Search for Dark Matter at Colliders

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Dark Matter at a LC

Third JCL

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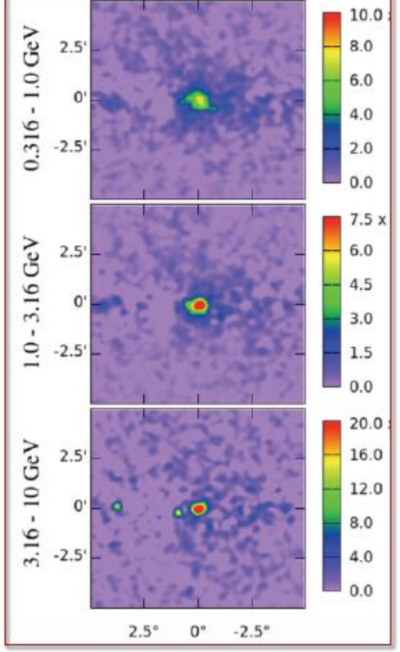
Introduction 1

- The issue of DM appears as a primordial goal in fundamental physics
- There is no definite prediction about the origin of the astrophysical observations (e.g. particles from μev to multi TeV scales or even macroscopic objects)
- Direct searches for wimps using liquid Xe are developing very fast and cover the wimp masses >10 GeV provided that these wimps interact coherently with nuclei (σ_{XA}~A^2)



Introduction 2

- Indirect searches detecting **photons** (Fermi) or positrons tend to observe excesses which could also originate from **classical sources**, pulsars or supernovae remnants
- If these excesses translate into **Direct signals**, one can hope to reach convincing evidence for DM
- It would however take a **collider** to understand the origin of these particles
- In certain cases only a collider can detect DM
- This is the topic of my presentation, focusing on e+e-

Possible approach

- Assume DM is made of fermions, Dirac or Majorana, without an explicit theoretical origin
- Assume DM annihilation goes through SM particles Z or H (skipped due to lack of time) or through BSM particles **Z’** or **A** (axial Higgs in a 2 doublet model)
- Assume that the coupling is chosen to avoid present Direct limits (no coherent interaction, **kinematical suppression when quarks have axial coupling**)

Couplings

- While for Z and H the fermion couplings are imposed **Z'** allows to choose a pure axial coupling to fermions not accessible to Direct searches
- For **A** an axial coupling to fermions is imposed

DM	Mediator	Interactions	Direct	LHC
Majorana	Z'	$\bar{X}\gamma^{\mu}\gamma^{5}X$, $\bar{f}\gamma^{\mu}\gamma^{5}f$	Yes	Yes
Dirac	Z'	$\bar{X}\gamma^{\mu}X$, $\bar{f}\gamma^{\mu}\gamma^{5}f$	No	Yes
Majorana	A	$\bar{X}\gamma^{5}X$, $\bar{f}\gamma^{5}f$	No	Yes

Z′ case

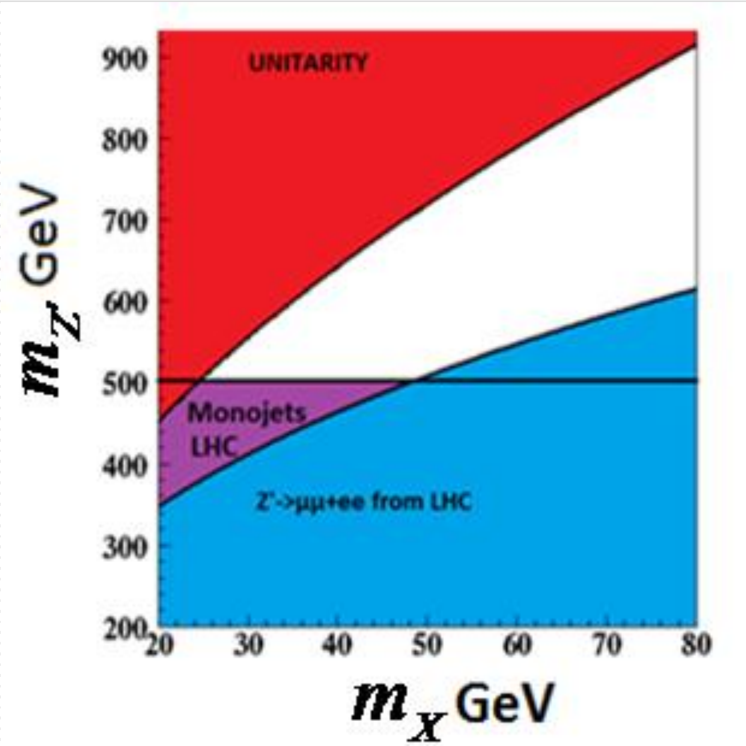
- One assumes a pure axial coupling of Z′ to SM fermions and a vector coupling to X
- The annihilation cross section given is by

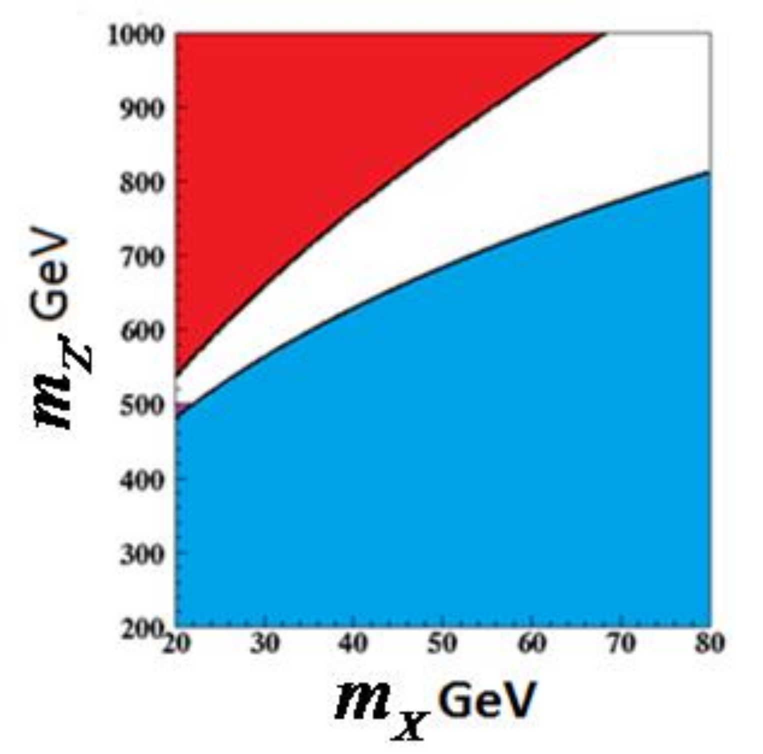
$$\sigma v = |g_V^X|^2 K^2 \sum_f n_{cf} |g_A^f|^2 \frac{2m_X^2 + s}{12\pi\left[(s - m_{Z'}^2)^2 + (m_{Z'}\Gamma_{Z'})^2\right]}, \quad s = 4m_X^2$$

- If one takes SM couplings to fermions ($K^2=1$), DM solutions predict an invisible Z′ (BR >90%)
- $K^2<1$ allows to escape LHC limits on Z′
- gVX has an upper limit due to unitarity

FR, G. Arcadi, Y. Mambrini
arXiv:1411.0088

Allowed domain



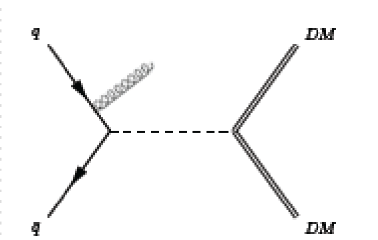


K²=0.1

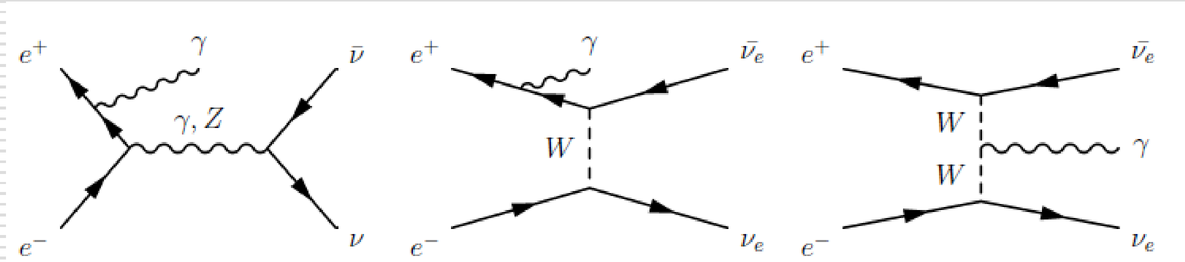
K²=0.2

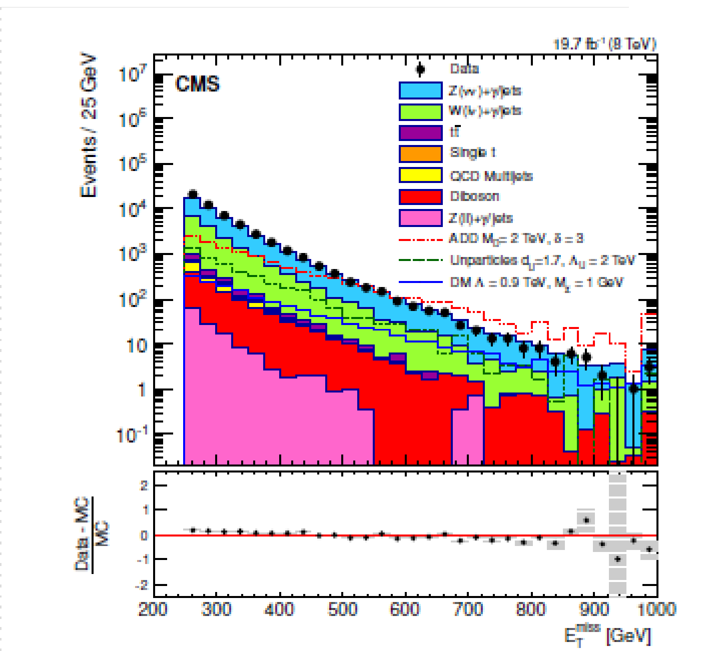
Searches techniques

- Monojets at LHC



- ISR at a LC

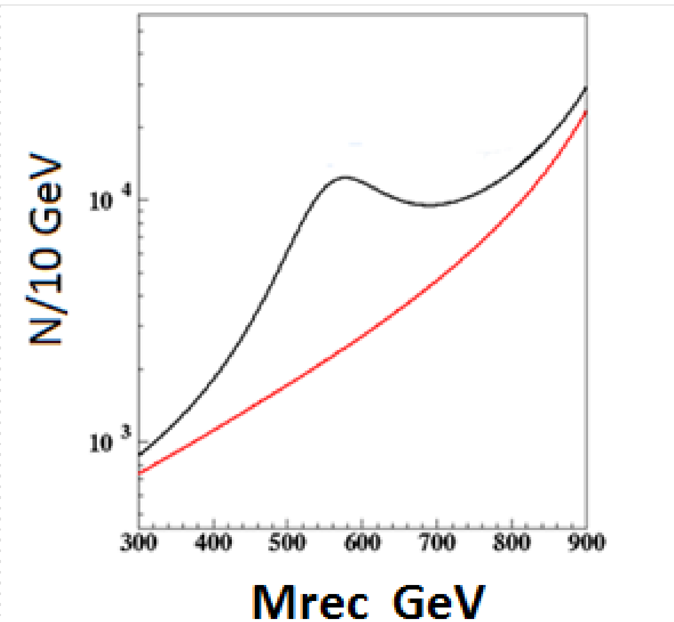


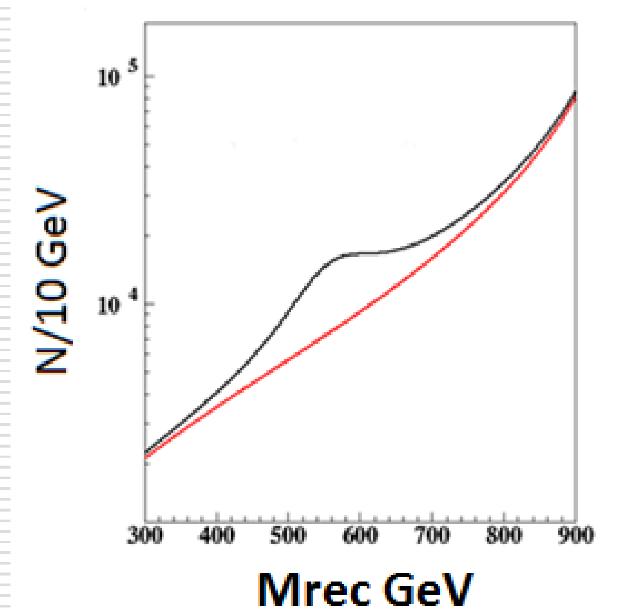


- For mZ’>mZ W exchange dominates
- Use right handed e-
- Try to reach the highest **polarisation**

FR, G. Arcadi, Y. Mambrini
arXiv:1411.0088

Expected signals





Pe-=0.9
Pe+=-0.6

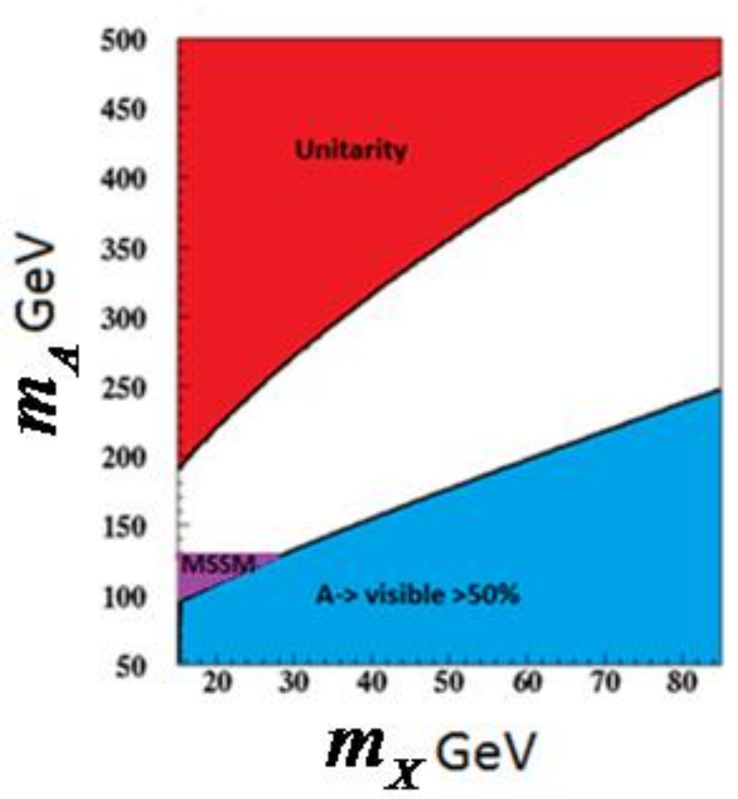
Pe-=0.8
Pe+=-0.3

Comments

- Clear advantage due to **beam polarization**
- Knowing the **initial sate partons E/p** one can reconstruct the mass of the invisible Z’
- High rate, clean signal providing mass, width and coupling to e+e-
- Extra assumption: no contribution from Bhabhas ee → eeγ which requires **perfect vetoing of electrons** in the forward region
- Worries: **arXiv:1006.3402**

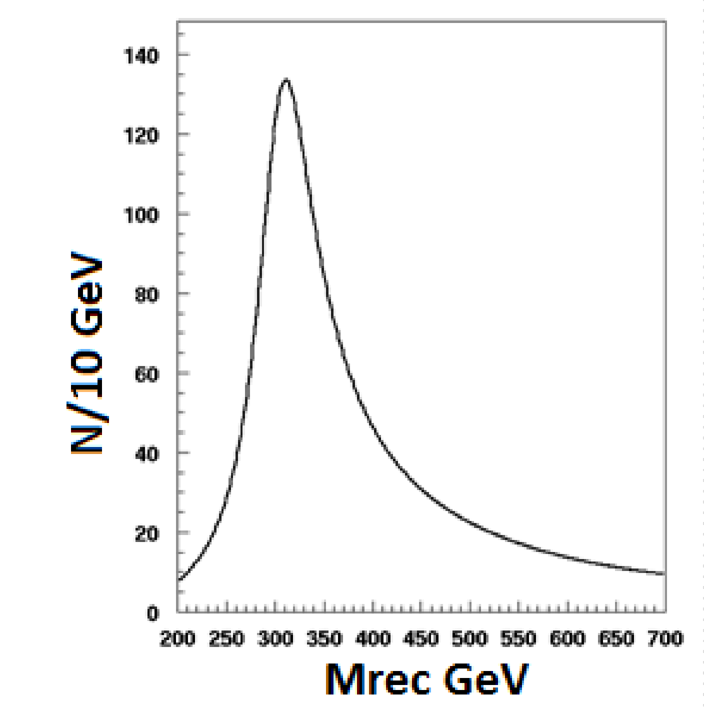
XX→A scenario

- Fulfills all constraints since it couples axially to SM fermions
- Mass limit deduced from H± at LHC assuming MSSM
- e+e-→HA for tanβ=5 with mA~mH and H→2h
- This signal in the 4 b mode is background free since top pairs have only 2b



Expected signal

- mA can be reconstructed as the **recoil mass** to H → 2h
- Illustrates again the power offered by initial energy momentum constraints and good hadronic reconstruction
- As with Zh, ILC gives the opportunity to measure Higgs **invisible decays** for the non minimal sector at the1% level



mA=mH=300 GeV 1 TeV 1ab-1. 7000 evts

Conclusions

- High energy colliders could provide a decisive understanding of the origin of DM
- They are complementary to Direct searches specially when DM interactions with nuclei get suppressed
- While LHC can identify invisible decays associated to DM, it takes an e+e- collider with well defined energy momentum for **'bump hunting'** allowing to identify the underlying mechanism
- **Beam polarization** gives a major tool for the **'invisible Z''** scenario
- Measuring invisible modes in the **non minimal Higgs sector** also fits ideally in an LC scenario

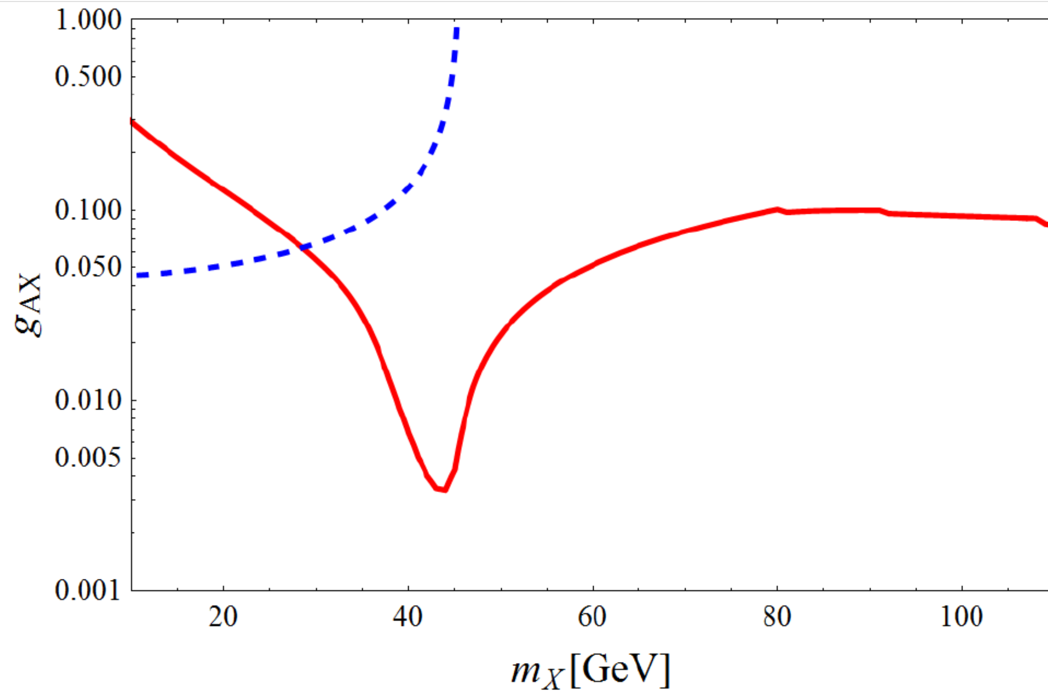
BACK UP SLIDES

XX → Z → ff

$$\sigma v_{FO} = \sum_f n_{cf} (|g_V^f|^2 + |g_A^f|^2) \frac{|g_A^X|^2 \langle v^2 \rangle s}{12\pi \left[(s - m_Z^2)^2 + (m_Z \Gamma_Z)^2 \right]} \qquad s = 4 m_X^2$$

$$g_V^f = \frac{g}{2c_W}(I_3 - 2Q s_W^2) \quad g_A^f = \frac{g}{2c_W} I_3$$

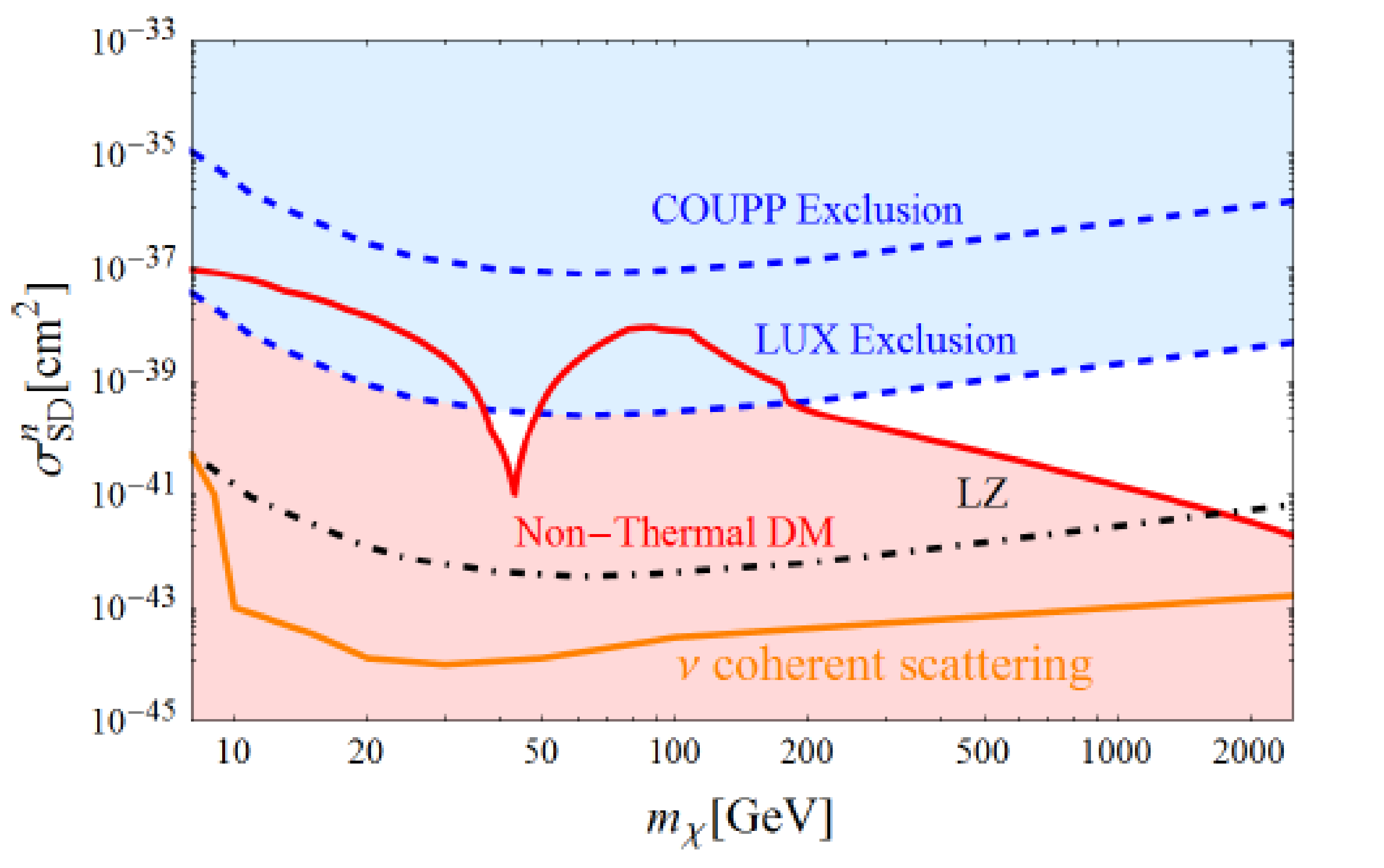
- DM annihilation depends on v which decreases from decoupling to present temperatures
- Needs **Sommerfeld enhancement**



G. Arcadi, Y. Mambrini, FR
arXiv:1411.2985

Direct limits

G. Arcadi, Y. Mambrini, FR
arXiv:1411.2985



Photon excess in Galactic Center

- Quoting **arXiv:1402.6703** 'the signal is observed to extend to at least ~10^0 from the Galactic Center (GC), disfavoring the possibility that this emission originates from millisecond pulsars'.
- mX 20-55 GeV and even more if XX->WW,ZZ,hh
- Note the 3.5 KeV line interpreted as DM does not show this angular dispersion
- Recent dwarf galaxy survey shows a 'slight tension'
- http://fermi.gsfc.nasa.gov/science/mtgs/symposia/2014/program/17_Anderson.pdf

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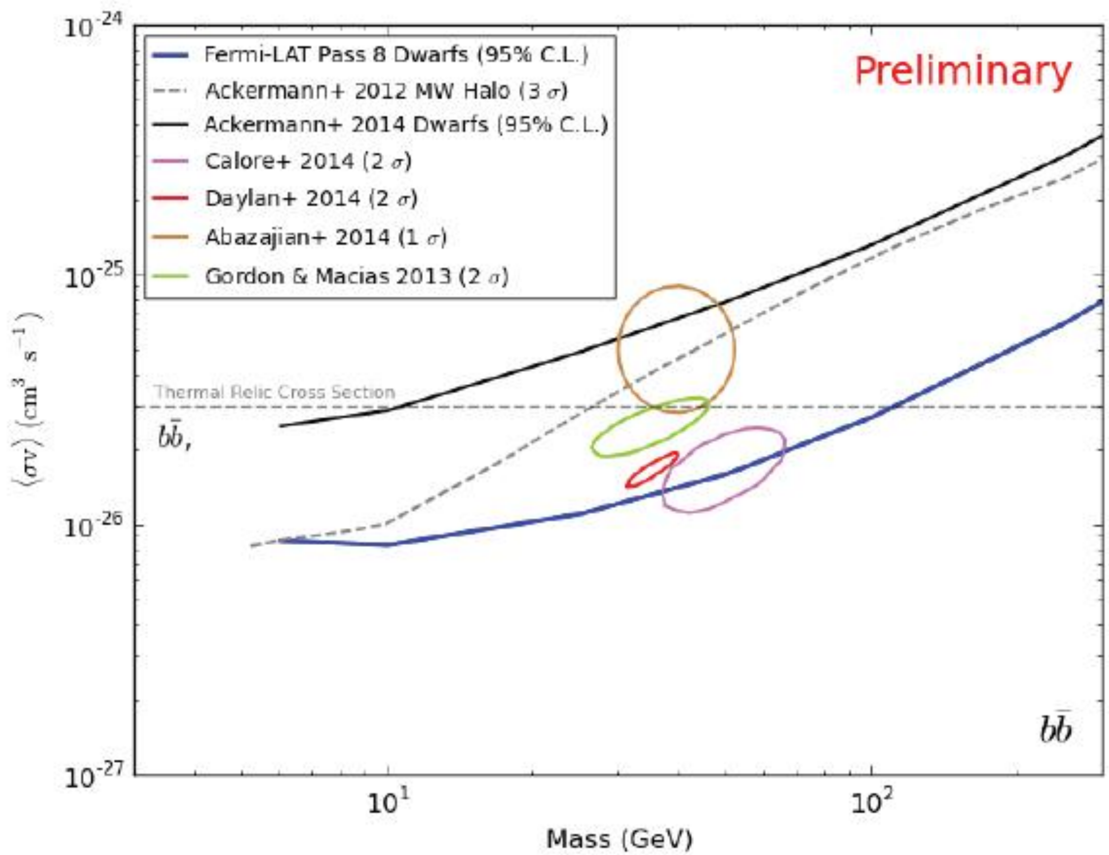
Galactic Center Excess (GCE) Compatibility



Brandon Anderson, Stockholm University | 5th Fermi Symposium 14