



Search for Dark Matter at Colliders

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Dark Matter at a LC



Third JCL (Journées Collisionneur Linéaire)

1-3 December 2014 LPSC Grenoble



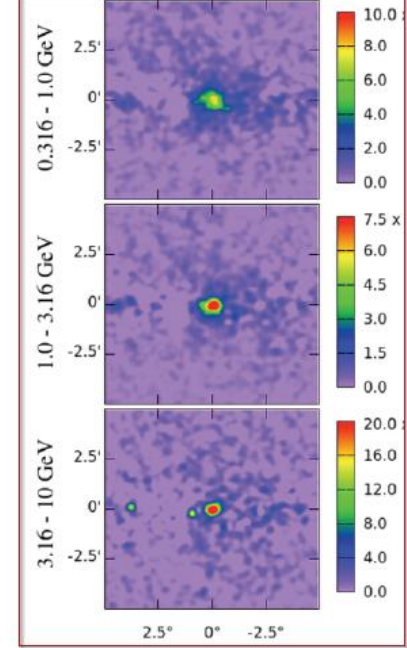
François Richard LAL/Orsay

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 ($\sigma_{\chi A} \sim A^2$)

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 \mathbf{Z}' or \mathbf{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 |

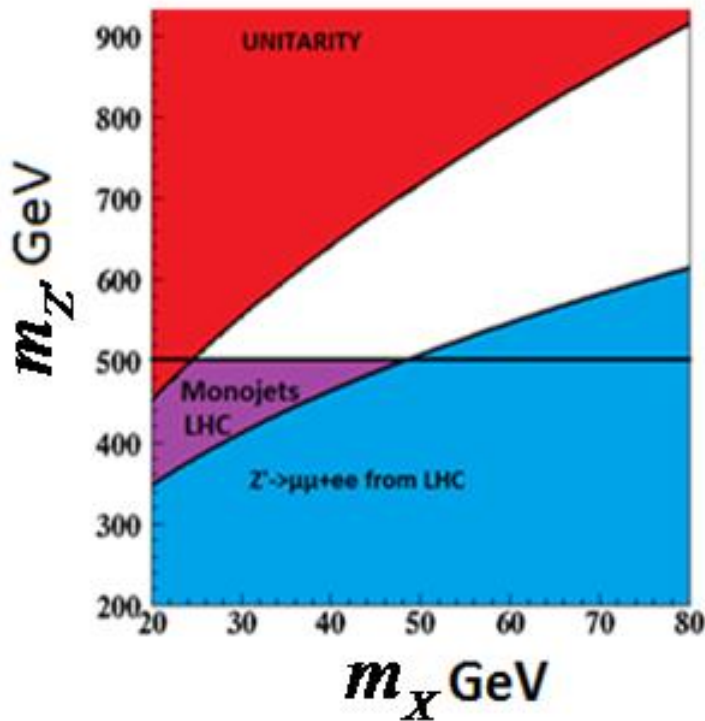
Z' case

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

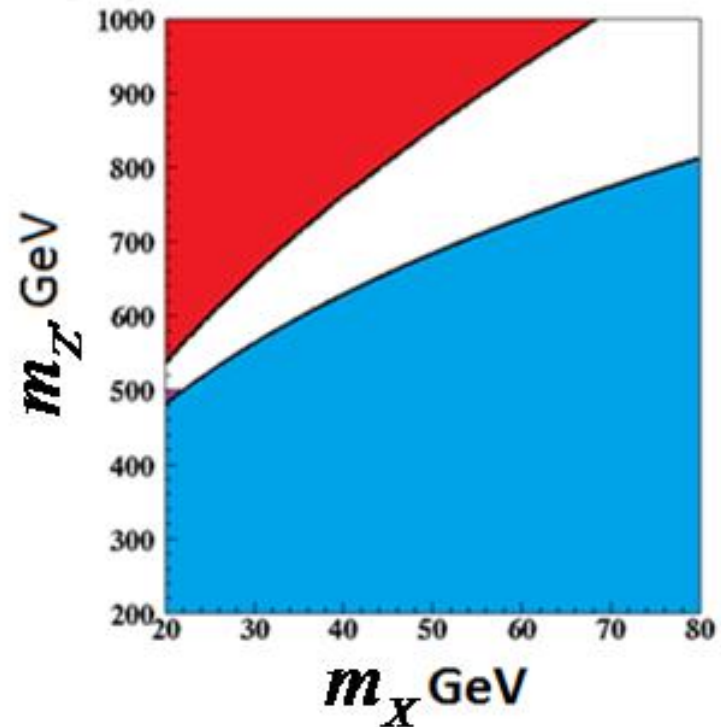
$$\sigma_{\text{V}} = |g_{\text{V}}^{\text{X}}|^2 K^2 \sum_f n_{\text{cf}} |g_{\text{A}}^f|^2 \frac{2m_{\text{X}}^2 + s}{12\pi \left[(s - m_{\text{Z}'}^2)^2 + (m_{\text{Z}'}\Gamma_{\text{Z}'})^2 \right]}, s = 4m_{\text{X}}^2$$

- 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'
- g_{VX} has an upper limit due to unitarity

Allowed domain



$K^2 = 0.1$

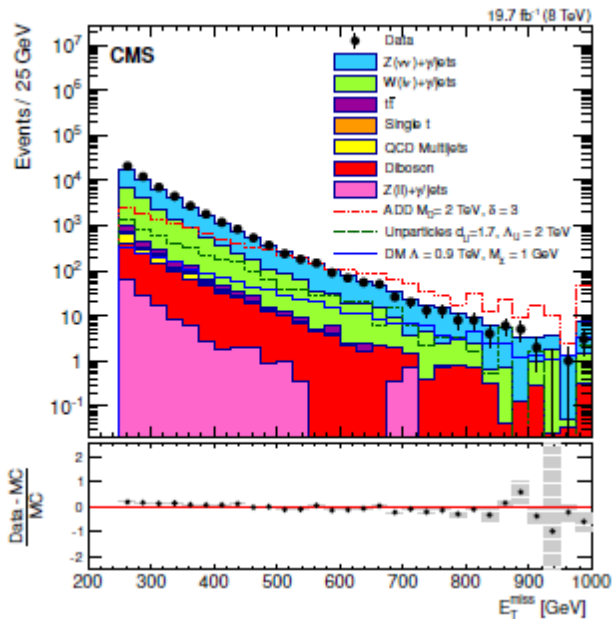
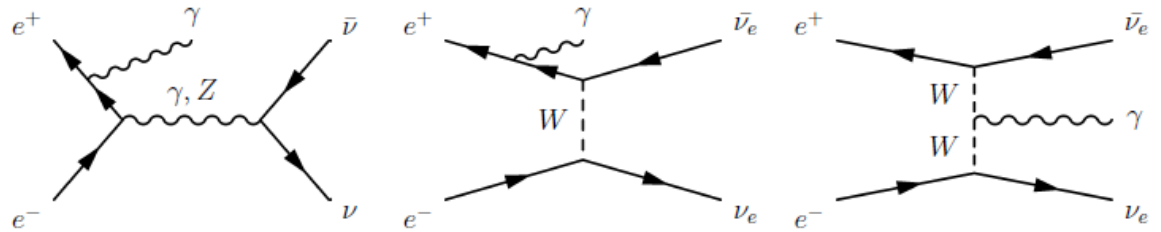
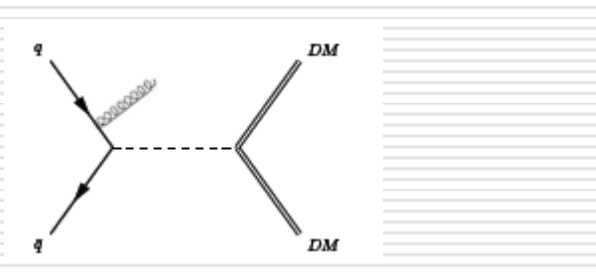


$K^2 = 0.2$

Searches techniques

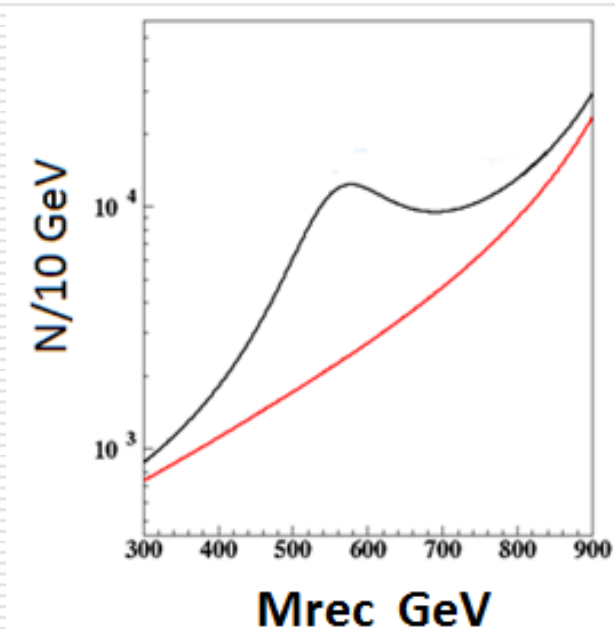
□ Monojets at LHC

□ ISR at a LC

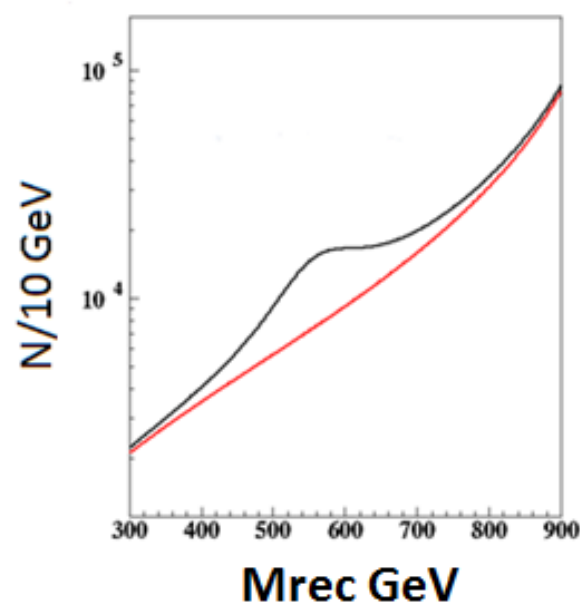


- For $m_{Z'} > m_Z$ W exchange dominates
- Use right handed e^-
- Try to reach the highest **polarisation**

Expected signals



$P_{e^-} = 0.9$
 $P_{e^+} = -0.6$



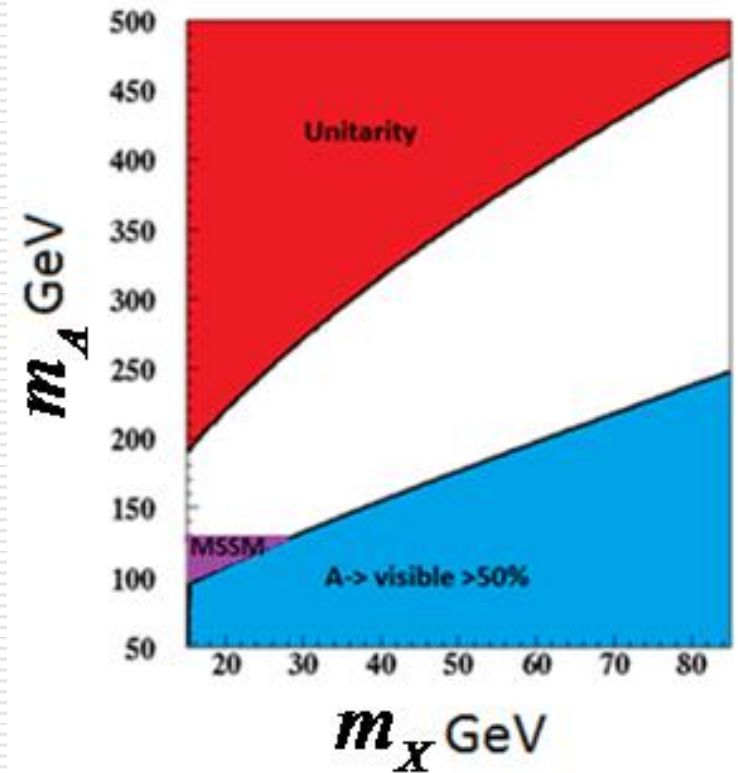
$P_{e^-} = 0.8$
 $P_{e^+} = -0.3$

Comments

- Clear advantage due to **beam polarization**
- Knowing the **initial state 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 $ee \rightarrow ee\gamma$ which requires **perfect vetoing of electrons** in the forward region
- Worries: [arXiv:1006.3402](https://arxiv.org/abs/1006.3402)

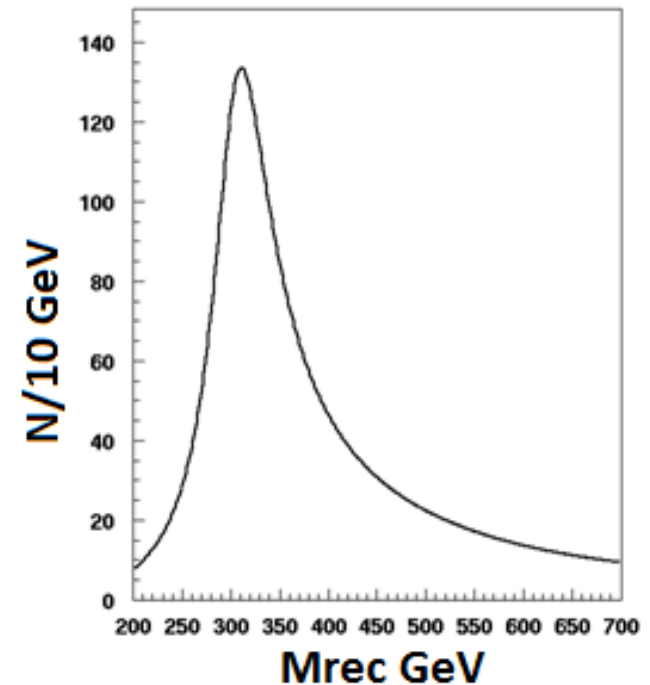
$XX \rightarrow A$ scenario

- Fulfills all constraints since it couples axially to SM fermions
- Mass limit deduced from H_{\pm} at LHC assuming MSSM
- $e+e^- \rightarrow HA$ for $\tan\beta=5$ with $m_A \sim m_H$ and $H \rightarrow 2h$
- This signal in the $4b$ mode is background free since top pairs have only $2b$



Expected signal

- m_A can be reconstructed as the **recoil mass** to $H \rightarrow 2h$
- 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 the 1% level



**$m_A = m_H = 300$ 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

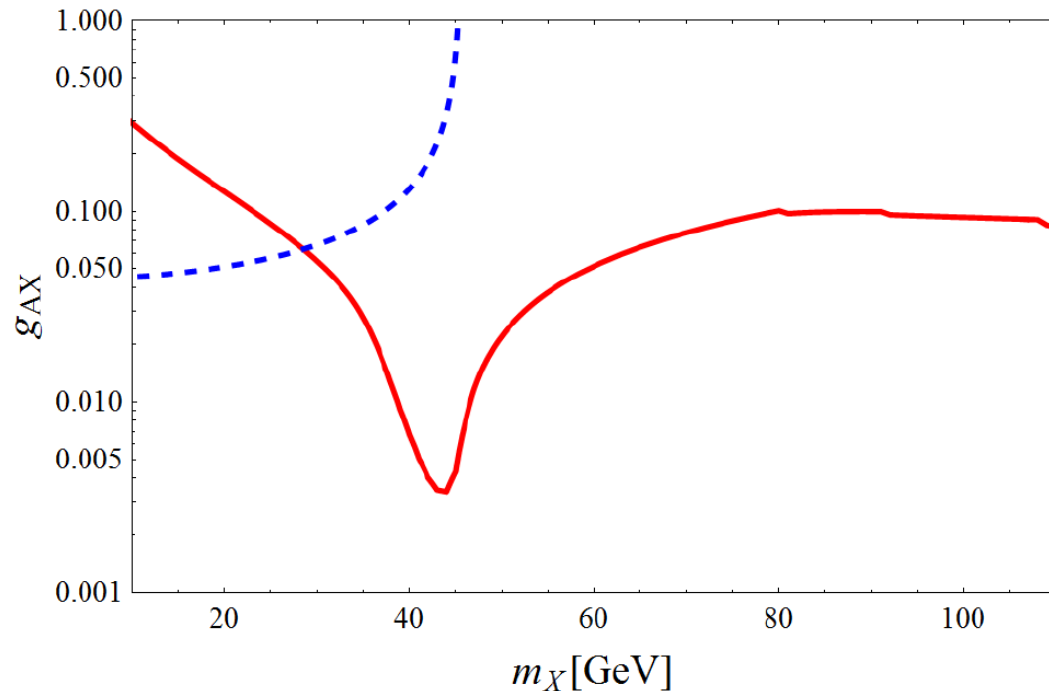
XX \rightarrow Z \rightarrow ff

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

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

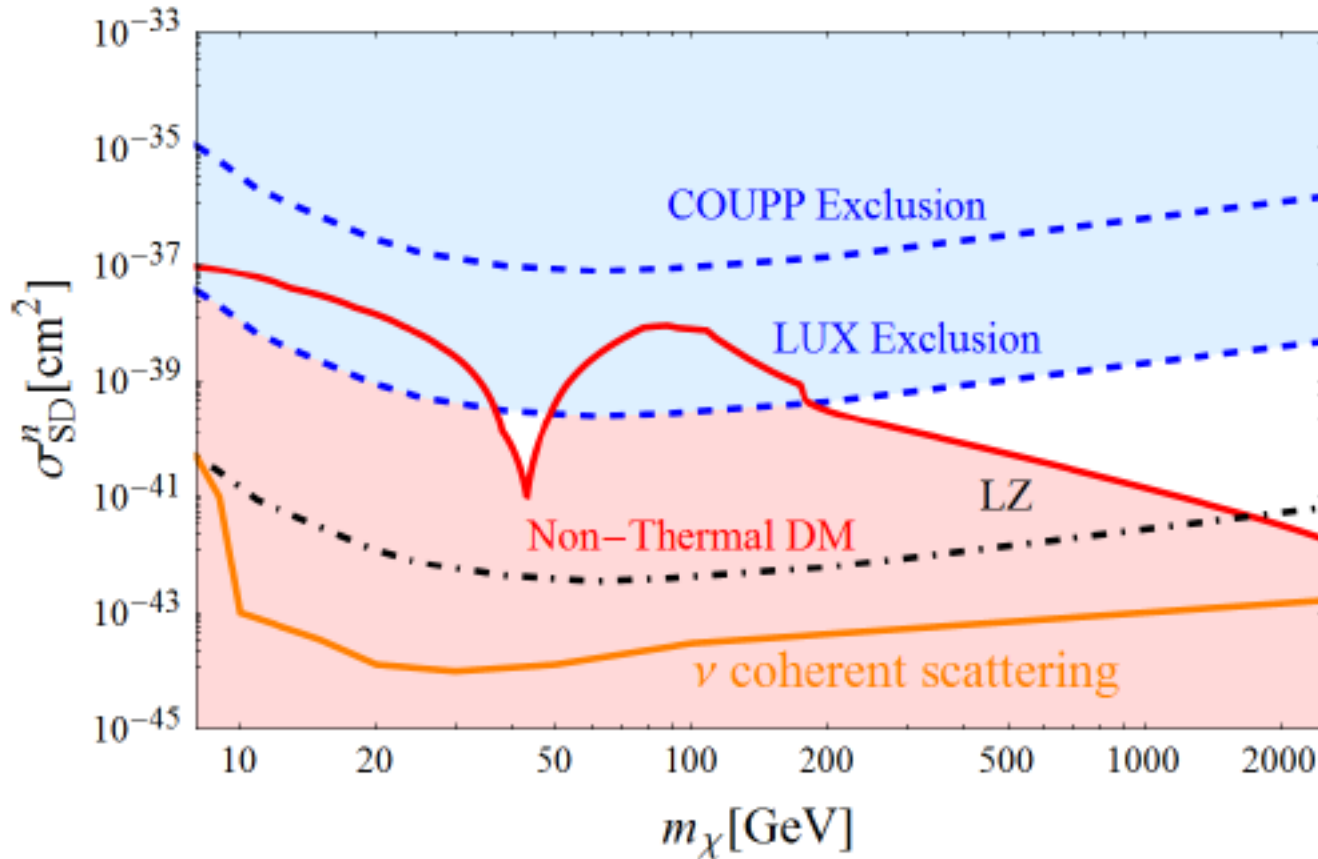
□ DM annihilation depends on v which decreases from decoupling to present temperatures

□ Needs **Sommerfeld enhancement**



Direct limits

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



Photon excess in Galactic Center

- Quoting [arXiv:1402.6703](https://arxiv.org/abs/1402.6703) 'the signal is observed to extend to at least $\sim 10^0$ from the Galactic Center (GC), disfavoring the possibility that this emission originates from millisecond pulsars'.
- mX 20-55 GeV and even more if $XX \rightarrow WW, ZZ, hh$
- 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



Galactic Center Excess (GCE) Compatibility

