# Latest Developments in the Search for Supersymmetry with Tau Leptons at the ATLAS Experiment

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DPG Frühjahrstagung, Münster, 29-03-2017

# Status after 2015 Data Taking @ 13 TeV

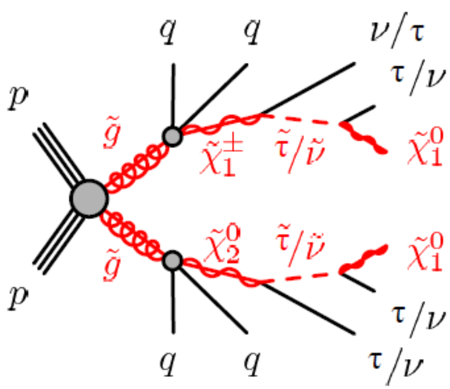
- Two-step gluino-gluino decays
  - Tailored towards tau final states
- GMSB alongside

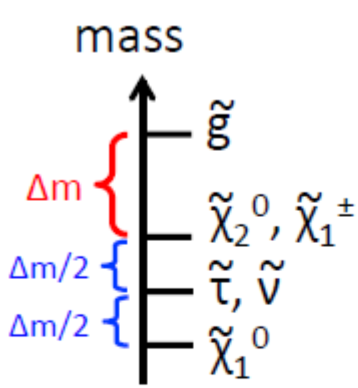
Run-1 publications:

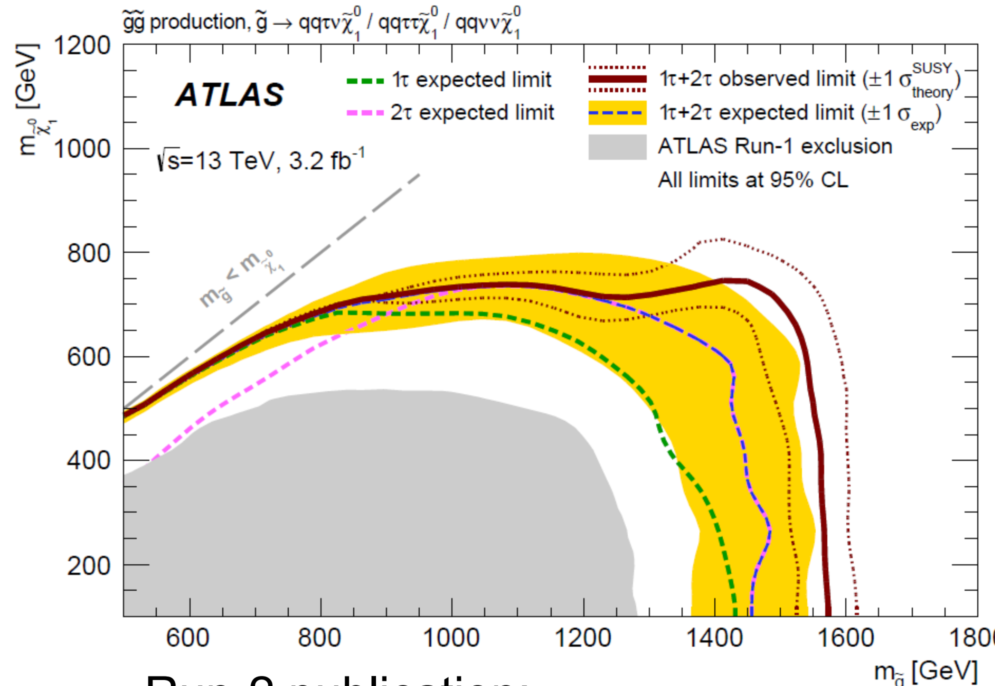
Eur.Phys.J. C72 (2012) 2215

JHEP 09 (2014) 103

JHEP 10 (2015) 054




Run-2 publication:

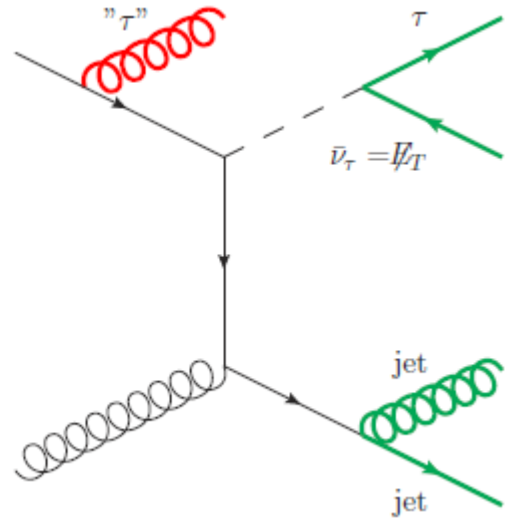
Eur. Phys. J. C76 (2016) 783

# Analysis Setup

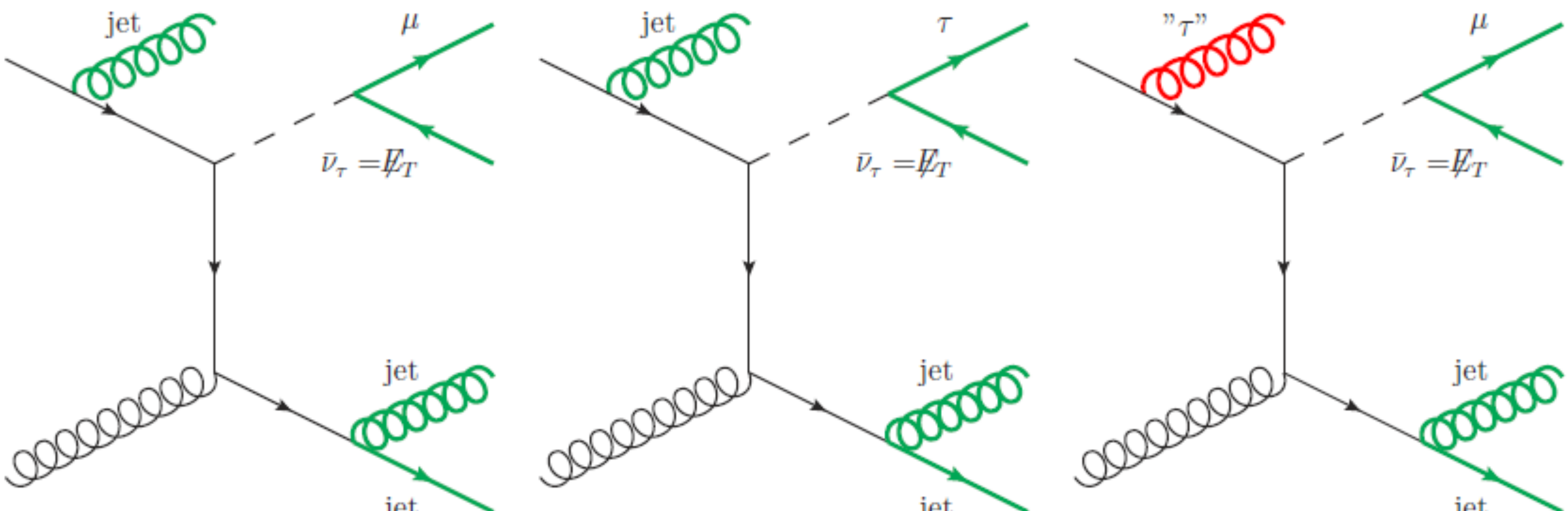
- Close collaboration with University of Bergen
- OneTau channel:
  - Low/medium gluino mass regime
- DiTau channel:
  - High gluino mass regime
- Define phasespace regions
  - CRs (Top, W, Z, QCD-Multijet), obtain scaling factors
  - VRs, validate scaling factors
  - SR, apply scaling factors
- Fitting procedure: HistFitter
  - Simultaneous multi-region fit
  - Multi-bin shape fit in SRs, single bin in CRs

# Background Estimation

- Determine Top/W fake/true contributions individually
- Fit $Z \rightarrow \tau\tau/\upsilon\upsilon$ inclusively




Signal-like W+Jets




(a) Kinematics (b) Real taus (c) Fake taus

# Background Estimation

| | Top/W<br>kinematic | Top/W<br>True Tau | Top/W<br>Fake Tau | $Z \rightarrow \nu\nu$ | $Z \rightarrow \tau\tau$ |
|---|---|---|---|---|---|
| Trigger plateau | $E_T^{\text{miss}} > 180\,\text{GeV}$<br>$p_T^{J1} > 120\,\text{GeV}$<br>$N_{\text{jet}} > 1$<br>$p_T^{J2} > 25\,\text{GeV}$ | | | | |
| QCD-Multijet suppression | $\Delta\phi(p_T^{J1}, p_T^{\text{miss}}) > 0.4$<br>$\Delta\phi(p_T^{J2}, p_T^{\text{miss}}) > 0.4$ | | | | |
| | $\Delta\phi(p_T^{J1}, p_T^{\text{miss}}) < \pi - 0.2$ | | | — | — |
| Taus | $N_\tau^{\text{medium}} = 0$ | $N_\tau^{\text{medium}} = 1$ | | | $N_\tau^{\text{medium}} = 2, \text{OS}$ |
| Additional jets | $N_{\text{jet}} > 2$ | | — | — | — |
| Light leptons | $N_l = 1$ | $N_l = 0$ | $N_l = 1$ | $N_l = 0$ | — |
| W/Top separation | $N_{\text{b-jet}} = 0/\geq 1$ | | | $N_{\text{b-jet}} = 0$ | |
| CR cuts | $\text{HT} < 800\,\text{GeV}$ | | | | |
| | $E_T^{\text{miss}} < 300\,\text{GeV}$ | | | | — |
| | $m_T^l < 100\,\text{GeV}$ | — | $m_T^l < 100\,\text{GeV}$ | — | — |
| | — | $m_T^\tau < 80\,\text{GeV}$ | — | $100\,\text{GeV} \leq m_T^\tau < 200\,\text{GeV}$ | — |
| | — | — | — | — | $m_T^{\tau_1} + m_T^{\tau_2} < 150\,\text{GeV}$ |
| | — | — | — | — | $m_{T2} < 70\,\text{GeV}$ |
| | — | — | — | $\Delta\phi(p_T^{J1}, p_T^{\text{miss}}) > 2.0$ | — |
| | — | — | — | $\Delta\phi(p_T^{\tau_1}, p_T^{\text{miss}}) > 1.0$ | — |
| | — | — | — | $E_T^{\text{miss}}/m_{\text{eff}} > 0.3$ | — |

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Work In Progress

Phasespace definitions: CRs

- Trigger on MET, additional cuts: general event quality
- Orthogonality: SRs (red), CRs (blue)

# Background Estimation

| | $N_\tau^{\text{reco}} = 0$ (kinematic CRs) | $N_\tau^{\text{reco}} = 1$ (True/Fake CRs) | $N_\tau^{\text{reco}} \geq 2$ (VRs/SRs) |
|---|---|---|---|
| $N_\tau^{\text{true}} = 0$ $(W \to \tau\nu, t\bar{t})$ | $\omega_{\text{kin}}$ | $\omega_{\text{kin}} \times \omega_{\text{fake}}$ | $\omega_{\text{kin}} \times \omega_{\text{fake}} \times \omega_{\text{fake}}$ |
| $N_\tau^{\text{true}} = 1$ $(W \to \tau\nu, t\bar{t})$ | — | $\omega_{\text{kin}} \times \omega_{\text{true}}$ | $\omega_{\text{kin}} \times \omega_{\text{true}} \times \omega_{\text{fake}}$ |
| $N_\tau^{\text{true}} = 2$ $(t\bar{t})$ | — | $\omega_{\text{kin}} \times \omega_{\text{true}}$ | $\omega_{\text{kin}} \times \omega_{\text{true}} \times \omega_{\text{true}}$ |

**ATLAS**
Work In Progress

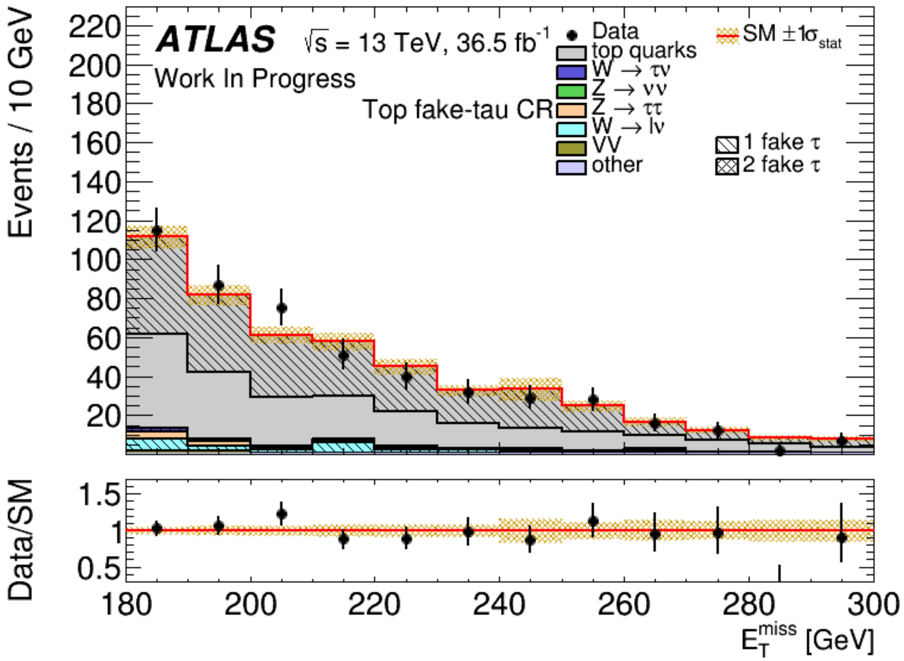
| Scaling | Value |
|---|---|
| $\omega_{\text{kin}}(\text{top})$ | $0.99 \pm 0.01$ |
| $\omega_{\text{true}}(\text{top})$ | $1.09 \pm 0.02$ |
| $\omega_{\text{fake}}(\text{top})$ | $1.09 \pm 0.13$ |
| $\omega_{\text{kin}}(W)$ | $0.89 \pm 0.06$ |
| $\omega_{\text{true}}(W)$ | $1.05 \pm 0.02$ |
| $\omega_{\text{fake}}(W)$ | $0.78 \pm 0.14$ |
| $\omega_{Z \to \tau\tau}$ | $1.00 \pm 0.10$ |
| $\omega_{Z \to \nu\nu}$ | $1.51 \pm 0.21$ |

**ATLAS**
Work In Progress

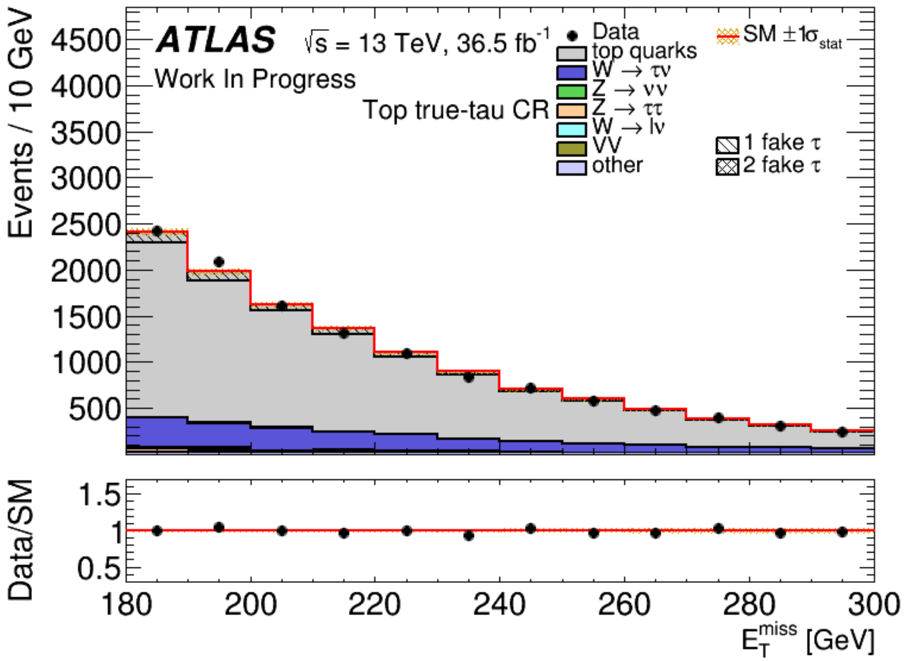
- No systematic uncertainties taken into account
- QCD-Multijet not included in plots or fits

# Background Estimation – Top-CRs

- Good agreement



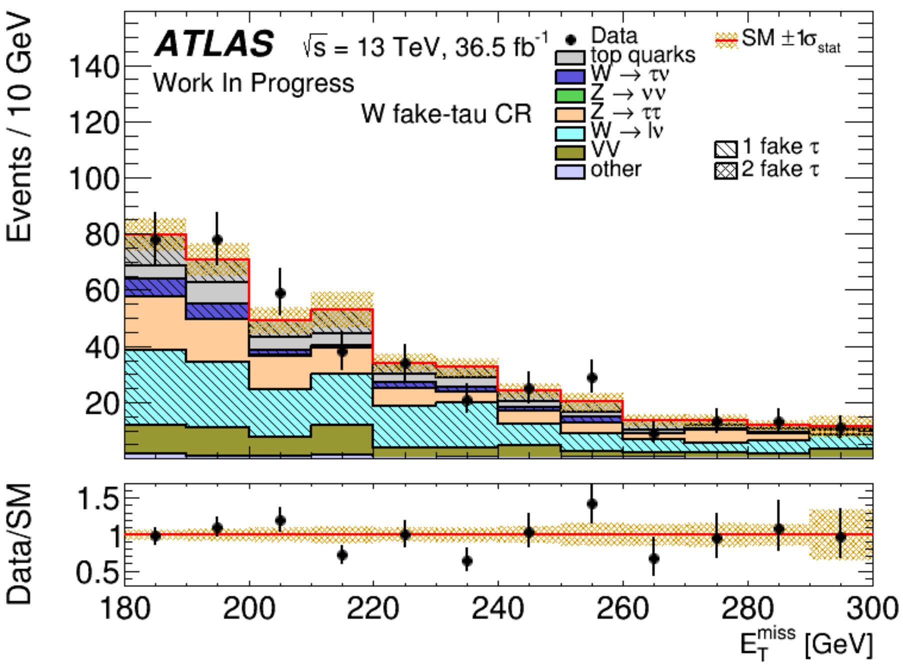

Top-Fake CR



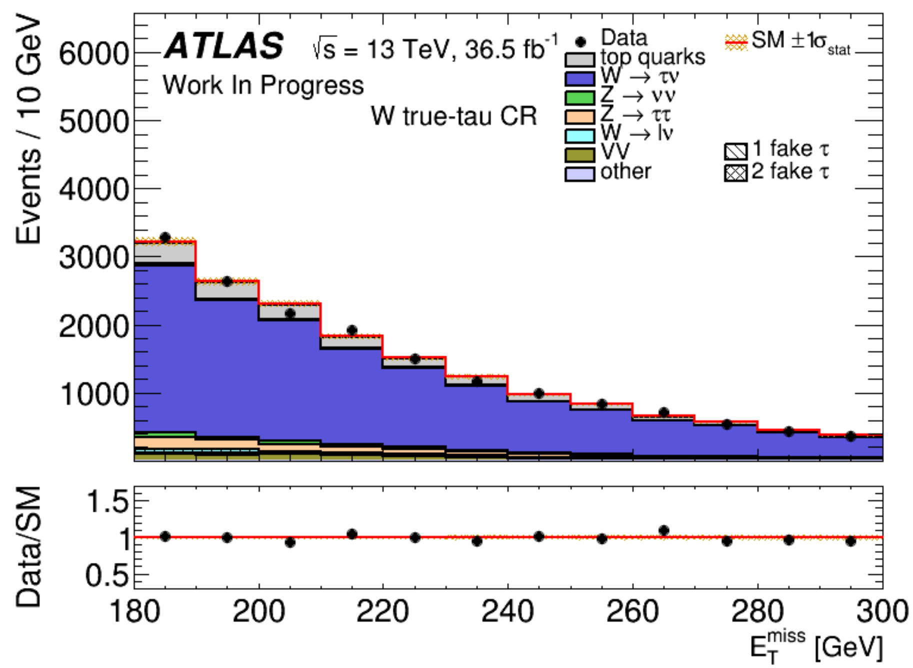

Top-True CR

# Background Estimation – W-CRs

- Good agreement




W-Fake CR




W-True CR

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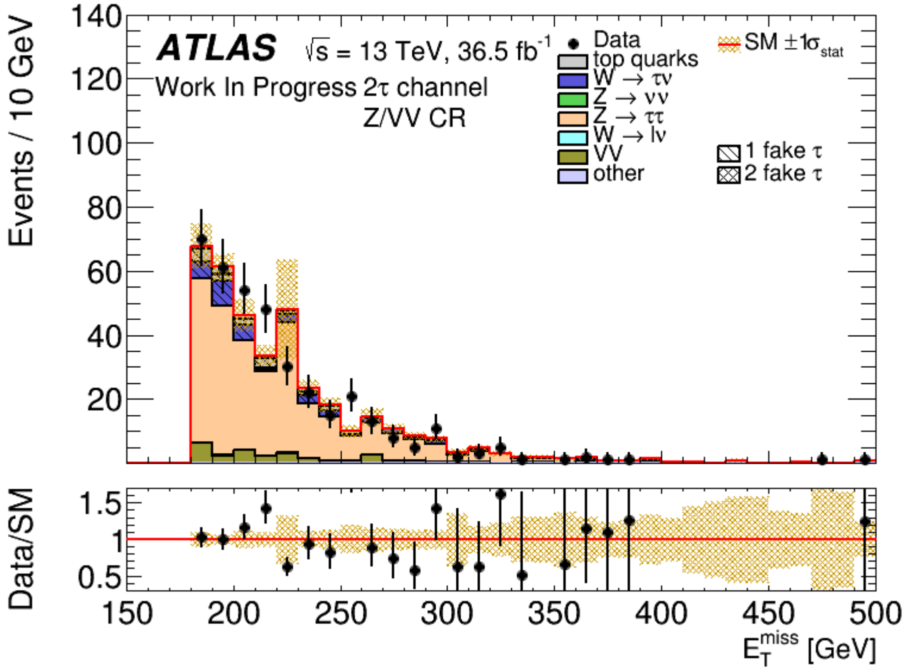
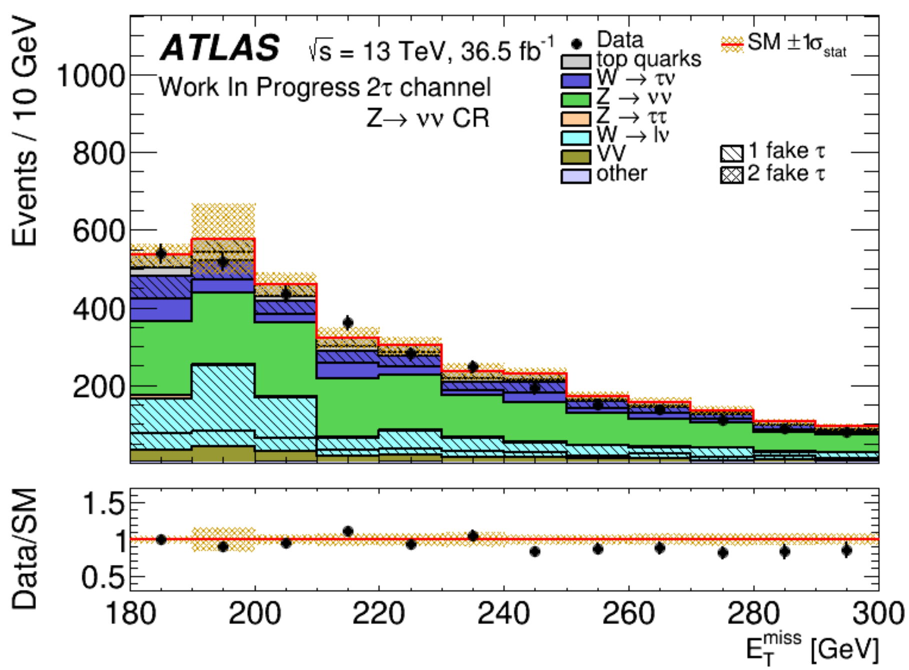
# Background Estimation – Z-CRs

- Good agreement




$Z \rightarrow \tau\tau$-CR




$Z \rightarrow \nu\nu$-CR

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# SR Design

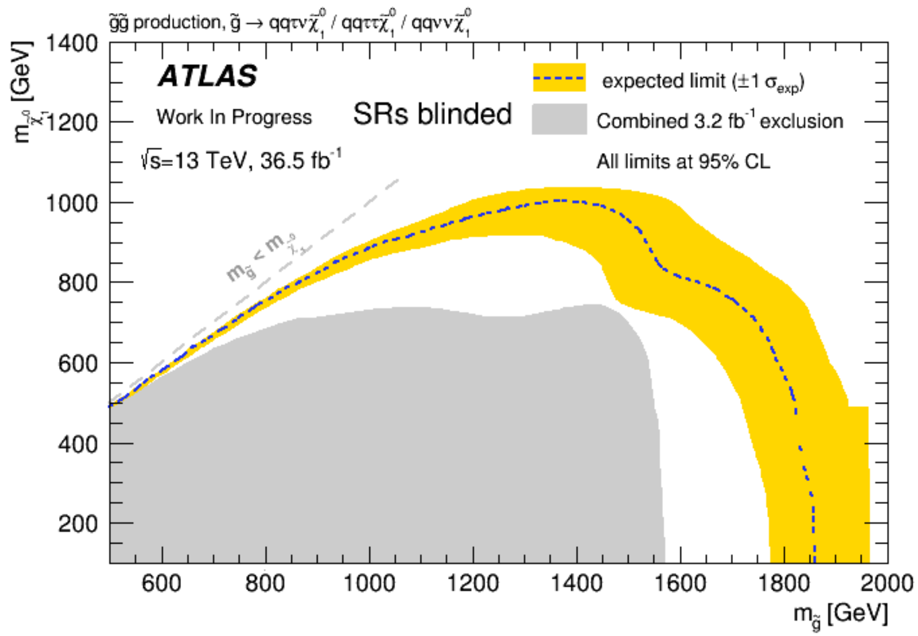
| | OneTau SRs Compressed | OneTau SRs Medium Mass | DiTau SRs Compressed | DiTau SRs High Mass |
|---|---|---|---|---|
| Trigger plateau | $E_T^{\text{miss}} > 180\,\text{GeV}$<br>$p_T^{J1} > 120\,\text{GeV}$<br>$N_{\text{jet}} > 1$<br>$p_T^{J2} > 25\,\text{GeV}$ | | | |
| QCD-Multijet suppression | $\Delta\phi(p_T^{J1}, p_T^{\text{miss}}) > 0.4$<br>$\Delta\phi(p_T^{J2}, p_T^{\text{miss}}) > 0.4$ | | | |
| Taus | $N_\tau^{\text{medium}} = 1$<br>$p_T^{\tau_1} < 45\,\text{GeV}$<br>$m_T^{\tau_1} > 80\,\text{GeV}$<br>— | $p_T^{\tau_1} > 45\,\text{GeV}$<br>$m_T^{\tau_1} > 250\,\text{GeV}$<br>— | $N_\tau^{\text{medium}} \geq 2$<br>—<br>—<br>$m_{T2} > 60\,\text{GeV}$ | —<br>$m_T^{\tau_1} + m_T^{\tau_2} > 350\,\text{GeV}$<br>— |
| Jets | — | $N_{\text{jet}} > 4$ | — | — |
| General event properties | $E_T^{\text{miss}} > 400\,\text{GeV}$<br>—<br>— | $H_T > 1000\,\text{GeV}$<br>— | —<br>$H_T < 1100\,\text{GeV}$<br>$\sum m_T^{\text{taus,jets}} > 1600\,\text{GeV}$ | —<br>$H_T > 1100\,\text{GeV}$<br>— |

**ATLAS**
Work In Progress

Phasespace definitions: SRs

- Orthogonality: SRs (blue), CRs (red)

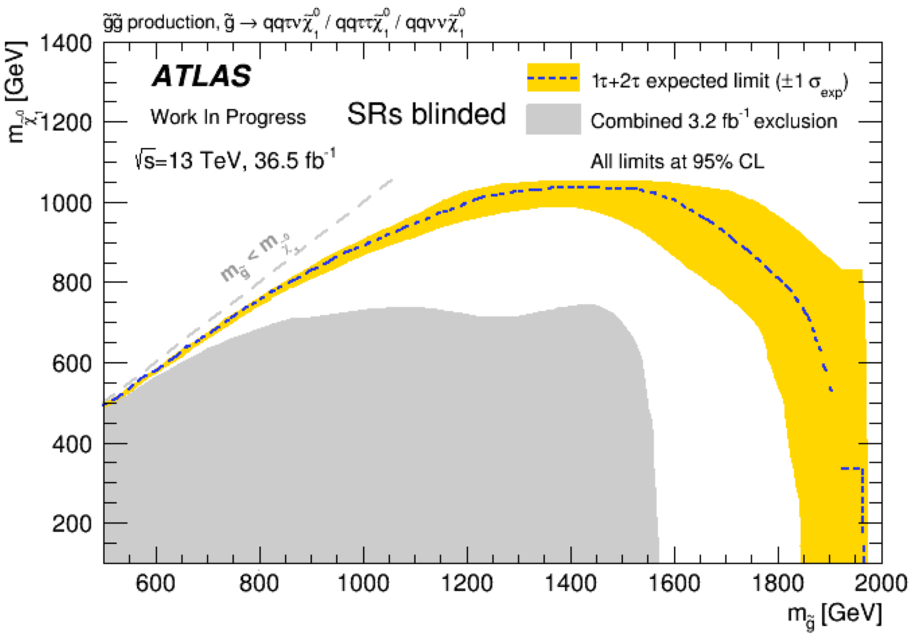
# Expected Limits – Combined Phasespace



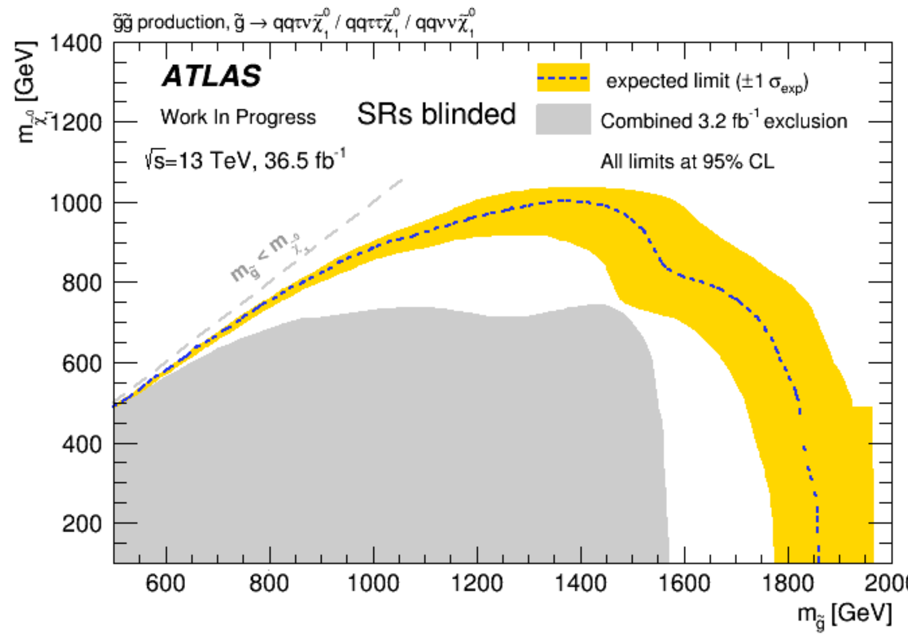

Best-CLs SR, 1-bin

- Combination of OneTau (Comp., MM) and DiTau (Comp. HM) channels

# Expected Limits – Combined Phasespace



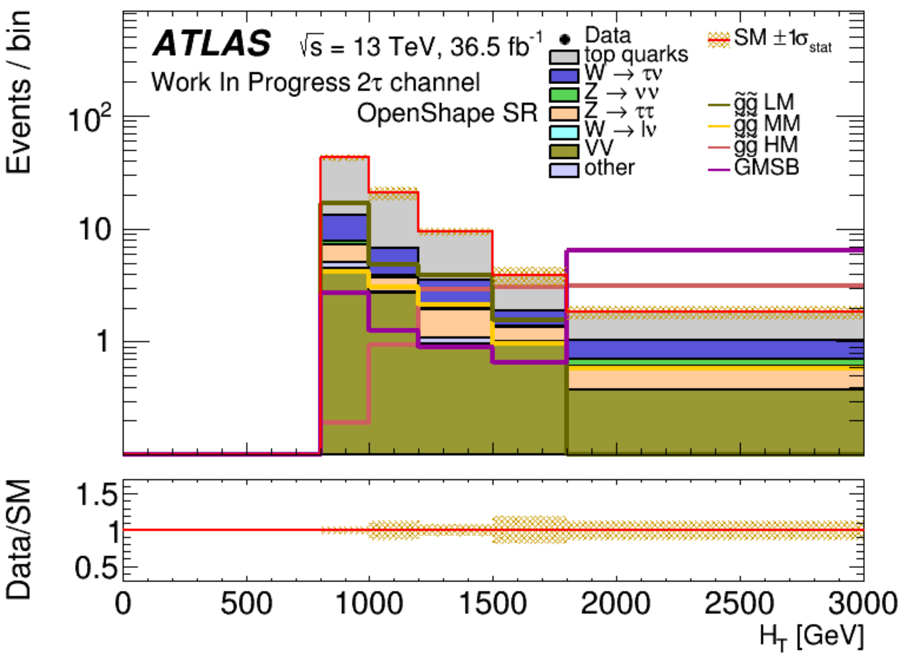

Fully orthogonal 1-bin combination



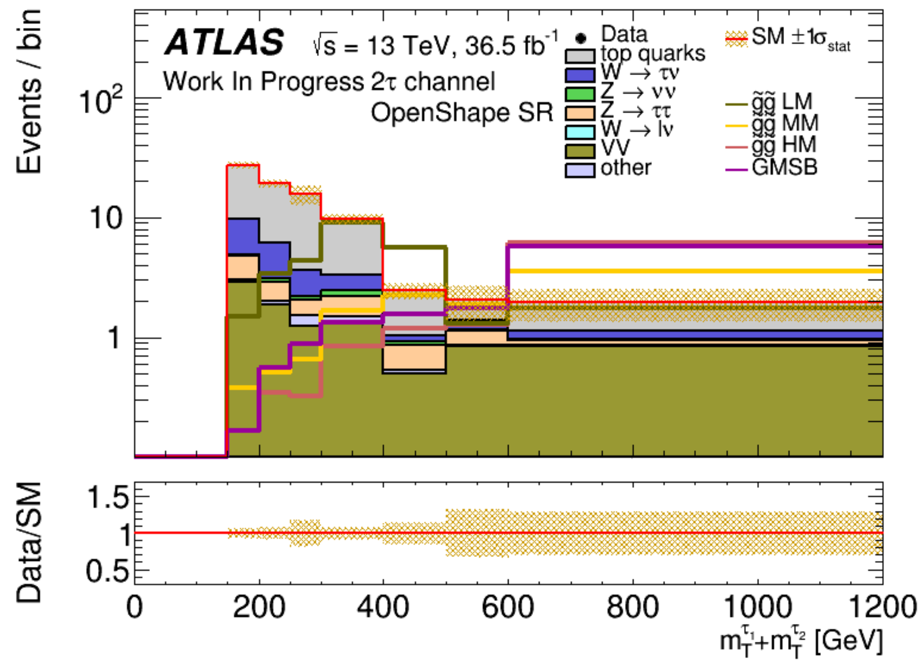

Best-CLs SR, 1-bin

- Combination of OneTau (Comp., MM) and DiTau (Comp. HM) channels
- Fully orthogonal combination even more powerful

# DiTau Signal Region Shape Fit – Intro



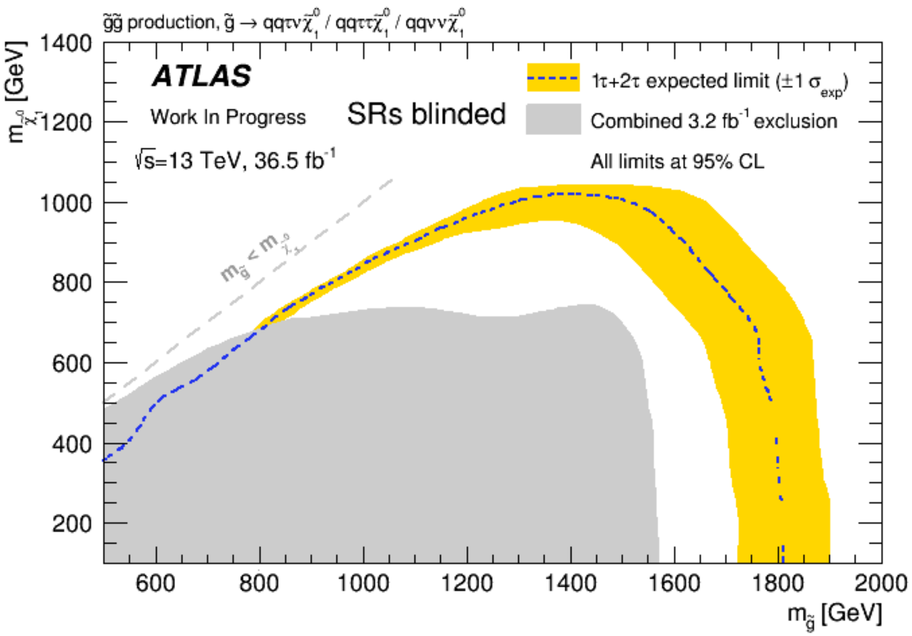

DiTau OpenShape SR, $H_T$



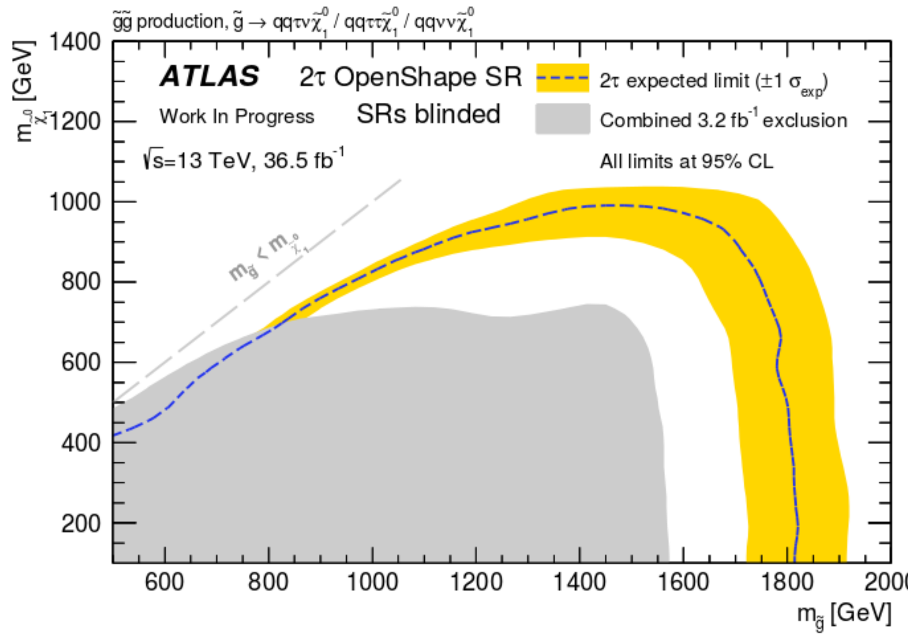

DiTau OpenShape SR, $m_T^{\tau 1} + m_T^{\tau 2}$

- DiTau OpenShape SR
- Binning chosen to have enough statistics everywhere

# Expected Limits – Shape Fit Performance



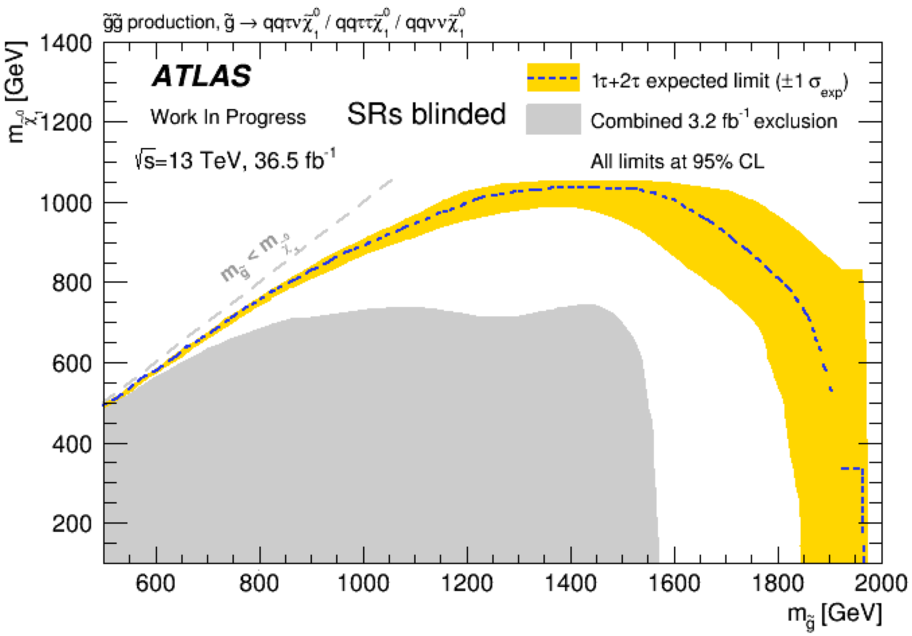

Fully orthogonal 1-bin combination, DiTau



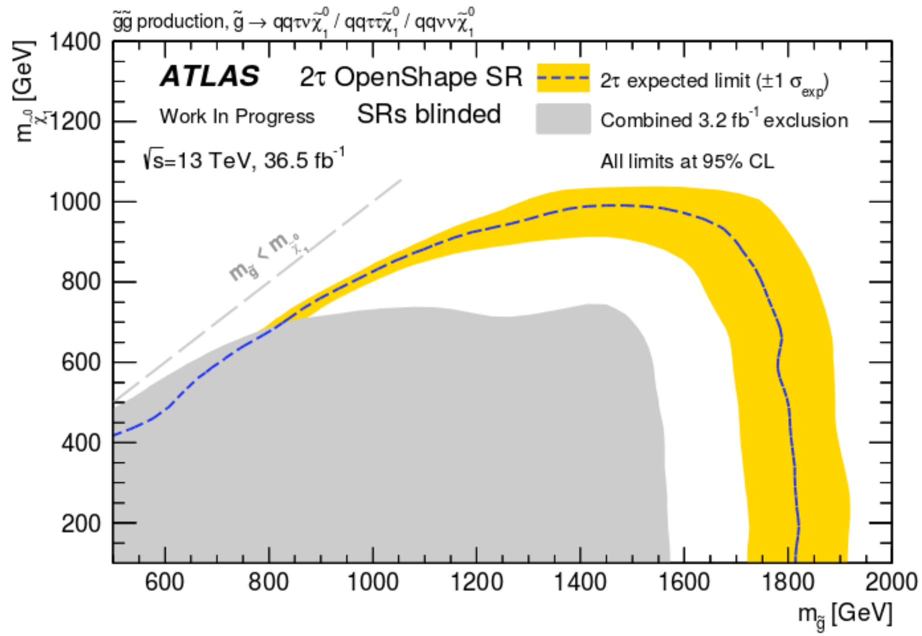

DiTau Shape Fit

- Shape fit (in $m_T^{\tau 1} + m_T^{\tau 2}$) better than 1-bin fits
- To Do:
  - Further improve OpenShape SR (based on HM-SR)
  - Develop OneTau Shape fit SR

# Expected Limits – Shape Fit Performance




Fully orthogonal 1-bin combination

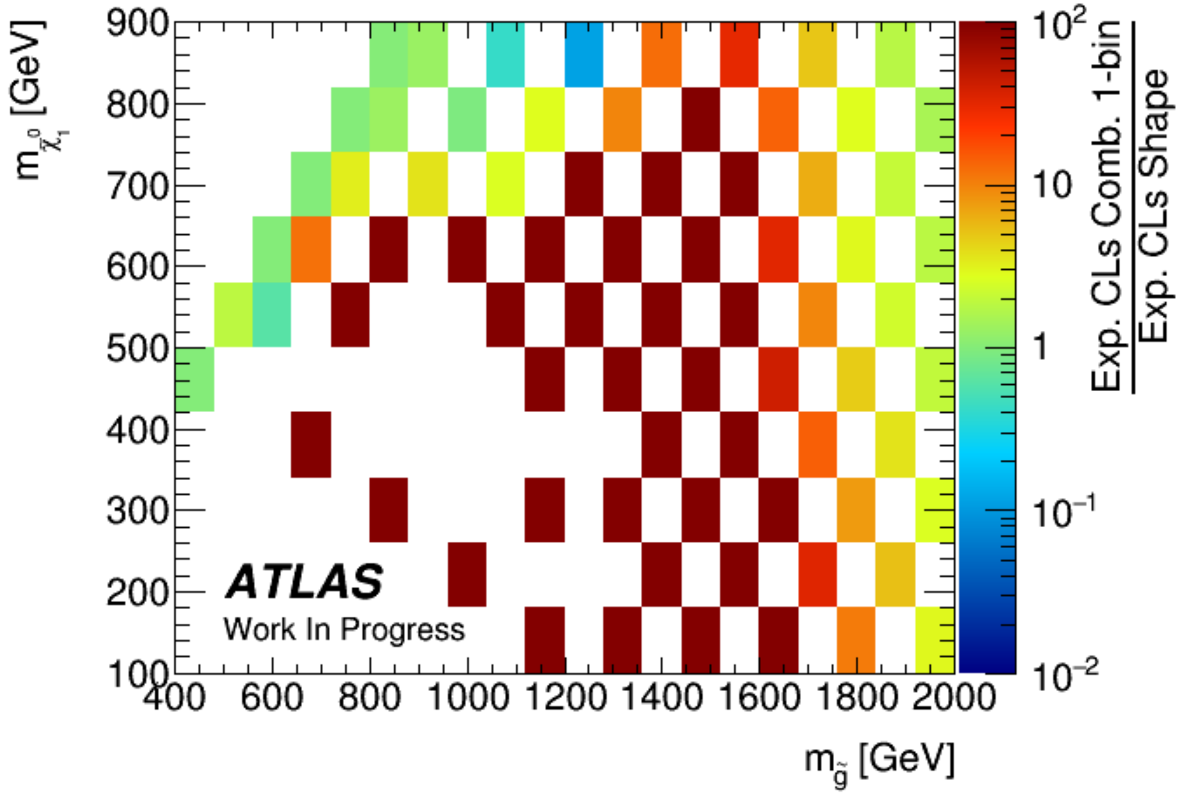



DiTau Shape Fit

- DiTau Shape Fit based on OpenShape SR
  - Simultaneous fit in 7 bins of ${m_T}^{\tau 1} + {m_T}^{\tau 2}$
  - Does not consider OneTau SRs (!)
- Exclusion almost compatible

# Expected Limits – Shape Fit Performance

- Shape fit change CLs values
- >1 → higher exclusion power
- Exclusion can become stronger



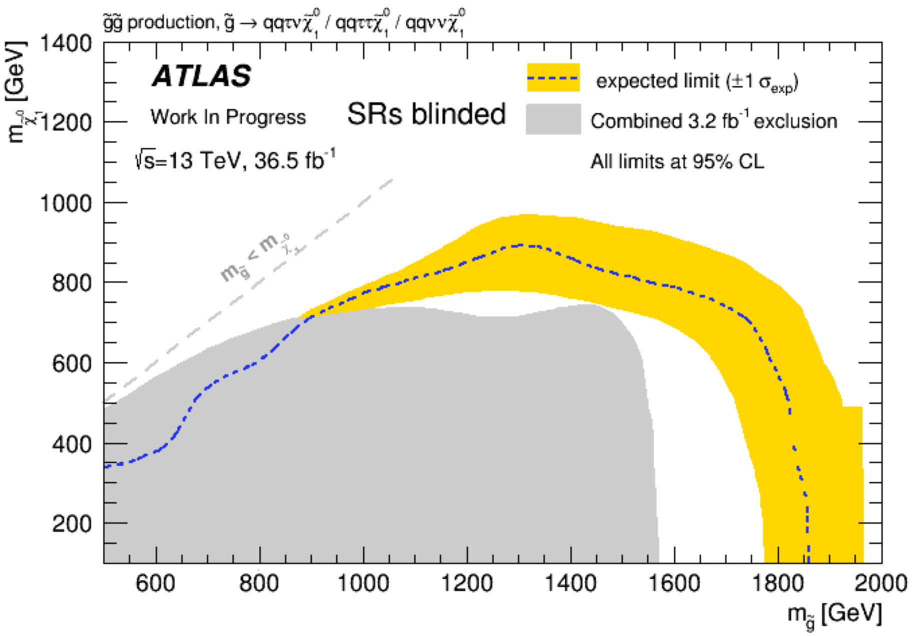

CLs comparison
Shape Fit vs. 1-bin Combination

# Take-Home Message

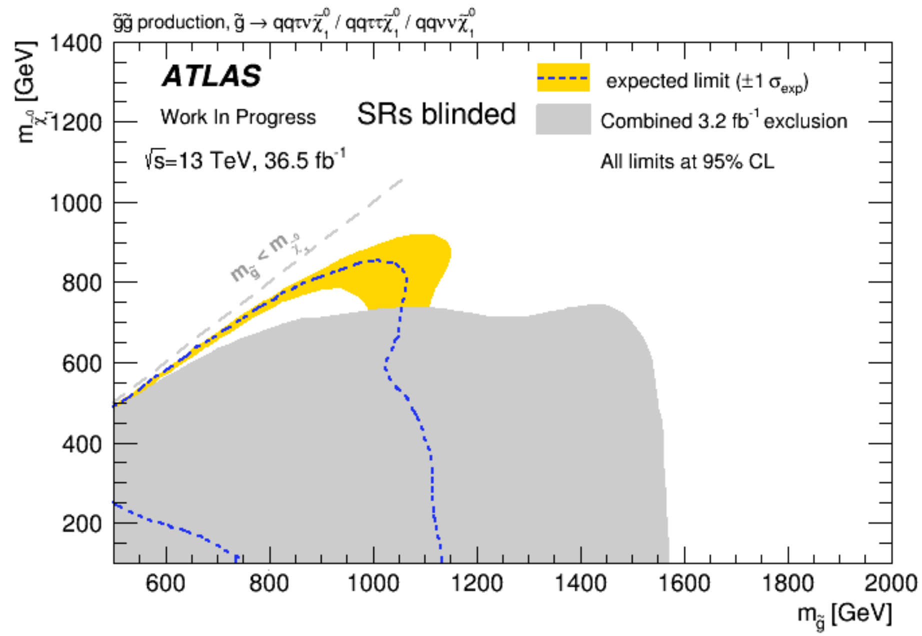
- Larger statistics (36.5 $fb^{-1}$ vs. 3.2 $fb^{-1}$) allow for new approaches
- Already implemented:
  - Fully orthogonal phasespace regions
    - One set of CRs for all SRs
    - Statistical combination in final fit
    - Good agreement between data and MC
  - Shape fits (multi-bin fits) in SRs
    - Improved limits
    - Stronger exclusions
  - Semi-data-driven QCD-Multijet estimate for all channels
- Yet to come / next steps
    - Shape fits in CRs
    - VR design

# Backup

# Expected Limits – OneTau Channels

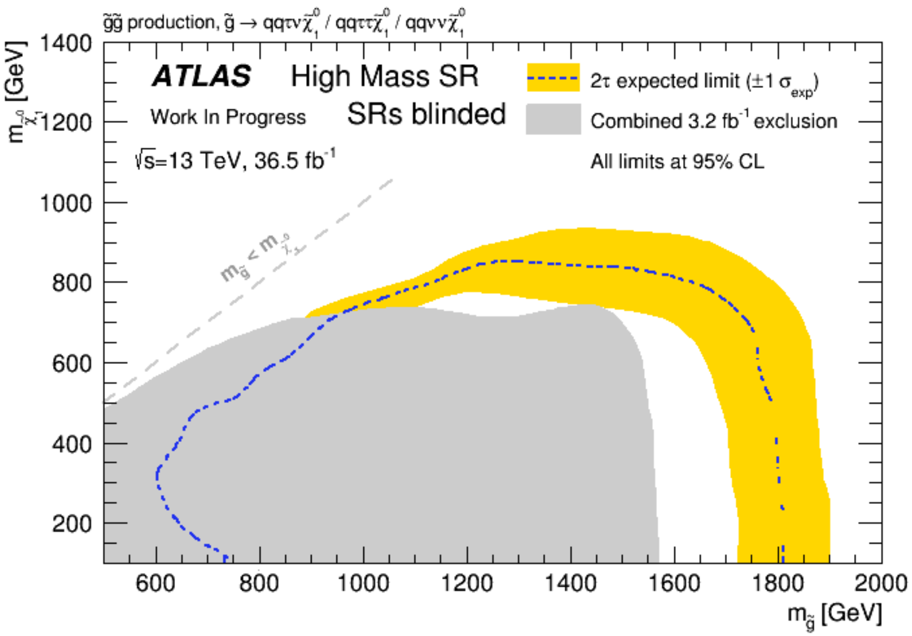



OneTau Medium-Mass SR, 1-bin

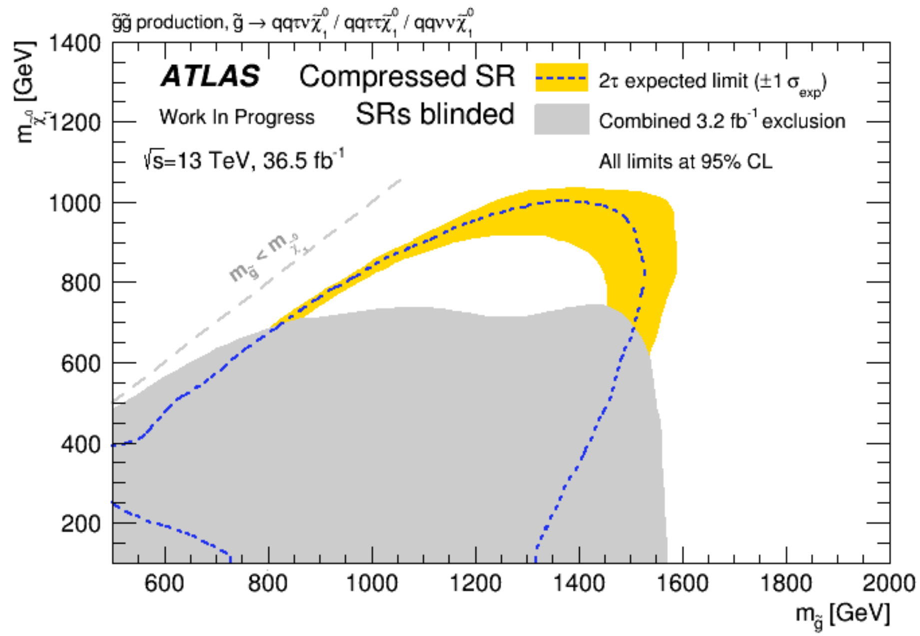



OneTau Compressed SR, 1-bin

# Expected Limits – DiTauChannels

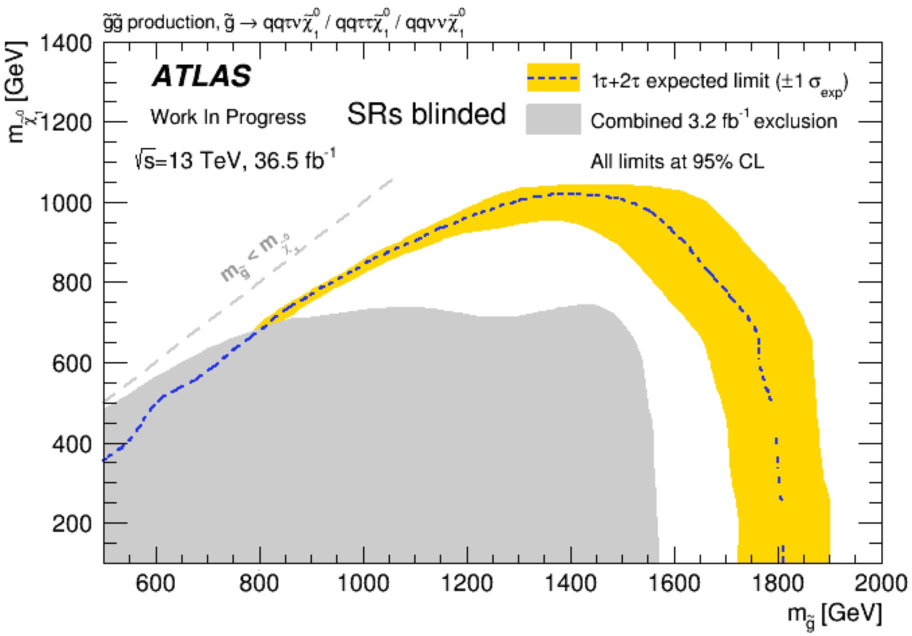



DiTau High-Mass SR, 1-bin

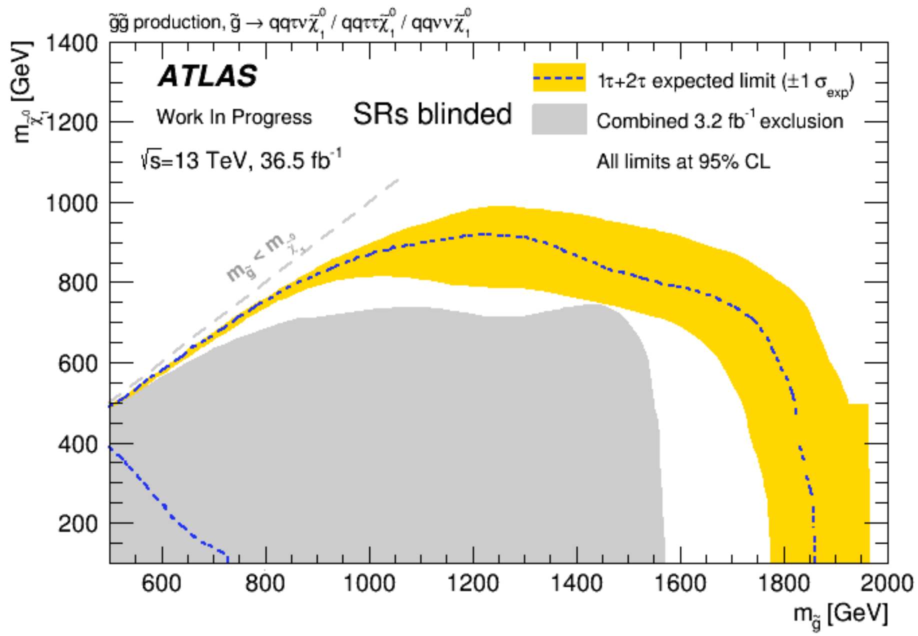



DiTau Compressed SR, 1-bin

# Expected Limits – One/DiTau Combination

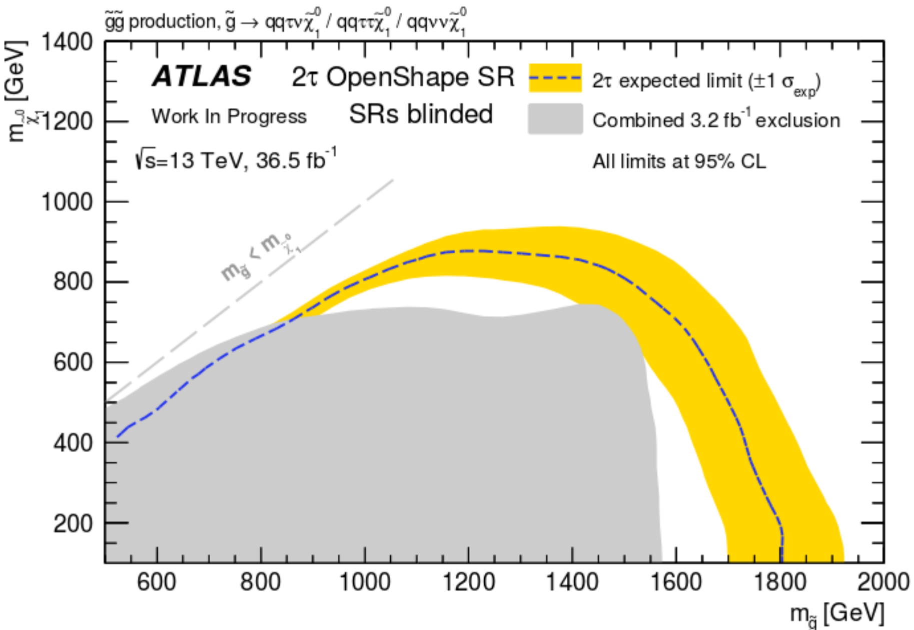



DiTau fully orthogonal combination, 1-bin

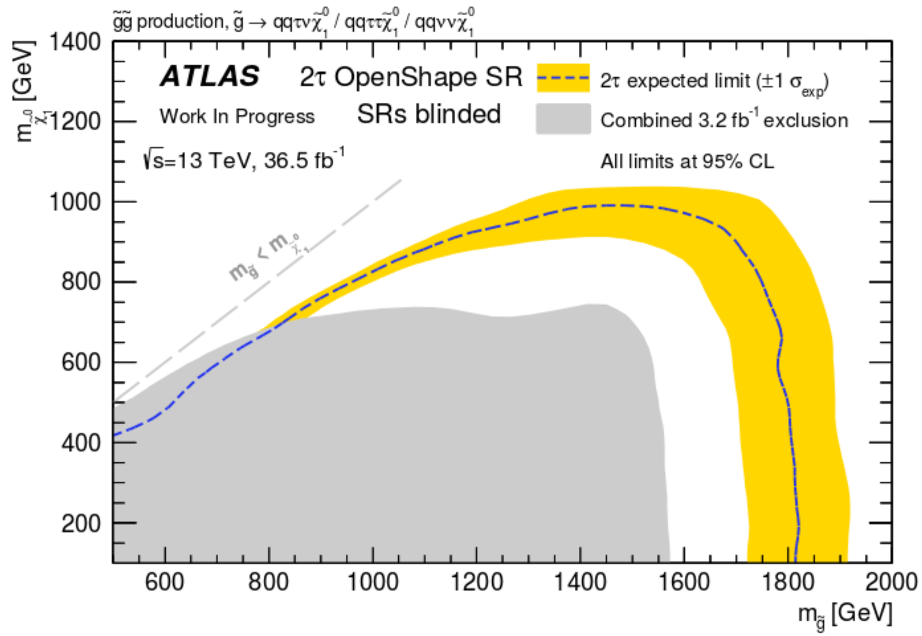



OneTau fully orthogonal combination, 1-bin

# Expected Limits – Shape Fit Performance




DiTau Shape Fit, 5 bins of $H_T$




DiTau Shape Fit, 7 bins of $m_T^{\tau 1} + m_T^{\tau 2}$