GeV-Photon beam facilities and future plans in Japan

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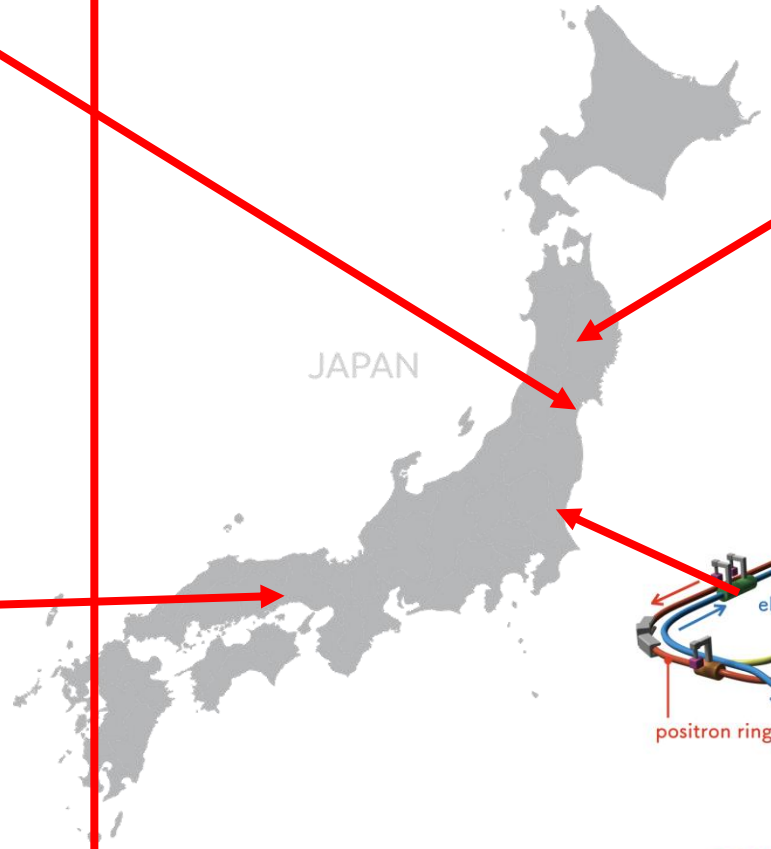
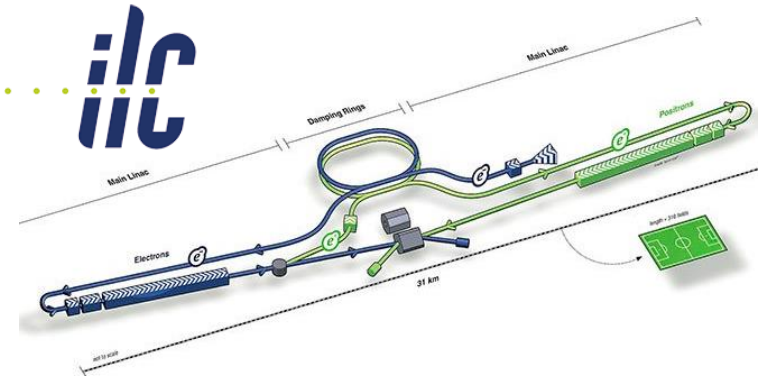
1st Workshop on New Light Physics and Photon-beam Experiments
March 8th-10th, 2021

Electron beam facility for high energy physics in Japan

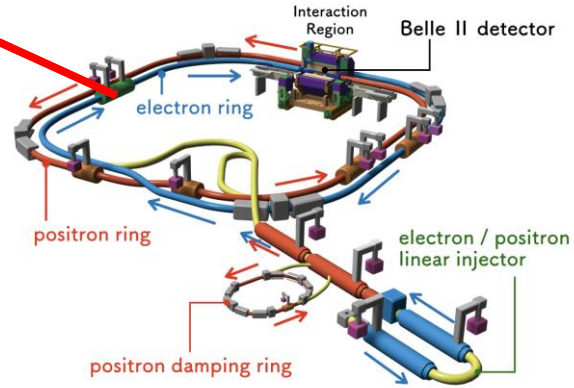
☆ELPH(1966~)
E(e⁻) = 1.2 GeV
Hadron physics

☆SPring-8 (1997~)
E(e⁻) = 8 GeV
Multi-purpose





☆ ILC (2026?~)
E(e⁻/e⁺)= 0.5 – 1 TeV
Higgs-factory



☆KEKB (2009~)
E(e⁻) = 7 GeV
E(e⁺) = 4 GeV
B-factory

Overview of my talk

☆ELPH(1966~)
E(e^-) = 1.2 GeV
Hadron physics

☆SPring-8 (1997~)
E(e^-) = 8 GeV
Multi-purpose

1. Review of Two facilities
   (1. ELPH and 2. SPring-8)

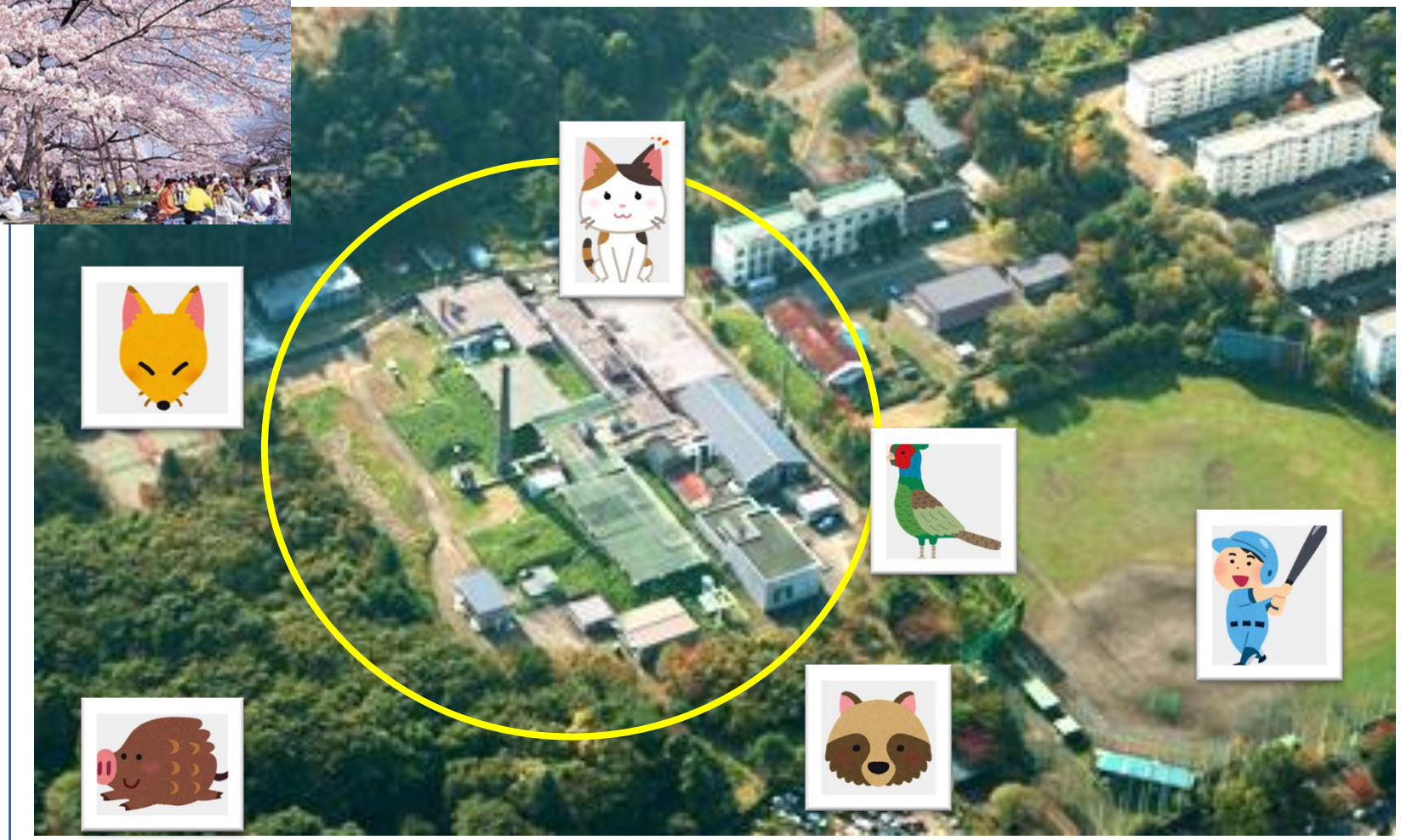
2. The specs of the photon beam
   The on-going experiments

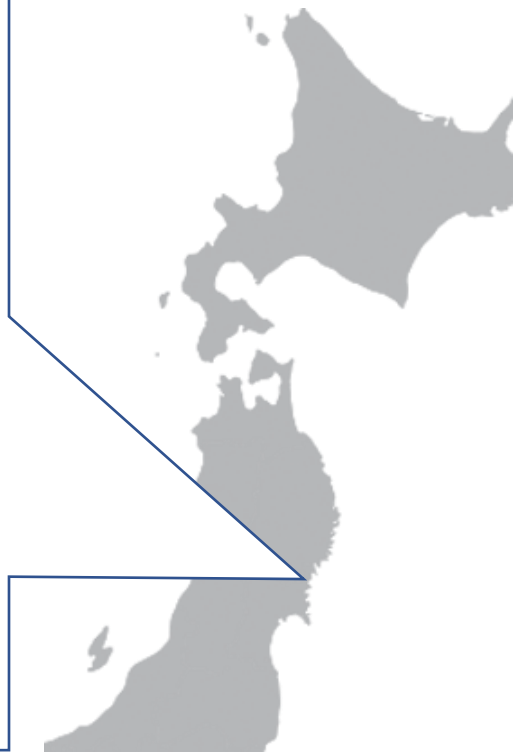
3. Some ideas of new physics.
   (Excellent talks in the session yesterday…)

ELPH

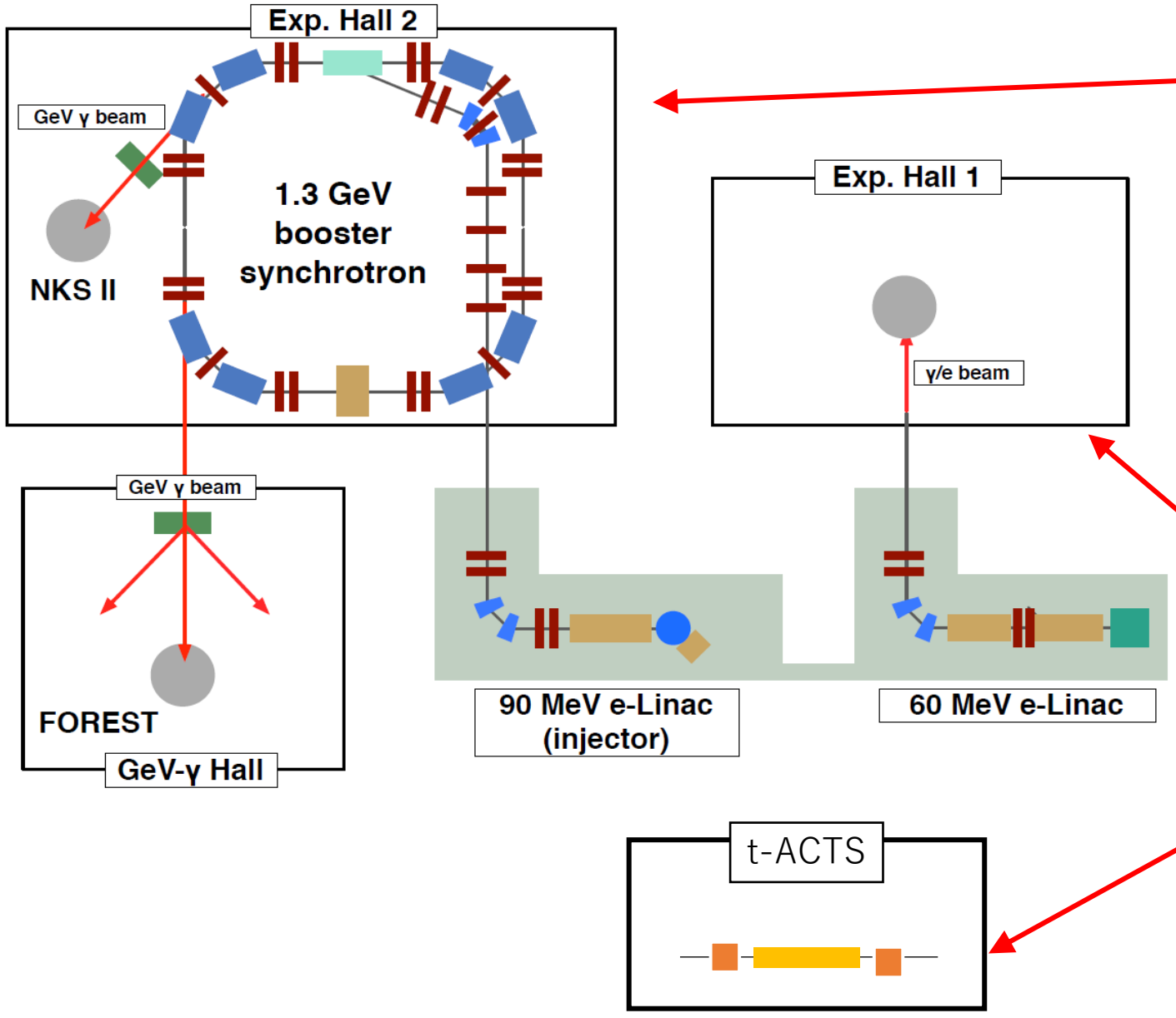
Research Center for ELectron PHoton Science (ELPH)

Mikamine Park



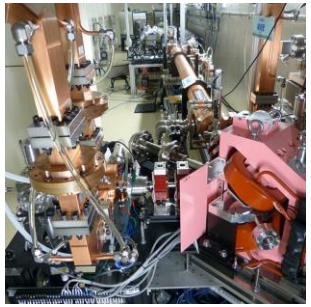


Electron Accelerators in ELPH



- E=1.35 GeV
- Rep. =0.05 Hz
- I = 30mA
- Bremsstrahlung γ
- Hadron physics

Oldest in Japan!
- E=10 – 60 MeV
- Rep. = 300 Hz
- I = 120 μA
- RI production
  Nuclear physics



- E= 50 MeV
- Rep. = 300 Hz
- I = 50 μA
- 1 THz coherent
  light source

Experiments at ELPH

FOREST

-Tagged Photon 0.9 – 1.25 GeV
- Intensity =10^7 cps, $\sigma(E\gamma) \sim 2$ MeV
- Calorimeter+ spectrometer
  → Exotic hadron search
  (Dibaryon, Penta-quark…)

NKS

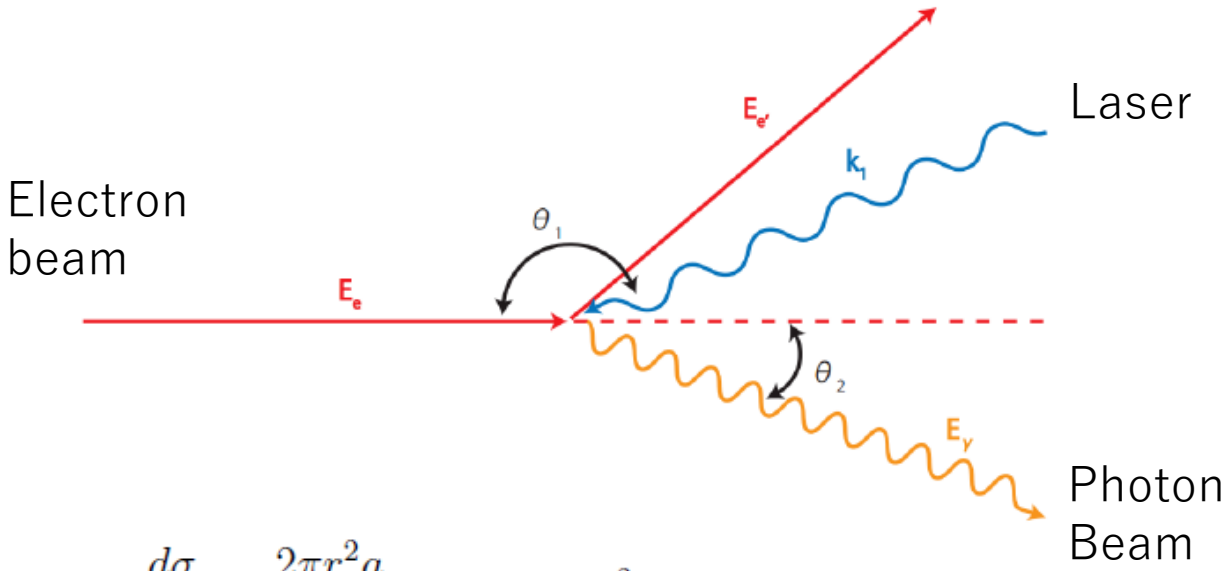
-Tagged Photon 0.8 – 1.26 GeV
- Intensity =10^6 cps $\sigma(E\gamma) \sim 5$ MeV
- spectrometer (large acceptance)
→ Strangeness nuclear physics

ULQ2

-Electron 20 – 60 MeV
-I_{max} = 1uA, $\sigma(E_e)/E_e$ = 0.06 %
→ Electron scattering
(proton radius measurement)
Virtual Photon $Q^2 < 0.005$ $(GeV/c)^2$

+ BSM physics by BCS beamline (future plan)

Backward Compton Scattering



$$\frac{d\sigma}{dE_\gamma} = \frac{2\pi r_e^2 a}{E_\gamma^{max}}(\chi + 1 + \cos^2\alpha)$$

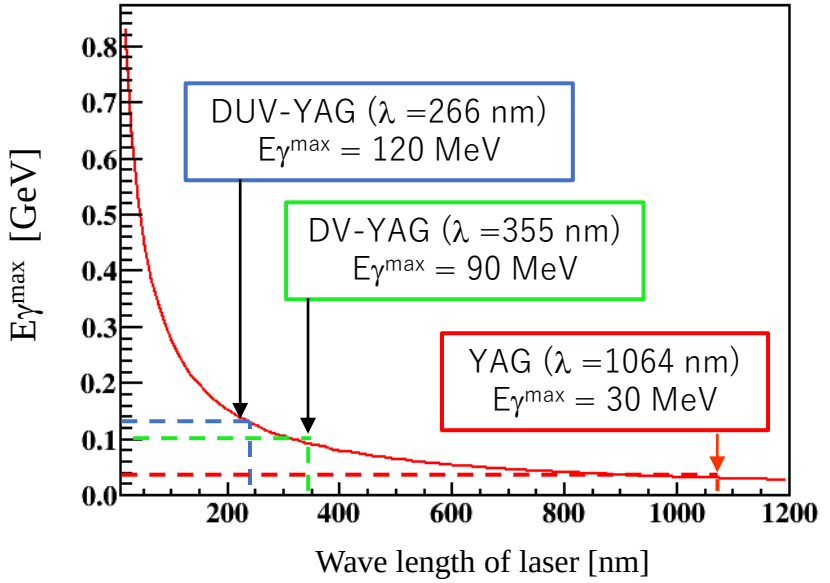
$$a = \frac{1}{1 + 4\,(E_e E_{laser}/m_e^2)}$$

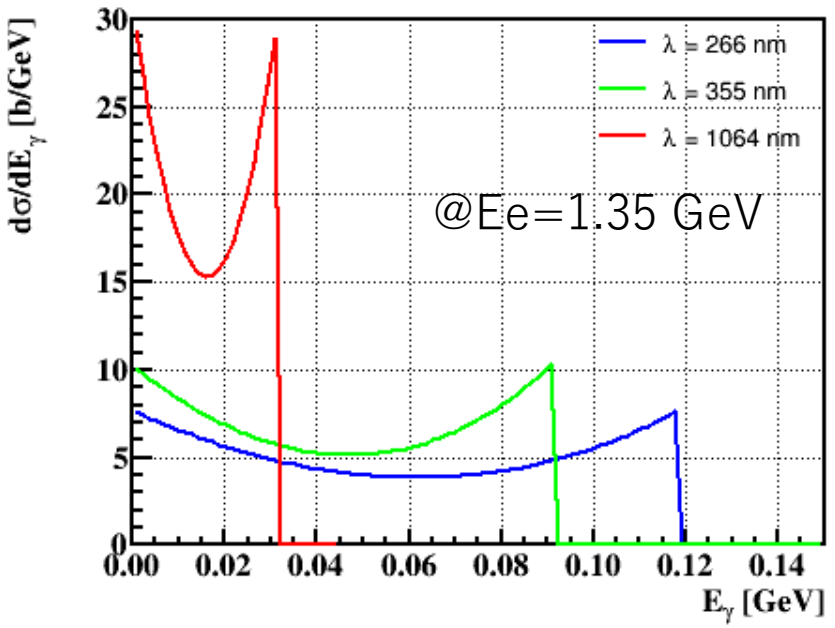
$$\rho = \frac{E_\gamma}{E_\gamma^{max}} = \frac{1}{1 + a\,(\theta_2 \gamma)^2} \quad (0 < \rho \leqq 1)$$

$$\chi = \frac{\rho^2\,(1-a)^2}{1 - \rho\,(1-a)} \quad \left(0 < \chi \leqq \frac{(1-a)^2}{a}\right)$$

$$\cos\alpha = \frac{1 - \rho\,(1+a)}{1 - \rho\,(1-a)} \quad (-1 \leqq \cos\alpha \leqq 1)$$

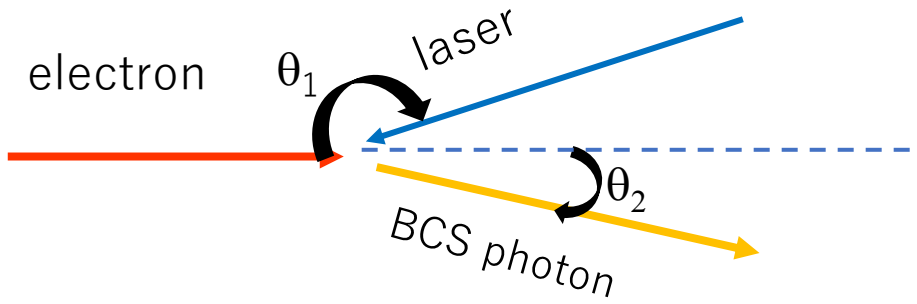
Ref) A. D'Angelo et al, NIM A 455(2000) 1-6



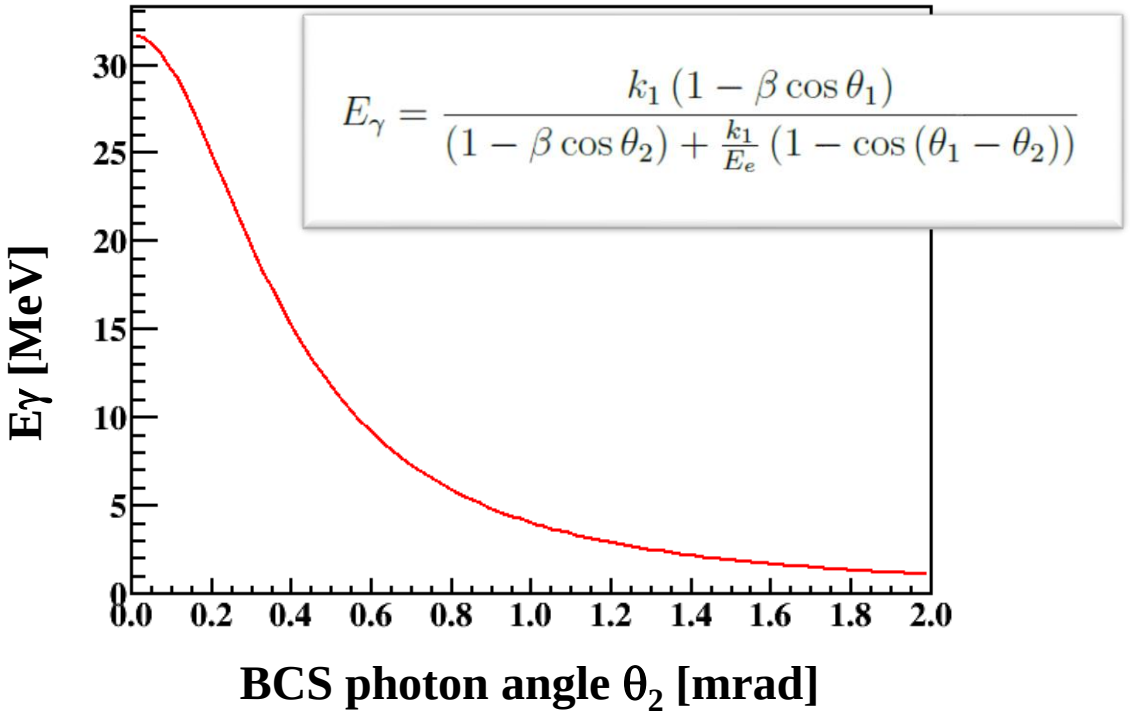


Characteristics of BCS photon beam

1. mono-chromatic beam



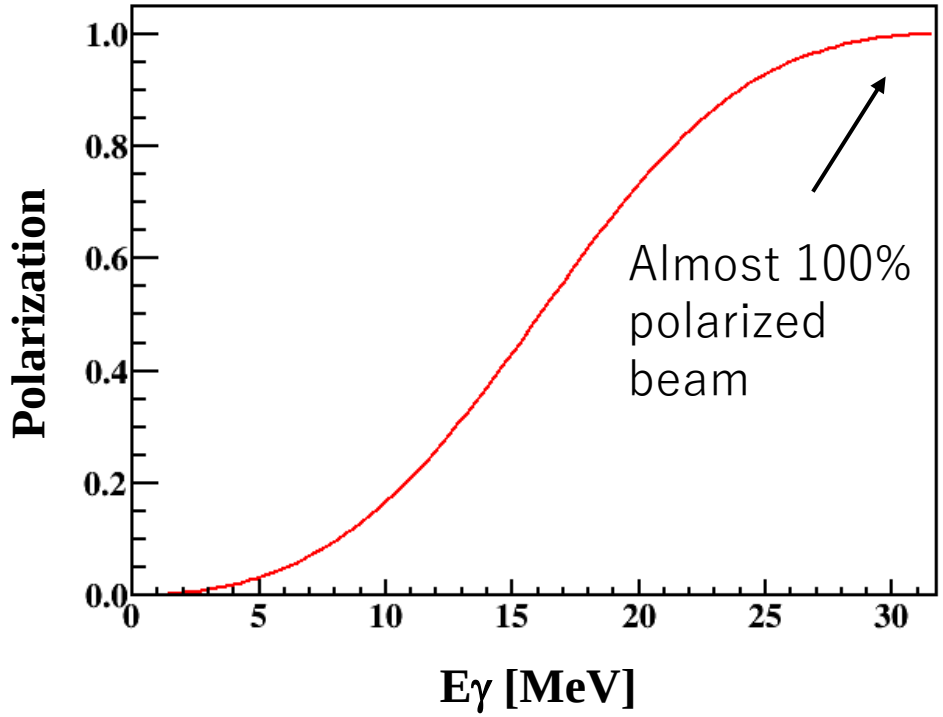
$$E_\gamma = \frac{k_1\,(1-\beta\cos\theta_1)}{(1-\beta\cos\theta_2)+\frac{k_1}{E_e}\,(1-\cos\,(\theta_1-\theta_2))}$$



2. Highly polarized beam

$$P_\gamma = \underbrace{P_{laser}}_{\sim 98\%}\frac{(1-\cos\alpha)^2}{2(\chi+1+\cos^2\alpha)}$$

$$a=\frac{m_e^2}{m_e^2+4E_e k_1}$$
$$\chi=\frac{\rho^2(1-a)^2}{1-\rho(1-a)}$$
$$\cos\alpha=\frac{1-\rho(1+a)}{1-\rho(1-a)}$$
$$\rho=\frac{E_\gamma}{E_\gamma^{max}}$$

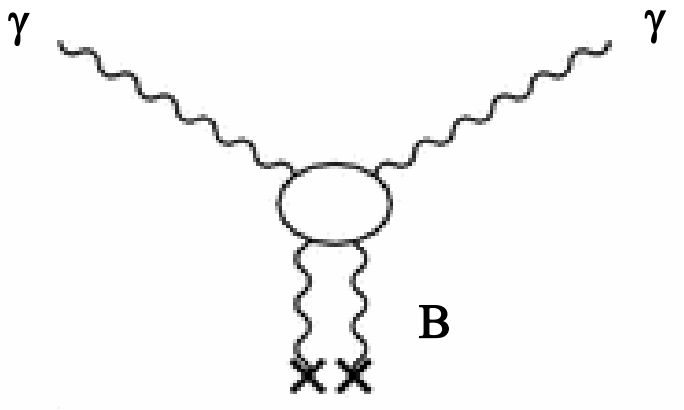


Vacuum birefringence

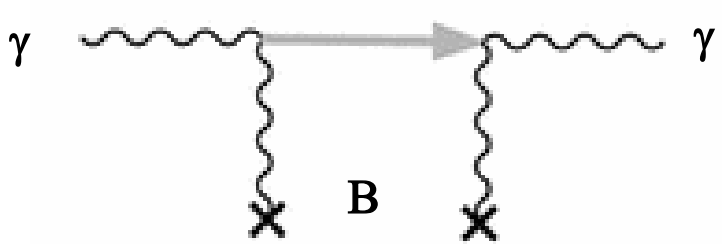
γ B

Photon-photon interaction

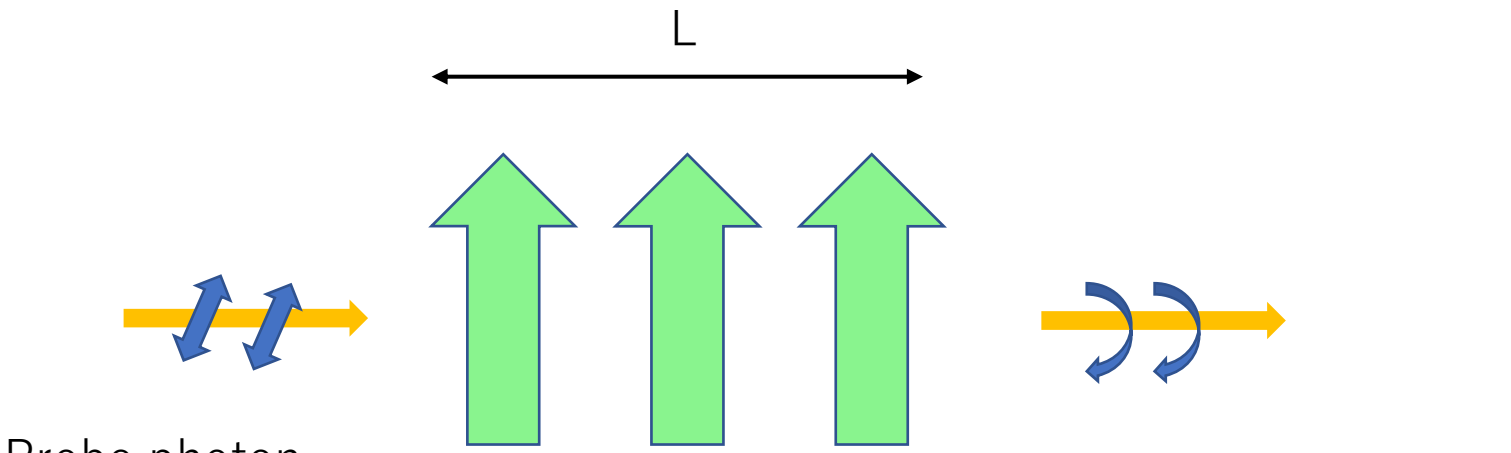
→ Not observed experimentally



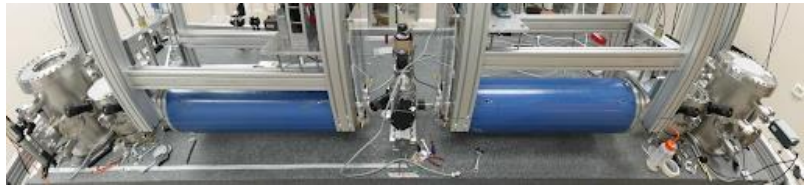
e^+/e^- virtual loop (QED)



Production of BSM particles which couple to two photons.



$F.O.M = B^2L$



World record by PVLAS

7 * QED limit

Ref) Phys.Rep.871 (2020)1

Experimental setup

Ref1) K. Nakamiya and K. Homma, Phys.Rev.D96, 053002(2017)
Ref2) X.Fan et al., EPJD,71(2017)308
Ref3) Phys.Rep.765(2018)1

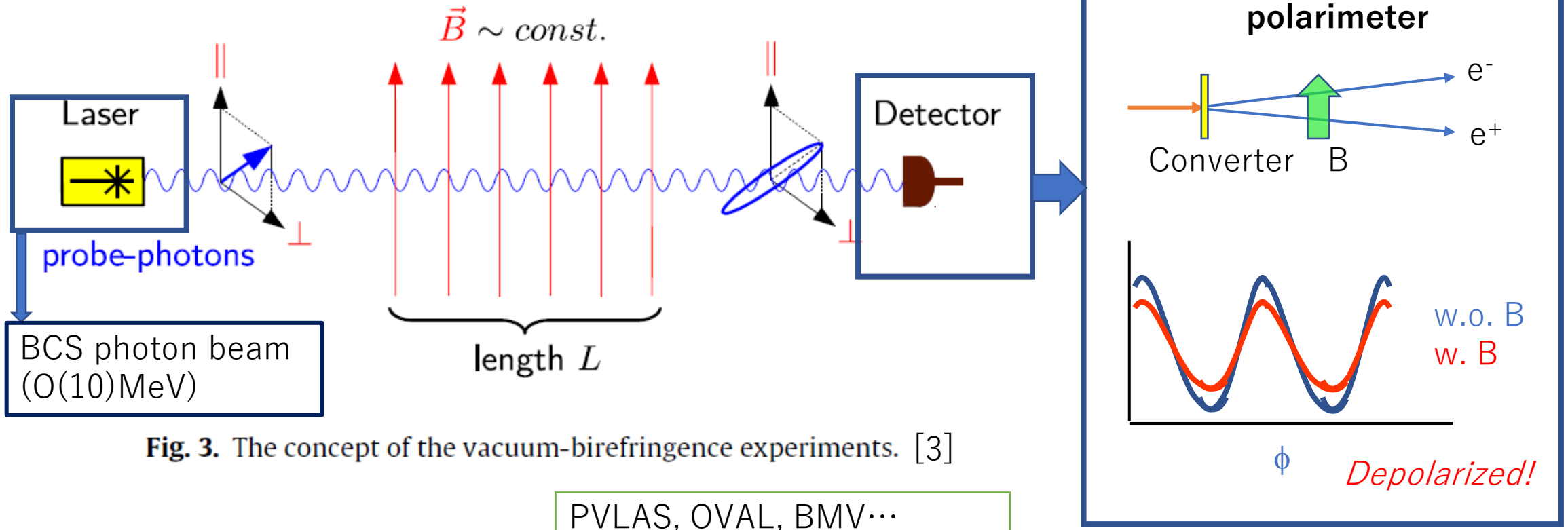


Fig. 3. The concept of the vacuum-birefringence experiments. [3]

$$\Phi = 2\pi \frac{L}{\lambda} \Delta n$$

$$\Delta n = n_{\parallel} - n_{\perp} \approx 4.0 \cdot 10^{-24}\,\mathrm{T}^{-2}\,|\vec{B}|^2$$

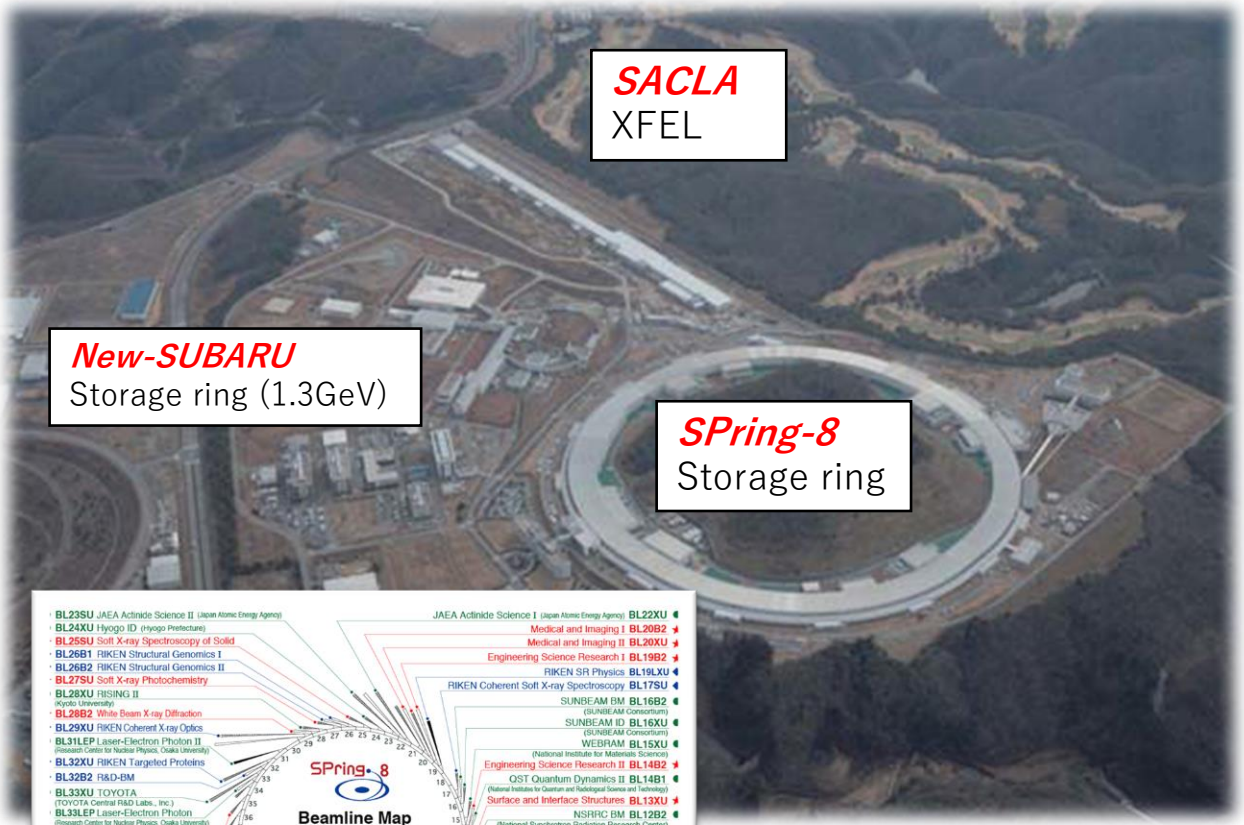
PVLAS, OVAL, BMV…
Eγ= 1.2 eV → λ=1064 nm
Use cavity (F~O(10^6)) to increase sensitivity

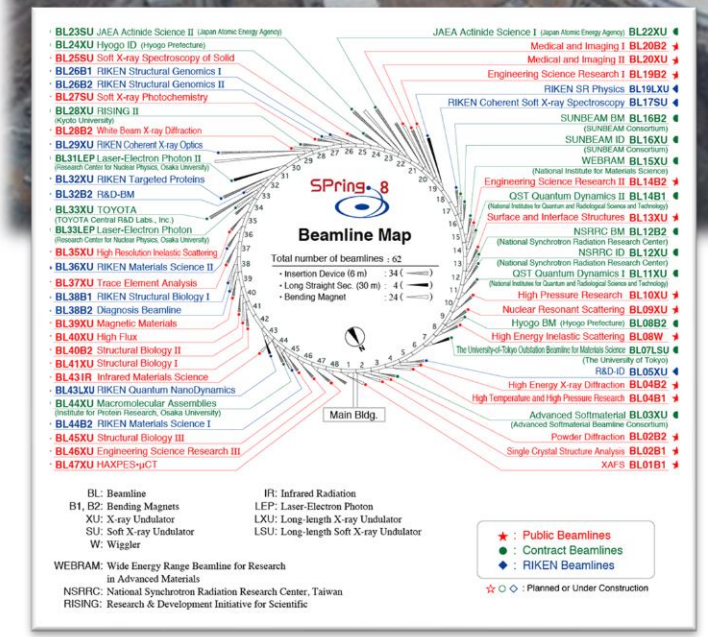
Eγ ~10 MeV → λ < pm
→ x 10^7

Comparable to world record if $B^2L = 10^2$ $T^2 \cdot m$

SPring-8

SPring-8 (Super Photon ring-8)





48 beamlines

BL33LEP
→ LEPS experiment
BL31LEP
→ LEPS2 experiment

SPring-8 : The largest synchrotron radiation facility in the world.

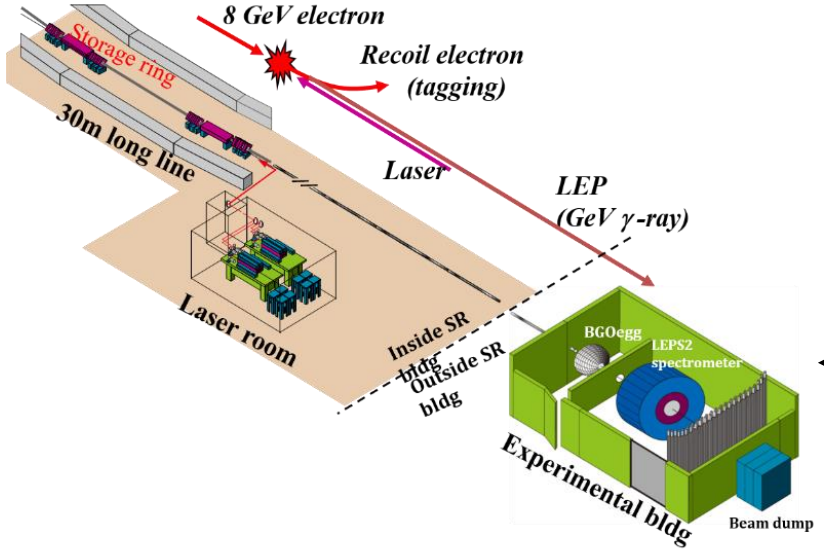
beam energy	< 8 GeV
circumference	1435.95 m
nominal stored current	100 mA
critical photon energy / wavelength	28.9 keV / 0.429 Å
natural emittance	2.4 nm•rad

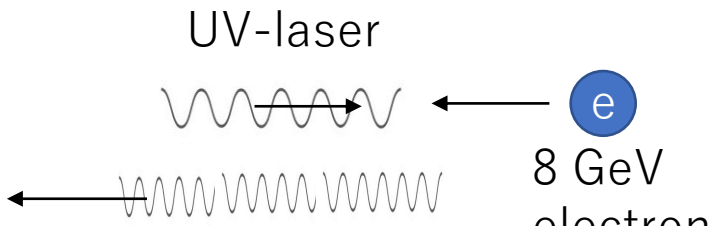
Note)

* LEPS experiment at BL33 was finished.
Large data set for 20-years is available.
Target: LH_2, LD_2, LHe, Li, C, Cu, Pb
Charged particle tracking in the forward region.
(Acceptance < 15 deg. $\Delta p/p < 1$ %)
→ good for the study Compton-like reaction
Call for new proposal (detectors exist).

* SPring-8 will be upgraded in the near future.
Injector : SACLA
Ee : 8 → 6 GeV
emittance : 2.4 nm*rad→100 pm*rad
CDR: http://rsc.riken.jp/pdf/SPring-8-II.pdf

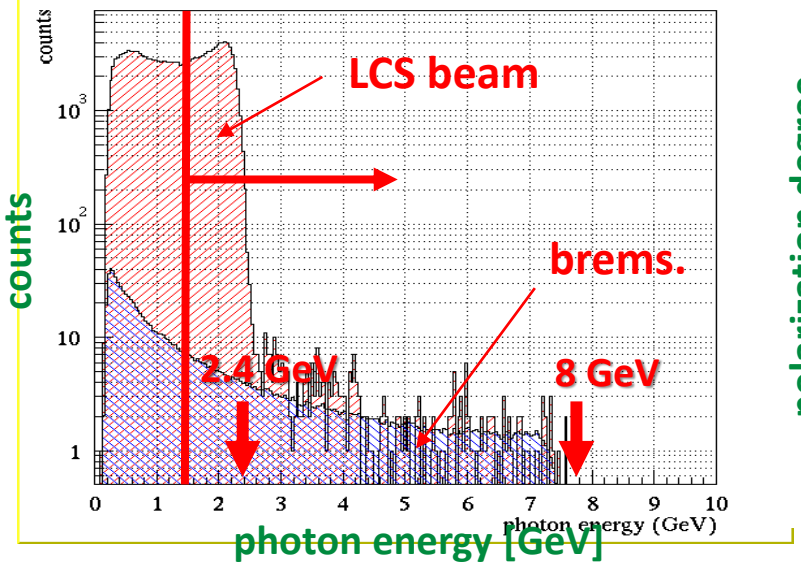
LEPS2 beamline



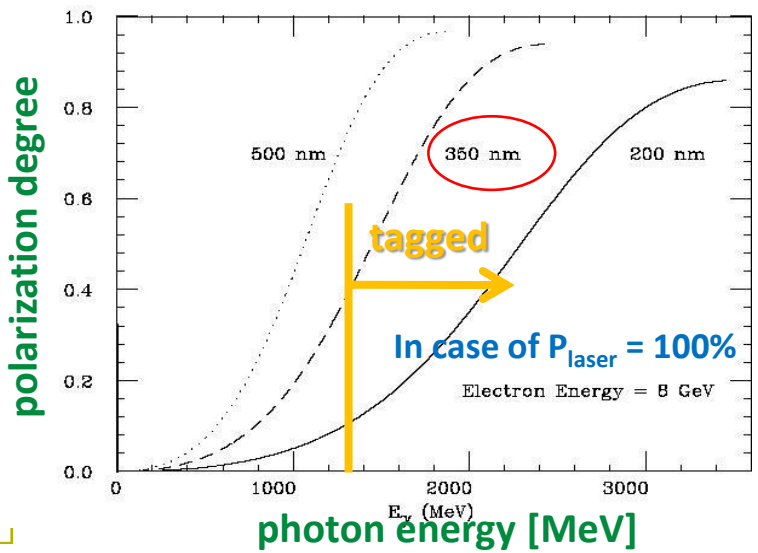


backward-Compton scattering
with UV laser and 8 GeV electron.
→ Small BG of low energy γ
E_γ 1.3～2.4/2.9 GeV (355/266 nm)
ΔEγ ~ 12 MeV
beam intensity 2 -5 Mcps
beam polarization
> 90% at maximum energy

E_γ spectrum (PWO calorimeter)



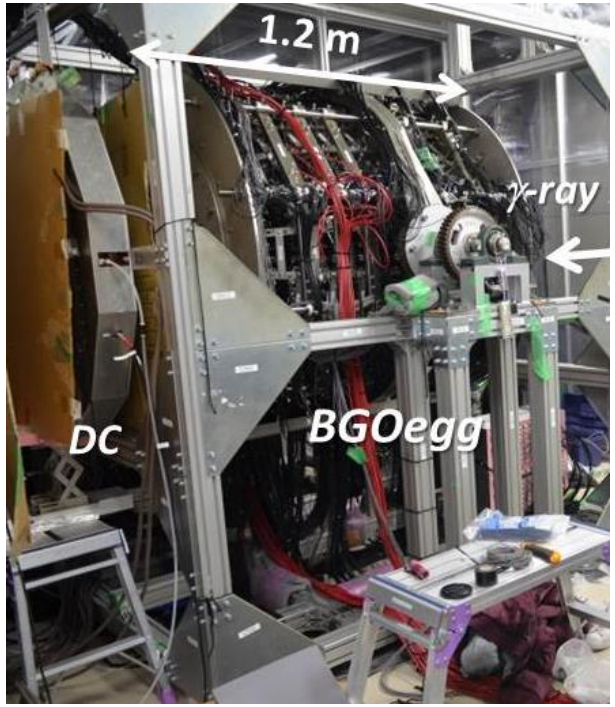
Linear polarization

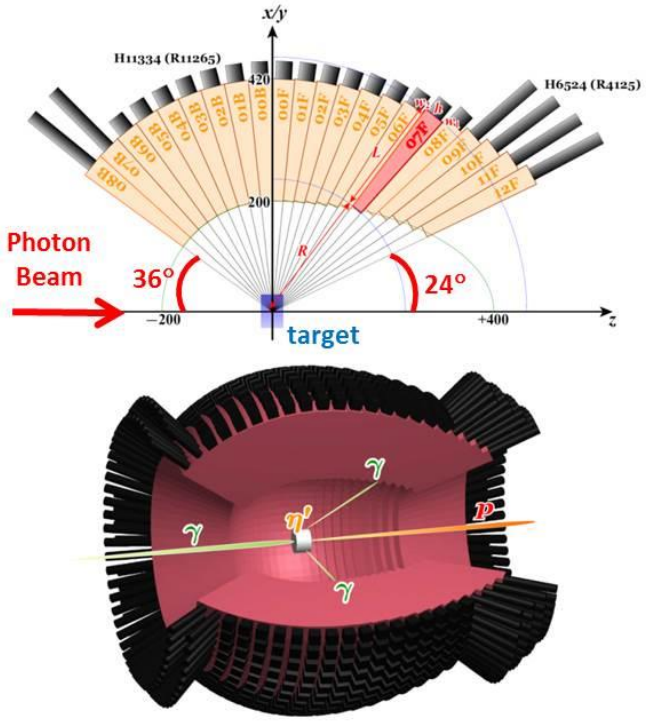


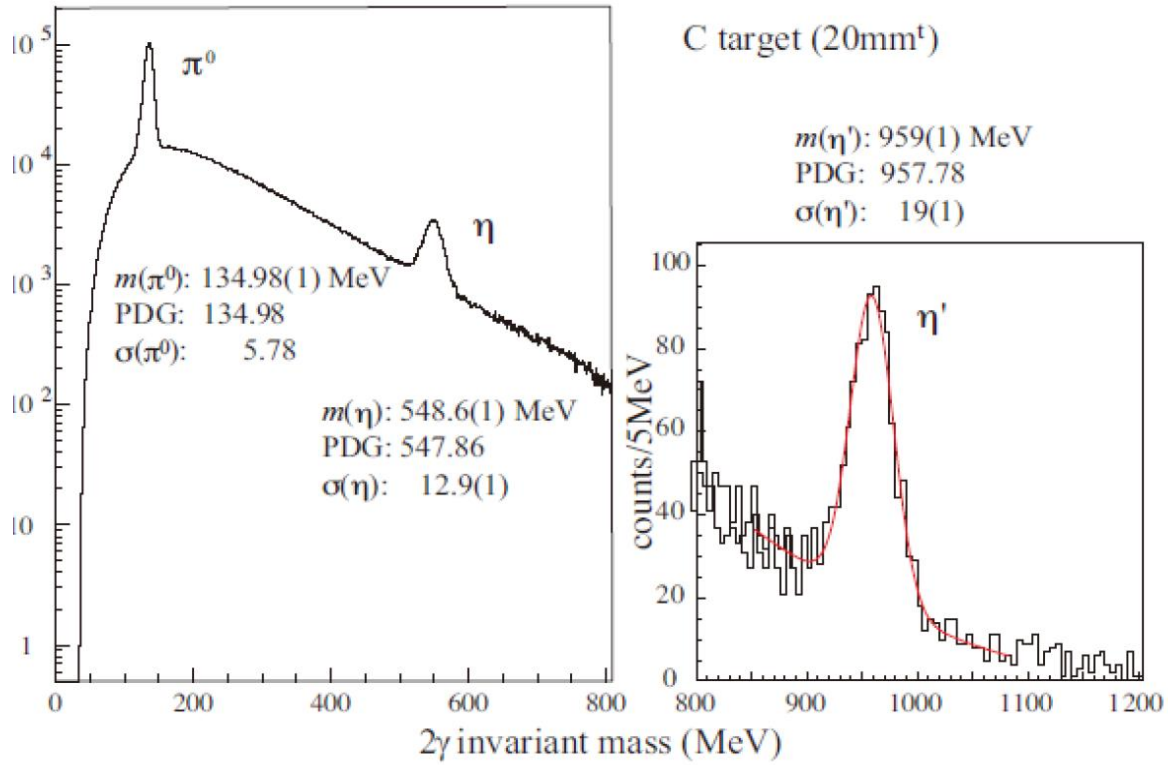
1. BGOegg experiment
   → DP search via visible decay

2. LEPS2-solenoid experiment
   → DP search via invisible decay
   → Compton like process
   (Detector development
   in the forward region)

BGOegg experiment







*Egg-shape EM calorimeter which consists of 1320 BGO crystal.
*Acceptance: 24 - 144 degrees
*World's best energy resolution (1.3% at 1 GeV)

Invariant mass resolutions of
5.8 MeV(π^0), 12.9 MeV(η), and 19.0 MeV(η')

Invisible decay

Search in the Dalitz decay of meson.

π^0

$BR(e^+e^-\gamma) = 1.174 \pm 0.035 \times 10^{-2}$

η

$BR(e^+e^-\gamma) = 6.9 \pm 0.4 \times 10^{-3}$

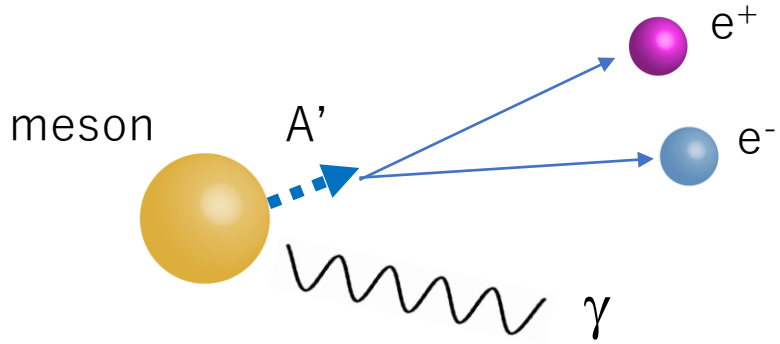
$BR(\mu^+\mu^-\gamma) = 3.1 \pm 0.4 \times 10^{-4}$

ω

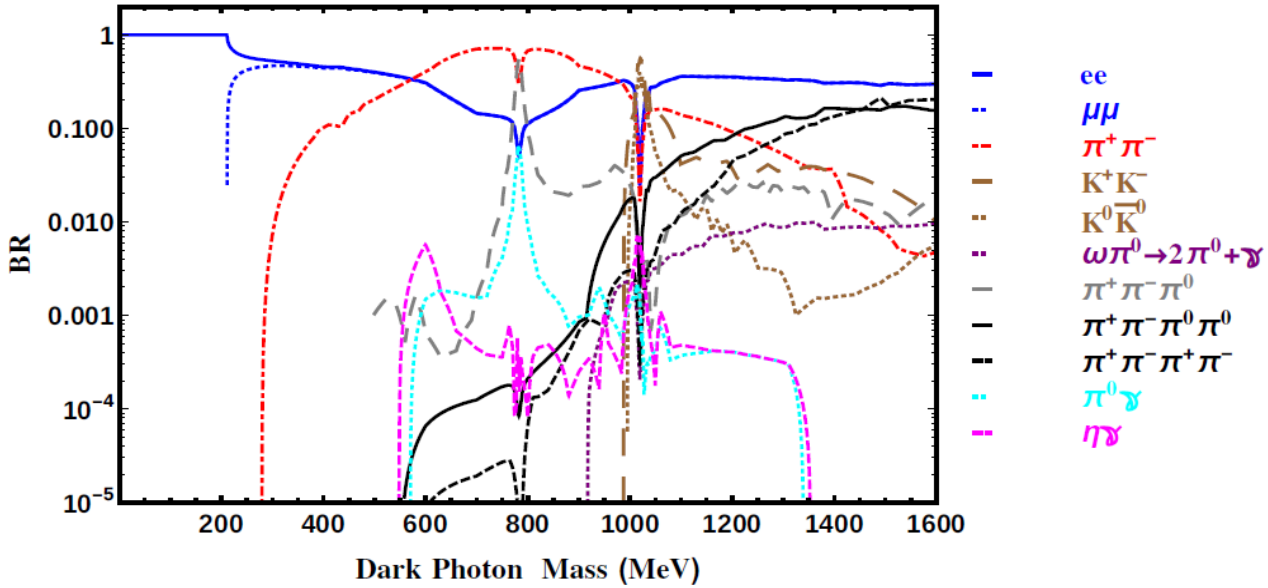
$BR(\pi^0 e^+e^-) = 7.7 \pm 0.6 \times 10^{-4}$

$BR(\pi^0\mu^+\mu^-) = 1.34 \pm 0.18 \times 10^{-4}$

$J^P=0^-$ $J^P=1^+$?

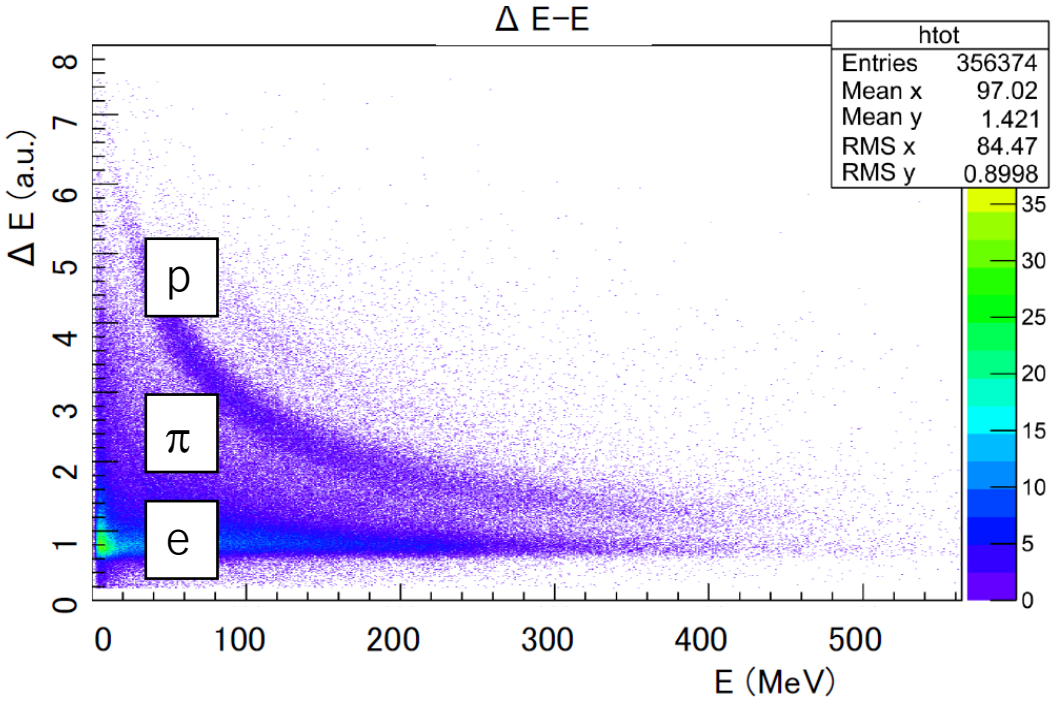


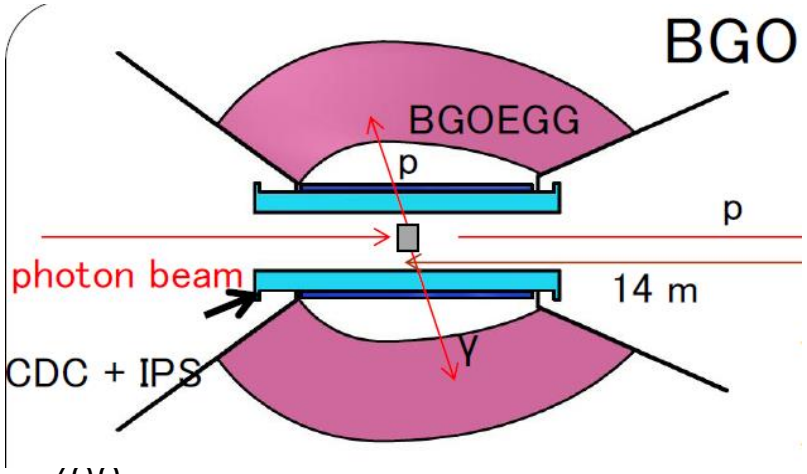
BR of visual decay mode of A'

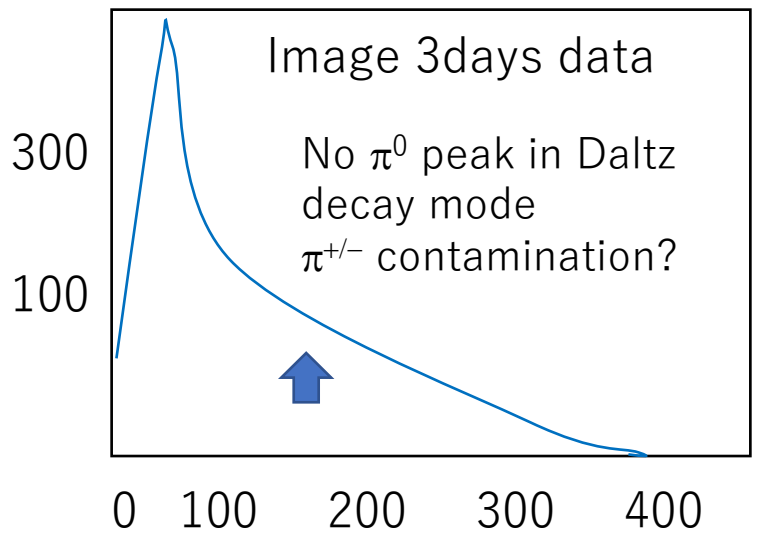


Ref) Jia Liu et al., JHEP 08(2015) 05

Dark photon search in BGOegg exp







Particle ID in δE (internal hodoscope)-E (BGOegg) plot

Requirement:

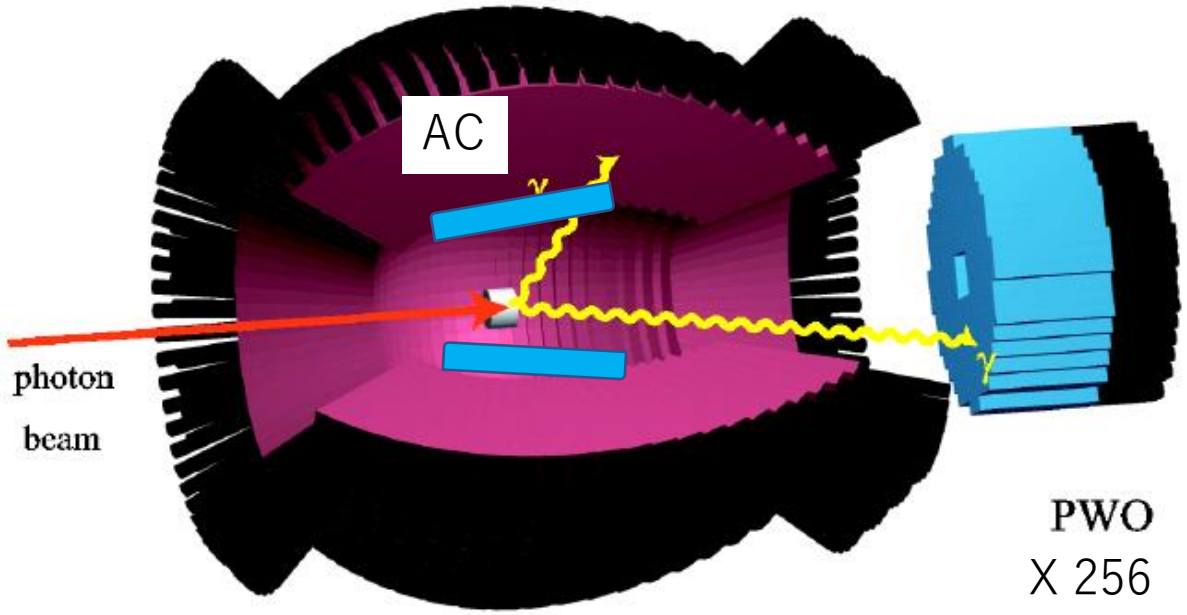
- electron identification
- σ (γ p → M p) = O(10) μb

→ acceptance upgrade, proton target → nuclear target.

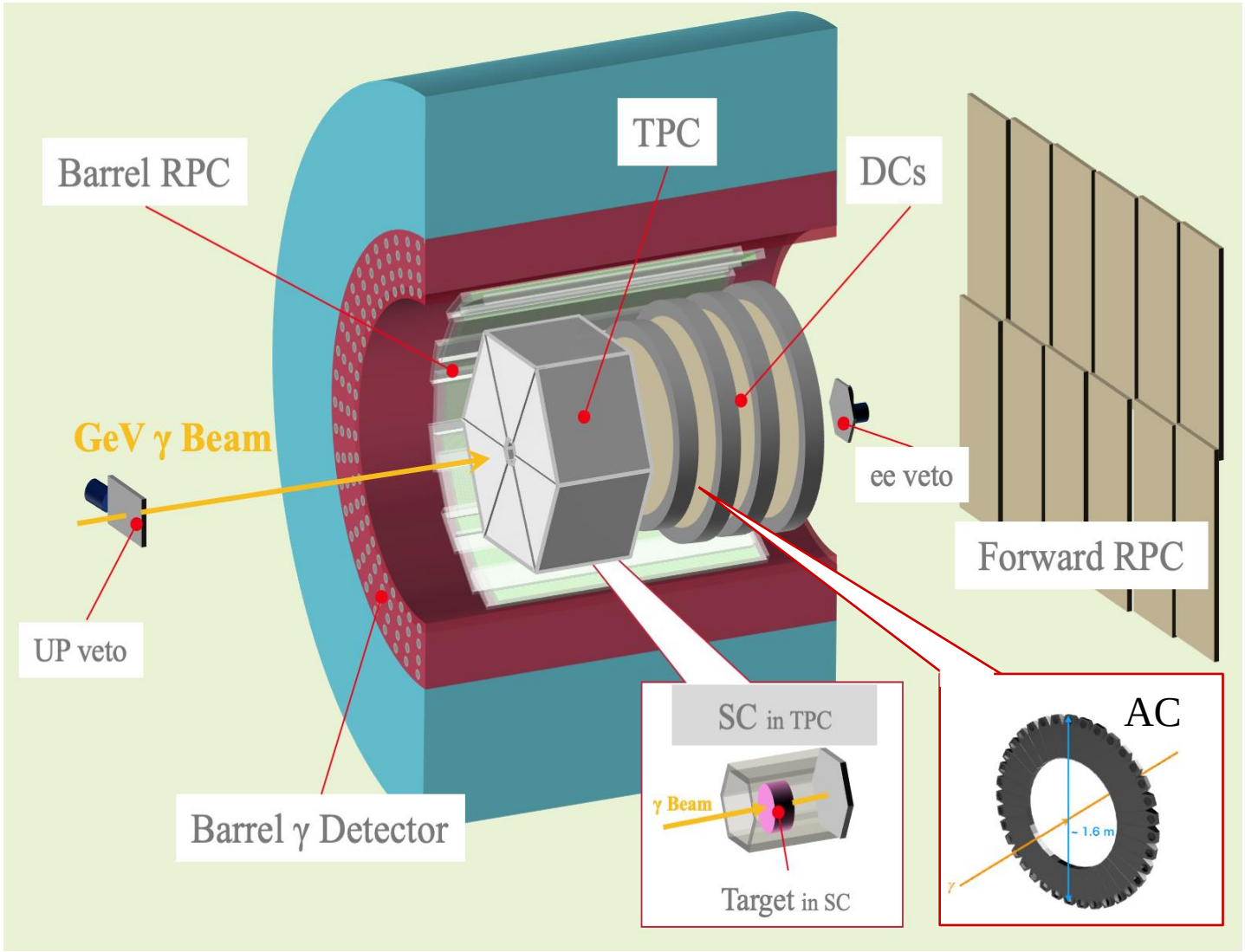
BGOegg Upgrade experiment

- Target LH_2 → Cu
- Higher energy g by using DUV laser.
  $E_{\gamma max}$: 2.4 → 2.9 GeV
- Aerogel Cherenkov counter for electron ID.
- Fwd-γ calorimeter

10^8 – 10^9 mesons will be identified
for 100 days beam time
→ Comparable to the existing experiments



Overview of LEPS2-solenoid Experiment



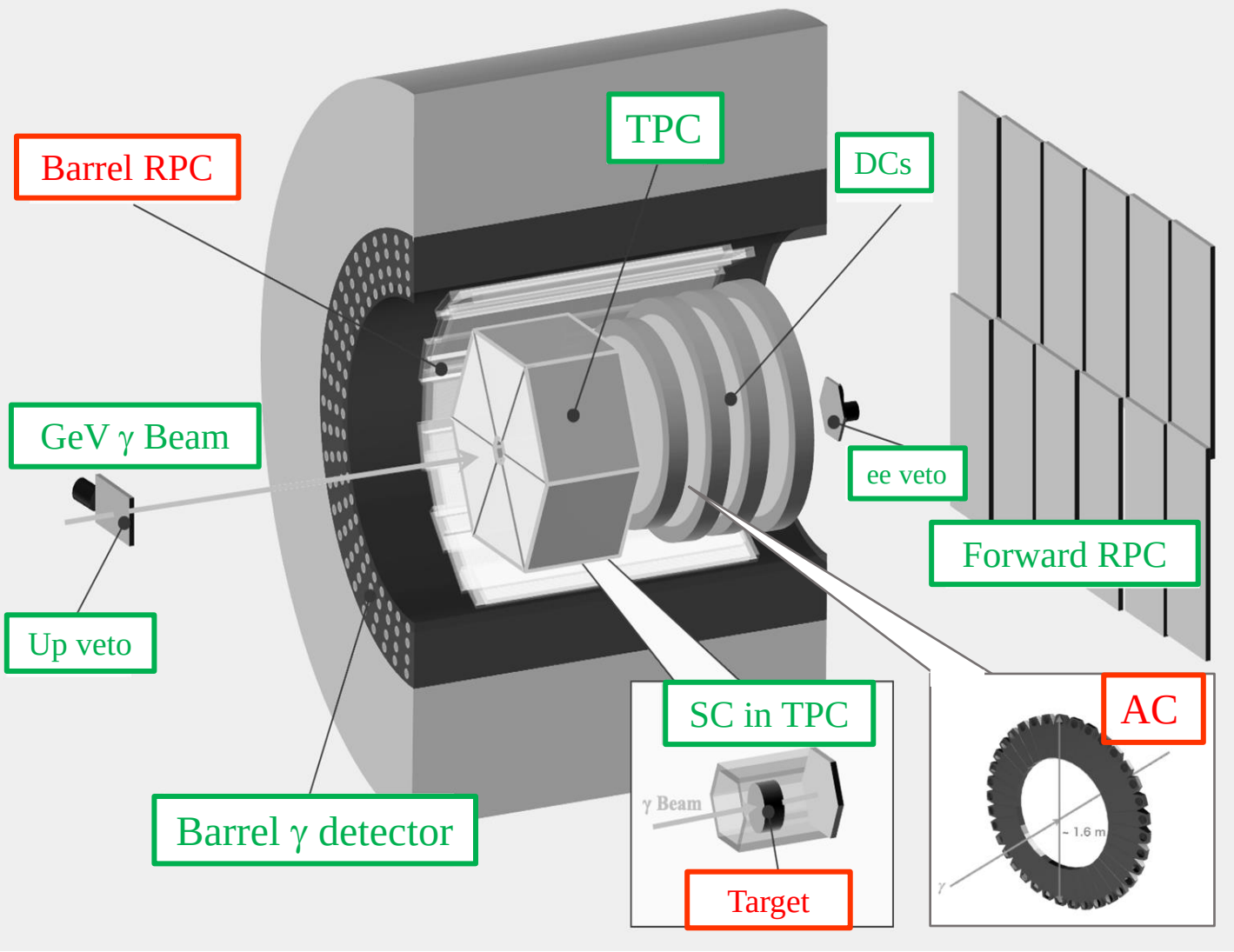
* Charged particles tracking:
  Acceptance : 7° – 110°
  Side: Time Projection Chamber (TPC)
  Forward : Drift Chamber (DC x 4)
  $\Delta p / p \sim 2 - 10$ %

* γ -rays
  Acceptance : 40° – 110°
  Barrel-γ 1st – 2nd layer (6.48 X_0)

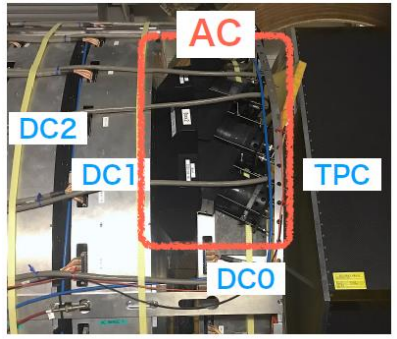
* Particle Identification
  Side: Barrel Resistive Plate Chamber (RPC)
  Middle : Aerogel Cherenkov Counter
  Forward: Forward RPC

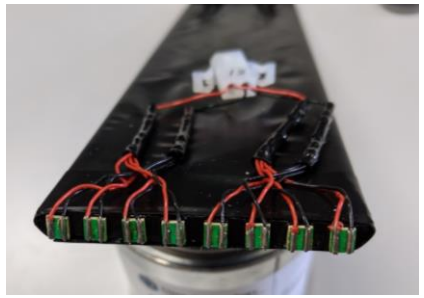
* Data is taken with a minimum biased trigger.
  (one-hadron is produced)

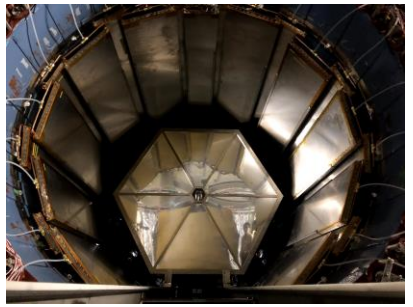
Current Status of LEPS2 solenoid experiment

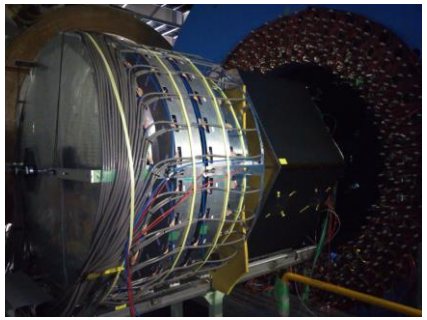


— Ready — In preparation









* Main detectors will be installed this FY.

* Remaining work for taking the physics data.
- DAQ upgrade.
- Development of the target system.
- Beam monitoring system.

* Data taking with physics data after taking calibration data from next FY.

Invisible decay

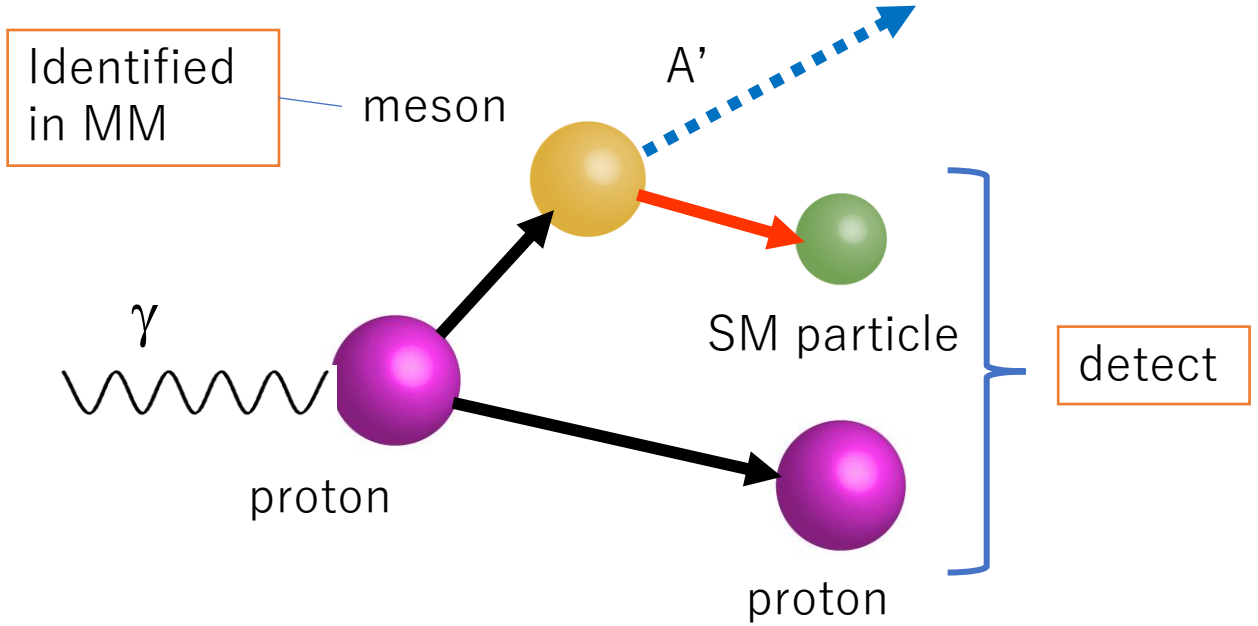
1. γ p → X p
   γ p → M p, M → (SM particle) + A

Ex) $K^+ \rightarrow \pi^+$ A decay

Ref) NA62 Collaboration
arXiv:2011.11329

Excellent Existing data

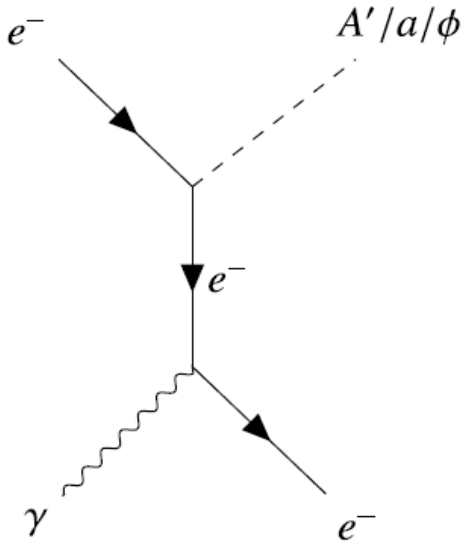
δM=10-20 MeV

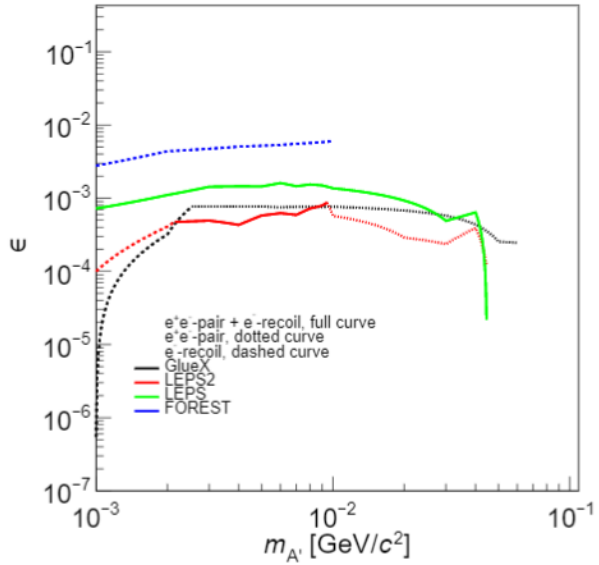


1. γ e^- → A'/a/ϕ e^-
   (Compton-like process)

Ref) S. S. Chakrabaraty and I. Jaegle,
arXiv:1903.06225v1

$$\sigma_{Comp} \sim \frac{4\pi\alpha^2\epsilon^2}{s} \log\left(\frac{1-x_M^2}{x_m}\right)$$





Summary

1. ELPH (E_e = 1.35 GeV, I = 50 mA) :

- Bremsstrahlung photon beam : E = 0.9 – 1.25 GeV, δE=2MeV, Intensity~10^7 cps

- BCS photon beam (newly proposed) : $E_{\gamma max}$ ~ 10-30 MeV, vacuum birefringence, P > 97%

2. SPring-8 (E_e = 8 GeV, I = 100 mA) :

- BCS photon beam (LEPS2 beamline) : E = 0.9 – 1.25 GeV, δE=12MeV, Intensity~ 5 x 10^6 cps, P > 90%

  * BGOegg experiment
    Detectors : calorimeter with acceptance 24-144, 3-166 deg (upgrade)
    Physics : Search for DP with visible decay mode

  * LEPS2-solenoid experiment
    Detectors : Spectrometer charged 7 – 110 deg, neutral 40-110 deg (upgrade)
    Physics : Search for DP with invisible decay mode