Long Lived BLSSM particles

arXiv:1804.09778

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Speaker

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The Model: BLSSM

$$SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$$

Extra gauge group requires:

- One extra vector boson Z'

- To Cancel the gauge anomalies, three right handed neutrinos and it super partners are required

- Breaking $U(1)_{B-L}$ two scalar singlets are needed

  η and $\bar{\eta}$

Super potential extended to be

$$W = Y_u^{ij}\, \hat{u}_i^c\, \hat{Q}_j\, \hat{H}_u - Y_d^{ij}\, \hat{d}_i^c\, \hat{Q}_j\, \hat{H}_d - Y_e^{ij}\, \hat{e}_i^c\, \hat{L}_j\, \hat{H}_d + \mu\, \hat{H}_u\, \hat{H}_d$$
$$+ Y_\nu^{ij}\, \hat{\nu}_i^c\, \hat{L}_j\, \hat{H}_u - \mu'\, \hat{\eta}\, \hat{\bar{\eta}} + Y_x^{ij}\, \hat{\nu}_i^c\, \hat{\eta}\, \hat{\nu}_j^c$$

Super potential extended to be

$$W = Y_u^{ij}\,\hat{u}_i^c\,\hat{Q}_j\,\hat{H}_u \;-\; Y_d^{ij}\,\hat{d}_i^c\,\hat{Q}_j\,\hat{H}_d \;-\; Y_e^{ij}\,\hat{e}_i^c\,\hat{L}_j\,\hat{H}_d \;+\; \mu\,\hat{H}_u\,\hat{H}_d$$
$$+\; Y_\nu^{ij}\,\hat{\nu}_i^c\,\hat{L}_j\,\hat{H}_u \;-\; \mu'\,\hat{\eta}\,\hat{\bar{\eta}} \;+\; Y_x^{ij}\,\hat{\nu}_i^c\,\hat{\eta}\,\hat{\nu}_j^c$$

Original MSSM potential

Super potential extended to be

$$W = Y_u^{ij}\,\hat{u}_i^c\,\hat{Q}_j\,\hat{H}_u - Y_d^{ij}\,\hat{d}_i^c\,\hat{Q}_j\,\hat{H}_d - Y_e^{ij}\,\hat{e}_i^c\,\hat{L}_j\,\hat{H}_d + \mu\,\hat{H}_u\,\hat{H}_d$$
$$+ Y_\nu^{ij}\,\hat{\nu}_i^c\,\hat{L}_j\,\hat{H}_u - \mu'\,\hat{\eta}\,\hat{\bar{\eta}} + Y_x^{ij}\,\hat{\nu}_i^c\,\hat{\eta}\,\hat{\nu}_j^c$$

Original MSSM potential

Soft breaking terms extended by

$$-\mathcal{L}_{soft} = m^2|\eta|^2 + m^2|\bar{\eta}|^2 + m^2(\tilde{\nu}^c)^*\tilde{\nu}^c + T\eta\tilde{\nu}^c\tilde{\nu}^c + TH\tilde{\nu}^c\tilde{L} + B\mu'\eta\bar{\eta}$$

$$+1/2 M_{B-L}\tilde{Z}_{B-l}\tilde{Z}_{B-l} + M'_{BB}\tilde{Z}_{B-l}\tilde{Z}$$

CP even Higgs sector

After symmetry breaking Higgs fields doublet and singlets acquire vacuum expectation value

$$H_d^0 = \frac{1}{\sqrt{2}}\left(\sigma_d + v_d + i\phi_d\right), \qquad H_u^0 = \frac{1}{\sqrt{2}}\left(\sigma_u + v_u + i\phi_u\right)$$

$$\eta = \frac{1}{\sqrt{2}}\left(\sigma_\eta + v_\eta + i\phi_\eta\right), \qquad \bar{\eta} = \frac{1}{\sqrt{2}}\left(\sigma_{\bar{\eta}} + v_{\bar{\eta}} + i\phi_{\bar{\eta}}\right)$$

In analogy to MSSM $\quad \tan\beta' = v_\eta / v_{\bar{\eta}}$

CP even Higgs sector

AT tree level the mass matrix squared in the basis $(h_d, h_u, h_\eta, h_{\bar\eta})$

$$\begin{pmatrix} m^2_{A^0} s^2_\beta + g^2_\Sigma v^2_u & -m^2_{A^0} c_\beta s_\beta - g^2_\Sigma v_d v_u & \frac{\bar g g_{BL}}{2} v_d v_\eta & -\frac{\bar g g_{BL}}{2} v_d v_{\bar\eta} \\ -m^2_{A^0} c_\beta s_\beta - g^2_\Sigma v_d v_u & m^2_{A^0} c^2_\beta + g^2_\Sigma v^2_d & -\frac{\bar g g_{BL}}{2} v_u v_\eta & \frac{\bar g g_{BL}}{2} v_u v_{\bar\eta} \\ \frac{\bar g g_{BL}}{2} v_d v_\eta & -\frac{\bar g g_{BL}}{2} v_u v_\eta & m^2_{A^0_\eta} c^2_{\beta'} + g^2_{BL} v^2_\eta & -m^2_{A^0_\eta} c_{\beta'} s_{\beta'} - g^2_{BL} v_\eta v_{\bar\eta} \\ -\frac{\bar g g_{BL}}{2} v_d v_{\bar\eta} & \frac{\bar g g_{BL}}{2} v_u v_{\bar\eta} & -m^2_{A^0_\eta} c_{\beta'} s_{\beta'} - g^2_{BL} v_\eta v_{\bar\eta} & m^2_{A^0_\eta} s^2_{\beta'} + g^2_{BL} v^2_{\bar\eta} \end{pmatrix}$$

CP even Higgs sector

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$$\begin{pmatrix} m^2_{A^0}s^2_\beta + g^2_\Sigma v^2_u & -m^2_{A^0}c_\beta s_\beta - g^2_\Sigma v_d v_u & \frac{\bar g g_{BL}}{2} v_d v_\eta & -\frac{\bar g g_{BL}}{2} v_d v_{\bar\eta} \\ -m^2_{A^0}c_\beta s_\beta - g^2_\Sigma v_d v_u & m^2_{A^0}c^2_\beta + g^2_\Sigma v^2_d & -\frac{\bar g g_{BL}}{2} v_u v_\eta & \frac{\bar g g_{BL}}{2} v_u v_{\bar\eta} \\ \frac{\bar g g_{BL}}{2} v_d v_\eta & -\frac{\bar g g_{BL}}{2} v_u v_\eta & m^2_{A^0_\eta}c^2_{\beta'} + g^2_{BL}v^2_\eta & -m^2_{A^0_\eta}c_{\beta'}s_{\beta'} - g^2_{BL}v_\eta v_{\bar\eta} \\ -\frac{\bar g g_{BL}}{2} v_d v_{\bar\eta} & \frac{\bar g g_{BL}}{2} v_u v_{\bar\eta} & -m^2_{A^0_\eta}c_{\beta'}s_{\beta'} - g^2_{BL}v_\eta v_{\bar\eta} & m^2_{A^0_\eta}s^2_{\beta'} + g^2_{BL}v^2_{\bar\eta} \end{pmatrix}$$

With gauge kinetic mixing vanishes the MSSM higgs sector decouples

NH $\longleftrightarrow v_\eta, v_{\bar\eta} > v_u, v_d \longleftrightarrow h_d(SM) < h_u < h_\eta < h_{\bar\eta}$

IH $\longleftrightarrow v_\eta, v_{\bar\eta} < v_u, v_d \longleftrightarrow h_\eta < h_{\bar\eta} < h_d(SM) < h_u$

Neutrino Masses

With TeV scale B-L breaking neutrino mass matrix

$$M_\nu = \begin{pmatrix} 0 & m_D \\ m_D^\dagger & M_N \end{pmatrix}$$

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Dirac neutrino mass $\sim 10^{-5} GeV$

Majorana neutrino mass $\sim \mathcal{O}(TeV)$

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Dirac neutrino mass $\sim 10^{-5} GeV$ **Majorana neutrino mass** $\sim \mathcal{O}(TeV)$

mass eigenstates

$$m_L \sim m_D M_N^{-1} m_D^\dagger$$
$$m_H \sim M_N$$

S-Neutrino Masses

$$\mathcal{M}^2 = \begin{pmatrix} M_{LL}^2 & M_{LR}^2 \\ (M_{LR}^2)^\dagger & M_{RR}^2 \end{pmatrix}$$

$$M_{LL}^2 = \begin{pmatrix} m_{\tilde{L}}^2 + m_D^2 + \frac{1}{2}M_Z^2\cos 2\beta - \frac{1}{2}M_{Z'}^2\cos 2\beta' & 0 \\ 0 & m_{\tilde{L}}^2 + m_D^2 + \frac{1}{2}M_Z^2\cos 2\beta - \frac{1}{2}M_{Z'}^2\cos 2\beta' \end{pmatrix}$$

$$M_{RR}^2 = \begin{pmatrix} M_N^2 + m_{\tilde{N}}^2 + m_D^2 + \frac{1}{2}M_{Z'}^2\cos 2\beta' & M_N(A_N - \mu'\cot\beta') \\ M_N(A_N - \mu'\cot\beta') & M_N^2 + m_{\tilde{N}}^2 + m_D^2 + \frac{1}{2}M_{Z'}^2\cos 2\beta' \end{pmatrix}$$

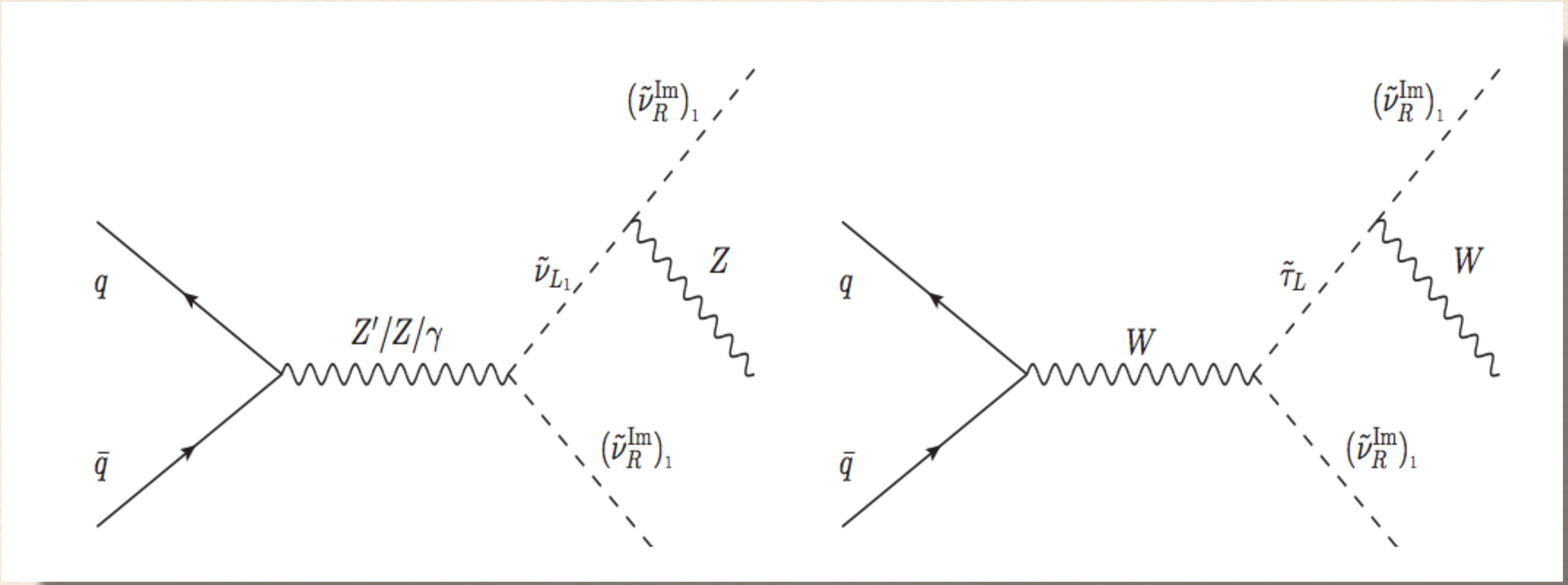
$$M_{LR}^2 = \begin{pmatrix} m_D(A_\nu - \mu\cot\beta + M_N) & 0 \\ 0 & m_D(A_\nu - \mu\cot\beta + M_N) \end{pmatrix}$$

S-Neutrino Masses

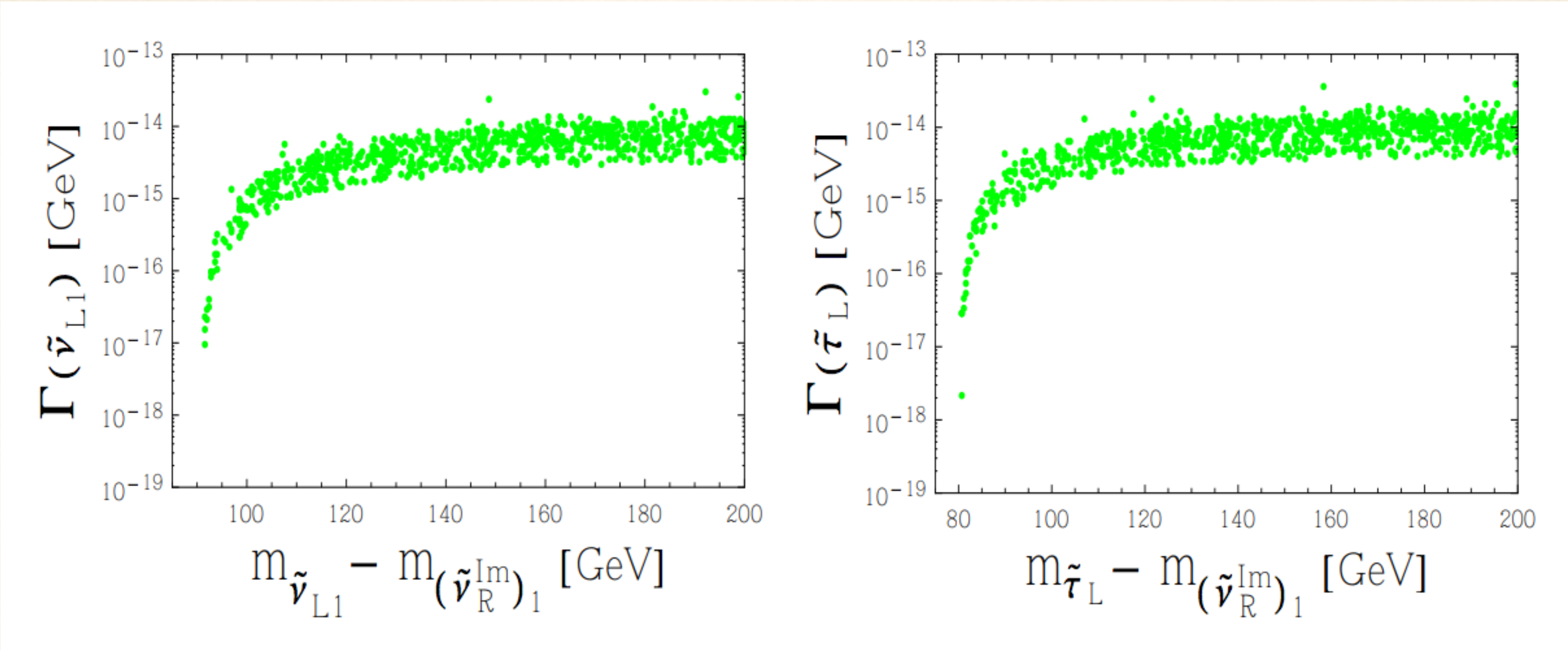
$$\mathcal{M}^2 = \begin{pmatrix} M^2_{LL} & M^2_{LR} \\ (M^2_{LR})^\dagger & M^2_{RR} \end{pmatrix}$$

Naturally suppressed causing the mixing between left and right handed S-neutrino very small

IN case for very high suppression the masses of left handed S-neutrino and S-leptons are almost degenerate

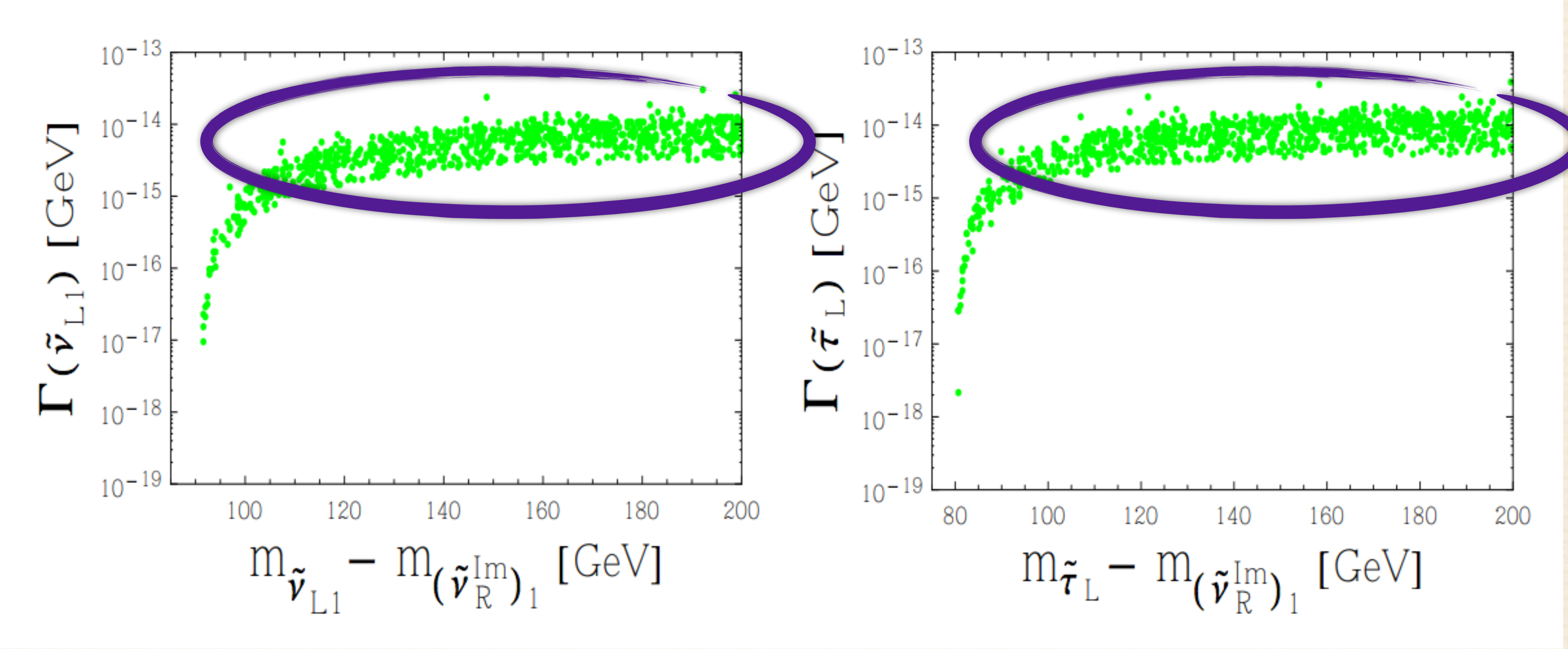


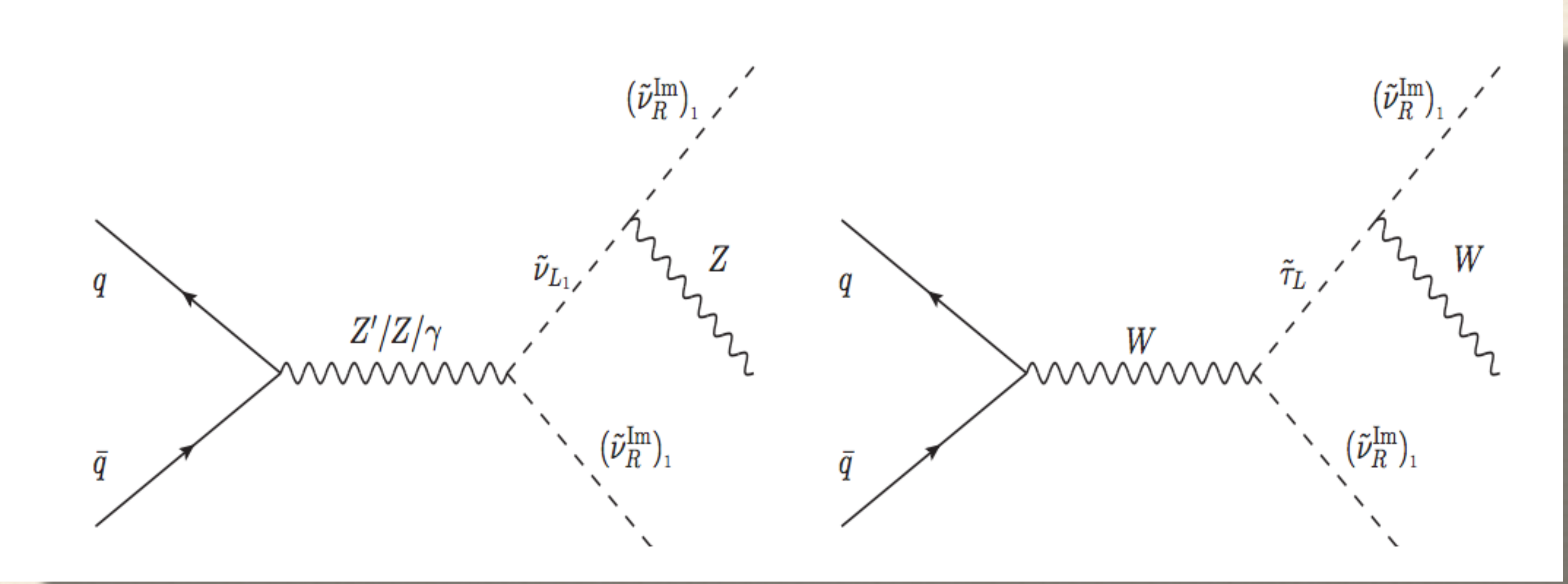
q
$\bar{q}$
$Z'/Z/\gamma$
$\tilde{\nu}_{L_1}$
$(\tilde{\nu}_R^{\rm Im})_1$
Z
$(\tilde{\nu}_R^{\rm Im})_1$
q
$\bar{q}$
W
$\tilde{\tau}_L$
$(\tilde{\nu}_R^{\rm Im})_1$
W
$(\tilde{\nu}_R^{\rm Im})_1$



$\Gamma(\tilde{\nu}_{L1})$ [GeV]
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
100 120 140 160 180 200
$m_{\tilde{\nu}_{L1}} - m_{(\tilde{\nu}_R^{\rm Im})_1}$ [GeV]
$\Gamma(\tilde{\tau}_L)$ [GeV]
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
80 100 120 140 160 180 200
$m_{\tilde{\tau}_L} - m_{(\tilde{\nu}_R^{\rm Im})_1}$ [GeV]

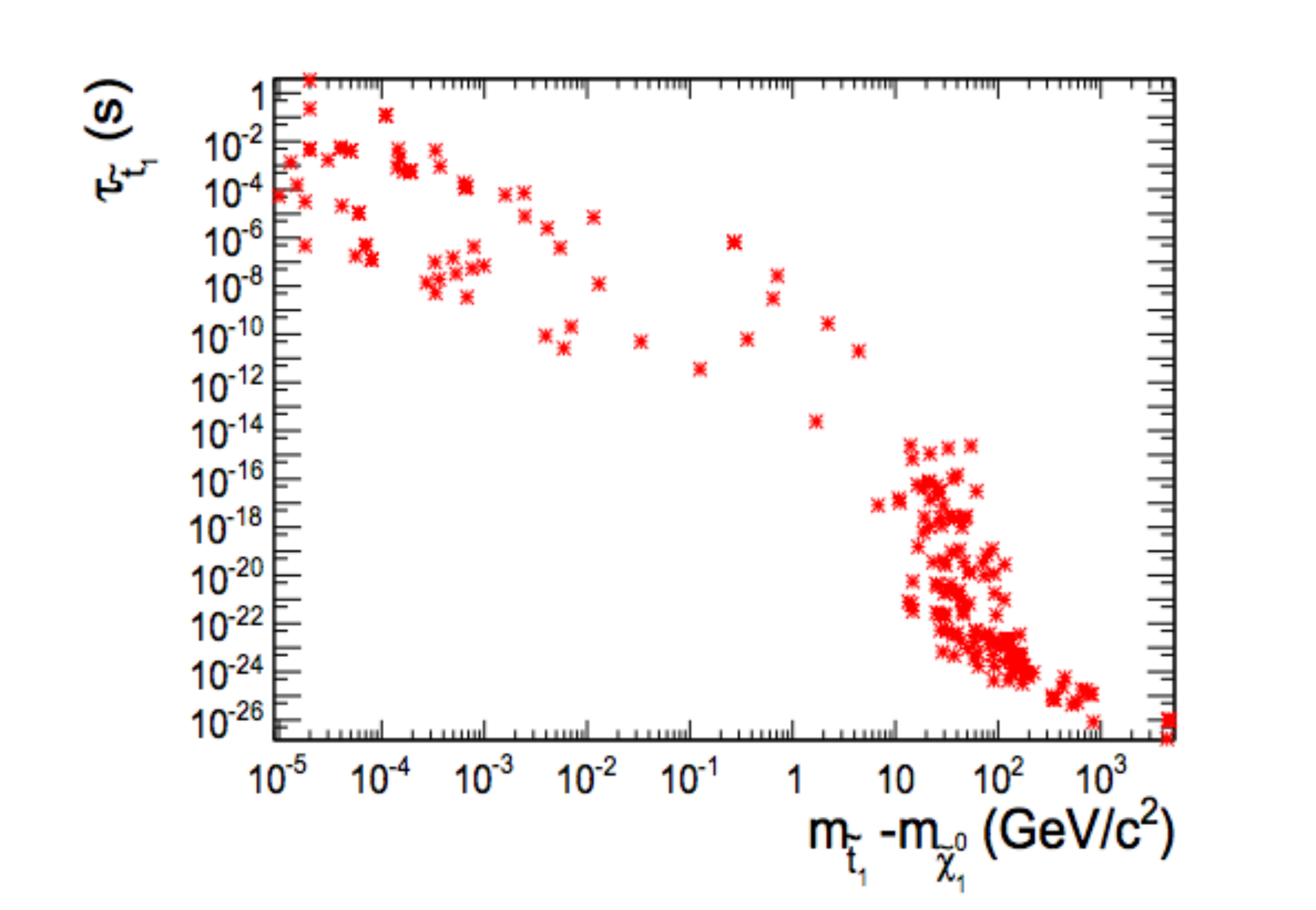
Even for large mass difference we still can have a small decay width





Cant we get a similar results
in MSSM if we replace
the S-neutrinos with neutralino ??

In MSSM Such scenario requires a large fine tuning for masses of NLSP and LSP



[1] S. Kaneko, H. Saito, J. Sato, T. Shimomura, O. Vives and M. Yamanaka, *Correlation between flavour violating decay of long-lived slepton and tau in the coannihilation scenario with Seesaw mechanism*, *Phys. Rev.* **D83** (2011) 115005 [arXiv:1102.1794].

[2] M. Johansen, J. Edsjo, S. Hellman and D. Milstead, *Long-lived stops in MSSM scenarios with a neutralino LSP*, *JHEP* **08** (2010) 005 [arXiv:1003.4540].

[3] S. Kaneko, J. Sato, T. Shimomura, O. Vives and M. Yamanaka, *Measuring lepton flavor violation at LHC with a long-lived slepton in the coannihilation region*, *Phys. Rev.* **D87** (2013) 039904 [arXiv:0811.0703].

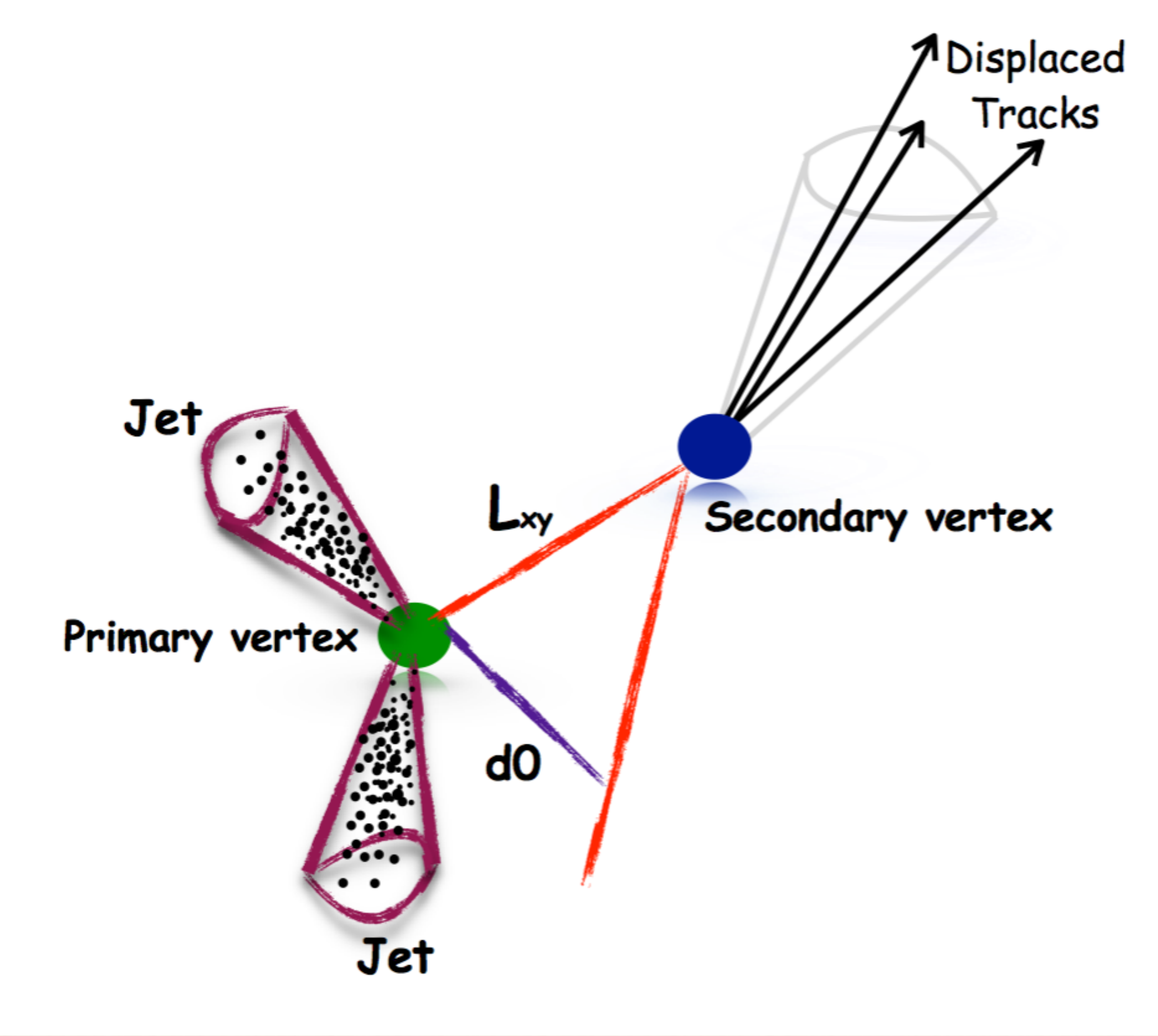
Long lived Analysis

Charged Long lived S-tau

Neutral Long lived S-neutrino

Neutral long lived

Long lived neutral signature probed by its displaced distance in X-Y plane L_xy and the impact parameter d0



$$d0 = L_{xy} \times \sin\theta$$

Charged long lived

Unlike the neutral case the charged long lived candidate make tracks in the inner tracker

*For displaced vertex search we rely on momentum associated to DV track as well TOF

MonteCarlo "truth"

```
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 8      1 +3.9607856e+01 6.90898500e+02 7.29735300e-03 9.73292500e-02
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        2 -1    0    0  501    0 +0.0000000000e+00 -0.0000000000e+00 -2.5870145533e+03 2.5870145533e+03 2.5000000000e-03 0.0000e+00 -1.0000e+00
  1000012  2    1    2    0    0 -1.9090883370e+02 +5.2638786020e+01 -2.1770930695e+03 2.1981117260e+03 2.2966040580e+02 7.1775e+02 0.0000e+00
       23  2    3    3    0    0 -6.5867617410e+01 -3.8785863448e+00 -8.8347097841e+02 8.9045061110e+02 8.9597626486e+01 0.0000e+00 0.0000e+00
  4000012  1    3    3    0    0 -1.2504121629e+02 +5.6517372365e+01 -1.2936220911e+03 1.3076611149e+03 1.3300360000e+02 0.0000e+00 0.0000e+00
       11  1    4    4    0    0 -8.8177852069e+01 -4.4877687173e+00 -7.4110437163e+02 7.4634520386e+02 5.1099890000e-04 0.0000e+00 -1.0000e+00
      -11  1    4    4    0    0 +2.2310234658e+01 +6.0918237245e-01 -1.4236660677e+02 1.4410540725e+02 5.1099890000e-04 0.0000e+00 1.0000e+00
  4000012  1    1    2    0    0 +1.9090883370e+02 -5.2638786020e+01 -3.6379294536e+02 4.3503136586e+02 1.3300360000e+02 0.0000e+00 0.0000e+00
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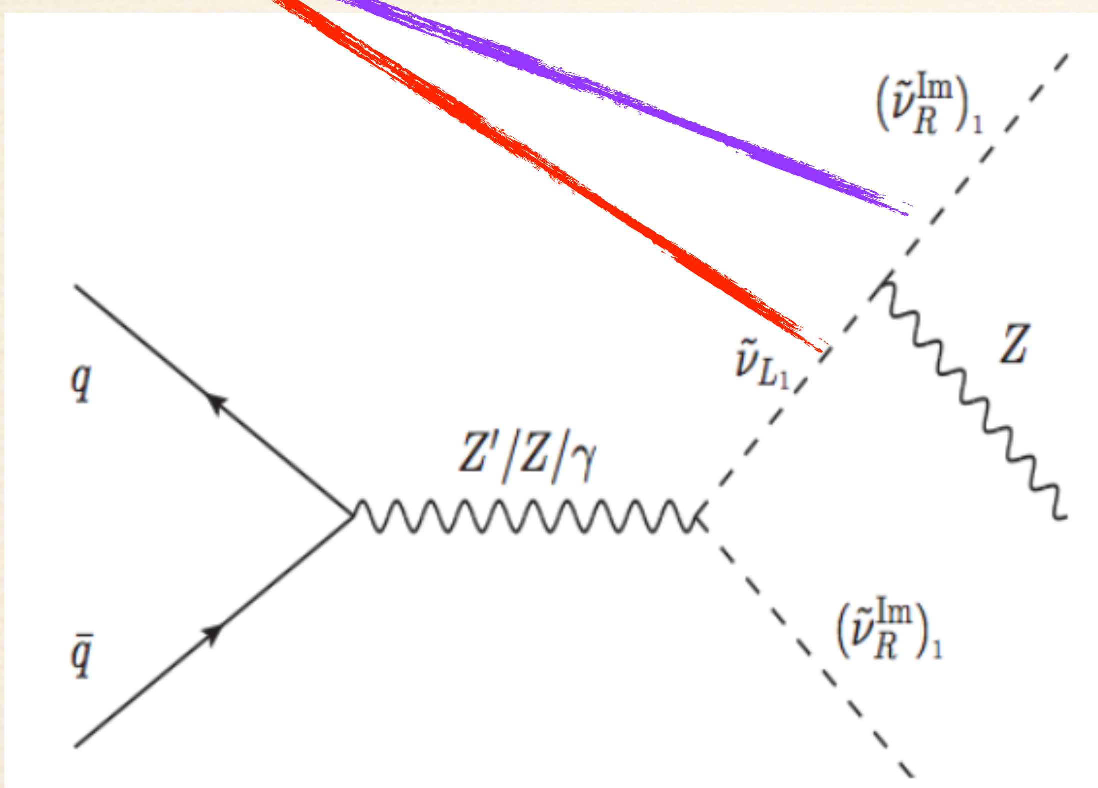

MonteCarlo “truth”

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</event>
<event>
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       -2 -1    0    0    0  501 -0.0000000000e+00 +0.0000000000e+00 +4.6128538452e+01 4.6128538520e+01 2.5000000000e-03 0.0000e+00 1.0000e+00
        2 -1    0    0  501    0 +0.0000000000e+00 -0.0000000000e+00 -2.5870145533e+03 2.5870145533e+03 2.5000000000e-03 0.0000e+00 -1.0000e+00
  1000012  2    1    2    0    0 -1.9090883370e+02 +5.2638786020e+01 -2.1770930695e+03 2.1981117260e+03 2.2966040580e+02 7.1775e+02 0.0000e+00
       23  2    3    3    0    0 -6.5867617410e+01 -3.8785863448e+00 -8.8347097841e+02 8.9045061110e+02 8.9597626486e-01 0.0000e+00 0.0000e+00
  4000012  1    3    3    0    0 -1.2504121629e+02 +5.6517372365e+01 -1.2936220911e+03 1.3076611149e+03 1.3300360000e+02 0.0000e+00 0.0000e+00
       11  1    4    4    0    0 -8.8177852069e+01 -4.4877687173e+00 -7.4110437163e+02 7.4634520386e+02 5.1099890000e-04 0.0000e+00 -1.0000e+00
      -11  1    4    4    0    0 +2.2310234658e+01 +6.0918237245e-01 -1.4236660677e+02 1.4410540725e+02 5.1099890000e-04 0.0000e+00 1.0000e+00
  4000012  1    1    2    0    0 +1.9090883370e+02 -5.2638786020e+01 -3.6379294536e+02 4.3503136586e+02 1.3300360000e+02 0.0000e+00 0.0000e+00
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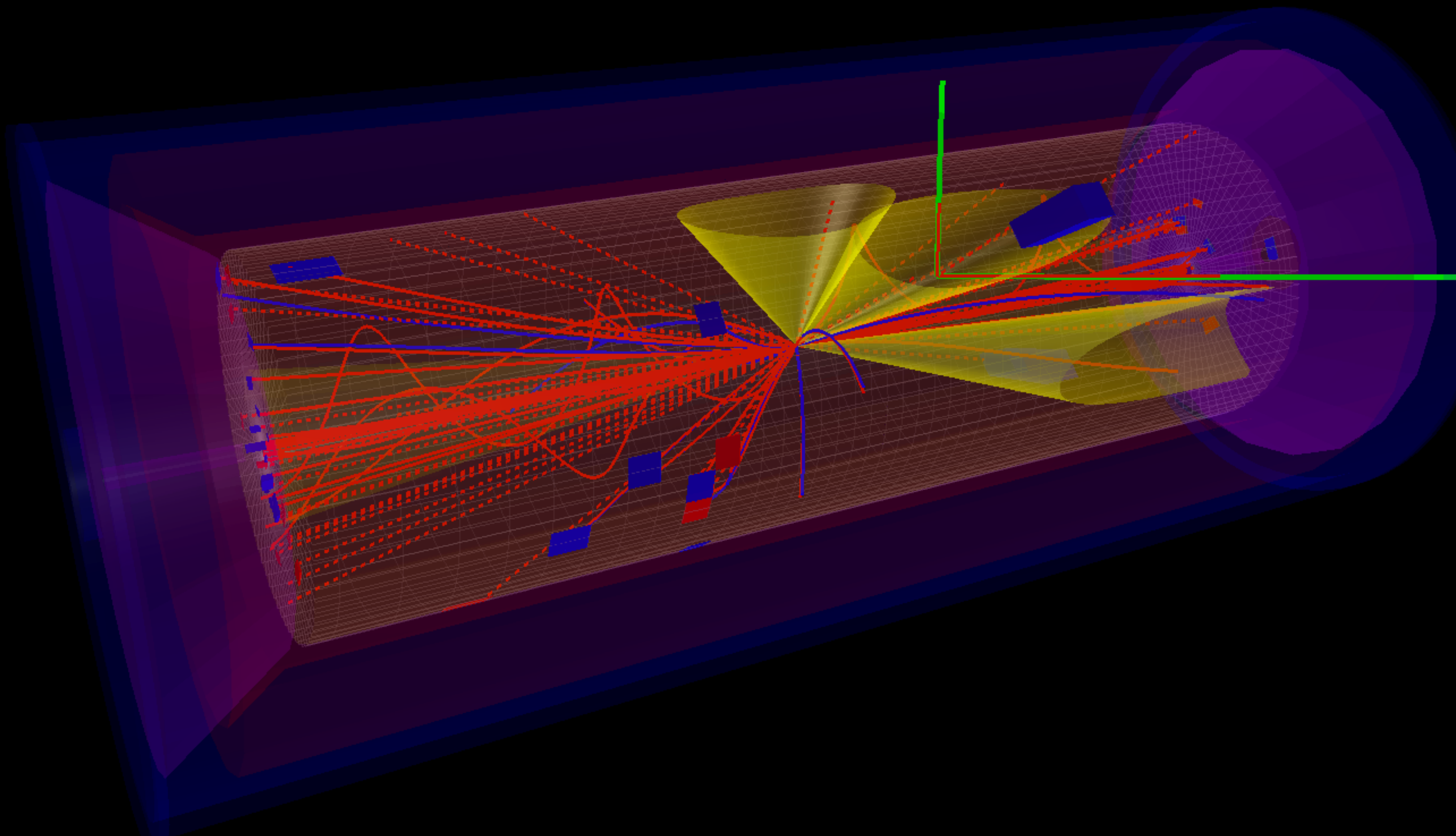
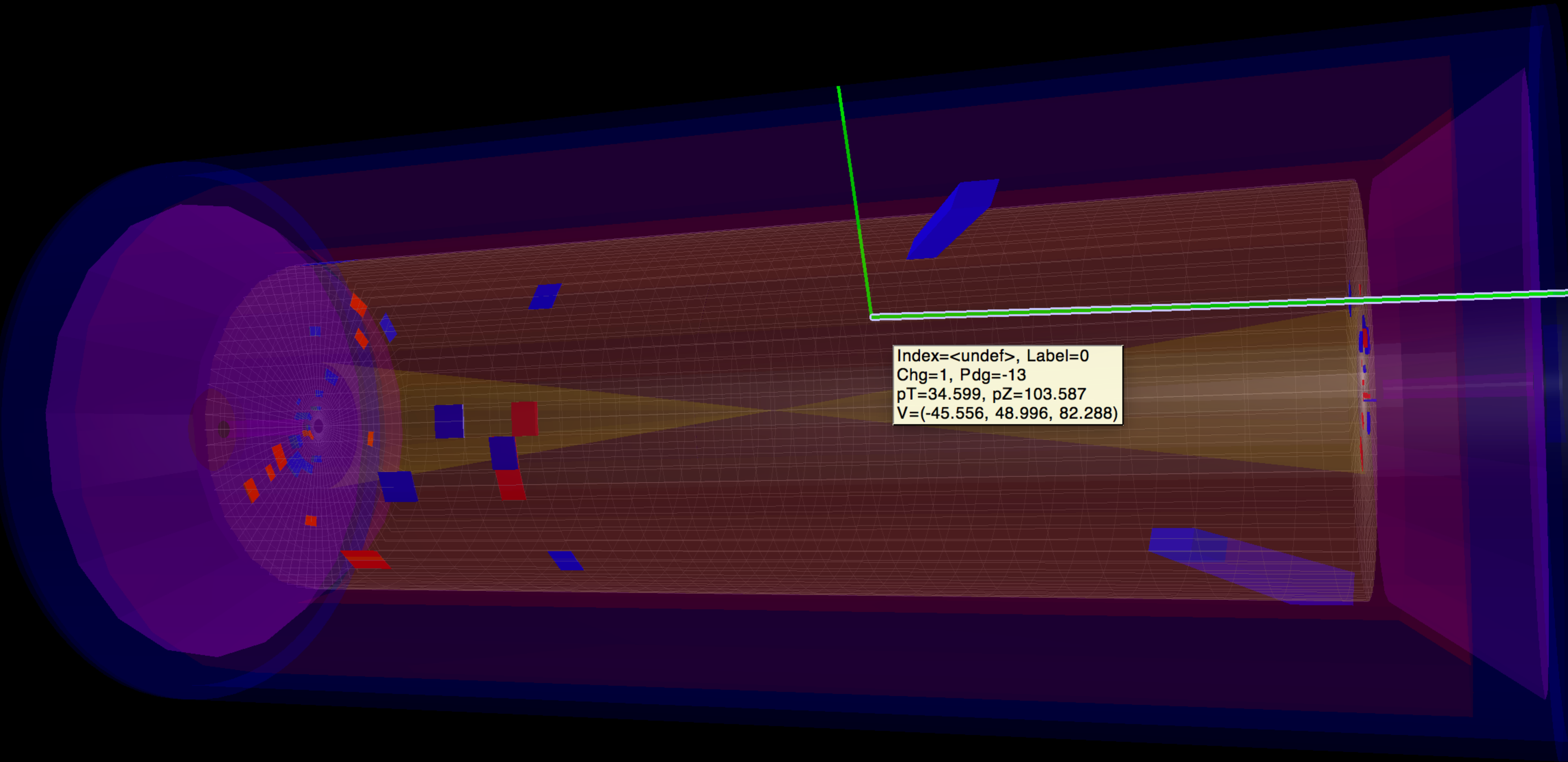
displaced distance added by MadGraph in mm

MadGraph generate the displaced distance by applying a exponential distribution function

Event display by Delphes for S-neurino long lived candidate



Event display by Delphes for S-neurino long lived candidate



Analysis

Charged

Signature : Charged Tracks
reconstructed as a slow moving muon
search variables : track p_T and time of flight
study case : $c\tau_0$ = 85 cm , 6.9 m
Xsec : 1.7, 9.6 fb

Neutral

Signature : displaced di-leptons
SM Z boson decays to OSSF lepton pair
search variables : L_{xy} and d_0
study case : $c\tau_0$ = 90 cm , 6.5 m
Xsec : 4.9, 7.6 fb

Analysis

HSCP 8, 13 TeV

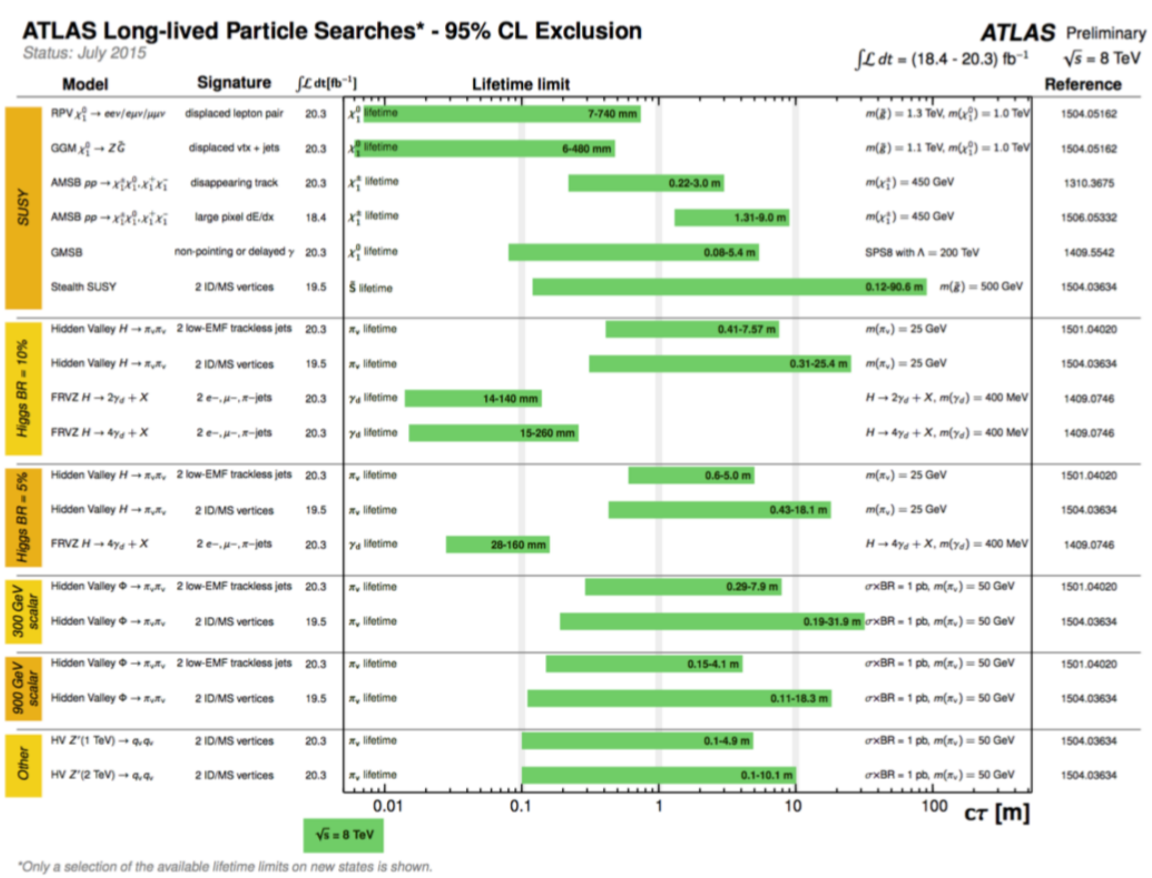
arXiv:1305.0491, CMS-PAS-EXO-16-036

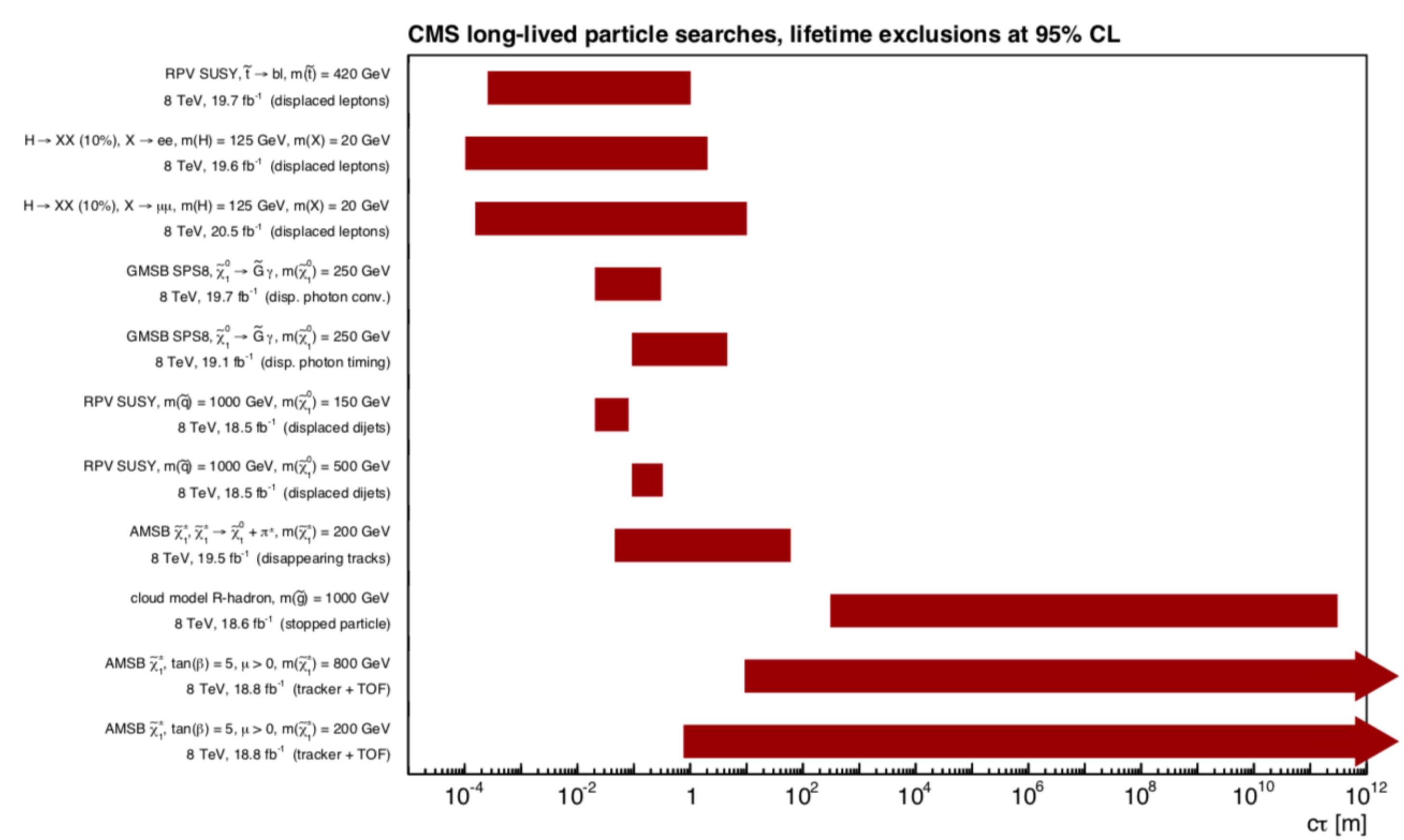
	Final state targeted	7 TeV	8 TeV
1	displaced SF dilepton pairs	1211.2472	1411.6977
2	displaced μ-μ pairs in muon system		2005761
3	displaced e-μ pairs		1409.4789
4	displaced μ-μ pairs (dark photons)		1506.00424
5	displaced photons using ECAL timing	1212.1838	2063495
6	displaced photons using conversions	1207.0627	2019862
7	displaced vertices		to appear
8	displaced dijets		1411.6530
9	short, highly ionizing disappearing tracks		thesis
10	disappearing tracks		1411.6006
11	kinked tracks		thesis
12	fractionally charged particles	1210.2311	1305.0491
13	heavy stable charged particles (HSCP)	1205.0272	1305.0491
14	stopped particles	1207.0106	1501.05603
15	out of time muons		thesis

direct searches

indirect searches

13 TeV HSCP: 2114818





Analysis S-Neutrino

C.O.M.E = 13 TeV
integrated Lumi = 100 1/fb

Set of cuts:

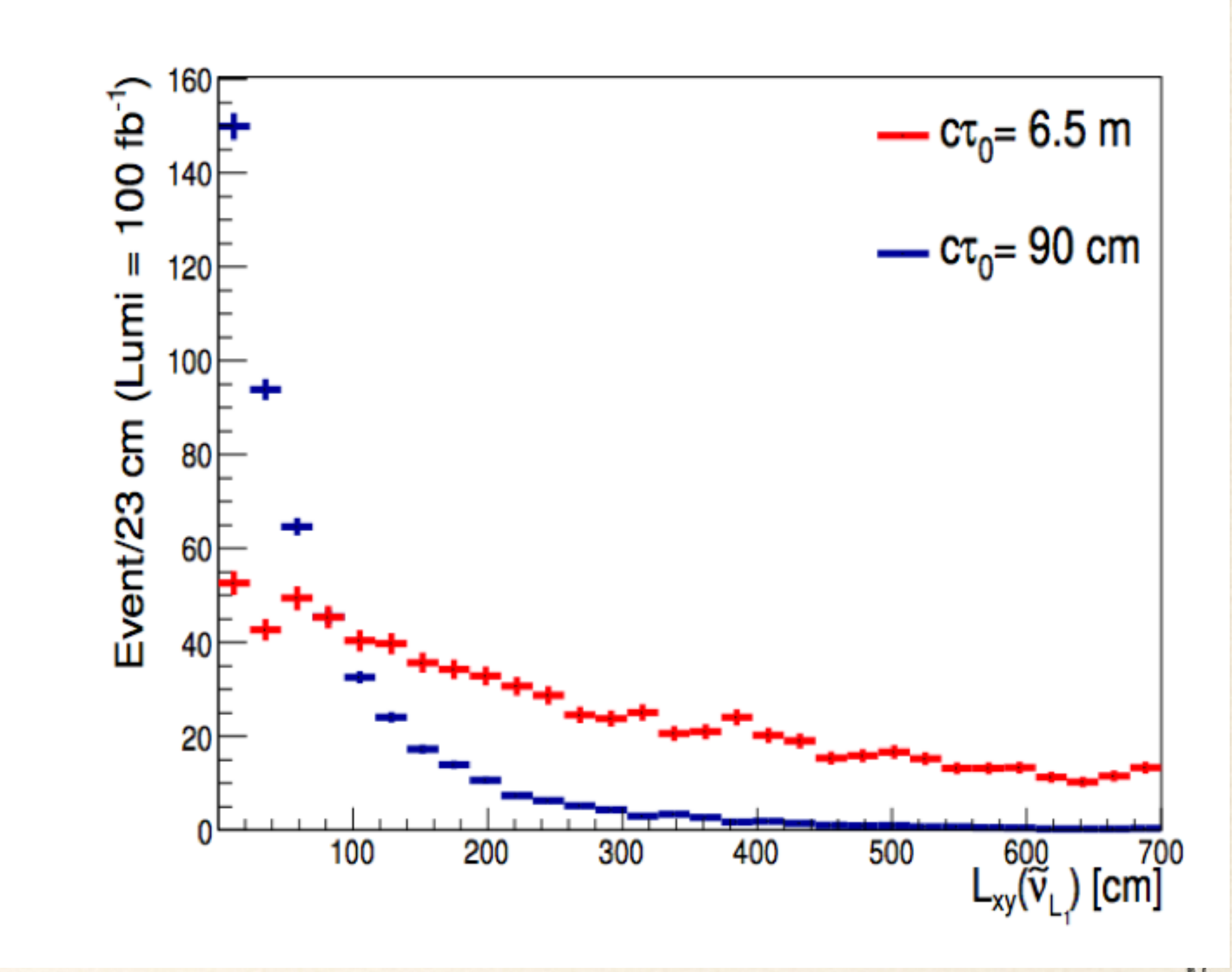
1- lepton momentum > 25 GeV
2- isolation cone radios < 0.1

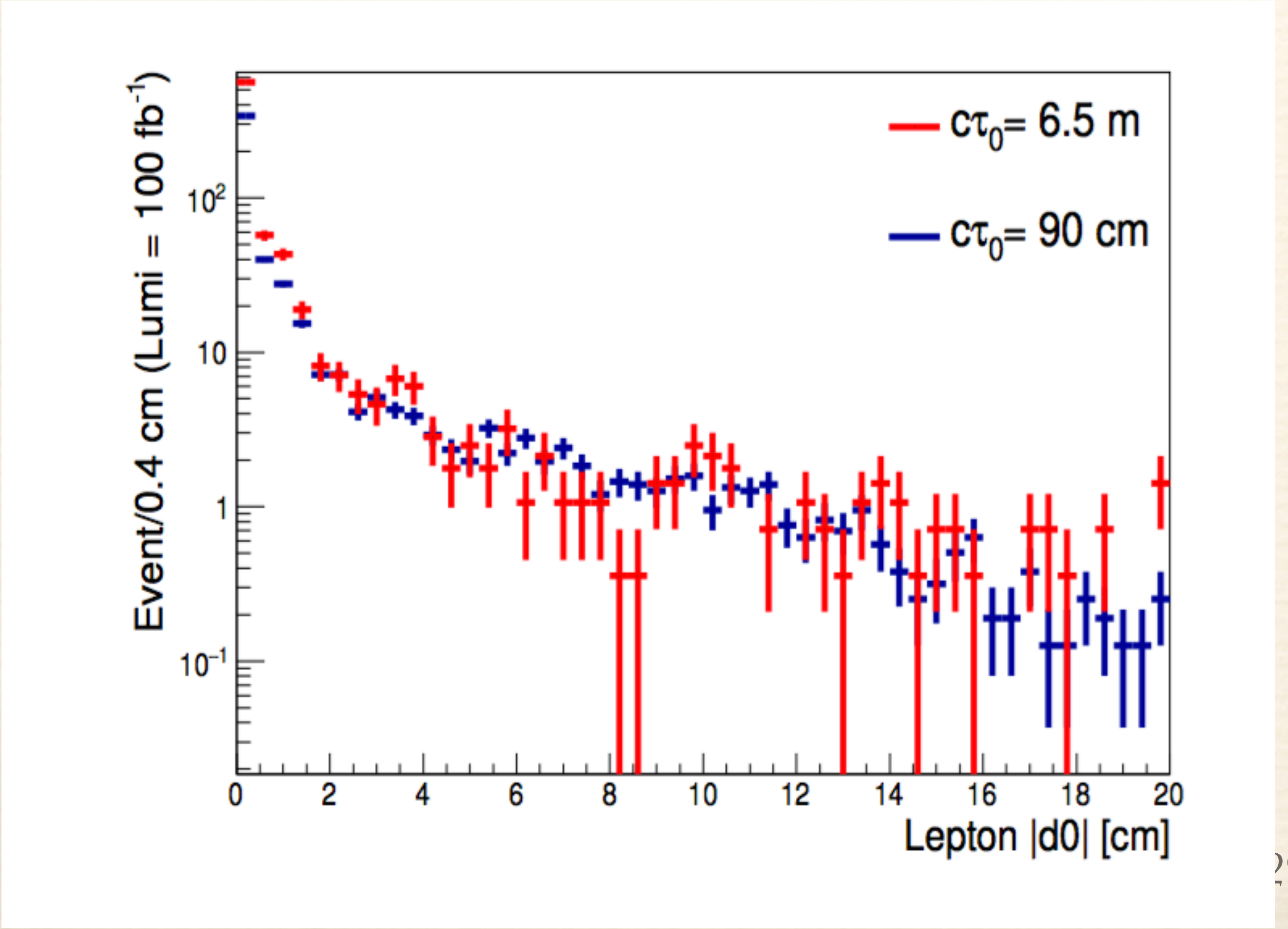
→ Reduces the charge mis-identification of leptons and jet mis-identification

1- L_xy > 20 mm
2- d0 > 4 mm

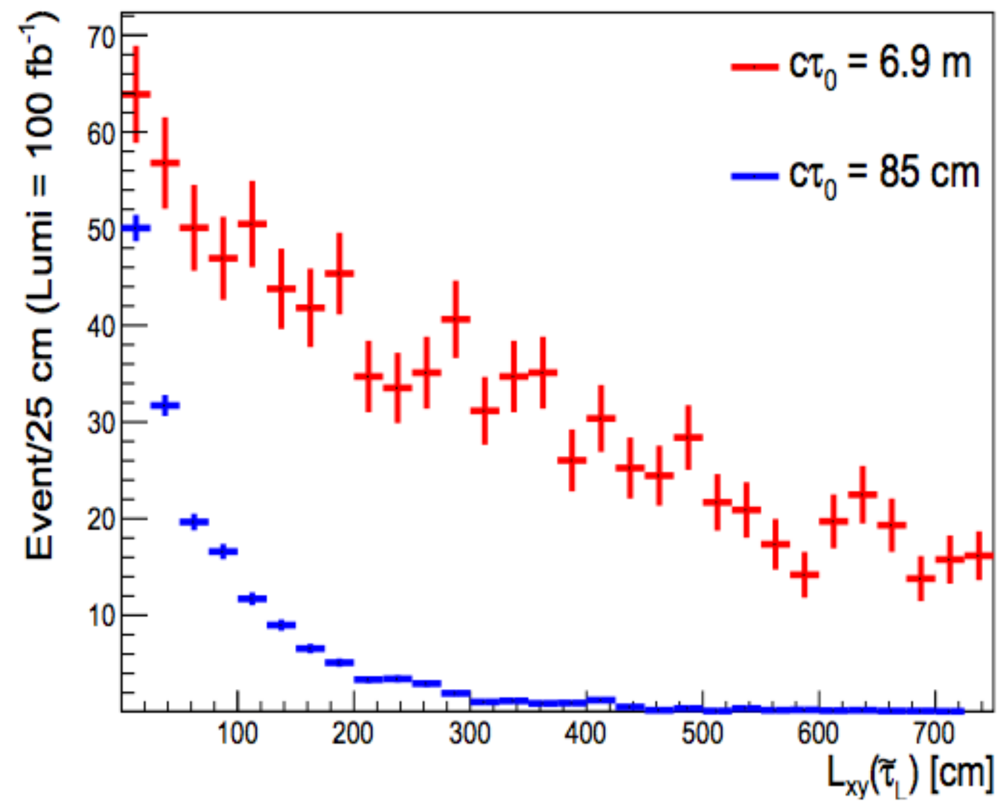
→ Reduces Non prompt SM candidate and soft leptons from heavy object decay

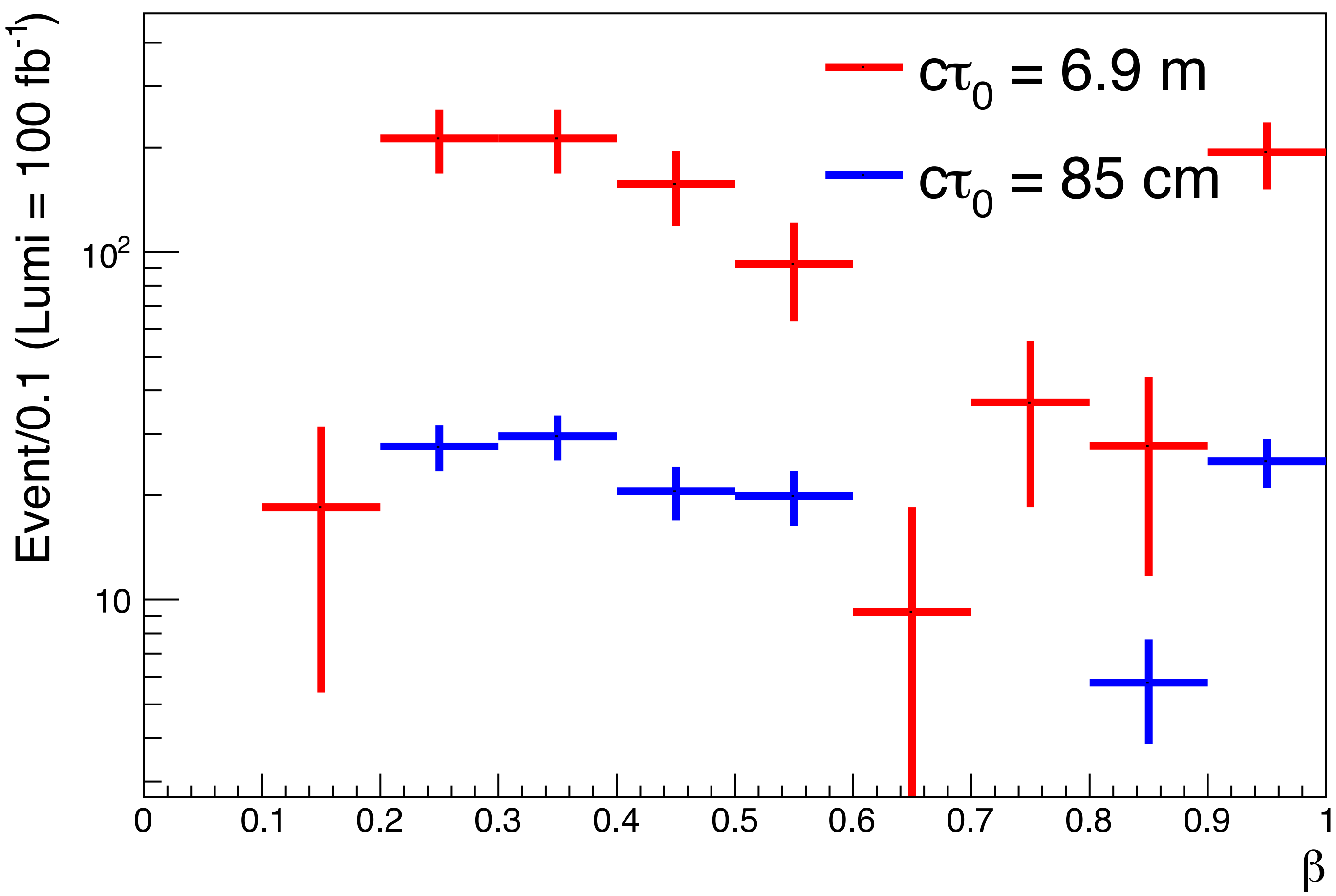
Results S-Neutrino





Results S-tau





Summary

* B-L Extension of MSSM can provide wide spectrum for neutral and charged long lived particles

* Unlike MSSM, the life time is independent of the mass difference between NLSP and LSP

* Fast detector simulation has been done, while with full simulation more info will provided

* For the neutral LLP we rely on L_xy and d0 parameter as discriminator

* For the charged LLP we rely on the track + TOF info