New dark matter search channels at electron colliders

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BESIII实验物理研讨会

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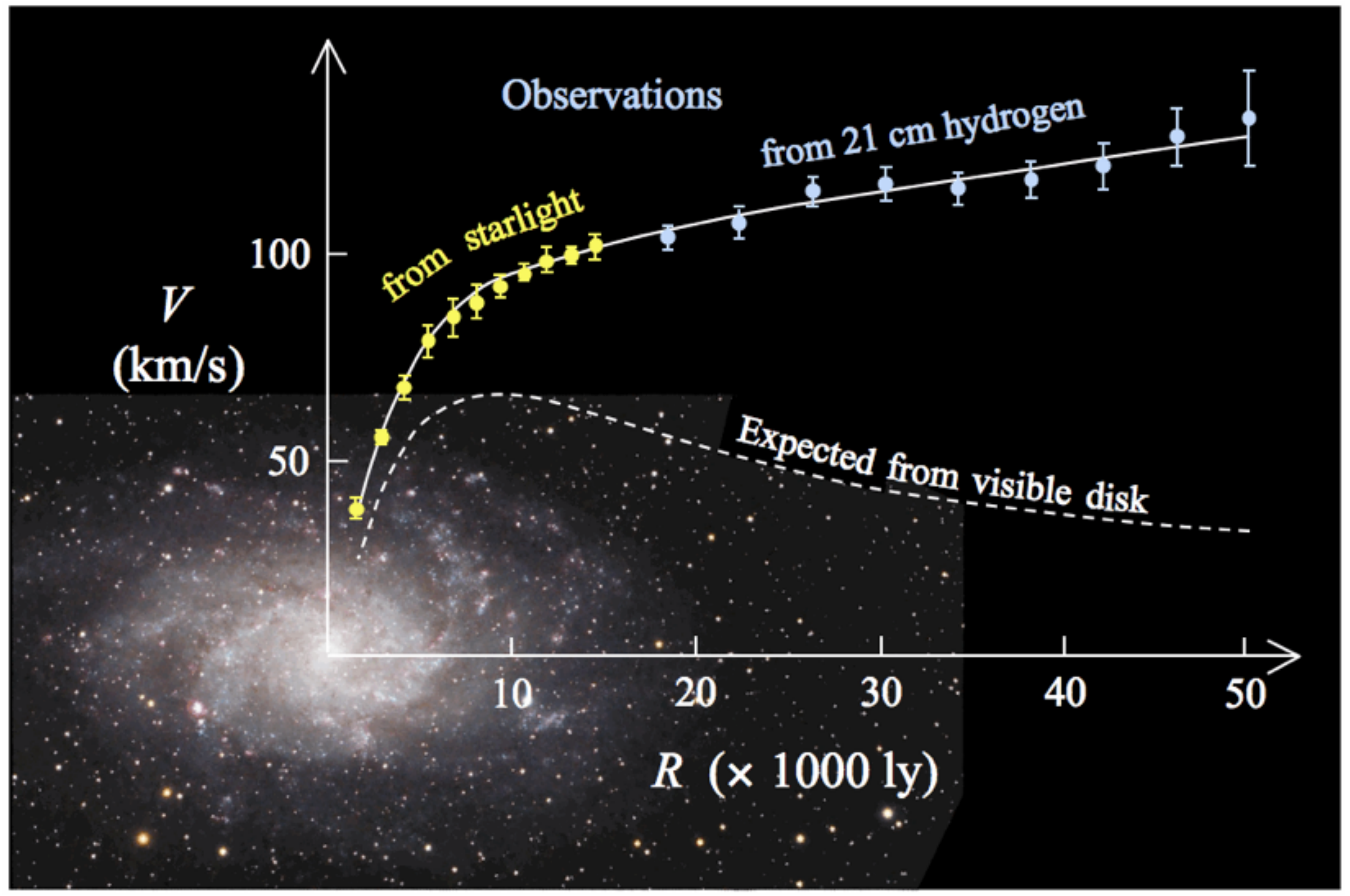
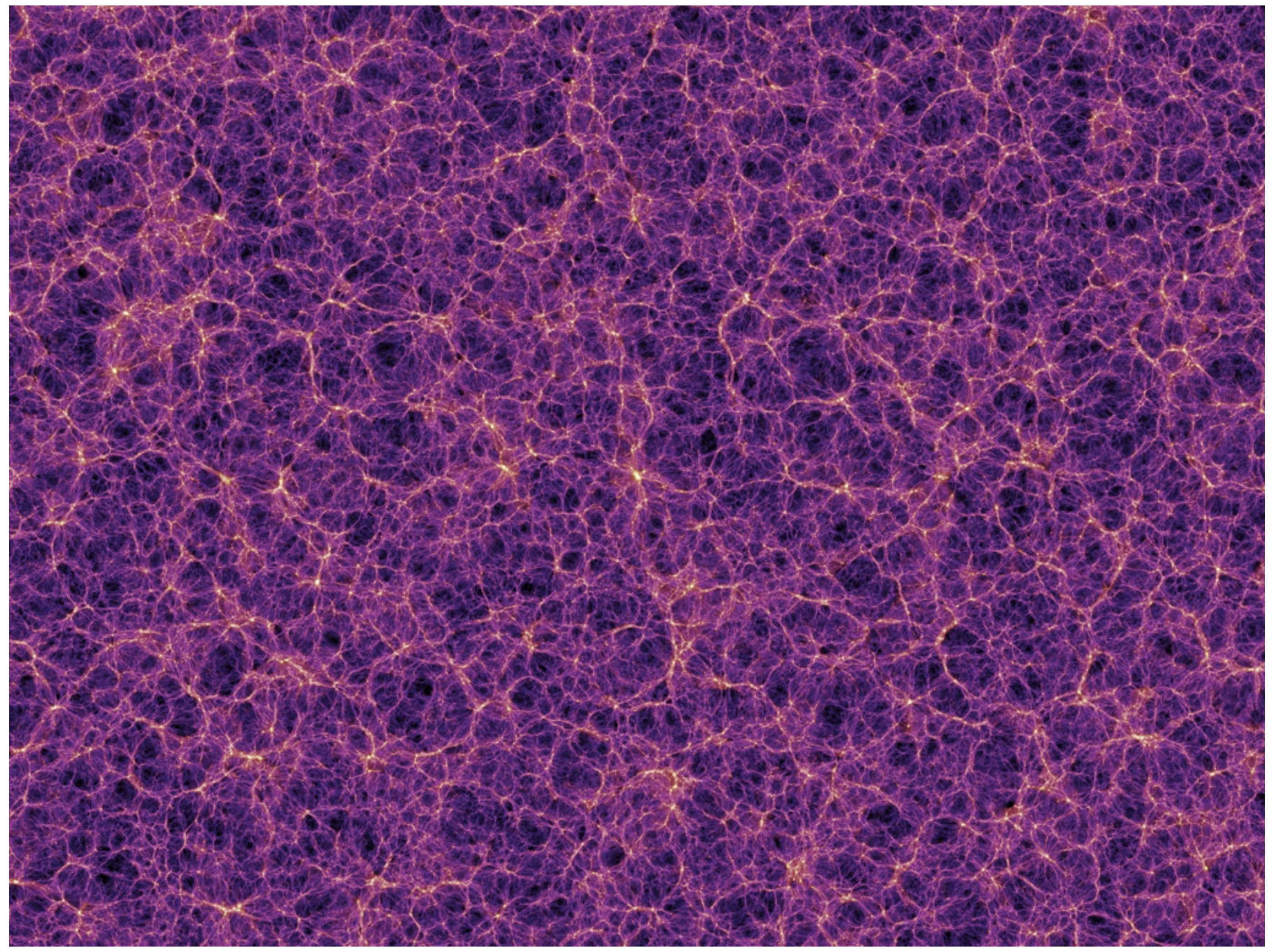
Evidence of dark matter

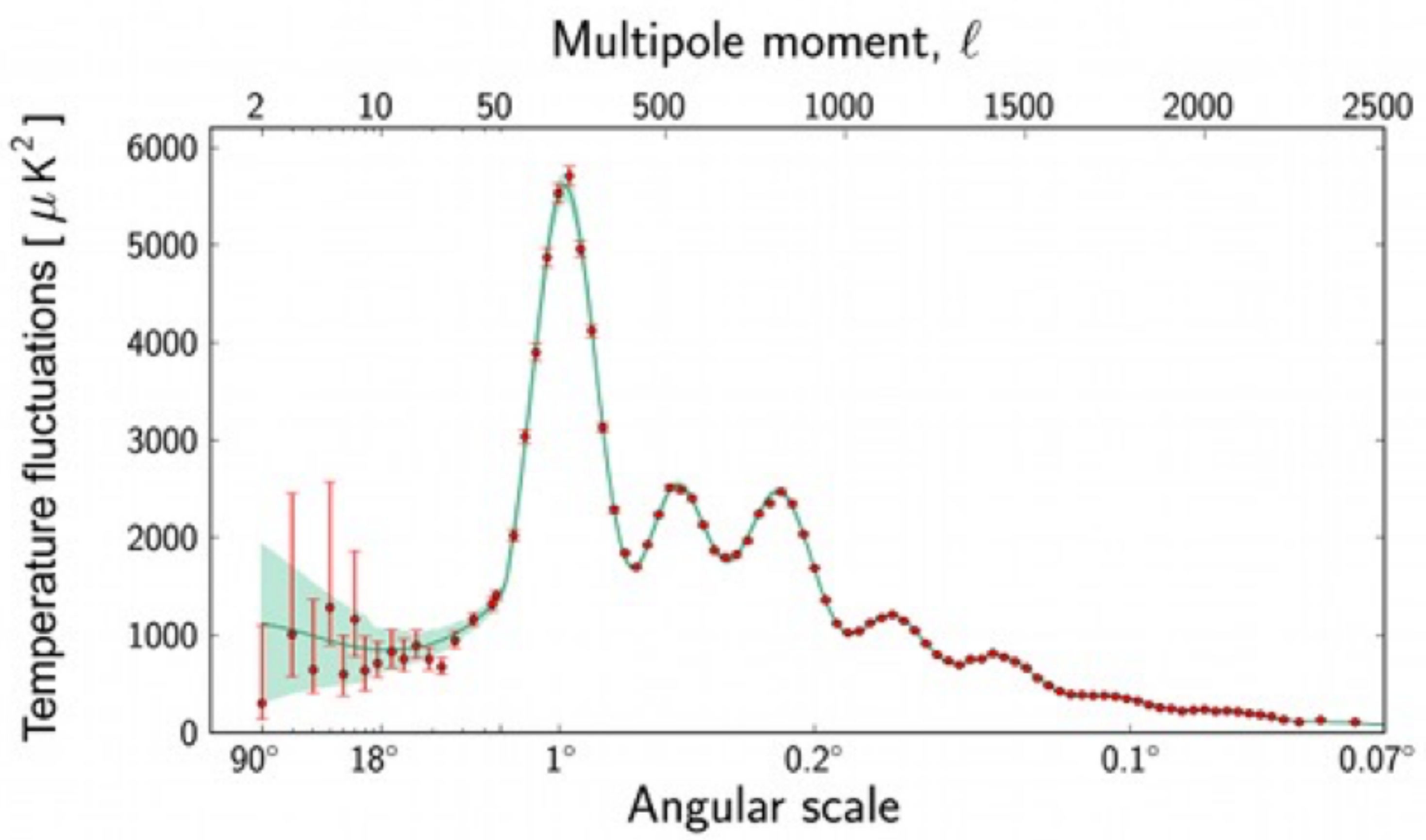
galaxy rotation curve



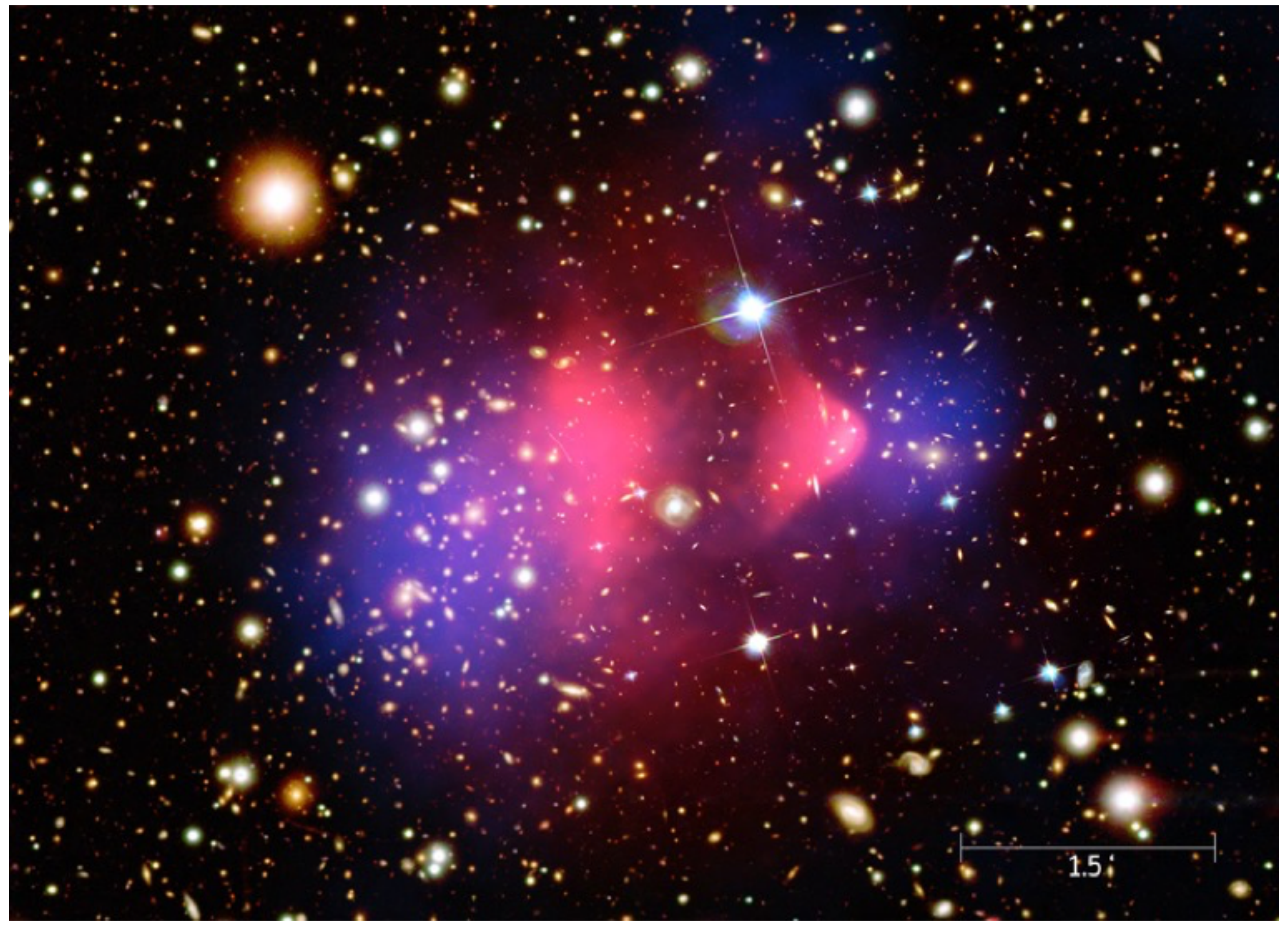
large scale structure



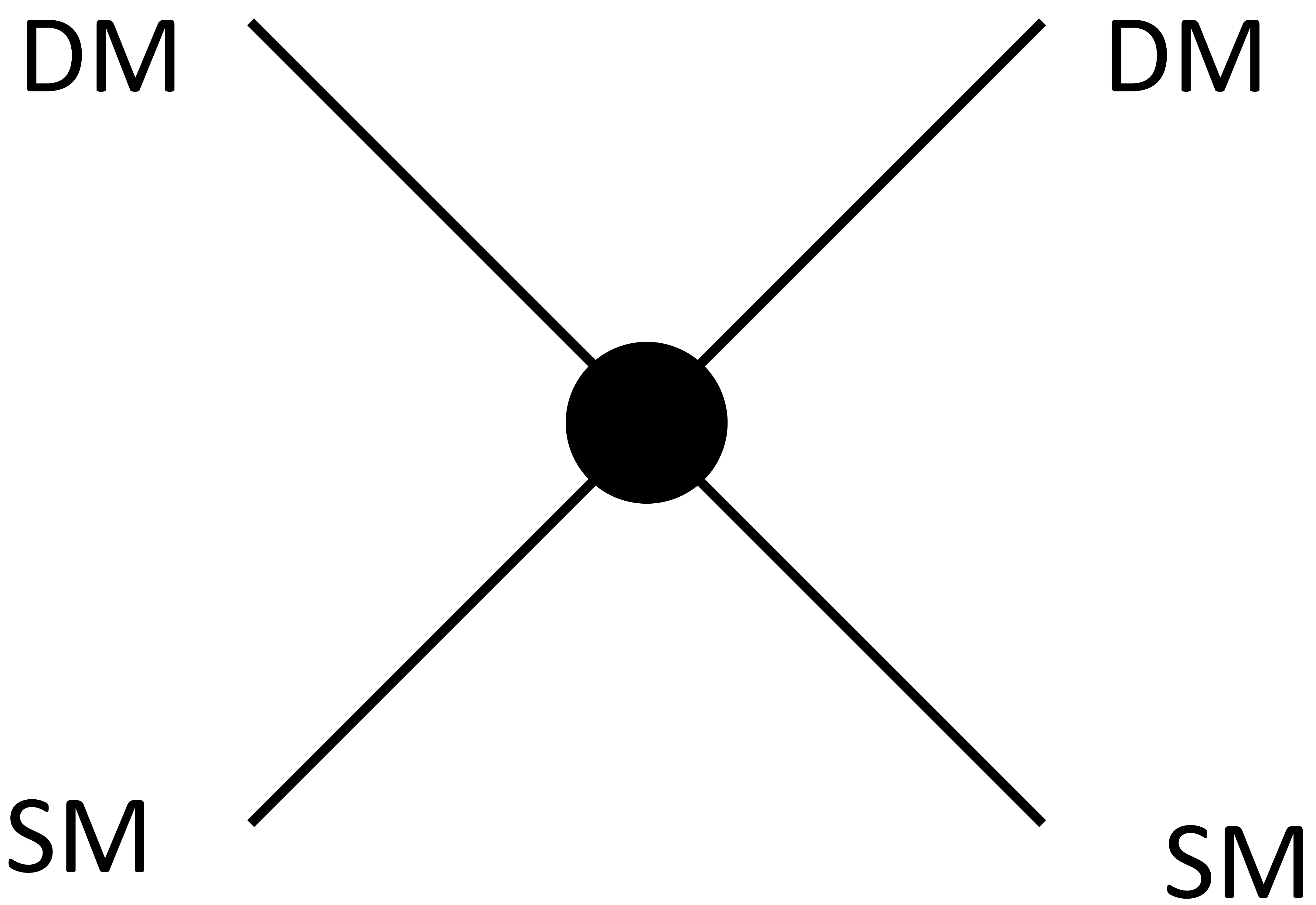
cosmic microwave background



gravity lensing

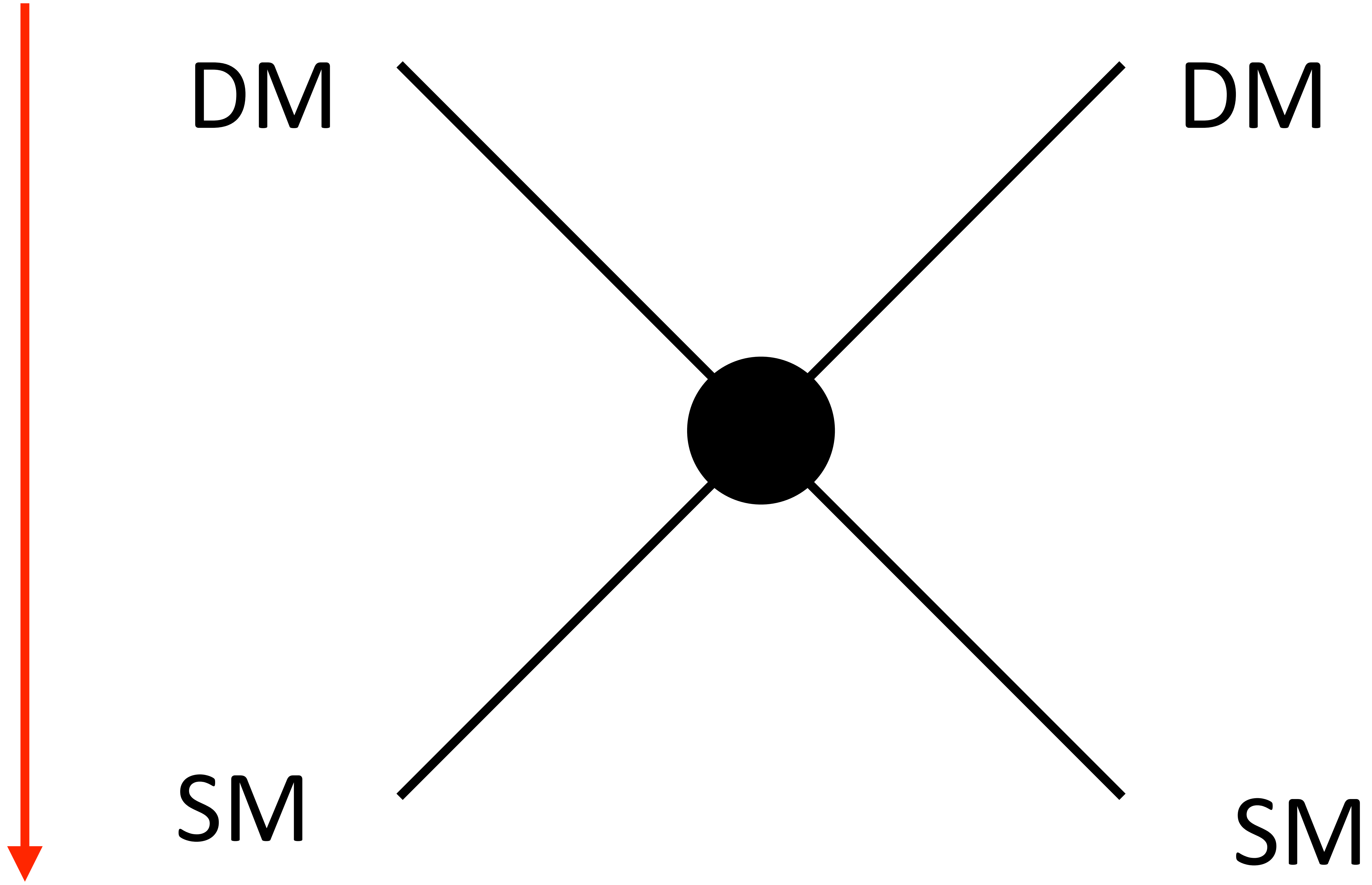


Searches for particle dark matter in experiments



Searches for particle dark matter in experiments

indirect
detection
(annihilation)



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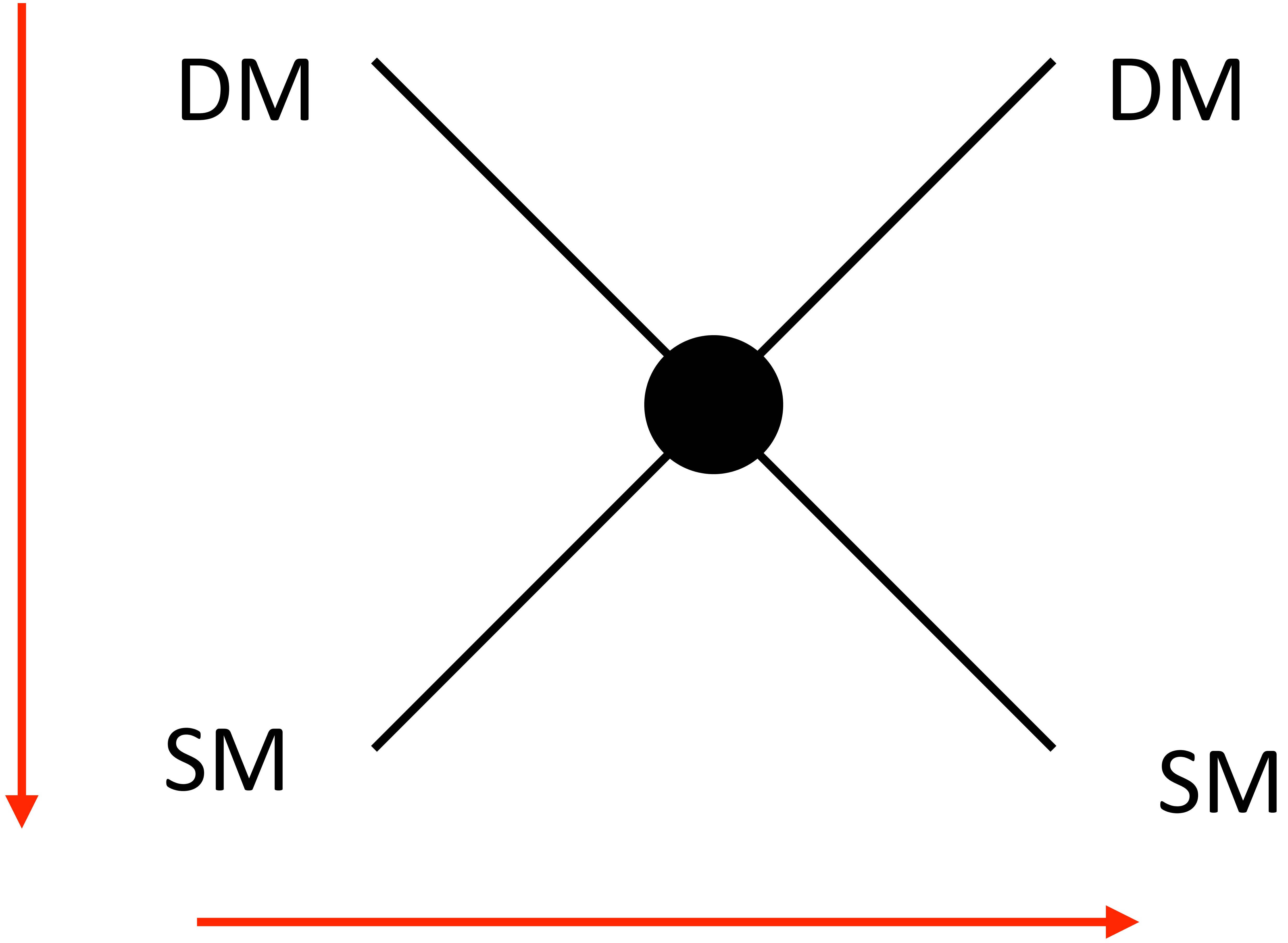
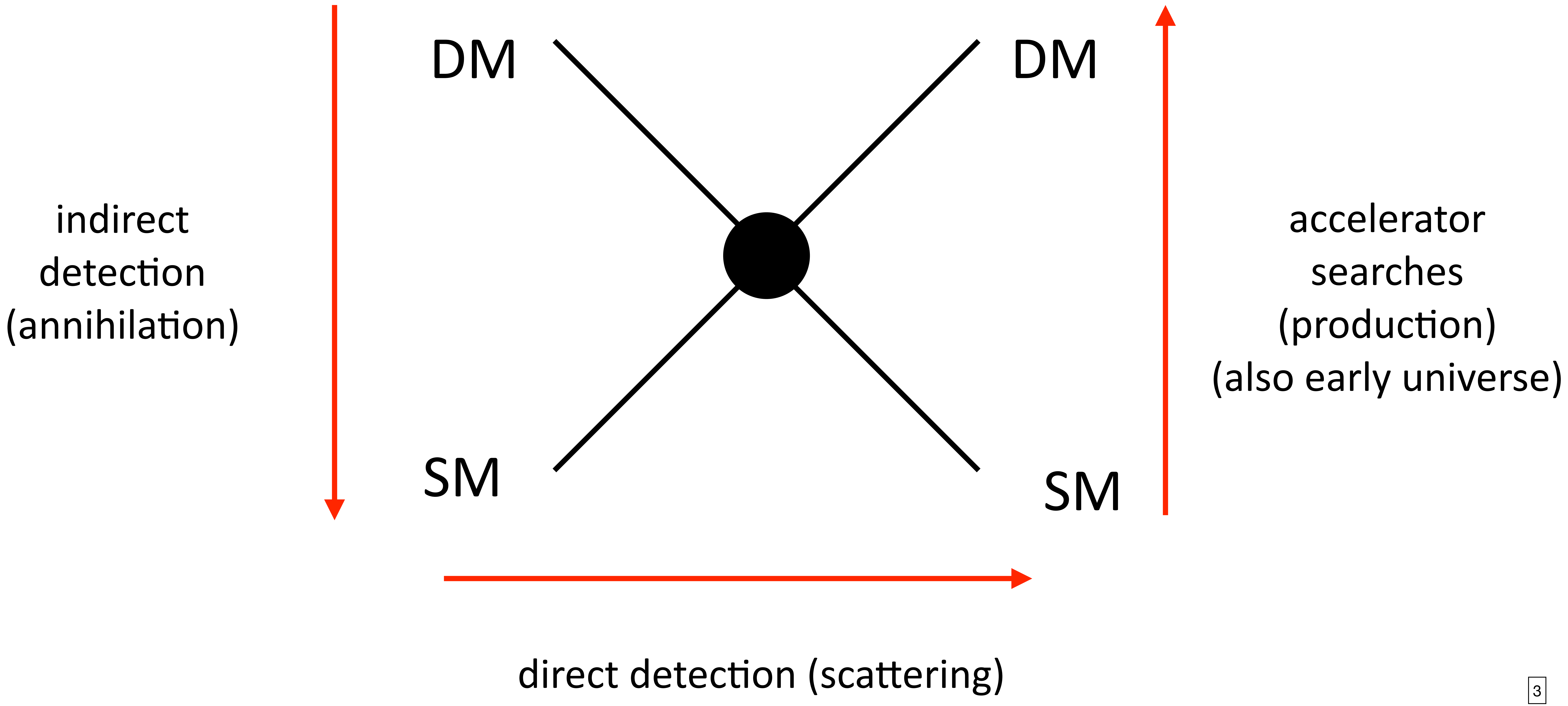


direct detection (scattering)

Searches for particle dark matter in experiments



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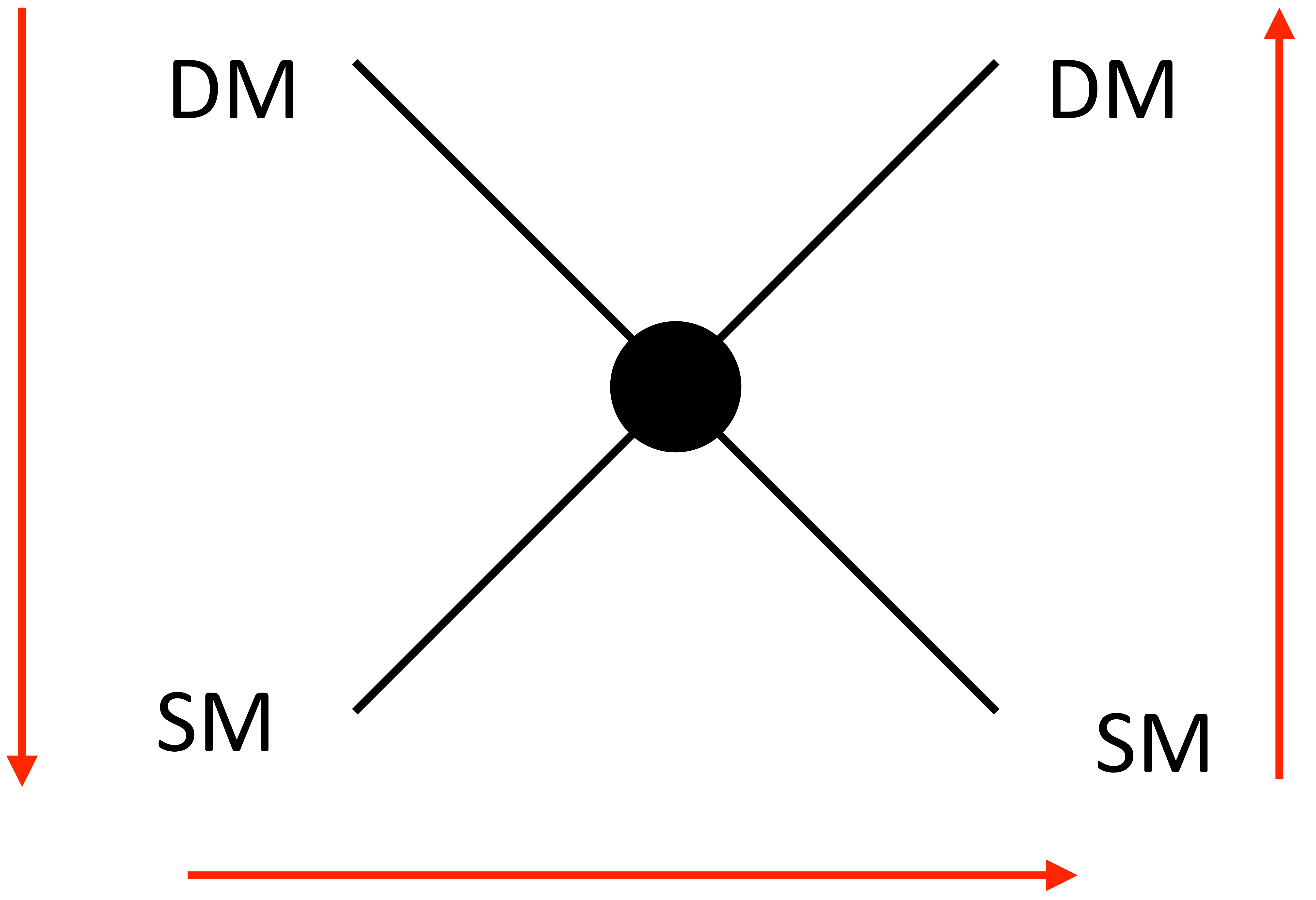


indirect
detection
(annihilation)

accelerator
searches
(production)
(also early universe)

direct detection (scattering) ←

same physics but
different processes

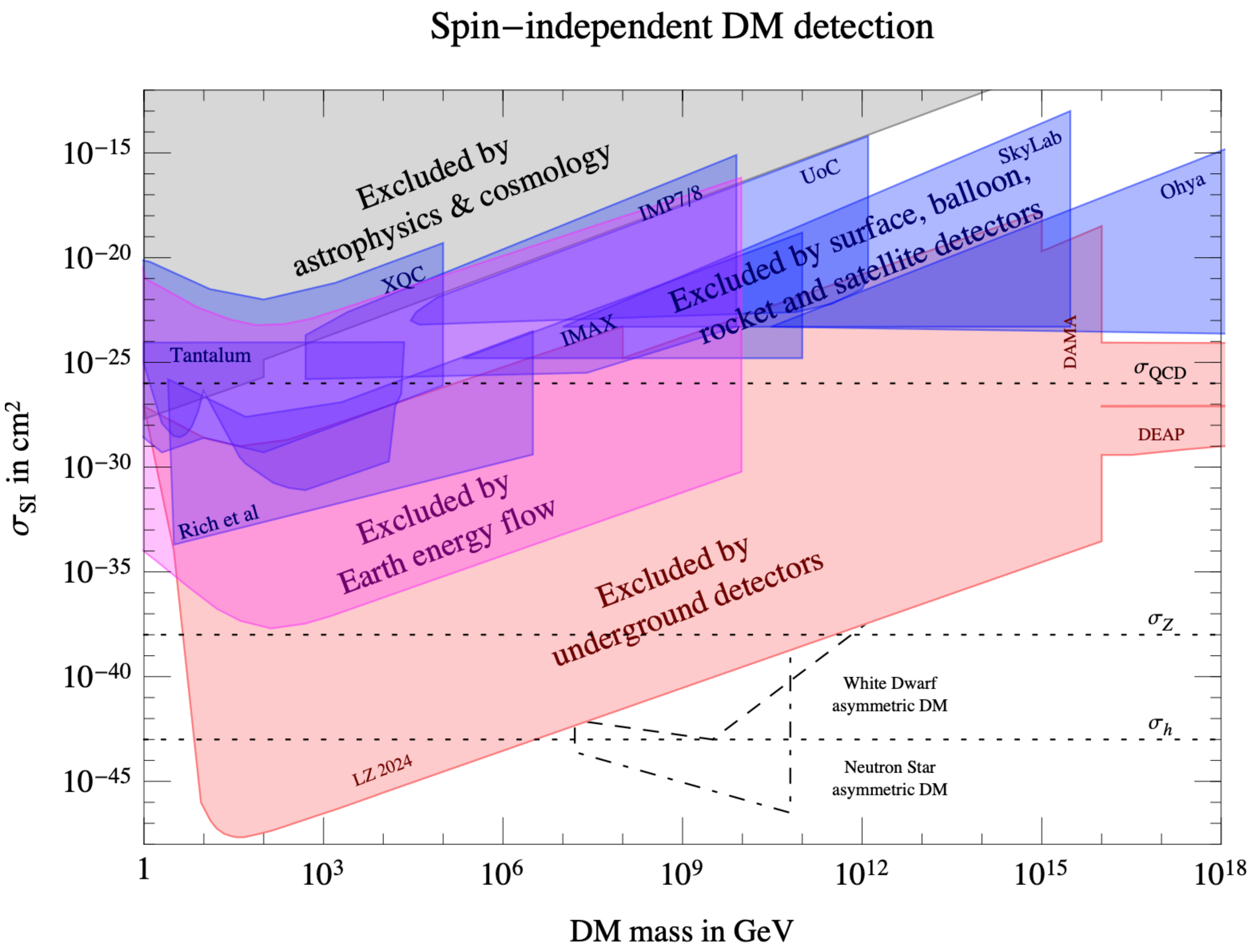
dark matter detection

[Cirelli, Strumia, Zupan, 2406.01705v3]

New DMDD limits, see also

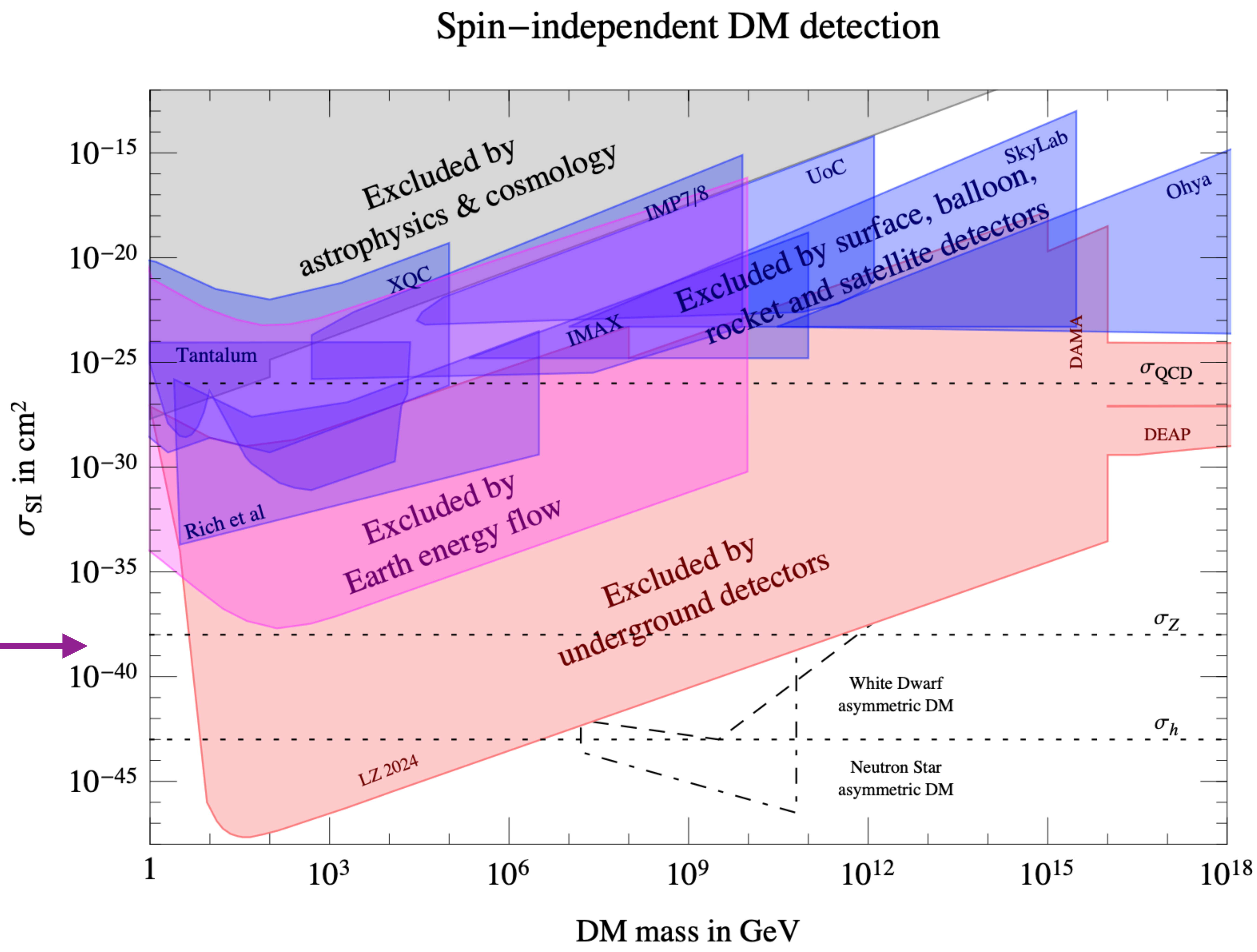
2507.11930 (PandaX-4T)

2510.21458 (CDEX)



dark matter detection

[Cirelli, Strumia, Zupan, 2406.01705v3]



New DMDD limits, see also

2507.11930 (PandaX-4T)

2510.21458 (CDEX)

probe below DMDD →

NR threshold

ER or Migdal

dark matter detection

[Cirelli, Strumia, Zupan, 2406.01705v3]

New DMDD limits, see also

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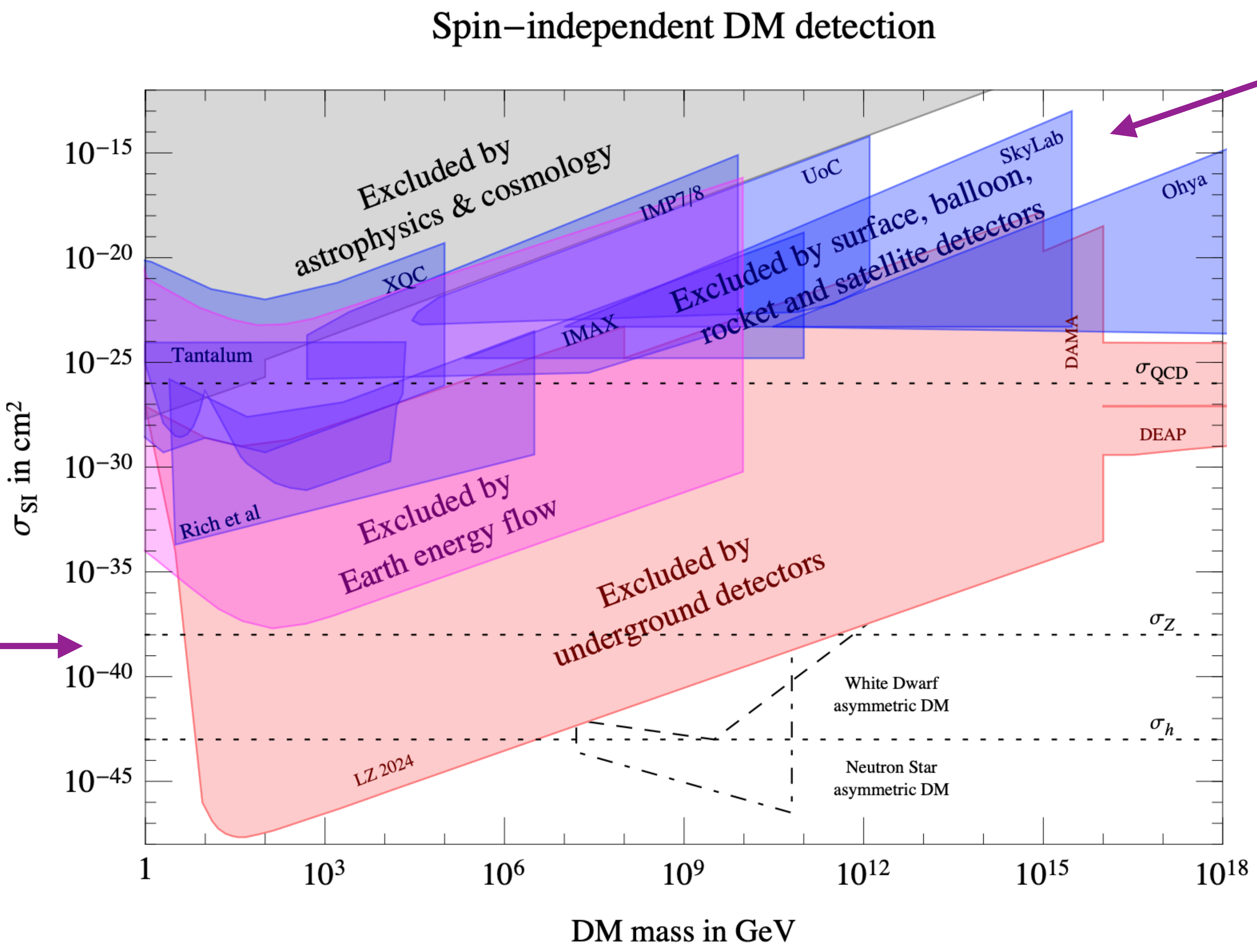

probe above DMDD

probe below DMDD

NR threshold

ER or Migdal

shielding effects due to rocks above underground labs

Outline

1. Probing diff DM via mono-photon @ electron colliders

   [ZL, Zhang, 1808.00983]
   [Liang, ZL, Ma, Zhang, 1909.06847]
   [Liang, ZL, Yang, 2111.15533]

2. New dark matter channel @ Belle II

   [Liang, ZL, Yang, 2212.04252] **[Ge, Liang, ZL, Min, 2505.10302]**

3. Belle II probes of strongly-interacting dark matter

   [Liang, ZL, Yang, 2312.08970]

Outline

1 Probing diff DM via mono-photon @ electron colliders

below & above DMDD

[ZL, Zhang, 1808.00983]
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[Liang, ZL, Yang, 2111.15533]

2 New dark matter channel @ Belle II

below DMDD

[Liang, ZL, Yang, 2212.04252] [Ge, Liang, ZL, Min, 2505.10302]

3 Belle II probes of strongly-interacting dark matter

above DMDD

[Liang, ZL, Yang, 2312.08970]

1

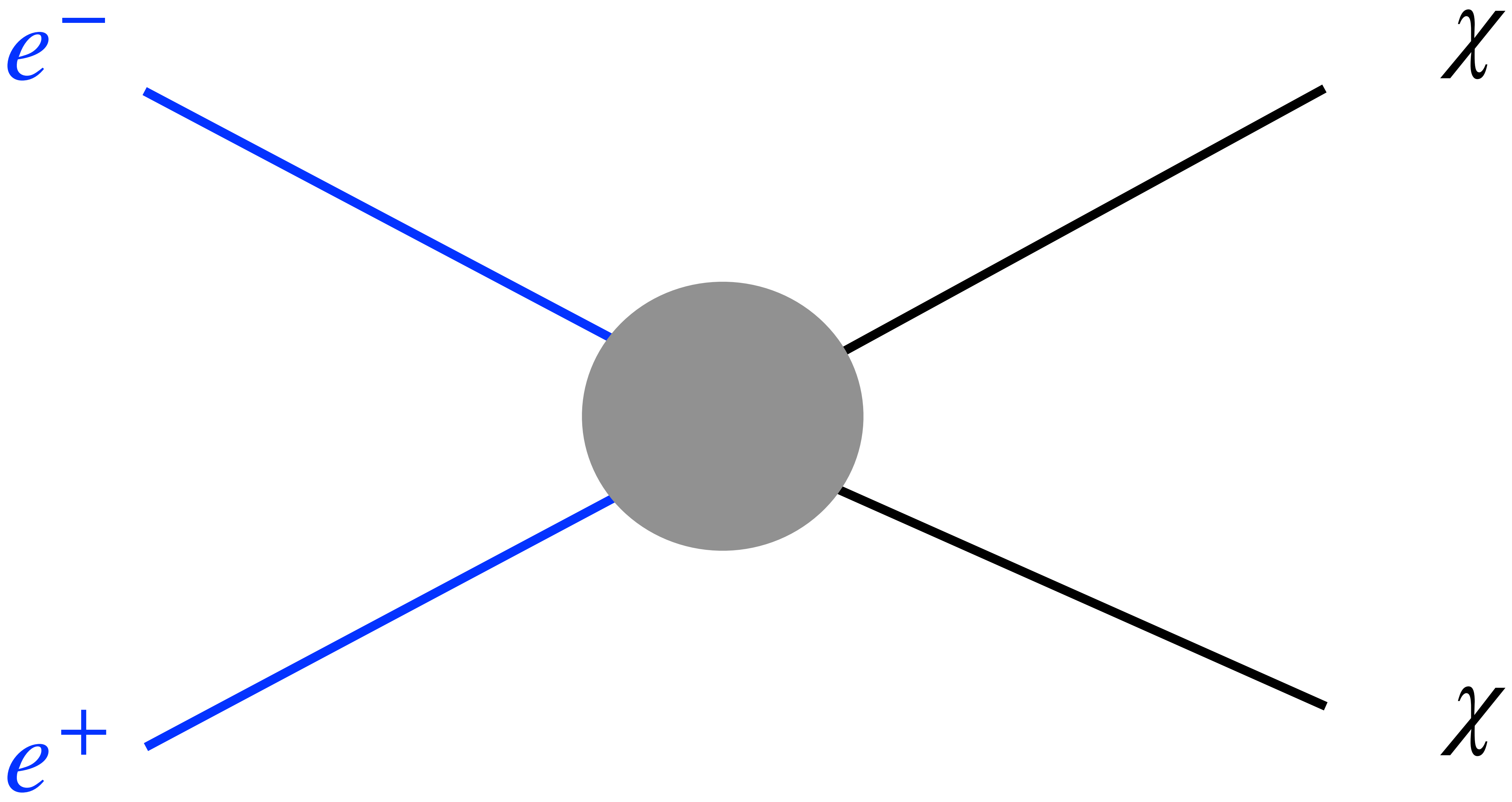
Probing different DM models via mono-photon @ electron colliders

[ZL, Zhang, 1808.00983]

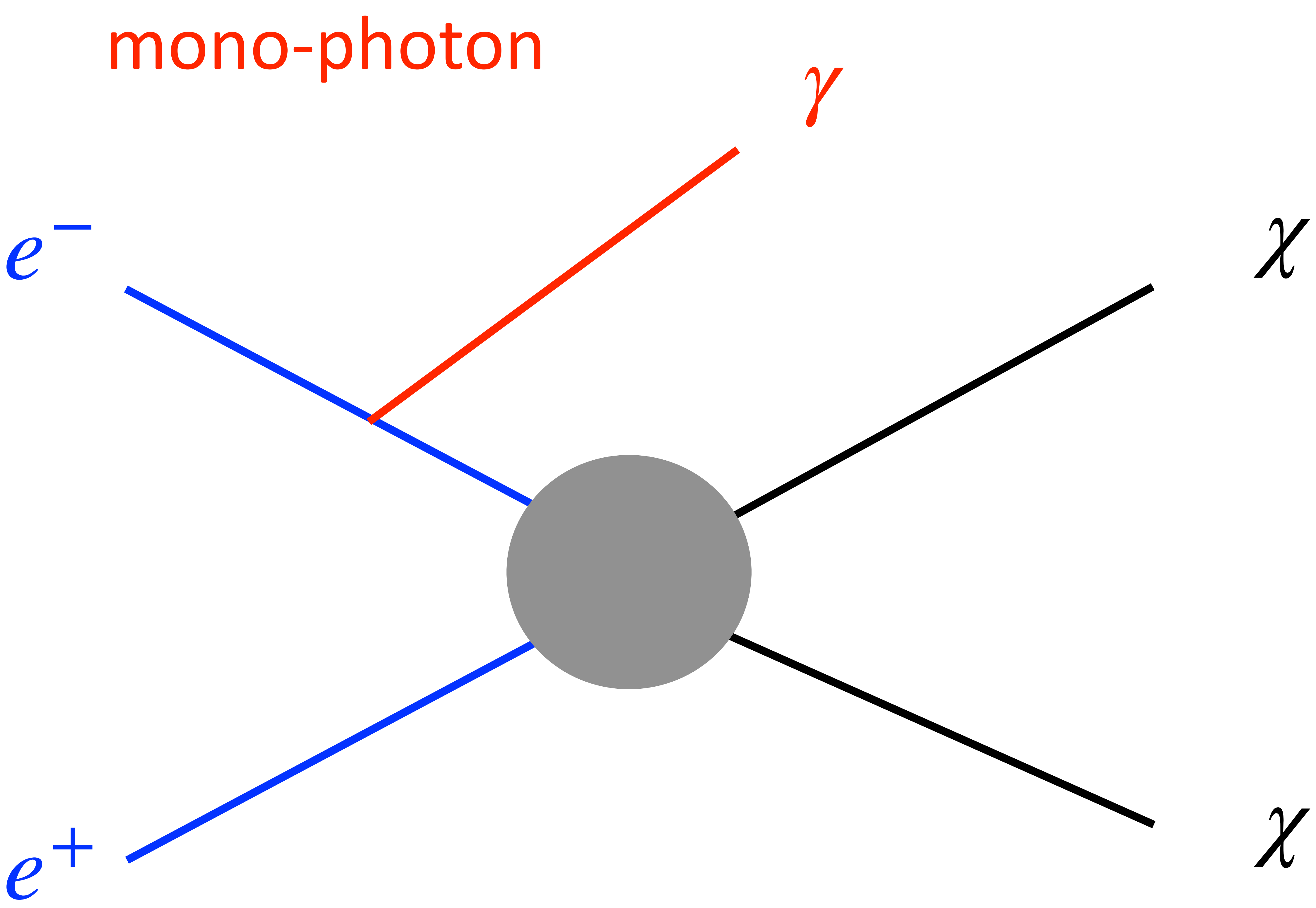
[Liang, ZL, Ma, Zhang, 1909.06847]

[Liang, ZL, Yang, 2111.15533]

Mono-photon signature at electron colliders



Mono-photon signature at electron colliders



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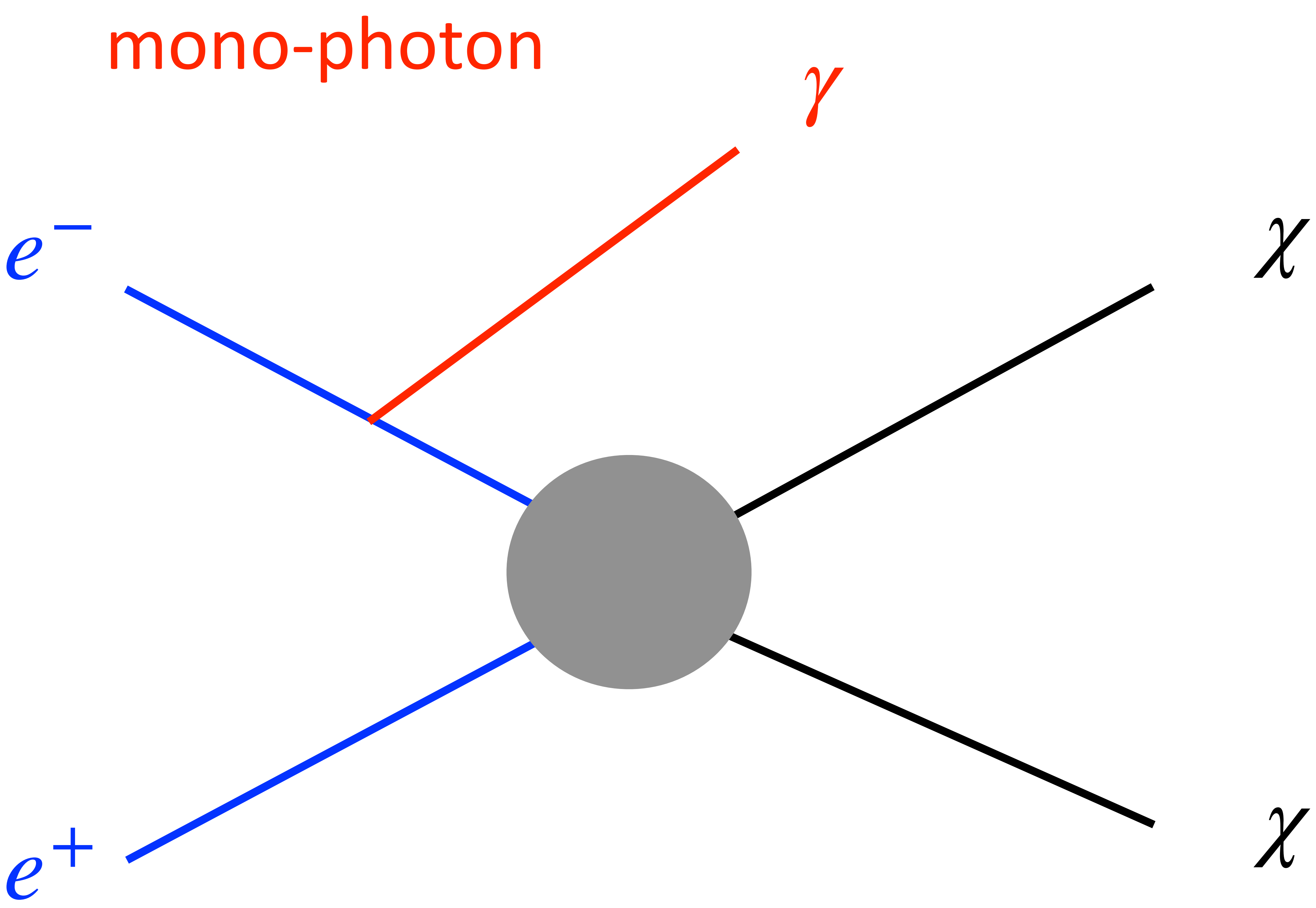
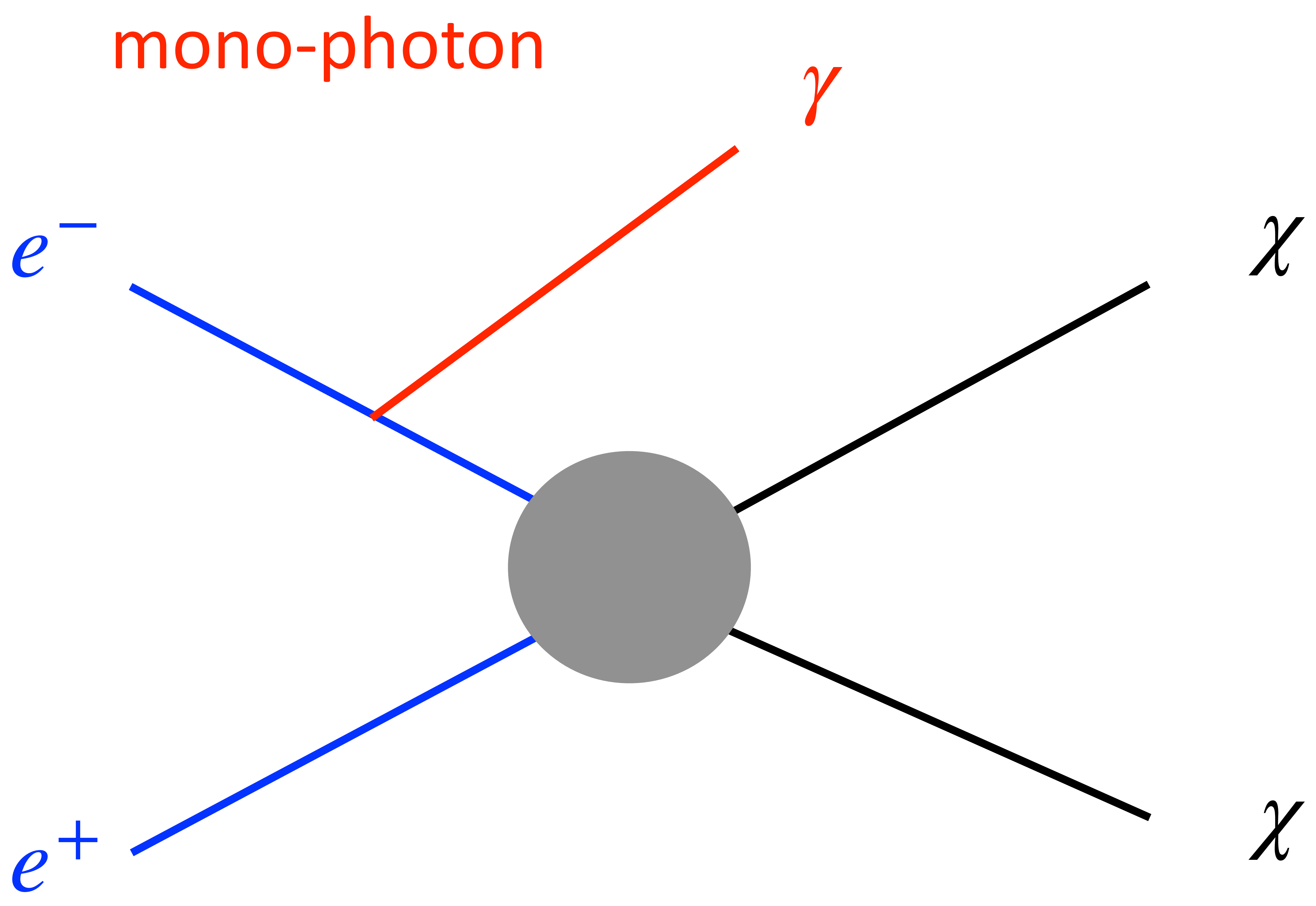


- millicharged particles
- light mediator DM
- EFT DM

Mono-photon signature at electron colliders

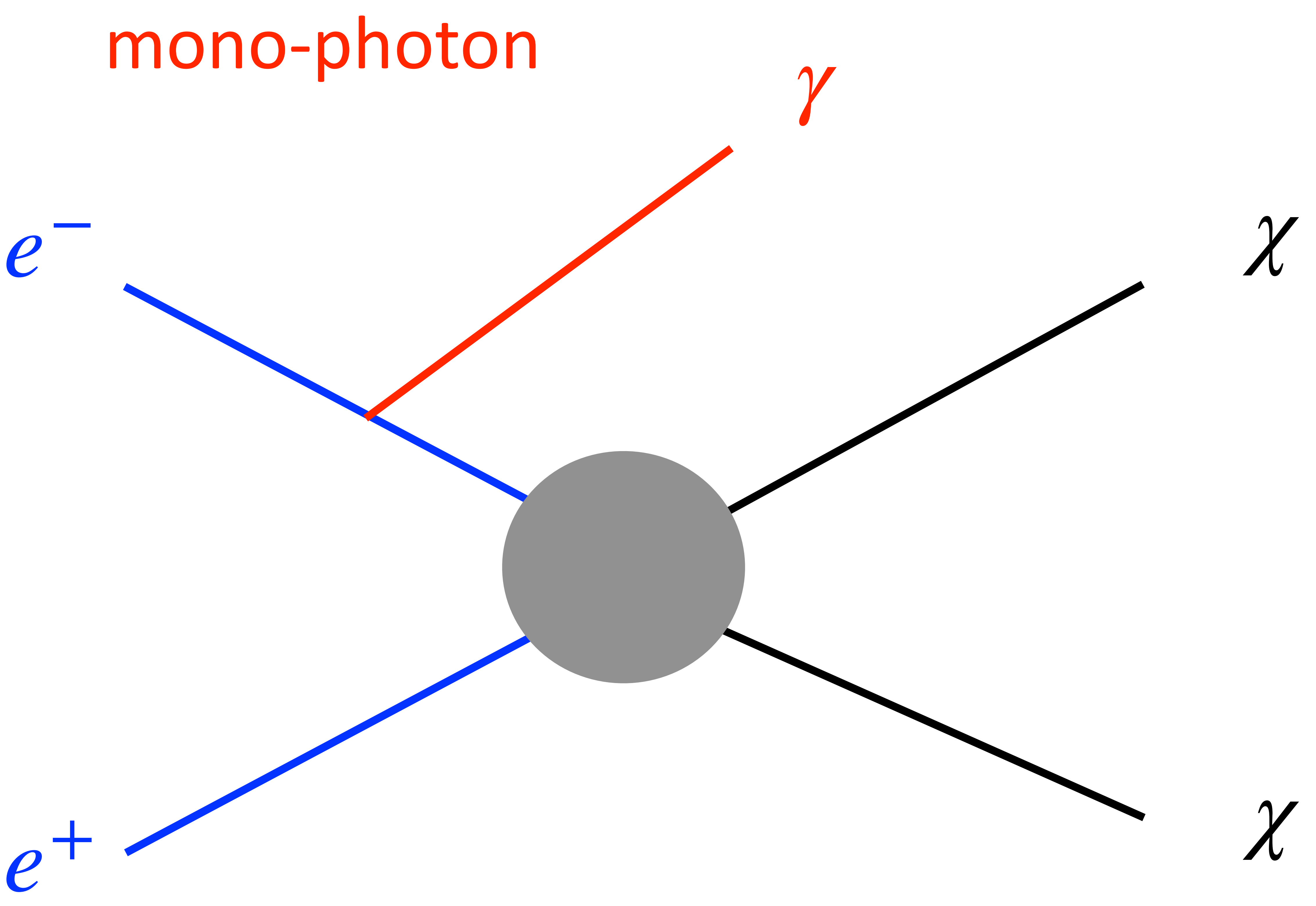


massless mediator

- millicharged particles
- light mediator DM
- EFT DM

heavy mediator

Mono-photon signature at electron colliders



massless mediator

- millicharged particles
- light mediator DM
- EFT DM

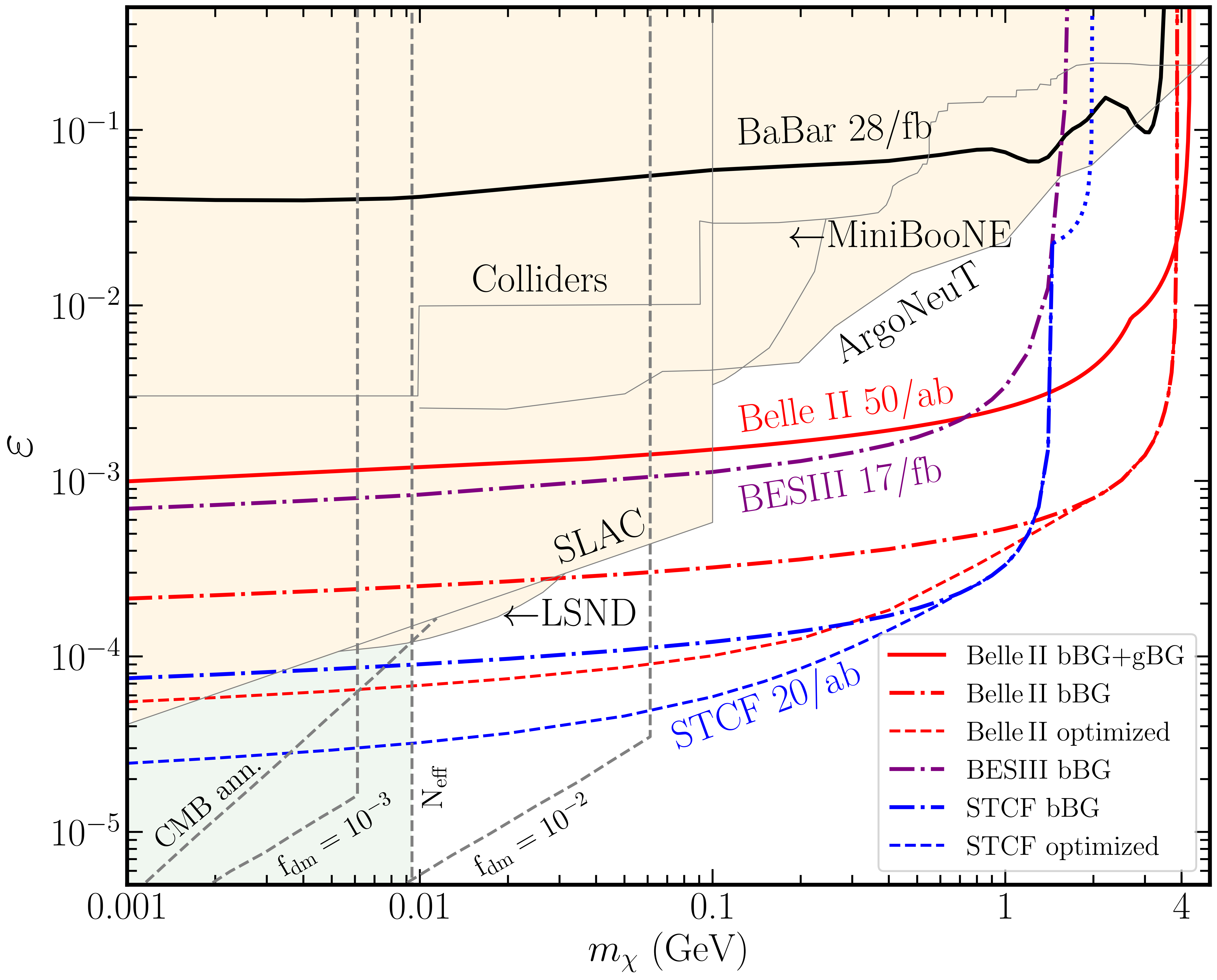
heavy mediator

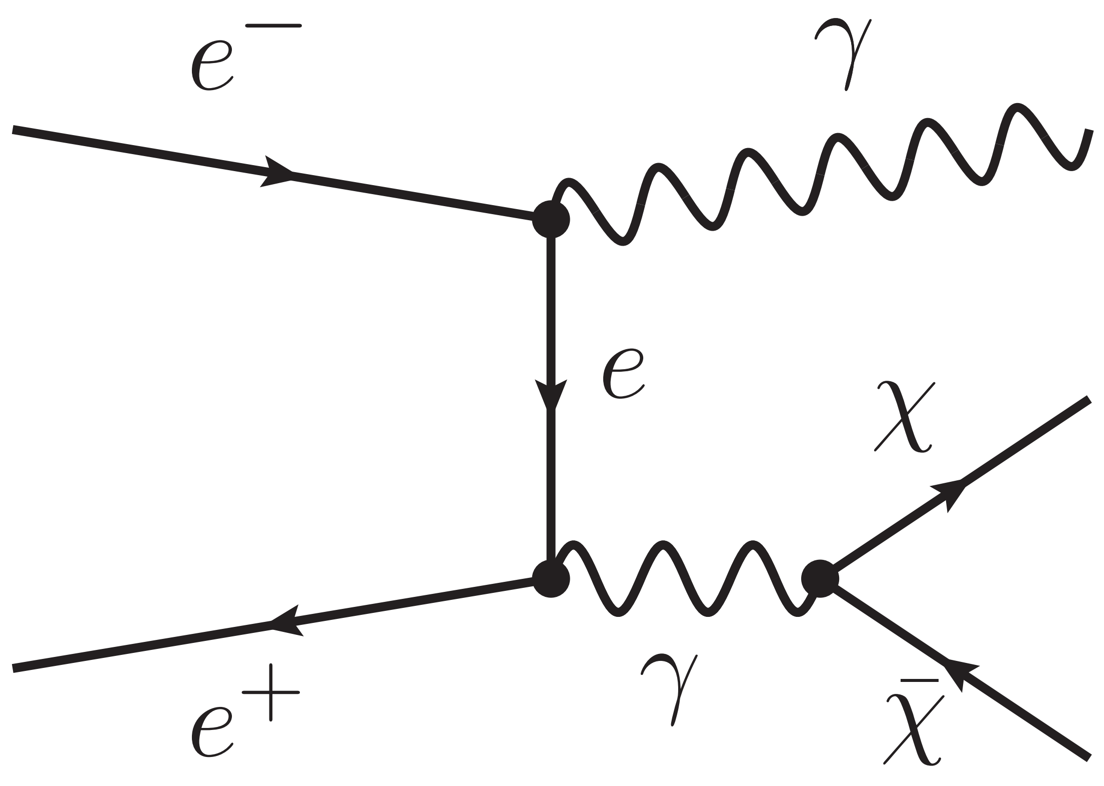
electron colliders' sensitivities on DMDD xsec are very sensitive to the mediator mass!

millicharged particles

(massless mediator)

Millicharged particles probed by electron colliders





$\epsilon e A_\mu \bar{\chi} \gamma^\mu \chi$

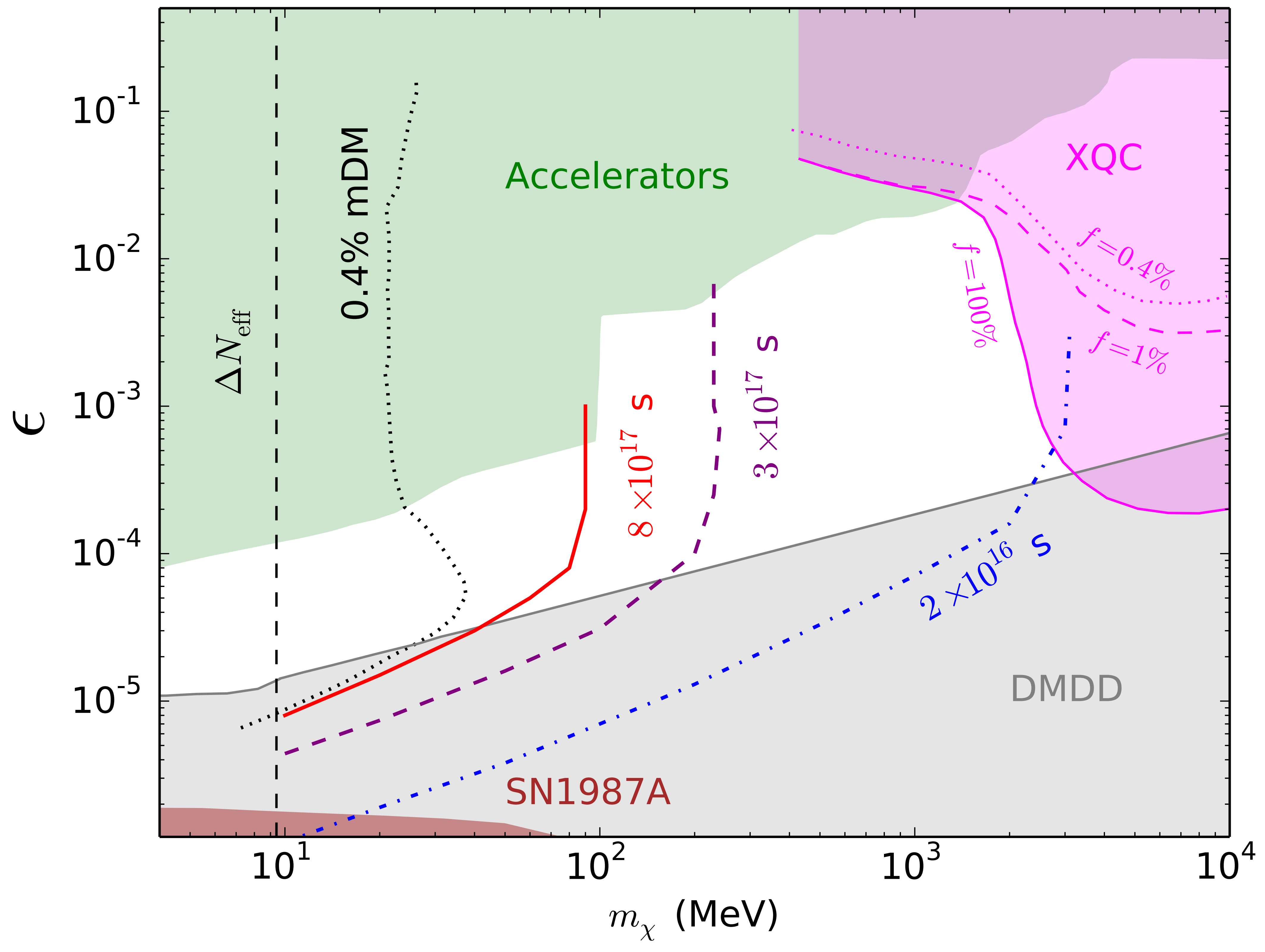
electron colliders probe new parameter space

above DMDD ceiling

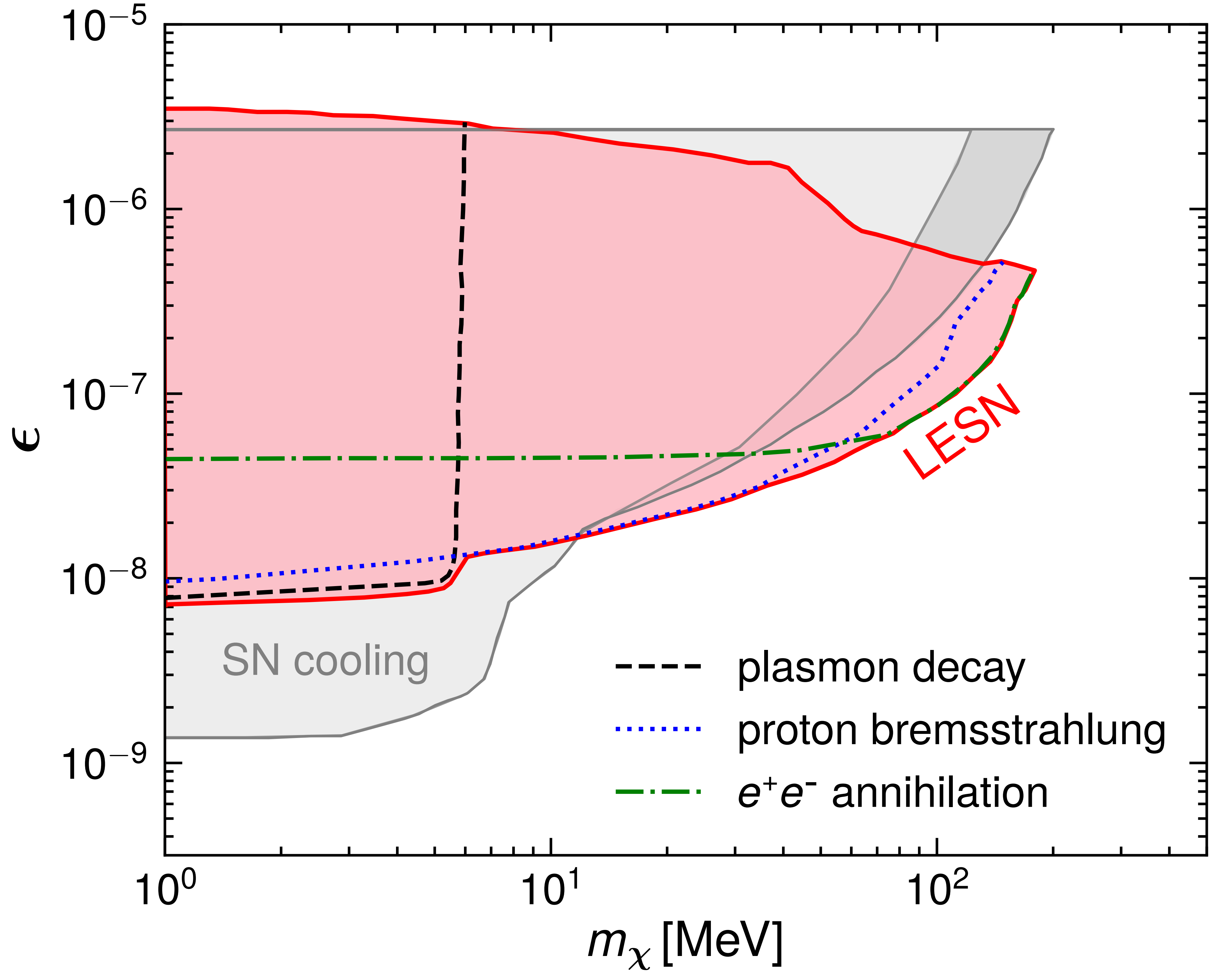
[ZL, Zhang, 1808.00983]

[Liang, ZL, Ma, Zhang, 1909.06847]

Different experiments probing millicharged particles



- Accelerator
- XQC
- DMDD
- Supernova

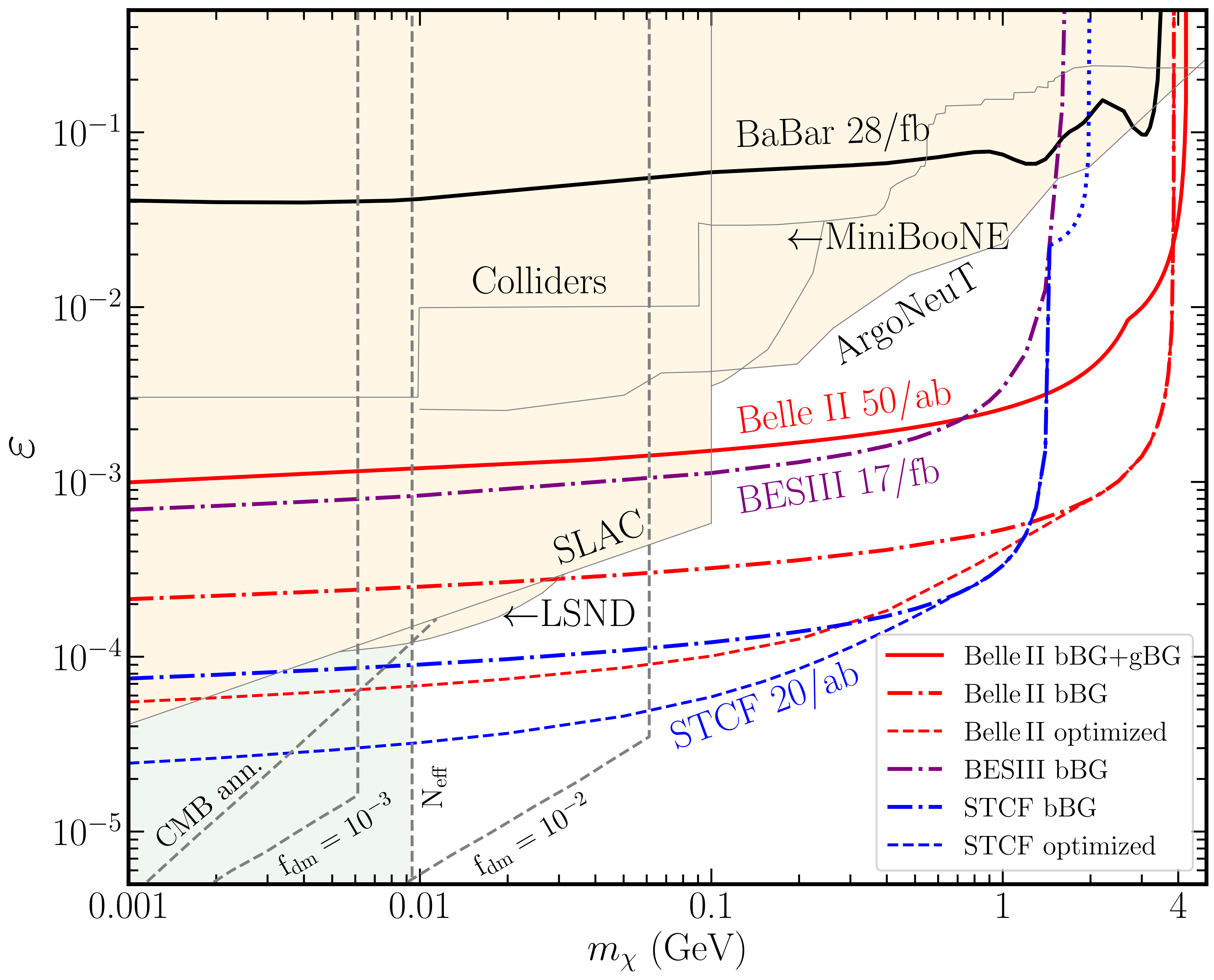


[Li, ZL, 2110.14996]

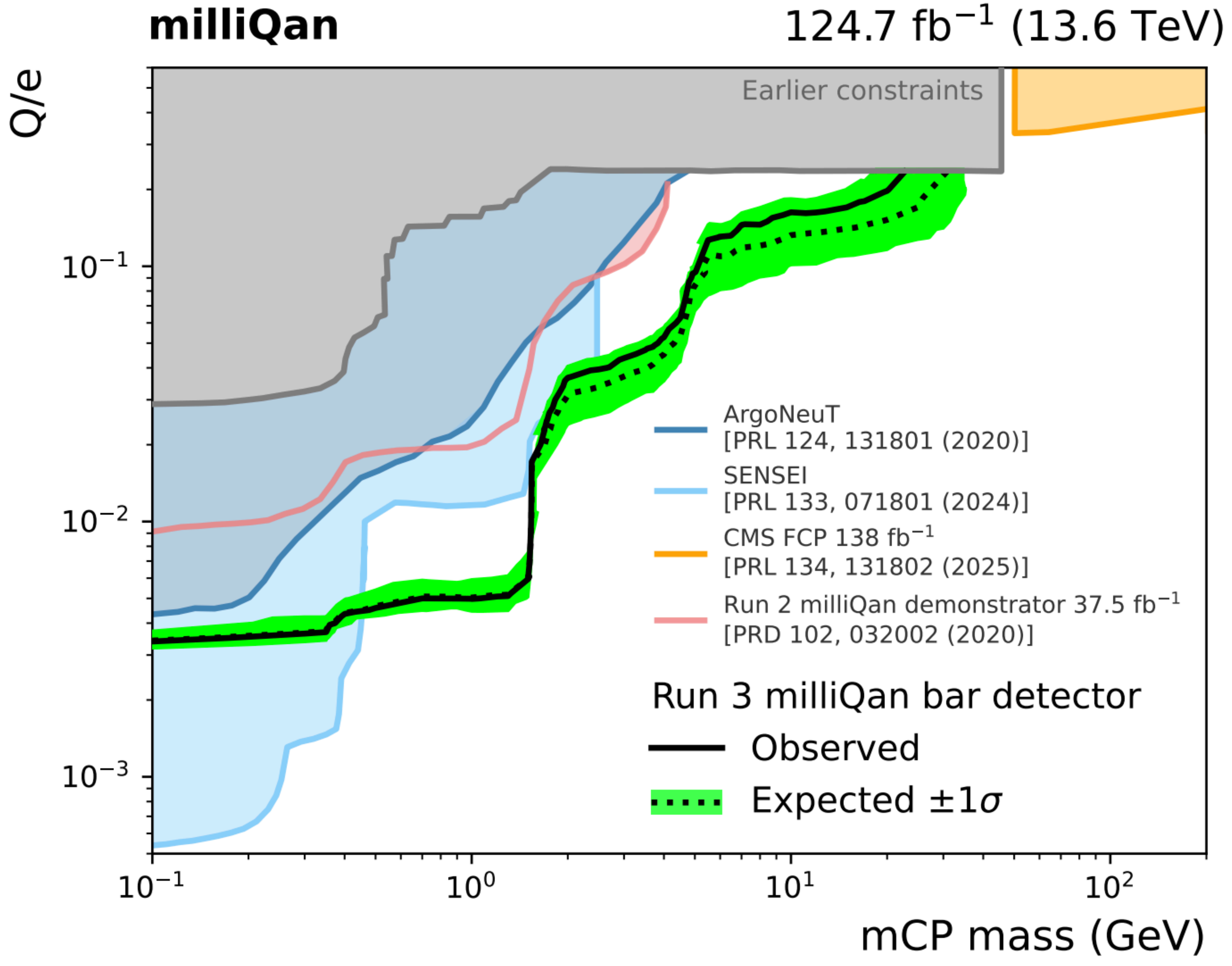
[Li, ZL, Lu, Ye, 2408.04953]

(XQC & DMDD are applicable only to DM)

Electron colliders can outperform milliQan



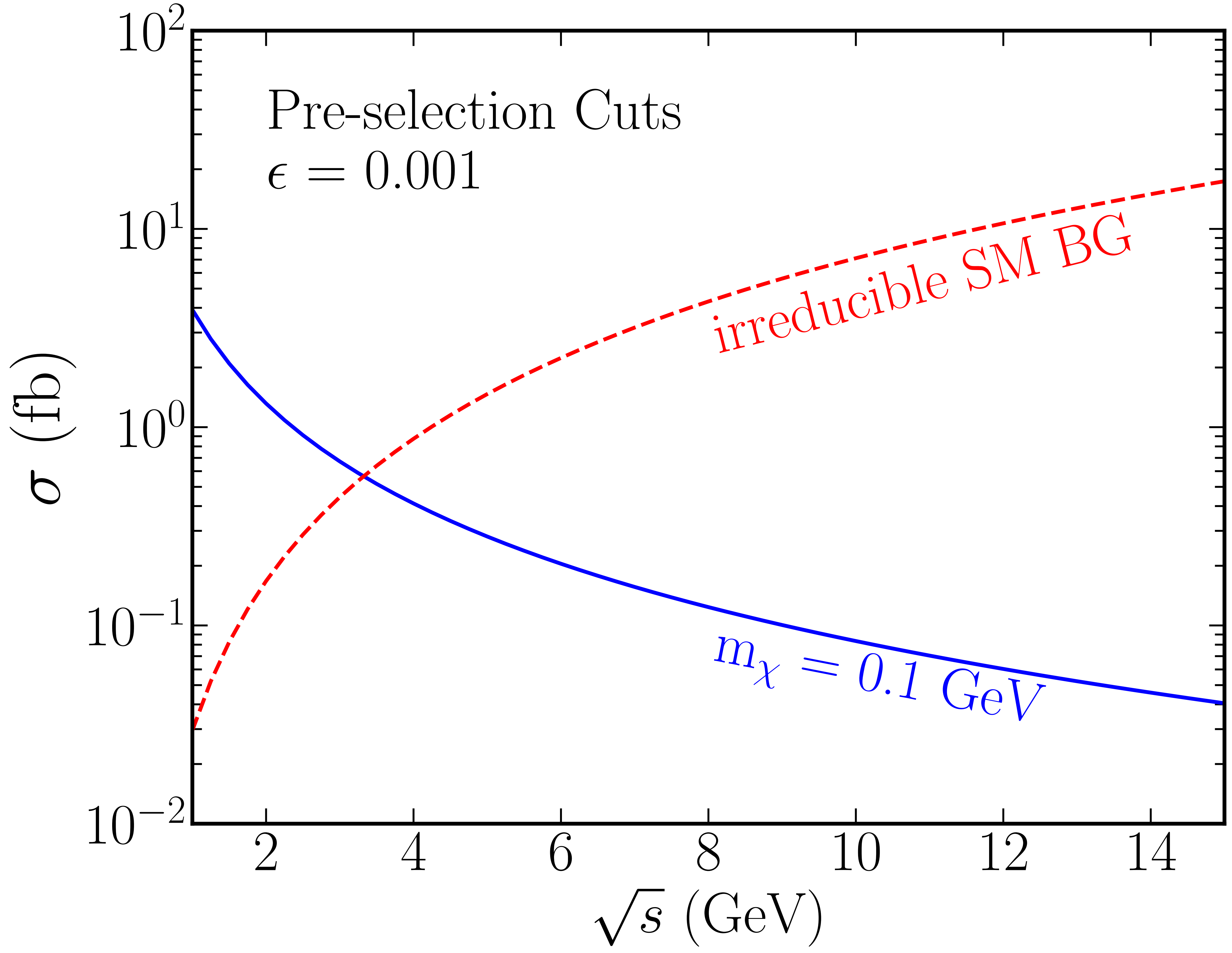
[Liang, ZL, Ma, Zhang, 1909.06847]



[2506.02251]

Low colliding energy is better to probe MCPs

considering only irreducible BG



BESIII/STCF is better than Belle II in probing MCPs

$e^+e^- \to \gamma \bar{\nu} \nu$

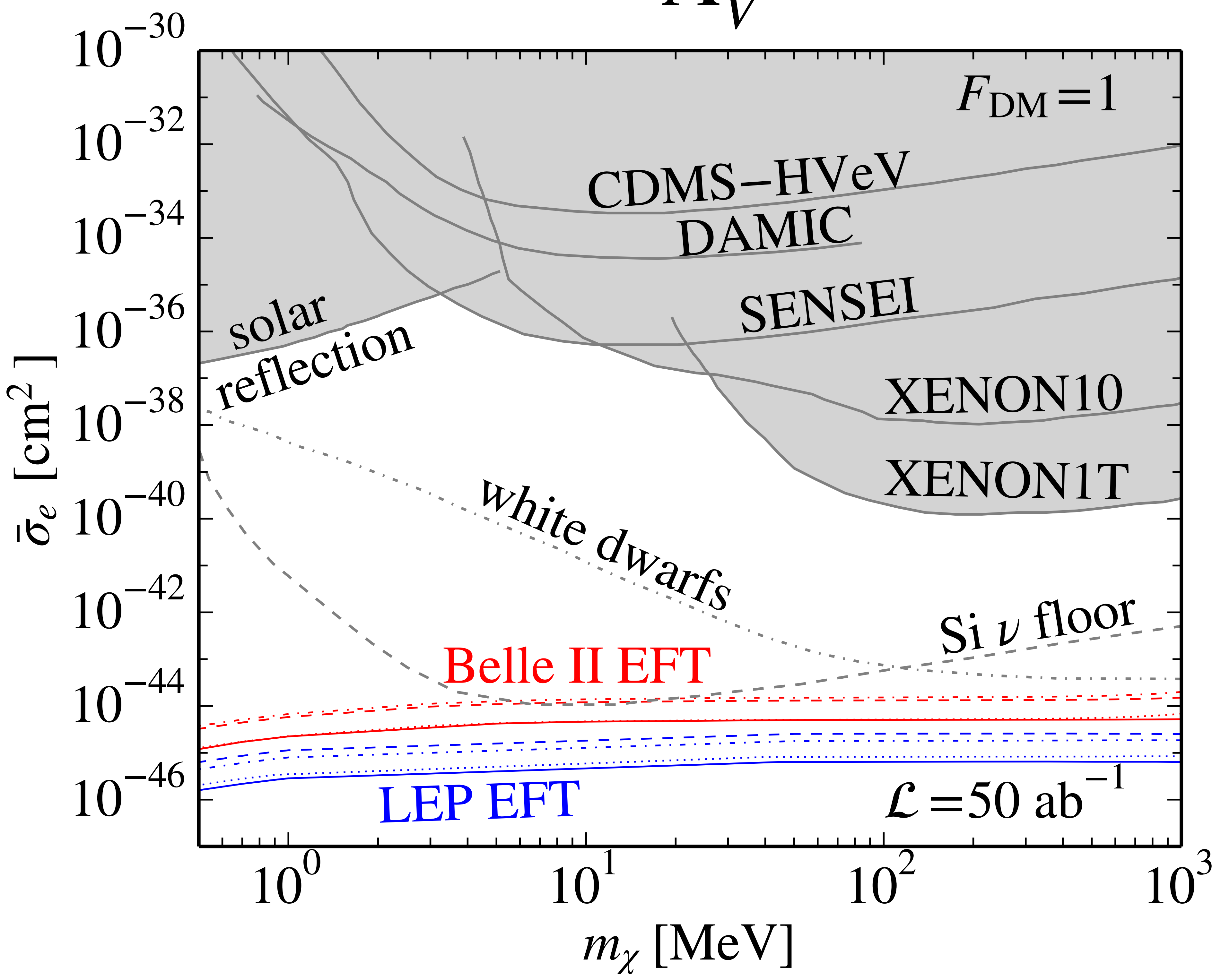
$e^+e^- \to \gamma \bar{\chi} \chi$

EFT DM (high-mediator)

& light-mediator DM

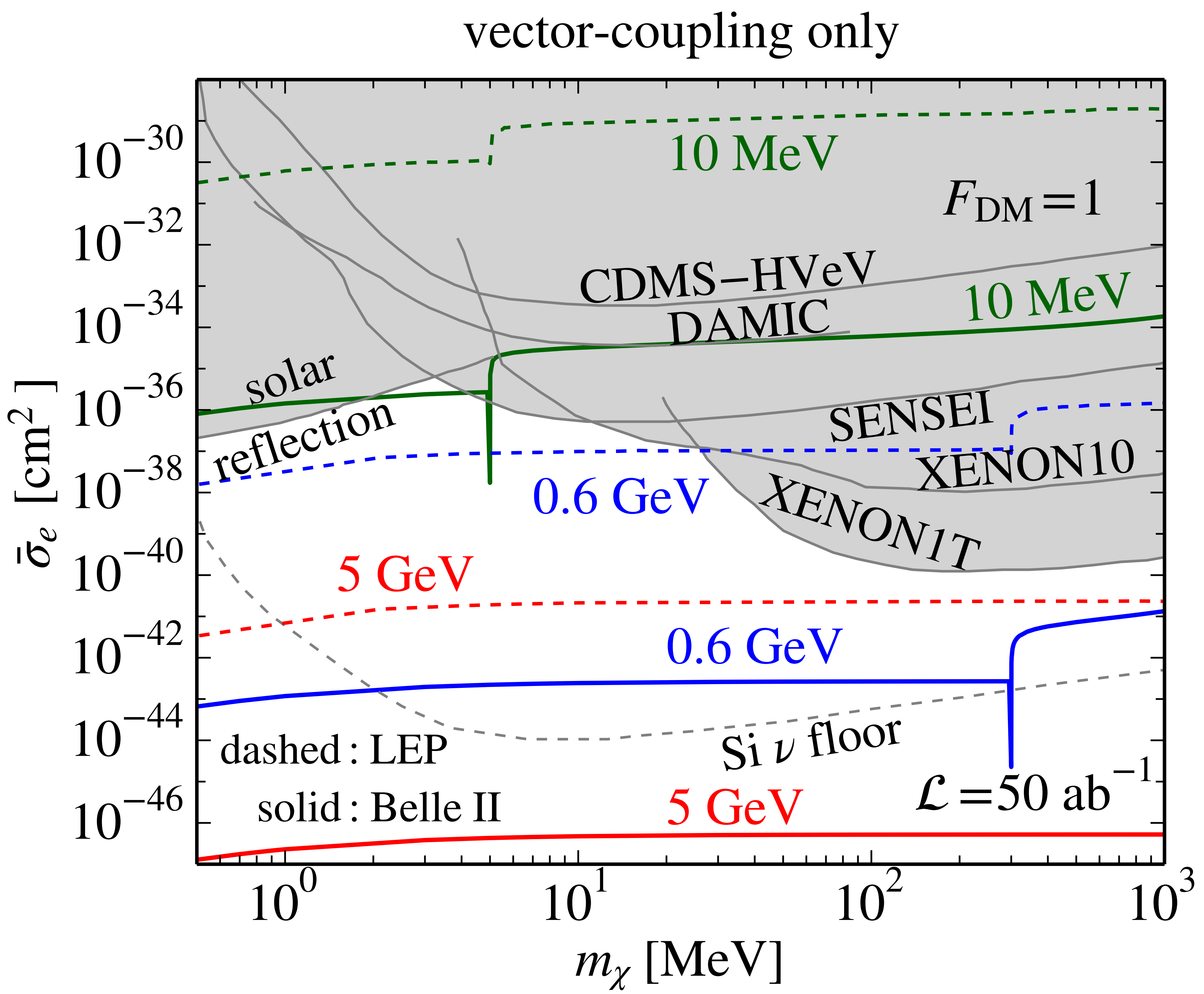
Belle II/BESIII can probe new para space beyond DMDD

EFT DM $\frac{1}{\Lambda_V^2}\bar{\chi}\gamma_\mu\chi\bar{\ell}\gamma^\mu\ell$



LEP is better than Belle II

light mediator DM $Z'_\mu(g_v^\chi\bar{\chi}\gamma^\mu\chi + g_v^\ell\bar{\ell}\gamma^\mu\ell)$



Belle II is better than LEP

[Liang, ZL, Yang, 2111.15533]

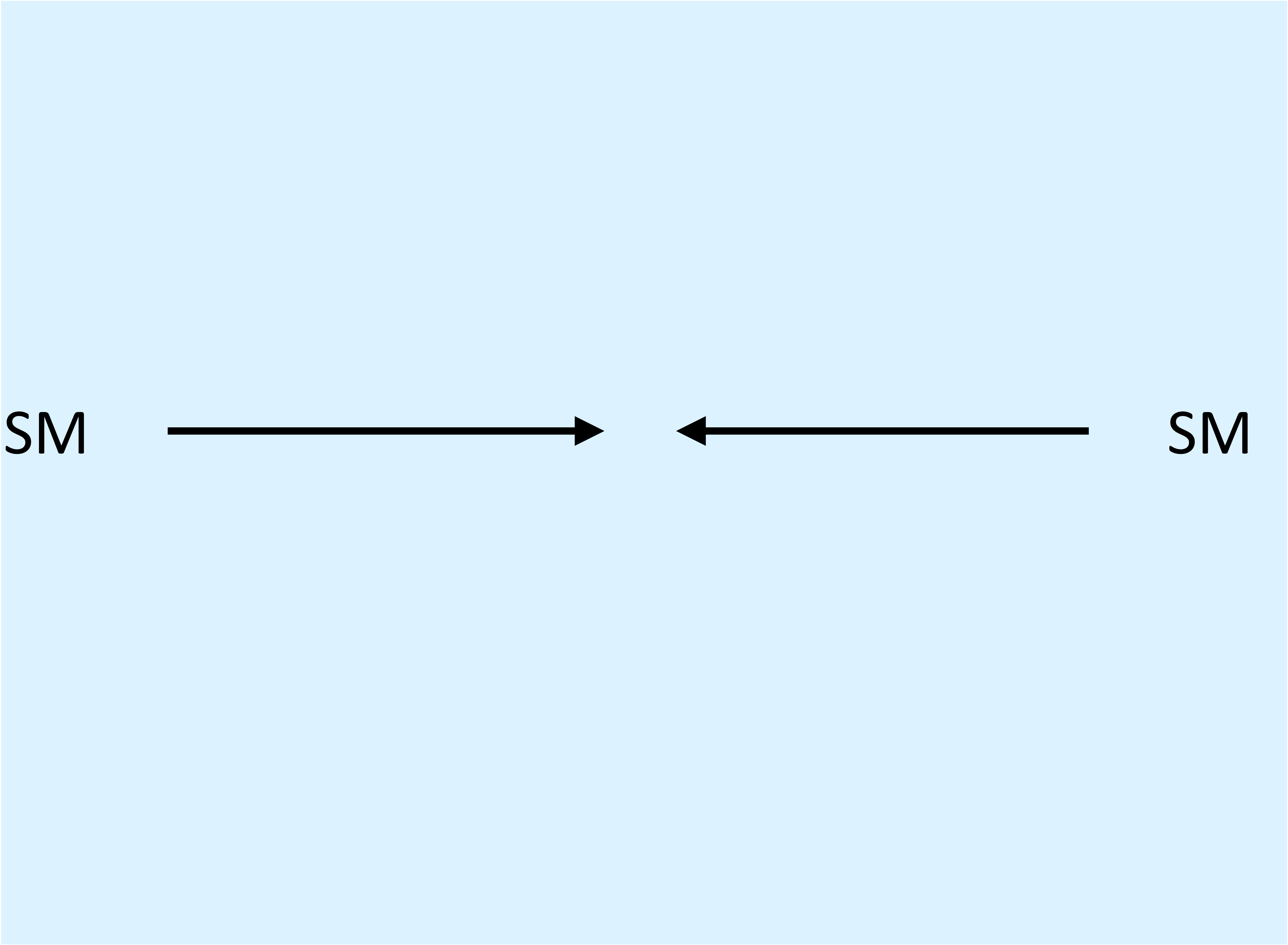
$M_{Z'}$ = 5 GeV, 0.6 GeV, 10 MeV

2 New dark matter channel @ Belle II

[Liang, ZL, Yang, JHEP, arXiv:2212.04252]

Previous dark matter detection channels at colliders

Most studies focus on mono-X channel with SM X produced at the primary vertex



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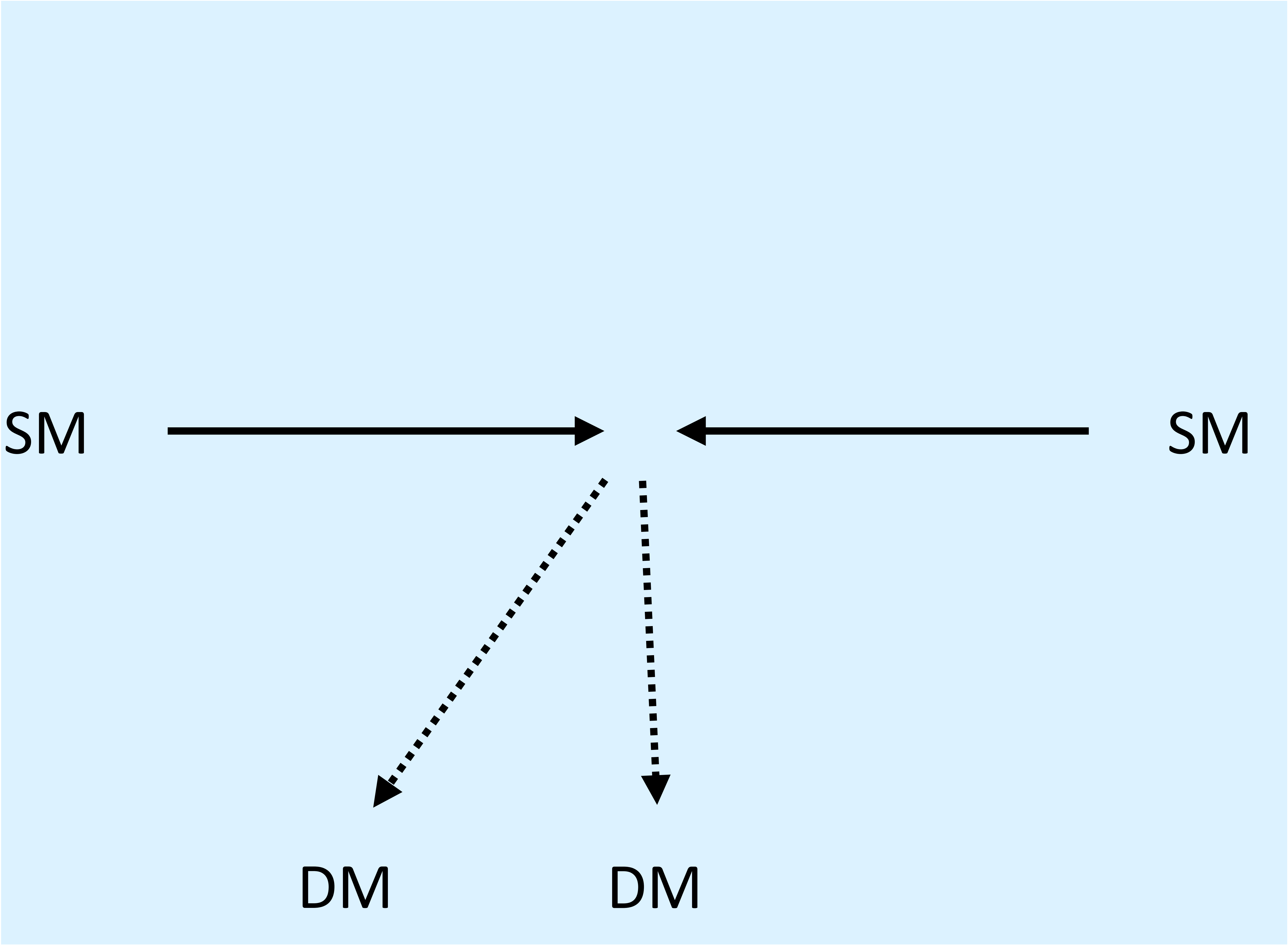

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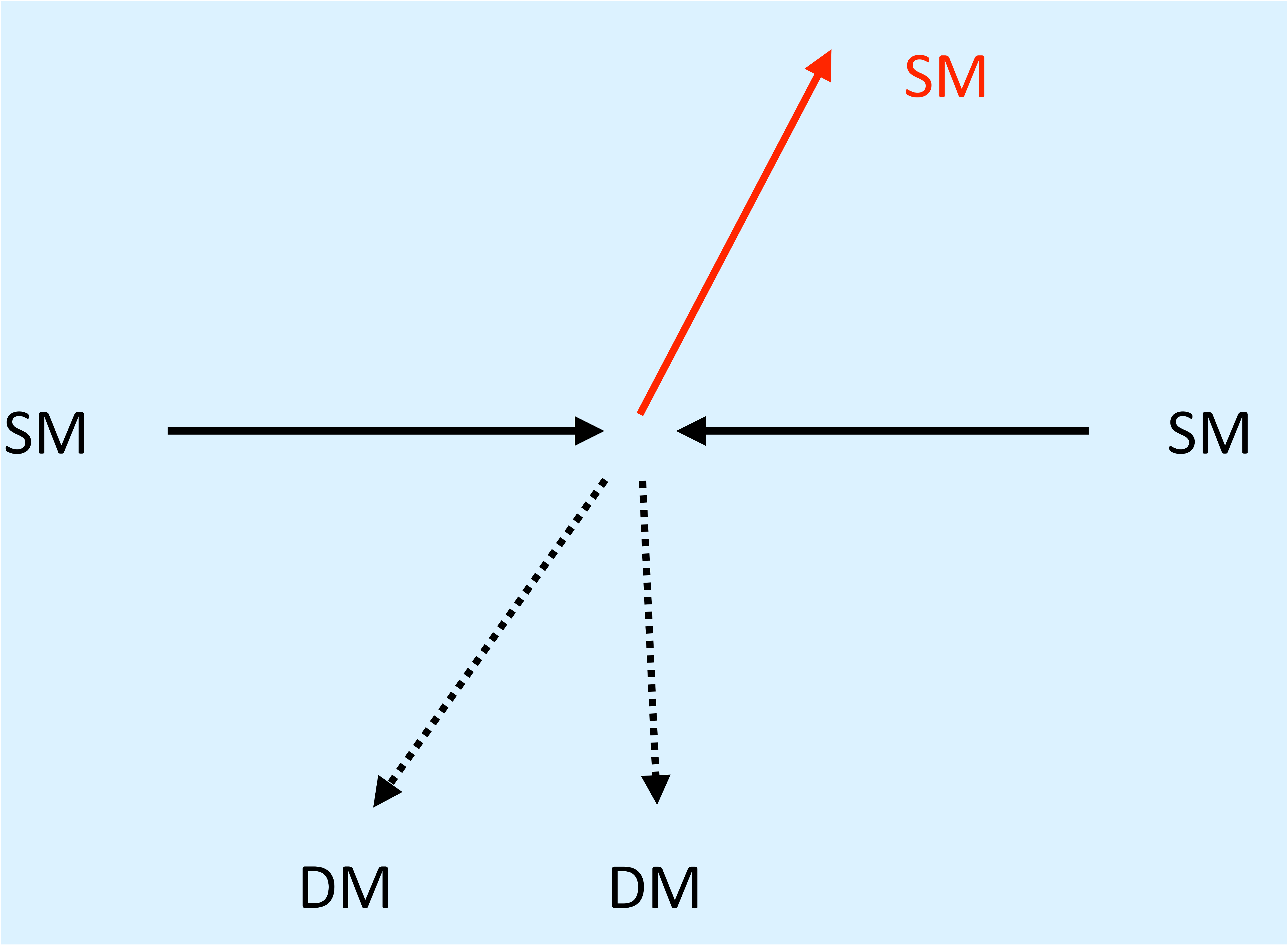

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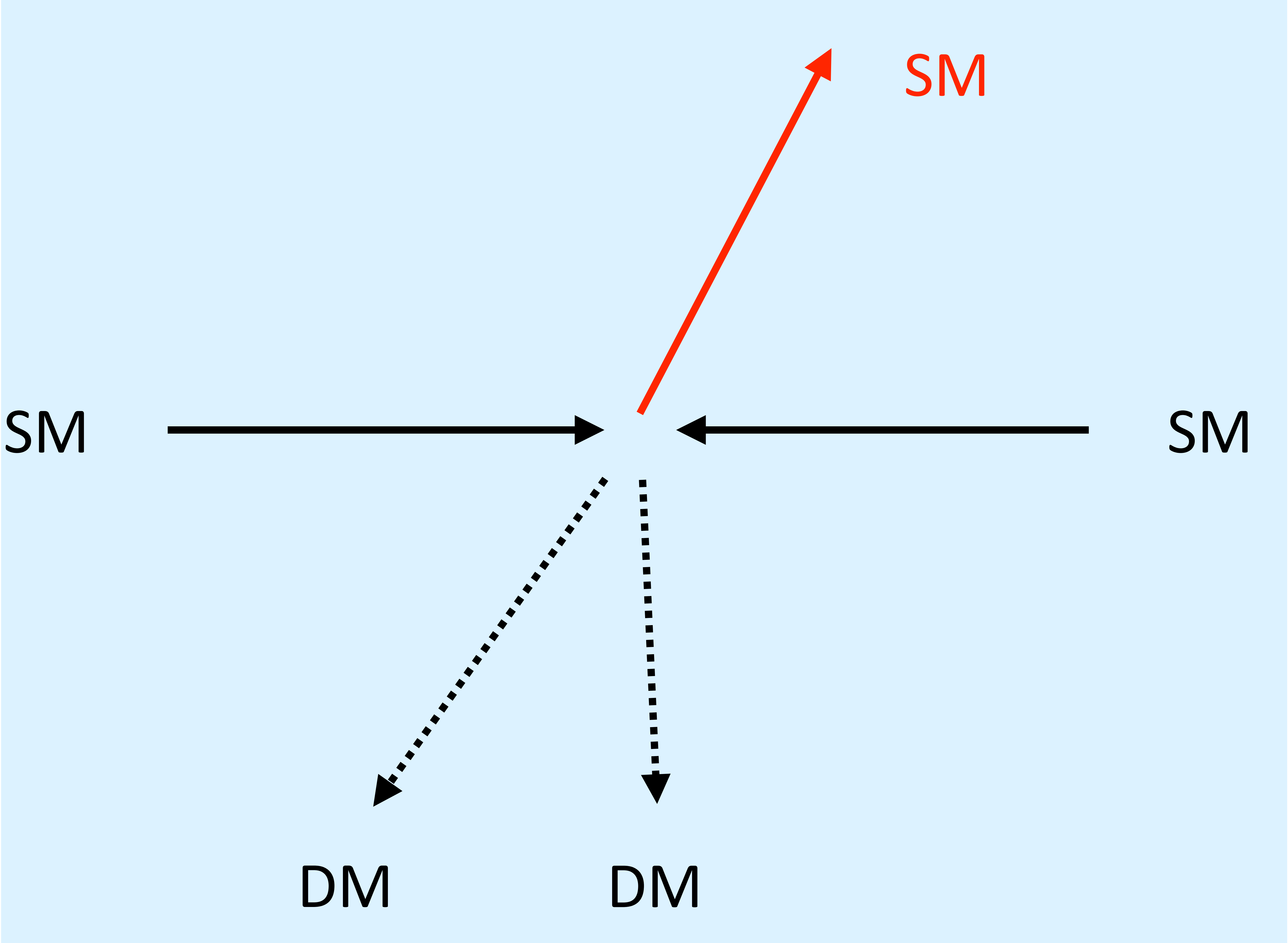
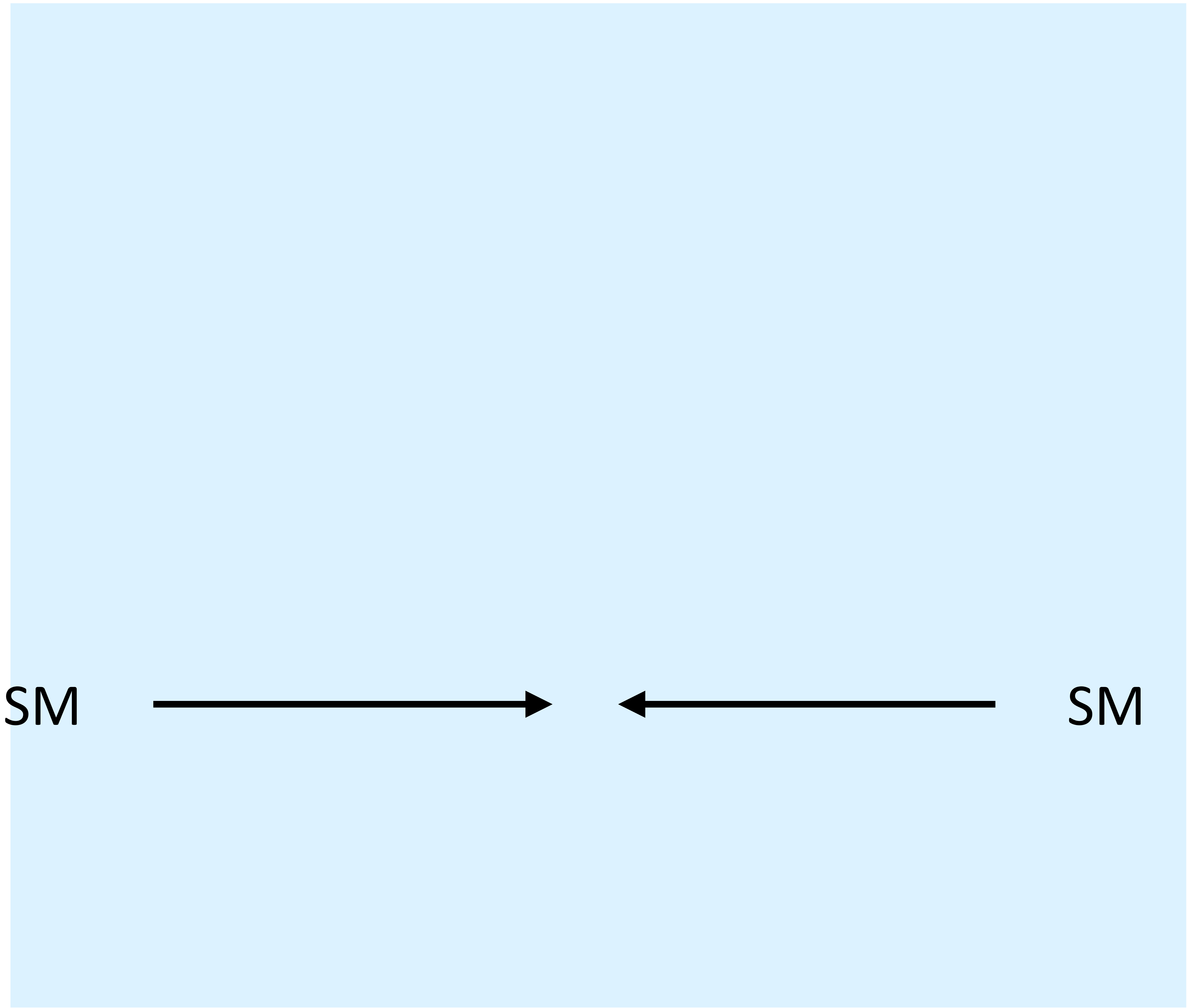


Different mono-X channels

- mono-photon
- mono-jet
- mono-Higgs
- mono-Z
- mono-top

We propose a new dark matter channel at colliders

We propose a new dark matter channel at colliders



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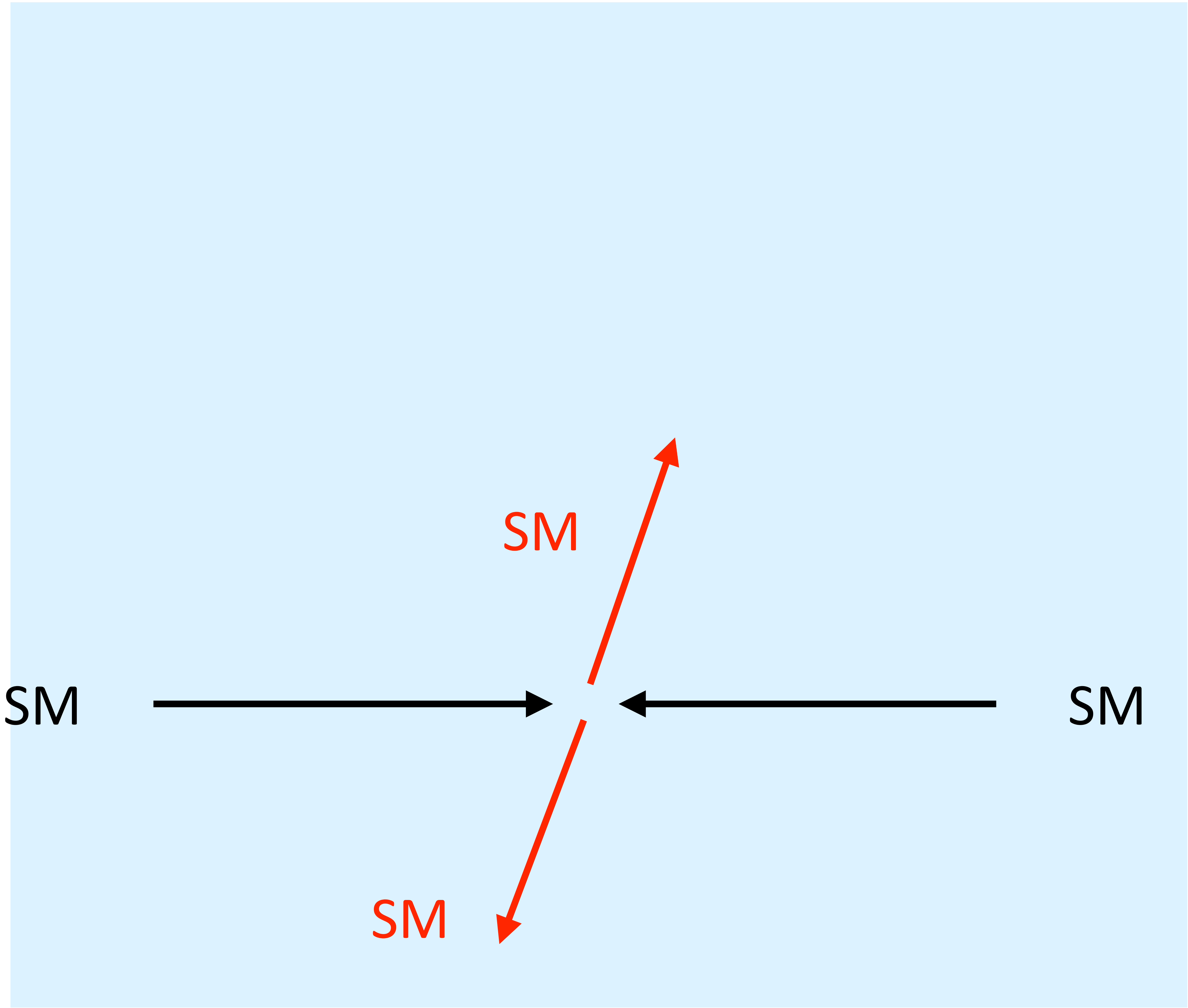
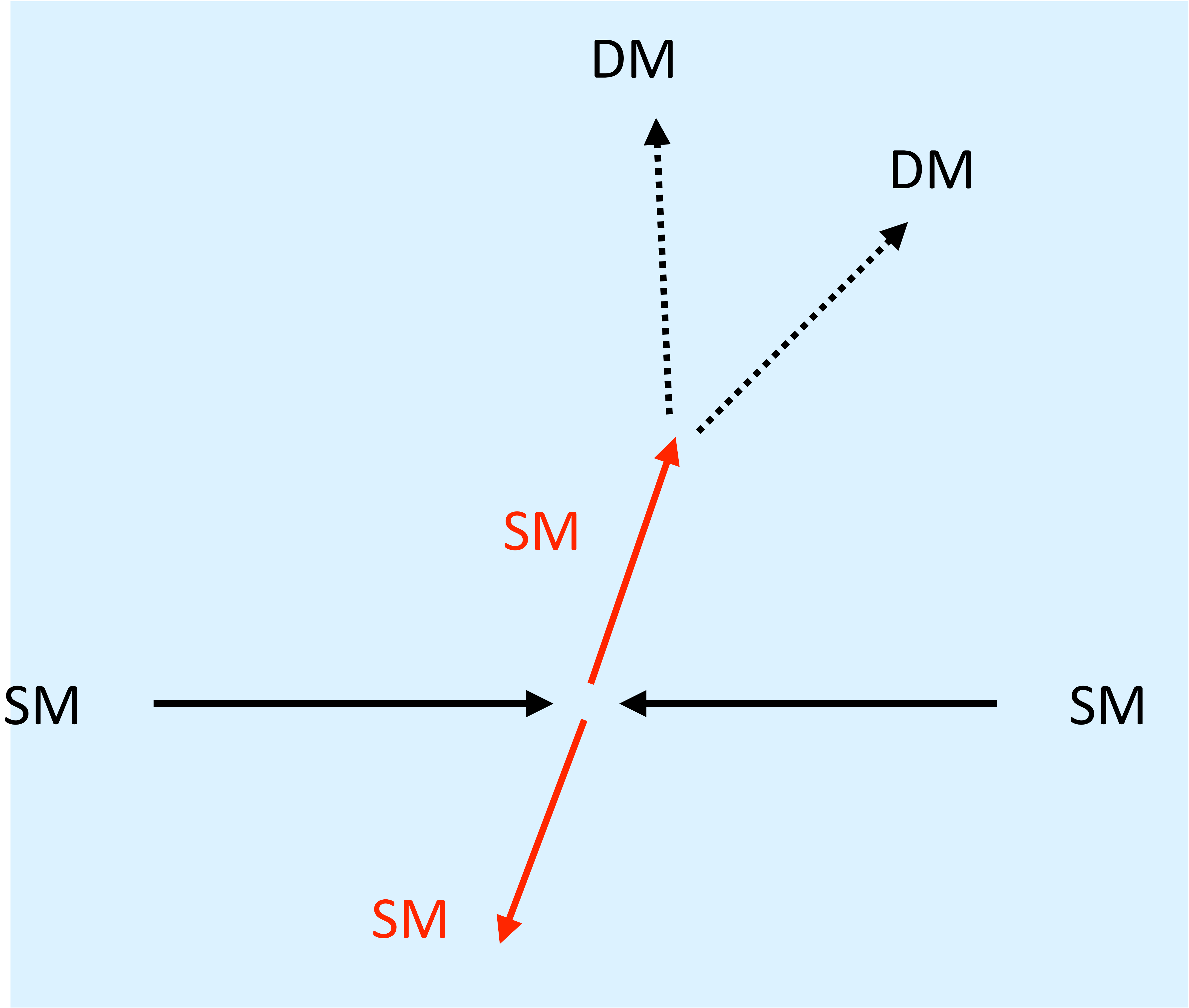


A pair of SM particles produced at the primary vertex

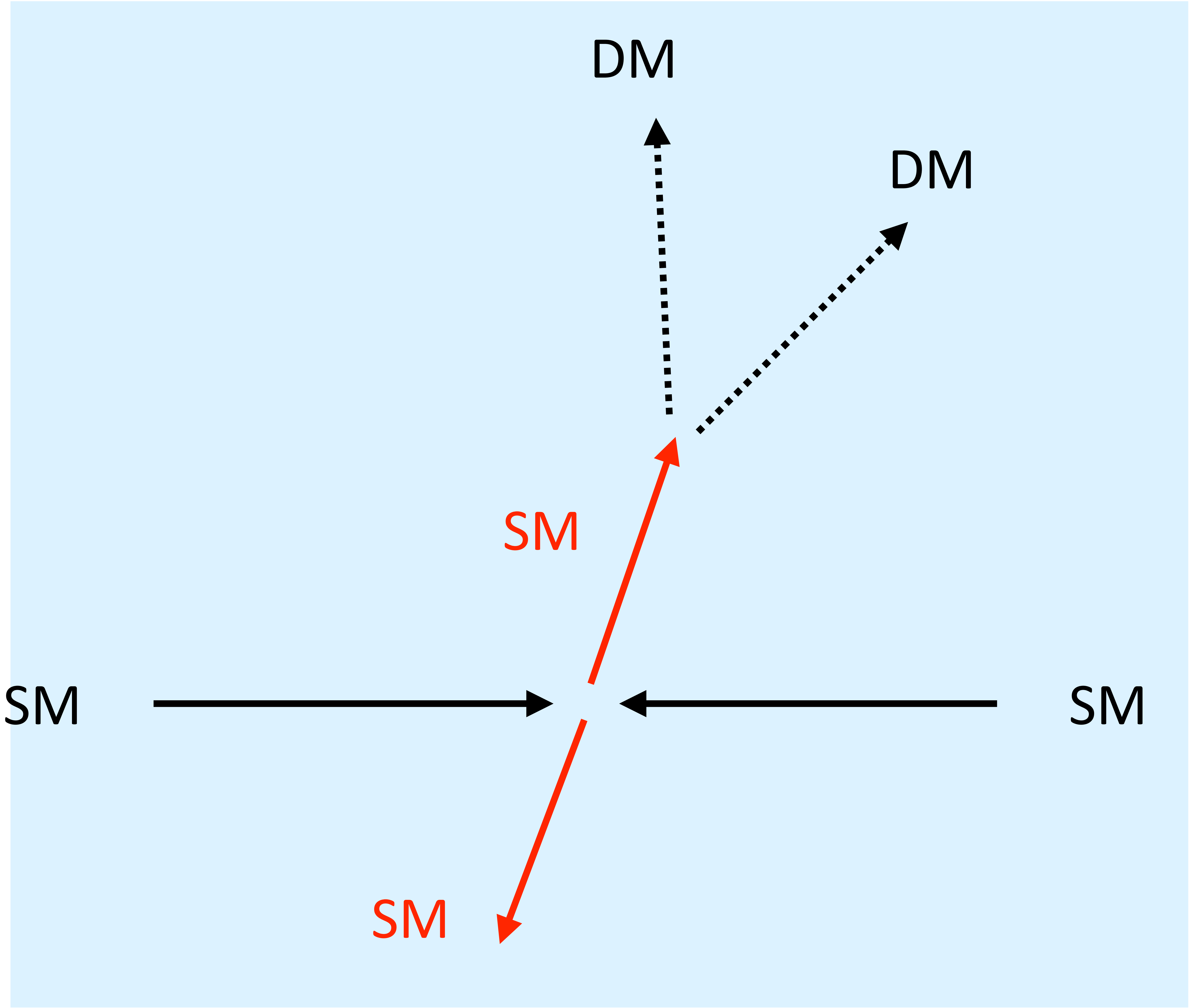
We propose a new dark matter channel at colliders



One SM particle interacts with the detector to produce a pair of DM particles

A pair of SM particles produced at the primary vertex

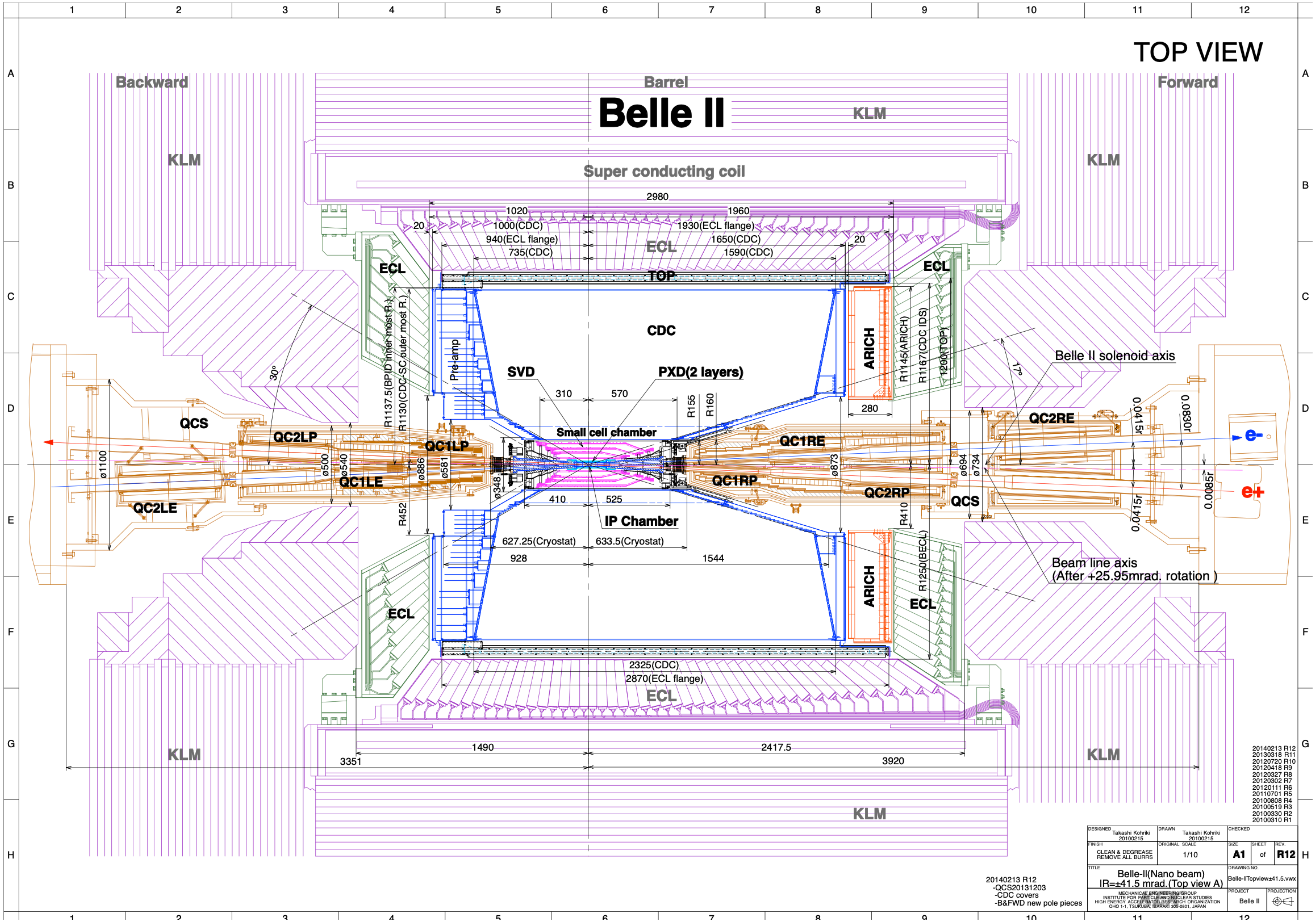
We propose a new dark matter channel at colliders



One SM particle interacts with the detector to produce a pair of DM particles

A pair of SM particles produced at the primary vertex

fixed target in collider


TOP VIEW
Backward
Barrel
Forward
Belle II
KLM
Super conducting coil
ECL
TOP
CDC
ARICH
SVD
PXD(2 layers)
Pre-amp
Small cell chamber
IP Chamber
QCS
QC2LP
QC1LP
QC1LE
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QC1RE
QC1RP
QC2RE
QC2RP
Belle II solenoid axis
Beam line axis
(After +25.95mrad. rotation)
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1020
1960
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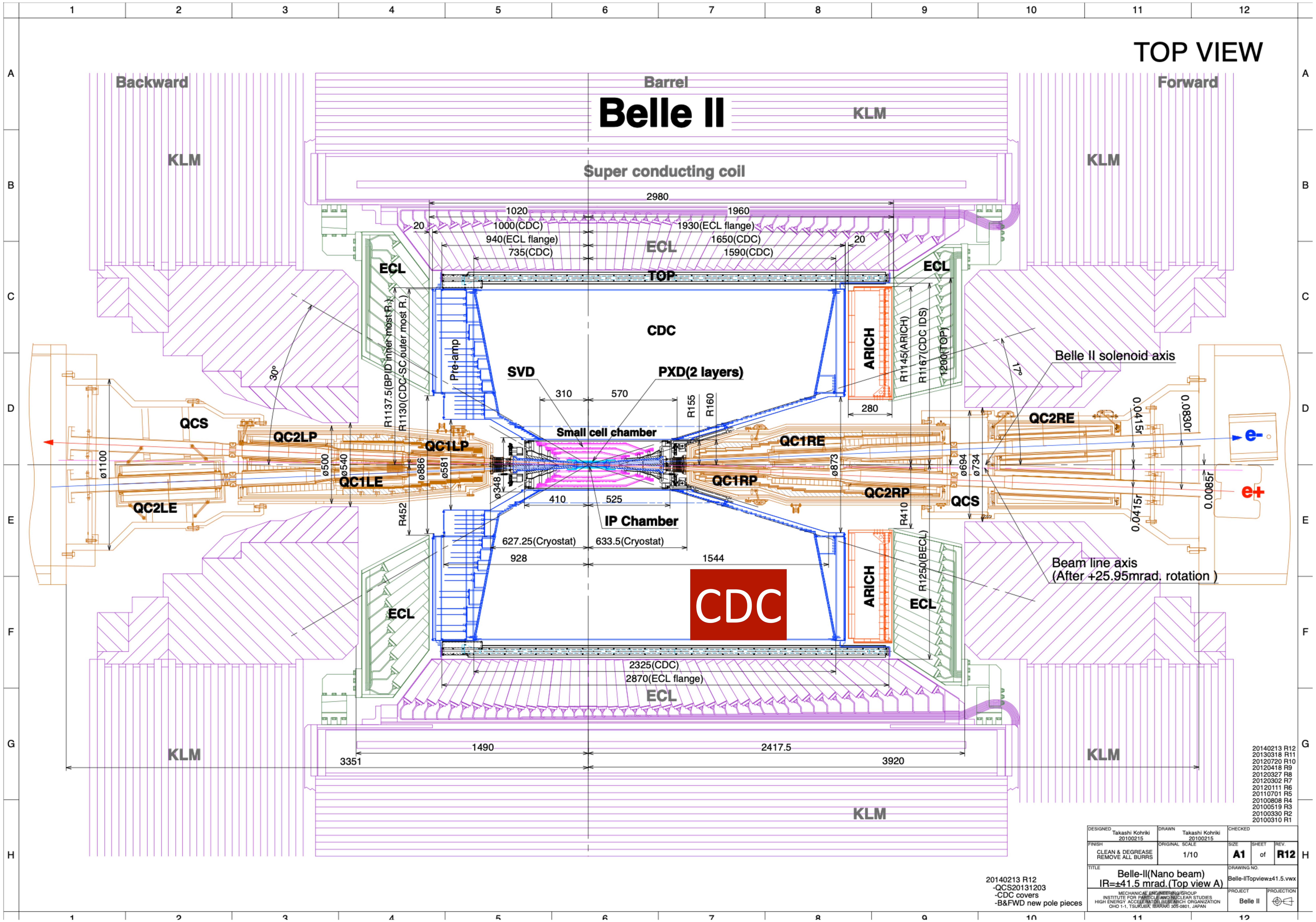
20130318 R11
20120720 R10
20120418 R9
20120327 R8
20120302 R7
20120111 R6
20110701 R5
20100808 R4
20100519 R3
20100330 R2
20100310 R1
20140213 R12
-QCS20131203
-CDC covers
-B&FWD new pole pieces
DESIGNED Takashi Kohriki 20100215
DRAWN Takashi Kohriki 20100215
CHECKED
FINISH CLEAN & DEGREASE REMOVE ALL BURRS
ORIGINAL SCALE 1/10
SIZE A1
SHEET of
REV. R12
TITLE Belle-II(Nano beam) IR=±41.5 mrad.(Top view A)
DRAWING NO. Belle-IITopview±41.5.vwx
MECHANICAL ENGINEERING GROUP
INSTITUTE FOR PARTICLE AND NUCLEAR STUDIES
HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION
OHO 1-1, TSUKUBA, IBARAKI 305-0801, JAPAN
PROJECT Belle II
PROJECTION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Takashi Kohriki
20100215
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REMOVE ALL BURRS
1/10
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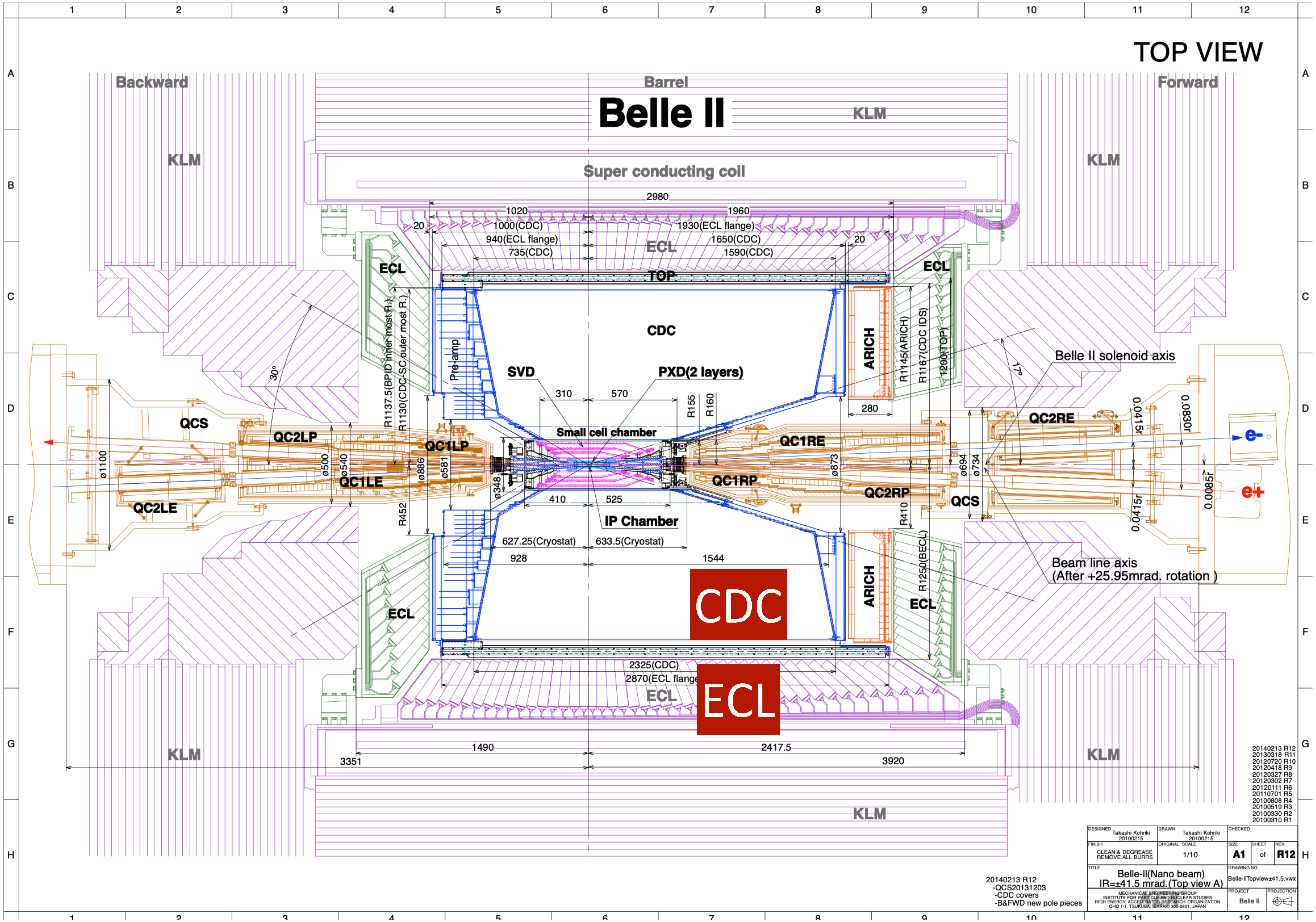
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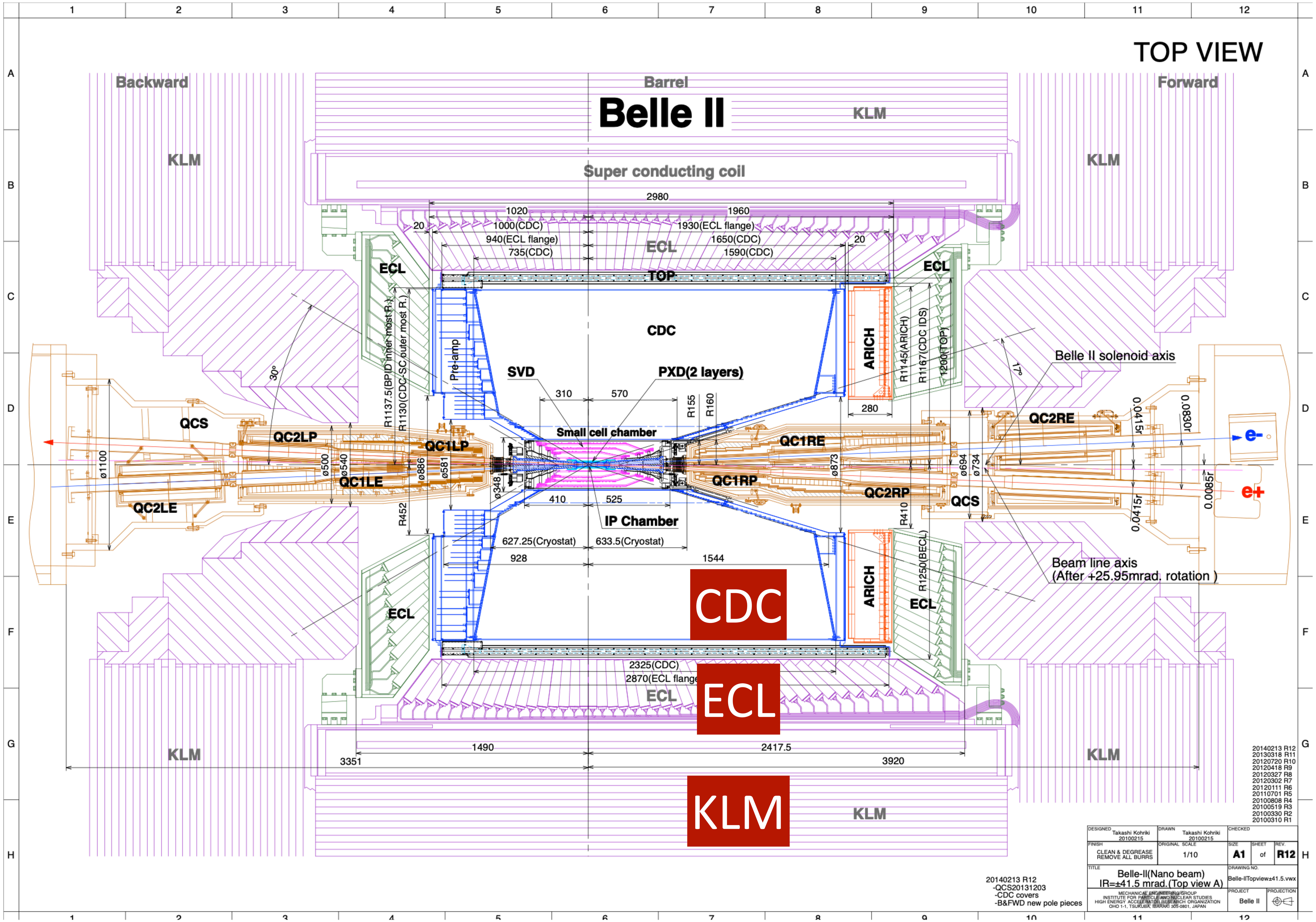
Takashi Kohriki
A1
R12
1/10
Belle II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R12
1/10
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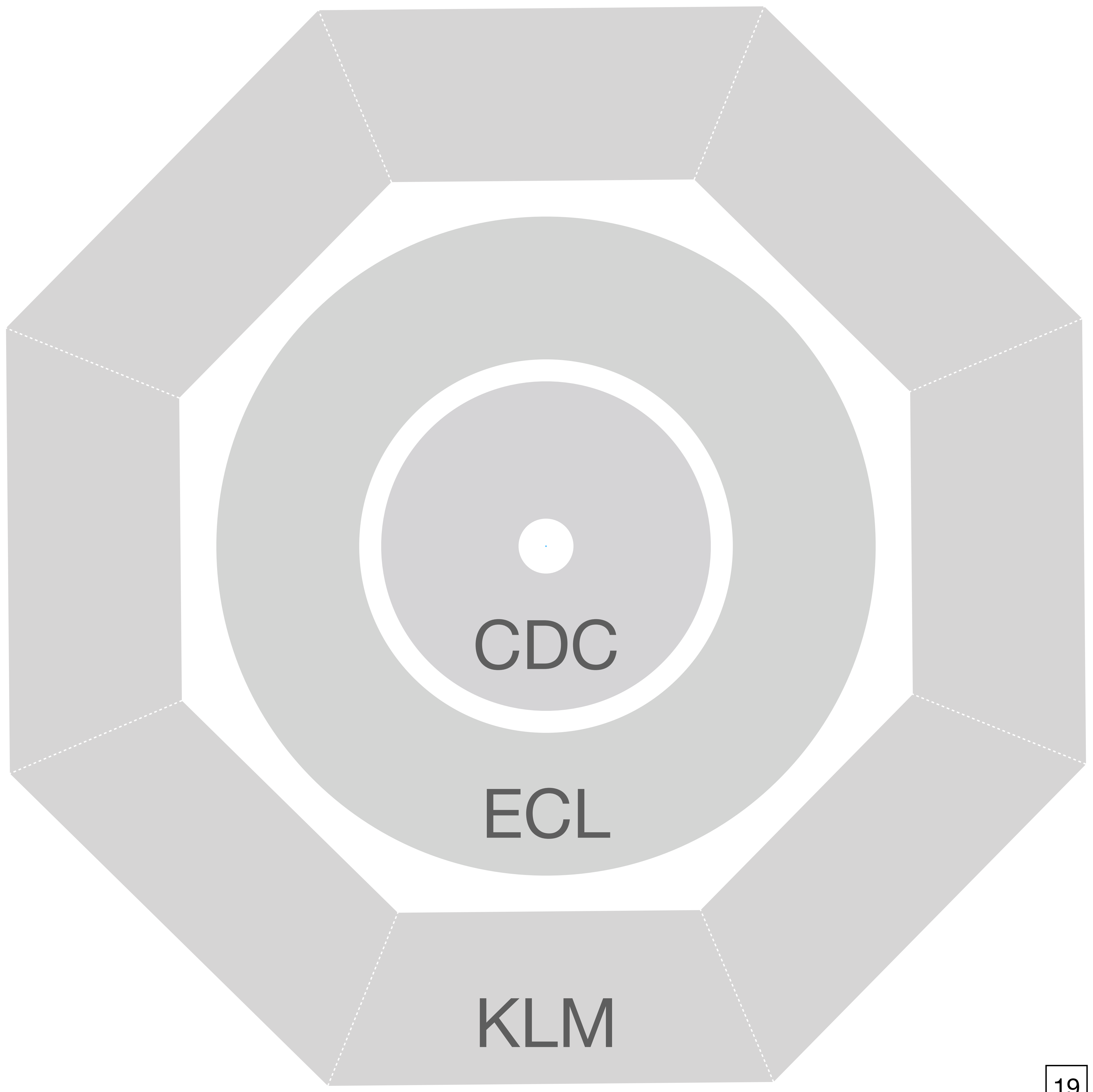
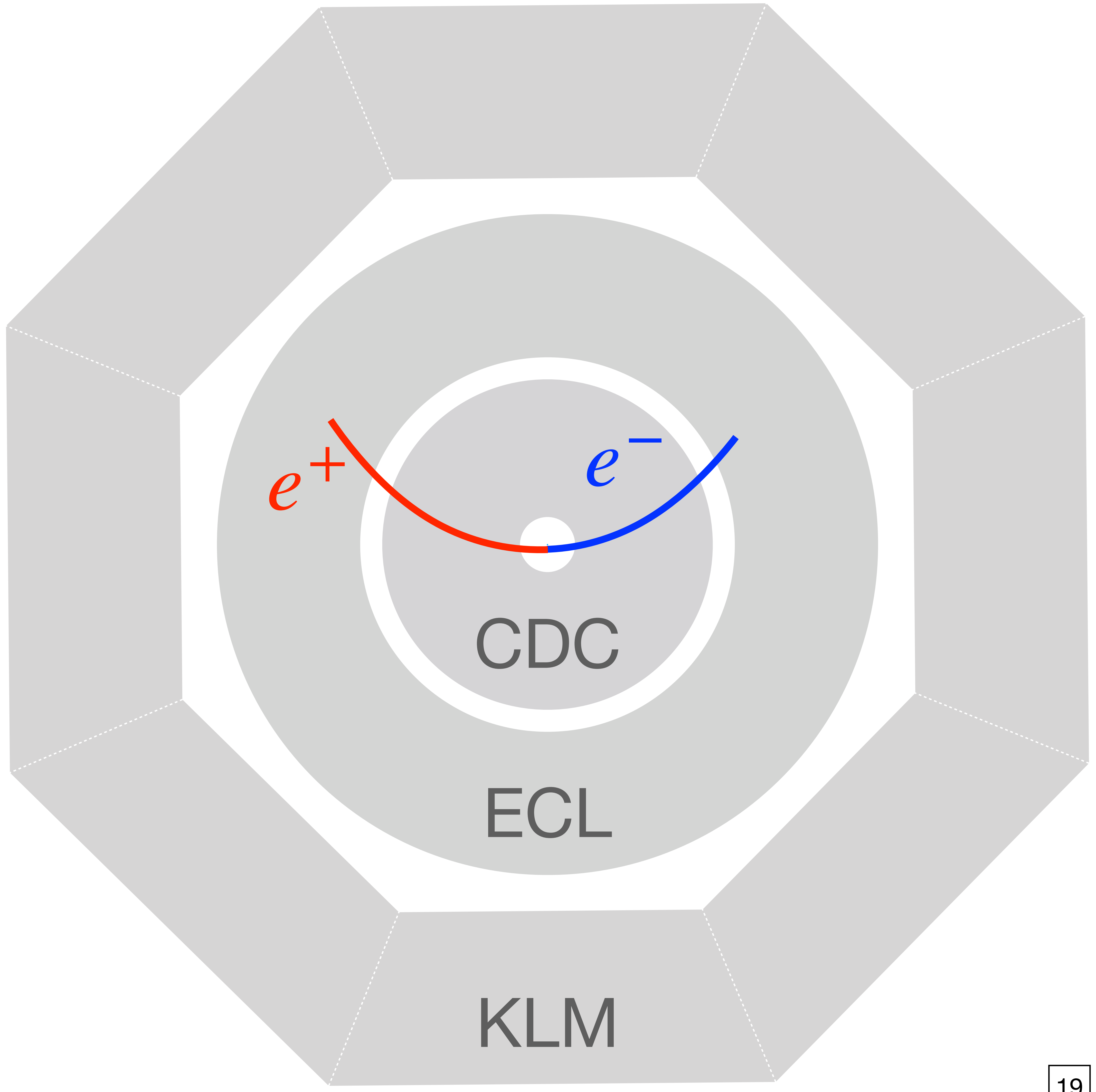
New DM channel @ Belle II (x-y plane)



New DM channel @ Belle II (x-y plane)

Bhabha scattering

$$e^+e^- \to e^+e^-$$

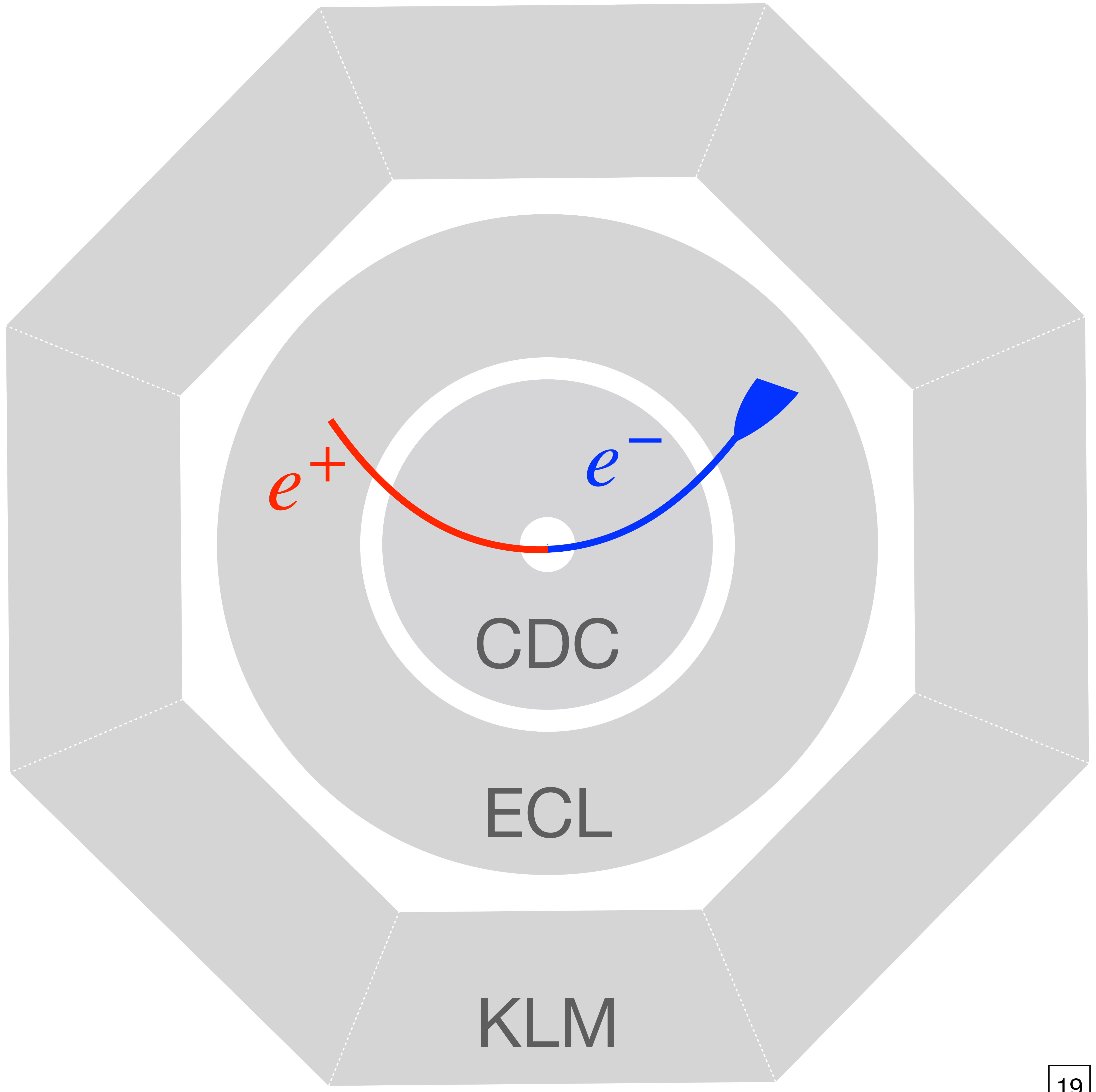


New DM channel @ Belle II (x-y plane)

Bhabha scattering

$$e^+e^- \rightarrow e^+e^-$$

- e^- deposit energy in ECL

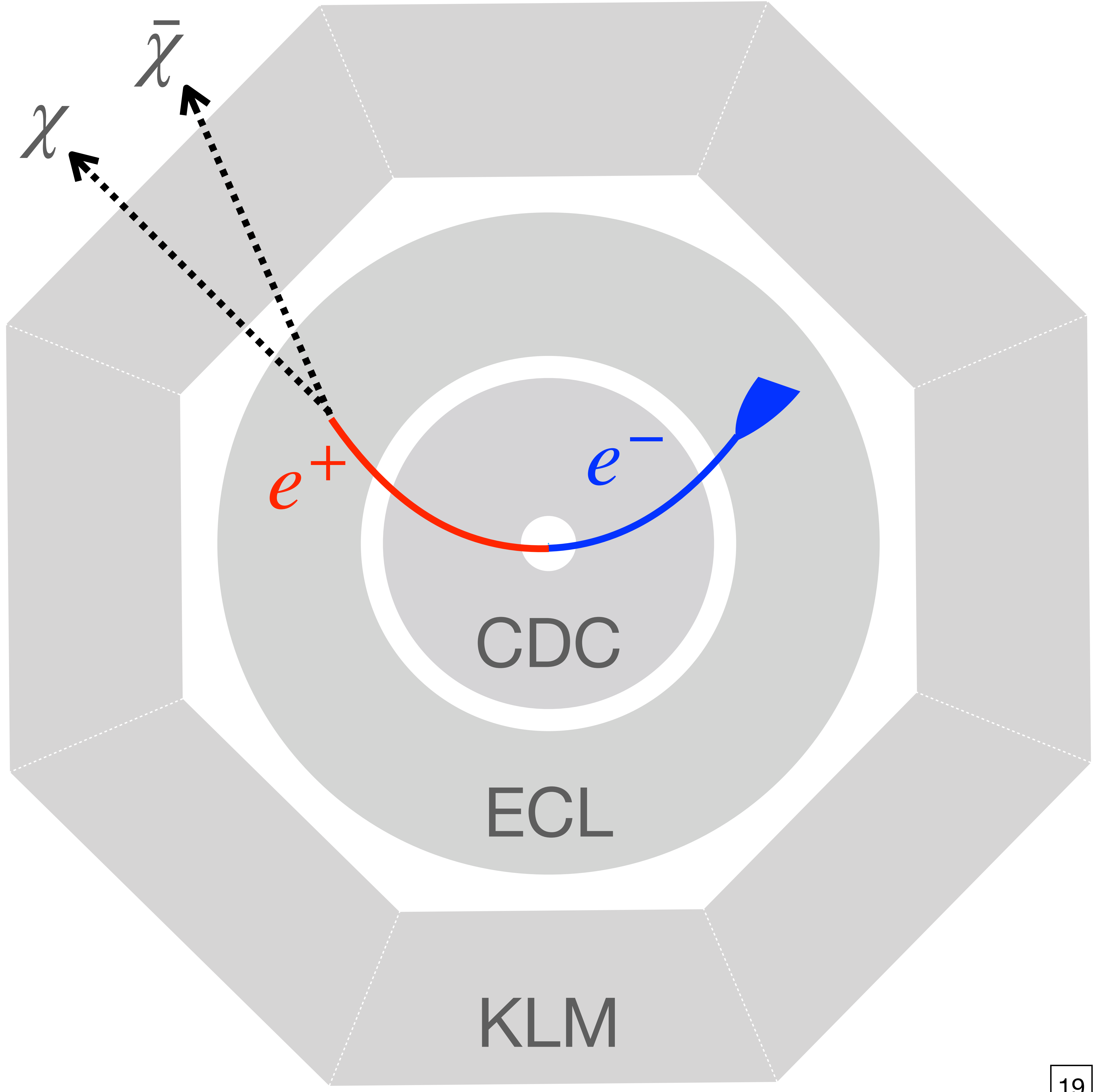


New DM channel @ Belle II (x-y plane)

Bhabha scattering

$$e^+e^- \to e^+e^-$$

- e^- deposit energy in ECL
- e^+ interact with ECL to produce DM



New DM channel @ Belle II (x-y plane)

Bhabha scattering

$$e^+e^- \to e^+e^-$$

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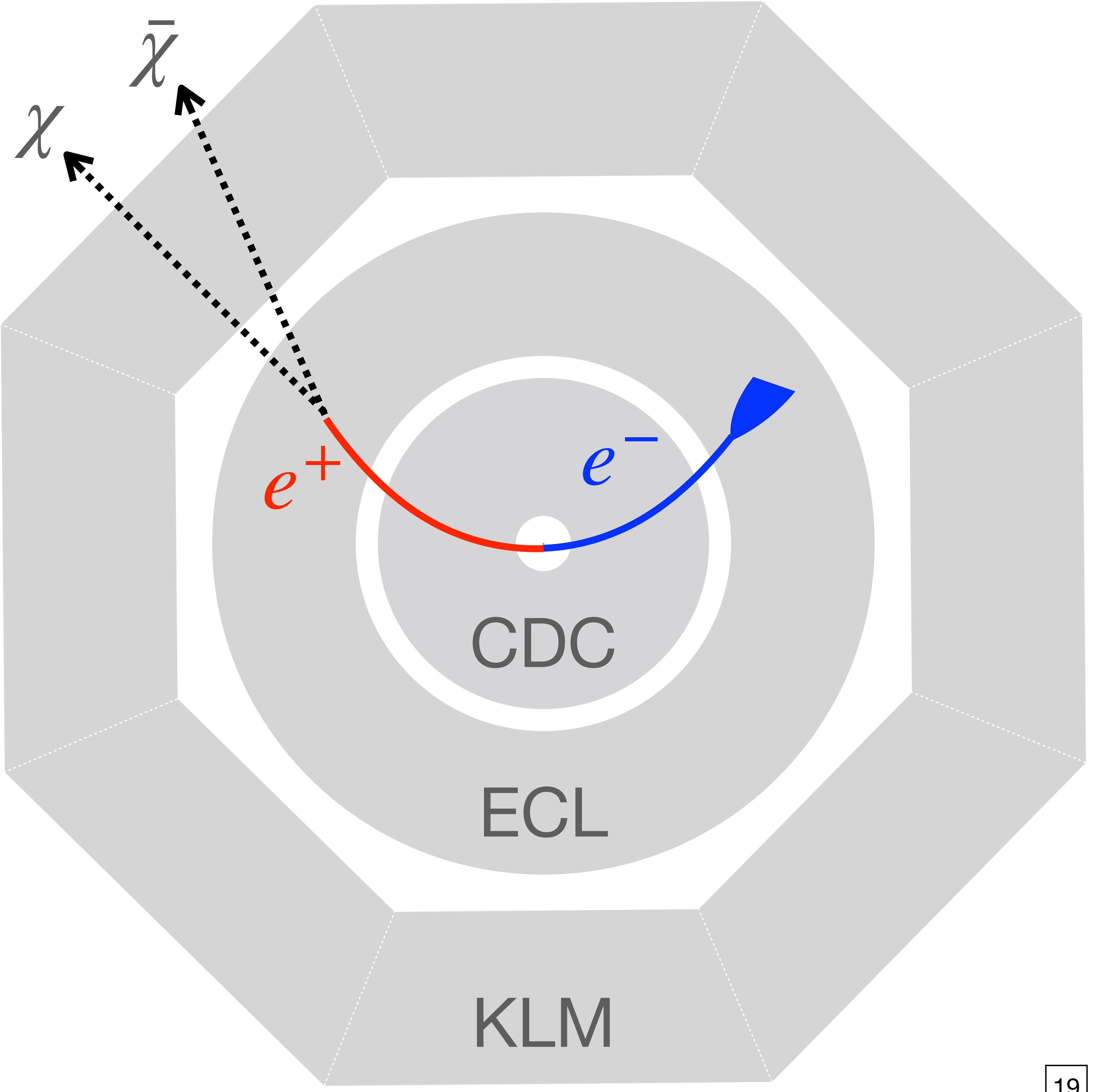
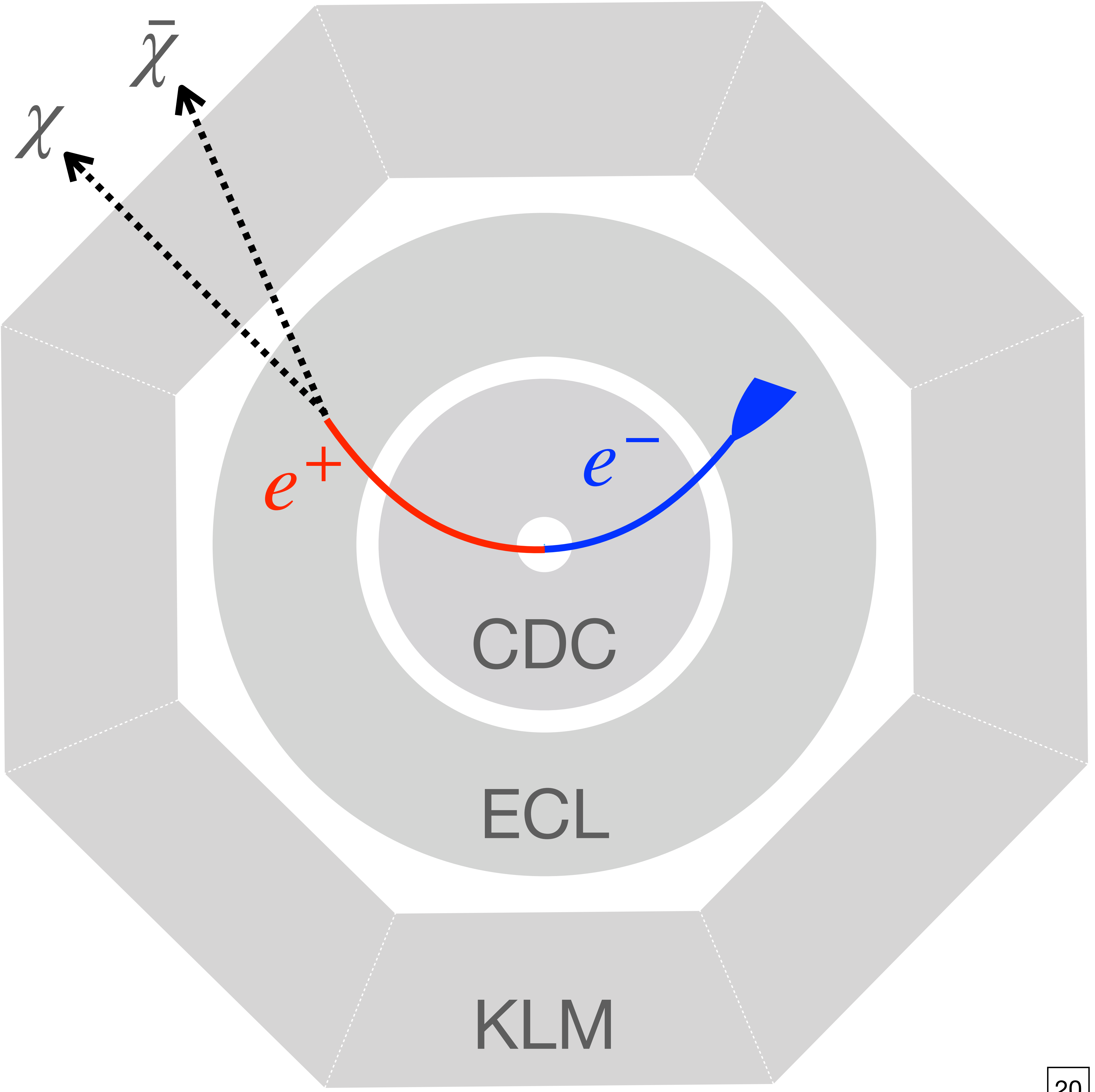
disappearing positron track



“disappearing positron track” signature

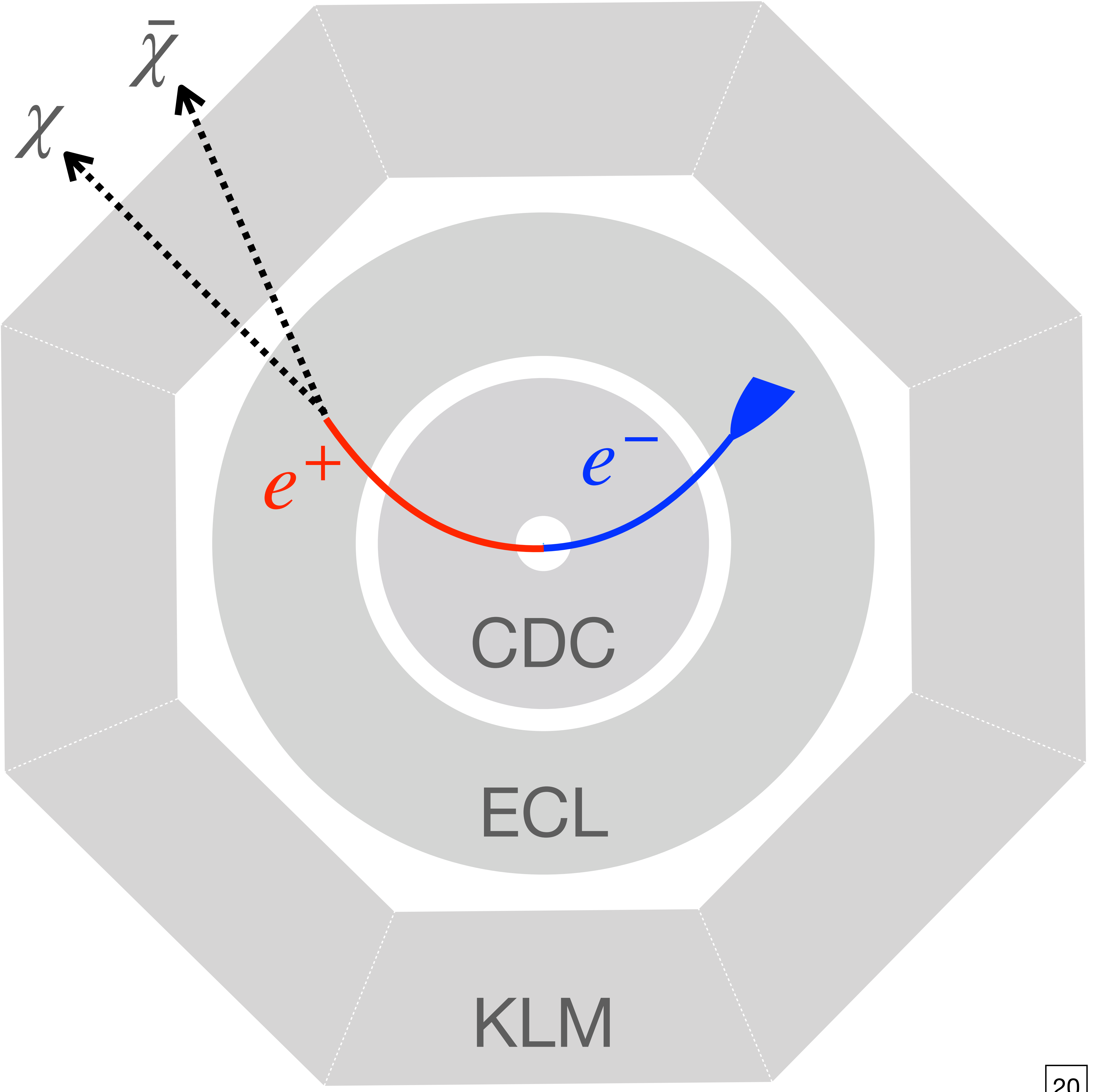


“disappearing positron track” signature

- CDC: e^- & e^+

CDC: $\dfrac{\delta p_T}{p_T} \simeq 0.4\,\%$ for $p_T \simeq 3$ GeV

Equal & opposite momenta for e^- & e^+ in the CM frame



“disappearing positron track” signature

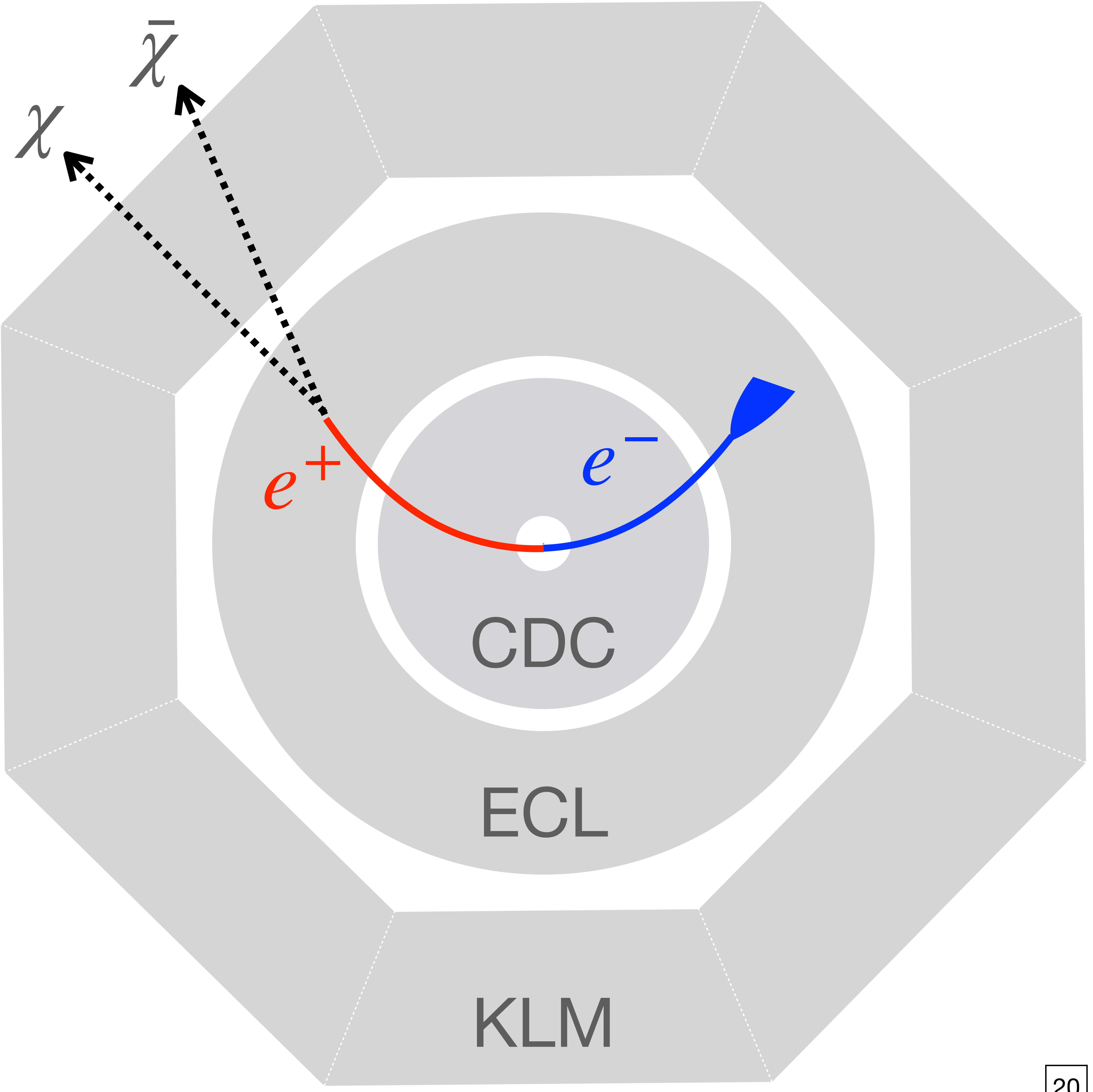
- CDC: e^- & e^+

  CDC: $\dfrac{\delta p_T}{p_T} \simeq 0.4\,\%$ for $p_T \simeq 3$ GeV

  Equal & opposite momenta for e^- & e^+ in the CM frame

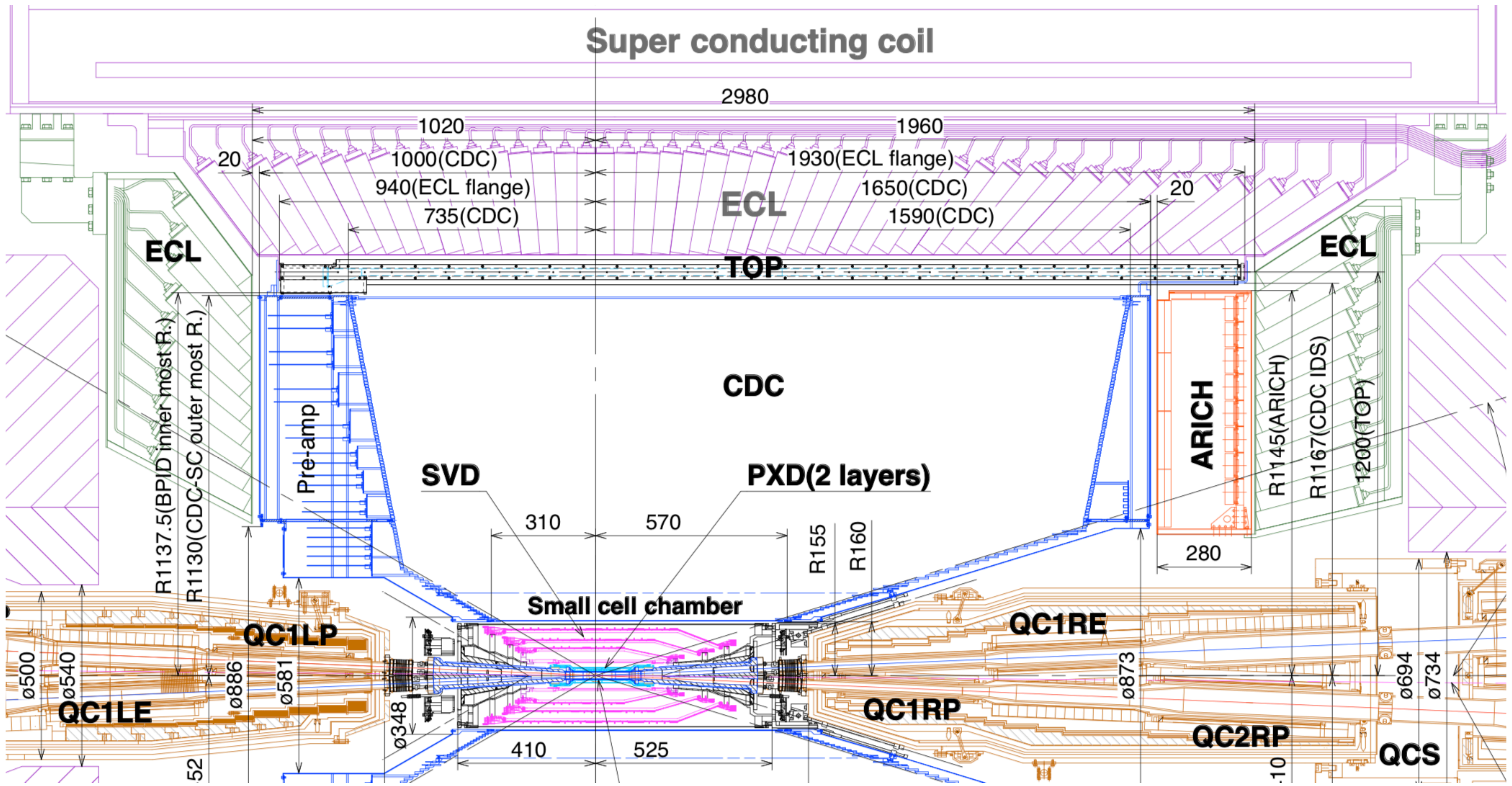
- ECL: e^- & e^+

  missing energy: <5% e^+ energy in ECL



Use the ECL barrel region as the fixed target

ECL barrel: $32.2° < \theta < 128.7°$



- Better hermiticity (non-projective gaps between ECL crystals)
- Less non-instrumented setups (e.g., magnetic wires) between ECL & KLM
- More beam BG in endcaps

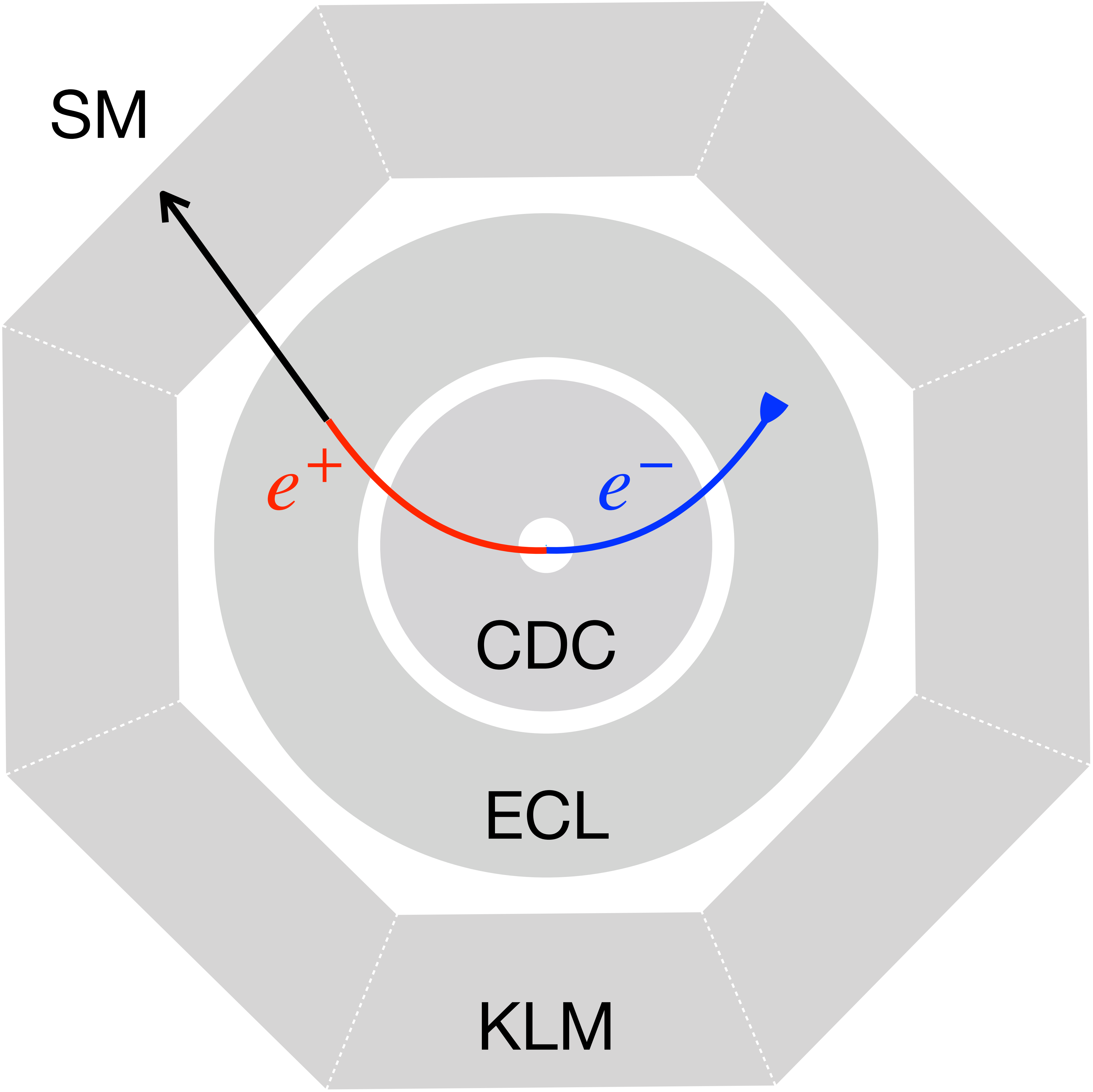
$6 \times 10^{11}\ e^+e^-$ events from Bhabha scattering in the barrel region with 50/ab

Standard model backgrounds

Standard model backgrounds

BG: e^+ + ECL $\rightarrow$ SM

SM particles escape detection



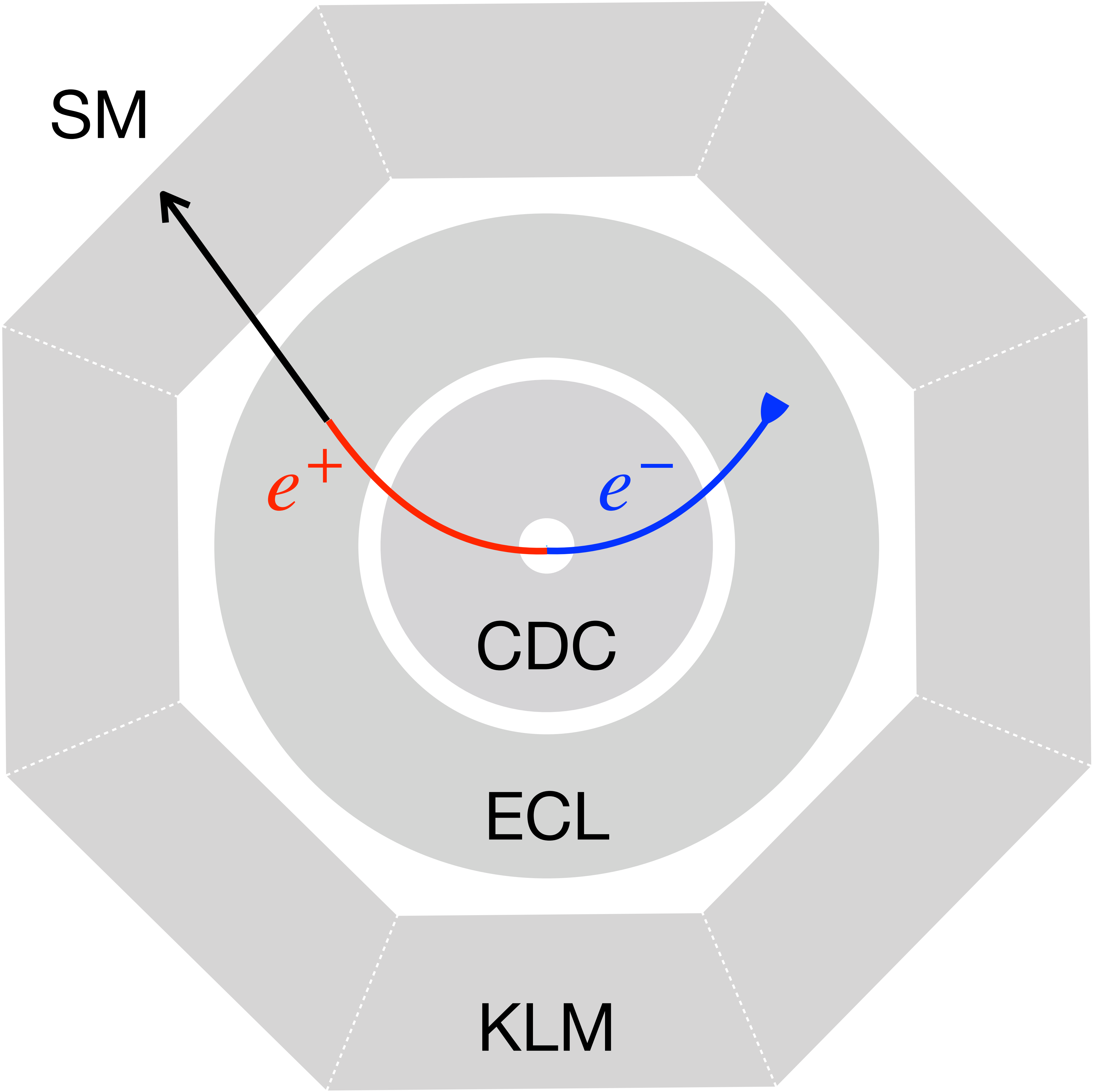
Standard model backgrounds

BG: e^{+} + ECL $\rightarrow$ SM

SM particles escape detection

- Charged particles (e, μ, $\pi^{\pm}$): unlikely to contribute

- Neutral particles (n, γ, ν): neutrino BG is small
  main BG are due to n & γ



Photon-induced BG: high-E photons escape ECL

Photon spectrum (e^+ in matter) [Tsai & Whitis 1966]

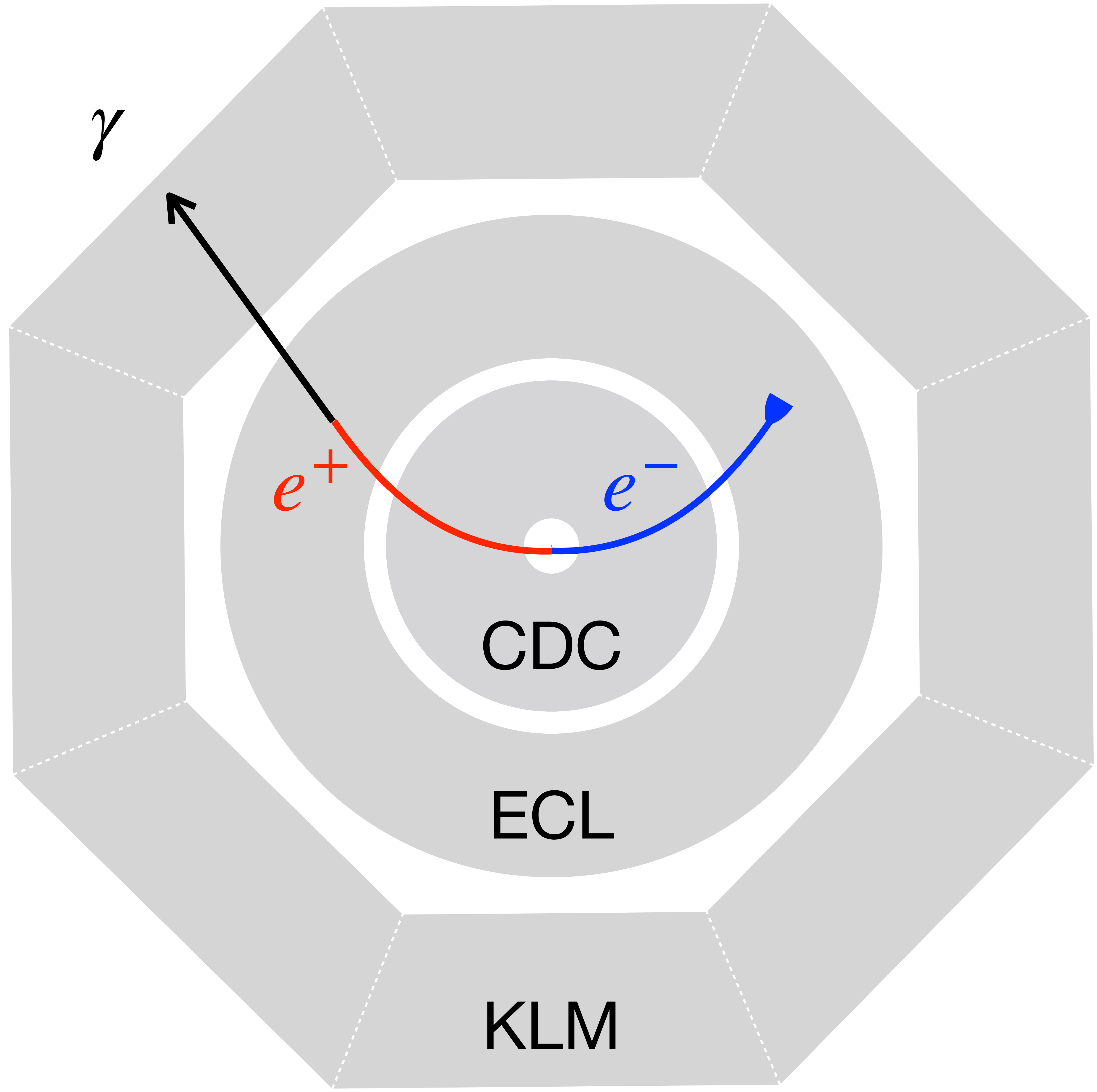
$$\frac{dN_\gamma}{dx_\gamma}(t, x_\gamma) \simeq \frac{1}{x_\gamma} \frac{(1 - x_\gamma)^{(4/3)t} - e^{-(7/9)t}}{7/9 + (4/3)\ln(1 - x_\gamma)}$$

$x_\gamma = E_\gamma / E_e \qquad t = \#$ of X_0

prob of high-E γ = $\displaystyle\int_{0.95}^{1} dx_\gamma \frac{dN_\gamma}{dx_\gamma}(16, x_\gamma) \simeq 4.7 \times 10^{-8}$

6×10^{11} e^+ hit ECL which has 16-X_0 CsI crystals

# of high-E $\gamma \sim 2.8 \times 10^4$ after ECL

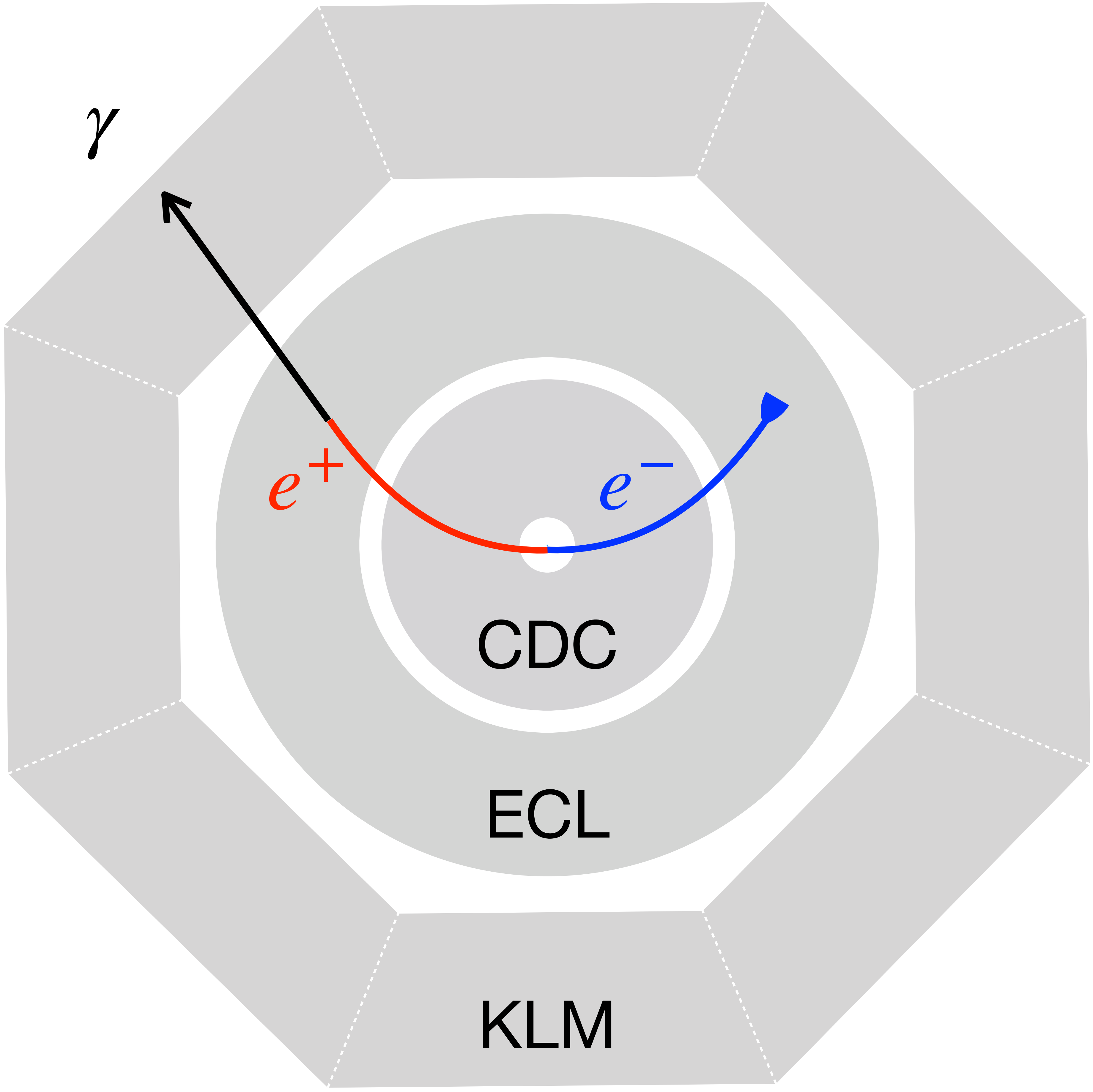


KLM veto capability on photon

- KLM = alternating layers of 4.7-cm iron plates & active detectors $\Longrightarrow$ difficult for GeV γ to penetrate

- However, γ can be absorbed by non-instrumented setups (e.g., magnet coil)

- KLM veto efficiency = 4.5×10^{-4} (IFR @ BaBar) $\Longrightarrow$ 13 photon BG (for 6×10^{11} incident e^+)

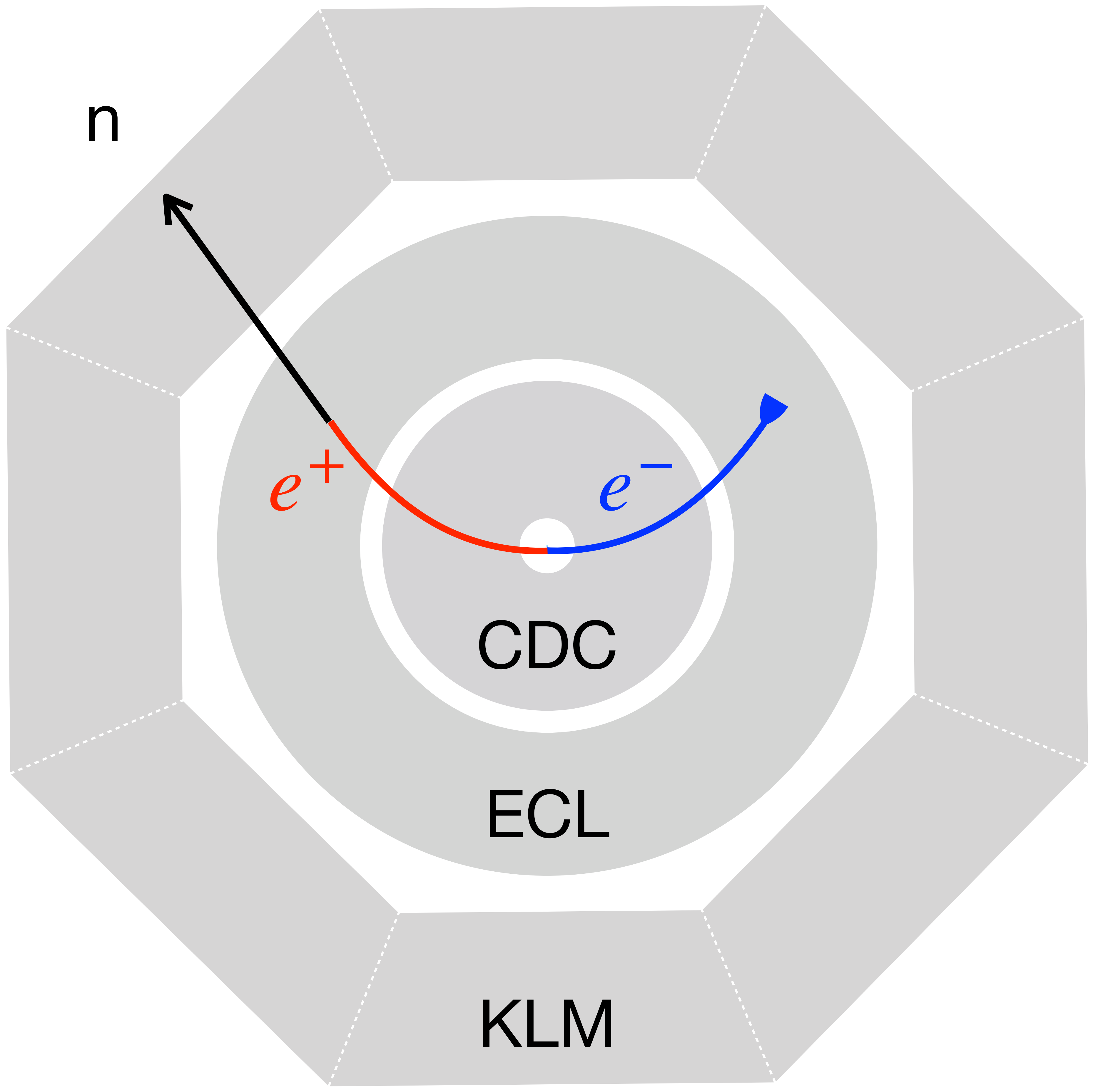


Neutron-induced backgrounds: GEANT4 simulations

- GEANT4 simulation: $10^9\, e^+$ with a CsI target with 1 X_0

- Neutrons with significant energy are produced in the first X_0 (confirmed with 2-X_0 simulations)

- Require at least one neutron with E > 3 GeV



Probability for a neutron to penetrate ECL & KLM

Prob to penetrate a target with length L

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

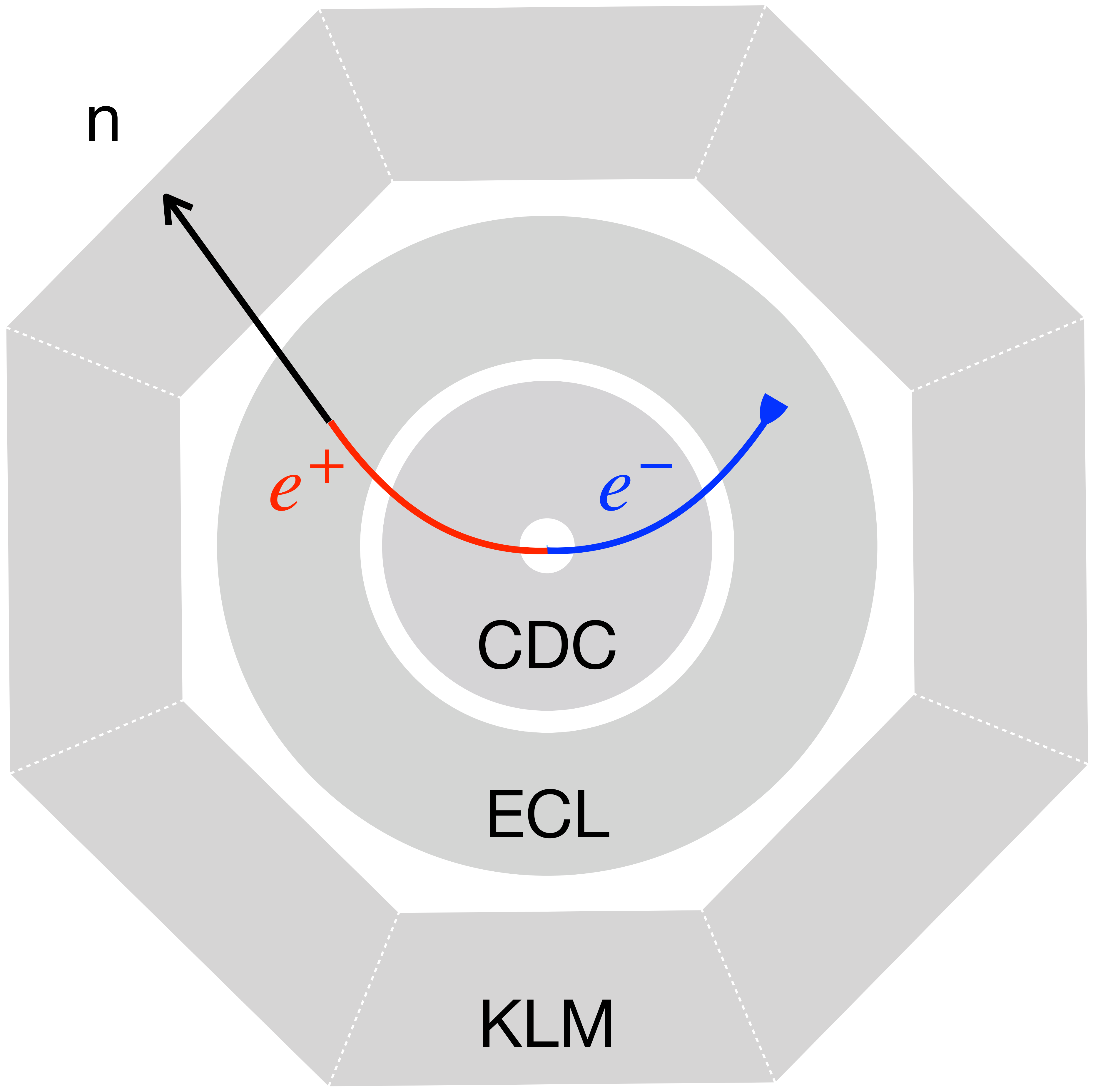
λ_0 = hadronic interaction length

KLM $\sim 3.9\,\lambda_0$ ECL $\sim 0.8\,\lambda_0$

Prob to penetrate ECL & KLM $\sim 1\,\%$

Neutron-induced BG ~ 81

Both photon & neutron-induced BG ~ 94



Sensitivity on invisible dark photon

Invisible dark photon

$\delta B_{\mu\nu} X^{\mu\nu}$ or $m^2 \epsilon B_\mu X^\mu$

$\Downarrow$

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

[Holdom 1986]

[Foot & He 1991]

[Feldman, ZL, Nath, hep-ph/0702123, 437 cites]

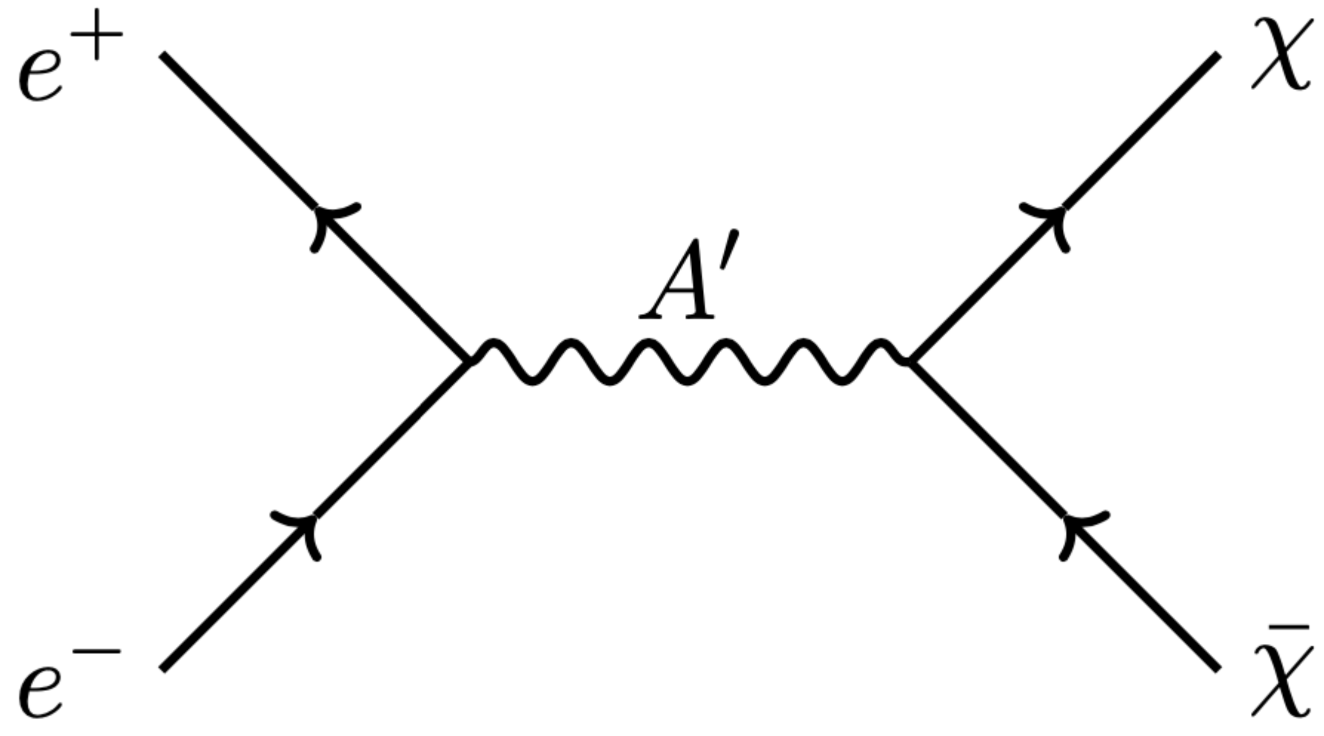
dark photon A'_μ

couplings: $g_\chi \gg e\epsilon$

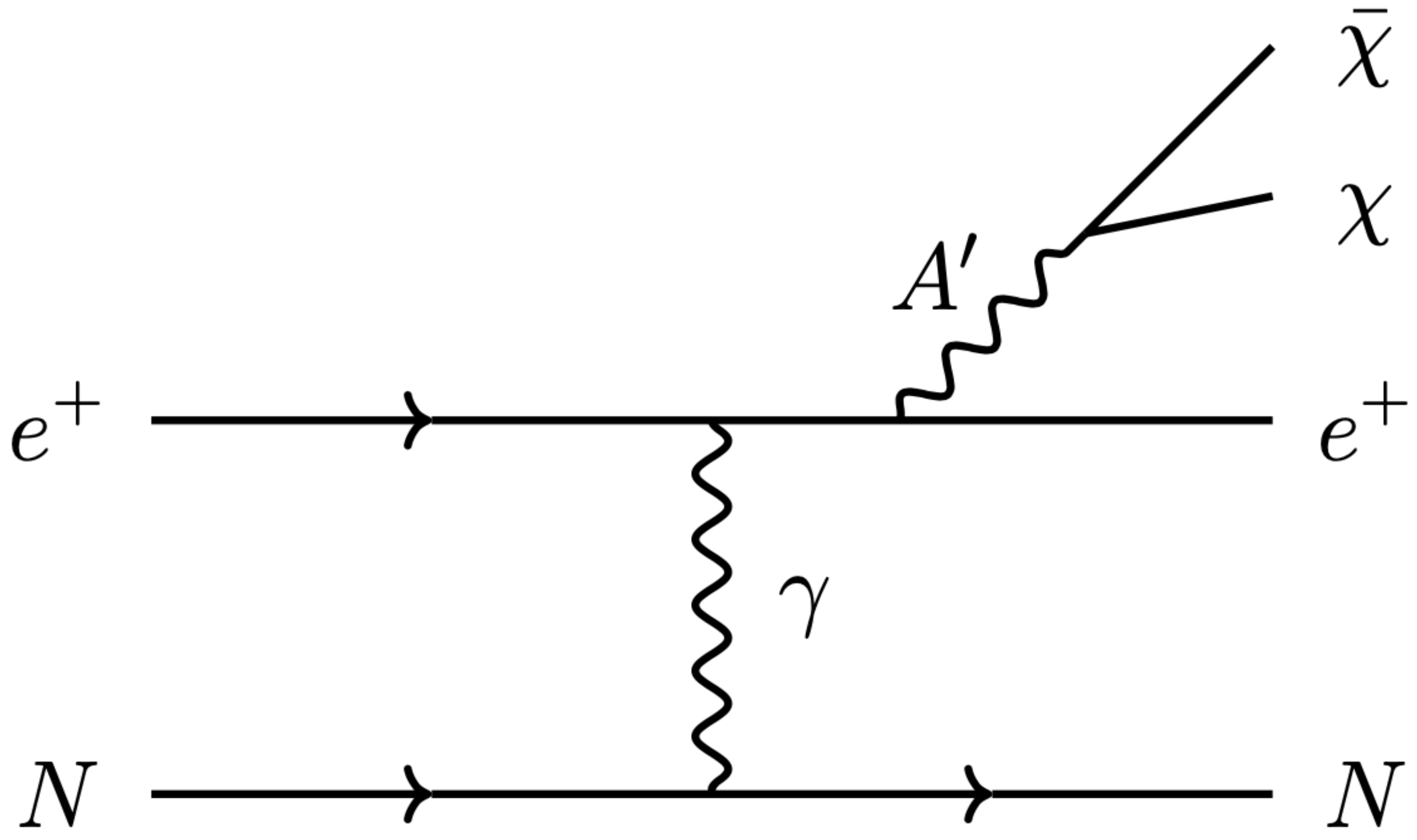
$m_{A'} = 3m_\chi$

⇨ invisible decay dominates

Positron interaction with ECL

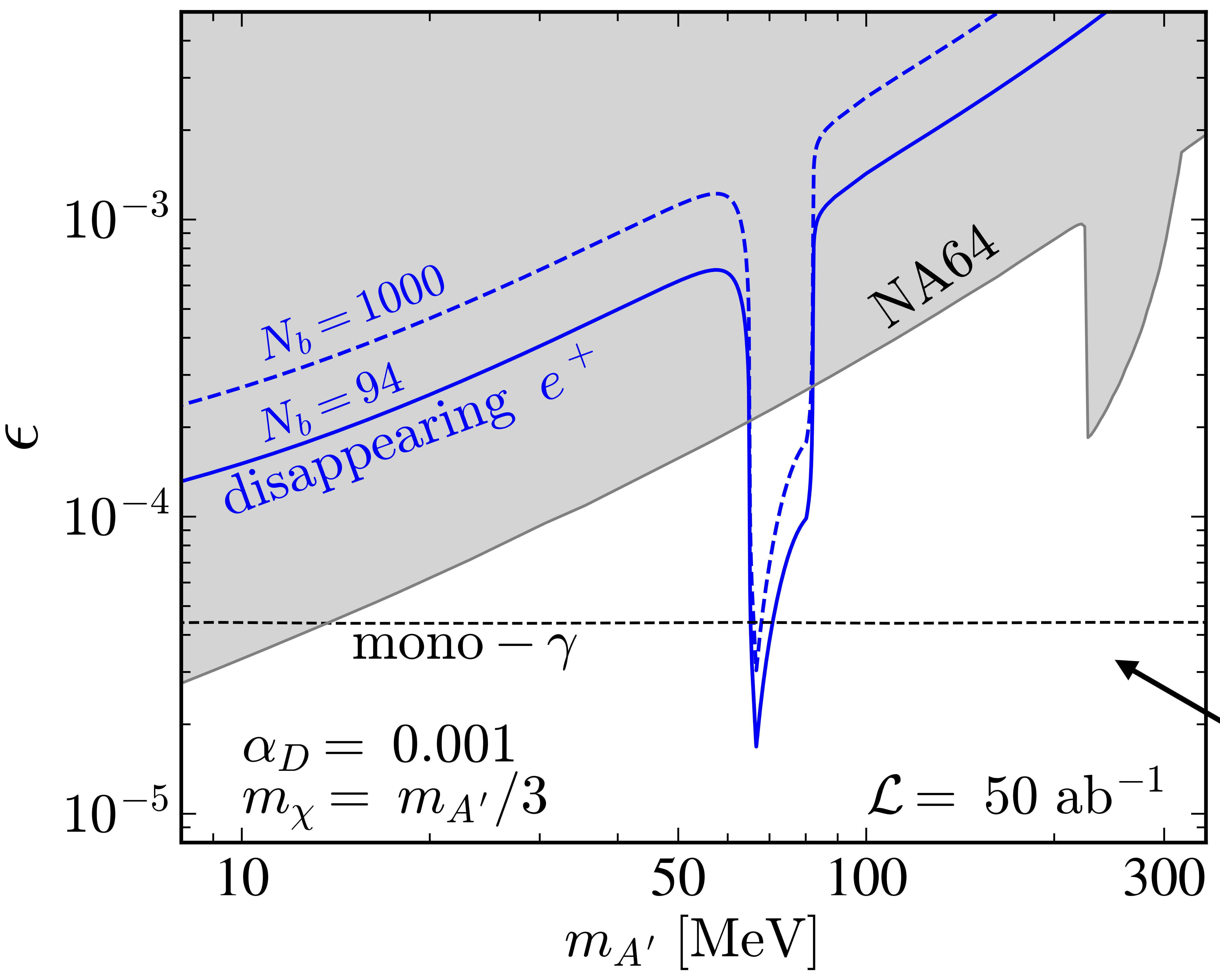


annihilation w/
atomic electrons



bremsstrahlung w/
target nucleus

Belle II sensitivity on invisible dark photon



[Liang, ZL, Yang, 2212.04252]

probing new parameter space beyond mono-photon and NA64

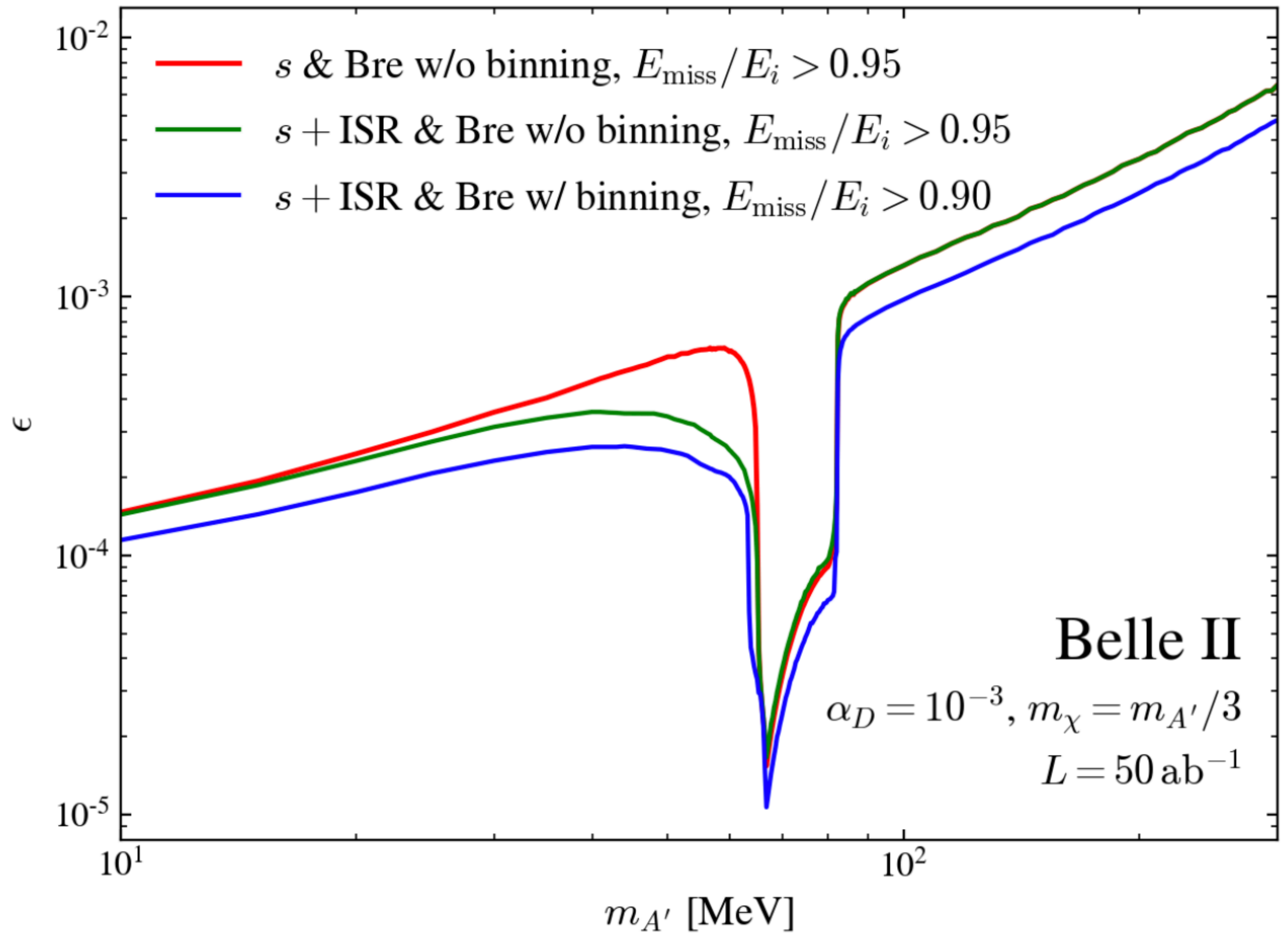
best-probed region ~66 MeV:

- annihilation with atomic electrons
- $m_{A'} \sim \sqrt{2 m_e E_{e^+}}$ depends on energy

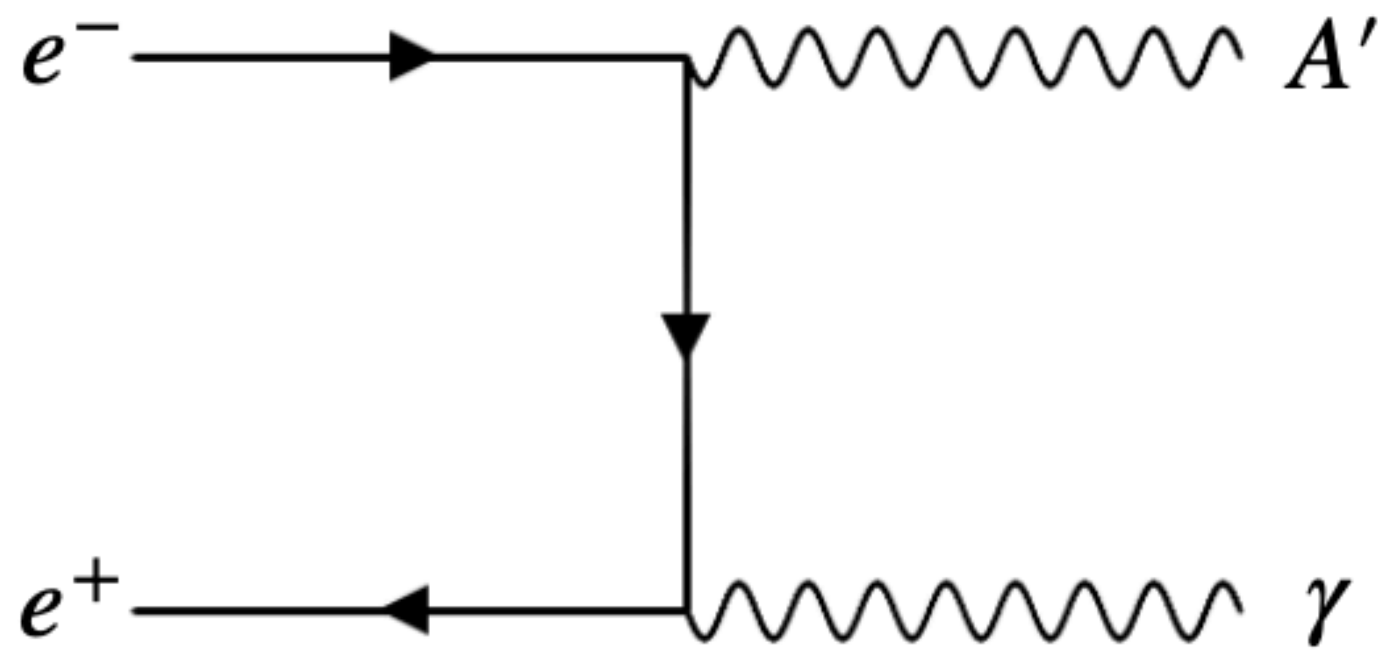
mono-photon projections subject to potential CRBG for DP m < 2 GeV [2207.06307, Belle II, Snowmass]

Belle II sensitivity with ISR included

[Shao-Feng Ge, Jinhan Liang, ZL, Ui Min, 2505.10302]



also consider binning on photon energy



improved sensitivity (more significantly for low masses)

3

Belle II probes of strongly-interacting dark matter

[Liang, ZL, Yang, PRD, 2312.08970]

Strongly-interacting dark matter

Strongly interacting dark matter

DM is usually assumed to have a weak interaction w/ SM, e.g., WIMPs

However, strongly-interacting DM w/ a small abundance are allowed

& are interesting because they can get boosted by various astro sources

- cosmic ray **[Cappiello+, 1810.07705] [Bringmann+, 1810.10543][Ema+, 1811.00520]**
- diffuse supernova neutrino **[Das+, 2104.00027]**
- blazars **[Wang+, 2111.13644]**

Detection of strongly interacting DM can be difficult

strongly-interacting DM can be difficult to detect

- strong interaction xsec
- small abundance (because the strong interaction xsec)

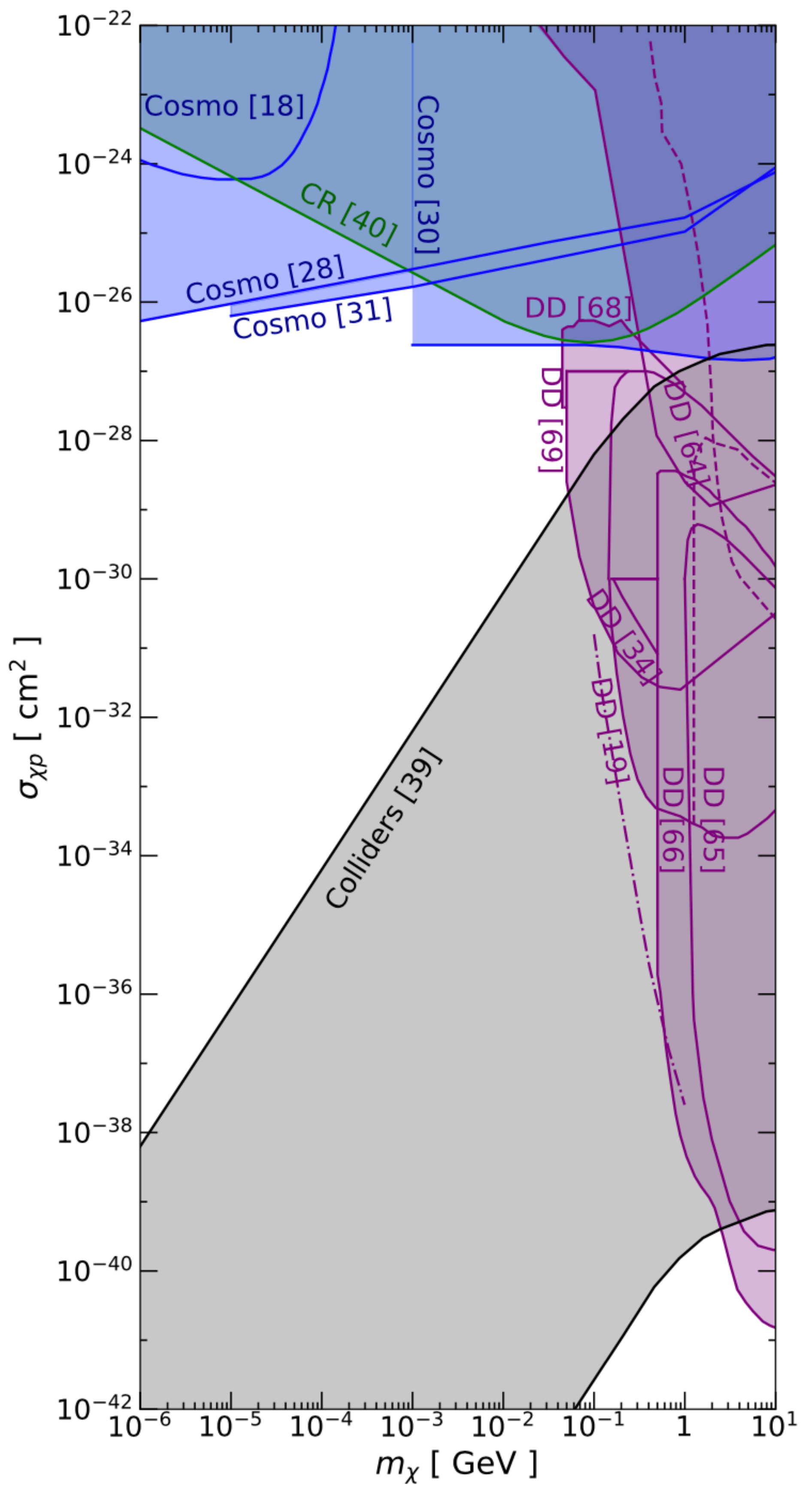
- DMID: suppressed by small abundance
- DMDD: suppressed by small abundance & shielded by rock/air (like CR)
- CMB: unconstrained if the abundance is <0.4% **[Boddy +, 1808.00001]**

Colliders are ideal probes of such DM, unconstrained by these two factors

Ceiling of collider searches

strongly-interacting DM starts to interacts w/ detectors ⇒ no more mono-X

[Cappiello+ 1810.07705]



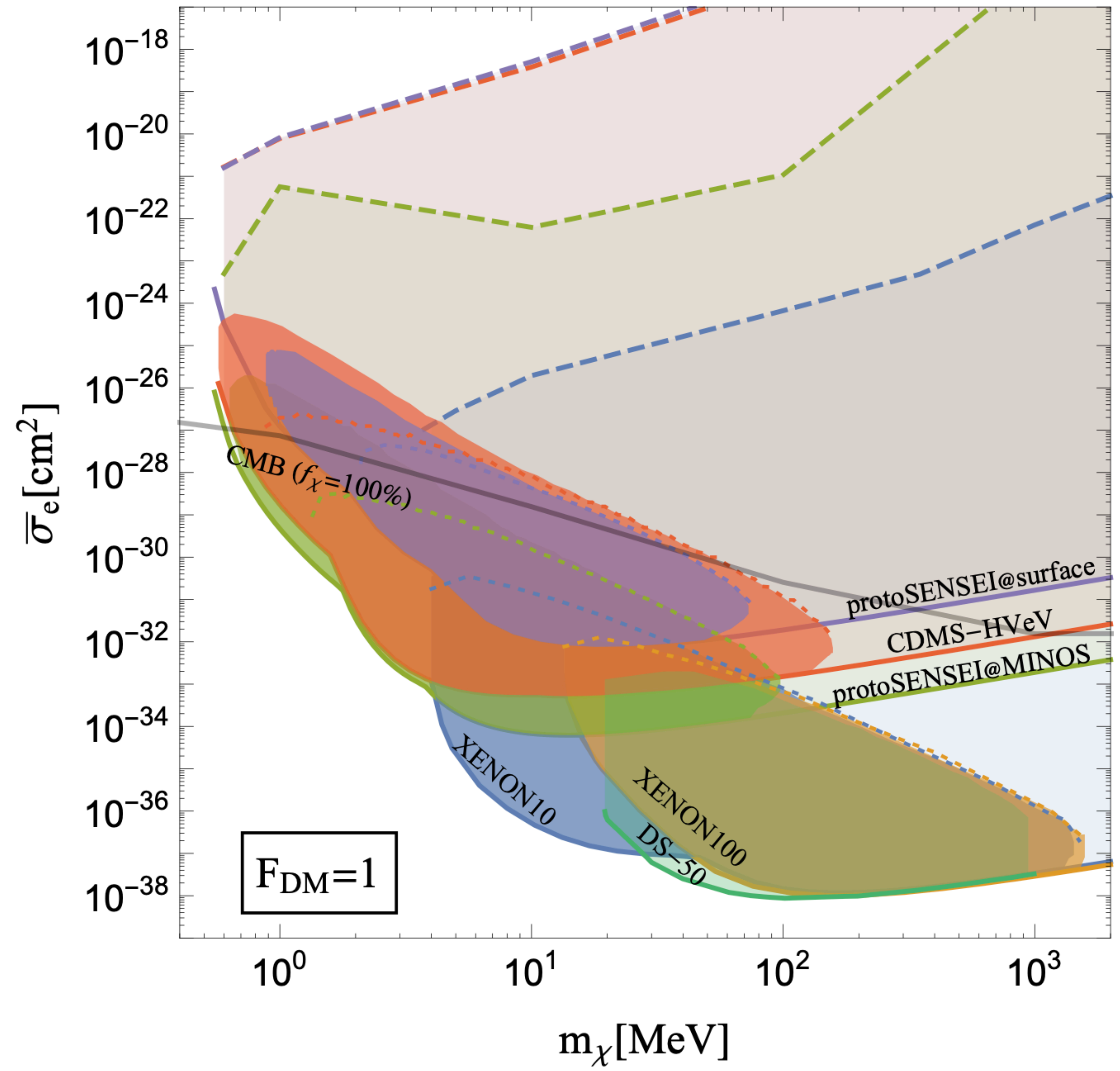
DM interactions with LHC detectors

[Bai & Rajaraman 1109.6009]

[Daci et al., 1503.05505]

[Bauer et al., 2005.13551]

[Emken+ 1905.06348]

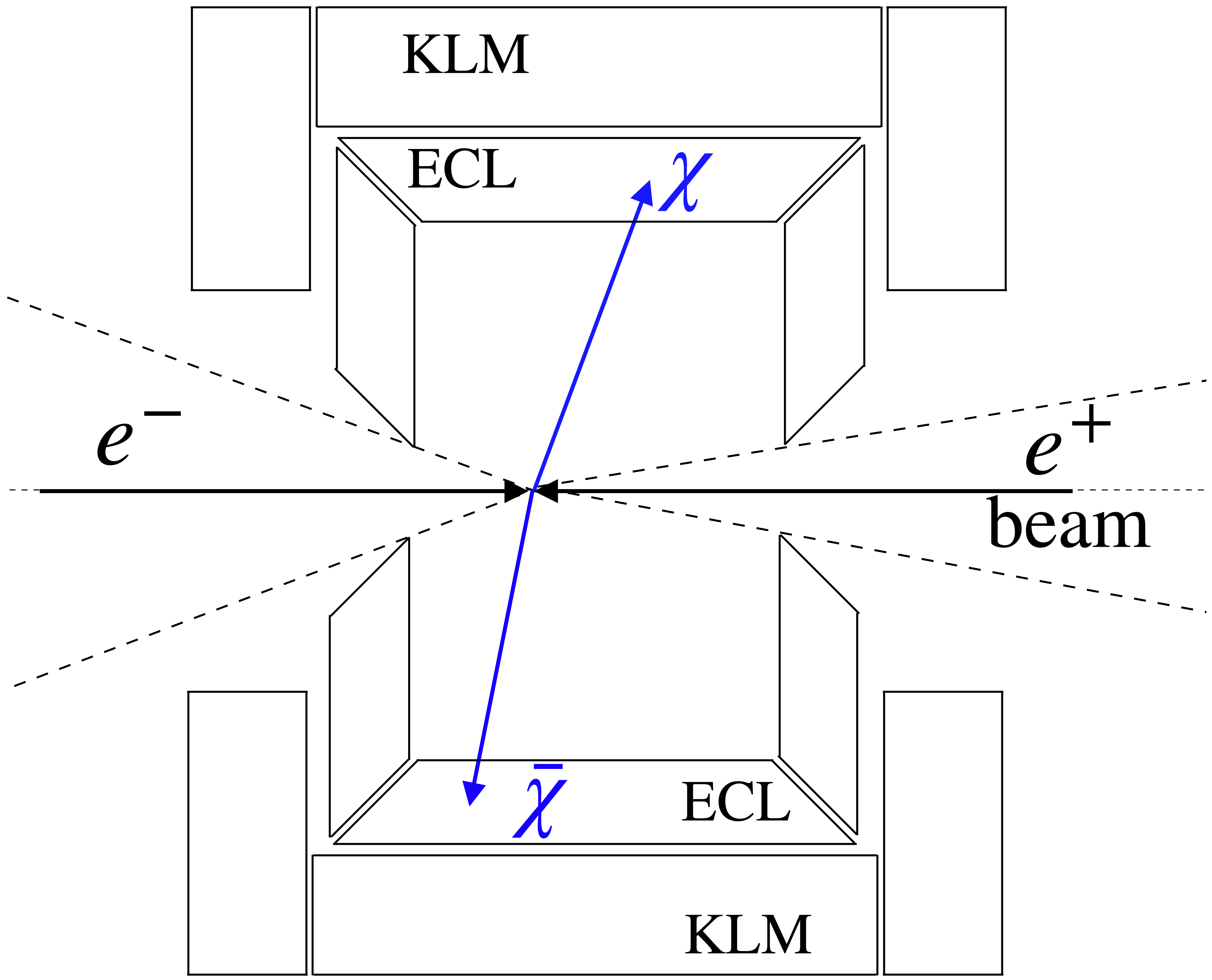


Probing strongly-interacting DM

at electron colliders

DM scattering w/ ECL @ Belle II

[Liang, ZL, Yang, 2312.08970]



DM interacts strongly w detector ⇒ multiple electron recoils (generates a DM-induced ECL "cluster")

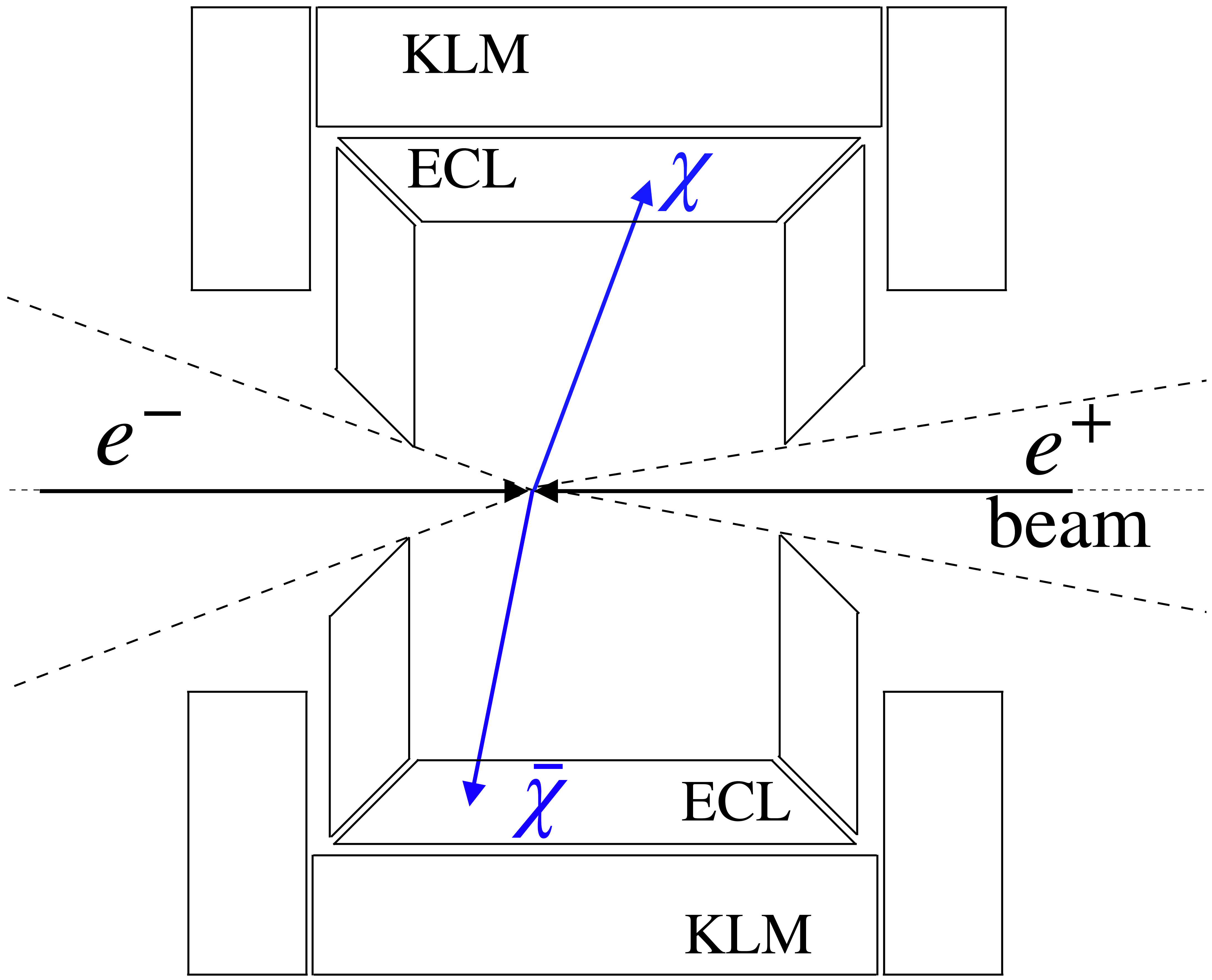
this is similar to photon signals at Belle II

- mono-cluster (from one DM)
- di-cluster (from both DM)

$E_{\text{cluster}} \leq E_\chi - m_\chi$ for DM-induced ECL cluster

DM scattering w/ ECL @ Belle II

[Liang, ZL, Yang, 2312.08970]



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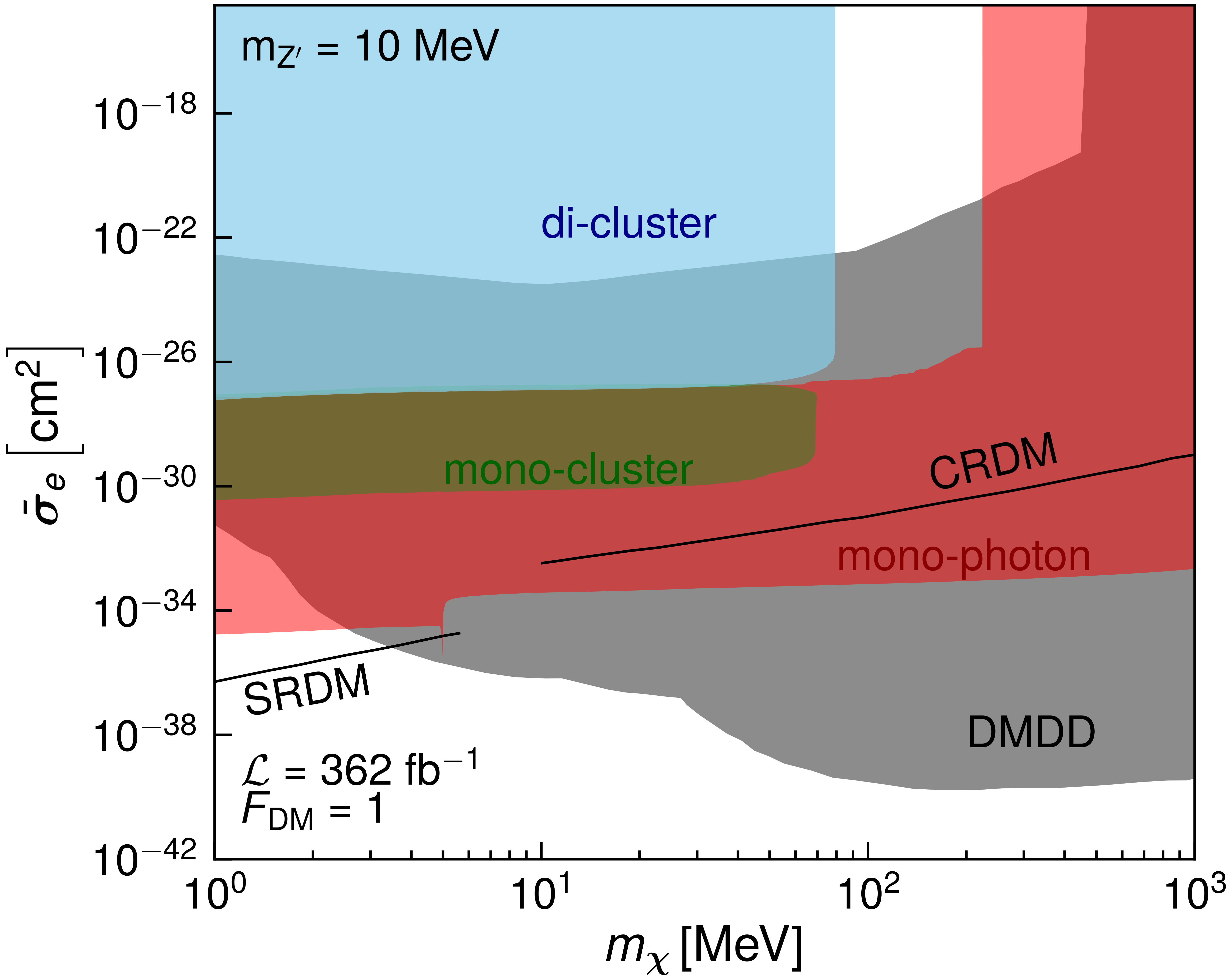
DMDD in collider

Belle II vs DMDD (10 MeV Z' w only vector couplings)



[Liang, ZL, Yang, 2312.08970]

$$\mathcal{L}_{\rm int}^V = Z'_\mu (g_\chi^V \bar{\chi}\gamma^\mu\chi + g_e^V \bar{e}\gamma^\mu e)$$

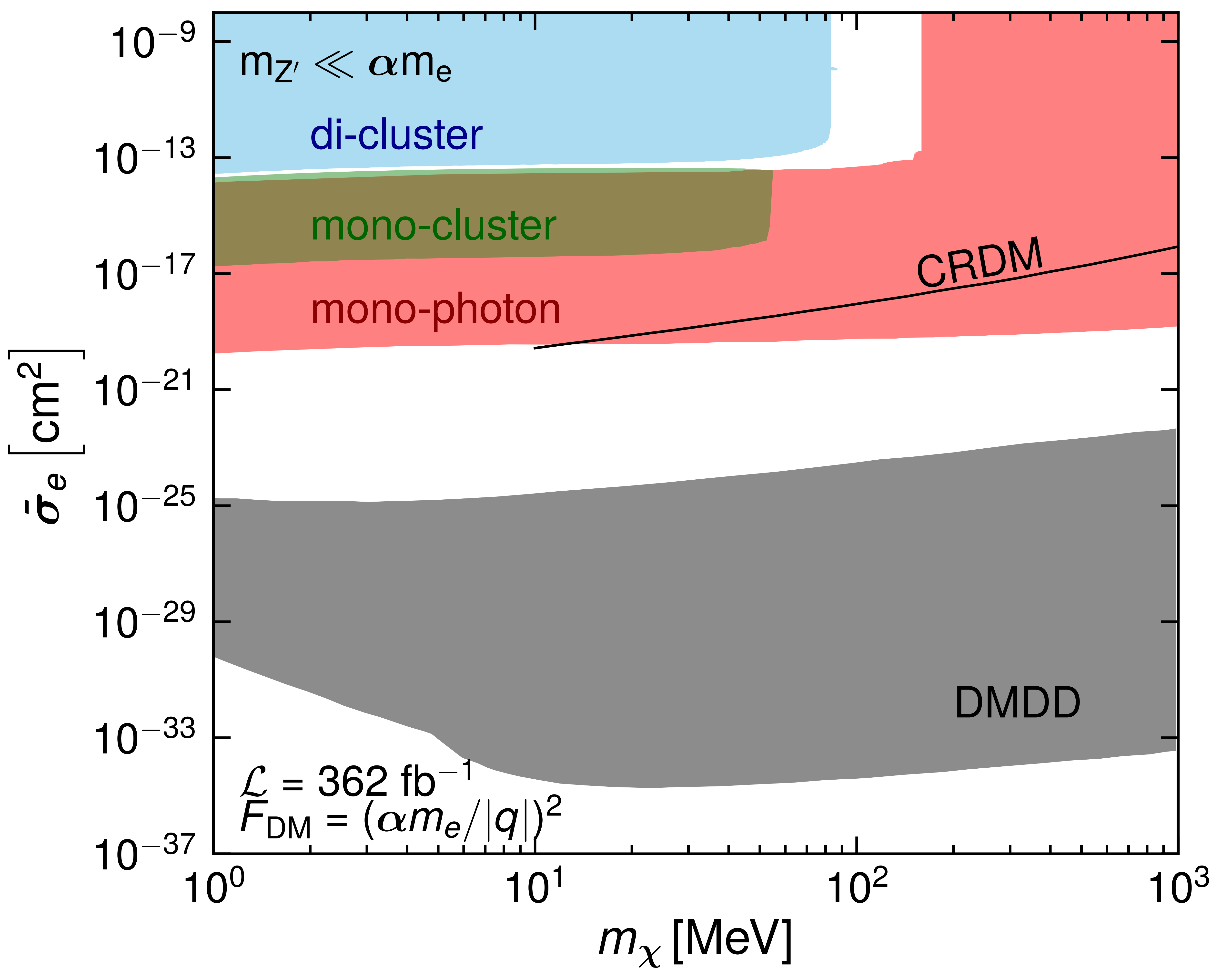
para space above DMDD ceiling probed by electron colliders

- mono-photon (very small xsec)
- mono-cluster (small xsec)
- di-cluster (large xsec)

DMDD xsec @ $|q| = \alpha m_e$

FF = 1 (heavy mediator in DMDD)

Belle II sensitivity versus DMDD (ultralight Z')



$$\mathscr{L}^V_{\rm int} = Z'_\mu(g^V_\chi \bar{\chi}\gamma^\mu\chi + g^V_e \bar{e}\gamma^\mu e)$$

FF $\propto |q|^{-2}$ (ultralight mediator in DMDD)

large xsec region probed by colliders

allowed para space between colliders & DMDD

[Liang, ZL, Yang, 2312.08970]

Summary

- Mono-photon channel at electron colliders can probe new parameter space for millicharged particles, light-mediator dark matter (DM), EFT DM. Electron colliders can outperform DMDD and DMID experiments in probing these DMs. **[ZL, Zhang, 1808.00983] [Liang, ZL, Ma, Zhang, 1909.06847] [Liang, ZL, Yang, 2111.15533]**

- We propose a new DM search channel at Belle II in which ECL acts both as the fixed target and as the detector. This new channel can probe new parameter space of invisible dark photon, surpassing mono-photon at Belle II & the missing momentum search at NA64. **[Liang, ZL, Yang, 2212.04252] [Ge, Liang, ZL, Min, 2505.10302]**

- We study electron collider constraints on strongly-interacting DM by analyzing the visible signatures (mono-cluster & di-cluster). We find that current Belle II data can probe the parameter space w/ a large DMDD cross section, which is difficult to probe in DMDD & DMID experiments. **[Liang, ZL, Yang, 2312.08970]**

backup slides

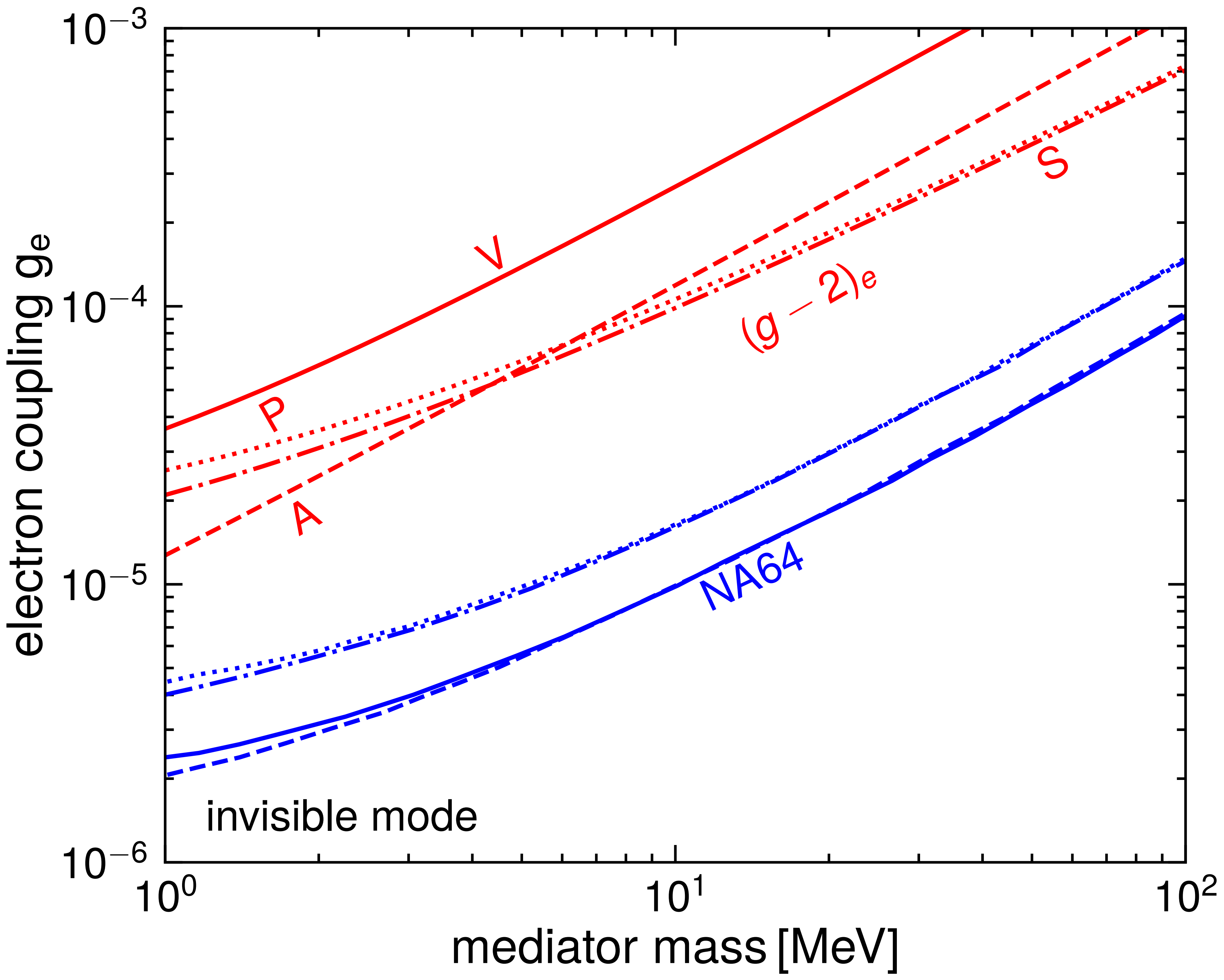
Strong DM-electron interaction via a light mediator

spin-1 (vector)	$\mathscr{L}_{\text{int}}^{V} = Z'_\mu(g_\chi^V \bar{\chi}\gamma^\mu\chi + g_e^V \bar{e}\gamma^\mu e)$
spin-1 (axial-vector)	$\mathscr{L}_{\text{int}}^{A} = Z'_\mu(g_\chi^A \bar{\chi}\gamma^5\gamma^\mu\chi + g_e^A \bar{e}\gamma^5\gamma^\mu e)$
spin-0 (scalar)	$\mathscr{L}_{\text{int}}^{S} = \phi(g_\chi^S \bar{\chi}\chi + g_e^S \bar{e}e)$
spin-0 (pseudo-scalar)	$\mathscr{L}_{\text{int}}^{P} = \phi(i g_\chi^P \bar{\chi}\gamma^5\chi + i g_e^P \bar{e}\gamma^5 e)$

a light mediator is needed to generate a large DMDD xsec

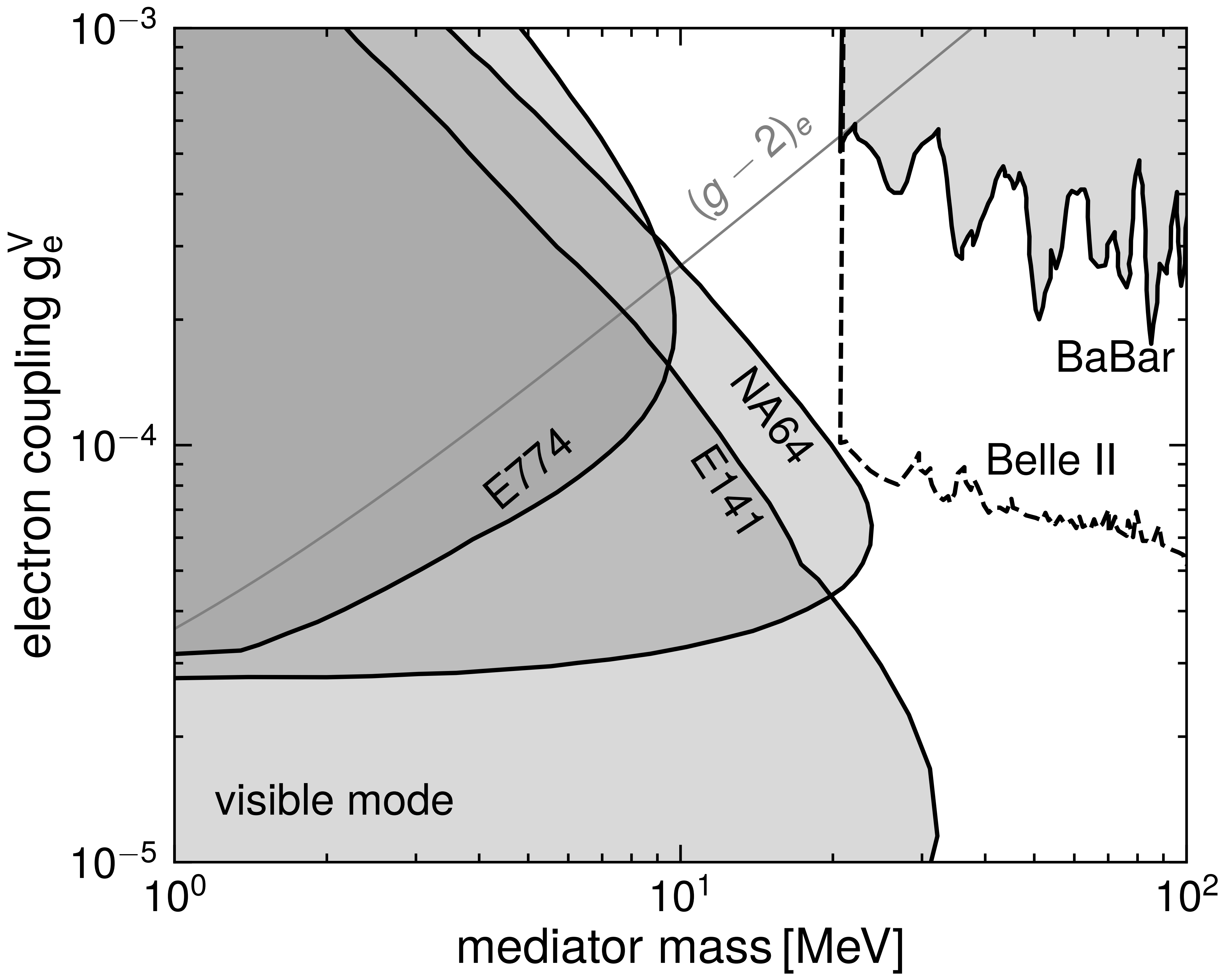
Experimental constrains on mediators

electron g-2 & NA64



invisible scenario

electron beam-dump & collider



visible scenario

Kinetic mixing & mass mixing

$SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_X$

[Feldman, ZL, Nath, hep-ph/0702123, 437 cites]

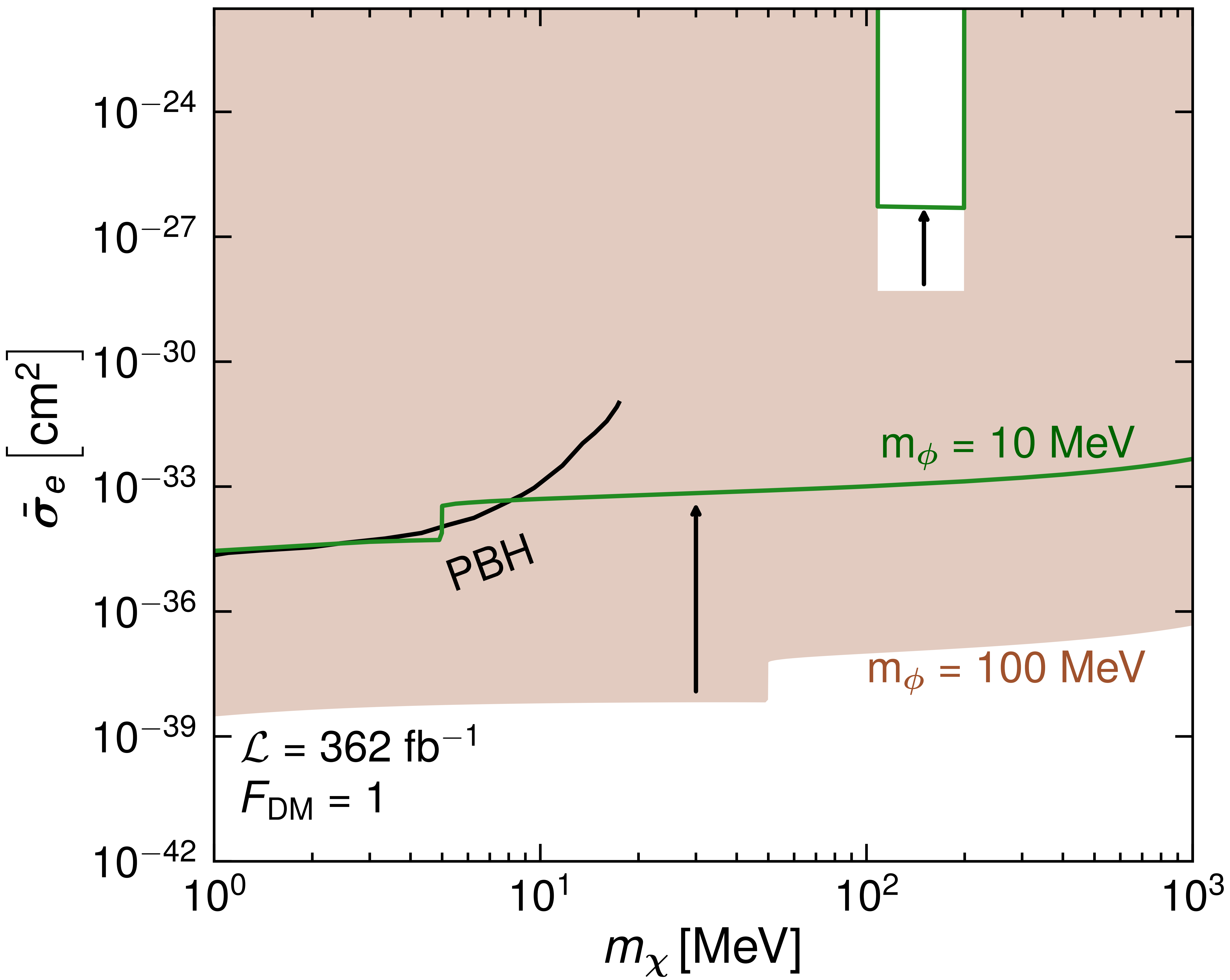
$$\mathscr{L} = -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}X_{\mu\nu}X^{\mu\nu} + g_D X_\mu \bar{\chi}\gamma^\mu \chi - \frac{\tilde{\delta}}{2} B_{\mu\nu} X^{\mu\nu} - \frac{M_1^2}{2}(\partial_\mu \sigma + X_\mu + \tilde{\epsilon} B_\mu)^2$$

kinetic mixing

mass mixing

kinetic mixing $\tilde{\delta}$ & mass mixing $\tilde{\epsilon}$ are degenerate (w/o χ): only $\epsilon \sim (\tilde{\epsilon} - \tilde{\delta})$ is physical

Comparison with primordial black hole



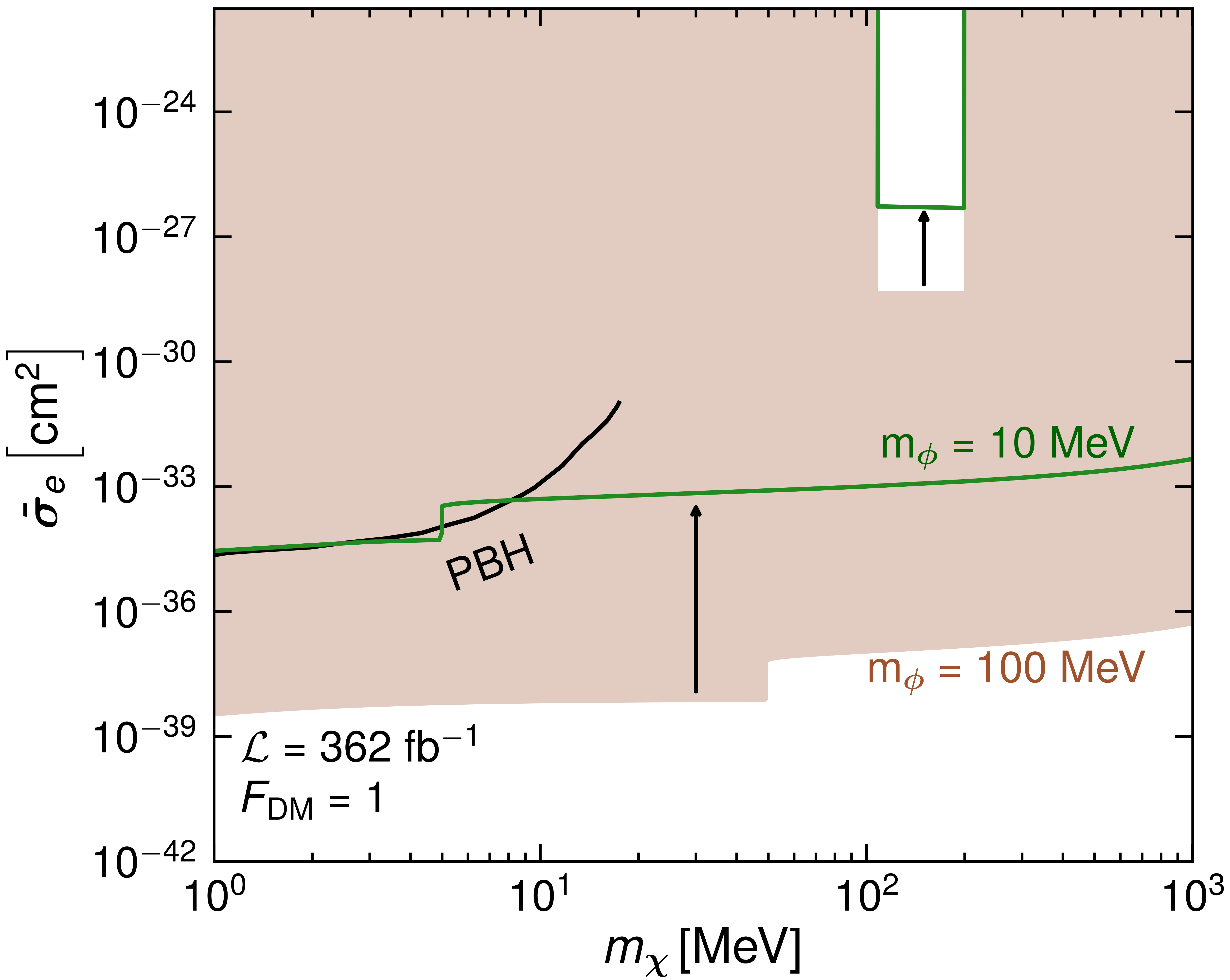
BSM particle w/ mass below Hawking temperature can be produced in PBH ⇒ ER @ SK

PBH $E = 10$ MeV

detection via $\bar{\chi}\chi\bar{e}e/\Lambda^2$

[Calabrese+, 2203.17093]

Comparison with primordial black hole



BSM particle w/ mass below Hawking temperature can be produced in PBH ⇒ ER @ SK

PBH $E = 10$ MeV

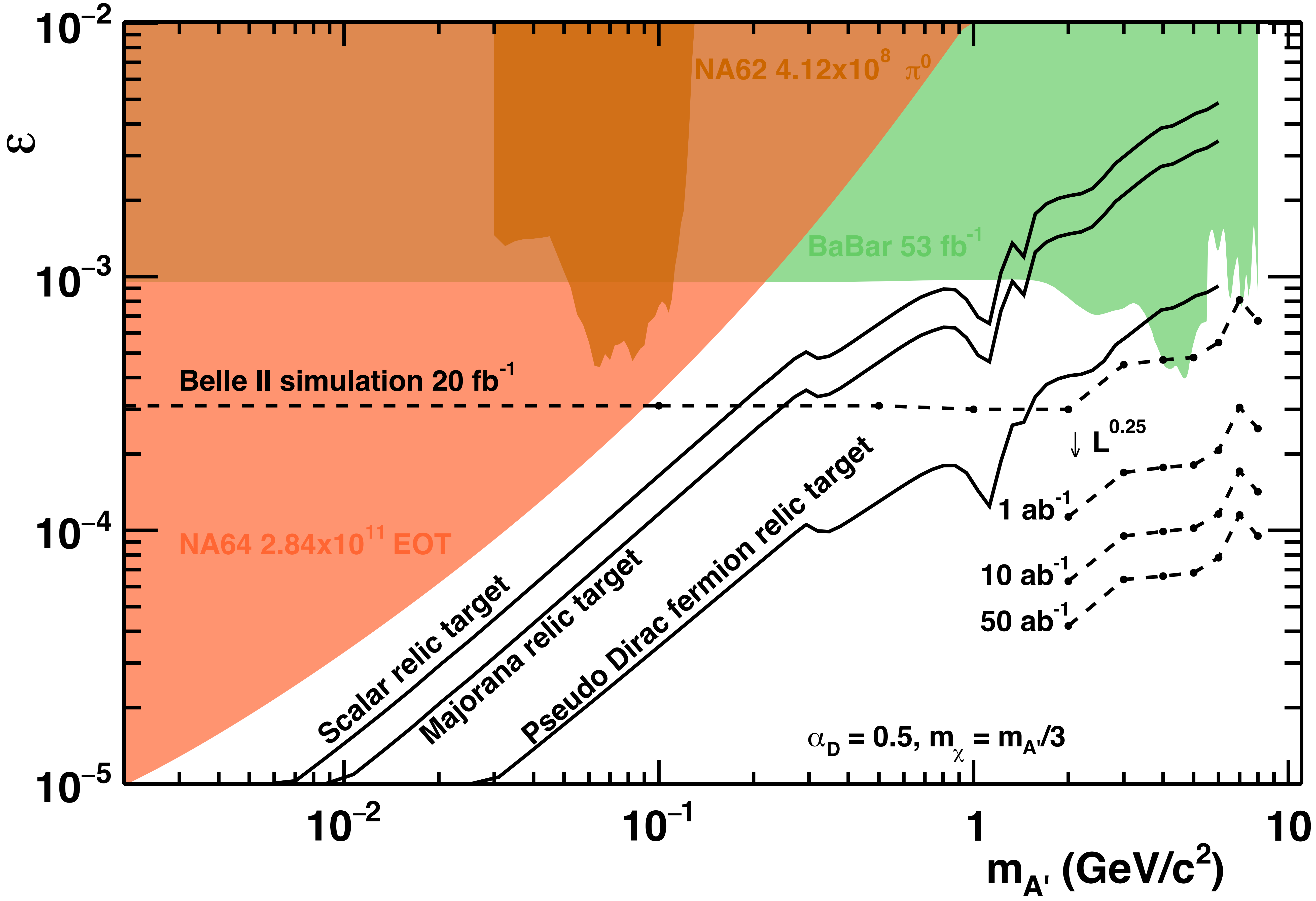
detection via $\bar{\chi}\chi\bar{e}e/\Lambda^2$

[Calabrese+, 2203.17093]

Belle II limits for the scalar mediator

- 10^4 times better w/ m = 100 MeV
- similar to PBH w/ m = 10 MeV

CRBG for DP m < 2 GeV



potential CRBG for DP m < 2 GeV [2207.06307]

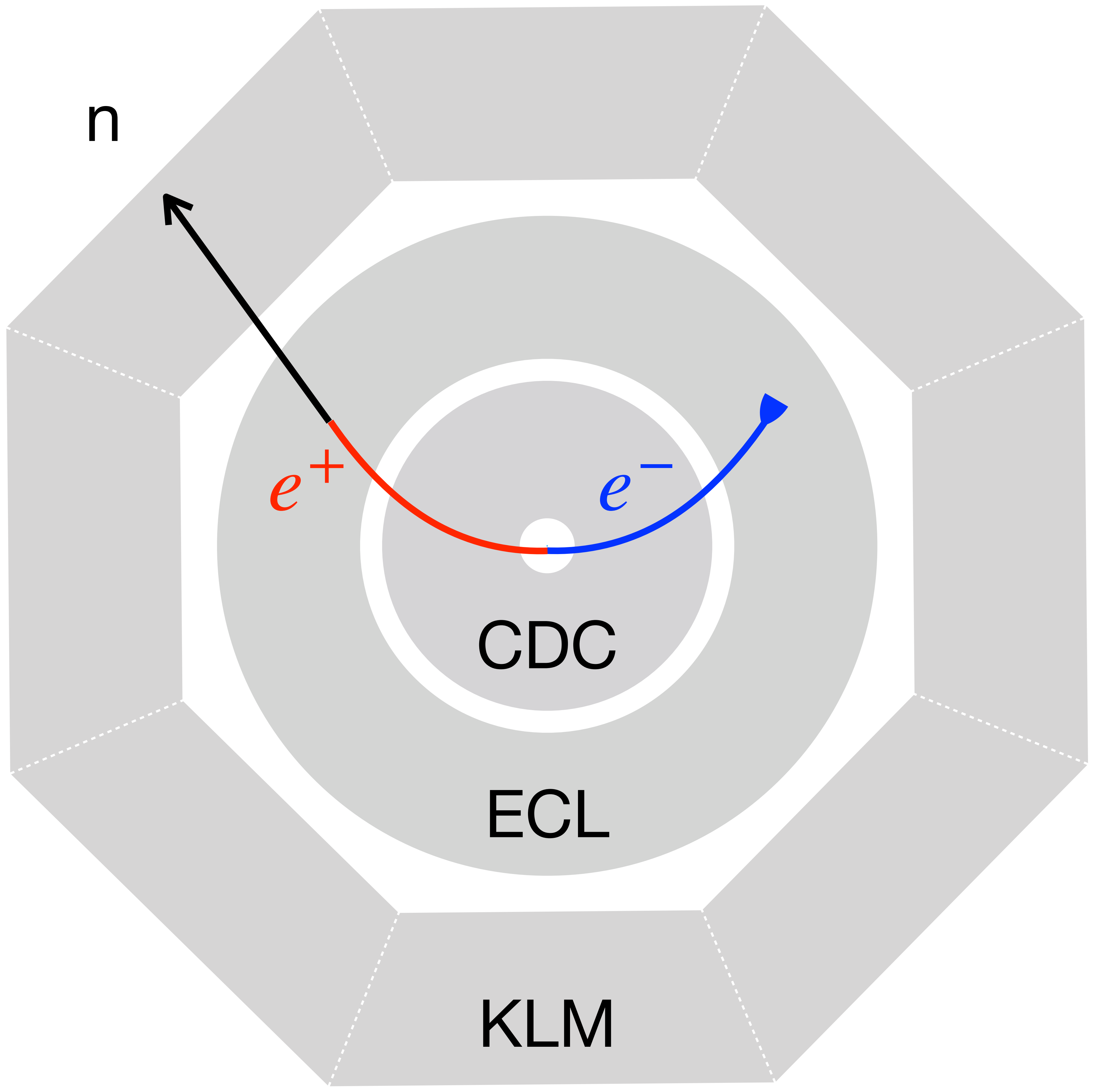
Selection in GEANT4 simulations

At least 1 neutron with energy > 3 GeV

Energy deposition in ECL < 5%

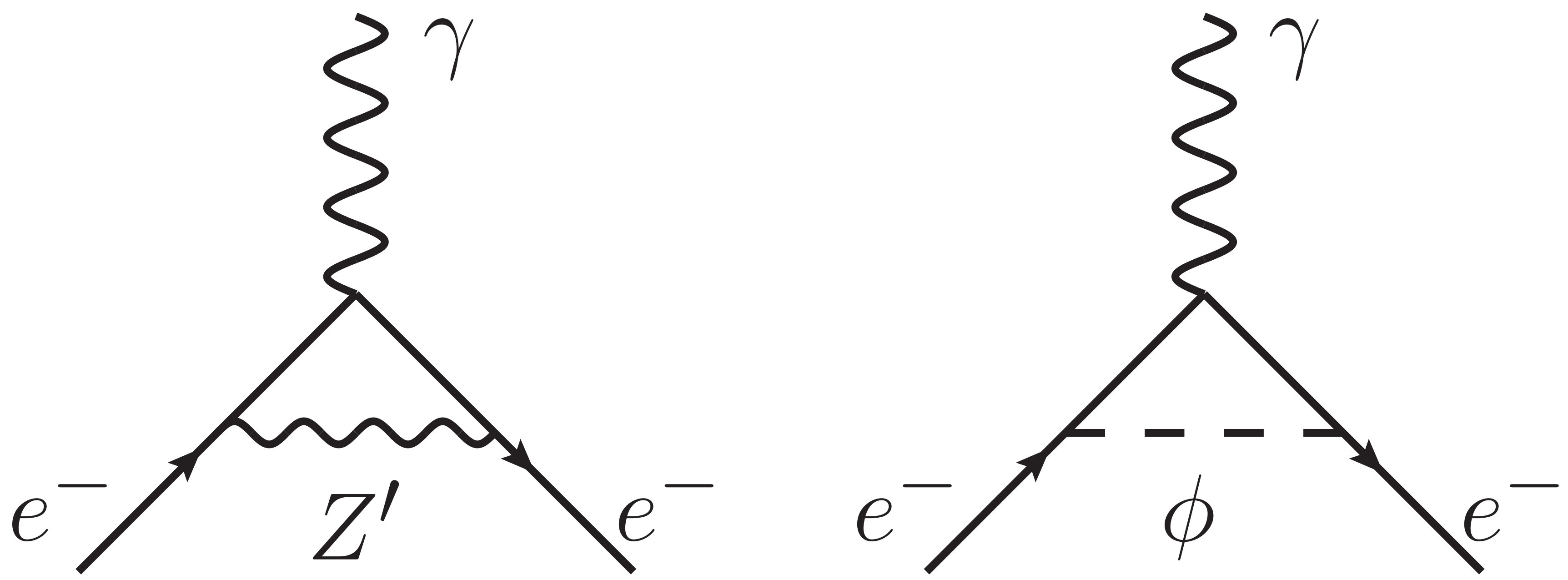
Veto $p/\pi^{\pm}$ with momentum > 0.6 GeV (either deposit energy in ECL or produce tracks in KLM)

Count # of neutrons with K.E. > 280 MeV (hadronic shower threshold)



Experimental constraints on light mediators

- Electron g-2

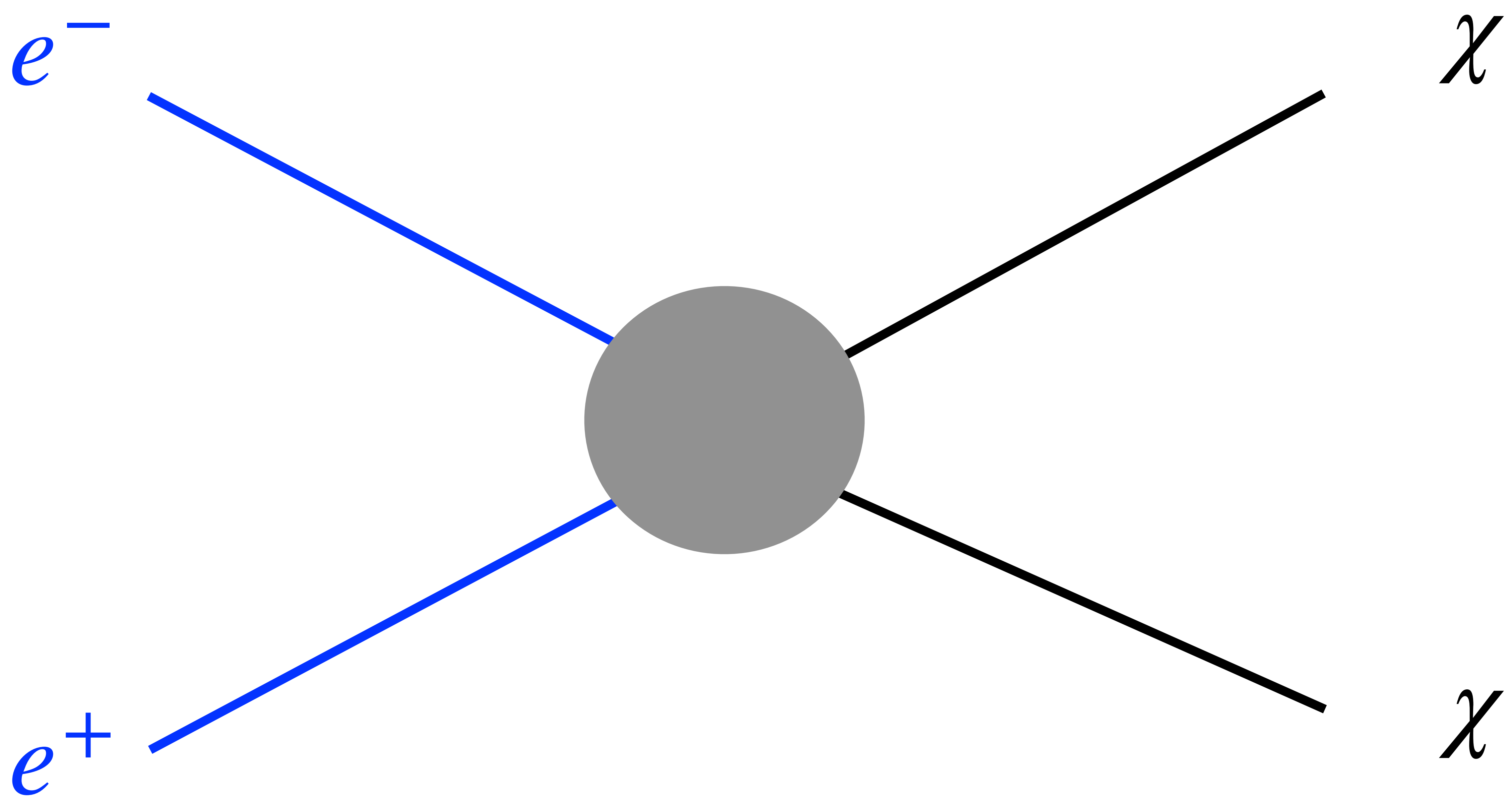


- Electron beam dump & BaBar
  - visible mode
  - invisible mode

- Moller scattering (SLAC E158) $|g_e^V g_e^A| \lesssim 10^{-8}$

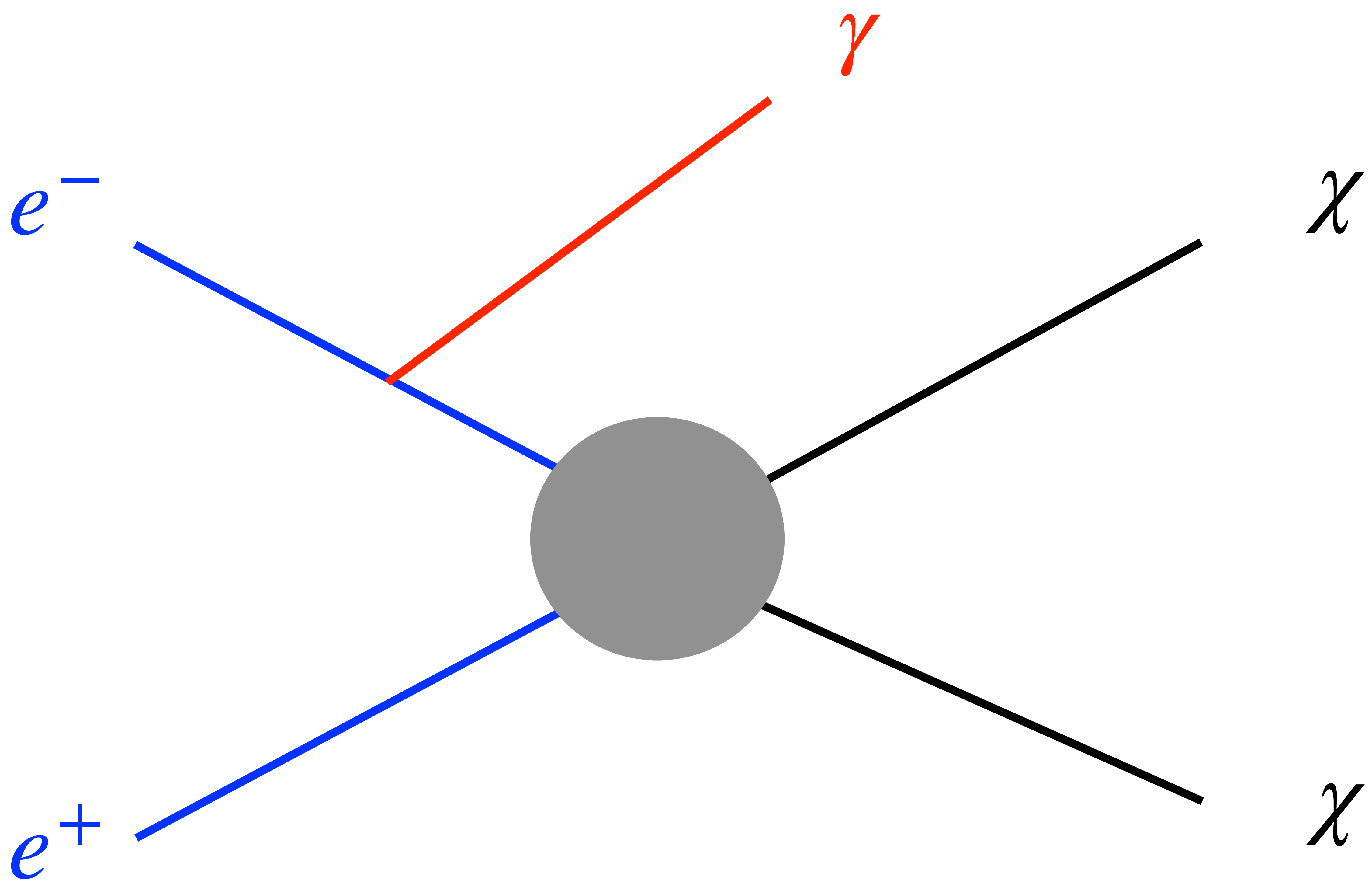
dark matter & millicharged particles

Mono-photon signature at electron colliders

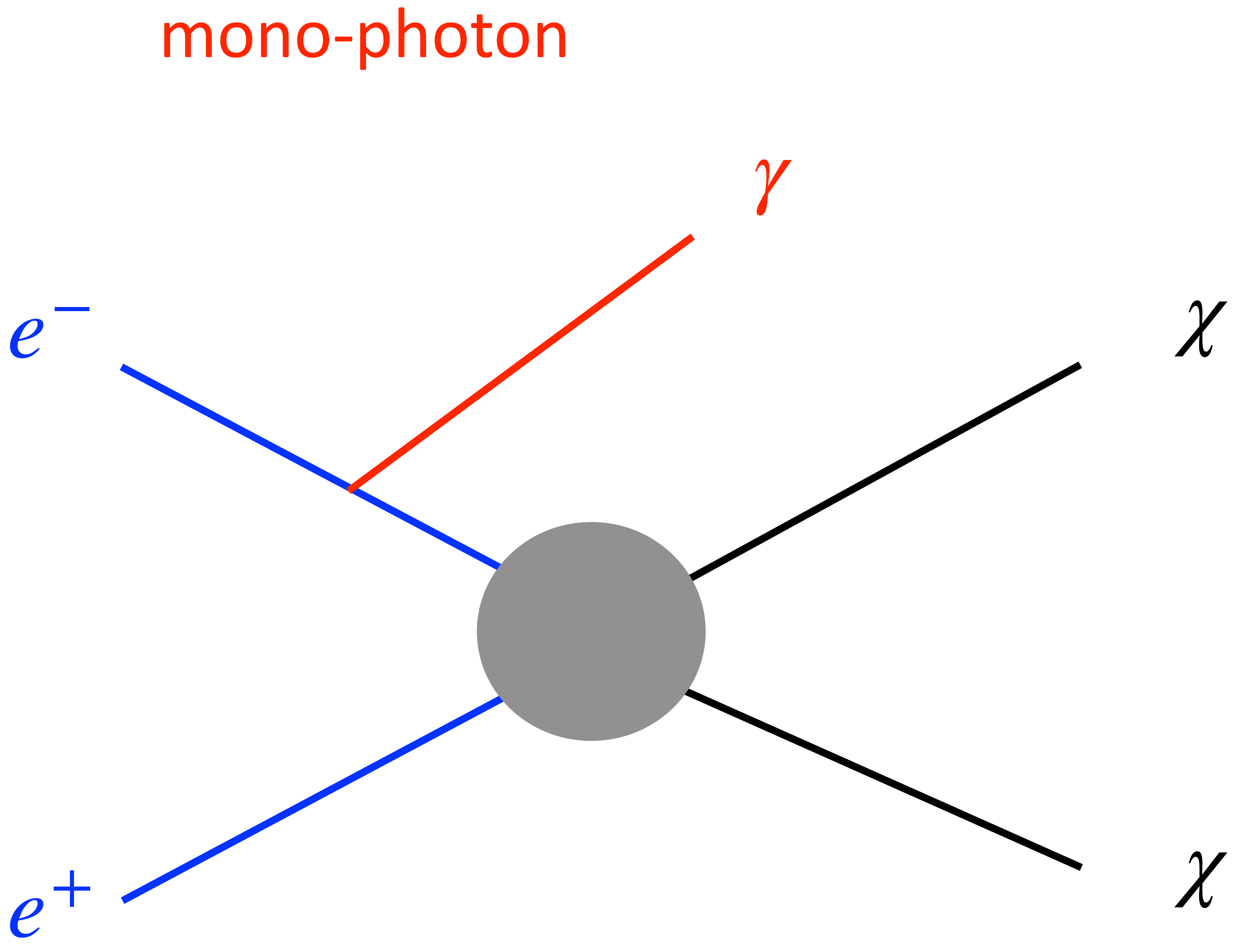


Mono-photon signature at electron colliders

mono-photon



Mono-photon signature at electron colliders



probe a variety of models:

- EFT DM
- light mediator DM
- millicharged particles (undetectable ionization)
- invisible dark photon

Different sub-GeV DM models (diff mediator mass)

EFT DM	$\frac{1}{\Lambda_V^2}\bar{\chi}\gamma_\mu\chi\bar{\ell}\gamma^\mu\ell$	$\frac{1}{\Lambda_A^2}\bar{\chi}\gamma_\mu\gamma_5\chi\bar{\ell}\gamma^\mu\gamma_5\ell$	$\frac{1}{\Lambda_s^2}\bar{\chi}\chi\bar{\ell}\ell$	$\frac{1}{\Lambda_t^2}\bar{\chi}\ell\bar{\ell}\chi$

[ZL, Zhang, 1808.00983] [Liang, ZL, Ma, Zhang, 1909.06847] [Liang, ZL, Yang, 2111.15533]

Different sub-GeV DM models (diff mediator mass)

EFT DM

$$\frac{1}{\Lambda_V^2}\bar{\chi}\gamma_\mu\chi\bar{\ell}\gamma^\mu\ell \qquad \frac{1}{\Lambda_A^2}\bar{\chi}\gamma_\mu\gamma_5\chi\bar{\ell}\gamma^\mu\gamma_5\ell \qquad \frac{1}{\Lambda_s^2}\bar{\chi}\chi\bar{\ell}\ell \qquad \frac{1}{\Lambda_t^2}\bar{\chi}\ell\bar{\ell}\chi$$

Light mediator DM

$$Z'_\mu\bar{\chi}\gamma^\mu\left(g_v^\chi - g_a^\chi\gamma_5\right)\chi + Z'_\mu\bar{\ell}\gamma^\mu\left(g_v^\ell - g_a^\ell\gamma_5\right)\ell$$

[ZL, Zhang, 1808.00983] [Liang, ZL, Ma, Zhang, 1909.06847] [Liang, ZL, Yang, 2111.15533]

Different sub-GeV DM models (diff mediator mass)

EFT DM $\frac{1}{\Lambda_V^2}\bar{\chi}\gamma_\mu\chi\bar{\ell}\gamma^\mu\ell$ $\frac{1}{\Lambda_A^2}\bar{\chi}\gamma_\mu\gamma_5\chi\bar{\ell}\gamma^\mu\gamma_5\ell$ $\frac{1}{\Lambda_s^2}\bar{\chi}\chi\bar{\ell}\ell$ $\frac{1}{\Lambda_t^2}\bar{\chi}\ell\bar{\ell}\chi$

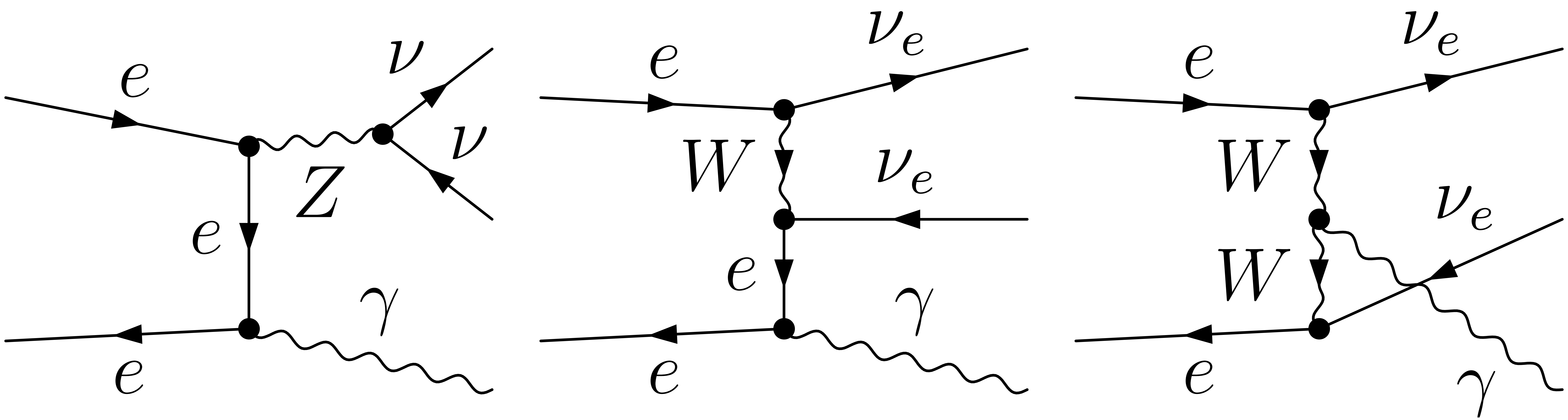
Light mediator DM $Z'_\mu\bar{\chi}\gamma^\mu\left(g_v^\chi - g_a^\chi\gamma_5\right)\chi + Z'_\mu\bar{\ell}\gamma^\mu\left(g_v^\ell - g_a^\ell\gamma_5\right)\ell$

Millicharged particles $\epsilon e A_\mu\bar{\chi}\gamma^\mu\chi$

[ZL, Zhang, 1808.00983] [Liang, ZL, Ma, Zhang, 1909.06847] [Liang, ZL, Yang, 2111.15533]

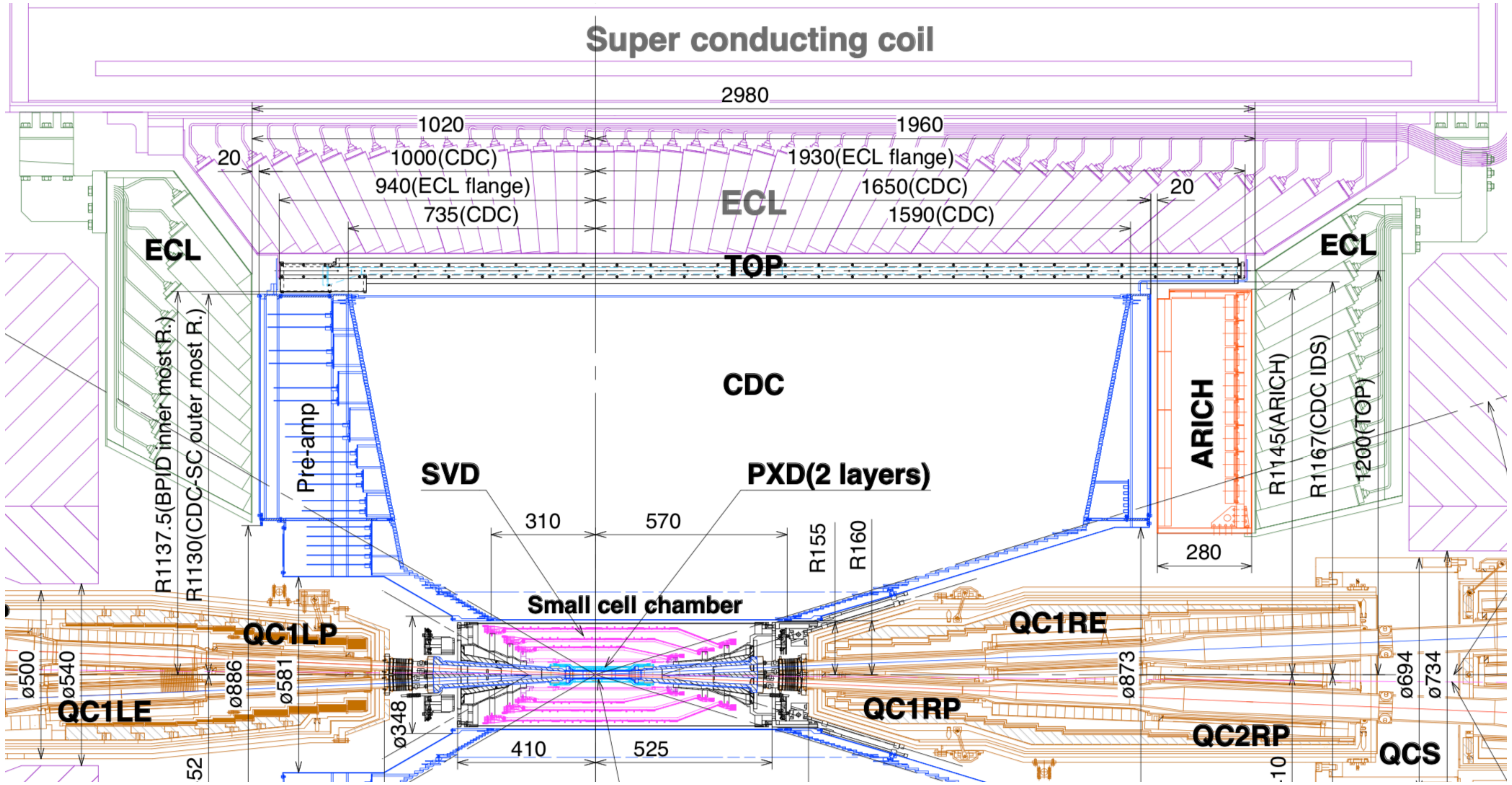
Irreducible background for mono-photon

Irreducible BG: $e^+e^- \rightarrow \gamma\nu\nu$

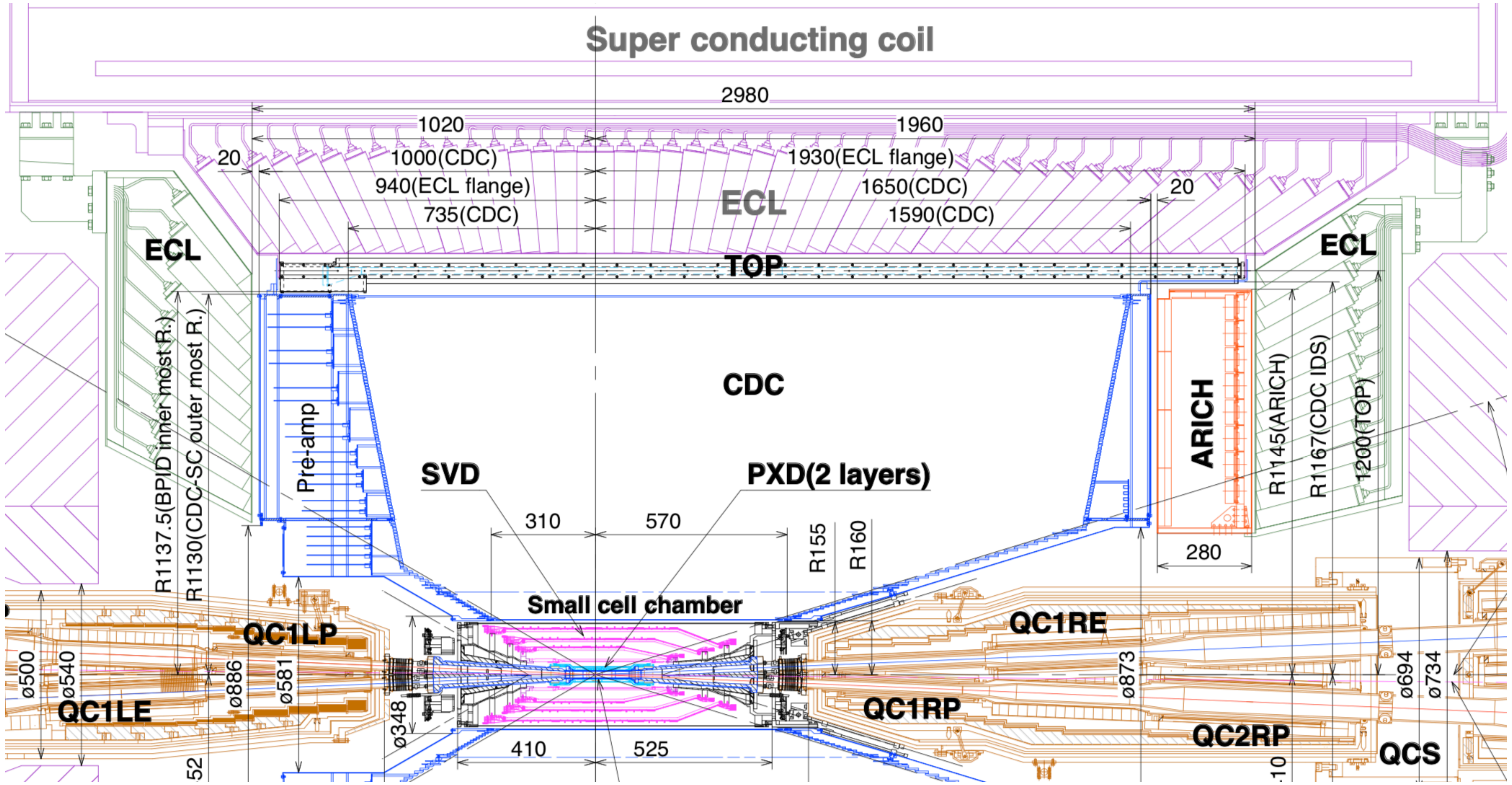


more challenging: reducible BG (due to limitations of the detectors)

Reducible background @ Belle II



Reducible background @ Belle II



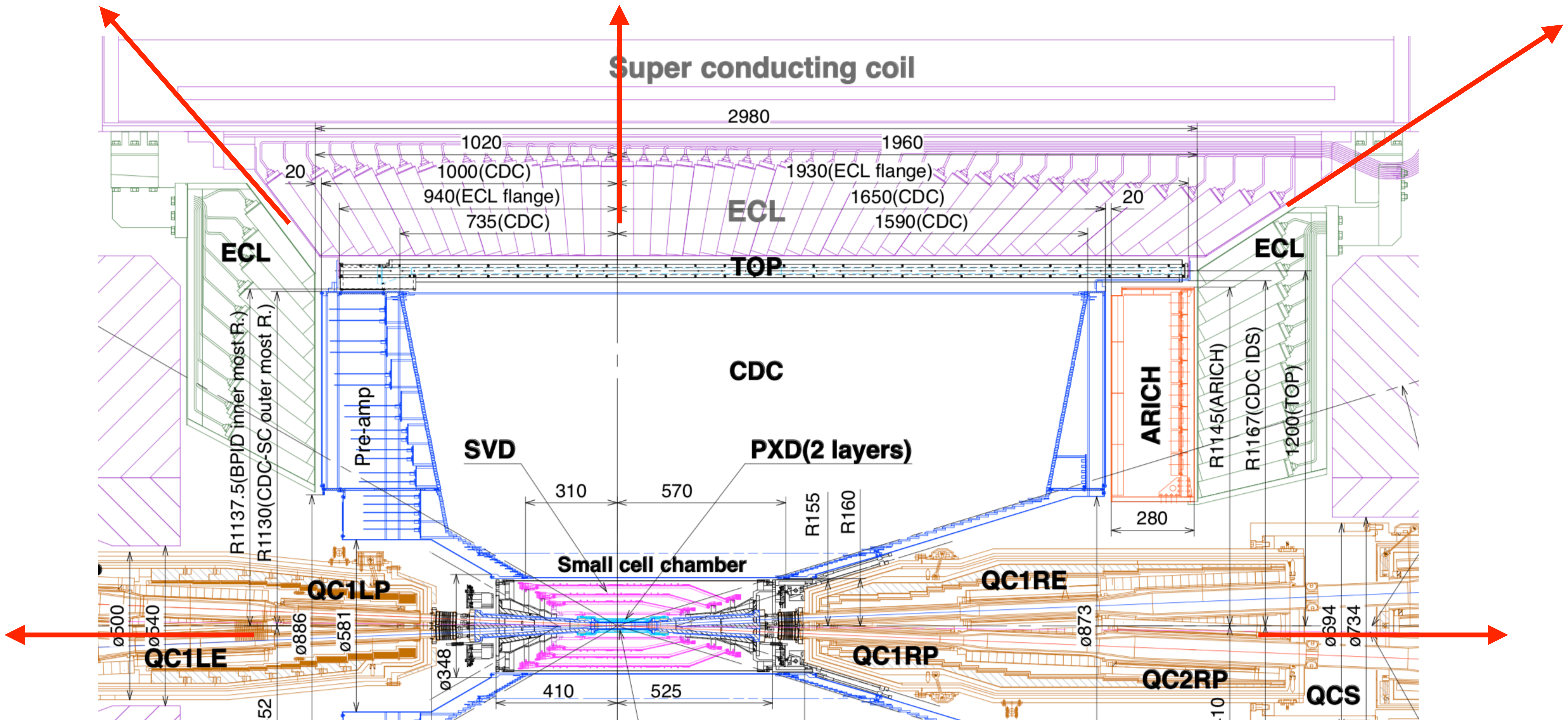
ECL angles

(lab frame)

$$12.4^\circ < \theta < 31.4^\circ$$
$$32.2^\circ < \theta < 128.7^\circ$$
$$130.7^\circ < \theta < 155.1^\circ$$

[Belle II 1808.10567]

Reducible background @ Belle II



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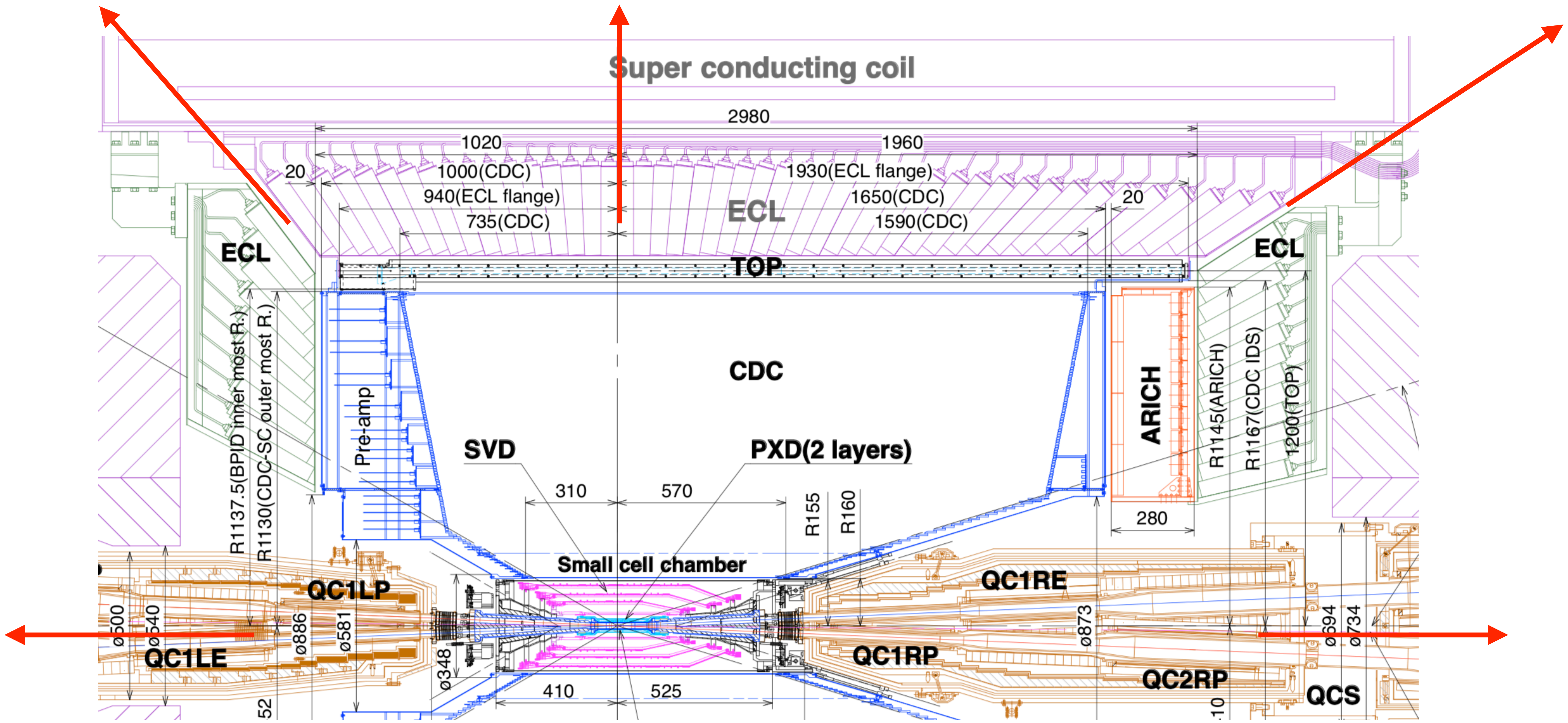

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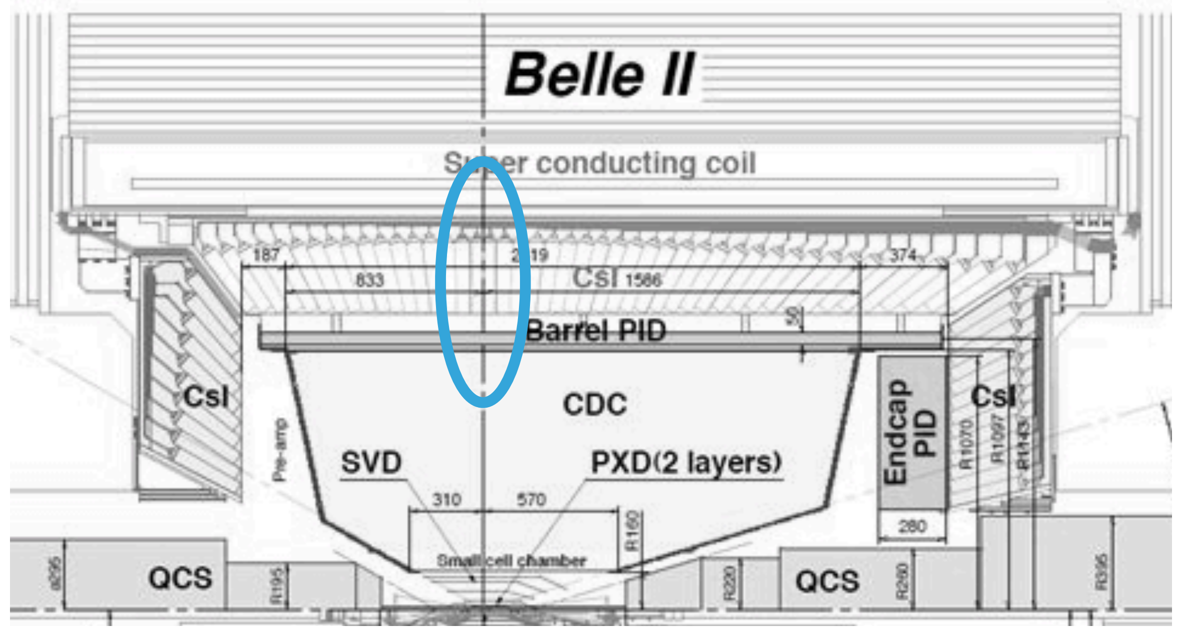
[Belle II 1808.10567]

reducible BG
- BG due to ECL gaps (gBG)
- BG due to beam (bBG)

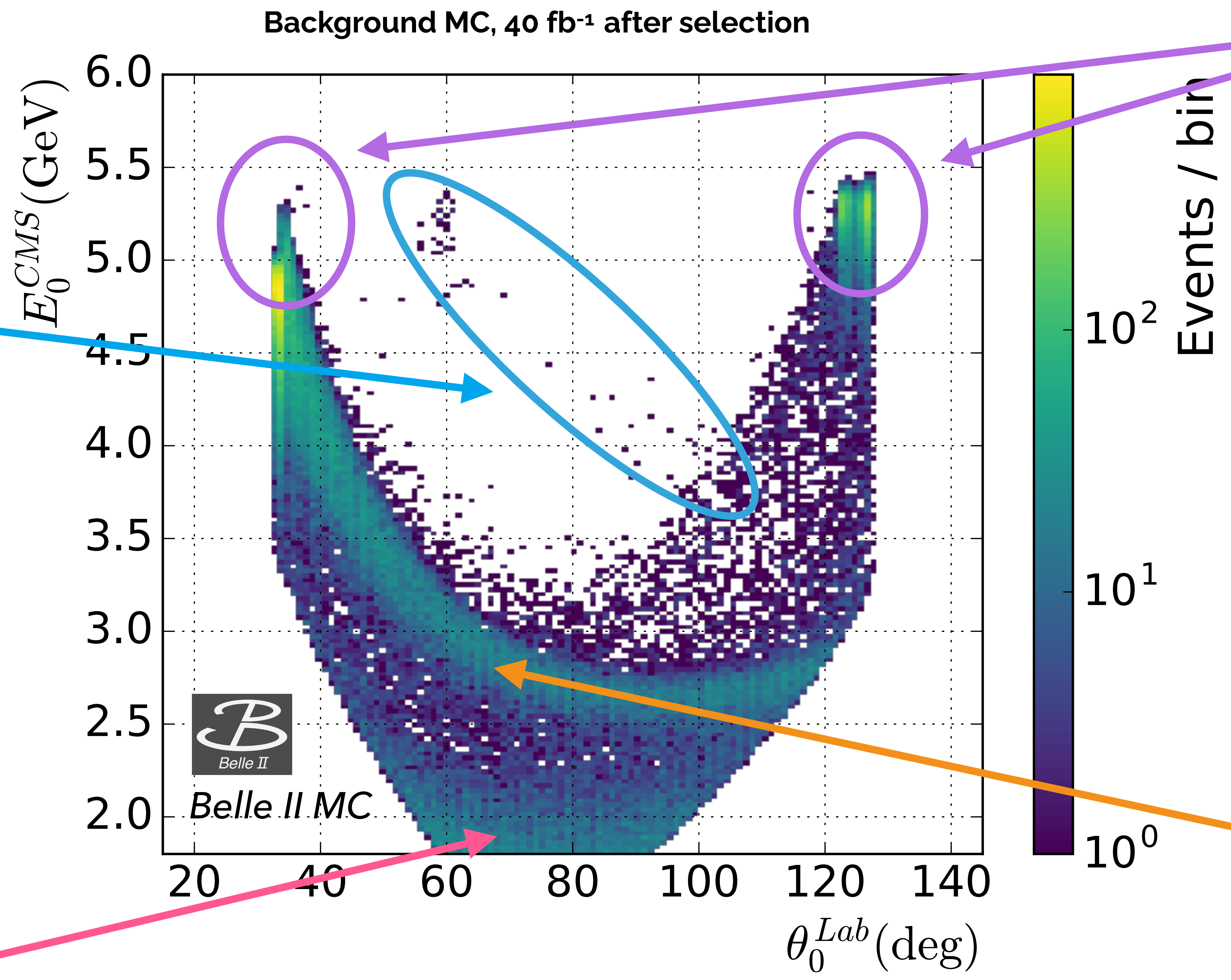
[from Ferber's talk]

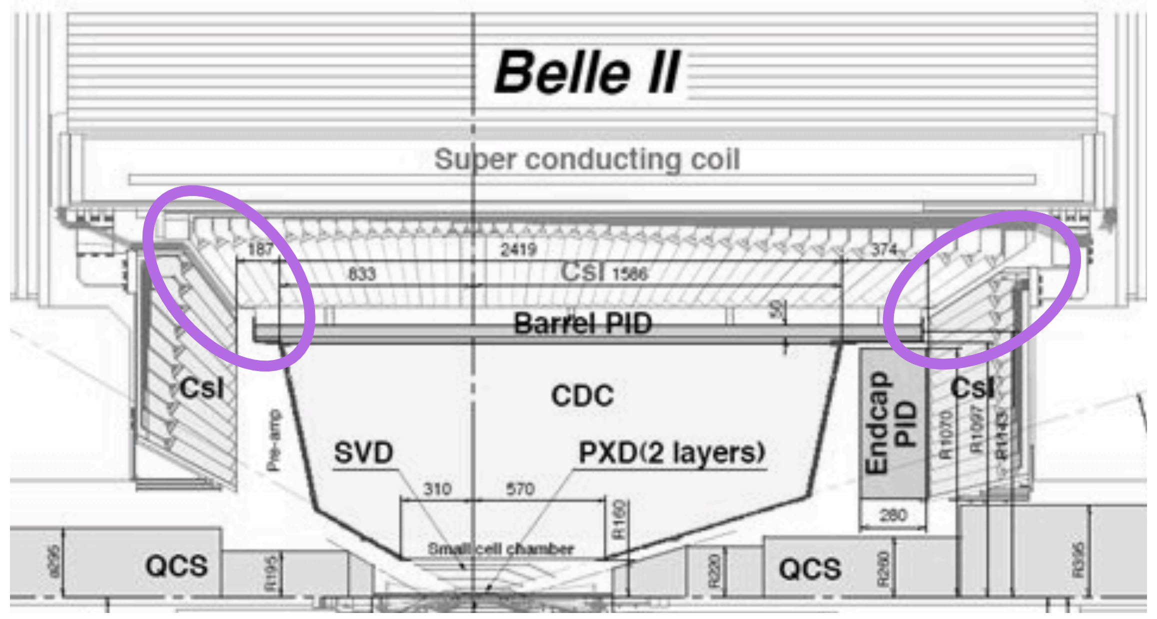
B: Invisible Dark Photon searches



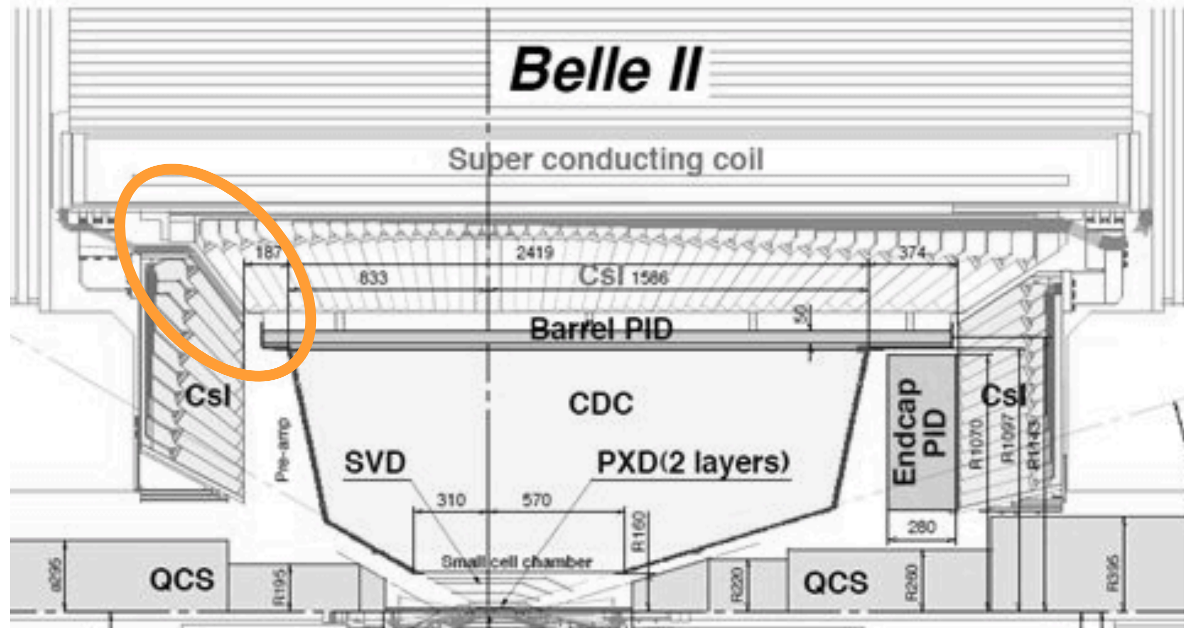
ee→2γ and 3γ
1γ in ECL 90° gap
1γ out of ECL acceptance

$$E_\gamma = \frac{s - M_{A'}^2}{2\sqrt{s}}$$





ee→2γ
1γ in ECL BWD or FWD gap

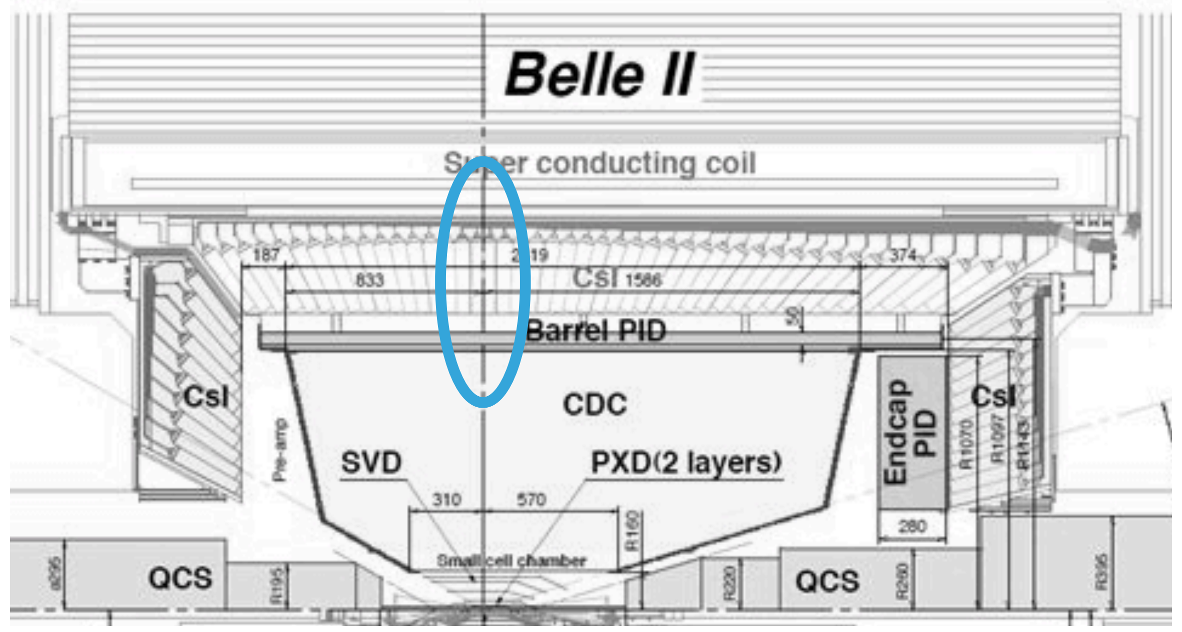


ee→3γ
1γ in ECL BWD gap
1γ out of ECL acceptance

ee→eeγ
both electrons
out of tracking acceptance

[from Ferber's talk]

B: Invisible Dark Photon searches



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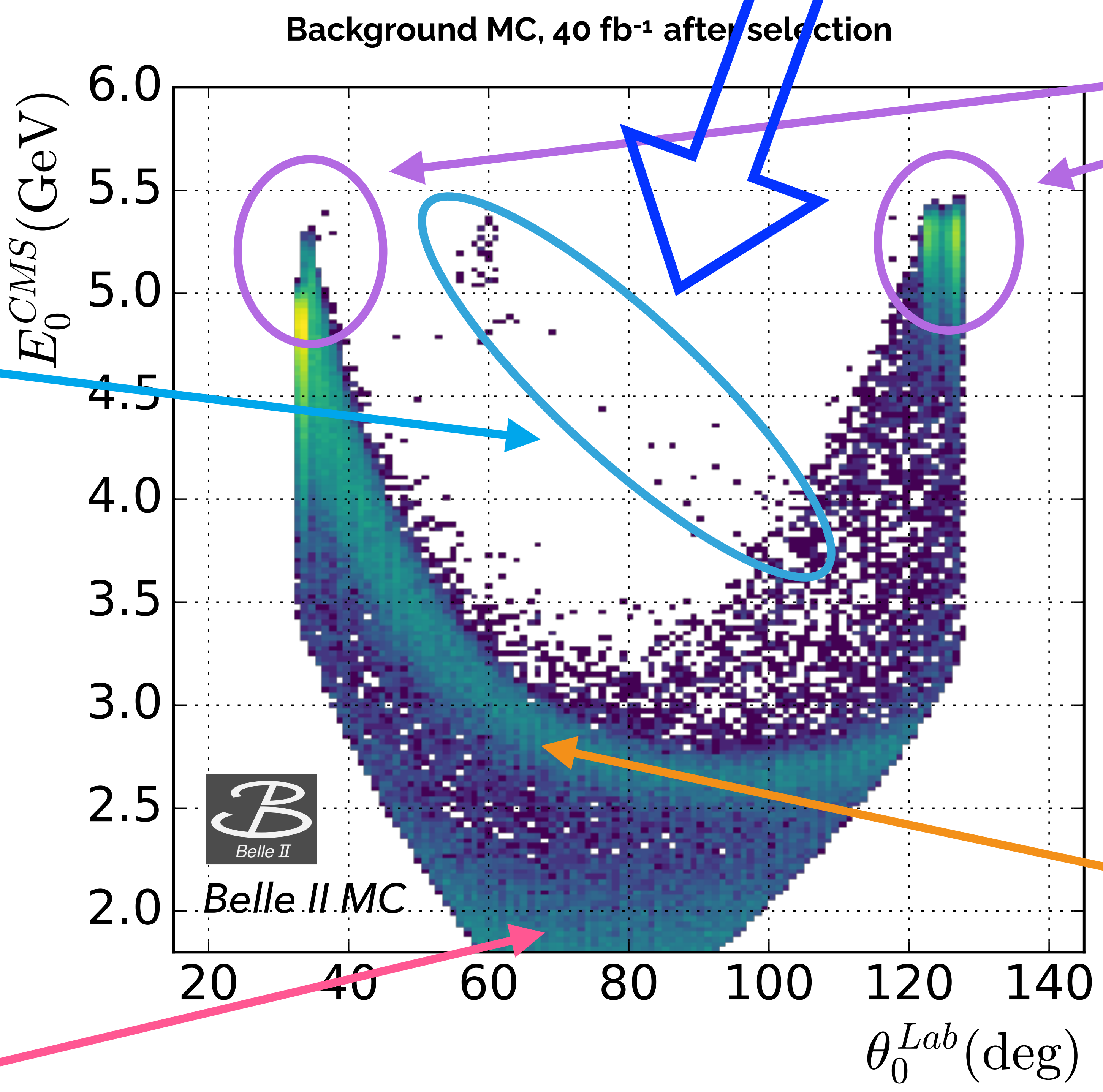

ee→eeγ
both electrons
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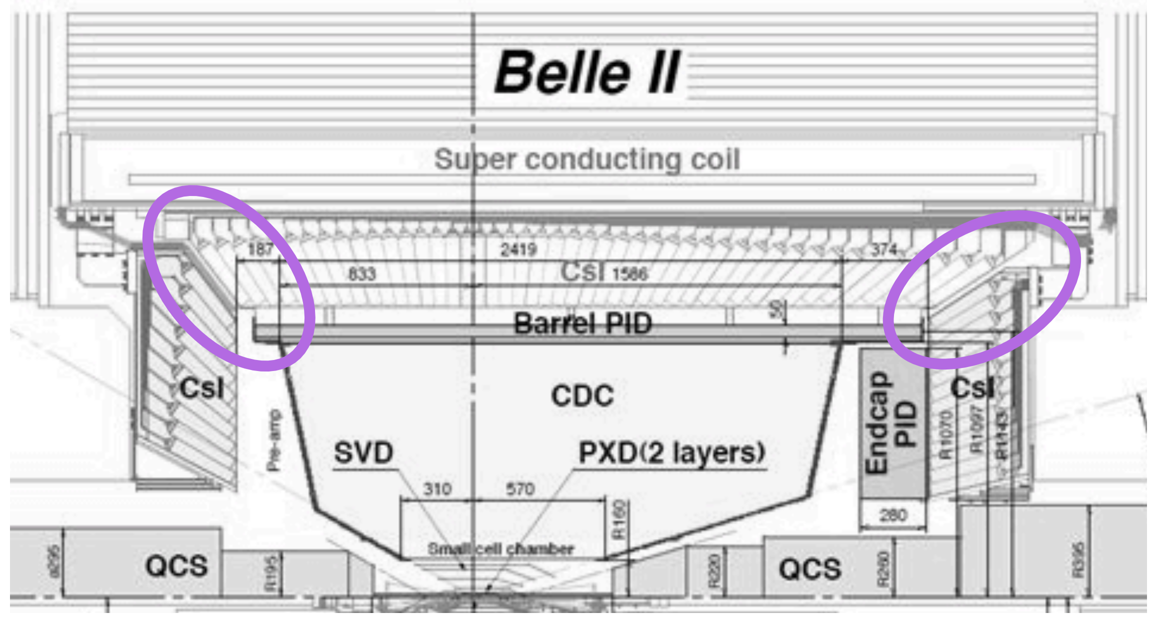

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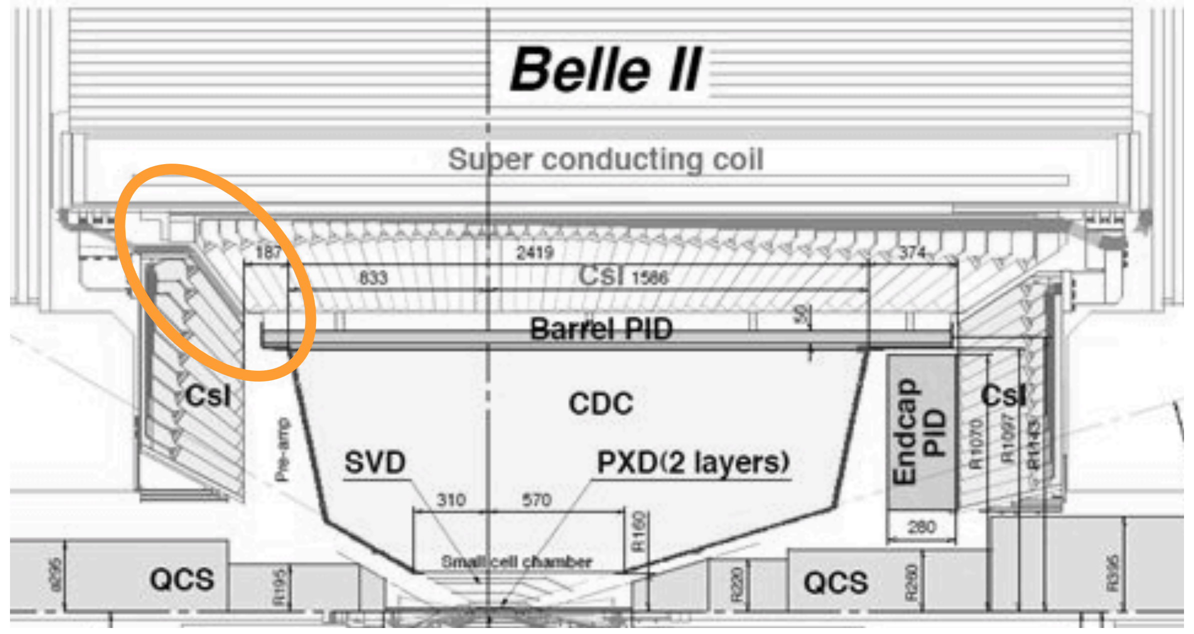
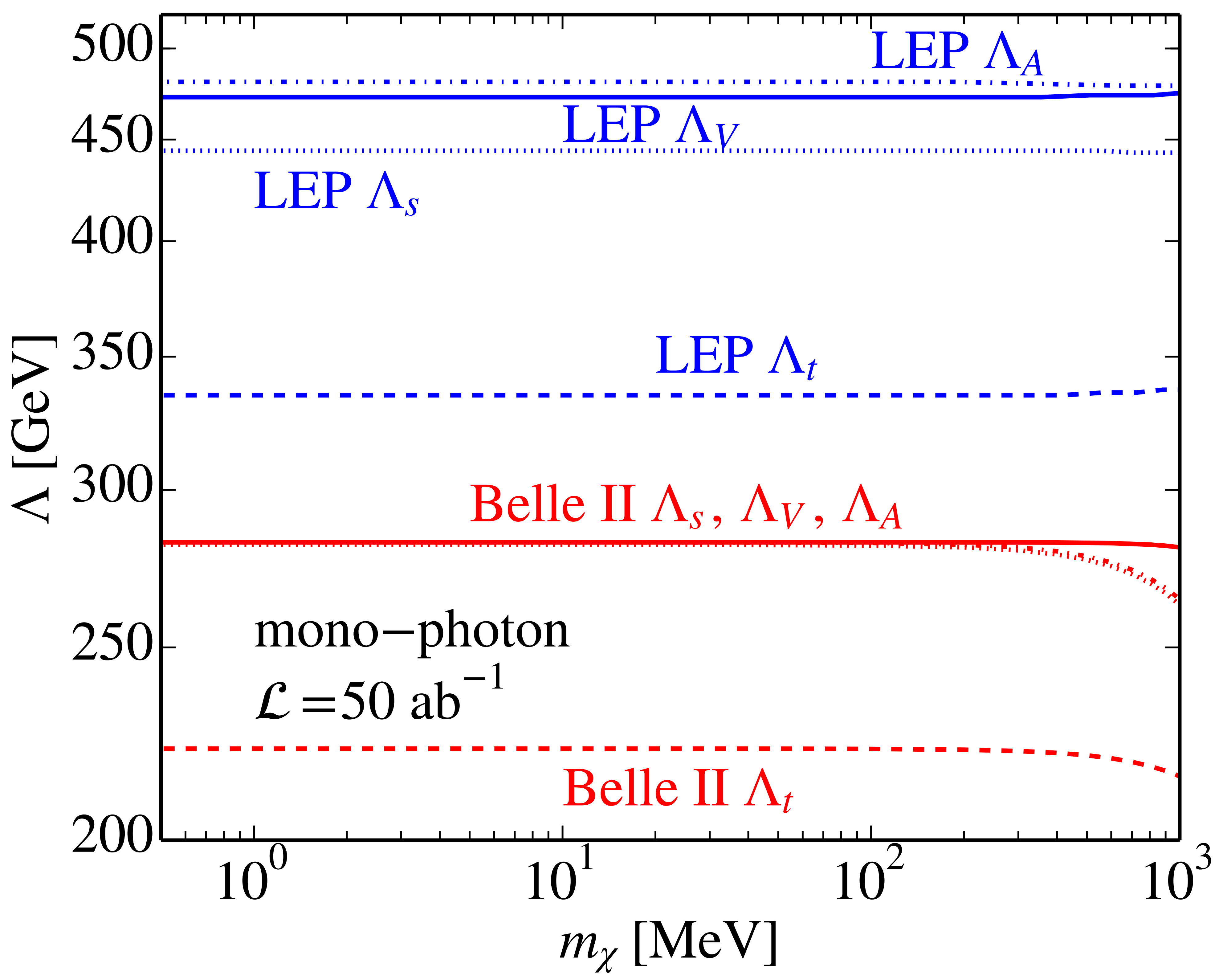


ee→3γ
1γ in ECL BWD gap
1γ out of ECL acceptance

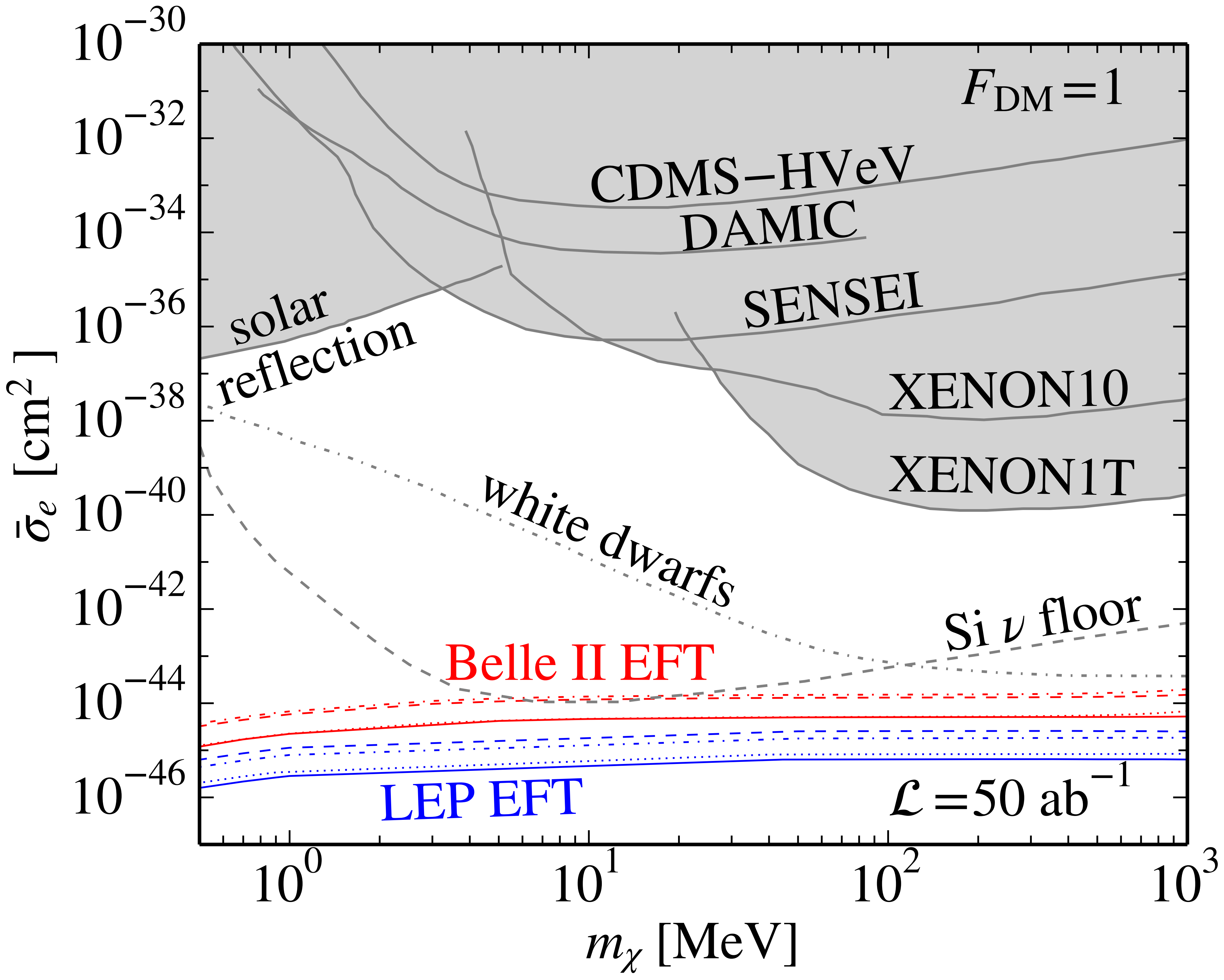
EFT DM probed by Belle II (50/ab)

[Liang, ZL, Yang, 2111.15533]

LEP is better than Belle II for EFT-DM



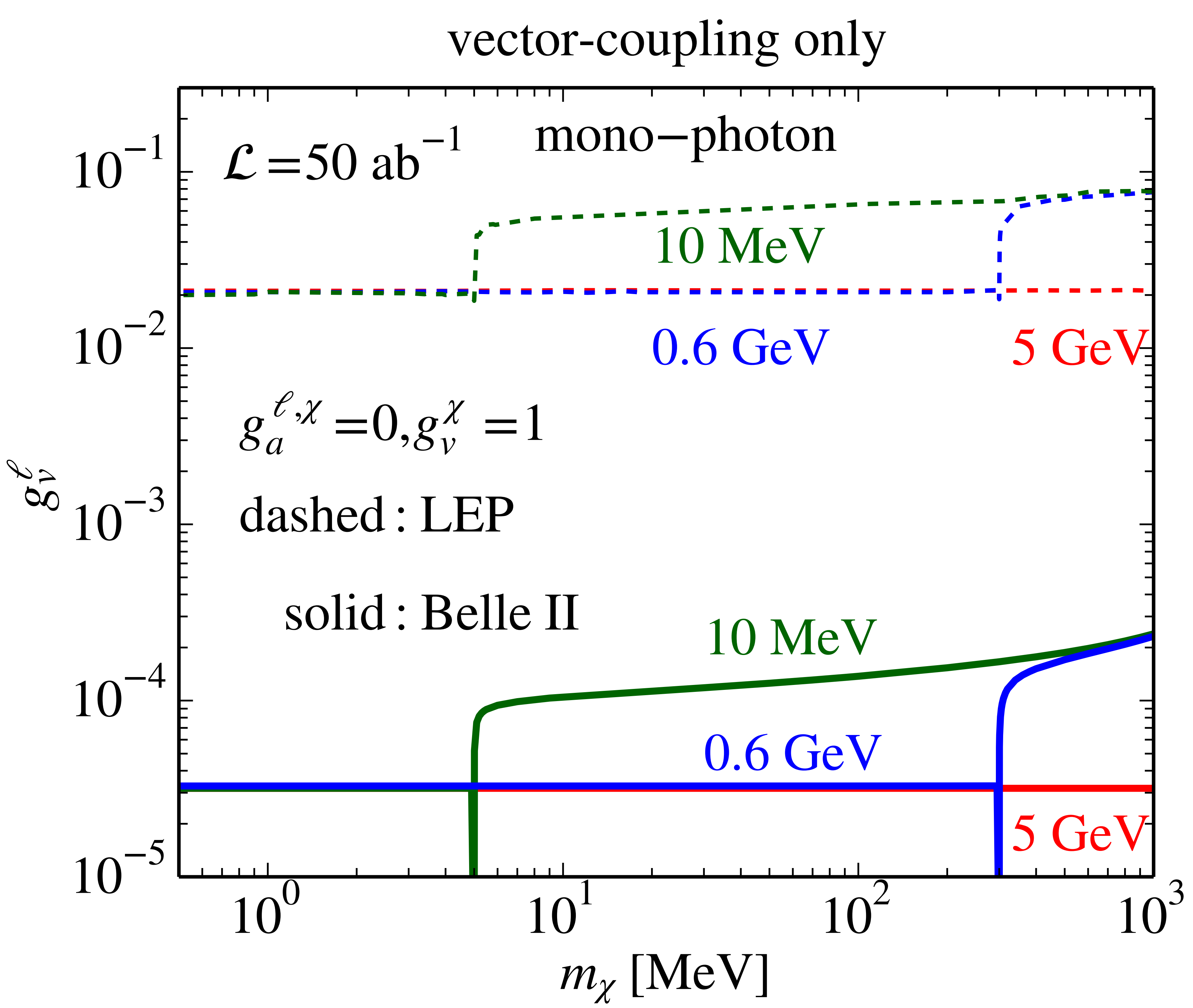
Electron colliders are better than DMDD



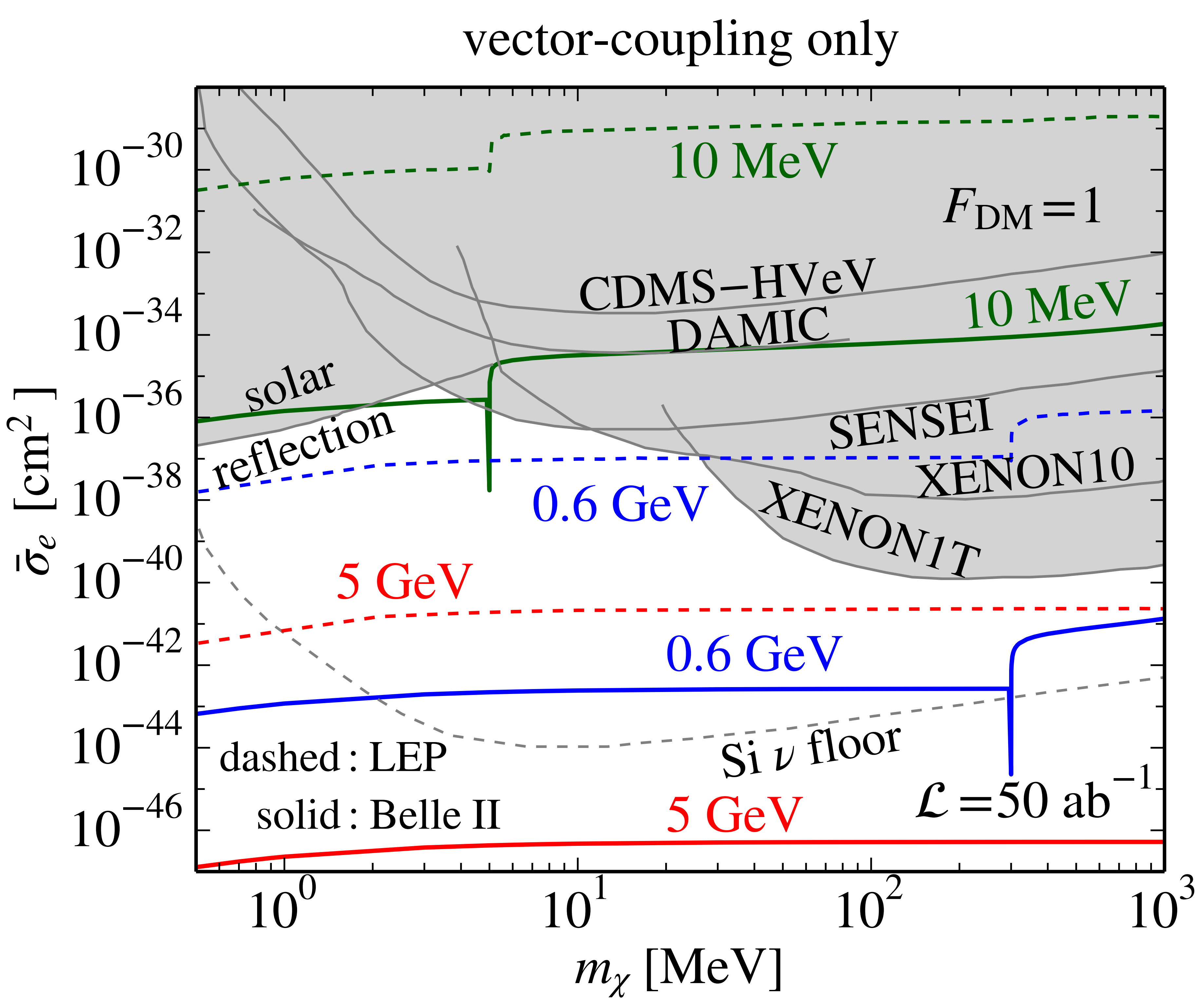
$$\frac{1}{\Lambda_V^2}\bar{\chi}\gamma_\mu\chi\bar{\ell}\gamma^\mu\ell$$

Light mediator DM probed by Belle II (50/ab) [2111.15533]

Belle II is better than LEP for light mediator DM



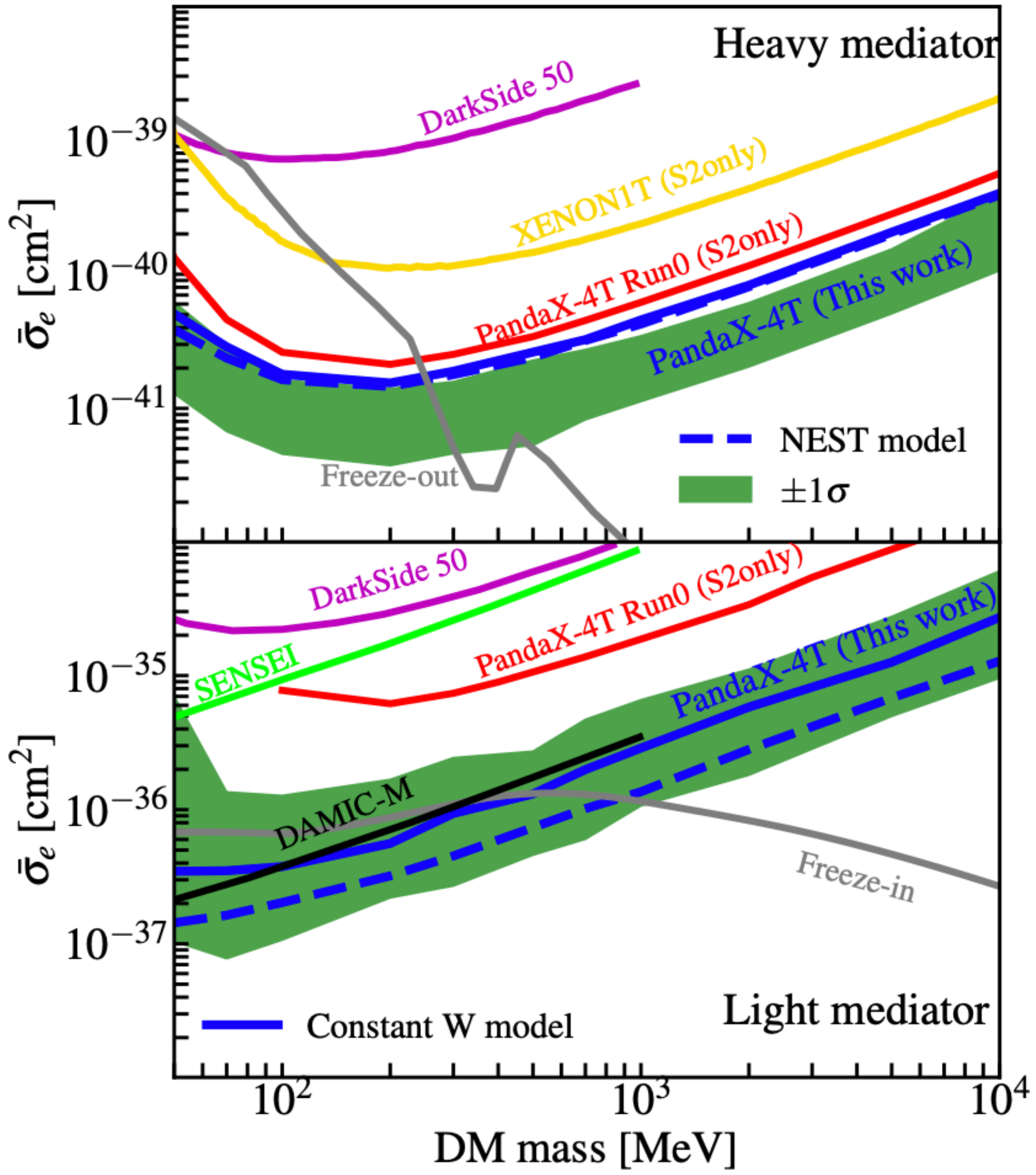
Electron colliders can be better than DMDD



$$Z'_\mu \bar{\chi}\gamma^\mu \left(g_v^\chi - g_a^\chi \gamma_5\right)\chi + Z'_\mu \bar{\ell}\gamma^\mu \left(g_v^\ell - g_a^\ell \gamma_5\right)\ell$$

$M_{Z'} =$ 5 GeV, 0.6 GeV, 10 MeV

PandaX-4T limits on light DM

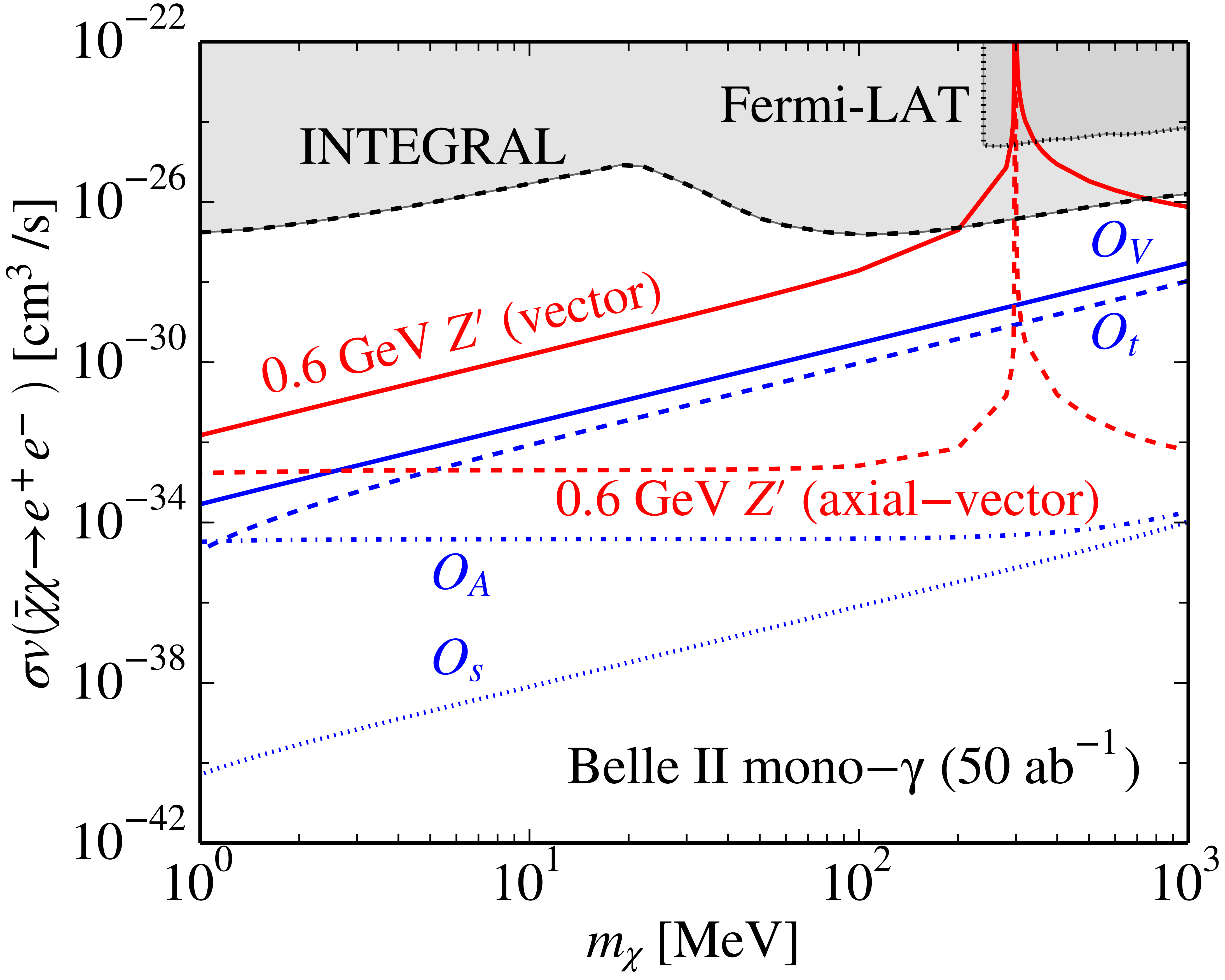


Search for Light Dark Matter with 259 Days of Data in PandaX-4T

[PandaX-4T, 2507.11930]

Belle II vs dark matter indirect detection experiments

Electron colliders can be better than DMID



Photons from DM annihilation

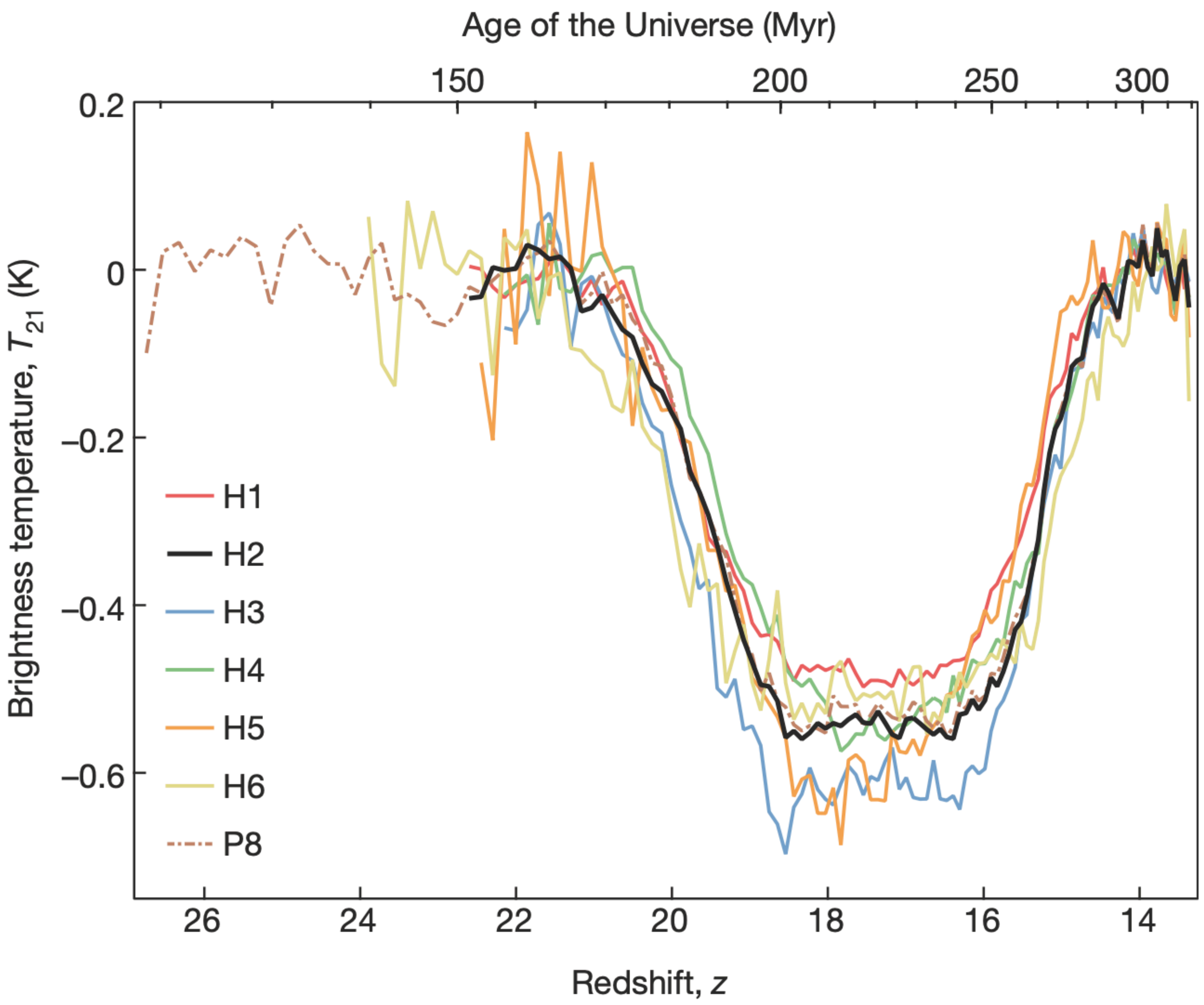
INTEGRAL

Fermi-LAT

[Liang, ZL, Yang, 2111.15533]

millicharged particles

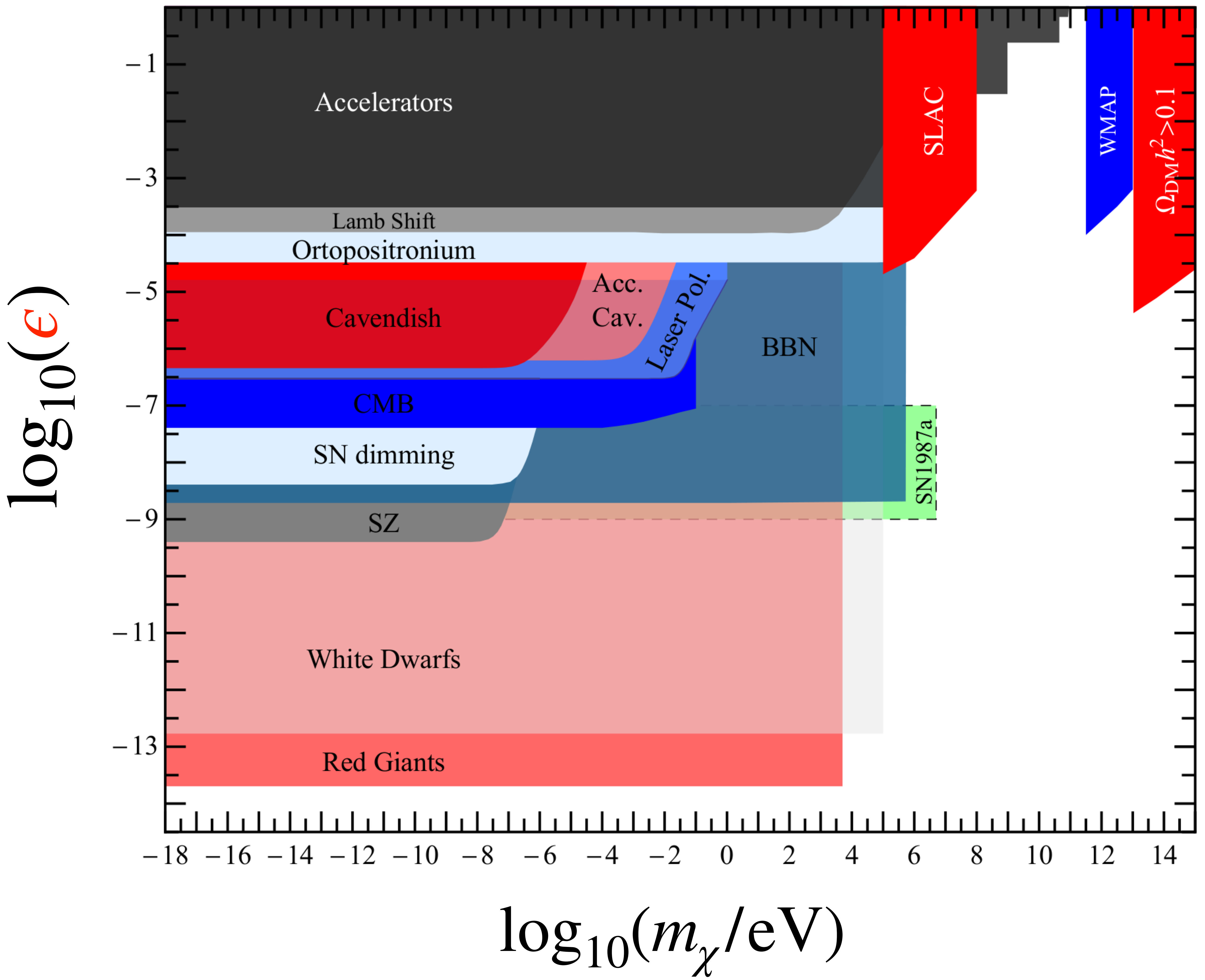
Millicharged dark matter can explain EDGES 21 cm anomaly



[Bowman teal, Nature 555 (2018) 67–70]

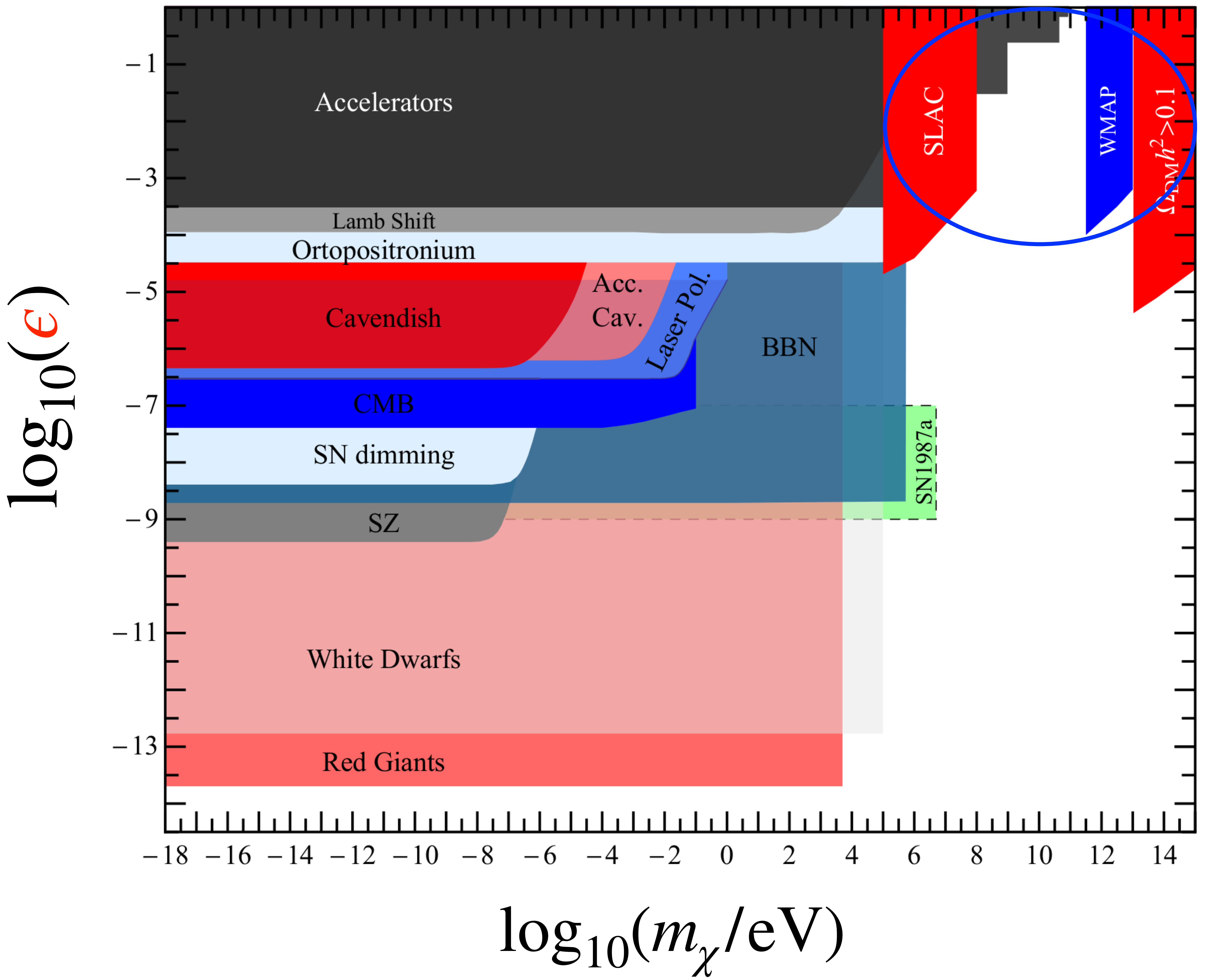
[Munoz & Loeb, Nature 557 (2018) 684]

Millicharge in BSM can be quite "large"



[Jaeckel, Ringwald, 1002.0329]

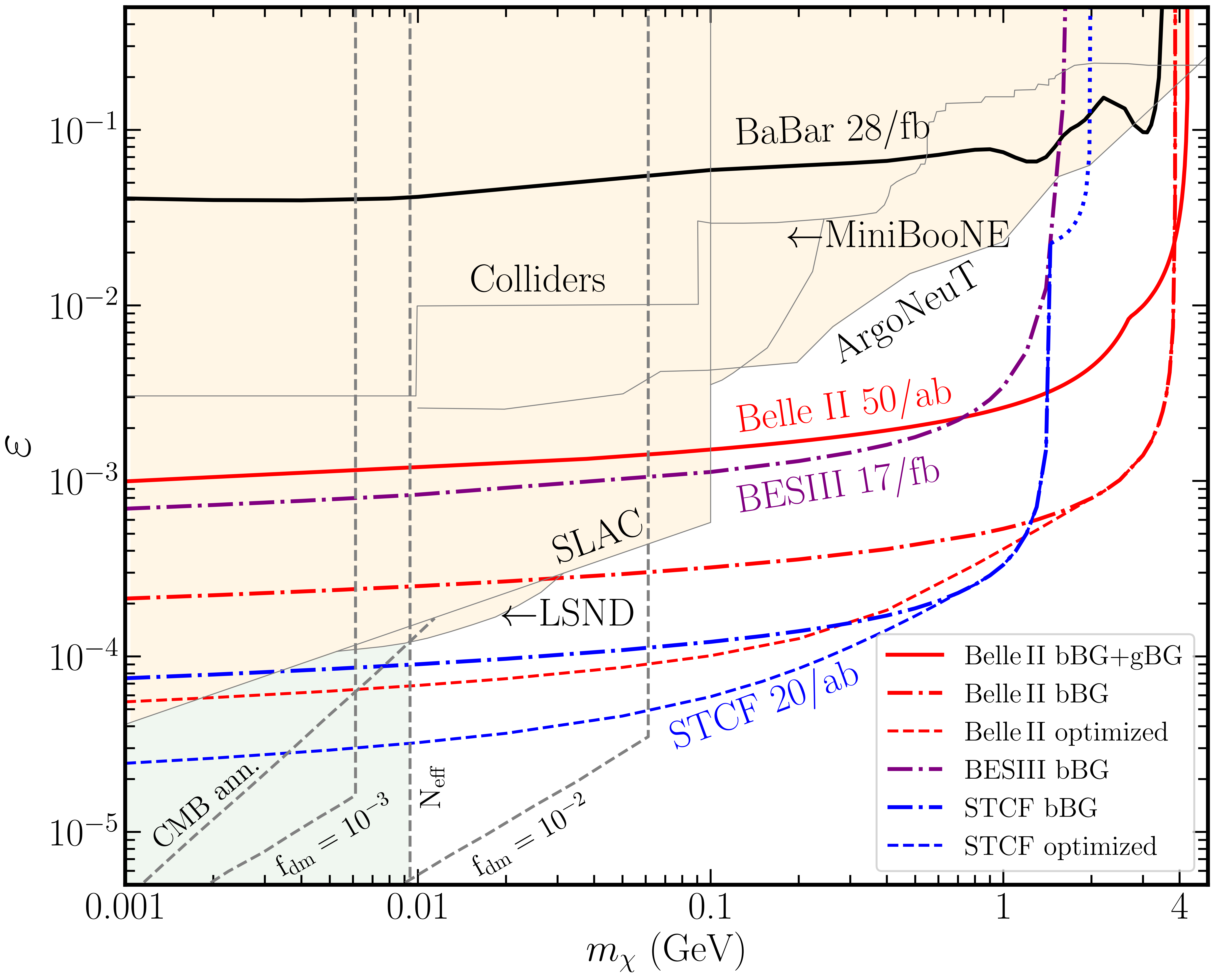
Millicharge in BSM can be quite "large"



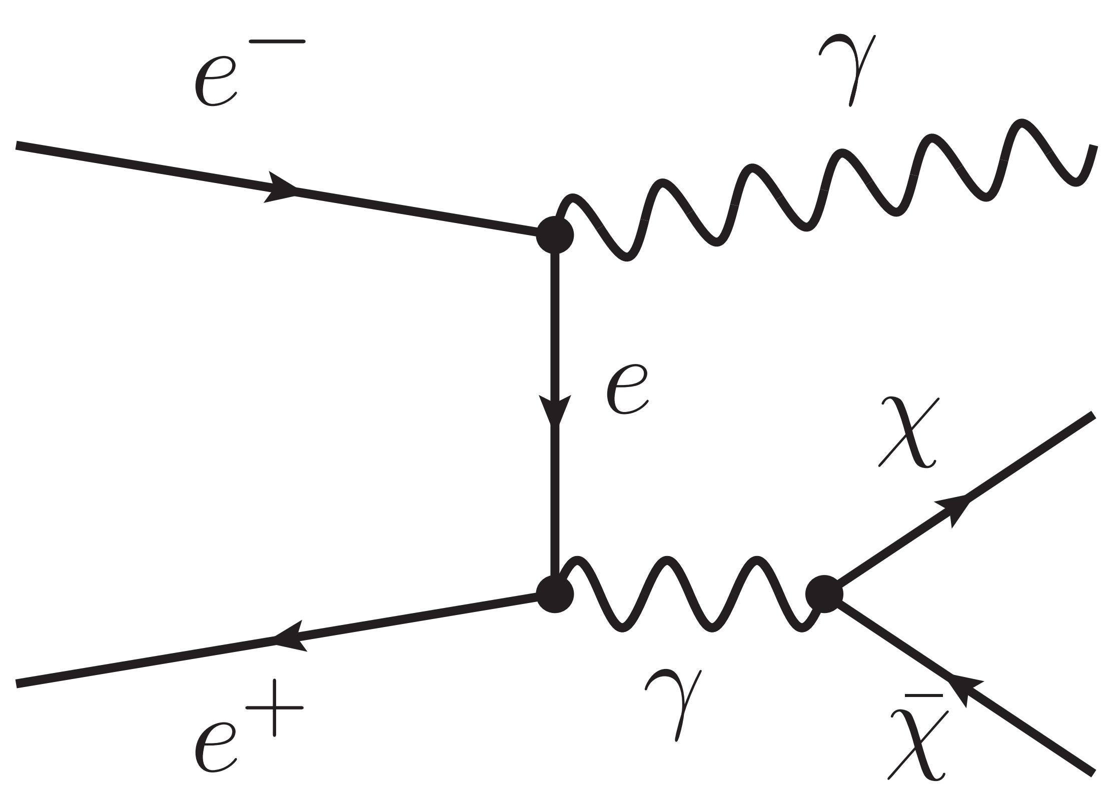
probed by e^+e^- colliders

[Jaeckel, Ringwald, 1002.0329]

Millicharged particles probed by electron colliders



mono-photon

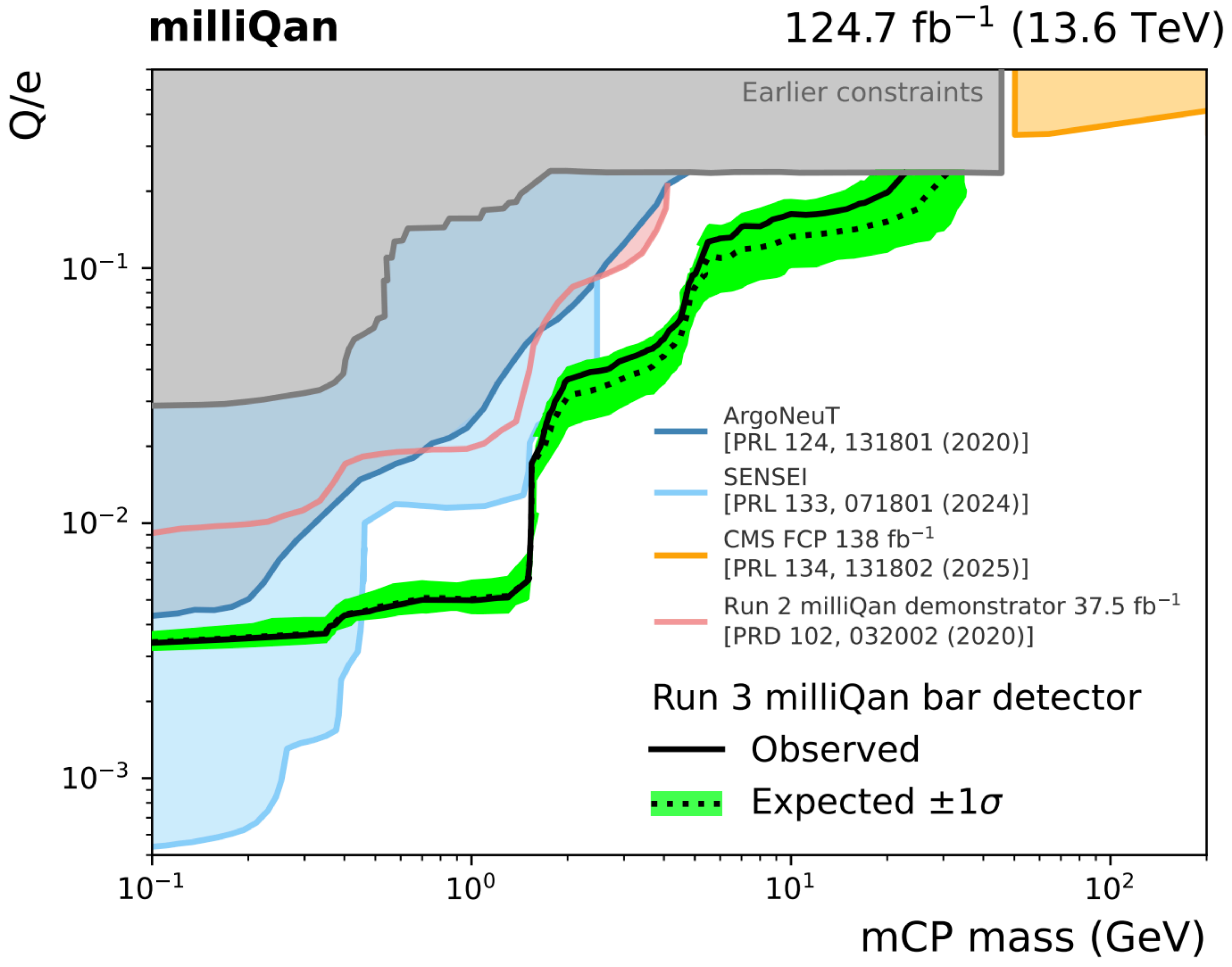


electron collider can probe new parameter space

[ZL, Zhang, 1808.00983]

[Liang, ZL, Ma, Zhang, 1909.06847]

Run 3 milliQan bar detector

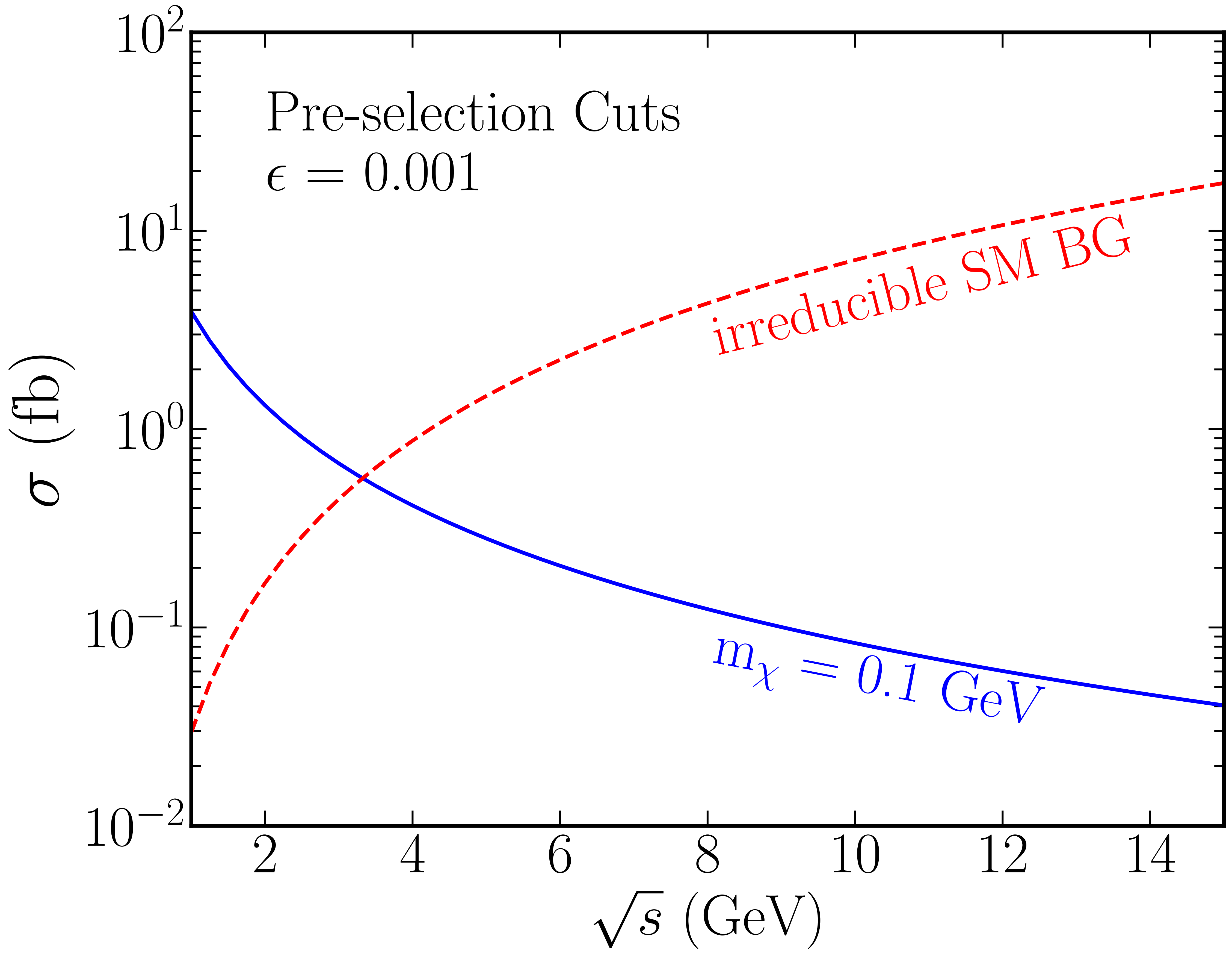


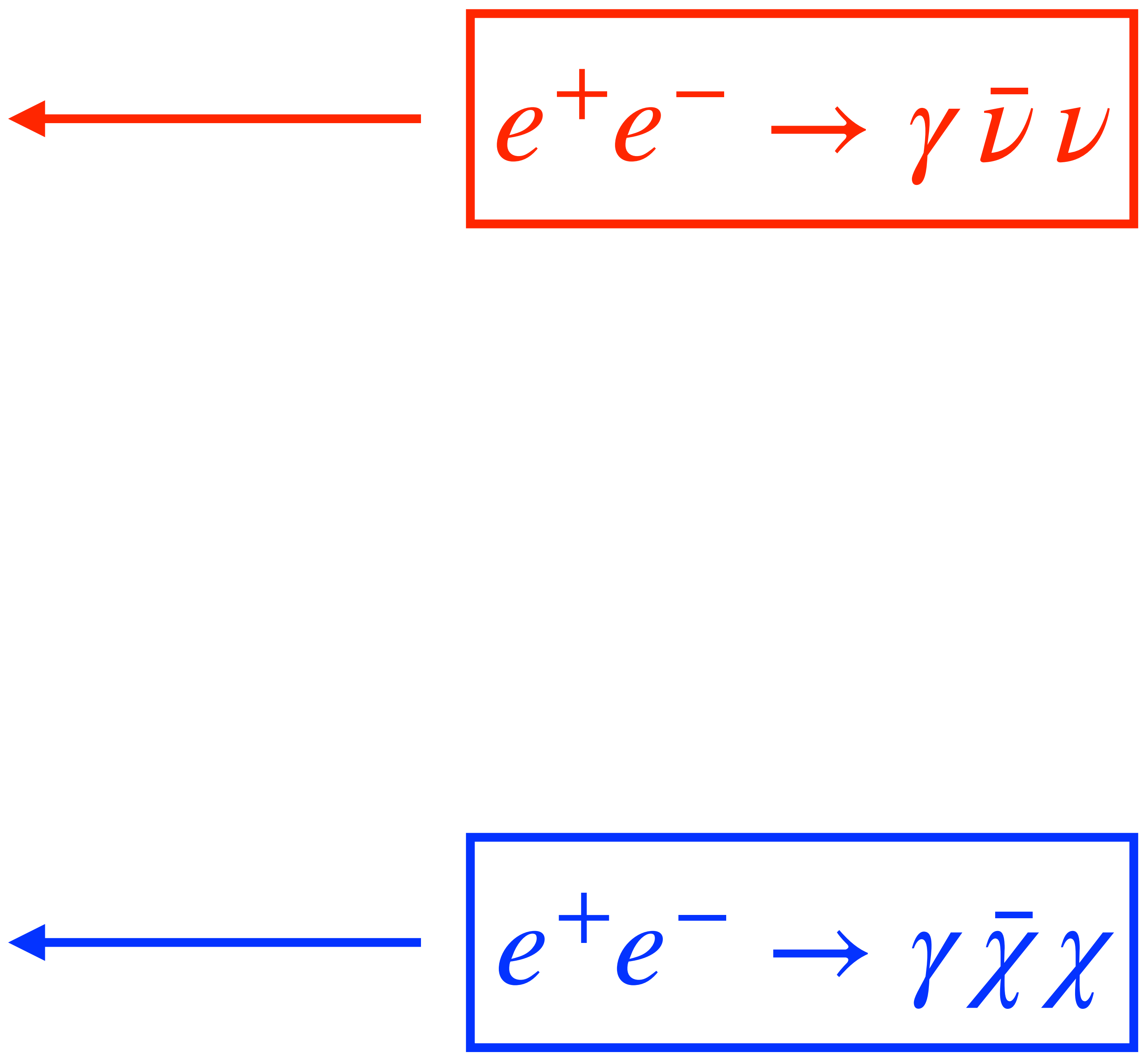
[2506.02251]

Low colliding energy is better to probe MCPs

if irreducible BG is the only important BG

BESIII/STCF vs Belle II





A wish list of an ignorant theorist

- Better hermicity of ECL (less or no gaps?)
- More angular coverage
- More powerful KLM-kind detector (veto)
- Place another detector when there is a gap?