Complementarity of Lepton Collider Probes of Dark Matter

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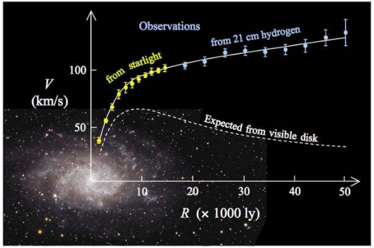
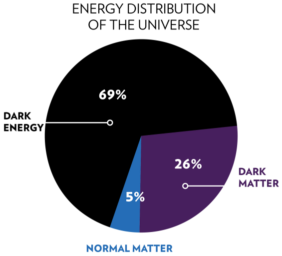
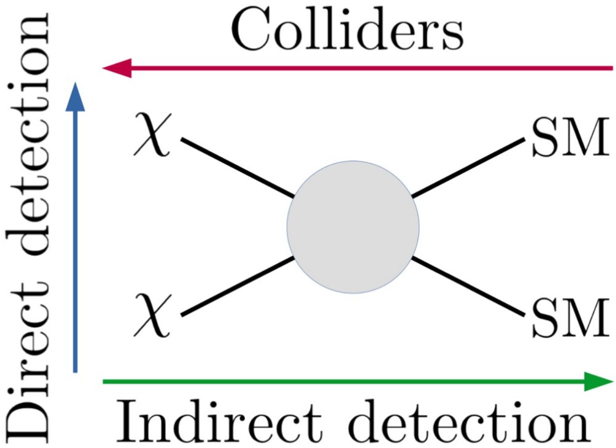
CEPC 味物理-新物理和相关探测技术研讨会

Aug/17, 2023

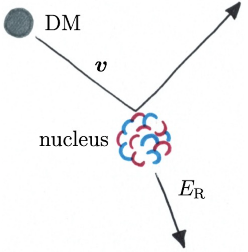
Dark Matter: Existence and Detection

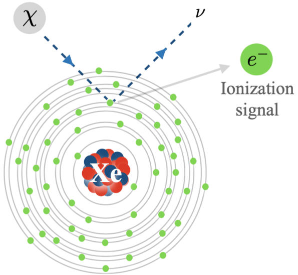






Absorptive DM by Nucleon and Electron

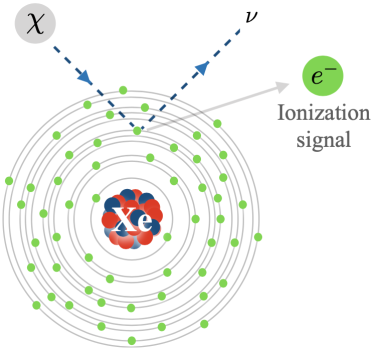




Direct detection experiments attempt at measuring the energy released in the detector by DM particles scattering off detector nuclei or outer electrons.

Absorptive DM by Electron

Absorption of Dark Matter (DM) on electron target is sensitive probe to sub-MeV DM.



Xenon Binding Energies [eV]

$n \backslash l$	s	p	d
5	25.7	12.4	–
4	213.8	163.5	75.6
3	1093.2	958.4	710.7
2	5152.19	4837.7	–
1	33317.4	–	–

arxiv:2011.01940

Absorptive DM by Electron

Absorption of Dark Matter (DM) on electron target is sensitive probe to sub-MeV DM (χ).

$$\mathcal{O}^{\mathcal{S}}_{e\nu\chi} = (\bar{e}e)(\bar{\nu}_{\mathcal{L}}\chi_{\mathcal{R}}) ,$$

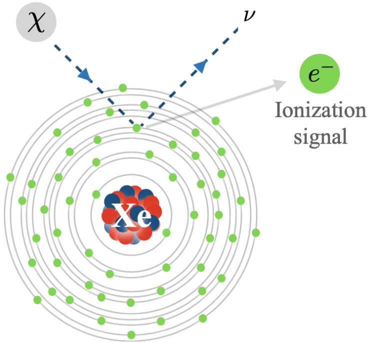
$$\mathcal{O}^{\mathcal{P}}_{e\nu\chi} = (\bar{e}i\gamma_5 e)(\bar{\nu}_{\mathcal{L}}\chi_{\mathcal{R}}) ,$$

$$\mathcal{O}^{\mathcal{V}}_{e\nu\chi} = (\bar{e}\gamma_\mu e)(\bar{\nu}_{\mathcal{L}}\gamma^\mu\chi_{\mathcal{L}}) ,$$

$$\mathcal{O}^{\mathcal{A}}_{e\nu\chi} = (\bar{e}\gamma_\mu\gamma_5 e)(\bar{\nu}_{\mathcal{L}}\gamma^\mu\chi_{\mathcal{L}}) ,$$

$$\mathcal{O}^{\mathcal{T}}_{e\nu\chi} = (\bar{e}\sigma_{\mu\nu} e)(\bar{\nu}_{\mathcal{L}}\sigma^{\mu\nu}\chi_{\mathcal{R}}) .$$

e^+e^- colliders are also expected to be powerful probes of the “Electron flavored" couplings.



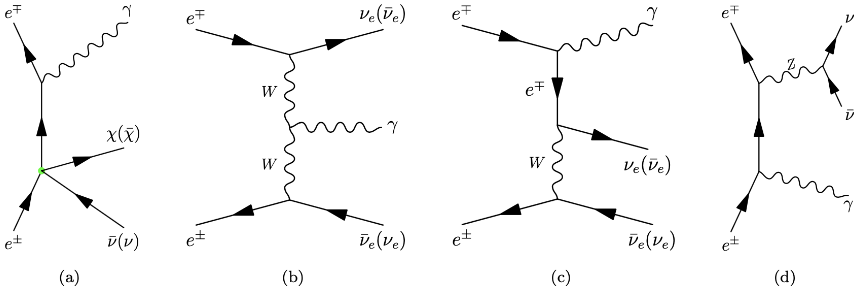
arxiv:2011.01940

Collider Detection @ Mono-γ

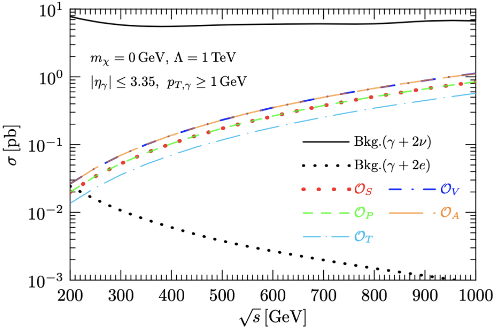
The process $e^+e^- \to \chi\nu$ is a kind of inverse process of the absorption channel, as long as the center-of-mass (COM) energy $\sqrt{s} > m_\chi$.

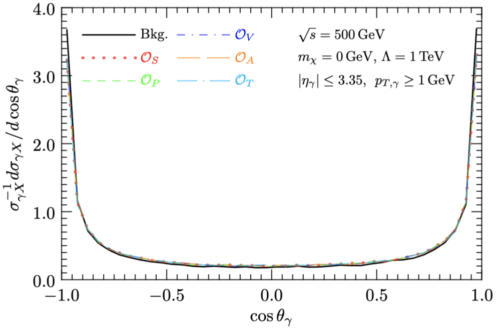
Mono-γ production:

$$e^+ + e^- \longrightarrow \gamma + \chi(\bar{\chi}) + \bar{\nu}(\nu)\,.$$



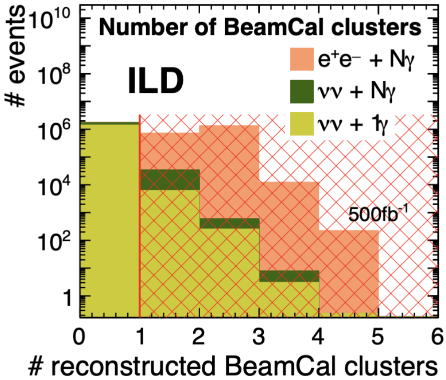
Differential Cross Sections @Mono-γ

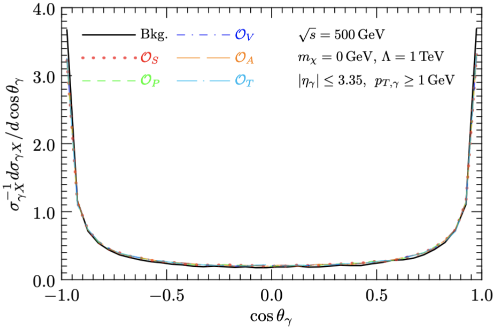




- Signals grow with $\sqrt{s}$, while the background is nearly a constant.
- Both signals and background are dominant at forward and backward regions.
- There are huge contamination from radiative BhaBha process.

Differential Cross Sections @Mono-γ





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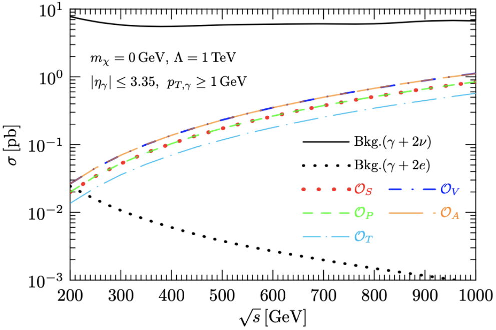

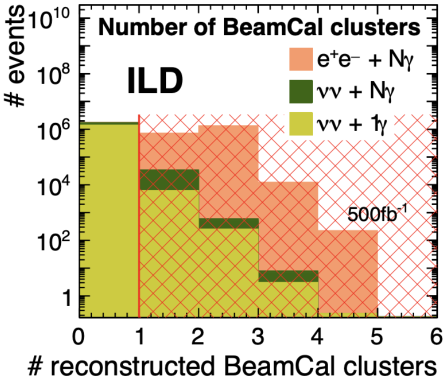

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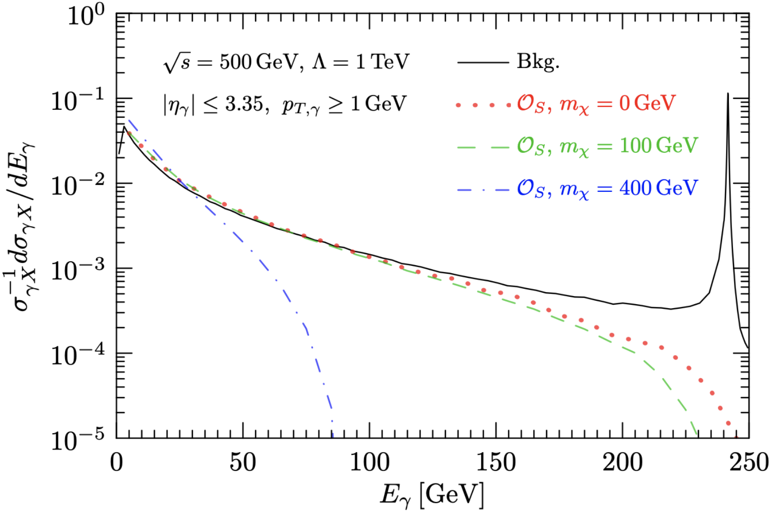

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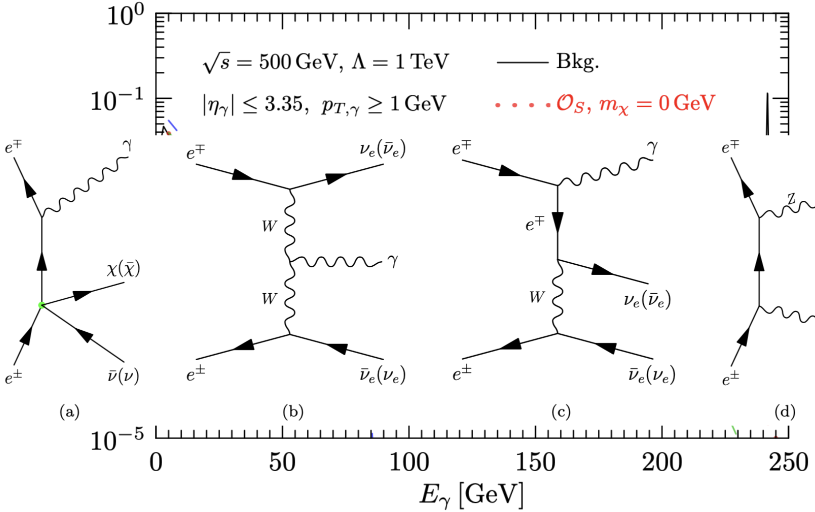
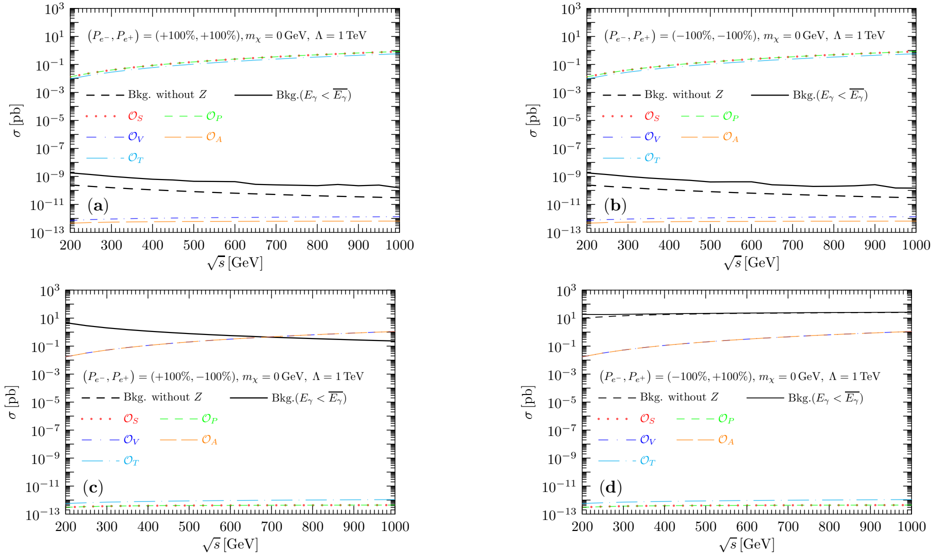


Beam Polarization Effects @Mono-γ



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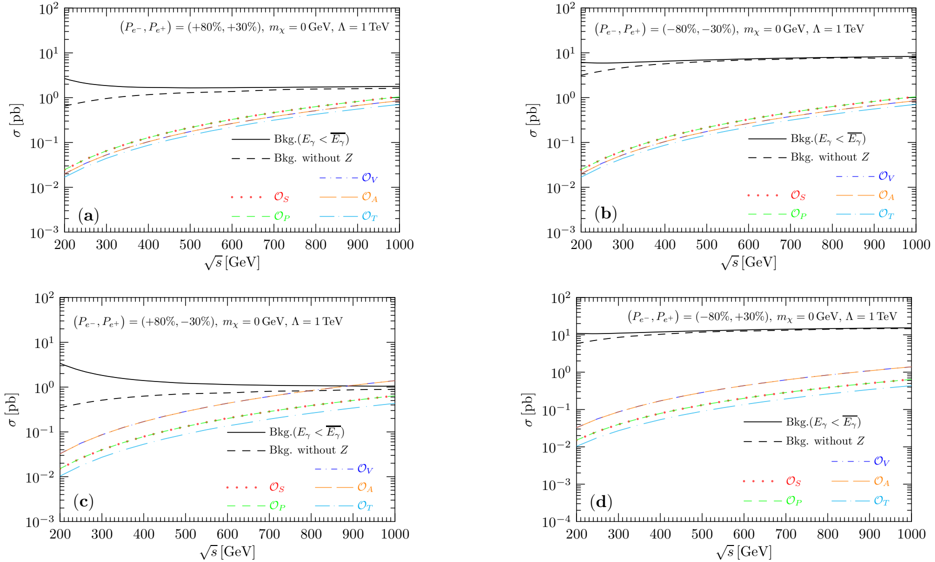


Expected Exclusion Limit at 95% @ Mono-γ

Table: Running modes and the corresponding projected luminosities of the colliders.

	CEPC	ILC			CLIC
$\sqrt{s}\,[GeV]$	240	500			3000
$(\mathcal{P}_{e^-}, \mathcal{P}_{e^+})$	$(0\%,\ 0\%)$	$(0\%,\ 0\%)$	$(\pm 80\%,\ \mp 30\%)$	$(\pm 80\%,\ \pm 30\%)$	$(0\%,\ 0\%)$
$\mathcal{L}\,[\,ab^{-1}]$	5.6	4	1.6	0.4	5

Kinematical cuts:

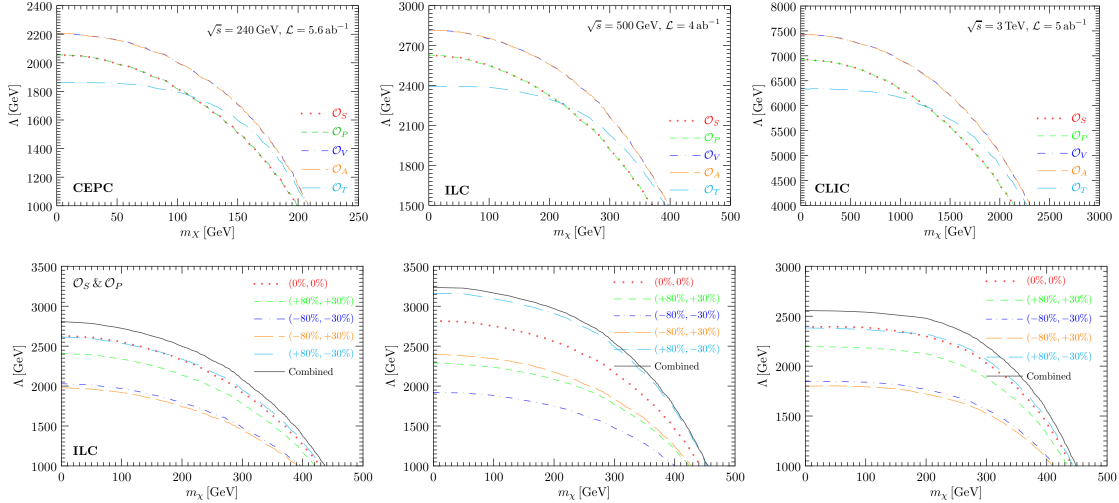
$$E_\gamma < \min\left\{E_\gamma^Z - 5\Gamma_Z, E_\gamma^X\right\} \ ,$$

$$p_{T,\gamma} > 0.5\,GeV, \quad |\eta_\gamma| < 2.65\,, \qquad \text{CEPC;}$$

$$p_{T,\gamma} > 6\,GeV, \quad |\eta_\gamma| < 2.79\,, \qquad \text{ILC;}$$

$$p_{T,\gamma} > 60\,GeV, \quad |\eta_\gamma| < 2.44\,, \qquad \text{CLIC.}$$

Expected Exclusion Limit at 95% @ Mono-γ



The left-, middle- and right-panels stand for the (pseudo-)scalar, (axial-)vector and tensor operators, respectively, with $\sqrt{s} = 500\,GeV$.

Collider Detection @ Electron Pair Production

Electron pair production in associated with $\not{E}_T$:

$$e^+ + e^- \rightarrow e^+ + e^- + \chi(\bar{\chi}) + \bar{\nu}(\nu)\,, \quad (1)$$

$$e^+ + e^- \rightarrow e^+ + e^- + \nu + \bar{\nu}\,. \quad (2)$$

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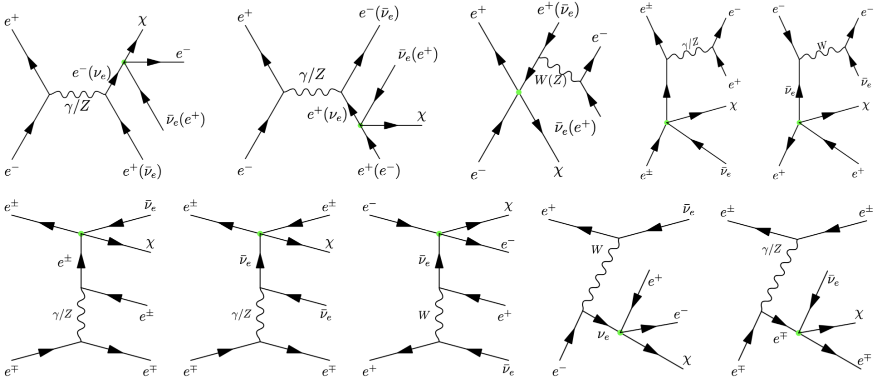

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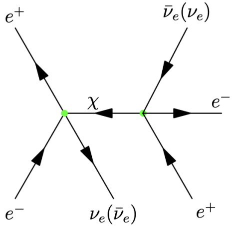
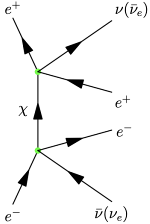
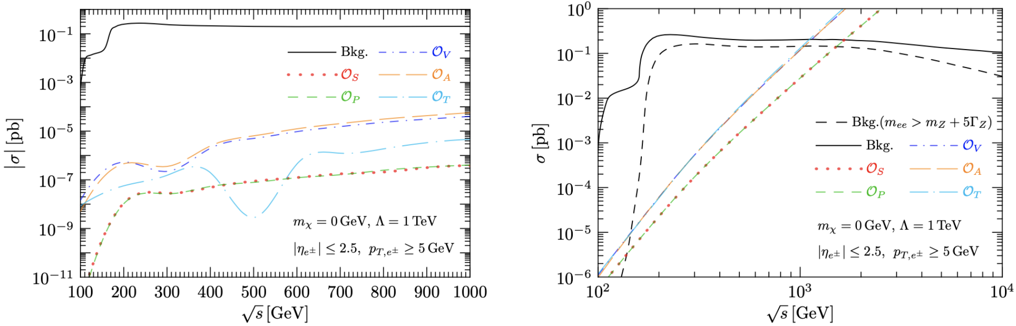




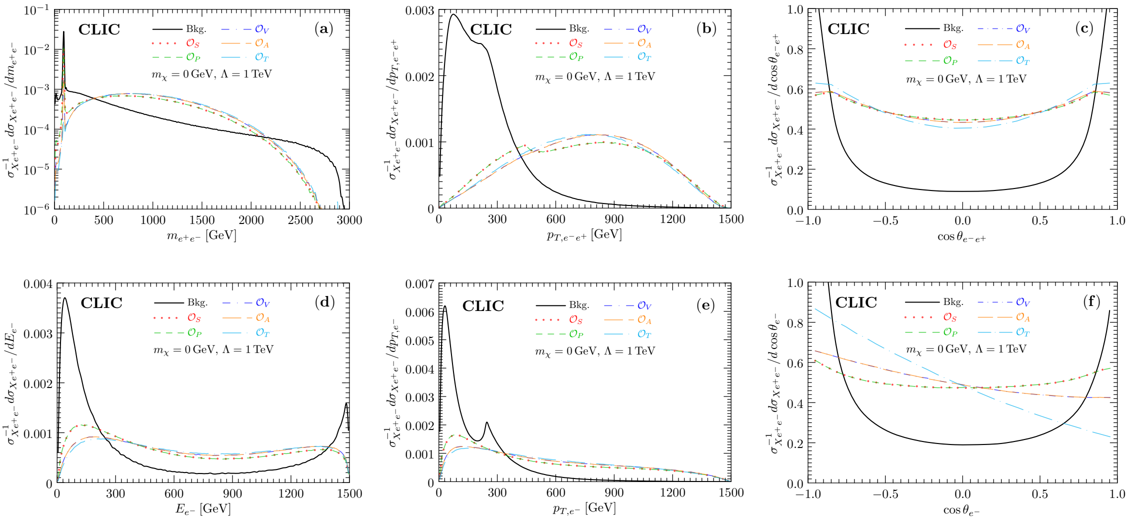
While the first channel can only be initiated by the effective four-fermion operators, the second one is not only background of the final state $e^+e^- + \not{E}_T$, but also receives contributions from the NP operators by exchanging the dark fermion χ via either s- or t-channel.

Differential Cross Sections @$e^+e^-\not{E}_T$

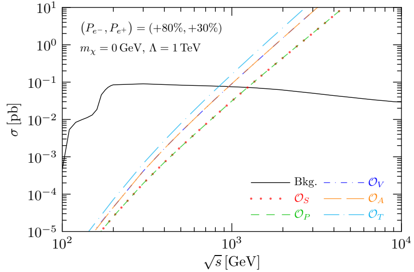


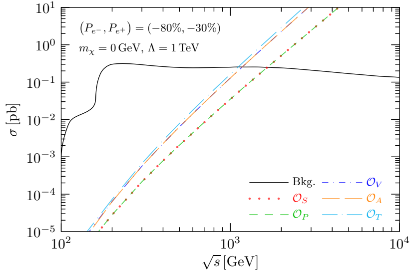
- The interference contribution is negligible.
- Signals grow very quickly with $\sqrt{s}$, while the background is nearly a constant (above the W and Z pair production threshold).
- Around $\sqrt{s} = 1\,TeV$ (for $\Lambda = 1\,TeV$), signal and background are at the same level.
- The electron pair production is a promising channel at high energy collider.

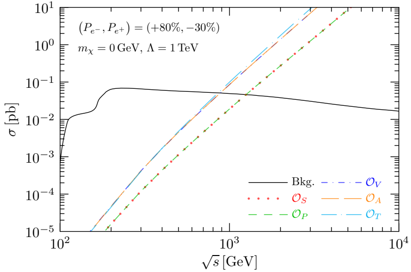
Differential Cross Sections @$e^+e^-\not{E}_T$

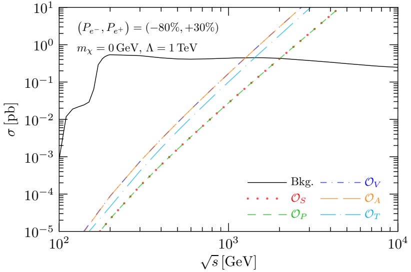


Beam Polarization Effects @ $e^+e^- \not{E}_T$









Expected Exclusion Limit at 95% @ $e^+e^-\not{E}_T$

Differential cross sections of the signals not only have significant differences from the one of the background, but also distinct for different Lorentz structures of the NP operators. With this in mind, we choose invariant mass of the electron pair ($m_{e^+e^-}$), energy (E_{e^-}) and transverse momentum (p_{T,e^-}) of the electron as three representative observables, and the experimental significance is estimated by calculating following χ^2,

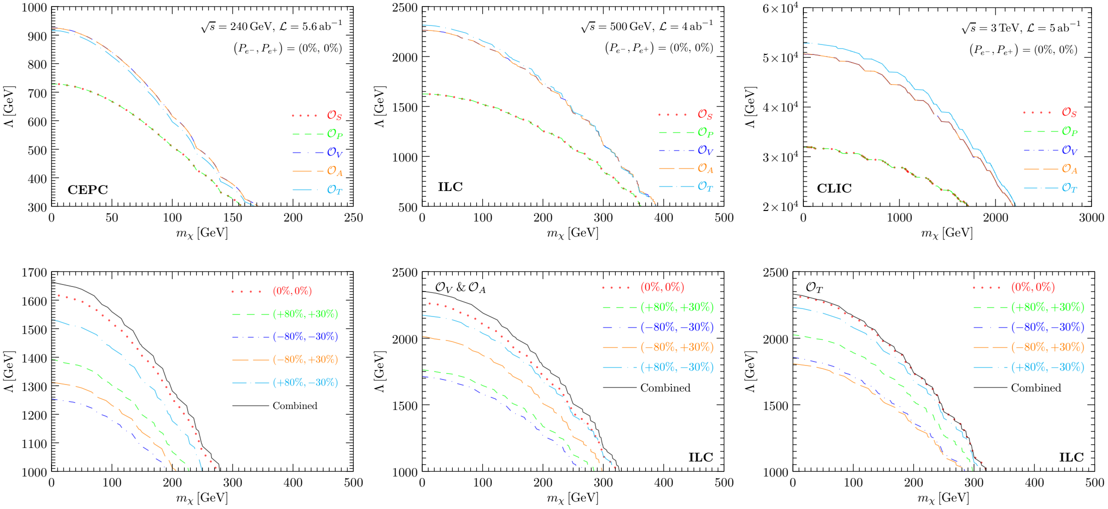
$$\chi^2 = \sum_a \sum_i \frac{\left(\mathcal{N}_i^{Sig}(\mathcal{O}_a)\right)^2}{\mathcal{N}_i^{Bkg}(\mathcal{O}_a) + \mathcal{N}_i^{Sig}(\mathcal{O}_a)} , \tag{3}$$

where $\mathcal{O}_a = m_{e^+e^-}, E_{e^-}, p_{T,e^-}$ is the representative observable, and $\mathcal{N}_i^{Bkg}(\mathcal{O}_a)$ and $\mathcal{N}_i^{Sig}(\mathcal{O}_a)$ are background and signal events in the i-th bin of the observable $\mathcal{O}_a$.

Kinematical cuts:

$$p_{T,e^\pm} > 5\,GeV , \qquad |\eta_{e^\pm}| < 2.5 .$$

Expected Exclusion Limit at 95% @ $e^+e^- \not{E}_T$



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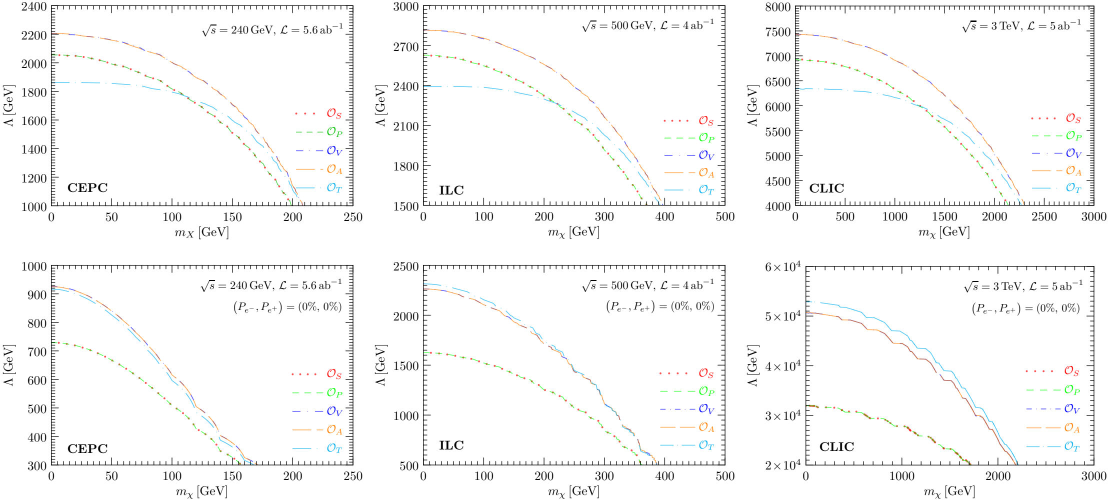
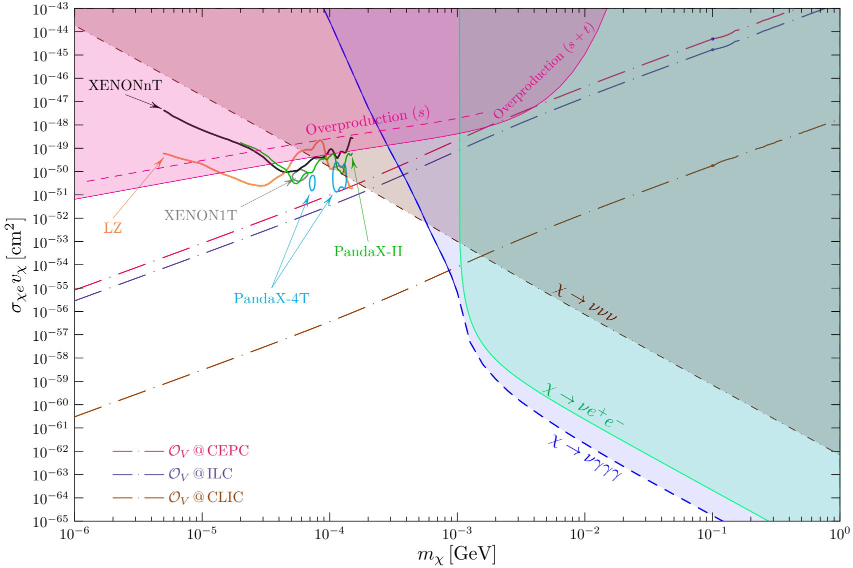
Expected Sensitivities @Compare



Top: mono-γ process. Bottom: $e^+e^- \to e^+e^- \not{E}_T$

Complementarity of Collider and Cosmo. & Astro.



Updates:

1, t-channel contribution to the overproduction constraint.

2, decay channel $\chi \to \nu e^+ e^-$ in case of $m_\chi > 2m_e$.

3, decay channel $\chi \to \nu\gamma\gamma\gamma$ in case of $m_\chi > 2m_e$.

4, PandaX-4T.

5, XENONnT.

6, LZ.

Details of the Cosmo. & Astro. constraints can be find in arXiv:2201.11497.

Summary

- e^+e^- collision is an inverse process of the DM absorption, hence can be probes of DM.
- Mono-*gamma* process has larger sensitivity at low energy colliders (CEPC), production of $e^+e^-\not{p}_T$ gives larger sensitivity at high energy colliders (CLIC).
- Colliders can provide complementary searches for DM (absorptive on electron target).
- We are working on the case of that the DM can be absorbed by nucleus (searched for by PandaX-4T), signals at the LHC and future hadron colliders.


Thank you.