CEPC LLP Study in Two-lepton Chanel

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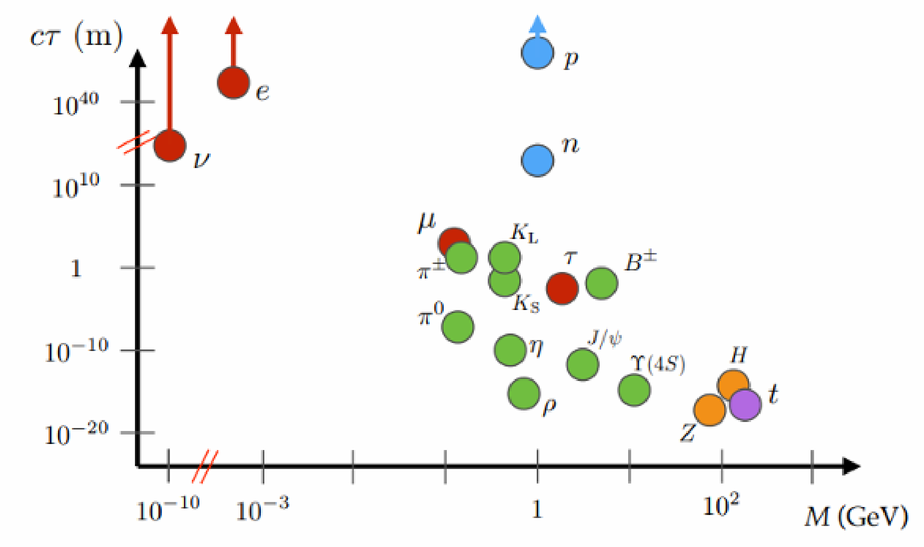
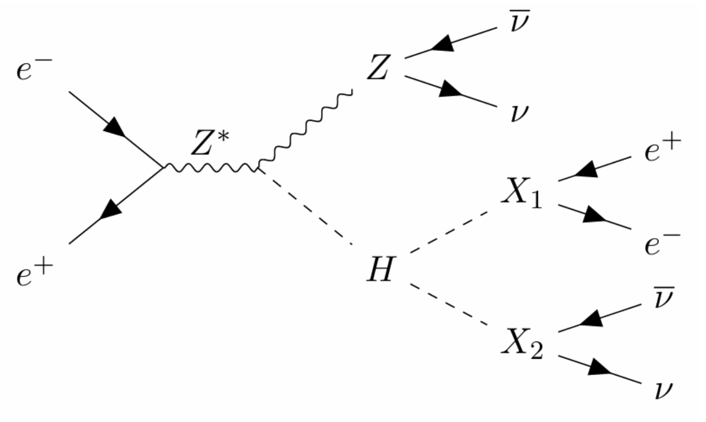
LLP Searches

- Long-lived particles (LLPs) are important portals to new physics
- BSM particles may have a relatively long lifetime due to weak coupling to SM particles
  - New scalars, dark photons, ALP, SUSY….
- A distinct signature for detection:
  - Displaced vertex with some distance from the main vertex
- Long-live particle searches can benefit from good detector performance and acceptance of CEPC
- Focus on the lepton channel (X->ll) for this talk
  - Lepton pair with a displaced vertex





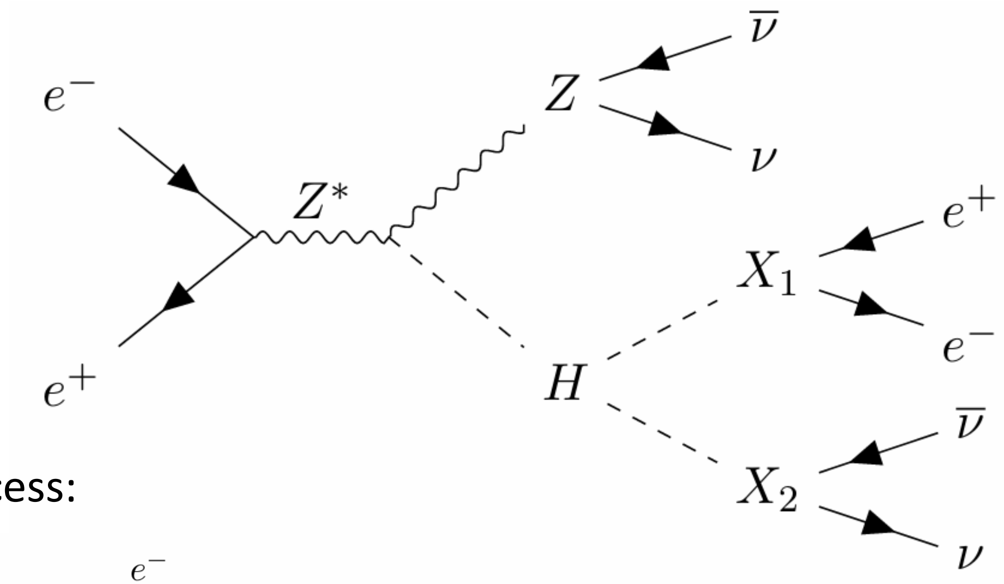
Signal Production

- Full simulation samples generated using CEPCSW (v25.3.6) with an integrated luminosity of 20 ab^{-1}
- LLP signal sample is generated by Madgraph5 and showered by Pythia8
- Displaced vertex of LLPs: $\mathbf{0} \leq \boldsymbol{r}_{\mathbf{decay}} \leq \mathbf{6[m]}$
- Only one LLP decays to visible lepton pair
  - Good acceptance if the decay length is within the reach of the CEPC detector

Acceptance (%)	Lifetime [ns]				
Mass [GeV]	0.001	0.1	1	10	100
1	100.00 ± 0.00	99.86 ± 0.01	48.76 ± 0.18	6.49 ± 0.09	0.67 ± 0.03
10	100.00 ± 0.00	100.00 ± 0.00	99.78 ± 0.01	46.80 ± 0.16	6.22 ± 0.08
50	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	99.31 ± 0.03	40.37 ± 0.16

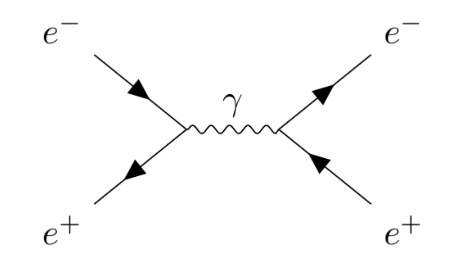
Two-electron Channel Analysis

Signal:

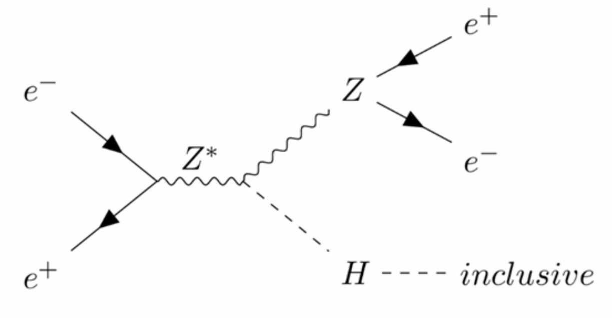


Signal events: 100,000, $M_{X1,2}$: 1,10, 50GeV
Bhabha process events: 98,000
vvHX events: 1,000,000
eeHX events: 1,000,000
eeZ events: 500,000
evW events: 500,000

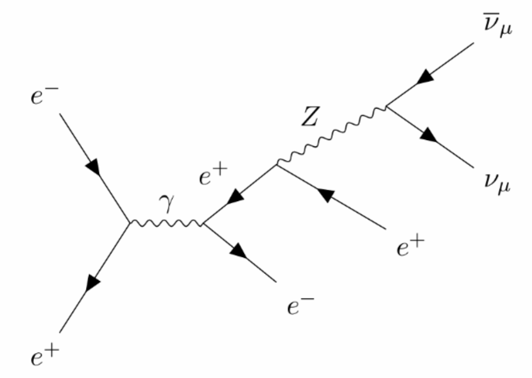
Bhabha process:



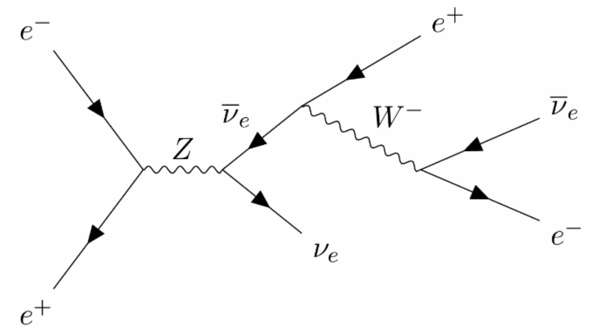
eeHX:



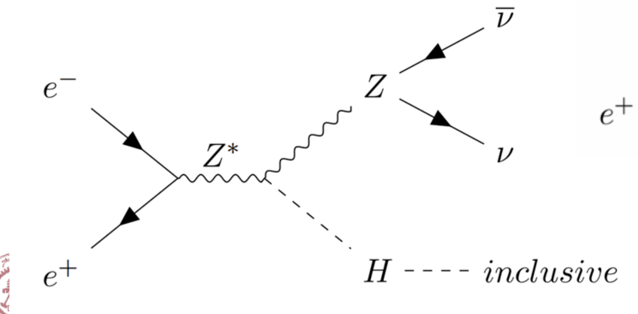
eeZ process:
Final state: ee $\nu_{\mu,\tau}\nu_{\mu,\tau}$



evW process:
Final state: $ee\nu_e\nu_e$



vvHX:



Event Selection Summary

Total events
nPFO<20: Jet veto
Displaced vertex: 2 tracks with distance between vertex and IP lower than 1 mm (3.5mm for LLP 1 GeV)
Lepton pair: exactly two opposite sign lepton
$\Delta\theta$: Two leptons back-to-back
Recoil mass(GeV): Z veto
Invariant mass(GeV): LLP signal mass selection
$\Delta T > 0.1$ ns(0.05ns): LLP decay signal has large time difference

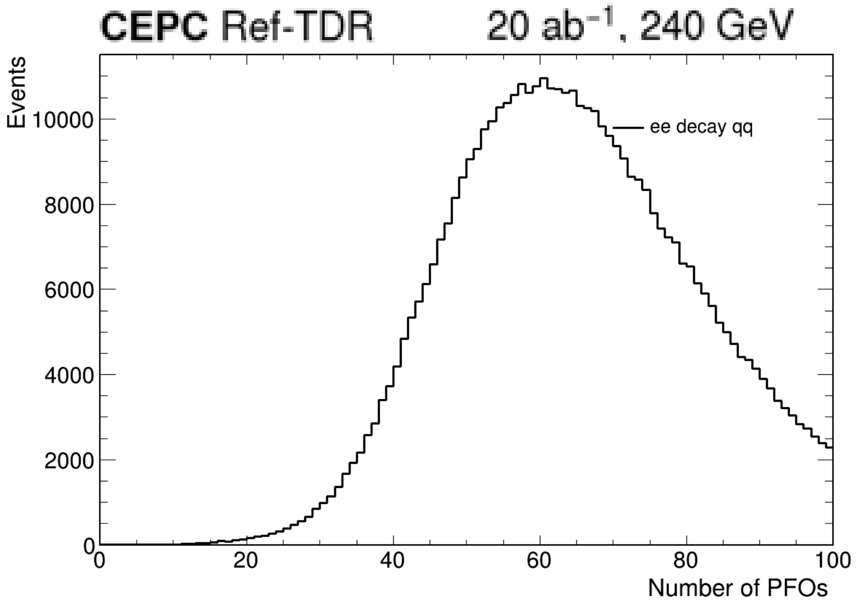
- The most effective selections are the displaced vertex and invariant mass selection
- Timing information can also help in some cases

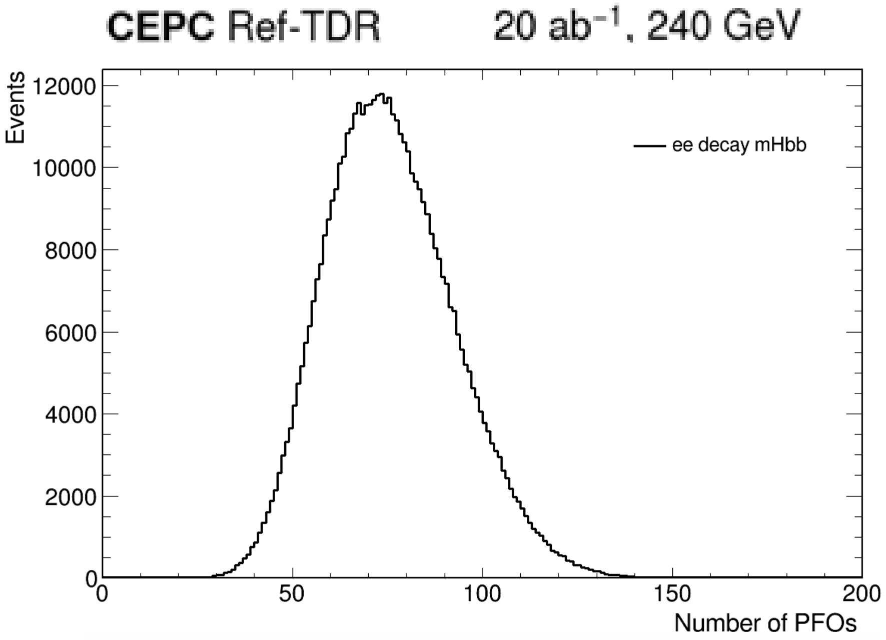
$$\Delta T = t_{hit,i} - r_{hit,i}/c$$

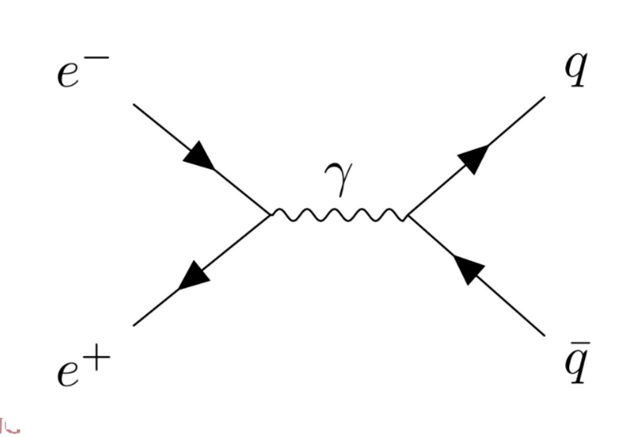
$t_{hit,i}$: hit time of the ith component in the object cluster recorded by the detector;
$r_{hit,i}$: ith Euclidean distance to the IP;
c : light speed in vacuum.

Jet Veto

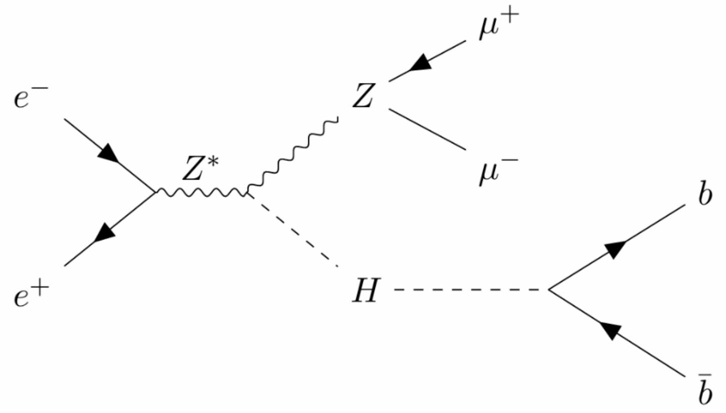
The jet veto is done by the number of particle flow objects





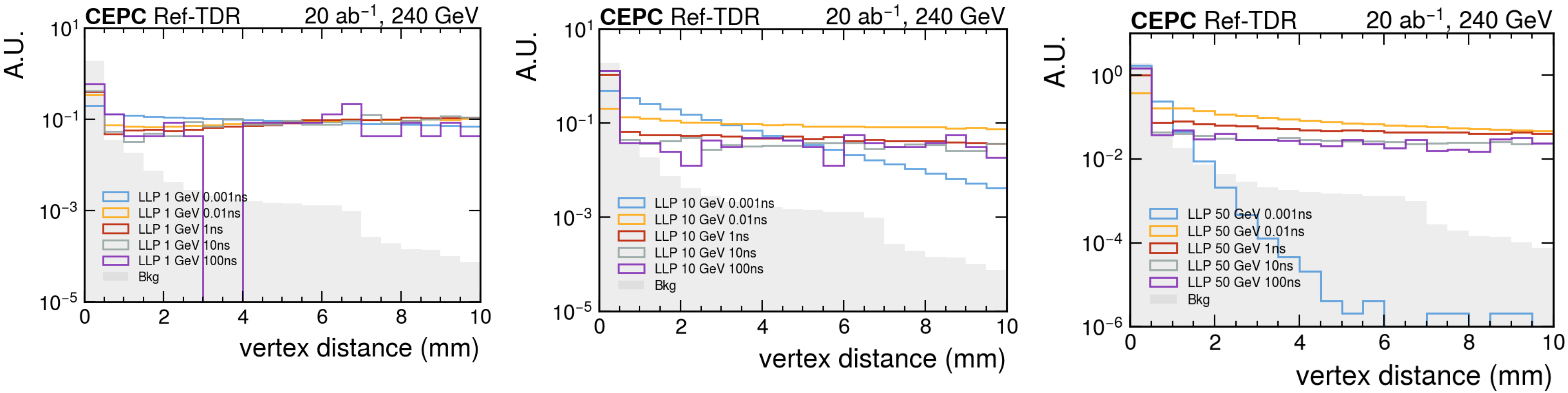


Jet Veto:
nPFO<20

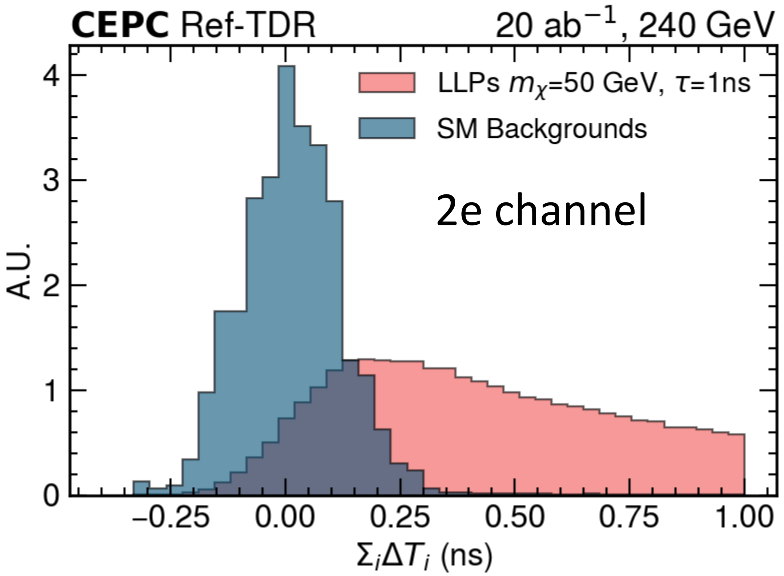


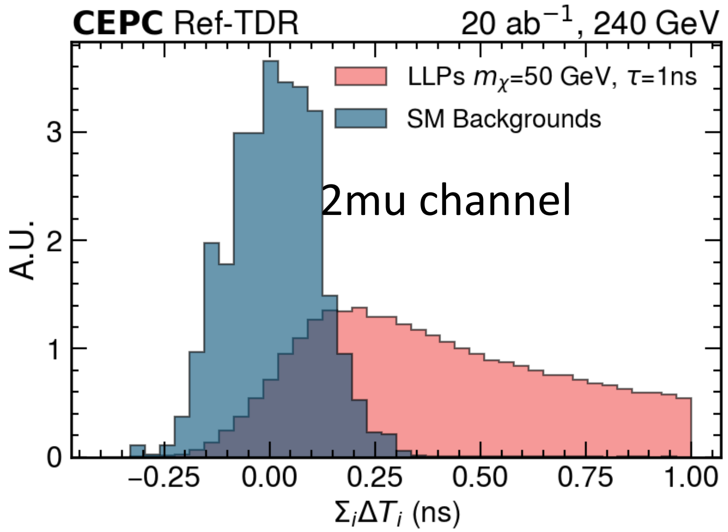
Primiary Vertex Reconstruction

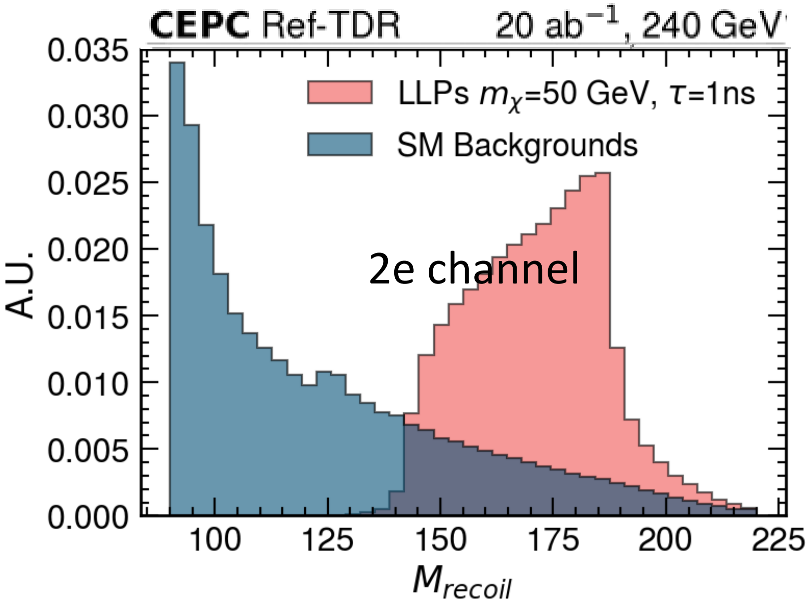
- Re-vertexing package (thanks to Chengguang)
  - Ability to find displaced vertex
- Most LLPs with lifetime over 0.1ns has significantly displaced vertex comparing to SM processes

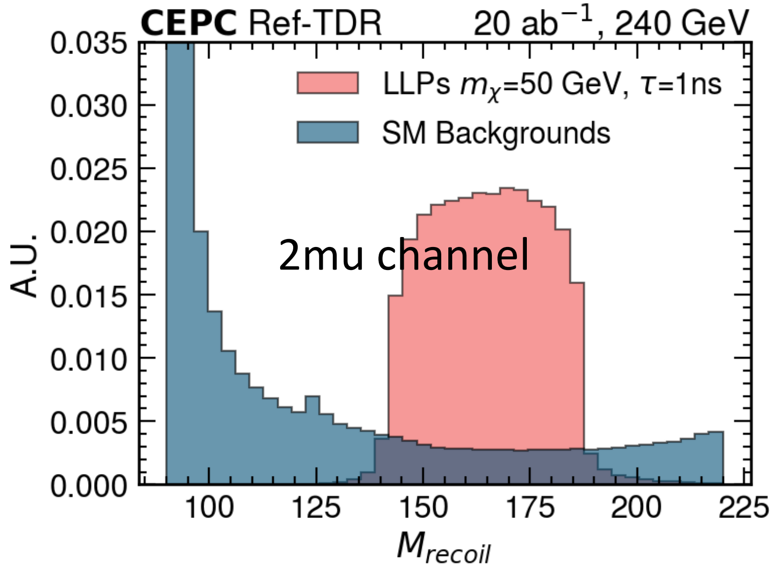


Kinematics Distributions









Cut-flow for Two-electron Channel

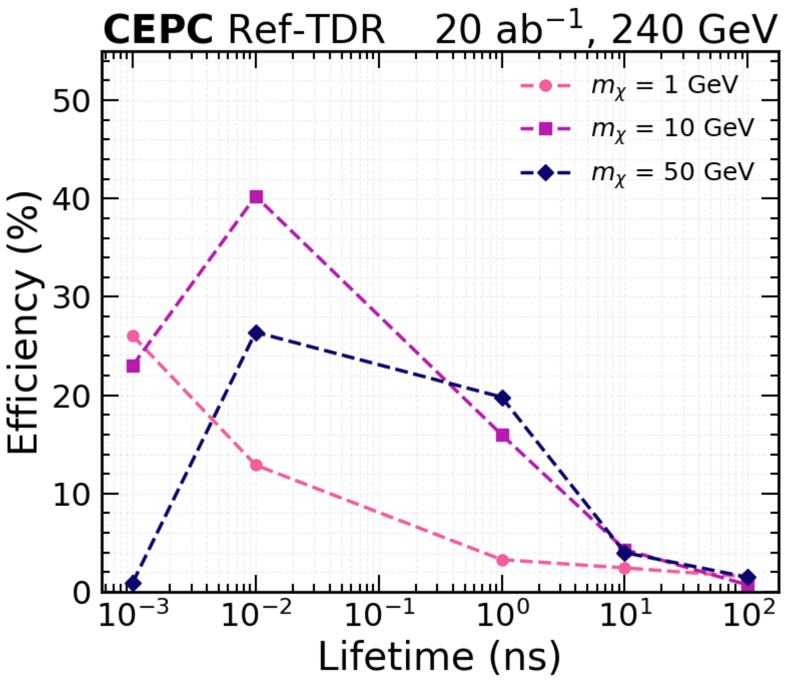
- The cut-flow for the electron channel, m_{llp} = 10 GeV

Cuts	0.001 ns (%)	0.01 ns (%)	1ns (%)	10ns (%)	100ns (%)	eeH (%)	barbar (%)	eeZ (%)	evW(%)
All Events	100.00	100.00	100.0	100.00	100.00	100.00	100.00	100.00	100.00
Jet veto	99.98	99.93	99.91	99.97	99.98	6.56	64.05	99.36	99.81
Z veto	99.98	99.93	99.91	99.97	99.98	5.21	63.50	79.58	93.33
2 tracks	83.99	88.3	47.78	14.53	11.39	0.13	24.51	56.80	75.73
Displaced vertex (>1 mm)	44.07	86.60	46.59	14.07	11.03	0.00	9.60	0.71	0.18
Recoil mass >140 GeV	29.79	55.68	27.84	8.71	1.34	0.00	0.20	0.30	0.07
2 electrons after PID	29.7	55.68	27.84	8.71	1.34	0.00	0.20	0.30	0.07
OS	29.74	55.64	27.82	8.71	1.34	0.00	0.14	0.01	0.01
1< $\Delta\theta$ < 60	28.68	53.85	26.87	8.41	1.28	0.00	0.0 (10^{-4})	0.0 (10^{-5})	0.00
Invariant mass cut $\|m_{ll}-10\| < 1$ GeV	23.00	40.24	16.00	4.61	0.70	0.00	0.00	0.00	0.00

Two-electron Channel Signal Efficiency

- Best signal efficiency reaches 40% with background free condition

LLP signal efficiency for ee channel

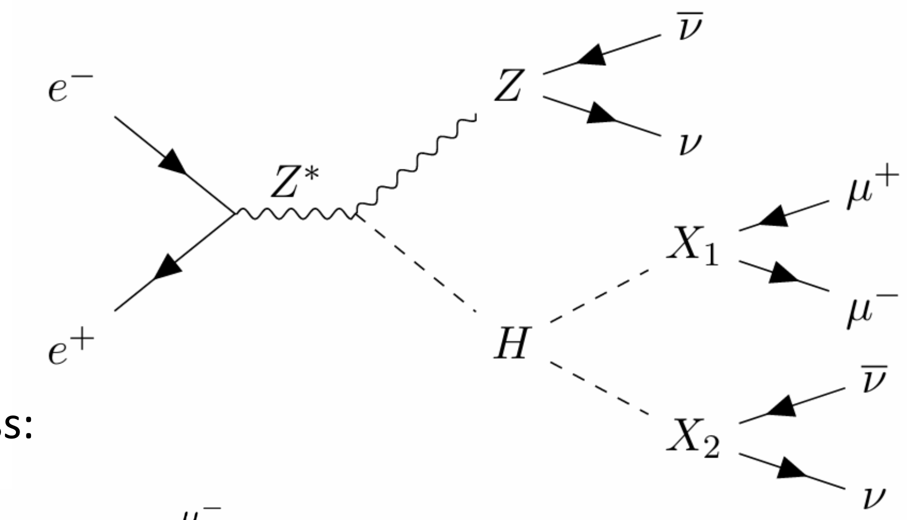


LLP signal efficiency for ee channel

2 Muon	0.001ns	0.01 ns	1 ns	10 ns	100 ns
LLP 1 GeV	26.08	12.9	3.28	2.44	1.53
LLP 10 GeV	23.00	40.24	15.99	4.31	0.70
LLP 50 GeV	0.91	26.41	19.81	4	1.48

Two-muon Channel Analysis

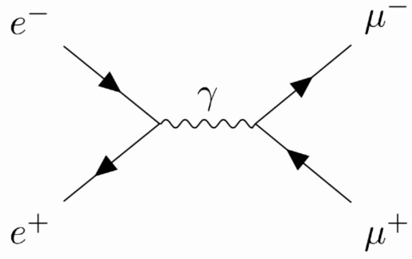
Signal:



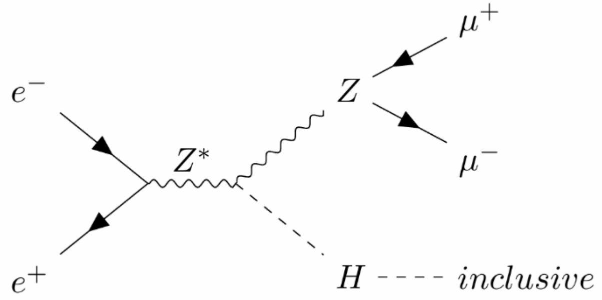
Signal events: 100,000, MX1,2: 1,10,50 GeV

μμ process events: 98,000
vvHX events: 1,000,000
μμHX events: 1,000,000
ee->ZZ->μμ events : 1,250,000
ee->Z->μμ events : 500,000

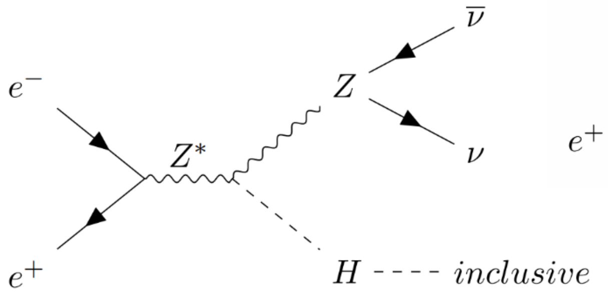
μμ process:



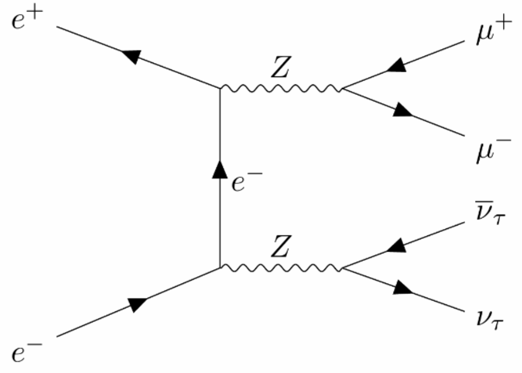
μμHX



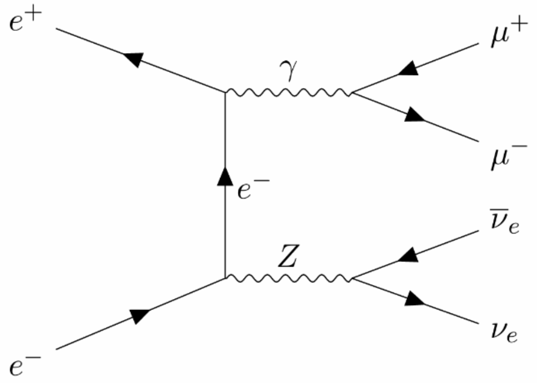
vvHX:



ee->ZZ->μμ process:
Final state: $\nu_\tau \nu_\tau \mu\mu$



ee->Z->μμ process:
Final state: $\nu_e \nu_e \mu\mu$



Cut-flow for Two-muon Channel

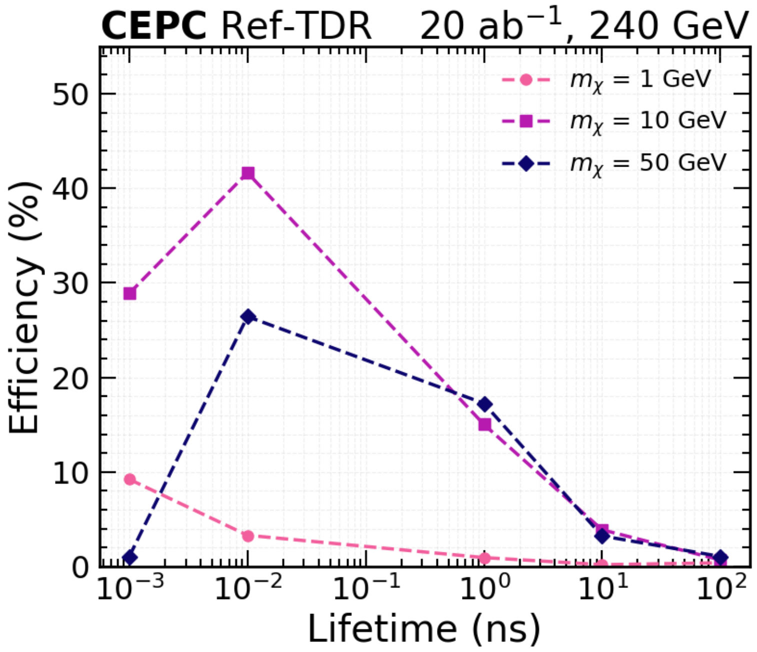
- The cut-flow for the muon channel, m_{llp} = 1 GeV

Cuts	0.001ns (%)	0.01ns (%)	1ns (%)	10ns (%)	100ns (%)	vvHX (%)	mmHX (%)	barbar (%)	Signal Z (%)	ZZ (%)	WW(%)
All Events	100	100	100	100	100	100	100	100	100	100	100
Jet veto	100	100	100	100	100	8.04	7.7	97.94	99.67	99.42	99.94
Z veto	100	100	100	100	100	7.98	5.05	72.09	88.09	79.15	93.89
2 tracks	97.62	60.12	19.56	15.36	15.57	5.2	0.09	54.49	58.14	47.01	85.7
displaced vertex (>3.5 mm)	78.7	58.92	19.14	15.04	15.24	0.02	0	0.59	0.47	0.46	0.05
recoil mass >130 GeV	34.59	17.96	5.58	0.97	2.15	0.01	0	0.01	0.14	0.08	0
2 muons after PID	33.3	16.73	5.19	0.89	2.01	0	0	0.01	0.13	0.07	0
OS	33.3	16.73	5.19	0.89	2.01	0	0	0.01	0.13	0.07	0
1< $\Delta\theta$ < 60	24.24	12.55	3.93	0.69	1.37	0	0	0	0.002	0.002	0
Invariant mass cut $\lvert m_{ll}-1\rvert$ < 0.6 GeV	24.24	12.55	3.93	0.69	1.37	0	0	0	10^{-4}	10^{-4}	0
ΔT > 0.05 ns	9.23	3.31	0.95	0.2	0.4	0	0	0	0	0	0

Two-muon Channel Signal Efficiency

- Best signal efficiency reaches 40% with background free condition
  - Signal efficiency for 1 GeV is low due to additional ΔT selection

LLP Signal efficiency for $\mu\mu$ channel

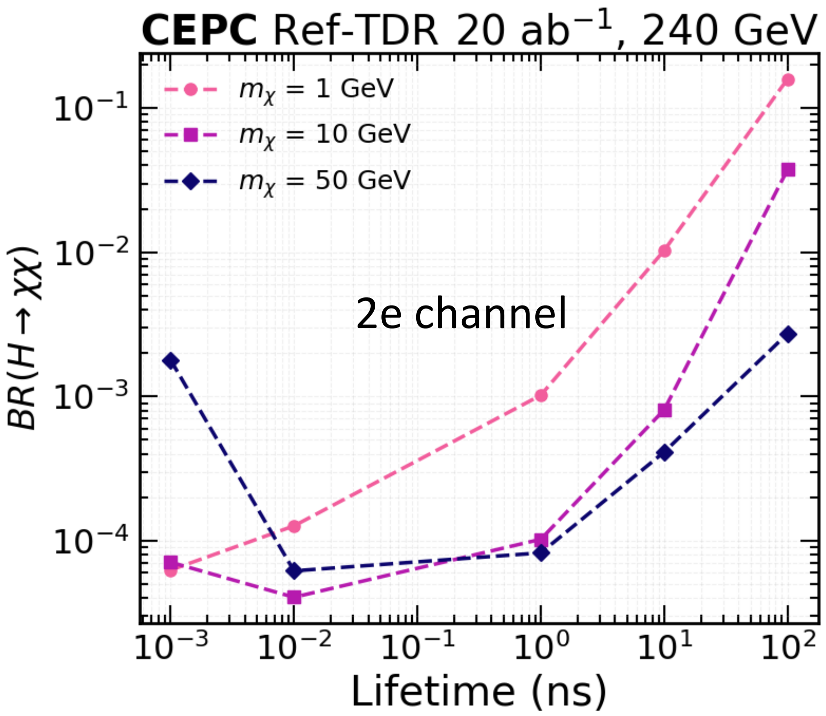


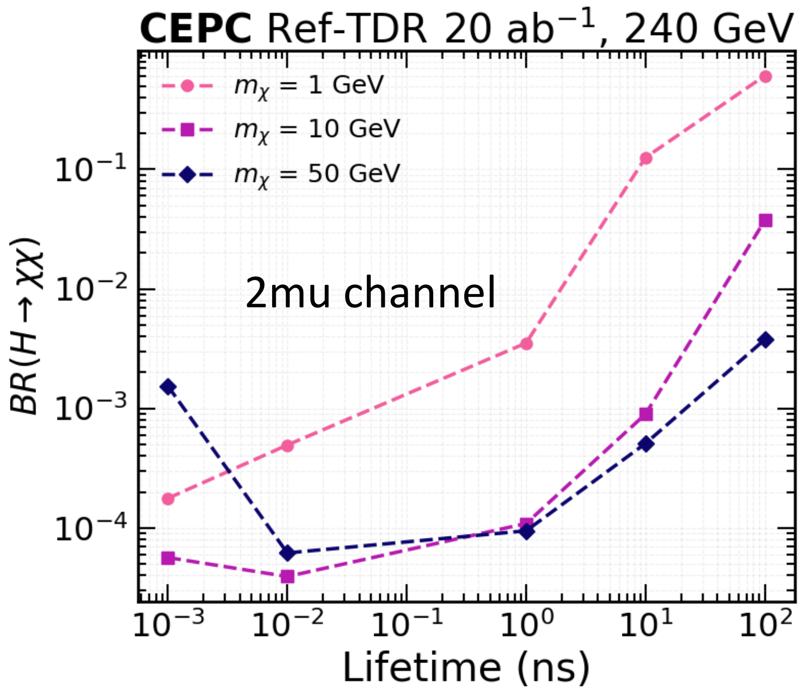
LLP Signal efficiency for $\mu\mu$ channel

2 Muon	0.001	0.01	1	10	100
LLP 1 GeV	9.23	3.31	0.95	0.2	0.4
LLP 10 GeV	28.89	41.65	15.03	3.89	0.7
LLP 50 GeV	1.06	26.44	17.26	3.24	1.07

Expected Limit

- Assuming BR(LLPs->leptons) is 0.2
- Best BR(H->LLPs->leptons) upper limit reaches 4*10^{-5} at 240 GeV with 20 ab^{-1}
  - For comparison, previous study using ML-based methods sets best BR(H->LLPs->jets) upper limit at ~10^{-6}



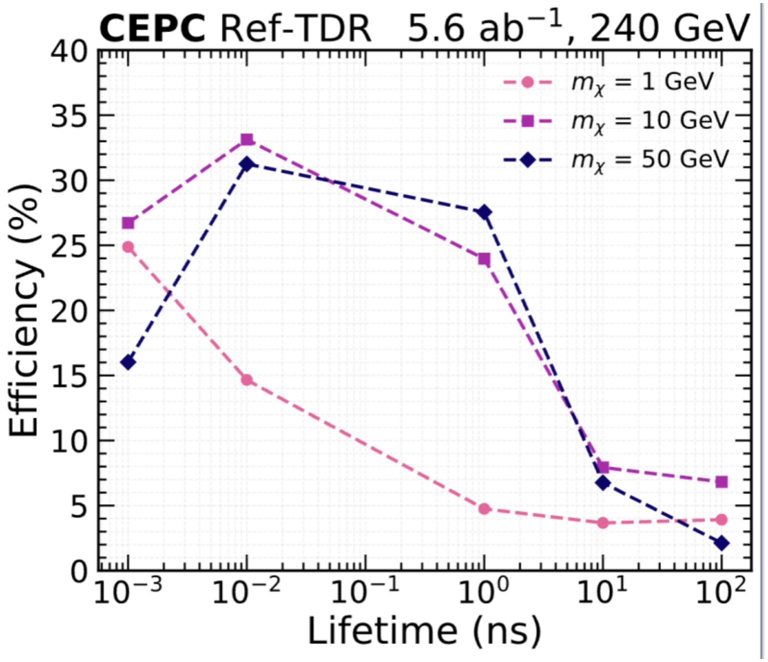


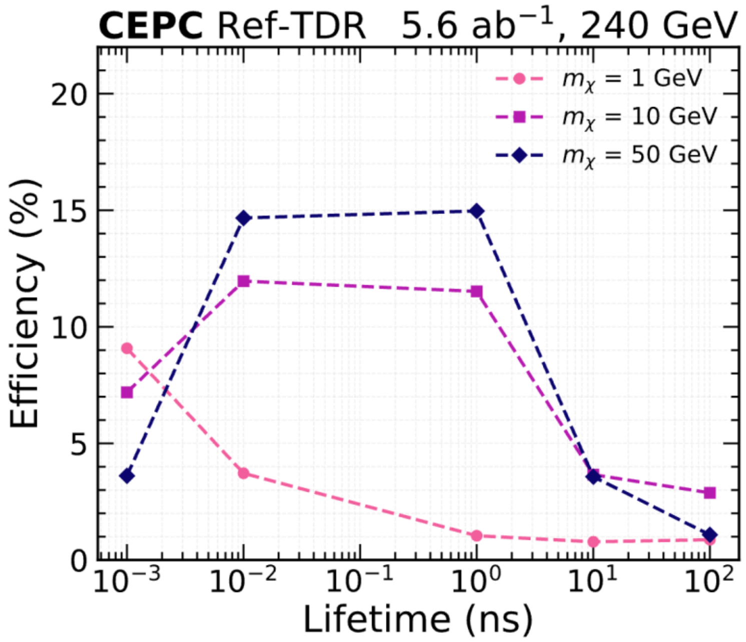
Summary & To-do

- Major improvements shown compared to previous round of analysis
  - Significant improvements from PID
    - Best WP with XGBoost option
  - Displaced vertex reconstruction further improves background rejection
    - ΔT selection is no longer needed for most LLP mass points
  - Best BR(H->LLPs->leptons) upper limit reaches $4*10^{-5}$ at 240 GeV with 20 ab^{-1}

Backup

Previous Results



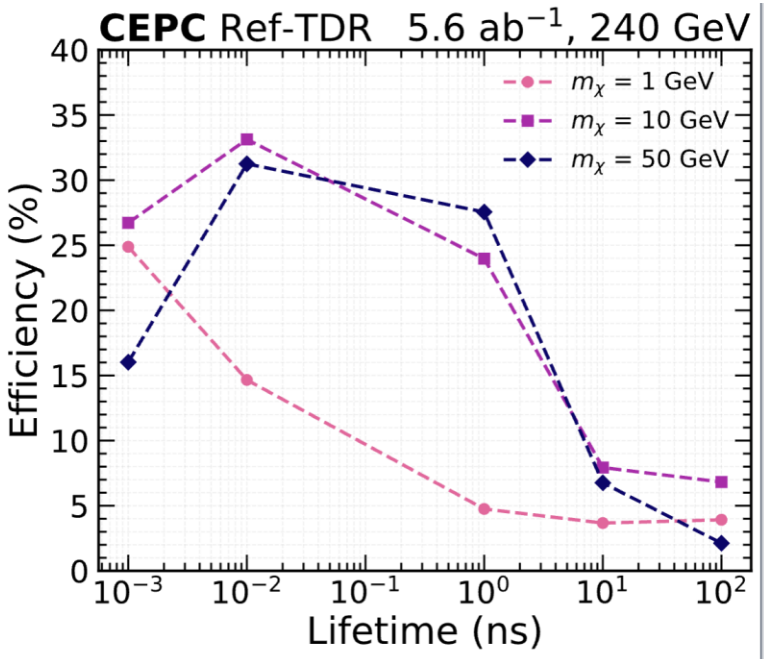


Mass	ee	4f_szeorsw_l	4f_sze_l0nunu	vvHX	eeHX
LLP 1 GeV	0.02%	1.30%	1.10%	0.06%	0.06%
LLP 10 GeV	0.03%	2.57%	2.58%	0.09%	0.09%
LLP 50 GeV	0.03%	2.57%	2.58%	0.09%	0.09%

2 Muon	e2e2	4f_sznu	4f_szz	4f_szzorww	vvHX	mmHX
LLP 1 GeV	0.13%	4.02%	1.62%	0.62%	0.04%	0.01%
LLP 10 GeV	0.13%	2.76%	1.09%	0.77%	0.05%	0.03%
LLP 50 GeV	0.13%	2.76%	1.09%	0.77%	0.05%	0.03%

Preliminary Result

The cutflow for 2-electron channel is shown in below



No deltaT for 10 GeV and 50 GeV

Background free

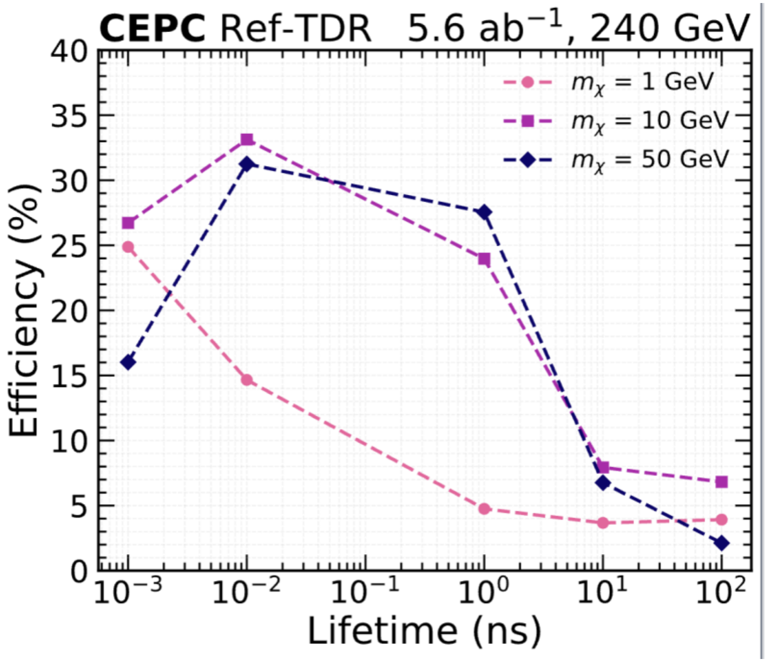
2 Muon	0.001	0.01	1	10	100
LLP 1 GeV	26.08	12.9	3.28	2.44	1.53
LLP 10 GeV	23.00	40.24	15.99	4.31	0.70
LLP 50 GeV	0.91	26.41	19.81	4	1.48

Mass	ee	4f_szeorsw_l	4f_sze_l0nunu	vvHX	eeHX
LLP 1 GeV	0.02%	1.30%	1.10%	0.06%	0.06%
LLP 10 GeV	0.03%	2.57%	2.58%	0.09%	0.09%
LLP 50 GeV	0.03%	2.57%	2.58%	0.09%	0.09%

bkg	ee	4f_szeorsw_l	4f_sze_l0nunu	vvHX	eeHX
1 GeV	0.0001%	0	0.001%	0	0
10 GeV	0.001%	0.0001%	0.0001%	0	0

Preliminary Result

The cutflow for 2-electron channel is shown in below



No deltaT for 10 GeV and 50 GeV

Background free

2 Muon	0.001	0.01	1	10	100
LLP 1 GeV	26.08	12.9	3.28	2.44	1.53
LLP 10 GeV	23.00	40.24	15.99	4.31	0.70
LLP 50 GeV	0.91	26.41	19.81	4	1.48

Mass	ee	4f_szeorsw_l	4f_sze_l0nunu	vvHX	eeHX
LLP 1 GeV	0.02%	1.30%	1.10%	0.06%	0.06%
LLP 10 GeV	0.03%	2.57%	2.58%	0.09%	0.09%
LLP 50 GeV	0.03%	2.57%	2.58%	0.09%	0.09%

bkg	ee	4f_szeorsw_l	4f_sze_l0nunu	vvHX	eeHX
1 GeV	0.0001%	0	0.001%	0	0
10 GeV	0.001%	0.0001%	0.0001%	0	0