Beyond collider experiments at a Linear Collider

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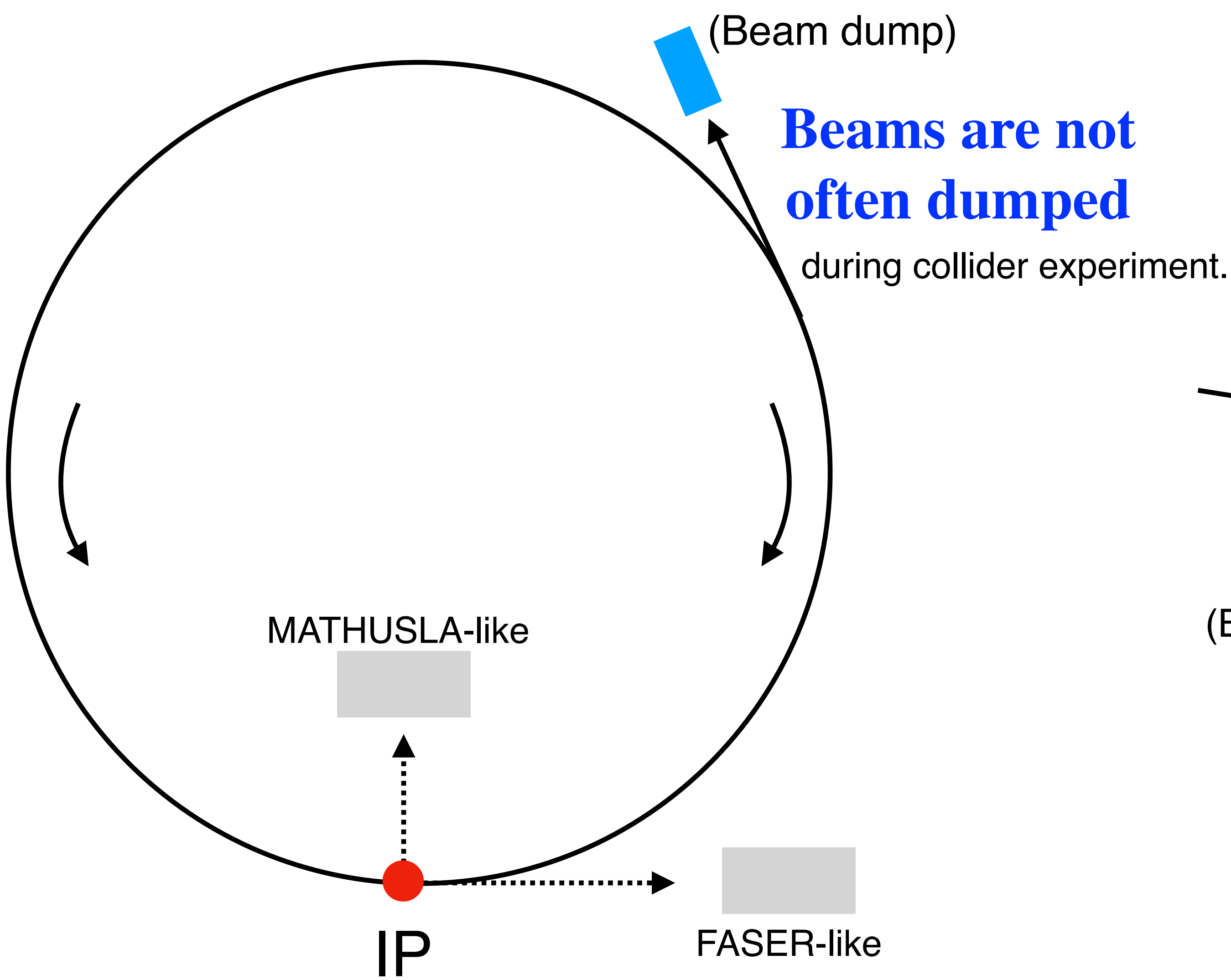
International Workshop on Future Linear Colliders (LCWS2024), U. Tokyo, 8-11 July 2024

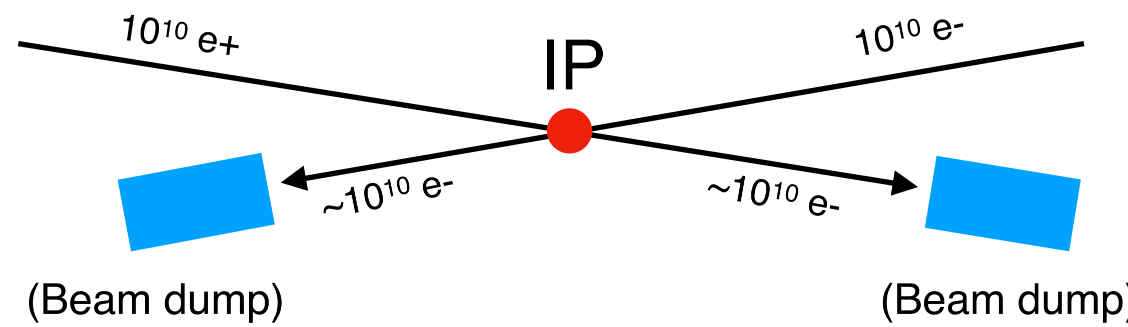
PBC oppotunity of beam dumps at a linear collider

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

Circular



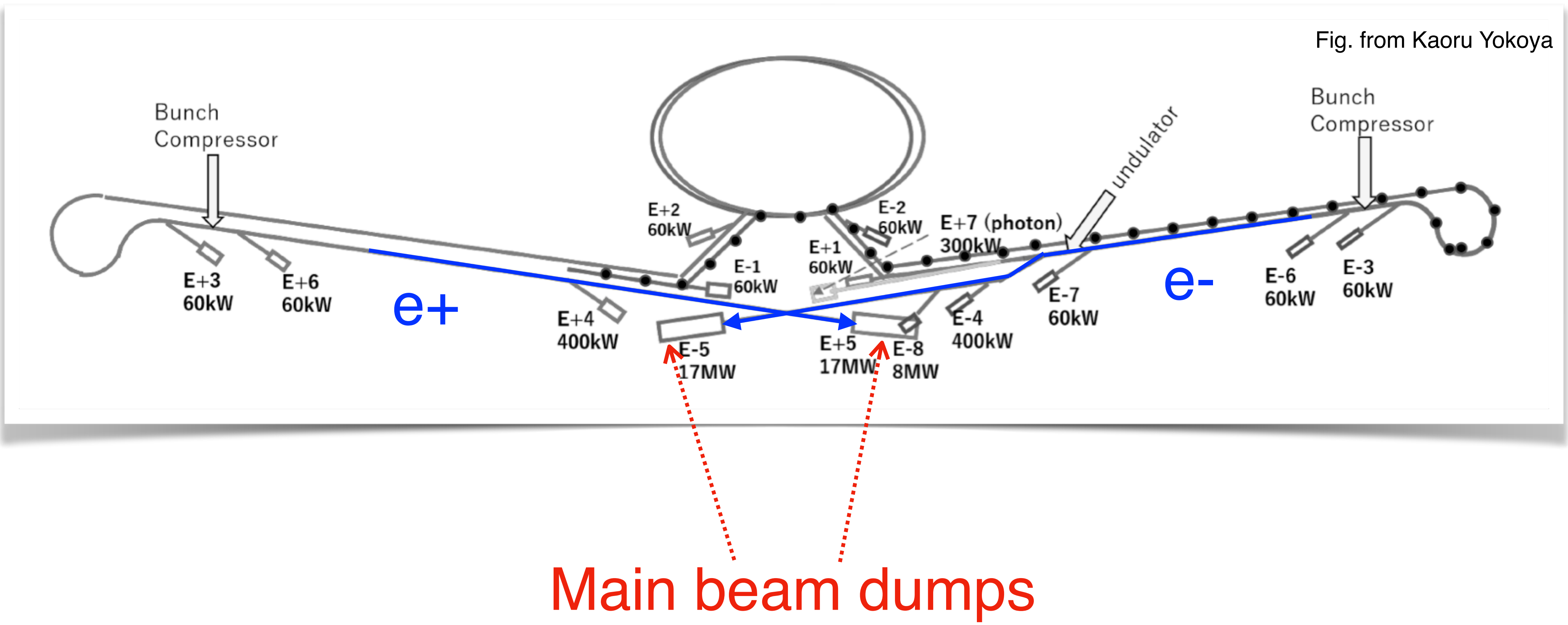
Linear



Beams are continuously dumped

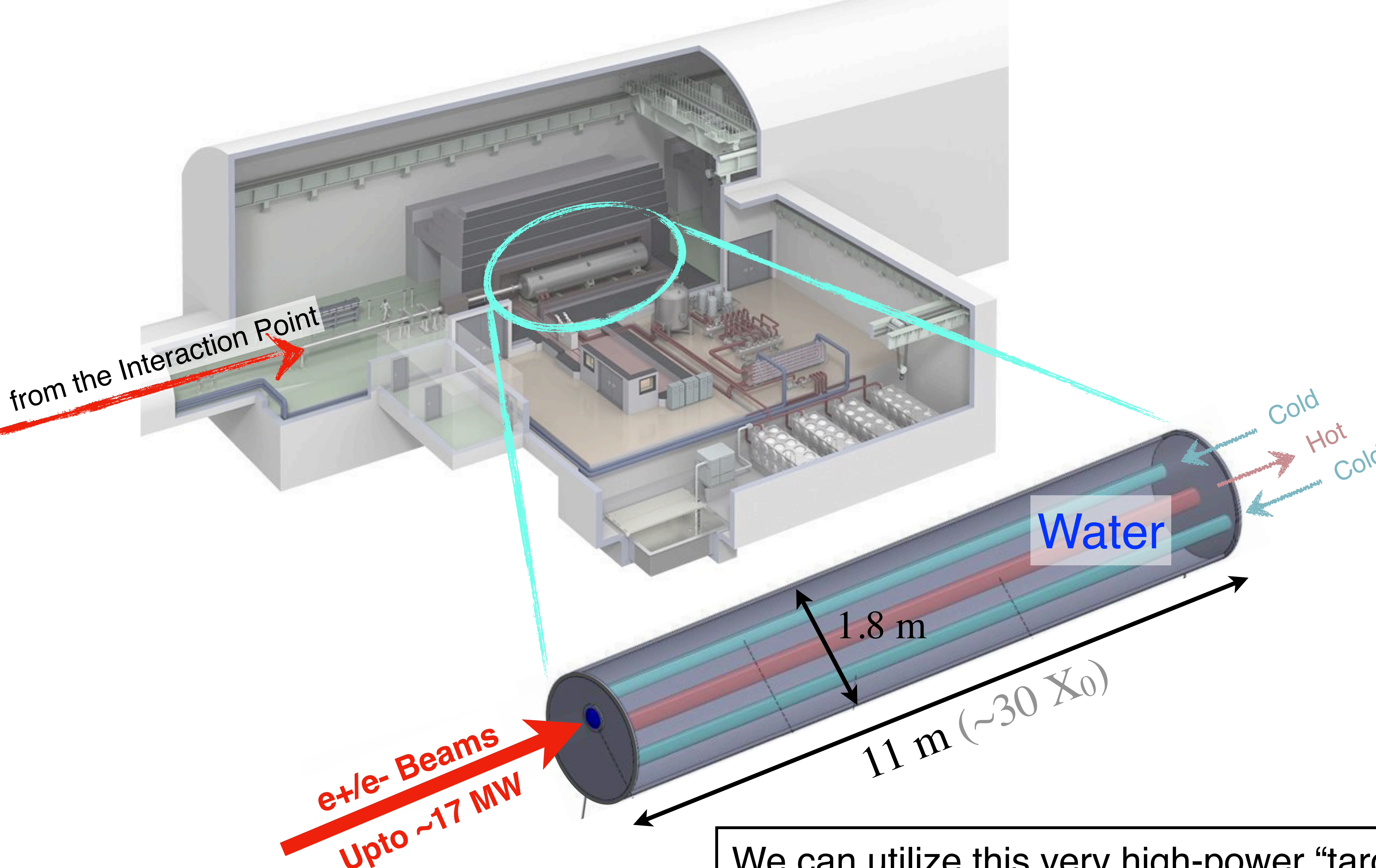
This talk will focus on the PBC opportunity at the ILC beam dumps

15 Beam dumps at ILC



Focus on the potential of main beam dumps

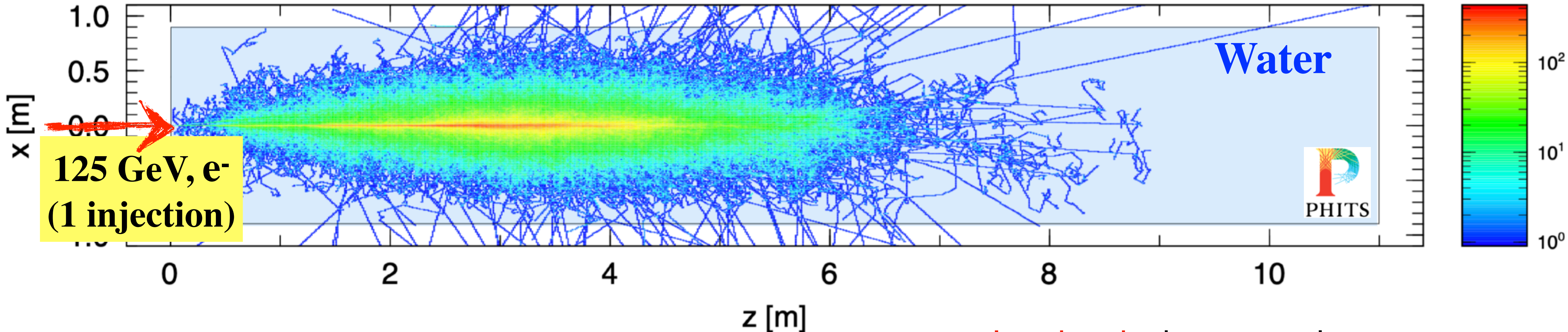
Main beam dumps

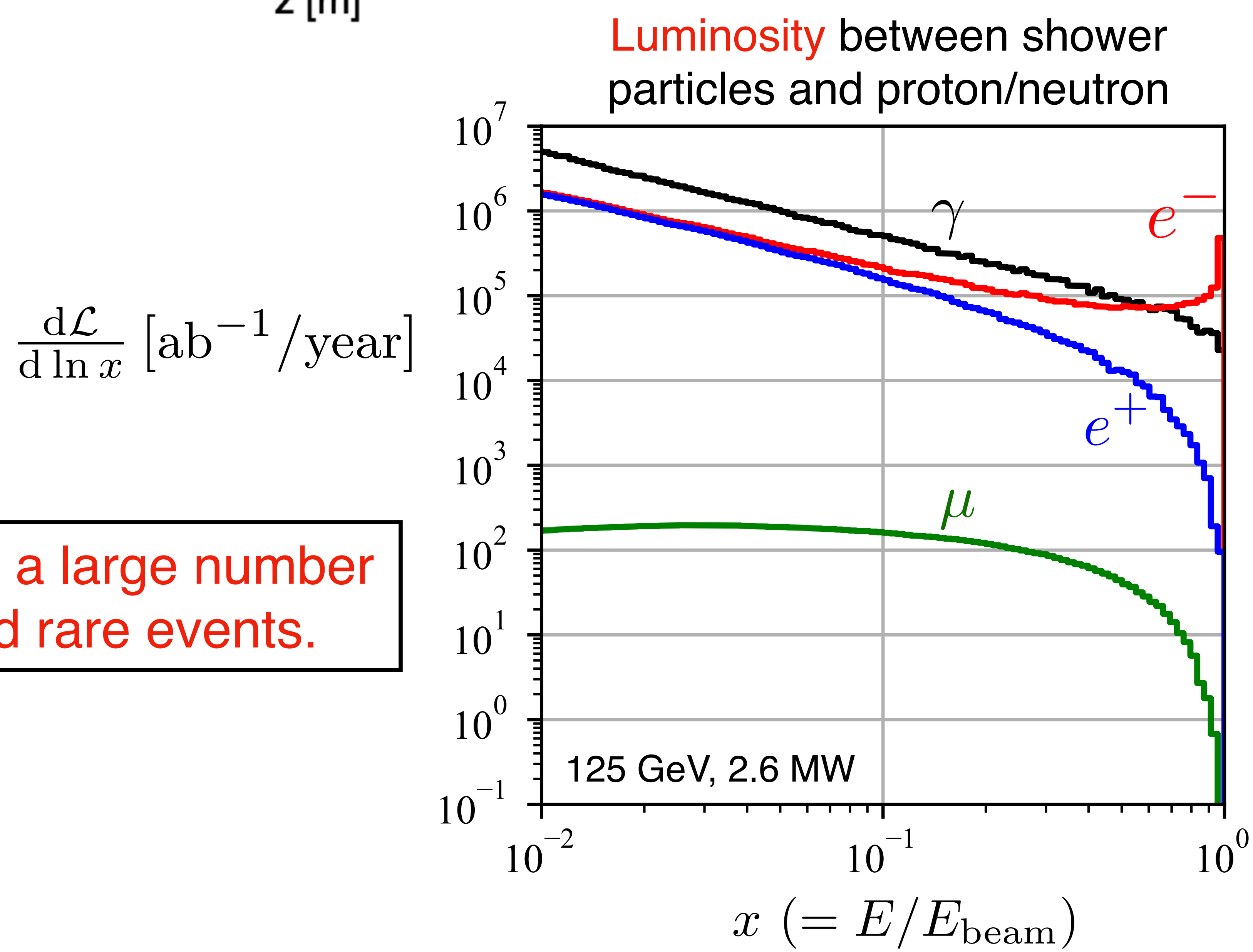


We can utilize this very high-power "target" without any additional cost.

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

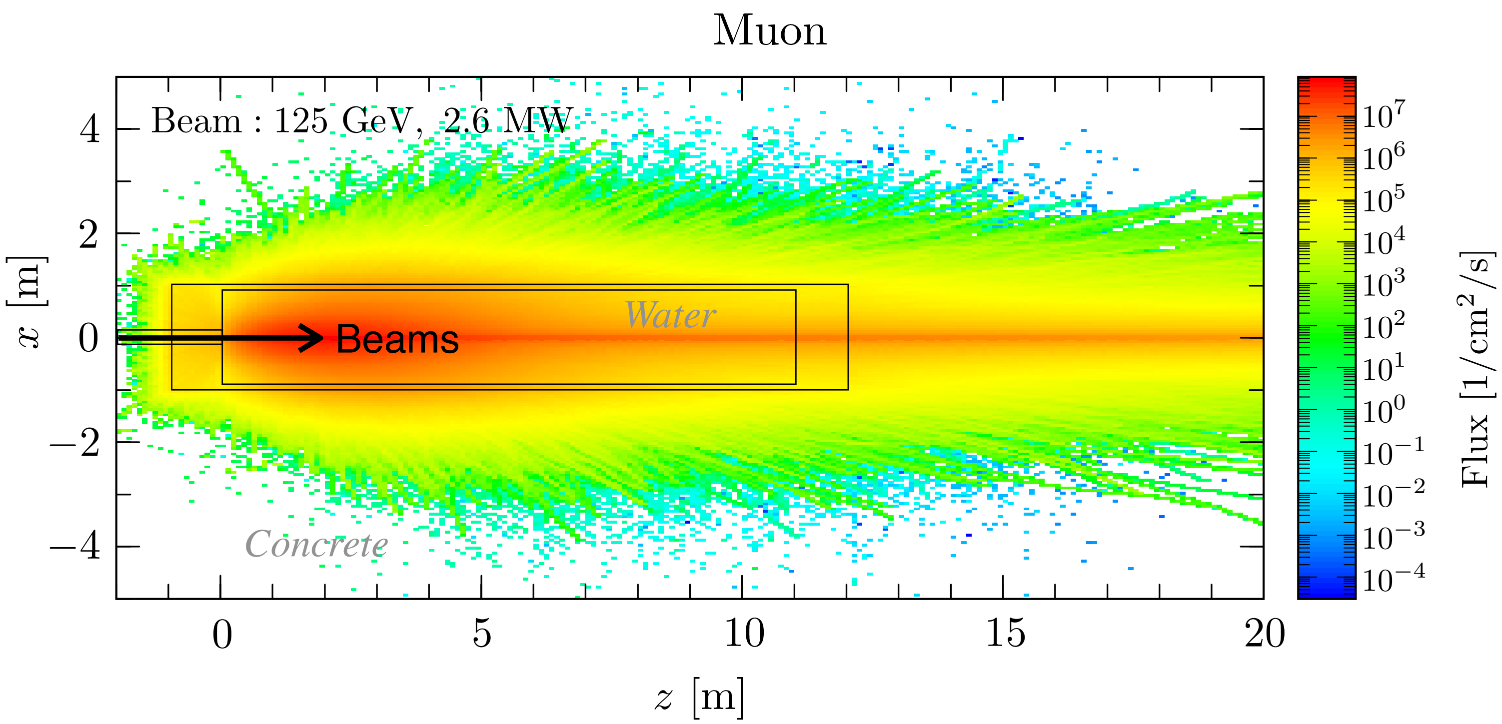
Secondary particles

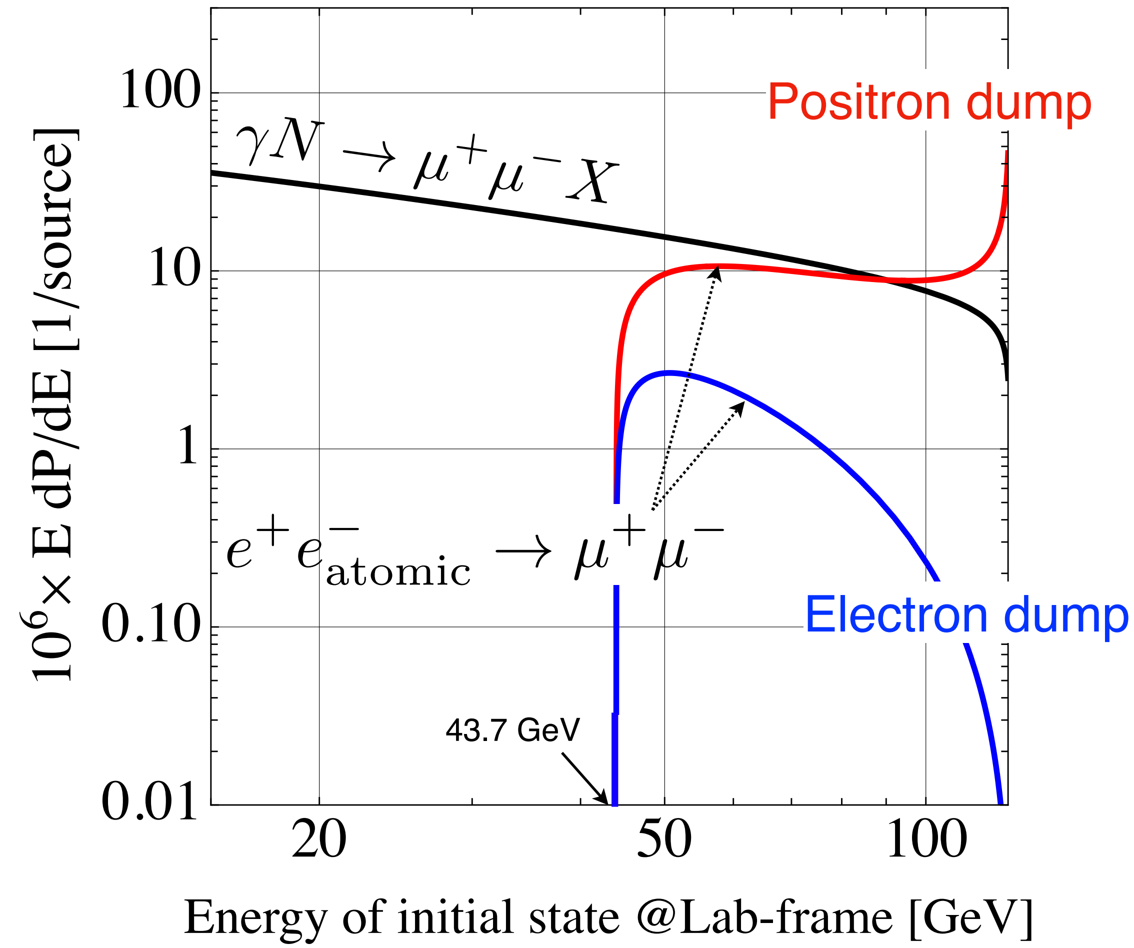




Shower particles can create a large number of secondary particles and rare events.

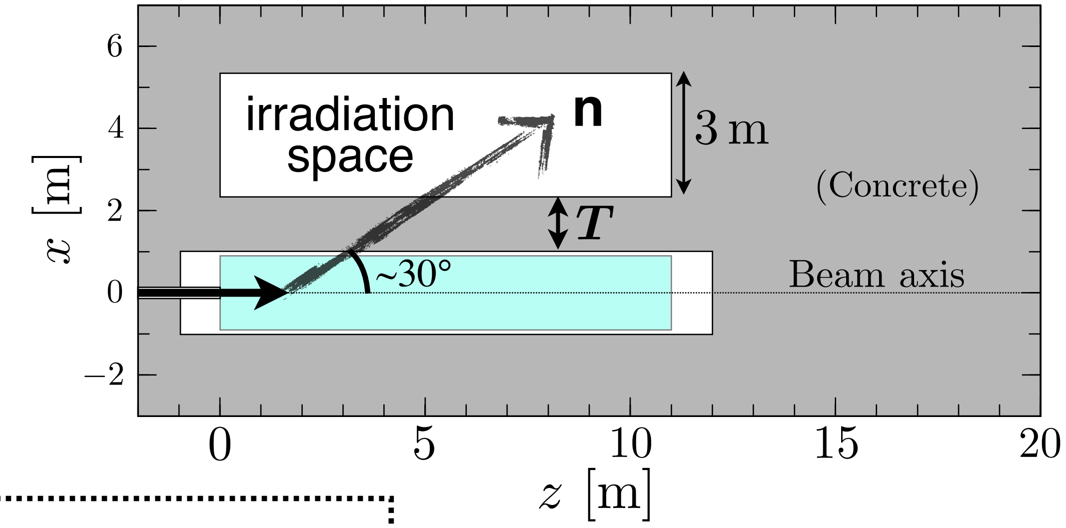
Muons

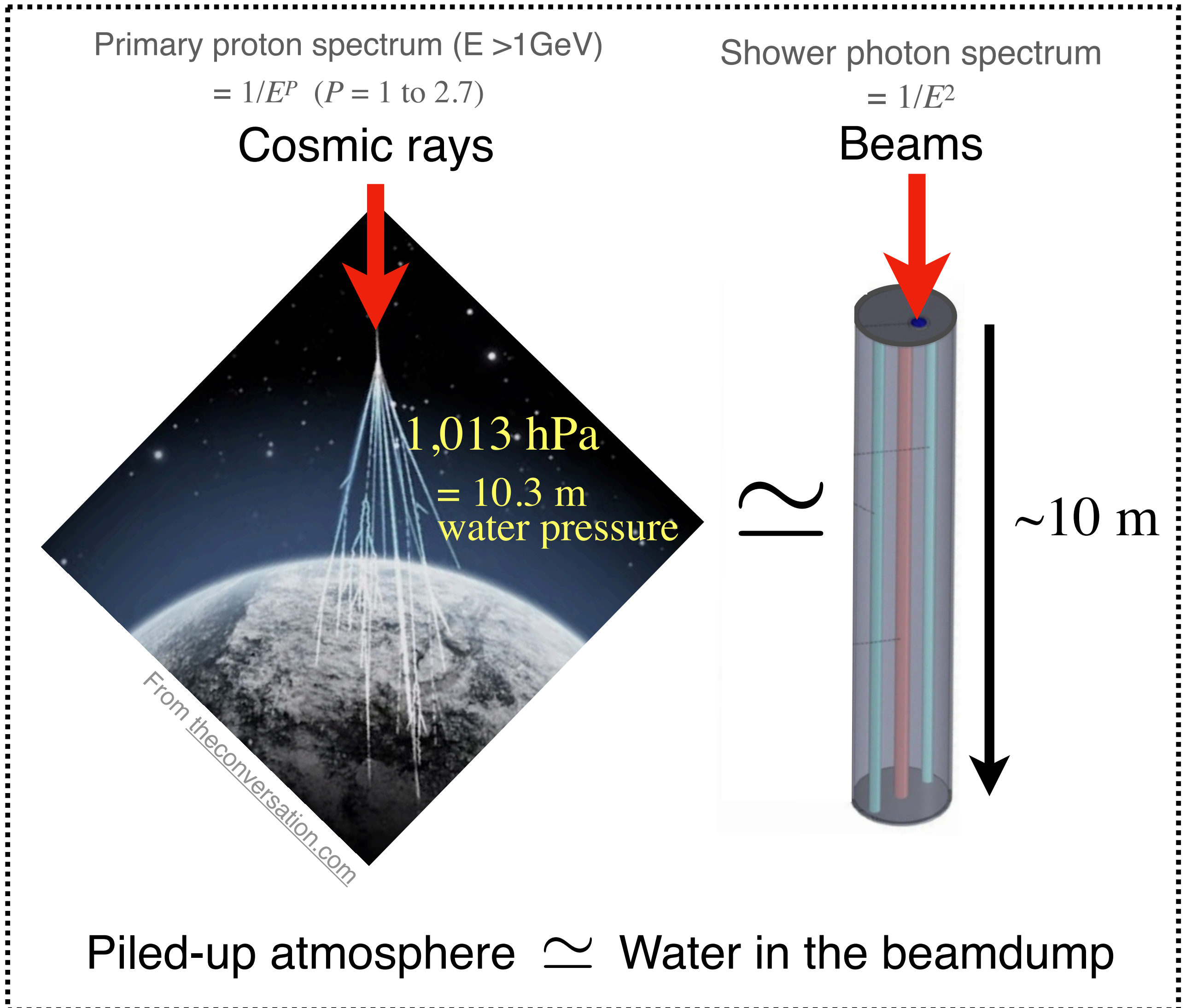


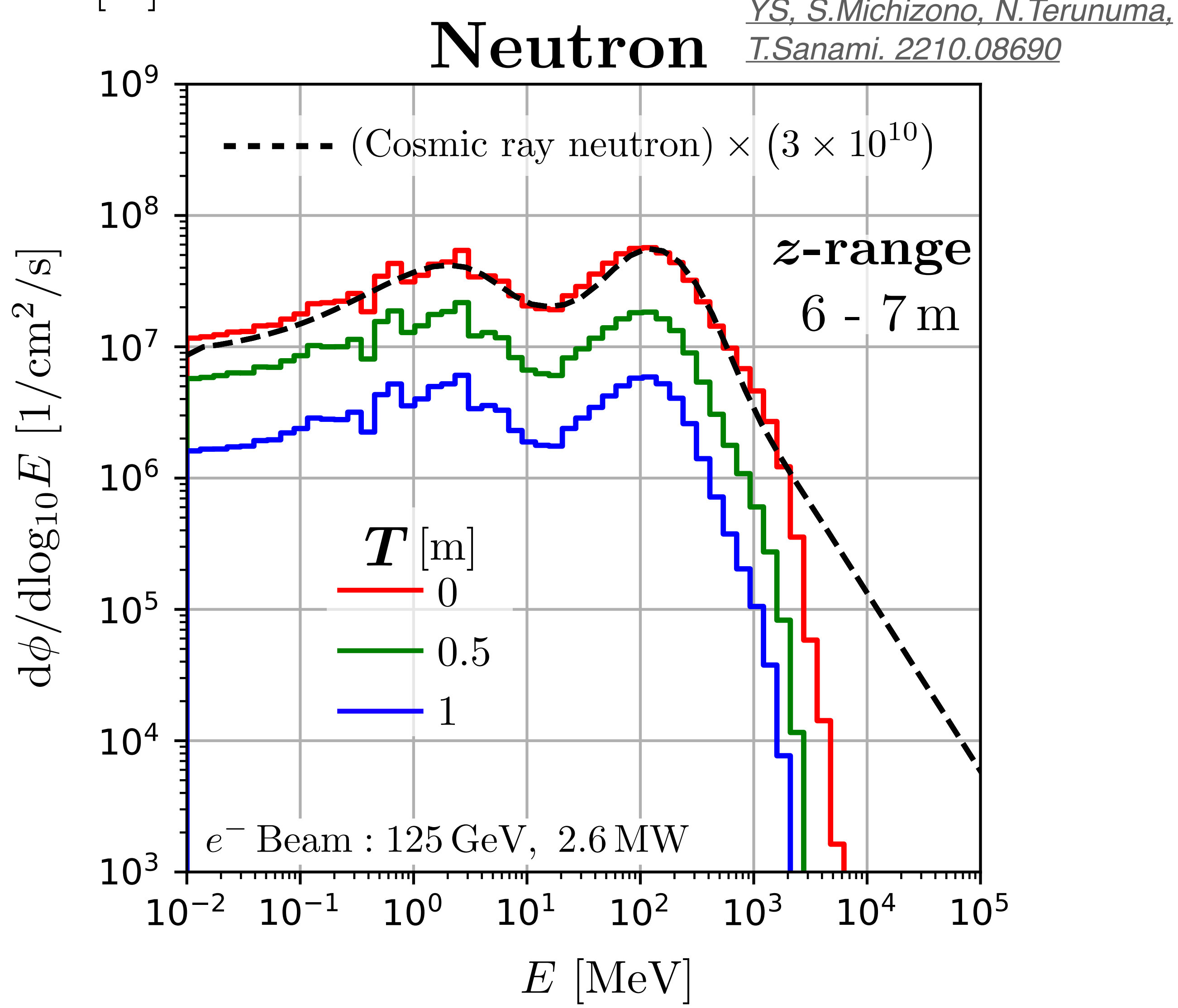


- Very forward muons are obtained by e± beams.
- Positron dump generates more high-energy muons.

Neutrons



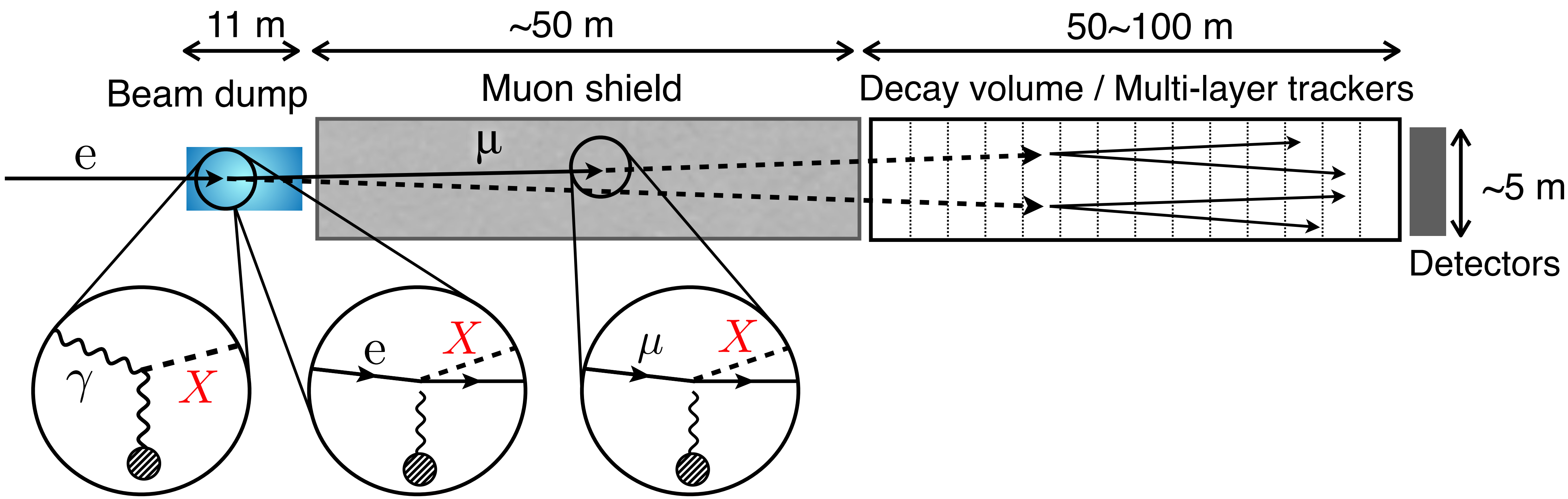




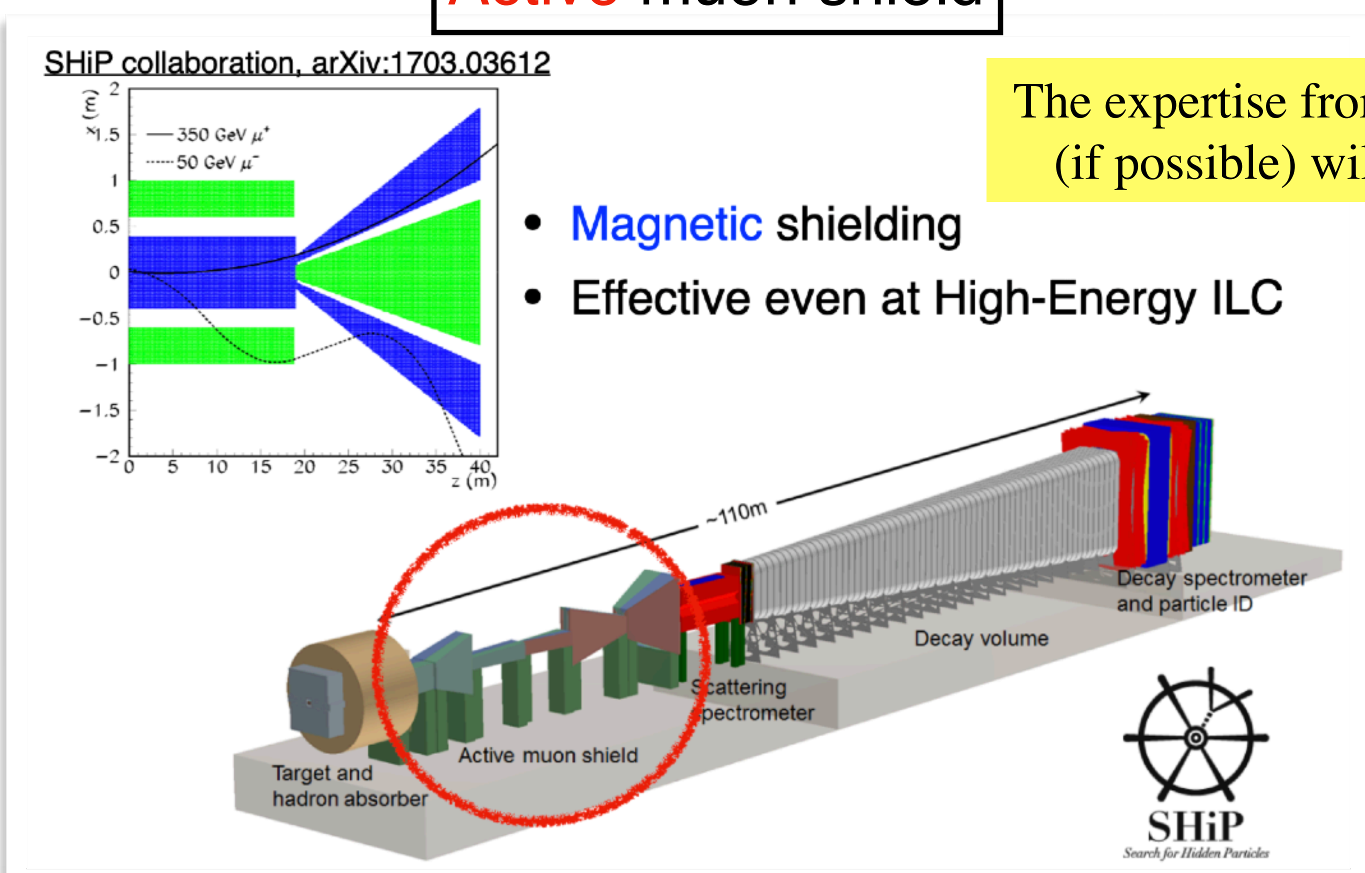
- Atmospheric-like neutrons are obtained. (Consistent up to a few GeV.)
- An irradiation field suitable for studying soft errors in integrated circuits, etc.

➡ An industrial application of the ILC beam dump

Searches for Long-Lived Particles



Active muon shield

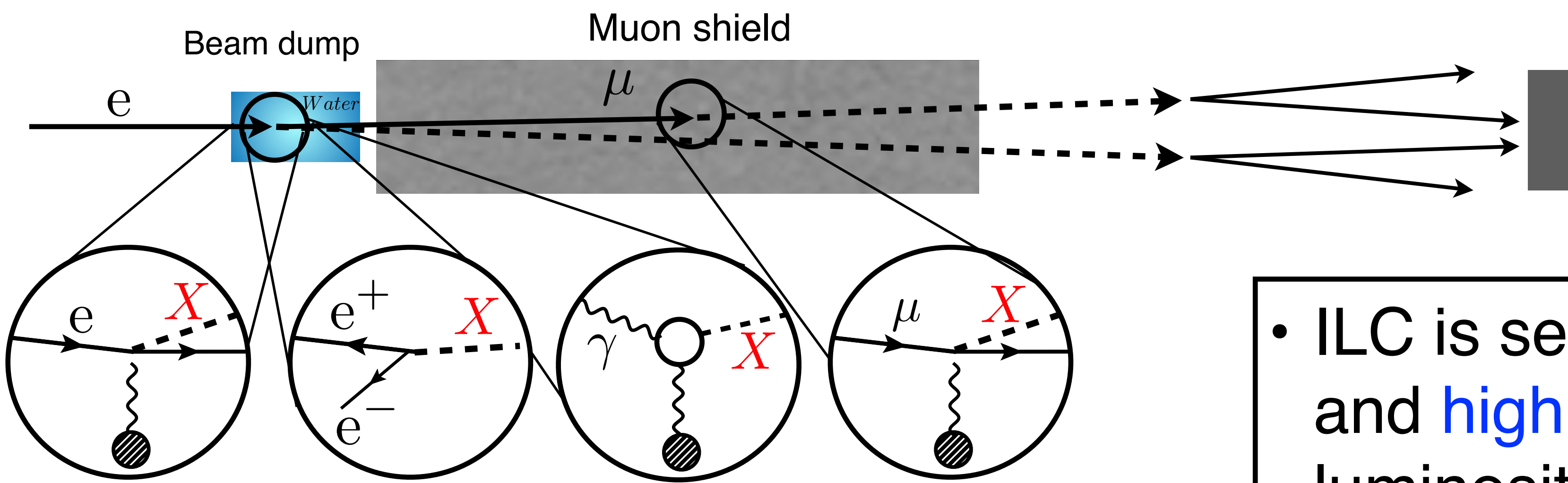


- Magnetic shielding
- Effective even at High-Energy ILC

The expertise from SHiP and the partial reuse of its equipment (if possible) will enhance the ILC beam dump experiment.

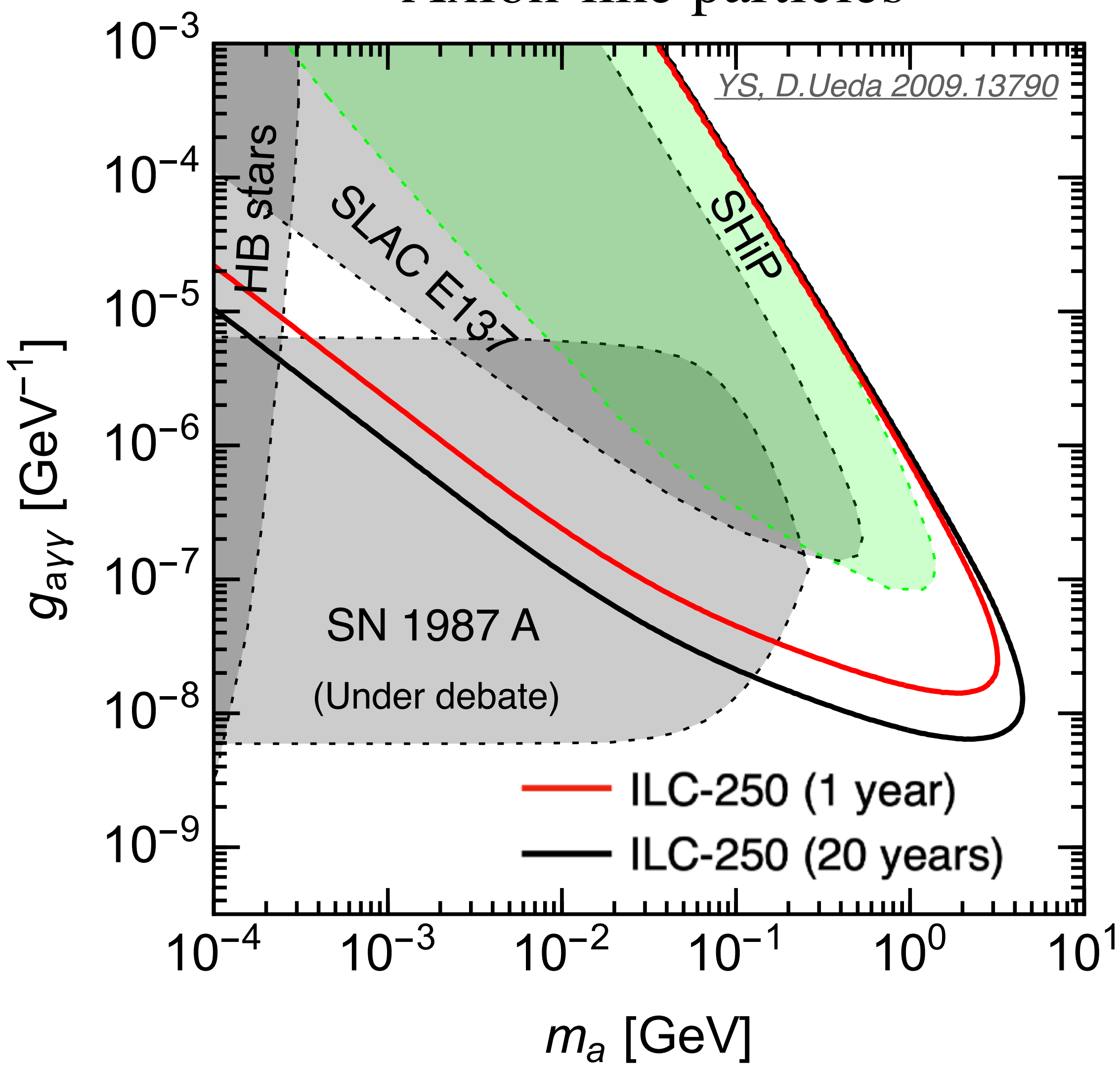
New particles from electromagnetic showers

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

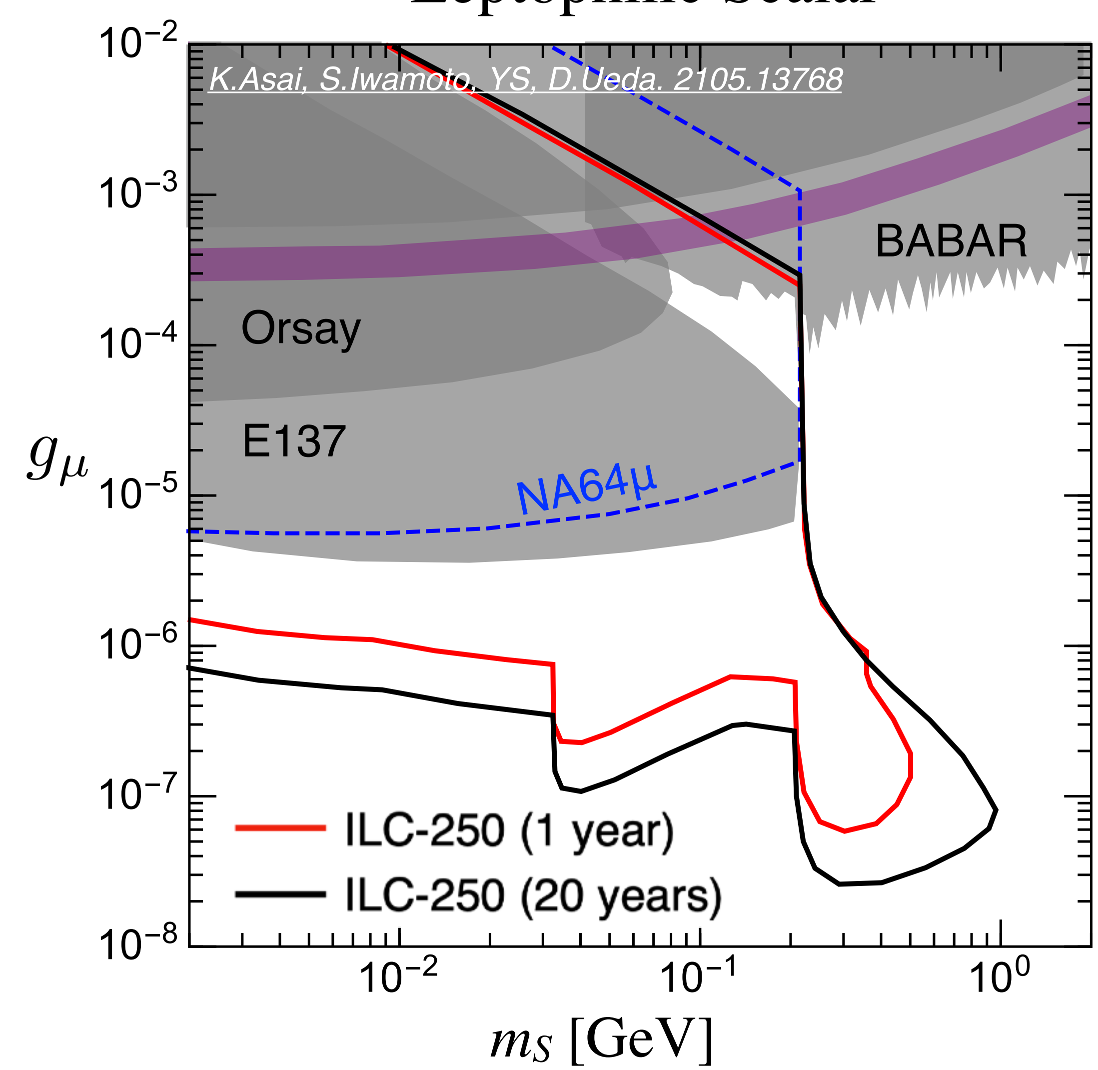


- ILC is sensitive to small coupling and high mass region due to its large luminosity and energy

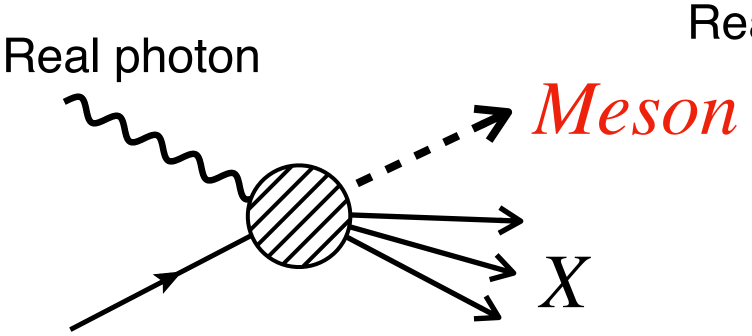
Axion-like particles



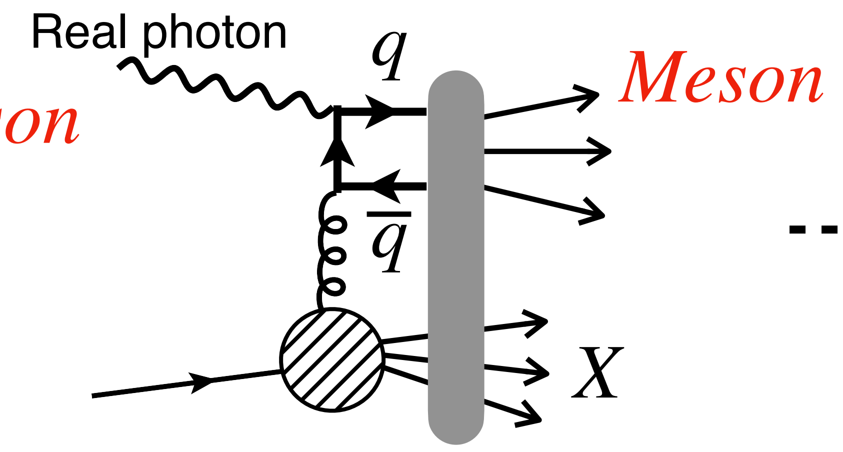
Leptophilic Scalar



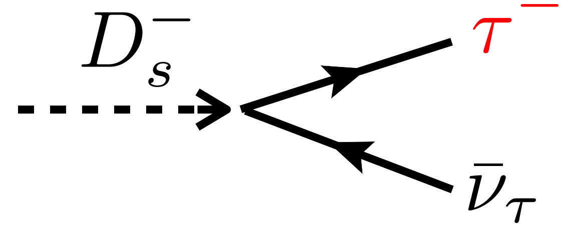
Heavy mesons & Tau leptons



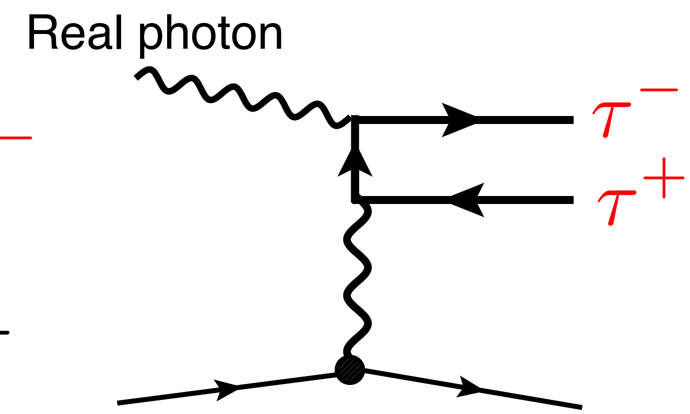
Non-diffractive



Hard QCD

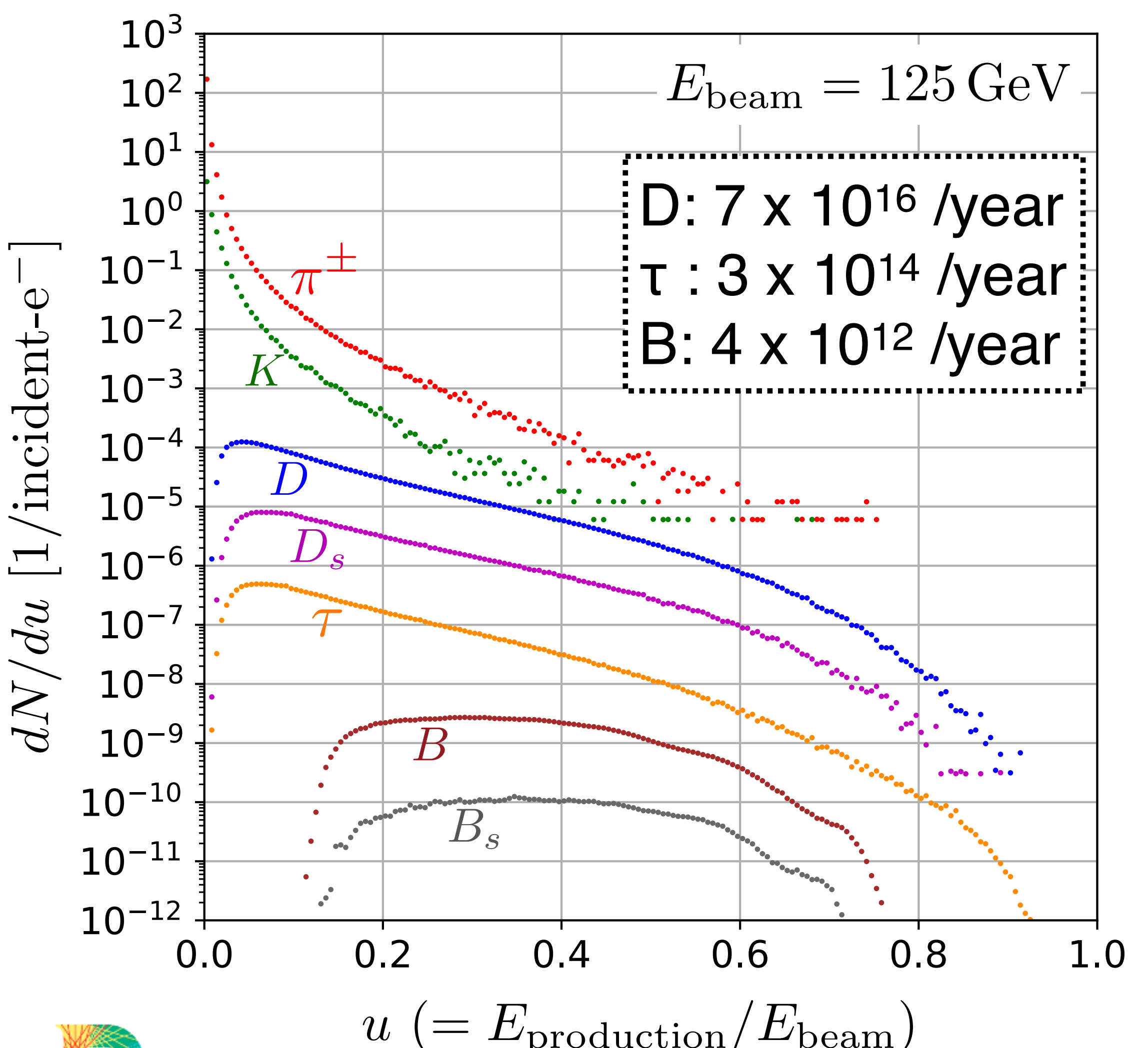


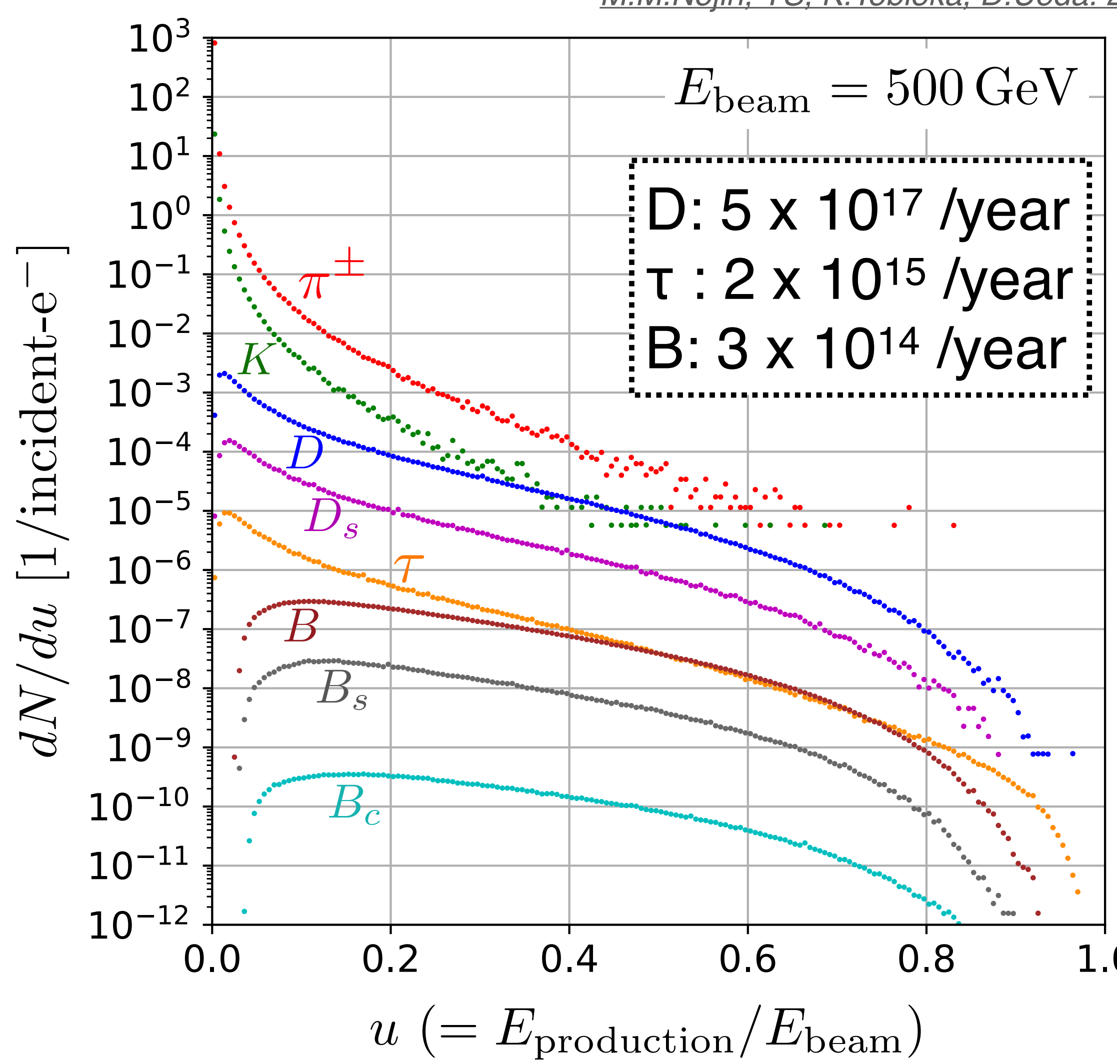
Br = 5.48 %



Coherent, Quasi-elastic, Inelastic

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





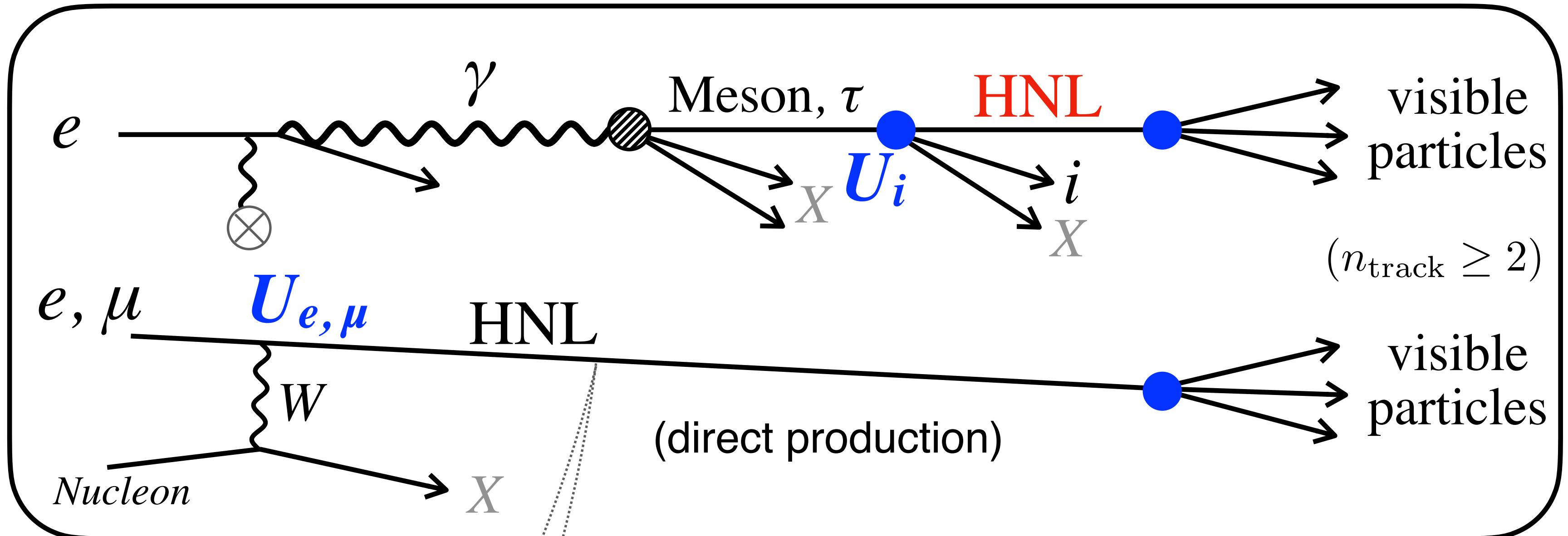
Pythia8 PHITS

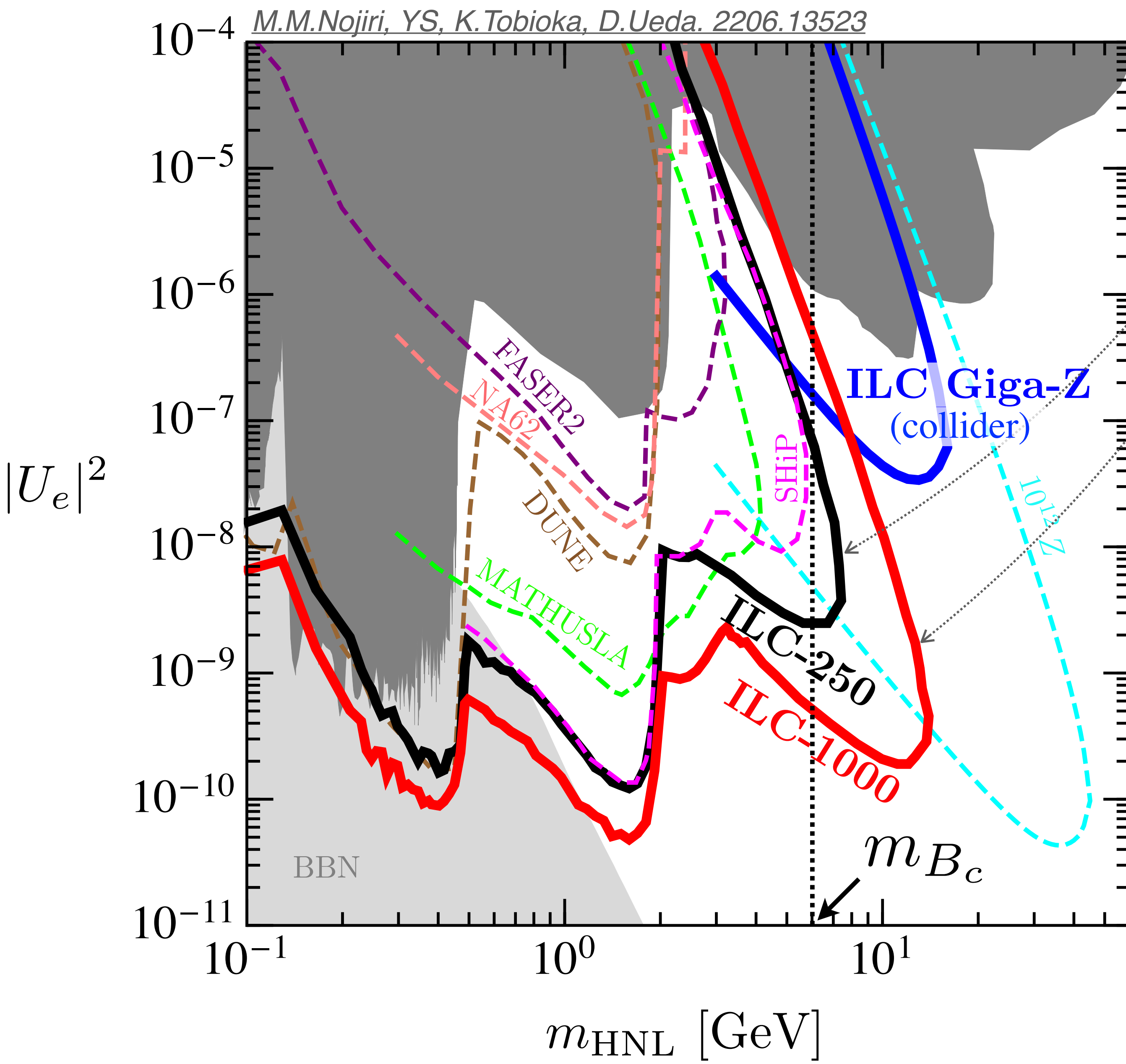
Heavy Neutral Leptons (HNLs)

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

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

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

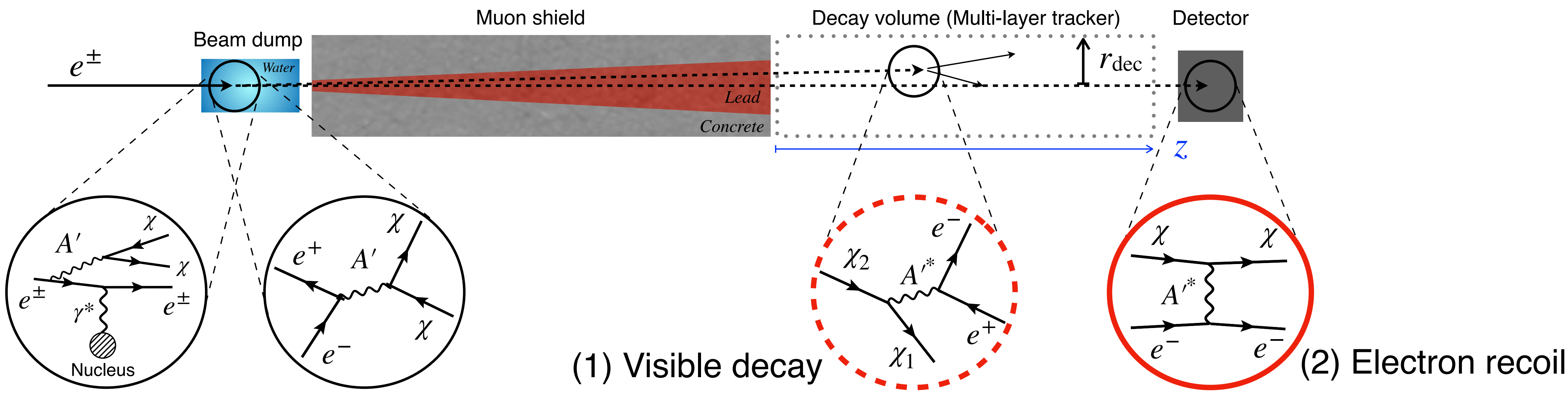




- Beam dump and ILC Collider experiment is complementary
- HNL direct production from e± expand sensitivity at high mass region

Similar to BDX@JLab

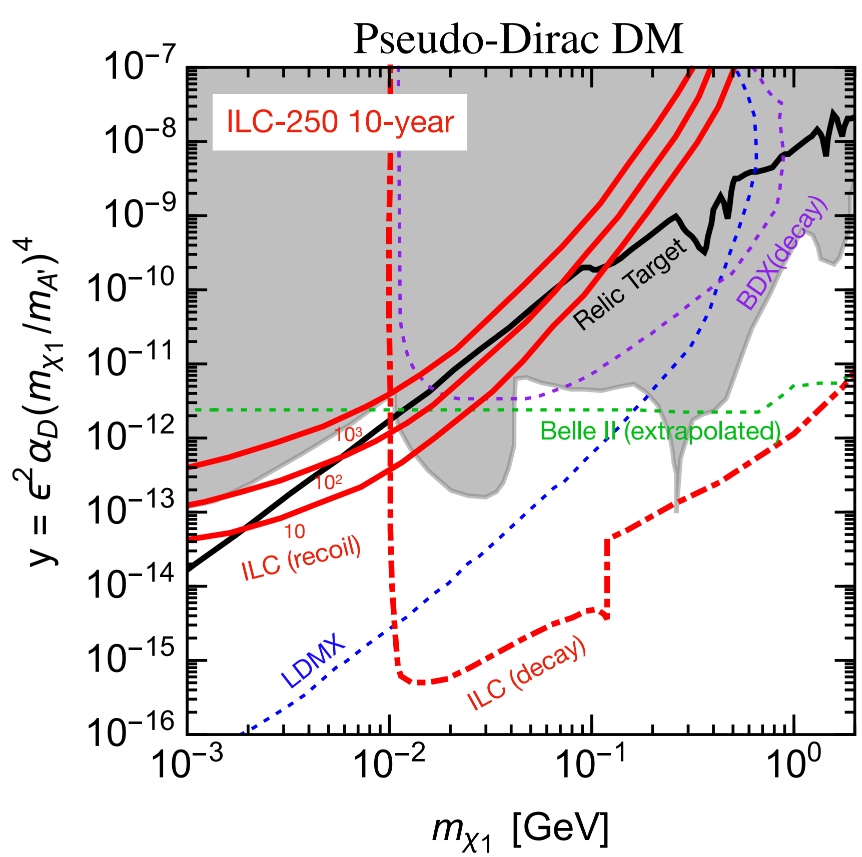
Dark matter

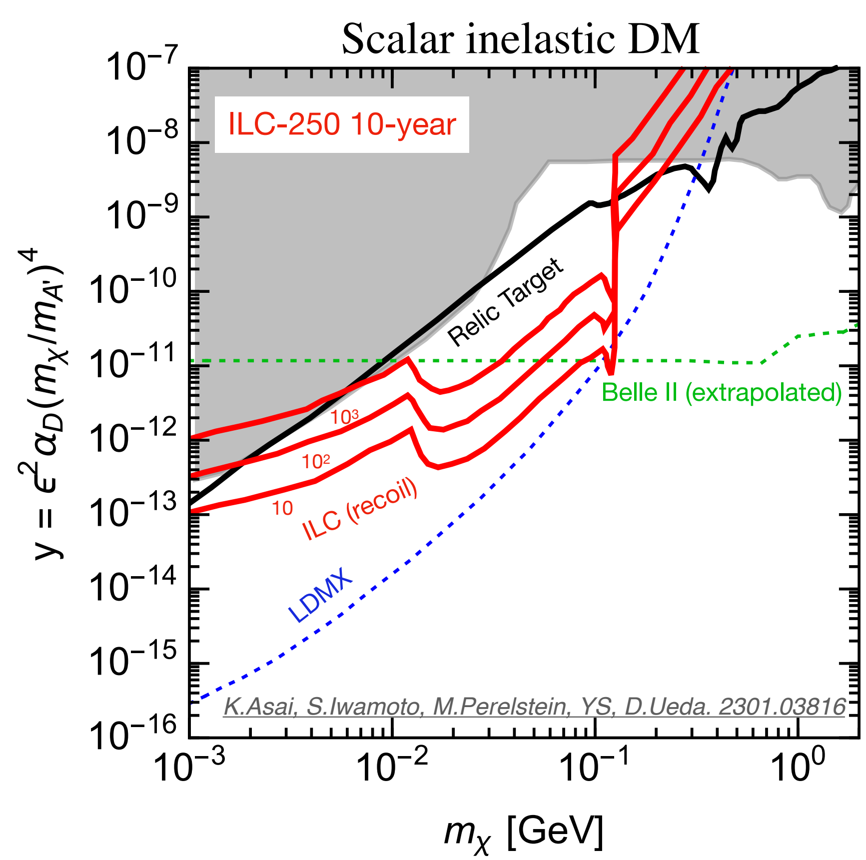


Bunched beam is better
(ILC, BDX)

Continuous beam is better
(LDMX)

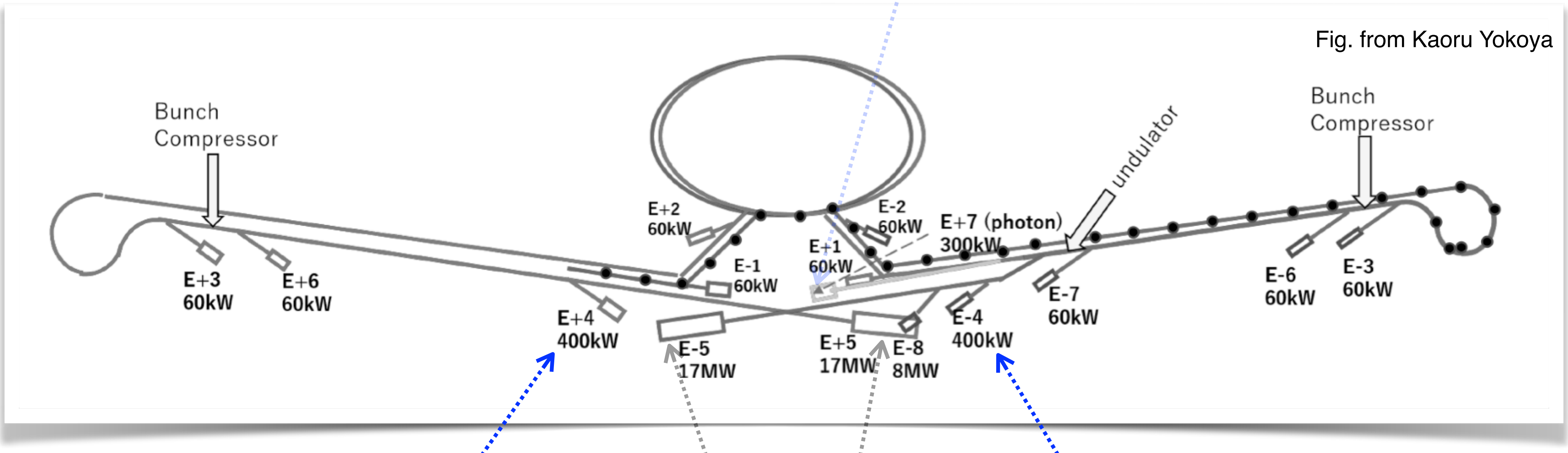
ILC complements dark matter searches using continuous beams.





Other places

Photon beam dump

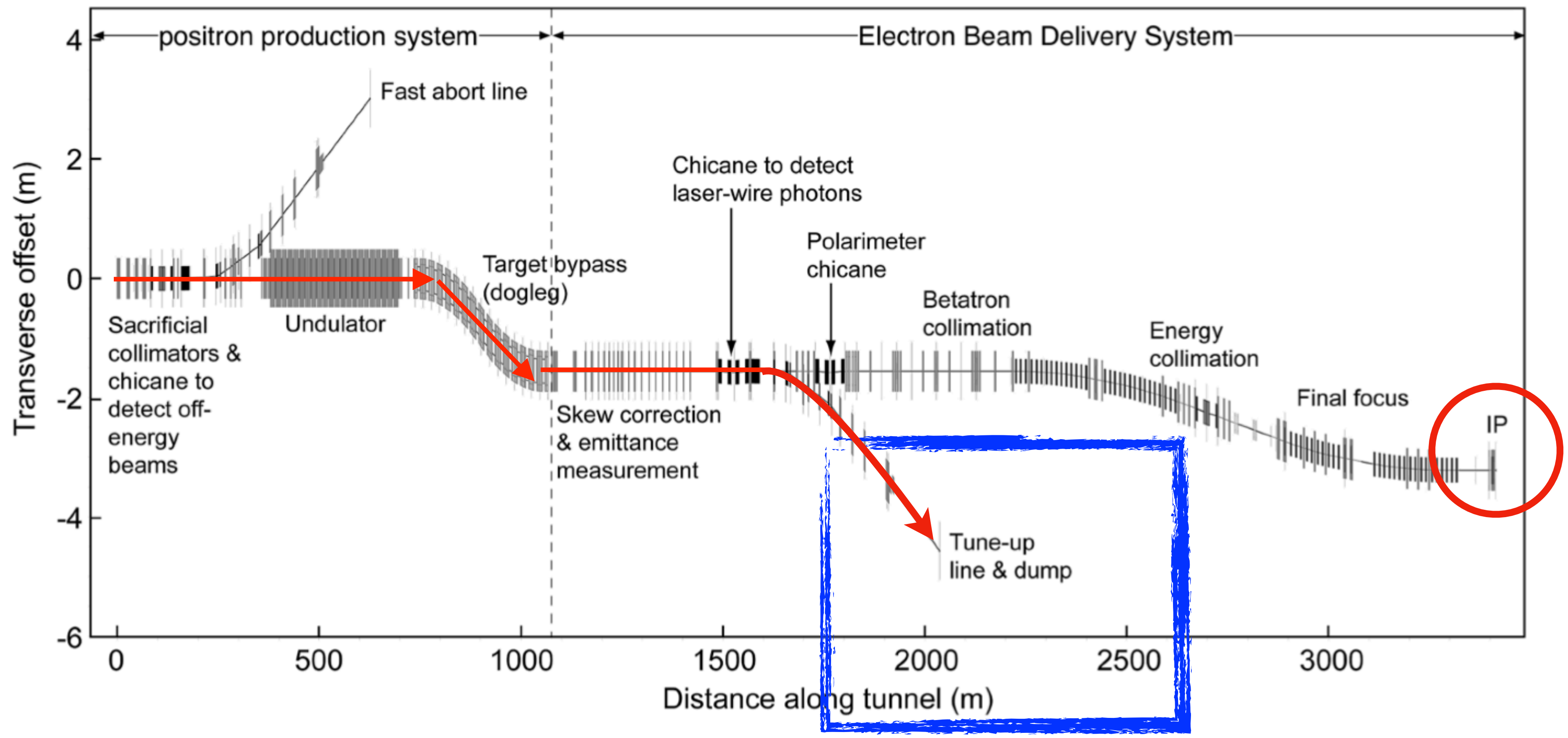


Tune-up dump for e+

Main beam dumps

Tune-up dump for e-

Tune-up dumps

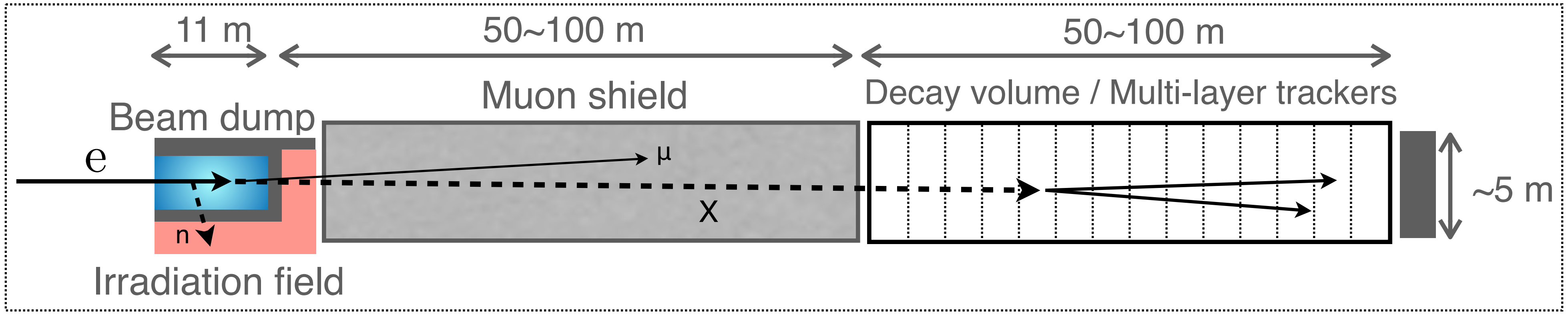


- Best place to perform dedicated experiments
  - ✓ Maximum beam energy available
  - ✓ Bunch charge can be adjusted
  - ✓ Beams in good condition before the collision is available

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



- **Beam dumps of a linear collider are used continuously**.
- We can utilize the very high-power beam dump without any additional cost.

  ➡ new particle searches, industrial applications and so on.
- In tuneup dump areas, high-energy bunched electron-positron beams can be utilized before the collision point.
- The ILC can accommodate a variety of PBC programs, and the facility design is improving to maximize the potential of the programs.

Backup

Introduction

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

Examples include the Fixed Target and Far Detector experiments, which are highly sensitive to light new particles (MeV~10 GeV) that feebly couple to Standard Model particles.

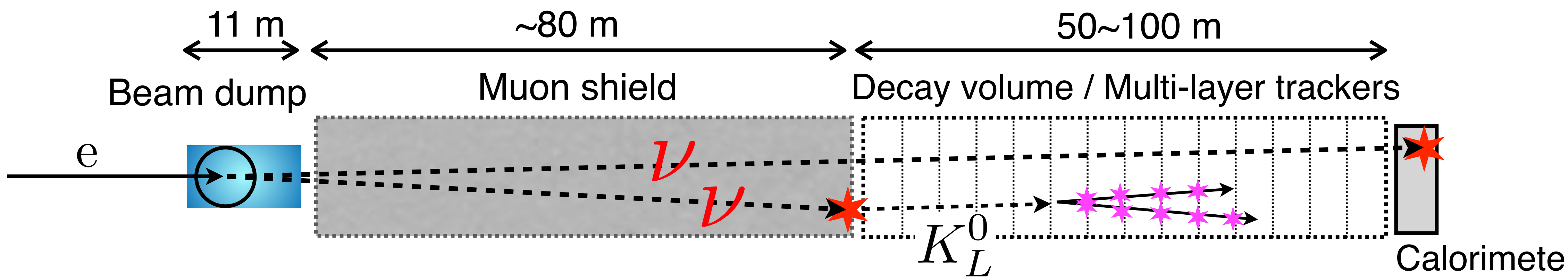
The PBC programs complement the collider experiment, in the absence of the discovery of heavy new particles at the LHC.

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

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

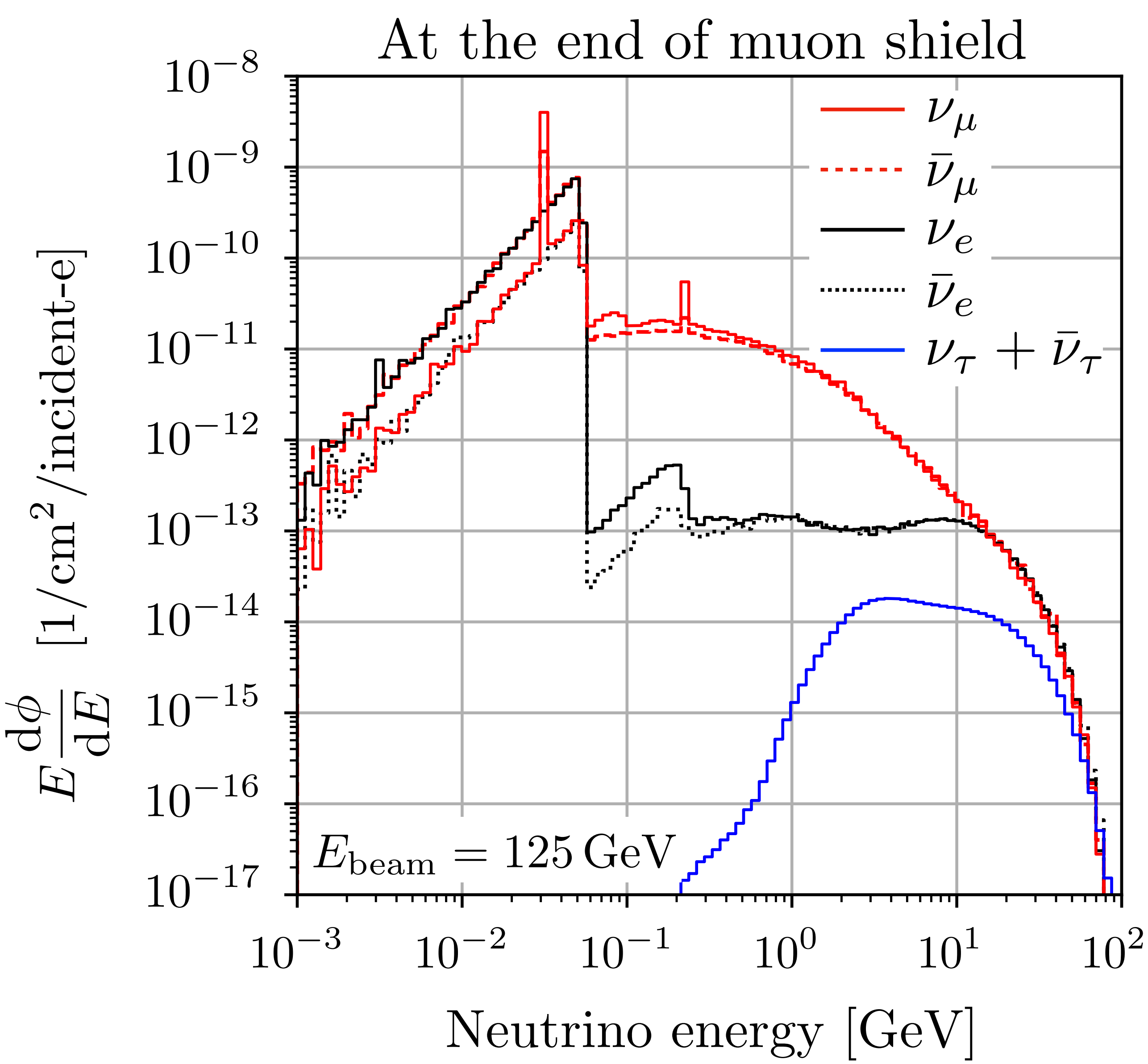
[1] US Cosmic Visions: New Ideas in Dark Matter 2017: Community Report, (1707.04591).
[2] Physics Beyond Colliders at CERN: Beyond the Standard Model Working Group Report, (1901.09966).

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

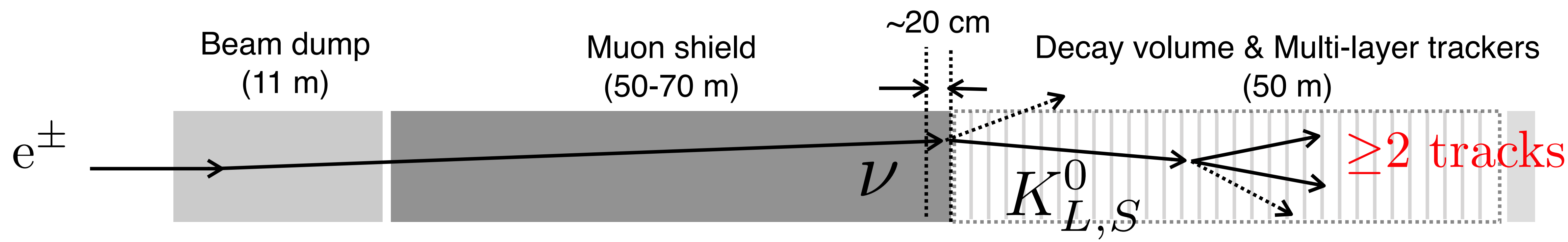


The cosmic-ray BG is negrigible due to:
- the deep underground location
- timing coincidence with the bunched beams

A study on the e + N → ν_e + X process in the (polarized) electron-positron beam dump is onging.

Background

Neutrinos hit the edge of muon shield



In the SHiP's study, the following cuts/veto are imposed:

- ✓ (1) Decays into charged particles inside decay volume
- ✓ (2) two tracks of opposite charge (x 10^{-3})
- ✓ (3) simple topology cuts (x $6*10^{-3}$)
- ✓ (4) veto system of SHiP (x 10^{-4})

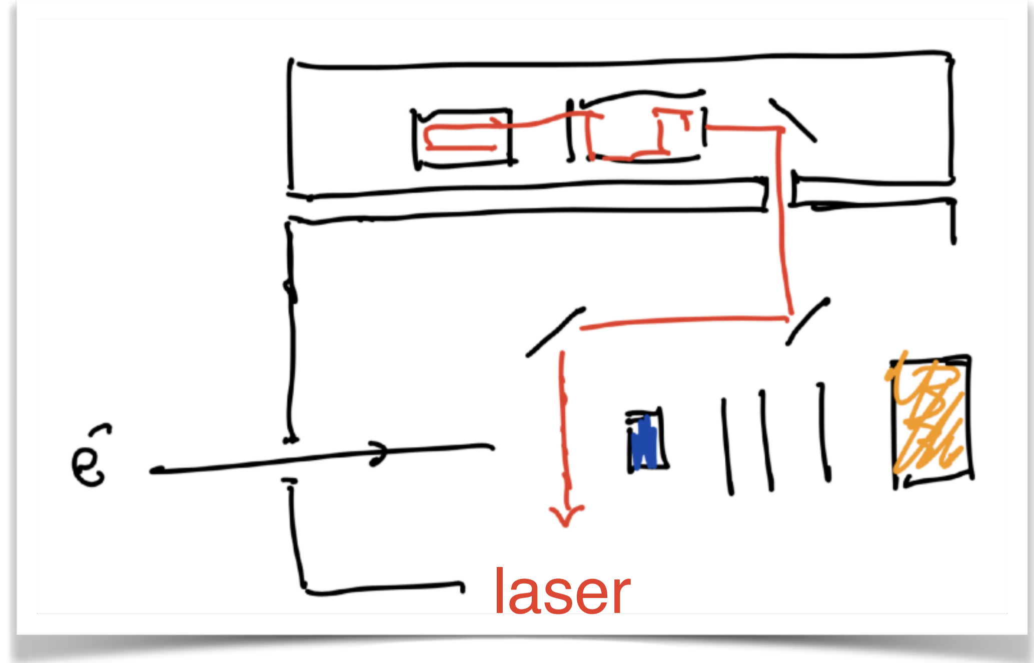
➡ ~ Zero Background

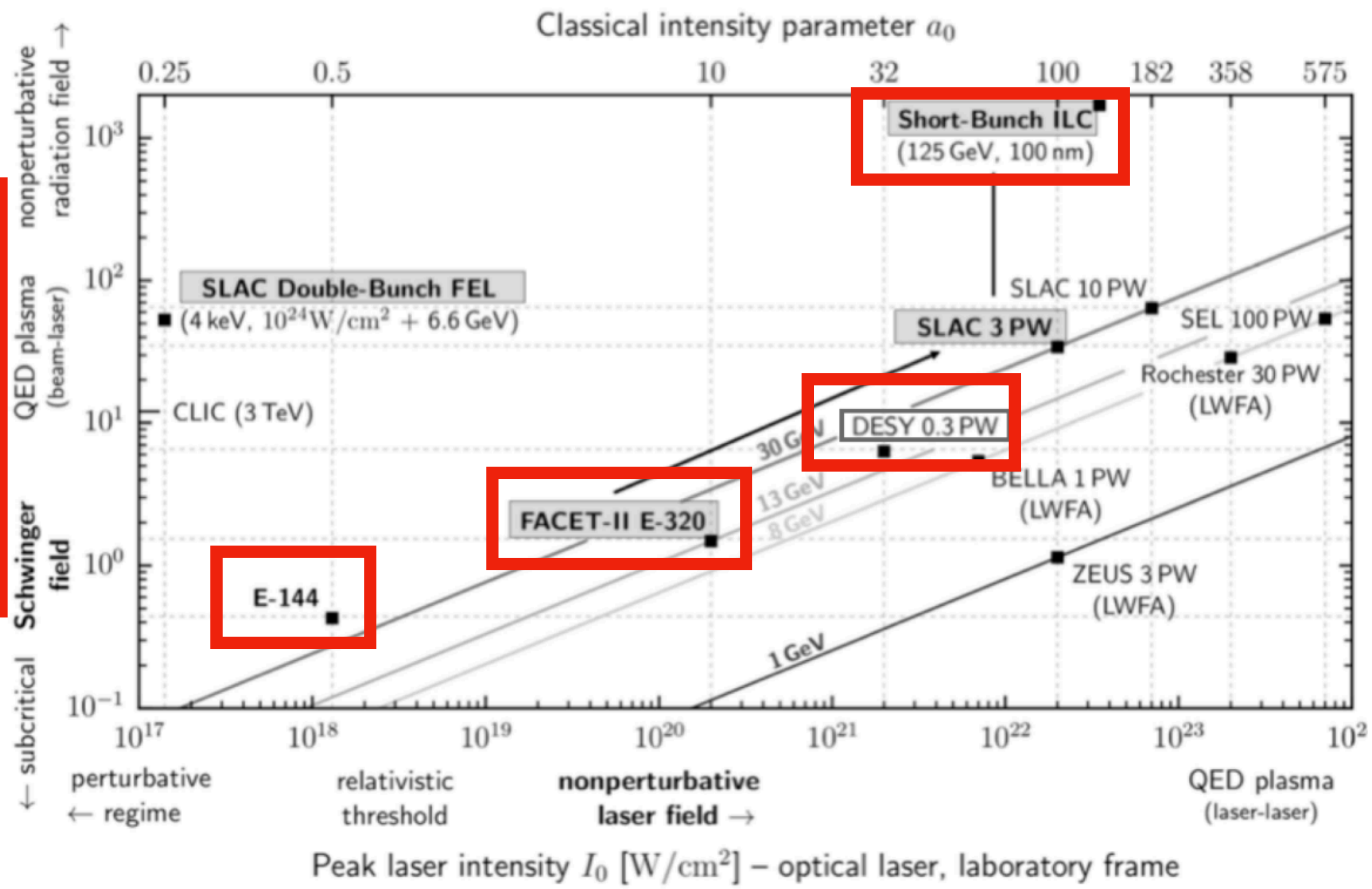
We assume 5 (20) BG at ILC-250(-1000) GeV with the conditions other than (4)

Non-linear QED

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.



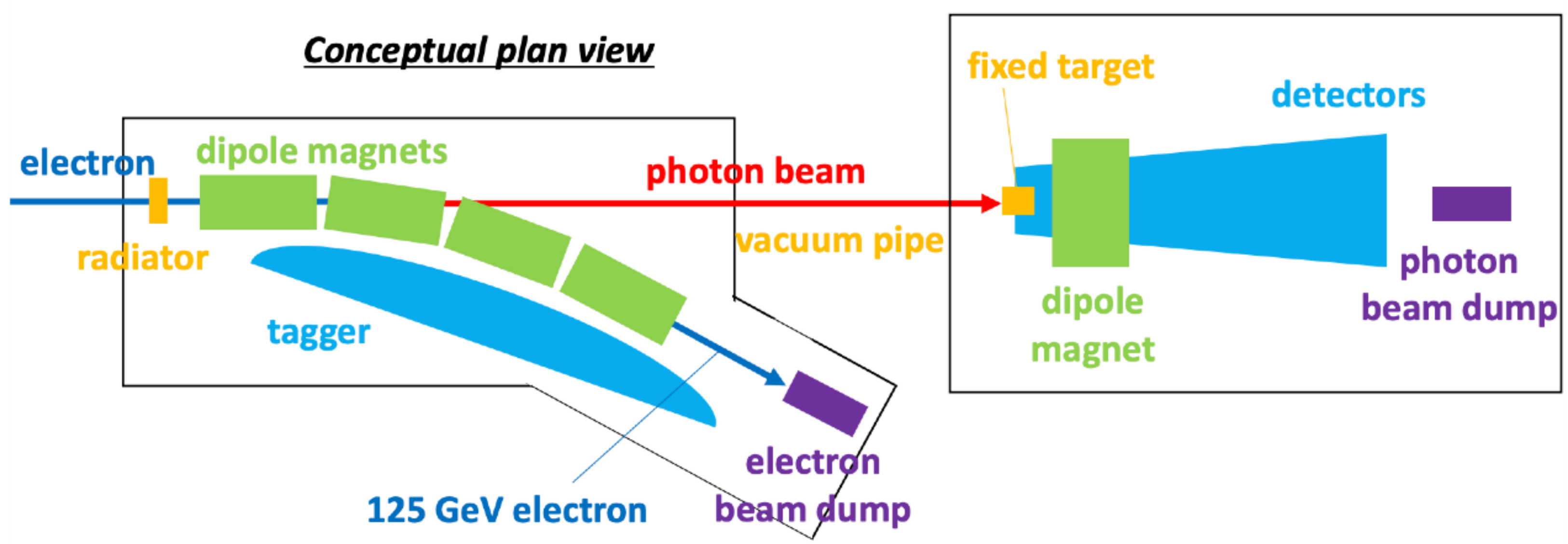


- A large quantum parameter χ can be reached with ILC beams and high intensity lasers.
- This large number makes possible to study interesting non-linear QED processes

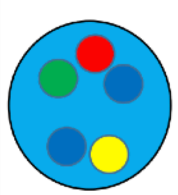
Photoproduction of Exiotic hadrons and Heavy hadrons

From Norihito Muramatsu's talk @ ILCX2021

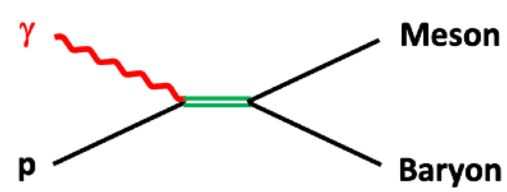
Setup for hadron photoproduction experiments

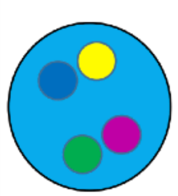


Exotic hadrons

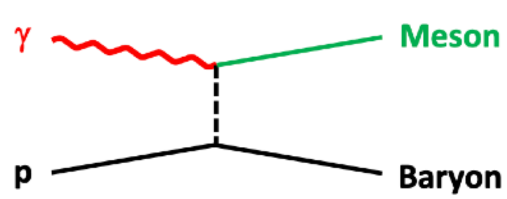


$uud c\bar{c}$ pentaquark
$P_c(4312)^+$ etc in $\Lambda_b^0 \to J/\psi\, pK^-$
$P_c(4337)^+$ in $B_s^0 \to J/\psi\, p\bar{p}$





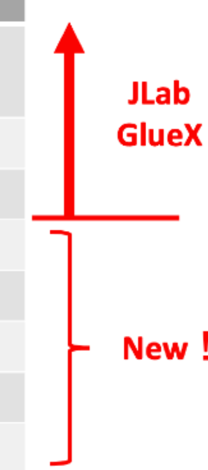
4-quark state including $c\bar{c}$
X(3872) in $B^\pm \to K^\pm \pi^+ \pi^- J/\psi$
$Z^+(4430)$ in $B^0 \to K^- \pi^+ \psi'$



Heavy hadron photoproduction

- Photoproduction cross sections & spin observables must be sensitive to hadron properties.
  ⇒ Complementary to LHCb, Belle-II, J-PARC, …

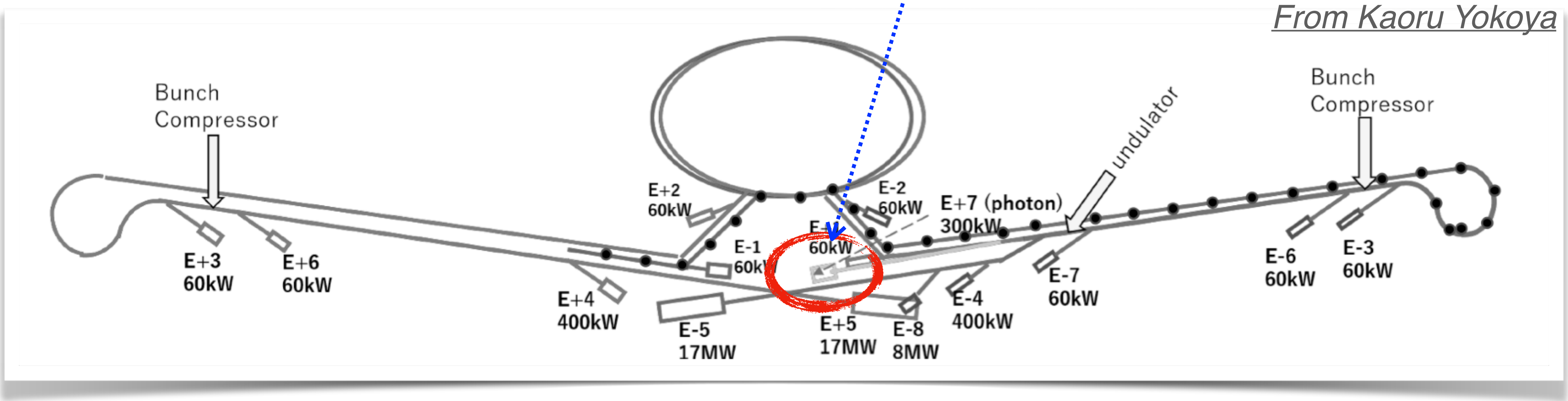
reaction	E_γ threshold
$\gamma p \to J/\psi\, p$ $\gamma p \to P_c(4312) \to J/\psi\, p$	8.21 GeV (9.44 GeV)
$\gamma p \to \bar{D}^0 \Lambda_c^+$	8.71 GeV
$\gamma p \to \bar{D}^0 \Sigma_c^+$	9.47 GeV
$\gamma p \to X(3872)\, p$	11.9 GeV
$\gamma p \to Z^+(4430)\, n$	14.9 GeV
$\gamma p \to$ X(6900) p	32.3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



Photon beam from Helical undulator

Photon beam dump

From Kaoru Yokoya



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

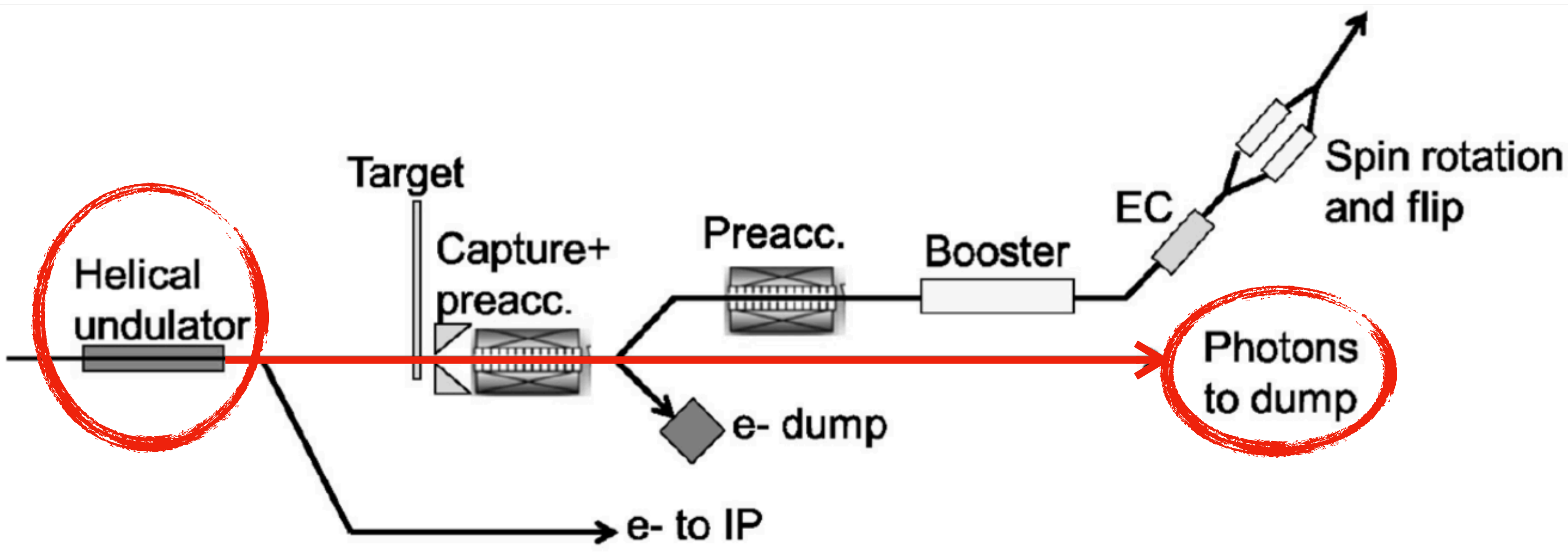
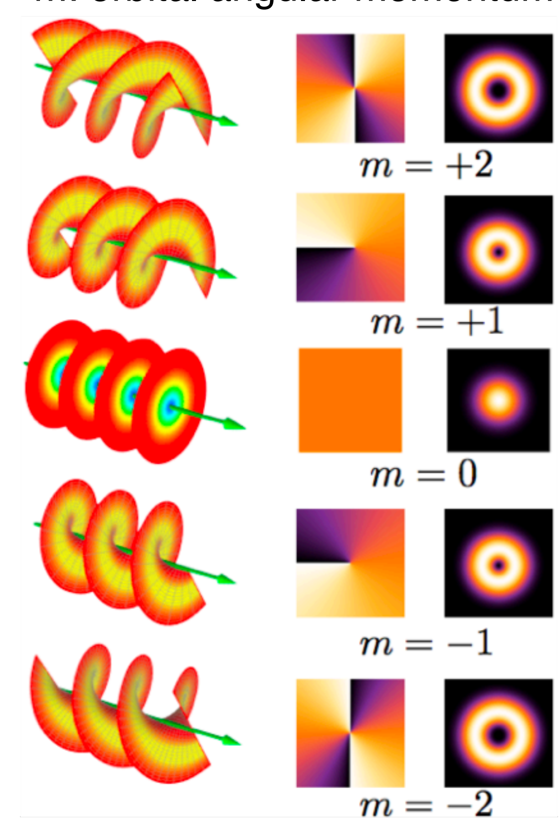


Figure 1: Sketch of the undulator-based ILC positron source.

Figure From F. Dietrich et.al, 1902.07744

Optical vortex

m: orbital angular momentum

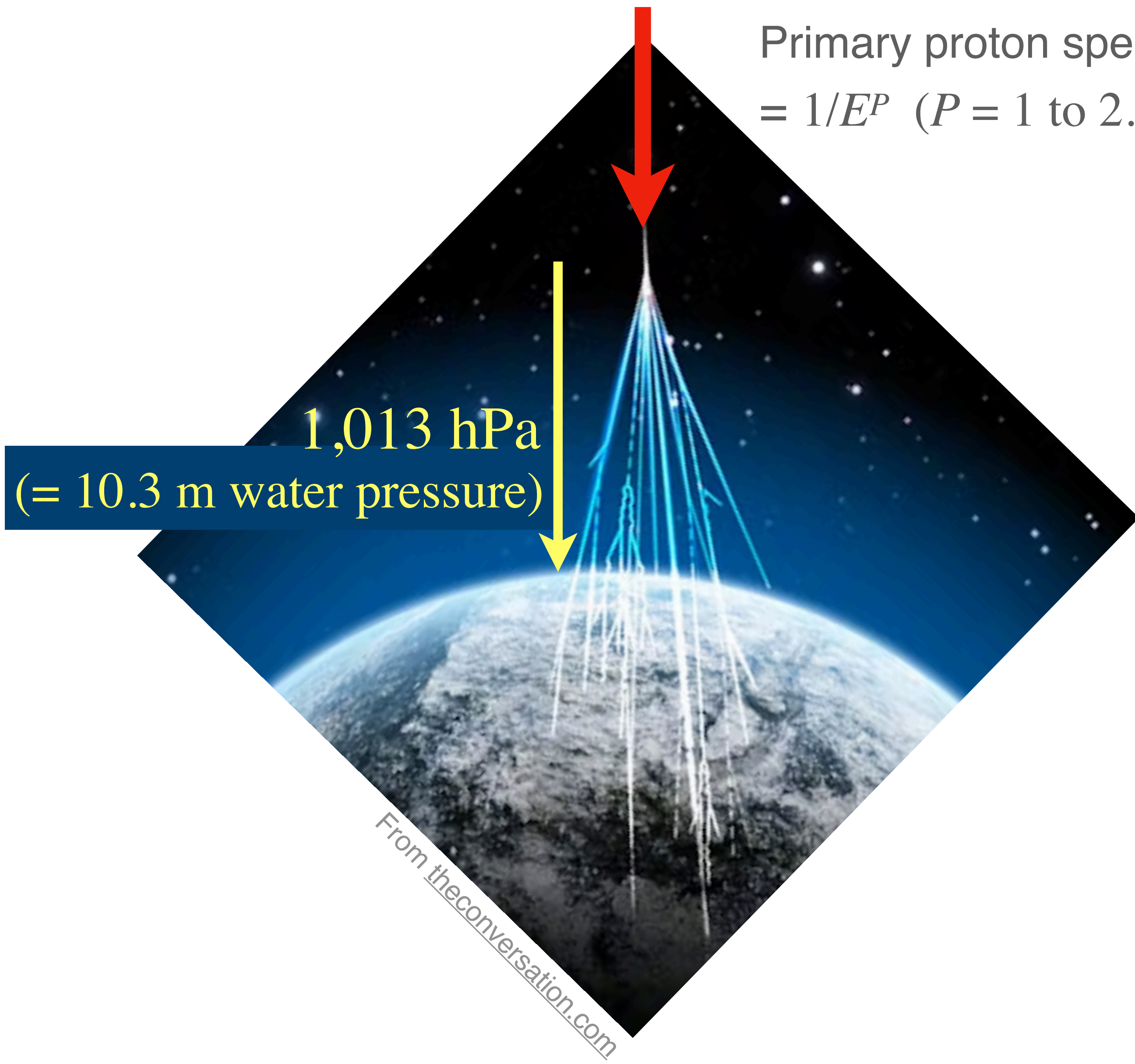


From Wikipedia

ILC beam dumps may provide atmospheric-like radiation fields

Primary cosmic rays

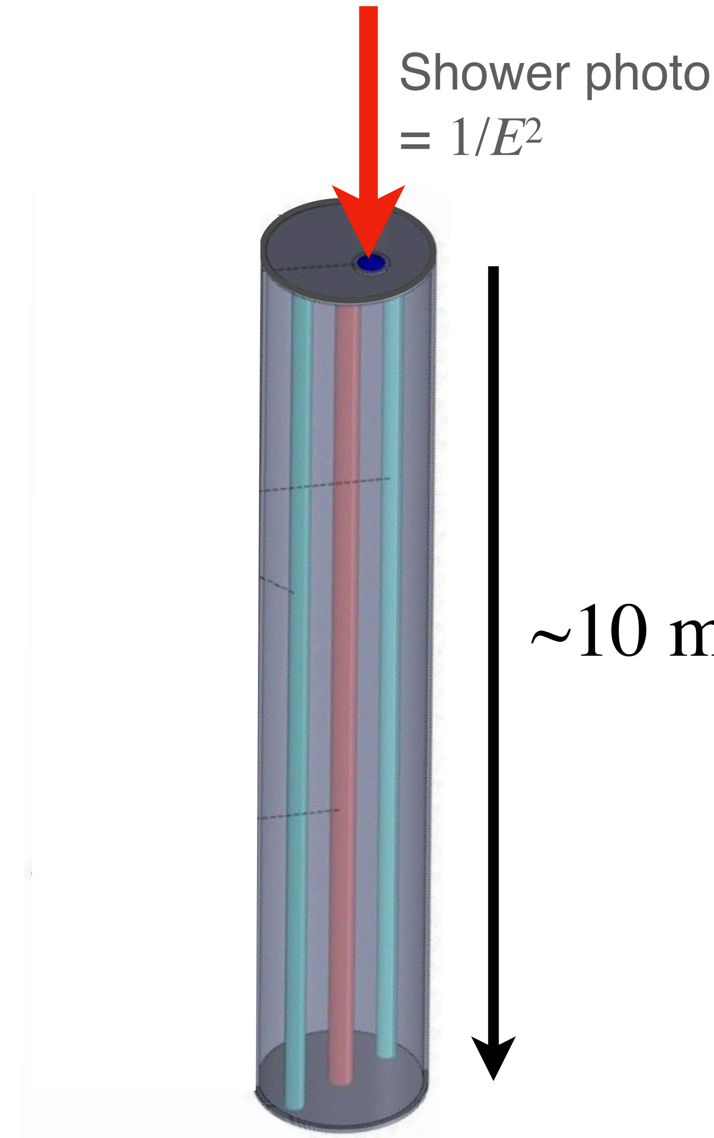
Primary proton spectrum (E >1GeV)
$= 1/E^P \quad (P = 1 \text{ to } 2.7)$



$\simeq$

Primary beams

Shower photon spectrum
$= 1/E^2$

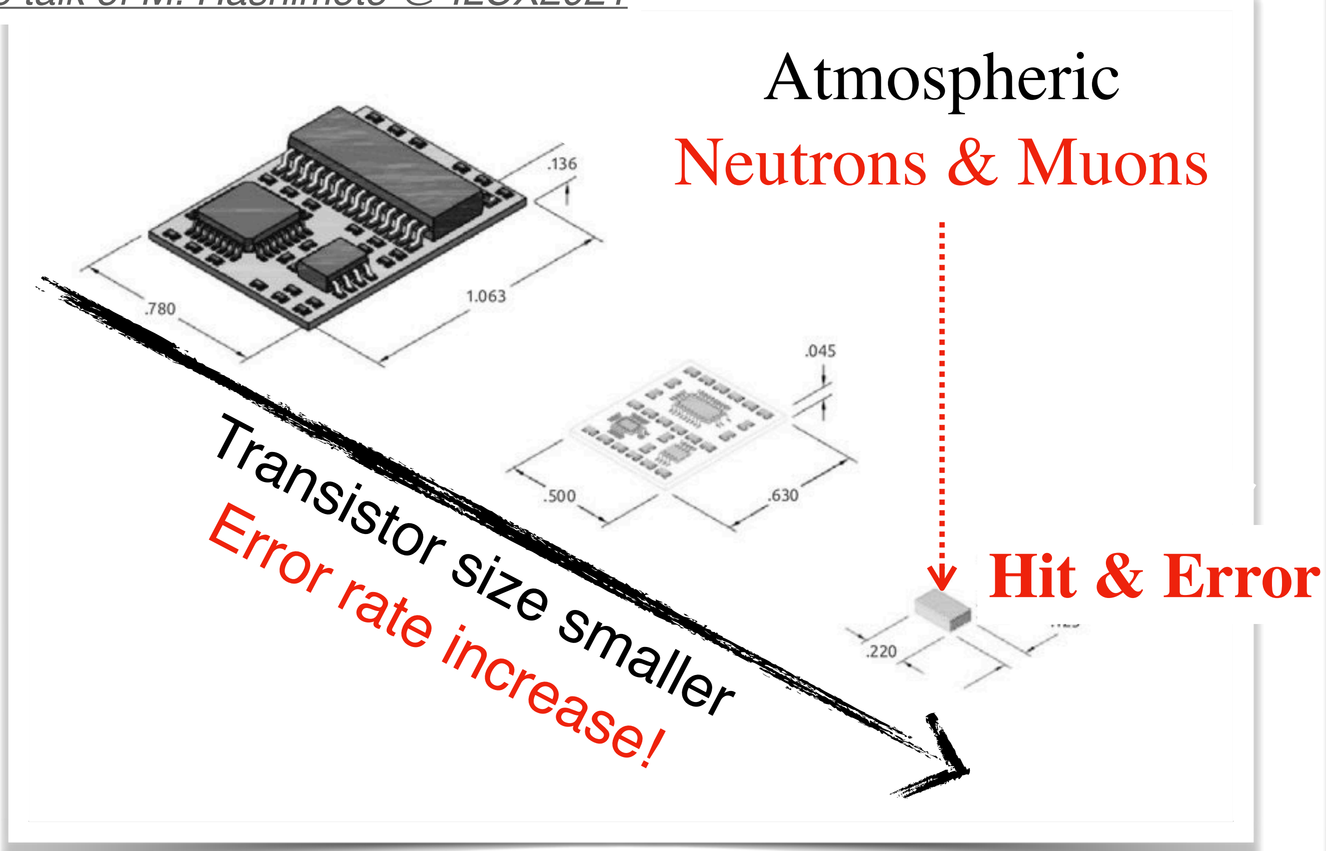


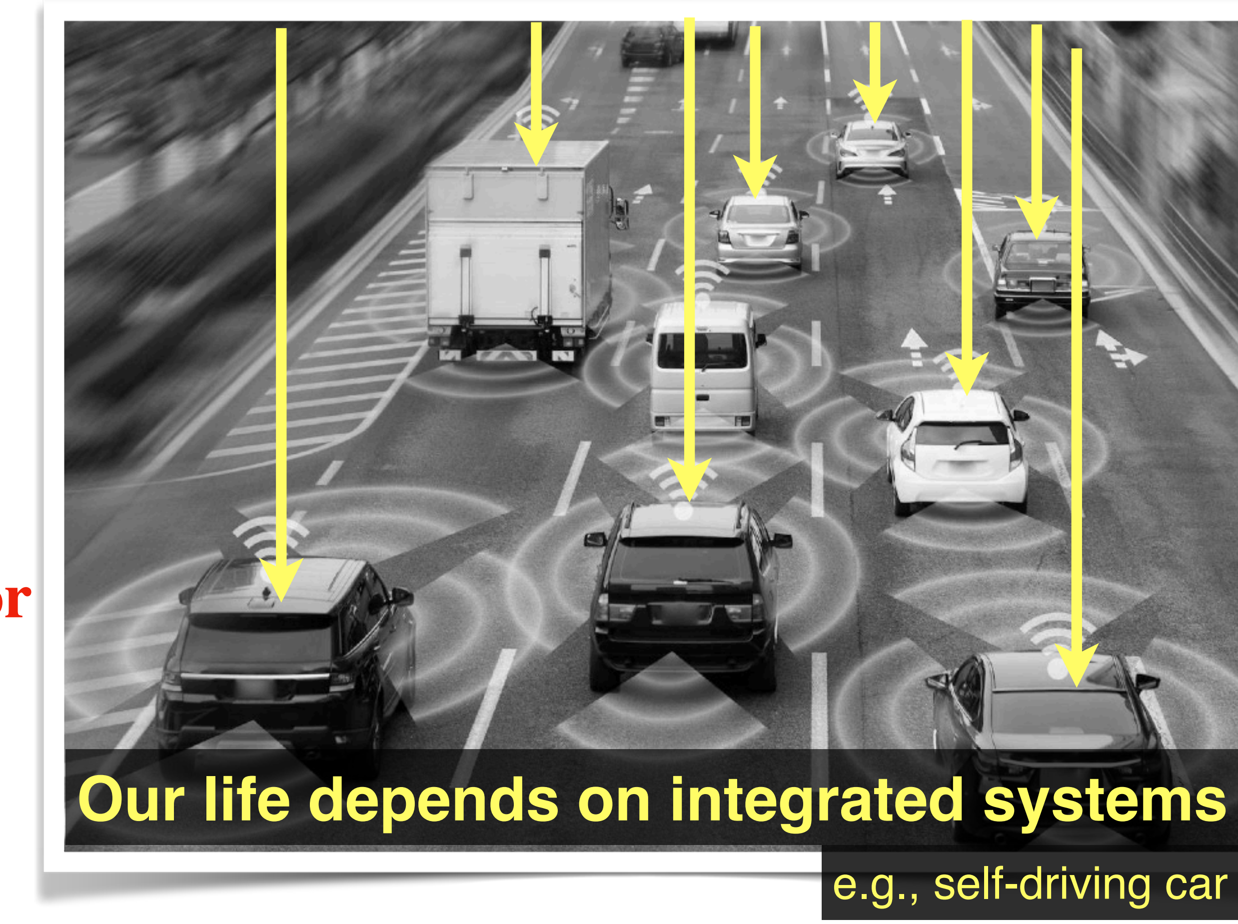
- Material of the same weight as the ILC beam dump is piled up on the ground.

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

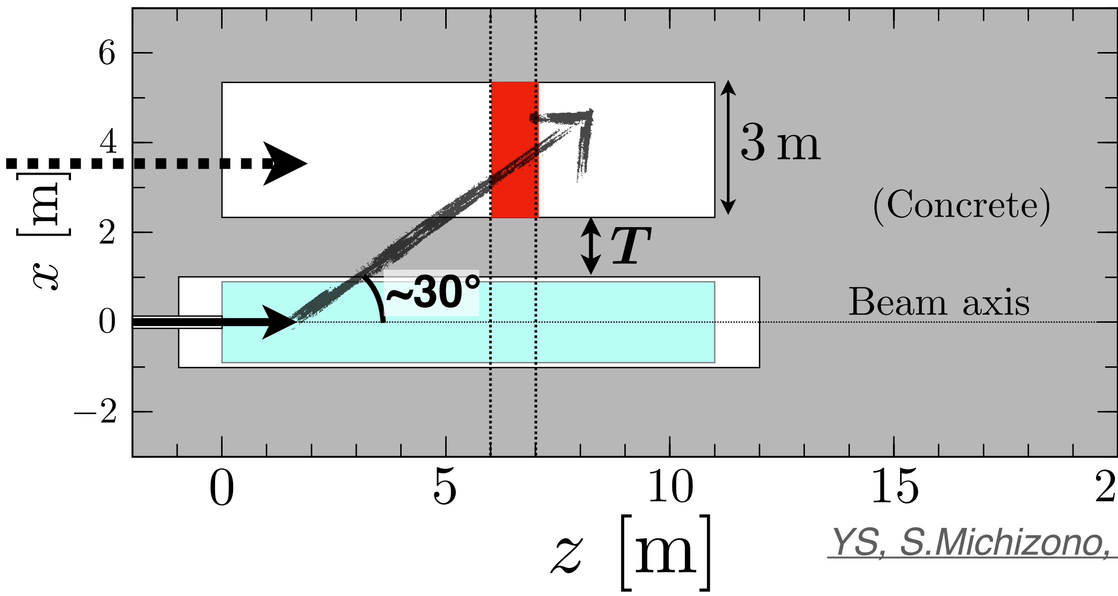




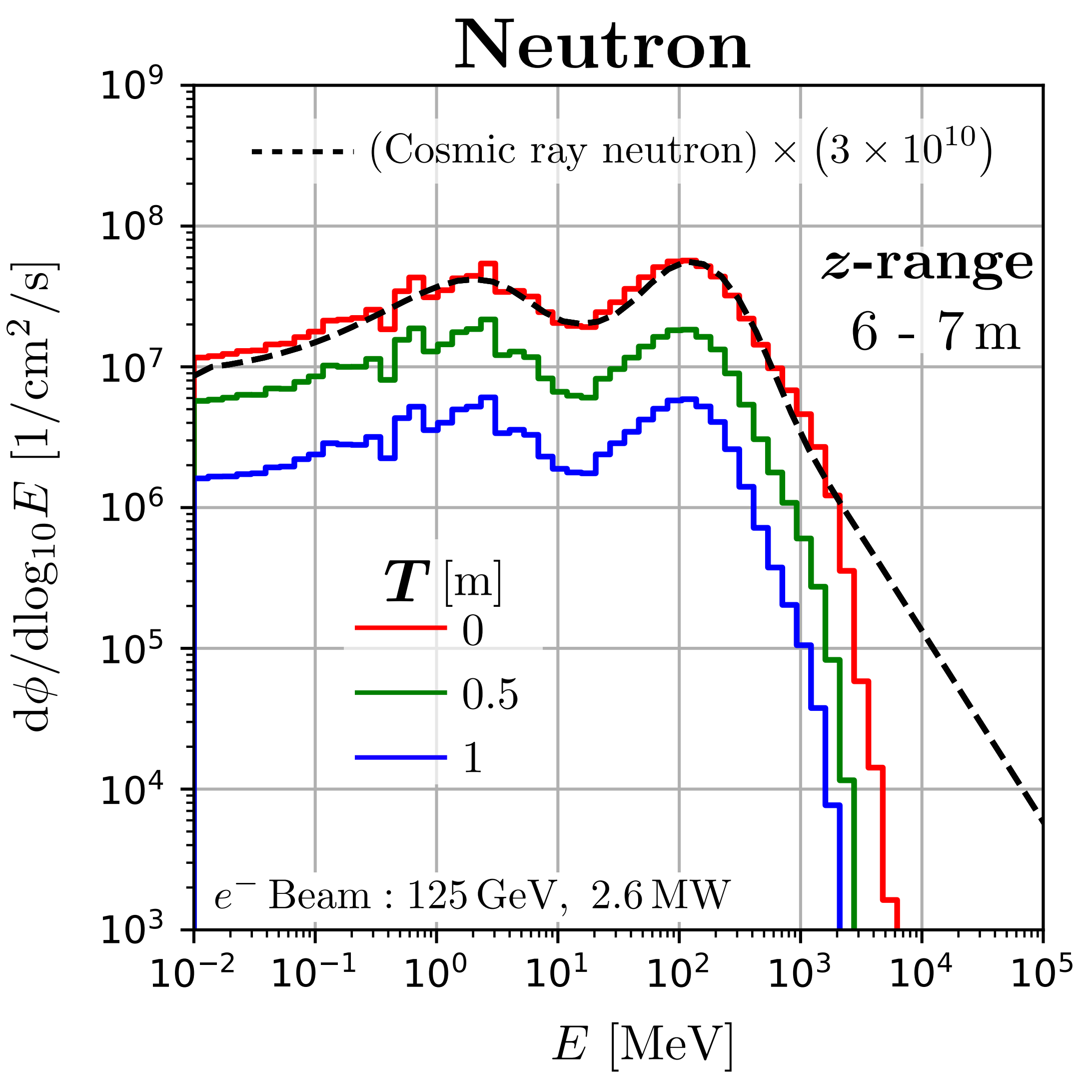
- Irradiation fields that provide *high-intensity*, *large-area*, and *atmospheric-like spectra* are favored.

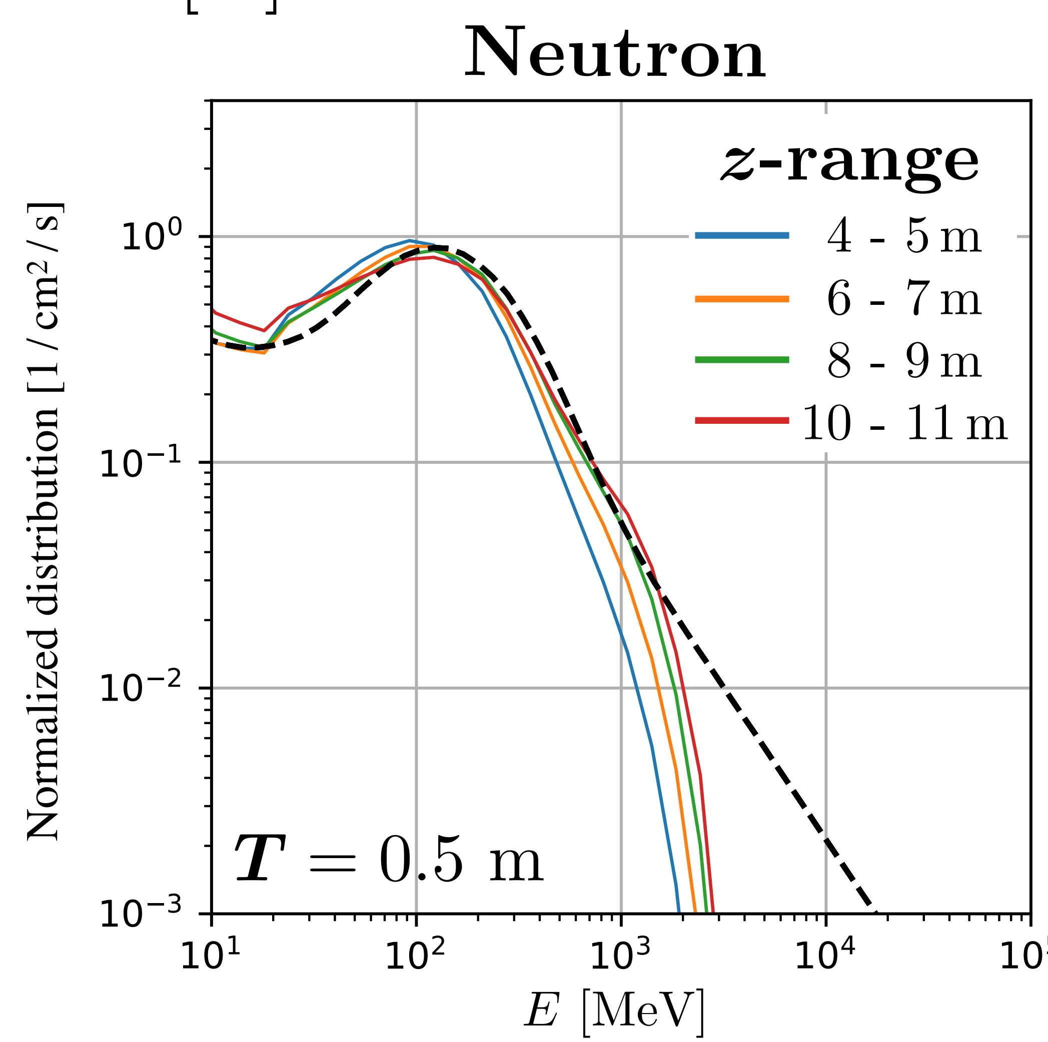
Neutrons and muons at ILC beam dump have atmospheric-like spectra?

Space beside beam dump



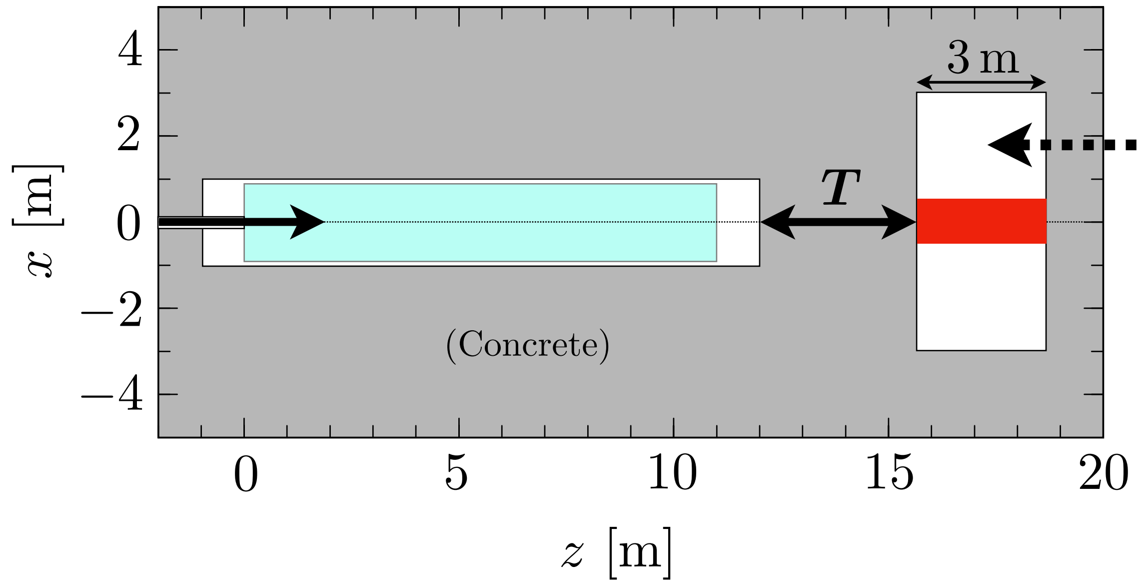
YS, S.Michizono, N.Terunuma, T.Sanami. 2210.08690



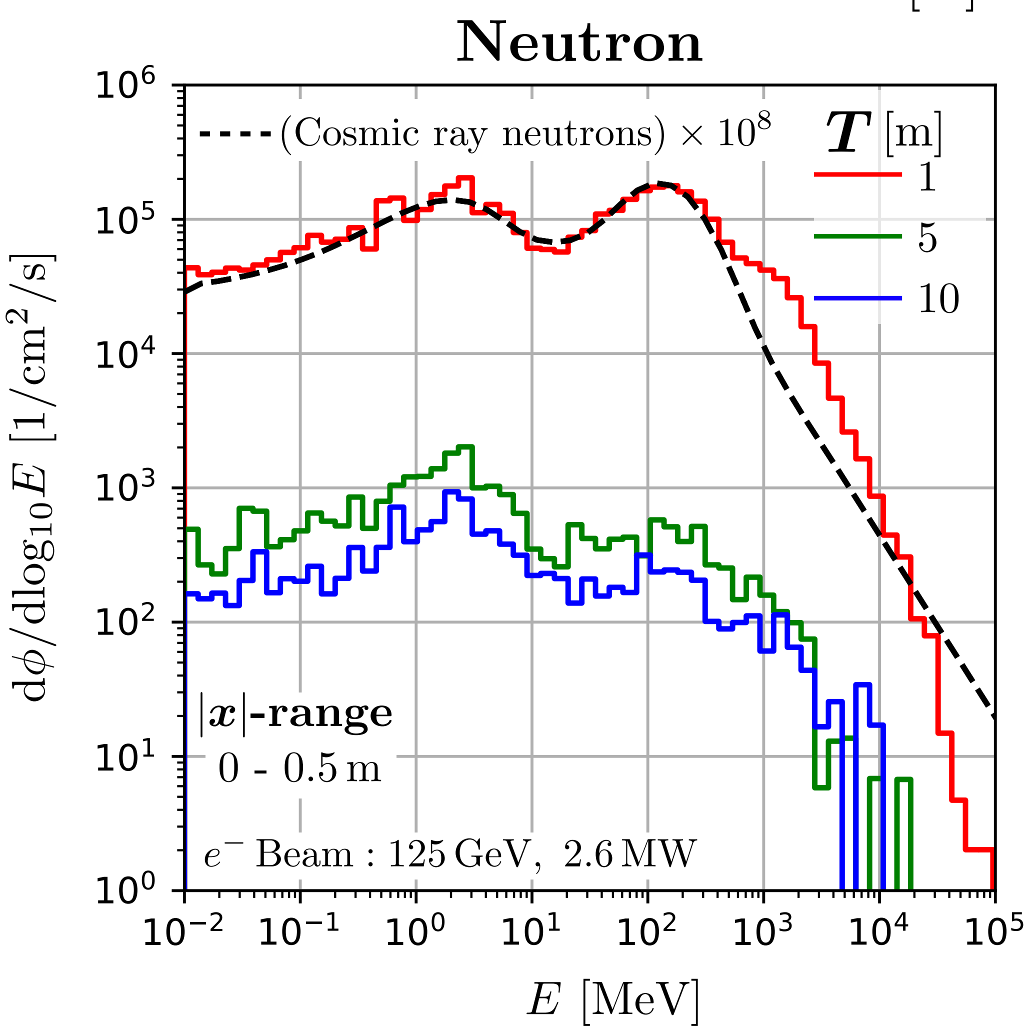


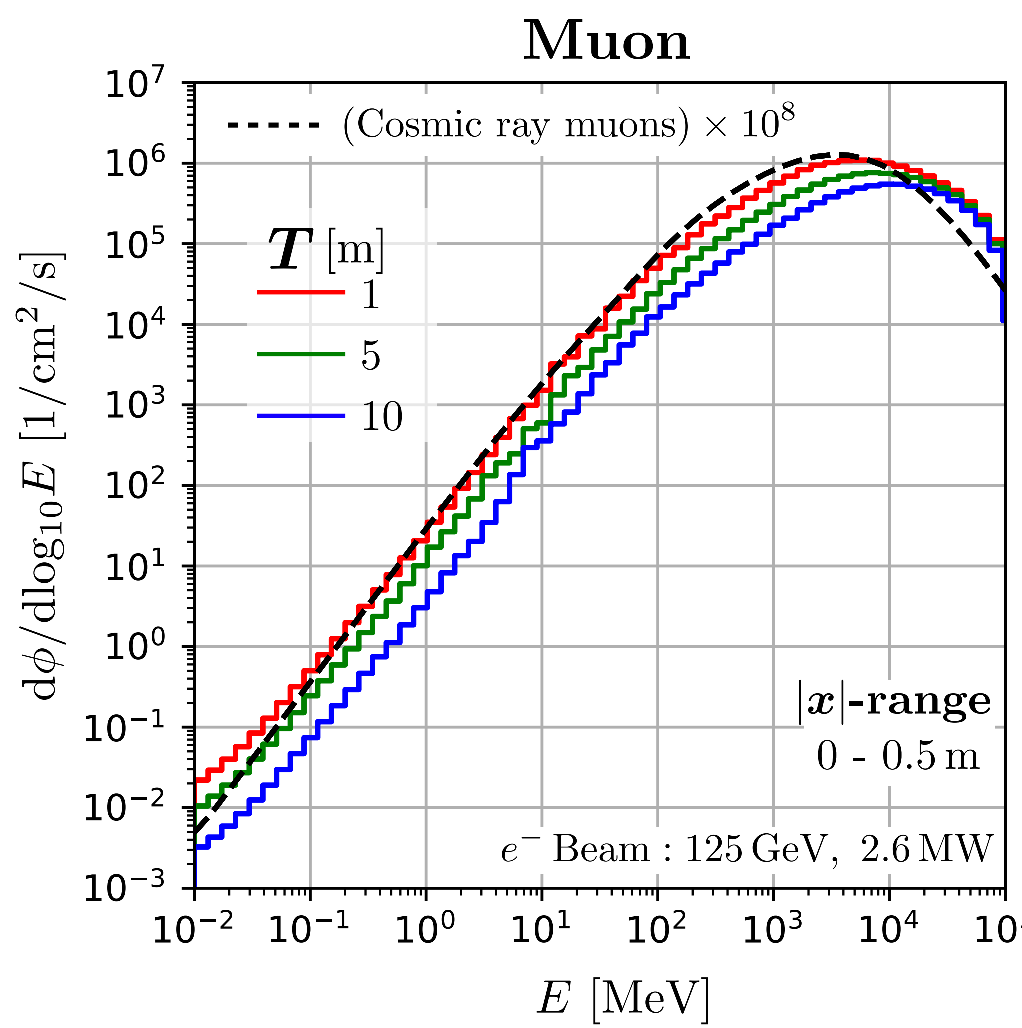
- Atmospheric-like neutrons are obtained. (consistent up to a few GeV!)
  - ➡ High-energy tail behavior slightly depends on z-range
  - ➡ Especially consistent at z=6-7m (~30 degrees)

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



Downstream of beam dump

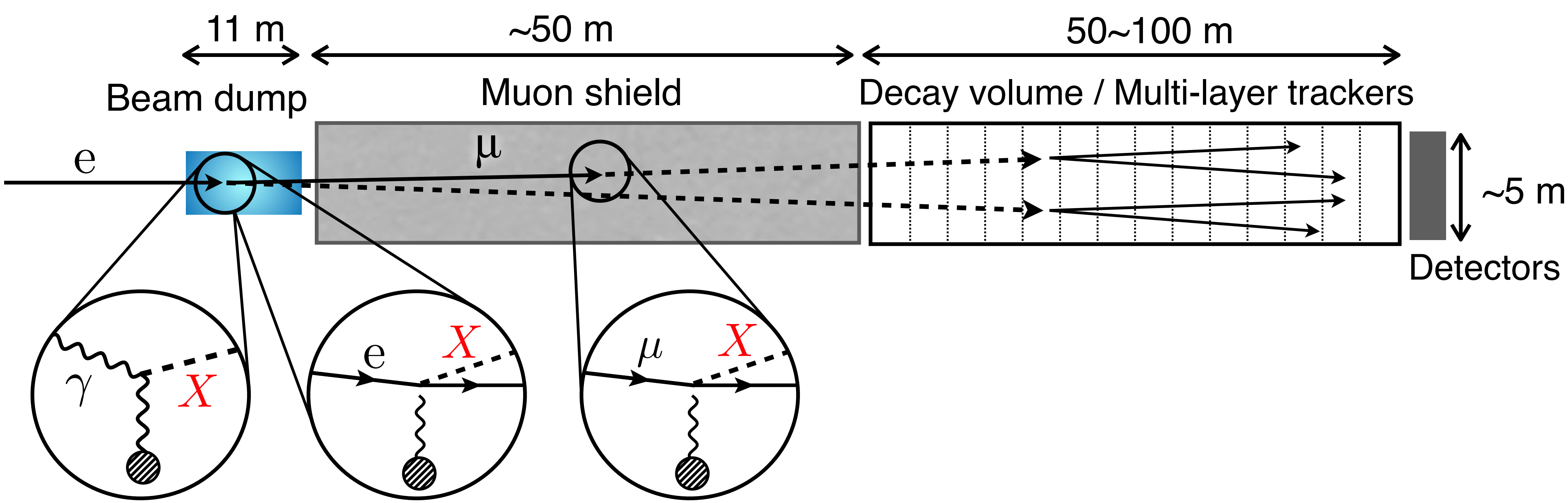




- Both neutrons and muons have atmospheric-like spectra.
- Muon dominant beam is available with thick shielding.

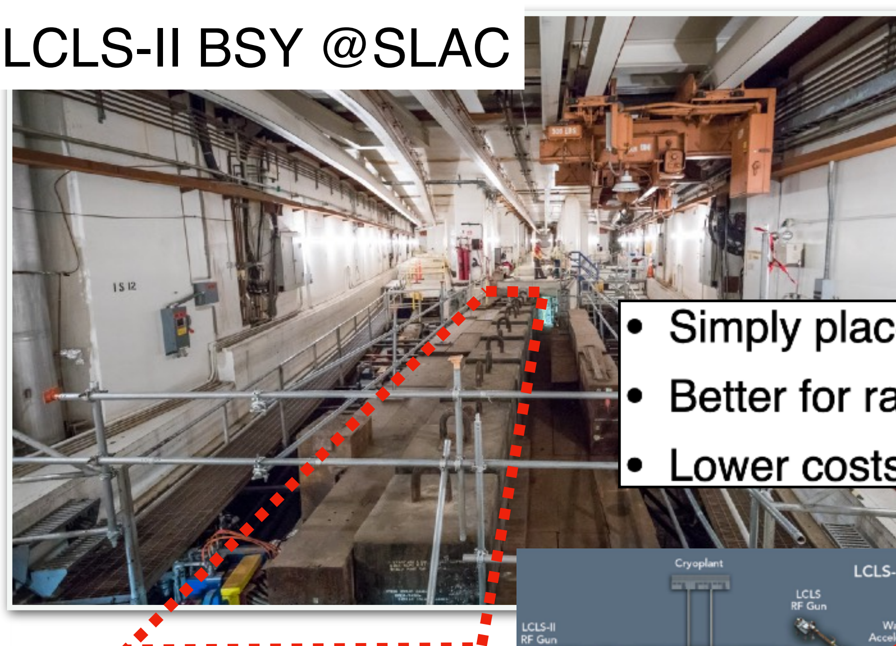
ILC can also be used for industrial studies.

Searches for Long-Lived Particles



Passive muon shield

LCLS-II BSY @SLAC



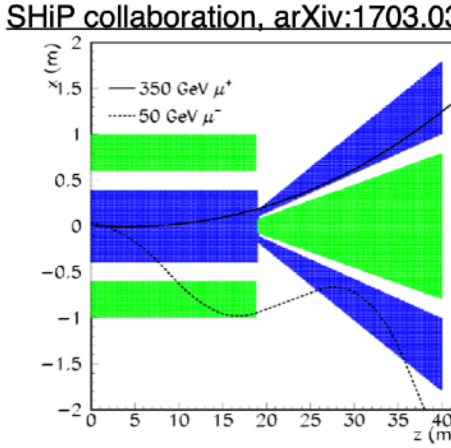
- Simply placed heavy objects
- Better for radiation issues
- Lower costs?

Iron blocks for muon

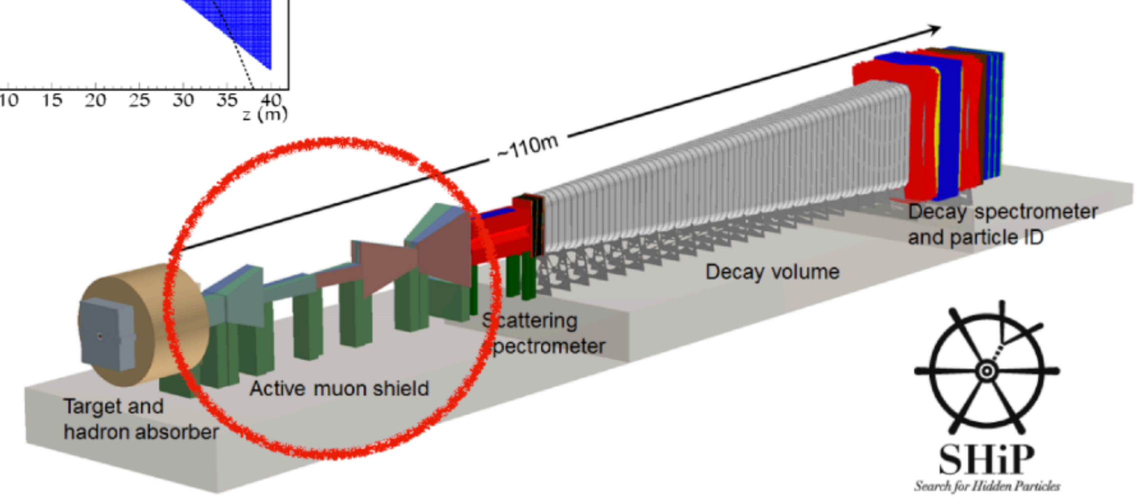
(for radiation safety)

Active muon shield

SHiP collaboration, arXiv:1703.03612



- Magnetic shielding
- Effective even at High-Energy ILC



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