LC Vision Community Event:

Beyond Collider Physics Opportunities

08.01.2024, CERN

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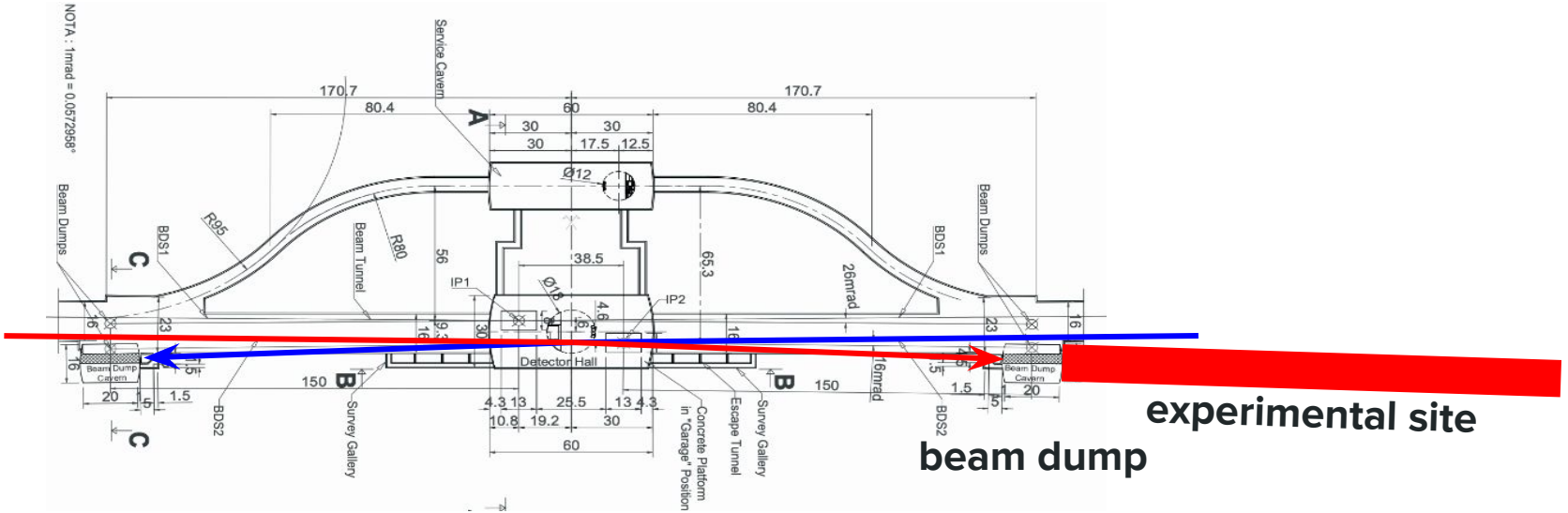
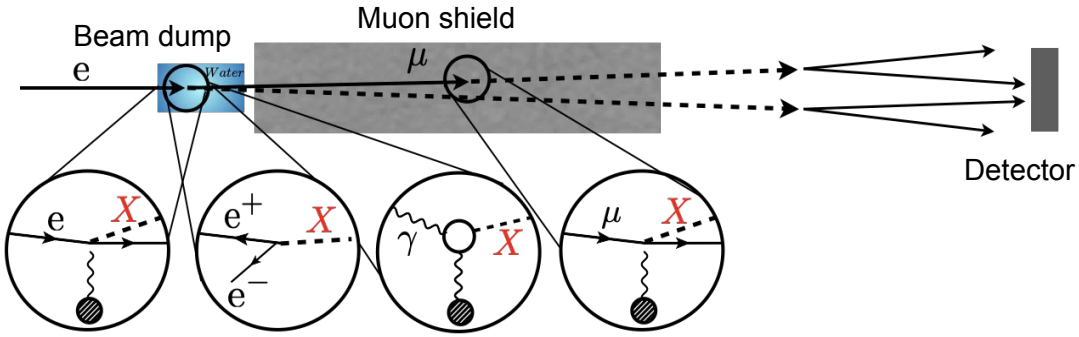
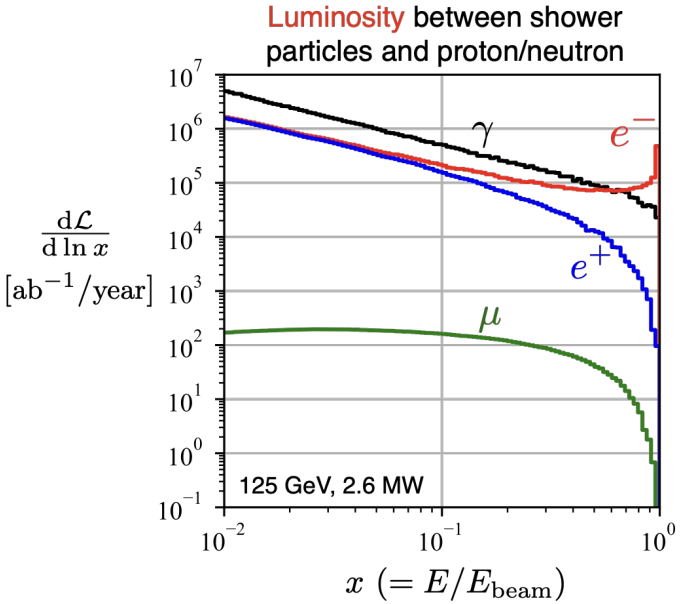
Long-lived particles – Window to the dark sector



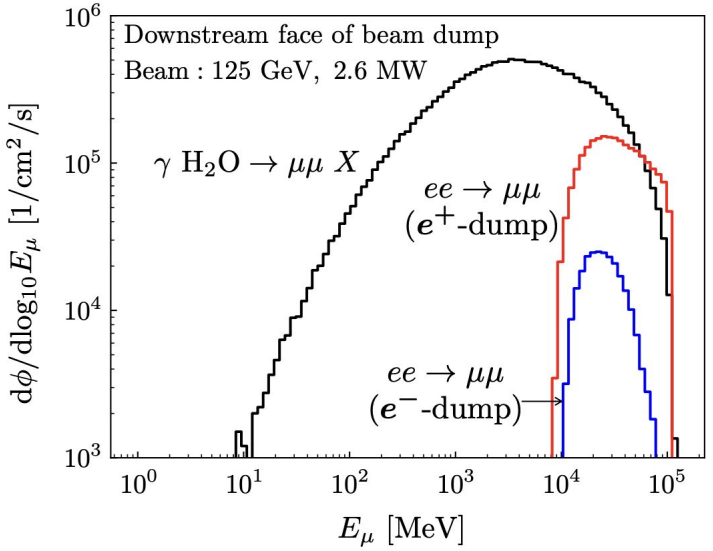
- Almost all accelerated particles can be utilized for the beam dump experiment.
  - Suitable for searching feebly interacting particles.
- A very high-power targets (main beam dumps) can be used without additional cost.

New particles from electromagnetic showers

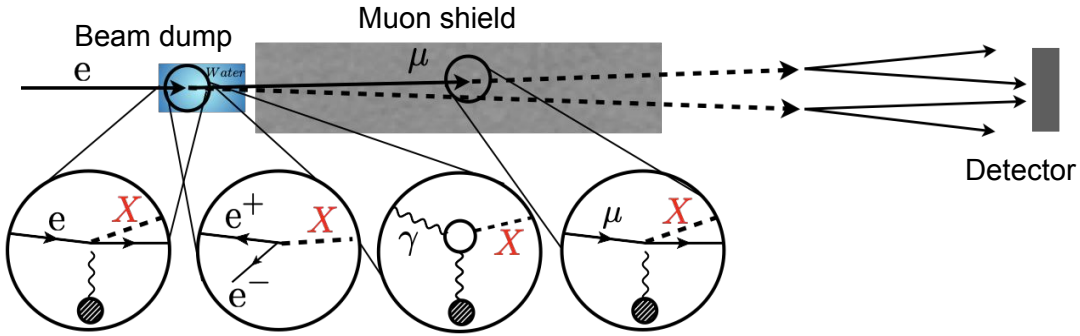


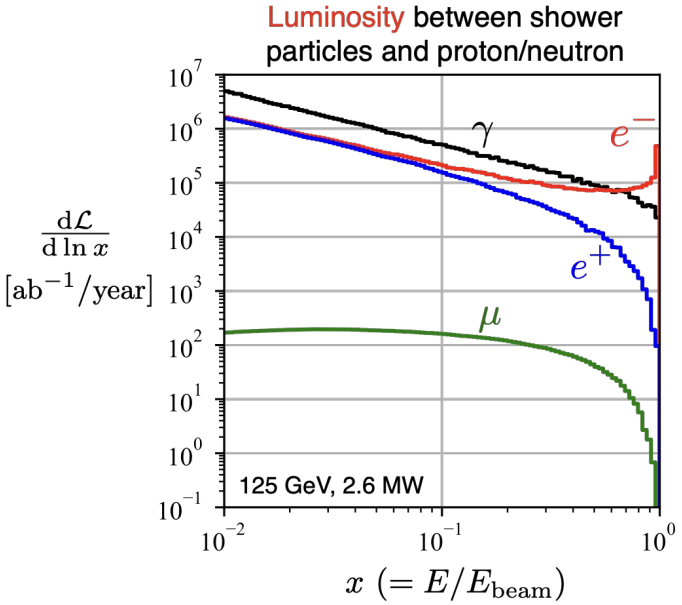


- The e+ dump provides more forward-directed high-energy muons.

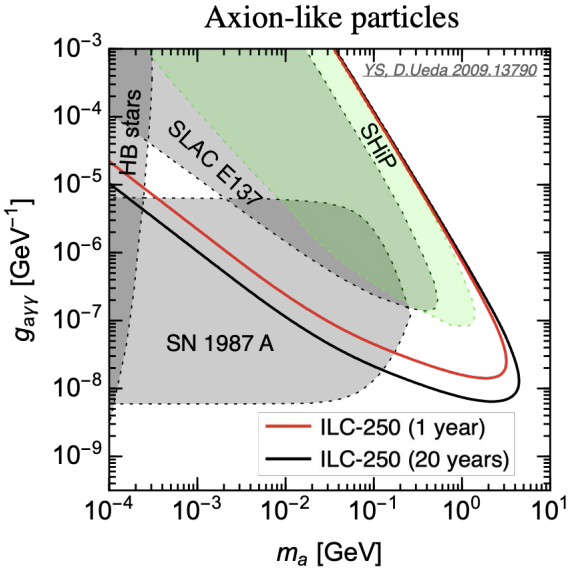


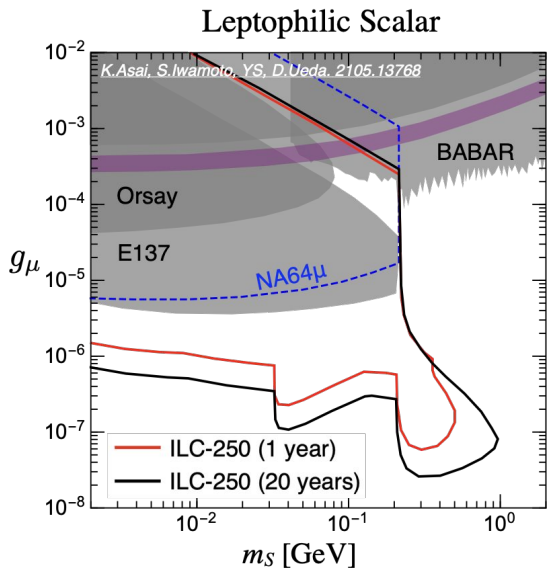
New particles from electromagnetic showers



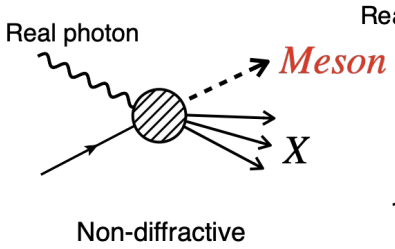


- Highly sensitive to particles that couple to shower particles.

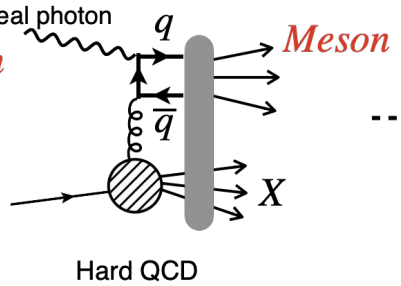




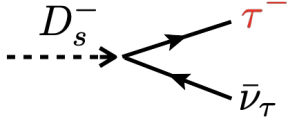
Heavy mesons and Tau leptons



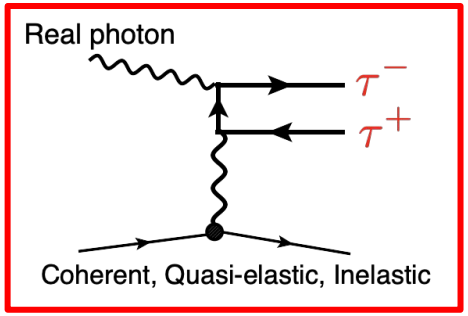
Non-diffractive



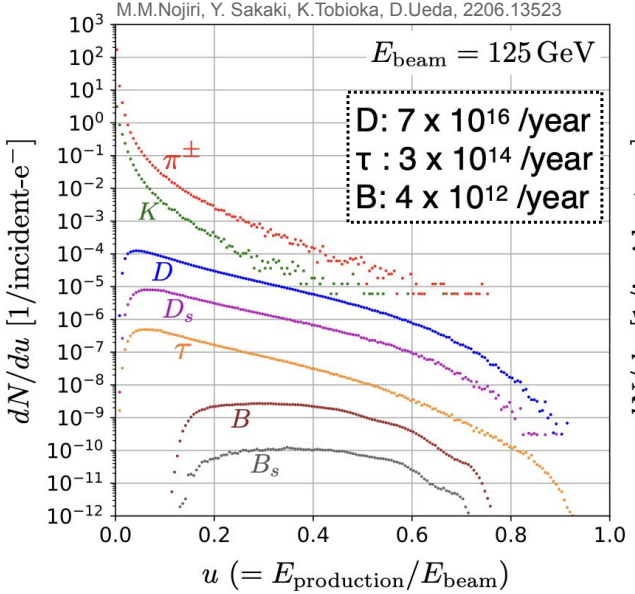
Hard QCD

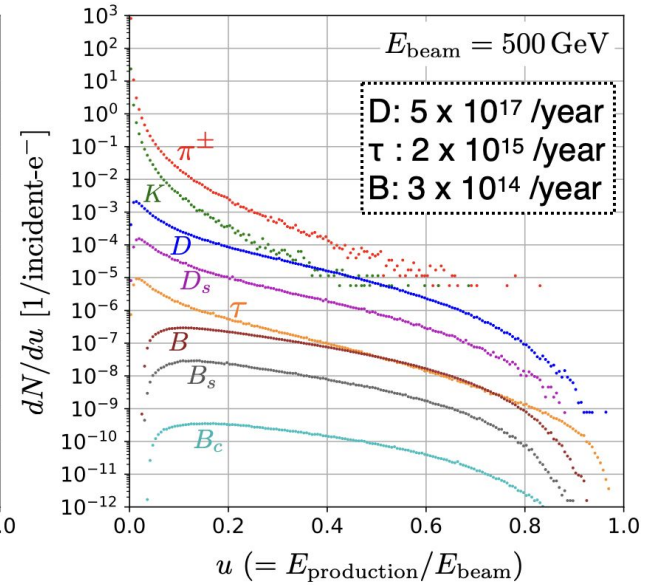


Br = 5.48 %



M.M.Nojiri, Y. Sakaki, K.Tobioka, D.Ueda, 2206.13523





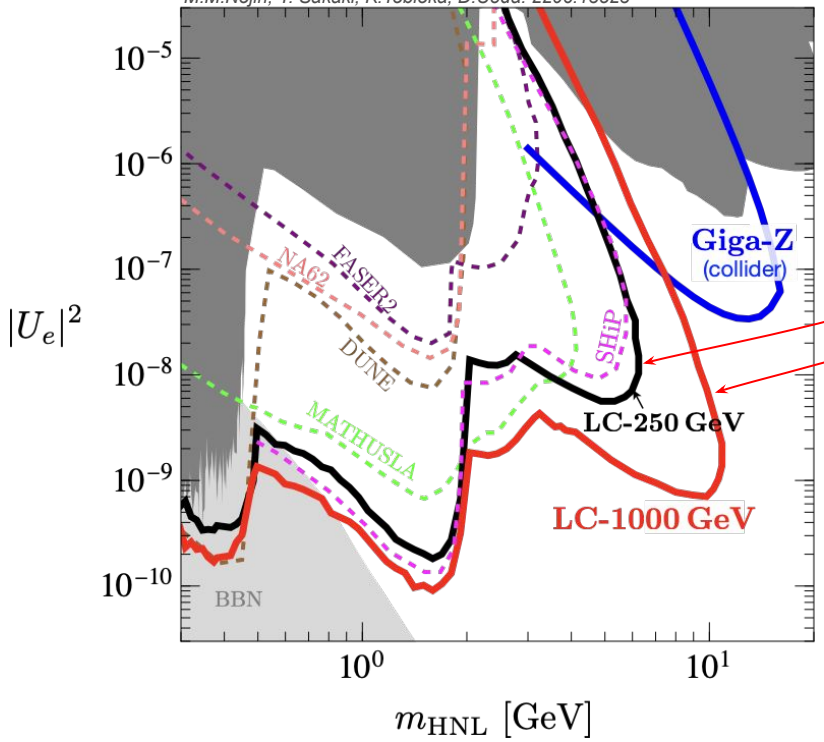
- Hadrons are mainly produced through photoproduction.
- Regarding τ and ν_τ, EM process ($\gamma \rightarrow \tau+ \tau-$) is dominant in high-energy regions ($u > 0.65$).
- High energy beams produce B mesons more.

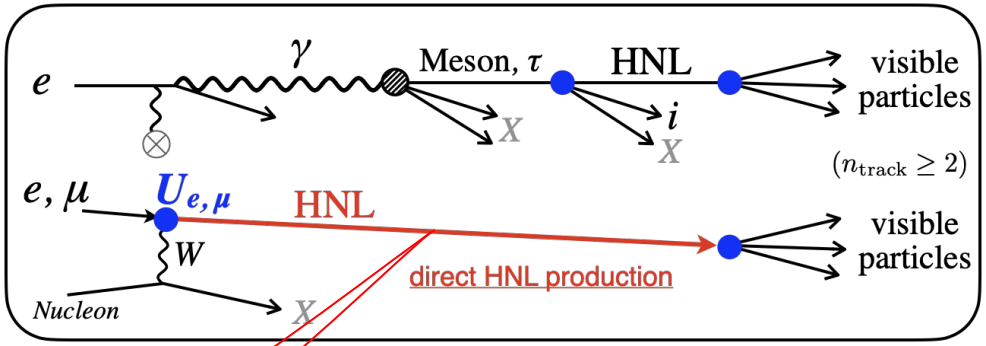
Heavy Neutral Leptons

$$\mathcal{L} = -\lambda_{iI}(\bar{L}_i \tilde{H}) N_I - \frac{1}{2} M_I \bar{N}_I^c N_I + \text{h.c.},$$

$$U_{Ii}^2 = \frac{v^2 |\lambda_{iI}|^2}{M_I^2}$$

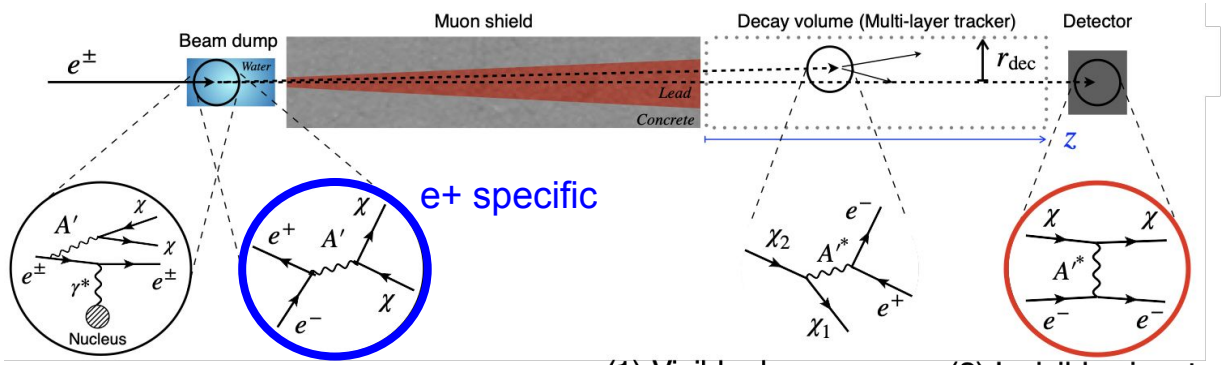
M.M.Nojiri, Y. Sakaki, K.Tobioka, D.Ueda. 2206.13523





- Direct HNL production from $e^{\pm}$ expand sensitivity at high mass region
- Polarized beams should modify the rates of the direct production processes:
  - $e_L + N \to \nu_e / \mathrm{HNL}_e + X$
- *Beam dump* and *Collider* is complementary

Dark matter



BDX@JLab like

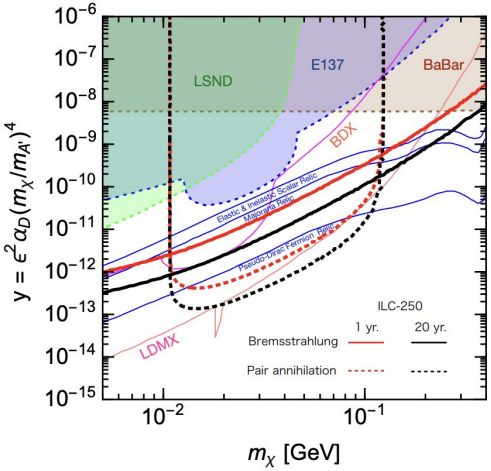
(1) Visible decay

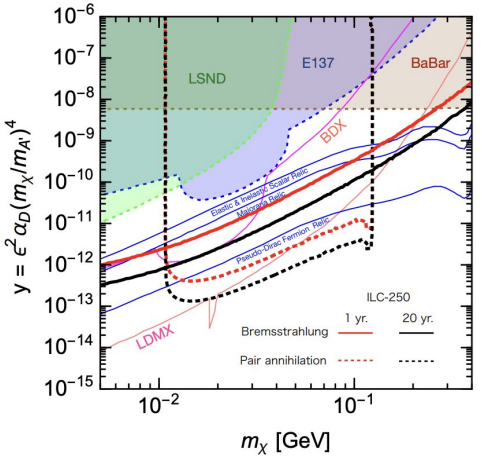
Beam dump is better
(ILC, BDX)

(2) Invisible signature

Missing searches is better
(LDMX, NA64)

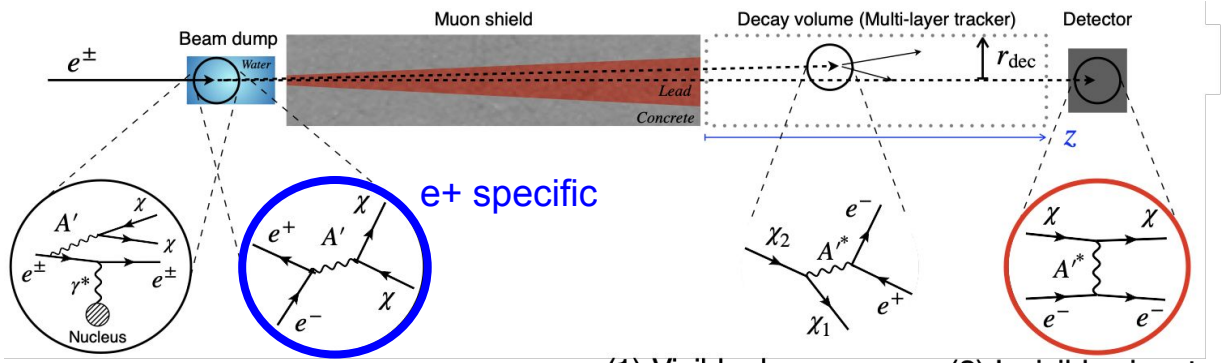
(In the ILC contours, the contribution from meson decay has not yet been considered.)





- e^+ beam expands sensitivity
- LC beam dump complements missing searches (LDMX, NA64).
  - Higher sensitivity for visible decay signature.
  - Beam dump: Direct DM detection, Missing searches: Indirect detection.
  - Beam dump can detect NP interacting not only with electron recoil but also with nucleons and other particles as recoil events on the detector side. This capability could be used in combination with LDMX to discriminate between models.

Dark matter



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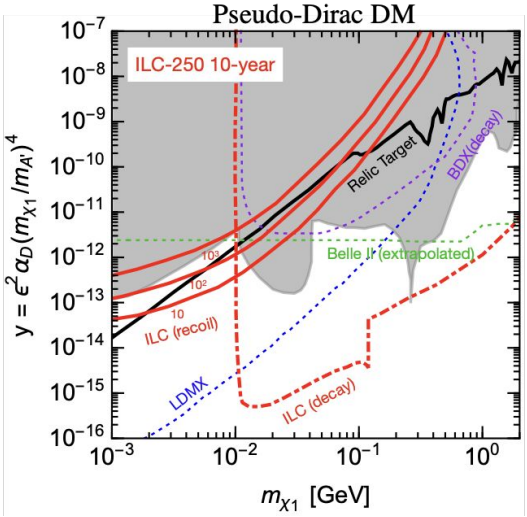

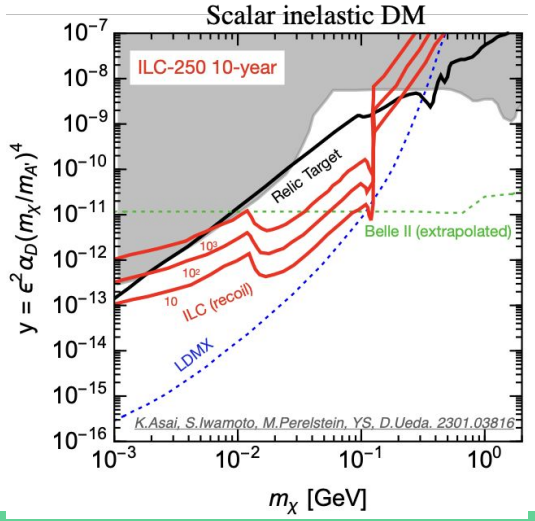

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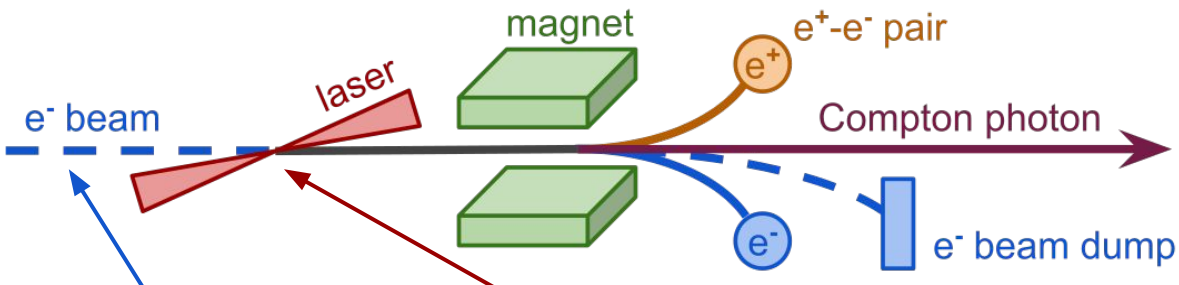
Strong-Field QED: Beam-Laser Interaction



$$\eta = \gamma \frac{\omega_L}{m_e}(1 + \cos(\theta)) \qquad \xi = \sqrt{4\pi\alpha}\left(\frac{\epsilon_L}{\omega_L m_e}\right)$$

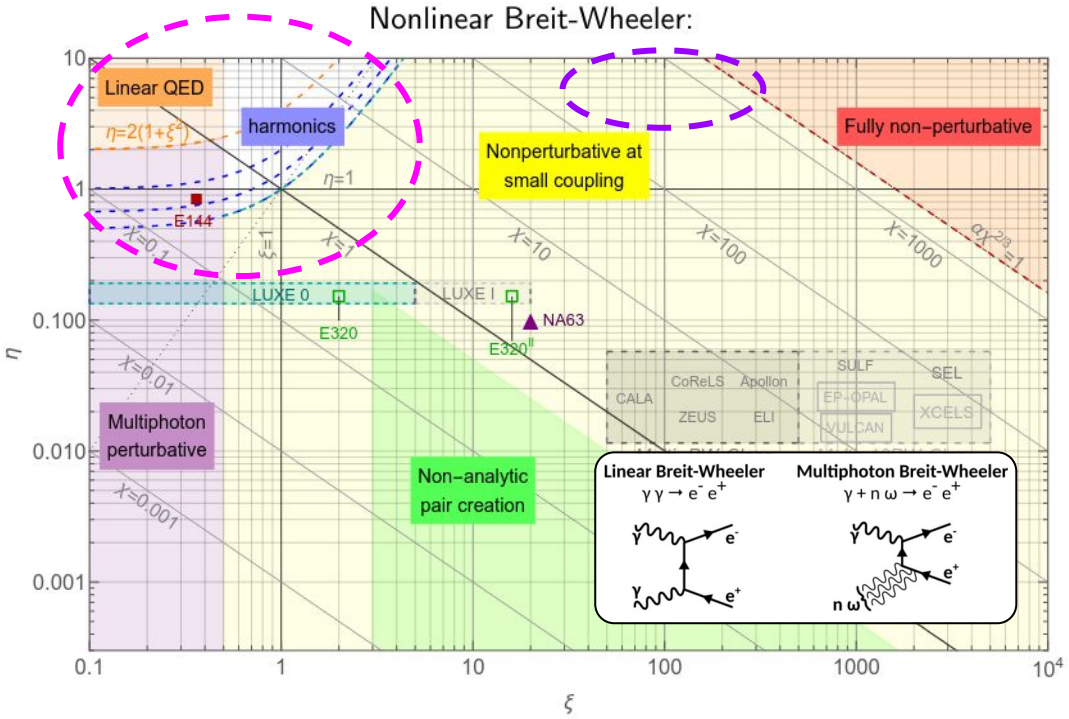
parameter space determined by:

- **beam energy** ($\propto \eta$)
- **laser intensity** ($\propto \xi$)

non-linear if $\chi = \eta\xi > 1$

frequency of Laser in electron rest frame

Strong-Field QED: Beam-Laser Interaction



courtesy: B. King (SFQED 2024)

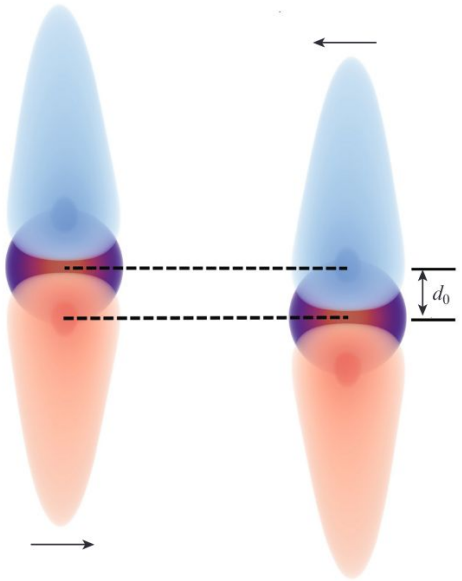
Breit-Wheeler pair harmonics

- λ_L = 800 nm
- E_e up to 1 TeV
  ➔ η up to 11.6
- frequency doubling as alternative

Transition to fully non-perturbative regime

- transition at $\chi = \eta\xi = 1600$
- with $\eta = 11.6$
  ➔ $\xi = 138$
- reachable with current laser systems

Strong-Field QED: Beam-Beam Interaction



courtesy: M. Filipovic et al. (2021)

- particles in each beam radiate due to interaction with the electromagnetic fields generated by the opposite beam
- characterized by:
  - quantum non-linearity parameter

$$\Upsilon_{\text{avg}} = \frac{5 r_e^2 \gamma N_e}{6 \alpha \sigma_z (\sigma_x + \sigma_y)}$$

  - number of emitted photons

$$n_\gamma \approx 2.54 \frac{\alpha \sigma_z}{\bar{\lambda}_e \gamma} \frac{\Upsilon}{\sqrt{1 + \Upsilon^{2/3}}}$$

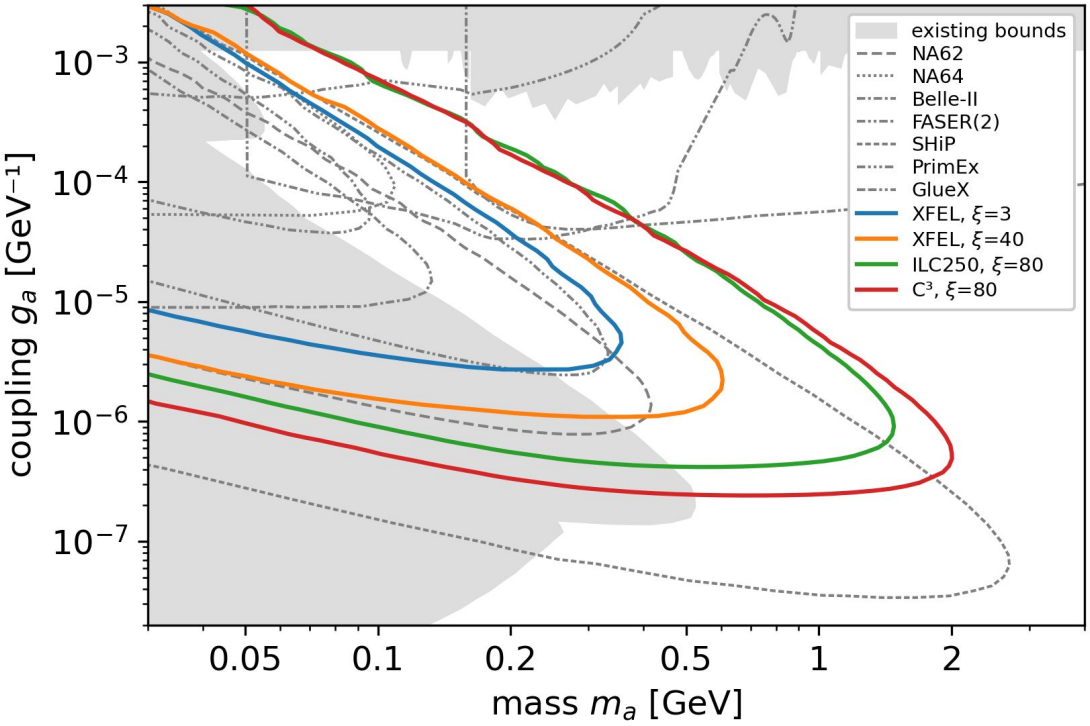
  - relative energy loss

$$\delta_{BS} \approx 1.24 \frac{\alpha \sigma_z}{\bar{\lambda}_e \gamma} \frac{\Upsilon^2}{(1 + (1.5\Upsilon)^{2/3})^2}$$

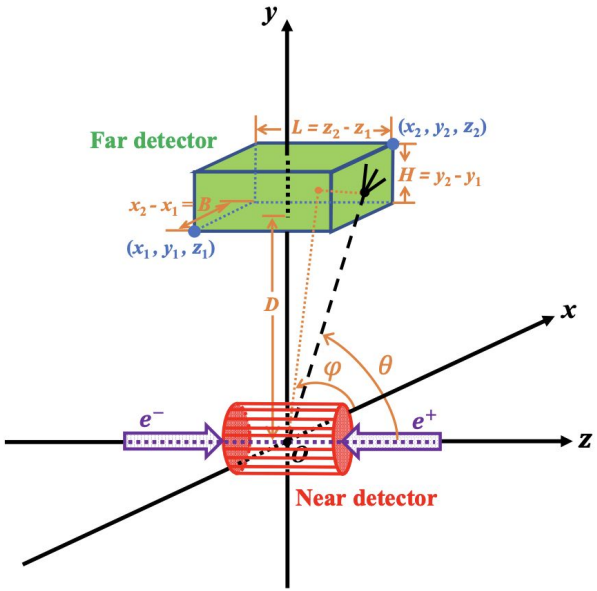
E_{cm} [GeV]	δ_{BS} [%]	N_{e+e-}
250	2.6	
500	4.5	
1'000	10.5	$O(10^5)$
5'000	O(40)	$O(10^9)$

Backup

Strong-Field QED: Compton-Photon Dump Search



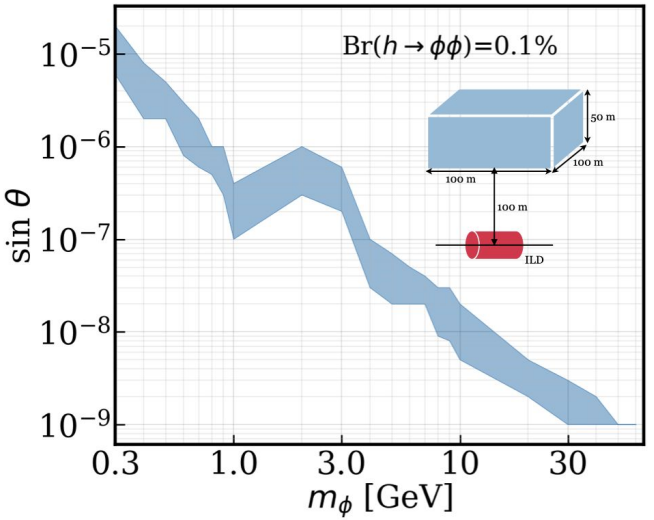
Far Detectors



courtesy: Z. S. Wang and K. Wang (2020)

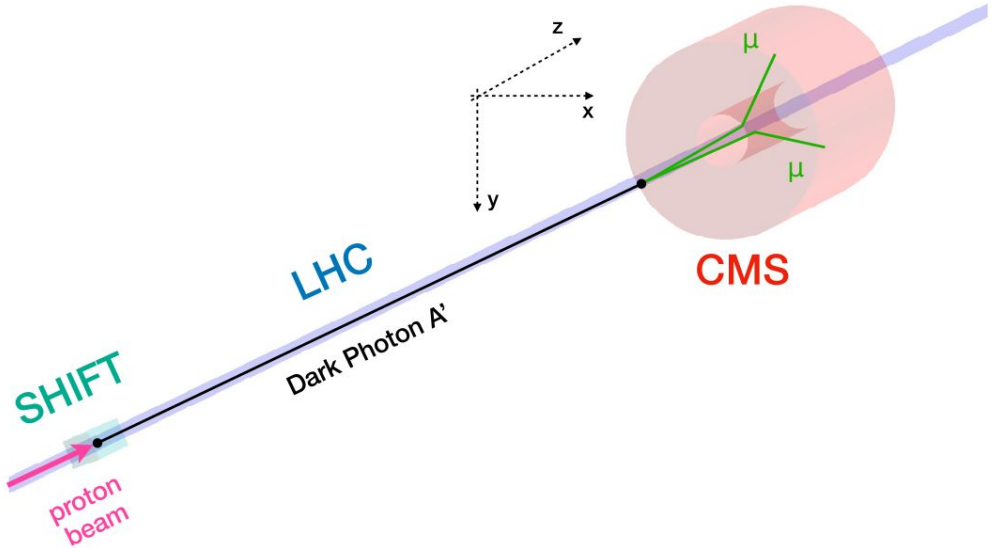
detector in forward region (FASER-like) not of interest

detector on surface (MATHUSLA-like) can enhance the sensitivity moderately



Courtesy **Rhitaja Sengupta**

SHIFTed Fixed-Target Experiment



courtesy: J. Niedziela (2024)

- possible 10^2 - 10^3 improvement compared to collider LLP searches
- currently in planning phase for HL-LHC
- minimal costs and no additional facility/detector required
- maybe not suited for linear colliders since there is no bent section before IP?