The search for the Z-funnel WIMP at 250GeV ILC

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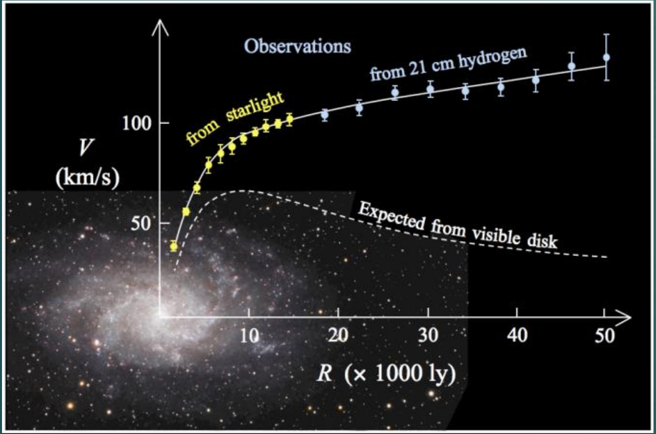
Dark matter

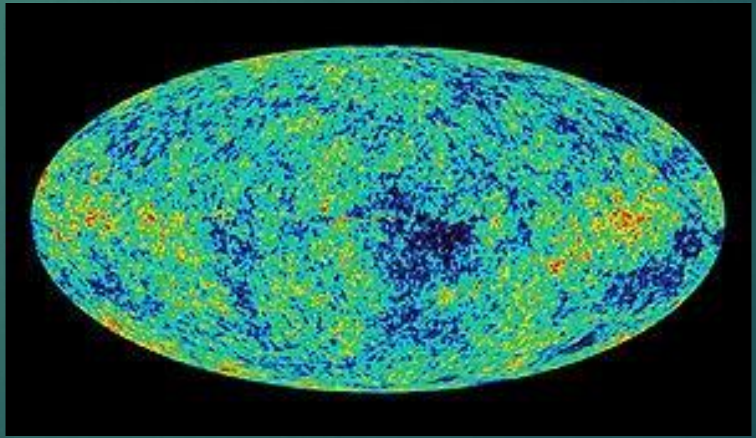
We know there are dark matters in universe, from the several experiments and datas.

（Galaxy rotation, Cosmic microwave background ...etc）

Dark matters are massive and there are plenty of them in our universe, but we don’t know what they are actually.



Galaxy rotation problem



Fluctuation of CMB

Kinds of dark matter model

There are many models of dark matter.

- Primordial black hole
- WIMP, Axion, Sterile neutrino...etc (particle like)

This is too large to cover all of them, we focus on WIMP at this talk.

About WIMP

Merit

- WIMP could be detected at near future experiment.
- If the WIMP mass is around 100GeV, there may be the relation with EW symmetry.

Difficulty

- Many models to make WIMP
- Large mass range (from 10^{-3} GeV to 10^{5} GeV)

How to search WIMP effectively

Classifying WIMP by their quantum numbers.

Symmetry : Lorentz symmetry, and $SU(3)_C \times SU(2)_L \times U(1)_Y$.

$U(1)_{EM}$ and $SU(3)_C$ charge is 0. (WIMP has no electric charge.)

⇨Focus on Lorentz symmetry and $SU(2)_L$ representation.

Lorentz group
Scalar
Fermion
Vector

$SU(2)_L$	$U(1)_Y$
Singlet	±0
Doublet	1/2 , -1/2
Triplet	1 or 0 or -1
…	…

Start from Majorana fermion and SU(2) singlet case.

How to make Lagrangian

We can't make renormalizable Lagrangian
from SM field and WIMP field only.

→ introduce mediator particle

When the mass of mediator particle is much higher than WIMP mass, we can go to the effective field theory by integrating out the mediator.

⇨We can deal with the interaction of SM particle and WIMP directly.

Effective field theory

$$\mathcal{L} = \mathcal{L}_{\rm sm} + \frac{1}{2}\overline{\chi}(i\partial\!\!\!/ - M_\chi)\chi + \mathcal{L}_{\rm int}$$

$$\mathcal{L}_{\rm int} = \frac{g_s}{\Lambda}\overline{\chi}\chi H^\dagger H + \frac{1}{\Lambda^2}(\overline{\chi}\gamma_\mu\gamma_5\chi) \times \sum_f (g_f \overline{f}\gamma^\mu f) + \frac{g_D}{\Lambda^2}(\overline{\chi}\gamma_\mu\gamma_5\chi)(H^\dagger i D^\mu H) + \text{h.c}$$

Λ is the constant which has one mass dimension, and it correspond to the mass of the mediator particle.

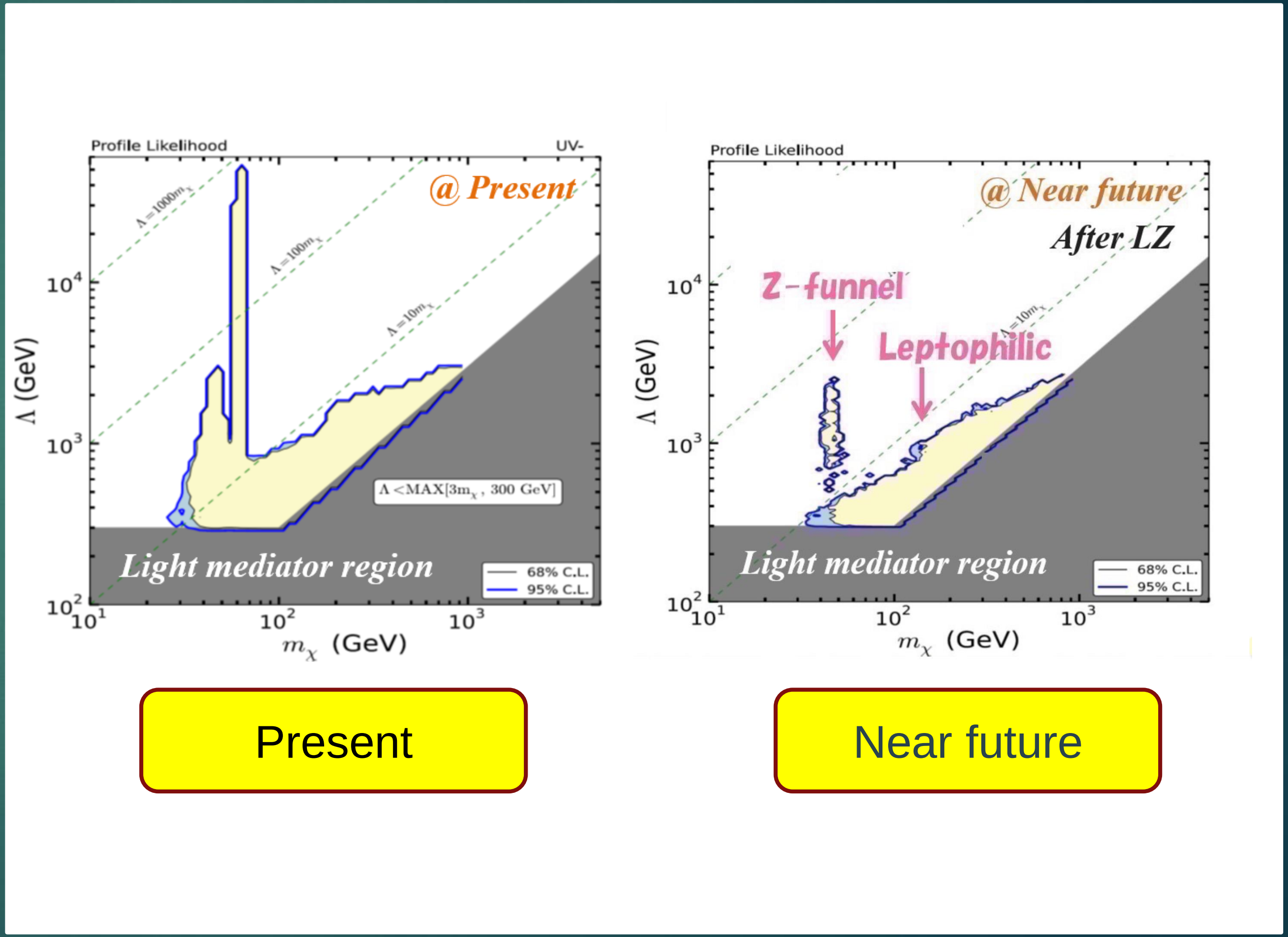
Λ is much larger than the mass of WIMP.

Limit on the parameters

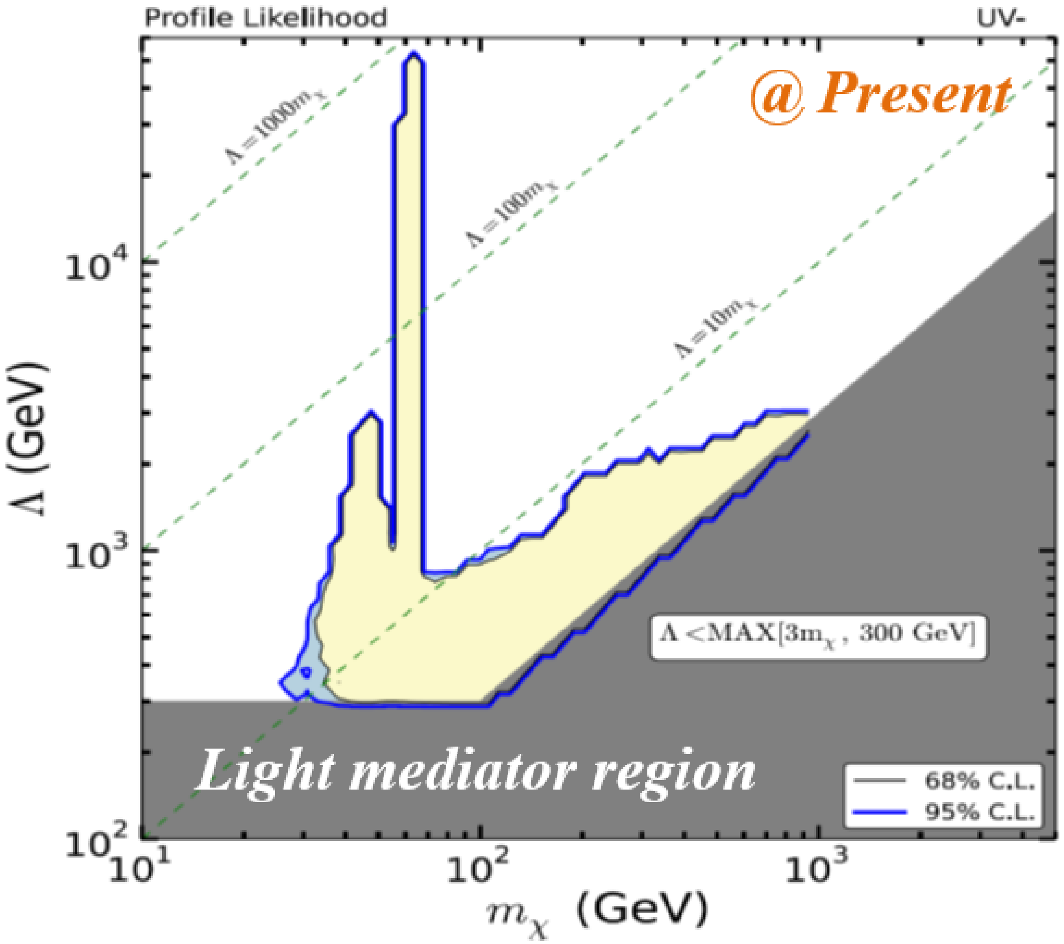
This figure shows the limit on dark matter mass (m_χ) and Λ, when the coupling constant g_s,g_f,g_d move around from -1 to 1.

The yellow area means the uncovered region and the gray area means the region where we can't apply effective theory.

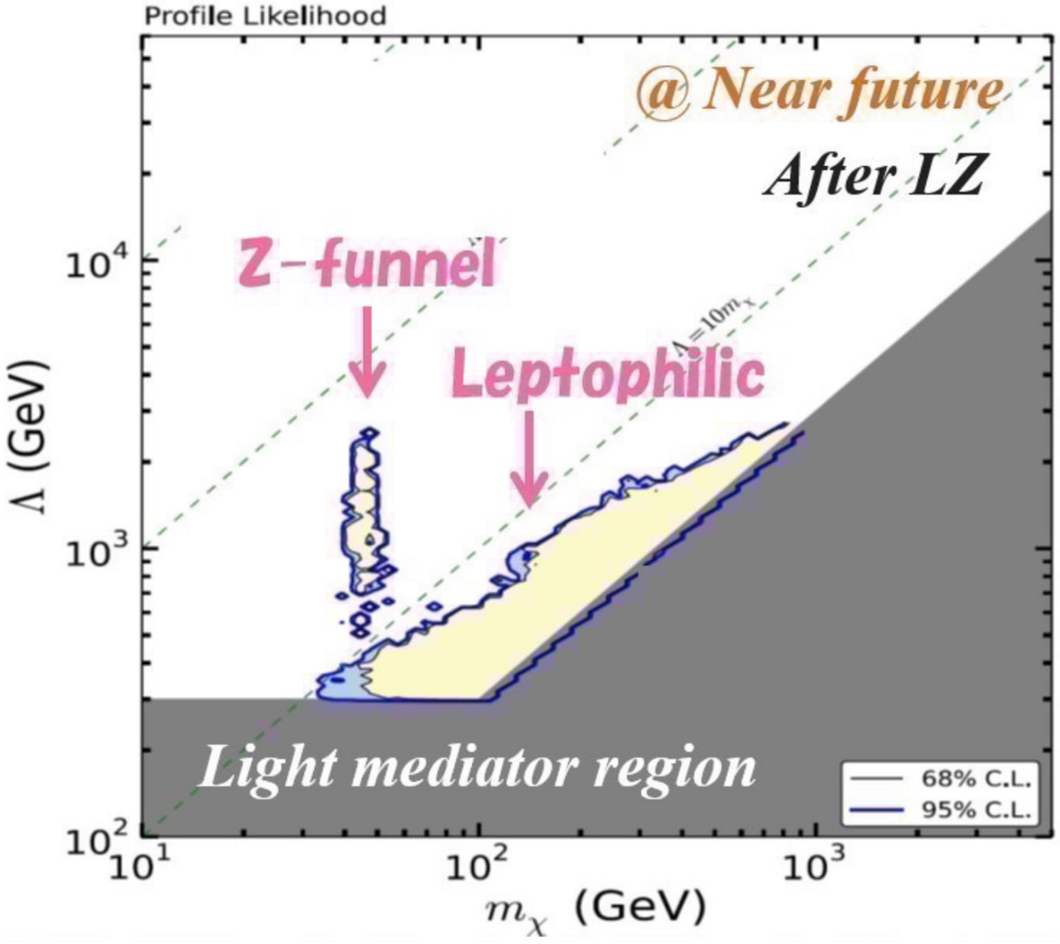
We will focus on the Z-funnel region especially.



(Limited by relic abundance and direct detection)



Present



Near future

The model used in this talk

Z-funnel region is the region where WIMP mass is almost half of the Z-boson mass (91GeV).
It is enough to think the interaction with Z-boson.

After electro weak symmetry breaking, WIMP has such a interaction.

$$\frac{g_D}{\Lambda^2}(\overline{\chi}\gamma_\mu\gamma_5\chi)(H^\dagger iD^\mu H) + \mathrm{h.c} \quad \Rightarrow \quad \frac{g_{\chi\chi Z}}{2}(\overline{\chi}\gamma_\mu\gamma_5\chi)Z^\mu$$

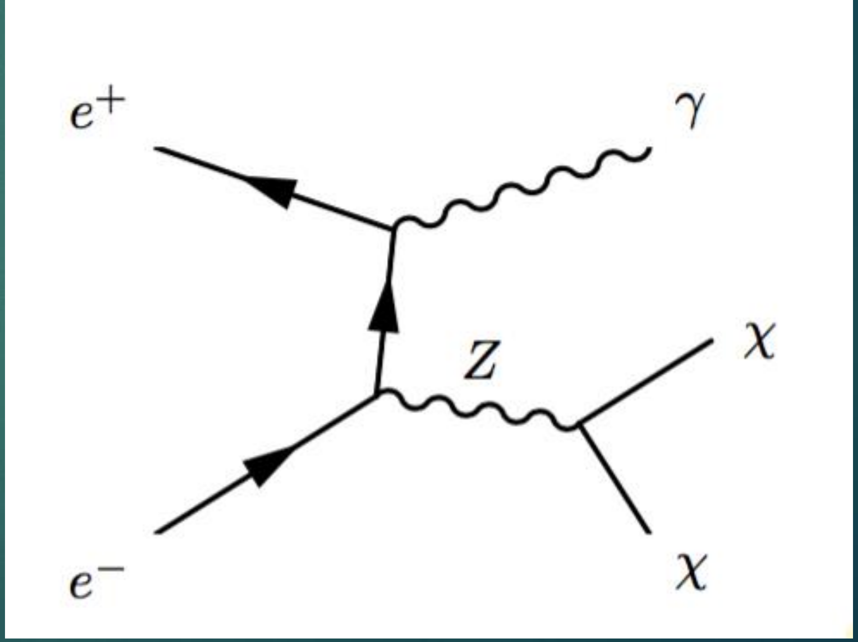
In this model, all interactions between SM particle and WIMP are done through Z-boson, and the variables that we must think is only two (WIMP mass m_χ and coupling constant $g_{\chi\chi Z}$).

The search of WIMP at ILC mono-photon search

The mono-photon event is the best process to search WIMP.

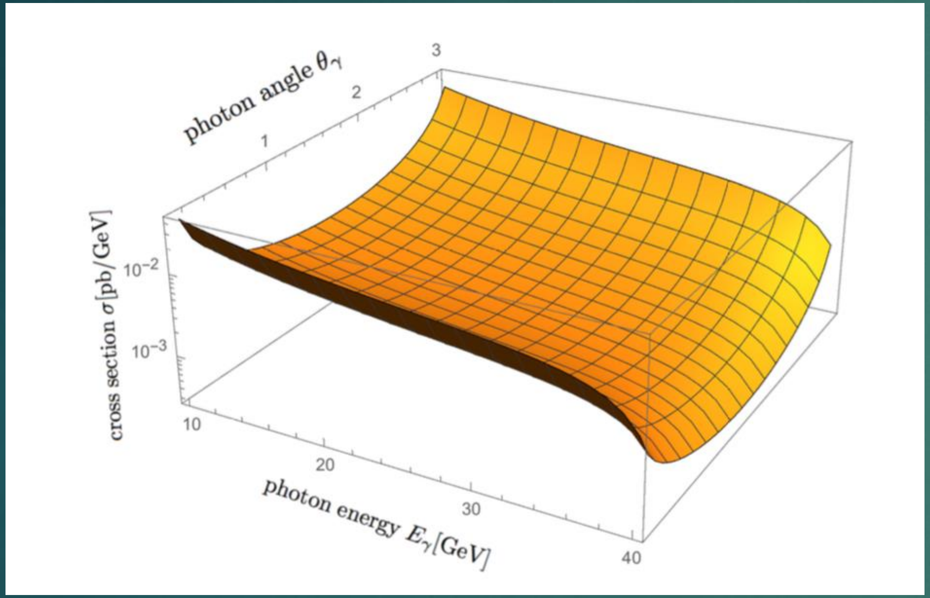
$$e^- + e^+ \to \gamma + \chi + \chi$$

Analyze the energy dependence or angle dependence of the photon with missing energy

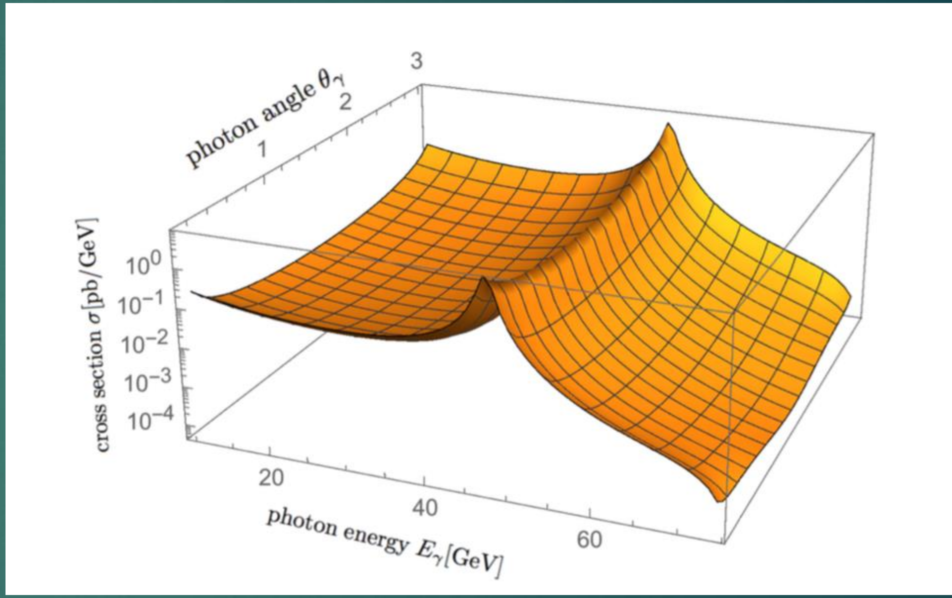


Signal and background

Background mainly comes from the process, $e^- + e^+ \rightarrow \gamma + \nu + \nu$.



differential cross section of signal

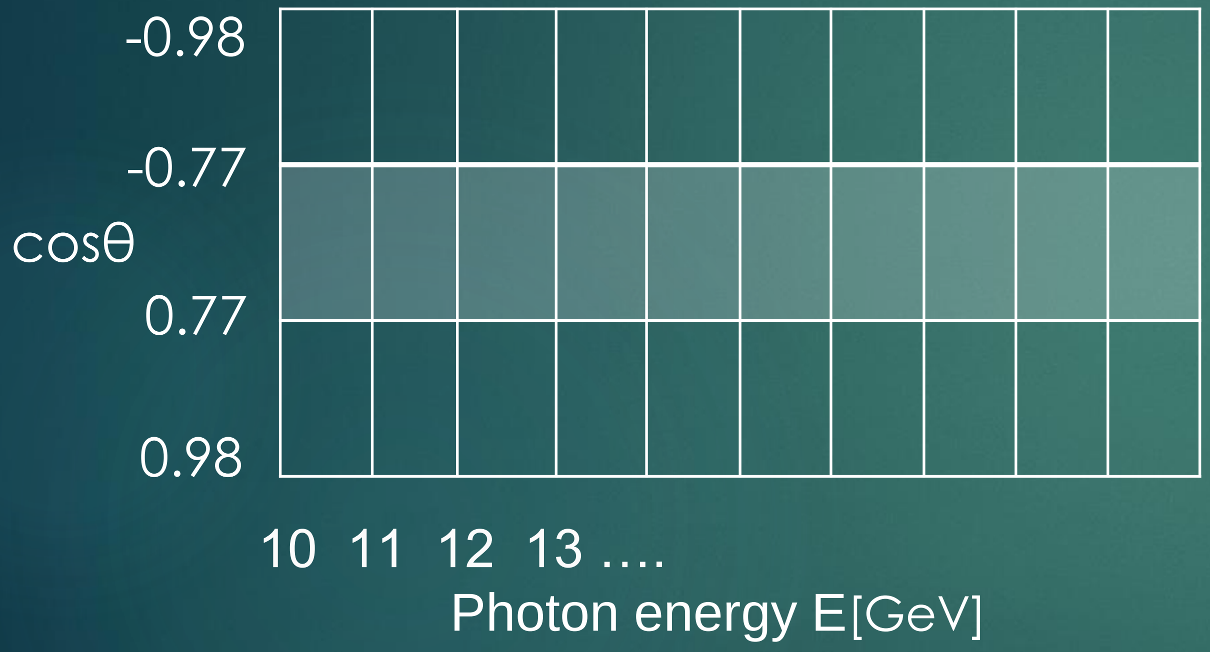


differential cross section of background

When the beam energy is 150GeV, m_X is 50GeV and g_{XXZ} is 1

Likelihood analysis

Analyzing the data by counting the event number on each bin.



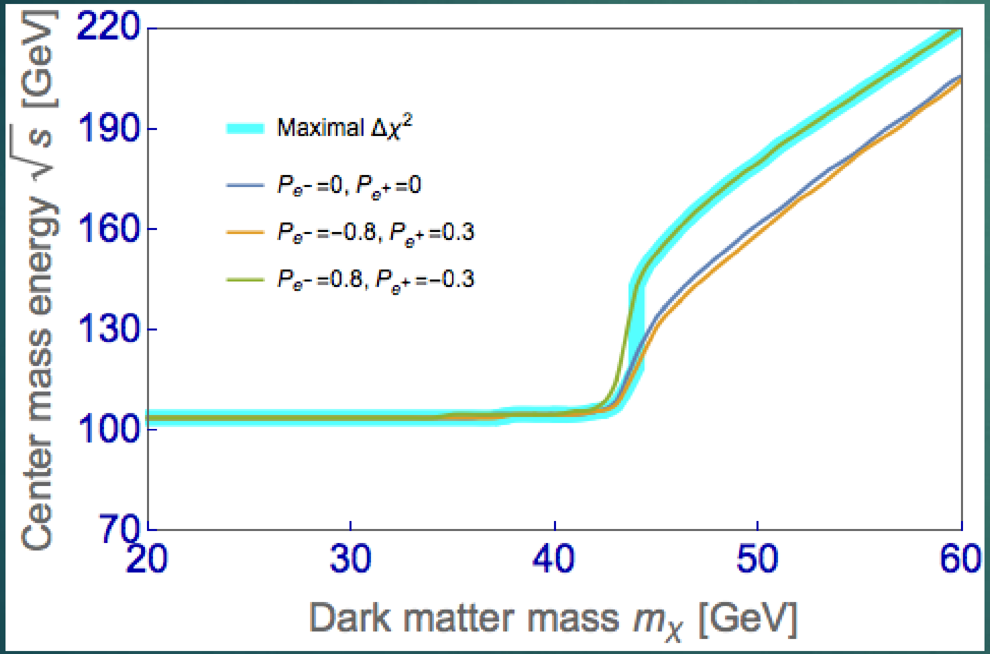
Likelihood function and χ-square analysis

$$L[m_\chi, g_{\chi\chi z}] = \prod_i \exp\left(\frac{-(N_i^{exp} - N_i^{th})^2}{2N_i^{th}} \right)$$

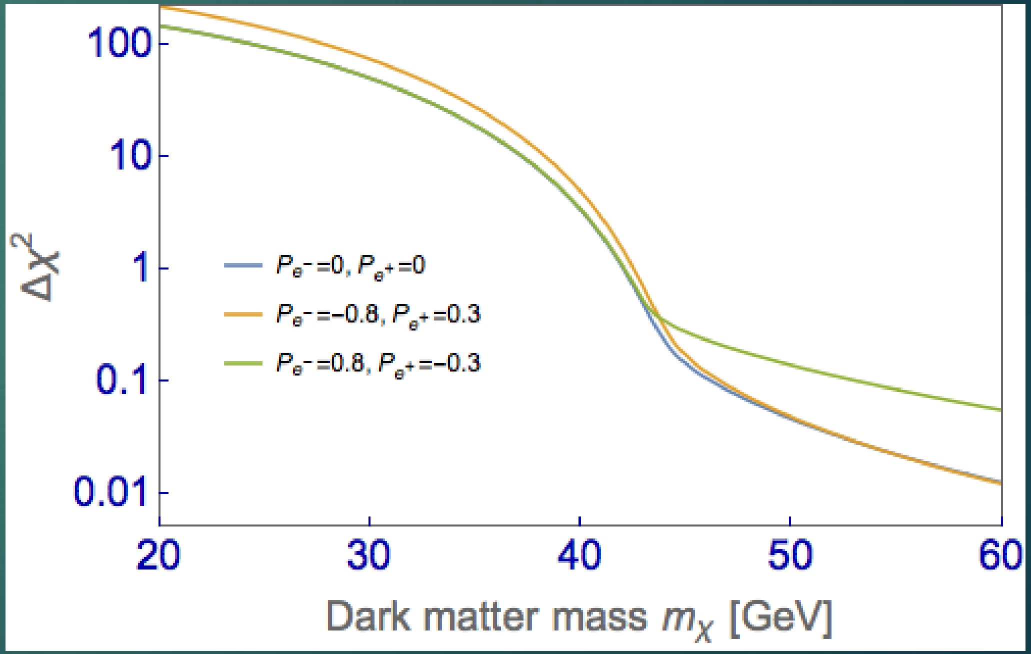
$$\Delta\chi^2 = \sum_i \frac{(N_i^{SG})^2}{N_i^{BG}}$$

Beam energy and polarization

What beam energy and beam polarizations are the best ?

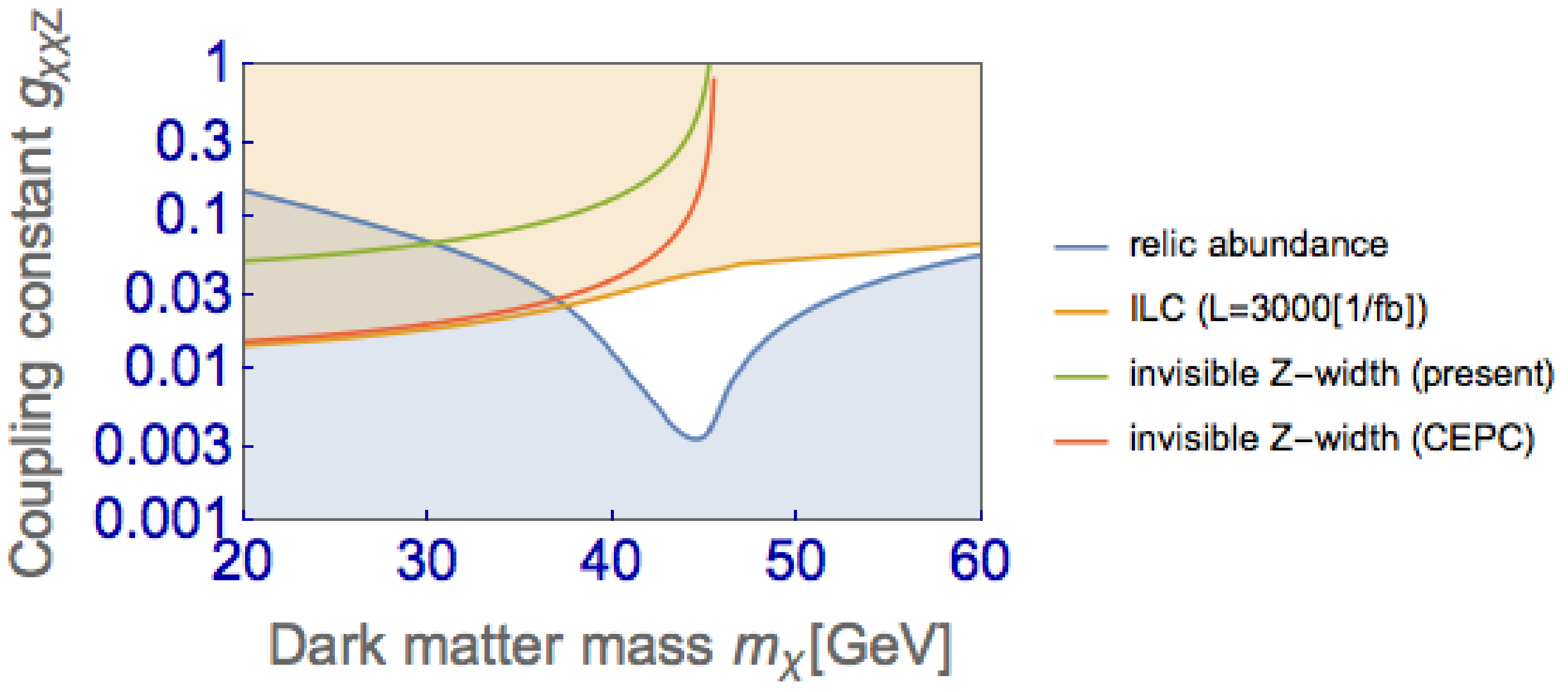


(best center mass energy)



($\Delta\chi^2$ when $g_{\chi\chi Z}$=1 and Luminosity is 1 pb^{-1})

Result



2σ Limit on $g_{\chi\chi Z}$ for each dark matter mass

Summary

We revealed the role of collider experiment for Z-funnel WIMP, by the model independent approach using effective field theory.

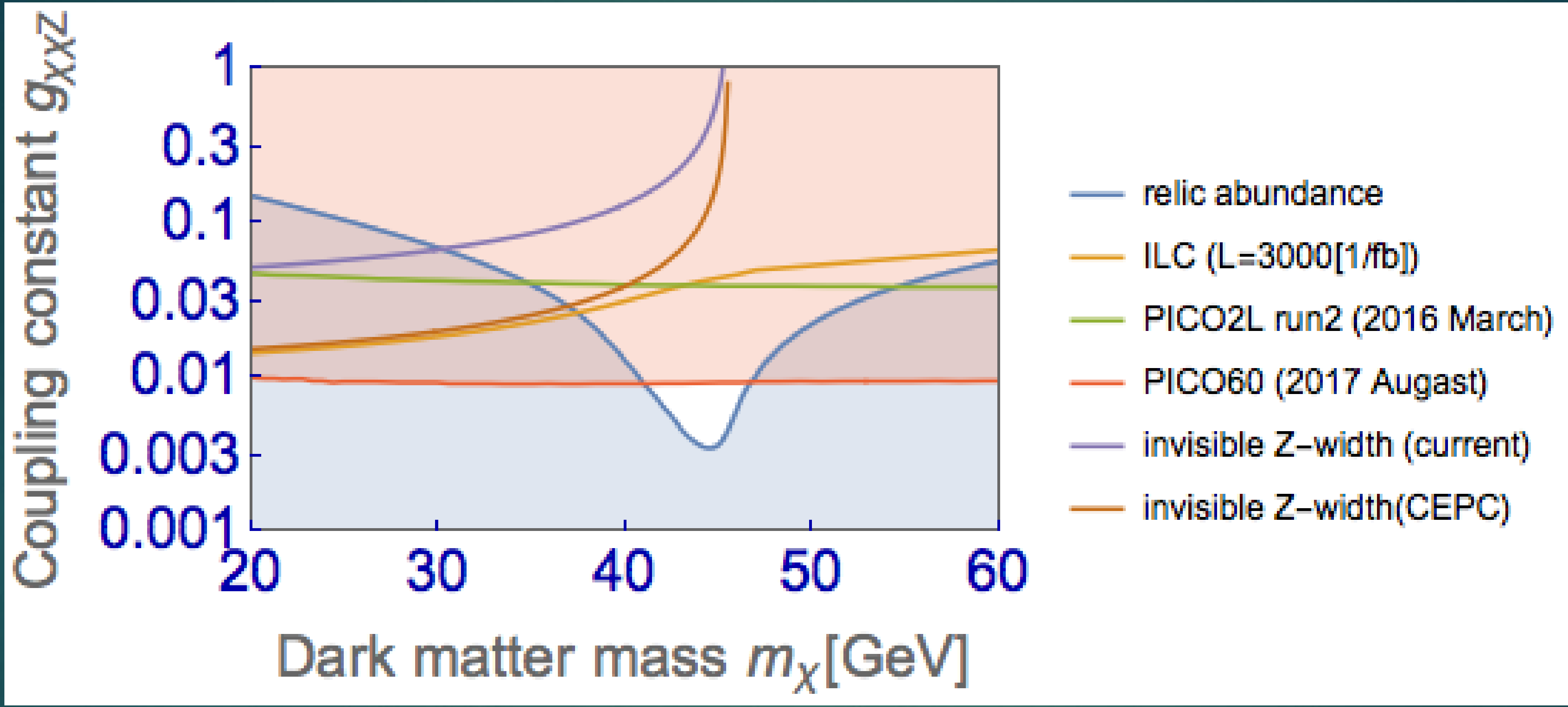
Unexplored Z-funnel region will be remaining after ILC.

This approach can be extended to the leptophilic region of WIMP, or the WIMP which has another quantum numbers.

In addition, in the leptophilic region the coupling of WIMP and leptons are dominant, so ILC is expected to play a big role.

THANK YOU FOR YOUR ATTENTION!

Backup



Direct detection gives a strict constraint.
If the relic abundance is made from several types of DM, this limil will be weaker.