

SUSY (and BSM in general) vs The LHC

Jamie Tattersall

RWTH Aachen

What do we want?

What do we want?

Write the Lagrangian down

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Write the Lagrangian down

Press “Enter”

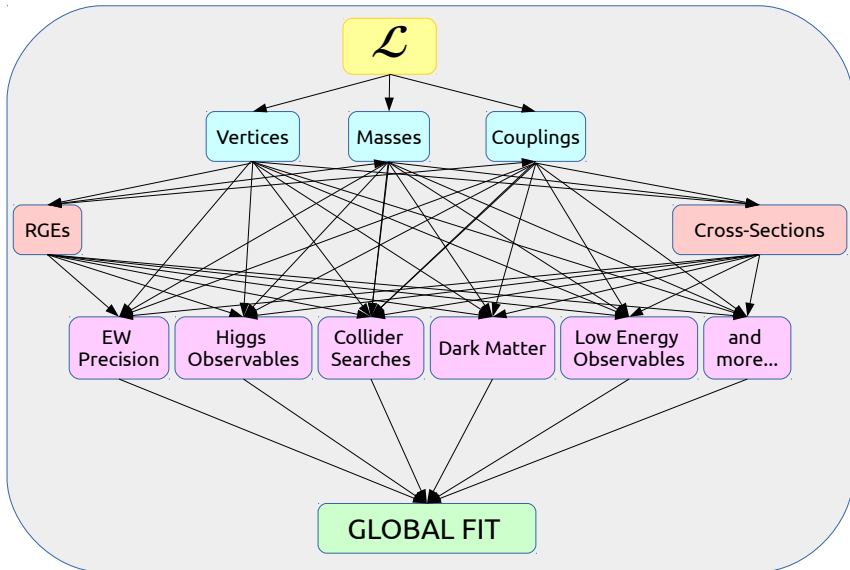
What do we want?

Write the Lagrangian down

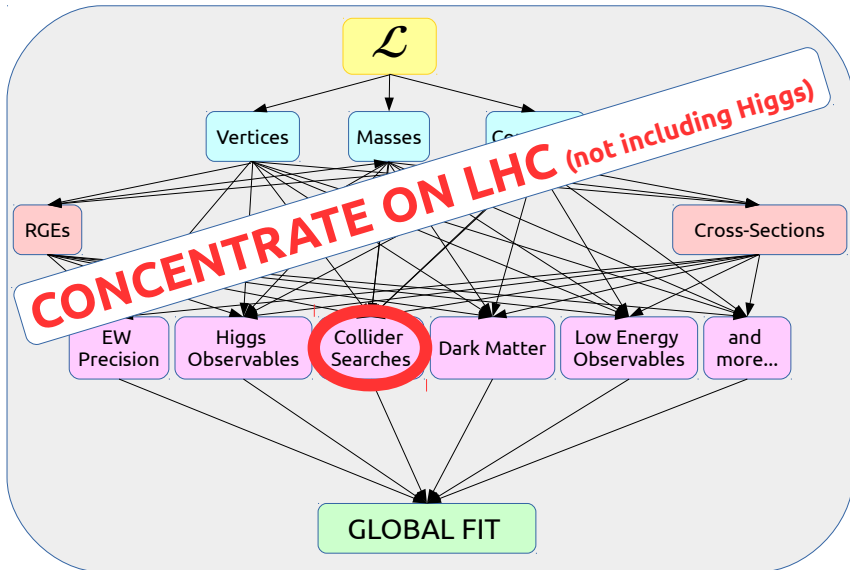
Press “Enter”

*Computer fits the model
parameters to all relevant
observables*

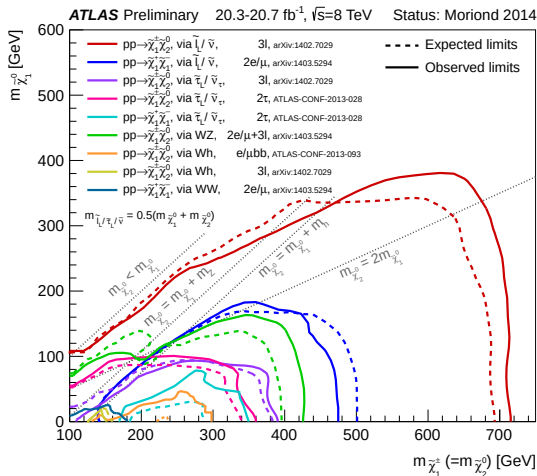
Overview



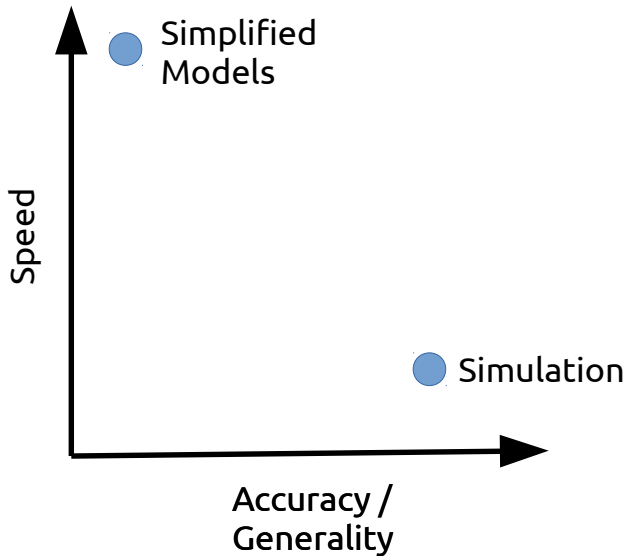
Overview



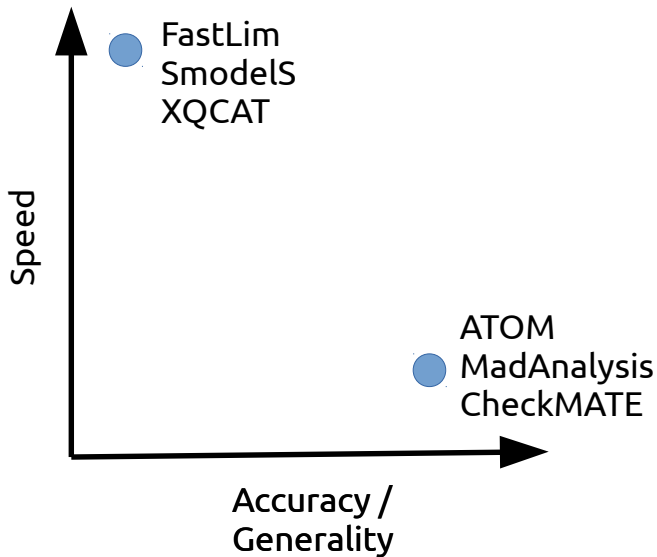
LHC Interpretation



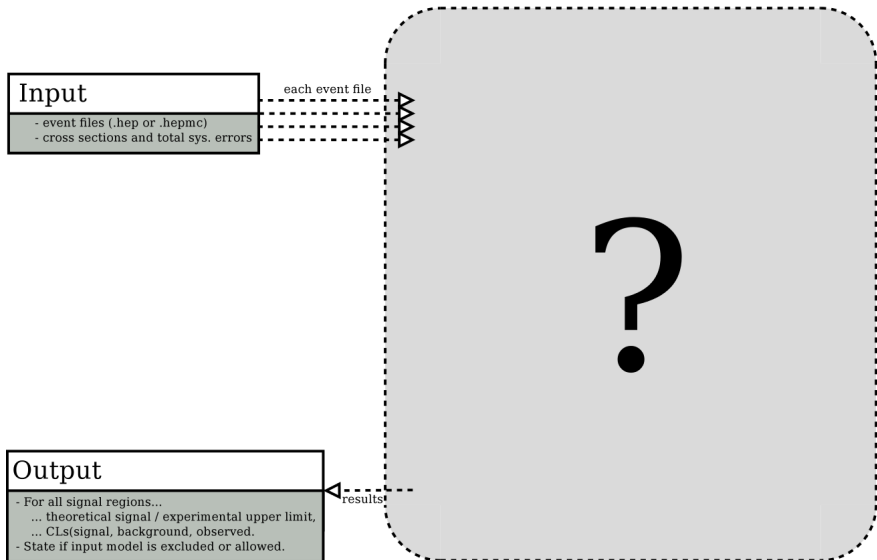
Current approaches



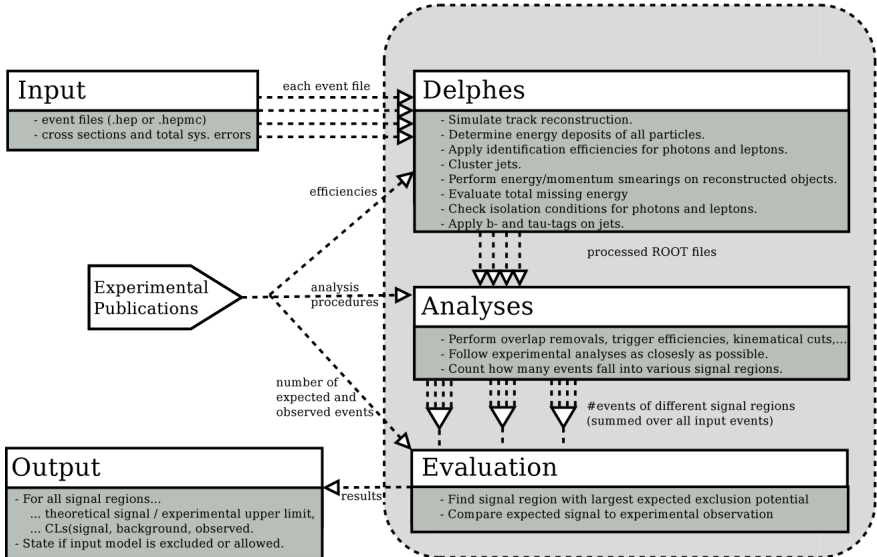
Current approaches



Simulation Program Flow



Simulation Program Flow



Available tools

MadAnalysis5 (Bein, Chalons, Conte, Dumont, Fuks, Kulkarni, Kraml, Schmitt, Sengupta, Wymant)

- 7 validated analyses (+ 18 unvalidated)
- Based on Delphes3 (de Favereau, Delaere, Demin, Giammanco, Lemaître, Mertens, Selvaggi)
- Soon cross-compatible with CheckMATE

CheckMATE (Desai, Drees, Dreiner, Kim, Rolbiecki, Schmeier, JT)

- 19 validated analyses (+ 20 unvalidated)
- Also based on Delphes3
- CheckMATE 2 soon public (SLHA input, MG5+Pythia8 built in, 2x faster, designed for cluster)

ATOM (Kim, Papucci, Sakurai, Weiler)

- Not yet public (available if you ask nicely)
- ~ 15 analyses
- Based on Rivet (Buckley, Butterworth, Lonnblad, Grellscheid, Hoeth, Monk, Schulz, Siebert)

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- See Daniel Schmeier's talk at 14.30!

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Investigating excesses

Example – CMS dilepton edge

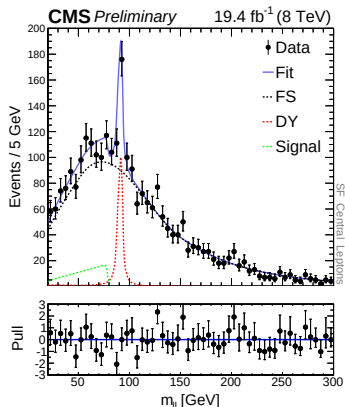
- $\sim 2.6\sigma$ excess

Gluino Model

- Neutralinos produced in decay
- Off-shell $Z \rightarrow$ di-leptons

Other Models

- Squarks, sbottoms, stops
- Sleptons in chain



Investigating excesses

Example – CMS dilepton edge

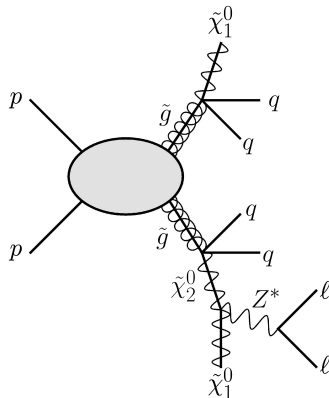
- $\sim 2.6 - \sigma$ excess

Gluino Model

- Neutralinos produced in decay
- Off-shell $Z \rightarrow$ di-leptons
- Other ideas $\rightarrow$ Squarks, sbottoms, stops, sleptons in decay

Other Models

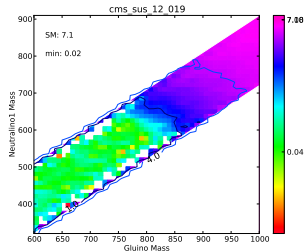
- Squarks, sbottoms, stops
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SUSY Fit

Dilepton fit

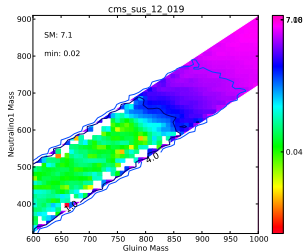
- Tune di-leptonic branching ratio to match edge
- Find solution for wide range of masses



SUSY Fit

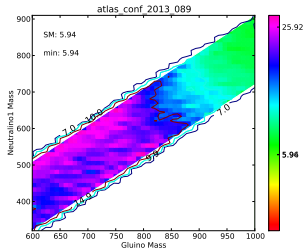
Dilepton fit

- Tune di-leptonic branching ratio to match edge
- Find solution for wide range of masses



Other SUSY searches

- Must check other SUSY searches
- Gluino solution ruled out at over $3\text{-}\sigma$ by ATLAS 2 lepton search (atlas_conf_2013_089)



Global Fit

No good SUSY solution

(Grothaus, Liew, Sakurai; 2015)

(Kim, Rolbiecki, JT; 2015)

- Fit gives point with no visible edge
- Same is true for Squarks, Sbottoms, Stops
 - Slepton mediated decays are even worse

- ATLAS $\rightarrow$ nothing below Z
(1503.03290) ...but 3.0σ on- Z

(Liew, Mariotti, Mawatari, Sakurai, Vereecken; 2015)

(Cahill-Rowley, Hewett, Ismail, Rizzo; 2015)

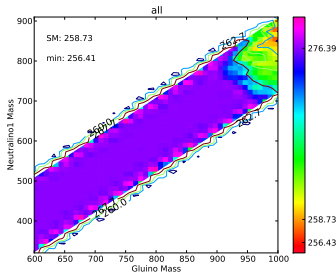
(Cao, Shang, Yang, Zhang; 2015)

(Collins, Dror, Farina; 2015)

(Lu, Shirai, Terada; 2015)

...

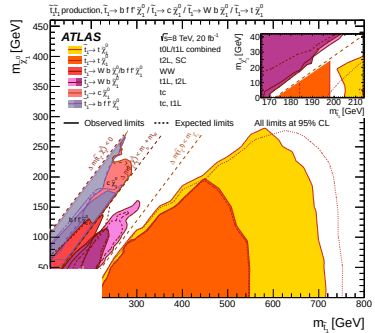
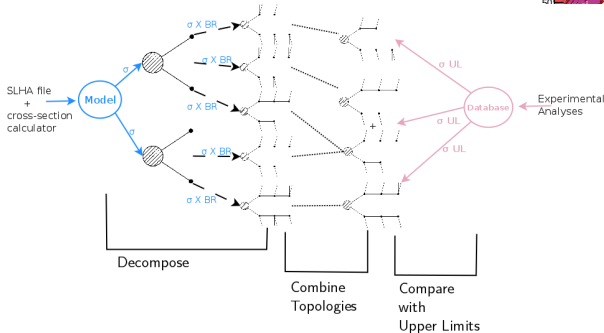
- See Takahiro Terada's talk at 16.30



Simplified Model Tools

Simplified Models

- Set limits on specific topology instead
- Assume 100% branching ratio
- Easily rescaled to model



Simplified Model Tools

Available Tools

- FastLim (10 analyses) (Papucci, Sakurai, Weiler, Zeune; 2014)
- SModelS (26 analyses) (Kraml, Kulkarni, Laa, Lessa, Magerl, Magerl et al; 2014)
- XQCAT (5 analyses) (Barducci, Belyaev, Buchkremer, Cacciapaglia, Deandrea et al; 2014)

Advantages

- Fast! (few seconds per point)
- Use actual experimental results

Disadvantages

- Based around a particular model (usually MSSM)
- Limits conservative (sometimes very)
 - More than 1-step decays difficult
 - Limited coverage of asymmetric decays
- Probably difficult to apply to fitting a signal

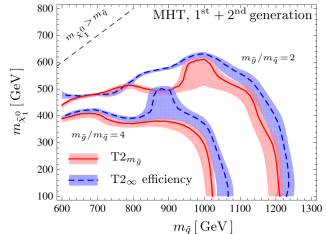
Setting Limits

How far can we push simplified models?

Squark production

- Gluino mass changes kinematics
- Limits look reasonable

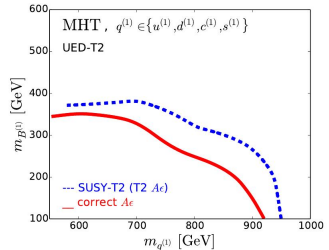
(Edelhäuser, Heisig, Krämer, Oymanns, Sonneveld; 2014)



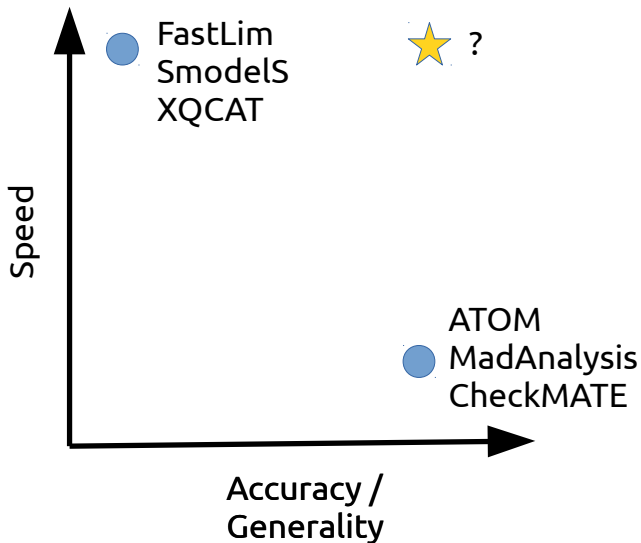
UED Example

- Spin changes kinematics

(Edelhäuser, Krämer, Sonneveld; 2014)



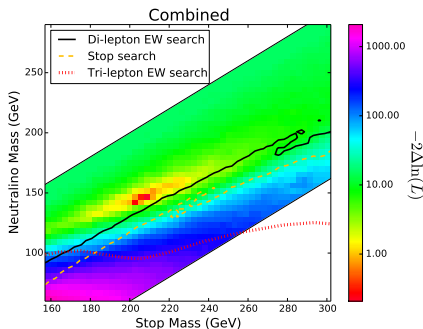
Can we do better?



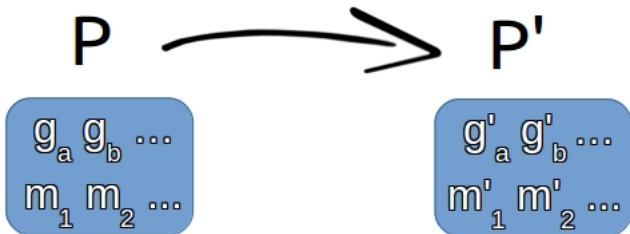
LHC inverse problem

Models with MET are difficult

- Want to perform fit with many free parameters
- Signal regions may have very low acceptance
- 2d scans already have CPU as limiting factor



Parameter scans



Moving from $P \rightarrow P'$, need:

- Final state cross-sections
- Distributions

Aim

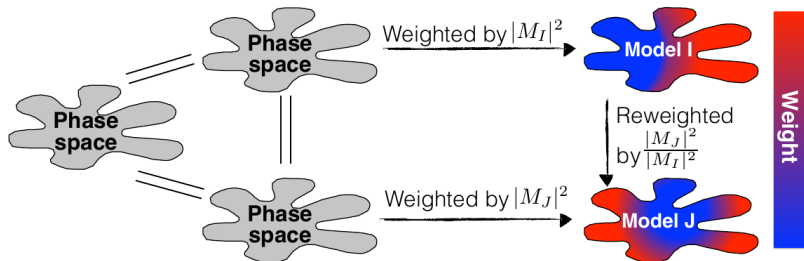
- Per point evaluation $\rightarrow \mathcal{O}(\text{secs})$
- Accuracy $\rightarrow 10\%$ on acceptance
- Arbitrary BSM models
- Arbitrary Monte-Carlo generators

Parameter scans

Matrix element method for arbitrary BSM scans

(Gainer, Lykken, Matchev, Mrenna, Park; 2014)

- Central idea → Re-use events via re-weighting
 - Experiments generate large samples of unweighted events for arbitrary topologies
 - Full parton shower and detector simulation performed
 - BSM events by reweighting ME at same phase space point



Parameter scans

Two key practical issues

- Requires experiments to do more work
 - In addition far more detailed detector information can be derived
- Only allows changes in couplings and spins
 - Crucially masses must be the same

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Two key practical issues

- Requires experiments to do more work
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Our idea

- Optimise for speed
 - No matrix element evaluation
 - Re-use parton shower
 - Re-use detector sim
 - Re-use jet algorithm
- Allow masses to vary
- Keep spins the same
- Model and Monte-Carlo agnostic

Couplings

First order effects

- Total Cross-Section
- Branching Ratio

Second order effects → ignore

- Kinematical Distributions
- Requires
 - Interference terms small
 - Narrow width approximation satisfied

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Solution

- Simply reweight events → Total normalisation guaranteed
- Generally, acceptances only weakly depend on coupling structures

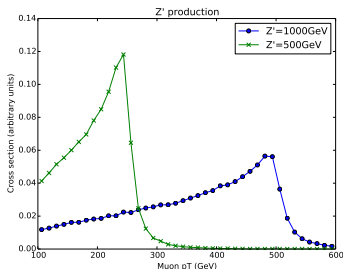
Masses

Easy part

- Total Cross-Section $\rightarrow$ Reweight
- Branching Ratios $\rightarrow$ Reweight

More difficult

- Kinematical Distributions
 - Clearly not a sub-leading effect for mass changes



Idea

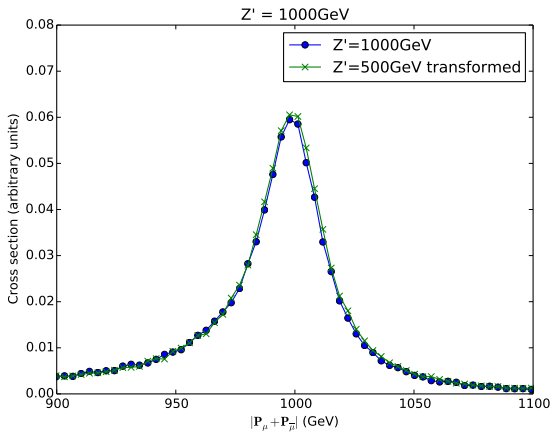
Guiding principle

- Production: $\vec{p} \rightarrow \vec{p}, m \rightarrow m'$
 - Ensures we sample full phase space
 - 'Off-shellness' constant
- Decays: Rest frame angles conserved
 - All kinematics specified by momentum conservation
- Final state particles: Matched to hard event
 - Kinematics determined by hard partons
 - Smeared in proportion to original event particles

Reweighting

- $1/s$: Leading cross-section behaviour
- PDFs: Leading LHC angular distribution behaviour
- α_s : If QCD production (and ISR)

Z' example

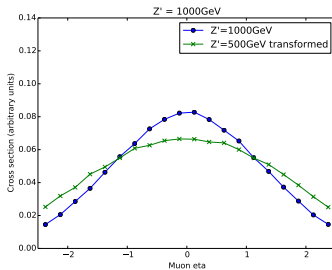


By definition, invariant mass is reproduced

Z' example

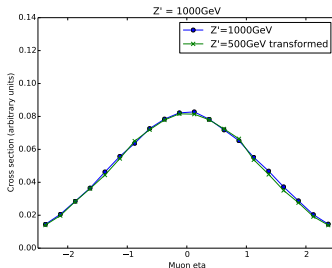
Without PDF reweighting

- At higher $\sqrt{s}$ production becomes more central

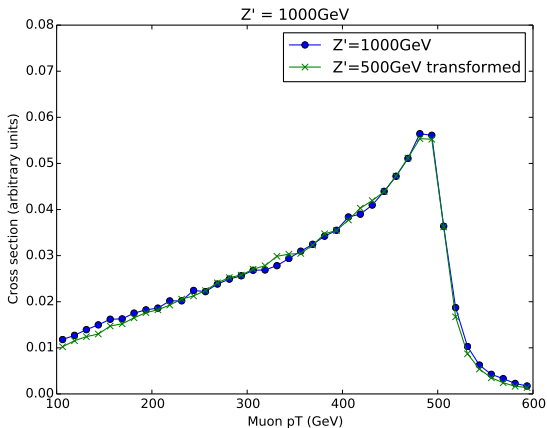


With PDF reweighting

- PDF reweighting corrects production angles



Z' example



Other distributions also reproduced

Future plans

Seems to work for Z'

- Now playing with top model $\rightarrow$ multi-stage decays
- Apply to SUSY and recalculate exclusions
- Completely testable for any parameter point

Generalise

- Algorithm should work automatically with any BSM model
- Any choice of Monte-Carlo event generator
- User simply supplies FeynRules model and parameter ranges
- Offer matrix element evaluation as an option

Optimise

- Currently $\rightarrow \sim 5$ secs for 100,000 events

Summary

Automatic model testing now a reality

- Tools simple and easy to use

Simplified Models

- Rapid model testing

Fast simulation

- Model agnostic
- Allows for fitting to LHC signals

New ideas still needed for speed and accuracy

What I ignore (I'm sorry...)

Lagrangian/Superpotential interpretation

- **SARAH** (Staub, Ohl, Porod, Speckner, Dreiner, Nickel, Vicente, Goodsell)
- **FeynRules** (Christensen, Duhr, Fuks, Degrande, Grellscheid, Mattelaer, Reiter, Alloul, D'Hondt, De Causmaecker, De Trautenberg, de Aquino, Deutschmann, Garcia-Cely, Mawatari, Oexl, Takaesu)
- **Susyno** (Fonseca)

Spectrum Generation/RGE's

- **SPheno** (Staub, Porod)
- **SoftSUSY** (Allanach, Athron, Bednyakov, Bernhardt, Grellscheid, Hanussek, Kom, Ruiz de Austri, Slavich, Tunstall, Voigt, Williams)
- **Suspect** (Djouadi, Kneur, Moutaka, Ughetto, Zerwas)
- **ISAJET/ISASUGRA** (Paige, Protopopescu, Baer, Tata)
- **FlexibleSUSY** (Athron, Park, Stöckinger, Voigt)
- **SuSeFLAV** (Chowdhury, Garani, Vempati)
- **NMSSMTools** (Ellwanger, Gunion, Hugonie, Jean-Louis, Das, Teixeira)

What I ignore (I'm sorry...)

Monte-Carlo generation

- **MadGraph** (Alwall, Frederix, Frixione, Hirschi, Maltoni, Mattelaer, Stelzer + many more...)
- **Pythia (6 or 8)** (Sjöstrand, Ask, Desai, Ilten, Mrenna, Prestel, Skands + many more...)
- **Herwig** (Richardson, Webber, Gieseke, Grellscheid, Platzer, Seymour + many more...)
- **Sherpa** (Krauss, Gleisberg, Höche, Schumann, Schönherr, Siegert, Winter + many more...)
- **Whizard** (Kilian, Ohl, Reuter, Bach, Nejad, Schmidt, Sekulla, Speckner, Weiss + many more...)

Decay widths

- **SUSY-HIT** (Djouadi, Kalinowski, Mambrini, Mühlleitner, Spira)

What I ignored (I'm sorry...)

Higgs

- HiggsBounds/HiggsSignals (Bechtle, Brein, Heinemeyer, Stål, Stefaniak, Weiglein, Williams)
- FeynHiggs (Heinemeyer, Thomas Hahn, Heidi Rzehak, Georg Weiglein, Wolfgang Hollik)
- Lilith (Bernon, Dumont)
- SusHi (Harlander, Liebler, Mantler)
- 2HDMC (Eriksson, Rathsmann, Stål)

Dark Matter

- micrOMEGAs (Bäcker, Boudjema, Pukhov, Semenov)
- DM@NLO (Herrmann, Klasen, Kovarik, Harz, Le Boulc'h, Meinecke, Steppeler)
- DarkSUSY (Gondolo, Edsjö, Ullio, Bergström, Schelke, Baltz, Bringmann, Duda)

What I ignored (I'm sorry...)

Cross-Sections @ NLO

- **Prospino** (Beenakker, Höpker, Klasen, Krämer, Plehn, Spira, Zerwas)
- **NLL-FAST** (Beenakker, Brensing-Thewes, Borschensky, Krämer, Kulesza, Motyka, Laenen, Niessen)
- **MadGolem** (Goncalves Netto, Lopez-Val, Mawatari, Plehn, Wigmore)
- **Resummino** (Bozzi, Fuks, Klasen, Lamprea, Rothering, Debove)
- **MadGraph5_aMC@NLO** (Alwall, Frederix, Frixione, Hirschi, Maltoni, Mattelaer, Shao, Stelzer, Torrielli, Zaro, de Visscher, Vittoria Garzelli, Pittau, Degrande, Fuks, Proudome, Shoa)
- **GoSam** (Cullen, Deurzen, Greiner, Heinrich, Luisoni, Mirabella, Peraro, Schlenk, von Soden-Fraunhofen)

What I ignored (I'm sorry...)

Global Fitting (mostly private)

- **GAMBIT** (Athron, Balazs, Bringmann, Buckley, Chrzaszcz, Conrad, Cornell, Dal, Edsjö, Farmer, Hsu, Jackson, Krislock, Kvellestad, Mahmoudi, Martinez, Pato, Putze, Raklev, Rogan, Saavedra, Savage, Scott, Serra, Weniger, White)
- **Mastercode** (Bagnaschi, Buchmüller, Cavanaugh, Citron, De Roeck, Dolan, Ellis, Flächer, Heinemeyer, Isidori, Marrouche, Santos, Olive, Sakurai, de Vries, Weiglein)
- **Fittino** (Bechtle, Desch, Sarrazin, Uhlenbrock, Wienemann, Dreiner, Stefaniak, Hamer, Krämer, Porod, O'Leary, Prudent, Bringmann, Hensel, Nguyen)
- **SFitter** (Lafaye, Plehn, Rauch, Zerwas, López-Val, Klute)
- Lots of 'unbranded' fits as well...