Possible experimental opportunities at the ILC beam dumps

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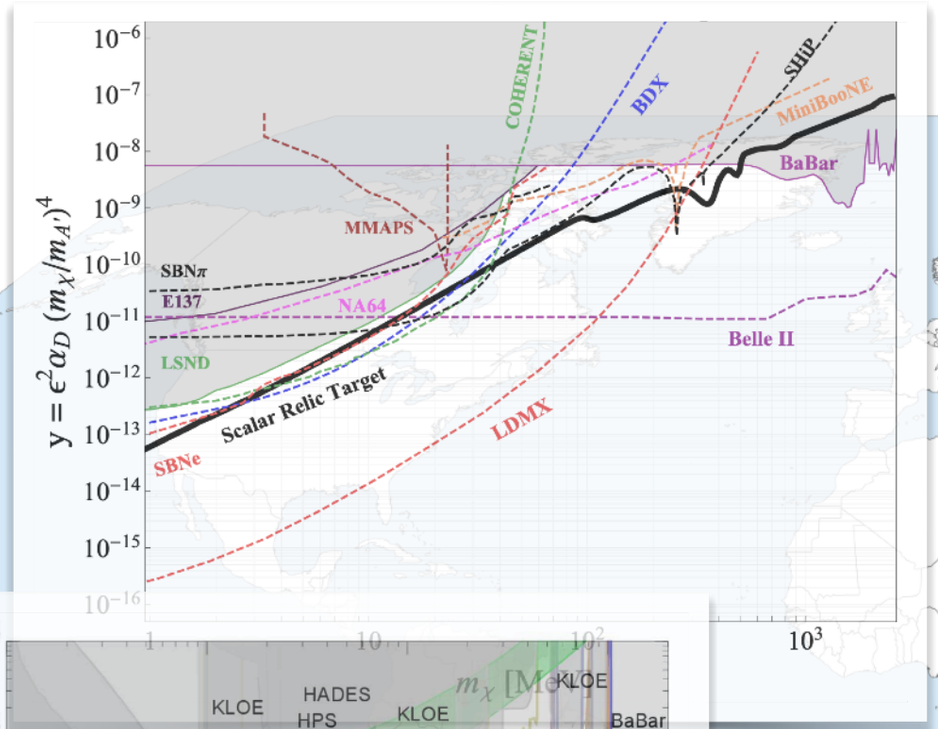
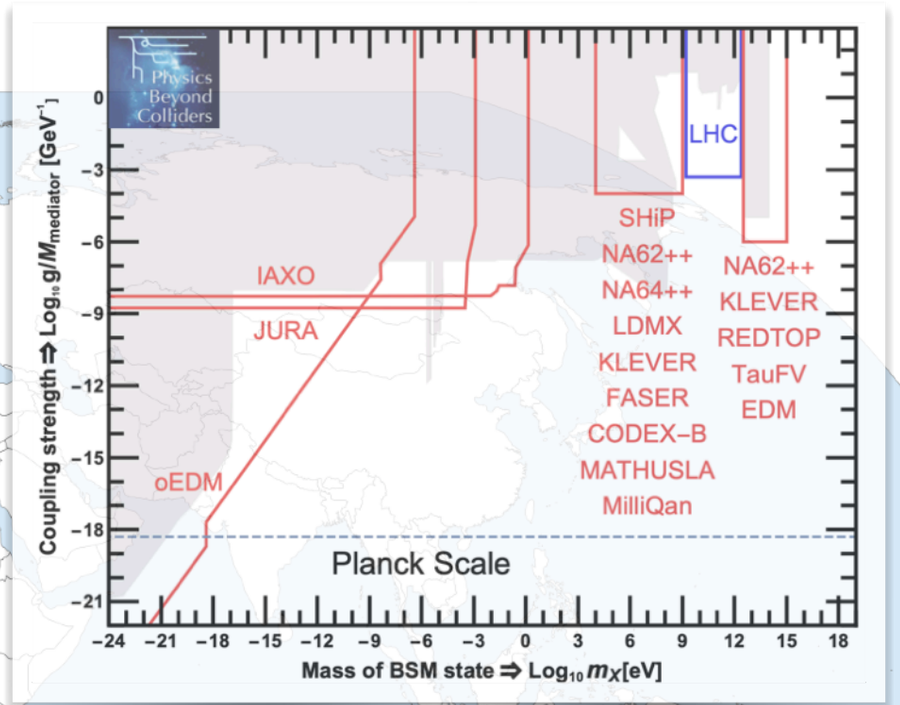
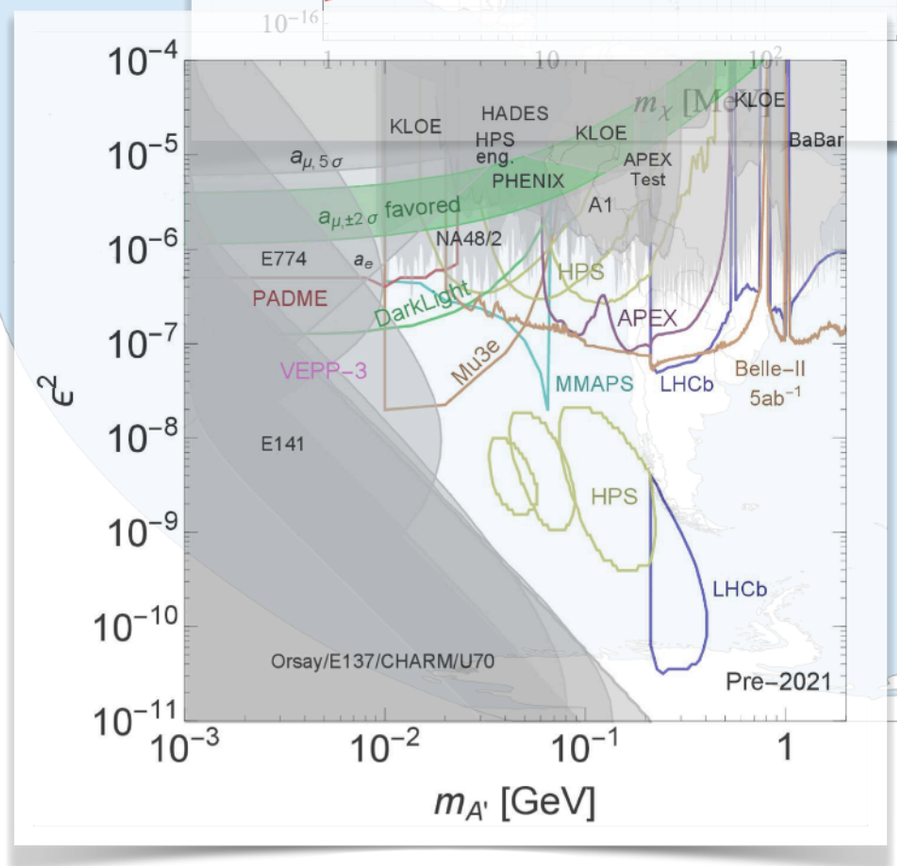
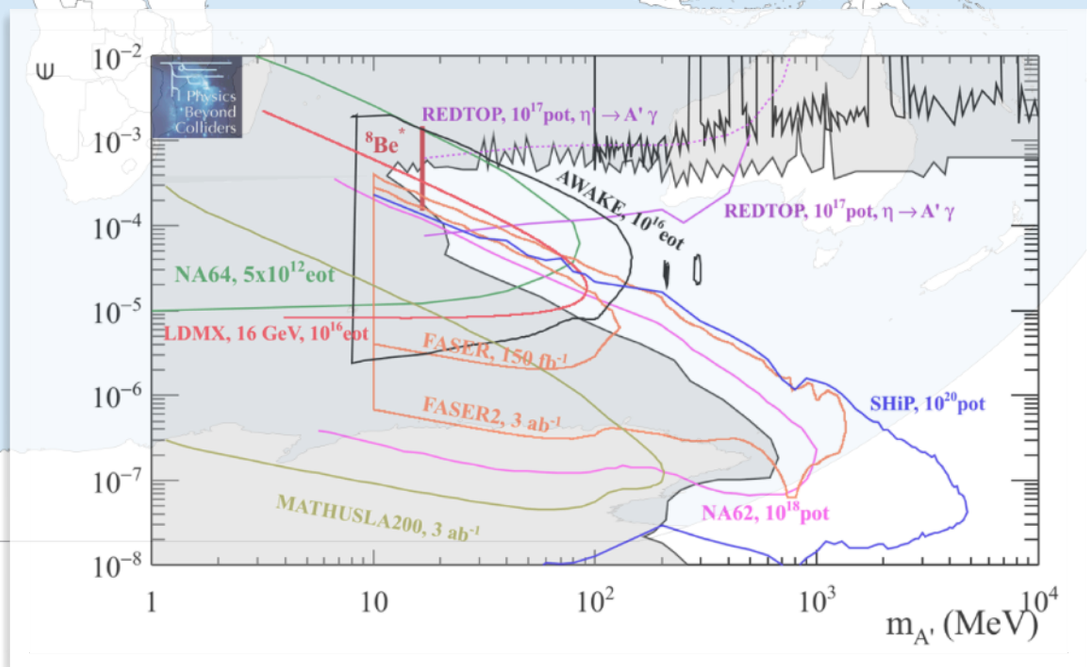
ECFA HF WG1: 1st Workshop of the WG1-SRCH group, Online, 25 May 2022

Many studies on “Physics Beyond Colliders” (PBC) in the last decade



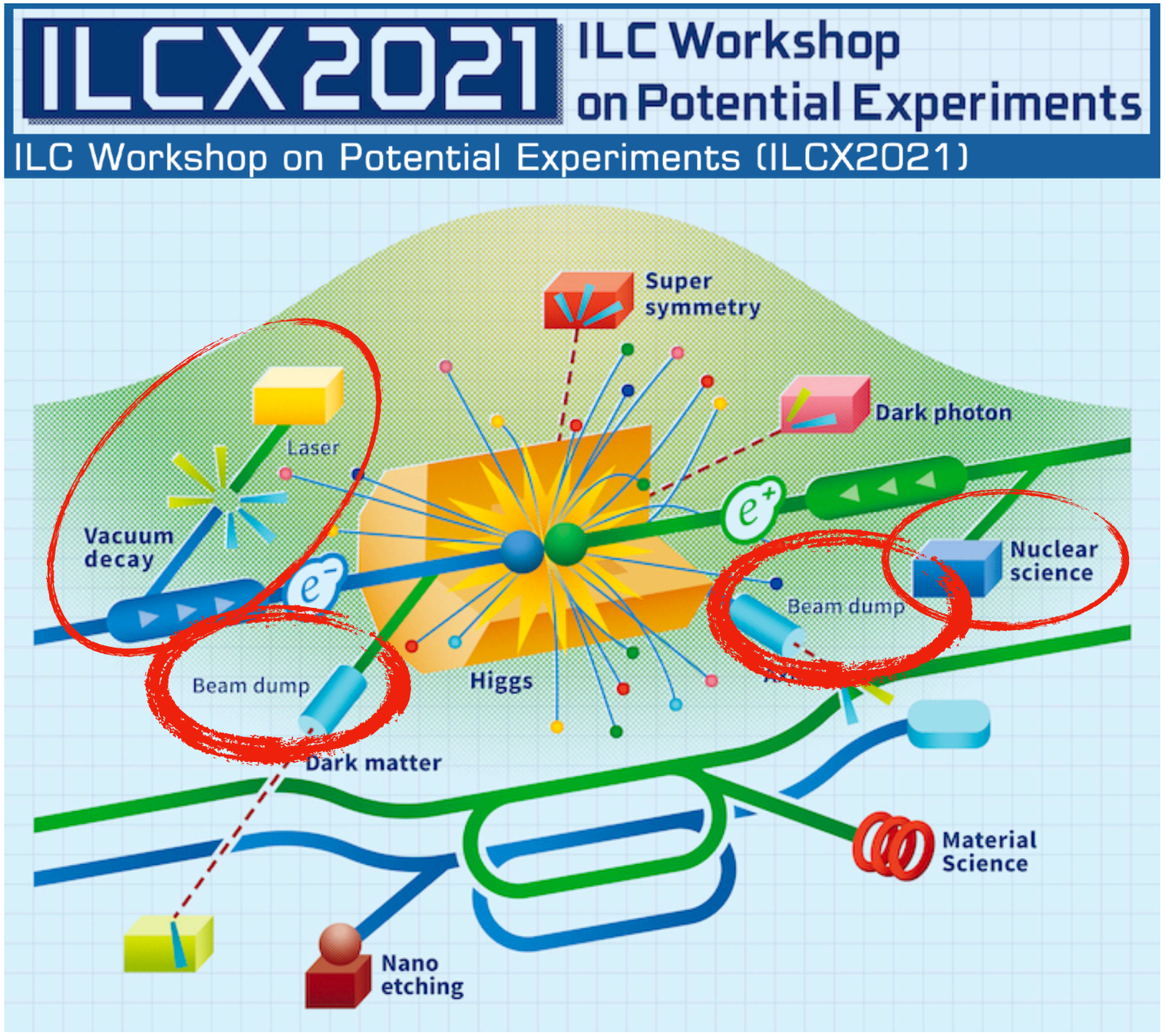






This collective knowledge will give a significant impact on the optimization of the ILC facility design

Use of ILC infrastructure other than the Higgs Factory

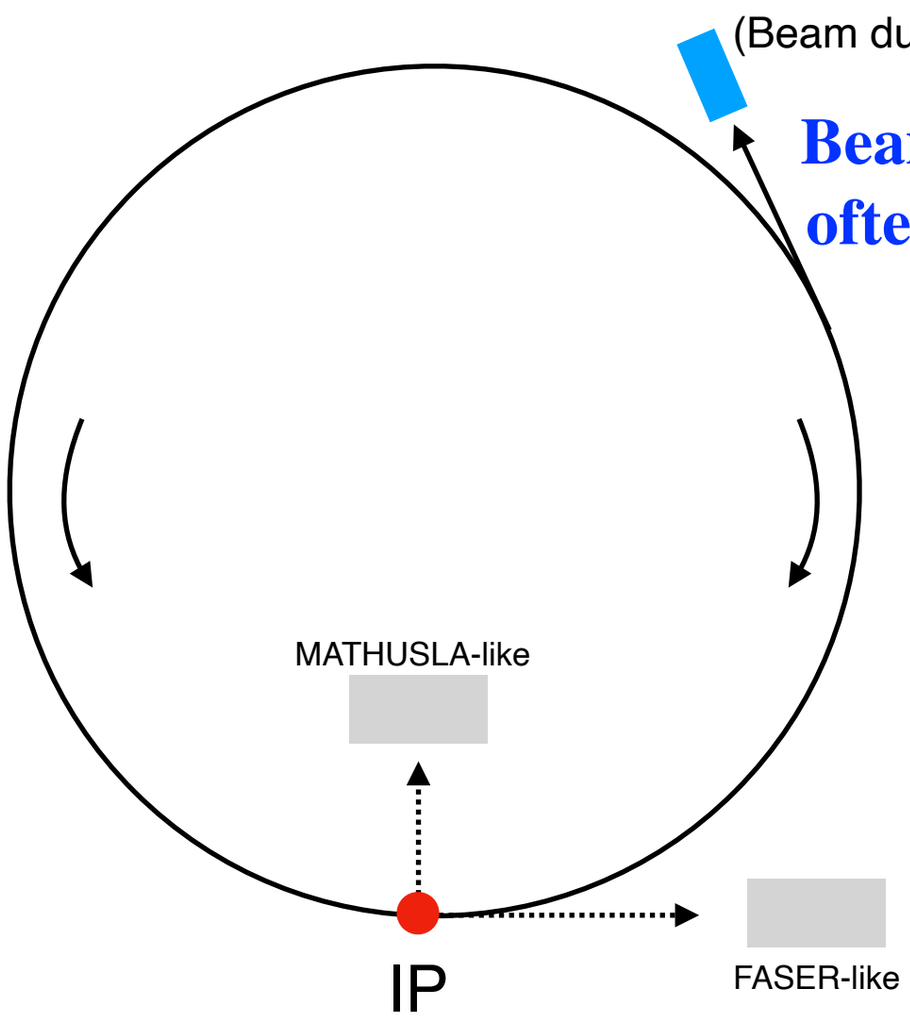


Ideas related to PBC: https://agenda.linearcollider.org/event/9211/program

Session O: Fixed target / Dark sectors / Applications outside particle physics

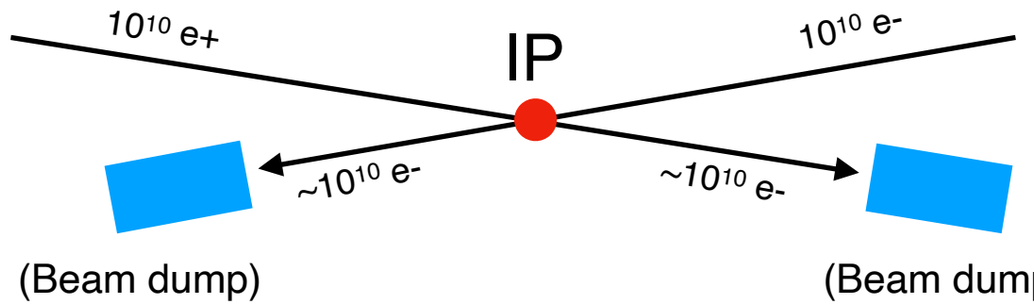
Session S: ILC application (to physics, material science, etc.)

Circular collider



Beams are not often dumped

Linear collider

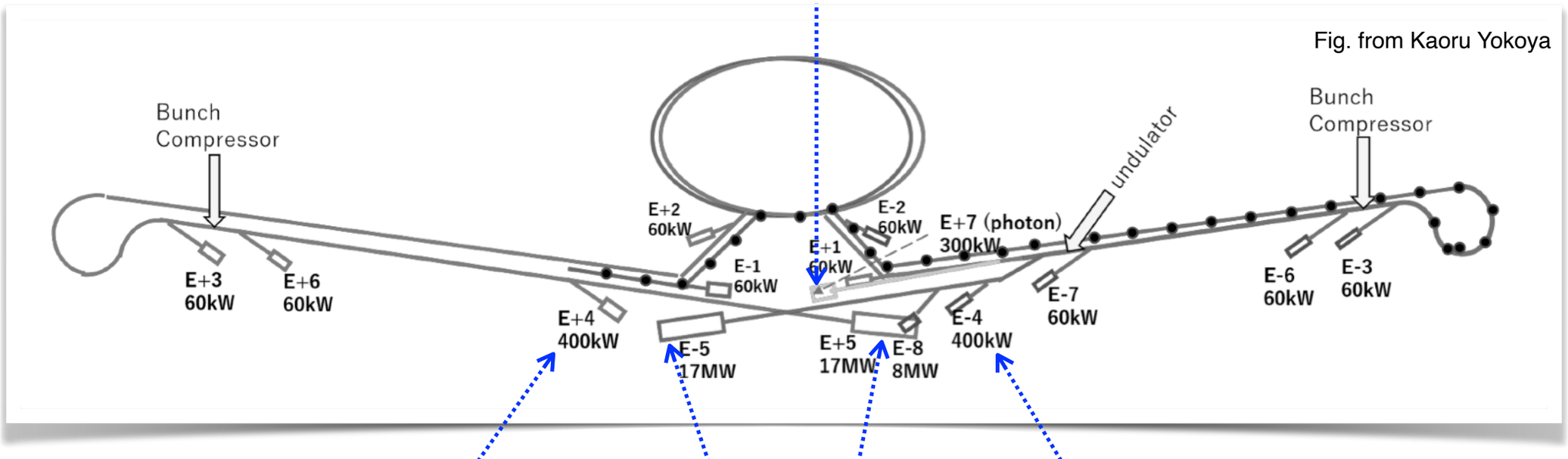


Beams are always dumped

Linear collider EXP and Beam dump EXP coexist naturally

Beam dumps at ILC

Photon beam dump



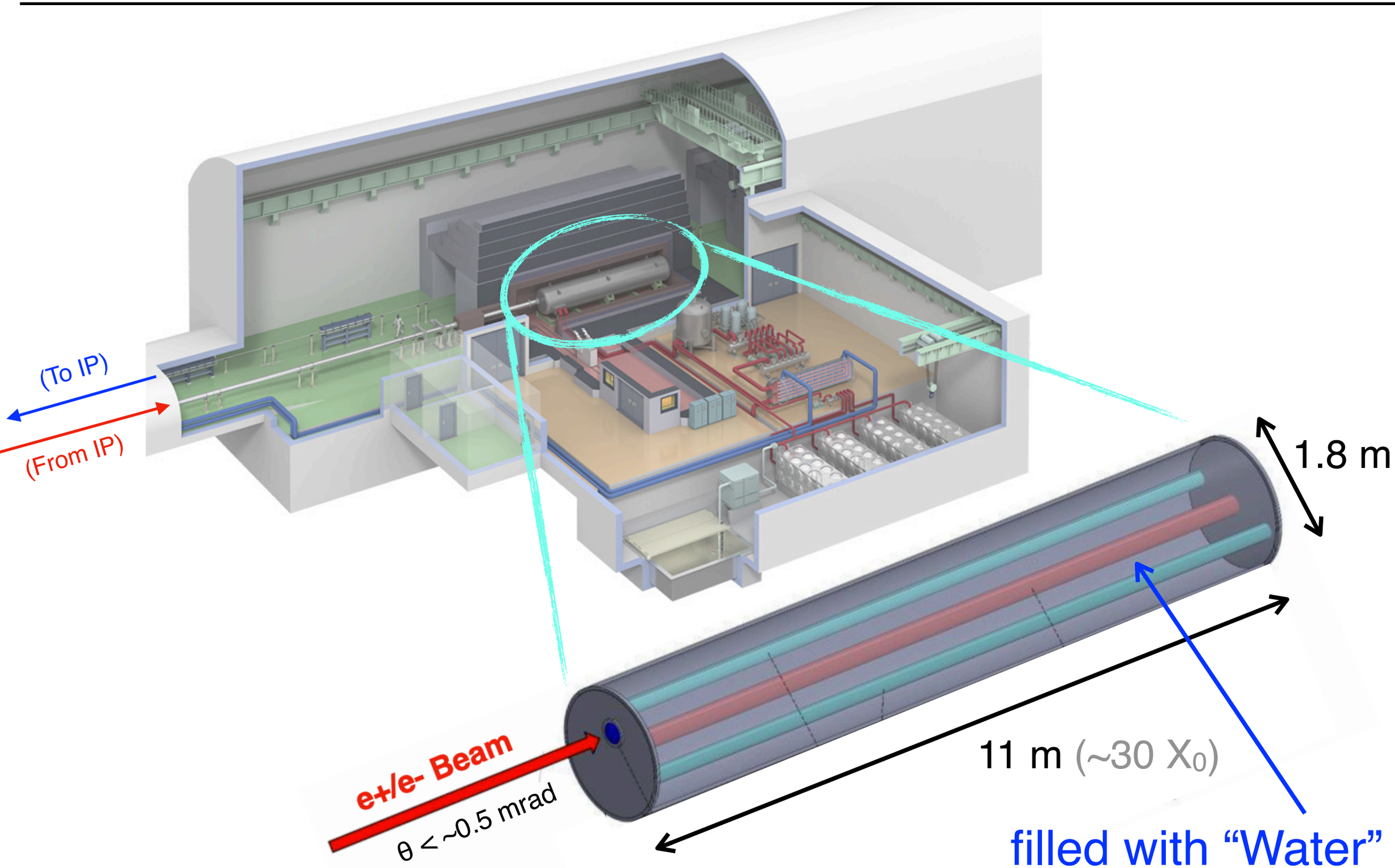
Tune-up dump for e+

Main beam dumps

Tune-up dump for e-

Consider the potential of these beam dump facilities.

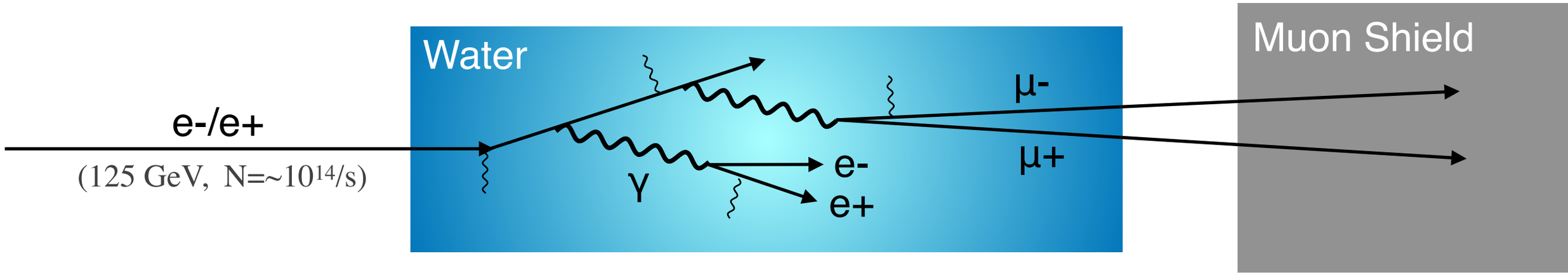
Main beam dumps



(Base design) P. Satyamurthy, et.al., NIM A 679 (2012)

Being developed by N. Terunuma and Y. Morikawa

Luminosity

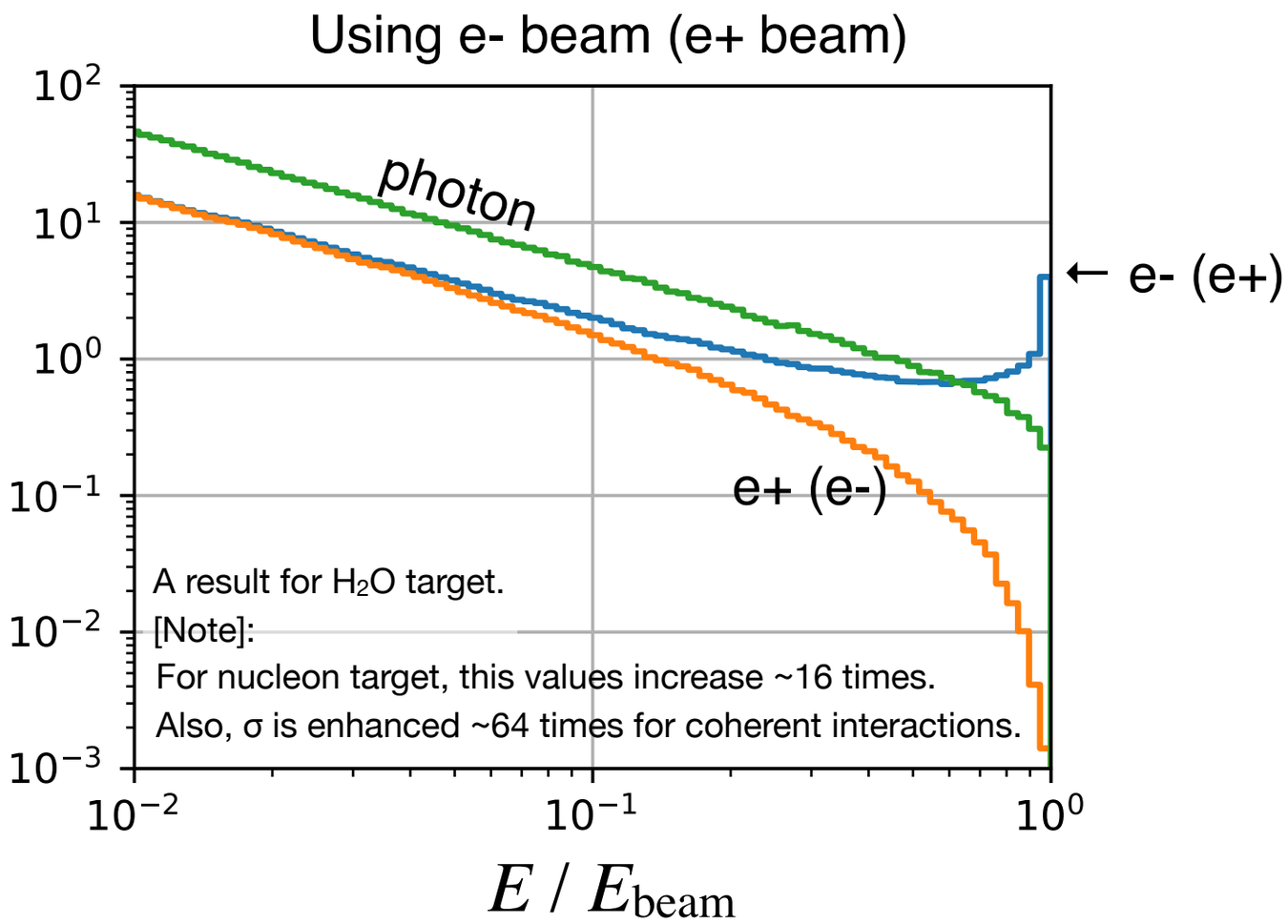


N(events) = (Luminosity) x (Cross section)

(Luminosity) = (# density of target) x (track length)

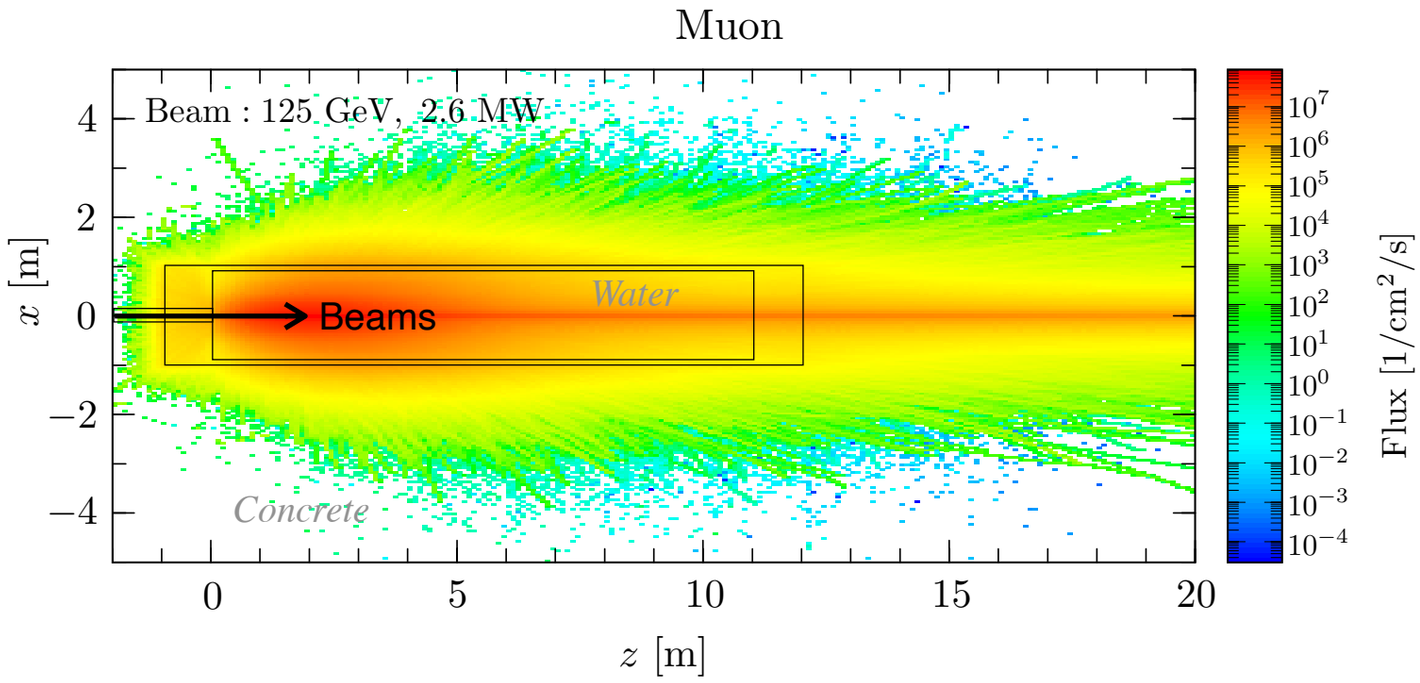
$$\frac{d(\text{Luminosity})}{d\log_{10}(E/E_{\text{beam}})}\ [\text{fb}^{-1}/\text{s}]$$

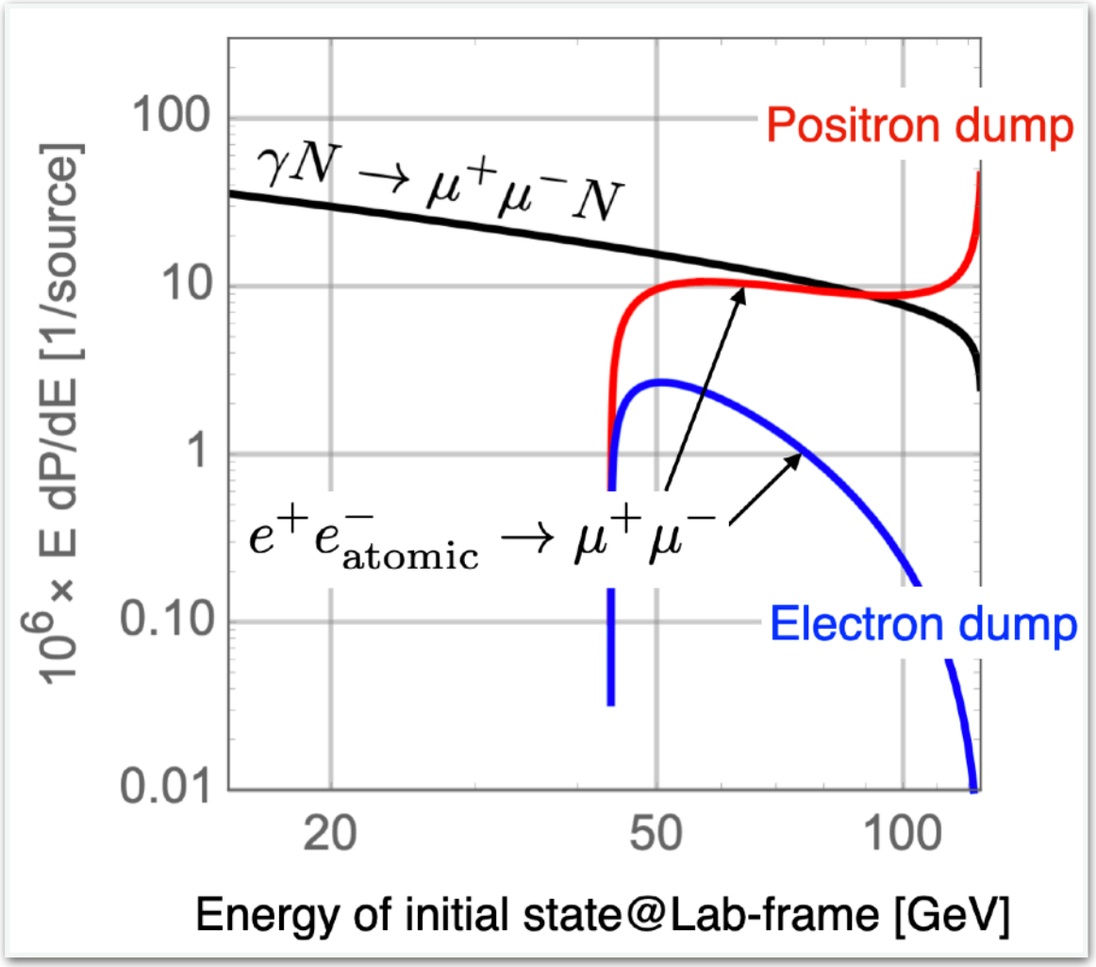
1 year ~ 5000 hour operation
~ 2 x 10^7 s



Beam dump EXP is Luminosity frontier

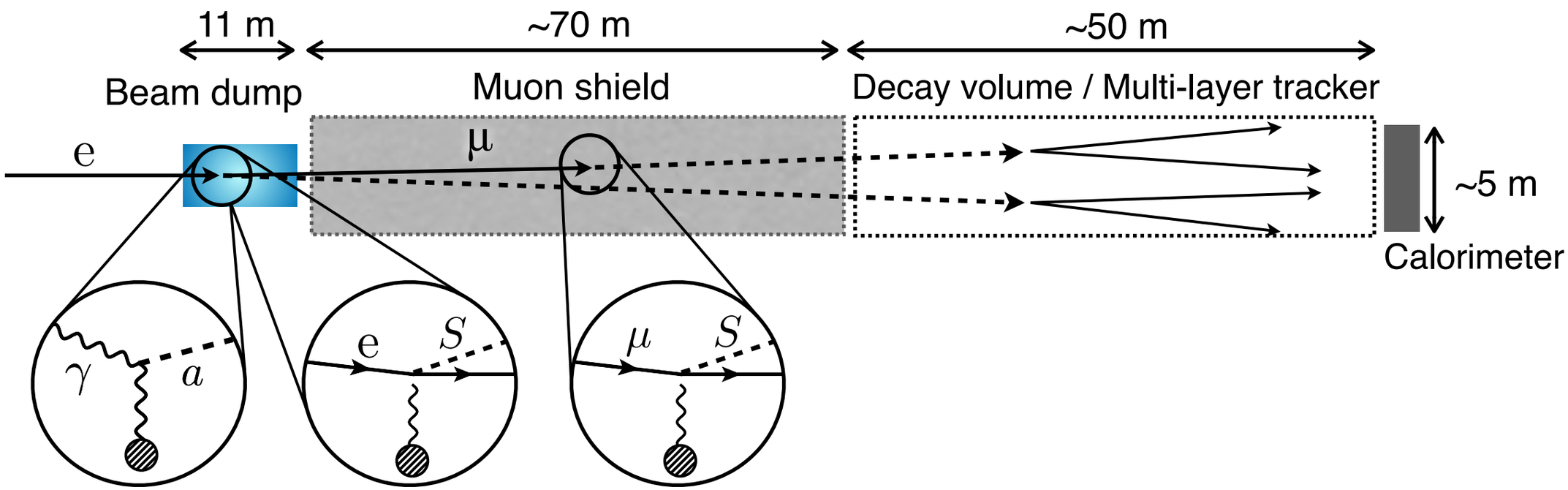
Muon beam





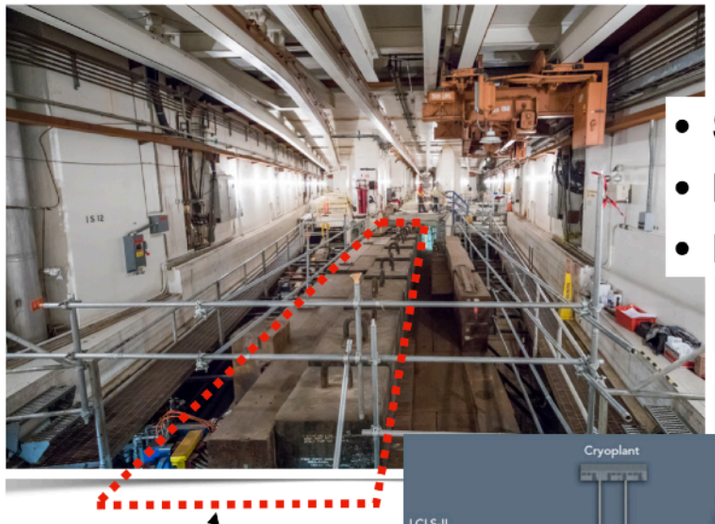
- Very forward muon beams are obtained by $e^{\pm}$ beams.
- Positron dump generates more high-energy muons.
- The flux are ~10^8 times greater than the cosmic-ray.
  (Neutron flux is ~10^{11} times greater than the cosmic)

Main beam dump experiment



Passive muon shield

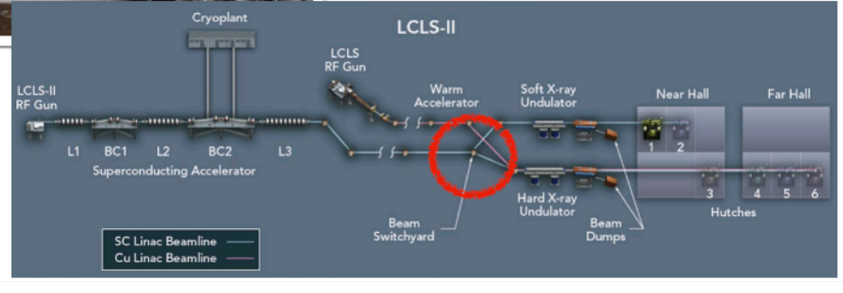
LCLS-II BSY @ SLAC



- Simply placed heavy objects
- Better for radiation issues
- Lower costs?

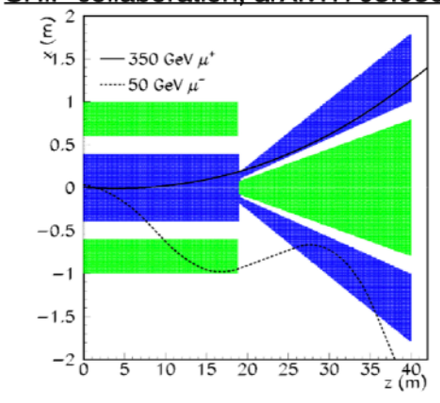
Iron Muon Wall

(for radiation safety)

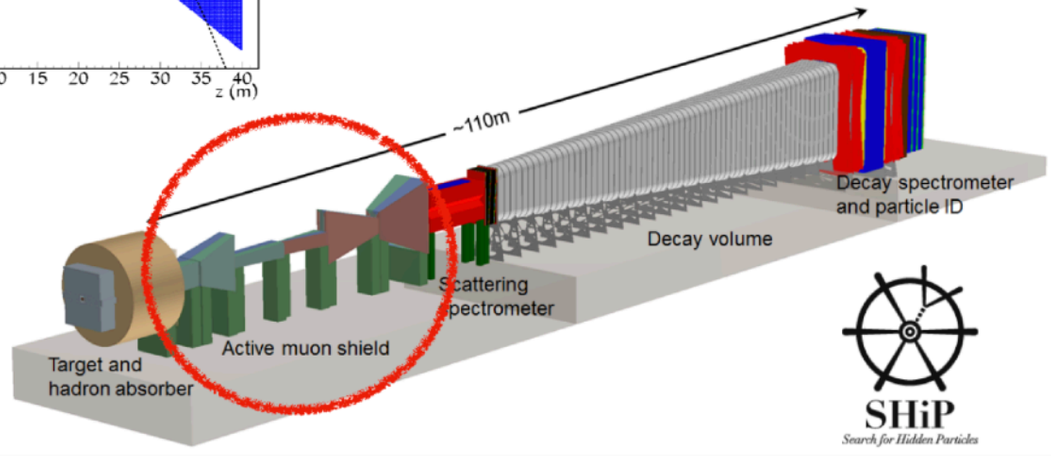


Active muon shield

SHiP collaboration, arXiv:1703.03612



- Magnetic shielding
- Effective even at High-Energy ILC

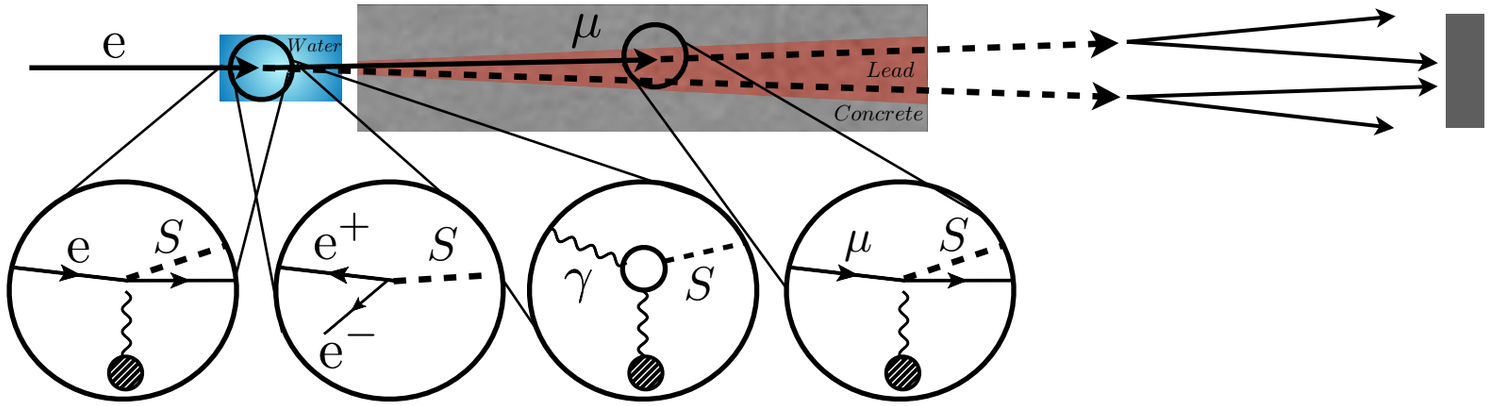


Scalar

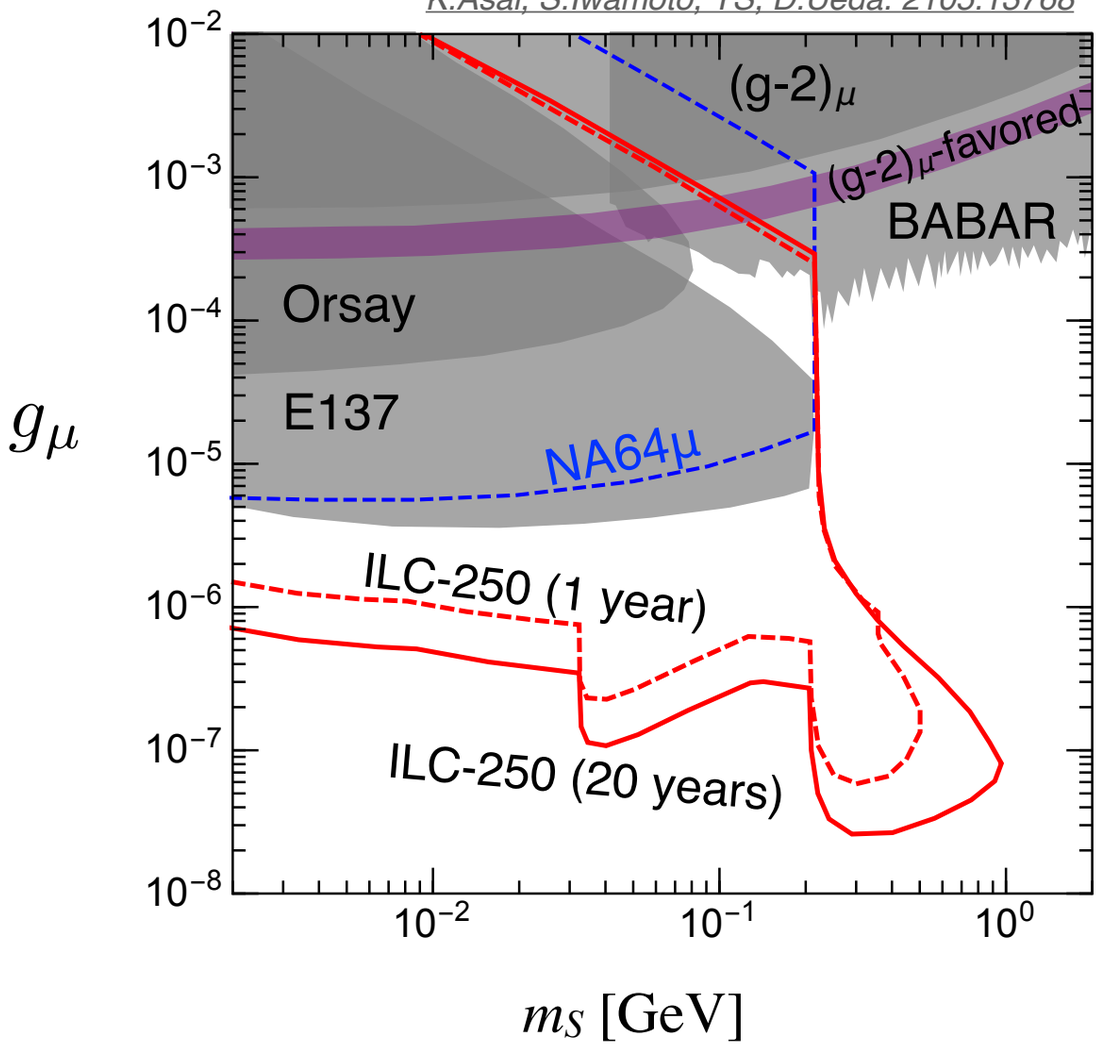
Leptophilic Scalar

$$\delta\mathcal{L} = \frac{1}{2}(\partial_\mu S)^2 - \frac{1}{2}m_S^2 S^2 - \sum_{\ell=e,\mu,\tau} g_\ell S\bar{\ell}\ell,$$

Case: $g_\ell \propto \frac{m_\ell}{\Lambda}$

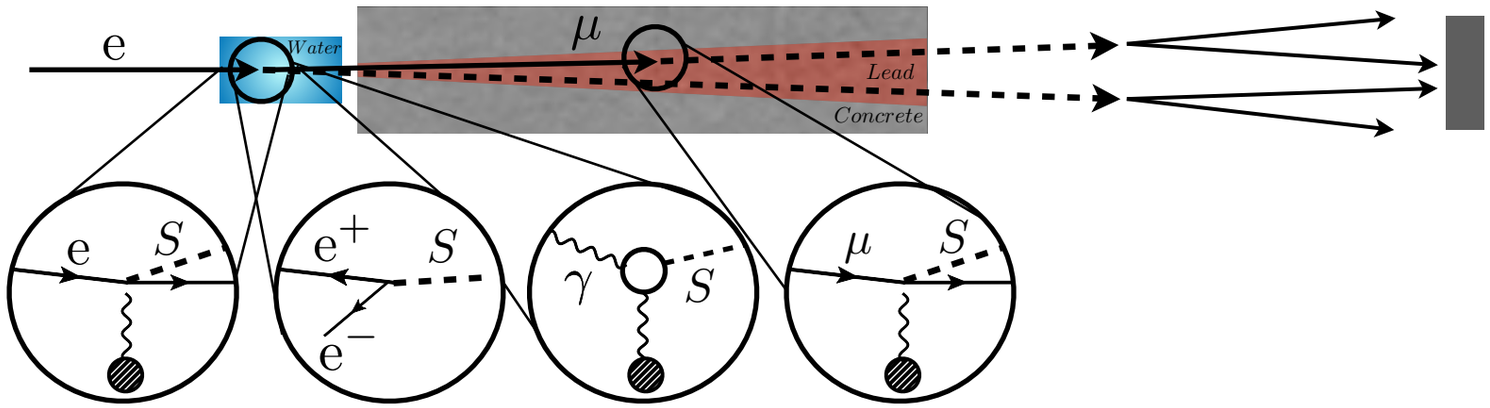


K.Asai, S.Iwamoto, YS, D.Ueda. 2105.13768



ILC is sensistive to small coupling region due to its large Luminosity

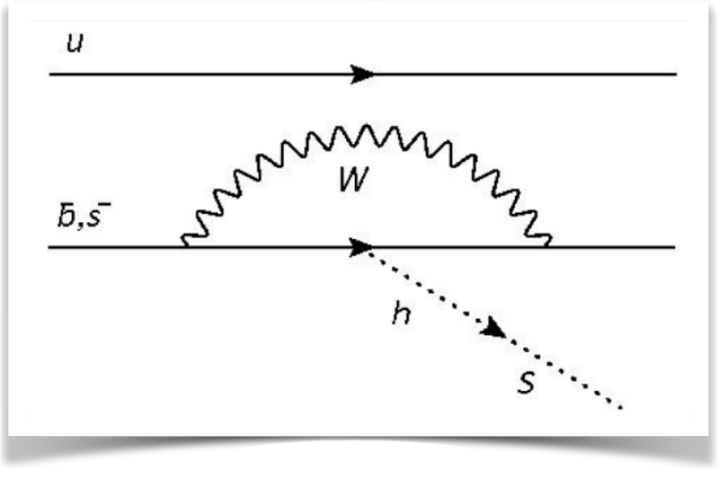
Scalar



How about general cases with quark coupling?

(e.g., Dark scalar mixing with the Higgs)

$$\mathcal{L}_{\text{scalar}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{DS}} - (\mu S + \lambda S^2) H^\dagger H.$$



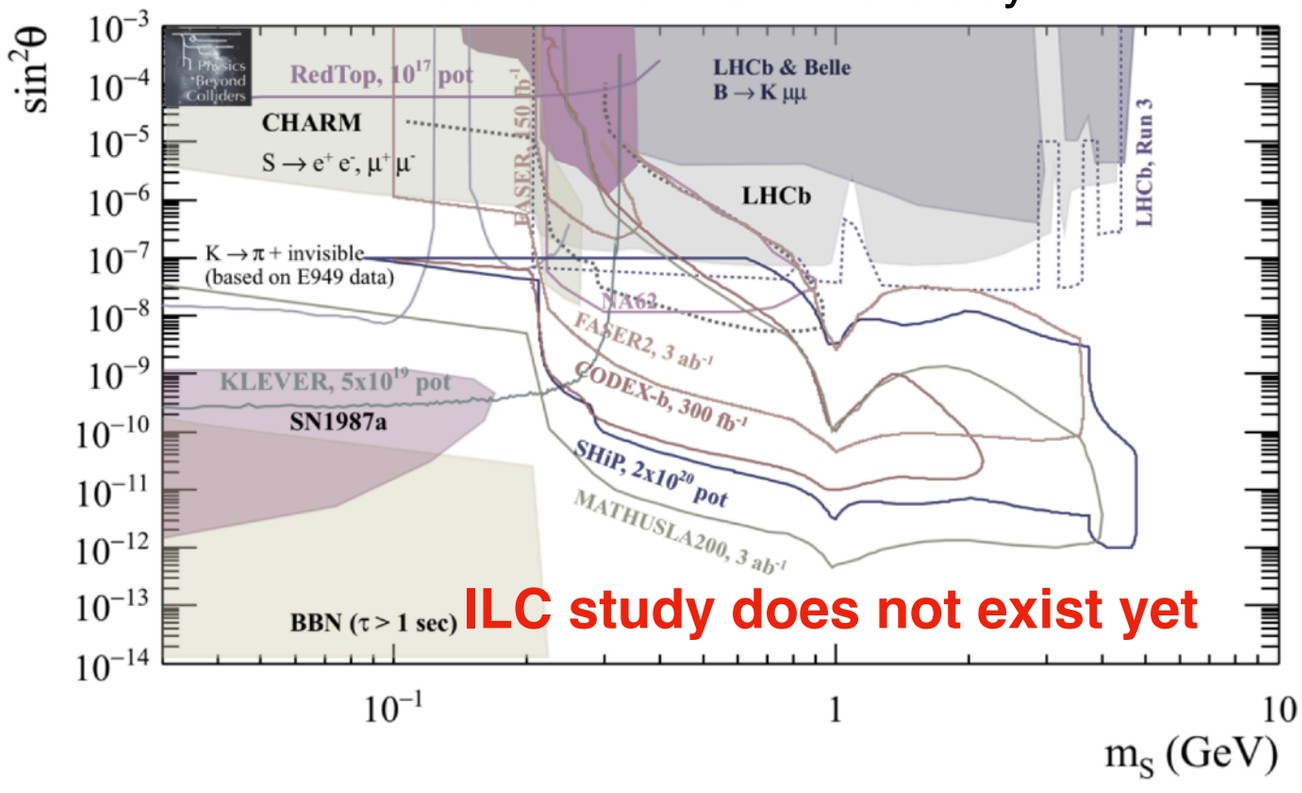
Meson decay is dominant.

→ ILC beam dumps generate lots of mesons

(See HNL results)

G. Lanfranchi et.al., 1901.09966

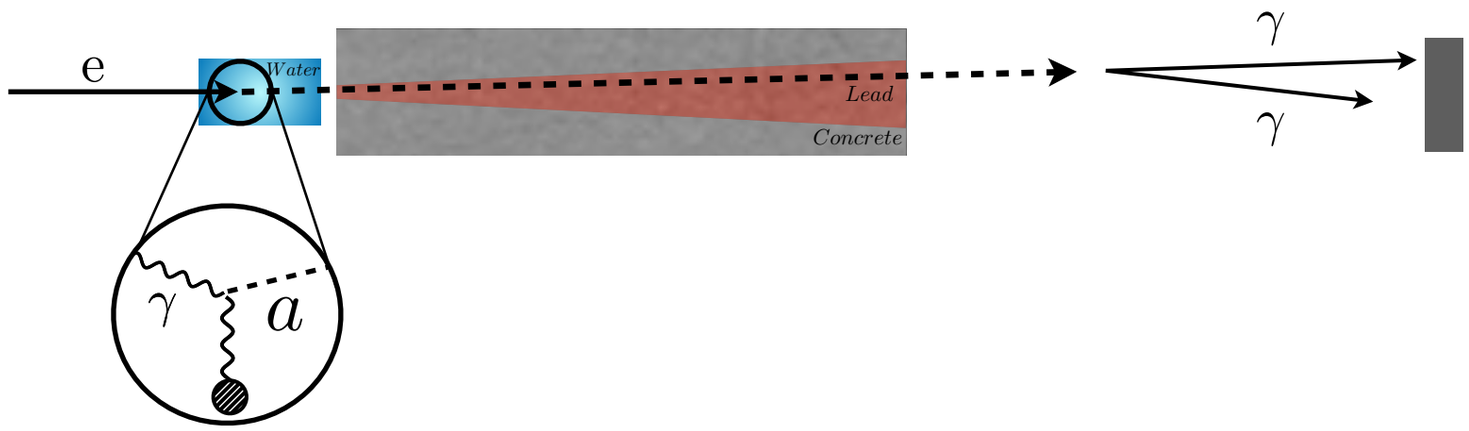
A bench mark of PBC study

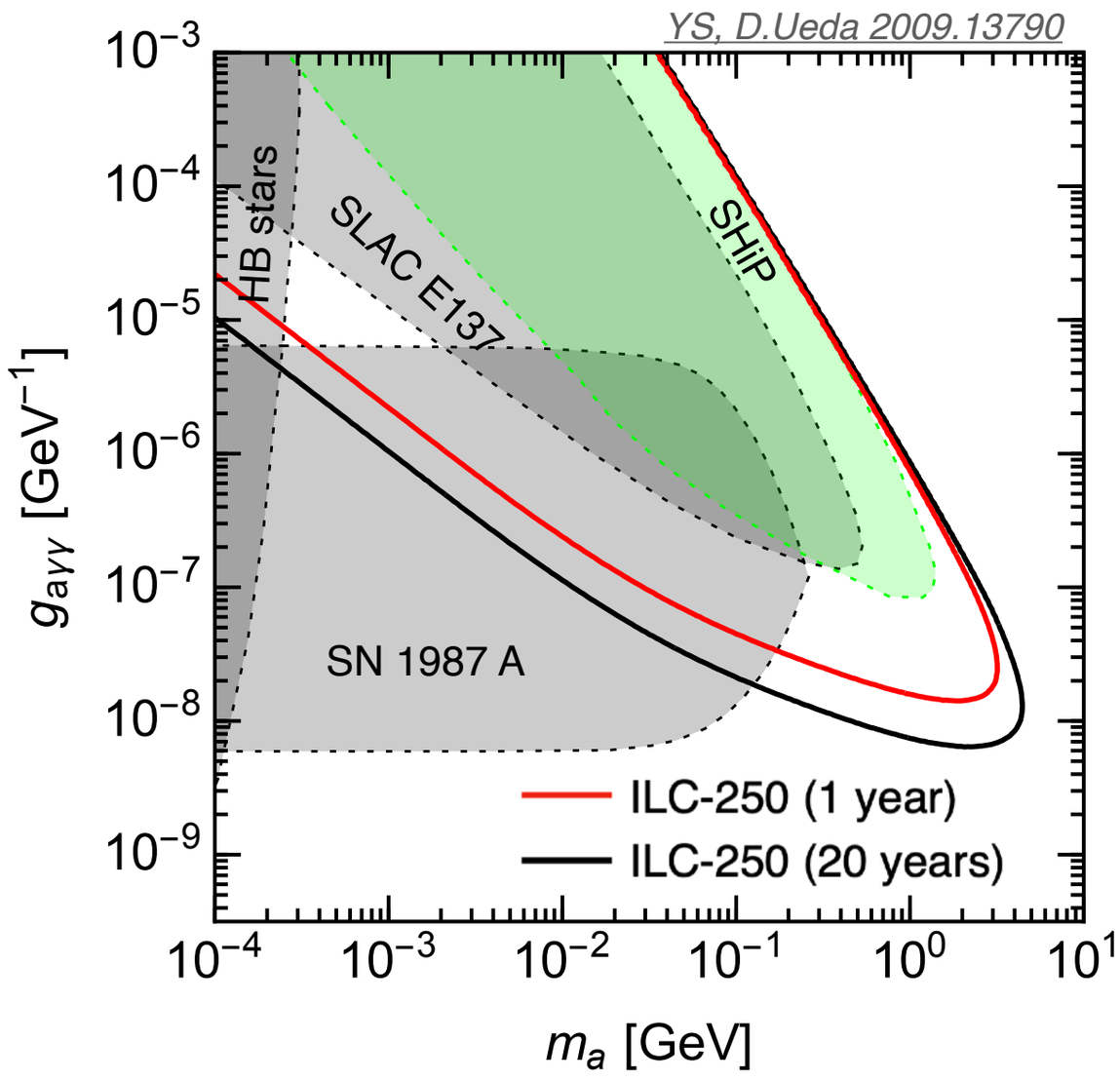


Pseudo-Scalar

Axion-like particles (ALPs)

$$\mathcal{L} \supset -\frac{1}{4} g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu} + \frac{1}{2}(\partial_\mu a)^2 - \frac{1}{2} m_a^2 a^2$$



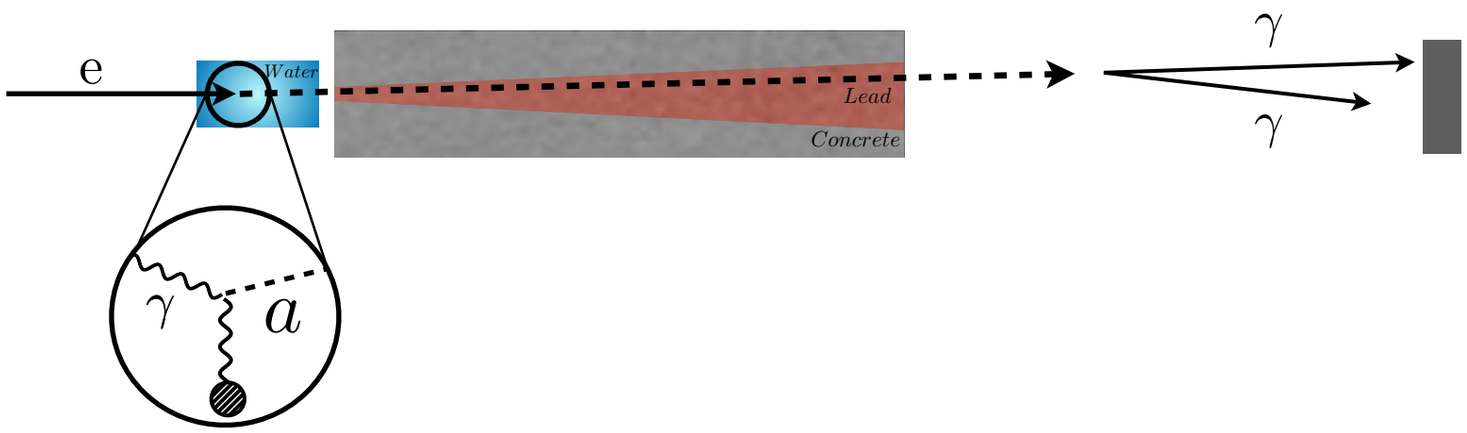


- An order of magnitude better sensitivity than other beam dump experiments.
- Robustness of SN1987 result is still under debated. *[Nitsan Bar, Kfir Blum, Guido D'Amico, 1907.05020]*
  - ✓ It can be confirmed directly.

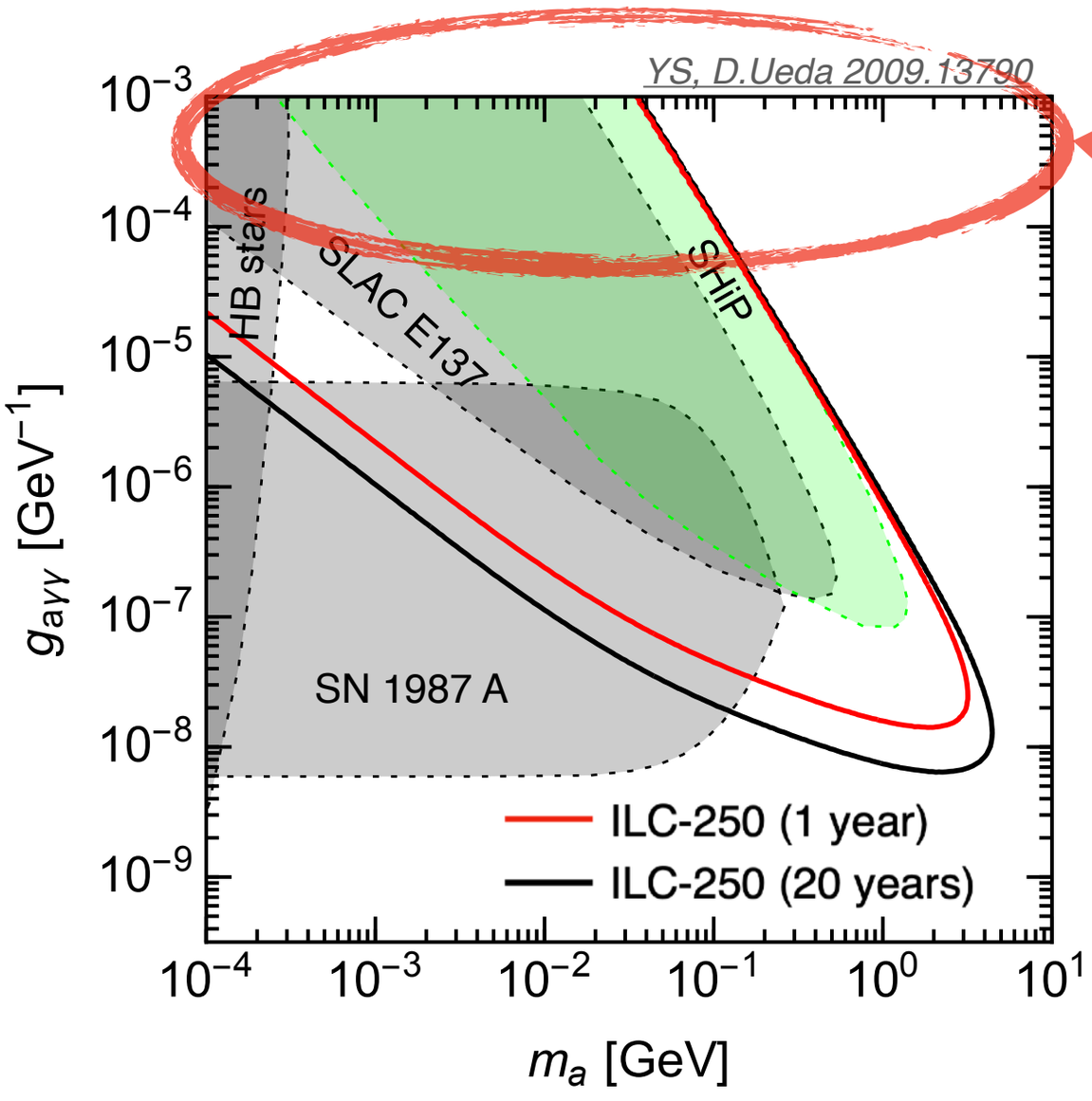
Pseudo-Scalar

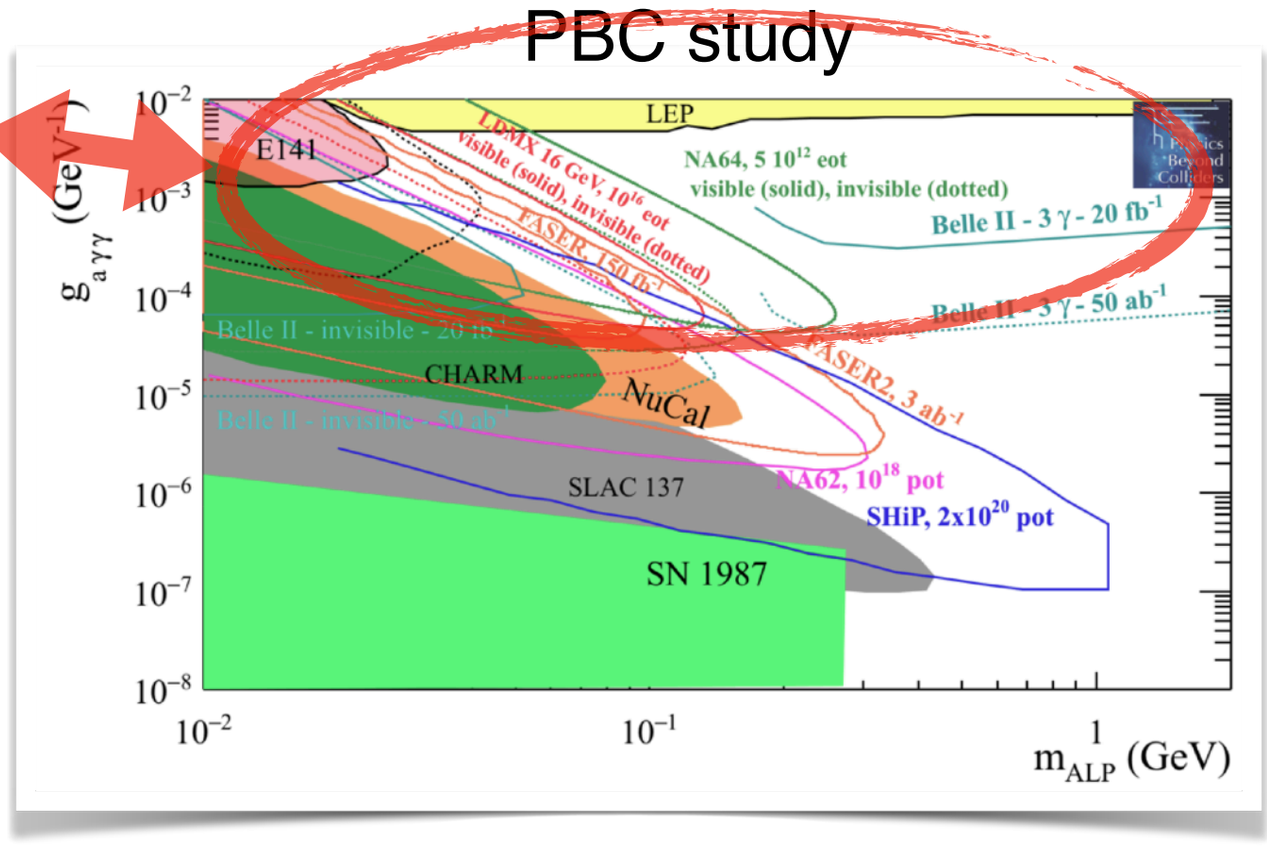
Axion-like particles (ALPs)

$$\mathcal{L} \supset -\frac{1}{4} g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu} + \frac{1}{2}(\partial_\mu a)^2 - \frac{1}{2} m_a^2 a^2$$



G. Lanfranchi et.al., 1901.09966





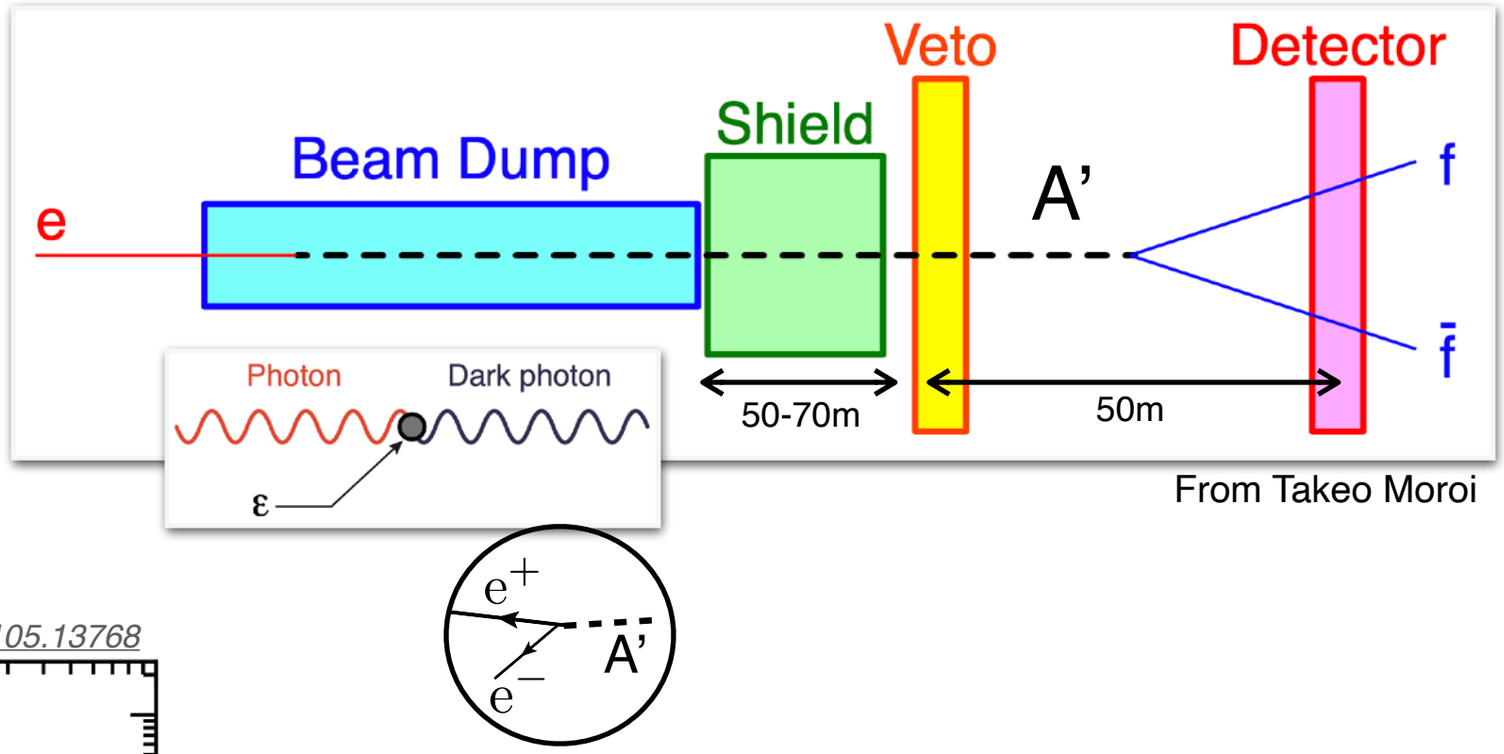
- Complementaly with other proposals.

Vector

Dark photon, A'

$$\mathcal{L} \supset -\frac{1}{4}F^{(A')}_{\mu\nu}F^{(A')\mu\nu} - \frac{\epsilon}{2}F^{(\mathrm{em})}_{\mu\nu}F^{(A')\mu\nu} + \frac{m^2_{A'}}{2}A'_{\mu}A'^{\mu}$$

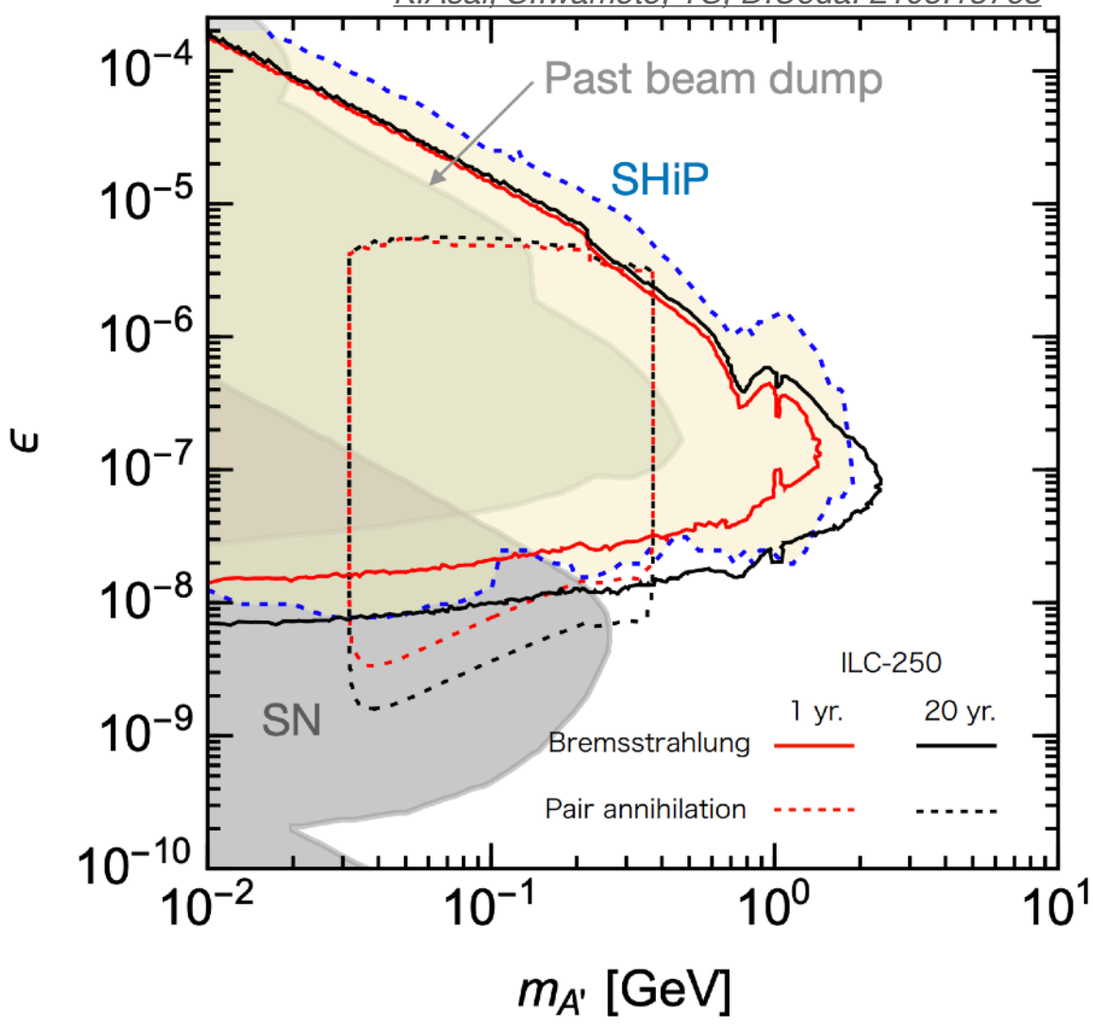
$$\mathcal{L}_{\mathrm{int}} \simeq -\epsilon e A'_{\mu} j^{\mu}_{\mathrm{em}}$$



From Takeo Moroi

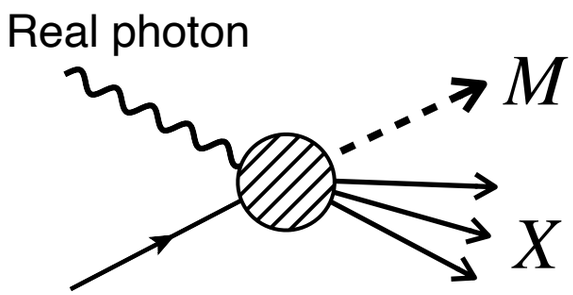
✳ Shower and annihilation effects are improved from the first study of ILC beam dump
[S.Kanemura, T.Moroi, T.Tanabe, 1507.02809]

K.Asai, S.Iwamoto, YS, D.Ueda. 2105.13768

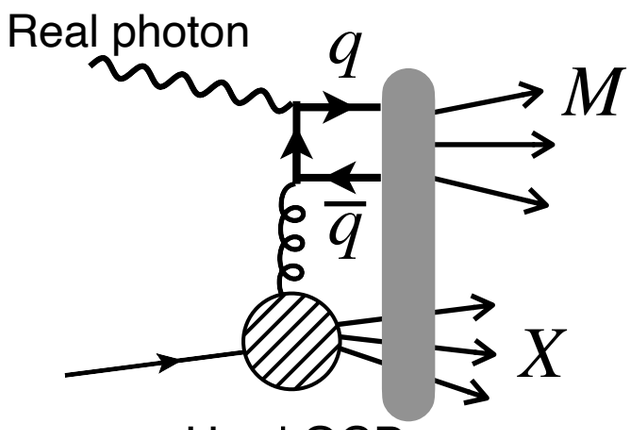


- Equivalent sensitivity to SHiP

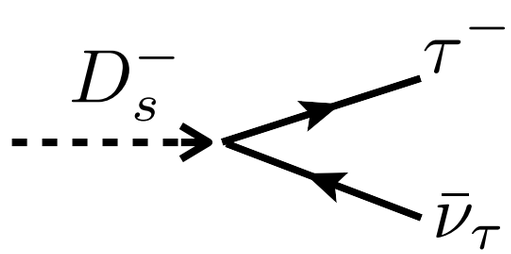
ILC Beam dumps generate lots of **Mesons** and **tau-lepton**



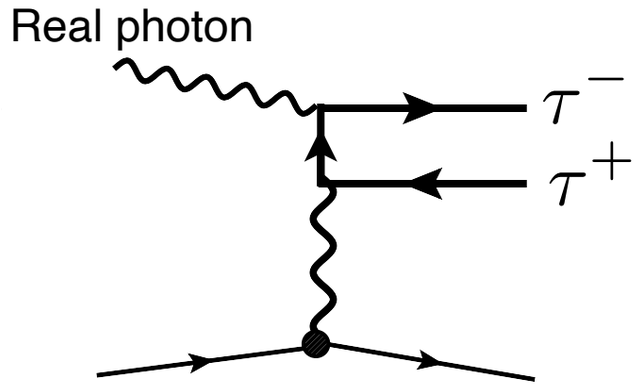
Non-diffractive



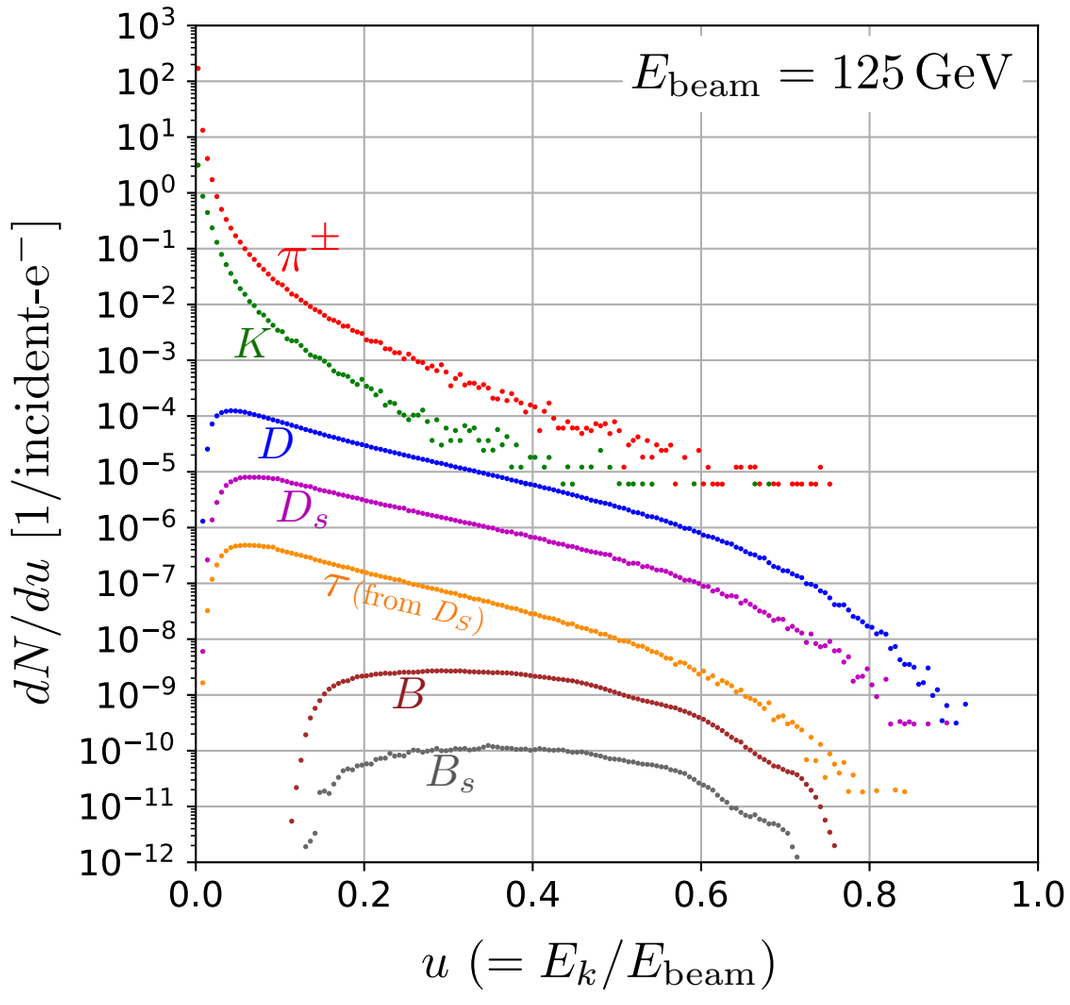
Hard QCD

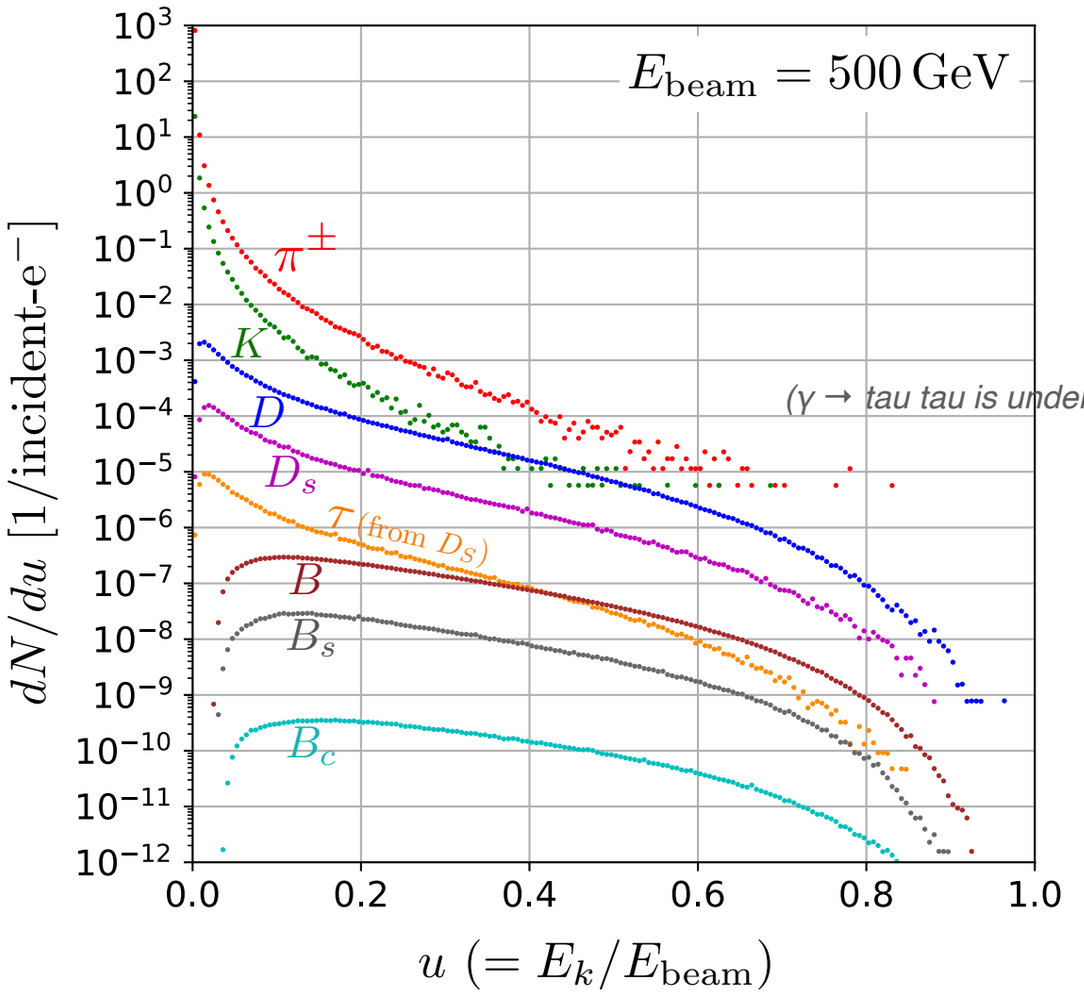


Br = 5.48 %



Coherent, Quasi-elastic, Inelastic





($\gamma \rightarrow$ tau tau is under estimation)

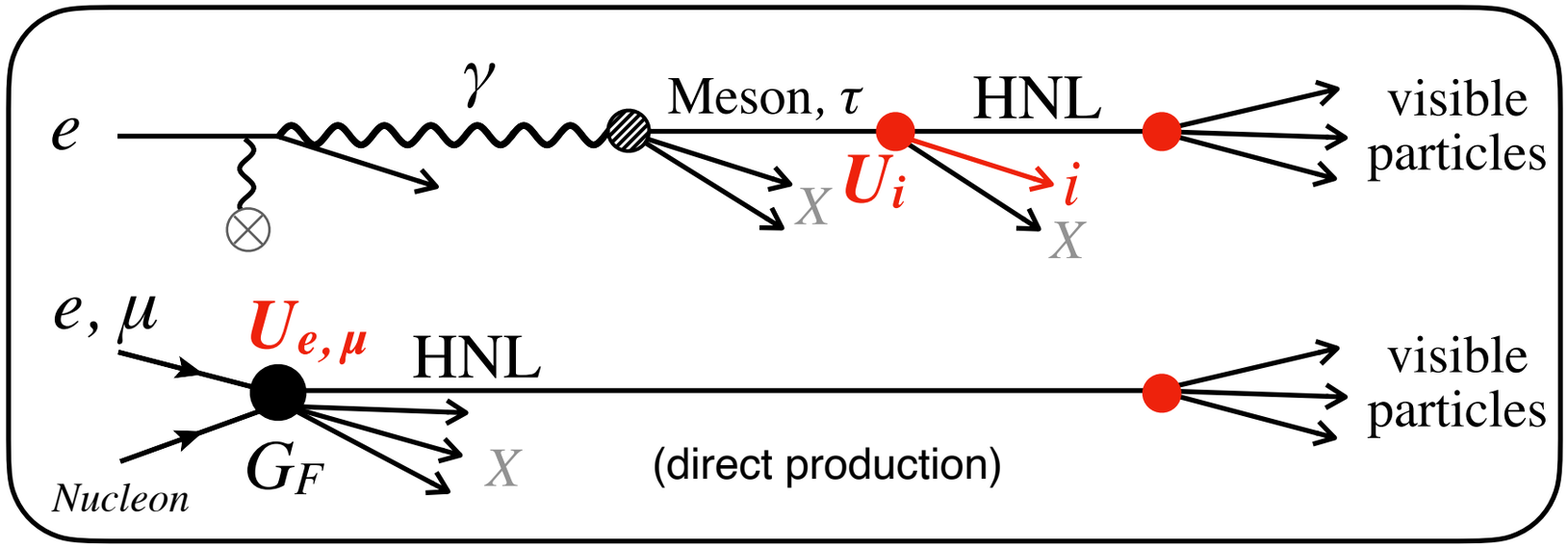
ILC beam dumps generate lots of mesons and tau-lepton

Heavy Neutral Leptons (HNLs)

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

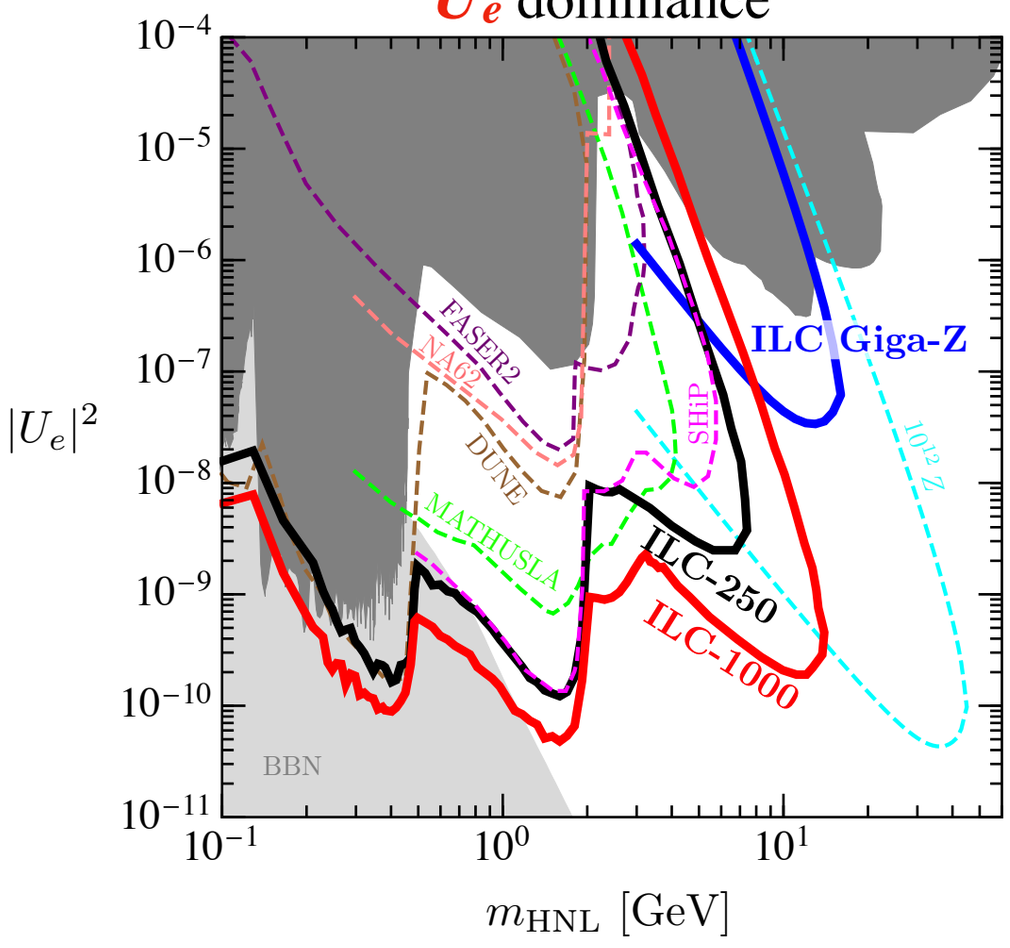
$$U_{Ii}^2 = \frac{v^2|\lambda_{iI}|^2}{M_I^2}$$

For simplicity, consider single HNL and omit index of HNL I.

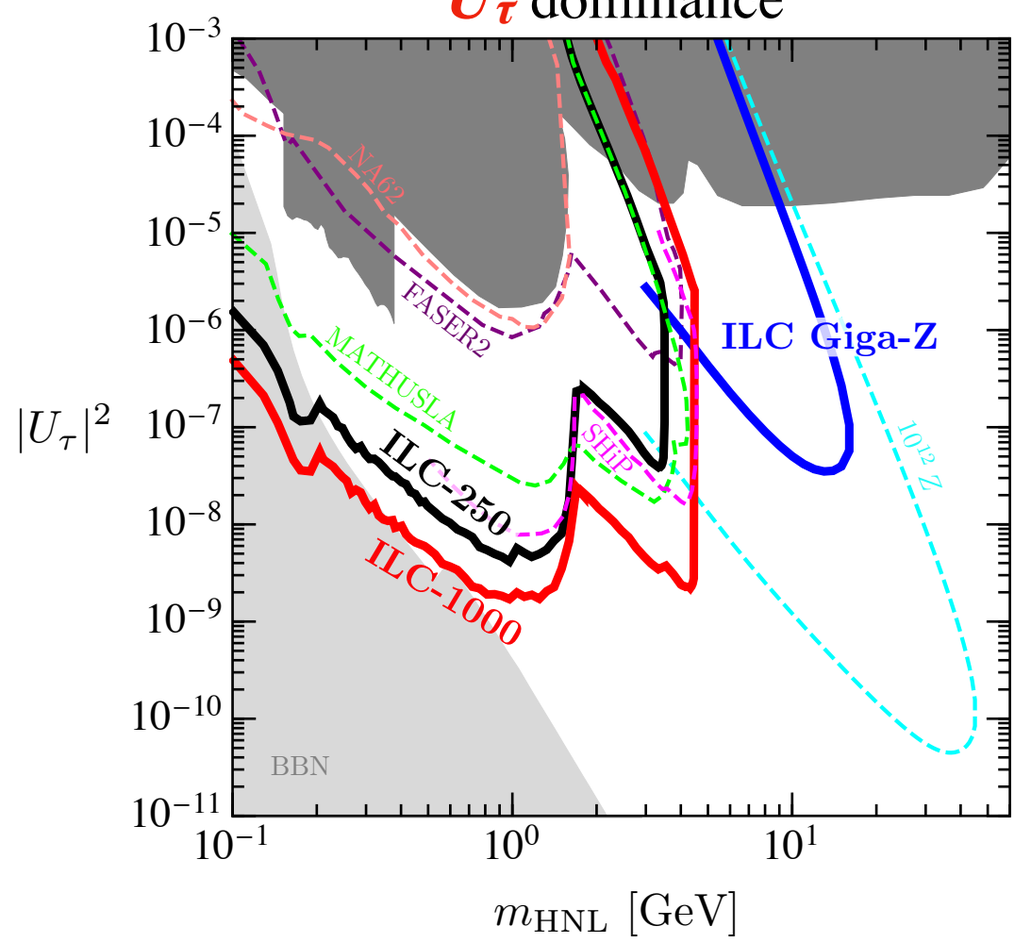


M.M.Nojiri, YS, K.Tobioka, D.Ueda. 2206.XXXXX

U_e dominance



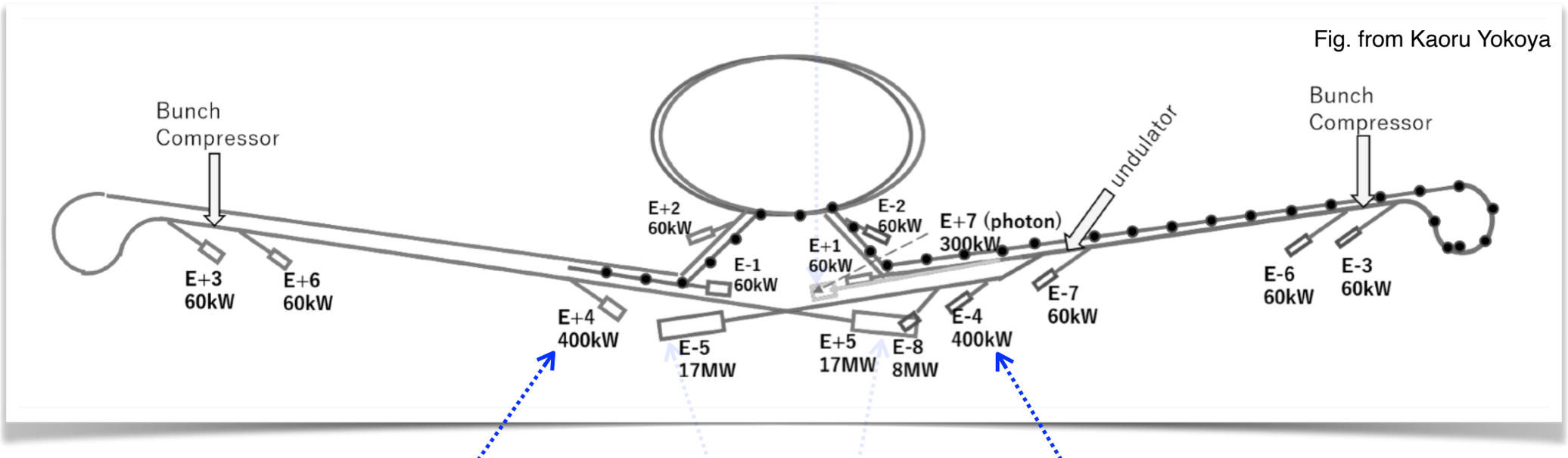
U_τ dominance



- Beam dump EXP and ILC Collider EXP is complementary
- HNL direct production from e± expand sensitivity at high mass region

15 beam dumps at ILC

Photon beam dump

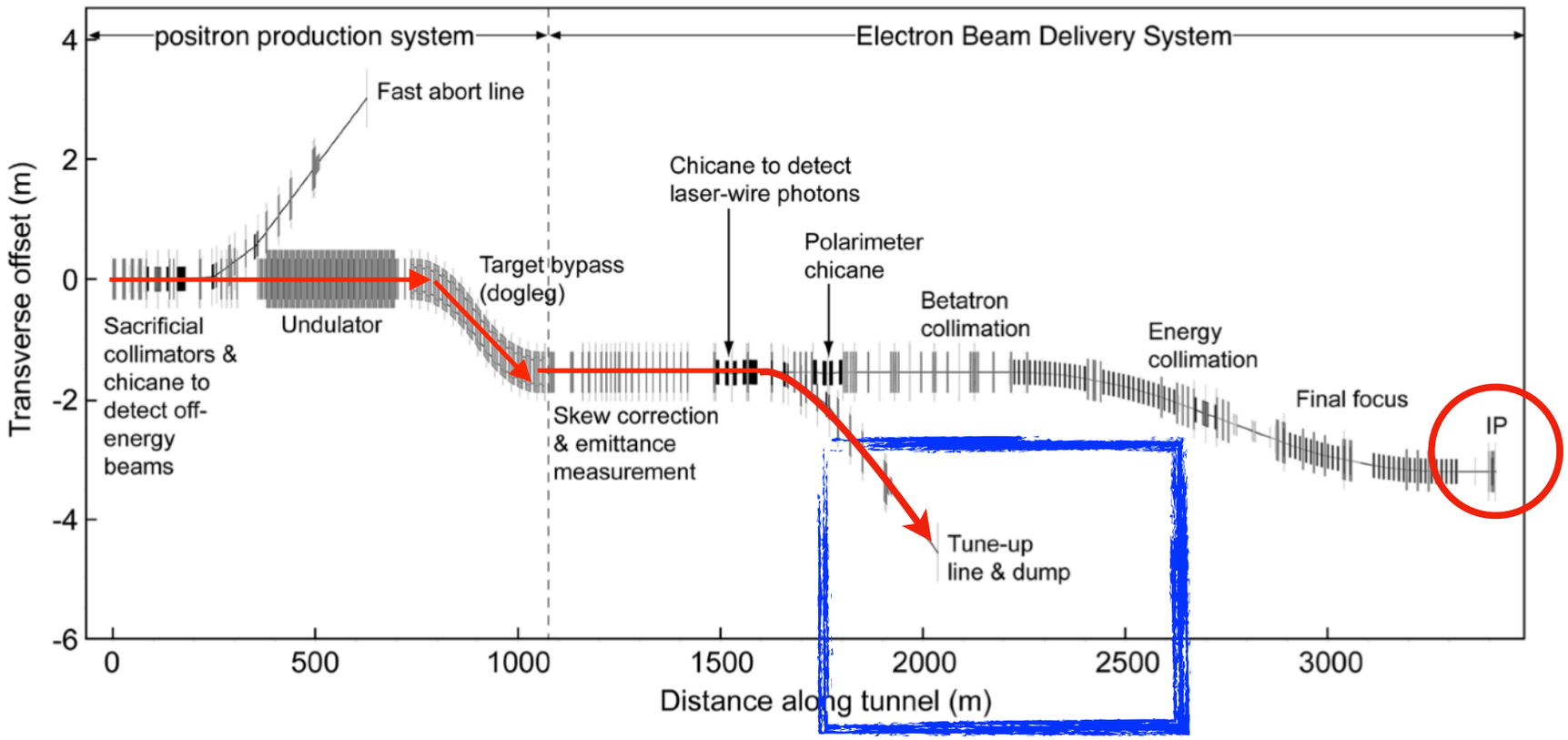


Tune-up dump for e+

Main beam dumps

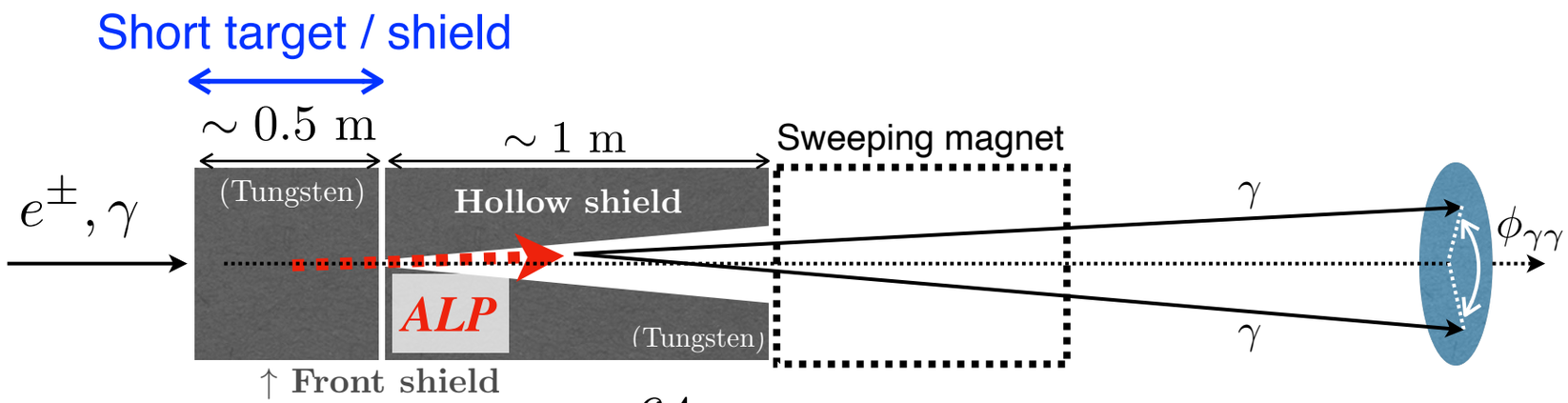
Tune-up dump for e-

Tune-up dumps



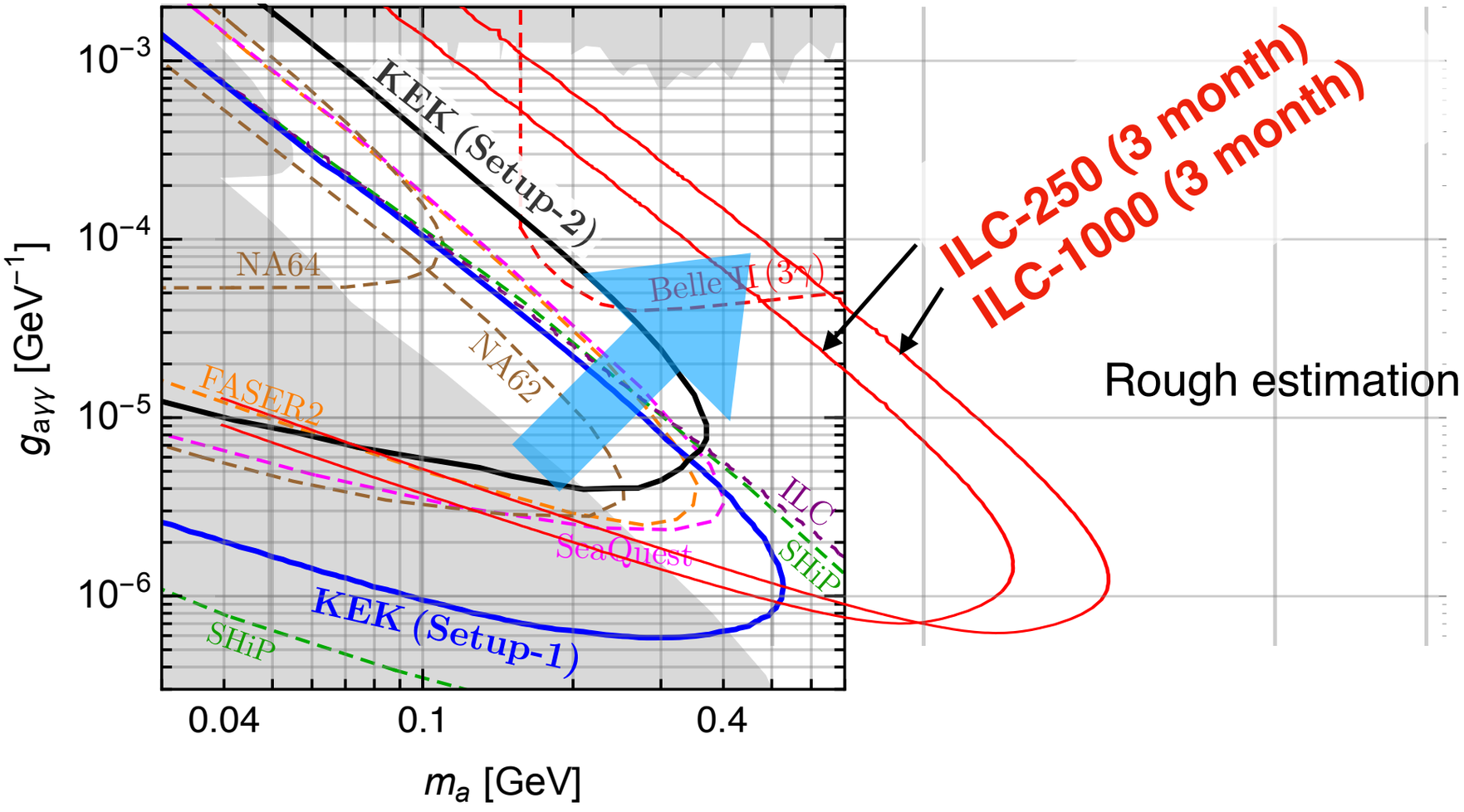
- Best place to perform dedicated experiments
  - ✓ Maximum beam energy available
  - ✓ Bunch charge can be adjusted
  - ✓ Beams in good condition before the collision is available
- The facility design in this area will be modified for various experimental possibilities.

Search on shorter lifetime region with shorter shielding setup



$$\tau_{\rm ALP} = \frac{64\pi}{g_{a\gamma\gamma}^2 m_a^3}$$

The use of short shielding increases sensitivity to short lifetime region

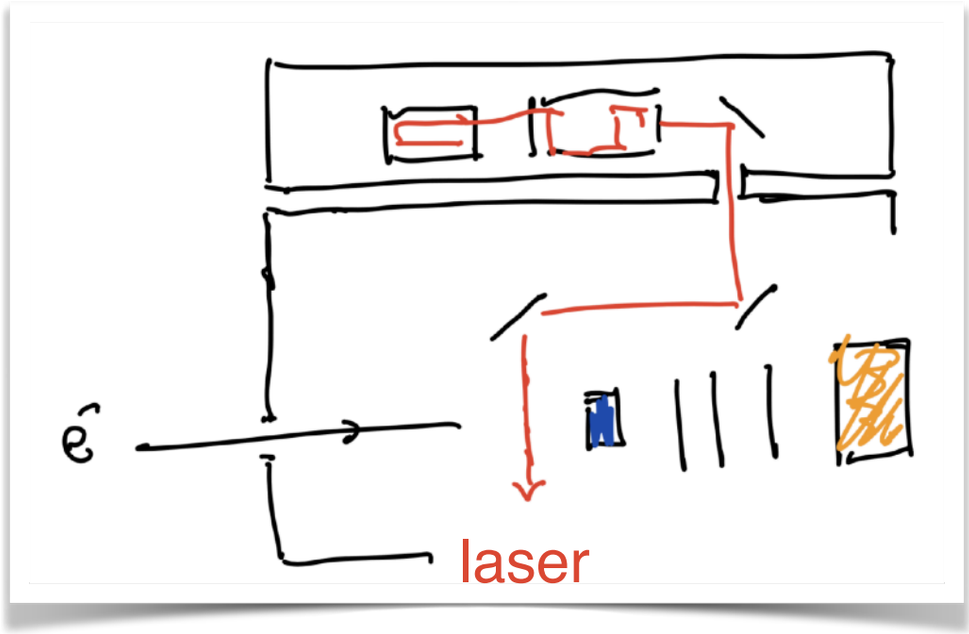


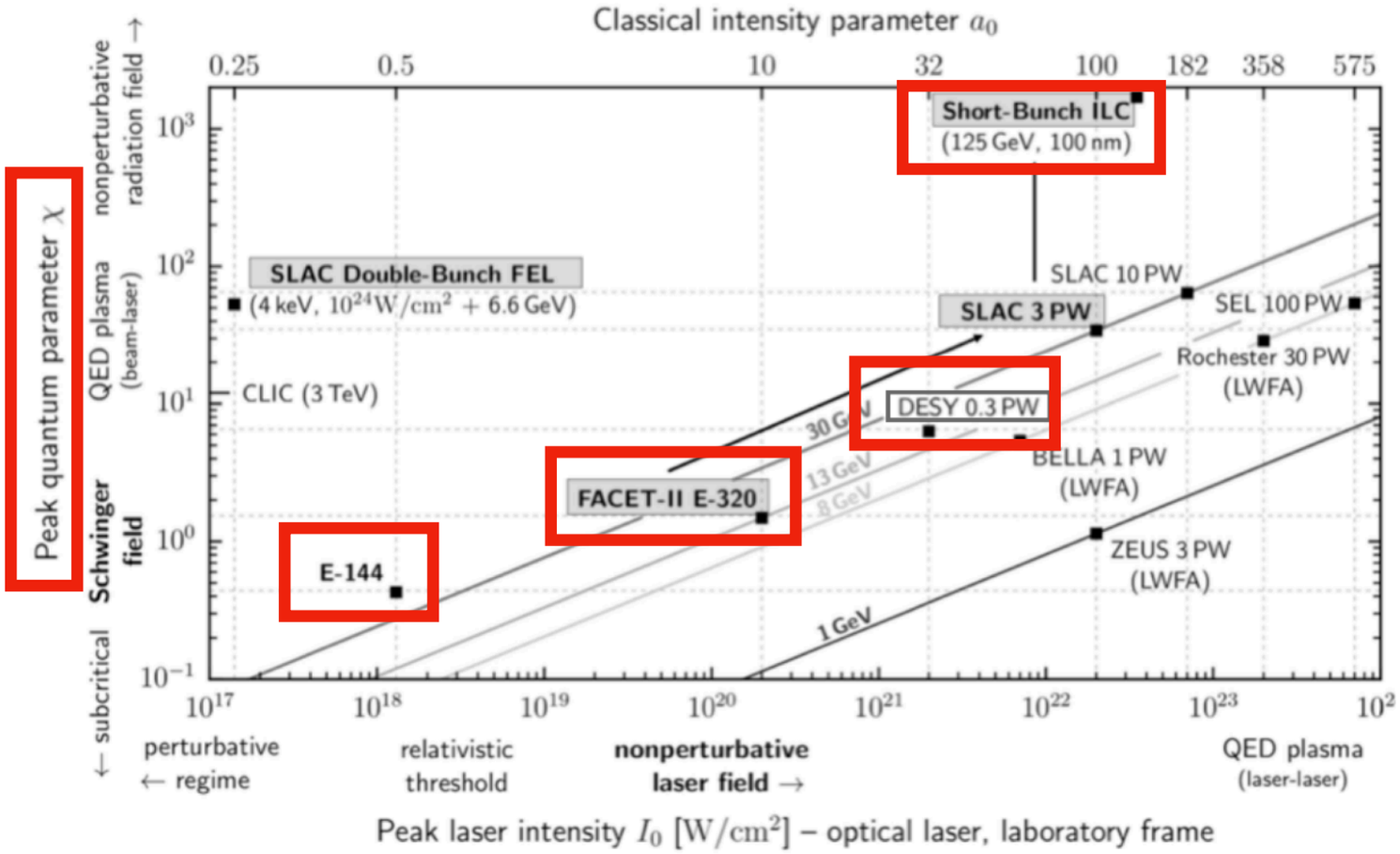
Non-linear QED

From M. E. Peskin's talk @ ILCX2021

Study of non-linear QED phenomena
by electron - laser bunch collisions

- This understanding can also affect other research such as astrophysics and future accelerator development.



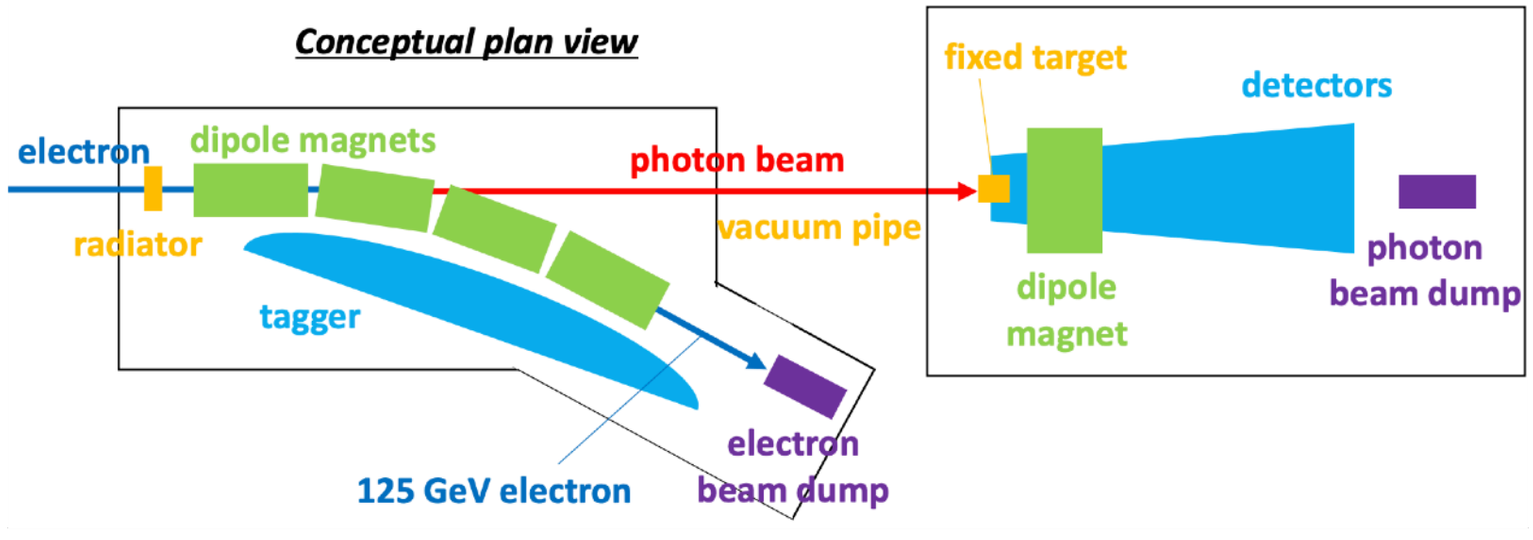


- A large quantum parameter χ can be reached with ILC beams and high intensity lasers.
- This large number makes possible to study interesting non-linear QED processes

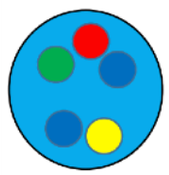
Photoproduction of Exiotic hadrons and Heavy hadrons

From Norihito Muramatsu's talk @ ILCX2021

Setup for hadron photoproduction experiments



Exotic hadrons



$uudc\bar{c}$ pentaquark

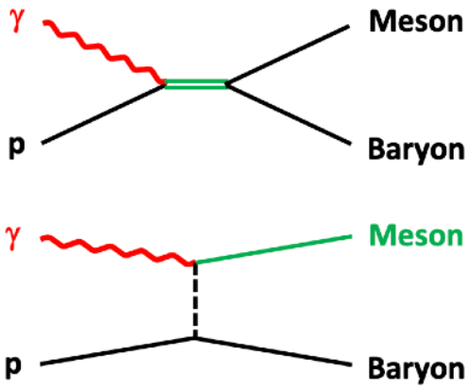
$P_c(4312)^+$ etc in $\Lambda_b^0 \to J/\psi\, pK^-$

$P_c(4337)^+$ in $B_s^0 \to J/\psi\, p\bar{p}$

4-quark state including $c\bar{c}$

X(3872) in $B^\pm \to K^\pm \pi^+ \pi^- J/\psi$

$Z^+(4430)$ in $B^0 \to K^- \pi^+ \psi'$



Heavy hadron photoproduction

- **Photoproduction cross sections** & **spin observables** must be sensitive to **hadron properties**.

  ⇒ Complementary to **LHCb**, **Belle-II**, **J-PARC**, …

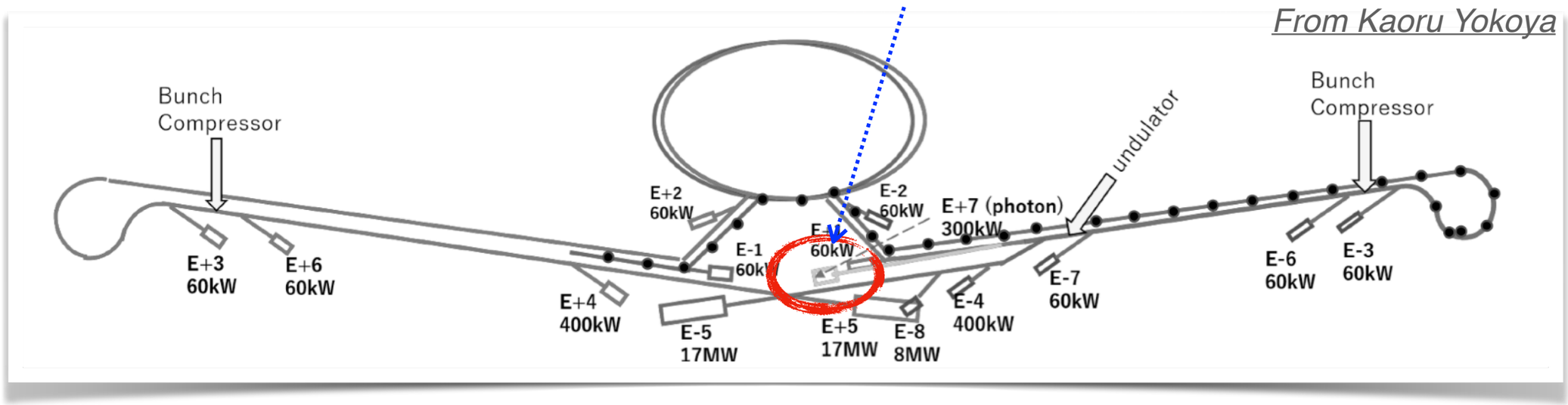
reaction	E_γ threshold
$\gamma p \to J/\psi\, p$ $\gamma p \to P_c(4312) \to J/\psi\, p$	8.21 GeV (9.44 GeV)
$\gamma p \to \bar{D}^0 \Lambda_c^+$	8.71 GeV
$\gamma p \to \bar{D}^0 \Sigma_c^+$	9.47 GeV
$\gamma p \to X(3872)\, p$	11.9 GeV
$\gamma p \to Z^+(4430)\, n$	14.9 GeV
$\gamma p \to \mathrm{X}(6900)\, p$	32.3 GeV
$\gamma p \to \Upsilon(1S)\, p$	57.2 GeV
$\gamma p \to B^+ \Lambda_b$	62.8 GeV

JLab GlueX

New !

Photon beam from Helical undulator

Photon beam dump



~10^{24} photon/year. E~10 MeV

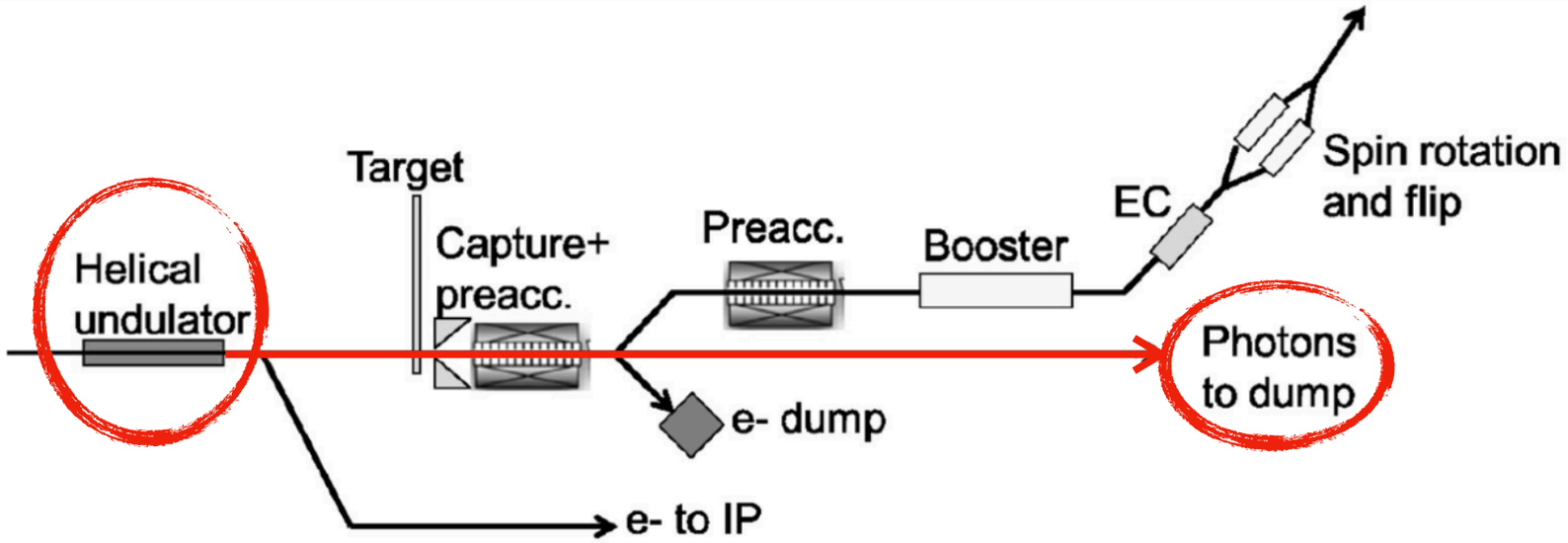
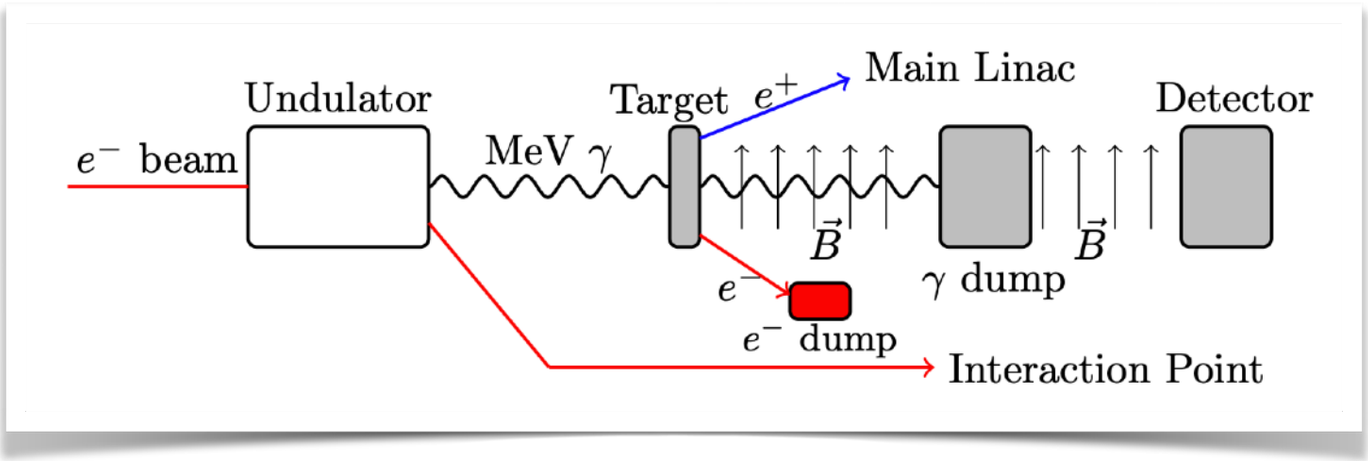


Figure 1: Sketch of the undulator-based ILC positron source.

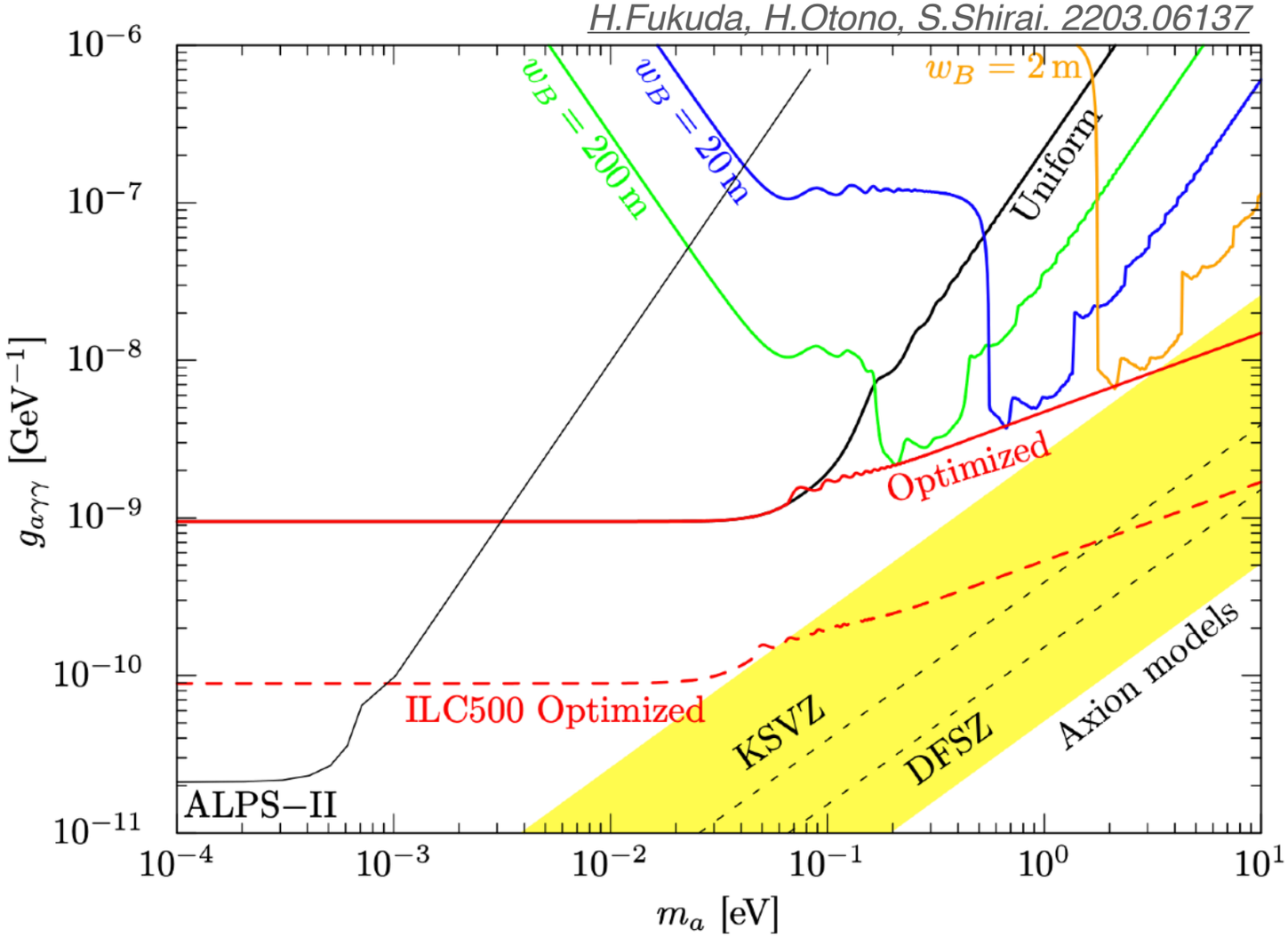
F. Dietrich et.al, 1902.07744

QCD Axion search using undulator photons



A well-motivated parameter region is testable with long magnetic field

H.Fukuda, H.Otono, S.Shirai. 2203.06137



Summary

- Linear collider EXP and Beam dump EXP coexist naturally.

- ILC beam dumps produce a large number of light shower particles (γ,e,μ) as well as heavy mesons and tau-lepton.

- These can be used to search for Scalar particles and various other new particle candidates.

- The ILC beam dump facility is capable of performing a variety of experimental programs.