WIMP Search and L*

Moritz Habermehl

ILD Software and Technical Meeting

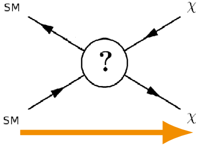
Lyon
25 April 2017

WIMPs and L*

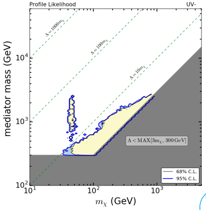
The Physics Case

- Weakly Interacting Massive Particles (WIMPs) are candidates for dark matter
- WIMPs can be searched for
  - directly
  - indirectly
  - **at colliders**

    ⇒ idea: SM particles → WIMP pair production



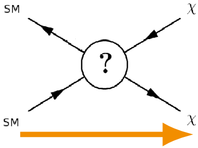
- singlet-like fermion WIMP (Shigeki Matsumoto et al., arxiv:1604.02230])
- likelihood analysis of
  - Planck, PICO-2L, LUX, XENON100
  - LEP, LHC
  - plus LZ, PICO250 projections
- Is the ILC sensitive in the surviving region?



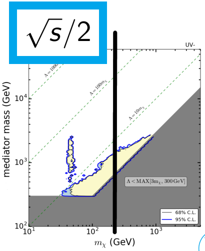
The Physics Case

- Weakly Interacting Massive Particles (WIMPs) are candidates for dark matter
- WIMPs can be searched for
  - directly
  - indirectly
  - **at colliders**

  ⇒ idea: SM particles → WIMP pair production



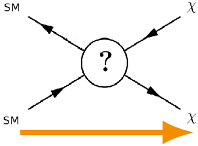
- singlet-like fermion WIMP (Shigeki Matsumoto et al., arxiv:1604.02230])
- likelihood analysis of
  - Planck, PICO-2L, LUX, XENON100
  - LEP, LHC
  - plus LZ, PICO250 projections
- Is the ILC sensitive in the surviving region?



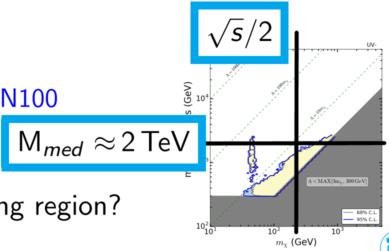
The Physics Case

- Weakly Interacting Massive Particles (WIMPs) are candidates for dark matter
- WIMPs can be searched for
  - directly
  - indirectly
  - **at colliders**

    $\Rightarrow$ idea: SM particles $\rightarrow$ WIMP pair production

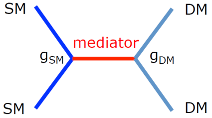


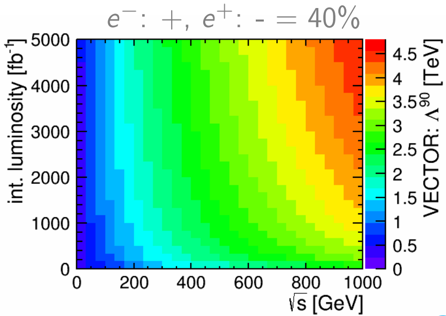
- singlet-like fermion WIMP (Shigeki Matsumoto et al., arxiv:1604.02230])
- likelihood analysis of
  - Planck, PICO-2L, LUX, XENON100
  - LEP, LHC
  - plus LZ, PICO250 projections
- Is the ILC sensitive in the surviving region?



What about Staging ?

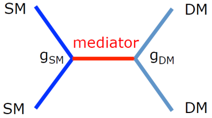
- one a the few BSM channels for which new phase space is explored also at 250 GeV
  - centre-of-mass energy (slightly) higher than at LEP
  - more luminosity
  - polarisation
- extrapolation of sensitivity from full simulation at $\sqrt{s} = 500\,\text{GeV}$
  - reachable energy scale at different $\sqrt{s}$ and integrated luminosities
  - energy scale: $\Lambda = M_{mediator} / \sqrt{g_f g_\chi}$

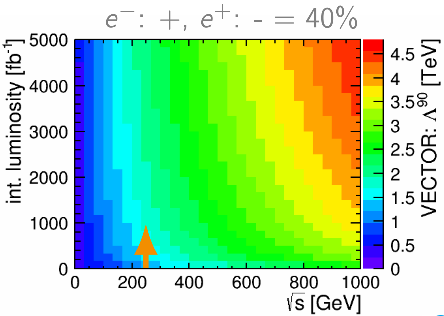




What about Staging ?

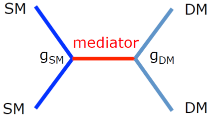
- one a the few BSM channels for which new phase space is explored also at 250 GeV
  - centre-of-mass energy (slightly) higher than at LEP
  - more luminosity
  - polarisation
- extrapolation of sensitivity from full simulation at $\sqrt{s} = 500\,\text{GeV}$
  - reachable energy scale at different $\sqrt{s}$ and integrated luminosities
  - energy scale: $\Lambda = M_{mediator}/\sqrt{g_f g_\chi}$

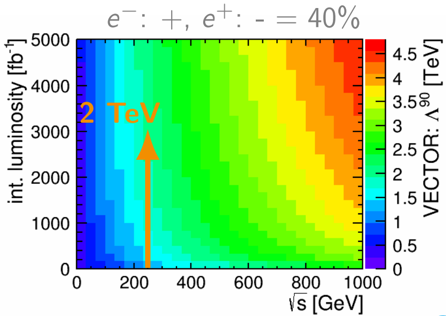




What about Staging ?

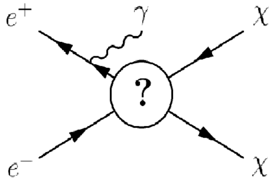
- one a the few BSM channels for which new phase space is explored also at 250 GeV
  - centre-of-mass energy (slightly) higher than at LEP
  - more luminosity
  - polarisation
- extrapolation of sensitivity from full simulation at $\sqrt{s} = 500\,\text{GeV}$
  - reachable energy scale at different $\sqrt{s}$ and integrated luminosities
  - energy scale: $\Lambda = M_{mediator} / \sqrt{g_f g_\chi}$

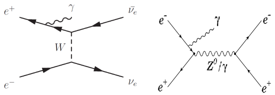




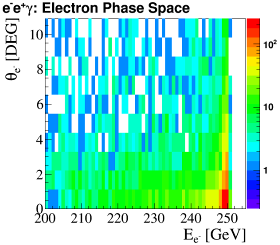
WIMP Detection at ILC

- **Signal**
  - **WIMP pair production with a photon from initial state radiation** $e^+e^- \to \chi\chi\gamma$
  - quasi model-independent
  - single photon in an "empty" detector $\to$ missing four-momentum
  - observables: E_γ, θ_γ

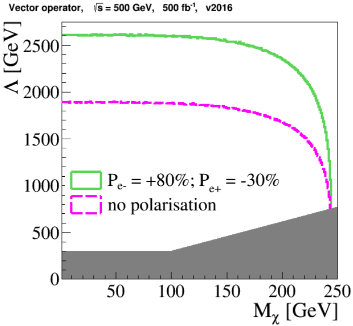




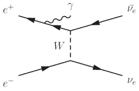
- **Main Background Processes**
  - **Neutrino pairs** $e^+e^- \to \nu\bar{\nu}\gamma$
    - irreducible
    - polarisation: enhance or suppress
  - **Bhabha scattering** $e^+e^- \to e^+e^-\gamma$
    - huge cross section
    - cross section rises for low polar angles
    - mimics signal if leptons in forward region are undetected

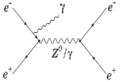


Role of Polarisation



$N_{500fb^{-1}}$	**unpolarised**	**$P_{e-}= +80\%$ $P_{e+}= -30\%$**
$\nu\nu\gamma$	2479.19	483.51
$e^+e^-\gamma$	84.74	83.06





- background
  - neutrinos can be suppressed for right-handed electrons and left-handed positrons
- WIMPs
  - chirality of interaction can be tested

Status of WIMP Analysis at ILD

- Christoph Bartels, 2011
  - full detector simulation at $\sqrt{s} = 500\,\text{GeV}$
  - Whizard 1.96 with RDR beam parameters
  - ILCSoft v01-06
  - detector models: ILD_00, partially LDC_PrimeSc_01
  - interpretation: cosmological approach
- Andrii Chaus, 2014: re-interpretation: effective operators (Λ)
- Shigeki Matsumoto et al.: likelihood analysis
- me (and Tomohiko Tanabe), since 2014:
  - full detector simulation at $\sqrt{s} = 500\,\text{GeV}$ + extrapolation
  - Whizard 2.2.4 with TDR beam spectrum (Circe2)
  - improved reconstruction in ILCSoft v17-11
  - Bhabha phase space and new L*
  - status: waiting for final MC samples

WIMP Search and L*

WIMP Search at the ILC

Improvements in New Analysis

BeamCal and L*

Bhabha Background Suppression

$e^+e^-\gamma$	ilcsoft v01-06 Christoph Bartels	ilcsoft v01-17
sig.def.	100%	100%
p_T	21.1%	26.1%
E_{vis}	16.0%	1.9%
BCal	0.29%	0.02%

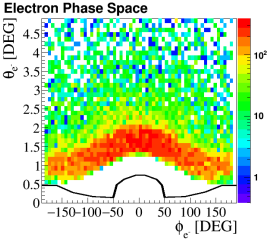
- suppression efficiency
  - preliminary (waiting for final MC samples)
  - all normalised to signal definition of Christoph Bartels

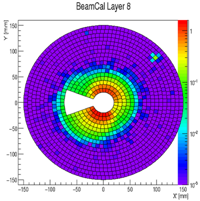
- signal definition: minimum $p_{T,\gamma}$, minimum θ_γ
- selection criteria
  - veto events with track with $p_T > 3$ GeV
  - additional visible energy < 20 GeV (PFOs)
  - no cluster in BeamCal
- from ILCSoft v01-06 to v01-17-11
  - suppression of Bhabha background profits from
    - better photon reconstruction in Pandora PFA
    - better BeamCal reconstruction using BeamCalClusterReco

Closing the Gap in the Bhabha Phase Space

- Bhabha samples used so far:
  Whizard (1) default cuts
  - invariant mass of all possible particle pairs $> 4\,\text{GeV}$
  - $\rightarrow \theta_e \approx 1$ DEG (on MC level)
  - (ϕ dependence due to crossing angle)

$\Rightarrow$ at low θ: some part of BeamCal phase space is not covered

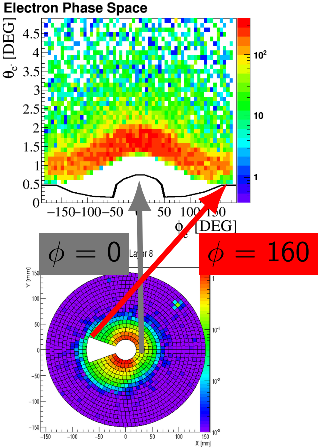




Closing the Gap in the Bhabha Phase Space

- Bhabha samples used so far:
  Whizard (1) default cuts
  - invariant mass of all possible particle pairs $> 4\,\text{GeV}$
  - $\rightarrow \theta_e \approx 1$ DEG (on MC level)
  - (ϕ dependence due to crossing angle)

  $\Rightarrow$ at low θ: some part of BeamCal phase space is not covered

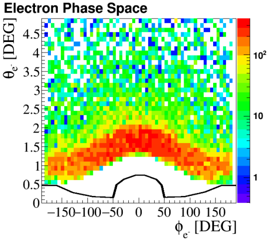


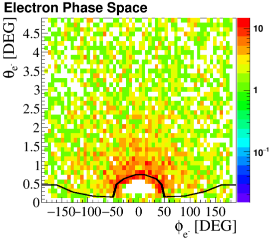
Closing the Gap in the Bhabha Phase Space

- Bhabha samples used so far: Whizard (1) default cuts
  - invariant mass of all possible particle pairs $> 4\,\mathrm{GeV}$
  - $\rightarrow \theta_e \approx 1$ DEG (on MC level)
  - (ϕ dependence due to crossing angle)

  $\Rightarrow$ at low θ: some part of BeamCal phase space is not covered
- new sample with $M_{inv} > 1\,\mathrm{GeV}$

  $\Rightarrow$ **gap is closed**

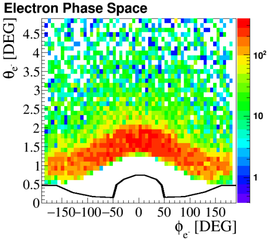


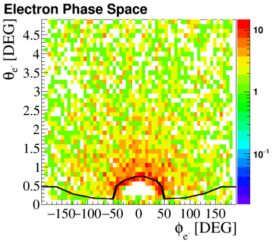


Closing the Gap in the Bhabha Phase Space

- Bhabha samples used so far:
  Whizard (1) default cuts
  - invariant mass of all possible particle pairs $> 4\,\text{GeV}$
  - $\rightarrow \theta_e \approx 1$ DEG (on MC level)
  - (ϕ dependence due to crossing angle)

  $\Rightarrow$ at low θ: some part of BeamCal phase space is not covered
- new sample with $\text{M}_{inv} > 1\,\text{GeV}$
  $\Rightarrow$ **gap is closed**
- only now:
  discovered that previous signal definition allows Bhabha events where both leptons go down the beam pipe
  $\Rightarrow$ **solved with new signal definition**





Bhabha Background Suppression II

$e^+e^-\gamma$	ilcsoft v01-06 $M_{inv} > 4$ GeV Christoph Bartels	ilcsoft v01-17 $M_{inv} > 4$ GeV old sig def	ilcsoft v01-17 $M_{inv} > 1$ GeV old sig def	ilcsoft v01-17 $M_{inv} > 1$ GeV new sig def
sig.def.	100%	100%	235%	375%
p_T	21.1%	26.1%	71.4%	161.0%
E_{vis}	16.0%	1.9%	17.6%	37.3%
BCal	0.29%	0.02%	0.40%	0.45%

- new Bhabha sample and new signal definition
  - allow realistic estimate of Bhabha background
  - now in good shape to study importance of forward region
- new Bhabha sample has larger cross-section
- new signal definition keeps more events
  $\Rightarrow$ increased signal-to-noise ratio
- BeamCal suppression: improved from 1/55 to 1/83

Bhabha Background Suppression II

$e^+e^-\gamma$	ilcsoft v01-06 $M_{inv} > 4$ GeV Christoph Bartels	ilcsoft v01-17 $M_{inv} > 4$ GeV old sig def	ilcsoft v01-17 $M_{inv} > 1$ GeV old sig def	ilcsoft v01-17 $M_{inv} > 1$ GeV new sig def
sig.def.	100%	100%	235%	375%
p_T	21.1%	26.1%	71.4%	161.0%
E_{vis}	16.0%	1.9%	17.6%	37.3%
BCal	0.29%	0.02%	0.40%	0.45%

- new Bhabha sample and new signal definition
  - allow realistic estimate of Bhabha background
  - **now in good shape to study importance of forward region**
- new Bhabha sample has larger cross-section
- new signal definition keeps more events
  $\Rightarrow$ increased signal-to-noise ratio
- BeamCal suppression: improved from 1/55 to 1/83

BeamCalClusterReco: Overview

- Marlin processor: BeamCalClusterReco
- by André Sailer and Andrey Sapronov
- hermeticity in forward region crucial to identify Bhabha background
- challenge: find e^+e^- from Bhabhas in energy deposition from the overlay of low p_T pairs
- overlay (technically):
  - full detector simulation (done separately from simulation of physics sample)
  - input file: BeamCal_bg_E500-TDR_ws.root
  - option used: “Parametrised”
    $\Rightarrow$ distribution of energy deposition described by parametrisation for each pad

BeamCalClusterReco: Criteria for Cluster

- after subtraction of the average pair background in each pad...
- ... events have to fulfill the following to be considered as Bhabha event:
  - **SigmaCut**:
    energy in pad: $2{\cdot}\sigma$ above the average
  - **ETPadMin**:
    energy in pad has to be higher than 0.01 GeV
  - **MinimumTowerSize**:
    pads in 6 consecutive layers
  - **StartLookingInLayer**:
    first layers contain most overlay
    $\rightarrow$ ignore first layer
- parameters were tuned to find optimal values
  - minimise fakes
  - increase efficiency to find e^+e^- from Bhabhas

WIMP Search and L*

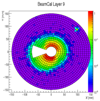
WIMP Search at the ILC

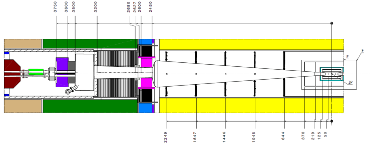
Improvements in New Analysis

BeamCal and L*

New L*

- if we want to have a realistic estimate of the Bhabha suppression in BeamCal...
- ...need BeamCalClusterReco...
- ...for which the pair background (overlay) must be fully simulated, some estimate is not enough





- new L*: BeamCal has to be moved closer to interaction point by 40 cm

  → need new input file for pair distribution

  → need new detector simulation of pairs
- simulation currently done by Alejandro Perez Perez

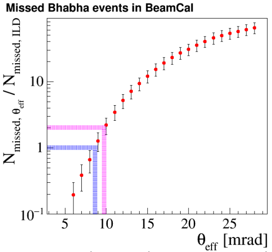
Sensitivity Depends on Forward Detector Design

- How does the number of missed Bhabhas change if BeamCal is moved along the z axis ?
- for now: **geometrical estimate**
- idea: apply a hard theta cut: inside nothing is reconstructed, outside everything
- which θ_{eff} cut mimics the BeamCal reconstruction: 8.62 mrad
- θ_{eff} grows when BeamCal is moved closer to IP: 9.74 mrad

approx. 2 times more Bhabhas are missed

$\Rightarrow$ sensitivity loss: $\Delta\Lambda = $ 50-100 GeV or 2-4%

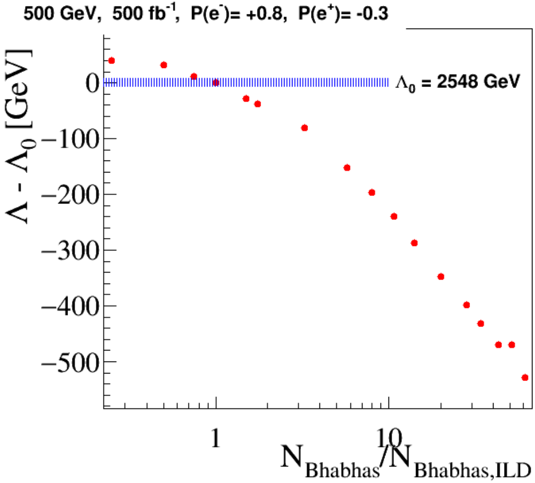
(for 500 fb^{-1}, P_{e-}= +80%, P_{e+}= -30%)



Summary

- mono-photon channel is general approach to WIMP search
- largest reducible background: Bhabha scattering
- Bhabha background and hence entire analysis depend heavily on design of forward region
- influence of new L*
  - geometrical estimate
    - Bhabha level goes up by factor 2
    - sensitivity to new physics is estimated to drop by few %
- new samples are underway
  - complete Bhabha phase space
  - larger signal definition
  - will allow realistic study of new L*

Sensitivity as a Function of the Bhabha Background

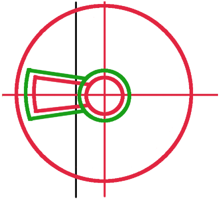


Signal Definition and Preselection Cuts

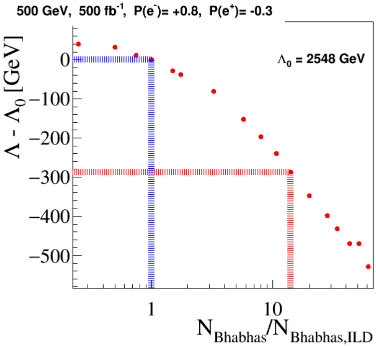
- preselection cuts on generator level
  - reduce phase space
  - safety margin

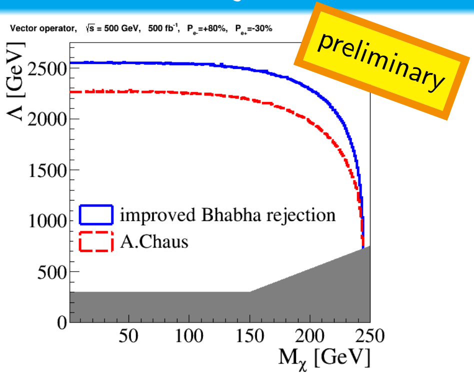
	signal definition	**preselection**
avoid Z return	$E_\gamma < 220$ GeV	-
tracking	$\lvert\cos(\theta_\gamma)\rvert < 0.996$ ($\theta > 5.13$ DEG)	$\lvert\cos(\theta_\gamma)\rvert < 0.9975$ ($\theta > 4.05$ DEG)
distinguish from noise, ensure Bhabha detection	$p_{T,\gamma} > 2$ or > 5 GeV (in BCal coordinates)	1 GeV

- θ in preselection: just inside beam pipe
- p_T cut is ϕ-dependent:
  - $\lvert\phi_\gamma\rvert < 35$: $p_T > 5.71$ GeV (corresponding $e^\pm$ on "incoming" side)
  - $\lvert\phi_\gamma\rvert > 35$: $p_T > 1.97$ GeV (corresponding $e^\pm$ on "outgoing" side)



Higher Sensitivity with Improved Bhabha Rejection





lower Bhabha background than in previous ILD analysis (A.Chaus)

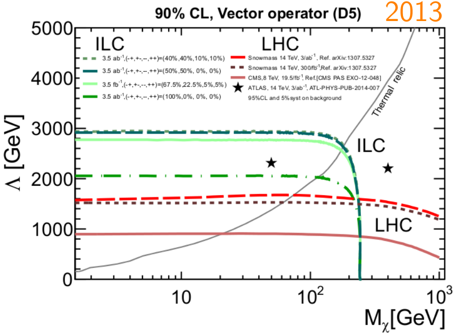
sensitivity is improved by 300 GeV $\hat{=}$ by 15%
for right-handed electrons and left-handed positron

for "vector" operator, $\sqrt{s} = 500$ GeV, 500 fb^{-1}

LHC vs. ILC

- LHC
  - tests couplings to quarks/gluons
  - sensitive to higher M_χ

A.Chaus 2013



- ILC
  - tests coupling to leptons
  - sensitive to higher Λ

- low systematic uncertainties of BG
- no pile-up, no beam remnants

- polarisation

$\Rightarrow$ signal can be enhanced

$\Rightarrow$ background can be suppressed

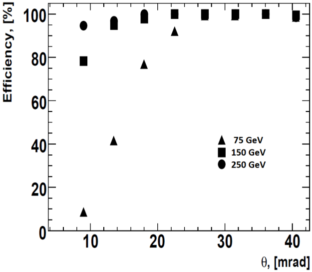
type of interaction can be tested

- well known initial state

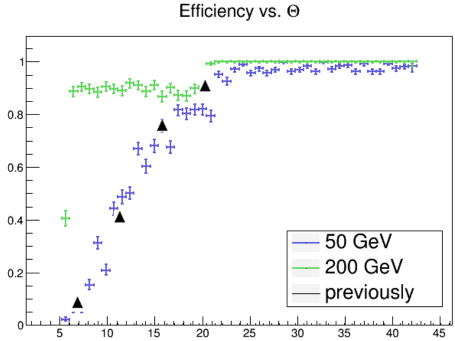
$\Rightarrow$ allows to calculate M_χ

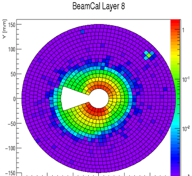
BeamCalClusterReco: Reconstruction Efficiencies

- previously ...



- now...





- tuned parameters are included in
/ILDConfig/v01-17-09/StandardConfig/current/ bbudsc_3evt_stdreco.xml