CEPC Precision of Electroweak Oblique Parameters and Fermionic WIMPs

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Dark Matter

Astrophysical and cosmological observations suggest that most of the matter component in the Universe are made of **Dark matter (DM)**.

Assuming that DM particles (χ) were thermally produced in the early Universe, and they annihilate in pair through weak interaction with $SU(2)_L$ gauge coupling $g \simeq 0.64$. The annihilation cross section $\langle \sigma_{\text{ann}} v \rangle$:

$$\langle \sigma_{\text{ann}} v \rangle \sim \frac{g^4}{16\pi^2 m_\chi^2} \sim \mathcal{O}(10^{-26})\ \text{cm}^3/\text{s}$$

for $m_\chi \sim \mathcal{O}(\text{TeV})$. It determines the **relic abundance** of DM to be

$$\Omega_\chi h^2 \simeq \frac{3 \times 10^{-27}\ \text{cm}^3/\text{s}}{\langle \sigma_{\text{ann}} v \rangle} \simeq 0.1$$

which miraculously matches the observation value.
$\Rightarrow$ A very attractive class of DM candidates:

Weakly interacting massive particles (WIMPs)

CEPC Project

Recently, the Chinese HEP community proposes the **Circular Electron Positron Collider (CEPC)**, which mainly serve as a Higgs factory at $\sqrt{s} \sim 240$ GeV. (http://cepc.ihep.ac.cn/preCDR/volume.html)

CEPC can also operate at the Z pole ($\sqrt{s} \sim 91$ GeV, 10^{10} Z bosons/year) and near the WW threshold ($\sqrt{s} \sim 160$ GeV), leading to essential improvements for **electroweak (EW) precision measurements**

In many WIMP models, there are **EW multiplets** whose electrically neutral components serve as DM candidates; such multiplets will affect EW precision observables (or **oblique parameters**) via **loop corrections**

$\Downarrow$

CEPC provides an excellent opportunity to indirectly probe WIMP DM models

Electroweak Oblique Parameters

EW oblique parameters S, T, and U are introduced to describe **new physics contributions** through oblique corrections [Peskin & Takeuchi, '90, '92]

$$S = 16\pi[\Pi'_{33}(0) - \Pi'_{3Q}(0)]$$

$$T = \frac{4\pi}{s_W^2 c_W^2 m_Z^2}[\Pi_{11}(0) - \Pi_{33}(0)], \quad U = 16\pi[\Pi'_{11}(0) - \Pi'_{33}(0)]$$

Here $\Pi'_{IJ}(0) \equiv \partial \Pi_{IJ}(p^2)/\partial p^2|_{p^2=0}$, $s_W \equiv \sin\theta_W$, $c_W \equiv \cos\theta_W$

γ  γ $\quad = ie^2\Pi_{QQ}(p^2)g^{\mu\nu} + (p^\mu p^\nu \text{ terms})$

Z  γ $\quad = \frac{ie^2}{s_W c_W}[\Pi_{3Q}(p^2) - s_W^2\Pi_{QQ}(p^2)]g^{\mu\nu} + (p^\mu p^\nu \text{ terms})$

Z  Z $\quad = \frac{ie^2}{s_W^2 c_W^2}[\Pi_{33}(p^2) - 2s_W^2\Pi_{3Q}(p^2) + s_W^4\Pi_{QQ}(p^2)]g^{\mu\nu} + (p^\mu p^\nu \text{ terms})$

W  W $= \frac{ie^2}{s_W^2}\Pi_{11}(p^2)g^{\mu\nu} + (p^\mu p^\nu \text{ terms})$

Electroweak Precision Observables

For evaluating CEPC precision of oblique parameters, we use a simplified set of EW precision observables in the **global fit**[Gfitter Group, 2014]:

$$\alpha_s(m_Z^2),\ \Delta\alpha_{\rm had}^{(5)}(m_Z^2),\ m_Z,\ m_t,\ m_h,\ m_W,\ \sin^2\theta_{\rm eff}^{\ell},\ \Gamma_Z$$

Free parameters: the first 5 observables, S, T, and U

The remaining 3 observables are determined by the free parameters:

$$m_W = m_W^{\rm SM}\left[1-\frac{\alpha}{4(c_{\rm W}^2-s_{\rm W}^2)}(S-1.55T-1.24U)\right]$$

$$\sin^2\theta_{\rm eff}^{\ell} = (\sin^2\theta_{\rm eff}^{\ell})^{\rm SM}+\frac{\alpha}{4(c_{\rm W}^2-s_{\rm W}^2)}(S-0.69T)$$

$$\Gamma_Z = \Gamma_Z^{\rm SM}-\frac{\alpha^2 m_Z}{72 s_{\rm W}^2 c_{\rm W}^2(c_{\rm W}^2-s_{\rm W}^2)}(12.2S-32.9T)$$

The calculation of SM predictions are based on 2-loop radiative corrections

CEPC Precision of Electroweak Observables

	Current data	CEPC-B precision	CEPC-I precision
$\alpha_s(m_Z^2)$	0.1185 ± 0.0006	$\pm 1 \times 10^{-4}$	
$\Delta\alpha_{\text{had}}^{(5)}(m_Z^2)$	0.02765 ± 0.00008	$\pm 4.7 \times 10^{-5}$	
m_Z [GeV]	91.1875 ± 0.0021	$\pm 5 \times 10^{-4}$	$\pm 1 \times 10^{-4}$
m_t [GeV]	$173.34 \pm 0.76_{\text{ex}} \pm 0.5_{\text{th}}$	$\pm 0.2_{\text{ex}} \pm 0.5_{\text{th}}$	$\pm 0.03_{\text{ex}} \pm 0.1_{\text{th}}$
m_h [GeV]	125.09 ± 0.24	$\pm 5.9 \times 10^{-3}$	
m_W [GeV]	$80.385 \pm 0.015_{\text{ex}} \pm 0.004_{\text{th}}$	$(\pm 3_{\text{ex}} \pm 1_{\text{th}}) \times 10^{-3}$	
$\sin^2\theta_{\text{eff}}^{\ell}$	0.23153 ± 0.00016	$(\pm 2.3_{\text{ex}} \pm 1.5_{\text{th}}) \times 10^{-5}$	
Γ_Z [GeV]	2.4952 ± 0.0023	$(\pm 5_{\text{ex}} \pm 0.8_{\text{th}}) \times 10^{-4}$	$(\pm 1_{\text{ex}} \pm 0.8_{\text{th}}) \times 10^{-4}$

For **CEPC baseline (CEPC-B) precisions**, experimental uncertainties will be mostly reduced by CEPC measurements; theoretical uncertainties of m_W, $\sin^2\theta_{\text{eff}}^{\ell}$, and Γ_Z can be reduced by fully calculating 3-loop corrections in the future

CEPC improved (CEPC-I) precisions need

- A high-precision beam energy calibration for improving m_Z and Γ_Z measurements
- A $t\bar{t}$ threshold scan for the m_t measurement at other e^+e^- colliders, like ILC

Global Fit

We use a modified χ^2 function for the global fit :
[J. Fan, M. Reece & L.-T. Wang, JHEP 09 (2015) 196]

$$\chi^2 = \sum_i \left(\frac{O_i^{\text{meas}} - O_i^{\text{pred}}}{\sigma_i} \right)^2 + \sum_j \left\{ -2 \ln \left[\text{erf}\left(\frac{O_j^{\text{meas}} - O_j^{\text{pred}} + \delta_j}{\sqrt{2}\sigma_j} \right) - \text{erf}\left(\frac{O_j^{\text{meas}} - O_j^{\text{pred}} - \delta_j}{\sqrt{2}\sigma_j} \right) \right] \right\}$$

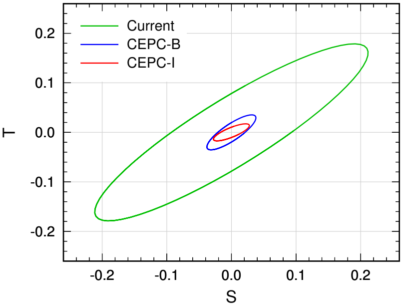
The experimental uncertainty σ_j and the theoretical uncertainty δ_j of an observable O_j are treated as Gaussian and flat errors, respectively

Fit results for $U = 0$

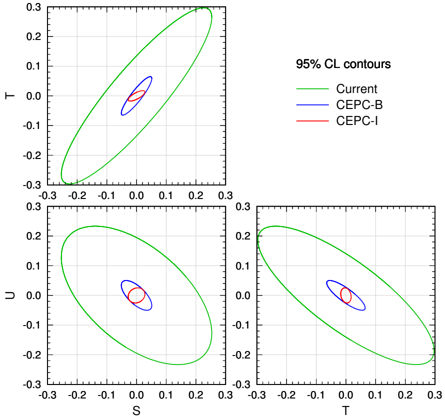
	σ_S	σ_T	ρ_{ST}
Current	0.085	0.072	+0.90
CEPC-B	0.015	0.014	+0.83
CEPC-I	0.011	0.0069	+0.80

The correlation between S and T is positive and close to 1

95% CL contours for U = 0



Fit Results for free U



	σ_S	σ_T	σ_U	ρ_{ST}	ρ_{SU}	ρ_{TU}
Current	0.10	0.12	0.094	+0.89	−0.55	−0.80
CEPC-B	0.021	0.026	0.020	+0.90	−0.68	−0.84
CEPC-I	0.011	0.0071	0.010	+0.74	+0.15	−0.21

Fermionic WIMP models

We consider a dark sector consisting of fermionic EW multiplets and study the potential CEPC sensitivity to them.

A Z_2 symmetry is introduced for stabilizing the DM particle. The dark sector is assumed to be odd under a Z_2 parity while the SM particles are assumed to be even. This discrete symmetry also forbid a single fermionic multiplet coupling to the Higgs (together with another SM fermion)

$\Rightarrow$ no mass contribution from EW symmetry breaking

$\Rightarrow$ the components have exactly degenerate masses at tree level

$\Rightarrow$ cannot contribute to S, T, and U

Therefore, the minimal choice is to consider **two types of multiplets** whose dimensions differ by one:

- **SDFDM:** 1 singlet + 2 doublet Weyl spinors
- **DTFDM:** 2 doublet + 1 triplet Weyl spinors
- **TQFDM:** 1 triplet + 2 quadruplet Weyl spinors

The lightest mass states of the mixed neutral components is a DM candidate

Singlet-Doublet Fermionic Dark Matter (SDFDM)

Introduce left-handed Weyl fermions in the dark sector:

$$S \in (\mathbf{1}, 0), \quad D_1 = \begin{pmatrix} D_1^0 \\ D_1^- \end{pmatrix} \in (\mathbf{2}, -1/2), \quad D_2 = \begin{pmatrix} D_2^+ \\ D_2^0 \end{pmatrix} \in (\mathbf{2}, +1/2)$$

$$\mathcal{L}_{\mathrm{S}} = iS^\dagger \bar{\sigma}^\mu \partial_\mu S - \frac{1}{2}(m_S SS + \mathrm{h.c.})$$

$$\mathcal{L}_{\mathrm{D}} = iD_1^\dagger \bar{\sigma}^\mu D_\mu D_1 + iD_2^\dagger \bar{\sigma}^\mu D_\mu D_2 - (m_D \epsilon_{ij} D_1^i D_2^j + \mathrm{h.c.})$$

Yukawa couplings: $\mathcal{L}_{\mathrm{HSD}} = y_1 H_i S D_1^i - y_2 H_i^\dagger S D_2^i + \mathrm{h.c.}$

Custodial symmetry limit $y = y_1 = y_2$ $\Rightarrow$ $\mathrm{SU}(2)_{\mathrm{L}} \times \mathrm{SU}(2)_{\mathrm{R}}$ invariant form:

$$\mathcal{L}_{\mathrm{D}} + \mathcal{L}_{\mathrm{HSD}} = i\mathcal{D}_A^\dagger \bar{\sigma}^\mu D_\mu \mathcal{D}^A - \frac{1}{2}[m_D \epsilon_{AB} \epsilon_{ij} (\mathcal{D}^A)^i (\mathcal{D}^B)^j + \mathrm{h.c.}] + [y \epsilon_{AB} (\mathcal{H}^A)_i S (\mathcal{D}^B)^j + \mathrm{h.c.}]$$

$\mathrm{SU}(2)_{\mathrm{R}}$ doublets: $(\mathcal{D}^A)^i = \begin{pmatrix} D_1^i \\ D_2^i \end{pmatrix}, \quad (\mathcal{H}^A)_i = \begin{pmatrix} H_i^\dagger \\ H_i \end{pmatrix}$

SDFDM: State Mixing

The dark sector involves 3 Majorana fermions and 1 singly charged fermion

$$\mathcal{L}_{\rm mass} = -\frac{1}{2}(S \quad D_1^0 \quad D_2^0)\mathcal{M}_{\rm N}\begin{pmatrix} S \\ D_1^0 \\ D_2^0 \end{pmatrix} - m_D D_1^- D_2^+ + \text{h.c.} = -\frac{1}{2}\sum_{i=1}^{3} m_{\chi_i^0}\chi_i^0\chi_i^0 - m_{\chi^\pm}\chi^-\chi^+ + \text{h.c.}$$

$$\mathcal{M}_{\rm N} = \begin{pmatrix} m_S & \frac{1}{\sqrt{2}}y_1 v & \frac{1}{\sqrt{2}}y_2 v \\ \frac{1}{\sqrt{2}}y_1 v & 0 & -m_D \\ \frac{1}{\sqrt{2}}y_2 v & -m_D & 0 \end{pmatrix}, \quad \begin{pmatrix} S \\ D_1^0 \\ D_2^0 \end{pmatrix} = \mathcal{N}\begin{pmatrix} \chi_1^0 \\ \chi_2^0 \\ \chi_3^0 \end{pmatrix}$$

$$\mathcal{N}^{\rm T}\mathcal{M}_{\rm N}\mathcal{N} = \text{diag}(m_{\chi_1^0}, m_{\chi_2^0}, m_{\chi_3^0}), \quad \chi^+ = D_2^+, \quad \chi^- = D_1^-$$

Couplings of the **DM candidate** χ_1^0 to the Higgs and Z bosons:

$$\mathcal{L} \supset \frac{1}{2} g_{h\chi_1^0\chi_1^0} h \bar{\chi}_1^0 \chi_1^0 + \frac{1}{2} g_{Z\chi_1^0\chi_1^0} Z_\mu \bar{\chi}_1^0 \gamma^\mu \gamma_5 \chi_1^0$$

$$g_{h\chi_1^0\chi_1^0} = -\sqrt{2}(y_1\mathcal{N}_{21} + y_2\mathcal{N}_{31})\mathcal{N}_{11}, \quad g_{Z\chi_1^0\chi_1^0} = -\frac{g}{2c_{\rm W}}(|\mathcal{N}_{21}|^2 - |\mathcal{N}_{31}|^2)$$

Custodial symmetry limit $y_1 = y_2 \Rightarrow T = U = 0$ and $g_{Z\chi_1^0\chi_1^0} = 0$

$y_1 = y_2$ and $m_D < m_S \Rightarrow g_{h\chi_1^0\chi_1^0} = 0$

Doublet-Triplet Fermionic Dark Matter (DTFDM)

Introduce left-handed Weyl fermions in the dark sector:

$$D_1 = \begin{pmatrix} D_1^0 \\ D_1^- \end{pmatrix} \in (\mathbf{2}, -1/2), \quad D_2 = \begin{pmatrix} D_2^+ \\ D_2^0 \end{pmatrix} \in (\mathbf{2}, +1/2), \quad T = \begin{pmatrix} T^+ \\ T^0 \\ T^- \end{pmatrix} \in (\mathbf{3}, 0)$$

$$\mathcal{L}_{\mathrm{D}} = iD_1^\dagger \bar{\sigma}^\mu D_\mu D_1 + iD_2^\dagger \bar{\sigma}^\mu D_\mu D_2 + (m_D \epsilon_{ij} D_1^i D_2^j + \mathrm{h.c.})$$

$$\mathcal{L}_{\mathrm{T}} = iT^\dagger \bar{\sigma}^\mu D_\mu T - \frac{1}{2}(m_T T^a T^a + \mathrm{h.c.})$$

Yukawa couplings: $\mathcal{L}_{\mathrm{HDT}} = y_1 H_i T^a (\sigma^a)^i_j D_1^j - y_2 H_i^\dagger T^a (\sigma^a)^i_j D_2^j + \mathrm{h.c.}$

Custodial symmetry limit $y = y_1 = y_2$ $\Rightarrow$ $\mathrm{SU}(2)_{\mathrm{L}} \times \mathrm{SU}(2)_{\mathrm{R}}$ invariant form:

$$\mathcal{L}_{\mathrm{D}} + \mathcal{L}_{\mathrm{HDT}} = i\mathcal{D}_A^\dagger \bar{\sigma}^\mu D_\mu \mathcal{D}^A + \frac{1}{2}[m_D \epsilon_{AB} \epsilon_{ij} (\mathcal{D}^A)^i (\mathcal{D}^B)^j + \mathrm{h.c.}] + [y \epsilon_{AB} (\mathcal{H}^A)_i T^a (\sigma^a)^i_j (\mathcal{D}^B)^j + \mathrm{h.c.}]$$

$$\mathrm{SU}(2)_{\mathrm{R}} \text{ doublets: } (\mathcal{D}^A)^i = \begin{pmatrix} D_1^i \\ D_2^i \end{pmatrix}, \quad (\mathcal{H}^A)_i = \begin{pmatrix} H_i^\dagger \\ H_i \end{pmatrix}$$

DTFDM: State Mixing

The dark sector involves 3 Majorana fermions and 2 singly charged fermions

$$\mathcal{L}_{\text{mass}} = -\frac{1}{2}(T^0 \quad D_1^0 \quad D_2^0)\mathcal{M}_{\text{N}} \begin{pmatrix} T^0 \\ D_1^0 \\ D_2^0 \end{pmatrix} - (T^- \quad D_1^-)\mathcal{M}_{\text{C}} \begin{pmatrix} T^+ \\ D_2^+ \end{pmatrix} + \text{h.c.}$$

$$= -\frac{1}{2}\sum_{i=1}^{3} m_{\chi_i^0}\chi_i^0\chi_i^0 - \sum_{i=1}^{2} m_{\chi_i^\pm}\chi_i^-\chi_i^+ + \text{h.c.}$$

$$\mathcal{M}_{\text{N}} = \begin{pmatrix} m_T & \frac{1}{\sqrt{2}}y_1 v & -\frac{1}{\sqrt{2}}y_2 v \\ \frac{1}{\sqrt{2}}y_1 v & 0 & m_D \\ -\frac{1}{\sqrt{2}}y_2 v & m_D & 0 \end{pmatrix}, \quad \mathcal{M}_{\text{C}} = \begin{pmatrix} m_T & -y_2 v \\ -y_1 v & -m_D \end{pmatrix}$$

$$\begin{pmatrix} T^0 \\ D_1^0 \\ D_2^0 \end{pmatrix} = \mathcal{N} \begin{pmatrix} \chi_1^0 \\ \chi_2^0 \\ \chi_3^0 \end{pmatrix}, \quad \begin{pmatrix} T^+ \\ D_2^+ \end{pmatrix} = \mathcal{C}_{\text{L}} \begin{pmatrix} \chi_1^+ \\ \chi_2^+ \end{pmatrix}, \quad \begin{pmatrix} T^- \\ D_1^- \end{pmatrix} = \mathcal{C}_{\text{R}} \begin{pmatrix} \chi_1^- \\ \chi_2^- \end{pmatrix}$$

Custodial symmetry limit $y_1 = y_2 \;\Rightarrow\; T = U = 0$ and $g_{Z\chi_1^0\chi_1^0} = 0$

$y_1 = y_2$ and $m_D < m_T \;\Rightarrow\; g_{h\chi_1^0\chi_1^0} = 0$

Triplet-Quadruplet Fermionic Dark Matter (TQFDM)

Introduce left-handed Weyl fermions in the dark sector:

$$T = \begin{pmatrix} T^+ \\ T^0 \\ T^- \end{pmatrix} \in (\mathbf{3}, 0), \quad Q_1 = \begin{pmatrix} Q_1^+ \\ Q_1^0 \\ Q_1^- \\ Q_1^{--} \end{pmatrix} \in (\mathbf{4}, -1/2), \quad Q_2 = \begin{pmatrix} Q_2^{++} \\ Q_2^+ \\ Q_2^0 \\ Q_2^- \end{pmatrix} \in (\mathbf{4}, +1/2)$$

$$\mathcal{L}_{\mathrm{T}} = iT^\dagger \bar{\sigma}^\mu D_\mu T - \frac{1}{2}(m_T TT + \mathrm{h.c.})$$

$$\mathcal{L}_{\mathrm{Q}} = iQ_1^\dagger \bar{\sigma}^\mu D_\mu Q_1 + iQ_2^\dagger \bar{\sigma}^\mu D_\mu Q_2 - (m_Q Q_1 Q_2 + \mathrm{h.c.})$$

Yukawa couplings: $\mathcal{L}_{\mathrm{HTQ}} = y_1 \epsilon_{jl} (Q_1)_i^{jk} T_k^i H^l - y_2 (Q_2)_i^{jk} T_k^i H_j^\dagger + \mathrm{h.c.}$

Custodial symmetry limit $y = y_1 = y_2 \;\Rightarrow\; \mathrm{SU}(2)_{\mathrm{L}} \times \mathrm{SU}(2)_{\mathrm{R}}$ invariant form:

$$\mathcal{L}_{\mathrm{Q}} + \mathcal{L}_{\mathrm{HTQ}} = i\mathcal{Q}_A^\dagger \bar{\sigma}^\mu D_\mu \mathcal{Q}^A - \frac{1}{2}[m_Q \epsilon_{AB} \epsilon_{il} (\mathcal{Q}^A)_k^{ij} (\mathcal{Q}^B)_j^{lk} + \mathrm{h.c.}] + [y \epsilon_{AB} (\mathcal{Q}^A)_i^{jk} T_k^i (\mathcal{H}^B)_j + \mathrm{h.c.}]$$

$\mathrm{SU}(2)_{\mathrm{R}}$ doublets: $(\mathcal{Q}^A)_k^{ij} = \begin{pmatrix} (Q_1)_k^{ij} \\ (Q_2)_k^{ij} \end{pmatrix}, \quad (\mathcal{H}^A)_i = \begin{pmatrix} H_i^\dagger \\ H_i \end{pmatrix}$

TQFDM: State Mixing

3 Majorana fermions, 3 singly charged fermions, 1 doubly charged fermion

$$\mathcal{L}_{\text{mass}} = -\frac{1}{2}(T^0, Q_1^0, Q_2^0)\mathcal{M}_{\text{N}} \begin{pmatrix} T^0 \\ Q_1^0 \\ Q_2^0 \end{pmatrix} - (T^-, Q_1^-, Q_2^-)\mathcal{M}_{\text{C}} \begin{pmatrix} T^+ \\ Q_1^+ \\ Q_2^+ \end{pmatrix} - m_Q Q_1^{--} Q_2^{++} + \text{h.c.}$$

$$= -\frac{1}{2}\sum_{i=1}^{3} m_{\chi_i^0} \chi_i^0 \chi_i^0 - \sum_{i=1}^{3} m_{\chi_i^\pm} \chi_i^- \chi_i^+ - m_Q \chi^{--} \chi^{++} + \text{h.c.}$$

$$\mathcal{M}_{\text{N}} = \begin{pmatrix} m_T & \frac{1}{\sqrt{3}} y_1 v & -\frac{1}{\sqrt{3}} y_2 v \\ \frac{1}{\sqrt{3}} y_1 v & 0 & m_Q \\ -\frac{1}{\sqrt{3}} y_2 v & m_Q & 0 \end{pmatrix}, \quad \mathcal{M}_{\text{C}} = \begin{pmatrix} m_T & \frac{1}{\sqrt{2}} y_1 v & -\frac{1}{\sqrt{6}} y_2 v \\ -\frac{1}{\sqrt{6}} y_1 v & 0 & -m_Q \\ \frac{1}{\sqrt{2}} y_2 v & -m_Q & 0 \end{pmatrix}$$

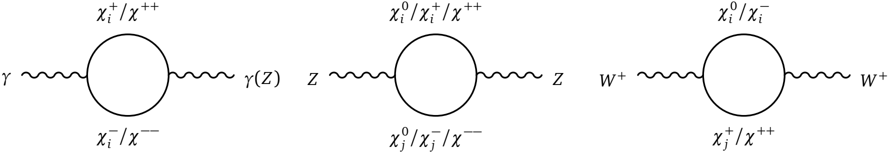
$$\begin{pmatrix} T^0 \\ Q_1^0 \\ Q_2^0 \end{pmatrix} = \mathcal{N} \begin{pmatrix} \chi_1^0 \\ \chi_2^0 \\ \chi_3^0 \end{pmatrix}, \quad \begin{pmatrix} T^+ \\ Q_1^+ \\ Q_2^+ \end{pmatrix} = \mathcal{C}_L \begin{pmatrix} \chi_1^+ \\ \chi_2^+ \\ \chi_3^+ \end{pmatrix}, \quad \begin{pmatrix} T^- \\ Q_1^- \\ Q_2^- \end{pmatrix} = \mathcal{C}_R \begin{pmatrix} \chi_1^- \\ \chi_2^- \\ \chi_3^- \end{pmatrix}, \quad \begin{matrix} \chi^{--} \equiv Q_1^{--} \\ \chi^{++} \equiv Q_2^{++} \end{matrix}$$

Custodial symmetry limit $y_1 = y_2 \;\Rightarrow\; T = U = 0$ and $g_{Z\chi_1^0\chi_1^0} = 0$

$y_1 = y_2$ and $m_Q < m_T \;\Rightarrow\; g_{h\chi_1^0\chi_1^0} = 0$

Phenomenology of the DM models

Dark sector fermions contribute to S, T, and U through vacuum polarizations of EW gauge bosons (diagrams for the TQFDM model):



The couplings of the DM candidate χ_1^0 to the Higgs and Z bosons

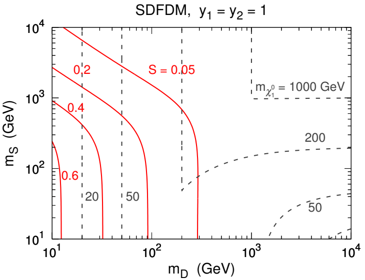
$$\mathcal{L} \supset \frac{1}{2} g_{h\chi_1^0\chi_1^0} h \bar{\chi}_1^0 \chi_1^0 + \frac{1}{2} g_{Z\chi_1^0\chi_1^0} Z_\mu \bar{\chi}_1^0 \gamma^\mu \gamma_5 \chi_1^0$$

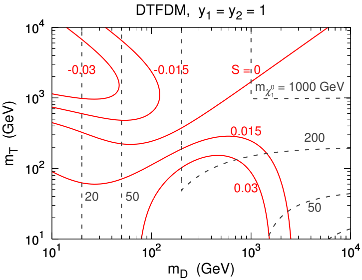
induce **spin-independent (SI)** and **spin-dependent (SD)** scatterings between DM and nuclei, respectively

Most stringent constraints from current direct detection experiments:

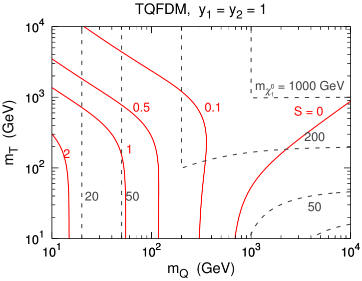
- **SI:** PandaX-II [1607.07400], LUX [1608.07648]
- **SD:** LUX (neutron) [1602.03489], PICO (proton) [1503.00008, 1510.07754]

Contours of S for $y_1 = y_2 = 1$ (Custodial Symmetry)





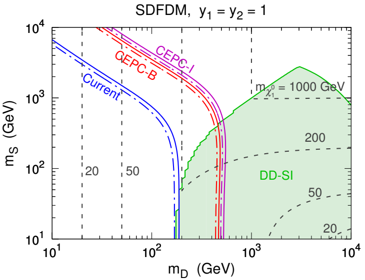
The behaviors of S in the SDFDM and TQFDM models are similar, while that in the DTFDM model is quite different

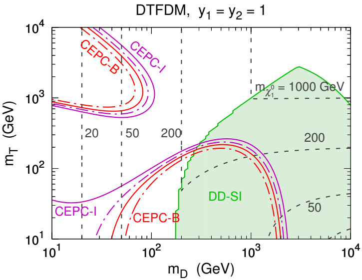


SDFDM & TQFDM: one dark sector fermion ($\chi^{\pm}$ or $\chi^{\pm\pm}$) remains unmixed

DTFDM: all dark sector fermion mix with others $\Rightarrow$ cancellation effects for S

$y_1 = y_2 = 1$ (Custodial Symmetry)

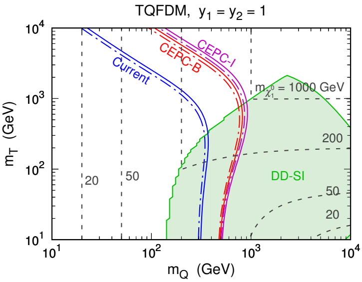




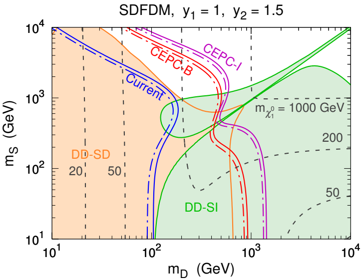
Expected 95% CL constraints from **current**, **CEPC-B**, and **CEPC-I** precisions of EW oblique parameters

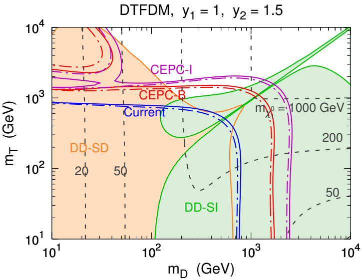
Solid lines: assuming $U = 0$
Dashed lines: free U

DD-SI: excluded by spin-independent direct detection at 90% CL



$y_1 = 1$ and $y_2 = 1.5$ (Custodial Symmetry Violation)

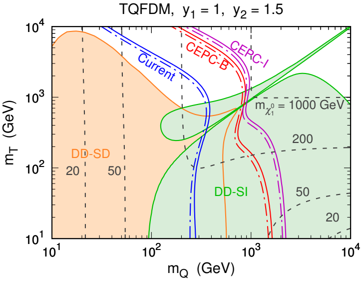




Expected 95% CL constraints from **current**, **CEPC-B**, and **CEPC-I** precisions of EW oblique parameters

Solid lines: assuming $U = 0$
Dashed lines: free U

DD-SI: excluded by SI direct detection
DD-SD: excluded by SD direct detection



Conclusion

1. The precision of EW oblique parameters will be substantially improved in CEPC. It provides a great opportunity to indirectly probe WIMP models.
2. When the SDFDM, DTFDM and TQFDM models respect custodial symmetries, the EW precision measurements in CEPC can probe a large parameter region where hard to be reached by direct detection experiments.
3. For the current precision of EW oblique parameters, it is hard to probe the custodial symmetric DTFDM model, however it is possible in CEPC.
4. In the custodial symmetry violating cases, EW precision measurements in CEPC can probe an area overlap with the spin-dependent direct detection experiments. For some region, it behaves better than the direct detection experiments.

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Thanks for your attention!