



Light $B - L$ scalar and gauge bosons at DUNE

Yongchao Zhang
(張永超)

Southeast University, China

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Higgs as a Probe of New Physics 2021 (online)

based on

Bhupal Dev, Bhaskar Dutta, Kevin Kelly, Rabi Mohapatra & YCZ, 210x.abcde

Low-energy $U(1)_{B-L}$ model

- Extending the SM:

$$SU(2)_L \times U(1)_Y \times U(1)_{B-L}$$

- Natural framework for type-I seesaw and DM pheno...
- Light Z' and scalar φ boson at the low-energy scale:

$$\varphi : \text{breaking } U(1)_{B-L}$$

- **Prospects of Z' and φ at DUNE?**

See also other high-intensity/precision probes of light scalars and other particles:
ILC ([S. Heinemeyer](#)), KOTO ([F. Correia](#)), FASER ([T. Shimomura](#))

Model details

- The decay of light φ :
 - mixing with the SM Higgs ($\sin \vartheta$):

$$\varphi \rightarrow e^+e^-, \mu^+\mu^-, \pi\pi, \gamma\gamma: \quad \Gamma_i \propto \sin^2 \vartheta$$

- gauge coupling to Z' :

$$\varphi \rightarrow Z'Z': \quad \Gamma \propto g_{BL}^2$$

- Right-handed neutrinos N_i ($i = 1, 2, 3$): heavy enough to decouple from the game of Z' and φ :

$$m_{N_i} > m_{Z'}/2, m_\varphi/2$$

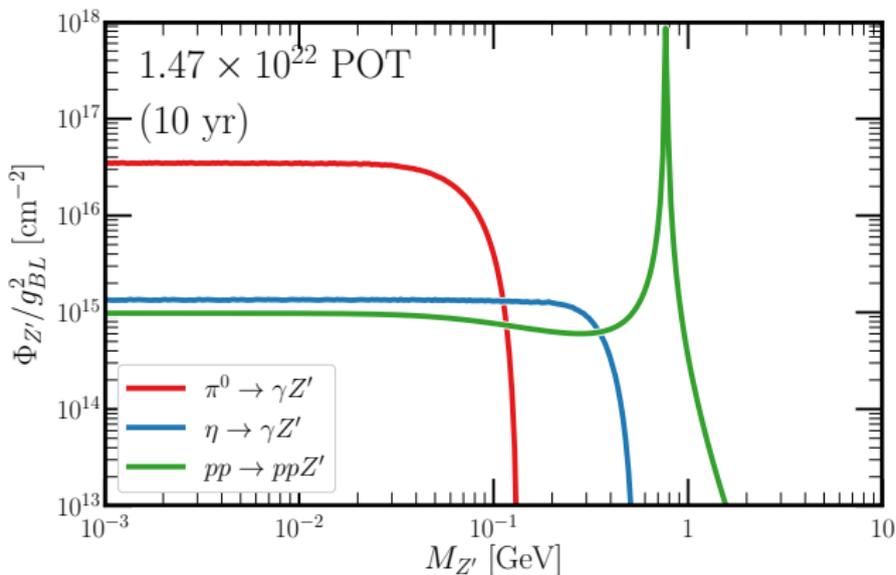
- Free parameters in the model

$$m_{Z'}, \quad m_\varphi, \quad g_{BL}, \quad \sin \vartheta$$

Four different scenarios

- Pure Z' case
- Pure φ case
[see Berryman, de Gouvêa, Fox, Kayser, Kelly & Raaf '20 [JHEP]]
- $\varphi + Z'$ case (effects of $\varphi \rightarrow Z'Z'$)
- Associate production of φ & Z'

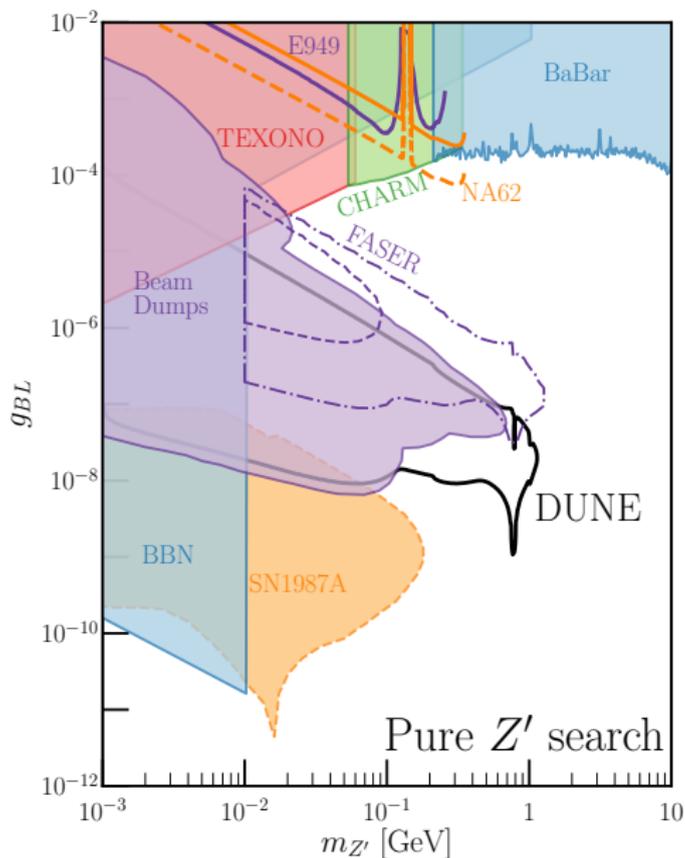
Production of Z' at DUNE (near detector complex)



example: $\Phi_{mZ'} = \frac{c_m N_{\text{POT}}}{A_{\text{Det.}}} \epsilon(m_{Z'}) \text{BR}(m \rightarrow \gamma Z'),$

$$= \frac{c_m N_{\text{POT}}}{A_{\text{Det.}}} \epsilon(m_{Z'}) \left[2 \left(\frac{g_{BL}^2}{e^2} \right) \text{BR}(m \rightarrow \gamma\gamma) \left(1 - \frac{m_{Z'}^2}{m_m^2} \right)^3 \right].$$

DUNE sensitivity: pure Z' case



Lab limits from Bauer,
Foldenauer & Jaeckel '18
[JHEP]

BBN & SN1987A limits from
Knapen, Lin & Zurek '17
[PRD]

Comparing DUNE and FASER:
DUNE events' energy is lower,
thus probing smaller g_{BL} .

Benchmark points of φ decay BRs

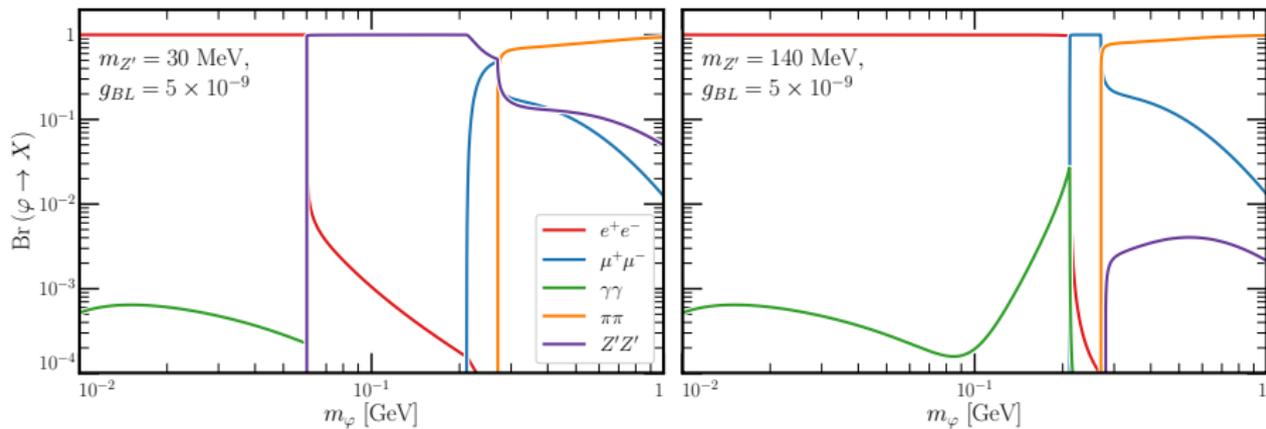
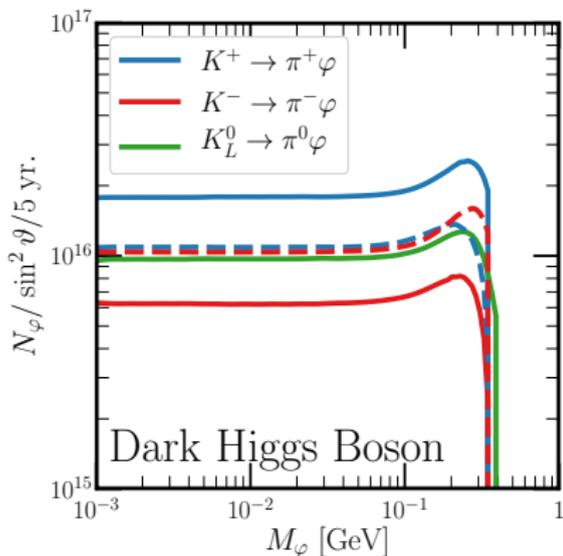


Figure: Decay BRs of the scalar φ

φ production at DUNE

Berryman, de Gouvêa, Fox, Kayser, Kelly & Raaf '20 [JHEP];

Batell, Pospelov & Ritz '11 [PRD]



$$\Gamma(K^\pm \rightarrow \pi^\pm \varphi) \simeq \frac{m_{K^\pm} |y_{sd}|^2 \sin^2 \vartheta}{64\pi} \times \frac{m_{K^\pm}^2}{m_\varphi^2} \lambda(m_{K^\pm}, m_{\pi^\pm}, m_\varphi),$$

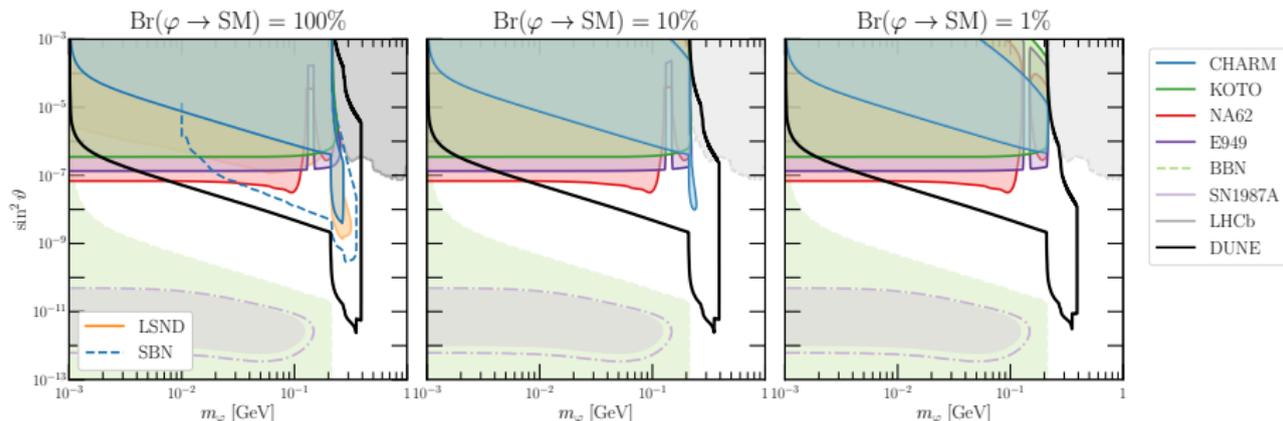
$$\Gamma(K_L \rightarrow \pi^0 \varphi) \simeq \frac{m_{K_L} (\text{Re } y_{sd})^2 \sin^2 \vartheta}{64\pi} \times \frac{m_{K^0}^2}{m_\varphi^2} \lambda(m_{K_L}, m_{\pi^0}, m_\varphi),$$

$$y_{sd} = \frac{3\sqrt{2}G_F m_t^2 V_{ts}^* V_{td}}{16\pi^2} \frac{m_\varphi}{\sqrt{2}v_{EW}}$$

$pp \rightarrow pp\varphi$ process contribution is comparatively small. [Batell, Berger & Ismail '19 \[PRD\]](#)

Effects of $\varphi \rightarrow Z'Z'$ on φ prospects at DUNE

Dev, Mohapatra & YCZ '20 [PRD]; Egana-Ugrinovic, Homiller & Meade '20 [PRL]

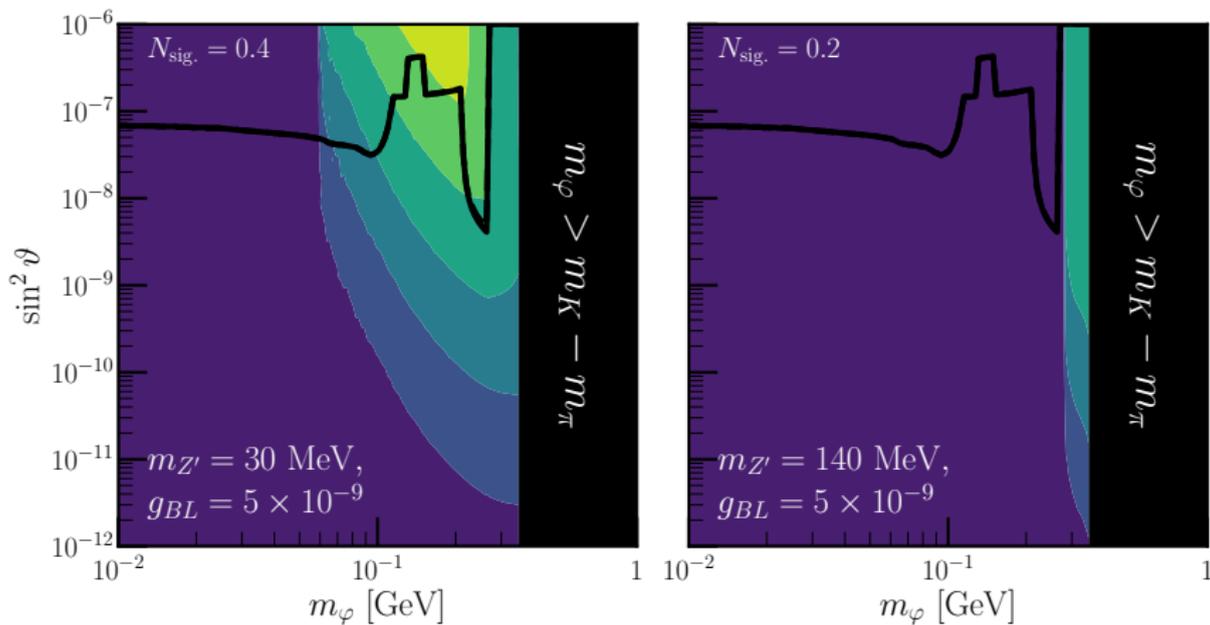


Effects of $\varphi \rightarrow Z'Z'$:

- Modifying its branching fraction into visible particles;
- Shortening its lifetime.

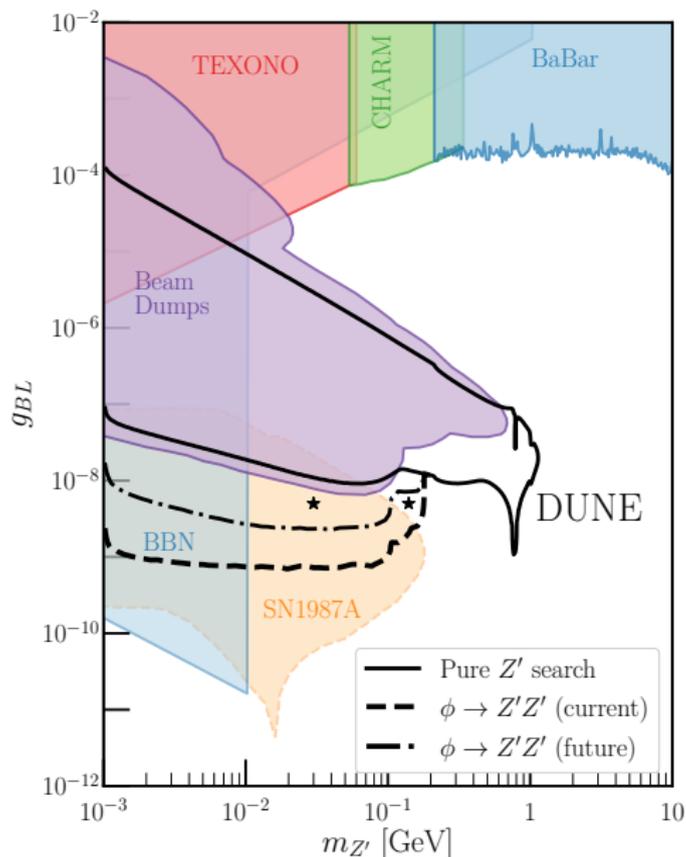
SN1987A limits from [Dev, Mohapatra & YCZ '20 \[JCAP\]](#); [Dev, Fortin, Harris, Sinha & YCZ, 210x.abcde](#)

Numbers of Z' at DUNE in presence of φ



Color change: a factor of 10

Effects of $\phi \rightarrow Z'Z'$ on Z' prospects at DUNE



Lab limits from Bauer, Foldenauer & Jaeckel '18 [JHEP]

BBN & SN1987A limits from Knapen, Lin & Zurek '17 [PRD]

Improving the pure Z' case by up to **a factor of 45**.

SN1987A limit might change dramatically if we include DM Yue Zhang '14 [JCAP]

Associate production of φ and Z'

- Channels:

$$\pi^0 \rightarrow \gamma + Z' + \varphi, \quad K \rightarrow \pi + Z' + \varphi, \quad \rho \rightarrow Z' + \varphi$$

- If φ is produced from gauge coupling to Z'

$$\text{flux} \propto g_{BL}^4 \quad \text{too small!}$$

- If φ is produced from Yukawa coupling to mesons

$$\text{flux} \propto \sin^2 \vartheta g_{BL}^2 \quad \text{too small!}$$

Conclusion

- The DUNE near detector complex can probe large regions of parameter space of the light φ and Z' bosons in low-energy $B - L$ models.
- In presence of the gauge coupling $\varphi Z' Z'$, the prospects of φ at DUNE are to some extent weakened, compared to the case without the gauge interaction.
- The DUNE sensitivity of Z' can be significantly improved by the decay $\varphi \rightarrow Z' Z'$, even by one order of magnitude, for $m_{Z'} \lesssim 200$ MeV.
- The DUNE sensitivities of φ and Z' are largely complementary to other laboratory searches as well as the cosmological and astrophysical limits.

Thank you very much!