Sensitivity of future linear colliders to processes of dark matter production with light mediator exchange

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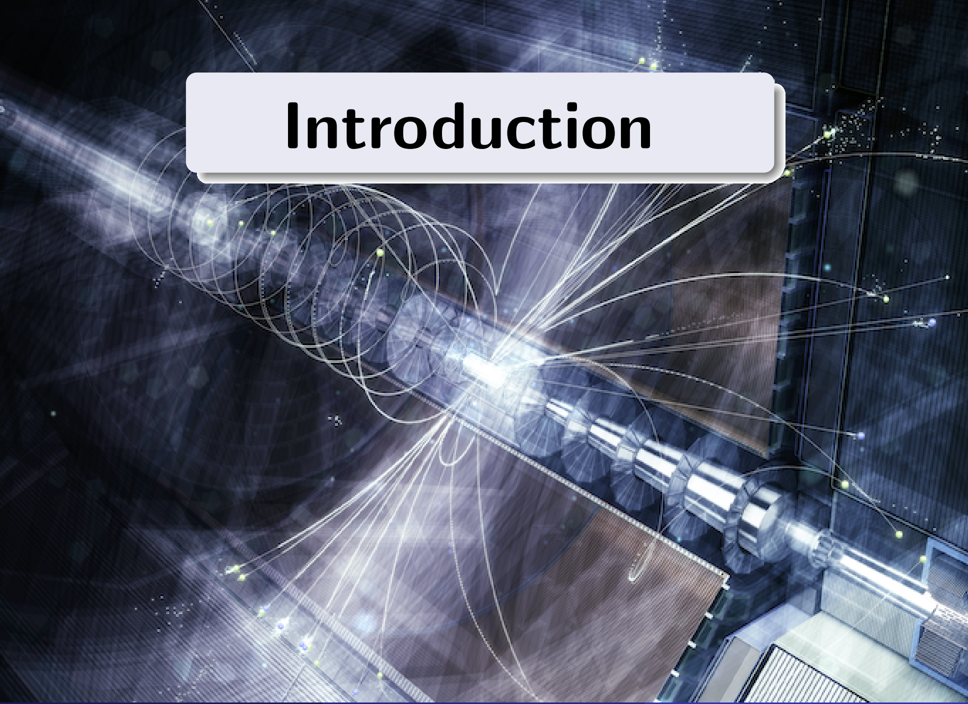
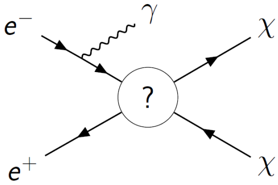
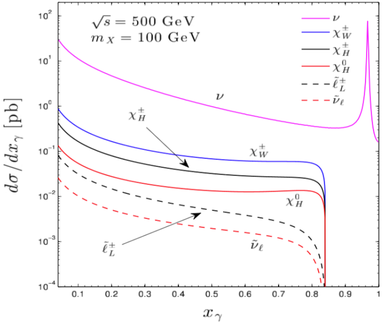
Introduction



Mono-photon signature

The mono-photon signature is considered to be the most general way to look for DM particle production in future e^+e^- colliders.





DM can be pair produced in the e^+e^- collisions via exchange of a new mediator particle, which couples to both electrons (SM) and DM states

This process can be detected, if additional hard photon radiation from the initial state is observed in the detector...

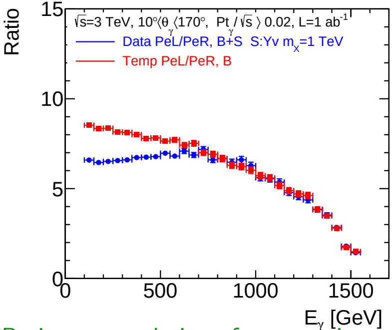
Heavy mediator approximation, generator level

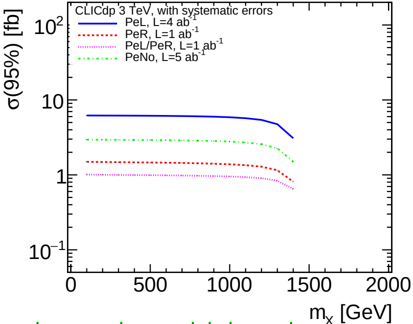
arXiv:2103.06006

Mono-photon signature:

high energy, isolated photon no other “hard” activity in the detector

Highest sensitivity to DM production from the ratio of the photon energy distributions measured for the two electron beam polarisations





Ratio ⇒ cancelation of systematic uncertainties, but results model-dependent

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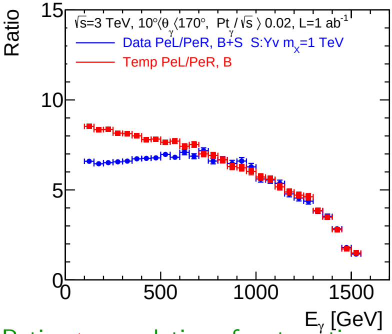

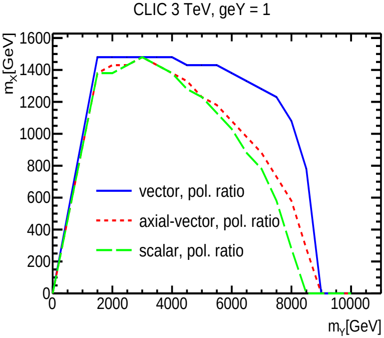

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Heavy mediator (EFT limit), full simulation

arXiv:2001.03011

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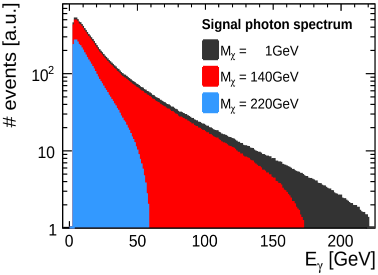

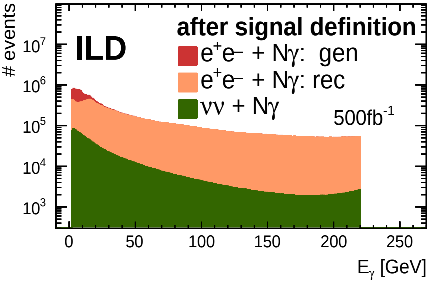

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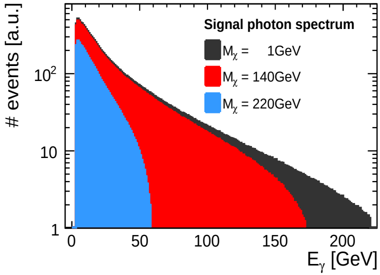

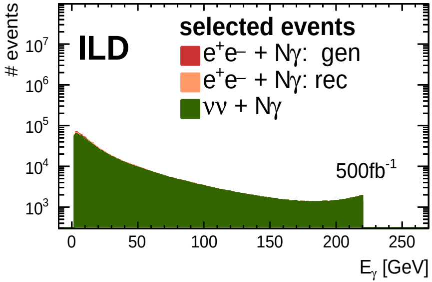

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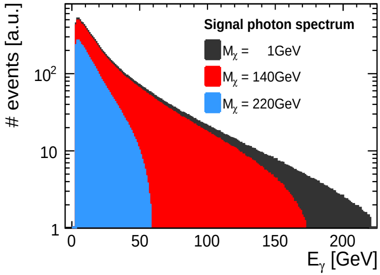
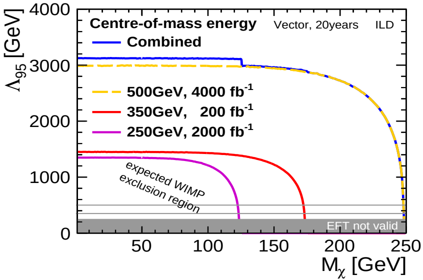
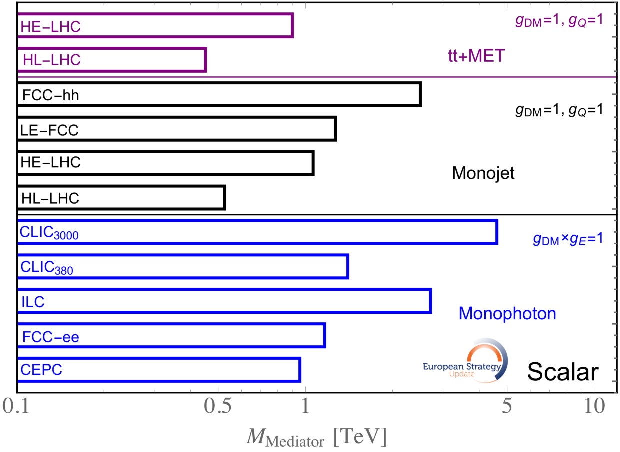




Sensitivity to the BSM mass scales up to $\Lambda \sim$3 TeV

$$\Lambda^2 = \frac{M_Y^2}{|g_{eeY} g_{\chi\chi Y}|}$$

Comparison of mass scale limits calculated in the EFT framework



e^+e^- mass reach comparable with that of FCC-hh !!!

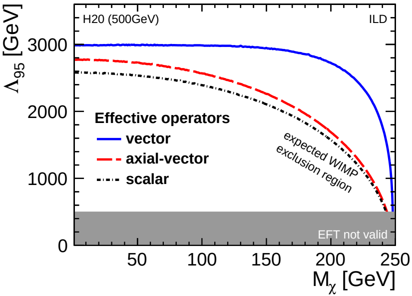
Mono-photon study

New analysis approach

Most of the studies performed so far focused on heavy mediator exchange (EFT limit) and coupling values $\mathcal{O}(1)$
$\Rightarrow$ extracted were limits on DM or mediator masses

In our study:

- focus on light mediator exchange (DM even lighter)
- consider very small mediator couplings to SM, $\Gamma_{SM} \ll \Gamma_{tot}$



ILD study: arXiv:2001.03011
Phys. Rev. D 101, 075053 (2020)

CLIC study: arXiv:2103.06006

"Experimental-like" approach $\Rightarrow$ focus on cross section limits as a function of mediator mass and width

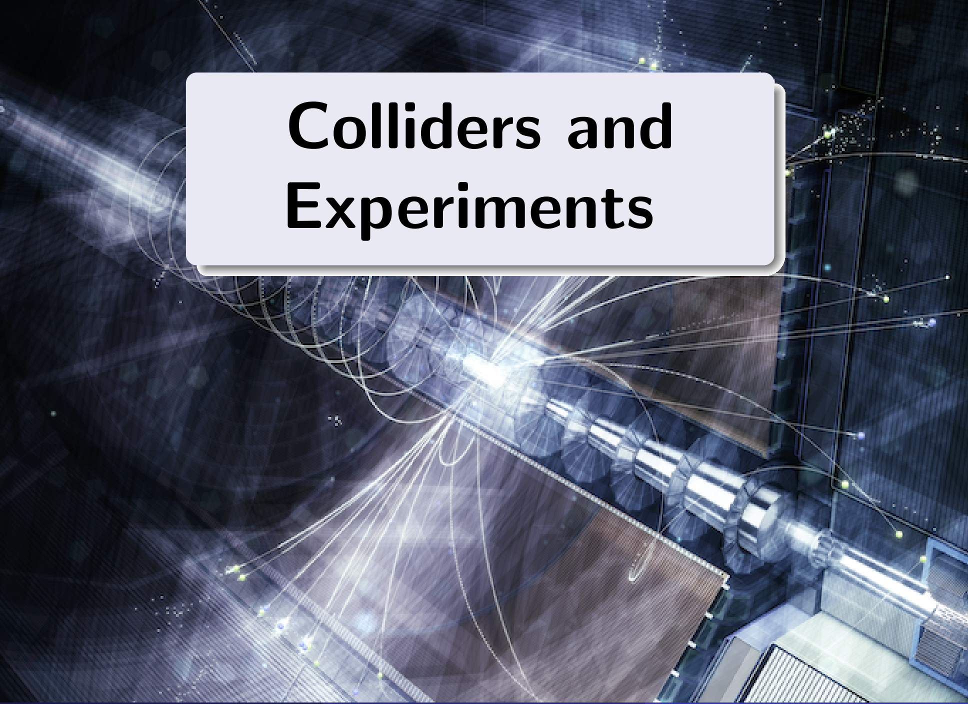
Publications

- J. Kalinowski et al., *Simulating hard photon production with WHIZARD*, Eur. Phys. J. C 80 (2020) 634, arXiv:2004.14486
- J. Kalinowski et al., *Sensitivity of future linear e^+e^- colliders to processes of dark matter production with light mediator exchange*, Eur. Phys. J. C *in print*, arXiv:2107.11194

Conference presentations

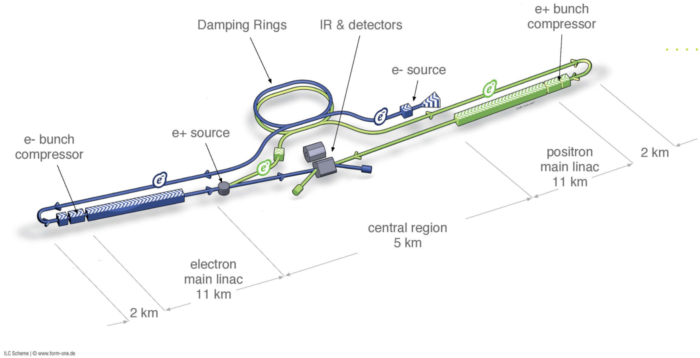
- P.Sopicki, *Simulating hard photon production with WHIZARD*, ICHEP'2020
- A.F.Żarnecki, *Dark matter searches with mono-photon signature at future e^+e^- colliders*, DIS'2021 & Dark Matter 2021
- A.F.Żarnecki, *Probing Dark Matter with ILC*, SUSY'2021 & PANIC'2021
- A.F.Żarnecki, *Sensitivity to dark matter production at future e^+e^- colliders*, Corfu'2021
- J.Kalinowski, *Sensitivity of future e^+e^- colliders to processes of dark matter production with light mediator exchange*, SUSY'2021
- A.F.Żarnecki, *Sensitivity of future e^+e^- colliders to processes of dark matter production with light mediator exchange*, Matter To The Deepest 2021
- A.F.Żarnecki, *The use of beam polarization in the search for dark matter at the ILC*, SPIN'2021

Outline



Colliders and Experiments

International Linear Collider

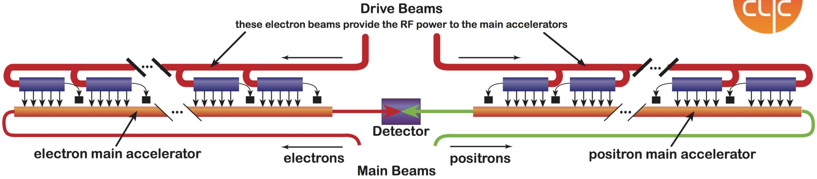


Technical Design (TDR) completed in 2013

arXiv:1306.6328

- superconducting accelerating cavities
- 250 – 500 GeV c.m.s. energy (baseline), 1 TeV upgrade possible
- footprint 31 km
- polarisation for both e^- and e^+ (80%/30%)

Compact LInear Collider



Conceptual Design (CDR) presented in 2012 CERN-2012-007

- high gradient, two-beam acceleration scheme
- staged implementation plan with energy from 380 GeV to 3 TeV
- footprint of 11 to 50 km
- e^- polarisation (80%)

For details refer to arXiv:1812.07987

Running scenarios

Staged construction assumed for both ILC and CLIC.

In our study we focused on the highest energy stages.

ILC

Total of 4000 fb^{-1} assumed at 500 GeV (H-20 scenario)

- $2\times1600\,\mathrm{fb}^{-1}$ for LR and RL beam polarisation combinations
- $2\times400\,\mathrm{fb}^{-1}$ for RR and LL beam polarisation combinations

assuming polarisation of $\pm80\%$ for electrons and $\pm30\%$ for positrons

arXiv:1903.01629

CLIC

Total of 5000 fb^{-1} assumed at 3 TeV

- 4000 fb^{-1} for negative electron beam polarisation
- 1000 fb^{-1} for positive electron beam polarisation

assuming polarisation of $\pm80\%$ for electrons

arXiv:1812.06018

Detector Requirement

"Particle Flow" concept:

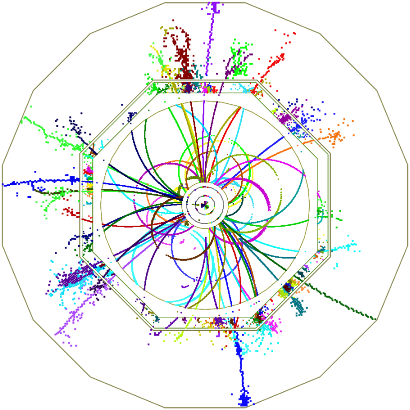
High calorimeter granularity
$\Rightarrow$ single particle reconstruction/ID

Precise momentum measurement
$\Rightarrow$ best energy for charged particles
$\Rightarrow$ dominates jet energy resolution

High precision vertex detector
$\Rightarrow$ very efficient flavour tagging

Instrumentation down to smallest angles
$\Rightarrow$ hermecity, missing energy tagging

Example event
$e^+e^- \rightarrow t\bar{t} \rightarrow 6j$

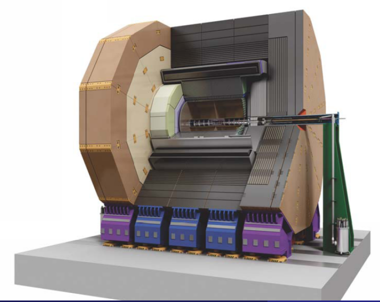


Detector Requirements same for ILC and CLIC

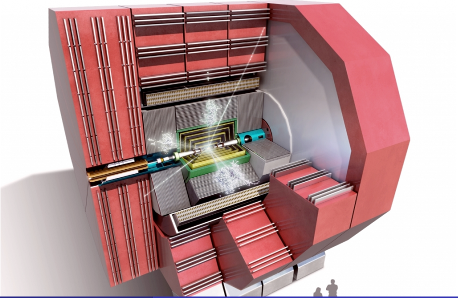
- Track momentum resolution: $\sigma_{1/p} < 5 \cdot 10^{-5}$ GeV^{-1}
- Impact parameter resolution: $\sigma_d < 5\mu m \oplus 10\mu m \frac{1\,\mathrm{GeV}}{p\ \sin^{3/2}\Theta}$
- Jet energy resolution: $\sigma_E/E = 3 - 4\%$ (for highest jet energies)
- Hermecity: $\Theta_{min} = 5$ mrad

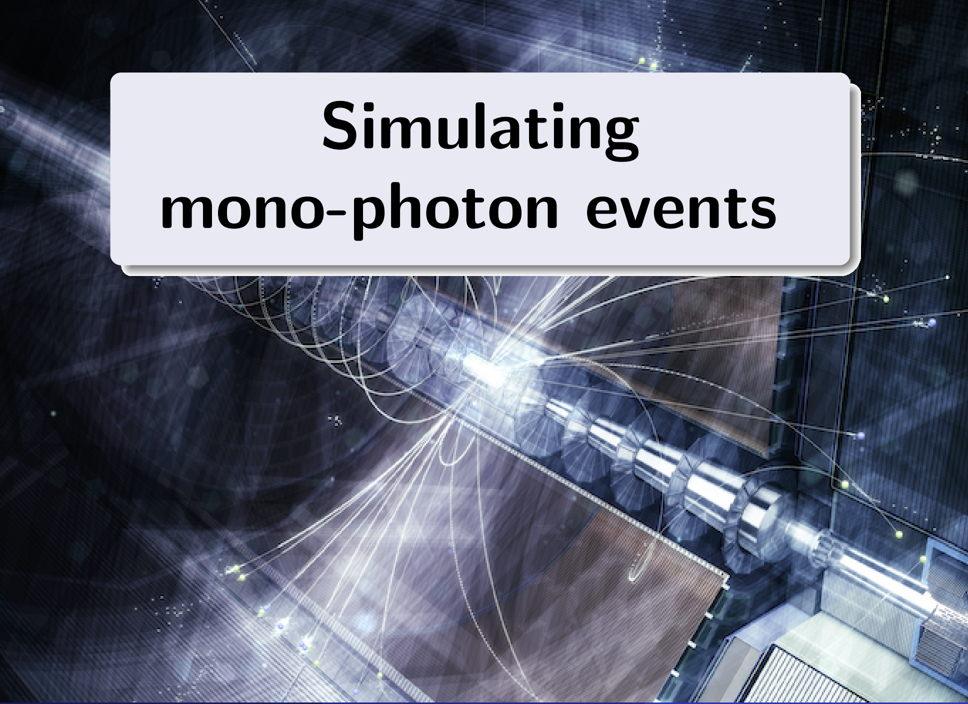
Detailed detector concepts for ILC and CLIC:

ILD



CLICdet



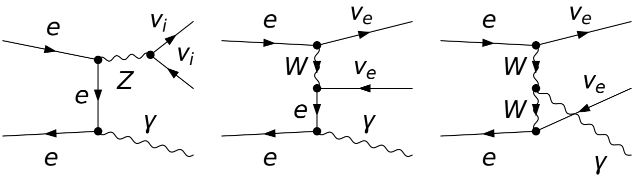


Simulating mono-photon events

Simulating mono-photon events in WHIZARD

For proper estimate of the mono-photon signature sensitivity consistent simulation of BSM processes and of the SM backgrounds is crucial.

"Irreducible" background comes from radiative neutrino pair-production



Detector acceptance & reconstruction efficiency
$\Rightarrow$ significant contribution from radiative Bhabha scattering

WHIZARD provides the ISR structure function option that includes all orders of soft and soft-collinear photons as well as up to the third order in high-energy collinear photons.

However, WHIZARD ISR photons are not ordinary final state photons: they represent all photons radiated in the event from a given lepton line.

Simulating mono-photon events in WHIZARD

ISR structure function can not account for hard non-collinear photons
⇒ all "detectable" photons generated on Matrix Element level

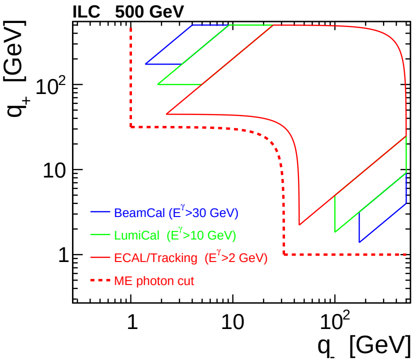
Dedicated procedure developed to avoid double-counting of ISR and ME

For details: J. Kalinowski et al., Eur. Phys. J. C 80 (2020) 634, arXiv:2004.14486

Two variables, calculated separately for each emitted photon:

$$q_- = \sqrt{4E_0 E_\gamma} \cdot \sin\frac{\theta_\gamma}{2},$$
$$q_+ = \sqrt{4E_0 E_\gamma} \cdot \cos\frac{\theta_\gamma}{2},$$

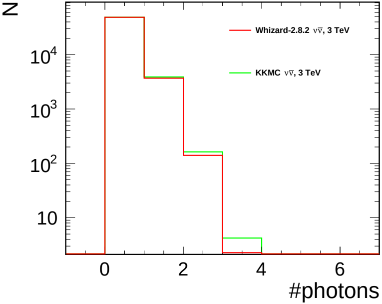
are used to separate "soft ISR" emission region from the region described by ME calculations.

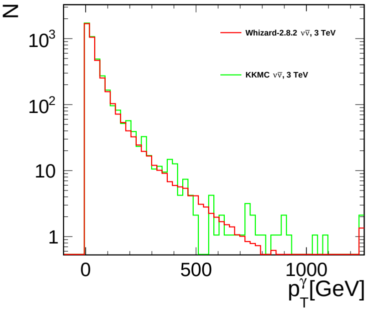


Validation of the procedure

WHIZARD predictions were compared to the results from the KKMC code for $e^+e^- \to \nu\bar{\nu} + \mathrm{N}\gamma$

3 TeV CLIC





$\Rightarrow$ very good agreement observed (both for shape and normalisation)

For more details:

J. Kalinowski et al., Eur. Phys. J. C 80 (2020) 634, arXiv:2004.14486

Simplified DM model

UFO model covering most popular scenarios of DM pair-production

⇒ Feynrules

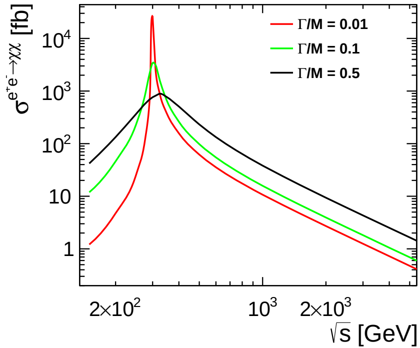
Possible mediators:

- scalar
- pseudo-scalar
- vector
- pseudo-vector
- V−A coupling
- V+A coupling

Possible DM candidates:

- real or complex scalar
- Majorana or Dirac fermion
- real vector

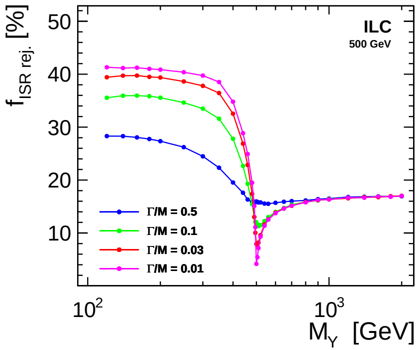
Cross section for $e^+e^- \to \chi\chi$ for $M_\chi = 50\ GeV$ and $M_Y = 300\ GeV$



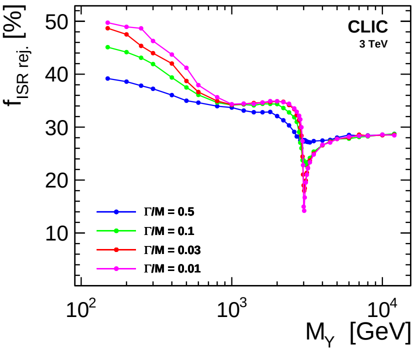
ISR rejection probability

Fraction of events generated by WHIZARD **removed** in merging procedure
(ISR photons emitted in the phase-space region covered by ME)

ILC @ 500 GeV



CLIC @ 3 TeV



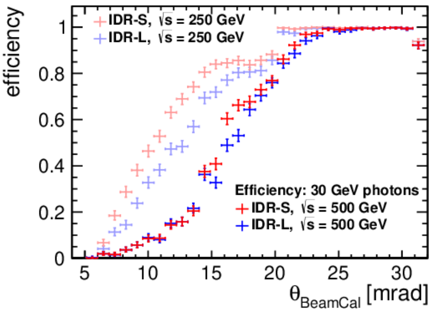
Detector simulation for ILC running at 500 GeV

Hundreds of signal scenarios to consider ⇒ DELPHES fast simulation

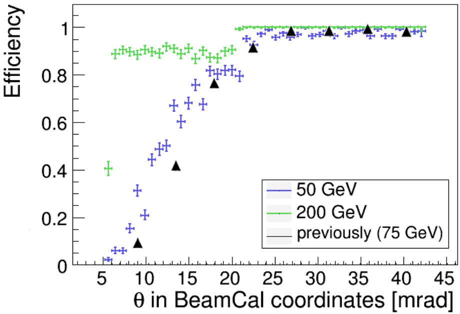
Modeling of the forward detector performance crucial for the analysis

Results on BeamCal efficiency from full simulation:

ILD IDR



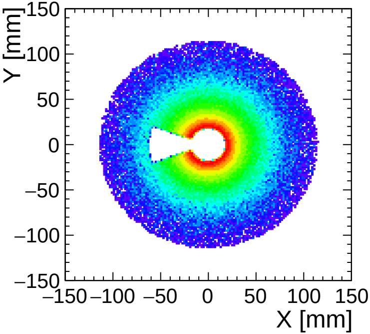
Moritz Hebermehl PhD Thesis



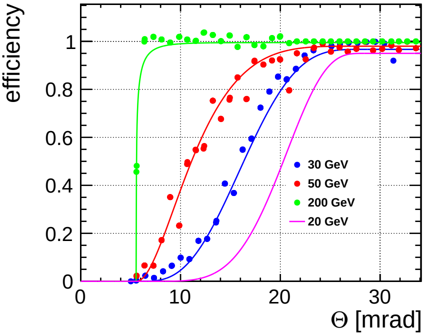
Detector simulation for ILC running at 500 GeV

ILCgen model for DELPHES includes proper modelling of forward detectors

BeamCal geometry



Parameterisation of the full simulation results



Included in the official DELPHES repository as `delphes_card_ILCgen.tcl`

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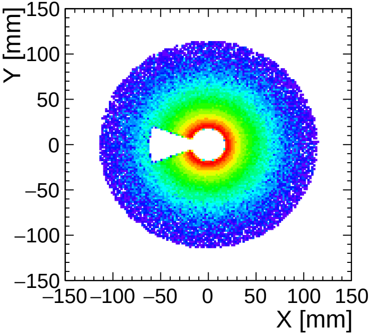
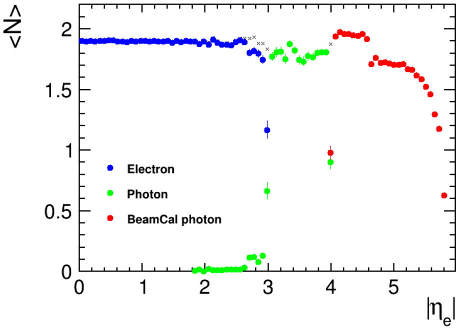


Reconstruction results for $e^+e^- \to e^+e^-$



Included in the official DELPHES repository as `delphes_card_ILCgen.tcl`

Tagging efficiency

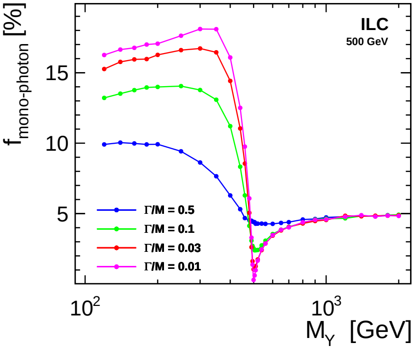
based on DELPHES simulation

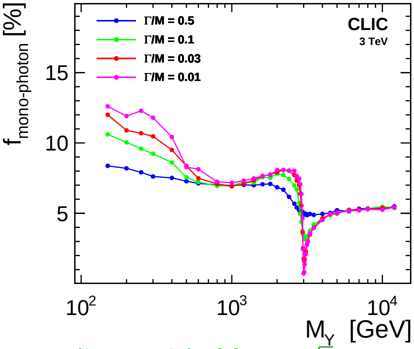
Mono-photons reconstructed only in a fraction of generated signal event

$$\sigma\left(e^+e^- \to \chi\,\chi\,\gamma_{tag}\right) \;=\; f_{\text{mono-photon}}\cdot\sigma\left(e^+e^- \to \chi\,\chi\,(\gamma)\,\right)$$

ILC @ 500 GeV

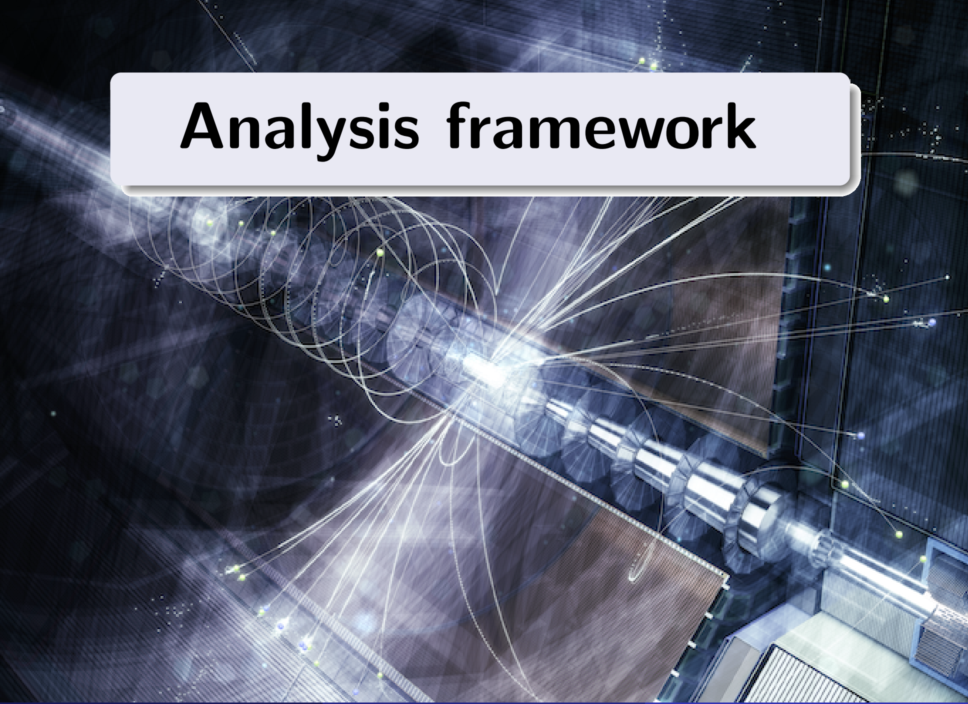
CLIC @ 3 TeV





Emission strongly suppressed for narrow mediator with $M_Y \sim \sqrt{s}$

Analysis framework



Event selection

On generator level:

- 1, 2 or 3 ME photons

  nonradiative events for signal only (for normalisation)

- all ME photons with
  $q_{\pm} > 1\,GeV \quad \& \quad E^{\gamma} > 1\,GeV$

  rejected are events with
  $q_{\pm} > 1\,GeV \quad \& \quad E^{\gamma} > 1\,GeV$
  for any of the ISR photons

- at least one ME photon with
  $p_T^{\gamma} > 2\,GeV \;\; \& \;\; 5^{\circ} < \theta^{\gamma} < 175^{\circ}$ (ILC 500 GeV)
  $p_T^{\gamma} > 5\,GeV \;\; \& \;\; 7^{\circ} < \theta^{\gamma} < 173^{\circ}$ (CLIC 3 TeV)

DELPHES framework used for detector simulation and event reconstruction.

Require:

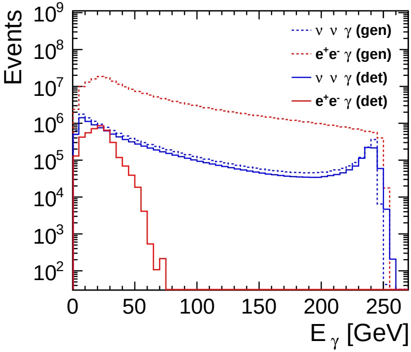
- single photon with

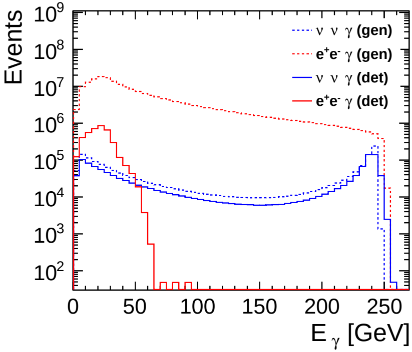
$p_T^{\gamma} > 3\,GeV \;\; \& \;\; |\eta^{\gamma}| < 2.8$ (ILC)
$p_T^{\gamma} > 10\,GeV \;\; \& \;\; |\eta^{\gamma}| < 2.6$ (CLIC)

- no other activity in the detector
  other reconstructed objects
  - no electrons
  - no LumiCal photons
  - no BeamCal photons
  - no jets

Background distributions

Two SM backgrounds considered: with up to 3 ME photons
Bhabha scattering and (radiative) neutrino pair production





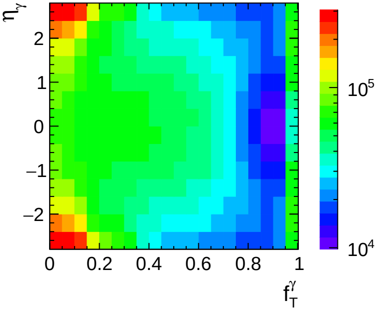
ILC 500 GeV
(–80%/+30%) 1600 fb^{-1} (+80%/–30%) 1600 fb^{-1}

Background vs Signal distributions

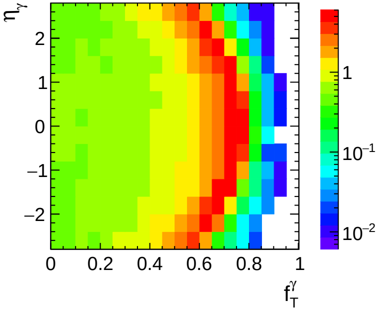
arXiv:2107.11194

For mono-photon events, two variables fully describe event kinematics
⇒ use 2D distribution of (p_T^γ, η) to constrain DM production

Background



Signal



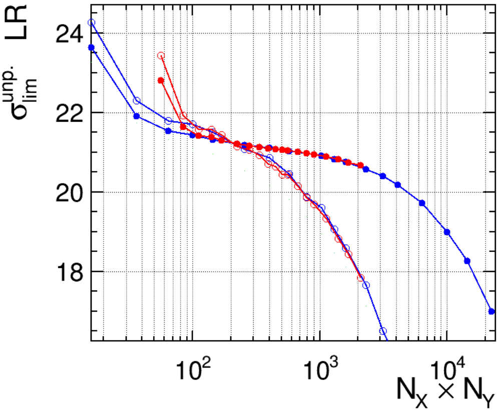
ILC 500 GeV (-80%/+30%) 1600 fb^{-1} $M_Y = 400$ GeV, $\Gamma/M = 0.03$

Signal normalised to unpolarised DM pair-production cross section of 1 fb

Analysis framework

Histogram binning

Cross section limits for vector mediator exchange, M_Y=2TeV, Γ/M=0.1 as a function of the number of histogram bins:



Signal MC statistics: 100k (open symbols) and 1M (full symbols)

Systematic uncertainties

following ILD study: Phys. Rev. D 101, 075053 (2020), arXiv:2001.03011

Considered sources of uncertainties:

- Integrated luminosity uncertainty of 0.26%
  uncorrelated between polarisations
- Luminosity spectra shape uncertainty
  correlated between polarisations
- Uncertainty in neutrino background normalisation of 0.2% (th+exp)
  correlated between polarisations
- Uncertainty in Bhabha background normalisation of 1% (th+exp)
  correlated between polarisations
- Uncertainty on beam polarisation of 0.02–0.08% (ILC)/0.2% (CLIC)
  correlated for runs with same beam polarisation at ILC

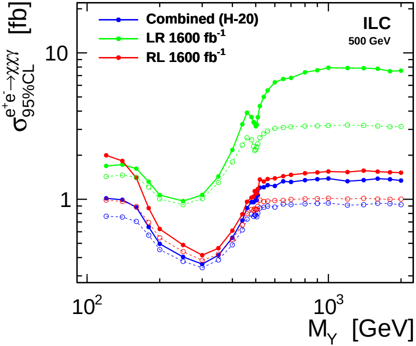
⇒ nuisance parameters in the RooStat model fit (11 for ILC, 7 for CLIC)

Systematic uncertainties

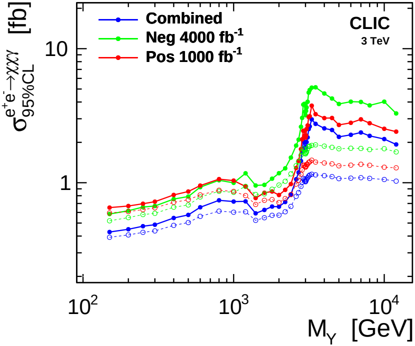
Cross section limits for radiative events (with tagged photon)

Vector Mediator $\Gamma/M = 0.03$ with and without systematics

ILC @ 500 GeV



CLIC @ 3 TeV

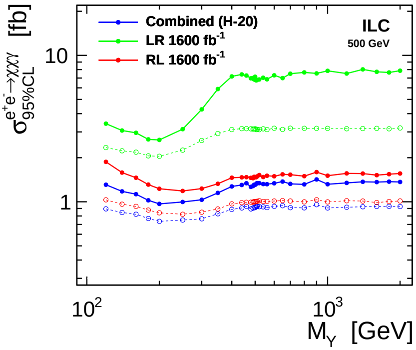


Systematic effects reduced for on-shell production of narrow mediator

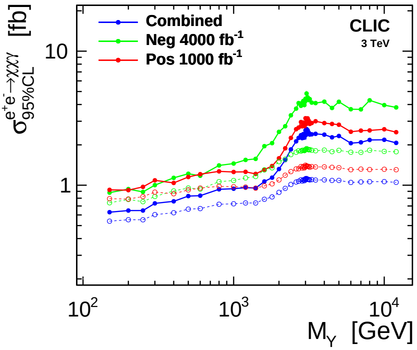
Cross section limits for radiative events (with tagged photon)

Vector Mediator $\Gamma/M = 0.5$ with and without systematics

ILC @ 500 GeV



CLIC @ 3 TeV

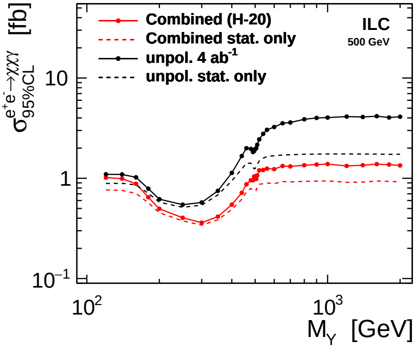


Systematic effects reduced for on-shell production of narrow mediator

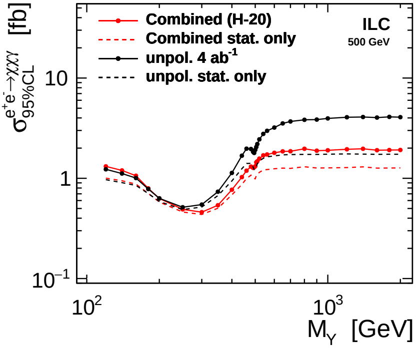
Cross section limits for radiative events (with tagged photon)

Impact of beam polarisation assuming 4 ab^{-1} for ILC @ 500 GeV

Vector mediator



Scalar mediator



Polarisation significantly reduces impact of systematic uncertainties...

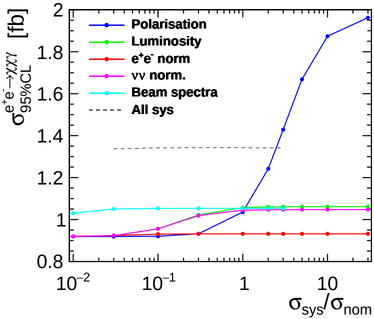
Systematic uncertainties

Impact of constraints

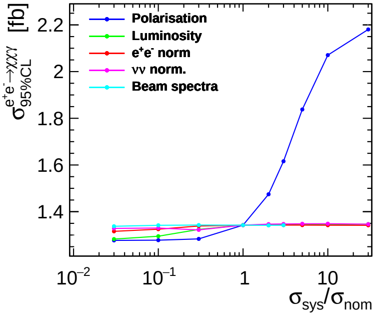
How important are the external constraints on the systematic effects?
Eg. precision of the lumionosity measurement or theoretical calculations...

Radiative cross section limits for Vector mediator M_{Y}=2 TeV, Γ/M=0.03

Single uncertainty only



All systematics (one varied)



Most of the systemactic effects are constrained by the data itself!!!

Limit setting

Experimental-like approach

Cross section for DM pair-production via mediator exchange depends on

- mediator mass, M_Y, and DM mass m_χ
- SM-mediator coupling value, g_{eeY} and coupling structure $\mathcal{O}_{eeY}$
- DM-mediator coupling value, $g_{\chi\chi Y}$ and coupling structure $\mathcal{O}_{\chi\chi Y}$

Experimental-like approach

Cross section for DM pair-production via mediator exchange depends on

- mediator mass, M_Y, and DM mass m_χ
- SM-mediator coupling value, g_{eeY} and coupling structure $\mathcal{O}_{eeY}$
- DM-mediator coupling value, $g_{\chi\chi Y}$ and coupling structure $\mathcal{O}_{\chi\chi Y}$

The cross section can also be expressed in terms of the widths

$$\sigma(e^+e^- \to Y \to \chi\chi) \;=\; \frac{12\pi}{M_Y^2}\,\frac{s\,\Gamma_{ee}\,\Gamma_{\chi\chi}}{(s-M_Y^2)^2 + M_Y^2\Gamma_Y^2}$$

In the limit $\Gamma_{ee} \ll \Gamma_{\chi\chi} \approx \Gamma_Y$ the cross section depends only on M_Y, Γ_Y, g_{eeY} and $\mathcal{O}_{eeY}$ (dependence on m_χ, $g_{\chi\chi Y}$ and $\mathcal{O}_{\chi\chi Y}$ "absorbed" in Γ_Y)

$\Rightarrow$ study limits on the DM pair-production cross section (or g_{eeY}) as a function of the mediator mass and width (for given $\mathcal{O}_{eeY}$)

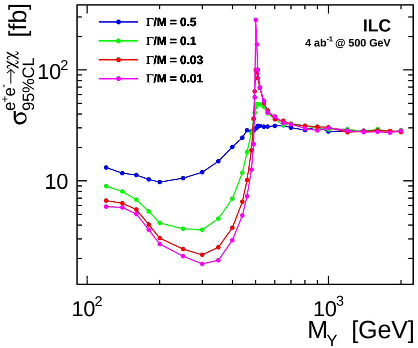
Results

Cross section limits for total DM production cross section

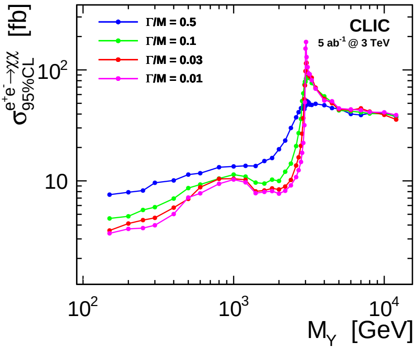
Corrected for probability of hard photon tagging!

Combined limits for Vector mediator

ILC @ 500 GeV



CLIC @ 3 TeV



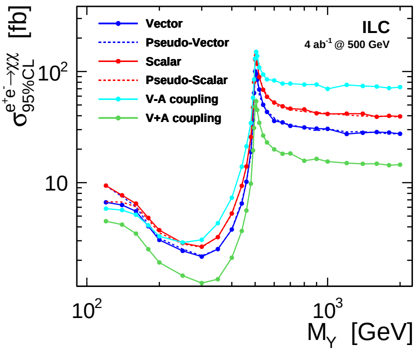
Radiation suppressed for narrow mediator with $M_Y \sim \sqrt{s} \Rightarrow$ weaker limits

Cross section limits for total DM production cross section

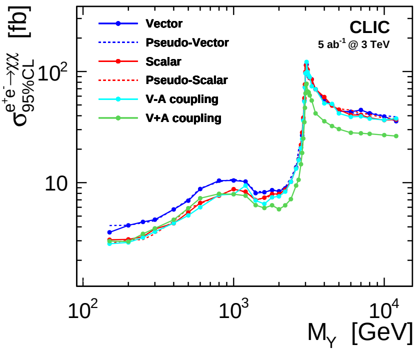
Corrected for probability of hard photon tagging!

Combined limits for mediators with $\Gamma/M = 0.03$

ILC @ 500 GeV



CLIC @ 3 TeV

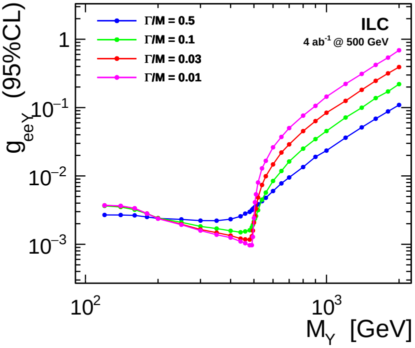


Radiation suppressed for narrow mediator with $M_Y \sim \sqrt{s} \Rightarrow$ weaker limits

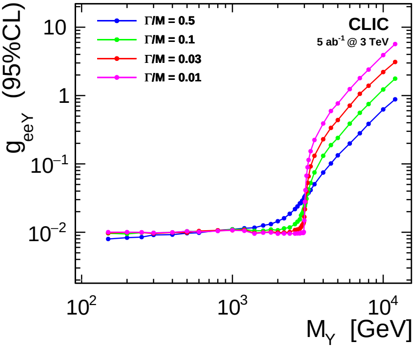
Coupling limits

Combined limits for Vector mediator

ILC @ 500 GeV



CLIC @ 3 TeV

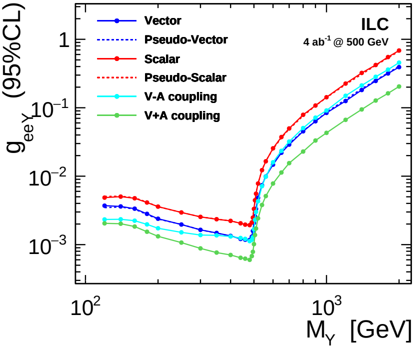


Almost uniform sensitivity to mediator coupling g_{eeY} up to kinematic limit.

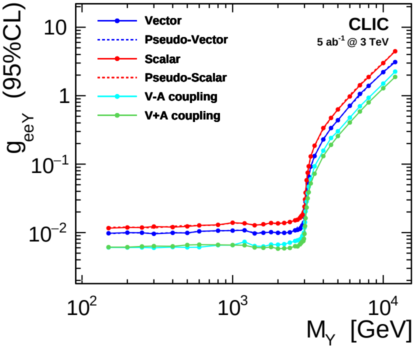
Coupling limits

Combined limits for mediators with $\Gamma/M = 0.03$

ILC @ 500 GeV



CLIC @ 3 TeV

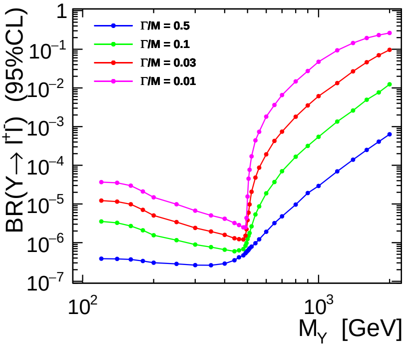


Almost uniform sensitivity to mediator coupling g_{eeY} up to kinematic limit.

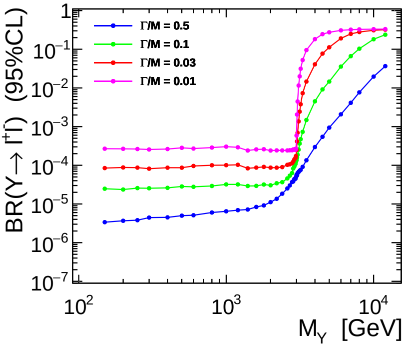
Prospects for SM decay observation

Limits on the SM-mediator couplings can be translated into limits on the mediator branching ratio to charged leptons

ILC @ 500 GeV



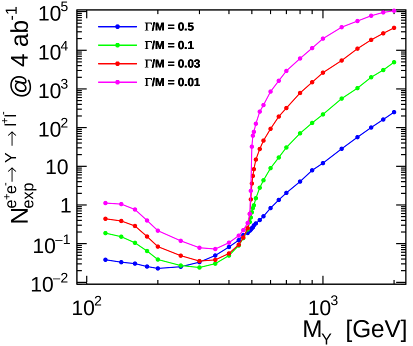
CLIC @ 3 TeV



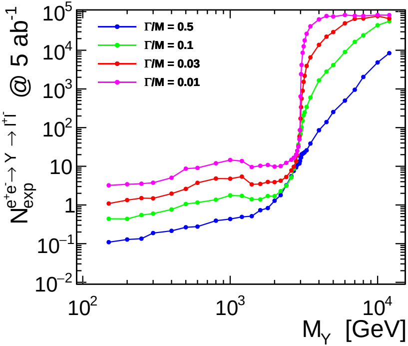
Prospects for SM decay observation

Limits on the SM-mediator couplings can be translated into expected numbers of produced lepton pairs

ILC @ 500 GeV



CLIC @ 3 TeV



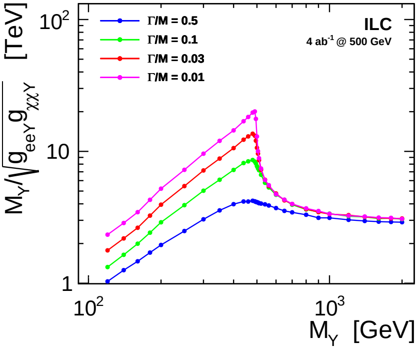
Limits from mono-photon analysis more stringent than those expected from direct resonance search in SM decay channels

Effective mass scale limits

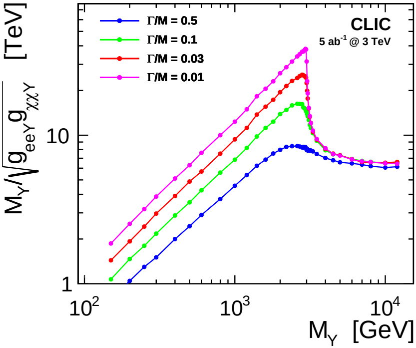
$$\Lambda^2 = \frac{M_Y^2}{|g_{eeY}\, g_{\chi\chi Y}|}$$

Combined limits for Vector mediator

ILC @ 500 GeV



CLIC @ 3 TeV



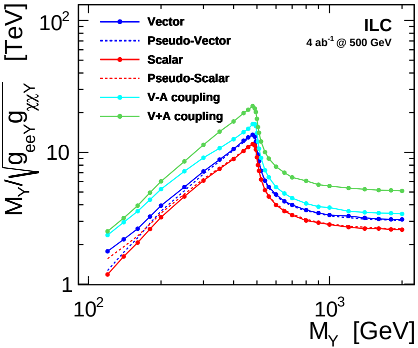
EFT approach valid only for $M_Y \gtrsim 3\sqrt{s}$!...

Effective mass scale limits

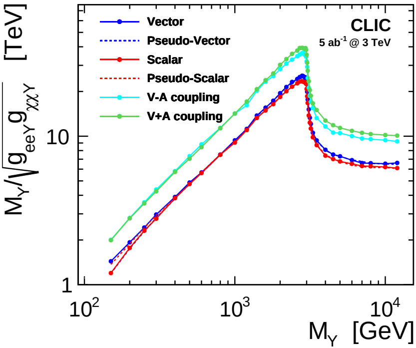
$$\Lambda^2 = \frac{M_Y^2}{|g_{eeY}\, g_{\chi\chi Y}|}$$

Combined limits for mediators with $\Gamma/M = 0.03$

ILC @ 500 GeV



CLIC @ 3 TeV



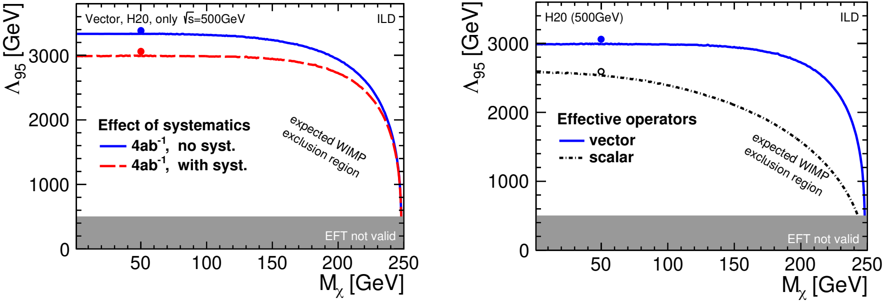
EFT approach valid only for $M_Y \gtrsim 3\sqrt{s}$!...

Comparison with ILD study

arXiv:2001.03011

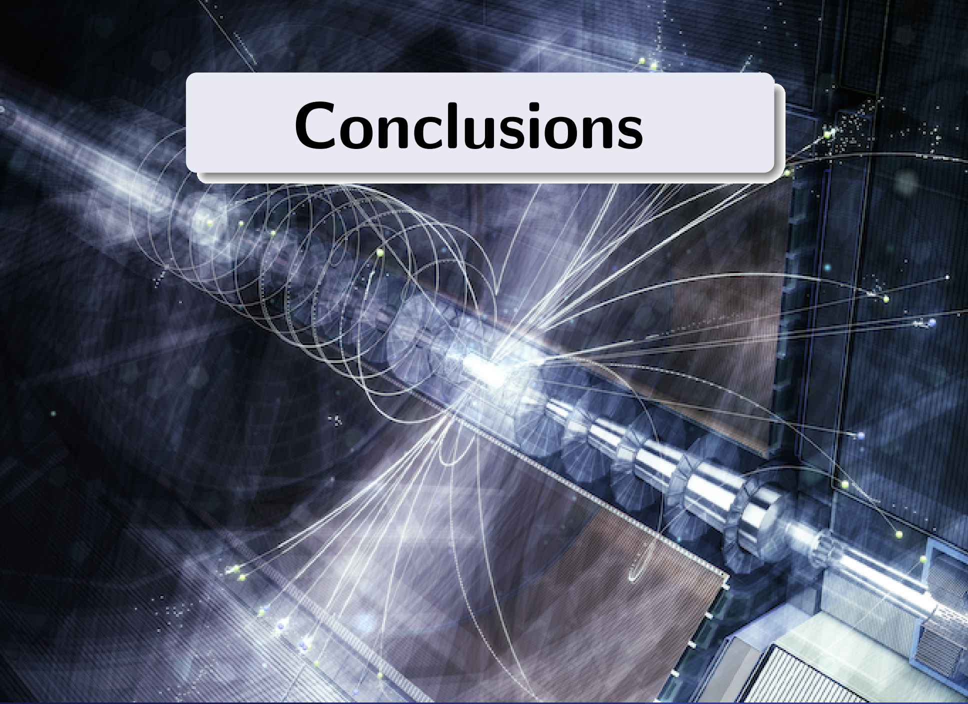
Effective mass scale limits: $$\Lambda^2 = \frac{M_Y^2}{|g_{eeY} g_{\chi\chi Y}|}$$

Limits from fast simulation (points) vs limits from full simulation (lines)



Very good agreement between full simulation and fast simulation results!
$\Rightarrow$ reliable extrapolation to low mediator mass domain...

Conclusions



Conclusions

Sensitivity of future linear e^+e^- colliders to processes of dark matter production with light mediator exchange

arXiv:2107.11194, in print

Mono-photon signature: the most general way to look for DM production, EFT sensitivity extending to the $\mathcal{O}(10)$ TeV mass scales

New framework for mono-photon analysis developed
focus on light mediator exchange and very small mediator couplings to SM

- $\mathcal{O}(1\,\text{fb})$ limits on the radiative production $e^+e^- \rightarrow \chi\chi\gamma_{\text{tag}}$
- $\mathcal{O}(10\,\text{fb})$ limits on the DM pair-production $e^+e^- \rightarrow \chi\chi(\gamma)$
  except for the resonance region $M_Y \sim \sqrt{s}$
- $\mathcal{O}(10^{-3} - 10^{-2})$ limits on the mediator coupling to electrons
  up to the kinematic limit $M_Y \leq \sqrt{s}$

For light mediators limits more stringent than those expected from direct resonance search in SM decay channels

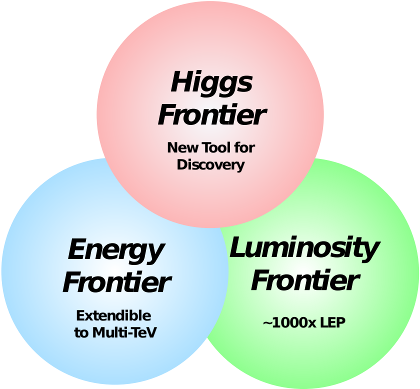
Other options for probing Dark Matter

Dark Matter

Many hints for existence of Dark Matter (DM), but its nature is unknown.
Many possible scenarios, wide range of masses and couplings to consider.

High energy e^+e^- machines offer many options for DM searches:

ILC overview talks given at SUSY'2021 and PANIC'2021

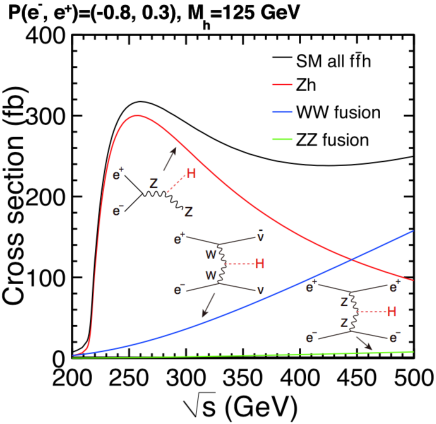


Tomohiko Tanabe @ LCWS'2021

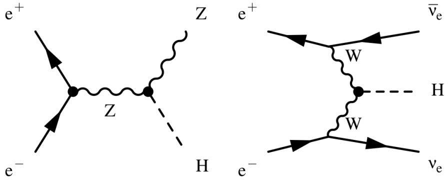
Section image: Rey.Hori (copied from ILC Newsline)

First ILC running stage will clearly be focused on Higgs measurements

Production cross section



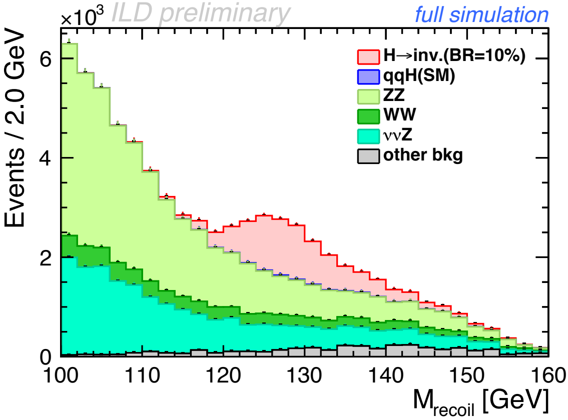
At 250 GeV dominated by Higgs-strahlung (ZH production)



but we still profit from combining two production channels
$\Rightarrow$ model independent analysis

Invisible decays

High sensitivity to invisible Higgs boson decays with recoil mass technique



Expected 95% C.L. limit for 2 ab^{-1} collected at 250 GeV ILC: 0.23%

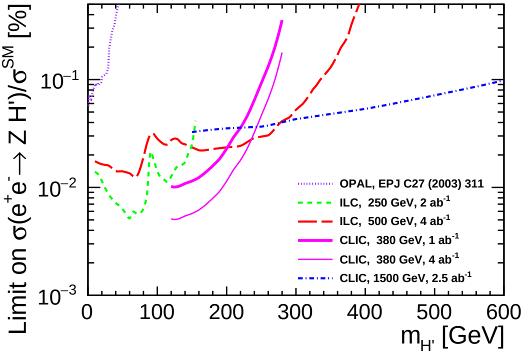
a factor of 10 better than the HL-LHC prospect. arXiv:2002.12048

Search for new scalars

Many BSM models introduce extended Higgs sectors.

New scalars could be light, if their couplings to SM particles are small.

Search for new scalars: arXiv:1903.01629 arXiv:2005.06265 arXiv:2002.06034

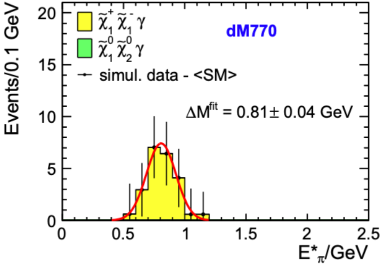


ILC search independent on the scalar decay: $e^+e^- \to Z\ S^0 \to \mu^+\mu^- + X$

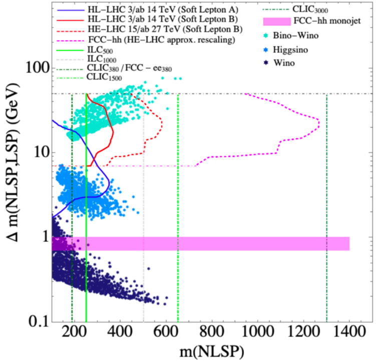
Soft SUSY scenarios

Thanks to clean environment, sensitivity of e^+e^- colliders extends down to very small NLSP-LSP mass differences

Chargino pair production study



arXiv:1307.3566



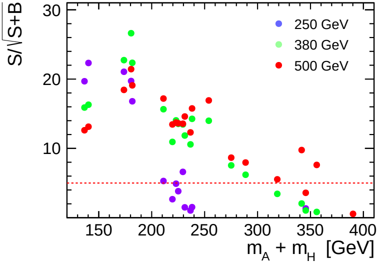
arXiv:2105.06408

Search for IDM scalar production

Production of IDM scalars at e^+e^- colliders dominated by two processes:

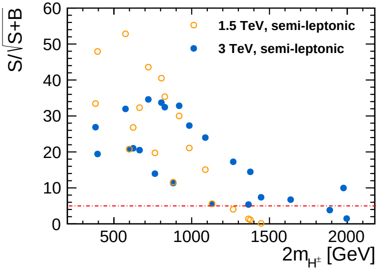
$$e^+e^- \rightarrow A \; H \qquad\qquad e^+e^- \rightarrow H^+ H^-$$

Search for AH production
leptonic channel



arXiv:2002.11716

Search for H^+H^- production
semi-leptopnic channel

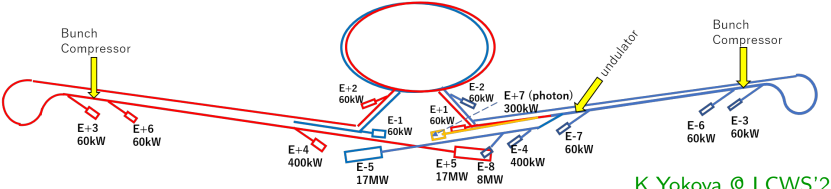


arXiv:2107.13803

ILC beam dumps

Electron and positron beams, with extreme intensities ($\sim 10^{22} e^{\pm}/y$)

Many beam dump points planned around the ILC facility



K.Yokoya @ LCWS'2021

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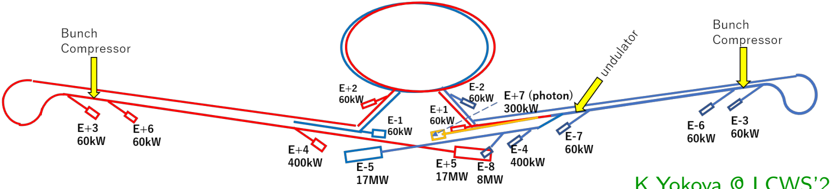
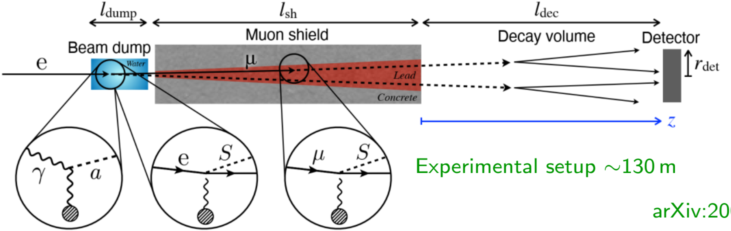


K.Yokoya @ LCWS'2021

Concept of main beam dump experiments searching for axion-like particles or new scalars:



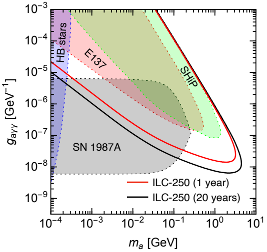
Experimental setup ~130 m

arXiv:2009.13790

Main beam dump experiments

Looking for SM decays of new exotic particles produced in the beam dump

arXiv:2009.13790



Axion-like particle model   looking for $a \to \gamma\gamma$

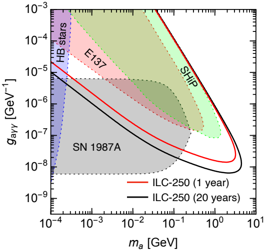
$$\mathcal{L} \ni -\frac{1}{4} g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu} + \frac{1}{2}(\partial_\mu a)^2 - \frac{1}{2} m_a^2 a^2$$

An order of magnitude better sensitivity than other experiments

Main beam dump experiments

Looking for SM decays of new exotic particles produced in the beam dump

arXiv:2009.13790



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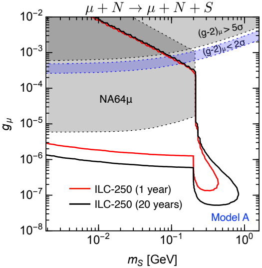

Light scalar coupled to charged leptons

$$\mathcal{L} \ni \frac{1}{2}(\partial_\mu S)^2 - \frac{1}{2} m_S^2 S^2 - \sum_{l=e,\mu,\tau} g_l S \bar{l} l$$

Model A: $g_l \propto m_l$

Sensitivity down to very small couplings

Main beam dump experiments

M.Perelstein @ LCWS'2021

Scenarios with Dark Photon (A') and Dirac fermion DM (χ)

$$\mathcal{L} \ni -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}m^2_{A'}A'_\mu A'^\mu - \frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu} + \bar{\chi}(\imath \not{D} - m_\chi)\chi$$

Resonant ($e^+e^- \to A'$), associated prod. ($e^+e^- \to A' \gamma$) or radiation ($e^\pm N \to e^\pm N A'$)

$\Rightarrow$ collimated stream of DM particles from A' decay ($A' \to \chi\chi$)

$\Rightarrow$ looking for elastic χ interactions in the detector

Approach used in SLAC Beam Dump Experiment E137

arXiv:1406.2698

Non-collider experiments

Main beam dump experiments

M.Perelstein @ LCWS'2021

Scenarios with Dark Photon (A') and Dirac fermion DM (χ)

$$\mathcal{L} \ni -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}m^2_{A'}A'_{\mu}A'^{\mu} - \frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu} + \bar{\chi}(\imath \not{D} - m_{\chi})\chi$$

Resonant ($e^+e^- \to A'$), associated prod. ($e^+e^- \to A'\,\gamma$) or radiation ($e^\pm N \to e^\pm N\, A'$)

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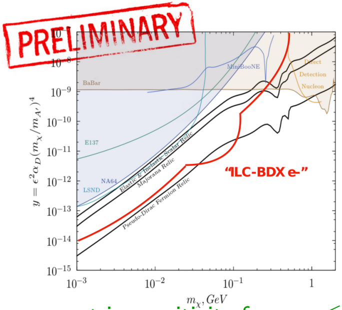
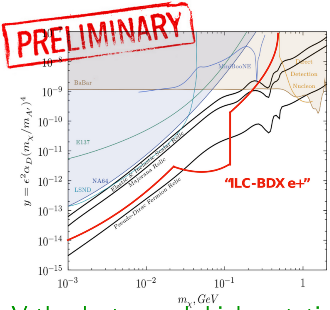




Huge improvement in sensitivity for $m_{A'} \lesssim 1$ GeV thanks to much higher statistics

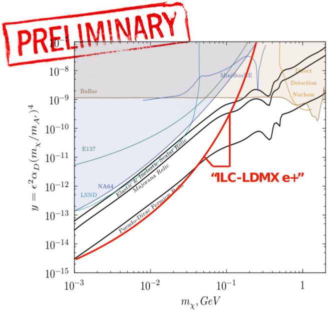
Experiments with extracted beams

M.Perelstein @ LCWS'2021

Searching for Dark Photons with extracted positron beams

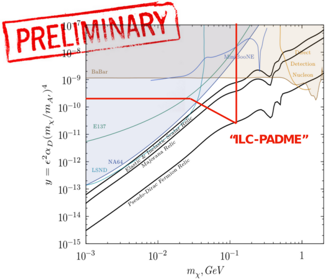
$$e^+e^- \to A'\gamma$$

Missing energy reconstruction in thick active target



LDMX for SLAC: arXiv:1807.05884

Thin target, missing mass reconstruction in dedicated detector



PADME @ Frascati: arXiv:1910.00764

Sensitivity extending down to the minimum couplings allowed by relic density bounds

Probing Dark Matter with ILC

ILC will offer many complementary options for DM searches.

- Different scenarios can be constrained via precision Higgs studies.
- Clean environment and kinematic constraints of e^+e^- collisions result in high sensitivity to different DM production scenarios.
- Sensitivity extends to the TeV mass scales,
  order of magnitude higher than the collision energy.

The ILC will also offer highest energy electron and positron beams, with unprecedented intensities, for beam dump and extracted beam exp.

Fixed-target experiments offer many interesting opportunities for dark sector searches in the low mass domain and other science goals.

Thank you!

Simplified DM model

Dark matter particles, X_i, couple to the SM particles via an mediator, Y_j.

Each simplified scenario is characterized by one dark matter candidate and one mediator from the set listed below:

	particle	mass	spin	charge	self-conjugate	type
DM	X_R	m_{X_R}	0	0	yes	real scalar
	X_C	m_{X_C}	0	0	no	complex scalar
	X_M	m_{X_M}	$\frac{1}{2}$	0	yes	Majorana fermion
	X_D	m_{X_D}	$\frac{1}{2}$	0	no	Dirac fermion
	X_V	m_{X_V}	1	0	yes	real vector
mediator	Y_R	m_{Y_R}	0	0	yes	real scalar
	Y_V	m_{Y_C}	1	0	yes	real vector
	T_C	m_{T_C}	0	1	no	charged scalar