A new channel to search for dark matter at Belle II

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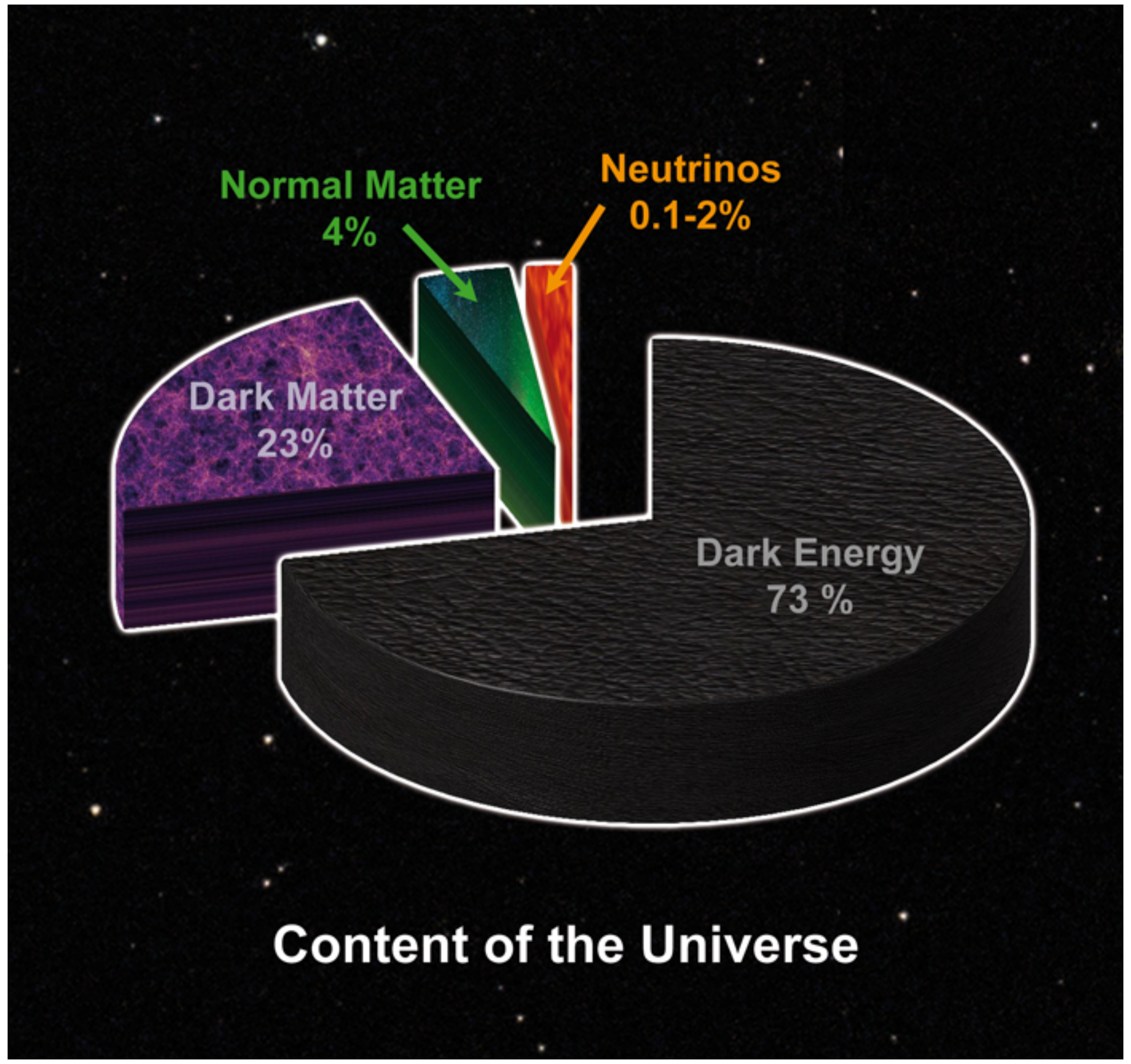
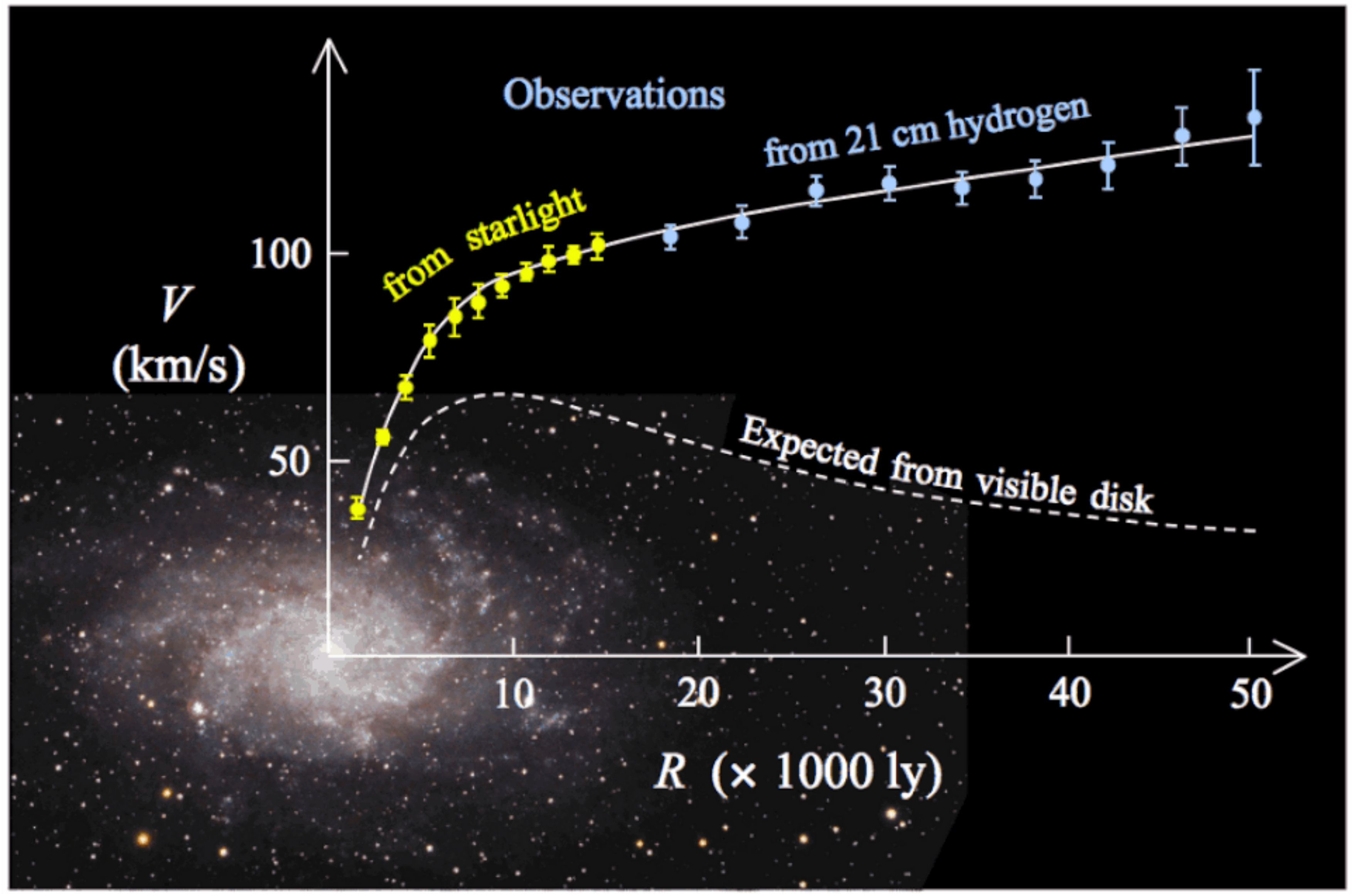
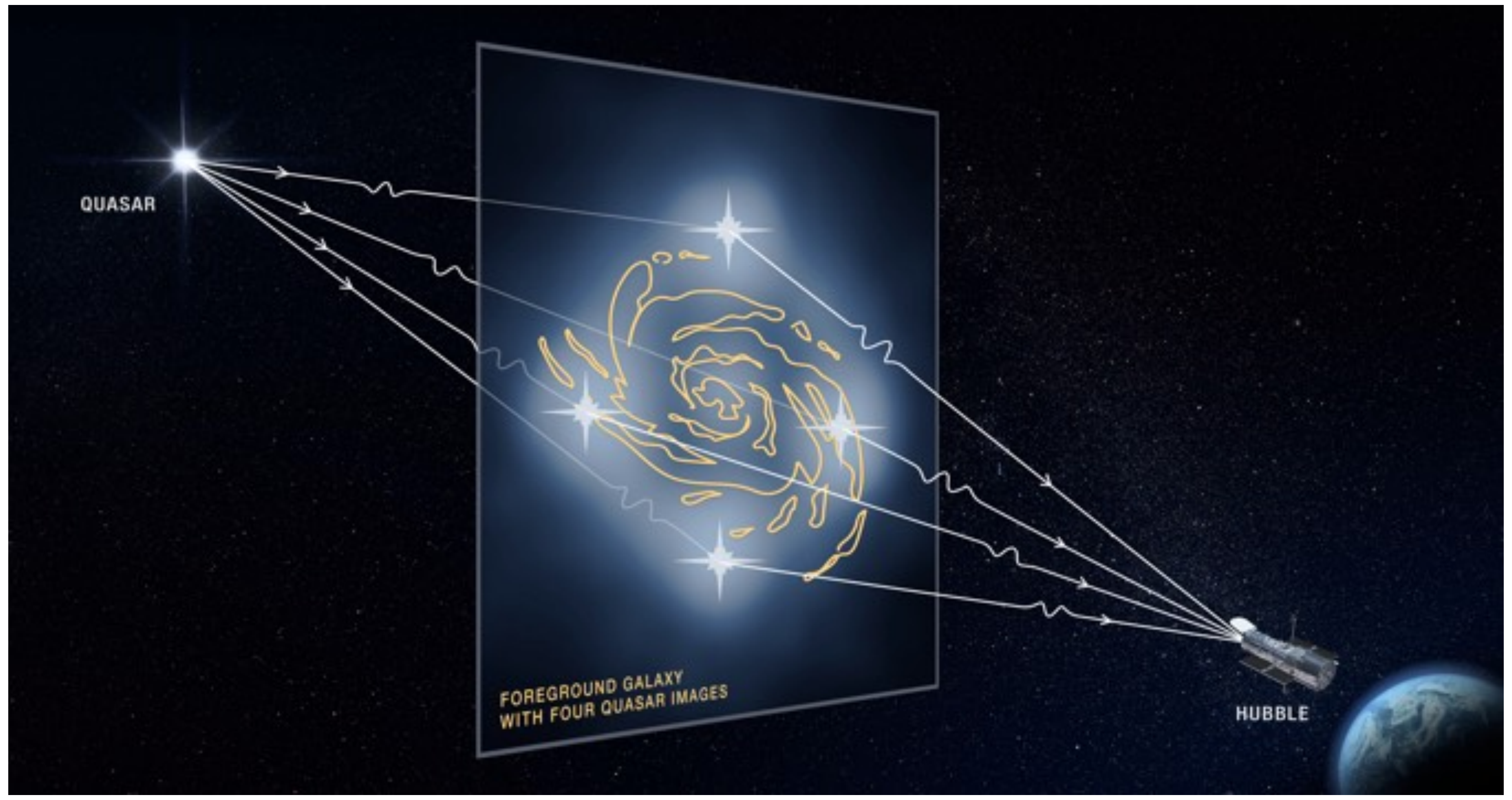
arXiv: 2212.04252

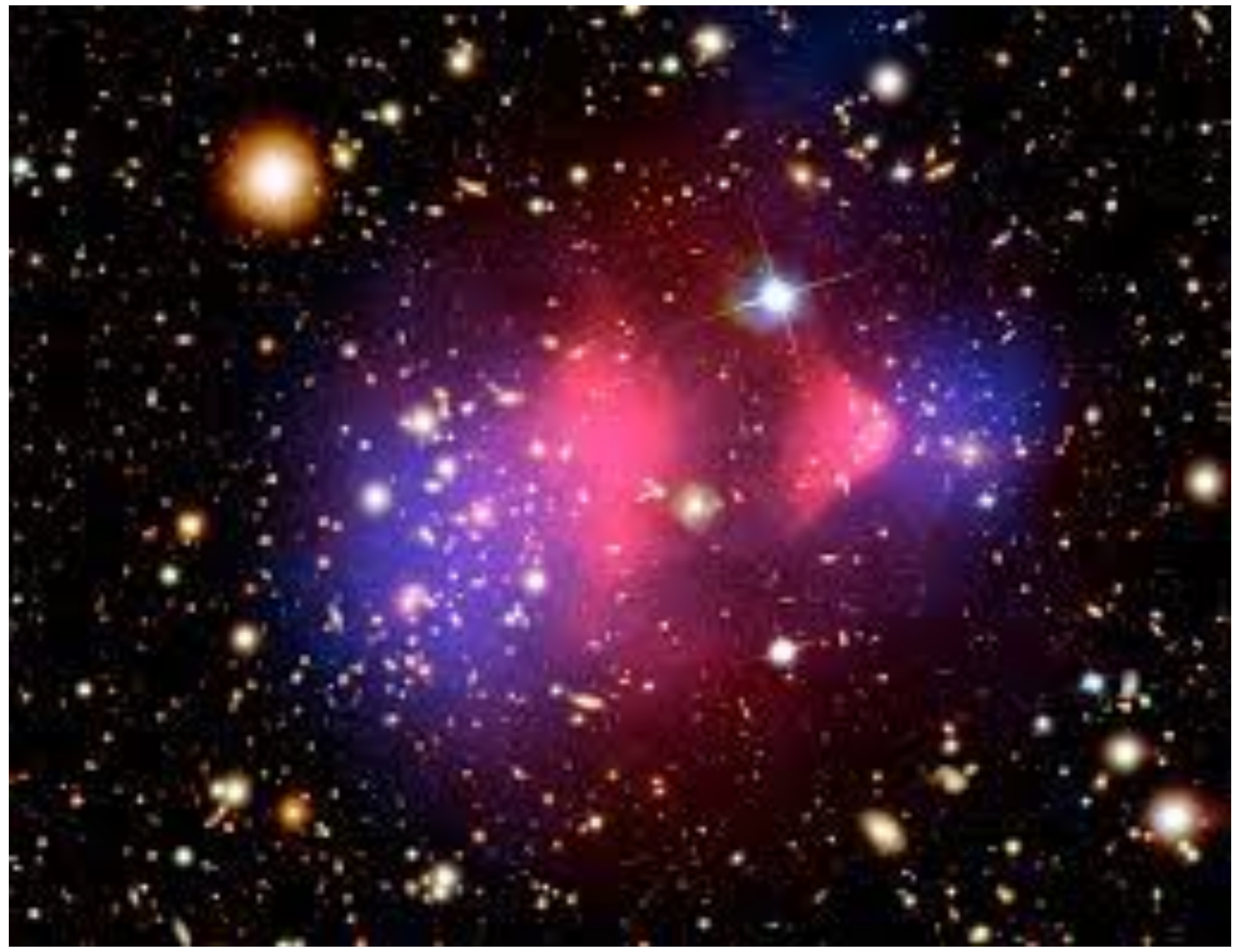
HFCPV2022

DM evidence

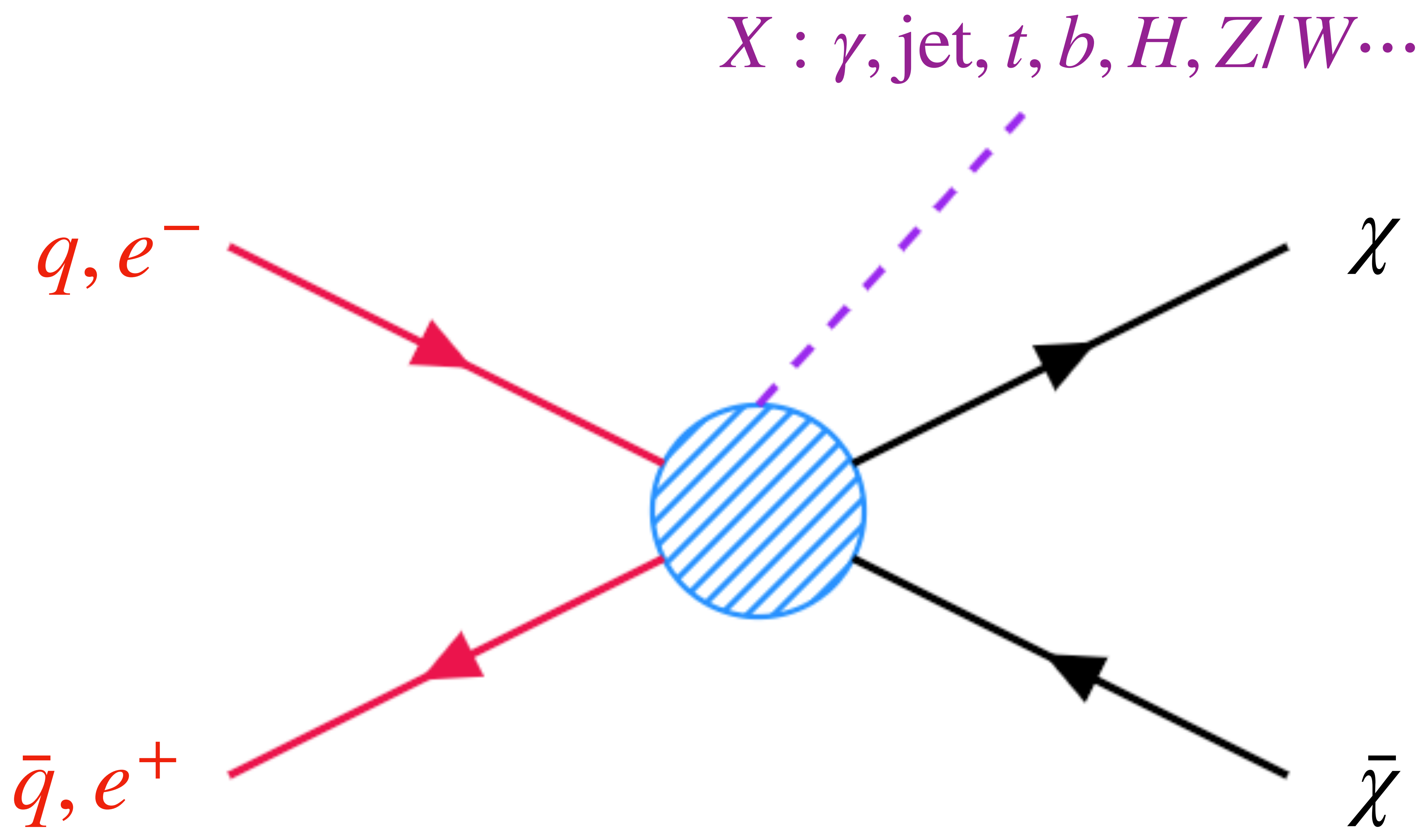

Normal Matter
4%
Neutrinos
0.1-2%
Dark Matter
23%
Dark Energy
73 %
Content of the Universe


Observations
from 21 cm hydrogen
from starlight
100
50
V
(km/s)
Expected from visible disk
10
20
30
40
50
R (× 1000 ly)


QUASAR
FOREGROUND GALAXY
WITH FOUR QUASAR IMAGES
HUBBLE



Mono-X channel at collider



DMs are produced

at the primary collision point

and performed as missing energy

γ: Birkedal2004, Fox2011…

Jet: Feng2005, Bai2010…

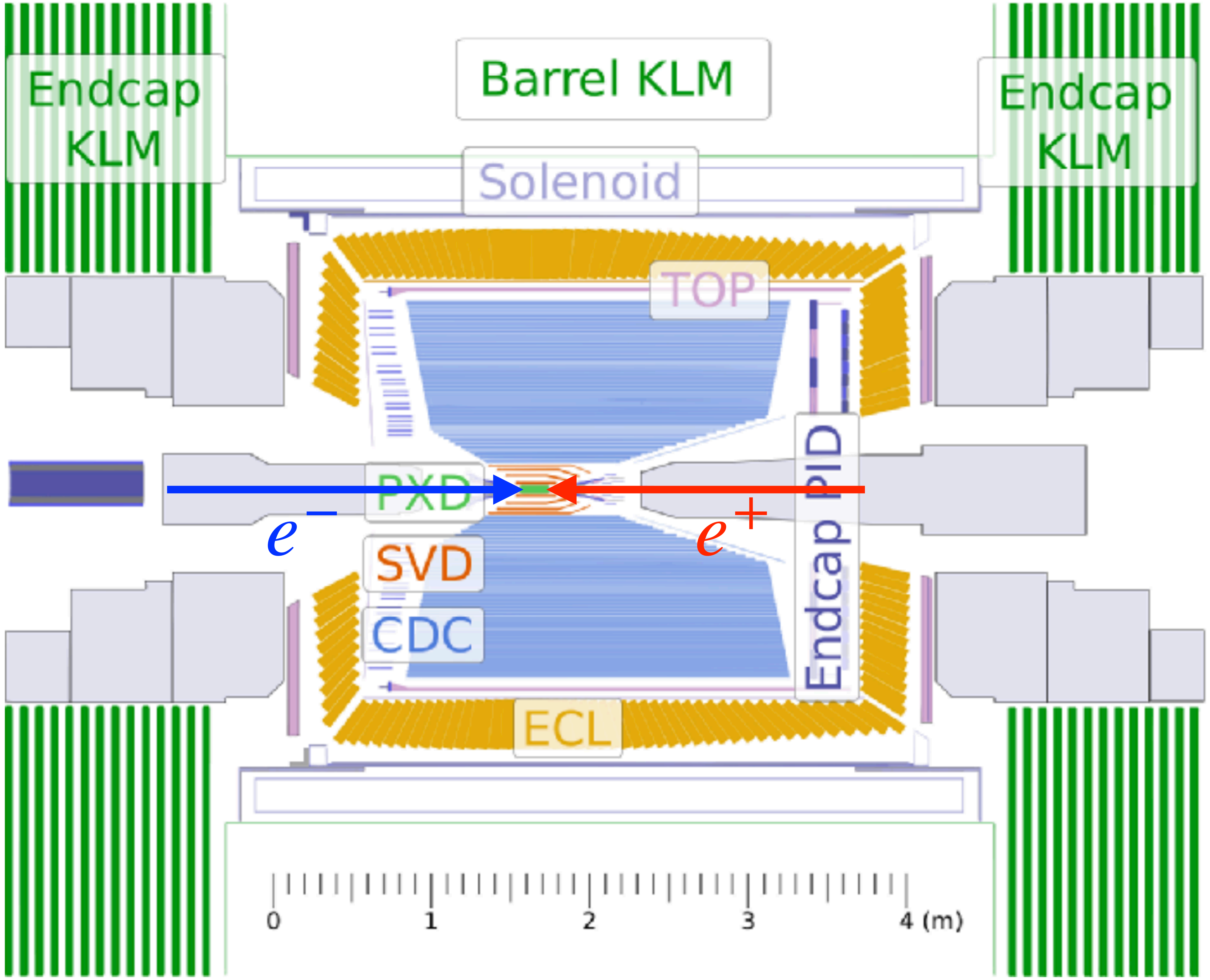
t: Andrea2011, Agram2013…

b: Lin2013, Izaguirre2014…

Z/W: Petriello:2008, Bell:2012…

H: Petrov:2013, Carpenter:2013…

Belle II detectors



$\mathscr{L} = 50/\mathrm{ab}, \sqrt{s} = 10.58\ \mathrm{GeV}$

CDC:

$\delta p_T / p_T \simeq 0.4\,\%$ **for** $p_T \simeq 3\ \mathrm{GeV}$

ECL:

16 X_0 **CsI crystals,**

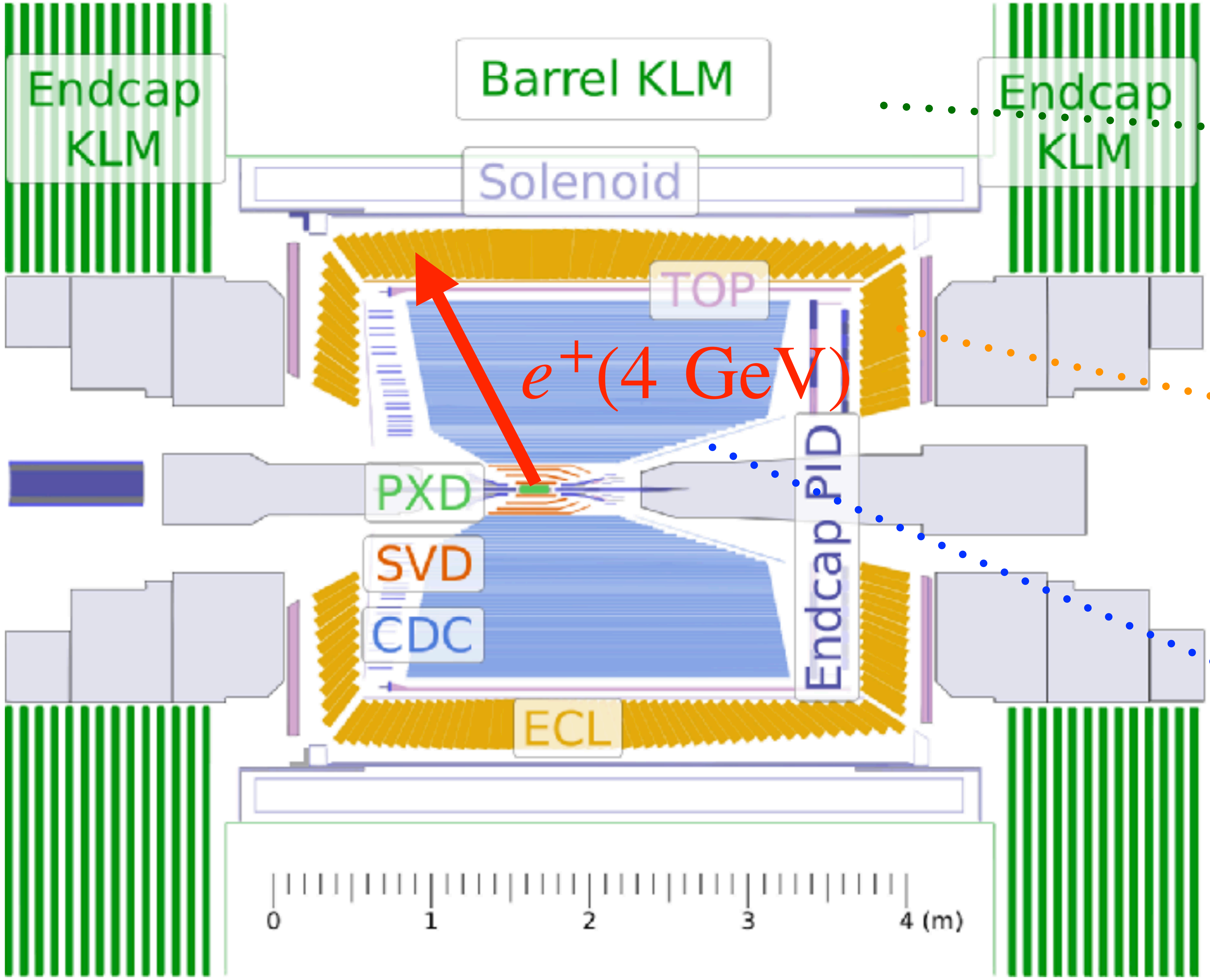
$\sigma_E / E = 1.6\,\%$ **for** $E \simeq 8\ \mathrm{GeV}$

KLM:

Alternating sandwich of iron plates and active detector elements (RPC and scintillator strips)

Belle II physics book, 1808.10567

Belle II detectors

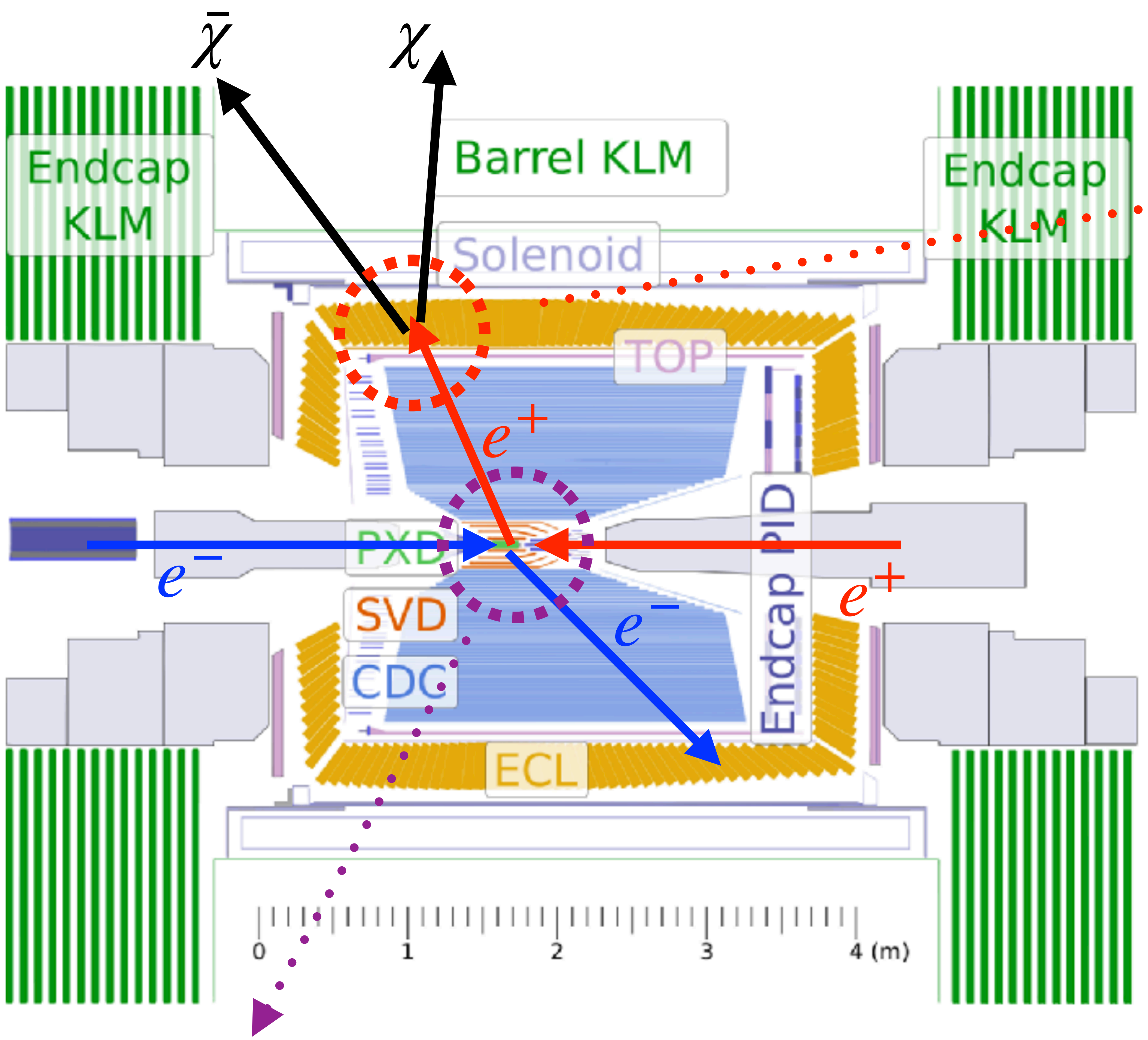


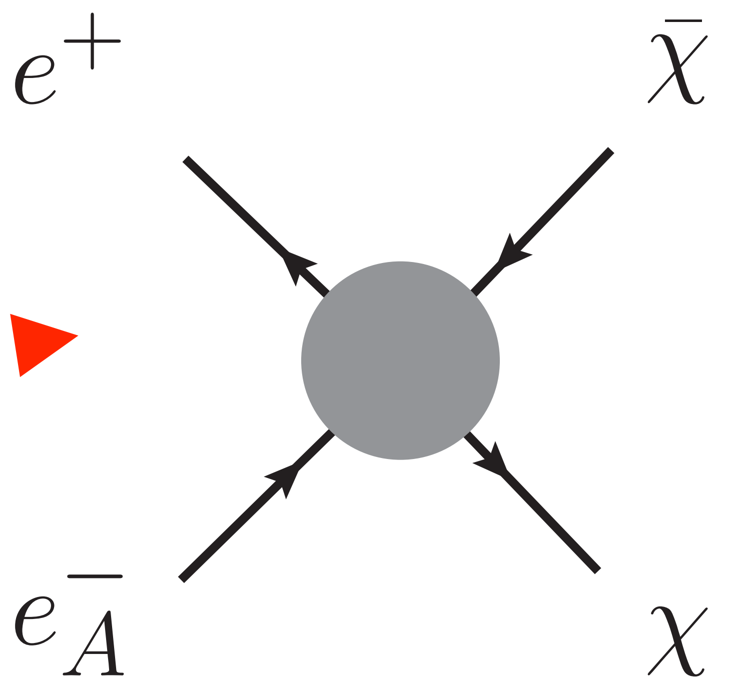
KLM:
No activity at KLM

ECL:
4 GeV deposited energy

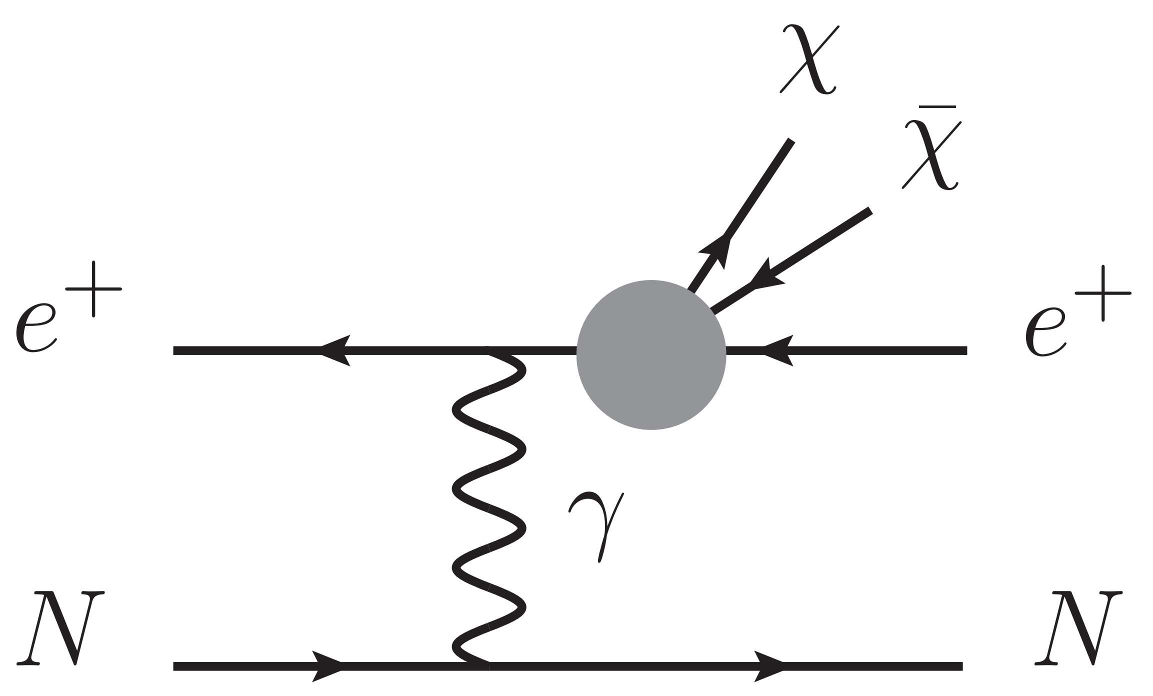
CDC:
A charged track with $p = 4\ \mathrm{GeV}$

New channel at Belle II experiment





Annihilation

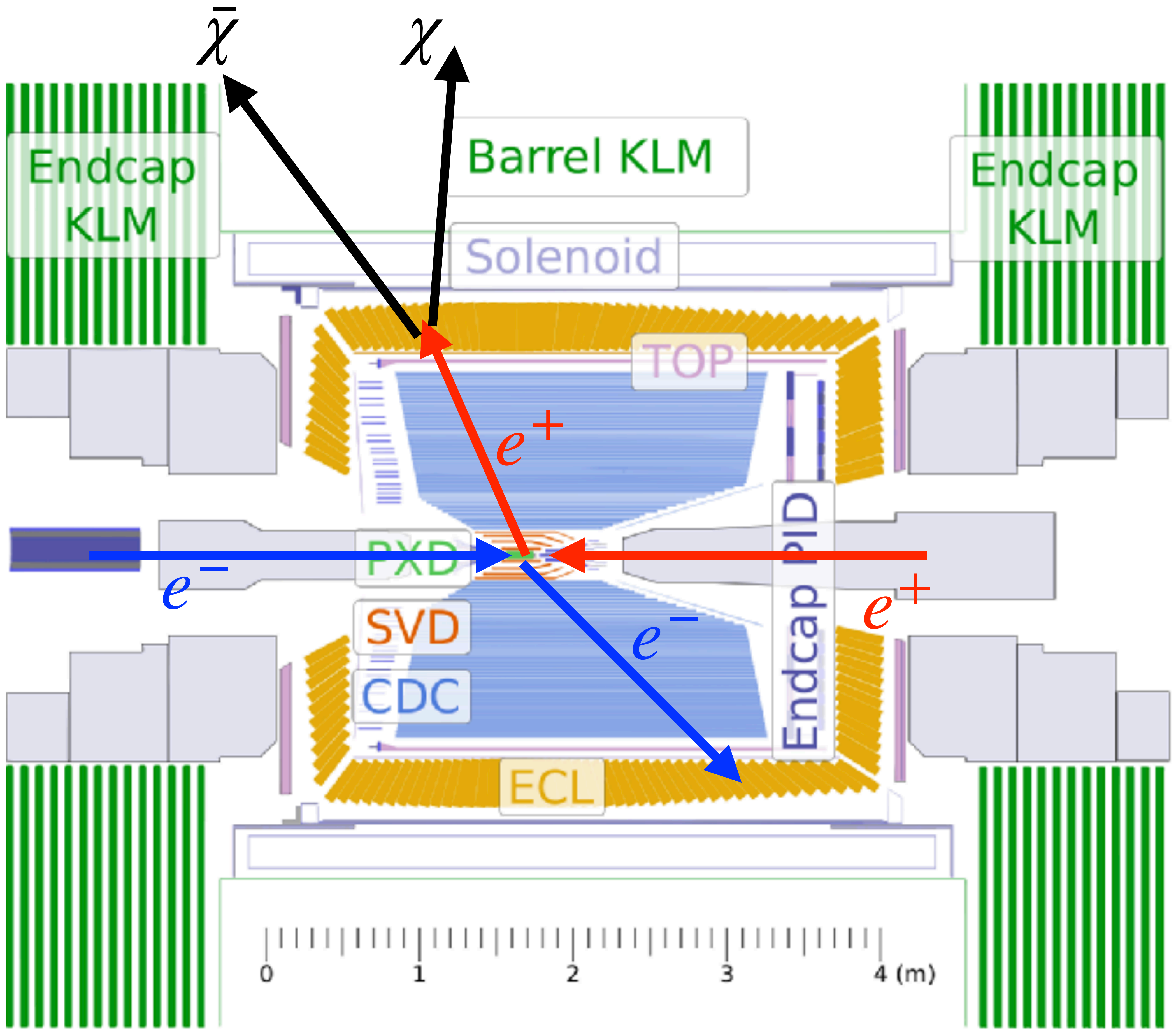


Bremsstrahlung

DMs are generated in collisions between the positron and the ECL.

Bhabha scattering

New channel at Belle II experiment



Signal:

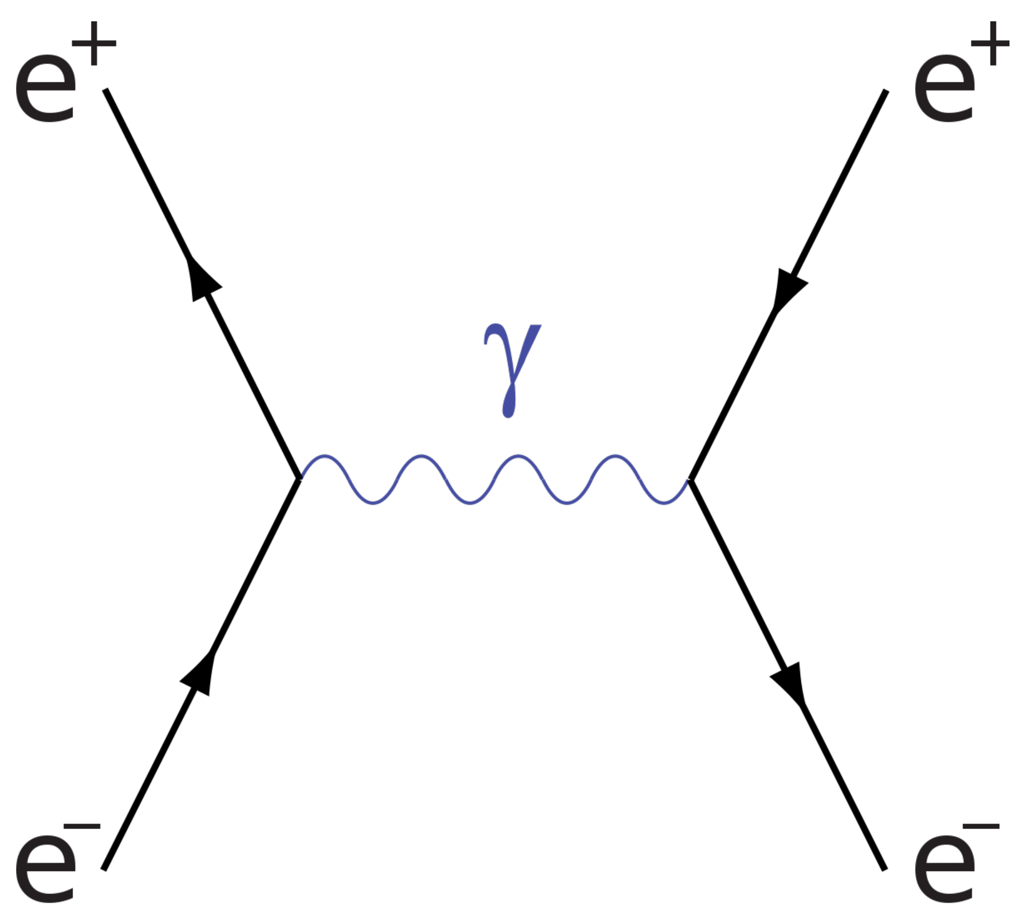
(1) Positron: a clear track in the CDC, very little energy deposited in the ECL

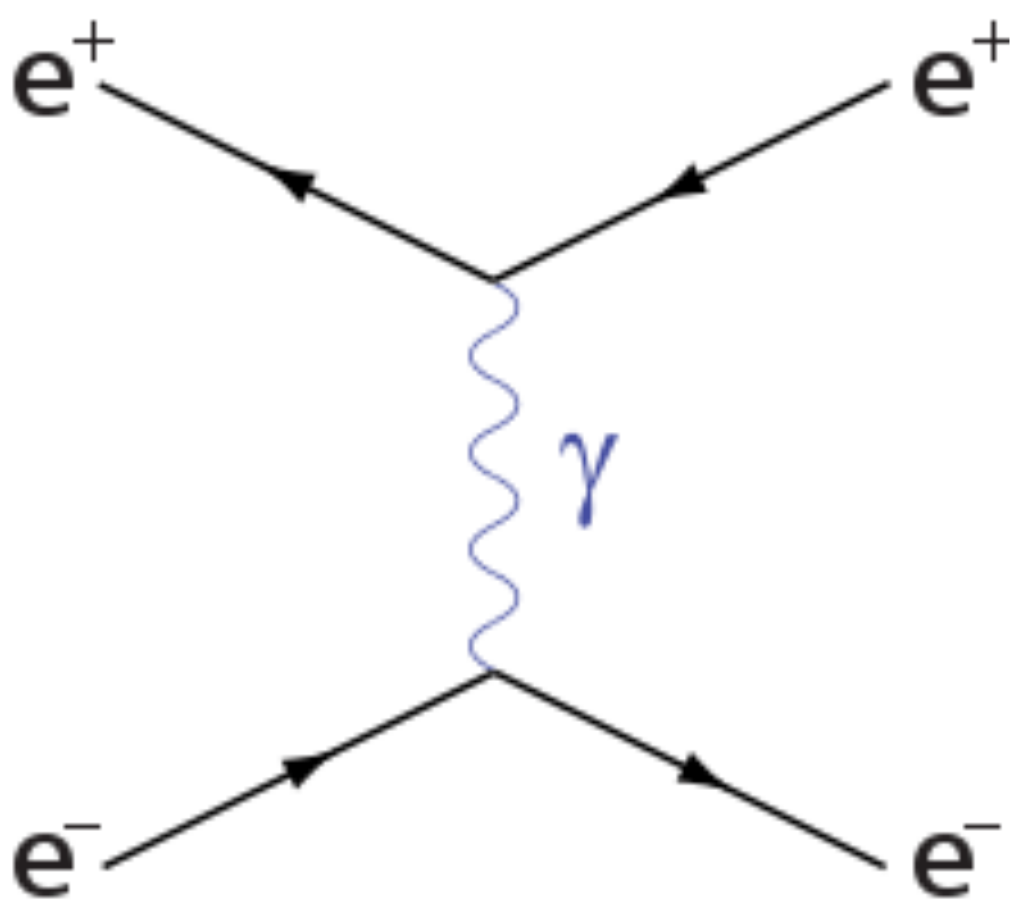
(2) Electron: a clear track in the CDC, full energy deposited in the ECL

(3) No tracks or clusters in the KLM

We treat Belle II as a positron fixed target experiment with the ECL as the target.

Positron flux from Bhabha scattering



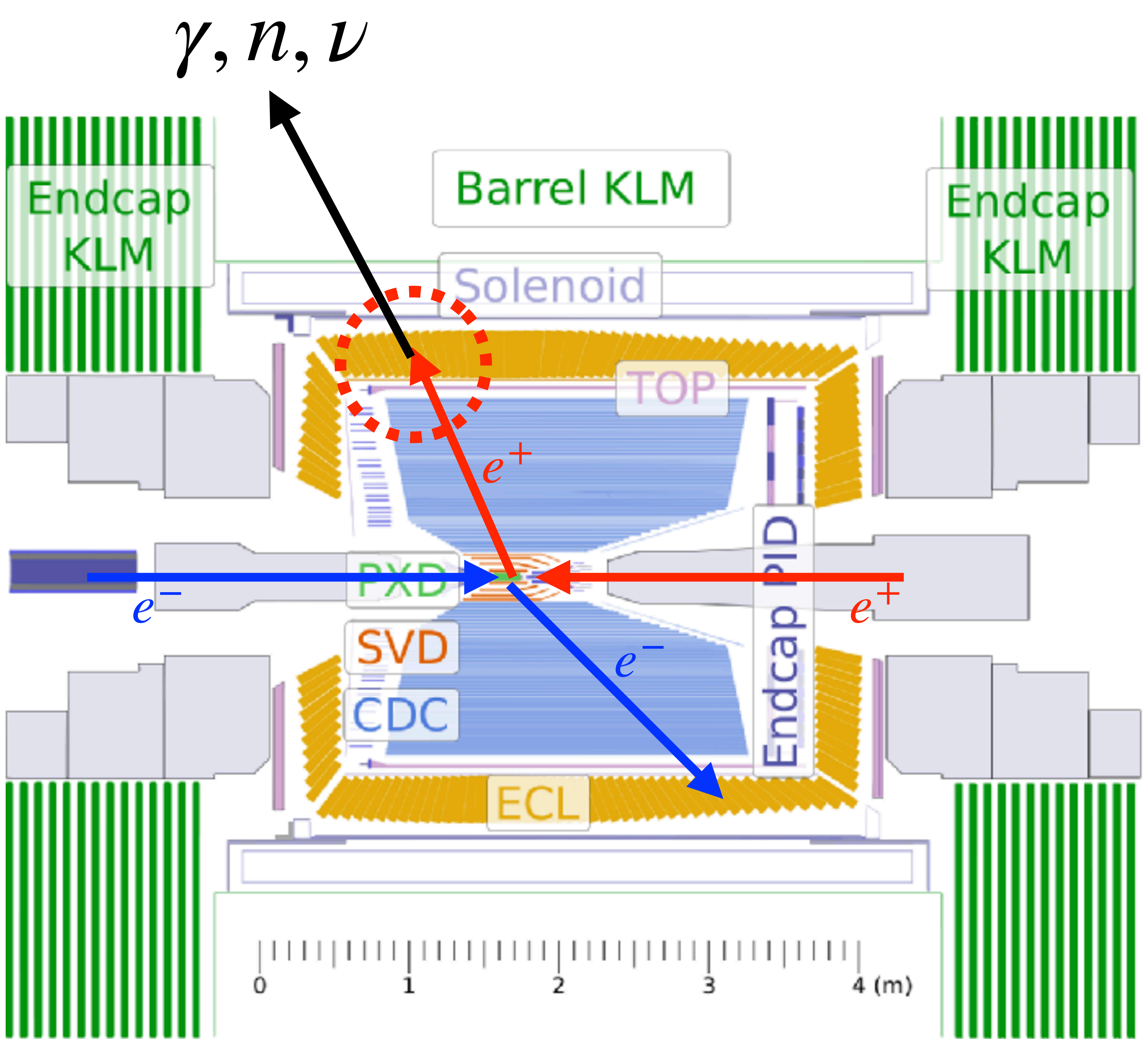


$$\frac{d\sigma_B}{d\cos\theta^*} = \frac{\pi\alpha^2}{2s}\frac{(3+\cos^2\theta^*)^2}{(1+\cos\theta^*)^2},$$

$$N_{e^+} \simeq 6\times 10^{11}\ (\mathscr{L} = 50/ab)$$

for the ECL barrel region

Backgrounds



Cuts:

(1) Less than 5% of the positron energy deposited in the ECL barrel

(2) No clusters or tracks in the KLM

$$N_\gamma \simeq 13,\ N_n \simeq 81$$

New channel constraints on dark photon model

$$\mathscr{L}_{\text{int}} = A'_\mu(eQ_f\epsilon\bar{f}\gamma^\mu f + g_\chi\bar{\chi}\gamma^\mu\chi)$$

A'_μ **: dark photon**

χ **: Dirac dark matter**

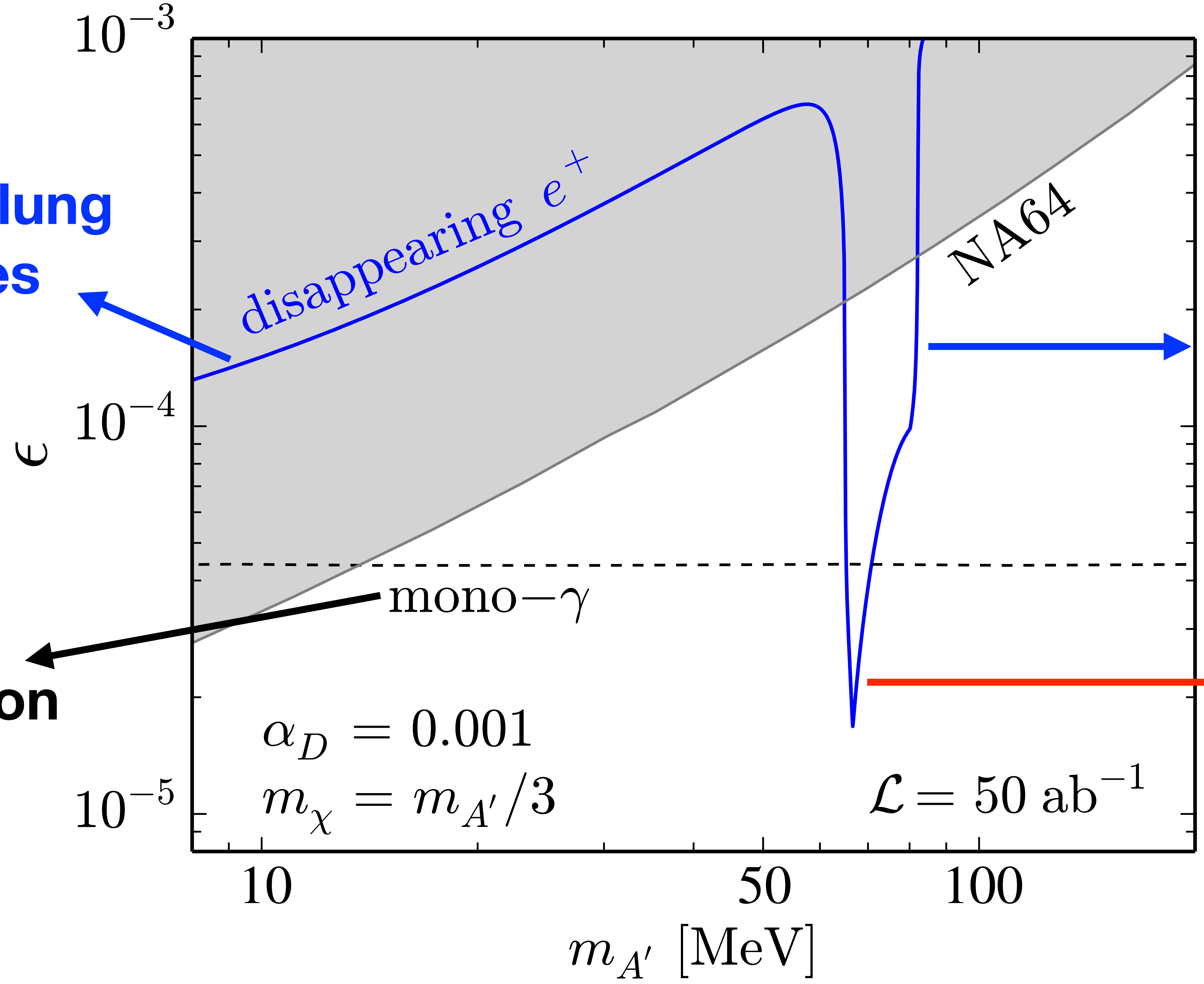
f **: SM fermion with charge** Q

ϵ, g_χ **: coupling constants**

New channel constraints on dark photon model

Bremsstrahlung dominates

Belle II mono-photon



Annihilation dominates

Leading constraint at $m_{A'} \simeq 66$ MeV

JL, Liu, Yang, 2212.04252

Summary

- The leading DM signature studied at colliders is mono-X channel, in which DMs are generated in the primary collision vertex.
- We propose a new DM searching channel at Belle II, in which DMs are generated in collisions between positrons and the ECL.
- For this new channel, the dominant backgrounds are from missing photons and neutrons.
- We use the dark photon model as the benchmark model and find that this new channel can set leading constraints in the mass region of $m_{A'} \simeq 66\ \mathrm{MeV}$.

Thank You!

Backup

Photon Background estimation

The energy distribution of photons that are produced in the collision between a positron with energy E and the ECL:

$$\frac{dN_\gamma}{dx_\gamma}(t, x_\gamma) \simeq \frac{1}{x_\gamma}\frac{(1-x_\gamma)^{(4/3)t} - e^{-(7/9)t}}{7/9 + (4/3)\ln(1-x_\gamma)},$$

tX_0: positron of the photon in the detector, $x_\gamma = E_\gamma/E$

The probability of a photon carrying more than 95% of the positron energy to escape the ECL detector:

$$\int_{0.95}^{1} dx_\gamma \frac{dN_\gamma}{dx_\gamma}(t=16, x_\gamma) \simeq 4.7 \times 10^{-8}\,.$$

2.8×10^4

potential backgrounds after the ECL with 50/ab

Photon Background estimation

Photon KLM veto efficiency

Photons may be not detected in the KLM due to not-instrumented setups

↓

Adopt BABAR IFR veto efficiency $\epsilon = 4.5 \times 10^{-4}$ as a conservative estimate.

↓

$\simeq 13$ photon backgrounds after KLM veto

Neutron Background estimation

High energy neutron generation rate estimate with GEANT4 simulation

Simulate collisions of 10^9 positrons with 4.35 GeV energy onto a CsI target with one X_0, by using GEANT4 with the FTFP_BERT physics list.

(1) At least one neutron with energy exceeding 3 GeV

(2) The deposited energy in the ECL to be less than 5% of the positron energy

→ **64 events survive after two vetos**

Neutron Background estimation

Neutron KLM veto efficiency

Classify the remaining events according to the number of neutrons that have kinetic energy exceeding 280 MeV

13 events with a single neutron

51 events with more than 2 neutrons

The probability for a neutron to penetrate a target with length L

$$P = \exp(-L/\lambda_0) \simeq 0.01$$

λ_0: the hadronic interaction length; The KLM (ECL) has $3.9(0.8)\lambda_0$

$\simeq 81$ neutron backgrounds for 50/ab after KLM veto