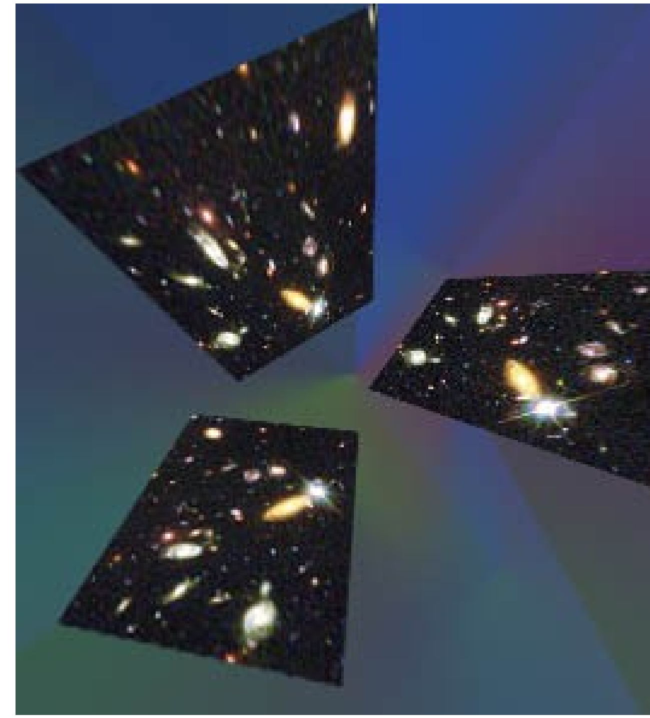
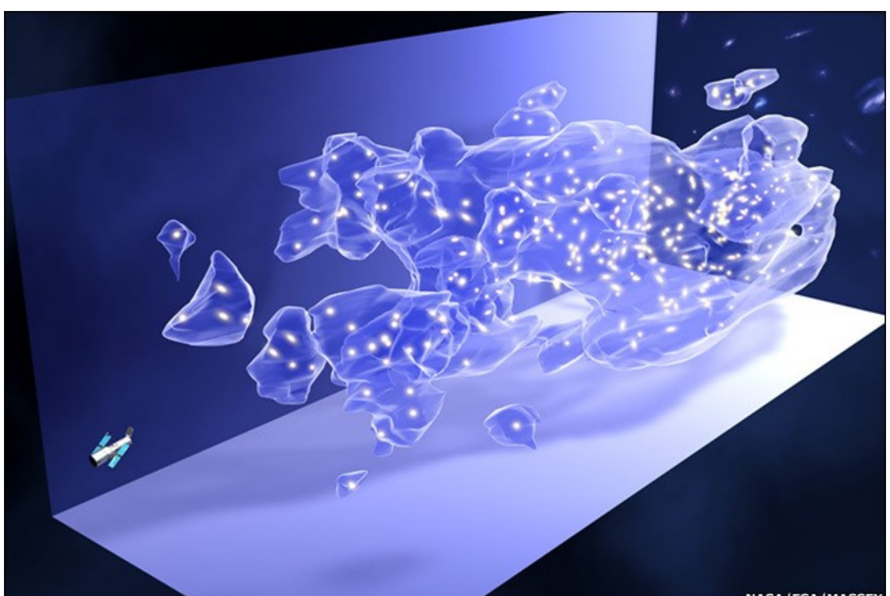
Search for monojets and monophotons with the ATLAS detector

Jalal Abdallah -IFAE
On behalf of ATLAS Collaboration

Motivation and outline

- Search for high pT jet/photon associated with invisible new particles:
  - Sensitivity to a large number of new physics models
  - Well understood backgrounds from electro-weak processes Z/W+jet/photon
- [ATLAS public results]





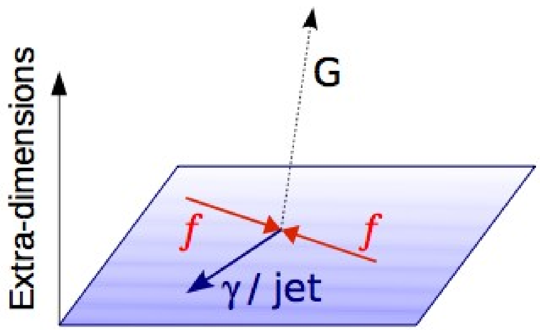
Outline of the talk

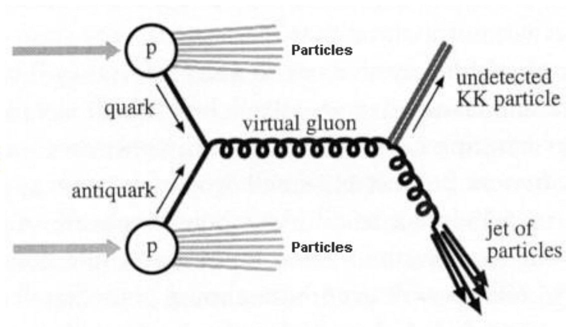
- Description of analyses
- Interpretations in terms of:
  - Large Extra-Dimensions
  - Gravitino production
  - WIMP production

Monojet/monophoton final states

Large extra dimensions

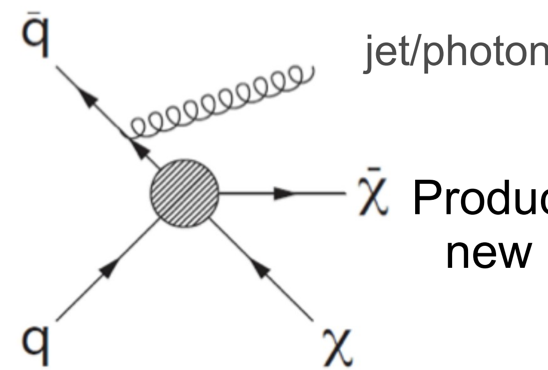
Graviton propagates into extra dimensions





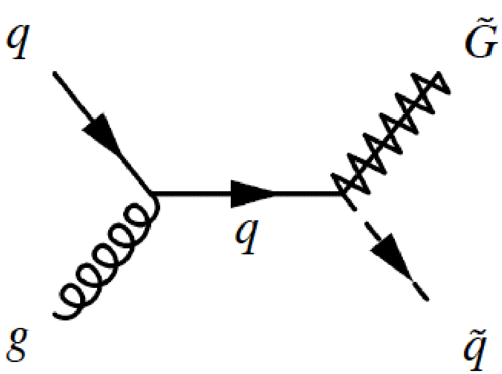
Arkani-Hamed, Dimopoulos, Dvali (ADD)

Dark Matter production



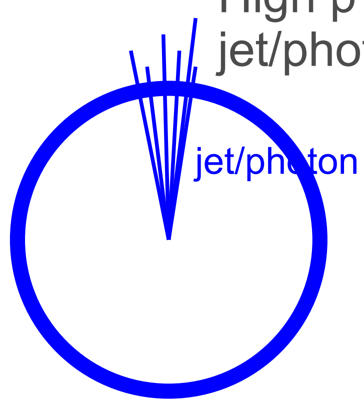
Production of undetected new particles and ISR

Light Gravitino production

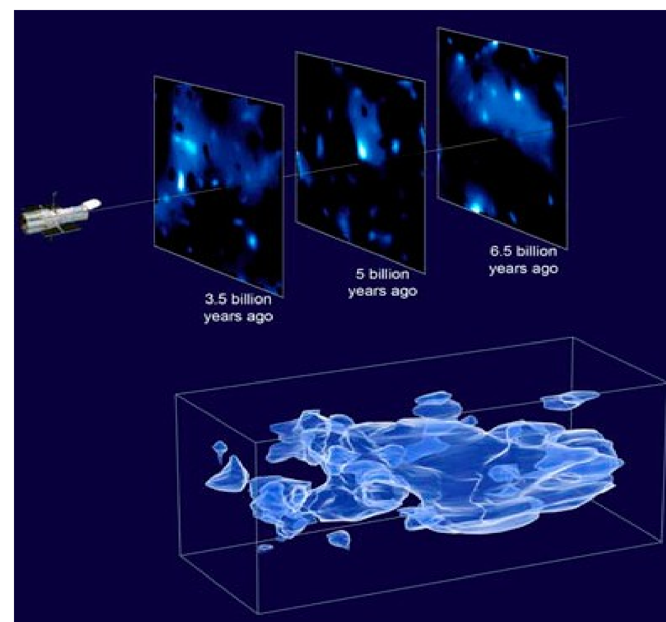


$$m_{3/2} = \langle F \rangle / \sqrt{3}\,\overline{M}_{\rm Pl}$$

High pT jet/photon



Large MET *

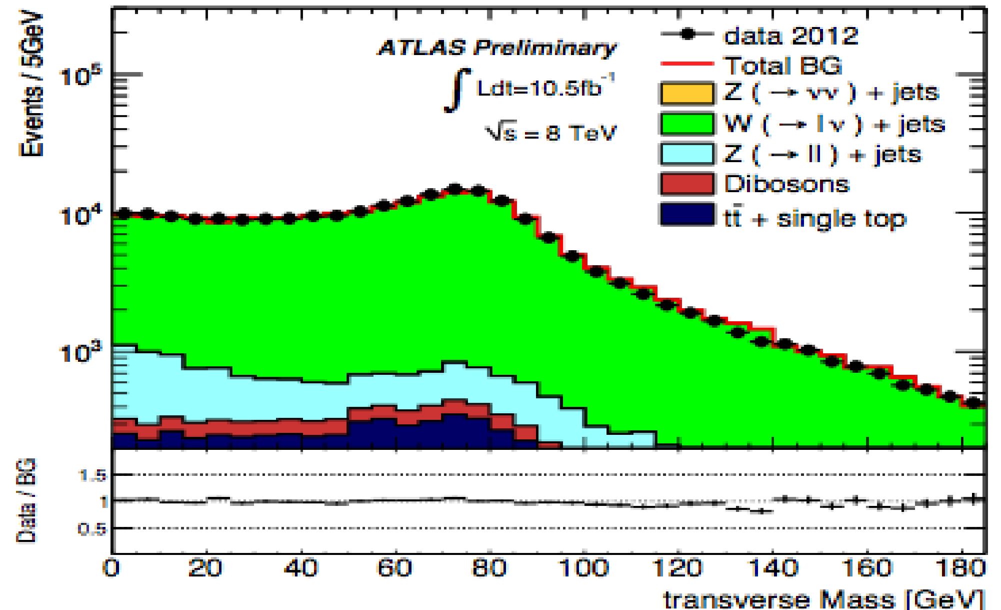


*MET = Missing Transverse Momentum

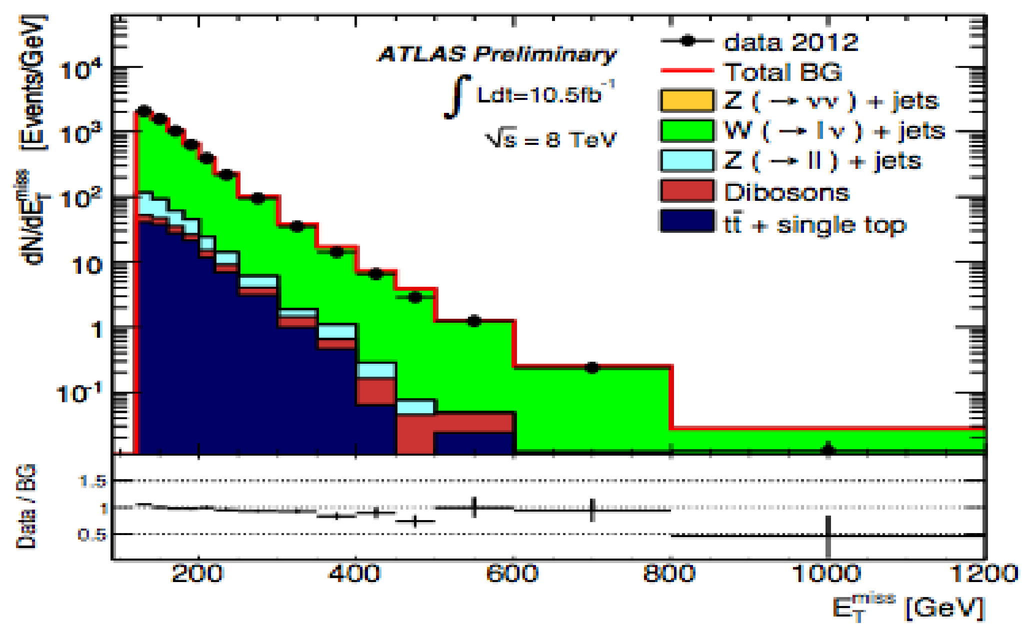
Monojet final states

[arXiv:1210.4491 (7 TeV)](arXiv:1210.4491)
ATL-CONF-2012-147 (8 TeV)

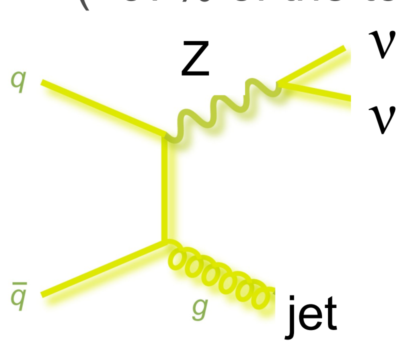
Selection criteria				
Primary vertex				
$E_T^{miss} > 120$ GeV				
Jet cleanup requirements				
Leading jet with $p_T > 120$ GeV and $\|\eta\| < 2.0$				
At most two jets with $p_T > 30$ GeV and $\|\eta\| < 4.5$				
$\Delta\phi(\text{jet}, E_T^{miss}) > 0.5$ (second-leading jet)				
Lepton vetoes				
signal region	SR1	SR2	SR3	SR4
minimum leading jet p_T (GeV)	120	220	350	500
minimum E_T^{miss} (GeV)	120	220	350	500

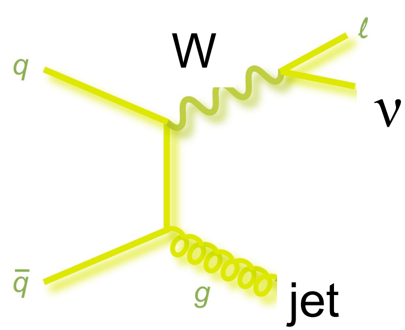


Wμν Control Region



- Z/W+jets → Main background (BG) (~97% of the total)





- Estimated in a data driven way using well defined leptonic Control Regions
- QCD and non-collision BG from data, Top and Dibosons from MC.
- Good control over the background

Background estimation

arXiv:1210.4491 (7 TeV)
ATL-CONF-2012-147 (8 TeV)

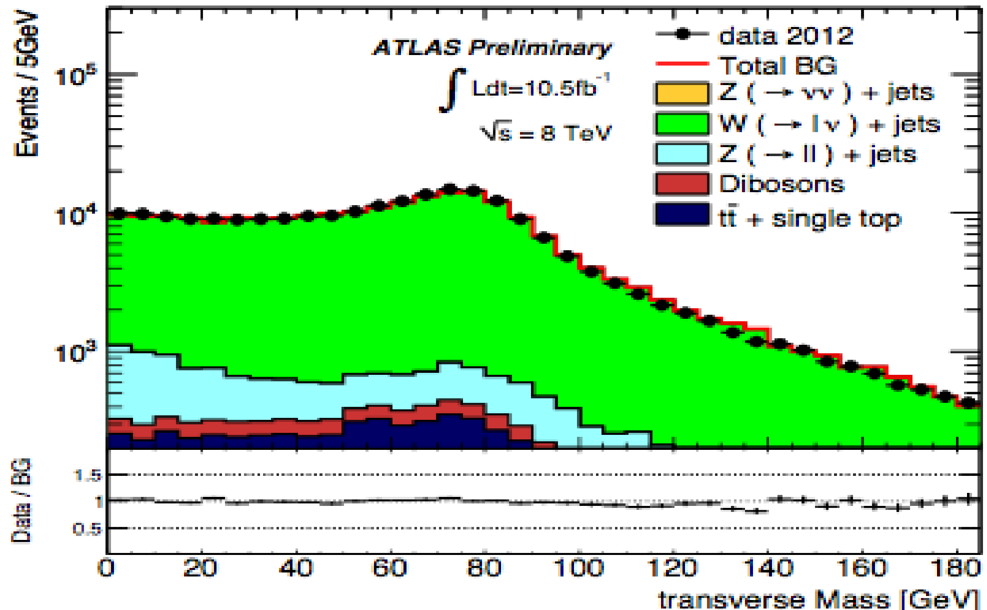
- Data driven estimation can be done using different control regions:

SR	$Z \to \nu\bar{\nu}$+jets	$W \to \tau\nu$+jets $W \to \mu\nu$+jets	$W \to e\nu$+jets	$Z \to \tau^+\tau^-$+jets $Z \to \mu^+\mu^-$+jets
CR	$W \to e\nu$+jets $W \to \mu\nu$+jets $Z \to e^+e^-$+jets $Z \to \mu^+\mu^-$+jets	$W \to \mu\nu$+jets	$W \to e\nu$+jets	$Z \to \mu^+\mu^-$+jets

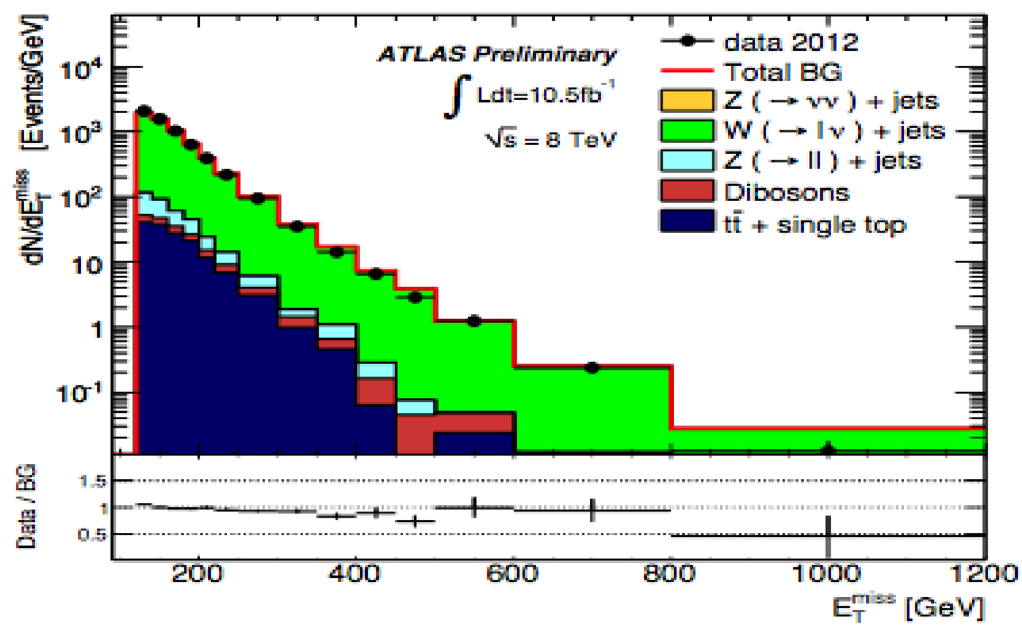
- Background estimation:

$$N_{\rm SR}^{\rm predicted} = (N_{\rm CR}^{\rm Data} - N_{\rm Bkg}) \cdot C \cdot \frac{N_{\rm SR}^{\rm MC}}{N_{{\rm jet}/E_{\rm T}^{\rm miss}}^{\rm MC}}$$

  - Correction factor for the lepton acceptance and reconstruction efficiency, trigger, luminosity.
  - Transfer factor from the CR to SR



Wμν Control Region

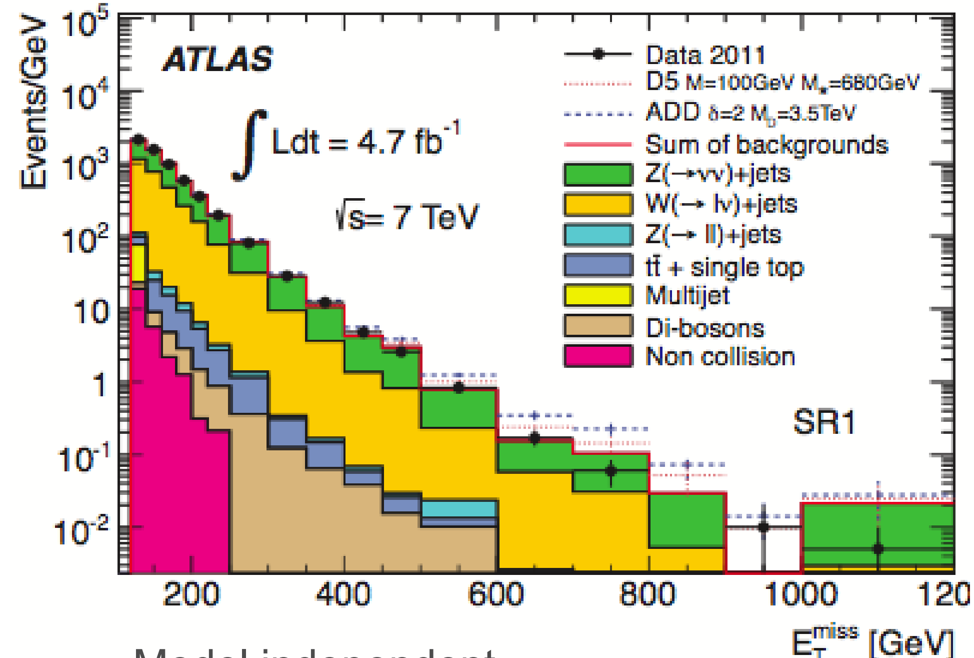


Monojet results

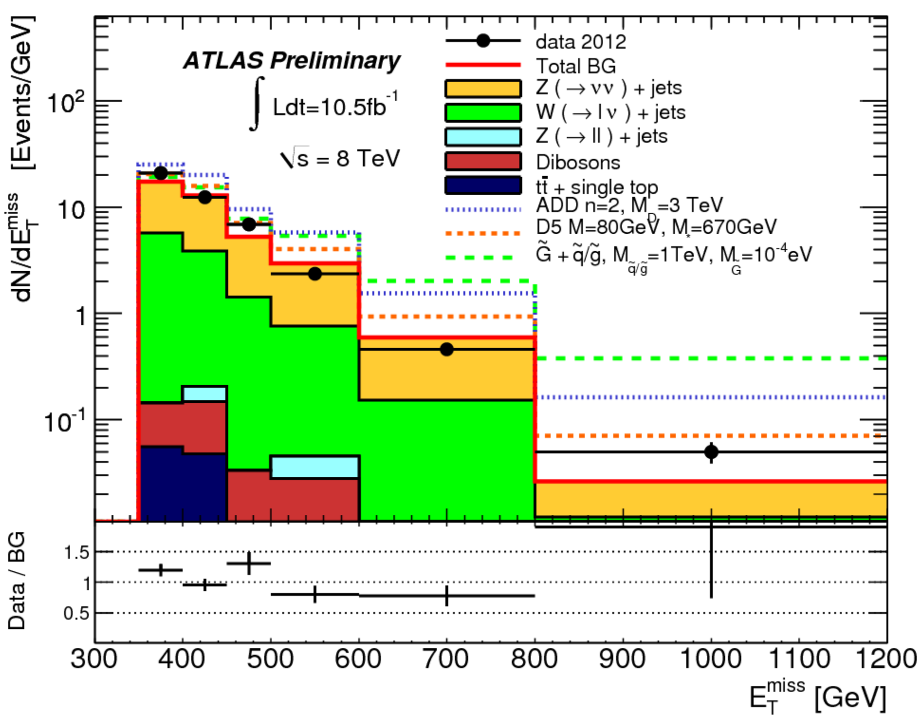
[arXiv:1210.4491 (7 TeV)](arXiv:1210.4491)
ATL-CONF-2012-147 (8 TeV)

- Typical uncertainties on background: from 3 to 15% for SR1 to SR4.
- Good agreement with the SM expectation
- The 8 TeV analysis suffered from limited MC statistics → limits are equivalent to the 7TeV analysis.

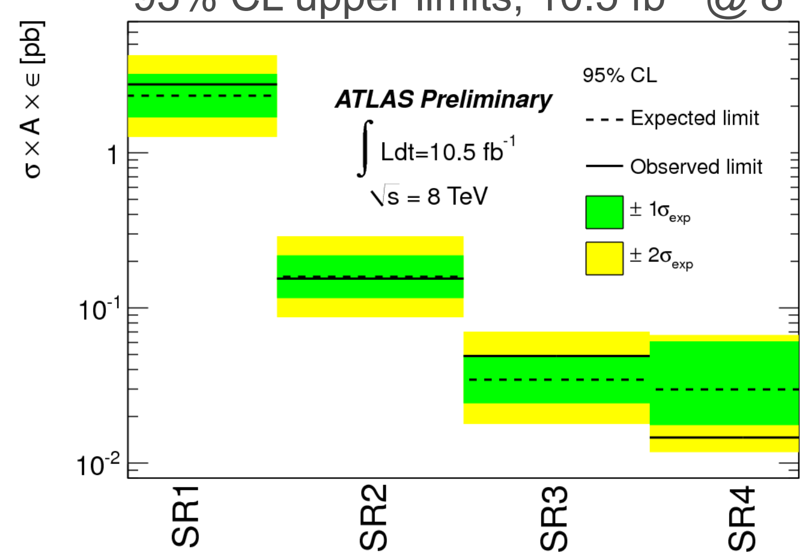
SR1, 4.7 fb^{-1} @ 7 TeV



SR3, 10.5 fb^{-1} @ 8 TeV

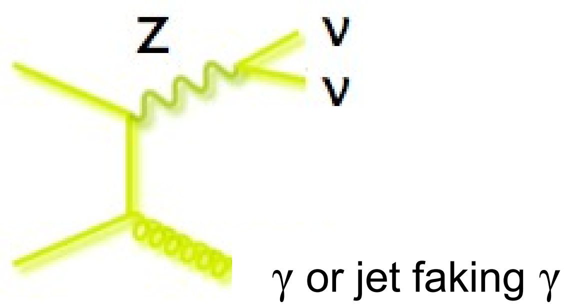


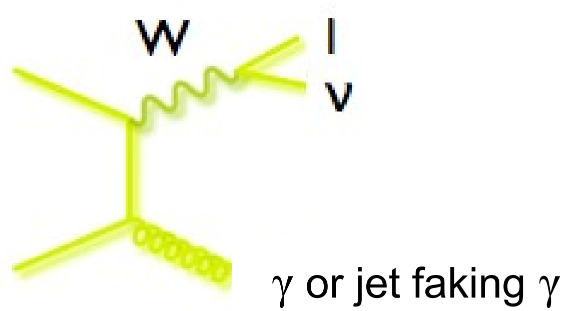
Model independent
95% CL upper limits, 10.5 fb^{-1} @ 8 TeV



Monophoton final states

arXiv:1209.4625



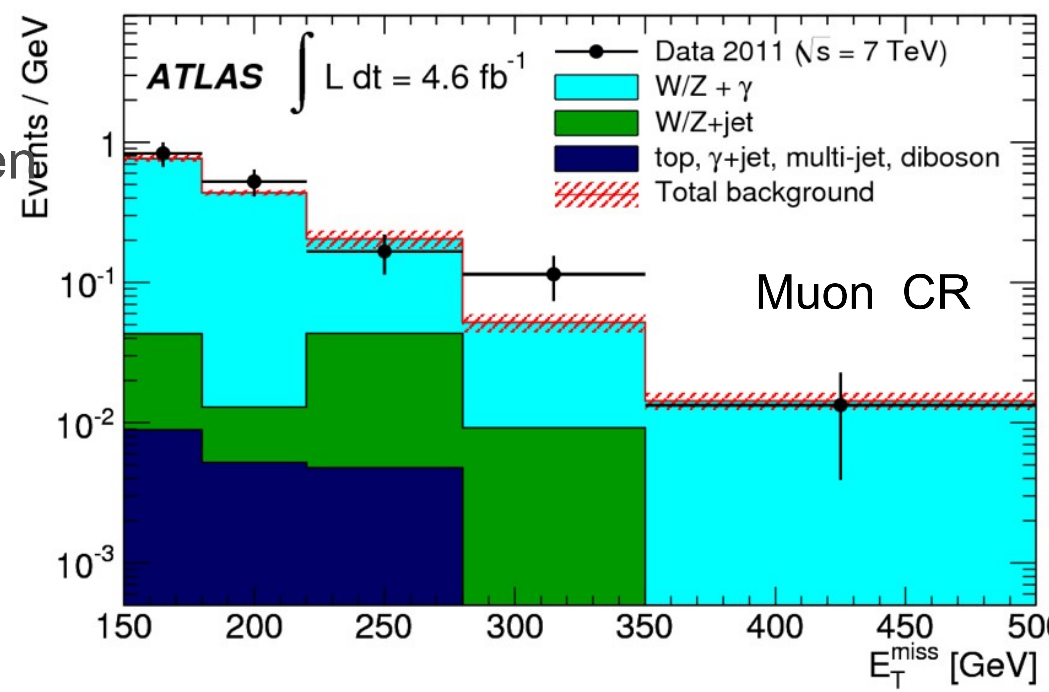


Event selection

- High ETmiss > 150 GeV
- 1 high pT photon > 150 GeV
- Allow 1 jet (pT>30 GeV)
- Jets/photons far from MET direction: Δφ>0.5
- Veto on leptons (e pT>20 GeV, μ pT>7 GeV)

SM backgrounds

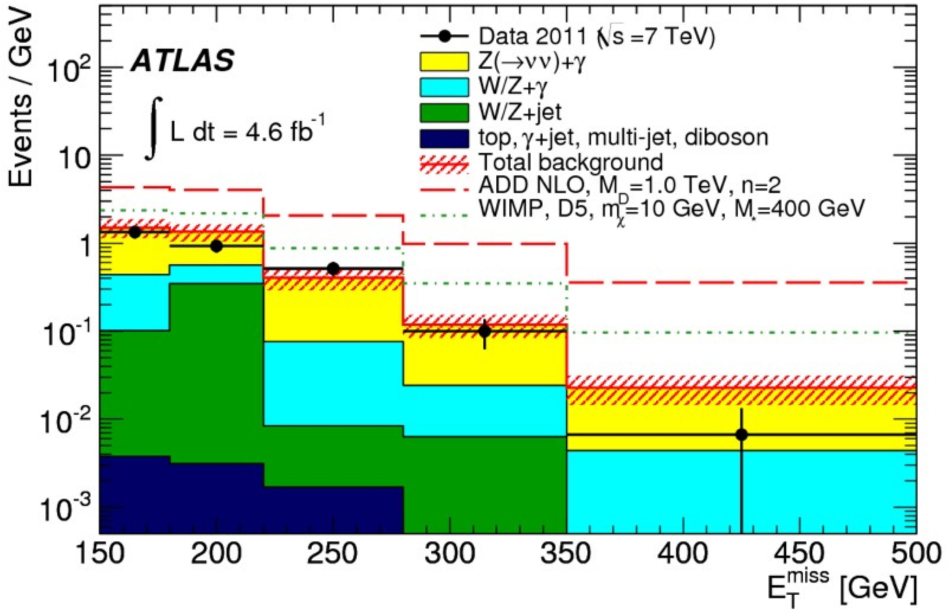
- Z/W + γ (85%) estimated in data-driven way from a muon control region
- Z/W + e/jet faking γ (13%) measured from data
- γ+jet and multijets from data, top and dibosons from MC (2%)

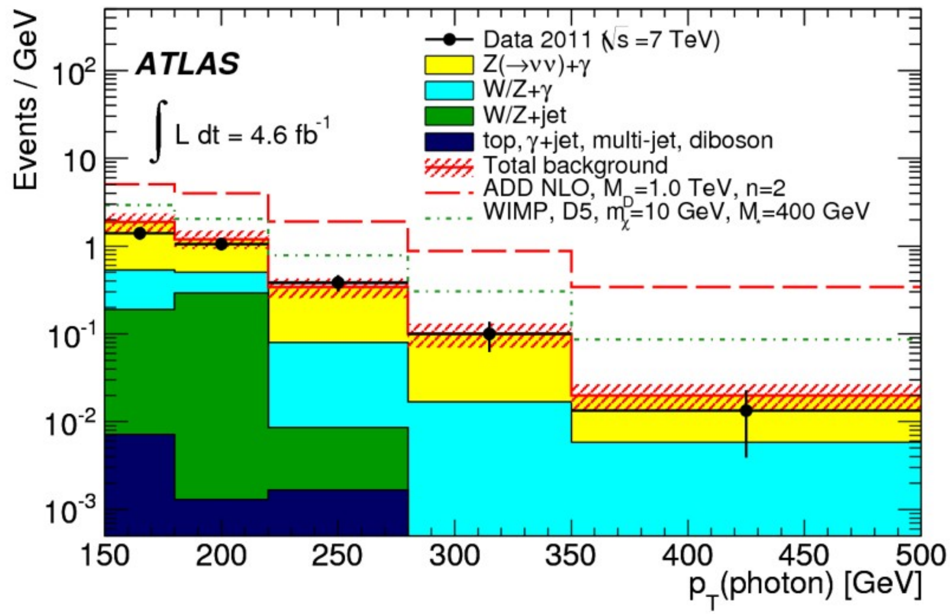


Monophoton results

arXiv:1209.4625

- Uncertainties are dominated by statistics (data in CR) ~ 13%
- Systematic uncertainties (energy scales, photon identification, parton shower modeling, …) 7%
- Data are compatible with the SM predictions



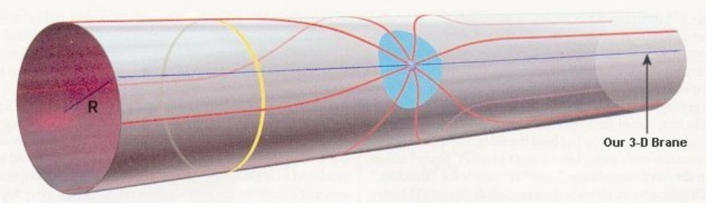


Background source	Prediction	± (stat.)	± (syst.)
$Z(\rightarrow \nu\bar{\nu}) + \gamma$	93	± 16	± 8
$Z/\gamma^*(\rightarrow \ell^+\ell^-) + \gamma$	0.4	± 0.2	± 0.1
$W(\rightarrow \ell\nu) + \gamma$	24	± 5	± 2
W/Z + jets	18	–	± 6
Top	0.07	± 0.07	± 0.01
$WW, WZ, ZZ, \gamma\gamma$	0.3	± 0.1	± 0.1
γ+jets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

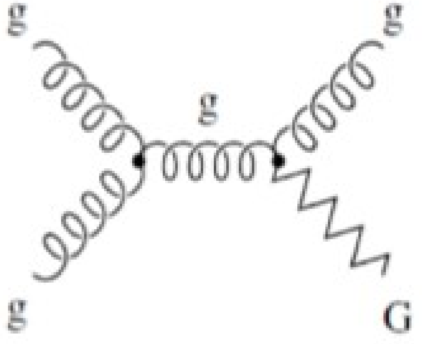
Large Extra Dimensions (ADD)

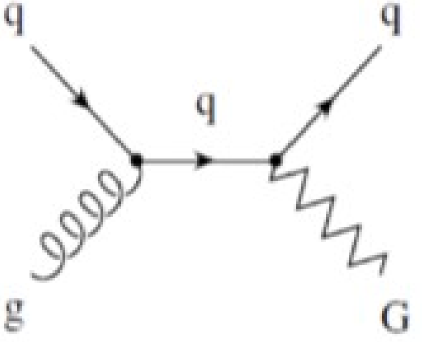
- The weakness of gravity could be explain by the existence of Extra Dimensions → Solution to the hierarchy problem.
- Arkani-Hamed, Dimopoulos, Dvali (ADD)
- The weakness of gravity in our usual 4D space-time could be explained by the "leaking" of the gravitational field into the Extra Dimensions.
- The inverse square law of gravity is modified → New fundamental Planck scale M_D $O(m_W)$ in 4+n dimensions appears:

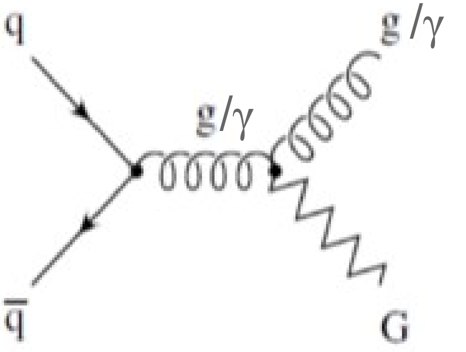
$$M_{Pl}{}^2 \sim M_D{}^{2+n} R^n$$



- The extra dimensions are compactified resulting in Kaluza-Klein towers of massive graviton modes.
- LHC production channels:



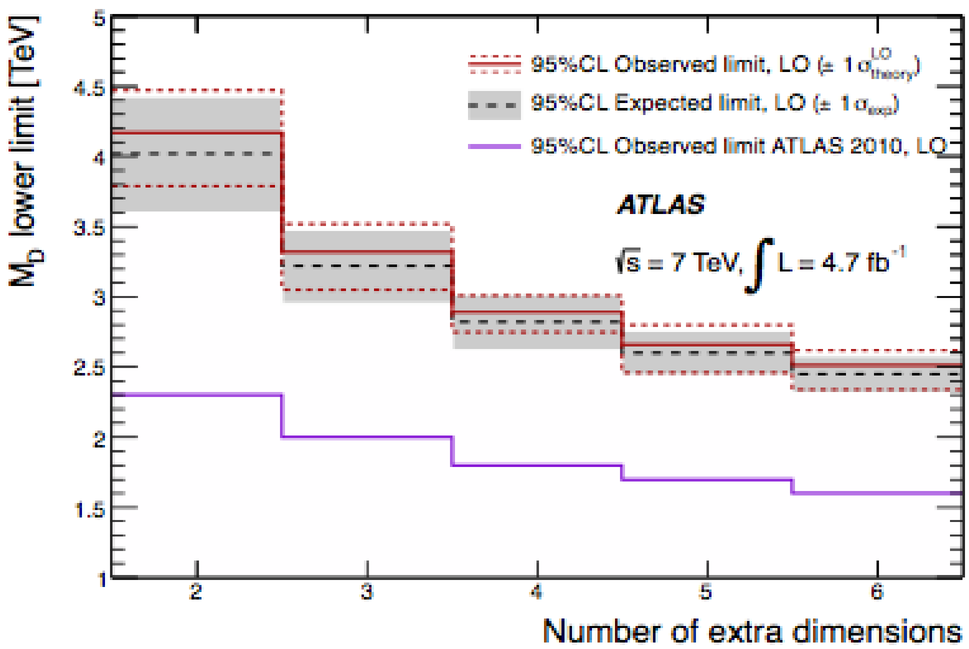




Limits on MD

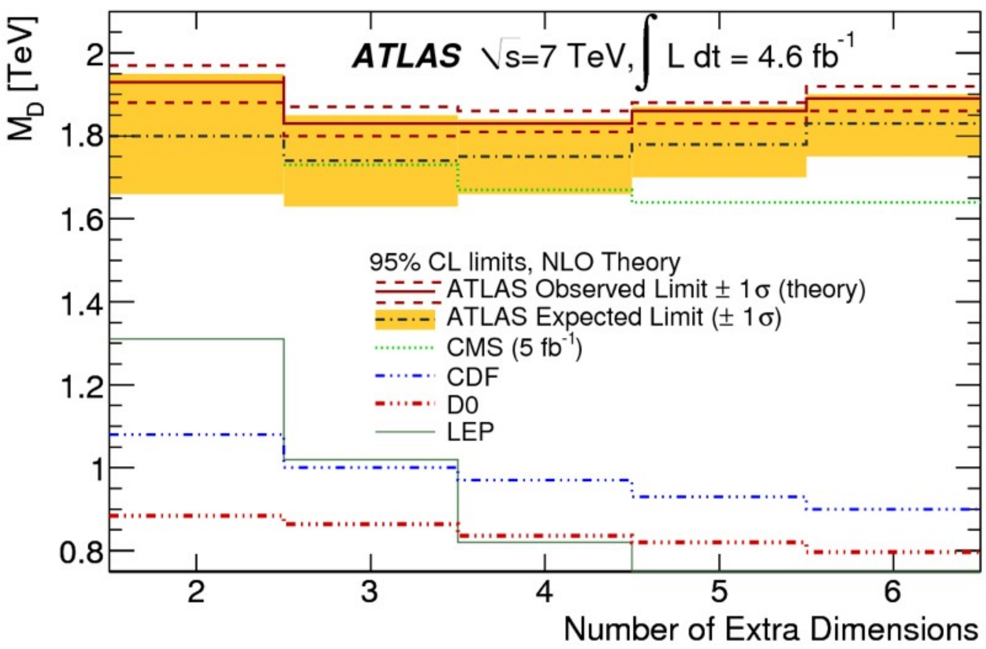
arXiv:1210.4491 (7 TeV)
ATL-CONF-2012-147 (8 TeV)

Monojet



Monophoton

arXiv:1209.4625



- Uncertainty bands are associated with PDF, ISR/FSR, factorization and normalization scales.
- Lower 95% CL limits on MD as a function of the number of extra dimensions:
  - Monojet: M_D>3.8 TeV for n=2, M_D>2.3 TeV for n=6
  - Monophoton: M_D>1.7 TeV for n=2, M_D>1.9 TeV for n=6

Gravitino production

ATL-CONF-2012-147 (8 TeV)

- GMSB scenario with very light gravitino (spin 3/2) as LSP
- Associated production with squark/gluino

  arXiv:hep-ph/0610160

  arXiv:1010.4255

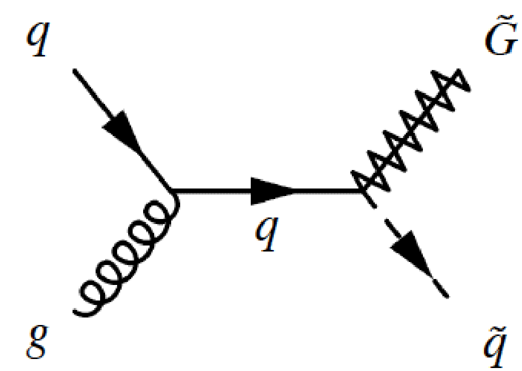
- Gravitino mass probes the SUSY-breaking scale

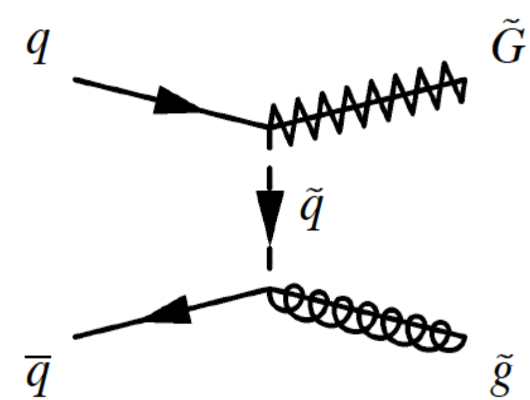
$$m_{3/2} = \langle F \rangle / \sqrt{3}\,\overline{M}_{\rm Pl}$$

- Too light to be the only DM but in some models it represent a significant fraction of DM composition

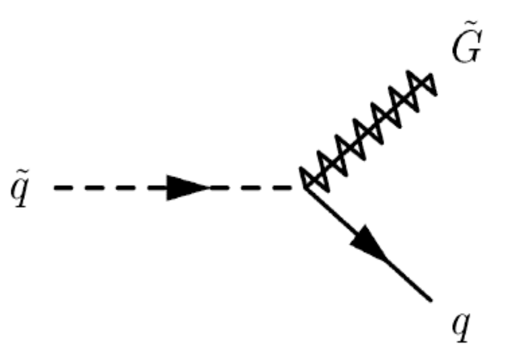
  arXiv:1004.4213

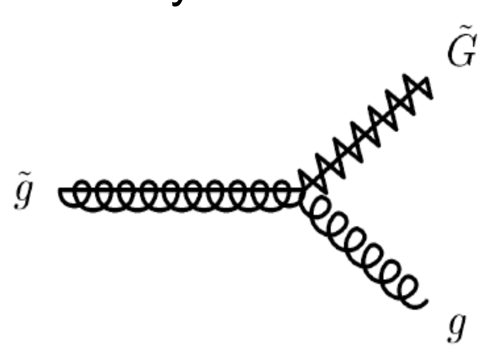
Production of squark/gluino-gravitino





squark/gluino decay modes





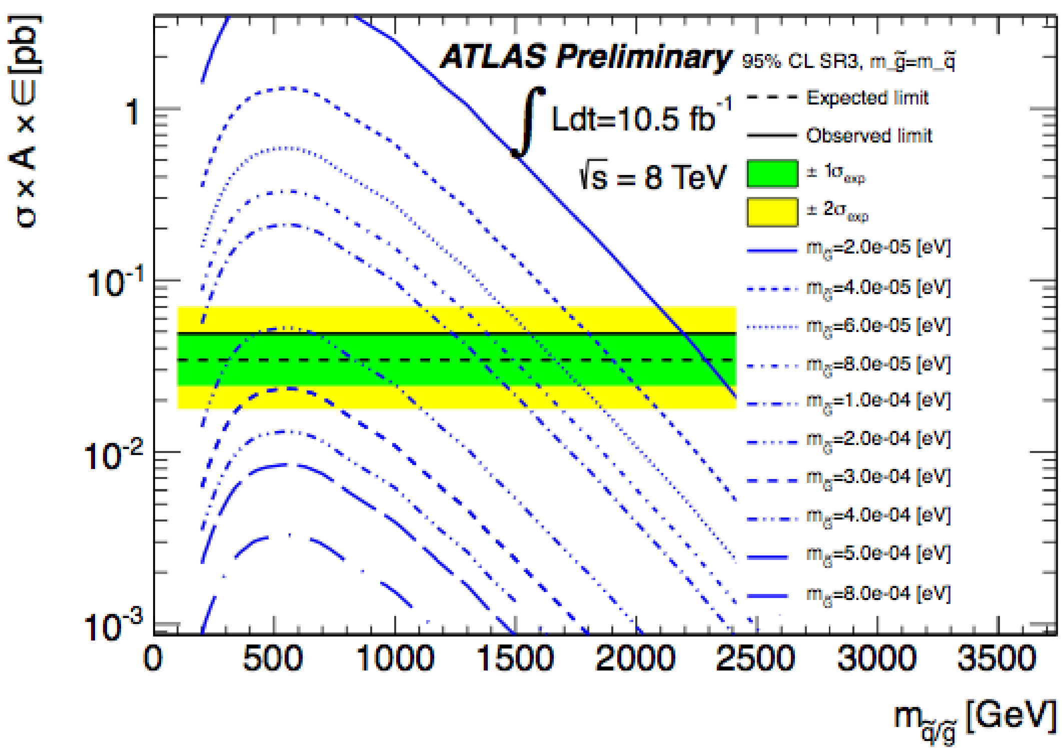
Gravitino limits for $m_{\tilde{q}} = m_{\tilde{g}}$

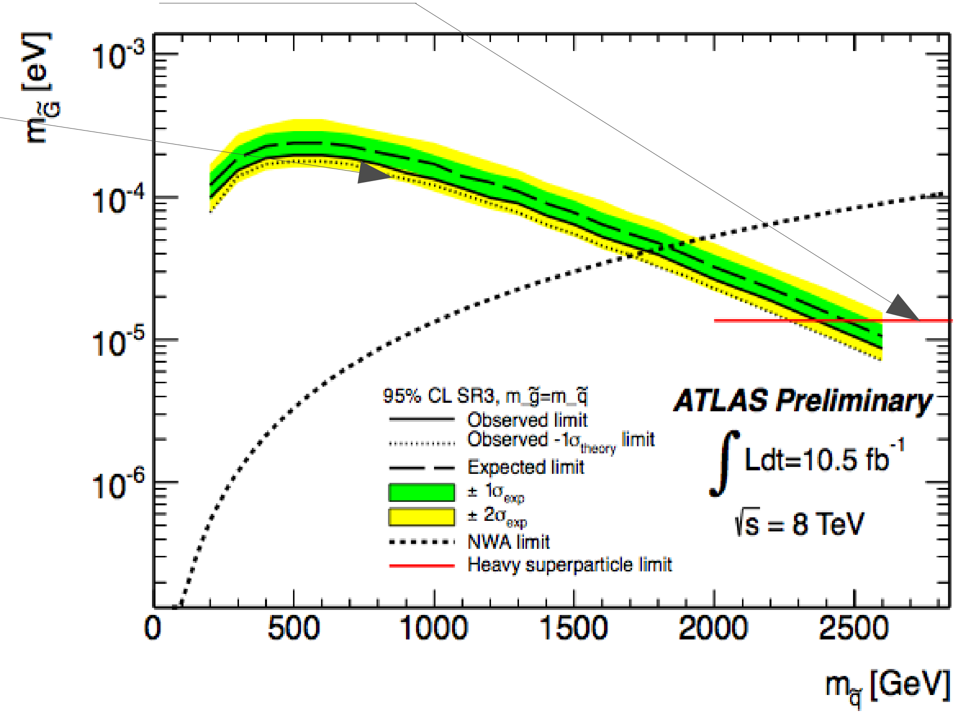
ATL-CONF-2012-147 (8 TeV)

- The limits on the visible cross section are translated into limits in the squark/gravitino mass plane (for a given squark/gluino combination).
- ATLAS limits on gravitino mass are one order of magnitude higher than LEP/Tevatron limits:

LEP/Tevatron: $m_{\tilde{G}} > 1.37 \times 10^{-5}$ eV

ATLAS: $m_{\tilde{G}} > 1.0 \times 10^{-4}$ eV
for $m_{\tilde{q}} = m_{\tilde{g}} \approx 1$ TeV



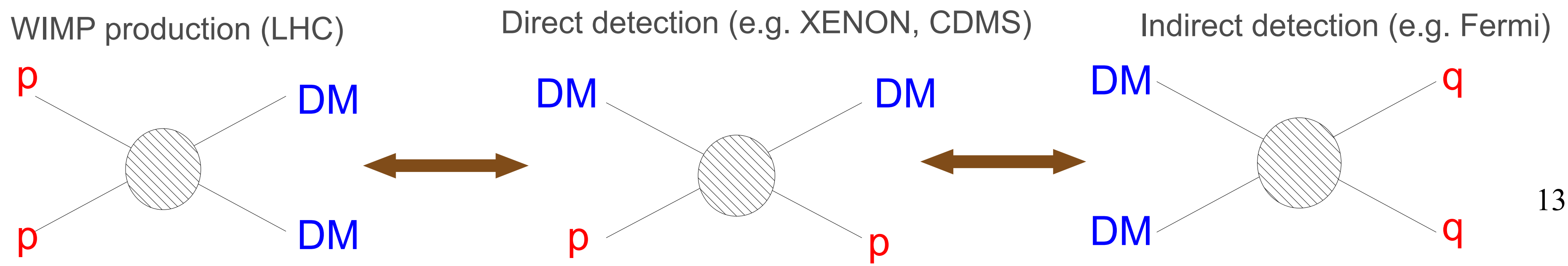


WIMP production at collider

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	$\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

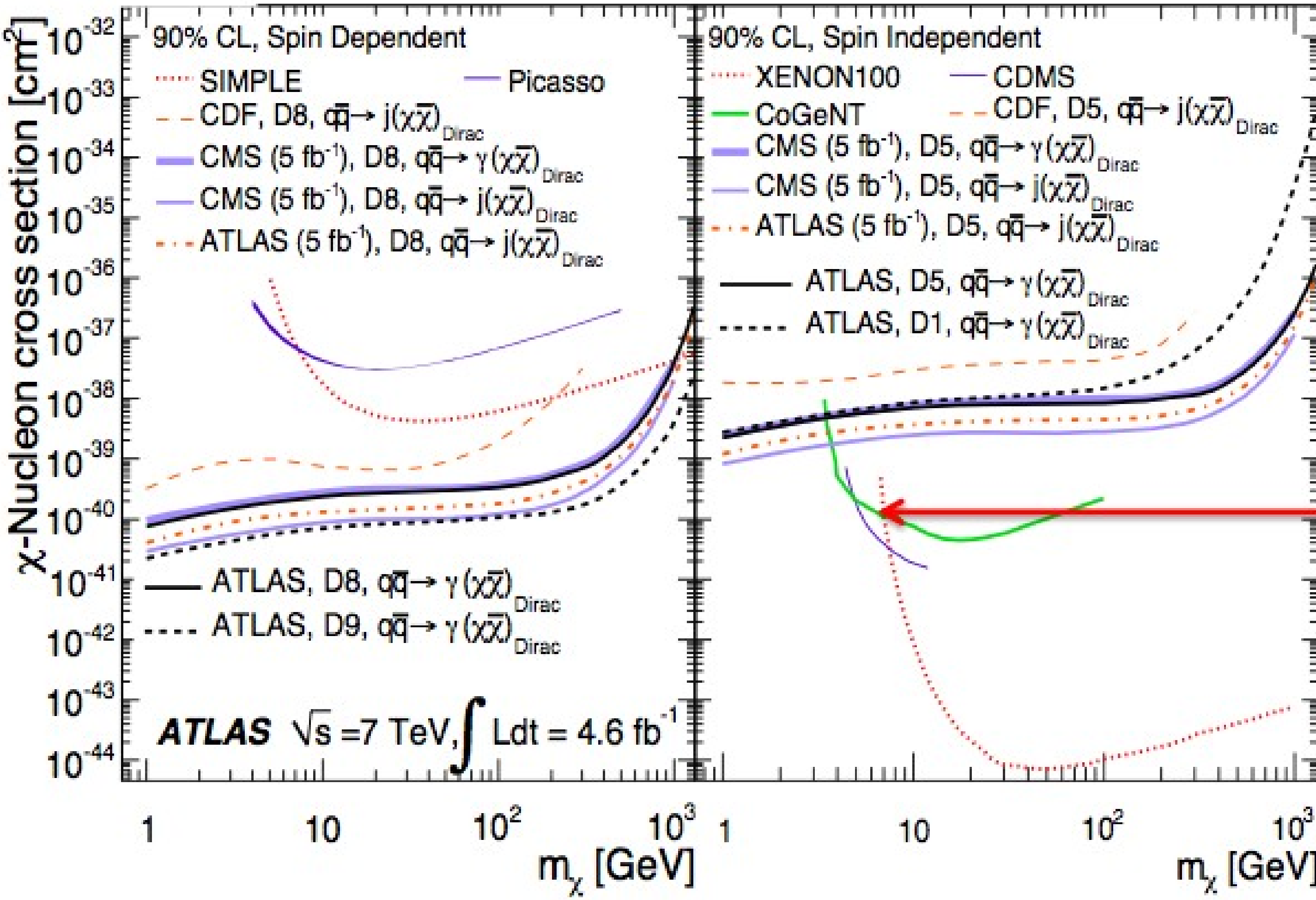
Suppression scale is defined by $M_* = M_{mediator}/g$; g is χ- SM coupling

- Effective theory based on different interaction operators, assuming χ is a Dirac fermion
- Detection via an initial state photon or gluon
- Comparison with direct and indirect experiments can be done under some assumptions

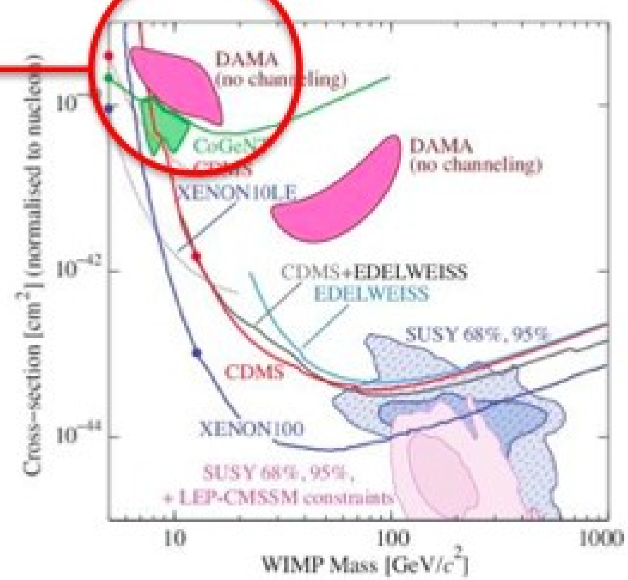


WIMP-nucleon cross section

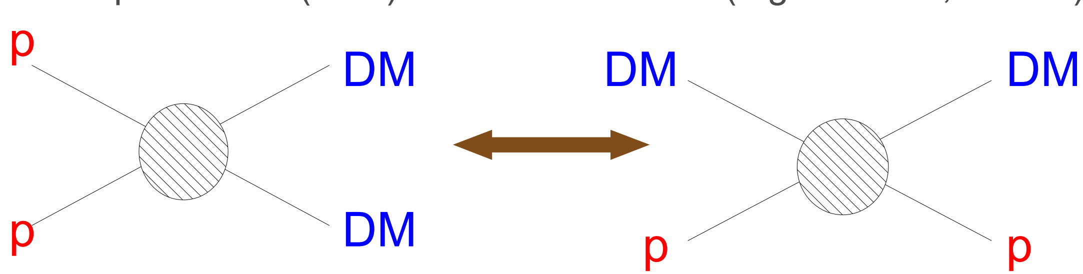
Monojet/monophoton



ATLAS sensitivity nearing the region that contains the CoGeNT/DAMA excess at m_χ=10 GeV



WIMP production (LHC) Direct detection (e.g. XENON, CDMS)



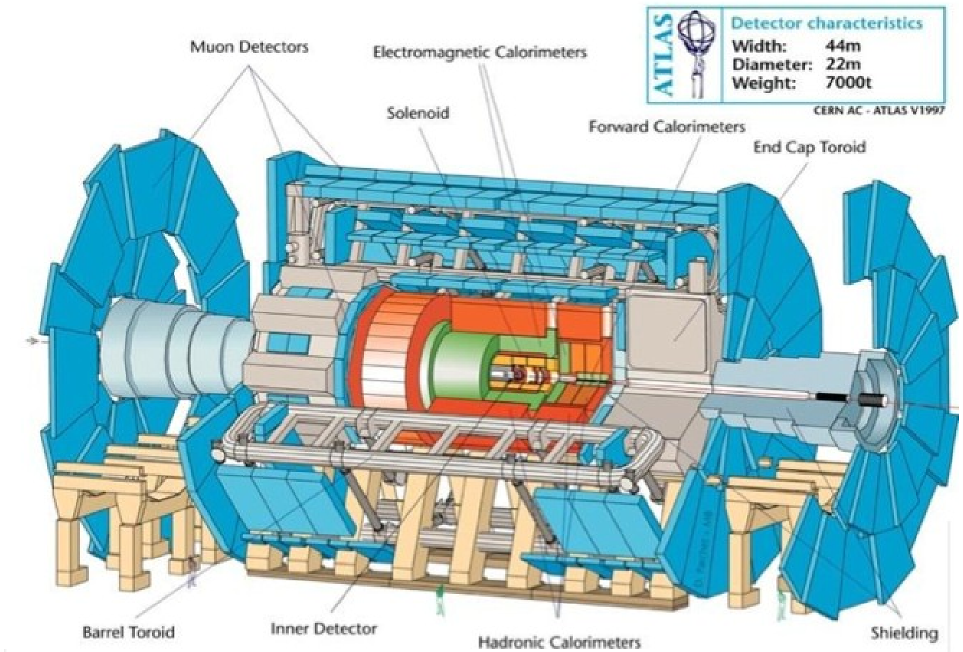
Summary

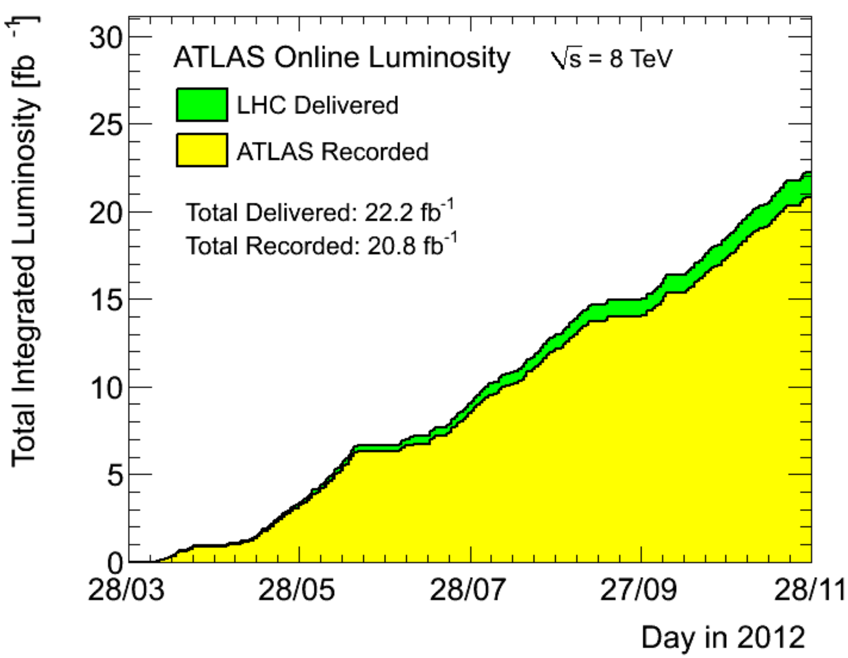
- Monojet and monophoton searches do not show significant excess above the Standard Model predictions.
  - Model independent limits are set on the visible cross section.
- Interpretation of the results done in terms of ADD, Gravitino production and WIMP production.
- ATLAS results are competitive/complementary to direct and indirect DM experiments.
- New results based on full 2012 luminosity will come soon.
- Stay tuned!

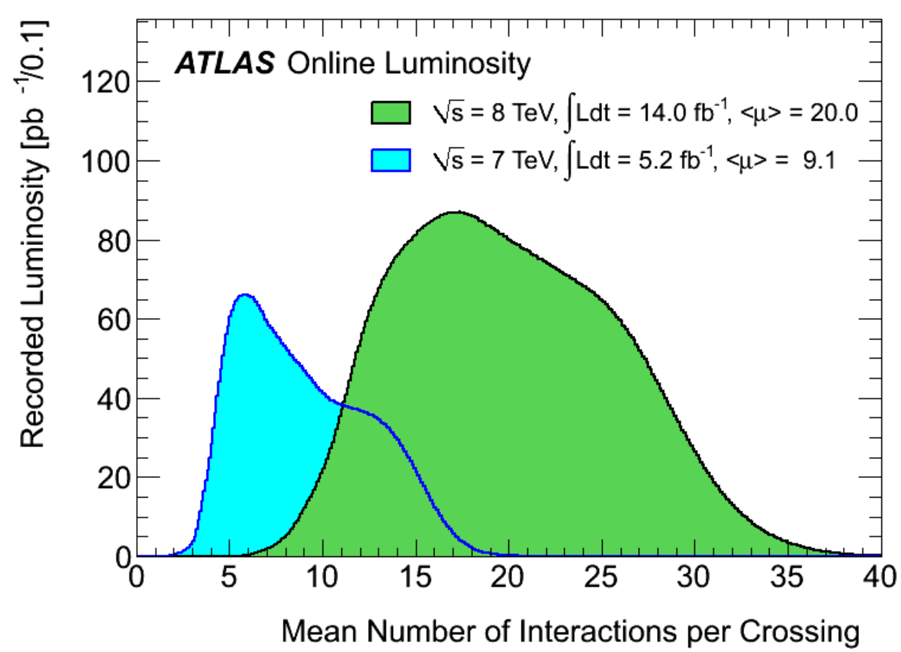
Bonus slides

ATLAS and LHC Operations

- The LHC has delivered a total luminosity of more than 20 fb^{-1}!
- ATLAS data taking efficiency has been about 94%.



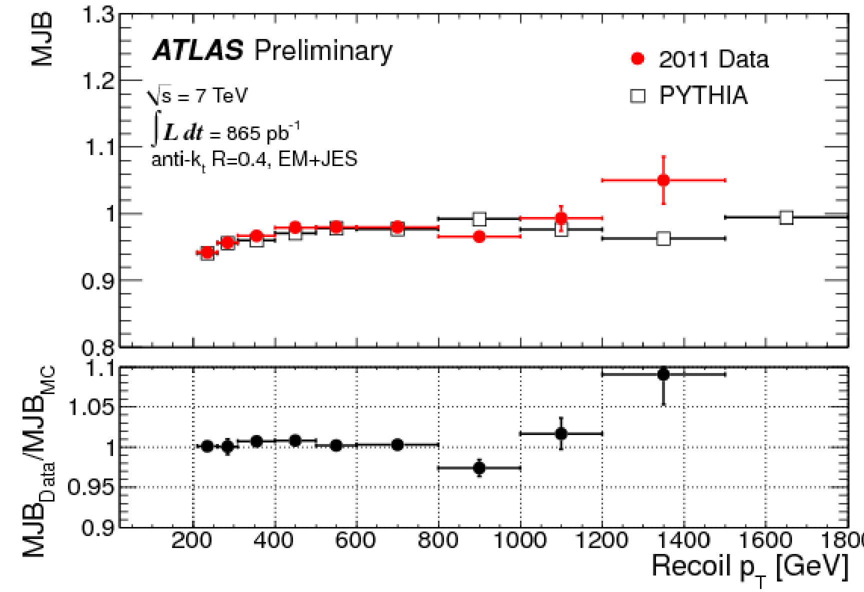


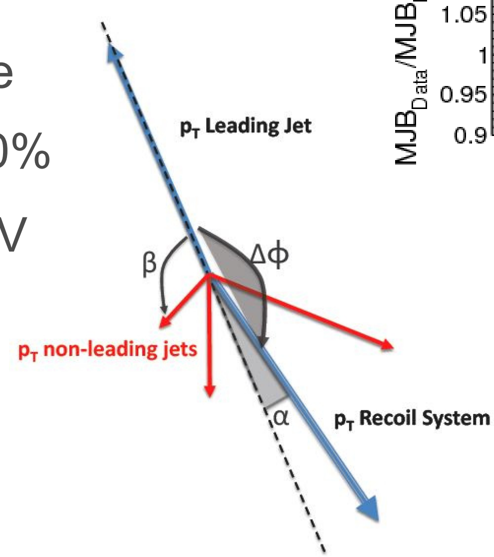


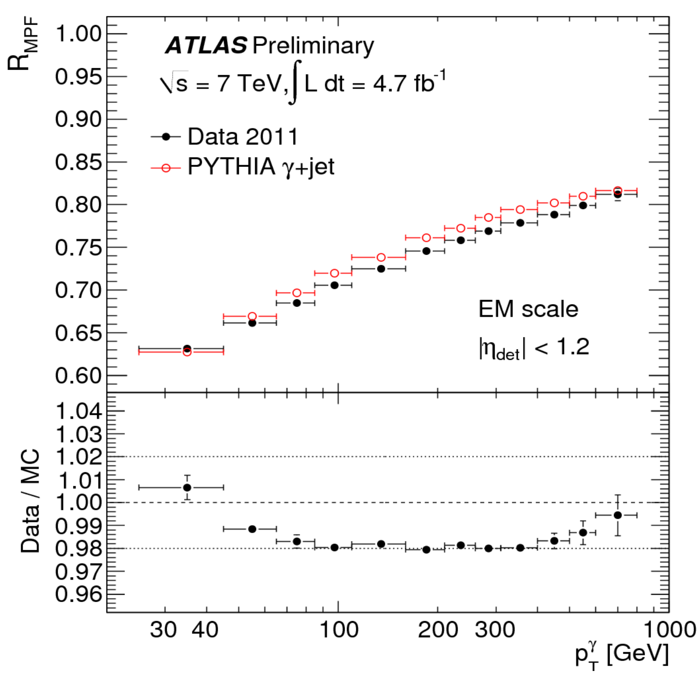
Performance of Jet Energy measurement

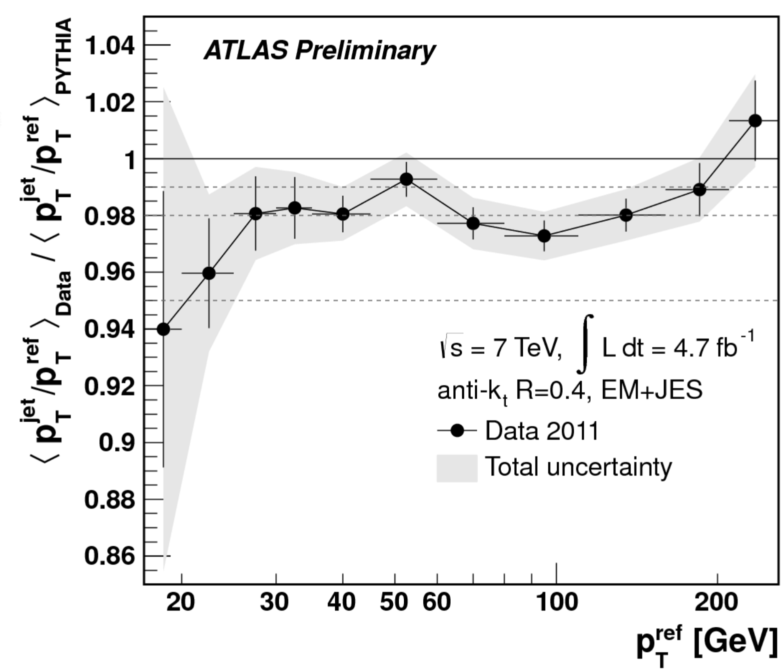
- Multiple methods for setting the Jet Energy Scale (JES)
  - Z-jet balance
  - Gamma-jet balance
  - Balance of high-pT jet against low-pT recoil system
- Hight pT central jets performance
  - JES < 2.5%, Resolution < 10%
  - JES uncertainty up to 1.4 TeV

ATLAS-CONF-2012-063
ATL-CONF-2012-053





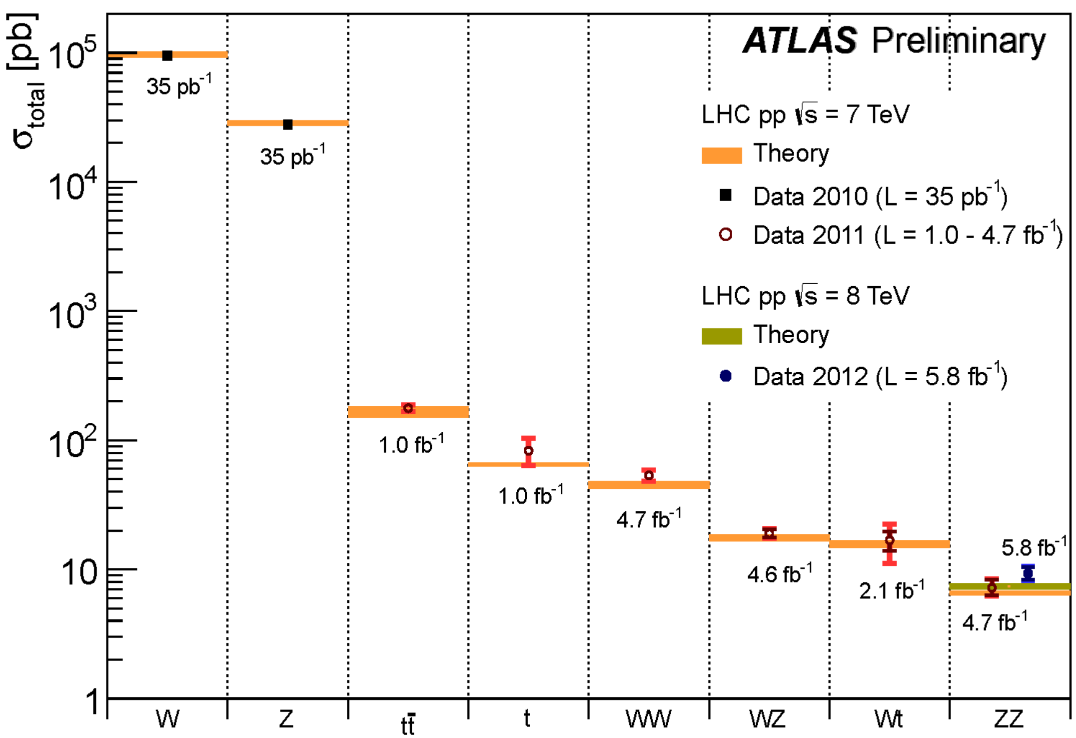




Standard Model measurements

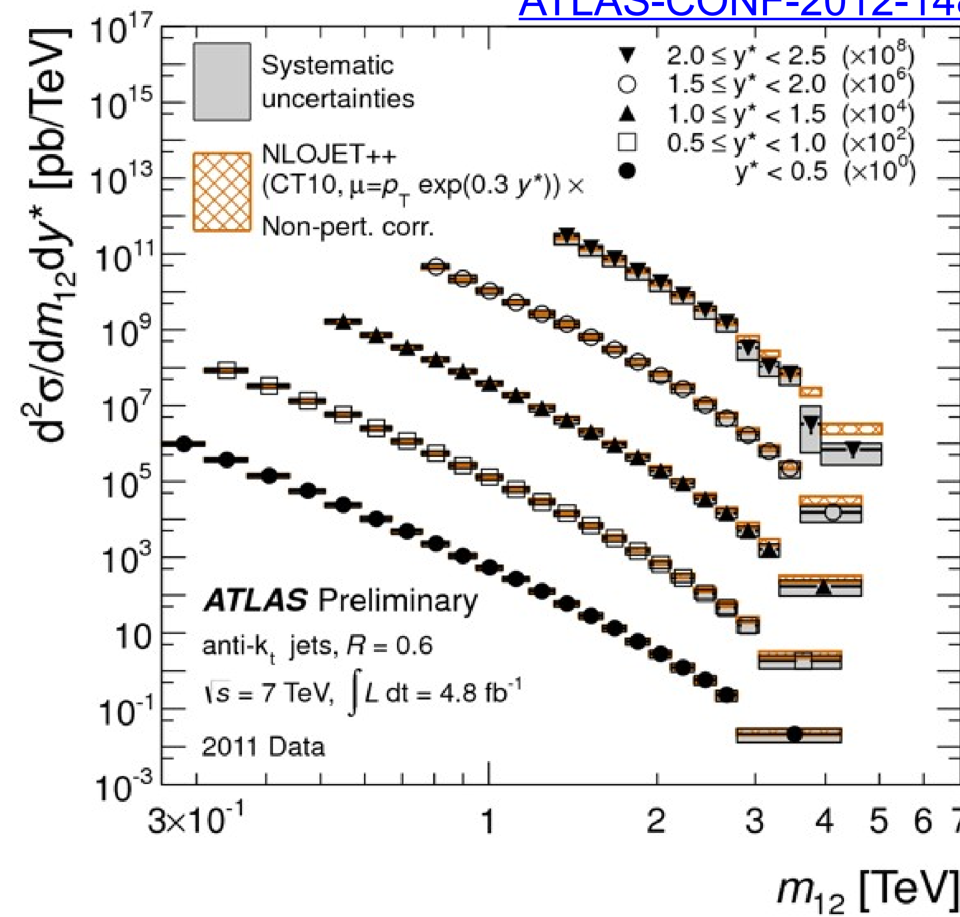
- Deep understanding of the Standard Model (SM) processes is a basic requirement for any Beyond SM search
- Very good agreement between measured cross sections and theoretical predictions

SM total production cross section



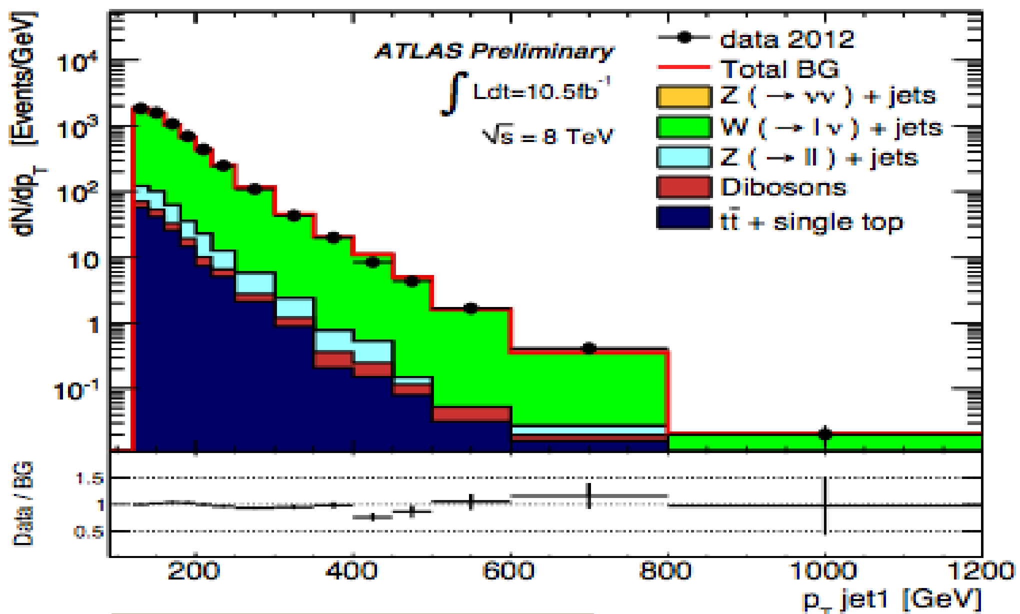
Inclusive jet cross section

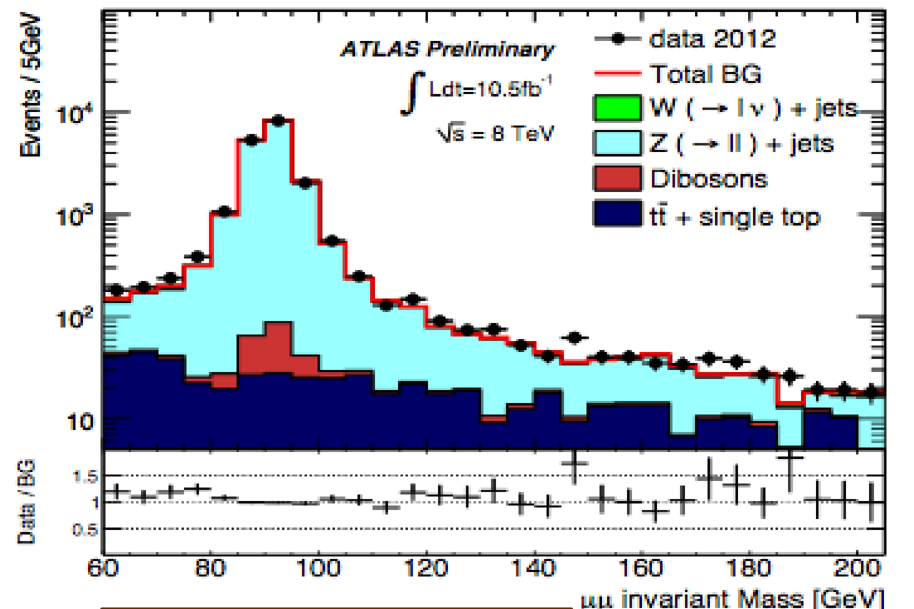
ATLAS-CONF-2012-148



More plots in CRs

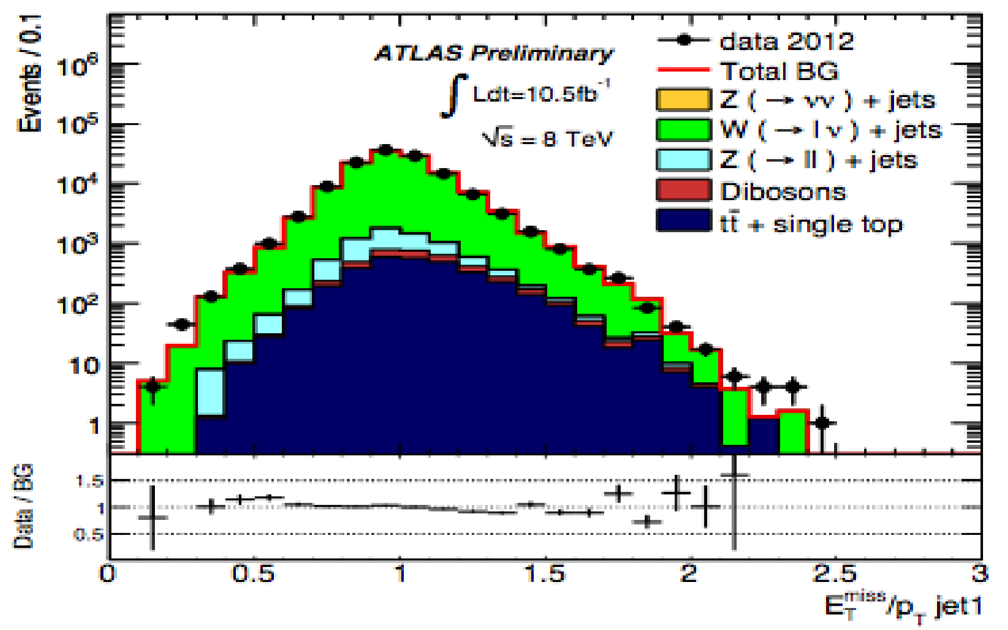
arXiv:1210.4491 (7 TeV)
ATL-CONF-2012-147 (8 TeV)

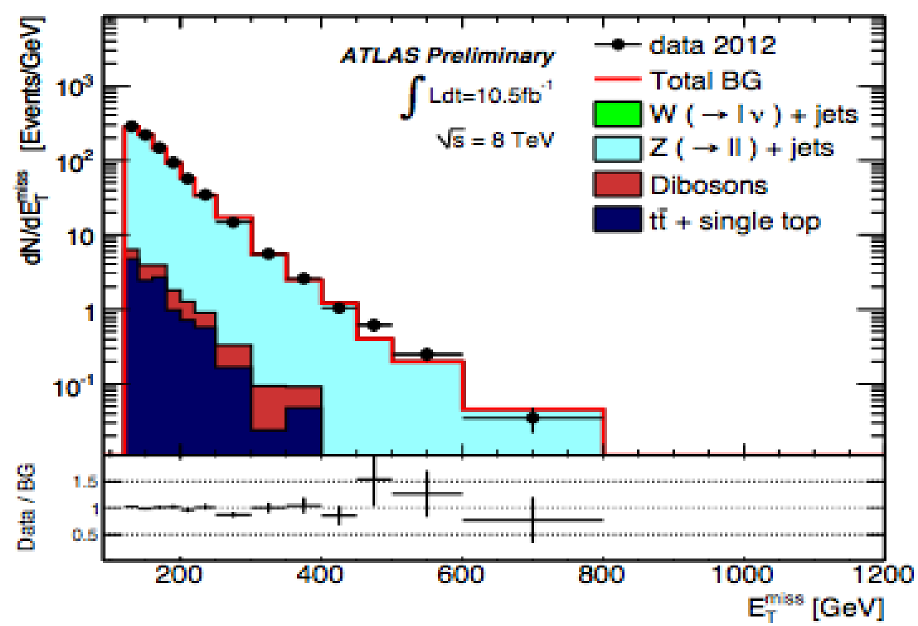




$W\mu\nu$ Control Region

$Z\mu\mu$ Control Region





Monojet results

arXiv:1210.4491 (7 TeV)
ATL-CONF-2012-147 (8 TeV)

- Observed number of events consistent with SM background predictions.
- Uncertainties of the 8 TeV results are dominated by MC statistics.
- Limits are set on the visible cross section (σxAxε).

4.7 fb^{-1} @ 7 TeV

	SR1	SR2	SR3	SR4
$Z \rightarrow \nu\bar{\nu}$+jets	63000 ± 2100	5300 ± 280	500 ± 40	58 ± 9
$W \rightarrow \tau\nu$+jets	31400 ± 1000	1853 ± 81	133 ± 13	13 ± 3
$W \rightarrow e\nu$+jets	14600 ± 500	679 ± 43	40 ± 8	5 ± 2
$W \rightarrow \mu\nu$+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	-	-
$Z/\gamma^* \rightarrow \tau\tau$+jets	421 ± 25	15 ± 2	2 ± 1	-
Di-bosons	302 ± 61	29 ± 5	5 ± 1	1 ± 1
$Z/\gamma^* \rightarrow \mu\mu$+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

10.5 fb^{-1} @ 8 TeV

	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 σxAxε limits

Monojet: √s= 8 TeV, L=10/fb

	90% CL Expected [pb]	90% CL Observed [pb]	95% CL Expected [pb]	95% CL Observed [pb]
Region1	1.98	2.37	2.35	2.76
Region2	0.144	0.142	0.162	0.160
Region3	0.029	0.042	0.035	0.049
Region4	0.023	0.011	0.030	0.015

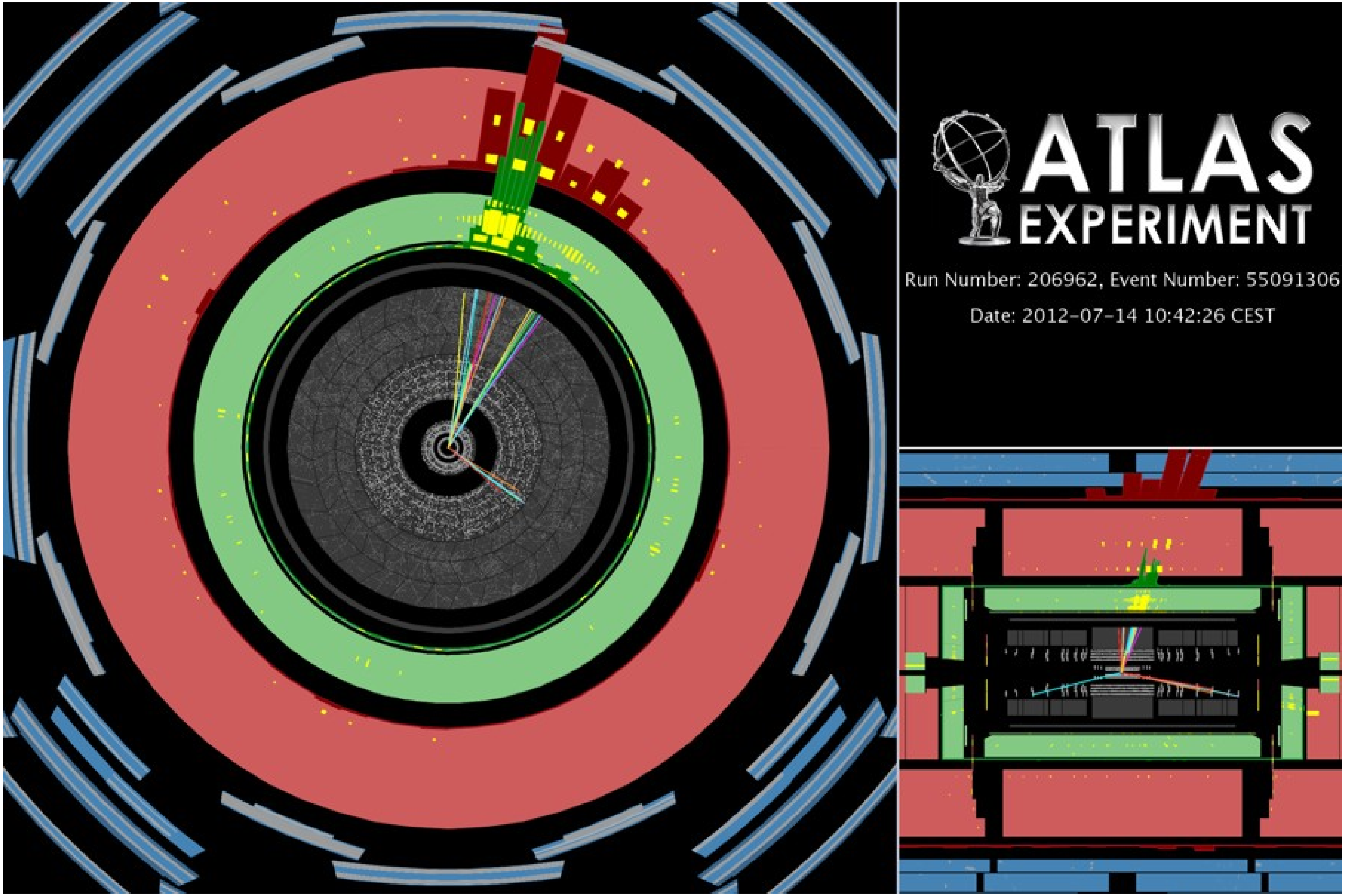
Monojet: √s= 7 TeV, L=4.7/fb

	SR1	SR2	SR3	SR4
σ_{vis}^{obs} at 90% [pb]	1.63	0.13	0.026	0.006
σ_{vis}^{exp} at 90% [pb]	1.54	0.15	0.020	0.006
σ_{vis}^{obs} at 95% [pb]	1.92	0.16	0.030	0.007
σ_{vis}^{exp} at 95% [pb]	1.82	0.17	0.024	0.008

Monophoton: √s= 7 TeV, L=4.7/fb

σ×A×ε [fb]	Observed	Expected
Limit at 90% CL	5.6	7.5
Limit at 95% CL	6.8	8.9

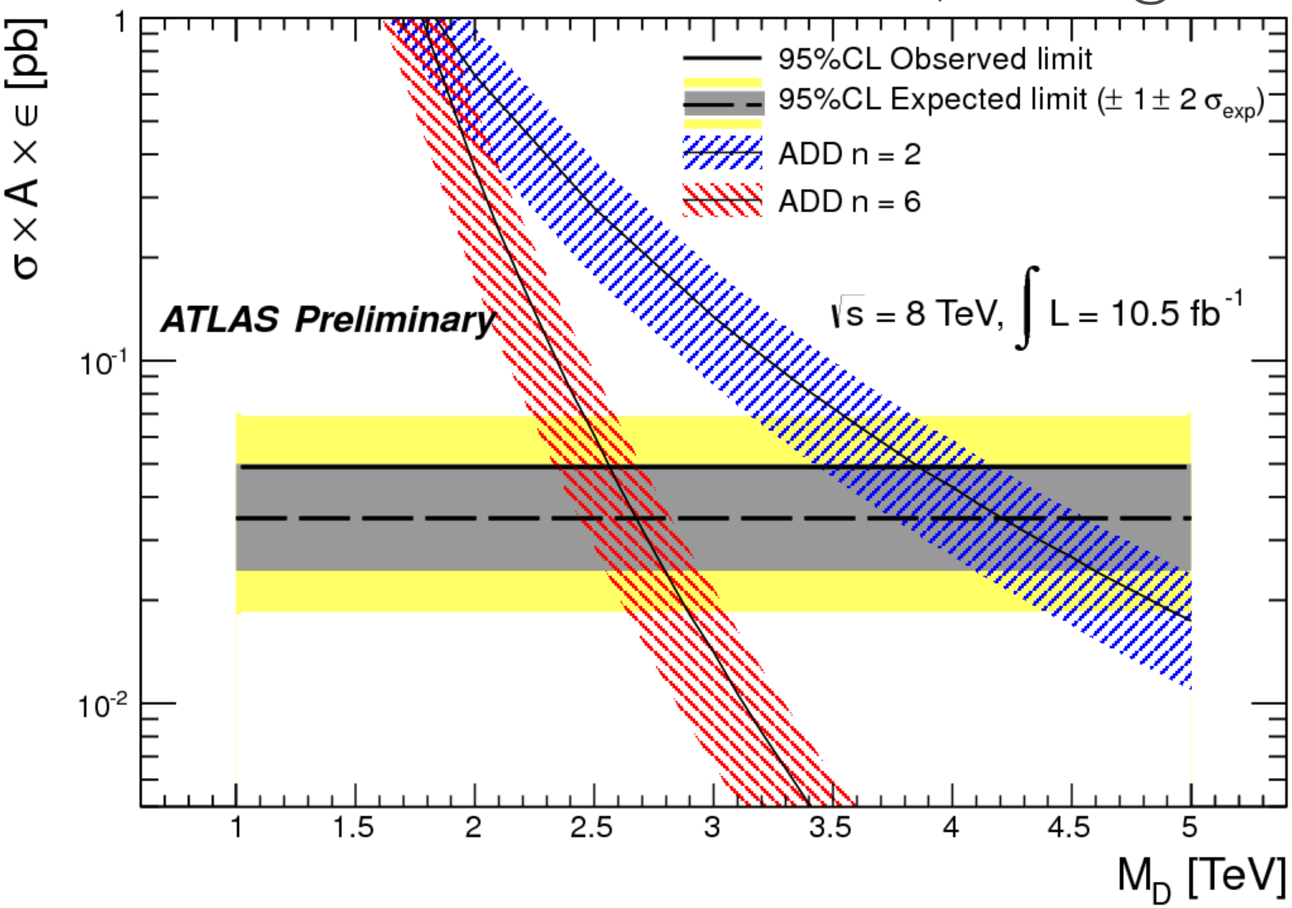
Monojet event at 8 TeV

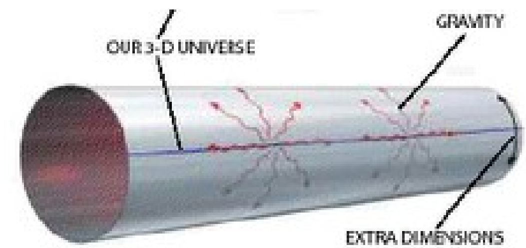


Limits on the cross section

arXiv:1210.4491 (7 TeV)
ATL-CONF-2012-147 (8 TeV)

SR3, 10.5 fb^{-1} @ 8 TeV





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

$$\sigma \propto 1/M_D{}^{n+2}$$

- Expected and observed limits (horizontal lines) are compared to theoretical cross sections.
- Uncertainty bands on the theoretical cross section curves from PDF, ISR/FSR, factorization and normalization scales

Gravitino production...

ATL-CONF-2012-147 (8 TeV)

- GMSB scenario with very light gravitino (spin 3/2) as LSP
- Associated production with squark/gluino

  arXiv:hep-ph/0610160

  arXiv:1010.4255

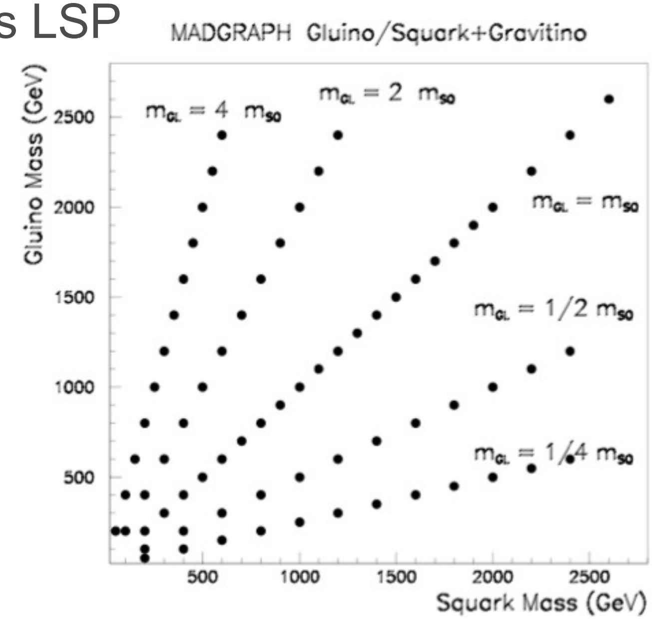
- Gravitino mass probes the SUSY-breaking scale

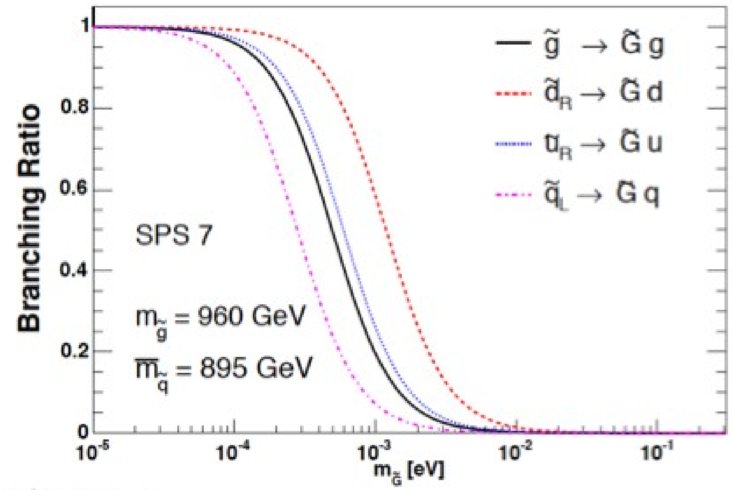
$$m_{3/2} = \langle F \rangle / \sqrt{3}\,\overline{M}_{\rm Pl}$$

- Too light to be the unique DM but in some models it represent a significant fraction of DM composition

  arXiv:1004.4213

- Assuming 100% branching ratio of gluino/squark decay to gluino/quark + gravitino and limit the phase space to the so-called narrow width approximation (NWA):



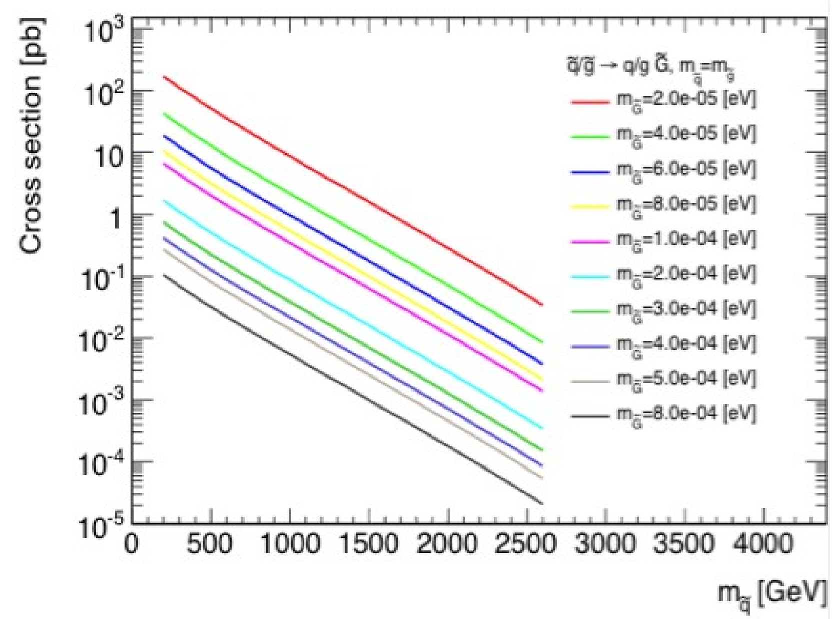


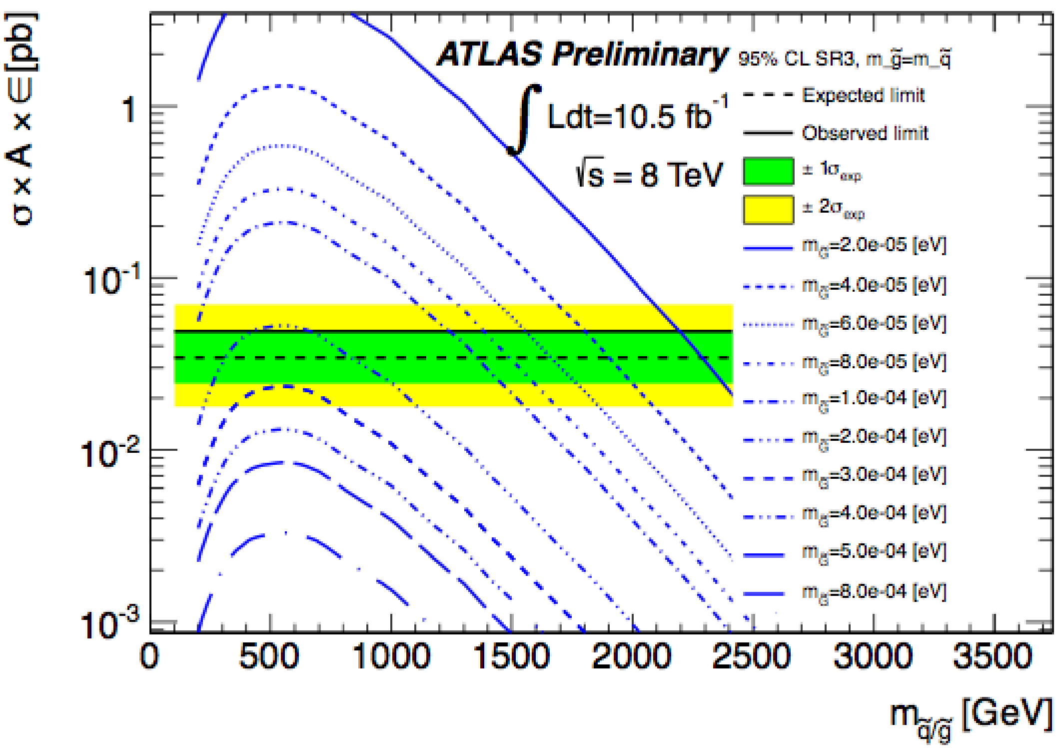
$$\Gamma_{\tilde{g}(\tilde{q})\to g(q)\tilde{G}} = \frac{m^5_{\tilde{g}(\tilde{q})}}{48\pi \overline{M}^2_{\rm Pl} m^2_{3/2}}$$ < 25% of the gluino (squark) mass

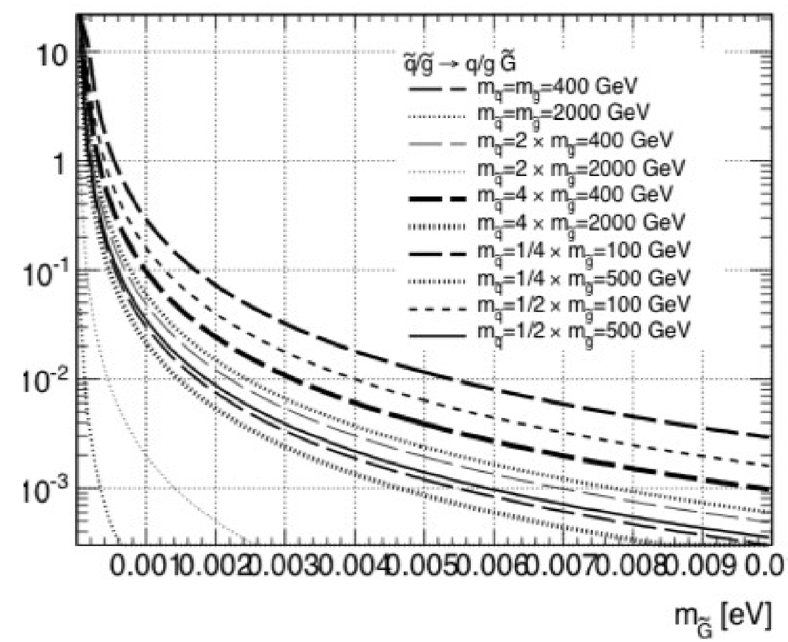
Gravitino production

ATL-CONF-2012-147 (8 TeV)

- The cross section decreases exponentially with the squark/gluino mass and quadratically with the Gravitino mass
- The acceptance doesn't depend on the Gravitino mass (but depends slightly on the squark/gluino mass)



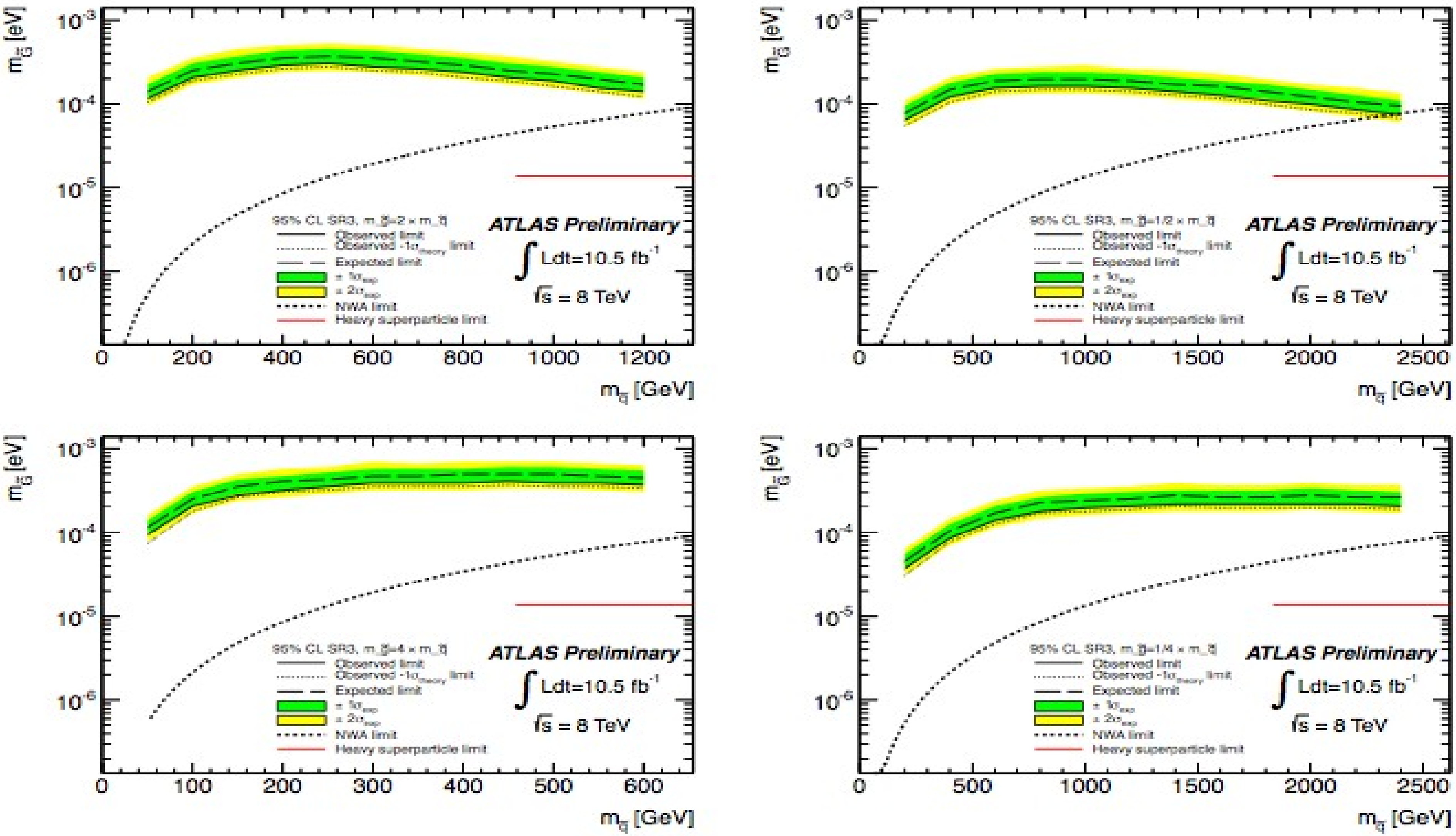




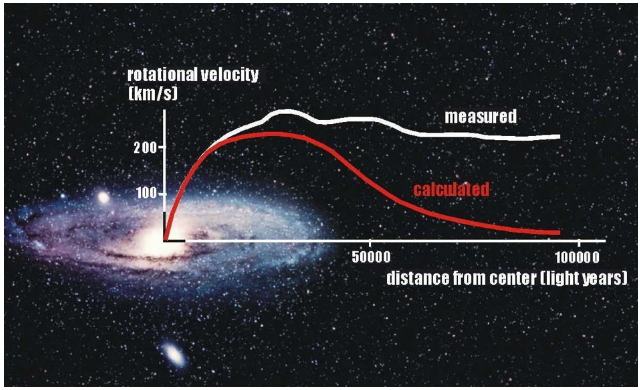
Gravitino limits for $m_{\tilde{q}} \neq m_{\tilde{g}}$

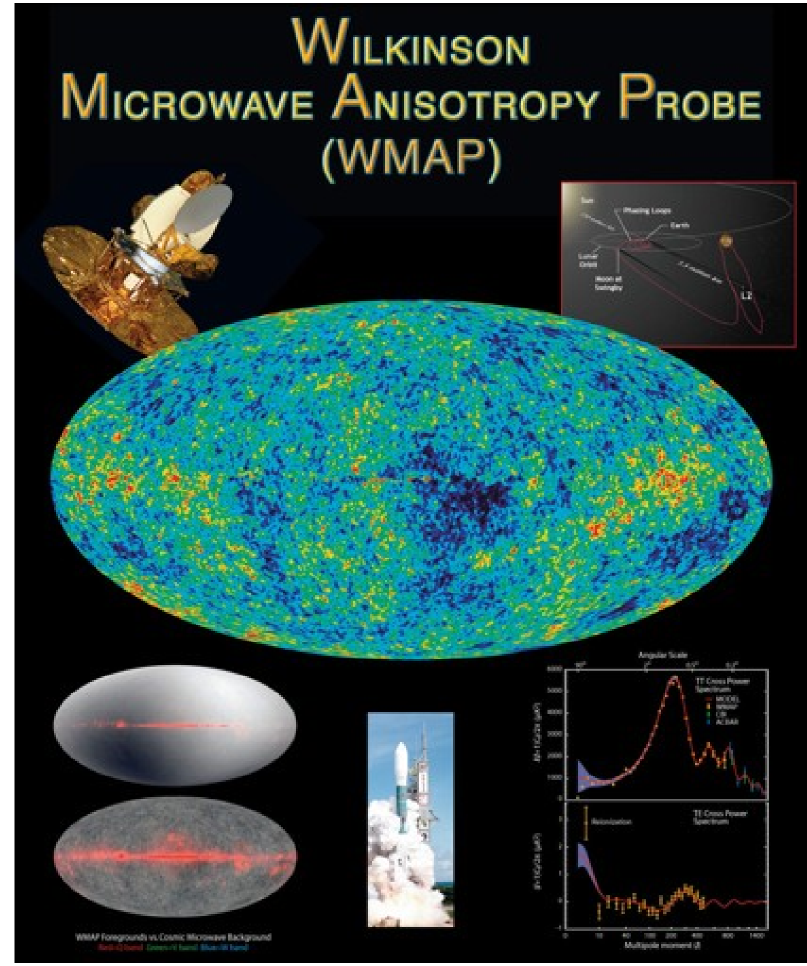
ATL-CONF-2012-147 (8 TeV)

- The limits obtained for different squark/gluino mass combinations are in general better than the equality case.
- Best limits are for the configuration where the gluino mass is four time the mass of the squark



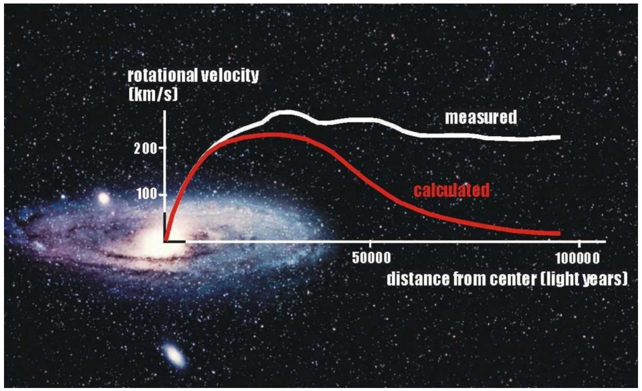
Evidence for Dark Matter

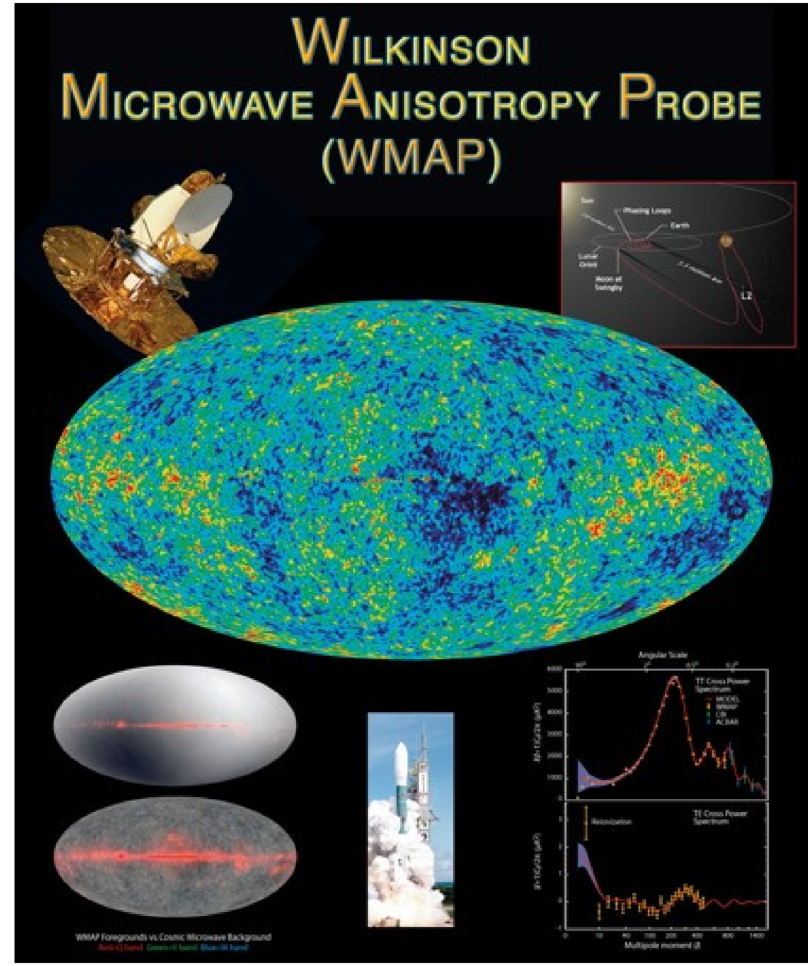




- Dark Matter exists!
  - Rotation curves of galaxies
  - Lensing effect in the Hubble deep field
  - Anisotropy in the CMB measurements: essential for the formation of super structures in the universe.

Dark Matter: WIMP Miracle



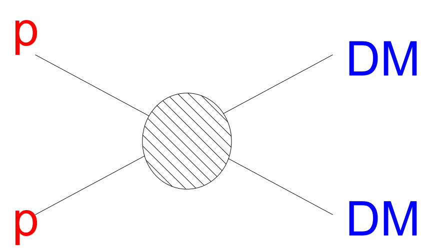


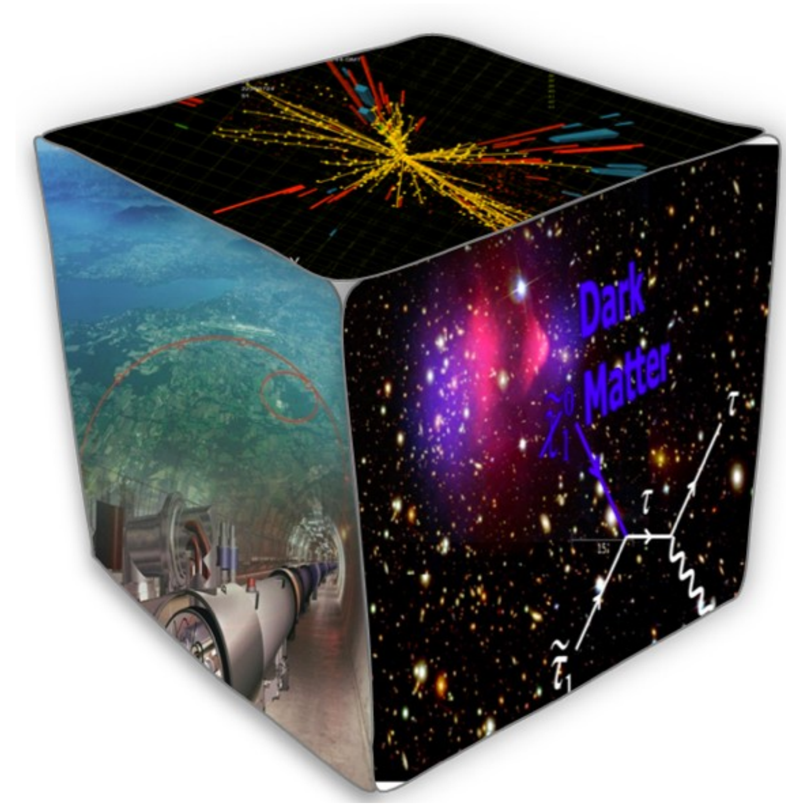
- Dark Matter exists!
  - DM is neutral, long lived and feebly interacting particles
  - DM is at weak-scale mass (10 GeV, 1 TeV)
  - Weakly interacting: $\langle \sigma v \rangle = 3.10^{-26}$ cm^3/s
  - Gives the correct DM abundance

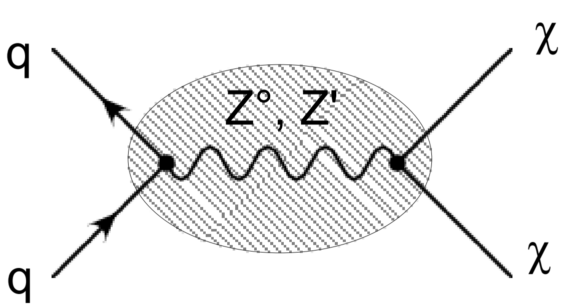
WIMP production at collider

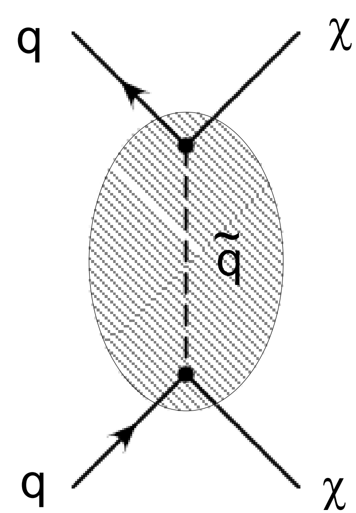
- Dark Matter contact interaction
- Mediators are too heavy and can be integrated out very much like a Fermi interaction

WIMP production (LHC)







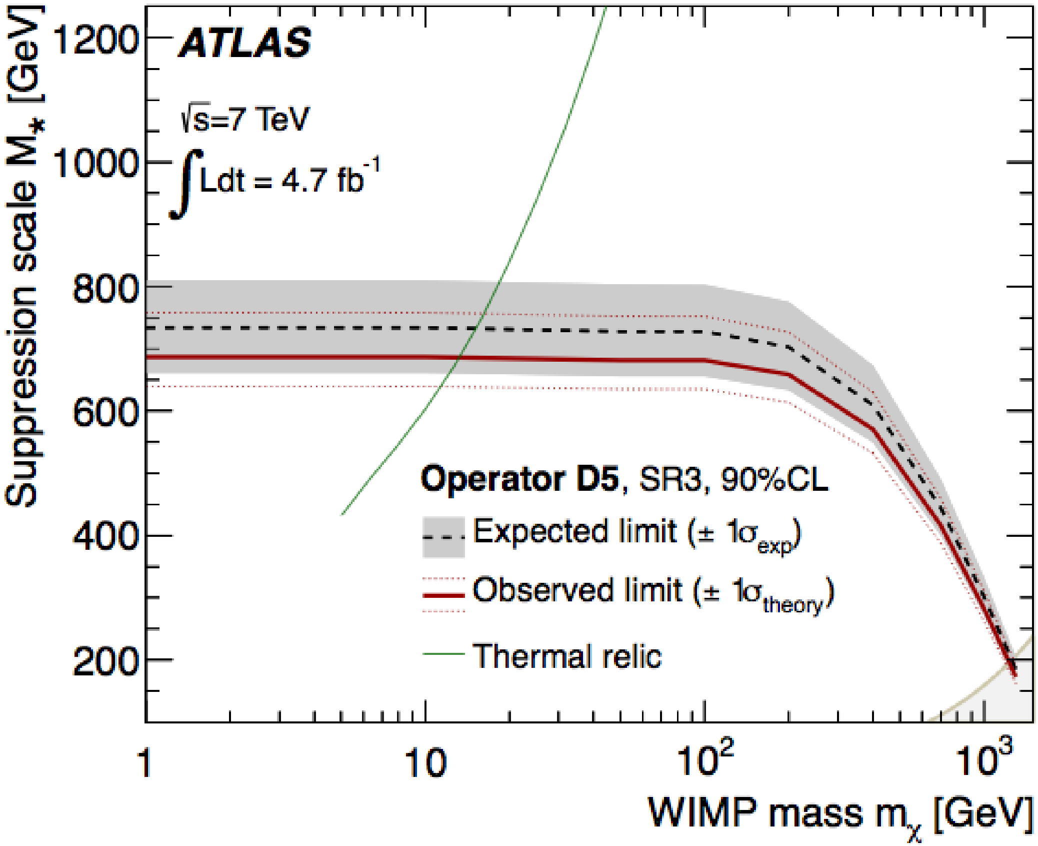


- The suppression scale is defined by

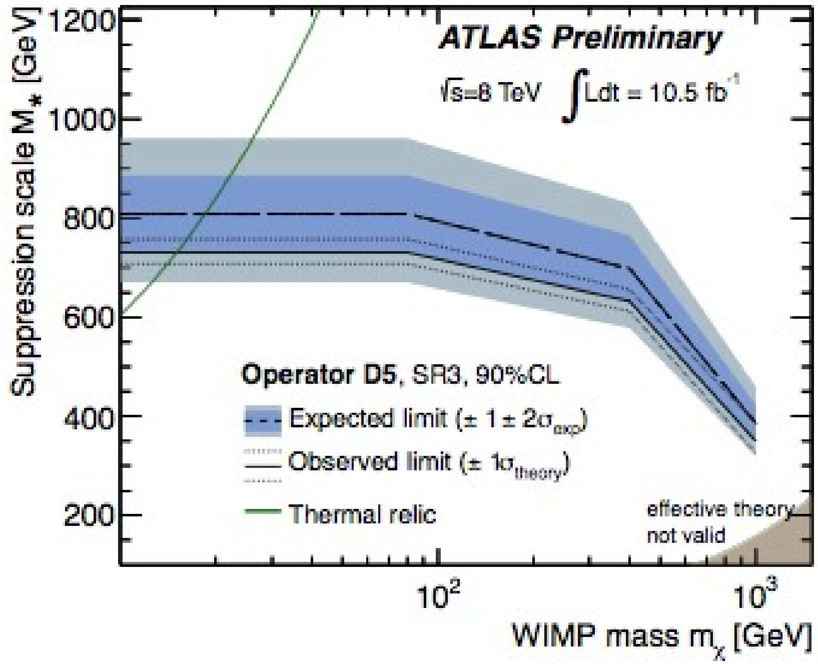
$M_* = M_{mediator}/g$ where g is χ- SM coupling

Suppression scale limits

[arXiv:1210.4491 (7 TeV)](#)
[ATL-CONF-2012-147 (8 TeV)](#)



$$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$$

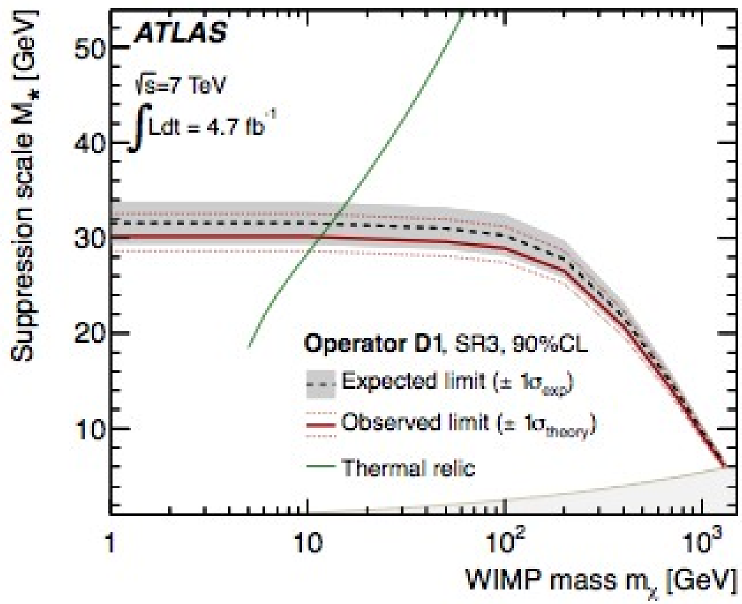


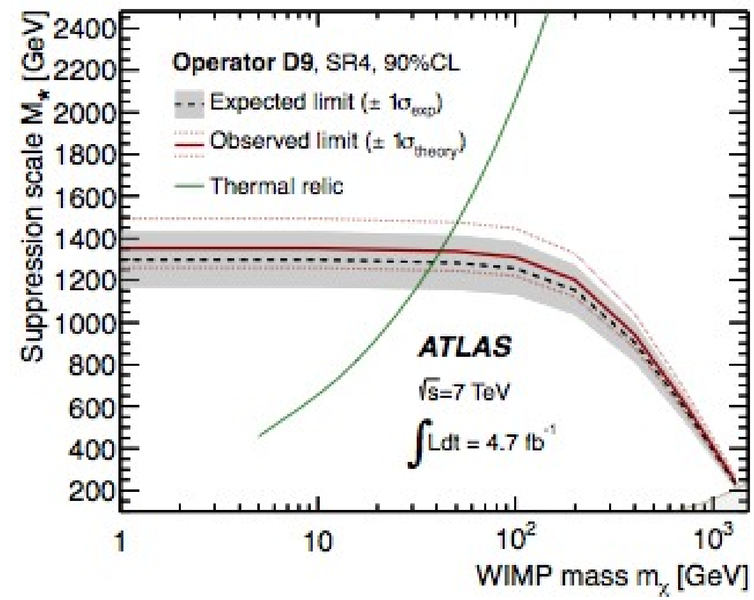
$$\Omega_X \propto \frac{1}{\langle\sigma v\rangle} \sim \frac{m_X^2}{g_X^4}$$

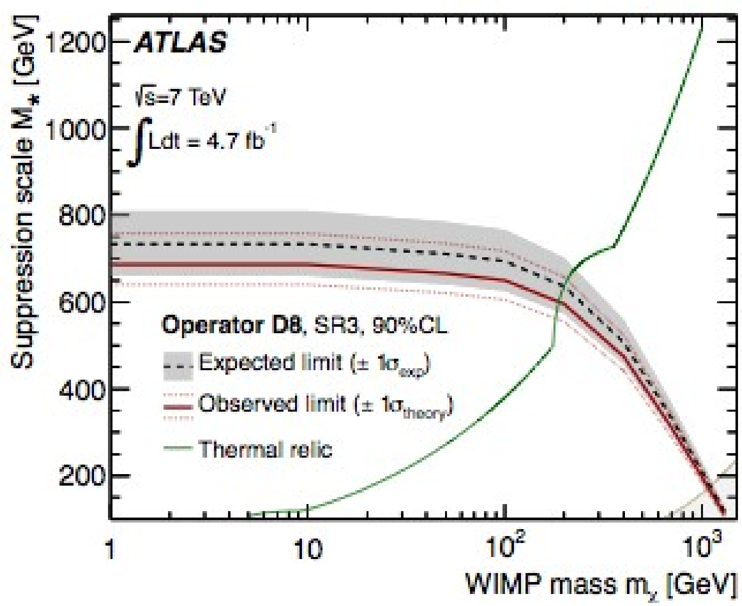
- The suppression scale M_* sets the DM-SM coupling, which then translates into annihilation cross section of χ to SM.
- The LHC is probing the thermal relic measured by WMAP!
- M_* above the thermal relic line means exclusion or negative interference or additional annihilation (e.g. to leptons).
- The 8 TeV limits are weaker than the 7 TeV ones! But not because of a signal!

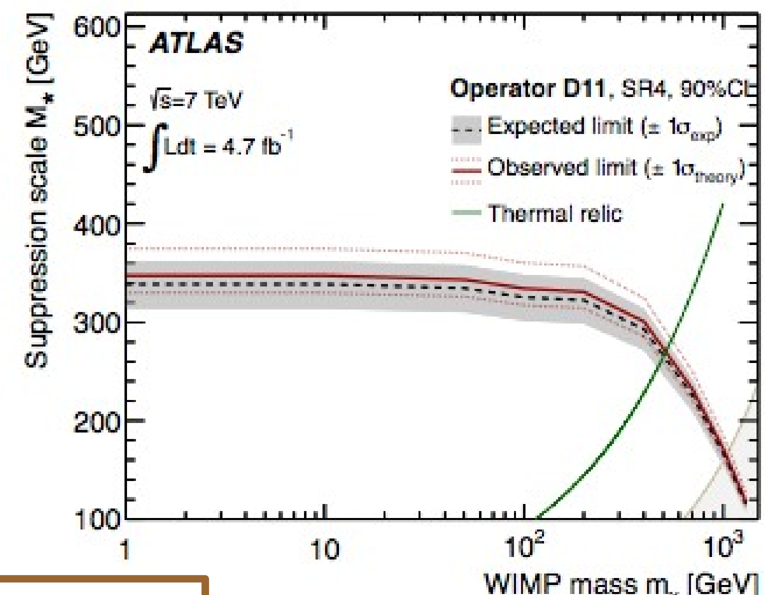
Suppression scale limits

[arXiv:1210.4491 (7 TeV)](arXiv:1210.4491)
ATL-CONF-2012-147 (8 TeV)









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

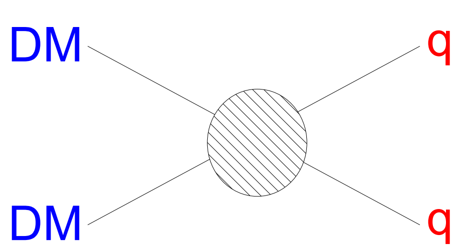
WIMP annihilation limits

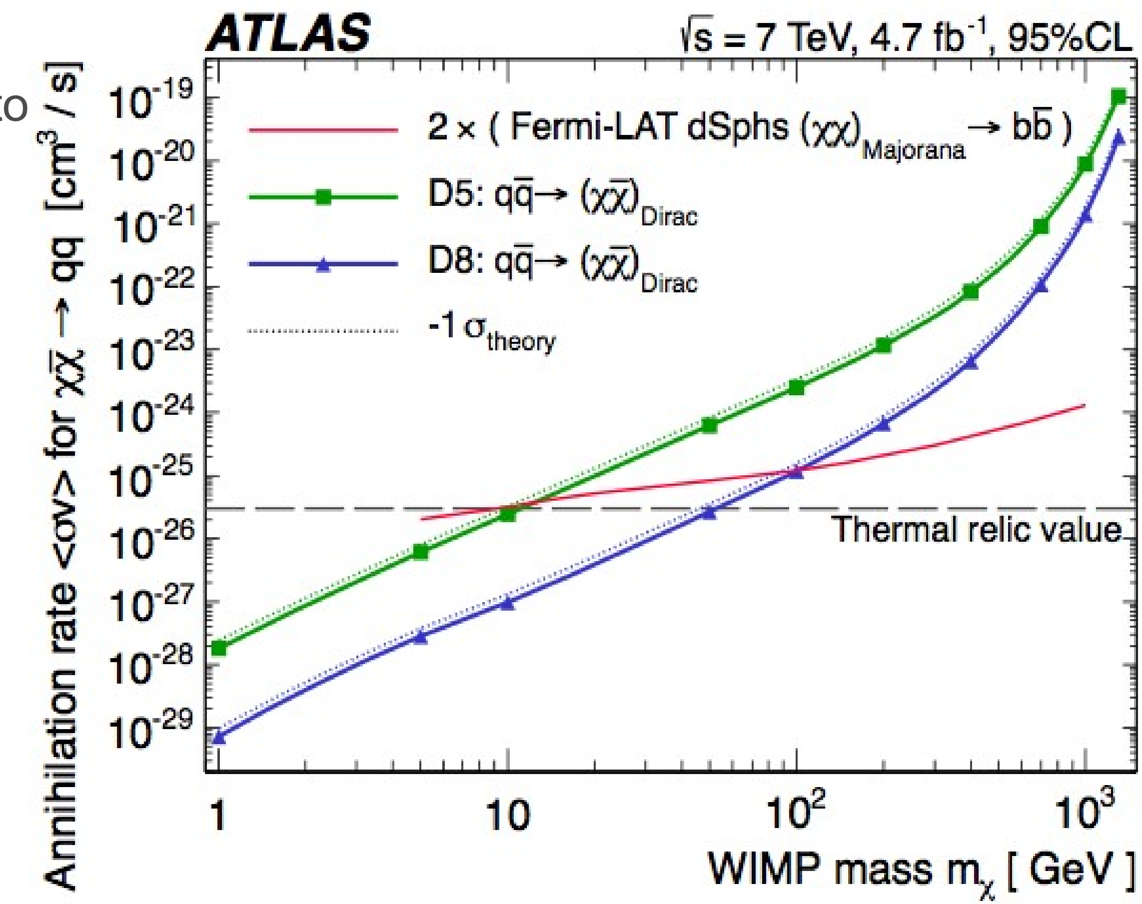
[arXiv:1210.4491 (7 TeV)](#)
[ATL-CONF-2012-147 (8 TeV)](#)

- The results are also interpreteted in terms of limits on WIMPs annihilation to light quarks

  [arXiv:1109.4398 [hep-ph]](#)

Indirect detection WIMPs annihilation





- Comparison with FERMI LAT

- Below 10 GeV for D5 and 70 GeV for D8, the ATLAS limits are below the values needed for WIMPs to make up the cold dark matter abundance in the early universe