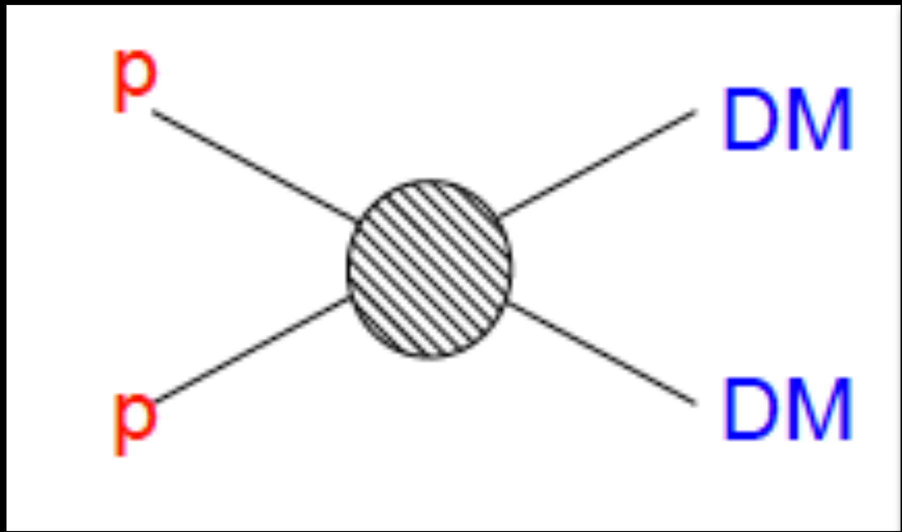




Chargino mass > 600 GeV
Neutralino mass > 300 GeV

Very sensitive to the details of the scenario considered

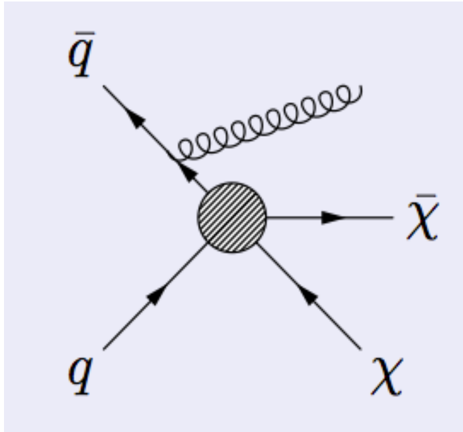
DM pair production at the LHC



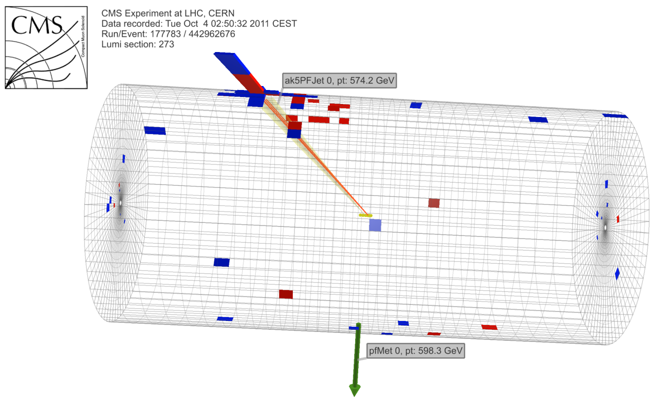
WIMP Pair Production at Colliders

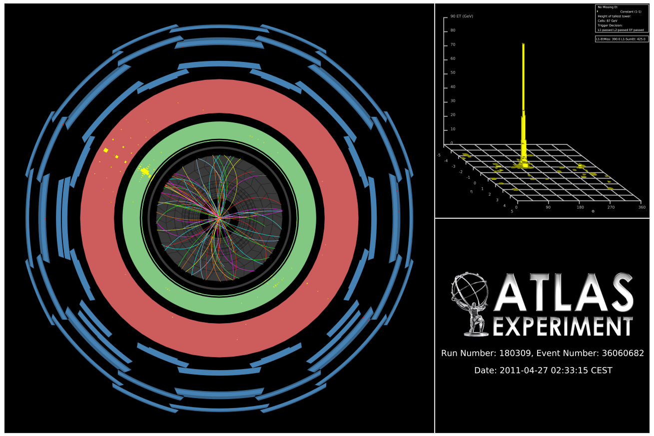
At colliders (LHC) WIMPs can be produced in pairs leading to "nothing to detect" in the final state

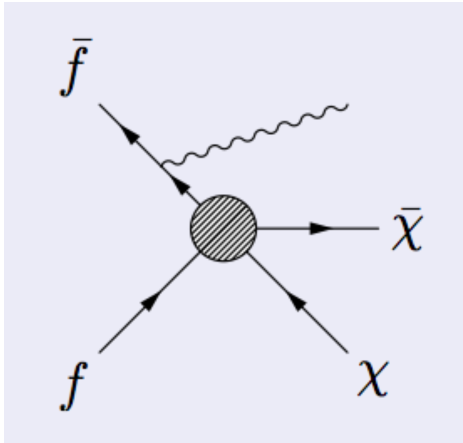
Such events are tagged via the presence of an energetic jet or a photon from initial state radiation



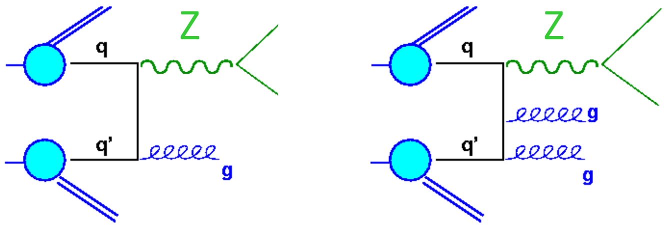
→Monojets and Monophotons





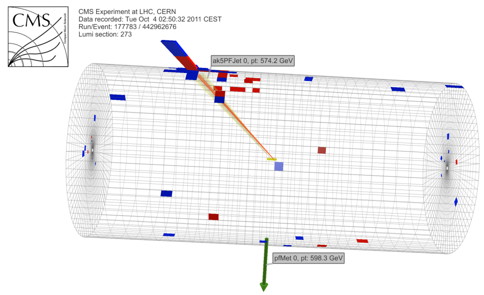


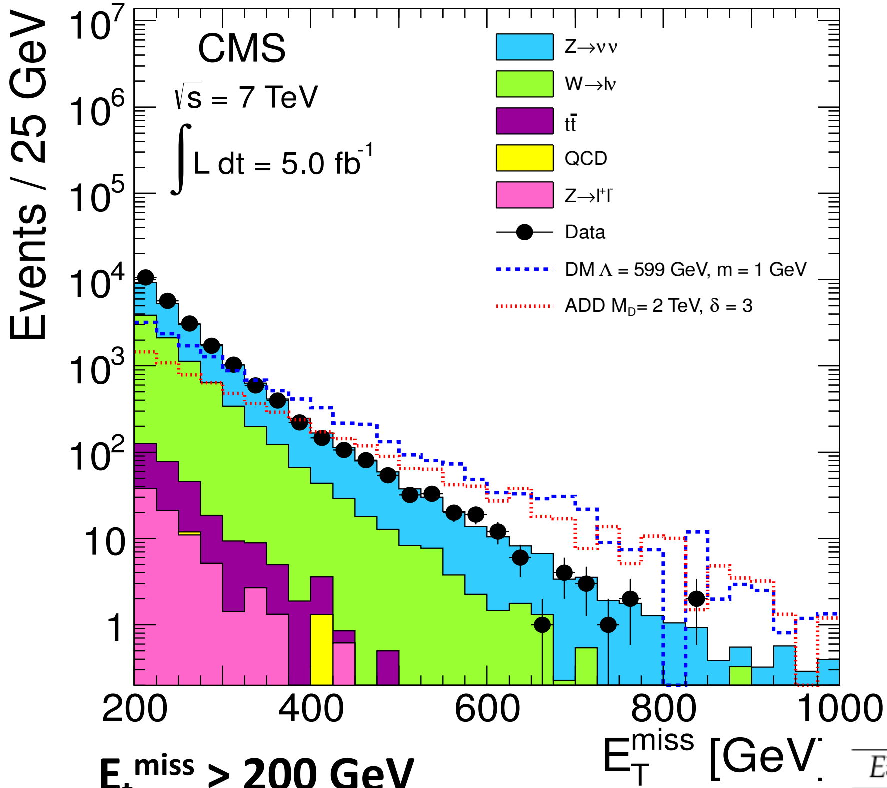
Rather spectacular and distinctive signature to search for new physics (also relevant in searches for large extra spatial dimensions, etc...)



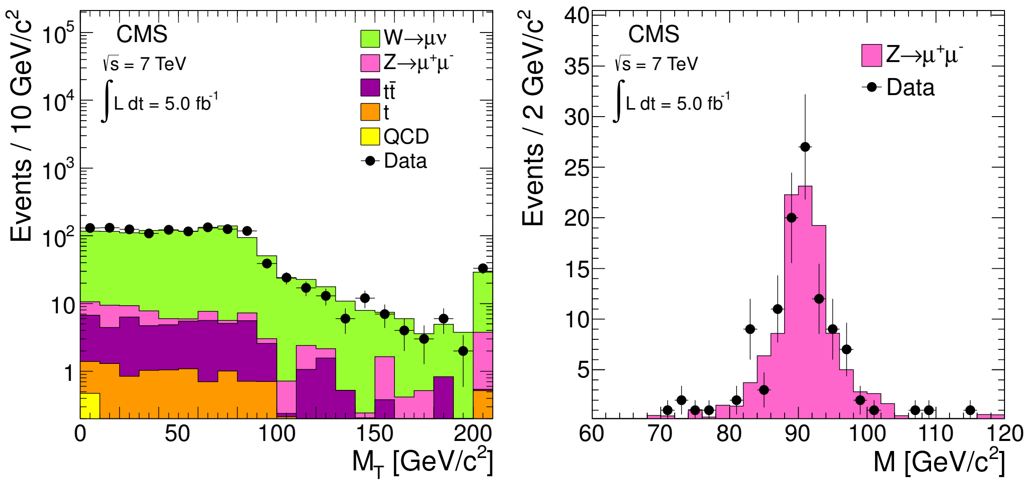
Monojets

JHEP09(2012)094





Data driven estimation of the dominant Z+jets and W+jets background using control regions



E_t^{miss} > 200 GeV

p_T (j1) > 110 GeV

$N_{jet}(p_T >$ 30 GeV) < 3

Δϕ (j1,j2) < 2.5

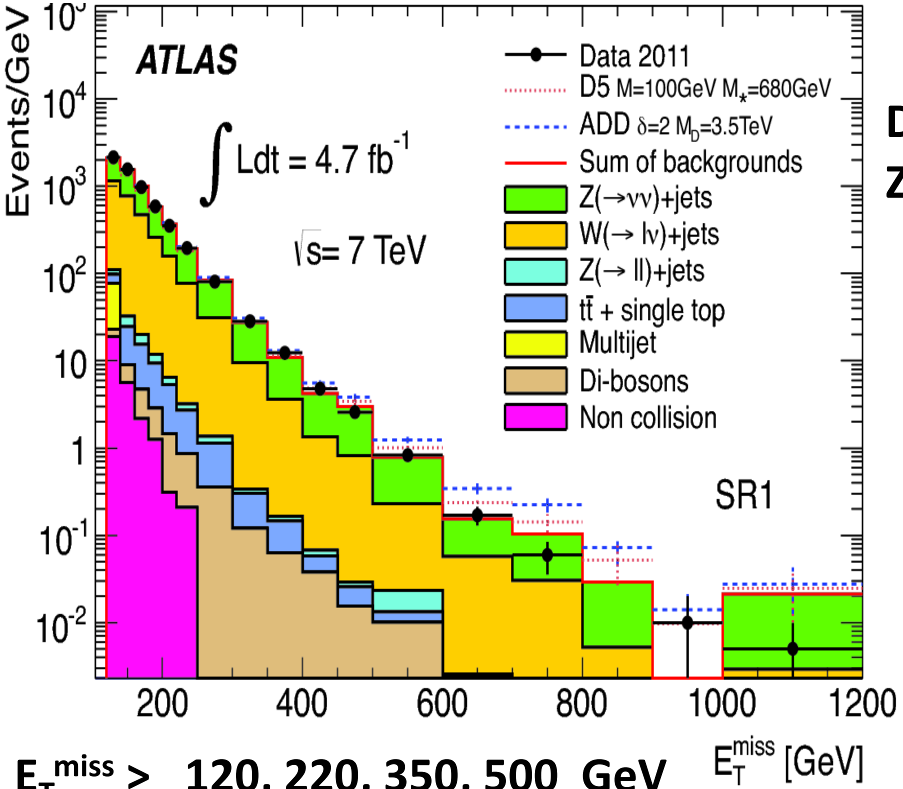
Lepton vetoes

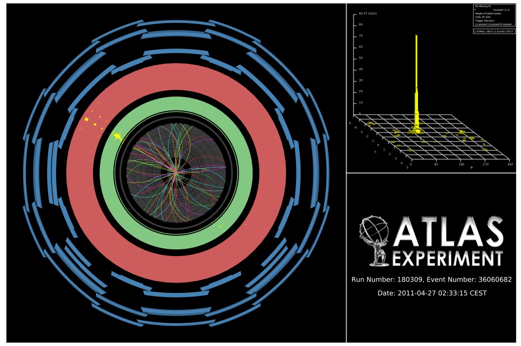
E_T^{miss} (GeV/c) →	≥ 250	≥ 300	≥ 350	≥ 400
Process	Events			
$Z(\nu\bar{\nu})$+jets	5106 ± 271	1908 ± 143	900 ± 94	433 ± 62
W+jets	2632 ± 237	816 ± 83	312 ± 35	135 ± 17
tt̄	69.8 ± 69.8	22.6 ± 22.6	8.5 ± 8.5	3.0 ± 3.0
$Z(\ell\ell)$+jets	22.3 ±22.3	6.1 ± 6.1	2.0 ± 2.0	0.6 ± 0.6
Single t	10.2 ±10.2	2.7 ± 2.7	1.1 ± 1.1	0.4 ± 0.4
QCD Multijets	2.2 ±2.2	1.3 ±1.3	1.3 ±1.3	1.3 ±1.3
Total SM	7842 ± 367	2757 ± 167	1225 ± 101	573± 65
Data	7584	2774	1142	522
Expected upper limit non-SM	779	325	200	118
Observed upper limit non-SM	600	368	158	95

Good agreement with SM

Monojet

arXiv:1210.4491
(submitted to JHEP)





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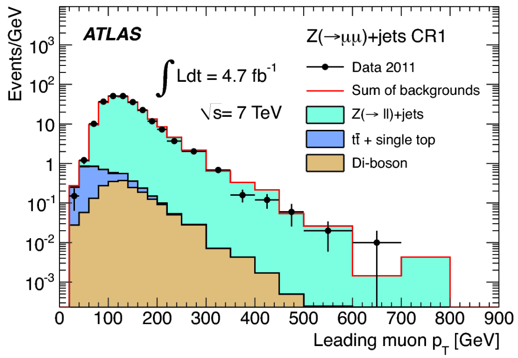
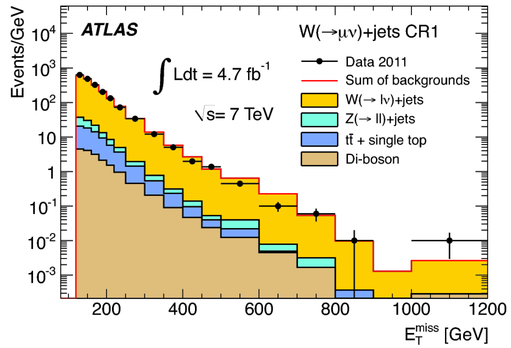




E_T^{miss} > 120, 220, 350, 500 GeV
p_T (j1) > 120, 220, 350, 500 GeV
$N_{jet}(p_T$ > 30 GeV) < 3

$\Delta\phi$ (E_T^{miss}, j2) > 0.5
Lepton vetoes

	SR1	SR2	SR3	SR4
$Z \to \nu\bar{\nu}$+jets	63000 ± 2100	5300 ± 280	500 ± 40	58 ± 9
$W \to \tau\nu$+jets	31400 ± 1000	1853 ± 81	133 ± 13	13 ± 3
$W \to e\nu$+jets	14600 ± 500	679 ± 43	40 ± 8	5 ± 2
$W \to \mu\nu$+jets	11100 ± 600	704 ± 60	55 ± 6	6 ± 1
$t\bar{t}$ + single t	1240 ± 250	57 ± 12	4 ± 1	-
Multijets	1100 ± 900	64 ± 64	8^{+9}_{-8}	-
Non-coll. Background	575 ± 83	25 ± 13	-	-
$Z/\gamma^* \to \tau\tau$+jets	421 ± 25	15 ± 2	2 ± 1	-
Di-bosons	302 ± 61	29 ± 5	5 ± 1	1 ± 1
$Z/\gamma^* \to \mu\mu$+jets	204 ± 19	8 ± 4	-	-
Total Background	124000 ± 4000	8800 ± 400	750 ± 60	83 ± 14
Events in Data (4.7 fb^{-1})	124703	8631	785	77

Good agreement with SM

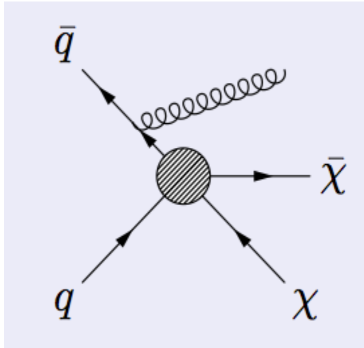
Effective Theory

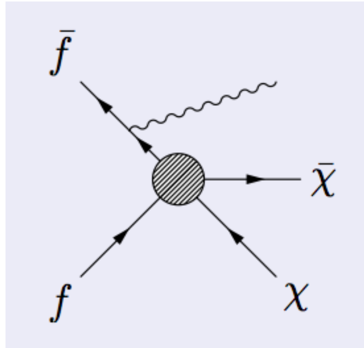
(model independent approach)

Effective Lagrangian approach (contact interaction) with parameters M_* (Λ) and m_χ

$$M_*^2 \sim M^2/g_1 g_2$$

assuming the interaction is mediated by a heavy particle with mass M and couplings g_1 and g_2





Different operators are considered with different structures and here χ will be taken as Dirac fermions

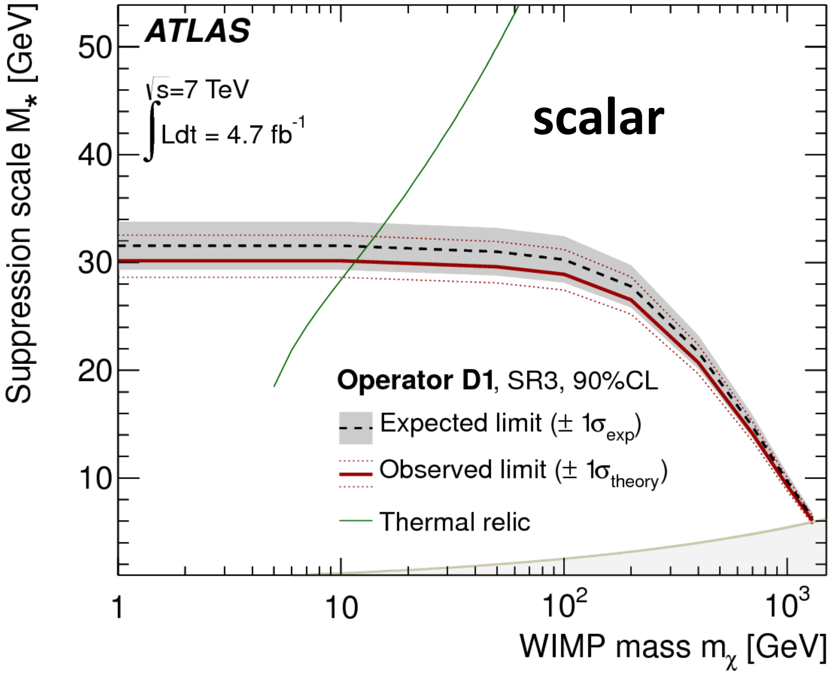
Name	Initial state	Type	Operator
D1	qq	scalar	$\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_\star^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

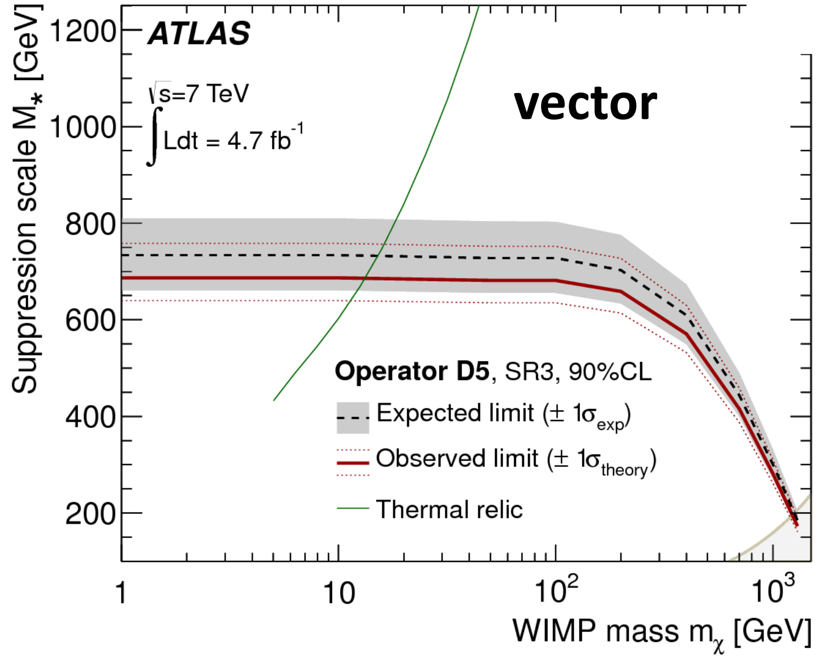
Important note:

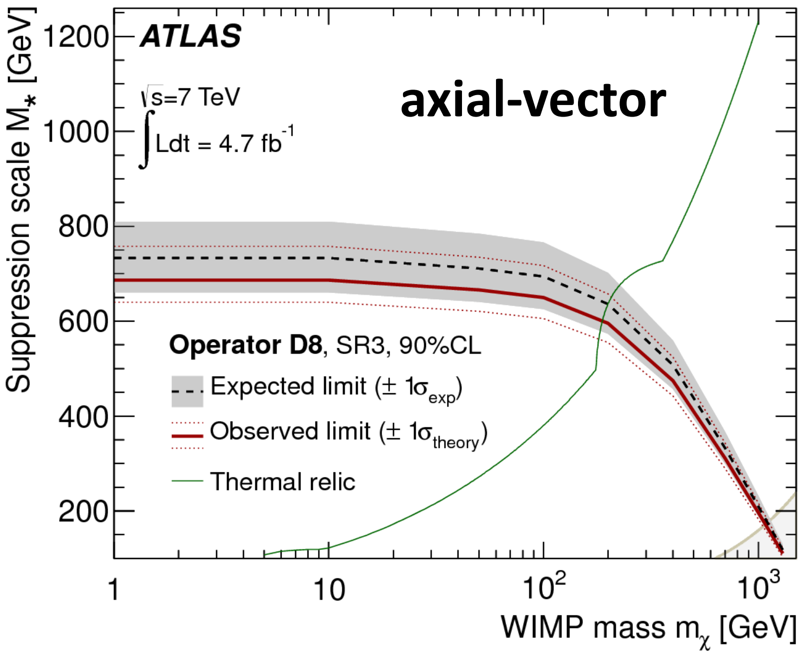
Not clear whether the effective approach under- or over-estimates the cross sections since this depends on the details of the unknown UV limit of the theory

Strictly speaking theory only applicable when M is much larger than the energy scale present in the reaction [$Q^2 << (4\pi M_*)^2$]

Limits on WIMP production



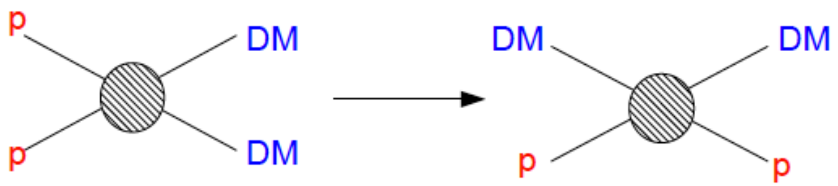




90% CL on the visible cross sections for new physics are translated into limits on M_* as a function of the WIMP mass for the different operators

Line indicates the values for M_* and m_χ leading to the proper abundance (WMAP)

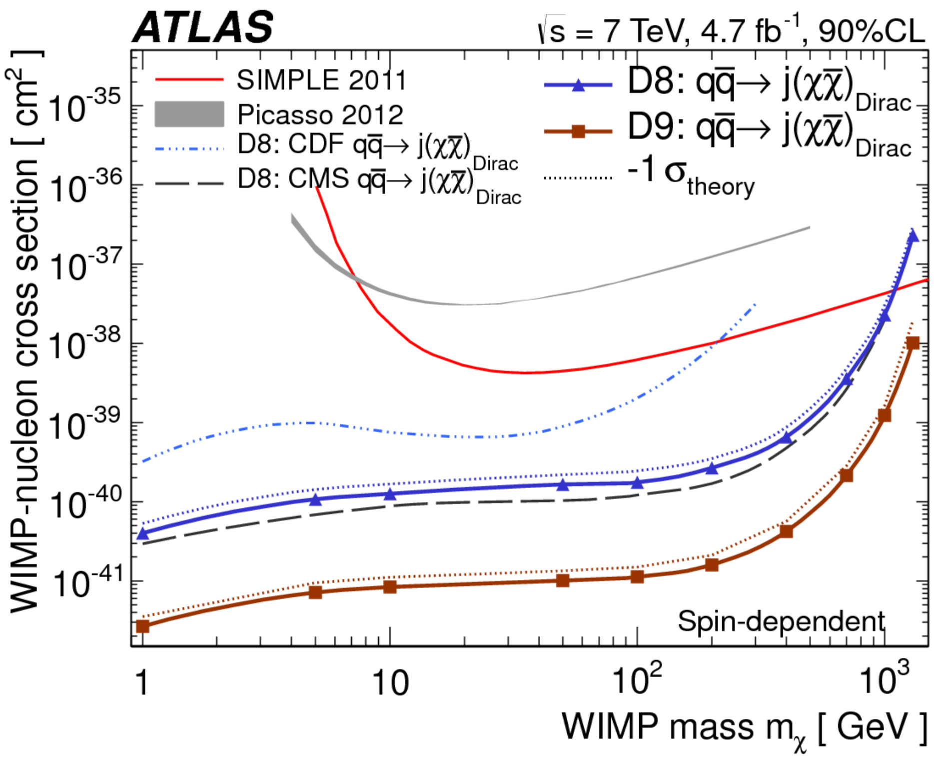
WIMP-nucleon cross section

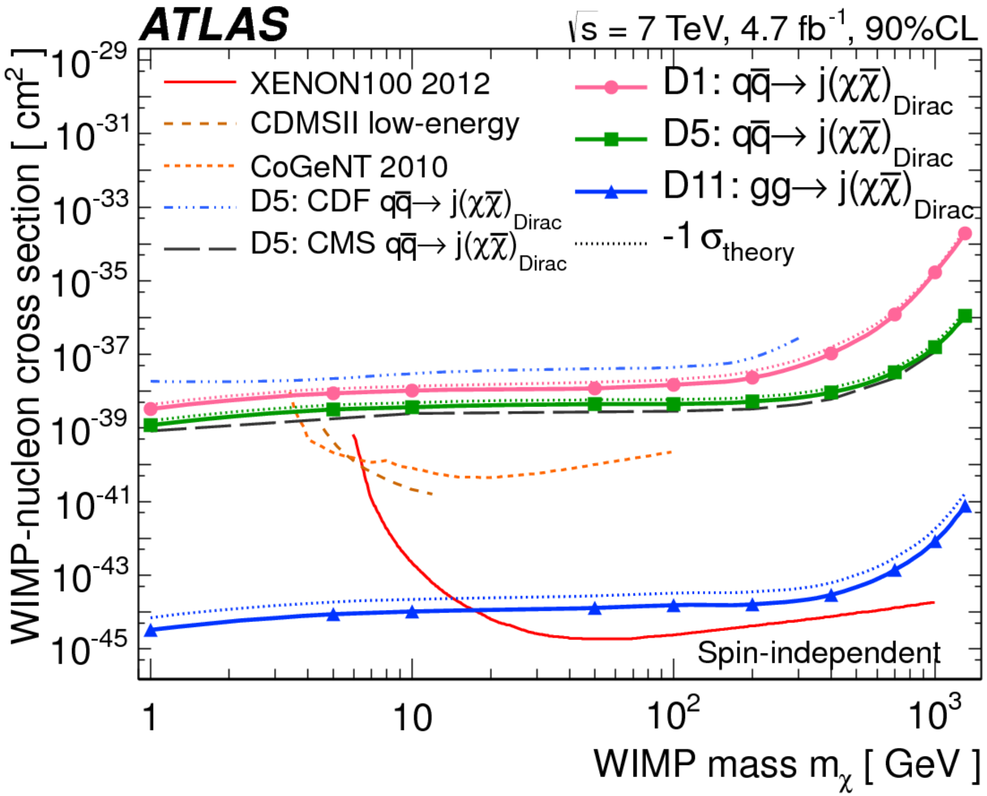


$$\sigma_0^{D1} = 1.60 \times 10^{-37}\mathrm{cm}^2 \left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2 \left(\frac{20\mathrm{GeV}}{M_*}\right)^6,$$

$$\sigma_0^{D5,C3} = 1.38 \times 10^{-37}\mathrm{cm}^2 \left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2 \left(\frac{300\mathrm{GeV}}{M_*}\right)^4,$$

Different operators contribute either to spin-dependent or spin-independent WIMP-nucleon cross sections

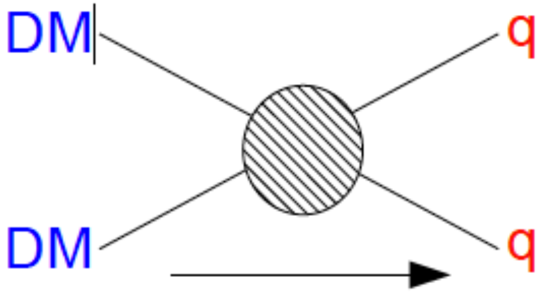




***Within the assumption of the validity of the effective theory* the LHC results are competitive to direct detector experiments (particularly relevant at m_χ < 10 GeV)**

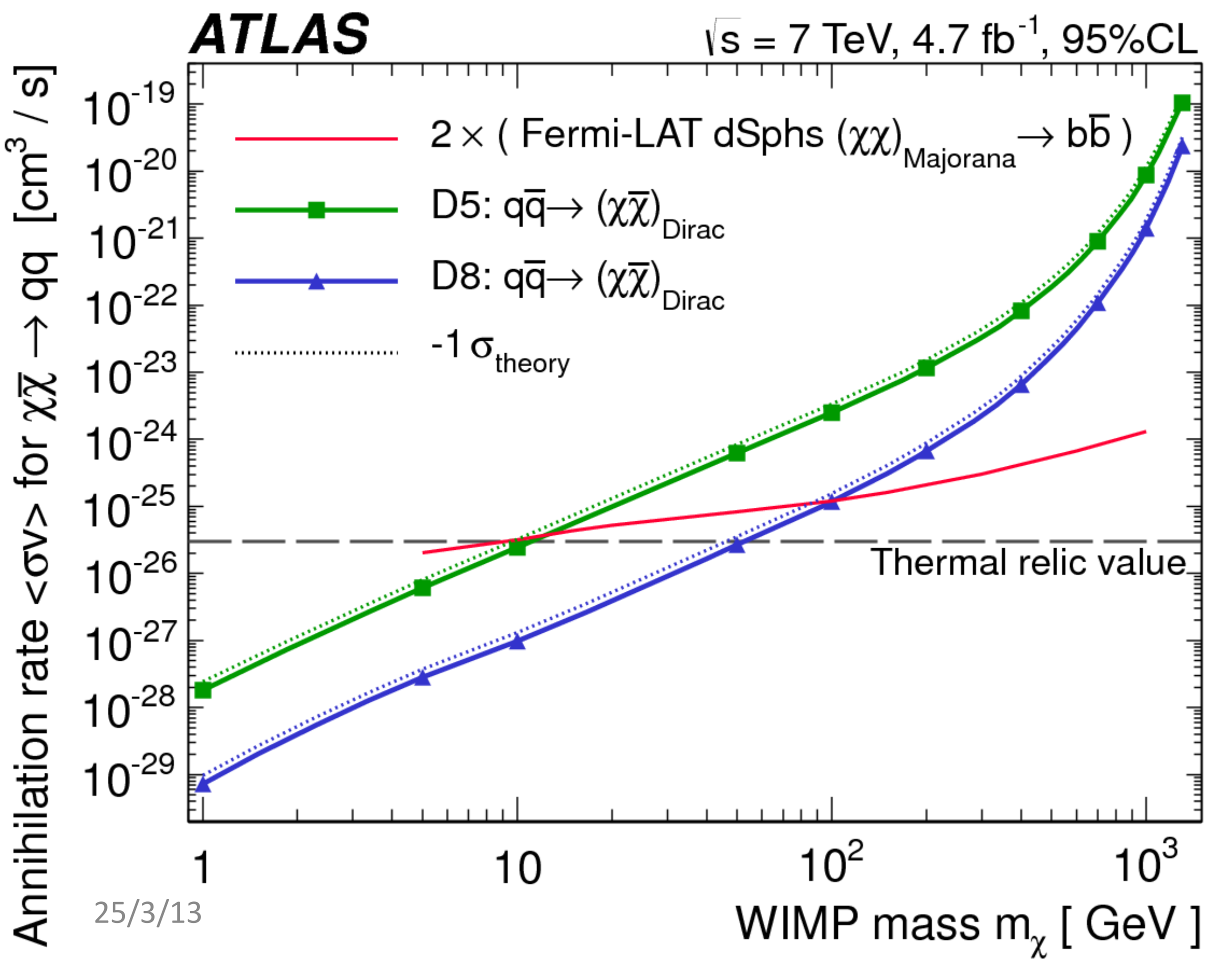
Large sensitivity in case of D11 (gg initiated)

WIMP-WIMP annihilation



$$\sigma_V v_{\rm rel} = \frac{1}{16\pi\Lambda^4}\sum_q \sqrt{1-\frac{m_q^2}{m_\chi^2}}\left(24(2m_\chi^2+m_q^2)+\frac{8m_\chi^4-4m_\chi^2 m_q^2+5m_q^4}{m_\chi^2-m_q^2}v_{\rm rel}^2\right),$$

$$\sigma_A v_{\rm rel} = \frac{1}{16\pi\Lambda^4}\sum_q \sqrt{1-\frac{m_q^2}{m_\chi^2}}\left(24m_q^2+\frac{8m_\chi^4-22m_\chi^2 m_q^2+17m_q^4}{m_\chi^2-m_q^2}v_{\rm rel}^2\right).$$



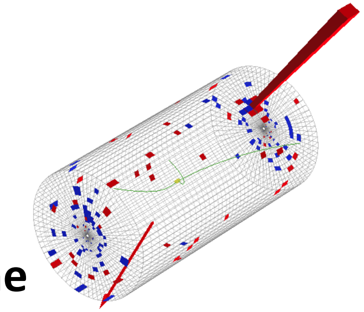
Results can be expressed in terms of limits on WIMP-WIMP annihilation cross section (assuming the interaction is dominated by a given operator)

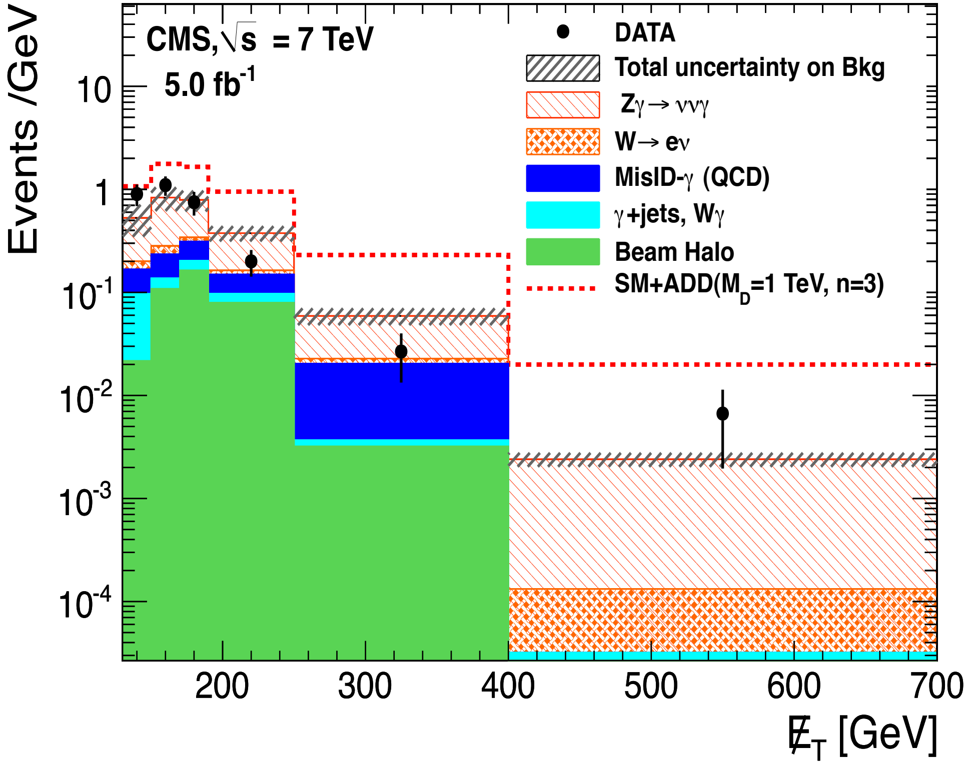
For a given operator, WIMPS are required to have a minimum mass to meet the annihilation rate (and therefore the proper relic abundance)

Alternatively, for light WIMPS more than a single process is needed

Mono-photons

Phys. Rev. Lett.108 261803





Background dominated by the irreducible Zγ (→ ννγ) contribution followed by photon fakes and non-collision background, plus other small contributions

- **QCD-jet fakes data driven using EM-enriched sample with loose photon requirements**
- **Time distribution of the calorimeter energy deposit used to estimate non-collision background**

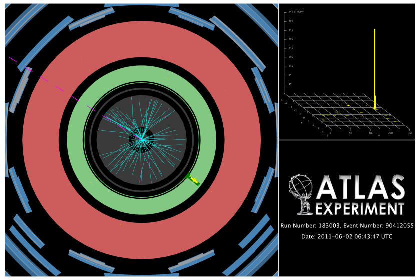
P_t^{γ} >145 GeV, $|\eta^{\gamma}|$ < 1.44, isolated
E_t^{miss} > 130 GeV
Veto on leptons, isolated tracks, jets

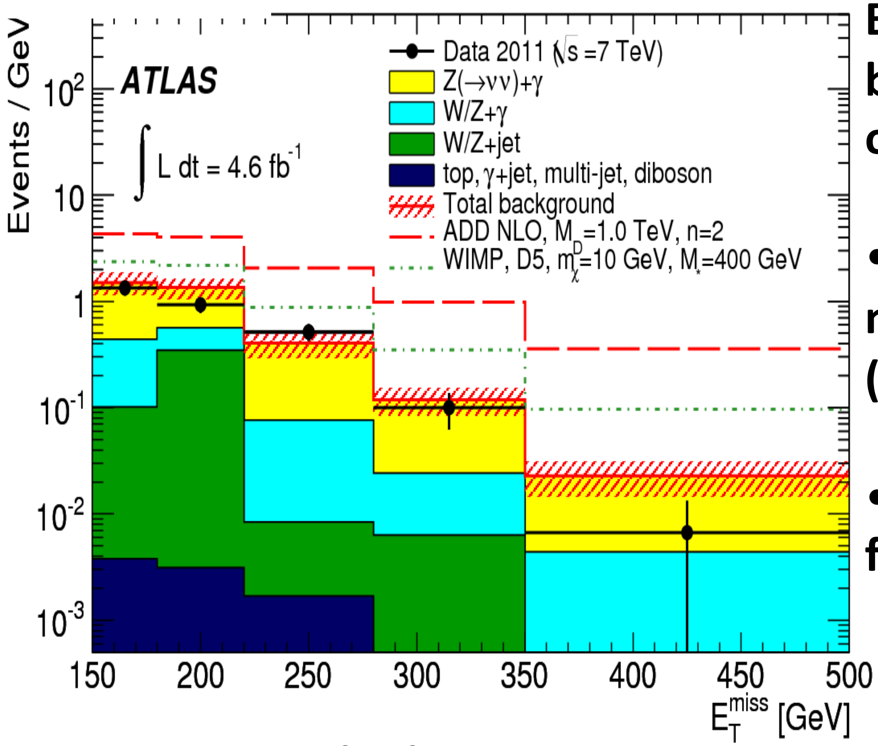
Source	Estimate
Jet Mimics Photon	11.2 ± 2.8
Beam Halo	11.1 ± 5.6
Electron Mimics Photon	3.5 ± 1.5
$W\gamma$	3.0 ± 1.0
γ+jet	0.5 ± 0.2
$\gamma\gamma$	0.6 ± 0.3
$Z(\nu\bar{\nu})\gamma$	45.3 ± 6.9
Total Background	75.1 ± 9.5
Total Observed Candidates	73

Good agreement with SM

Mono-photons

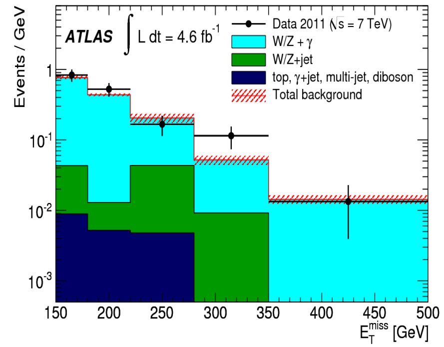
Phys. Rev. Lett 110, 011802 (2013)





Background dominated by Z/W+γ followed by contributions with jets faking photons plus other small contributions

- Z/W+γ contributions from MC normalized in control regions (γ+ μ + E_t^{miss} control sample)



- Jet and electron fakes fully data driven

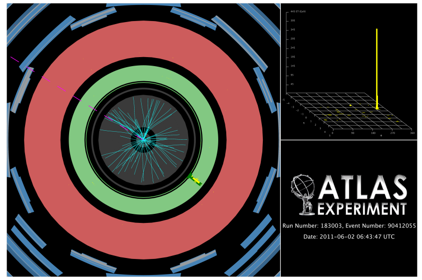
P_t^γ >150 GeV, $|\eta^\gamma|$ < 2.37, isolated
E_t^{miss} > 150 GeV
N^{jet} < 2 (p_T > 30 GeV)
$\Delta\phi$ (γ, E_T^{miss}) >0.4, $\Delta\phi$ (jet, E_T^{miss}) >0.4
Veto on leptons

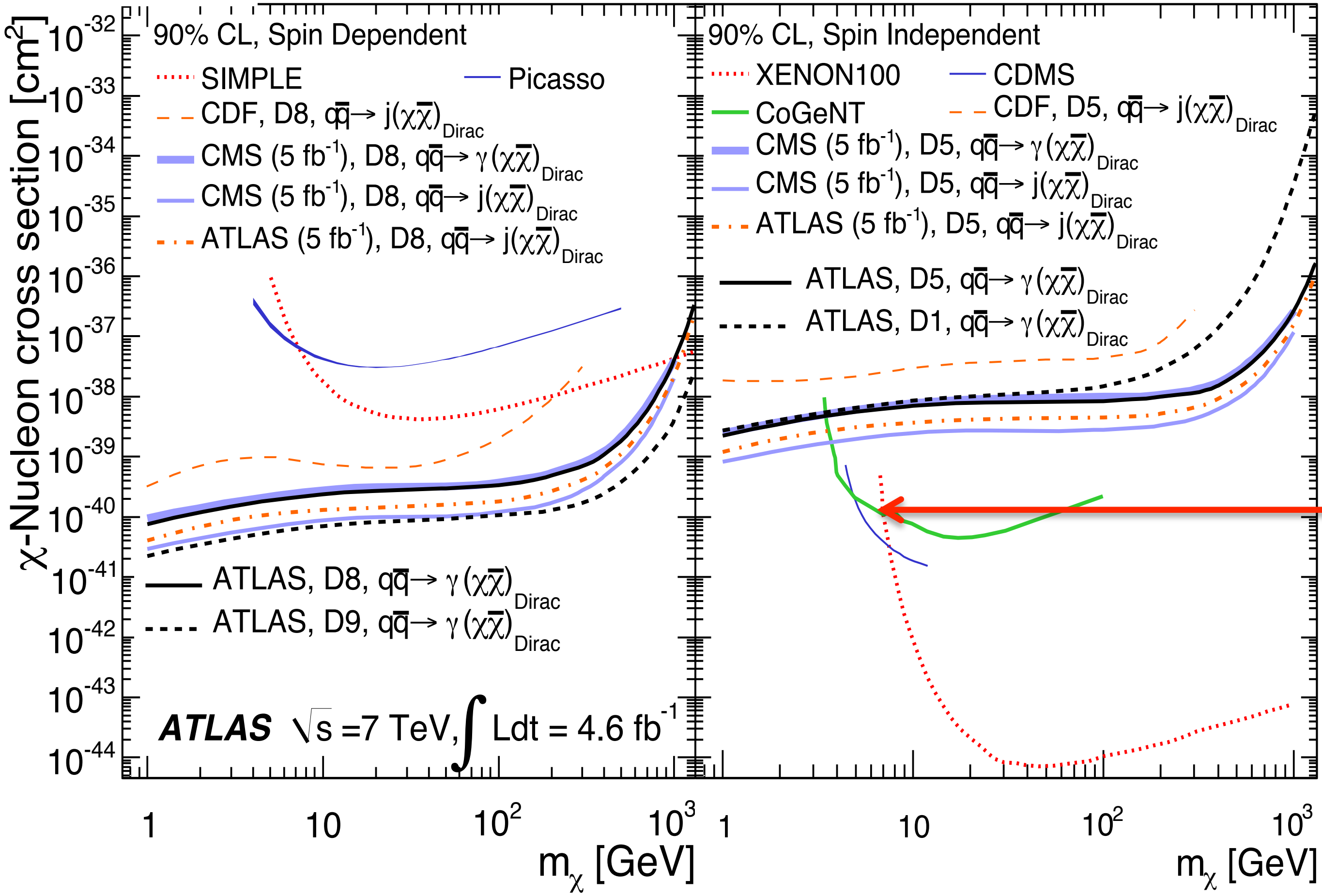
Background source	Prediction	± (stat.)	± (syst.)
$Z(\to \nu\bar{\nu}) + \gamma$	93	± 16	± 8
$Z/\gamma^*(\to \ell^+\ell^-) + \gamma$	0.4	± 0.2	± 0.1
$W(\to \ell\nu) + \gamma$	24	± 5	± 2
W/Z + jets	18	–	± 6
Top	0.07	± 0.07	± 0.01
$WW, WZ, ZZ, \gamma\gamma$	0.3	± 0.1	± 0.1
γ+jets and multi-jet	1.0	–	± 0.5
Total background	137	± 18	± 9
Events in data (4.6 fb^{-1})	116		

Good agreement with SM

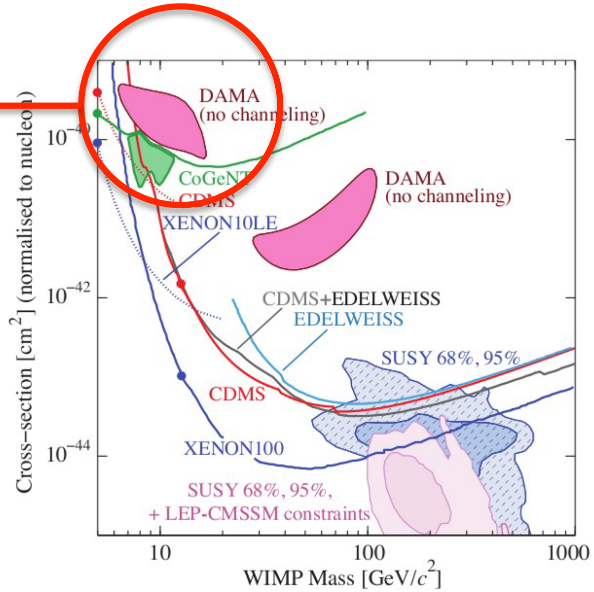
WIMPS

(monojets & monophotons)

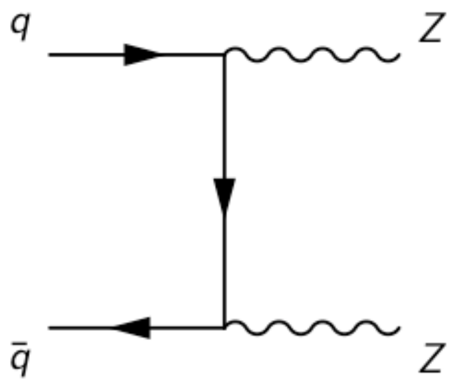




Not enough sensitivity yet to exclude/confirm the CoGeNT/DAMA excess at m_χ~10 GeV in case the of D1/D5 models



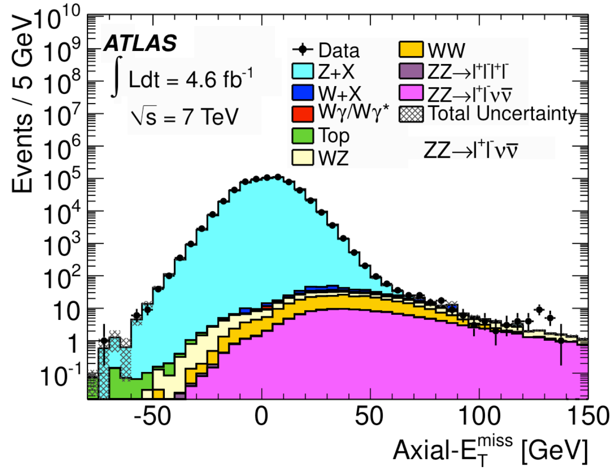
Very significant improvement on limits compared to Tevatron
For m_χ < 100 GeV : WIMPS-nucleon cross sections above 3×10^{-40} cm² (10^{-39} cm²) are excluded for spin –dependent (spin-independent) operators



Mono-Z

(ZZ → ll νν)

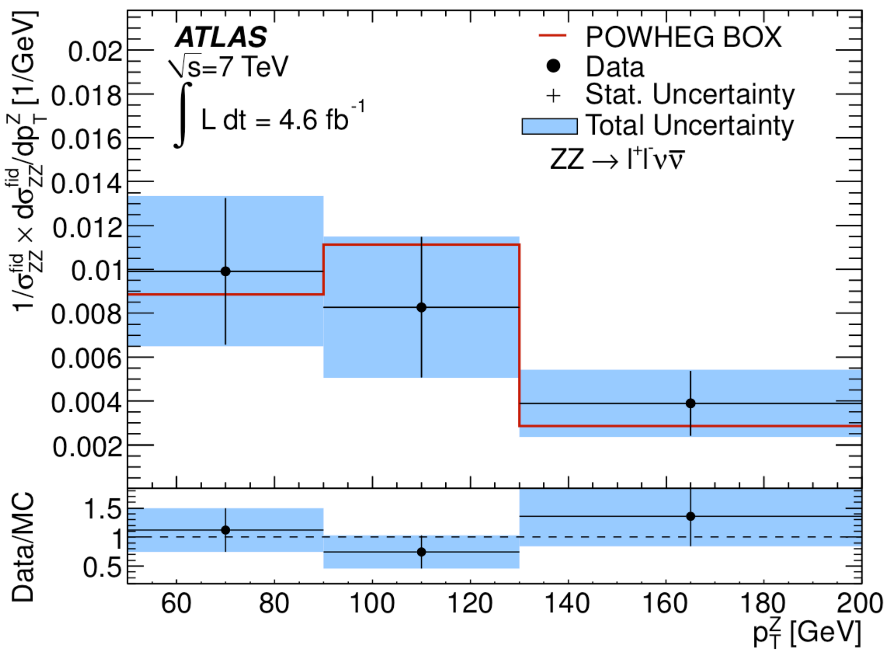
arXiv:1211.6096

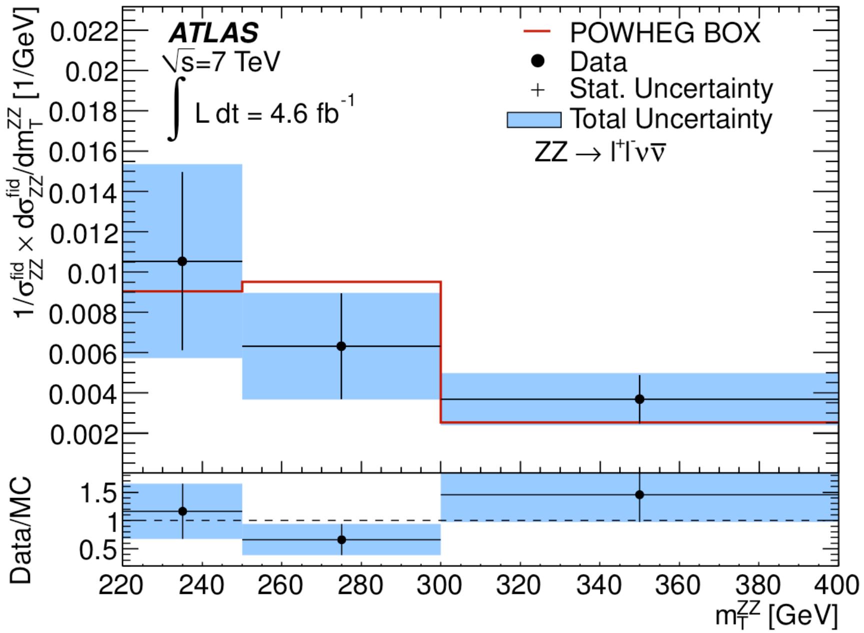


No jets with p_T above 25 GeV

$$(|p_T^{\nu\bar{\nu}} - p_T^Z|)/p_T^Z < 0.6$$

$$-p_T^{\nu\bar{\nu}} \times \cos(\Delta\phi(p_T^{\nu\bar{\nu}}, p_T^Z)) > 80 \text{ GeV}$$





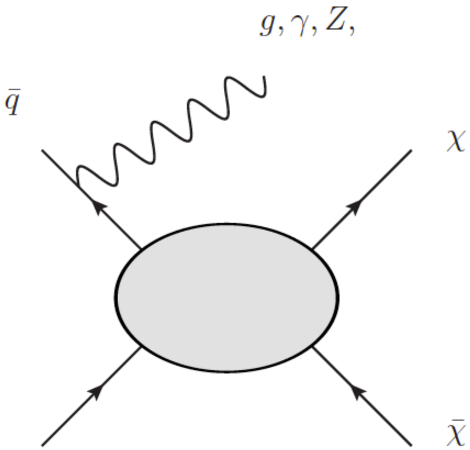
$$\sigma^{\text{fid}}_{ZZ\to\ell^+\ell^-\nu\bar{\nu}} = 12.7^{+3.1}_{-2.9}\ (\text{stat.})\ ^{+1.7}_{-1.7}\ (\text{syst.}) \pm 0.5\ (\text{lumi.})\ \text{fb}.$$

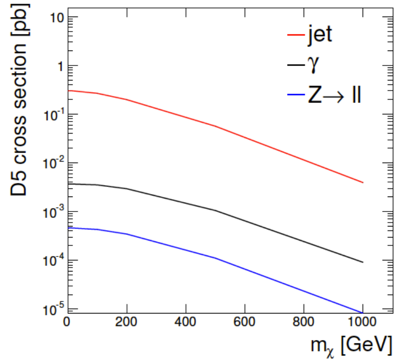
In good agreement with SM predictions

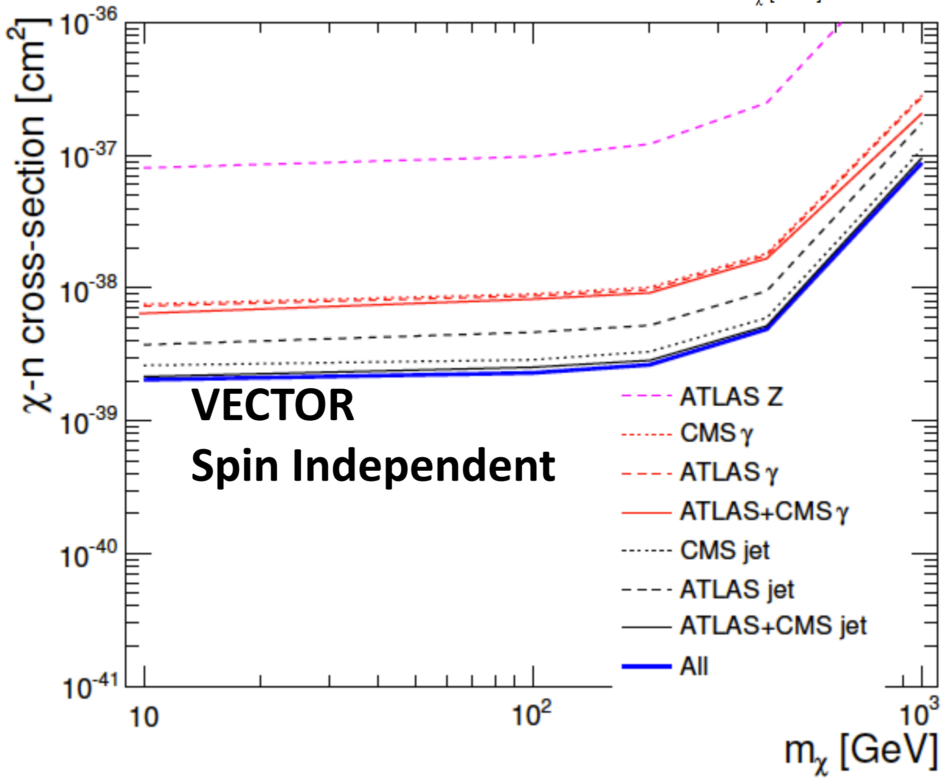
This can be used to put limits on χχ+Z

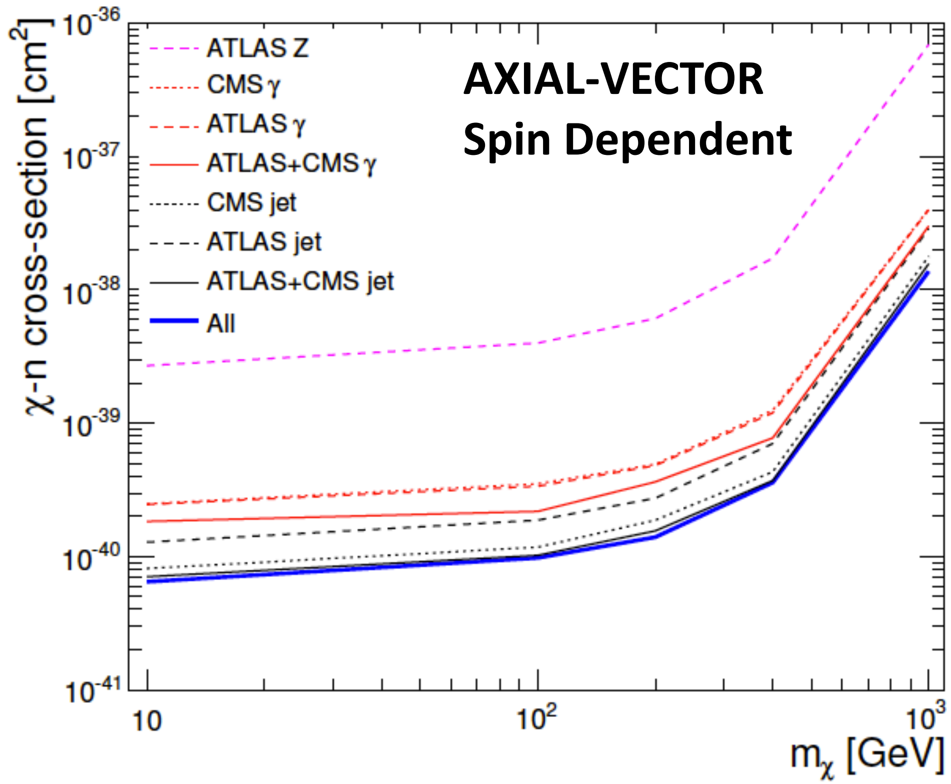
Un-official combination ATLAS & CMS Mono-X

Ning Zhou et al., arXiv:1302.3619









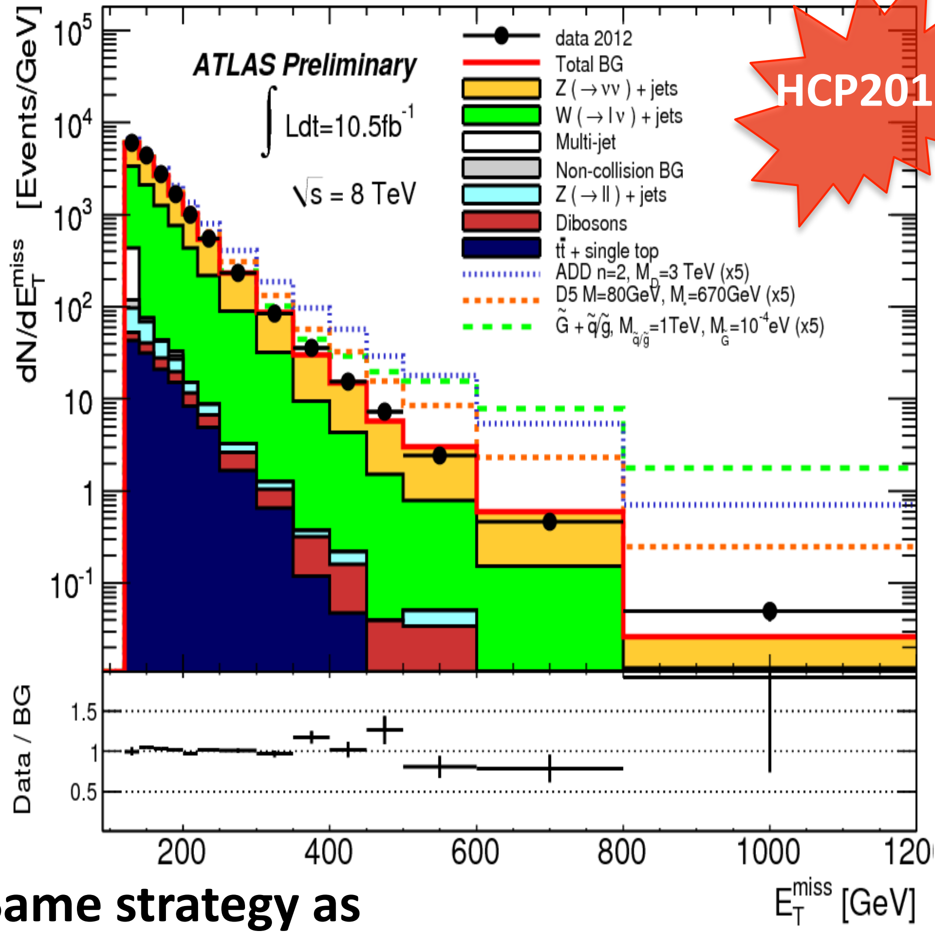
As expected the combination is totally dominated by the mono-jet results

8 TeV Monojets

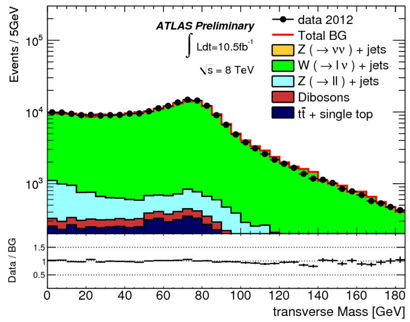
HCP2012

10 fb^{-1}

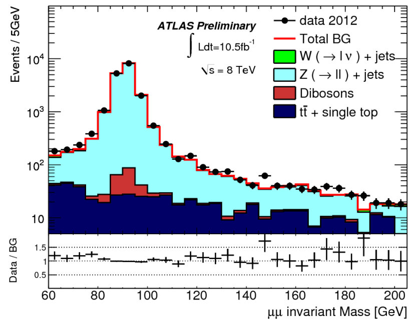
ATLAS-CONF-2012-147



single-muon events



dimuon events

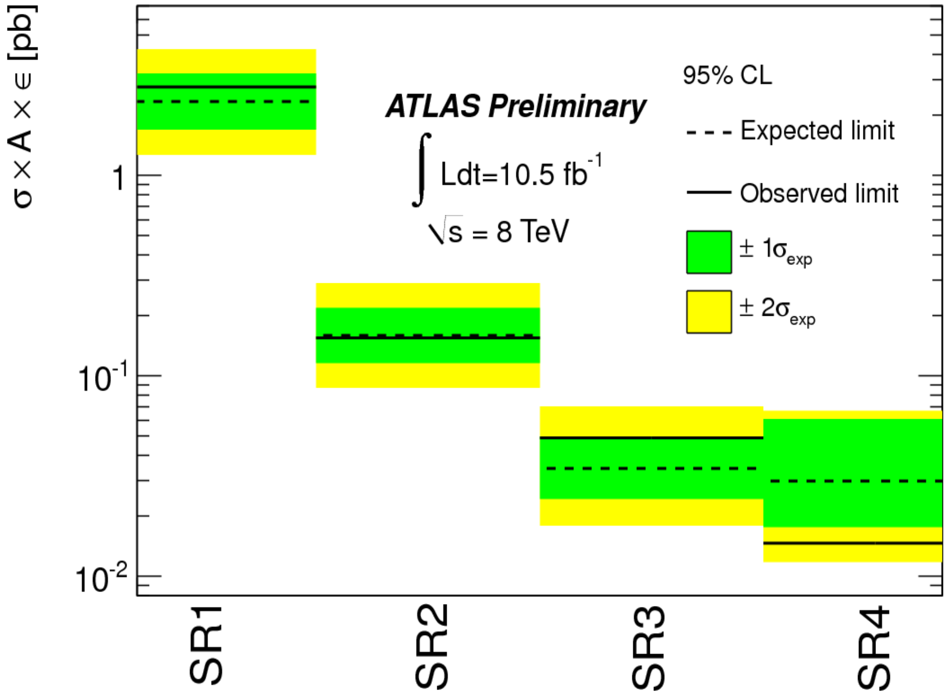


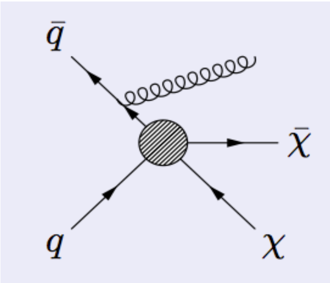
Same strategy as in the 7 TeV analysis

E_T^{miss} > 120, 220, 350, 500 GeV
p_T (j1) > 120, 220, 350, 500 GeV
$N_{jet}(p_T$ > 30 GeV) < 3
$\Delta\phi$ (E_T^{miss}, j2) > 0.5
Lepton vetoes

Good agreement with SM predictions

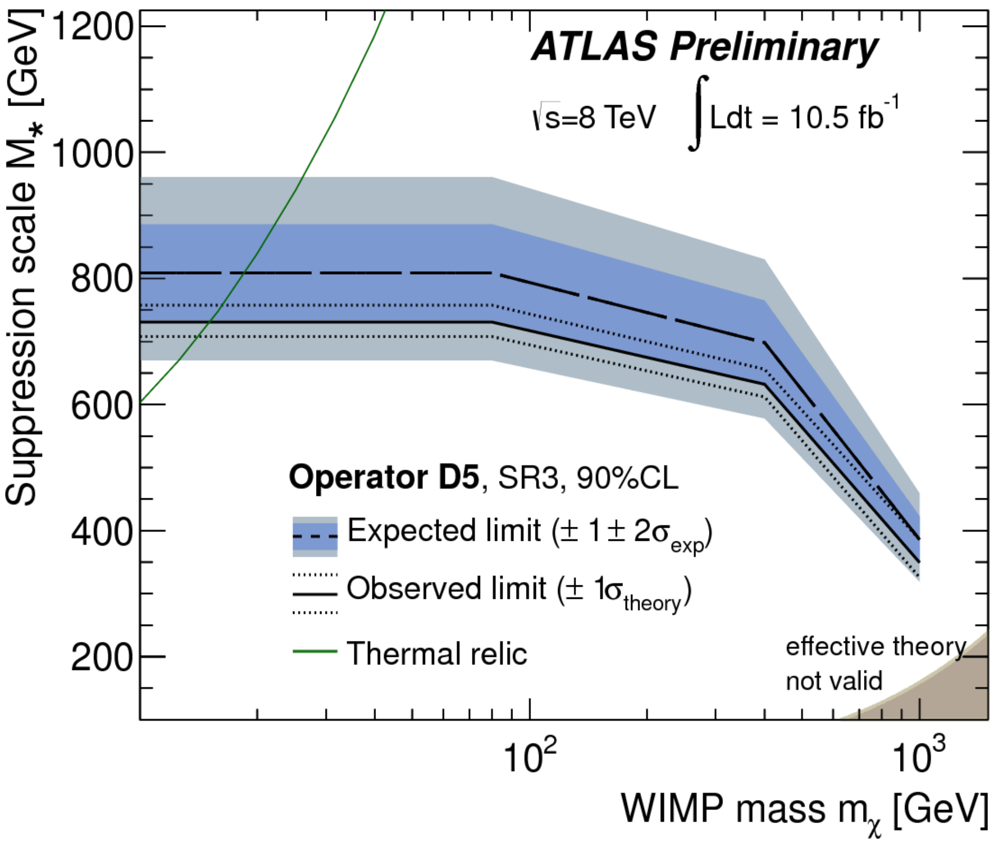
(suffered from lack of MC statistics)



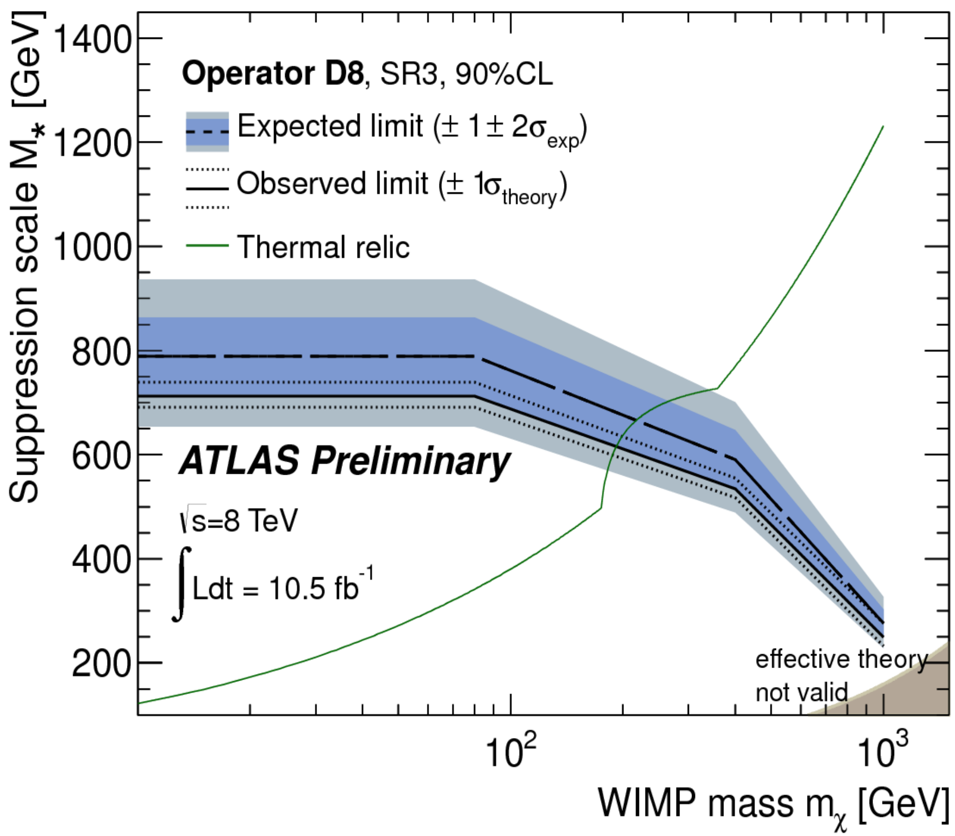


90% CL Limits on suppression scale

VECTOR



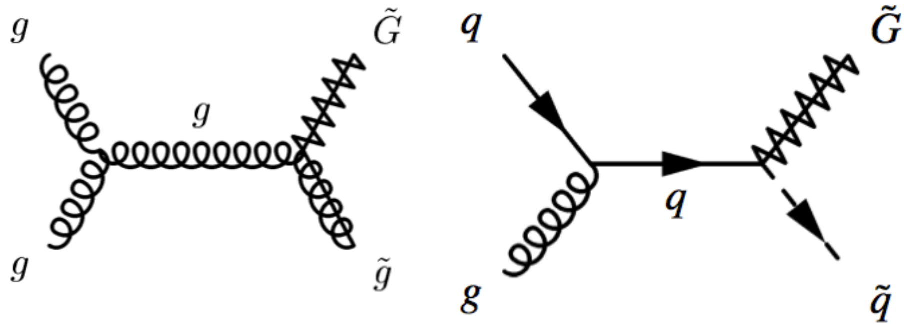
AXIAL-VECTOR



Modest (~10%) improved with respect to 7 TeV limits (due to Backg. MC statistics limitations)

GMSB Gravitino

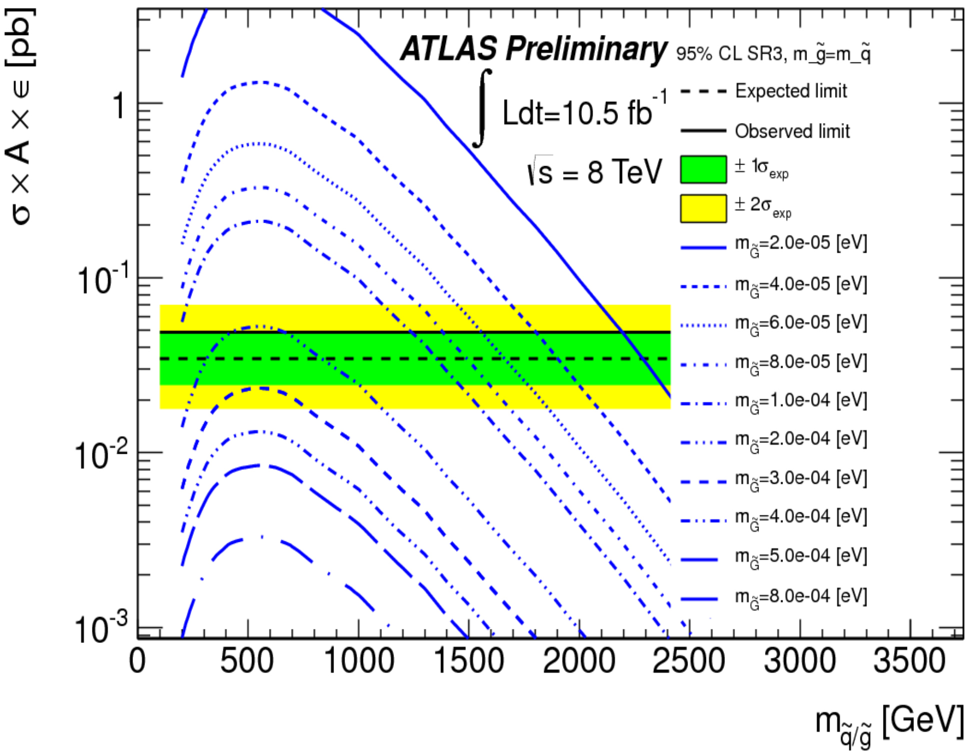
$$m_{3/2} = \langle F \rangle / \sqrt{3}\, \overline{M}_{\rm Pl}$$

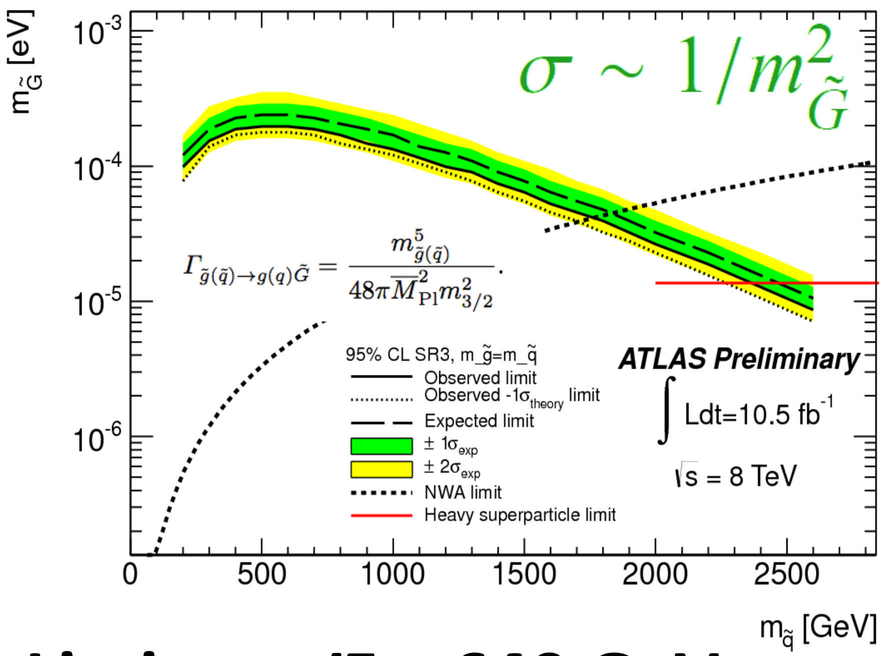


Interpreted in terms of GMSB gravitino+squark/gluino production

gluinos (squarks) decay to gluon (quark) plus Gravitino (100%)

Best limits to date on the gravitino mass

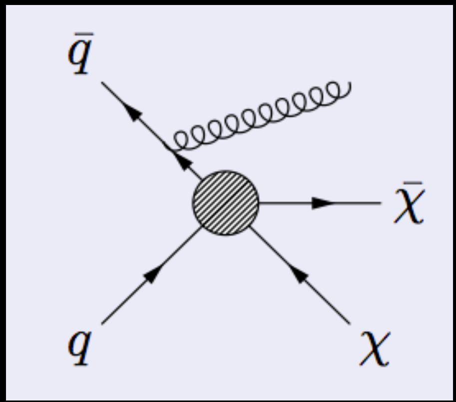


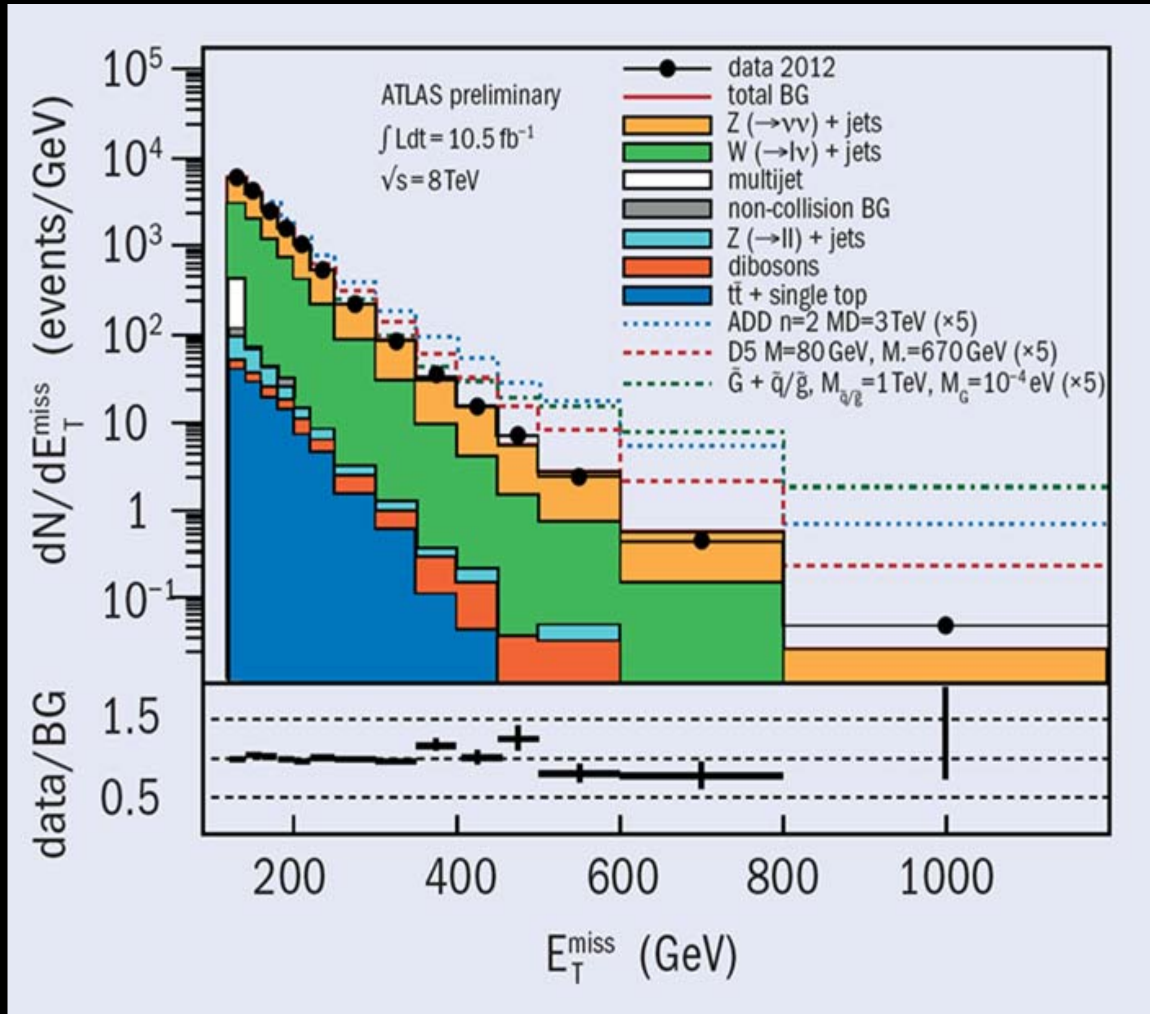


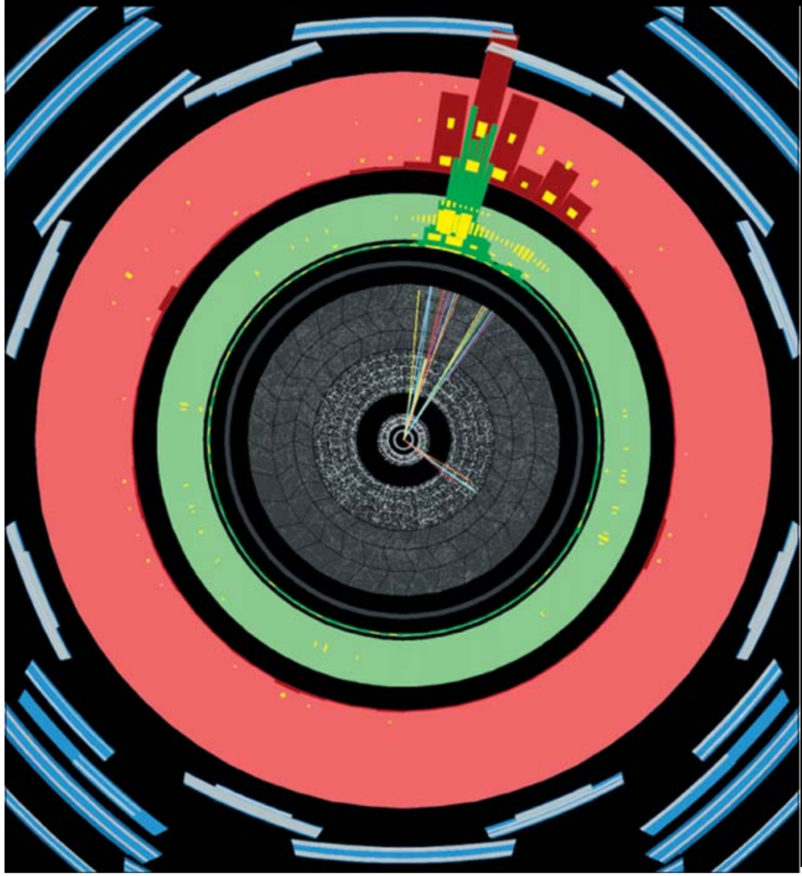
Limit on √F > 640 GeV

(LEP limit 240 GeV)

CERN Courier



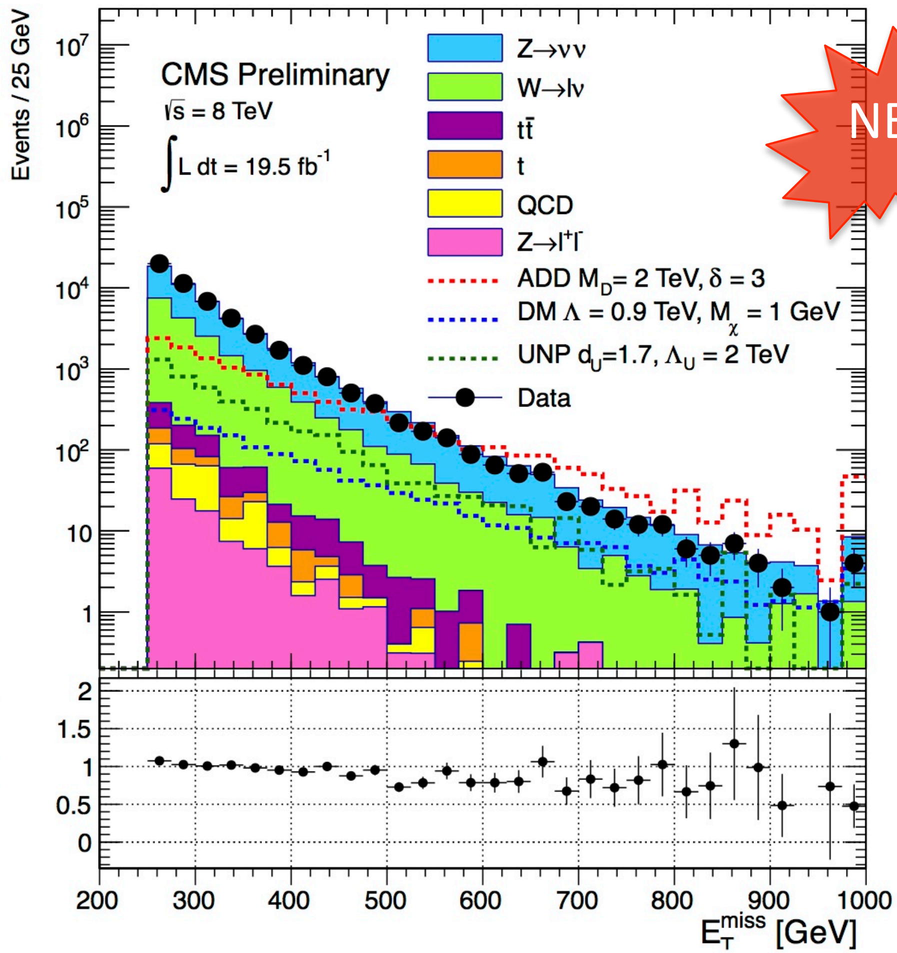




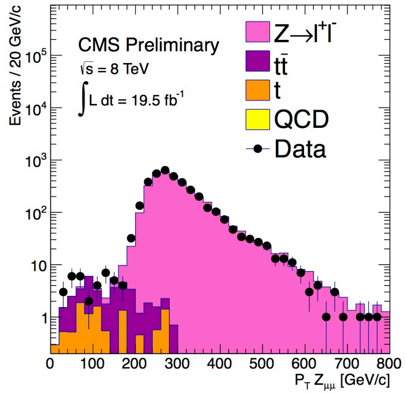
Highlight of the January 2013 Edition

Monojet 8 TeV 19.5 fb^{-1}

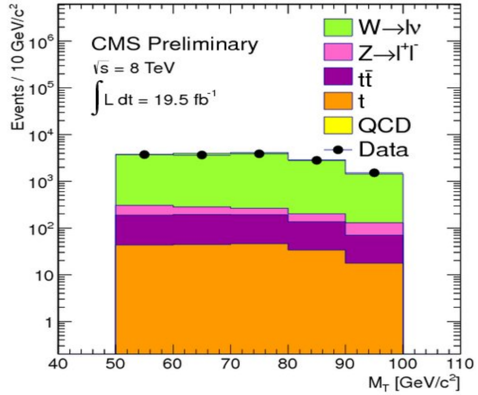
CMS-PAS-EXO-12-048



dimuon events



single-muon events

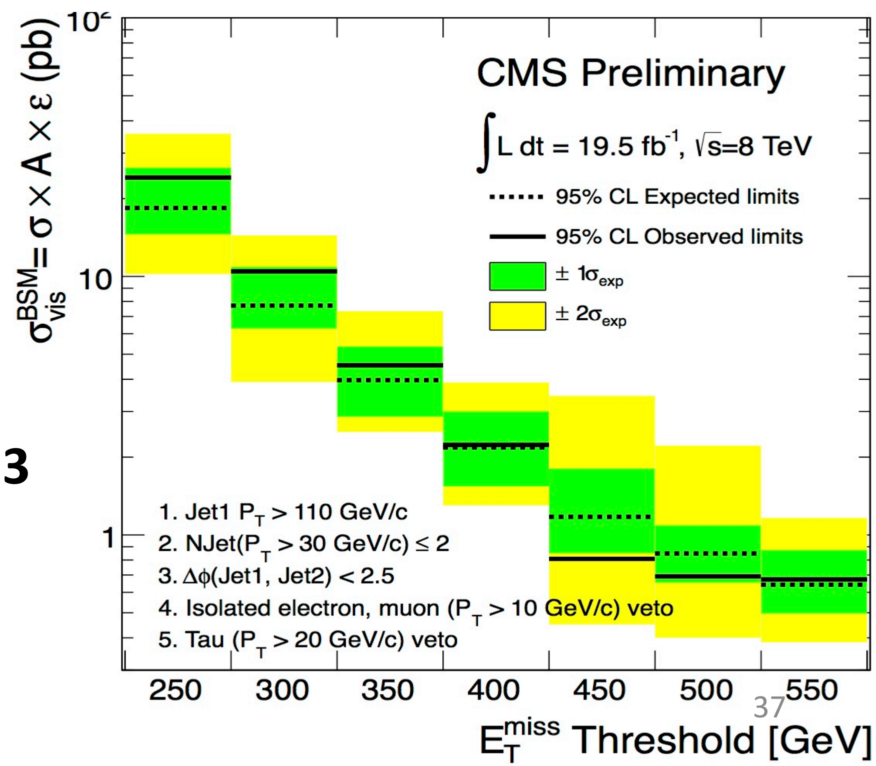


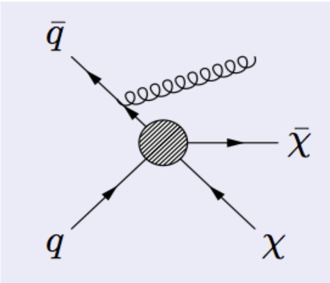
Same strategy as in the 7 TeV analysis

$E_t^{miss} > 200$ GeV
p_T (j1) > 110 GeV
$N_{jet}(p_T >$ 30 GeV) < 3

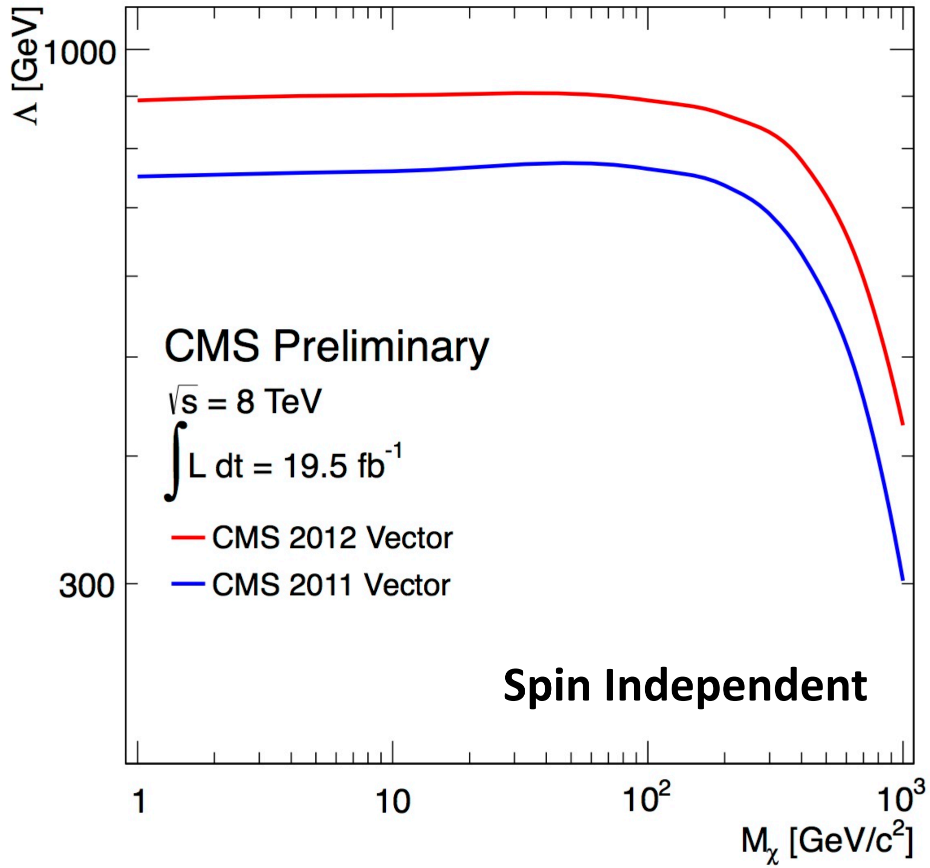
$\Delta\phi$ (j1,j2) < 2.5
Lepton vetoes

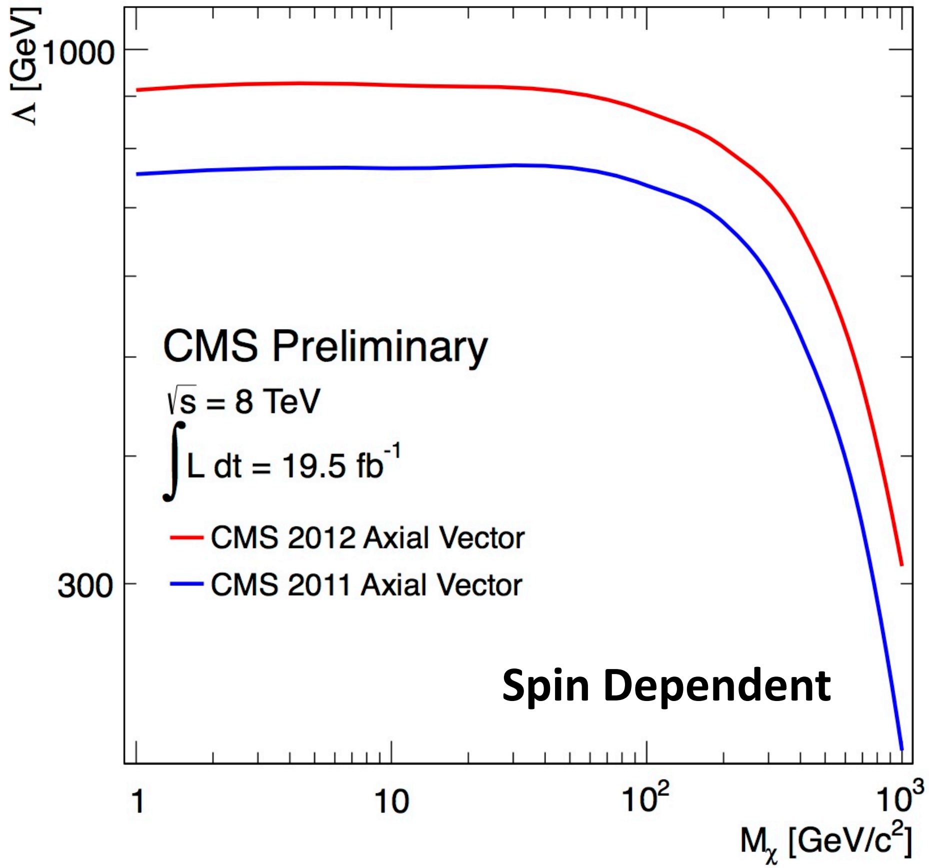
Good agreement with SM predictions



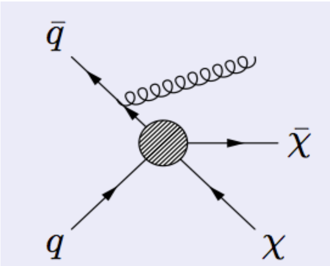


90% CL Limits on suppression scale

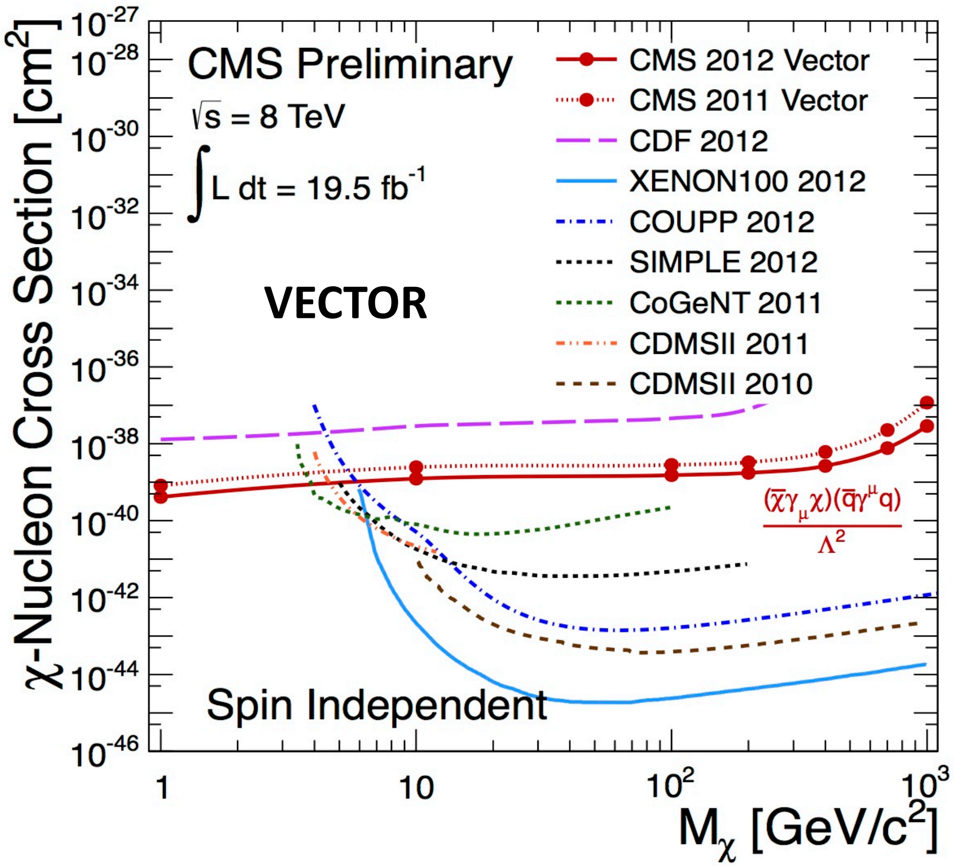


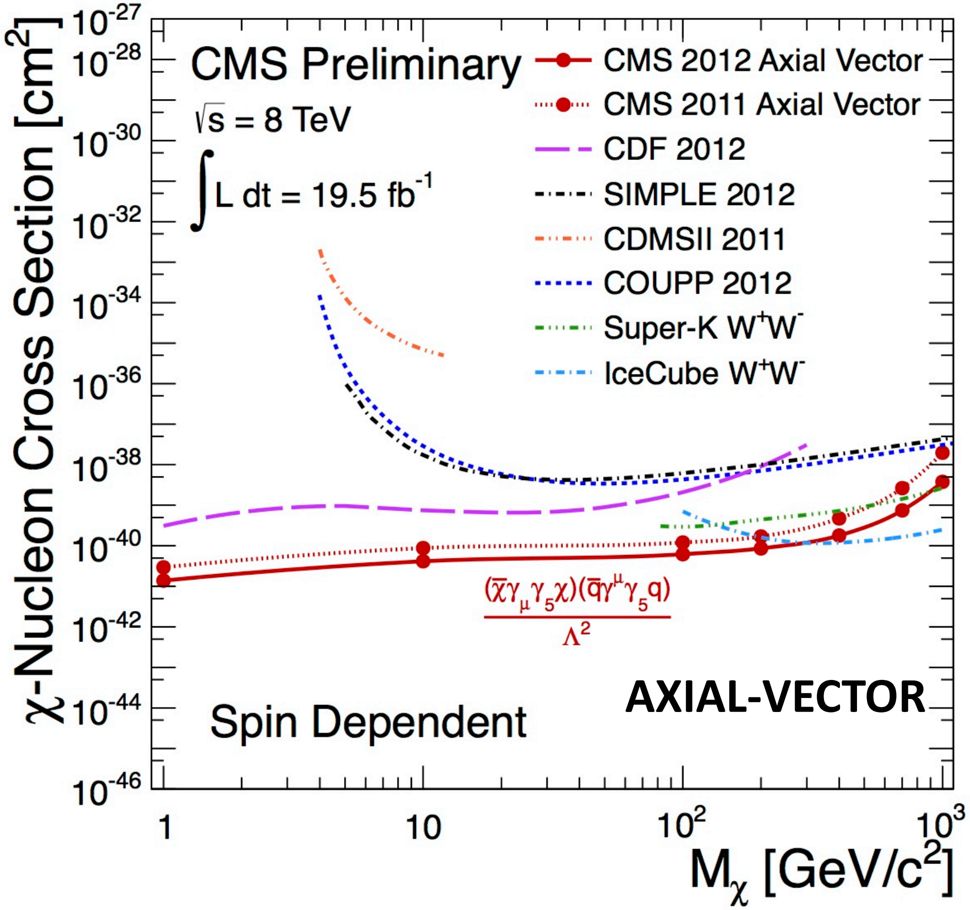


8 TeV data improves previous limits on Λ (M_*) by about 150 GeV (approaching the 1 TeV scale)



90% CL Limits on WIMP-nucleon

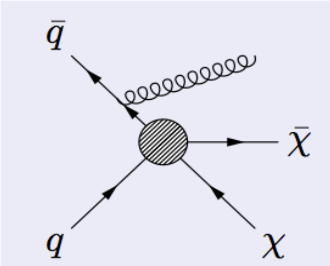




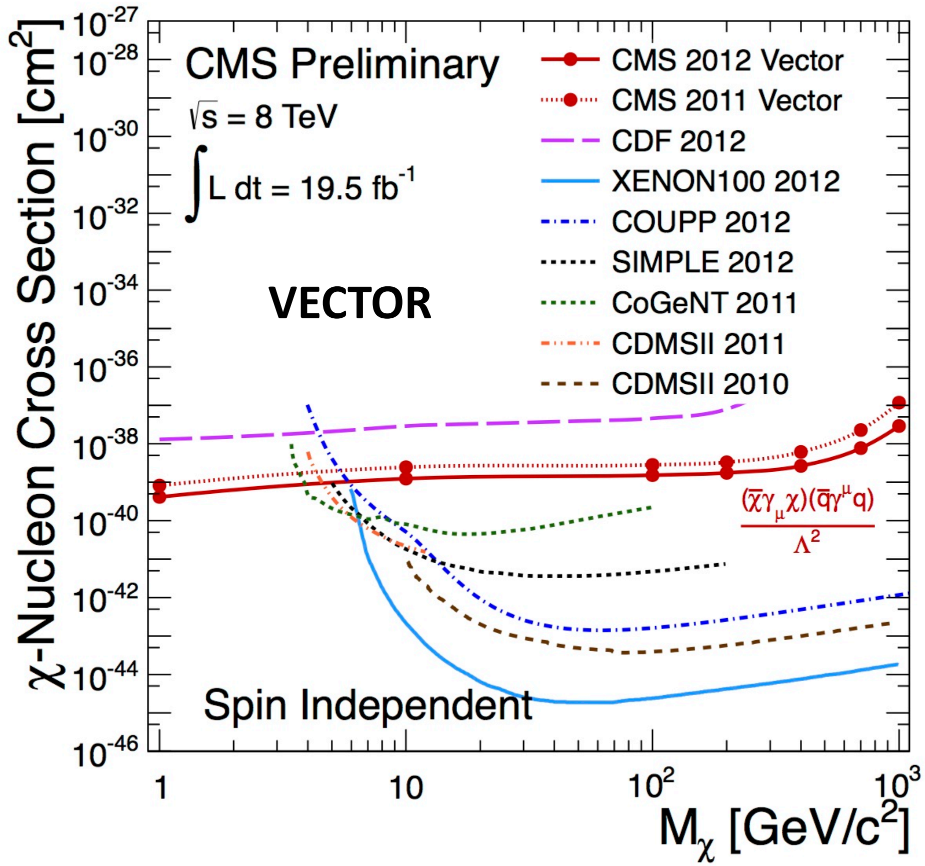
For m_χ ~ 10 GeV :

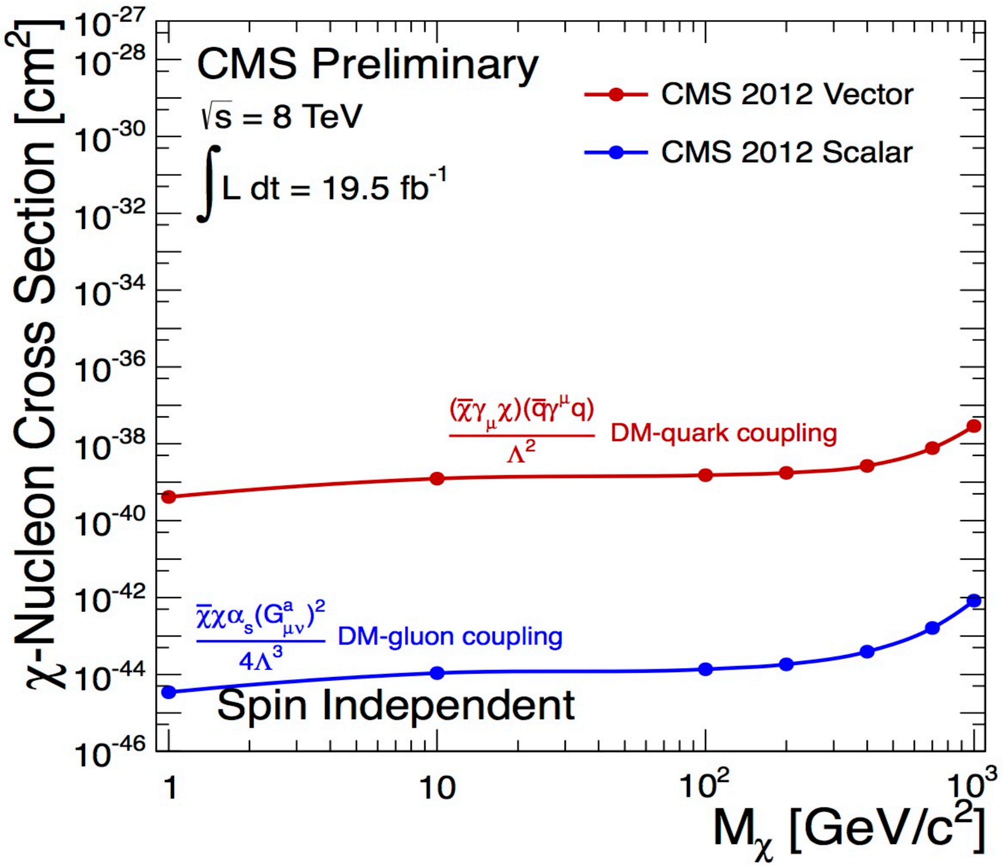
WIMP-nucleon x-section > 1.2 x10^{-39} cm^2 at 90% CL (vector operator)

WIMP-nucleon x-section > 4.2 x10^{-41} cm^2 at 90% CL (axial vector operator)



90% CL Limits on WIMP-nucleon





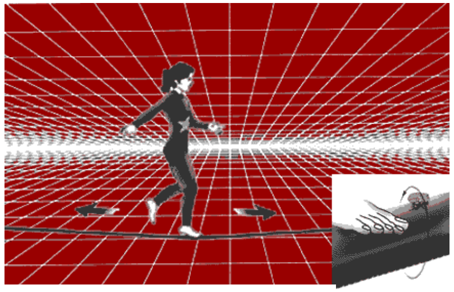
For m_χ ~ 10 GeV :

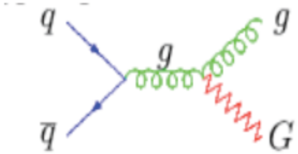
WIMP-nucleon x-section > 1.2 x10^{-39} cm^2 at 90% CL (vector operator)

WIMP-nucleon x-section > 1.1 x10^{-44} cm^2 at 90% CL (scalar)

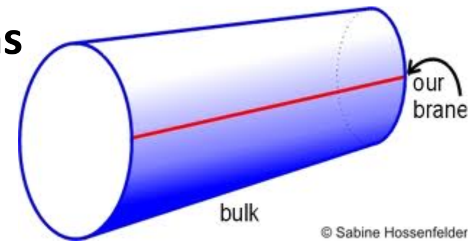

?
SUSY and/or DM discovery might eventually require more energy and more data ………

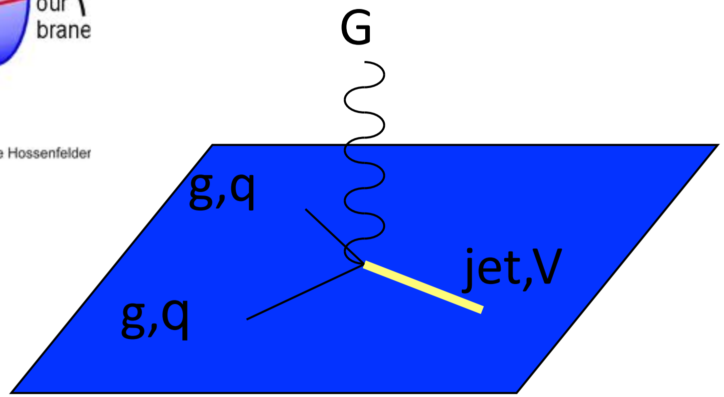
Large Extra Dimensions



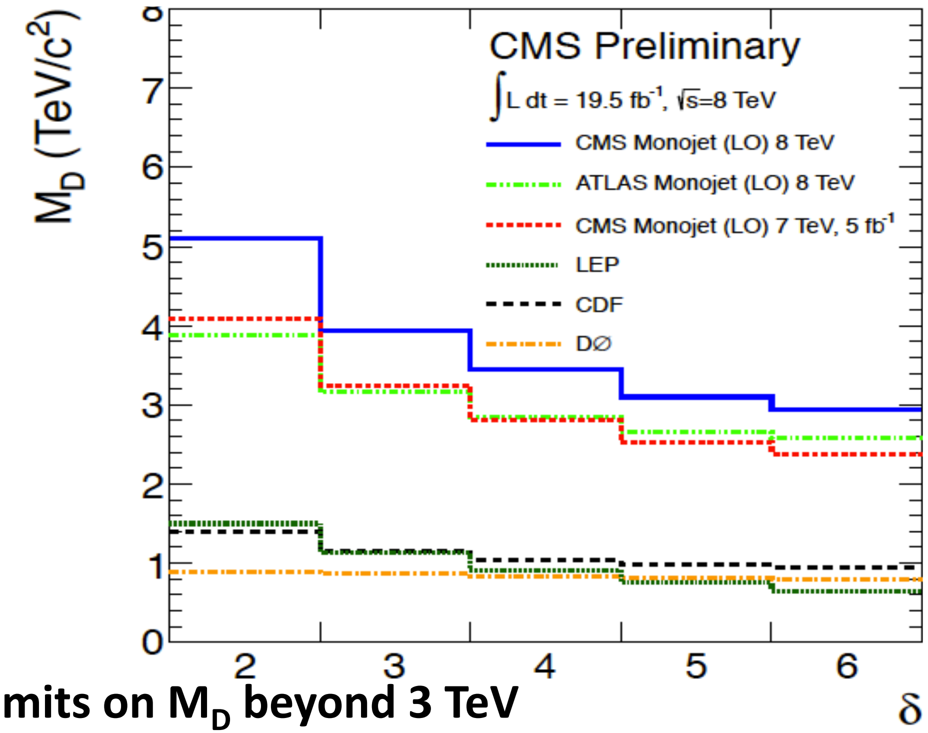


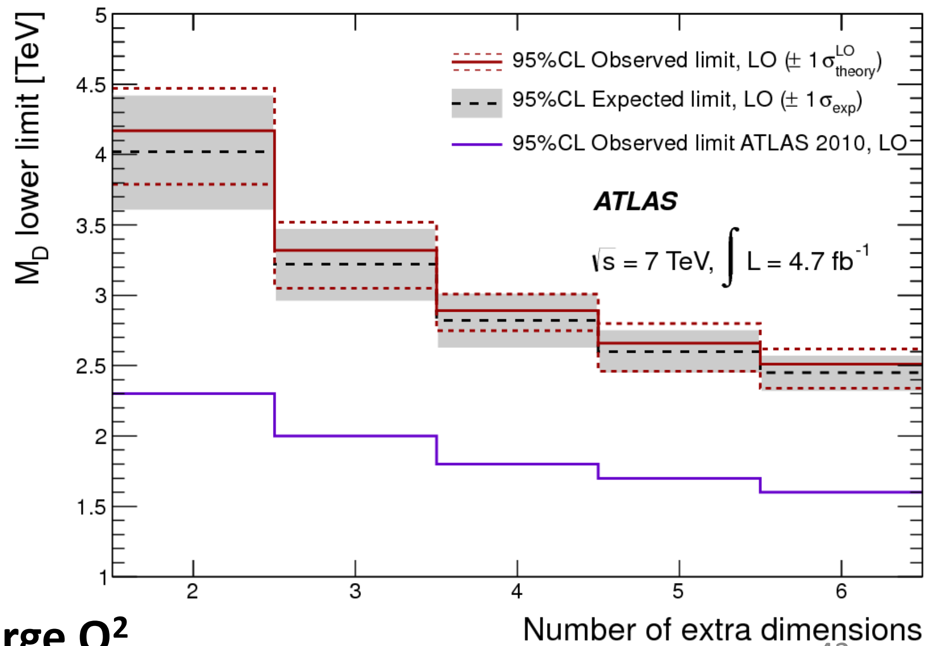
Extra spatial dimensions explain the apparent weakness of Gravity (relevant scale ~TeV)





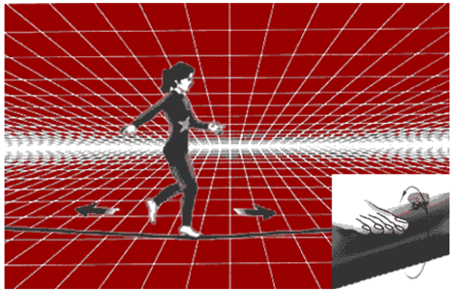
$$(M_{PL})^2 \sim R^n (M_D)^{2+n}$$





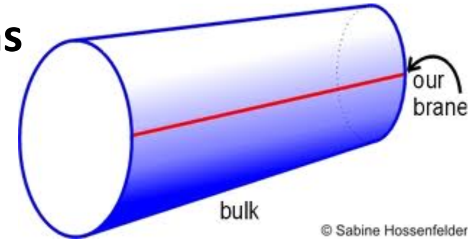
Limits on M_D beyond 3 TeV
(a real challenge of the model model validity)

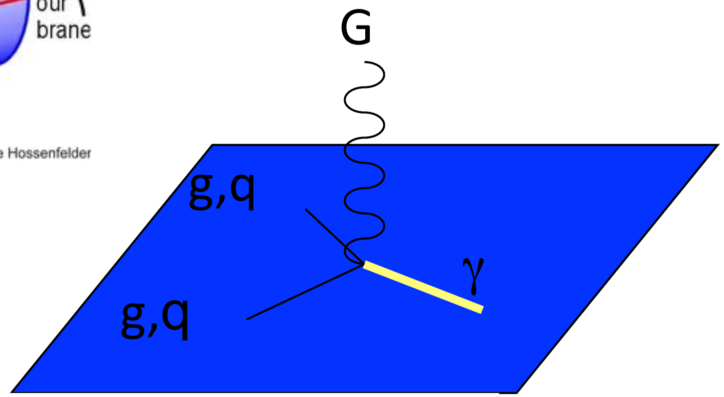
Note: Limits sensitive to the truncation strategy for s-hat > M_D^2 … LHC probing phase space at large Q^2



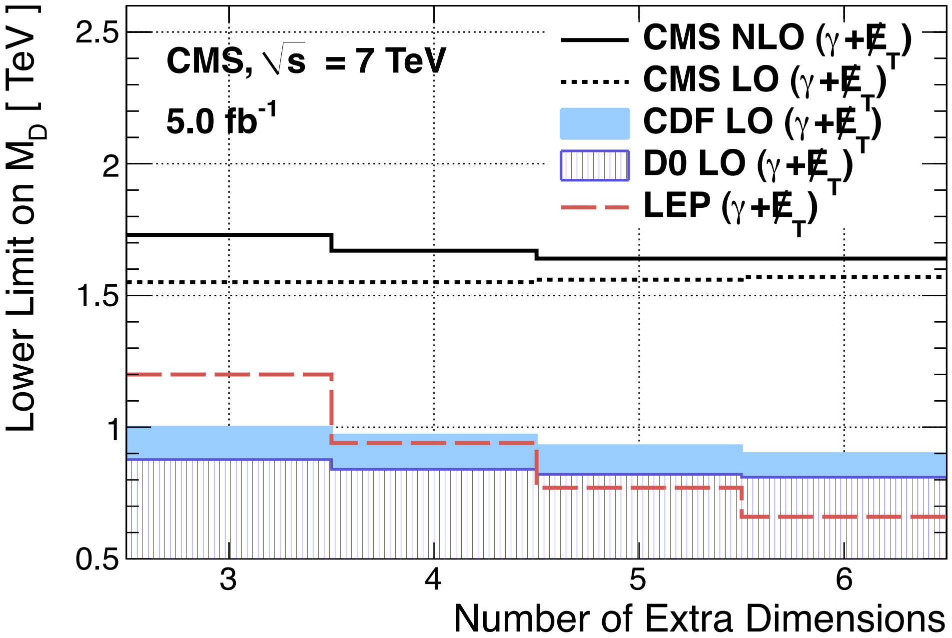
Large Extra Dimensions

Extra spatial dimensions explain the apparent weakness of Gravity (relevant scale ~TeV)

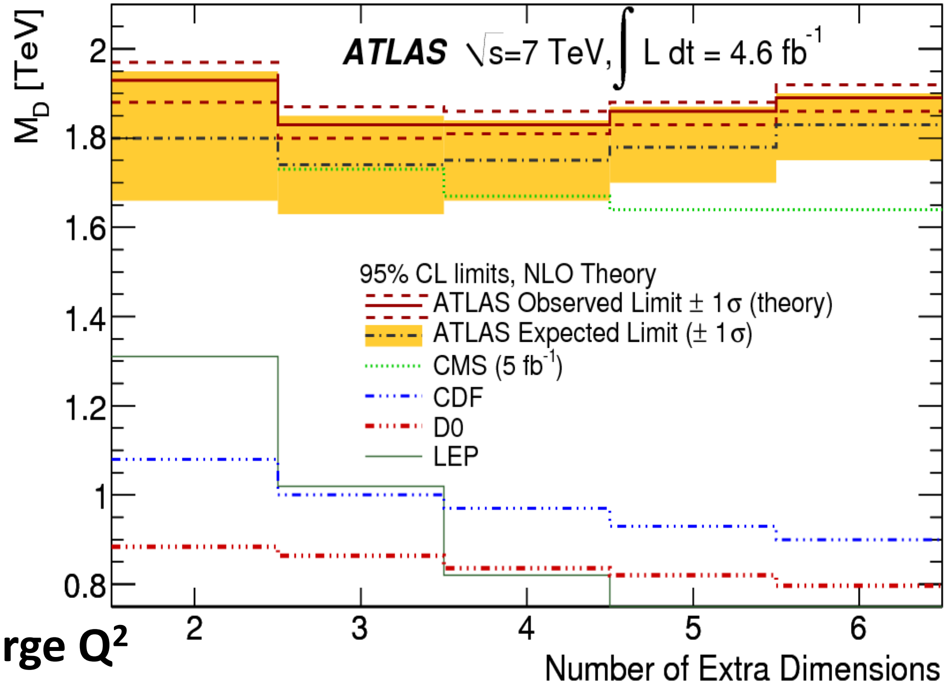




monophoton



$(M_{PL})^2 \sim R^n (M_D)^{2+n}$



Limits on M_D beyond 1.5 TeV
(a real challenge of the model model validity)

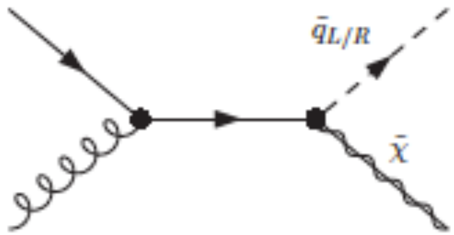
Note: Limits sensitive to the truncation strategy for s-hat > M_D^2 … LHC probing phase space at large Q^2

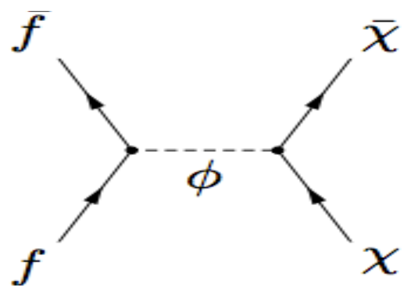
Final Notes

- **Very successful LHC operations during the last 3 years**
- **More than 26 fb-1 of data on tape for ATLAS/CMS (7 TeV & 8 TeV)**
- **The year of the Higgs discovery !!**
- **Searches drawing a picture with new physics beyond the SM above the 1 TeV scale ?**
- **Within the effective lagrangian framework the LHC DM searches are rather competitive**
- **Searches continue with the full 2012 dataset and including all possible mono-X channels (this includes also mono-b, mono-W, ….)**

"Just checking."

..and more data bring new things and more direct access to DM

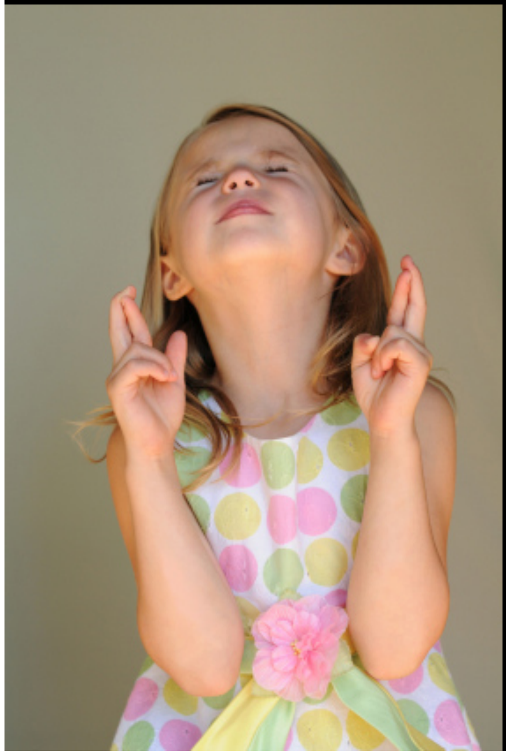




More Energy and More Data !

El LHC will almost double
the centre-of-mass energy
in 2015

8 TeV → 14 TeV
with increased luminosity



Ready for a new discovery ?

More Energy and More Data !

El LHC will almost double the centre-of-mass energy in 2015

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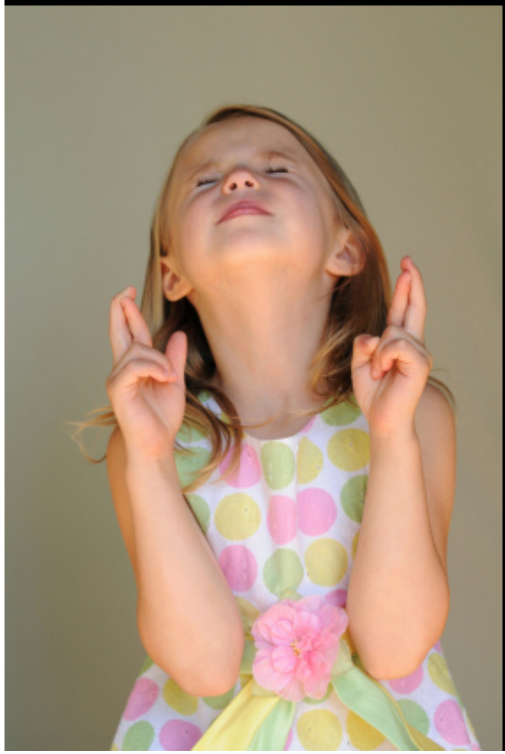
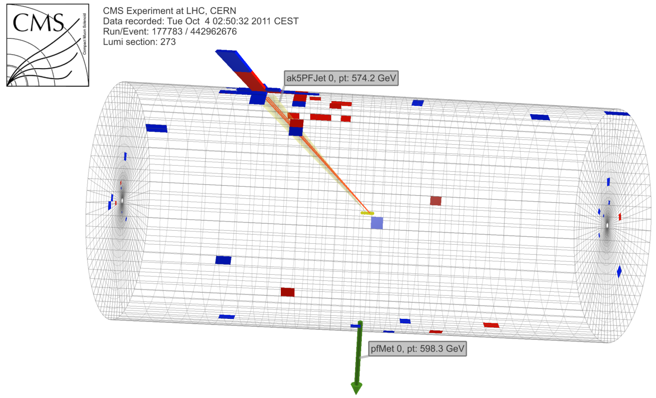
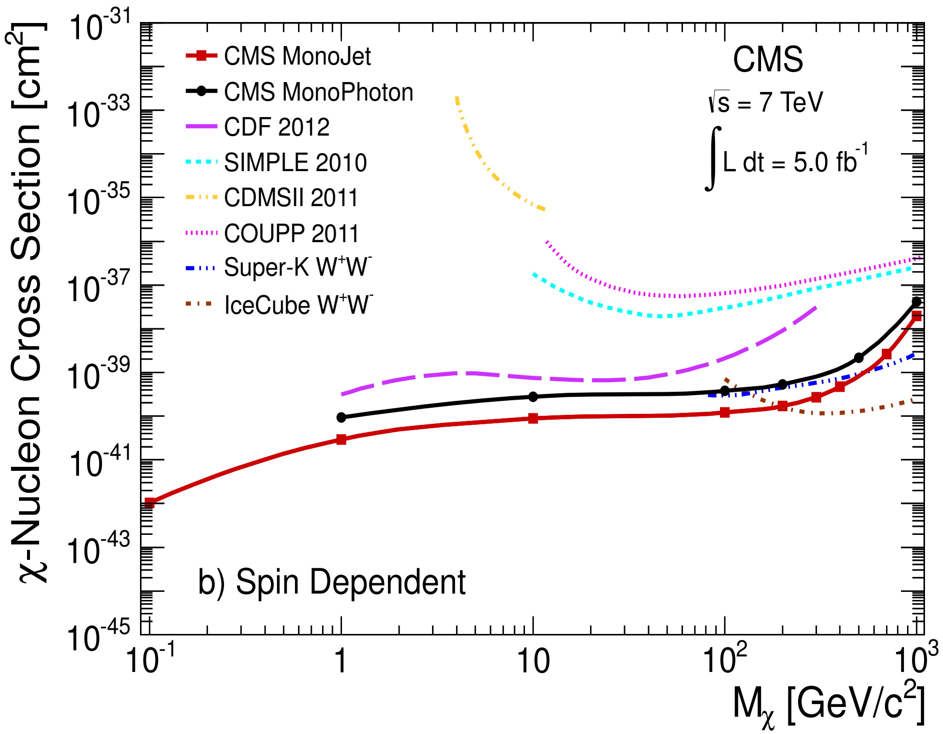


Ready for a new discovery ?

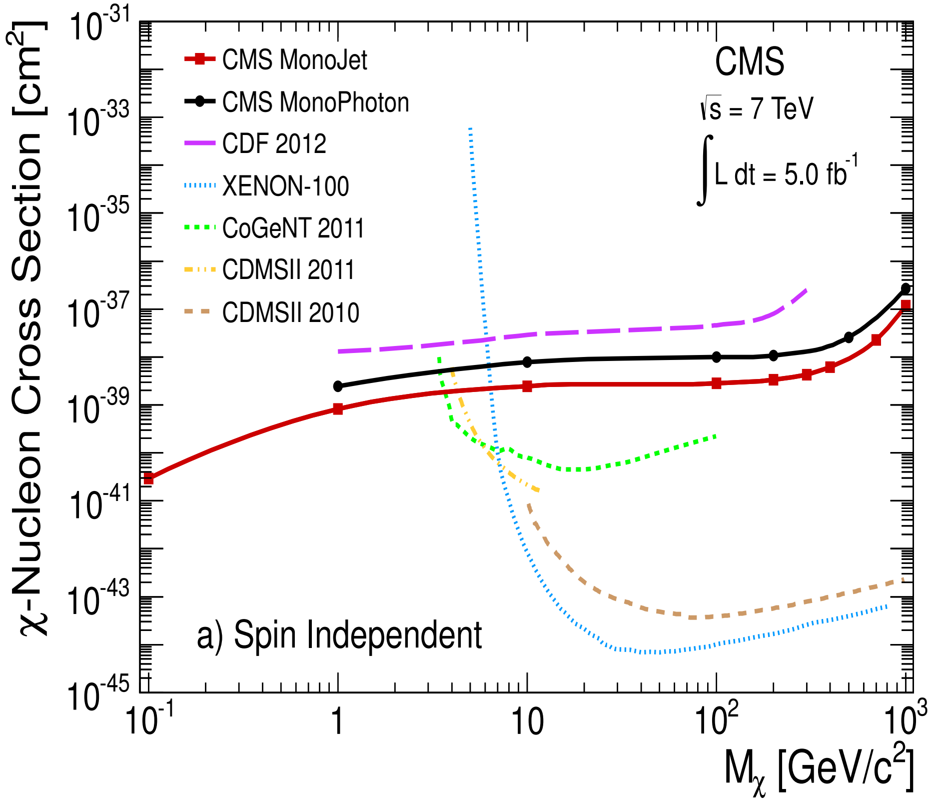
Monojets



CMS Experiment at LHC, CERN
Data recorded: Tue Oct 4 02:50:32 2011 CEST
Run/Event: 177783 / 442962676
Lumi section: 273
ak5PFJet 0, pt: 574.2 GeV
pfMet 0, pt: 598.3 GeV

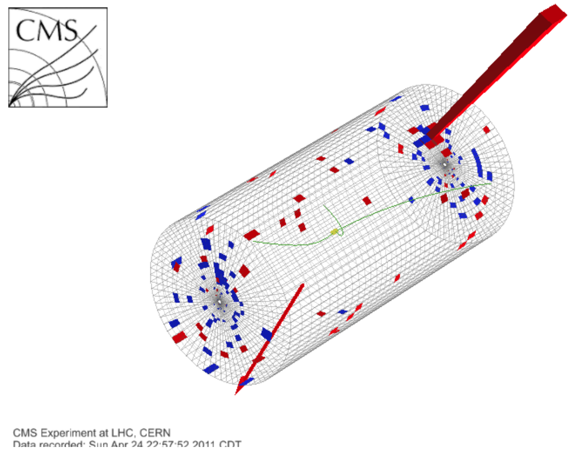


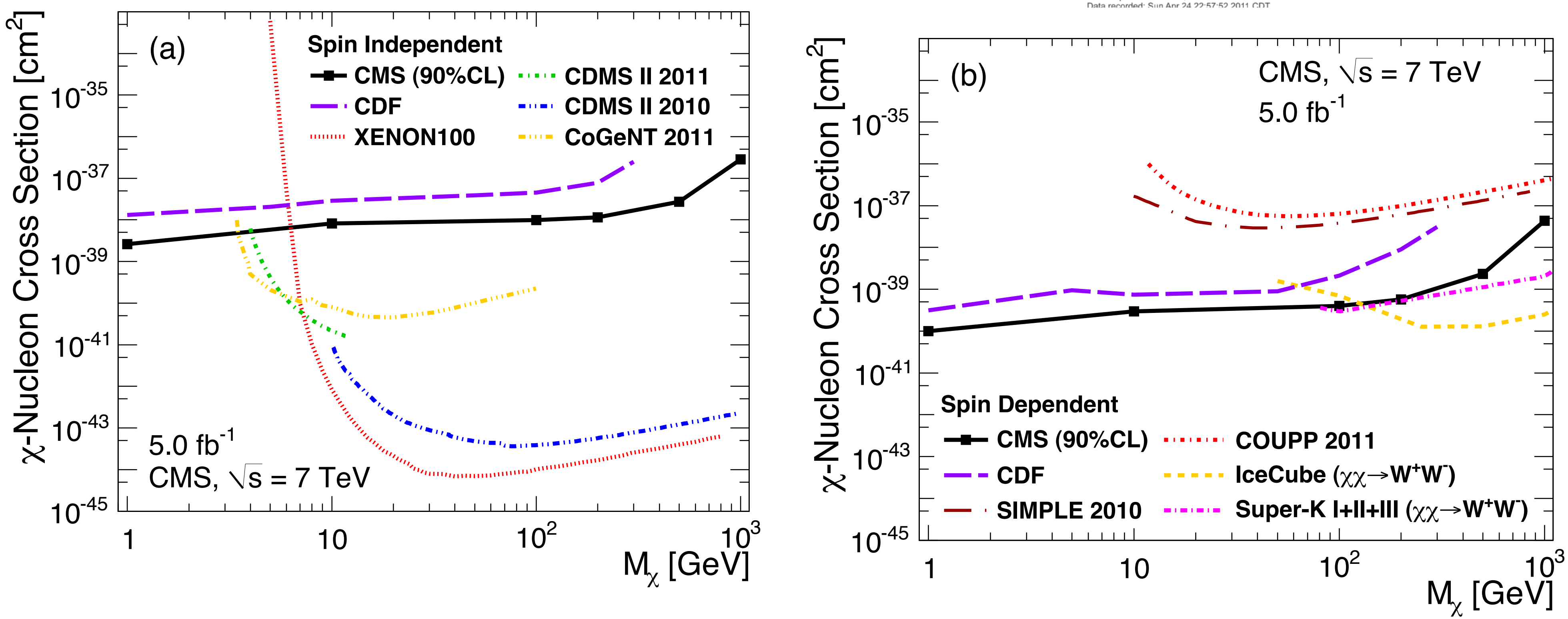
CMS MonoJet
CMS MonoPhoton
CDF 2012
SIMPLE 2010
CDMSII 2011
COUPP 2011
Super-K W+W-
IceCube W+W-
CMS
√s = 7 TeV
∫L dt = 5.0 fb-1
b) Spin Dependent
χ-Nucleon Cross Section [cm2]
Mχ [GeV/c2]



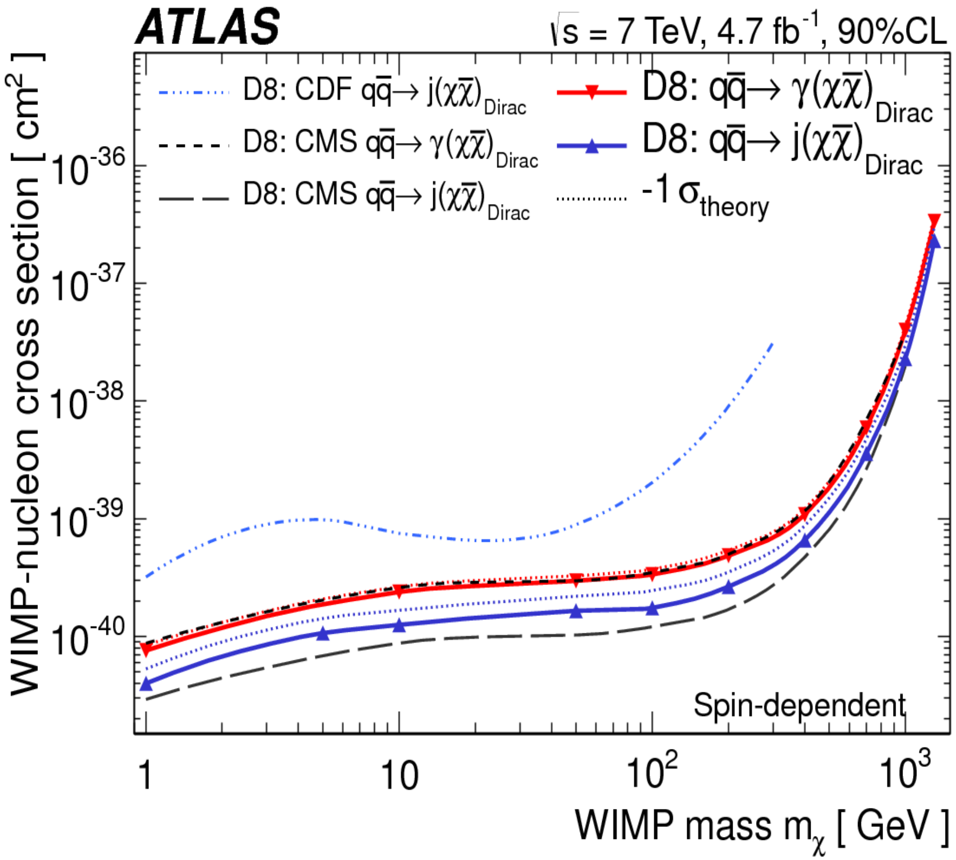
CMS MonoJet
CMS MonoPhoton
CDF 2012
XENON-100
CoGeNT 2011
CDMSII 2011
CDMSII 2010
CMS
√s = 7 TeV
∫L dt = 5.0 fb-1
a) Spin Independent
χ-Nucleon Cross Section [cm2]
Mχ [GeV/c2]

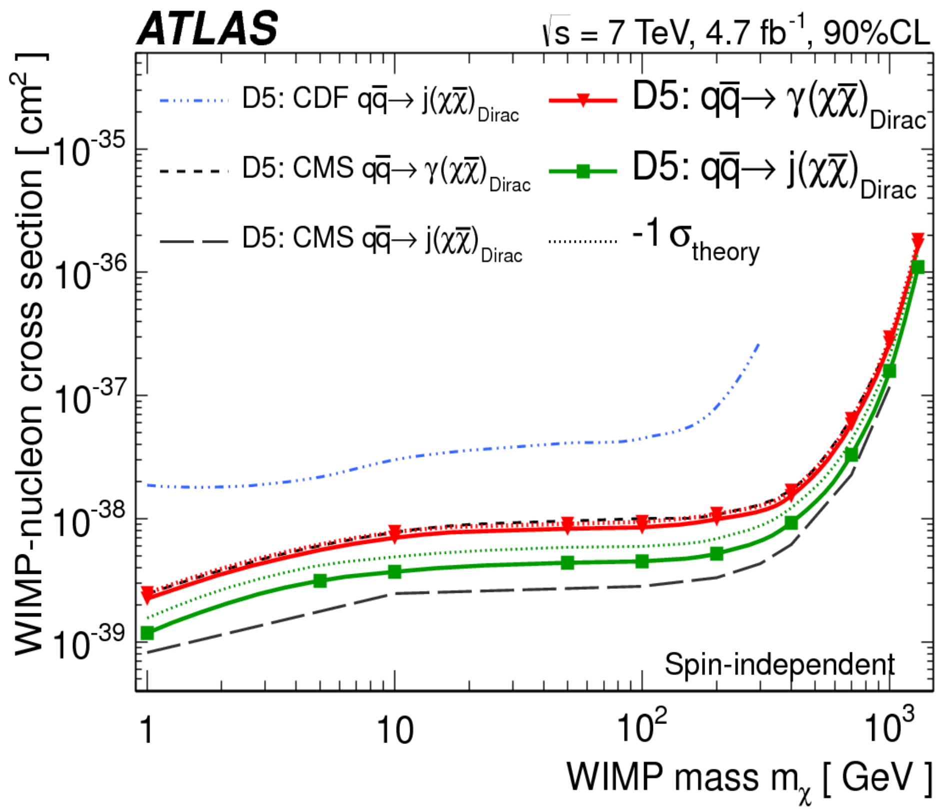
Mono-photons





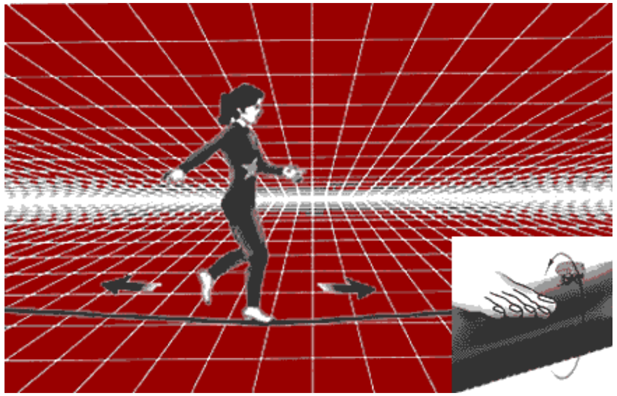
Collider-only plots



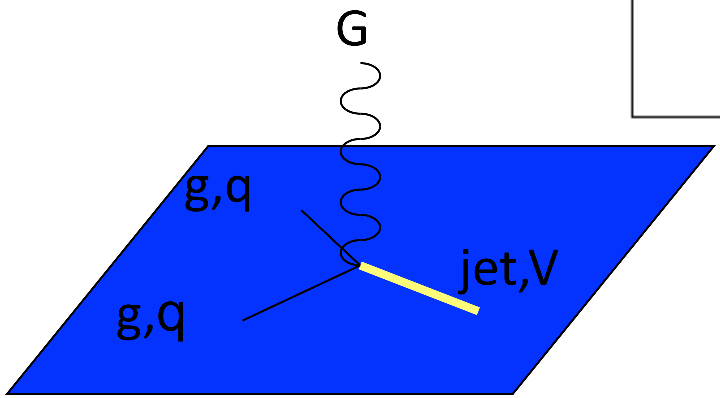


Extra Dimensions

Alternative to solve Hierarchy Problem



Extra spatial dimensions explain the apparent weakness of Gravity (relevant scale ~ 1 TeV)

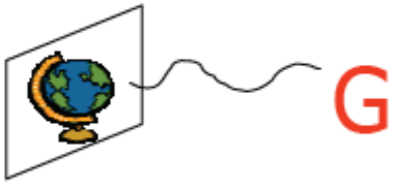


monojet/monophoton

ADD

Arkani-Hamed, Dimopoulos, Dvali,
Phys Lett B429 (98)

Many large compactified EDs In which G can propagate



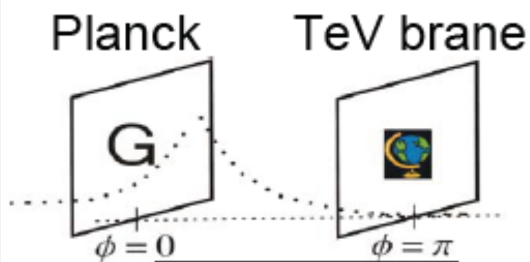
$M_{Pl}^2 \sim R^n M_{Pl(4+n)}^{(2+n)}$

Effective $M_{Pl} \sim$ 1TeV → if compact space (R^n) is large

RS

Randall, Sundrum,
Phys Rev Lett 83 (99)

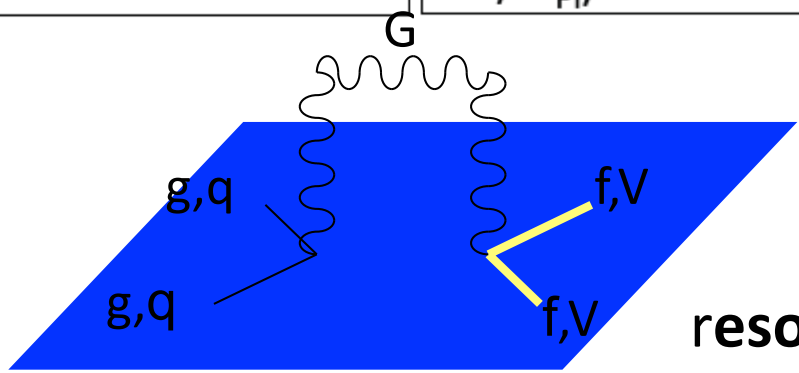
1 highly curved ED
Gravity localised in the ED



$\Lambda_\pi = \overline{M}_{pl} e^{-kR_c\pi}$

$\Lambda_\pi \sim$ TeV

if warp factor kR_c ~11-12
k/M_{Pl}, k: curvature scale

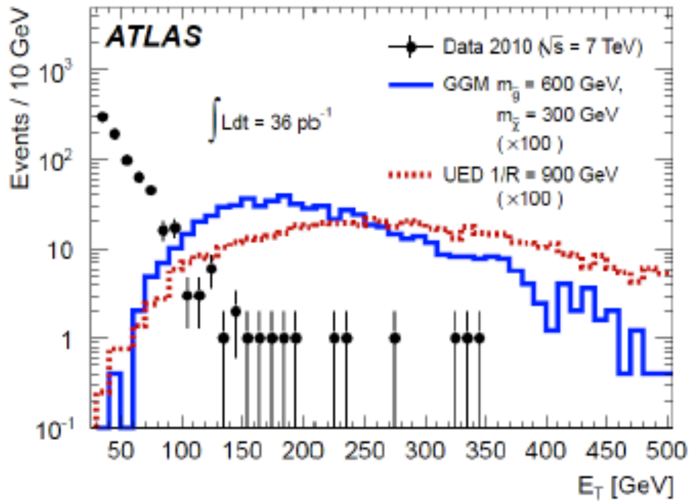


resonances

UED: Diphoton + MET

UED

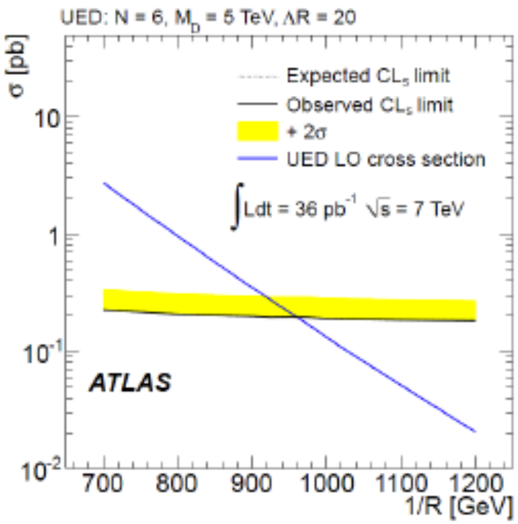
E_T^{miss} range [GeV]	Data events	Predicted background Total	Expected signal events UED
0 - 20	698	-	0.02 ± 0.01
20 - 75	63	61.4 ± 2.3	0.25 ± 0.02
75 - 125	1	0.38 ± 0.08	0.43 ± 0.02
> 125	0	0.10 ± 0.04	5.35 ± 0.11



[arXiv:1107.0561]

Model (in addition to SUSY*)

- One UED embedded in larger space with N = 6 additional dimensions
- Lightest KK particle = γ^*
  - Decays gravitationally to γ + Graviton
- Only 2010 results public at the moment



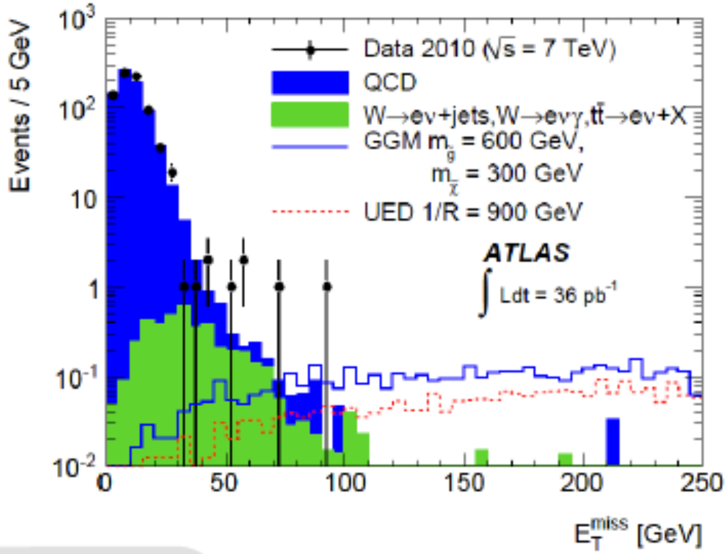
Observed 95% CLs limit

- **1/R > 961 GeV**

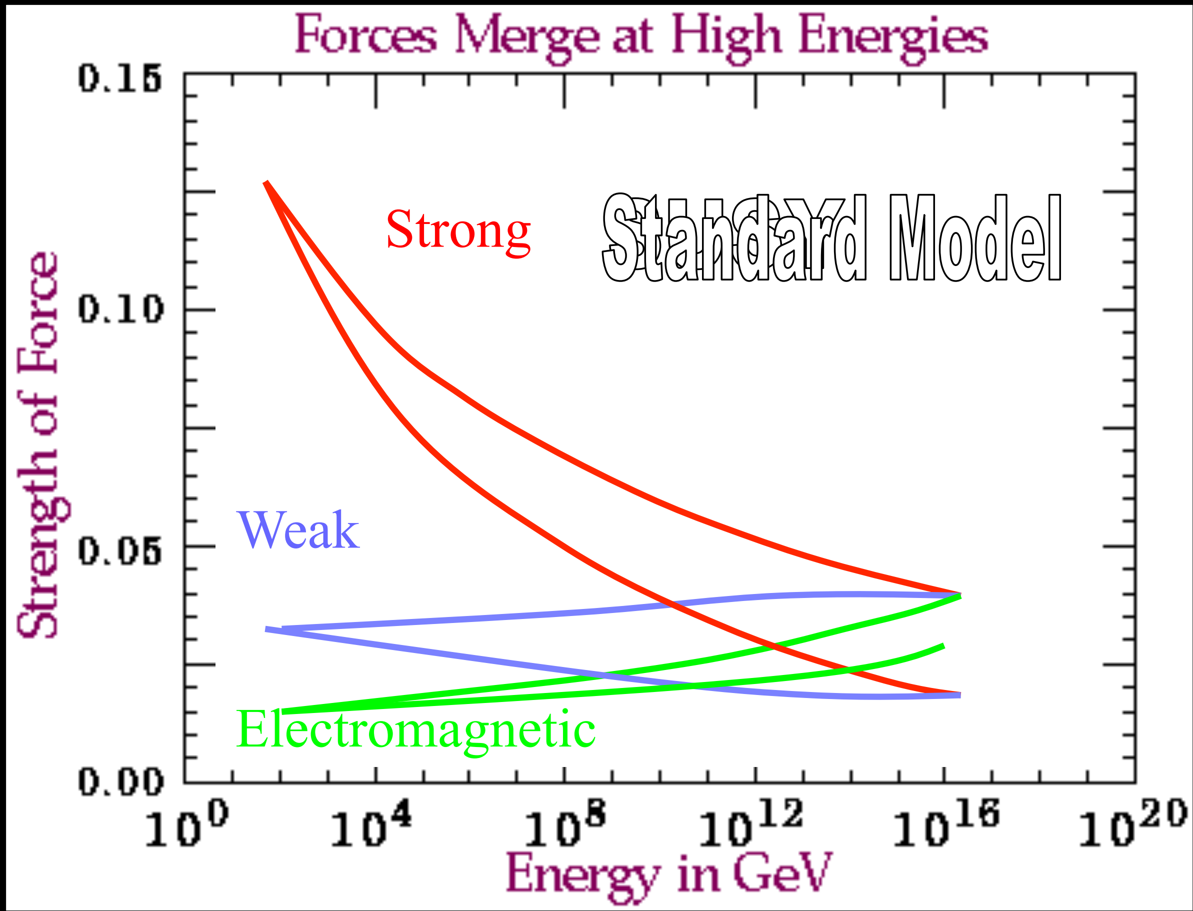
(M_D = 5 TeV, ΛR = 20)

Tevatron (D0)

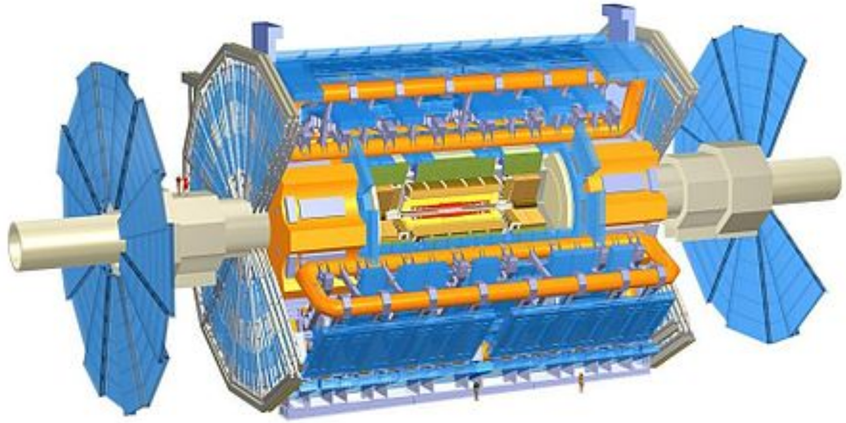
- 1/R > 477 GeV

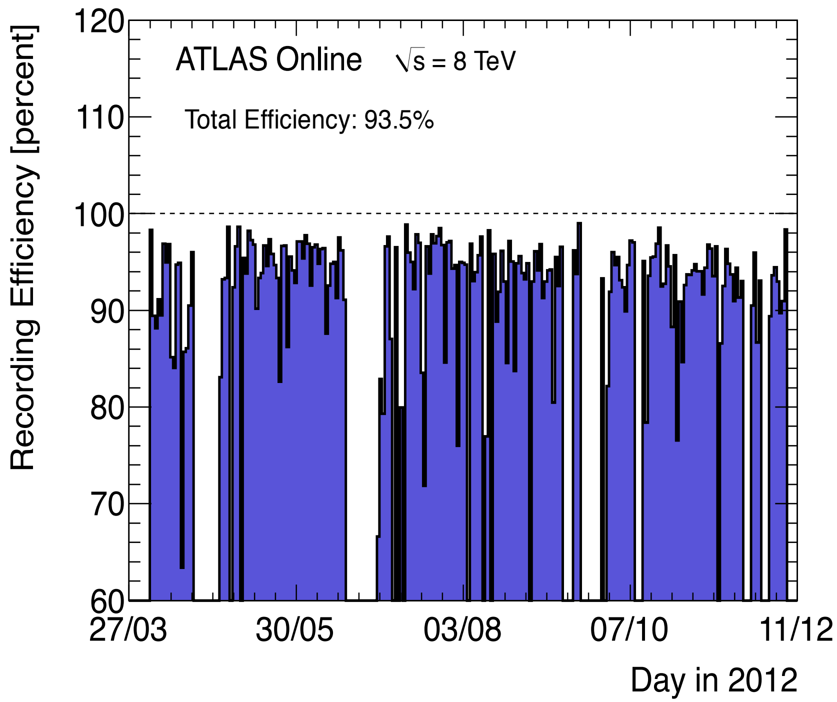


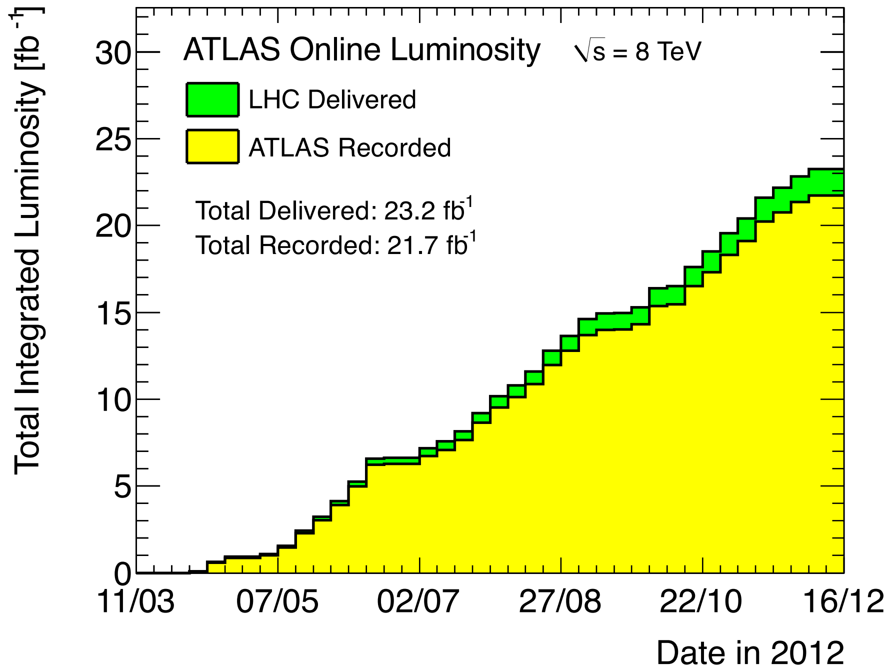
Unification of forces & SUSY



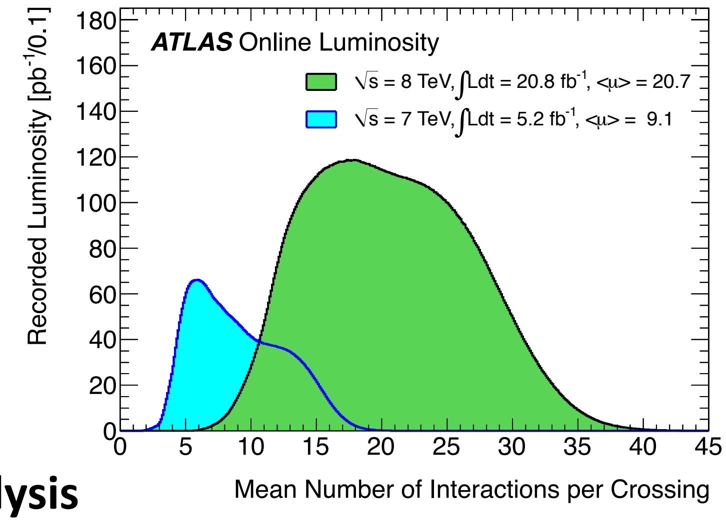
ATLAS





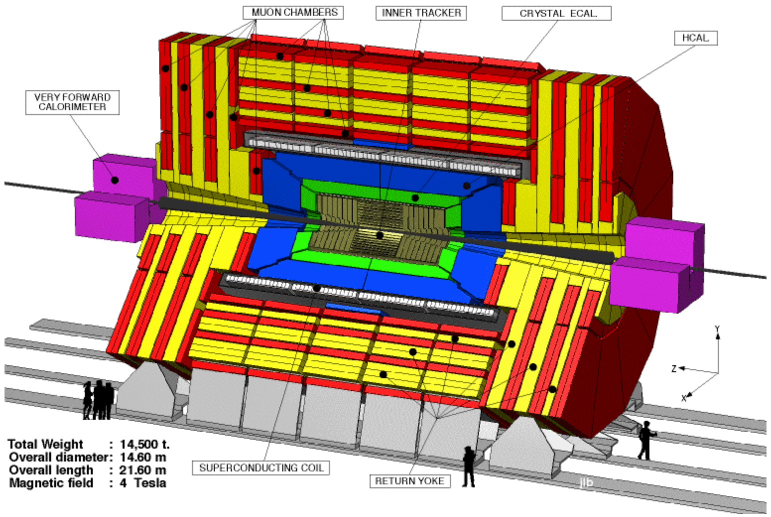


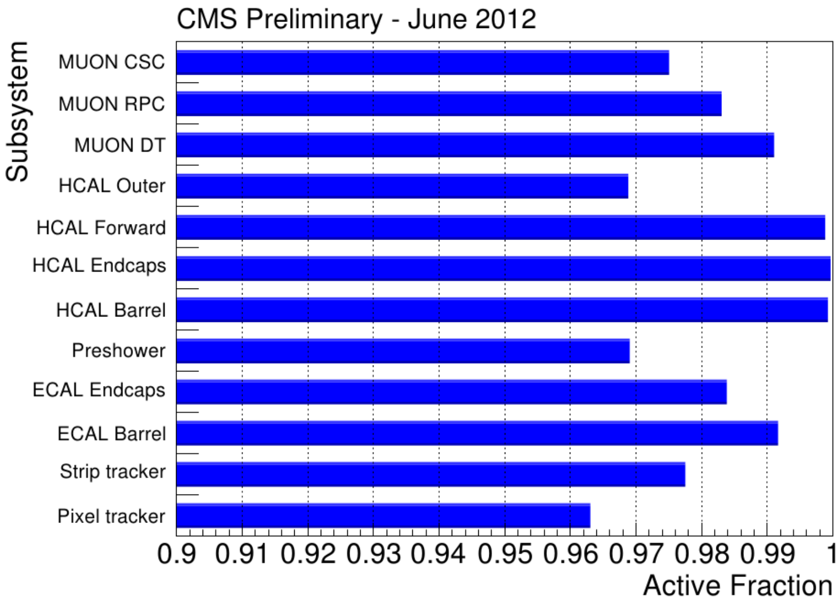
More than 21 fb-1 collected by ATLAS with a 93.5% efficiency

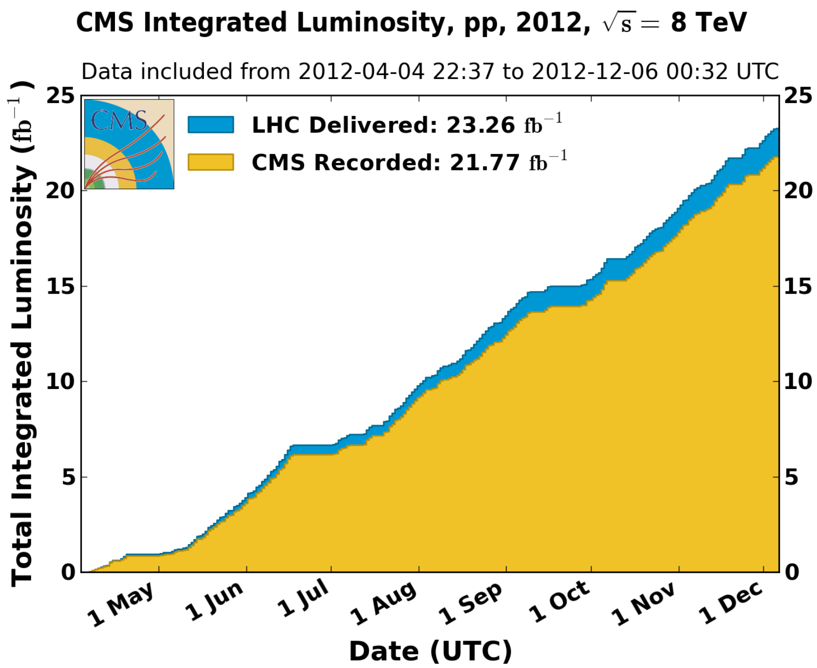


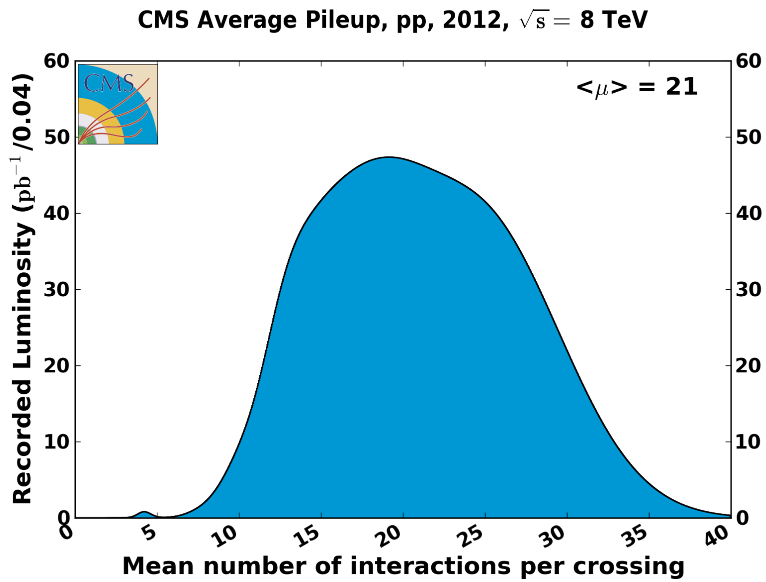
Challenging pile up conditions for the physics analysis

CMS









More than 21 fb-1 collected by CMS
challenging pile up conditions for the physics analysis