GALACTIC CENTER GeV GAMMA-RAY EXCESS FROM DARK MATTER WITH GAUGED LEPTON NUMBERS

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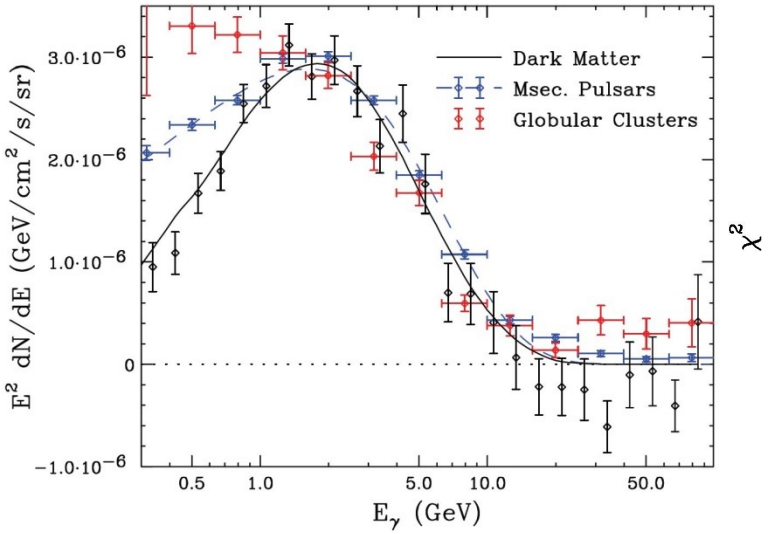
Outline

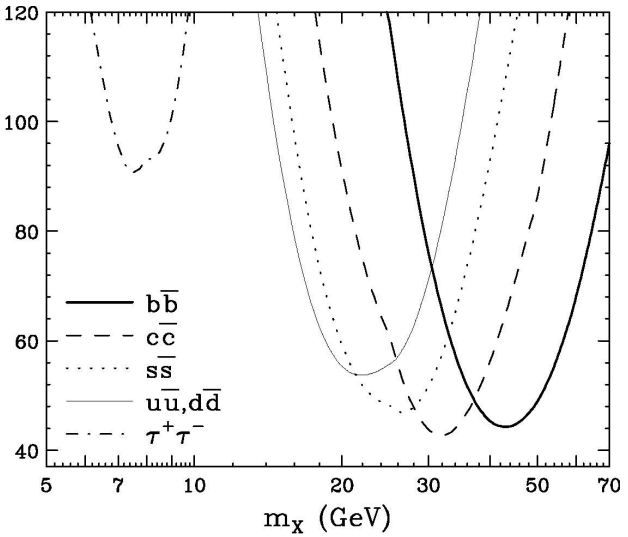
- Introduction
  - Fermi-LAT: GeV gamma-rays from the Galactic center
- Leptophilic Dark Matter
  - $U(1)_{L_\mu - L_\tau}$model
- Constraints
  - Muon g-2, tau decay, neutrino trident production
  - Direct detection
  - Z' search @ LHC
- Conclusion

INTRODUCTION –FERMI-LAT GEV EXCESS

Dan Hooper et al.(arXiv: 1402.6703)

- GeV gamma ray excess is very well fit by 30~40GeV DM particles annihilating to b quark final states
  - Required cross section is $\sigma v \sim 2*10^{-26}$ cm^3/s
- Leptonic final state analysis
  - Focus on prompt gamma ray emission
  - Annihilation of DM into pure lepton final states does not provide a good fit

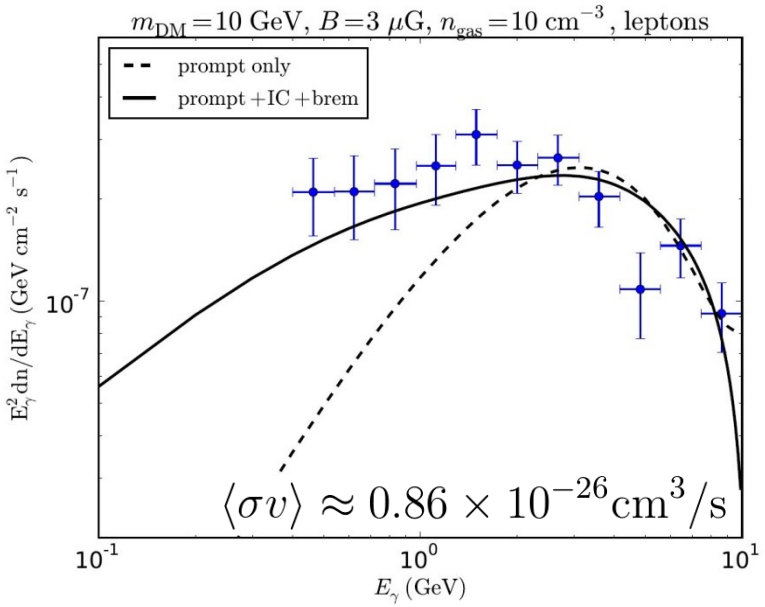


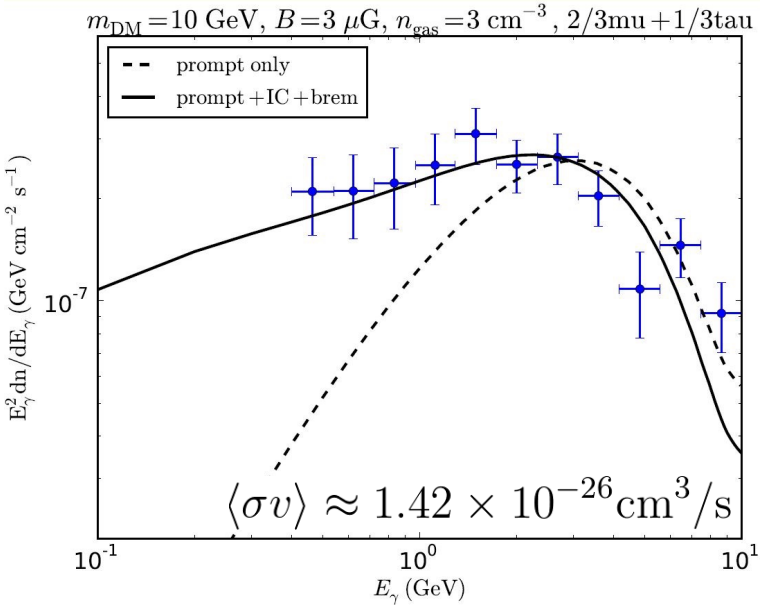


INTRODUCTION –FERMI-LAT GEV EXCESS

Joseph Silk et al.(arXiv: 1403.1987)

- Omitting the photon emission originating from primary and secondary electrons
  - Wrong conclusion : lepton final state → bad fit
- Including Inverse Compton Scattering and Bremsstrahlung contributions from electrons
  - Annihilation of DM into pure leptons provide a good fit

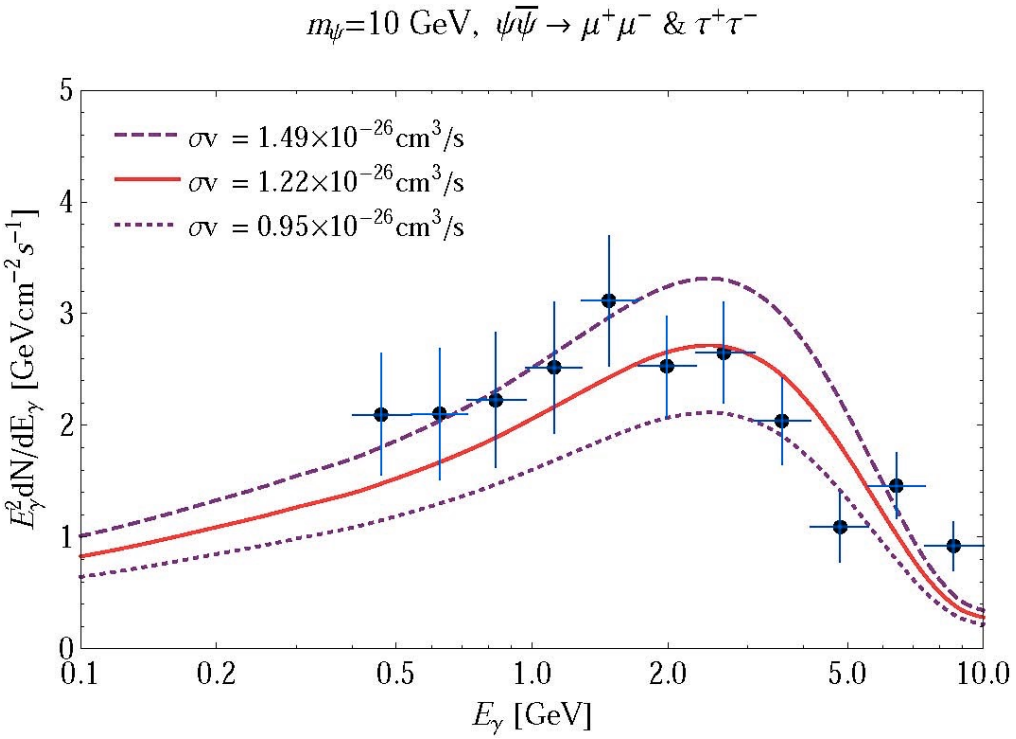




INTRODUCTION –FERMI-LAT GEV EXCESS

- Conduct the fit of the case of $\mu^+\mu^- : \tau^+\tau^- = 1 : 1$

- Best fit: $\langle \sigma v \rangle_{\psi\bar{\psi}\to\mu^+\mu^-:\tau^+\tau^-} \approx 1.22 \times 10^{-26} \mathrm{cm}^3/\mathrm{s}$

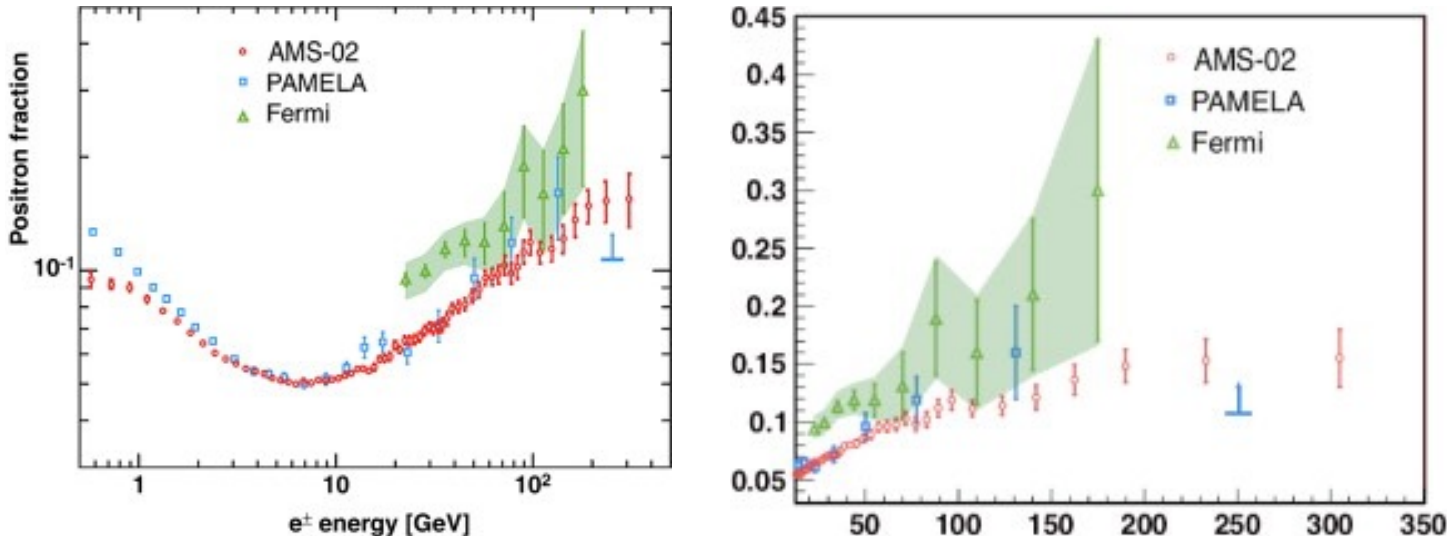


LEPTOPHILIC DM MODEL

- Cosmic ray detection experiments

  AMS-02 Collaboration (PRL 113(2014) 221102)

  - excess in positron fraction, but not in anti-proton



- Possible to gauge one of the differences of two lepton-flavor numbers

  - L_e-L_μ, L_μ-L_τ, L_τ –L_e : anomaly free

  X. G. He, R. Volkas et al., PRD(1991)
  R. Foot, Mod. Phys. Lett. A(1991)

- Symmetries including L_e are strongly constrained

LEPTOPHILIC DM MODEL

- New gauge symmetry $U(1)_{L_\mu - L_\tau}$ has influence on the 2nd and 3rd generations of leptons
- Dirac fermion plays a role of dark matter
- Charges under the gauged L_μ-L_τ symmetry

particle	ψ	$L_\mu = (\nu_{\mu L}, \mu_L)\ ,\ \mu_R,\ \nu_{\mu R}$	$L_\tau = (\nu_{\tau L}, \tau_L)\ ,\ \tau_R,\ \nu_{\tau R}$	others
charge	Q_ψ	$+1$	-1	0

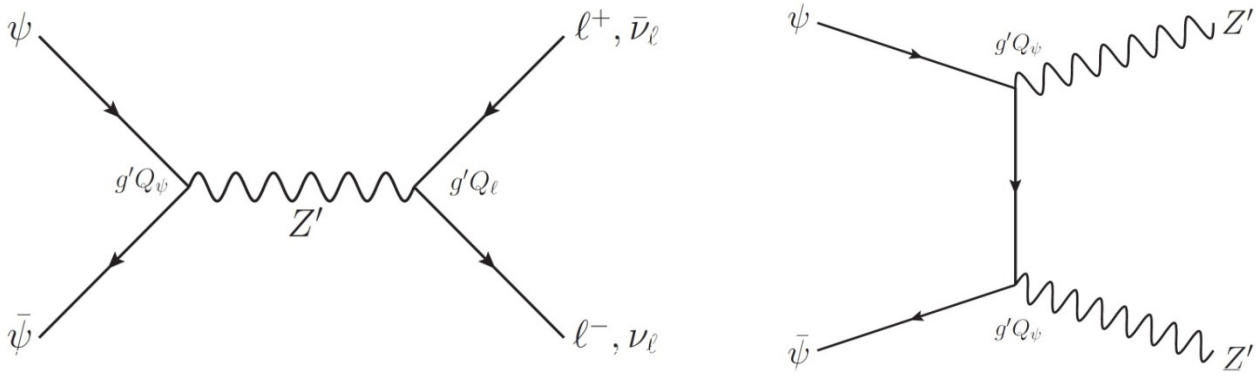
- Model set-up

$$\mathcal{L} \supset \mathcal{L}_{SM} - \frac{1}{4} Z'_{\alpha\beta} Z'^{\alpha\beta} + i\overline{\psi}\gamma_\alpha \partial^\alpha \psi + \frac{1}{2} m^2_{Z'} Z'_\alpha Z'^\alpha - m_\psi \overline{\psi}\psi$$

$$+ g' Q'_\psi Z'_\alpha \overline{\psi}\gamma^\alpha \psi + g' Z'_\alpha \sum_{f=\mu,\tau,\nu_\mu,\nu_\tau} Q'_f \overline{f}\gamma^\alpha f$$

Relic Abundance

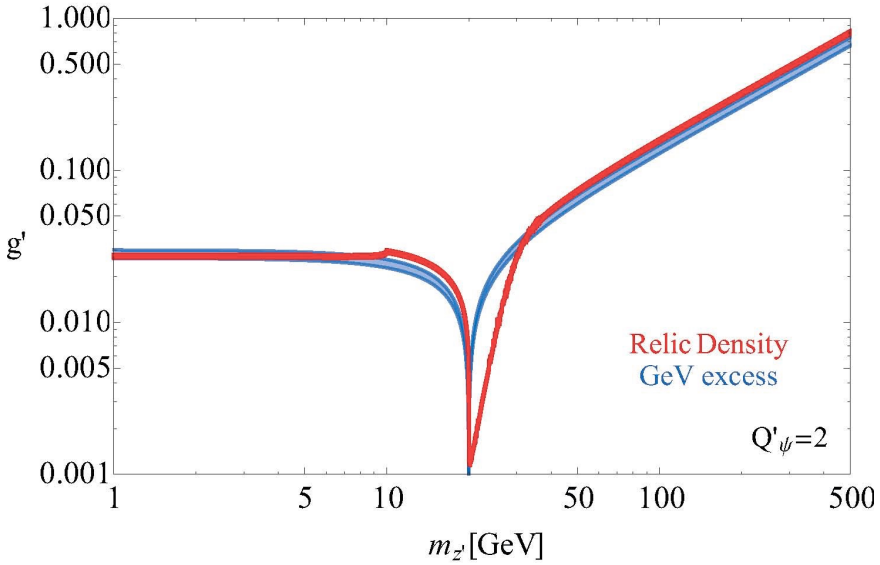
- Dominant annihilation channels of DM:



- DM annihilates into leptons through s-channel contribution
- DM annihilates into a Z pair through t-channel contribution
  - kinematically allowed only when $m_\psi \geq m_{Z'}$
- Relic density : $0.11 < \Omega_{\rm DM} h^2 < 0.13$ Planck Collaboration (arXiv: 1502.01589)

FERMI-LAT GEV EXCESS

- DM annihilation into charged lepton final states
  - The required dark matter mass : $m_\psi \approx 10\mathrm{GeV}$
  - The preferred cross section : $\langle \sigma v \rangle = (0.95 - 1.49) \times 10^{-26} \mathrm{cm}^3/\mathrm{s}$
- parameter plane ($m_{Z'}$, $g_{'}$)



- Same range with thermal relic density
- The s-channel resonance effect around $m_{Z'} \approx 2m_\psi$

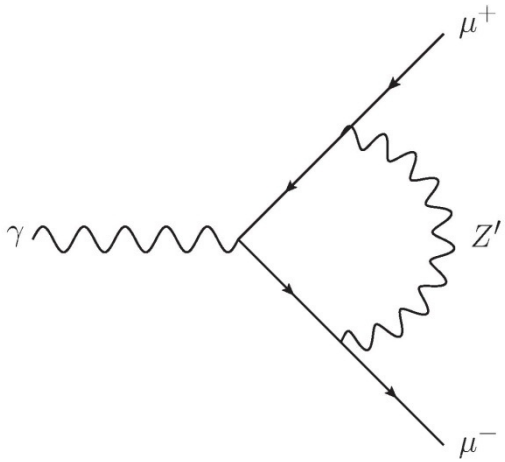
Constraints

CONSTRAINTS – MUON ANOMALOUS MAGNETIC MOMENT

- Experimental value: $a_\mu^{\rm Exp} = (11659209.1 \pm 6.3) \times 10^{-10}$ Particle Data Group 2014
- SM prediction : $a_\mu^{\rm SM} = (11659180.3 \pm 4.9) \times 10^{-10}$
- Difference between them :

$$\Delta a_\mu = a_\mu^{\rm Exp} - a_\mu^{\rm SM} = (28.8 \pm 8.0) \times 10^{-10}$$

- A positive contribution to muon (g-2):

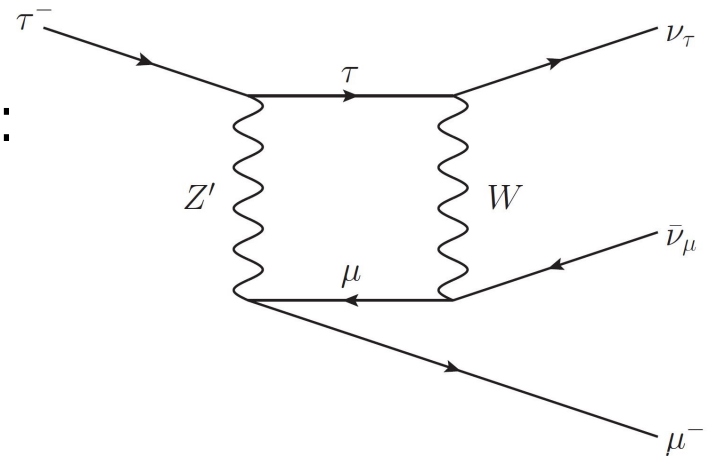


$$\Delta a_\mu = \frac{g'^2}{12\pi^2}\frac{m_\mu^2}{m_{Z'}^2}$$ E. Ma et al.(arXiv: 0110146)

CONSTRAINTS – TAU DECAY

M. Pospelov et al.(arXiv: 1403.1269)

- Z'boson makes new contributions to tau decay processes
- one-loop box diagram:



- Experimental value is more than 2σ level above the SM prediction :

$$\frac{\mathrm{Br}(\tau \to \mu\nu_\tau\overline{\nu}_\mu)}{\mathrm{Br}(\tau \to \mu\nu_\tau\overline{\nu}_\mu)_{\mathrm{SM}}} \simeq 1 + \Delta$$

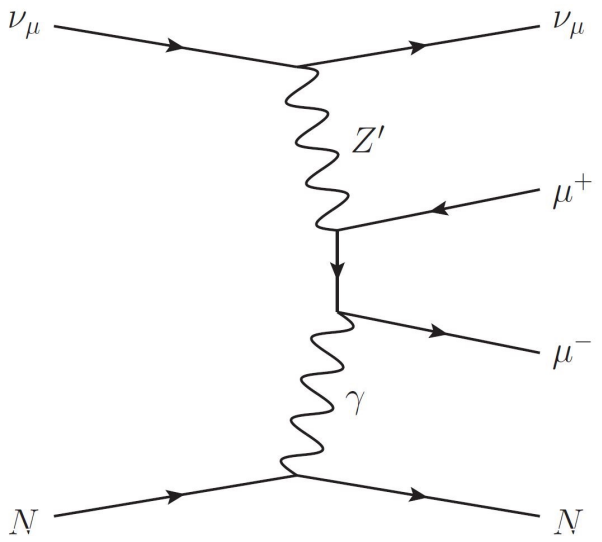
with $\Delta = (7.0 \pm 3.0) \times 10^{-3}$

- correction due to $U(1)_{L_\mu - L_\tau}$ symmetry: $\Delta = \dfrac{3g'^2}{4\pi^2}\dfrac{\log(m_W^2/m_{Z'}^2)}{1 - m_{Z'}^2/m_W^2}$

CONSTRAINTS – NEUTRINO TRIDENT PRODUCTION

M.Pospelov et al.(arXiv: 1406.2332)

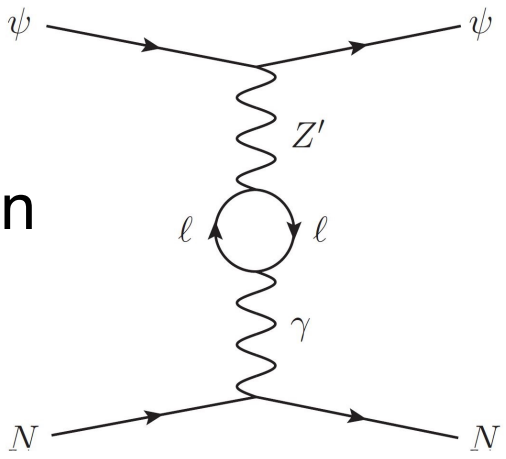
- Production of a muon pair from the scattering of a muon neutrino with heavy nuclei
- The leading order Z'contribution:



- Measurements stringently constrain a model with a new gauge boson that couples to both a muon and muon-neutrino

CONSTRAINTS – DIRECT DETECTION FROM LUX

- Dominant direct detection process



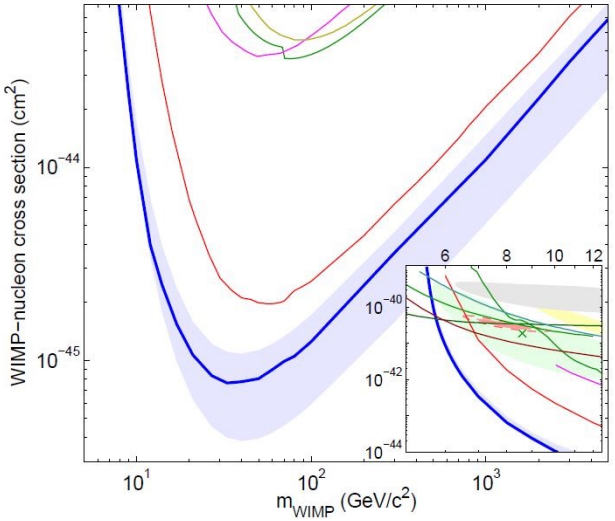
- Cross section between DM and nucleon

$$\sigma_{\psi n} = \frac{1}{A^2}\frac{\mu_n^2}{9\pi}\left[\left(\frac{\alpha_{\rm EM} Z}{\pi\Lambda^2}\right)\log\left(\frac{m_\mu^2}{m_\tau^2}\right)\right]^2$$

  - A : the mass number of the target
  - Z : the charge number of the target
  - reduced mass: $\mu_n = \dfrac{m_p \cdot m_\psi}{m_\psi + m_p}$

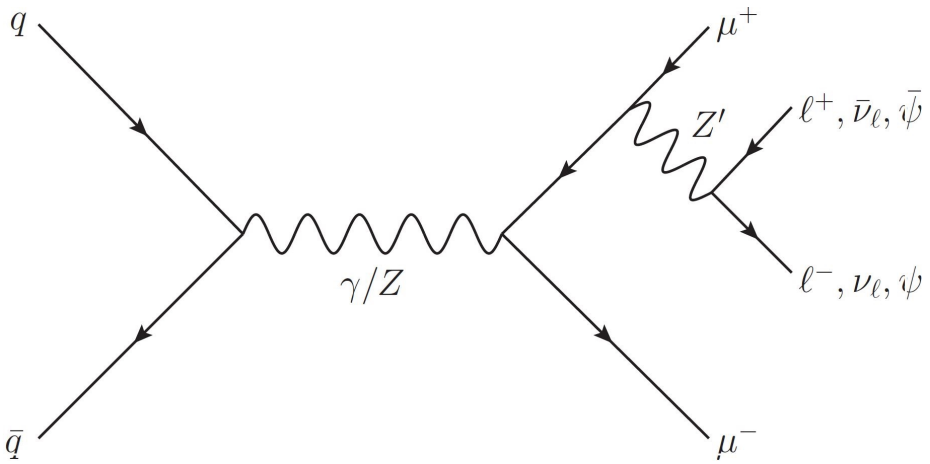
- The most stringent result
  - LUX experiment

LUX Collaboration (arXiv: 1310.8214)



CONSTRAINTS – LHC PHENOMENOLOGY

- The lowest order Z'production process at collider
  - Produce a charged lepton pair through Drell-Yan process
  - Z'is radiated from one of leptons

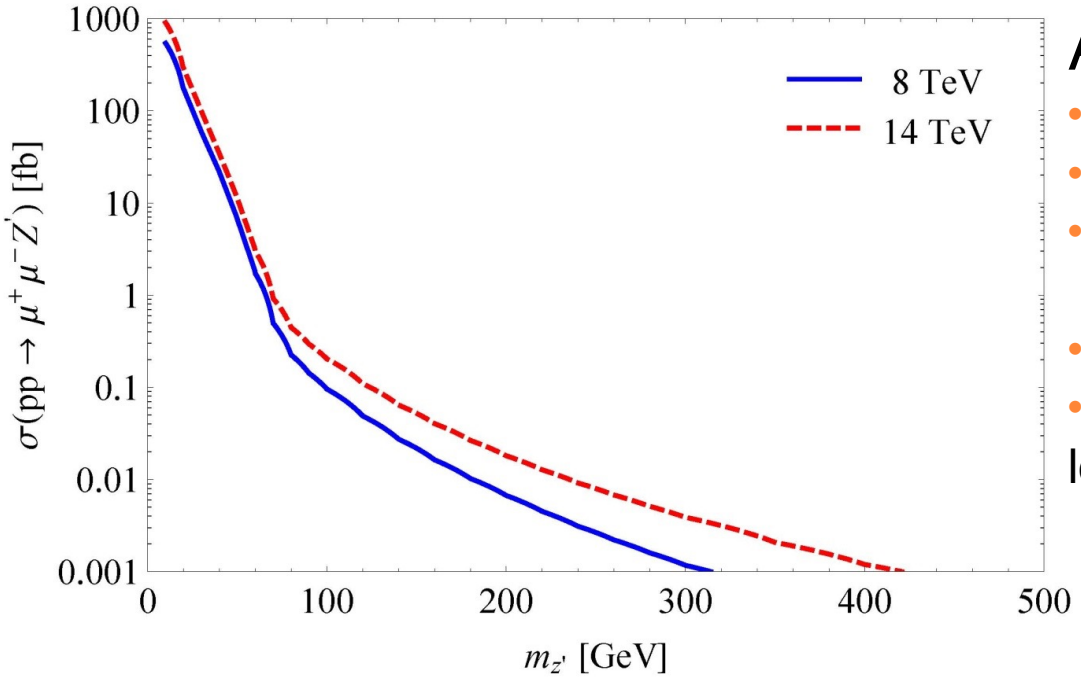


- LHC Measures 4 leptons process at the Z boson resonance
- Interesting final state : 4 muons
  - Dominant SM background : $p\ p \to \mu^+\ \mu^- Z \to \mu^+\mu^-\mu^+\mu^-$

$$p\ p \to Z\ Z \to \mu^+\mu^-\mu^+\mu^-$$

CONSTRAINTS – LHC PHENOMENOLOGY

- Perform Z'production at LHC 8TeV & 14TeV using MadGraph
- Set g'=0.1, ATLAS selection cut



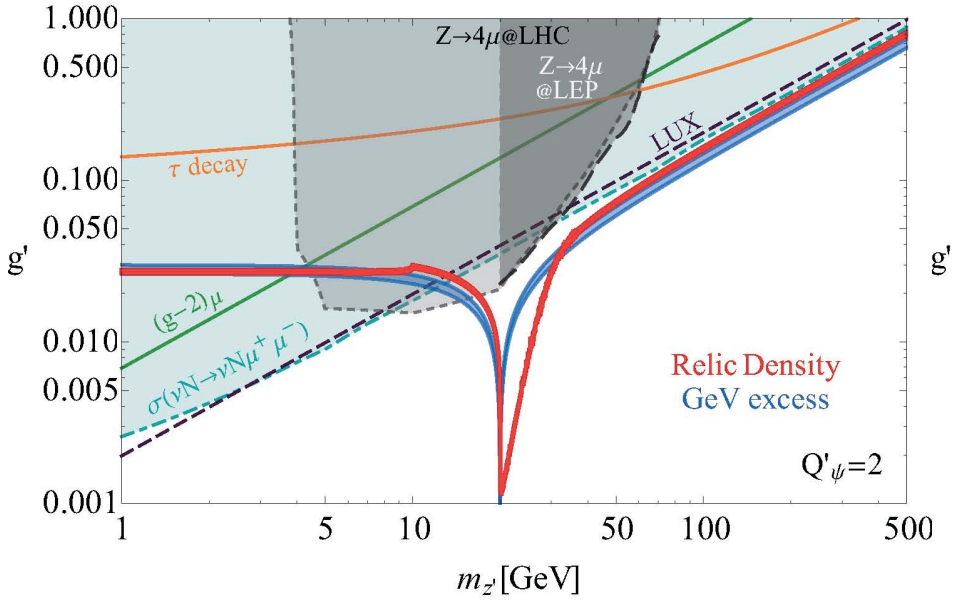
ATLAS selection cuts

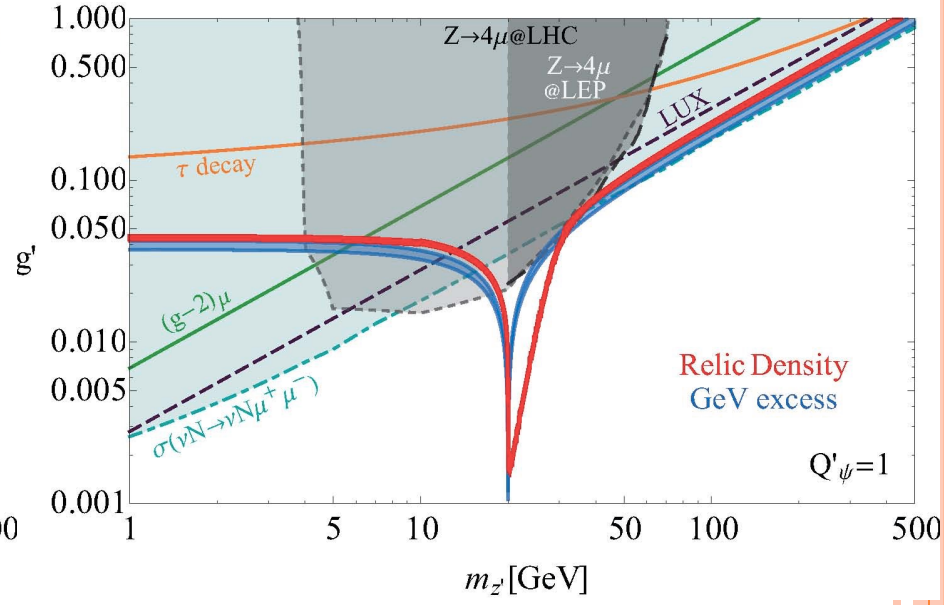
- $p_{T,\ell} > 4\text{GeV}$
- $|\eta| < 2.7$
- Candidate separation of $\Delta R_{\mu\mu} > 0.1$
- $m_{\mu^+\mu^-} > 5\text{GeV}$
- Invariant mass of four leptons:

$$80 < m_{4\ell} < 100\text{GeV}$$

CONSTRAINTS

- parameter space ($m_{Z'}$, $g_{'}$)





- Exclusion region
  - from muon (g-2) & tau decay @ 2σ level
  - from 4muon search at LHC @ 3 σ level
  - from dark matter direct detection: LUX 90% confidence limit + 1 σ
  - from neutrino trident production @ CCFR: 2 σ level

Conclusion

- DM with gauged L_μ-L_τ symmetry can explain Fermi-LAT GeV gamma ray excess near galactic center
- DM does not interact with SM quarks at tree level. However, DM couples to SM quarks in nucleus through the loop-suppressed interaction
- Leptophilic DM additionally contributes to muon (g-2), tau decay, neutrino trident production
- Parameter space is already partially constrained by 8TeV LHC for light Z'and will be tested by 14TeV LHC

Thank

YOU