Recasting LHC searches for long-lived particles with MadAnalysis 5

Jack Y. Araz
Institute For Particle Physics Phenomenology
Durham University

with Benjamin Fuks, Mark Goodsell & Manuel Utsch

Searching for long-lived particles at the LHC and beyond:
10th workshop of the LLP community

November 11th, 2021

Durham University

Science & Technology Facilities Council

MCnet

IP3

Outline

- Introduction
  - Briefly MadAnalysis 5
- LHC recasting with MadAnalysis 5
  - NEW Particle propagation module
  - Current status of recasted LLP analyses
- Conclusion

Introduction

Why designing & recasting is important?

- Exploiting the full potential of LHC (for new physics)
  - *Designing* new analyses (based on MC simulations)
  - *Recasting* LHC analyses (The LHC legacy)
- Data preservation in HEP is mandatory
  - Going beyond raw data via analyses
- Related tools need to be supported by the entire community
  - Both theorists & experimentalists
- Universal recasting tool

Les Houches Recommendations (EPJC '12)

Reinterpretation Forum Report (SciPost '20)

MadAnalysis 5

What is MadAnalysis 5?

- A framework for phenomenological analyses
- Any level of sophistication: partonic, hadronic, detector, reconstructed
- Several input formats: STDHEP, HEPMC, LHE, LHCO, ROOT (from Delphes)
- User-friendly, flexible & Fast!!!
- Interfaces several HEP packages: MadGraph, FastJet, Delphes, pyhf

Normal Mode

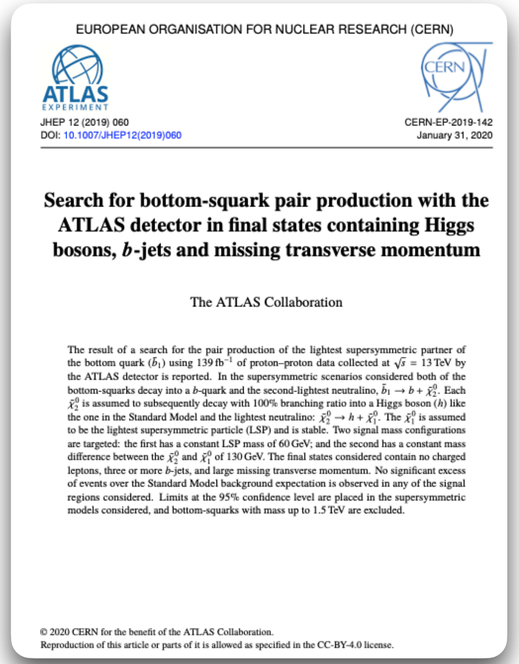
- Intuitive commands typed in the Python interface
- Analysis performed behind the scenes (black box)
- Human readable output: HTML and LaTeX

Expert Mode

- C++ programming with the SampleAnalyzer framework
- Support for multiple sub-analyses, an efficient way for handling cuts and histograms, etc.

LHC recasting with MadAnalysis 5

Reimplementing an analysis in MadAnalysis 5



EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

ATLAS EXPERIMENT

CERN

JHEP 12 (2019) 060
DOI: 10.1007/JHEP12(2019)060

CERN-EP-2019-142
January 31, 2020

Search for bottom-squark pair production with the ATLAS detector in final states containing Higgs bosons, *b*-jets and missing transverse momentum

The ATLAS Collaboration

The result of a search for the pair production of the lightest supersymmetric partner of the bottom quark ($\tilde{b}_1$) using 139 fb^{-1} of proton–proton data collected at $\sqrt{s}$ = 13 TeV by the ATLAS detector is reported. In the supersymmetric scenarios considered both of the bottom-squarks decay into a *b*-quark and the second-lightest neutralino, $\tilde{b}_1 \to b + \tilde{\chi}_2^0$. Each $\tilde{\chi}_2^0$ is assumed to subsequently decay with 100% branching ratio into a Higgs boson (h) like the one in the Standard Model and the lightest neutralino: $\tilde{\chi}_2^0 \to h + \tilde{\chi}_1^0$. The $\tilde{\chi}_1^0$ is assumed to be the lightest supersymmetric particle (LSP) and is stable. Two signal mass configurations are targeted: the first has a constant LSP mass of 60 GeV; and the second has a constant mass difference between the $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ of 130 GeV. The final states considered contain no charged leptons, three or more *b*-jets, and large missing transverse momentum. No significant excess of events over the Standard Model background expectation is observed in any of the signal regions considered. Limits at the 95% confidence level are placed in the supersymmetric models considered, and bottom-squarks with mass up to 1.5 TeV are excluded.

Signal Events
(STDHEP or HEPMC format)

JYA, Fuks, Polykratis EPJC '21

De Favereau et al; JHEP '14

SFS@Ma5 or Delphes

Detector Simulation

C++

Recast

Validation

Public Analysis Database++;

Exclusion limit calculation

JYA, Frank, Fuks EPJC '20

Alguero, JYA, Fuks, Kraml; in progress

TH uncertainties, HL extrapolations simplified and full likelihoods

Cut-flows uncertainties

Dumont, Fuks, Kraml, et. al. EPJC '15

Reimplementing an analysis in MadAnalysis 5

Recasting toolbox

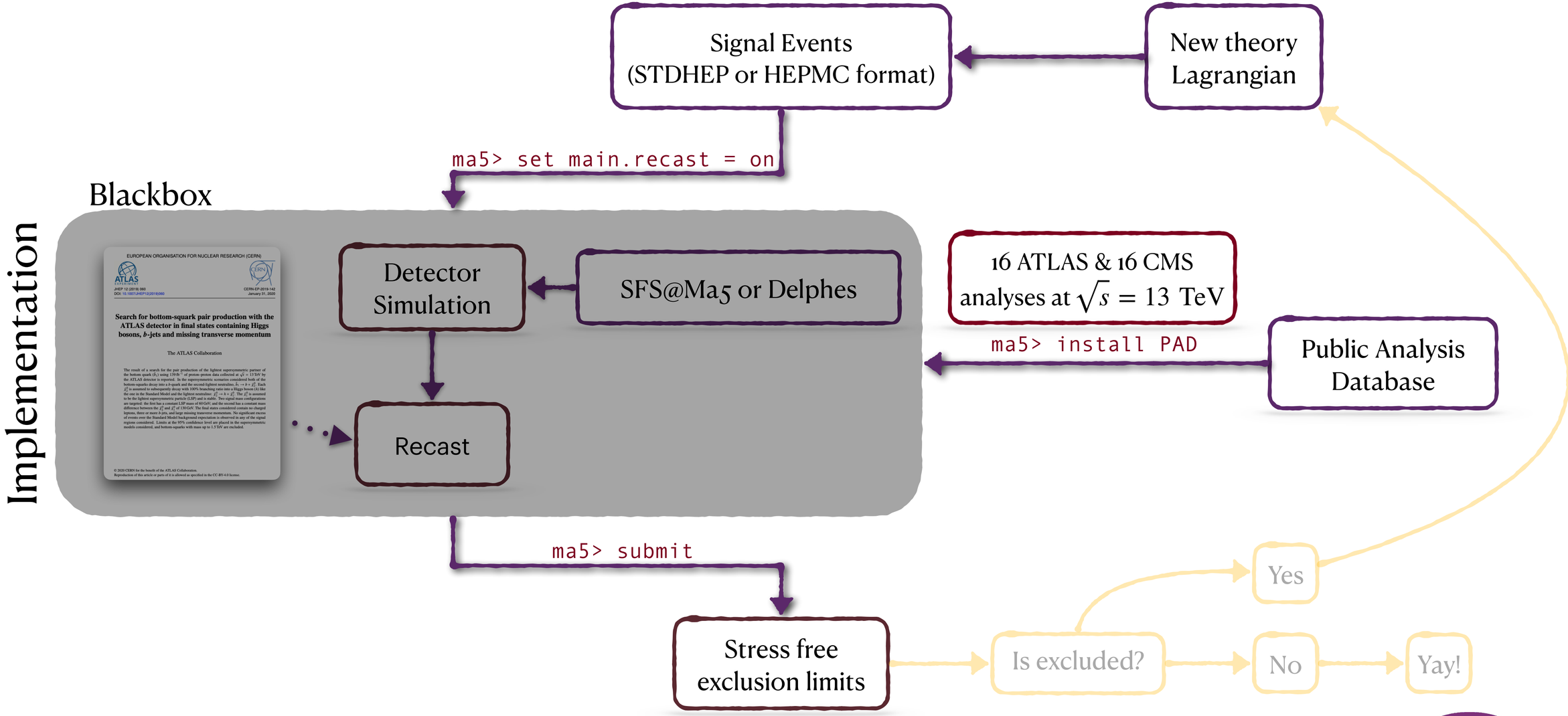
- Calculating exclusion limits, expected and observed excluded cross sections via uncorrelated signal regions.
- NEW Improved limits via full likelihoods with ATLAS' HistFactory-like likelihood profiles
- NEW Improved limits via simplified likelihoods with CMS' correlation matrices

For details see the talk at "Publication of statistical models: hands on workshop"

- Exclusion limits with theoretical uncertainties & higher luminosity extrapolations JYA, Frank, Fuks EPJC '20

Dumont, Fuks, Kraml, et. al. EPJC '15

Reimplementing an analysis in MadAnalysis 5



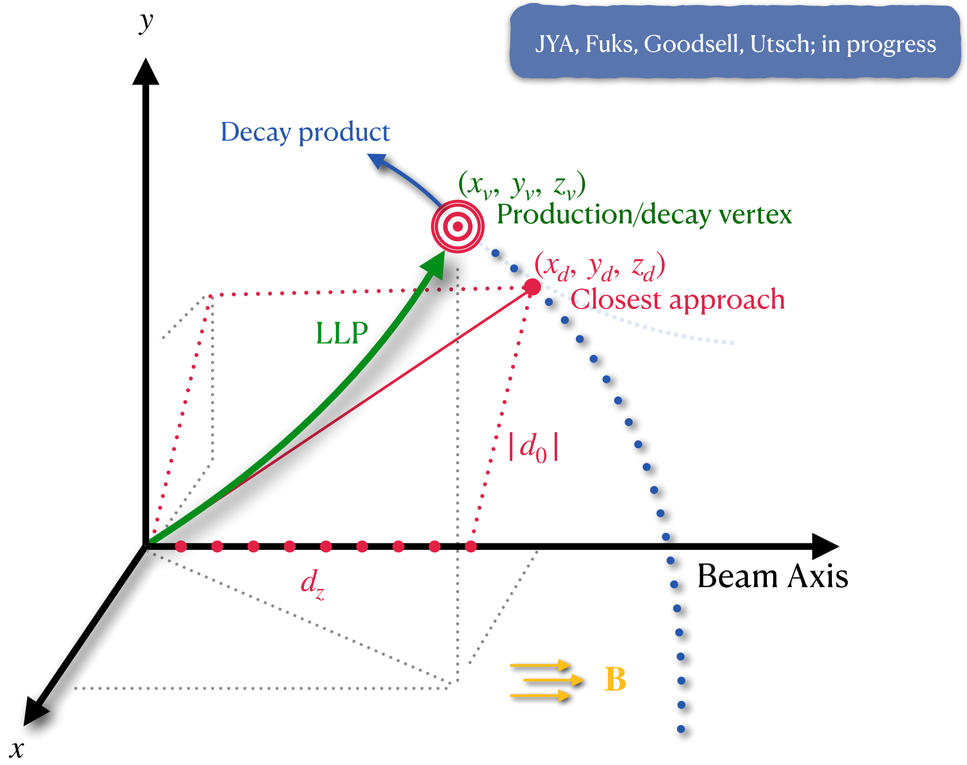
Dumont, Fuks, Kraml, et. al. EPJC '15

Particle propagation in SFS

JYA, Fuks, Polykratis EPJC '21

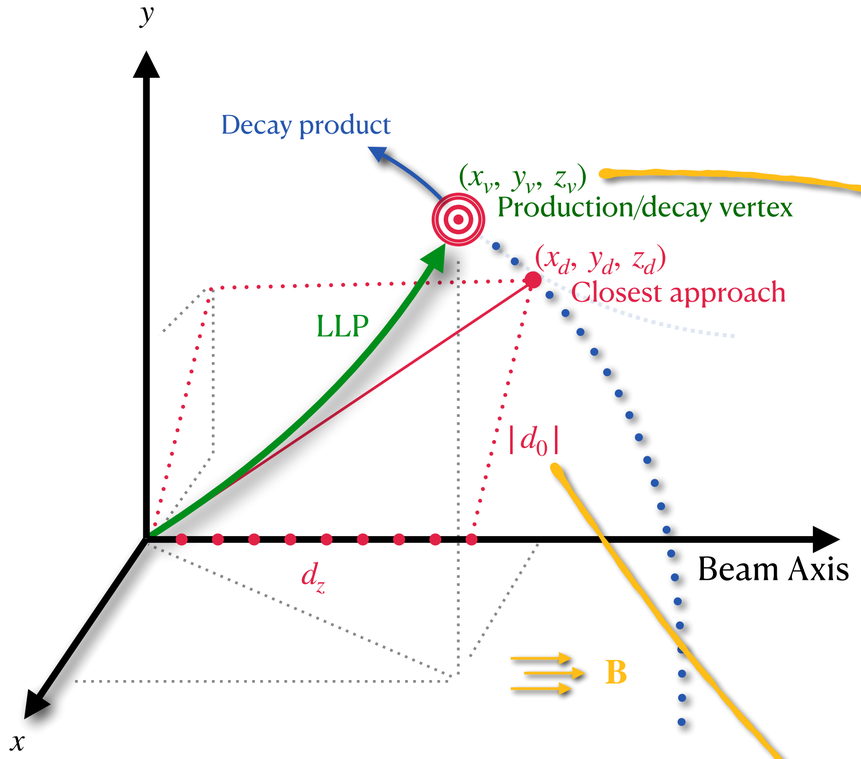
- SFS module allows for simple observable smearing based on transfer functions.
- Transverse impact parameter (d_0) and longitudinal impact parameter (d_z) can be calculated with straight trajectory assumption (default behaviour for other recasting softwares).
- Modification of particle trajectories under constant magnetic field can provide relevant effects for unusual particle signatures.

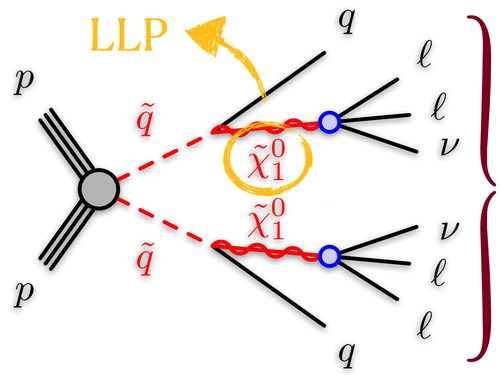
JYA, Fuks, Goodsell, Utsch; in progress



Particle propagation in SFS

JYA, Fuks, Goodsell, Utsch; in progress





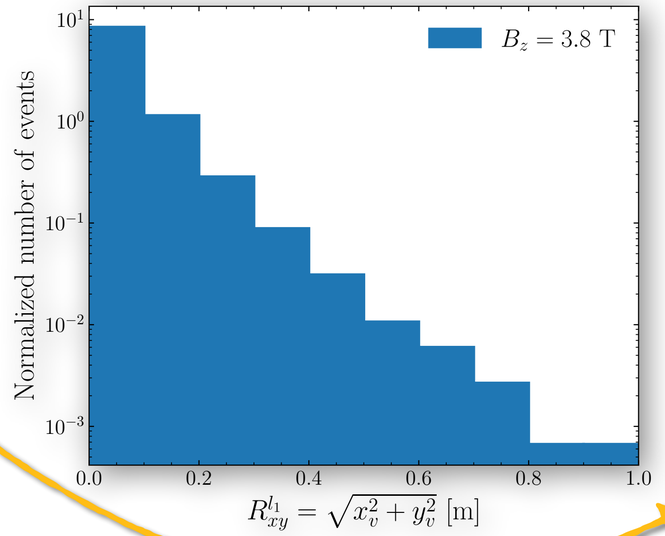
RPV - SUSY

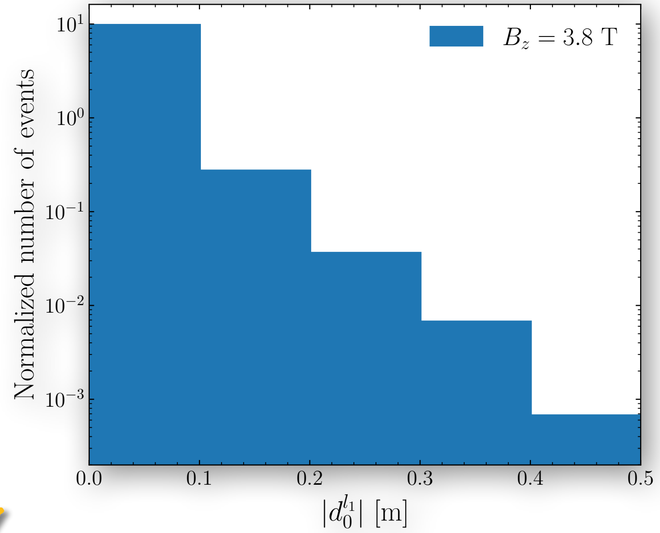
$\mathrm{BR}(\tilde{\chi}_1^0 \to ee\nu) = 50\,\%$

$\mathrm{BR}(\tilde{\chi}_1^0 \to e\mu\nu) = 50\,\%$

$m_{\tilde{u}_1,\tilde{d}_1} = 1.6$ TeV

$m_{\tilde{\chi}_1^0} = 1.3$ TeV

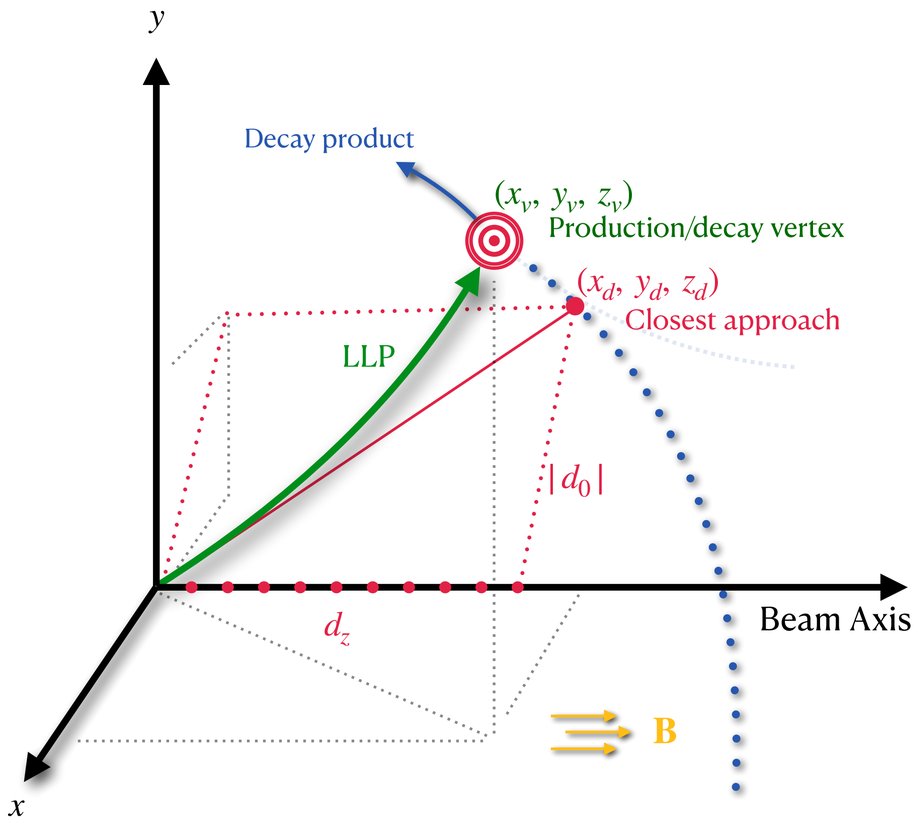





```
ma5> set main.fastsim.particle_propagator = on
ma5> set main.fastsim.magneticfield = 3.8
```

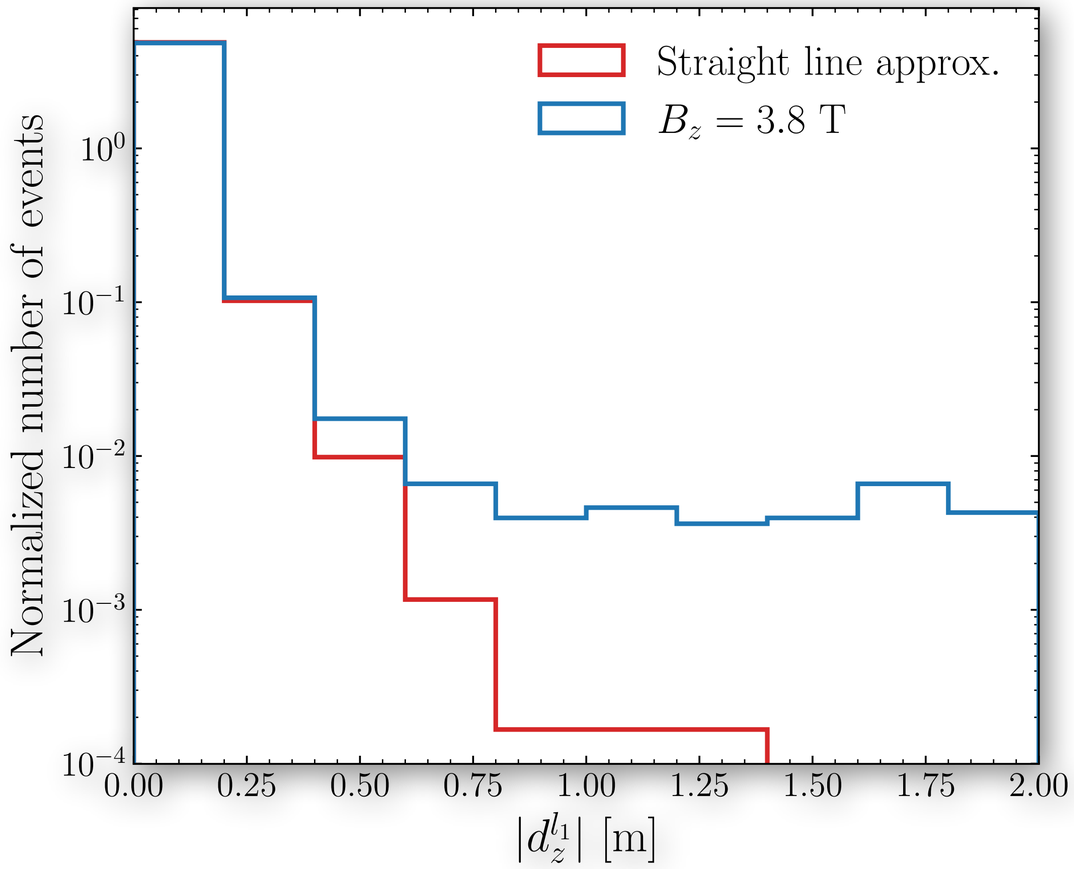
Particle propagation in SFS

JYA, Fuks, Goodsell, Utsch; in progress



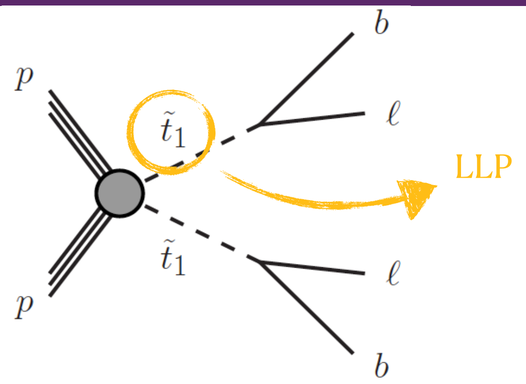
$$d_z = z_v + \frac{p_z}{qB}\arctan(\omega \Delta t_v)$$

$$\omega = \frac{qc^2 B}{E}$$

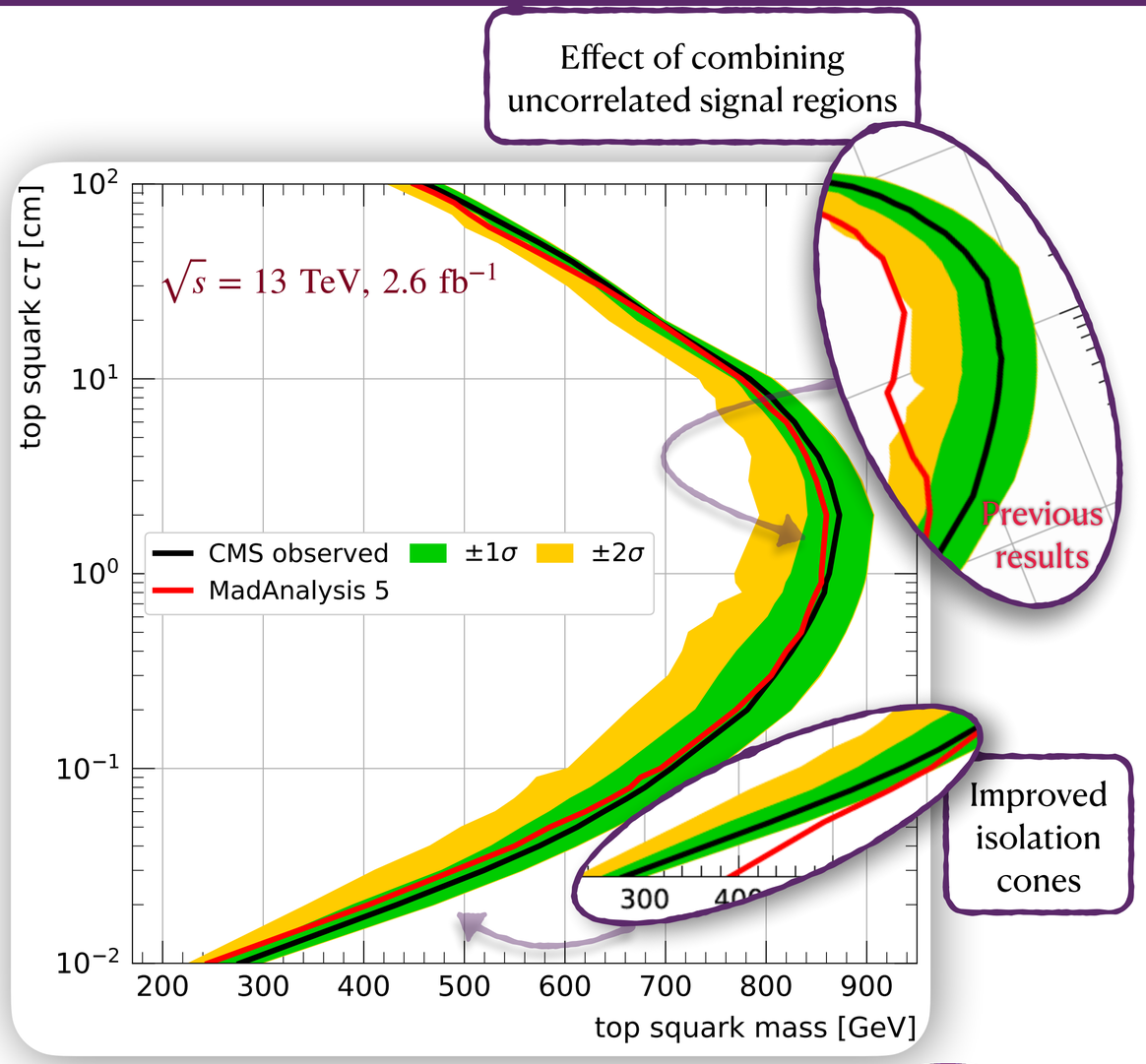


CMS-EXO-16-022: displaced leptons

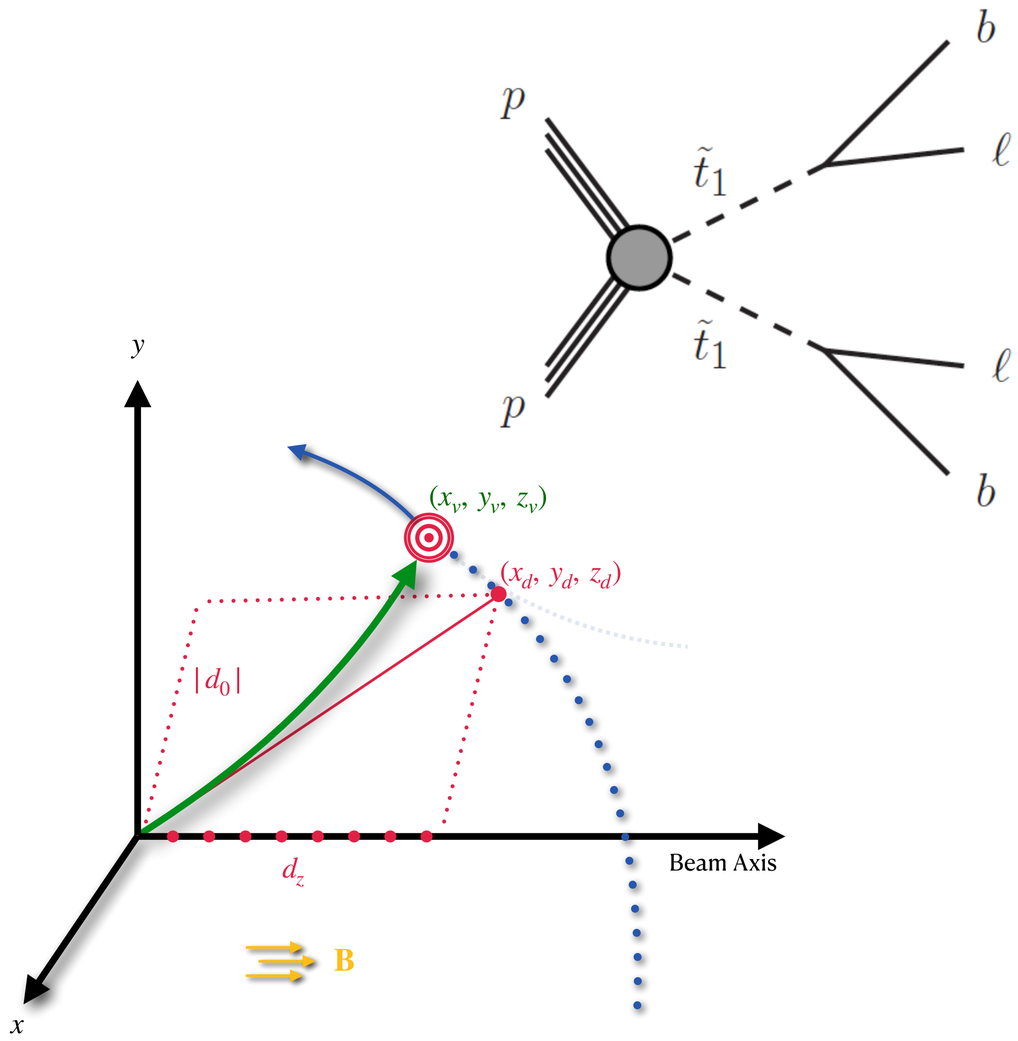
Recasted by Manuel Utsch



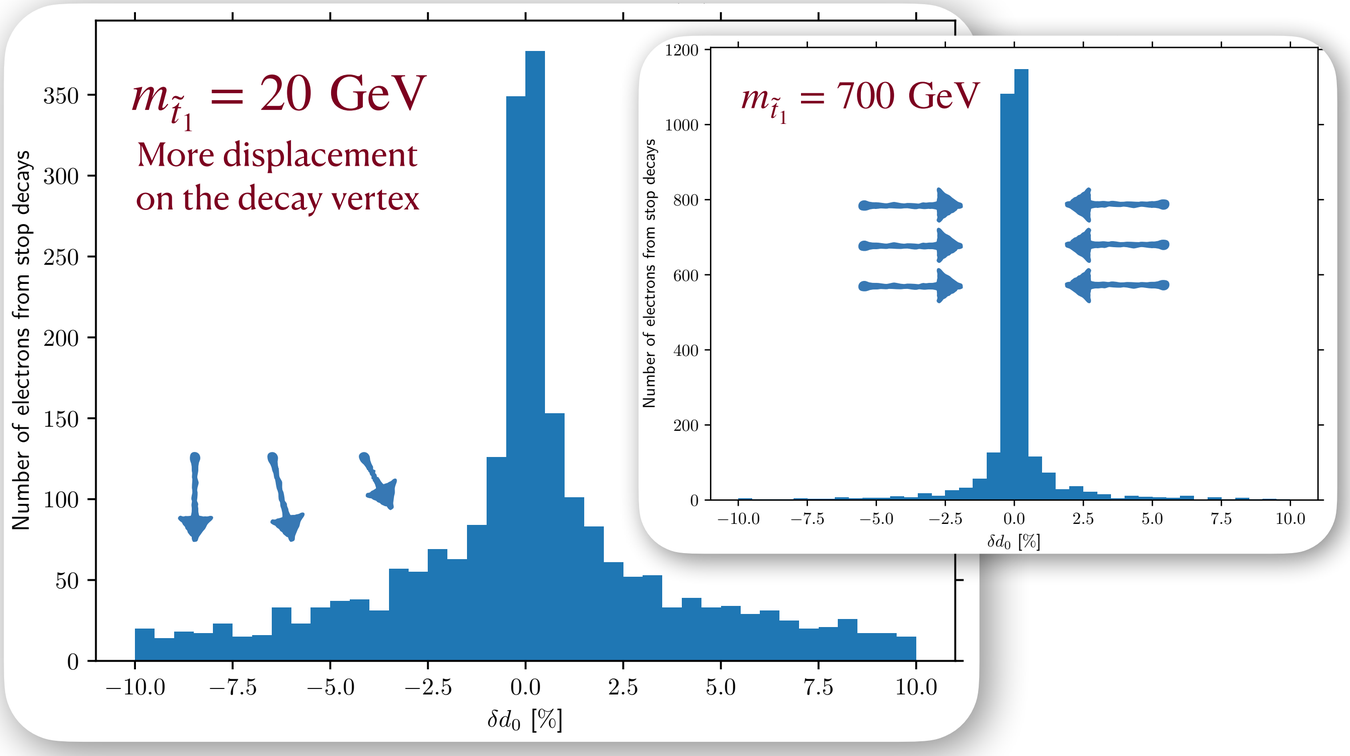
- Step I) Validation of the SFS module with particle propagator
- Existing recast from 2018 adapted to the SFS with particle propagation module.
- Improved track based isolation cones.
- Very scarce validation material.
- No available statistics!



CMS-EXO-16-022: Impact of the particle propagator

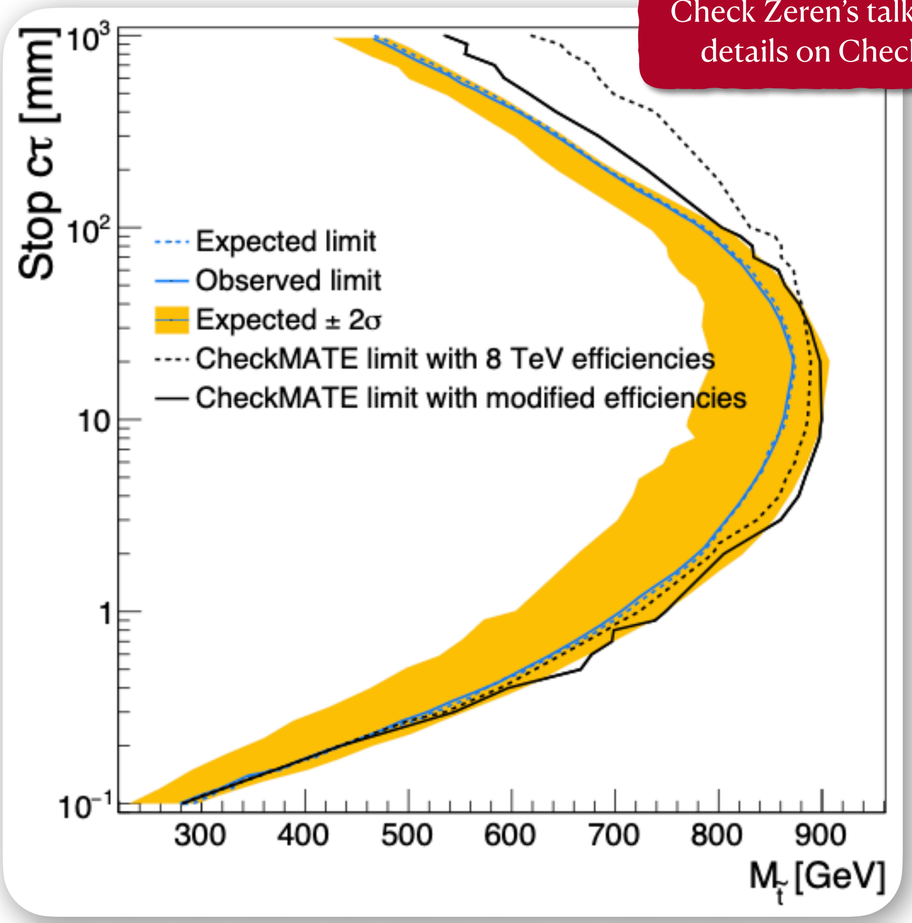


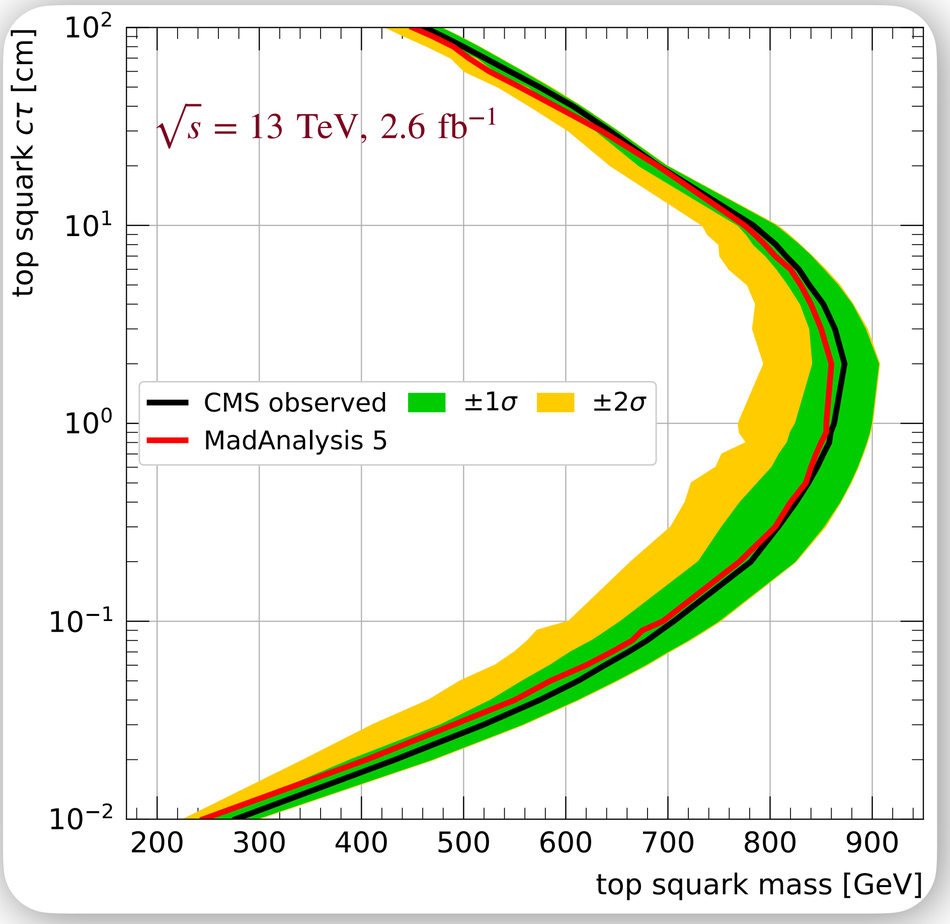
$$\delta d_0 = \frac{d_0 - d_0^{\text{approx}}}{d_0^{\text{approx}}}$$



CMS-EXO-16-022: displaced leptons

Check Zeren's talk for more details on CheckMATE





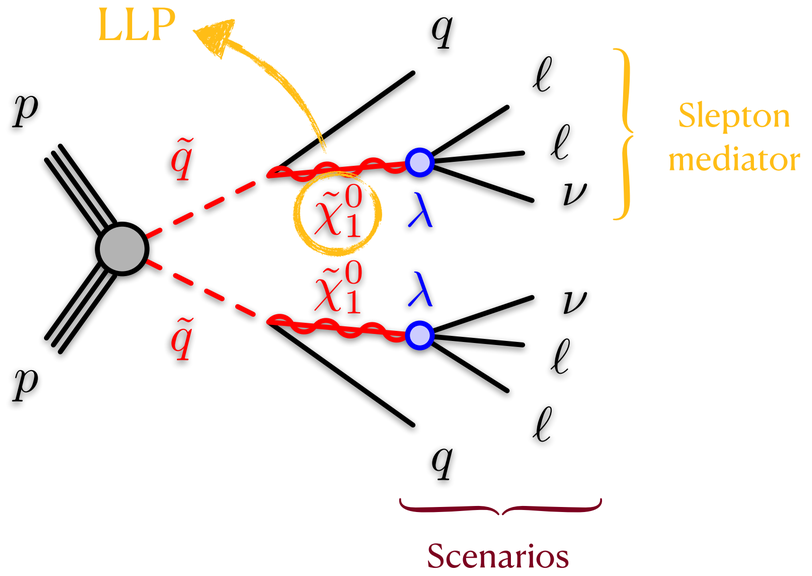
Thanks to CheckMATE team for the valuable discussion

ATLAS-SUSY-2017-04: displaced vertices

- Detailed auxiliary material (thanks!!)
  - Reconstruction efficiency maps
  - Maps for vetoed detector regions
  - Cut-flow tables
  - Digitized plots (next slide)

$\sqrt{s} = 13$ TeV, 32.8 fb^{-1}

RPV - SUSY



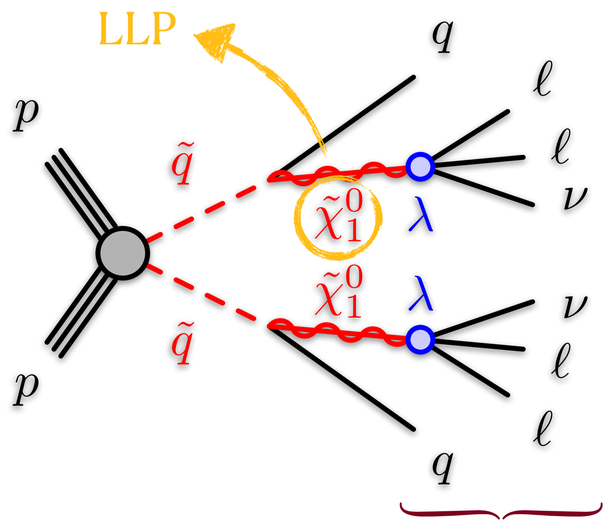
$\lambda_{121} := \mathrm{BR}(\tilde{\chi}_1^0 \to ee\nu) = \mathrm{BR}(\tilde{\chi}_1^0 \to e\mu\nu) = 50\,\%$

$\lambda_{122} := \mathrm{BR}(\tilde{\chi}_1^0 \to \mu\mu\nu) = \mathrm{BR}(\tilde{\chi}_1^0 \to e\mu\nu) = 50\,\%$

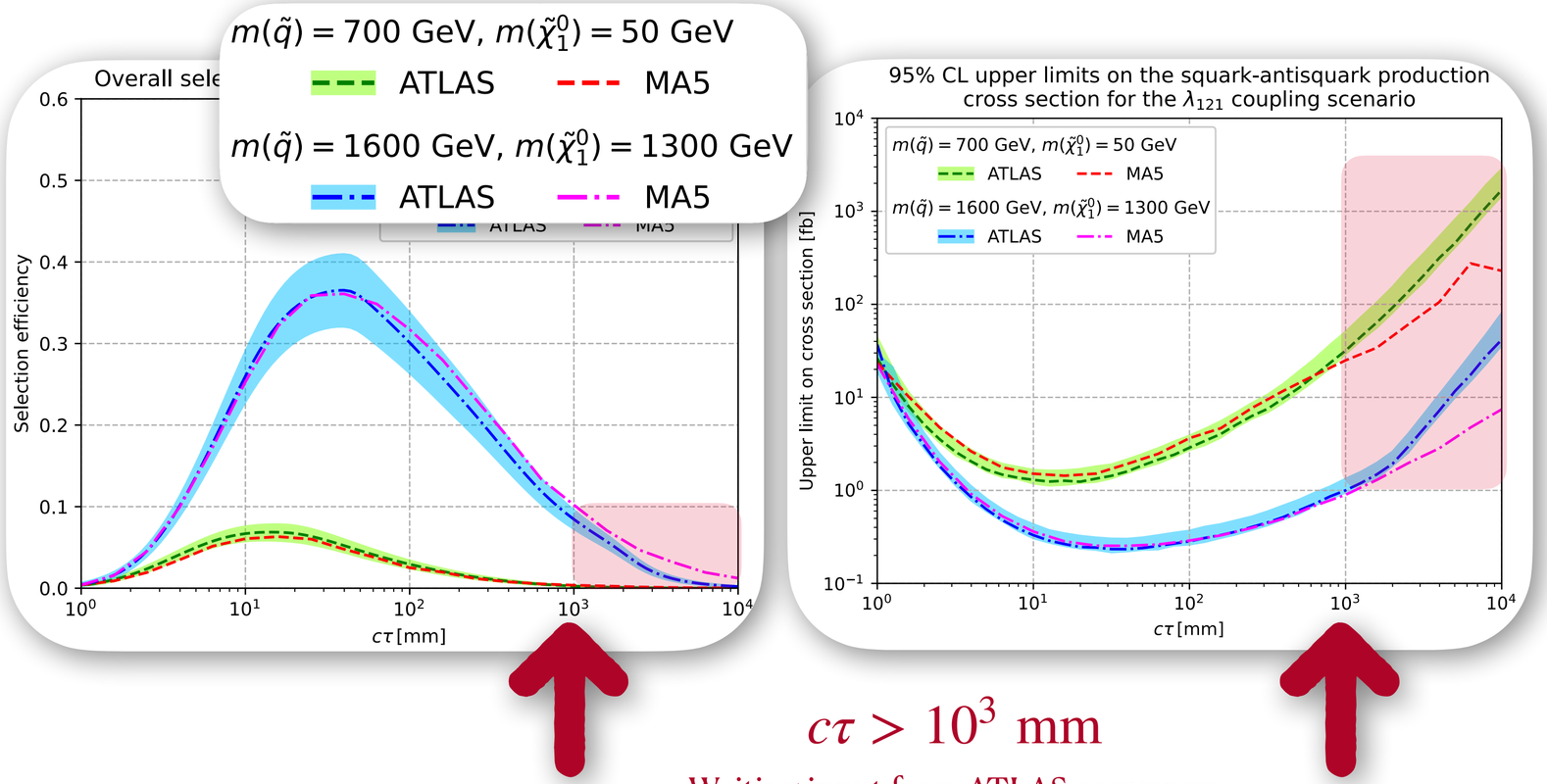
ATLAS-SUSY-2017-04: displaced vertices

Recasted by Manuel Utsch

$\sqrt{s} = 13$ TeV, 32.8 fb^{-1}



$\lambda_{121} :=$ BR($\tilde{\chi}_1^0 \to ee\nu$) = BR($\tilde{\chi}_1^0 \to e\mu\nu$) = 50 %



$c\tau > 10^3$ mm

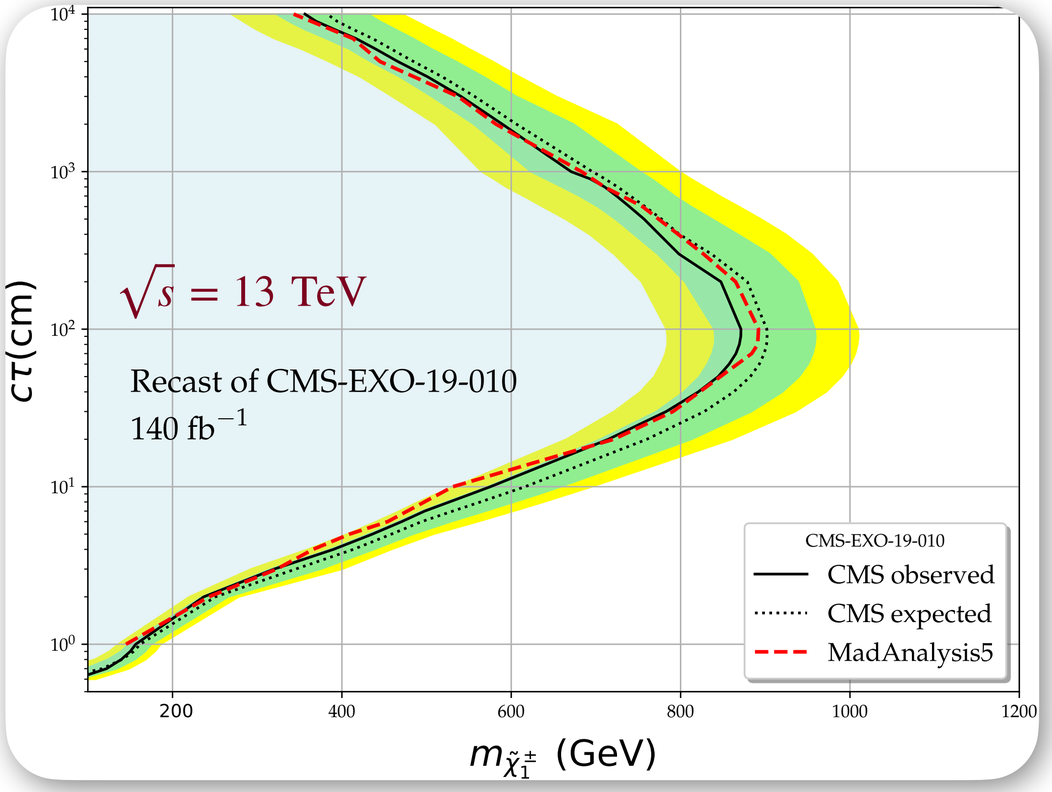
Waiting input from ATLAS conveners (since March!)

CMS-EXO-19-010: disappearing tracks

Check Mark's talk for more details

- Anomaly-mediated SUSY breaking with $m_{\tilde{\chi}_1^\pm} \simeq m_{\tilde{\chi}_1^0}$.
- Due to the minimal effect pile-up has been removed.
- Track based isolation cones implemented in SFS.
- Separate data periods are handled through reweighing SRs independently.

$pp \to \tilde{\chi}_1^\pm(\to \tilde{\chi}_1^0 \pi^\pm)\ \tilde{\chi}_1^0$



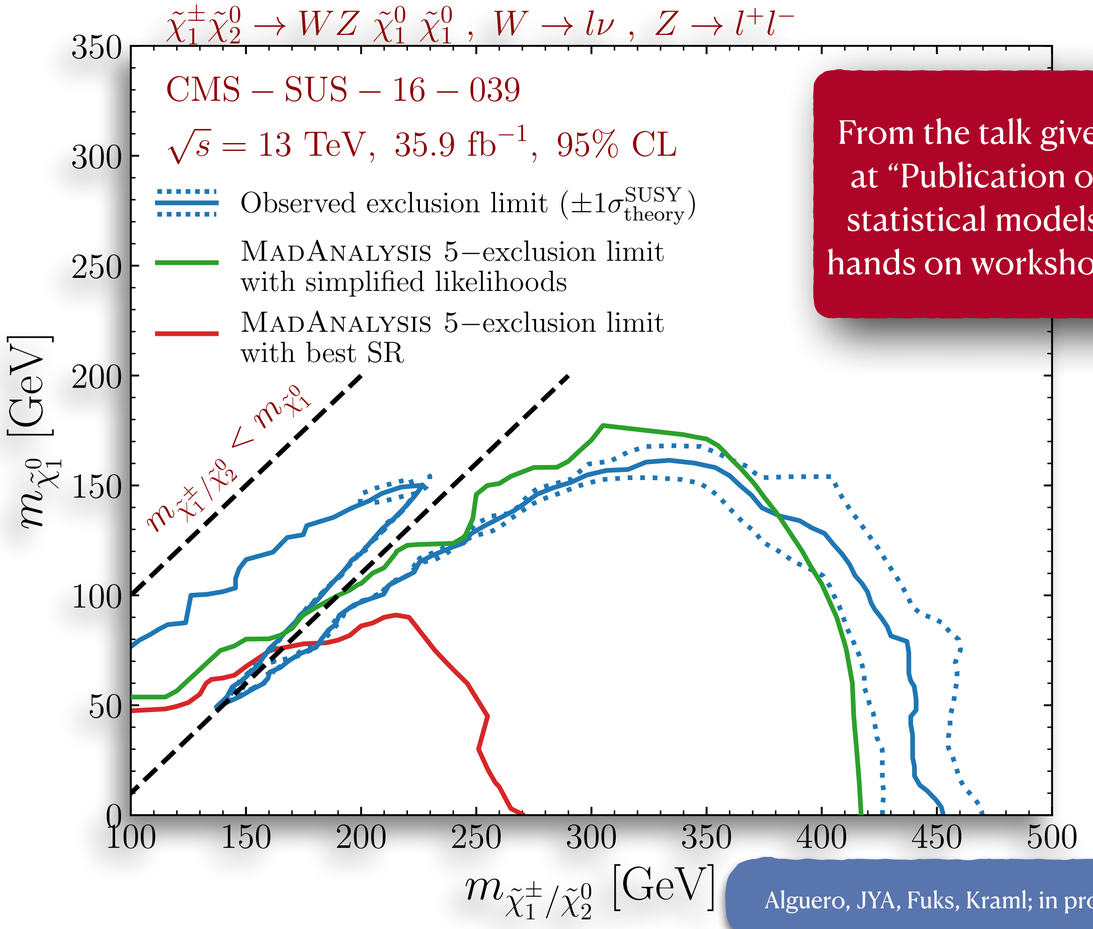
Conclusion

Conclusion

- Particle propagation can have significant effect on analysis outcome, depending on the theory behind.
- Uncorrelated signal regions do not represent the statistical model of the analysis well enough. Full or simplified likelihood profiles are essential for better reinterpretation.

NEW MadAnalysis 5 is fully capable of using correlation matrices and full likelihood profiles to improve exclusion limits.

NEW Particle propagation module is available with MadAnalysis v1.9 alongside with various LLP recasts.



From the talk given at "Publication of statistical models: hands on workshop"

Alguero, JYA, Fuks, Kraml; in progress

Conclusion

- Particle propagation can have significant effect on analysis outcome, depending on the theory behind.
- Uncorrelated signal regions do not represent the statistical model of the analysis well enough. Full or simplified likelihood profiles are essential for better reinterpretation.

NEW MadAnalysis 5 is fully capable of using correlation matrices and full likelihood profiles to improve exclusion limits.

NEW Particle propagation module is available with MadAnalysis v1.9 alongside with various LLP recasts.

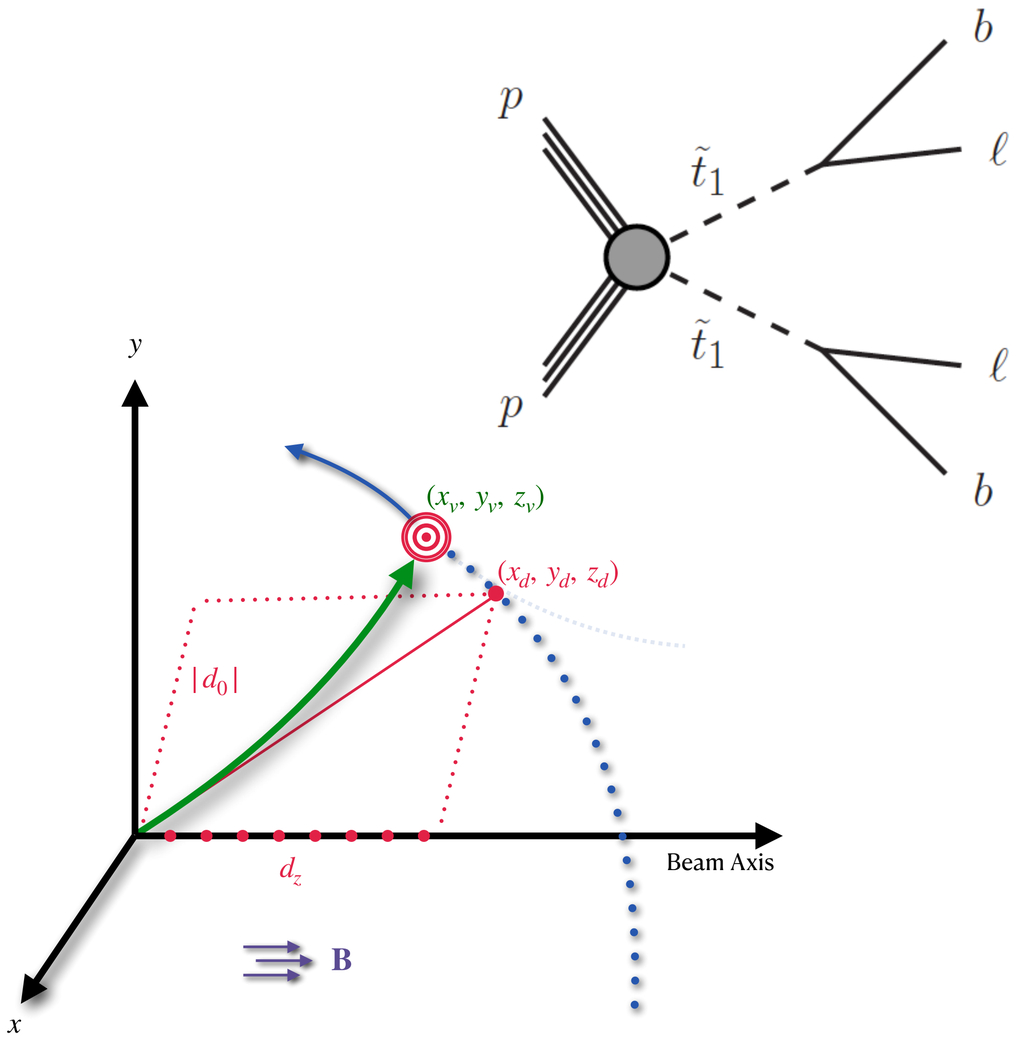
WANTED: Analysis codes

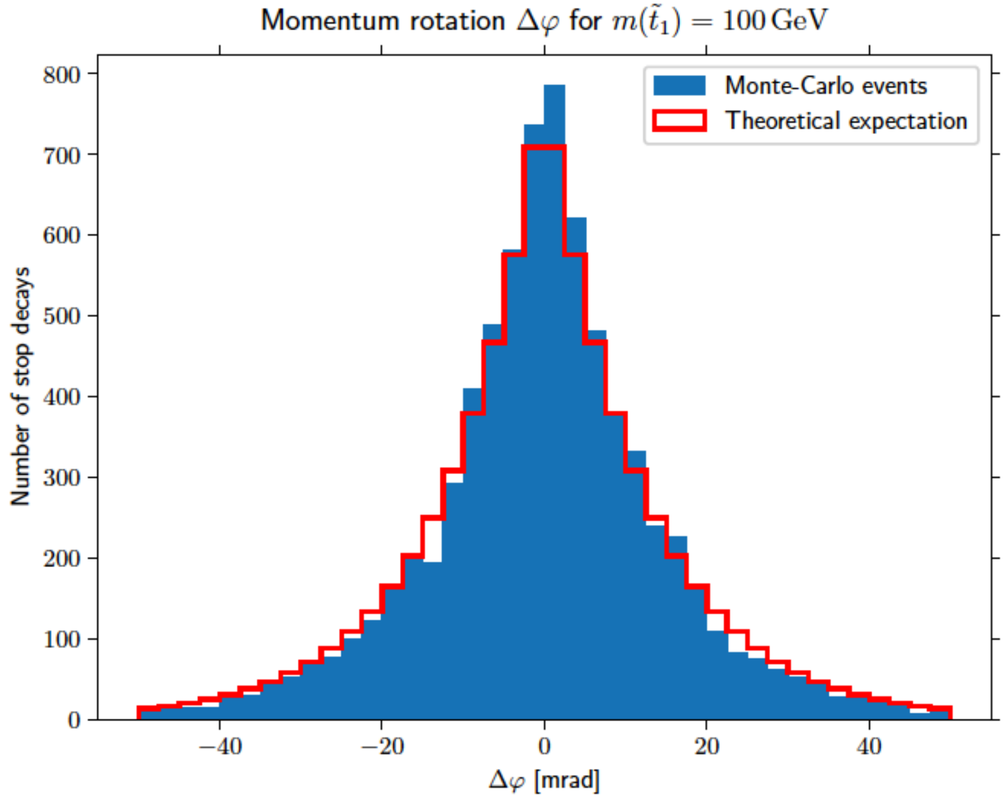
Scientific reproducibility and data preservation solely depend on preserving analysis logic in a reinterpretable form. You can contribute to the HEP community by sharing the LHC recast you have implemented in the MadAnalysis 5 framework, through Public Analysis Database! Please send us your analysis code, detector card, info file and validation note to be included in PAD for public use.

More information and examples can be found in the proceedings of the second MadAnalysis 5 Workshop on LHC recasting in Korea. Analysis codes have been published, documented and got a DOI so that they can now be cited.

Backup

CMS-EXO-16-022: Impact of the particle propagator





$$\Delta\varphi = qcB\frac{ct_0}{mc^2}$$