SModelS - development beyond Missing Energy

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ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

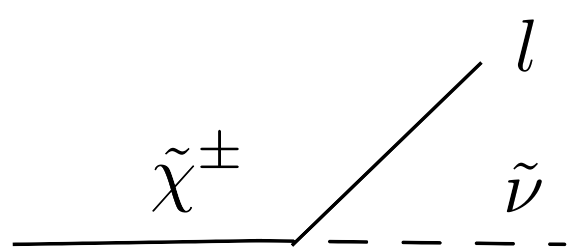
Discrete symmetries and new physics

1. Multiple examples of discrete symmetries in particle physics exist (within the Standard Model)
   - Charge
   - Parity
2. Many BSM scenarios employ discrete symmetries and are intimately tied to dark matter phenomenology
   - SUSY neutralino dark matter-> R -parity
   - Inert Doublet Model -> Z_2 symmetry
   - Self interacting dark matter -> e.g. Z_3 symmetry …
3. Collider signatures are a result of the symmetries, mass spectrum and couplings of the theory
   - Result in classic missing energy searches
   - Can also lead to more exotic final states

One model: many signatures

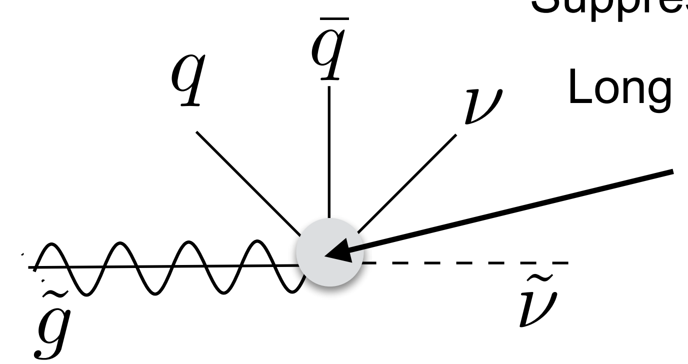
Kulkarni et al. JHEP 1505 (2015) 142

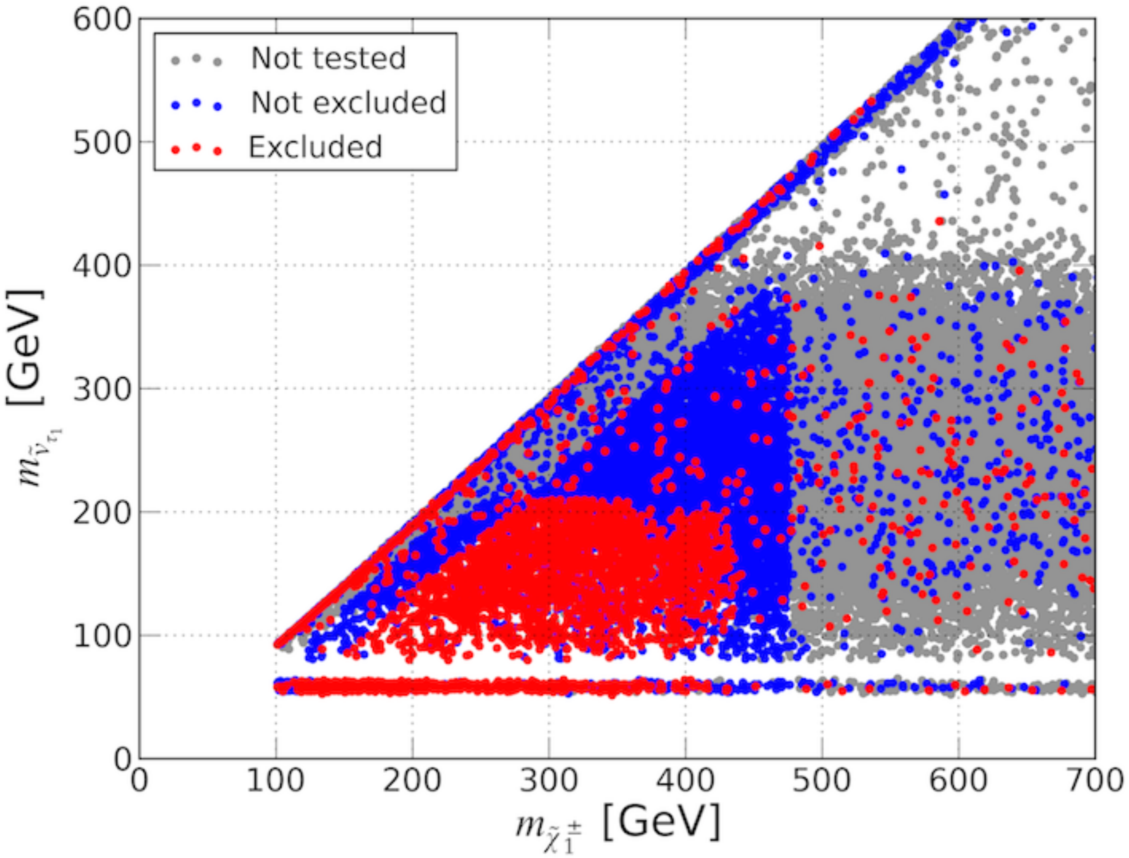
Spin 1/2

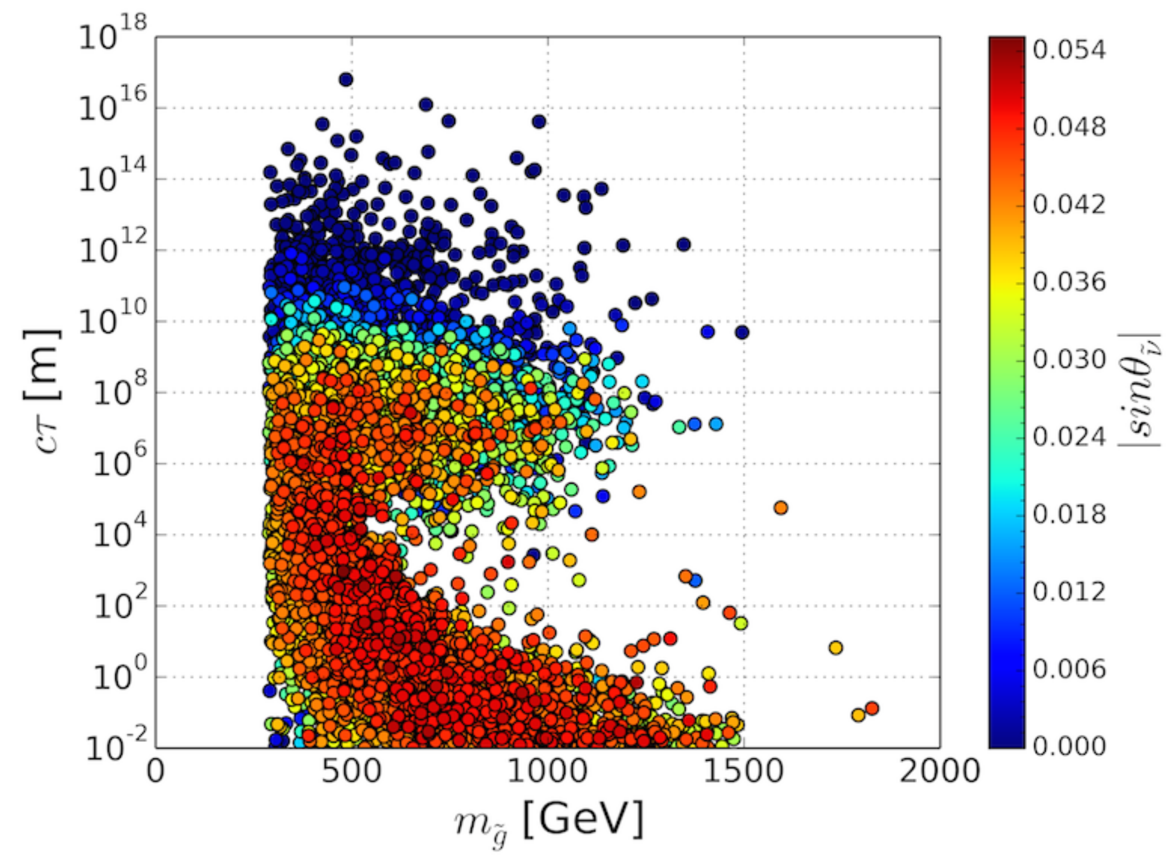


Suppressed coupling

Long lived gluino







- Results for Sneutrino LSP
- Caveat: left plot inverted also shows many points non-excluded (not shown here)
- Caveat: right plot also has dependence on LSP mass (not shown here)

One model - many signatures

Heavy neutral leptons

SIMPs

SUSY

Extended scalar sectors

Dark matter

Hidden valley

Extra dimensions

Current efforts beyond MET

- Apply efficiency maps given by experiments 'by hand' to single topologies (a la simplified models approach)
  - Constrains specific parts of parameter space but difficult to get global picture for full models

C.f. Evans et al JHEP 1604 (2016) 056, Belanger et al arXiv:1811.05478

- Improve fast detector simulators such as Delphes (see: Delphes 3.4.1)

C.f. https://inspirehep.net/record/1667603/, LLP workshop talk

- Classify signatures dynamically and confront them with experimental searches (SModelS)

C.f. Heisig et al. arXiv:1808.05229, Ambrogi et al. arXiv:1811.10624

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http://smodels.hephy.at/

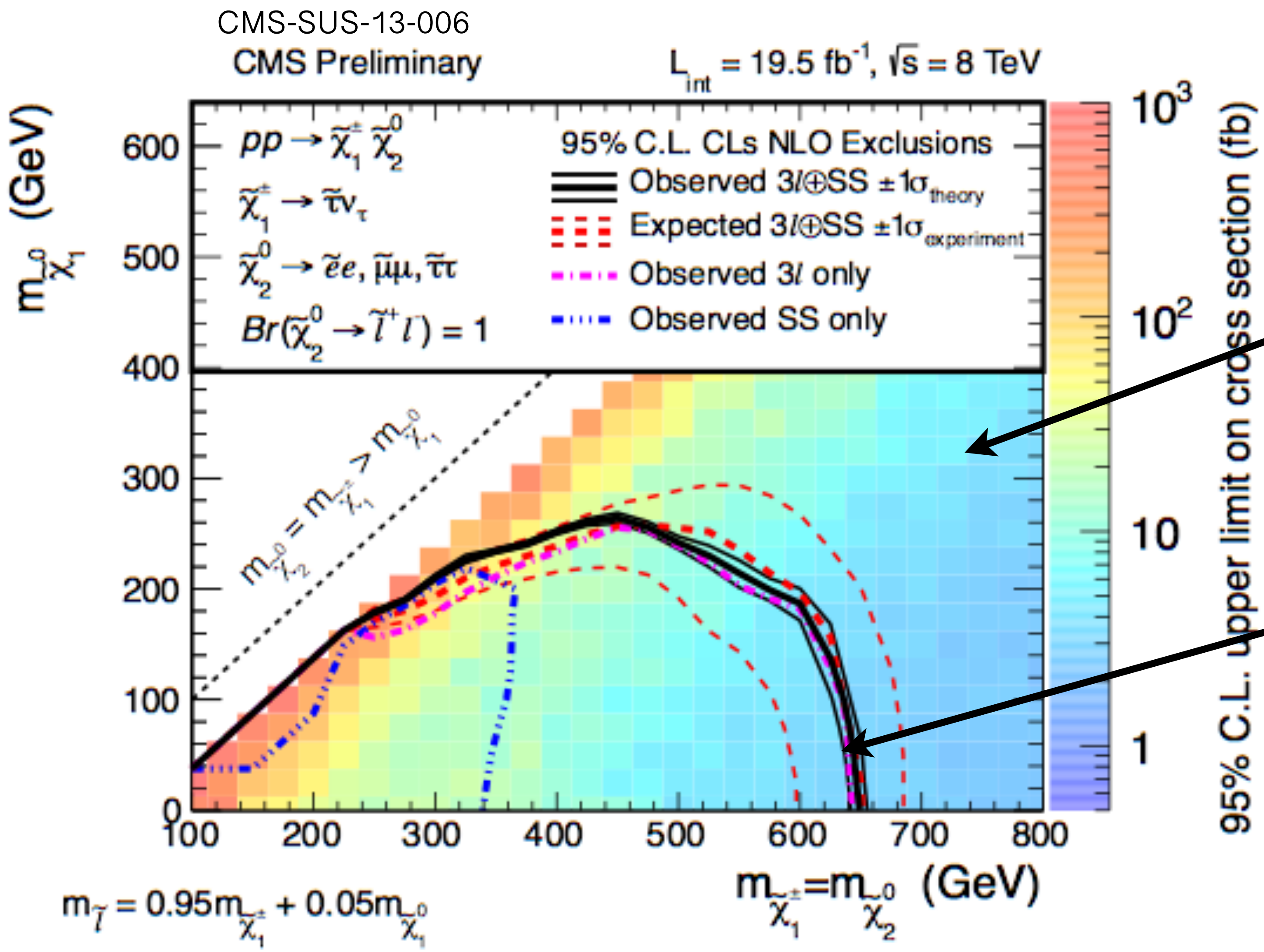
SModelS

- A tool to confront arbitrary (incl. non-SUSY) theoretical models with LHC results via decomposing theory models into simplified models dynamically

C.f. Heisig et al. arXiv:1808.05229

- Assumptions:
  - Model obeys Z_2 symmetry (R-parity)
    - ✴ Implications: applicable only to pair production of BSM particles (i.e. can't handle resonance searches at the moment)
  - All BSM particles decay to missing energy final states (SModelS v1.1.1)
  - Model can be approximated by sum over simplified models (i.e. long decay chains don't contribute to signal cross section significantly)
  - No dependence on nature of BSM particles (i.e. quantum numbers)
  - Most relevant quantities for confronting theory with experimental results are:
    - ✴ masses of BSM particles
    - ✴ SM final state particles
    - ✴ cross sections X branching ratios

Reading SMS result



We should use these numbers

Useful but not the most important outcome

- 95% CL UL is the maximum visible cross-section allowed for a specific decay chain and a mass combination

Is σ X BR (Mother mass, intermediate mass, LSP mass) of your model > the number on the plot? -- Yes, point excluded; No, point allowed

Kraml et al, arXiv:1412.1745
Eur.Phys.J. C74 (2014) 2868

Given
Spectra

$\tilde{\chi}_1^+, \tilde{\chi}_2^0$

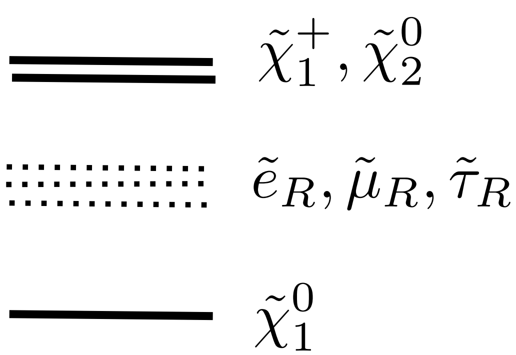
$\tilde{e}_R, \tilde{\mu}_R, \tilde{\tau}_R$

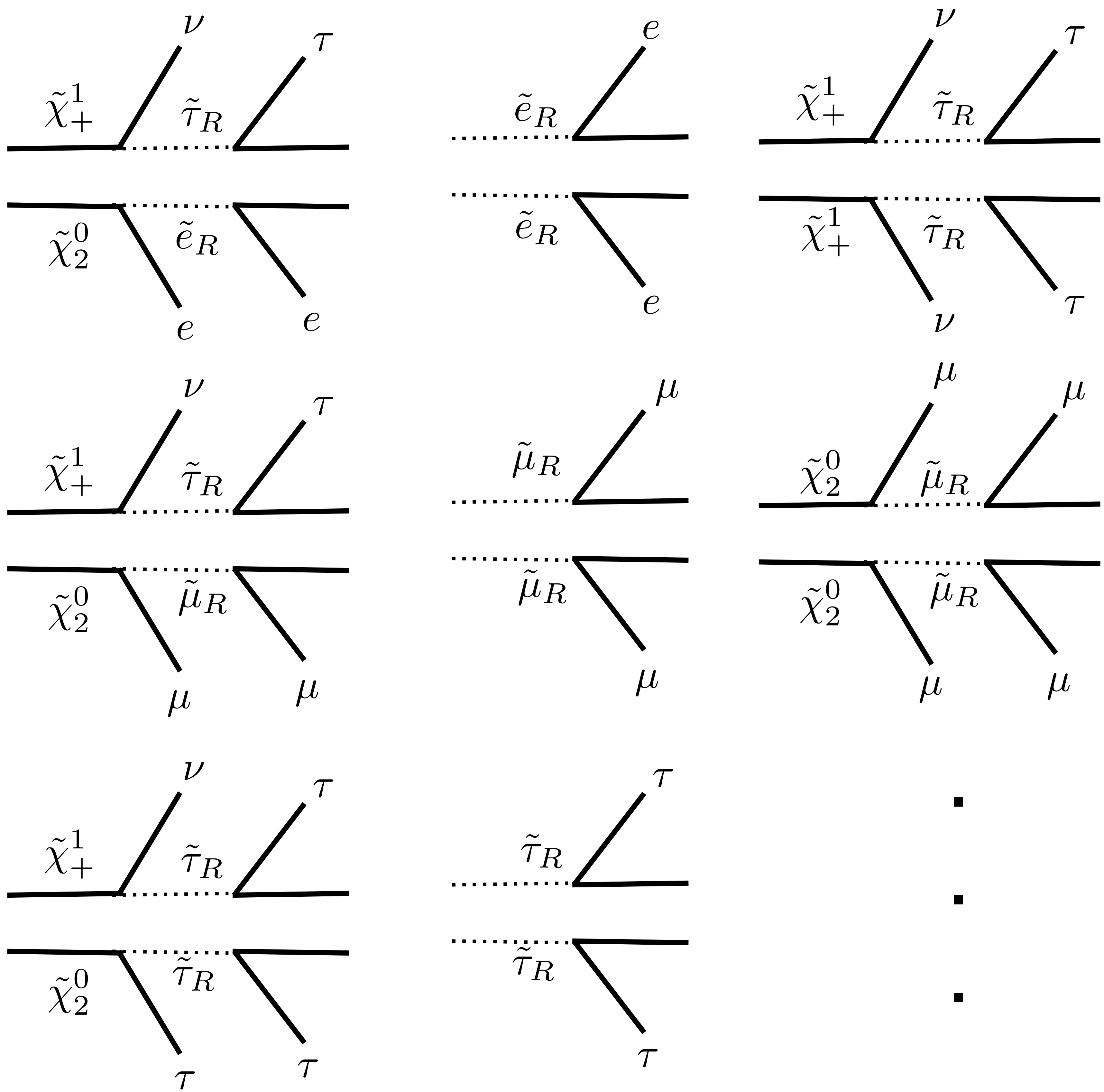
$\tilde{\chi}_1^0$

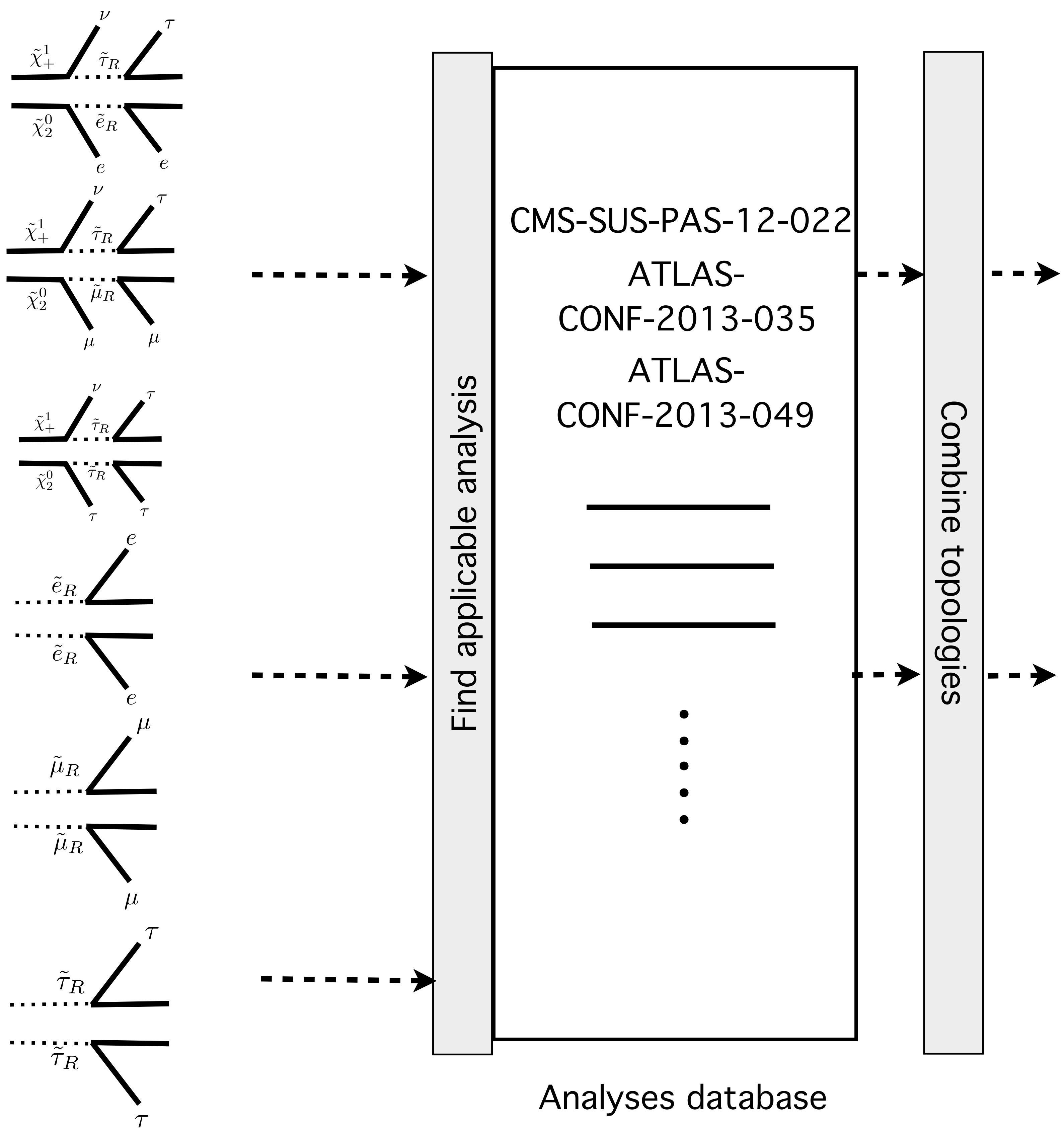
Decomposition

Kraml et al, arXiv:1412.1745
Eur.Phys.J. C74 (2014) 2868

Given Spectra



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ATLAS-
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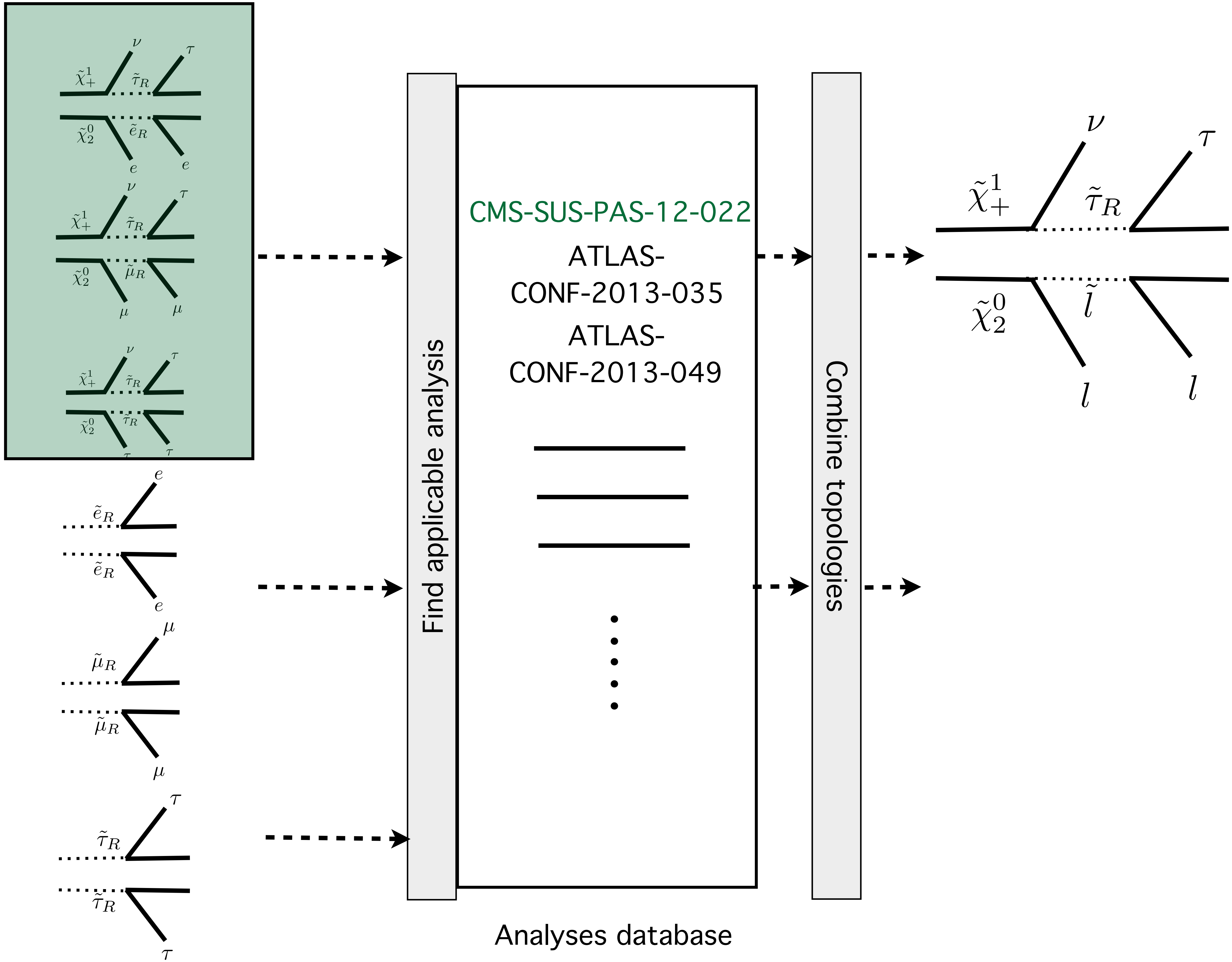
Find applicable analysis
Combine topologies
Analyses database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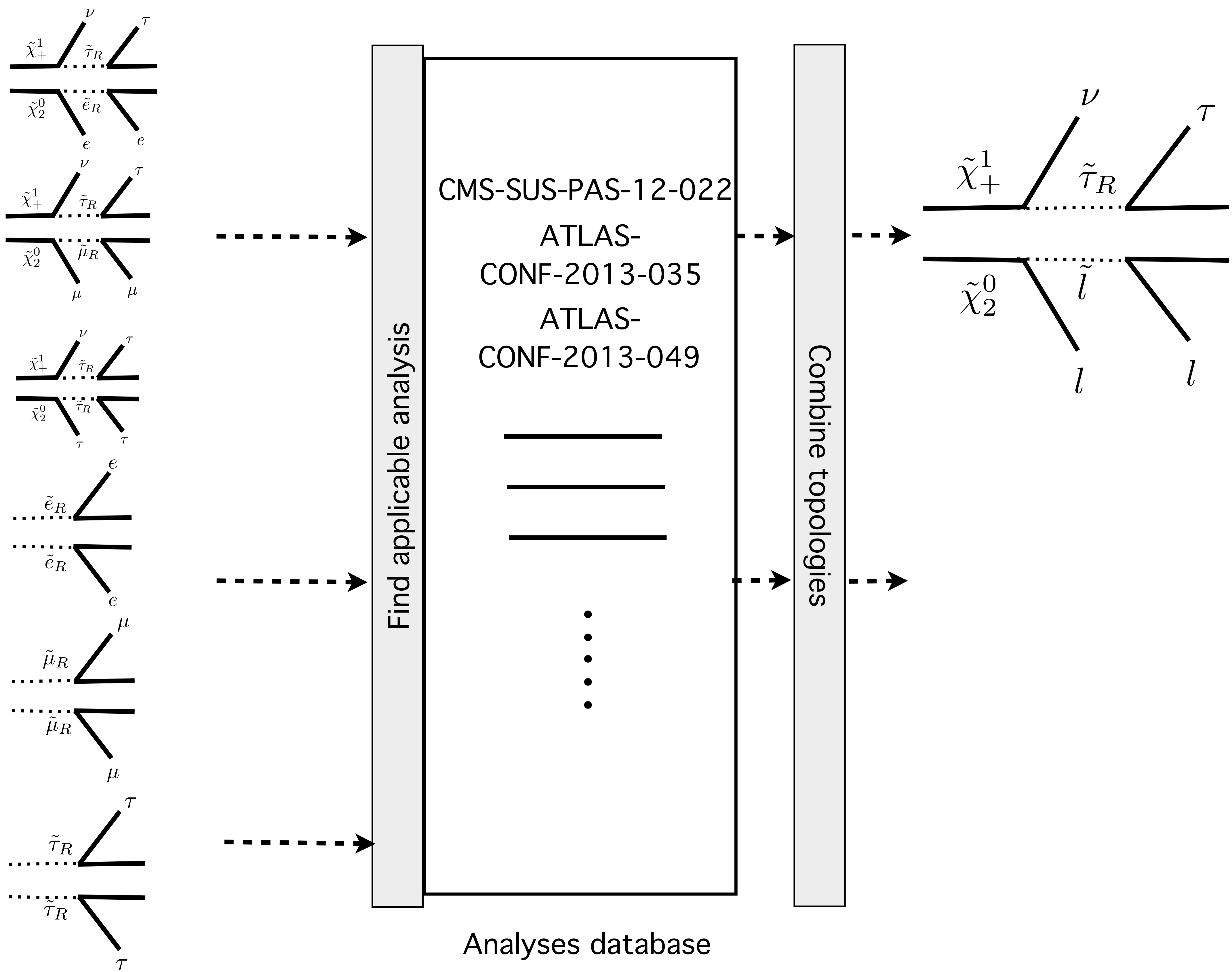
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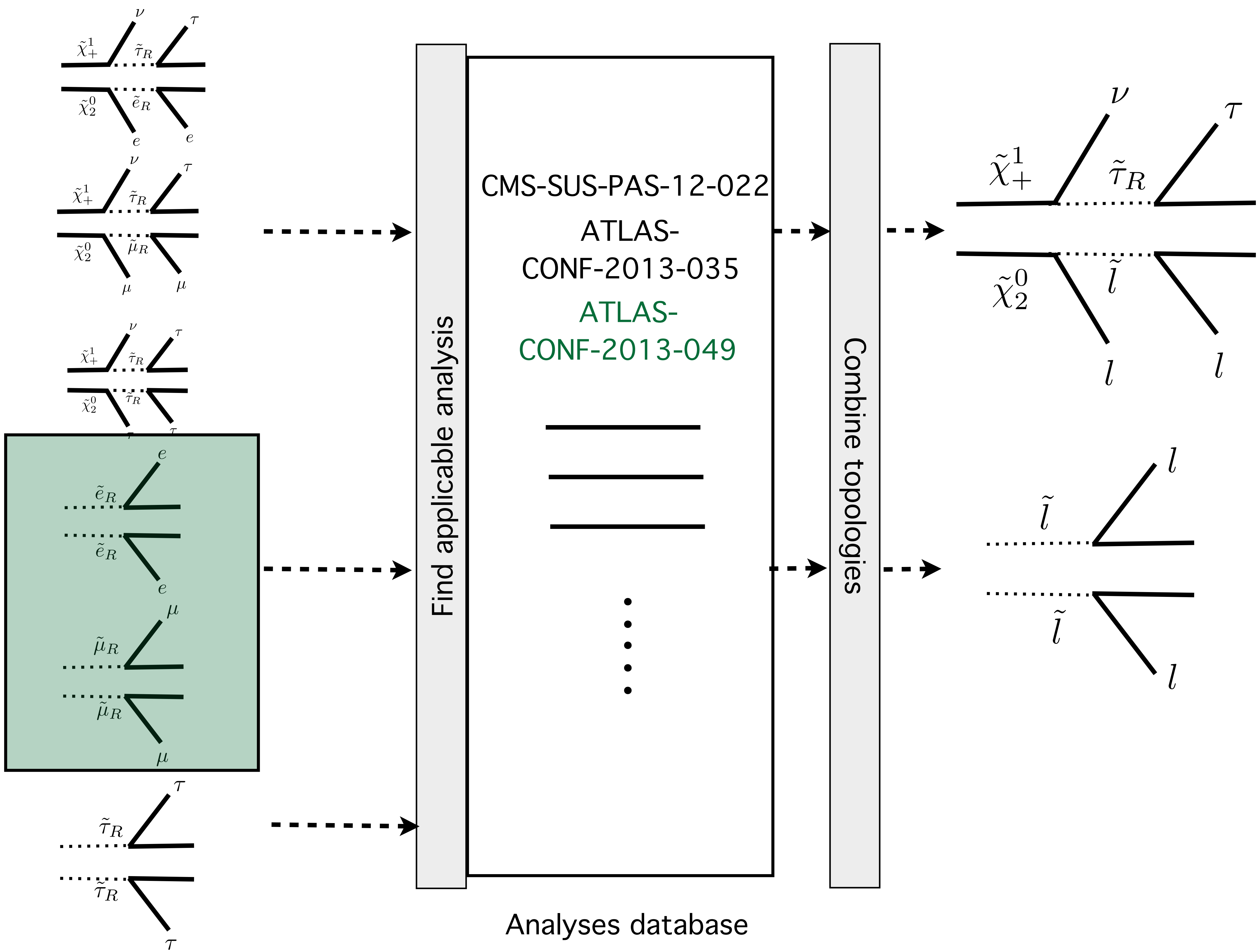

CMS-SUS-PAS-12-022
ATLAS-CONF-2013-035
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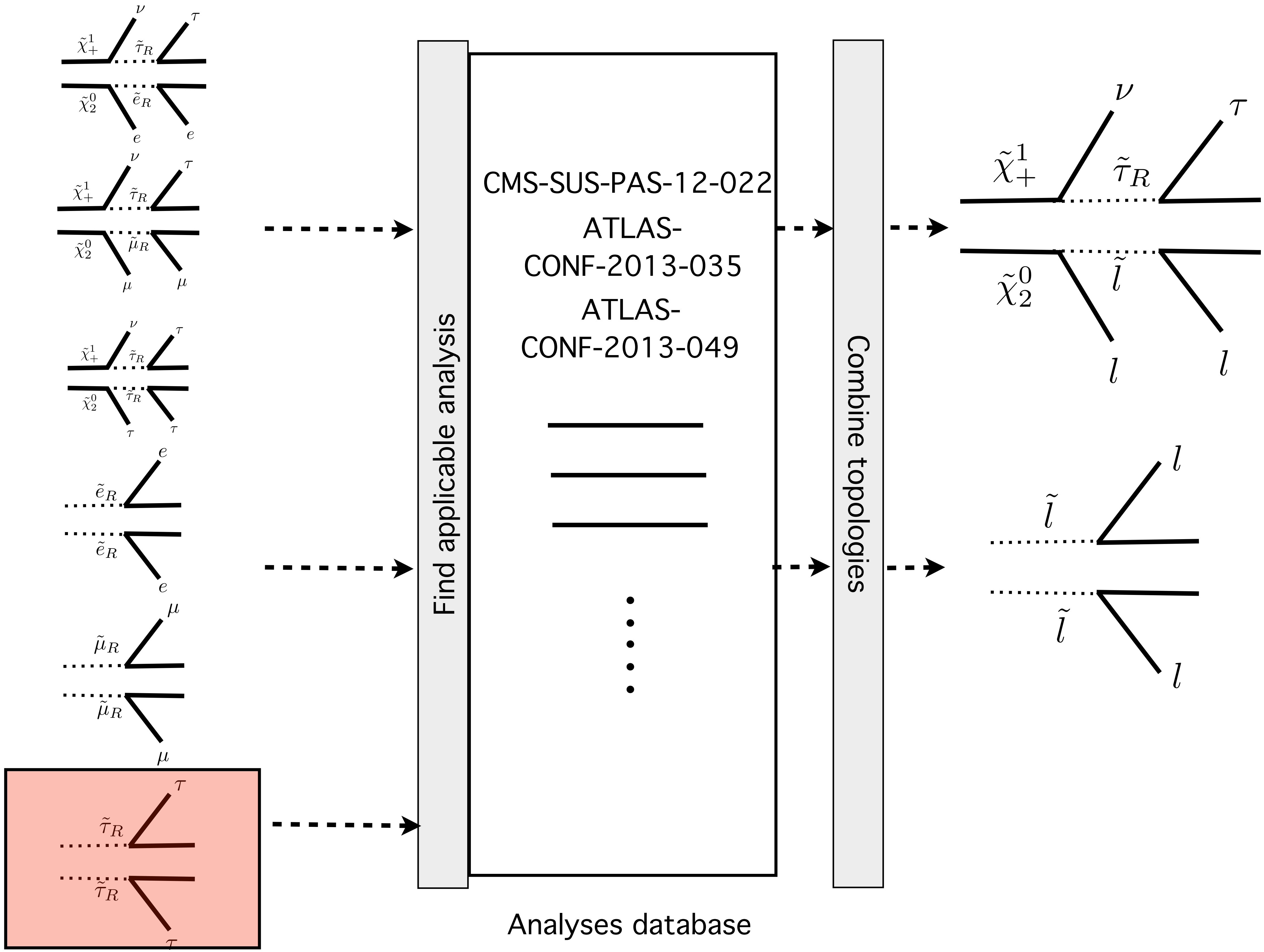
$\tilde{\chi}^1_+$
$\tilde{\chi}^0_2$
$\tilde{\tau}_R$
$\tilde{e}_R$
$\tilde{\mu}_R$
$\tilde{l}$
ν
τ
e
μ
l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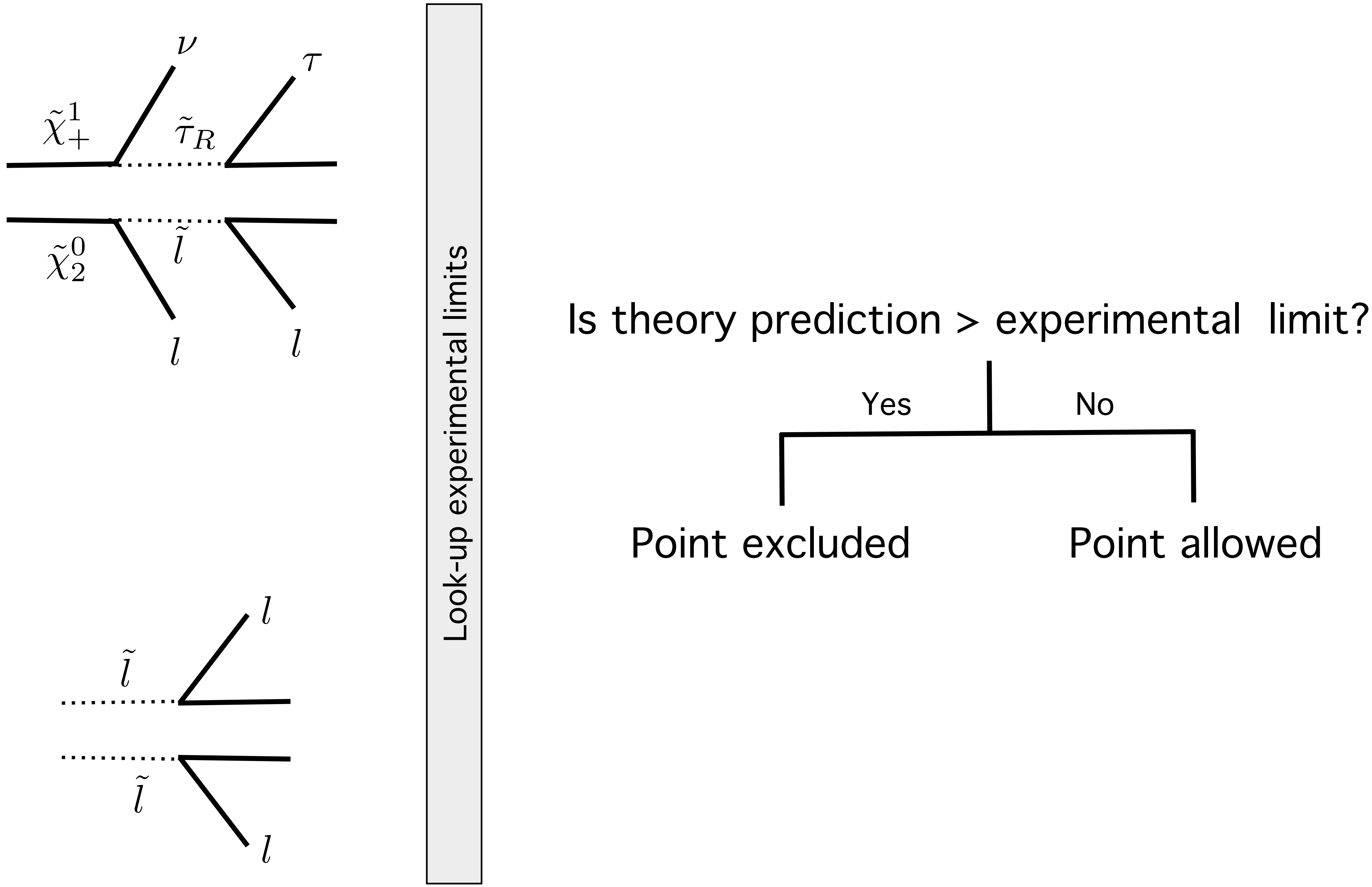

ν
τ
$\tilde{\chi}^1_+$
$\tilde{\tau}_R$
$\tilde{\chi}^0_2$
$\tilde{l}$
l
l
l
$\tilde{l}$
$\tilde{l}$
l
Look-up experimental limits
Is theory prediction > experimental limit?
Yes
No
Point excluded
Point allowed

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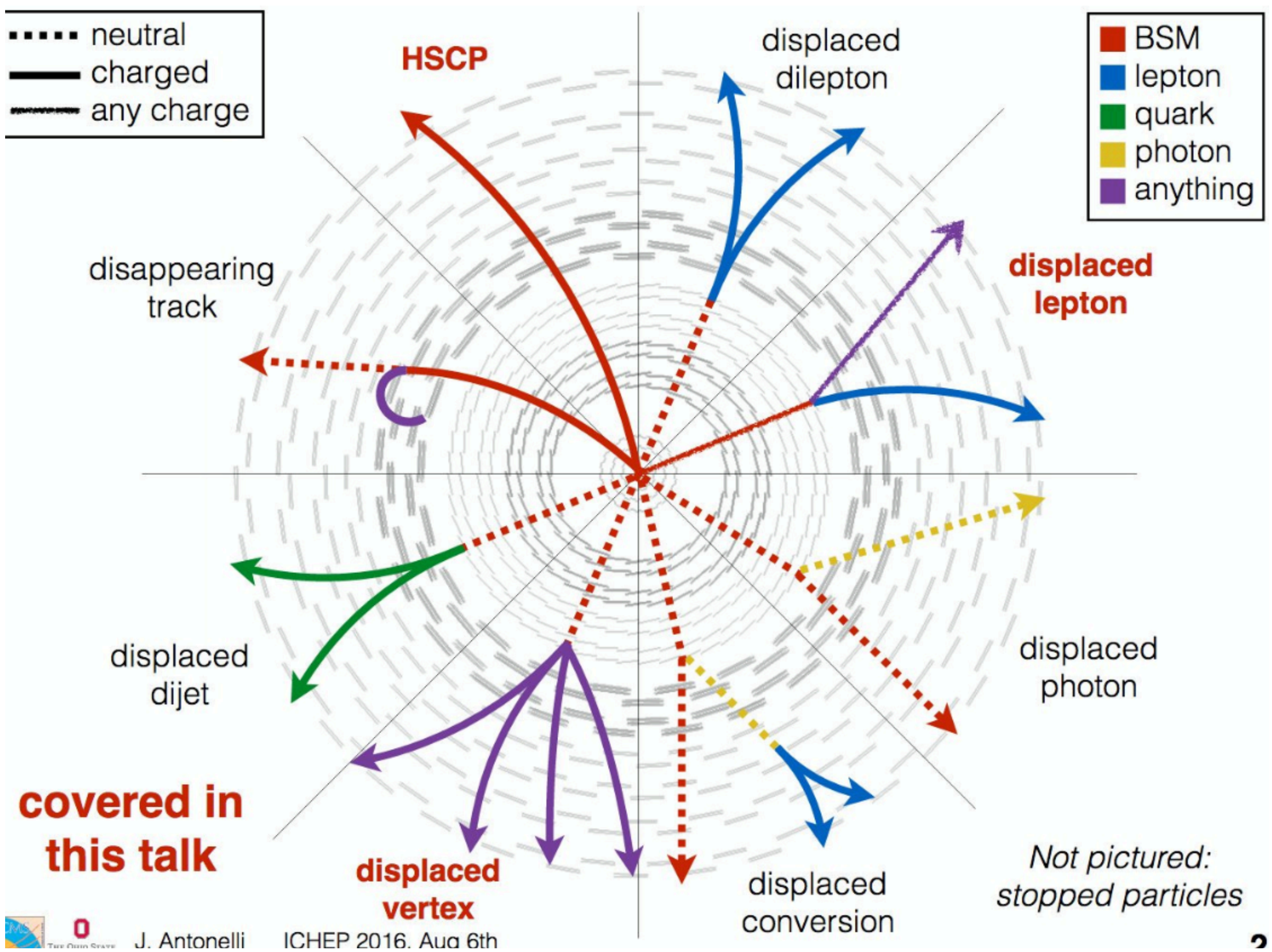
Going beyond Missing Energy

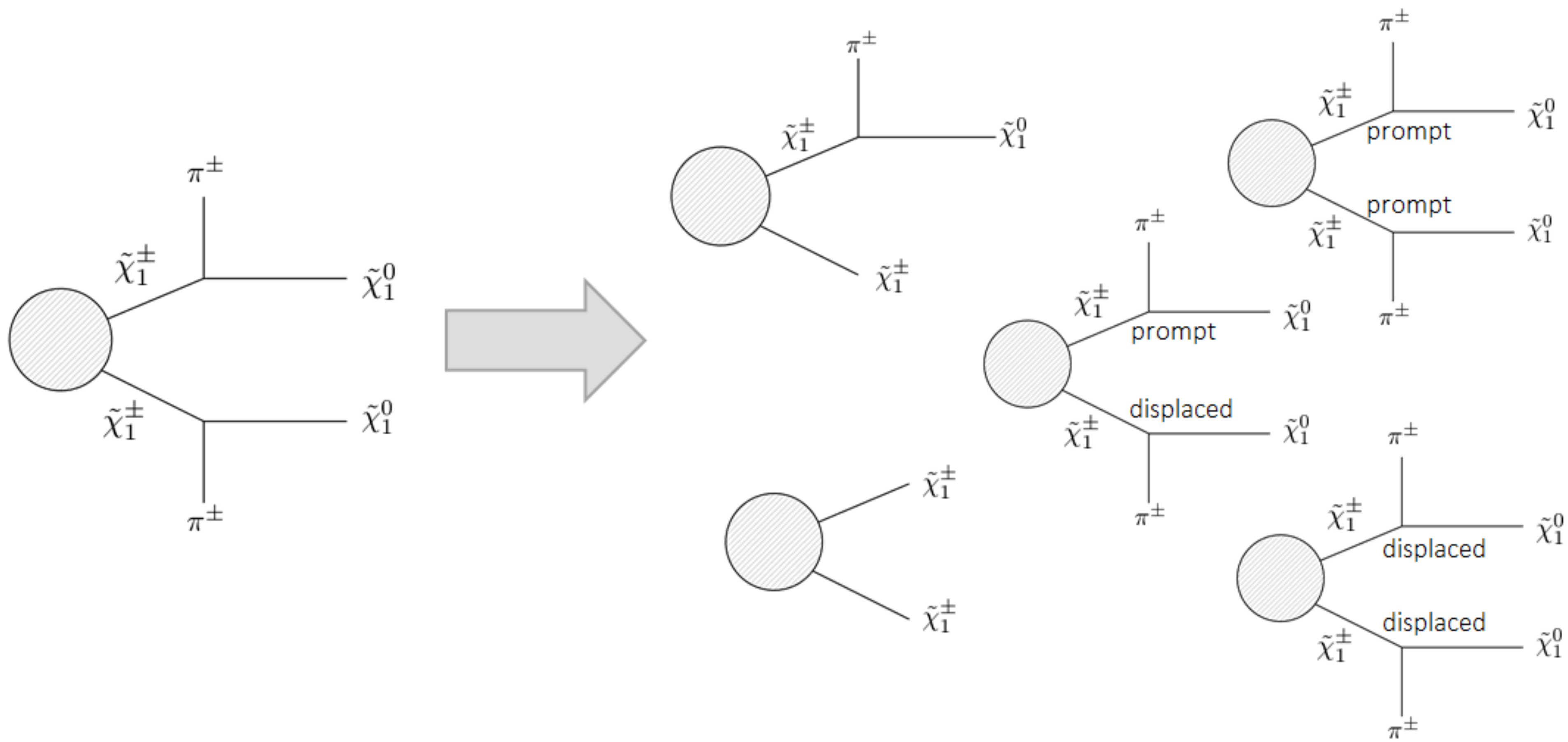
J. Antonelli



- Signatures depend on quantum numbers of the underlying particles
  - More things matter than just masses of BSM particles
  - Must keep track of the quantum numbers of the particles

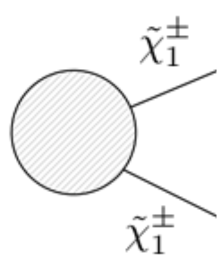
See: talk by A. Escalante del Valle for experimental results

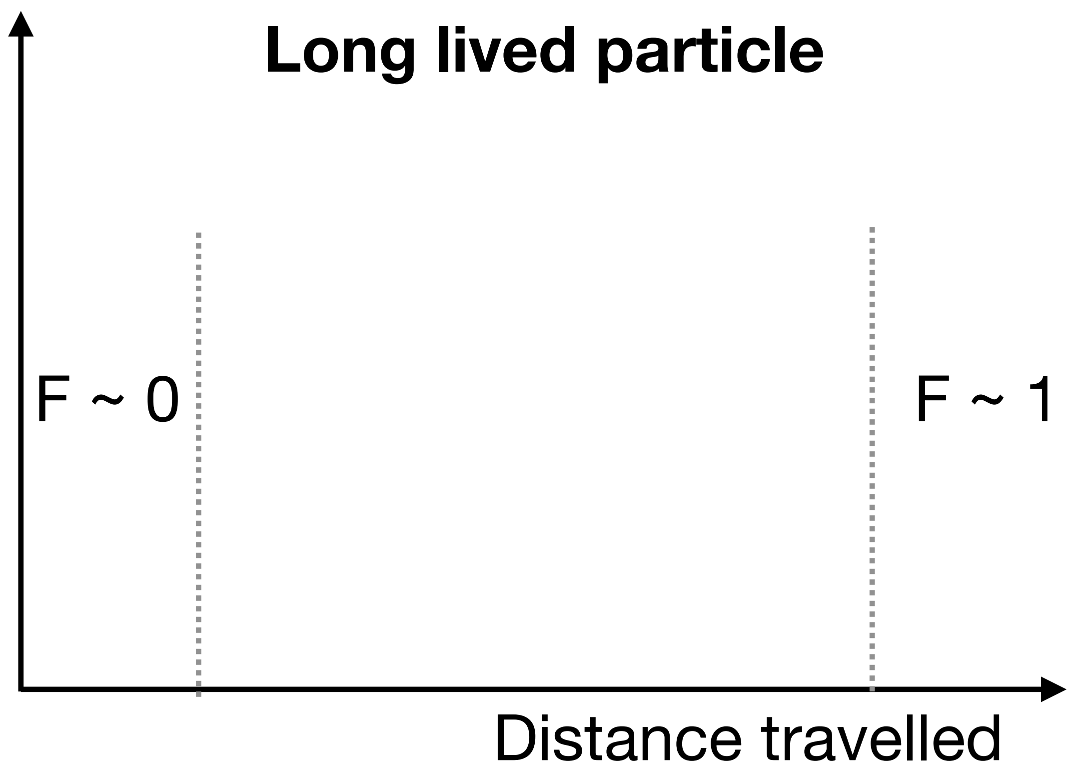
It explodes!

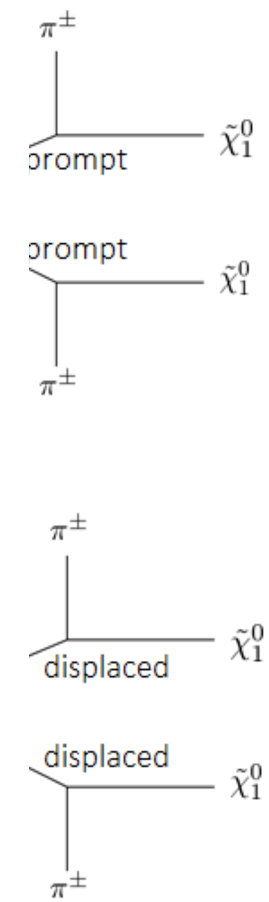


- A single production channel gives rise to many many final states
- Exact weight of final state depends on the width of the particle
- Survival probability: $F = exp(-\Gamma \frac{l}{\beta\gamma\hbar c})$

It explodes!







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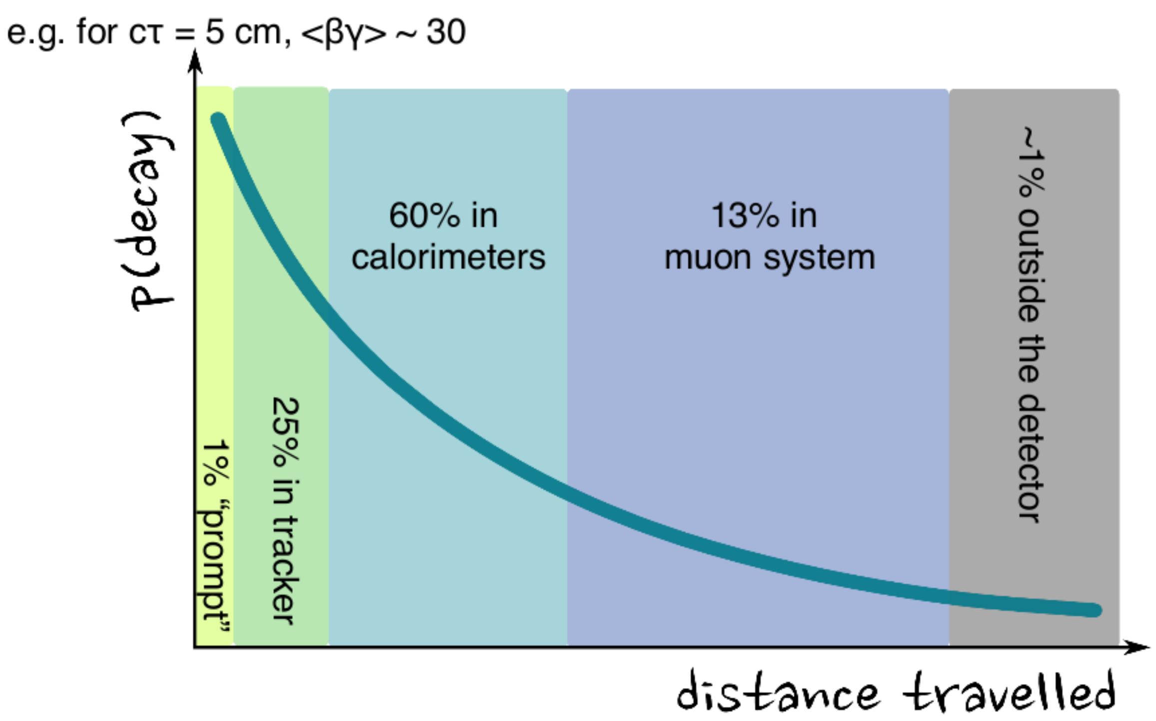
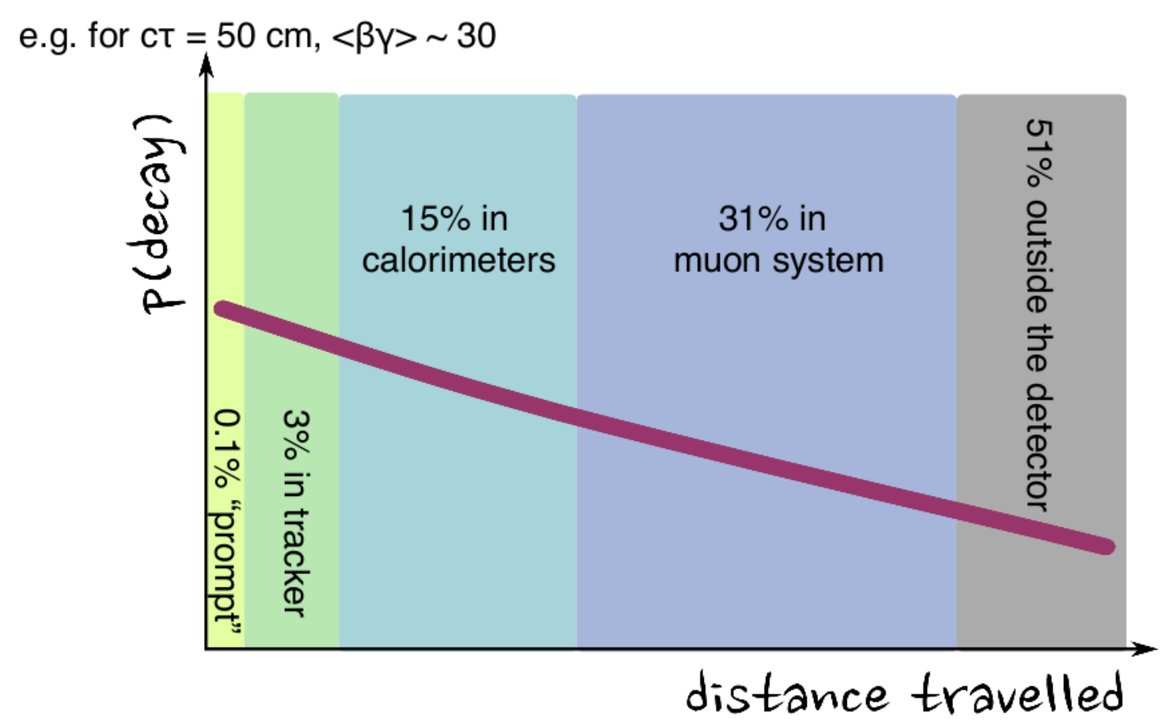
So start at extremes

Diagram for ATLAS by H. Russel



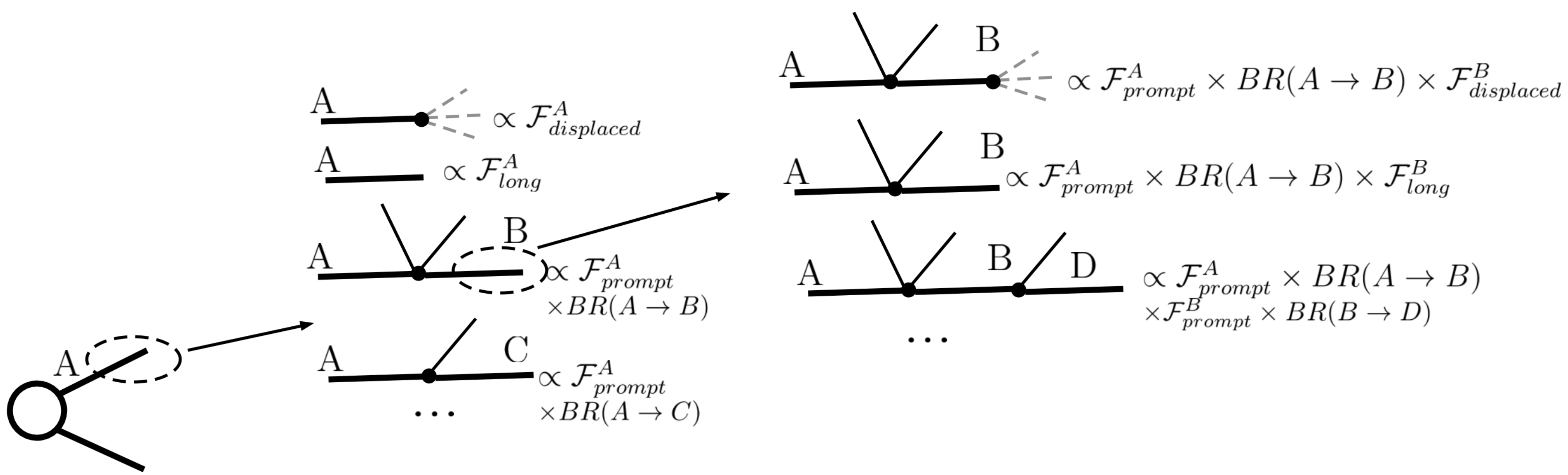


- In the first step either concentrate on prompt or stable fraction
- Discard everything else
- Reduces the number of diagrams
- Also need to think how to reinterpret all possible searches
- Even with this one can constrain large range of lifetimes if the cross sections are large -> not as limiting approach as it may look

Going beyond Missing Energy

$$\mathcal{F}_{\text{prompt}} = 1 - \exp\left(-\frac{1}{c\tau}\left\langle\frac{\ell_{\text{inner}}}{\gamma\beta}\right\rangle_{\text{eff}}\right)$$

$$\mathcal{F}_{\text{long}} = \exp\left(-\frac{1}{c\tau}\left\langle\frac{\ell_{\text{outer}}}{\gamma\beta}\right\rangle_{\text{eff}}\right).$$



- The cross section X branching ratio needs to be reweighted by the probabilities of BSM particles to decay promptly or outside the detector
- Reweight the theory cross section by this number

SModelS - recent news

Kulkarni et al. arXiv:1811.10624

- A version dealing with Heavy Stable Charged particles and R-hadron results is released
- Contains three analyses dealing with HSCP and R-Hadron searches
- Accounts for quantum numbers of particles in simple fashion: lists of quantum numbers
- Assumes constant boost for long lived particles
- Does not handle displaced vertices

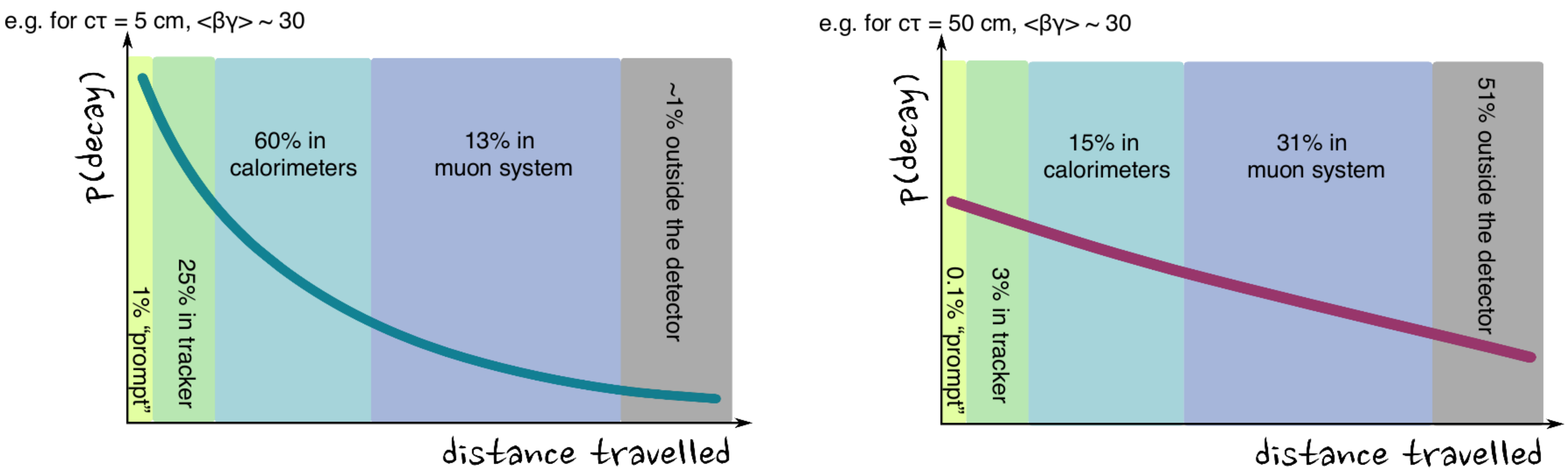
Assumes these to be constant

$$\mathcal{F}_{\text{prompt}} = 1 - \exp\left(-\frac{1}{c\tau}\left\langle\frac{\ell_{\text{inner}}}{\gamma\beta}\right\rangle_{\text{eff}}\right)$$

$$\mathcal{F}_{\text{long}} = \exp\left(-\frac{1}{c\tau}\left\langle\frac{\ell_{\text{outer}}}{\gamma\beta}\right\rangle_{\text{eff}}\right).$$

SModelS - going beyond

Diagram for ATLAS by H. Russel



- Fraction of particles decaying at a given point depend on boost and lifetime
- We discard everything in between prompt and stable particles
- We miss out on potentially powerful searches which constrain 'in between decays'

SModelS - going further

- An elegant way to handle exotic final states is to covert particles from strings to classes
- Basic particle properties well defined however mass, decay widths and decays are dynamically updated
- One of the crucial changes in the upcoming SModelS version
- Also very important for going beyond Z_2 symmetric models
- Triggers higher level changes as particles are basic entities in the code; converting particle type leads to readapting major parts of the code

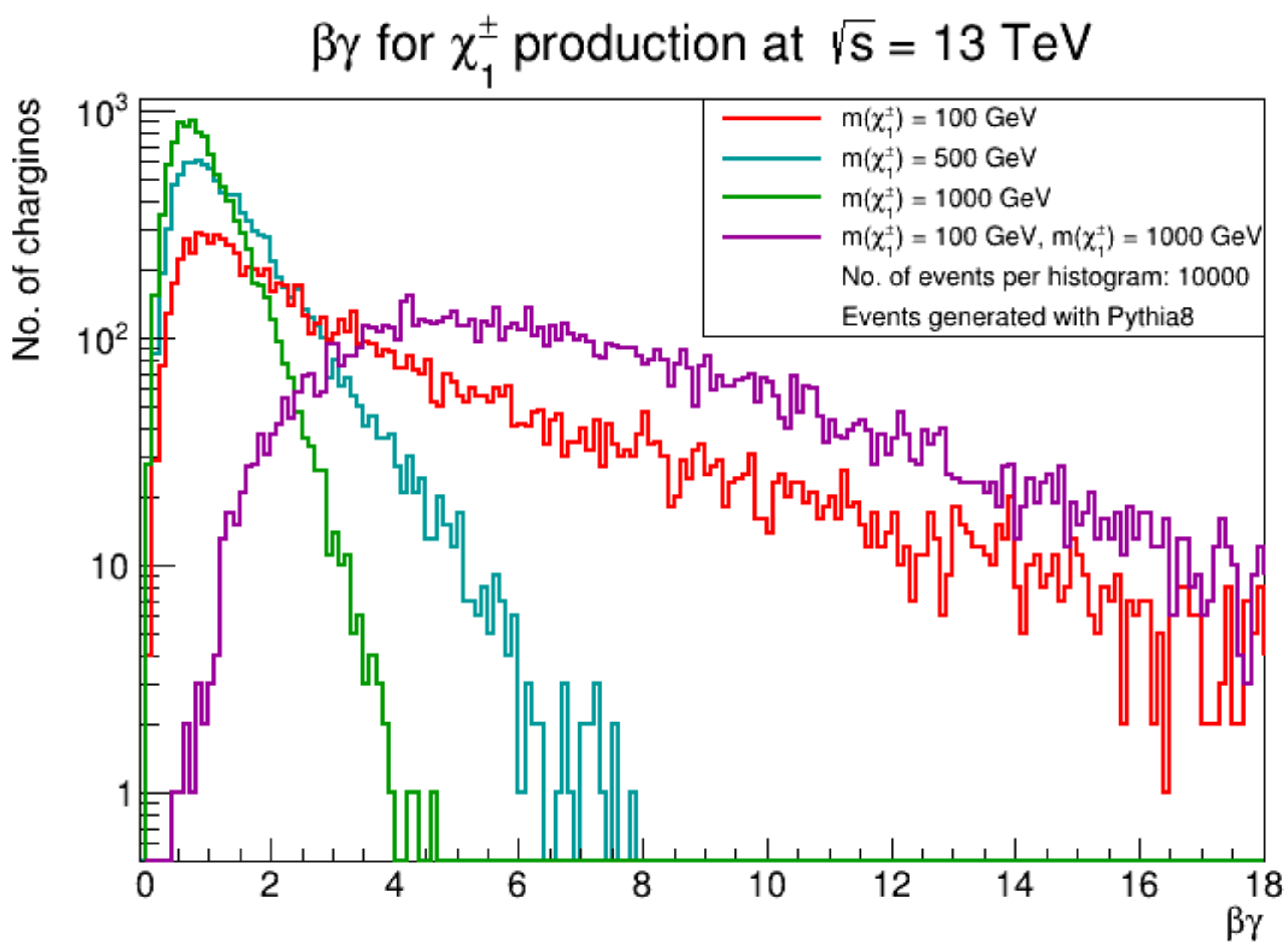
SM example:

```
e = Particle(
Z2parity='even',
label='e-',
pdg=11,
mass=0.5*MeV,
eCharge=-1,
colordim=0,
spin=1./2,
totalwidth = 0.*GeV,
decays=[])
```

BSM example:

```
gluino =
Particle(
Z2parity='odd',
label='gluino',
pdg=1000021,
eCharge=0,
colordim=8,
spin=1./2)
```

Topology dependent boost



red, green, blue:

$$pp \to \tilde{\chi}_1^\pm \tilde{\chi}_1^\pm$$

purple:

$$pp \to \tilde{\chi}_1^\pm \tilde{\chi}_2^0,$$

$$\tilde{\chi}_2^0 \to \tilde{\chi}_1^\pm \; soft \; SM$$

Topology dependent beta gamma → Simulate several different topologies

Dependence on the analysis → Reweight on the experimental side rather than theory

Where are we now?

- Conversion of particle entities from simple string implementation to object oriented completed
- All higher level changes in the code taken care of
- Implementation of experimental searches and derivation of efficiency mops ongoing
- Validation (making sure that results are correct) ongoing
- Hope to start with some physics studies soon!

Conclusions

- Absence of any concrete positive signal for BSM physics necessitates exploring signatures beyond missing energy searches
- Exotic final states appear in many models besides supersymmetry
- Automatic classification of final states in arbitrary models will be useful
- Needs a comprehensive database of experimental results which can be easily used in order to confront theory with the experiments
- SModelS is making progress in this direction
- Recently released a version which can handle R-Hadrons and HSCP searches
- Current development aims at improving existing treatment and going well beyond extremely long lived particles