My Session

T 106: Suche nach Dunkler Materie 4

Thursday, March 30, 2017, 16:45–18:55, VSH 19

Selection status for this session: not selected

⊕	16:45	T 106.1	Group Report: Why the Fermi GeV gamma-ray excess cannot be explained by dark matter annihilation — •Wim de
⊕	17:05	T 106.2	Search for Right-Handed Neutrinos from Dark Matter Annihilation with Fermi-LAT and H.E.S.S. Telescopes — •Migu
⊕	17:20	T 106.3	Search for Decaying Dark Matter with Astrophysical Muon Neutrinos Measured by IceCube — •Jöran Stettner, The Schoenen, and Christopher Wiebusch for the IceCube collaboration
⊕	17:35	T 106.4	Group Report: Status des ALPS Experiments — •Klaus Zenker für die ALPS-II Kollaboration
⊕	17:55	T 106.5	Search for chameleons with an InGrid based X-ray detector at the CAST experiment — Klaus Desch, Jochen Kamin Schmidt
⊕	18:10	T 106.6	Artificial Neural Networks as event classifiers for an InGrid detector at CAST — Klaus Desch, Jochen Kaminski, Chi
⊕	18:25	T 106.7	Suche nach Dunkler Materie in Ereignissen mit fehlender transversaler Energie und Jets beim ATLAS Experiment — Büscher, Katharina Jacobi, Manuel Lornatus und Jan Schäffer
⊕	18:40	T 106.8	WIMP search at the International Linear Collider — •Moritz Habermehl and Jenny List

WIMP Search at the International Linear Collider

Moritz Habermehl[1,2], Jenny List[1]

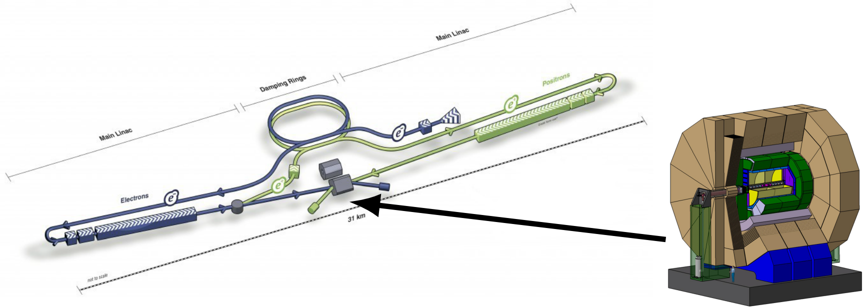
[1] Deutsches Elektronen-Synchrotron, Germany
[2] Universität Hamburg

DPG-Frühjahrstagung

Münster
30 March 2017

The International Linear Collider

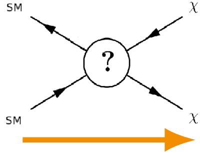
- a future electron positron collider
  - mature technology
  - waiting for political decision in Japan
- centre-of-mass energy: 250 - 500 GeV (upgrade: 1 TeV)
- $\mathcal{L} = 1.8 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (upgrade: $3.6 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$)
- polarised beams: $\mathrm{P(e^-)} = \pm 80\%$, $\mathrm{P(e^+)} = \pm 30\%$
- 2 detectors: SiD and **ILD** (International Large Detector)



How well can the ILC explore the WIMP paradigm ?

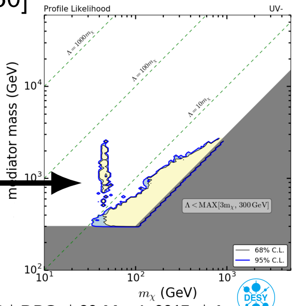
- Weakly Interacting Massive Particles (WIMPs) are candidates for dark matter
- WIMPs can be searched for
  - directly
  - indirectly
  - **at colliders**

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



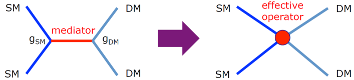
- singlet-like fermion WIMP [arxiv:1604.02230]
- likelihood analysis of
  - Planck, PICO-2L, LUX, XENON100
  - LEP, LHC
  - plus LZ, PICO250 projections
- surviving region
- couplings tested in [-1,1]

  $\Rightarrow$ “simplified model”



Theoretical Framework: Effective Operators

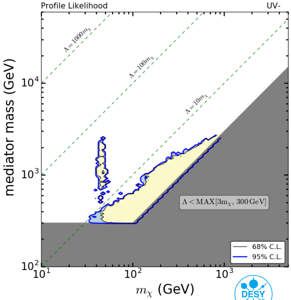
1. classify WIMP based on its quantum numbers (spin and weak isospin)
2. construct minimal effective Lagrangian
   $\Rightarrow$ general approach



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

- example: vector-like fermion WIMP and vector-like operator
  $\Rightarrow$ only one parameter
  "energy scale of new physics"

$$\Lambda = M_{mediator} / \sqrt{g_f g_\chi}$$



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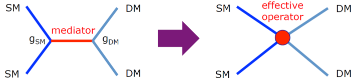

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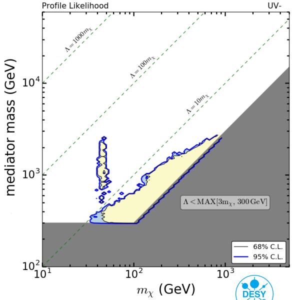
$$\Lambda = M_{mediator} / \sqrt{g_f g_\chi}$$

- validity (above grey area)
  - $M_{mediator} \gg \sqrt{s}$
  - $g_f,\ g_\chi \lesssim \sqrt{4\pi}$ (pertubativity)

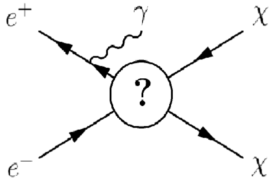
$\Rightarrow \Lambda > 3\ m_\chi$
$\Rightarrow \Lambda > 300$ GeV

above grey area:
simplified model reproduces EFT results

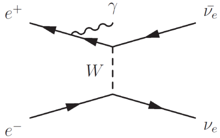


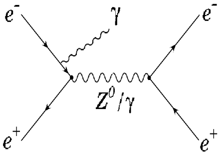
WIMP Detection at ILC

- **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

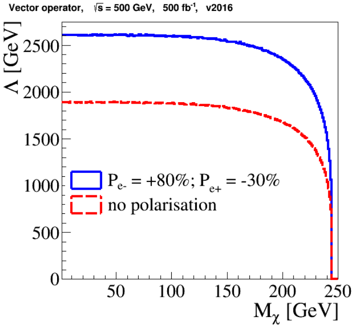


- **Main Background Processes**
  - **Neutrino pairs** $e^+e^- \to \nu\bar{\nu}\gamma$
    - irreducible
    - polarisation: enhance or suppress
  - **Bhabha scattering** $e^+e^- \to e^+e^-\gamma$
    - huge cross section
    - mimics signal if leptons are undetected

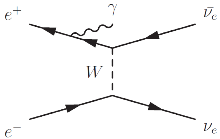


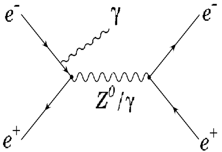


Role of Polarisation



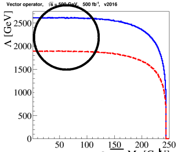
$N_{500fb^{-1}}$	**unpolarised**	**+80%, -30%**
$\nu\nu\gamma$	2479.19	483.51
$e^+e^-\gamma$	84.74	83.06

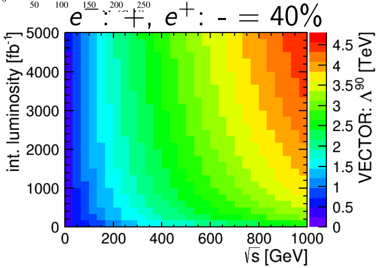


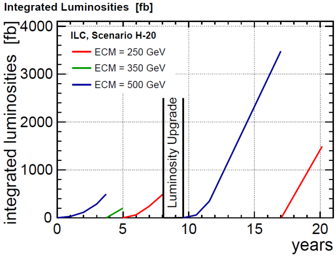


- background
  - neutrinos can be suppressed for right-handed electrons and left-handed positrons
- WIMPs
  - type of interaction can be tested

Sensitivity in Different Operation Scenarios







- extrapolation of sensitivity from full simulation
  - reachable Λ at different $\sqrt{s}$ and integrated luminosities
  - for small M_χ (< 100 GeV)
- allows to give estimates for sensitivity
  - for different time scales
  - for different running scenarios

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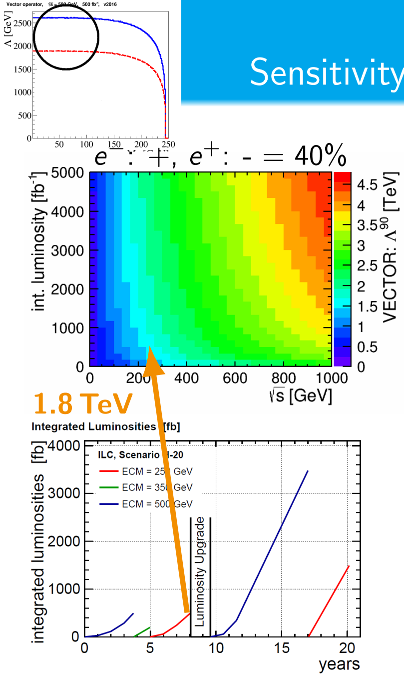

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- for $\sqrt{s} = 250$ GeV
  - after first 500 fb−1: **$\Lambda \approx$ 1.8 TeV**

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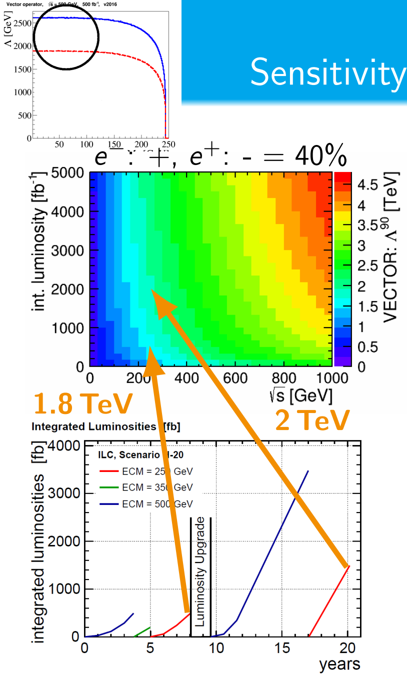

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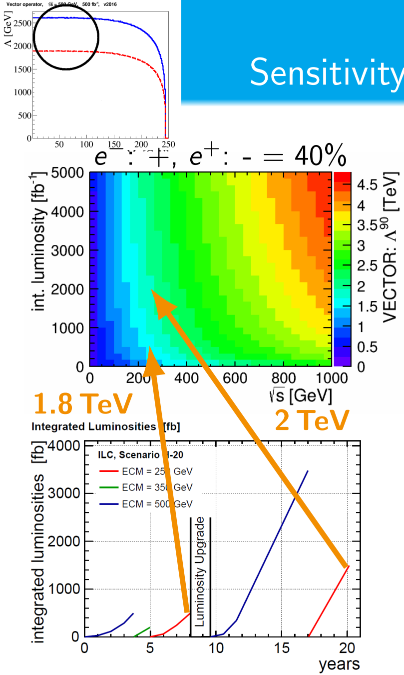

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- for $\sqrt{s} = 250$ GeV
  - after first 500 fb-1: **$\Lambda \approx$ 1.8 TeV**
  - after luminosity upgrade: **$\Lambda \approx$ 2 TeV**
- for $\sqrt{s} = 500$ GeV: **$\Lambda \approx$ 3 TeV**

Goal of this Analysis

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- goal: realistic estimate of systematics and background

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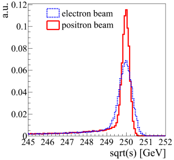
Luminosity Spectrum: "our PDF"



lepton collider: requirement of high instantaneous luminosity

$\Rightarrow$ beams are highly collimated

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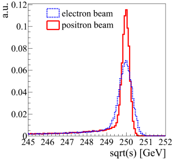

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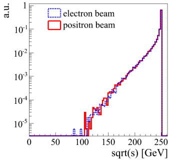

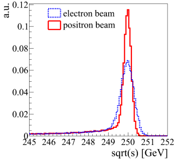

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$\Rightarrow$ e^+/e^- emit synchrotron radiation ("beamstrahlung")

$\Rightarrow$ ... and on average lose a few percent of their energy

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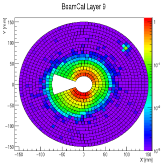
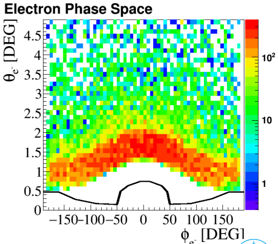
- updated analysis and exclusion limits are underway





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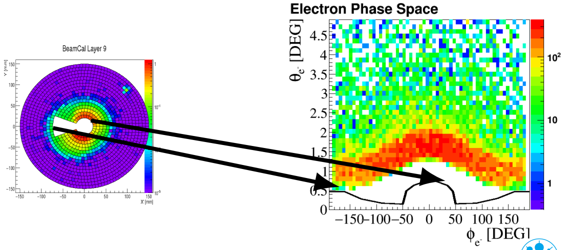

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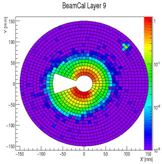
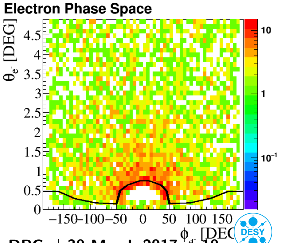
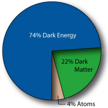
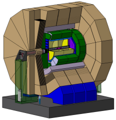
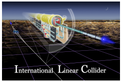




Summary: WIMP searches at the International Linear Collider

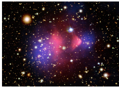
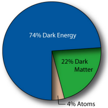


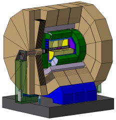
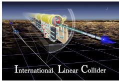


- WIMPs are still among favorite candidates for dark matter
  - ILC covers unique parameter space
  - complementary sensitivity to LHC searches
- goal: realistic estimate of sensitivity
  - taking systematics into account: e.g. luminosity spectrum
  - detailed modelling of the particle phase space

  $\Rightarrow$ input to
  - detector design (hermeticity in forward region)
  - machine design (luminosity spectrum)
- update of simulation study underway

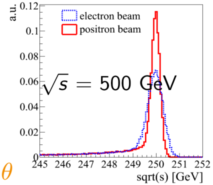




References

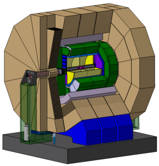
- International Linear Collider
  - Technical Design Report: arXiv:1306.6327
  - Operating Scenarios: arXiv:1506.07830
- Simulation Study
  - EFT interpretation, vector-like mediator:
    PhD thesis of Andrii Chaus, Université Paris-sud 11, 2014PA112300
  - Cosmological interpretation: arXiv:1206.6639
- Likelihood analysis
  - arXiv:1604.02230
  - arXiv:1603.07387
  - arXiv:1407.1859

Modelling of Signal and Background



- generated using WHIZARD 2.2.8
  - polarised beams
  - beam spectrum
  - photon modelling:
    - in **matrix element** "$\nu\bar{\nu}\gamma$" $\Rightarrow$ correct E, θ
    - as dedicated **ISR parametrisation**
      ISR implementation: all orders of soft-collinear photons, first three orders of hard-collinear photons $\Rightarrow$ best cross-section

  $\Rightarrow$ no double counting
- signal: $\chi\chi\gamma$
  - reweight $\nu\bar{\nu}\gamma$ according to WIMP mass, spin, ...
- background:
  - $\nu\bar{\nu} + \mathrm{n}\gamma$
  - $\mathrm{e}^+\mathrm{e}^- + \mathrm{n}\gamma$ (Bhabha scattering)
- full Geant4 based ILD simulation



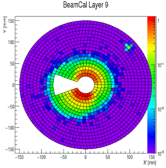
Signal Definition and Background Rejection

- signal definition (single photon plus missing energy)
  - $E_\gamma > 10$ GeV
  - $E_\gamma < 220$ GeV (Z return at 242 GeV: avoid large background)
  - $|\cos\theta_\gamma| < 0.98$ (tracking needed to distinguish γ from $e^{-/+}$)

  $\Rightarrow$ Bhabhas: hard photon boosts leptons in detector
- empty detector
  - veto events with track with $p_T > 3$ GeV
  - additional visible energy < 20 GeV
  - no e^+/e^- in forward region $\Rightarrow$ no cluster in BeamCal

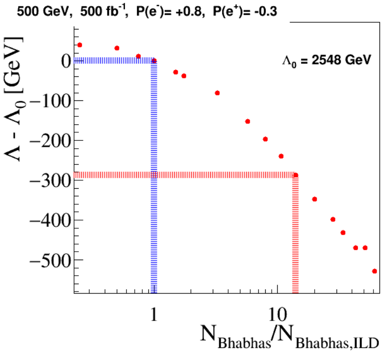
$\Rightarrow$ retains 90% of signal

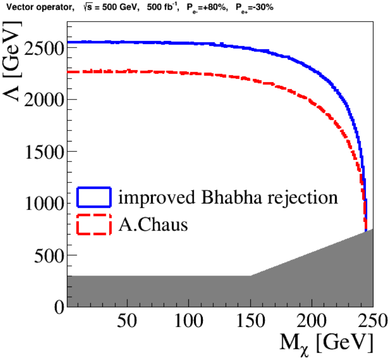
$\Rightarrow$ Bhabha background rejection improved by factor 15



$e^+e^-\gamma$	C.Bartels	new analysis
p_T	21.1%	26.1%
E_{vis}	16.0%	1.9%
BeamCal	0.29%	0.02%

Higher Sensitivity with Improved Bhabha Rejection



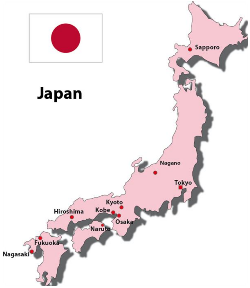


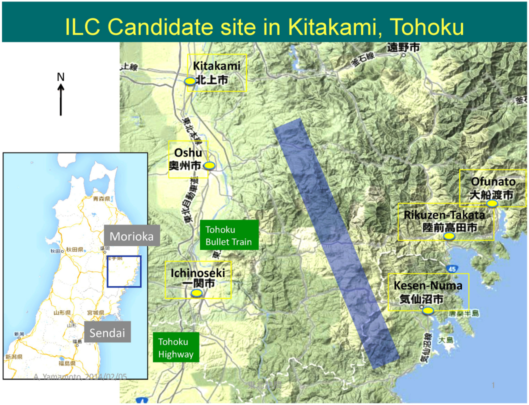
lower Bhabha background than in previous ILD analysis by A.Chaus

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

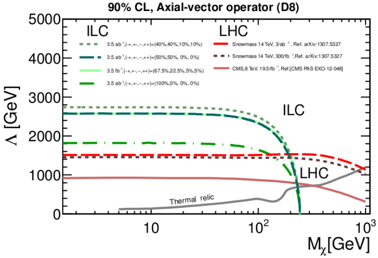
for "vector" operator, $\sqrt{s} = 500$ GeV, 500 fb^{-1}

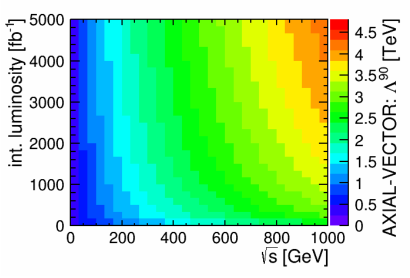
ILC Candidate Site: Kitakami



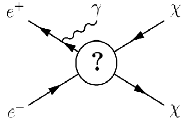


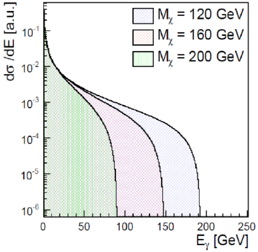
Results for an "Axial-Vector" Mediator

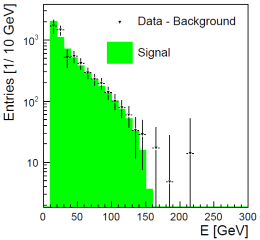




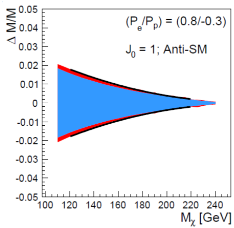
Measuring the WIMP Mass







- E_γ: shape information is used
- range depends on M_χ and $\sqrt{s}$
- lepton collider $\rightarrow$ initial state is known
- $\sqrt{s}$ known $\rightarrow$ M_χ
- uncertainty on $\sqrt{s}$ dominates accuracy of M_χ



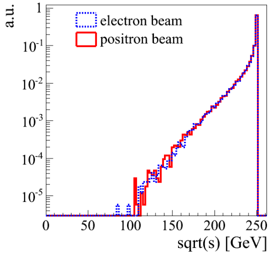
systematical uncertainty

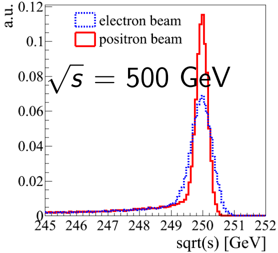
statistical uncertainty

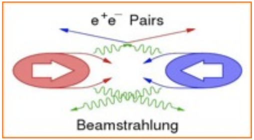
over-simplified approach

Luminosity Spectrum: “our PDF”

lepton collider: requirement of high instantaneous luminosity
- $\Rightarrow$ beams are highly collimated
- $\Rightarrow$ strong electro-magnetic fields
- $\Rightarrow$ both bunches are focussed in the field of the other beam
- $\Rightarrow$ e^+/e^- emit synchrotron radiation ("beamstrahlung")
- $\Rightarrow$ ... and on average lose a few percent of their energy
- $\Rightarrow$ this energy distribution leads to systematic uncertainty on M_χ
- $\Rightarrow$ beamstrahlung photons generate e^+/e^- pairs







Bhabha Scattering Background and the BeamCal

- if leptons are not detected
  $\rightarrow$ mimics mono-photon signal
- forward region of detector important: BeamCal
  (6 mrad $< \theta <$ 40 mrad $\Leftrightarrow$ 3.91 $< \eta <$ 5.85)
- beamstrahlung photons generate e^+/e^- pairs
  $\rightarrow$ energy deposition in detector
  $\rightarrow \epsilon \ll 1$ at very low angles
- reconstruction of Bhabha leptons in BeamCal reduces background by factor 60 - 100