Studying Exotic Gauge Bosons Using ILC Beam Dump

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Refs:

Kanemura, TM and Tanabe, PLB751 (2015) 25 [arXiv:1507.02809]

Asai, TM and Niki, PLB818 (2021) 136374 [arXiv:2104.00888]

TM and Niki, work in progress

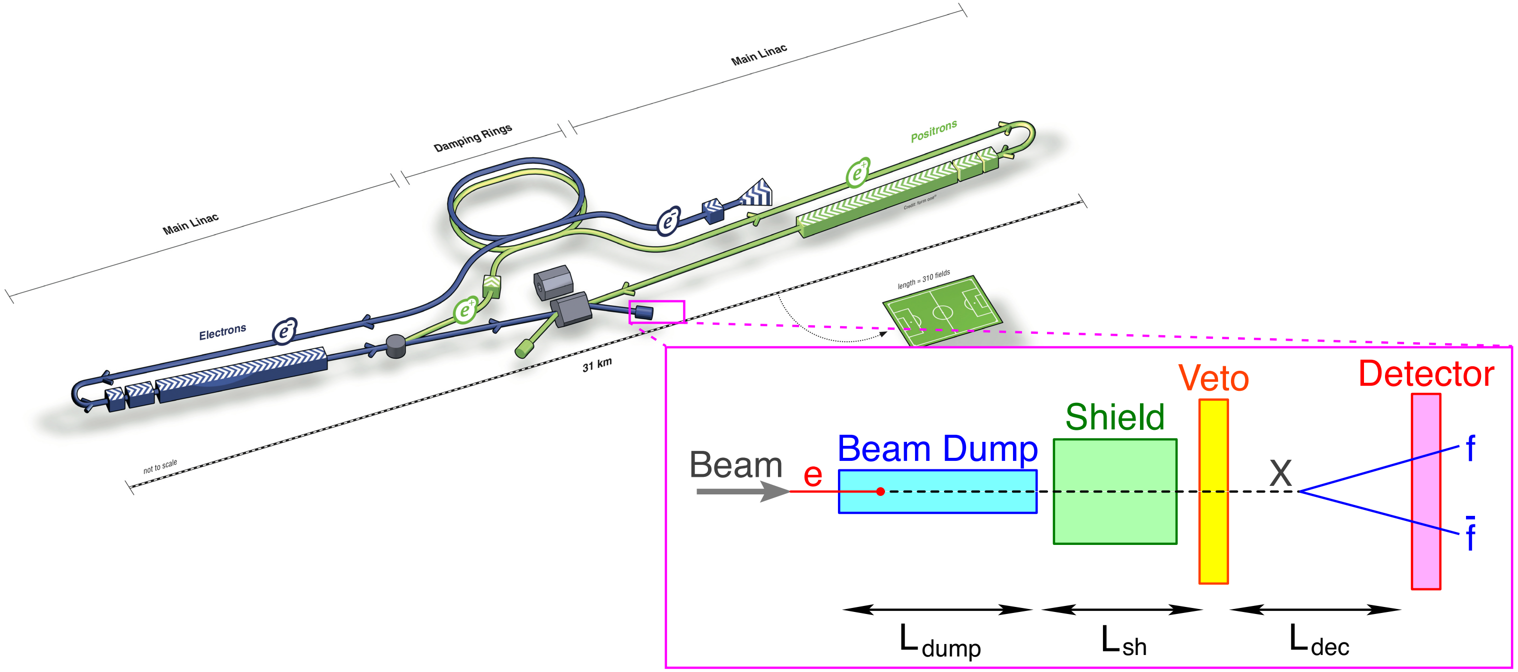
2021.10.28, ILC-X @ on-line

1. Introduction

“Hidden particles” are hardly studied at the ILC

⇒ An idea: Beam-dump experiment at the ILC (ILC-BD)

[Kanemura, TM & Tanabe (’15)]

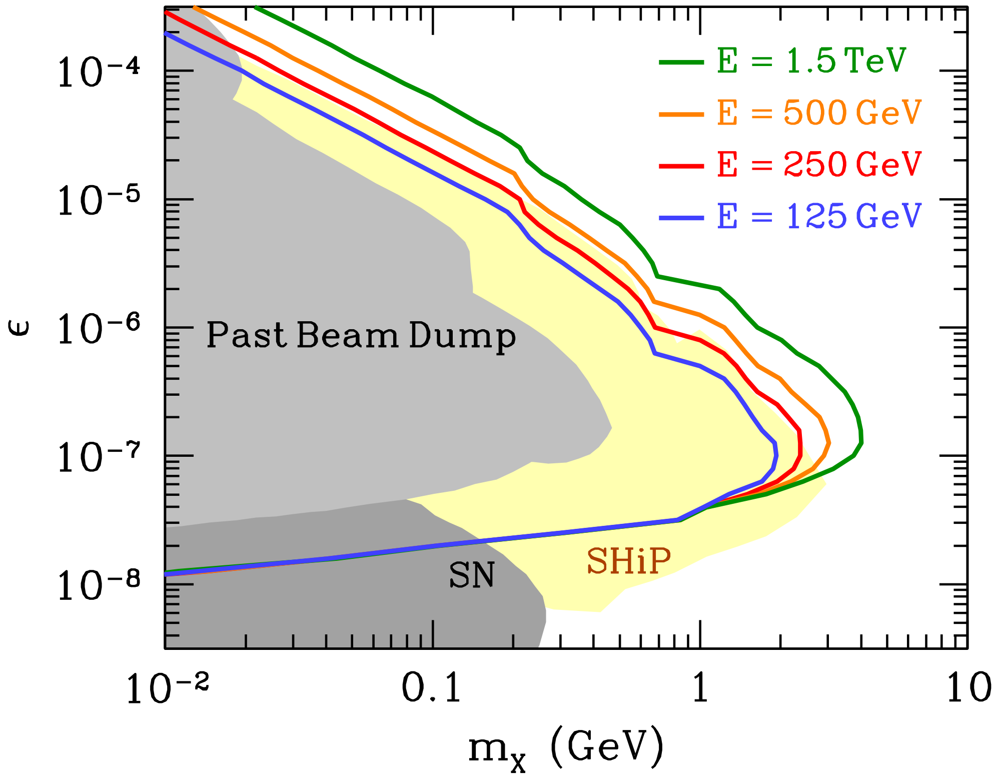


⇒ Hidden particles may be produced and detected if a detector is installed behind the dump

[Kanemura, TM & Tanabe (’15); Sakaki & Ueda (’21); Asai, TM & Niki (’21); Asai, Iwamoto, Sakaki & Ueda (’21); Araki, Asai & Shimomura (’21)]

Dark photon search (assuming no SM background)

$$\mathcal{L} = \mathcal{L}_{\text{SM}} - \frac{1}{4} X_{\mu\nu} X^{\mu\nu} - \frac{\epsilon}{2} F^{(\text{em})}_{\mu\nu} X^{\mu\nu} + \frac{m_X^2}{2} X_\mu X^\mu$$



$N_{\text{sig}} = 1/\text{year}$

$N_e = 4 \times 10^{21}$

$L_{\text{dump}} = 11\,\text{m}$

$L_{\text{sh}} = 50\,\text{m}$

$L_{\text{dec}} = 50\,\text{m}$

[Kanemura, TM & Tanabe ('15)]

$\Rightarrow$ ILC-BD can explore models which are currently viable

ILC beam dump: Target = H_2O

$\sim 4 \times 10^{21}$ electrons and positrons are dumped per year

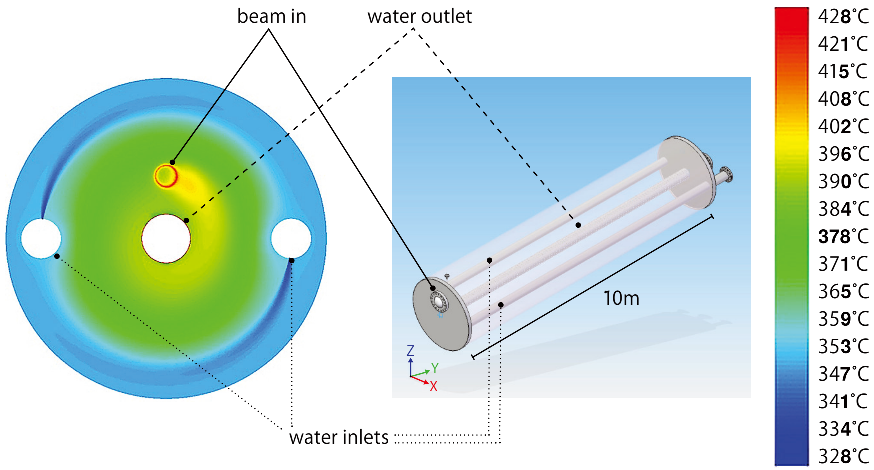
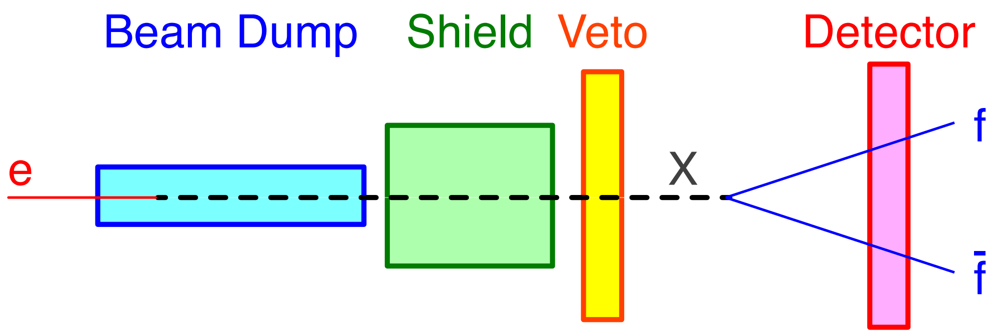


Figure 8.15 Temperature distribution at the shower maximum of the beam in the main 18 MW dump just after passage of the beam train (left). (The geometry of the dump is also shown on the right.) The colour bar shows temperature in kelvin; the maximum temperature is 155 °C [191].

[ILC TDR vol. 3.II]

Signal of "hidden" particle X

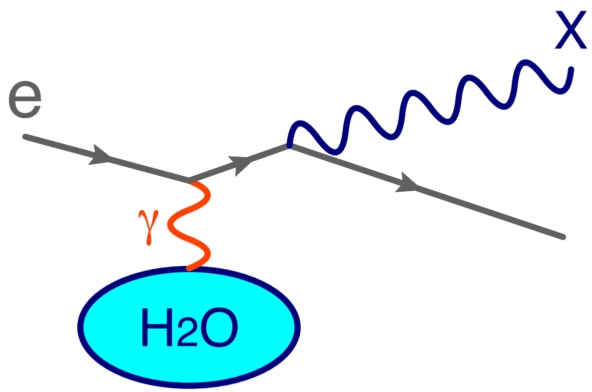


2. Leptophilic Gauge Bosons

$U(1)_{e-\mu}$ or $U(1)_{e-\tau}$ model

$$\mathcal{L} \ni g_X(\bar{e}\gamma^\mu e - \bar{\ell}\gamma^\mu \ell)X_\mu \qquad (\ell = \mu \text{ or } \tau)$$

Dominant production processes of X_μ:



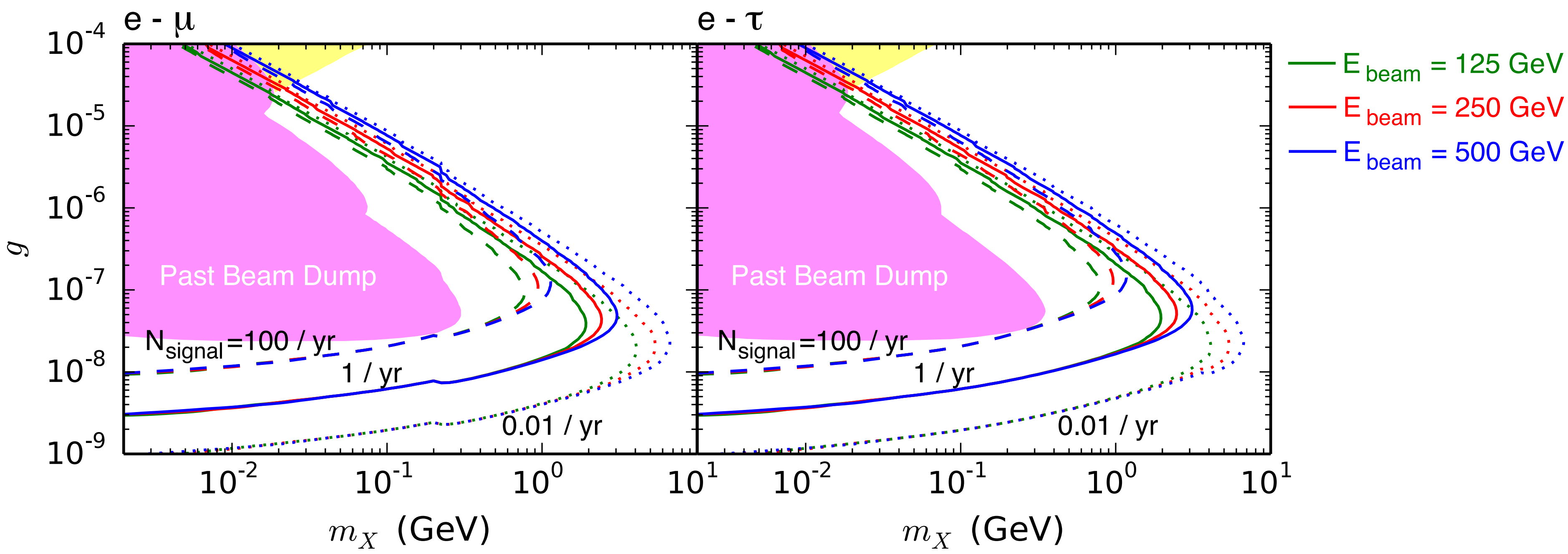
X_μ decays into charged lepton pair (as well as into $\bar{\nu}\nu$)

$$X_\mu^{(e-\mu)} \to e^+e^- \text{ and } \mu^+\mu^-$$

$$X_\mu^{(e-\tau)} \to e^+e^- \text{ (for } m_X < 2m_\tau)$$

Cases with $U(1)_{e-\mu}$ and $U(1)_{e-\tau}$

[Asai, TM & Niki ('21)]



- ILC-BD can access parameter regions which have not been explored yet
- After the discovery, we may distinguish models if a good particle identification is possible (see the next slide)

Decay pattern of hidden particle is model-dependent

$$r_e \equiv \frac{\Gamma_{X\to e^+e^-}}{\Gamma_X^{(\text{vis})}}, \quad r_\mu \equiv \frac{\Gamma_{X\to \mu^+\mu^-}}{\Gamma_X^{(\text{vis})}}, \quad r_h \equiv \frac{\Gamma_{X\to \text{had}}}{\Gamma_X^{(\text{vis})}}$$

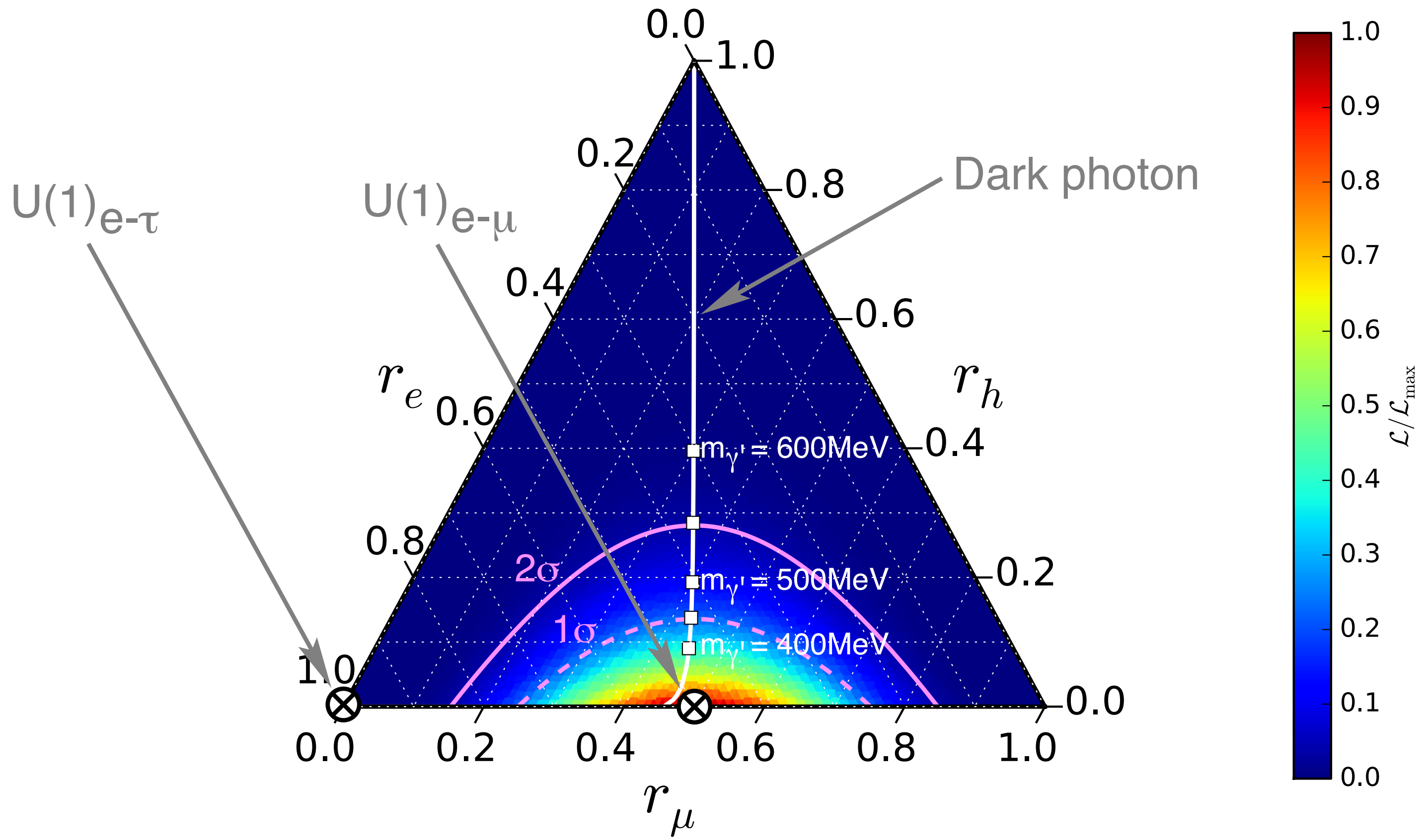
$$\Gamma_X^{(\text{vis})} = \Gamma_{X\to e^+e^-} + \Gamma_{X\to \mu^+\mu^-} + \Gamma_{X\to \text{had}} \quad \Rightarrow \quad r_e + r_\mu + r_h = 1$$

For $2m_\mu \lesssim m_X \lesssim 2m_\tau$:

	r_e	r_μ	r_h
$U(1)_{e-\mu}$	~ 0.5	~ 0.5	~ 0
$U(1)_{e-\tau}$	~ 1	~ 0	~ 0
Dark photon	$1/(2+R)$	$1/(2+R)$	$R/(2+R)$

R = R-ratio @ $\sqrt{s} = m_X$

With $N_{\text{signal}} = 10$ in $U(1)_{e-\mu}$ model (i.e., $N_{e^+e^-} = N_{\mu^+\mu^-} = 5$):

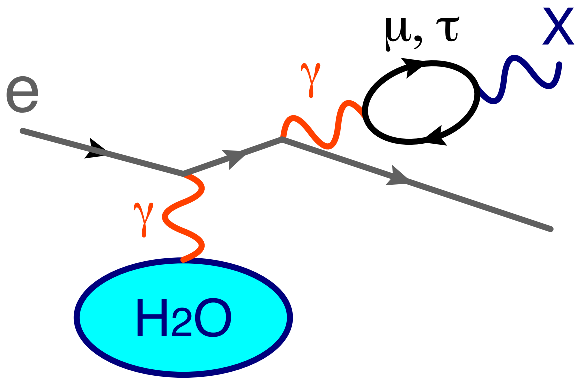


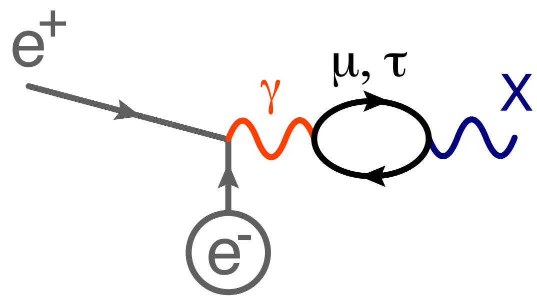
⇒ Various models can be distinguished if N_{signal} is sizable

$U(1)_{\mu-\tau}$ model

$$\mathcal{L} \ni g_X(\bar{\mu}\gamma^\mu\mu - \bar{\tau}\gamma^\mu\tau)X_\mu$$

Coupling to $e^\pm$ is via the loop-induced kinetic mixing

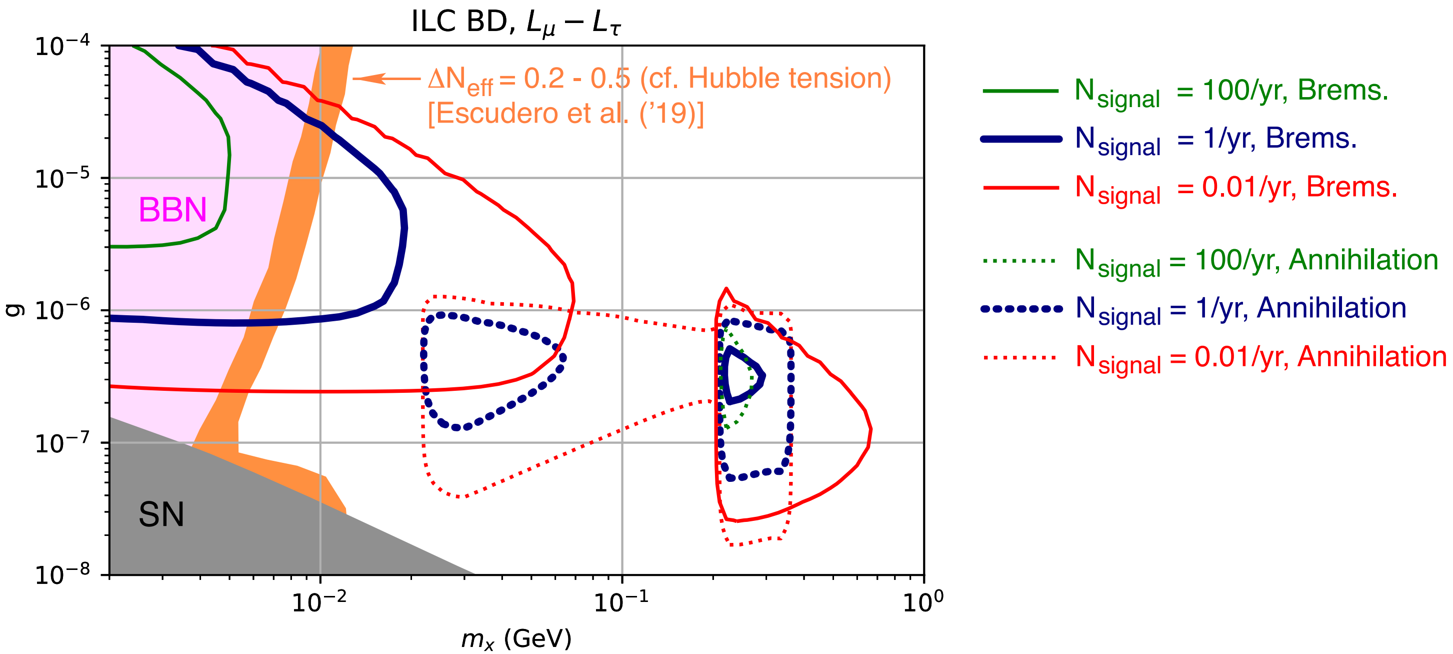




- Signal rate is suppressed when $m_X \lesssim 2m_\mu$, because X dominantly decays into $\bar{\nu}\nu$
- The pair annihilation process ($e^+e^- \to X$) enlarges the accessible region

Results for $U(1)_{\mu-\tau}$ model (preliminary)

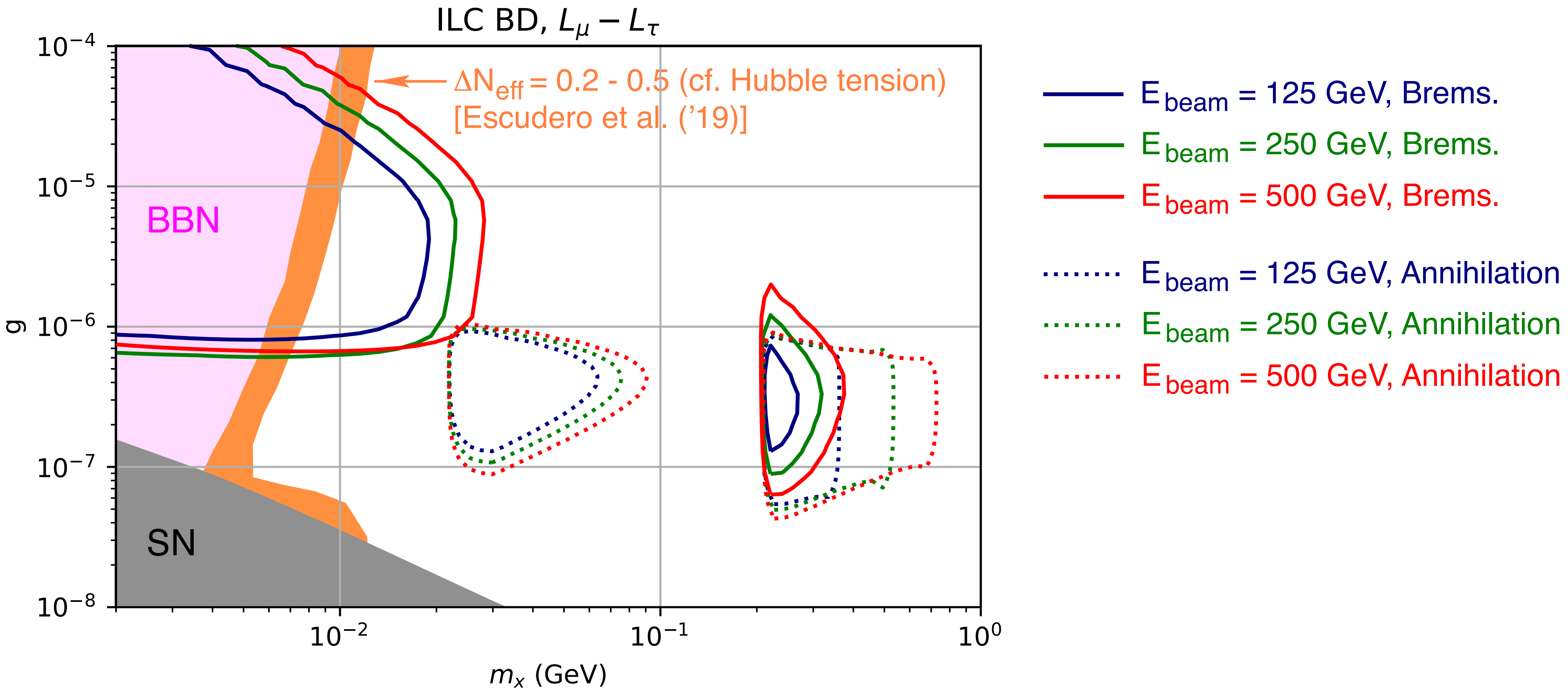
[TM & Niki, in preparation]



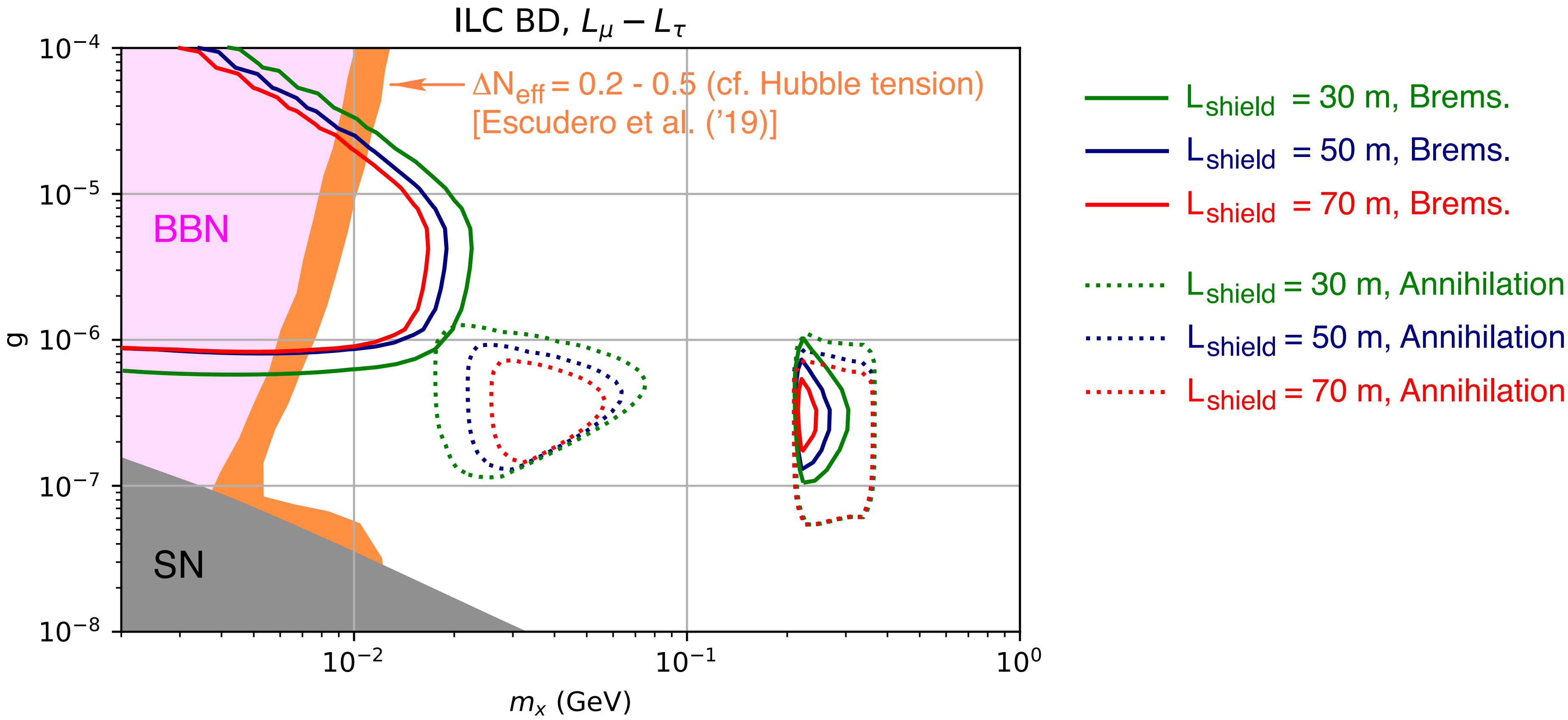
⇒ With e^+ beam, accessible region is enlarged because of the pair annihilation process

⇒ Parameter region favored by the Hubble tension can be accessed

$U(1)_{\mu-\tau}$ model: Dependence on the beam energy (preliminary)



$U(1)_{\mu-\tau}$ model: Dependence on the shield length (preliminary)



⇒ Shorter shield is better

3. Summary

ILC beam dump experiment is an interesting possibility:

- Discovery of exotic particles
- Discrimination of the model behind the exotic particles

Discovery reaches depend on the design:

- Compact shield & large decay volume are preferred
- With e^+ beam, e^+e^- annihilation processes become available

  [For ALPs, see Sakaki & Ueda ('21)]
- Good particle identification is desired to distinguish various models

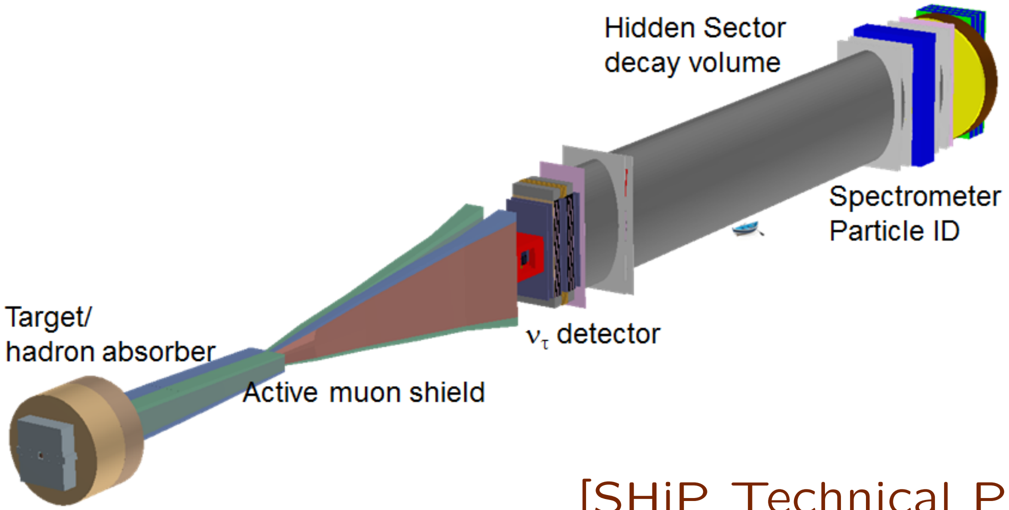
Backups

SM background (in particular, muons) should be removed

⇒ Shield is necessary

One idea to remove the muon background (SHiP's proposal)

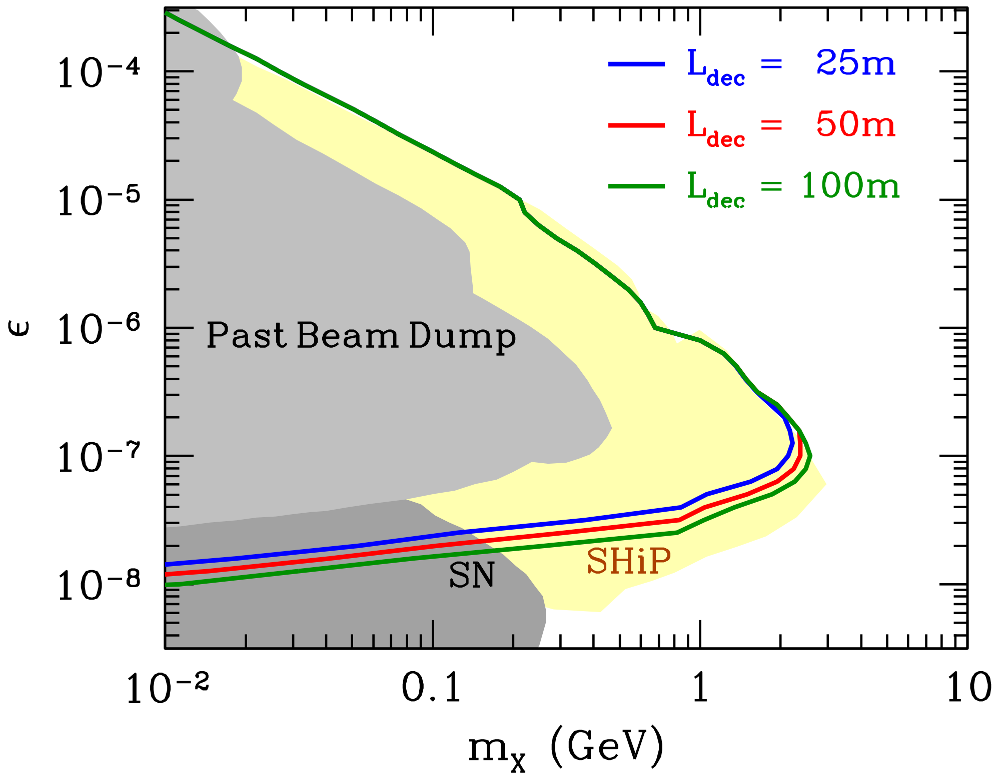
- Carefully designed magnetic field to bend the muons away
- With the magnetic field of $O(1\,\mathrm{T})$, $L_{\mathrm{sh}} \sim 50\,\mathrm{m}$ is needed



[SHiP Technical Proposal 1504.04956]

⇒ We assume that all the SM backgrounds can be removed

Dependence on the decay-volume size (dark photon case)



$N_{\text{sig}} = 1/\text{year}$

$N_e = 4 \times 10^{21}$

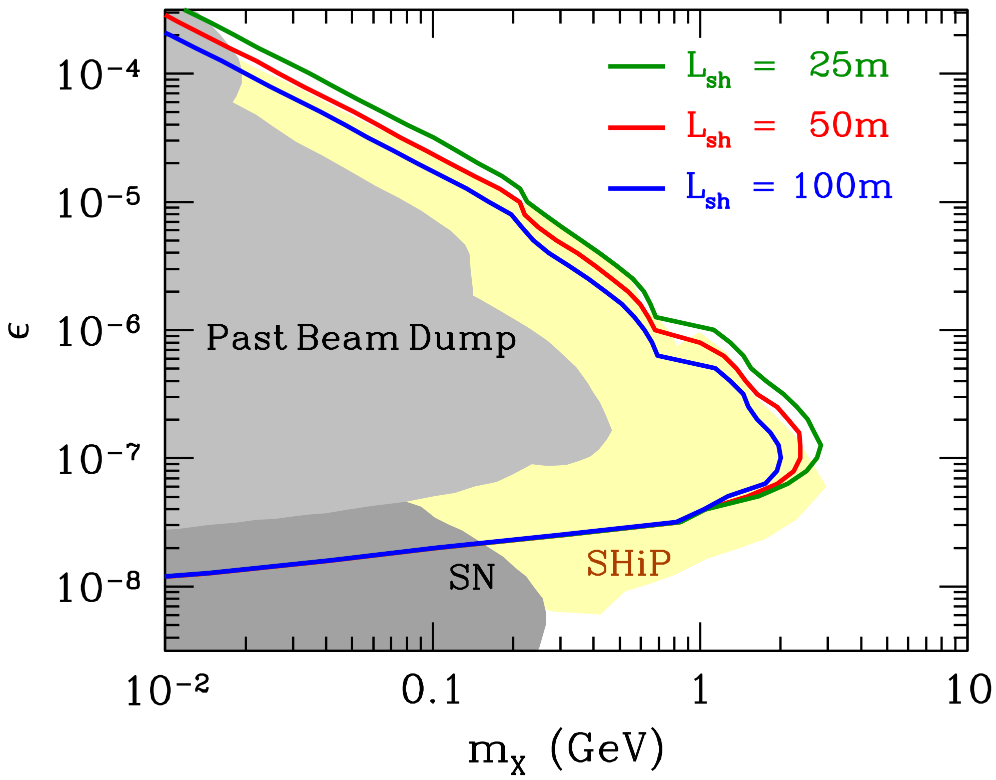
$L_{\text{dump}} = 11\,\text{m}$

$L_{\text{sh}} = 50\,\text{m}$

$L_{\text{dec}} = 25,\ 50$ and $100\,\text{m}$

$\Rightarrow$ Longer L_{dec} gives better discovery reach

Dependence on the shield length (dark photon case)



$N_{\text{sig}} = 1/\text{year}$

$N_e = 4 \times 10^{21}$

$L_{\text{dump}} = 11\,\text{m}$

$L_{\text{sh}} = 25,\ 50\ \text{and}\ 100\,\text{m}$

$L_{\text{dec}} = 50\,\text{m}$

$\Rightarrow$ Shorter L_{sh} gives better discovery reach

Assuming 10 signal events:

- Left: $U(1)_{e-\mu}$ $(N_{e^+e^-} = 5,\ N_{\mu^+\mu^-} = 5)$
- Right: $U(1)_{e-\tau}$ $(N_{e^+e^-} = 10,\ N_{\mu^+\mu^-} = 0)$