Diversified use of ILC: A possibility of hadron photoproduction experiments at a beam dump

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Contents

Proposing hadron photoproduction experiments at ILC beam dump by generating ***a real photon beam with circular or linear polarization in the energy region of several dozen GeV****.*

- **Motivation & Beam production methods**
- **Advantages & Beam properties at ILC**
- **Discussions of physics possibilities**

Second presentation on the photon beam production at ILC, following my talk @ LCWS2019 "Production of a coherent bremsstrahlung photon beam with several tens of GeV at ILC"

Motivation

*A photon beam is a **unique** tool to study hadrons.*

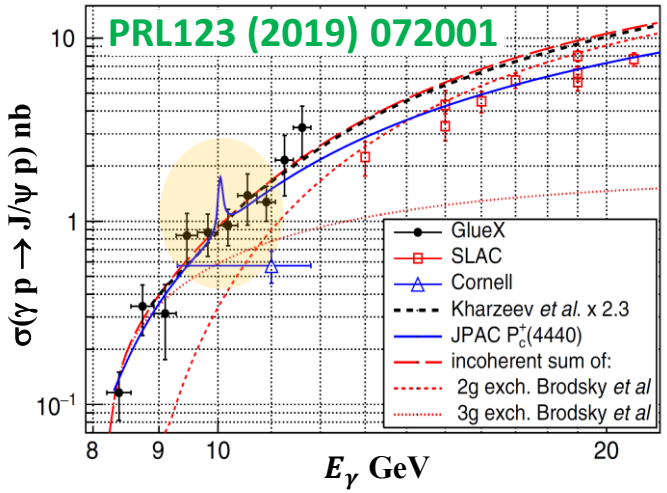
SPring-8, JLab, ELSA, MAMI, ELPH, …

*ILC can provide an **unprecedented** photon beam for hadron photoproduction.*

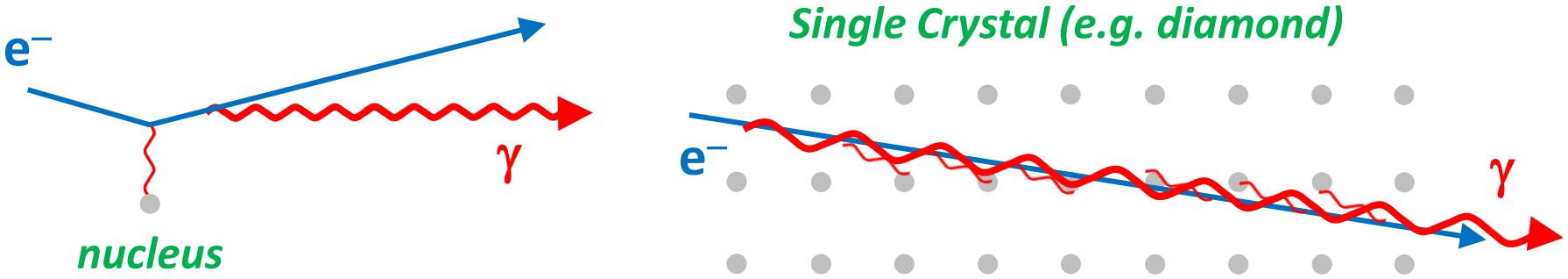
- **Very high energy** that can produce heavy hadrons including c & b **quarks**. (Effective to study **exotic hadrons** containing $q\bar{q}$.)
- **High polarization** can be easily achieved.

$\Rightarrow$ J^P **information** of hadrons

P_c pentaquark ($uudc\bar{c}$) search at GleuX



Bremsstrahlung beam production



γ-ray radiation by a relativistic $e^{\pm}$ in a narrow cone.

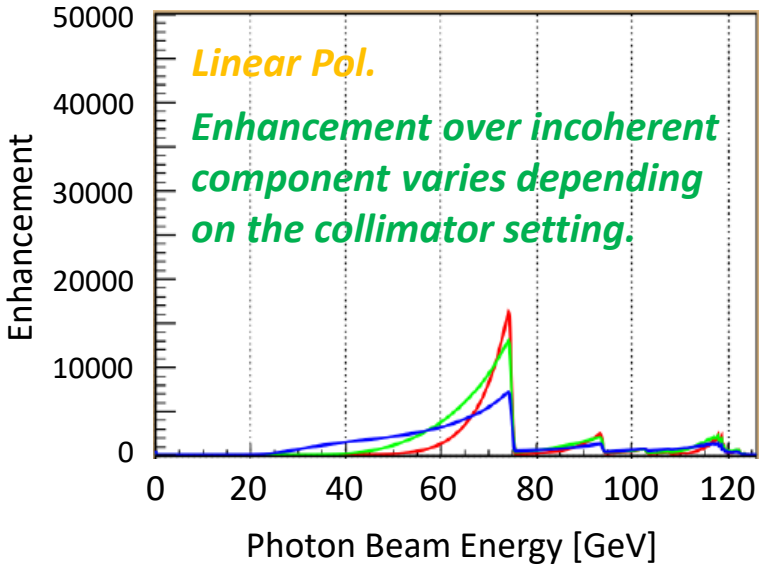
- If **$e^{\pm}$ is polarized**, the γ beam has **circular polarization** due to the conservation of angular momentum.
- If $e^{\pm}$ passes through **a periodic nuclear EM field**, the γ beam has **linear polarization**. (coherent bremsstrahlung)

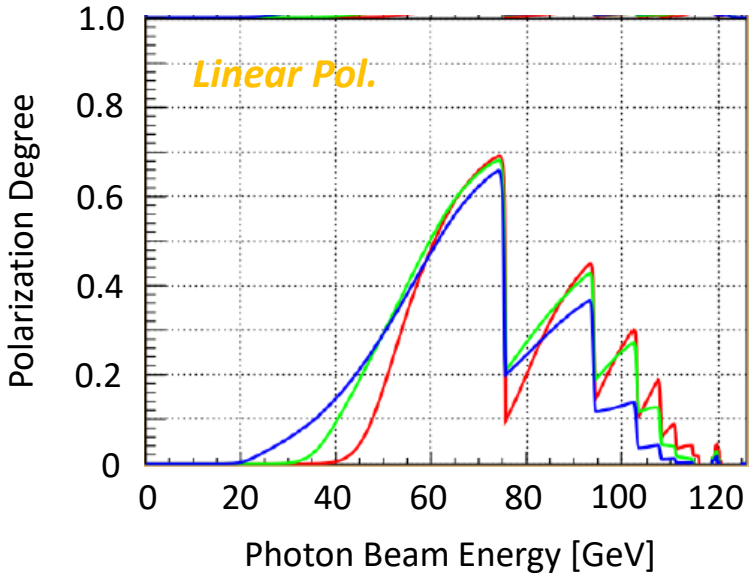
Such γ beams are now **in practical use** at many of hadron photoproduction experiments. (**Max. E_{γ}~9 GeV @JLab**)

Advantages of using ILC

- **High energy $e^{\pm}$ beam** (125 GeV)
  Amorphous radiator: **~$1/E_\gamma$** spectrum up to E_e.
  Crystal radiator (coherent brems.): A narrower E_γ range whose peak is adjustable to **20-80% of E_e**.
- **High $e^{\pm}$ current** (20 μA × 10% = **2 μA**)
  > J-Lab (12 GeV) Hall-D : **10^7 γ/sec with 200 nA**
- **Small $e^{\pm}$ beam divergence** (**~ 1 μrad**)
  < Characteristic cone angle **$\theta = 1/\gamma \sim 4$ μrad**
- **Longitudinally polarized $e^{\pm}$ beam** with **spin flip**
  ⇒ **Circular pol.** & Suppression of systematics
  ⇒ Spin-flipped data can be added for **linear pol.**

Photon beam properties





Formulation by Olsen & Maximon, PR114 (1959) 887.

➢ Circular polarization

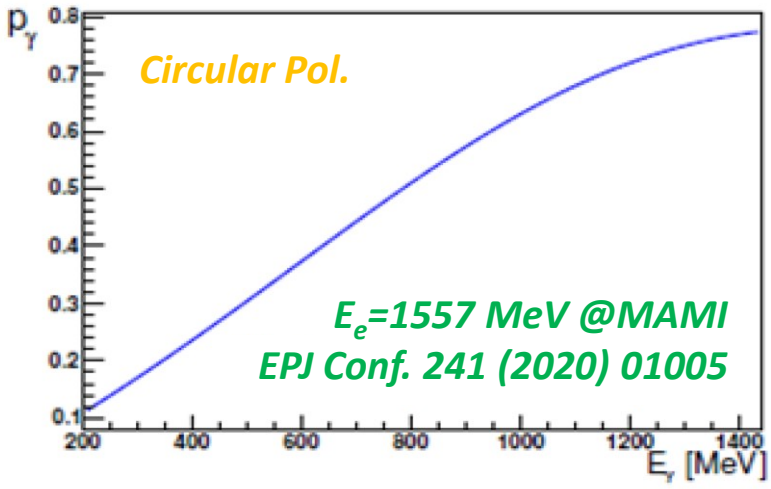
$$P_\gamma = \frac{4E_\gamma E_0 - E_\gamma^2}{4E_0^2 - 4E_\gamma E_0 + 3E_\gamma^2} \cdot P_e$$

➢ Linear polarization

*Calculated by **K. Livingston (Univ. of Glasgow)***

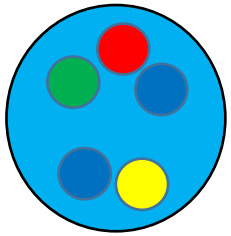
Peak energy setting by radiator angle at $E_\gamma = 0.6E_e$ (75 GeV)

$\Rightarrow P_{lin}^{max} \sim 70\%$



Exotic hadrons

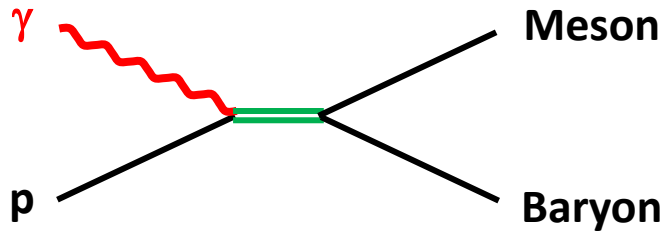
- In recent ~20 years, **many exotic hadrons** have been found for charm & bottom sectors. (They suggest rich structures in hadron confinement.)

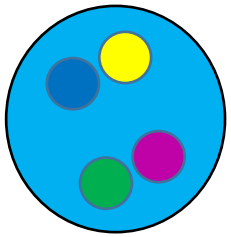


$uudc\bar{c}$ pentaquark

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

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

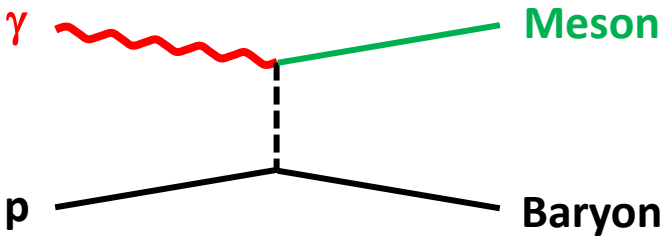




4-quark state including $c\bar{c}$

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

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



- Particularly, many new hadrons include $c\bar{c}$.

  $\Rightarrow$ Corresponding states in the b sector?

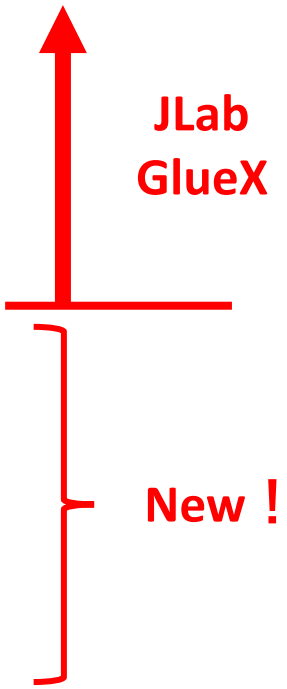
A high energy photon beam must be a suitable tool.

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



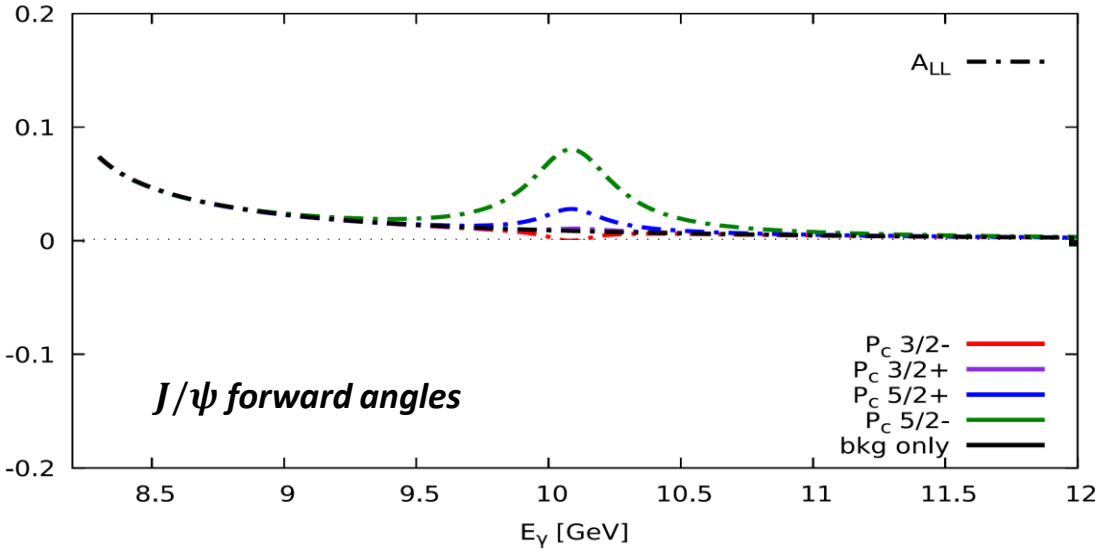
Use of circular polarization

e.g. **Double Polarization Observable** to constrain the J^P of $P_c(4450)$

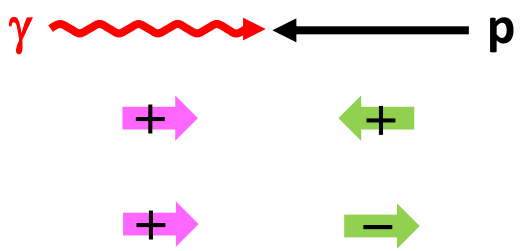
PRD 100 (2019) 034019

Note: Now considered as 2 overlapping peaks.

$$A_{LL} = \frac{1}{2}\left[\frac{d\sigma(++) - d\sigma(+-)}{d\sigma(++) + d\sigma(+-)} - \frac{d\sigma(-+) - d\sigma(--)}{d\sigma(-+) + d\sigma(--)}\right]$$



A_{LL} : Cross-section (σ) asymmetry depending on the **helicity combination**.



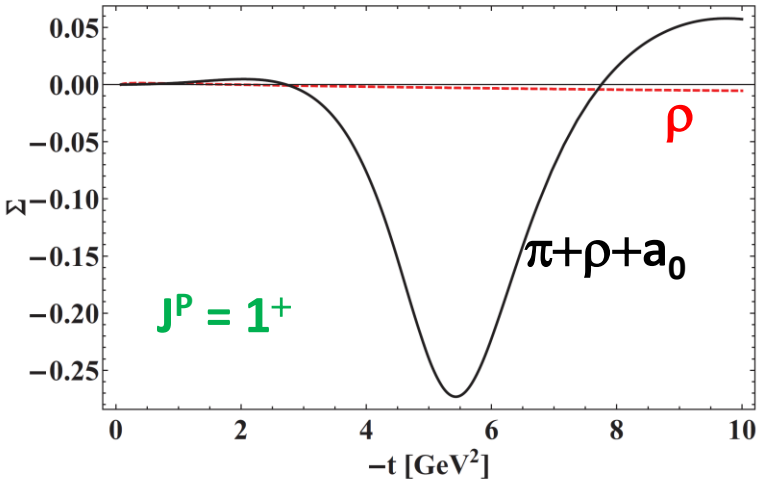
General comment : Spin observables are sensitive to the **interference** between different J^P states even if they are **overlapped** with each other.

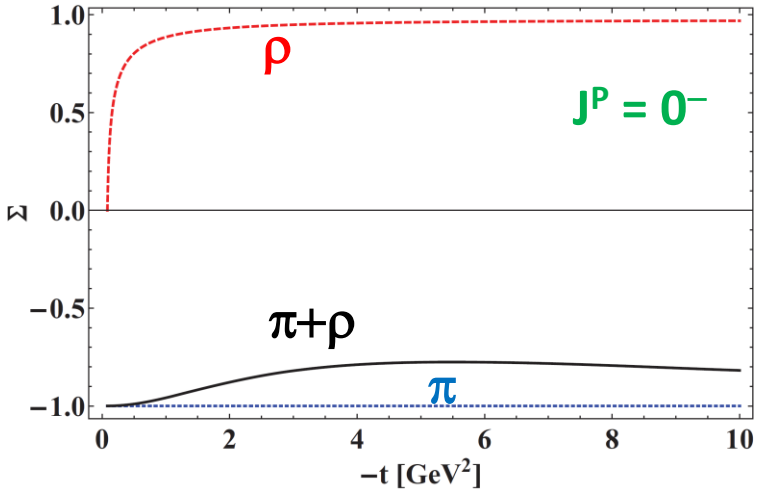
Use of linear polarization

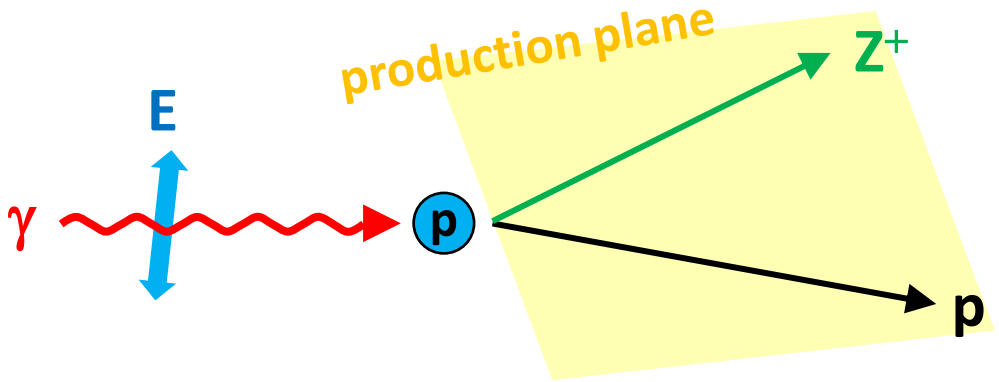
e.g. **Photon asymmetry** to extract the J^P of $Z^+(4430)$ *PRC 83 (2011) 065203*

$$\Sigma = \frac{1}{P_\gamma}\frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel}$$

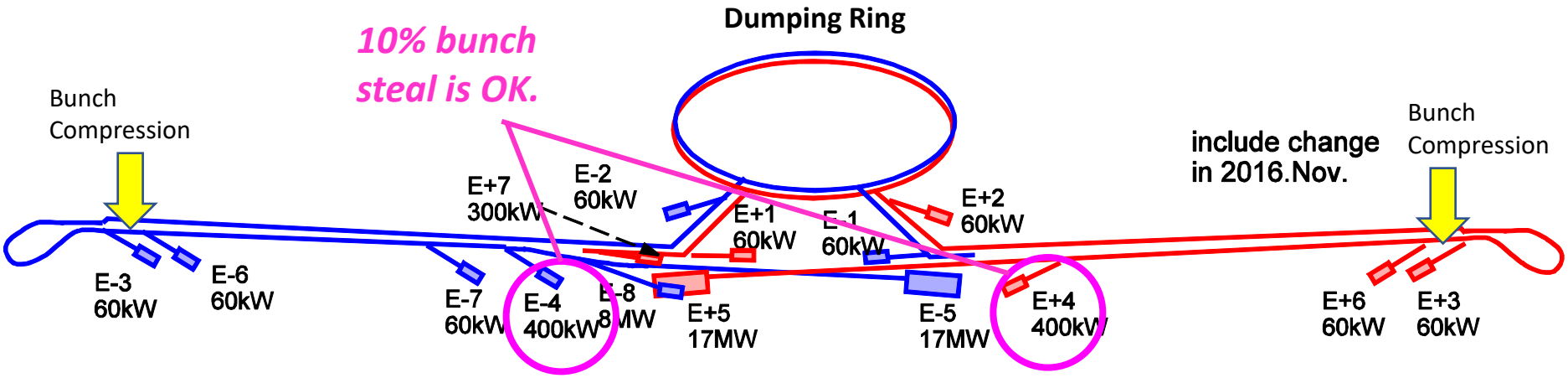
Note: Now J^P is determined to be 1^+.







Setup for hadron photoproduction experiments



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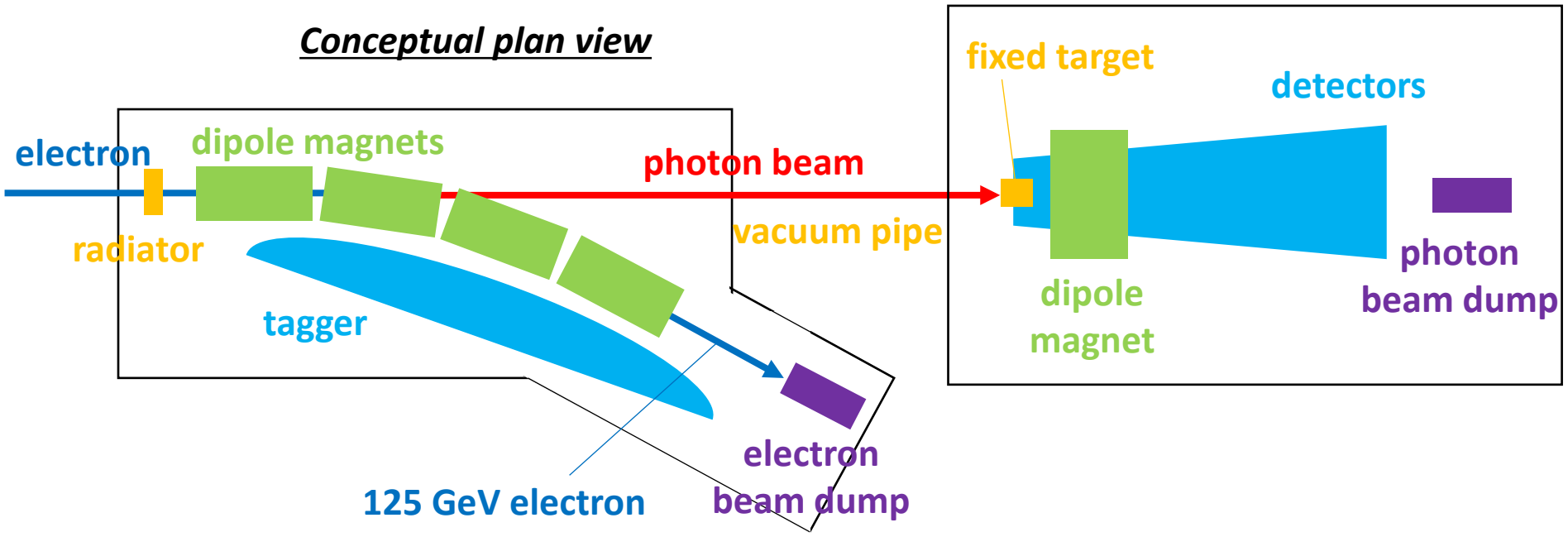

- ***Radiator*** with a Goniometer (e.g. **t20-50 μm diamond**)
- ***Tagger*** : Momentum measurement for recoil electrons.

  $\Rightarrow$ **Event-by-event determination of E_γ .**
- ***Spectrometer*** w/ a fixed target like CERN COMPASS exp.

Summary

- Proposing an experimental facility to provide **circularly and linearly polarized photon beams** via bremsstrahlung at a beam dump (E±4).
- An **unprecedented** photon beam with **dozens of GeV** & **high polarization** can be obtained at ILC.
- **Heavy exotic hadrons** including c & b **quarks** can be explored by photoproduction experiments.