SUSY Working Group Report

ATLAS Collaboration Week
Berlin I 8th October 2019

Will Fawcett (University of Cambridge)
On behalf of the SUSY WG

SUSY WG

HDBS

Exotics WG

Tracking CP

New

Common DM
(simplified DM, SUSY DM, etc.)
O. Brandt, **F. Ungaro**

analysis team

analysis team

~40 analysis teams, each with typically two contacts (wiki page).

Strong production
(gluinos, 1st & 2nd gen. squarks)
T.J. Khoo, **O. Ducu**

Electroweak
(charginos, neutralinos, sleptons)
D. Xu, **J. Dandoy**

Background forum
S. Alderweireldt, **J. Anders**

UEH
(long-lived & more)

RPV/LL
(R-parity violation & long-lived)
K. Pachal, **J. Montejo Berlingen**

3rd generation
(stops, sbottoms, DM+HF)
R. Simoniello, C. Macdonald

CP Liaisons
e/gamma: O. Ducu
Muons: **J.J. Junggeburth**
b-tagging: M. Saimpert
Taus: M. Ayoub
Jet/MET: M. LeBlanc
IFF: **F. Alonso**

LLP forum
UEH&RPV/LL conv.

SUSY Conveners
F. Meloni, **L. Jeanty**

Contacts

MC production: W. Fawcett, G. Stark
Cross sections: A. Mann
Derivations: A. Lopez Solis, **C. Rizzi**
Trigger: B. Hooberman, **C. Merlassino**
Upgrade studies: M. Vranjes Milosavljevic, **I. Vivarelli**

Combinations: C. Potter, G. Stark, F. Ungaro
HistFitter: S. Williams
HepDATA: K. Bozek, **S. Carra`**
Feynman diagrams: A. Mann

SUSY workshop, Lecce

[Workshop link]

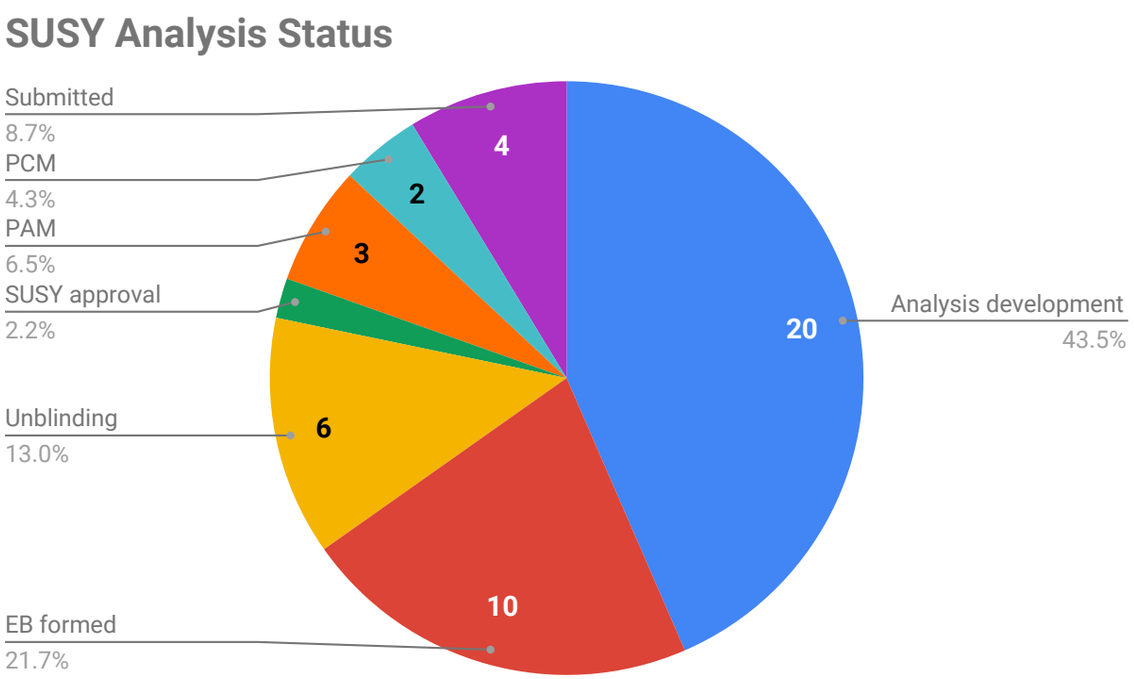
- **4 days, ~50 talks, ~100 participants**, many student and postdoc contributions!
- + 1 day theoretical introduction to SUSY for newcomers!

- **Inspiring theory talk**
  - Lots of room left for SUSY
  - Remember that SUSY searches cover more than just for SUSY

- **Successful workshop with lots of discussions**
  - Lots of fresh results and ideas
  - Plans for combination, reinterpretations and pMSSM scans

- **Results of the "analysis challenge"**
  - Unleash people on 36/fb dataset
  - Lots of new techniques, especially machine learning
  - Motivate us to continue to **focus on discovery**

Run 2 publication planning



Full Run 2 strategy for two “waves” of papers

- **1st wave: fast, first-pass analyses** with limited or simplified interpretations
- **2nd wave:** Searches of increased complexity
- **Topical summary papers** targeting specific sparticles or theories
  - Combinations across many searches (statistical combinations and pMSSM scans)
  - Requires **analysis preservation**

We are now cresting that first wave

Full Run 2 publications overview: 139/fb

Electroweak

Analysis Name	Glance
2L+2jets	ANA-SUSY-2018-05
3L mimic	ANA-SUSY-2018-06
3L (WZ, Wh) Δm ≥ 20 GeV	ANA-SUSY-2019-09
compressed scenarios	ANA-SUSY-2018-16
direct staus	ANA-SUSY-2018-04
WH(gamgam)	ANA-SUSY-2018-23
2L0J	ANA-SUSY-2018-32
All-had	ANA-SUSY-2018-41
1Lbb	ANA-SUSY-2019-08
SUSY 4L	ANA-SUSY-2018-02
Chargino B-L	ANA-SUSY-2018-36

Third generation

Analysis Name	Glance
tt+MET 0L	ANA-SUSY-2018-12
tt+MET 1L	ANA-SUSY-2018-07
tt+MET 2L	ANA-SUSY-2018-08
tt+Z/h	ANA-SUSY-2018-21
tt charm	ANA-SUSY-2018-25
sbottom multi-b	ANA-SUSY-2018-31
sbottom bb+MET	ANA-SUSY-2018-34
sbottom multi-b with taus	ANA-SUSY-2018-40

Inclusive

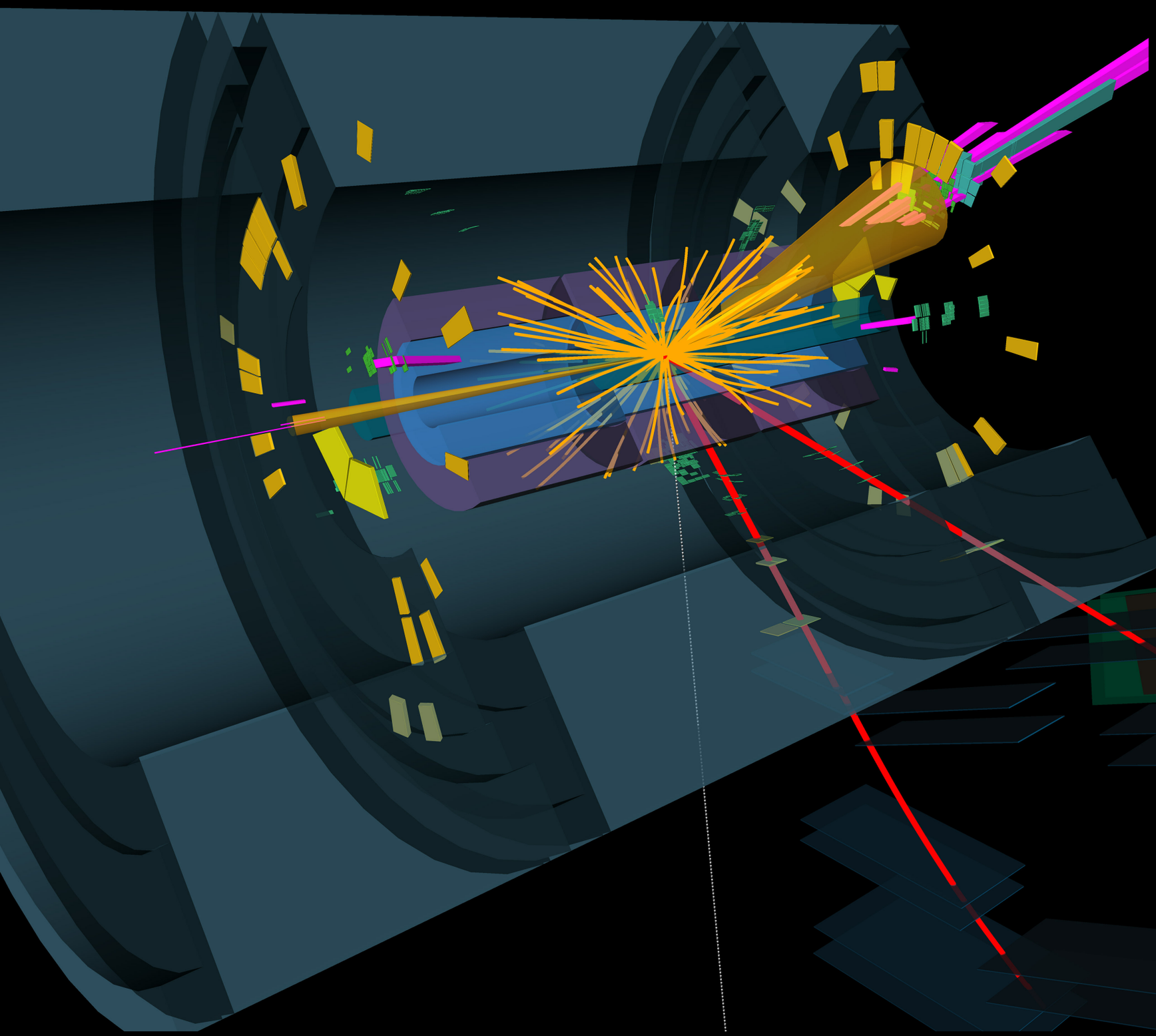
Analysis Name	Glance
0L 2--6 jets	ANA-SUSY-2018-22
0L Multijet	ANA-SUSY-2018-17
Multi-b	ANA-SUSY-2018-30
1L	ANA-SUSY-2018-10
SS/3L	ANA-SUSY-2018-09
photons + MET	ANA-SUSY-2018-11
tau+MET	ANA-SUSY-2019-18

RPV / LL

Analysis Name	Glance
Displaced leptons	ANA-SUSY-2018-14
Stopped particles	ANA-SUSY-2018-15
Disappearing tracks	ANA-SUSY-2018-19
DV + jets	ANA-SUSY-2018-13
DV+mu	ANA-SUSY-2018-33
2x2 / 2x3 RPV	ANA-SUSY-2018-39
RPV Multi-b	ANA-SUSY-2018-38
Multijet RPV 1L	ANA-SUSY-2019-04
Stop B-L	ANA-SUSY-2018-37
Pixel dE/dX	ANA-SUSY-2018-42
(Meta)stable massive particle	ANA-SUSY-2019-03
Displaced photon	ANA-SUSY-2019-14

https://twiki.cern.ch/twiki/bin/viewauth/AtlasProtected/SUSYPublicationsRun2

Electroweak and compressed SUSY



ATLAS EXPERIMENT

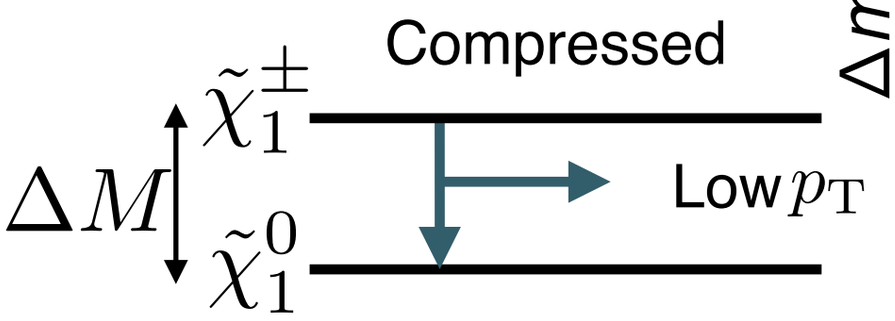
Run: 359918
Event: 1903038328
2018-09-04 22:58:39 CEST

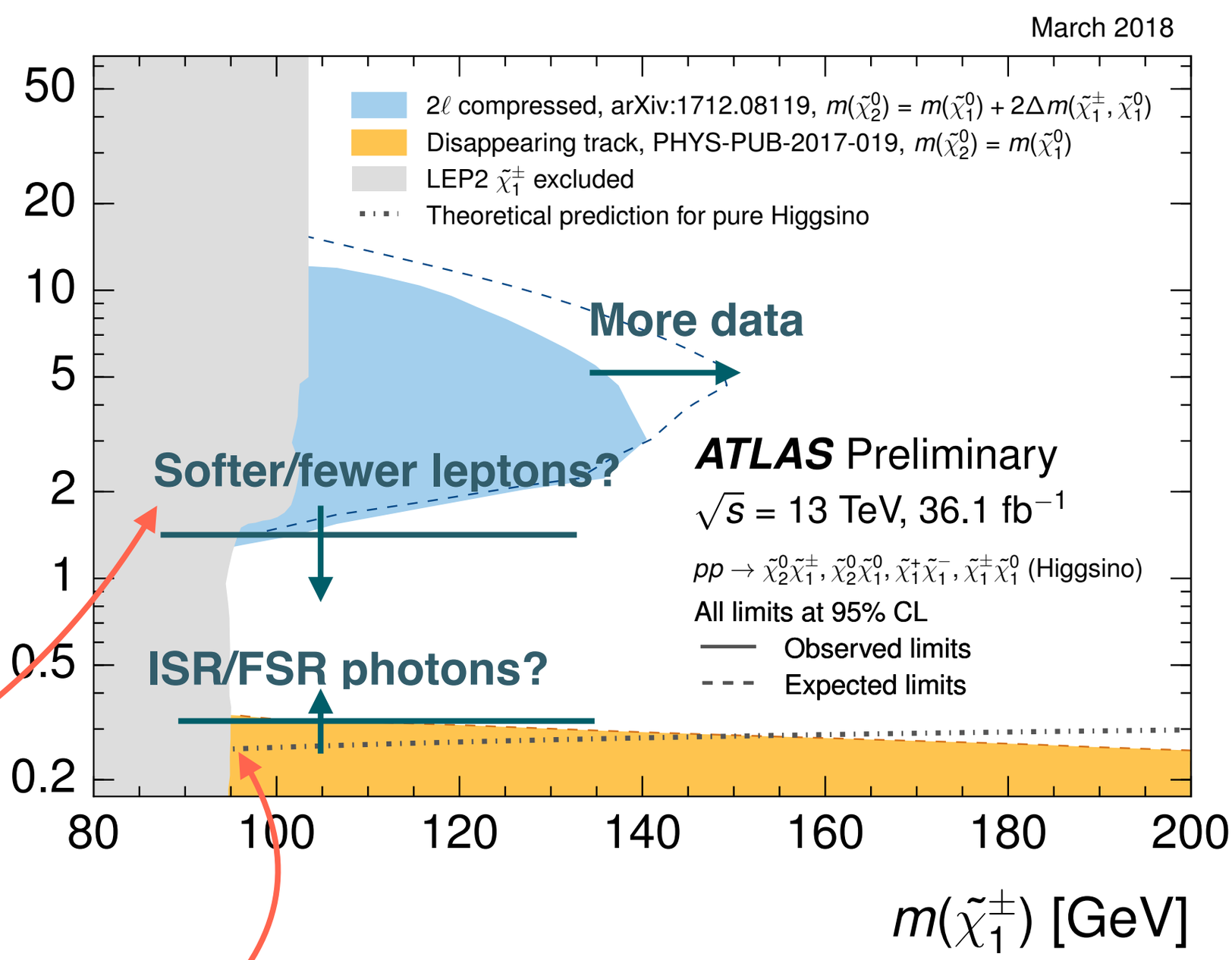
Event selected by VBF SR

Closing the gap: status at 36/fb

Light Higgsinos
Highly motivated by Dark matter relic and naturalness

Finding them is challenging!





Already down to 4 GeV electrons?

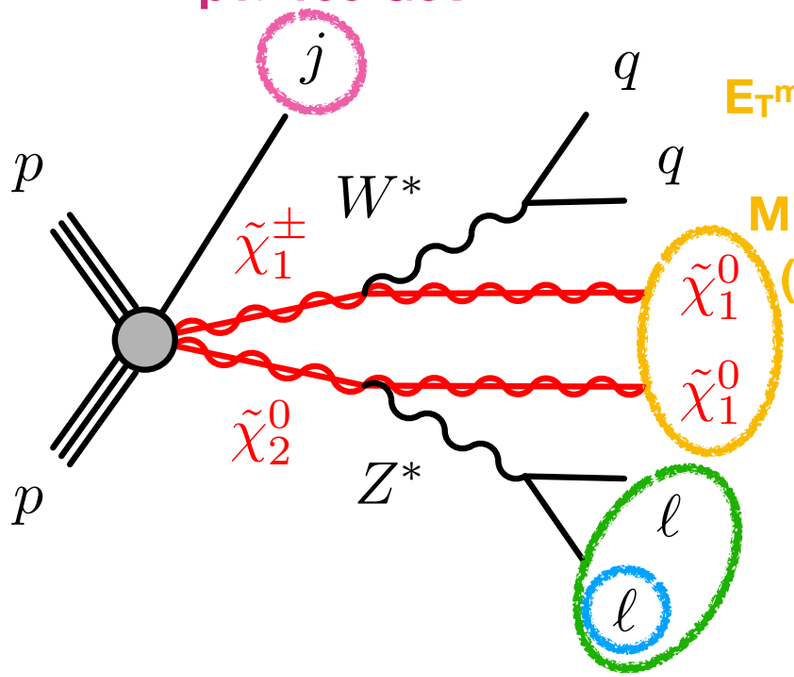
Larger mass gap: chargino decays promptly

Soft leptons: 1 lepton + 1 track

ATLAS-CONF-2019-014
Talk by Lorenzo Rossi

Improvements / innovations

Boost to MET from ISR jet pT>100 GeV

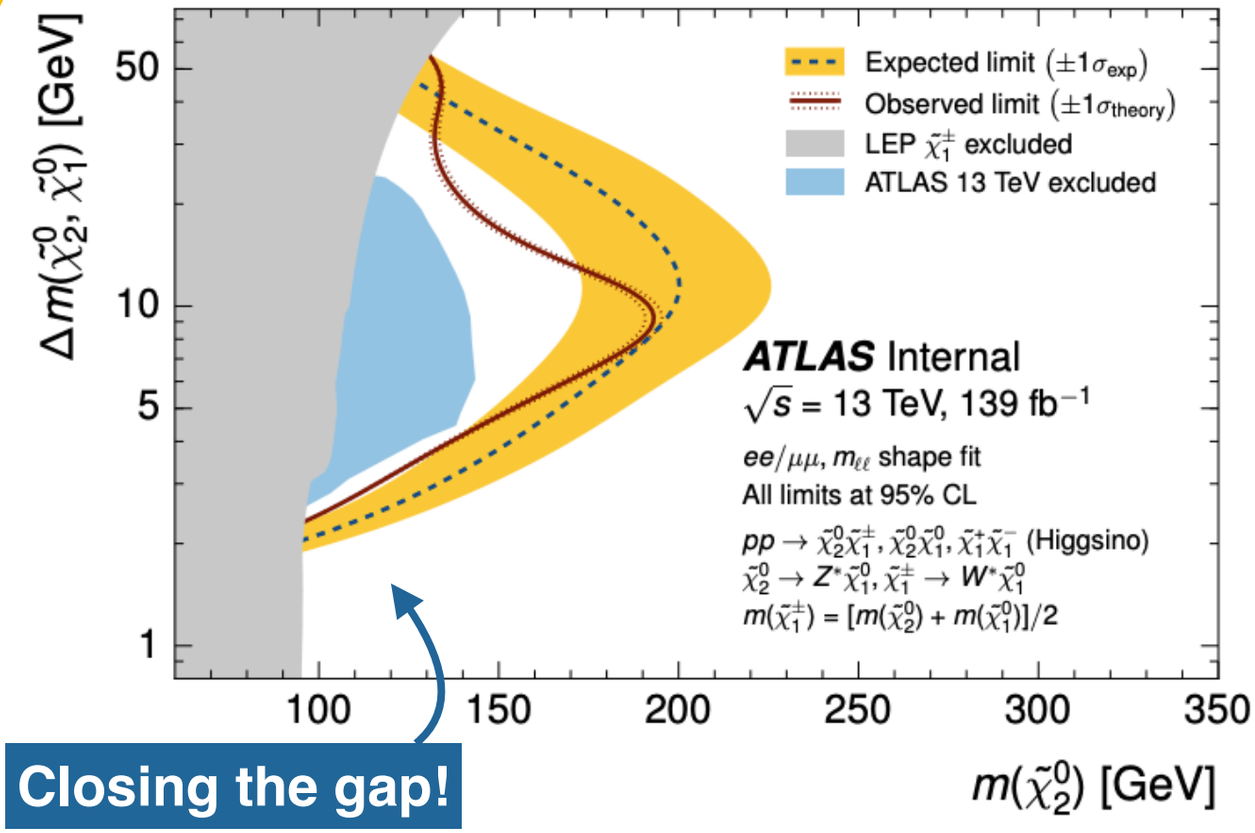


E_T^{miss}> 100 GeV
+
MET Triggers (below plateau)

Very soft leptons
p_T>3(4.5) GeV for muons (electrons)

1 lepton + 1 track
p_T>1 GeV for tracks

- Replace the second lepton with a track matched to a loose lepton
- Challenging as there are many tracks to choose from!
- Incorporated recursive jigsaw variables
- **First published SUSY search to use tracks as leptons!** [paper in 2nd circulation]

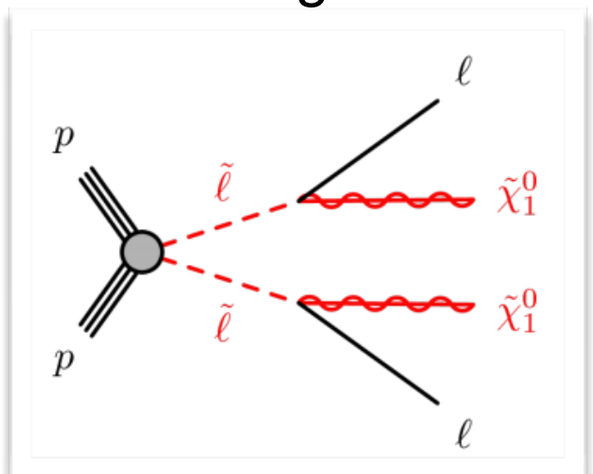


Closing the gap!

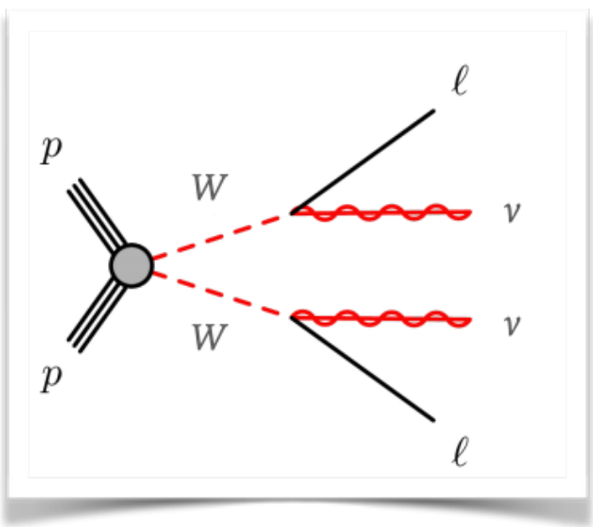
(Compressed) sleptons

Talk by Gabriel Gallardo

Signal

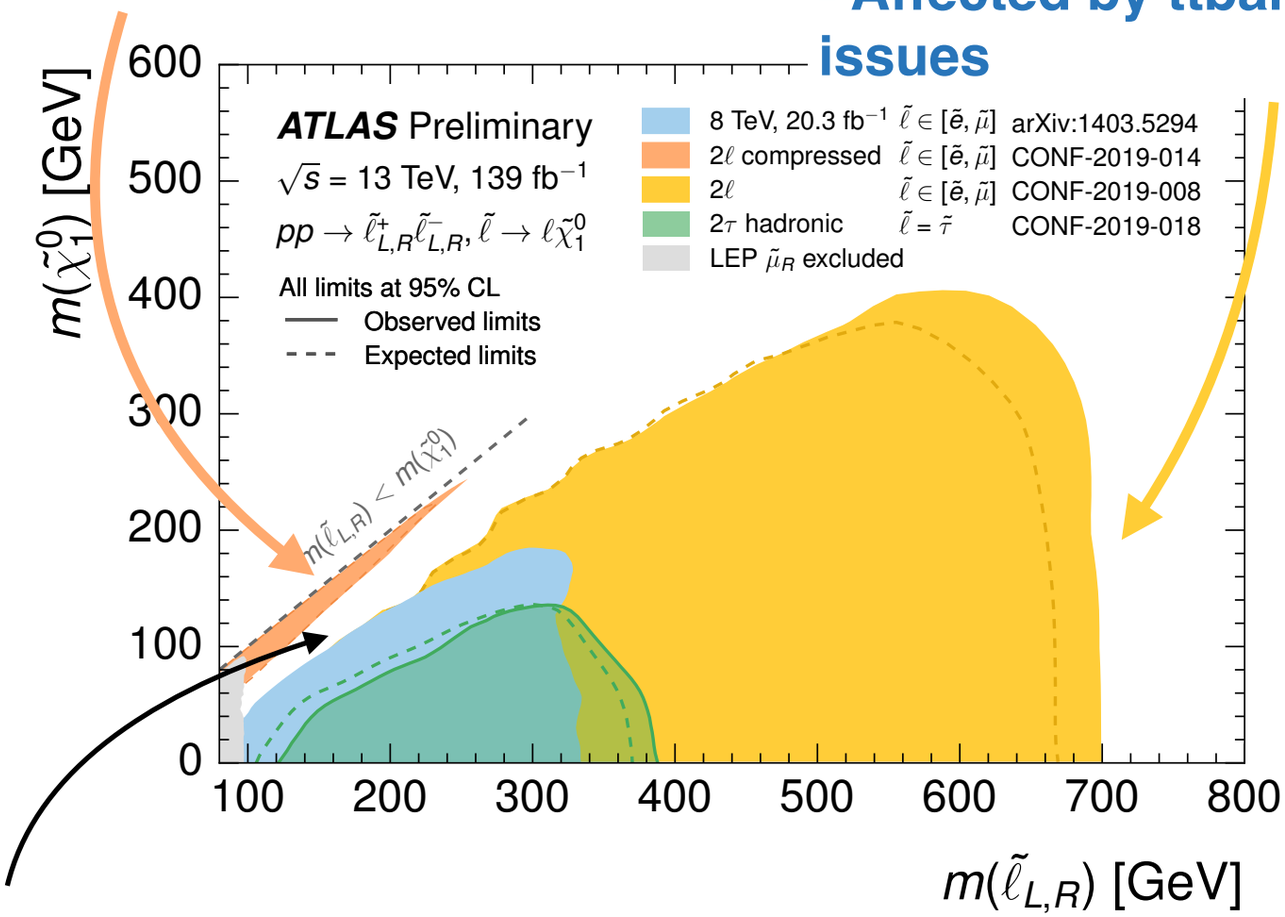


Background



ATLAS-CONF-2019-14

(previous slide)



New 2L0J arxiv:1909.08215

- Added fJVT
- M_{T2} optimisations
- **Affected by ttbar modelling issues**

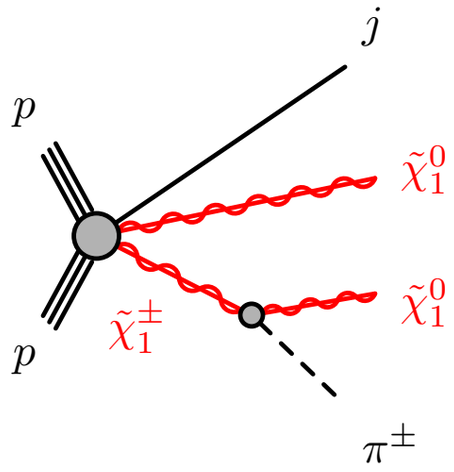
How will we close this gap?
New ideas and machine learning

Welcome to the jungle (of long-lived SUSY particles)

Inspired by Emily Thompson's SUSY workshop talk

Upcoming: Disappearing tracks

Disappearing track
Targets ultra-compressed wino and Higgsino

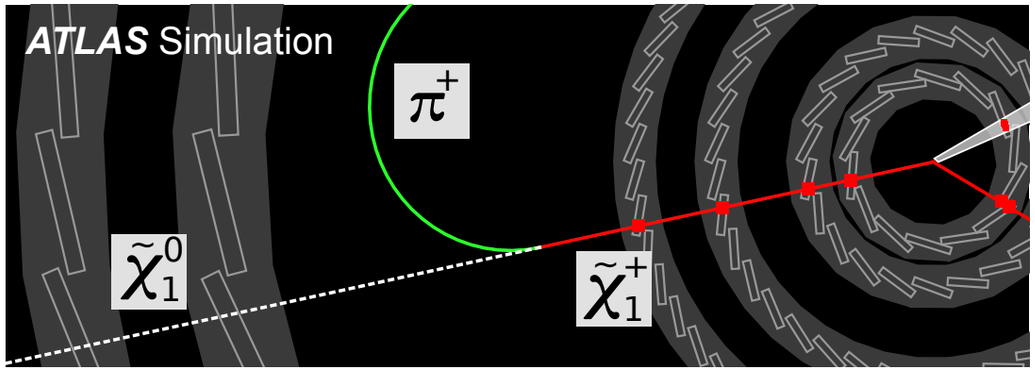


First wave: improvements since 36/fb analysis

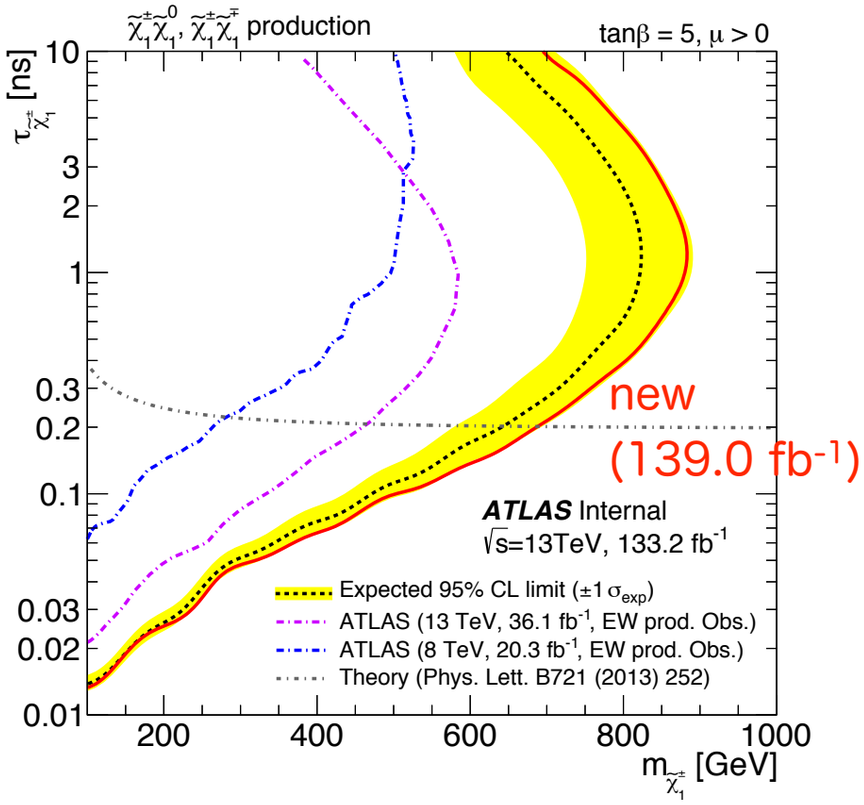
- Calorimeter veto → tracklets should not have associated activity in the calorimeter
- Custom GRL, stricter requirements on SCT status
- SR optimisation: jet pT, MET thresholds
- pT dependent smearing function

Second wave

- **Soft pion tagging: ATL-PHYS-PUB-2019-11**
- Move to DRAW RPVLL: additional track information not available in standard streams.



Toshiaki Kaji

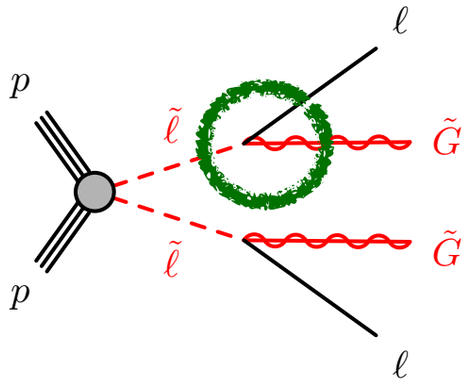


Also contributing at higher lifetimes
Pixel dE/dx [high priority, following up on excess]
Stable charged particles [**needs people!**]

New to LHC: high d_0 leptons

Emily Thompson's talk

Very weakly coupled gravitino
Long-lived slepton



No displaced vertex

Opposite sign
ee, *μμ*, e*μ*

Intermediate d_0 leptons (<3mm) — high d_0 leptons (>3mm)

Only standard tracking — Large-radius tracking

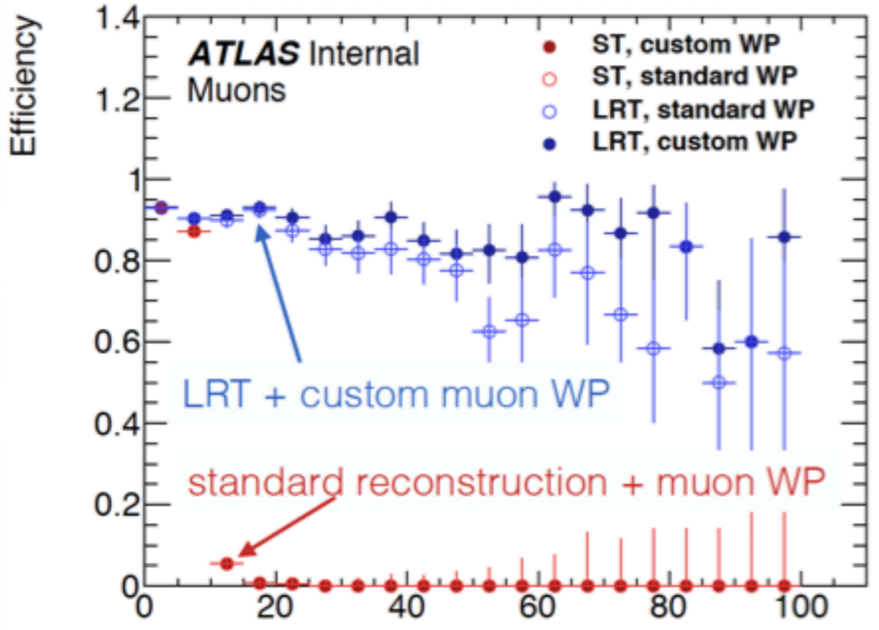
OS: *μμ* — OS: ee, *μμ*, e*μ*

- **Custom muon WP**: Medium ID w/o pixel hit requirement
- **Custom electron WP**: VeryLooseLLH w/o d_0 and si hits
- Reduction of **cosmic muon** background
  - Geometrical cuts on pairs of MS segments

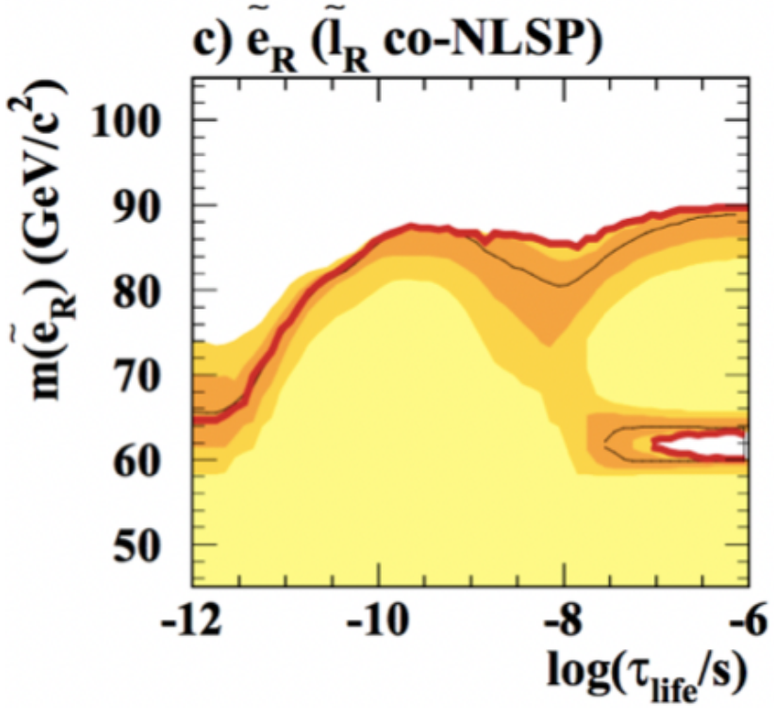
} Reject 90% cosmic
Keep 96.5% signal

- Many other LLP analyses dealing with cosmic muons [DV+muon, stopped particles]
- Having **dedicated cosmic runs** with normal detector conditions would be beneficial to have this in Run 3!
- Cosmic MC under development: ATLMCPROD-4508

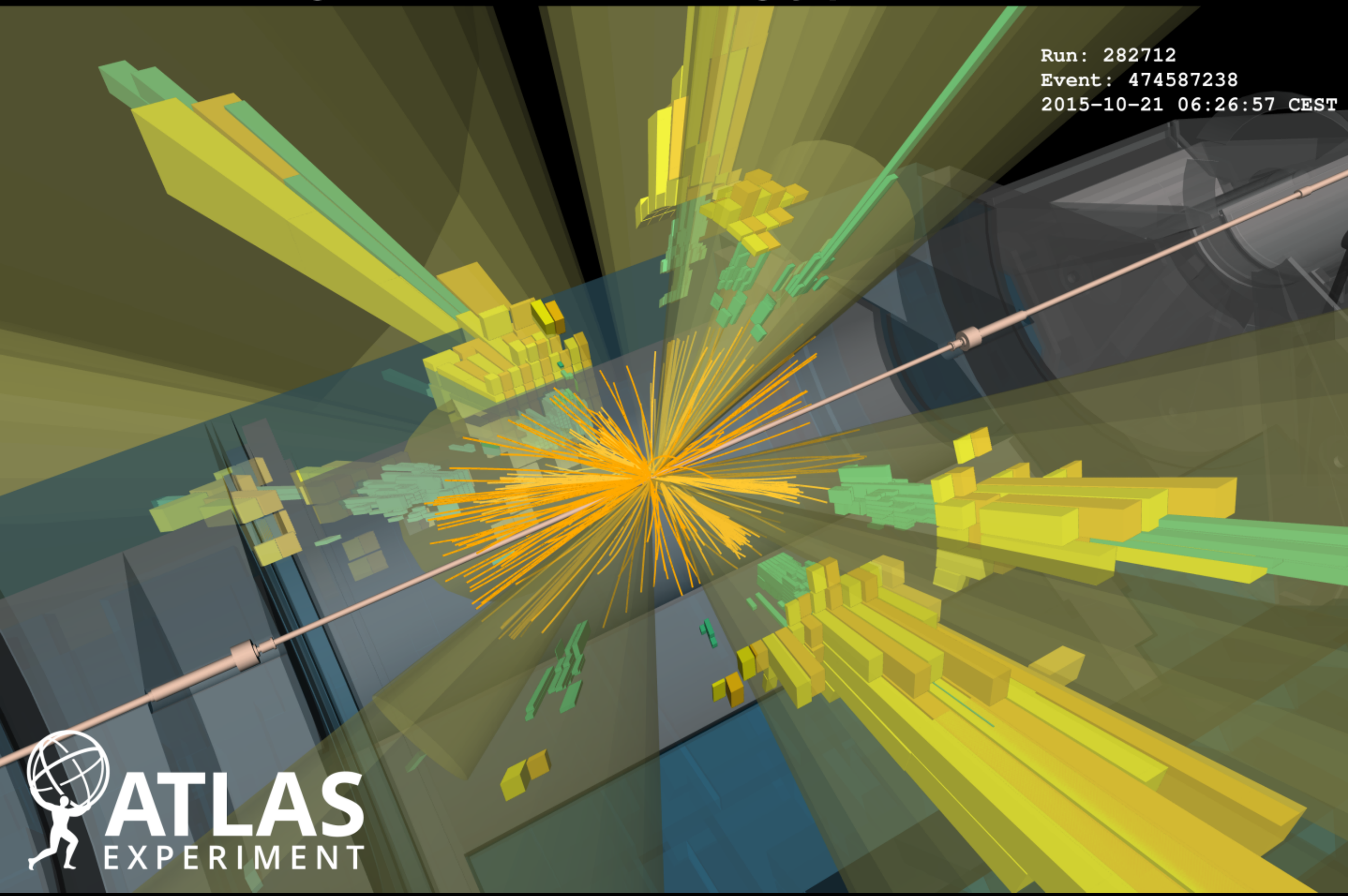
Custom muon WP



Previous limits from OPAL



Third generation and strongly produced SUSY



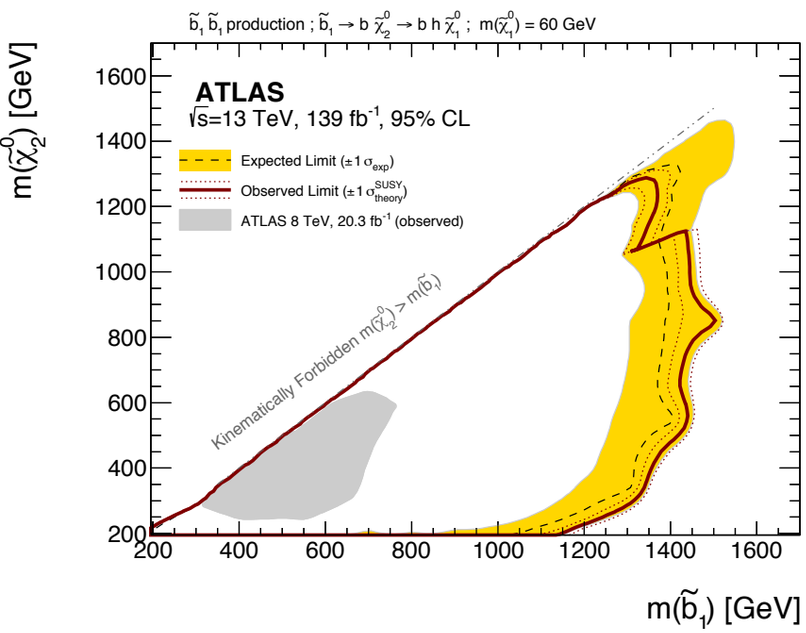
Third generation public results

See Paola Arrubarrena's summary talk

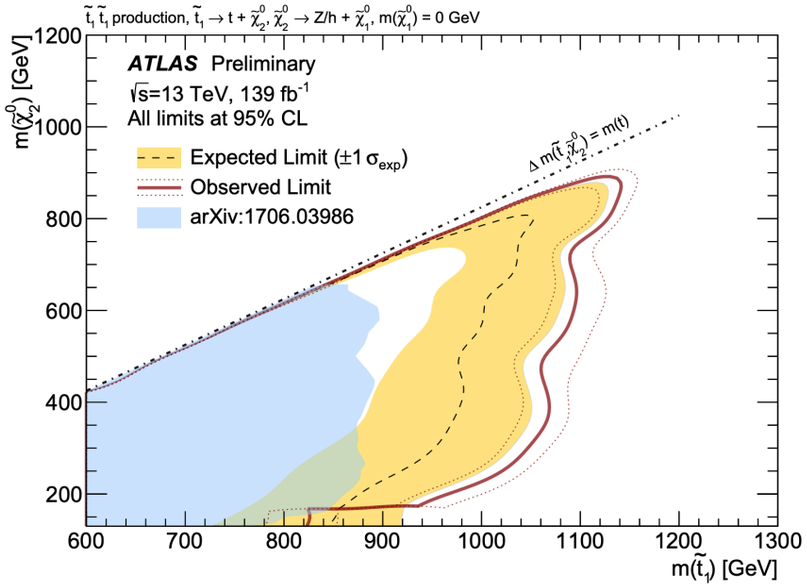
Public first-wave papers

CONF notes currently undergoing metamorphosis into papers

Sbottom multi-b
arxiv:1908.03122
METSig / m_{eff} multi-bin fit

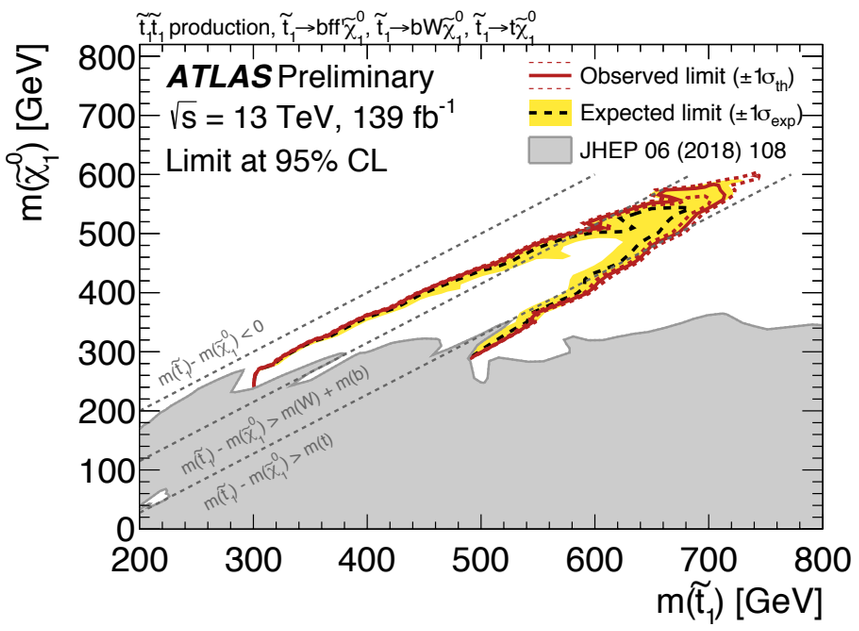


Stop Zh
ATLAS-CONF-2019-016
MET / lepton pT multi-bin fit



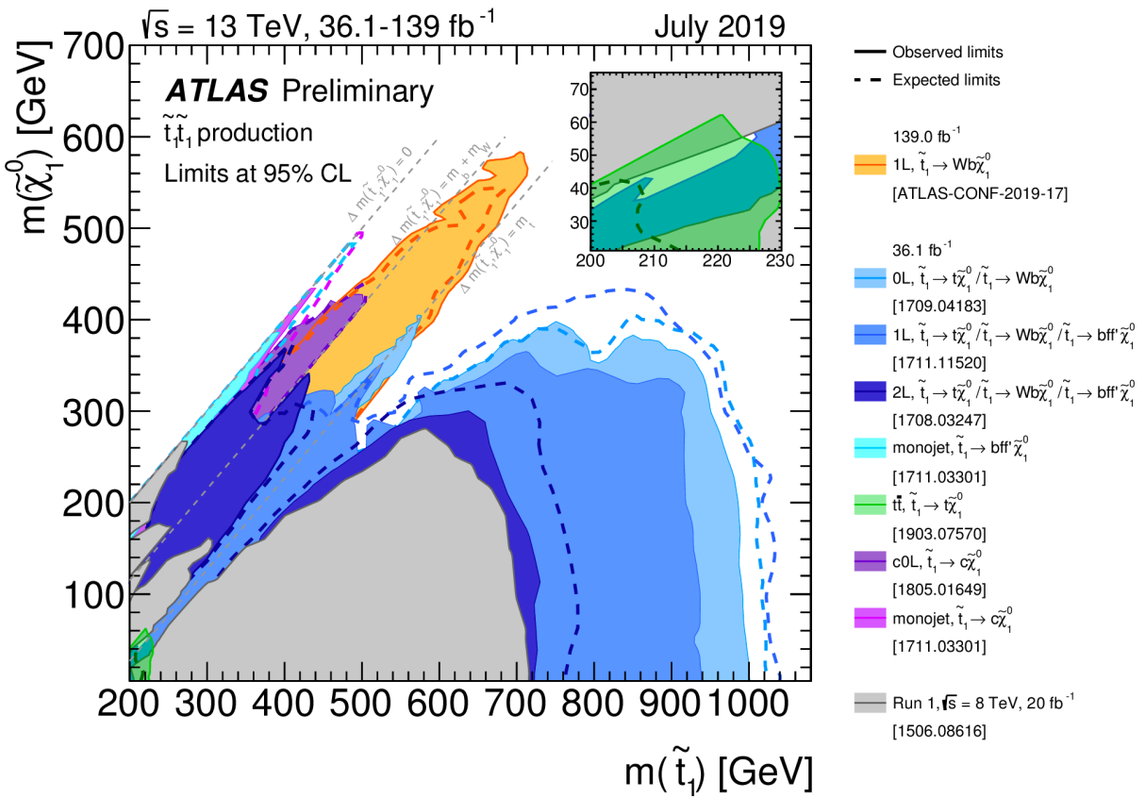
tt1L+MET (3 body)
ATLAS-CONF-2019-017

Used RNN to combine various N-jets in event, used as input to NN



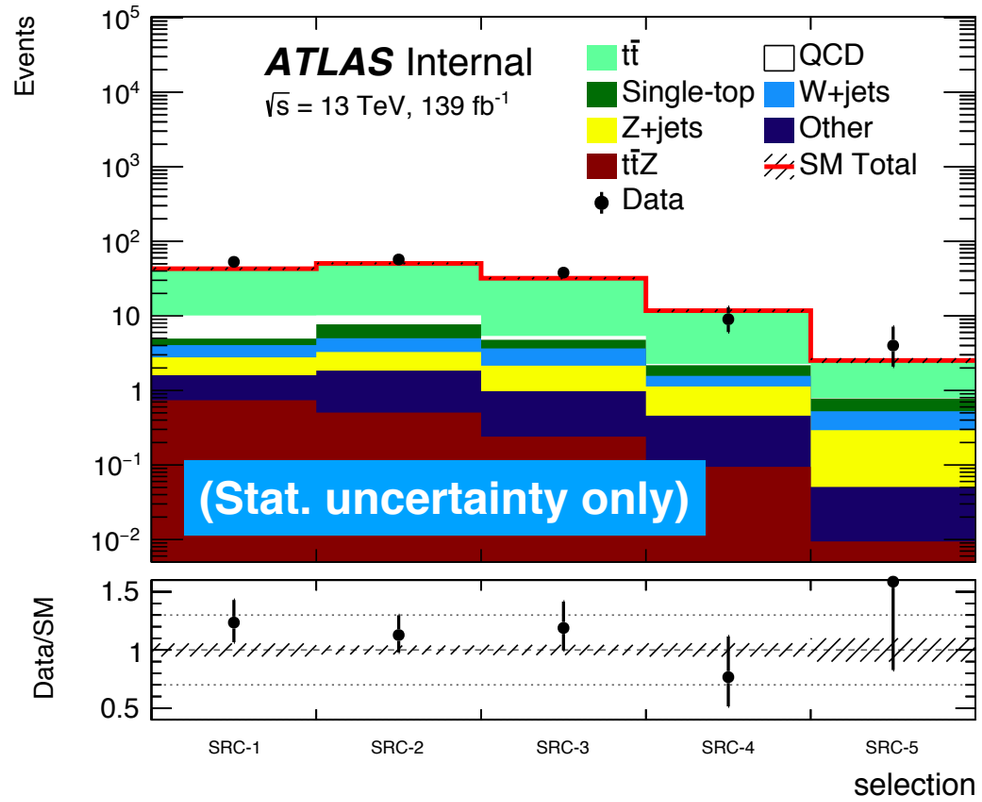
Upcoming: tt + MET 0L / 1L / 2L

- Three separate searches: 0L, 1L, 2L
  - All are in final analysis review stage
- **Soft b-tagging** explored in 4-body regions
  - **Dedicated effort** with FTAG to develop/ calibrate these algorithms (CONF note, there will be a **paper**)
- Good complementarity between stop searches and lepto-quark searches



- **0L team <u>recently unblinded</u>**
- 4 signal regions targeting increasingly compressed scenarios
- Recently unblinded: no excesses > 2σ
- SRC shown below, targets compressed region

Alvaro Lopez Solis

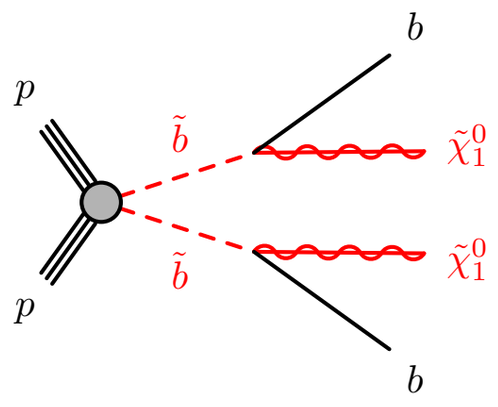


Increasing $R_{ISR} \propto m(\tilde{\chi}_1^0)/m(\tilde{t})$

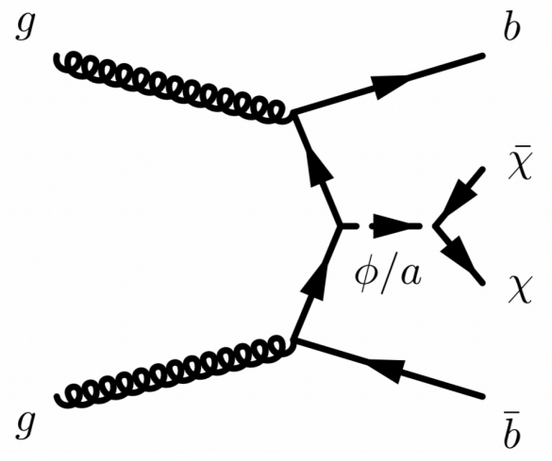
Upcoming: bb+MET

Signature

B-jets, MET
no leptons

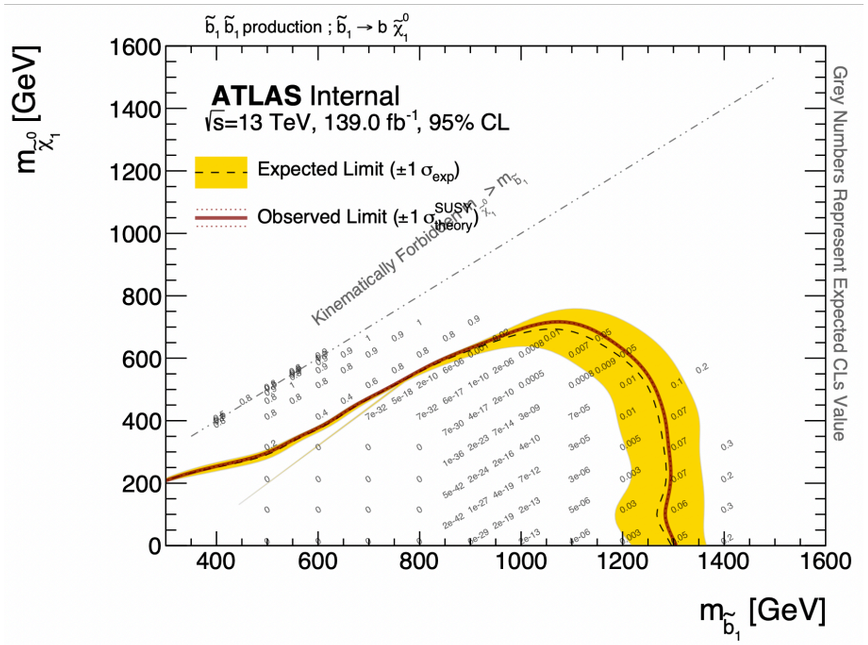


Also dark matter interpretation: see Patrick's slides

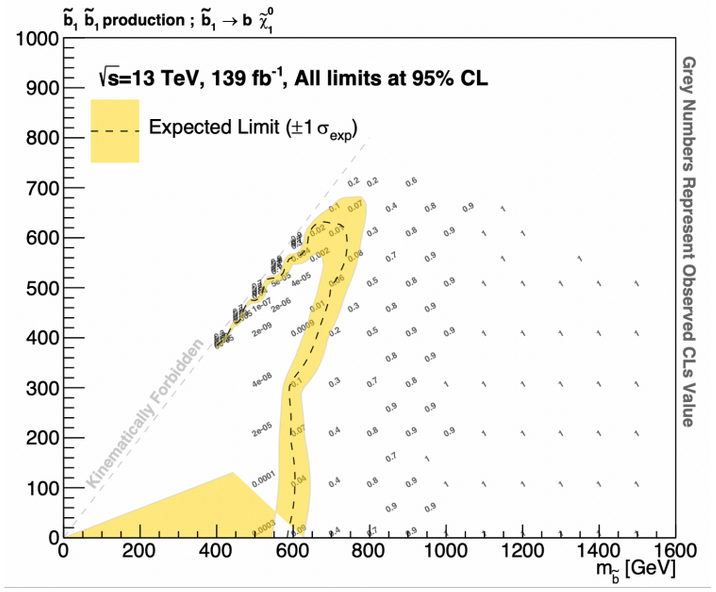


- Both signatures have identical final states, difference in analysis strategy is optimisation procedure
- Paper aiming for ~December

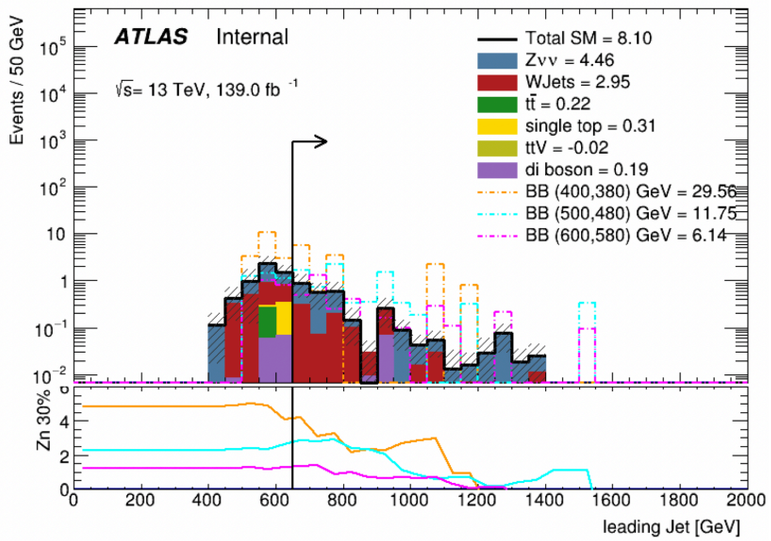
SR A
Multi-bin fit, m_{CT} and m_{eff}



SR B
BDT



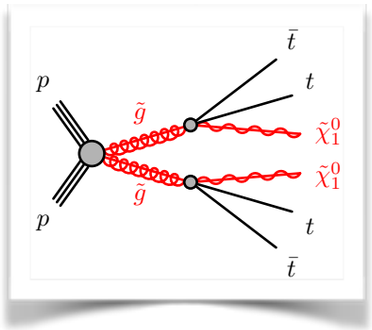
SR C
Soft b-tagging
Orthogonal to other regions for later combination

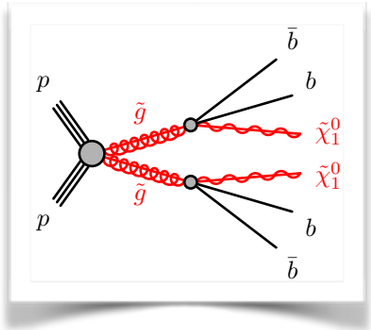


Multi b-jet search

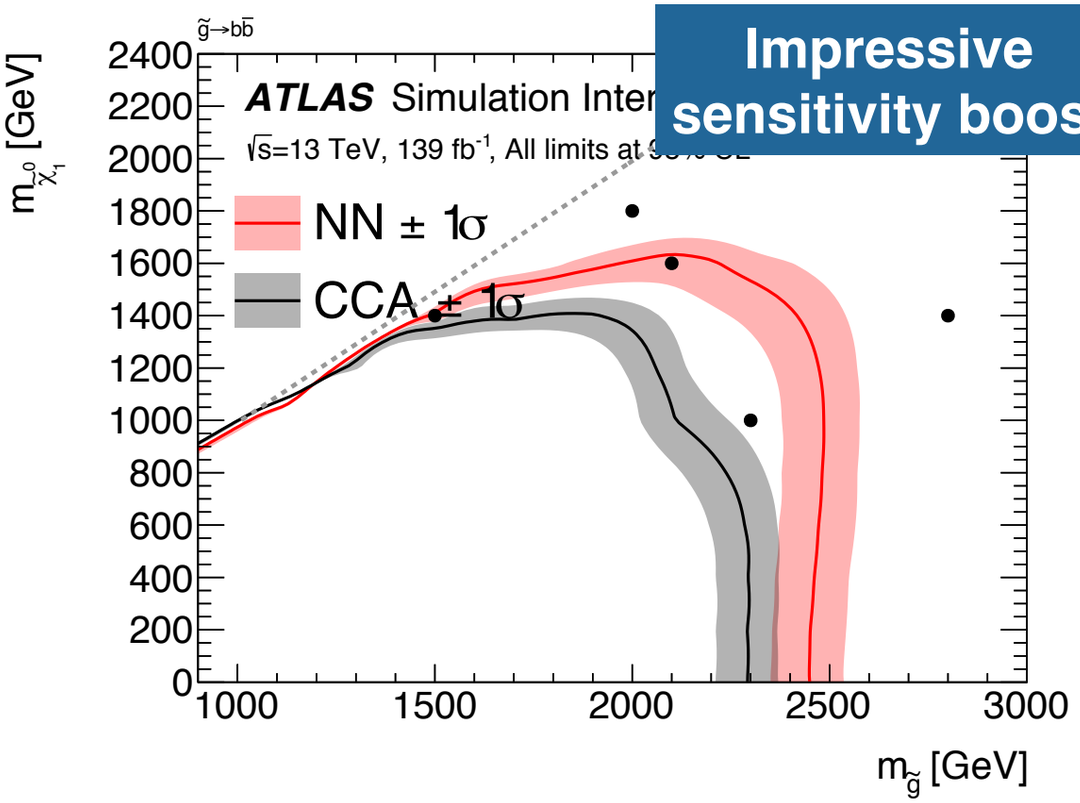
New techniques talk by L. Gagnon

- Developed neutral network technique to train across all the points two signal grids simultaneously
  - 3 layers, 90 input nodes



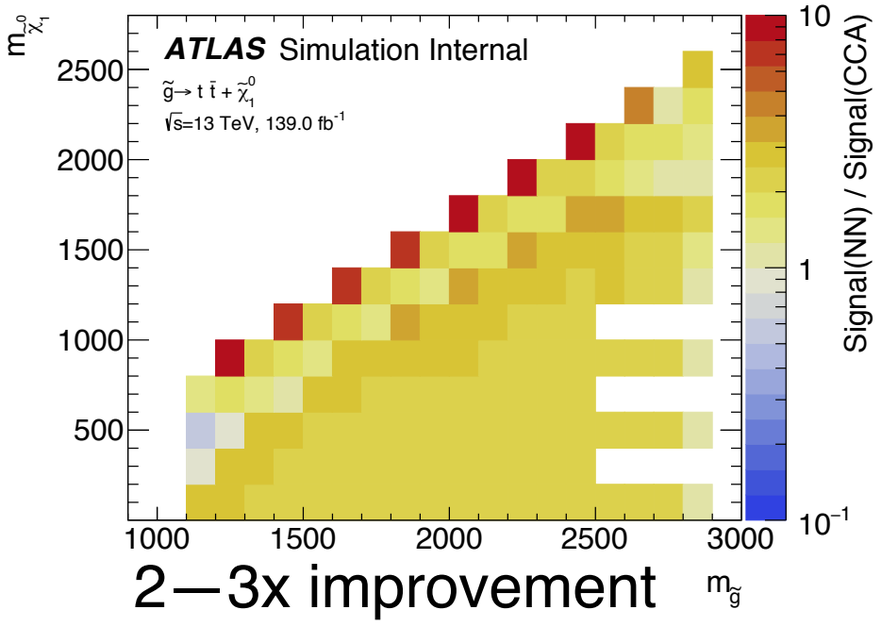


- Out-performs cut-and-count analysis



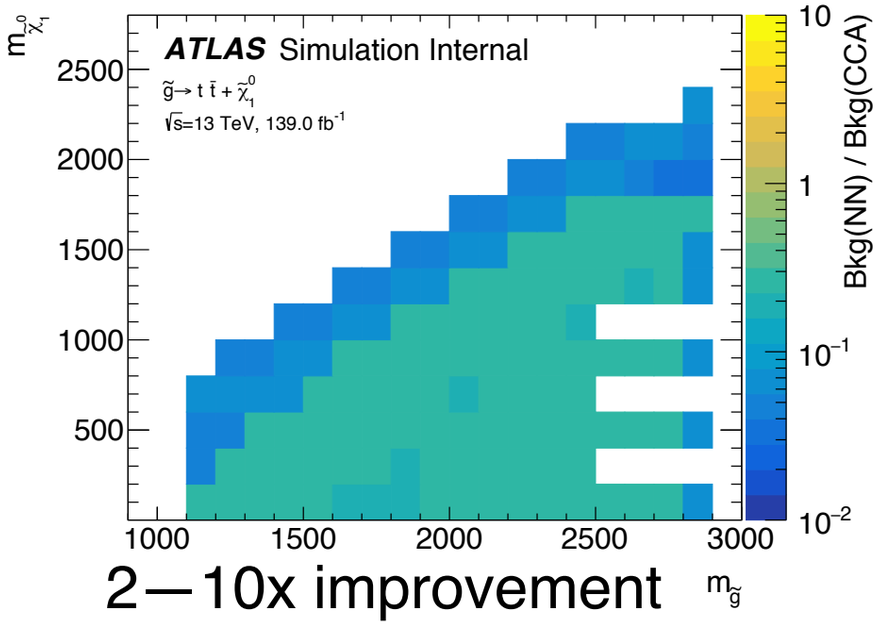
Impressive sensitivity boost

Signal



2—3x improvement

Background



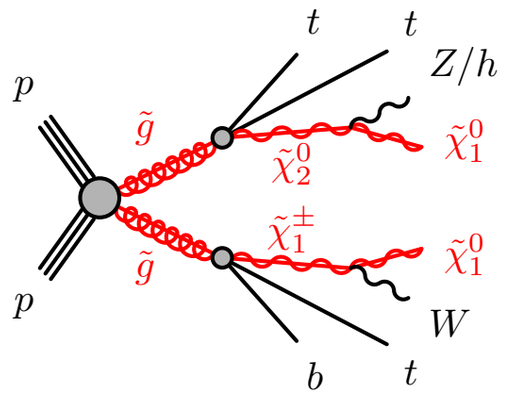
2—10x improvement

0L ≥7–12 jets: recently unblinded

ANA-SUSY-2018-17

Signature

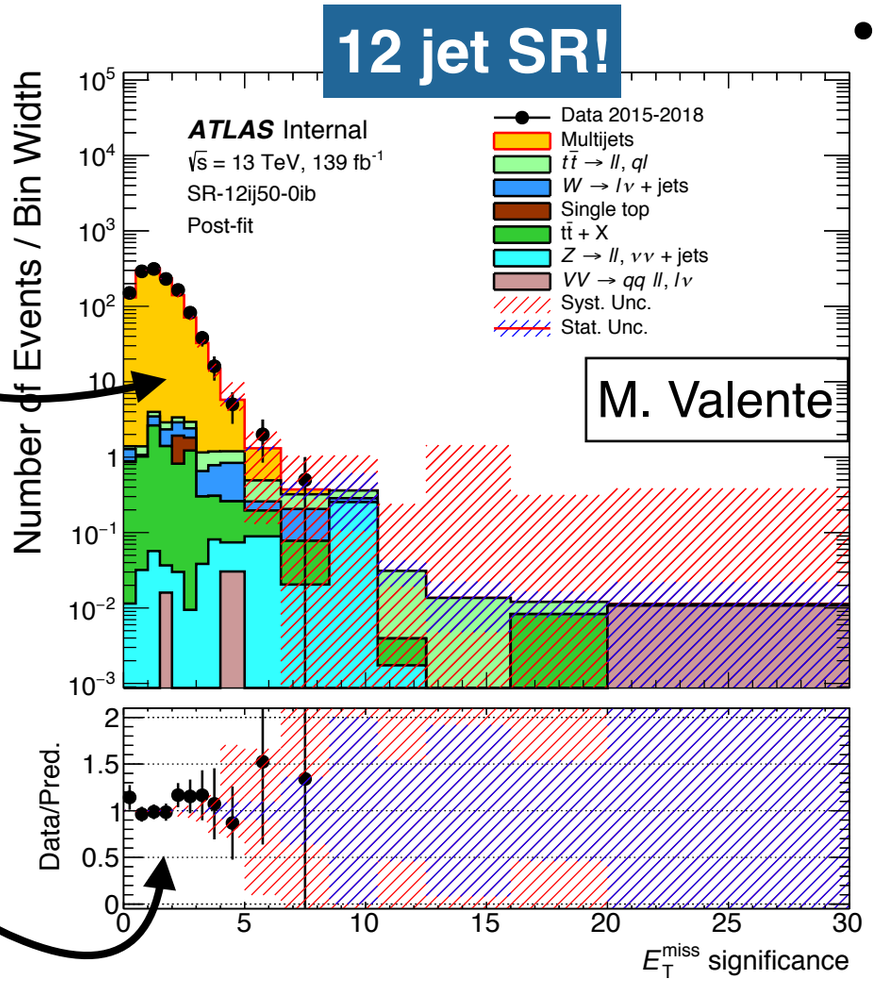
Long decay chain: lots of jets and little MET. No leptons

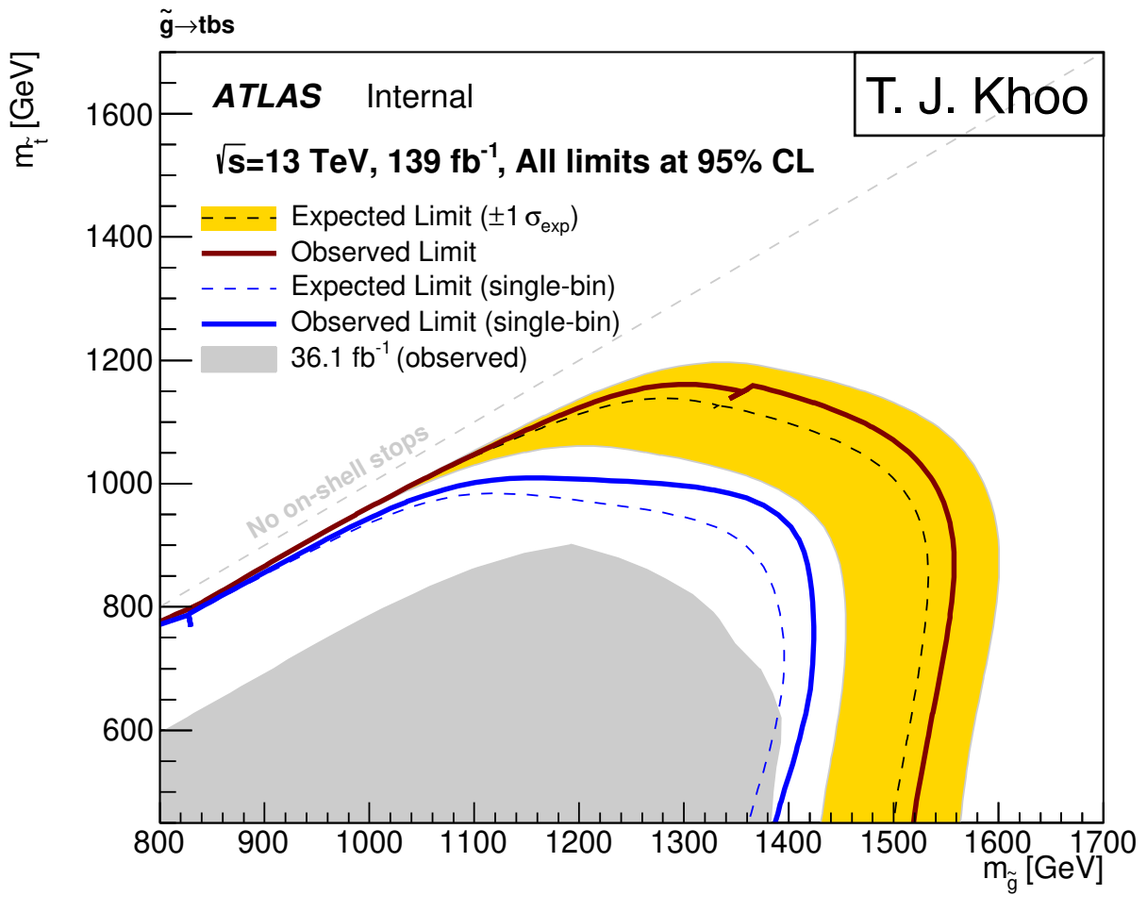


- High jet-multiplicity signal regions
  - Use of jet-substructure M_J^Σ
- **Data driven** template method to estimate multi-jet background
- **First** use of **p-flow jets** in a SUSY search
- Use of object-based MET significance
- Use of multi-bin fits

Data-driven background

Impressive prediction





A look to the future

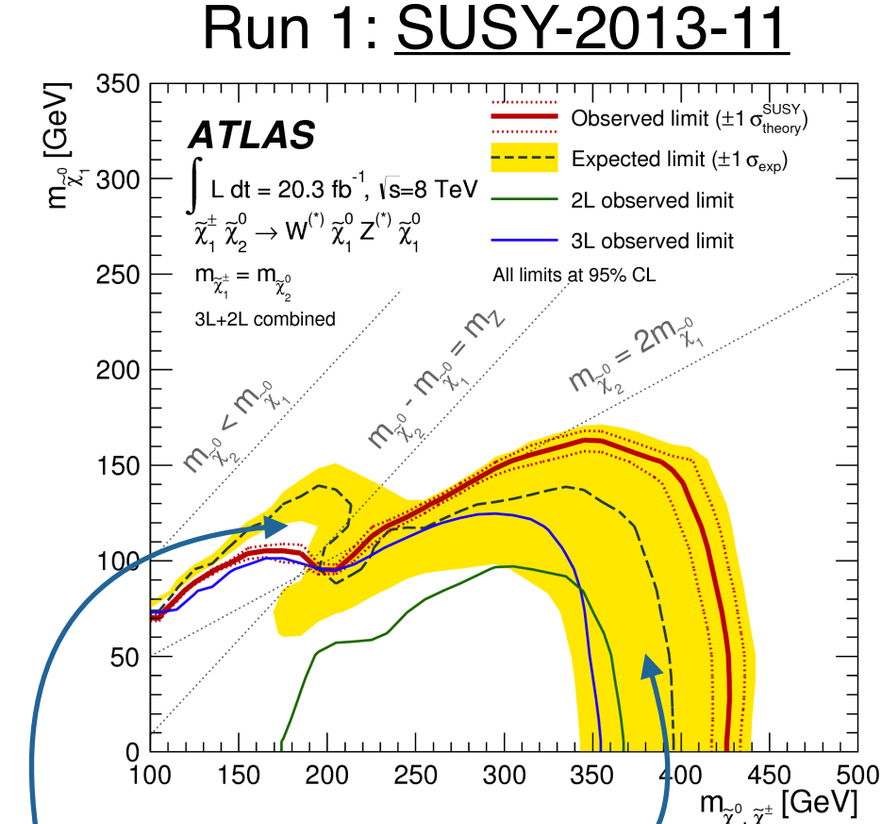
Combinations, pMSSM scans, Run3

Statistical combinations

Slides by Tina Potter's and Giordon Stark
Combinations team wiki

- Proven increase in sensitivity after statistically combining analyses
- Can take a critical look into our coverage
  - Can help plan the next moves
- Lot of effort put into trying to keep analyses orthogonal
- New statistical tools being utilised such as *pyhf*

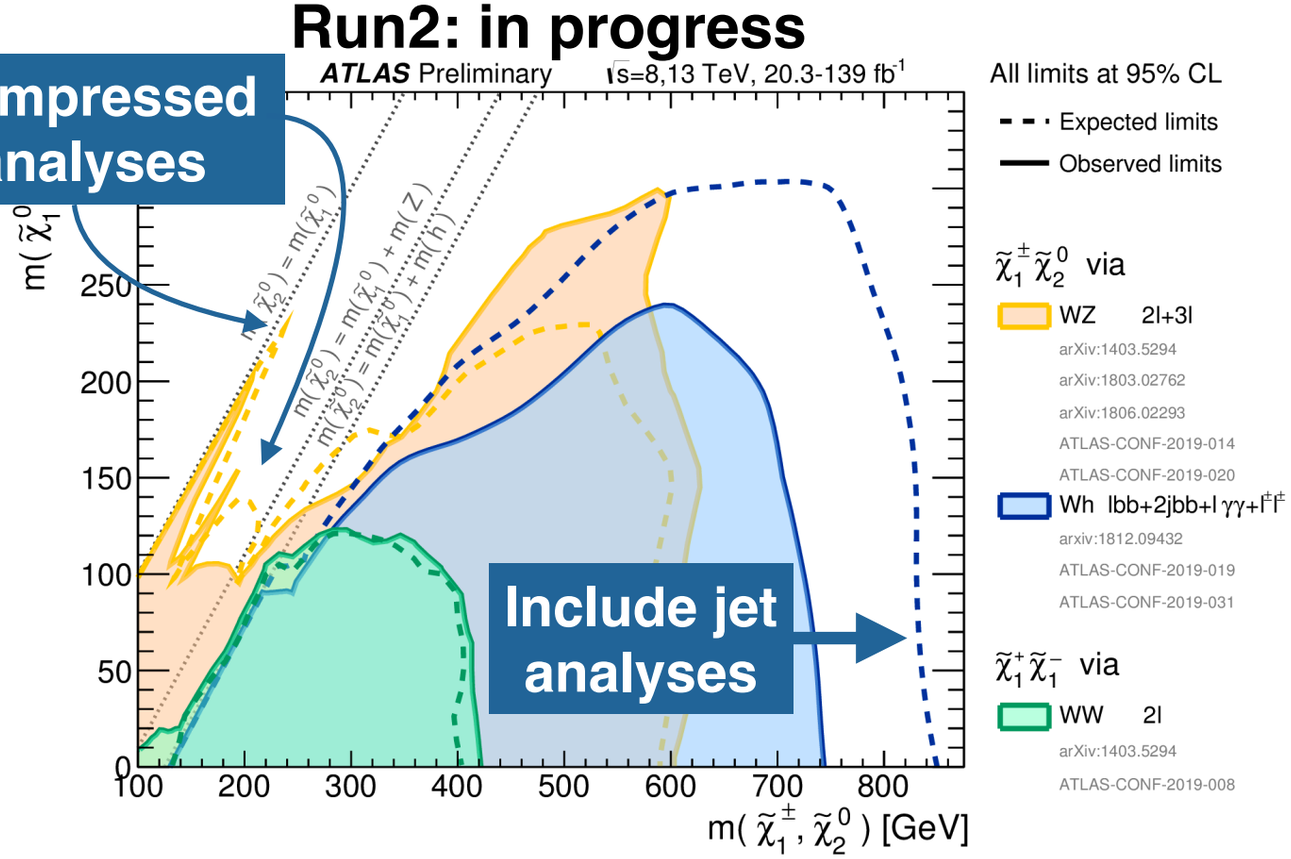
Run 1: SUSY-2013-11



Improved sensitivity

Run2: in progress

Compressed analyses

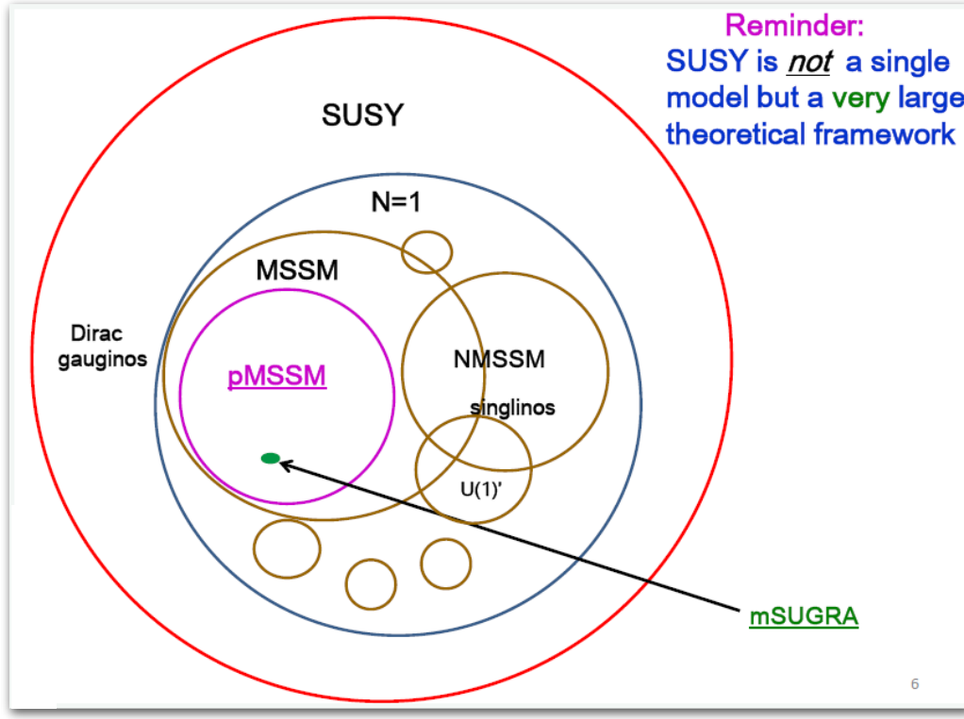


Include jet analyses

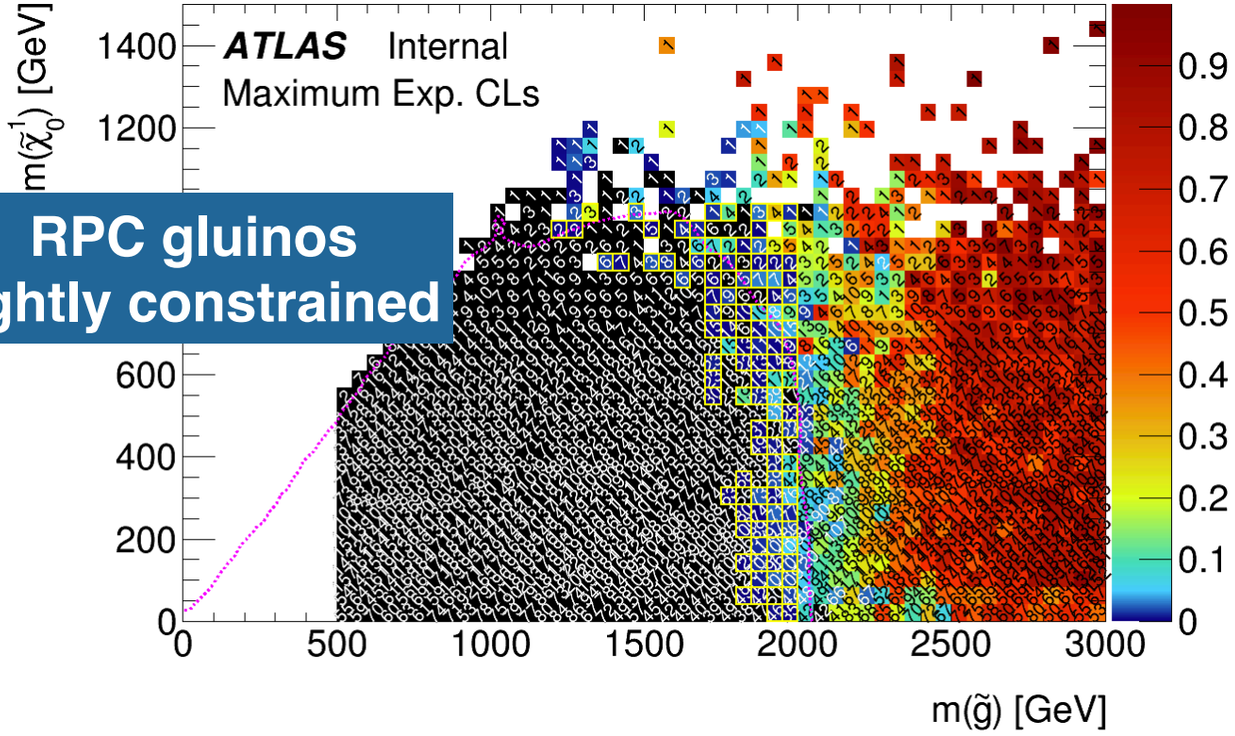
Phenomenological MSSM scans

B. Petersen's talk

- pMSSM scan: Sample O(100k) points in 19-D pMSSM space
  - Preparations well underway, coding infrastructure, scope
- Suggestion to have three papers: one large general scan and two dedicated scans, one for third generation and one for electroweak.

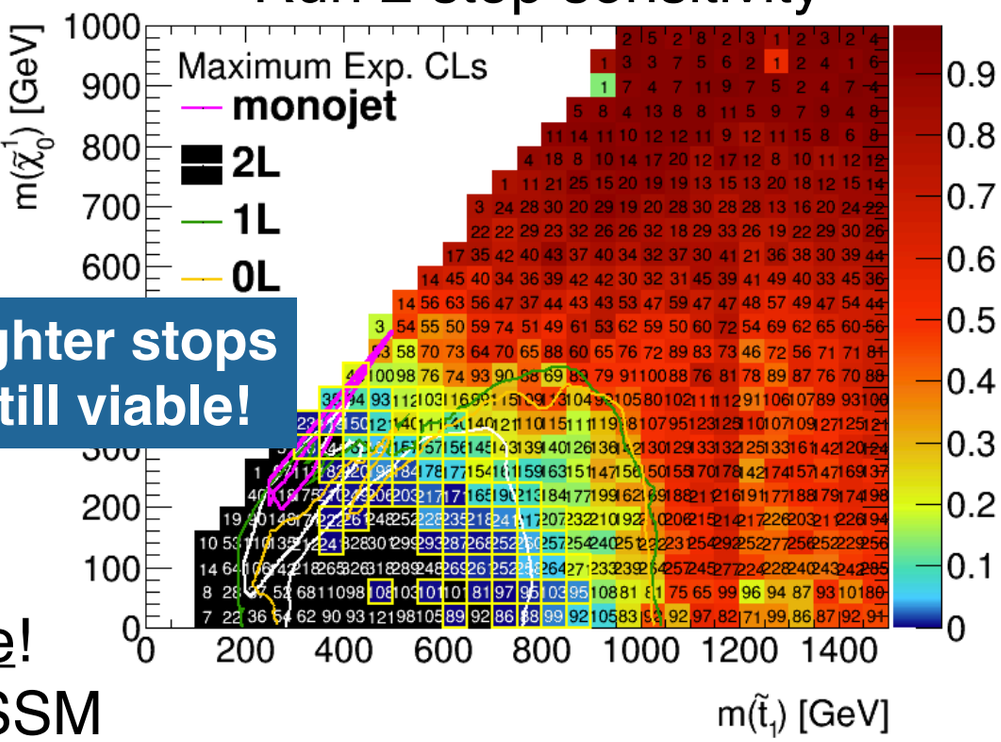


Run 2 gluino sensitivity



RPC gluinos tightly constrained

Run 2 stop sensitivity



Lighter stops still viable!

Check out very cool interactive plots here for and here!
See Run-1 pMSSM summary for more details on pMSSM

Summary

- Many first wave results now published of nearing final stages
  - Many already using more complex fits / BDTs

- 2nd wave R&D in progress with many new ideas, especially with machine learning
  - Lots of challenging scenarios to tackle

- **New analysers always welcome!**
  - Lots of room to make an impact on high-visibility analyses

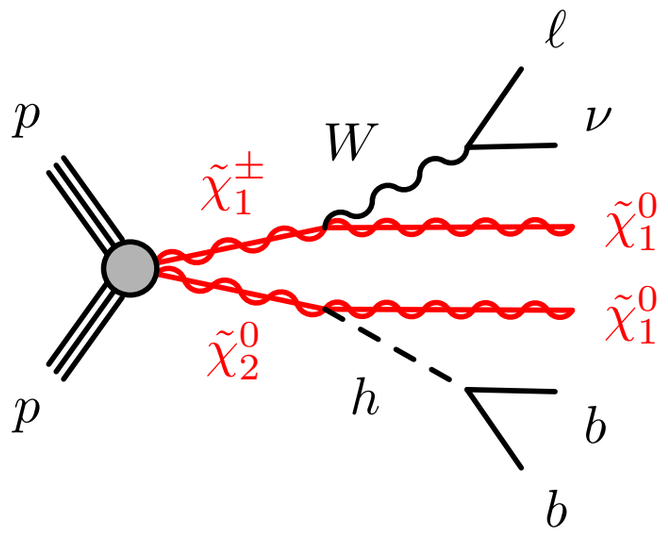
- There are still uncovered areas and places for SUSY to be hiding

Thank you

Backup

Submitted: Electroweak 1L

First wave: arxiv:1812.09432

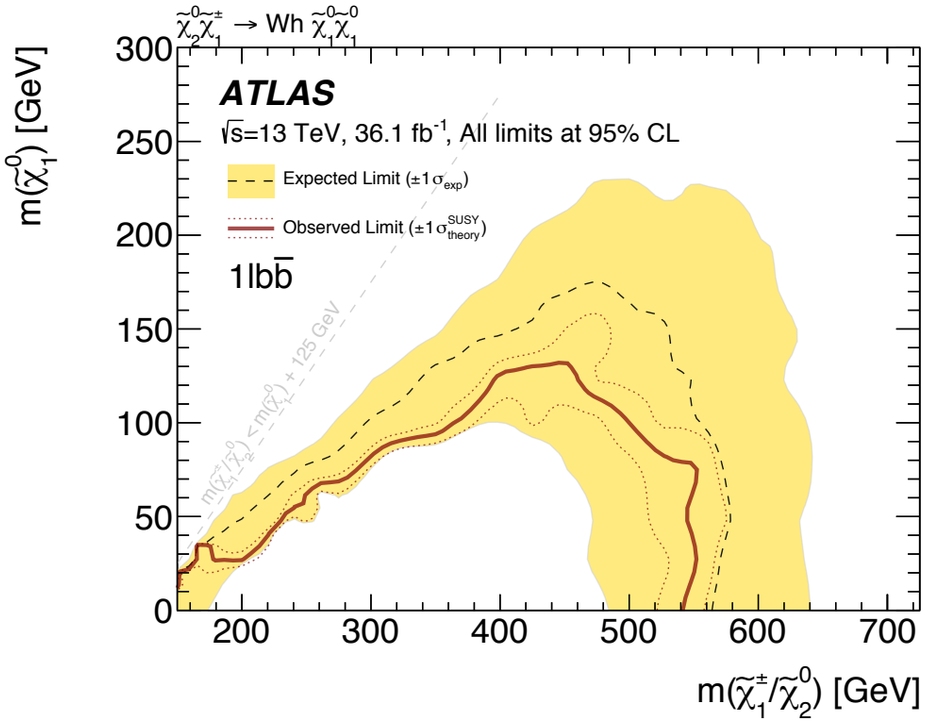


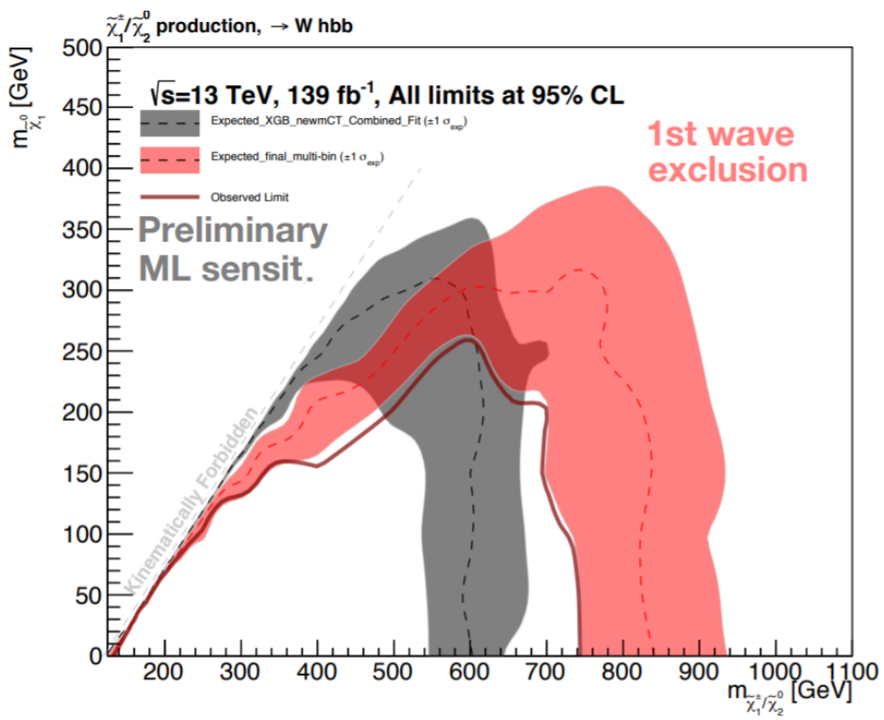
First wave result, conventional variables

- MET trigger, MET > 240 GeV
- 100 < m_{bb} < 140 GeV and transverse mass selection

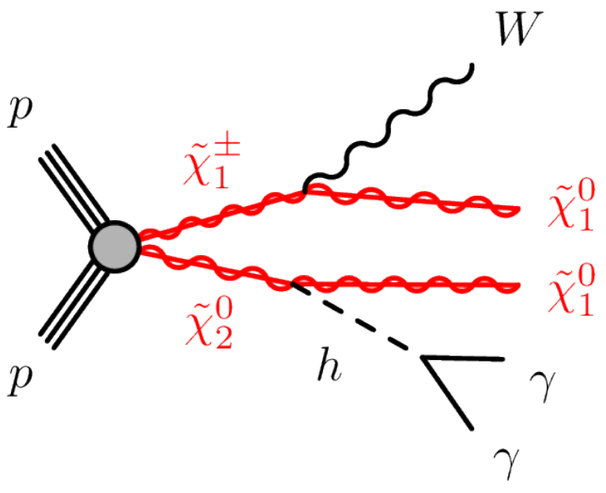
Second wave paper now in progress

- SR optimisation, conventional variables
- MVA techniques investigated
- Additional channels targeted

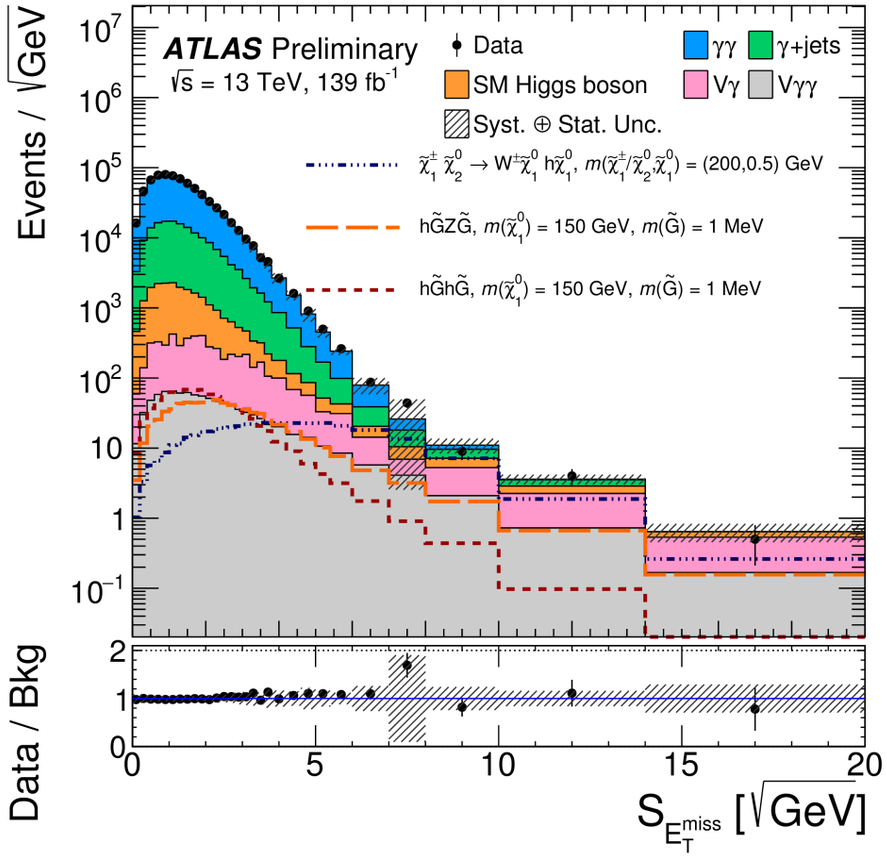


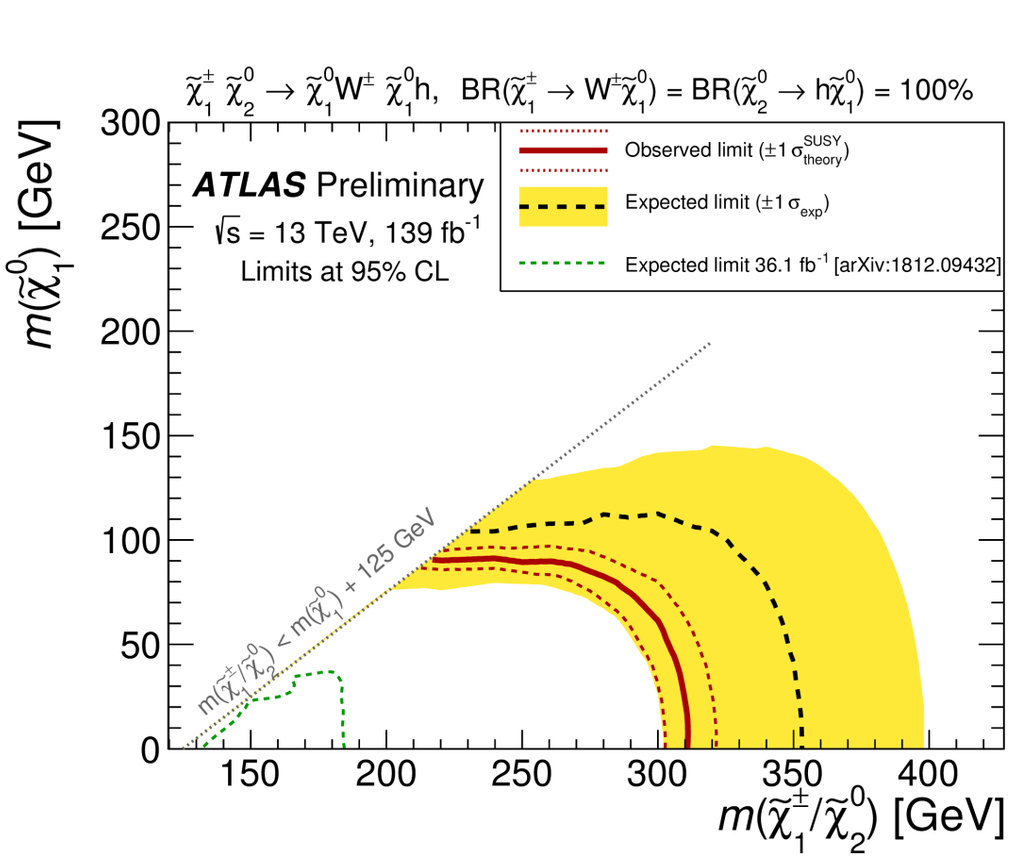


Excess follow-up: WhPhoton



- h→ $\gamma\gamma$ low BR, but excellent Higgs mass resolution
- sensitive to low MET regions, using diphoton trigger
- 2.5 σ excess in R20, but not in R21
- 120 GeV < $m_{\gamma\gamma}$ < 130 GeV
- SR categories base on E_T^{miss} sign. and n. lep/jets

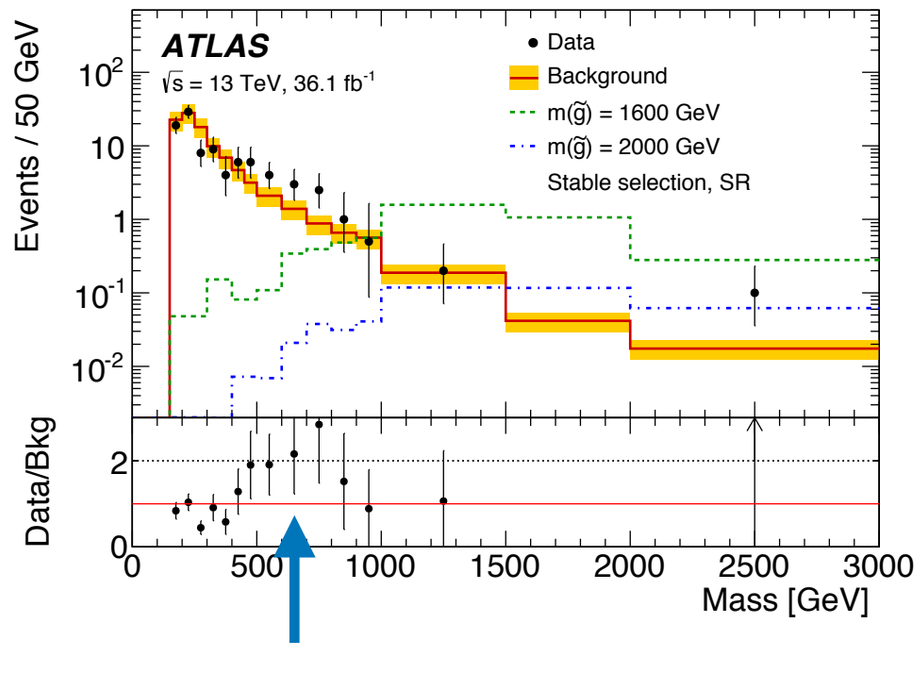


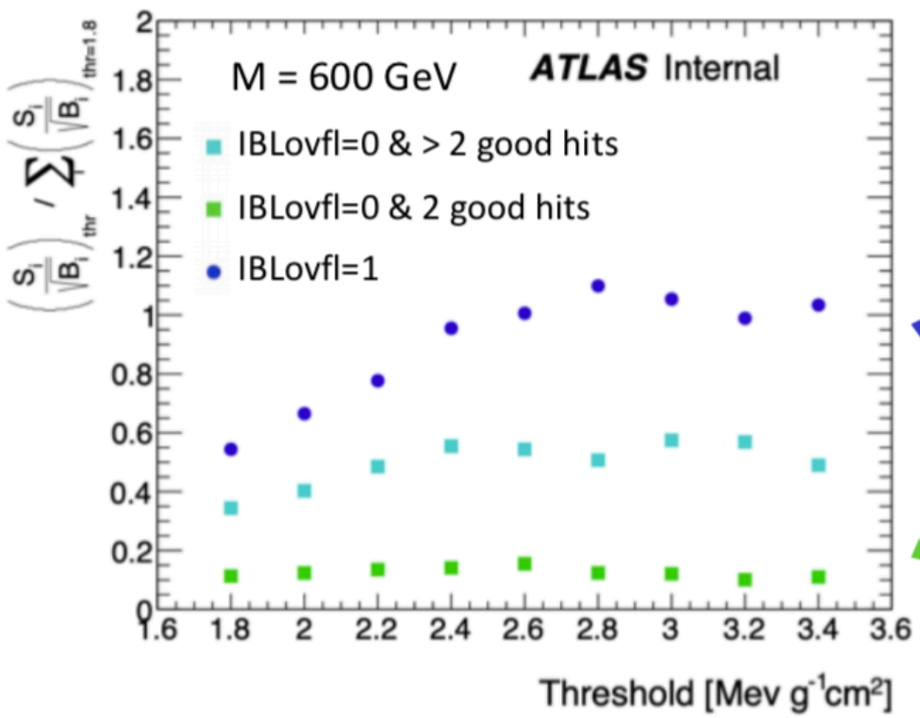


Pixel dE/dx excess follow-up

- Slow LLP will have high ionisation energy losses
- In 36/fb, 2.4σ (local) excess found in stable 600 GeV region
- Not yet unblinded: watch out for first full Run-2 analysis
- Improvements in all areas of analysis!

36/fb arxiv:1808.04095





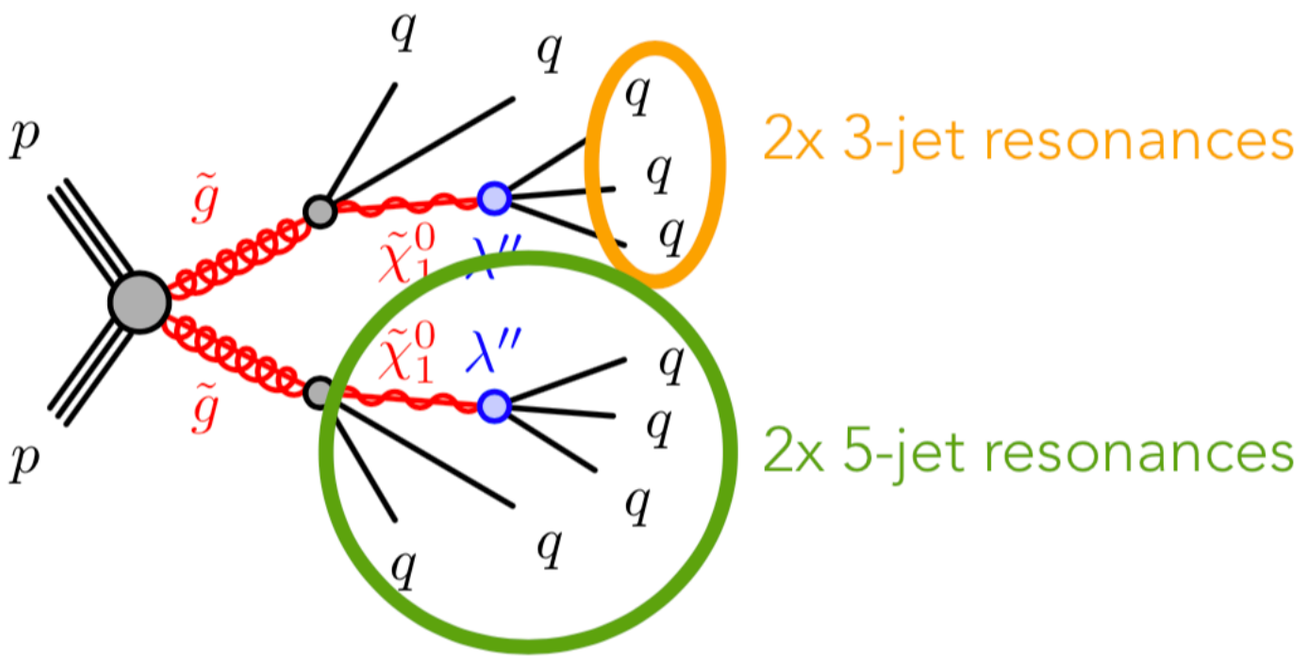
Example: **reoptimizing dE/dx thresholds** & split into categories

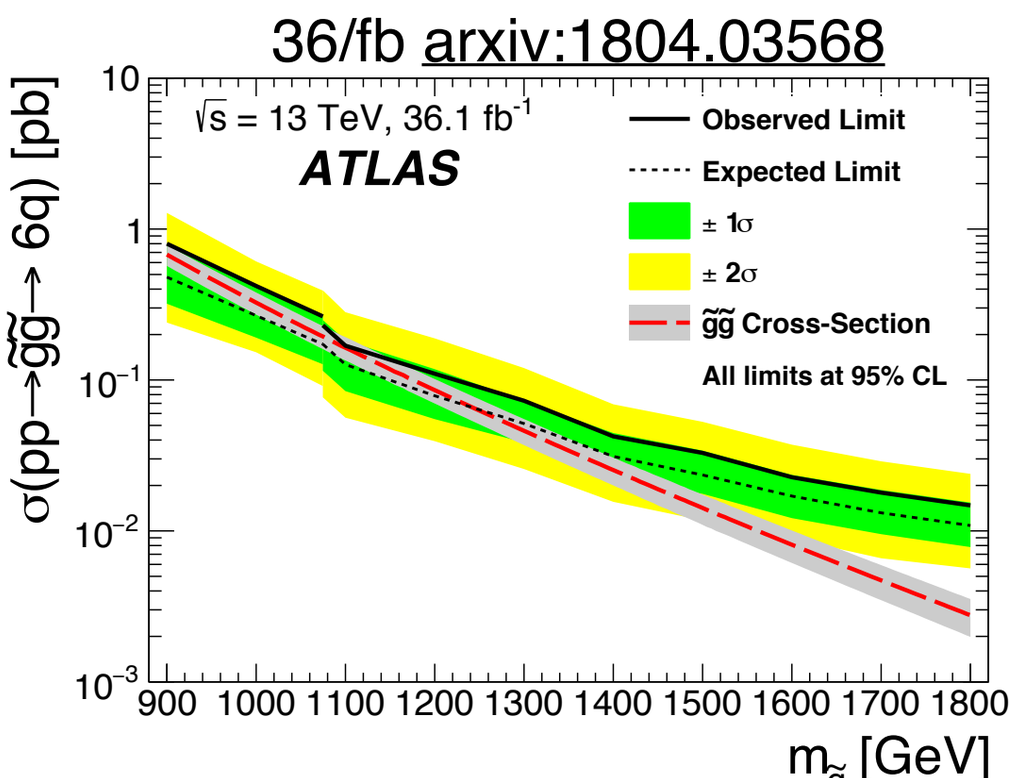
Observations:

1) low-βγ tracks are more likely to have IBL overflow
2) Tracks with only 2-good-hits have larger dE/dx tails

RPV multijets

Inspiring talk by Larry Lee





Pheno motivated: limits just under 1 TeV for the gluino

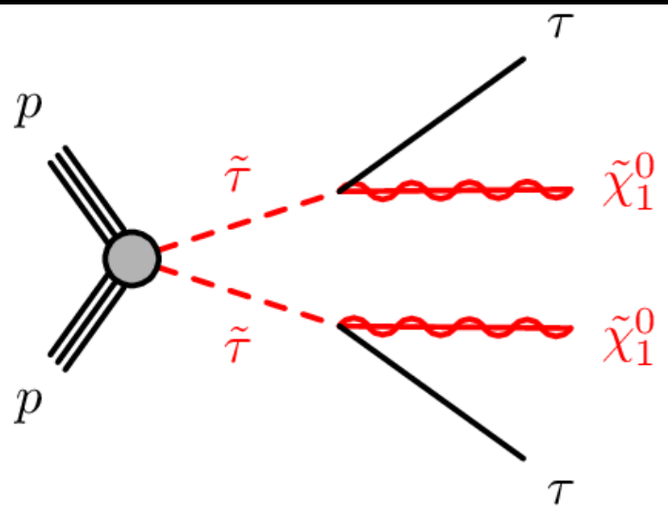
Machine learning needed

- 10 jet 4-vectors → 40D space
- Resonances: a great deal of structure in the decay, unlike the background

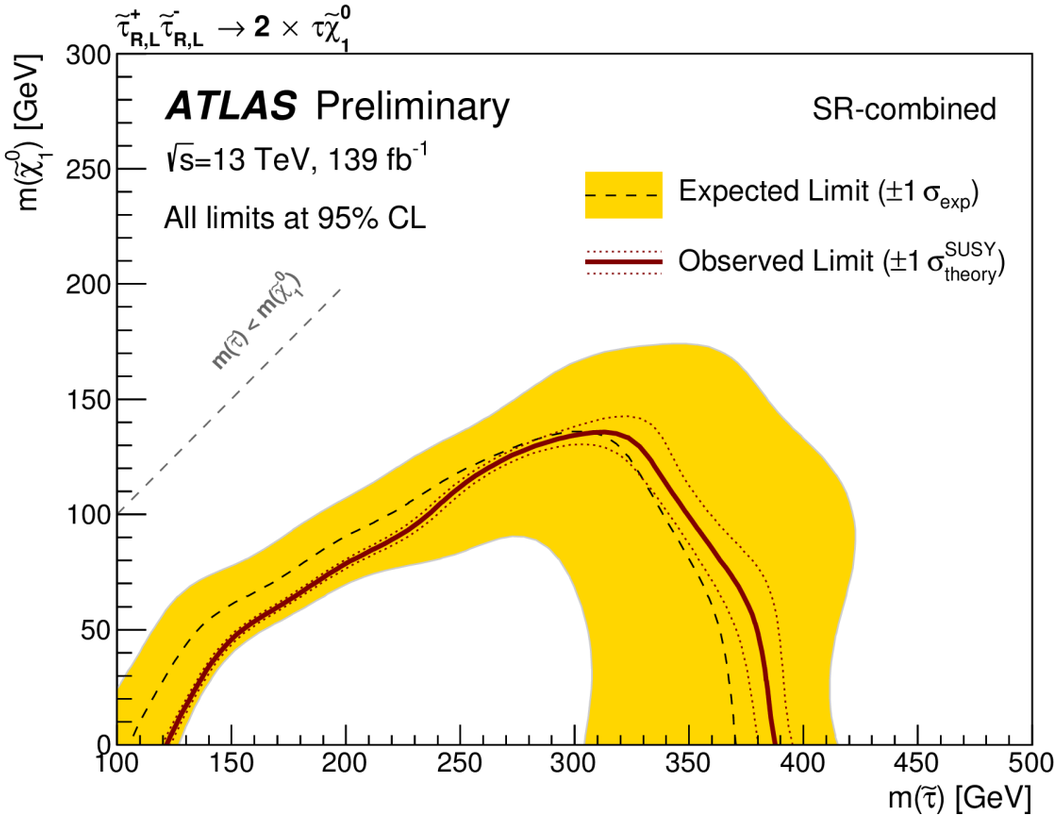
“The most motivated under-explored use of ML”

No person-power for the Run-2 effort

Direct Stau: first dedicated analysis at LHC



- **First LHC constraint on direct stau**
- Low E_T^{miss} SR: di-tau trigger
- Large E_T^{miss} SR: E_T^{miss} trigger+di-tau trigger
- hadronic tau only



Second wave R&D now ongoing

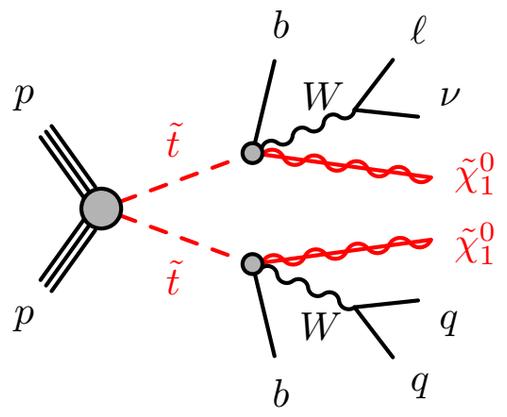
- Targeting compressed region, MVA techniques
- Additional tau decay channels: lep-had and lep-lep
- Addition models involving tau, and also stay from VBF

Stop 1L 3 body

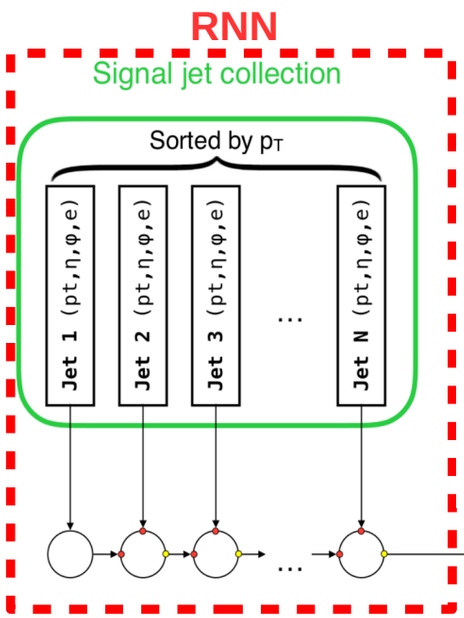
ATLAS-CONF-2019-017

Signature

Compressed $\tilde{t} - \tilde{\chi}_1^0$

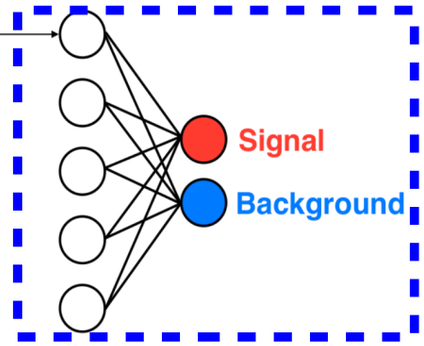


Analysis developments: ML algorithm based on two related techniques



Recurrent Neural Network (RNN)

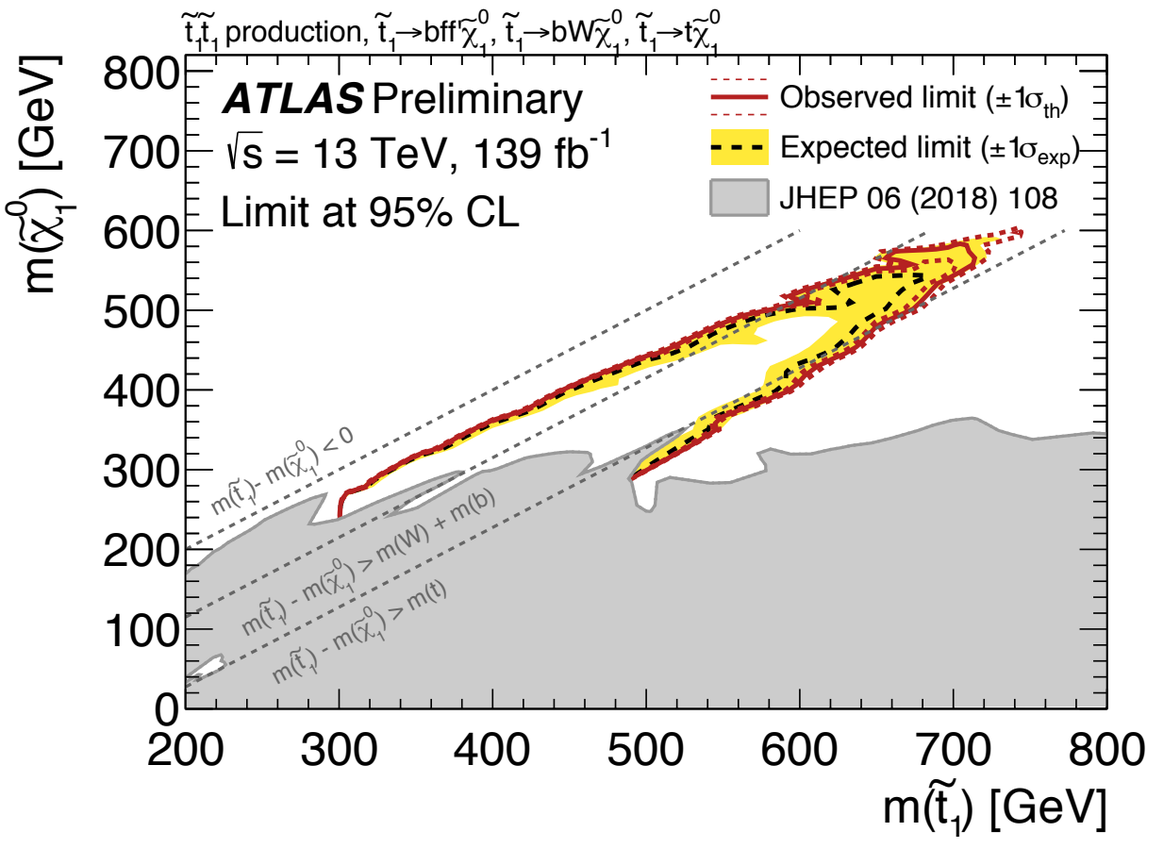
- Process inputs of variable length
- All jet 4-vectors
- Jets from SUSY and SM differ in multiplicity and kinematics



Neural Network (NN)

- output of RNN used as input to NN
- Together with lepton kinematics, MET, m_T

Impressive sensitivity improvement in compressed region!



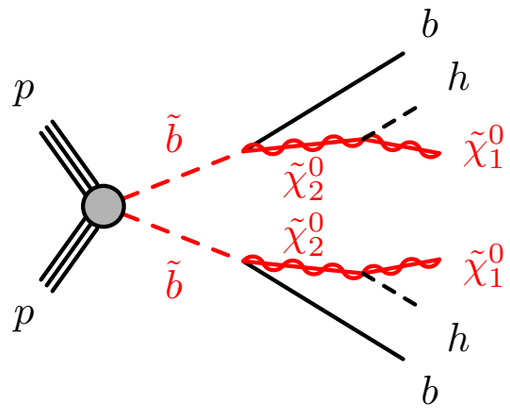
- CONF note currently undergoing metamorphosis into paper

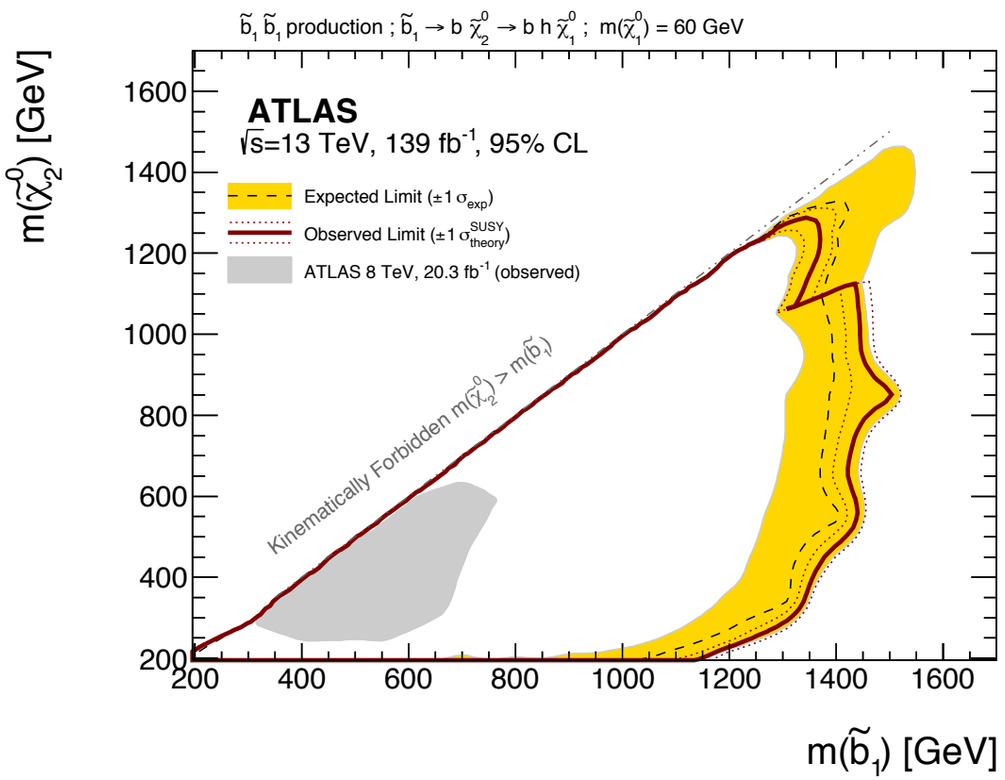
Submitted: bottom squarks and Higgs bosons

arxiv:1908.03122

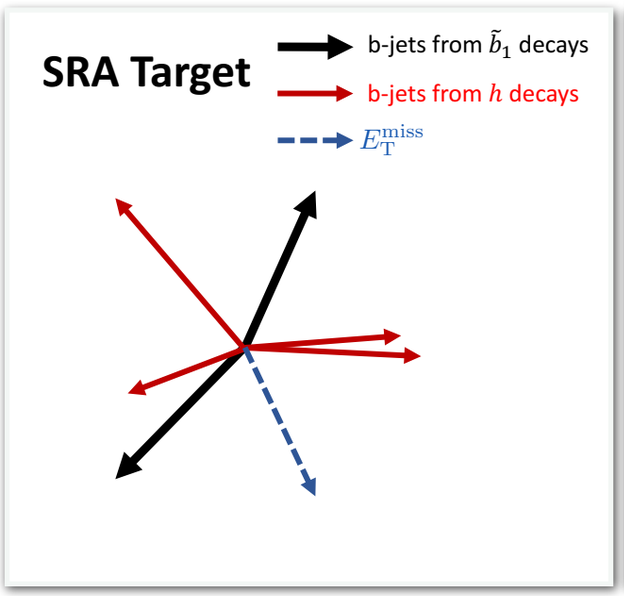
Signature

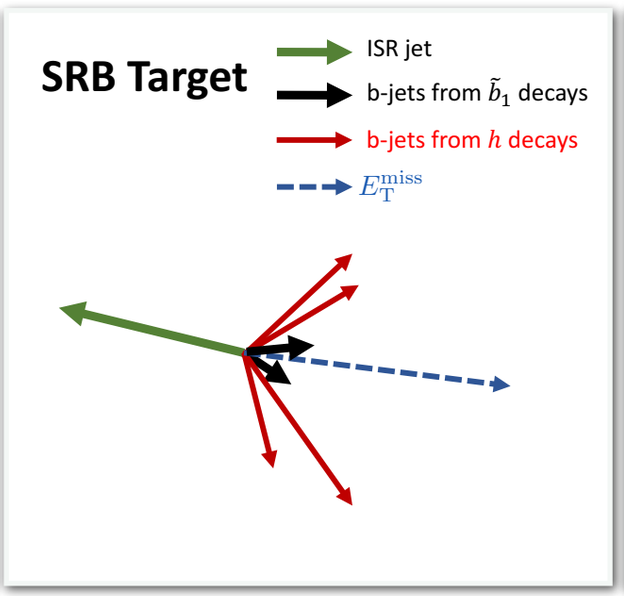
Jets, MET
no leptons

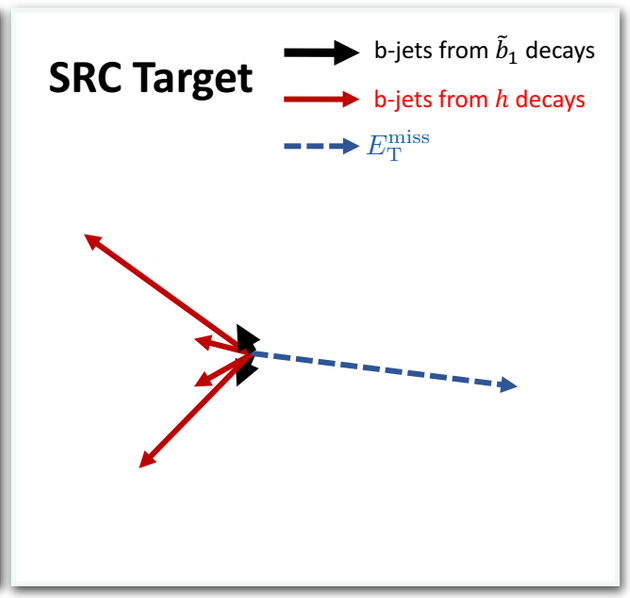




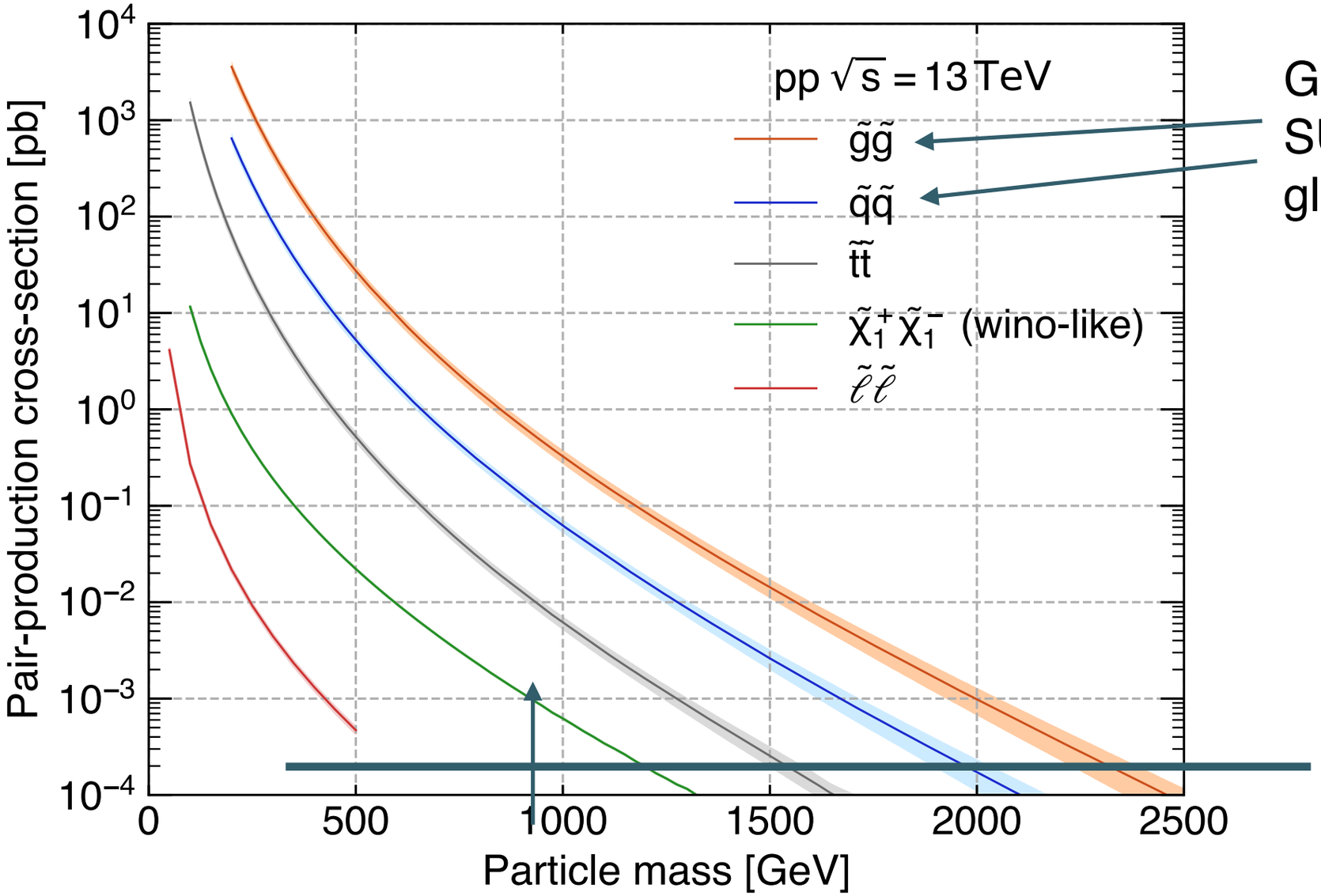
- Made use of METSig/m_{eff} multi-bin fits
- Would benefit from high pT b-tagging







The scale of the problem



Gluino $\tilde{g}$ and squark : SUSY partners of the gluon and quarks

~10 events in Run-2 dataset

- Each sparticle has different decay phenomenology, giving a rich set of signatures
- ATLAS has dedicated groups targeting each of these production mechanisms

tt+MET 0L

Variable	SRA-TT	SRA-TW	SRA-T0
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$		
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 250 GeV		
signal ℓ	0		
p_{T}^{ℓ}	–		
additional baseline ℓ	0		
$m(\ell, \ell)$	–		
$p_{\mathrm{T}}(\ell, \ell)$	–		
$\mathrm{N_{jets}}$	≥ 4		
$p_{\mathrm{T}}^{j_2}$, including $E_{\mathrm{T}}^{\mathrm{miss}}$ and non-Z lepton	> 80 GeV		
$p_{\mathrm{T}}^{j_4}$, including $E_{\mathrm{T}}^{\mathrm{miss}}$ and non-Z lepton	> 40 GeV		
$\mathrm{N_{b-jet}}$	≥ 2		
$\mathrm{m}(J_1; \mathrm{R} = 1.2)$	> 120 GeV		
$\mathrm{m}(J_2; \mathrm{R} = 1.2)$	> 120 GeV	[60, 120] GeV	< 60 GeV
$\mathrm{b-tagged}(J_1; \mathrm{R} = 1.2)$	✓		
$\mathrm{b-tagged}(J_2; \mathrm{R} = 1.2)$	✓	–	
$\mathrm{m}(J_1; \mathrm{R} = 0.8)$	> 60 GeV		
$m_{\mathrm{T}}^{b,\mathrm{min}}$	> 200 GeV		
m_{T2,χ^2}	> 450 GeV		
Object based $E_{\mathrm{T}}^{\mathrm{miss}}$ sig.	$> 25\sqrt{\mathrm{GeV}}$		
$\Delta R\,(b_1, b_2)$	> 1.0	–	
τ veto	✓