Dirac neutrino dark matter

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LAPTH- Annecy

based on

G. B, A.Pukhov, G. Servant CERN-PH-TH/2007-083

Outline

- Motivation
- Direct detection
- Relic density
- An explicit example : the LZP model
- Signals and conclusion

Motivation

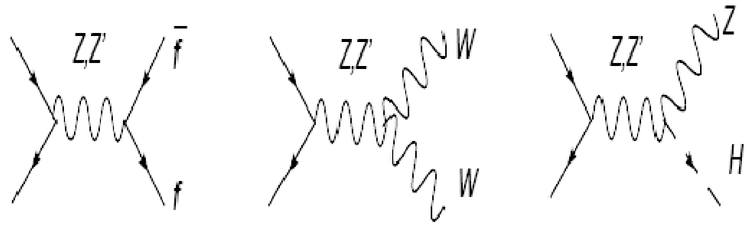
- Although evidence for Dark Matter has been accumulating over the years, still do not have evidence what this dark matter could be
- Natural link DM ~100GeV range and EWSB: new physics at weak scale can also solve both EWSB and DM
- Weakly interacting particles gives roughly the right amount of DM, $\Omega h^2 \sim 0.1$
- Supersymmetric models with R-parity have good candidate (neutralino LSP) but many other possibilities exist only need some symmetry to ensure that lightest particle is stable
  - UED, Little Higgs, Warped Xtra-Dim …
  - Superweakly interacting particles might also work (gravitino)
- Examine different candidates and study prospects for direct/indirect detection, collider searches

Dirac right-handed neutrino

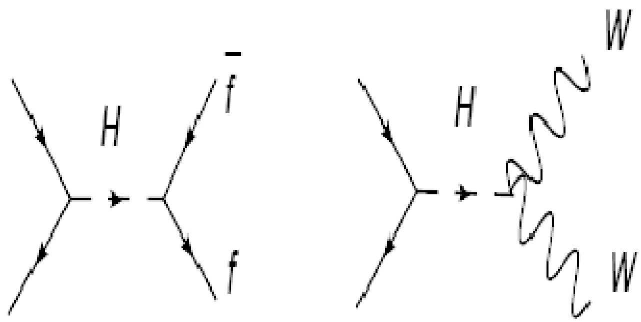
- Typical framework: sterile Dirac neutrino under SM but charged under $SU(2)_R$
- Phenomenologically viable model with warped extra-dimensions and right-handed neutrino (GeV-TeV) as Dark Matter was proposed (LZP)
  - Agashe, Servant, PRL93, 231805 (2004) – see explicit example later
- Models with LR symmetry and UED also can have RH neutrino dark matter
  - Hsieh, Mohapatra, Nasri, PRD74,066004 (2006).
- Stability requires additional symmetry , but symmetry might be necessary for EW precision or for stability of proton
- Explore more generic model with stable ν_R 1GeV– few TeV and examine properties of this neutrino ---- reexamine LZP model

Annihilation

- First assume only SM+ ν_R
- ν_R can couple to Z through ν'_L- ν_R mixing



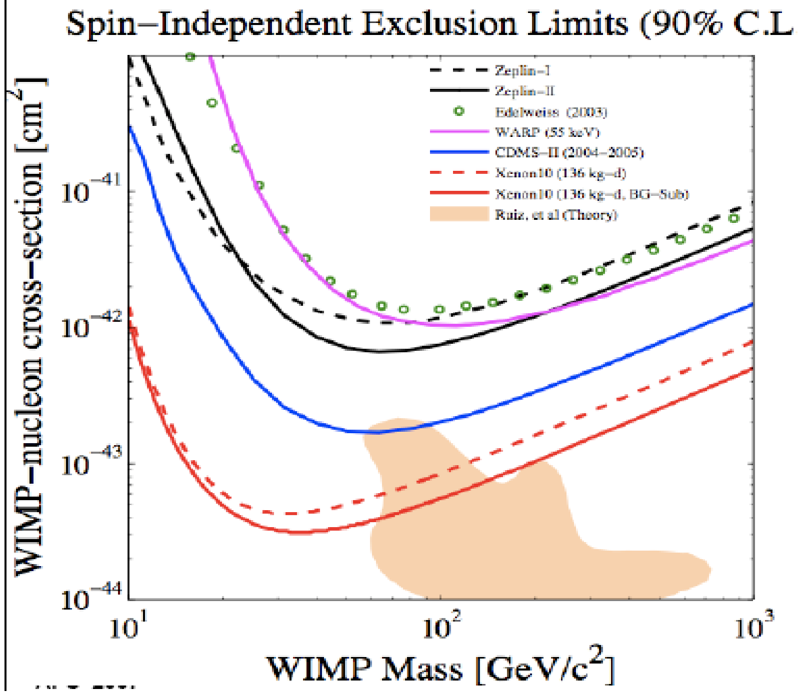
- Main annihilation channel – Z exchange
  - Ff, WW, Zh



- Also Higgs exchange

Direct detection - limits

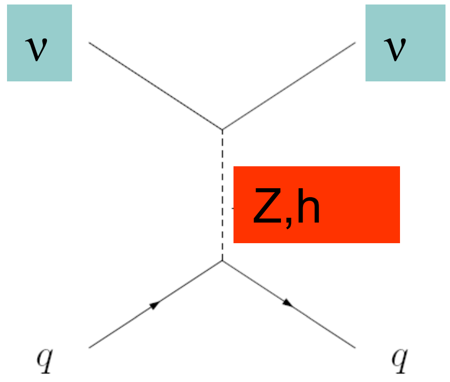
- Detect dark matter through interaction with nuclei in large detector
- Many experiments underway and planned
- In 2007 – new results announced from Xenon (Gran-Sasso) best limit ~factor 6 better than CDMS (Ge,Si)



E. Aprile, Talk @ APS 2007

Direct detection : Dirac neutrino

- Dirac neutrino: spin independent interaction dominated by Z exchange (vector-like coupling) → very large cross-section for direct detection
  - coupling $Z\nu_R\nu_R$ cannot be too large
  - also constraint from LEP : invisible decay of Z



- Z exchange: also main mechanism for annihilation of ν_R
  - $Z\nu_R\nu_R$ coupling cannot be too small

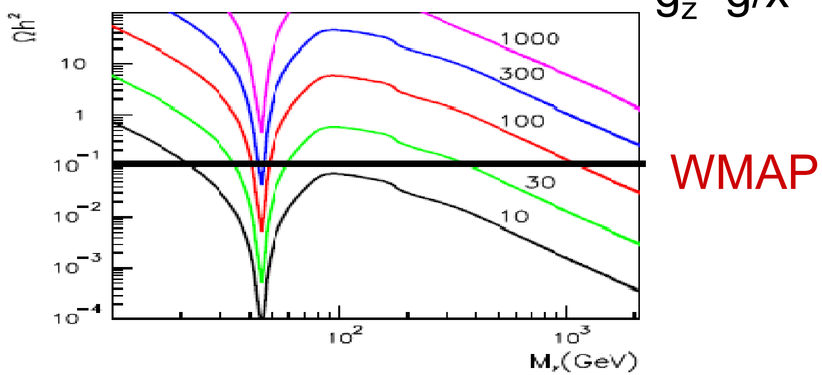
- Vectorial coupling : elastic scattering on proton << neutron
  - $\sigma_{\nu p} = (1 - 4 \sin^2 \theta_W)\, \sigma_{\nu n}$
  - For Majorana (neutralino) $\sigma_{\nu p} \sim \sigma_{\nu n}$

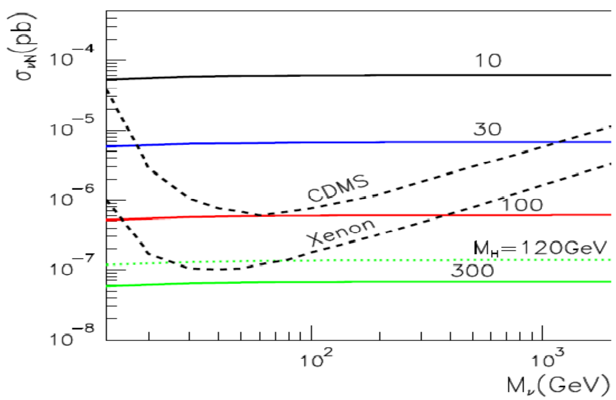
Relic density vs elastic scattering

$$g_Z \overline{\nu'} \gamma^\mu \frac{1 \pm \gamma_5}{2} \nu' Z_\mu$$

$$g_H \overline{\nu'} \nu' H$$

$g_Z = g/x$

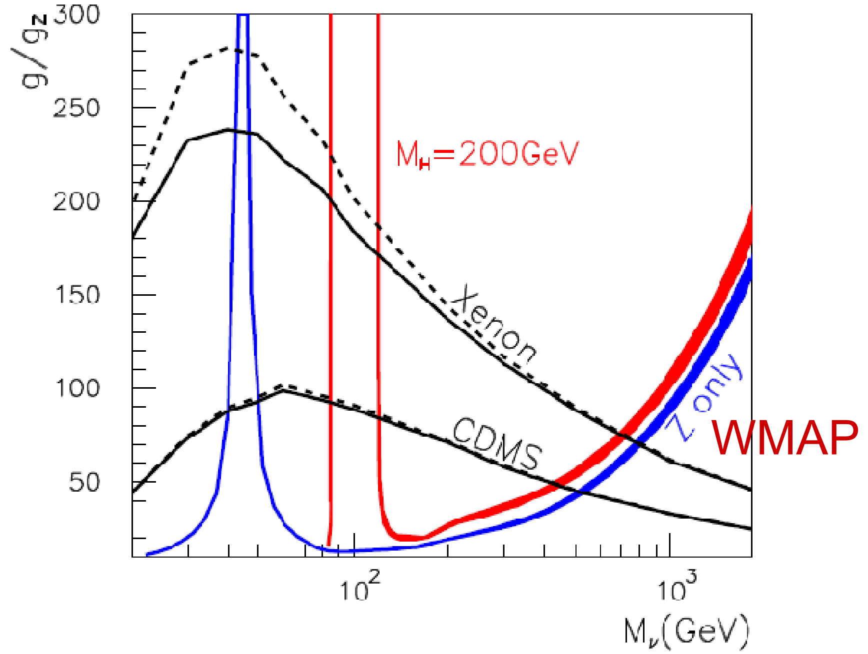




- Higgs exchange contribute for annihilation (near resonance) and for direct detection, << Z exchange, only relevant for weak coupling to the Z
- Uncertainties in DD limit – e.g velocity distribution of DM (up to factor 3)

Direct detection limits -WMAP

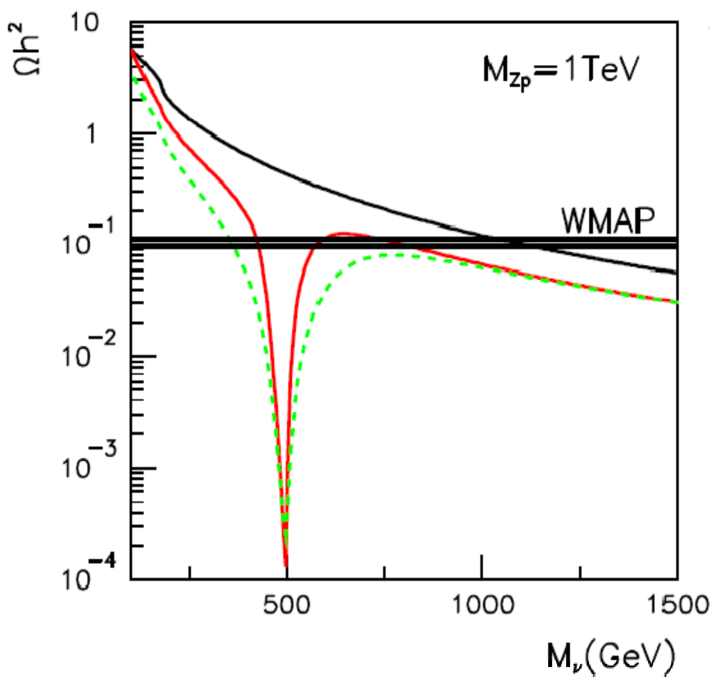
- Current DM experiments already restricts ν_R to be
  - $\sim M_Z/2$,
  - $\sim M_H/2$
  - $M(\nu_R) > 700\text{GeV}$
- Other mechanism for not so heavy neutrino DM?



Relic density computed with micrOMEGAs_2.0,

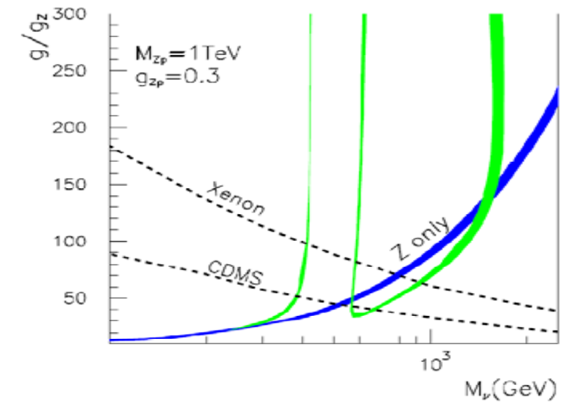
Extending the gauge group (LR)

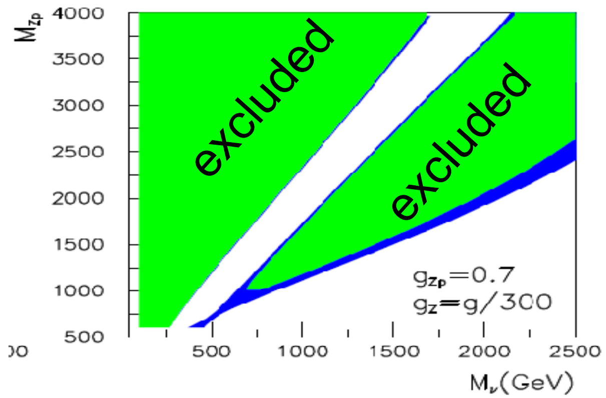
- New Z' (… and W')- $SU_{2L}XSU_{2R}XU_1$
- Could introduce τ' partner ν' +new quarks
- Constraints on Z' from EW precision: mixing small ~10^{-3} (T parameter)
- Assume Z' couples only to third generation fermions : weakens EW constraints but induces FCNC – constraints also depend on quark mixing matrices
    - Mz'~ 500GeV
- Coupling of ν_R to Z can also be induced by Z-Z' mixing
- Heavy Z' that couples to 3^{rd} gen.: no effect on DD
- Effect of W' in annihilation not so important



Relic density vs elastic scattering'

- As before viable neutrino DM around $M_Z/2$, $M_H/2$
- Depending on $M_{Z'}$ can have neutrino ~ 200GeV
- Not considered coannihilation
  - Need to specify properties of extra fermions





The LZP model

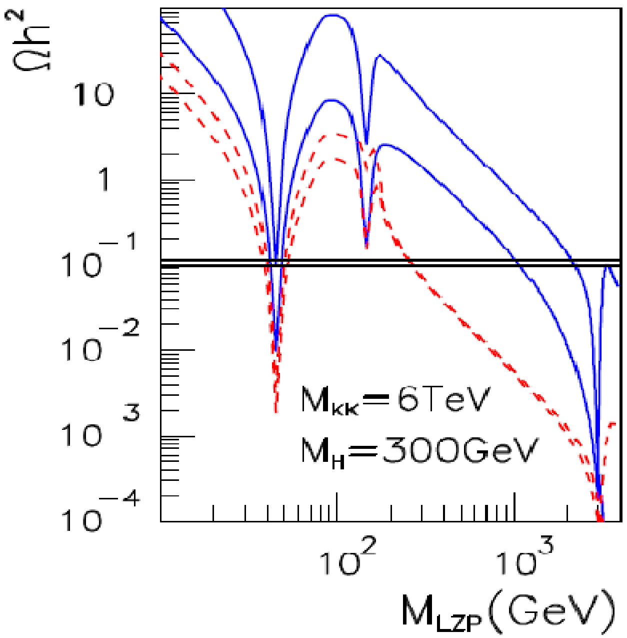
- Warped Xtra-Dim (Randall-Sundrum)
- GUT model with matter in the bulk
- Solving B violation in GUT models → stable KK particle
- Example based on SO(10) with Z_3 symmetry: LZP is KK RH-neutrino
    - Agashe, Servant, hep-ph/0403143
- Many features of our generic model:
    - LR symmetry with KK W',Z' gauge bosons
    - Many new generations of KK fermions, most are multi-TeV, lighter ones are those of third generation (choice of BC for heavy top quark)
    - $Z\nu_R\nu_R$ coupling induced via Z-Z' mixing or ν_R-ν'_L mixing
    - Z' $\nu_R\nu_R$ coupling ~1, Z' couples to 3rd generation fermions
    - H $\nu_R\nu_R$ coupling small

… LZP model

- Free parameters : masses of KK fermions, mass of KK gauge boson, M_H, coupling of Z'(g)
- Couplings to KK particles from wave functions overlap
- LZP is Dirac particle, coupling to Z through Z-Z' mixing and mixing with new LH neutrino
- $Z\nu_R\nu_R$cannot be too large otherwise elastic scattering on nucleon too large
  - Z-Z' mixing ~$1/M^2{}_{Z'}$ - gZ too large if Mz'<3-4TeV

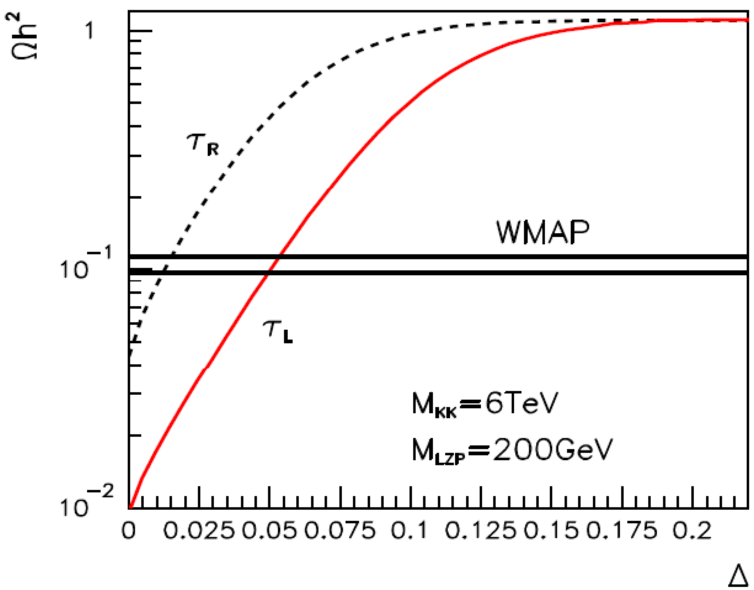
Relic density of LZP

- Qualitatively recover results of first study (Agashe, Servant), new features
  - Precise evaluation of relic density in micromegas_2.0
  - Include Higgs exchange
  - Include all coannihilations
- Compatibility with WMAP for LZP ~ 50GeV and 0.5- 2TeV depending on M_{KK}
- Large cross-sections for direct detection
  - Signal for next generation of detectors in large area of parameter space (10^{-9}pb)



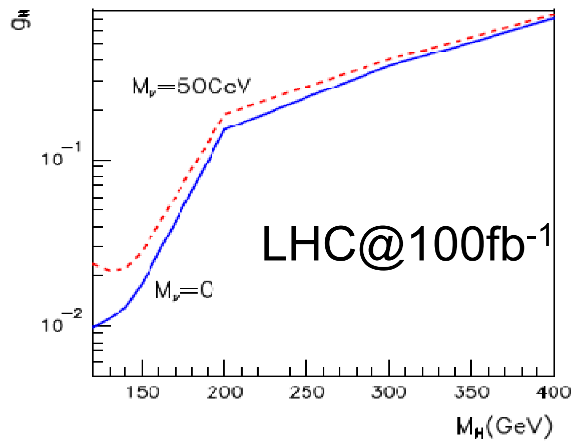
Coannihilation

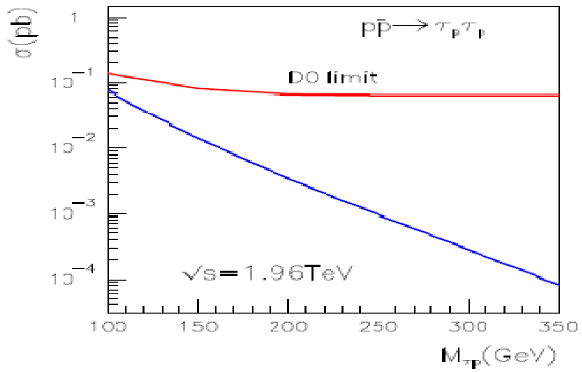
- Possibility to have LZP in range 100-500GeV with coannihilation
- Coannihilation decreases Ωh^2 but no effect on direct detection rate
- Need small mass differences (NLZP-LZP) ~few %



Signals - Colliders

- Higgs decay into invisible --
  - LHC: weak boson fusion+ZH
  - ILC
- Z invisible : LEP constraint OK
- As in MSSM : search for new particles
- Long-lived τ' : if τ' nearly degenerate with ν': can decay outside detector
  - signal : charged massive particle (only for small region of parameter space) – searches at Tevatron , LHC + ILC
  - More likely τ pair production and signal 2l+missing energy

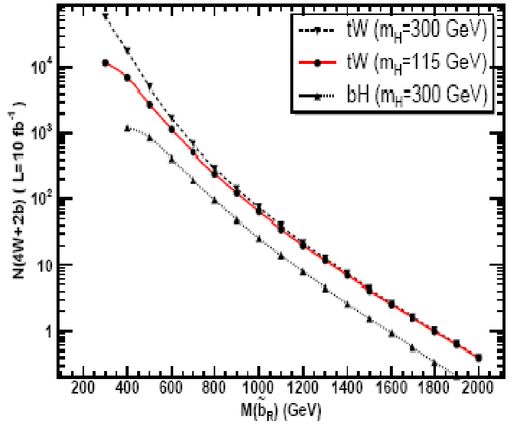




Signals - Colliders

- Only one study of LHC potential: signal for KK quarks in LZP model – b_R has no Z_3 charge
  - Pair produced via gg
  - Decay into tW
  - 4W+bb final state

- Z' search but only couples to W bosons and 3rd generation -- difficult
- Identify model, determination of parameters … still need to be studied, will involve DM detection



Signal 3W in jets 1W leptonic
Dijet mass distribution

- Dennis et al. hep-ph/0701158

Signals – indirect detection

- In LZP model
  - Hooper, Servant, hep-ph/0502247
- Good prospects for detecting HE neutrinos from the sun – $M_{\nu'}$ <100GeV, ν' pairs annihilate directly into ν pairs : accessible to AMANDA (max 5-10 events/yr) and Antares
- Also good signal in positron –Pamela
- LZP annihilation near galactic center might give gamma rays signal

Comparisons of DM scenarios

Scenario		SUSY1 bino	SUSY2 higgsino	SUSY3 gravitino	LZP ν_R	LTP heavy photon
LHC	Discovery precision	*** *	* No	** ?	* ?	** ?
ILC	Discovery precision	*** ***	** *	** ?	* ?	** ?
Direct		*	***	No	***	No
Indirect	γ or ν	*	***	No	**	***

Summary

- Dirac RH neutrino is viable DM candidate
- Mass range 40GeV-few TeV
- Need resonance annihilation and/or coannihilation for M<700GeV

- Distinctive feature: expect large signal in direct detection
- Need to further study collider potential for detecting new particles