Higgs boson measurements and searches for new phenomena with ATLAS

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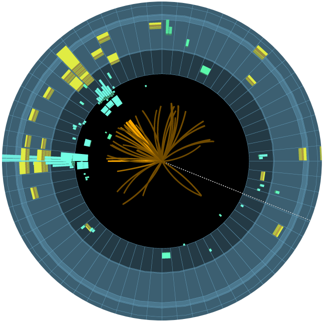
MPP Project Review
19 December 2017



Outline

- Higgs boson measurements

- Dark matter searches
- Di-boson resonance search
- Searches for Supersymmetry

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- Dataset used for these analyses: LHC Run 2, $\sqrt{s}_{pp} = 13$ TeV, integrated luminosity of 36.1 fb^{-1}

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- Higgs boson measurements
  - *ttH* production
  - Higgs boson Mass
  - Higgs boson couplings
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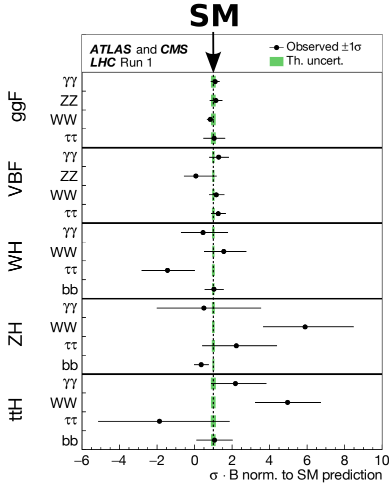
LHC Higgs Boson Physics

- LHC Run 1 Higgs boson legacy: Observation in different production and decay channels
  - Gluon fusion and vector boson fusion production
  - $\gamma\gamma$, ZZ, WW and $\tau\tau$ decays
  - Spin 0, CP even resonance
- LHC Run 2 Higgs boson program:
  - Investigate quark couplings - ttH production, $H \rightarrow bb$ decay
  - Higher precision of property measurements



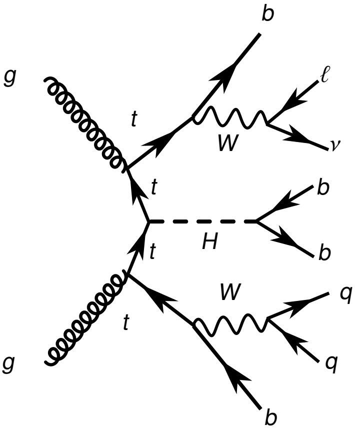
Search for *ttH* production

ATLAS-CONF-2017-076
ATLAS-CONF-2017-077

- *ttH* production: direct test of

$$\lambda_t = \frac{m_t}{<0|H|0>} \approx 1$$

- Large backgrounds ⇒ need to consider several *t* and *H* decay channels
- MPP contributions to the $H \rightarrow bb$ channel:
  - Boosted $H \rightarrow bb$ analysis
  - Top-quark modelling studies



Search for *ttH* production

ATLAS-CONF-2017-076
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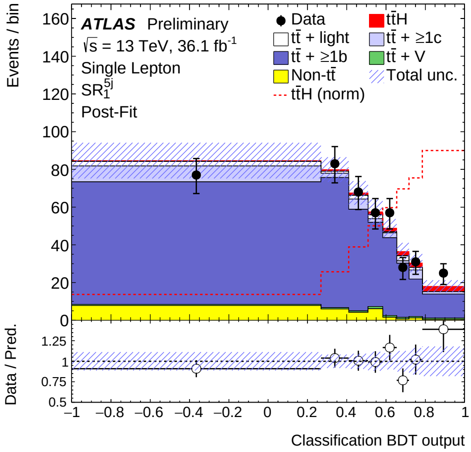
- Numerous signal and control regions
- Machine learning based classifiers for signal discrimination
- $H \to bb$ channel: 1.4 (1.6) σ observed (expected) signal significance



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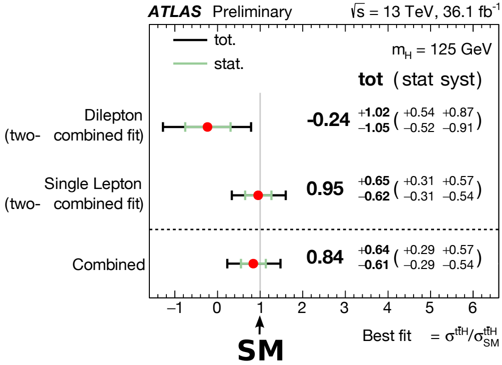

Search for *ttH* production

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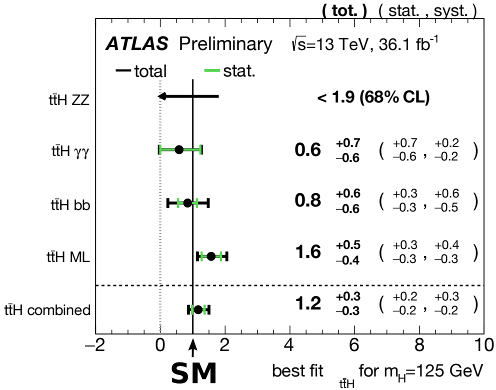
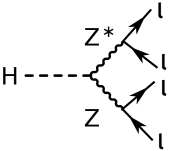
- Numerous signal and control regions
- Machine learning based classifiers for signal discrimination
- *H* → *bb* channel: 1.4 (1.6) σ observed (expected) signal significance
- Combination of *H* decay channels: 4.2 (3.8) σ signal significance

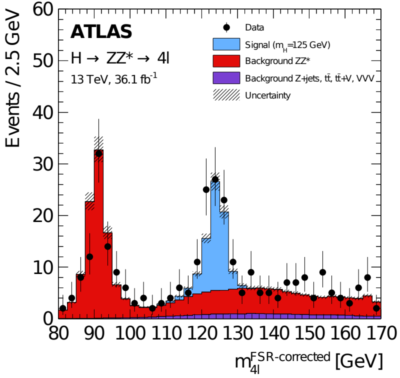


Higgs boson mass measurement

ATLAS-CONF-2017-046

- Combination of di-photon and 4 lepton (e, μ) channels
- MPP contributions:
  - Ansatz of the $m_{4\ell}$ measurement - take into account the event-wise $m_{4\ell}$ resolution
  - Muon momentum scale calibration, allowing for high precision





Higgs boson mass measurement

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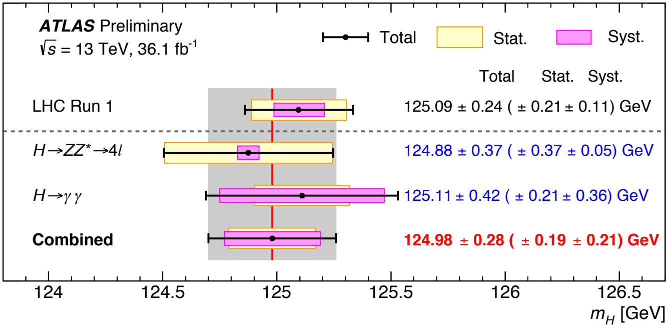


- Precision close to LHC Run 1 combination

$m_{4\ell}$ measurement:

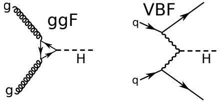
- Uncertainty dominated by statistics
- Will dominate future m_H measurements

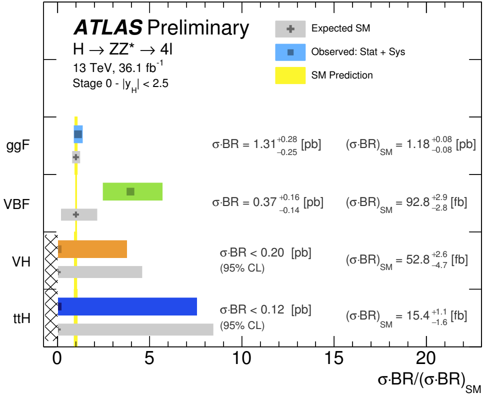
Higgs coupling measurements

Katharina Ecker
Verena Walbrecht
Maxim Sinner

arXiv:1712.02304

- Measurement of Higgs boson production cross-sections using the 4 lepton decay channel
  - Also as a function of jet multiplicity and Higgs boson p_T
- Measuring σ rather than σ/σ_{SM}: low impact of theory uncertainties
- Slight excess of 2.2 σ in the vector boson fusion category
- MPP contributions:
  - Background estimation
  - Evaluation of systematic uncertainties
  - Interpretation



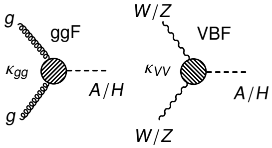


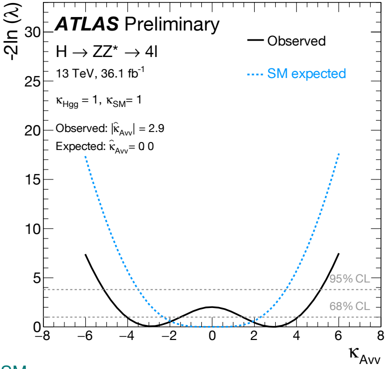
Tensor strucure of Higgs boson couplings

Katharina Ecker
Verena Walbrecht
Maxim Sinner

arXiv:1712.02304

- Search for non-SM couplings to gluons and W/Z bosons, both CP-even (H) and CP-odd (A)
  - Effective Field Theory approach
- Taking into account lepton distributions *and* production rates ⇒ large sensitivity increase
- Some deviation from the SM for the *HVV* and *AVV* couplings due to the VBF excess
- MPP contributions:
  - coordination, strategy and implementation





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  - Higgs boson couplings
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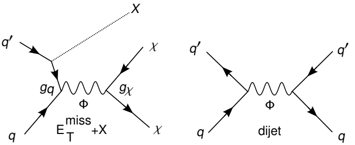
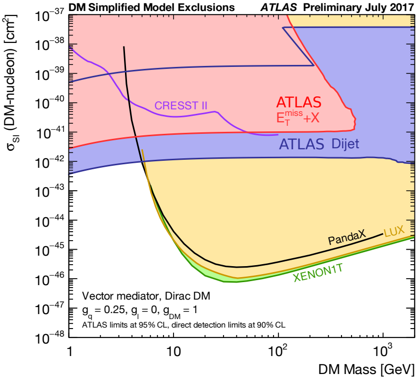
Dark matter searches at LHC

- Search for WIMP pair-production
  - Experimental signature: $X+E_{\mathrm{T}}^{\mathrm{miss}}$
  - Complementary searches for dijet resonances





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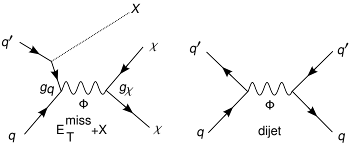
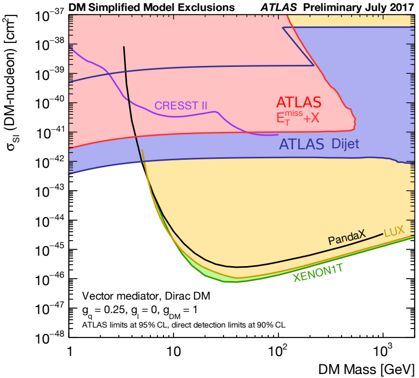
  - E.g. a single mediator Φ, different couplings
  - Assumption: at LHC energies further, heavier particles decouple





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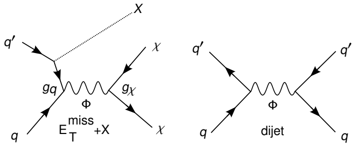

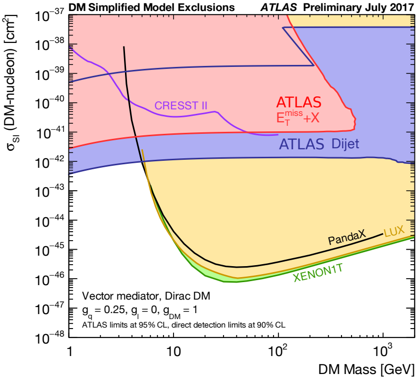

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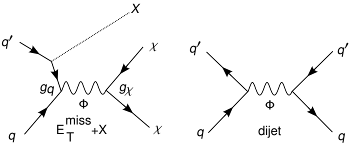

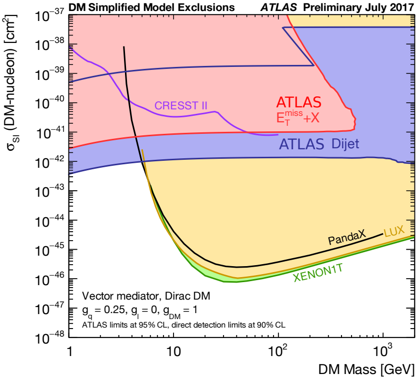

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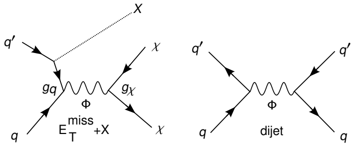
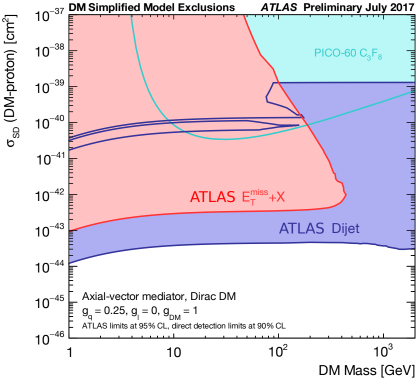
- Complementarity of searches at colliders, e.g. sensitivity to
  - Low dark matter masses
  - Axial-vector couplings

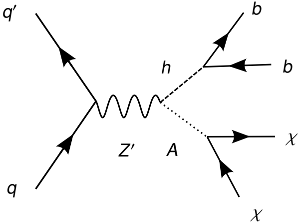




Mono-Higgs Dark Matter Search

Rainer Röhrig, Philipp Gadow

Phys. Rev. Lett. 119 (2017) 181804



- Associated production of dark matter and a Higgs boson $\Rightarrow$ no “ISR model”, probing dark matter interactions more directly
- Aiming for $H \to bb$ decays (largest branching ratio)

Rainer Röhrig, Philipp Gadow

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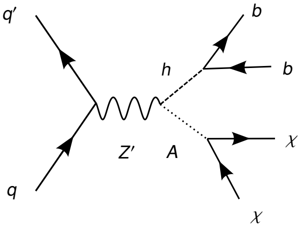

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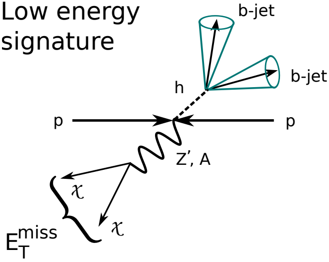
- Aiming for $H \to bb$ decays (largest branching ratio)

- 2 topologies, depending on the Higgs boson momentum
  - Pair of separated jets

Low energy signature



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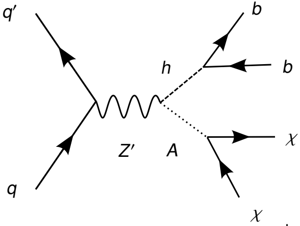
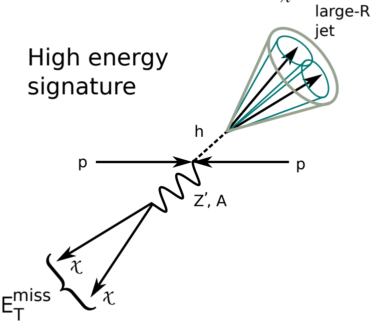
  - Pair of separated jets
  - Single large-Radius jet



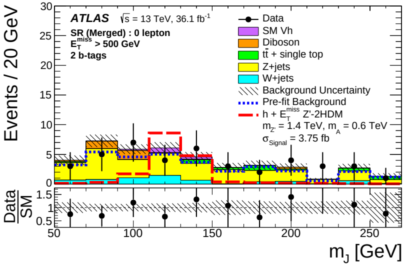


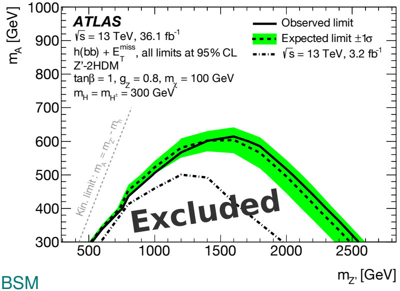
Mono-Higgs Dark Matter Search

Rainer Röhrig, Philipp Gadow

Phys. Rev. Lett. 119 (2017) 181804

- Discriminating variables:
  di-jet or large-R jet mass, E_T^{miss}
- Mass limits for new mediators, most stringent to date
- Also search for dark matter in W/Z+MET channel, paper in preparation
- MPP contributions:
  - Analysis coordination
  - Background estimation
  - Interpretation





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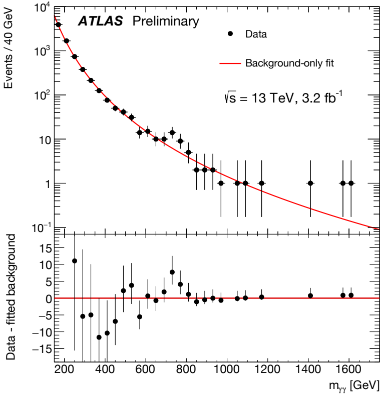
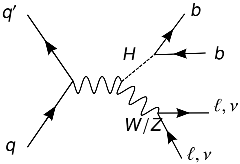
Di-boson resonance searches

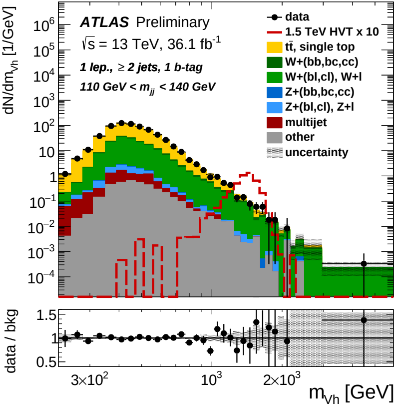
- Previous excitement: local excess in di-photon mass spectrum, 2015 data
- Despite this excess having vanished: SM extensions predicting new, heavy mediators coupling to pairs of bosons (e.g. 2 Higgs-doublet or composite Higgs models)
- Interpretation in terms of simplified models



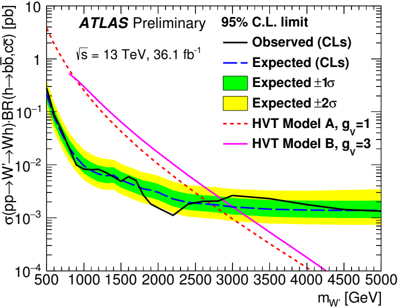


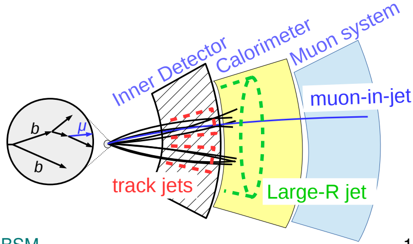
VH resonance search

- Search for new, heavy mediators coupling to *WH* or *ZH*
- Aim for leptonic W/Z decays (lower background) and $H \to bb$ decays (larger statistics)
  - Again, resolved and merged double *b*-jet topologies, depending on the Higgs boson momentum
- Search for a localised excess in *VH* mass spectra, only small model dependence



- Setting cross-section limits down to $\mathcal{O}(1\text{ fb})$, exclude model parameters like mediator masses
- MPP contributions:
  - Background estimation
  - $H \to bb$ tagging as a future improvement, under development: Higgs boson reconstruction based on large-R jet mass, substructure and *b*-tagging





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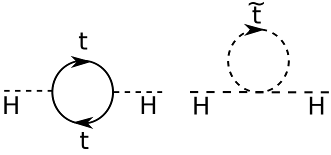
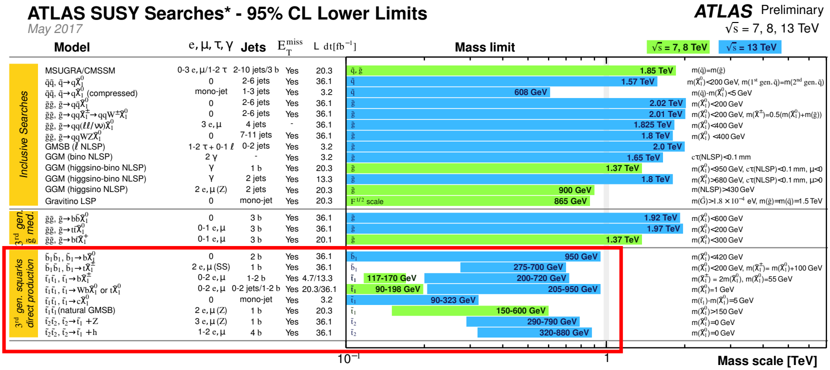
  - top-quark partners and Jets + MET final states
  - 4 lepton final states
  - Long lived particle search

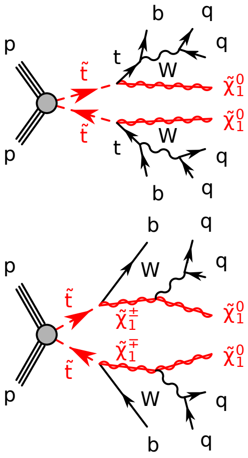
Searches for Supersymmetry

- Theoretical preference for sparticle mass scale $\lesssim$ 1 TeV
- Many LHC Run 1 SUSY limits beyond 1 TeV, except for top partners





- Considering top-squark pair production in different scenarios
- Aiming for hadronic top-quark decays
  - $E_{\mathrm{T}}^{\mathrm{miss}}$ caused only by neutralino
  - Complete top-quark reconstruction, including boosted topologies
- Complexity of final states $\Rightarrow$ comprehensive background estimations using control regions (single lepton, di-lepton, $tt\gamma$)

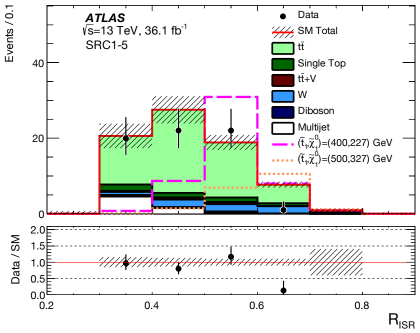


Top-Squark Search

Nicolas Köhler, Jonas Graw

arXiv:1709.04183

- Set limits on top-squark and neutralino masses
- Significant sensitivity increase due to luminosity increase and analysis improvements
- MPP contributions:
  signal and control region design,
  event selection implementation



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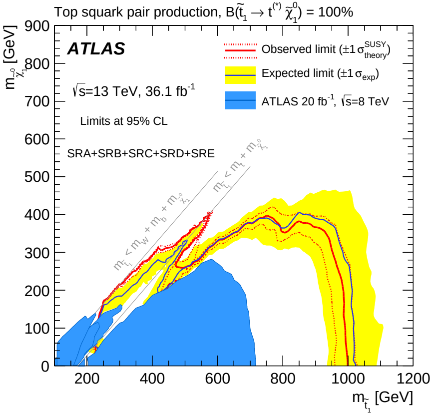
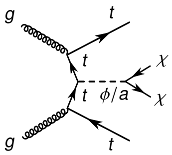
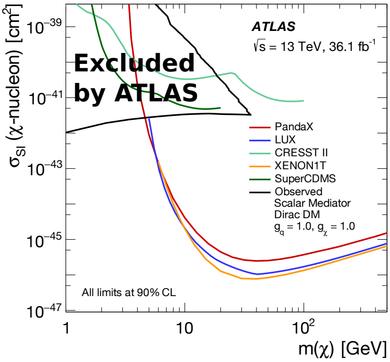




- Additional interpretation for the same final state: dark matter production with a new scalar mediator
  - Compared to SUSY: slightly softer p_T spectra
- Setting limits on the dark matter - nucleon cross-section and the dark matter mass within the scalar mediator model

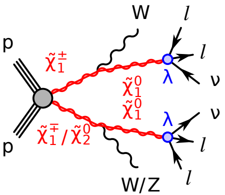


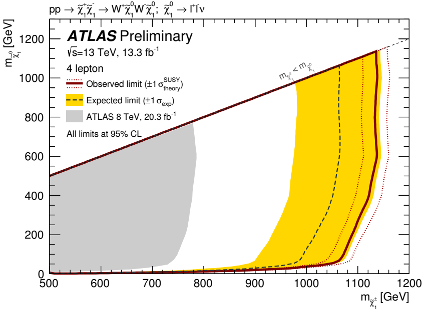
SUSY 4 lepton search

Johannes Junggeburth
Marian Rendel, Stefan Maschek

ATLAS-CONF-2016-075

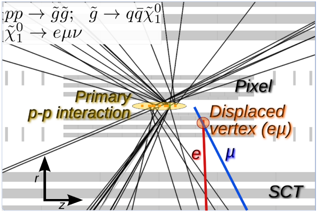
- No SUSY signals yet $\Rightarrow$ extend searches to more complicated scenarios
- R-parity violation (RPV): $\tilde{\chi}_1^0 \rightarrow \ell^+\ell^-\nu$
- Using 4 lepton final states, almost independent of the $\tilde{\chi}_1^0$ production mechanism
- MPP contributions:
  - Analysis coordination: driven by MPP since Run 1
  - Model development
  - Background estimates
  - Preparing update with 36 fb^{-1} testing more models, including τ leptons

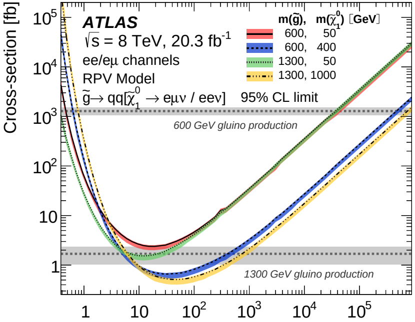




Dominik Krauss

- Alternative RPV scenario:
  small coupling $\lambda \Rightarrow$ long-lived $\tilde{\chi}_1^0$
- Signature: displaced vertices with two associated charged leptons in the inner detector
- Sensitivity to particles with lifetimes of order ps to ns
- MPP contributions:
  - Analysis leadership since Run 1





Phys. Rev. D 92, 072004 (2015)

Summary

- Leading and visible contributions of the MPP group to high priority studies of limitations of the Standard Model, in spite of the competitive research environment
  - Higgs precision measurements, Higgs physics as a portal to new phenomena
  - Searches for dark matter particle production and heavy di-boson resonances
  - Searches for SUSY particles in uncharted regions of the parameter space
- Analyses of Run 2 data in full speed - dataset increase to 120 fb^{-1} until the end of 2018
- Future prospects: Run 3 going to $\sqrt{s}_{pp} = 14$ TeV, followed by High-Luminosity LHC - dataset increase of about a factor of 100 compared to now
- Plan to stay at the collider energy frontier