Search for new phenomena in jet+MET and γ+MET final states at the ATLAS detector

Fuquan Wang
University of Wisconsin-Madison

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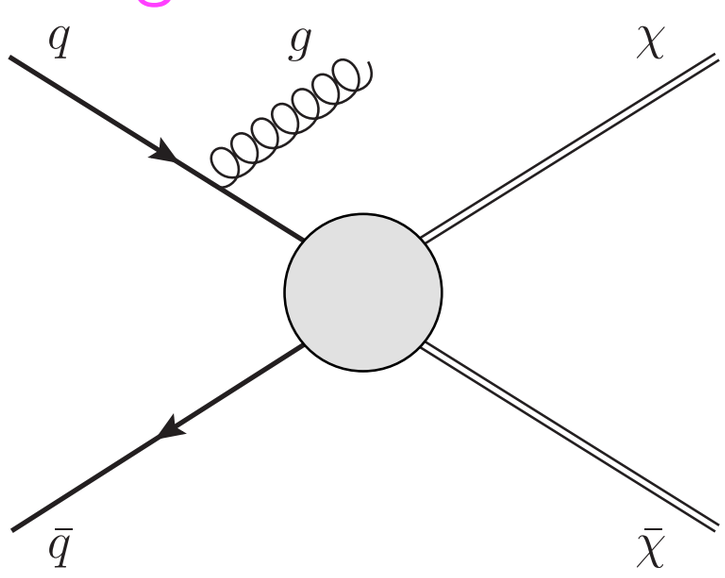
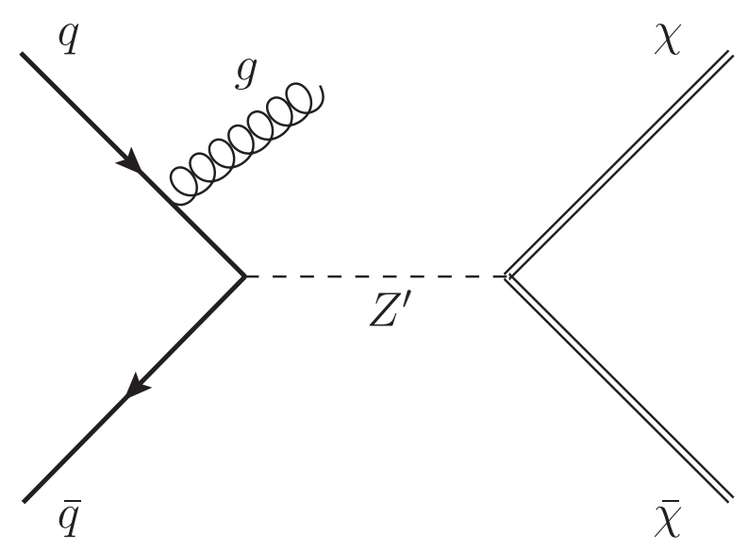
Motivation for jet+MET search

- Weakly interactive massive particles (**WIMP**s), dark matter candidates, can be produced in pair at colliders.
  - Large missing transverse energy (MET) from WIMPs.
- An energetic visible object is needed to tag these events.
  - Jets, from gluon initial state radiation, are dominating.
- jet+MET final state is the most sensitive channel in general dark matter search at LHC.
  - Same event signature can be interpreted in other searches
    - Large extra dimension or SUSY signatures



Effective field theory (EFT)

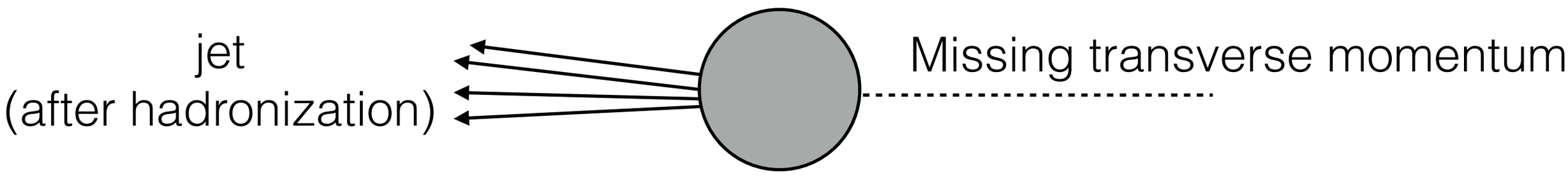


Simplified models

Event selection and backgrounds

jet+MET, Eur. Phys. J. C (2015) 75:299

- **Cut-and-count** analysis
- A good primary vertex, MET>150 GeV, p_T^{j1}>120 GeV
- Jet should be balancing the MET and in opposite direction
- Reject events with bad jets
  - Cosmic rays, detector noise or beam-related background
- Reject events with electrons, muons or isolated tracks
- Scan on MET to increase sensitivities

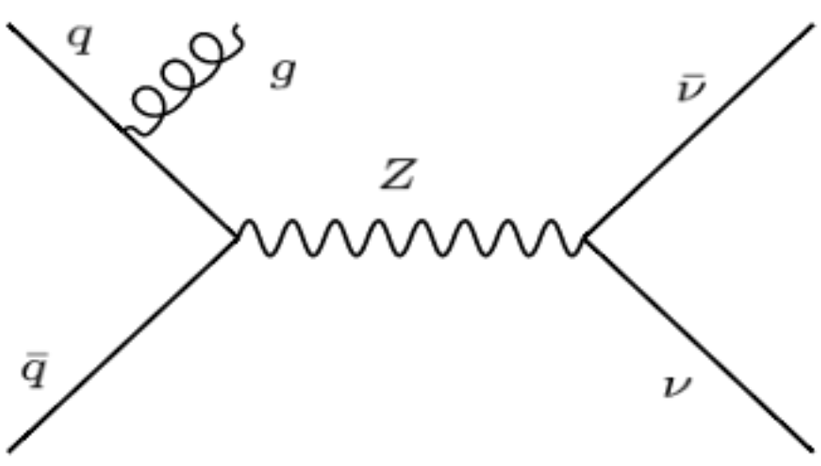


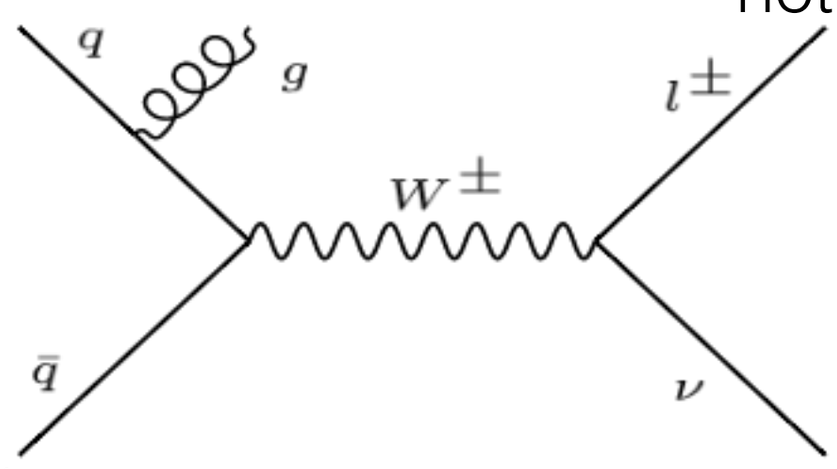
Event signature to be looked for

Event selection and backgrounds

jet+MET, Eur. Phys. J. C (2015) 75:299

- Major backgrounds:
  - Z(νν)/W(lν)+jets
  - Estimated with control regions (CR) data/MC transfer factors
  - Z(ll)/W(eν)/W(μν)+jets CRs
- Minor backgrounds:
  - Estimated from MC: Z/γ*(ll)+jets, ttbar, diboson
  - Estimated with data-driven method: multijets, non-collision backgrounds



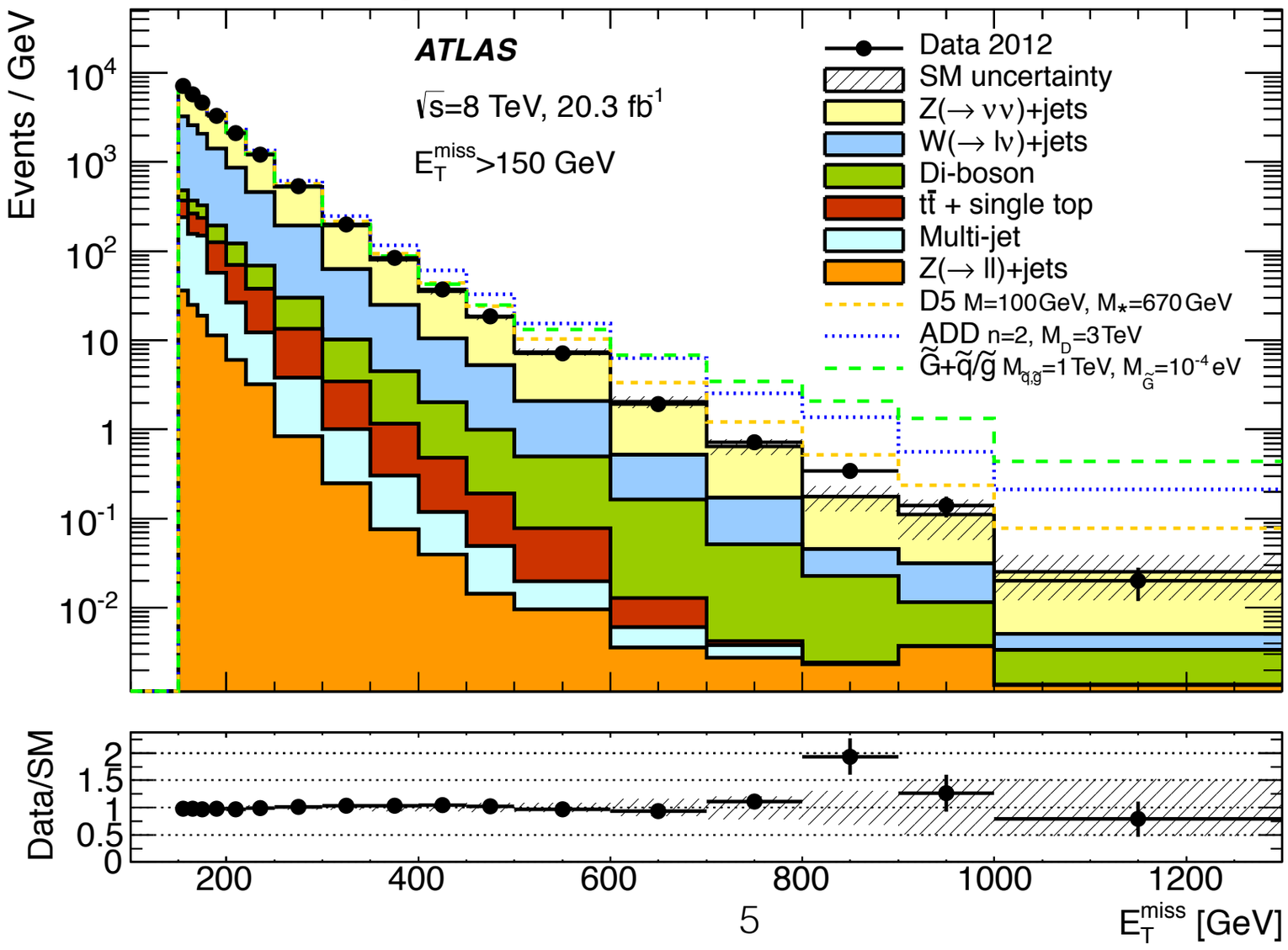


not reconstructed /identified

8 TeV results

jet+MET, Eur. Phys. J. C (2015) 75:299

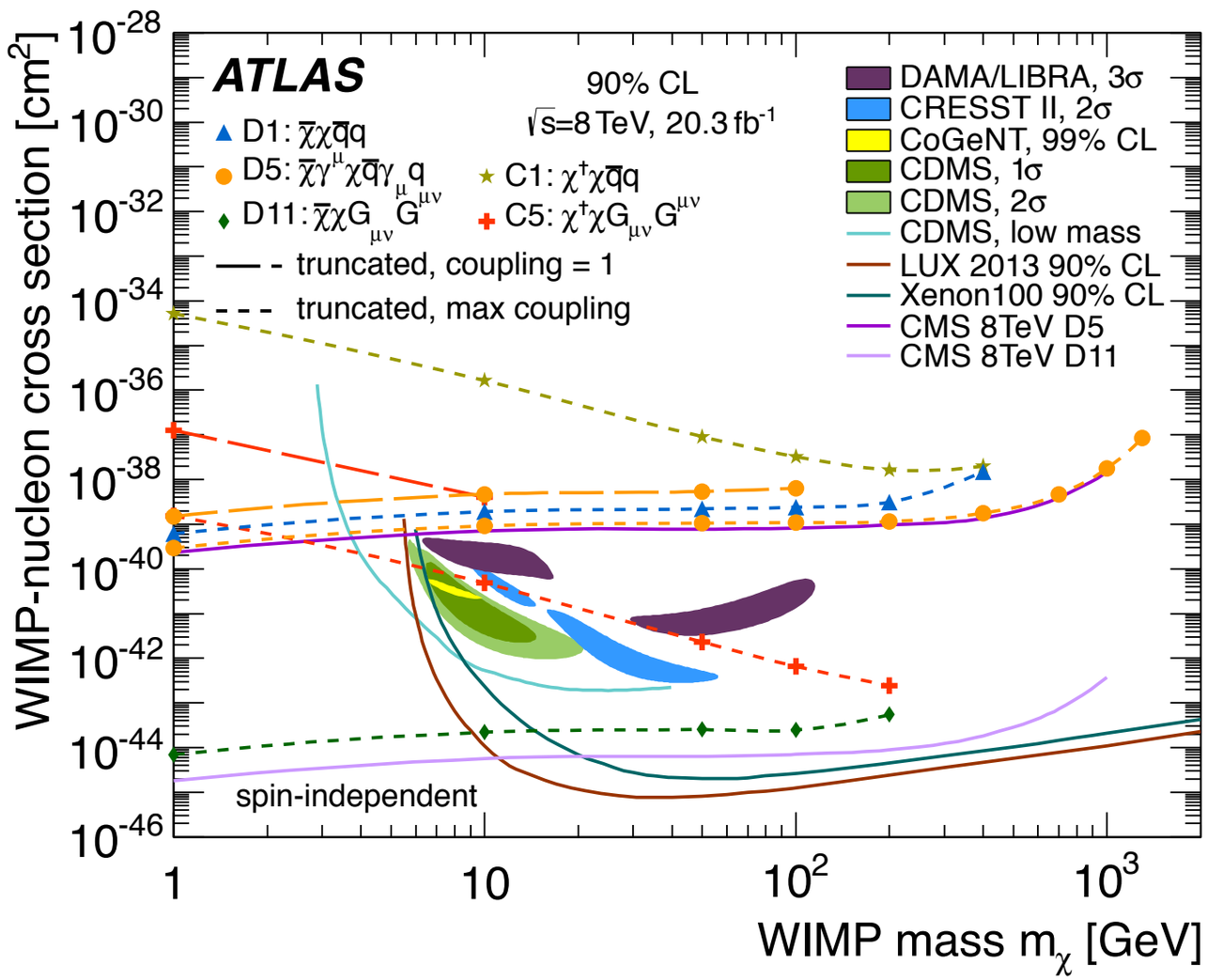
- No discrepancy between observation and Standard Model (SM) expectation.
- Limits are set on various signal models.
  - Tune MET cuts against models, use the most sensitive one

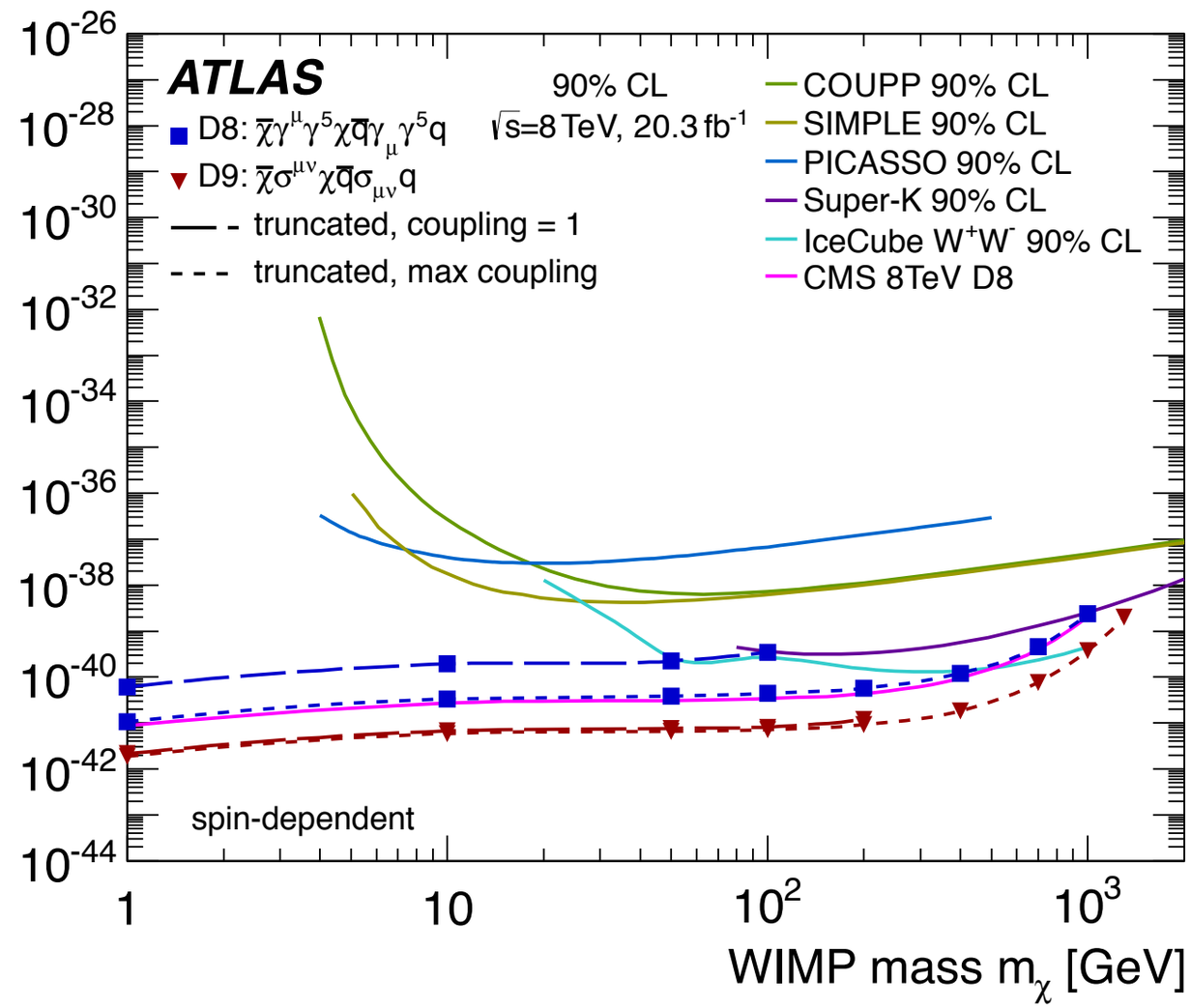


Interpretation in dark matter search

jet+MET, Eur. Phys. J. C (2015) 75:299

- The 90% CL limit is set on EFT models.
  - Interpretations in WIMP-nucleon cross section.
- Better sensitivity compared to direct detection experiments:
  - Low WIMP mass region for spin-independent models
  - Uniformly powerful for spin-dependent models

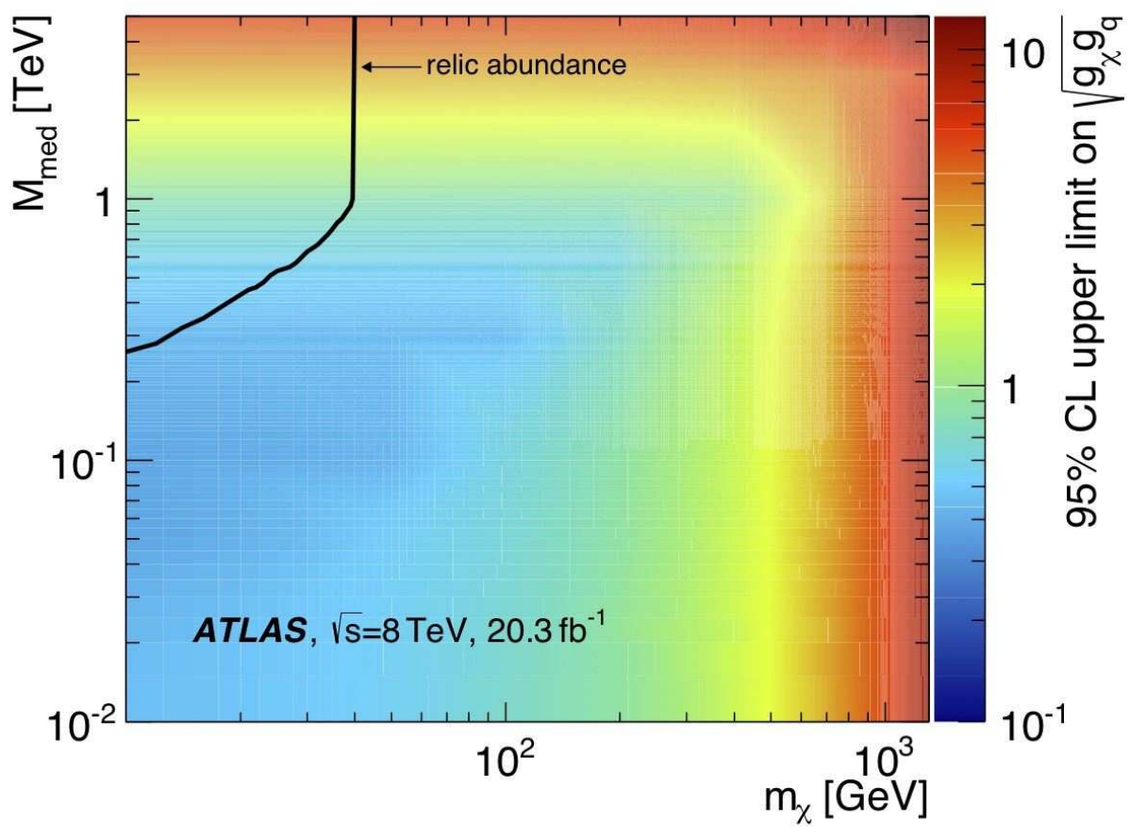


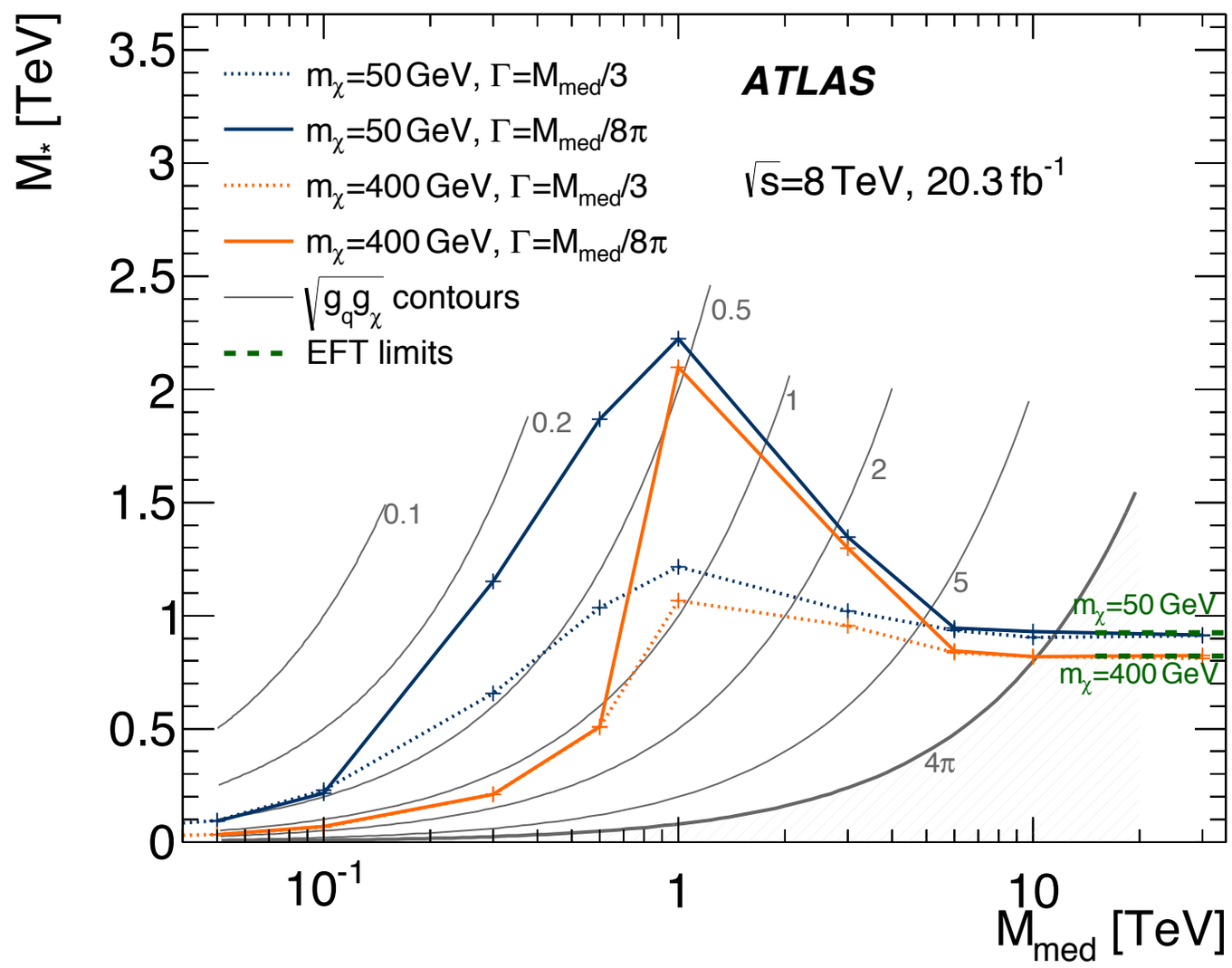


Interpretation in dark matter search

jet+MET, Eur. Phys. J. C (2015) 75:299

- 95% CL limit set on coupling strength in simplified models
- 95% CL limits on suppression scale (M_*) is compared between simplified models and EFT
  - Limits the same at high mediator mass, where the mediator is off-shell
  - $M_* = M_{\mathrm{mediator}}/\sqrt{g_\chi g_f}$

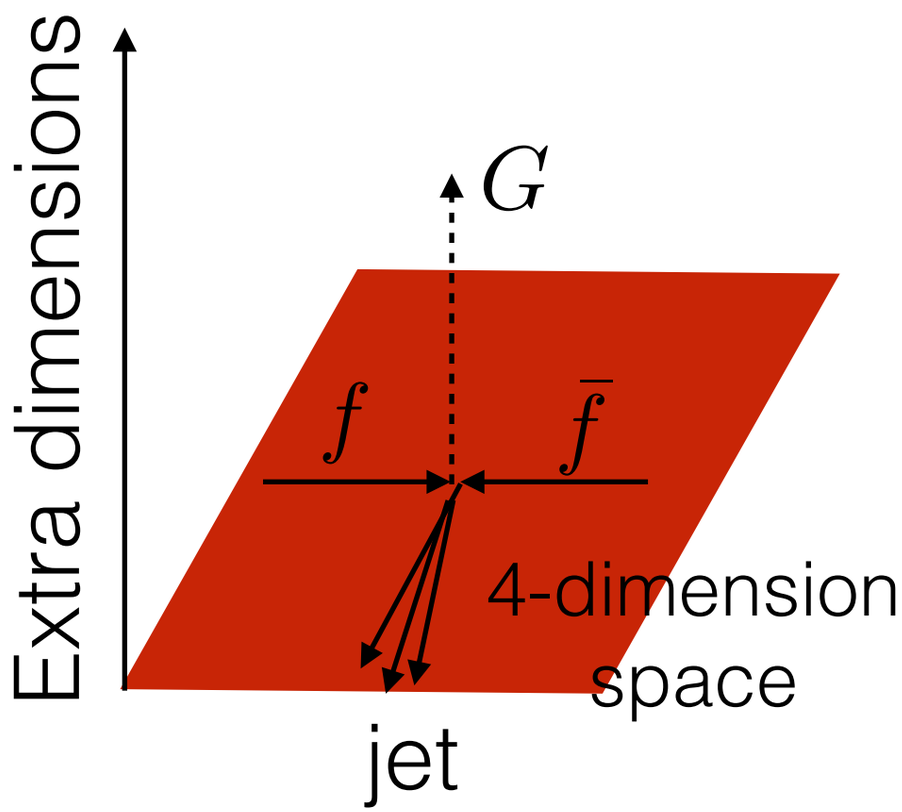


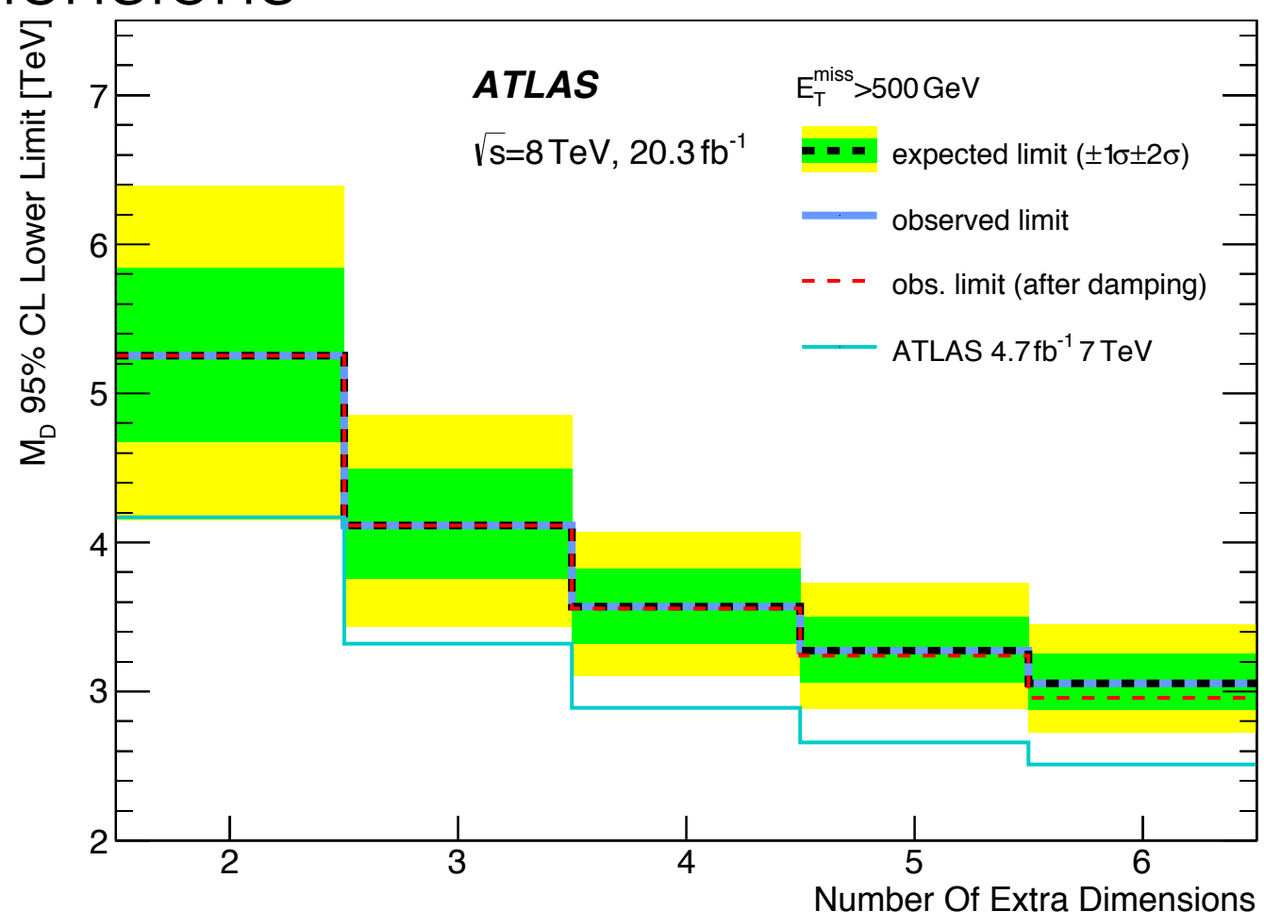


Interpretation for extra dimension search

jet+MET, Eur. Phys. J. C (2015) 75:299

- Arkani-Hamed, Dimopoulos, and Dvali (ADD) model allows the graviton to propagate in additional dimensions.
  - MET from the missing graviton
- 95% CL limit on fundamental Plank scale m_D in 4+*n* dimensions
  - $\sigma(n, M_D) \propto M_D^{-n-2}$
  - *n* is the number of extra dimensions

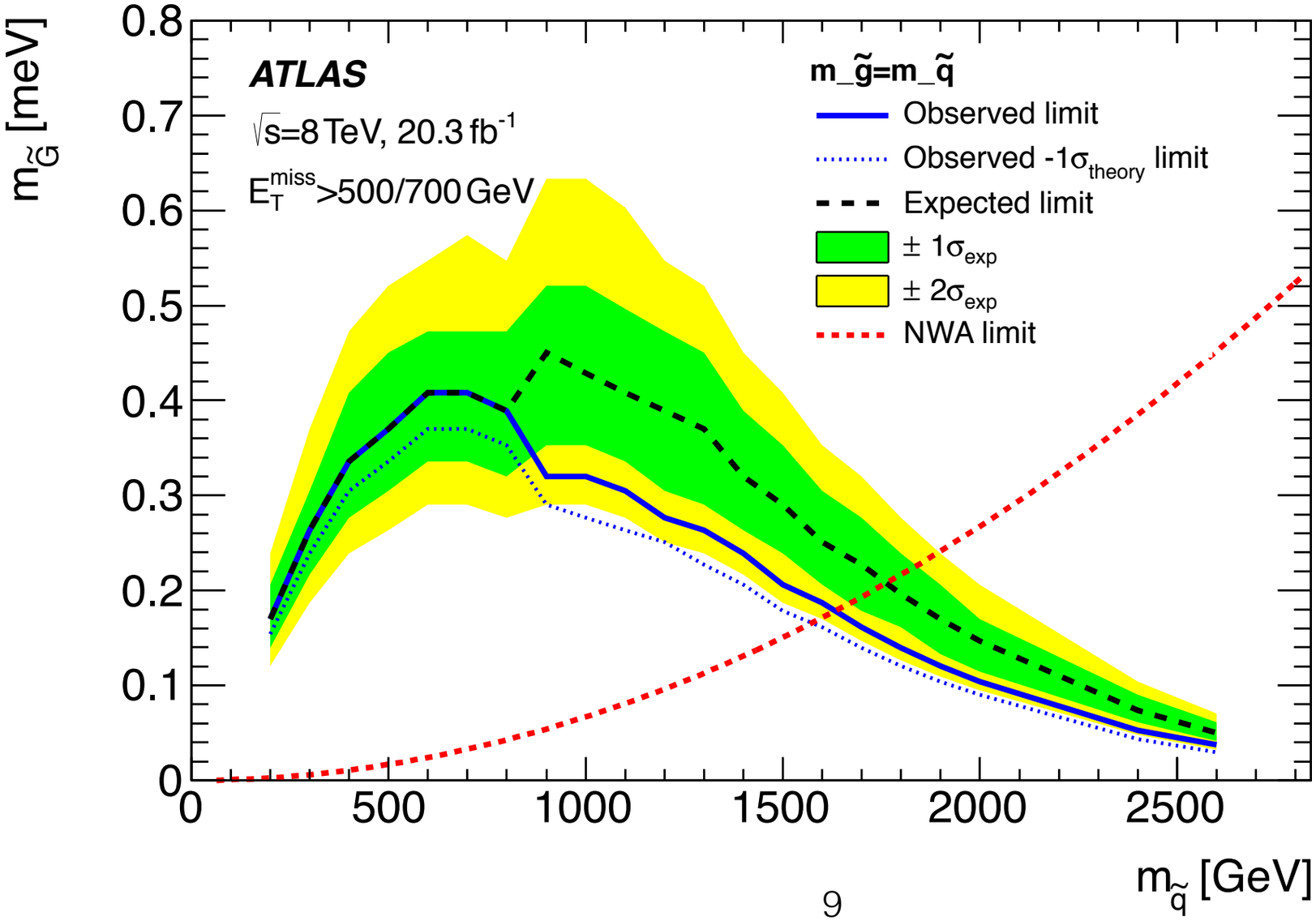




Interpretation for SUSY

jet+MET, Eur. Phys. J. C (2015) 75:299

- Associated production of a gravitino ($\tilde{G}$) and a gluino ($\tilde{g}$) or a squark ($\tilde{q}$)
- Similar final state as jet+MET signature
- 95% CL limit on gravitino mass $m_{\tilde{G}}$
  - Various $m_{\tilde{g}}/m_{\tilde{q}}$ configurations tested

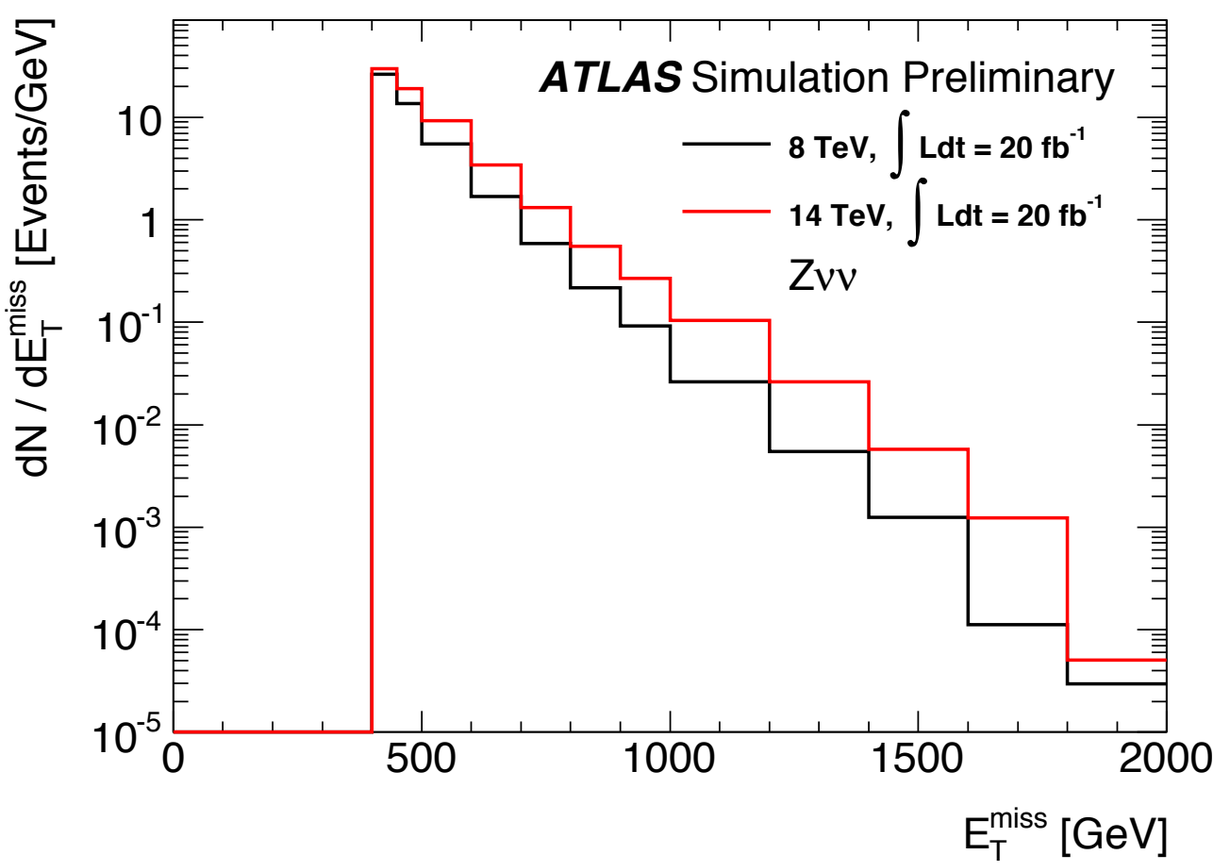


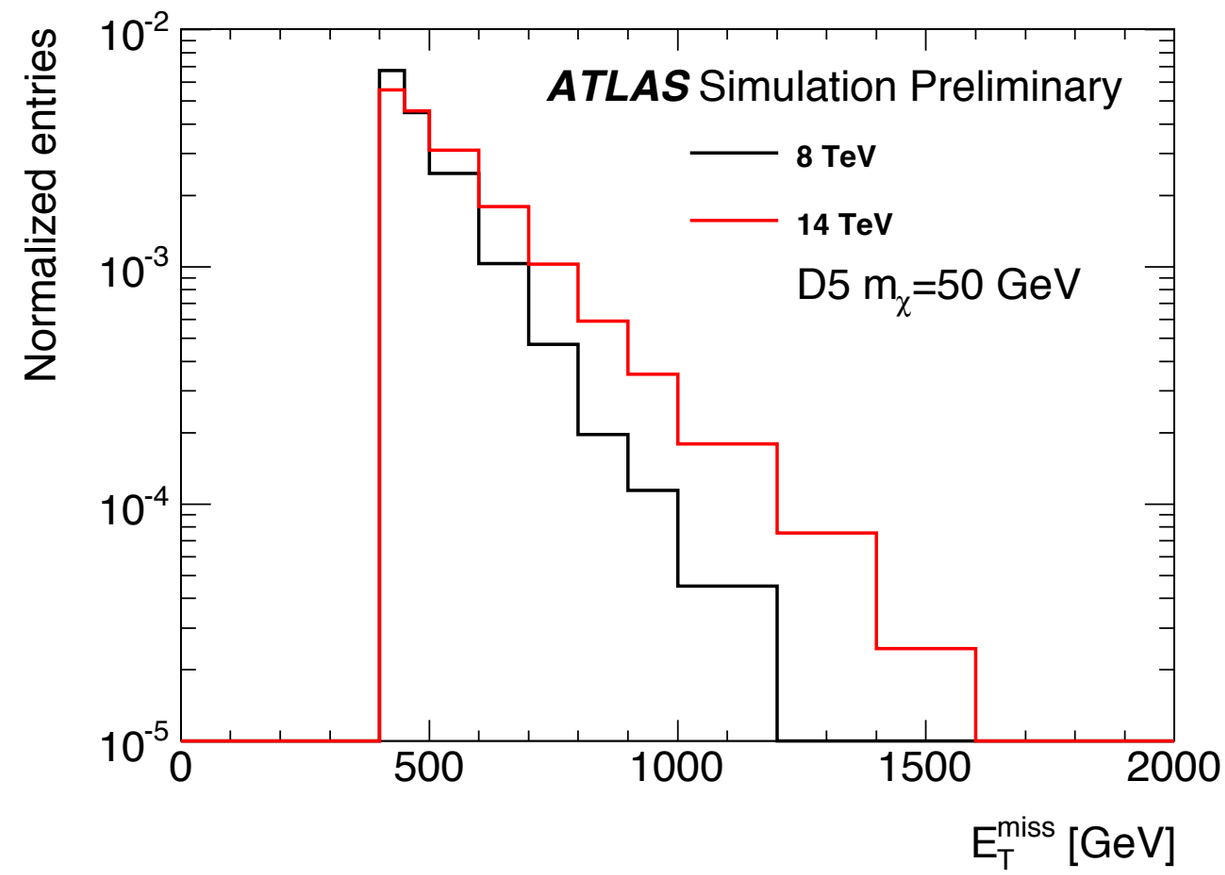
NWA = narrow width approximation

14 TeV prospects

jet+MET, ATL-PHYS-PUB-2014-007

- Study based on MC. EFT models only.
- With the increase of $\sqrt{s}$, the signal cross sections increase much faster than Z(νν)+jets background at high MET

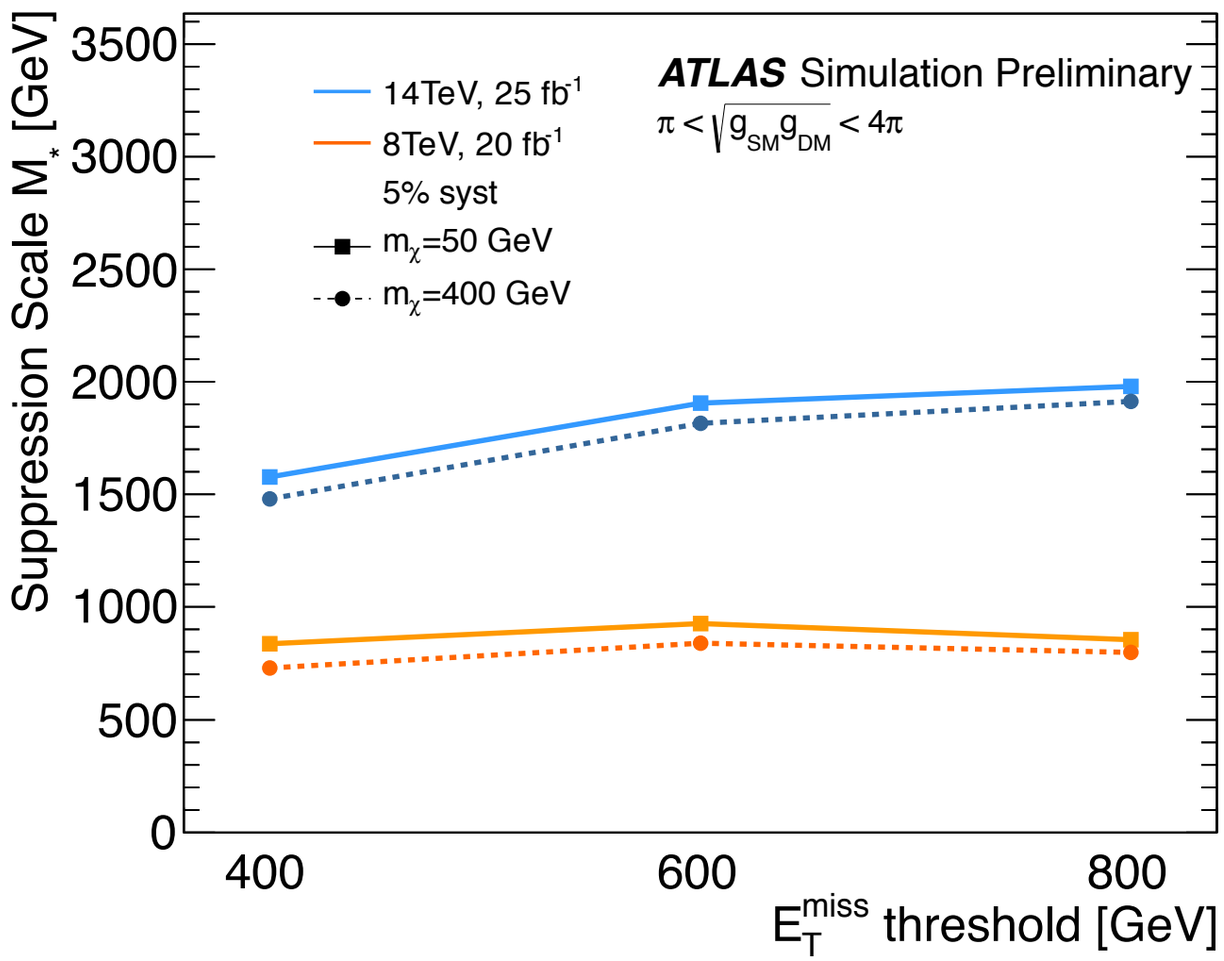


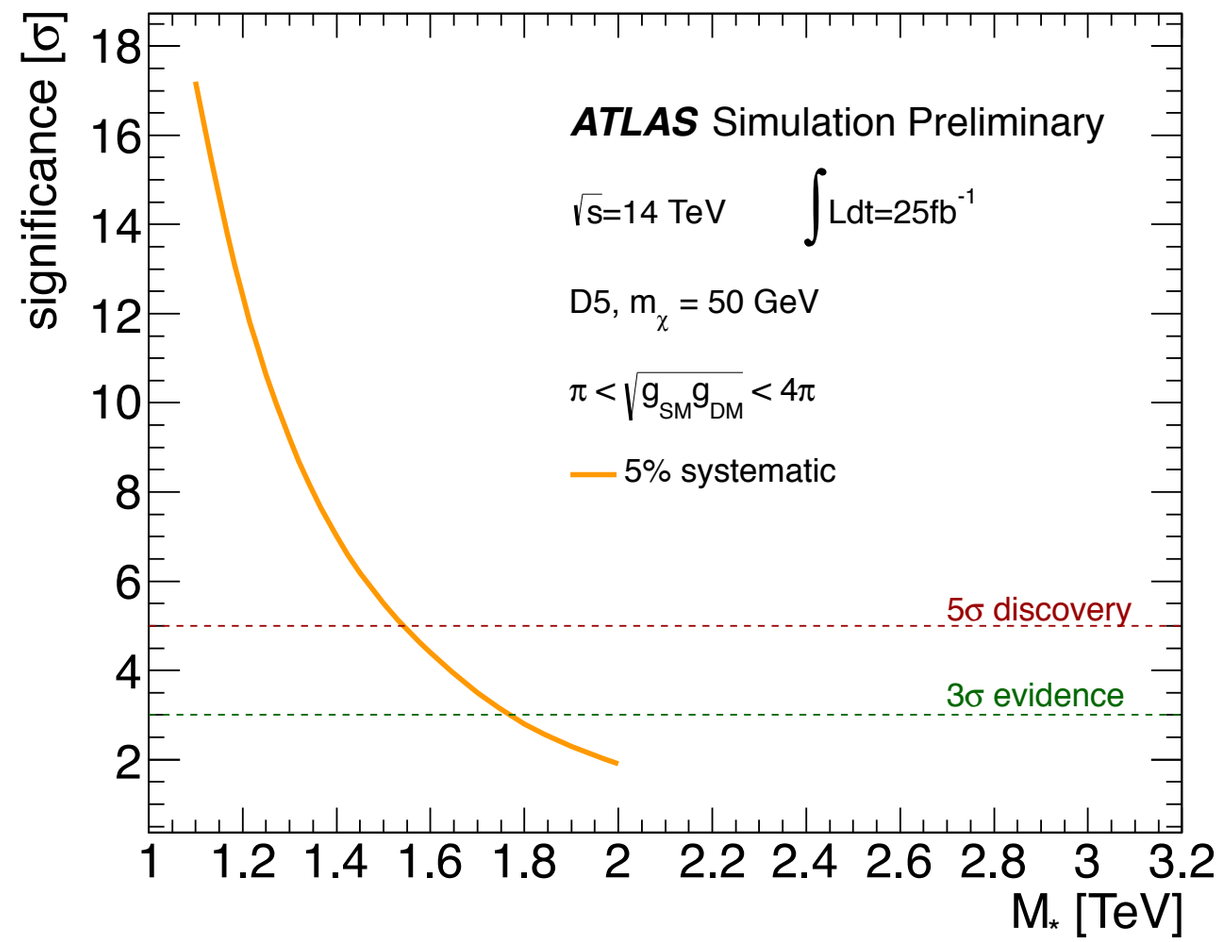


14 TeV prospects

jet+MET, ATL-PHYS-PUB-2014-007

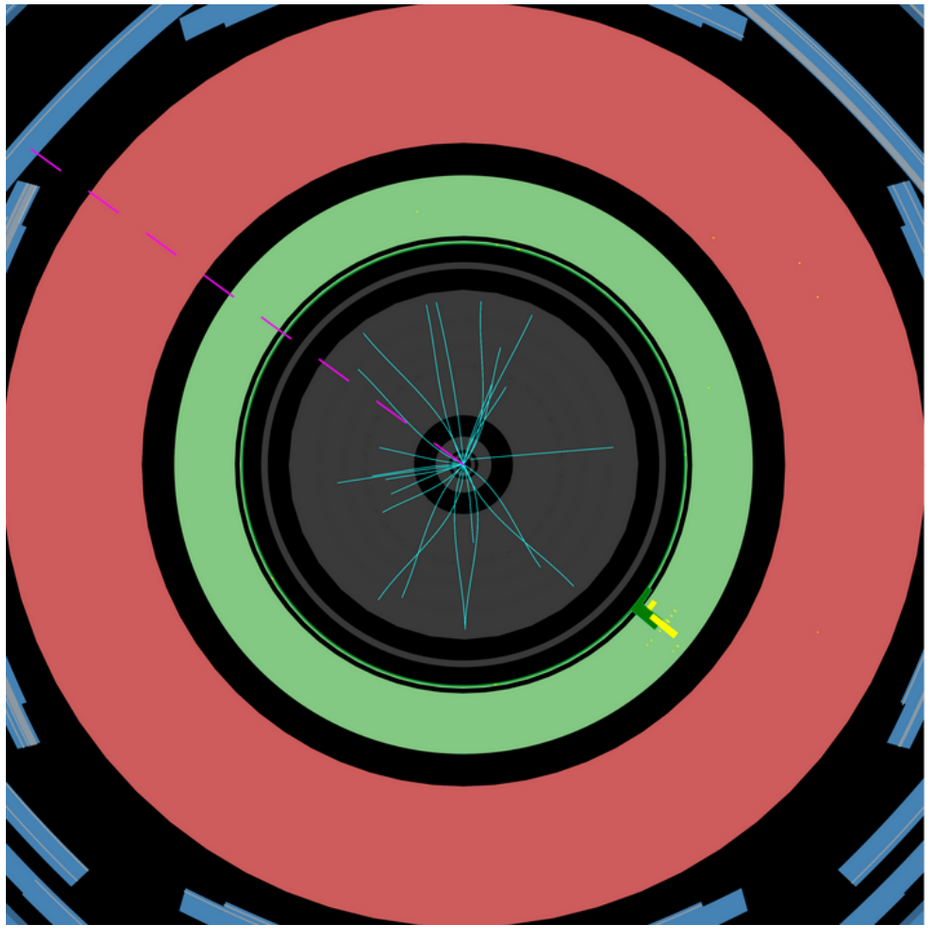
- Compared to 8 TeV:
  - More sensitive, greater potential for discovery.
- LHC Run-II operates at 13 TeV, close sensitivity with 14 TeV

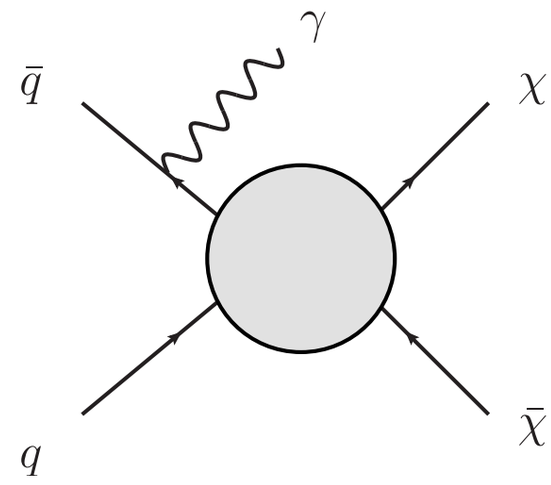


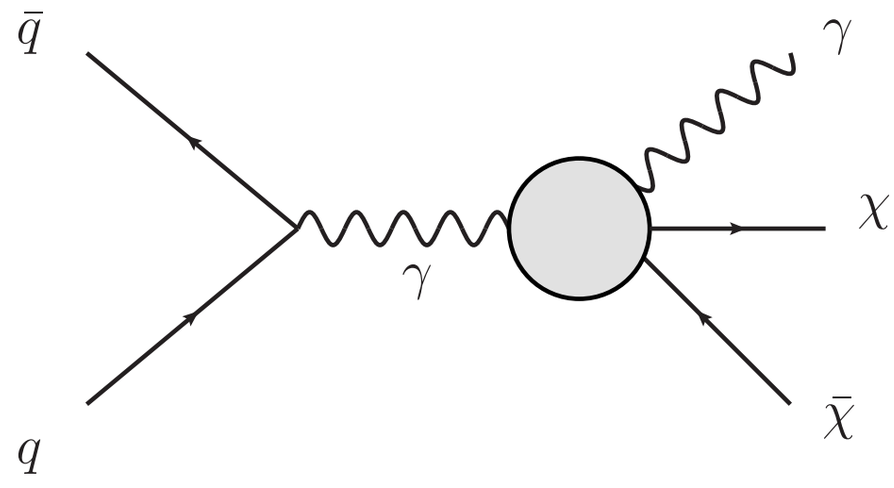


Motivation for γ+MET search

- Well measured γ object. Cleaner background from electro-weak processes
- Complements the initial state radiation search
- Exclusively sensitive to certain dark matter models
  - γ can be directly involved in dark matter vertex







$\gamma\gamma\chi\chi$ vertex

Event selection and backgrounds

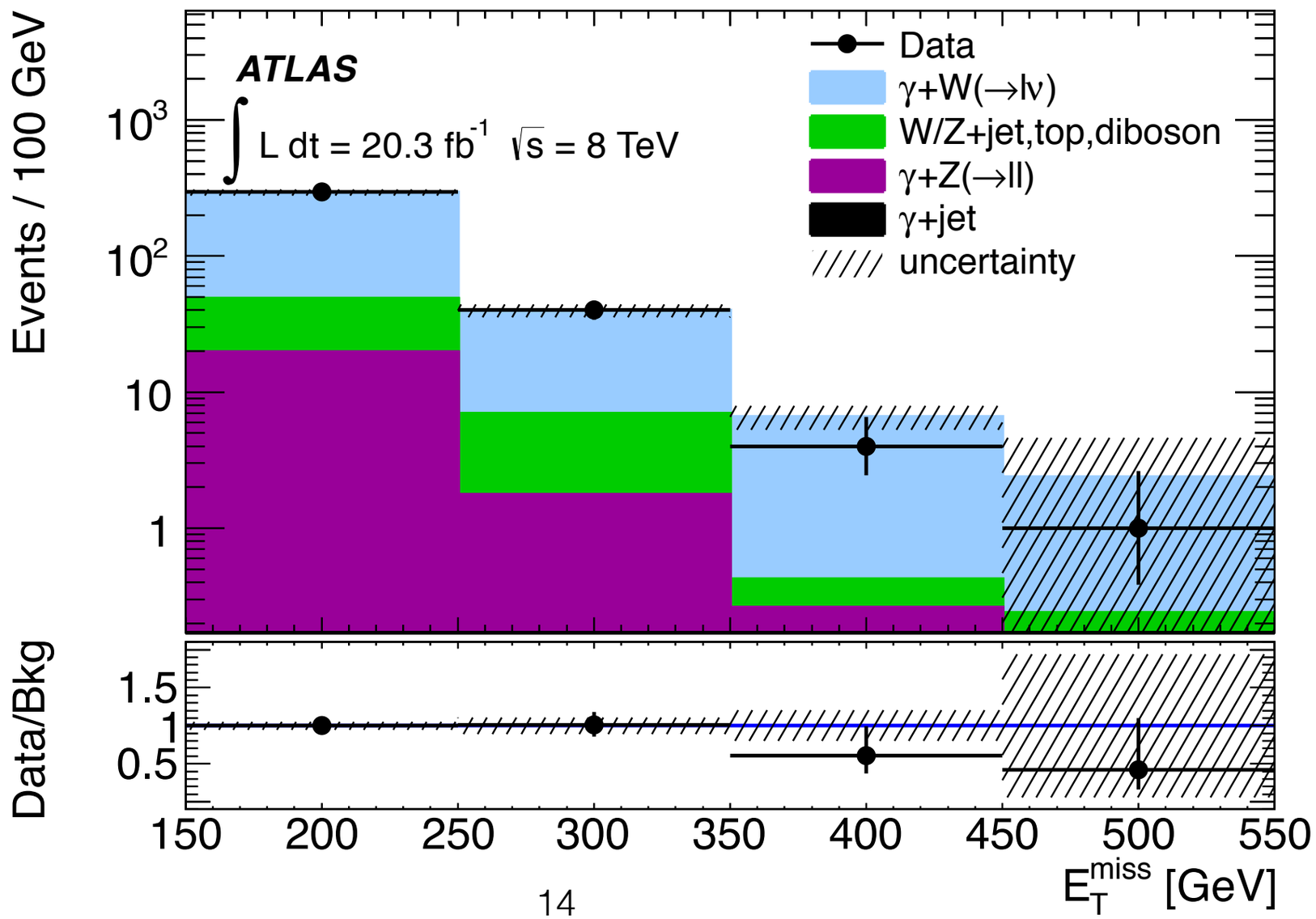
γ+MET, Phys. Rev. D 91, 012008 (2015)

- Selection: (no MET tuning on models, cut-and-count analysis)
  - Similar to jet+MET, replacing the jet with γ
  - Lepton veto. No more than 1 jet.
- Backgrounds:
  - Major backgrounds: Z(νν)+γ, W(lν)+γ (estimated with CRs)
  - W/Z+jets (estimated with data-driven jet→γ factor)
  - ttbar, single top, diboson (estimated with MC)
- Simultaneous fit with signal region and CRs (μμγ, eeγ, μνγ)
  - $N = \mathrm{Poiss}(N|\mu \times N_{\mathrm{sig}} + k_Z \times N_{Z\gamma} + k_W \times N_{W\gamma} + N_{\mathrm{other}})$
  - k_Z/k_W: shared scale factor in all regions for Zγ/Wγ process
  - $N_{Z\gamma}$/$N_{W\gamma}$: MC yields for Zγ/Wγ processes in each region
  - N_{other} from data-driven or MC

8 TeV results

γ+MET, Phys. Rev. D 91, 012008 (2015)

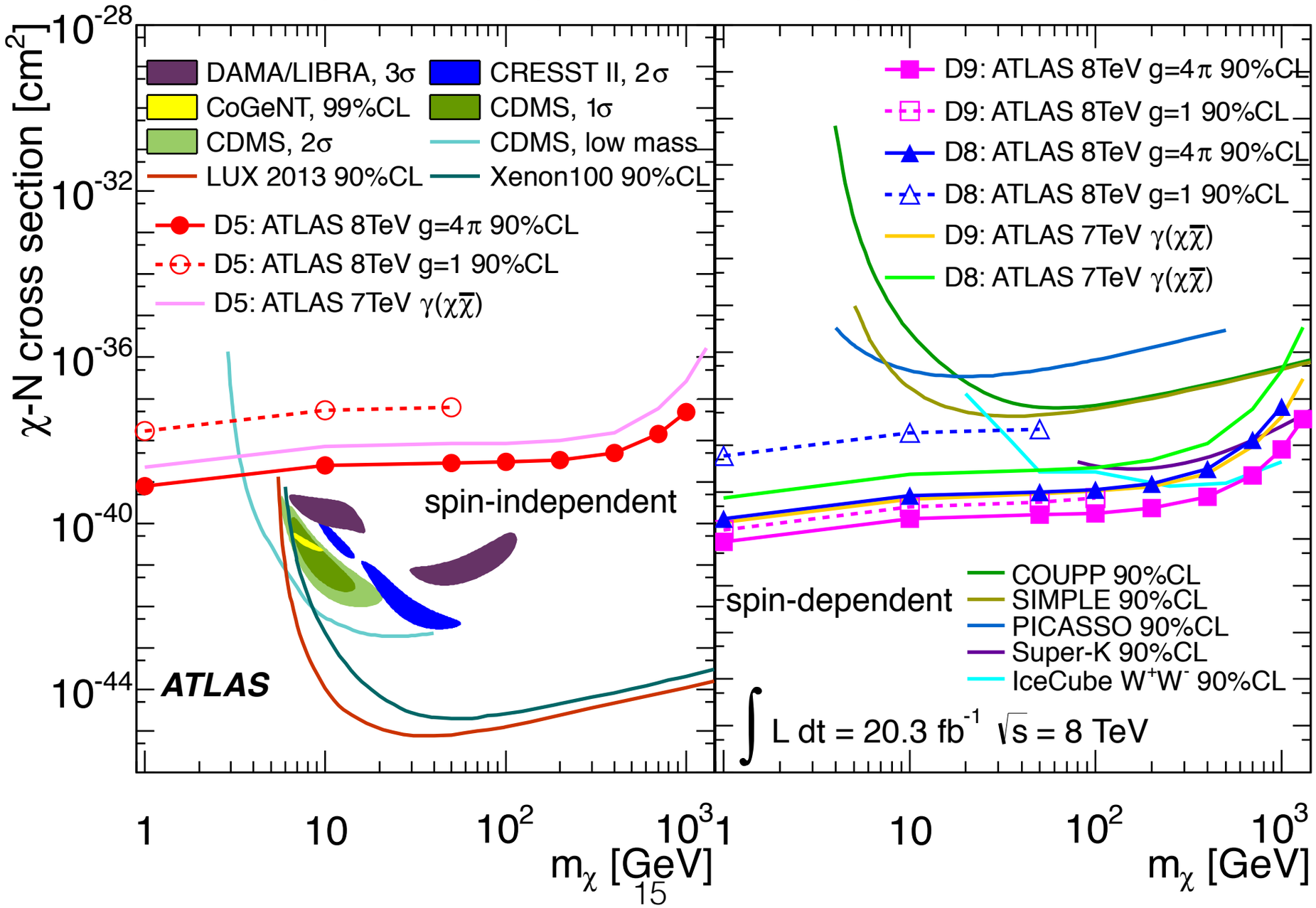
- No excess is observed compared to SM expectation.
  - Upper limit of model-independent cross section on possible excess: 5.3 fb at 95% CL



Dark matter interpretation

γ+MET, Phys. Rev. D 91, 012008 (2015)

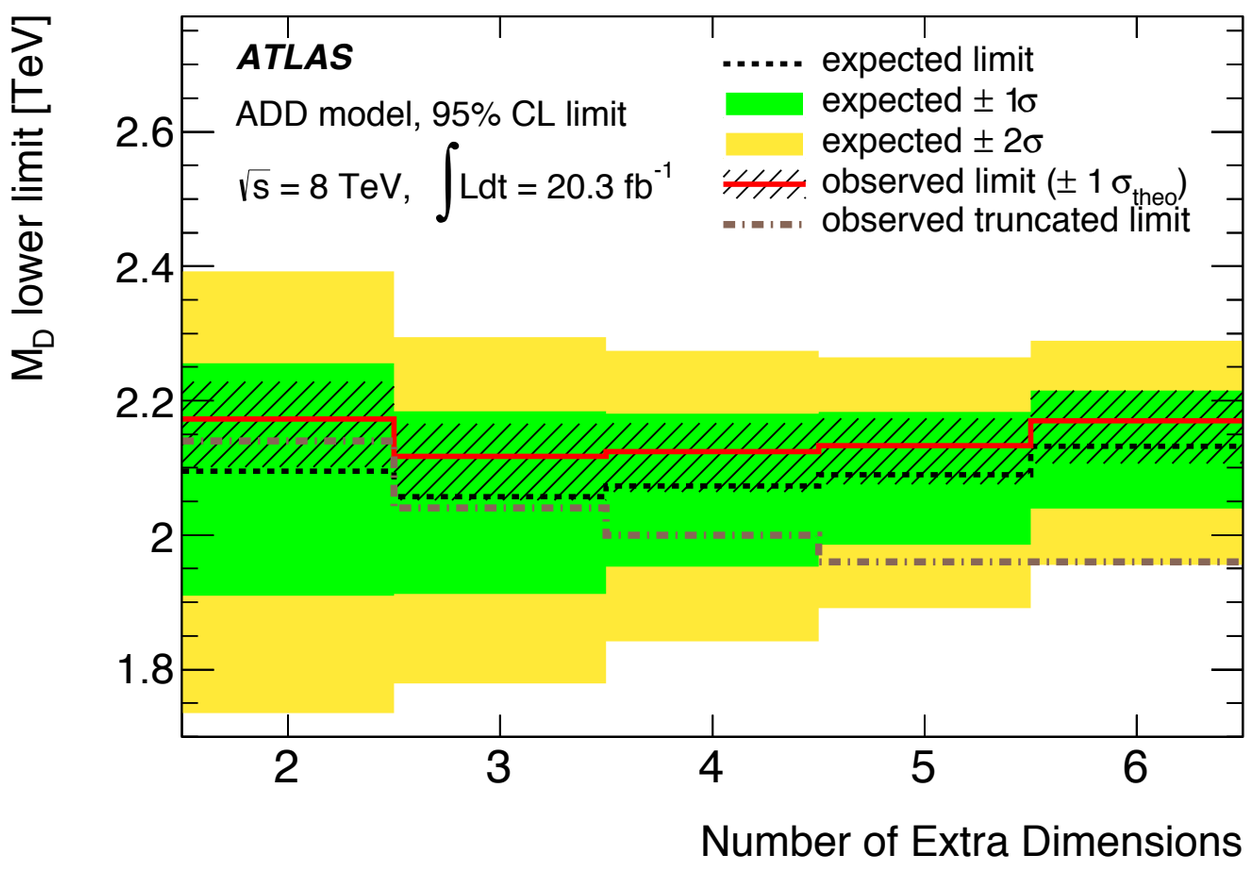
- 90% CL limit on EFT models translated into WIMP-nucleon cross section.
  - Similar with jet+MET compared to direct detections.
  - Less sensitive compared to jet+MET analysis.



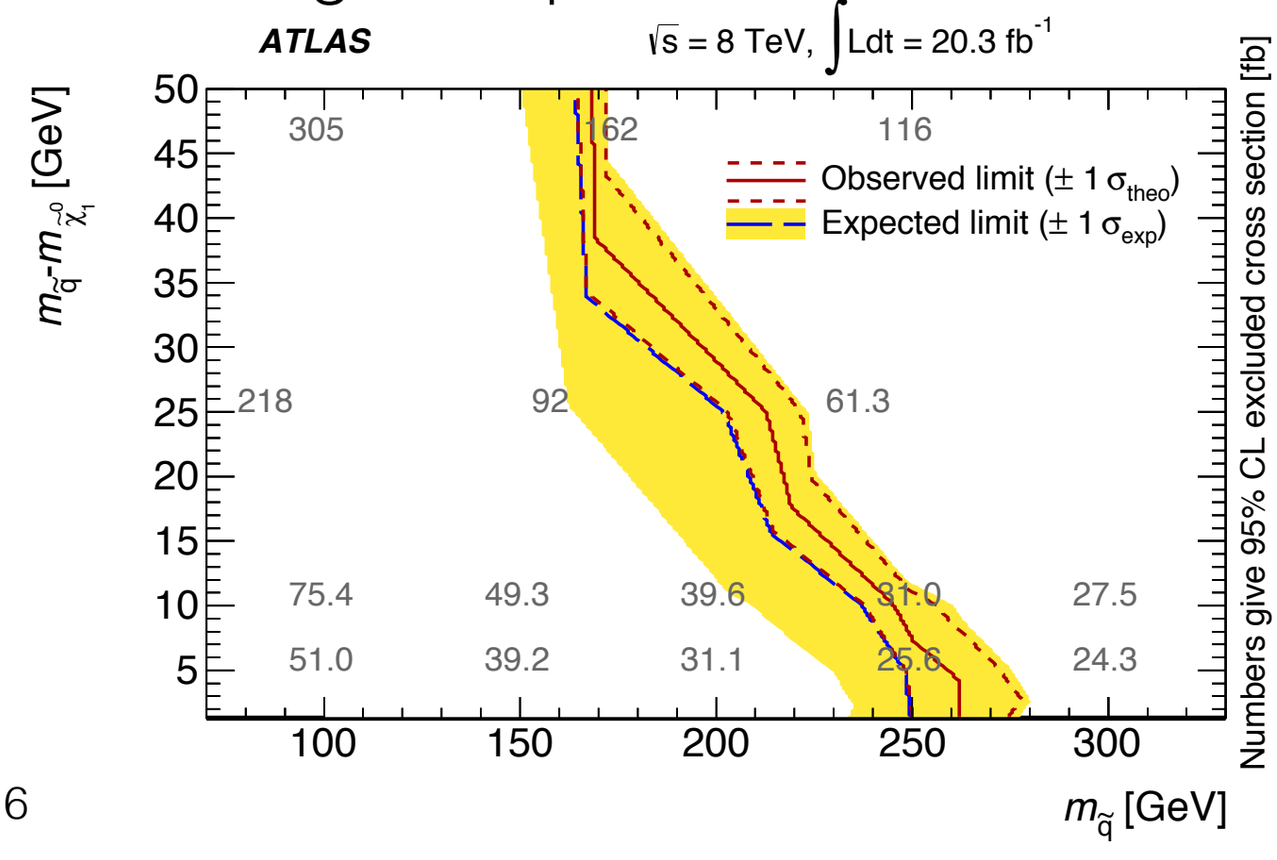
Interpretation for ADD/squark

γ+MET, Phys. Rev. D 91, 012008 (2015)

- ADD model
- 95% CL limit on Plank Scale vs. number of extra dimensions
- ~2.2 TeV for all number of extra dimensions



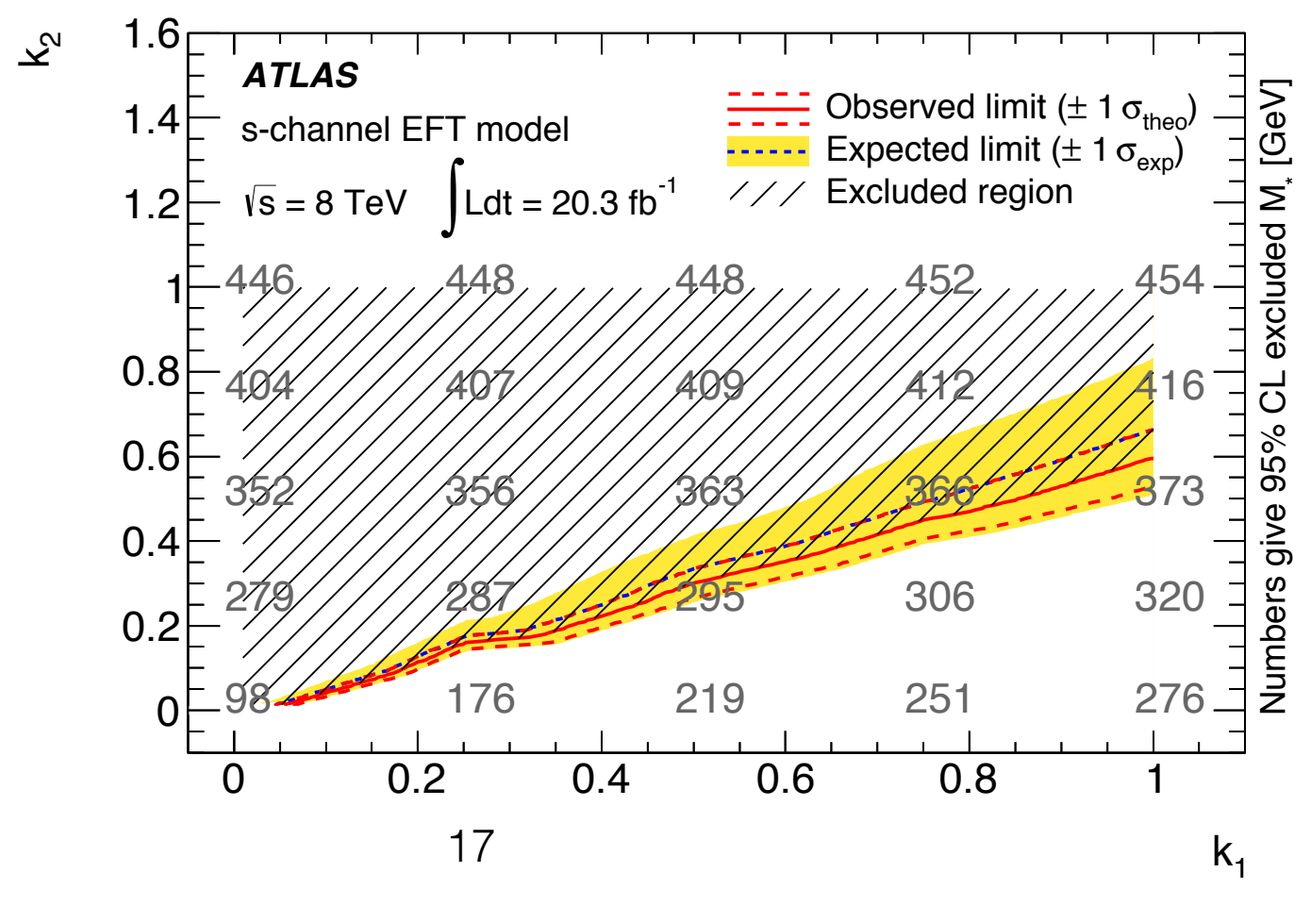
- Squark search:
  - pair production of squark
  - $\tilde{q} \rightarrow q + \mathrm{LSP}$, Lightest SUSY Particle can be invisible
- 95% CL limit on cross section for pair production.
- $m_{\tilde{q}}$ vs Δm plane:
- Left region of plane excluded



Interpretation in γγχχ EFT

γ+MET, Phys. Rev. D 91, 012008 (2015)

- Inspired by Fermi-LAT observed γ-ray spectrum at 130 GeV
  - *APJ 750 3 doi:10.1088/0004-637X/750/1/3*
- 95% CL limit on suppression scale M_*.
- Exclusion is set on (k_1,k_2) plane to generate Fermi-LAT observation in the rate of $\chi\bar{\chi} \to \gamma\gamma$ annihilation.
  - $\sigma \propto (k_1 \cos^2\theta_w + k_2 \sin^2\theta_w)/M_*^6$
  - Upper region of plane is excluded → $M_*^{\text{F-LAT}} < M_*$ lower limit from this analysis

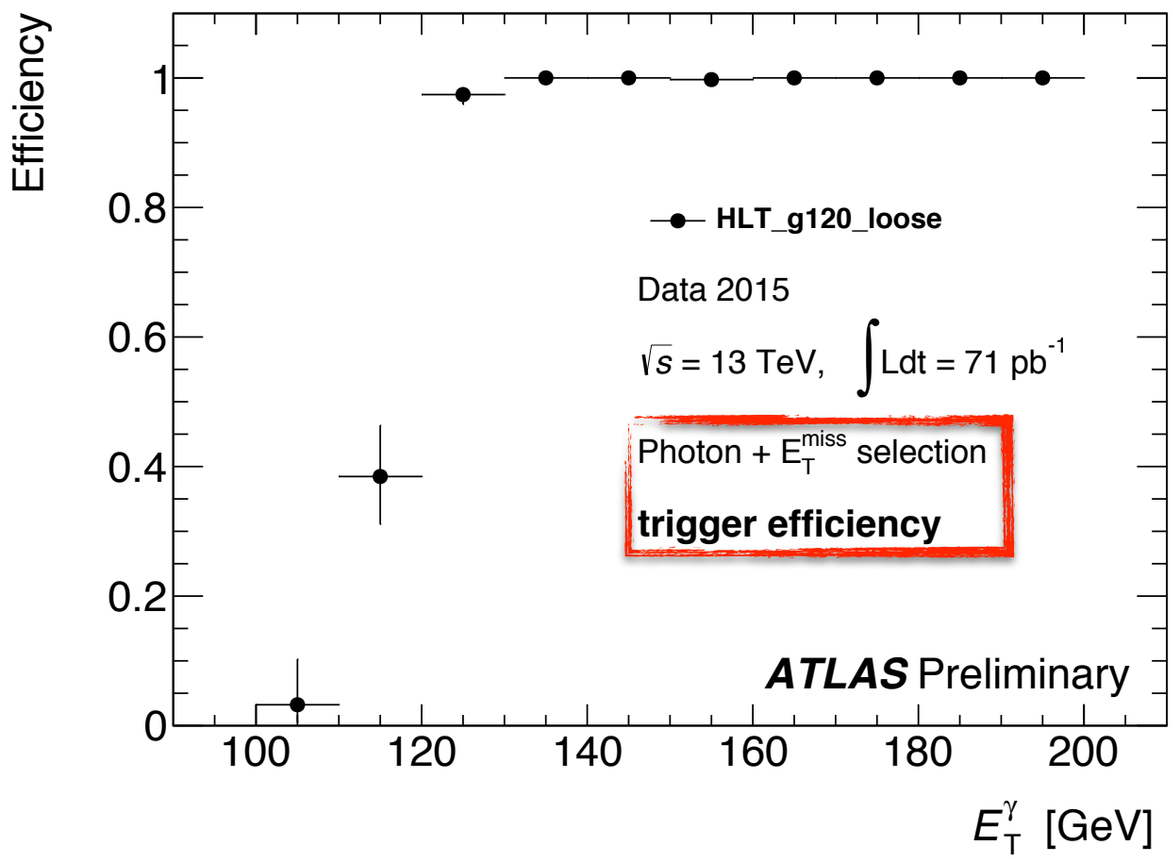


Models in Run-II

- LHC dark matter forum (DMF) recommends dark matter models for interpretation in run-II for ATLAS and CMS.
  - White paper on arXiv:1507.00966
- Simplified models will be the baseline as EFT models have validity issues, especially at high $\sqrt{s}$
  - Mediators can be vector/axial-vector, scalar/pseudo-scalar
  - Recommendation on the grid to be scanned:
    - Dark matter mass, mediator mass and width
- `POWHEG` as the default generator
- EFT models will be presented with truncation:
  - UV complete
  - Kinematics: $Q_{\rm tr} < \sqrt{g_q g_\chi} M_*$ or $E_{\rm cm} < \sqrt{g_q g_\chi} M_*$

13 TeV fresh data

- Performance plots with first 50 ns data.



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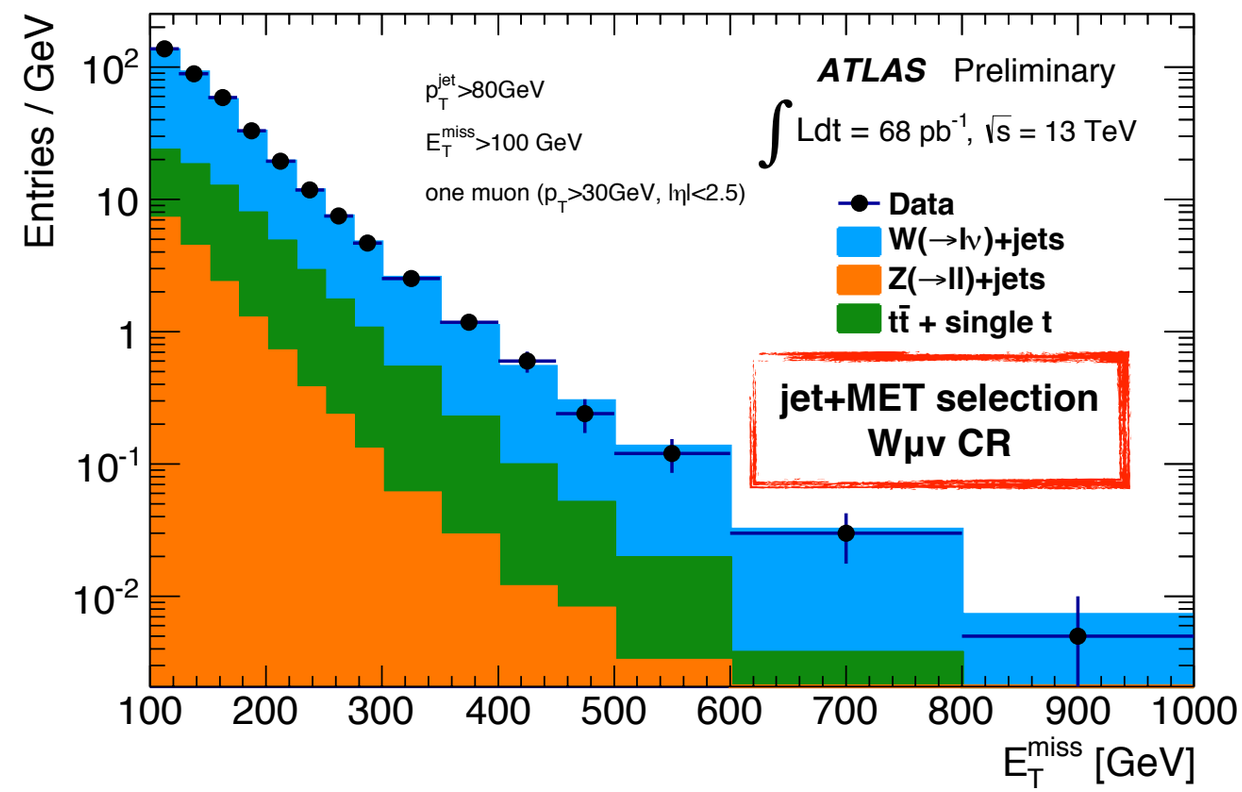


https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/EXOT-2015-005/

Summary

- The jet+MET and γ+MET final states at LHC are powerful to search dark matter candidates:
  - More sensitive compared to direct detections for spin-dependent operators or low m_χ for spin-independent ones
  - The same signature can also be interpreted in extra dimension or SUSY searches
- 8 TeV analyses show no excess compared to SM background expectations.
  - 95% CL model-independent limit on cross section
    - jet+MET: 726 fb (lowest MET SR), γ+MET 5.3 fb
- Run-II analyses
  - good potential for discovery
  - follow the LHC DMF mandate to interpret the results.

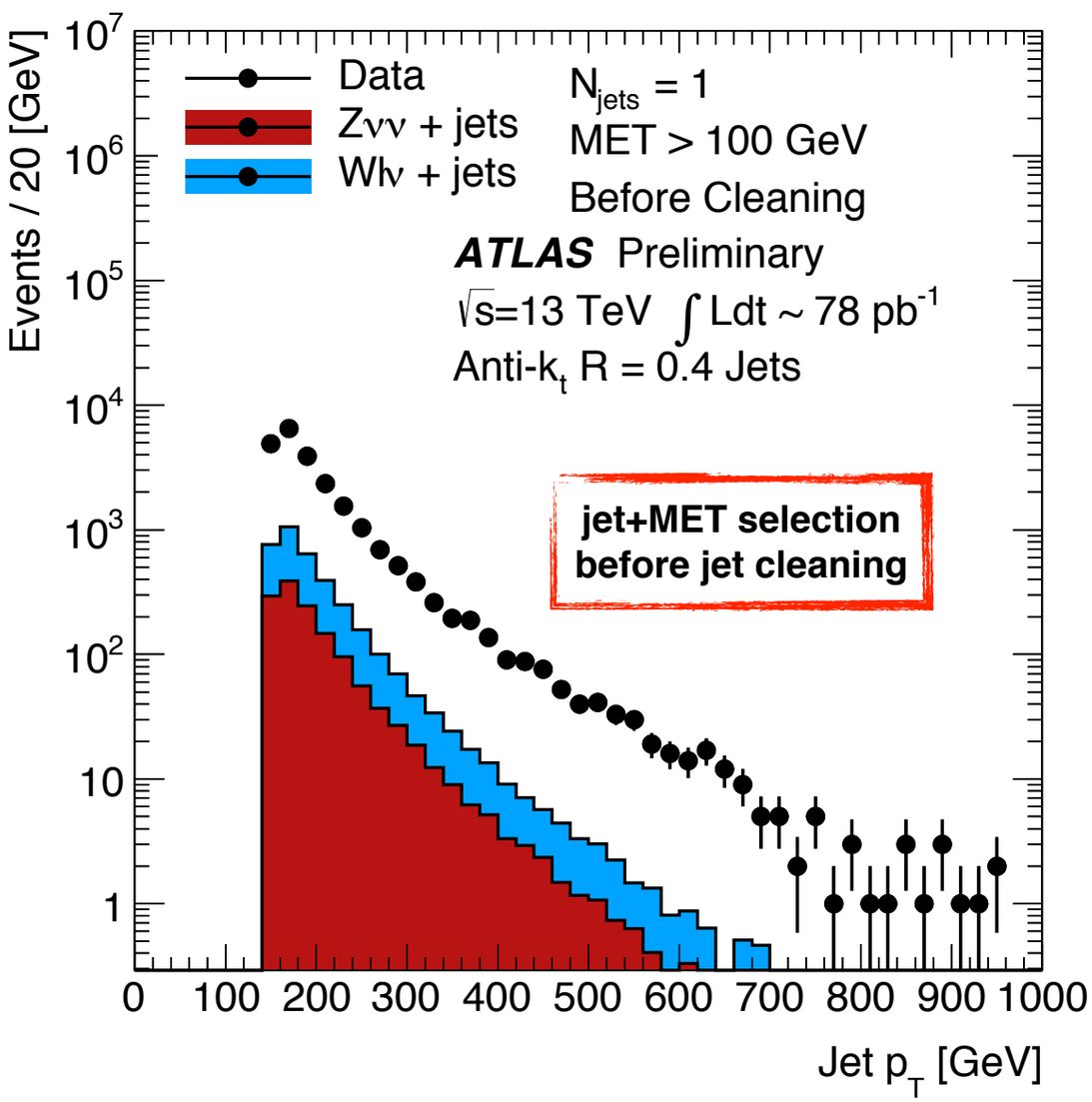
Backup

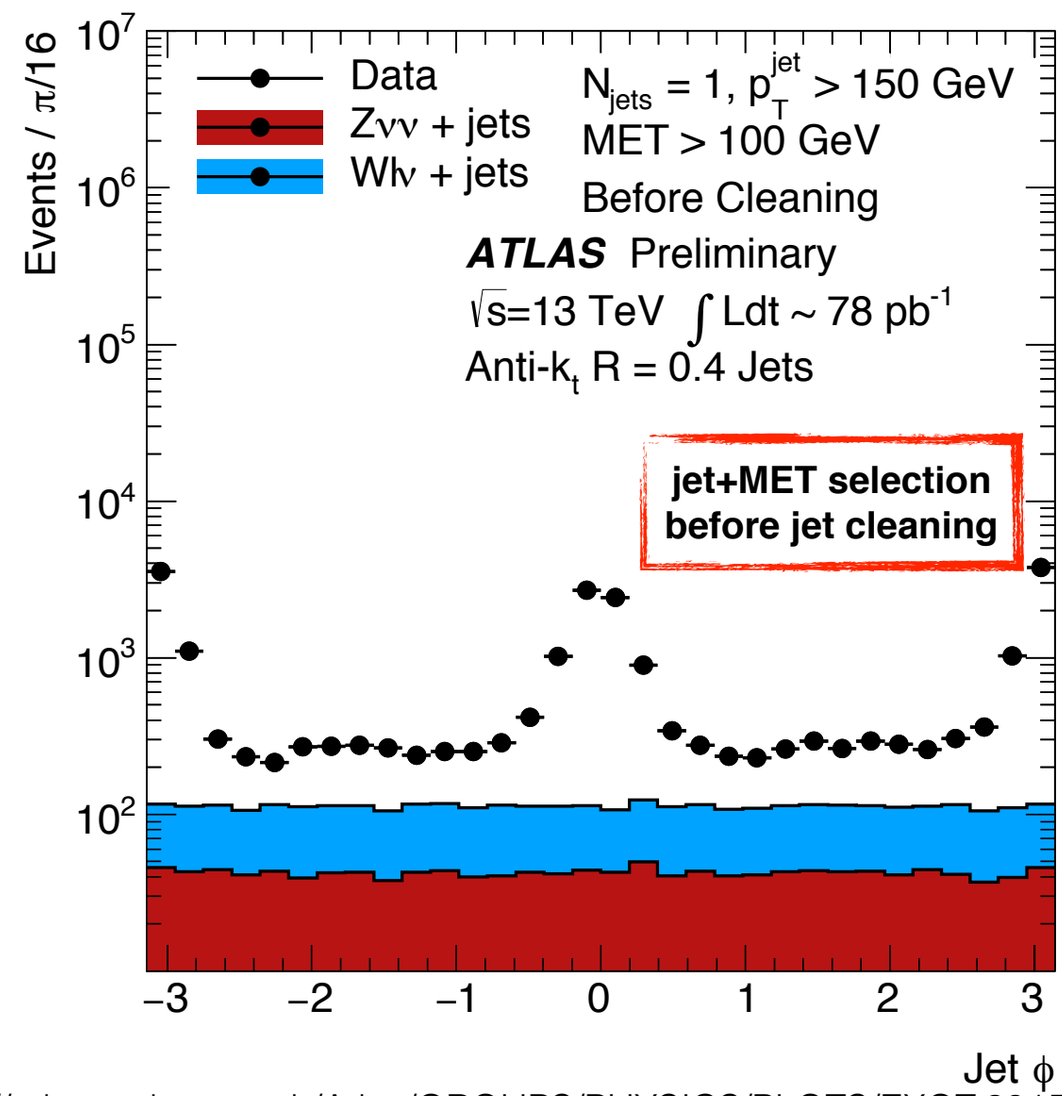
References

- Search for new phenomena in final states with an energetic jet and large missing transverse momentum in pp collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector
  - Eur. Phys. J. C (2015) 75:299
- Sensitivity to WIMP Dark Matter in the Final States Containing Jets and Missing Transverse Momentum with the ATLAS Detector at 14 TeV LHC
  - ATL-PHYS-PUB-2014-007
- Search for new phenomena in events with a photon and missing transverse momentum in pp collisions at sqrt(s)=8TeV with the ATLAS detector
  - Phys. Rev. D 91, 012008 (2015)
- Dark Matter Benchmark Models for Early LHC Run-2 Searches: Report of the ATLAS/CMS Dark Matter Forum
  - arXiv:1507.00966

13 TeV fresh data

- Performance plots with first 50 ns data.
- Effect for jet cleaning shown
  - Jet cleaning not applied.
  - Good jets from hard-collision MC (Zνν+jets, Wlν+jets)





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$m_{\tilde{G}}$ limits for jet+MET