Searches for SUSY in 2 and 3 lepton final states with ATLAS and SUSY global fits with GAMBIT

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Presented at CPPM

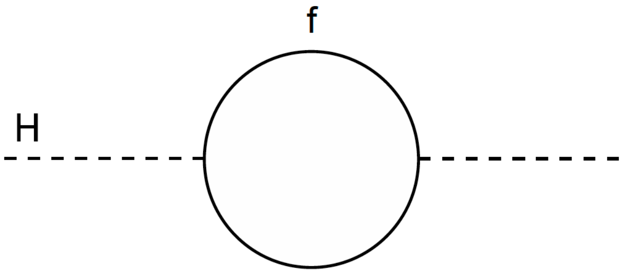
Outline

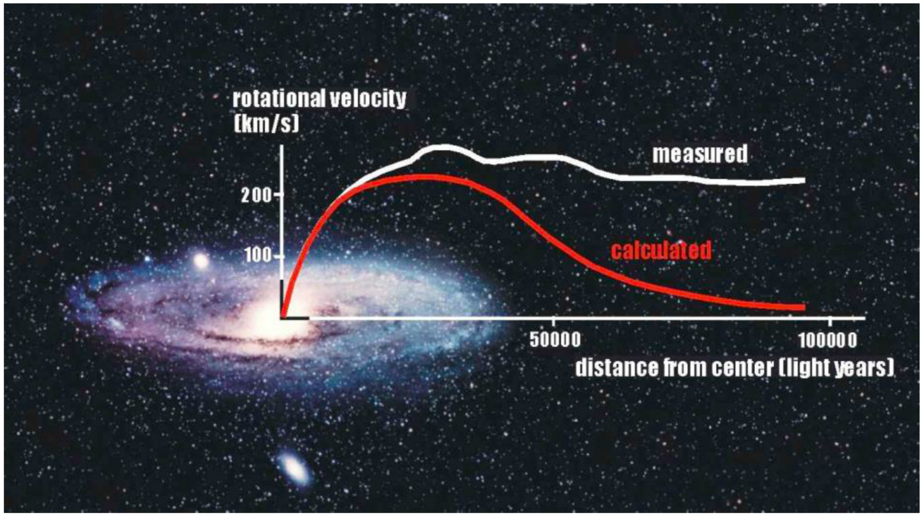
The physics program of ATLAS at the LHC

- New Physics (in particular SUSY) searches
- Status of Standard Model measurements
- Techniques we use for some searche
  - *An introduction to Recursive Jigsaw Reconstruction (RJR)*
- Application of RJR to searches for Electroweak SUSY with ATLAS data and recent results
- Constraints on EW-MSSM with GAMBIT
- Summary

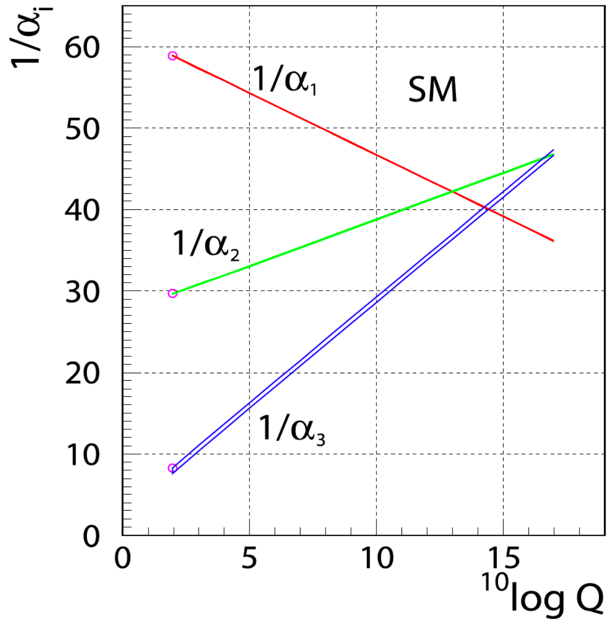
Open SM Questions

- **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



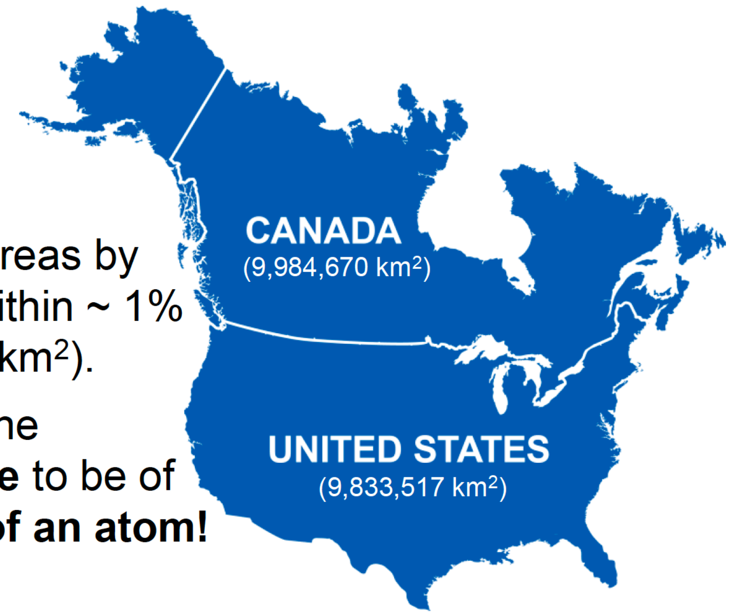
- **Grand unification:** Standard Model coupling constants do not unify at high scales.
  → SM does not imply a Grand Unified Theory

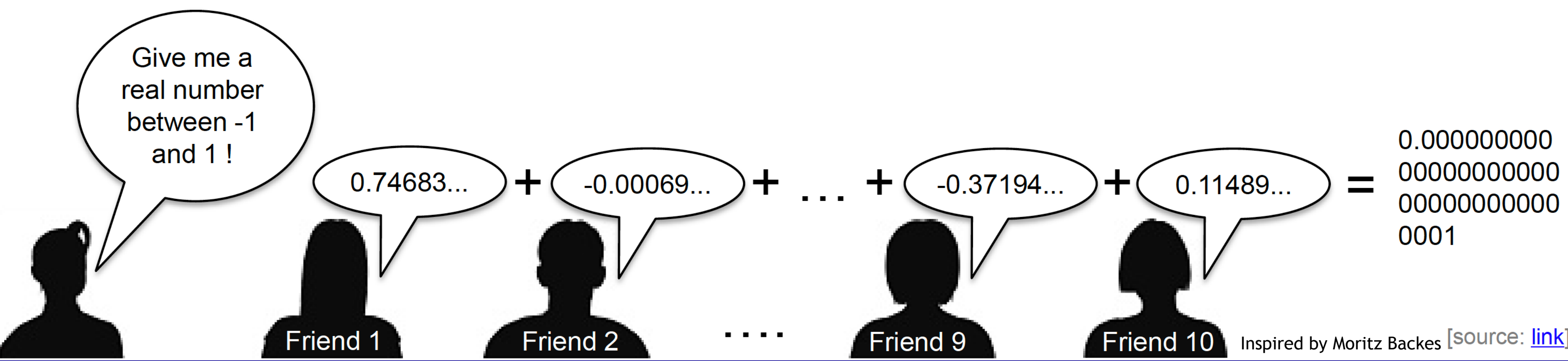
Analogies paint the picture

SM has a snowman's chance in hell

Surface areas by chance within ~ 1% ($151{,}153\ km^2$).

Imagine the **difference** to be of the **size of an atom!**





Inspired by Moritz Backes [source: link]

Analogies only for illustration. No liability for quantitative interpretation.

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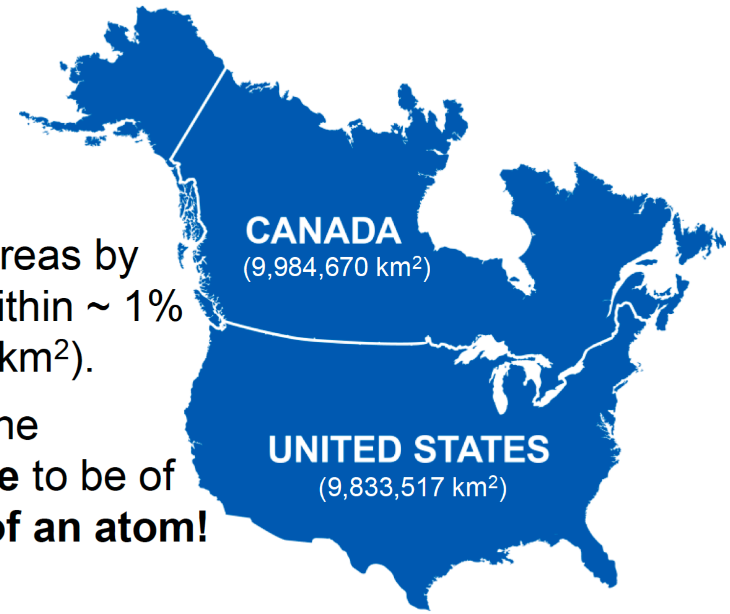
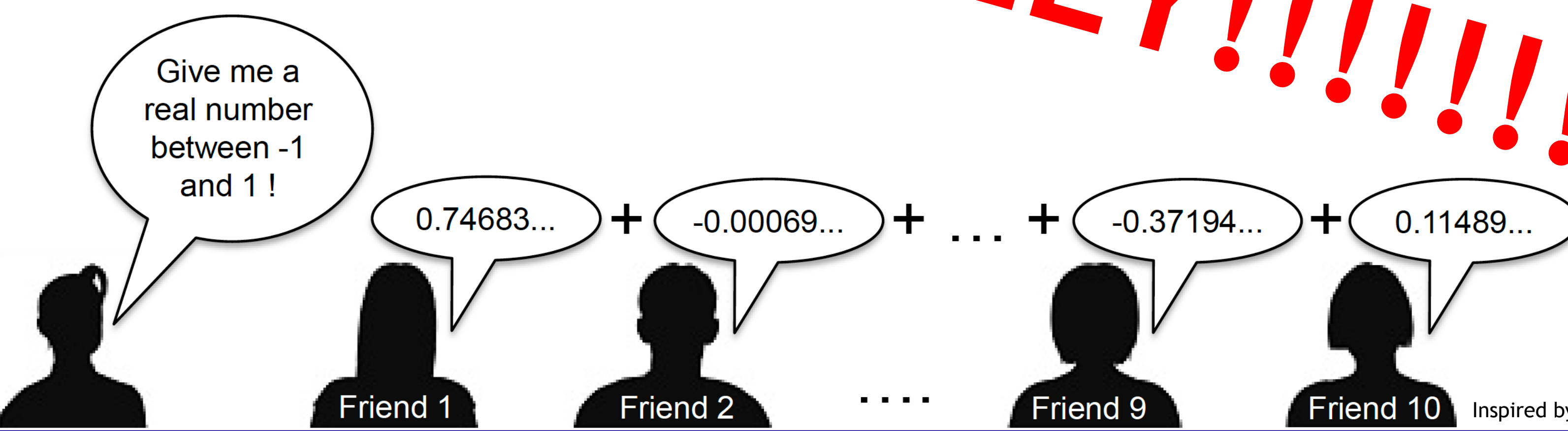


UNLIKELY!!!!!!!



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Inspired by Moritz Backes [source: link]

Analogies only for illustration. No liability for quantitative interpretation.

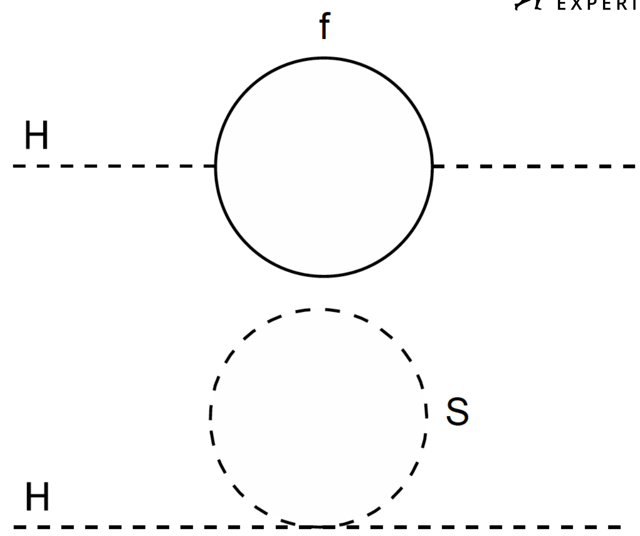
- Fundamental symmetry between fermions and bosons introducing a set of new partner particles to the SM particles with half-spin difference.

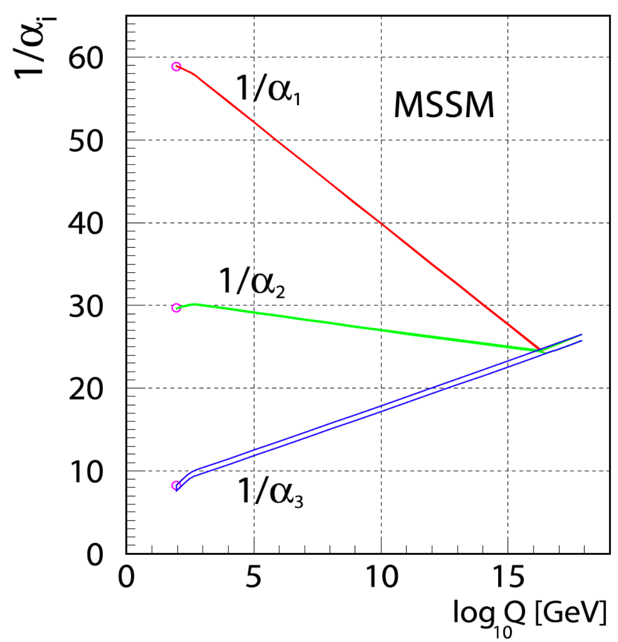
✓ Opposite-sign loop corrections from SUSY particles. Quadratic divergencies cancel. → No (little) fine-tuning.

✓ 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

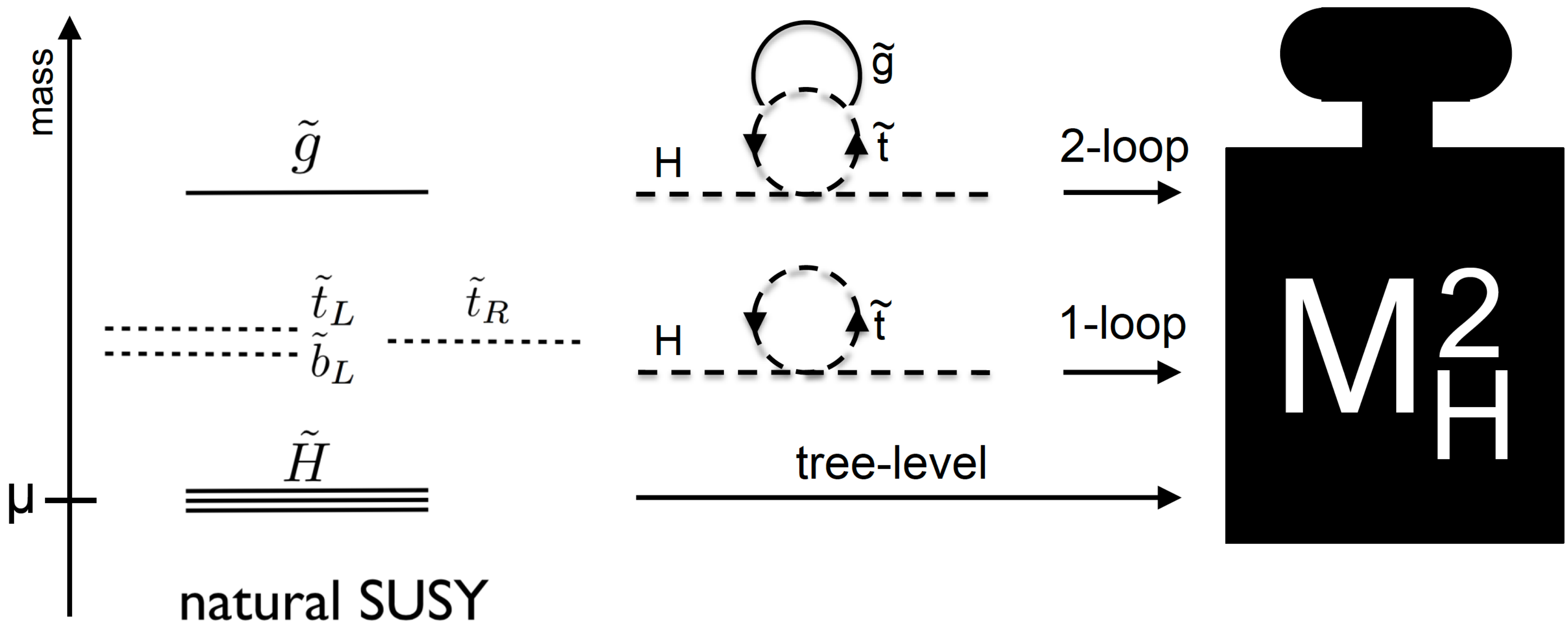




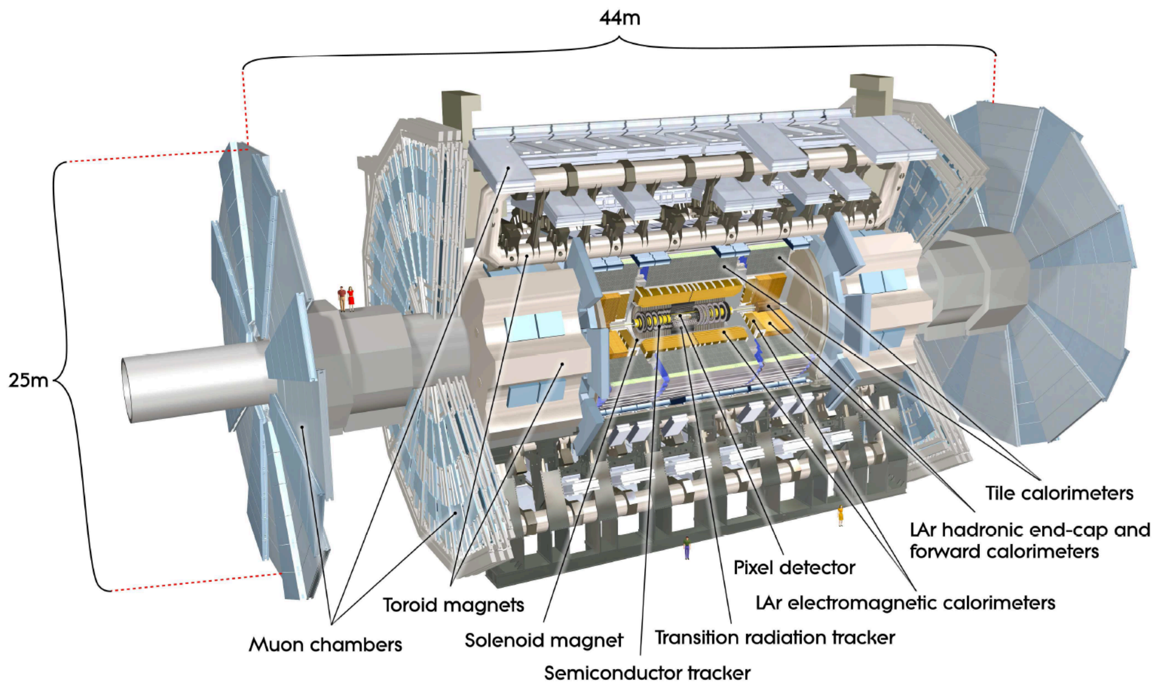
We need SUSY!

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



The ATLAS experiment



- Solenoidal magnetic field (2T) in the central region – momentum measurement
- Energy meas. down to ~1° to the beamline

- High resolution silicon detectors
- Granular EM and Had calorimetry
- Independent muon spectrometer

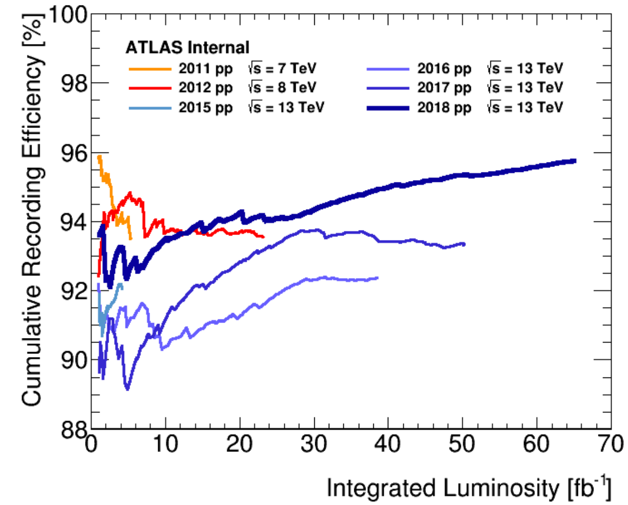
- Good coverage permits reconstruction of missing transverse momentum through object reconstruction

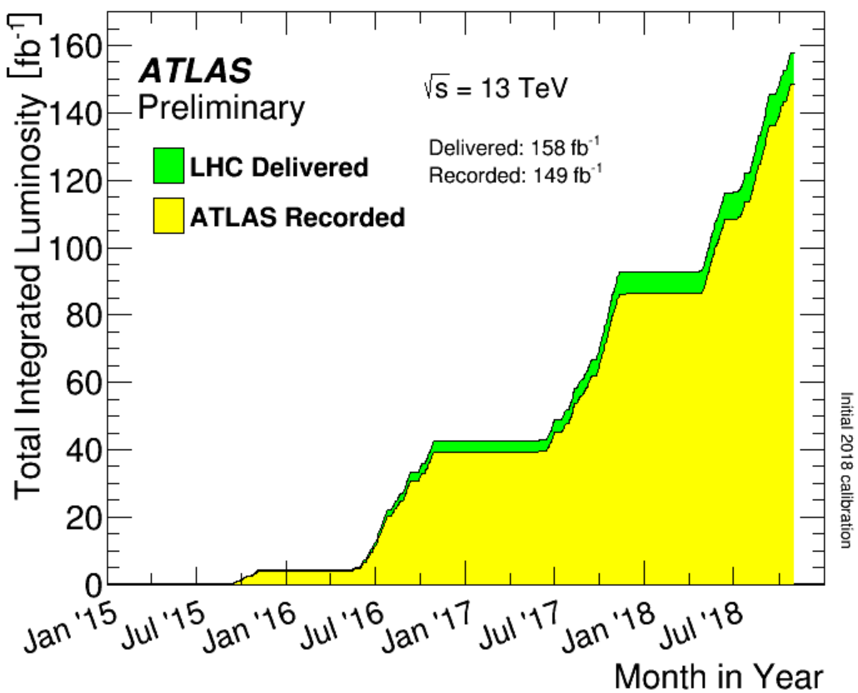
Data Samples – Run 2

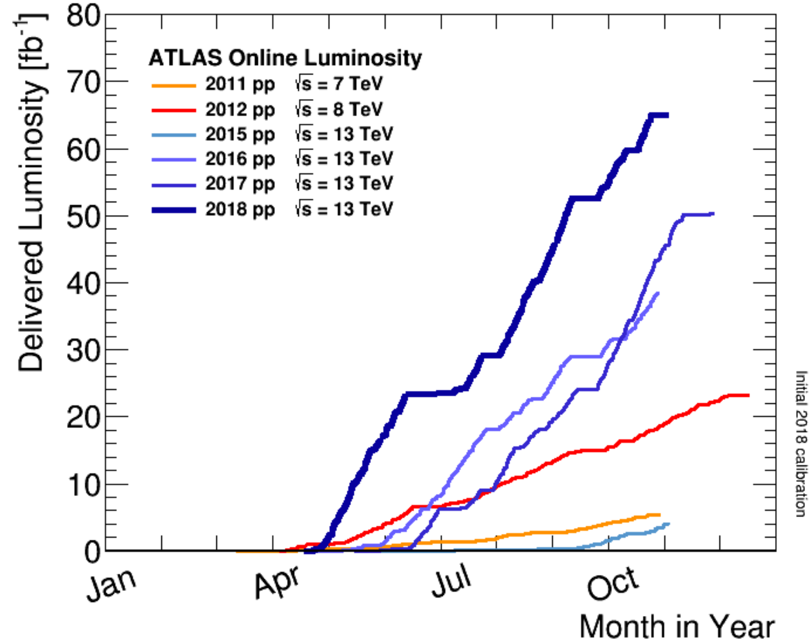
Exceptional LHC performance in 2015-2018
Improved luminosity and recording efficiency throughout the run.

Integrated ~150 fb^{-1} at end of Run2 pp collisions

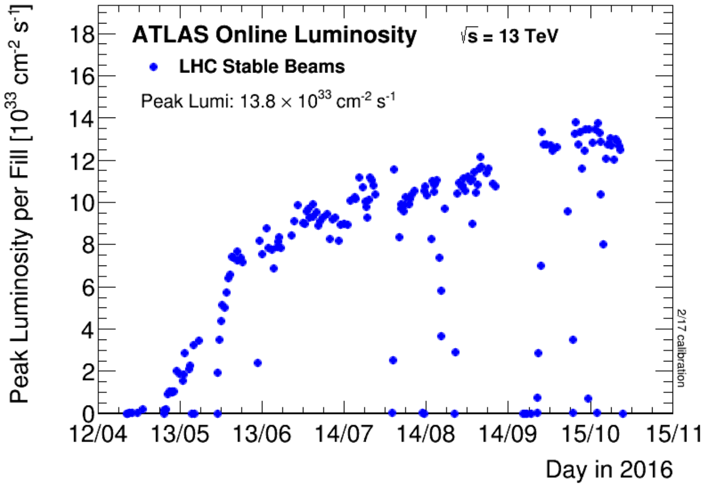
End of Run2 data taking in last couple of weeks





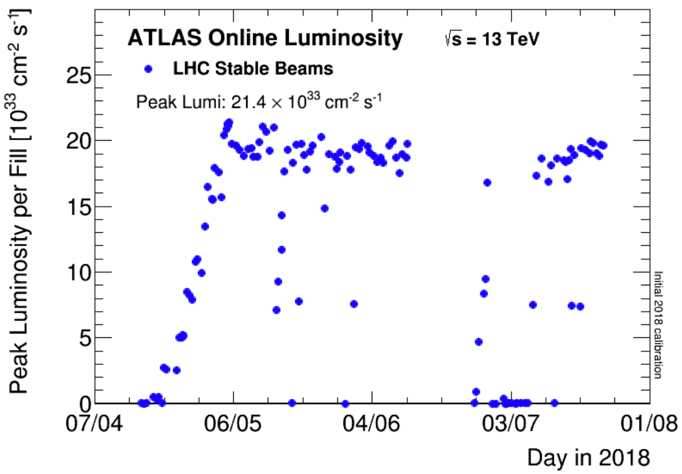


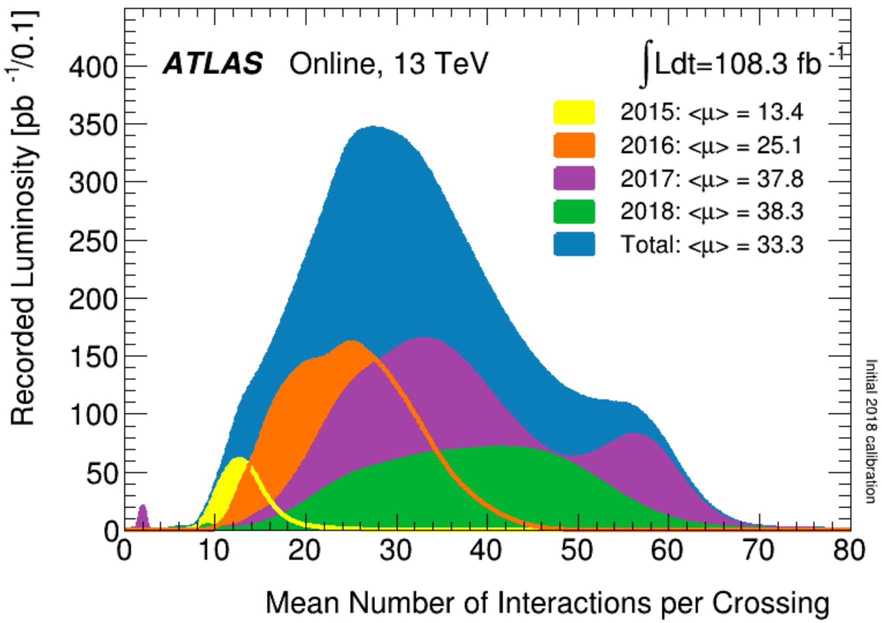
LHC: More than nominal Luminosity



LHC design: $L = 1.0 \times 10^{34}\ cm^{-2}\ s^{-1}$
Achieved (2016): $L = 1.4 \times 10^{34}\ cm^{-2}\ s^{-1}$
Achieved (2018): $L = 2.1 \times 10^{34}\ cm^{-2}\ s^{-1}$

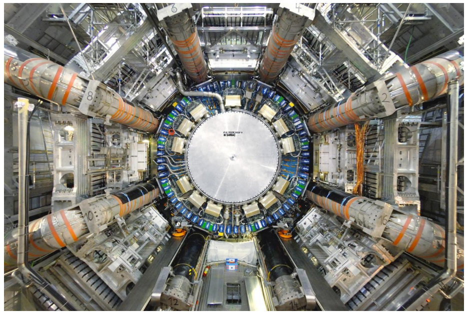
More lumi makes for a more challenging environment to extract results of interest

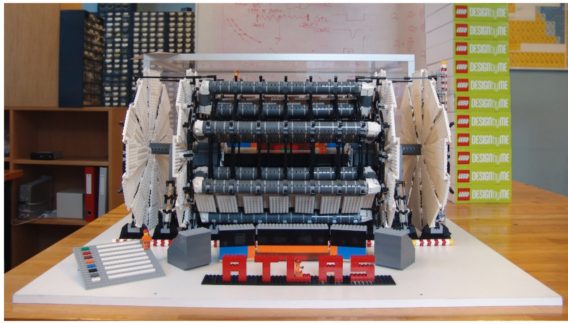




Data analysis

MC analysis



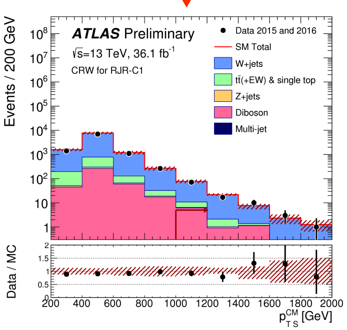


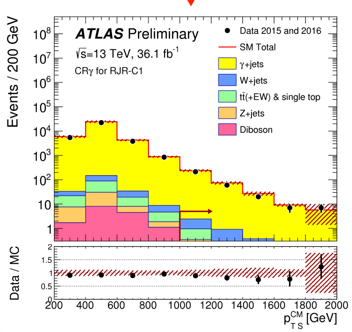
Make events → Measure events

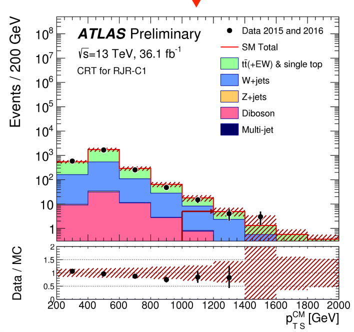
Generate events → Simulate events

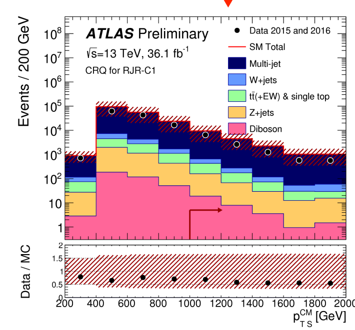
Select Objects/Data of Interest

Make Plots….measure something!

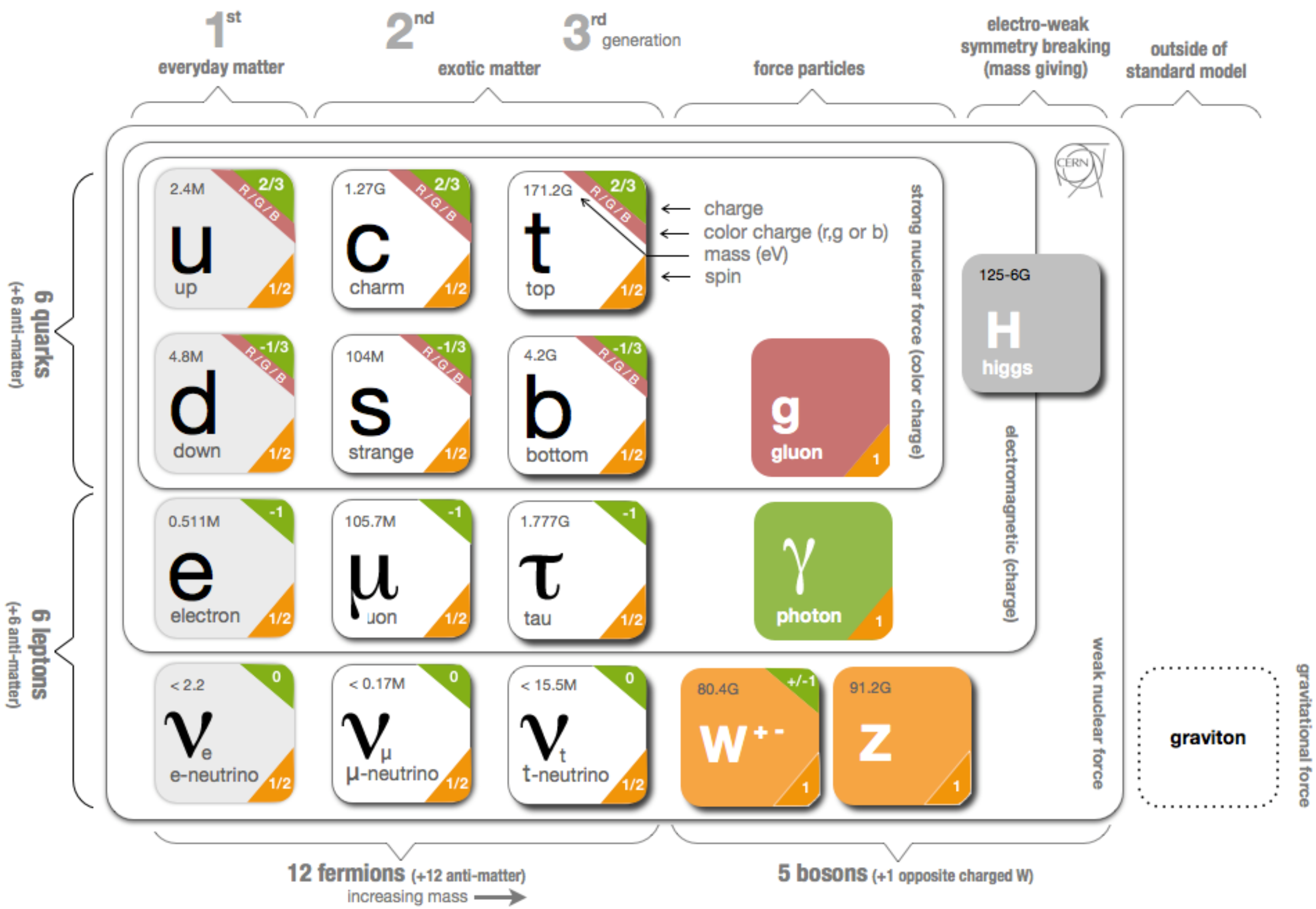




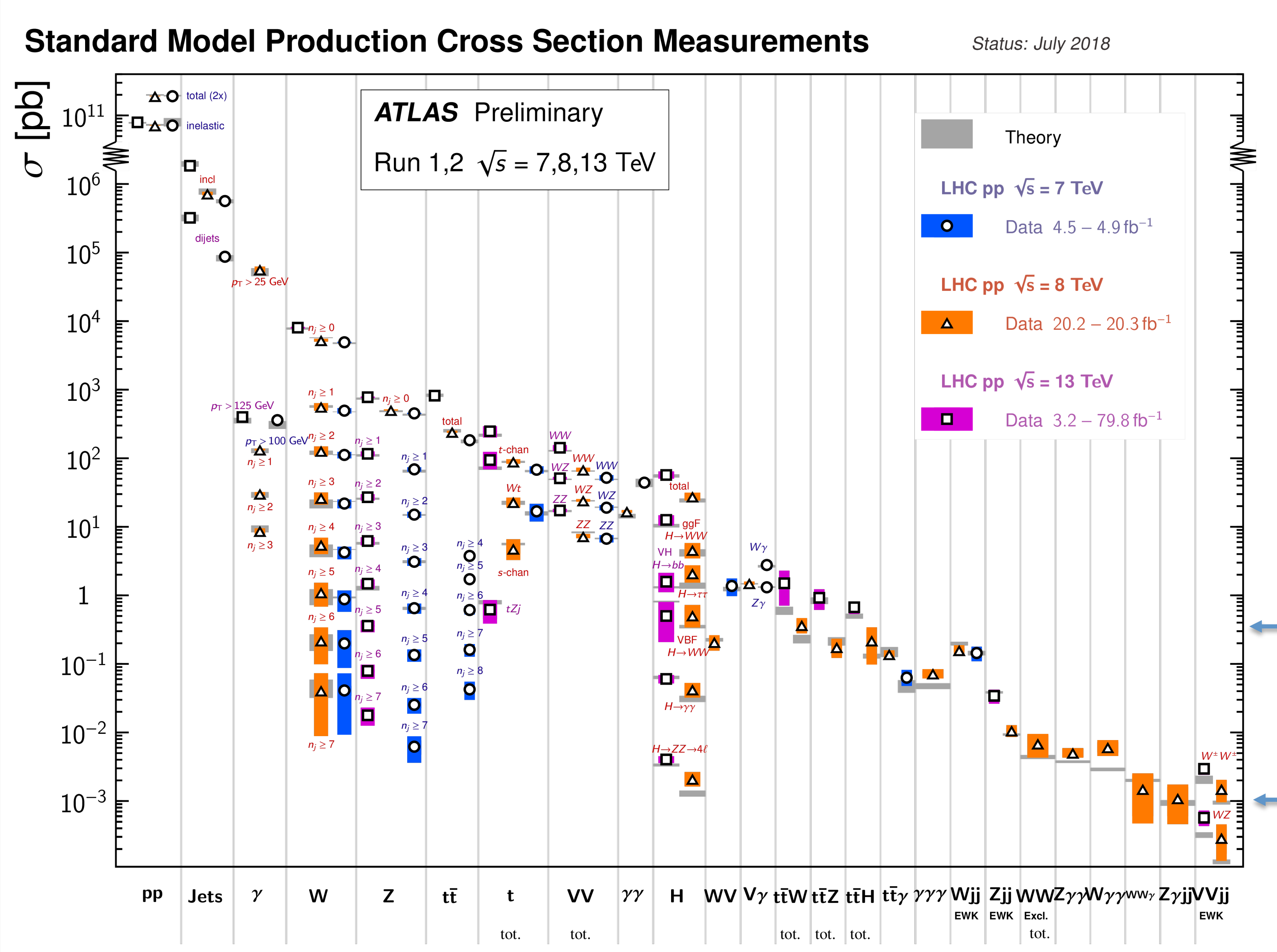




Measuring the Standard Model with ever increasing accuracy



SM - Backgrounds to SUSY searches



1 TeV gluino*

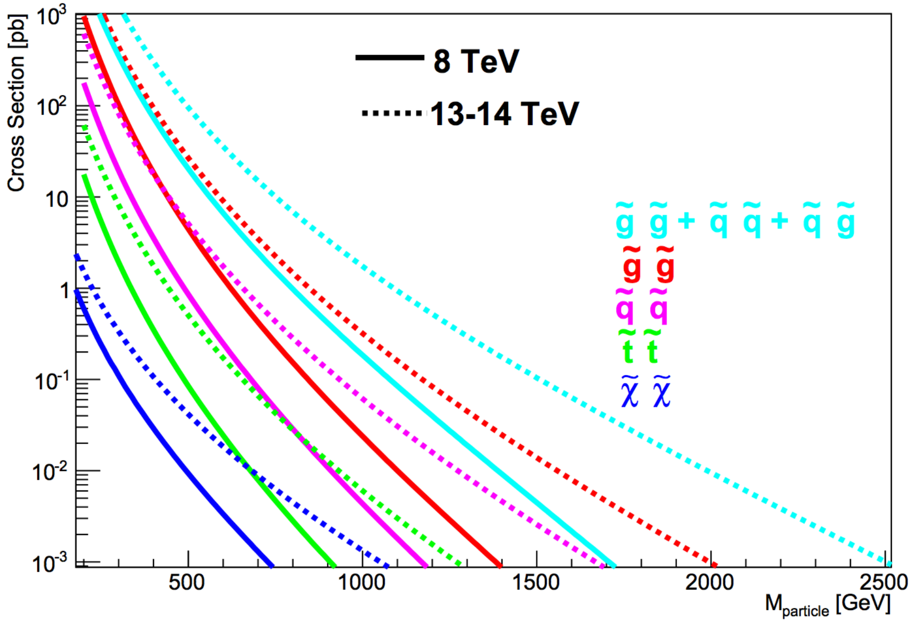
2 TeV gluino*

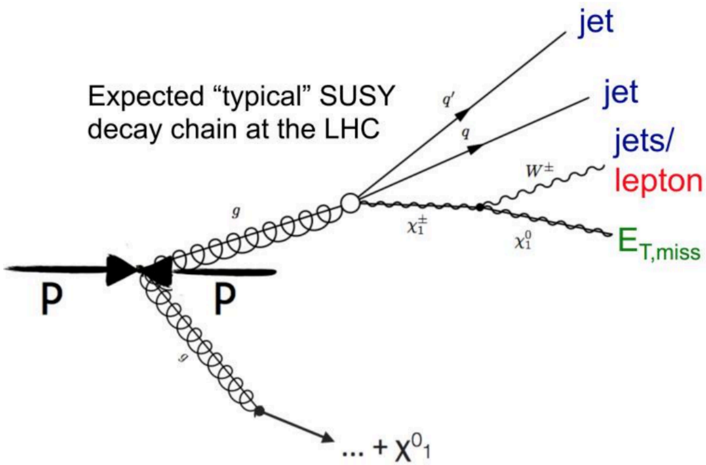
HOWTO search for SUSY

If SUSY particles are accessible at LHC energies

If R-Parity is conserved (RPV and Long-lived SUSY scenarios would be a different talk entirely)

- Pair-production via strong/EW interaction
- Direct or cascade decays to stable LSP
- Potentially many high pT SM objects and large missing transverse momentum





Search strategy for LHC Run2:

- Looks for gluinos/squarks decaying to jet enriched final states due to large XS
- ***Then focus on EWKino searches as they become more accessible and sensitive***

HOWTO search for SUSY

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

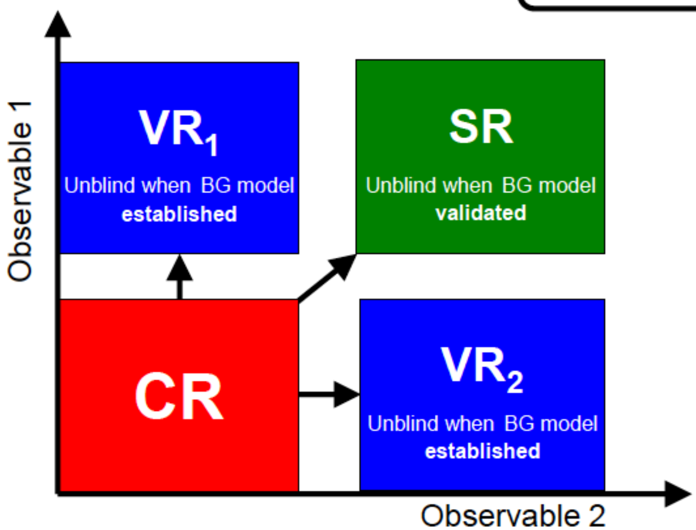
- Dominant processes:
  - MC normalised to data in process-enhanced control regions (**CR**s)
  - Extrapolation to validation regions (**VR**s) & **SR**s
- Subdominant processes: Pure MC predictions

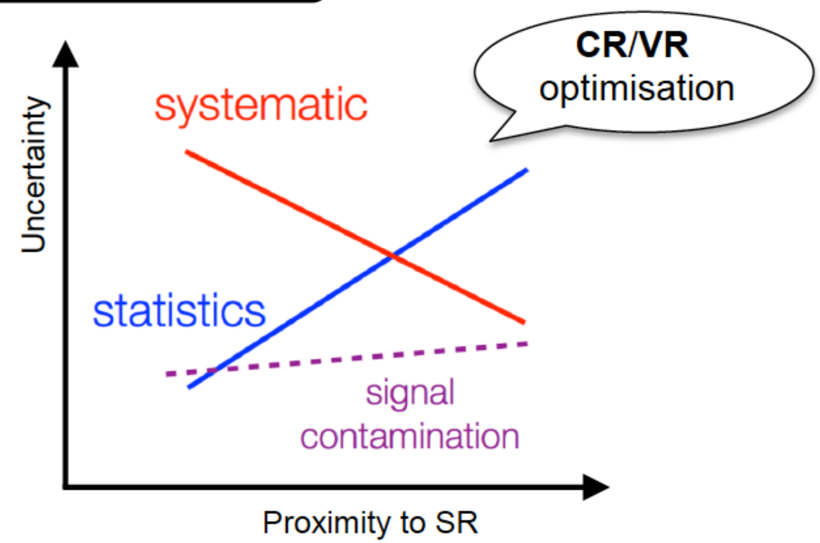
Reducible Backgrounds

- 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)





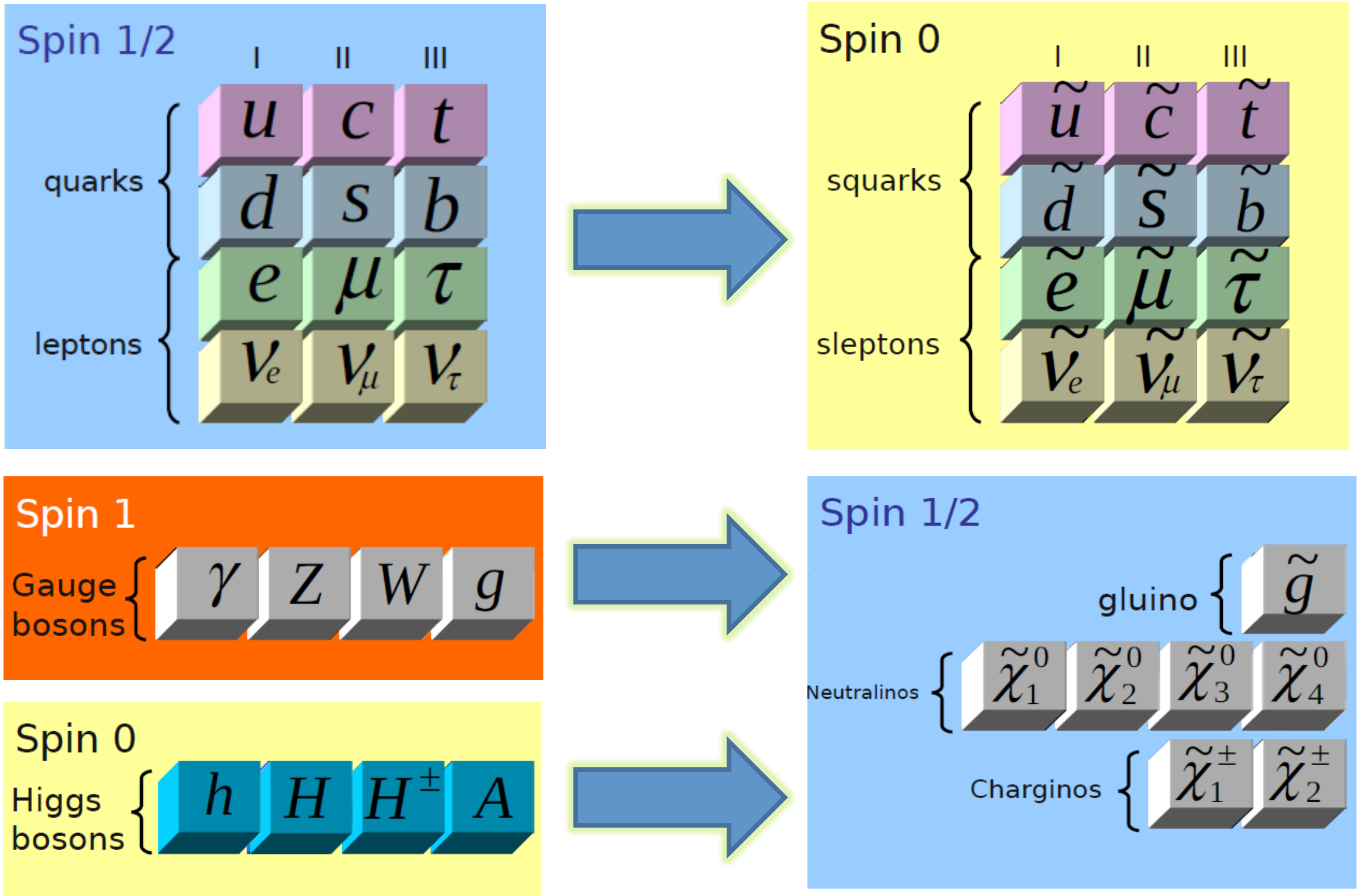
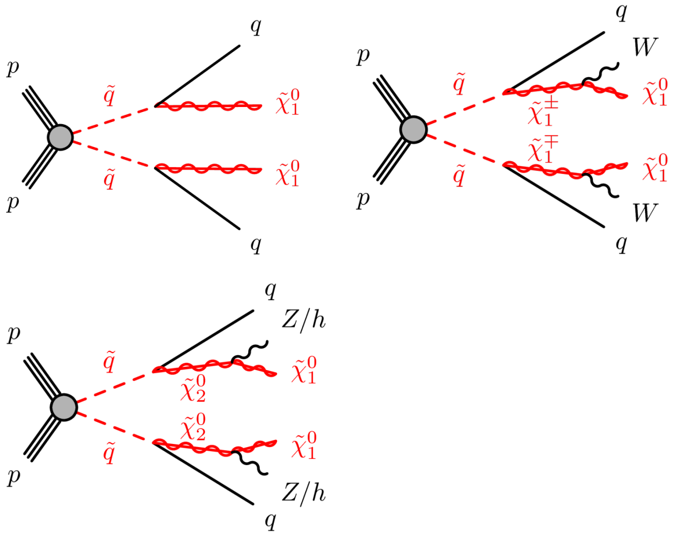


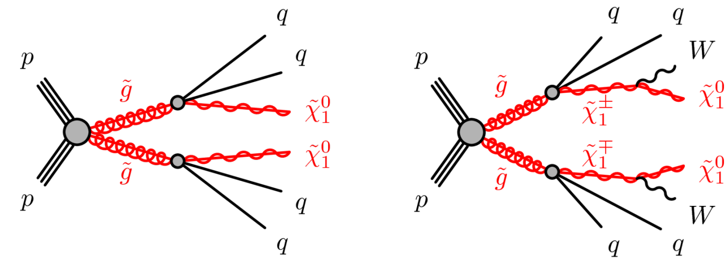
illustration by M-H Genest

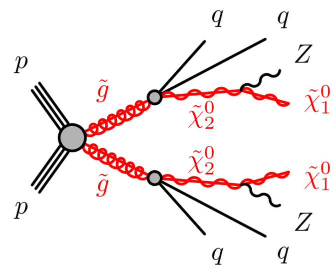
SUSY, this is what we often “claim” we’re searching for…

ATLAS EXPERIMENT

Squark and Gluino mediated light jets

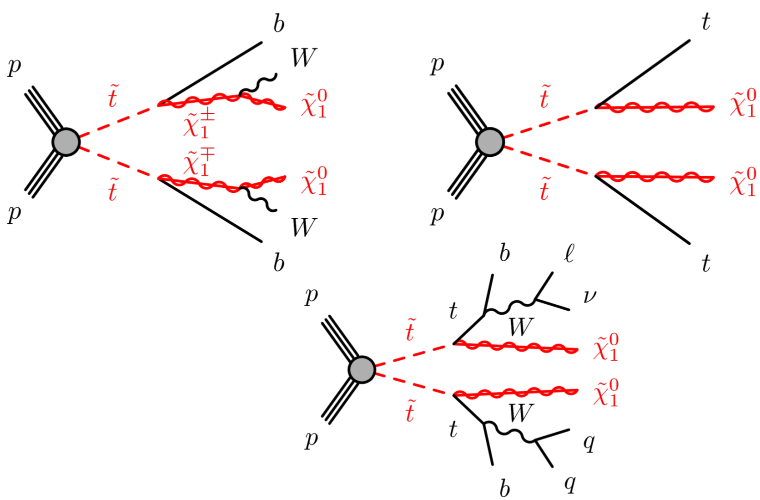




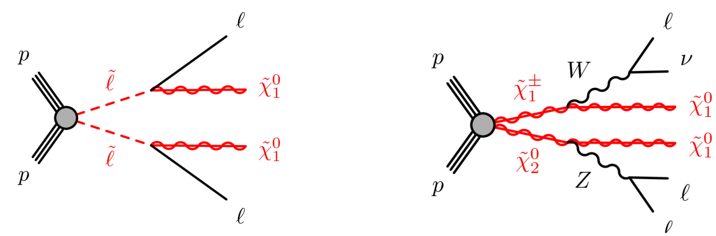


+ many more

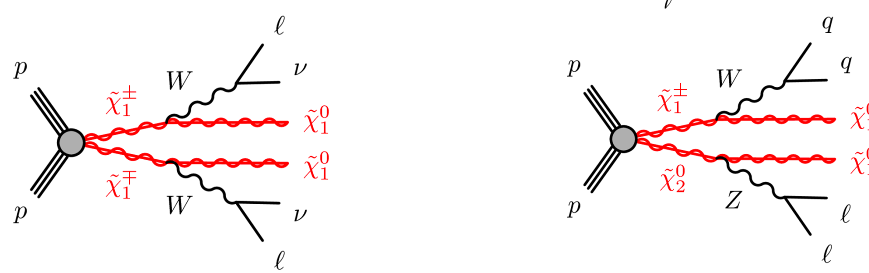
3rd generation squarks



EWKino and slepton production



+ many more



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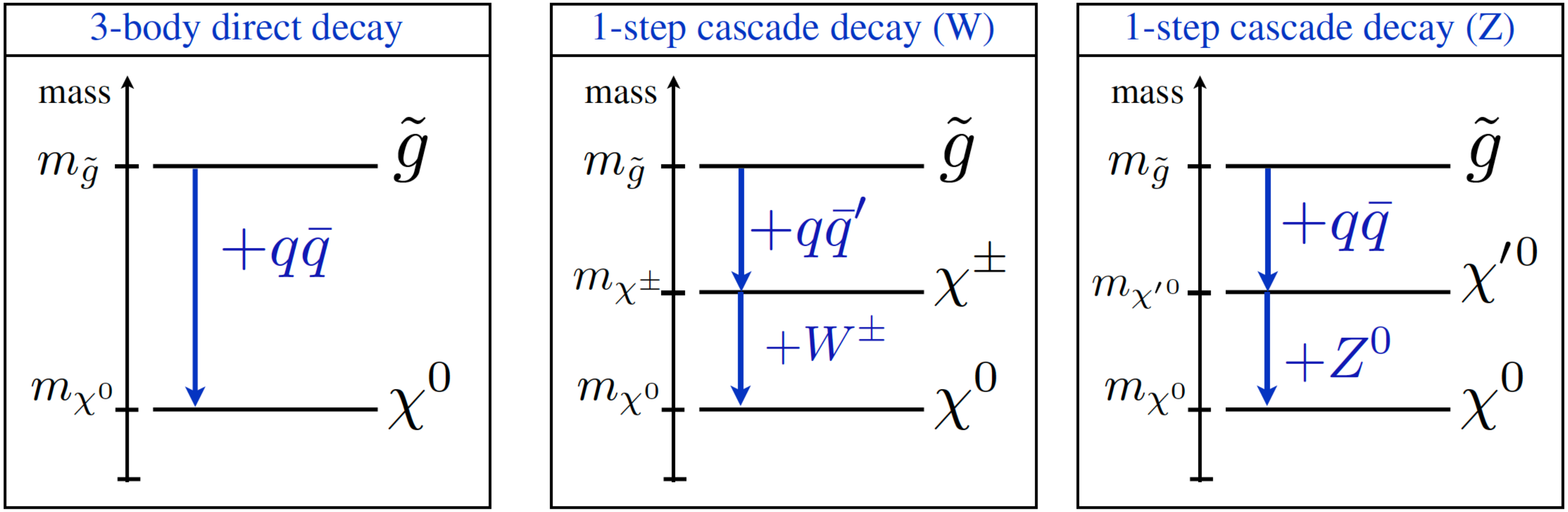
CoEPP ARC Centre of Excellence for Particle Physics at the Terascale

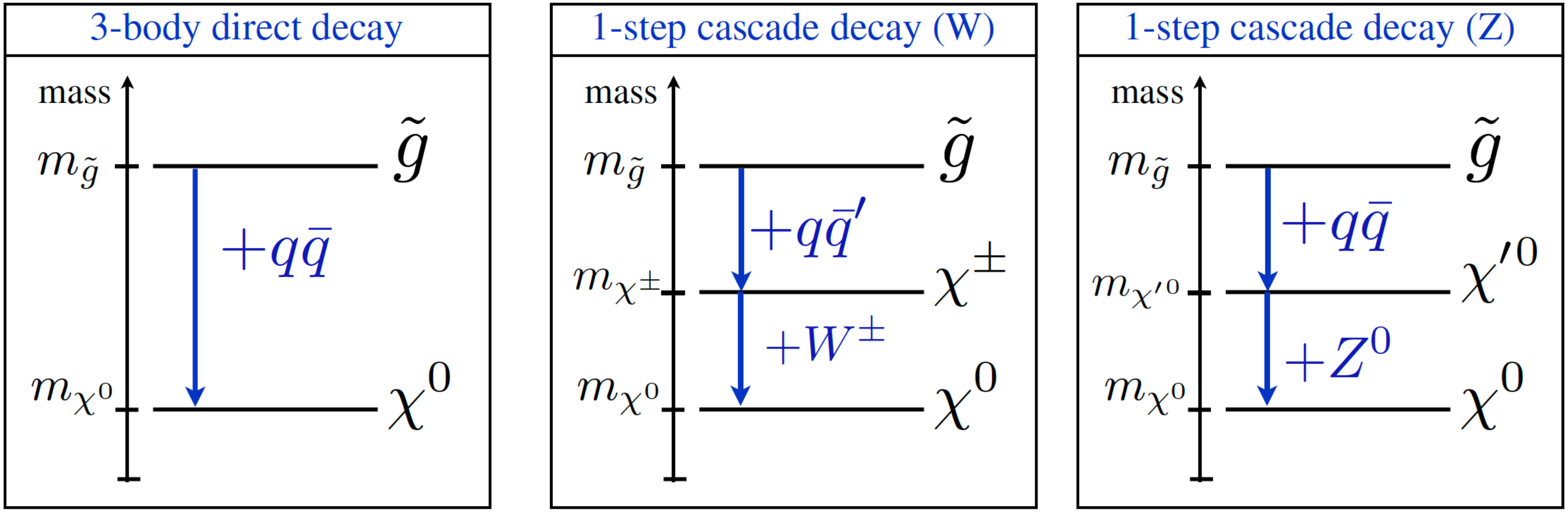


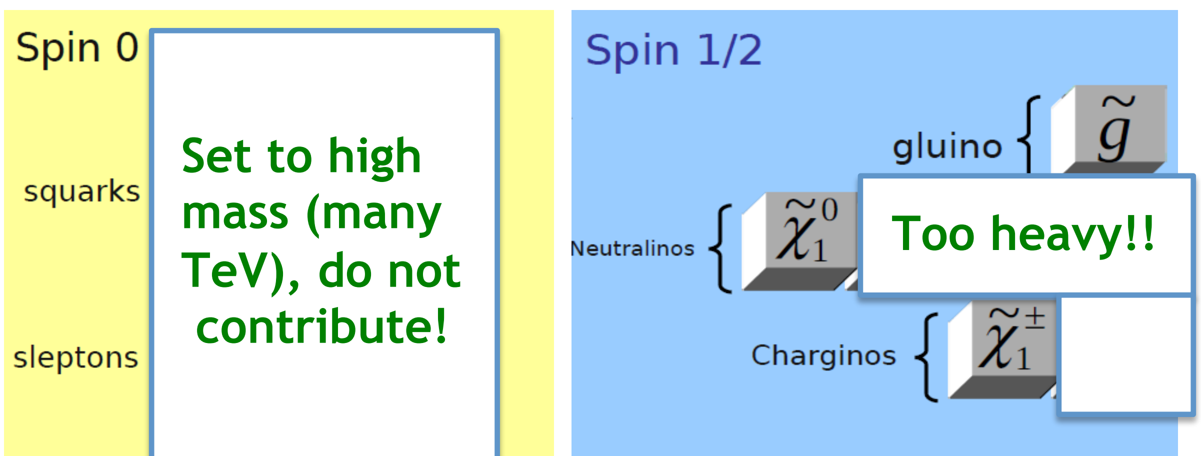
D. Alves et al J. Phys. G: Nucl. Part. Phys. 39 (2012) 105005

The way in which we design, *and optimize*, searches at LHC…..

…..not just an organising principle, this is what we search for!

Simplified Models





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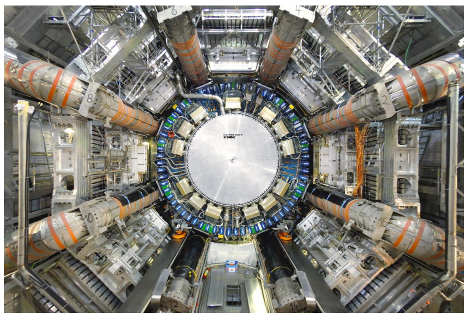
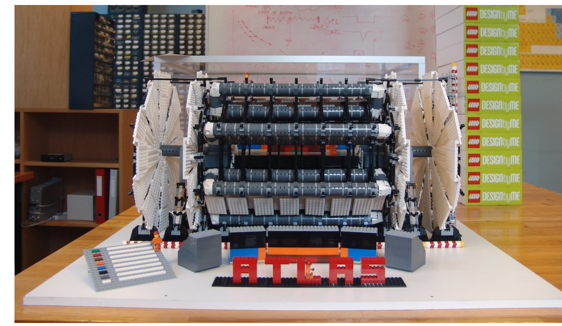




Make events

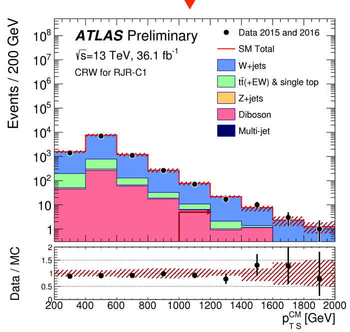
Measure events

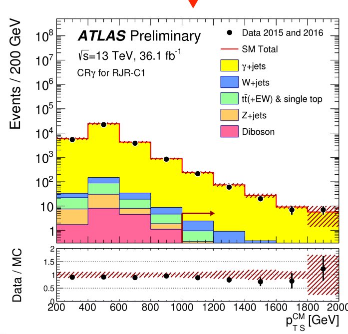
Generate events

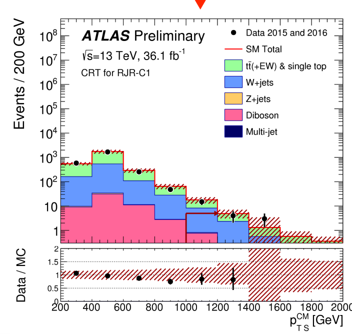
Simulate events

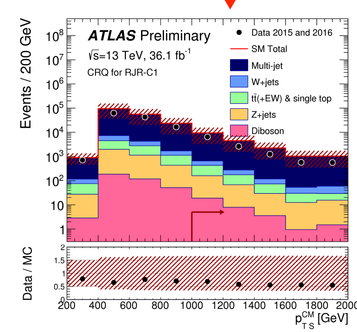
Choose Observables

Make Plots….measure something!









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

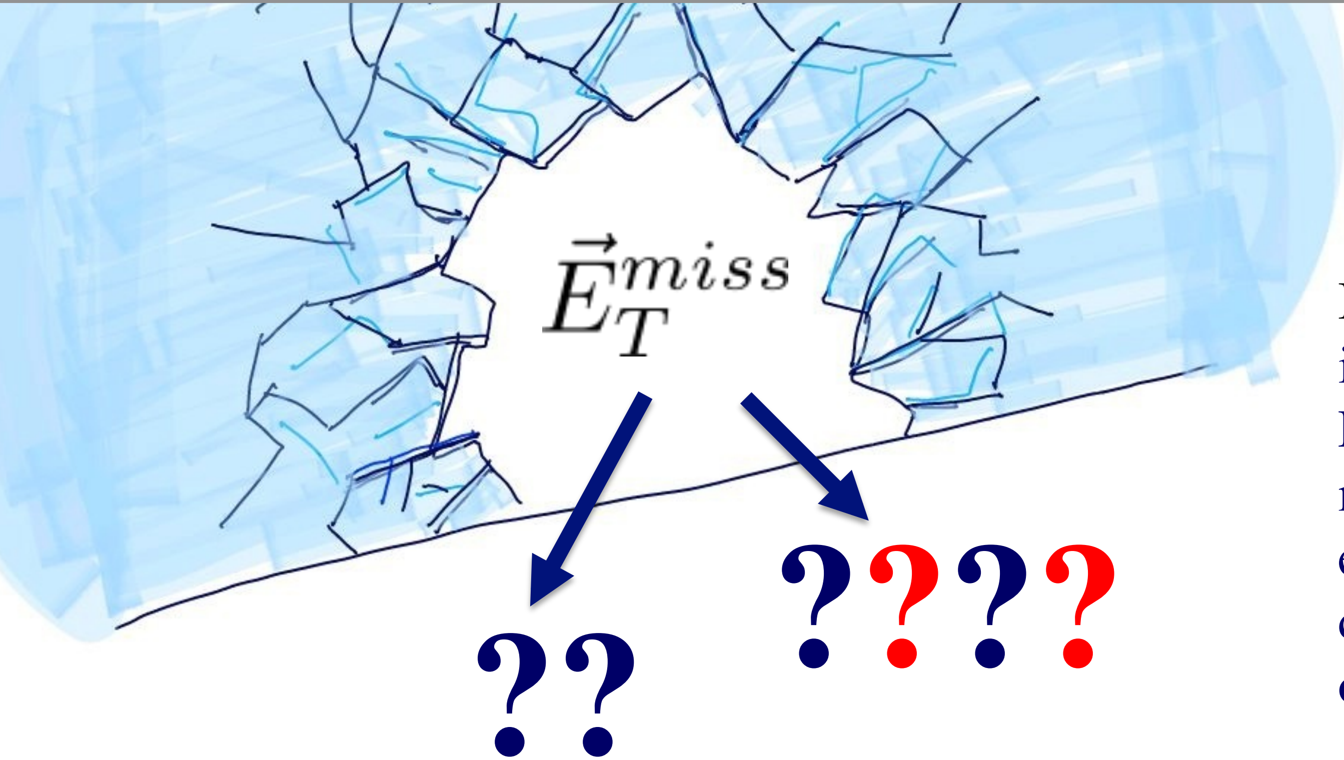
Sensitivity to New Physics

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

Missing Transverse Momentum

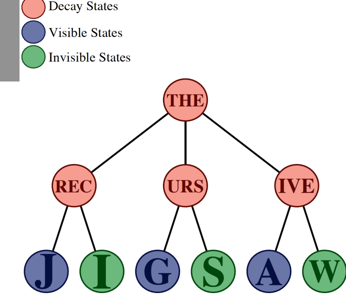


$$\vec{E}_T^{miss} \equiv -\sum_i^{\text{calo}} \vec{E}_T^{\,i}$$

Infer presence of weakly interacting particles in LHC events by looking for missing transverse energy…..may be composed of one or more objects, which may differ

We can learn more by using other information in an event to contextualize the missing transverse momentum ⇒
multiple weakly interacting particles?

New(ish) approach to reconstructing open final states



The strategy is to transform observable momenta iteratively ***reference-frame to reference-frame***, traveling through each of the reference frames relevant to the topology

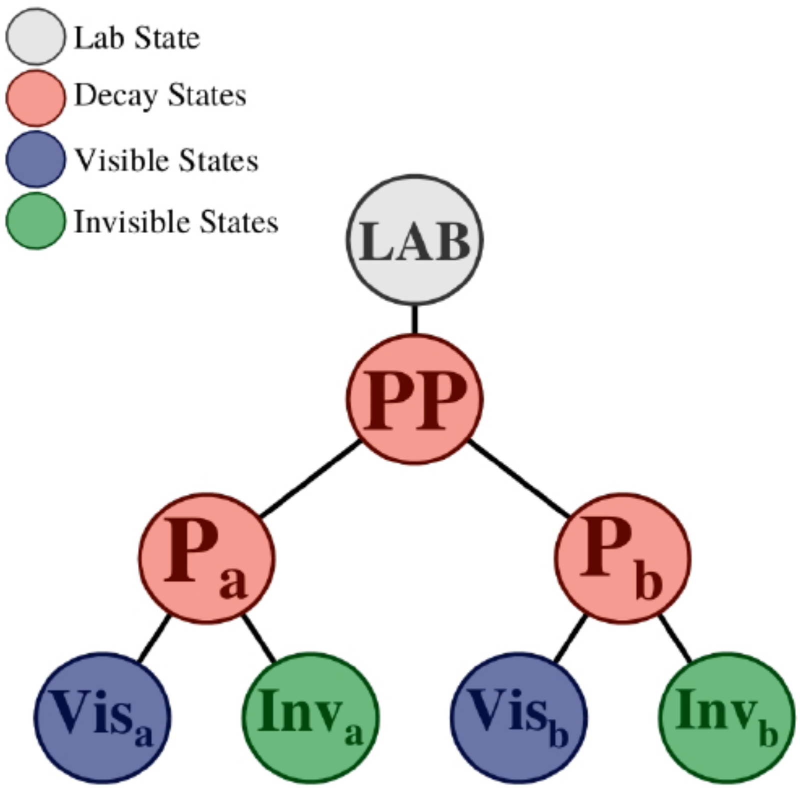
Recursive: At each step, specify only the relevant d.o.f.related to that transformation ⇒ apply a *Jigsaw Rule*.

Repeat procedure recursively according to particular rules defined for each topology (the topology relevant to each reference frame)

Jigsaw: Each of these rules is factorizable/customizable/interchangeable like (strange) jigsaw puzzle pieces

> Rather than obtaining one observable, get a *complete basis* of useful observables for each event

- Original method to **reconstructing** final states with weakly interacting particles.
- Transform observable momenta reference-frame to reference-frame
- **Jigsaw rules**: specify the unknown d.o.f. relevant to the transformation (customizable-interchangeable like jigsaw puzzle pieces)
- The procedure is repeated **recursively**, travelling through each of the reference frames relevant to the topology



- Rather than obtaining one observable, get a complete basis of useful variables *diagonalized* with physical observable: angles, energies, masses ...

PJ, C. Rogan, Phys. Rev. D96 112007 (2017)
PJ, C. Rogan, M. Santoni, Phys. Rev. D95 035031 (2017)
M. Santoni, "Probing Supersymmetry with Recursive Jigsaw Reconstruction", PhD Thesis Uni. Adelaide (Dec 2017)
M. Santoni, JHEP 1805 058 (2018)

RJR technique

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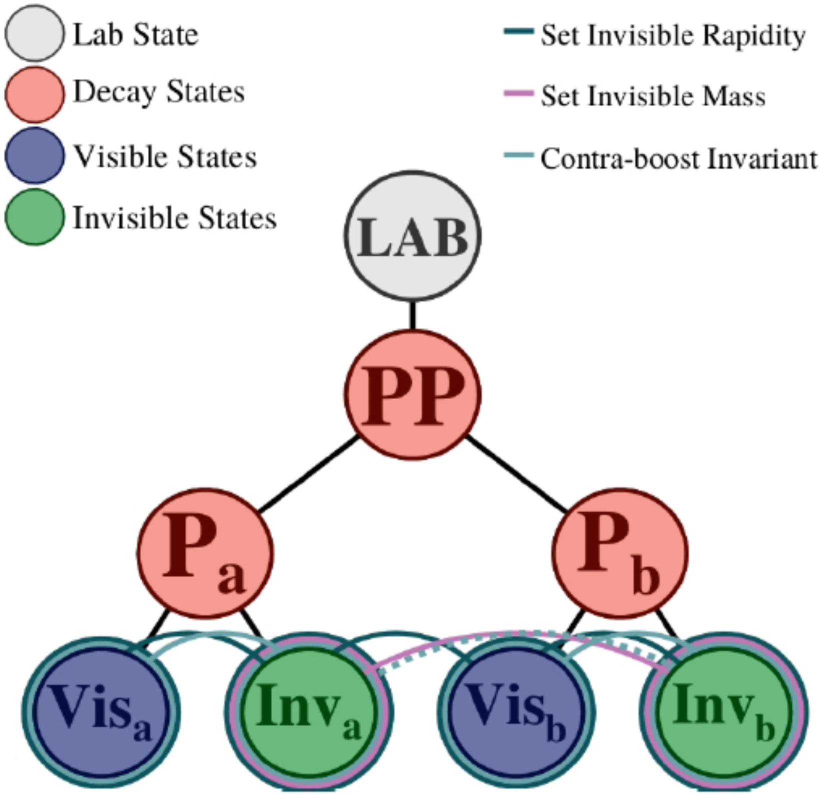

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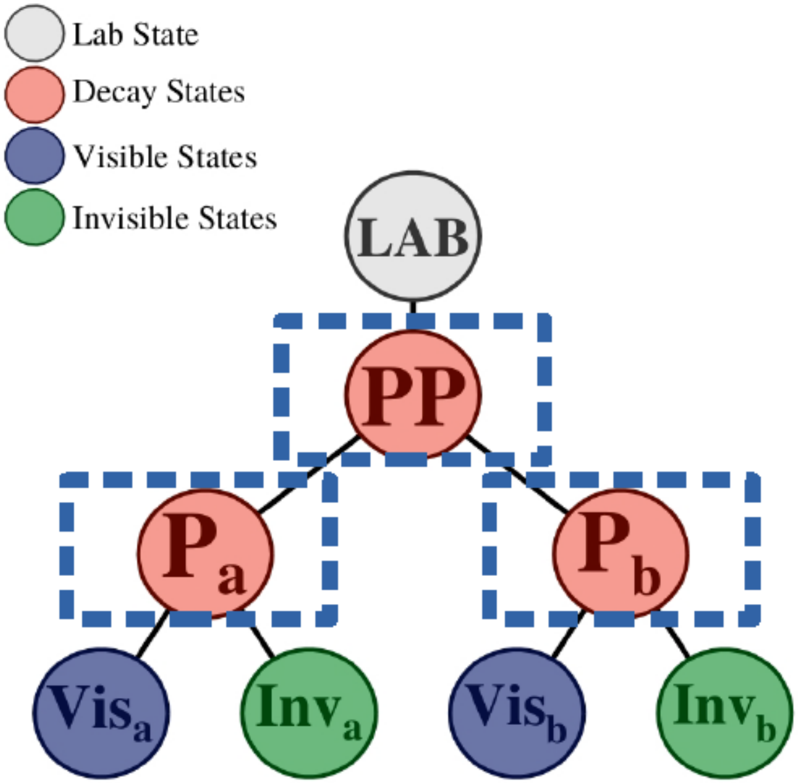

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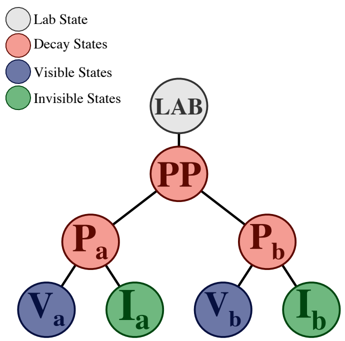
Scale Variables



$$H_{n,m}^{\mathcal{F}} = \sum_{1}^{n} \vec{p}_{vis,i}^{\,\mathcal{F}} + \sum_{1}^{m} \vec{p}_{inv,j}^{\,\mathcal{F}}$$

where:

n : number of *visible ojects* considered as independent

m : number of *invisible ojects* considered as independent

$\mathcal{F}$: frame under examination (can be PP $(\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0})$ or P $(\tilde{\chi}_1^{\pm}$ or $\tilde{\chi}_2^{0}))$

Examples used in this analysis:

$$H_{1,1}^{PP} = (\ell_1 + \ell_2 + \ell_3)^{PP}.P() + (\tilde{\chi}_{1a}^{0} + \tilde{\chi}_{1b}^{0} + \nu_a)^{PP}.P()$$

$$HT_{4,1}^{PP} = \ell_1^{PP}.Pt() + \ell_2^{PP}.Pt() + jet_1^{PP}.Pt() + jet_2^{PP}.Pt() + (\tilde{\chi}_{1a}^{0} + \tilde{\chi}_{1b}^{0})^{PP}.Pt()$$

$$H_{2,1}^{P_a} = \ell_1^{P_a}.P() + \ell_2^{P_a}.P() + \tilde{\chi}_1^{0\,P_a}.P()$$

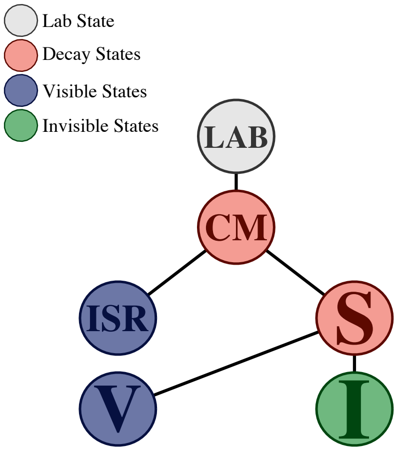
$$H_{2,1}^{P_b} = jet_1^{P_b}.P() + jet_2^{P_b}.P() + \tilde{\chi}_1^{0\,P_b}.P()$$

- In order to observe kinematic differences between signal and background we need an **ISR system to give our sparticles a transverse kick**: **the response of the sparticle decay products is sensitive to the mass of the LSP**
- In the limit of nearly degenerate parent sparticles $\tilde{p}$ and LSPs $\tilde{\chi}$:

$$\vec{E}_T^{\mathrm{miss}} \sim -\vec{p}_T^{\,\mathrm{ISR}} \times \frac{m_{\tilde{\chi}}}{m_{\tilde{p}}}$$

Rather than relying on a clean mono-ISR signal we would like to be able to separate "*ISR objects*" from "*sparticle objects*"

- Accomplished with a simple decay view of the event
- CM: centre-of-mass system – including all visible objects and MET
- ISR: radiation not coming from sparticle decays
- S: sparticle system
  - V: visible decay products
  - I: weakly interacting particles



Applications of RJR in ATLAS

General philosophy

The general principle of the **approach for high and intermediate masses is the same.**

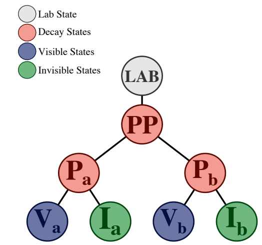
At much smaller mass splitting we need a different approach.

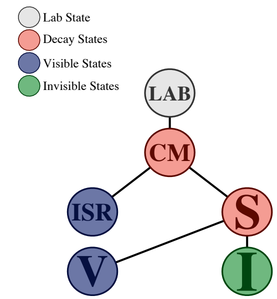
SRH – High Mass

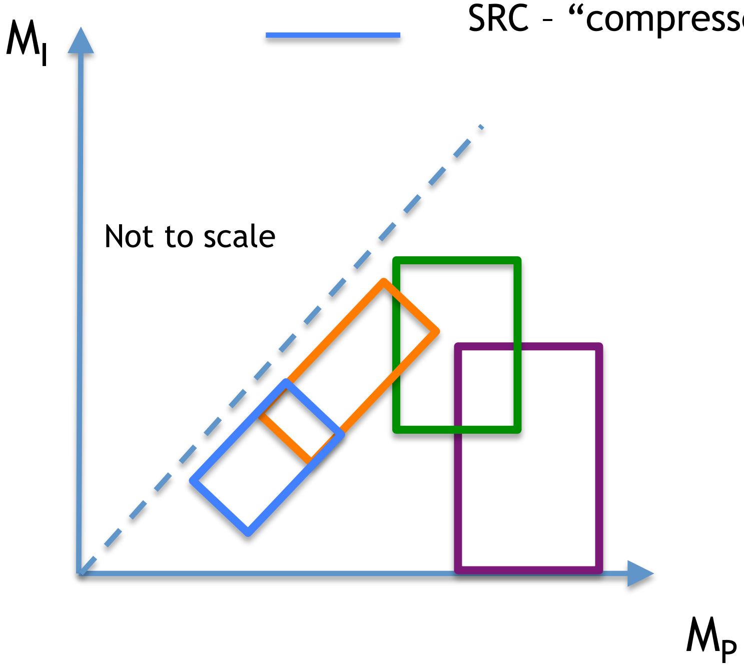
SRI - Intermediate Mass

SRL – Low Mass

SRC – “compressed” masses







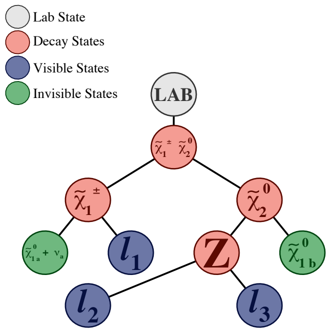
Need different cuts for different regions

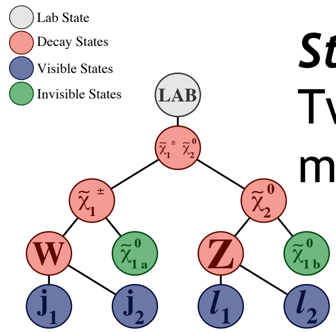
All optimized using simplified models 😐

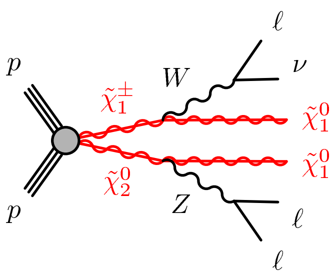
M_P = Parent mass

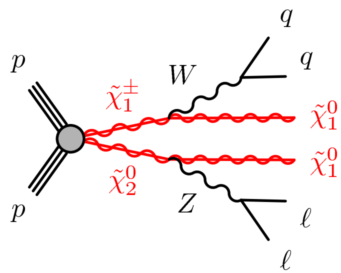
M_I = Invisible mass

Electroweak SUSY searches with RJR



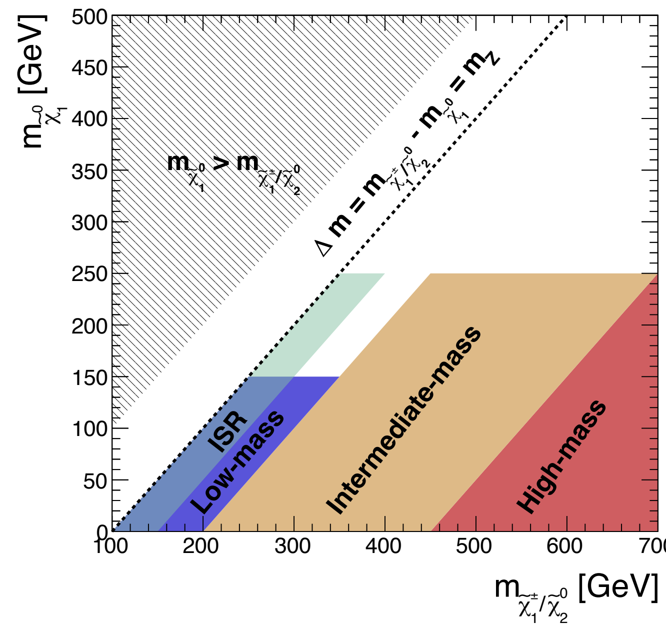


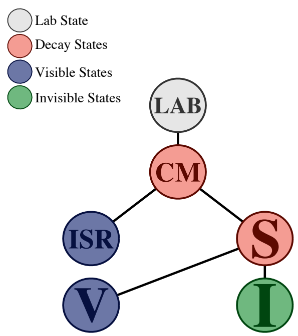




Standard Decay Tree

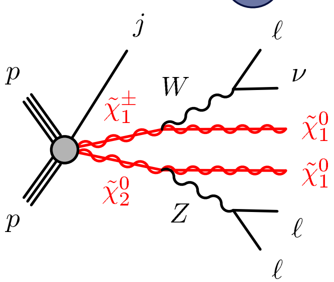
Two sets of SRs based on lepton multiplicity. High / Intermediate / Low

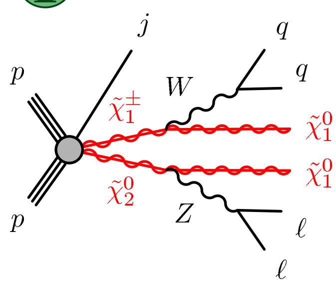




ISR Decay Tree

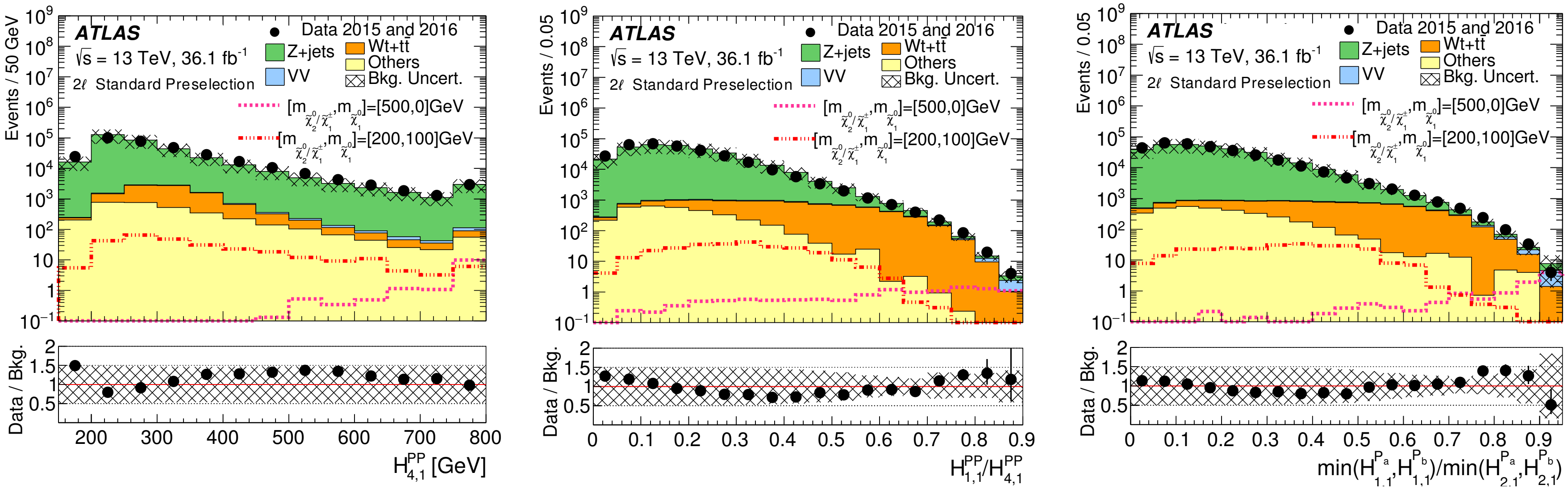
Requires a system of jet(s) to boost the signal





ISR and Low mass are designed to be orthogonal

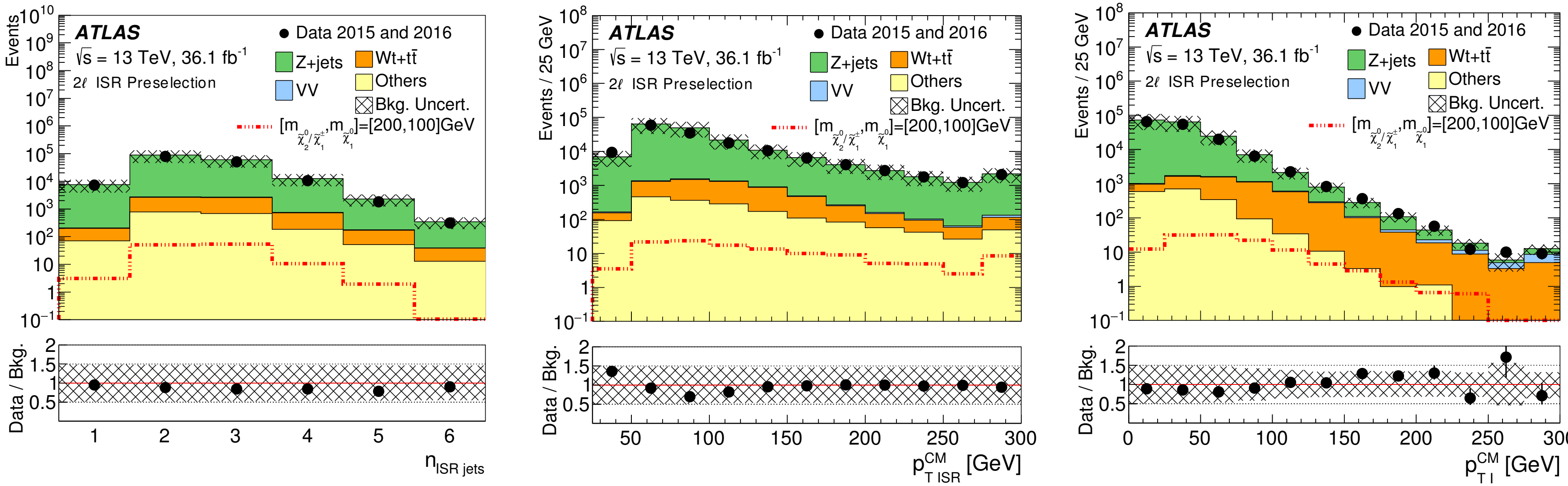
Preselection for the 2lepton Standard tree



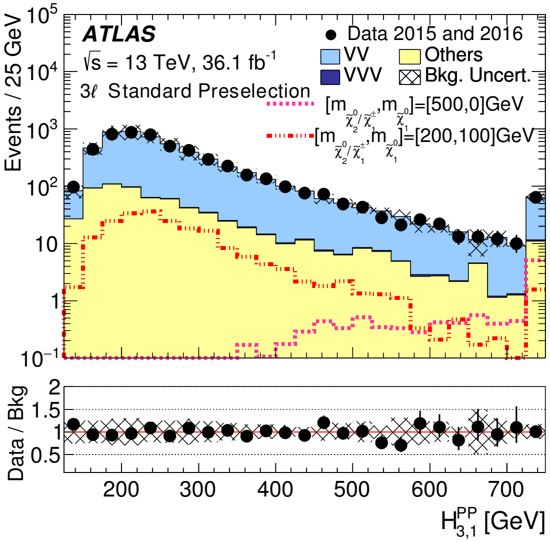
The different shapes of these variables in the signal models as compared to the major backgrounds can be used in a more targeted way.

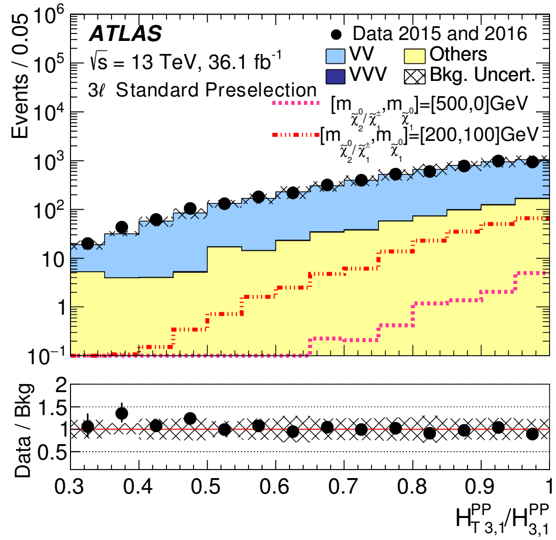
The interplay between the variables is also key – if we require one ratio to be large (for instance) it may make it **increasingly hard** for a complementary variable to have background events looking like signal events

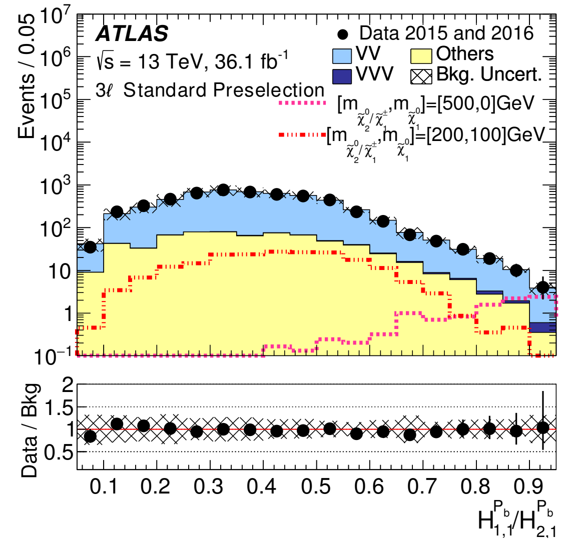
Preselection for the 2lepton ISR tree

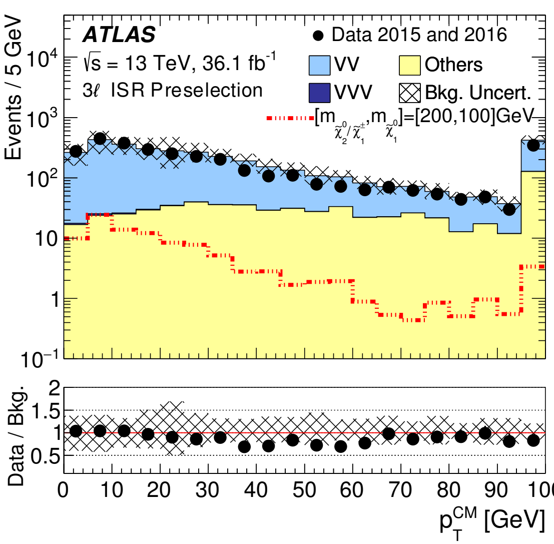


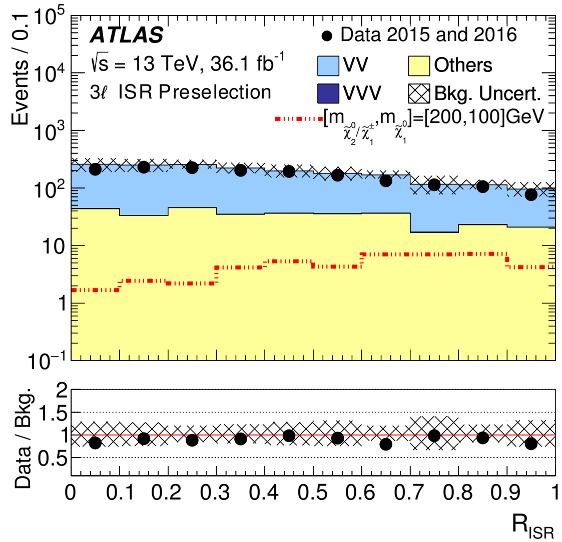
Similarly, where we require initial-state radiation, we need complementary variables to tease out sensitivity to a signal











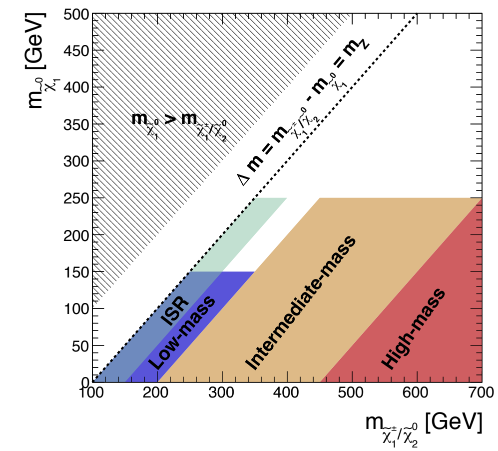
3 lepton selection is a similar story!

3lepton Standard Tree Definitions

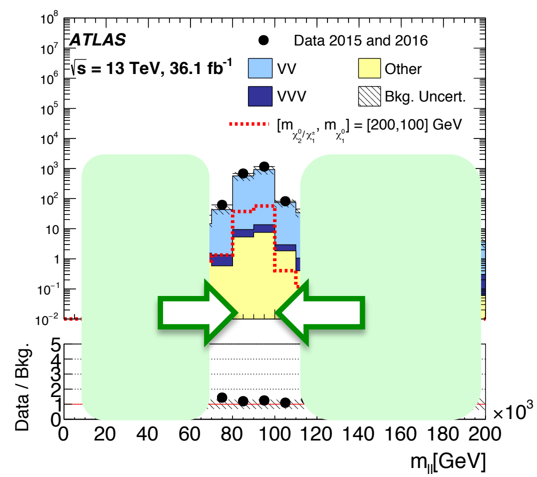
ATLAS EXPERIMENT

Region	n_{leptons}	n_{jets}	$n_{b\text{-tag}}$	$p_T^{\ell 1}$ [GeV]	$p_T^{\ell 2}$ [GeV]	$p_T^{\ell 3}$ [GeV]
CR3ℓ-VV	$= 3$	< 3	$= 0$	> 60	> 40	> 30
VR3ℓ-VV	$= 3$	< 3	$= 0$	> 60	> 40	> 30
SR3ℓ_High	$= 3$	< 3	$= 0$	> 60	> 60	> 40
SR3ℓ_Int	$= 3$	< 3	$= 0$	> 60	> 50	> 30
SR3ℓ_Low	$= 3$	$= 0$	$= 0$	> 60	> 40	> 30

Region	$m_{\ell\ell}$ [GeV]	m_T^W [GeV]	$H_{3,1}^{\text{PP}}$ [GeV]	$\frac{p_{T\,\text{PP}}^{\text{lab}}}{p_{T\,\text{PP}}^{\text{lab}}+H_{T\,3,1}^{\text{PP}}}$	$\frac{H_{T\,3,1}^{\text{PP}}}{H_{3,1}^{\text{PP}}}$	$\frac{H_{1,1}^{\text{P}_b}}{H_{2,1}^{\text{P}_b}}$
CR3ℓ-VV	$\in (75, 105)$	$\in (0, 70)$	> 250	< 0.2	> 0.75	–
VR3ℓ-VV	$\in (75, 105)$	$\in (70, 100)$	> 250	< 0.2	> 0.75	–
SR3ℓ_High	$\in (75, 105)$	> 150	> 550	< 0.2	> 0.75	> 0.8
SR3ℓ_Int	$\in (75, 105)$	> 130	> 450	< 0.15	> 0.8	> 0.75
SR3ℓ_Low	$\in (75, 105)$	> 100	> 250	< 0.05	> 0.9	–



Select events:
- with 3 high pT leptons
- l+l- pair at the Z-mass
- use RJ variables to define sensitive regions of phase space



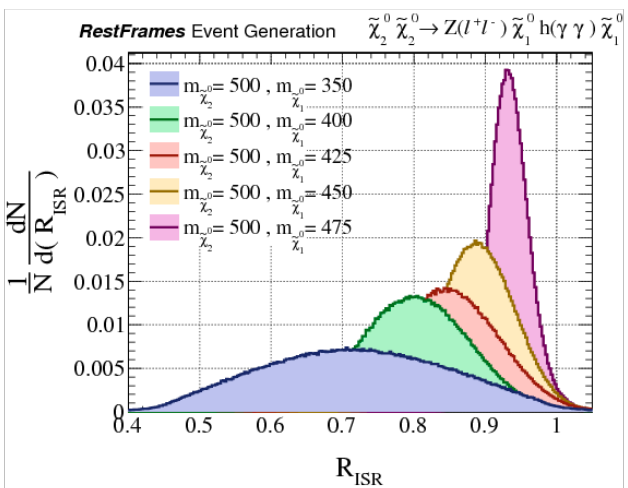
Can leverage the behavior of the variables we design to target signals in a more natural way.

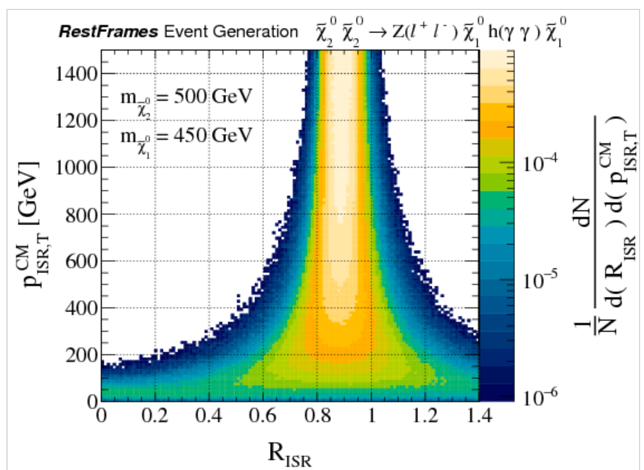
Similar selection optimization performed for 2lepton regions

3lepton ISR Tree Definitions

Region	n_{leptons}	n_{jets}	$n_{b\text{-tag}}$	$p_{\mathrm{T}}^{\ell_1}$ [GeV]	$p_{\mathrm{T}}^{\ell_2}$ [GeV]	$p_{\mathrm{T}}^{\ell_3}$ [GeV]
CR3ℓ_ISR-VV	$= 3$	≥ 1	$= 0$	> 25	> 25	> 20
VR3ℓ_ISR-VV	$= 3$	≥ 1	$= 0$	> 25	> 25	> 20
SR3ℓ_ISR	$= 3$	$\in [1, 3]$	$= 0$	> 25	> 25	> 20

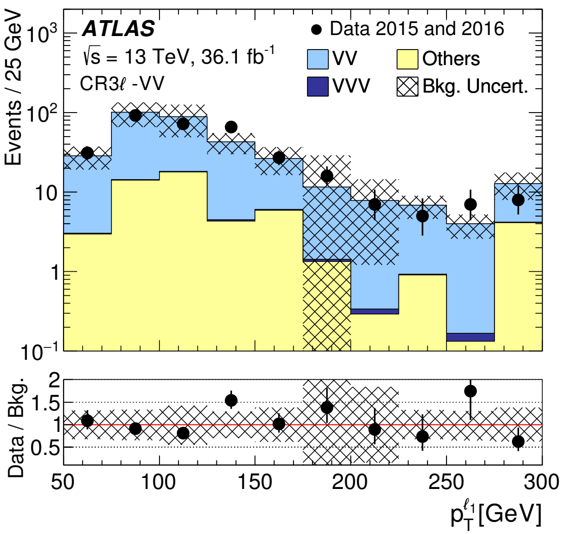
Region	$m_{\ell\ell}$ [GeV]	m_{T}^{W} [GeV]	$\Delta\phi^{\mathrm{CM}}_{\mathrm{ISR,I}}$	R_{ISR}	$p^{\mathrm{CM}}_{\mathrm{T\ ISR}}$ [GeV]	$p^{\mathrm{CM}}_{\mathrm{T\ I}}$ [GeV]	$p_{\mathrm{T}}^{\mathrm{CM}}$ [GeV]
CR3ℓ_ISR-VV	$\in (75, 105)$	< 100	> 2.0	$\in (0.55, 1.0)$	> 80	> 60	< 25
VR3ℓ_ISR-VV	$\in (75, 105)$	> 60	> 2.0	$\in (0.55, 1.0)$	> 80	> 60	> 25
SR3ℓ_ISR	$\in (75, 105)$	> 100	> 2.0	$\in (0.55, 1.0)$	> 100	> 80	< 25

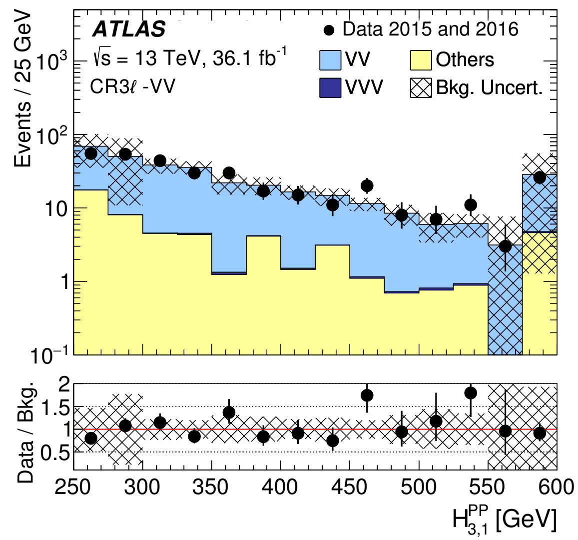


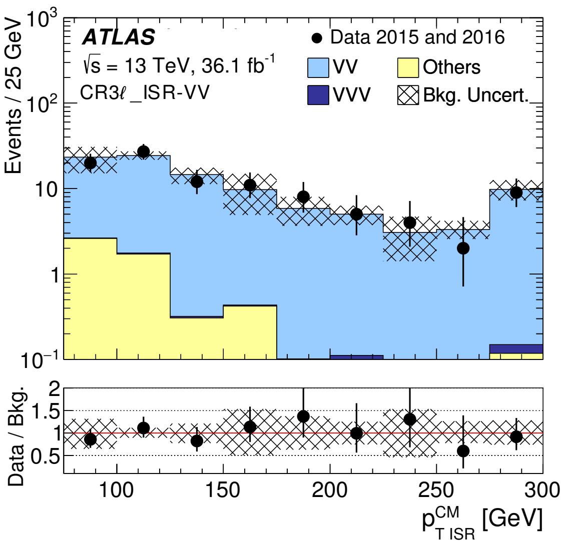


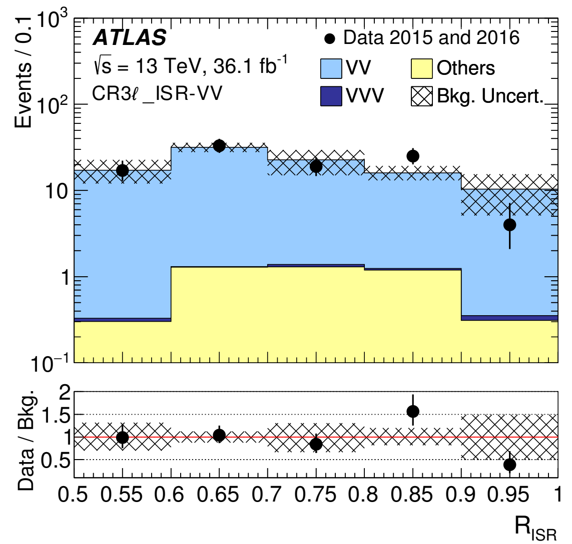
Complementarity between the R_{ISR} variable and $P_{\mathrm{T\ ISR}}$ studied in detail in:
PJ, C. Rogan, M. Santoni, PRD 95 035013 (2017)

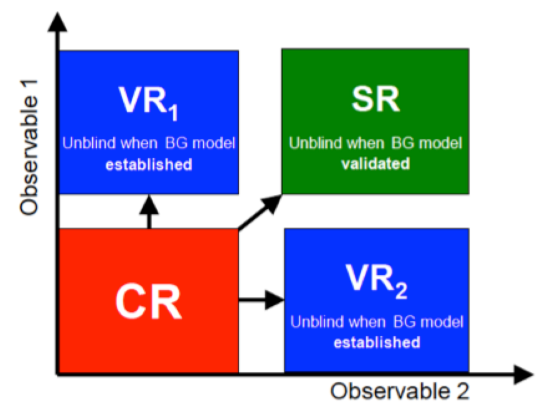
Control Regions – 3lepton



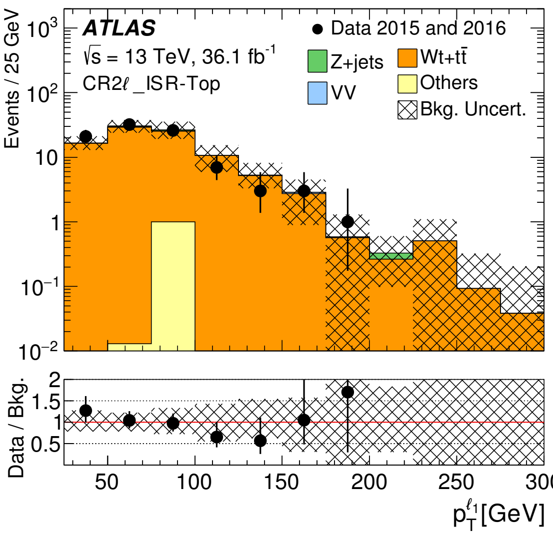


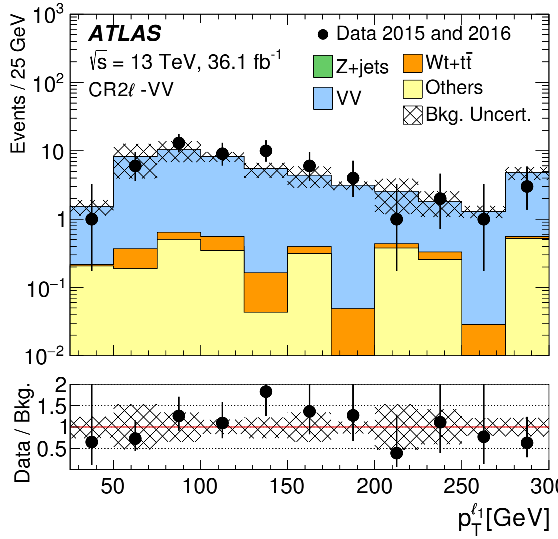


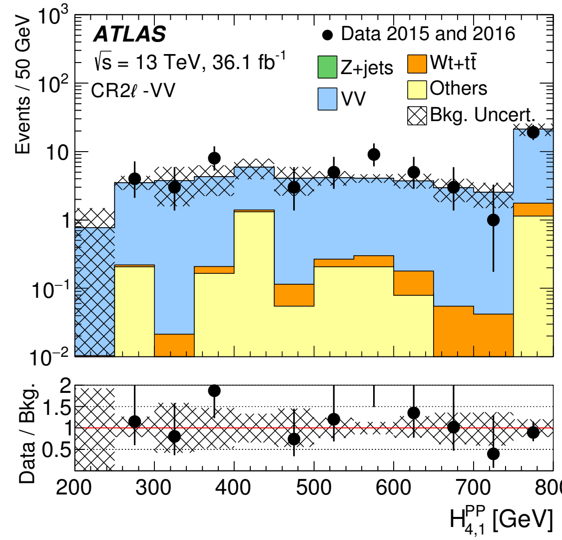


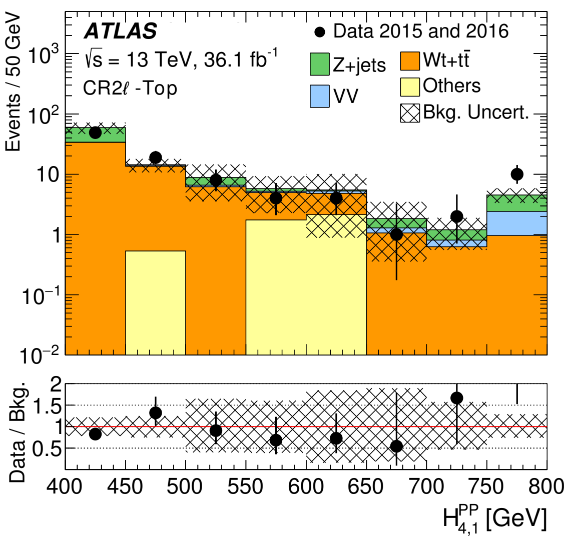


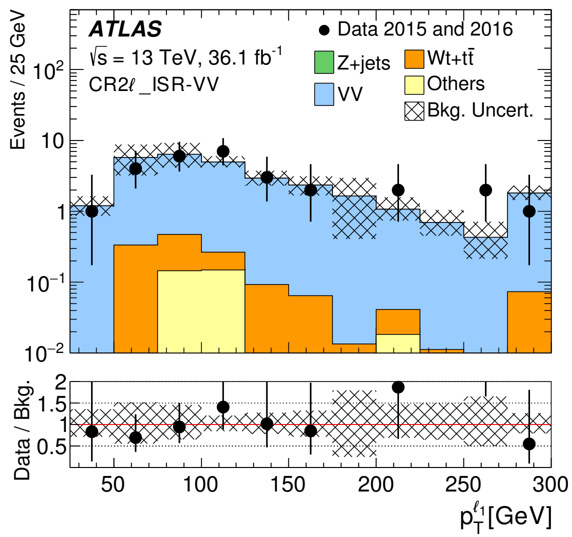
Control Regions – 2lepton

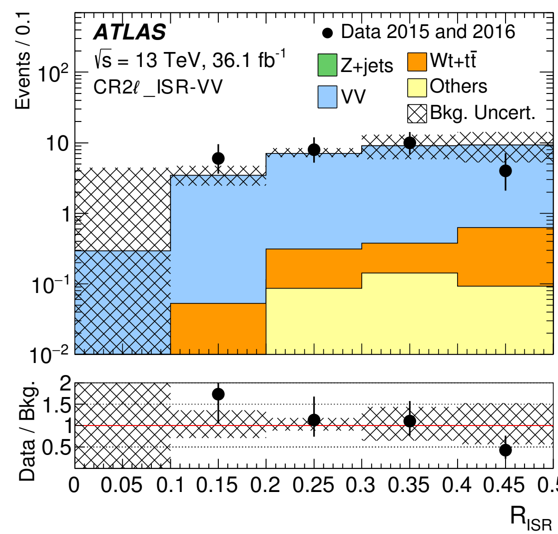




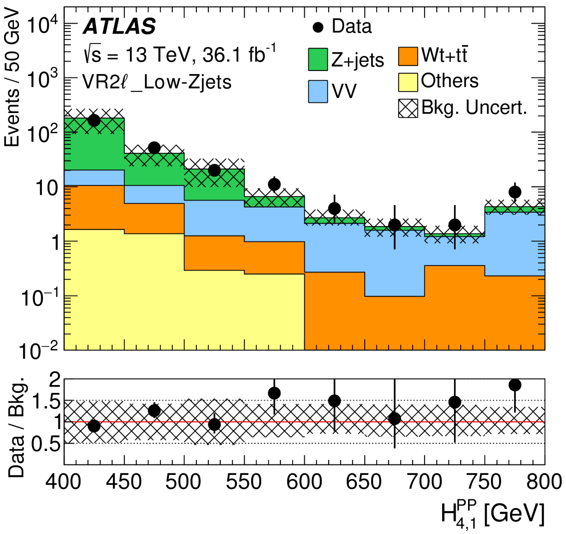


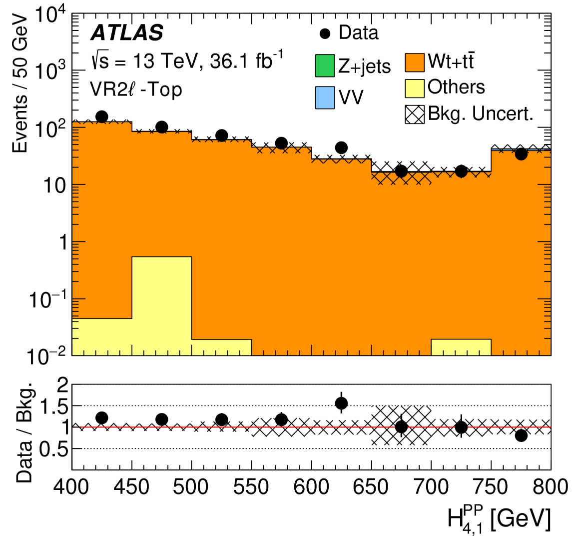


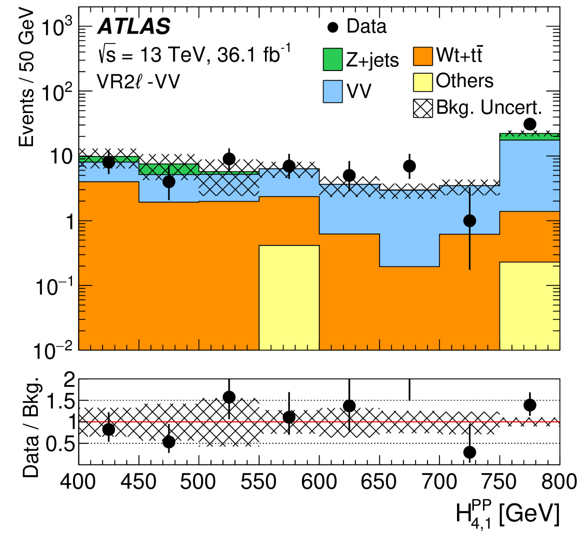


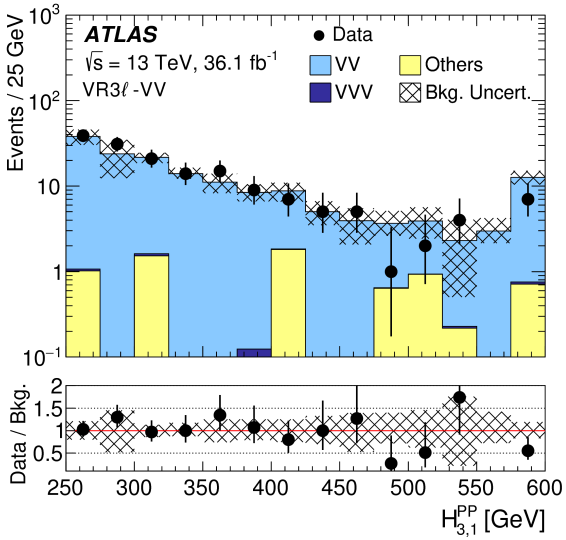


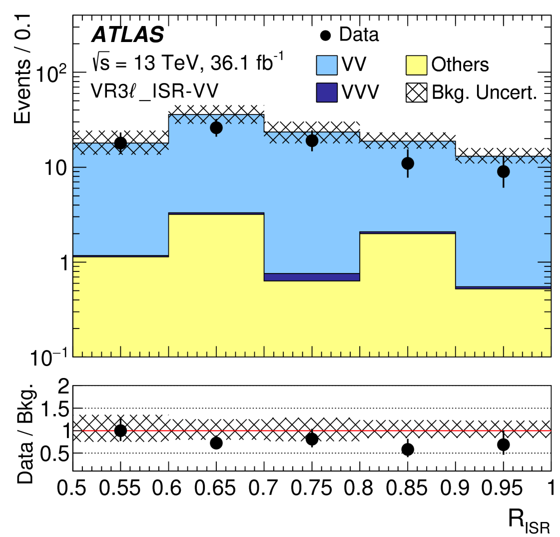
Validation Regions



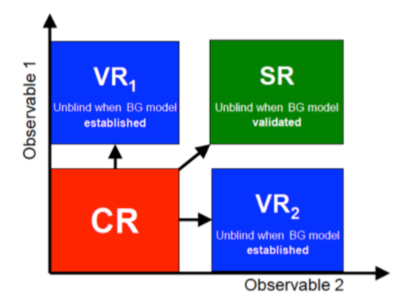






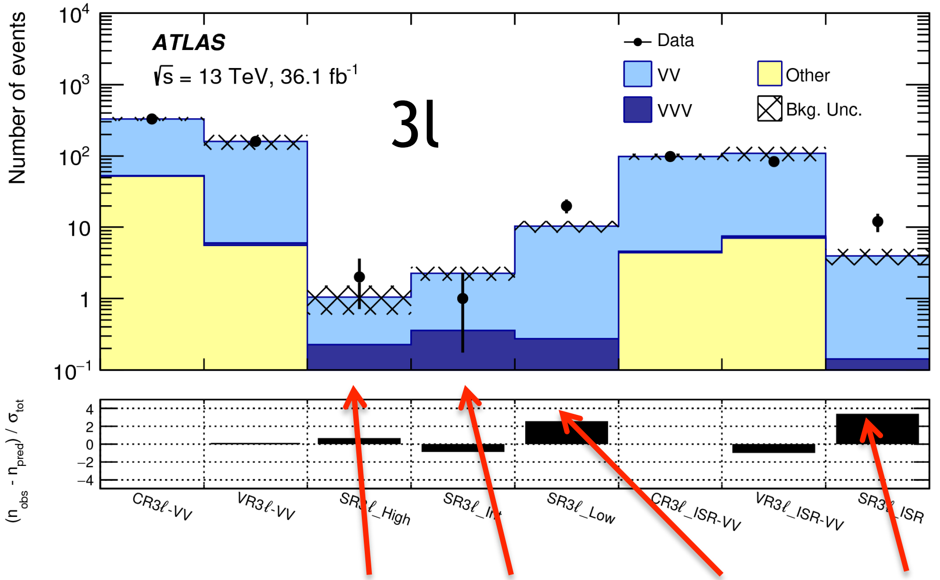


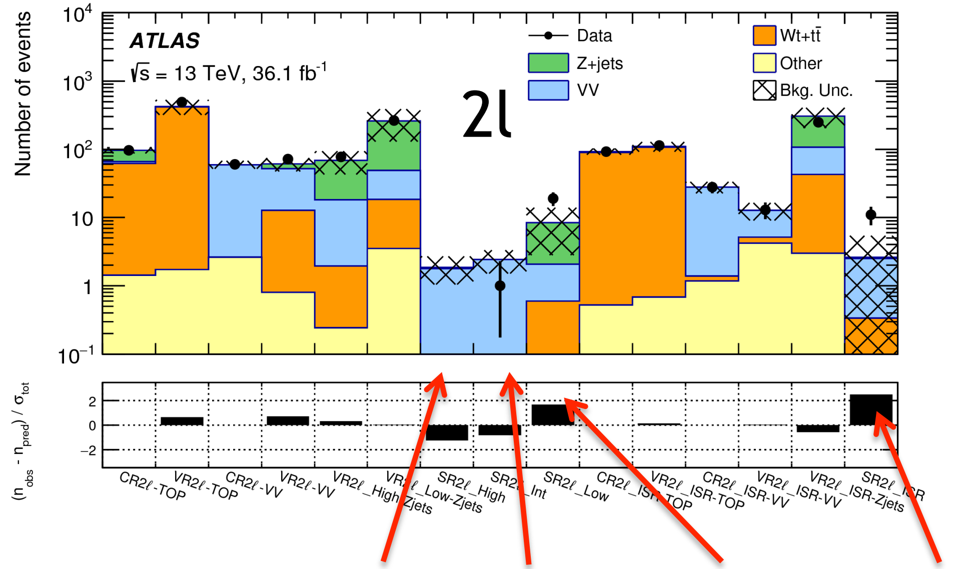
Study phase space even closer to the SR to check variables are well modelled.
All looks good.



Unblinded results

- Main background contribution is from VV (3l), VV and Z+jets (2l)
- Control and Validation Regions enriched in these processes demonstrate that the key backgrounds are well modeled
- Z+jets prediction from a dedicated photon template sample
- We see excesses, in 4 signal regions, all targeting the low mass splitting



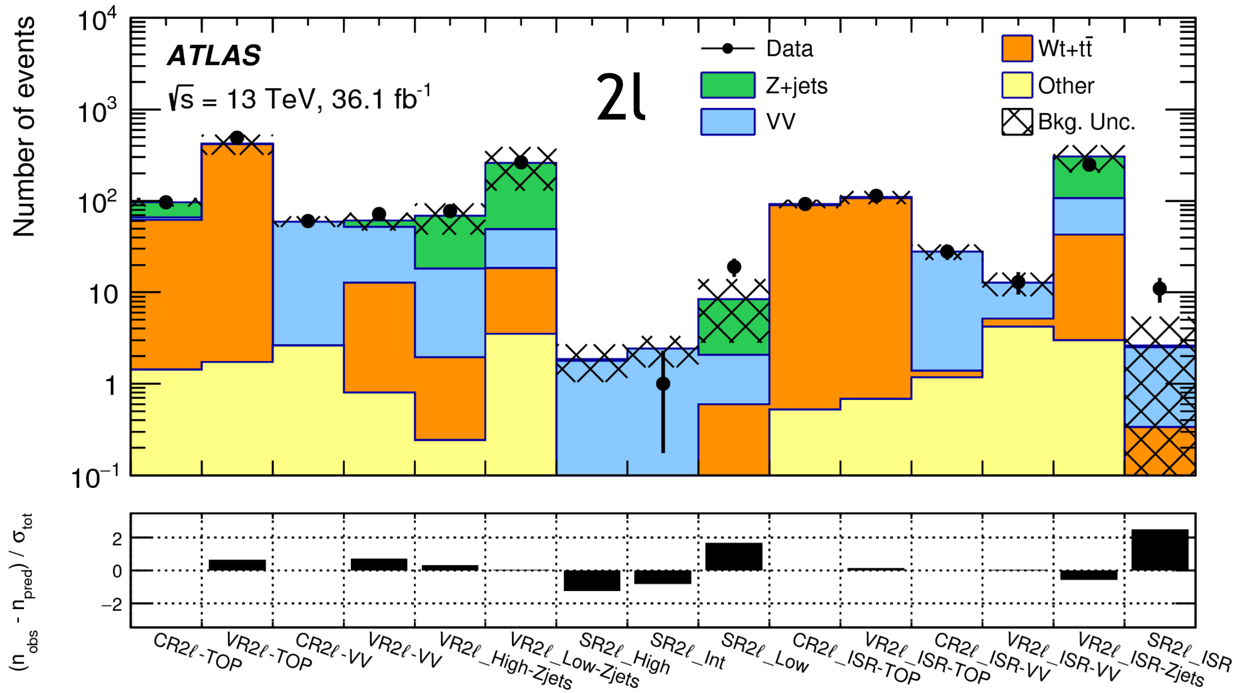


Signal Region	SR3ℓ_High	SR3ℓ_Int	SR3ℓ_Low	SR3ℓ_ISR
Total Observed events	2	1	20	12
Total Background events	1.1 ± 0.5	2.3 ± 0.5	10 ± 2	3.9 ± 1.0
Other	$0.03^{+0.07}_{-0.03}$	0.04 ± 0.02	$0.02^{+0.34}_{-0.02}$	$0.06^{+0.19}_{-0.06}$
Triboson	0.19 ± 0.07	0.32 ± 0.06	0.25 ± 0.03	0.08 ± 0.04
Fit output, *VV*	0.83 ± 0.39	1.9 ± 0.5	10 ± 2	3.8 ± 1.0
Fit input, *VV*	0.76	1.8	9.2	3.4

Signal Region	SR2ℓ_High	SR2ℓ_Int	SR2ℓ_Low	SR2ℓ_ISR
Total Observed events	0	1	19	11
Total Background events	1.9 ± 0.8	2.4 ± 0.9	8.4 ± 5.8	$2.7^{+2.8}_{-2.7}$
Other	0.02 ± 0.01	$0.05^{+0.12}_{-0.05}$	$0.02^{+1.07}_{-0.02}$	$0.06^{+0.33}_{-0.06}$
Fit output, $Wt + t\bar{t}$	0.00 ± 0.00	0.00 ± 0.00	0.57 ± 0.20	$0.28^{+0.34}_{-0.28}$
Fit output, *VV*	1.8 ± 0.7	2.4 ± 0.8	1.5 ± 0.9	2.3 ± 1.1
Z+jets	$0.07^{+0.78}_{-0.07}$	$0.00^{+0.74}_{-0.00}$	6.3 ± 5.8	$0.10^{+2.58}_{-0.10}$
Fit input, $Wt + t\bar{t}$	0.00	0.00	0.63	0.28
Fit input, *VV*	1.9	2.6	1.6	2.4

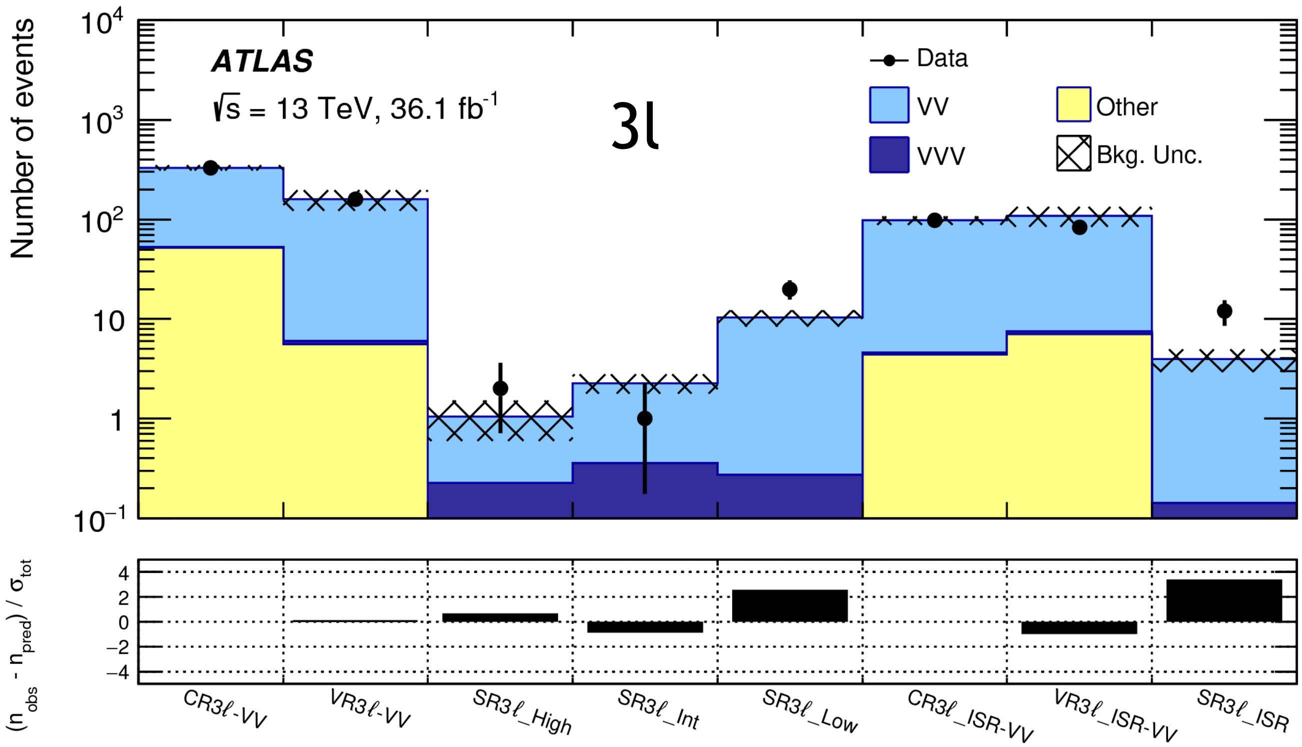
Results – 2lepton

Signal region	SR2ℓ_High	SR2ℓ_Int	SR2ℓ_Low	SR2ℓ_ISR
Total observed events	0	1	19	11
Total background events	1.9 ± 0.8	2.4 ± 0.9	8.4 ± 5.8	$2.7^{+2.8}_{-2.7}$
Other	0.02 ± 0.01	$0.05^{+0.12}_{-0.05}$	$0.02^{+1.07}_{-0.02}$	$0.06^{+0.33}_{-0.06}$
Fit output, $Wt + t\bar{t}$	0.00 ± 0.00	0.00 ± 0.00	0.57 ± 0.20	$0.28^{+0.34}_{-0.28}$
Fit output, VV	1.8 ± 0.7	2.4 ± 0.8	1.5 ± 0.9	2.3 ± 1.1
Z+jets	$0.07^{+0.78}_{-0.07}$	$0.00^{+0.74}_{-0.00}$	6.3 ± 5.8	$0.10^{+2.58}_{-0.10}$
Fit input, $Wt + t\bar{t}$	0.00	0.00	0.63	0.28
Fit input, VV	1.9	2.6	1.6	2.4

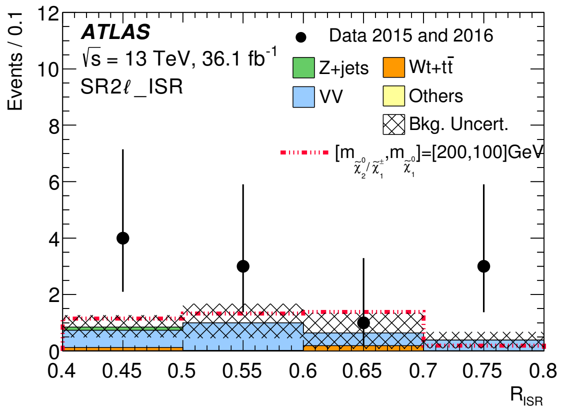


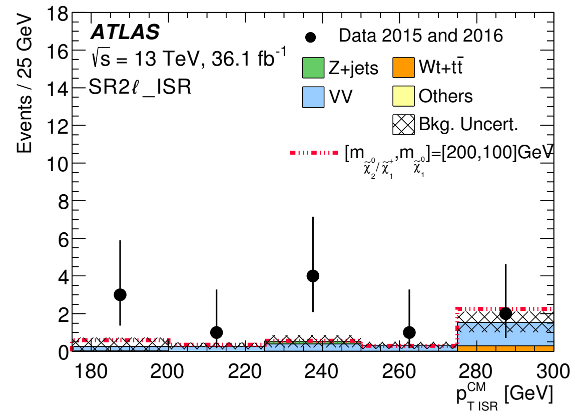
Results – 3lepton

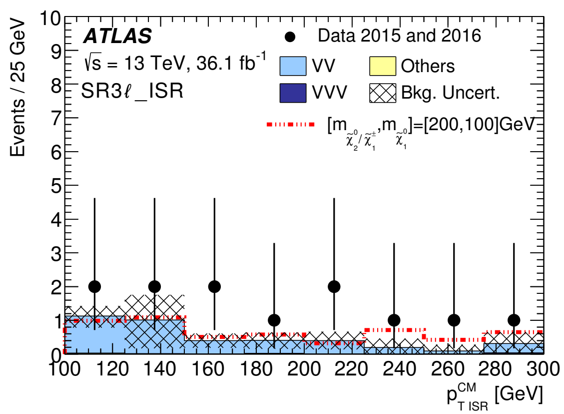
Signal region	SR3ℓ_High	SR3ℓ_Int	SR3ℓ_Low	SR3ℓ_ISR
Total observed events	2	1	20	12
Total background events	1.1 ± 0.5	2.3 ± 0.5	10 ± 2	3.9 ± 1.0
Other	$0.03^{+0.07}_{-0.03}$	0.04 ± 0.02	$0.02^{+0.34}_{-0.02}$	$0.06^{+0.19}_{-0.06}$
Triboson	0.19 ± 0.07	0.32 ± 0.06	0.25 ± 0.03	0.08 ± 0.04
Fit output, VV	0.83 ± 0.39	1.9 ± 0.5	10 ± 2	3.8 ± 1.0
Fit input, VV	0.76	1.8	9.2	3.4

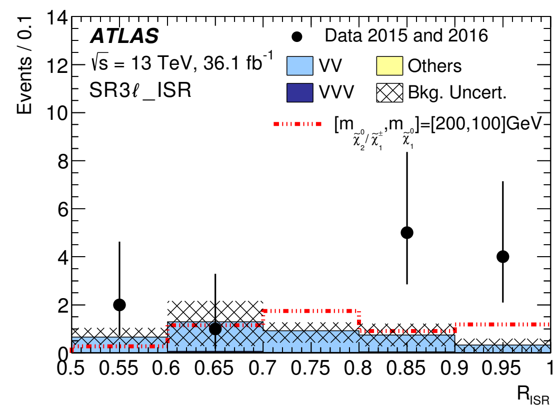


Results – ISR Signal Regions



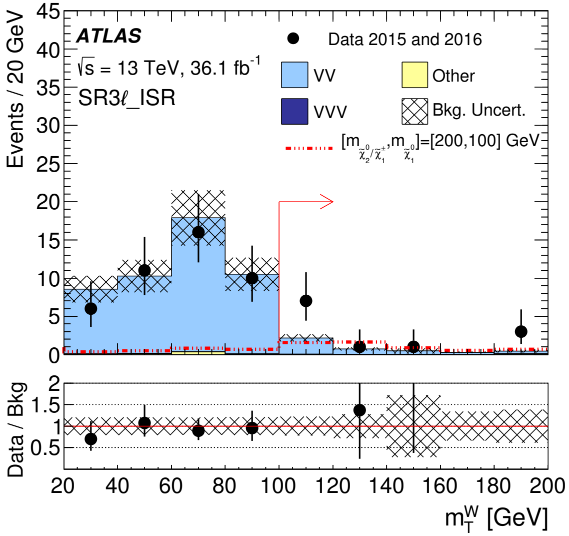


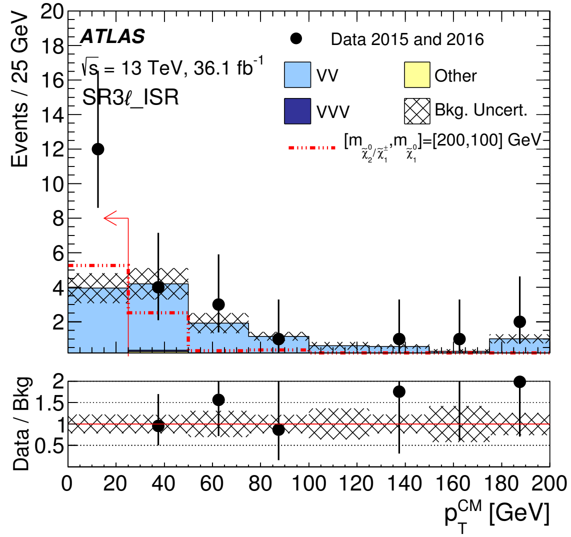


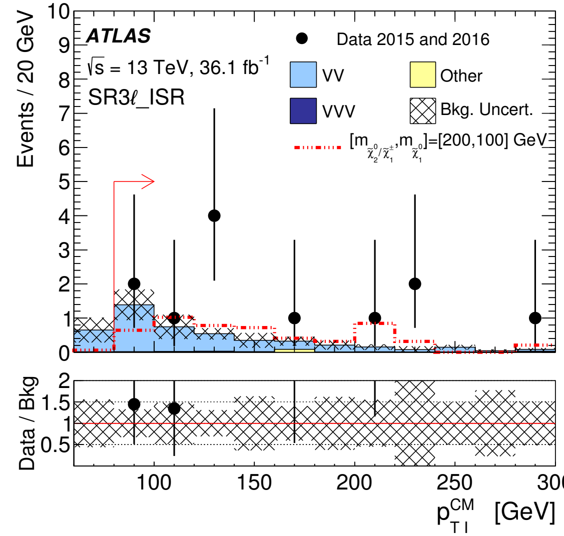


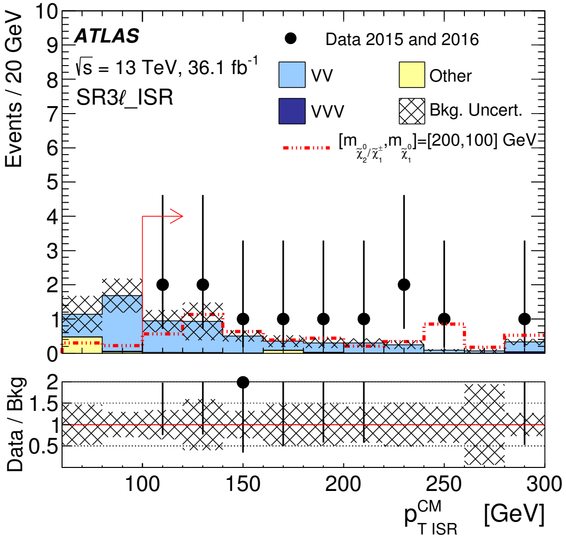
We see different yields in data compared to our prediction in the ISR SRs, most prominently in the 3 lepton region (lower plots).

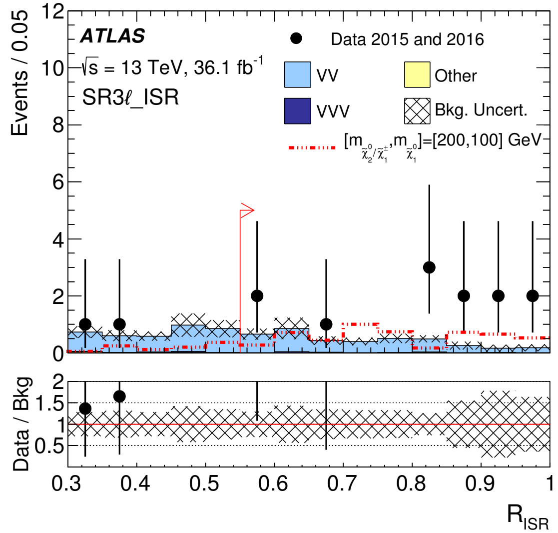
3lepton – ISR Signal Region





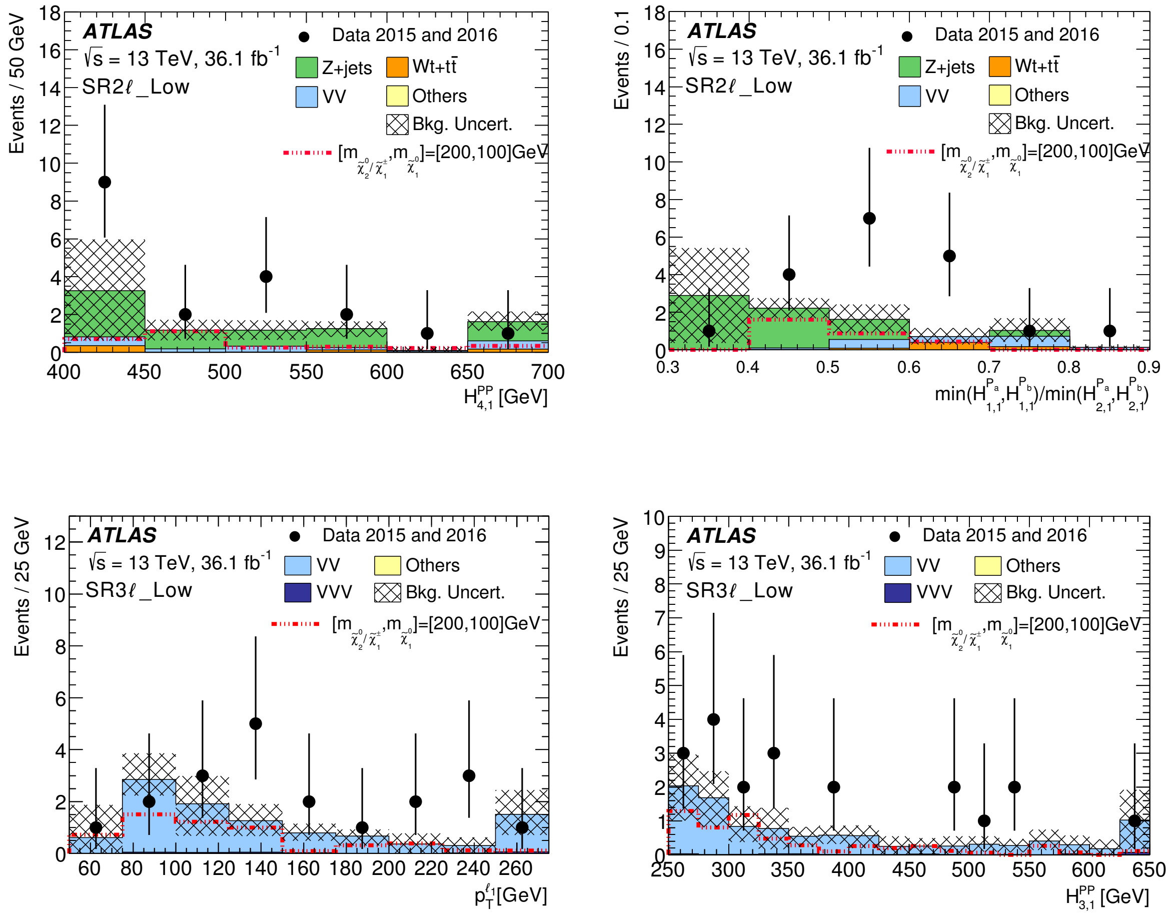






The shape of the excess events are similar to that predicted from the signal model used to optimize the search.

Results – Low Mass Signal Regions



Similarly, there are excess events in data compared to our prediction in the Low mass SRs. The upper right distribution ***was not used*** in the event selection.

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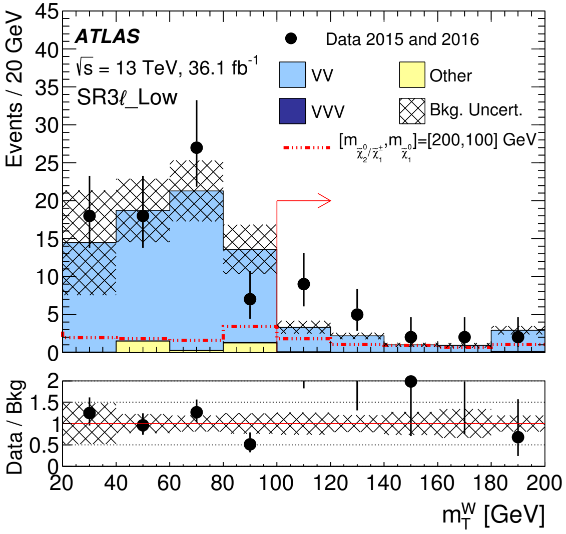
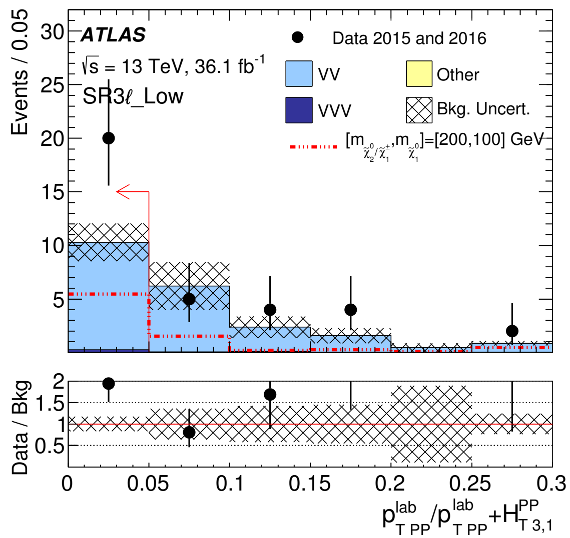
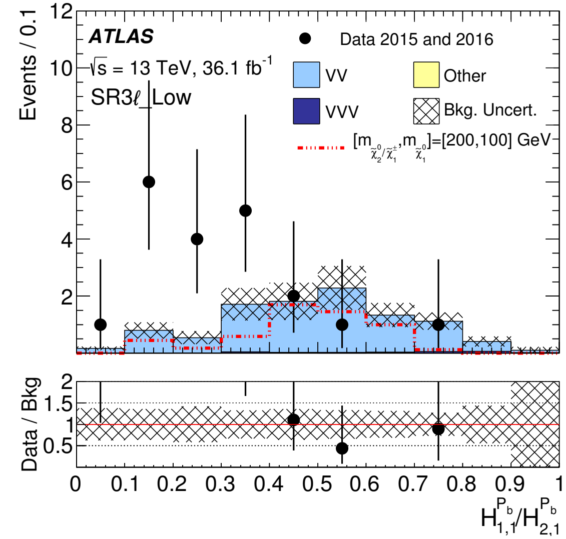
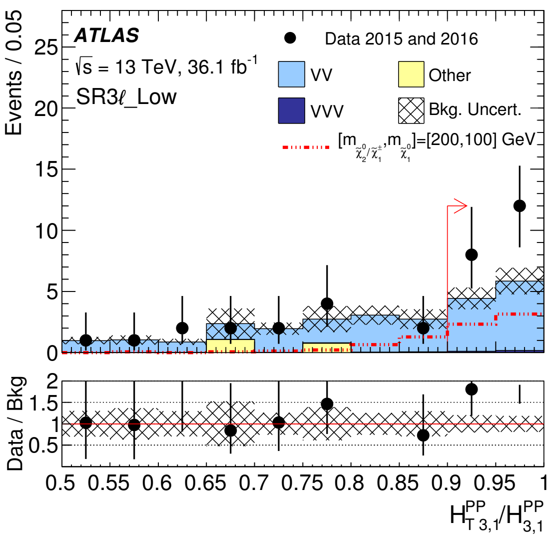
3lepton – Low Mass Signal Region

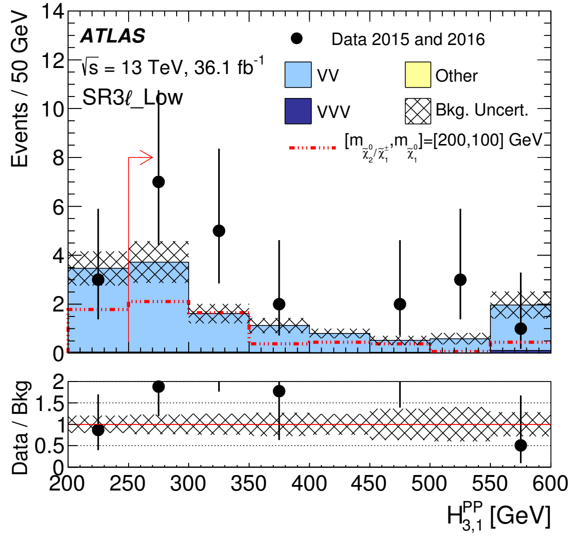
ATLAS EXPERIMENT









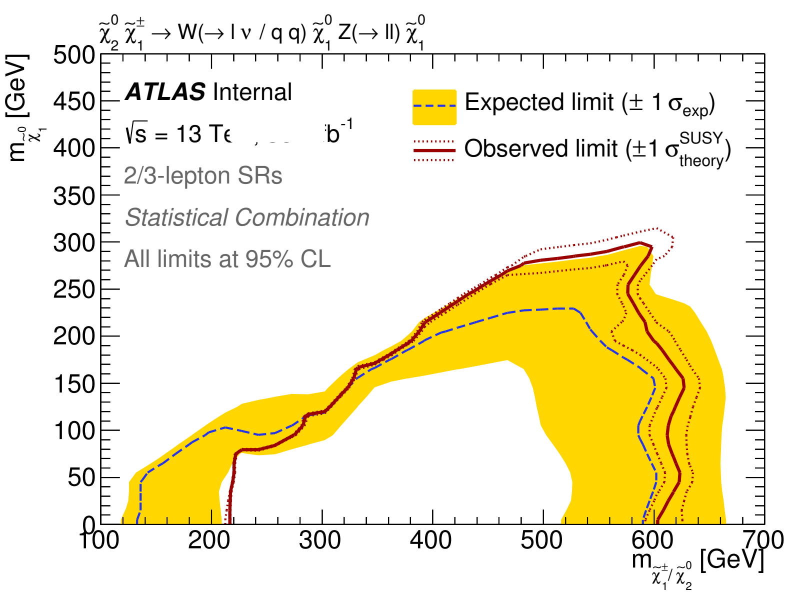


In this region, there are variables where the excess events clearly differ in shape from that predicted by the signal model.

Statistical interpretation

Signal region	$\langle\epsilon\sigma\rangle^{95}_{\text{obs}}$ [fb]	S^{95}_{obs}	S^{95}_{exp}	p_0 (Z)
SR3ℓ_ISR	0.42	15.3	$6.9^{+3.1}_{-2.2}$	0.001 (3.02)
SR2ℓ_ISR	0.43	15.4	$9.7^{+3.6}_{-2.5}$	0.02 (1.99)
SR3ℓ_Low	0.53	19.1	$9.5^{+4.2}_{-1.8}$	0.016 (2.13)
SR2ℓ_Low	0.66	23.7	$16.1^{+6.3}_{-4.3}$	0.08 (1.39)
SR3ℓ_Int	0.09	3.3	$4.4^{+2.5}_{-1.5}$	0.50 (0.00)
SR2ℓ_Int	0.09	3.3	$4.6^{+2.6}_{-1.5}$	0.50 (0.00)
SR3ℓ_High	0.14	5.0	$3.9^{+2.2}_{-1.3}$	0.23 (0.73)
SR2ℓ_High	0.09	3.2	$4.0^{+2.3}_{-1.2}$	0.50 (0.00)

To remain as conservative as possible, and to avoid model dependent statements, *we do not combine the significances*



Excesses of 3.0σ, 2.0σ, 2.1σ and 1.4σ in the four regions targeting moderately compressed EWK SUSY.

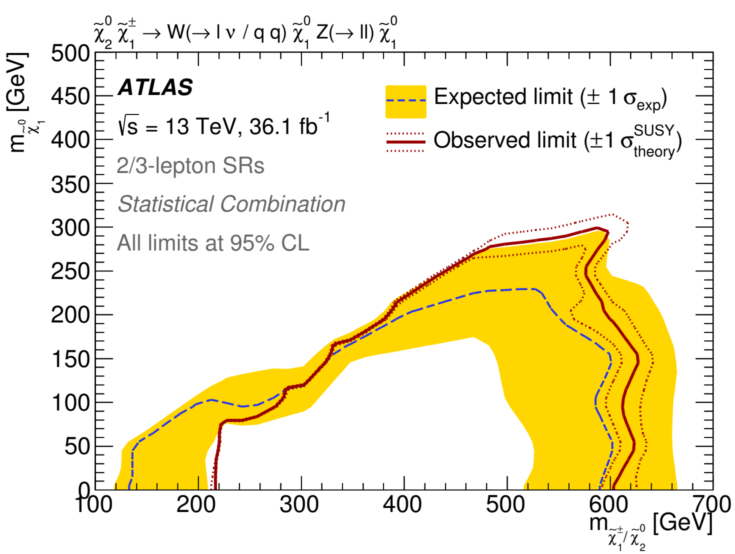
This is **the largest excess** seen at any LHC experiment in a search for Supersymmetry

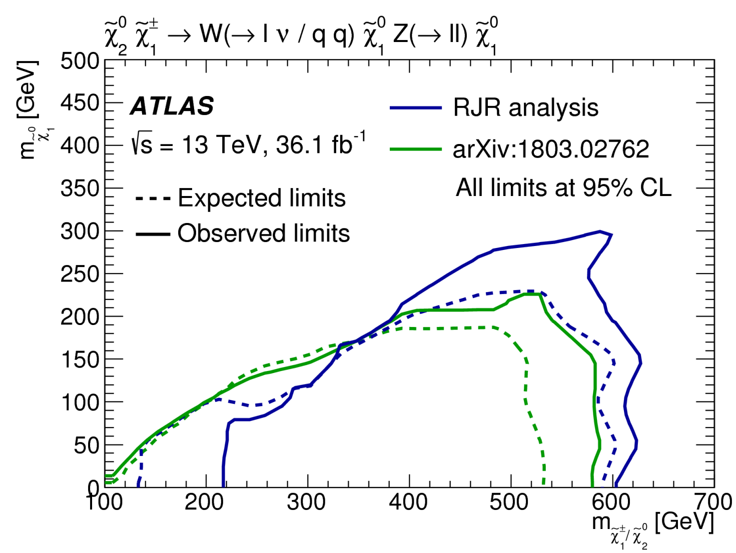
Statistical interpretation

Signal region	SR2ℓ_Low	SR2ℓ_ISR
ee	9 (4.5±3.9)	3 (1.2±1.2)
$\mu\mu$	10 (3.9±2.6)	8 (1.5±1.5)
Signal region	**SR3ℓ_Low**	**SR3ℓ_ISR**
eee	6 (3.5±0.7)	3 (1.1±0.3)
$ee\mu$	6 (2.0±0.4)	3 (0.9±0.3)
$\mu\mu\mu$	7 (2.7±0.6)	4 (1.5±0.4)
$\mu\mu e$	1 (1.9±0.4)	2 (0.4±0.1)

The four signal regions with excesses were studied in terms of their flavour composition – looks as expected. MANY other cross-checks done….

Improved limits at high mass compared to previous analysis…...with weaker limits at low mass due to excesses observed.





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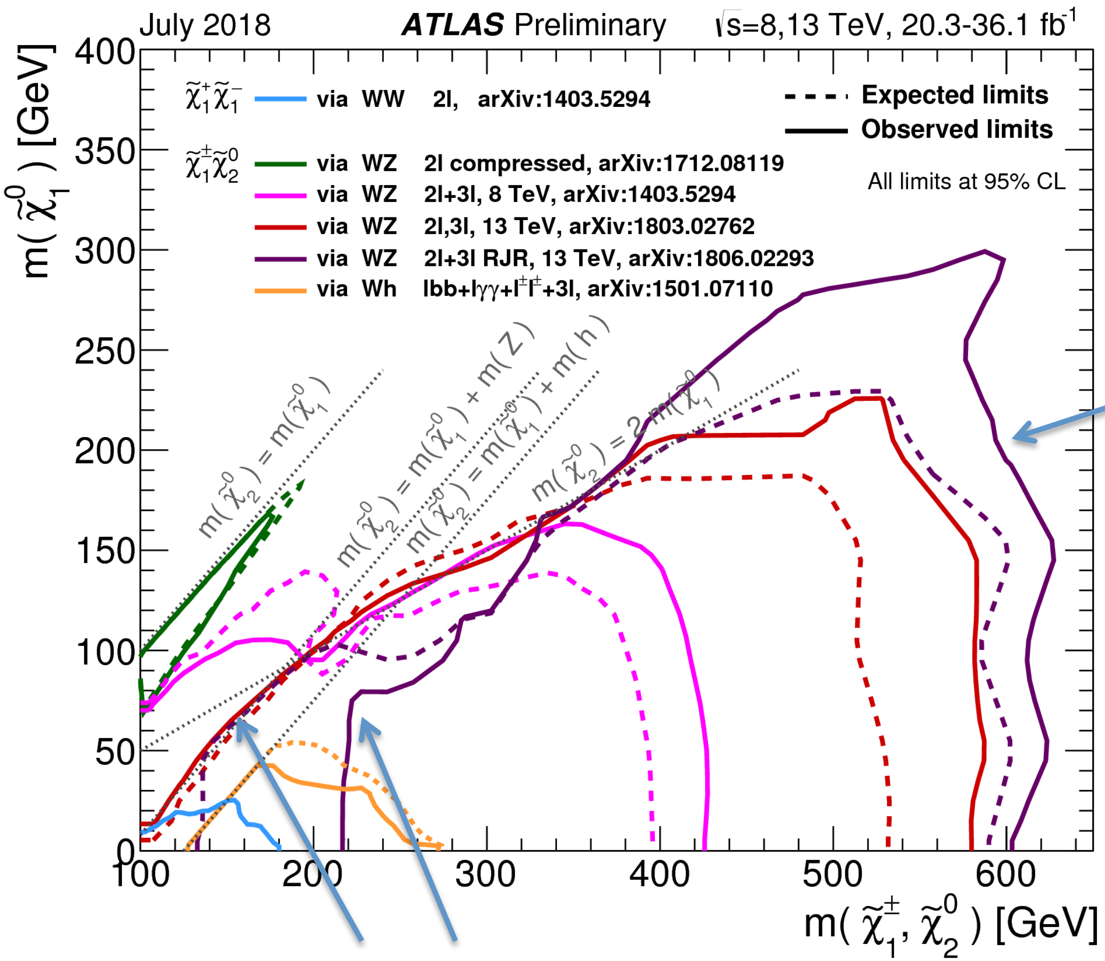
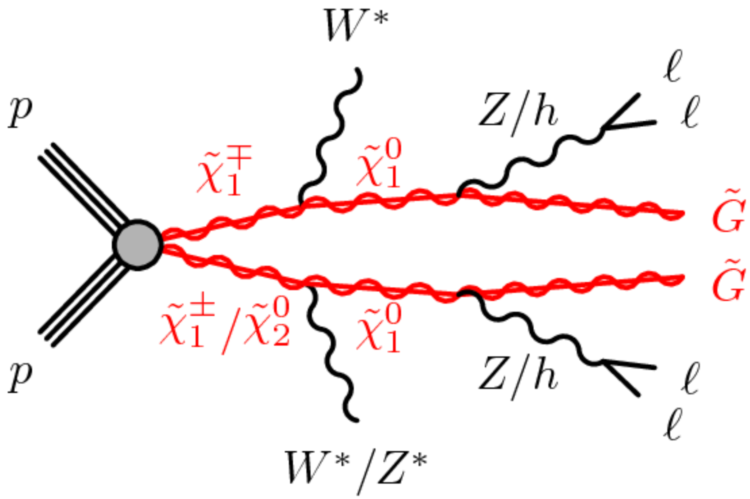


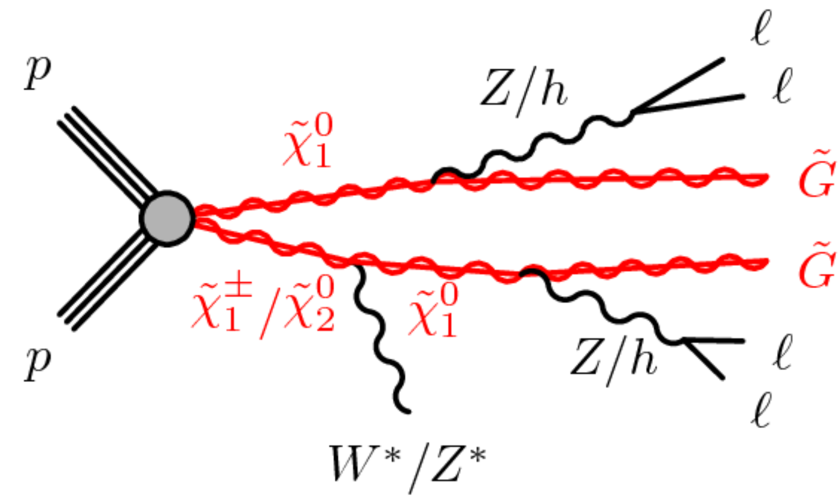
Analysis with the best reach in Electroweak searches with intermediate W/Z bosons.

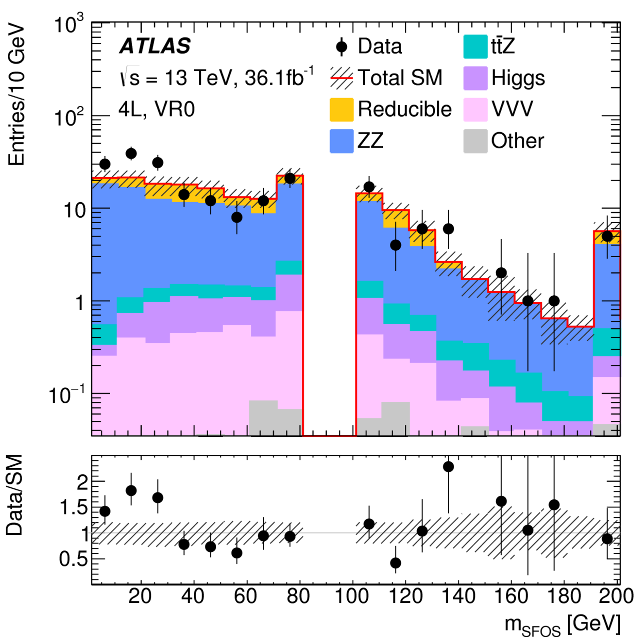
In the process of updating this work with full Run 2 data: 36 ->150 fb^{-1} (~4x more data)

Largest excess (≥ 3σ) in any SUSY search!

ATLAS – 4 lepton







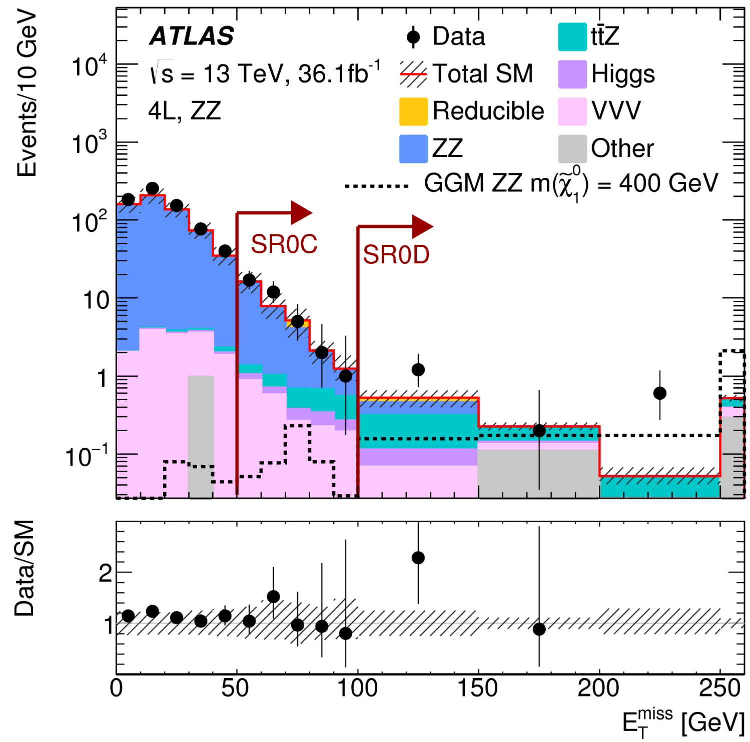
Hints in some EWK SUSY channels would suggest we should see excesses in similar phase space.

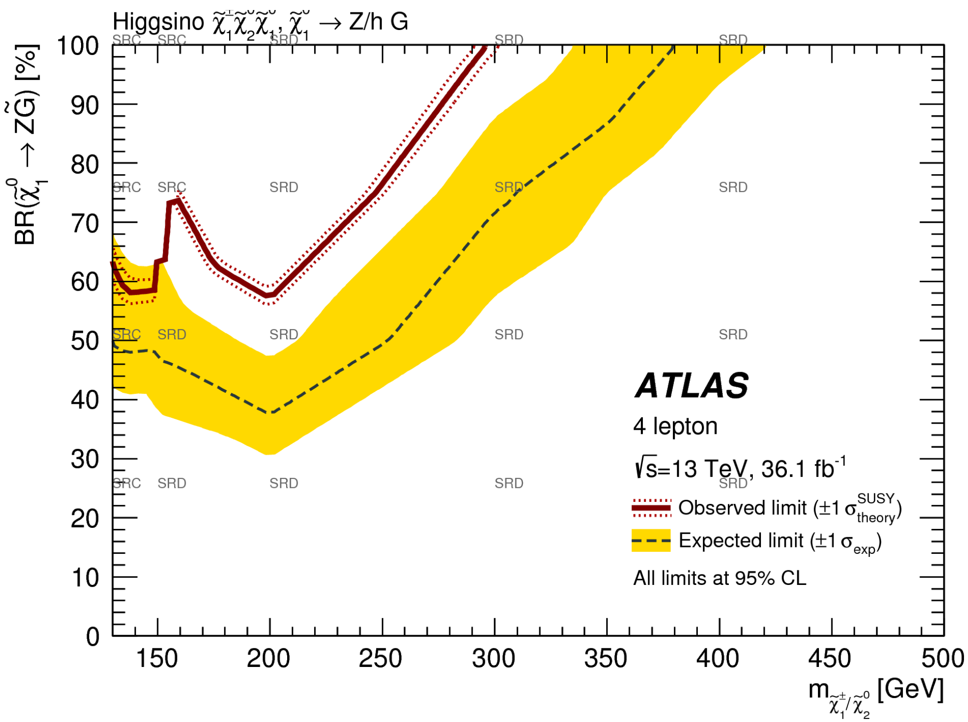
Region	$N(e,\mu)$	$N(\tau_{\text{had-vis}})$	$p_T\,(\tau_{\text{had-vis}})$	Z boson	Selection	Target
SR0A	≥ 4	$= 0$	> 20 GeV	veto	$m_{\text{eff}} > 600$ GeV	General
SR0B	≥ 4	$= 0$	> 20 GeV	veto	$m_{\text{eff}} > 1100$ GeV	RPV $LL\bar{E}12k$
SR0C	≥ 4	$= 0$	> 20 GeV	require 1st & 2nd	$E_T^{\text{miss}} > 50$ GeV	higgsino GGM
SR0D	≥ 4	$= 0$	> 20 GeV	require 1st & 2nd	$E_T^{\text{miss}} > 100$ GeV	higgsino GGM
SR1	$= 3$	≥ 1	> 30 GeV	veto	$m_{\text{eff}} > 700$ GeV	RPV $LL\bar{E}i33$
SR2	$= 2$	≥ 2	> 30 GeV	veto	$m_{\text{eff}} > 650$ GeV	RPV $LL\bar{E}i33$

arXiv:1804.03602, Phys. Rev. D 98, 032009 (2018)

New Physics interpretation

Sample	SR0A	SR0B	SR0C	SR0D	SR1	SR2
Observed	13	2	47	10	8	2
SM Total	10.2 ± 2.1	1.31 ± 0.24	37 ± 9	4.1 ± 0.7	4.9 ± 1.6	2.3 ± 0.8
ZZ	2.7 ± 0.7	0.33 ± 0.10	28 ± 9	0.84 ± 0.34	0.35 ± 0.09	0.33 ± 0.08
$t\bar{t}Z$	2.5 ± 0.6	0.47 ± 0.13	3.2 ± 0.4	1.62 ± 0.23	0.54 ± 0.11	0.31 ± 0.08
Higgs	1.2 ± 1.2	0.13 ± 0.13	0.9 ± 0.8	0.28 ± 0.25	0.5 ± 0.5	0.32 ± 0.32
VVV	0.79 ± 0.17	0.22 ± 0.05	2.7 ± 0.6	0.64 ± 0.14	0.18 ± 0.04	0.20 ± 0.06
Reducible	2.4 ± 1.4	$0.000^{+0.005}_{-0.000}$	$0.9^{+1.4}_{-0.9}$	$0.23^{+0.38}_{-0.23}$	3.1 ± 1.5	1.1 ± 0.7
Other	0.53 ± 0.06	0.165 ± 0.018	0.85 ± 0.19	0.45 ± 0.10	0.181 ± 0.022	0.055 ± 0.012
$\langle\epsilon\sigma\rangle^{95}_{obs}$ fb	0.32	0.14	0.87	0.36	0.28	0.13
S^{95}_{obs}	12	4.9	31	13	10	4.6
S^{95}_{exp}	$9.3^{+3.6}_{-2.3}$	$3.9^{+1.6}_{-0.8}$	23^{+8}_{-5}	$6.1^{+2.1}_{-1.3}$	$6.5^{+3.5}_{-1.3}$	$4.7^{+2.0}_{-1.3}$
CL_b	0.76	0.74	0.83	0.99	0.86	0.47
$p_{s=0}$	0.23	0.25	0.15	0.011	0.13	0.61
Z	0.75	0.69	1.0	2.3	1.2	0





2.3σ deviation from SM in 4lepton EWKino search in region sensitive to ≈200GeV

Still to be updated with 4x more data!

Combined Collider Constraints on Neutralinos and Charginos

arXiv: 1809.02097

GAMBIT: The Global And Modular BSM Inference Tool

gambit.hepforge.org   EPJC **77** (2017) 784   arXiv:1705.07908

- Extensive model database – not just SUSY
- Extensive observable/data libraries
- Many statistical and scanning options (Bayesian & frequentist)
- *Fast* LHC likelihood calculator
- Massively parallel
- Fully open-source
- Fast definition of new datasets and theories
- Plug and play scanning, physics and likelihood packages

Members of: ATLAS, Belle-II, CMS, CTA, *Fermi*-LAT, DARWIN, IceCube, LHCb, SHiP, XENON

Authors of: DarkSUSY, DDCalc, Diver, FlexibleSUSY, gamlike, GM2Calc, IsaJet, nulike, PolyChord, Rivet, SOFTSUSY, SuperIso, SUSY-AI, WIMPSim

Collaborators:
Peter Athron, Csaba Balázs, Ankit Beniwal, Florian Bernlochner, Sanjay Bloor, Torsten Bringmann, Andy Buckley, Eliel Camargo-Molina, Marcin Chrząszc, Jan Conrad, Jonathan Cornell, Matthias Danninger, Tom Edwards, Joakim Edsjö, Ben Farmer, Andrew Fowlie, Tomás Gonzalo, Will Handley, Sebastian Hoof, Selim Hotinli, Felix Kahlhoefer, Suraj Krishnamurthy, Anders Kvellestad, Julia Harz, Paul Jackson, Tong Li, Greg Martinez, Nazila Mahmoudi, James McKay, Are Raklev, Janina Renk, Chris Rogan, Roberto Ruiz de Austri, Patrick Stoecker, Roberto Trotta, Pat Scott, Nicola Serra, Daniel Steiner, Puwen Sun, Aaron Vincent, Christoph Weniger, Sebastian Wild, Martin White, Yang Zhang

40+ participants in 10 Experiments & 14 major theory codes

GAMBIT code structure

Models ⟷ **Core** ⟷ **ScannerBit**

Physics Modules

ColliderBit, DarkBit, FlavBit, PrecisionBit, SpecBit, DecayBit

Backends:

FlexibleSUSY, SPheno, FeynHiggs, HiggsBounds, HiggsSignals, PYTHIA, Delphes, BuckFast*, SUSYHit, DarkSUSY, micrOMEGAs, nuLike, DDCalc*, GamLike*, SuperISO, gm2Calc

Scanners:

MultiNest, Diver*, GreAT, twalk*

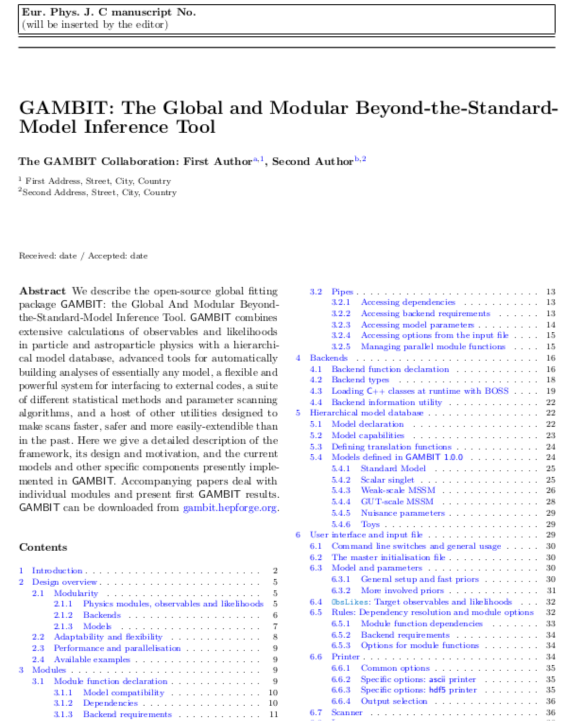
*New!

Model independent LHC limits

- Custom parallelised Pythia MC + custom detector sim
- Can generate 20,000 events on 12 cores in < 5 s (we use a lot more than that for recent papers)
- Then apply Poisson likelihood with nuisance parameters for systematics
- Combine analyses using best expected exclusion, unless public covariance matrix is available (CMS are being very helpful on this)

GAMBIT status

- GAMBIT was released as an ***open source public tool*** in 2017
- First physics studies include GUT-scale SUSY models, the MSSM7, axion models and Higgs portal dark matter models
- See **gambit.hepforge.org** for more info, all samples are available via **Zenodo**


Eur. Phys. J. C manuscript No.
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GAMBIT: The Global and Modular Beyond-the-Standard-Model Inference Tool

The GAMBIT Collaboration: First Author[a,1], Second Author[b,2]

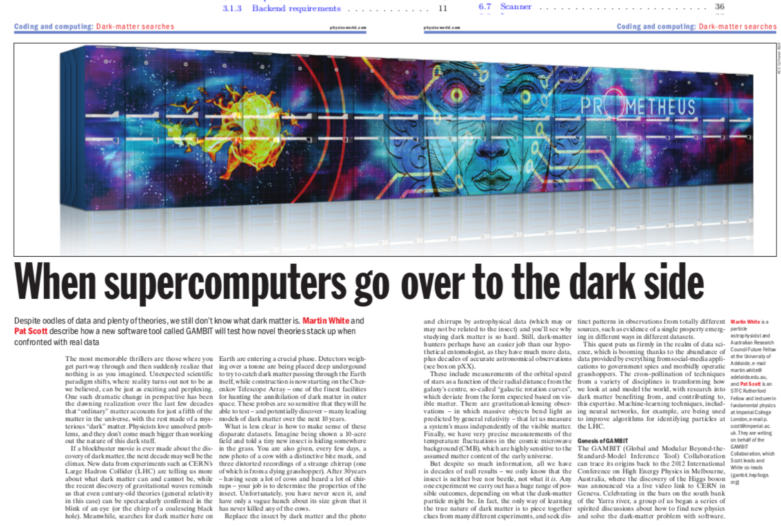
[1] First Address, Street, City, Country
[2] Second Address, Street, City, Country

Received: date / Accepted: date

Abstract We describe the open-source global fitting package GAMBIT: the Global And Modular Beyond-the-Standard-Model Inference Tool. GAMBIT combines extensive calculations of observables and likelihoods in particle and astroparticle physics with a hierarchical model database, advanced tools for automatically building analyses of essentially any model, a flexible and powerful system for interfacing to external codes, a suite of different statistical methods and parameter scanning algorithms, and a host of other utilities designed to make scans faster, safer and more easily-extendible than in the past. Here we give a detailed description of the framework, its design and motivation, and the current models and other specific components presently implemented in GAMBIT. Accompanying papers deal with individual modules and present first GAMBIT results. GAMBIT can be downloaded from gambit.hepforge.org.

Contents

1 Introduction . . . 2
2 Design overview . . . 5
2.1 Modularity . . . 5
2.1.1 Physics modules, observables and likelihoods . . . 5
2.1.2 Backends . . . 6
2.1.3 Models . . . 7
2.2 Adaptability and flexibility . . . 8
2.3 Performance and parallelisation . . . 9
2.4 Available examples . . . 9
3 Modules . . . 9
3.1 Module function declaration . . . 9
3.1.1 Model compatibility . . . 10
3.1.2 Dependencies . . . 10
3.1.3 Backend requirements . . . 11
3.2 Pipes . . . 13
3.2.1 Accessing dependencies . . . 13
3.2.2 Accessing backend requirements . . . 13
3.2.3 Accessing model parameters . . . 14
3.2.4 Accessing options from the input file . . . 15
3.2.5 Managing parallel module functions . . . 15
4 Backends . . . 16
4.1 Backend function declaration . . . 16
4.2 Backend types . . . 18
4.3 Loading C++ classes at runtime with BOSS . . . 19
4.4 Backend information utility . . . 22
5 Hierarchical model database . . . 22
5.1 Model declaration . . . 22
5.2 Model capabilities . . . 23
5.3 Defining translation functions . . . 24
5.4 Models defined in GAMBIT 1.0.0 . . . 24
5.4.1 Standard Model . . . 25
5.4.2 Scalar singlet . . . 25
5.4.3 Weak-scale MSSM . . . 26
5.4.4 GUT-scale MSSM . . . 28
5.4.5 Nuisance parameters . . . 29
5.4.6 Toys . . . 29
6 User interface and input file . . . 29
6.1 Command line switches and general usage . . . 30
6.2 The master initialisation file . . . 30
6.3 Model and parameters . . . 30
6.3.1 General setup and fast priors . . . 30
6.3.2 More involved priors . . . 31
6.4 ObsLikes: Target observables and likelihoods . . . 32
6.5 Rules: Dependency resolution and module options . . . 32
6.5.1 Module function dependencies . . . 33
6.5.2 Backend requirements . . . 34
6.5.3 Options for module functions . . . 34
6.6 Printer . . . 34
6.6.1 Common options . . . 35
6.6.2 Specific options: ascii printer . . . 35
6.6.3 Specific options: hdf5 printer . . . 35
6.6.4 Output selection . . . 36
6.7 Scanner . . . 36



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arXiv: 1809.02097

Eur. Phys. J. C manuscript No.
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CoEPP-MN-18-7

Combined collider constraints on neutralinos and charginos

The GAMBIT Collaboration: Peter Athron[1,2], Csaba Balázs[1,2], Andy Buckley[3], Jonathan M. Cornell[4], Matthias Danninger[5], Ben Farmer[6], Andrew Fowlie[1,2,9], Tomás E. Gonzalo[10], Julia Harz[11], Paul Jackson[2,12], Rose Kudzman-Blais[5], Anders Kvellestad[6,10,a], Gregory D. Martinez[13], Andreas Petridis[2,12], Are Raklev[10], Christopher Rogan[14], Pat Scott[6], Abhishek Sharma[2,12], Martin White[2,12,b], Yang Zhang[1,2]

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Received: date / Accepted: date

Abstract Searches for supersymmetric electroweakinos have entered a crucial phase, as the integrated luminosity of the Large Hadron Collider is now high enough to compensate for their weak production cross-sections. Working in a framework where the neutralinos and charginos are the only light sparticles in the Minimal Supersymmetric Standard Model, we use GAMBIT to perform a

relic density can be obtained through the Higgs-funnel and Z-funnel mechanisms, even assuming that all other sparticles are decoupled. All samples, GAMBIT input files and best-fit models from this study are available on Zenodo.

Contents

- The GAMBIT collaboration have recently performed the most comprehensive study of the MSSM electroweakino sector to date
- We focussed on collider constraints from LHC and LEP, but also looked at the implications for dark matter (precise implications depend on the mass scale of the sparticles that we decoupled)

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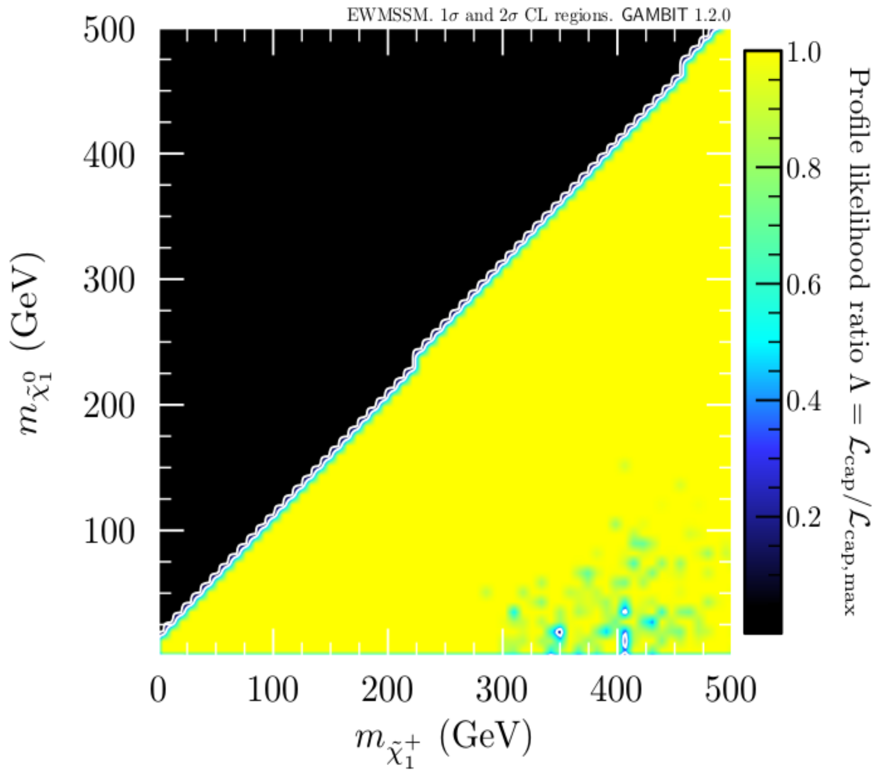
What if we assume there is no SUSY?

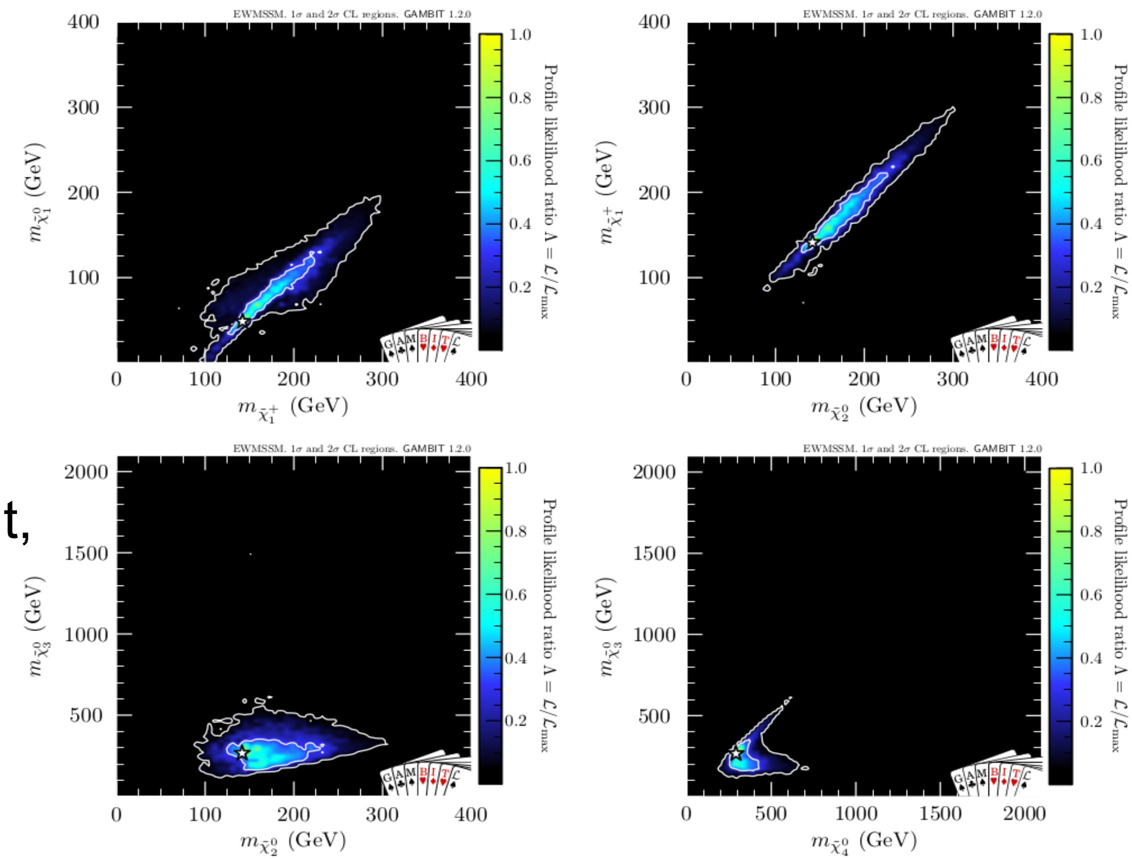
- We have the option of “capping” the LHC likelihood in our scan results, to prevent potential signals from providing a better fit to the data than the SM
- This amounts to testing the exclusion power of the included LHC searches
- We find ***no general constraint*** on the MSSM EW sector from the LHC in this case, and we also explain why (the searches are over-optimised on specific simplified SUSY models)



Uncapping the likelihood

- If we allow for the presence of a signal, our results get more interesting
- A particular mass scale is picked out by a series of anomalies in ATLAS and CMS searches
- All electroweakinos are light, and we either have:

Bino < winos < higgsinos
Or
Bino < higgsinos < winos



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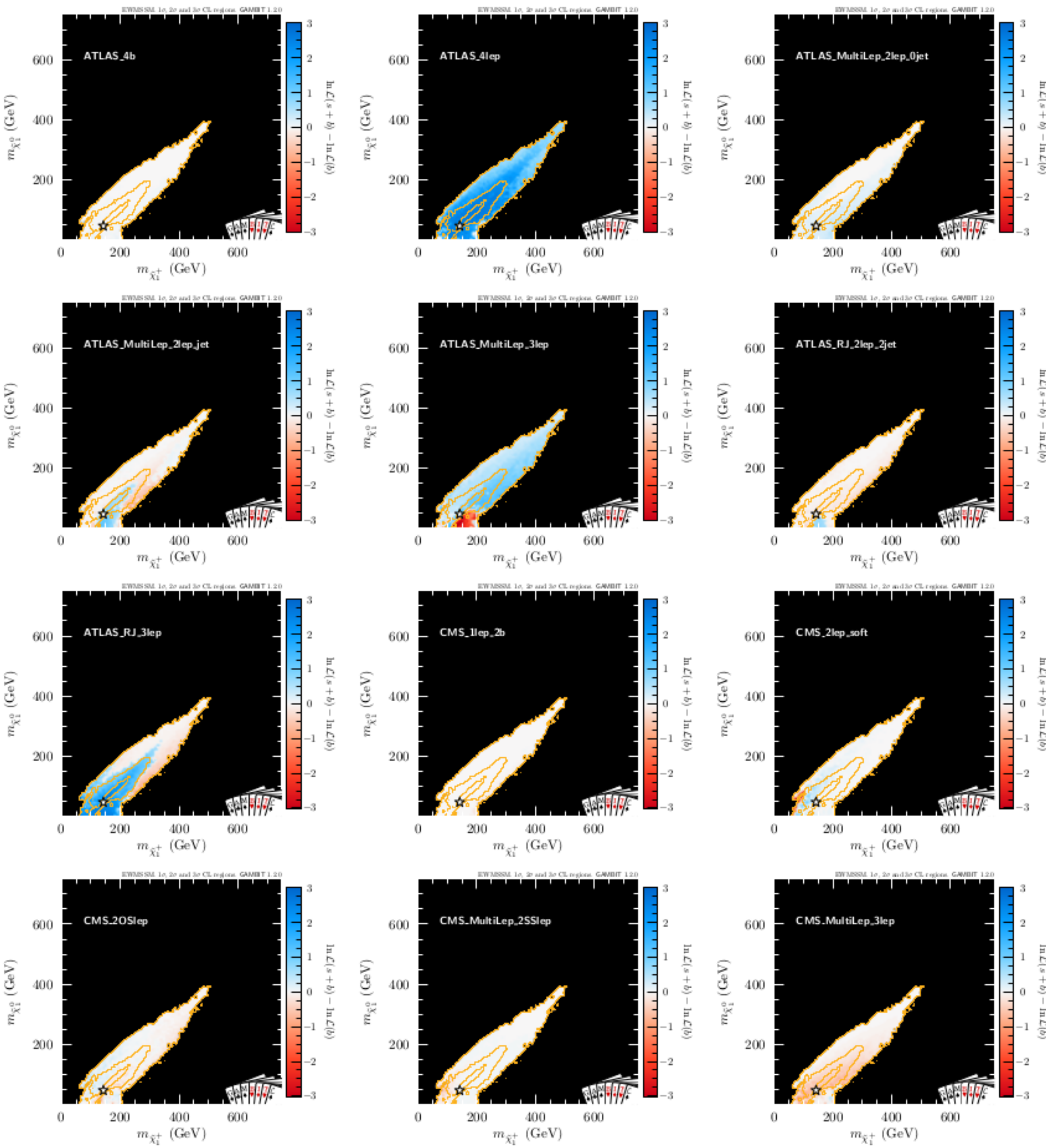
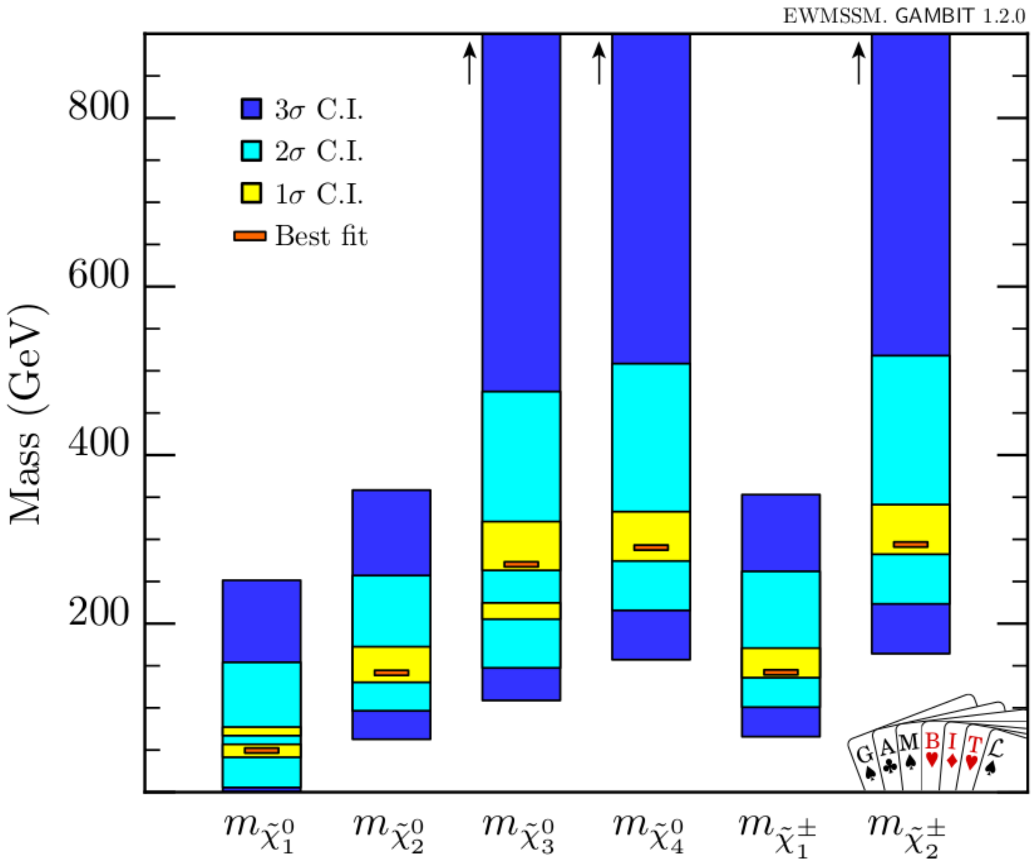


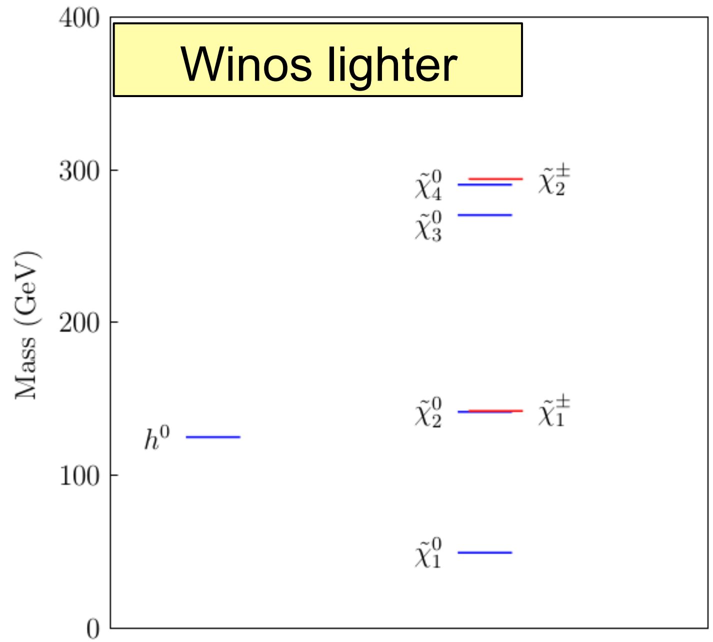
- **Contribution from each analysis** to the 1σ, 2σ and 3σ best-fit regions

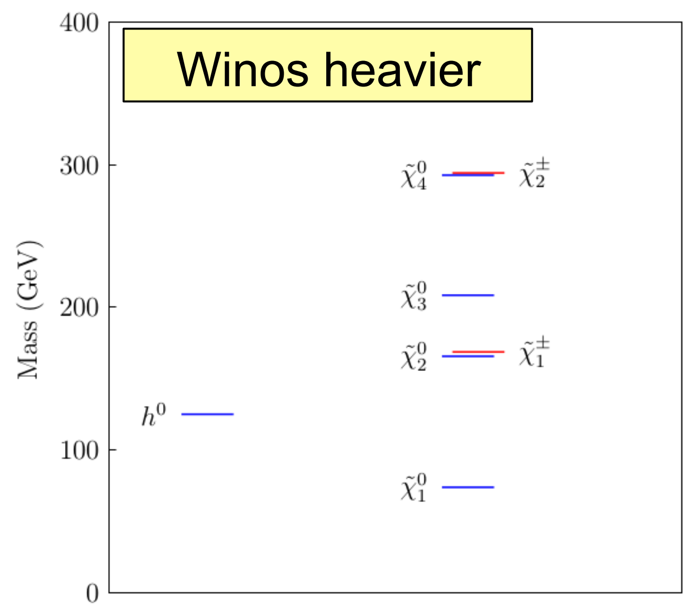
$$\ln \mathcal{L}(s+b) - \ln \mathcal{L}(b)$$

- **Blue**: **better** than background-only
  Red: **worse** than background-only

- Most important contributions to best-fit region:
  - **ATLAS_4lep**
  - **ATLAS_RJ_3lep**
  - **ATLAS_MultiLep_2lep_jet**
  - **ATLAS_MultiLep_3lep**
  - **CMS_MultiLep_3lep**

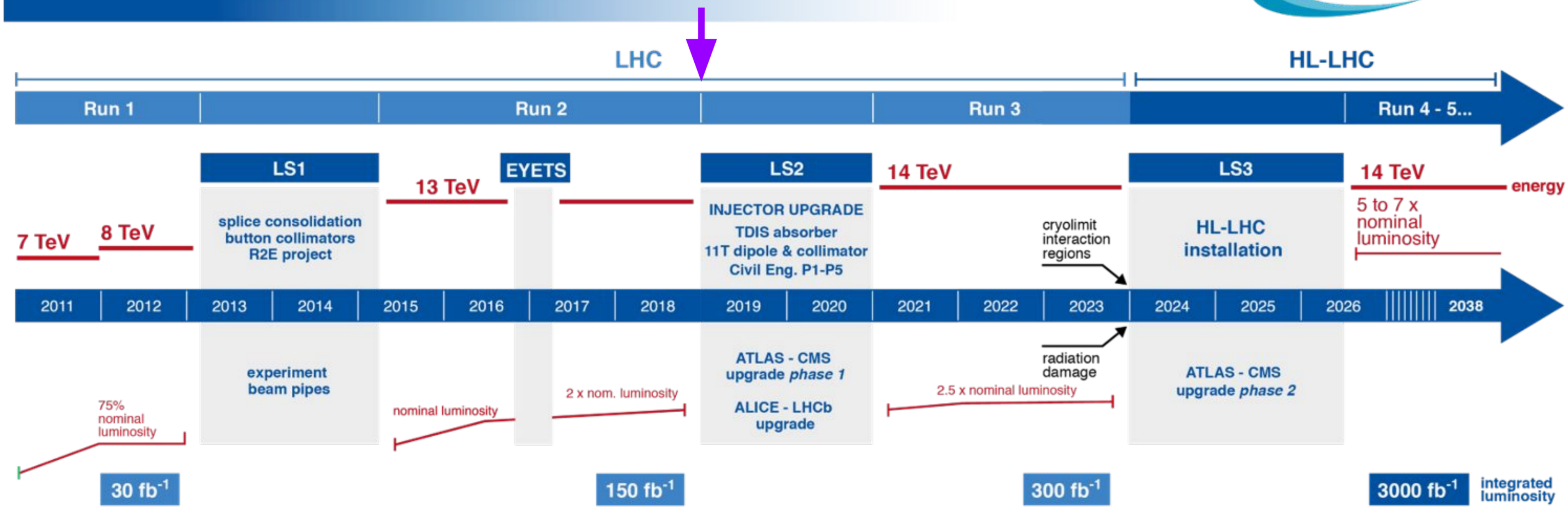






Best fit point from the GAMBIT analysis favours relatively light EWKinos (~100-200GeV) https://project-hl-lhc-industry.web.cern.ch/content/project-schedule

LHC / HL-LHC Plan



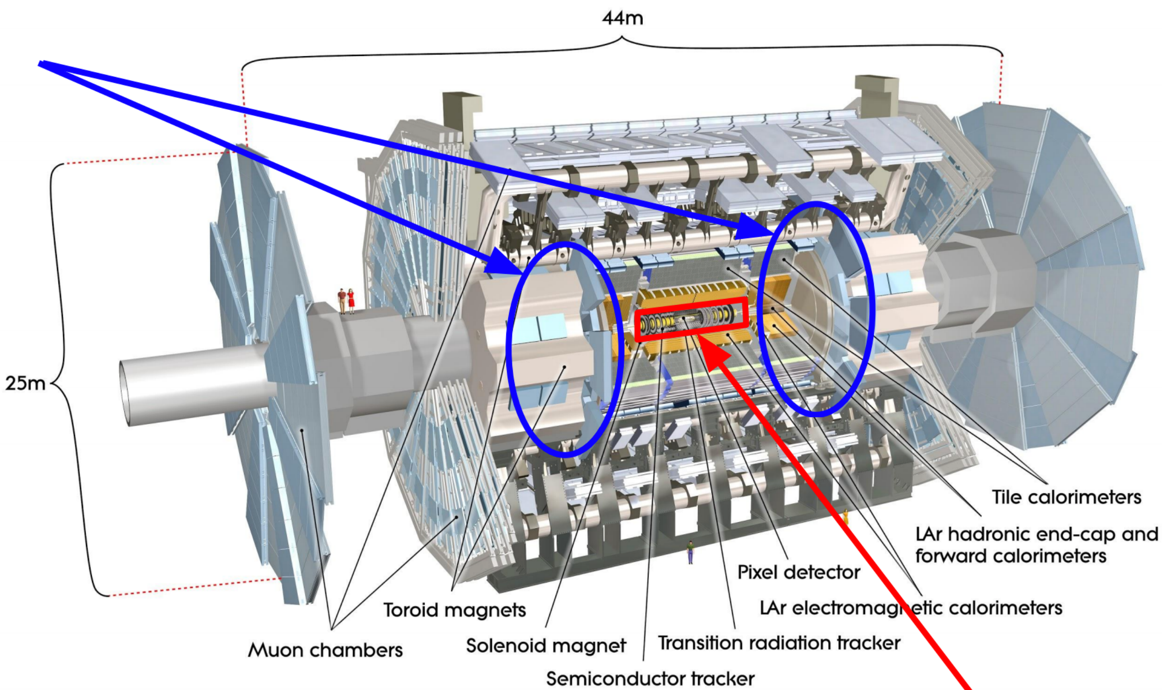
- LHC Run 1 and Run 2 have been completed.
  - Data analyses in full progress.
- LS2 (Long Shutdown 2019-2020) is about to start.
  - ATLAS Phase I Upgrade.
- LS3 (Long Shutdown 2024-2026) after Run 3.
  - LHC - Major Upgrade to HL-LHC (High Luminosity LHC).
  - ATLAS - Phase II Upgrade.

ATLAS Phase I Upgrade for LHC Run 3

- Run 3 LHC expectations: **$L = 3\times10^{24}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (int. $L = 300\ \mathrm{fb}^{-1}$) at $\sqrt{s} = 14$ TeV.**
- Need better trigger capabilities (efficiency and fake rejection).
- Maintain same acceptance and p_T thresholds with higher pile-up.

Muon System
New Small Wheel

Liquid Argon Calorimeter
Trigger Electronics FE & BE



Toroid and Solenoid Magnets

Tile Calorimeter

Inner Detector
TRT, SCT, Pixels
- Software
- Optical Readout

\+ **Trigger and Data Acquisition System**
Fast Tracker (FTK), Topological Triggers, High level Trigger, Common Readout, ...

Summary

- **The search for new physics at the LHC continues**
  - There is considerable scope to improve techniques and methods used to perform measurements and searches with the LHC data.
  - We have demonstrated this with one such method called *Recursive Jigsaw Reconstruction (RJR)*
  - We used RJR to execute a search in 3lepton and 2lepton+jets final states that yields one of the **largest excesses of any new physics search** performed by ATLAS (if real it may well be beyond 5σ with the full Run2 data).

  - These are included in a SUSY EWK-fit with GAMBIT, yielding results that point to a potential scale of new physics

CHEP 2019 – International Conference on Computing in High-Energy and Nuclear Physics

4-8 November, 2019
Adelaide, Australia

CoEPP
ARC Centre of Excellence for Particle Physics at the Terascale

SPECIAL RESEARCH CENTRE FOR THE SUBATOMIC STRUCTURE OF MATTER

Backup slides

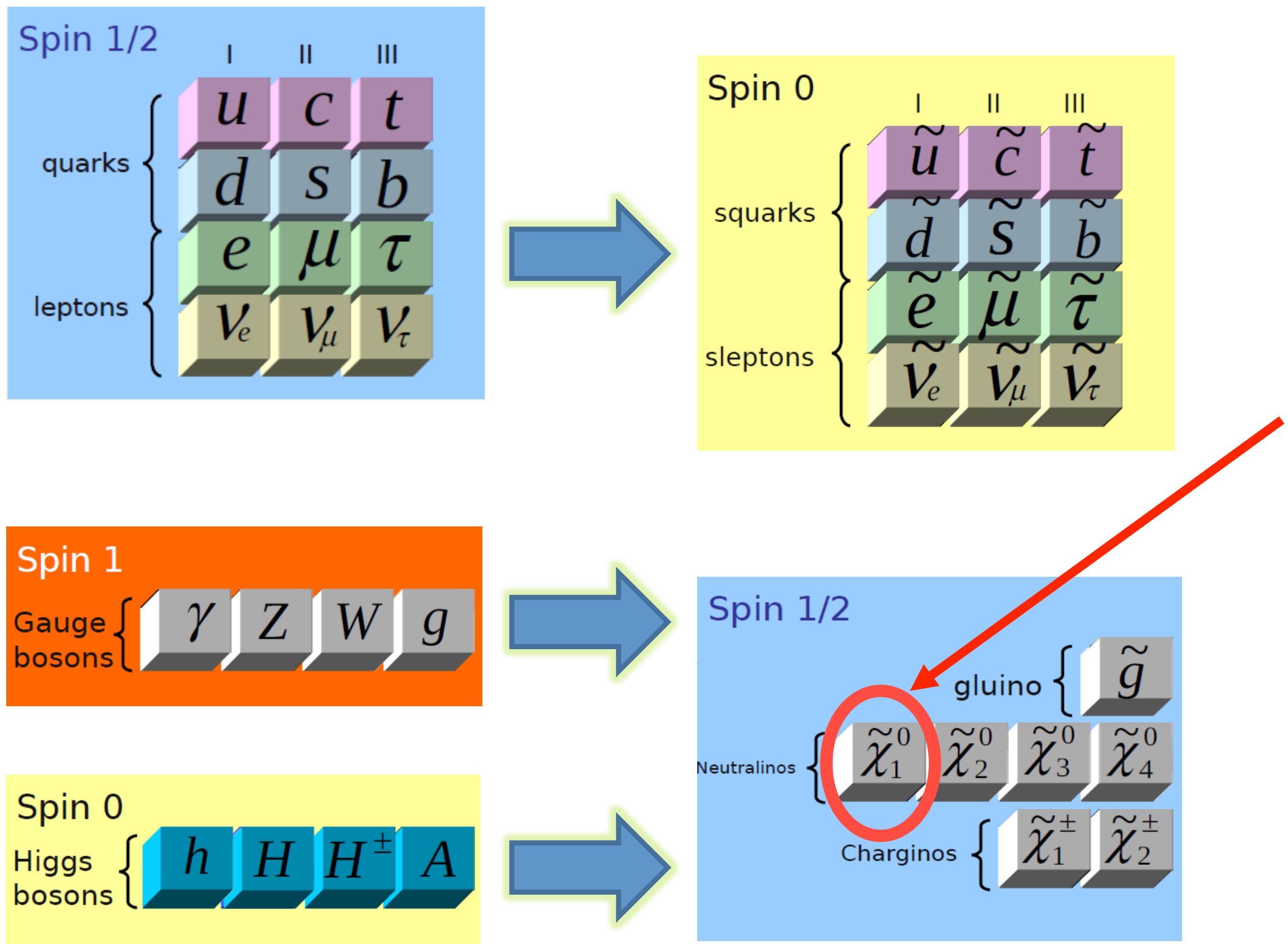
Questions we hear a lot from astrophysicicists

"We keep hearing that the lightest neutralino is a good dark matter candidate"

"You've spent almost a decade not seeing supersymmetry at the LHC"

"What are the LHC constraints on lightest neutralino dark matter?"

SUSY



The lightest neutralino is a natural dark matter candidate, and is the subject of most studies

illustration by M-H Genest

How the MSSM might appear...

Name	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	-1	$\widetilde{u}_L\ \widetilde{u}_R\ \widetilde{d}_L\ \widetilde{d}_R$	(same)
			$\widetilde{s}_L\ \widetilde{s}_R\ \widetilde{c}_L\ \widetilde{c}_R$	(same)
			$\widetilde{t}_L\ \widetilde{t}_R\ \widetilde{b}_L\ \widetilde{b}_R$	$\widetilde{t}_1\ \widetilde{t}_2\ \widetilde{b}_1\ \widetilde{b}_2$
sleptons	0	-1	$\widetilde{e}_L\ \widetilde{e}_R\ \widetilde{\nu}_e$	(same)
			$\widetilde{\mu}_L\ \widetilde{\mu}_R\ \widetilde{\nu}_\mu$	(same)
			$\widetilde{\tau}_L\ \widetilde{\tau}_R\ \widetilde{\nu}_\tau$	$\widetilde{\tau}_1\ \widetilde{\tau}_2\ \widetilde{\nu}_\tau$
neutralinos	1/2	-1	$\widetilde{B}^0\ \widetilde{W}^0\ \widetilde{H}_u^0\ \widetilde{H}_d^0$	$\widetilde{\chi}_1^0\ \widetilde{\chi}_2^0\ \widetilde{\chi}_3^0\ \widetilde{\chi}_4^0$
charginos	1/2	-1	$\widetilde{W}^\pm\ \widetilde{H}_u^+\ \widetilde{H}_d^-$	$\widetilde{\chi}_1^\pm\ \widetilde{\chi}_2^\pm$
gluino	1/2	-1	$\widetilde{g}$	(same)

Decoupled

Source: Anders Kvellestad

Parameters

Theory: parameter space

M_1 M_2 μ $\tan\beta$

Neutralinos

$$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$$

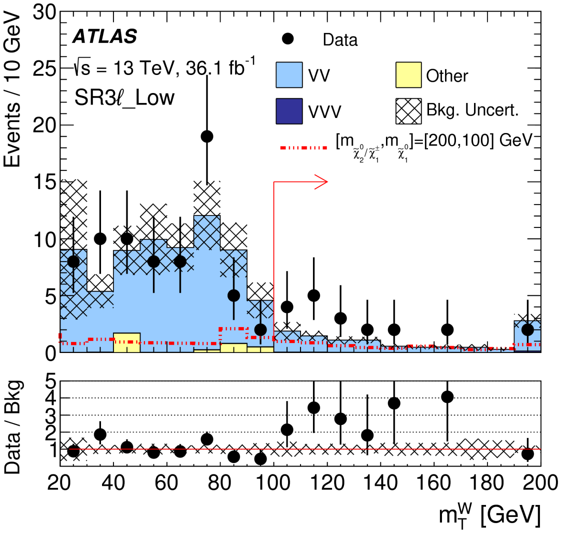
$$M_N = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g'vc_\beta & \frac{1}{2}g'vs_\beta \\ 0 & M_2 & \frac{1}{2}gvc_\beta & -\frac{1}{2}gvs_\beta \\ -\frac{1}{2}g'vc_\beta & \frac{1}{2}gvc_\beta & 0 & -\mu \\ \frac{1}{2}g'vs_\beta & -\frac{1}{2}gvs_\beta & -\mu & 0 \end{pmatrix}$$

Charginos

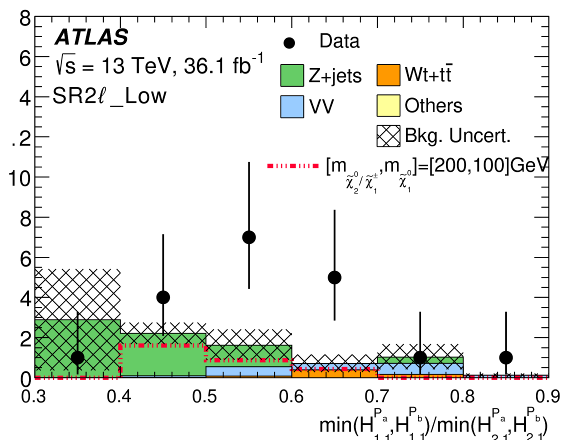
$$\psi^\pm = (\tilde{W}^+, \tilde{H}_u^+, \tilde{W}^-, \tilde{H}_d^-)$$

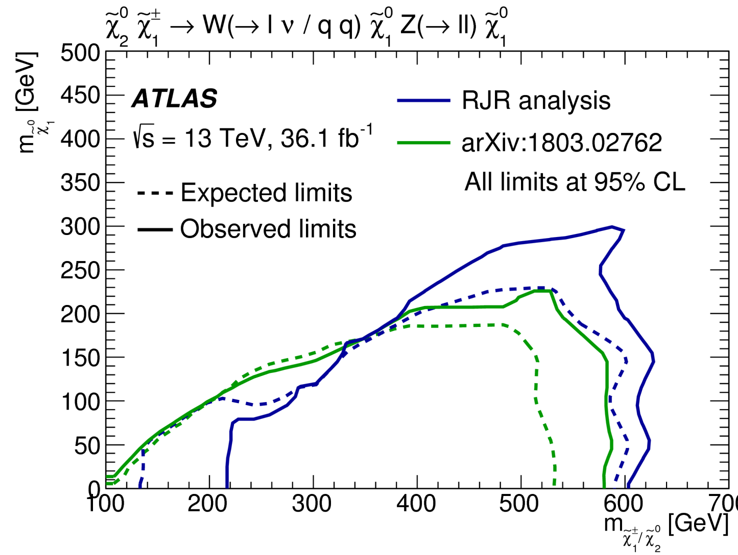
$$M_C = \begin{pmatrix} 0 & X^T \\ X & 0 \end{pmatrix}, \quad \text{where} \quad X = \begin{pmatrix} M_2 & \frac{gvs_\beta}{\sqrt{2}} \\ \frac{gvc_\beta}{\sqrt{2}} & \mu \end{pmatrix}.$$

Source: Anders Kvellestad



Excesses of 3.0, 2.0, 2.1 and 1.4 σ in the 3L ISR, 2L ISR, 3L low mass and 2L low mass respectively

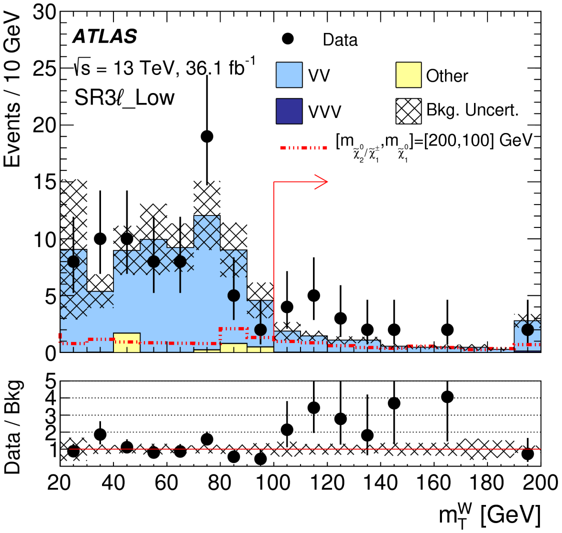




Largely unique selection of events compared to earlier analysis on same dataset

Exclusions for high mass reach 600 GeV and low mass points cannot be excluded due to excesses

Signal Region	$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$ [fb]	$S^{95}_{\rm obs}$	$S^{95}_{\rm exp}$	$p(s=0)$ (Z)
SR3ℓ_ISR	0.42	15.3	$6.9^{+3.1}_{-2.2}$	0.001 (3.02)
SR2ℓ_ISR	0.43	15.4	$9.7^{+3.6}_{-2.5}$	0.02 (1.99)
SR3ℓ_Low	0.53	19.1	$9.5^{+4.2}_{-1.8}$	0.016 (2.13)
SR2ℓ_Low	0.66	23.7	$16.1^{+6.3}_{-4.3}$	0.08 (1.39)



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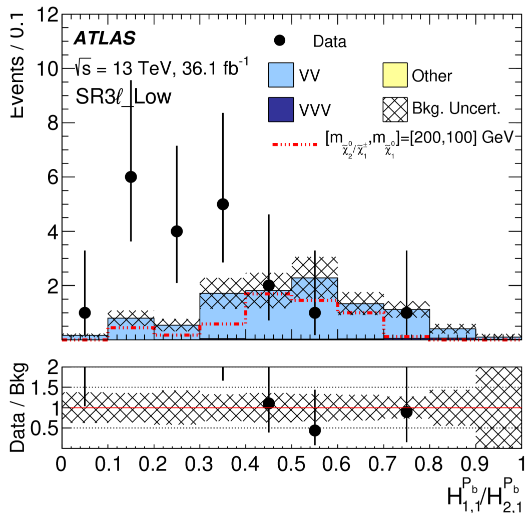

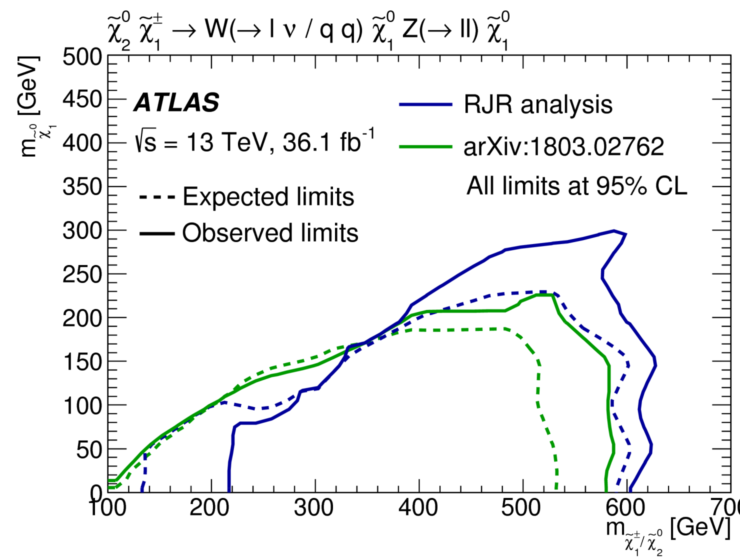

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2lepton Standard Tree Definitions

ATLAS EXPERIMENT

Region	n_{leptons}	n_{jets}	$n_{b\text{-tag}}$	$p_{\text{T}}^{\ell_1,\ell_2}$ [GeV]	$p_{\text{T}}^{j_1,j_2}$ [GeV]	$m_{\ell\ell}$ [GeV]	m_{jj} [GeV]	m_{T}^{W} [GeV]
CR2ℓ-VV	$\in [3,4]$	≥ 2	$=0$	> 25	> 30	$\in (80,100)$	> 20	$\in (70,100)$ if $n_{\text{leptons}} = 3$
CR2ℓ-Top	$= 2$	≥ 2	$=1$	> 25	> 30	$\in (80,100)$	$\in (40,250)$	–
VR2ℓ-VV	$= 2$	≥ 2	$=0$	> 25	> 30	$\in (80,100)$	$\in (40,70)$ or $\in (90,500)$	– –
VR2ℓ-Top	$= 2$	≥ 2	$=1$	> 25	> 30	$\in (20,80)$ or > 100	$\in (40,250)$	– –
VR2ℓ_High-Zjets	$= 2$	≥ 2	$= 0$	> 25	> 30	$\in (80,100)$	$\in (0,60)$ or $\in (100,180)$	– –
VR2ℓ_Low-Zjets	$= 2$	$= 2$	$= 0$	> 25	> 30	$\in (80,100)$	$\in (0,60)$ or $\in (100,180)$	– –
SR2ℓ_High	$= 2$	≥ 2	$= 0$	> 25	> 30	$\in (80,100)$	$\in (60,100)$	–
SR2ℓ_Int	$= 2$	≥ 2	$= 0$	> 25	> 30	$\in (80,100)$	$\in (60,100)$	–
SR2ℓ_Low	$= 2$	$= 2$	$= 0$	> 25	> 30	$\in (80,100)$	$\in (70,90)$	–

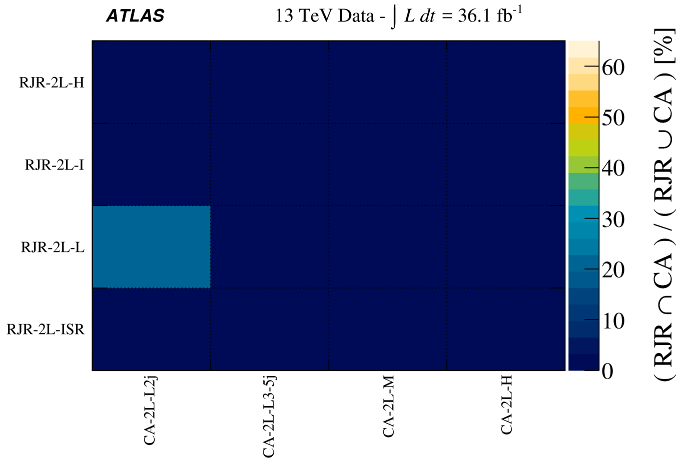
Region	$H_{4,1}^{\text{PP}}$ [GeV]	$H_{1,1}^{\text{PP}}$ [GeV]	$\frac{p_{\text{T PP}}^{\text{lab}}}{p_{\text{T PP}}^{\text{lab}} + H_{\text{T }4,1}^{\text{PP}}}$	$\frac{\min(H_{1,1}^{\text{P}_\text{a}}, H_{1,1}^{\text{P}_\text{b}})}{\min(H_{2,1}^{\text{P}_\text{a}}, H_{2,1}^{\text{P}_\text{b}})}$	$\frac{H_{1,1}^{\text{PP}}}{H_{4,1}^{\text{PP}}}$	$\Delta\phi_{\text{V}}^{\text{P}}$	$\min\Delta\phi(j_1/j_2, \vec{p}_{\text{T}}^{\text{ miss}})$
CR2ℓ-VV	> 200	–	< 0.05	> 0.2	–	$\in (0.3, 2.8)$	–
CR2ℓ-Top	> 400	–	< 0.05	> 0.5	–	$\in (0.3, 2.8)$	–
VR2ℓ-VV	> 400	> 250	< 0.05	$\in (0.4, 0.8)$	–	$\in (0.3, 2.8)$	–
VR2ℓ-Top	> 400	–	< 0.05	> 0.5	–	$\in (0.3, 2.8)$	–
VR2ℓ_High-Zjets	> 600	–	< 0.05	> 0.4	–	$\in (0.3, 2.8)$	–
VR2ℓ_Low-Zjets	> 400	–	< 0.05	–	$\in (0.35, 0.60)$	–	–
SR2ℓ_High	> 800	–	< 0.05	> 0.8	–	$\in (0.3, 2.8)$	–
SR2ℓ_Int	> 600	–	< 0.05	> 0.8	–	$\in (0.6, 2.6)$	–
SR2ℓ_Low	> 400	–	< 0.05	–	$\in (0.35, 0.60)$	–	> 2.4

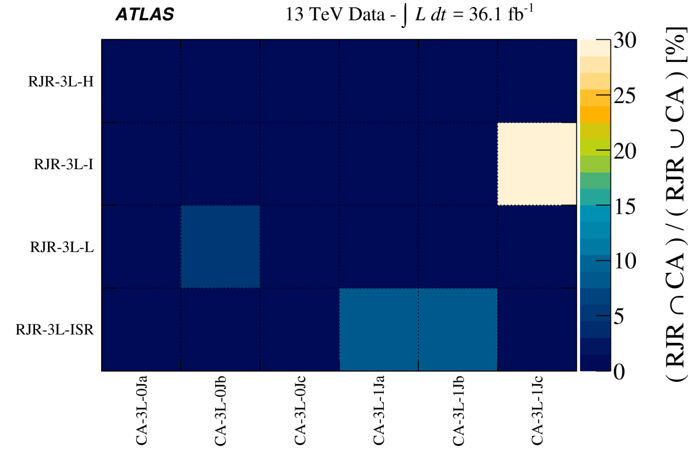
2lepton ISR Tree Definitions

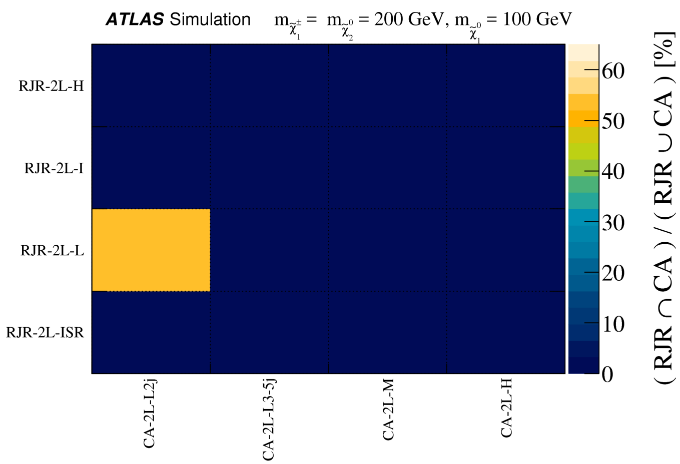
Region	n_{leptons}	$N_{\text{jet}}^{\text{ISR}}$	$N_{\text{jet}}^{\text{S}}$	n_{jets}	$n_{b\text{-tag}}$	$p_{\text{T}}^{\ell_1,\ell_2}$ [GeV]	$p_{\text{T}}^{j_1,j_2}$ [GeV]
CR2ℓ_ISR-VV	$\in [3,4]$	≥ 1	≥ 2	> 2	$= 0$	> 25	> 30
CR2ℓ_ISR-Top	$= 2$	≥ 1	$= 2$	$\in [3,4]$	$= 1$	> 25	> 30
VR2ℓ_ISR-VV	$\in [3,4]$	≥ 1	≥ 2	≥ 3	$= 0$	> 25	> 20
VR2ℓ_ISR-Top	$= 2$	≥ 1	$= 2$	$\in [3,4]$	$= 1$	> 25	> 30
VR2ℓ_ISR-Zjets	$= 2$	≥ 1	≥ 1	$\in [3,5]$	$= 0$	> 25	> 30
SR2ℓ_ISR	$= 2$	≥ 1	$= 2$	$\in [3,4]$	$= 0$	> 25	> 30

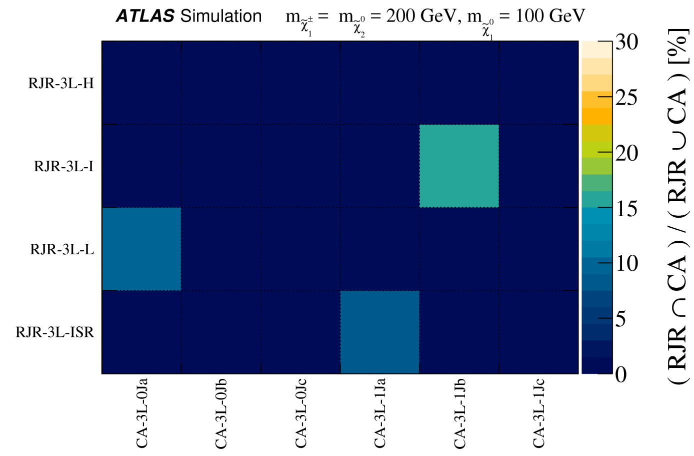
Region	m_Z [GeV]	m_J [GeV]	$\Delta\phi_{\text{ISR,I}}^{\text{CM}}$	R_{ISR}	$p_{\text{T ISR}}^{\text{CM}}$ [GeV]	$p_{\text{T I}}^{\text{CM}}$ [GeV]	p_{T}^{CM} [GeV]
CR2ℓ_ISR-VV	$\in (80,100)$	> 20	> 2.0	$\in (0.0,0.5)$	> 50	> 50	< 30
CR2ℓ_ISR-Top	$\in (50,200)$	$\in (50,200)$	> 2.8	$\in (0.4,0.75)$	> 180	> 100	< 20
VR2ℓ_ISR-VV	$\in (20,80)$ or > 100	> 20	> 2.0	$\in (0.0,1.0)$	> 70	> 70	< 30
VR2ℓ_ISR-Top	$\in (50,200)$	$\in (50,200)$	> 2.8	$\in (0.4,0.75)$	> 180	> 100	> 20
VR2ℓ_ISR-Zjets	$\in (80,100)$	< 50 or > 110	–	–	> 180	> 100	< 20
SR2ℓ_ISR	$\in (80,100)$	$\in (50,110)$	> 2.8	$\in (0.4,0.75)$	> 180	> 100	< 20

Overlap Plots



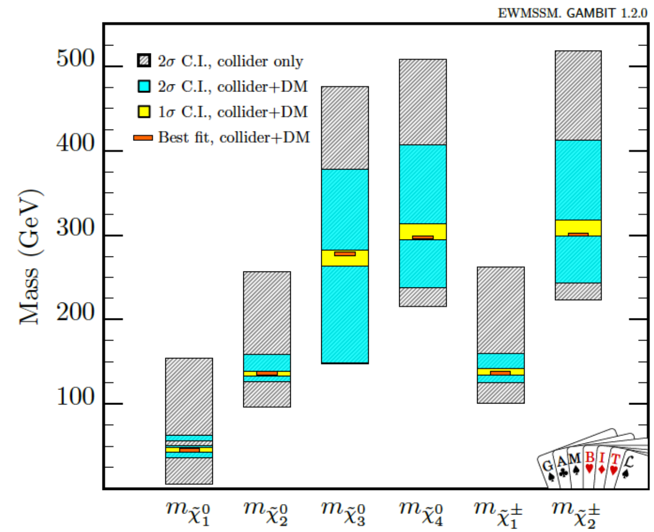


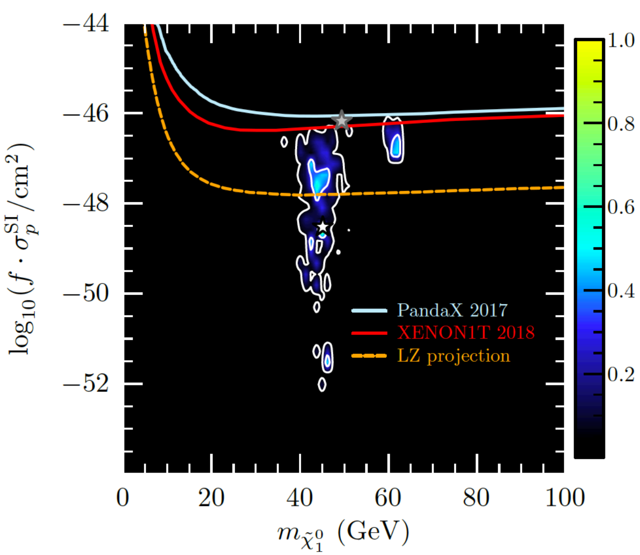




GAMBIT collaboration performed a global electroweak fit using available collider and direct DM constraints

Analysis	Best expected SRs: Local signif. (σ)	SM fit (σ)	EWMSSM fit (σ)	#SRs	All SRs; neglect correlations: Local signif. (σ)	SM fit (σ)	EWMSSM fit (σ)	#SRs
Higgs invisible width	0.9	0.3	0.2	1	0.9	0.3	0.2	1
Z invisible width	0	1.3	1.3	1	0	1.3	1.3	1
ATLAS_4b	0.7	0	0	1	2.1	0	0	2*
ATLAS_4lep	2.3	2.0	0	1	2.5	1.0	0	4
ATLAS_MultiLep_2lep_0jet	0.9	0.3	0.1	1	1.3	0	0	6
ATLAS_MultiLep_2lep_jet	0	0	0.5	1	0.8	0.5	0.3	3
ATLAS_MultiLep_3lep	1.8	1.6	0.6	1	1.2	0.4	0.3	11
ATLAS_RJ_2lep_2jet	0	0.3	0.5	1	1.5	1.8	1.5	4
ATLAS_RJ_3lep	2.8	2.4	1.0	1	3.5	2.6	0.5	4
CMS_1lep_2b	0.9	0.3	0.3	1	0	0	0	2
CMS_2lep_soft	0.4	0.2	0.2	12	0.4	0.2	0.2	12
CMS_2OSlep	0	0.4	0.6	7	0	0.4	0.6	7
CMS_MultiLep_2SSlep	0.2	0	0	1	0.2	0	0	2
CMS_MultiLep_3lep	0	0	0.5	1	0	0	0	6
Combined	3.5	1.5	0.3	31	4.2	1.3	0	65





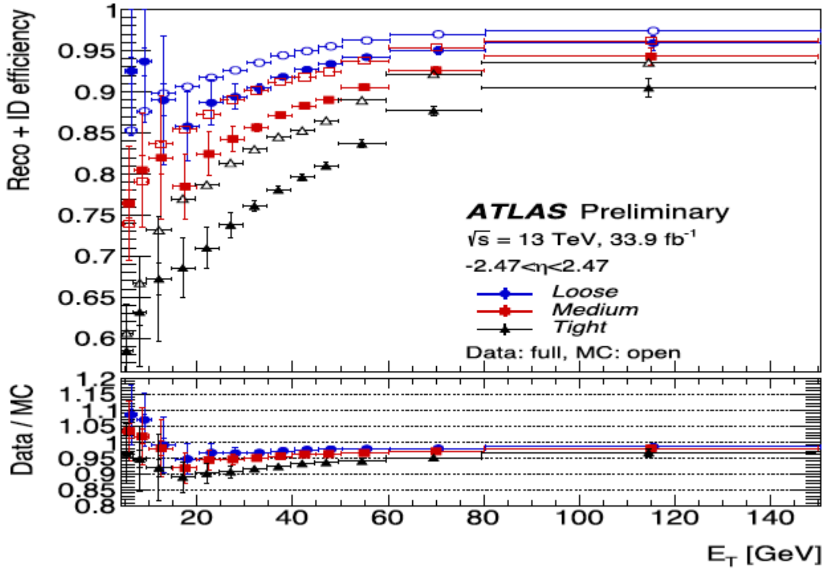
Our best-fit point has neutralino masses of $(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\chi}_3^0}, m_{\tilde{\chi}_4^0}) \approx (49.4, 141.6, 270.3, 290.2)$ GeV, and chargino masses of $(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_2^\pm}) \approx (142.1, 293.9)$ GeV. We find a local significance of 3.5σ for this excess. If there is indeed a supersymmetric signal resembling these properties the ATLAS and CMS experiments should be sensitive to it using the full LHC Run 2 dataset.

* GAMBIT: The Global and Modular Beyond-the-Standard-Model Inference Tool, Eur. Phys. J. C 77 (2017) 784, [arXiv:1705.07908].

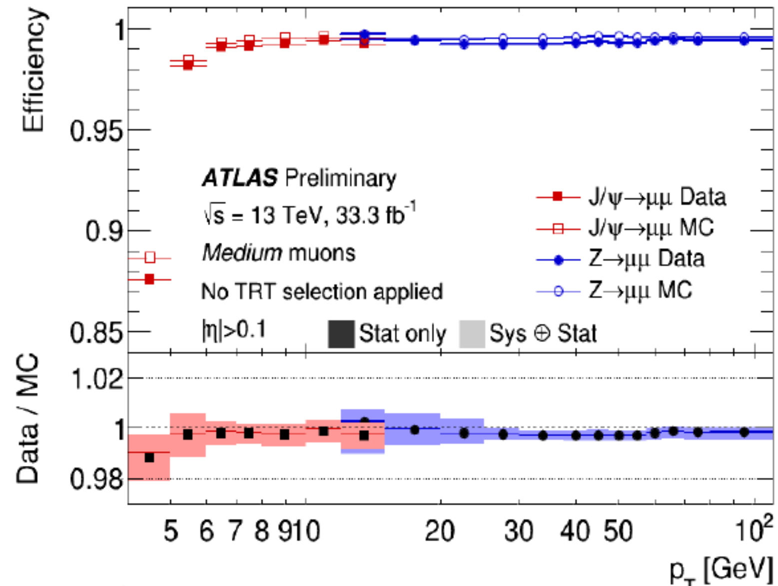
Detector Performance Highlights

ATLAS EXPERIMENT

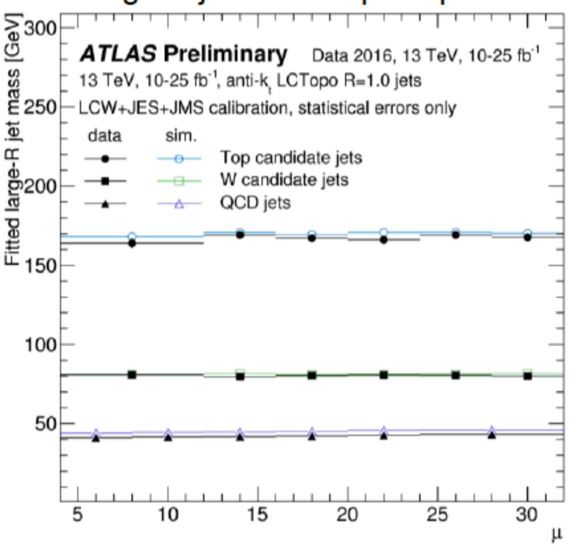
Electron performance measured down to 4.5 GeV



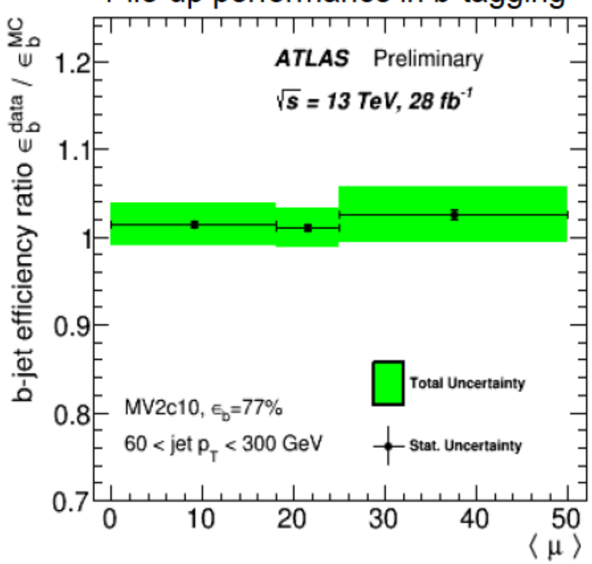
Muon performance measured down to 4 GeV



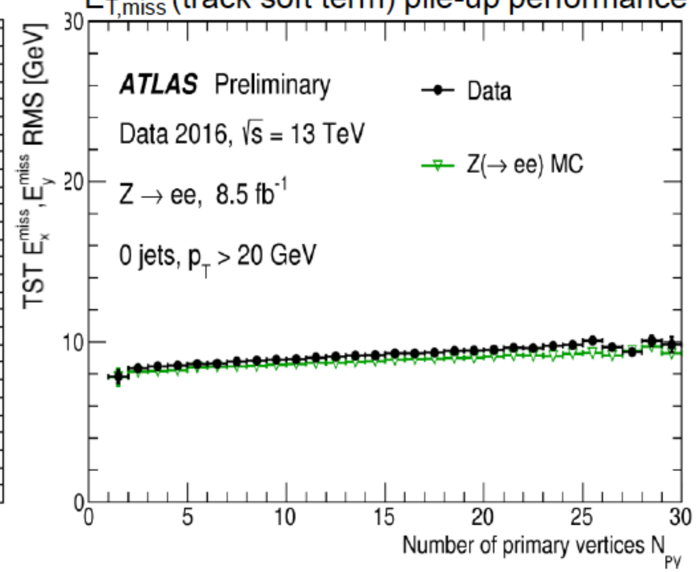
Large-R jet masses pile-up robust



Pile-up performance in b-tagging



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



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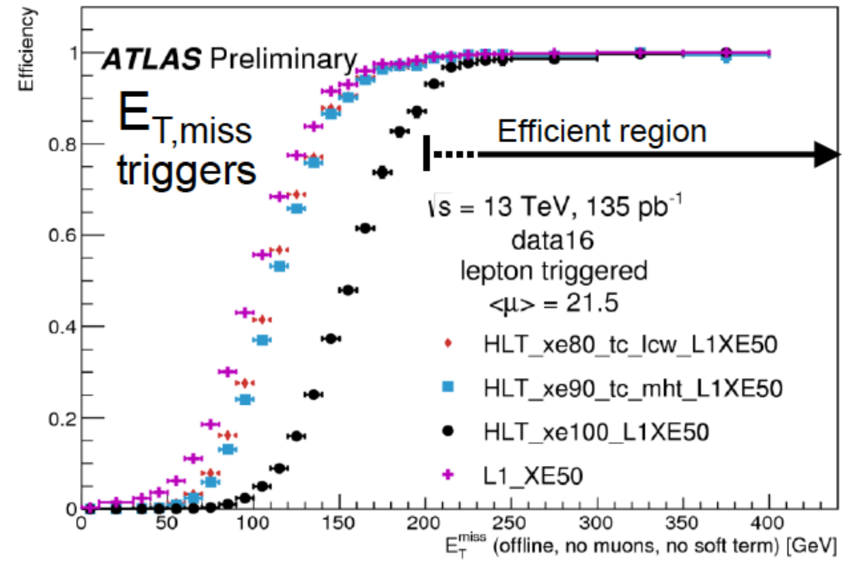
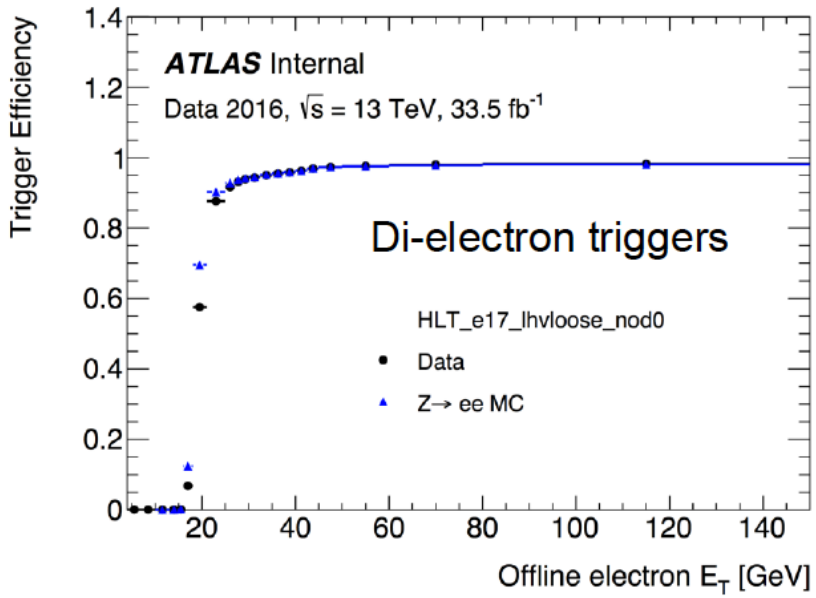
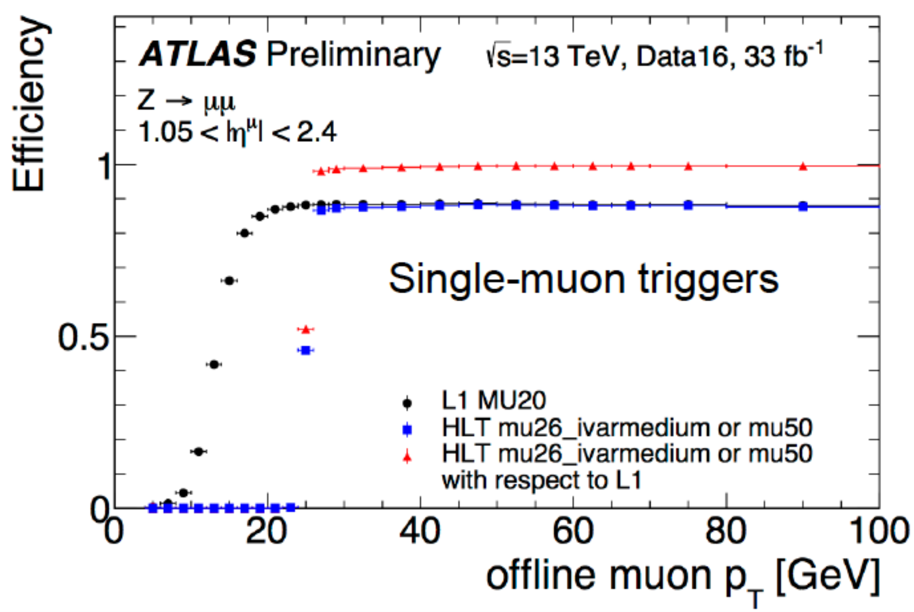
CoEPP ARC Centre of Excellence for Particle Physics at the Terascale

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**







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Inclusive 0lepton -complementarity

ATLAS EXPERIMENT

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

$H_T = \Sigma p_T^{jet}$,
$m_{eff} = H_T + E_{T,miss}$

m_{eff}-based Analysis Stream

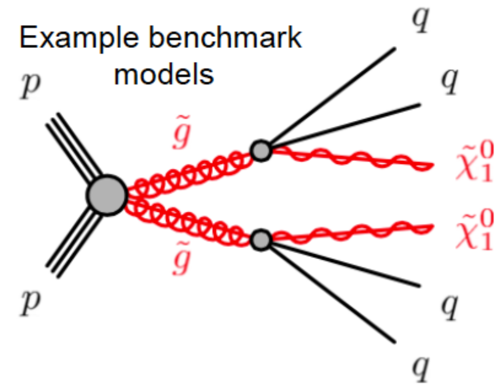
- **24 inclusive SRs** using the *effective mass* as final discriminant:
  - ≥2/3 jet regions → **direct** squark decays
  - ≥4/5 jet regions → **direct** gluino decays
  - ≥5/6 jet regions → gluino/squark decays **via $\chi^{\pm}$** with W bosons
  - ≥2 **large-R** jets → gluino/squark decays with **boosted**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

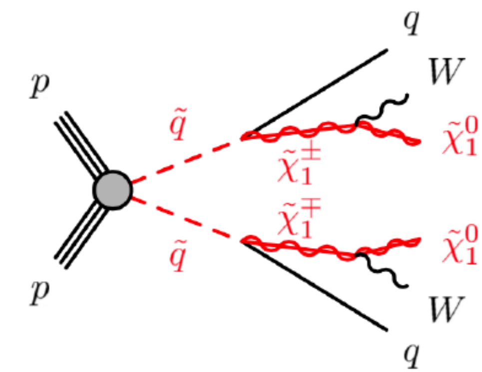
↕ not orthogonal but complementary

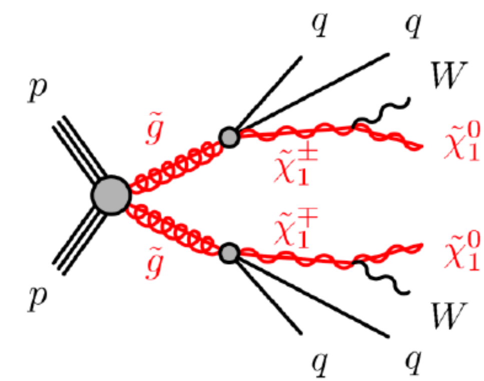
Recursive Jigsaw Analysis Stream

- **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

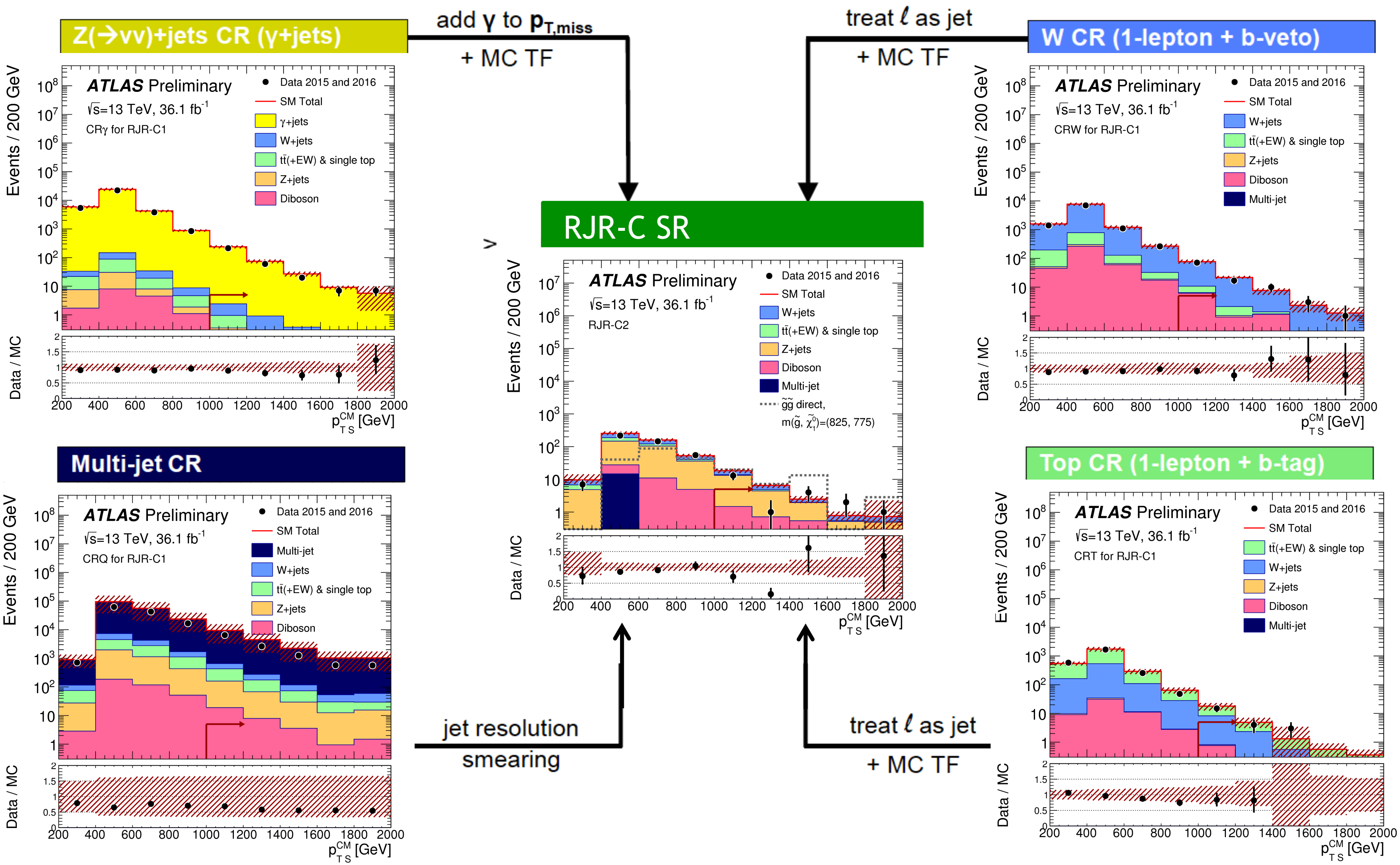






Inclusive 0lepton search - backgrounds

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



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ARC Centre of Excellence for Particle Physics at the Terascale

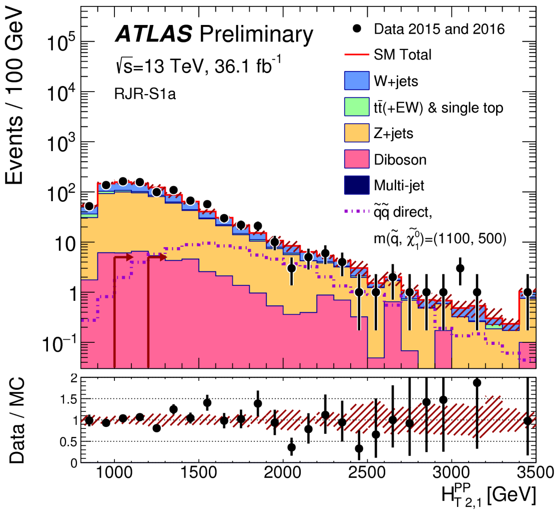
ATLAS EXPERIMENT

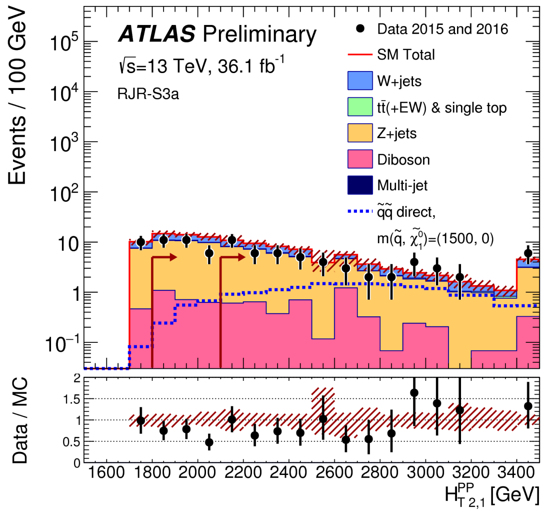
Example for gluino pair production with decays to jets and E_T^{miss}

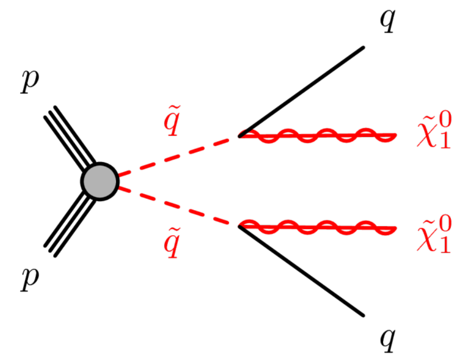
Fit components estimate the total background.
This is compared to the observed yield in the various signal region

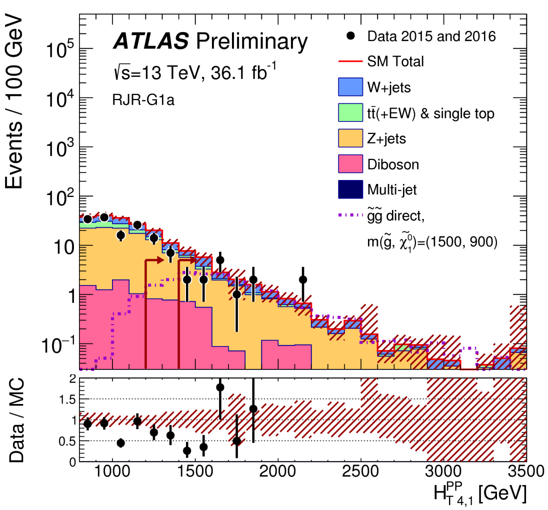
Signal Region	RJR-G1a	RJR-G1b	RJR-G2a	RJR-G2b	RJR-G3a	RJR-G3b	RJR-G4
MC expected events							
Diboson	3.06	1.54	2.91	1.34	0.80	0.37	0.24
Z/γ^*+jets	28.56	13.03	28.01	9.41	8.56	2.90	2.05
W+jets	13.99	6.40	14.66	4.98	4.45	1.71	0.99
$t\bar{t}$(+EW) + single top	6.04	1.96	6.50	1.99	2.74	1.32	0.97
Fitted background events							
Diboson	3.1 ± 0.6	1.5 ± 0.4	2.9 ± 0.8	1.34 ± 0.34	0.8 ± 0.24	0.37 ± 0.22	0.24 ± 0.13
Z/γ^*+jets	23.9 ± 3.0	10.9 ± 1.5	23.6 ± 2.8	7.9 ± 1.1	7.22 ± 1.0	2.5 ± 0.6	1.73 ± 0.33
W+jets	11.4 ± 1.7	5.2 ± 0.8	11.7 ± 2.1	4.0 ± 0.7	3.5 ± 0.7	1.4 ± 0.6	0.79 ± 0.27
$t\bar{t}$(+EW) + single top	4.8 ± 2.1	1.6 ± 1.1	5.6 ± 2.8	1.7 ± 1.0	2.4 ± 1.1	$1.14^{+1.20}_{-1.14}$	$0.83^{+1.19}_{-0.83}$
Multi-jet	[illegible]		[illegible]	[illegible]			
Total bkg	43 ± 4	19.2 ± 2.2	44 ± 4	15.2 ± 1.7	13.9 ± 1.6	5.3 ± 1.4	3.6 ± 1.3
Observed	38	16	48	15	19	11	6
$\langle\epsilon\sigma\rangle^{95}_{obs}$ [fb]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
S^{95}_{obs}	13.9	9.4	20.1	10.0	14.5	13.6	9.1
S^{95}_{exp}	$16.2^{+6.6}_{-4.9}$	$10.7^{+4.1}_{-2.8}$	$17.4^{+5.4}_{-5.5}$	$9.5^{+4.2}_{-2.4}$	$9.7^{+4.0}_{-2.1}$	$10.2^{+3.8}_{-1.4}$	$7.6^{+2.3}_{-1.7}$
p_0 (Z)	0.50 (0.00)	0.50 (0.00)	0.23 (0.73)	0.50 (0.00)	0.09 (1.36)	0.12 (1.15)	0.18 (0.90)

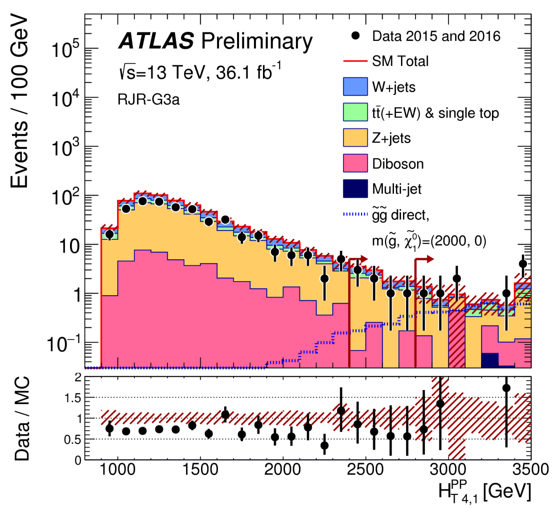
Signal region – 0lepton search results!

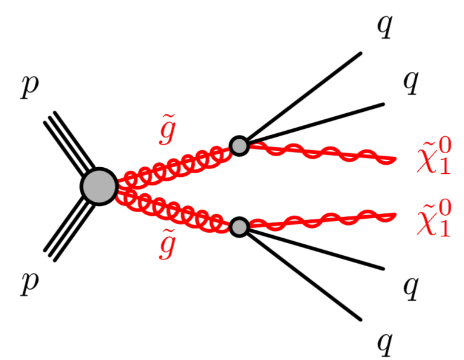






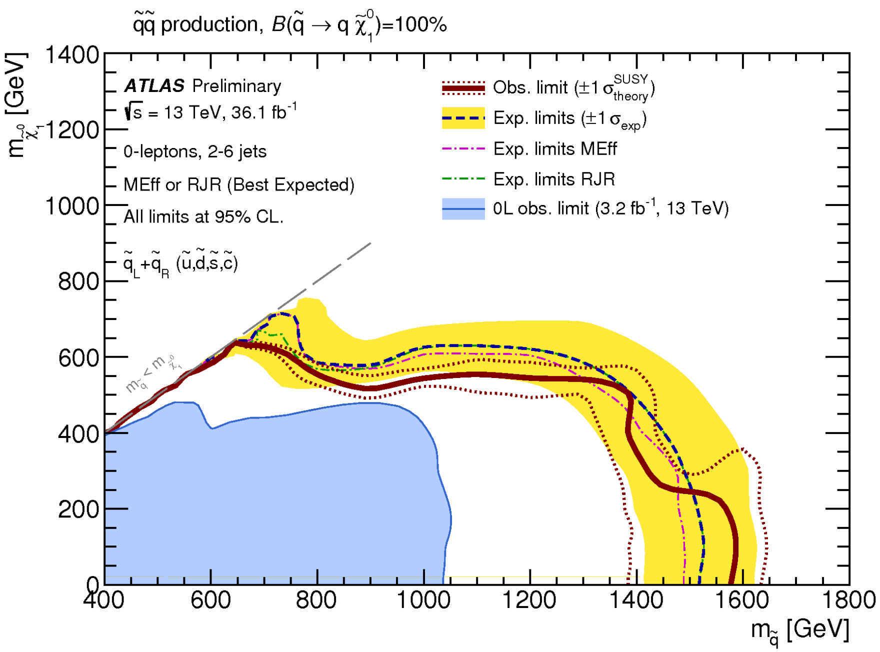


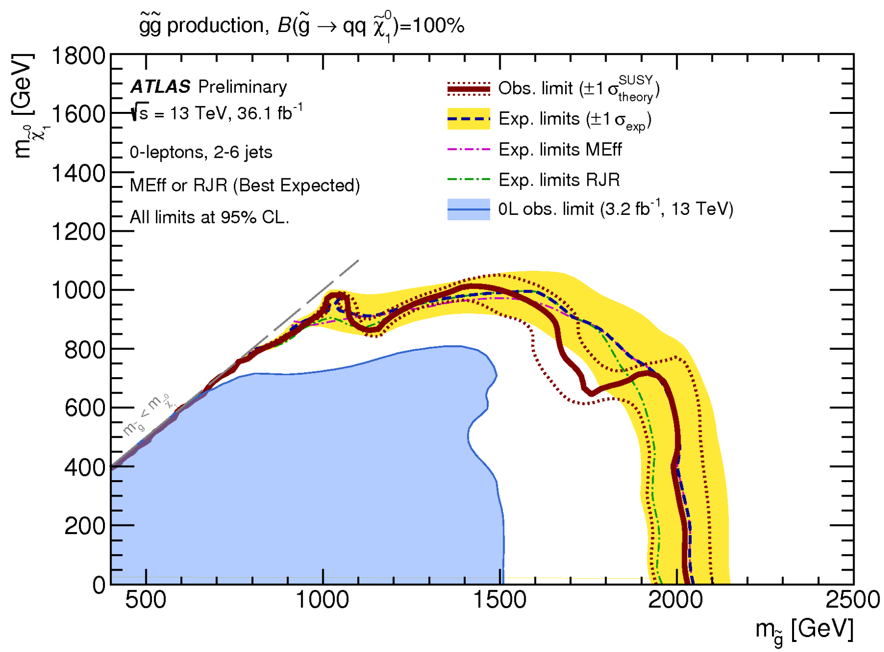




Good improvement on the parameter space we're now probing wrt run1 ☺

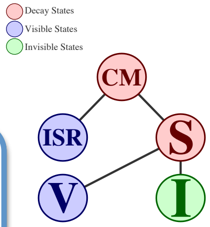
Still no clear signal ☹



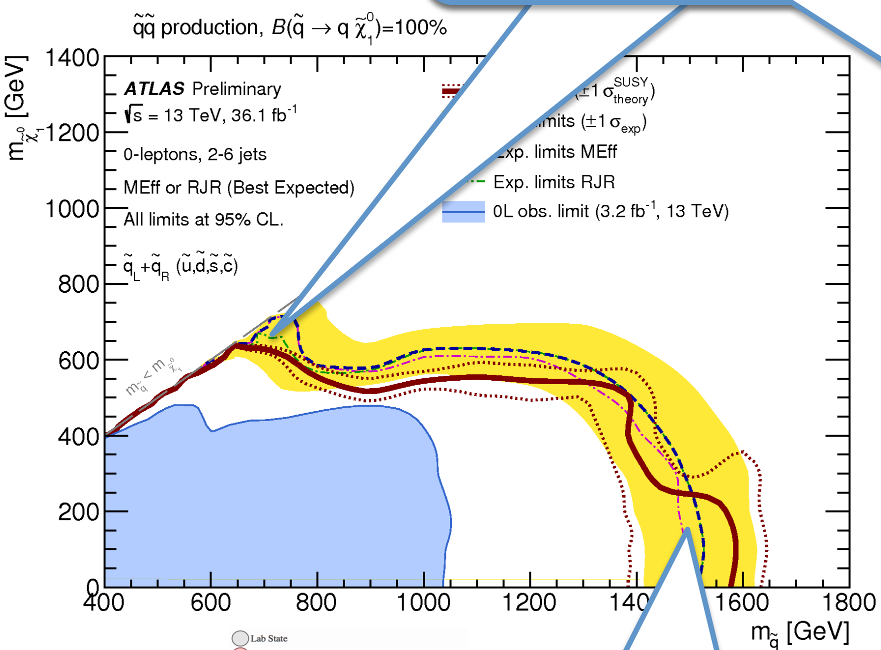


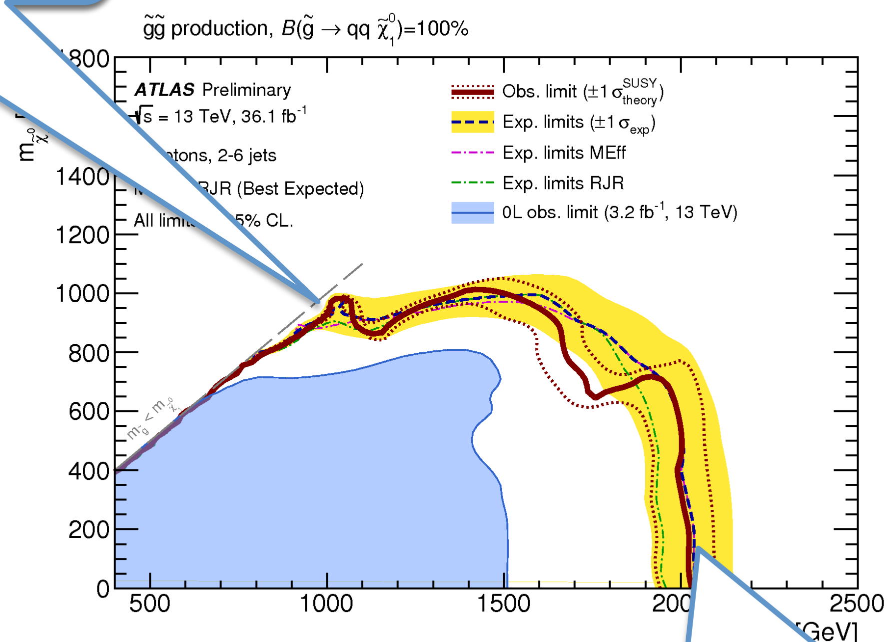
Phys. Rev. D 97, 112001 (2018)

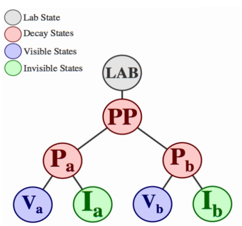
Signal region – 0lepton results!



Recursive Jigsaw for compressed regions



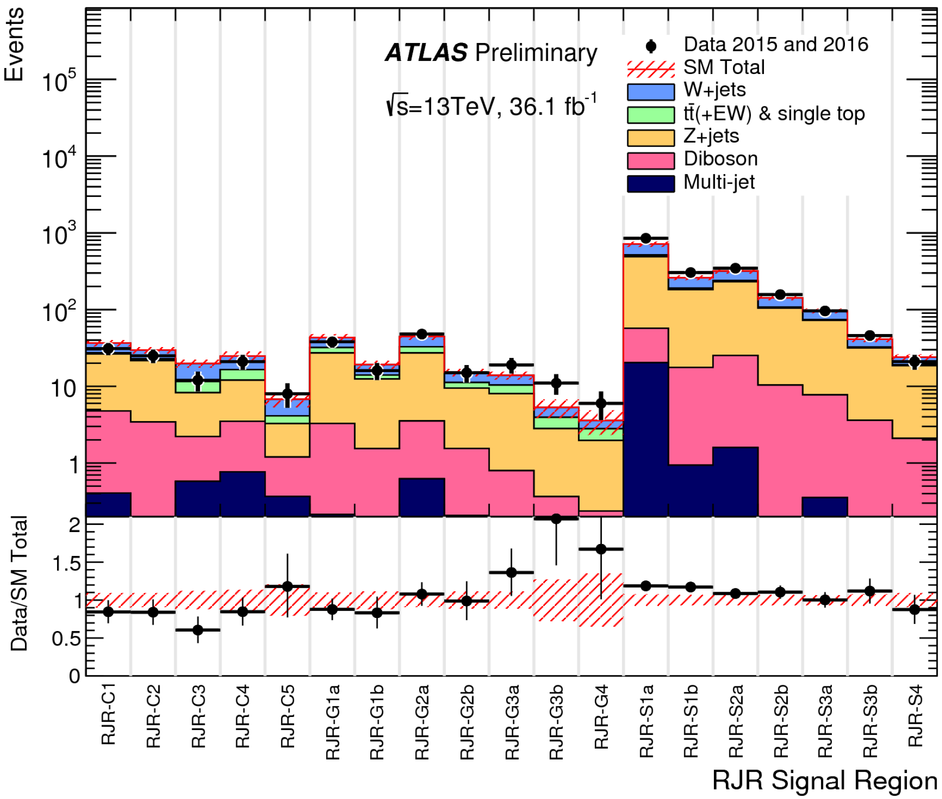


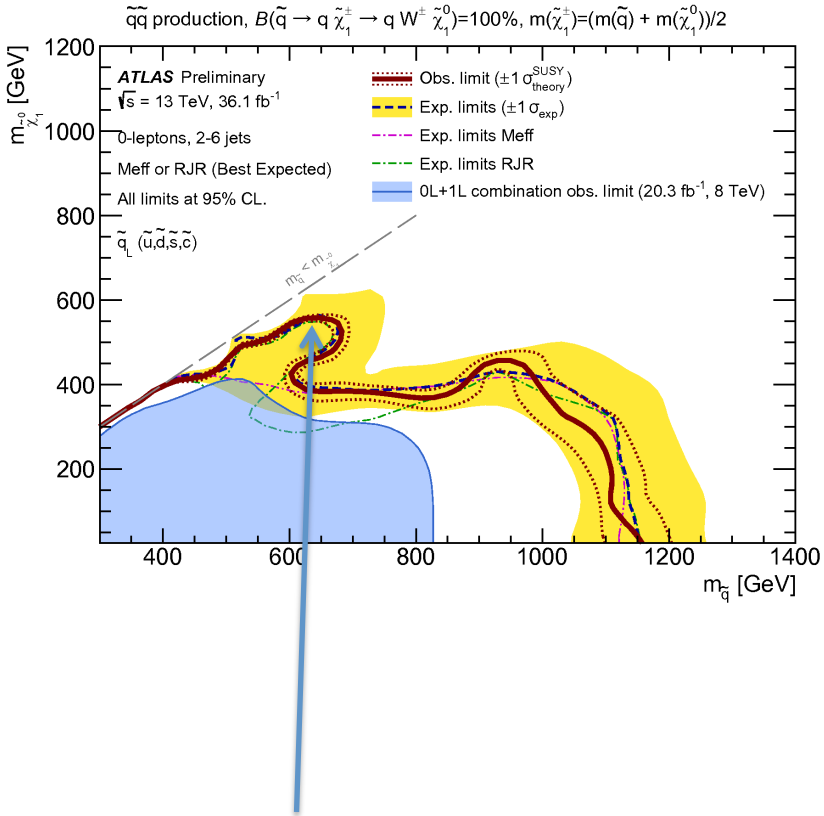


Recursive Jigsaw for squark signal regions

M_{eff} for high mass gluino signal regions

Phys. Rev. D 97, 112001 (2018)



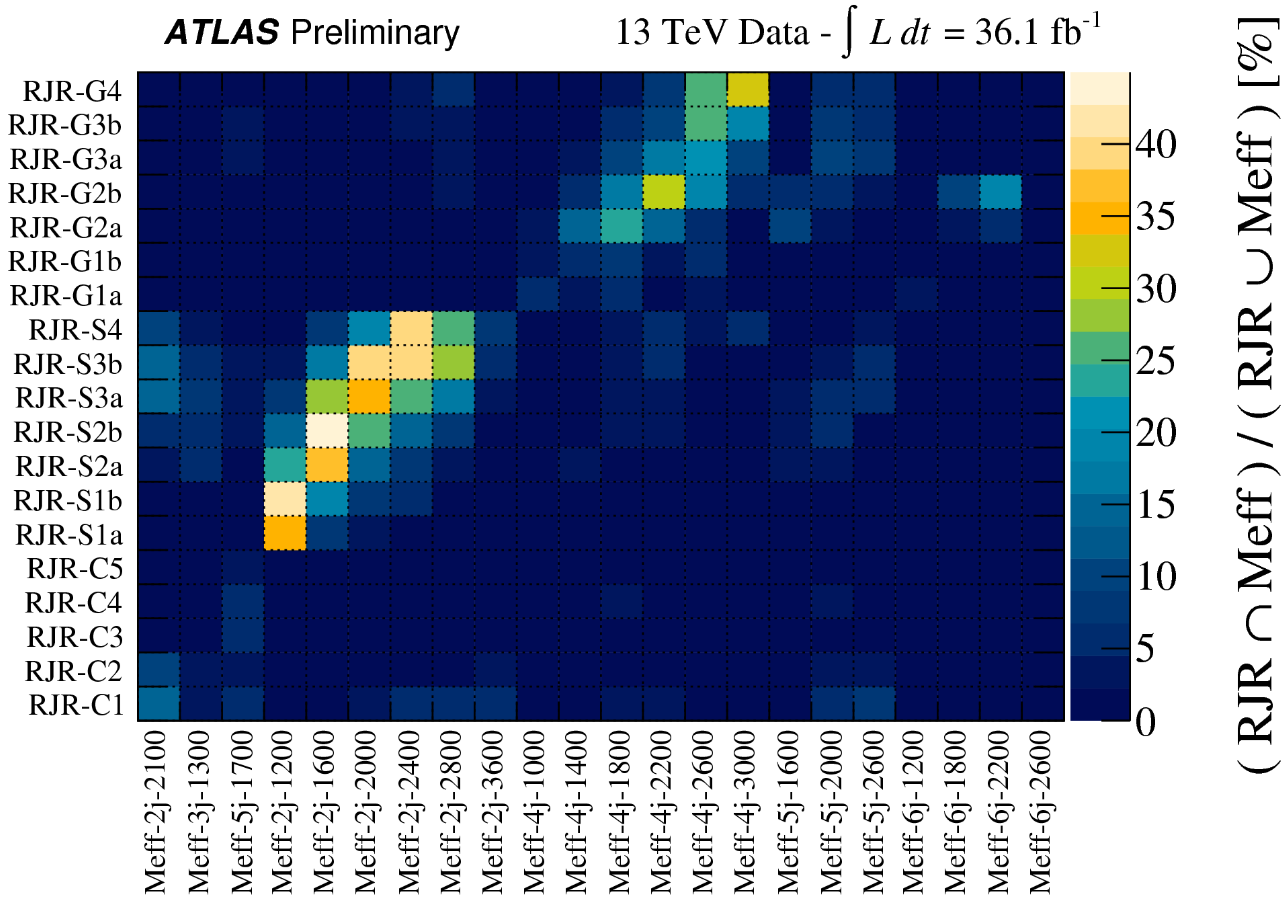


Yields in agreement with expectation, for the most part….some modest excess at the highest mass

Also has excellent performance in signal models that the analysis **wasn't optimised** to probe.

Phys. Rev. D 97, 112001 (2018)

What's the gain?



- Between the two analysis approaches we select non-overlapping events

- If we were to see an excess in both, or one and not the other, we get a very powerful piece of information instantly