Higgs Physics and SUSY Searches with ATLAS

Max Goblirsch, on behalf of the MPP ATLAS group

MPP Project Review 2014, 15.12.2014

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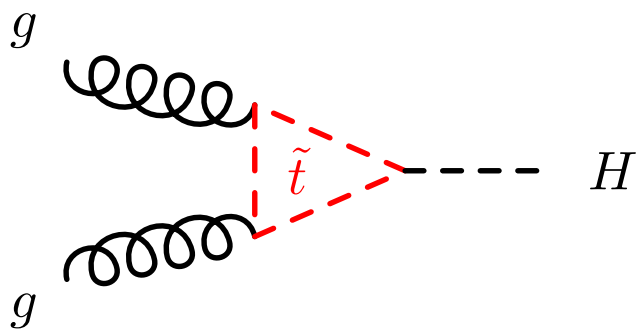
One main objective of the LHC: Search for physics **beyond the standard model**.

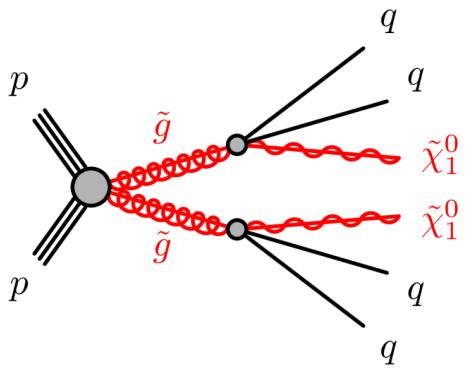
Two approaches:

Indirect - precision measurements



- Probe the standard model (SM) at high precision.
- Look for signs of deviations from the SM.
- The classic LHC probe: **top quarks** - See talk this morning!
- A brand-new probe: **The Higgs boson**!

Direct - production of new particles



- New particles can also be **directly produced**.
- Profit from growing collision energies.
- Look for excesses over SM in predicted decay topologies.
- Prominent example: **Supersymmetry searches**.

The MPP ATLAS group plays an important role in both fields.

Measurement of the Higgs boson **mass** and **decay width** in the $H \to ZZ \to 4\ell$ channel

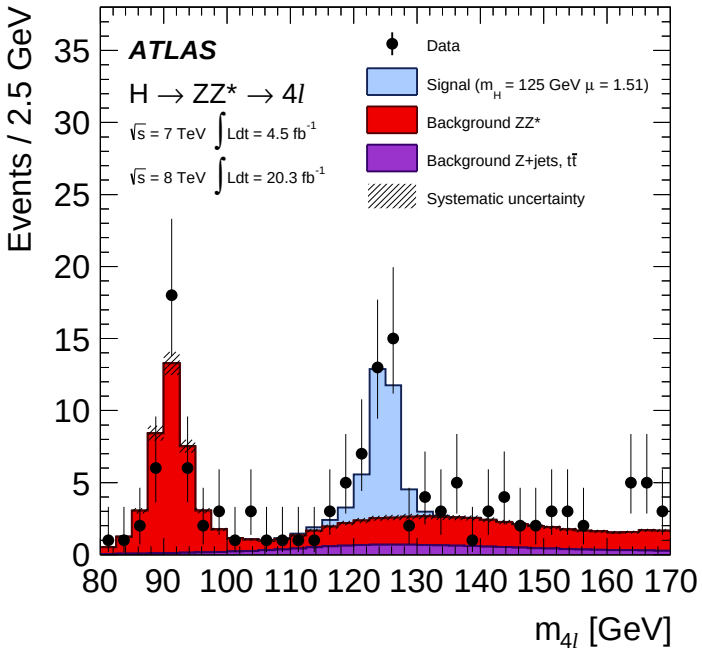
H.Kroha, S.Kortner, O.Kortner, R.Röhrig, K.Ecker, F.Sforza, S.Stern Phys. Rev. D. 90, 052004

Knowledge of the **Higgs boson mass** is essential for predicting all other Higgs boson properties

- **New: Highly reduced systematic uncertainty** due to improved energy calibration procedures. Now much lower than CMS analysis.

→ Muon momentum calibration with $Z \to \mu\mu$ and $J/\Psi \to \mu\mu$ data.

→ Development of an **analytic description** of the mass resolution.



Channel	Measured Mass [GeV]
$H \to ZZ \to 4\ell$	$124.51 \pm 0.52(\text{stat}) \pm 0.06(\text{sys})$
$H \to \gamma\gamma$	$125.98 \pm 0.42(\text{stat}) \pm 0.28(\text{sys})$
Combined	$125.36 \pm 0.37(\text{stat}) \pm 0.18(\text{sys})$

Compatibility of results from the two channels: 2.0 σ

First limits on Higgs boson natural width:

$\Gamma_H < 2.6$ GeV (95% CL)

Made possible by analytical description developed at MPP!

Probing the **tensor structure** of the $H \to ZZ$ coupling

H.Kroha, S.Kortner, O.Kortner, K.Ecker

ATL-PHYS-PUB-2013-013

The $H \to ZZ \to 4\ell$ channel allows for a **full reconstruction of the final state kinematics** - ideal for spin/CP measurements!

- SM Higgs: Spin 0, CP even
- ATLAS & CMS results point towards **Spin 0^+ with high probability**
- Beyond the standard model contributions could affect HZZ coupling (loops)

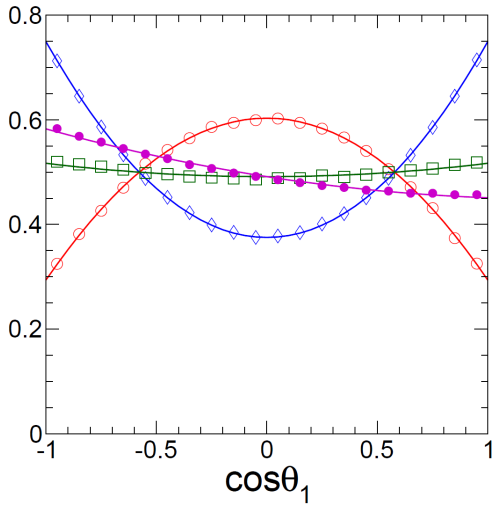
$$A(X_{J=0} \to ZZ) = v^{-1}[\underbrace{g_1 m_V^2 \epsilon_1^* \epsilon_2^*}_{\text{Tree-level SM}} + \underbrace{g_2 f_{\mu\nu}^{*(1)} f^{*(2)\mu\nu} + \ldots}_{\text{CP-even}} + \underbrace{g_4 f_{\mu\nu}^{*(1)} \tilde{f}^{*(2)\mu\nu}}_{\text{CP-odd}}]$$

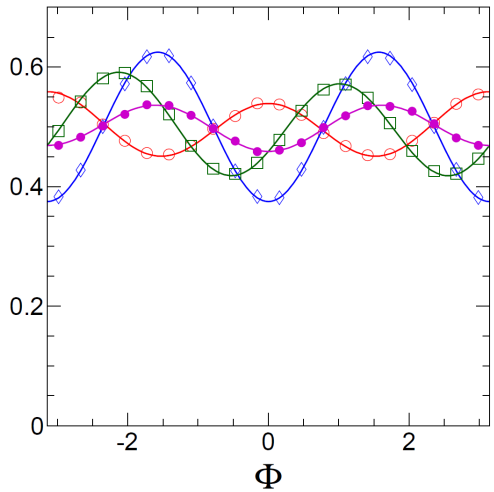
→ **Probe for admixtures in decay amplitudes by measuring final state angular distribution (sensitive to CP)**

- Sensitivity study for integrated luminosities 300 fb^{-1} and (3000 fb^{-1}):

  $|g_2|/g_1 < 1.39\ (0.81)$ at 95% CL

  $|g_4|/g_1 < 1.03\ (0.49)$ at 95% CL





Measurement of the Higgs coupling to **Vector bosons**

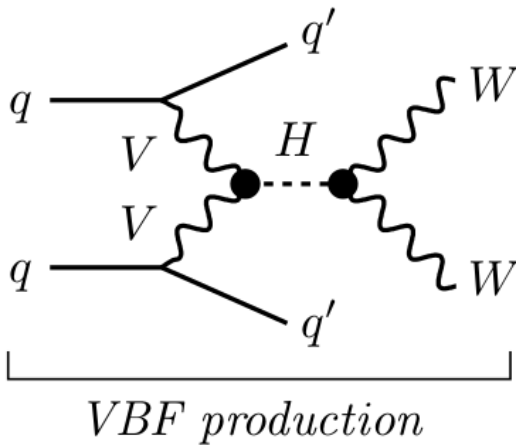
S.Kortner, H.Kroha, J.Bronner — ATLAS-CONF-2014-060, CERN-THESIS-2014-031

The $H \to WW$ channel allows a study of the Higgs coupling to vector bosons.

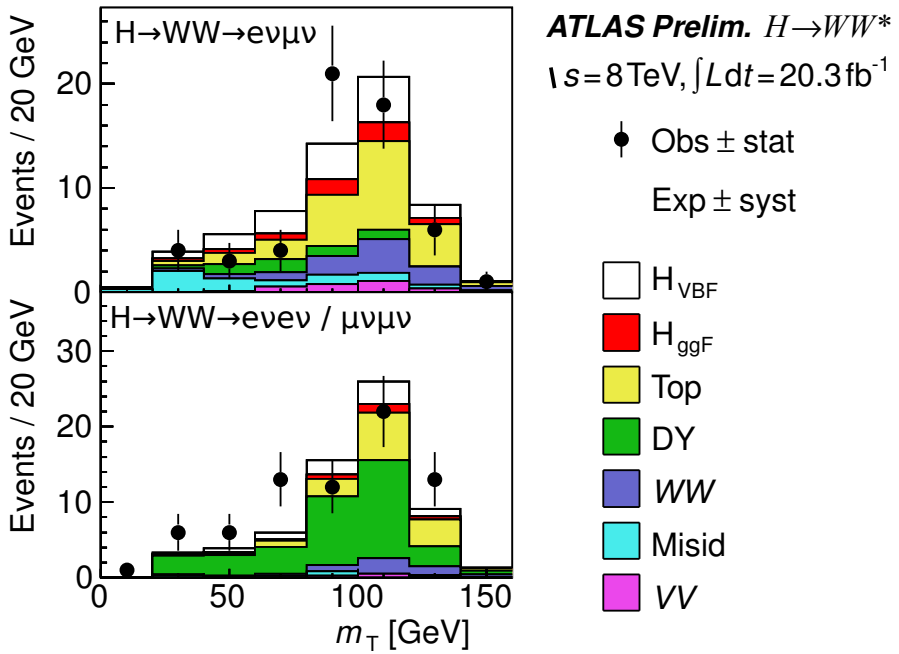
New:

- **Observation** of Higgs boson decays to WW (6.1 σ)
- **Evidence** for the Vector Boson Fusion (VBF) production mechanism(3.2 σ)

$\to$ Measurement of Higgs production via vector boson fusion with WW decay as a direct probe of the Higgs boson **coupling to vector bosons**



Transverse mass distribution in the VBF channels



Measured VBF Signal strength:

$\mu = 1.28 \pm 0.4(\text{stat}) \pm 0.25(\text{sys})$

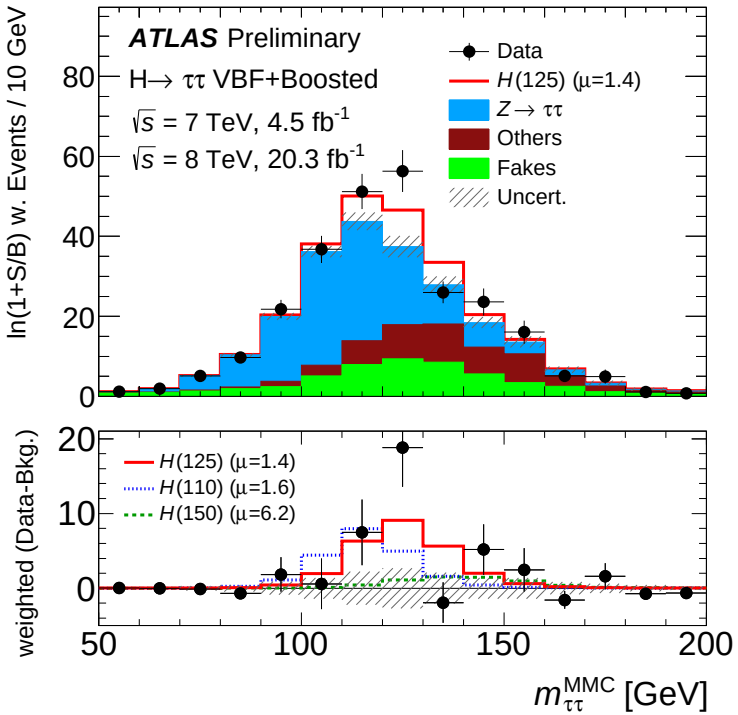
Measurement of the Higgs **coupling to fermions**

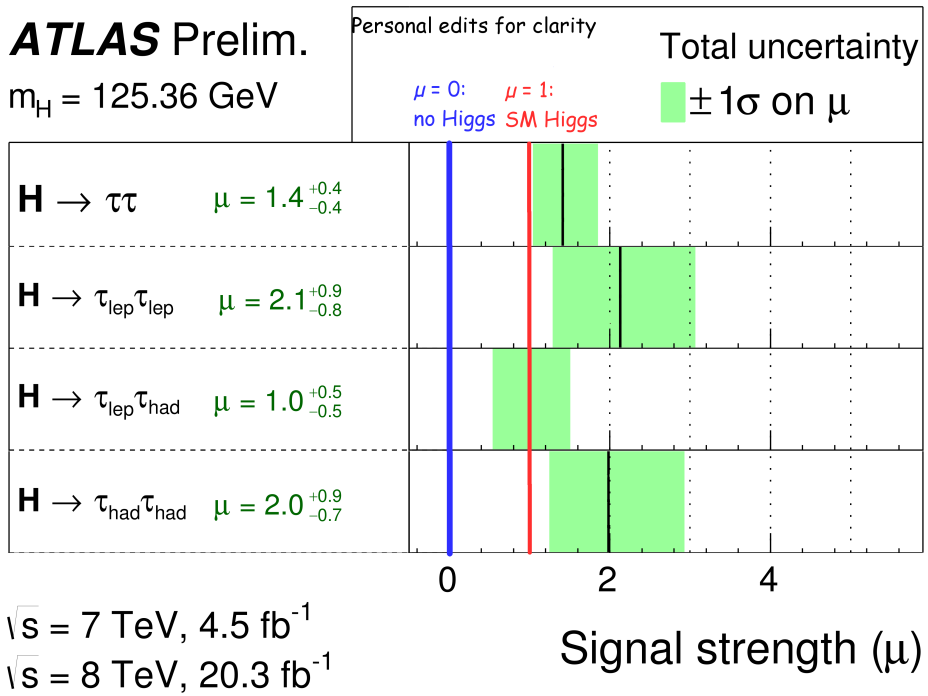
S.Kortner, H.Kroha, D.Zanzi

ATLAS-CONF-2014-061, CERN-THESIS-2014-085

The Higgs boson's direct coupling to fermions can be measured in the $H \to \tau\tau$ and $H \to b\bar{b}$ decays

- **first evidence** for the $H \to \tau\tau$ coupling (4.6σ)
- New: Multivariate analysis approaches, reduction of systematic uncertainties.
- Major contribution from **fully hadronic** final state.





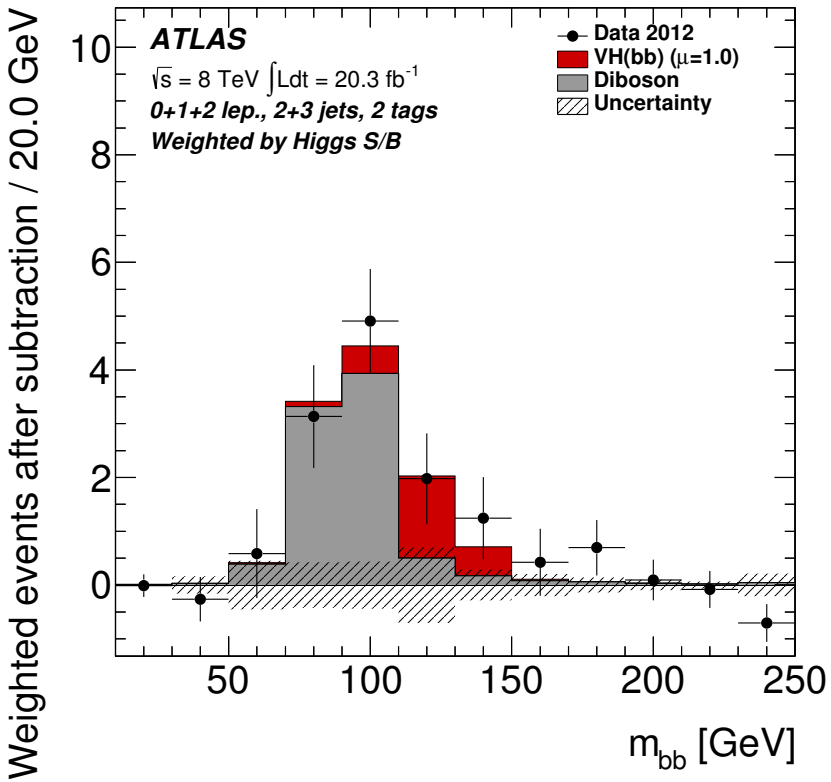
Measurement of the Higgs **coupling to fermions**

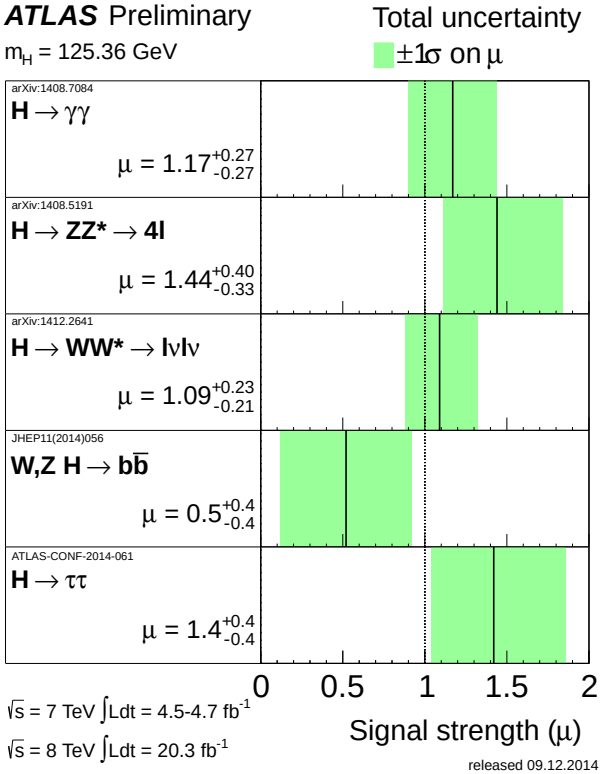
H.Kroha, S.Kortner, F.Müller, F.Sforza

arXiv:1409.6212

The Higgs boson's direct coupling to fermions can be measured in the $H \to \tau\tau$ and $H \to b\bar{b}$ decays

- Improved search for $VH \to Vb\bar{b}$, but no evidence yet (1.5σ).
  Ongoing optimisation for run 2 based on the **substructure** of boosted b-jets
- **Run 2:** Measure coupling to the top quark in the $t\bar{t}H$ production channel



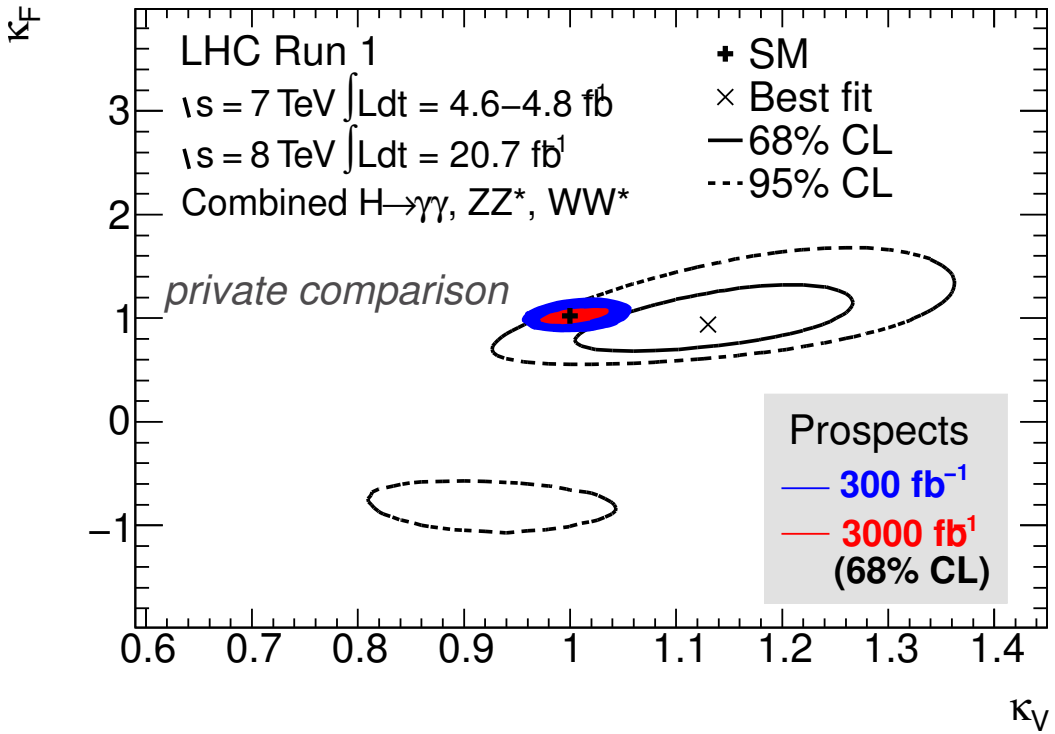


ATL-PHYS-PUB-2014-016, ATLAS-CONF-2014-009

Combine the results into a study of the Higgs boson couplings

- **Common fit of couplings** to fermions and vector bosons from individual measurements
- Currently still limited accuracy - expect **major improvements in run 2**
- MPP to contribute to individual measurements and global fit

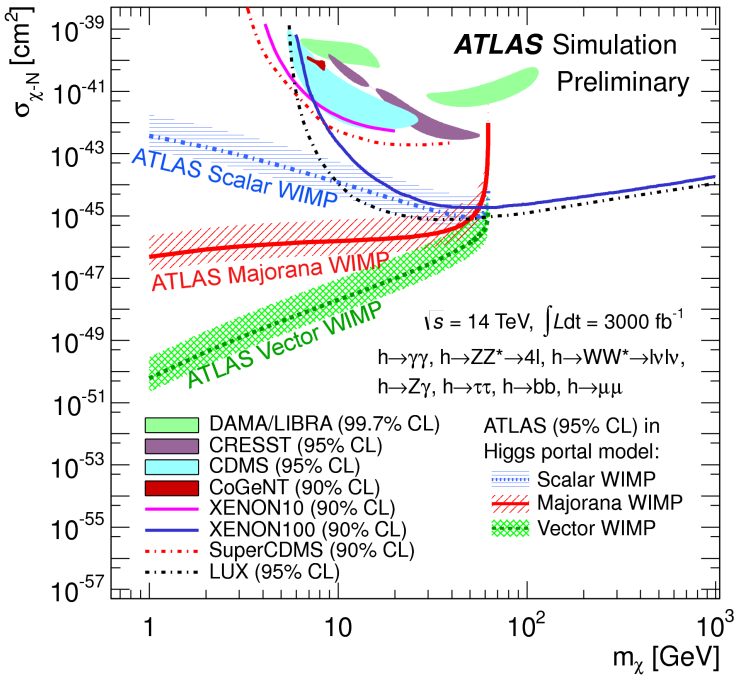
→ Important future ingredients: *ttH* and $VH \to Vb\bar{b}$ - no significant observation yet

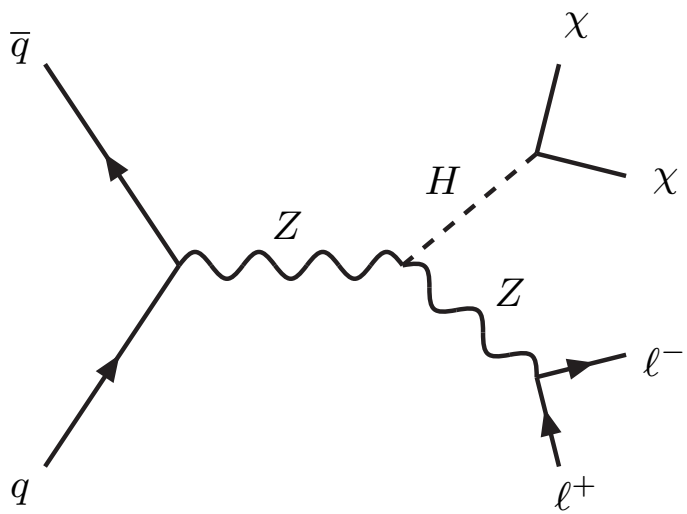


ATL-PHYS-PUB-2014-017

Major goal for run 2: use Higgs couplings results to constrain **dark matter** (DM)

- **Higgs portal scenario**: Competitive with direct searches at low DM masses





Further sensitivity to DM at the LHC:

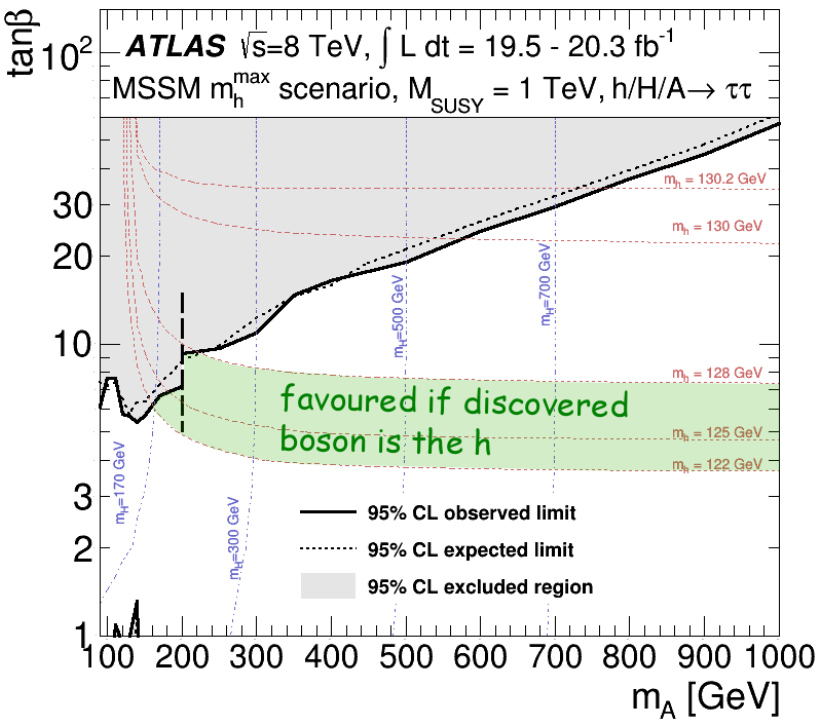
1. Direct search for **invisible Higgs decays**
2. Direct search for **recoils off invisible particles** (Monojets)
3. Direct **SUSY searches** (R-Parity conservation) assume presence of DM

Search for neutral MSSM Higgs bosons

S.Kortner, H.Kroha, A.Manfredini — ATLAS-CONF-2014-049, CERN-THESIS-2014-080

Higgs searches can also **directly target new physics** models

- Recently published ATLAS searches for **MSSM higgs bosons** based on 2012 data
- Exclusion limits on MSSM paramters (tan β, m_A) for various models
- Strong implications on viability of SUSY models



- Large range of tan β values excluded
- Heavier H/A bosons with $m_{A/H} > 200$ GeV preferred (m_h^{max}) if discovered boson is the h
- ATLAS-MPP: **fully leptonic** final state ($H \to \tau\tau \to \ell\nu\nu\ell\nu\nu$)

→ Important for excluding A/H masses below 200 GeV

Direct searches for Supersymmetry - Top Squarks

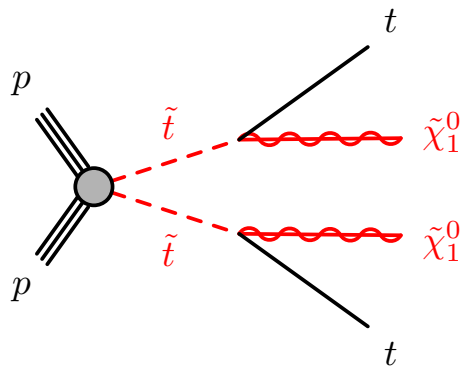
H.Kroha, O.Kortner, M.Flowerdew, N.Köhler

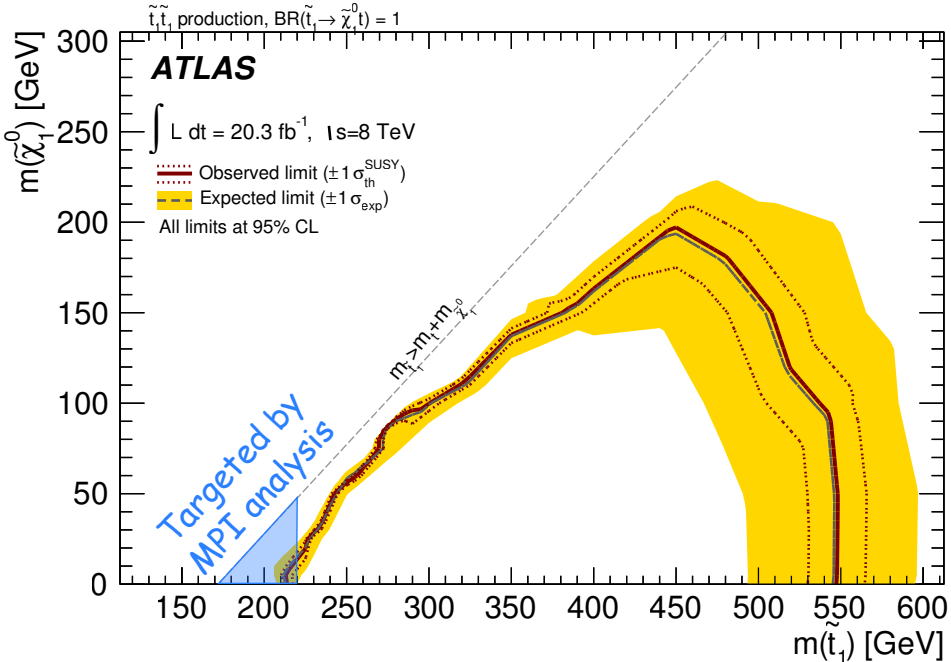
JHEP 06 (2014) 124

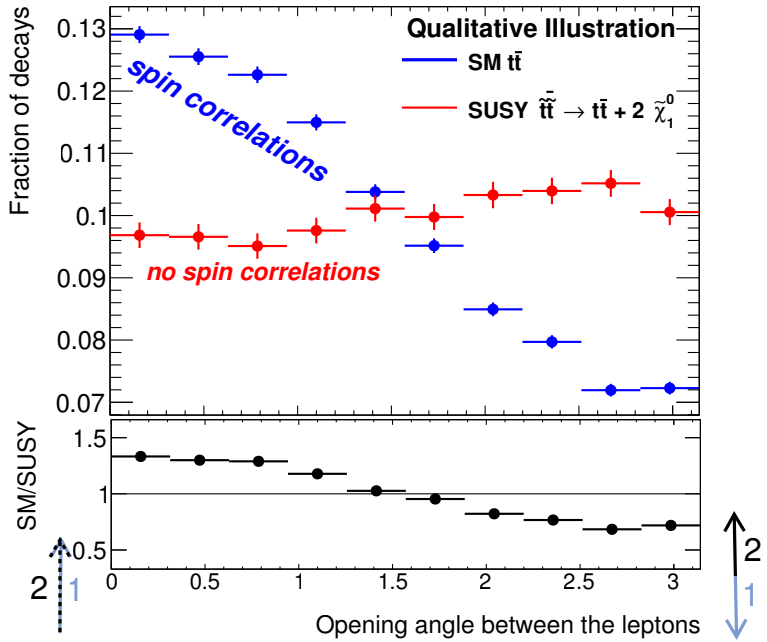
A light **top squark** is a key ingredient to **natural supersymmetry**

- **Challenging phase-space region** for existing searches: $m(\tilde{t}) \approx m(t)$
- New analysis approach exploiting **spin correlations** in the dileptonic $t\bar{t}$ decay greatly enhances sensitivity

→ Strong **MPP effort** - to be extended to general stop searches in run 2







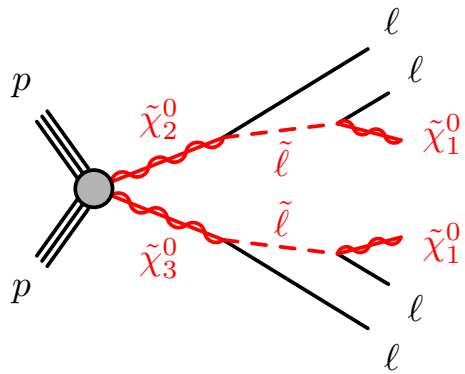
Direct searches for Supersymmetry - Electroweak production

H.Kroha, M.Flowerdew, M.Goblirsch, J.Junggeburth, F.Sforza

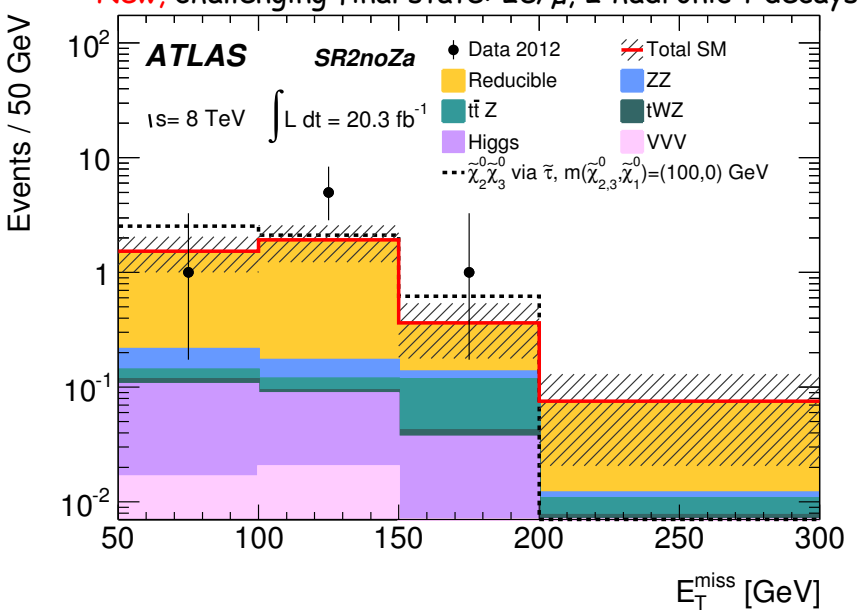
Phys. Rev. D. 90, 052001 (2014)

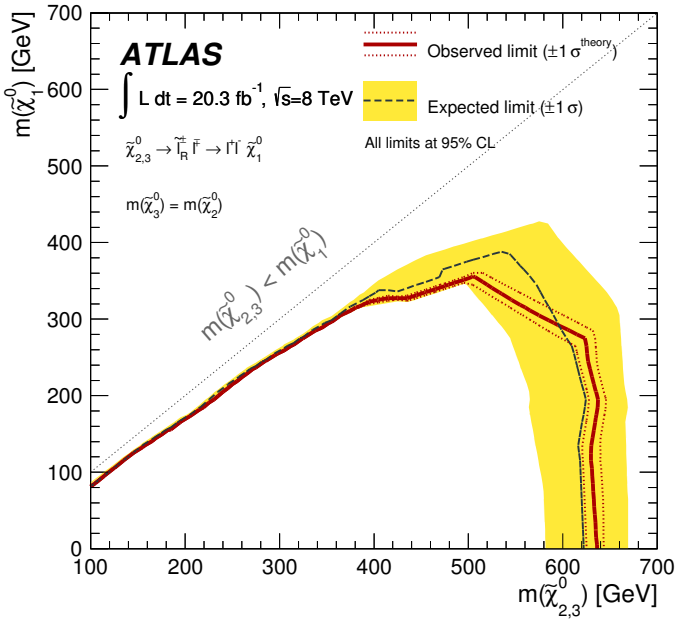
Can also target **electroweak production** of SUSY particles

- Can lead to **multi-lepton** final states - rare in the SM
- **Four-lepton search** led by MPP
- Final run 1 analysis: Significant analysis improvements, additional interpretations



New, challenging final state: 2e/μ, 2 hadronic τ decays





Direct searches for Supersymmetry - R-Parity violation

H.Kroha, M.Flowerdew, M.Goblirsch, J.Junggeburth, F.Sforza Phys. Rev. D. 90, 052001 (2014)

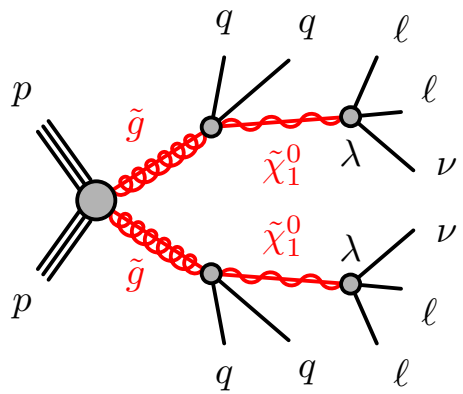
Main MPP SUSY focus: Searches for **R-Parity violating Supersymmetry** (RPV)

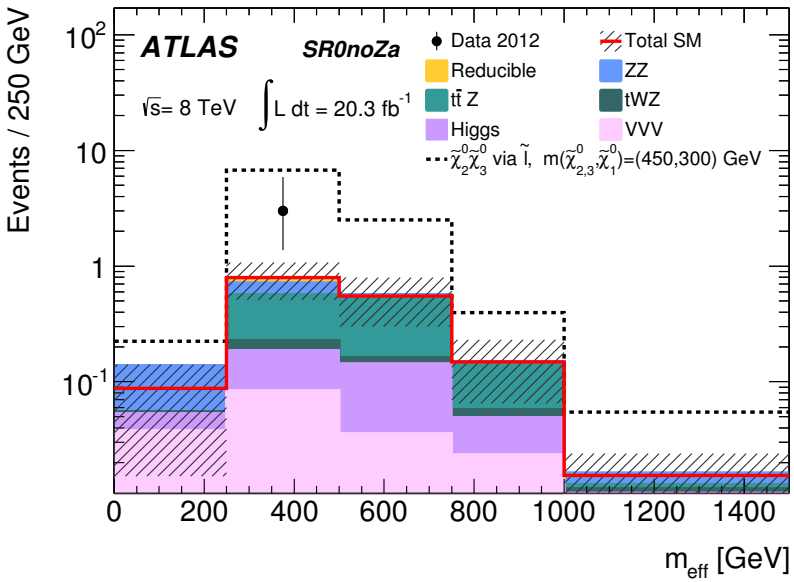
- Lightest supersymmetric particle **decays to SM particles**

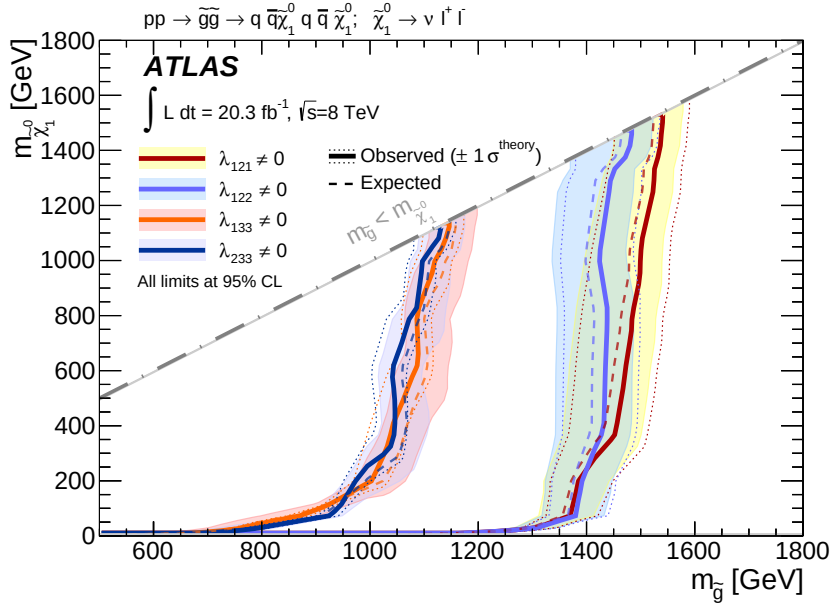
→ Requires dedicated search regions

- MPP leading ATLAS effort in search for **lepton-number violating** (LFV) RPV couplings
- Main tool for prompt LFV RPV decays: **4-lepton** search

→ highly versatile analysis







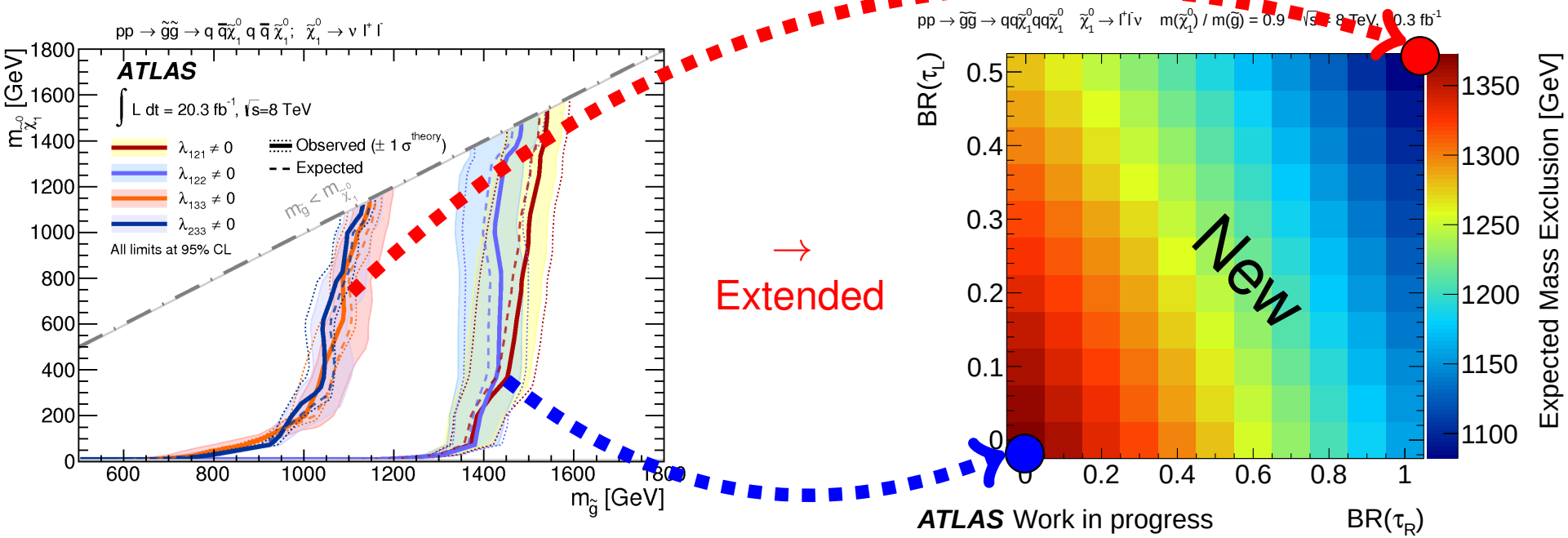
Direct searches for Supersymmetry - Reinterpretations

H.Kroha, M.Flowerdew, D.Krauss, J.Mellenthin

Can extend reach of existing analyses with **Reinterpretations**

- Interpret results of **existing analyses** in **new signal models**
- Example: **Generic RPV decay branching ratios** in 4-lepton search
- MPP also involved in **RPV interpretations of conventional SUSY searches**
- In addition: **pMSSM** interpretations of the 4-lepton analysis

→ Fully exploit existing work



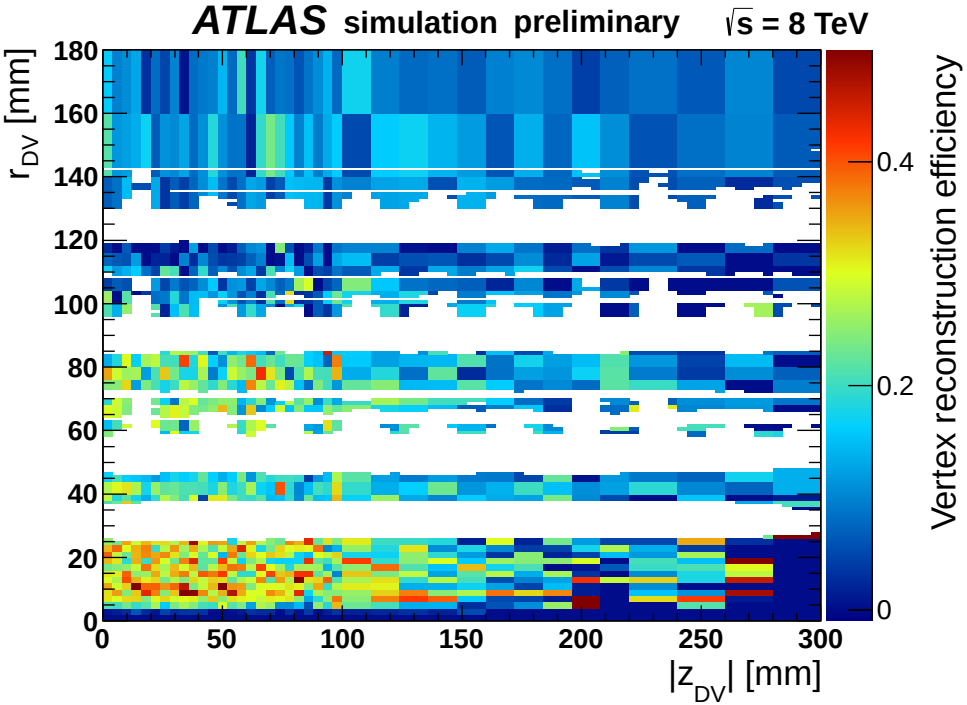
Direct searches for Supersymmetry - R-Parity violation, long-lived

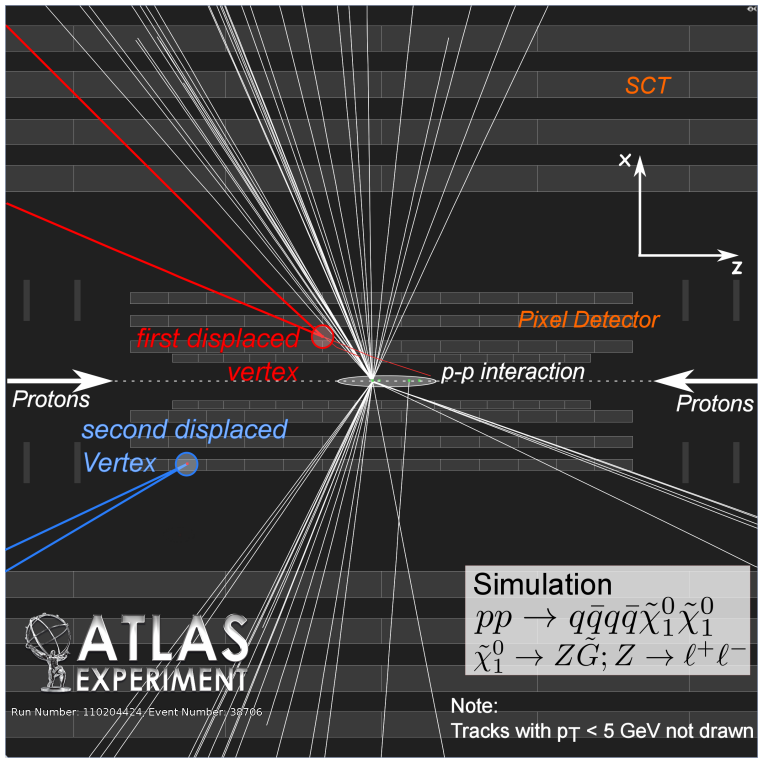
H.Kroha, M.Flowerdew, M.Goblirsch

ATLAS-CONF-2013-092

R-Parity violating decays can have a **significant lifetime**

- Long-lived decays can lead to **displaced vertex** signatures.
- MPP performing a **Displaced Dilepton** search (also targeting non-RPV models).
- **Technically challenging**: Need to rerun large parts of the ATLAS reconstruction.
- Build on work done by existing multi-track displaced vertex search.
- Results nearly final - expect publication early 2015.





Prospects for direct SUSY searches in run 2

ATL-PHYS-PUB-2014-010

Direct searches for heavy particles expected to **strongly profit of increased $\sqrt{s}$**

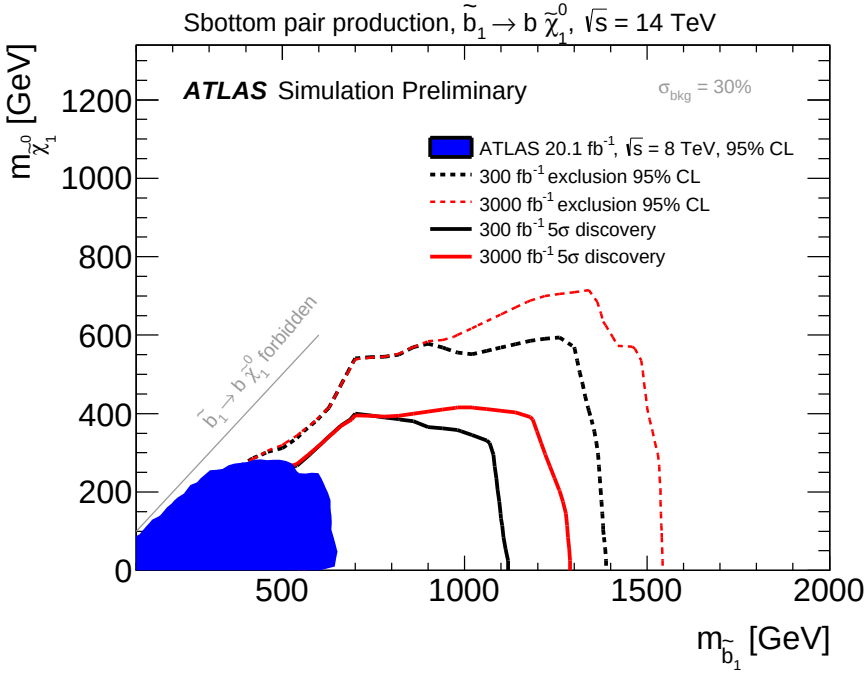
- Strong production: Can surpass existing sensitivity even with small datasets

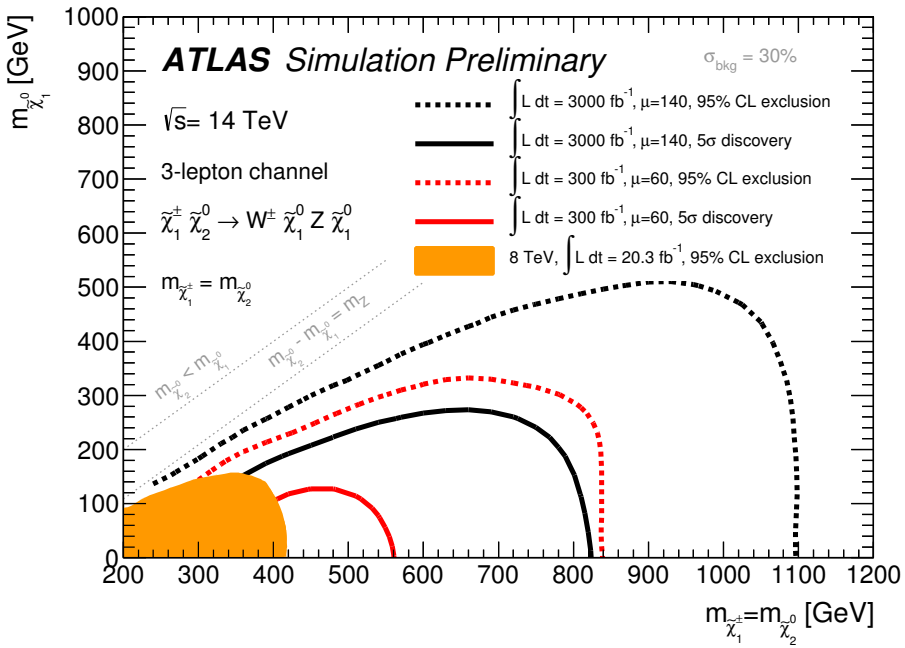
→ Expect results very early in run 2 (late 2015)

- Electroweak production: Statistically limited in early data

→ Slower pace than strong production, but also expected to surpass run 1 quickly

- Expect sensitivity to TeV-scale top squarks ('natural SUSY') with the full run-2 data.





Summary - Good times for new physics searches

ATLAS: Twofold approach to new physics searches

- **Precision studies** of Higgs boson and top quark physics
- **Direct searches** for new particles
- Strong **MPP presence** in both fields, leading several analysis efforts

Analysis of **run 1 data** drawing to a close

- Very mature analyses, advanced techniques
- Wide range of final states and interpretations
- No significant signs of new physics yet, but . . .

LHC run 2 is about to start!

- Dramatically **increased cross-sections** for direct searches
- **Enhanced statistics** for precision measurements
- 2015: $\sim$ 10fb^{-1} of 13 TeV data expected - first results by PR '15?