Neutrino dipole portal at electron colliders

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based on arXiv:2204.07802

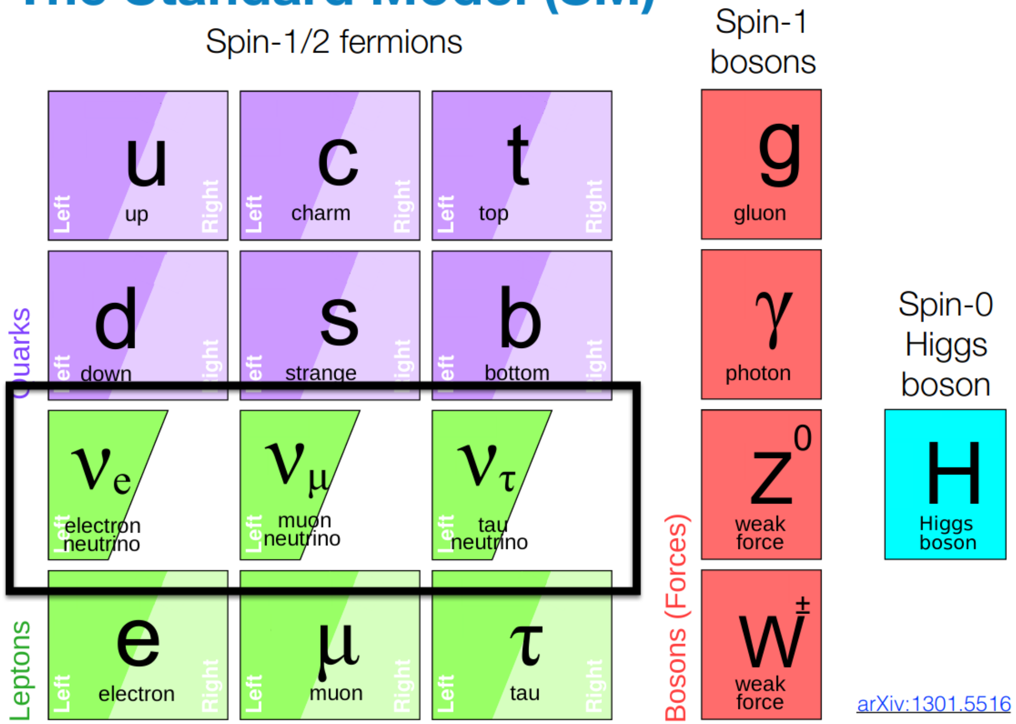
目录
CONTENTS

目录

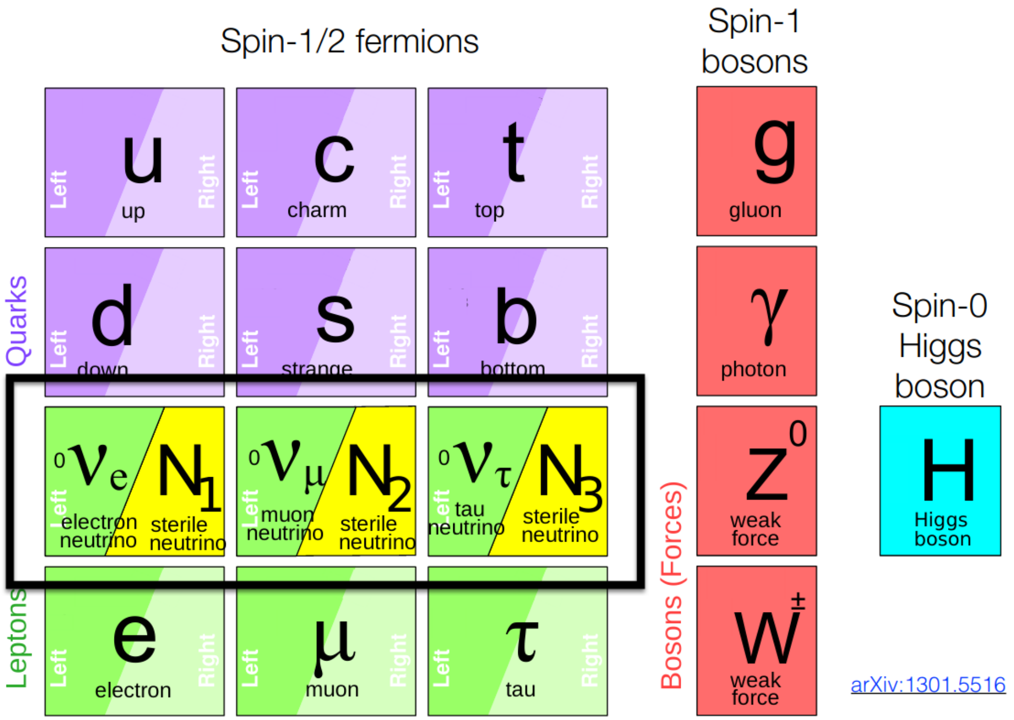
CONTENTS

Heavy Neutral Leptons

The Standard Model (SM)



SM Extension with 3 HNLs



- Best-known description of fundamental particles and their interactions (expect gravity)
- Neutrino oscillations suggest $m_\nu > 0$
- Non-zero neutrino mass is not included in SM

- Introduce right-hand heavy neutral lepton
- Seesaw mechanism e neutrino masses

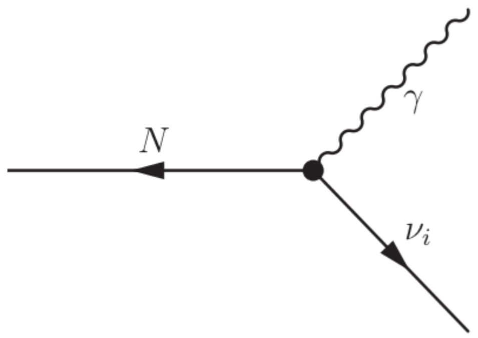
Seesaw mechanism

Lagrangian

$$\mathcal{L} \supset \bar{L}(d_{\mathcal{W}} \mathcal{W}^a_{\mu\nu}\tau^a + d_B B_{\mu\nu})\tilde{H}\sigma_{\mu\nu}N_D + \text{H.c.}$$

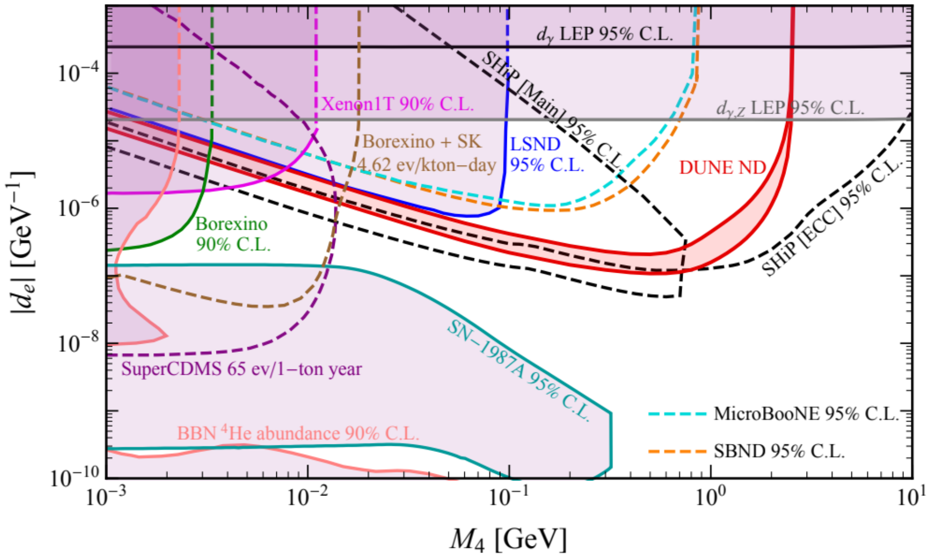
SSB

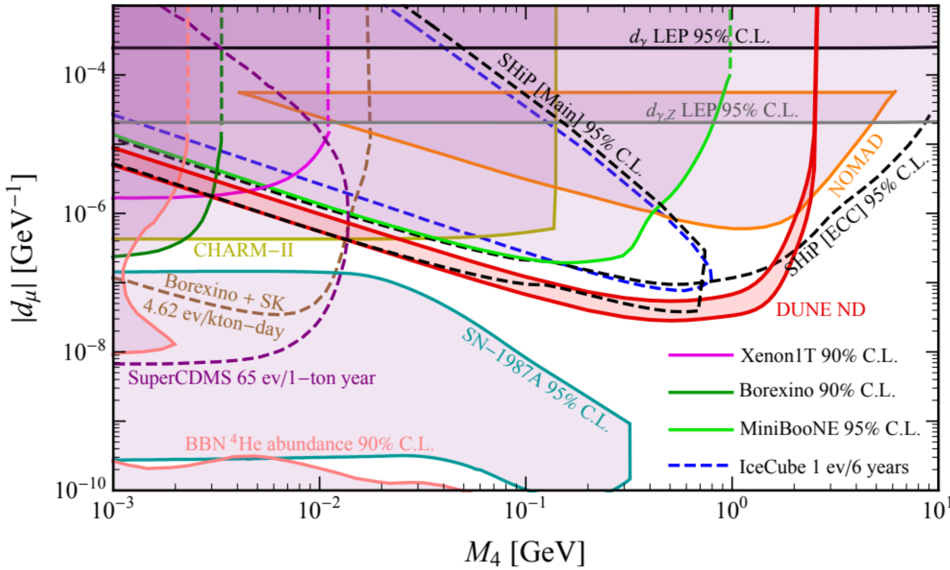
$$\mathcal{L} \supset d_W(\bar{\ell}_L W^-_{\mu\nu}\sigma^{\mu\nu}N_D) + \bar{\nu}_L[d_\gamma F_{\mu\nu} - d_Z Z_{\mu\nu}]\sigma^{\mu\nu}N_D + \text{H.c.}$$

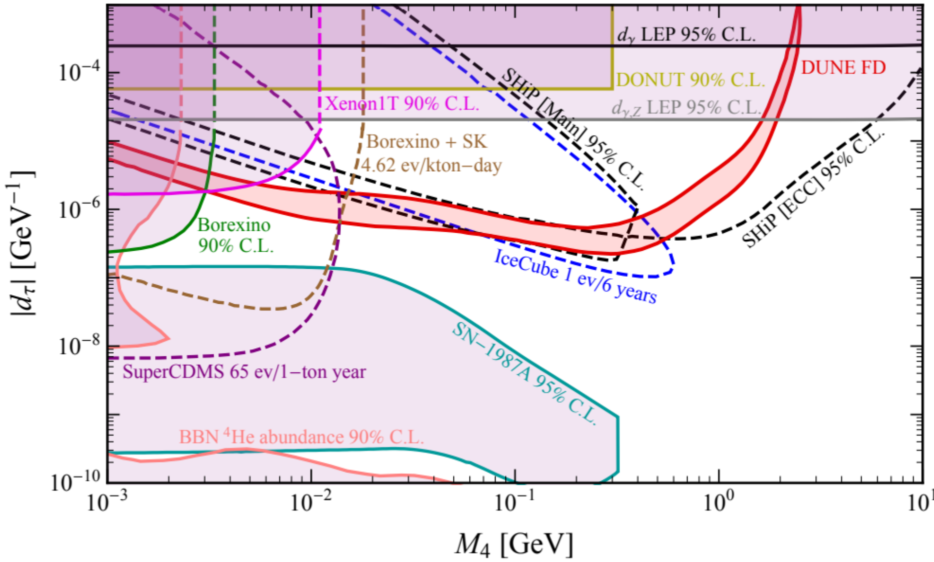


$$\mathcal{L} \supset d_k \bar{\nu}^k_L \sigma_{\mu\nu} F^{\mu\nu} N + \text{H.c.},$$

Current Constraints







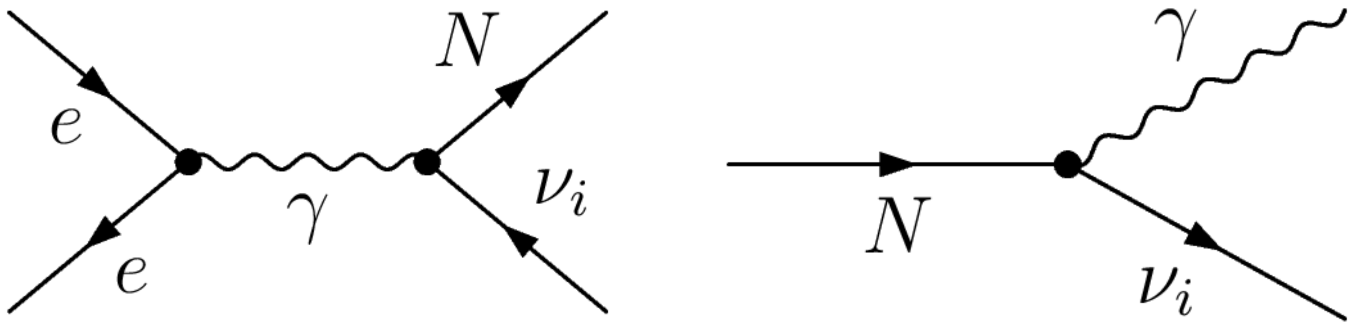
arXiv: 2105.09699

- Collider searches
- Beam-dump experiments
- Neutrino experiments
- Dark matter detection
- Astrophysical
- ……

目 录

CONTENTS

Mono-γ Signature at Electron Collider

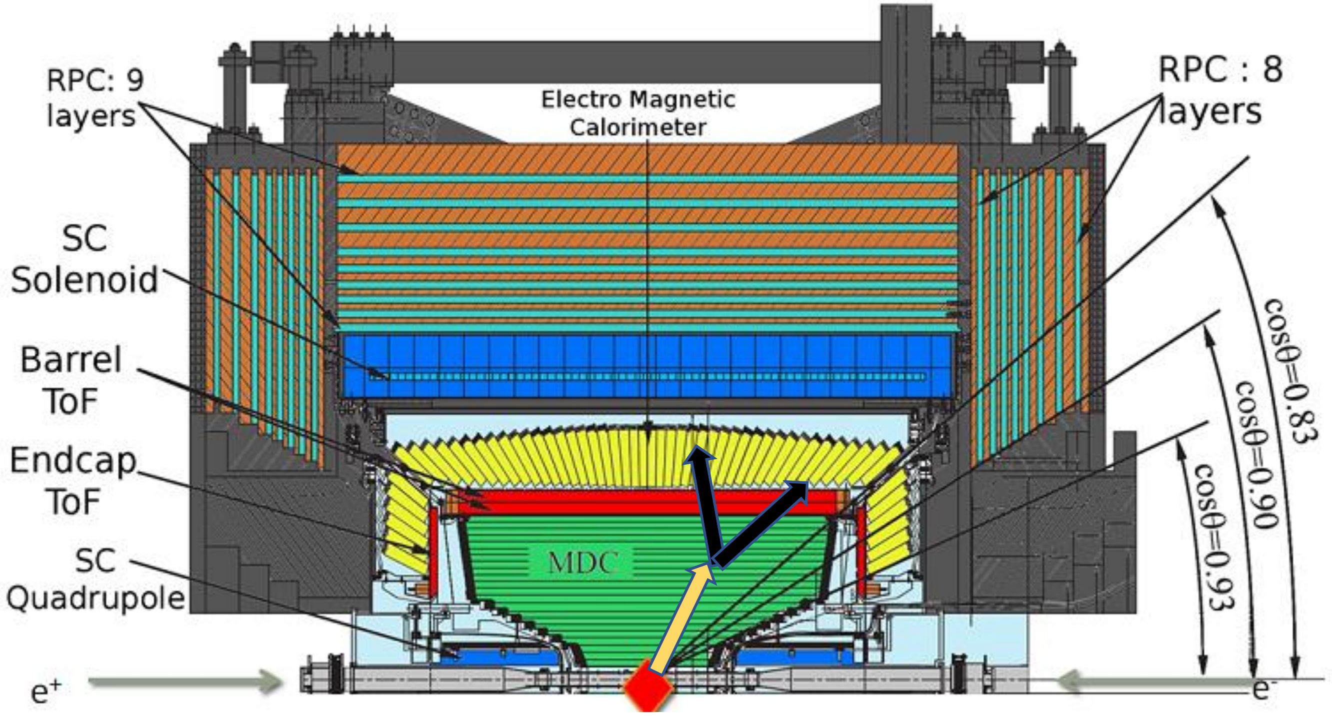


$$e^+e^- \to \gamma^* \to N(\to \gamma \upsilon)\bar{\upsilon}$$

$$\frac{d\sigma_{N\bar{\nu}}}{dz_N} = \frac{d^2\alpha\,(s - m_N{}^2)^2\left((1 - z_N^2)s + (1 + z_N^2)\,m_N^2\right)}{4s^3}$$

$$\sigma(e^+e^- \to N\bar{\nu}) = \frac{\alpha d^2(s - m_N^2)^2(s + 2m_N^2)}{3s^3}$$

Decay Length



$$\Gamma_{N\to\nu\gamma} = \frac{|d|^2 m_N^3}{4\pi}$$

$$l_{dec} = c\tau\beta\gamma = \frac{4\pi}{|d|^2 m_N^4}\sqrt{E_N^2 - m_N^2},$$

$$P_{dec}(l) = (1 - e^{-l/l_{dec}})\mathrm{Br}(N \to \nu\gamma).$$

$$N_s = L\sigma(e^+e^- \to N\nu)\mathrm{Br}(N \to \nu\gamma)\epsilon_{cuts}\epsilon_{det}P_{dec}(l_D)$$

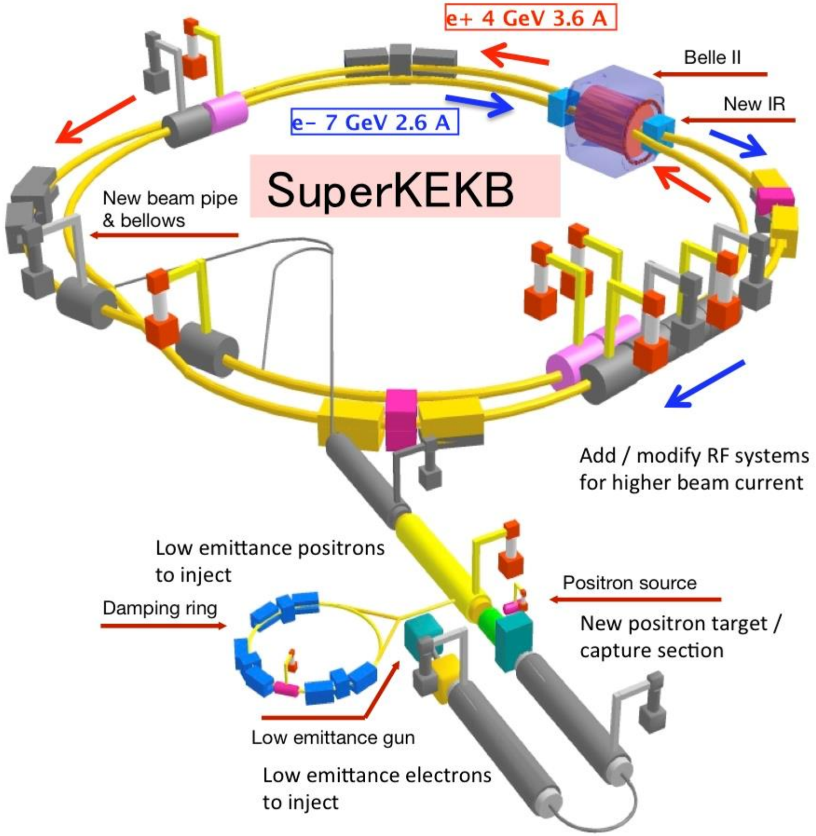
Backgrounds For Mono-γ

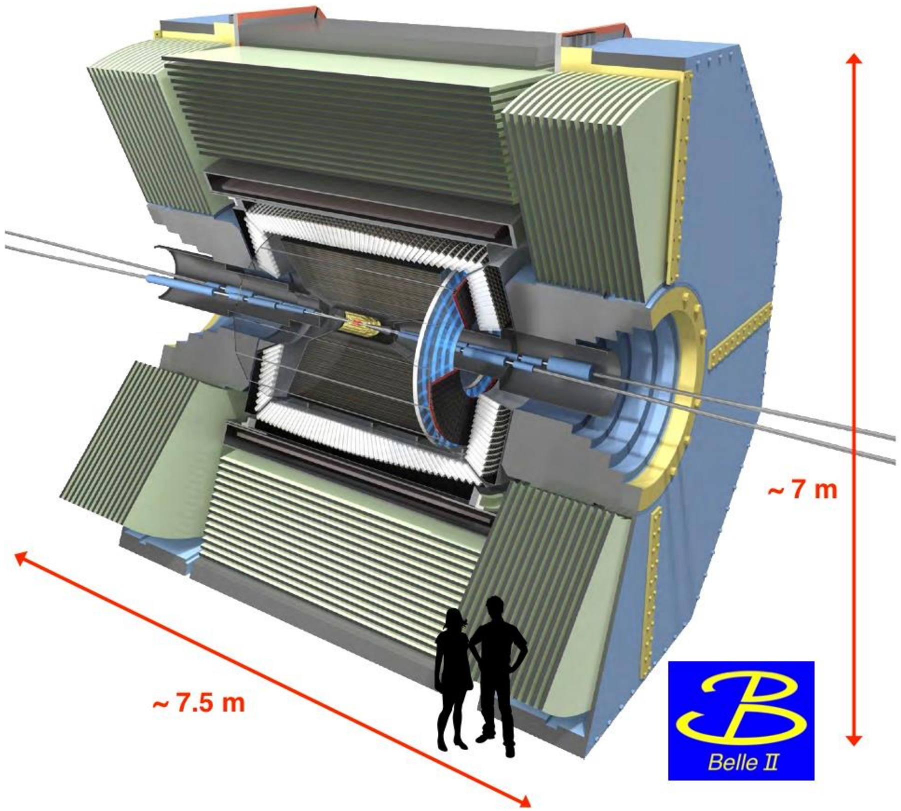
Irreducible Backgrounds $e^+e^- \to \nu\bar{\nu}\gamma$

Reducible Backgrounds $e^+e^- \to e^+e^-\gamma$

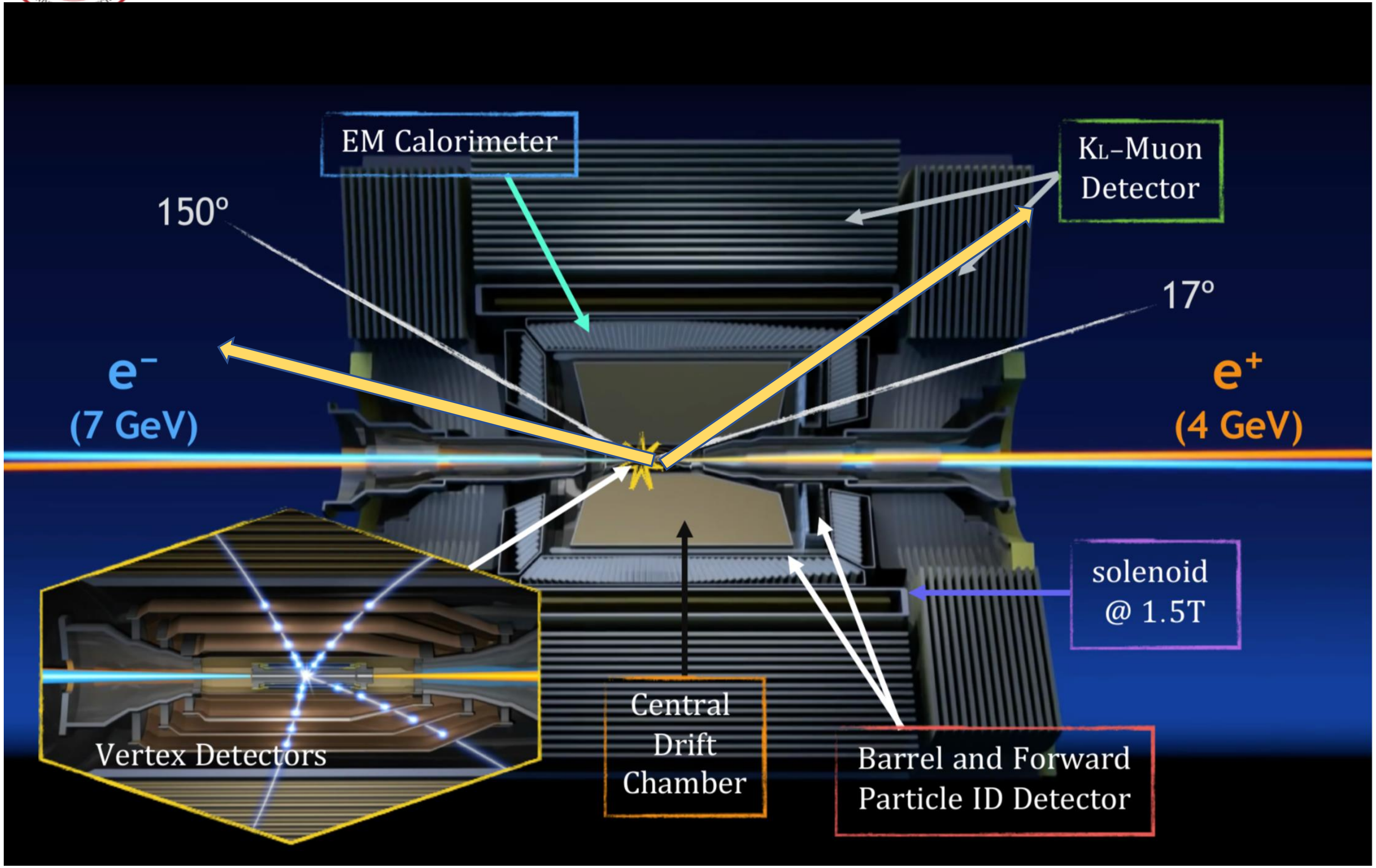
$e^+e^- \to \gamma\gamma(\gamma)$

SuperKEKB/Belle-II





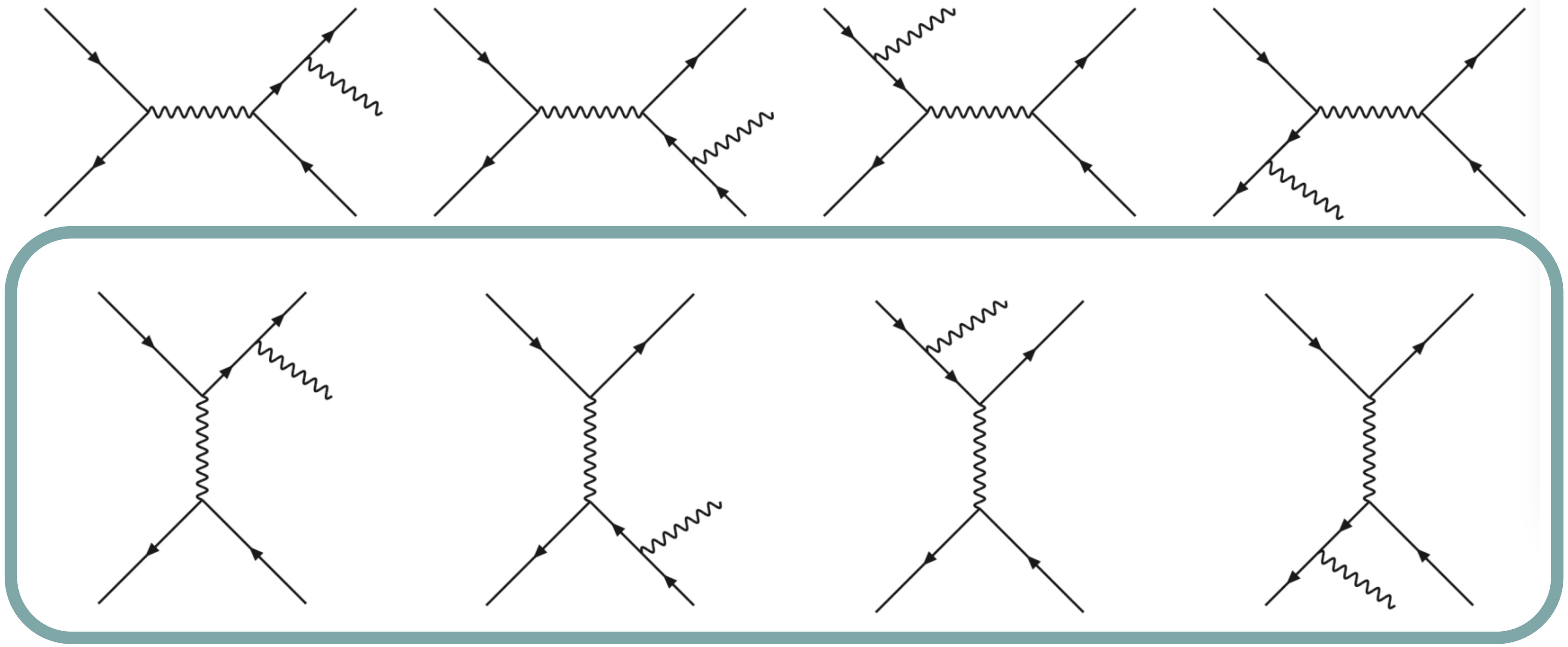
SuperKEKB/Belle-II



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

$$e^+e^- \rightarrow \gamma\gamma(\gamma)$$

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

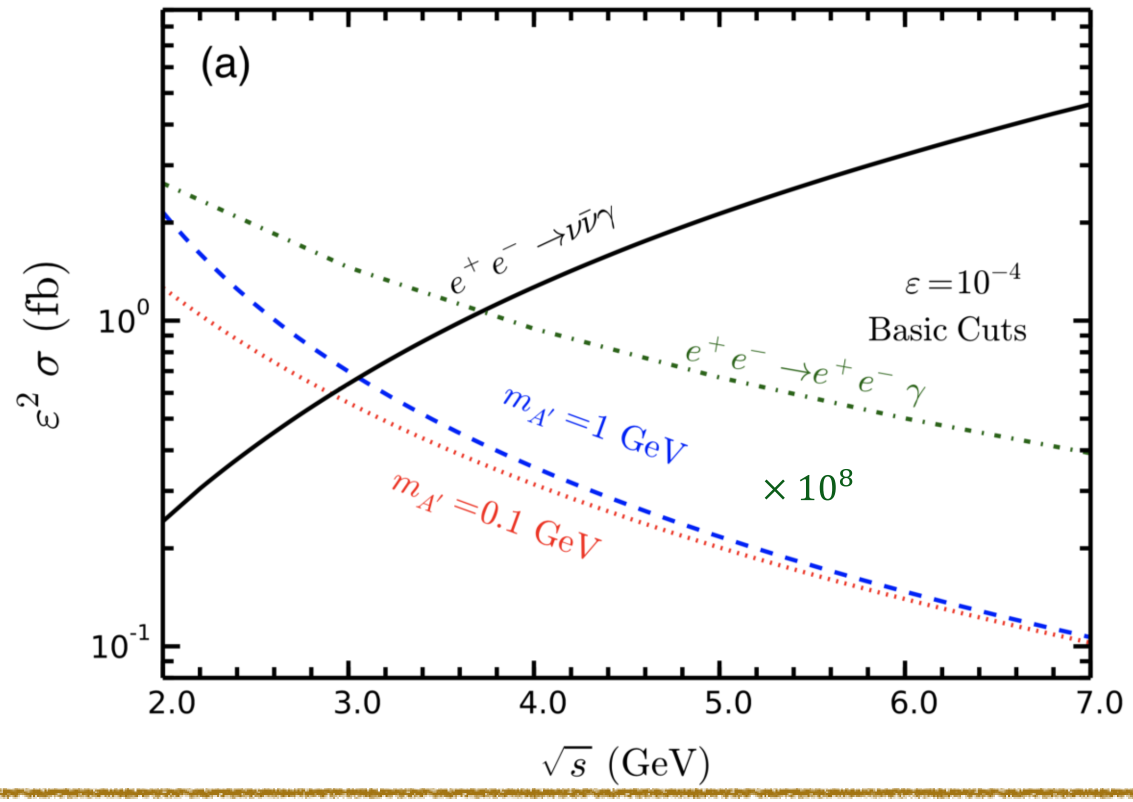


$$\overline{|\mathcal{M}|^2} \propto \frac{1}{t_{13}t_{24}} \sim \frac{1}{\theta_{13}^2 t_{24}} \quad \text{for} \quad \theta_{13} \ll 1 \;\&\; m_e \to 0$$

collinear singularity in the t-channel

Mono-γ Searches

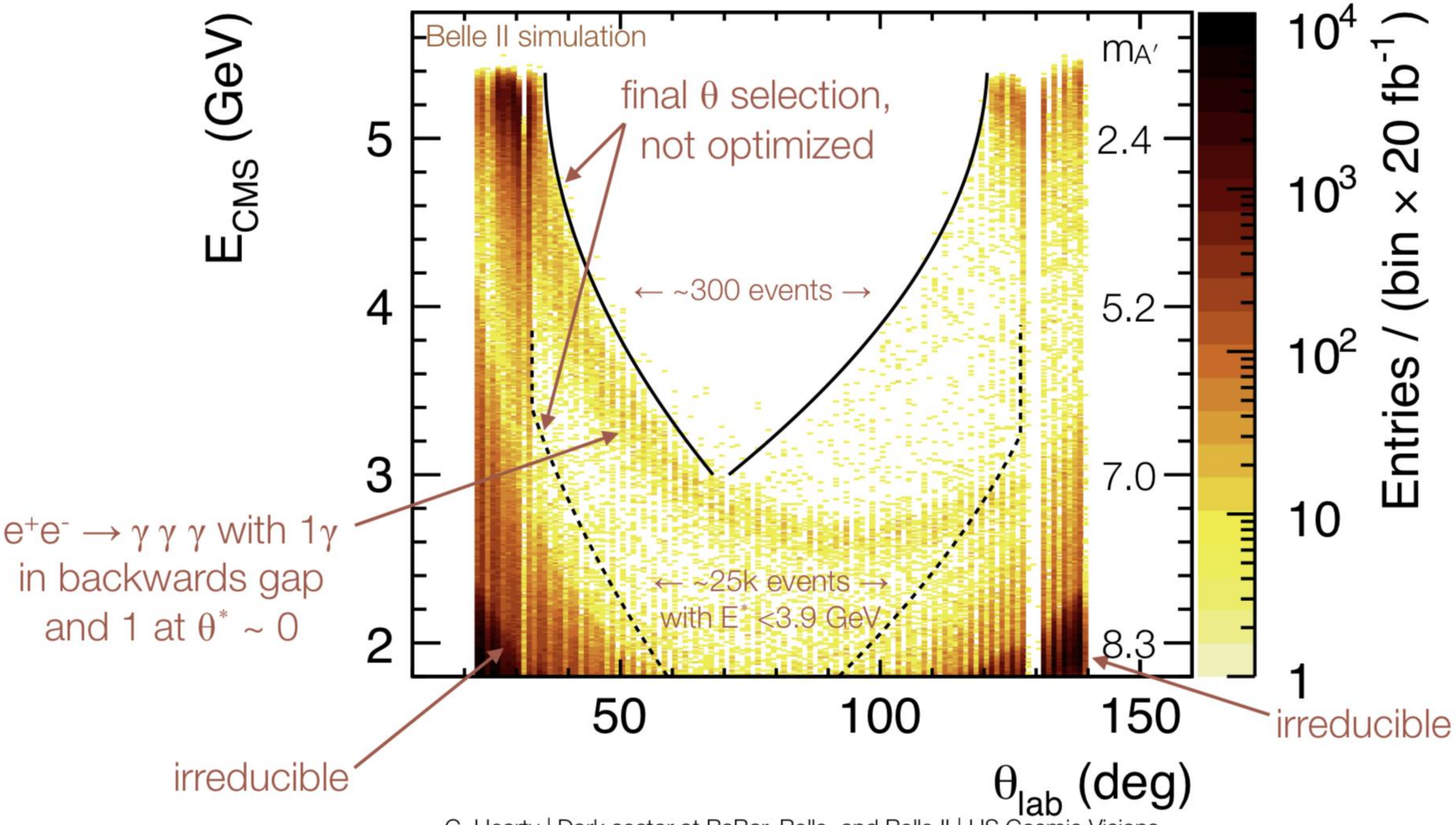
$$|\cos\theta_{e^{\pm}}| > 0.95$$



Only basic cuts, the reducible backgrounds are huge.

Predicted backgrounds in Belle II single photon analysis for 20 fb^{-1}. Loose selection, not optimized.

- Final sample is almost entirely $e^+e^- \rightarrow \gamma\gamma(\gamma)$ with ≥3γ



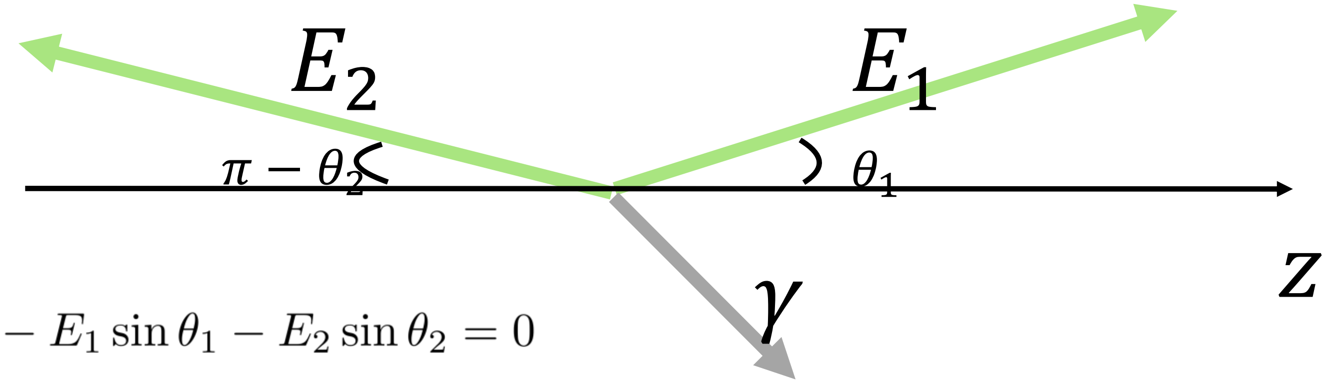
C. Hearty | Dark sector at BaBar, Belle, and Belle II | US Cosmic Visions 14

arXiv: 1808.10567

From Christopher Hearty

张宇（

bBG Cuts at Belle-II



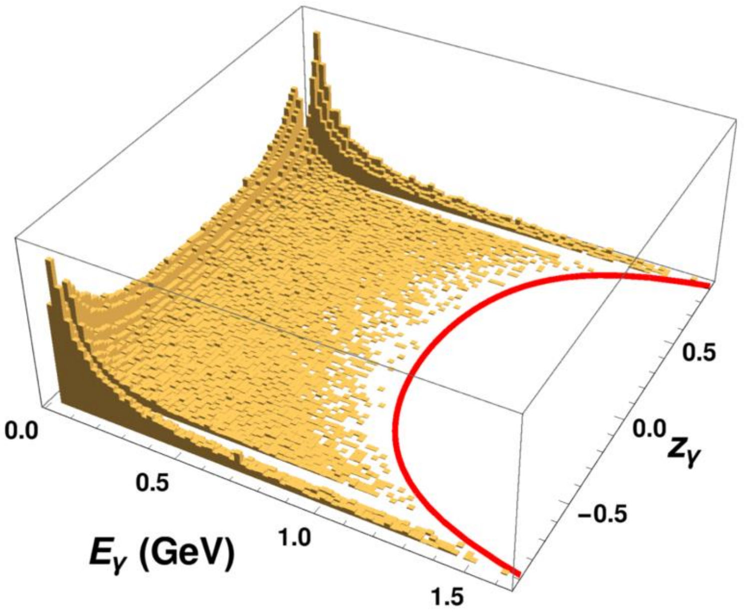
$$\begin{cases} E_\gamma^m \sin\theta_\gamma - E_1 \sin\theta_1 - E_2 \sin\theta_2 = 0 \\ E_\gamma^m \cos\theta_\gamma + E_1 \cos\theta_1 + E_2 \cos\theta_2 = 0 \\ E_\gamma^m + E_1 + E_2 = \sqrt{s}, \end{cases}$$

$$E_\gamma^m(\theta_\gamma) = \frac{\sqrt{s}(A\cos\theta_1 - \sin\theta_1)}{A(\cos\theta_1 - \cos\theta_\gamma) - (\sin\theta_\gamma + \sin\theta_1)}$$

$$A = (\sin\theta_1 - \sin\theta_2)/(\cos\theta_1 - \cos\theta_2)$$

$$\sin\theta_1 = \sin\theta_2 = \sin\theta_b$$

$$E_\gamma^m(\theta_\gamma) = \sqrt{s}\left(1 + \frac{\sin\theta_\gamma}{\sin\theta_b}\right)^{-1}$$

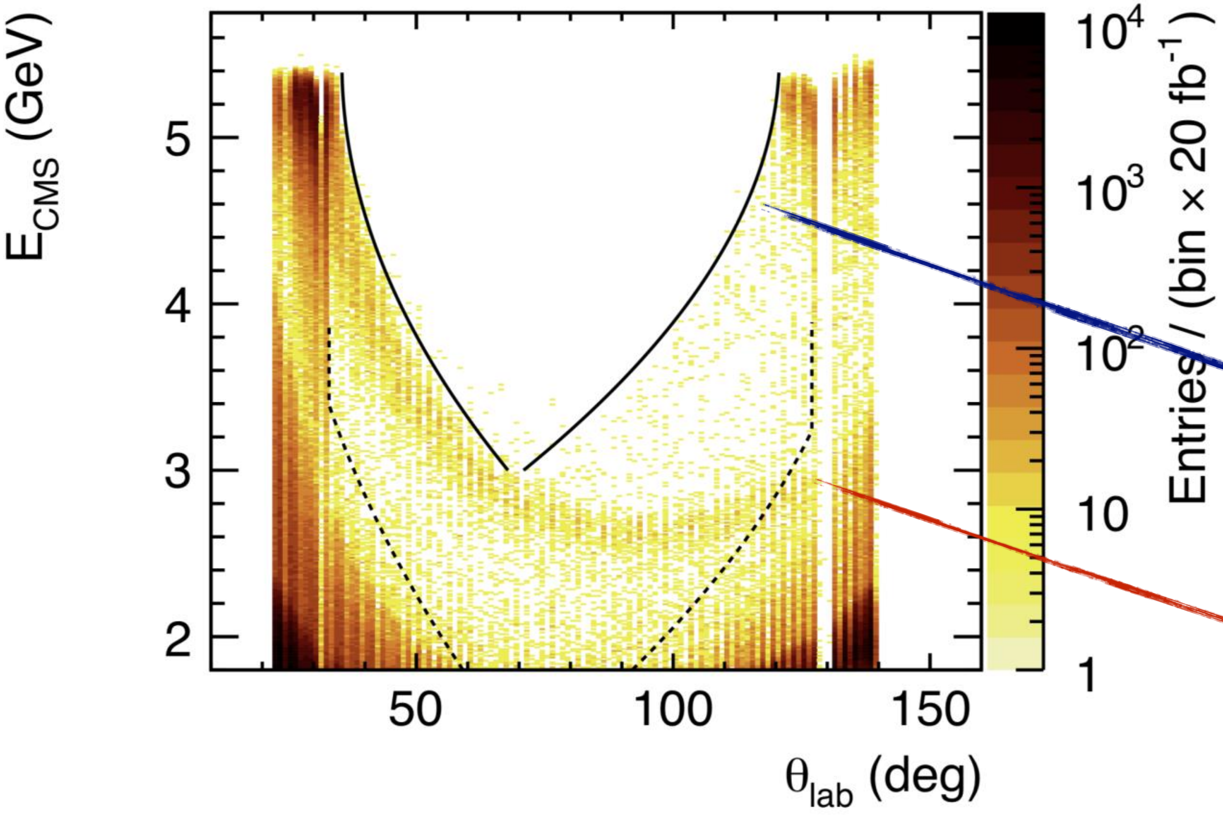


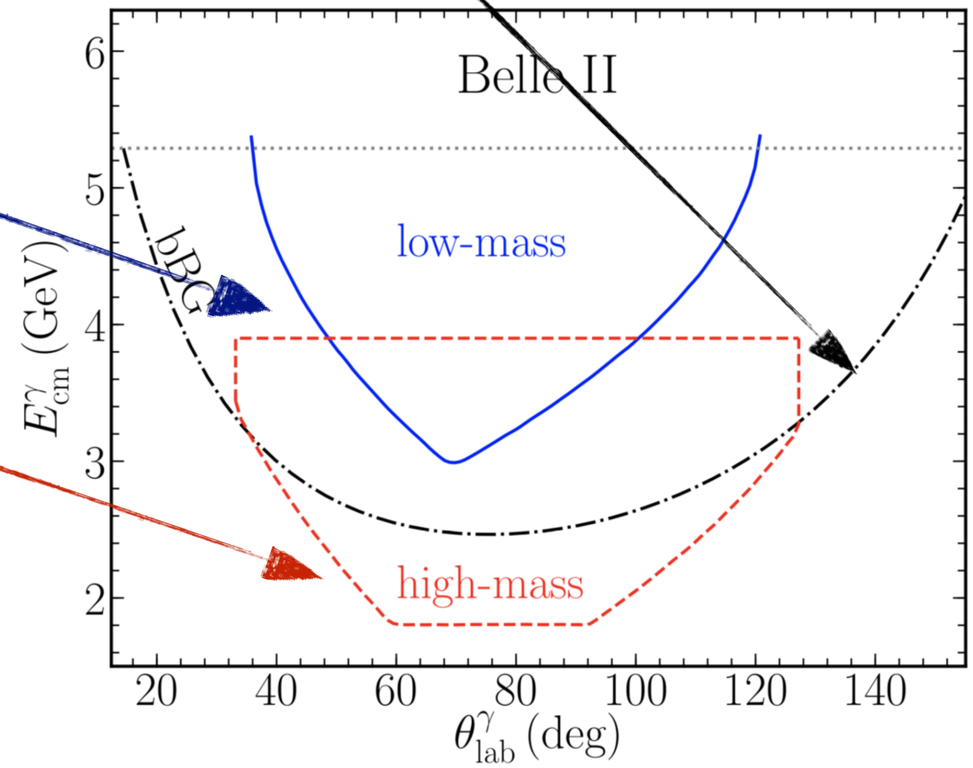
Cuts at Belle-II

$$E_\gamma^m(\theta_\gamma) = \frac{\sqrt{s}(A\cos\theta_1 - \sin\theta_1)}{A(\cos\theta_1 - \cos\theta_\gamma) - (\sin\theta_\gamma + \sin\theta_1)}$$

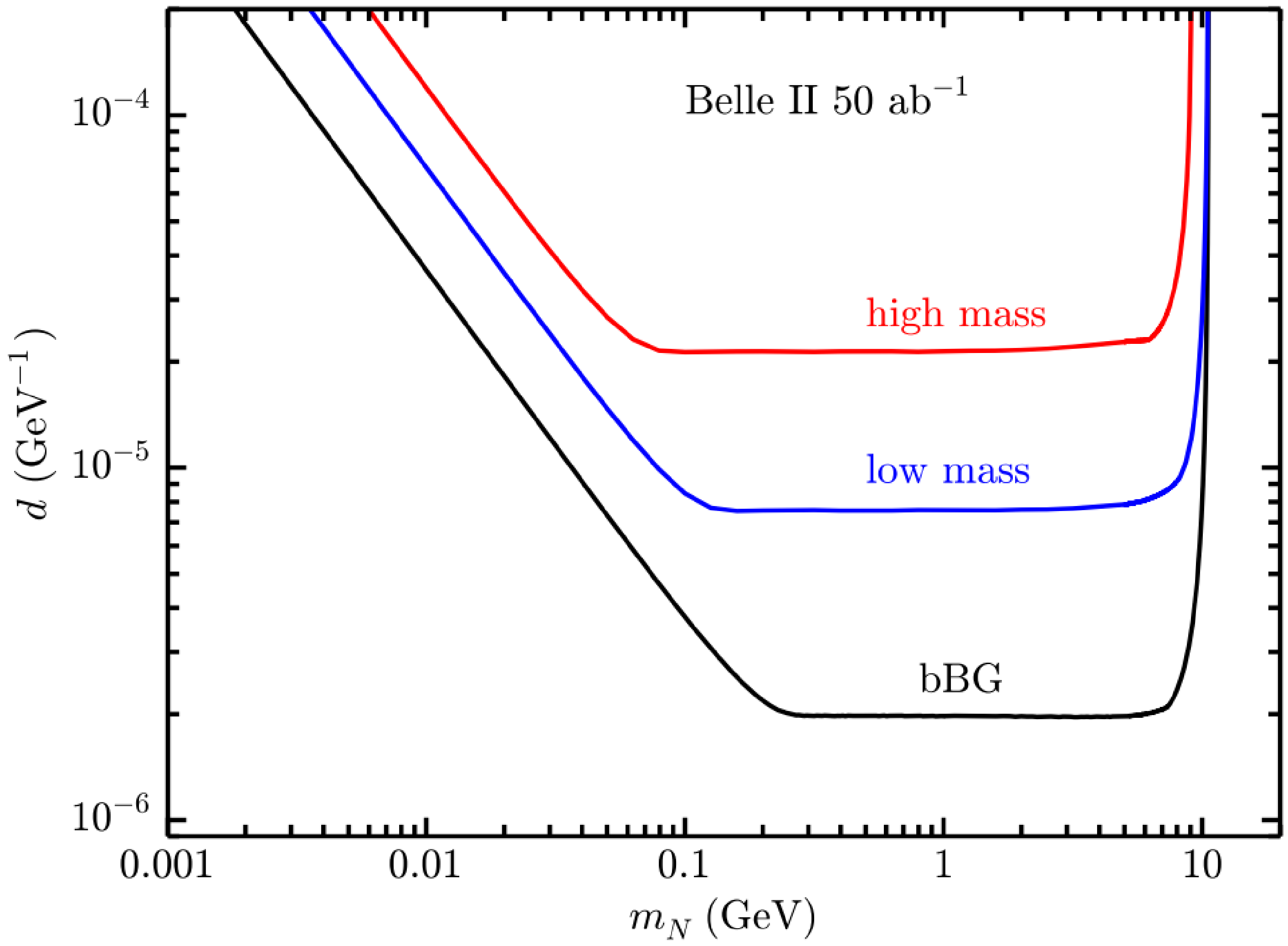
$$A = (\sin\theta_1 - \sin\theta_2)/(\cos\theta_1 - \cos\theta_2)$$

Belle II, 1808.10567





Results at Belle-II



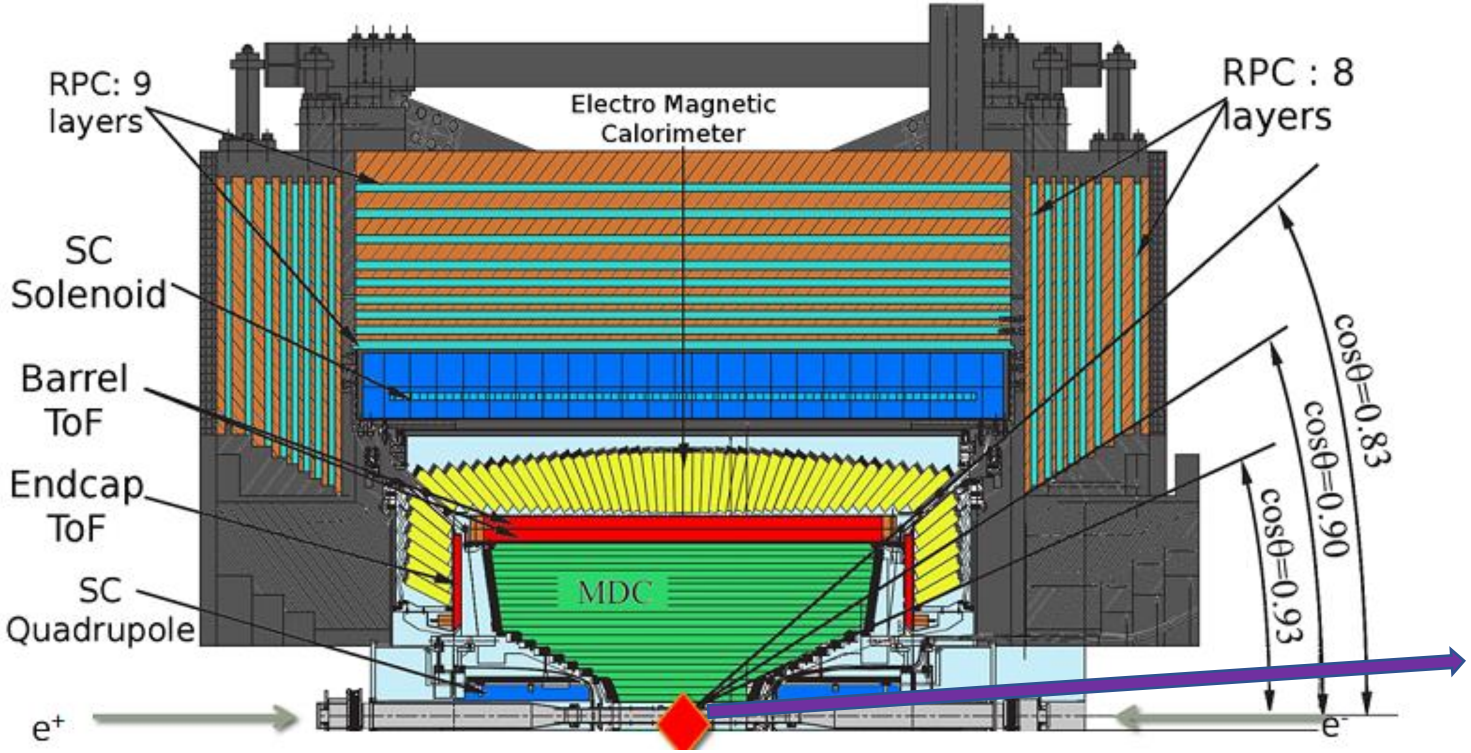
$$\chi^2(\varepsilon) \equiv \frac{S^2}{S+B}$$

$$\chi^2_{\rm tot}(d) = \chi^2(0) + 2.71$$

- The"low-mass cut" is always better than the "high-mass cut"
- The"bBG cut"can improve about 4 times

BEPCII/BESIII

BESIII



主漂移室（MDC）： $|\cos\theta| < 0.93$

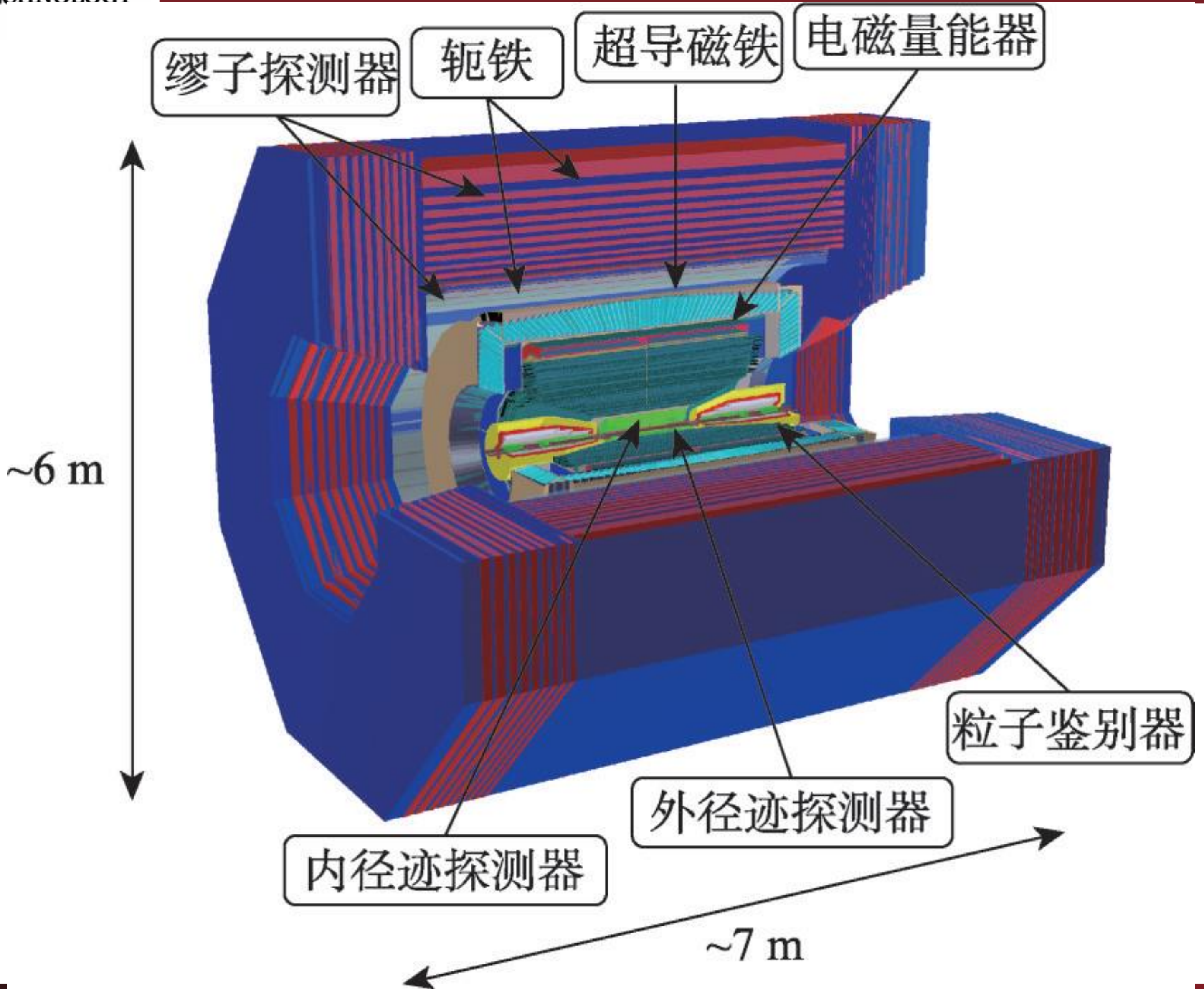
飞行时间计数器（TOF）： $|\cos\theta| < 0.83$ $0.85 < |\cos\theta| < 0.95$

电磁量能器（EMC）： $|\cos\theta| < 0.83$ $0.85 < |\cos\theta| < 0.93$

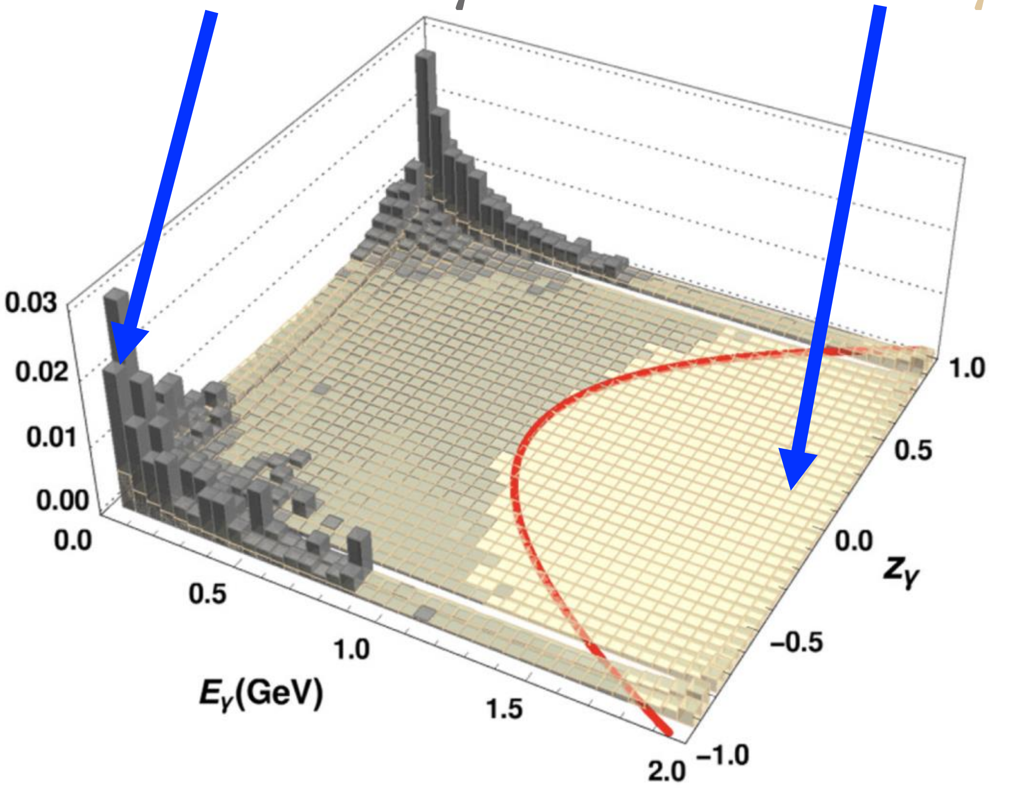
Super Tau-Charm Facility (STCF)

- Peak luminosity 0.5-1×10^{35} $cm^{-2}s^{-1}$ at 4 GeV
- Energy range E_{cm} = 2–7GeV
- Polarization available on electron beam (Phase II)
- Basic Features of machine :
  - Symmetric machine with dual-ring
  - Large Piwinski angle collision + crabbed waist solution for the IR
  - Siberia snake for polarization
  - Total cost 4B RMB

From H. Peng @CHARM18


缪子探测器
轭铁
超导磁铁
电磁量能器
~6 m
粒子鉴别器
外径迹探测器
内径迹探测器
~7 m

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

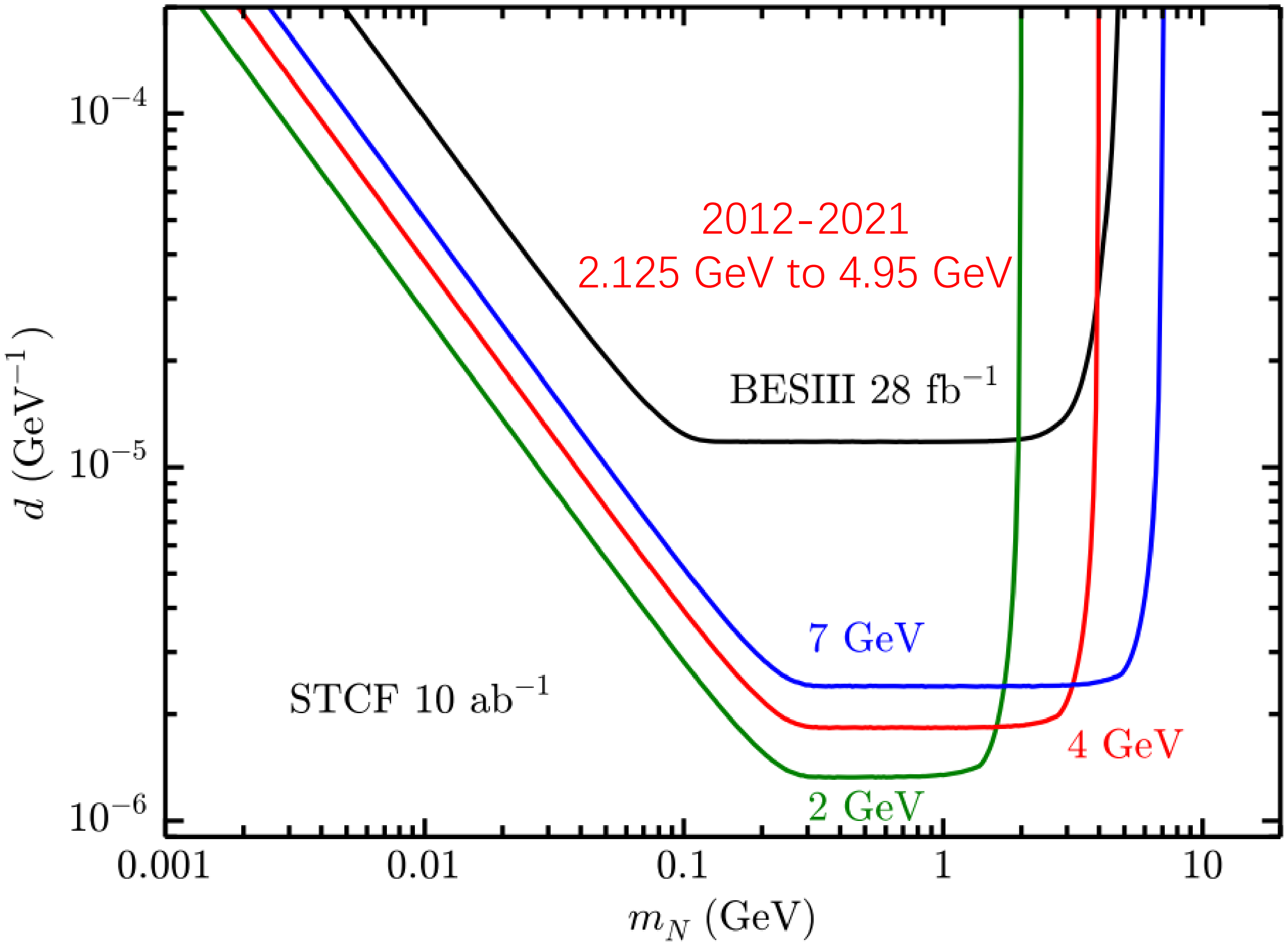


Advanced cuts:

$$E_\gamma > \quad E_\gamma^m(\theta_\gamma) = \sqrt{s}\left(1 + \frac{\sin\theta_\gamma}{\sin\theta_b}\right)^{-1}$$

$e^+e^- \to e^+e^-\gamma, |\cos\theta_{e^\pm}| > 0.95$

Results at BESIII and STCF



$$\chi_i^2(\varepsilon) \equiv \frac{S_i^2}{S_i + B_i}$$

$$\chi_{\text{tot}}^2(\varepsilon) = \sum_i \chi_i^2(\varepsilon)$$

$$\chi_{\text{tot}}^2(\varepsilon_{95}) = \chi^2(0) + 2.71$$

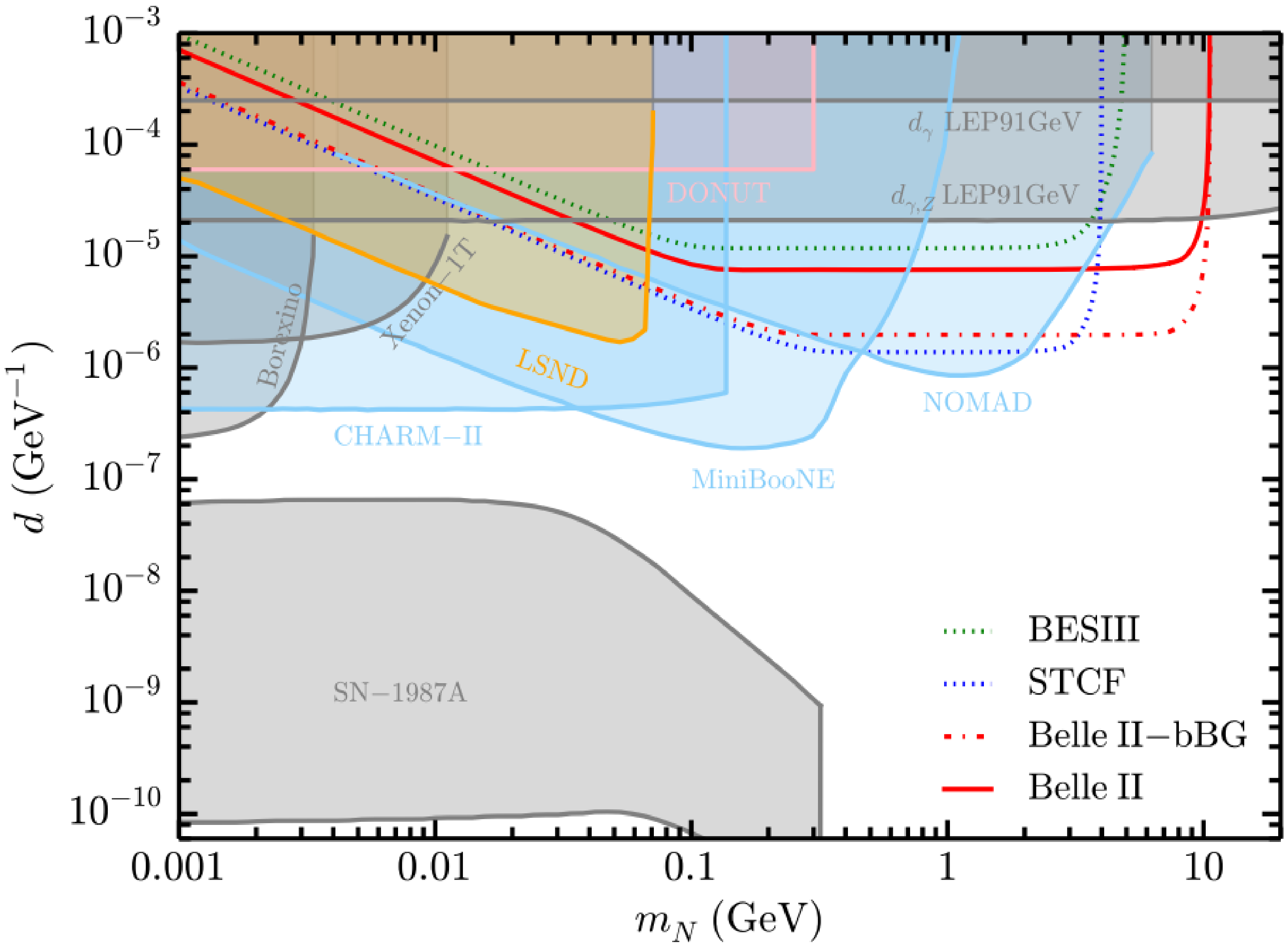
At lower energy, STCF has better sensitivity in probing the low-mass region.

$$\sigma(e^+e^- \to N\bar{\nu}) = \frac{\alpha d^2 (s - m_N^2)^2 (s + 2m_N^2)}{3s^3}$$

目录

CONTENTS

Results



- Gray regions for all 3 lepton flavors
- Orange regions only for electron-neutrino (d_e)
- Skyblue regions only for muon-neutrino (d_μ)
- Pink regions only for tau-neutrino (d_τ)

谢谢观看

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HEFEI UNIVERSITY OF TECHNOLOGY