LC Vision Community Event:

Beyond Collider Physics Opportunities

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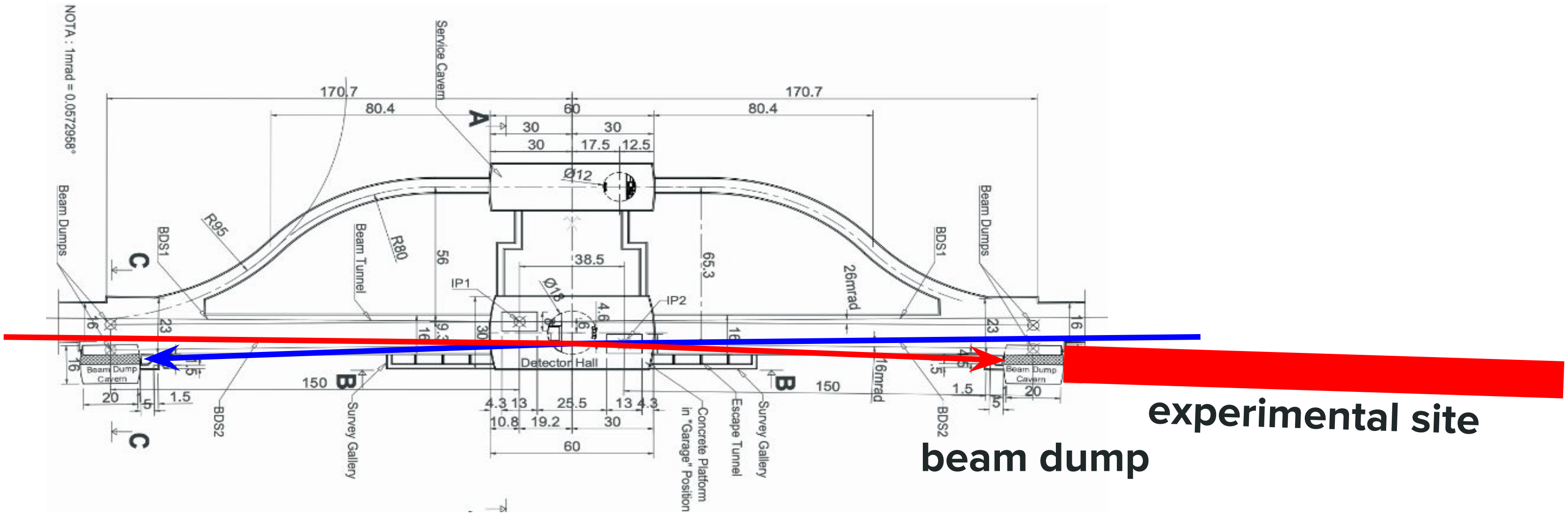
Shop List of Beyond the Collider (need some figure for overviewing)

High intensity and High Energy electron and positron beam

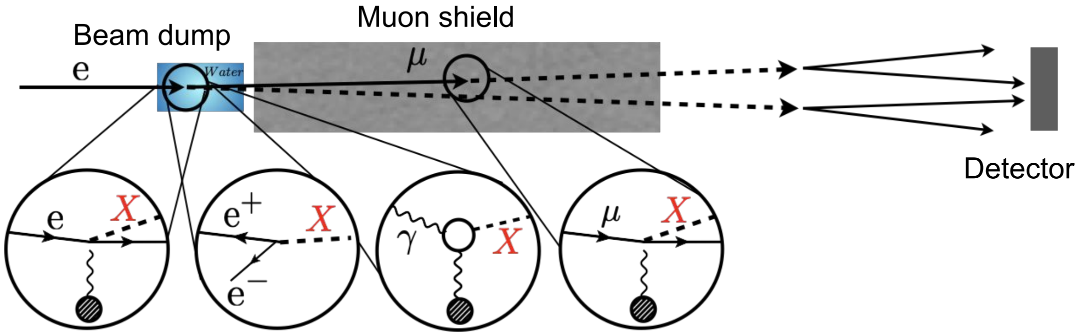
- Main beam dump
  - primary electron
  - secondaries
    - muon
    - neutrino
    - neutron
    - heavy hadrons (b, c, s) comparable to
- Othe

Long lived particle–Window to the dark sector

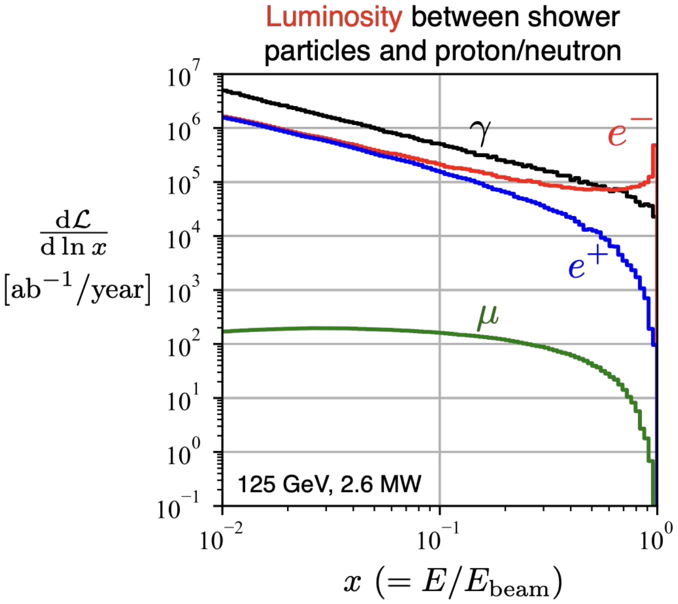


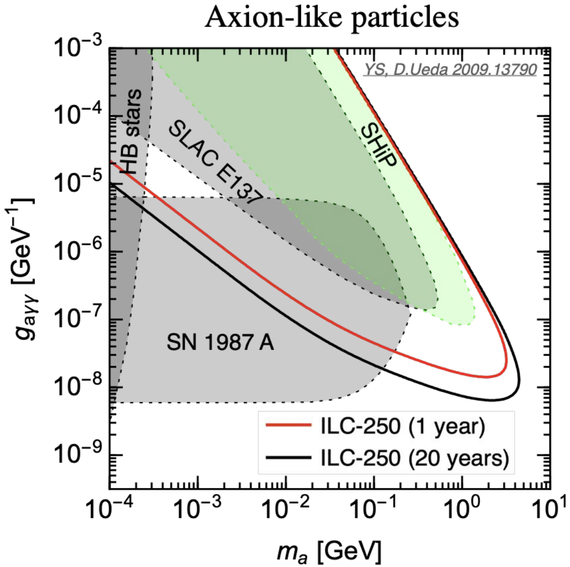
- Almost all accelerated particles can be utilized for the beam dump experiment.
  - Suitable for searching feebly interacting particles.
- A very high-power targets (main beam dumps) can be used without additional cost.

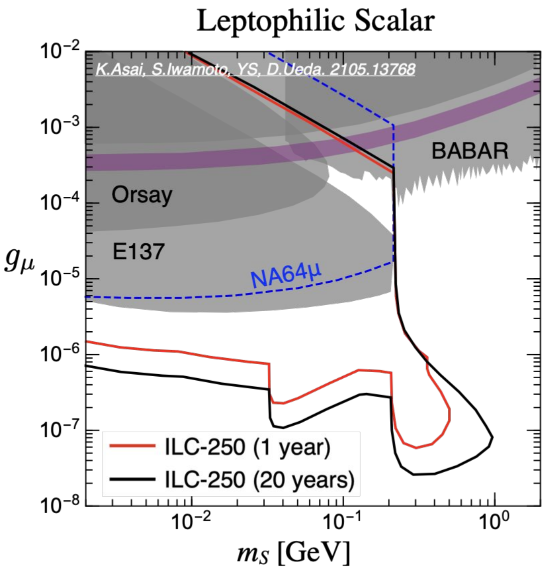
New particles from electromagnetic showers



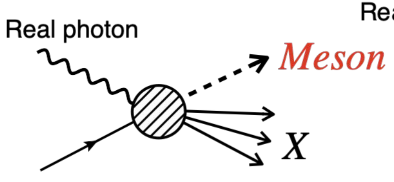
Highly sensitive to particles that couple to shower particles.



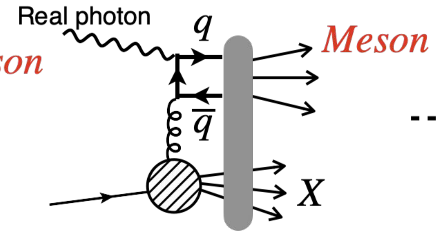




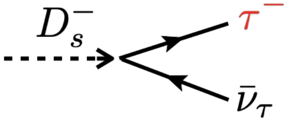
Heavy mesons and Tau leptons



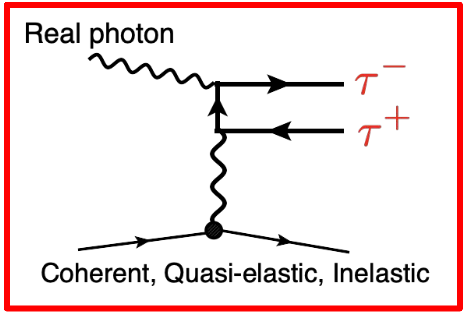
Non-diffractive



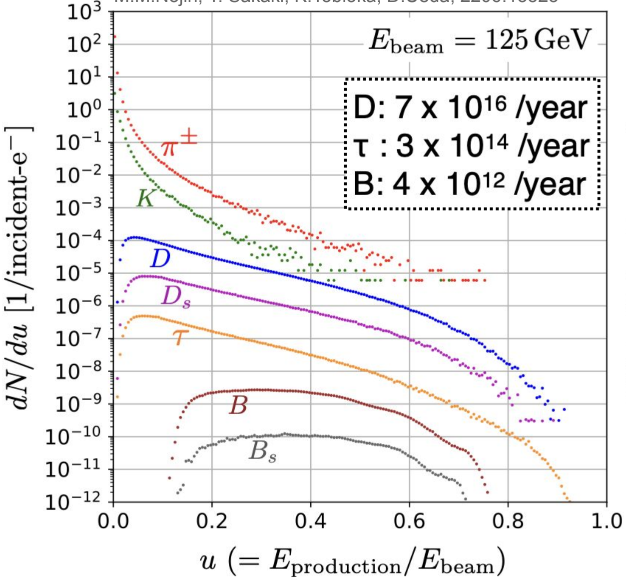
Hard QCD

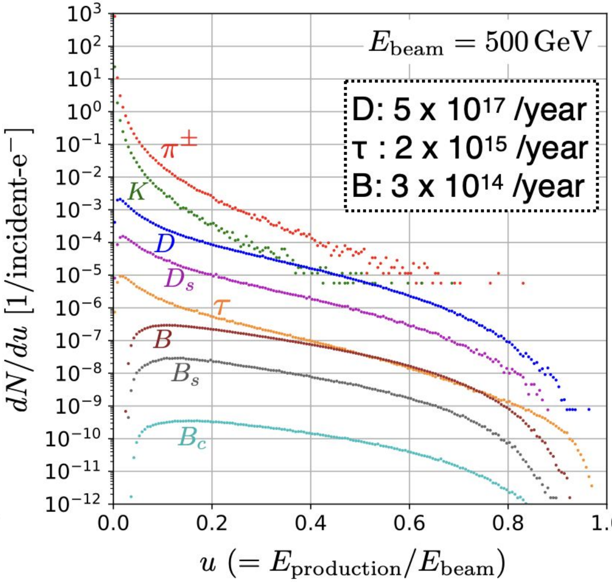


Br = 5.48 %



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





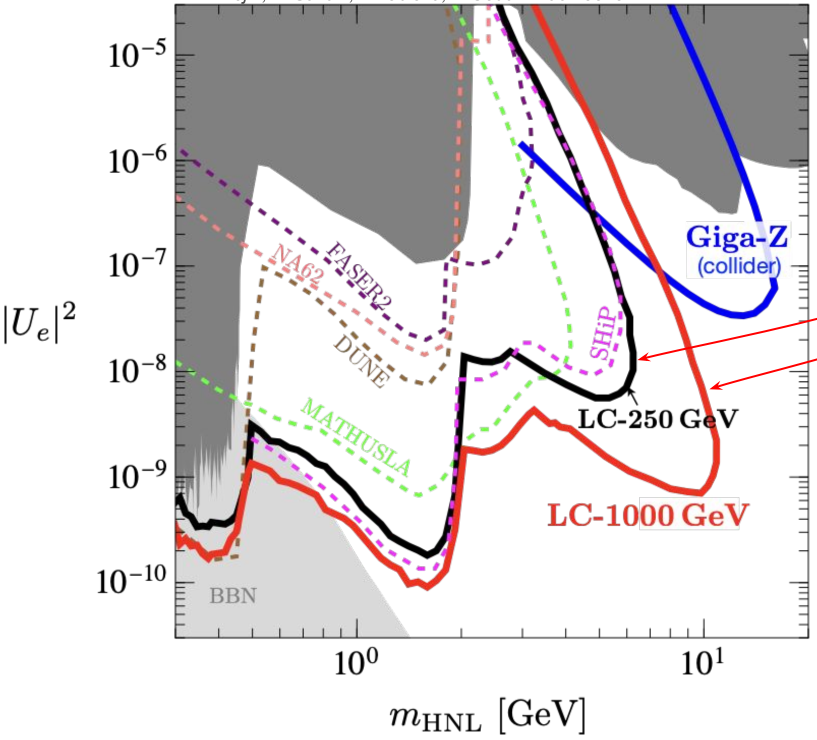
- Hadrons are mainly produced through photoproduction.
- Regarding tau leptons, EM interaction process ($\gamma \rightarrow \tau$+ τ−) is dominant in high-energy regions ($u > 0.65$).
- High energy beams produce B mesons more.

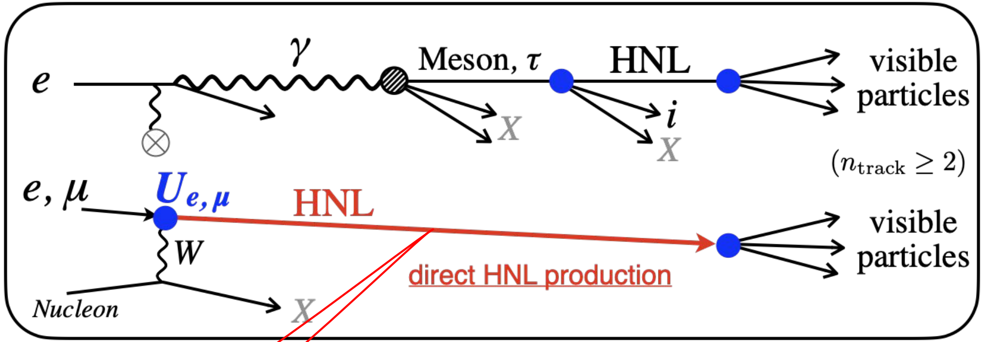
Heavy Neutral Leptons

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

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

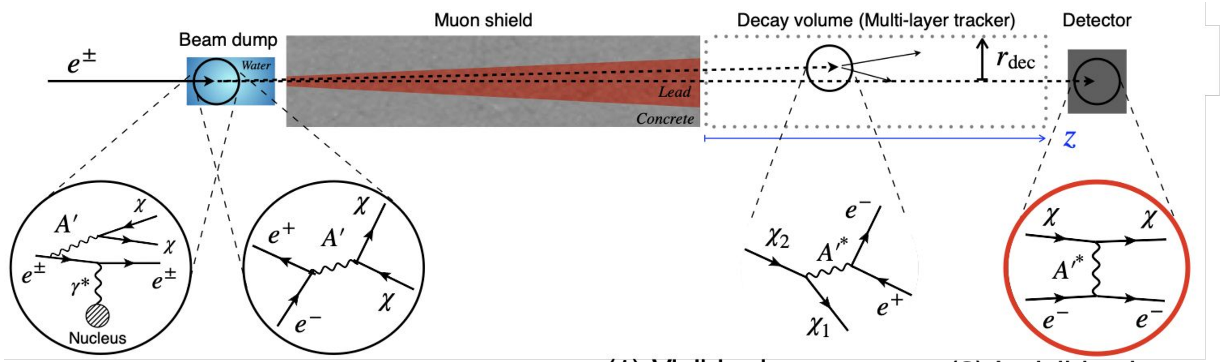
M.M.Nojiri, Y. Sakaki, K.Tobioka, D.Ueda. 2206.13523





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

Dark matter



(1) Visible decay

Beam dump is better
(ILC, BDX)

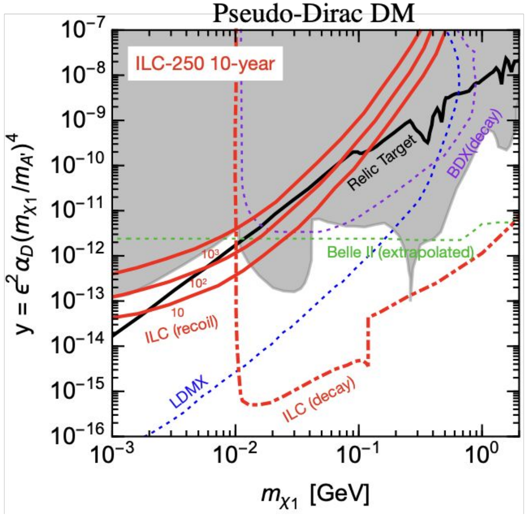
(2) Invisible signature

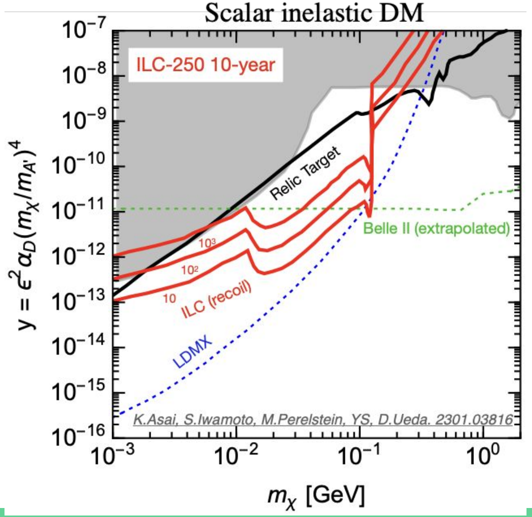
Missing searches is better
(LDMX, NA64)

BDX@JLab like

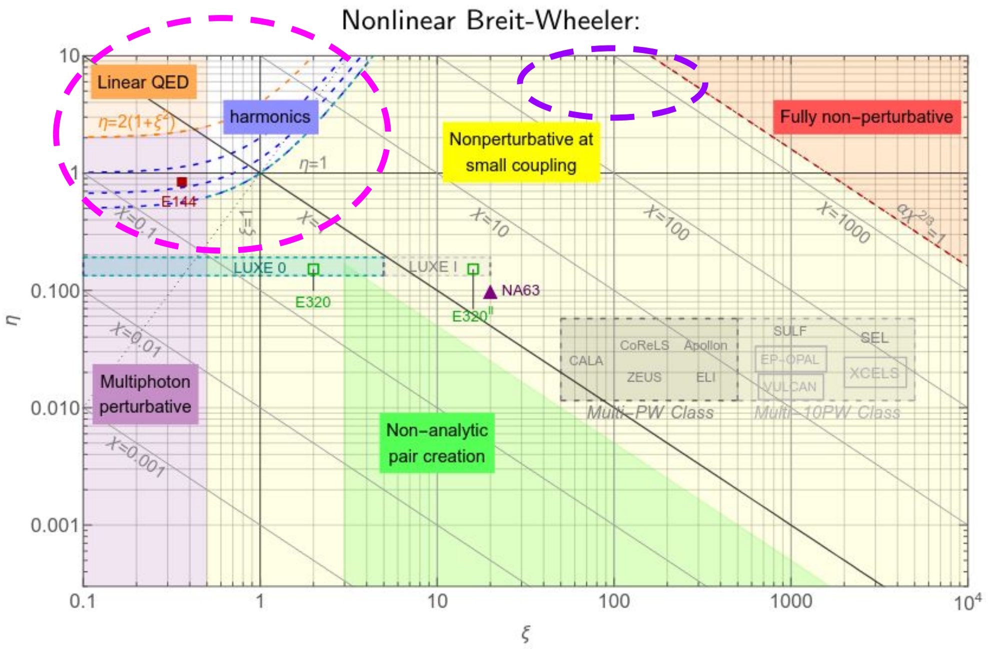
(In the ILC contours, the contribution from meson decay has not yet been considered.)

- 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.





Strong-Field QED: Beam-Laser Interaction

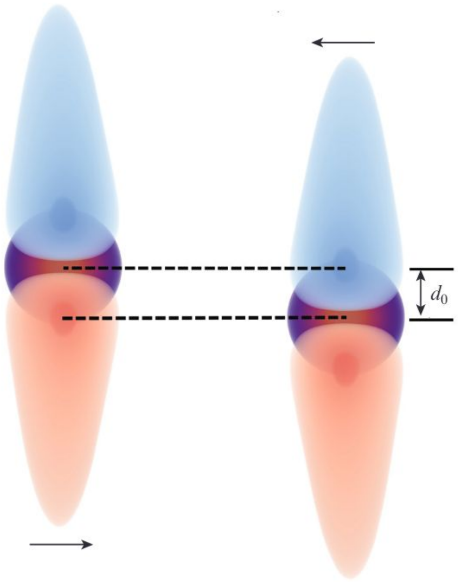


courtesy: B. King (SFQED 2024)

- **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 χ = ηξ = 1600
  - with η = 11.6
    ➔ ξ = 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

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

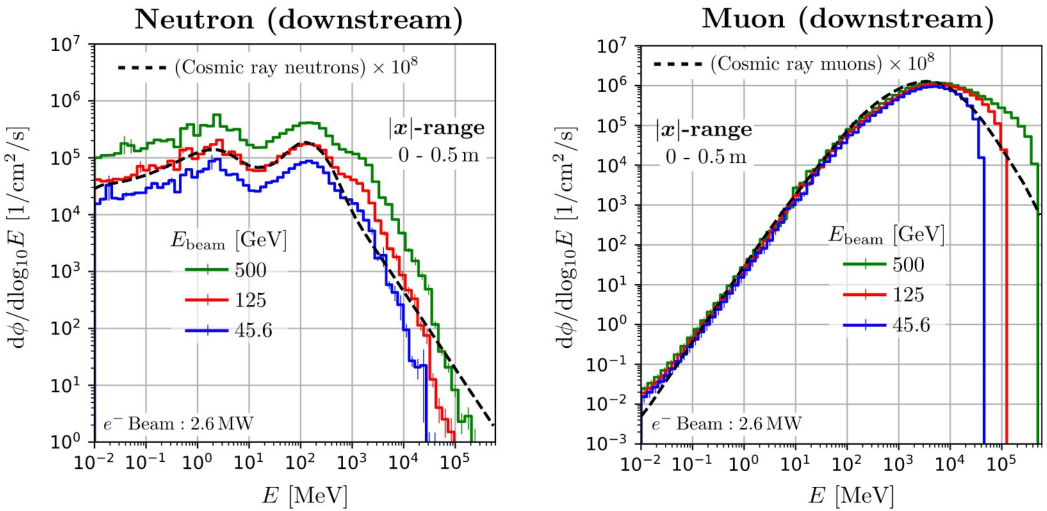
E_{cm} [GeV]	δ_{BS} [%]	N_{e+e-}
250	2.6	
500	4.5	
1'000	10.5	$O(10^5)$
5'000	O(40)	$O(10^9)$

Test Facilities: Cosmic Neutrons & Muons

- cosmic neutrons/muons create soft errors in semiconductors

- if facility produces cosmic spectra: no need to know soft error cross-section

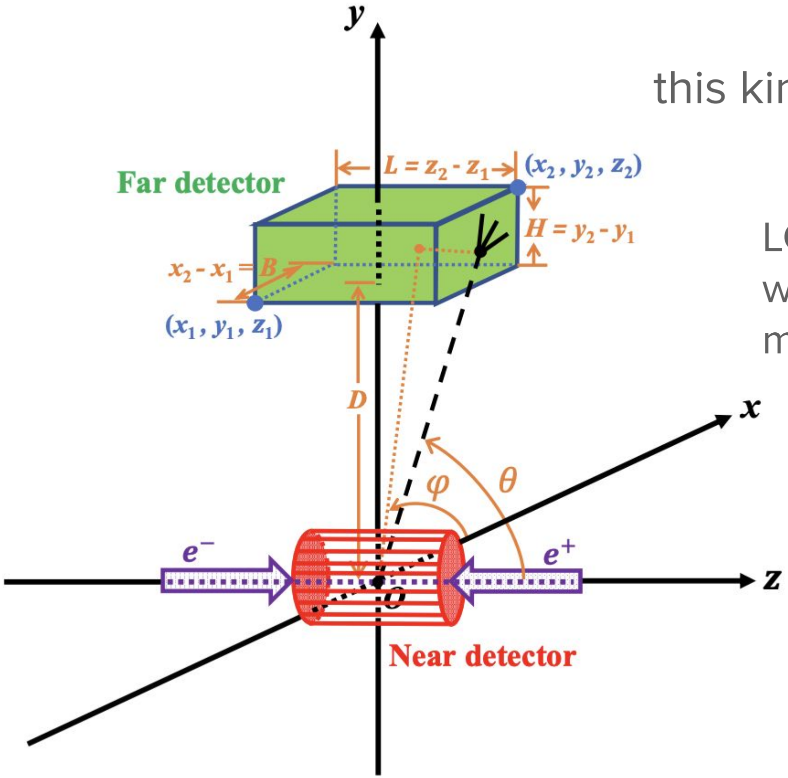
- good news: ILC-like water dump produces cosmic spectra



courtesy: Y. Sakaki et al. (2023)

Backup

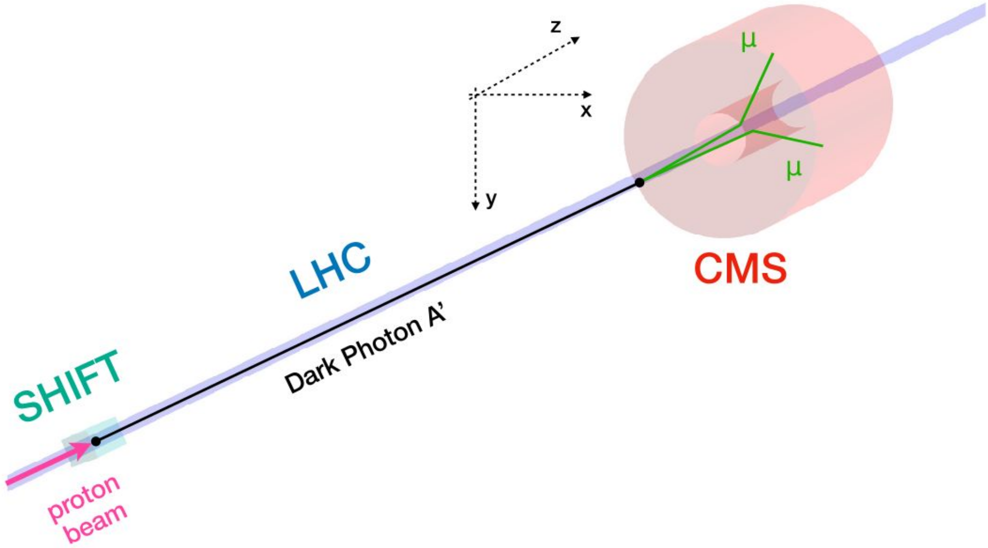
Far detector experiment opportunity (Yasu)



this kind image?

LC specific idea:
we can use coincidence between main detector and far detector

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

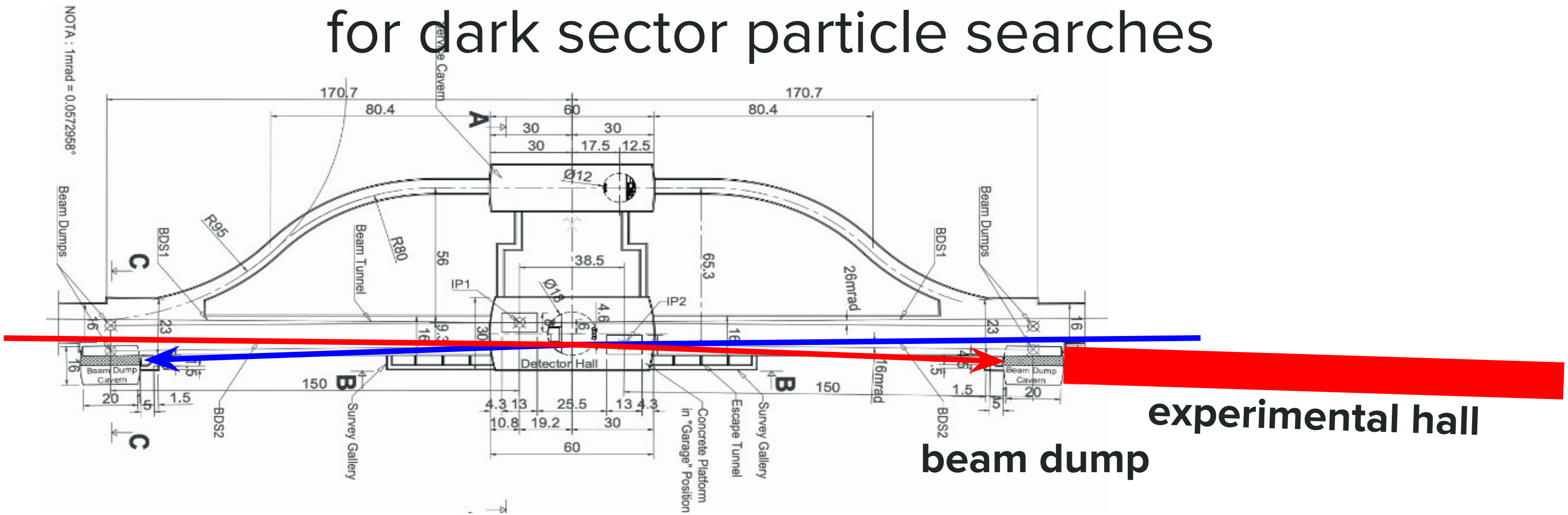
LC Vision Community Event:

Facilities for Beyond Collider Experiments and Technology R&D

09.01.2024, CERN

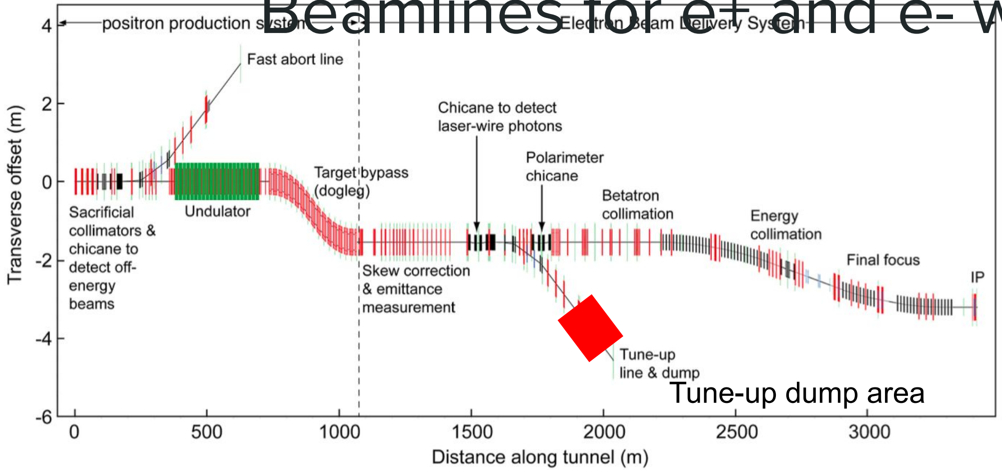
Stefania Gori, Mihoko Nojiri, Yasuhito Sakaki, **Ivo Schulthess**

Expansion of the Main Beam Dump Facility for dark sector particle searches



- Hall size: 5m x 5m x 100-200m
- The maximum hall width depends on the beam crossing angle and the distance between the IP and the main beam dump.

Beamlines for e+ and e- with maximum energy



courtesy: ILC TDR | Volume 3.II (2013)

ILC parameters at initial stage

Quantity	Symbol	Unit	Initial
Centre of mass energy	$\sqrt{s}$	GeV	250
Repetition frequency	$f_{\rm rep}$	Hz	5
Bunches per pulse	$n_{\rm bunch}$	1	1312
Bunch population	$N_{\rm e}$	10^{10}	2
Linac bunch interval	$\Delta t_{\rm b}$	ns	554
Beam pulse duration	$t_{\rm pulse}$	μs	727

courtesy: The International Linear Collider: Report to Snowmass 2021

- Beamlines for dedicated experiments:
  - Fixed target experiment
  - High energy Photon source
  - One of the candidate locations for conducting a SF-QED study.
- Two possible locations:
  - Tune-up dump area
  - Dedicated area
- Hall size: 10m x 5-10m x 50m
- How much can the bunch charge be reduced?
  - 3.2 nC → ?

Strong-Field QED: IP Facility

Beam-Beam Interaction:

- BDS to tune interaction parameters
  - beam shape
  - beam displacement
- diagnostics in forward region
  - Beamstrahlung
  - e^+e^- pairs (dipole spectrometer)

Beam-Laser Interaction:

- usage of beam
  - use of second IP possible?
  - use beam at tune-up dump?
  - extract beam in BDS section
- IP chamber (4 m^2)
- diagnostics in forward region
  - (quadrupole imaging system)
  - dipole spectrometer
  - electron/positron detection systems
  - photon detection systems

Strong-Field QED: Laser Hall

200 TW System

- e.g. Thales QUARK 200
- container-sized (4 x 4 m^2 optical table)

10 PW System

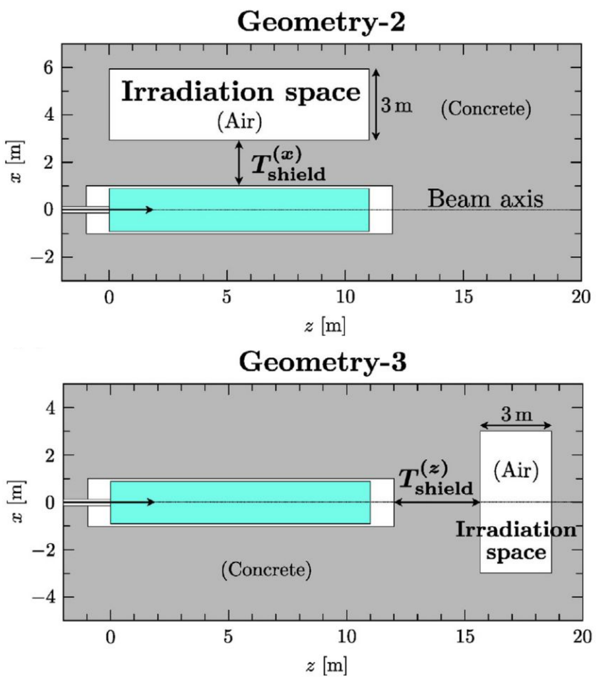
- e.g. ELI-NP, Apollon
- hall-sized (roughly 20 x 50 m^2)

Key Requirements

- building above ground
- feed-through to IP
- vibration stability
- MW power consumption
- thermal management
- cleanroom environment

Test Facilities: Cosmic Neutrons & Muons

- cavern of 3 x 3 x 6 m^3
- on the side of the main dump (neutron)
- downstream the main dump (muon)
- A mechanism that allows large integrated circuits and similar components to be automatically inserted and removed even during beam operation is desirable.



courtesy: Y. Sakaki et al. (2023)

Plasma-Wakefield Accelerator R&D (Ivo)

Facility Questions

- is it possible to have the 2nd IP further away in a separate interlock to have independent access?

- what are the beam properties at the tune-up dump and what needs to be added that it can be used for experiments?

- is a slow extraction for LDMX-like searches at a LC possible?