Dark Matter Search at ILC

1. Homework from MEXT
2. Experimental Issues
   a) Mono-photons
   b) 2-fermion process

Tomohiko Tanabe (U. Tokyo)

November 4, 2015

LCWS2015 @ Whistler

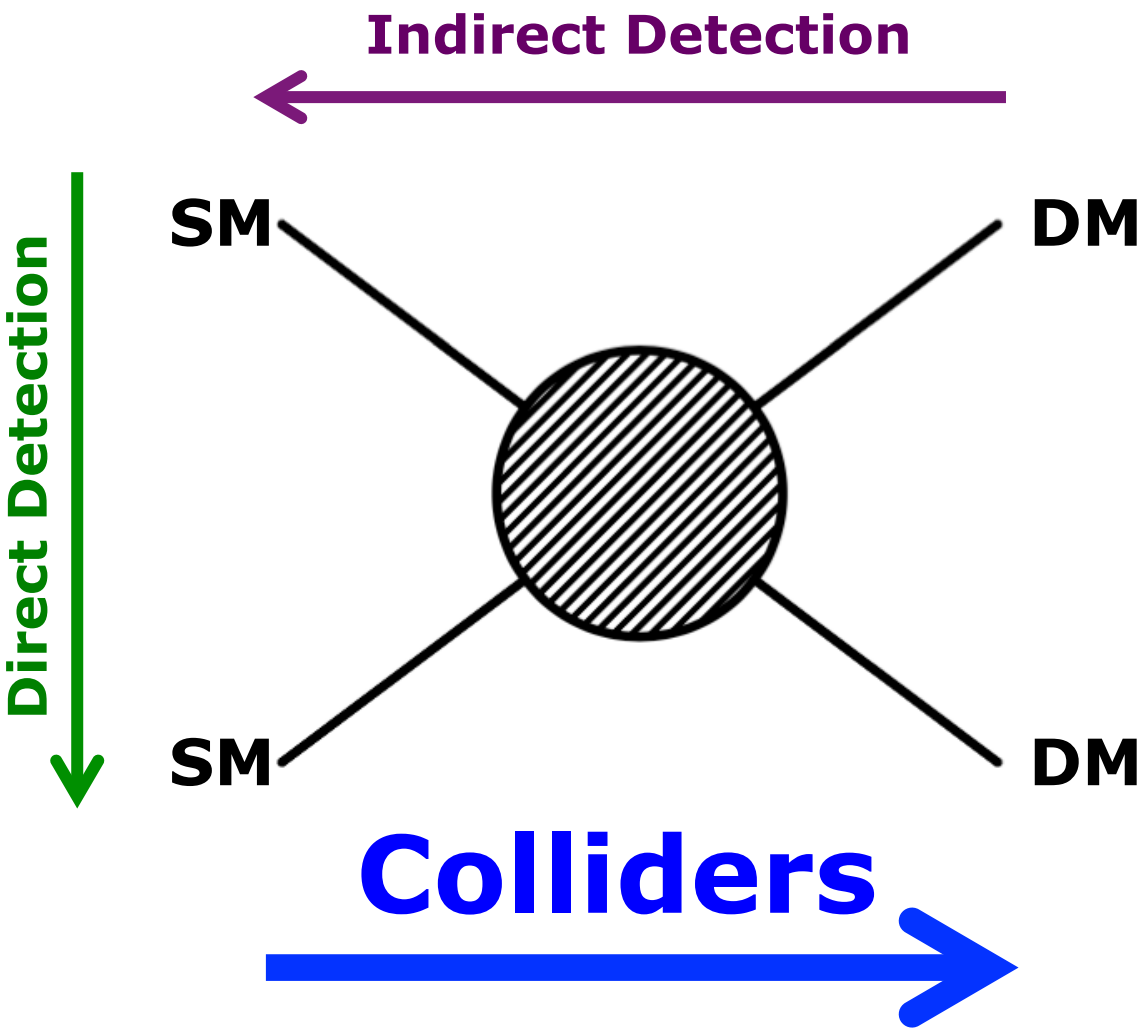
[ILD/SiD Joint Session]

On Fri, Oct 23, 2015 at 9:01 PM,
Keisuke Fujii <keisuke.fujii@kek.jp> wrote:

The MEXT ILC advisory panel requested a clear vision for new particle discovery potential. They required prospects for new particle discoveries in each of the following three cases:

1) **LHC finds no new particle.**
2) **LHC finds a (strongly interacting) new particle (say 1.6 TeV gluino for instance), which implies the existence of different kinds of new particle (say Ewkinos) within the ILC's reach.**
3) **LHC finds a (strongly interacting) new particle (say 2.0 TeV gluino for instance), which implies m_bino beyond the reach of the 500GeV ILC.**

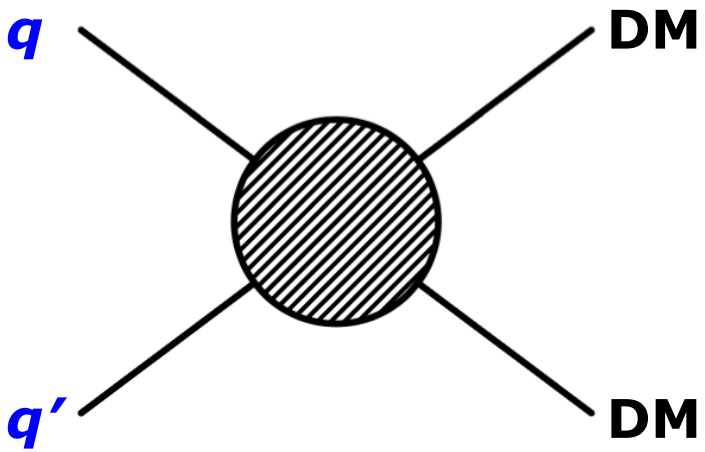
Dark Matter Searches



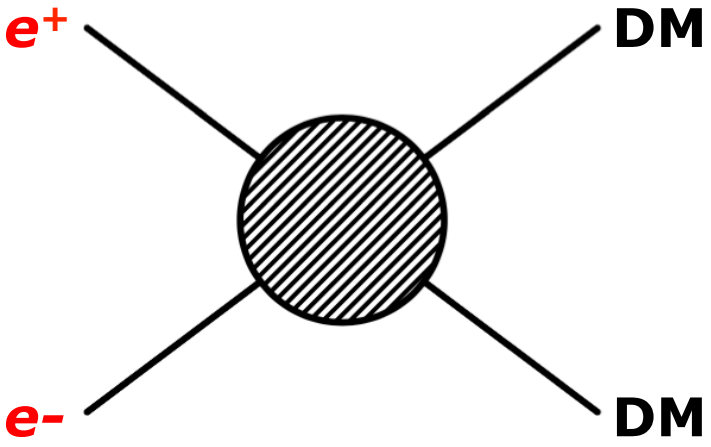
Complementary ways to search for DM

Dark Matter Searches

LHC

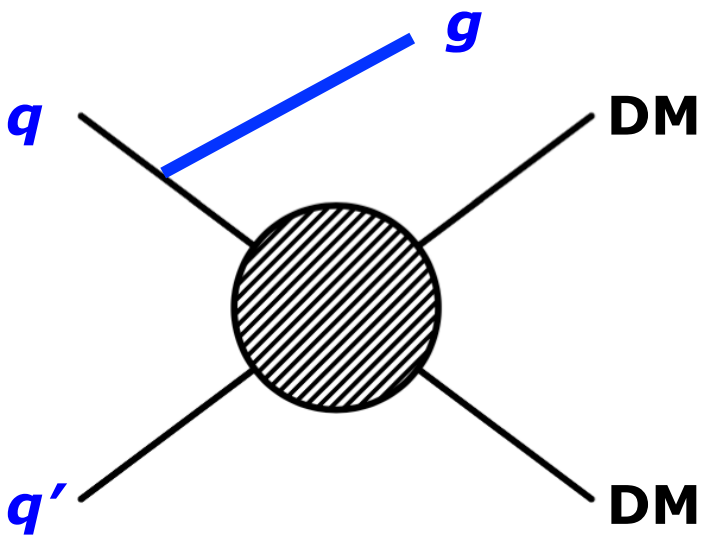


ILC



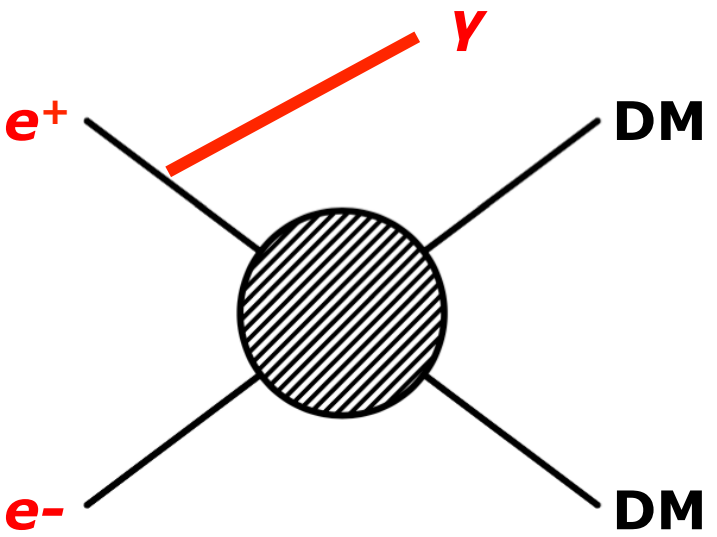
different initial state → complementary sensitivity to DM

Dark Matter Searches



LHC

mono-jets
also,
mono-photons
mono-Z/W/H

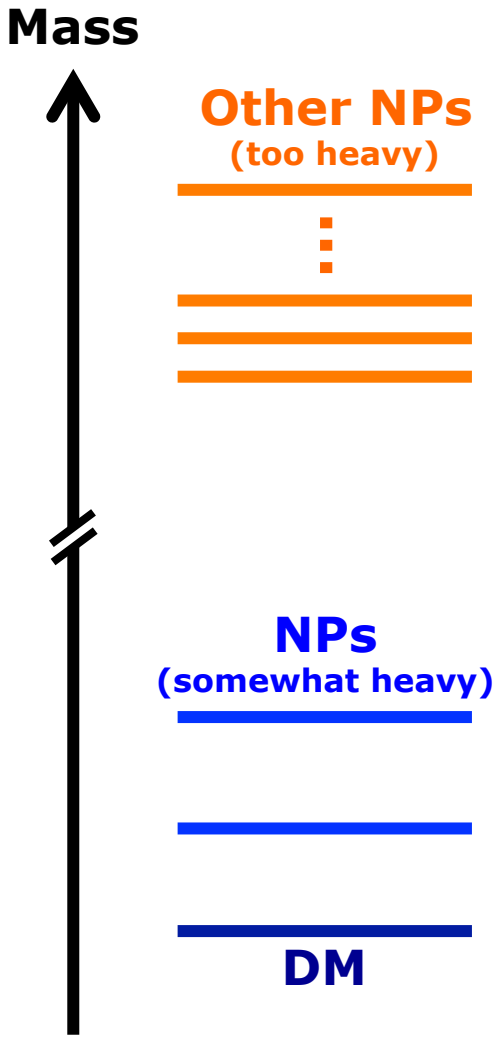


ILC

mono-photons

different initial state → complementary sensitivity to DM

Mass Spectra



Sufficiently large mass gaps between DM and other NPs:

At LHC:
Discovery likely.

At ILC:
Precise measurements of mass, spin & cross sections

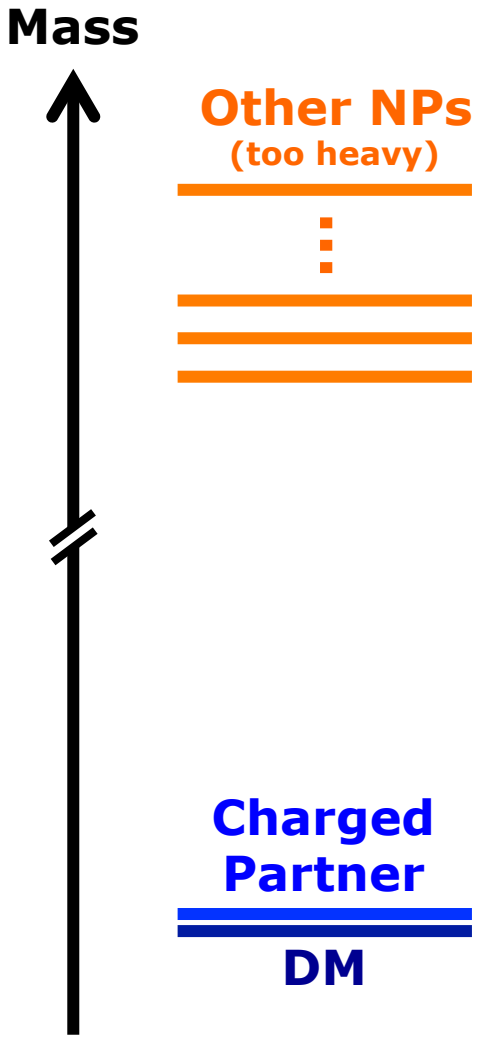
→ **check DM relic density**

Determine coupling structure with beam polarizations, e.g. SUSY or not

ILC's unique role: determine if new particle is actually DM

See next talk by M. Berggren, stau coannihilation scenario.

Mass Spectra



For compressed spectra:

At LHC:
Discovery **challenging**

At ILC:
Discovery **likely**

AND

Precise measurements of mass, spin & cross sections

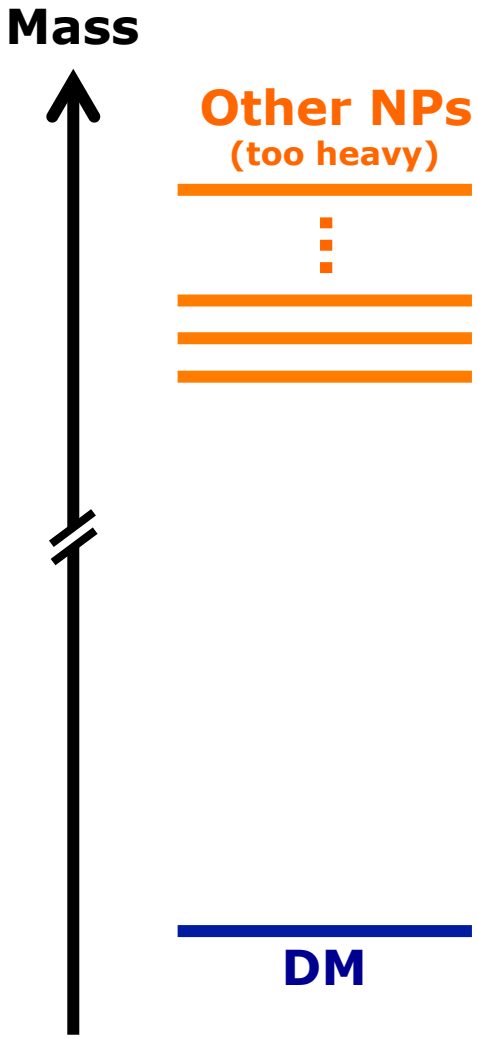
→ **check DM relic density**

Determine coupling structure with beam polarizations, e.g. SUSY or not

ILC's unique role: discovery potential for compressed spectra & determine if new particle is actually DM

See next talk by M. Berggren, light Higgsinos in natural SUSY scenario.

Mass Spectra



If DM is the only particle that is kinematically accessible:

At LHC:
Discovery possible

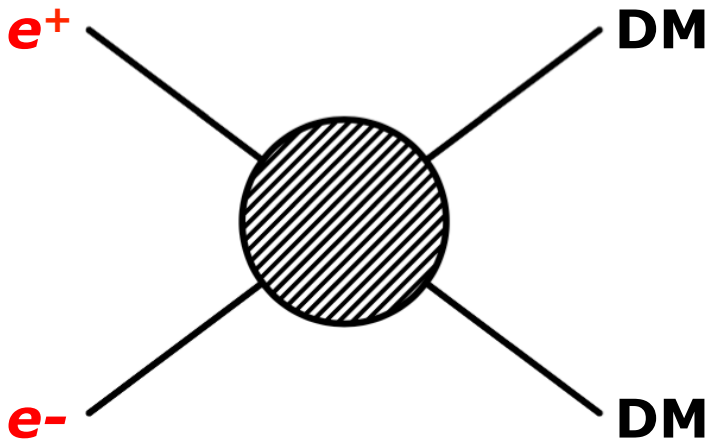
At ILC:
Discovery possible

Reach depends on type of DM → complementarity between LHC/ILC

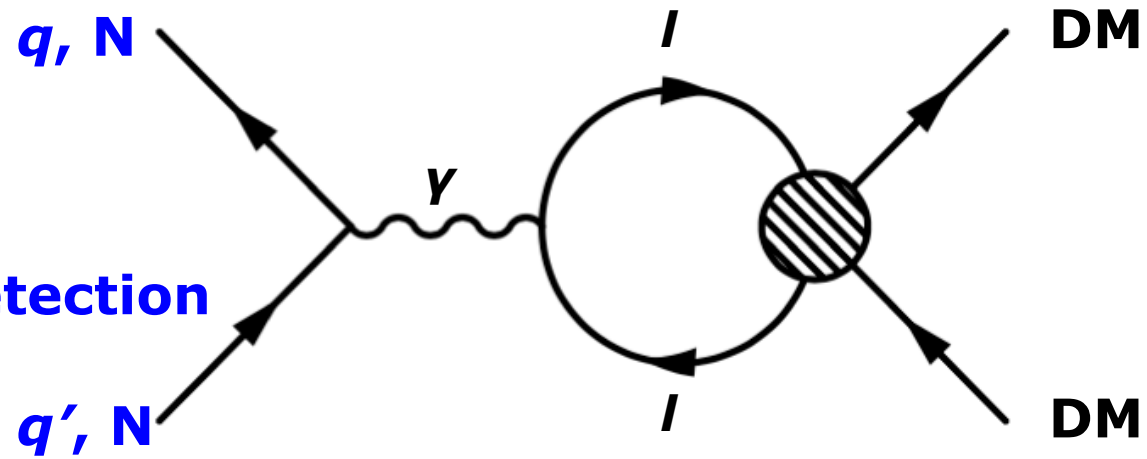
LHC and ILC have complementary capabilities in DM searches.

e.g.) Leptophilic DM

ILC



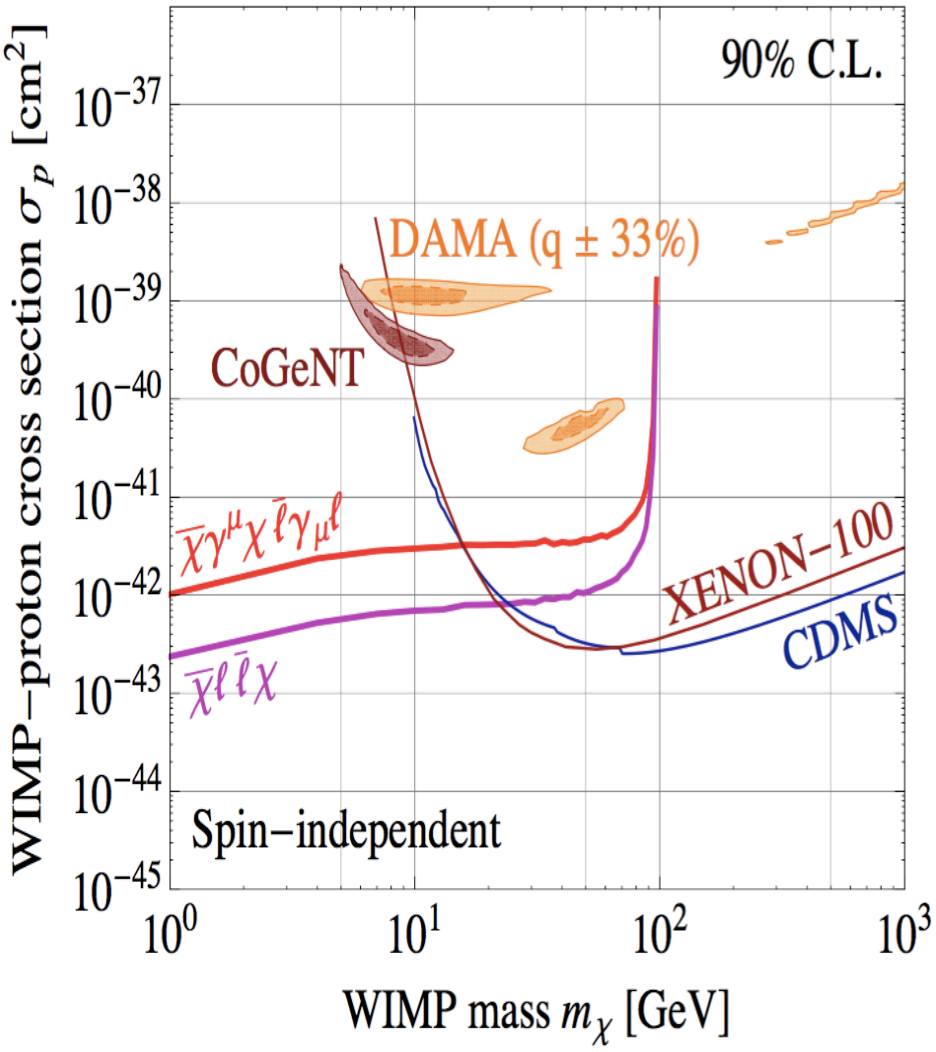
LHC,
Direct Detection



→ loop suppression

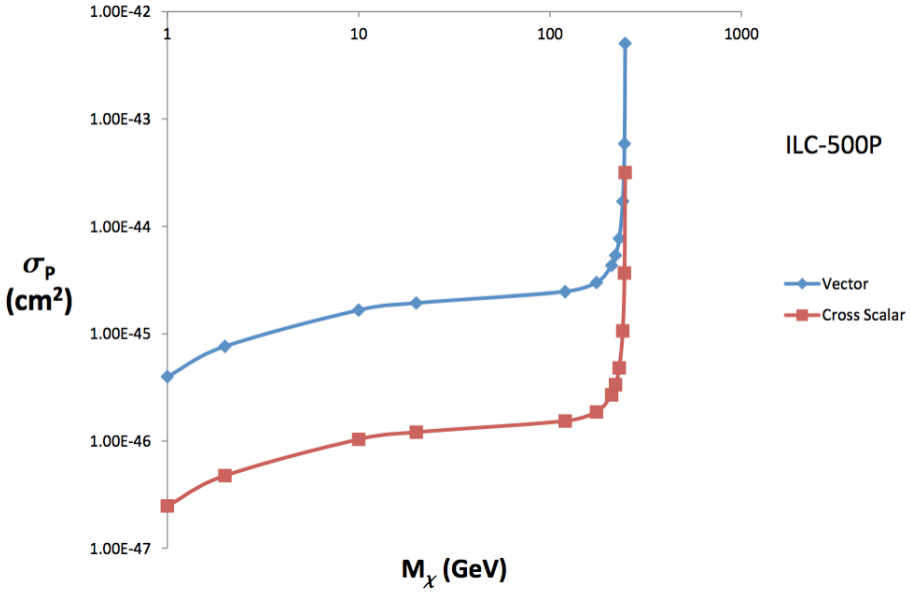
ILC has unique sensitivity to electron-DM coupling

Couplings to leptons only

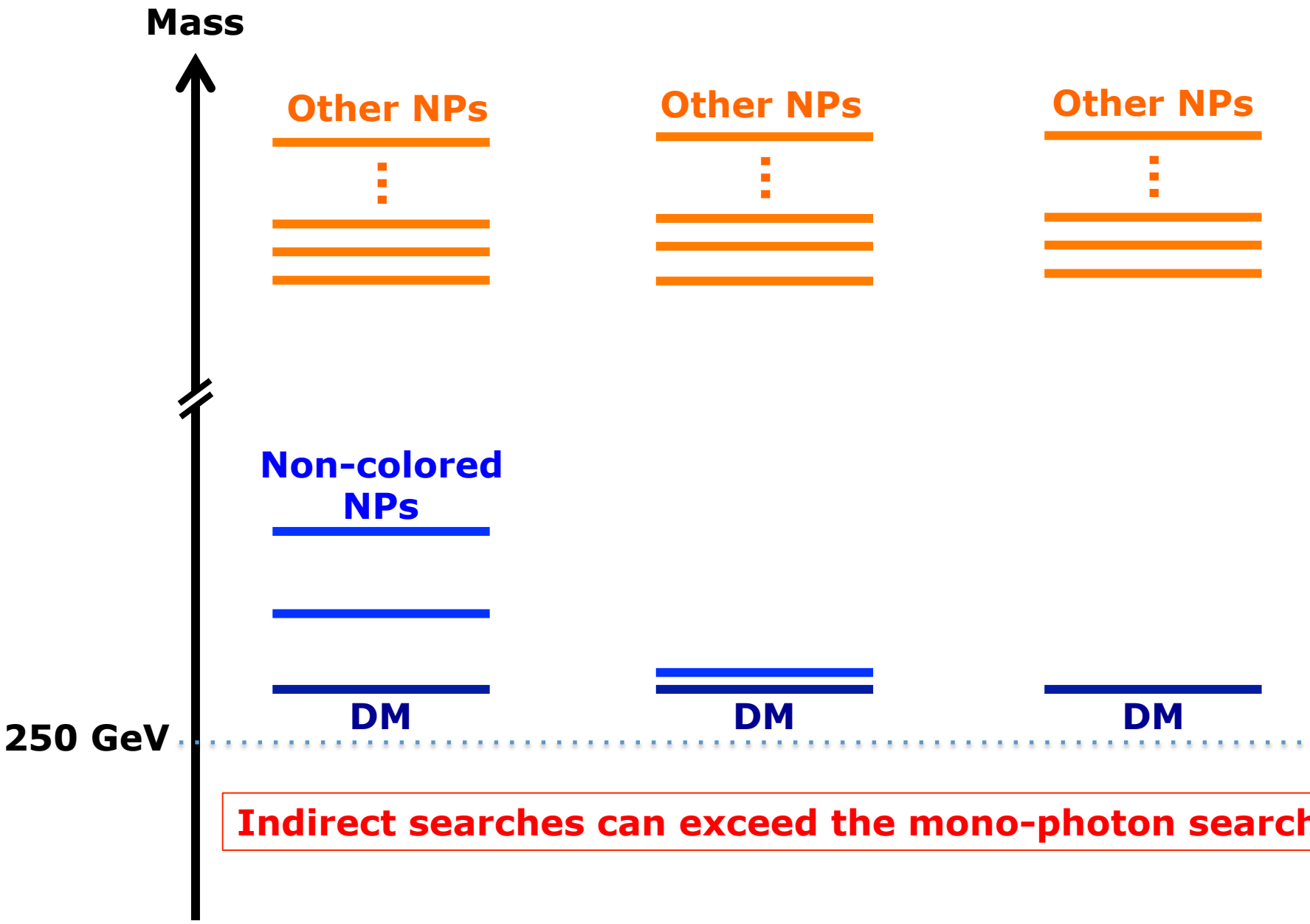


LEP limits
[Fox, Harnik, Kopp, Tsai, 1103.0240]

ILC 500 GeV
[Chae, Perelstein, 1211.4008]



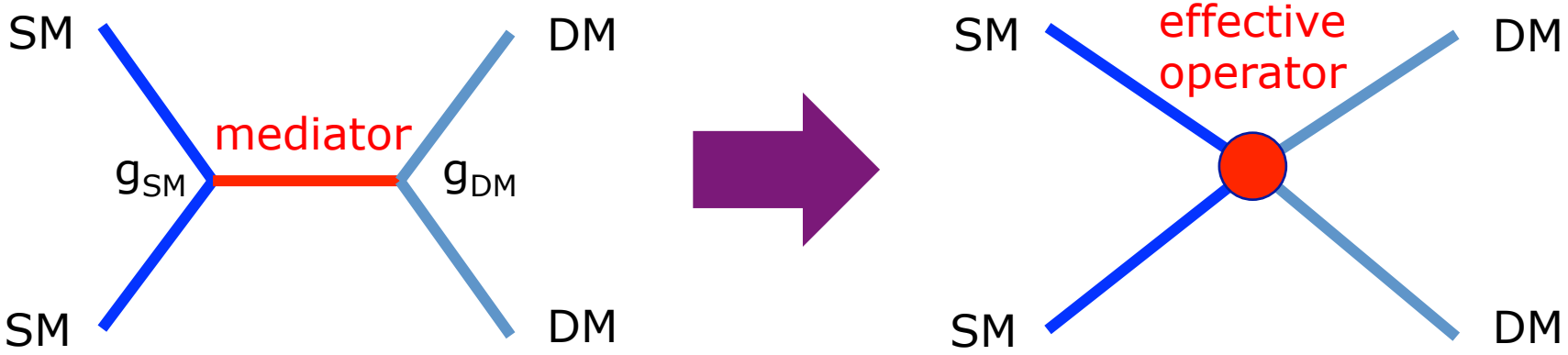
What if…?



Indirect searches can exceed the mono-photon search

Effective Field Theory

New physics interaction mediated by a heavy particle can be integrated out to give a four-point contact interaction:



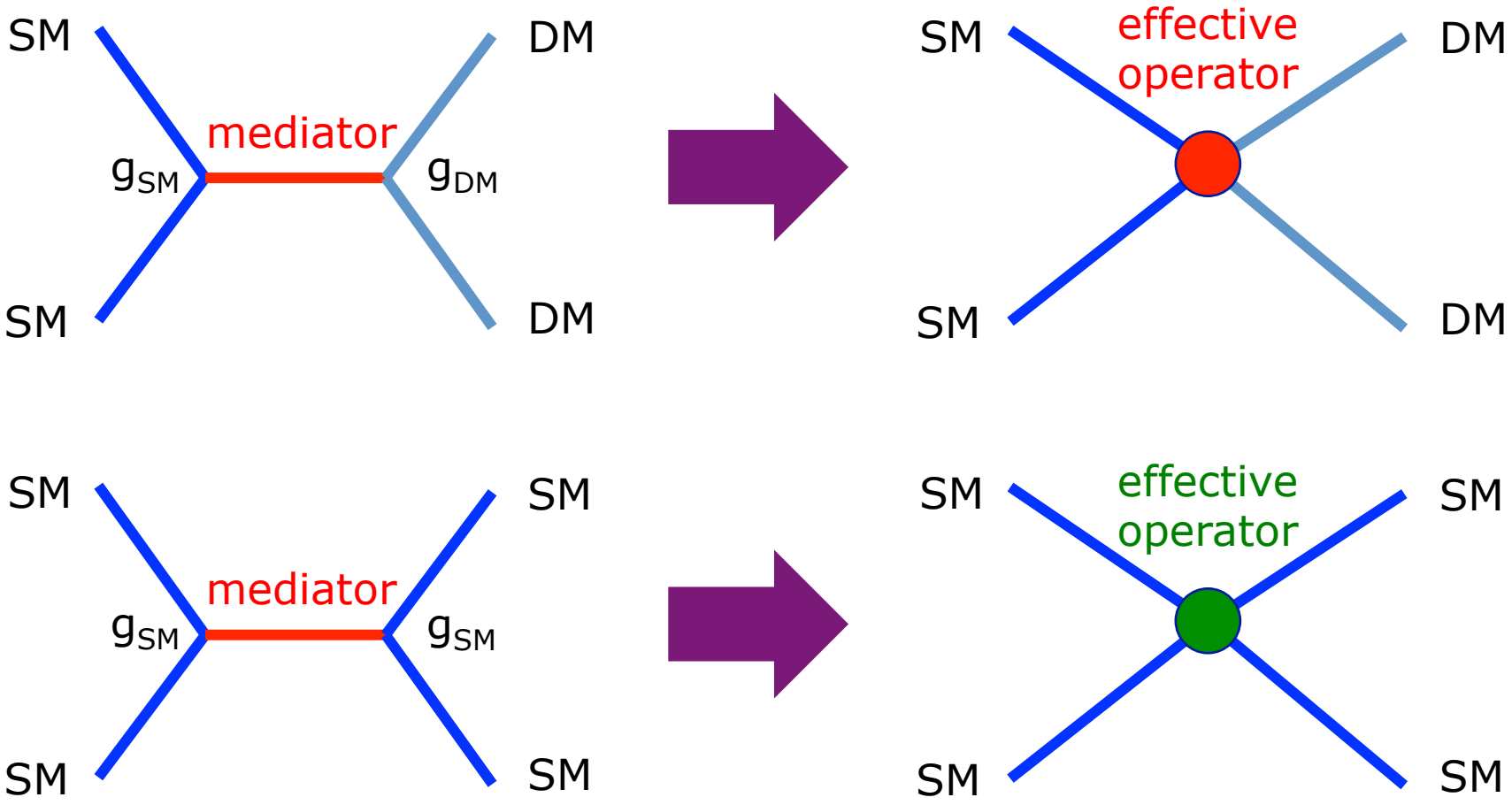
$$\left(\frac{g_f g_\chi}{q^2 - M^2}\right)(\overline{f}\gamma_\mu f)(\overline{\chi}\gamma^\mu \chi) \qquad \frac{1}{\Lambda^2}(\overline{f}\gamma_\mu f)(\overline{\chi}\gamma^\mu \chi)$$

EFT is valid for $\mathbf{M_{med} >> 2M_{DM}}$; identify: $\Lambda = M/\sqrt{g_f g_\chi}$

*Outside the domain of validity, must take into account effects of on-shell resonance enhancement and off-shell production.

Effective Field Theory

New physics interaction mediated by a heavy particle can be integrated out to give a four-point contact interaction:



*t-channel processes may also exist

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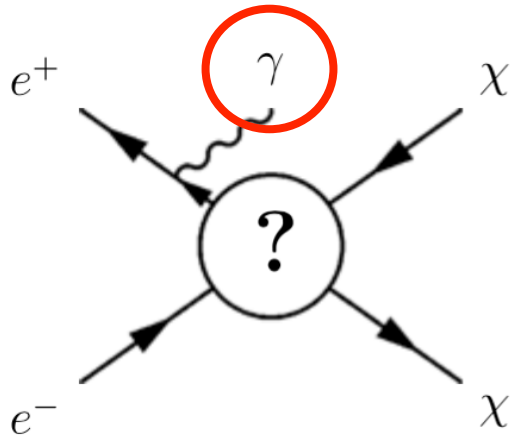
   - b) 2-fermion process

Mono-photons

Signal:

WIMP pair production with ISR photon

e+ e- → DM DM **γ**



- Initial state radiation (**ISR**) photon
- Missing energy + missing momentum

Observables: $\mathbf{E_\gamma}$, $\mathbf{\theta_\gamma}$

DM mass reach ~√s/2

Backgrounds:

Radiative neutrino production

e+ e- → ν ν **γ**

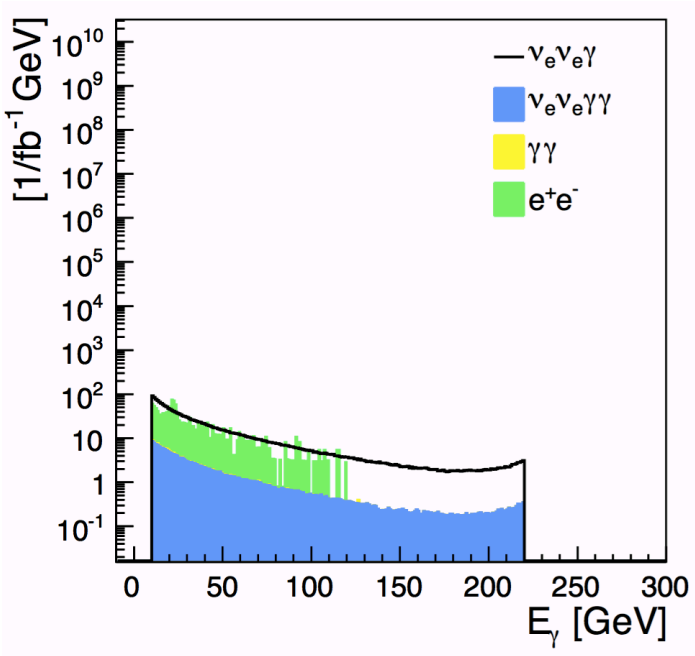
→ ν ν **γ γ** …

Contribution will be known / can be calibrated.

Bhabha scattering

e+ e- → e+ e- **γ**

where the electrons go down the beam pipe undetected. Coverage of forward detectors crucial.



[C.Bartels, Ph.D. Thesis at DESY]

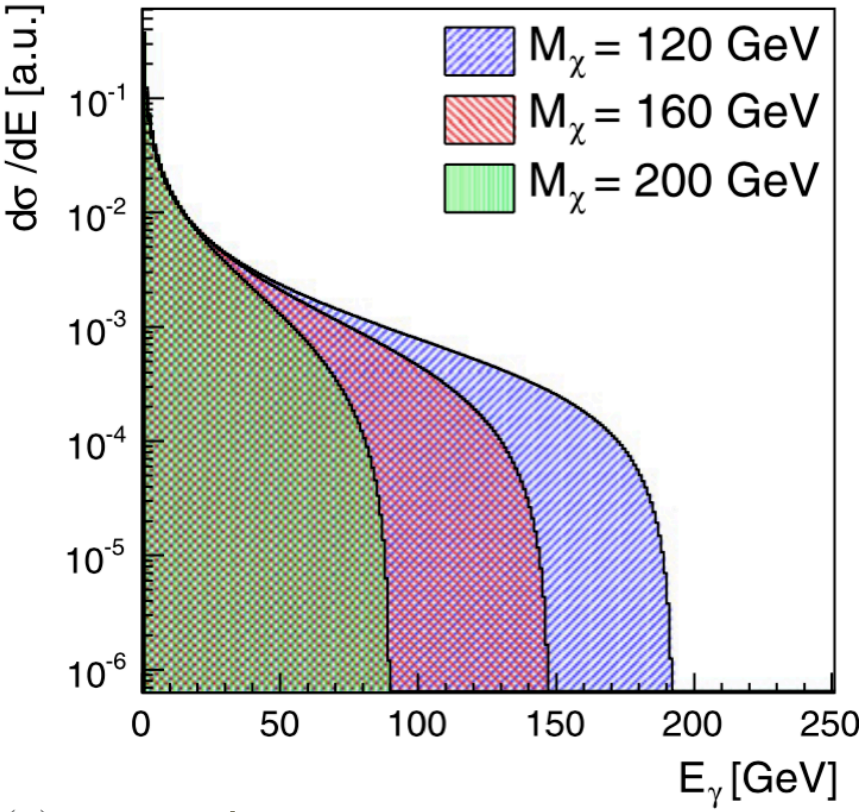
Status of Simulation

Geant4-based full simulation study

- Publication:
  C. Bartels, M. Berggren, J. List, EPJC 72:2213 [arXiv:1206.6639]

- √s = 500 GeV
- 1 GeV < M_{WIMP} < 250 GeV

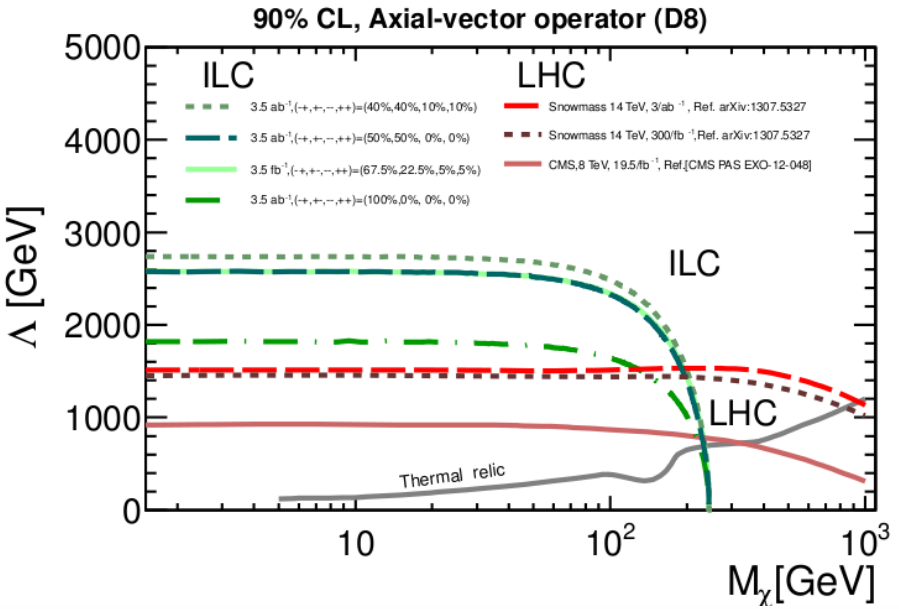
- WHIZARD 1.96
- ilcsoft v01-06
- Beam parameters: RDR
- Detector models:
  LDC_PrimeSc_02, ILD_00



Update plan:

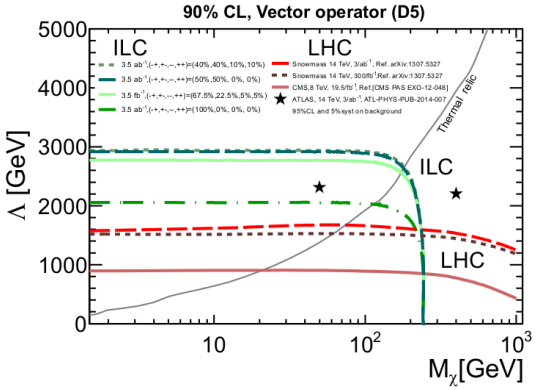
- Other √s, WHIZARD 2, latest software tools,
  TDR parameters, ILD_v1_o5 model

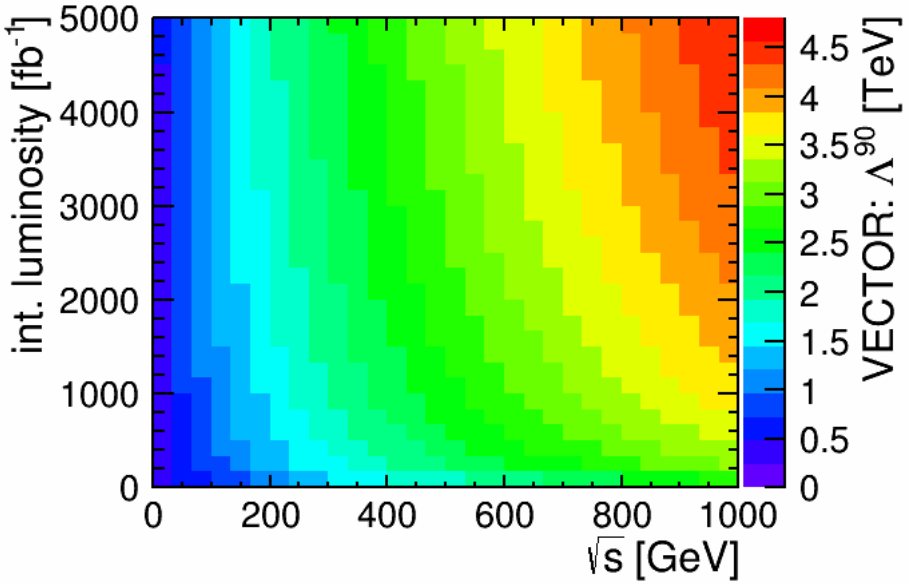
Application: EFT



Interpretation in terms of effective operators

[A. Chaus, J. List, M. Titov]

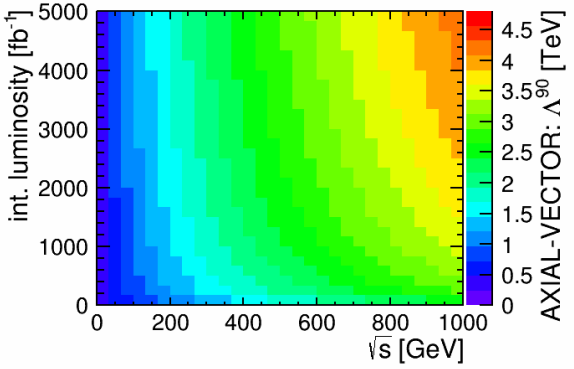




Extrapolation to other √s

[M. Habermehl, J. List]

See: AWLC2015 talk by Habermehl

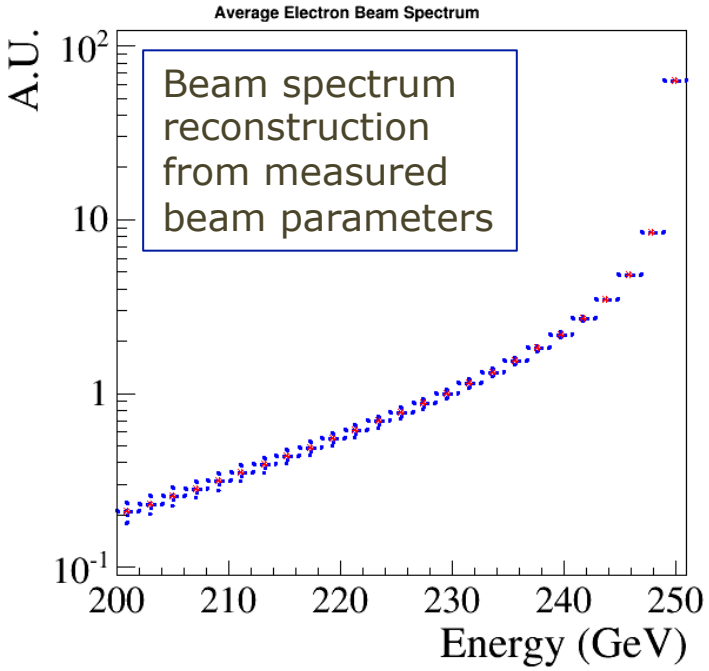


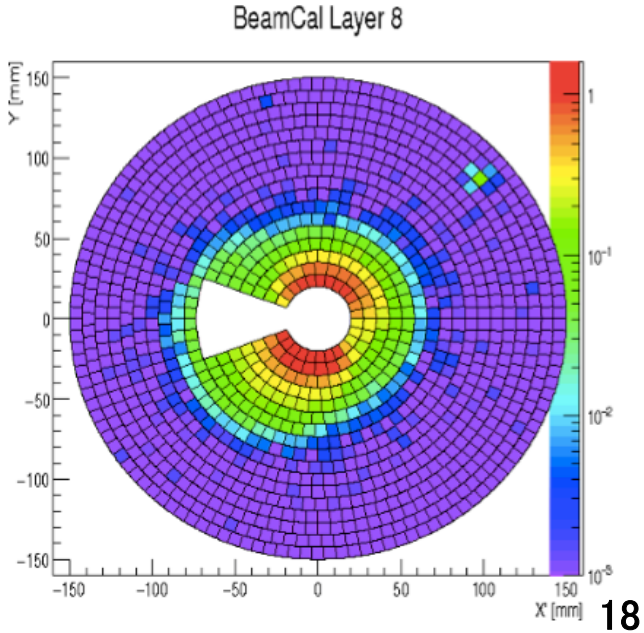
Machinery available to produce sensitivity plots in terms of EFT.

Tasklist for mono-photon analysis

- **Beam energy spectrum** currently the largest source of systematics:
  - New method developed to estimate this from measured beam parameters [M.Habermehl, J.List]
- **BeamCal** reconstruction:
  - Crucial for rejecting Bhabha events
  - Tuning for ILC is in progress [M.Habermehl]
- Ongoing work to exploit new development in the **software**:
  - WHIZARD2
  - Newly-tuned PandoraPFA

For details, please see my presentation on Wednesday in the Sim/Det/Rec session.





Dark Matter Search at ILC

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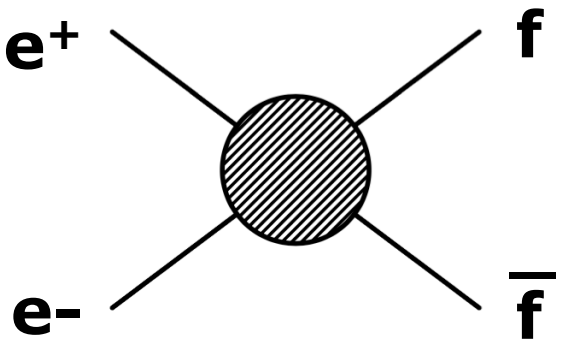
   a) Mono-photons
   b) 2-fermion process 

e+e- → 2 fermion process

- **e+e- → ff**
  - with f = u/d/s, c, b, t, e, μ, τ
  - **e+e- → WW, ZZ** may also be useful



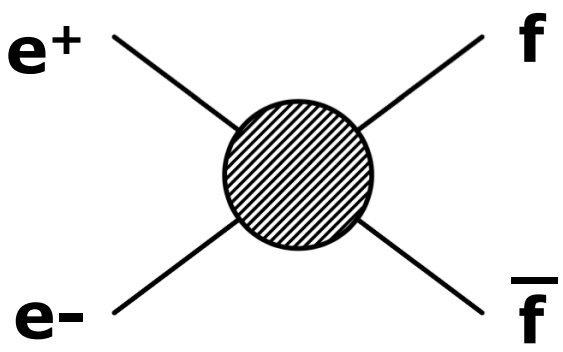
- **Observables:**
  - Polarized cross sections
  - Forward backward asymmetries
    (or equivalently differential cross section)

- The large cross section of these events implies measurements will quickly become **systematically limited.** Need to demonstrate control of all the relevant systematics; **it will immediately pay off !**

	Z' study [TDR]	**Baseline [Snowmass]**	**LumiUp [Snowmass]**
Luminosity	0.2%	0.1%	0.05%
Polarization	0.25%	0.1%	0.05%
b-tagging	0.5%	0.3%	0.15%

e+e- → 2f [SUSY DM example]

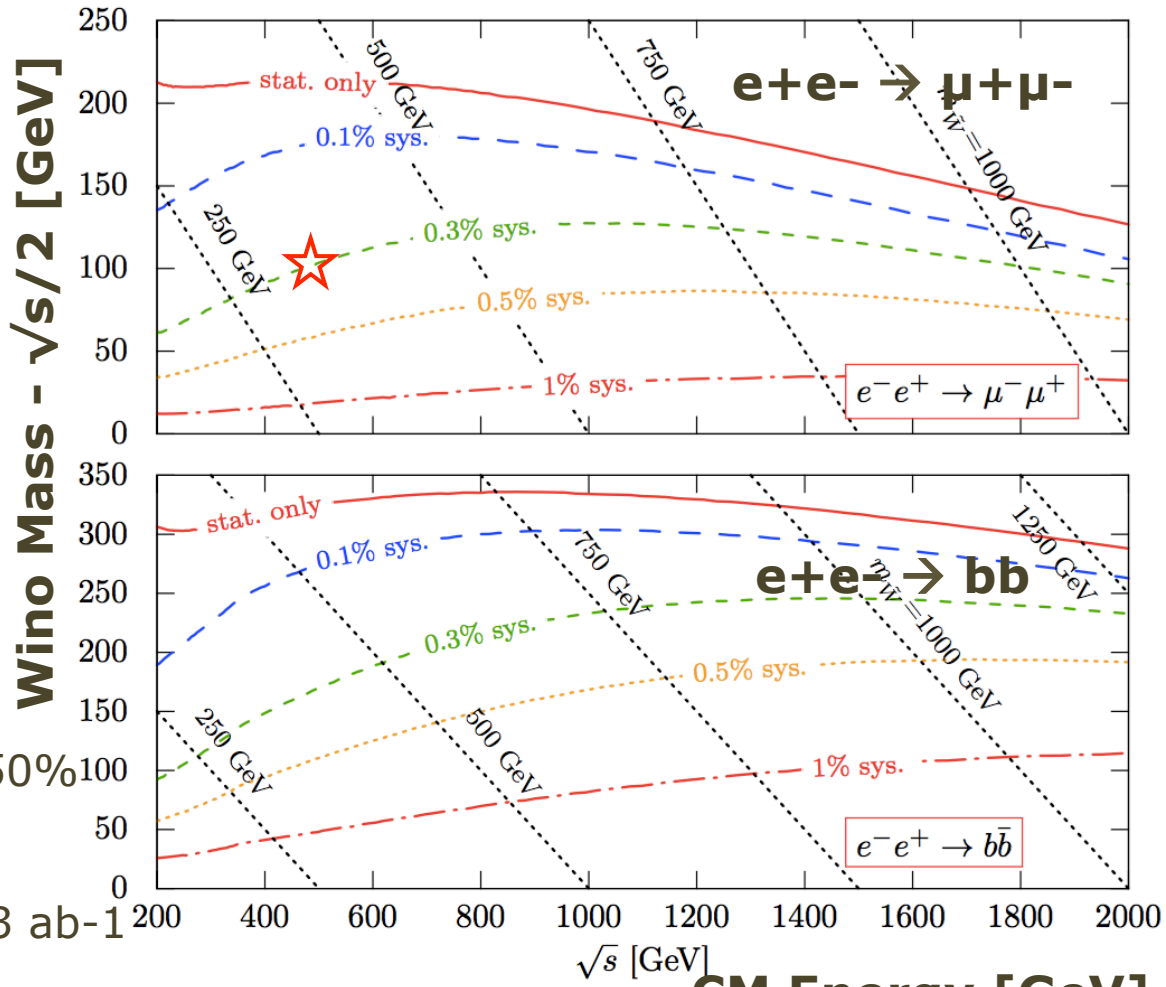
[Harigaya, Ichikawa, Kundu, Matsumoto & Shirai 1504.03402]



Binned likelihood analysis of differential cross sections, comparing expected number of events in BSM vs. that of SM.

Efficiencies assumed:
leptons 100%, b-jet 80%, c-jet 50%

Other assumptions
P(e-,e+) = (-0.8,+0.6), Lumi = 3 ab-1



Indirect reach significantly higher than direct search
<u>if systematics is under control</u>
e.g. for √s=500 GeV, e+e- →μ+μ- :
Wino mass reach = 350 GeV (for total systematics 0.3%)

Summary

Dark Matter search:

- Collider search complementary with direct detection / indirect detection

Advantages of ILC in DM studies:

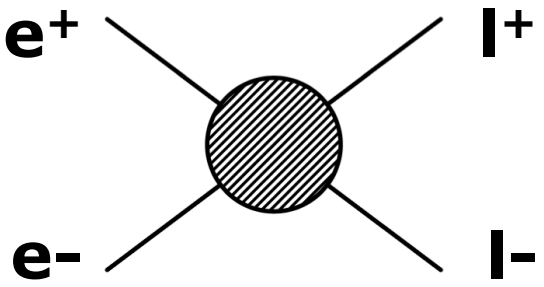
- Electron-DM coupling ("leptophilic DM")
- Compressed spectra (challenging for LHC) → Next talk by M. Berggren
- Once discovered, ILC can determine
  - Coupling structure, via beam polarization
  - Cross sections → compare with relic density

Methods to search for DM at the ILC:

- **Mono-photons**
  - Direct mass reach ~ √s/2
  - Update is underway, exploiting new development in software.
- **e+e- → 2f**
  - Indirect mass reach potentially higher than √s/2 if systematics can be controlled
  - Dedicated studies on systematics are desired

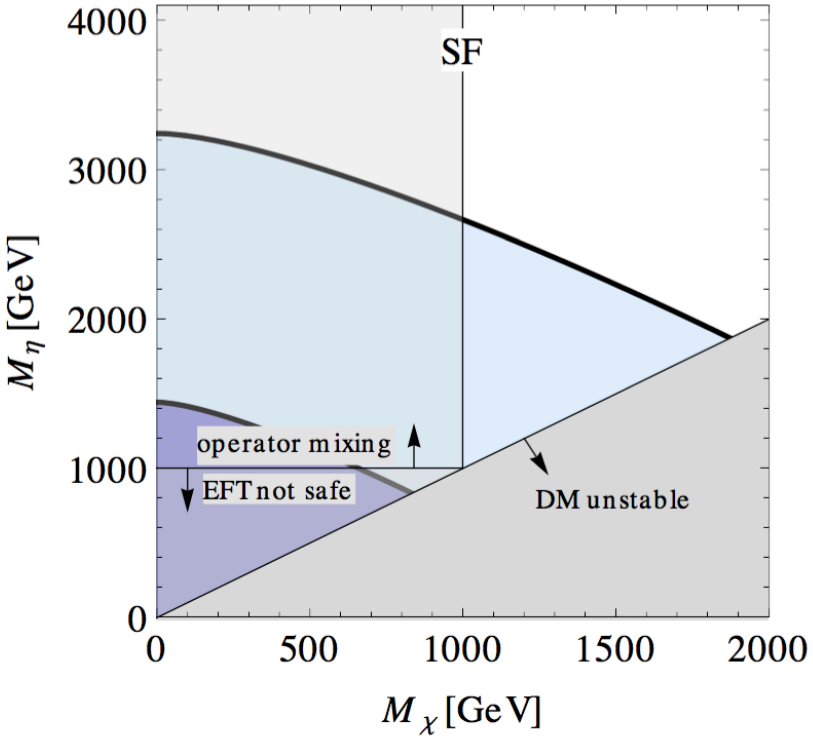
Additional Slides

4f interaction [Leptophilic DM]

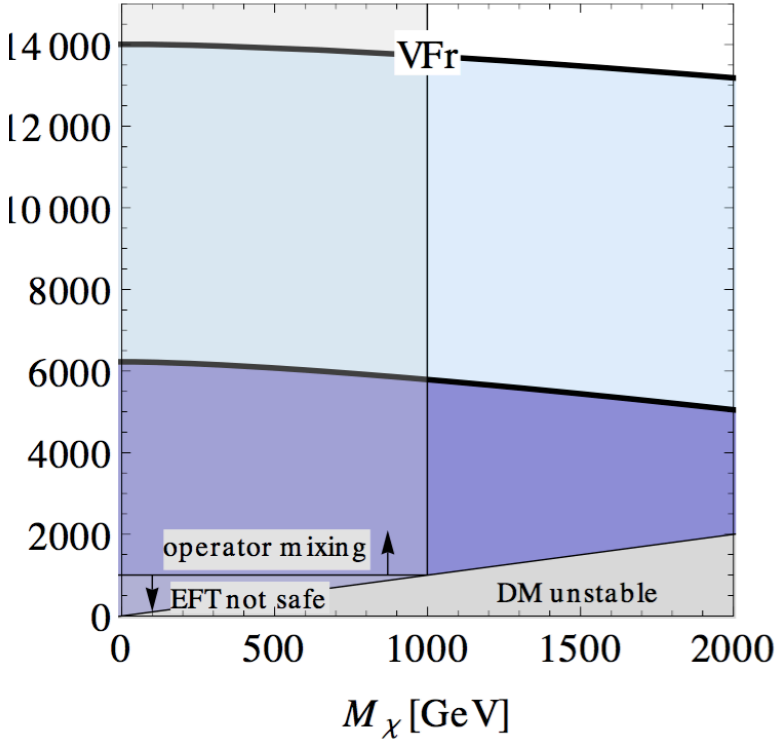


[Feritas, Westhoff 1408.1959]

- √s=1 TeV
- Lumi = 500 fb-1
- P(e-,e+)=(+0.8,+0.6)



Scalar DM & Fermion Mediator



Vector DM & Fermion Mediator