Physics with Four Leptons in the ATLAS experiment

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On behalf of ATLAS Collaboration

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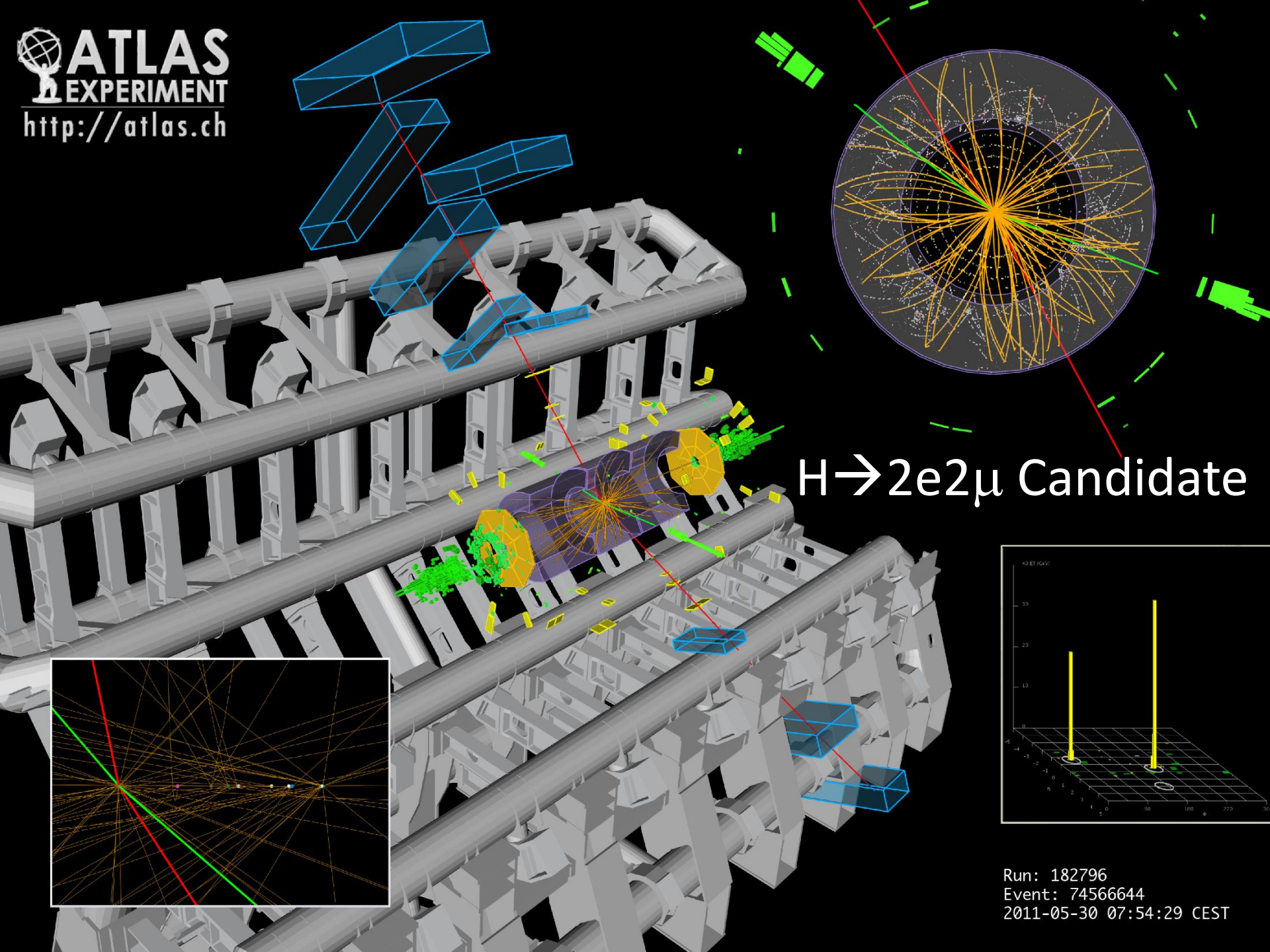
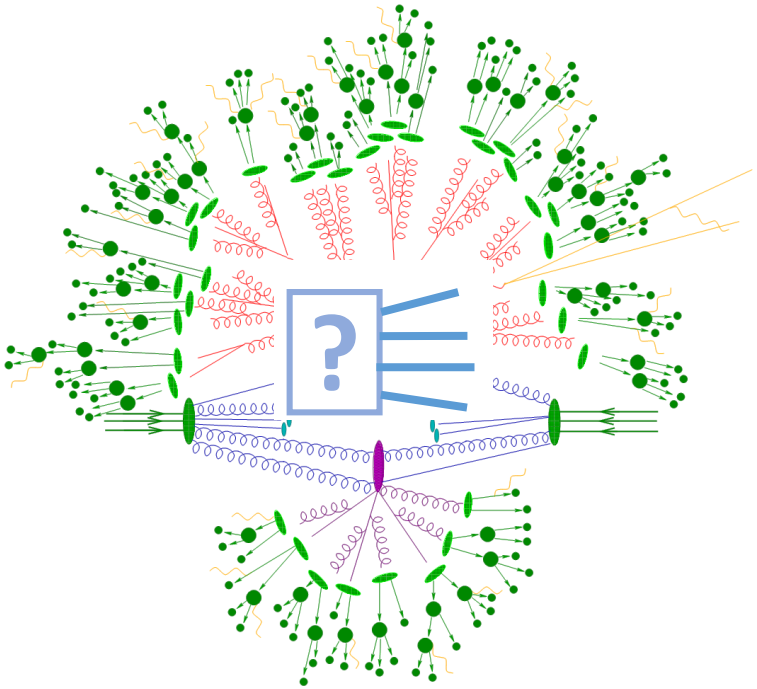
Facts about Four-Lepton Final Sate

- ❑ Clean signature
- ❑ Small cross-sections
- ❑ Straightforward to trigger low pT
  - ⇔ Studies span from O(GeV) to O(TeV)
- ❑ Precision in lepton calibration and resolution
  - ⇔ Uncertainty under control
- ❑ Fully reconstructable final state
  - ⇔ Measurement
- ❑ Importance grows as luminosity increases
- ❑ Generally, no τ-leptons considered in the studied channels


ATLAS
EXPERIMENT
http://atlas.ch
H→2e2μ Candidate
Run: 182796
Event: 74566644
2011-05-30 07:54:29 CEST

Physics with Four Leptons

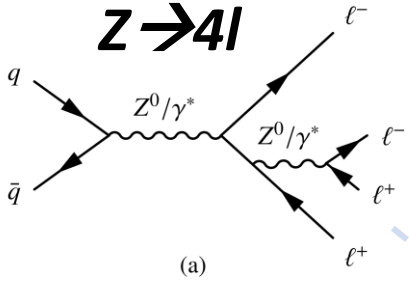


Heavy resonances ,
SUSY, extra-dimension, BSM Higgs,
Anomalous boson self-couplings
Dark matter …

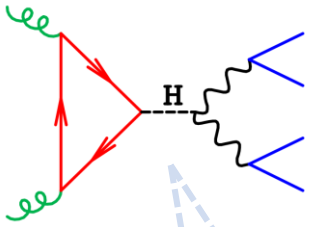
Production of
Diboson, Higgs ZZ/WW,
Di-onia, Tri-boson
VH, ttH, HH, …

Physics and Scales

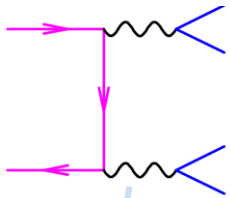
Z→4l



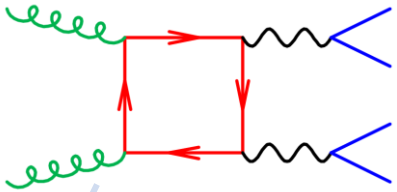
H→ZZ→4l



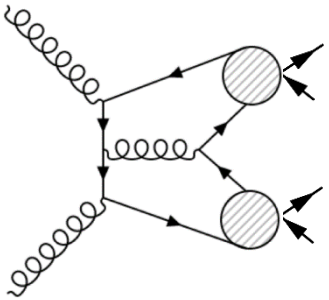
qq→ZZ→4l



gg→ZZ→4l

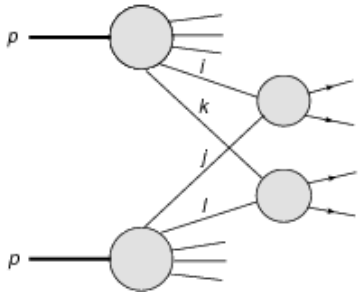


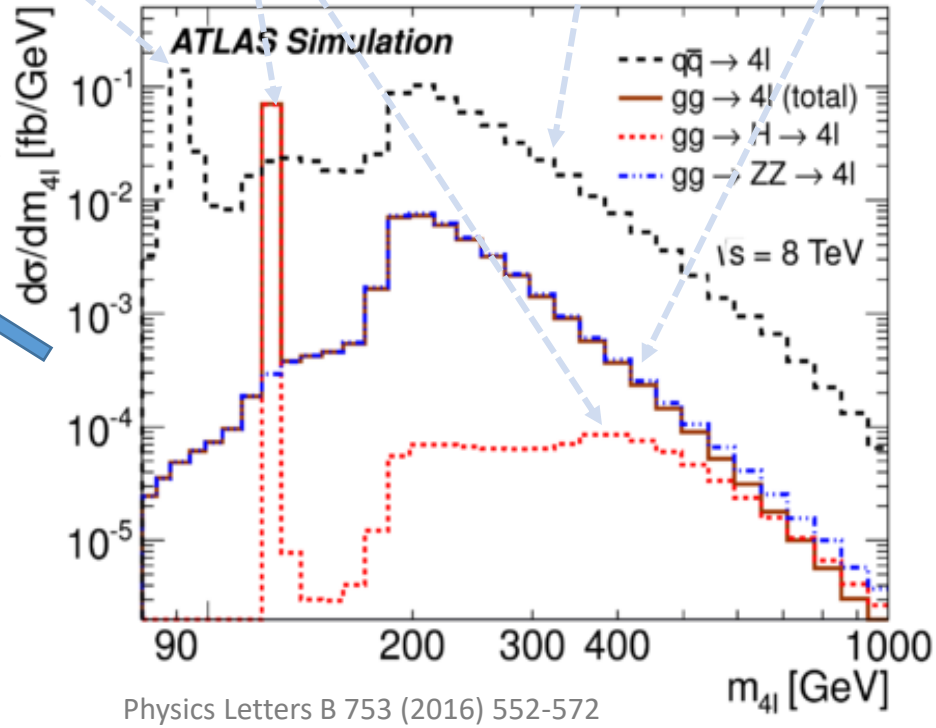
DiOnia→4l



To lower m(4l)

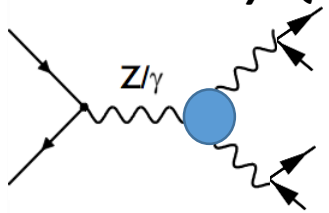
DPI→4l



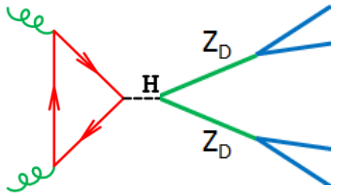


Physics Letters B 753 (2016) 552-572

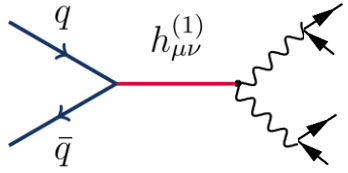
Neutral TGCs / QGCs



Dark Sector



Heavy Resonances



+ many more

?

Selected Four-lepton Results in ATLAS

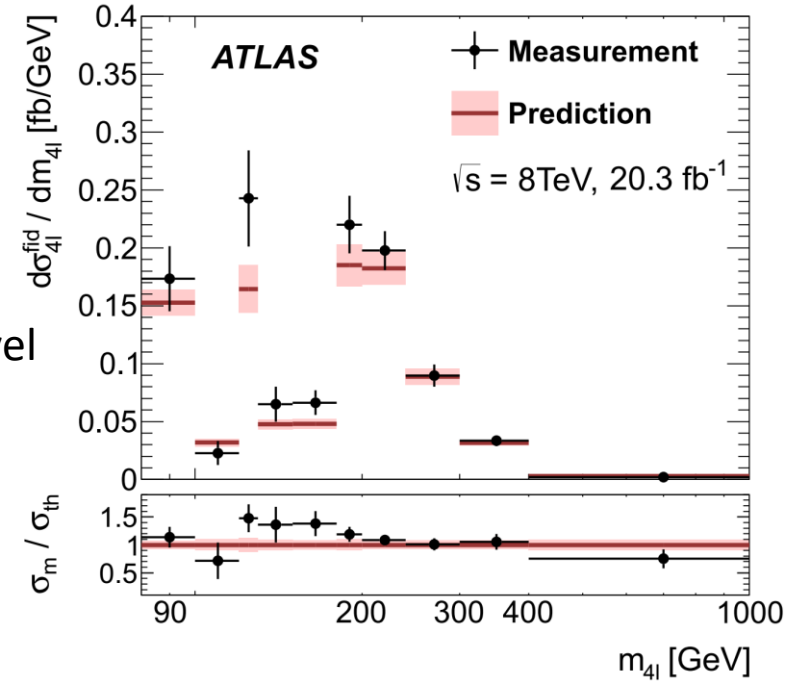
For a more complete search, take a look at ATLAS public page

Title	CME and Int. Luminosity	Paper Link	4l Mass Scale
4l Lineshape	8 TeV, 20.3 fb^{-1}	PLB 753 (2016) 552-572, Public Page	90-1000 GeV
J/ψ Pair Production	8 TeV, 11.4 fb^{-1}	EPJC 77 (2017) 76, Public Page	~10 GeV
Z→4l Production	7+8 TeV, 24.8 fb^{-1}	PRL 112, 231806 (2014), Public Page	~90 GeV
On-shell ZZ	13 TeV, 36.1 fb^{-1}	Submitted to PRD, Public Page	~200 GeV
On-shell H→4l	13 TeV, 36.1 fb^{-1}	Submitted to JHEP, Public Page	125 GeV
Off-shell H→4l/2l2ν	8 TeV, 20.3 fb^{-1}	EPJC 75 (2015) 335, Public Page	~400 GeV
H→ Dark Zs →4l	13 TeV, 36.1 fb^{-1}	To be submitted to JHEP, Public Page	125 GeV
Dark matter search in Z(ll)+$\nu\nu$	13 TeV, 36.1 fb^{-1}	PLB 776 (2017) 318, Public Page	200-600 GeV
Heavy Resonances	13 TeV, 36.1 fb^{-1}	To be submitted to EPJC, Public Page	400-1500 GeV
SUSY with 4l	13 TeV, 13.3 fb^{-1}	Conference Note, Public Page	~200 GeV

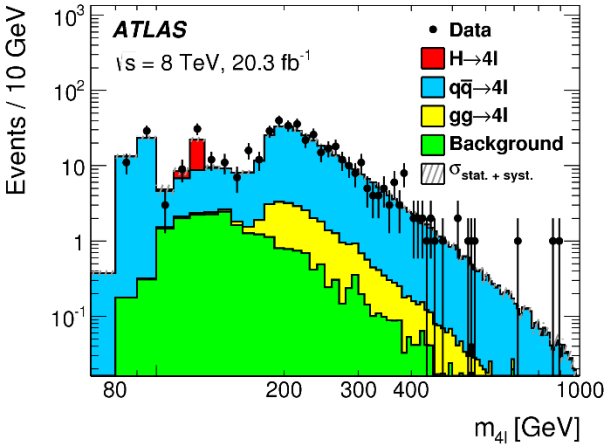
Four-lepton Lineshape

PLB 753 (2016) 552-572

Particle-level



Detector-level



Probing multi-scale physics at one go

Differential measurement compared to state-of-the-art MC predictions

NLO+PS qq->Z->4l

NLO+PS qq->ZZ->4l
with NNLO QCD and NLO EW k-factors

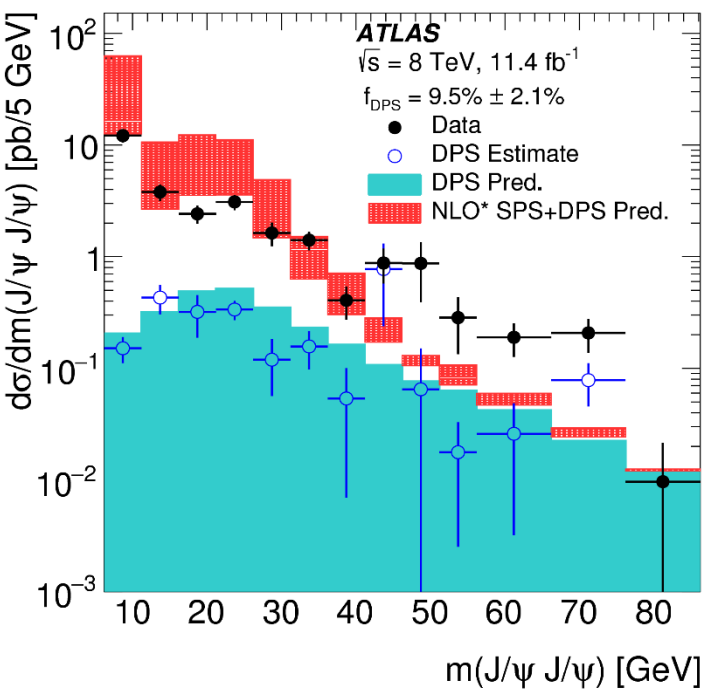
LO+PS non-res. gg->4l
Includes quark loop, off-shell Higgs, interference

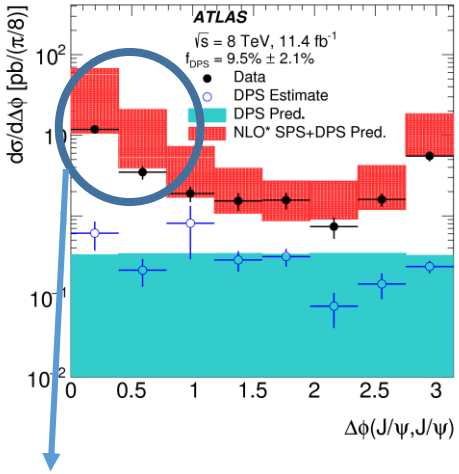
NLO+PS gg->H->4l
corrected with NNLO QCD, NLO EW, NNLL resummation

J/ψ Pair Production

Eur. Phys. J. C77 (2017) 76

Four muons with J/ψ mass window constraint



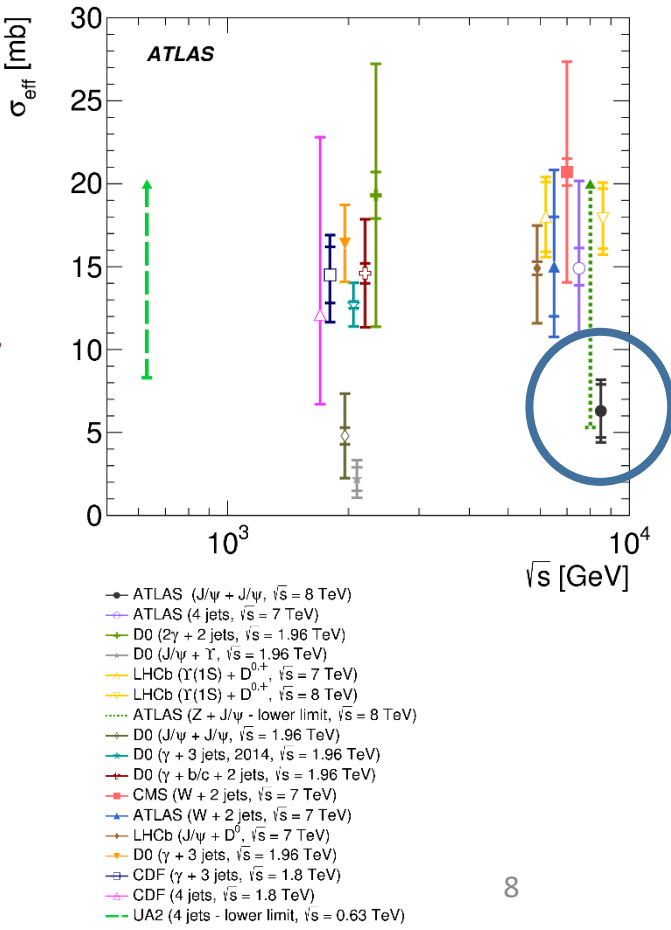


Data feature confirms the NLO prediction

Double Parton Interaction

Measured lower σ_{eff}

To be followed up with future measurements



Differential cross-sections in total PS

- compared to partial-NLO NRQCD color singlet

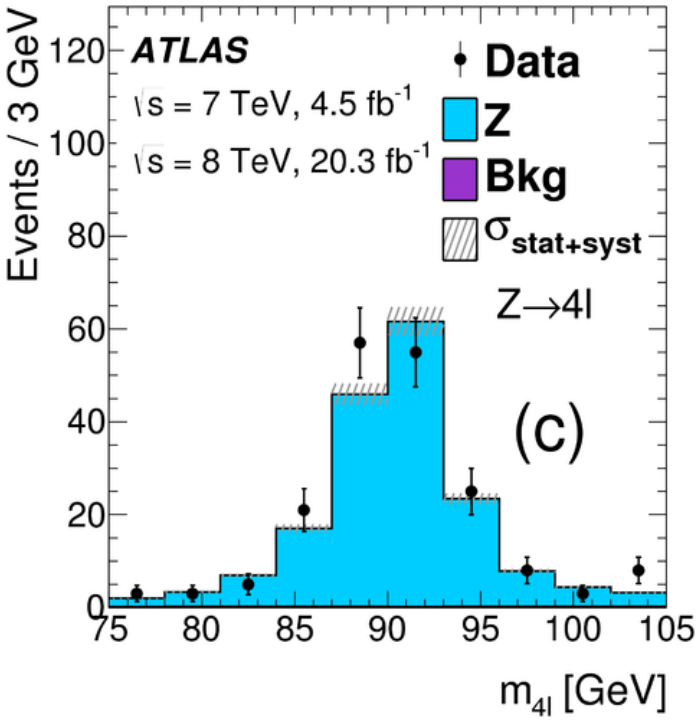
Discrepancy at large mass

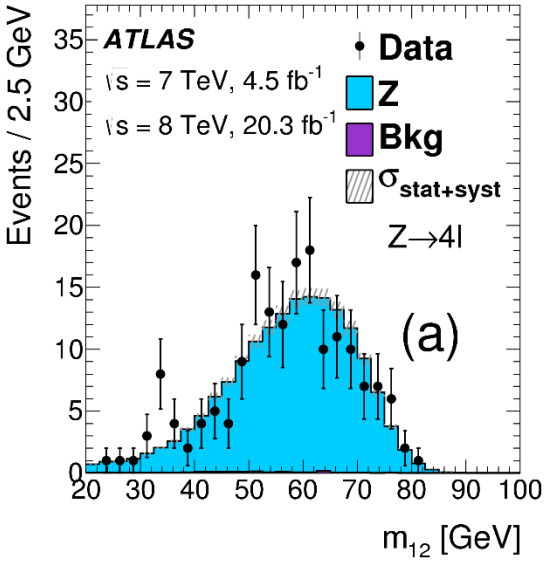
- possibly due to missing feed-down calculation

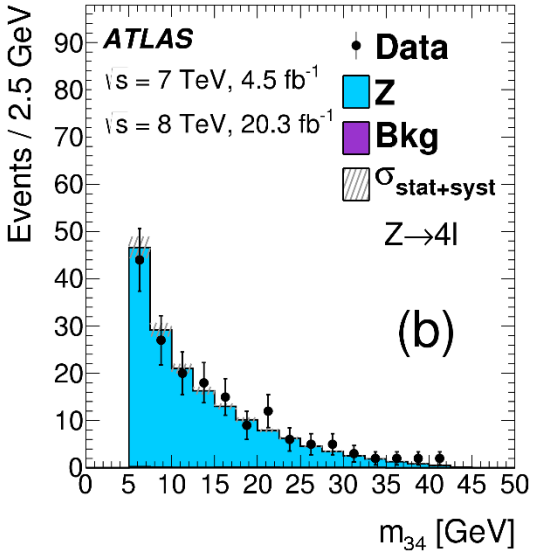
Z→4l

Soft lepton p_T or m(2l) down to ~5 GeV

Phys. Rev. Lett. 112, 231806 (2014)

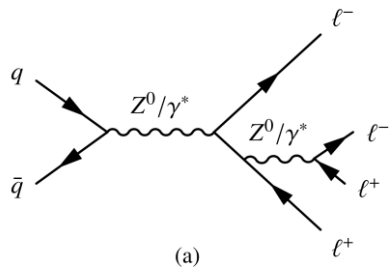






Radiative Z→4l decay measured with good precision

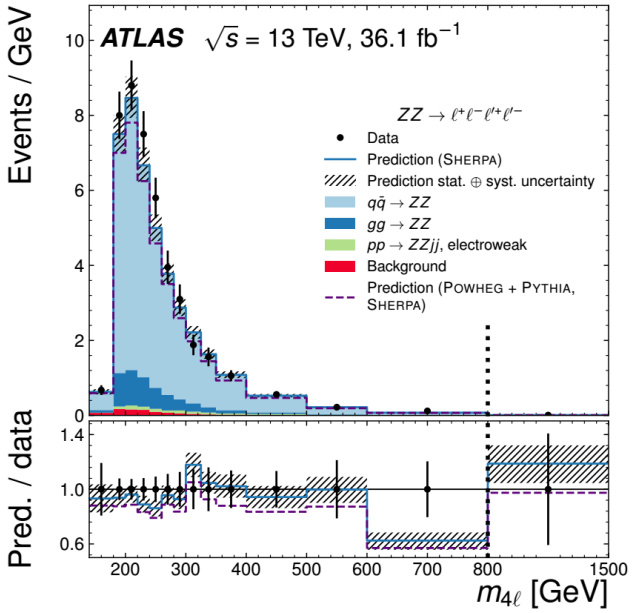
$$\Gamma_{Z\to 4\ell}/\Gamma_Z = (3.20 \pm 0.25\ (\text{stat}) \pm 0.13\ (\text{syst})) \times 10^{-6}$$

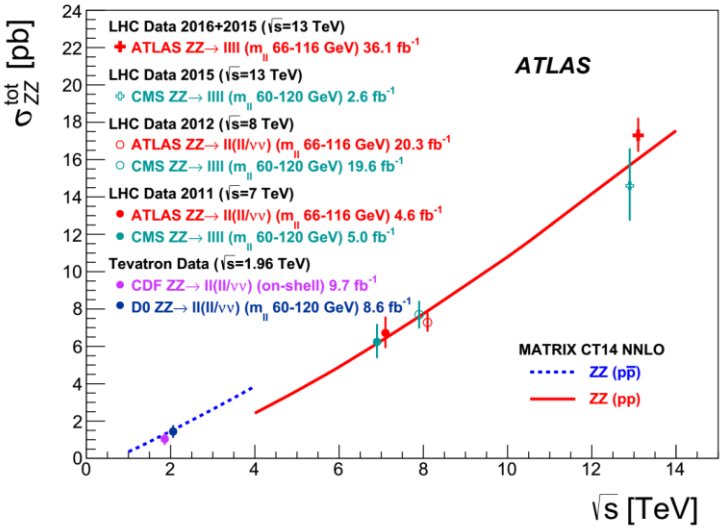


Consistent with SM prediction from PowHeg: (3.33±0.01) x 10^{-6}

On-shell ZZ

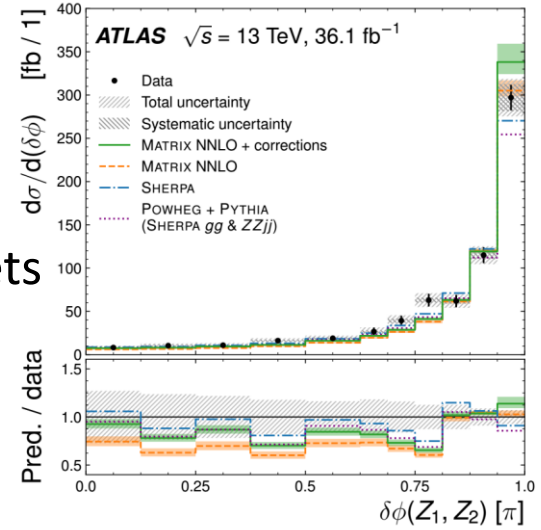
arXiv:1709.07703v1

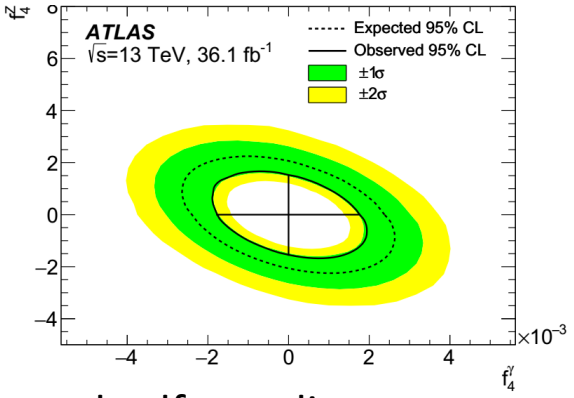




SM is so hard to beat

Measurements of mass, pT, angles, jets for different physics targets

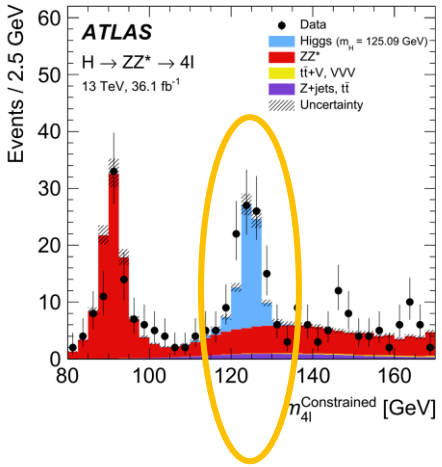


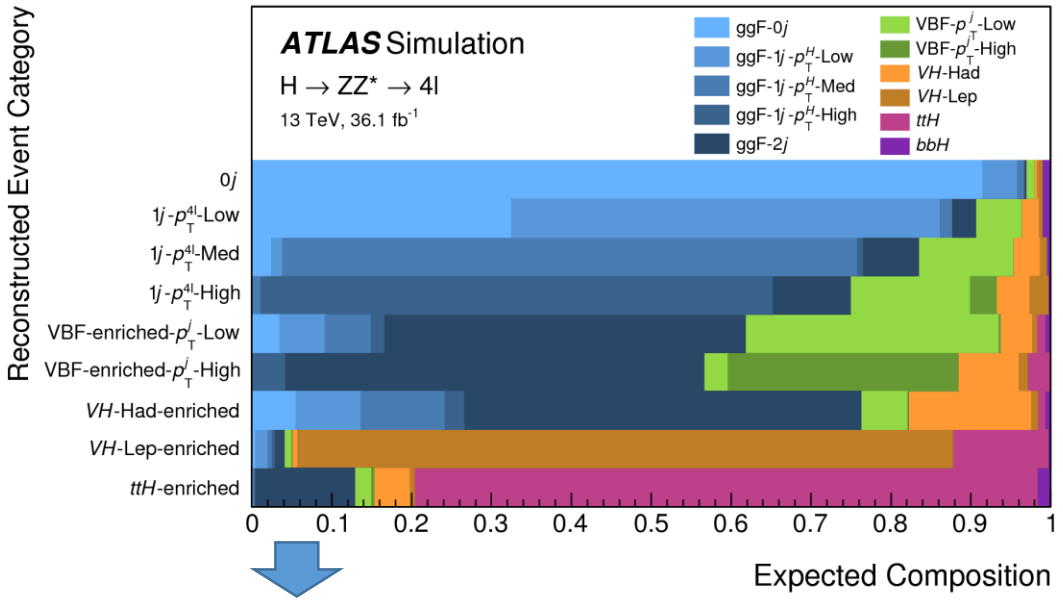


Neutral self-couplings not observed yet, will continue to search for neutral aTGCs down to O(10^{-4}) ~ SM loop effects

On-shell H→4l

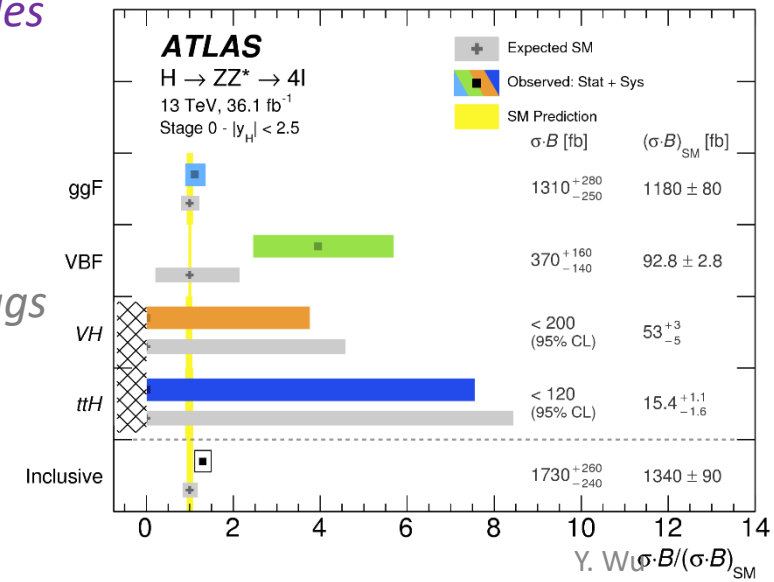
arXiv:1712.02304v1





Cut-based Categorization + MVA S/B separation

Full exploitation of data to study different Higgs production modes



Cross-section reported for Higgs phase space

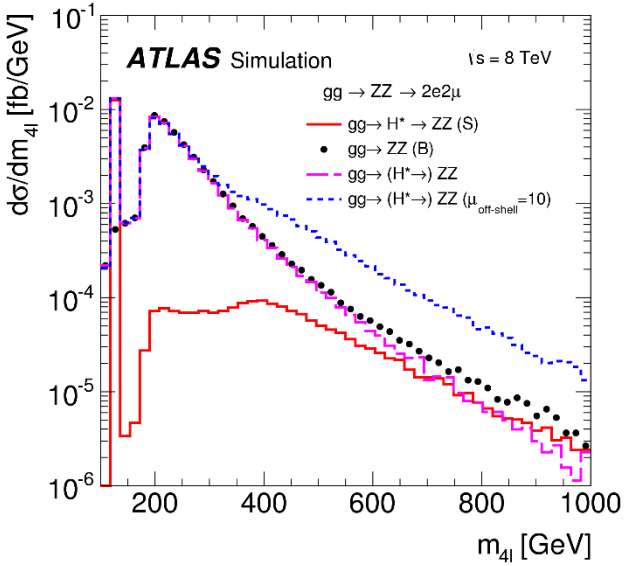
Re-establish H→4l Signal at 13 TeV

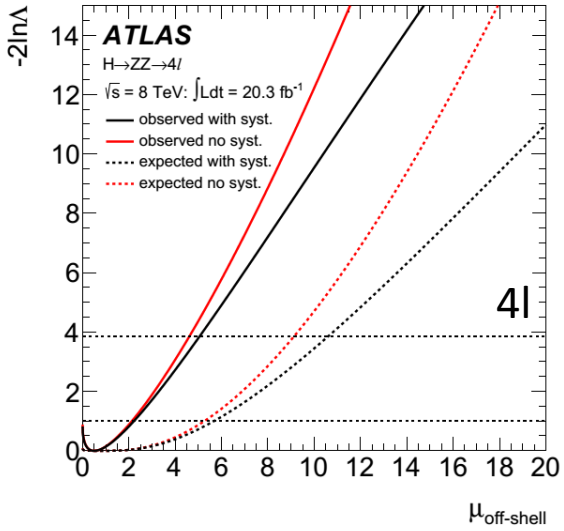
VBF excess likely statistical

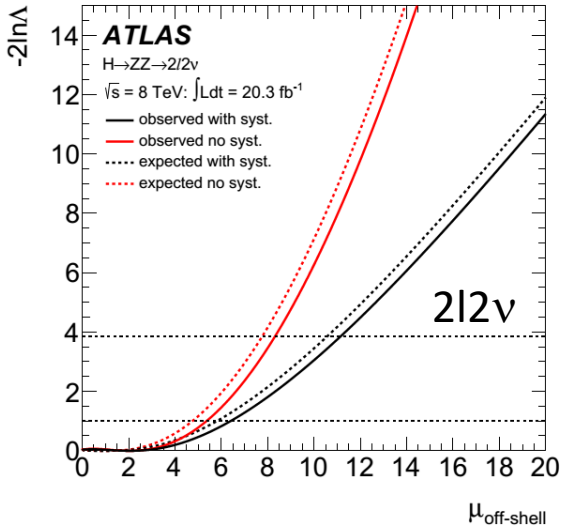
VH and ttH searched, but <1 event for each, still a long way to go

Off-shell Higgs

EPJC 75 (2015) 335



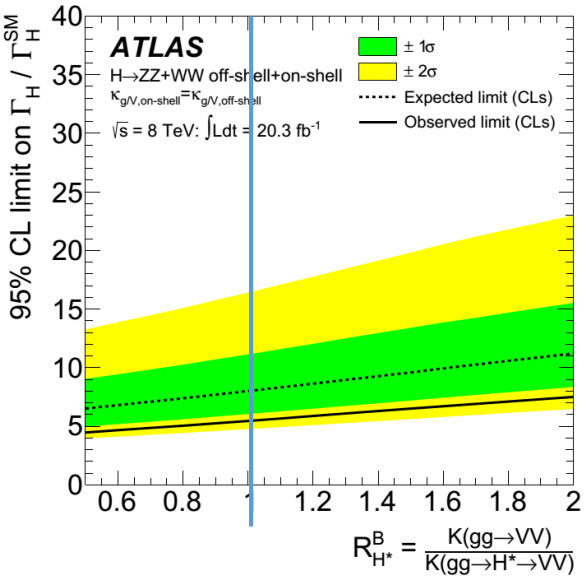




- Large off-shell Higgs production due to on-shell ZZ and ttbar
- Insights to the Higgs total width, which direct measurement cannot

$$\sigma_{\text{off-peak}} / \sigma_{\text{on-peak}} \propto \Gamma_H$$

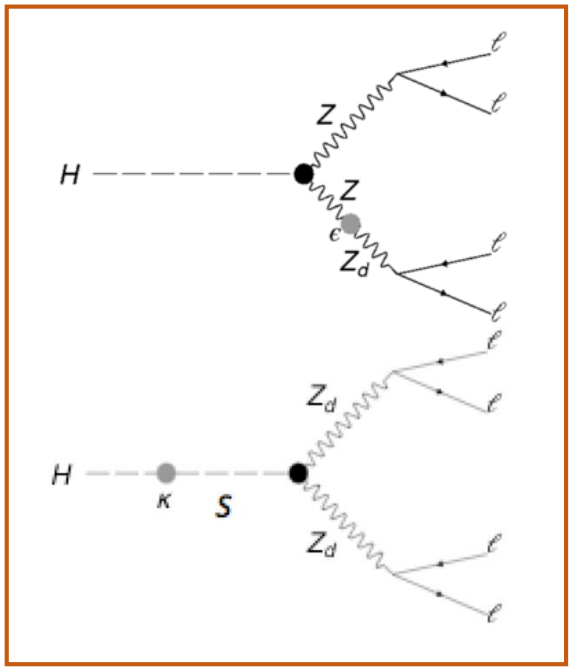
Phys. Rev. D88 (2013) 054024
with assumptions



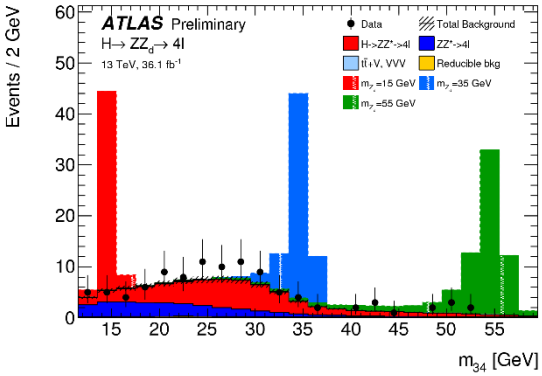
Upper limit on Γ(H) about 20 MeV, with assumptions on K-factors

Dark Sector

ATLAS-CONF-2017-042

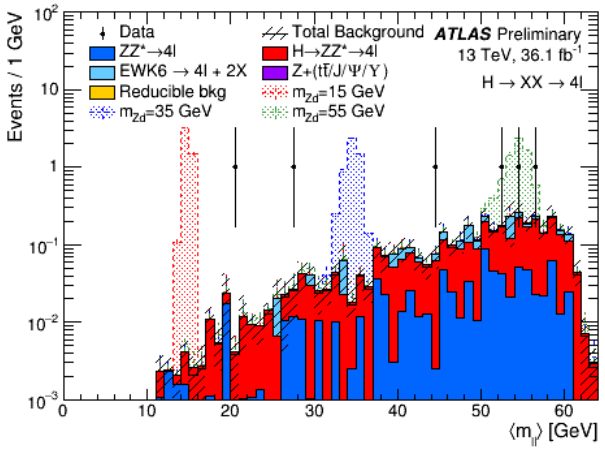


One Zd scenario



Two Zd scenario

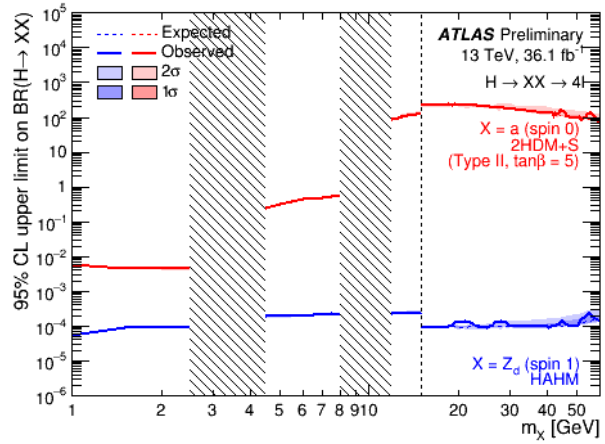
A few outliers to be followed up



Motivated to look at hidden dark sector connected to SM Higgs
=> Look at resonant peaks in low m(ll) regions

Kinematic constraints due to Higgs mass and/or dark-Z masses

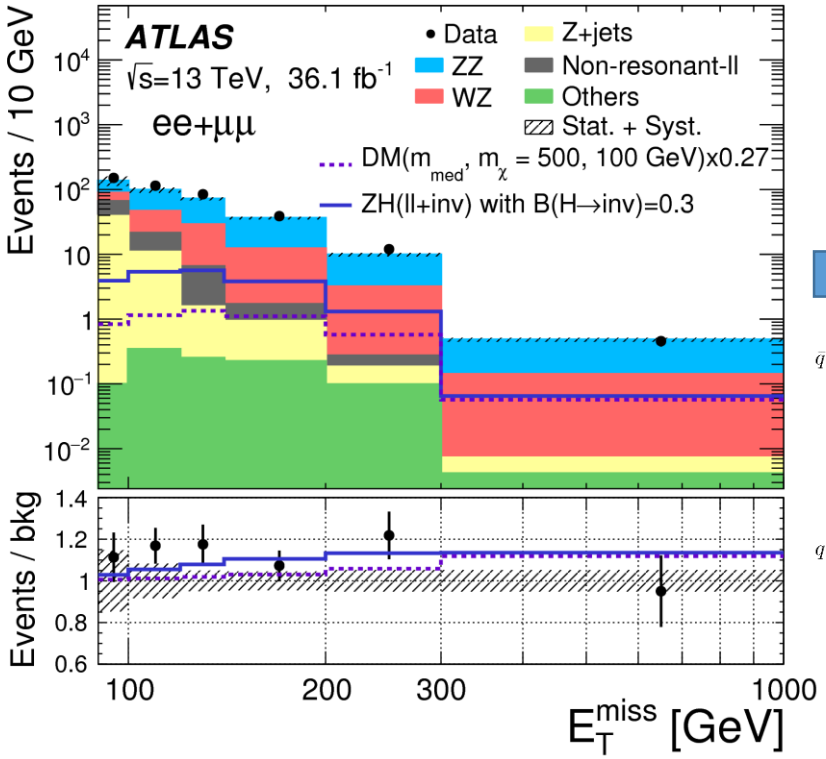
Limits on BSM cross-sections

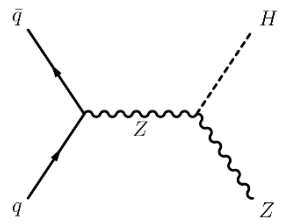


Dark Matter

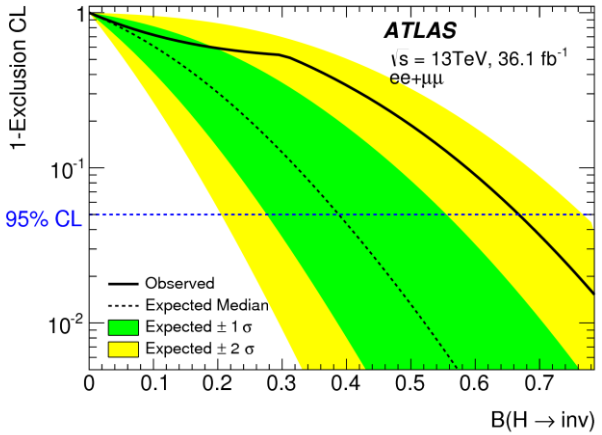
PLB 776 (2017) 318

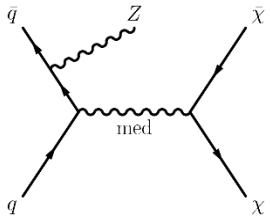
Z(ll) + νν has a clean signature and a larger branching fraction



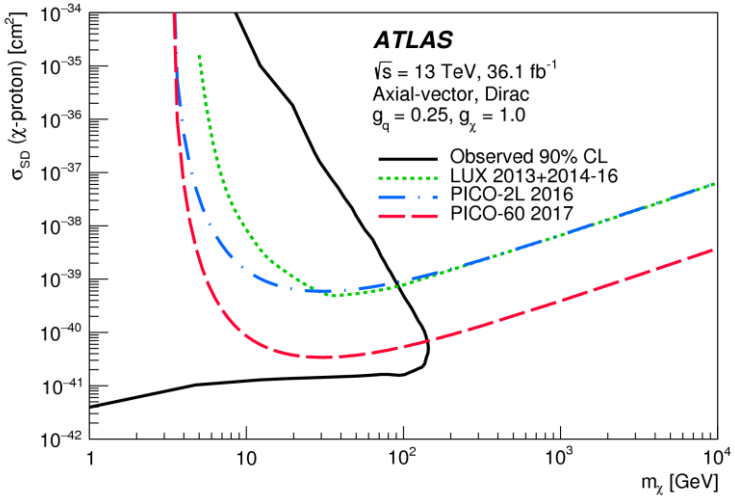


"Invisible" Higgs





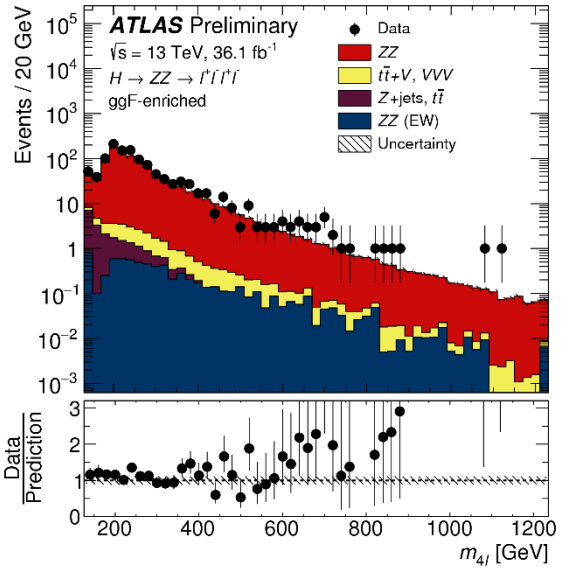
Constraint to simplified WIMP models, caveats of assumptions when comparing to direct exp.

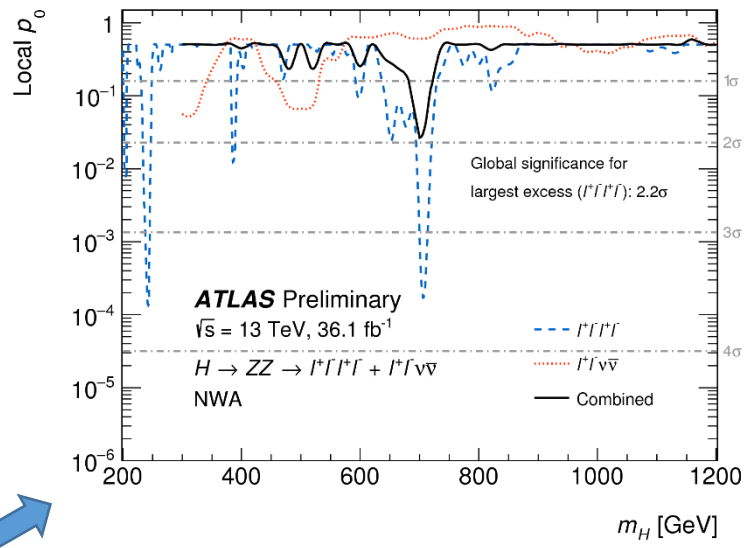


- Backgrounds larger, but still under control
- SM diboson irreducible to BSM signals (better way to separate ?)

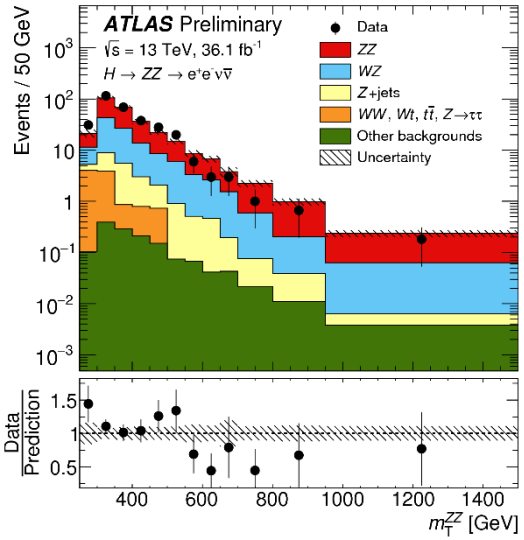
Heavy Resonances

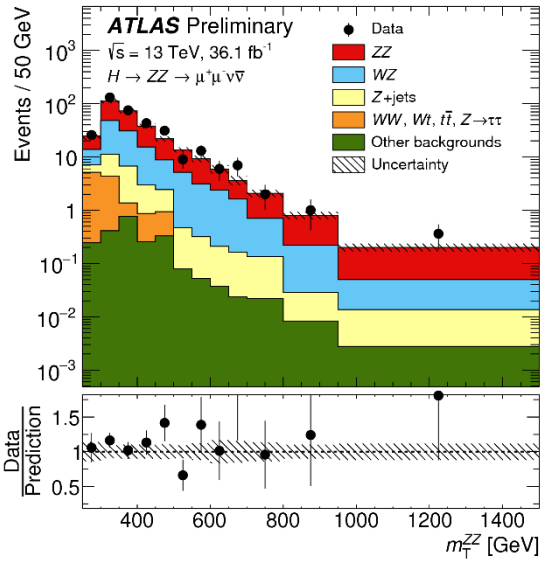
ATLAS-CONF-2017-058



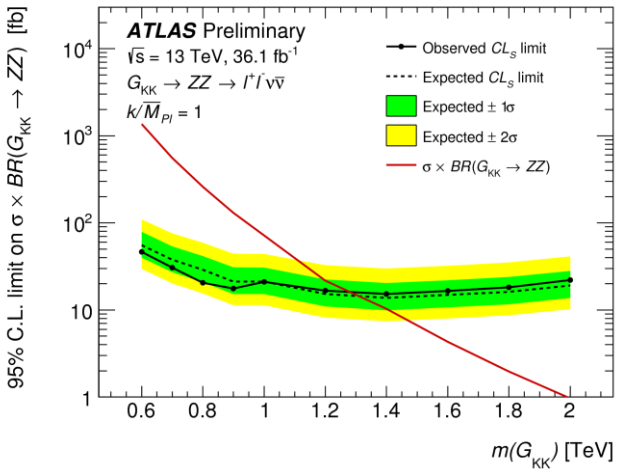


Fluctuations (e.g. in 4l) could come down after combining more relevant channels





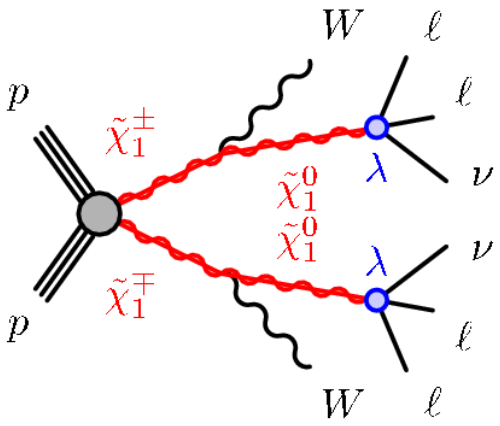
Interpretations: 2HDM, Heavy Scalar, Graviton, etc.



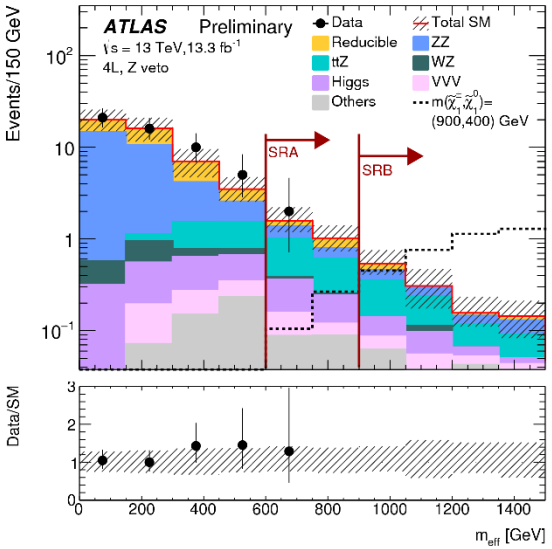
SUSY

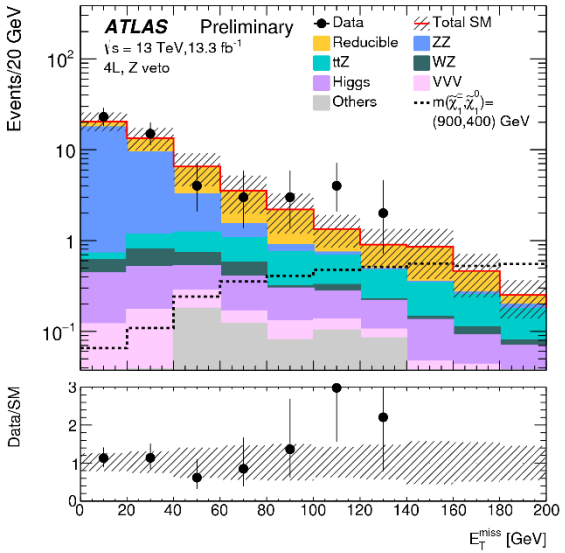
ATLAS-CONF-2016-075

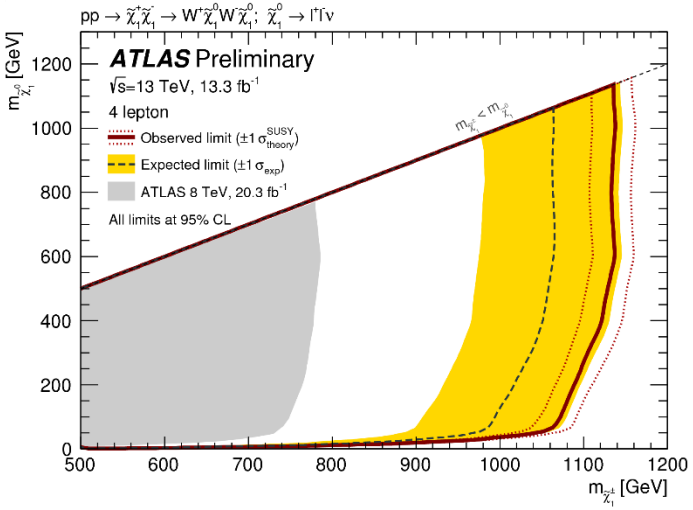
Charginos to LSPs
to >=4 leptons
in RPV models



- Veto Z bosons
- Sensitive variables
  - MET
  - m(eff): scalar pT sum of MET, jets, leptons







No clear signal observation
=> Limits on masses

Summary

- Brief summary of four-lepton physics results in ATLAS
  - Interesting and efficient to study all possible physics associated to a well-controlled and precise final state
- Four-lepton final state has its unique characteristics
  - Rich in physics, broad in scale
  - Precision measurement possible, more important as lumi. grows
  - Sensitivity to searches may not be the best comparing to other channels (jets, MET, …), but it can probe unique phase spaces, e.g. low mass, low pT
- Stay tuned for end-of-run-II results!