Recent results from searches for Supersymmetry at ATLAS

Boosting the sensitivity with the **full 13 TeV dataset**

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HEP Seminar
University College London

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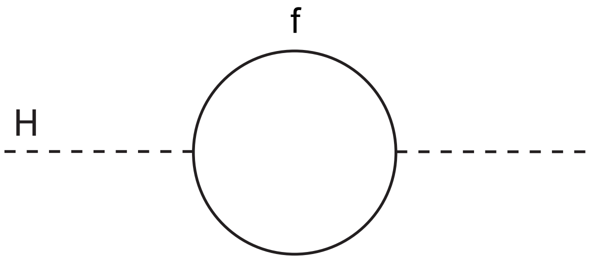
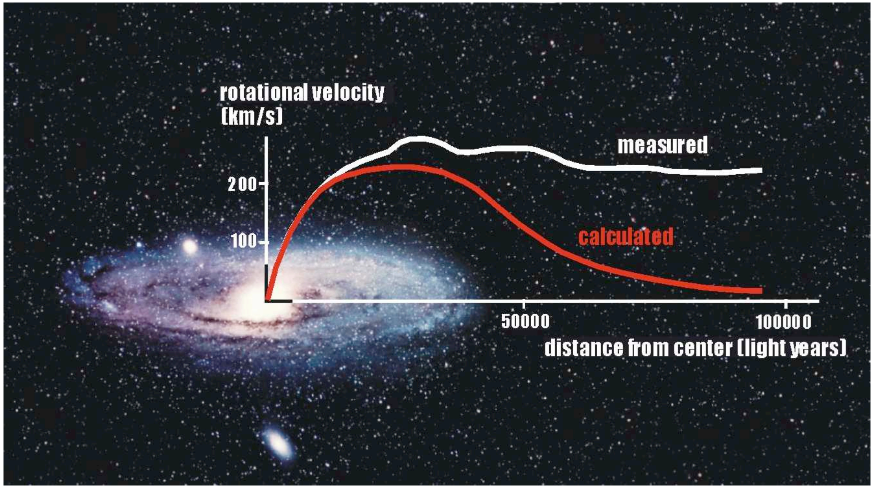
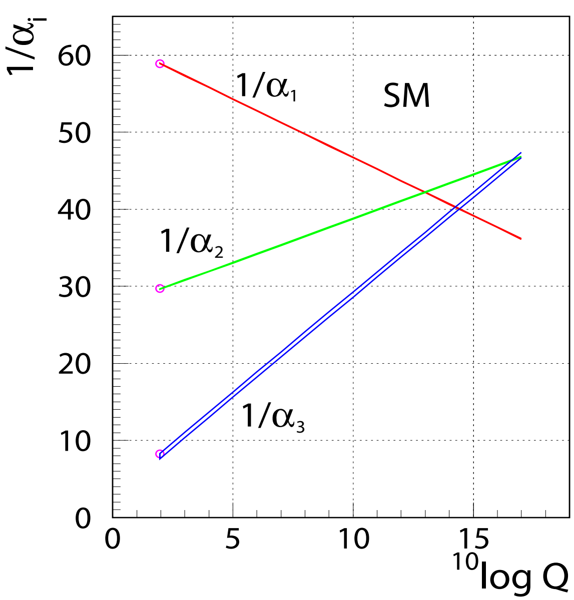
Open Questions of the Standard Model

- **Hierarchy problem**: Higgs mass subject to quadratically divergent loop corrections.
  → Incredible fine-tuning





- **Dark matter:** Cosmological data suggest presence of dark matter → No explanation within Standard Model



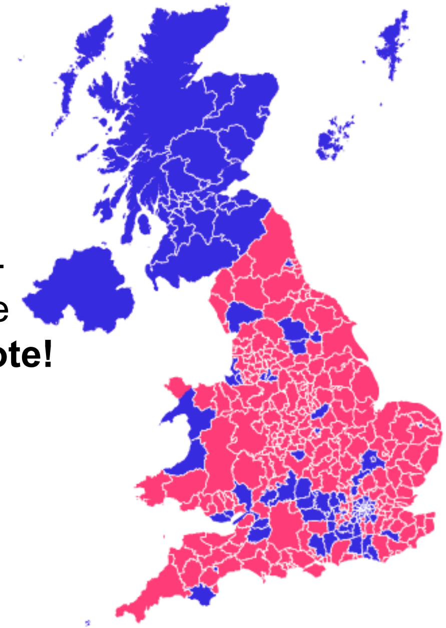
- **Grand unification:** Standard Model coupling constants do not unify at high scales.
  → SM does not imply a Grand Unified Theory

Never tired of analogies…

[source: http://www.quantumdiaries.org]

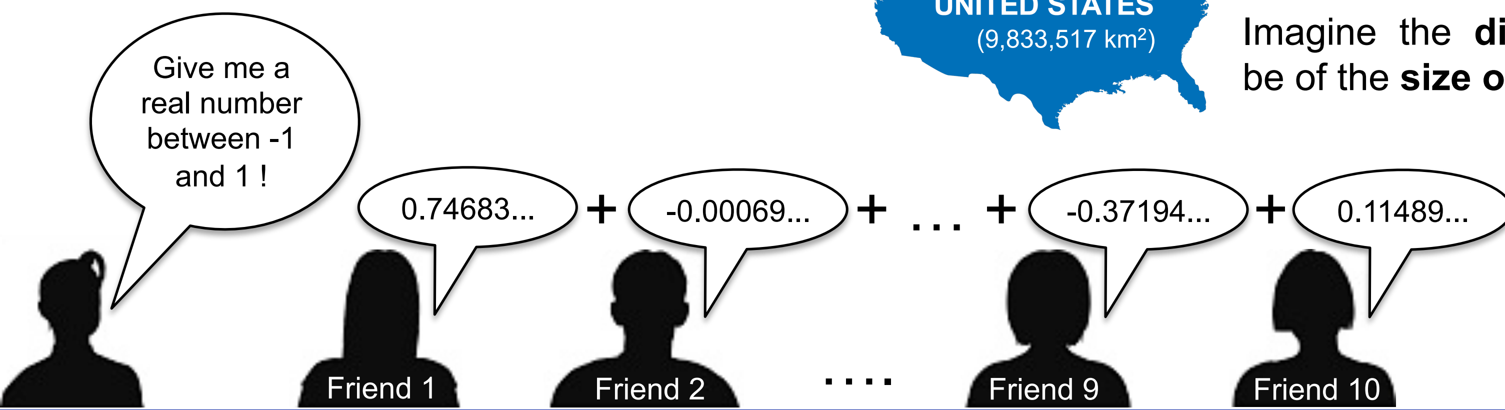
“The Higgs has a snowman’s chance in hell”

51.9% Leave 48.1% Remain



Imagine the remain-leave difference of the Brexit vote to be just the **10^{27}-th of a single vote!**

Surface areas by chance within ~ 1% (151,153 km²). Imagine the **difference** to be of the **size of an atom!**



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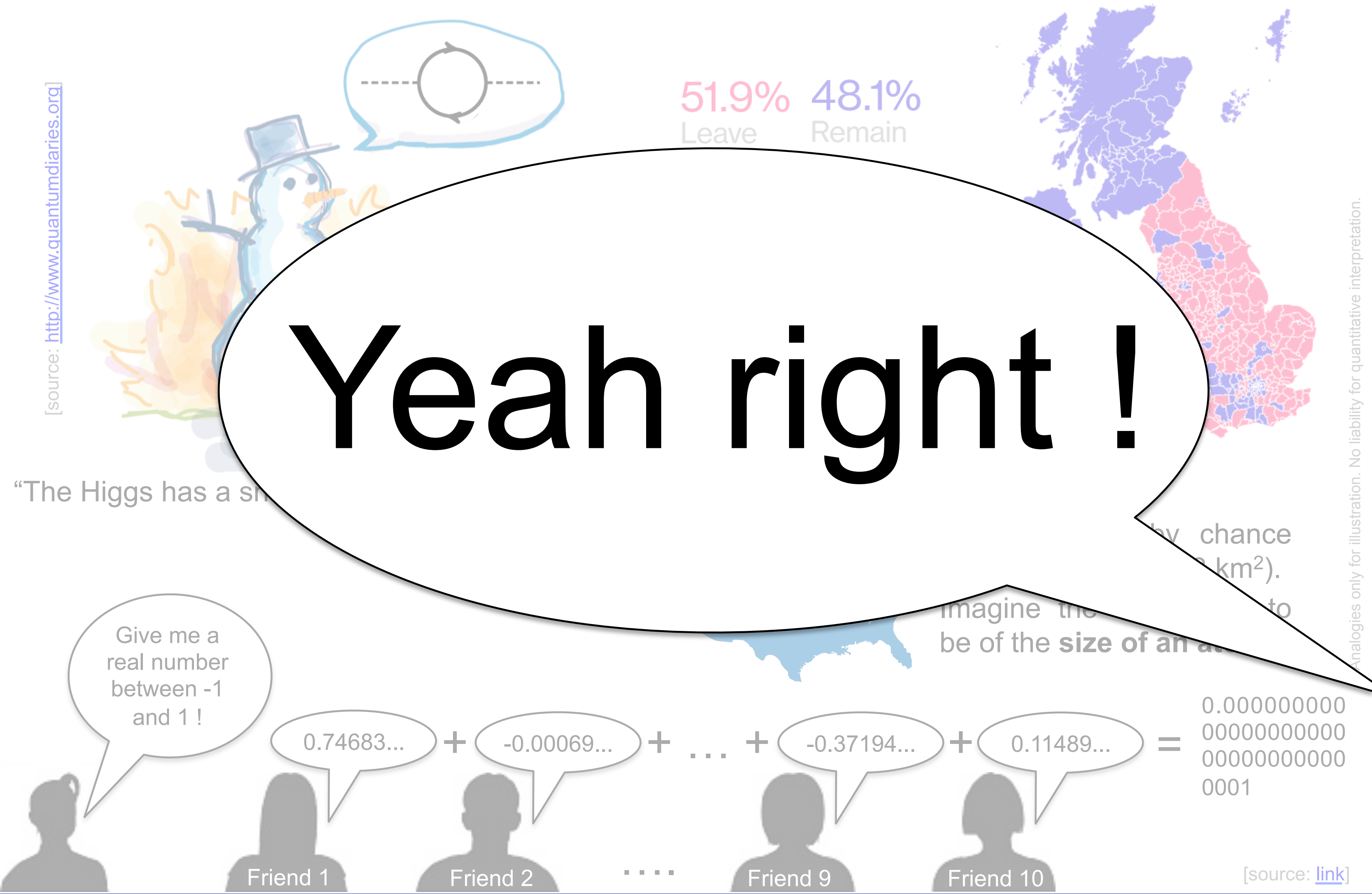
[source: link]

Analogies only for illustration. No liability for quantitative interpretation.

Never tired of analogies…



We need… Supersymmetry (SUSY)

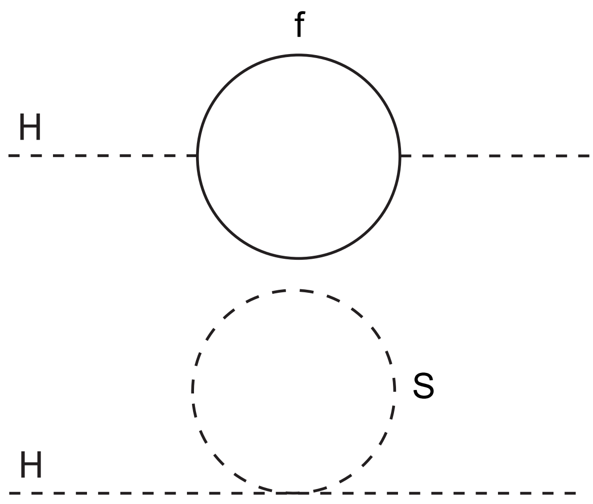
- Fundamental symmetry between fermions and bosons introducing a set of new partner particles to the SM particles with half-spin difference.

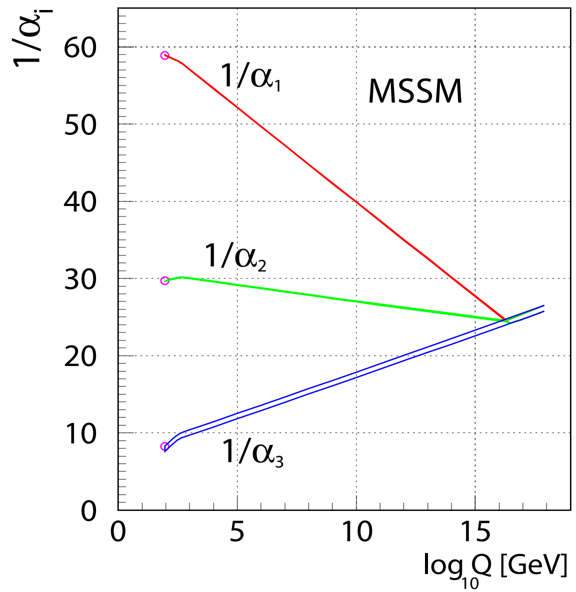
✓ Opposite-sign loop corrections from SUSY particles. Quadratic divergencies cancel. → No (little) fine-tuning.

✓ If R-parity conserved: Lightest SUSY Particle (LSP) stable. → Natural candidate for dark matter.

> R-parity = $(-1)^{3(B-L)+2s}$
> - SM particles: +1
> - SUSY particles: -1

✓ Unification of gauge couplings at $M_{GUT} \approx 10^{16}$ GeV

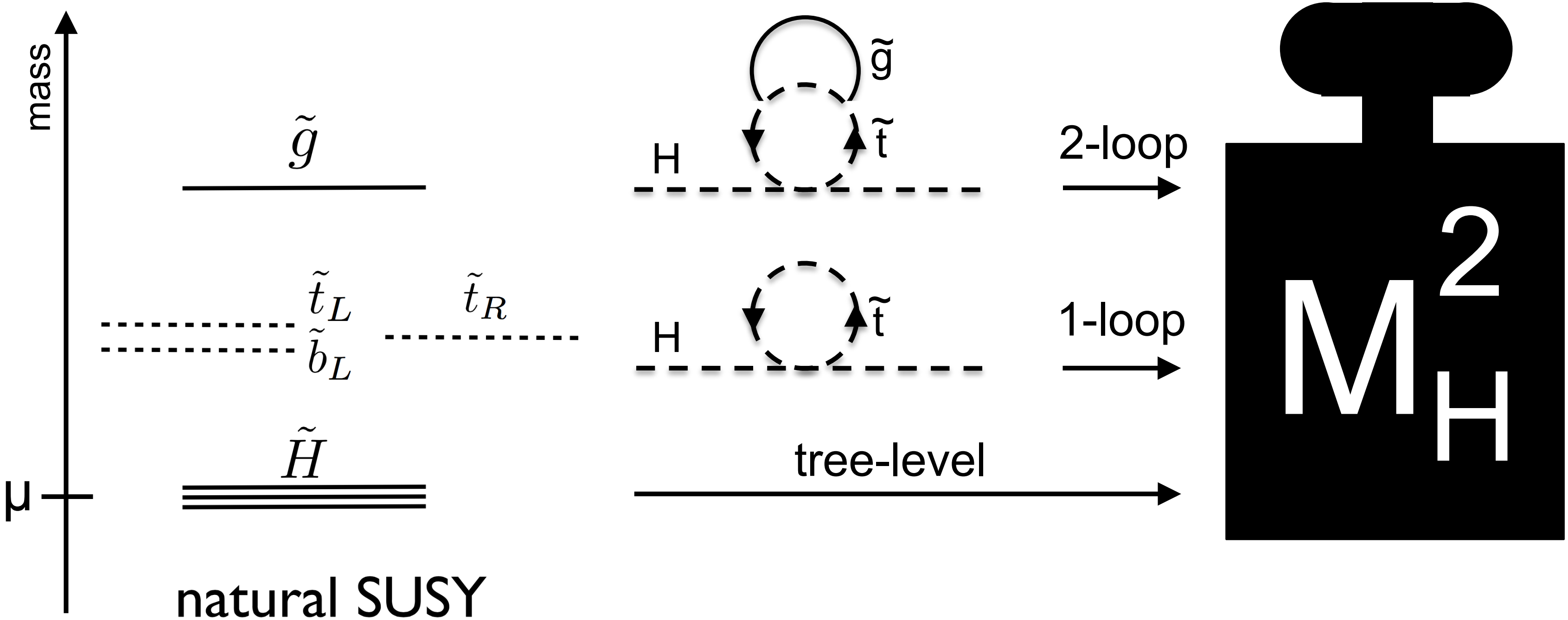




Not just any SUSY…

- Higgs boson discovery and strong experimental bounds have put vanilla SUSY under pressure
- Within the MSSM stop and gluino masses enter at **1 and 2 loop level** into the Higgs mass matrix, the Higgsino mass parameter μ **at tree level**

→ Search efforts focus around "**Natural SUSY**" (e.g. arXiv:1110.6926) with relatively **light gluinos, stops, higgsinos** (remaining SUSY particles can be decoupled at high masses)

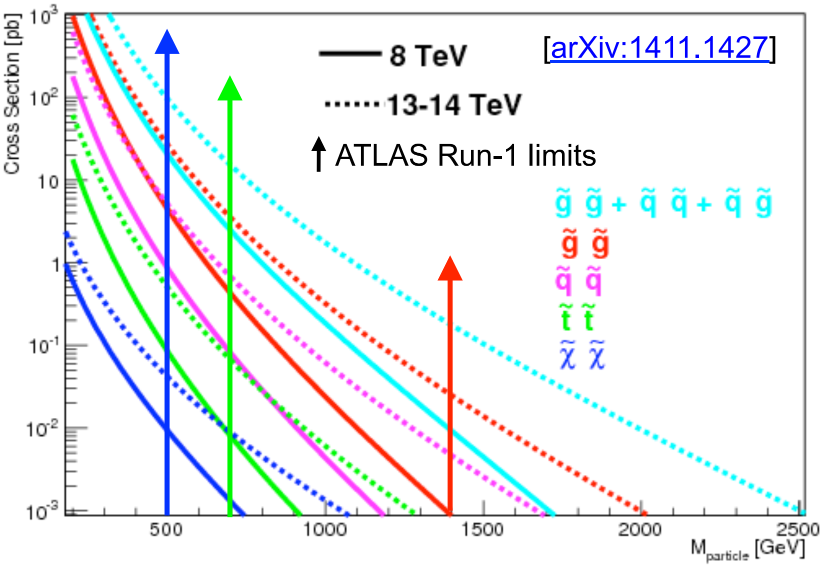


How to search for SUSY at the LHC

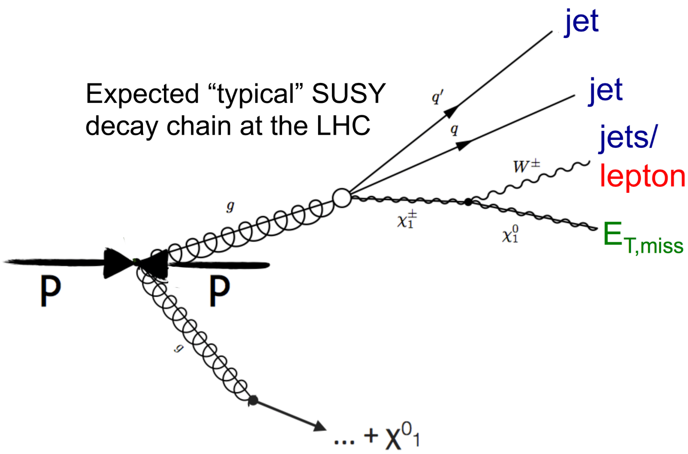
- If SUSY particles exist at LHC accessible energies:
  ① **R-parity conservation**
    - Pair-production via strong / EW interaction
    - Direct or cascade decays to the stable lightest SUSY particle (LSP).
    - Many high p_T SM decay products + large $E_{T,miss}$ (depending on the mass spectrum)

  ② **R-parity violation**
    - Multi-jets / multi-leptons signatures from LSP decay to SM particles
    - Displaced vertices from late LSP decays

  ③ **Long-lived particles**
    - Sparticles produced with long lifetimes due to mass degeneracy, small couplings, virtuality
    - Secondary decay vertex

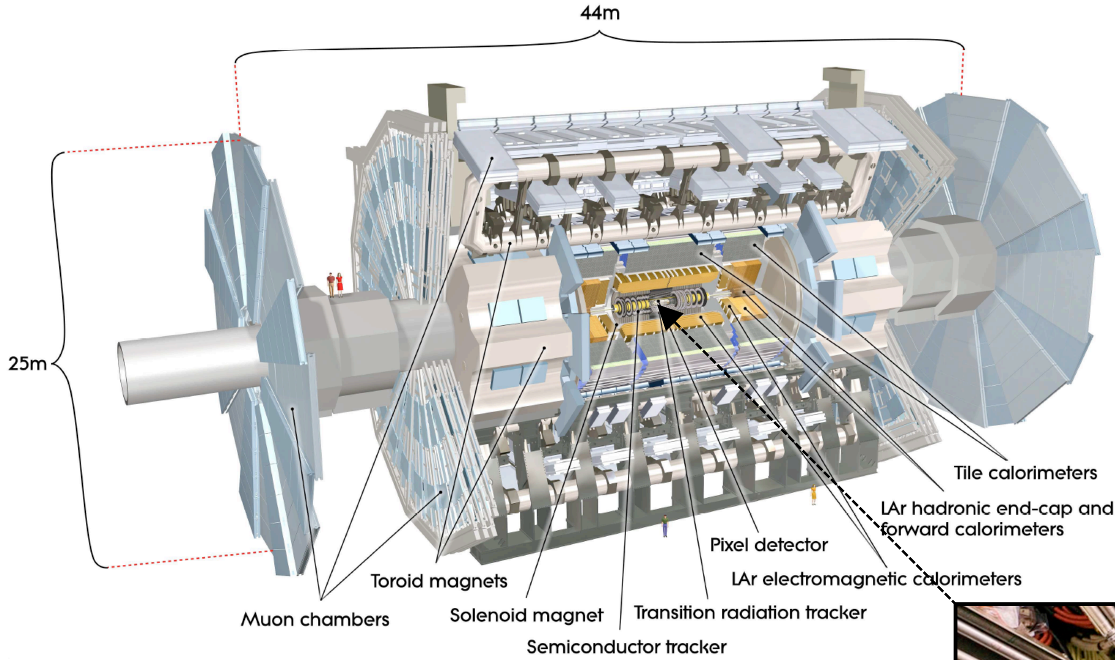


- Search strategy @ 13 TeV:
  → First data: **Gluino & 1st/2nd generation squark** searches have the largest potential due to enhanced cross-sections
  → Beyond ~10 fb^{-1}: Searches for **3rd generation squarks** and **EW production** start to exceed Run-1 sensitivity

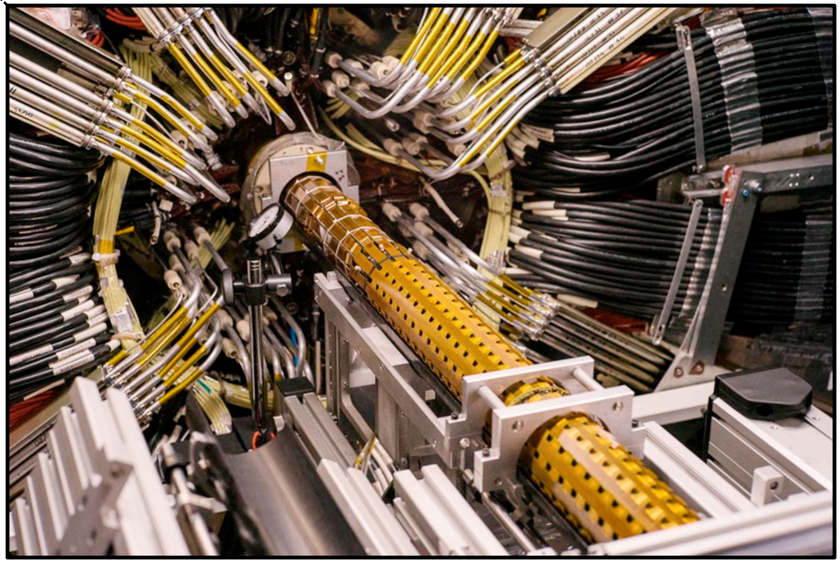


Tools & building blocks…

The ATLAS Experiment in Run-2



+ **New innermost pixel layer (IBL)** @ 3.3 cm from the beam line → additional 4th space-point measurement



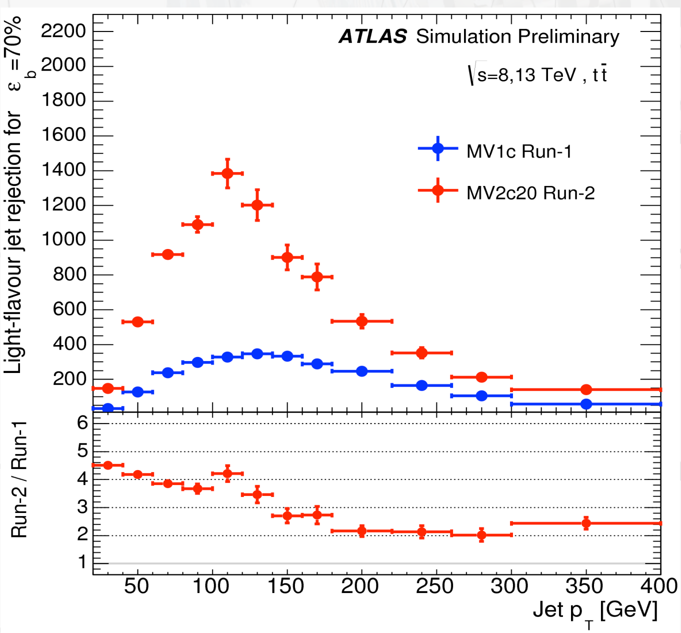
+ Upgraded **trigger/DAQ system** (improved bandwidths 75 kHz →100 kHz @ L1 & 1-1.5 kHz @ HLT)

+ Improved offline **reconstruction & analysis software**

+ …

The ATLAS Experiment in Run-2

- SUSY searches rely strongly on new **IBL**:
  - b-tagging crucial for many SUSY analyses: Improvements of a factor of 2 and more in light-flavour / c-jet rejection
  - Searches for long-lived particles: Improved track / secondary vertex reconstruction



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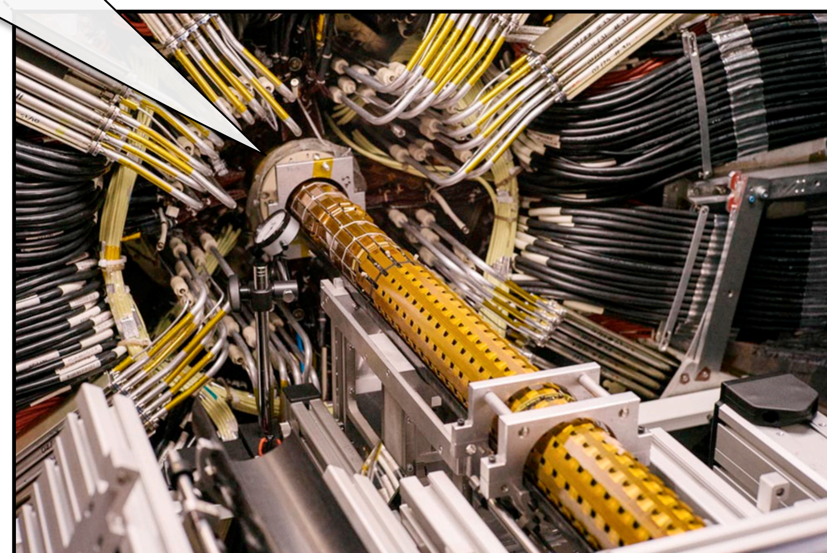
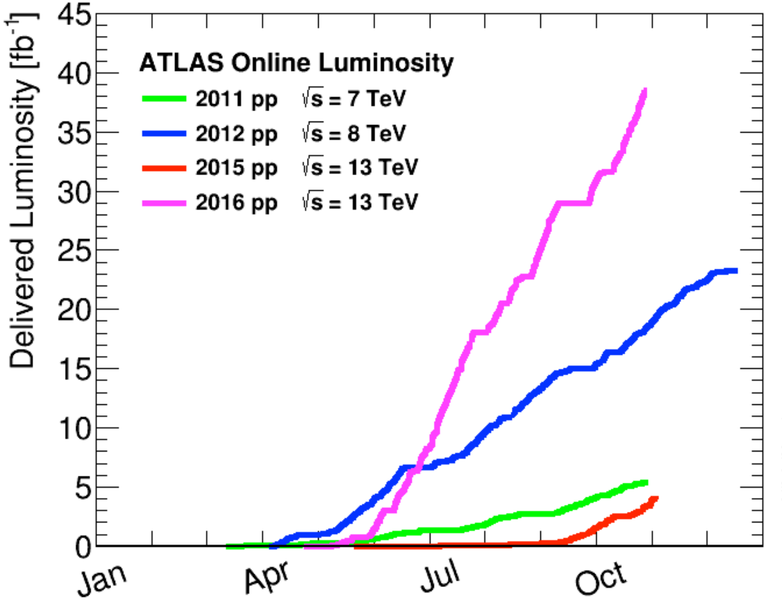
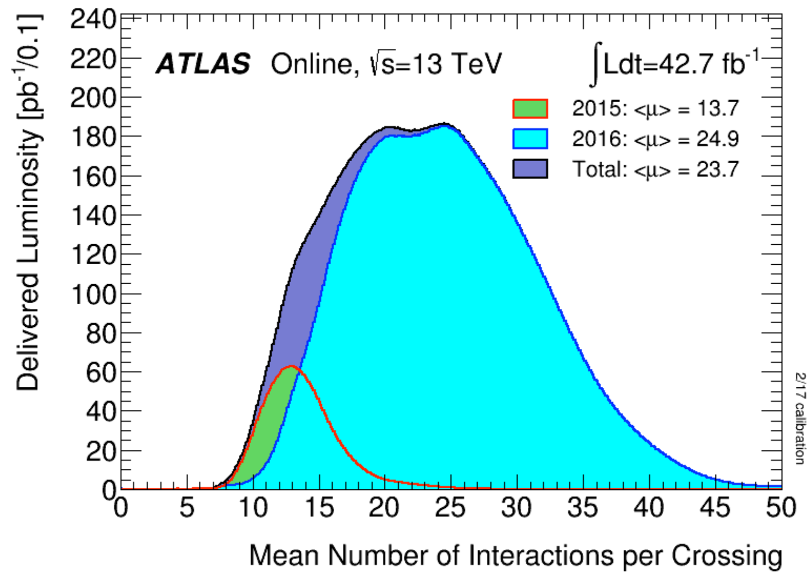


Data-taking 2015/2016

- Outstanding performance of the LHC in 2016:
  - **1680 hours** of **13 TeV** stable beams data-taking in 2016!
  - Peak instantaneous luminosity of **1.38 x 10^{34} cm^{-2} s^{-1}**
  - Pile-up of up to **50** interactions per crossing



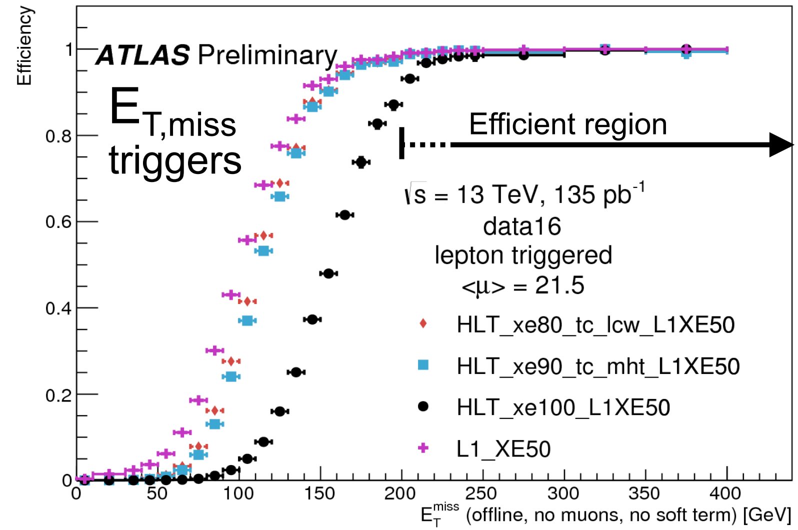
- Excellent Run-2 data-taking campaign for ATLAS:
  - **3.9 fb^{-1} + 35.6 fb^{-1}** recorded in 2015 + 2016
  - In total **36.1 fb^{-1}** (i.e. 91.4%) *good* for **SUSY searches**!

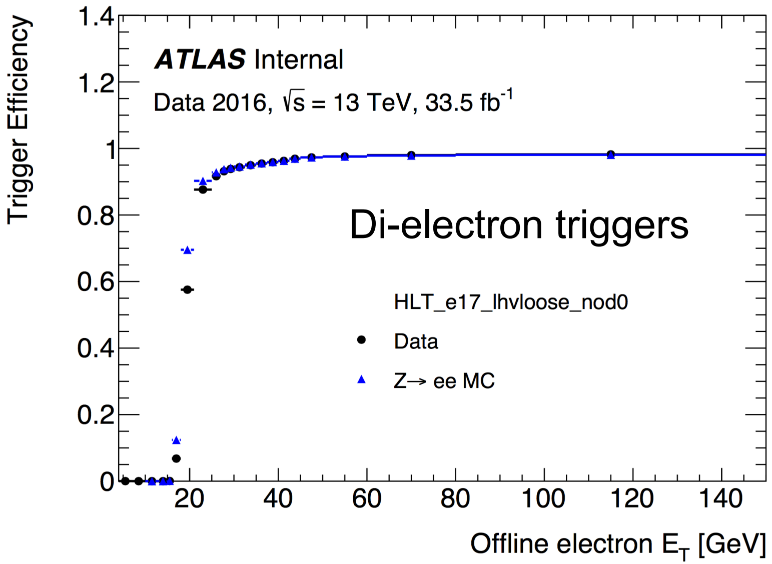


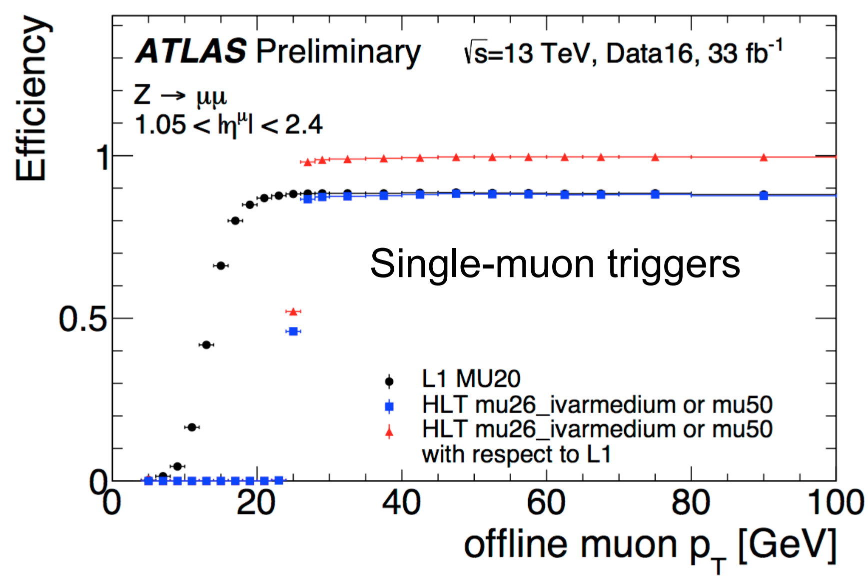
- Another ~43 fb^{-1} of data from 2017 (taken at record pile-up / luminosities conditions) on tape for future searches!!

Trigger Performance Highlights

- **ATLAS trigger and DAQ** systems form the basis for a successful data-taking
- Major **challenge** in 2016: **Maintain trigger performance** in fierce luminosity & pile-up conditions
- Main physics triggers for SUSY searches: Generic **$E_{T,miss}$, jet, lepton triggers**

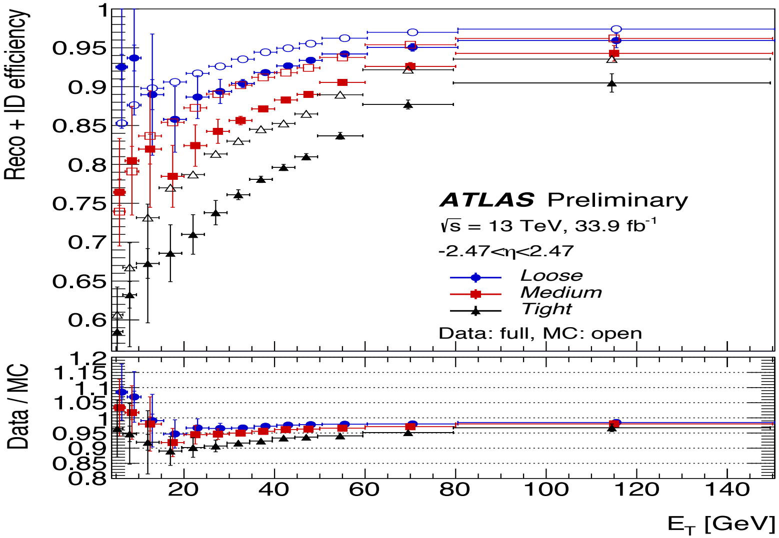




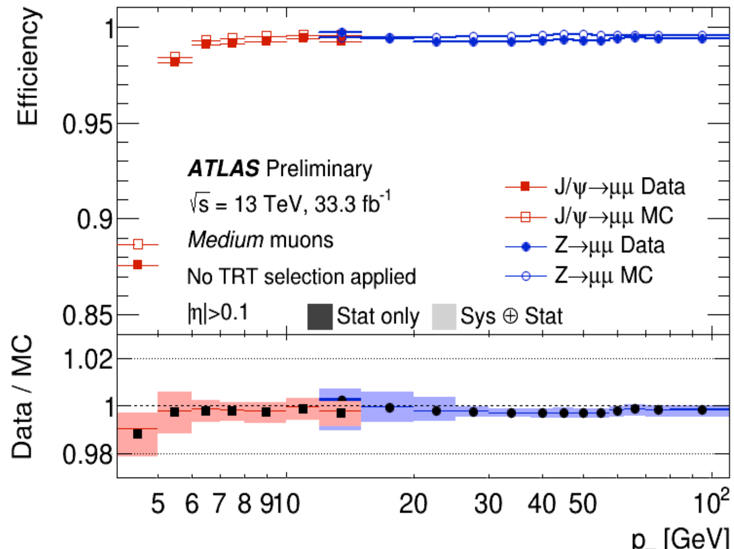


Detector Performance Highlights

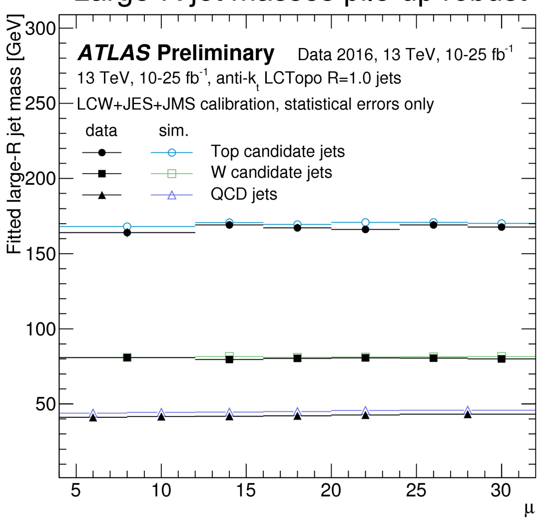
Electron performance measured down to 4.5 GeV



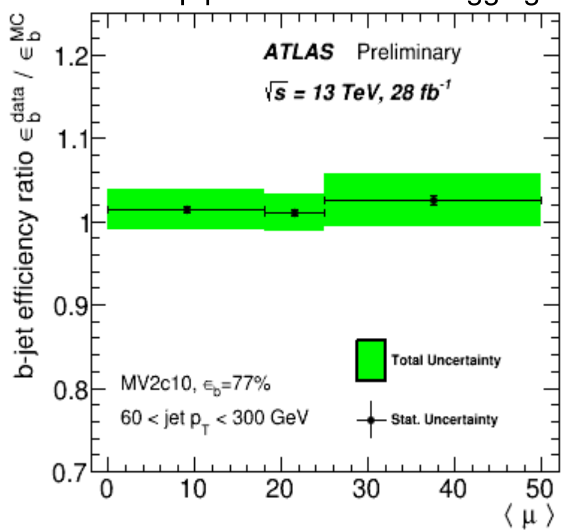
Muon performance measured down to 4 GeV



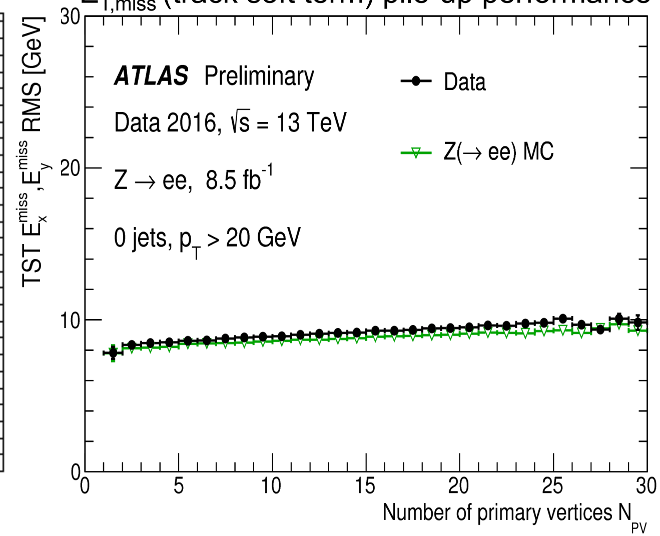
Large-R jet masses pile-up robust



Pile-up performance in b-tagging



$E_{T,miss}$ (track soft term) pile-up performance



Blueprint of a vanilla SUSY search

① Build signal regions (**SR**s) based on requirements on signal / background discriminating variables to target specific SUSY event topologies. Optimised for discovery & exclusion.

② Determine Standard Model background in the SRs:

Irreducible Backgrounds

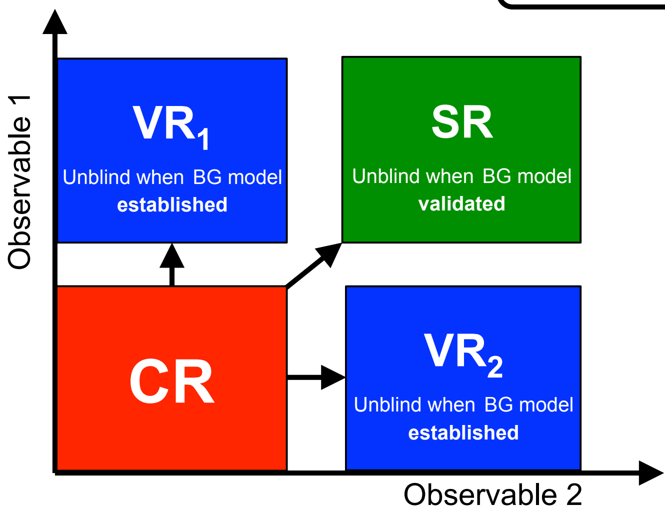
- Dominant processes:
  - MC normalised to data in process-enhanced control regions (**CR**s)
  - Extrapolation to validation regions (**VR**s) & **SR**s
- Subdominant processes: Pure MC predictions

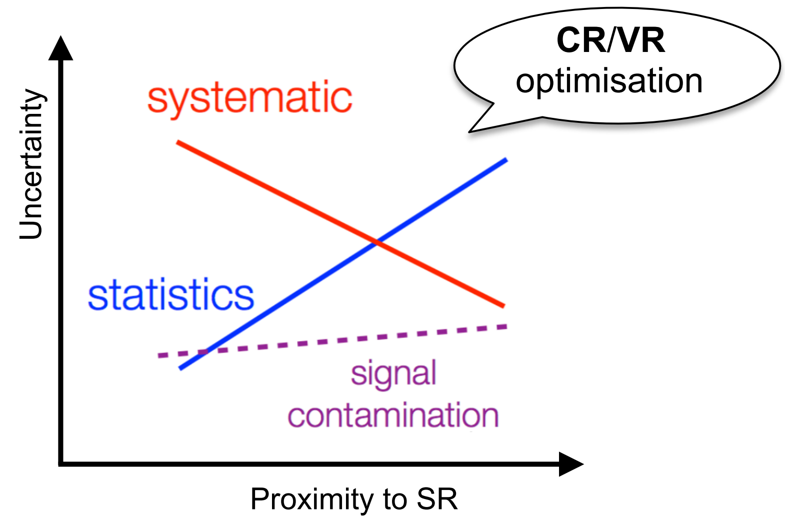
Reducible Backgrounds

- Fake $E_{T,miss}$, fake leptons backgrounds: Pure data-driven estimates
- Validation in **VR**s

Combined Fit

- Simultaneous fit of all components in **CR**s (and **SR**s for exclusion)





Discriminating variables in a nutshell

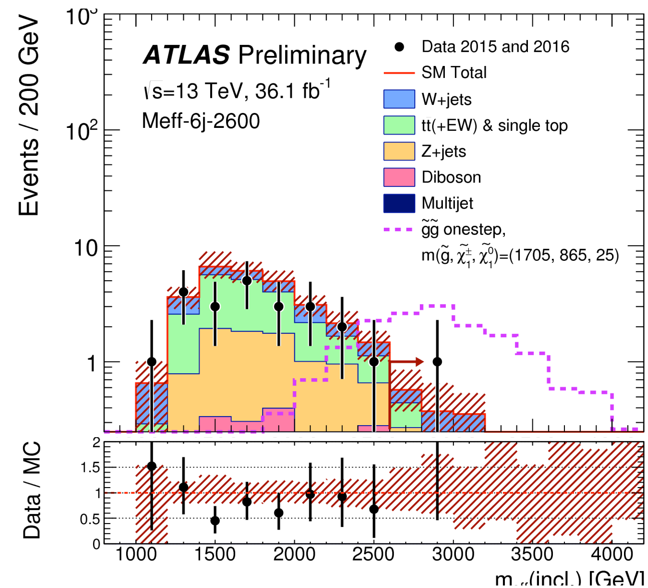
- Plethora of observables used by SUSY searches to maximally exploit event information:

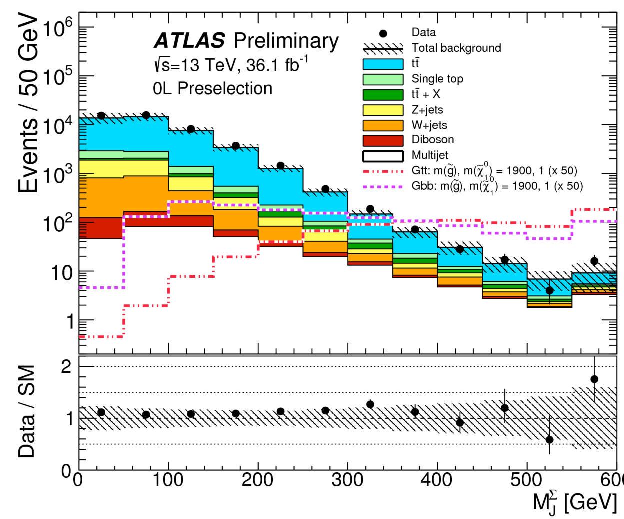
complexity

- Reconstructed object multiplicities, momenta, energies, e.g. $\mathbf{N_{jet/b\text{-}tag/\ell/\gamma}}$, $\mathbf{p_T}$, $\mathbf{E_{T,miss}}$, …
- Scale variables, e.g. $\mathbf{m_{eff}} = \Sigma p_T + E_{T,miss}$,
- Angular variables, e.g. **min** $\mathbf{\Delta\Phi}$(jet, $E_{T,miss}$), …
- Mass variables, e.g. $\mathbf{m_{\ell\ell}}$, $\mathbf{m_T^{b/\ell/j}}$, $\mathbf{\Sigma m_{fat\text{-}jet}}$, …
- Event shape variables, e.g. **Aplanarity**, …
- Hypothesis-based event variables e.g. $\mathbf{m_{T2}}$, …

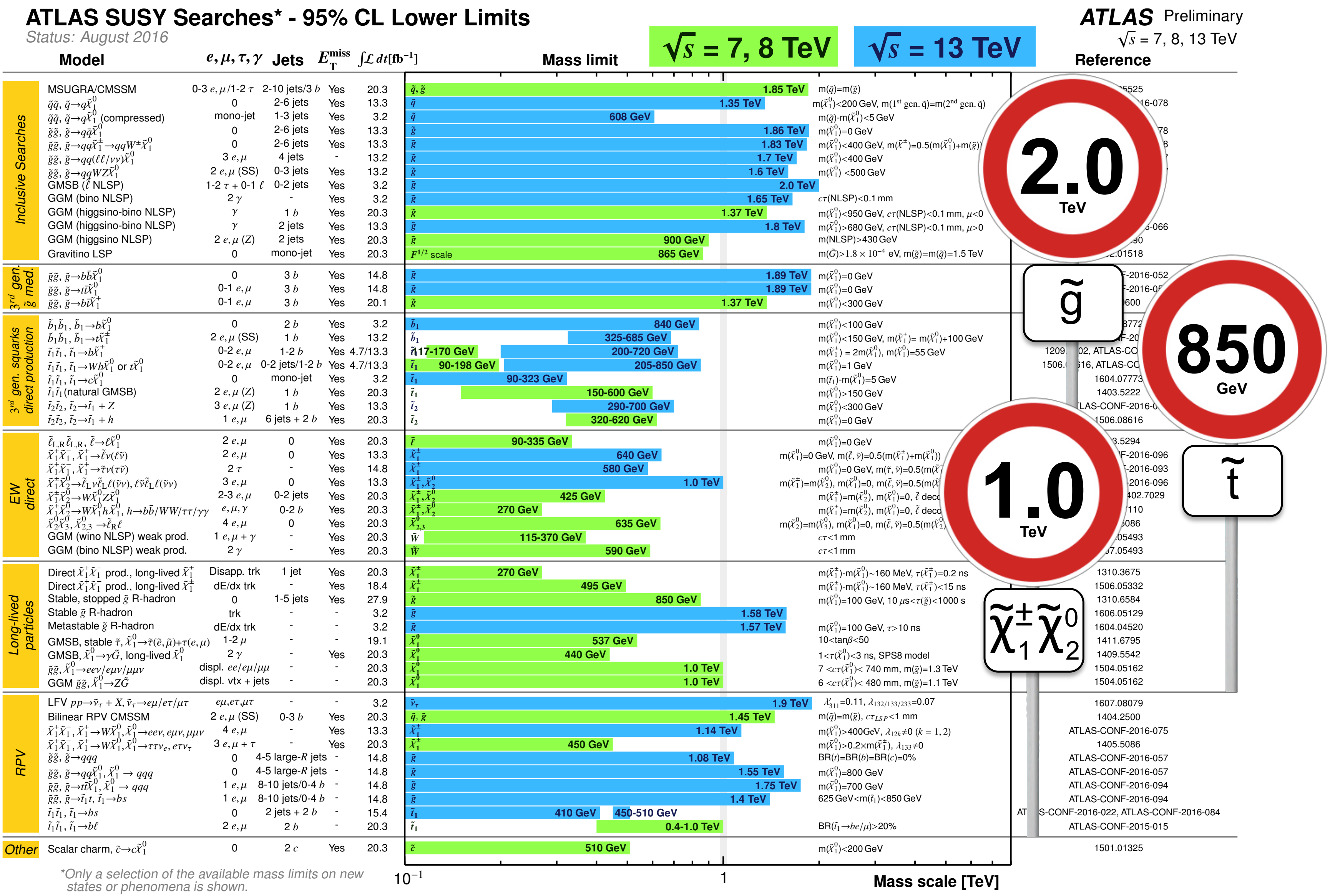
⋮

- More complex methods, e.g. new **recursive jigsaw reconstruction** [arxiv:1607.08307], …





ATLAS SUSY Searches: Status August '16



Results presented in this seminar

① **Inclusive searches for gluinos and squarks:**
- 1-ℓ + 2-9 jets + $E_{T,miss}$ [arXiv:1708.08232]

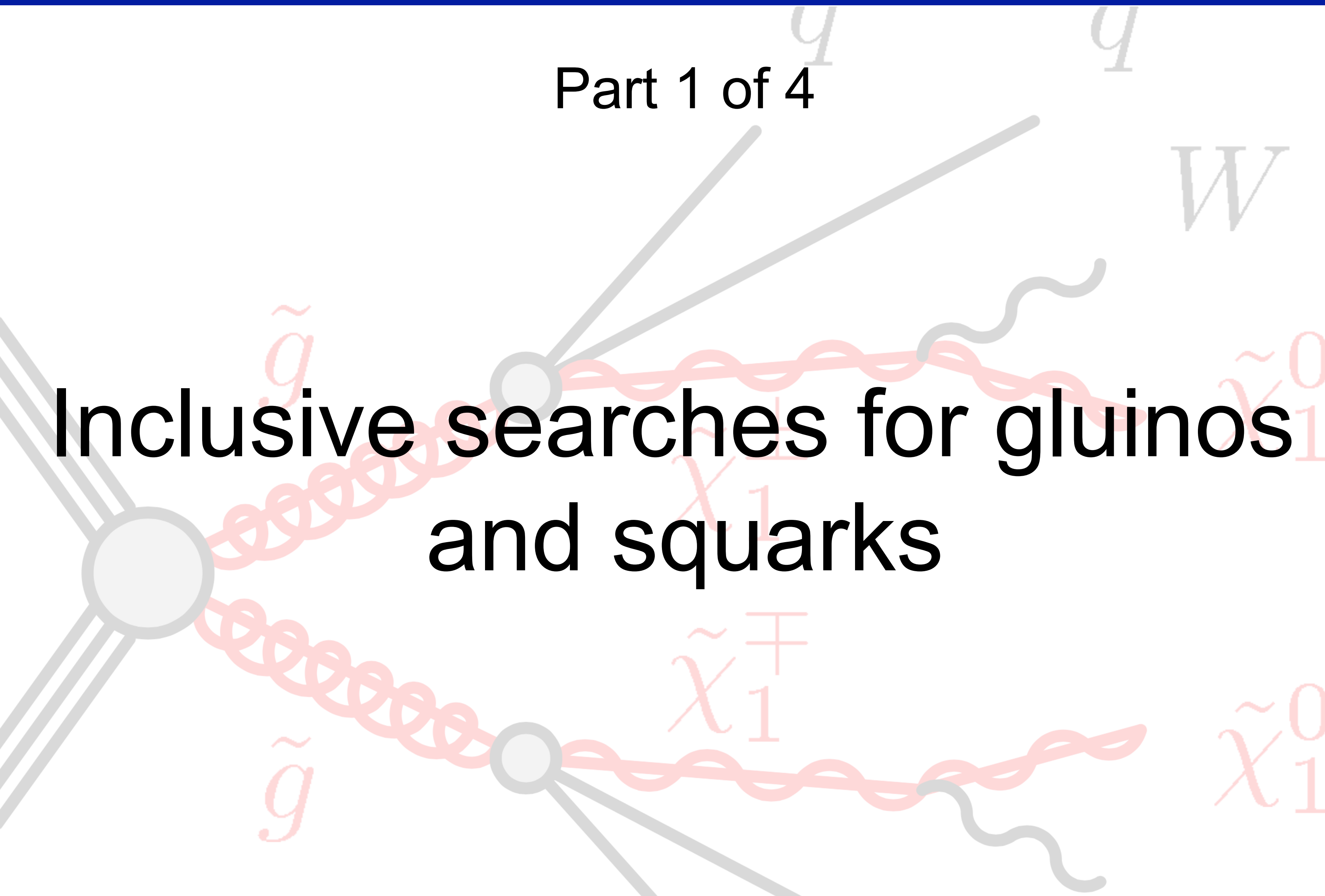
② **Searches for direct production of 3^{rd} generation squarks:**
- 0-ℓ + b-jets + $E_{T,miss}$ [arXiv:709.04183]

③ **Searches for electro-weak production of SUSY particles:**
- 2/3-ℓ + $E_{T,miss}$ [ATLAS-CONF-2017-039]

④ **Searches for long-lived particles:**
- Disappearing track signature (search for long-lived charginos) [ATLAS-CONF-2017-017]

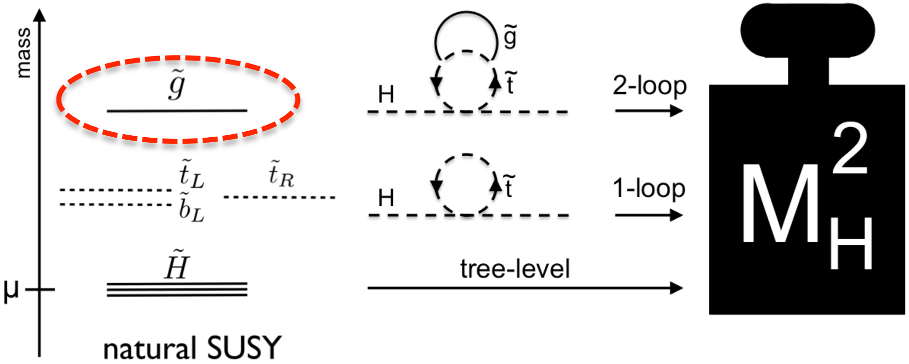
- All results available on the ATLAS SUSY public webpage:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults (contains 18 results with the full 2015+2016 dataset)

Part 1 of 4

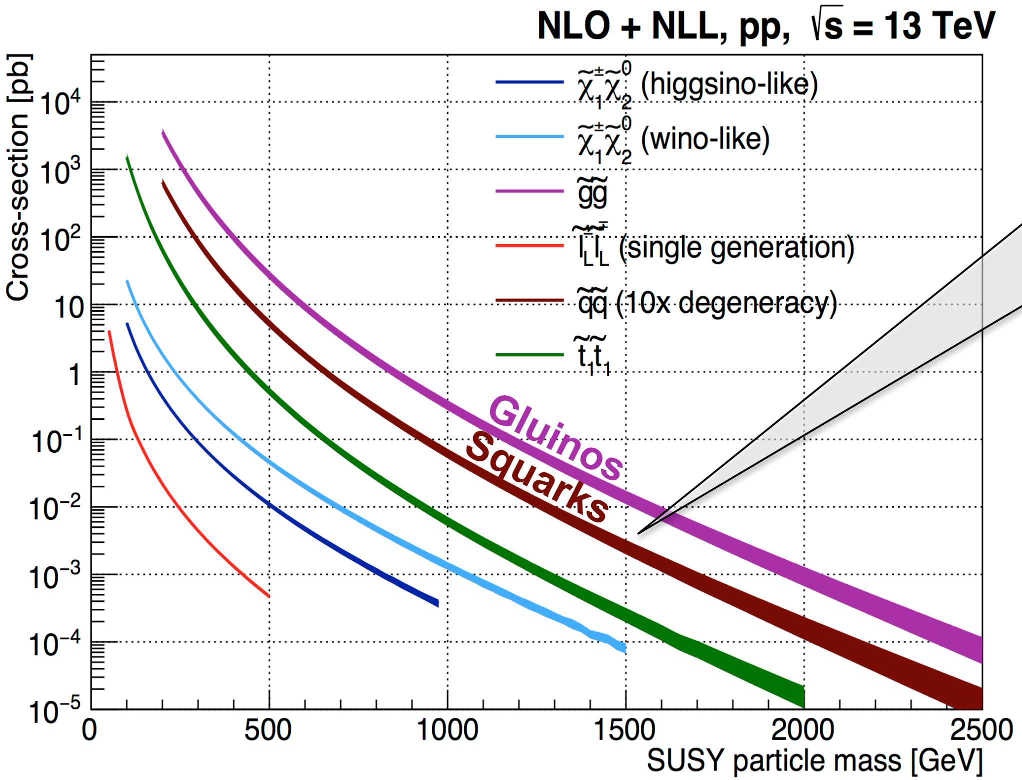


Inclusive searches for gluinos and squarks

Why Inclusive Searches for Gluinos / Squarks?



- TeV-scale Gluino's strongly motivated in the context of naturalness!



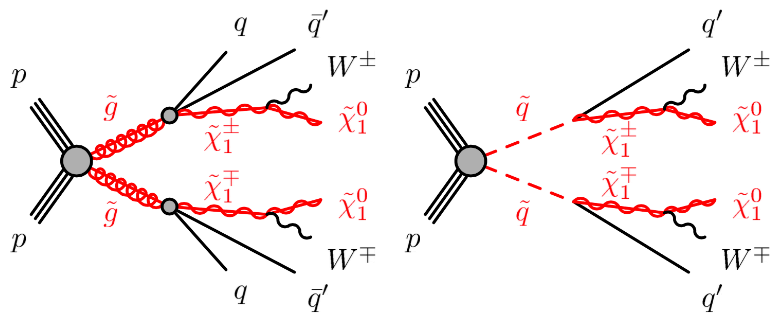
- Large cross-sections & large cross-section increase from 8 TeV to 13 TeV at high mass: Easiest and most promising signatures in the first 13 TeV data

+ Inclusive selections to remain sensitive to generic new physics signals

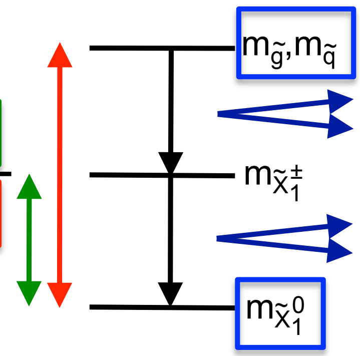
1-ℓ + jets + E_T^{miss} Search: Signal Regions

- Target final state: **1 lepton (soft/hard) + jets + E_T^{miss}**
- Two analysis streams

  (1) "2-6 jet stream": Targeting simplified models with gluino/squark production and 1-step decay via chargino to LSP



$$x = \frac{m_{\tilde{\chi}^{\pm}} - m_{\tilde{\chi}_1^0}}{m_{\tilde{g}/\tilde{q}} - m_{\tilde{\chi}_1^0}}$$



→ **Two model planes** to probe optimal slices of parameter space with x = ½ or variable x

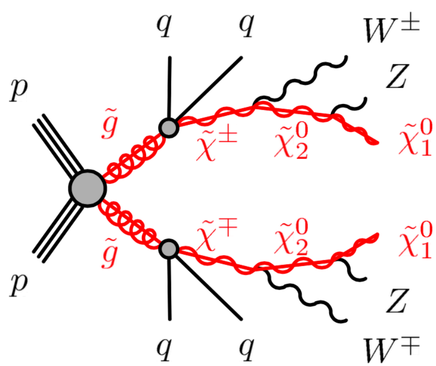
SR	2J	4J high-x	4J low-x	6J
N_ℓ	= 1	= 1	= 1	= 1
p_T^ℓ [GeV]	> 7(6) for $e(\mu)$ and < $\min(5 \cdot N_{jet}, 35)$	> 35	> 35	> 35
N_{jet}	≥ 2	4–5	4–5	≥ 6
E_T^{miss} [GeV]	> 430	> 300	> 250	> 350
m_T [GeV]	> 100	> 450	150–450	> 175
Aplanarity	–	> 0.01	> 0.05	> 0.06
E_T^{miss}/m_{eff}	> 0.25	> 0.25	–	–
N_{b-jet} (excl)	= 0 for b-veto, ≥ 1 for b-tag			
m_{eff} [GeV] (excl)	3 bins ∈ [700,1900] + [> 1900]	2 bins ∈ [1000,2000] + [> 2000]	2 bins ∈ [1300,2000] + [> 2000]	3 bins ∈ [700,2300] + [> 2300]
m_{eff} [GeV] (disc)	> 1100	> 1500	> 1650(1300) for gluino (squark)	> 2300(1233) for gluino (squark)

- **4 exclusive signal regions** targeting different mass splittings
- Includes **soft-lepton** 2J region to target compressed scenarios
- For discovery: Tight cuts on m_{eff}
- For exclusion: Further binning in m_{eff} and $N_{b\text{-}jet}$ to (28 regions in total) to maximise sensitivity to a wide range of models

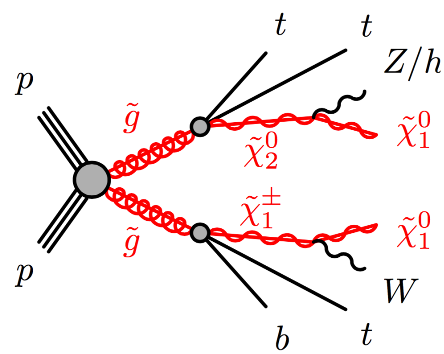
1-ℓ + jets + E_T^{miss} Search: Signal Regions

- Target final state: **1 lepton (soft/hard) + jets + E_T^{miss}**
- Two analysis streams

  (2) "9 jet stream": Targeting models with higher jet multiplicities:



"2-step W/Z"



"0-lepton + multi-jets pMSSM slice" ~

example decay chain

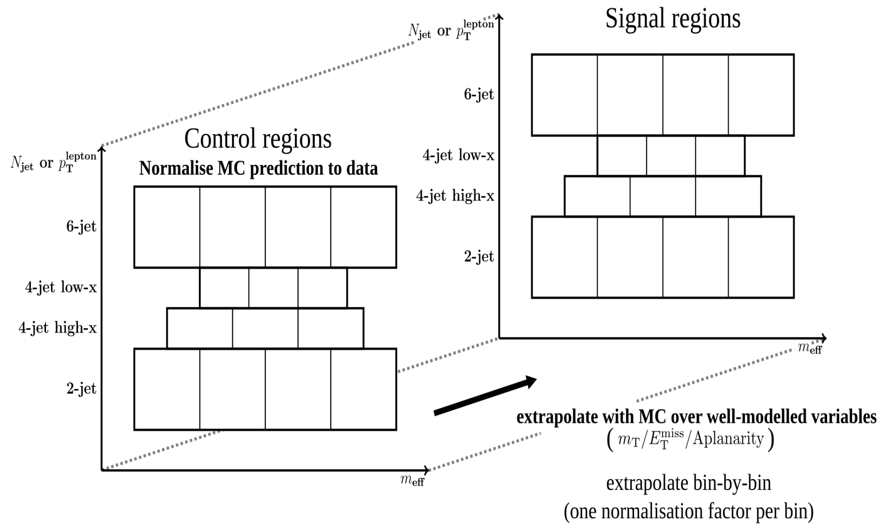
SR	9J
N_ℓ	= 1
p_T^ℓ [GeV]	> 35
N_{jet}	≥ 9
E_T^{miss} [GeV]	> 200
m_T [GeV]	> 175
Aplanarity	> 0.07
$E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$]	≥ 8
m_{eff} [GeV] (excl)	[1000, 1500], [>1500]
m_{eff} [GeV] (disc)	> 1500

- **Dedicated 9-jet signal region**
- For discovery: Tight cut on m_{eff}
- For exclusion: Binning in m_{eff} to maximise sensitivity

1-ℓ + jets + E_T^{miss} Search: Backgrounds

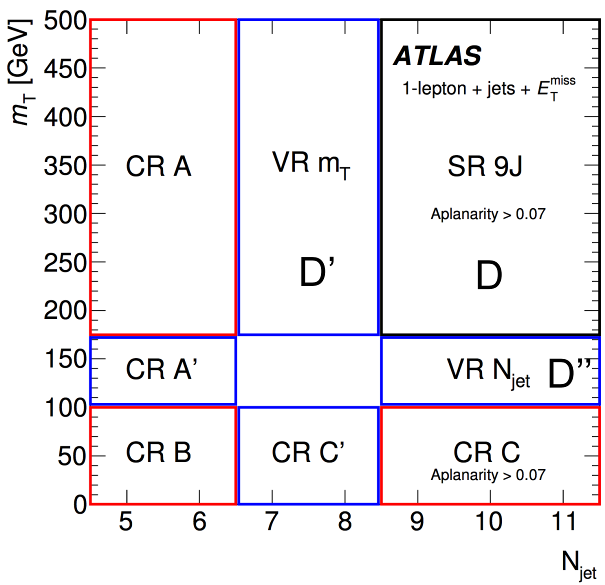
2-6 jet stream:

- Dominant **top & W+jets** backgrounds:
  - Dedicated control regions **in each m_{eff} bin** + extrapolation to **validation** and signal regions
- Other Backgrounds: Z+jets, tt+V, di-boson
  - From simulation



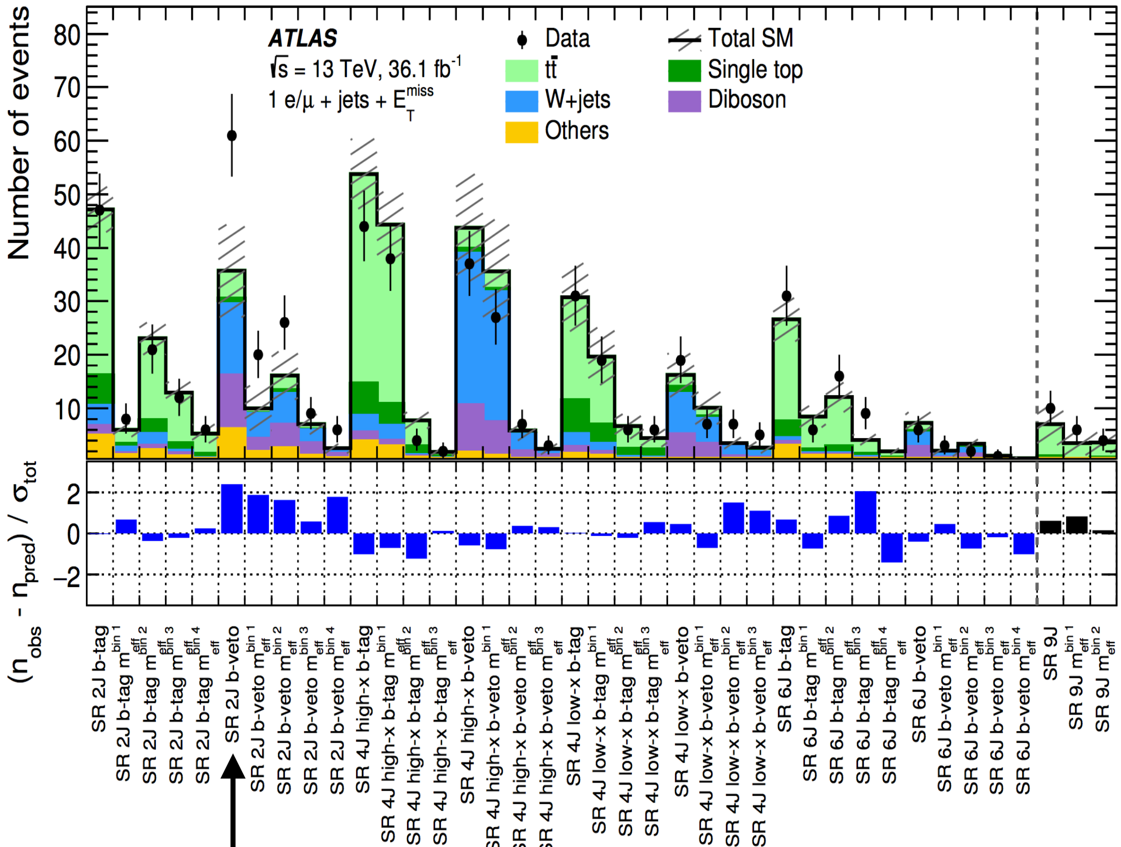
9 jet stream:

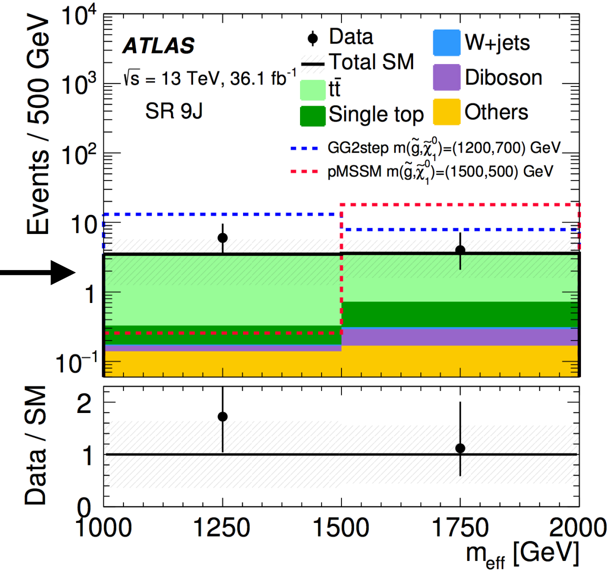
- Dominant **top & W+jets** background:
  - "ABCD" method based on invariance of transverse mass with jet multiplicity (~valid for tight cuts on m_{eff})
  - Simulation-based closure parameter to correct for residual correlations
  - Validation using ABC'D' and A'BCD'' setups
- Other Backgrounds: Z+jets, tt+V, di-boson
  - From simulation

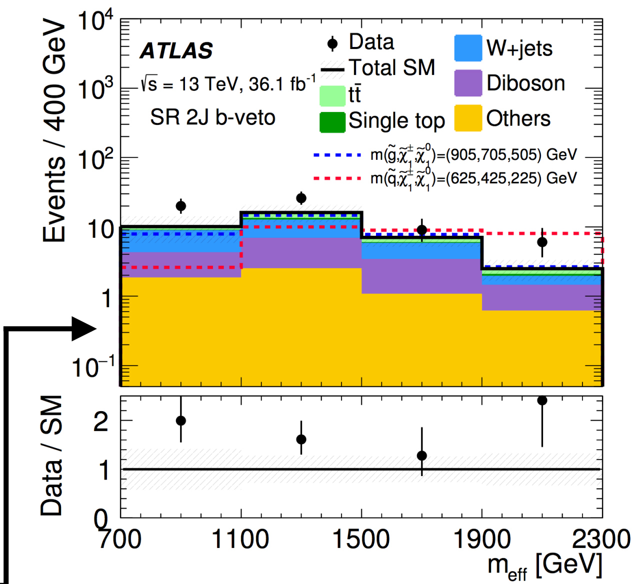


1-ℓ + jets + E_T^{miss} Search: Results

→ **No significant deviation** from the Standard Model expectation (largest deviation just above 2 sigma)

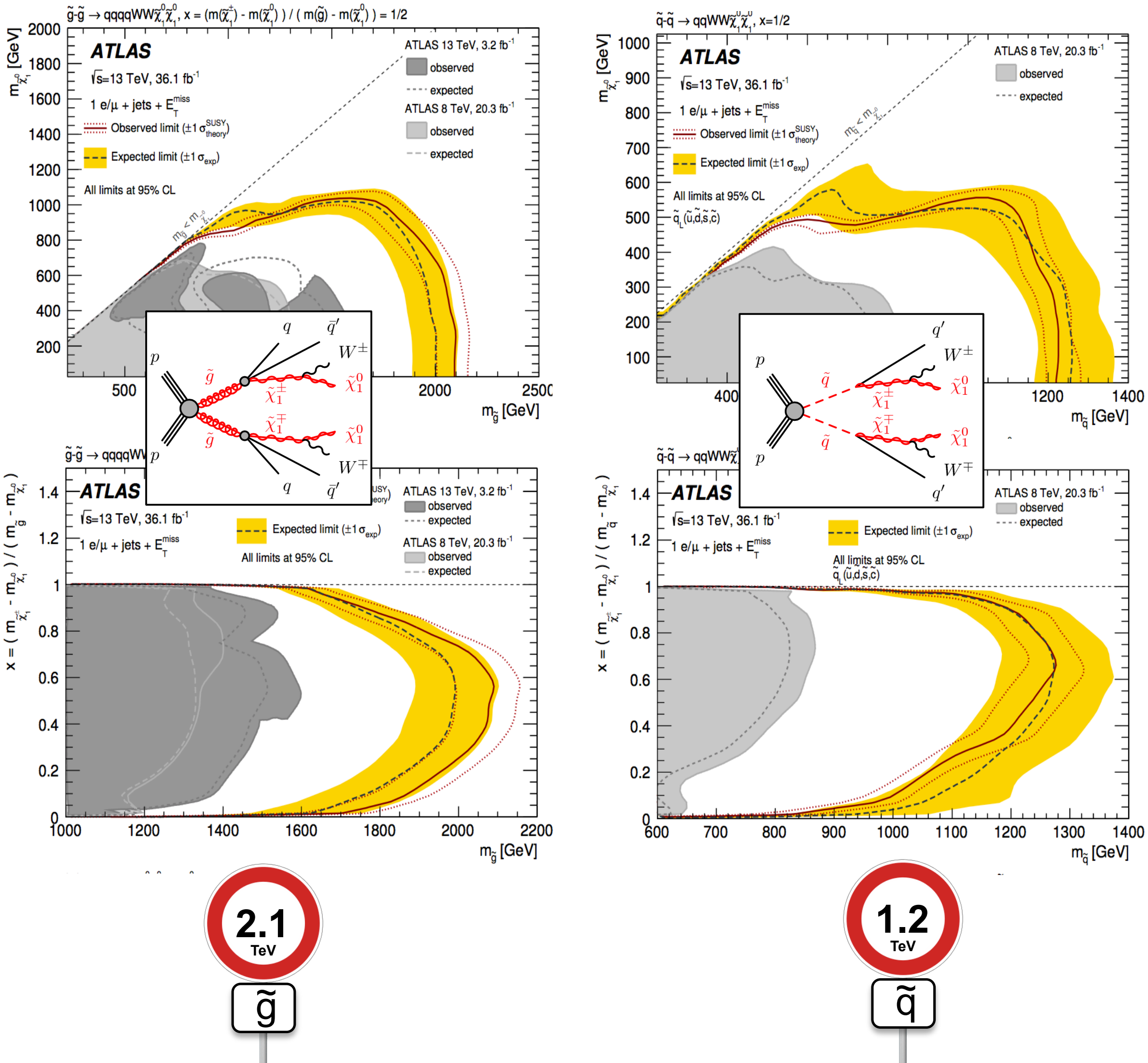




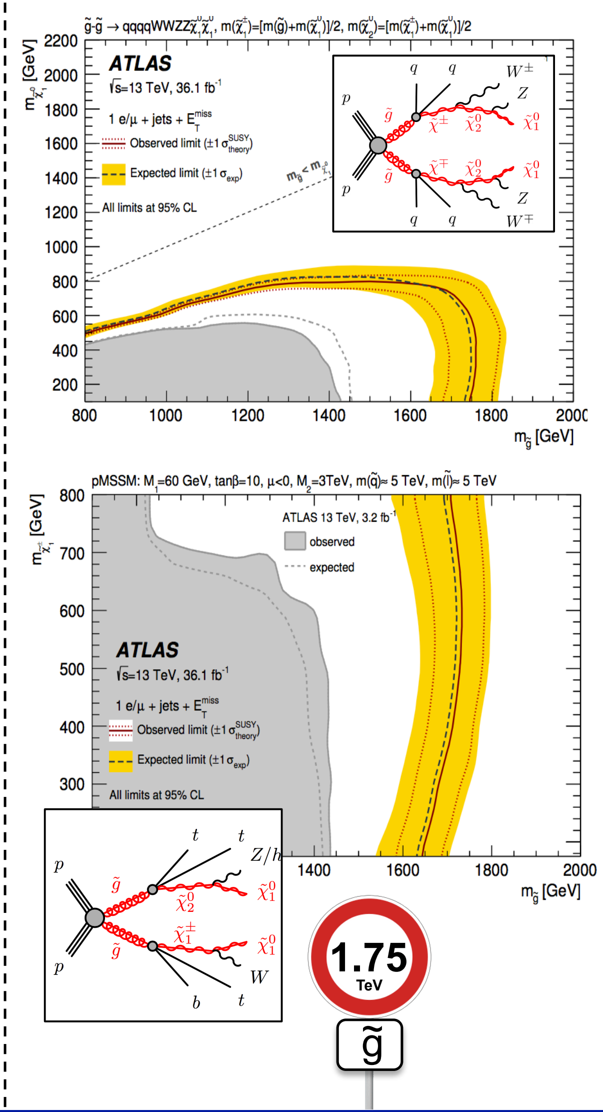


1-ℓ + jets + E_T^{miss} Search: Interpretation

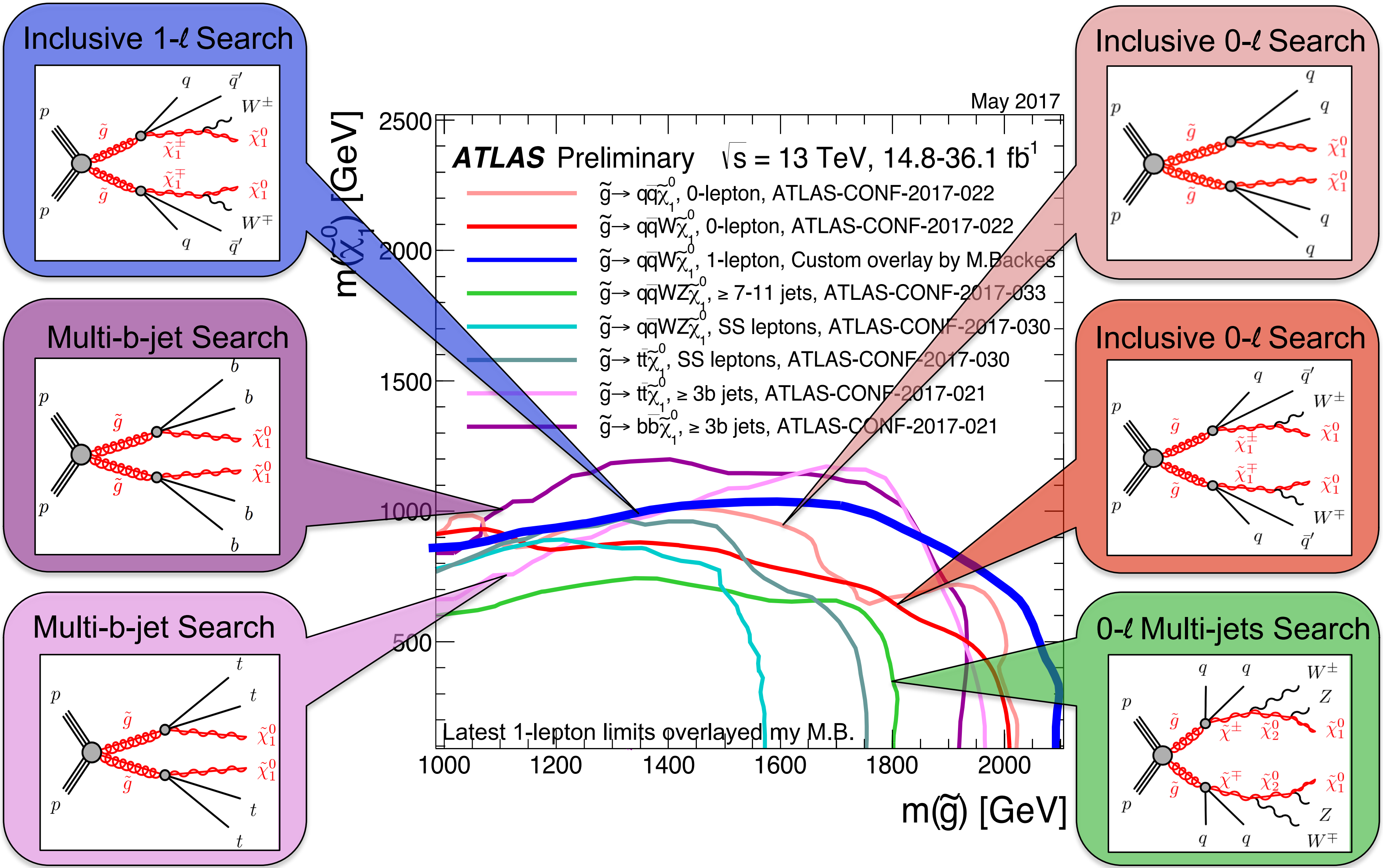
Full statistical combination of 2-6 jet stream exclusion regions



9 jet stream



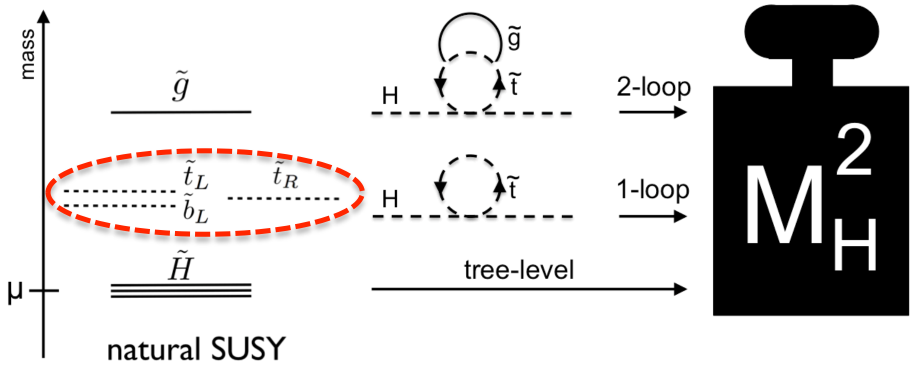
Putting it into context + other results



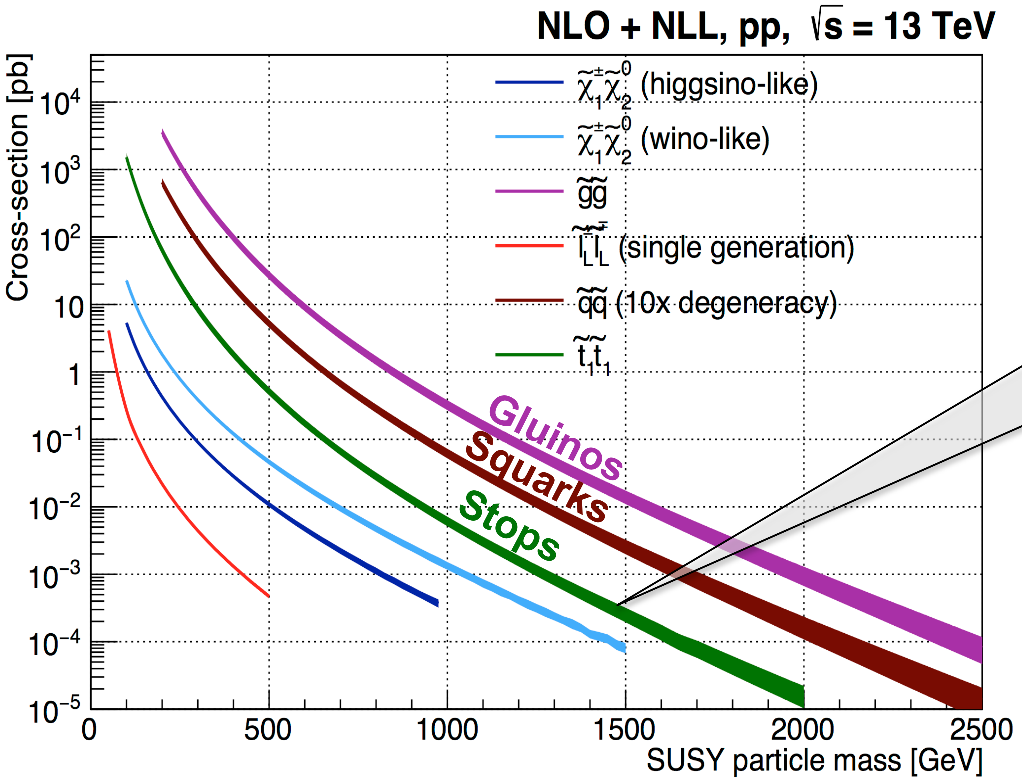
Part 2 of 4

Searches for 3rd Generation Squarks

Why 3rd Generation Squark Searches?



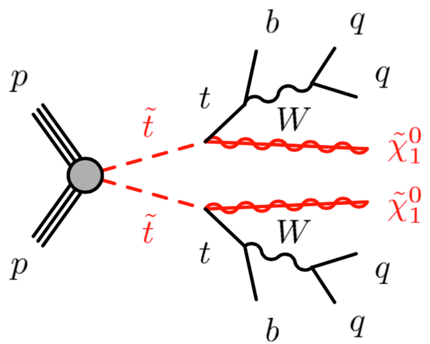
- Relatively light stops O(1 TeV) strongly motivated in the context of naturalness!

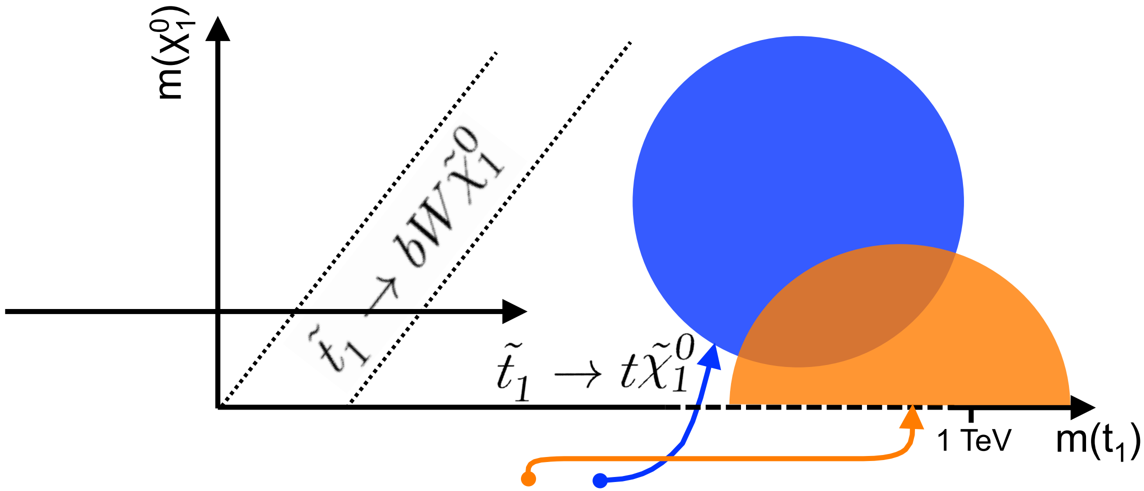


- In terms of cross-sections at the LHC our next best bet if no gluinos or 1st/2nd generation squarks found

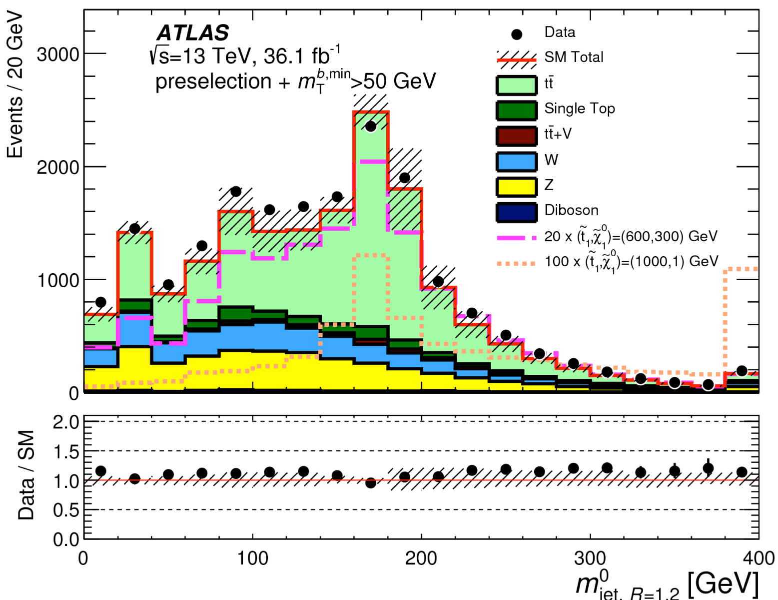
Stop 0-ℓ Search: Overview

- **Final state:**
  - b-jets + E_{Tmiss} (no leptons!)





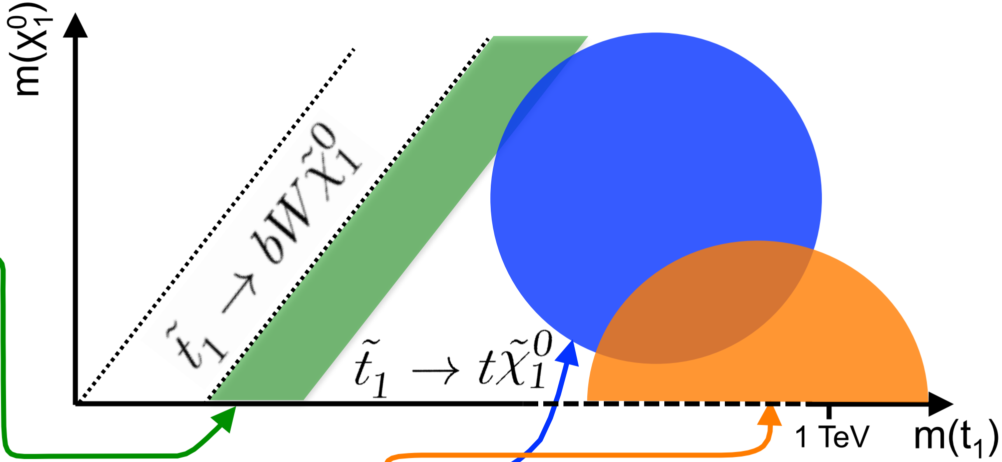
Signal Regions A & B



- **Boosted regime**: 3 orthogonal top reconstruction categories based on large-R jet mass requirements:
  - ① **2 tops**
  - ② **1 top + 1 W**
  - ③ **1 top only**
- Signal regions A:
  - **Tight requirements** $E_{T,miss}$ & m_{T2} to target high mass region
- Signal regions B:
  - **Looser requirements** to target intermediate mass region

Stop 0-ℓ Search: Overview

- **Final state:**
  - b-jets + E_{Tmiss} (no leptons!)



Signal Regions C

- Exploit **initial state radiation** for sensitivity in near diagonal region (**$m_{stop} \sim m_t + m_{LSP}$**)
- Scan regions of R_{ISR} (ratio of $E_{T,miss}$ and p_T^{ISR} in CM frame)

$$R_{\mathrm{ISR}} = \frac{E_{\mathrm{T}}^{\mathrm{miss}}}{p_{\mathrm{T}}^{\mathrm{ISR}}} \sim \frac{m_{\tilde{\chi}^0}}{m_{\tilde{t}}}$$

- Additional *recursive jigsaw* reconstruction based kinematic variables in the ISR and sparticle hemispheres

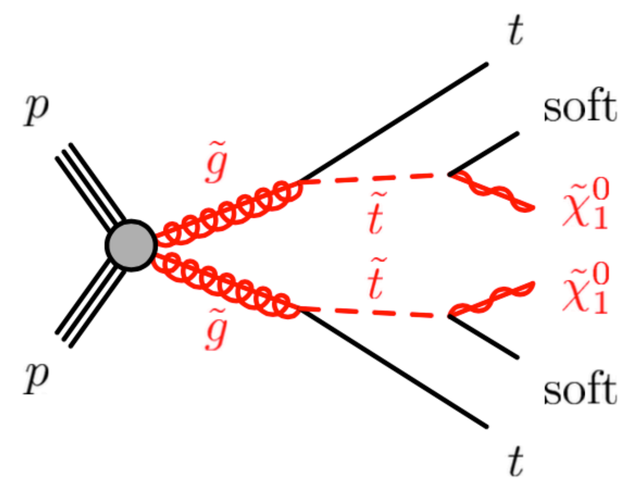
Signal Regions A & B

- Boosted regime: 3 orthogonal top reconstruction categories based on large-R jet mass requirements:
  ① **2 tops**
  ② **1 top + 1 W**
  ③ **1 top only**
- Signal regions A:
  - **Tight requirements** $E_{T,miss}$ & m_{T2} to target high mass region
- Signal regions B:
  - **Looser requirements** to target intermediate mass region

Stop 0-ℓ Search: Overview

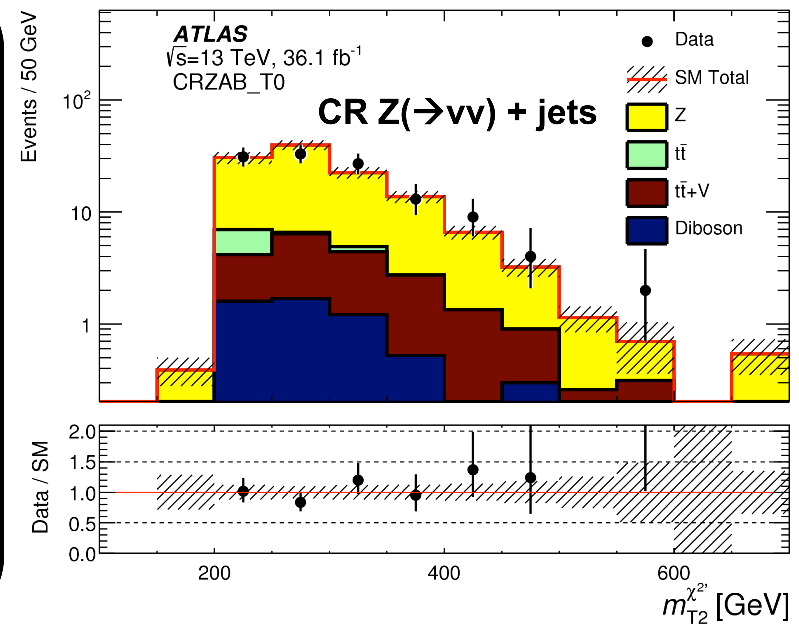
Signal Region E

- Targets **gluino-mediated** stop production with **highly boosted top quarks**
- Δm(gluino,stop) large, **Δm(stop,LSP)= 5 GeV**
- Requirements on 1st/2nd leading **large-R jet mass**
- Tight $E_{T,miss}$, H_T and $E_{T,miss}/\sqrt{H_T}$ selections

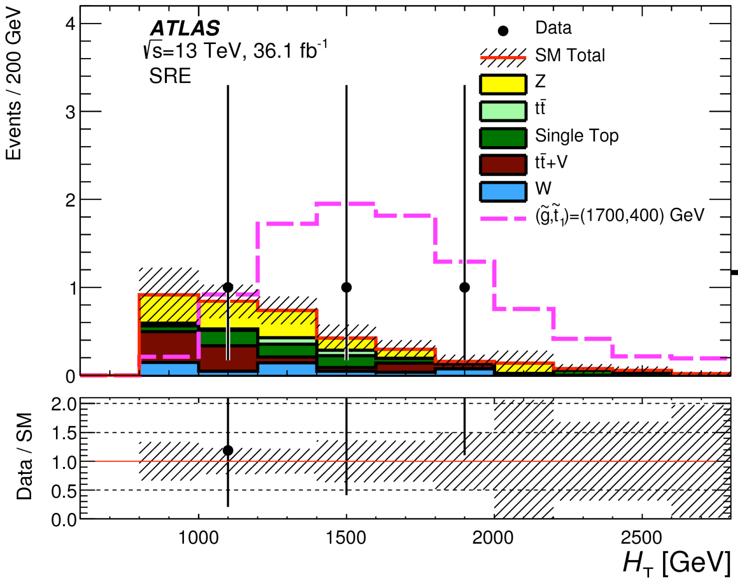


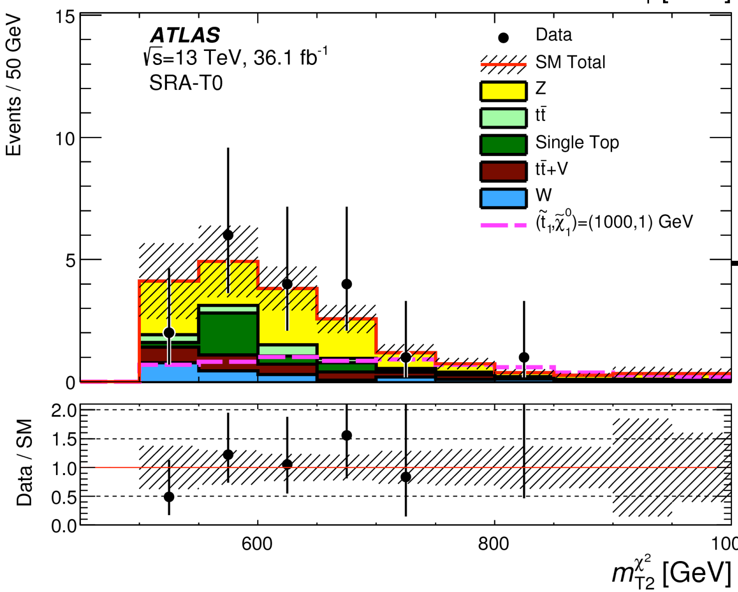
Background Estimation

- Dominant backgrounds:
  - **Z(→νν) + heavy flavour jets** [2ℓ CR]
  - **$t\bar{t}$** [1ℓ CR], **$t\bar{t}$+Z(→νν)** [1ℓ+1γ CR]
- Subdominant backgrounds:
  - **W + heavy flavour jets** [1ℓ CR],
  - **single-top** [1ℓ CR]
  - **Multi-jets** [Multi-jets CR]
- Semi data-driven background estimation with simulated based extrapolation to VRs & SRs
  - **Lepton** in **1ℓ CRs** → **jet**
  - **Leptons** in **2ℓ CR** → **p_{Tmiss}**
  - **Photon** → **p_{Tmiss}**

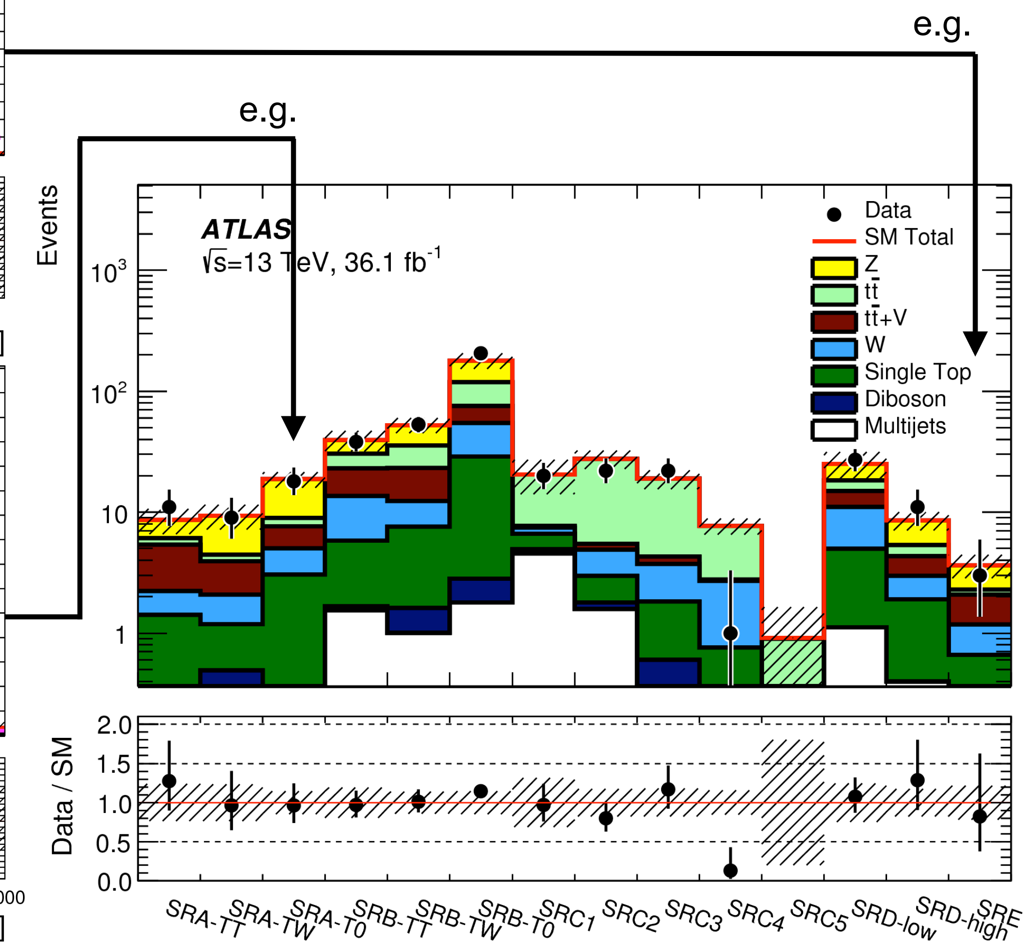


Stop 0-ℓ Search: Results

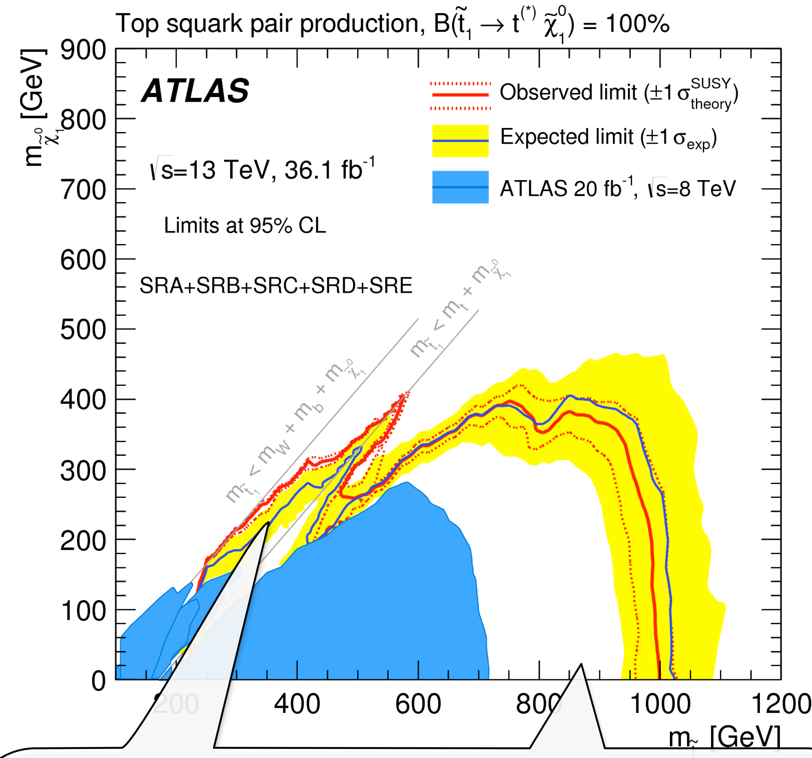


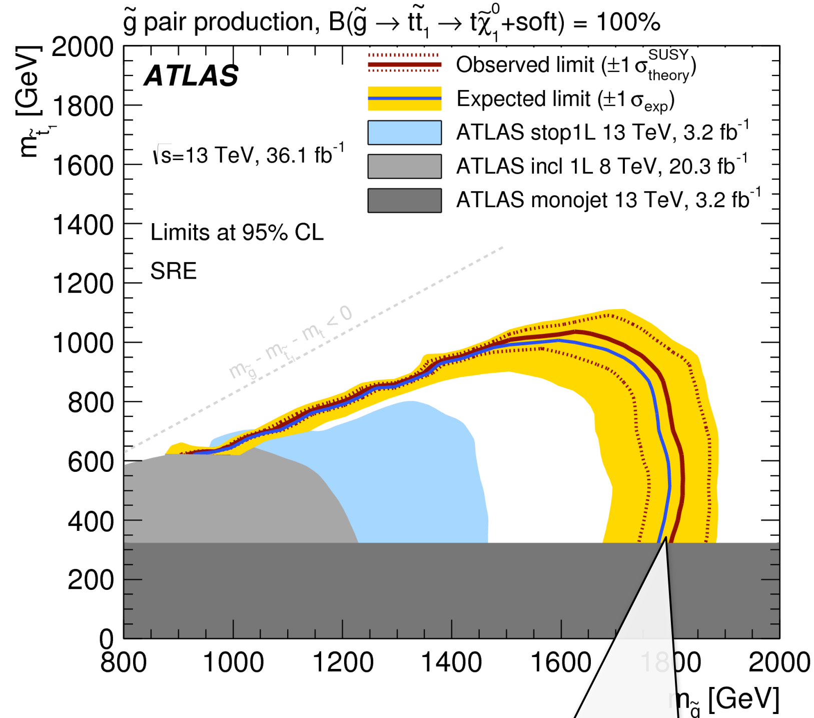


- **No significant deviations** in any of the signal regions



Stop 0-ℓ Search: Interpretation





- Simplified model with 100% branching fractions to t → t + LSP:
  - Bounds up to **m_{stop} ~ 940 GeV** @ low LSP masses
  - Stop mass range **250-430 GeV** excluded @ in diagonal region where **$m_{stop} \sim m_t + m_{LSP}$**

- Gluino-mediated stop production up to **m_{gluino} ~1.8 TeV**

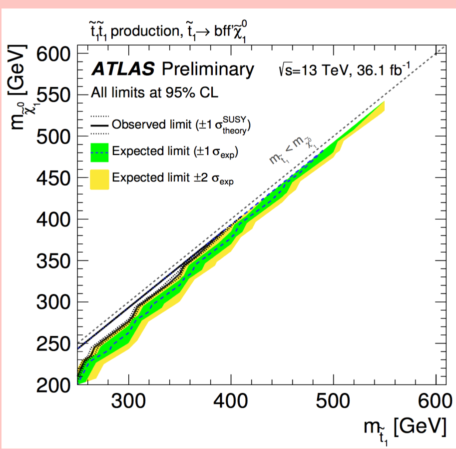
Putting it into context

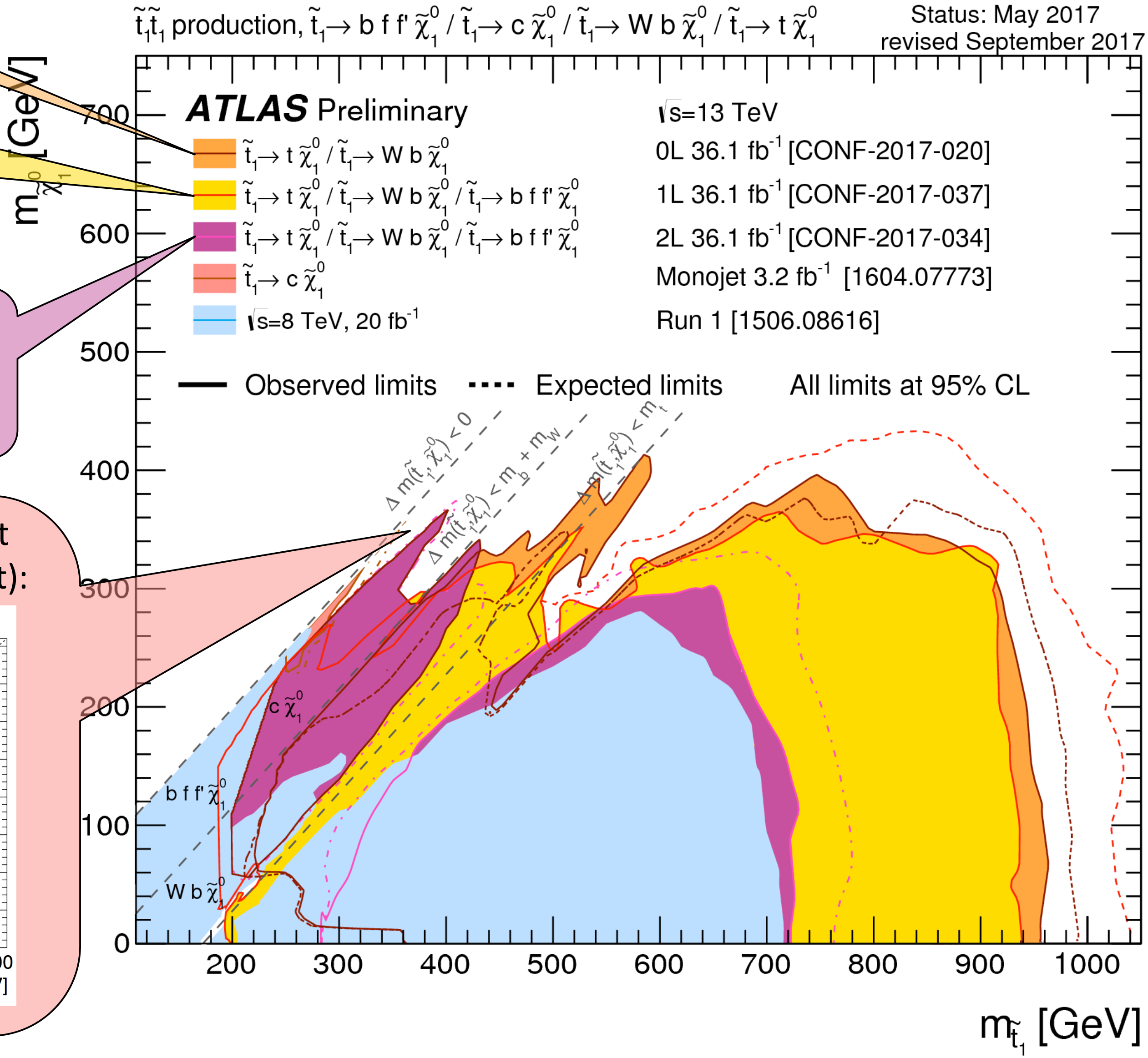
Stop 0-ℓ Search

Stop 1-ℓ Search with dedicated SRs for 2/3/4 body decays

Stop 2-ℓ Search provides strong unique sensitivity for 3/4 body decay scenarios

New results from Mono-jet Search (not yet on this plot):





Putting it into context

Stop 0-ℓ Search

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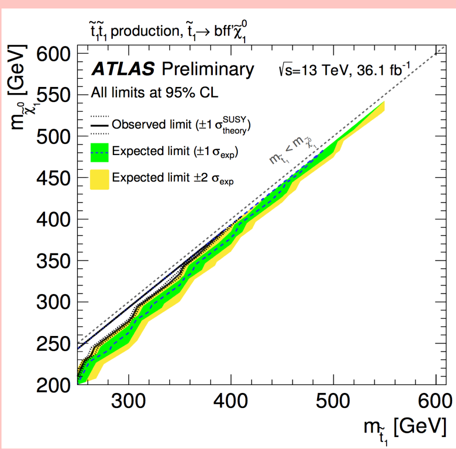
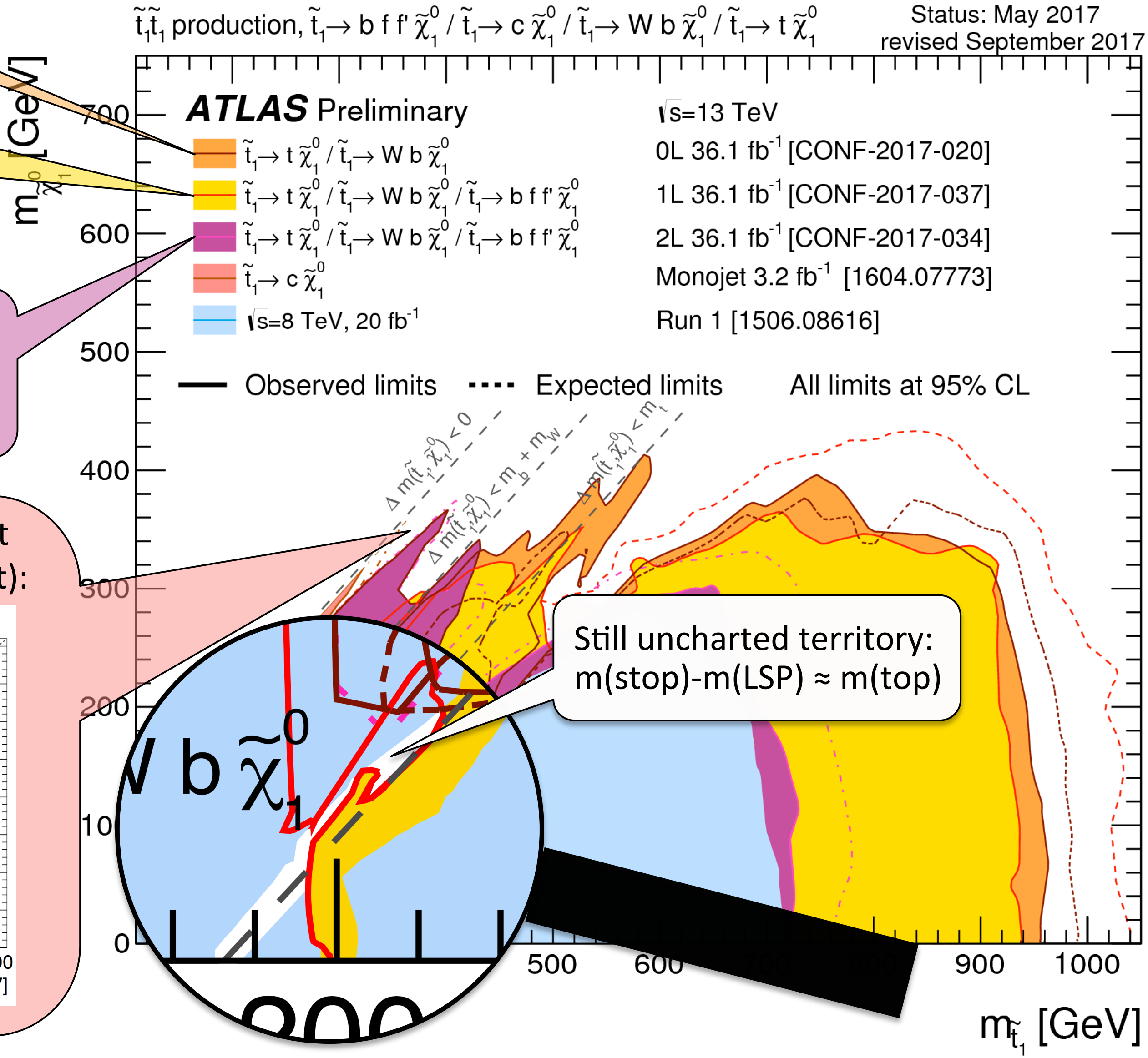
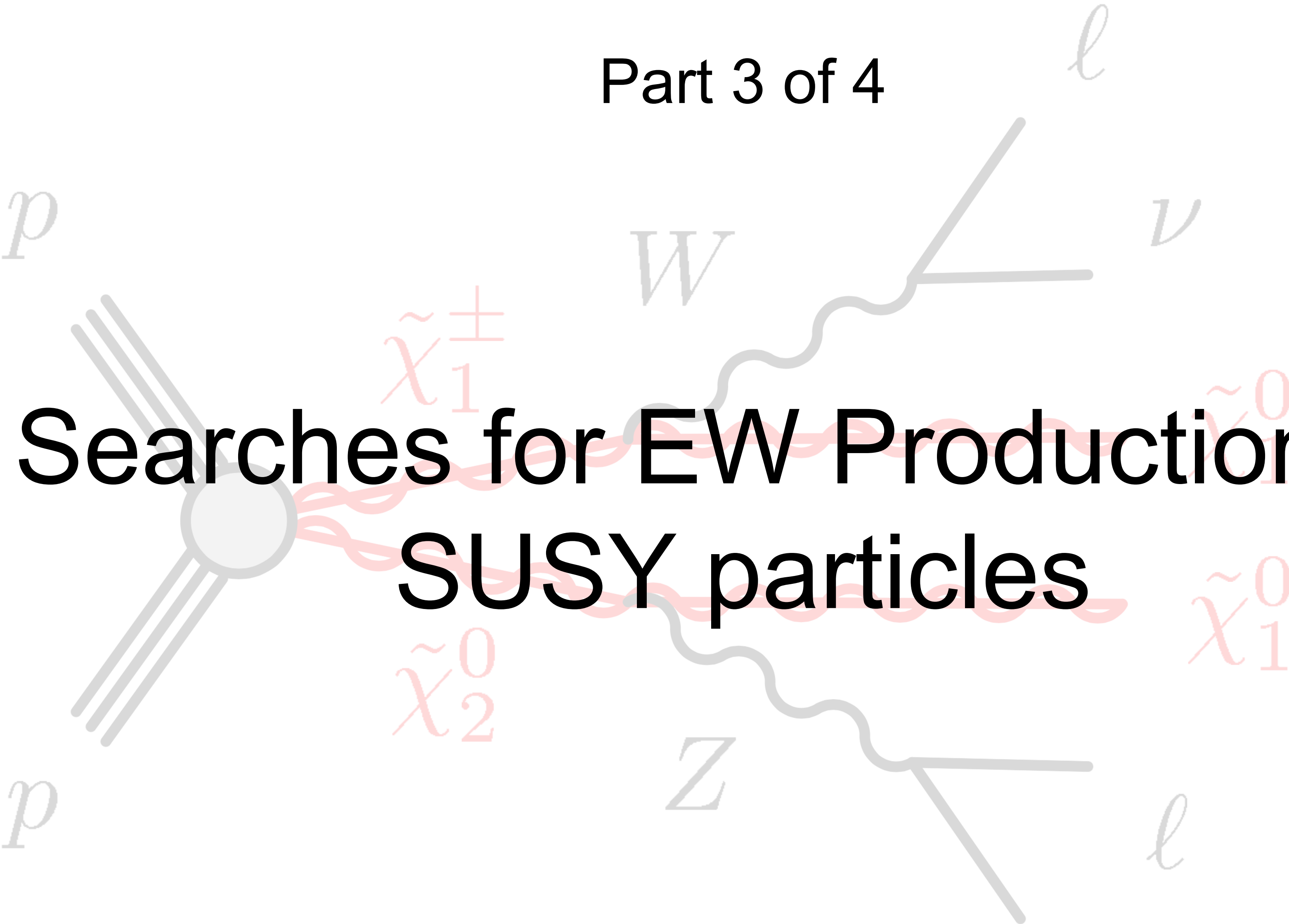


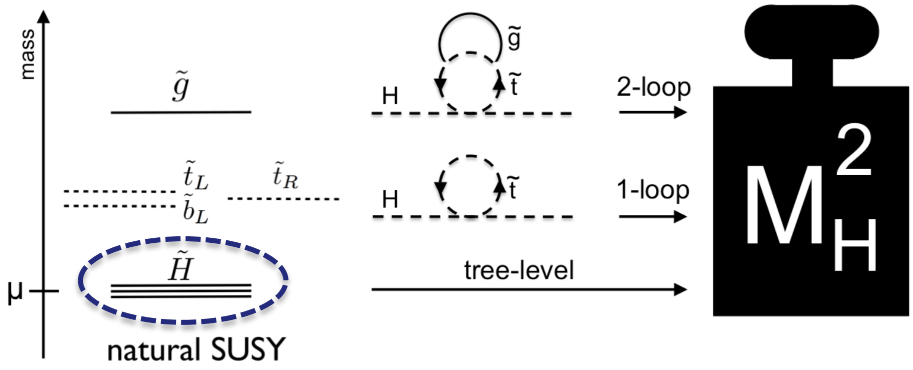


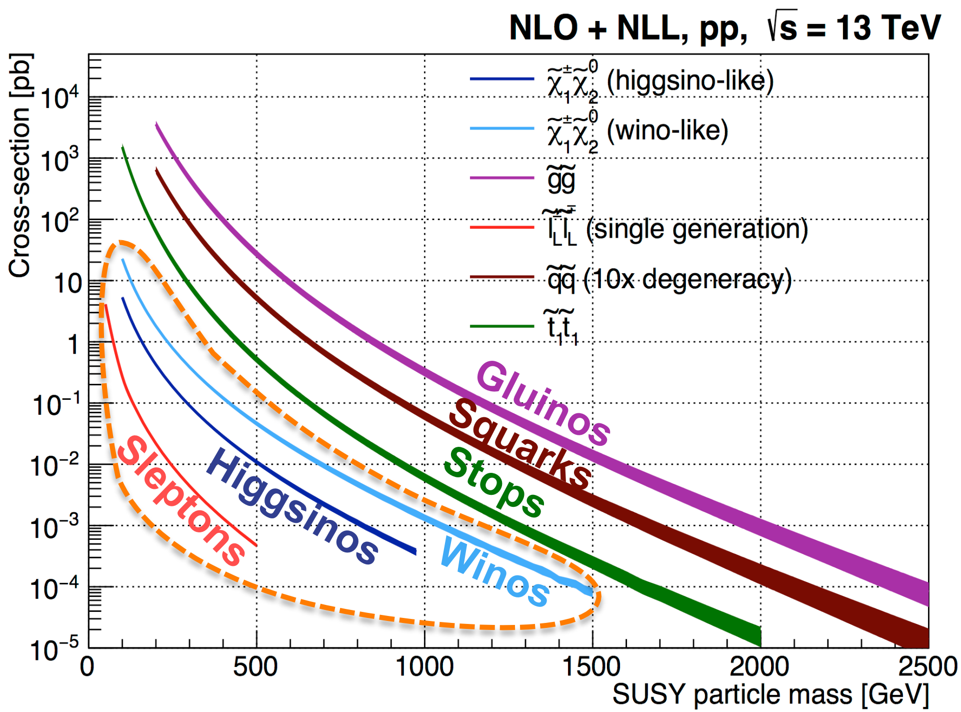
Part 3 of 4

Searches for EW Production of SUSY particles



Why Electro-weak SUSY Searches?





- Light electroweak particles well motivated in the context of **naturalness** (Higgsinos!)
- Searches are **challenging** due to low cross-sections (3-5 orders of magnitude below gluino pair production!)
- But typical **low-background multi-lepton signatures** make these scenarios accessible

→ Lack of evidence for coloured SUSY particles and **large amounts of data** collected @ 13 TeV are strong motivation to search for EW SUSY **now**!

Overview: EW 2/3-ℓ + $E_{T,miss}$ Search

- Search for direct electro-weak production of SUSY particles in 2/3 lepton + $E_{T,miss}$ final states with **3 dedicated analysis streams**

2ℓ + 0 jets stream

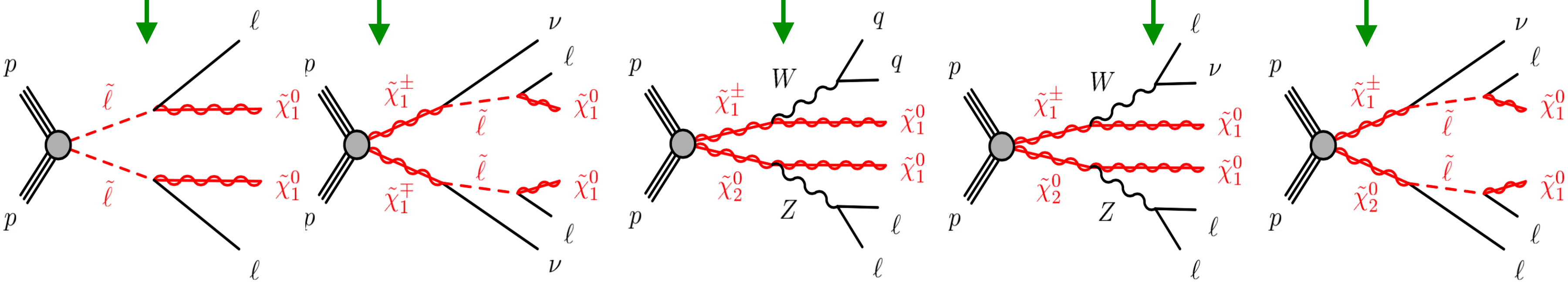
- Targets **models with sleptons**
- 2 categories of selections:
  - **SFOS** (e^+e^- / $\mu^+\mu^-$): 13 SRs binned in **m_{T2} and $m_{\ell\ell}$**
  - **DFOS** ($e^\pm\mu^\mp$): 4 SRs binned in **m_{T2}**

2ℓ + 2 jets stream

- Targets **W/Z-mediated decay**
- Dedicated SFOS (e^+e^- / $\mu^+\mu^-$) SRs for **large / medium** and **small mass splittings** Δm ($\chi^0_2/\chi^\pm_1$,χ^0_1)
- Small Δm regions exploit *ISR vs. W+Z+invisible* recoil

3ℓ stream

- At least one **SFOS pair** (e^+e^- / $\mu^+\mu^-$)
- **W/Z-mediated decay:**
  - Binned signal region in Z mass region
- **Slepton-mediated decay:**
  - Binned signal region in Z mass veto region



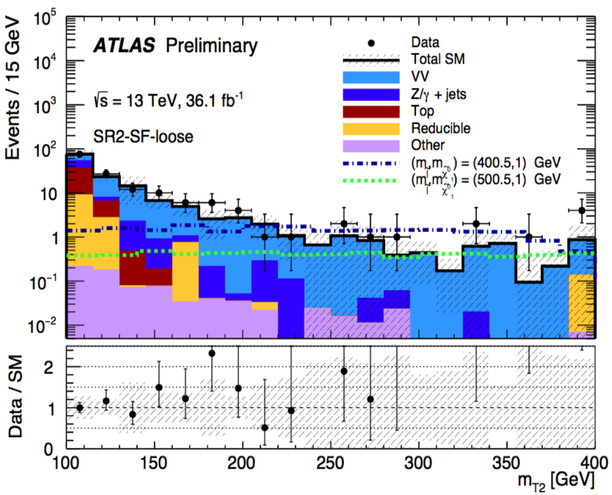
Bkgs. & Results: EW 2/3-ℓ + $E_{T,miss}$ Search

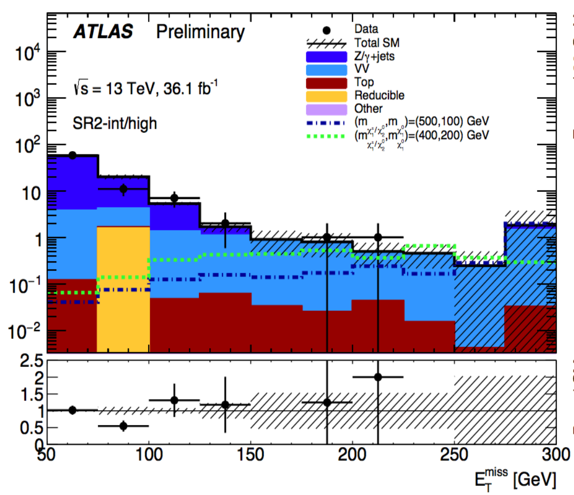
2ℓ + 0 jets stream & 2ℓ + 2 jets stream

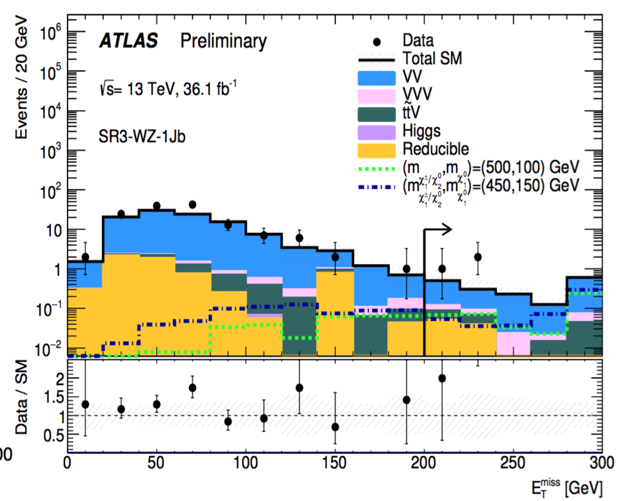
- Irreducible BGs:
  - Dominated by diboson then tt and Wt
  - MC normalised in dedicated CR for 2ℓ + 0 jets
  - Taken from MC for 2ℓ + 2 jets
- Reducible BGs:
  - Z+jets with fake $E_{T,miss}$ (from MC for 2ℓ + 0 jets / γ+jets events for 2ℓ + 2 jets)
  - Fake / non-prompt leptons (data-driven method)

3ℓ stream

- Irreducible BGs:
  - Dominated by diboson WZ (normalised in dedicated CRs)
- Reducible BGs:
  - Z+jets, tt, Wt, WW with ≥1 fake / non-prompt lepton region (data-driven method)

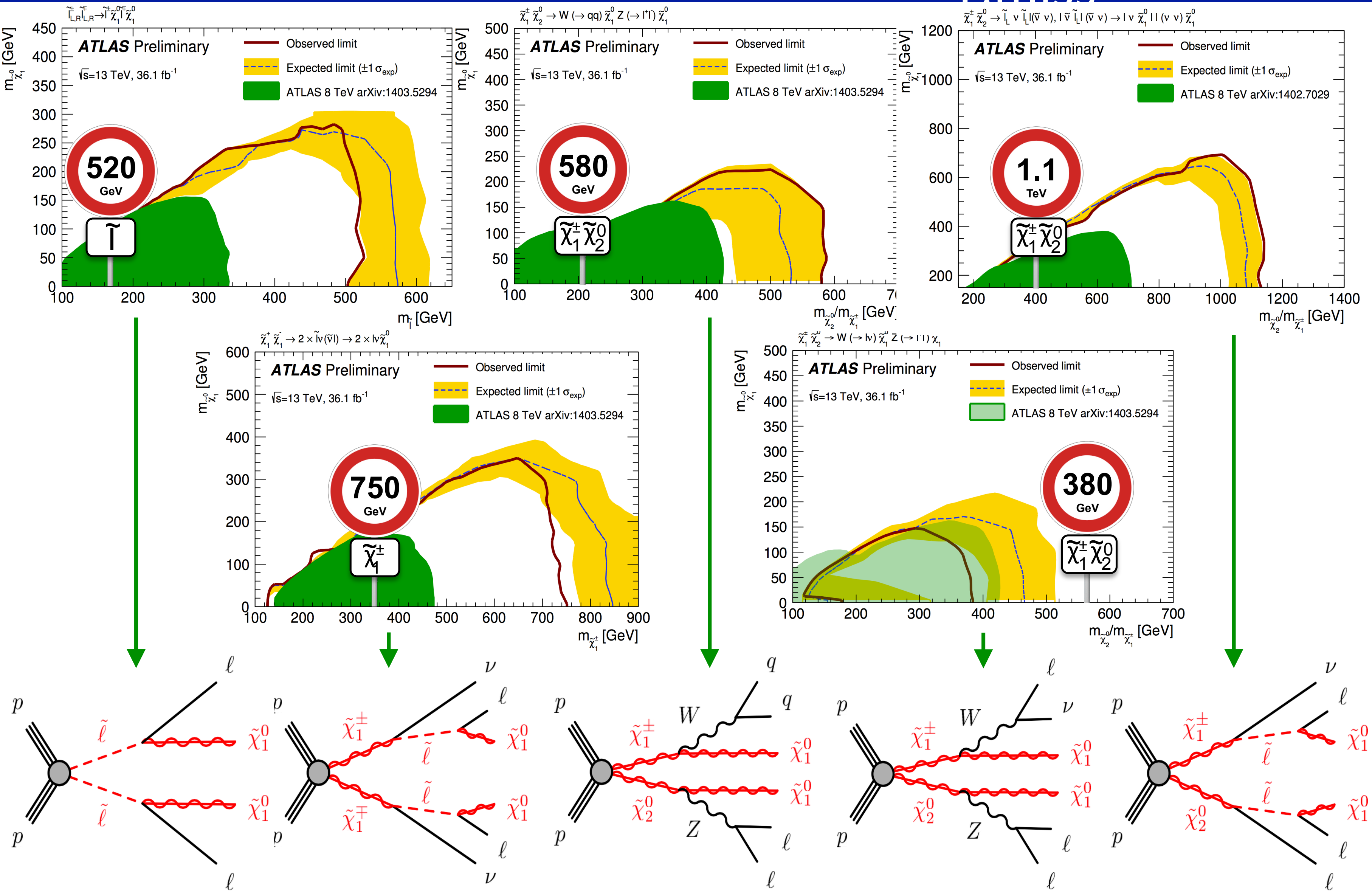






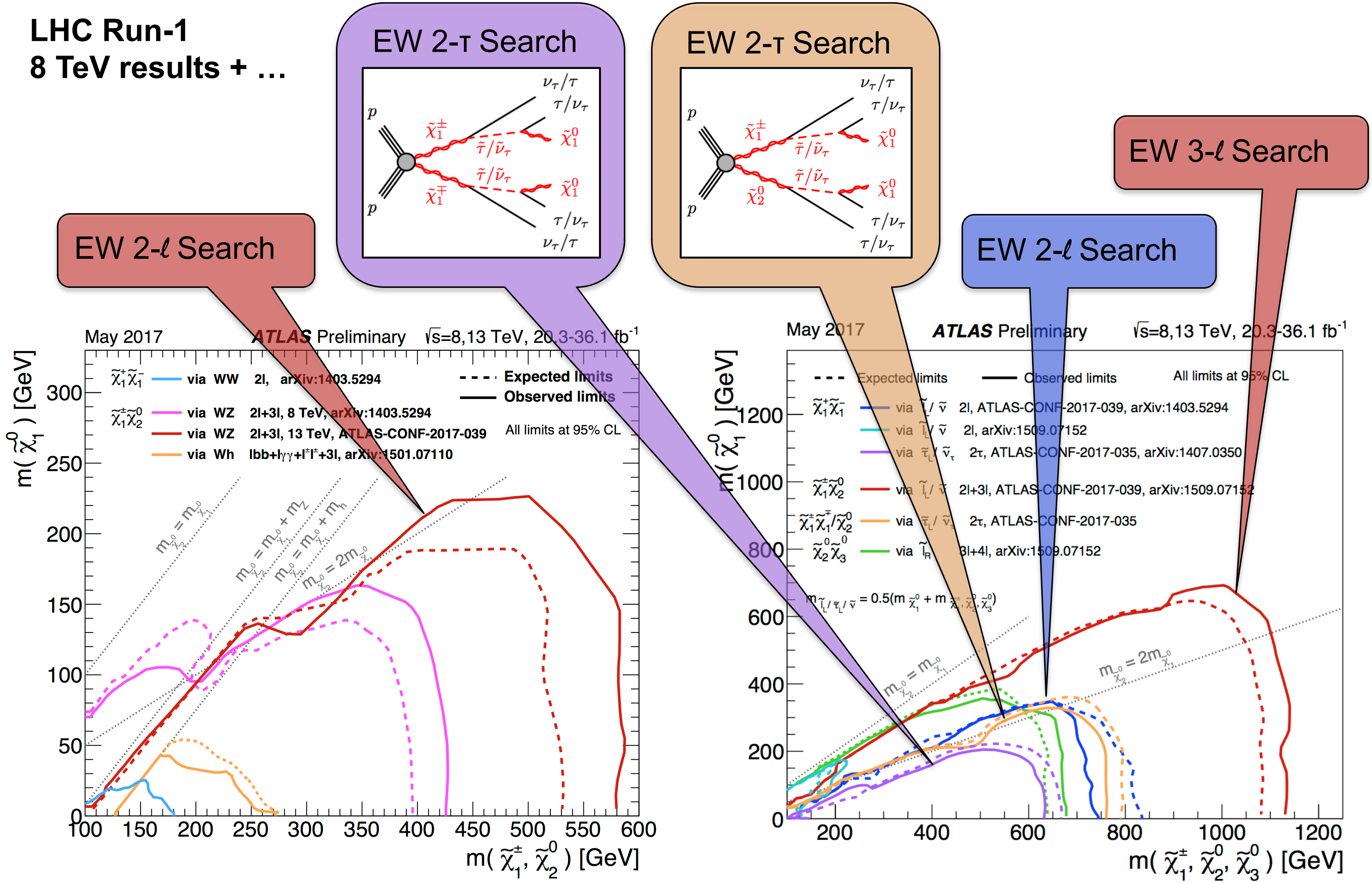
→ No significant deviations from the SM expectation

Backgrounds: EW 2/3-ℓ + $E_{T,miss}$ Search



Putting it into context

LHC Run-1
8 TeV results + …



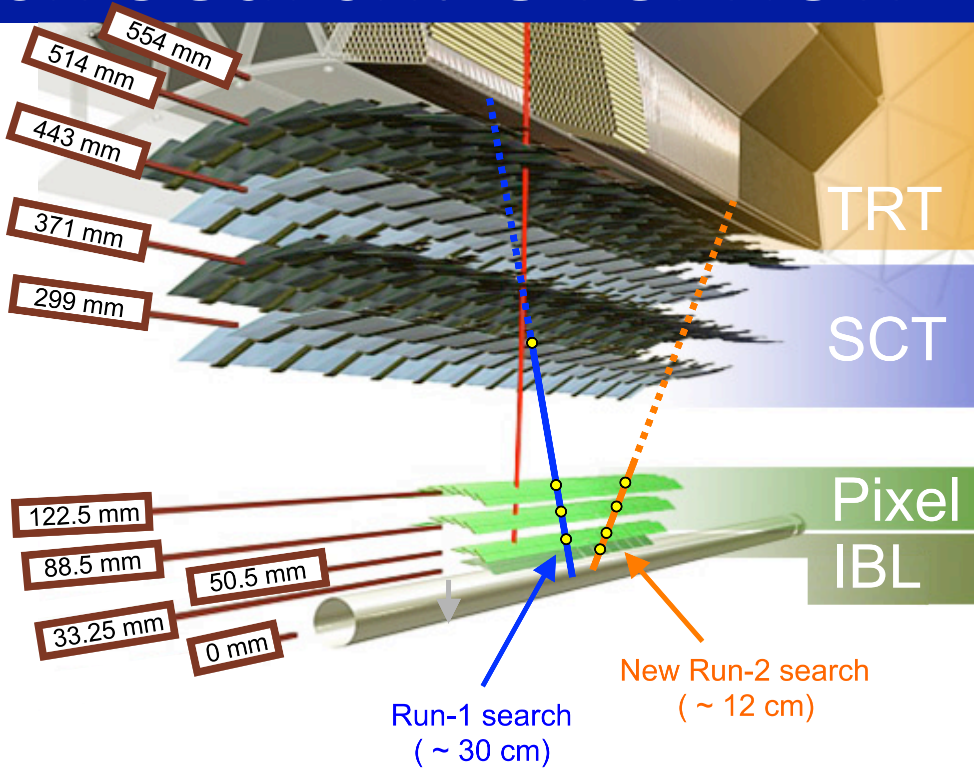
Part 4 of 4

Searches for Long-lived Particles

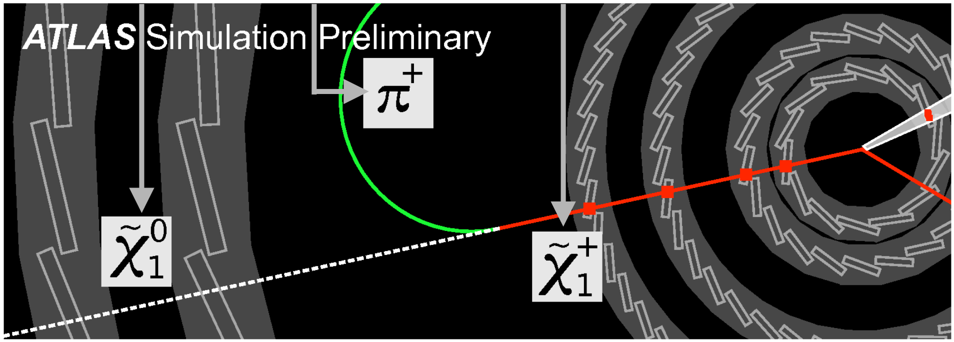
Disappearing Track Search: Overview

- If lightest chargino & neutralino are almost pure Wino (e.g. in **A**nomaly **M**ediated **S**USY **B**reaking)
  - **Mass degeneracy:** $\Delta m(\chi^{\pm}_1, \chi^0_1) \sim 160$ MeV
  - **Chargino long-lived:** $\tau \sim 0.2$ ns
  - **Sizable decay length:** $c\tau \sim 6$ cm
- Chargino decays into ultra-soft pion and neutralino
- Experimental signature to discriminate against SM backgrounds:
  - **Disappearing track**
  - **Large $E_{T,miss}$** from LSP
- Run-1 search was sensitive to disappearing tracks with **decay lengths starting from 30 cm ~ 1 ns**

→ New insertable pixel B-layer (IBL) installed during long shutdown opens up window to shorter life-times ($c\tau \sim 12$ cm) **for the very first time!**



$E_{T,miss}$ + pion (very soft) + disappearing track



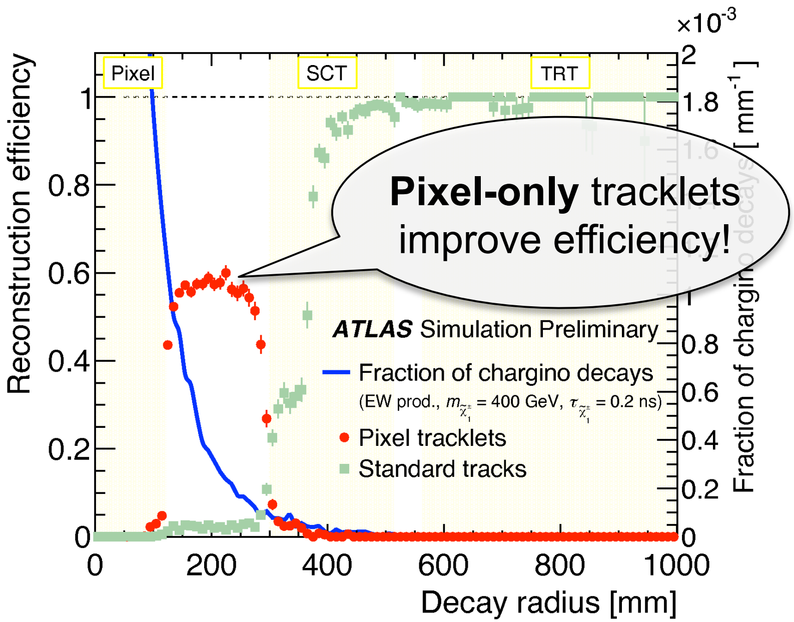
Disappearing Track Search: Overview

- **pMSSM reinterpretation** of 8 TeV ATLAS SUSY searches [JHEP 10 (2015) 134] showed that Run-1 analysis excluded **~30% of Wino-like models**

- **~70%** of the Wino-LSP models included in the pMSSM scan have **lifetimes of 0.15-0.25** ns

→ A **very generic lifetime range** in MSSM!

→ **Strong motivation** to search for disappearing track signals with **shorter decay lengths**!

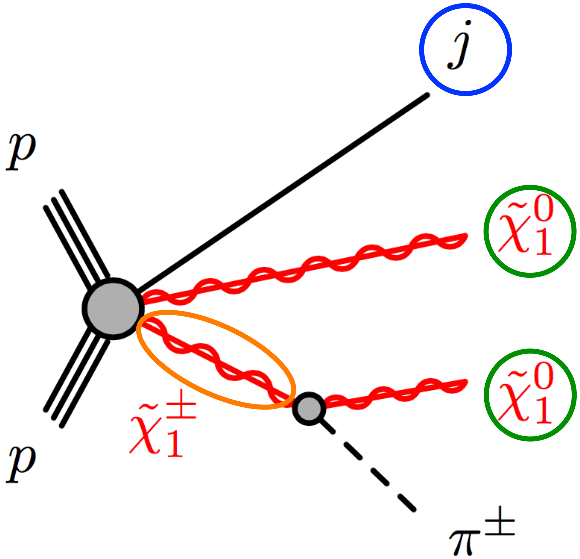


Analysis	All LSPs	Bino-like	Wino-like	Higgsino-like
0-lepton + 2–6 jets + E_T^{miss}	32.1%	35.8%	29.7%	33.5%
0-lepton + 7–10 jets + E_T^{miss}	7.8%	5.5%	7.6%	8.0%
0/1-lepton + 3b-jets + E_T^{miss}	8.8%	5.4%	7.1%	10.1%
1-lepton + jets + E_T^{miss}	8.0%	5.4%	7.5%	8.4%
Monojet	9.9%	16.7%	9.1%	10.1%
SS/3-leptons + jets + E_T^{miss}	2.4%	1.6%	2.4%	2.5%
$\tau(\tau/\ell)$ + jets + E_T^{miss}	3.0%	1.3%	2.9%	3.1%
0-lepton stop	9.4%	7.8%	8.2%	10.2%
1-lepton stop	6.2%	2.9%	5.4%	6.8%
2b-jets + E_T^{miss}	3.1%	3.3%	2.3%	3.6%
2-leptons stop	0.8%	1.1%	0.8%	0.7%
Monojet stop	3.5%	11.3%	2.8%	3.6%
Stop with Z boson	0.4%	1.0%	0.4%	0.5%
tb+E_T^{miss}, stop	4.2%	1.9%	3.1%	5.0%
ℓh, electroweak	0	0	0	0
2-leptons, electroweak	1.3%	2.2%	0.7%	1.6%
2-τ, electroweak	0.2%	0.3%	0.2%	0.2%
3-leptons, electroweak	0.8%	3.8%	1.1%	0.6%
4-leptons	0.5%	1.1%	0.6%	0.5%
Disappearing Track	11.4%	0.4%	29.9%	0.1%
Long-lived particle	0.1%	0.1%	0.0%	0.1%
$H/A \to \tau^+\tau^-$	1.8%	2.2%	0.9%	2.4%
Total	40.9%	40.2%	45.4%	38.1%

Most **powerful** search for Wino-LSPs !

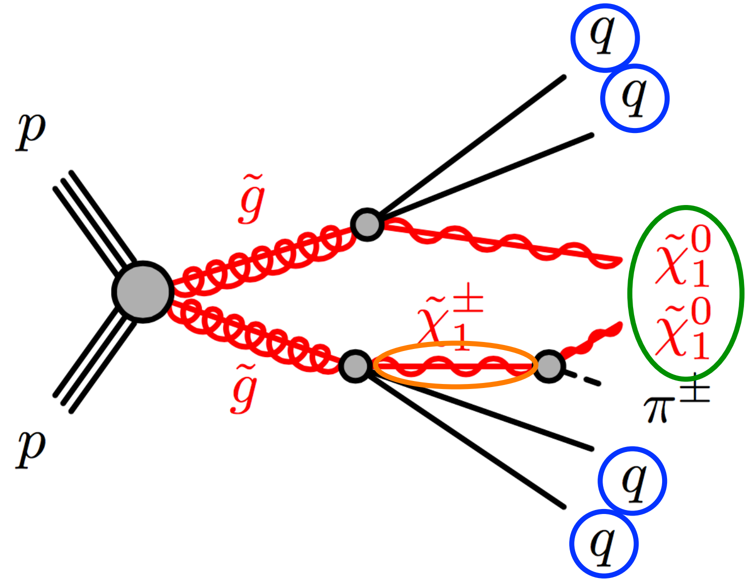
Disappearing Track Search: Overview

- Electroweak production channel



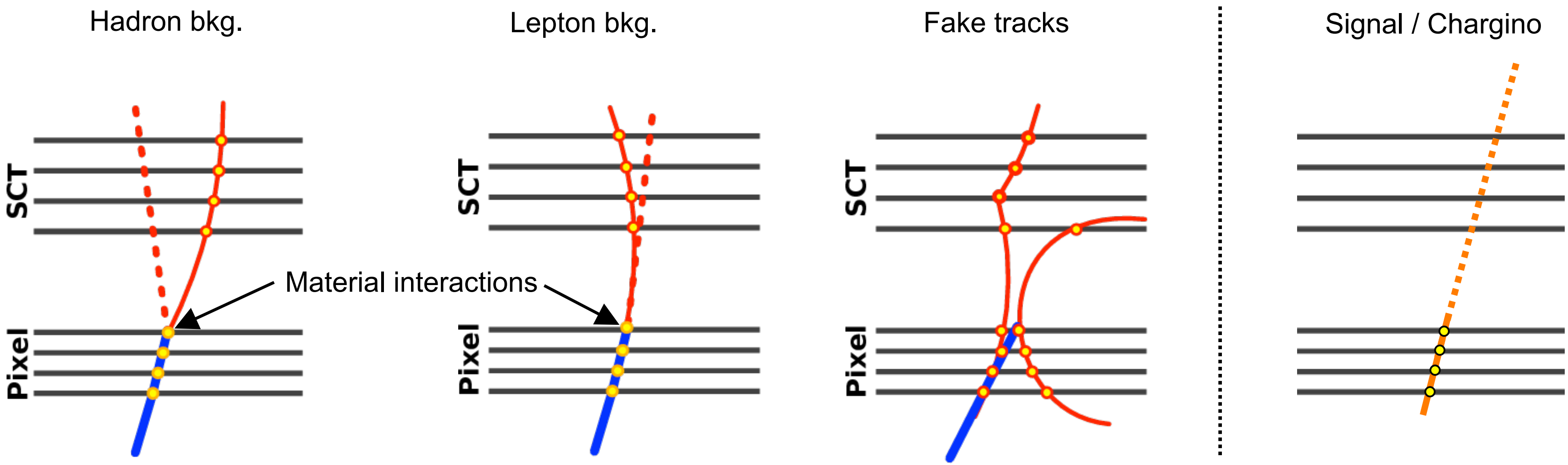
ISR jet + **$E_{T,miss}$** + **disappearing track**

- Gluino-mediated production channel



Multi-jet + **$E_{T,miss}$** + **disappearing track**

Disappearing Track Search: Backgrounds



Simultaneous **fit of tracklet p_T** distribution using **templates** for the 3 backgrounds (+ signal)

- Hadron / lepton templates obtained from **data control samples** without material interaction
- **Smearing** with resolution function (from Z → μμ events) to match tracklet p_T spectrum

- Fake track template obtained from **data control region** with large d_0 significance + no $E_{T,miss}$ selection
- Extrapolation to large $E_{T,miss}$ checked

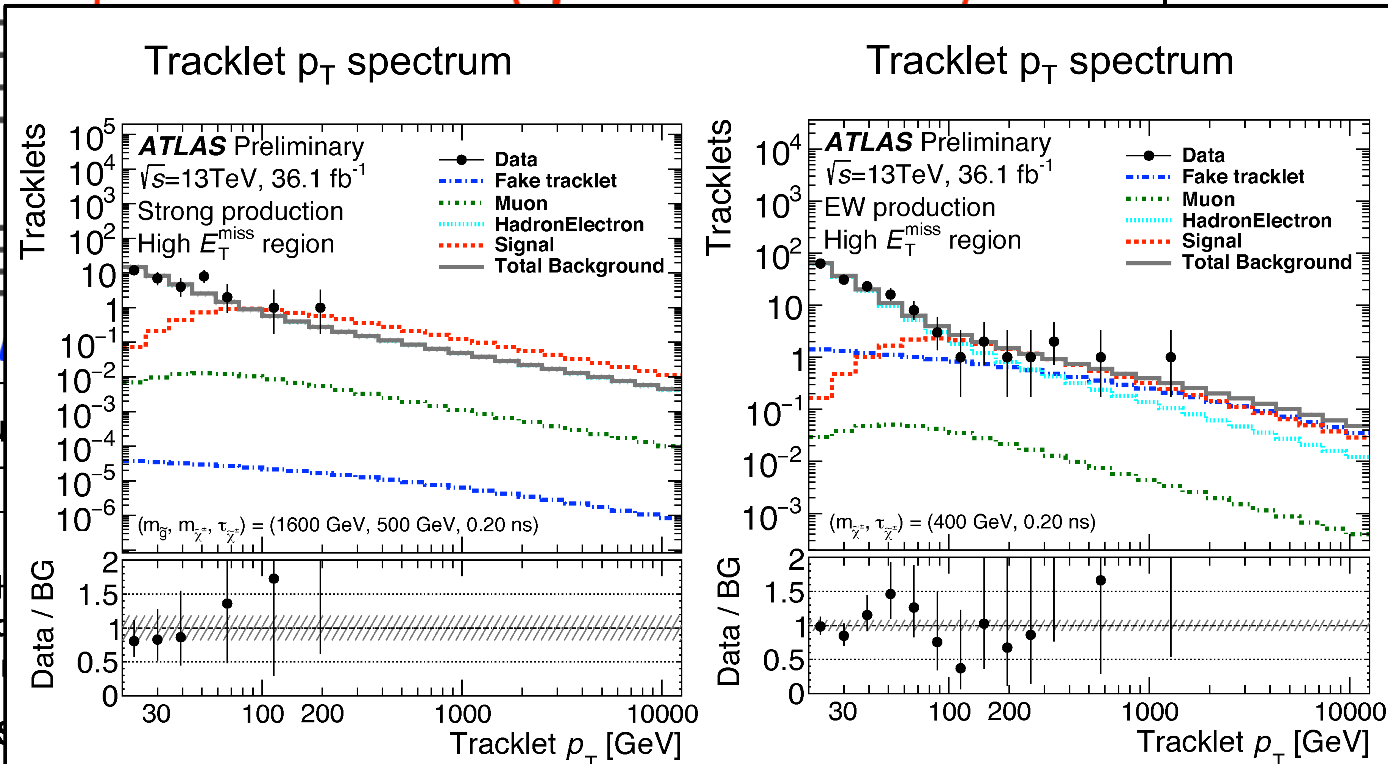
- Template from **MC smeared** with resolution function
- Smearing parameters from **muon data sample** corrected for muon / chargino differences in MC

Disappearing Track Search: Backgrounds

Hadron bkg. | Lepton bkg. | Fake tracks | Signal / Chargino

SCT

Pixel



Simu ... + signal

- H ... c ... i
- S ... → pp events to match tracklet p_T spectrum

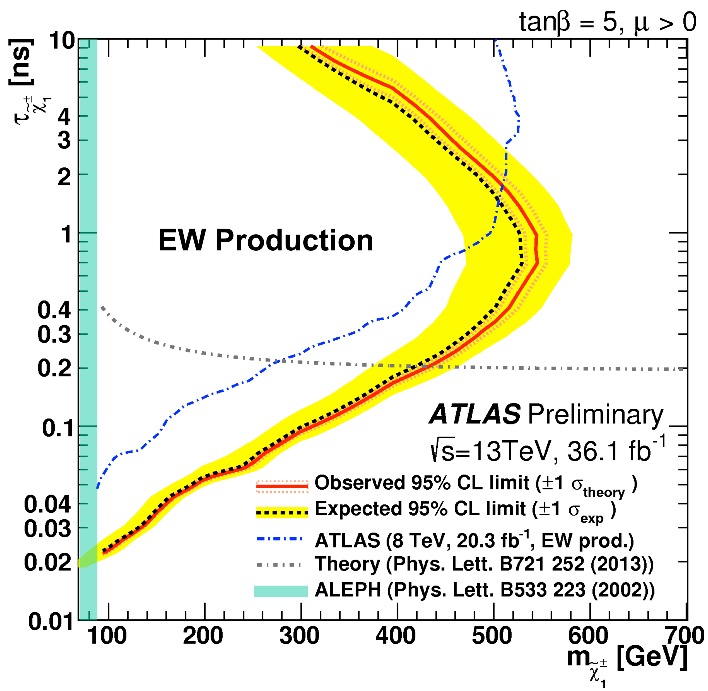
$E_{T,miss}$ selection

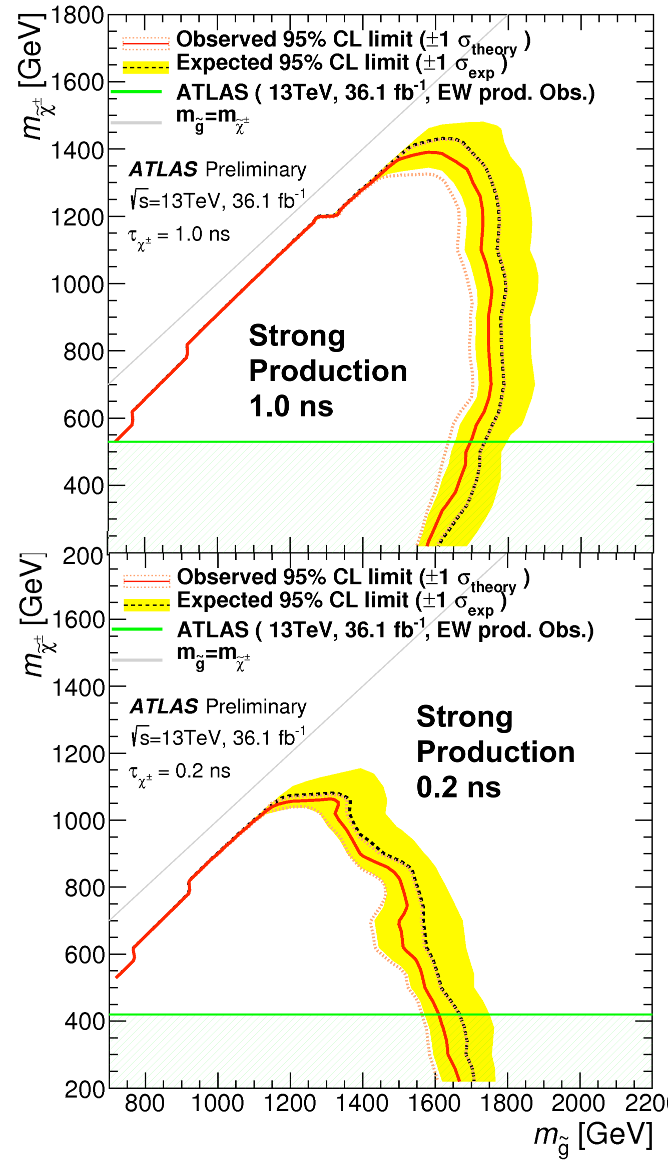
- Extrapolation to large $E_{T,miss}$ checked

... from **MC** with ... function ... rs from **muon data sample** corrected for muon / chargino differences in MC

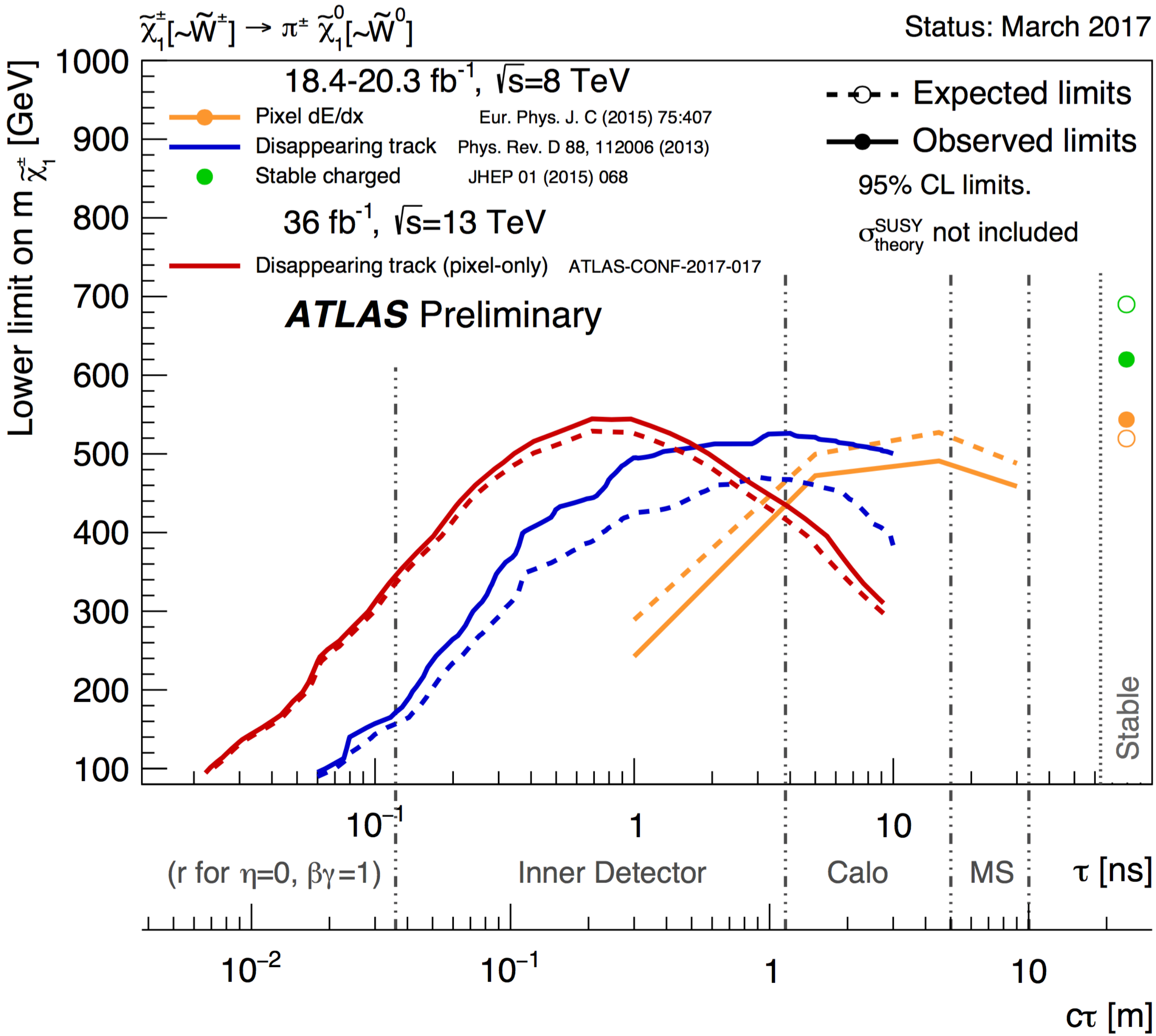
Disappearing Track Search: Results

- **No significant deviations** from the Standard Model expectation
- Limits set in EW and strong production channels:
  - **EW Production**: Significant improvement w.r.t. Run-1 at **lower lifetimes**
  - **Strong production**: Reaching to **1.4 (1.1) TeV in chargino** mass for lifetimes of 1.0 (0.2) ns





Putting it into context



Summary & Outlook

- Thanks to the fantastic performance of the LHC ATLAS has carried out an extensive search programme for SUSY leading to currently **20 public results** using the full **2015 + 2016 dataset of ~36 fb^{-1} at 13 TeV**

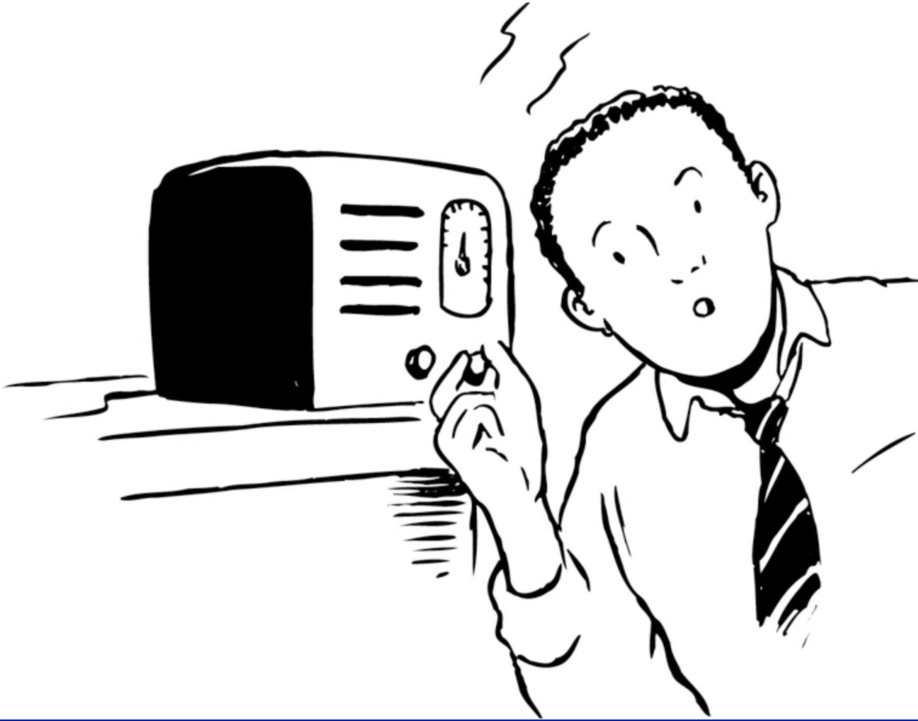
- **No significant deviations** from the SM

- **Significant boost in sensitivity** excluding gluino masses in some scenarios beyond 2 TeV!

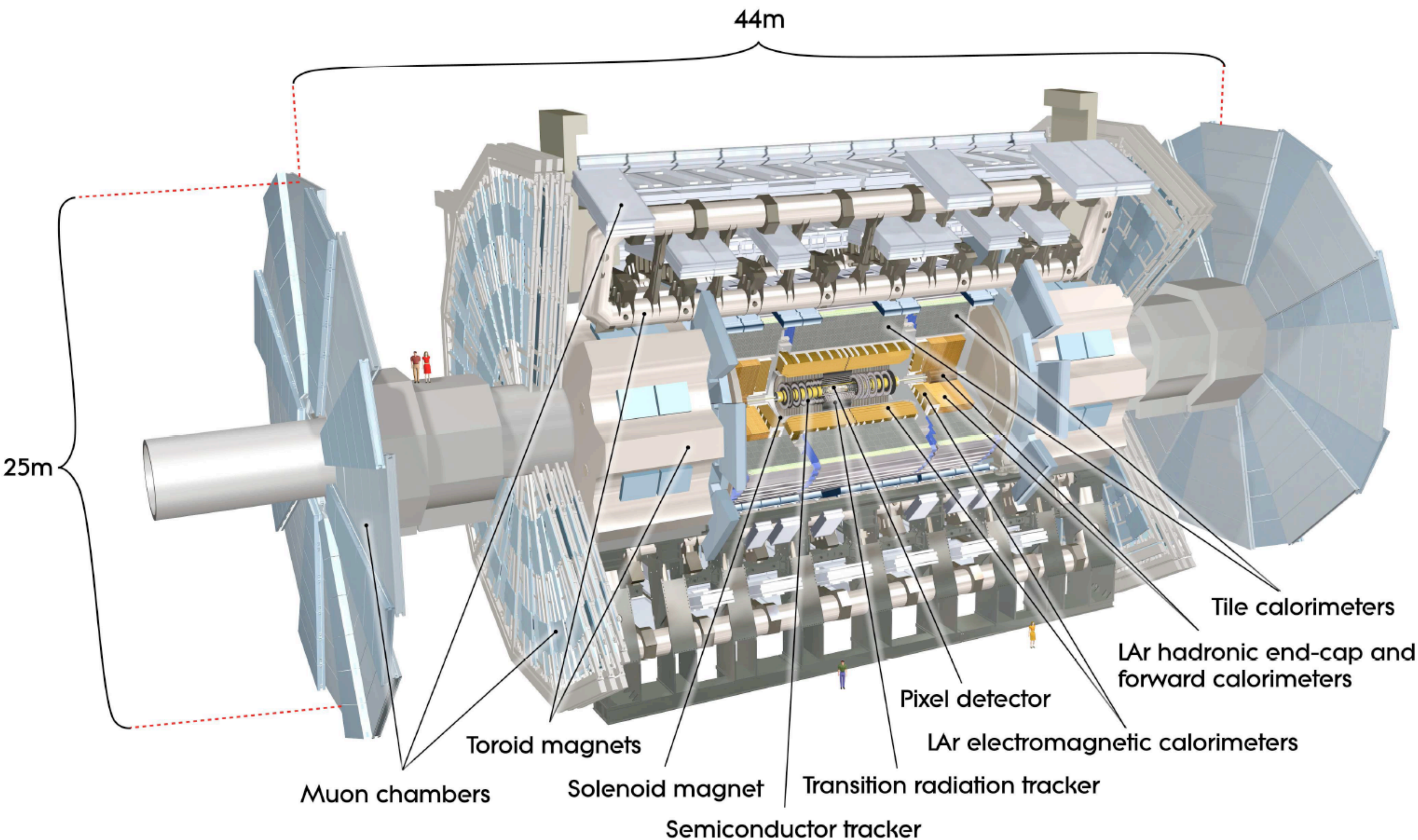
- More interesting results to come in particular for electroweak searches.

- An **additional ~43 fb^{-1}** of data from the 2017 campaign are ready to be analysed.

→ Stay **fine-tuned** for further news!

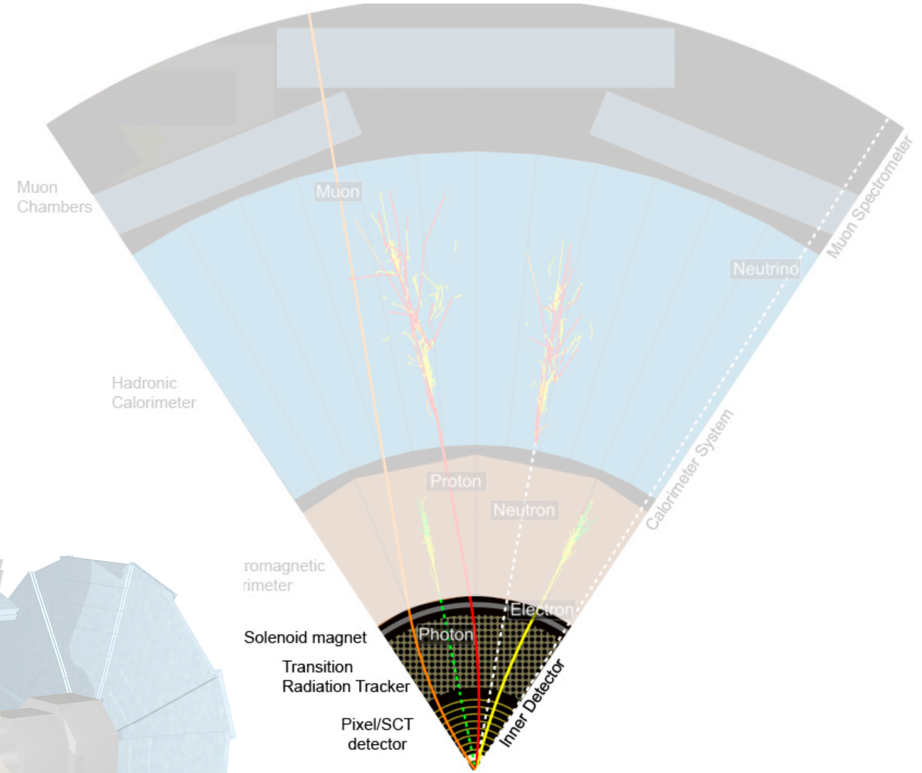


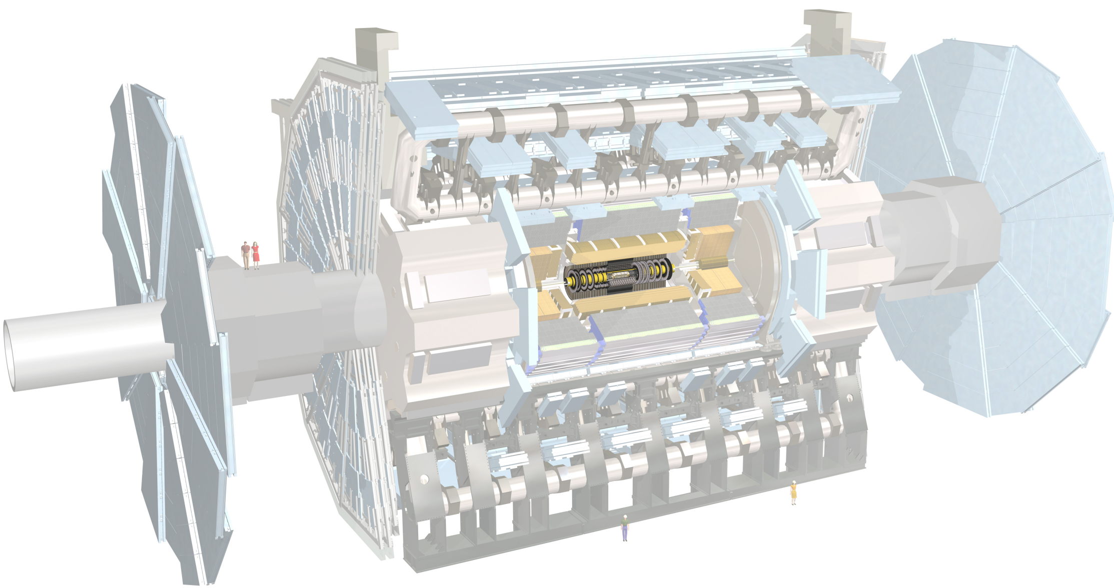
The ATLAS Experiment



ATLAS Inner Detector (ID)

- **Consists of three subsystems:**
  - Pixel detector
  - Silicon Microstrip Detector (SCT)
  - Transition Radiation Tracker (TRT)
- **Coverage up to |η| < 2.5**
- **Immersed in 2T solenoid magnetic field**





→ Reconstruction of charged particle **tracks** (e.g. from **electrons**, **muons**, **hadrons**)

→ **Vertex** reconstruction

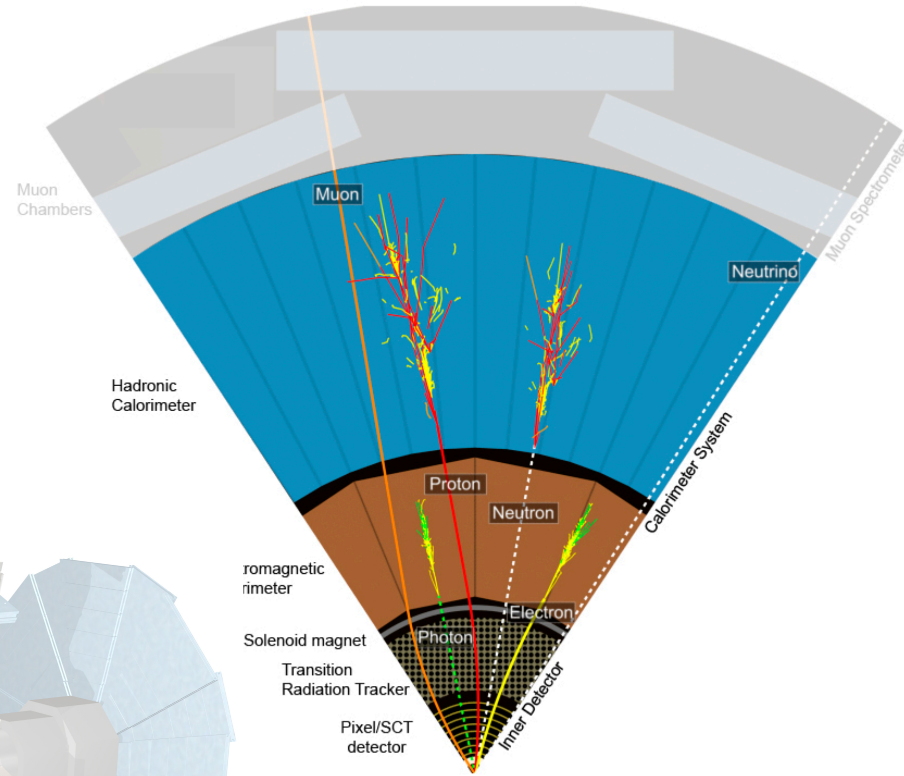
→ Particle ID (TRT)

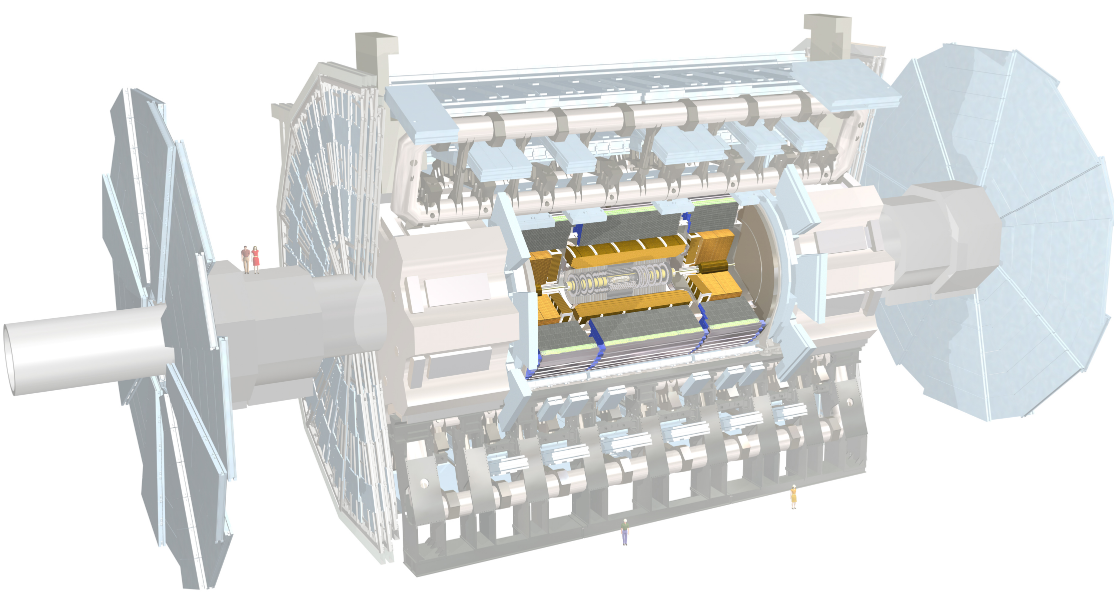
ATLAS Calorimeter System

- **Electromagnetic and Hadronic Calorimeters**
- **Coverage up to |η| < 4.9**

→ **Electrons** and **photons** deposit their energy in form of **electromagnetic showers** in the **electromagnetic calorimeter**.

→ **Hadrons** deposit their energy in form of **hadronic showers** in the **hadronic calorimeter** (reconstructed as "jets")





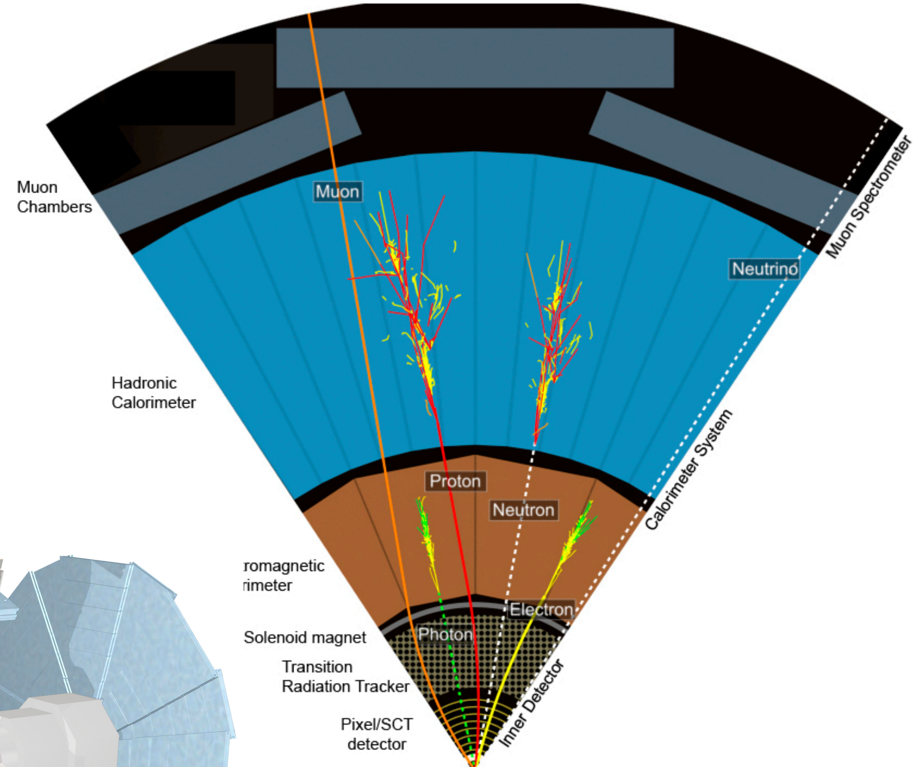
→ **Muons** leave small energy depositions in the **calorimeters**

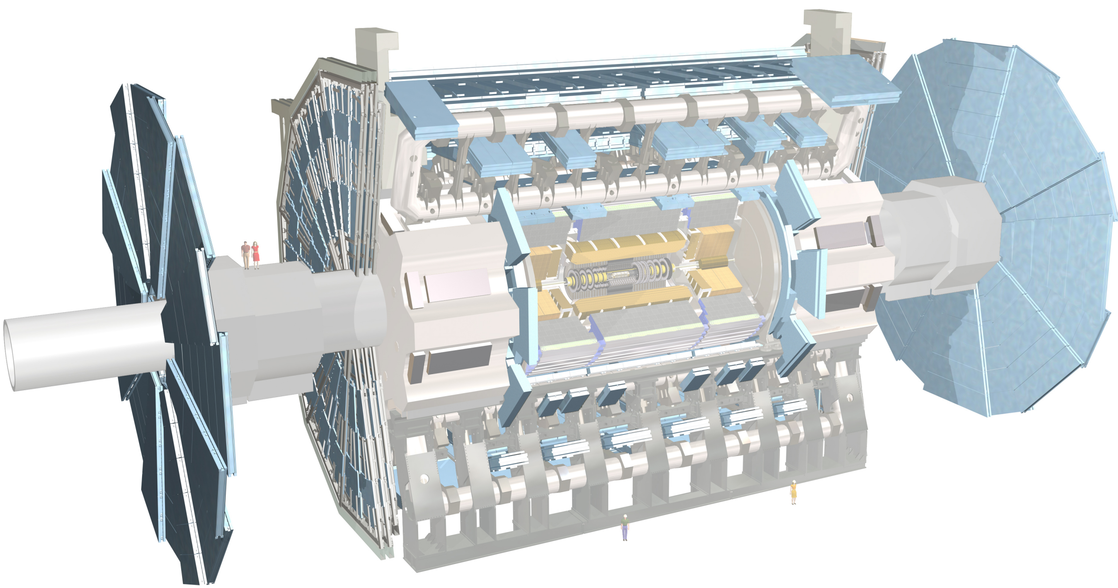
→ **Neutrinos** escape undetected but the **missing transverse energy** $E_{T,miss}$ is reconstructed.

ATLAS Muon Spectrometer (MS)

- **Precision tracking and trigger chambers**
- **Coverage up to |η| < 2.7**
- **Immersed in toroid magnetic field**

→ **Muons** leave a **track** in the **muon spectrometer**



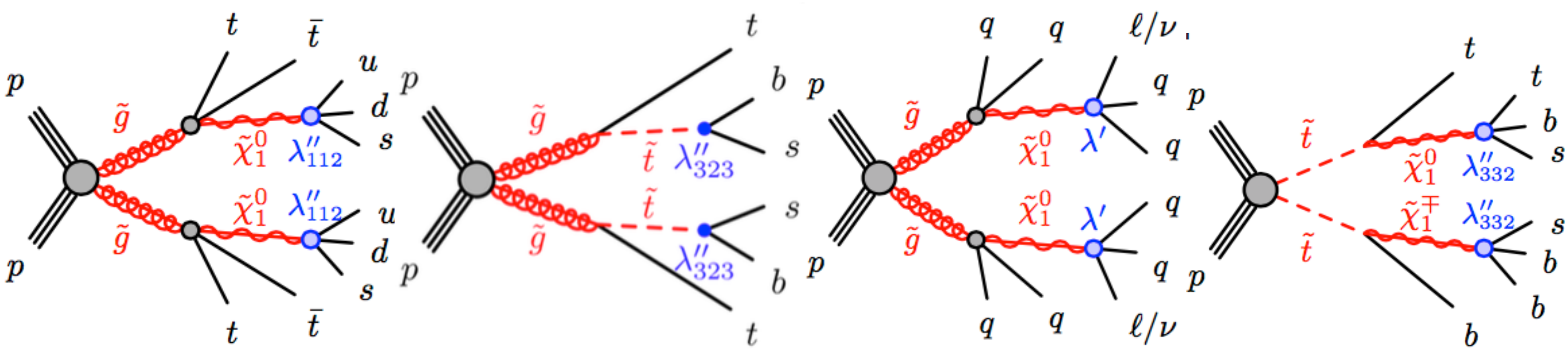


RPV 1ℓ Search – Overview

- Search for new physics in lepton + multi-jets (up to **≥12 jets**) final state
- Defining feature: **No m_T or $E_{T,miss}$ requirements**

→ Final state has been actively asked for by the theory community, e.g. [arXiv:1310.5758]

- RPV SUSY simplified models with gluino and stop pair production used as benchmark:

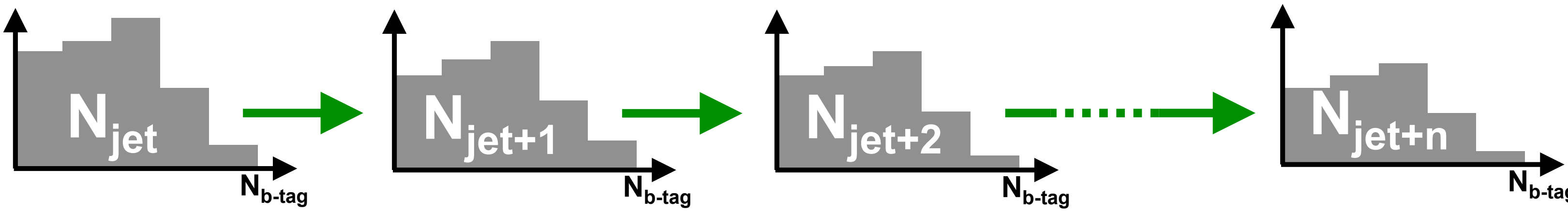


1-lepton + multi-jets selections

- 1 e / μ > 30 GeV with **tight ID and isolation** requirements (to counter fakes)
- **3 analysis streams** with jet p_T > 40/60/80 GeV
- Events in each stream categorized:
  ① N_{jets}: **5-7 jets** used to *build background model* only, **8 - ≥12 jets** used as *signal regions*
  ② $N_{b\text{-tags}}$: **0,1,2,3,≥4**

RPV 1ℓ Search: Backgrounds

- Dominant backgrounds: **$t\bar{t}$+jets** @ high $N_{b\text{-jet}}$ and **V+jets** @ low $N_{b\text{-jet}}$ → data-driven estimate
- Basic concept: **Parameterised extrapolation** of $N_{b\text{-tag}}$ spectrum from medium to high N_{jet}



$N_{b\text{-tag}}$	tt+jets	V+jets
Shape	• Initial shape from **5-jet** selection + evolution to higher N_{jet} parameterised with fixed probabilities of additional jets to be b-jets	• From MC for each N_{jet} slice
Normal-isation	• N_{jet}-evolution predicted with parameterised model based on combination of **staircase** and (extended) **Poisson scaling** of N_{jet} ratios $\mathbf{r_j = N_{j+1}/N_j}$ with scaling parameters $\mathbf{c_i}$ $$r_j = c_0 + c_1/(j + c_2)$$	

→ **Simultaneous fit** of shape & normalisation in all considered bins:

- **Discovery setup**: **Only $N_{b\text{-tag}}$ ==0, ≥3 bins** considered as SRs. Orthogonal bins with small signal contamination used to constrain background model.
- **Exclusion setup**: **All N_{jet} / $N_{b\text{-tag}}$ bins** used to constrain model.

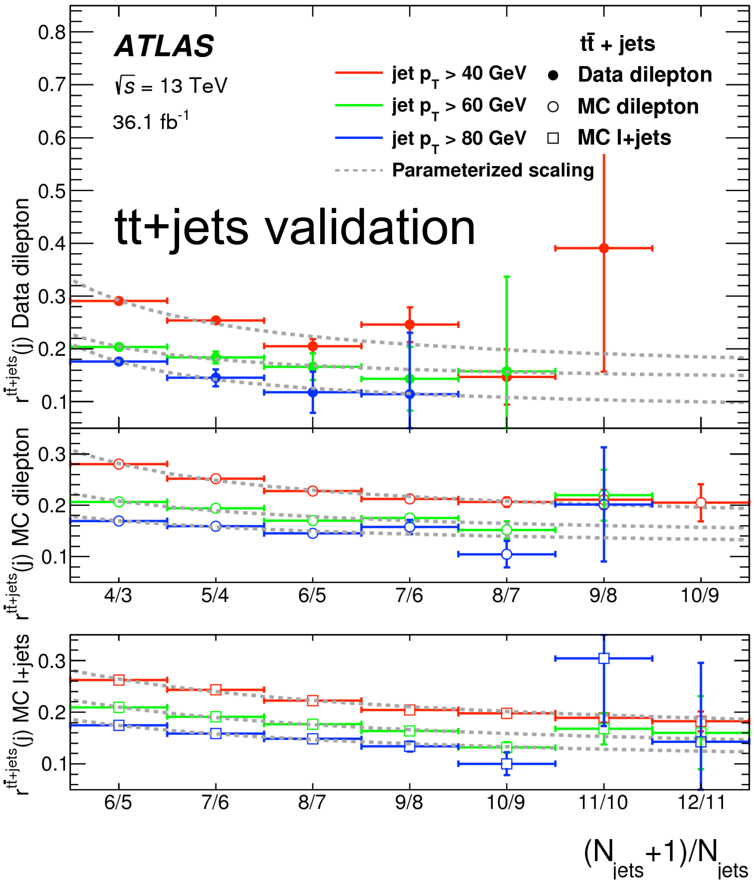
- Other backgrounds: **multi-jets** (data-driven matrix-method estimate), **diboson / single-top / tt+X** (from simulation - mostly < 10%)

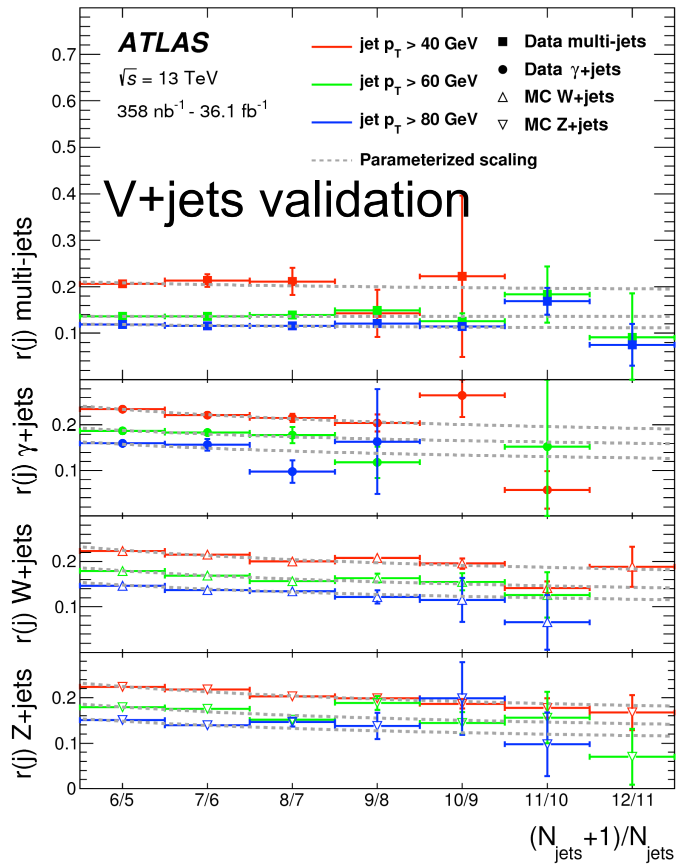
RPV 1ℓ Search: Validation

- Scaling of N_{jets} normalisation **validated** in **data** and **simulation**:

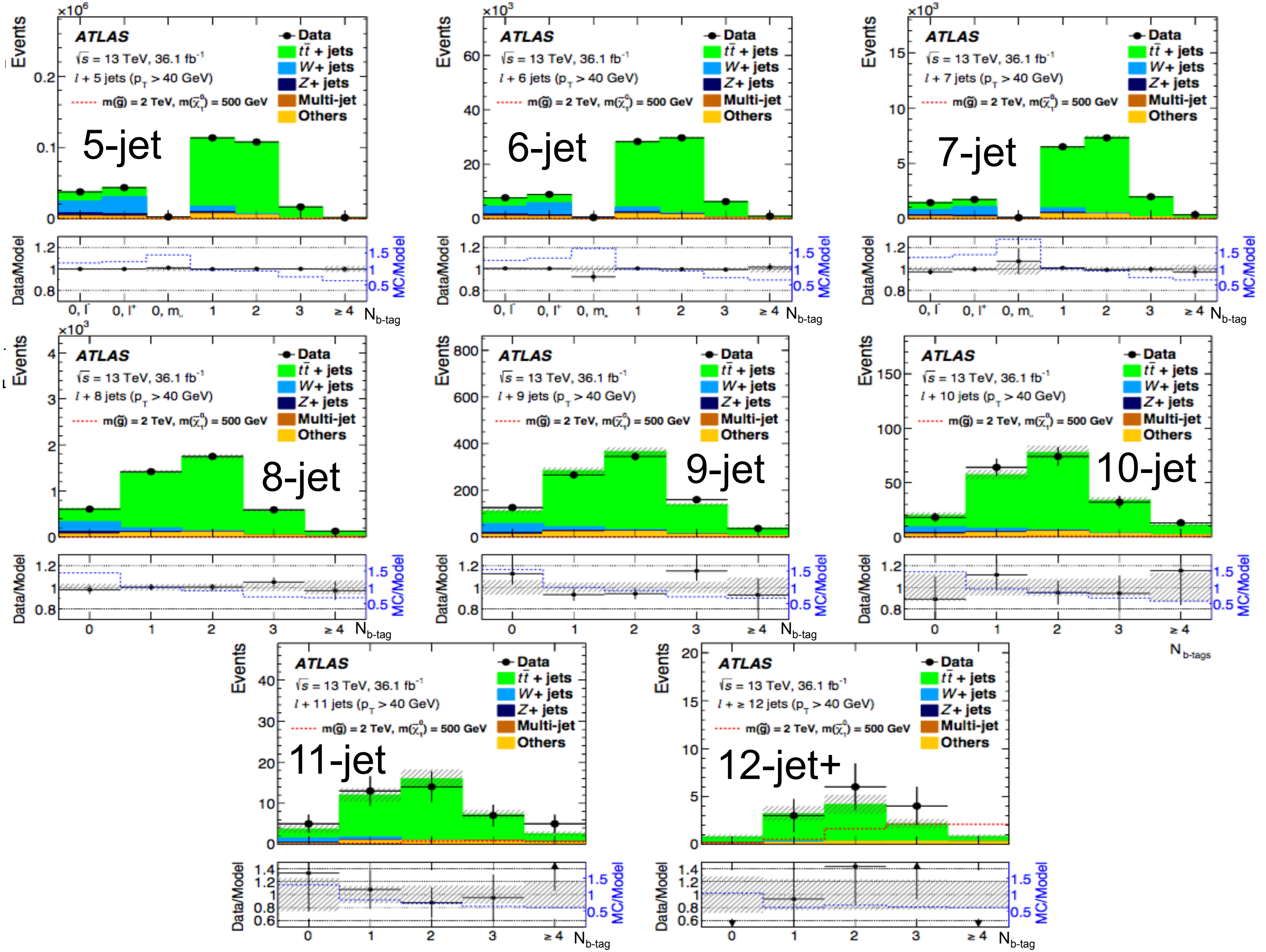
✓ tt̄ di-lepton selection (data validation)
✓ tt̄ di-lepton selection (MC closure)
✓ tt̄+jets + lepton (MC closure)

✓ γ+jets control selection (data validation)
✓ multi-jets selection (data validation)
✓ W+jets / Z+jets (MC closure)

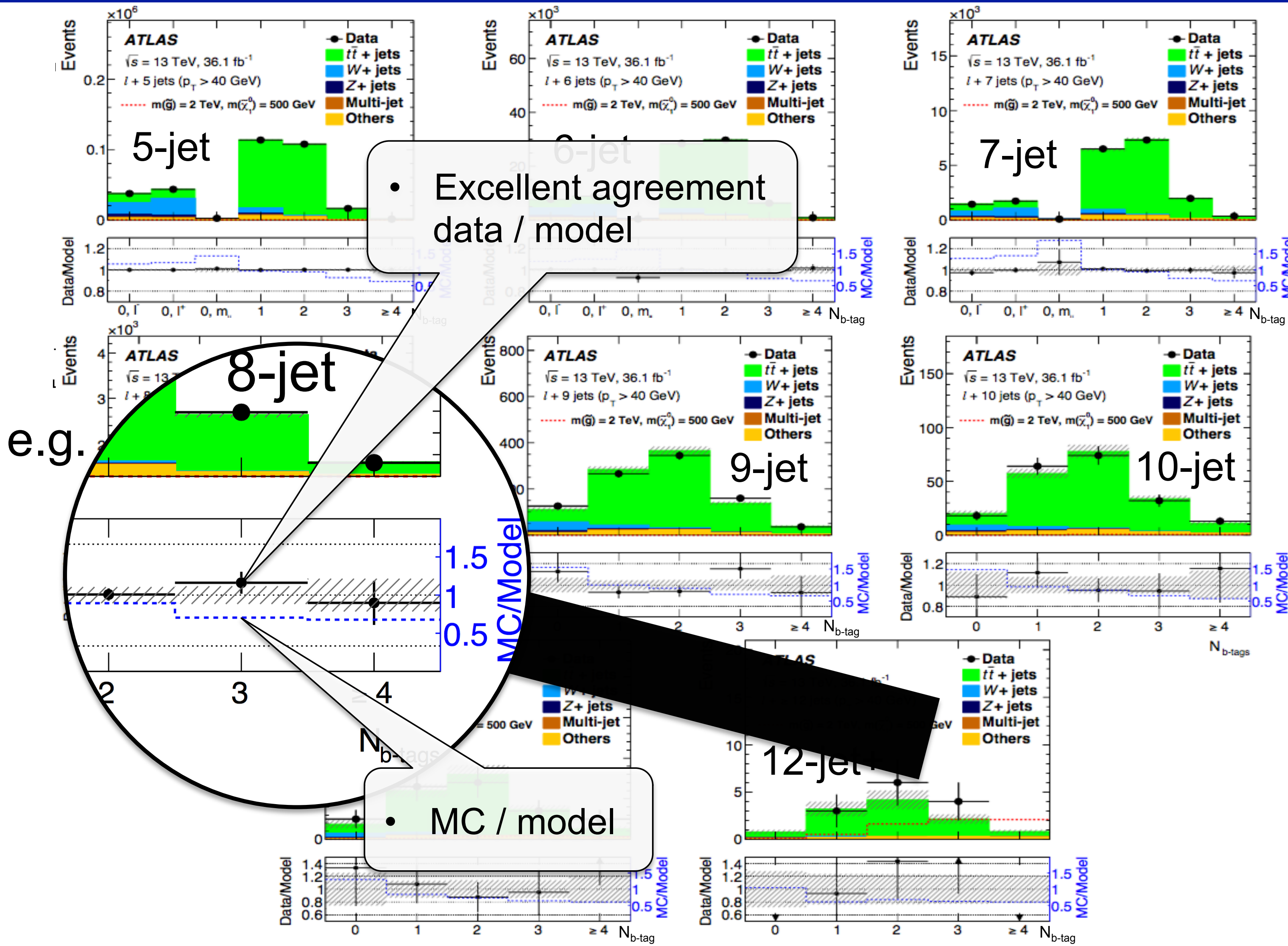




RPV 1ℓ Search: Results

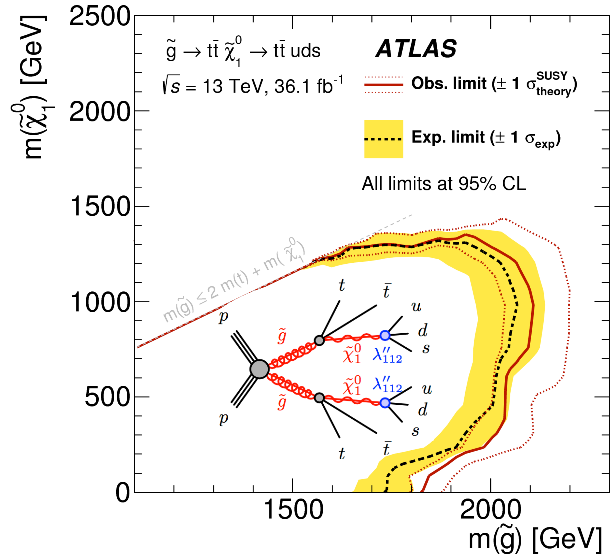


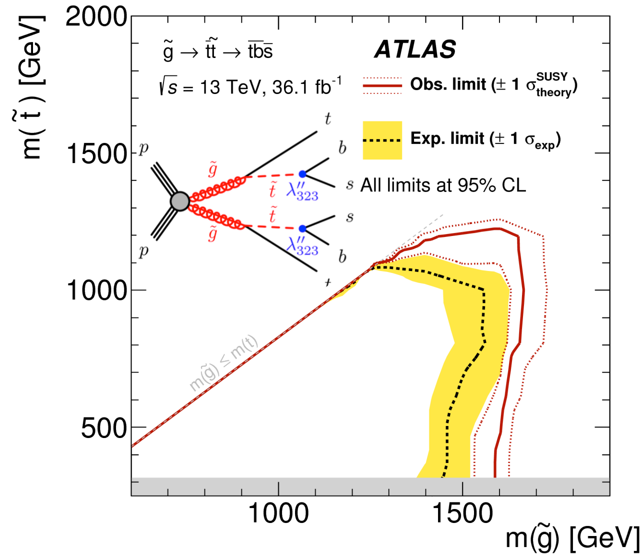
RPV 1ℓ Search: Results

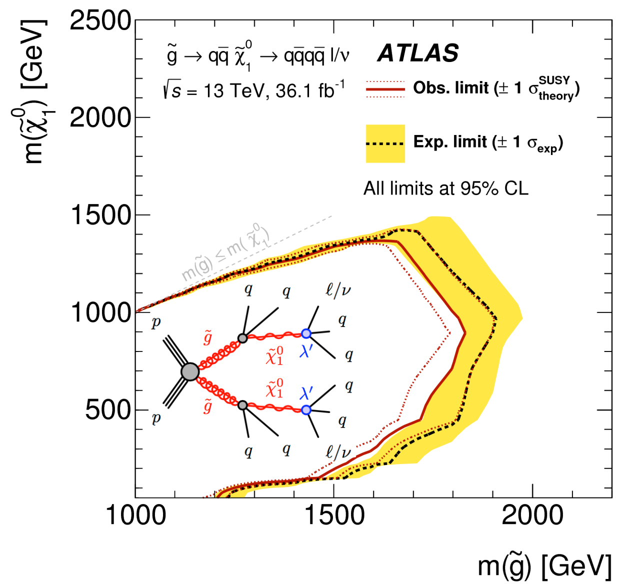


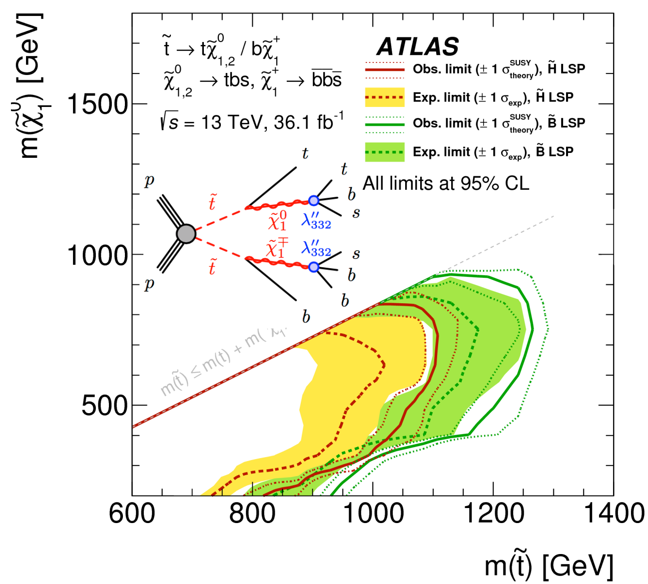
RPV 1ℓ Search: Interpretation

- Limits on 4 RPV SUSY models
  - Up to ~**2.1 TeV gluino mass** depending on model
  - Up to ~**1.25 TeV stop mass**
- Limit on **SM 4-top production of 6.5 x SM** (9.1 expected)



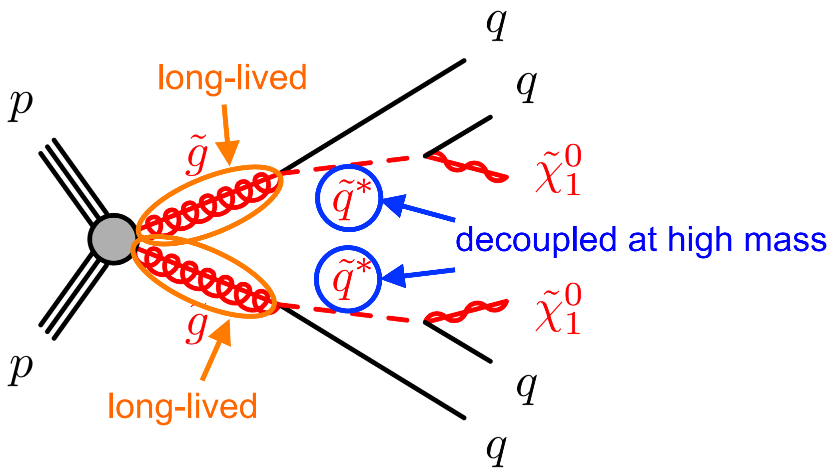






Displaced Vertex Search - Overview

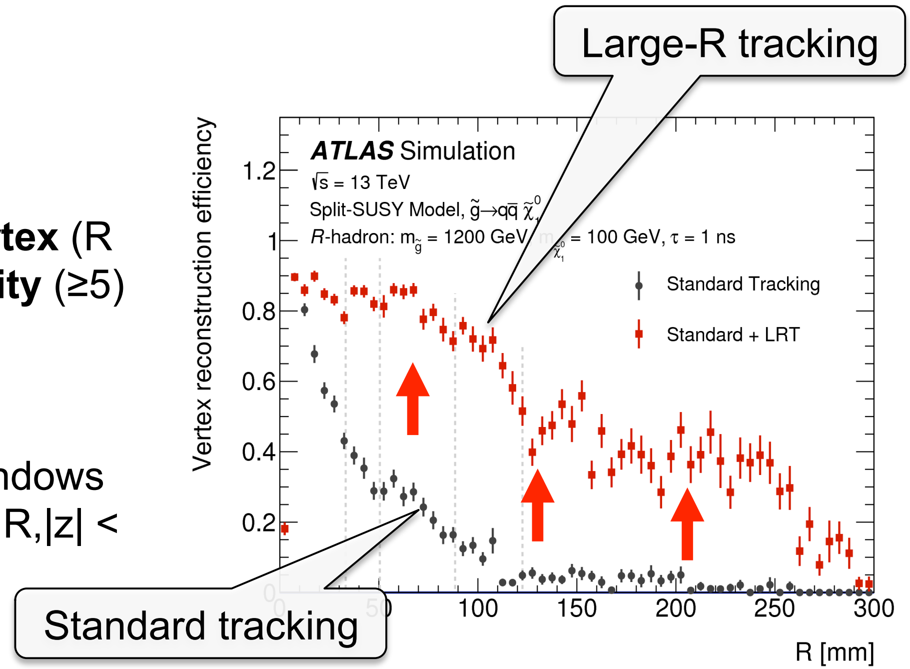
- Search for long-lived massive particles in the lifetime range O(10^{-2}) – O(10) ns
- Split-SUSY inspired simplified model as benchmark



- Long-lived gluinos form bound colour singlet states with SM particles (R-hadron) → decay in the inner tracker volume

- Experimental signature: **Displaced vertex** (R ~ 1-100 mm) with **high track multiplicity** (≥5) and **high mass** (>10 GeV) + $\mathbf{E_{T,miss}}$

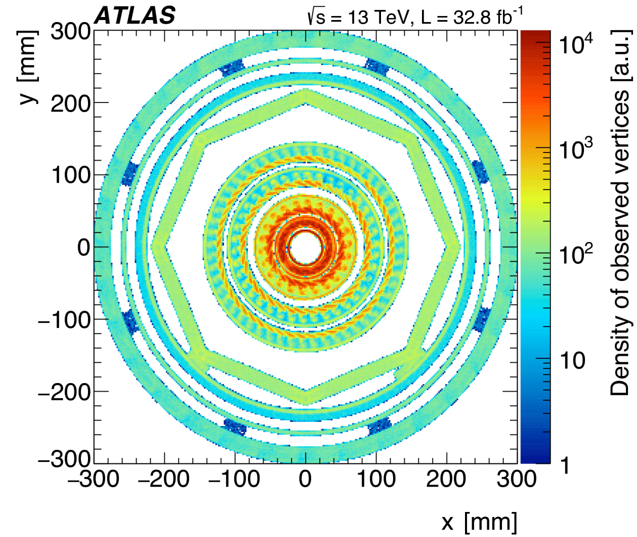
- Use of specialised **large radius track reconstruction** with extended d_0/z_0 windows to reconstruct displaced vertices within R,|z| < 30 cm

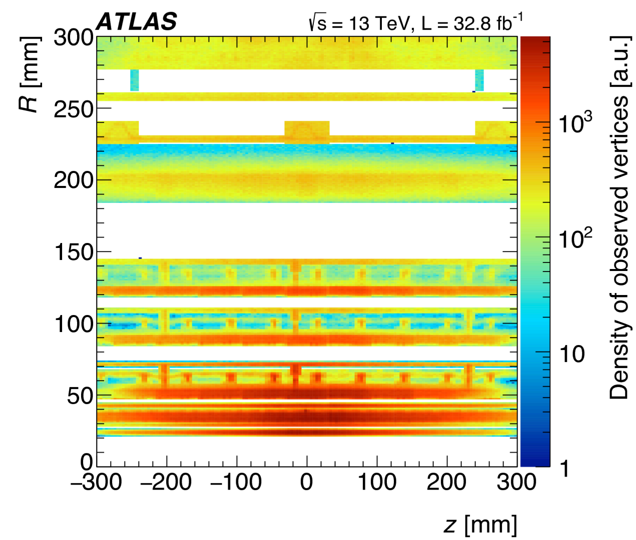


Displaced Vertex Search - Backgrounds

- **Hadronic interactions** with detector material → Produces displaced vertices:
  - Background significantly reduced by **removing material-rich regions** from fiducial volume (maps based on minimum bias data) → Discards **42% of detector volume**
  - Residual contribution estimated with exponential fit at low m_{DV} + extrapolation to high m_{DV}
- **Close-by short-lived SM particle decays** → Merge into common vertex thus passing N_{trk} and m_{DV} cuts
  - Estimated by merging vertices from distinct events randomly
- **Accidental crossing** of low mass vertices and tracks → Used in vertex reconstruction thus passing N_{trk} and m_{DV} requirements
  - Estimate by adding pseudo-track to vertices in a control region

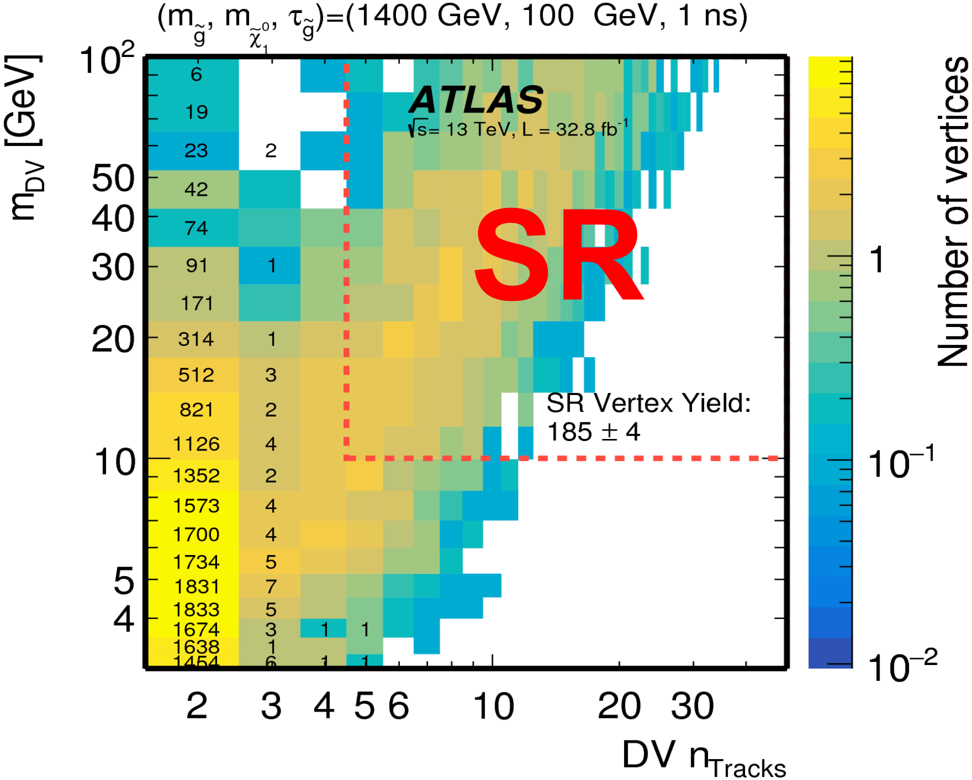
→ Several dedicated signal-depleted validation regions used for cross-checks

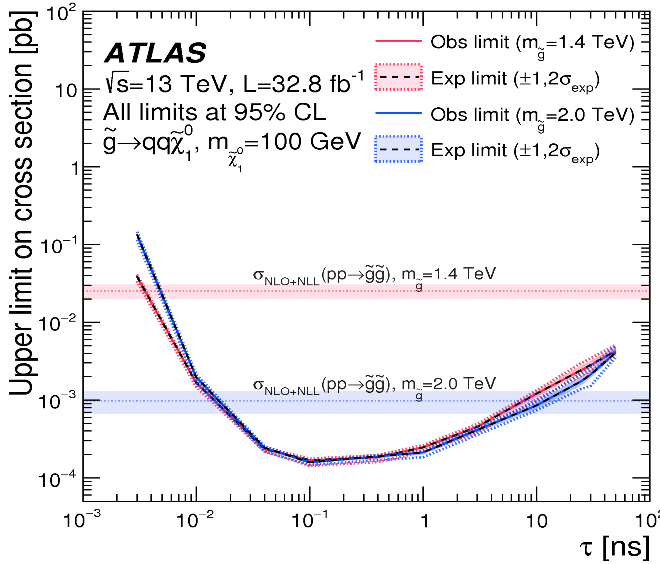


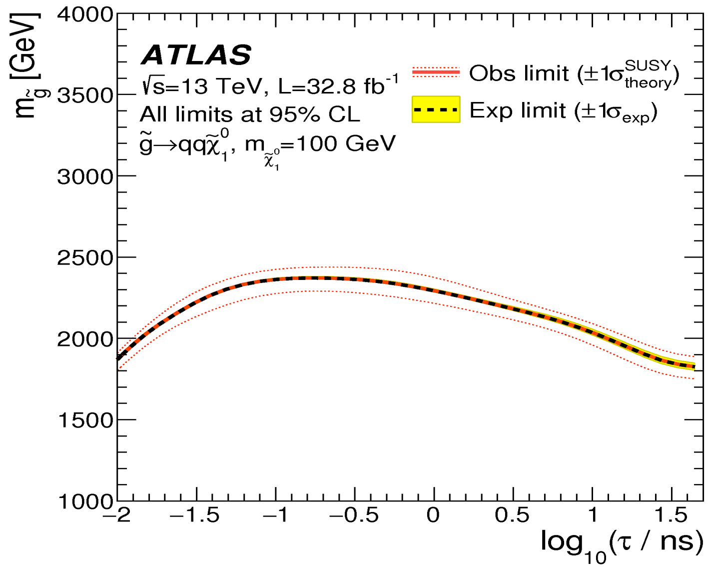


Displaced Vertex Search -Results

- **No event is observed** in the SR: Consistent with the background **expectation of 0.2 ± 0.2 events**
- Exclude long-lived gluinos up to **2.3 TeV** with lifetimes of ~ $O(10^{-2})$ - $O(10)$ ns







Inclusive 0-ℓ Search: Overview

- Final state: **2-6 Jets + E_{Tmiss} (no leptons!)**

H_T = Σp_T^{jet},
m_{eff} = $H_T + E_{T,miss}$

m_{eff}-based Analysis Stream

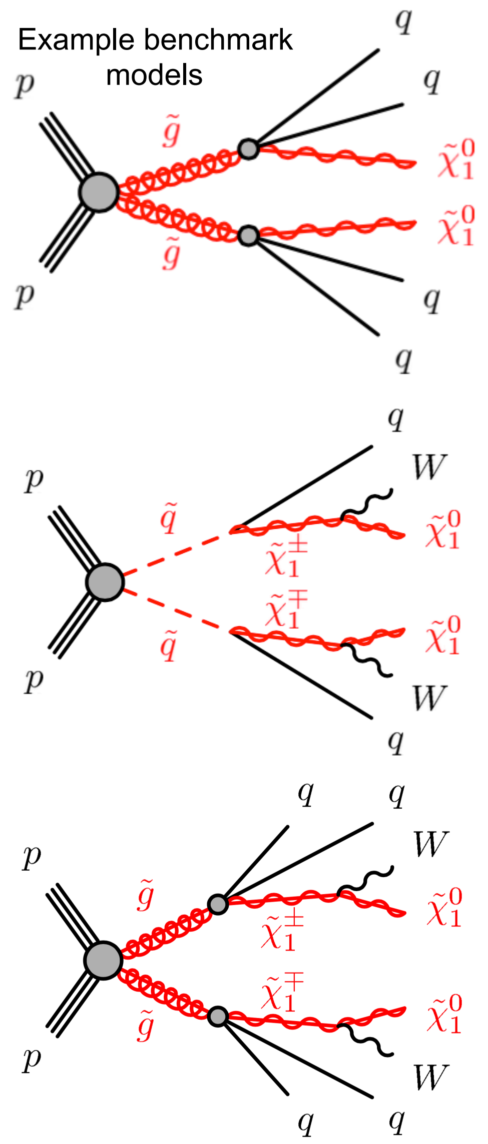
- **24 inclusive SRs** using the *effective mass* as final discriminant:
  - ≥2/3 jet regions → **direct** squark decays
  - ≥4/5 jet regions → **direct** gluino decays
  - ≥5/6 jet regions → gluino/squark decays **via χ±** with W bosons
  - ≥2 **large-R** jets → gluino/squark decays with **boosted** W bosons
  - → Scans **of m_{eff}, $E_{T,miss}/m_{eff}$ or $E_{T,miss}/\sqrt{H_T}$** to cover variety of mass spectra

not orthogonal but complementary

Recursive Jigsaw Analysis Stream

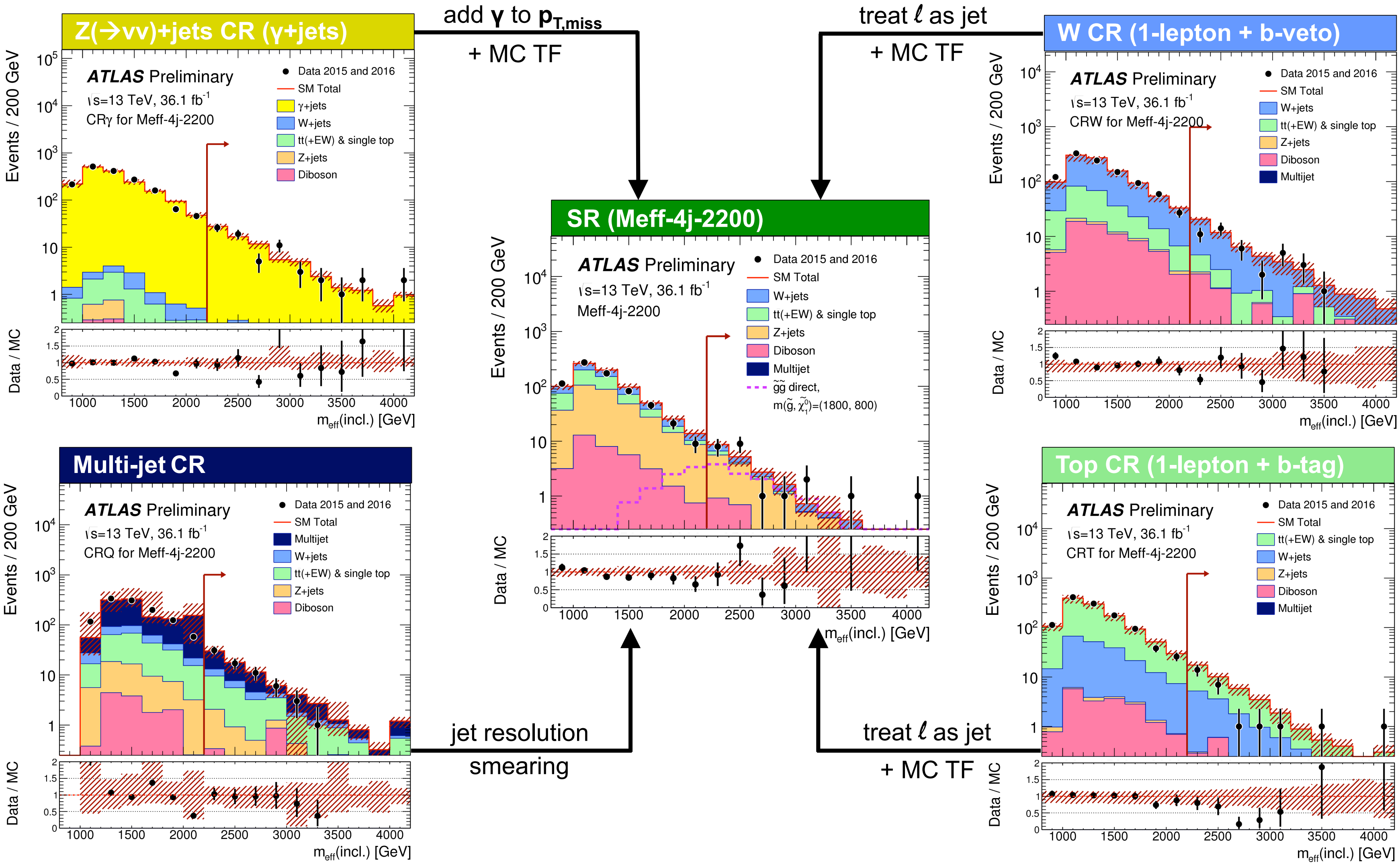
- **19 inclusive SRs** based on the *recursive jigsaw* reconstruction technique:
  - Impose specific decay hypothesis on event and assign four-momenta to invisible states.
  - Compute kinematic variables in the frames of the intermediate hypothesized particles

Example benchmark models



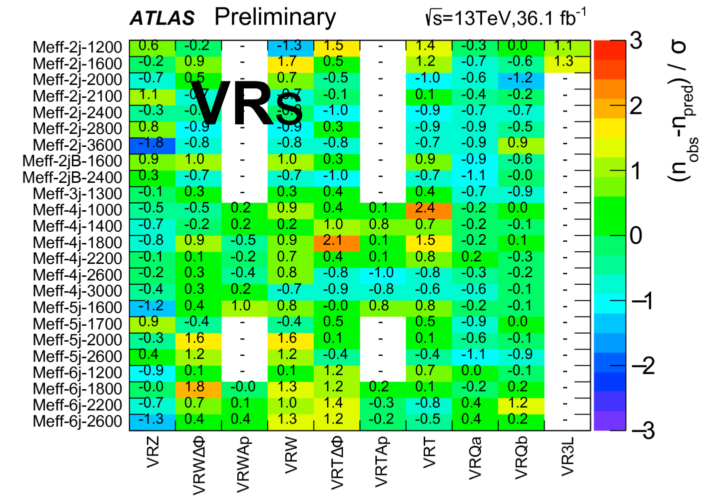
Inclusive 0-ℓ Search: Backgrounds

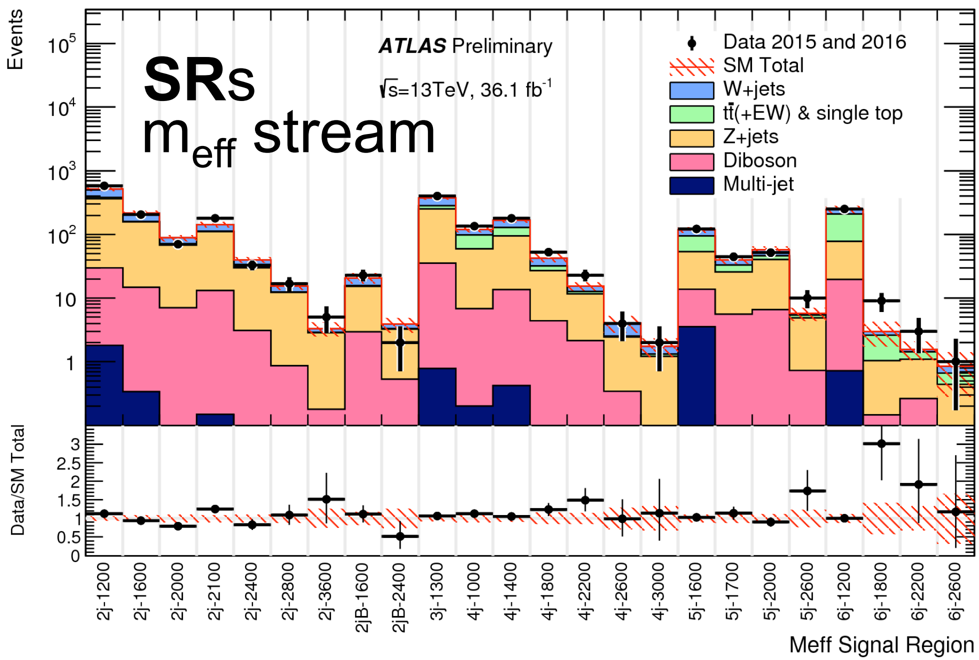
- Dominant backgrounds estimated in 4 CRs for each SR → extrapolation to VRs/SRs with transfer factors (TFs)

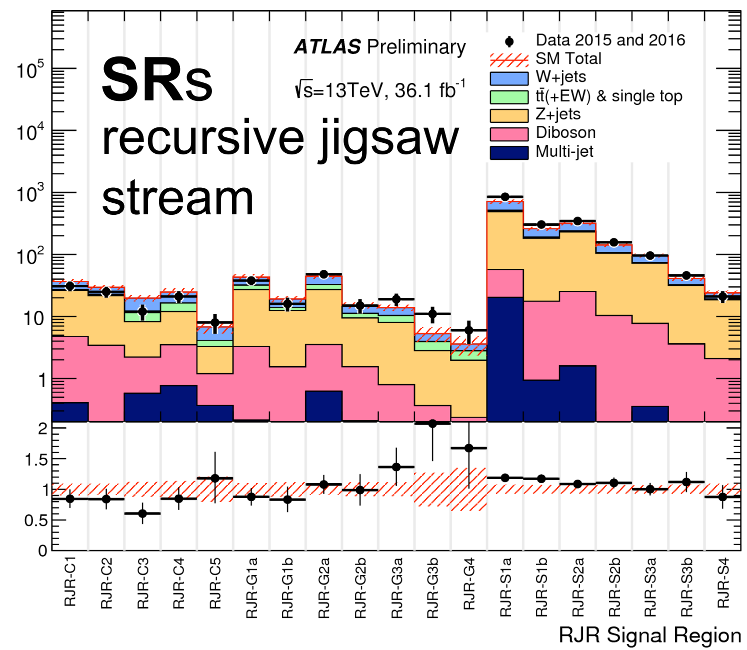


Inclusive 0-ℓ Search: Results

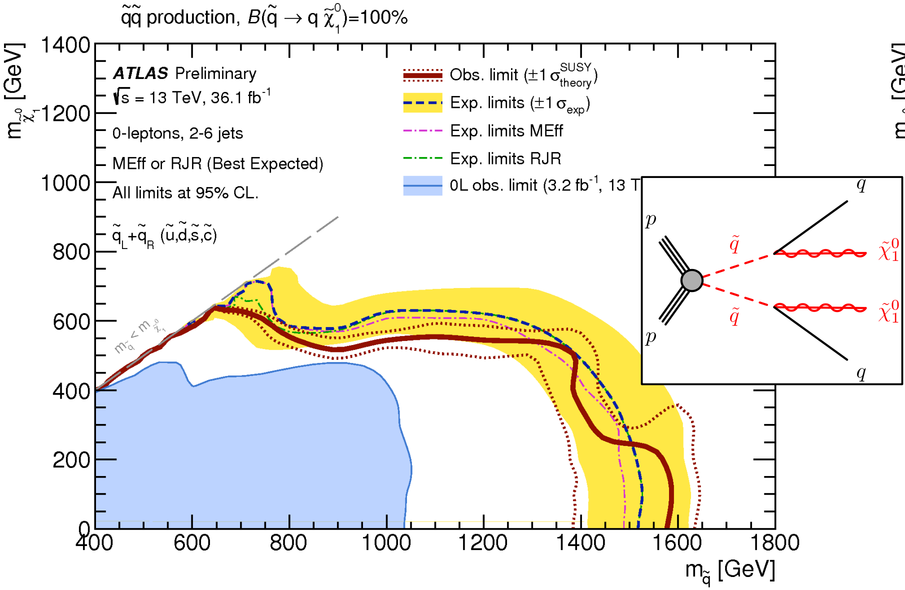
- Background estimates validated in **large amount of validations regions** for the major background processes
- **No significant deviations** from the Standard Model expectation in both streams

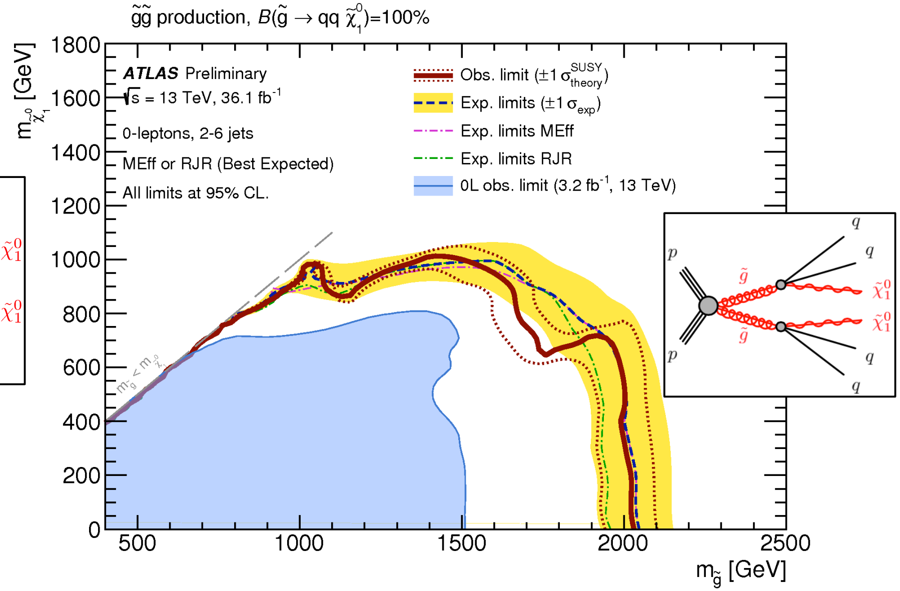


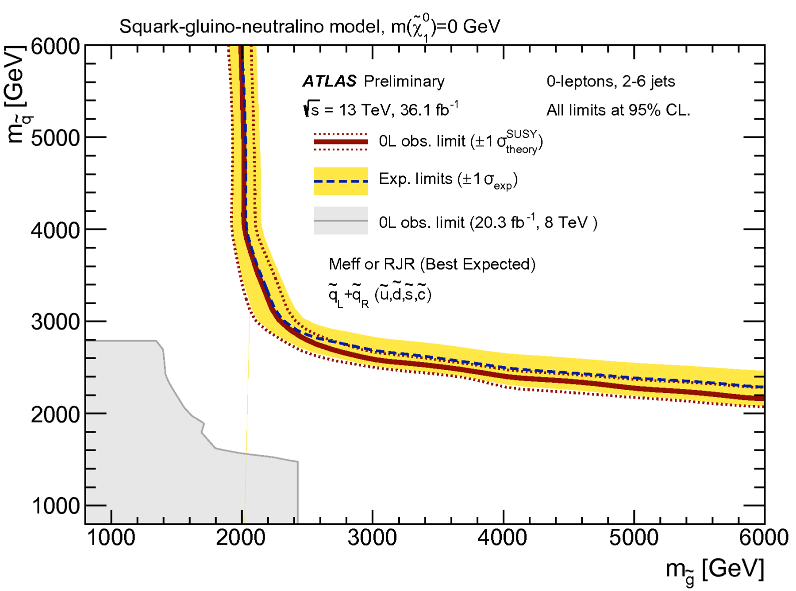


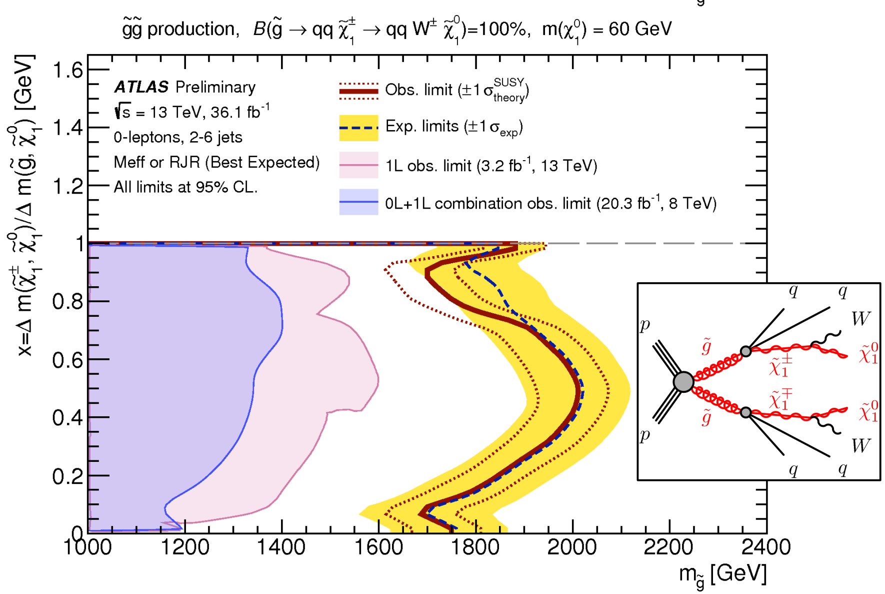


Inclusive 0-ℓ Search: Interpretations

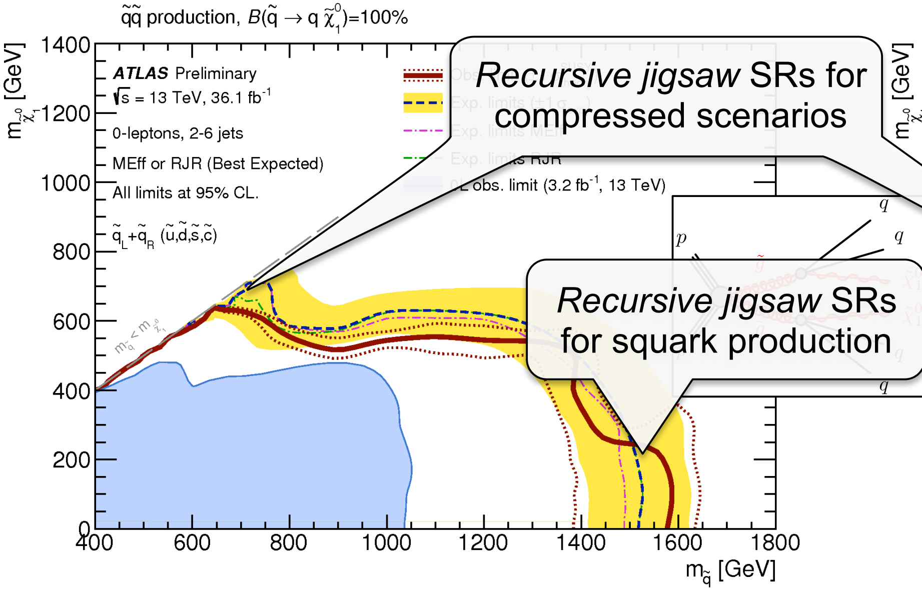


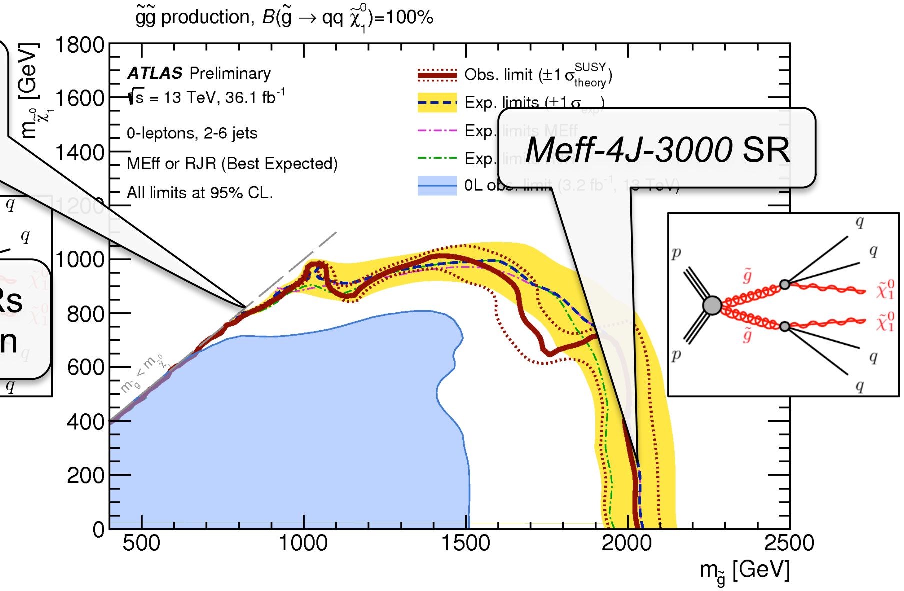


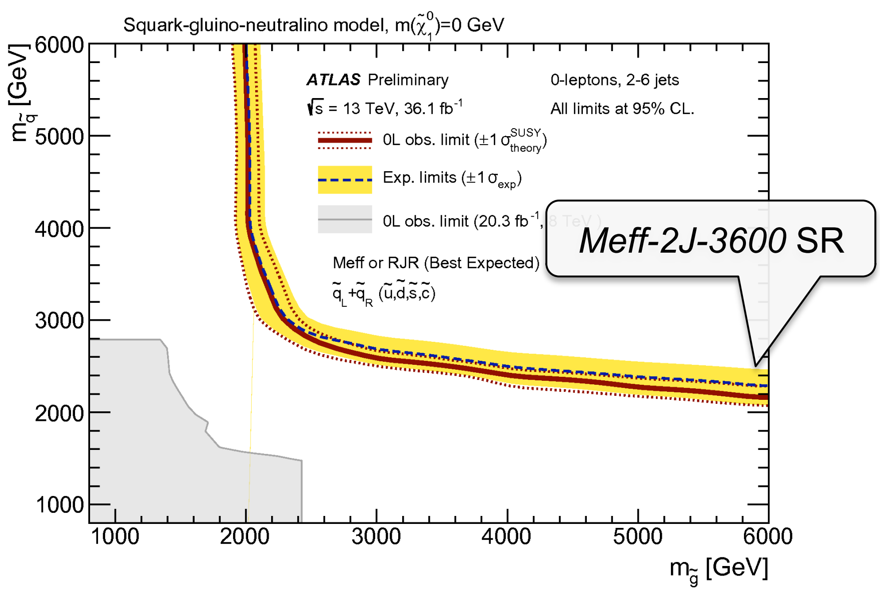


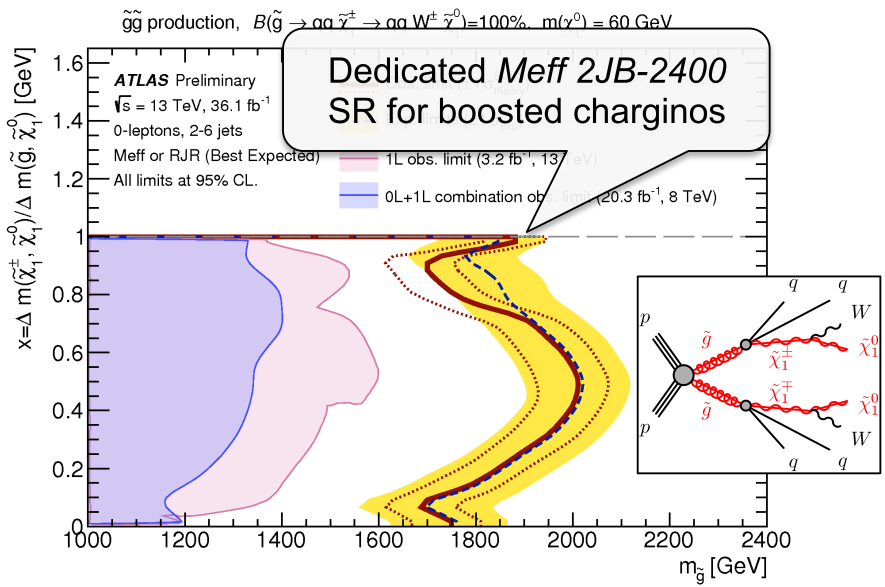


Inclusive 0-ℓ Search: Interpretations



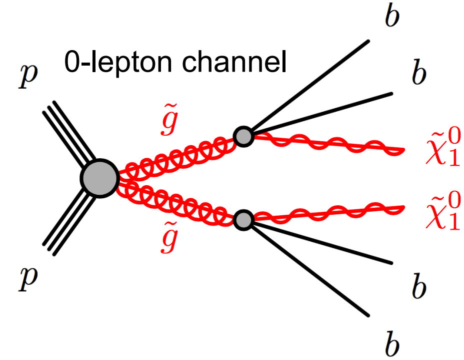






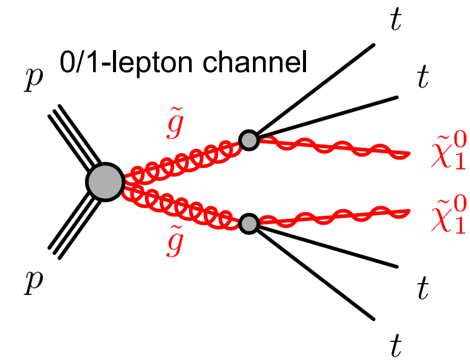
Multi b-jet Search: Overview

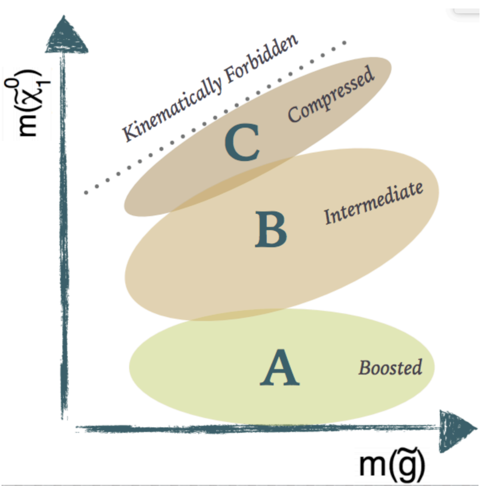
- Defining feature: **≥ 3 b-jets + 0/1 lepton + $E_{T,miss}$** final state
- Main benchmarks are gluino-mediated stop/sbottom production

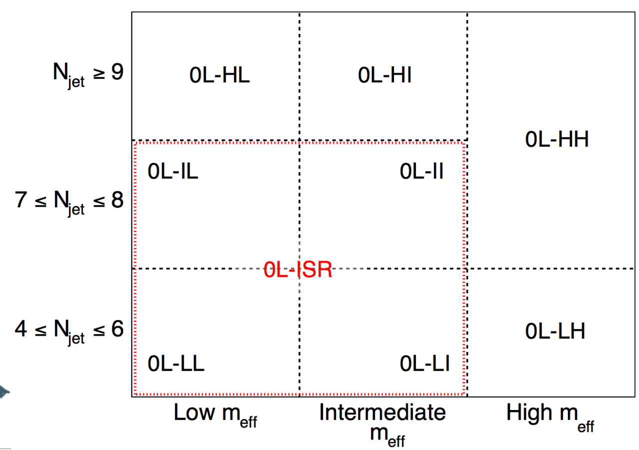


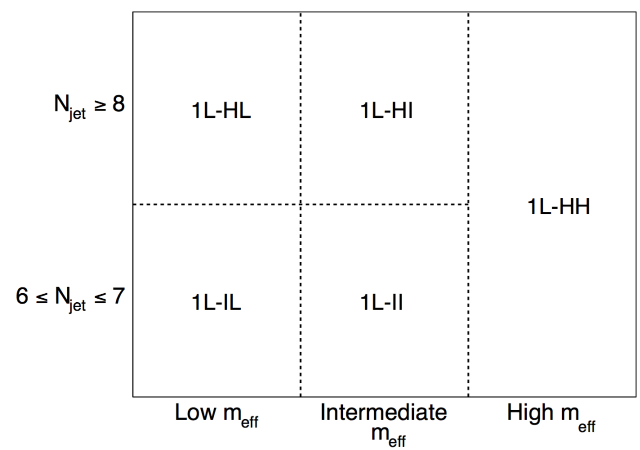
① 10 Inclusive signal regions optimised for discovery:
  – Selection: ≥ 3-8 jets using $N_{b\text{-tag}}$, m_{eff}, m_T, $E_{T,miss}$, $\Sigma m_{\text{large-R jets}}$ to target compressed, intermediate, & large mass splittings

② Binned orthogonal signal regions optimised for exclusion:
  – Selection: Ranging from low to high (m_{eff} & N_{jet}) to cover broad range of mass spectra
  – Combined fit over all bins to enhance exclusion power









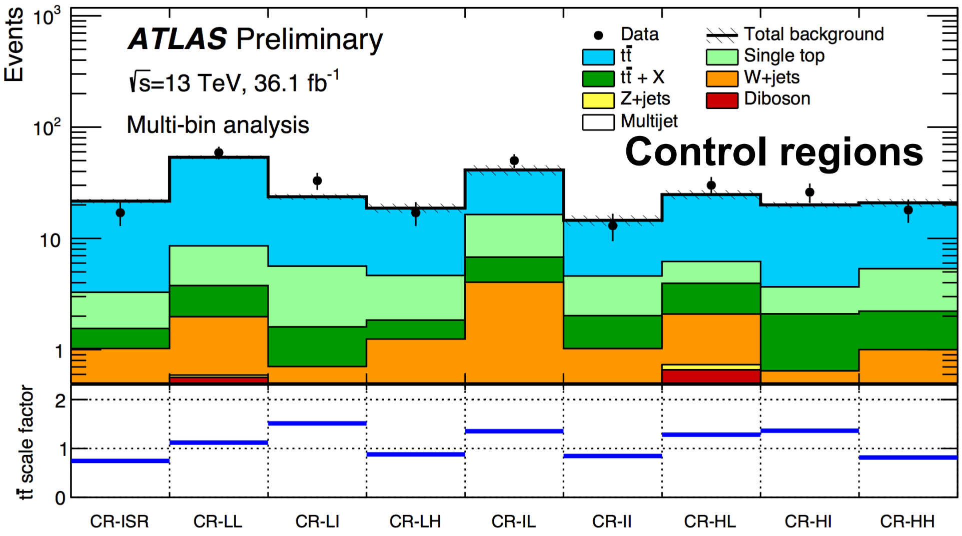
Multi b-jet Search: Backgrounds

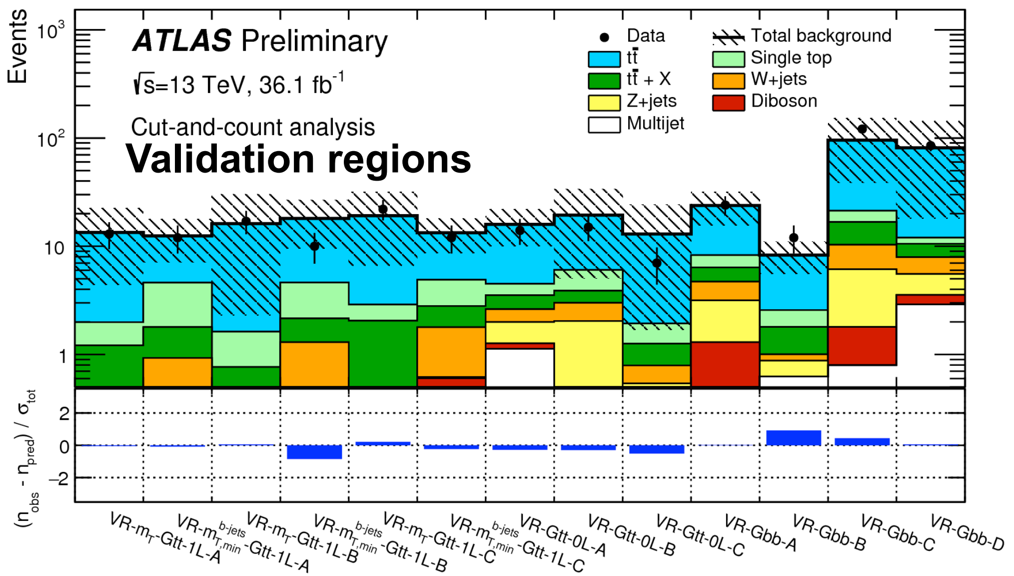
- Dominant background **$t\bar{t}$+jets** estimated with semi data-driven approach in dedicated **1-lepton control regions** + extrapolation to validation and signal regions

- **Other backgrounds** ($t\bar{t}$+X, Z+jets, single-top, di-boson) **from simulation**

- Multi-jets background negligible

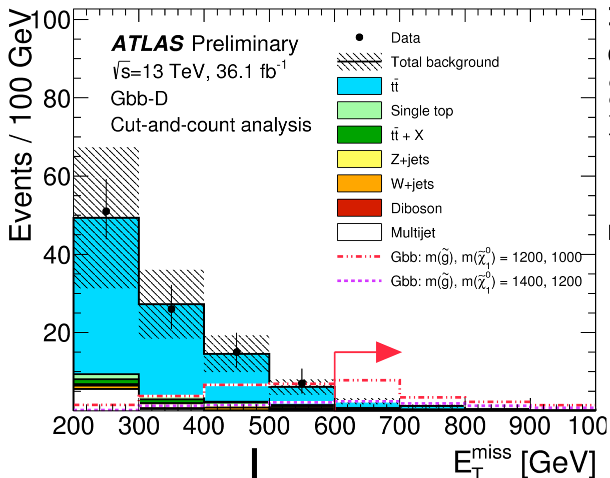
→ No evidence of significant background mis-modeling in the validation regions

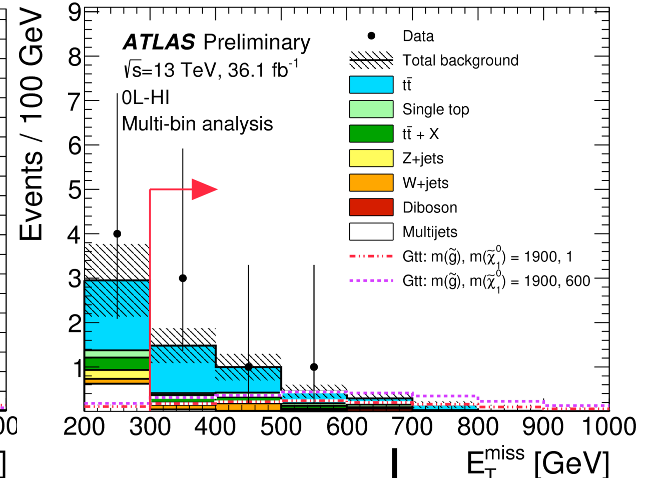


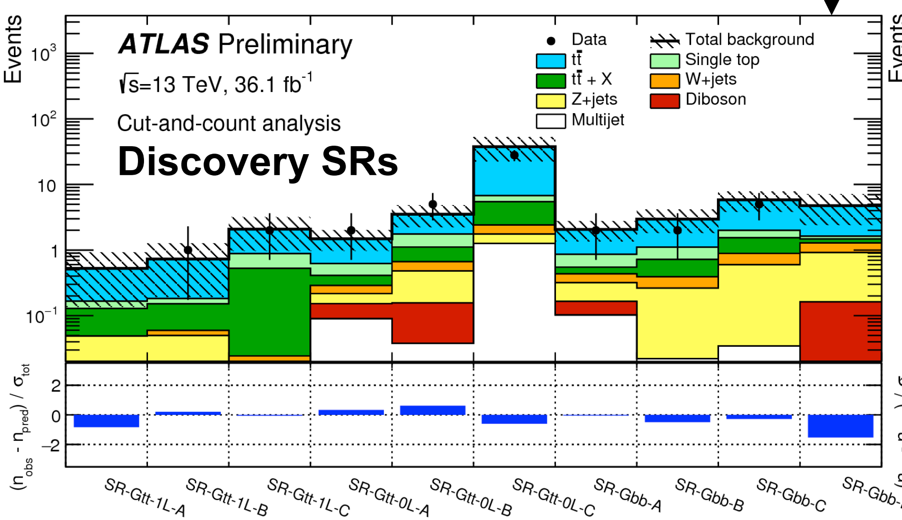


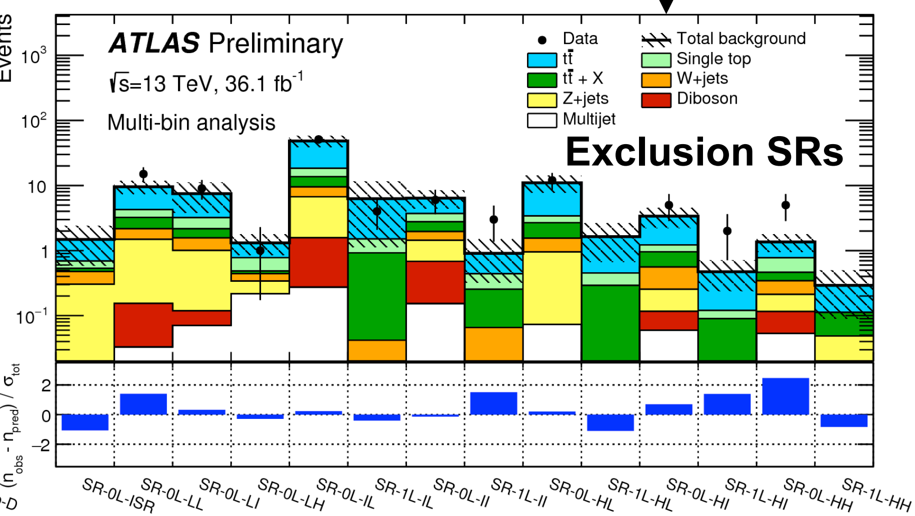
Multi b-jet Search: Results

- Generally **good agreement** between data and prediction in discovery and exclusion signal regions
- Small deviation in 0-lepton high-mass signal region ~ 2σ

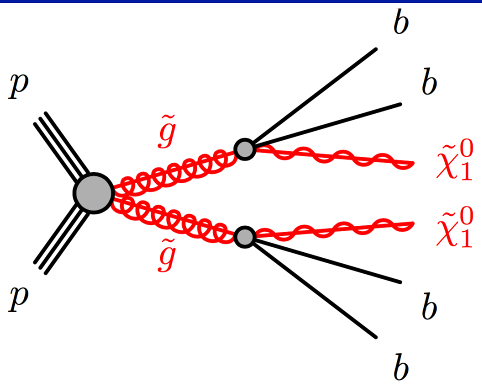


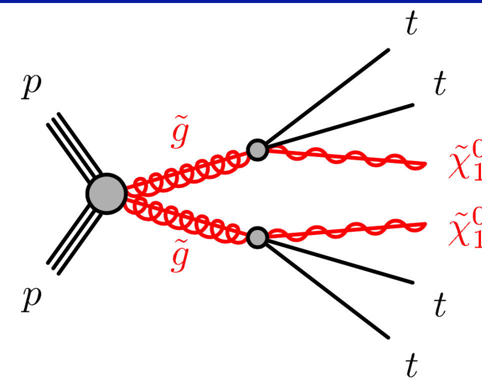


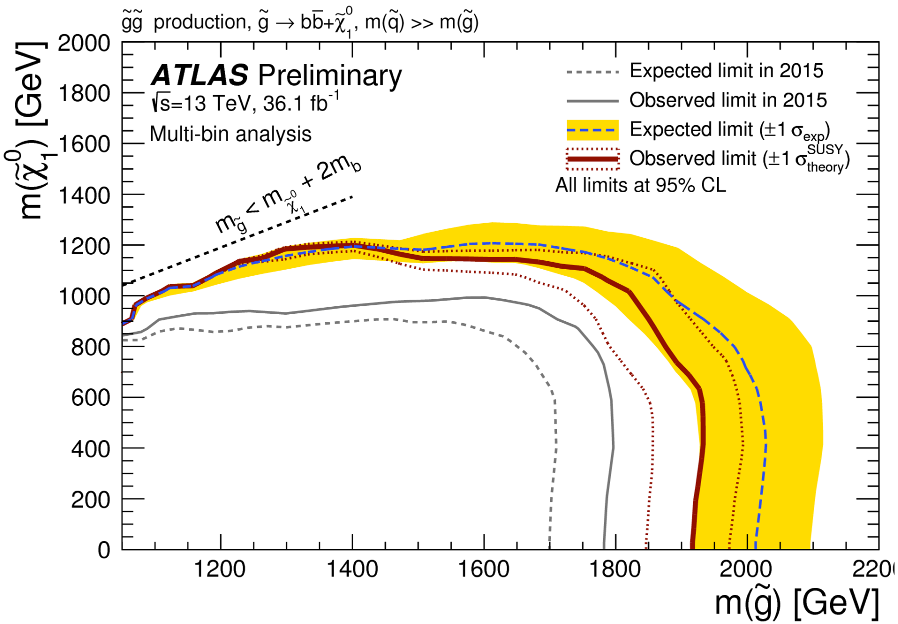


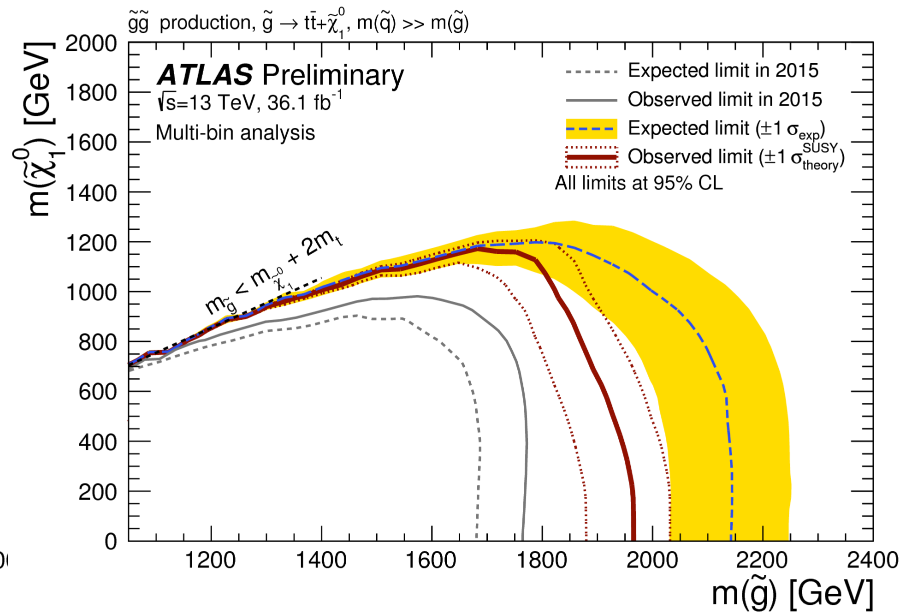


Multi b-jet Search: Interpretation







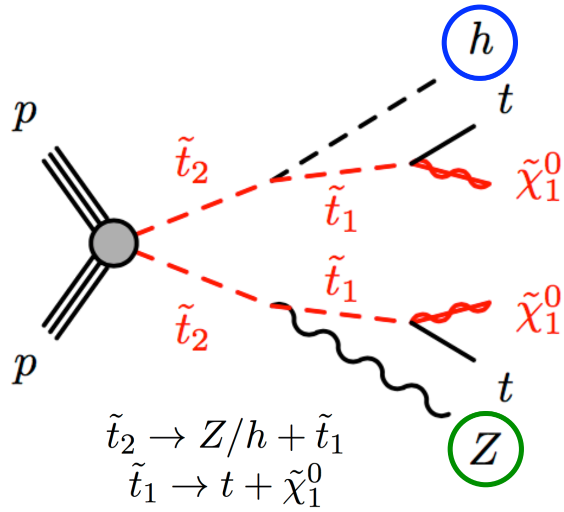


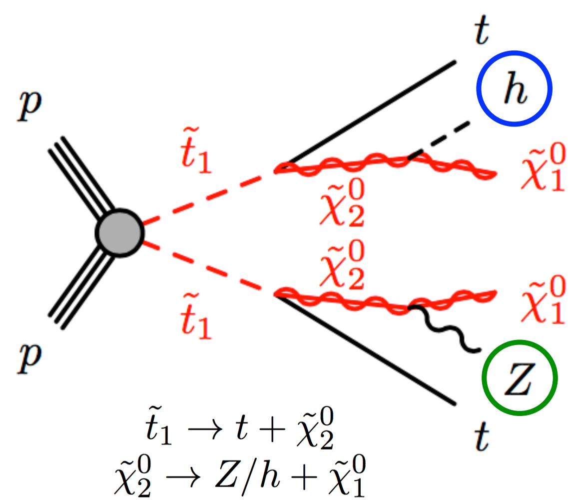
→ Sensitivity extended in g→bb+$\tilde{\chi}^0$ analysis extended by ~100 GeV w.r.t. 14.8 fb^{-1} analysis – observed **beyond 1.9 TeV**

→ Sensitivity extended in g→tt+$\tilde{\chi}^0$ analysis extended by ~200 GeV w.r.t. 14.8 fb^{-1} analysis – observed limit **beyond 1.95 TeV**

Stop Z / Higgs Search: Overview

- Search targeting direct stop production with a **Z or Higgs bosons** in the decay chain:



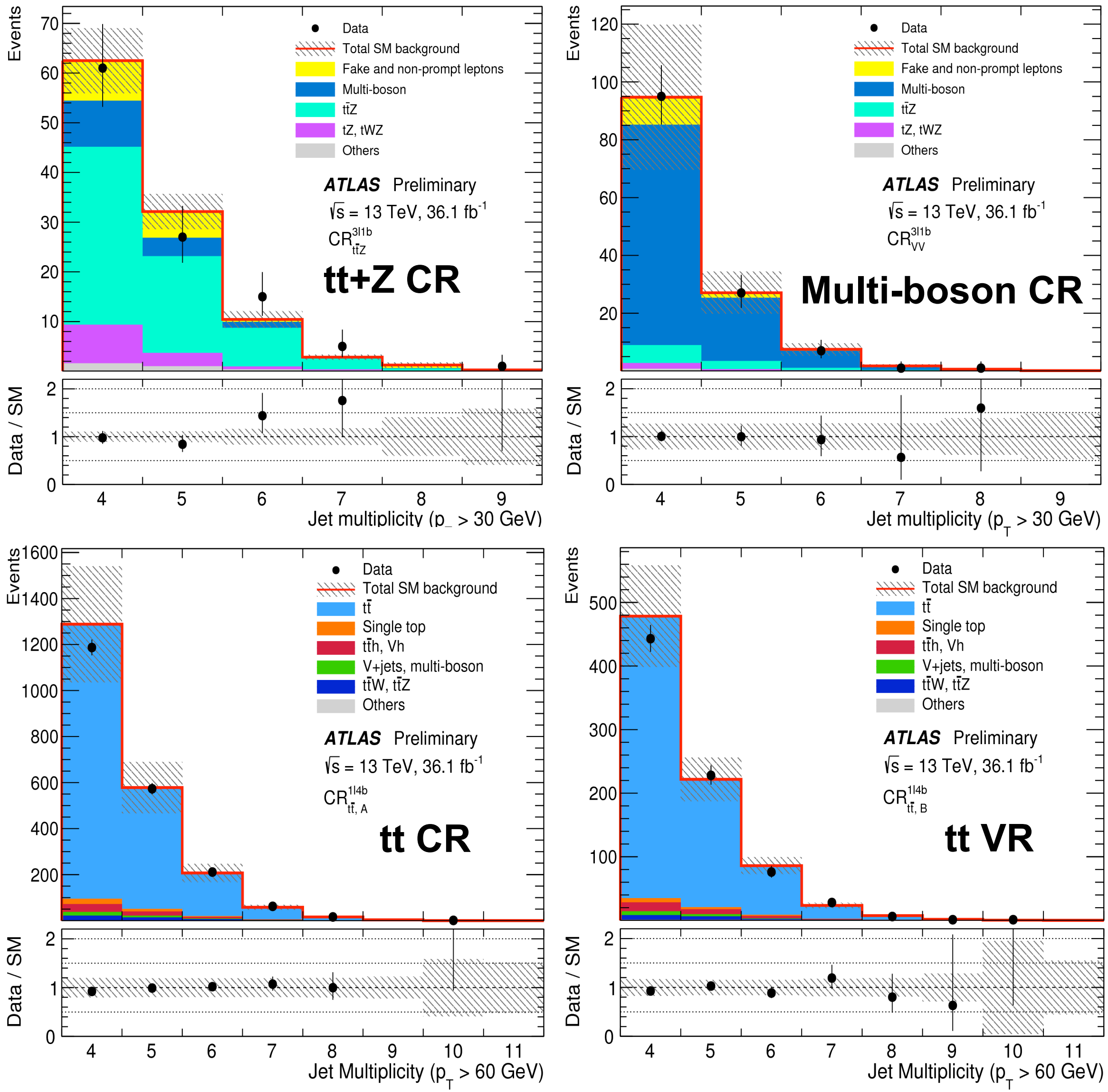


- Searches for t_2 can improve sensitivity in the regions $\mathbf{m_{stop,1} \sim m_t + m_{LSP}}$ → Difficult to access due to similarities with Standard Model tt production
- **2 analysis streams** with **3 signal regions each** to target large, intermediate, small mass differences:
  - 3-ℓ + 1 b-jet stream (targeting $Z \to \ell^+\ell^-$ decay): Use of Z boson with $p_T^{\ell\ell}$ requirements
  - 1/2-ℓ + 4 b-jets stream (targeting $h \to b\bar{b}$ decay): Use of p_T^{bb} and $m_{bb} \sim m_h$ requirements

Stop Z / Higgs Search: Backgrounds

- **3-ℓ + 1 b-jet stream:**
  - **$t\bar{t}$+Z & multi-boson** (dominant, dedicated CRs),
  - **multi-jets** (subdominant - data-driven matrix-method),
  - **$t\bar{t}$+W/H & rare SM processes** (minor, from simulation)

- **1/2-ℓ + 4 b-jets stream:**
  - **$t\bar{t}$** (dominant, dedicated CRs & VRs)
  - **single-t & $t\bar{t}$+H & rare SM processes** (minor, from simulation)

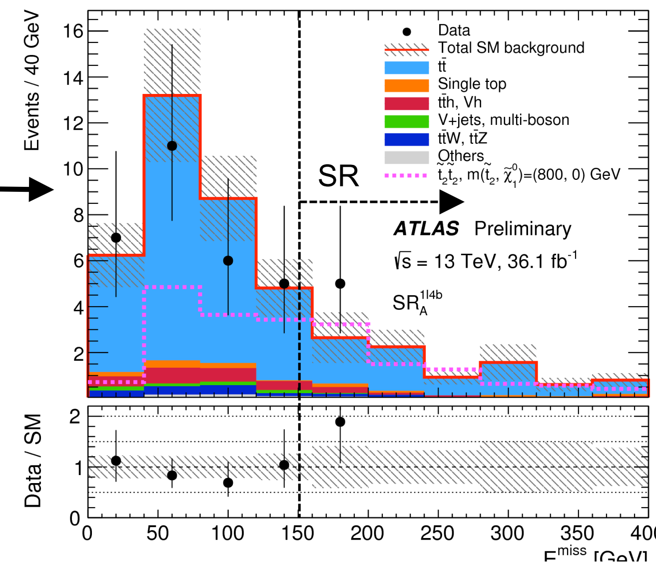


Stop Z / Higgs Search: Results

- **No significant deviations** in any of the signal regions

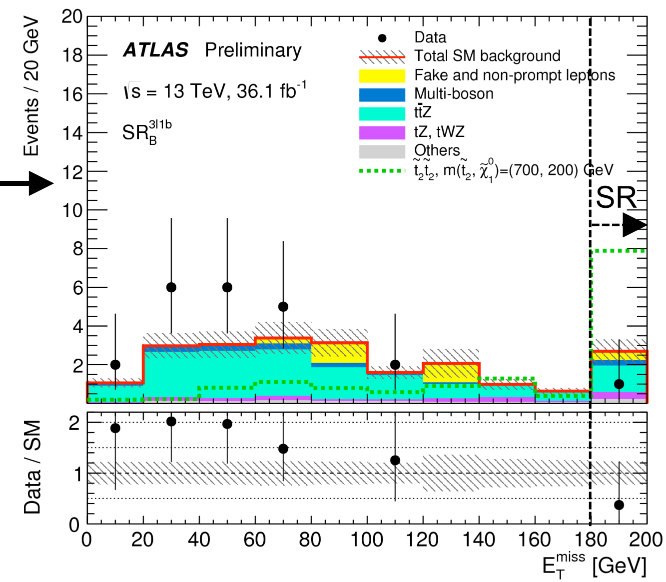
e.g.

	$SR_A^{1\ell 4b}$	$SR_B^{1\ell 4b}$	$SR_C^{1\ell 4b}$
Observed events	10	28	16
Total (constrained) SM events	13.6 ± 3.0	29 ± 5	10.5 ± 3.2
Fit output, $t\bar{t}$	11.3 ± 2.9	24 ± 5	9.3 ± 3.1
Single top	0.50 ± 0.18	1.7 ± 0.4	0.24 ± 0.07
V+jets, multi-boson	0.20 ± 0.15	0.23 ± 0.10	0.01 ± 0.01
$t\bar{t}h$, ggh, Vh	0.89 ± 0.16	1.19 ± 0.35	0.56 ± 0.13
$t\bar{t}W$, $t\bar{t}Z$	0.36 ± 0.21	1.09 ± 0.31	0.10 ± 0.10
Others	0.37 ± 0.20	1.33 ± 0.69	0.34 ± 0.18

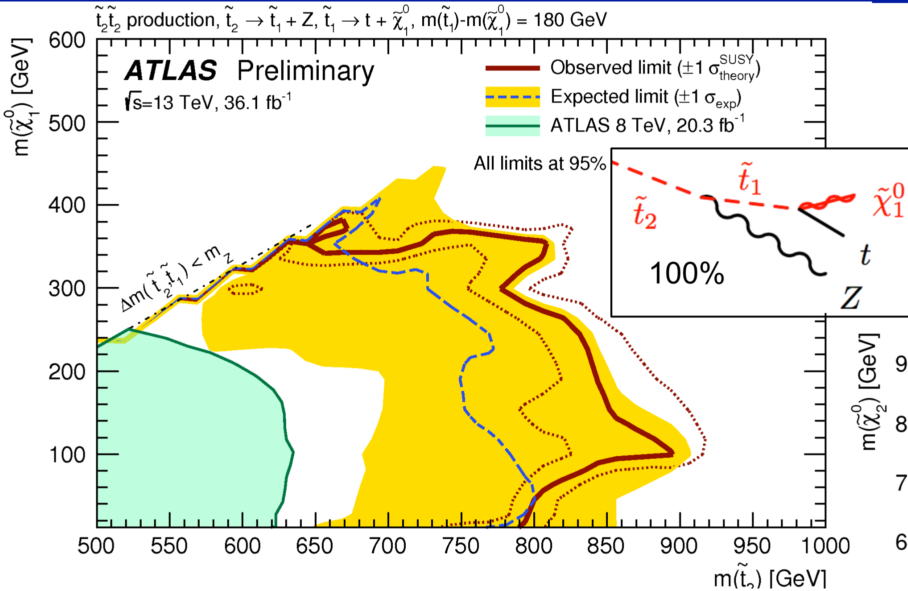


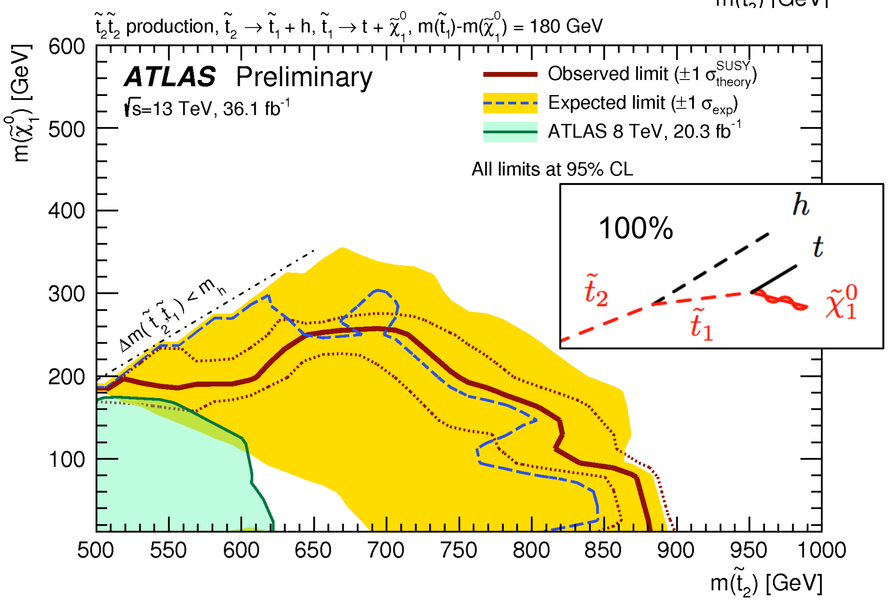
e.g.

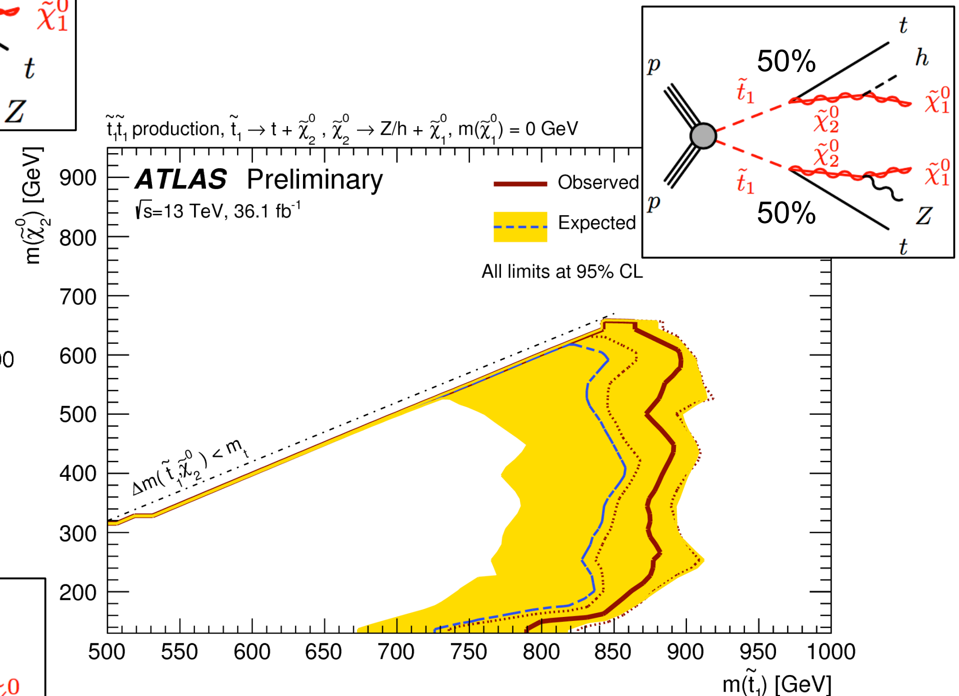
	$SR_A^{3\ell 1b}$	$SR_B^{3\ell 1b}$	$SR_C^{3\ell 1b}$
Observed events	2	1	3
Total (constrained) SM events	1.9 ± 0.4	2.7 ± 0.6	2.0 ± 0.3
Fit output, multi-boson	0.26 ± 0.08	0.28 ± 0.10	0.23 ± 0.05
Fit output, $t\bar{t}Z$	1.1 ± 0.3	1.4 ± 0.5	1.2 ± 0.3
tZ, tWZ	0.43 ± 0.23	0.36 ± 0.19	0.19 ± 0.10
Fake and non-prompt	$0.00^{+0.30}_{-0.00}$	0.45 ± 0.19	$0.00^{+0.30}_{-0.00}$
Others	0.09 ± 0.02	0.23 ± 0.06	0.36 ± 0.06



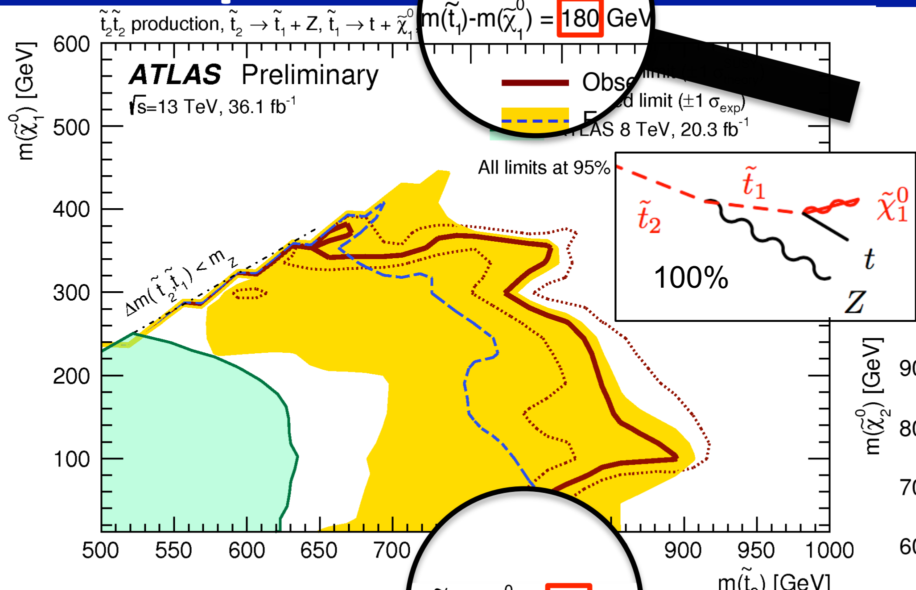
Stop Z / Higgs Search: Interpretation

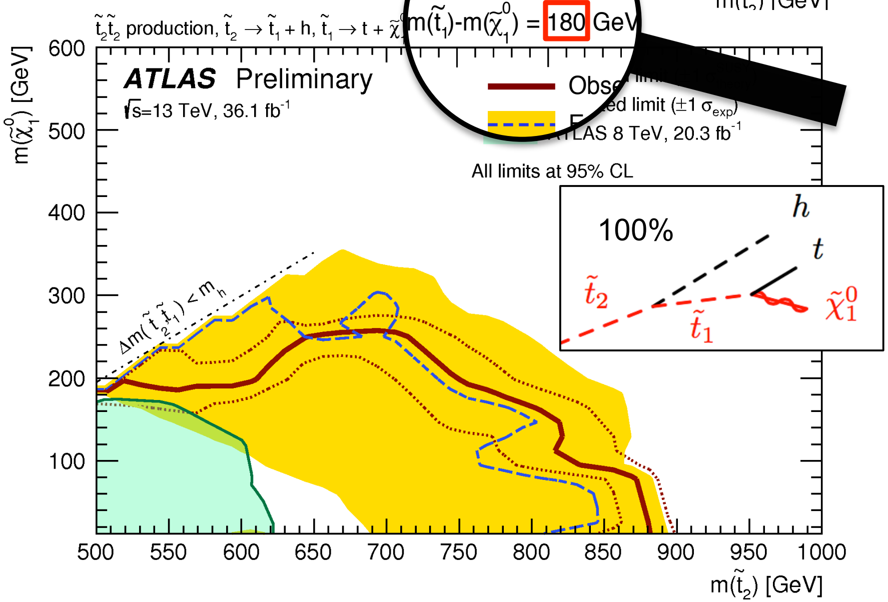


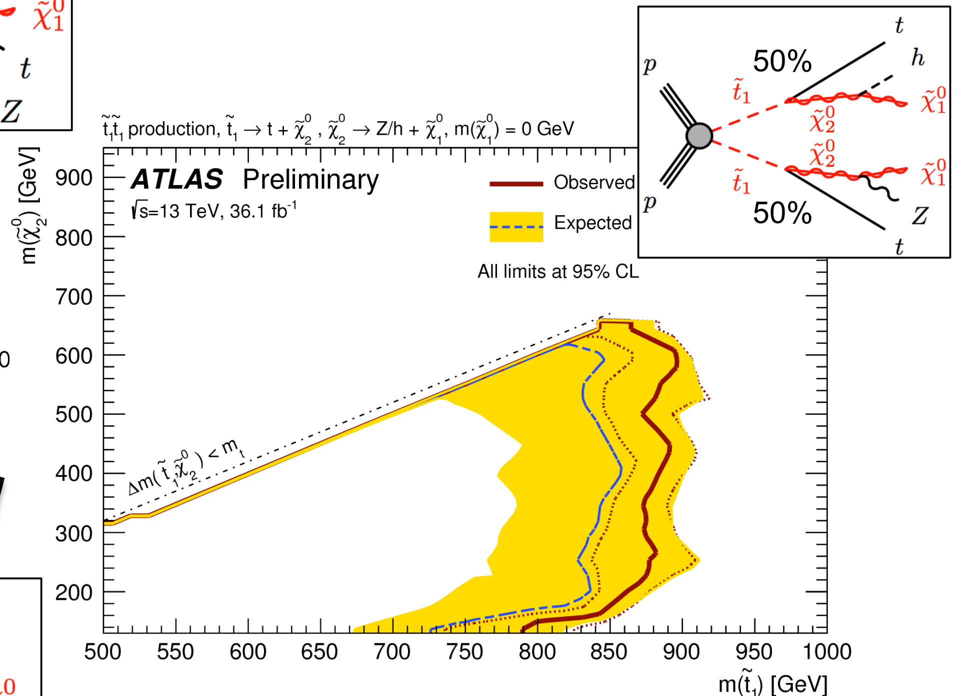




Stop Z / Higgs Search: Interpretation

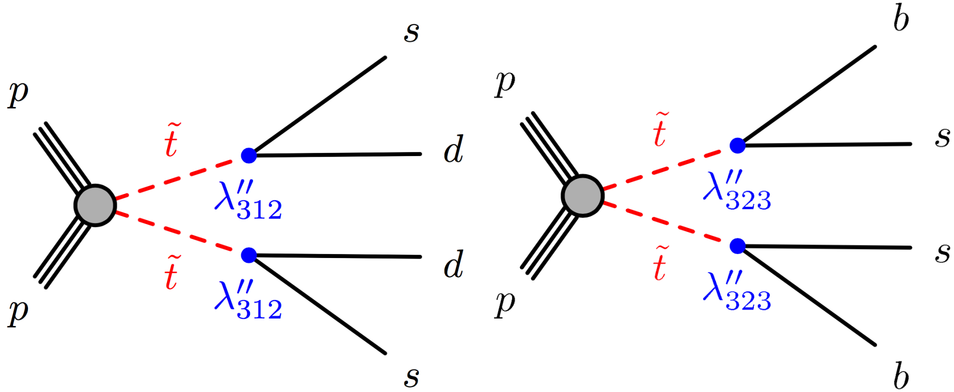






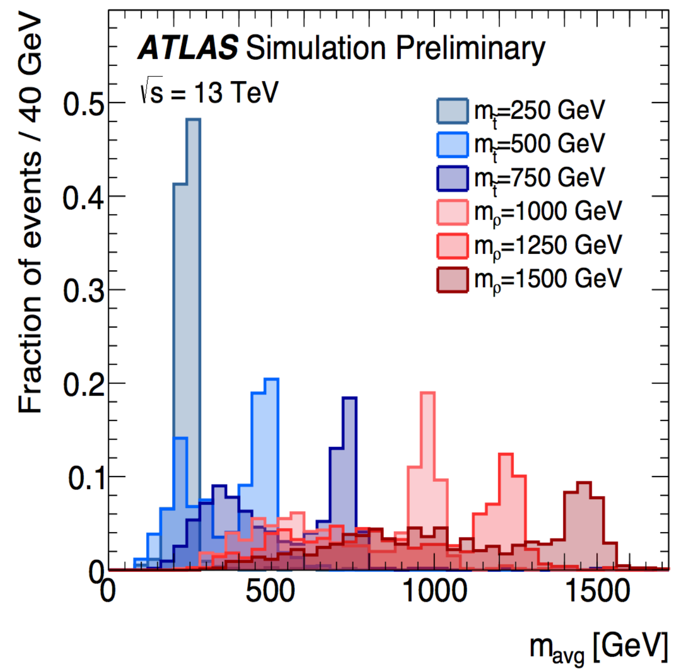
Stop RPV Search

- Motivation: If stops have R-parity violating decays (e.g. stop → jj) no / little sensitivity from $E_{T,miss}$-based searches → **stops could still be light**
- Dedicated search for 2 resonances in 4-jet final states targeting decays of stop to a pair of jets



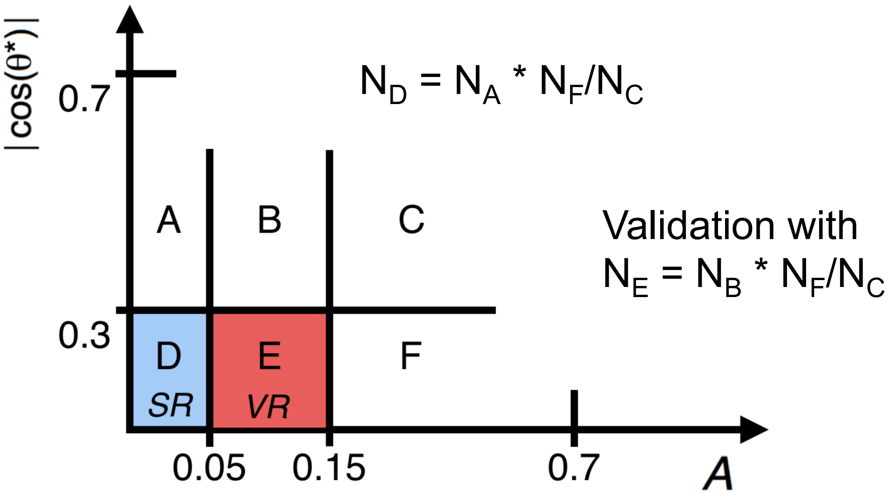
Signal region selections

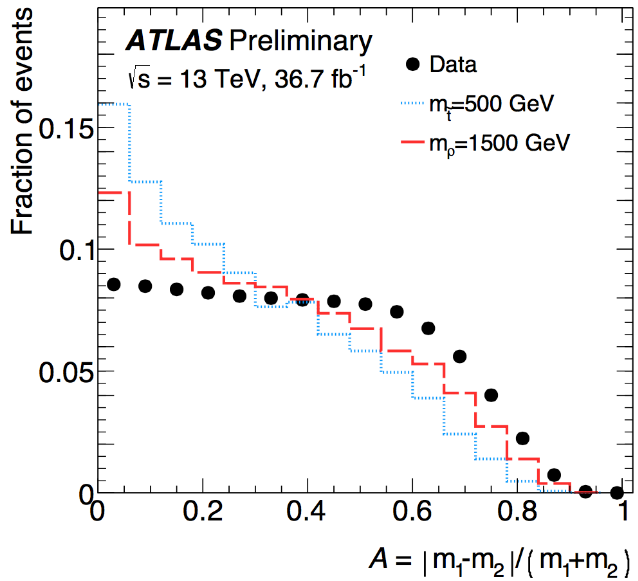
- Two resonance candidates built by pairing the four leading jets (p_T > 120 GeV) according to their angular separation
- **Inclusive** and **two b-tag selection** (one b-tag in each pair)
- Final discriminant: **Average mass** of candidate resonances: $m_{avg} = 0.5*(m_1 + m_2)$

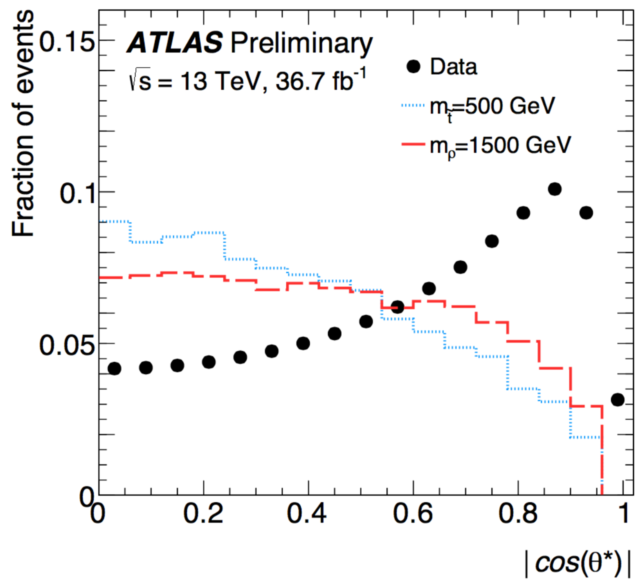


Stop RPV Search - Backgrounds

- Major background: **Multi-jets** production
- Reduced by further requirements using e.g.:
  - mass asymmetry: $A = |m_1-m_2| / (m_1+m_2)$
  - Angle θ* of jet pairs with beamline in rest-frame
- "ABCD-method" in A and |cosθ*| to estimate shape & normalisation in a data-driven way



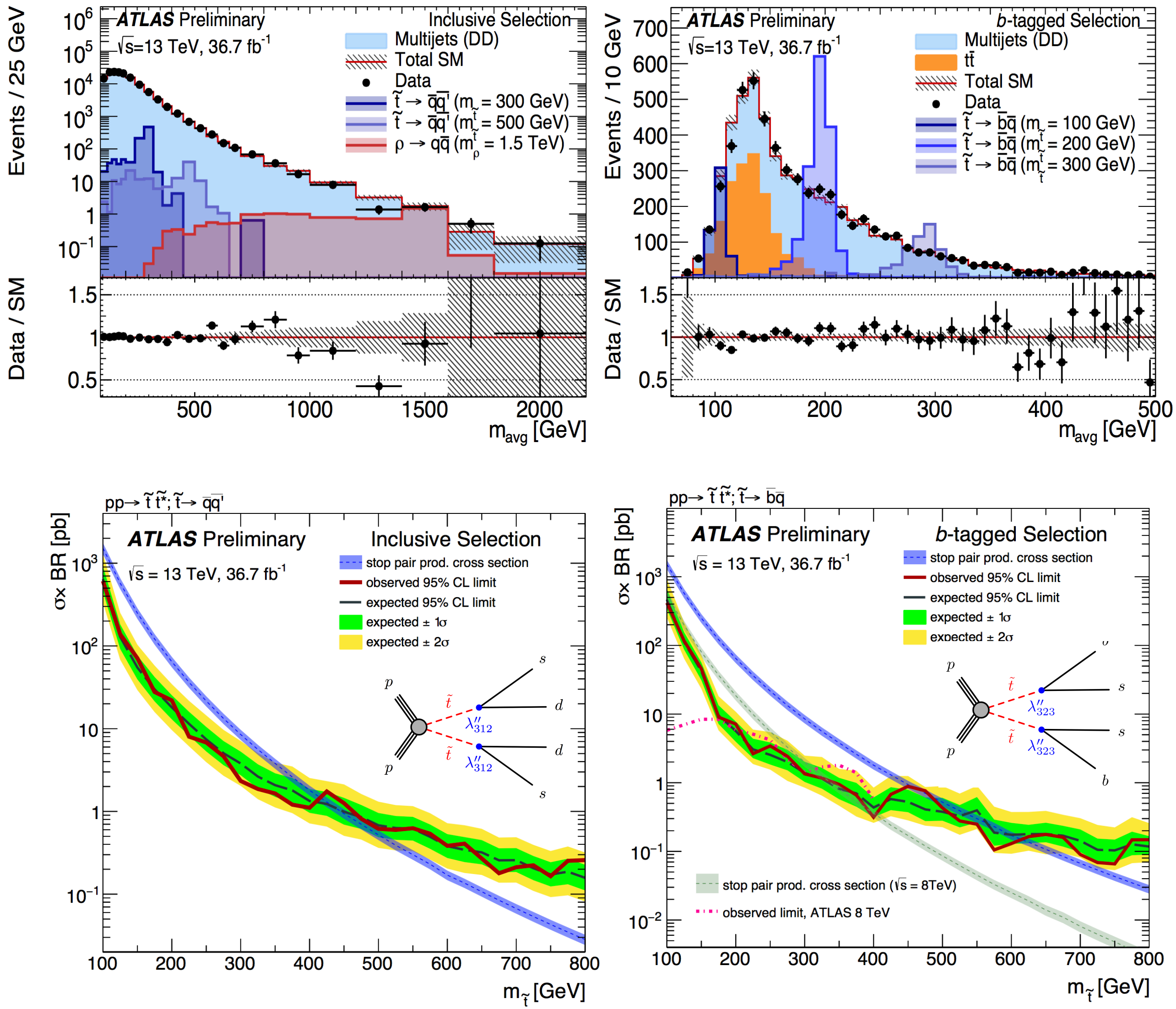




- **tt background** dominant in two b-tag region → taken from simulation

Stop RPV Search - Results

- **No evidence for resonances** in average di-jet mass
- **Stop decays to two quarks** excluded between **100 - 410 GeV** stop mass
- **Stop decays to bs** quark pair excluded between **100 - 610 GeV** of stop mass



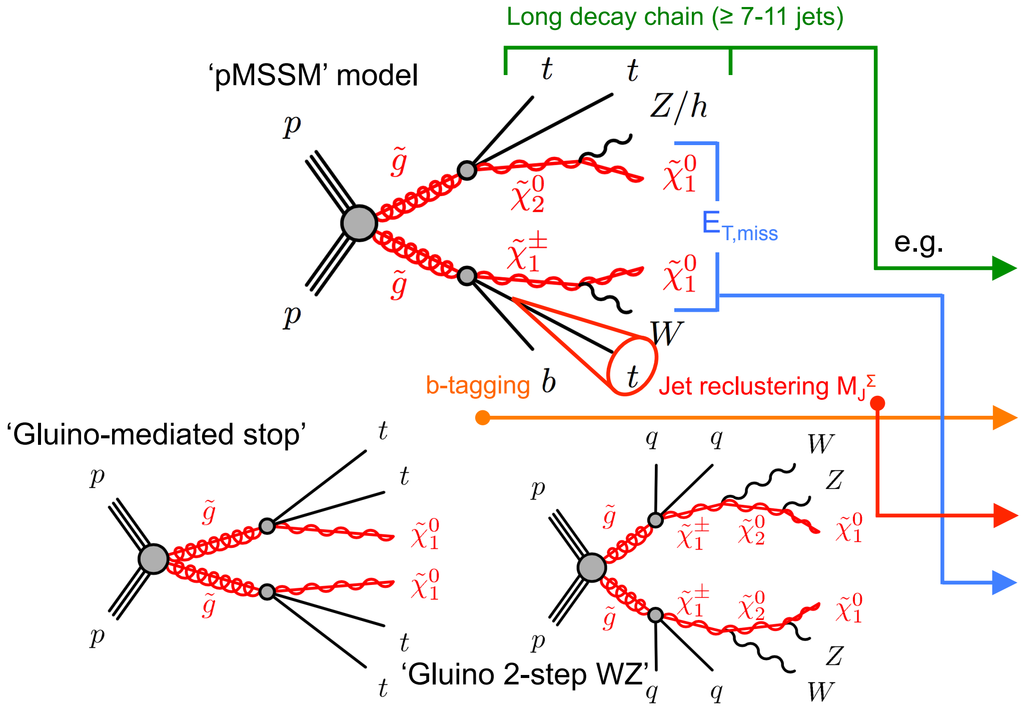
0-ℓ + multi-jets: Analysis Strategy

- Target final state: **0-lepton + ≥ 7-11 + low / moderate $E_{T,miss}$**
- Key feature: Use of $E_{T,miss}$ significance (instead of $E_{T,miss}$) as discriminating variable:

$$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}\text{, where: } H_{\mathrm{T}} = \sum_j p_{\mathrm{T},j}^{\mathrm{jet}}$$

→ Analysis also sensitive to scenarios with lower $E_{T,miss}$ (including RPV models)

- Benchmark scenarios for inclusive gluino & squark production (RPC):

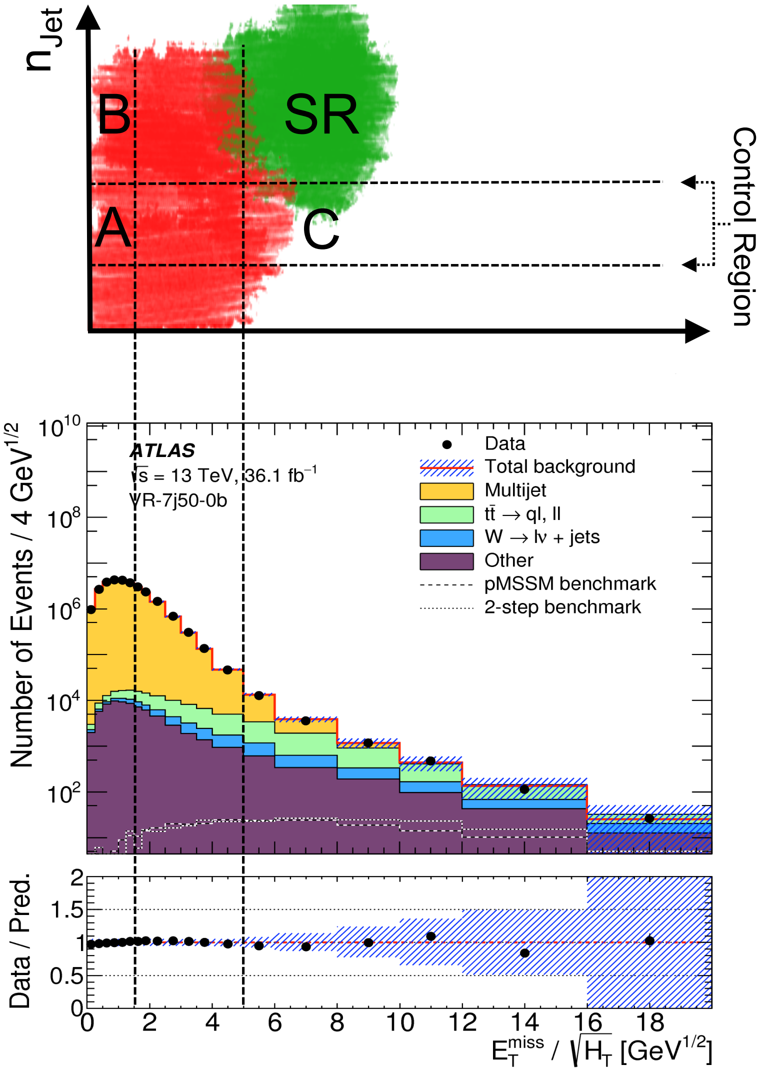


Two analysis streams (27 inclusive regions):

Criterion	Heavy-flavour channel		Jet mass channel
Jet $\lvert\eta\rvert$	< 2.0		
Jet p_{T} N_{jet}	> 50 GeV ≥ 8, 9, 10, 11	> 80 GeV ≥ 7, 8, 9	> 50 GeV ≥ 8, 9, 10
Lepton veto	No preselected e or μ after overlap removal		
b-jet selection Large-R-jet selection	$p_{\mathrm{T}} > 50$ GeV and $\lvert\eta\rvert < 2.0$ $p_{\mathrm{T}} > 100$ GeV and $\lvert\eta\rvert < 1.5$		
$N_{b\text{-tag}}$ M_{J}^{Σ} (*)	≥ 0, 1, 2 ≥ 0		≥ 0 ≥ 340, 500 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$	> 5 GeV$^{1/2}$		

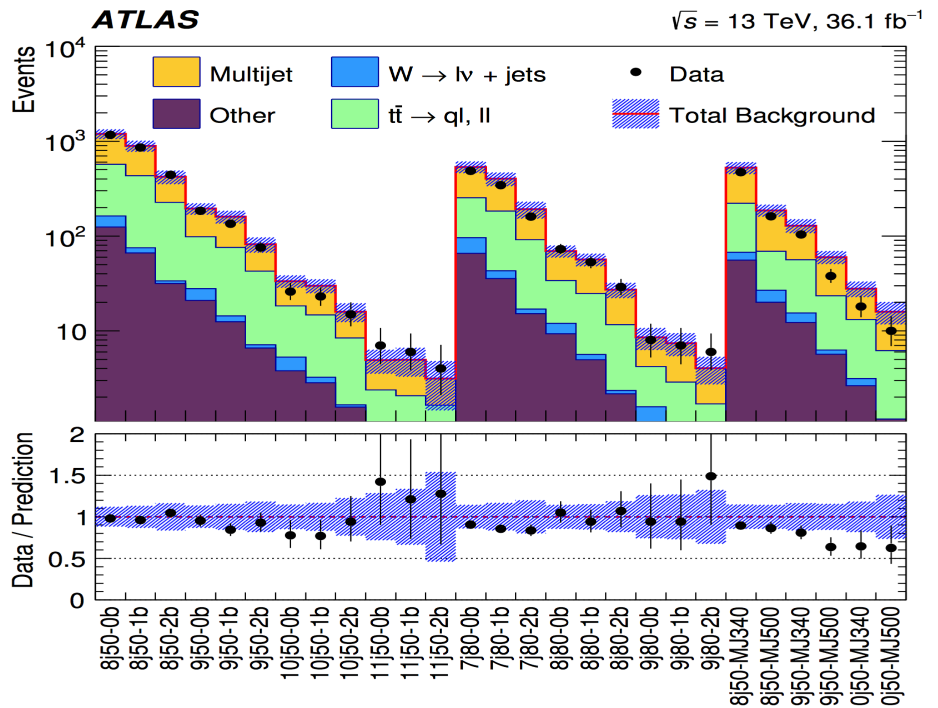
$(^*) M_{\mathrm{J}}^{\Sigma} = \sum_j m_j^{R=1.0}$

0-ℓ + multi-jets: Backgrounds & Results

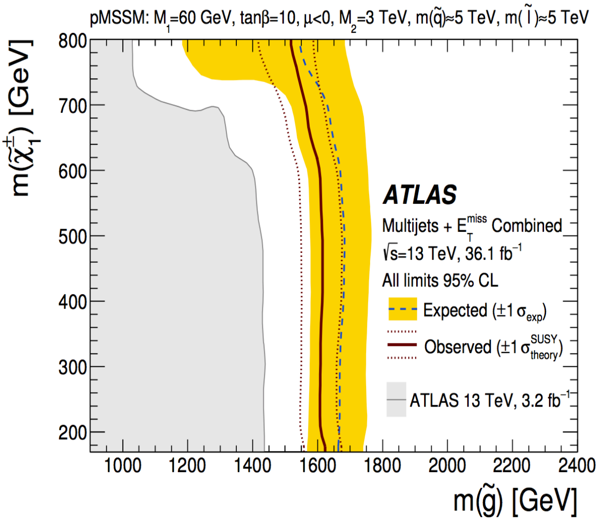


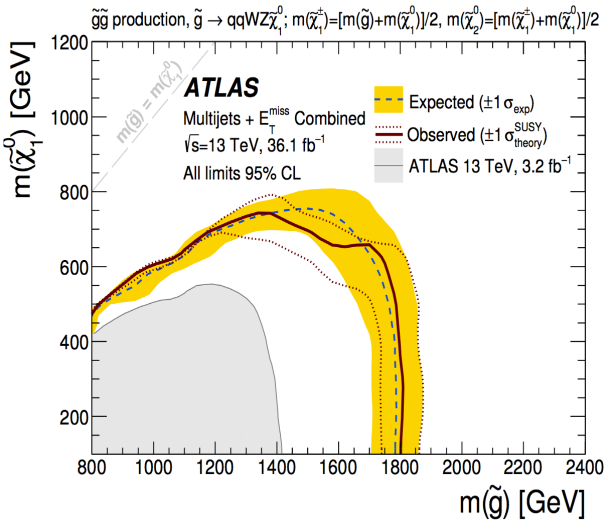
- Data-driven method for dominant multi-jet background (including fully hadronic tt):
  - $E_{T,miss} / \sqrt{H_T}$ template extracted from data @ lower N_{jet} & normalised @ low $E_{T,miss} / \sqrt{H_T}$ in SR
- Leptonic backgrounds (tt, V+jets, single-top, diboson):
  - 1-ℓ control regions (tt / W+jets) & simulation (others)

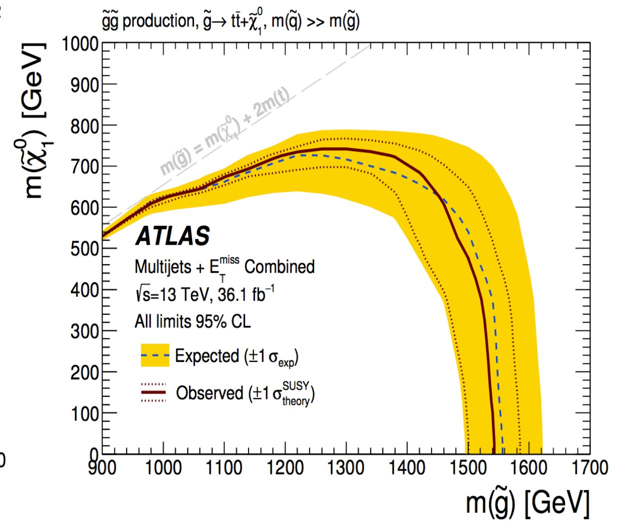
→ **No significant deviations** from the Standard Model expectation in both streams

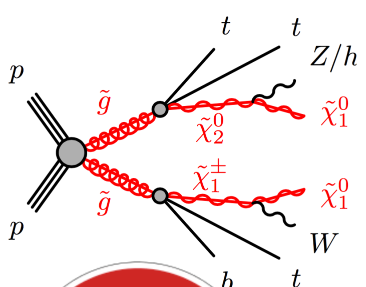


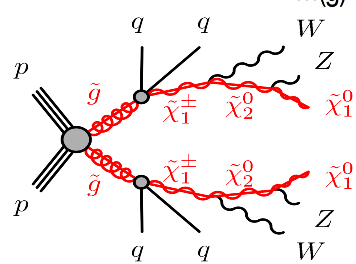
0-ℓ + multi-jets: Interpretation

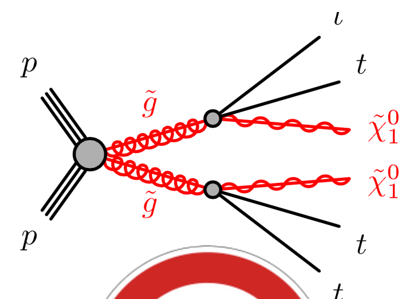






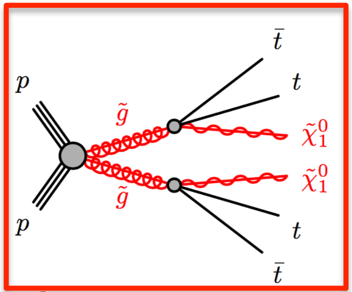


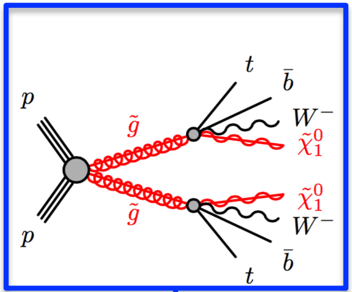


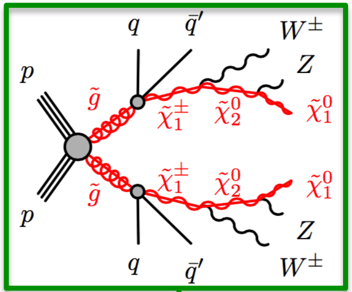


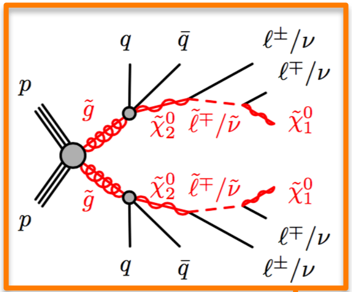
2-ℓ (same-sign) / 3-ℓ Search

- Target final state: **2 same-sign leptons** ($e^\pm e^\pm$, $e^\pm\mu^\pm$, $\mu^\pm\mu^\pm$) or **three leptons** (e/μ without flavour / charge selection)
- Key feature: SM backgrounds in same-sign final states small while rich SUSY / BSM phenomenology
  - → Can apply much looser kinematic requirements in this channel to discriminate signal from background
  - → Sensitive to large number of models (including e.g. compressed / RPV models)
- Benchmark scenarios for inclusive gluino & squark production (RPC):









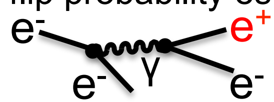
→ Ten inclusive signal regions to target the various scenarios:

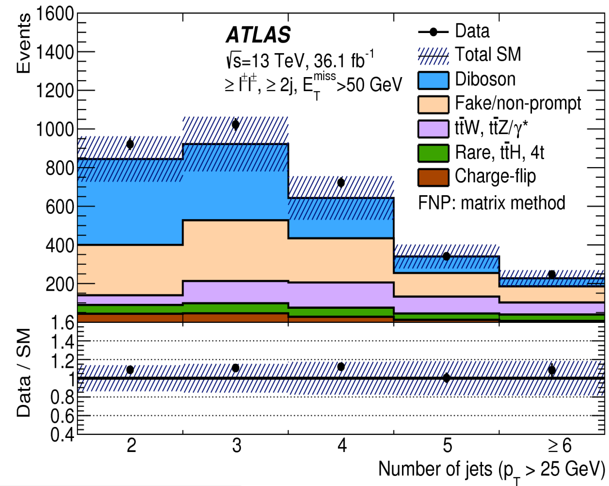
Signal region	$N_{\text{leptons}}^{\text{signal}}$	$N_{b\text{-jets}}$	N_{jets}	p_T^{jet} [GeV]	E_T^{miss} [GeV]	m_{eff} [GeV]	$E_T^{\text{miss}}/m_{\text{eff}}$	Other
Rpc2L2bS	≥ 2SS	≥ 2	≥ 6	> 25	> 200	> 600	> 0.25	–
Rpc2L2bH	≥ 2SS	≥ 2	≥ 6	> 25	–	> 1800	> 0.15	–
Rpc2Lsoft1b	≥ 2SS	≥ 1	≥ 6	> 25	> 100	–	> 0.3	$20,10 < p_T^{\ell_1}, p_T^{\ell_2} < 100$ GeV
Rpc2Lsoft2b	≥ 2SS	≥ 2	≥ 6	> 25	> 200	> 600	> 0.25	$20,10 < p_T^{\ell_1}, p_T^{\ell_2} < 100$ GeV
Rpc2L0bS	≥ 2SS	= 0	≥ 6	> 25	> 150	–	> 0.25	–
Rpc2L0bH	≥ 2SS	= 0	≥ 6	> 40	> 250	> 900	–	–
Rpc3L0bS	≥ 3	= 0	≥ 4	> 40	> 200	> 600	–	–
Rpc3L0bH	≥ 3	= 0	≥ 4	> 40	> 200	> 1600	–	–
Rpc3L1bS	≥ 3	≥ 1	≥ 4	> 40	> 200	> 600	–	
Rpc3L1bH	≥ 3	≥ 1	≥ 4	> 40	> 200	> 1600	–	

No specific target model – generalisation of Rpc3L0b to ≥ 1 b-jet final states

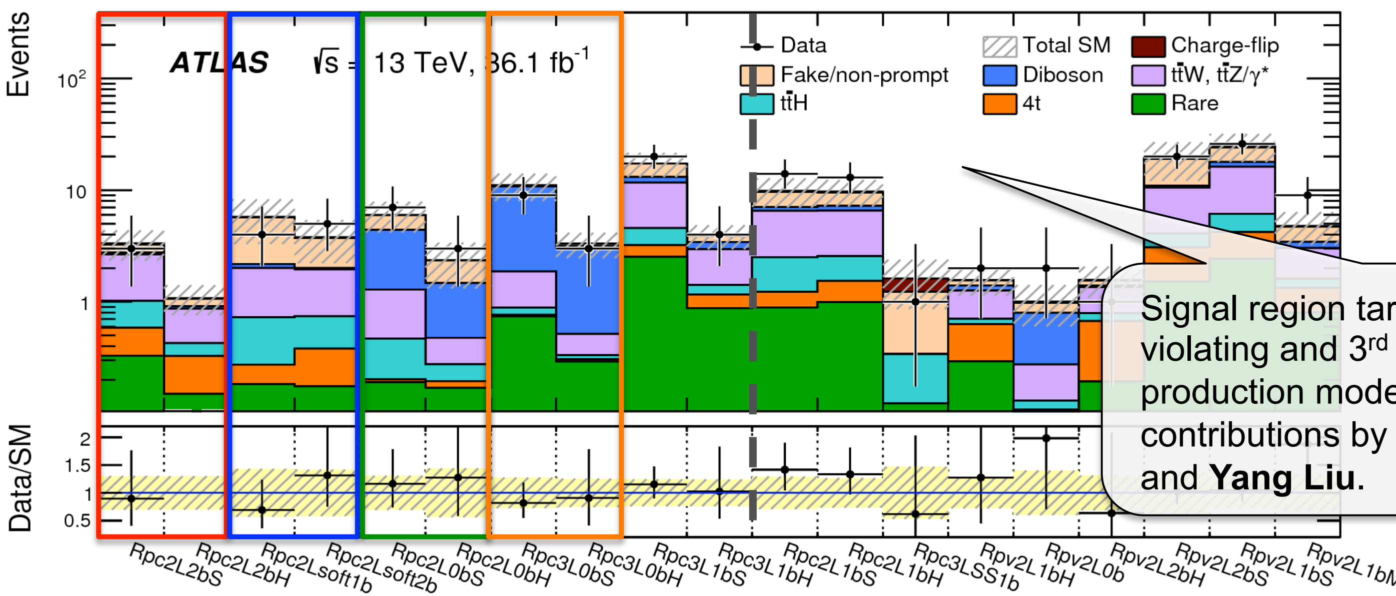
2-ℓ (SS) / 3-ℓ: Backgrounds & Results

- Dominant background: **Rare processes with prompt leptons** (mainly tt+V & diboson): Simulation + validation regions
- **Fake and non-prompt leptons (FNP):** 2 data-driven methods (loose-tight matrix-method & normalisation of FNP contributions in data control regions)
- **Electron charge mis-measurement** (dominated by hard bremsstrahlung conversion): Charge flip probability estimated from Z → ee events





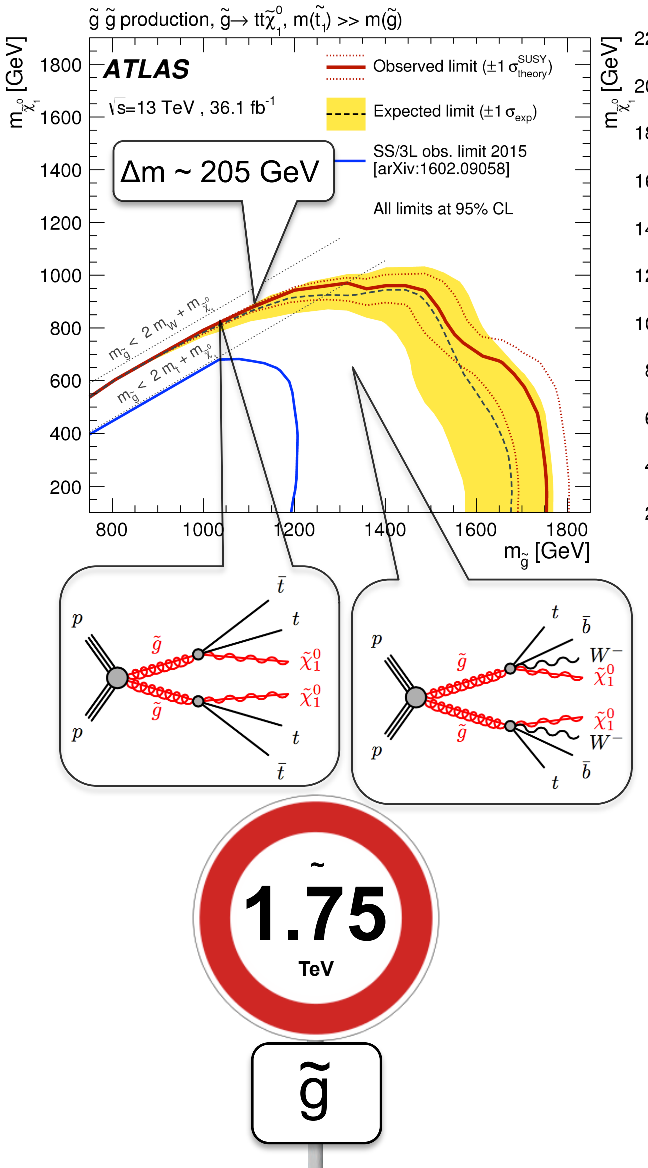
- Results: **No significant deviations** from the Standard Model:

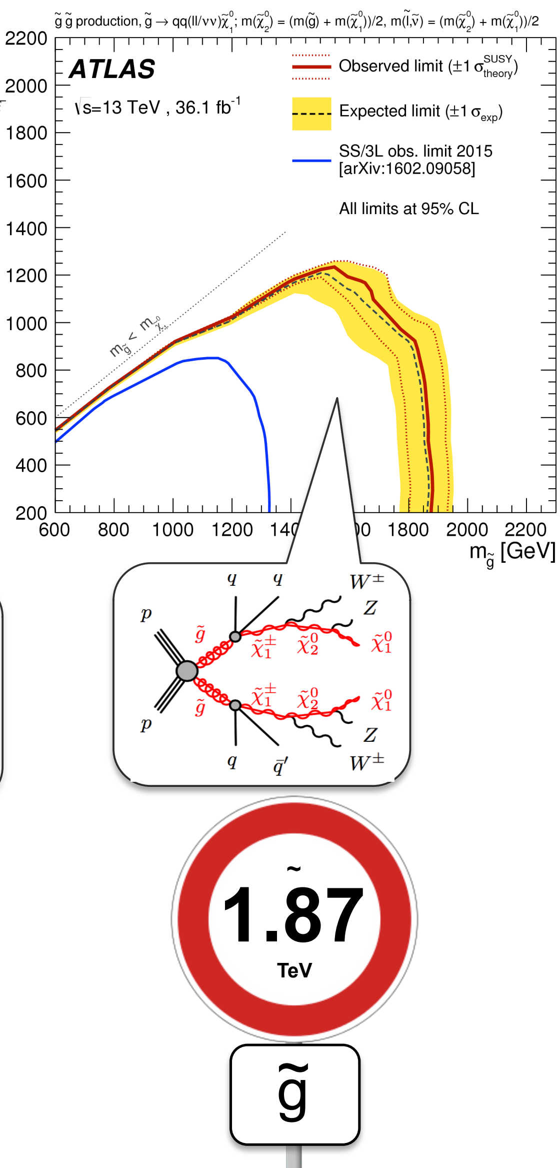


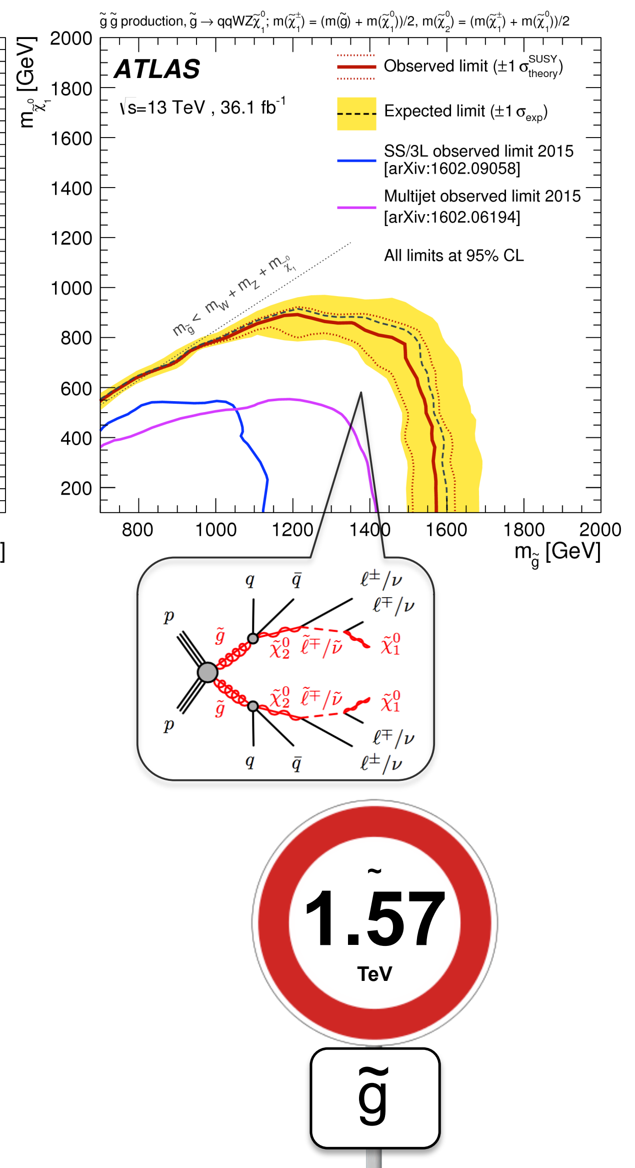
Signal region targeting R-parity violating and 3rd generation squark production models. See contributions by **Federico Meloni** and **Yang Liu**.

Regions relevant for inclusive gluino search

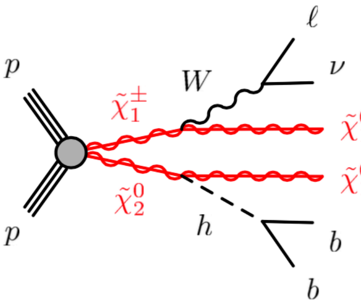
2-ℓ (SS) / 3-ℓ: Interpretation

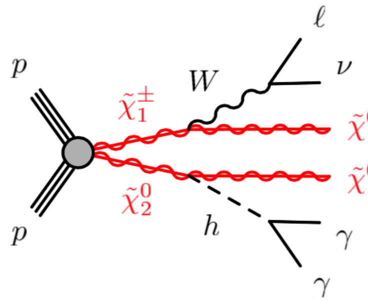


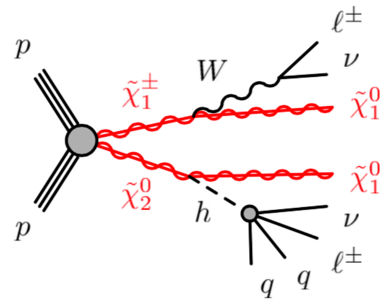


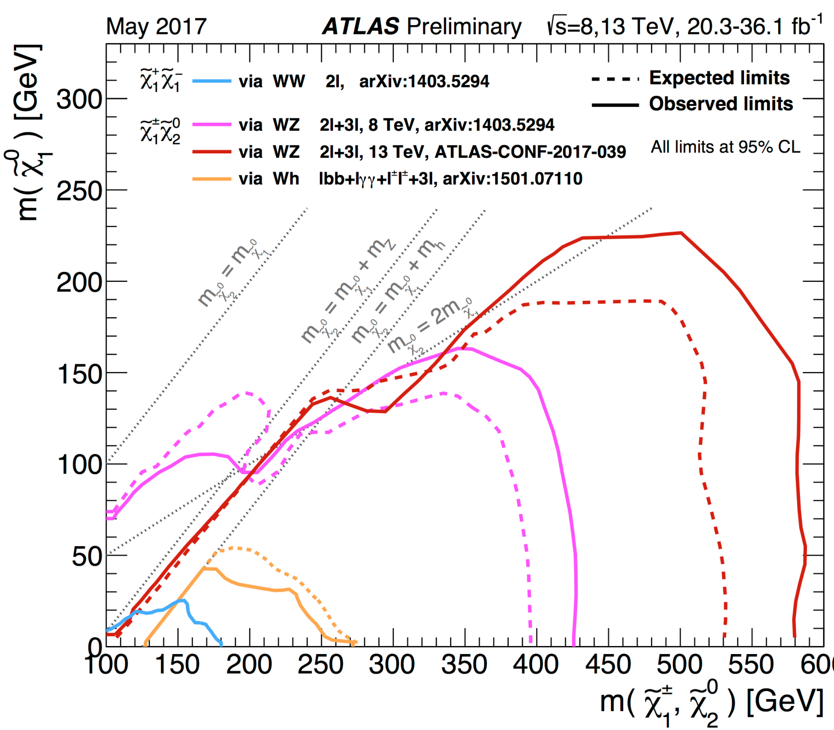


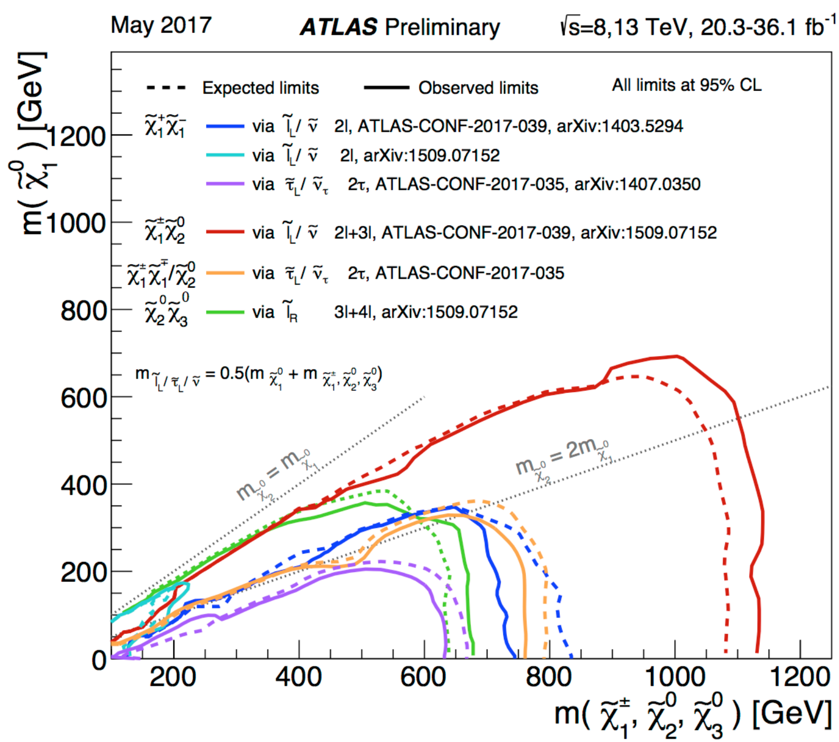
Putting it into context



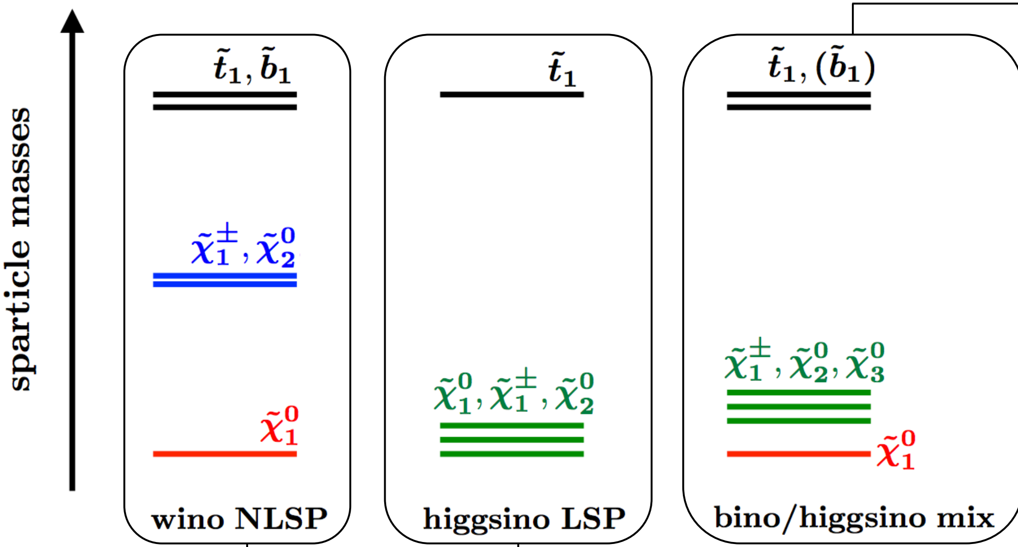


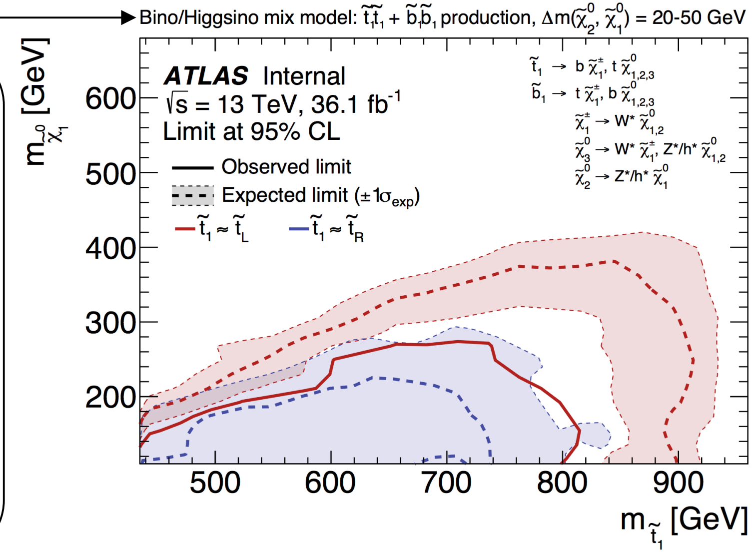


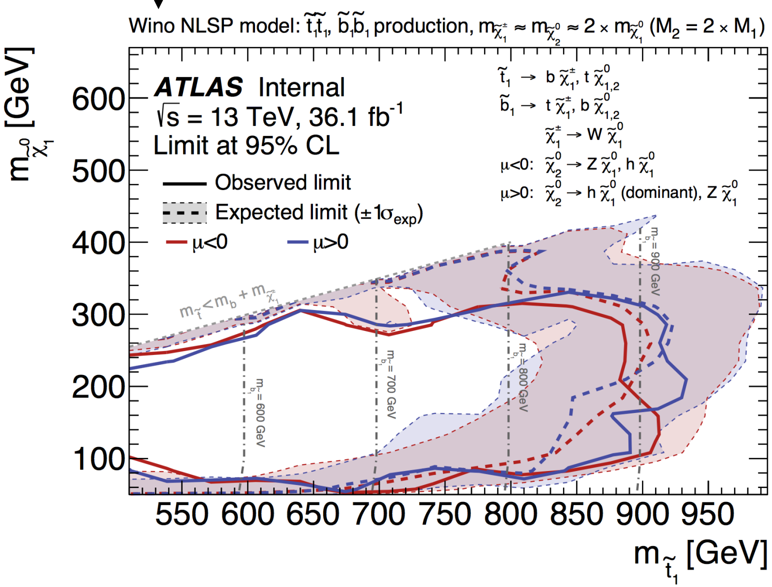


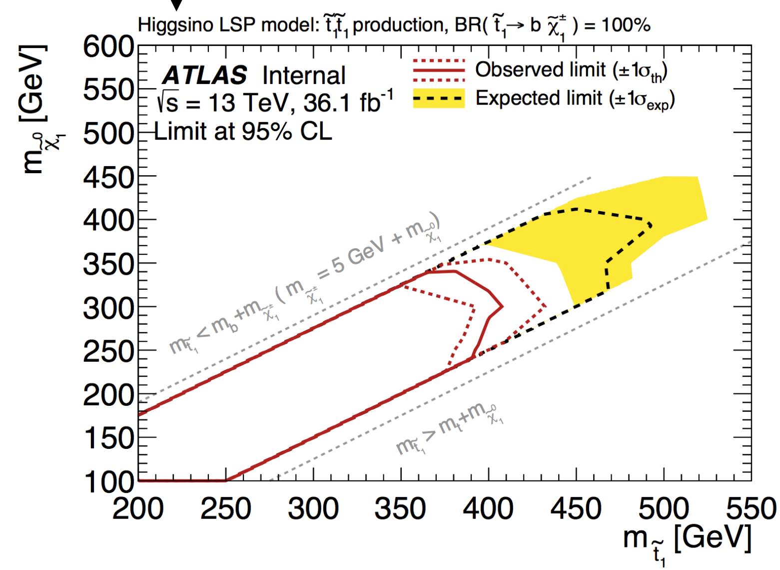


Other 3rd generation results (selection)









Multijet Background Estimation

Multijet background:

- jets misidentified as leptons
- real leptons created as part of a jet (heavy flavour, decay in flight)
- photons converted to electrons

→ very small due to high $E_{T,miss}$ selection

Data-driven matrix method:

- Define sample of preselected ("loose") leptons that pass or fail the signal lepton:

$$N_{\text{pass}} = \epsilon_{\text{real}} N_{\text{real}} + \epsilon_{\text{misid.}} N_{\text{misid.}}$$
$$N_{\text{fail}} = (1-\epsilon_{\text{real}}) N_{\text{real}} + (1-\epsilon_{\text{misid.}}) N_{\text{misid.}}$$

$$\epsilon_{\text{real}} = \frac{N^{\text{pass}}_{\text{real}}}{N^{\text{pass}}_{\text{real}} + N^{\text{fail}}_{\text{real}}} \qquad \epsilon_{\text{misid.}} = \frac{N^{\text{pass}}_{\text{misid.}}}{N^{\text{pass}}_{\text{misid.}} + N^{\text{fail}}_{\text{misid.}}}$$

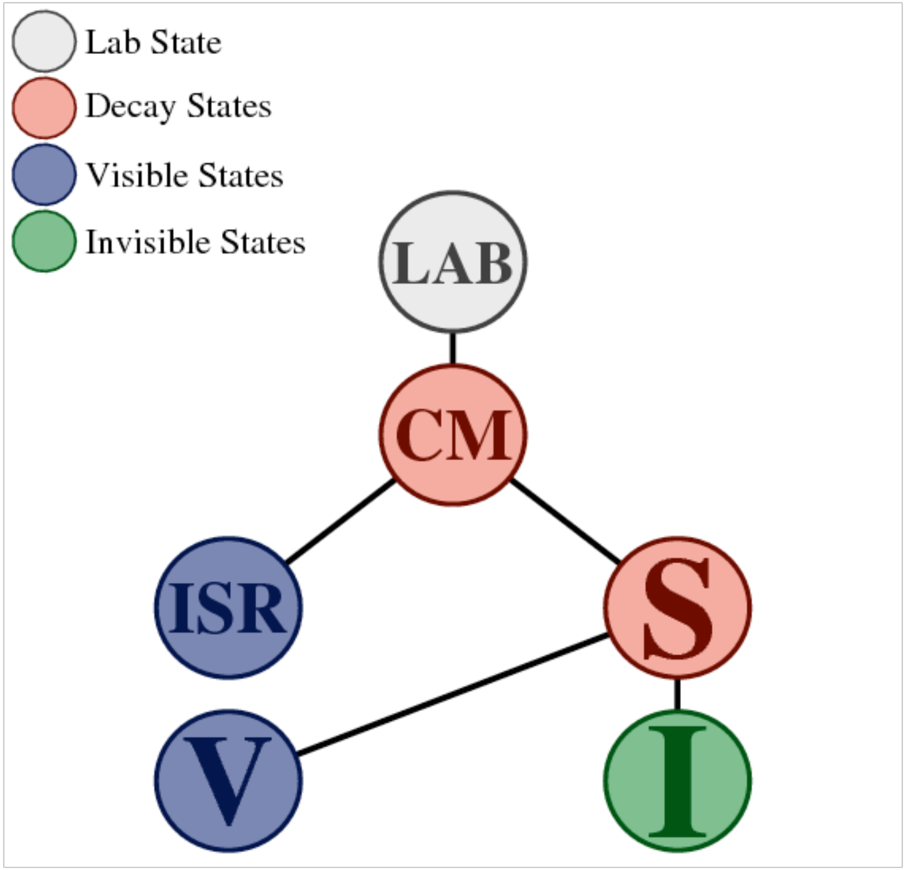
Measure from data

- Solve system of equation:

$$N^{\text{pass}}_{\text{misid.}} = \epsilon_{\text{misid.}} N_{\text{misid.}} = \frac{N_{\text{fail}} - (1/\epsilon_{\text{real}} - 1) N_{\text{pass}}}{1/\epsilon_{\text{misid.}} - 1/\epsilon_{\text{real}}}$$

- Measurement of ε_{real}:
  - Tag & probe with Z → ll events
  - Separate measurement in bins of |η|
- Measurement of ε_{fake}:
  - Di-jet sample (same-charge, same-flavour, outside Z-mass window) where both jets are mis-reconstructed as leptons

Recursive Jigsaw Reconstruction



g-2 and smuon masses