Z'-portal right-handed neutrino dark matter in the minimal U(1)x extended Standard Model

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Ref: NO & S. Okada, PRD 93, 075003 (2016)
PRD 95, 035025 (2017)

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Problems of the Standard Model

Although the Standard Model (SM) is the best theory so far, New Physics beyond SM is strongly suggested by both experimental & theoretical points of view

What is missing?

1. Neutrino masses and flavor mixings
2. Dark matter candidate

New Physics must supplement the missing pieces

For neutrino mass

Minimal gauged B-L extension of the Standard Model

- B-L is the unique anomaly free global symmetry in the SM
- Gauging the global B-L symmetry looks natural
- Anomaly free requirement → 3 right-handed neutrinos

In terms of LHC physics,

we focus on the B-L model @ TeV

Minimal Gauged B-L Extension of the SM

Mohapatra & Marshak;
Wetterich; others

The model is based on $SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$

Particle Contents

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_{B-L}$
q_L^i	$\mathbf{3}$	$\mathbf{2}$	$+1/6$	$+1/3$
u_R^i	$\mathbf{3}$	$\mathbf{1}$	$+2/3$	$+1/3$
d_R^i	$\mathbf{3}$	$\mathbf{1}$	$-1/3$	$+1/3$
ℓ_L^i	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	-1
New fermions: N_R^i	$\mathbf{1}$	$\mathbf{1}$	0	-1
e_R^i	$\mathbf{1}$	$\mathbf{1}$	-1	-1
H	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	0
New scalar: Φ	$\mathbf{1}$	$\mathbf{1}$	0	$+2$

New Yukawa terms in Lagrangian

$$\mathcal{L}_{Yukawa} \supset -\sum_{i,j} Y_D^{ij} \overline{\ell_L^i} H N_R^j - \frac{1}{2} \sum_k Y_N^k \Phi \overline{N_R^{k\,C}} N_R^k + \mathrm{h.c.}$$

B-L symmetry breaking via $\langle \Phi \rangle = \frac{v_{\mathrm{BL}}}{\sqrt{2}}$

➡ B-L gauge boson (Z' boson) mass

$$m_{Z'} = 2 g_{BL} v_{BL}$$

Mass scale is controlled by B-L Sym. Br. scale

Heavy Majorana neutrino mass

$$m_N^k = \frac{Y_N^k}{\sqrt{2}} v_{BL}$$

B-L sym breaking also generates RHN mass

➡ Seesaw mechanism after EW sym. breaking

DM candidate is still missing in TeV-scale minimal B-L model

There have been many proposal for introduction of DM particles

Concise model: no extension of the particle content

Instead, introduce a parity

J=1,2	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_{B-L}$	Z_2
N_R^j	1	1	0	-1	$+$
N_R	1	1	0	-1	$-$
Φ	1	1	0	$+2$	$+$

NO & Seto,
PRD 82 (2010) 023507

- Assigning odd parity for one RHN
- The others are all even

TeV-scale minimal B-L model with RHN DM

3 right-handed neutrinos → 2+1

- 2 RHNs for the minimal seesaw

King, NPB 576 (2000) 85;
Frampton, Glashow & Yanagida, PLB 548 (2002) 119

  - ✓ Neutrino oscillation data with one massless eigenstate

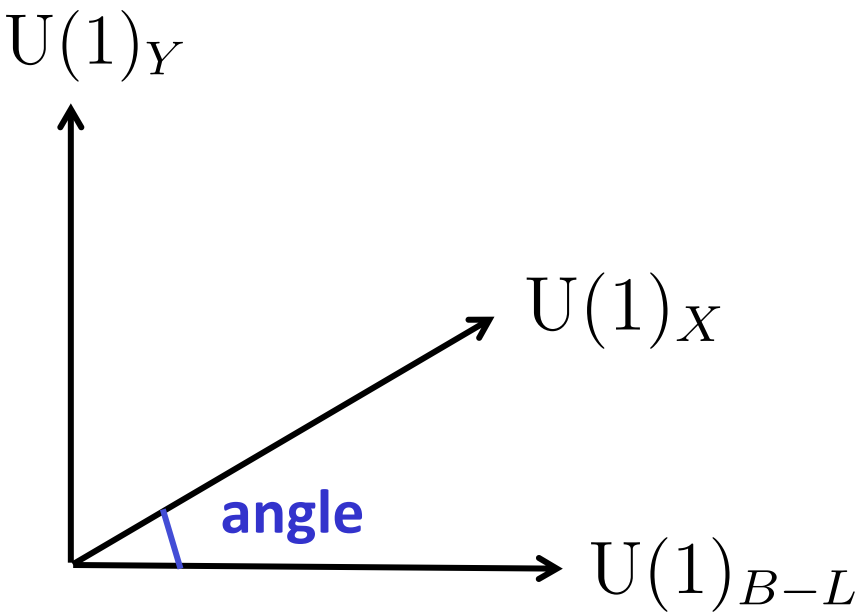
- Z_2-odd 1 RHN for thermal Dark Matter

More general gauged U(1) extension of the SM at TeV

→ Non-Exotic U(1) extension

Appelquist, Dobrescu & Hopper, PRD 68 (2003) 035012

U(1)x direction is a linear combination of the SM hypercharge & the gauged B-L directions



- Particle contents = the B-L model
- Anomaly Free
- One new parameter corresponding to angle

TeV-scale minimal U(1)x model with RHN DM

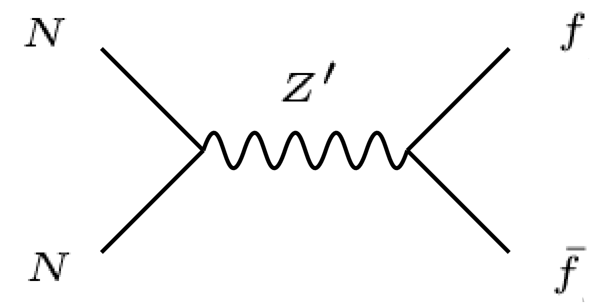
	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_X$	Z_2
q_L^i	$\mathbf{3}$	$\mathbf{2}$	$1/6$	$(1/6)x_H + (1/3)$	$+$
u_R^i	$\mathbf{3}$	$\mathbf{1}$	$2/3$	$(2/3)x_H + (1/3)$	$+$
d_R^i	$\mathbf{3}$	$\mathbf{1}$	$-1/3$	$-(1/3)x_H + (1/3)$	$+$
ℓ_L^i	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	$(-1/2)x_H - 1$	$+$
e_R^i	$\mathbf{1}$	$\mathbf{1}$	-1	$(-1)x_H - 1$	$+$
H	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	$(-1/2)x_H$	$+$
J=1,2 N_R^j	$\mathbf{1}$	$\mathbf{1}$	0	-1	$+$
N_R	$\mathbf{1}$	$\mathbf{1}$	0	-1	$-$
Φ	$\mathbf{1}$	$\mathbf{1}$	0	$+2$	$+$

- The minimal B-L model is in the limit of $x_H \to 0$

Phenomenology of TeV-scale minimal U(1)x model with RHN DM

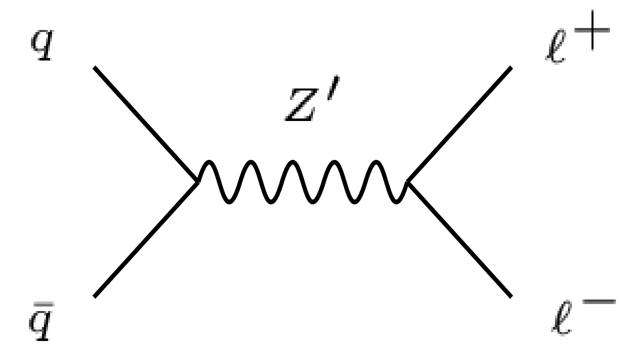
(1) Z'-portal RHN DM

RHN DM communicates with the SM particles through Z' boson mediated processes



(2) Z' boson search at the LHC Run-2

Search for a narrow resonance with the di-lepton final state at ATLAS and CMS with LHC Run-2

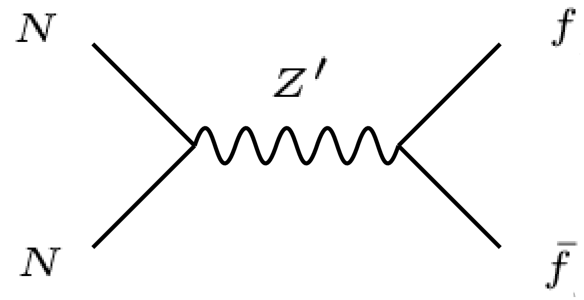


(3) We will discuss a complementarity between DM physics and LHC physics

(1) Z'-portal RHN dark matter

Z' B-L case: NO & S. Okada, PRD 93 (2016) 075003

- The RHN dark matter communicate with the SM particles through its U(1)x gauge interaction



- For Dark Matter physics, only 4 free parameters are involved

- U(1)X gauge coupling: $\alpha_X = \frac{g_X^2}{4\pi}$
- Z' boson mass: $m_{Z'}$
- SM Higgs U(1)x charge: x_H
- RHN DM mass: $m_{\rm DM}$

Note that the RHN DM has U(1)x charge -1

Cosmological constraint on Z' portal DM

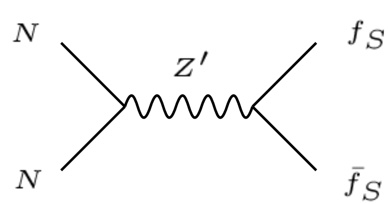
Observed Relic Abundance: $\Omega_{DM}h^2 = 0.1198 \pm 0.0015$

Planck 2015 (68% CL)

Thermal DM relic abundance is determined by the Boltzmann eq:

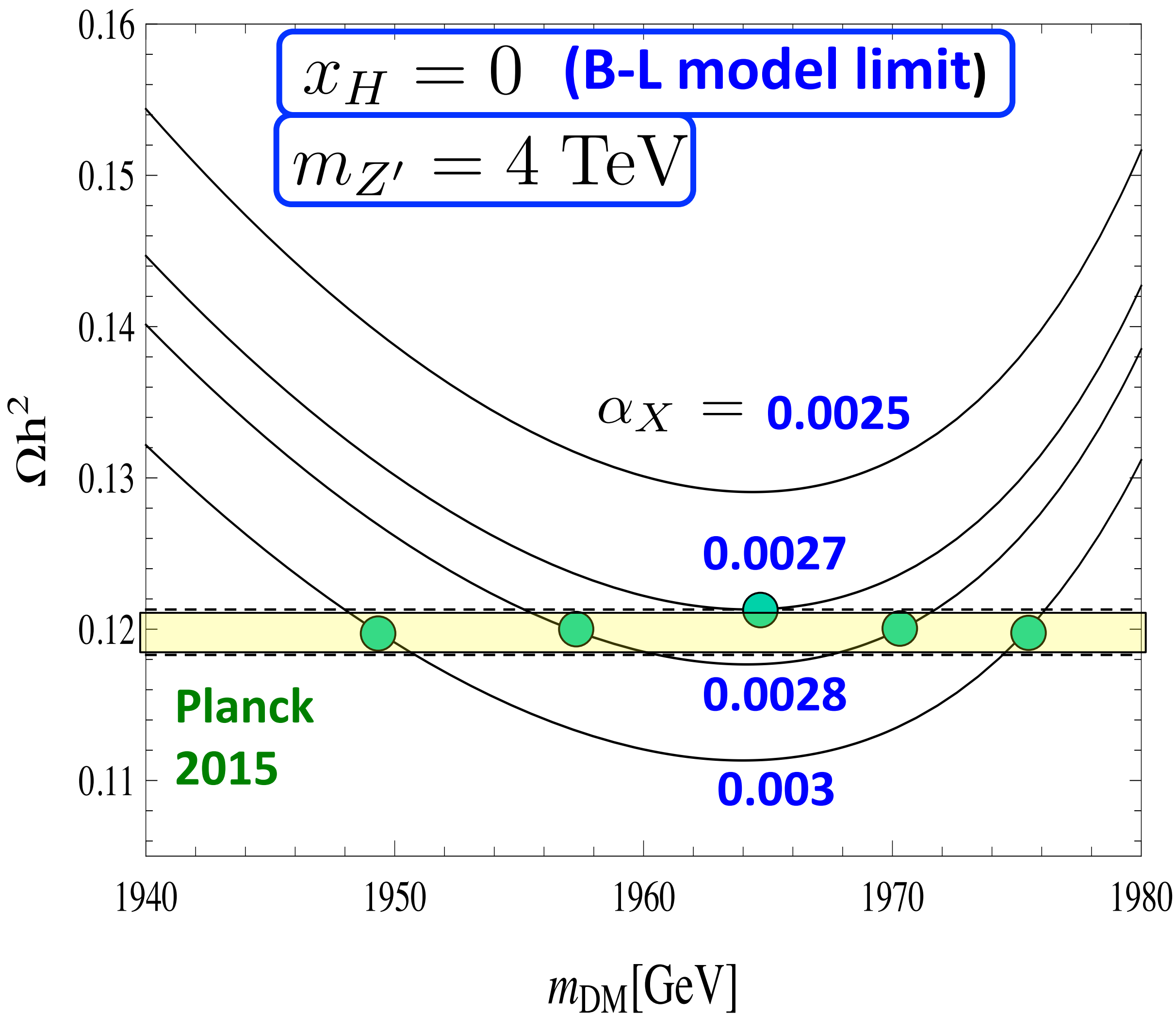
$$\frac{dn}{dt} + 3Hn = -\langle \sigma v \rangle (n^2 - n_{EQ}^2)$$

$$\begin{cases} H(T) = \sqrt{\frac{8\pi}{3}\frac{\rho}{M_{Pl}^2}} = \sqrt{\frac{4\pi^3}{45}g_\star}\frac{T^2}{M_{Pl}} \\ n(T) = sY_{EQ} = \frac{g_{DM}}{2\pi^2}\frac{m_{DM}^3}{x}K_2(x), \text{ where } x = \frac{m_{DM}}{T} \\ s = \frac{2\pi^2}{45}g_\star\frac{m_{DM}^3}{x^3} \\ \langle \sigma v \rangle = \end{cases}$$



Thermally averaged annihilation cross section

Relic abundance for various α_X for fixed x_H and $m_{Z'}$



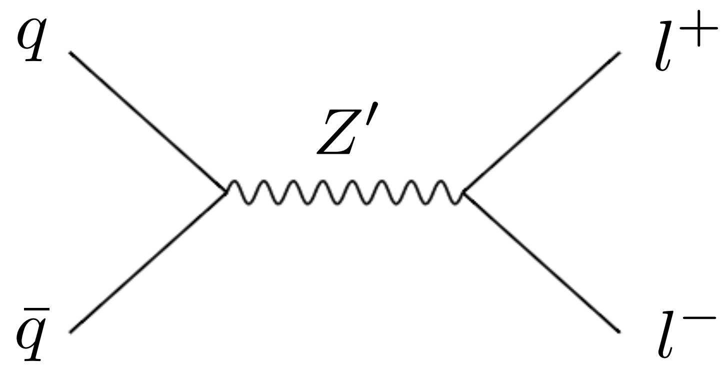
- xH=0 fixed
- As gauge coupling is lower, DM abundance becomes lower
- DM mass ~mz'/2 is adjusted to find the solution
- Too small gauge coupling, no solution

Lower bound on α_X for fixed x_H and $m_{Z'}$

(2) LHC Run-2 phenomenology

pp → Z' +X → ll +X

- The ATLAS and CMS collaborations have been searching for Z' boson resonance with a dilepton final state at the LHC Run-2



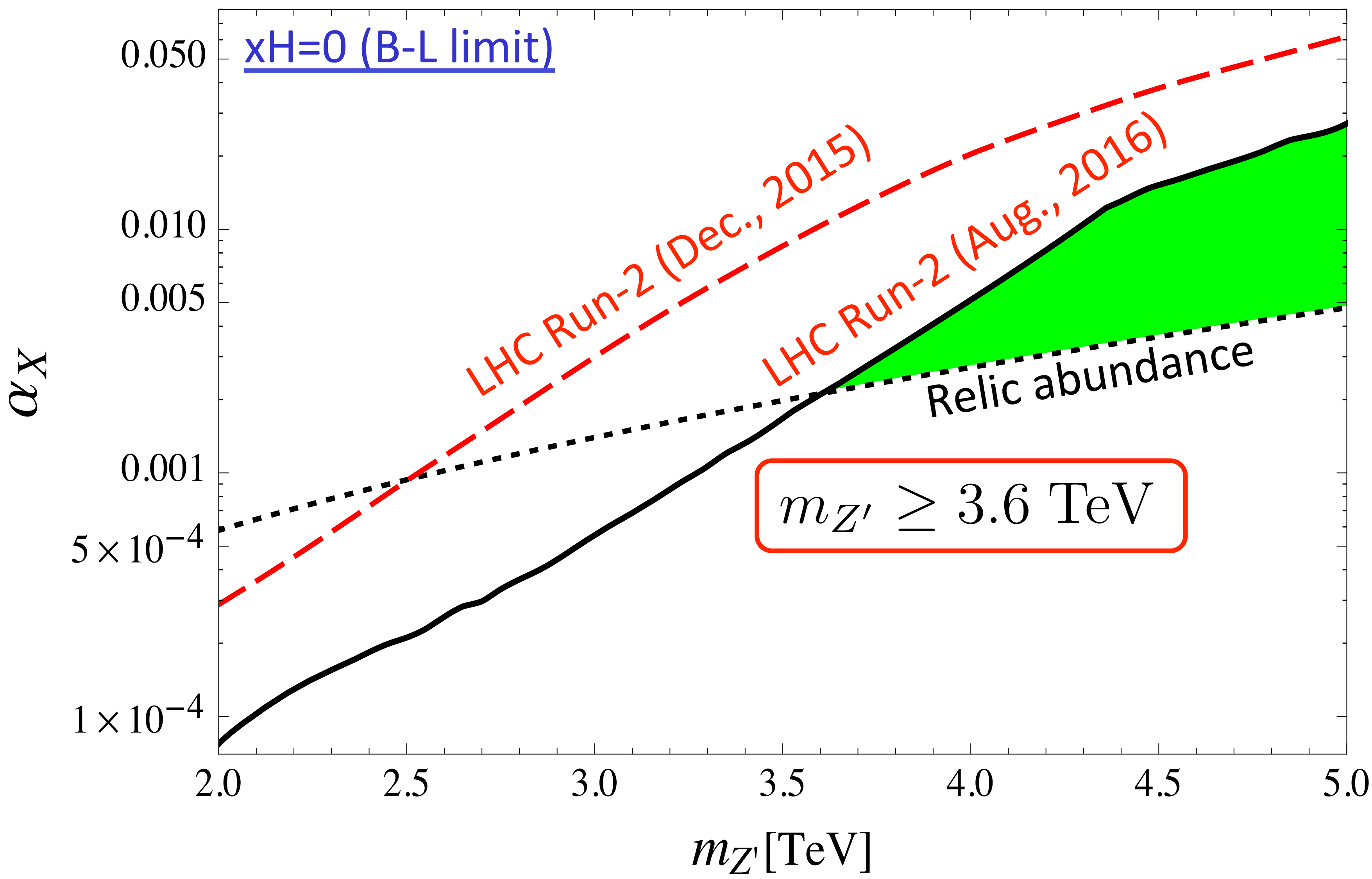
- Upper bounds on the cross section for the sequential Z' model have been obtained

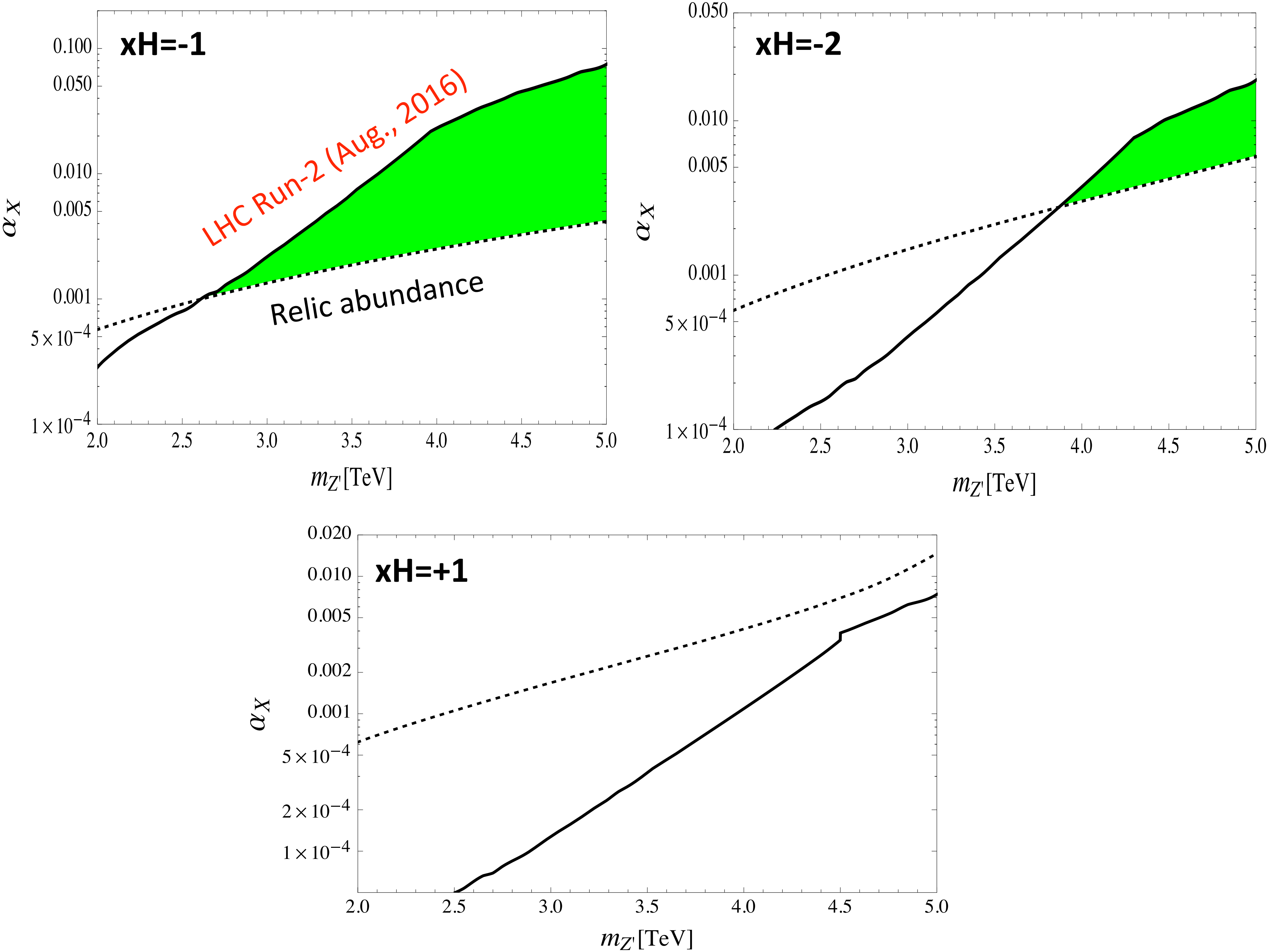
Sequential Z': heavy vector boson with the SM Z coupling

We interpret the ATLAS & the CMS X-sec bounds into U(1)_X Z'

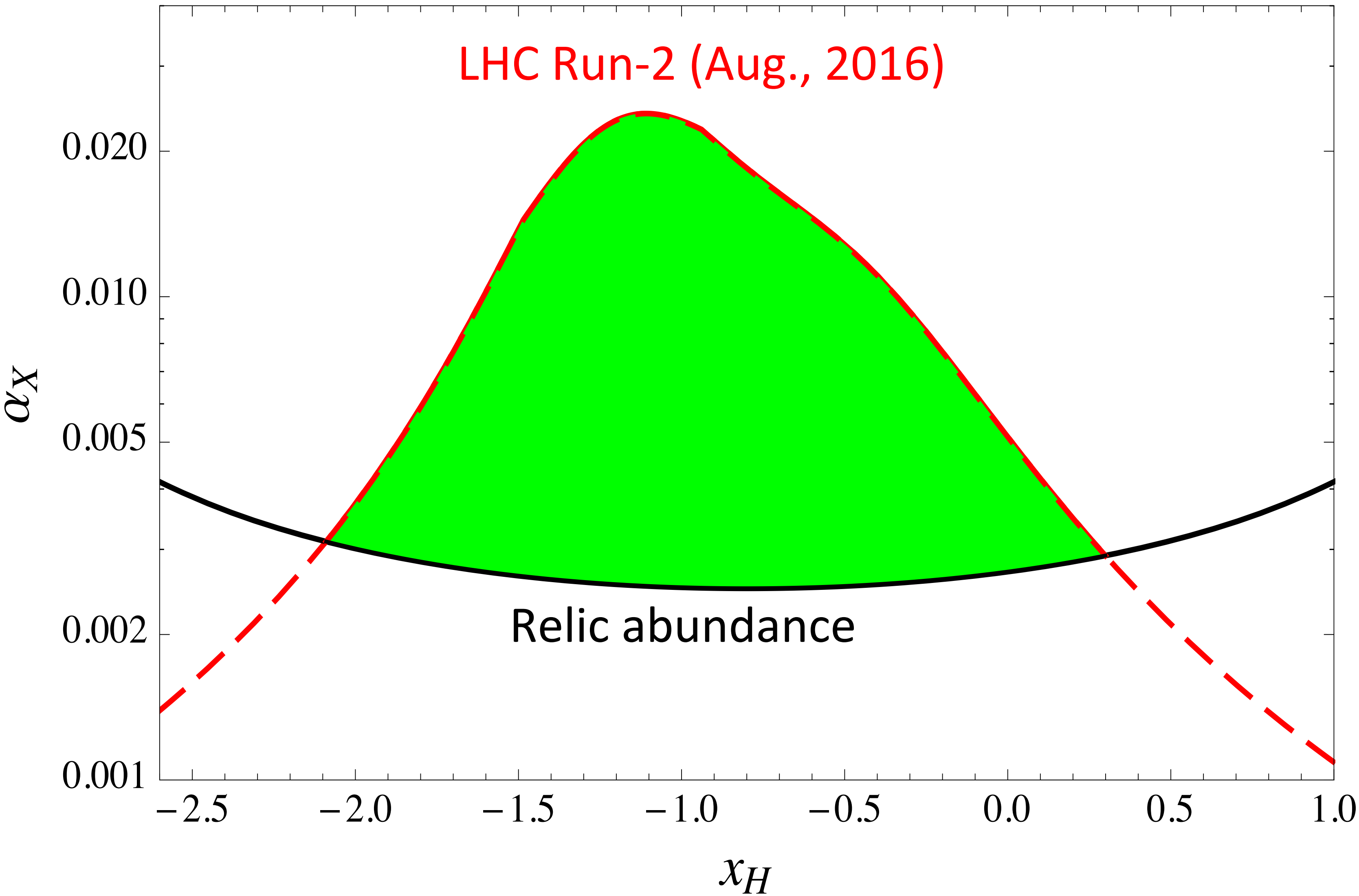
→ Upper bound on α_X for fixed x_H and $m_{Z'}$

(3) Complementarity between Cosmological & LHC bounds




xH=-1
LHC Run-2 (Aug., 2016)
Relic abundance
α_X
$m_{Z'}$[TeV]
0.100
0.050
0.010
0.005
0.001
5×10^{-4}
1×10^{-4}
2.0
2.5
3.0
3.5
4.0
4.5
5.0
xH=-2
α_X
$m_{Z'}$[TeV]
0.050
0.010
0.005
0.001
5×10^{-4}
1×10^{-4}
2.0
2.5
3.0
3.5
4.0
4.5
5.0
xH=+1
α_X
$m_{Z'}$[TeV]
0.020
0.010
0.005
0.002
0.001
5×10^{-4}
2×10^{-4}
1×10^{-4}
2.0
2.5
3.0
3.5
4.0
4.5
5.0

For Z’ boson mass =4 TeV

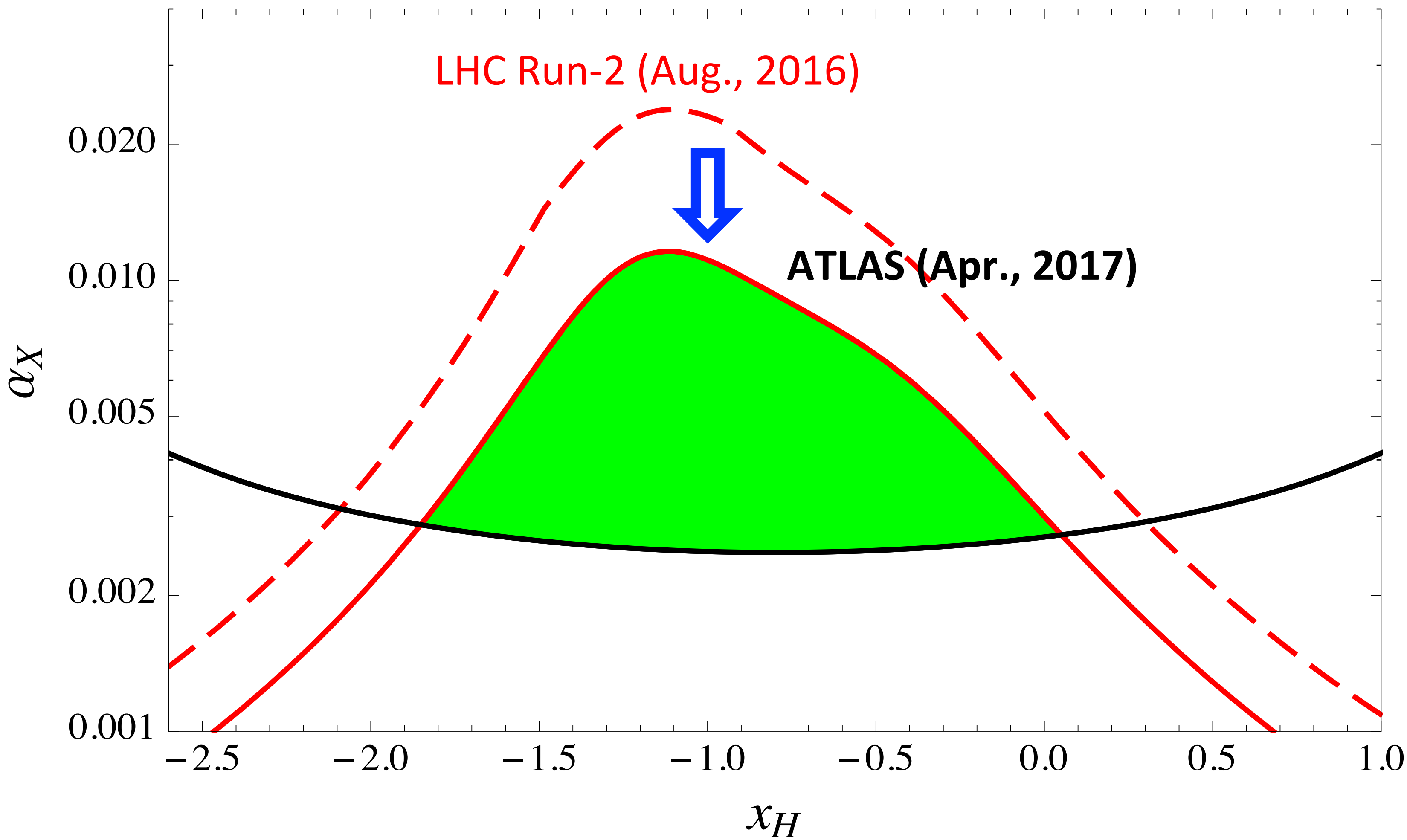


$$-2.1 \leq x_H \leq 0.3$$

For Z' boson mass =4 TeV

ATLAS update (April, 2017)

ATLAS-CONF-2017-027 **36.1/fb**



$$-2.1 \leq x_H \leq 0.3 \quad \Rightarrow \quad -1.9 \leq x_H \leq 0.051$$

Summary

- We have considered the minimal U(1)_X extension of the Standard Model with right-handed neutrino dark matter
  - Minimal seesaw with 2 RHNs for the neutrino oscillation data
  - 1 RHN serves as DM
- The RHN DM communicates with the SM particles through the Z'-boson exchange (Z'-portal DM)

  Phenomenology is controlled by

  - U(1)X gauge coupling: $\alpha_X = \frac{g_X^2}{4\pi}$
  - Z' boson mass: $m_{Z'}$
  - SM Higgs U(1)x charge: x_H
  - RHN DM mass: $m_{\rm DM}$

Summary (cont'd)

- We have considered phenomenological constraints
  - The observed DM relic abundance
  - LHC Run-2 constraints from Z' resonance search

and identified an allowed parameter region.

These constraints are complementary with each other to narrow the model parameter space

Thank you

for your attention!