Leptophilic Dark Matter at Linear Collider

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(based on) P. K. Das, BD, A. Guha and S. Kundu, arXiv: 2107.abcde

Sixteenth Marcel Grossmann Meeting

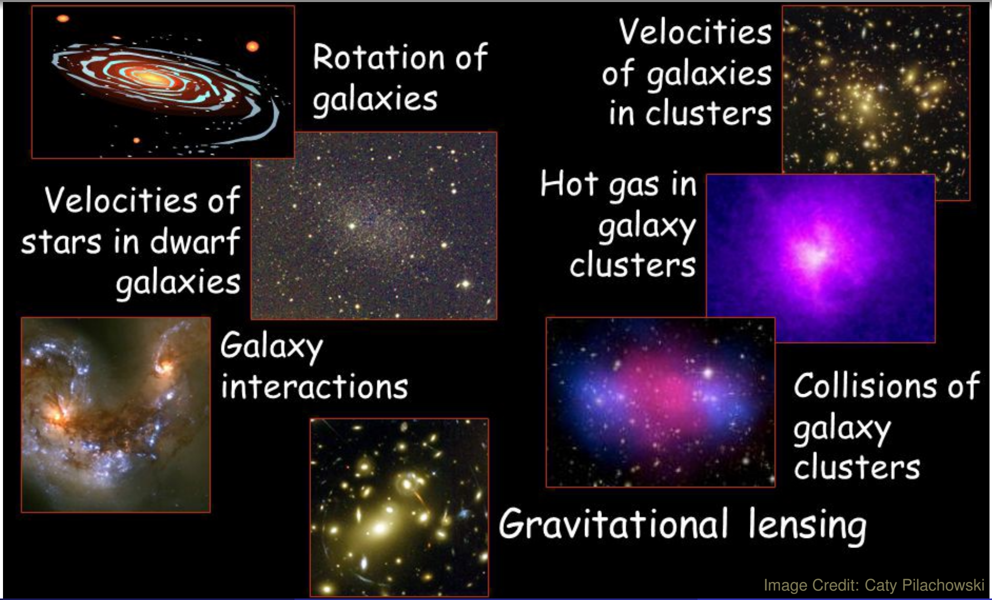
DM6: Dark Matter and Rare Processes

July 7, 2021

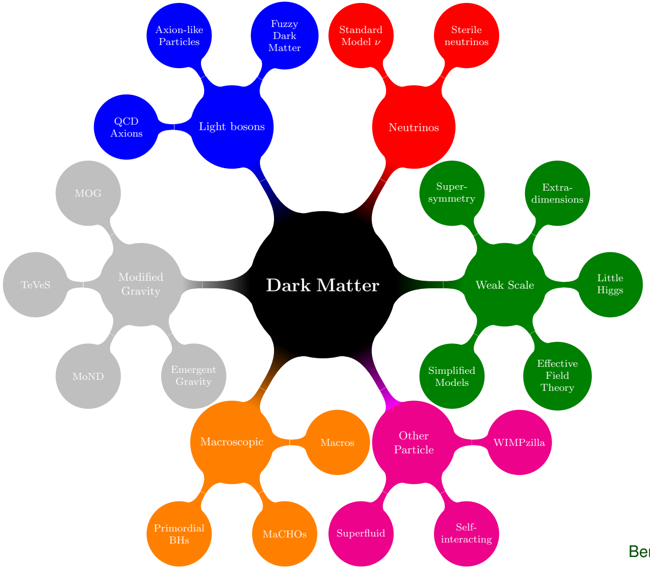
Outline

- Why Leptophilic DM?
- EFT Approach
- Mono-photon Channel
- Mono-Z Channel
- Conclusion

Evidence for Dark Matter

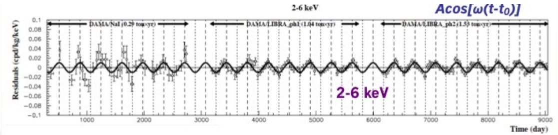


What could it be?

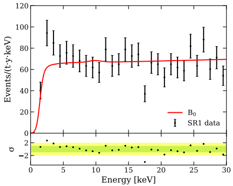


Bertone, Tait, 1810.01668 (Nature '18)

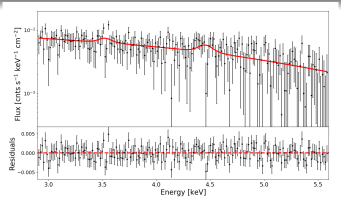
Hints from Anomalies



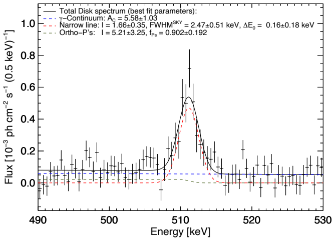
DAMA/LIBRA, 1907.06405 (J. Nucl. Phys. Atom. Energy); talk by P. Belli



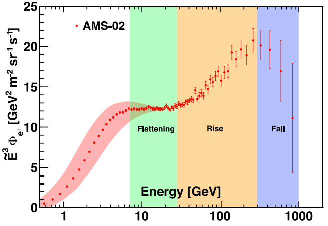
XENON1T, 2006.09721 (PRD)



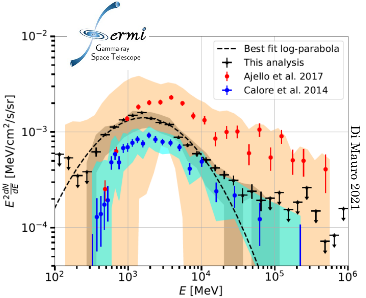
Sicilian et al, 2008.02283 (ApJ)



Siegert et al, 1512.00325 (A&A)

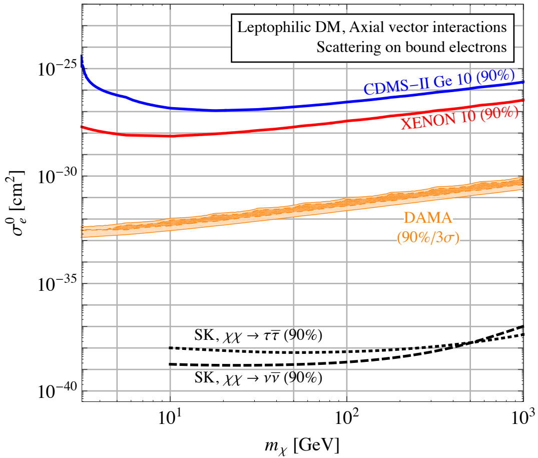


AMS-02, Phys. Rep. **894**, 1 (2021)

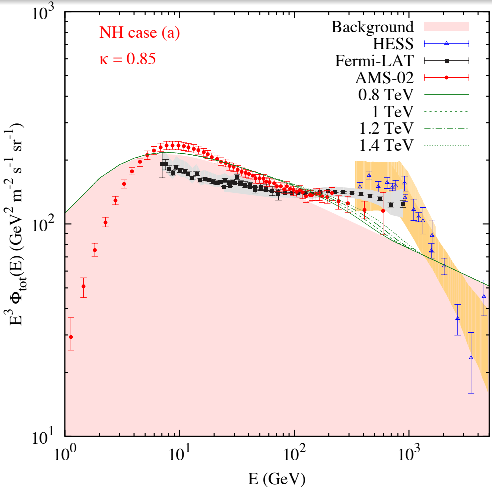


Fermi-LAT, 1704.03910 (ApJ); talk by M. Ricci

Case for Leptophilic DM

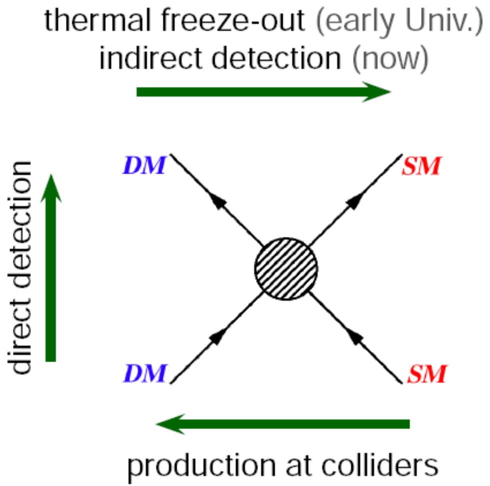


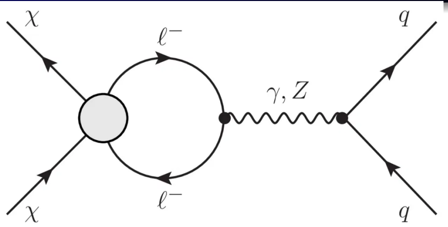
Kopp, Niro, Schwetz, Zupan, 0907.3159 (PRD)



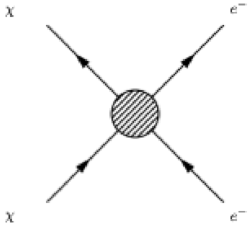
BD, Ghosh, Okada, Saha, 1307.6204 (PRD)

Many other examples: Bernabei et al (PRD '08); Fox, Poppitz (PRD '09); Ibarra, Ringwald, Tran, Weniger (JCAP '09); Cohen, Zurek (PRL '10); Agrawal, Chacko, Verhaaren (JHEP '14); Lu, Zong (PRD '16); Athron, Balazs, Fowlie, Zhang (JHEP '17); Foot (2011.02590); Garani et al (2105.12116); ...





DM-nucleon interactions are loop suppressed



Lepton colliders provide an ideal testing ground

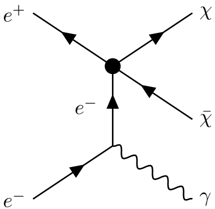
EFT Approach

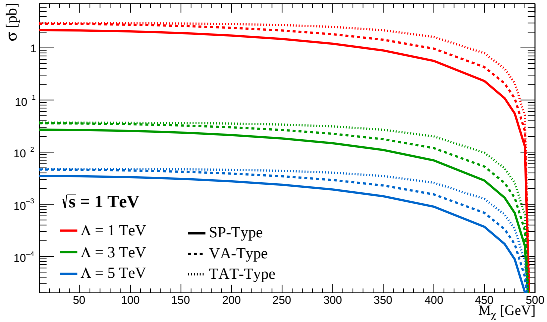
$$\mathcal{L} = \frac{1}{\Lambda^2} \sum_j (\bar{\chi}\Gamma^j_\chi \chi)(\bar{e}\Gamma^j_e e)$$

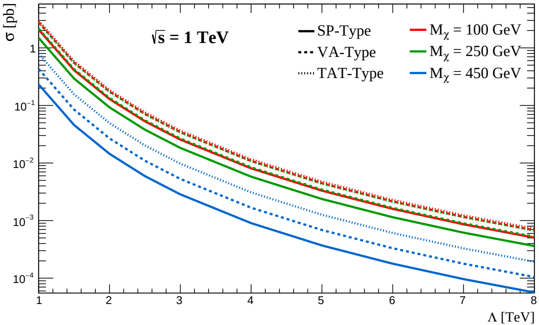
Scalar - Pseudoscalar (S-P) type :	$\Gamma_\chi = c_S^\chi + i c_P^\chi \gamma_5$,	$\Gamma_e = c_S^e + i c_P^e \gamma_5$
Vector - Axial vector (V-A) type :	$\Gamma_\chi^\mu = \gamma^\mu \left(c_V^\chi + c_A^\chi \gamma_5\right)$,	$\Gamma_{e\mu} = \gamma^\mu \left(c_V^e + c_A^e \gamma_5\right)$
Tensor - Axial Tensor (T-AT) type :	$\Gamma_\chi^{\mu\nu} = \left(c_T^\chi + i c_{AT}^\chi \gamma_5\right) \sigma^{\mu\nu}$,	$\Gamma_{e\mu\nu} = \sigma_{\mu\nu}$

- Model-independent analysis.
- Agnostic about mediator mass M (map $c_\chi c_e/\Lambda^2 \to g_e g_\chi/M^2$ in a given model).
- Assume $c_j = 1$ (unless otherwise specified), and derive sensitivity on Λ at future e^+e^- collider.
- Previous studies considered only one coefficient at a time.
  Kopp, Niro, Schwetz, Zupan, 0907.3159 (PRD);
  Fox, Harnik, Kopp, Tsai, 1103.0240 (PRD);
  Dreiner, Huck, Krämer, Schmeier, Tattersall, 1211.2254 (PRD);
  Dutta, Rawat, Sachdeva, 1704.03994 (EPJC);
  Habermehl, Berggren, List, 2001.03011 (PRD)

Mono-photon Channel







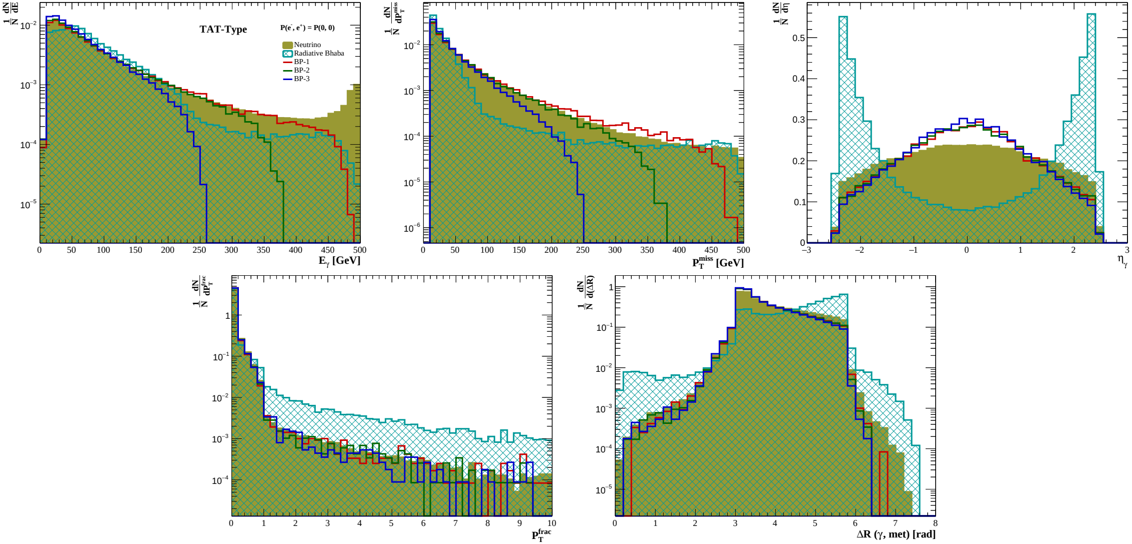
Process Type	Unpol. Beams	Pol. Scheme	Cross-sections (pb) for $P(e^-, e^+)$			
			$(+,+)$	$(+,-)$	$(-,+)$	$(-,-)$
$\nu\bar{\nu}\gamma$	4.782 pb	$(80, 0)$	1.106	-	8.506	-
		$(80, 20)$	1.268	0.963	10.160	6.793
		$(80, 30)$	1.393	0.860	10.993	5.931
$e^- e^+ \gamma$	68.439 pb	$(80, 0)$	67.920	-	68.867	-
		$(80, 20)$	67.909	68.386	69.285	68.297
		$(80, 30)$	67.809	68.566	69.502	68.181
SP-Type	0.0255 pb	$(80, 0)$	0.0255	-	0.0255	-
		$(80, 20)$	0.0296	0.0214	0.0214	0.0296
		$(80, 30)$	**0.0316**	0.0194	0.0194	0.0316
VA-Type	0.0343 pb	$(80, 0)$	0.0617	-	0.0069	-
		$(80, 20)$	0.0494	0.0741	0.0055	0.0082
		$(80, 30)$	0.0432	**0.0803**	0.0048	0.0089
TAT-Type	0.0365 pb	$(80, 0)$	0.0365	-	0.0365	-
		$(80, 20)$	0.0423	0.0306	0.0306	0.0423
		$(80, 30)$	**0.0452**	0.0277	0.0277	0.0452

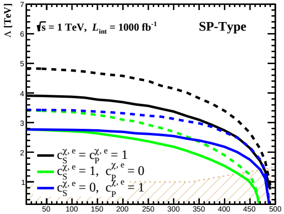
(Signal BP: $m_\chi = 100$ GeV, $\Lambda = 3$ TeV)

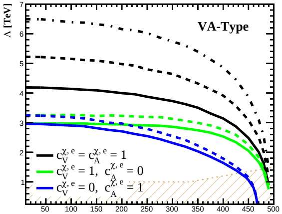
Cut-based Analysis

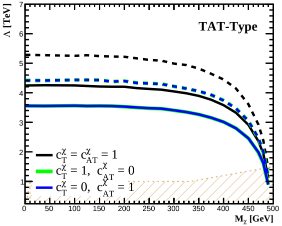
	BP-1	BP-2	BP-3
Definition	$M_\chi = 100$ GeV, $\Lambda = 6$ TeV	$M_\chi = 250$ GeV, $\Lambda = 6$ TeV	$M_\chi = 350$ GeV, $\Lambda = 6$ TeV
Baseline-selection	$E_\gamma > 10$ GeV, $\lvert\eta_\gamma\rvert < 2.45$, $P_T^{miss} > 10$ GeV		
SP-type			
Cut-1	$E_\gamma < 450$ GeV	$E_\gamma < 340$ GeV	$E_\gamma < 250$ GeV
Cut-2	$\lvert\eta_\gamma\rvert < 1.6$		
Cut-3	$P_T^{miss} < 450$ GeV	$P_T^{miss} < 340$ GeV	$P_T^{miss} < 240$ GeV
Cut-4	$P_T^{frac} < 1.3$		
Cut-5	$1.1 < \Delta R_{\gamma,met} < 4.5$		
VA-type			
Cut-1	$E_\gamma < 440$ GeV	$E_\gamma < 350$ GeV	$E_\gamma < 250$ GeV
Cut-2	$\lvert\eta_\gamma\rvert < 1.7$		
Cut-3	$P_T^{miss} < 400$ GeV	$P_T^{miss} < 340$ GeV	$P_T^{miss} < 250$ GeV
Cut-4	$P_T^{frac} < 1.2$		
Cut-5	$1.1 < \Delta R_{\gamma,met} < 4.5$		
TAT-type			
Cut-1	$E_\gamma < 460$ GeV	$E_\gamma < 360$ GeV	$E_\gamma < 230$ GeV
Cut-2	$\lvert\eta_\gamma\rvert < 1.7$		
Cut-3	$P_T^{miss} < 450$ GeV	$P_T^{miss} < 350$ GeV	$P_T^{miss} < 230$ GeV
Cut-4	$P_T^{frac} < 1.2$		
Cut-5	$1.1 < \Delta R_{\gamma,met} < 4.4$		

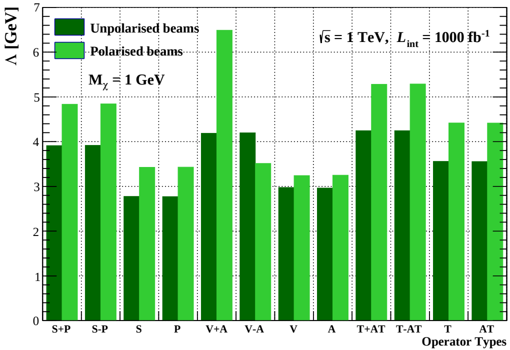
Kinematic Distributions

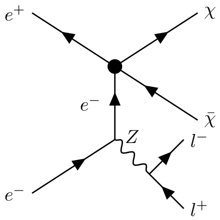



SP-Type
√s = 1 TeV, L_int = 1000 fb^-1
Λ [TeV]
c_S^{χ,e} = c_P^{χ,e} = 1
c_S^{χ,e} = 1, c_P^{χ,e} = 0
c_S^{χ,e} = 0, c_P^{χ,e} = 1

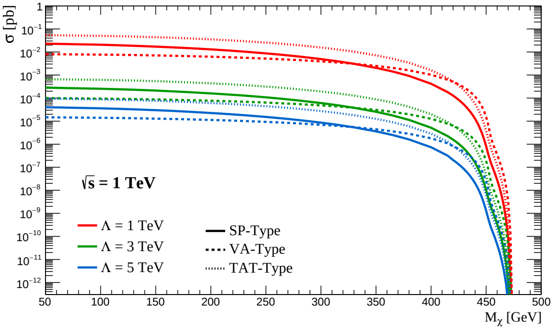

VA-Type
Λ [TeV]
c_V^{χ,e} = c_A^{χ,e} = 1
c_V^{χ,e} = 1, c_A^{χ,e} = 0
c_V^{χ,e} = 0, c_A^{χ,e} = 1


TAT-Type
Λ [TeV]
c_T^χ = c_AT^χ = 1
c_T^χ = 1, c_AT^χ = 0
c_T^χ = 0, c_AT^χ = 1
M_χ [GeV]

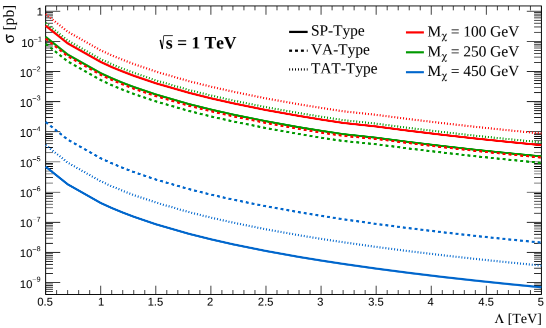

Unpolarised beams
Polarised beams
√s = 1 TeV, L_int = 1000 fb^-1
M_χ = 1 GeV
Λ [GeV]
S+P
S-P
S
P
V+A
V-A
V
A
T+AT
T-AT
T
AT
Operator Types



e^+
χ
e^-
$\bar{\chi}$
Z
l^-
e^-
l^+



σ [pb]
$\sqrt{s}$ = 1 TeV
Λ = 1 TeV
Λ = 3 TeV
Λ = 5 TeV
SP-Type
VA-Type
TAT-Type
M_χ [GeV]



σ [pb]
$\sqrt{s}$ = 1 TeV
SP-Type
VA-Type
TAT-Type
M_χ = 100 GeV
M_χ = 250 GeV
M_χ = 450 GeV
Λ [TeV]

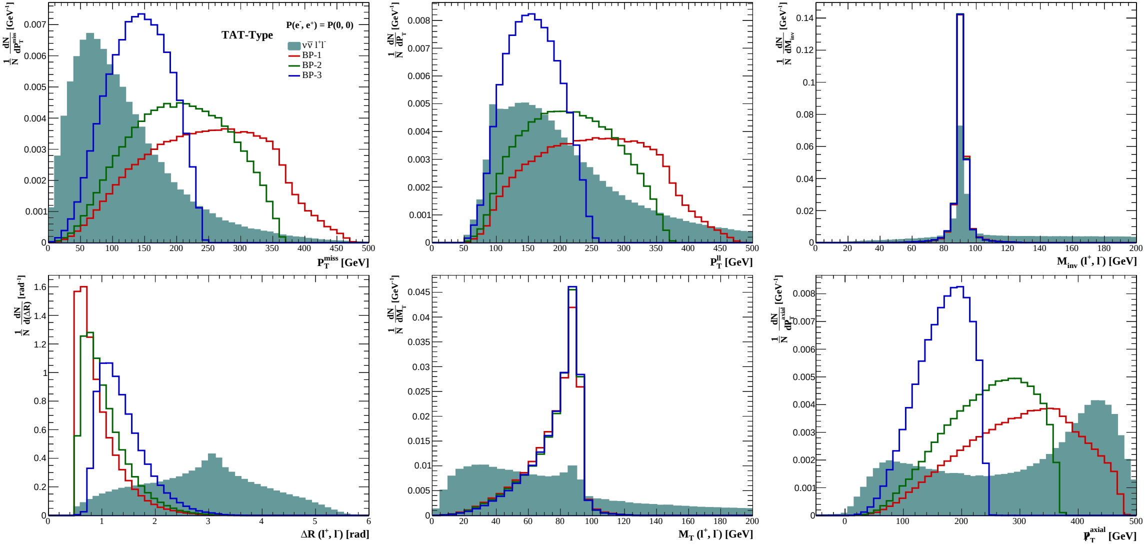
Signal vs. Background

Process type	Unpol. Beams	Pol. scheme	Cross-sections (pb) for $P(e^-, e^+)$			
			$(+,+)$	$(+,-)$	$(-,+)$	$(-,-)$
$\nu\bar{\nu}\ell^-\ell^+$	0.4205 pb	(80, 0)	0.1161	–	0.7231	–
		(80,20)	0.1347	0.09756	0.8556	0.5902
		(80, 30)	0.145	0.0884	0.9258	0.5234
SP-Type	2.78×10^{-4} pb	(80, 0)	2.55×10^{-4}	–	2.54×10^{-4}	–
		(80,20)	2.96×10^{-4}	2.15×10^{-4}	2.14×10^{-4}	2.94×10^{-4}
		(80, 30)	$\mathbf{3.17 \times 10^{-4}}$	1.93×10^{-4}	1.93×10^{-4}	3.15×10^{-4}
VA-Type	8.33×10^{-5} pb	(80, 0)	1.50×10^{-4}	–	1.66×10^{-5}	–
		(80,20)	1.20×10^{-4}	1.79×10^{-4}	1.34×10^{-5}	1.99×10^{-5}
		(80, 30)	1.05×10^{-4}	$\mathbf{1.94 \times 10^{-4}}$	1.16×10^{-5}	2.16×10^{-5}
TAT-Type	6.78×10^{-4} pb	(80, 0)	6.19×10^{-4}	–	6.19×10^{-4}	–
		(80,20)	7.19×10^{-4}	5.19×10^{-4}	5.19×10^{-4}	7.19×10^{-4}
		(80, 30)	$\mathbf{7.69 \times 10^{-4}}$	4.70×10^{-4}	4.71×10^{-4}	7.71×10^{-4}

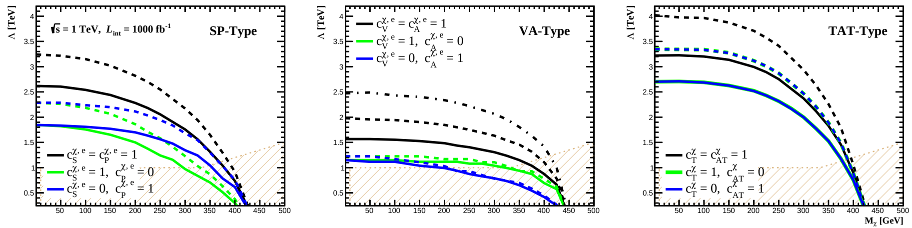
Cut-based Analysis

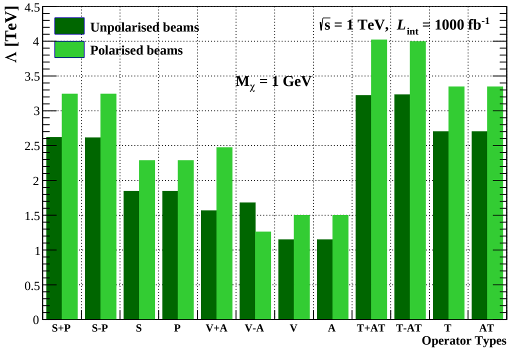
	BP-1	BP-2	BP-3
Definition	$M_\chi = 100$ GeV, $\Lambda = 3$ TeV	$M_\chi = 250$ GeV, $\Lambda = 3$ TeV	$M_\chi = 350$ GeV, $\Lambda = 3$ TeV
Baseline-selection	OSSF lepton-pairs with $P_{T,l_1} > 30$ GeV, $P_{T,l_2} > 20$ GeV, $\lvert\eta_l\rvert < 2.45$		
SP-type			
Cut-1	70 GeV $\leq M_{inv}(\ell^- \ell^+) \leq$ 110 GeV		
Cut-2	160 GeV $< \not{E}_T$	115 GeV $< \not{E}_T <$ 350 GeV	100 GeV $< \not{E}_T <$ 230 GeV
Cut-3	$\Delta\eta_{\ell\ell} < 1.35$, $\Delta\phi_{\ell\ell} < 1.3$ rad		
Cut-4	$M_T(\ell^- \ell^+) > 60$ GeV		
Cut-5	100 GeV $< \not{P}_T^{axial} <$ 435 GeV	115 GeV $< \not{P}_T^{axial} <$ 350 GeV	100 GeV $< \not{P}_T^{axial} <$ 230 GeV
VA-type			
Cut-1	70 GeV $\leq M_{inv}(\ell^- \ell^+) \leq$ 110 GeV		
Cut-2	$p_T^{\ell\ell} <$ 360 GeV	$p_T^{\ell\ell} <$ 270 GeV	$p_T^{\ell\ell} <$ 215 GeV
Cut-3	$\Delta\eta_{\ell\ell} < 1.2$, $\Delta\phi_{\ell\ell} < 2.6$ rad		
Cut-4	$M_T(\ell^- \ell^+) > 35$ GeV		
Cut-5	60 GeV $< \not{P}_T^{axial} <$ 380 GeV	60 GeV $< \not{P}_T^{axial} <$ 290 GeV	60 GeV $< \not{P}_T^{axial} <$ 220 GeV
TAT-type			
Cut-1	70 GeV $\leq M_{inv}(\ell^- \ell^+) \leq$ 110 GeV		
Cut-2	210 GeV $< \not{E}_T$	165 GeV $< \not{E}_T <$ 360 GeV	110 GeV $< \not{E}_T <$ 230 GeV
Cut-3	$\Delta\eta_{\ell\ell} < 1.2$, $\Delta\phi_{\ell\ell} < 1.2$ rad		
Cut-4	$M_T(\ell^- \ell^+) > 60$ GeV		
Cut-5	100 GeV $< \not{P}_T^{axial} <$ 475 GeV	100 GeV $< \not{P}_T^{axial} <$ 370 GeV	100 GeV $< \not{P}_T^{axial} <$ 240 GeV

Kinematic Distributions



Results for the Mono-Z (leptonic) Channel





Conclusion

- Particle nature of DM (mass, spin, interactions with SM particles,...) remains unknown.
- Taken at face value, current DM anomalies might provide some clue.
- Leptophilic DM is a well-motivated candidate to explain some of the anomalies.
- Ideal to search for at future lepton colliders.
- In an EFT approach, found that 3σ sensitivity at $\sqrt{s} = 1$ TeV ILC can reach up to $\Lambda \sim 6.5$ TeV in the mono-photon channel and up to $\Lambda \sim 4$ TeV in the mono-Z channel.

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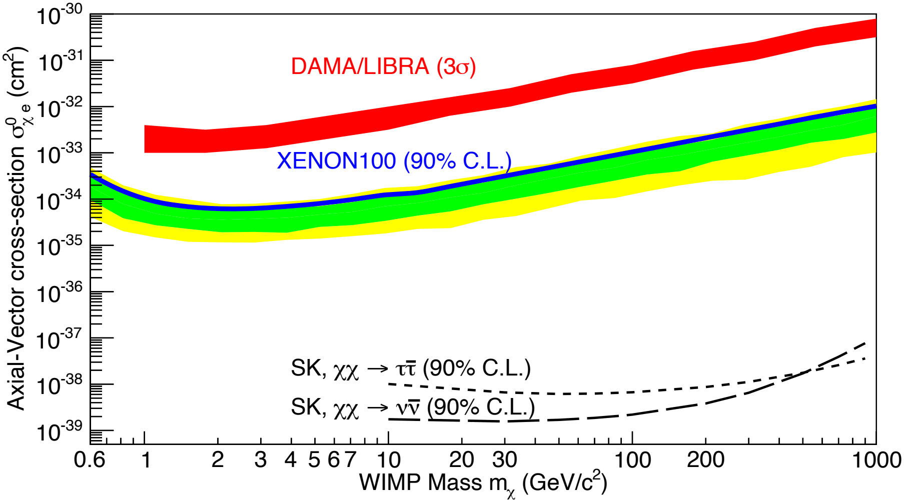
- In an EFT approach, found that 3σ sensitivity at $\sqrt{s} = 1$ TeV ILC can reach up to $\Lambda \sim 6.5$ TeV in the mono-photon channel and up to $\Lambda \sim 4$ TeV in the mono-Z channel.

Thank you.

XENON100 update on Leptophilic DM



XENON100, 1507.07747 (Science)