Searching for new physics with emu asymmetry at ATLAS

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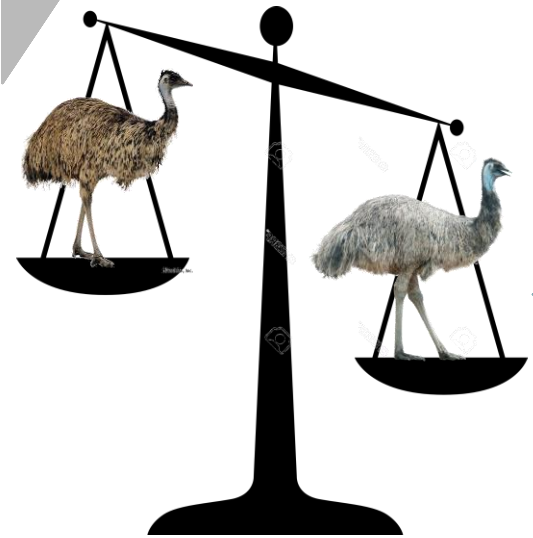
IOP HEPP/APP 2019

Topics

1. The Idea
2. Signal Models
3. Backgrounds and Biases
4. Expected Results

Fig. Emus patrolling for signs of suspicious event yields in Adelaide

Idea: The measurement



1. Measure the ratio: $\mathrm{R} = \dfrac{e^{+}\mu^{-}}{e^{-}\mu^{+}}$

in very general, broad regions of **data**

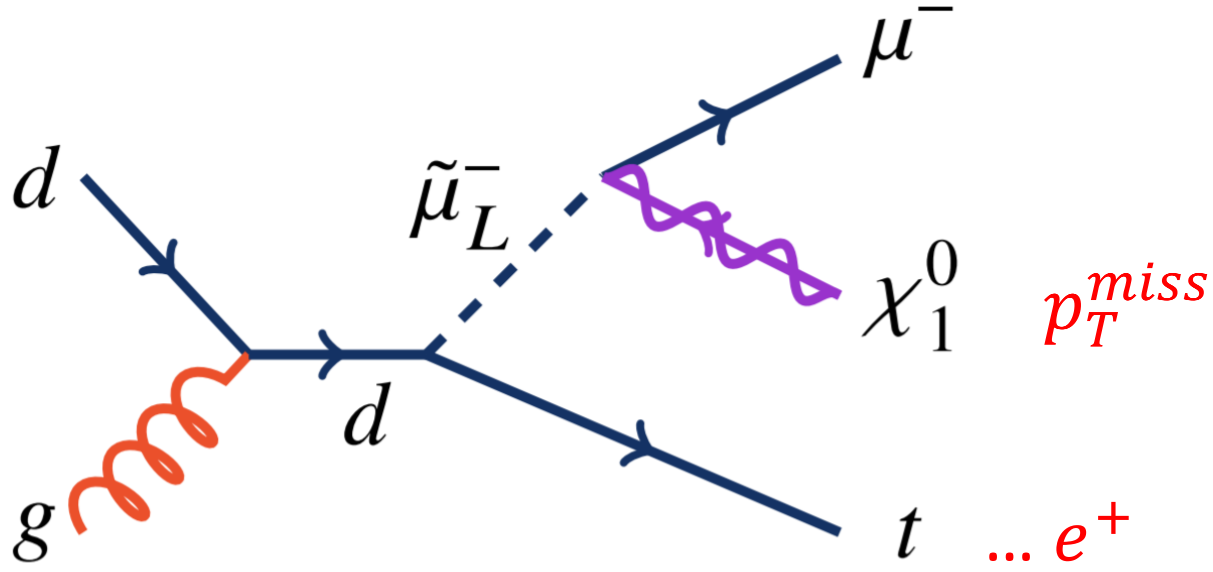
2. Produce Model Independent upper limits on R, possible $e^{+}\mu^{-}$ excess.
3. Produce Model Dependent limits on some example BSM model in optimised regions of data.

Idea: Why…

- any simple SM tests not done?
  - Uncharged final state less affected by proton charge asymmetry ☺
  - Generally ATLAS detection is independent of the lepton charge… ☺
  - Expect ratio in SM(+ATLAS) to be ~≤1
  - No reason to assume ratio is ~1 in BSM!
- After run-2 ended we have:
  - Loads of data
  - Relatively less MC
- Focus on comparing data-data?
  - Ratios allow cancelation of some uncertainties (luminosity etc.)
  - Compared to direct measurement – probe rarer signals because the overall BG yield is less important.

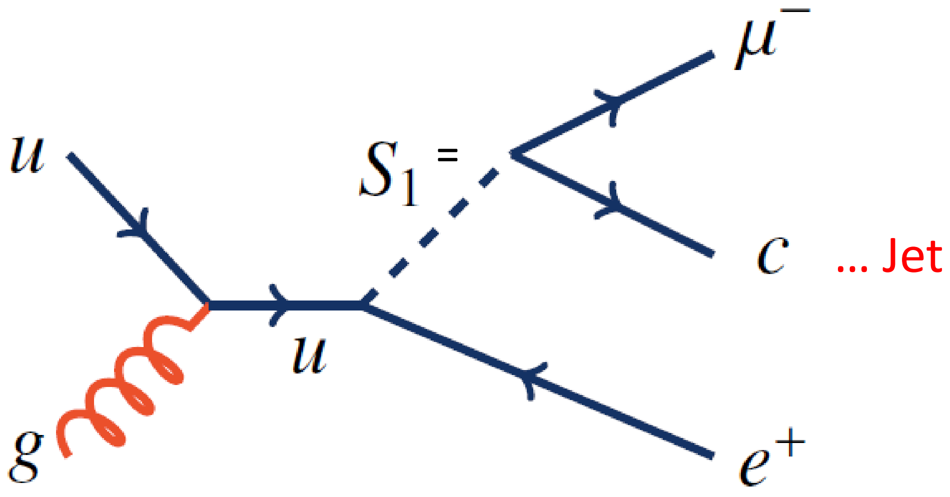
Signals: RPV-SUSY

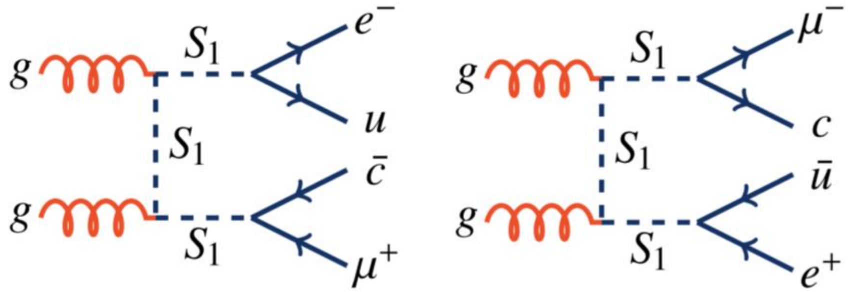
- Look for any BSM models which might give a $\frac{e^+\mu^-}{e^-\mu^+} > 1$?
- MSSM+ an RPV, lepton-flavour violating coupling set non-zero: λ'_{231}
- Proton = uud …
  - more d than $\bar{d}$…
  - more μ^- than μ^+ …
  - expect Ratio>1
- t can decay to an oppositely charged electron.
- Sensitivity in region with high p_T^{miss}



Signals: Scalar Leptoquarks

- Scalar leptoquark model (LO_LQ_S1)
  - 1 Scalar LQ: “S1”
  - Switch on $coupling(S1\ e\ u), coupling(S1\ \mu\ c)$ others 0.
  - Diagram: $e^+\mu^- > e^-\mu^+$ from proton PDF asymmetry (more u than $\bar{u}$)
- Constraints from HERA, etc., still leave some phase space uncovered
- Sensitivity in region with low p_T^{miss} and 1 jet





Can avoid region of phase space where symmetric pair production could wash out signal.

Backgrounds and Biases

$$\frac{N_{obs}(e^+\mu^-)}{N_{obs}(e^-\mu^+)} = \frac{\sigma(e^+\mu^-)}{\sigma(e^-\mu^+)} \times \boldsymbol{biases} \times \frac{poisson(exp \to obs)}{poisson(exp \to obs)}$$

- σ refers to the 'true' cross section ignoring detector biases and non-prompt processes
- Biasing backgrounds:
  - W+jet faking lepton
    - Charge asymmetry: more W^+ than W^-
    - Flavour asymmetry: more fake e than fake μ
    - Estimate using Matrix Method [arXiv:1012.1792]
  - Everything else: symmetric to leading order.

Backgrounds and **Biases**

- Possible other biases:

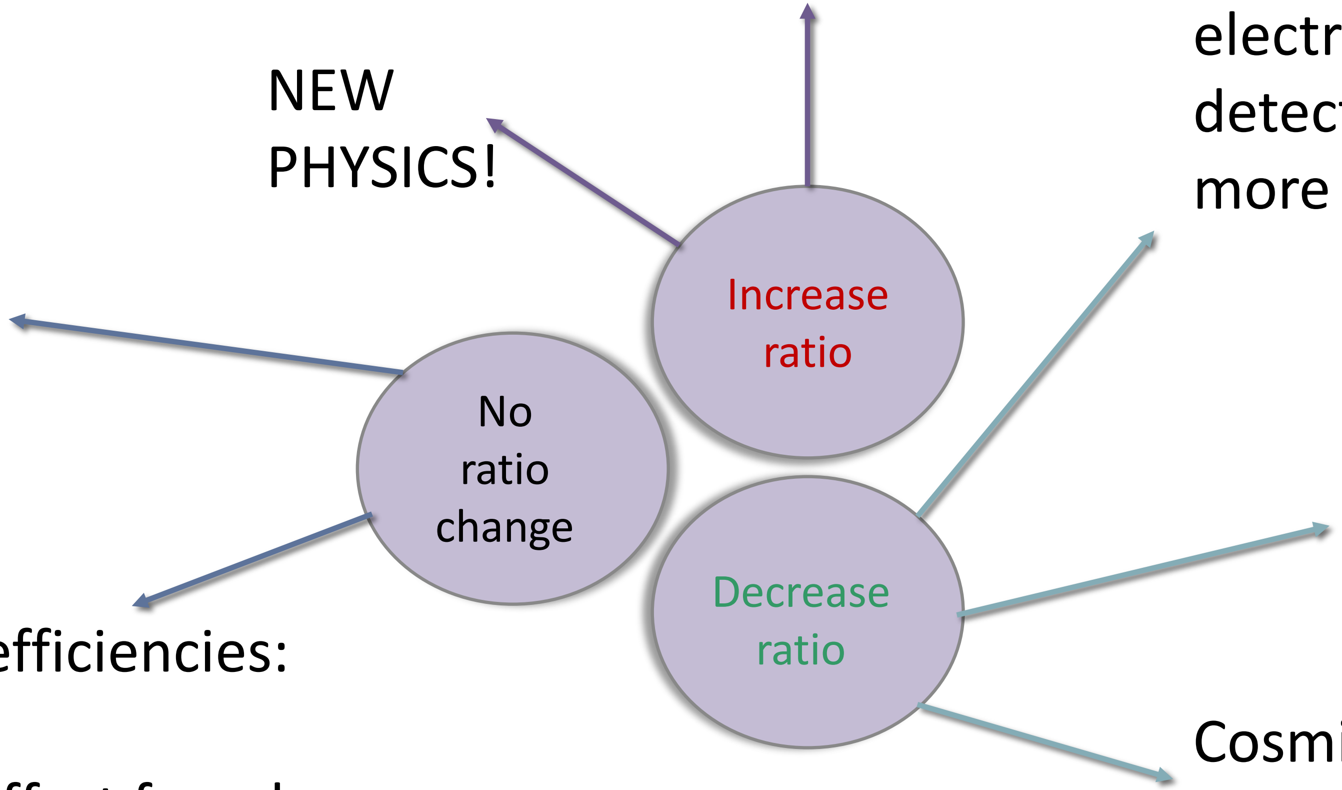
arXiv: 1612.02697
contains more examples

Divine intervention

NEW PHYSICS!

δ rays – recoil electrons from detector material, more e- than e+

Initial state positive charge – Backgrounds independent to 1st order



e/μ mass difference – π→μν more π+, more μ+

Cosmic rays – more μ+ than μ-

Charge dependent efficiencies:

- e : negligible bias
- μ : muons small effect found can be accounted for

Results: Variables for R

- Calculate R in bins of some variable which would give R>>1 for our example models.
- Current idea: use Transverse mass m_T
  - In high p_T^{miss} topology – $m_T(l, p_T^{miss})$ approximates bound on mass of heavy decaying particle e.g. $\tilde{\mu}$
  - In jet topology - $m_T(l, jet)$ approximates bound on mass of heavy decaying particle e.g. S1.

$$m_T \approx \sqrt{2|p_1||p_2| - 2\vec{p}_1.\vec{p}_2} = \sqrt{2p_T^{\ell} \not{p}_T^{miss}\,(1 - \cos\Delta\phi)}$$

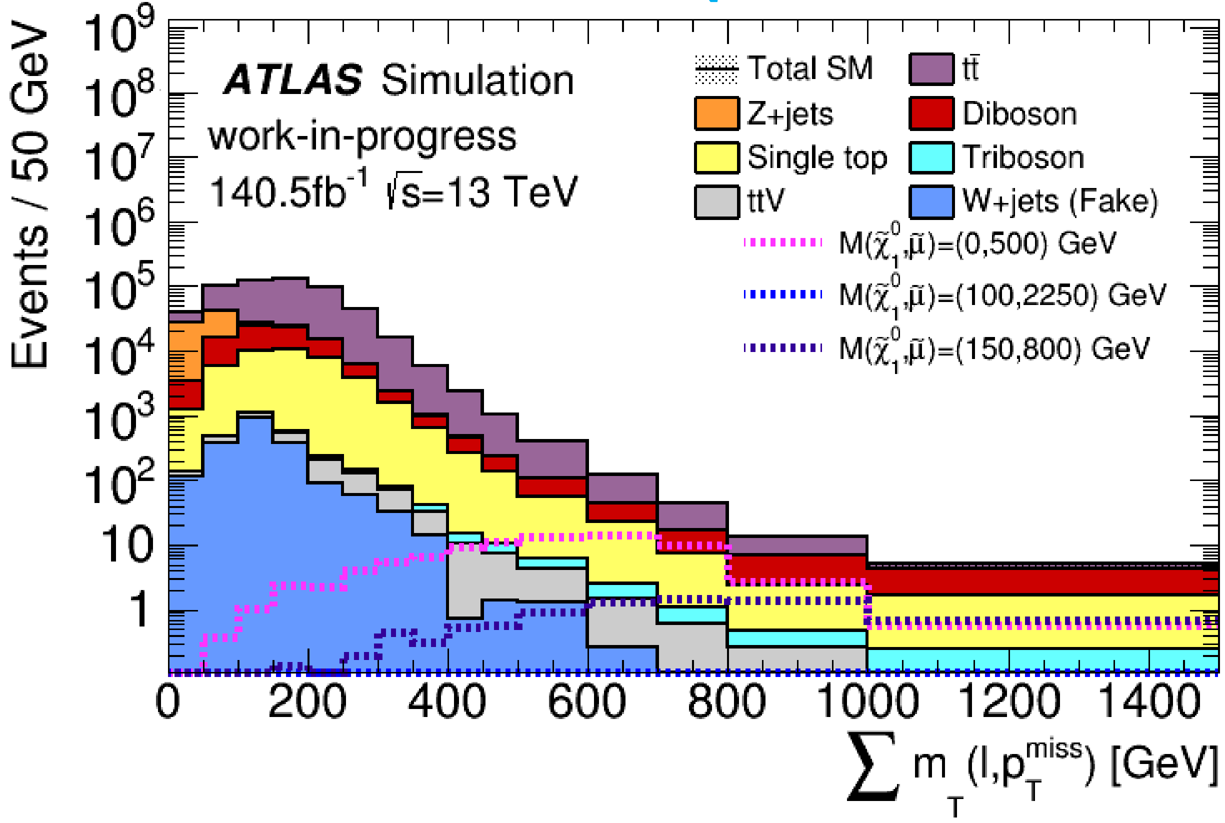
  - Sum over 2 leptons to avoid introducing any charge/flavour bias to the variable.

1. ptmiss Region (for RPV-like models): 2 'good' leptons $e^+\mu^-$ or $e^-\mu^+$, no cuts on jets etc.
   Calculate R in bins of $\sum m_T(l, p_T^{miss})$
2. JET Region (for LQ-like models): 2 'good' leptons $e^+\mu^-$ or $e^-\mu^+$,
   ≥1 jet with $p_T > 20$ GeV, $|\eta| < 2.4$.
   Calculate R in $\sum m_T(l, jet1)$, where jet1=highest p_T Jet.

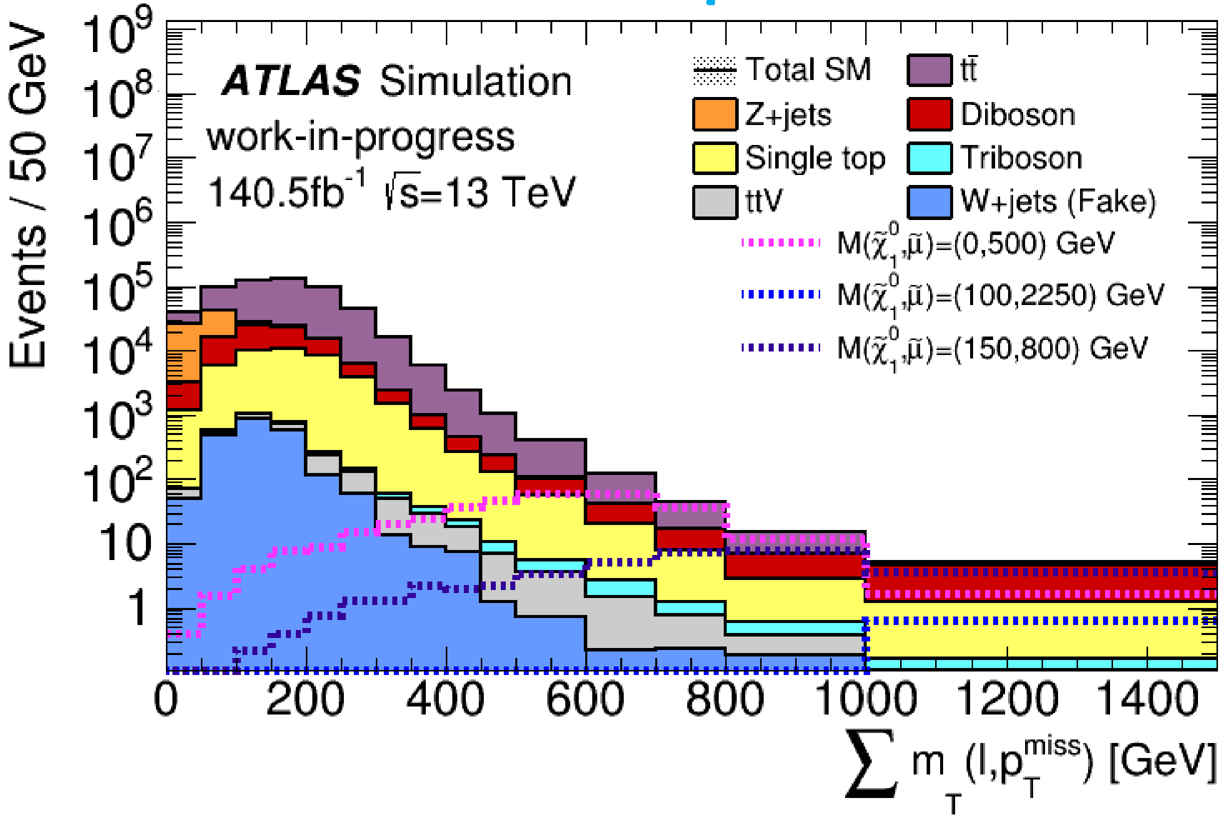
Results: Distributions for R

- $\sum m_T(l, p_T^{miss})$
- Benchmark RPV-SUSY signals overlaid
- SM: Yields about the same for both cases ☺
- Signals: More events for $e^+\mu^-$ ☺

$e^-\mu^+$



$e^+\mu^-$



Results: Distributions for R

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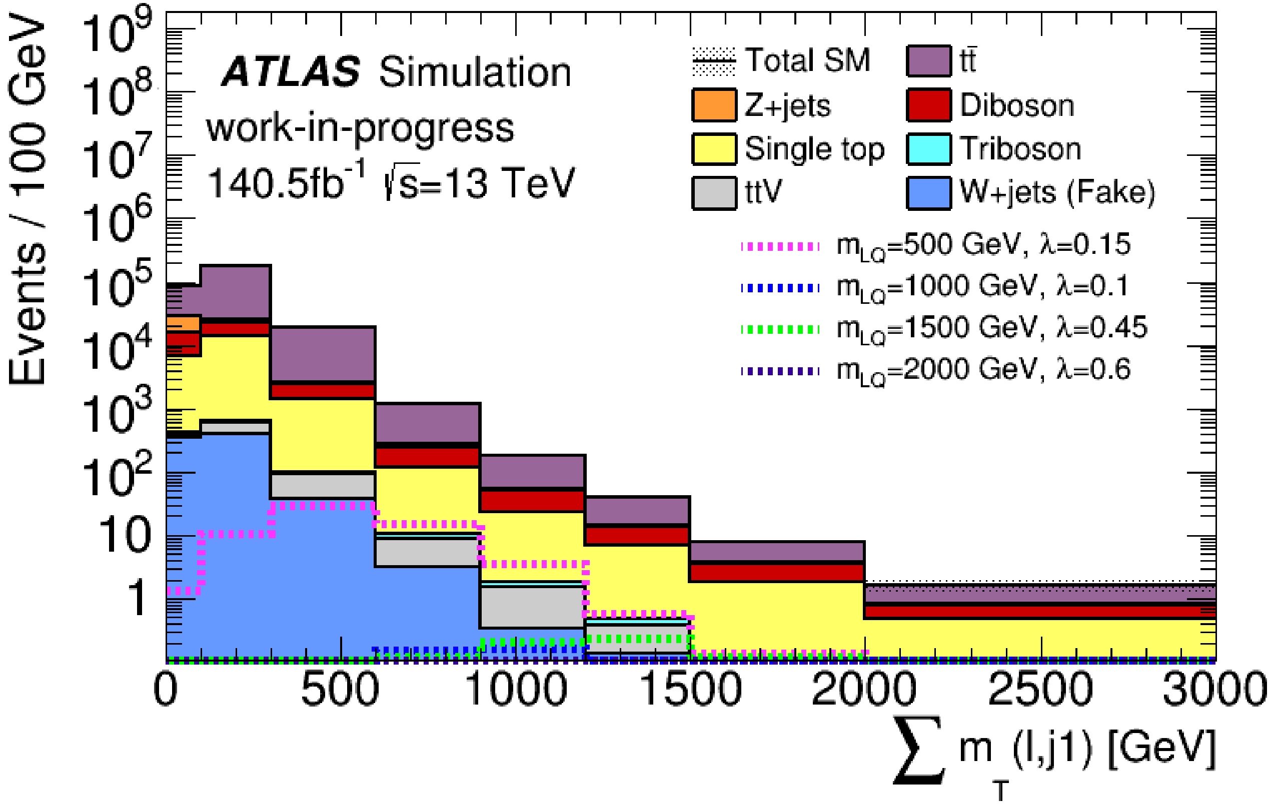
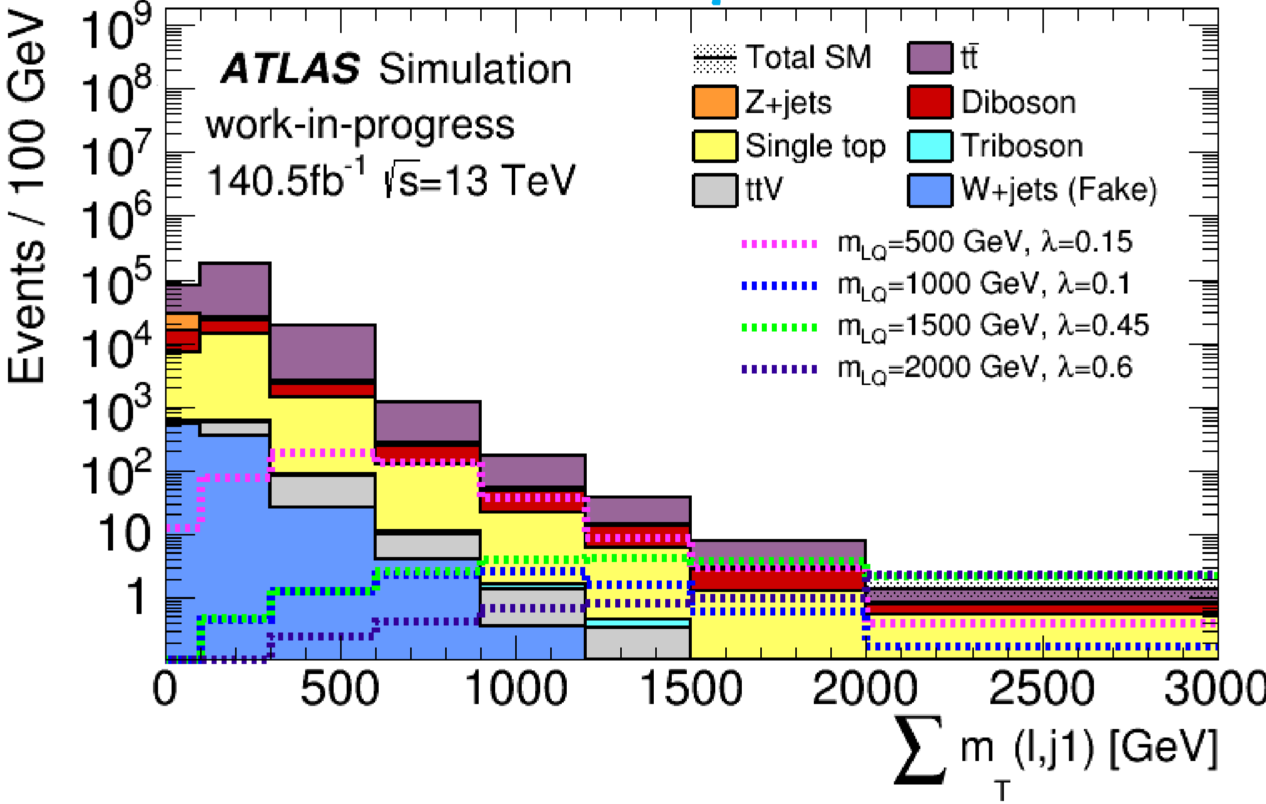
$e^-\mu^+$



$e^+\mu^-$



Results: The plan

1. Use a likelihood model for the ratio measurement in data: Maximise $\log(\mathcal{L})$ for an estimate of:
   - r (charge ratio in each bin)
   - μ (yield in non-signal-like $e^-\mu^+$ channel)

Uncertainties as nuisance parameters

$$\mathcal{L} = \prod_{i \in \text{bins}} \left(\text{Pois}(N_i^{-+} | \mu_i) \times \text{Pois}(N_i^{+-} | r_i \mu_i) \right) \times \prod_{j \in \text{systs}} \text{Gaus}(\tilde{\theta}_j, \theta_j)$$

2. Set upper limit on a signal-like excess:

$$\mathcal{L} = \prod_{i \in \text{bins}} \left(\text{Pois}(N_i^{-+} | \mu_i + (1 - R_s) s_i) \times \text{Pois}(N_i^{+-} | \mu_i + R_s s_i) \right) \times \prod_{j \in \text{systs}} \text{Gaus}(\tilde{\theta}_j, \theta_j)$$

   - μ (yield in non-signal-like channel)
   - s (excess in signal-like $e^+\mu^-$ channel)
   - R_s = Fraction of signal entering $e^+\mu^-$

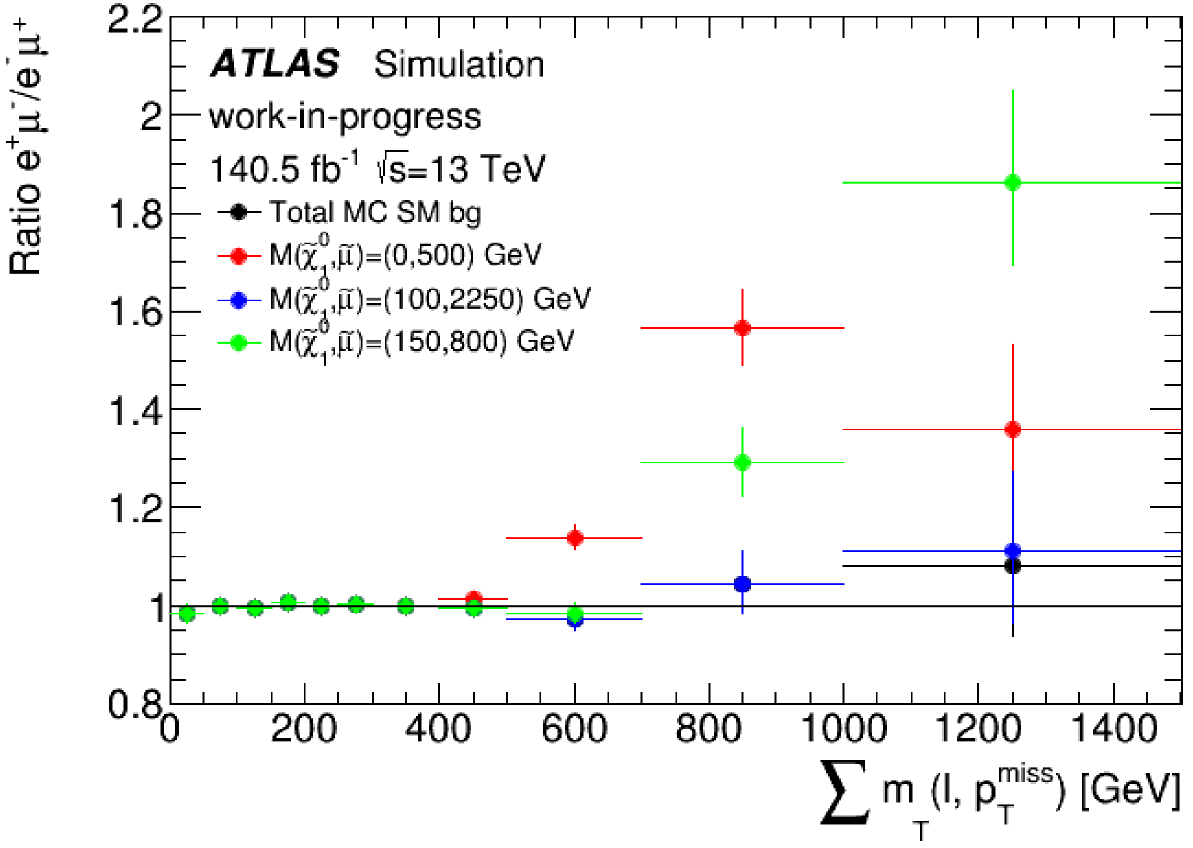
Fig. Unusual results hiding amongst the emu.

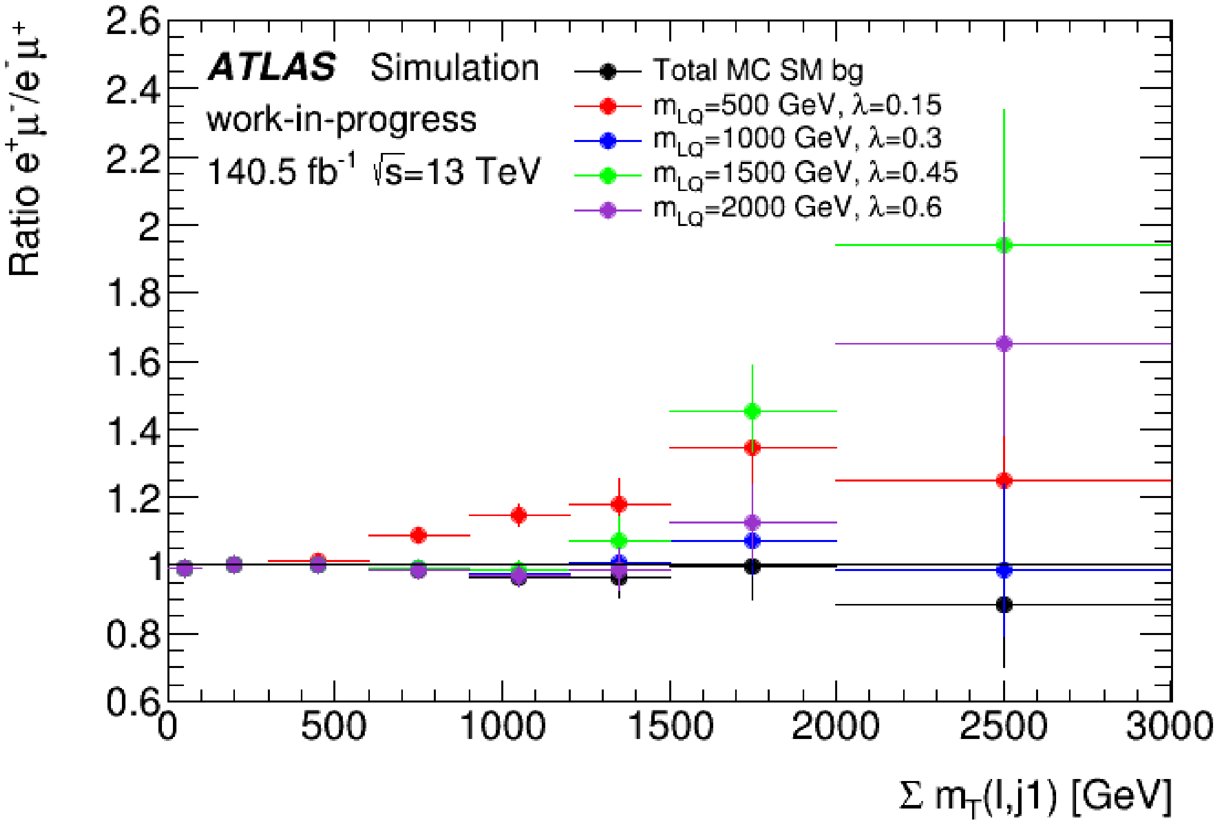
3. Set model-dependent limits on RPV-susy and leptoquark models

Results: Expected R

- Left: MC including RPV-SUSY $\sum m_T(l, met)$
- Right: MC including leptoquarks $\sum m_T(l, jet1)$

- SM: Ratio consistent with 1 for both cases ☺
  Signals: Ratio>>1 for high bins as expected ☺
- Statistical errors only..





Conclusion

- We are working on a **brand new, unique** analysis to produce:
  - Measurement of potential charge-flavour asymmetry never looked at before
  - Model independent approach to place limits on possible BSM physics
  - Place first ATLAS limits on these specific RPV-SUSY and leptoquark processes.
- Aiming for publication using **full $140\ fb^{-1}$** of run-2 ATLAS data

Thanks for listening!

Any questions….

Emu Image credits

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- https://perryponders.com/2015/03/10/in-1932-australia-waged-a-war-against-emus/ (FYI, the Emus won)