Beyond-collider physics opportunities at a Linear Facility

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Introduction

The Physics Beyond Colliders (PBC) program aims to leverage the infrastructure of accelerator facilities to create new value.

Examples are the Fixed Target and Far Detector experiments, which have a strong sensitivity to light new particles (MeV~10 GeV) that feebly couple to SM particles.

The PBC programs can complement the collider experiment in the absence of heavy new particles (~TeV) at the LHC.

Many studies on PBC in the last decade (e.g., [1], [2]) have a significant impact on the design of future facilities.

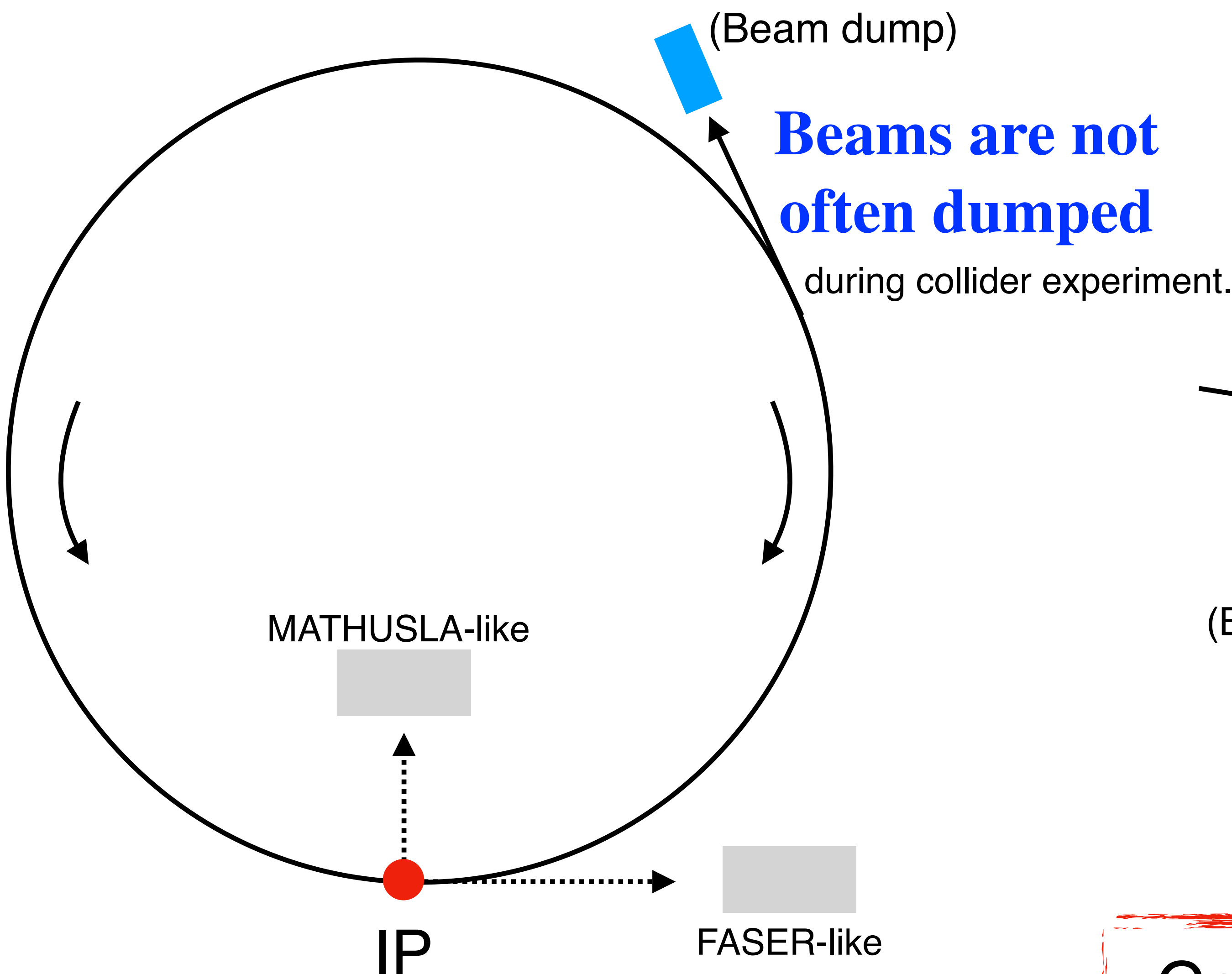
This talk will focus on the PBC opportunity at the ILC.

[1] US Cosmic Visions: New Ideas in Dark Matter 2017: Community Report, (1707.04591).

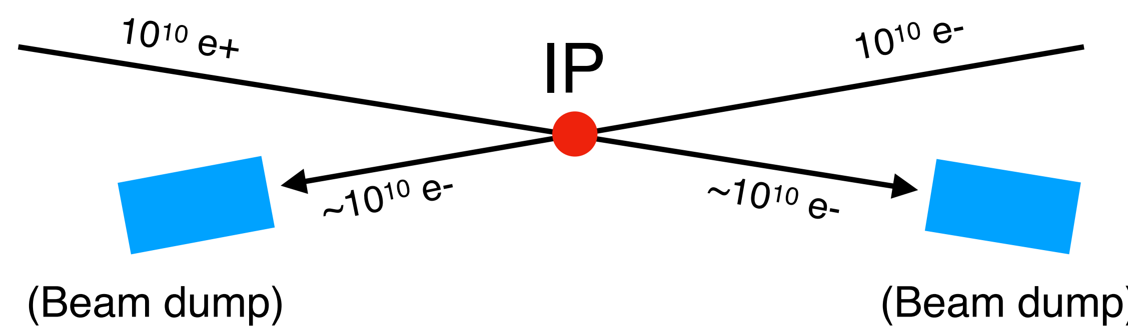
[2] Physics Beyond Colliders at CERN: Beyond the Standard Model Working Group Report, (1901.09966).

Beam dumps at a linear collider

Circular



Linear

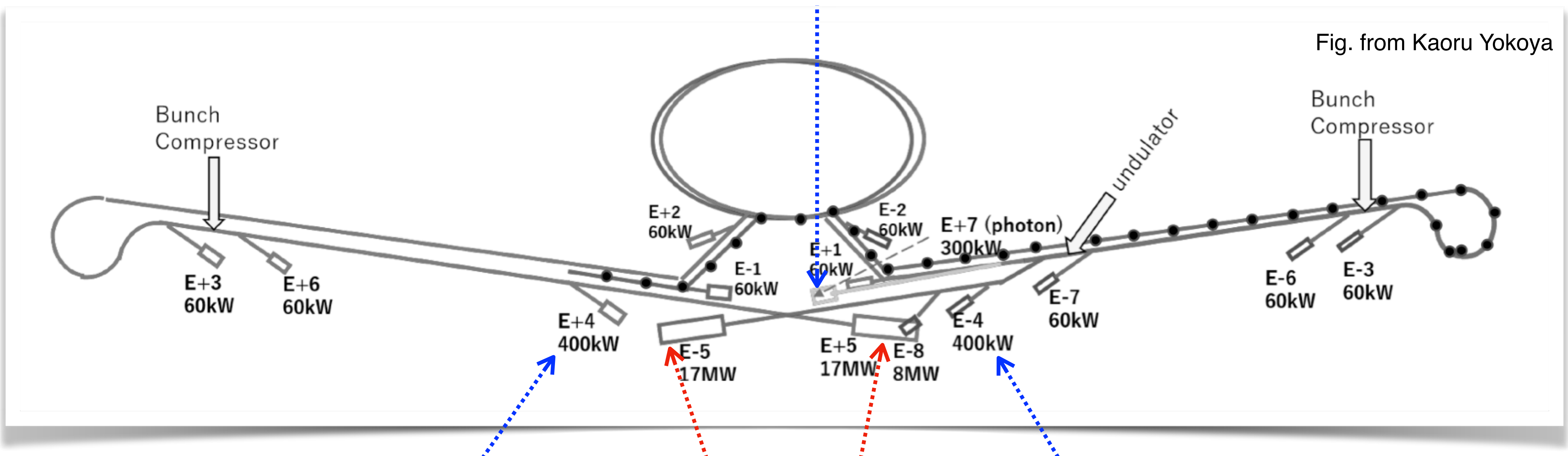


Beams are always dumped

Collider Expt. and Beam dump Expt. coexist naturally

15 Beam dumps at ILC

Photon beam dump



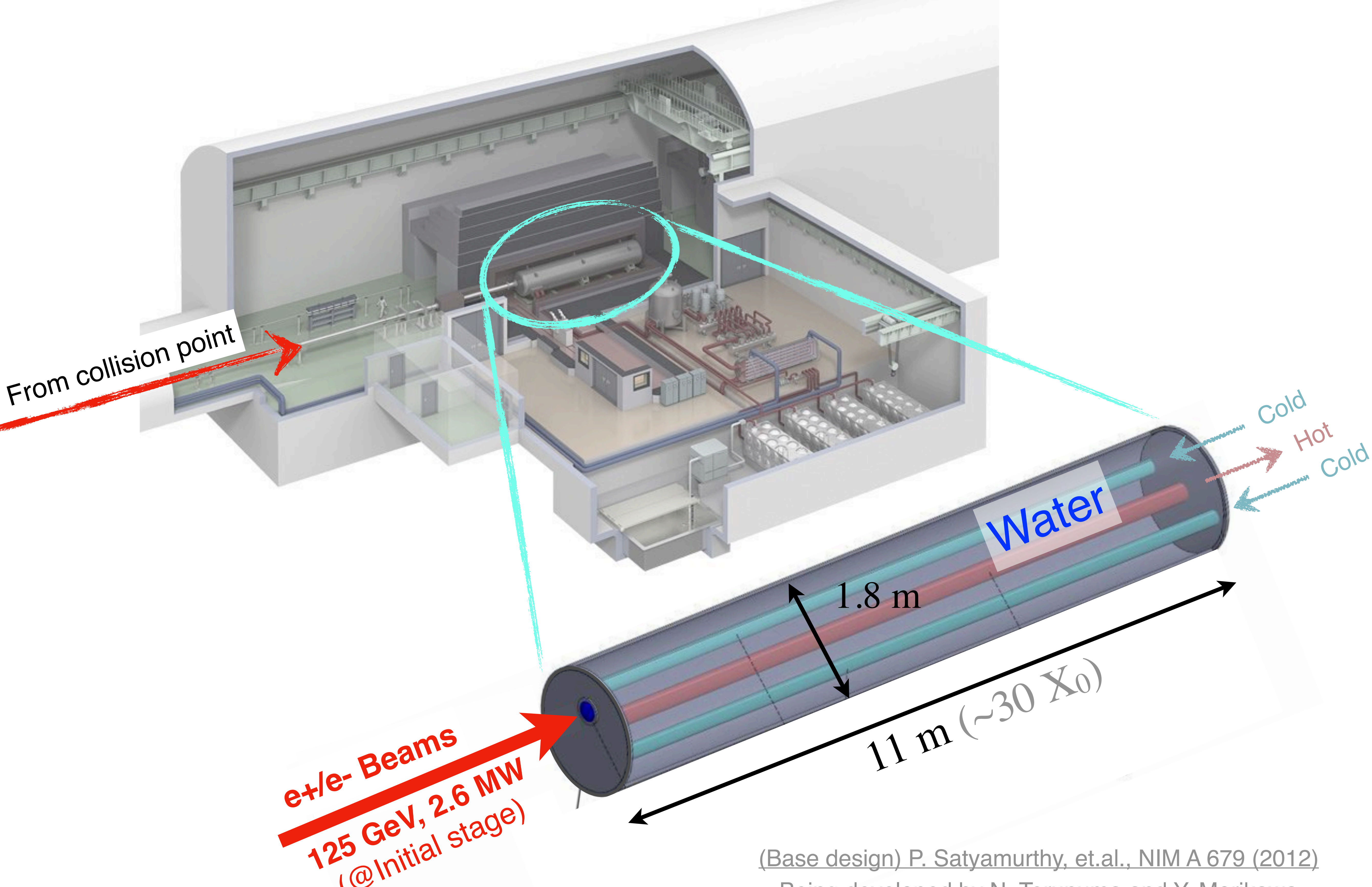
Tune-up dump for e+

Main beam dumps

Tune-up dump for e-

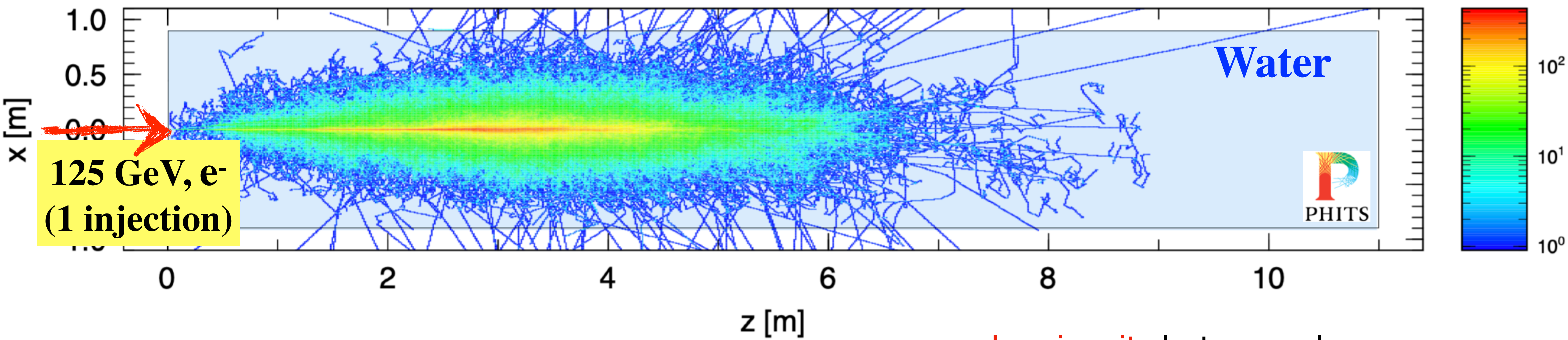
Focus on the potential of main beam dumps

Main beam dumps

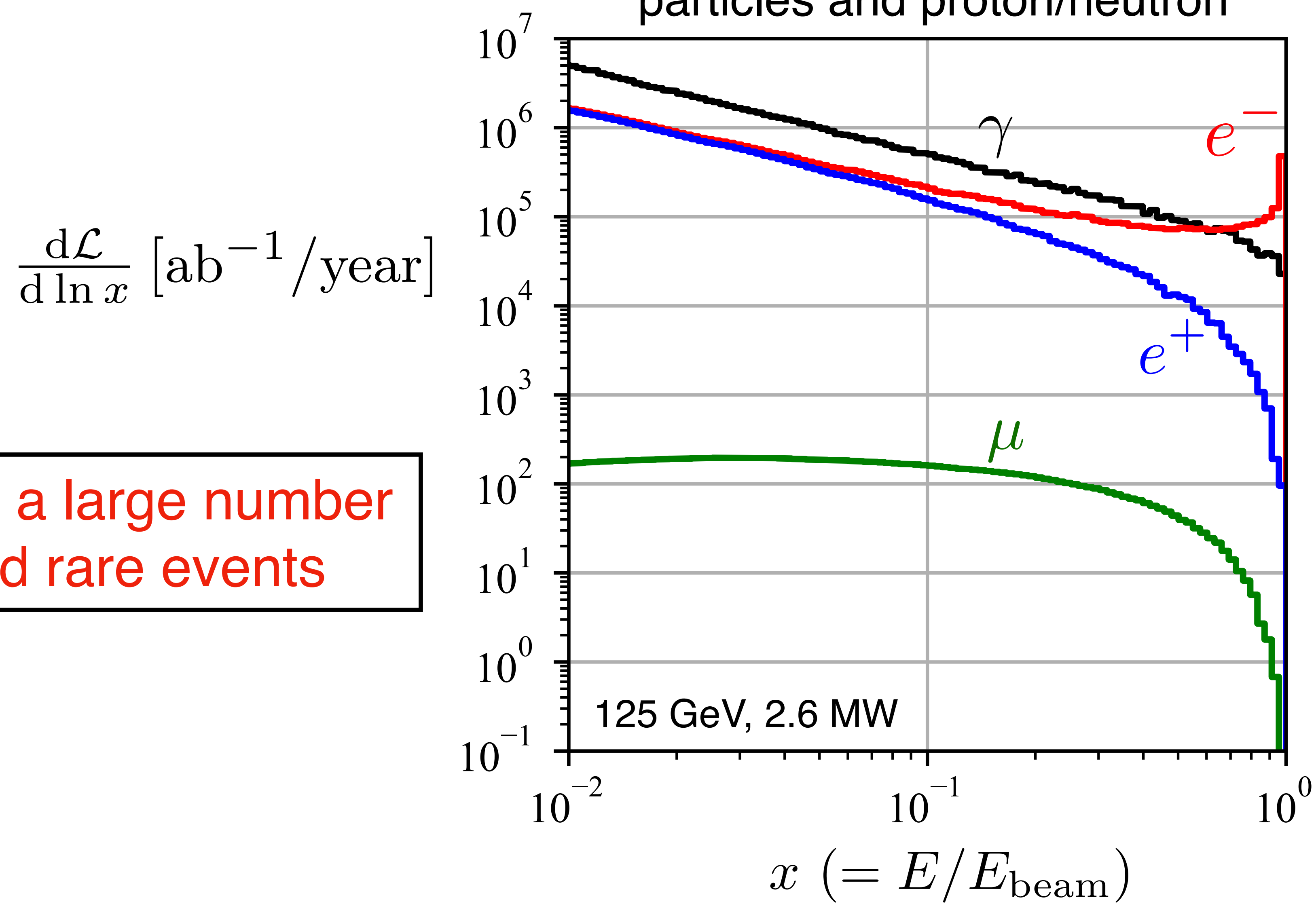


(Base design) P. Satyamurthy, et.al., NIM A 679 (2012)
Being developed by N. Terunuma and Y. Morikawa

Secondary particles



Luminosity between shower particles and proton/neutron



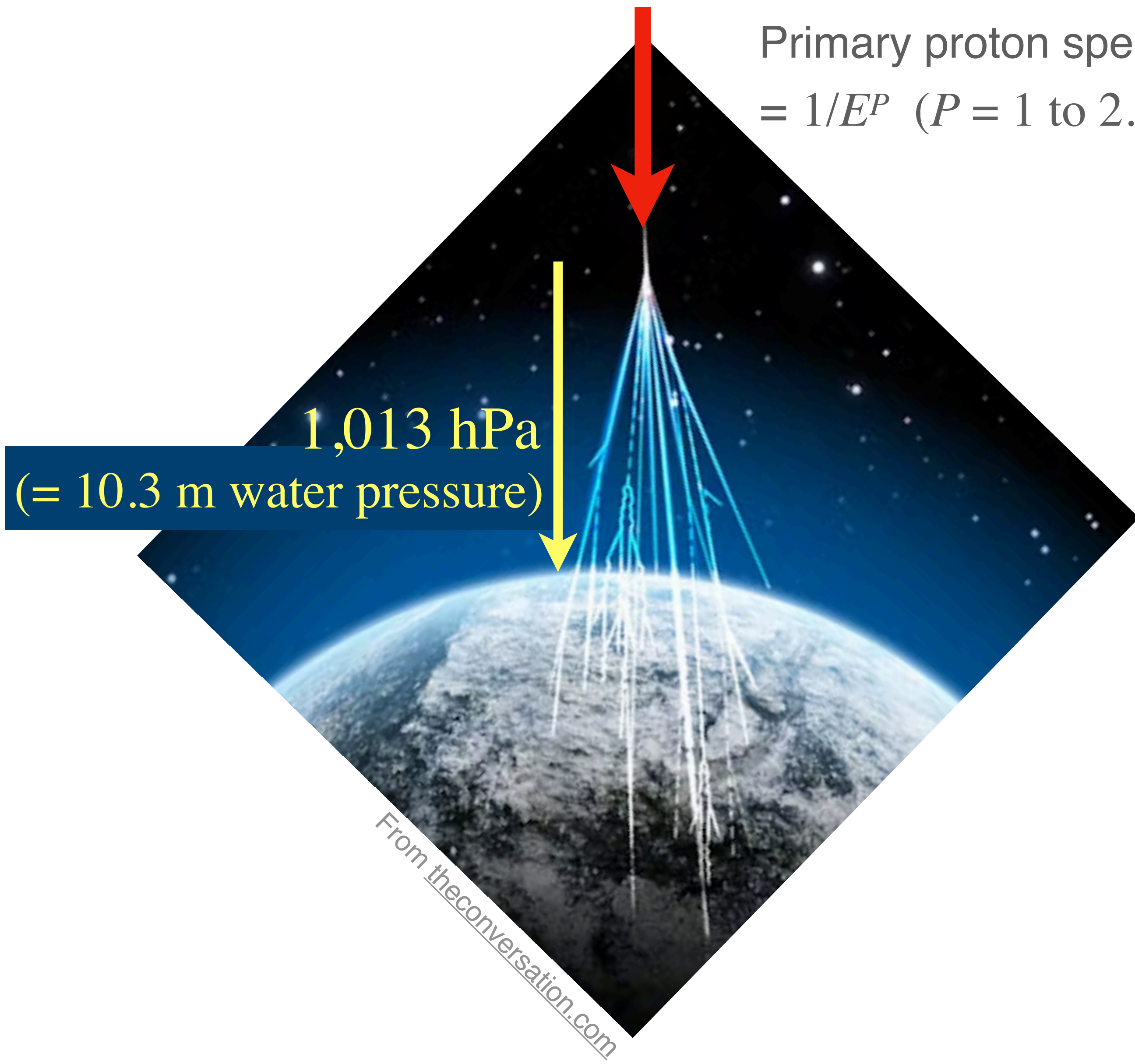
Shower particles can create a large number of secondary particles and rare events

Application examples of the main beam dump:

(1) Large-area irradiation field

(2) New physics search

ILC beam dumps may provide atmospheric-like radiation fields



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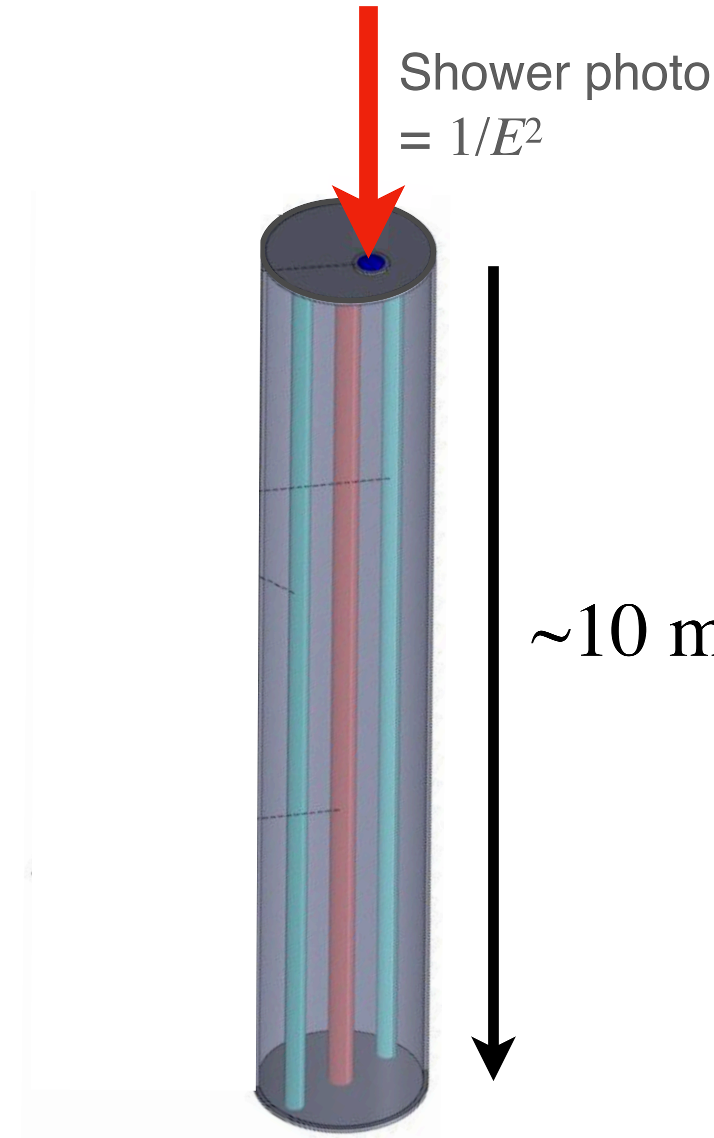
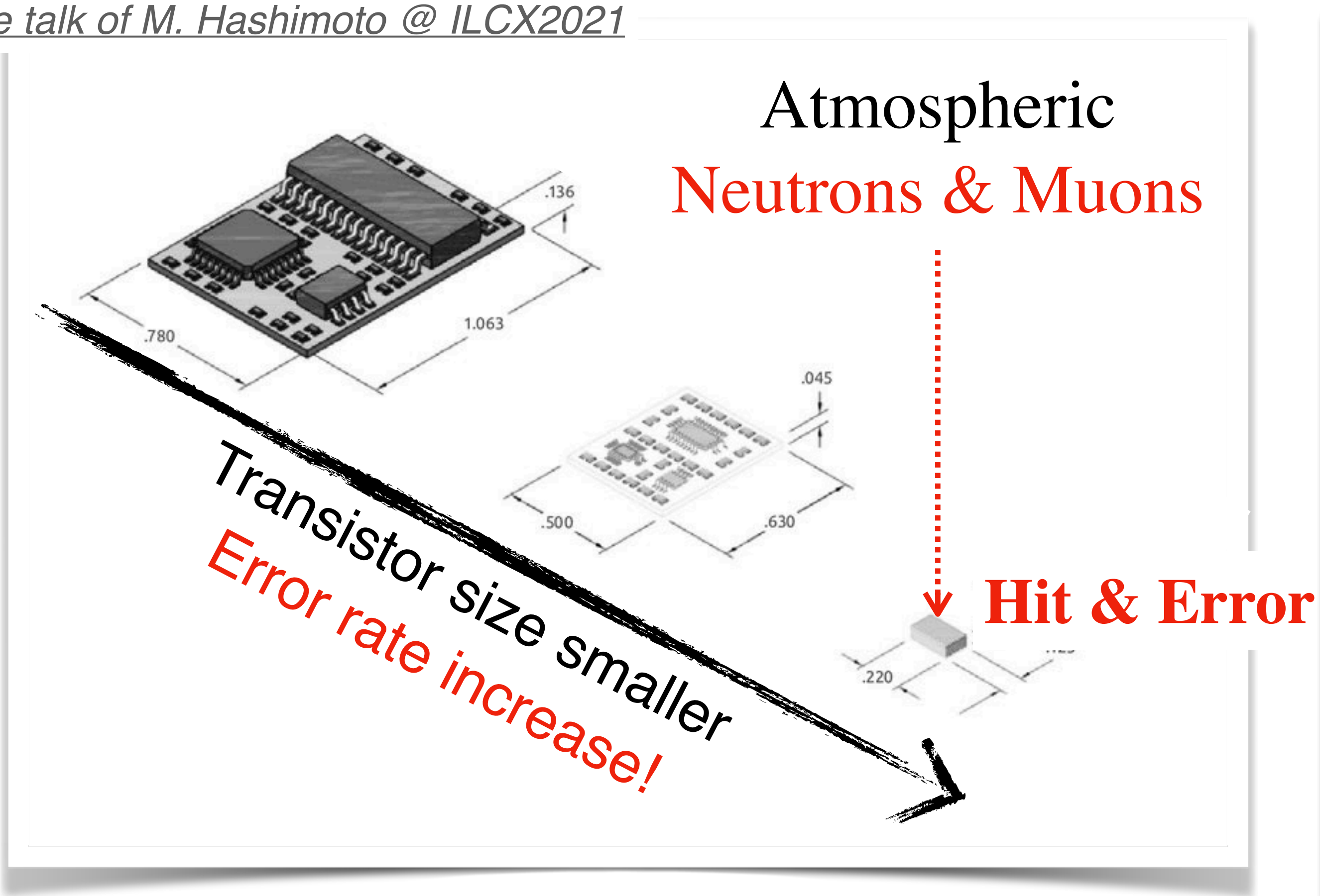


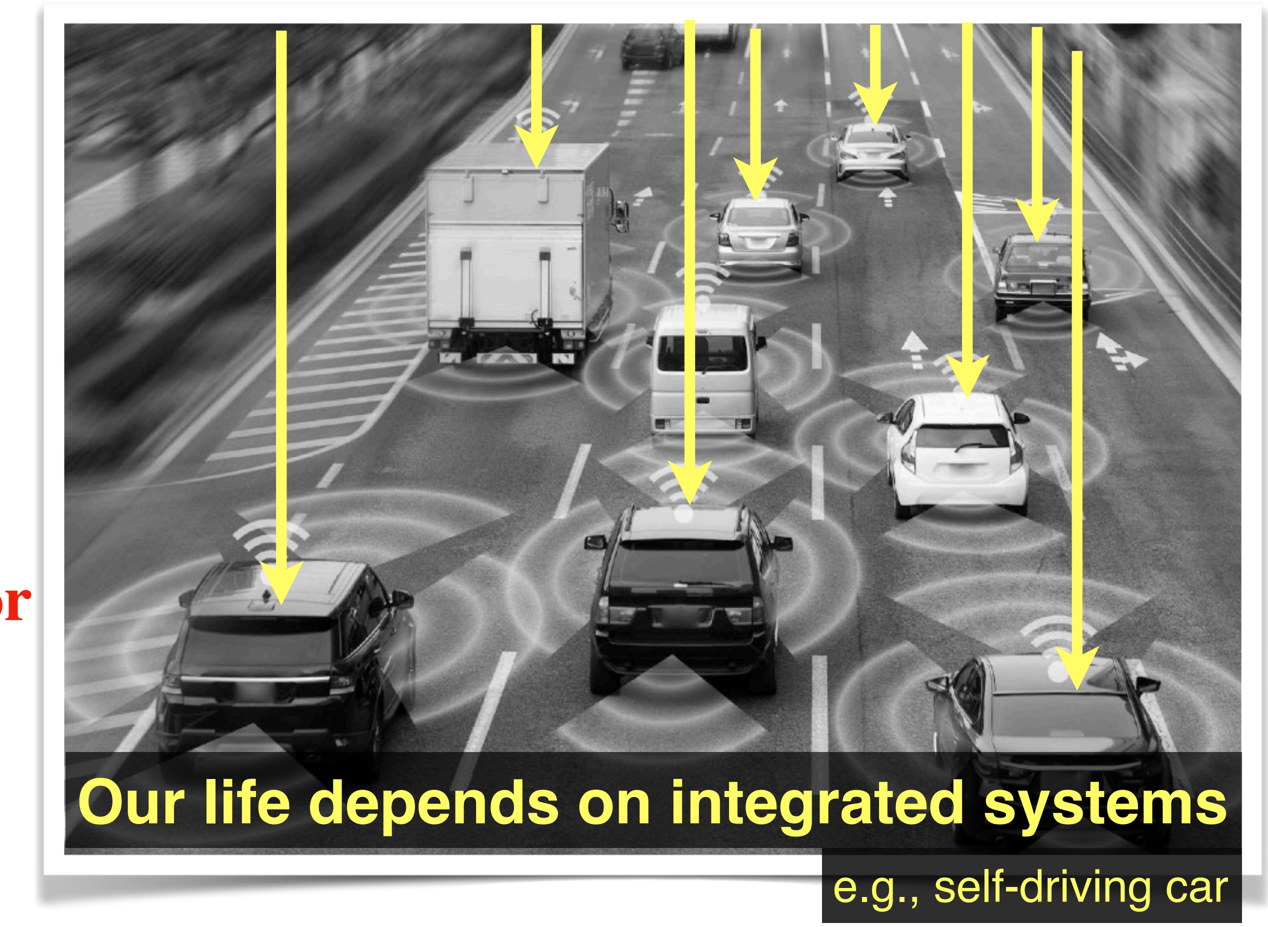
- Material of the same weight as the ILC beam dump is piled up on the ground.

Atmospheric-like radiation field is needed for **soft error** studies

- Soft error is a temporary malfunction of transistor, mainly caused by atmospheric neutrons and muons.

See talk of M. Hashimoto @ ILCX2021

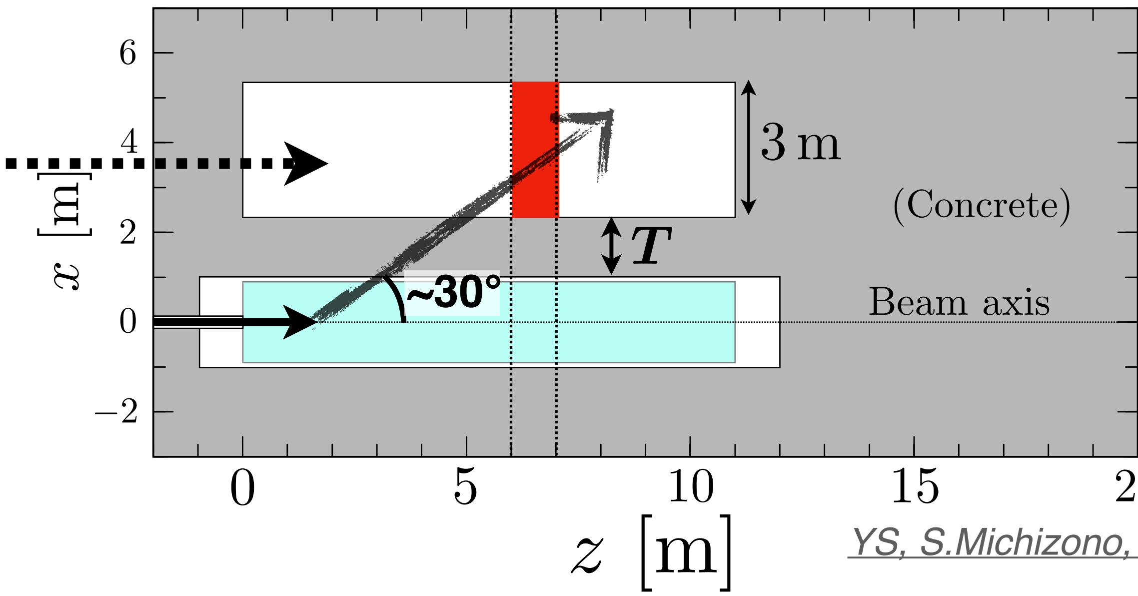




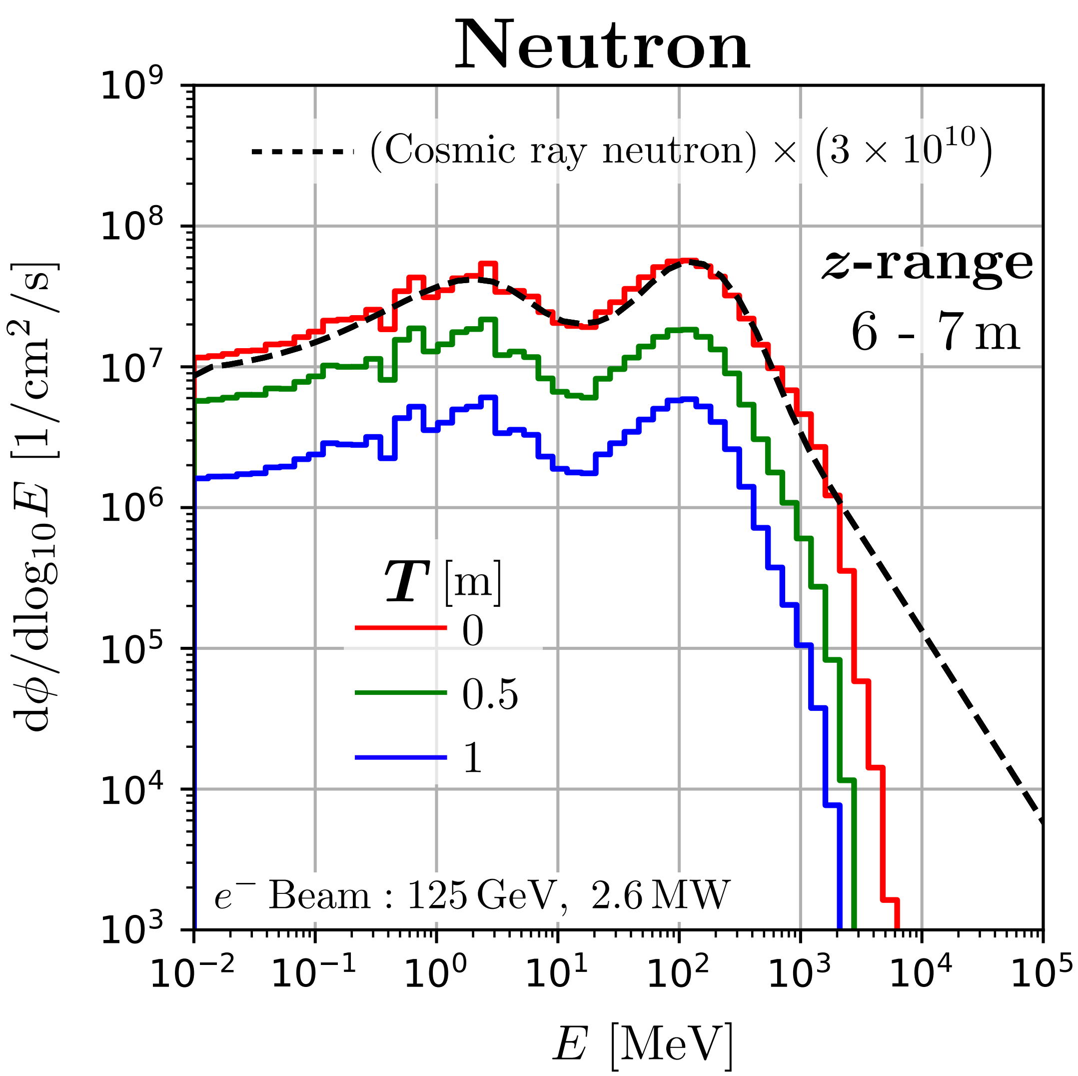
- Irradiation fields that provide *high-intensity*, *large-area*, and *atmospheric-like spectra* are favored.

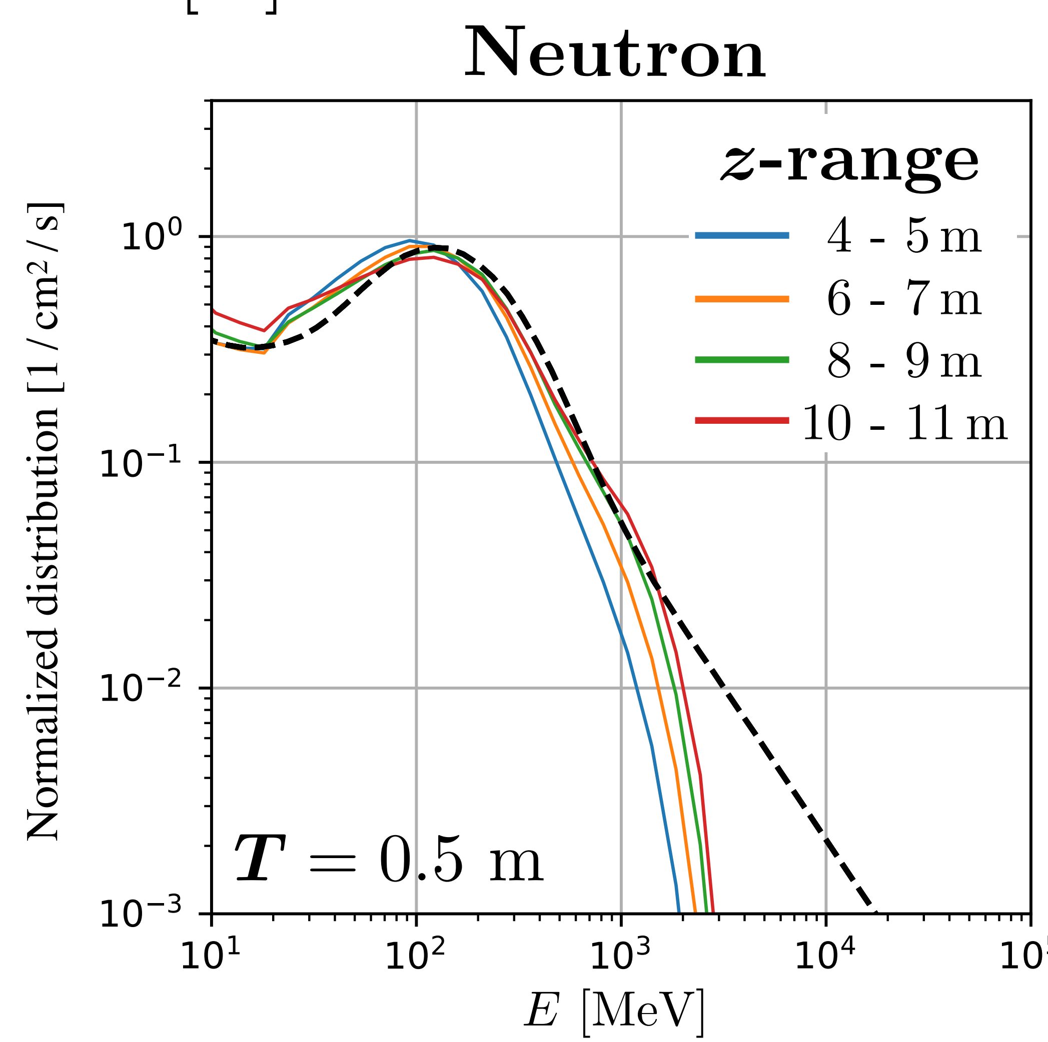
Neutrons and muons at ILC beam dump have atmospheric-like spectra?

Space beside beam dump



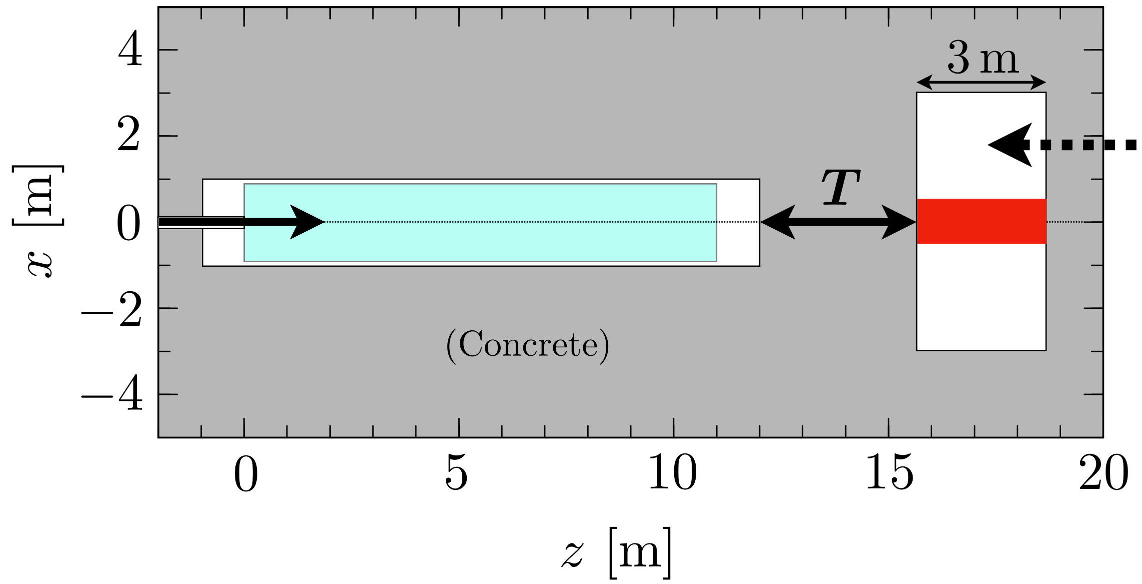
YS, S.Michizono, N.Terunuma, T.Sanami. 2210.08690



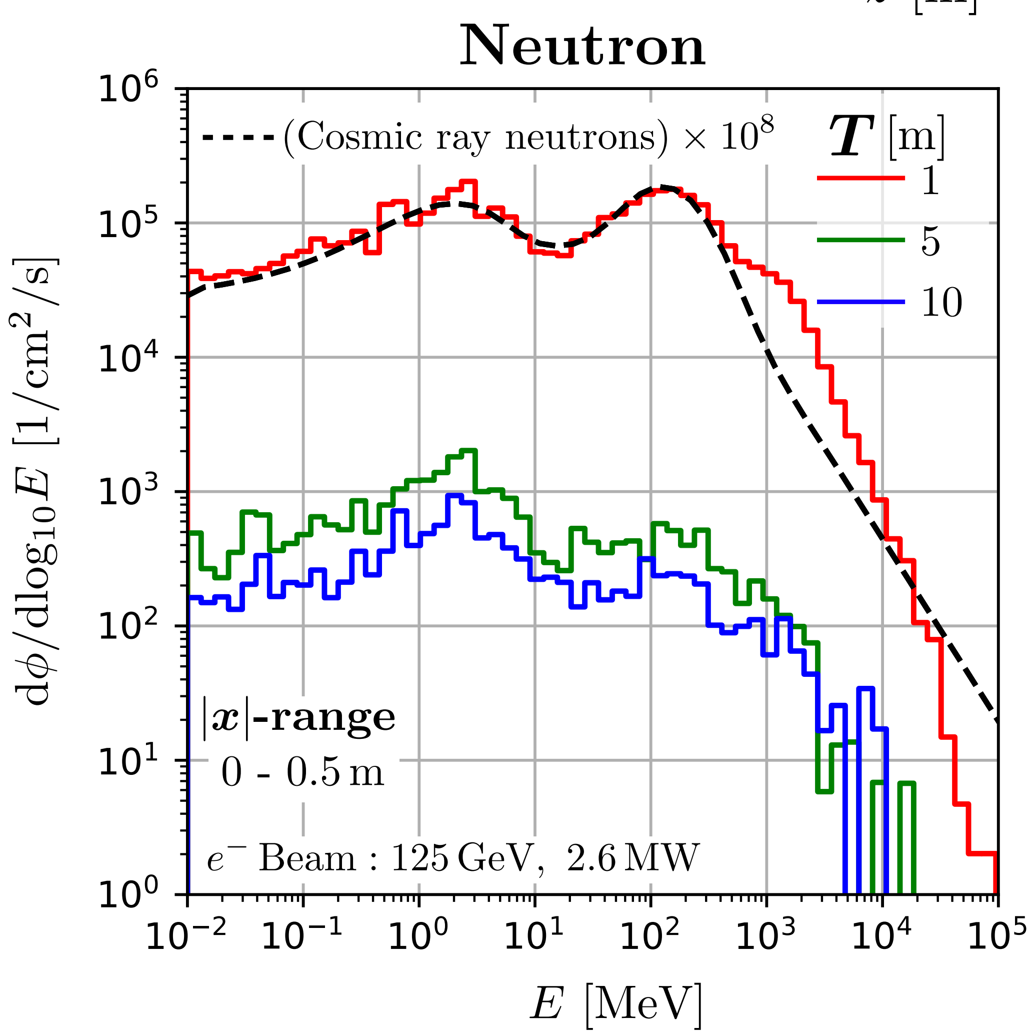


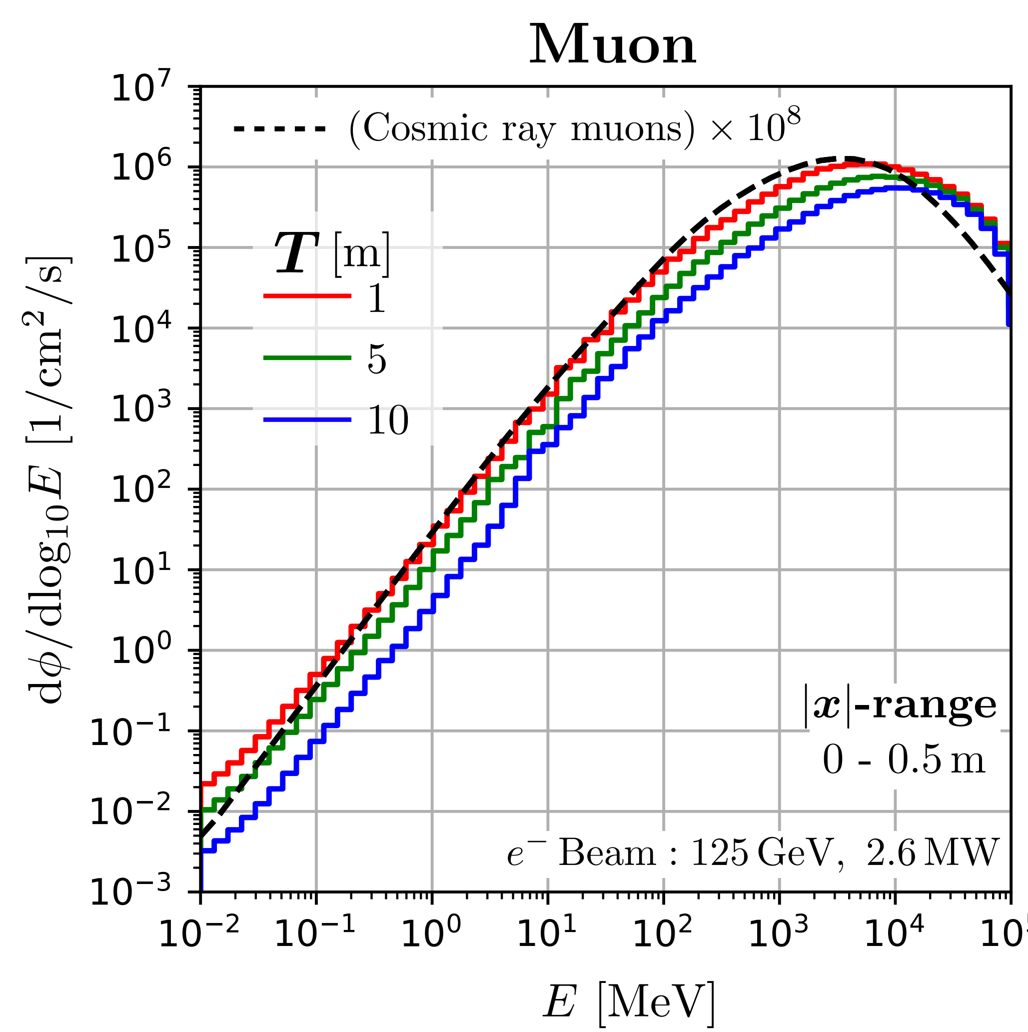
- Atmospheric-like neutrons are obtained. (consistent up to a few GeV!)
  - ➡ High-energy tail behavior slightly depends on z-range
  - ➡ Especially consistent at z=6-7m (~30 degrees)

YS, S.Michizono, N.Terunuma, T.Sanami. 2210.08690



Downstream of beam dump





- Both neutrons and muons have atmospheric-like spectra.
- Muon dominant beam is available with thick shielding.

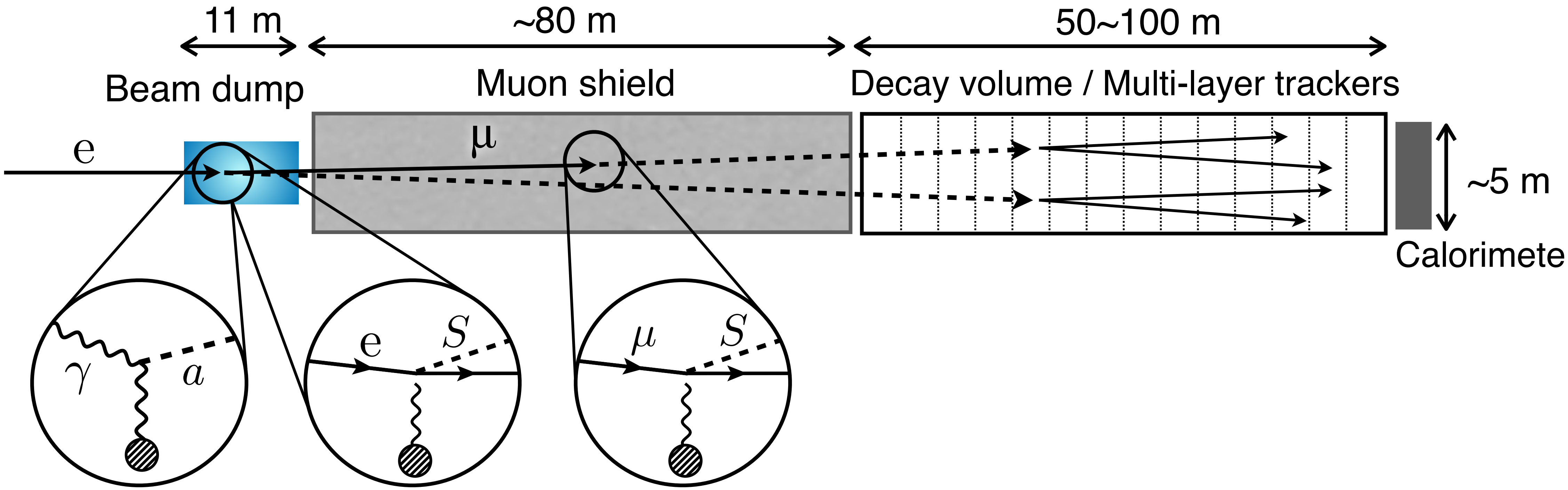
ILC can also be used for industrial studies.

Application examples of the main beam dump:

(1) Large-area irradiation field

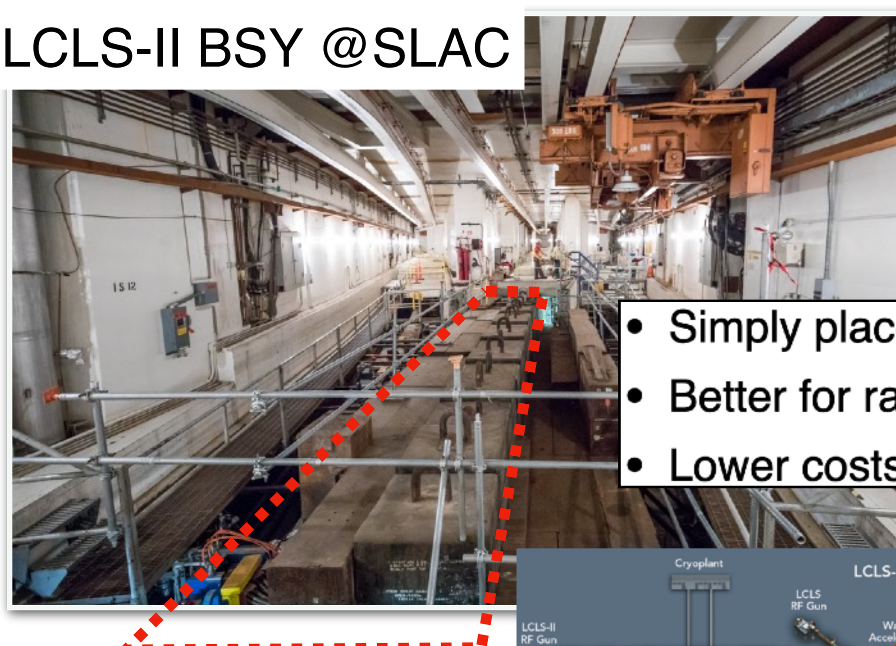
(2) New physics search

Main beam dump experiment



Passive muon shield

LCLS-II BSY @SLAC



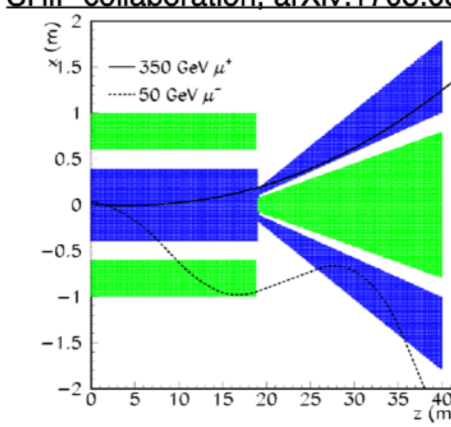
- Simply placed heavy objects
- Better for radiation issues
- Lower costs?

Iron blocks for muon

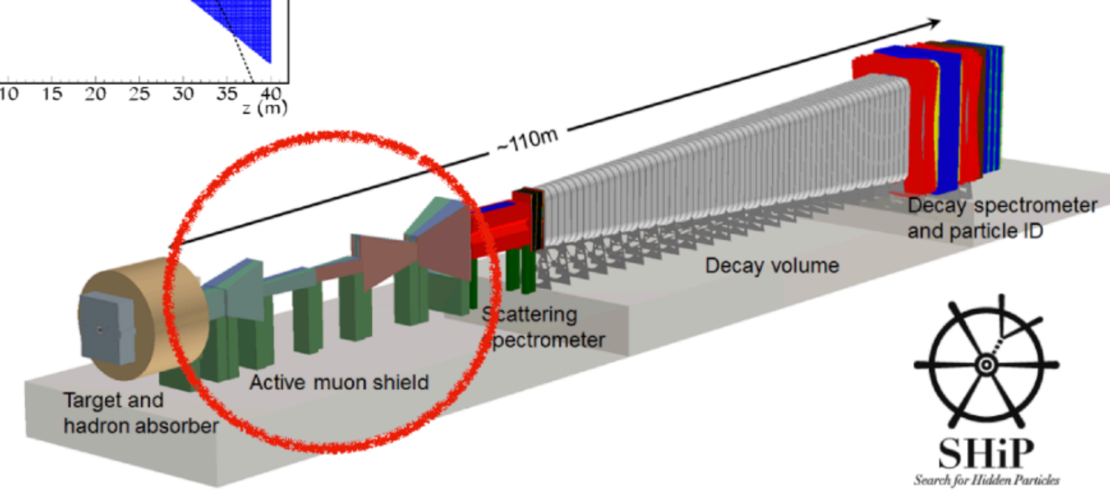
(for radiation safety)

Active muon shield

SHiP collaboration, arXiv:1703.03612

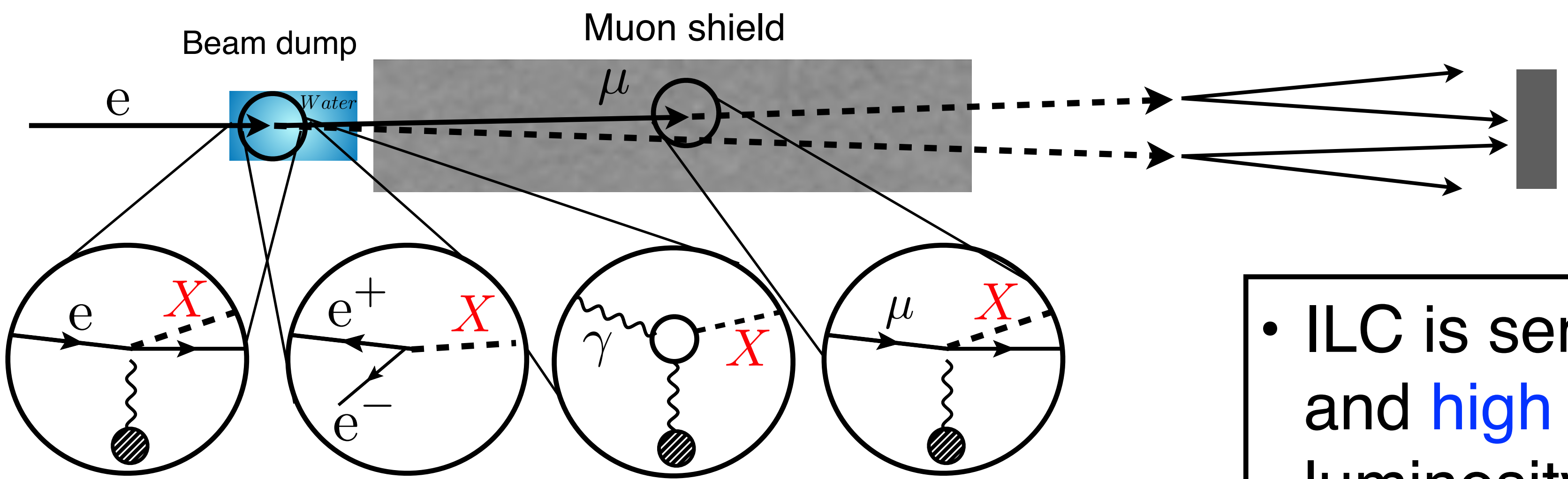


- Magnetic shielding
- Effective even at High-Energy ILC



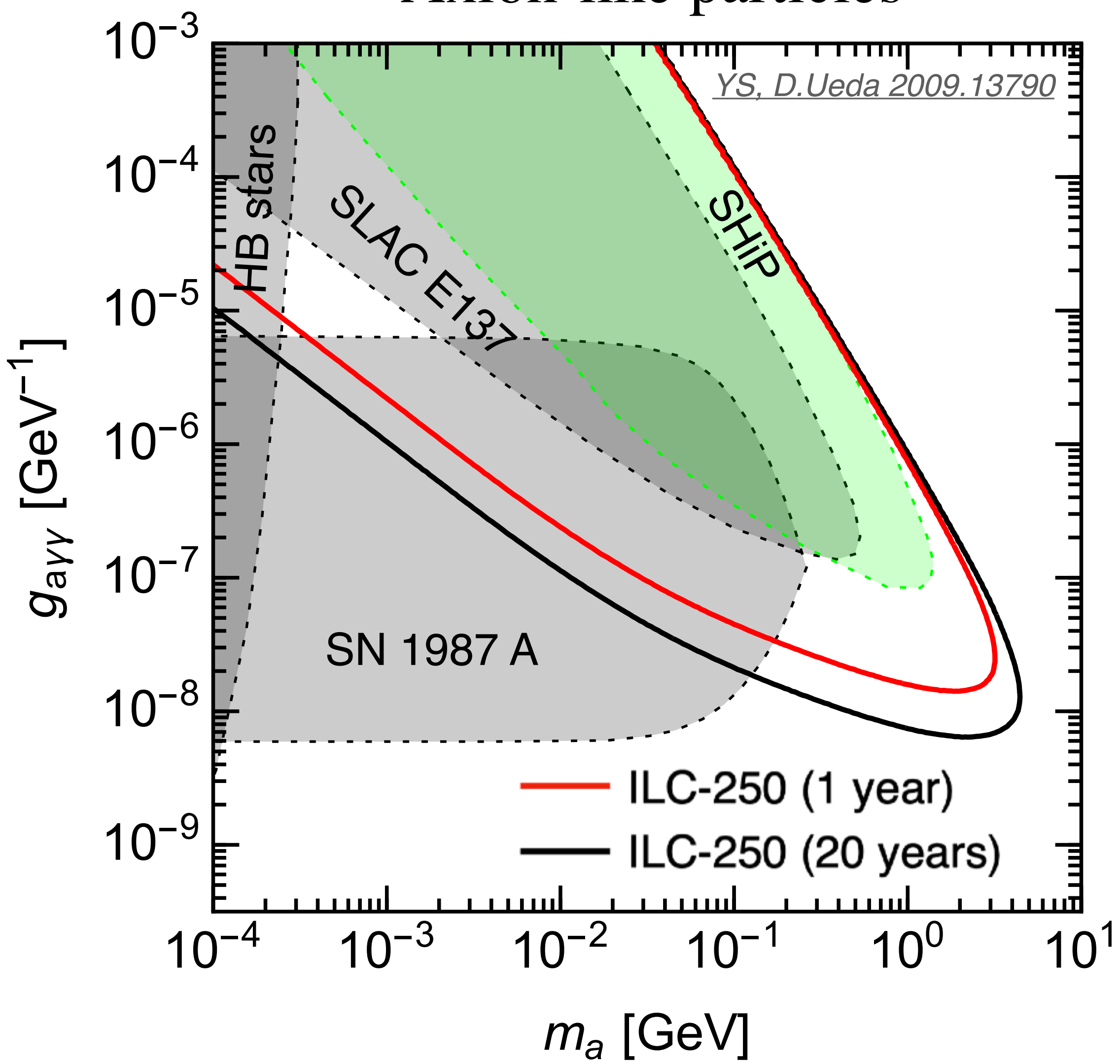
New particles from shower particles

1st study: S.Kanemura, T.Moroi, T.Tanabe, 1507.02809

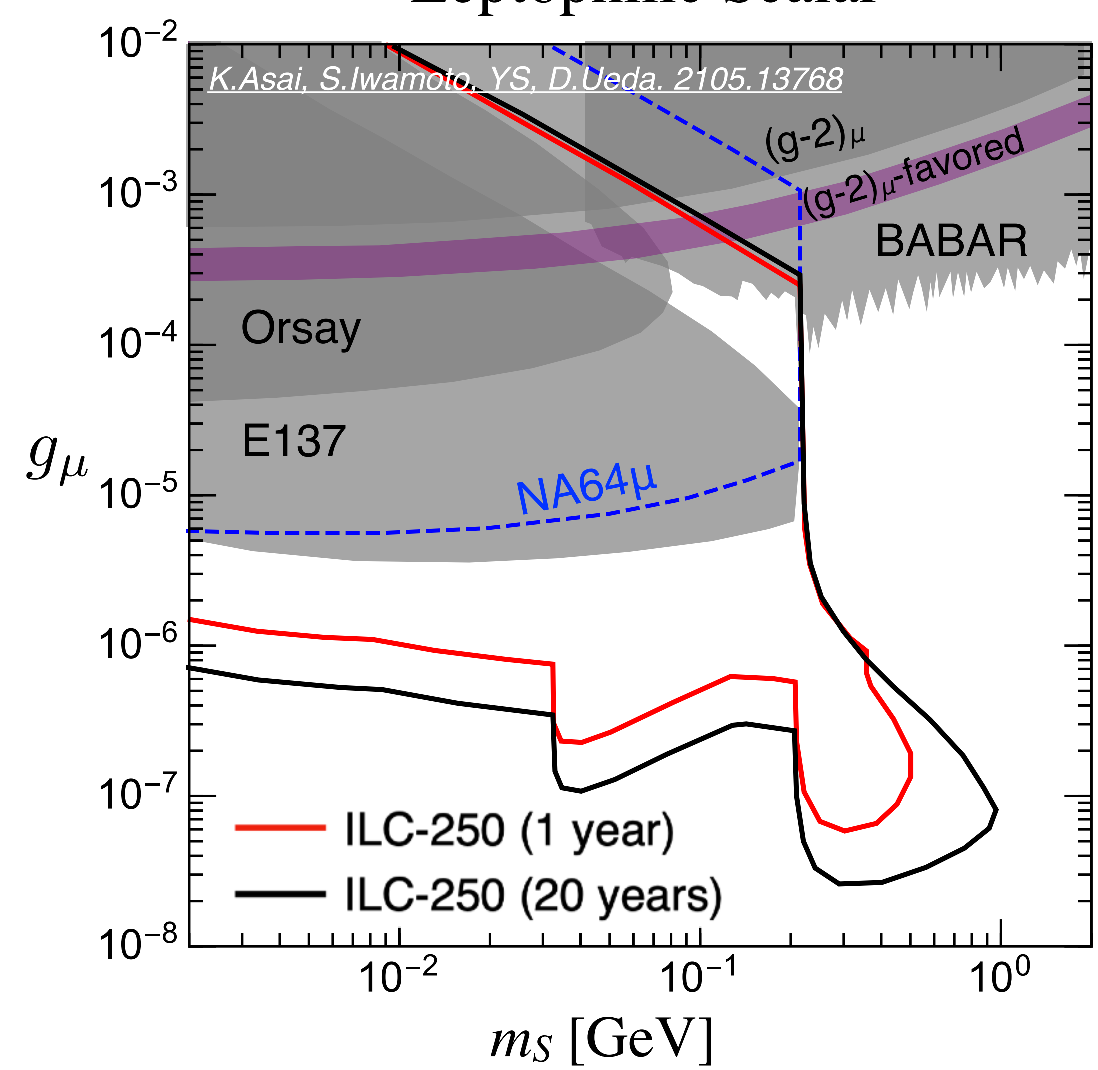


- ILC is sensitive to small coupling and high mass region due to its large luminosity and energy

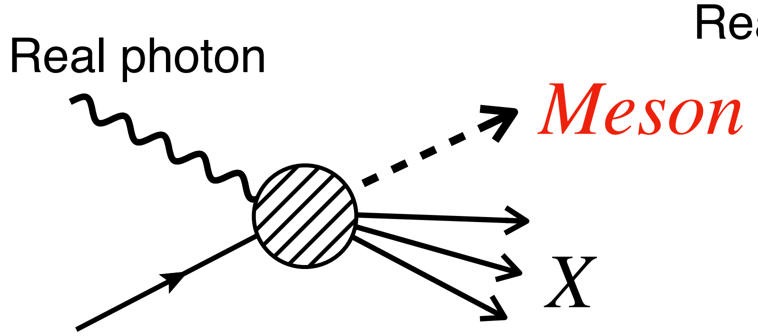
Axion-like particles



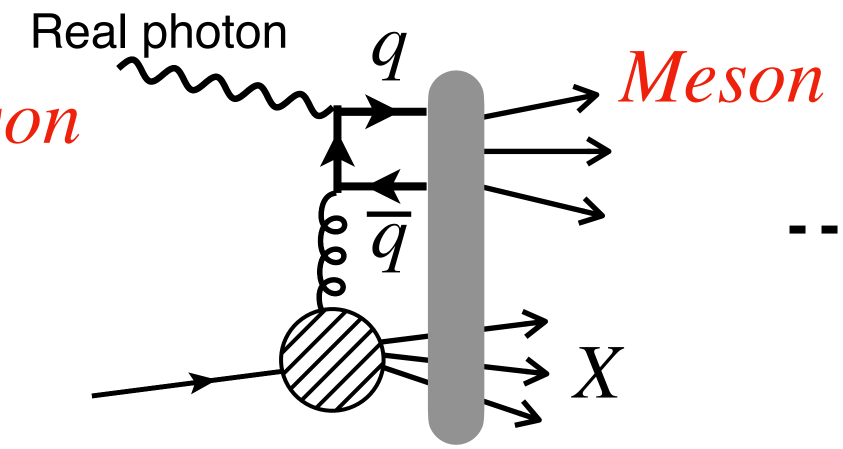
Leptophilic Scalar



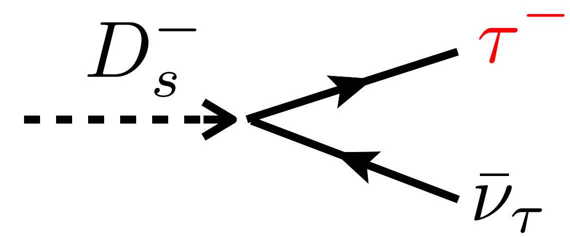
Heavy mesons & Tau leptons



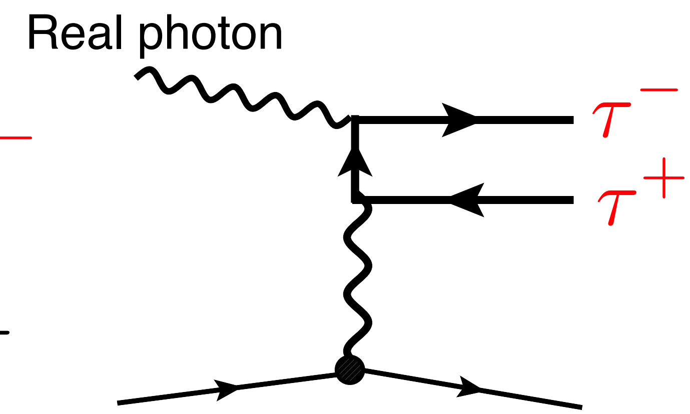
Non-diffractive



Hard QCD

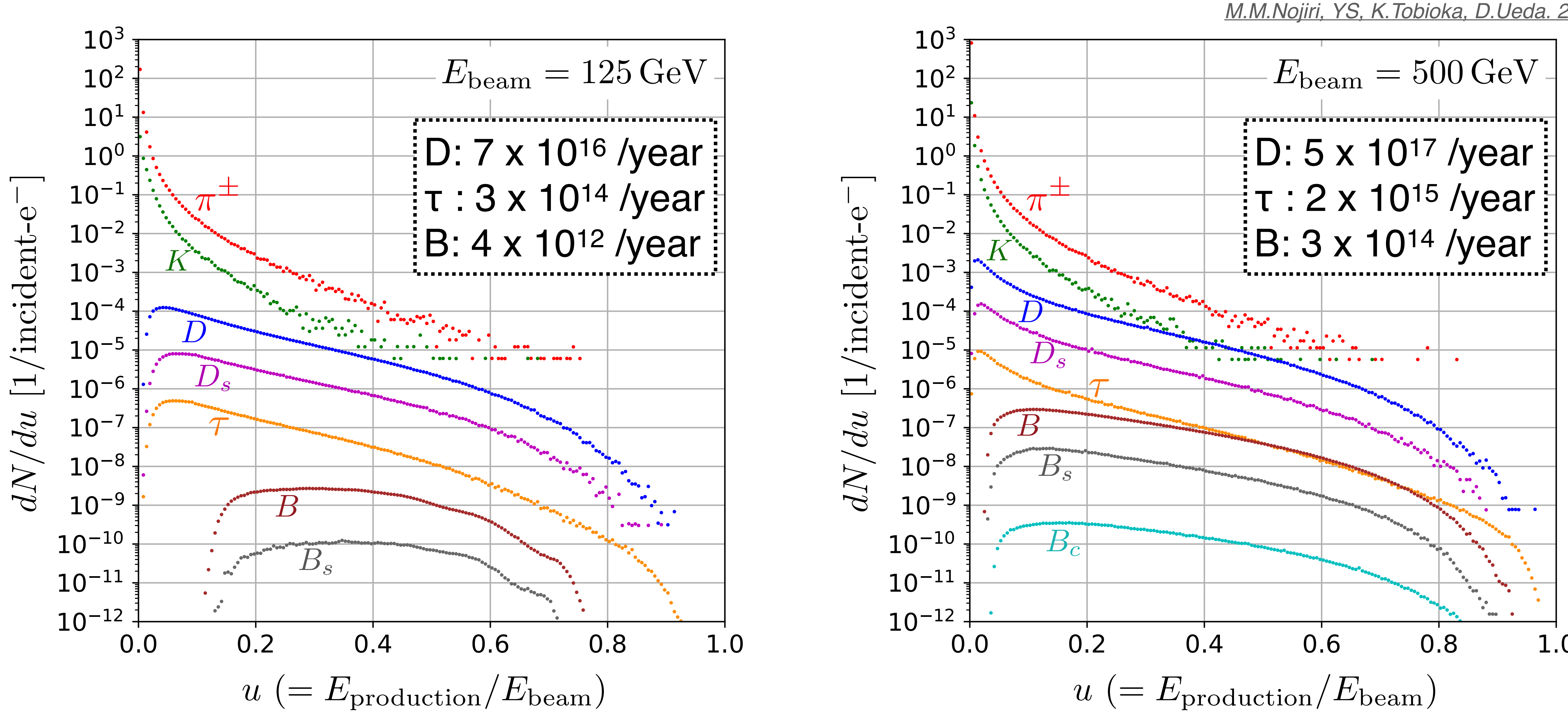


Br = 5.48 %



Coherent, Quasi-elastic, Inelastic

M.M.Nojiri, YS, K.Tobioka, D.Ueda. 2206.13523

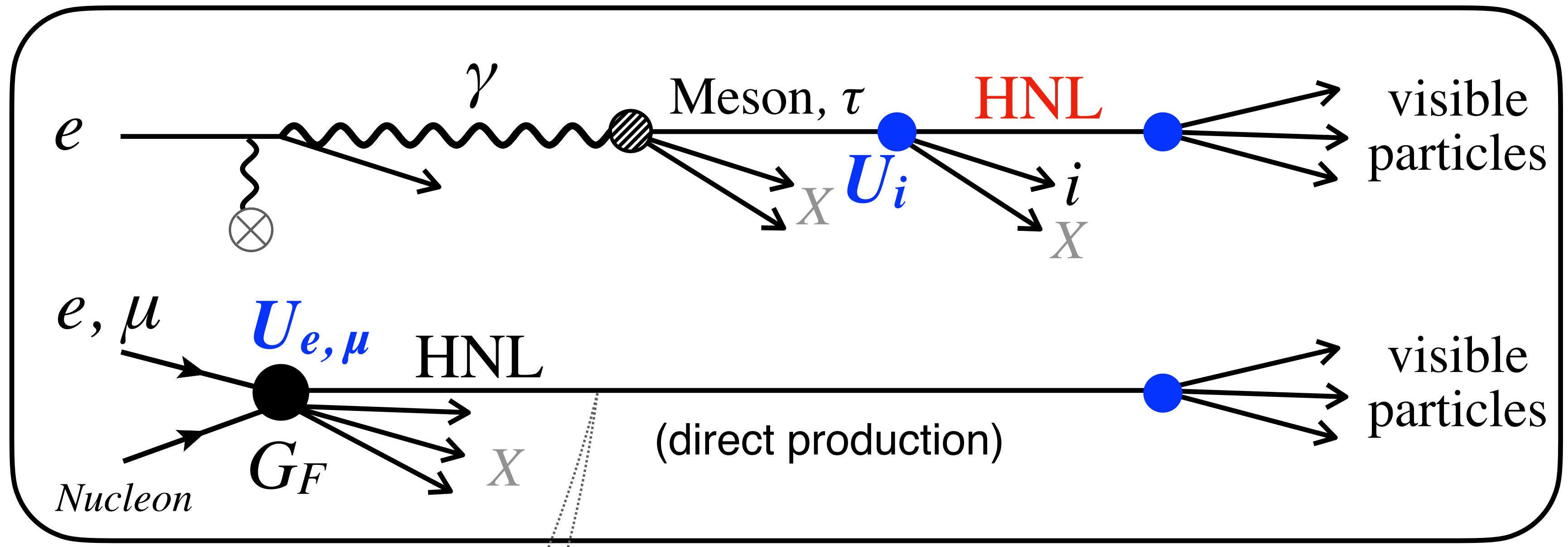


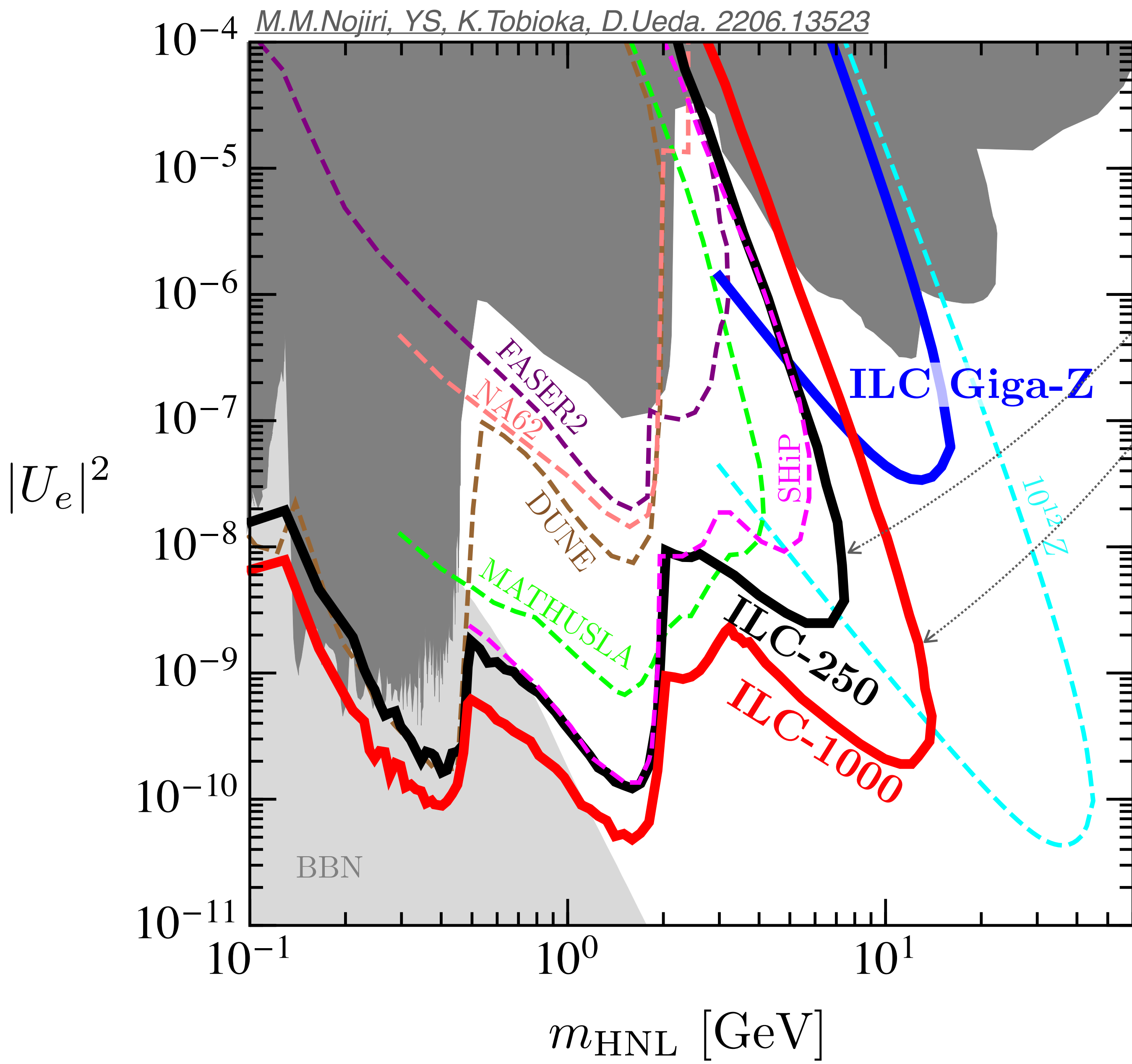
Heavy Neutral Leptons (HNLs)

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

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

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



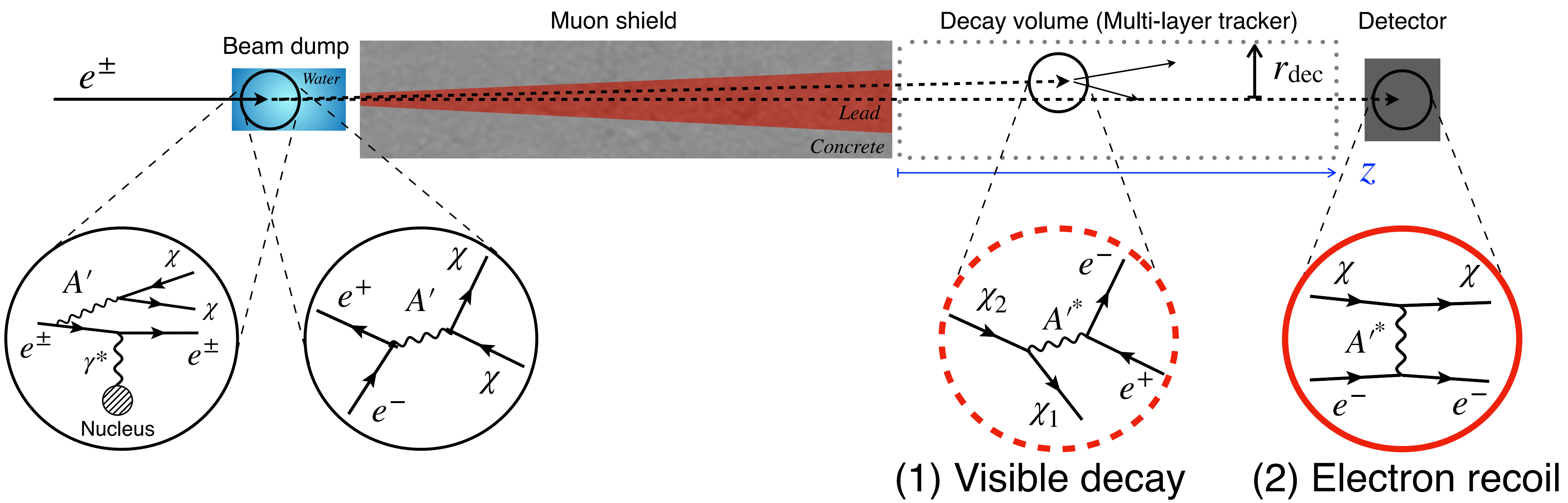


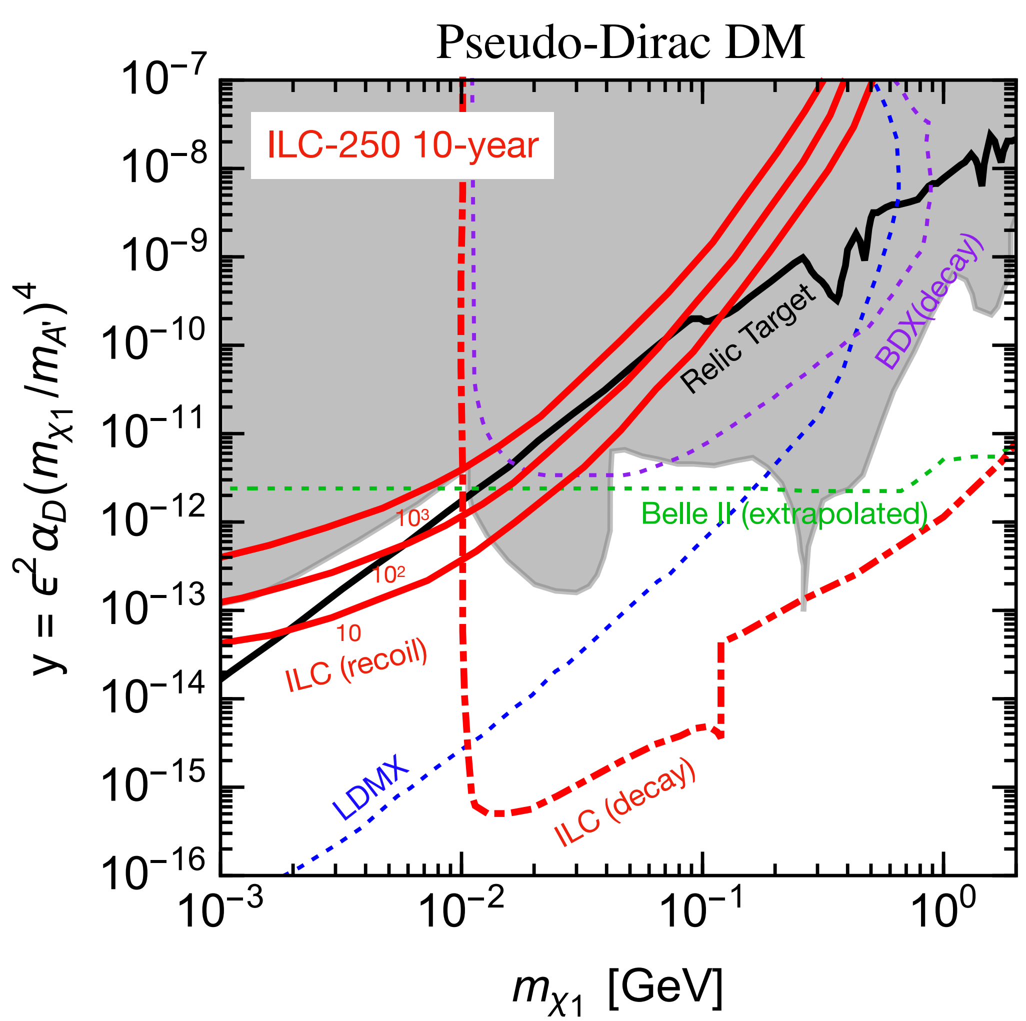
- Beam dump Expt. and ILC Collider Expt. is complementary
- HNL direct production from e± expand sensitivity at high mass region

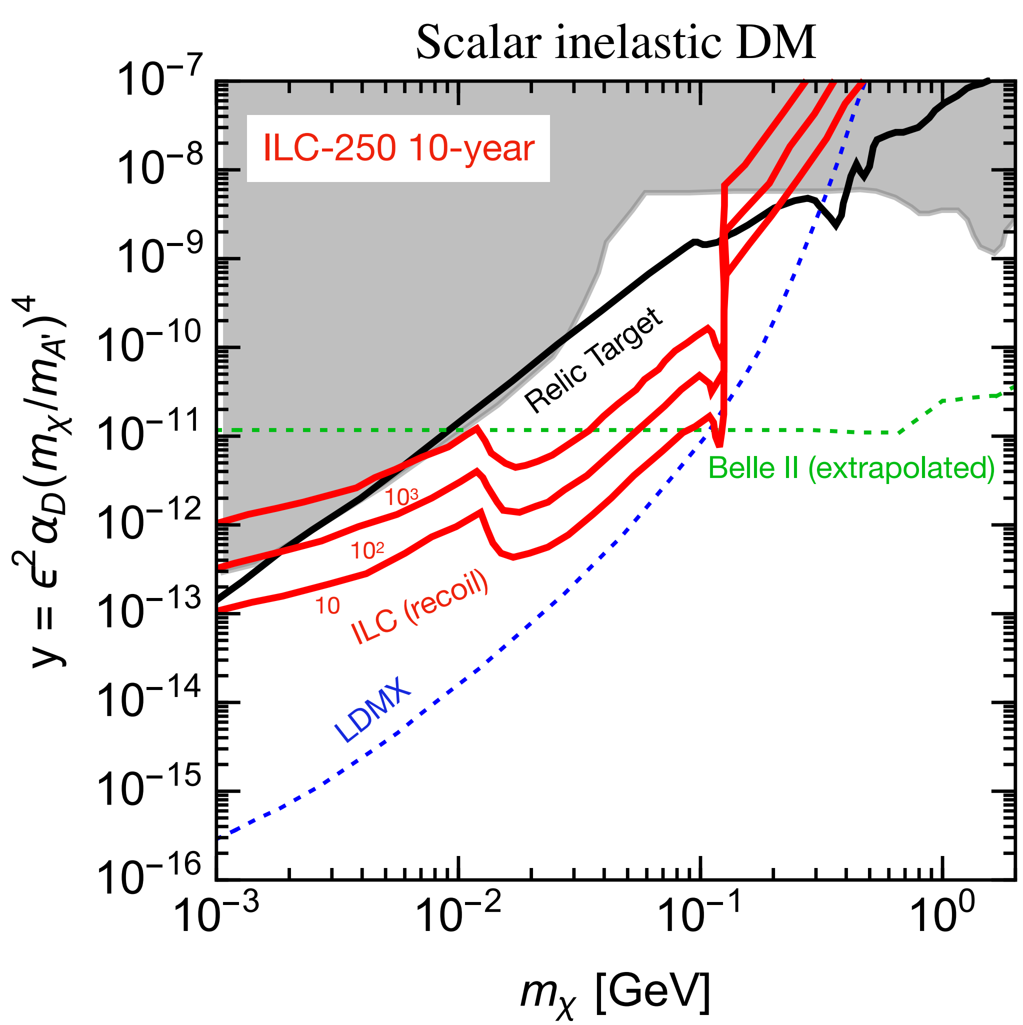
Dark matter

K.Asai, S.Iwamoto, M.Perelstein, YS, D.Ueda. 2301.03816

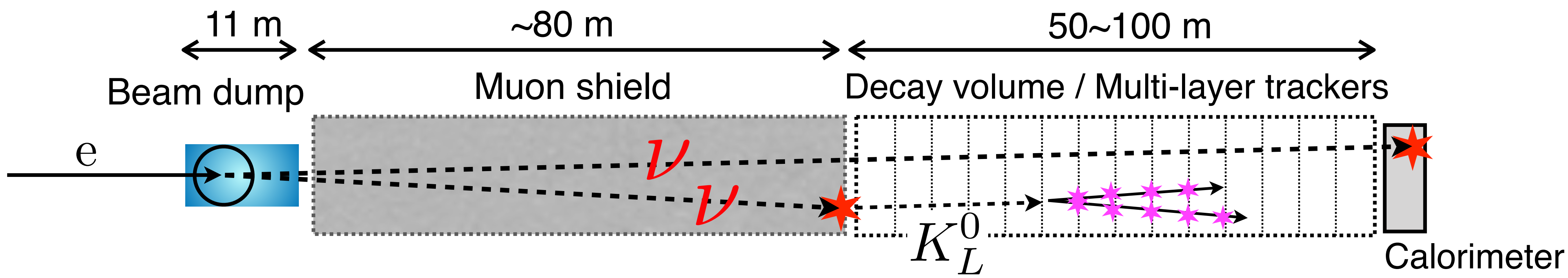
Similar to BDX@JLab







Background



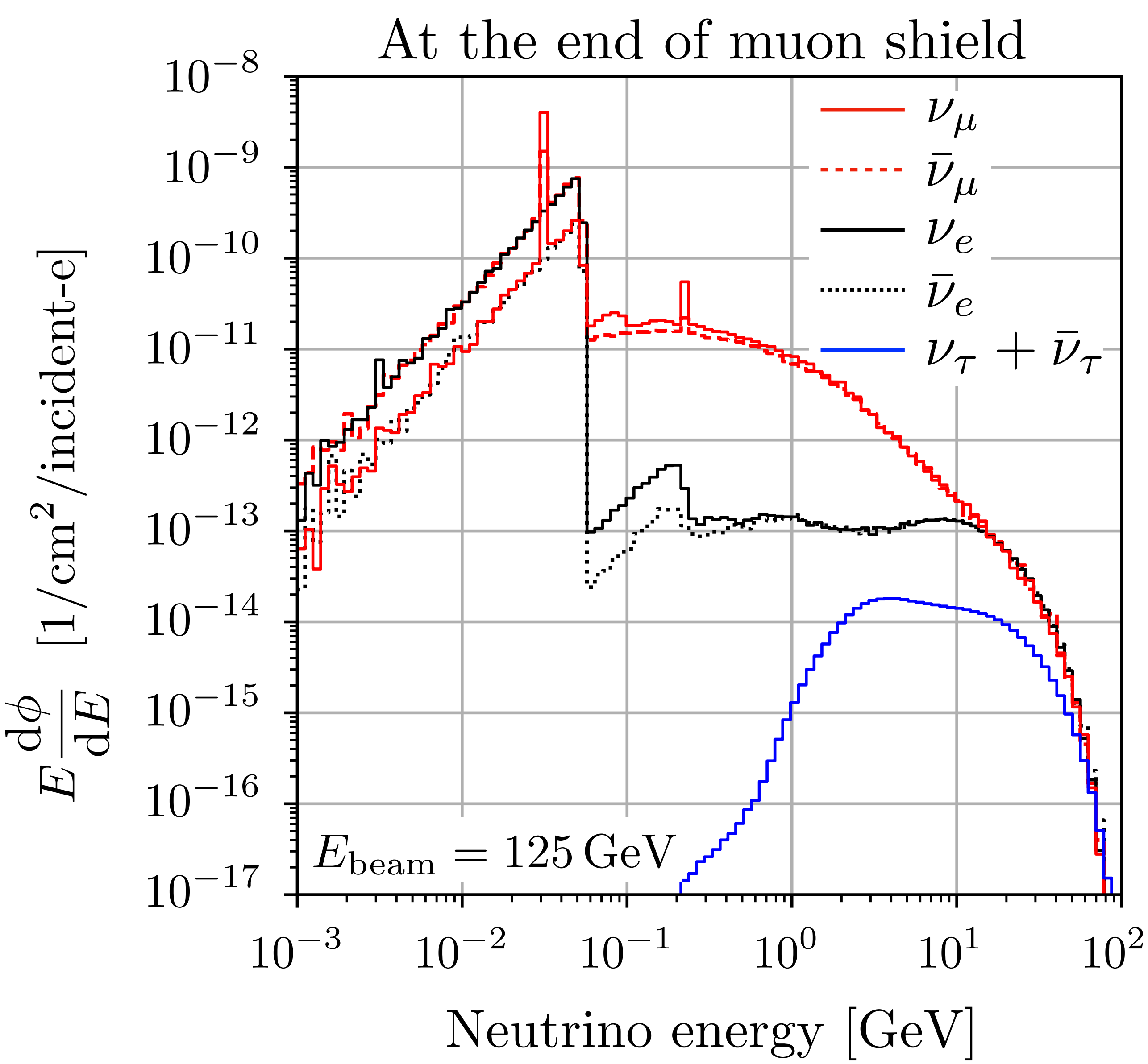
The neutrinos hit:

- the end of the muon shield
- the wall surrounding the decay volume
- the detector

Details of BG study by SHiP Collaboration
→ arXiv: 1310.1762, 1504.04956

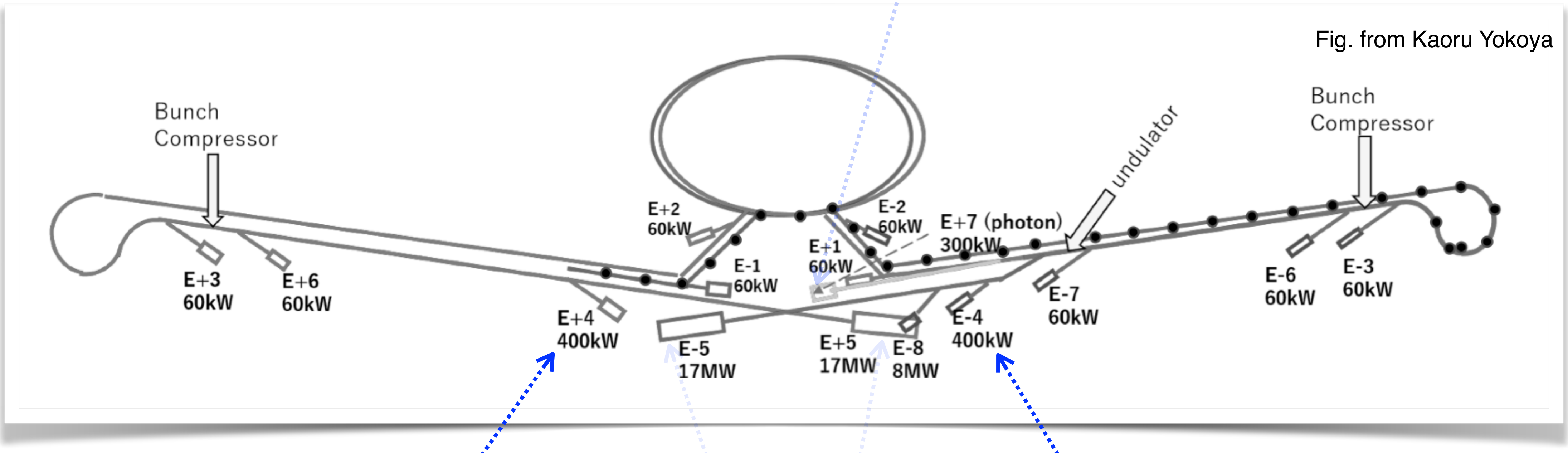
The cosmic-ray BG is negrigible due to:

- the deep underground location
- timing coincidence with the bunched beams



Other places

Photon beam dump

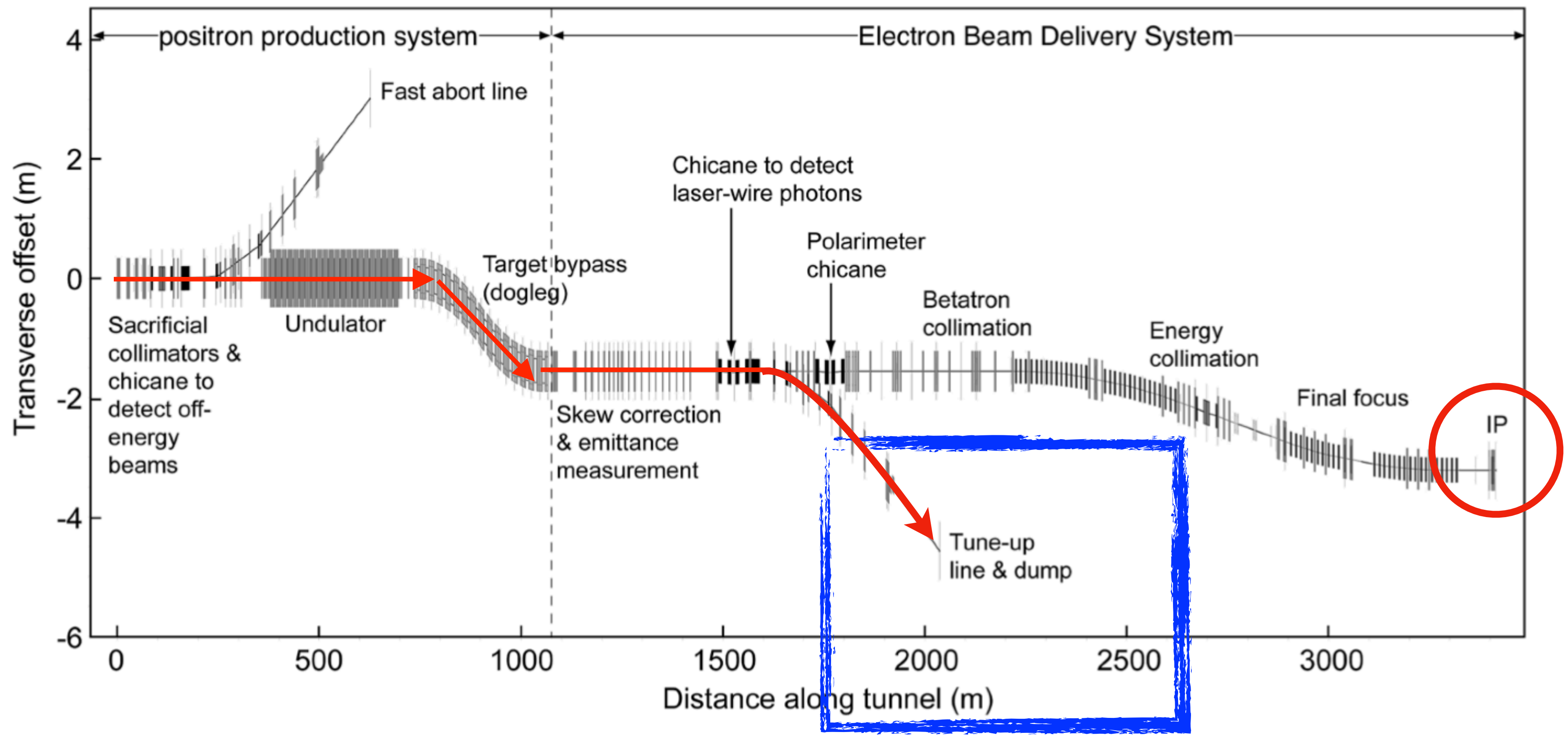


Tune-up dump
for e+

Main beam dumps

Tune-up dump
for e-

Tune-up dumps



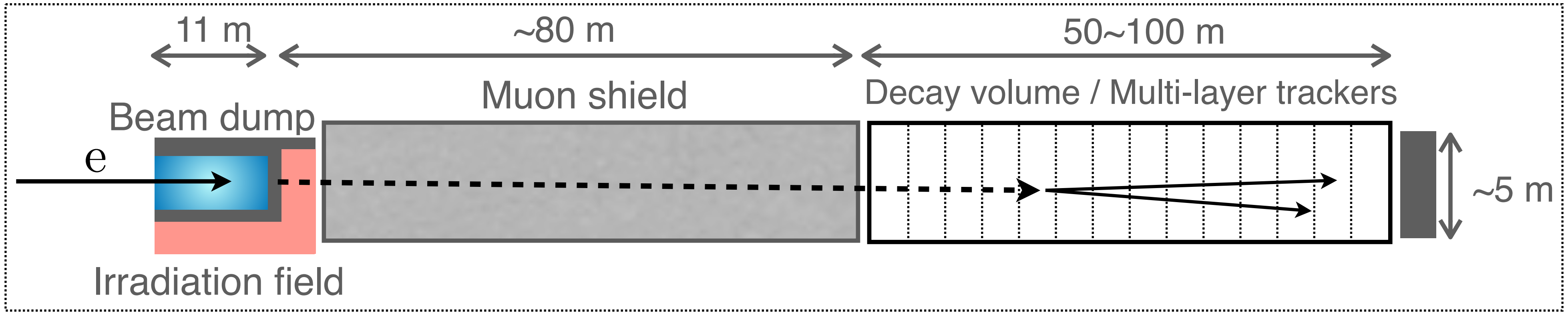
- Best place to perform dedicated experiments
  - ✓ Maximum beam energy available
  - ✓ Bunch charge can be adjusted
  - ✓ Beams in good condition before the collision is available

See talks @ILCX2021:
Strong QED with high-power laser, M.E.Peskin.
Exotic hadron photoproduction, N.Muramatsu.
...

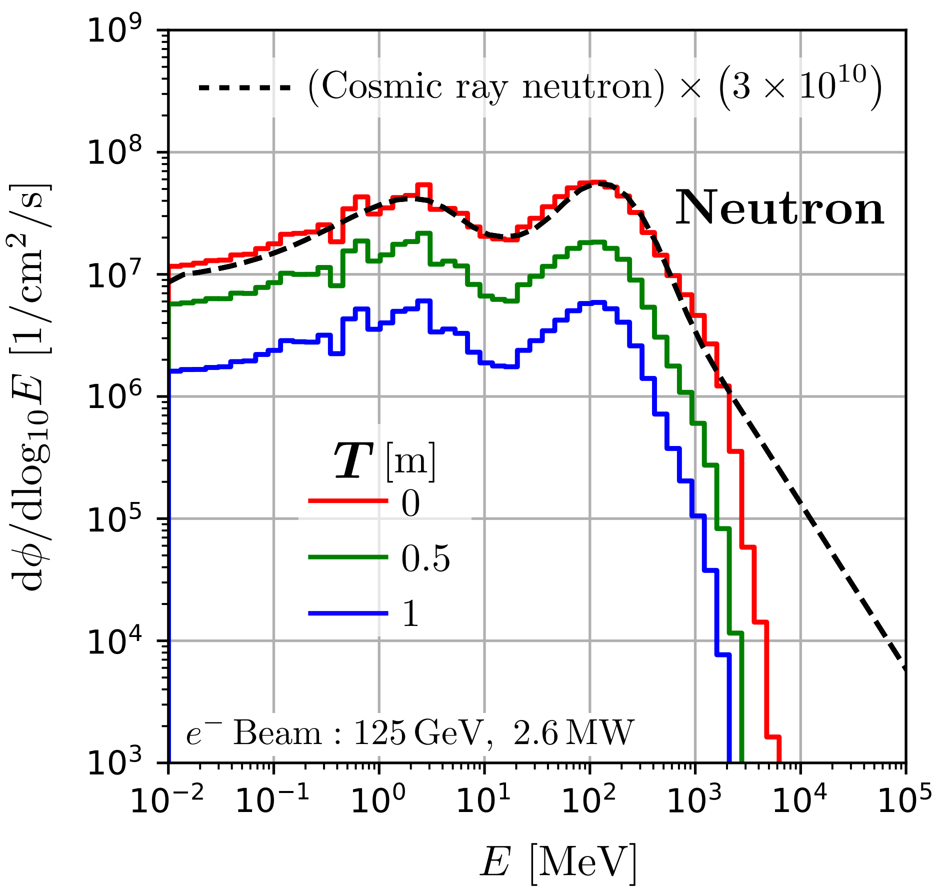
- The facility design in this area will be modified for various experimental possibilities.

Summary

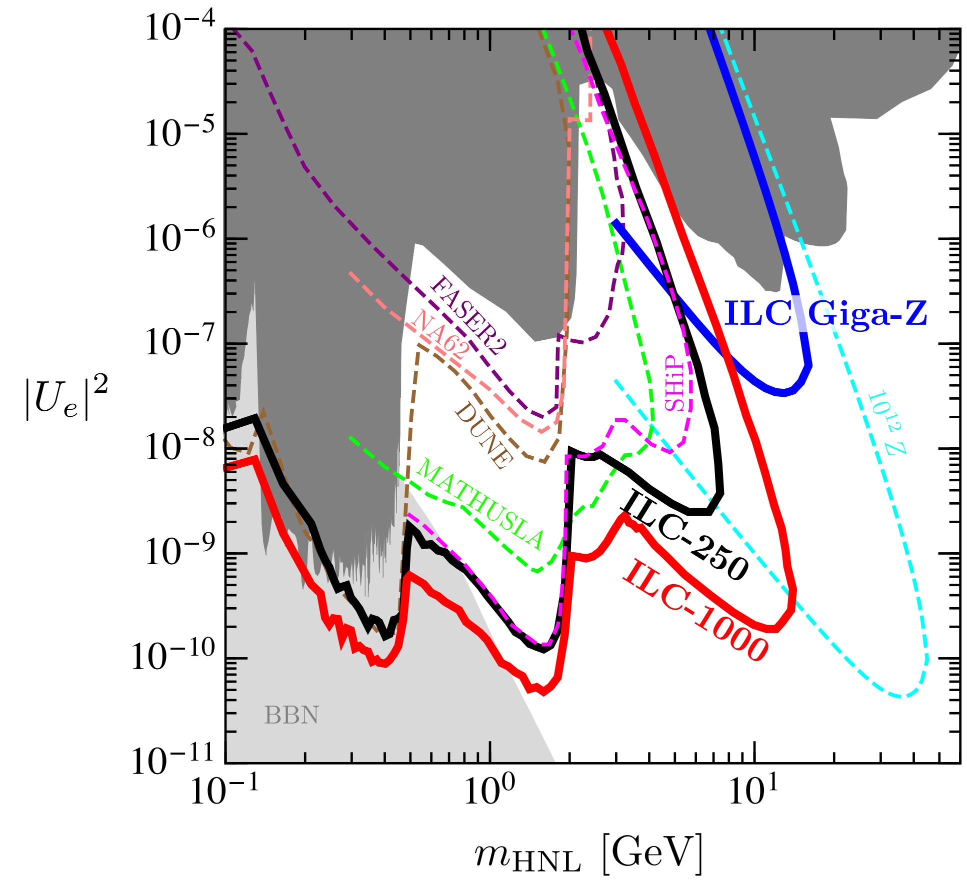
- Two examples of PBC program at ILC:



- Atmospheric-like neutron and muon
- Soft error study for large integrated system



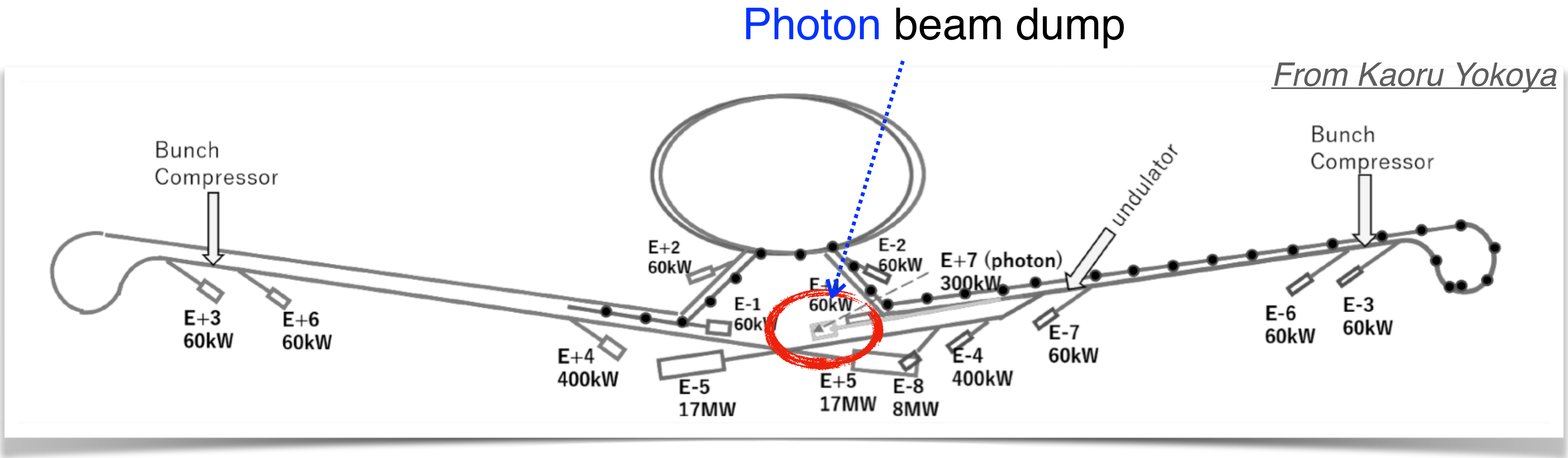
- Beamdump experiment for new physics search
- Sensitive to small coupling and high mass region



- The ILC can accommodate a variety of PBC programs, and the facility design is improving to maximize the potential of the programs.

Backup

Photon beam from Helical undulator



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

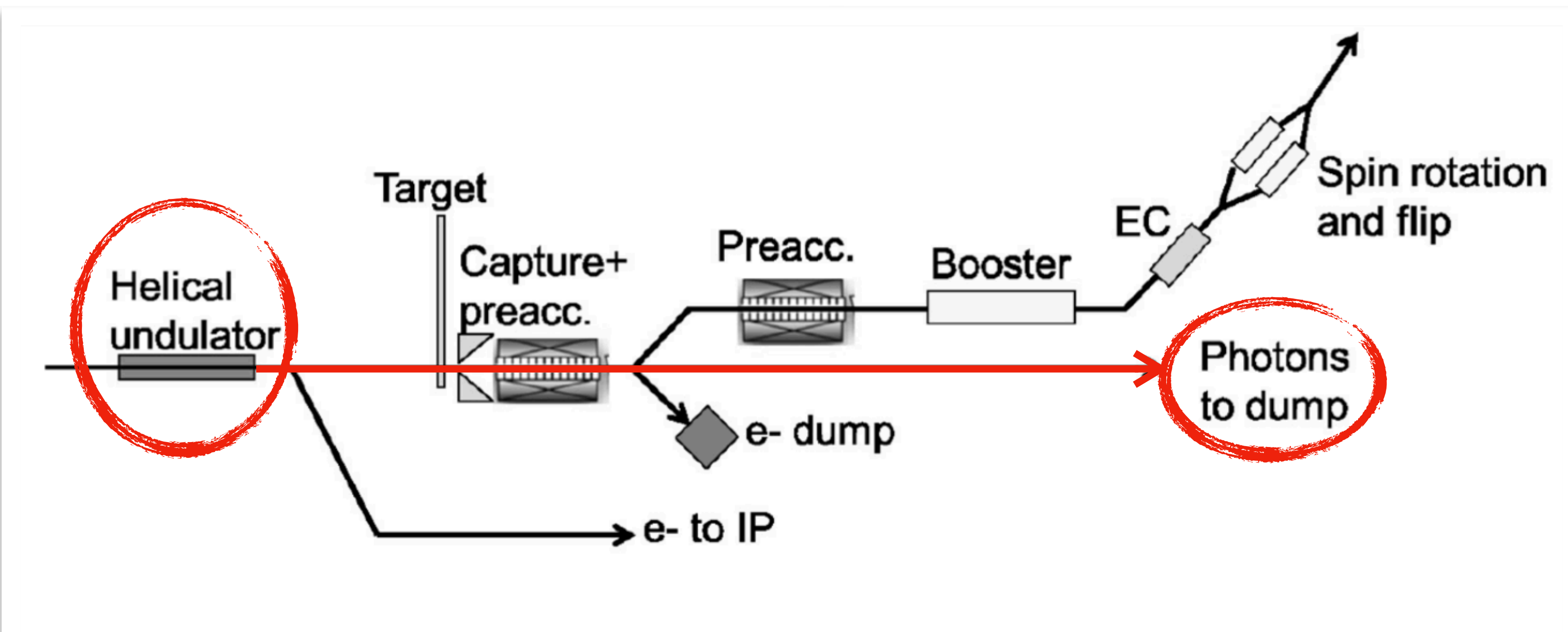
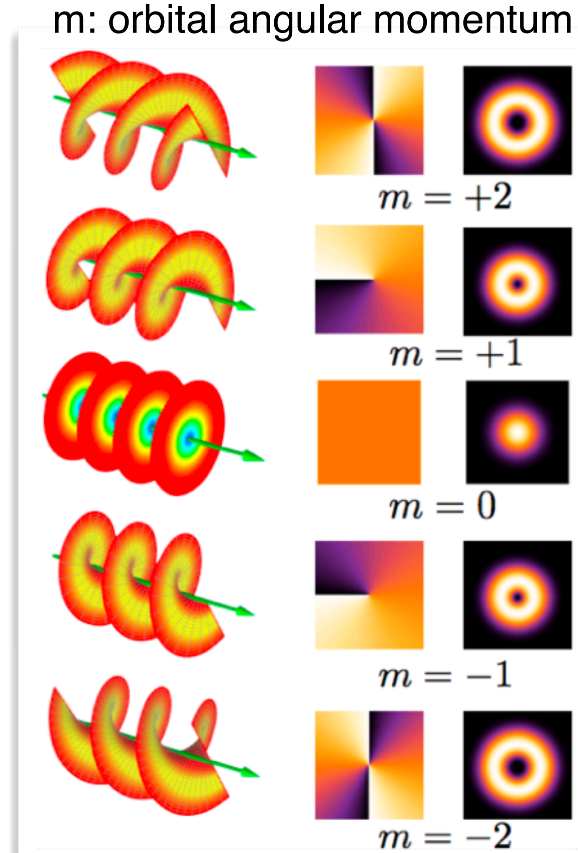


Figure 1: Sketch of the undulator-based ILC positron source.

Figure From F. Dietrich et.al, 1902.07744

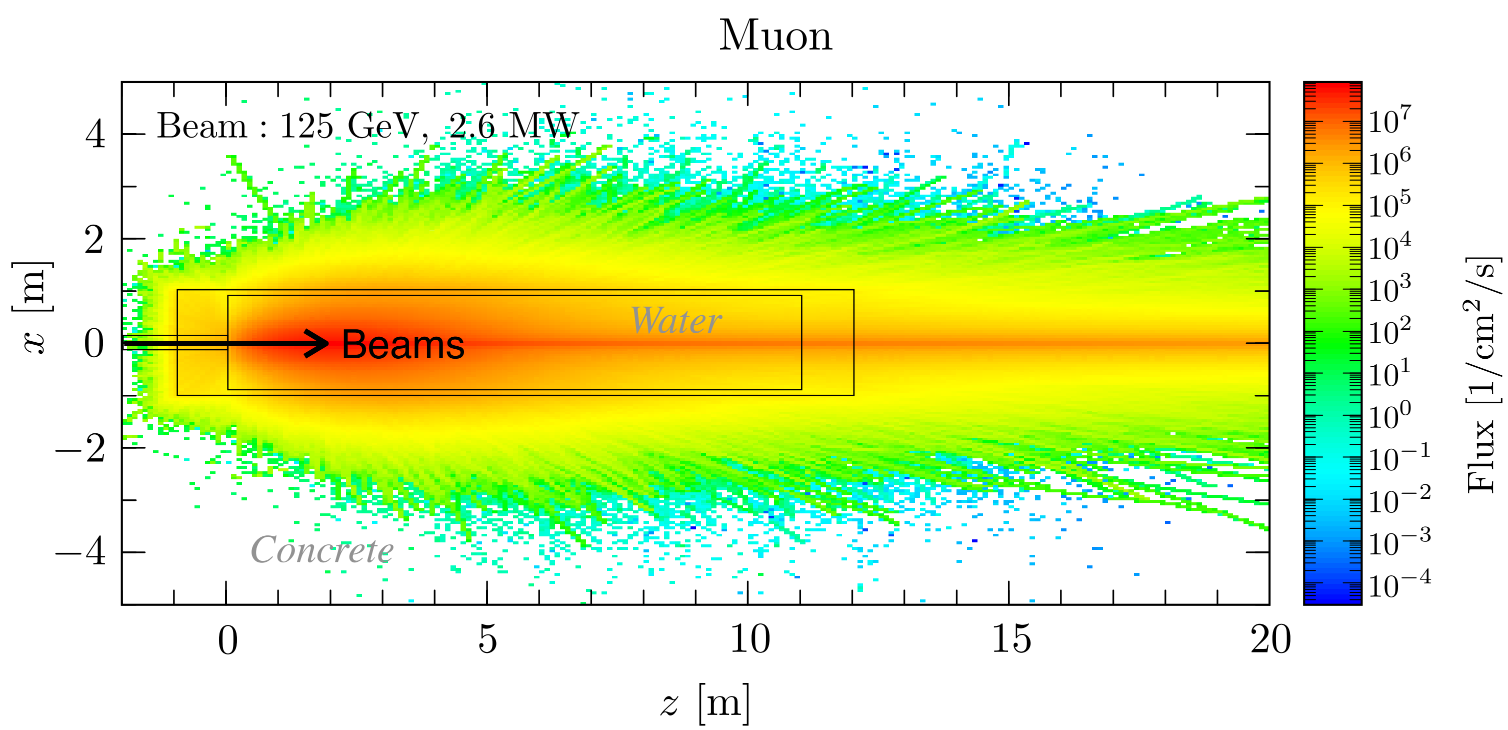
Optical vortex

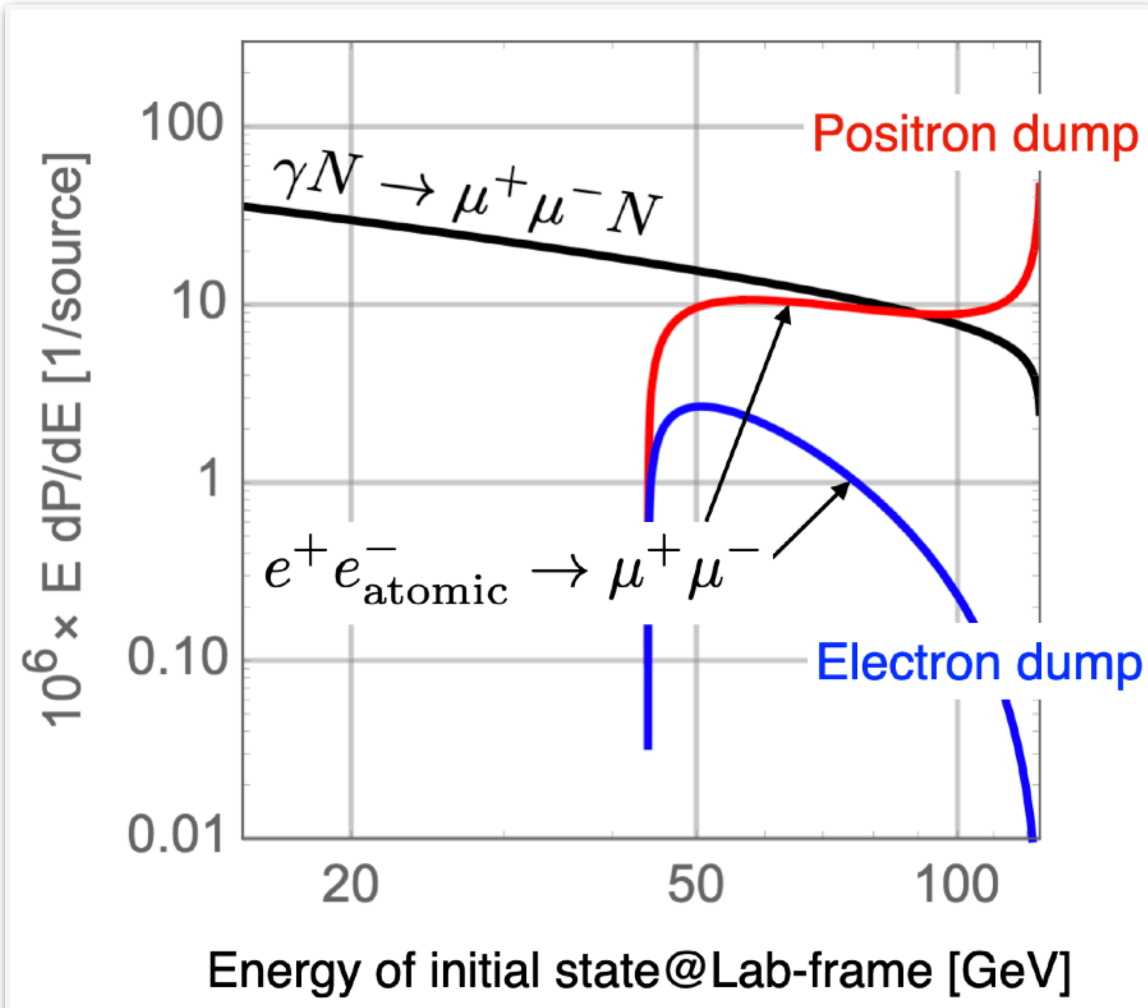
m: orbital angular momentum



From Wikipedia

Muon beam





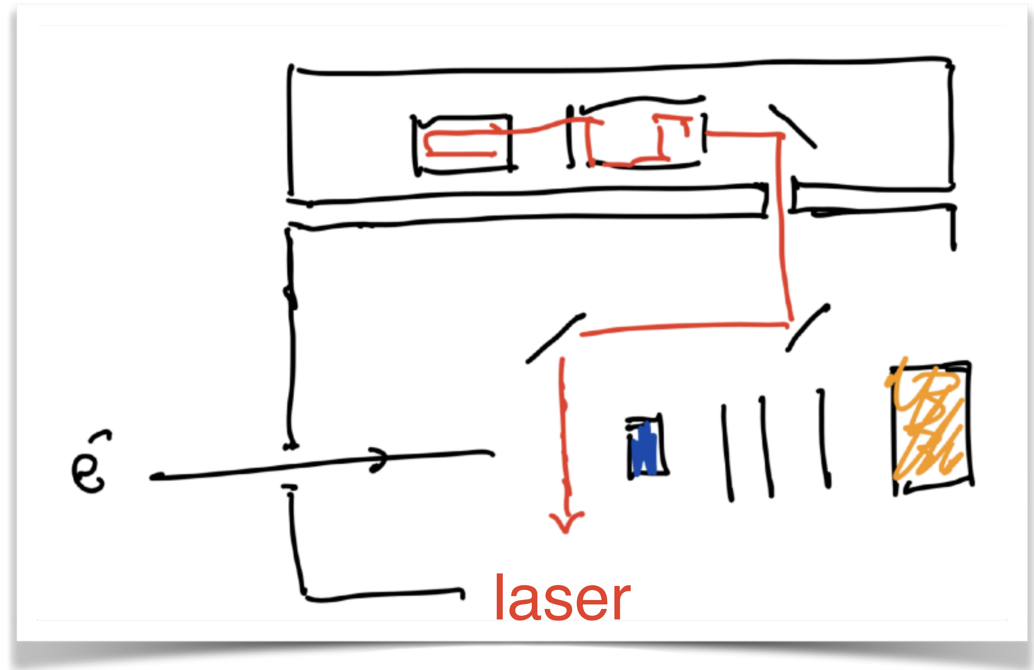
- Very forward muon beams are obtained by e± beams.
- Positron dump generates more high-energy muons.
- The flux are ~10^8 times greater than the cosmic-ray.
  (Neutron flux is ~10^{11} times greater than the cosmic)

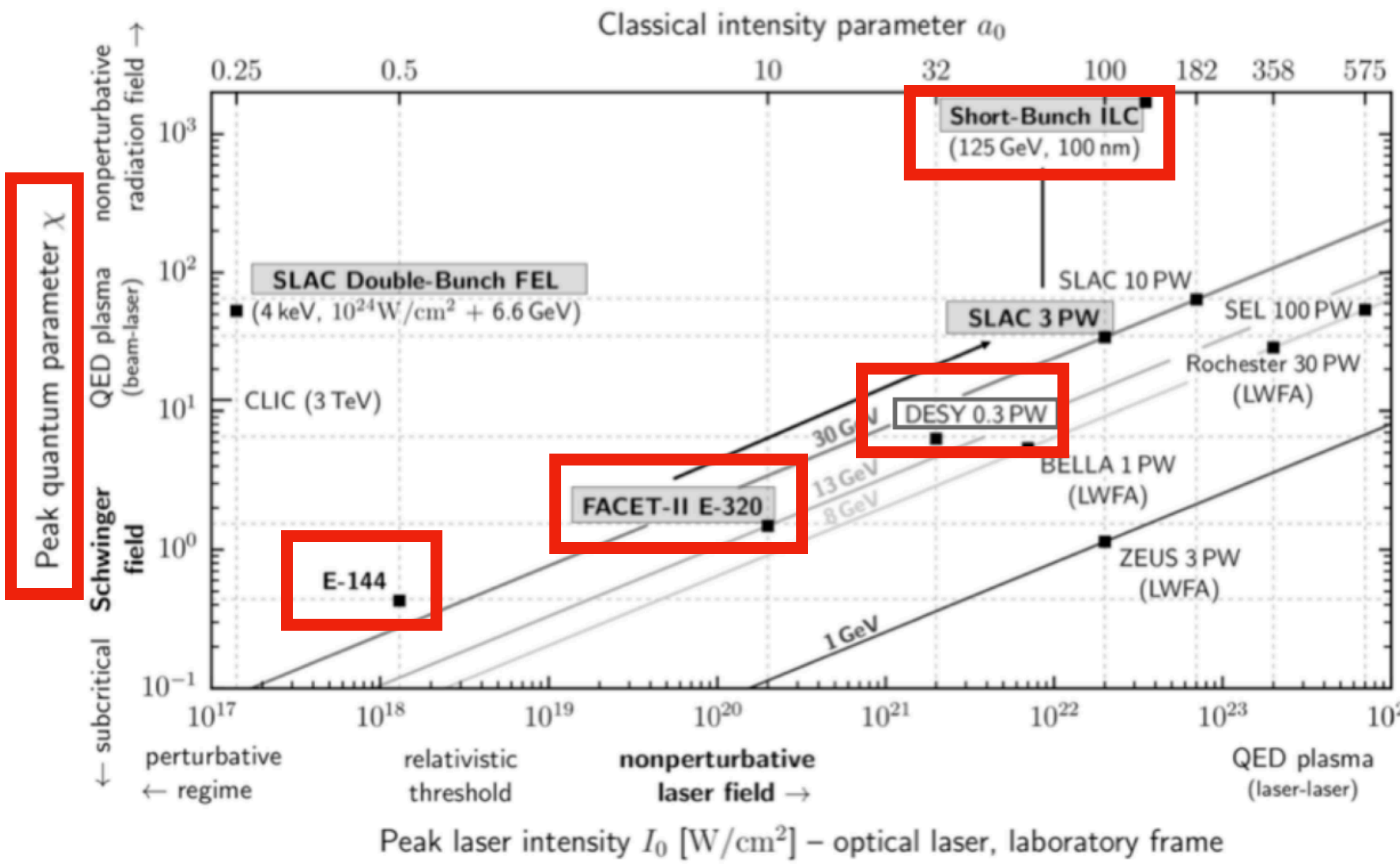
Non-linear QED

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.



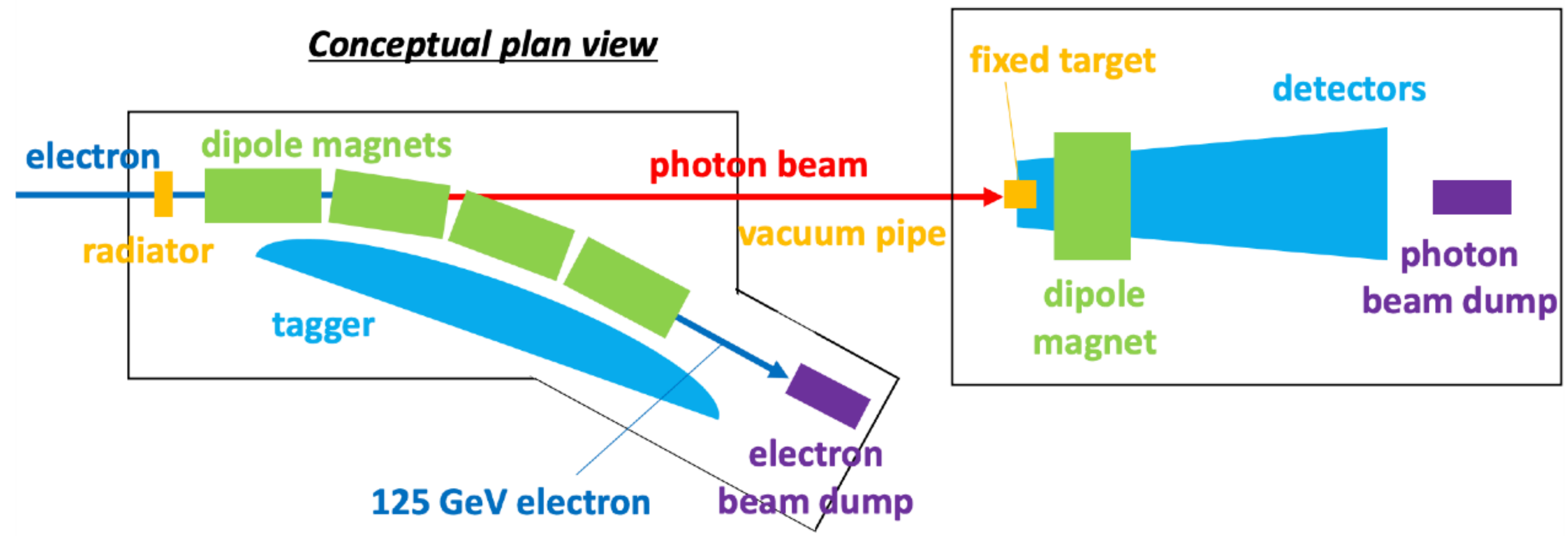


- A large quantum parameter χ can be reached with ILC beams and high intensity lasers.
- This large number makes possible to study interesting non-linear QED processes

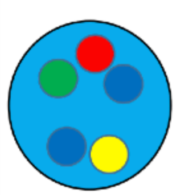
Photoproduction of Exiotic hadrons and Heavy hadrons

From Norihito Muramatsu's talk @ ILCX2021

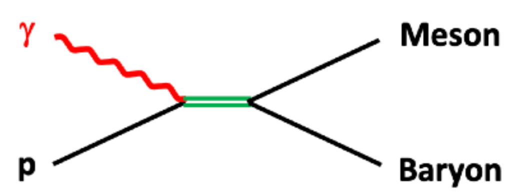
Setup for hadron photoproduction experiments

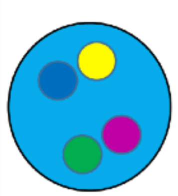


Exotic hadrons

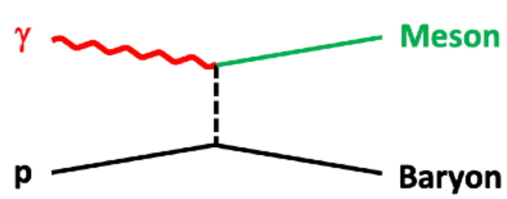


uudc$\bar{c}$ pentaquark
$P_c(4312)^+$ etc in $\Lambda_b^0 \to J/\psi\, pK^-$
$P_c(4337)^+$ in $B_s^0 \to J/\psi\, p\bar{p}$





4-quark state including $c\bar{c}$
X(3872) in $B^\pm \to K^\pm\pi^+\pi^- J/\psi$
$Z^+(4430)$ in $B^0 \to K^-\pi^+\psi'$

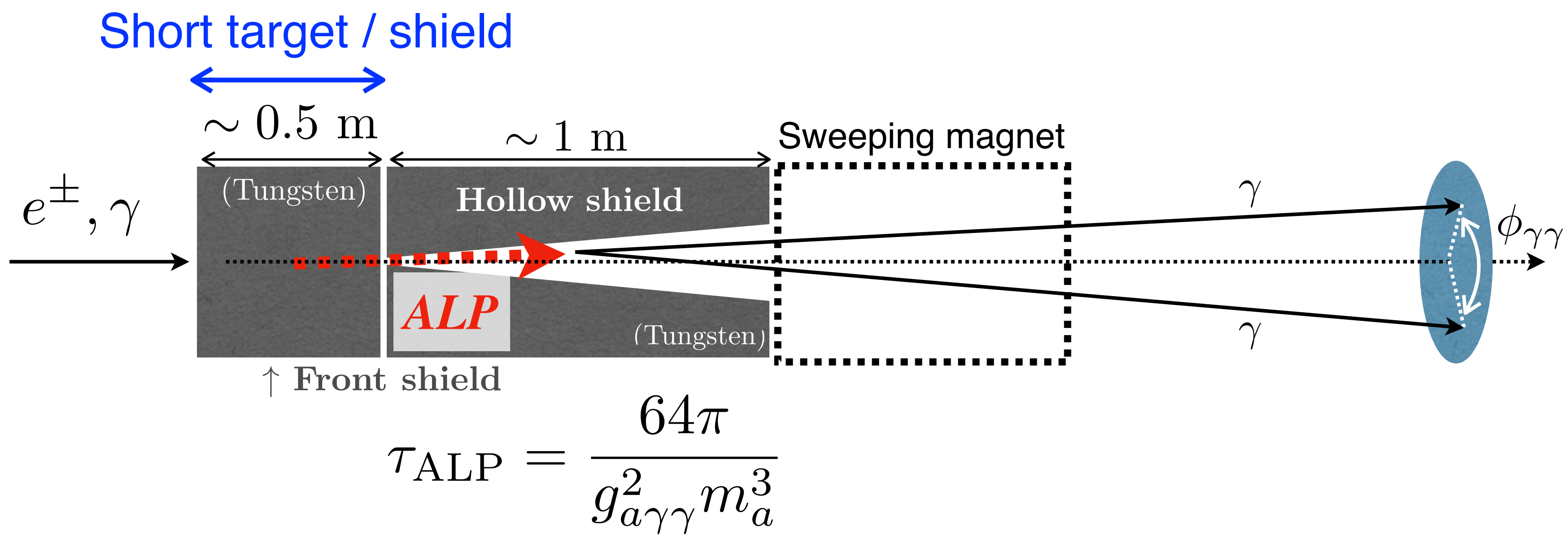


Heavy hadron photoproduction

➢ **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)	JLab GlueX
$\gamma p \to \bar{D}^0 \Lambda_c^+$	8.71 GeV	JLab GlueX
$\gamma p \to \bar{D}^0 \Sigma_c^+$	9.47 GeV	JLab GlueX
$\gamma p \to X(3872)\, p$	11.9 GeV	New !
$\gamma p \to Z^+(4430)\, n$	14.9 GeV	New !
$\gamma p \to X(6900)\, p$	32.3 GeV	New !
$\gamma p \to \Upsilon(1S)\, p$	57.2 GeV	New !
$\gamma p \to B^+ \Lambda_b$	62.8 GeV	New !

Search on shorter lifetime region with shorter shielding setup



The use of short shielding increases sensitivity to short lifetime region