Model-independent WIMP Characterization

Using ISR

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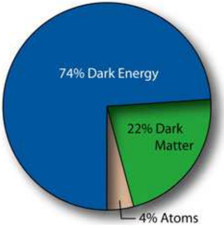
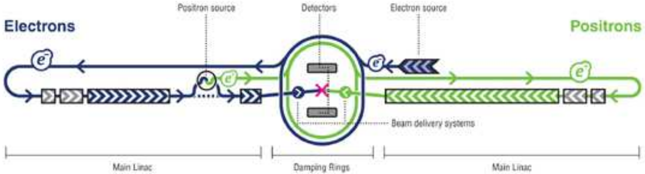
Dark Matter at the ILC?



- WIMP properties:
  - Electrically neutral
  - Stable $\Rightarrow$ new conserved quantum number
  - Cold, i.e. non-relativistic
  - Cross sections $\mathcal{O}(100\mathrm{fb})$
  - Massive $M \sim 100$ GeV

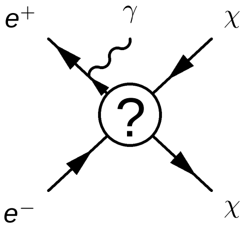


- Well known initial state $\Rightarrow$ precision physics
- Longitudinal polarized beams: $P_{e^-} = 80\%$ and $P_{e^+} \geq 30\%$
- Machine Parameters: RDR, SB-2009 impact beam energy spectrum

Direct WIMP Production in e^+e^--Collisions

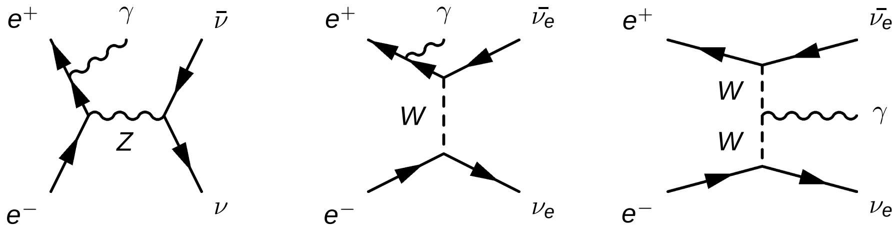
Model-independent WIMP pair production (Birkedal *et al.*):

- Annihilation cross section determined by relic DM abundance
- Annihilation and production cross sections related by detailed balancing
- $\Rightarrow e^+e^- \rightarrow \chi\chi$, invisible in collider experiment, use ISR



- Search for high p_T photons balancing invisible WIMP system
- Model dependent interpretation (SUSY) → O. Kittel tomorrow

Dominant SM Background Process

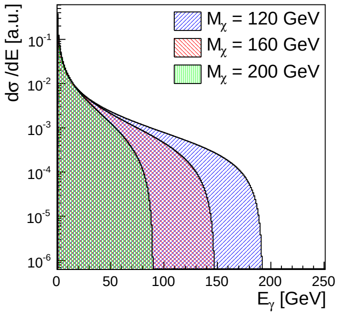


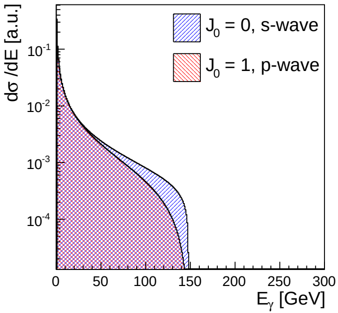
- Neutrino pair production $e^+e^- \to \nu\nu\gamma$
  - Irreducible
  - Large production cross section
  - Polarization dependent

- $\Rightarrow$ Precise event reconstruction, excellent $\delta P/P$
- Other: Multi-photon, radiative Bhabha scattering

Analysis Strategy I

- Observables: Photon energy E_γ (and polar angle Θ_γ)
- Measure from ISR spectrum
  Cross sections, Coupling structure, Mass, Partial wave

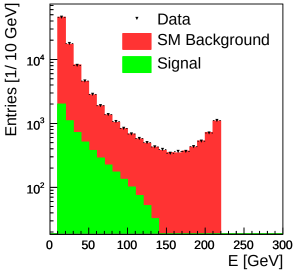


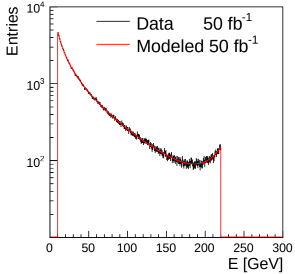


- Threshold energy ⇔ missing mass, threshold behaviour ⇔ partial wave
- Achievable precision, influence of polarization measurement?

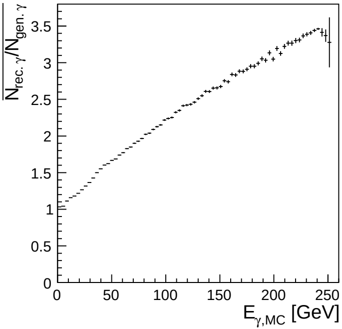
Analysis Strategy II

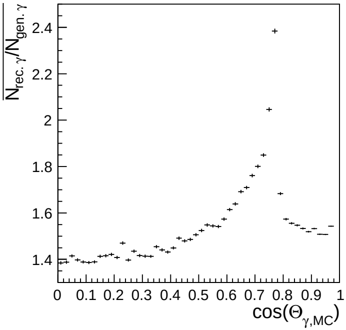
- Large WIMP parameter space
  - Select irreducible $e^+e^- \to \nu\nu\gamma$ background
  - Reweight $\nu\nu\gamma$ events with $\frac{\sigma(\chi\chi\gamma)}{\sigma(\nu\nu\gamma)}$
- Large backgrounds: $S/B \approx \mathcal{O}(10^{-3})$
  - Include photon in matrix element
  - Full detector simulation
  - Photon reconstruction
- Precise background prediction required
  - Parametrization of independent background sample
  - Generate signal prediction from parametrization





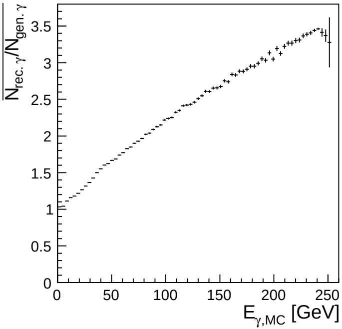
Photon Cluster Fracturing

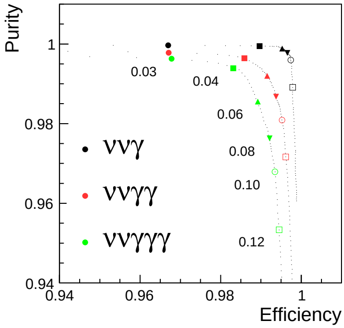




- Reconstruction algorithm tends to split electromagnetic clusters
- Photons: no tracking information, fracturing not recovered
- Merge photon candidates with cone based method
- Optimize cone opening angle w.r.t. purity and efficiency
- Small amount of fracturing remaining at high photon energies

Photon Cluster Fracturing





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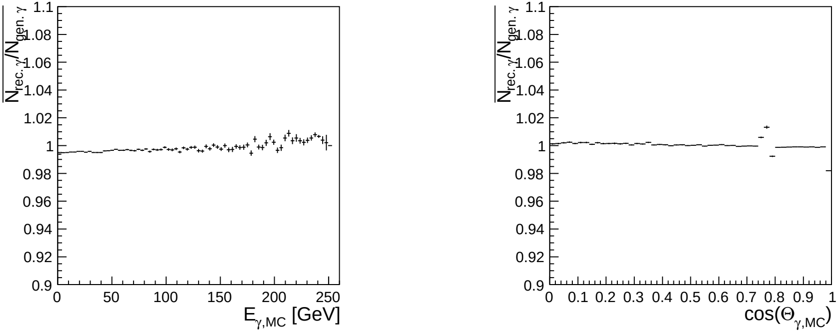

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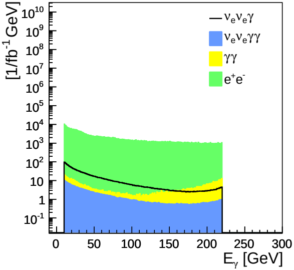
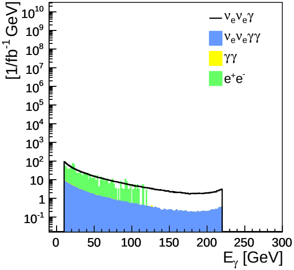
Event Selection

Selection of single high p_T photons

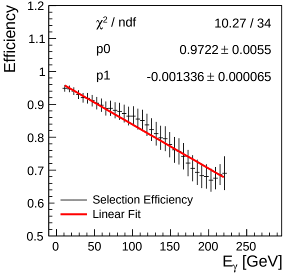
- Signal definition:
  - 10 GeV$< E_\gamma < 220$ GeV, $|\cos\Theta_\gamma| < 0.98$
  - Low energy ISR, massless Z final state
  - Tracking and calorimetric acceptance
- Maximal exclusive visible energy
  - $E_{vis} - E_\gamma < 20$ GeV
  - Reject multi-photon final states
  - Reject hadronic and leptonic final states
- Tag electrons in forward calorimeters
  - Reduce abundant Bhabha background
- Veto high p_T tracks
  - $p_T < 3$ GeV
  - Reject hadronic and leptonic final states

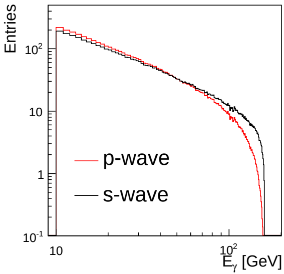




Selection Efficiencies

$\nu\nu\gamma$ $\Rightarrow$ $\chi\chi\gamma$

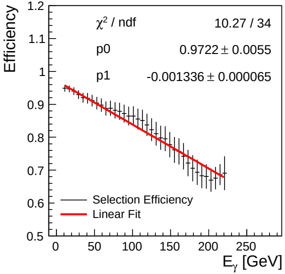


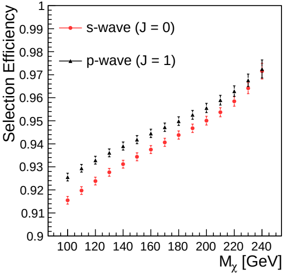


- Selection efficiency of $\nu\nu\gamma$ background energy dependent
- Reduced efficiency due to remaining cluster fracturing at high E_γ
- Signal photon spectrum mass dependent
- P-wave WIMP spectrum peaked sharper at low E_γ

Selection Efficiencies

$\nu\nu\gamma$ $\Rightarrow$ $\chi\chi\gamma$

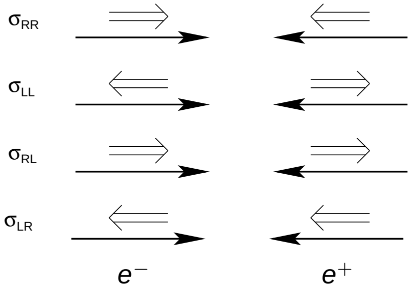




- Selection efficiency of $\nu\nu\gamma$ background energy dependent
- Reduced efficiency due to remaining cluster fracturing at high E_γ
- Signal photon spectrum mass dependent
- P-wave WIMP spectrum peaked sharper at low E_γ
- WIMP selection efficiency mass dependent $\epsilon > 90\%$

Cross Section and Coupling Structure

$$\sigma = \mathcal{F}(\sigma_{RR}, \sigma_{LL}, \sigma_{RL}, \sigma_{LR}; P_{e^-}, P_{e^+})$$



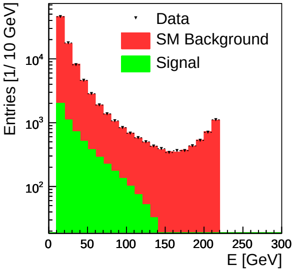
Fully polarized cross sections
$\Leftrightarrow$ Coupling structure of
WIMP interactions

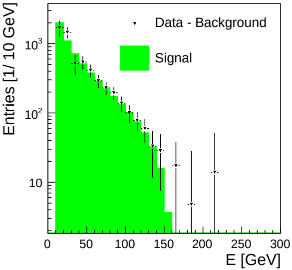
- Study three scenarios:
  - **"Equal"**: $\sigma_{RR} = \sigma_{LL} = \sigma_{RL} = \sigma_{LR}$
  - **"Helicity"**: $\sigma_{RL} = \sigma_{LR}$
  - **"Anti-SM"**: σ_{RL}
- Requires four measurements with polarized beams:
  - 200 fb^{-1} with $(+|P_{e^-}|; -|P_{e^+}|)$,
  - 200 fb^{-1} with $(-|P_{e^-}|; +|P_{e^+}|)$,
  - 50 fb^{-1} with $(+|P_{e^-}|; +|P_{e^+}|)$,
  - 50 fb^{-1} with $(-|P_{e^-}|; -|P_{e^+}|)$.
- Assume $\sigma_0 = 100$ fb throughout

Systematic Uncertainties

- $\delta P/P$:
  - Cross sections, coupling structure $\sigma_{\{R,L\}}$
  - 0.25% to 0.1%
- $\delta\mathcal{L}/\mathcal{L}$:
  - Cross sections, coupling structure $\sigma_{\{R,L\}}$
  - 0.01%
- $\delta\epsilon/\epsilon$:
  - Cross sections, coupling structure $\sigma_{\{R,L\}}$
  - 2.0%
  - Calibrate with radiative Z-return
- Beam energy spectrum
  - Cross sections, Partial wave, Mass
  - Estimate from signal spectra of SB2009 and RDR parameter sets
- Beam energy scale
  - Mass
  - Calibrate with radiative Z-return

Coupling structure

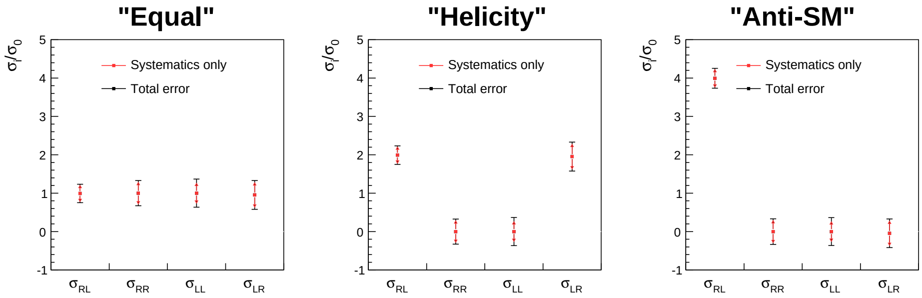




"Equal" scenario, $P_{e^-} = +0.8$, $P_{e^+} = -0.3$, $\mathcal{L} = 50\ \mathrm{fb}^{-1}$, $\sigma_{P_{e^-},P_{e^+}} = 100$ fb

Parameter	value	$\delta\sigma$ [fb]
$\delta P/P$	0.25%	5.7
$\delta\epsilon/\epsilon$	1.73%	1.7
$\delta\mathcal{L}/\mathcal{L}$	0.01%	0.01
Total		5.9

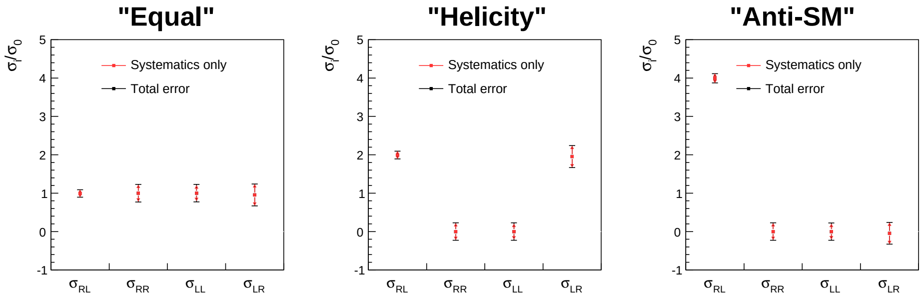
Coupling Structure



$|P_{e^-}| = 0.8$ $|P_{e^+}| = 0.3$ $\delta P/P = 0.25\%$

- Scenarios distinguishable with $\chi^2/ndf > 10$ ($p < 10^{-8}$)
- $|P_{e^+}| = 0.3$, $\delta P/P = 0.25\%$: $\Delta\sigma_{\{R,L\}}$ = 20 fb to 40 fb

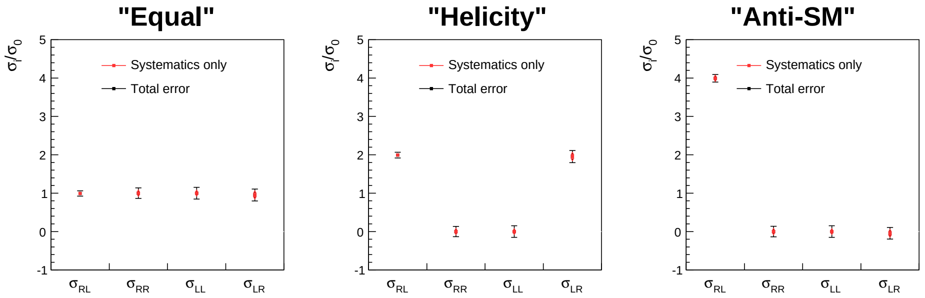
Coupling Structure



$|P_{e^-}| = 0.8 \quad |P_{e^+}| = 0.6 \quad \delta P/P = 0.25\%$

- Scenarios distinguishable with $\chi^2/ndf > 10$ ($p < 10^{-8}$)
- $|P_{e^+}| = 0.3$, $\delta P/P = 0.25\%$: $\Delta\sigma_{\{R,L\}}$ = 20 fb to 40 fb
- $|P_{e^+}| = 0.6$, $\delta P/P = 0.25\%$: $\Delta\sigma_{\{R,L\}}$ = 10 fb to 30 fb

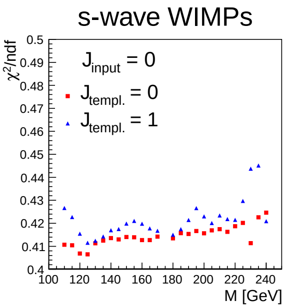
Coupling Structure



$|P_{e^-}| = 0.8 \quad |P_{e^+}| = 0.6 \quad \delta P/P = 0.10\%$

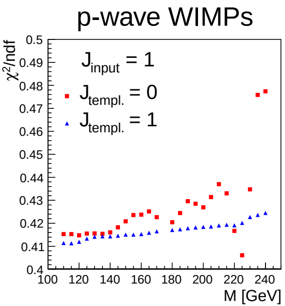
- Scenarios distinguishable with $\chi^2/ndf > 10$ ($p < 10^{-8}$)
- $|P_{e^+}| = 0.3$, $\delta P/P = 0.25\%$: $\Delta\sigma_{\{R,L\}}$ = 20 fb to 40 fb
- $|P_{e^+}| = 0.6$, $\delta P/P = 0.25\%$: $\Delta\sigma_{\{R,L\}}$ = 10 fb to 30 fb
- $|P_{e^+}| = 0.6$, $\delta P/P = 0.10\%$: $\Delta\sigma_{\{R,L\}}$ = 7 fb to 20 fb
- Combine measurements: $\Delta\sigma_0/\sigma_0 = 2\%$ to 5%

Partial Wave Determination



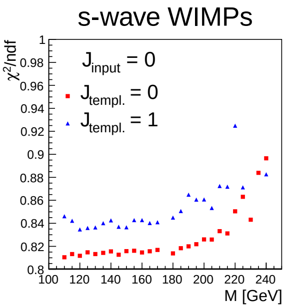
$P_{e^-} = +0.0$

$P_{e^+} = +0.0$



- $\mathcal{L} = 500\ \mathrm{fb}^{-1}$, **"Helicity"** scenario
- Test template s- and p-wave spectra against data spectrum
- χ^2_{min} indicates partial wave

Partial Wave Determination



$$P_{e^-} = +0.8$$

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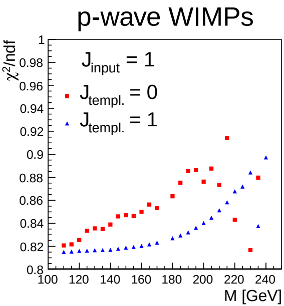
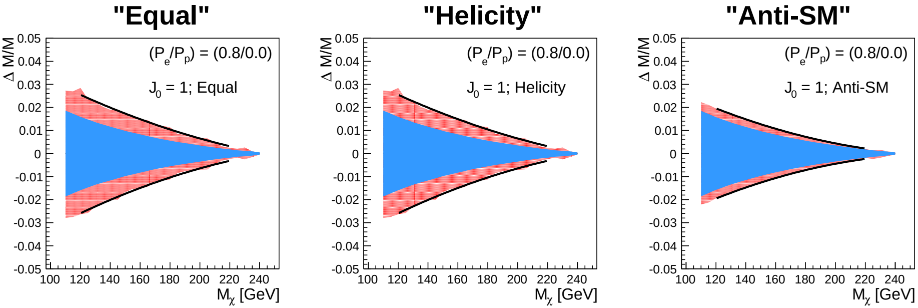


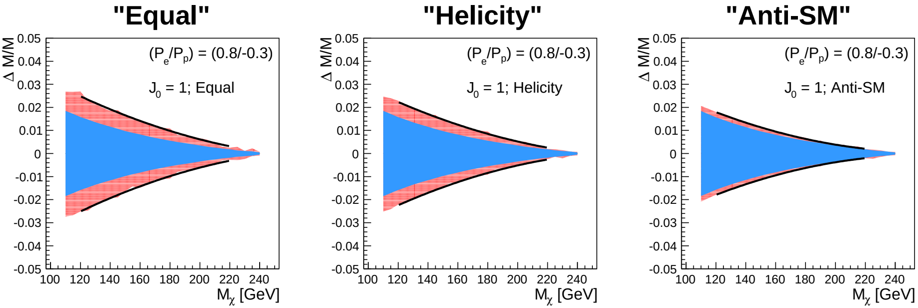
- $\mathcal{L} = 500\ \mathrm{fb}^{-1}$, **"Helicity"** scenario
- Test template s- and p-wave spectra against data spectrum
- χ^2_{min} indicates partial wave
- Partial wave determination requires polarized beams

Mass Measurement



- $\mathcal{L} = 500\ \mathrm{fb}^{-1}$, p-wave WIMPs, $\sigma_0 = 100$ fb
- Relative errors mass dependent: $\Delta M/M = 0.5\%$ to 2.5%
- Scenario dependent increase in precision for polarized beams
- Systematic errors: Luminosity spectrum, beam energy scale

Mass Measurement



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Conclusion

- Model independent WIMP search by detection of high p_T photons
- Structure of studied coupling scenarios distinguishable
- Unpolarized cross section σ_0 determined to 2% to 5%
- Dominant uncertainty: Polarization measurement

- Partial wave can be determined with polarized beams
- Masses determined to $\leq$ 2.5%
- Dominant uncertainty: Beam energy spectrum

- Increased precision on Polarization measurement $\rightarrow$ factor two reduction of systematic errors
- Study of e.g. SUSY scenarios where only $\tilde{\chi}_1^0$ accessible (see O. Kittel tomorrow)