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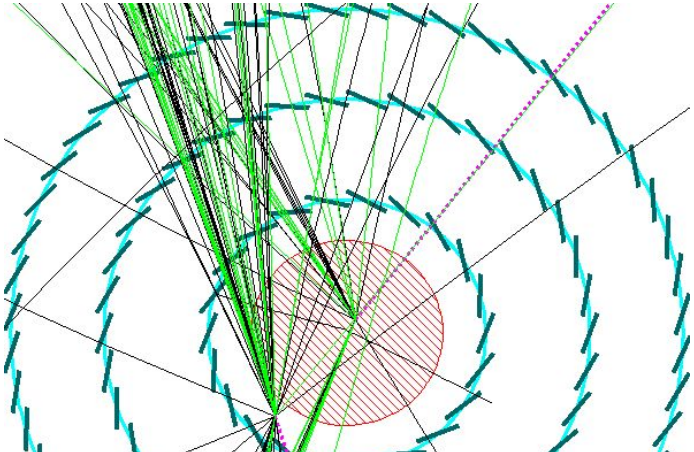
Neutrino reinterpretation and particle masses with displaced vertices

Giovanna Cottin



Searching for long-lived particles at the LHC:
Third workshop of the LHC LLP Community
May 2018

Using Displaced Vertices @ LHC to shed light on New Physics

How? Two studies in this talk (motivated by neutrinos and dark matter):

1) **Displaced multitrack strategy in the context of long-lived sterile neutrinos. Left-Right symmetric model as benchmark.** Based on Phys. Rev. D 97, 055025 (2018) [arXiv:1801.02734] G. Cottin, J.C. Helo, M. Hirsch

2) **Proposing a mass reconstruction method that uses information on displaced vertices to find the masses of neutral daughters (i.e dark matter) and their parents.** Based on JHEP 03, 137 (2018) [arXiv:1801.09671] G. Cottin.

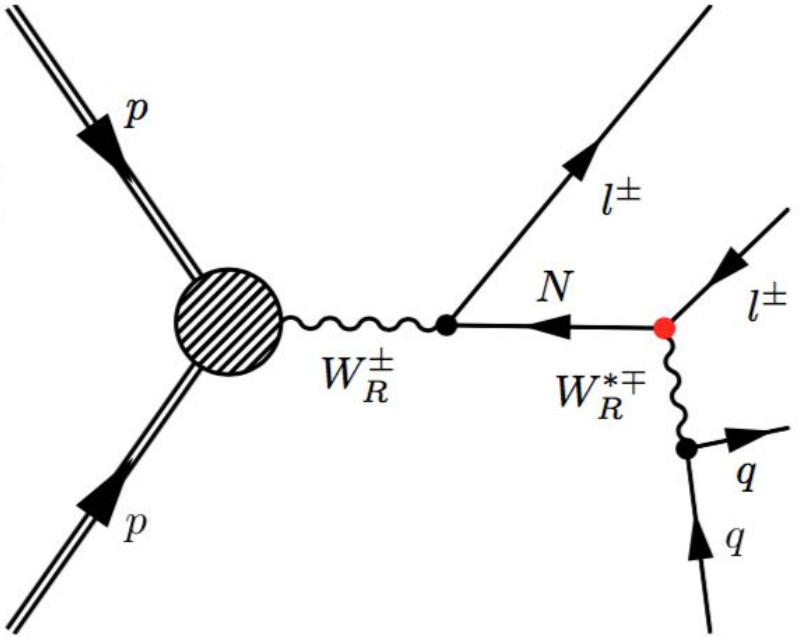
1) Displaced vertex Searches @ LHC. Looking for a light, long-lived sterile neutrino from Left-Right symmetric model

Phys. Rev. D 97, 055025 (2018) [arXiv:1801.02734] G. Cottin, J.C. Helo, M. Hirsch

See talk by G. Popara

$$c\tau_N \sim 0.12 \left(\frac{10\ \text{GeV}}{m_N}\right)^5 \left(\frac{m_{W_R}}{1000\ \text{GeV}}\right)^4 \ [\text{mm}]$$

$$m_N \ll m_{W_R}, m_N < m_W$$



LR model:

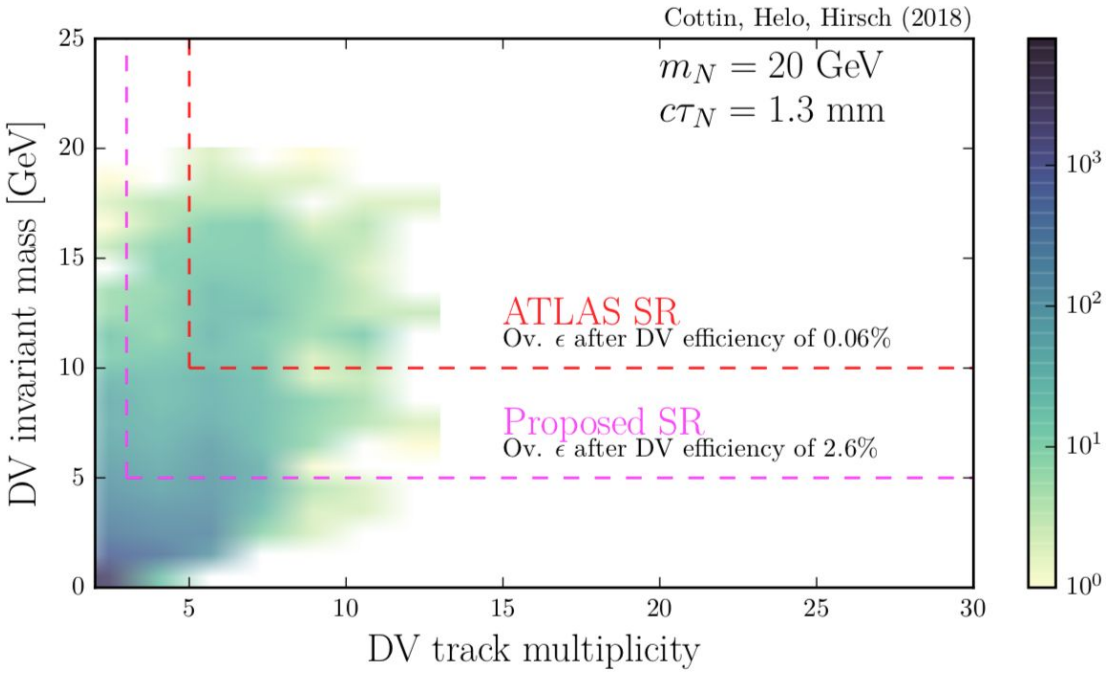
J. C. Pati and A. Salam, Phys. Rev. D10, 275 (1974)
R. N. Mohapatra and J. C. Pati, Phys. Rev. D11, 2558 (1975)
R. N. Mohapatra and G. Senjanovic, Phys. Rev. D23, 165 (1981)

ATLAS Multitrack DV 13 TeV search

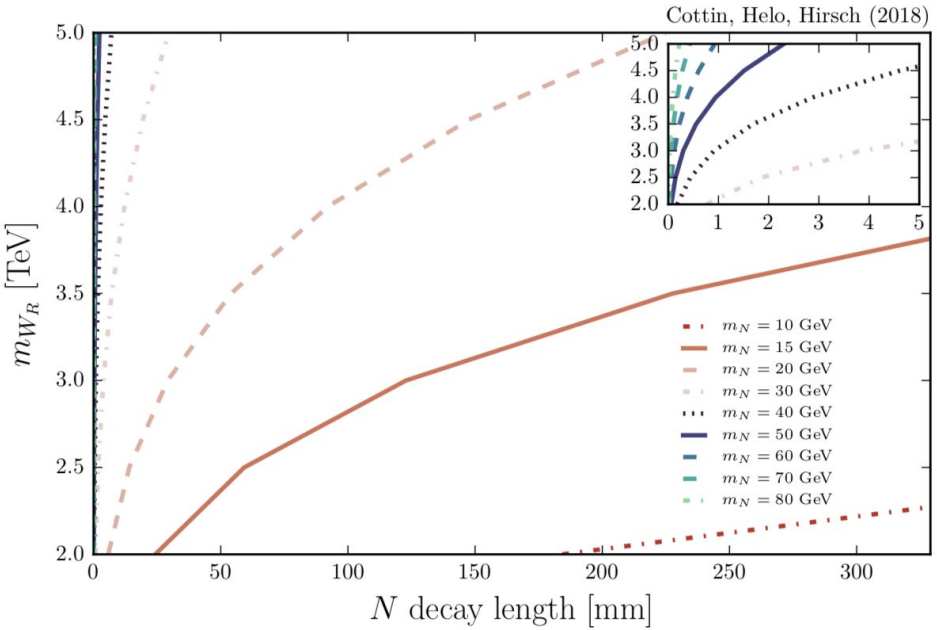
arXiv:1710.04901

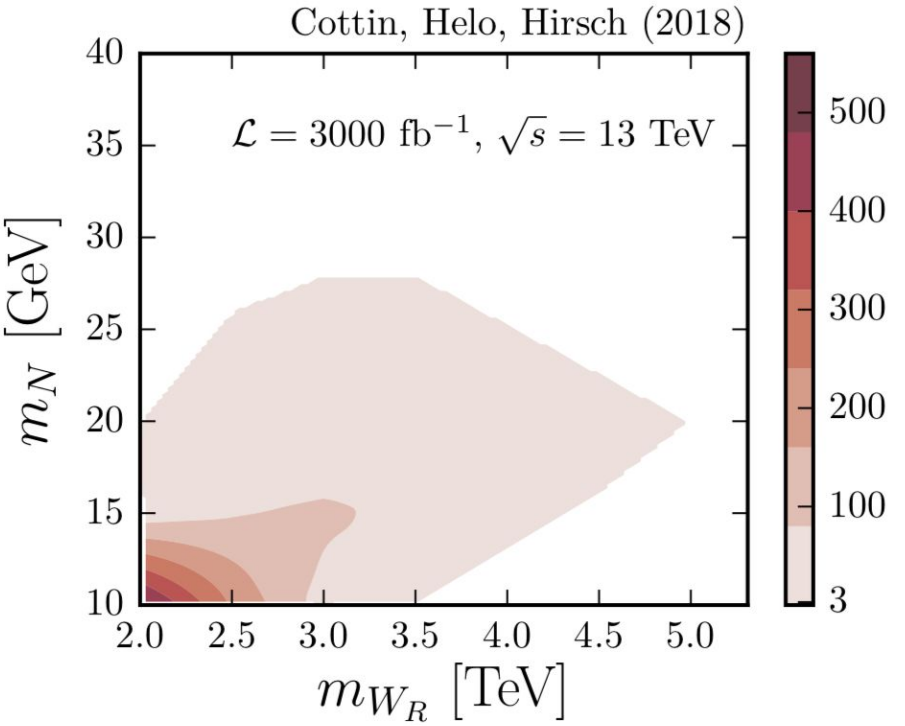
See J. Roloff, N.Desai and Hideyuki Oide's talks

- Signatures inside inner tracker
- Analysis triggers on MET. We use prompt lepton. High mass and track multiplicity DVs. We relax these cuts
- Analysis provides efficiency maps depending on DV mass, tracks and decay distance (within 4 and 300 mm). We use them to model detector response to DVs (and assume model independance of factorized maps at the vertex level)



Sensitivity with "prompt lepton + loose DV multitrack"





Acceptance region:

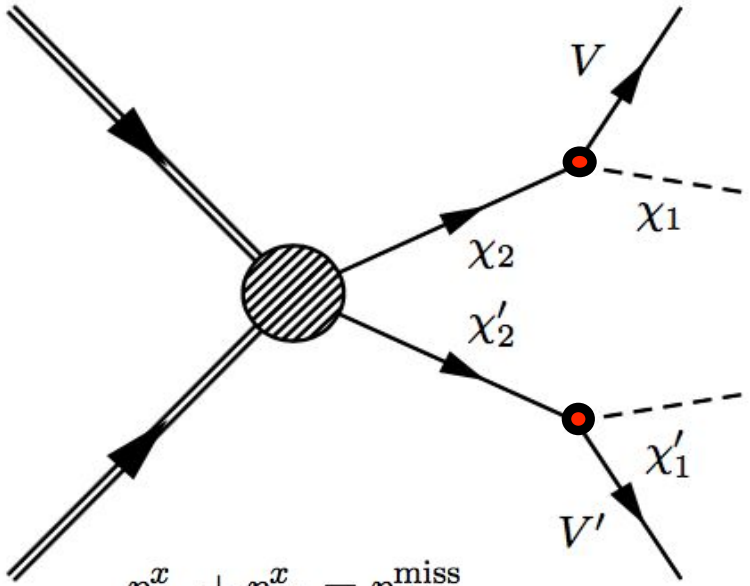
$10\ \text{GeV} < m_N < 40\ \text{GeV}$

$2\ \text{TeV} < m_{W_R} < 5\ \text{TeV}$

Optimized cuts in ATLAS DV multitrack inspired search needed to cover more parameter space in LR model

See talk by G. Popara for reach with other searches

2) What else could be measured at colliders (and what could thus be inferred about the nature of dark matter) given a displaced vertex signal? JHEP 03, 137 (2018) [arXiv:1801.09671] G. Cottin.



$$p^x_{\chi_1} + p^x_{\chi'_1} = p^{\text{miss}}_x$$
$$p^y_{\chi_1} + p^y_{\chi'_1} = p^{\text{miss}}_y$$

$$m^2_{\chi_1} = p^2_{\chi_1} = p^2_{\chi'_1}$$
$$m^2_{\chi_2} = (p_V + p_{\chi_1})^2 = (p_{V'} + p_{\chi'_1})^2$$

$$\boldsymbol{p_{\chi_2}} = |\boldsymbol{p_{\chi_2}}|\frac{\boldsymbol{r}}{r} = |\boldsymbol{p_{\chi_2}}|\hat{\boldsymbol{r}}$$

We can solve event-by-event, the system is fully constrained

$$m_{\chi_2}^2 = m_{\chi_1}^2 + \alpha\sqrt{m_{\chi_1}^2 + \beta} + \gamma$$

$$m_{\chi_2}^2 = m_{\chi_1}^2 + \delta\sqrt{m_{\chi_1}^2 + \epsilon} + \zeta$$

(Known) inputs to solve the system

$$(\boldsymbol{r}, \boldsymbol{r'}, \boldsymbol{p_V}, \boldsymbol{p_{V'}}, p_x^{\text{miss}}, p_y^{\text{miss}})$$

Testing the method on the simplified displaced dark matter model in **JHEP 1709 (2017) 076 [arXiv:1704.06515]** (Buchmueller, De Roeck, Hahn, McCullough, Schwaller, Sung,Yu)

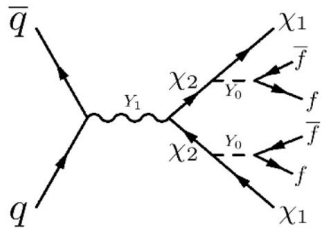
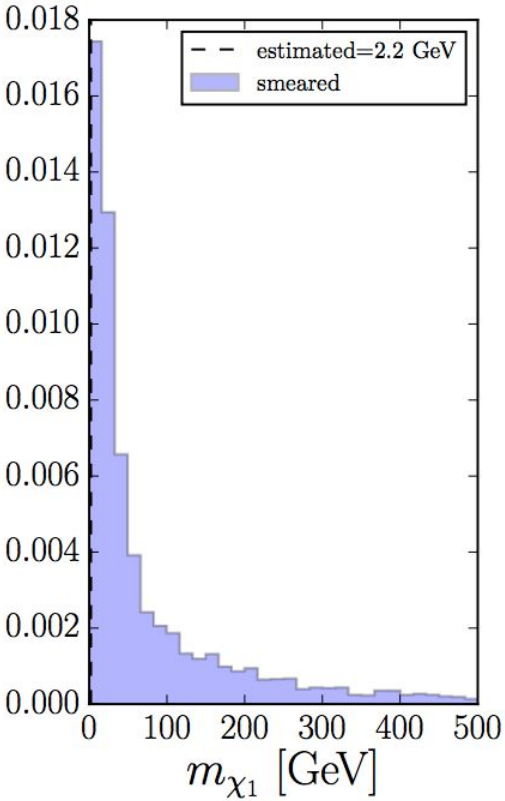
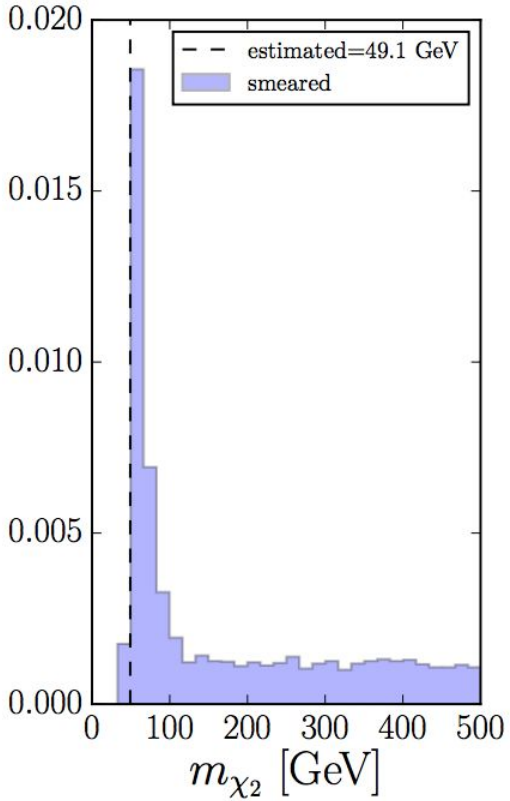


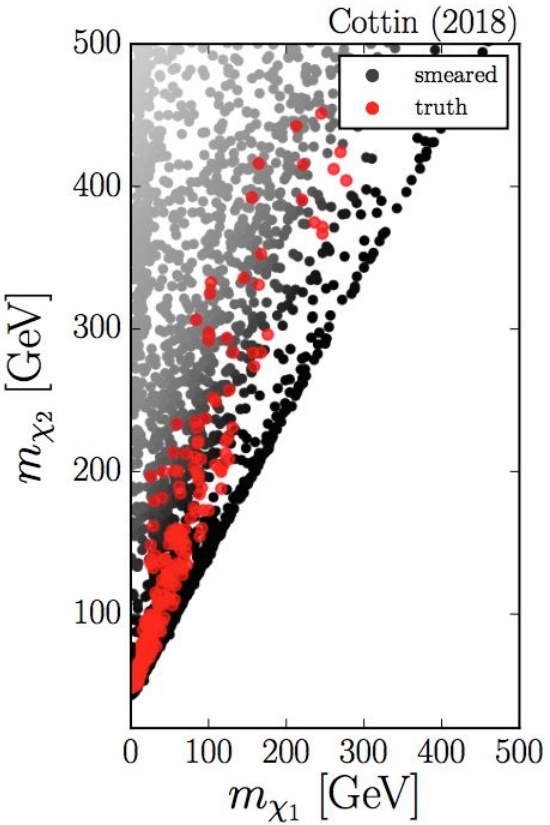
Figure 3. A representative diagram from the `DisplacedDM` model that produces displaced verticies plus $\not{E}_T$. The subscripts on Y indicate the spin of the mediator.

Smeared inputs from detector simulation

Truth masses (1,50) GeV





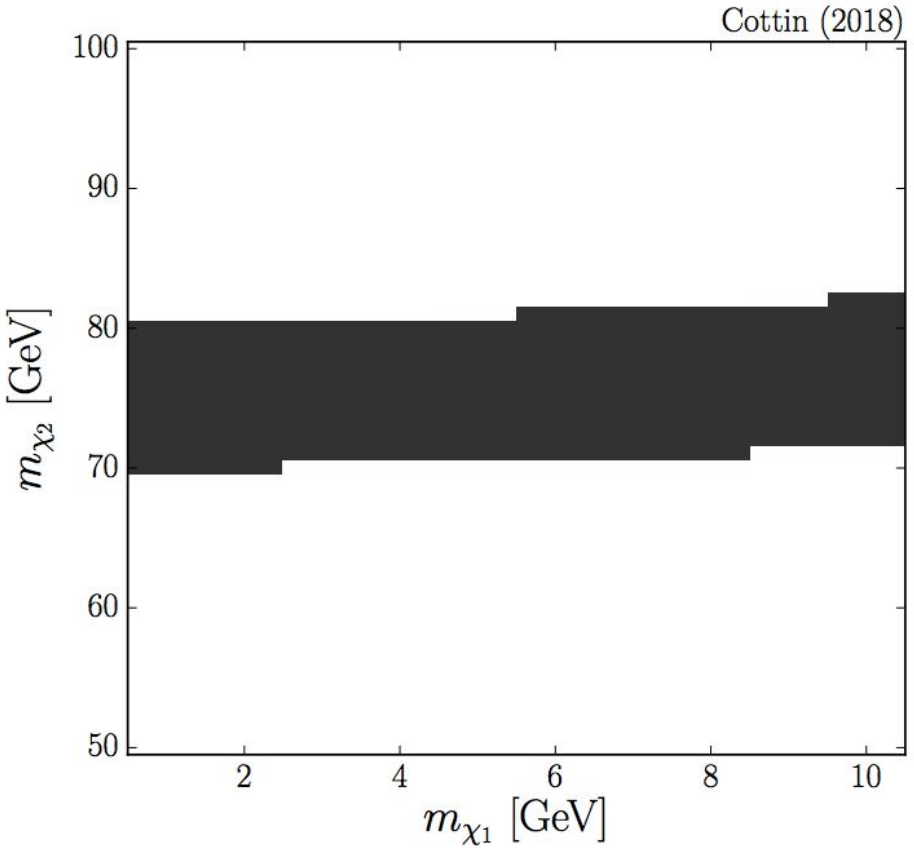


Construction of a confidence region based on the mass estimates. Extract both masses from the "data"

Confidence interval that might result from the observation of one event containing displaced vertices in this simplified model.

The real masses will lie in the region at least 95% of the time.

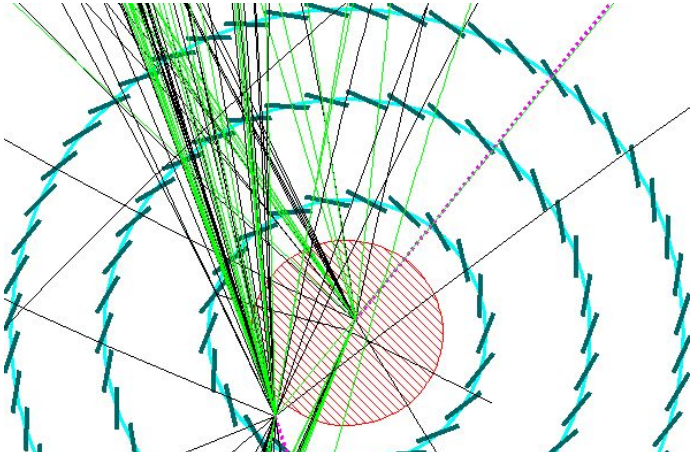
Method can be applied to other models and (displaced) final states



To take home

Huge interest in probing HNL with DVs ! DV multitrack inspired strategy could be sensitive to several models with a **prompt lepton trigger.** Can access **higher masses** in Left-Right model if analysis considers **decays below 4mm*.** Lower masses can be probed by **lowering DV invariant mass cut**

A “displaced mass” like-variable can be constructed and may be potentially useful in event-selection/cuts. If displaced events are seen at the LHC, the technique could also help shed light on the **mass of dark matter**



*See work in these lines:
arXiv:1803.00234
arXiv:1702.08613
Extending LHC reach with sub-millimiter DVs