The role of future lepton colliders for fermionic Z-portal dark matter

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Dark Matter

Many observation suggest the existence of dark matter.

- ✔ Galaxy rotation curve
- ✔ Existence of large scale structure
- ✔ PLANCK observation suggest $\Omega_c h^2 = 0.120 \pm 0.001$

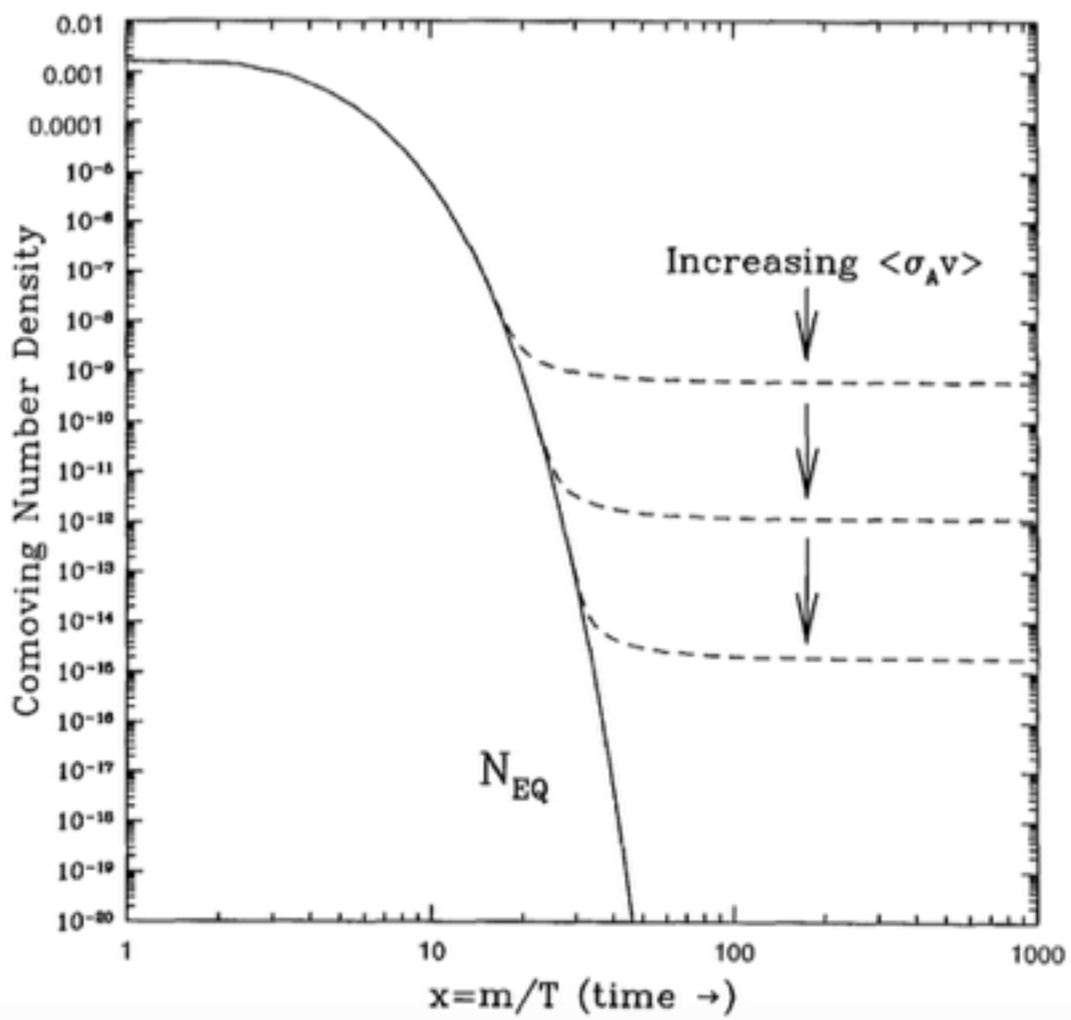
And there are many candidates of dark matter.

- ✔ Weakly Interacting Massive Particle (WIMP)
- ✔ Axion
- ✔ Sterile Neutrino
- ✔ Primordial Black Hole (PBH)

On this talk we will focus on WIMP.

WIMP

WIMP is attractive, because if it is on the electroweak scale, which can explain the amount of dark matter density. (WIMP miracle)

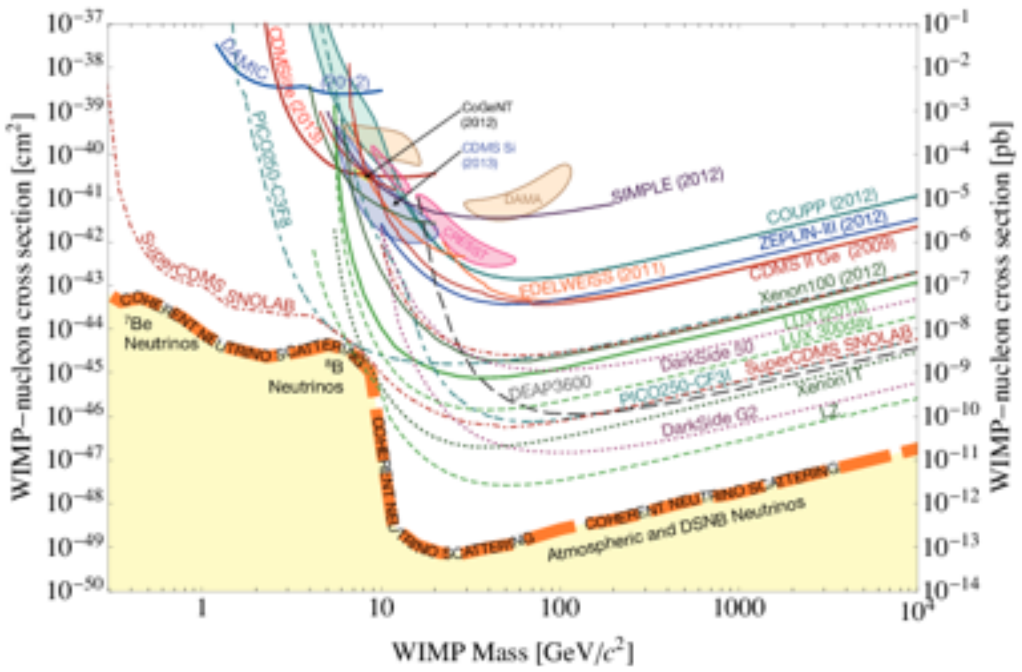


If the cross section of
DM + DM → SM + SM
is bigger, DM remain in the equilibrium longer, and the amount of dark matter decrease.

Current status

Effective search on over 10GeV DM
by direct detection experiment.

However, some parameter regions are difficult to access by direct detection if the WIMP is SU(2) singlet fermion.



✔ Z-funnel region (this talk)

The mass of dark matter is almost half of Z-boson, and mainly couple with Z-boson.
This dark matter can remain in equilibrium longer, even with small coupling.

✔ Leptophilic region

Dark matter mainly couple with leptons.

Our model

Using effective field theory approach,
we can write SM gauge invariant operator.
We also impose Z_2 symmetry.

$$\frac{g_D}{\Lambda^2}(\overline{\chi}\gamma_\mu\gamma_5\chi)(H^\dagger i\overleftrightarrow{D}^\mu H) + \mathrm{h.c} \xrightarrow{\text{Symmetry breaking}} \frac{g_{\chi\chi Z}}{2}(\overline{\chi}\gamma_\mu\gamma_5\chi)Z^\mu$$

In this model, the parameters are only two.

- ∗ Dark matter mass m_χ
- ∗ Coupling constant with Z-boson $g_{\chi\chi Z}$

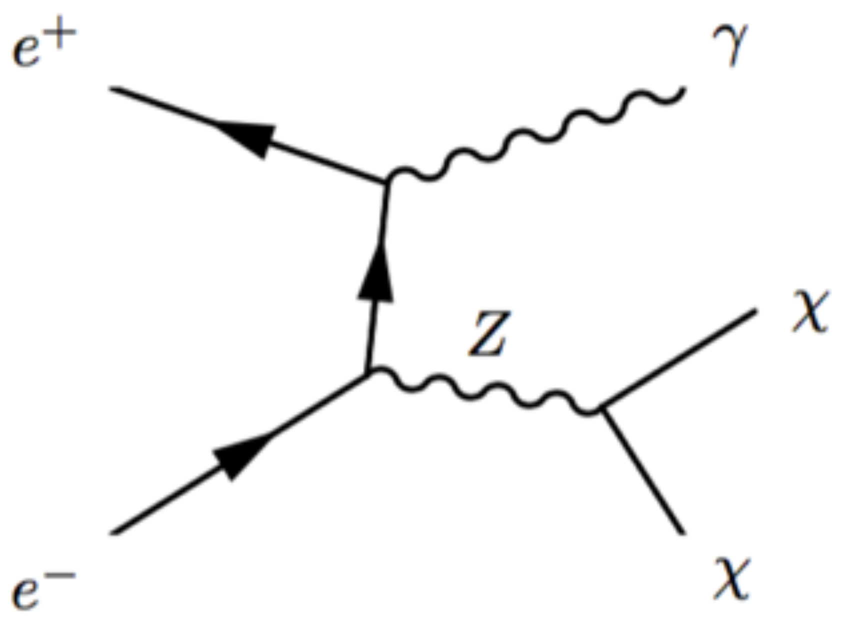
All interaction happen through Z-boson.

Signal at Lepton collider

At least, we must have 2 WIMPs and 1 observable particle.
→ Mono-photon channel is best. (largest cross section)

$$e^- + e^+ \rightarrow \gamma + \chi + \chi$$

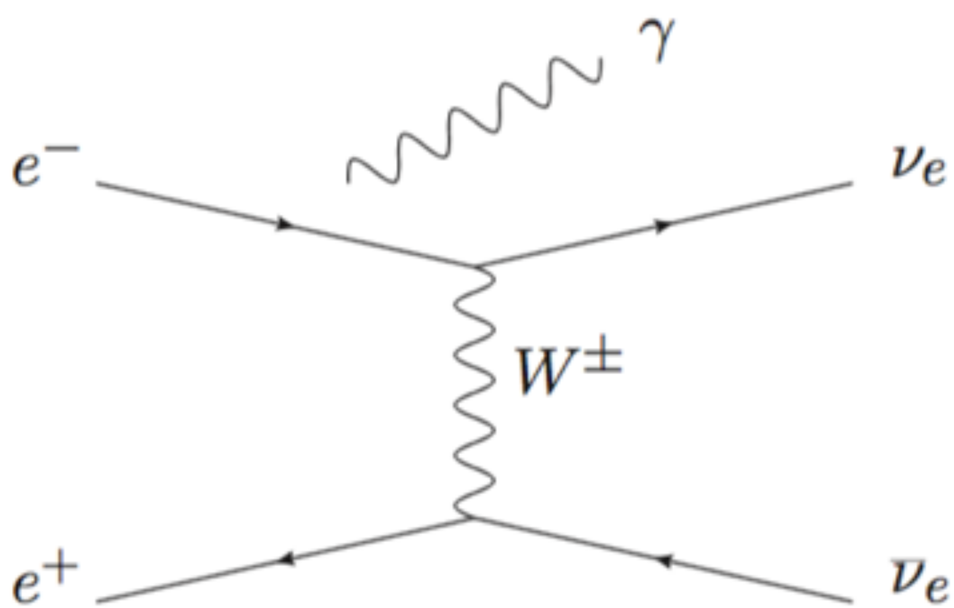
Think the cross section of this process, looking the energy dependence of this photon.
(the angle dependence is very small)

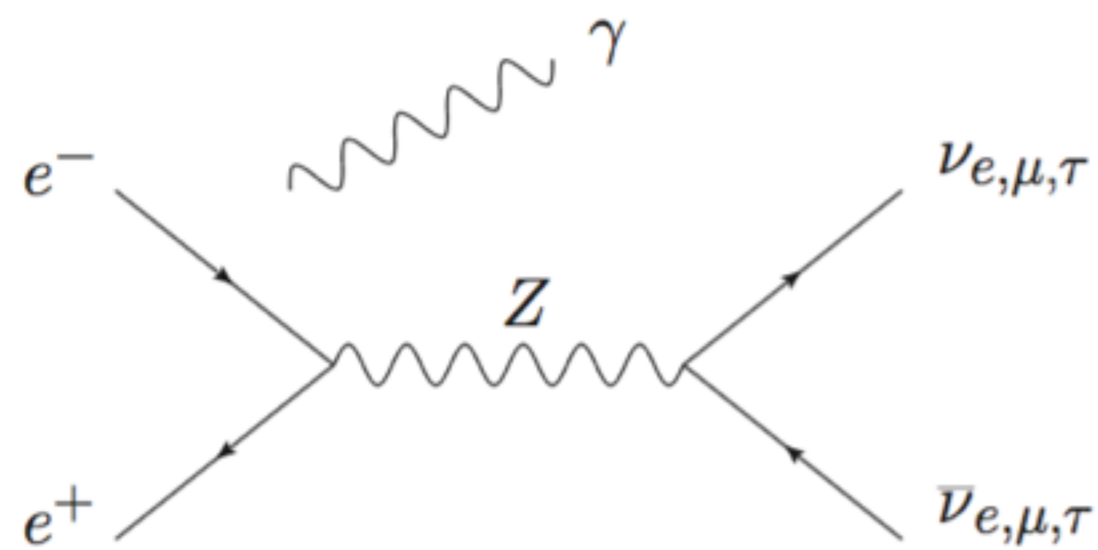


Main background

$e^- + e^+ \rightarrow \gamma + \nu + \bar{\nu}$ (irreducible BG)

This process is very similar to signal process, and we can't reduce the amount of this back ground.



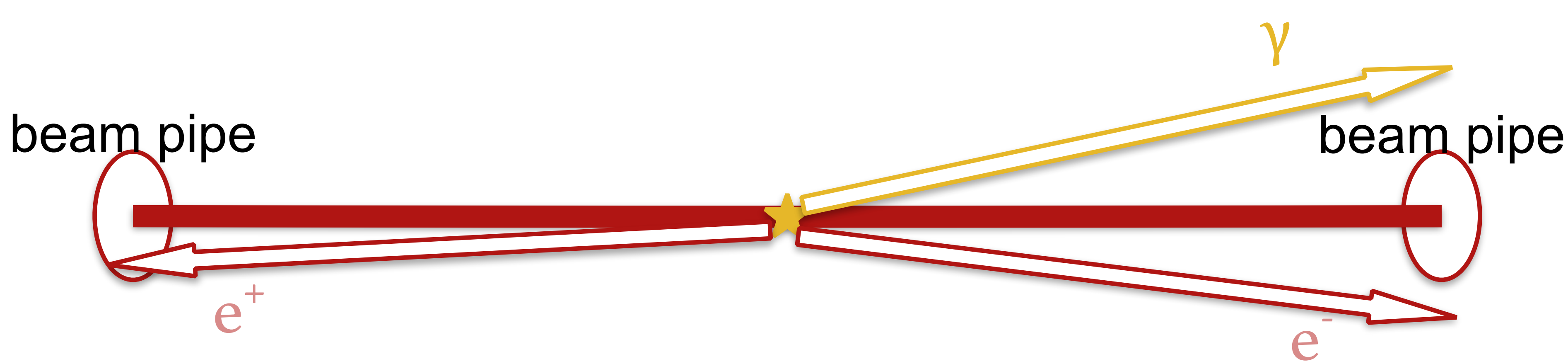


(can be reduced by choosing beam polarization)

Other backgrounds

$e^- + e^+ \to \gamma + e^- + e^+$ (Bhabha scattering)

We can reduce this back ground by putting proper cut on the photon energy and angle.
One of electron or positron must have detectable transverse momentum.



We set E_γ>10GeV and $|\text{Cos}\theta_\gamma|$<0.98.

Other backgrounds

$$e^- + e^+ \longrightarrow n\gamma + \nu + \bar{\nu}$$

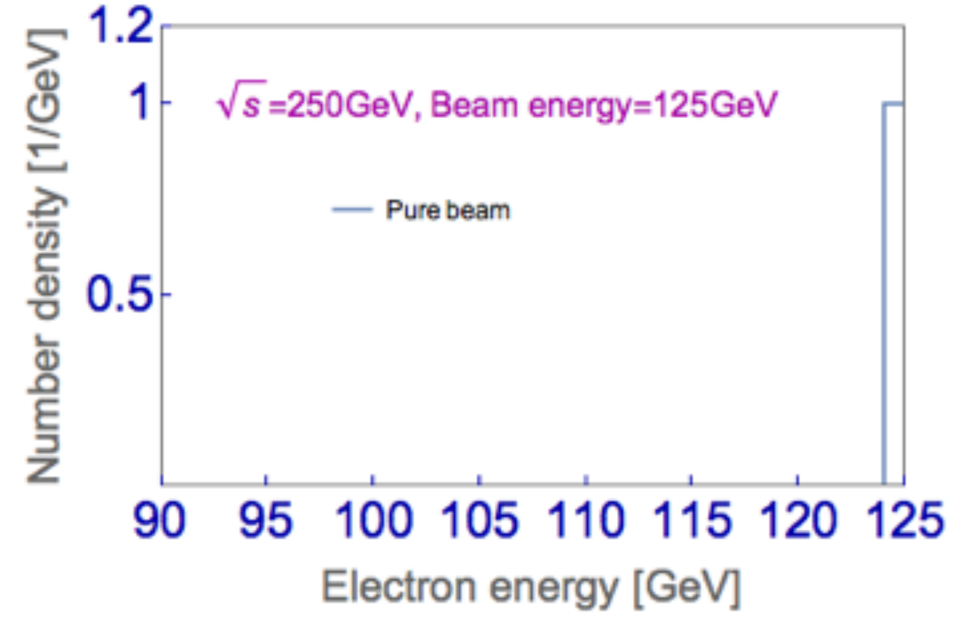
If one photon is observed and other photons are missing (very weak or going beam line), this process can be back ground.

This process will be taken into account through initial state radiation and bremsstrahlung effect of beam.

Beam effects

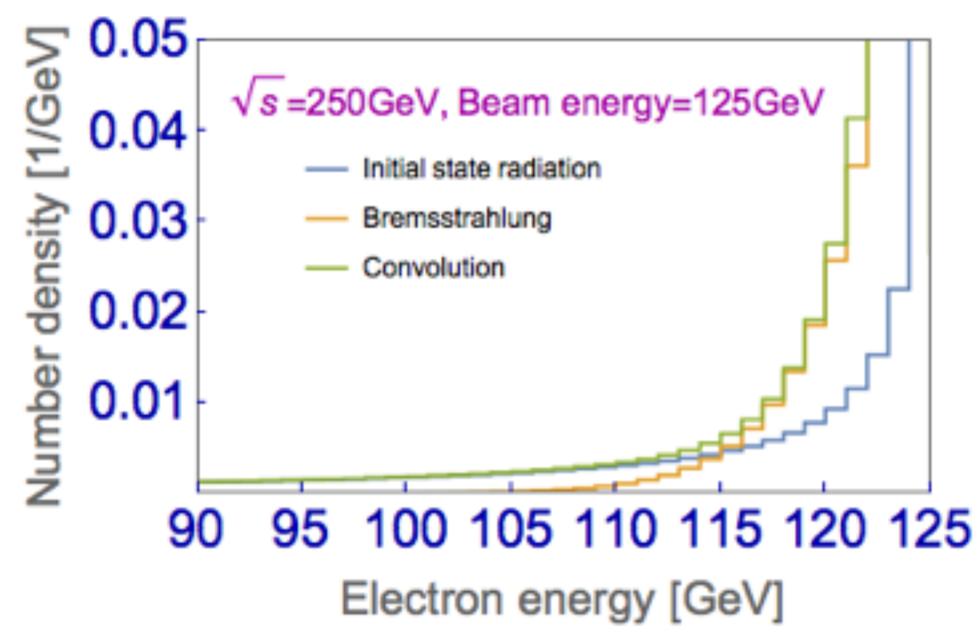
Bremsstrahlung effect

When electron beam and positron beam come near, they are effected by each electromagnetic field, and lose energy by emitting photon.

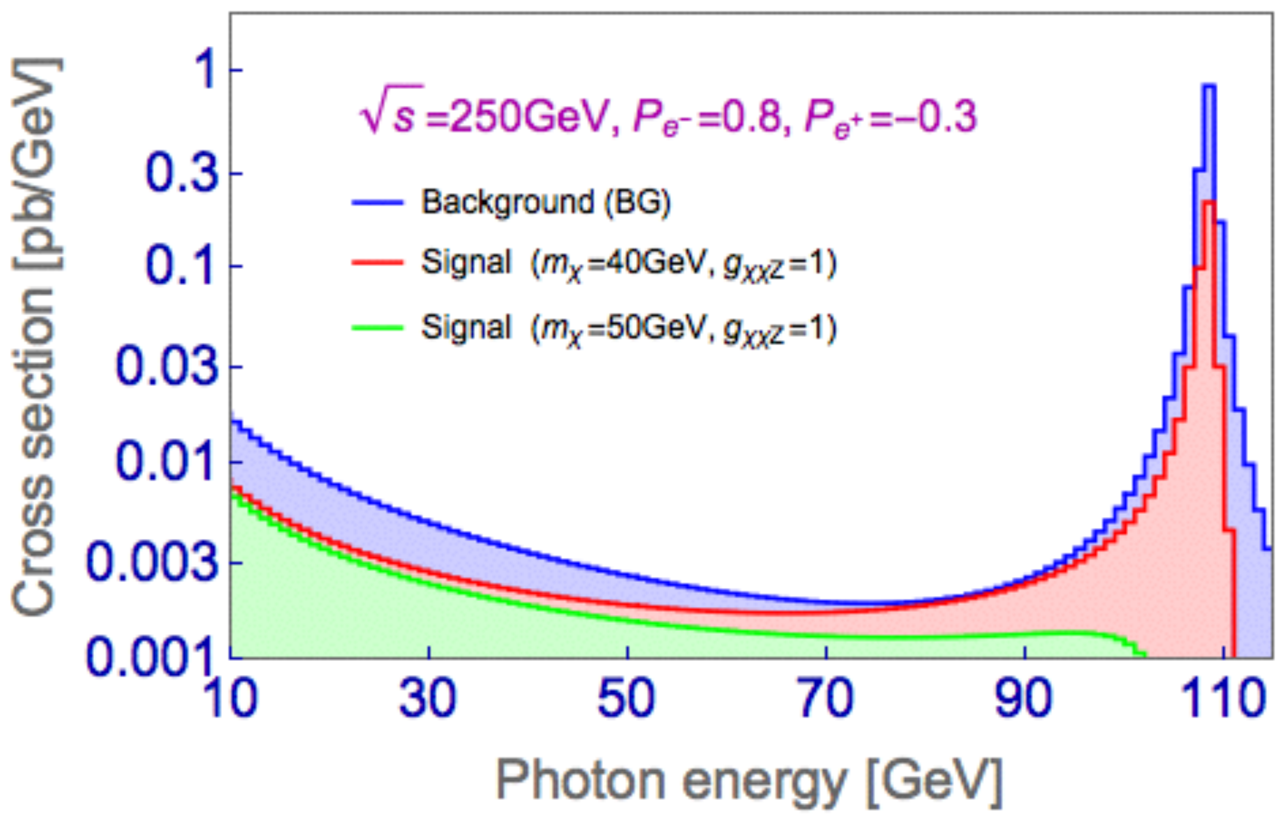


Initial state radiation (ISR) effect

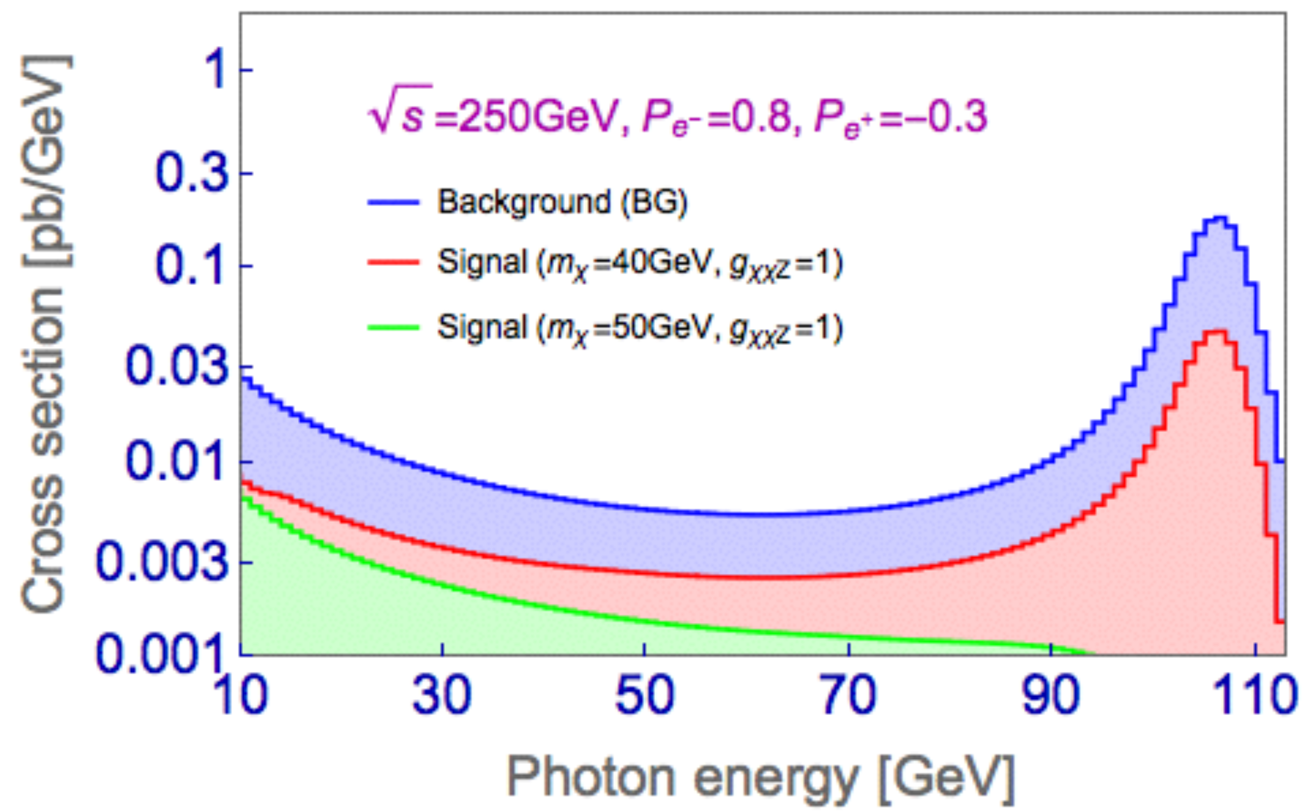
The effect of losing beam energy by emitting photon other than bremsstrahlung effect.



Differential cross section



Without ISR and bremsstrahlung



With ISR, bremsstrahlung and detector effect

Analysis

$\Delta\chi^2$ function

$$\Delta\chi^2 = \sum_i \frac{(N_i - N_i^{\mathrm{BG}})^2}{N_i^{\mathrm{BG}}}$$

Without sys. error

$$\Delta\chi^2 = \mathrm{Max}\left(\frac{\{N(X) - N^{\mathrm{BG}}(X)\}^2}{\delta N^{\mathrm{BG}}(X)^2 + N^{\mathrm{BG}}(X)} \middle| \, 10\,\mathrm{GeV} \le E_\gamma \le X\,\mathrm{GeV} \right)$$

With sys. error

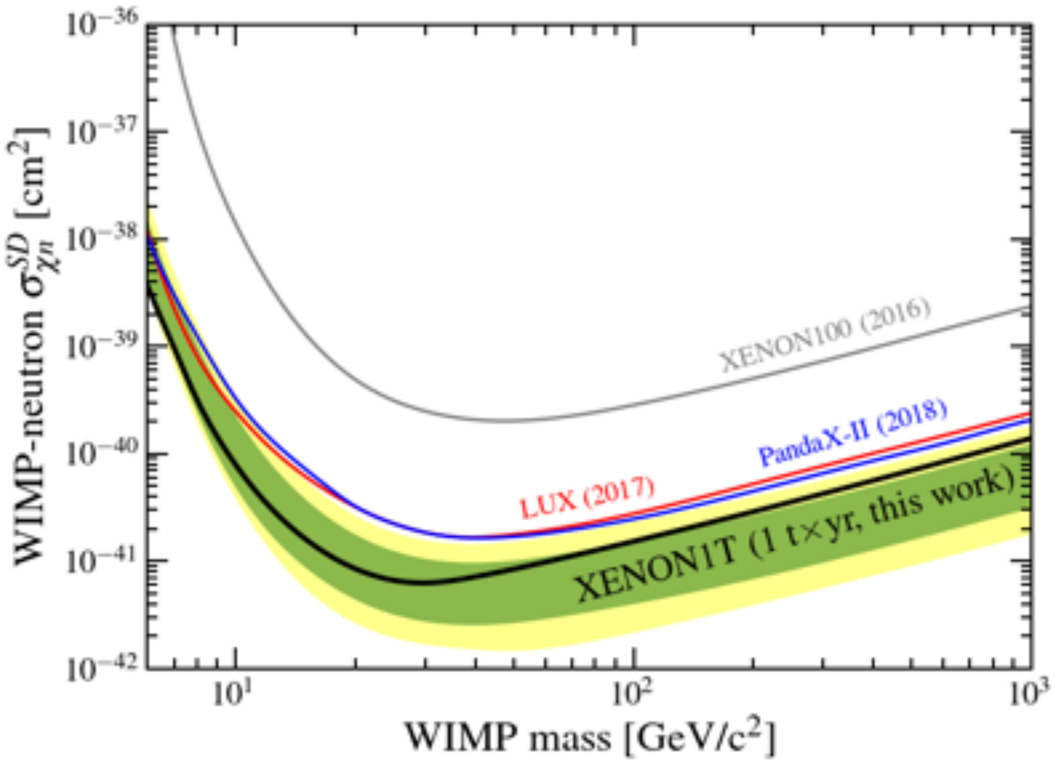
- ✔ N is the number of the event per each bin.
- ✔ We used two types of binning. One is 1GeV bin for photon energy, which is used for the analysis without systematic error. And another is taking all event number as one bin, which is used for the analysis with systematic error. In this case, the maximum energy is chosen to maximize $\Delta\chi^2$.

Other constraint

Direct detection

$$\frac{g_{\chi\chi Z}}{2}(\overline{\chi}\gamma_\mu\gamma_5\chi)Z^\mu$$

Spin dependent direct detection is effective to search this dark matter.

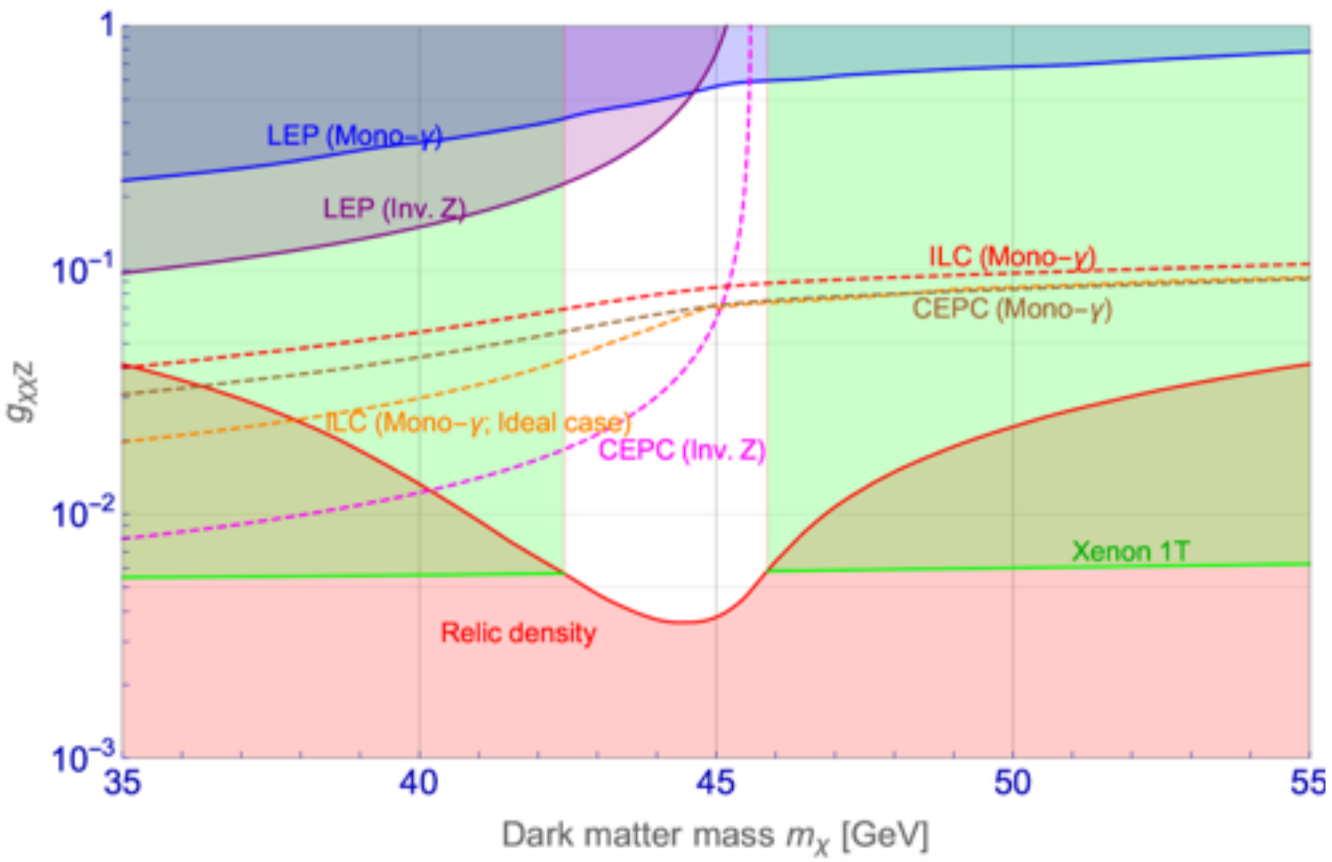


Invisible Z-decay

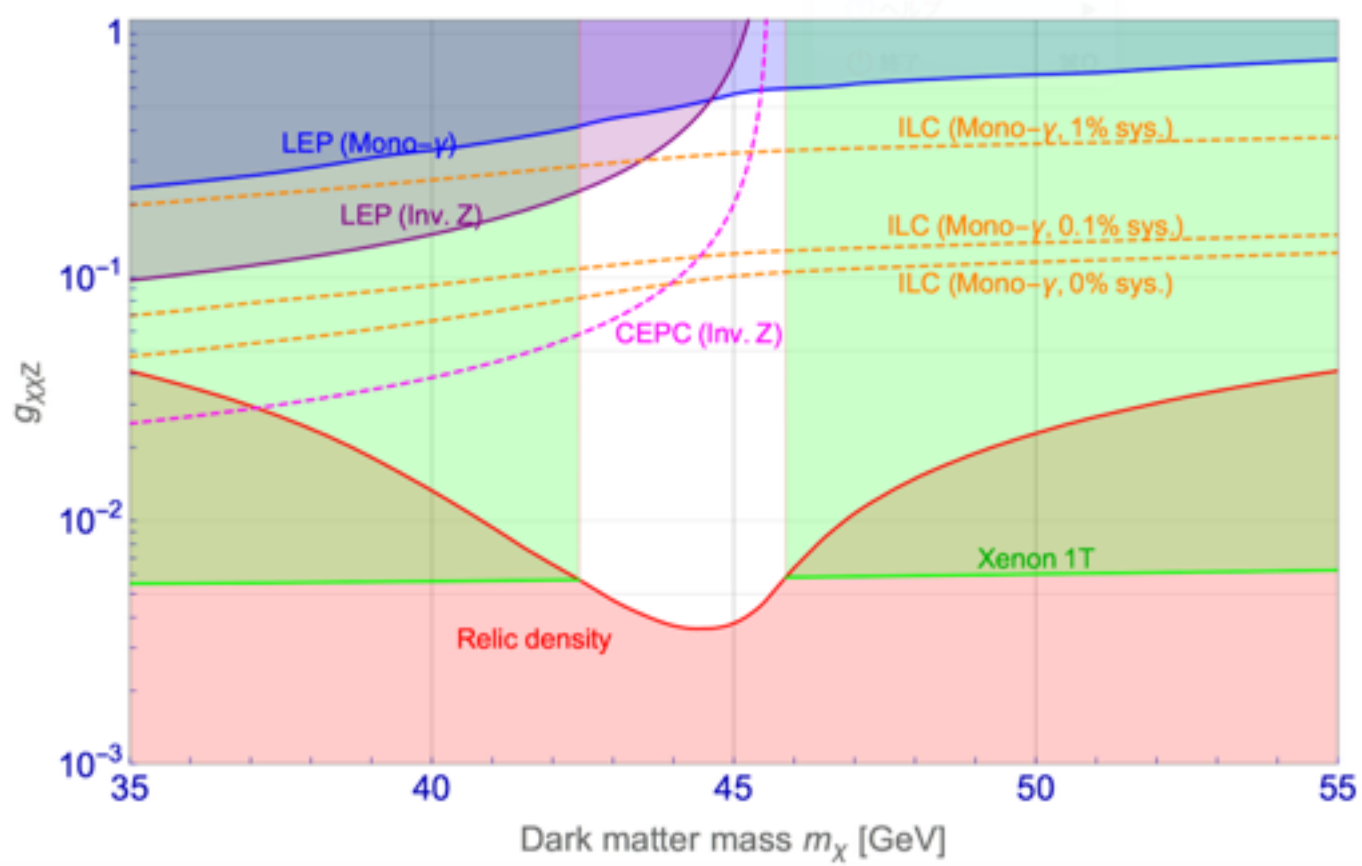
Z-boson can decay into two dark matters. Lepton collider can measure the decay width of Z-boson precisely, and we analyze this also.

$$\Gamma(Z \to \chi\chi) = \frac{g^2_{\chi\chi Z} m_Z}{24\pi}\left(1 - \frac{4m^2_\chi}{m^2_Z}\right)^{3/2}$$

Result



Without sys. error



With sys. error

If all dark matters in the universe are Z-portal dark matter, it must be on the red line. If dark matters are composed of several different types, the constraint is like these figure.