Searches for monojets and monophotons with the ATLAS detector

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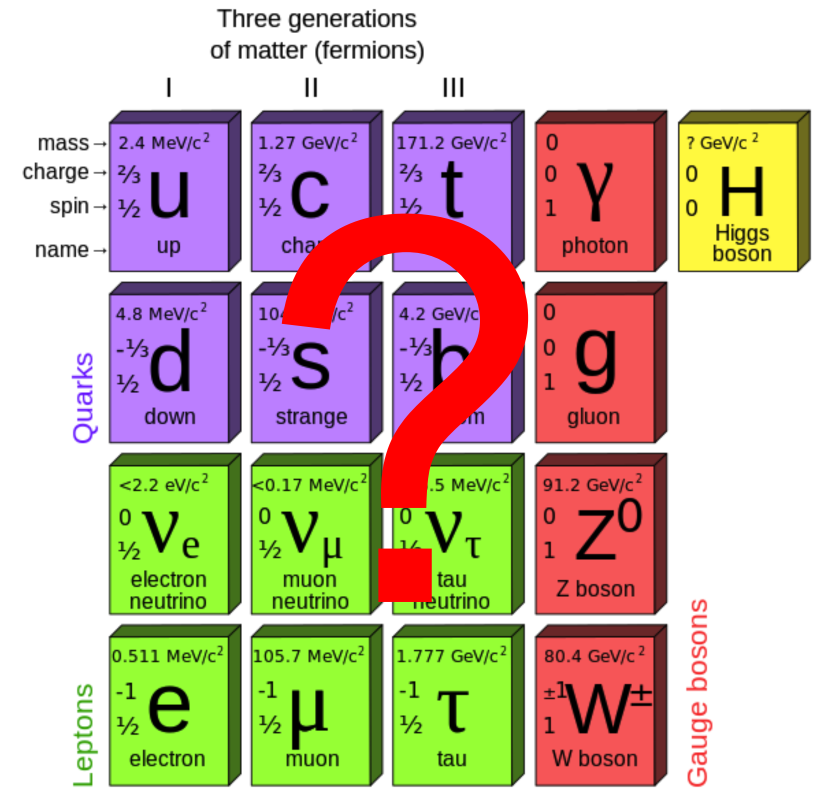
On behalf of the ATLAS Collaboration

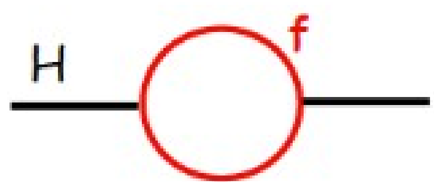
Outline

- Motivation
- Mono-jet 7 TeV analysis
- Mono-photon 7 TeV analysis
- Interpretation in terms of:
  - ADD Large Extra Dimensions
  - WIMP production and WIMP-nucleon cross-section
- Mono-jet 8 TeV analysis
- Interpretation in terms of GMSB gravitino mass



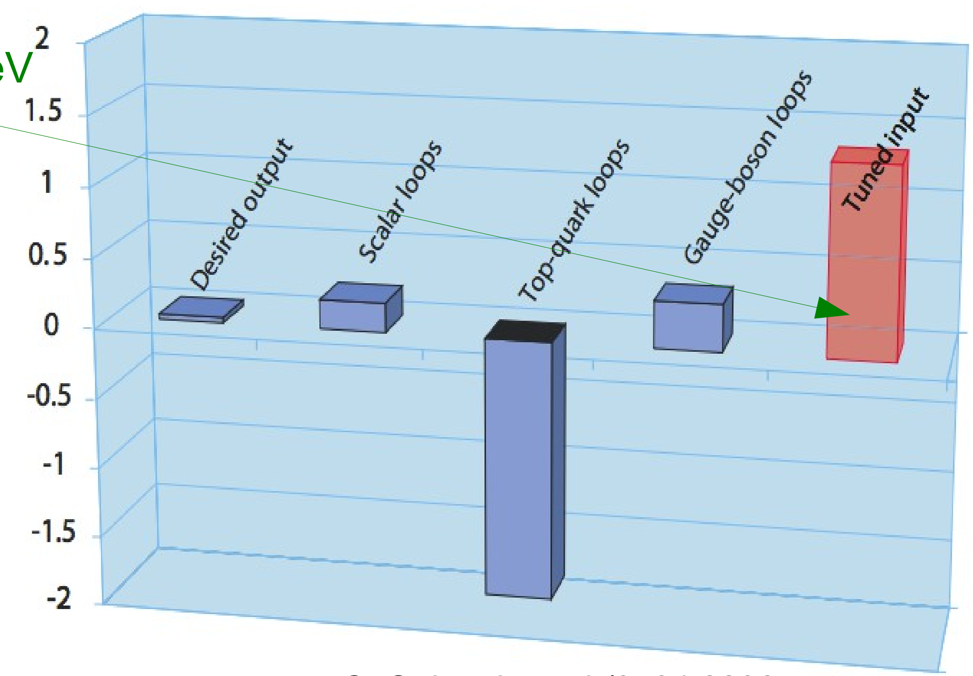
Hierarchy problem

- Particles in the SM have masses of around the EW scale.
  - No new particles between M_W (~10^2 GeV) and M_P (~10^{18} GeV)?
- Higgs mass receives quantum corrections from every particle to which it couples.
  - Corrections can be up to 30 orders of magnitude larger than m_H (if Λ_{UV} ~ M_P).



$$\Delta m_H^2 = -\frac{|\lambda_f|^2}{8\pi^2}\Lambda_{\rm UV}^2 + \ldots.$$

Already a serious problem at 5 TeV to cancel top, gauge and Higgs loops



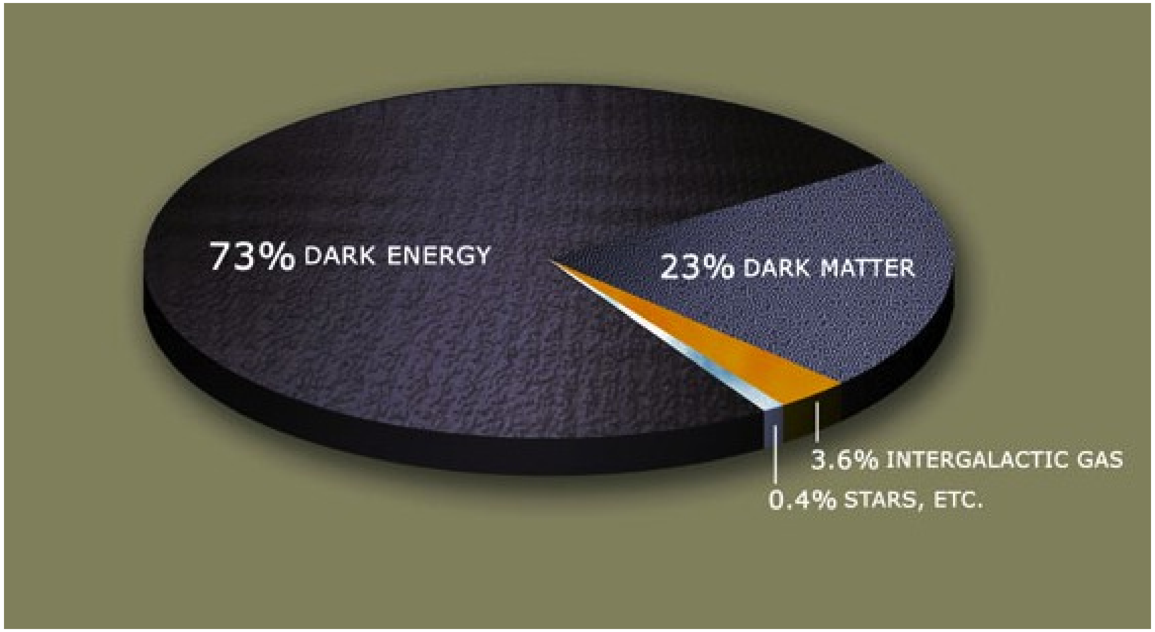
C. Quigg, hep-ph/0704.2232

- Planck mass is not as large as ~10^{18} GeV? Extra-dimensions?
- SuperSymmetry?

Dark matter

- Rotation of stars around the center of the galaxies is not consistent with the amount of mass observed.
- Gravitational lensing is an indication of DM in galaxy clusters.
- Collisions of clusters of galaxies.

- Neutrino is NOT a good DM candidate.
- What is DM?



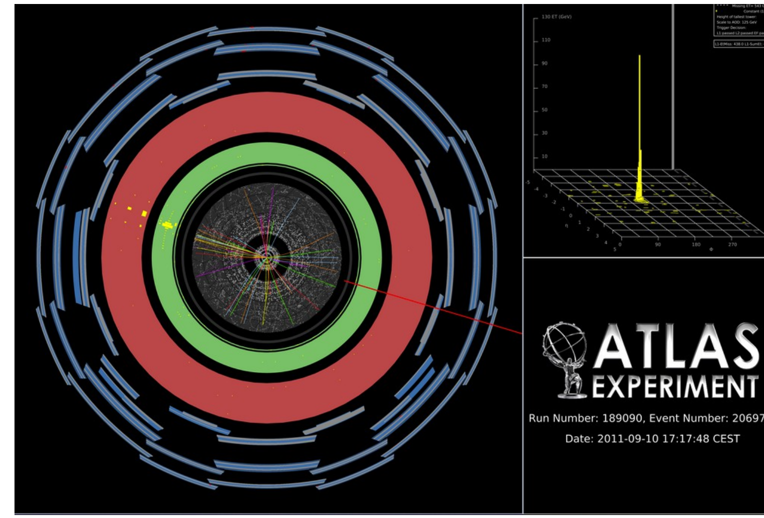
Why mono-jet and mono-photon?

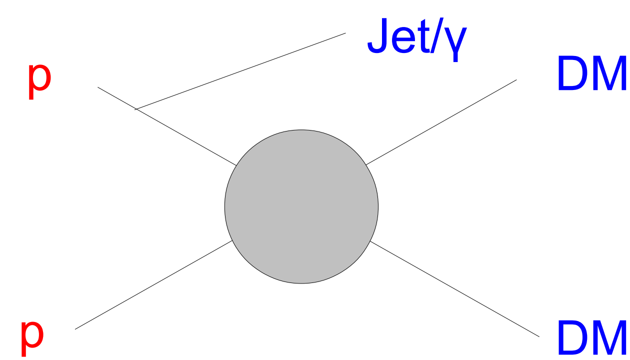
- Mono-jet and mono-photon: search for invisible new particles in association to a high Pt jet/photon.

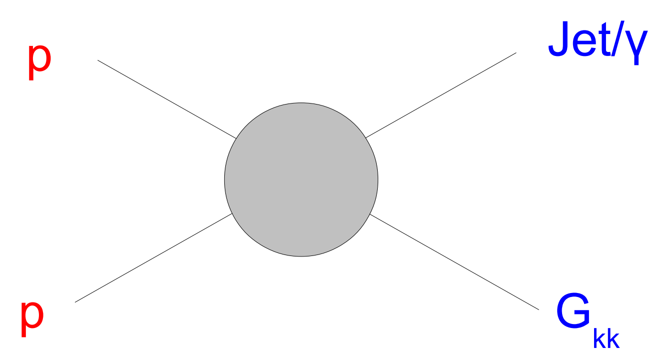
- Clean and distinctive signature for new physics.
  - Dark matter candidates.
  - Large Extra Dimensions.
  - SUSY.

- Simple selection cuts.

- Fully data-driven estimations for most of the SM processes involved are possible.







7 TeV, $\mathcal{L}$=4.7 fb-1

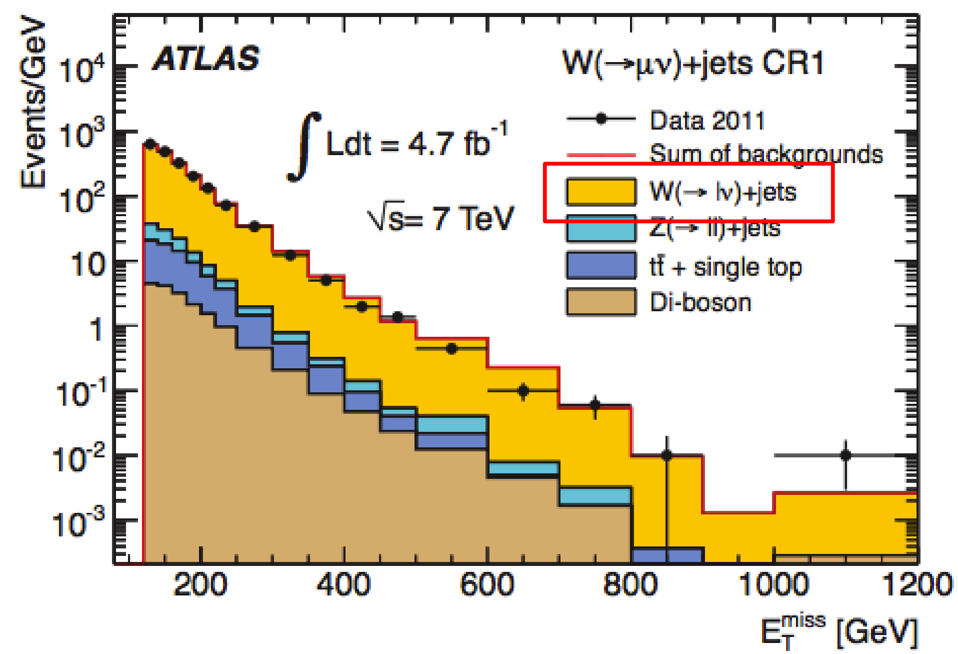
Mono-jet search in ATLAS

- Event selection: SR1 SR2 SR3 SR4
  - High missing E_T: Etmiss > 120, 220, 350, 500 GeV
  - 1 High p_T jet: Pt(j1) > 120, 220, 350, 500 GeV
  - Njet(Pt > 30 GeV) < 3
  - $\Delta\varphi(E_T$, any jet) > 0.5
  - Lepton veto

ArXiv:1210.4491 (submitted to JHEP)

$$N_{SR}^{bin\,i}(corr.) = N_{SR}^{bin\,i}(MC) \times \frac{[N_{CR}^{bin\,i}(Data) - N_{CR}^{bin\,i}(bkg)]}{N_{CR}^{bin\,i}(MC)}$$

- Control regions:
  - Data-driven correction of main backgrounds.
  - Correct normalization/shape.
  - Same kinematic cuts, revert lepton veto + Pt(boson) requirements



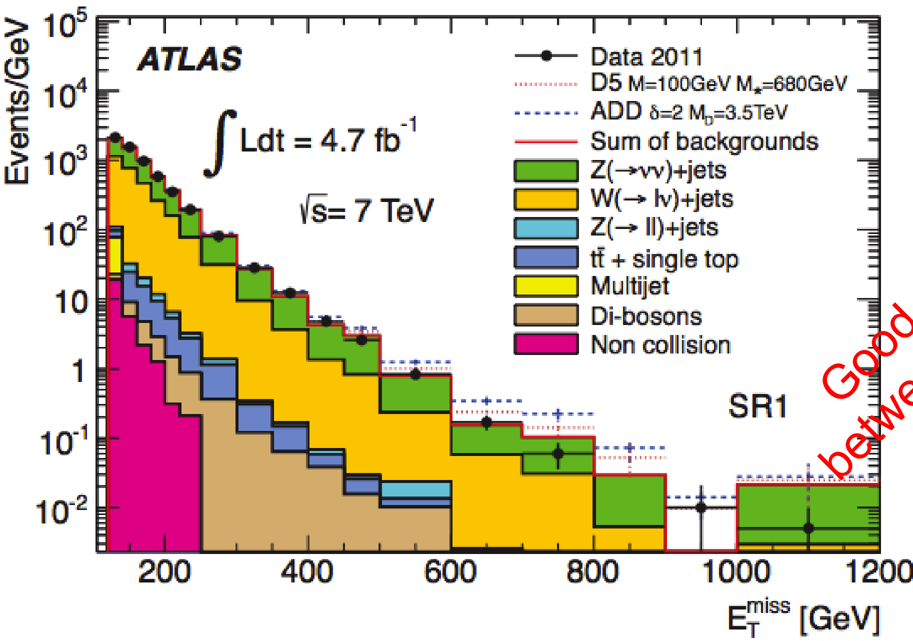
- 4 CR:
  - W(→eν)+jets, W(→μν)+jets, Z(→ee)+jets, Z(→μμ)+jets

- Additional corrections for CR/SR differences in efficiency and kinematics

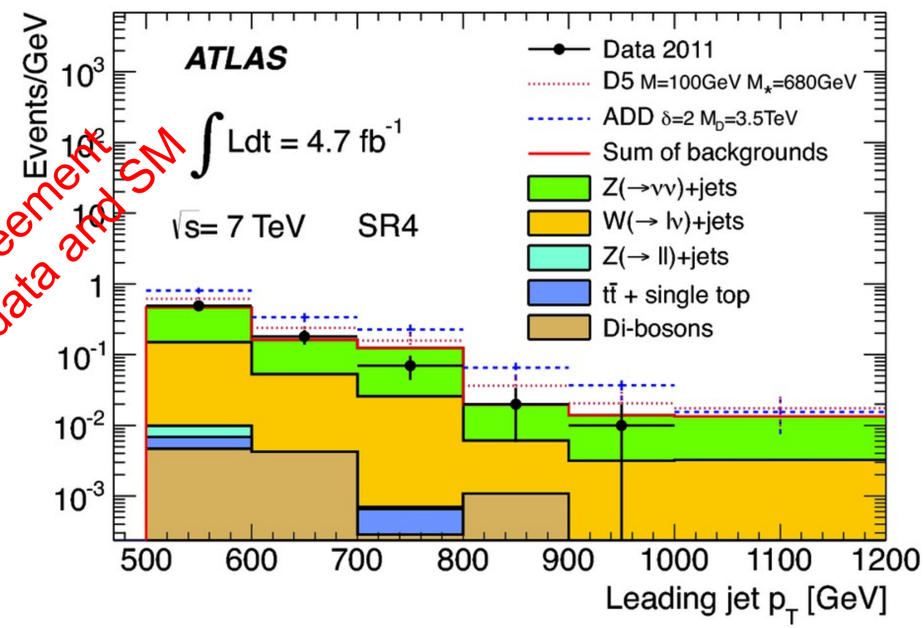
7 TeV, $\mathscr{L}$=4.7 fb-1

Mono-jet search in ATLAS

- CR transfer functions applied to W/Z + jets backgrounds.
- Data-driven estimation for multijet and non-collision background.
- Systematic uncertainties (energy scales, parton shower modeling, lepton efficiencies...) 3.4% (SR1) to 11.1% (SR4)



Good agreement between data and SM



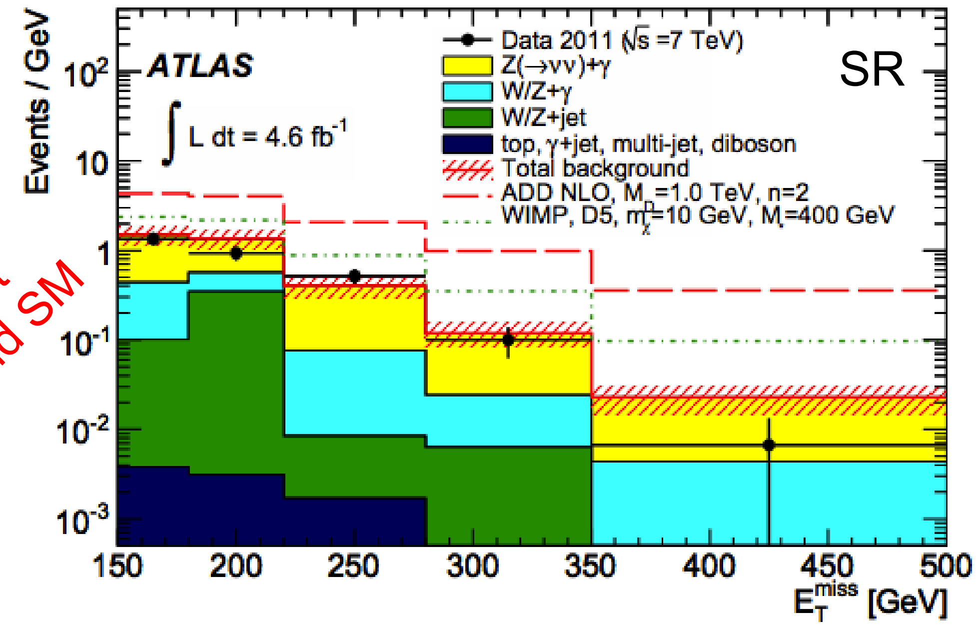
	SR1	SR2	SR3	SR4
Total Background	124000 ± 4000	8800 ± 400	750 ± 60	83 ± 14
Events in Data (4.7 fb^{-1})	124703	8631	785	77

7 TeV, $\mathscr{L}$=4.6 fb-1

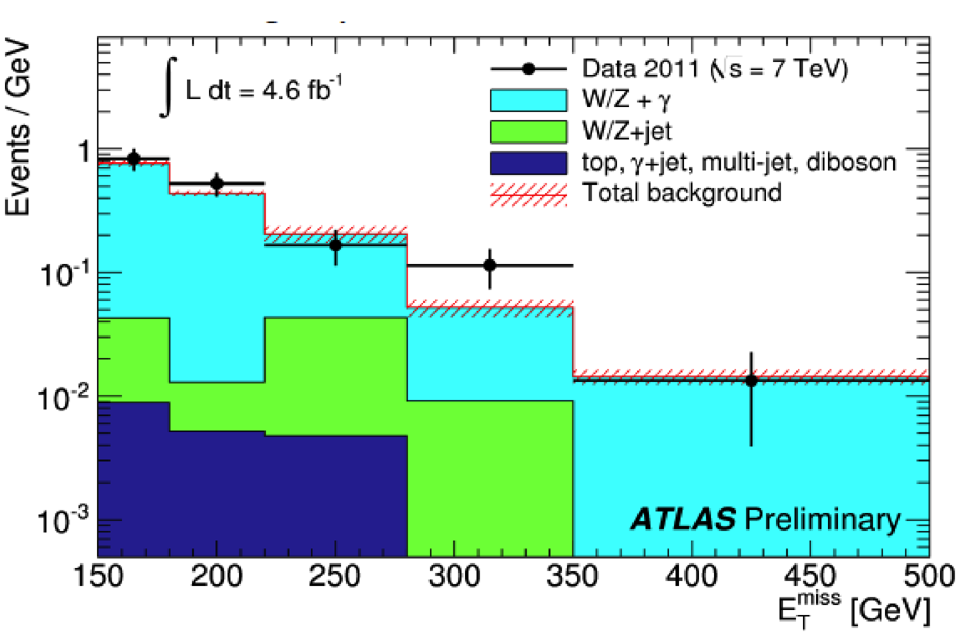
Mono-photon search in ATLAS

- Event selection:
  - High missing E_T: Etmiss > 150 GeV
  - 1 High p_T photon: Pt(γ) > 150 GeV
  - Njet(Pt > 30 GeV) < 2
  - Δφ(E_T, any jet/γ) > 0.5
  - Lepton veto

Good agreement between data and SM



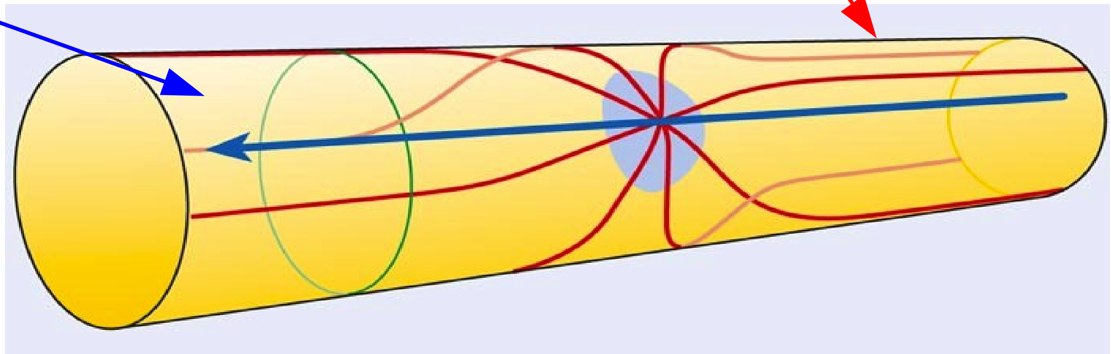
Phys. Rev. Lett. 110, 011802 (2013)



- Control regions:
  - ($e \rightarrow \gamma$) and ($jet \rightarrow \gamma$) fakes measured with data-driven method.
  - W(lν)/Z(ll)+γ background obtained by MC normalization in a μ+γ+Etmiss control region

Large Extra Dimensions (LED)

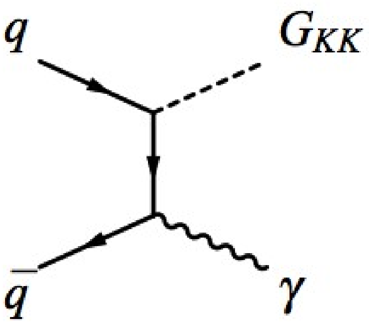
- Proposed as a way to solve the hierarchy problem.
- Several models. Focus on ADD (Arkani-Hamed, Dimopoulos, Dvali):
  - Gravity propagates through 4+*n* dimensional bulk.
  - Other SM fields confined to usual 4D.



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

- Allows a fundamental Planck scale (M_D) of the order of EW scale.
  - $n=2,\dots,6 \rightarrow R \sim 0.5\,mm,\dots,0.1\,MeV$

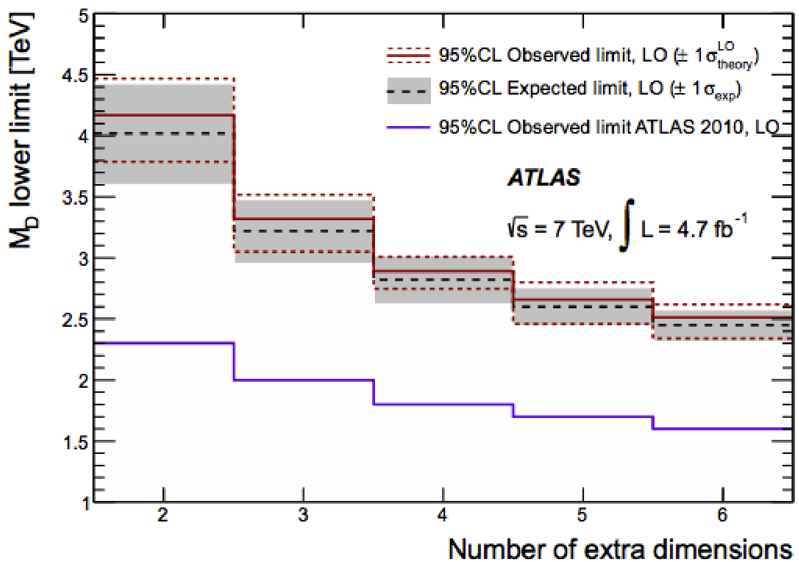
- Signature:
  1 photon/jet + Graviton (Etmiss) + ISR/FSR



Limits on M_D (ADD model for LED)

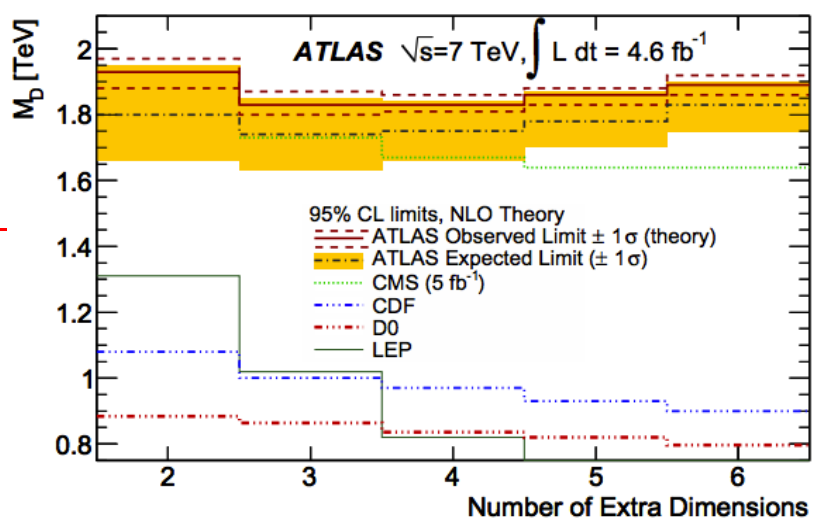
- 95% CL on the visible cross-section for the effective ADD theory are translated to limits on M_D for different number of extra dimensions.

Mono-jet, SR4



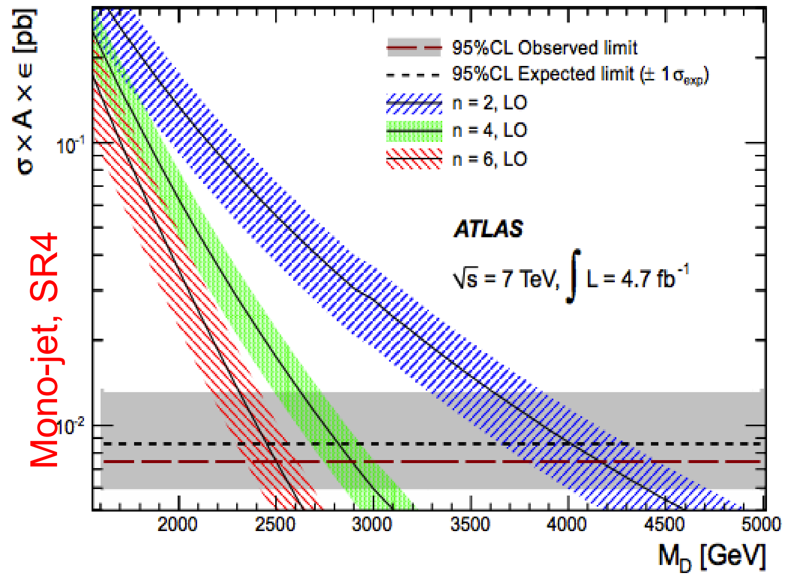
n	M_D [TeV]	
	LO	NLO
2	4.17	4.37
3	3.32	3.45
4	2.89	2.97
5	2.66	2.71
6	2.51	2.53

Mono-photon



n	M_D [TeV]	
	LO	NLO
2	1.74	1.93
3	1.74	1.83
4	1.78	1.83
5	1.82	1.86
6	1.87	1.89

Mono-jet, SR4



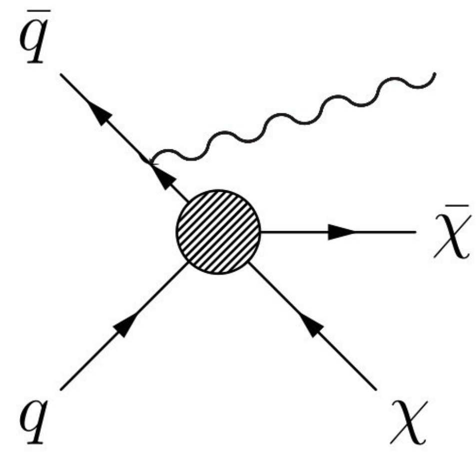
- Improved limits on fundamental Plank mass, M_D, wrt previous collider results.

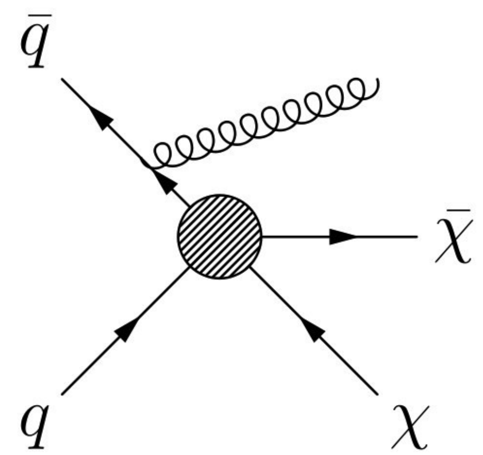
- Limits start to be challenging for the model (exclusion up to few TeV scale)

Weak Interacting Massive Particles

- Candidates for Dark Matter need to be:
  - Electrically neutral (“dark”)
  - Stable (lifetime larger than the age of the Universe)
  - Massive and weakly interacting
- Effective theories of SM interaction with WIMPs.
- At colliders, they can be produced in pairs.
  - They escape detection, so events with WIMPs are tagged via the presence of an energetic jet or photon coming from ISR
- Signature:

  1 photon/jet + Etmiss





WIMPs effective theory

- Effective Lagrangian approach with parameters M* and m_χ.
- Assume interaction is mediated by a heavy particle of mass M and couplings g_1 and g_2

$$M^{*2} = \frac{M^2}{g_1 g_2}$$

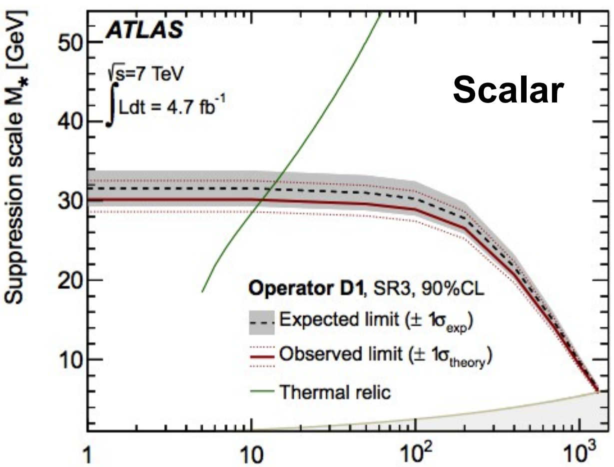
- The WIMP is taken as a Dirac fermion.
- Different operators are considered with different structures

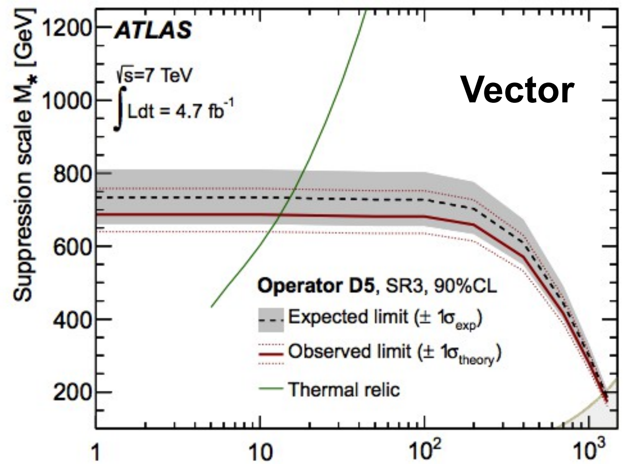
Name	Initial state	Type	Operator
D1	qq	scalar	$\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_\star^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$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

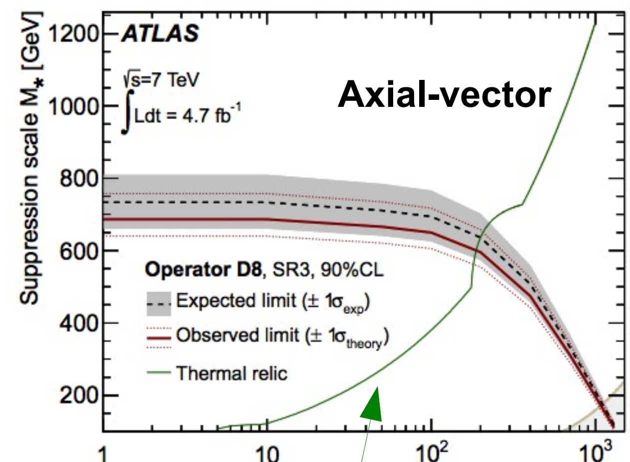
This theory is only applicable when M is much larger than the energy scale present in the reaction.

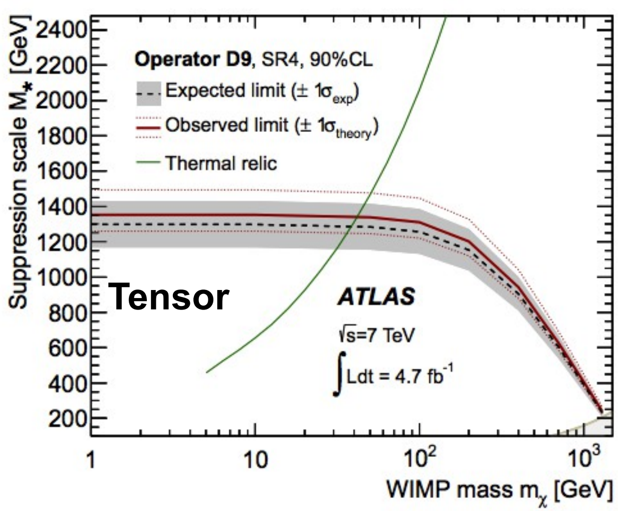
Limits on WIMP production

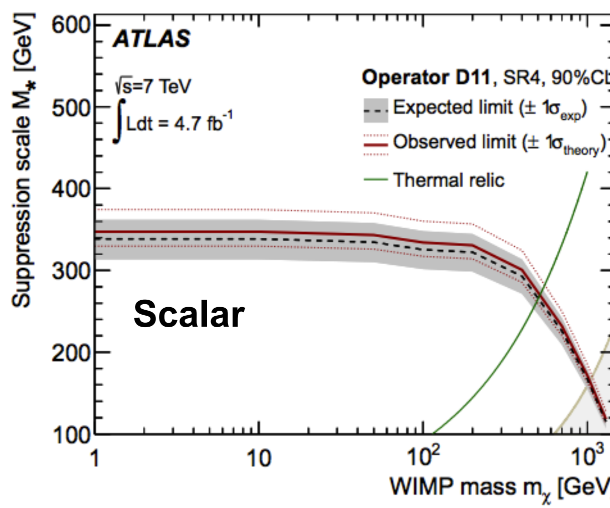
- 90% CL on the visible cross-sections for new physics are translated into limits on M* as a function of the WIMP mass for the different operators.







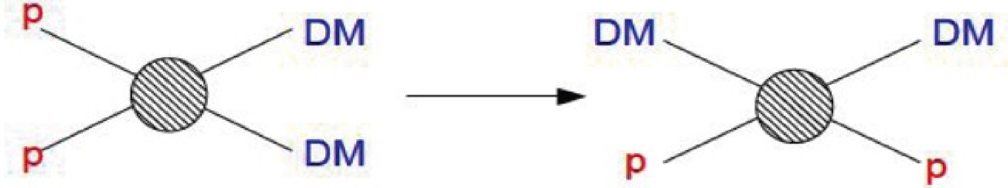




The green line indicates the values (from WMAP) for M* and m_χ leading to the proper abundance.

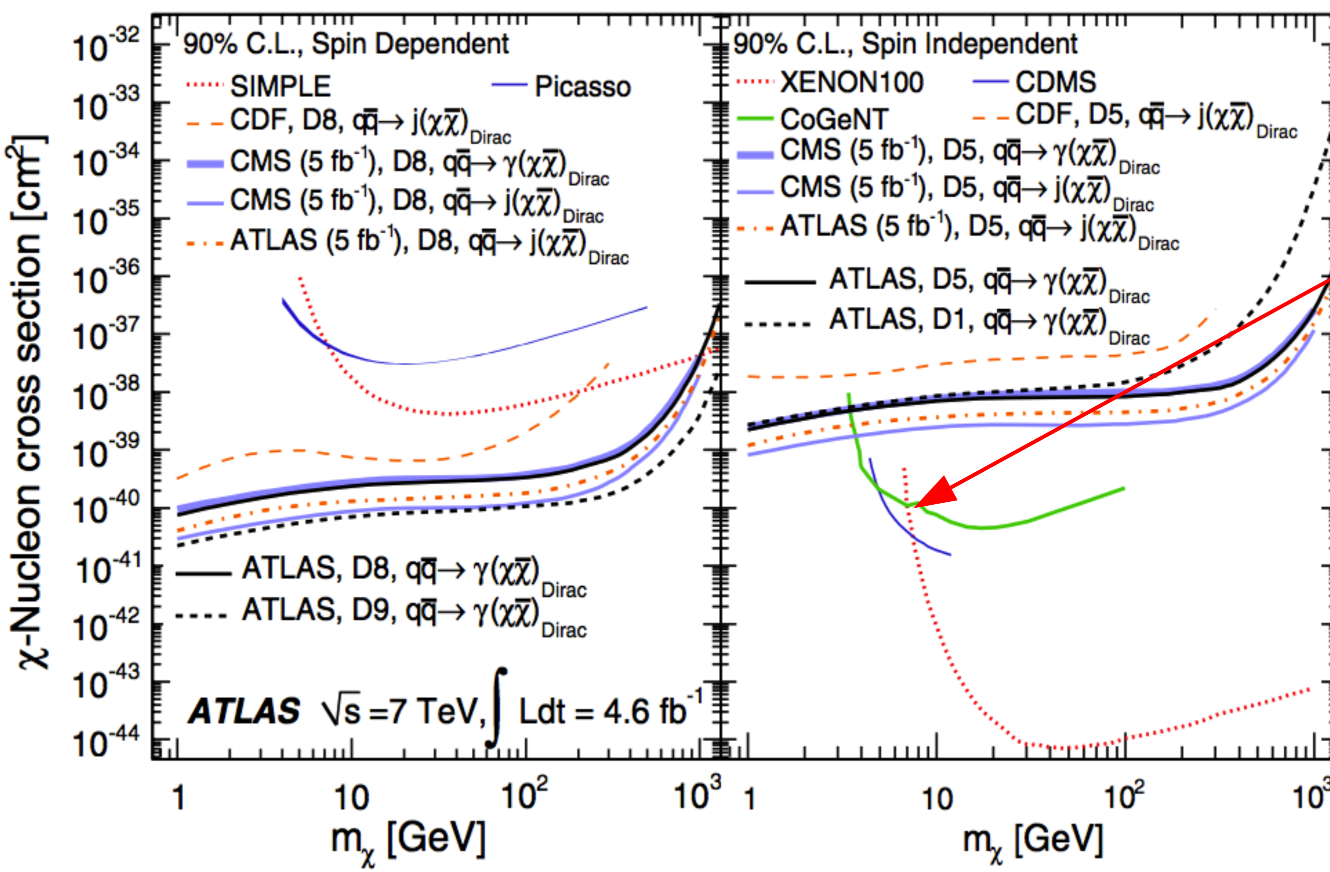
M>>2χ and perturbative g_1, g_2 are not accomplished anymore

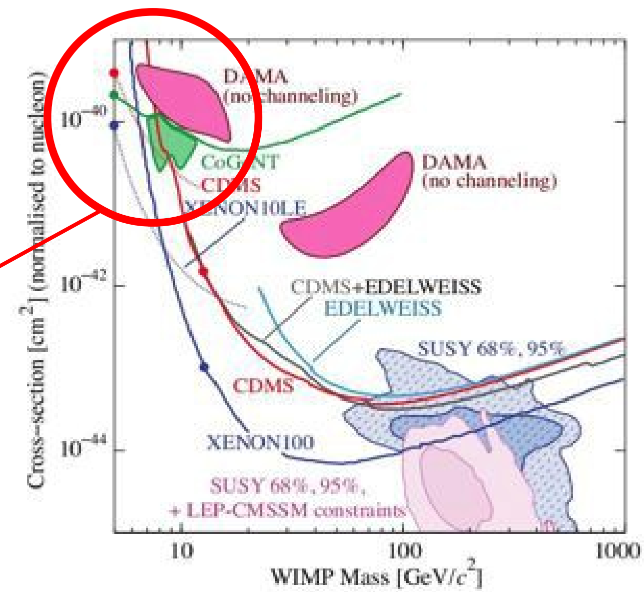
WIMP-nucleon cross-section



No enough sensitivity yet to exclude/confirm the CoGeNT/DAMA excess at m_χ < 100 GeV in D1/D5 models

- The different operators contribute to spin-dependent or independent WIMP-nucleon cross-sections.





- Very significant improvement on limits compared to Tevatron.

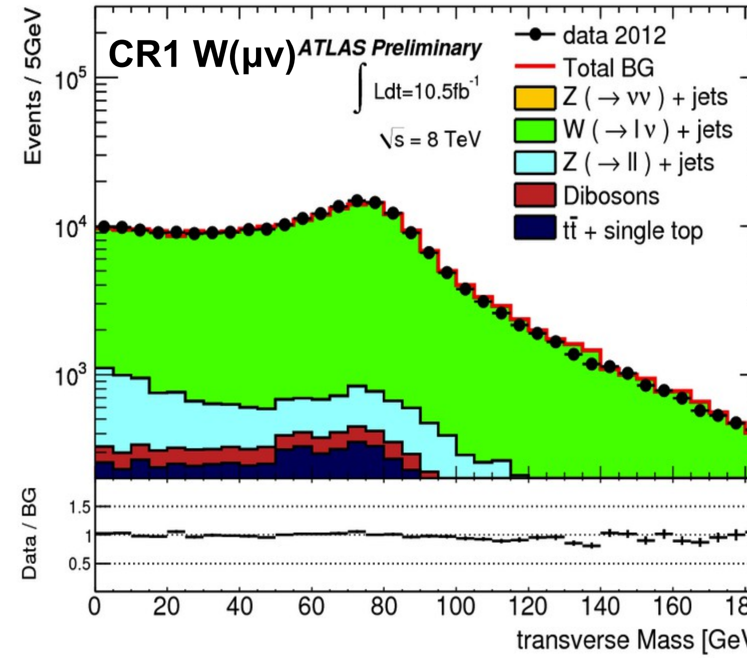
- Under assumption of validity: results competitive to direct detector experiments.

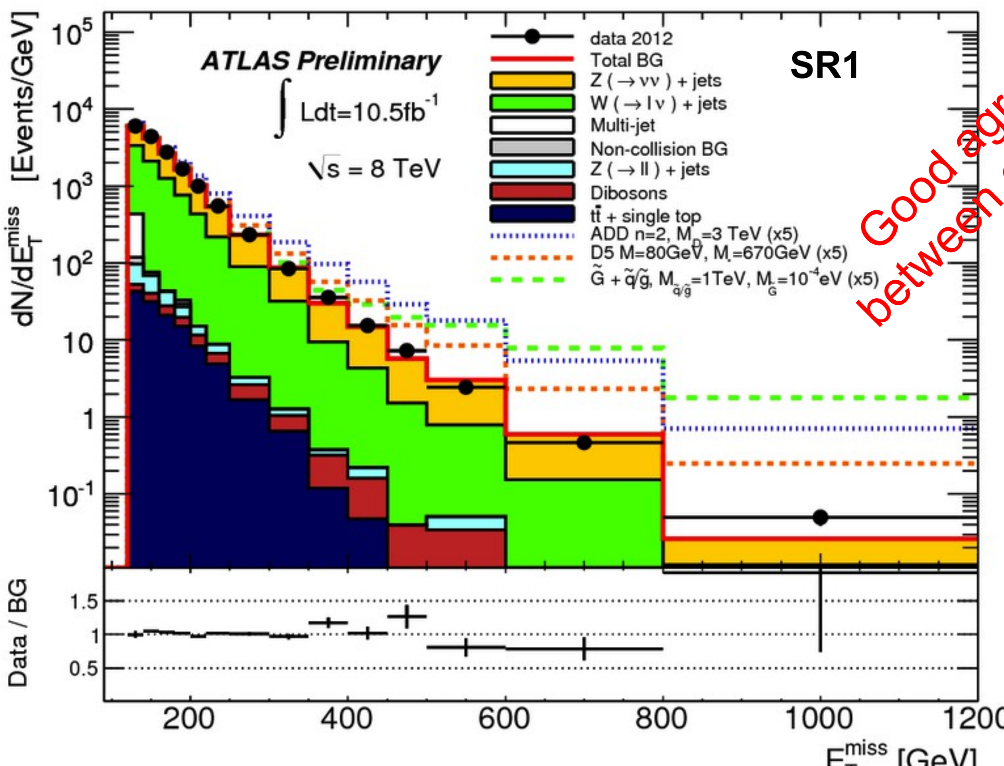
8 TeV, $\mathscr{L}$=10.5 fb-1

Mono-jet 8 TeV search in ATLAS

- Same strategy and event selection as in the 7 TeV analysis.
  - Etmiss, p_T leading jet > 120, 220, 350, 500 GeV
  - Njet(Pt > 30 GeV) < 3
  - $\Delta\varphi(E_T$, any jet) > 0.5
  - Lepton veto

ATLAS-CONF-2012-147





Good agreement between data and SM

- Results interpreted in terms of ADD and WIMPS production and Gravitino+Squark/Gluino (GMSB) (new).
- Only the latest will be shown in next slides.

8 TeV, $\mathscr{L}$=10.5 fb-1

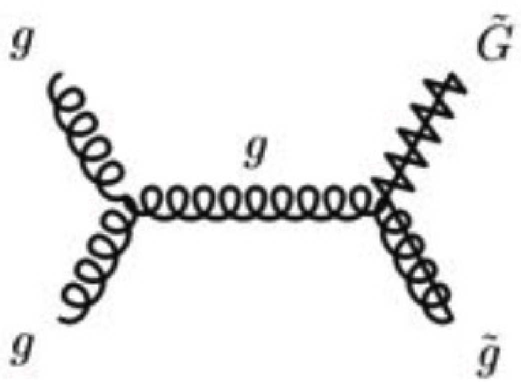
GMSB Gravitino

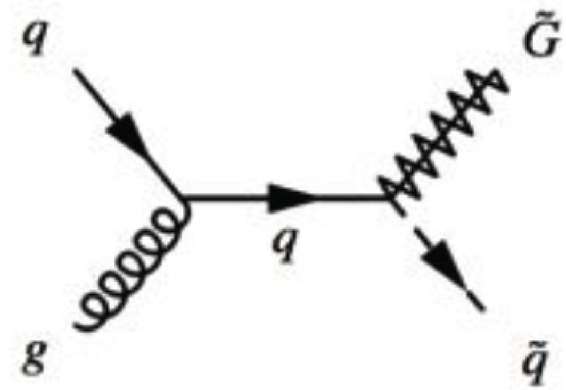
- Gravitino is considered the LSP in gauge-mediated SUSY breaking (GMSB) scenarios.

- Potential contribution to total amount of Dark Matter.

- Interpreted in terms of GMSB gravitino+squark/gluino production.
  - Gluinos (squarks) decay to gluon (quark) plus gravitino (100%)

- Signature:
  1 jet + Gravitinos (Etmiss)





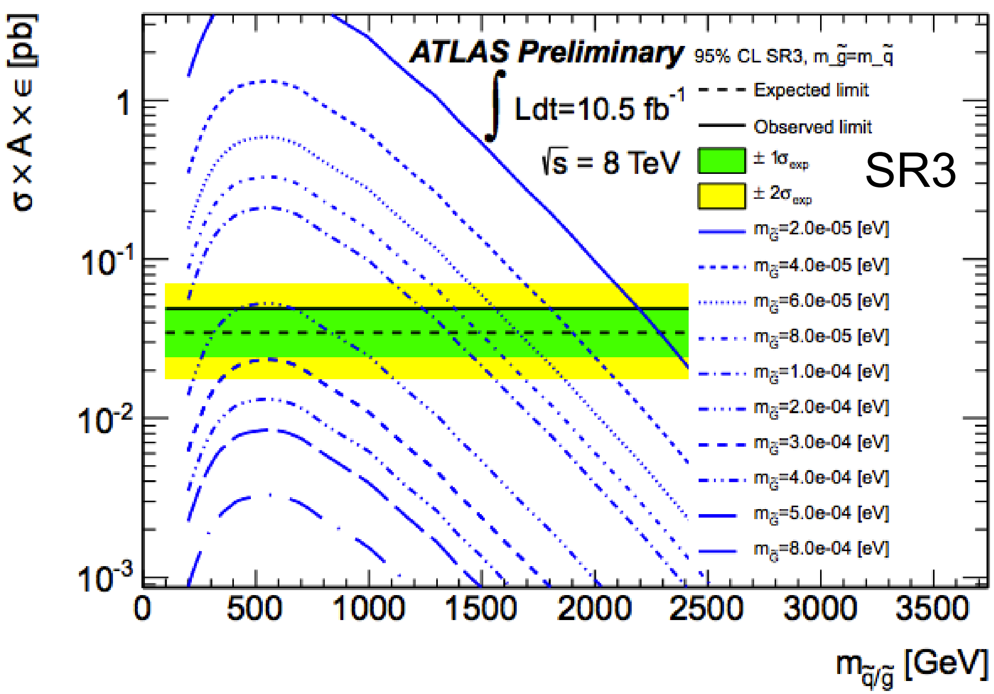
Limits on GMSB Gravitino mass

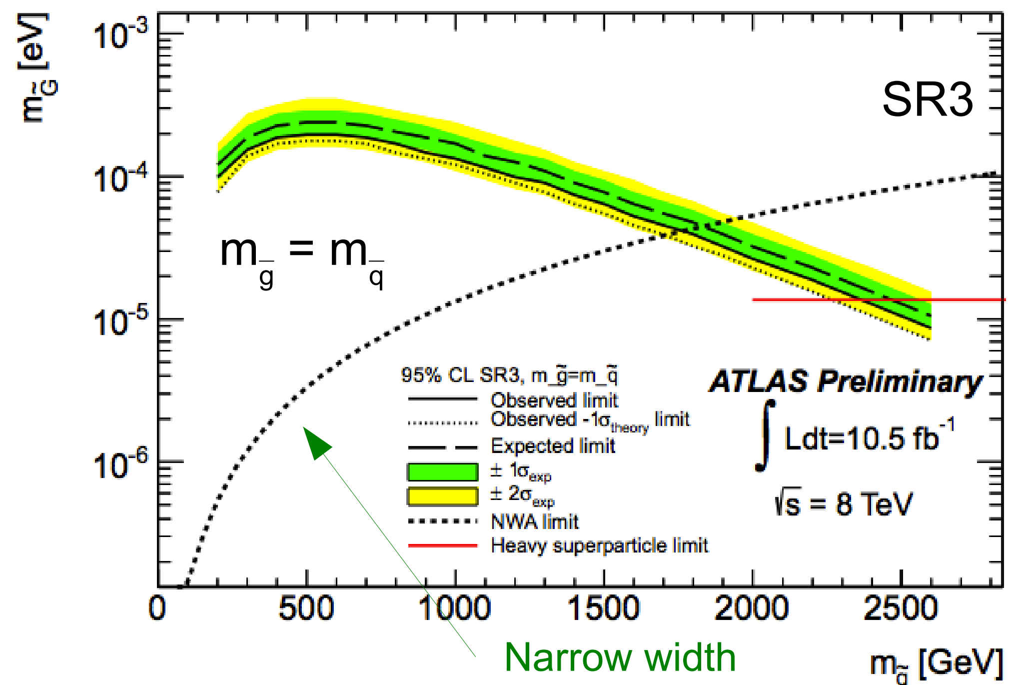
8 TeV, $\mathscr{L}$=10.5 fb-1

- 95% CL limits on the mass of the GMSB gravitino as a function of the squark or gluino masses.

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

Supersymmetry breaking VEV





Narrow width approximation

- Best limits to date in the gravitino mass.
- $m_{\tilde{G}}$ in the range $[3\cdot10^{-4}, 4\cdot10^{-9}]$ eV are excluded (depending on $m_{\tilde{g}}$ and $m_{\tilde{q}}$).

Limit on $\sqrt{F}$ > 640 GeV
(In LEP, the limit was 240 GeV)

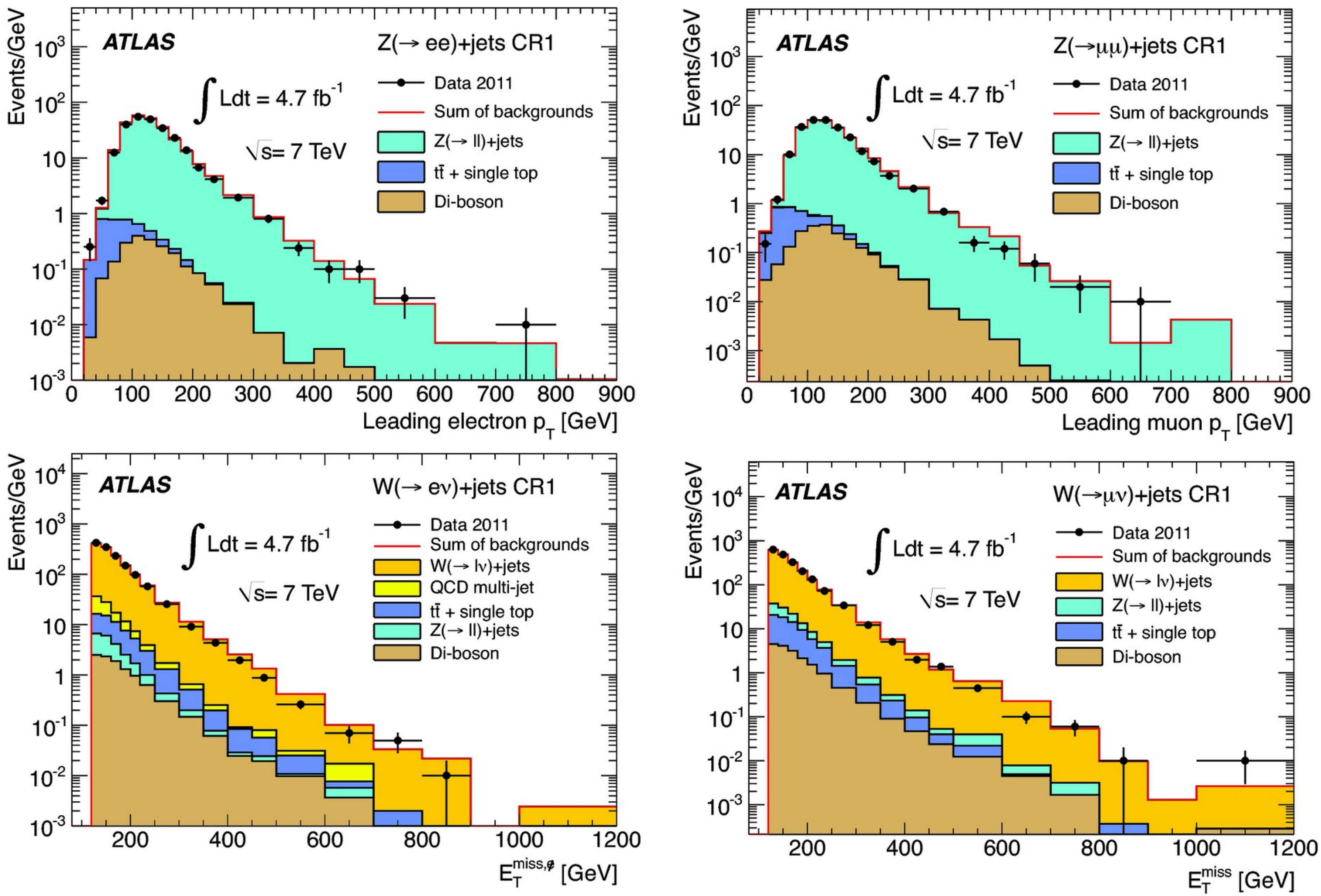
Conclusions

- Final states with a high Pt jet/photon and high Etmiss are distinctive signatures on searches for new physics.
- No significant excesses with respect to the SM expectation for both mono-jet and mono-photon analyses.
- Improvement of limits on Large Extra Dimensions ADD model.
- Limits on M* and WIMP-nucleon scattering cross-section.
- Interpretation in terms of GMSB gravitino mass.

Backup slides

Mono-jet search in ATLAS

7 TeV, $\mathscr{L}$=4.6 fb-1



7 TeV, $\mathscr{L}$=4.6 fb-1

Mono-jet search in ATLAS

Background Predictions ± (stat.data)± (stat.MC) ± (syst.)				
	SR1	SR2	SR3	SR4
$Z(\rightarrow \nu\bar{\nu})$+jets	173600 ± 500 ± 1300 ± 5500	15600 ± 200 ± 300 ± 500	1520 ± 50 ± 90 ± 60	270 ± 30 ± 40 ± 20
$W \rightarrow \tau\nu$+jets	87400 ± 300 ± 800 ± 3700	5580 ± 60 ± 190 ± 300	370 ± 10 ± 40 ± 30	39 ± 4 ± 11 ± 2
$W \rightarrow e\nu$+jets	36700 ± 200 ± 500 ± 1500	1880 ± 30 ± 100 ± 100	112 ± 5 ± 18 ± 9	16 ± 2 ± 6 ± 2
$W \rightarrow \mu\nu$+jets	34200 ± 100 ± 400 ± 1600	2050 ± 20 ± 100 ± 130	158 ± 5 ± 21 ± 14	42 ± 4 ± 13 ± 8
$Z \rightarrow \tau\tau$+jets	1263 ± 7 ± 44 ± 92	54 ± 1 ± 9 ± 5	1.3 ± 0.1 ± 1.3 ± 0.2	1.4 ± 0.2 ± 1.5 ± 0.2
$Z/\gamma^{*}(\rightarrow \mu^{+}\mu^{-})$+jets	783 ± 2 ± 35 ± 53	26 ± 0 ± 6 ± 1	2.7 ± 0.1 ± 1.9 ± 0.3	–
$Z/\gamma^{*}(\rightarrow e^{+}e^{-})$+jets	–	–	–	–
Multijet	6400 ± 90 ± 5500	200 ± 20 ± 200	–	–
$t\bar{t}$ + single t	2660 ± 60 ± 530	120 ± 10 ± 20	7 ± 3 ± 1	1.2 ± 1.2 ± 0.2
Dibosons	815 ± 9 ± 163	83 ± 3 ± 17	14 ± 1 ± 3	3 ± 1 ± 1
Non-collision background	640 ± 40 ± 60	22 ± 7 ± 2	–	–
Total background	344400 ± 900 ± 2200 ± 12600	25600 ± 240 ± 500 ± 900	2180 ± 70 ± 120 ± 100	380 ± 30 ± 60 ± 30
Data	350932	25515	2353	268

Model independent limits

- Good agreement is observed between the data and the SM predictions in both final states.

- Translated into upper limits on the visible cross section $(\sigma \times A \times \epsilon)$ on the presence of new physics.

Mono-jet (for Etmiss > 500 GeV)

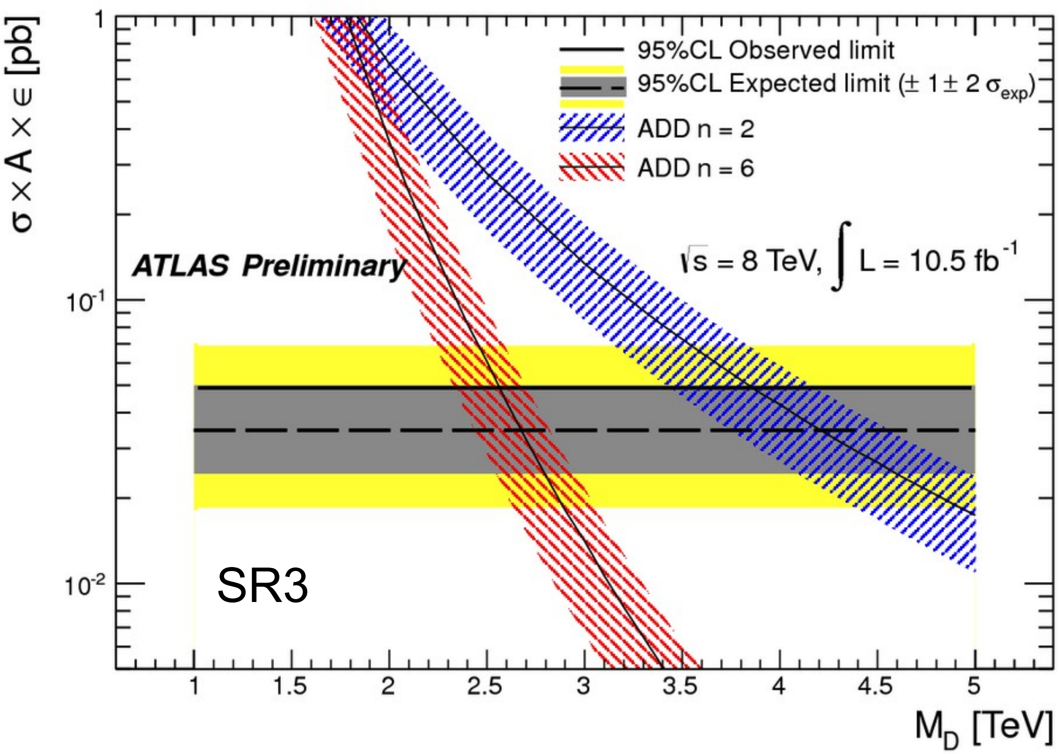
$(\sigma \times A \times \epsilon)$ [fb]	Observed	Expected
Limit @ 90% CL	5.5	6.4
Limit @ 95% CL	6.9	7.9

Mono-photon (for Etmiss > 150 GeV)

$(\sigma \times A \times \epsilon)$ [fb]	Observed	Expected
Limit @ 90% CL	5.6	7.5
Limit @ 95% CL	6.8	8.9

Limits on M_D (ADD model for LED)

- As in the 7 TeV analysis, 95% CL on the visible cross-section for the effective ADD theory are translated to limits on M_D.



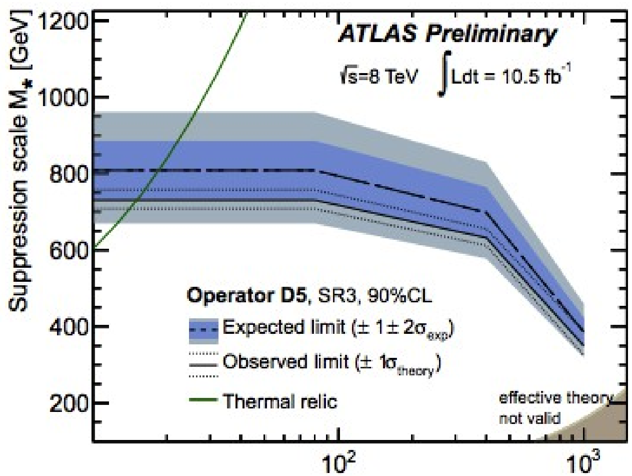
- Limits on M_D are lower than for the 7 TeV analysis due to the lack of MC statistics.
  - SR3 is used instead of SR4

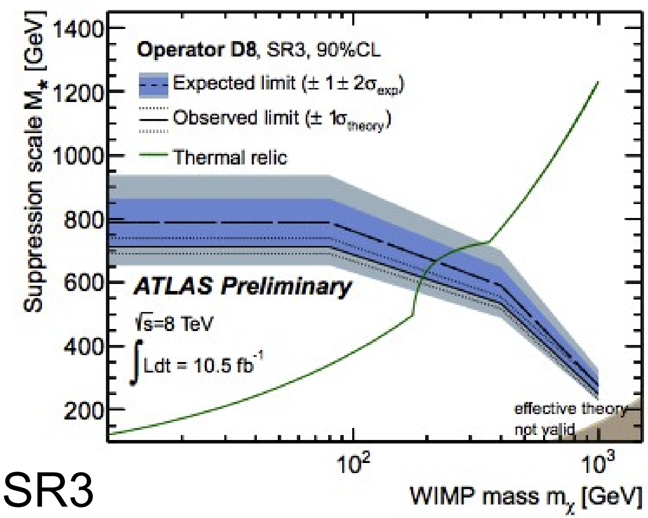
8 TeV, $\mathscr{L}$=10.5 fb-1

95% CL limits on ADD model using LO signal cross sections						
n extra-dimensions	95% CL observed limit on M_D [TeV] +1σ(theory)	Nominal	−1σ(theory)	95% CL expected limit on M_D [TeV] +1σ	Nominal	−1σ
2	+0.32	3.88	−0.42	−0.36	4.24	+0.39
3	+0.21	3.16	−0.29	−0.24	3.39	+0.46
4	+0.16	2.84	−0.27	−0.16	3.00	+0.20
5	+0.16	2.65	−0.27	−0.13	2.78	+0.15
6	+0.13	2.58	−0.23	−0.11	2.69	+0.11

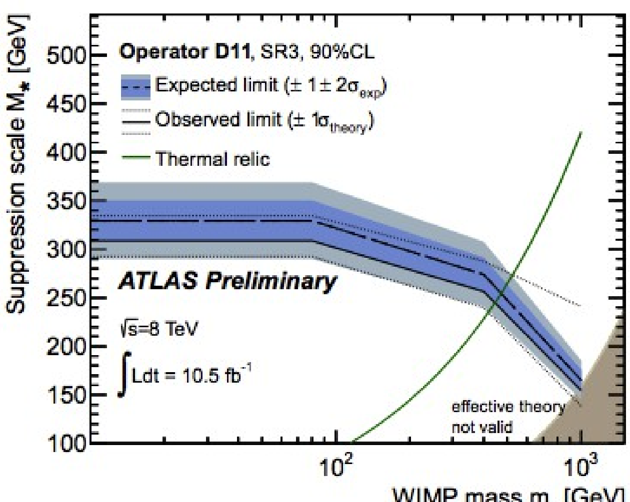
90% CL limits on suppression scale

- Lower limits on M* as a function of the WIMP mass for the different operators is computed following the same steps as for the 7 TeV analysis.





SR3

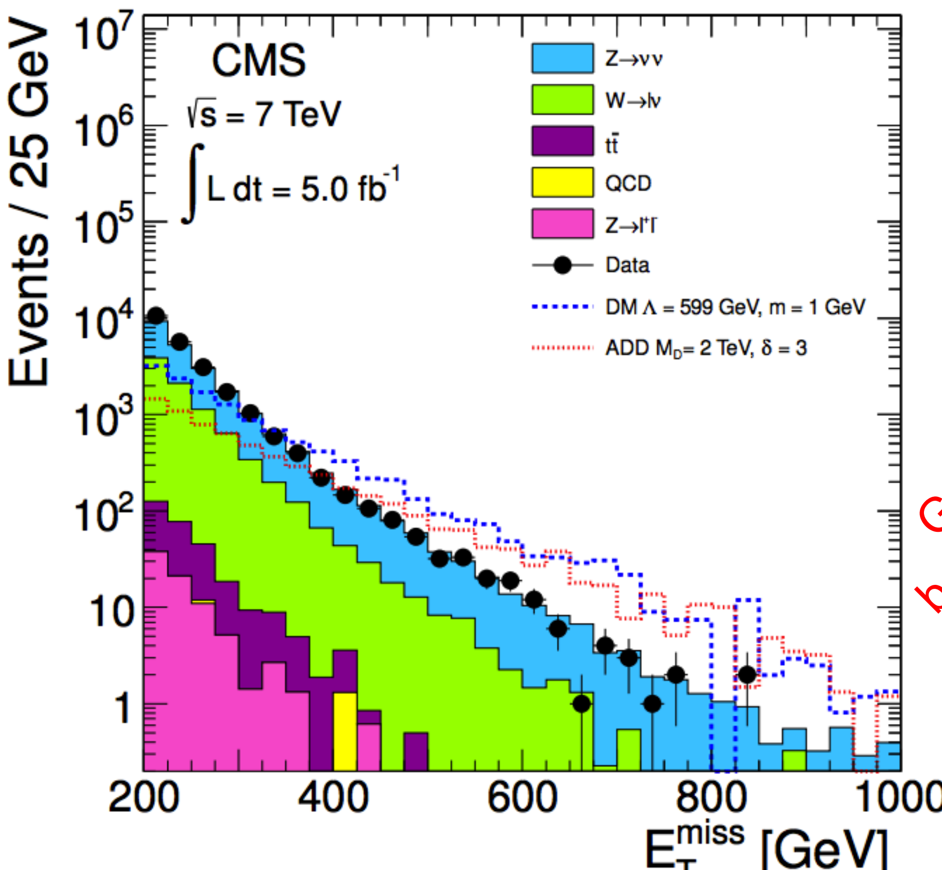


The limits in M* are improved by about 150 GeV with the 8 TeV data

8 TeV, $\mathscr{L}$=10.5 fb-1

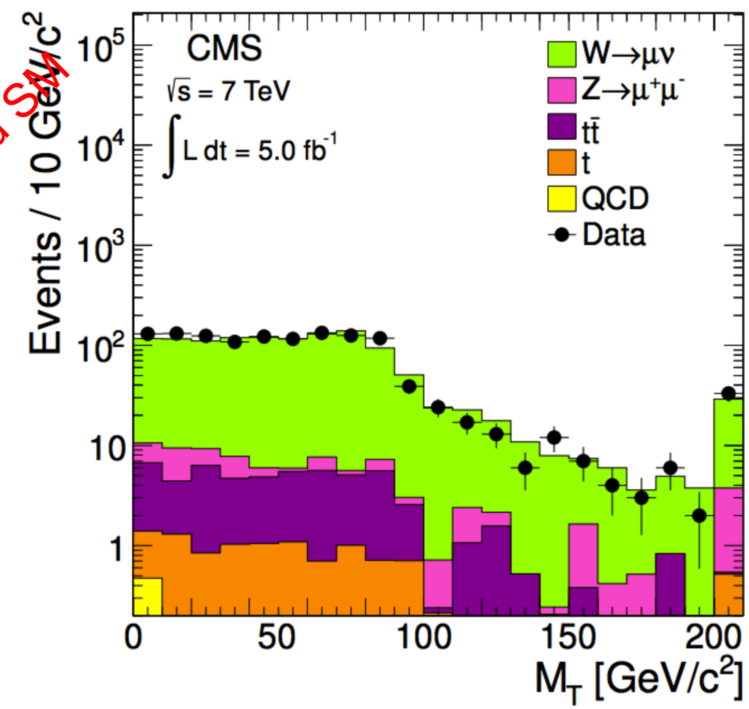
7 TeV, $\mathscr{L}$=5.0 fb-1

Mono-jet search in CMS



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

Good agreement between data and SM



- High missing E_T: Etmiss > 200 GeV
- 1 High p_T photon: Pt(γ) > 110 GeV
- Njet(Pt > 30 GeV) < 3
- Δφ(jet1, jet2) < 2.5
- Lepton veto

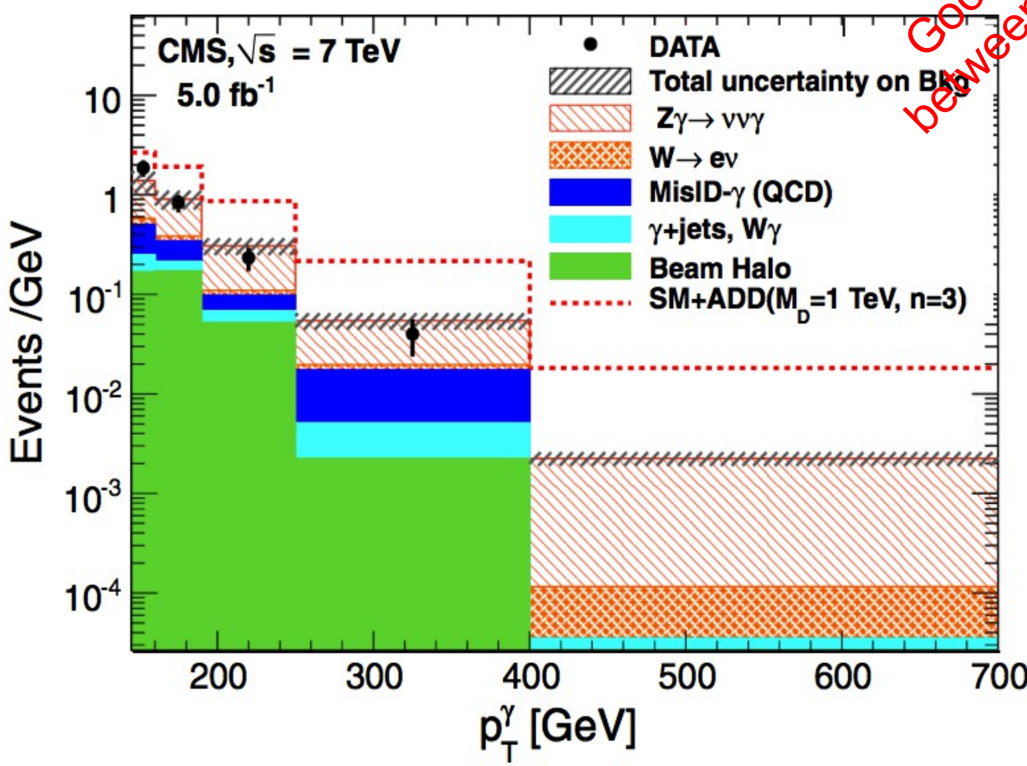
E_T^{miss} (GeV/c) →	≥ 250	≥ 300	≥ 350	≥ 400
Total SM	7842 ± 367	2757 ± 167	1225 ± 101	573 ± 65
Data	7584	2774	1142	522
Expected upper limit non-SM	779	325	200	118
Observed upper limit non-SM	600	368	158	95

Mono-photon search in CMS

- Event selection:
  - High missing E_T: Etmiss > 130 GeV
  - 1 High p_T photon: Pt(γ) > 145 GeV
  - |η(γ)| < 1.44, isolated
  - Lepton veto, isolated tracks, etc.

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 between data and SM



- 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.