Beam-Dump Experiment at the ILC

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Refs:

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

2015.11.04, LCWS15

ILC:

- Good for studying particles with EW quantum numbers
- Very weakly interacting particles are hardly studied

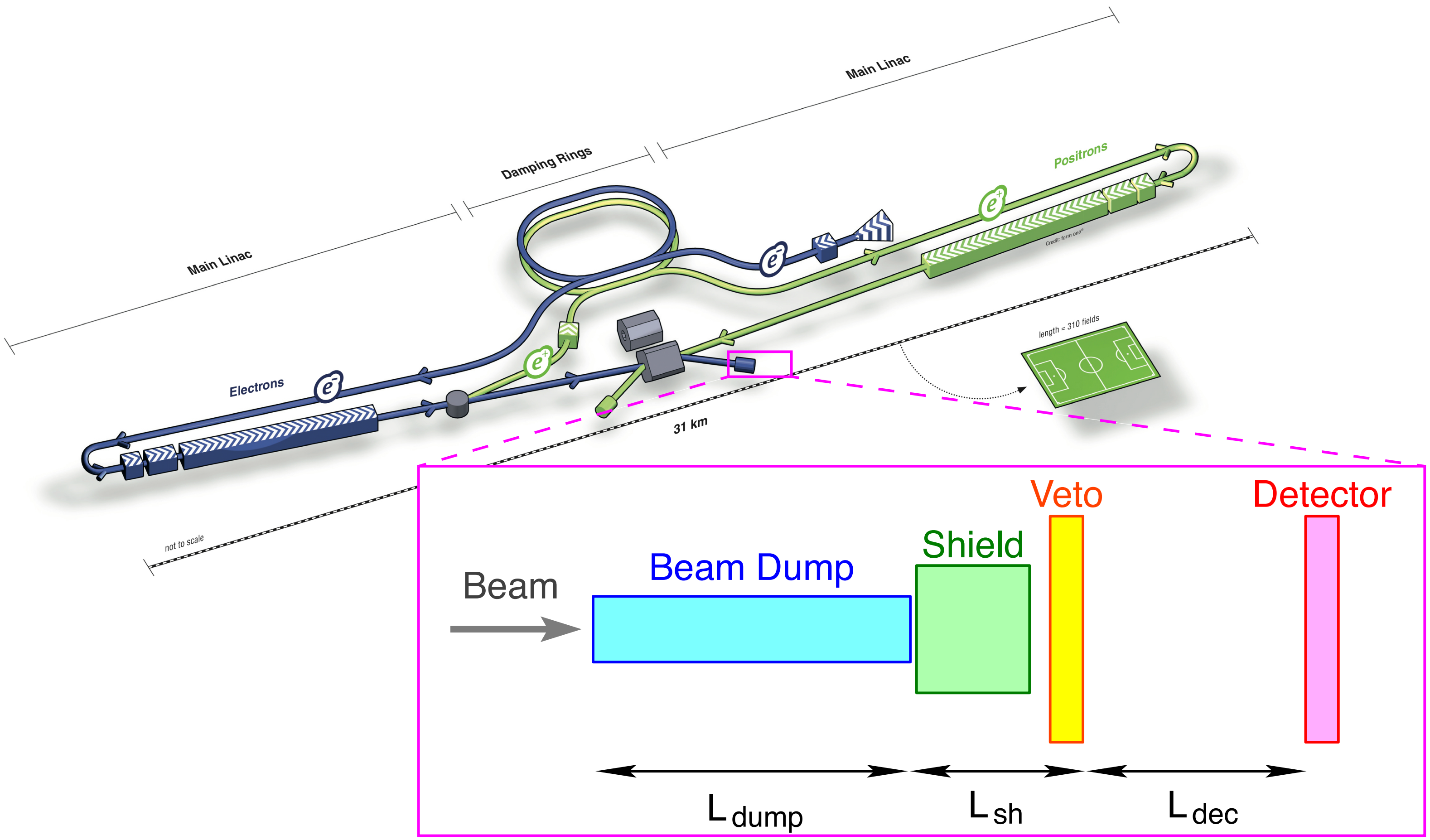
Very weakly interacting particles ("hidden particles")

- Hidden photon
- Axion-like scalar particles
- Sterile neutrinos
- $\cdots$

Can we study hidden particles at the ILC?

$\Rightarrow$ Probably no, with the current design, but $\cdots$

Proposal: Beam-dump experiment at e^+e^- collider (BDee)



Advantage: $e^{\pm}$ beams are dumped just after each collision

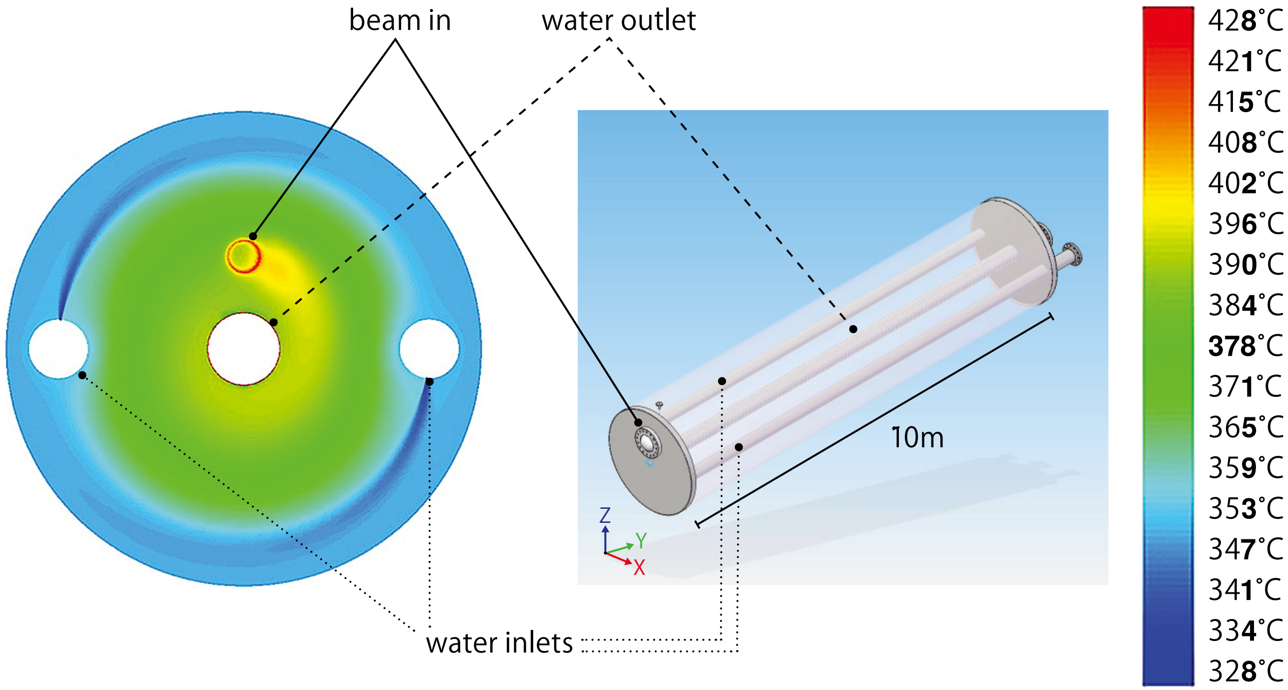
$\Rightarrow$ Large amount of $e^{\pm}$ are available for BDee

Beam-dump at the ILC: Target = H_2O

- $O(10^{21})$ electrons are dumped per year

  (5 trains/sec, 1312 bunches/train, 2×10^{10} e/bunch)

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 ℃ [191].



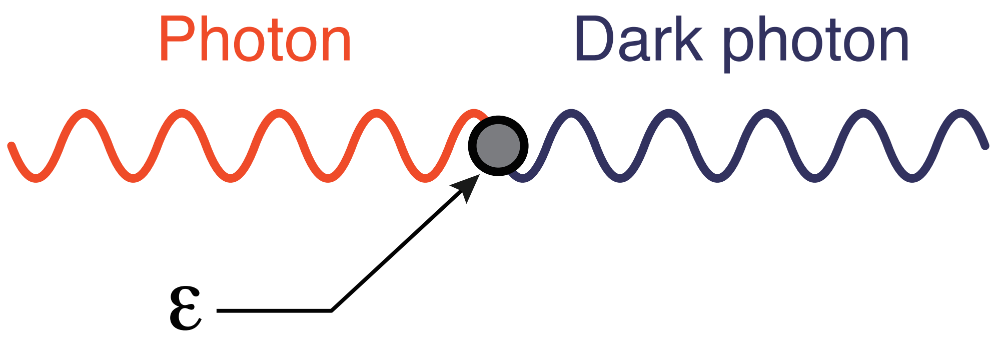
- Hidden particles produced in the dump may be observed by the detector behind the dump

Case with hidden-photon X_μ

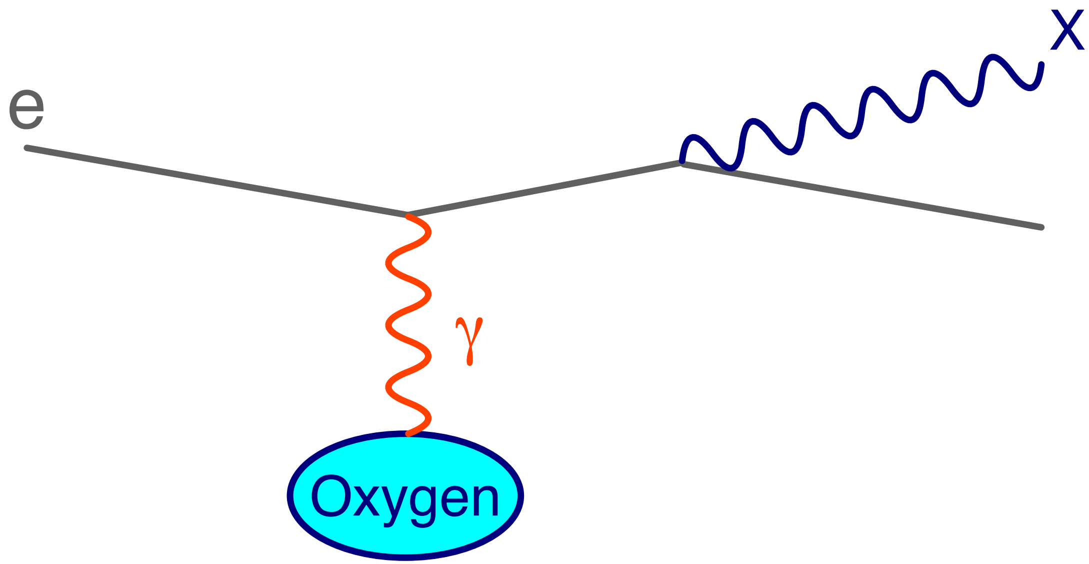
$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{4} F^{(X)}_{\mu\nu} F^{(X)}_{\mu\nu} - \frac{\epsilon}{2} F^{(\rm em)}_{\mu\nu} F^{(X)}_{\mu\nu} + \frac{m_X^2}{2} X_\mu X_\mu$$

Model parameters:

- m_X: mass of hidden photon
- ϵ: mixing parameter ($\epsilon \ll 1$)



Hidden photon production: $e^{\pm} + \mathrm{H_2O} \to e^{\pm} + X + \cdots$

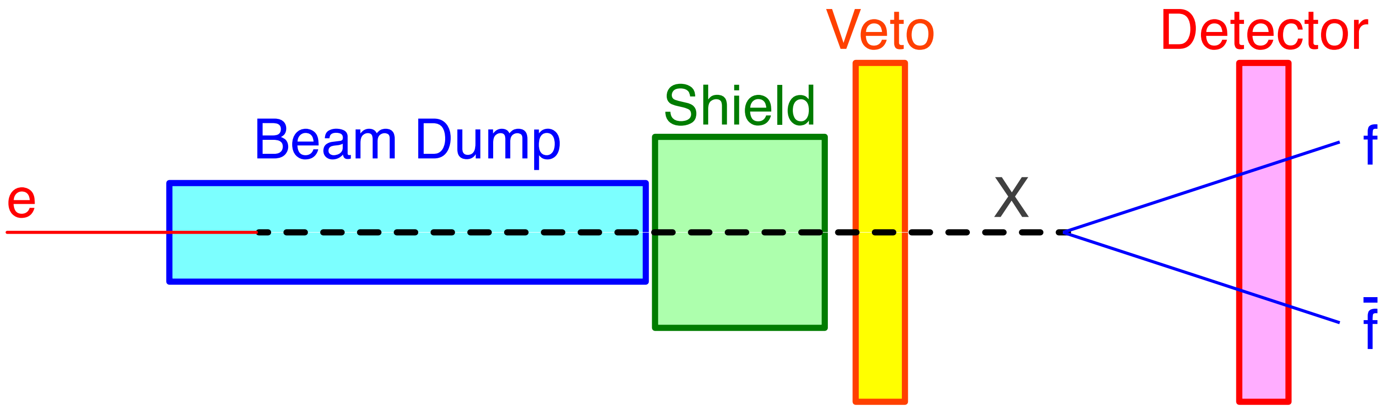


Hidden photon decays into SM fermions via mixing

$$\Gamma_{X\to\ell^+\ell^-} = \frac{\alpha\epsilon^2}{3} m_X \left(1 + \frac{2m_\ell^2}{m_X^2}\right) \sqrt{1 - \frac{4m_\ell^2}{m_X^2}}$$

Hidden photon signal at BDee

SM particles from the decay volume

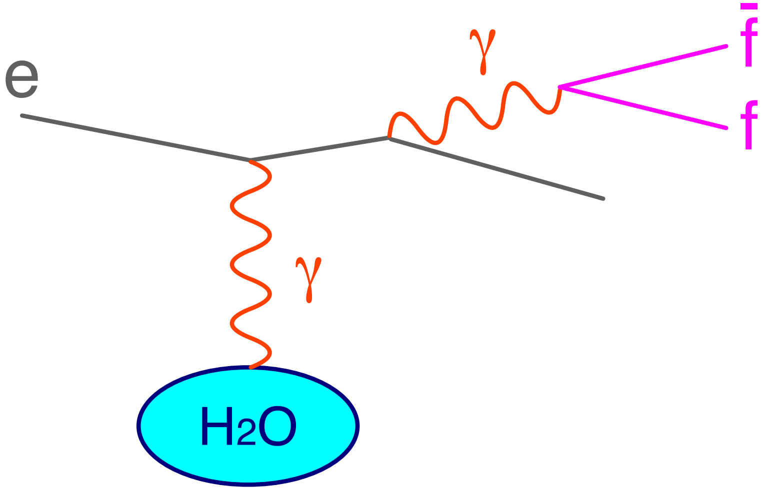


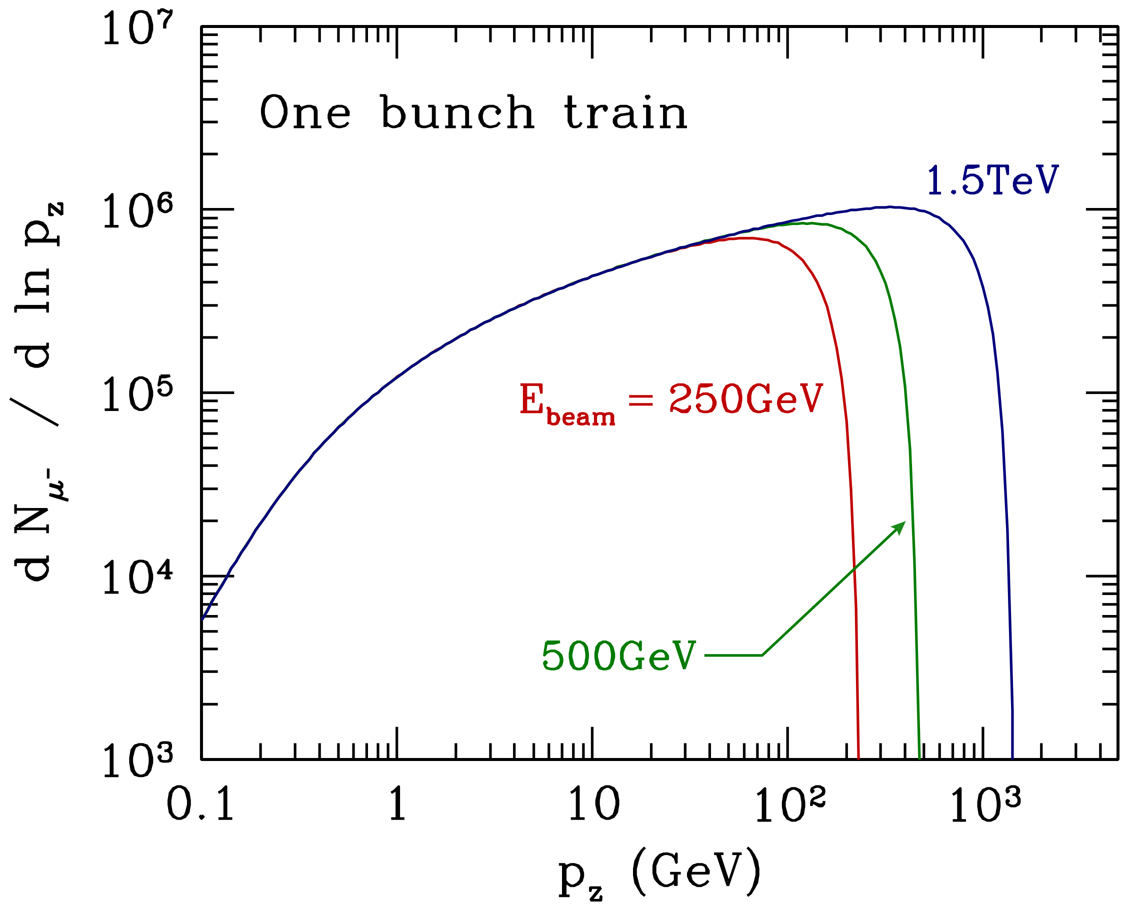
Cross section: we use Weizsäcker-Williams approximation

$$N_{\text{signals}} \sim N_e \times \frac{\sigma(e^\pm + H_2O \to e^\pm + X + \cdots)}{\sigma(e^\pm + H_2O \to e^\pm + \gamma + \cdots)}$$

$$\times e^{-\langle\Gamma_X\rangle(L_{\text{dump}}+L_{\text{sh}})}(1 - e^{-\langle\Gamma_X\rangle L_{\text{dec}}})$$

We should remove SM backgrounds (in particular, muons)





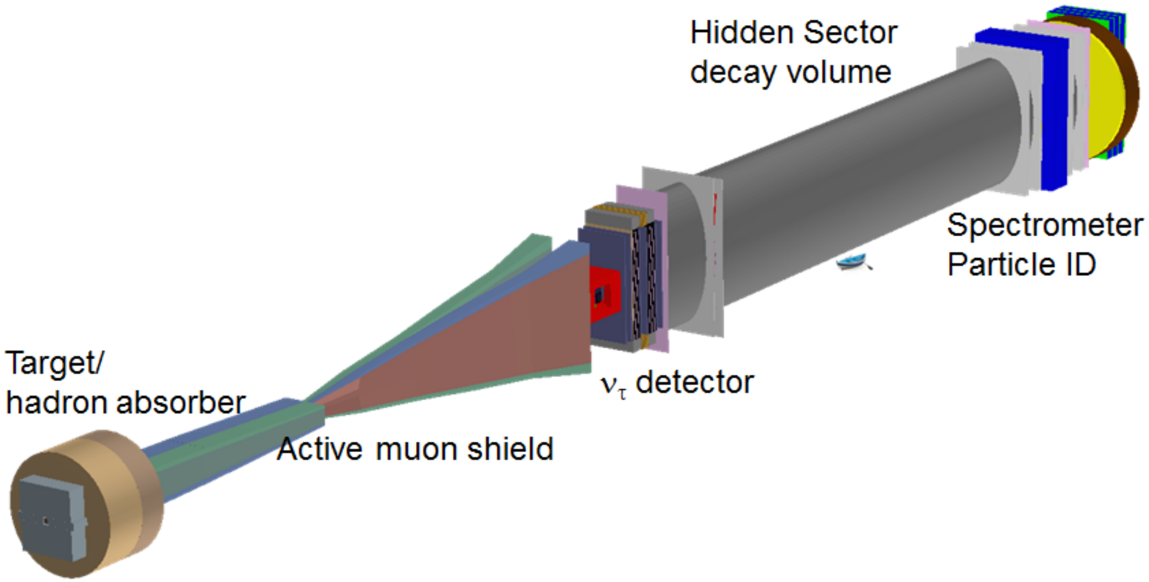
$\Rightarrow$ $O(10^6)$ muon pairs with the injection of one bunch train

$\Rightarrow$ Energy of the muon is comparable to the beam energy

We need to remove muons

⇒ SHiP TDR claims that the muons can be removed with carefully-designed magnetic field

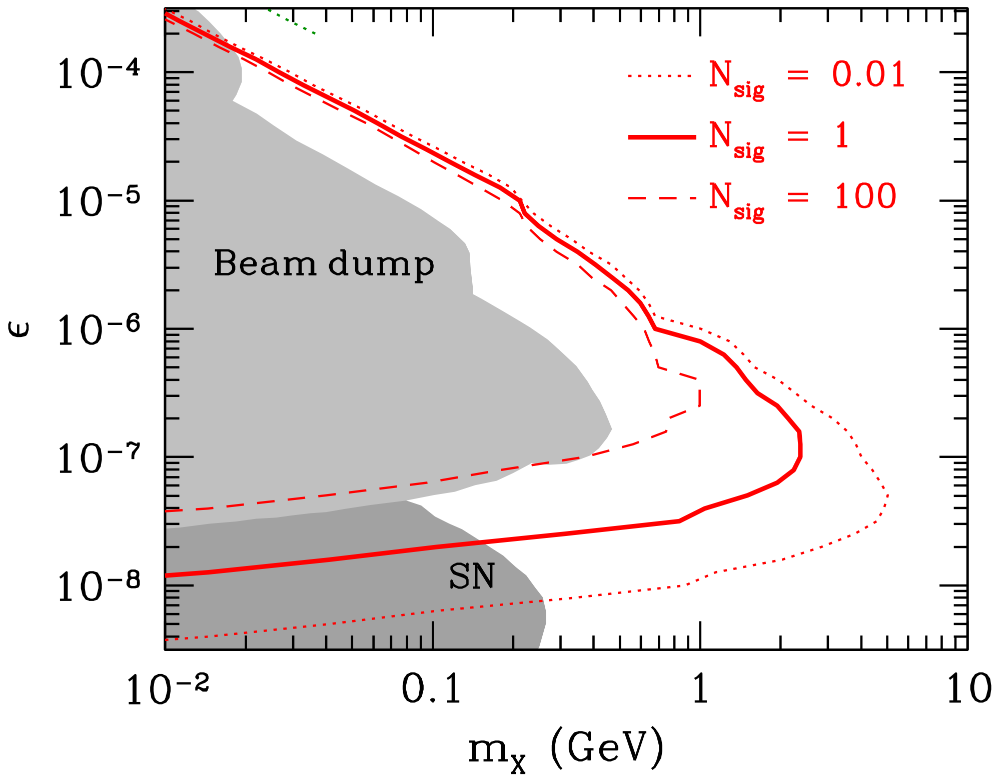
SHiP: Beam-dump experiment proposed in CERN



With the magnetic field of $O(1\ \mathrm{T})$, $L_{\mathrm{sh}} \sim O(10\ \mathrm{m})$ is needed

⇒ Hereafter, we assume that all the muons can be removed

Number of signals with one-year operation



$E_{\text{beam}} = 250$ GeV

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

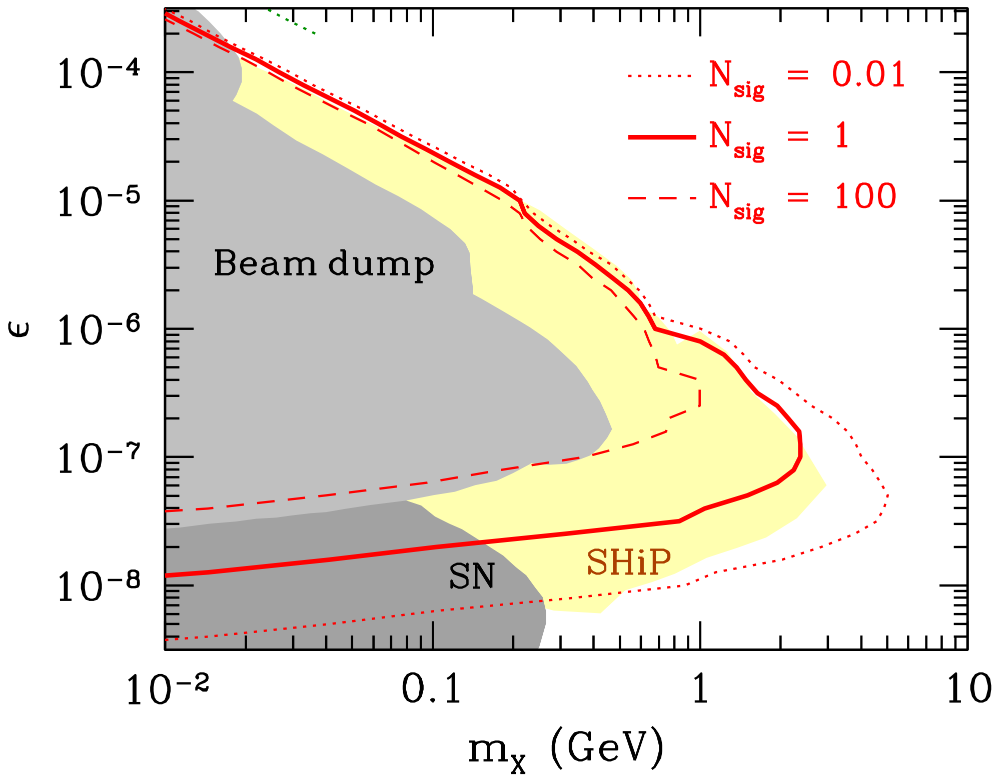
$L_{\text{dump}} = 11$ m

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

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

- With large ϵ, X decays before reaching the decay volume
- With small ϵ, production and decay rates of X are suppressed

Number of signals: comparison with SHiP



$E_{\text{beam}} = 250$ GeV

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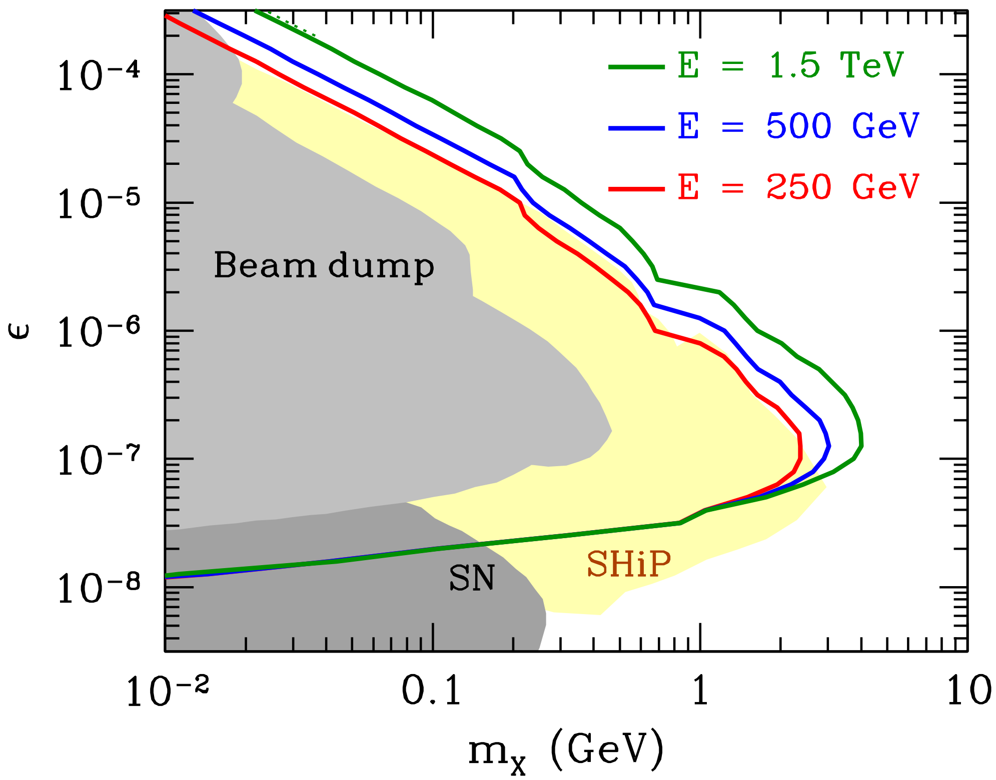
Dependence on the beam energy



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

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

$L_{\rm dump} = 11$ m

$L_{\rm sh} = 50$ m

$L_{\rm dec} = 50$ m

$\Rightarrow$ Larger $E_{\rm beam}$ gives (slightly) better discovery reach

To make BDee possible, we need to consider:

- Other physics cases
  - Axion-like particles
  - Sterile neutrinos
  - Any other model?
- Experimental details
  - Background reduction (in particular, muons)
  - Space issue: can we have an experimental hall behind the dump?
- Competition with SHiP (and other experiments)
  - BDee uses $e^{\pm}$ beam, while SHiP uses proton beam

In summary, I have discussed the possibility of BDee

- Beam-dump experiment at the ILC

BDee may be useful to look for hidden particles

- For the hidden-photon model, BDee covers the parameter region which has not been explored
- Studies for other models are needed

Advantages of BDee at the ILC

- Large amount of electrons are available: $N_e \sim O(10^{21})$/year

  $\Leftrightarrow$ For the case of FCC-ee: $N_e \sim O(10^{18})$/year