LHCC Poster Session - CERN, 13 March 2013

Search for New Phenomena in Monojet Final States with the ATLAS Detector

A search for new phenomena in monojet final states with large missing transverse momentum was performed on 10.5 fb^{-1} of $\sqrt{s}$ = 8 TeV data collected in 2012 with the ATLAS detector at the LHC. Good agreement is observed between the number of events in data and the Standard Model predictions. The results are translated into limits on pair production of weakly interacting dark matter candidates, as well as on the production of light gravitinos, leading to the best lower bound to date on the gravitino mass. Limits on models with large extra spatial dimensions are also presented.

ATLAS-CONF-2012-147

Motivation

A monojet event is characterized by one energetic jet and large missing transverse momentum (E_T^{miss})

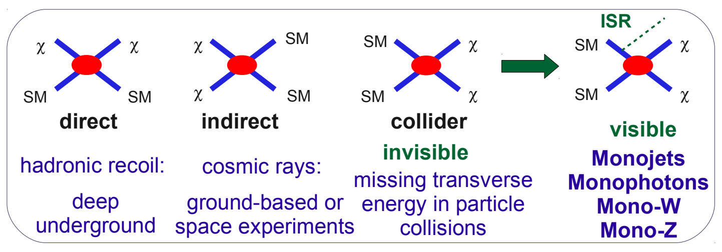
- Well-defined final state, interesting to probe physics models containing new stable, massive particles that escape the detector

Three interpretations are presented:

- **WIMPs as dark matter candidates:** weakly interacting massive particles (WIMPs) with masses between 1 GeV and 1 TeV are promising candidate for the dark matter component in the universe. Such particles would be in reach of the LHC, leaving a signature of large E_T^{miss} and possibly a jet from initial state radiation.
- **Probing large extra dimensions (ADD):** large extra dimensions could provide an explanation for the hierarchy problem. The compactified extra dimension(s) would lead to a tower of graviton-states, which would escape the detector, if produced at the LHC.
- **Gravitino in gauge-mediated SUSY:** the cross section of gravitino production in association with a squark or gluino becomes significant if the gravitino mass is low. Monojet signatures can constrain the gravitino mass and give the best lower bound on its mass to date.

Limits on Dark Matter Production

WIMP searches at colliders provide an independent and complementary approach to direct and indirect dark matter searches!



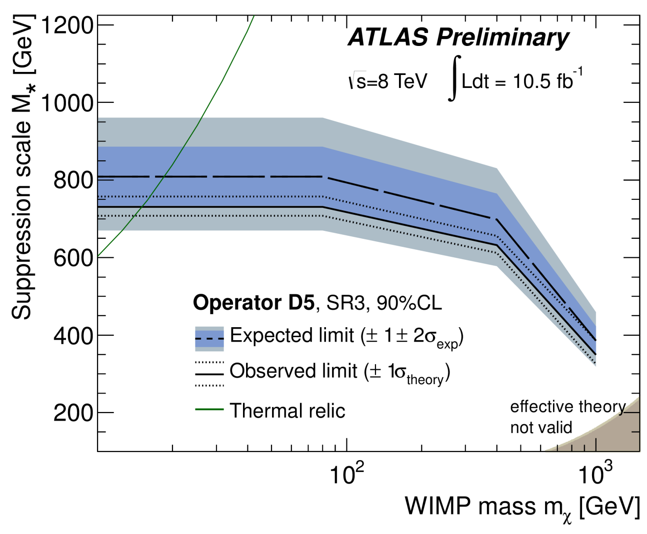
Model-independent approach for interaction between Standard Model (SM) particles and dark matter candidates (χ):

- WIMP χ is Dirac Fermion (conclusions for Majorana Fermions also possible)
- SM - χ mediator is very heavy, χ is only new particle in LHC reach,

  → Effective field theory approach: **Contact interaction!**

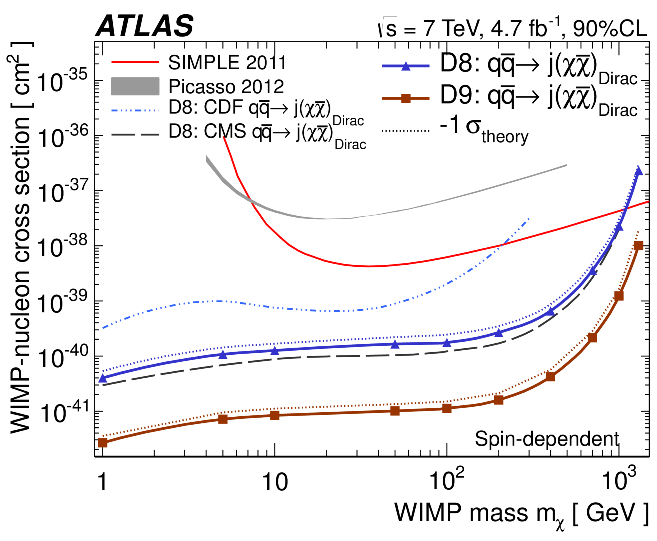
The limits are presented in terms of the WIMP mass and the suppression scale M_*

- Interaction can happen via different operators, set limits on each separately (shown here: vector interaction operator D5)
- Limits can be compared to thermal relic density from WMAP measurements



Effective field theory approach allows to compare collider limits to (in)direct detection experiments

- Depending on the interaction operator, bounds on WIMP-nucleon cross section are calculated for spin-dependent or spin-independent case (shown here: spin-dependent axial-vector operator D8 and tensor operator D9)
- Collider bounds are especially powerful for low WIMP masses (< 10 GeV)



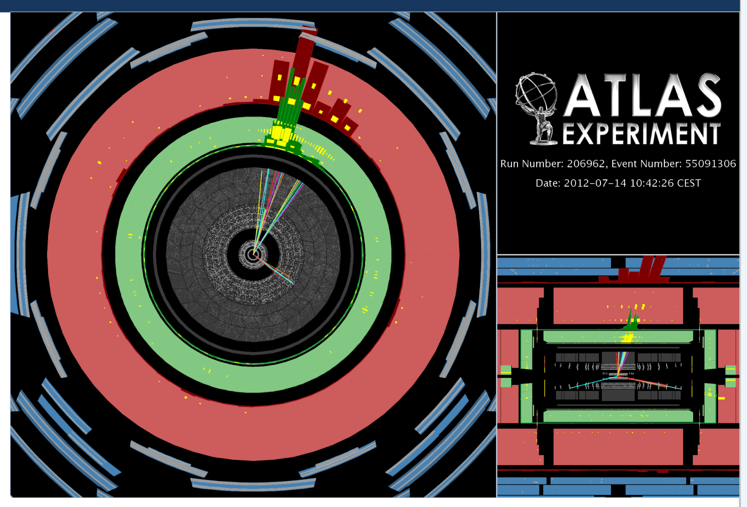
Analysis Setup

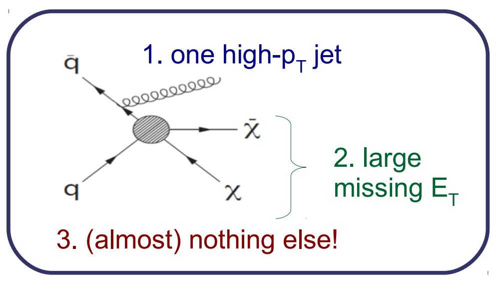
Physics Objects Definition:

- **Jets:** reconstructed with anti-k_t algorithm (R = 0.4)
- **Missing transverse momentum (E_T^{miss}):** reconstructed from energy-deposits in the calorimeter up to $|\eta|$ of 4.5
- **Electrons:** selection criteria based on shower shape and track selection, p_T>20 GeV, $|\eta|$<2.47
- **Muons:** selection based on match of inner detector and muon system track, p_T>7 GeV, $|\eta|$<2.5

Event Selection:

- Events passed trigger on E_T^{miss} > 80 GeV
- Quality cuts to reject non-collision backgrounds: reject events containing jets with anomalous charge or electromagnetic fraction or timing
- Leading jet p_T > 120 GeV, $|\eta|$ < 2
- E_T^{miss} > 120 GeV, $|\Delta\varphi$ (jet$_2$, E_T^{miss})$|$ > 0.5 (suppress di-jet events)
- ≤ 2 jets with p_T > 30 GeV and $|\eta|$ < 4.5, no leptons





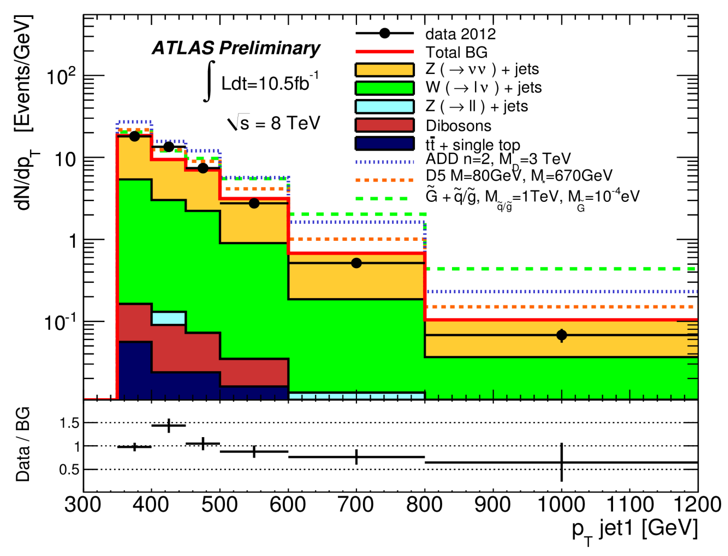
Systematic Uncertainties

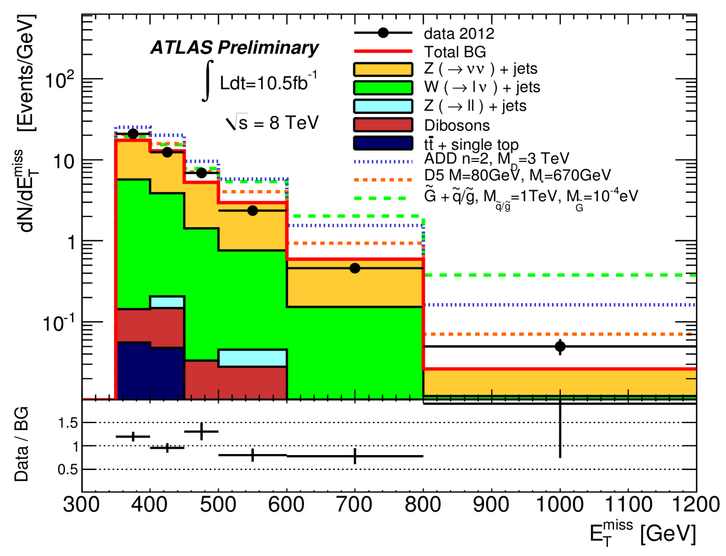
- **Electroweak (EW) Background Estimation:**
  - Jet Energy Scale/Resolution (JES/JER): 2 – 4% on transfer factor (TF)
  - Lepton identification efficiencies: 1 - 3% on TF
  - Remaining non-EW backgrounds: 20% → 1% uncertainty in signal regions
  - Parton shower and hadronization modeling: 3%
- **Multijet Background:** Different fits used in data-driven estimation: < 100% on background → 1% in signal regions
- **Other backgrounds:** 20% on top and diboson backgrounds
- **Signal uncertainties:** JES/JER, trigger efficiency, luminosity, ISR/FSR, PDFs, nomalization and factorization scales

Results

The data are compared with the background estimation in 4 different signal regions (SRs), categorized by leading jet p_T and missing transverse momentum E_T^{miss}:

SR1: p_T (jet1), E_T^{miss} > 120 GeV, **SR2:** p_T (jet1), E_T^{miss} > 220 GeV,
SR3: p_T (jet1), E_T^{miss} > 350 GeV, **SR4:** p_T (jet1), E_T^{miss} > 500 GeV





Event yields are compared with the Standard Model prediction in each signal region

- The measured number of events agrees well with the background prediction within the errors from statistical and systematic uncertainties for all signal regions
- The largest fraction of events comes from Zνν (50 - 70%), the Wlν backgrounds add up to 30 - 46%, of which Wτν has the largest contribution (16 - 25%)

	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

The fact that no new physics signals are observed can be translated into model-independent limits on the visible cross section times acceptance times efficiency → starting point for setting limits on specific models.

Summary

A search for new physics in events with a monojet signature and large missing transverse energy was performed on 10.5 fb^{-1} of $\sqrt{s}$ = 8 TeV proton-proton collision data recorded with the ATLAS experiment at the LHC during 2012.

No evidence for new phenomena is observed, the data agrees well with the Standard Model prediction.

This is translated into model-independent upper limits on the visible cross section as well as in the context of various theories of physics beyond the Standard Model.

- Limits on the suppression scale M_* as a function of the WIMP mass for the pair production of dark matter candidates are presented
- M_D and the number of extra dimensions were probed in the ADD model of large extra dimensions
- Lower bounds on the gravitino mass for gravitino production in association with squarks or gluinos in a gauge-mediated SUSY scenario are presented, they are the best bounds on the gravitino mass to date.

Background Estimation

Main Backgrounds:

- **Electroweak:**
  pp → Z (→ νν) + jets: irreducible
  pp → W (→ lν) + jets, pp → Z/γ (→ ll) + jets: very large cross section, but smaller E_T^{miss}
- **Multijets:** from mis-reconstructed jets, estimated from di-, tri-jet events in data
- **Non-collision background:** noise, cosmic rays, beam-induced fake jets
- **Single top and ttbar:** large E_T^{miss}, many jets
- **Dibosons:** E_T^{miss} from W decay

data-driven estimate
estimated from MC

Estimation of Electroweak Backgrounds

By inverting the lepton veto and selecting W and Z candidates, electroweak background-enriched control regions (CRs) are constructed

- Number of background events in signal regions is estimated from the control region via an MC transfer factor:

$$N_{SR}^{predicted} = (N_{CR}^{data} - N_{Bkg}^{CR}) \cdot \frac{N_{SR}^{MC}}{N_{CR}^{MC}}$$

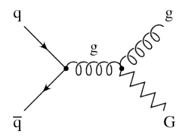
Limits on Large Extra Dimensions

The limits on the visible cross section are interpreted in terms of the ADD model of large extra dimensions

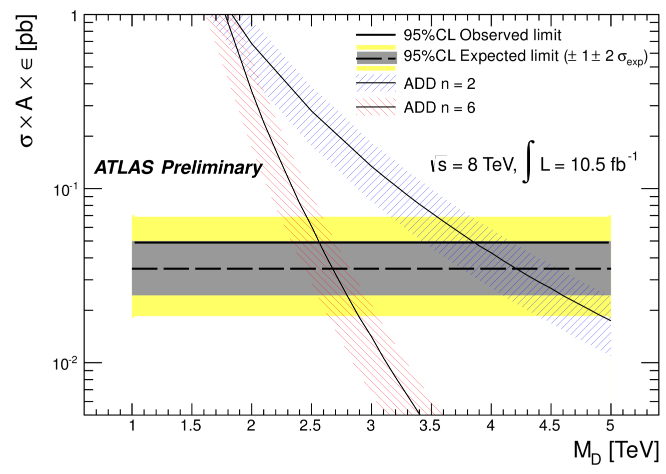
- Large difference between the electroweak scale and the Planck scale might be explained:

$$M_{Pl} \sim M_D^{2+n} R^n \quad n\text{: number of extra dimensions}$$

- Tower of Kaluza-Klein graviton states from compactification of the extra dimension(s): would escape the detector, leaving a monojet signature



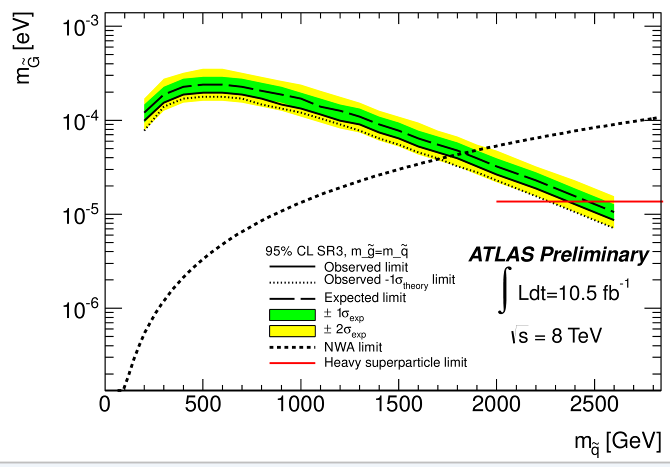
- The limits can be presented as limits on M_D or the number of large extra dimensions



Limits on Gravitino Production

A gravitino being the lightest supersymmetric particle (LSP) in gauge-mediated SUSY scenarios can lead to monojet signatures:

- Associated production of gravitinos with a squark/gluino, giving rise to monojet final states, becomes important for light gravitinos
- Cross section is inversely proportional to the gravitino mass → limits give lower bounds on it
- Previous bounds from colliders lie at 1.37*10^{-5} eV, assuming high squark/gluino masses (> 2 TeV) → no production in final state!
- The presented limit, considering associate production with squarks/gluinos, covers also lower squark/gluino masses



References

- The results are documented in: ATLAS-CONF-2012-147 and arXiv:1210.4491
- WIMP interpretation and the effective field theory approach: T.Tait, et al., arXiv:1008.1783v2
- For the ADD model: N. Arkani-Hamed, et al., arXiv:hep-ph/9803315
- Gravitino interpretation: e.g. G. Giudice, R. Rattazzi, arXiv: hep-ph/9801271

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