合肥工業大學
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Probing active-sterile neutrino transition magnetic moments at colliders

张宇

合肥工业大学物理学院

Daniele Barducci, Wei Liu, Arsenii Titov, Zeren Simon Wang, **YZ**, **Phys.Rev.D** 108 (2023) 11, 115009；
YZ, Wei Liu, **Phys.Rev.D** 107 (2023) 9, 095031；
Wei Liu, **YZ**, **Eur.Phys.J.C** 83 (2023) 7, 568；
YZ, Mao Song, Ran Ding, Liangwen Chen, **Phys.Lett.B** 829 (2022) 137116

2024年BESIII新物理研讨会
2024年8月28日 杭州

dayu@hfut.edu.cn

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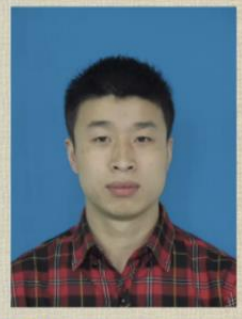
北京谱仪新物理论坛 BESIII New Physics Forum
BENEF #00004

- **Title:** 高亮度正负电子对撞机上隐藏区间的唯象学研究
- **Speaker:** 张宇（安徽大学）
- **Time:** 15:30, Apr 20 (Tue), 2021
- **Tencent Meeting ID:** 355 795 075

https://meeting.tencent.com/s/PxuJXNlzh3Wp



- **Abstract**

粒子物理学中的一些基本问题，如中微子质量和振荡的起源、暗物质的自然属性以及重子生成机制等，仍待回答。一种可行的方案是引入隐藏区间。目前对于隐藏区间的寻找，尤其高能量前沿的LHC实验，还没有任何明确的信号，因此人们逐渐转向了高亮度前沿对于MeV到GeV质量范围的新粒子的探测。诸如我国的BESIII等高亮度正负电子对撞机实验是高亮度前沿的重要代表。特别地，它们的运行能区对MeV到GeV质量范围的新粒子的探索有着独特的优势。本报告将针对一些典型的隐藏区间粒子，探讨BESIII等高亮度正负电子对撞机实验对于它们的探测潜力。

- **About the Speaker**

张宇，安徽大学物质科学与信息技术研究院特任研究员。2009于重庆大学数理学院获得学士学位，2015年于中国科学技术大学近代物理系获得博士学位。2015年至2016年于昆明理工大学工作，2016年至2018年在南京大学从事博士后研究。2018年加入安徽大学物质科学与信息技术研究院。主要从事高能物理唯象学研究，包括粒子对撞机上散射过程量子效应的精确计算、重夸克偶素的产生与衰变以及新物理的寻找等。

- **Contact**

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Probing millicharge at BESIII via monophoton searches #2
Zuowei Liu (Nanjing U. and Peking U., CHEP and CAS, CEPP, Beijing), Yu Zhang (Nanjing U. and CAS, CEPP, Beijing) (Aug 2, 2018)
Published in: *Phys.Rev.D* 99 (2019) 1, 015004 • e-Print: 1808.00983 [hep-ph]
pdf DOI cite claim reference search 30 citations

Probing dark matter particles at CEPC #3
Zuowei Liu (Nanjing U. and Peking U., CHEP and CAS, CEPP, Beijing), Yong-Heng Xu (Nanjing U.), Yu Zhang (CAS, CEPP, Beijing and Hefei, CUST) (Mar 28, 2019)
Published in: *JHEP* 06 (2019) 009 • e-Print: 1903.12114 [hep-ph]
pdf DOI cite claim reference search 29 citations

Probing invisible decay of dark photon at BESIII and future STCF via monophoton searches #4
Yu Zhang (Hefei, CUST and Anhui U.), Wei-Tao Zhang (Anhui U.), Mao Song (Hefei, CUST and Anhui U.), Xue-An Pan (Anhui U.), Zhong-Ming Niu (Hefei, CUST and Anhui U.) et al. (Jul 16, 2019)
Published in: *Phys.Rev.D* 100 (2019) 11, 115016 • e-Print: 1907.07046 [hep-ph]
pdf DOI cite claim reference search 18 citations

Millicharged particles at electron colliders #5
Jinhan Liang (Nanjing U.), Zuowei Liu (Nanjing U. and Peking U., CHEP and CAS, CEPP, Beijing), Yue Ma (Nanjing U.), Yu Zhang (Hefei, CUST and Anhui U.) (Sep 15, 2019)
Published in: *Phys.Rev.D* 102 (2020) 1, 015002 • e-Print: 1909.06847 [hep-ph]
pdf DOI cite claim reference search 28 citations

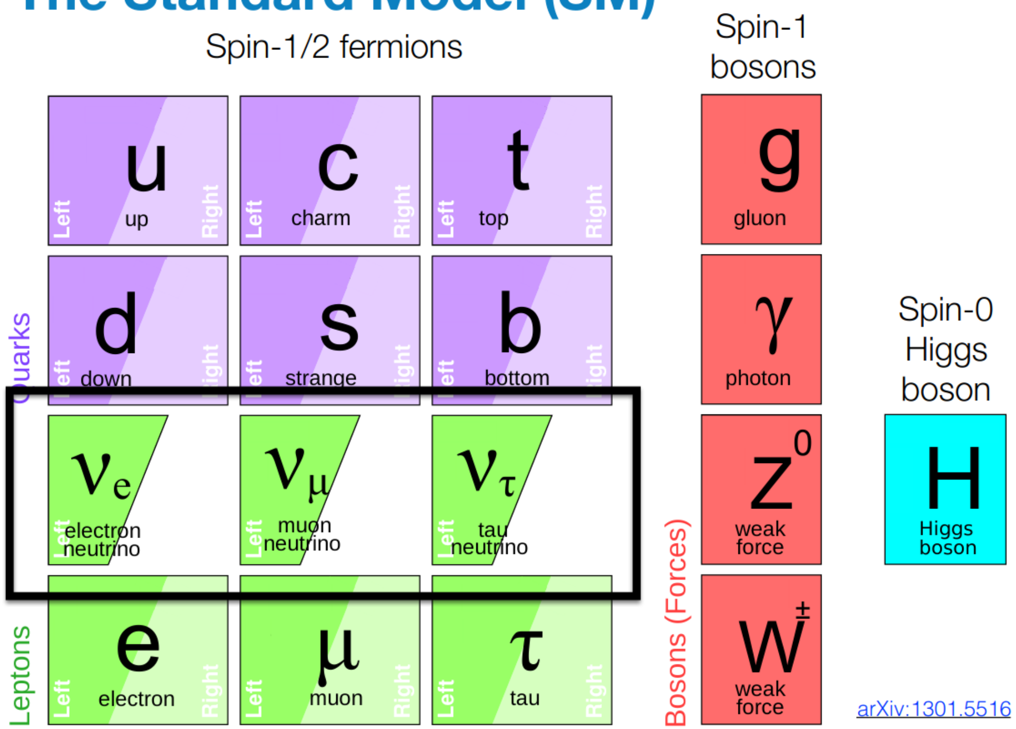
Probing the $L_\mu - L_\tau$ gauge boson at electron colliders #6
Yu Zhang (Anhui U. and Anhui U. Sci. Tech.), Zhuo Yu (Anhui U. Sci. Tech.), Qiang Yang (Zhejiang U., Inst. Mod. Phys.), Mao Song (Anhui U.), Gang Li (Anhui U.) et al. (Dec 20, 2020)
Published in: *Phys.Rev.D* 103 (2021) 1, 015008 • e-Print: 2012.10893 [hep-ph]
pdf DOI cite claim reference search 14 citations

Constraining nonstandard neutrino interactions at electron colliders #7
Jiajun Liao (Zhongshan U.), Yu Zhang (Anhui U.) (May 24, 2021)
Published in: *Phys.Rev.D* 104 (2021) 3, 035043 • e-Print: 2105.11215 [hep-ph]
pdf DOI cite claim reference search 4 citations

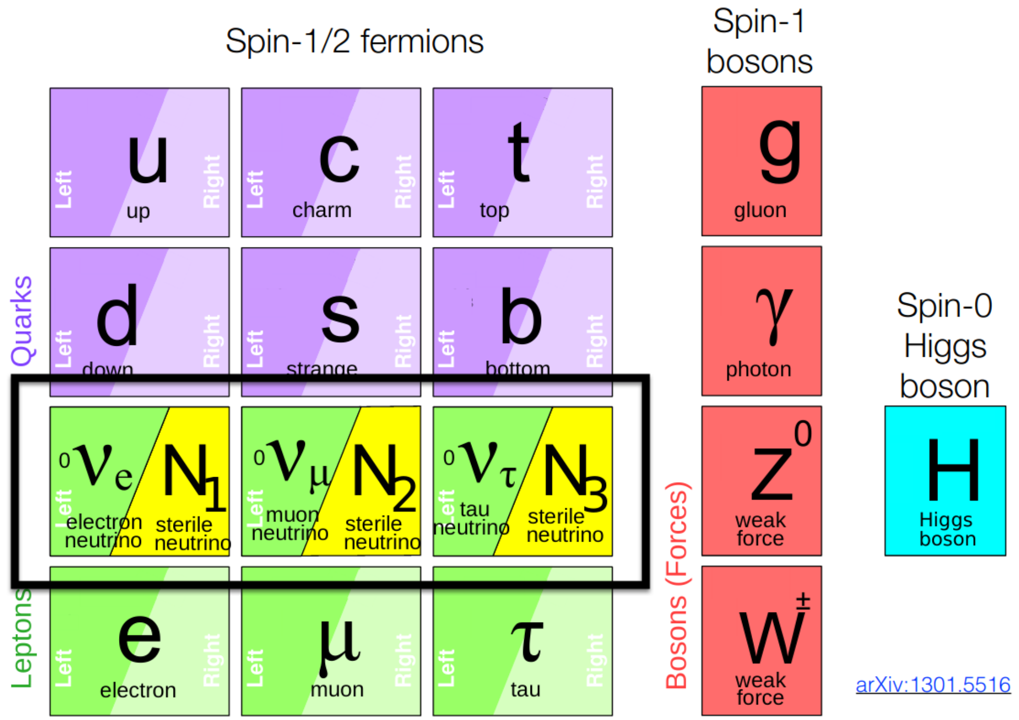
Neutrino dipole portal at electron colliders #8
Yu Zhang (Hefei U. Technol.), Mao Song (Anhui U.), Ran Ding (Anhui U.), Liangwen Chen (Lanzhou U. and Guangzhou U.) (Apr 16, 2022)
Published in: *Phys.Lett.B* 829 (2022) 137116 • e-Print: 2204.07802 [hep-ph]
pdf DOI cite claim reference search 9 citations

Sterile neutrino

The Standard Model (SM)



SM Extension with 3 HNLs



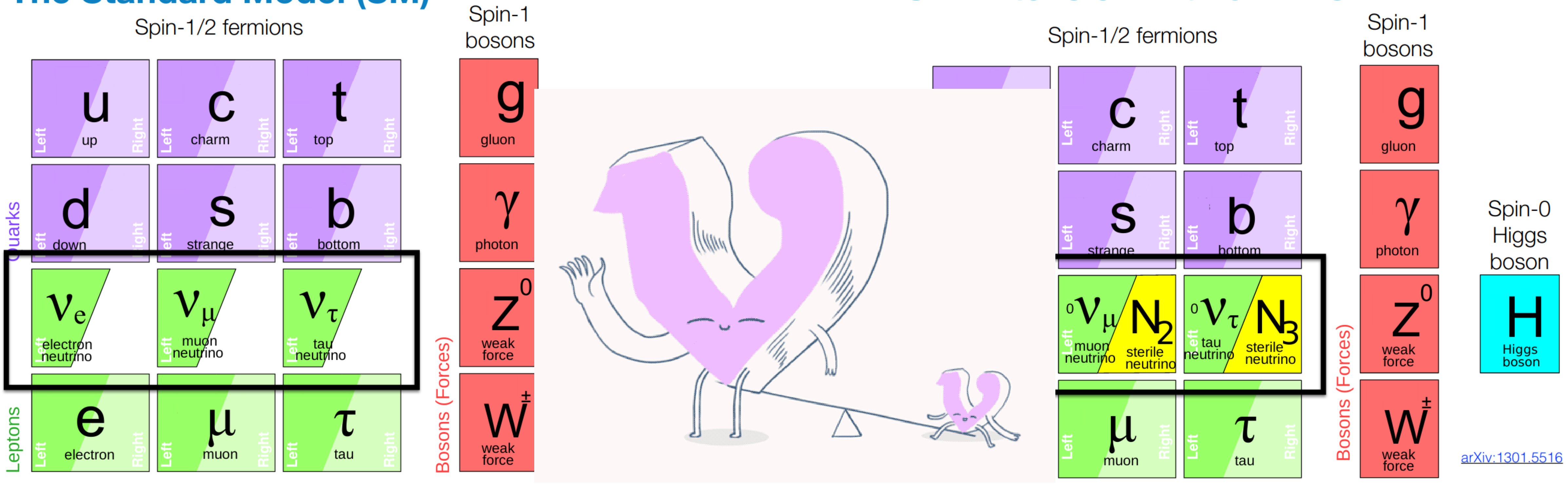
- Best-known description of fundamental particles and their interactions (expect gravity)
- Neutrino oscillations suggest $m_\nu > 0$
- Non-zero neutrino mass is not included in SM

- Introduce right-handed states known as heavy neutral leptons (HNLs)
- Seesaw mechanism explains light neutrino masses

Sterile neutrino

The Standard Model (SM)

SM Extension with 3 HNLs



- Best-known description of fundamental particles and their interactions (expect gravity)
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- Introduce right-handed states known as heavy neutral leptons (HNLs)
- Seesaw mechanism explains light neutrino masses

Minimal scenario

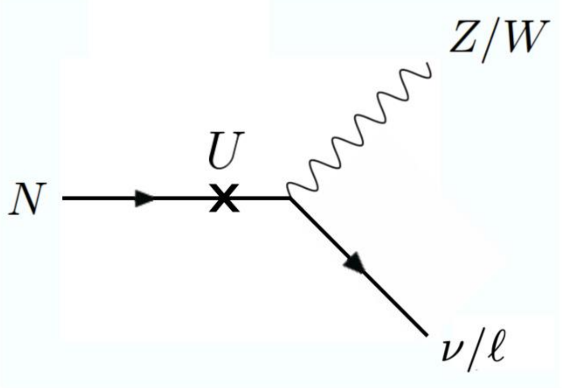
The basic Lagrangian for the model is given by

$$\mathscr{L} \supset N^{\dagger}\bar{\sigma}^{\mu}\partial_{\mu}N - \left[\frac{1}{2}M\,NN + y\,LHN + \mathrm{h.c.}\right]$$

Seesaw mechanism — mass mixing:

$$(\nu \quad N)\begin{pmatrix} 0 & yv \\ yv & M \end{pmatrix}\begin{pmatrix} \nu \\ N \end{pmatrix} \Longrightarrow m_\nu \sim \frac{y^2v^2}{M}, \quad m_N \sim M$$

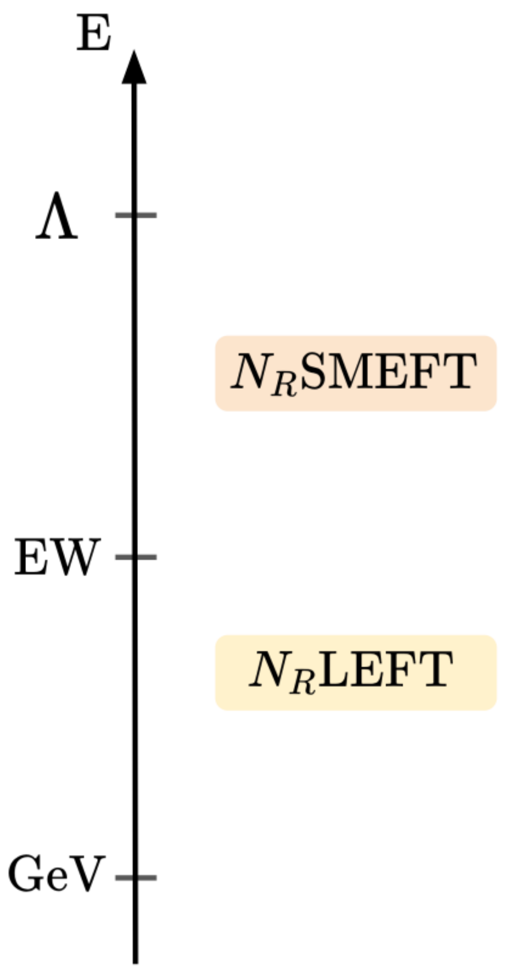
Heavy neutrino, or heavy neutral lepton (HNL), inherits weak interaction of light neutrino



Beyond the minimal scenario

If sterile neutrinos couple to heavy new physics at $\boldsymbol{\Lambda}$

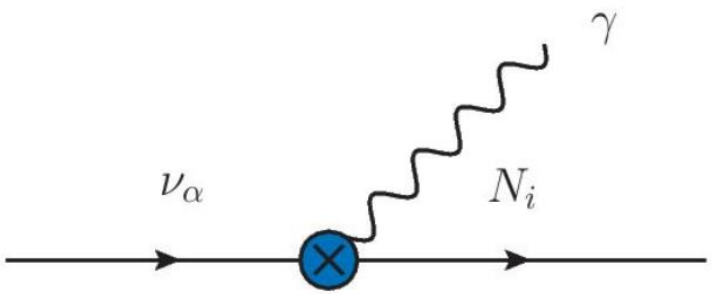
$$\mathscr{L} = \mathscr{L}_{\mathrm{SM}+N} + \sum_{d=5}^{\infty} \frac{1}{\Lambda^{d-4}} \sum_{i}^{n_d} c_i^{(d)} \mathcal{O}_i^{(d)}$$



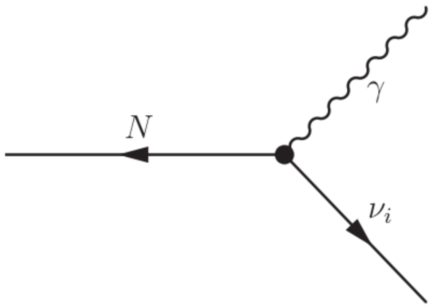
Neutrino magnetic moments

$$\mathcal{L}_{dim\ 5} \supset d_a \overline{\nu_L}_a \sigma_{\mu\nu} F^{\mu\nu} N$$

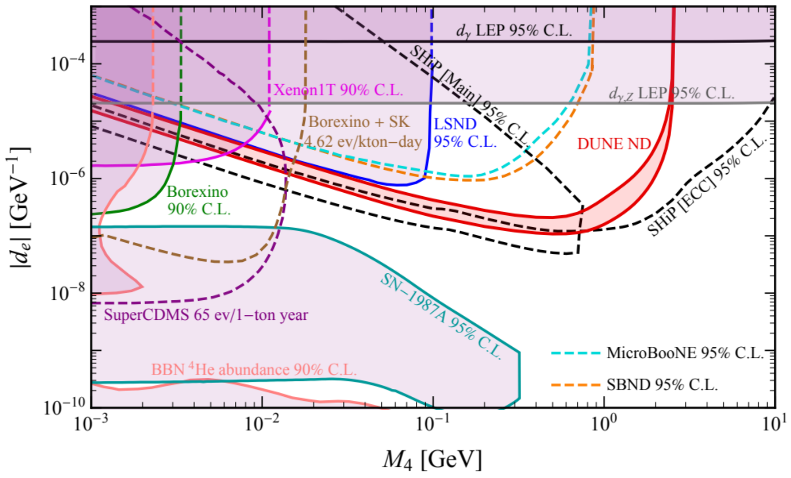
Dipole Portal

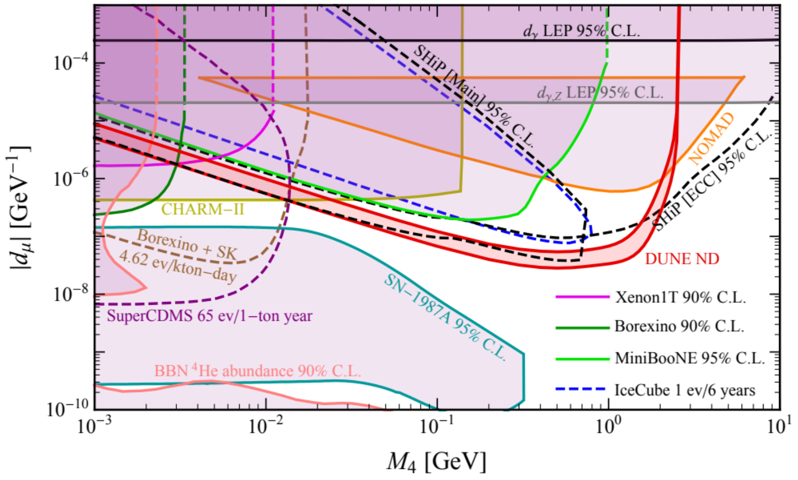


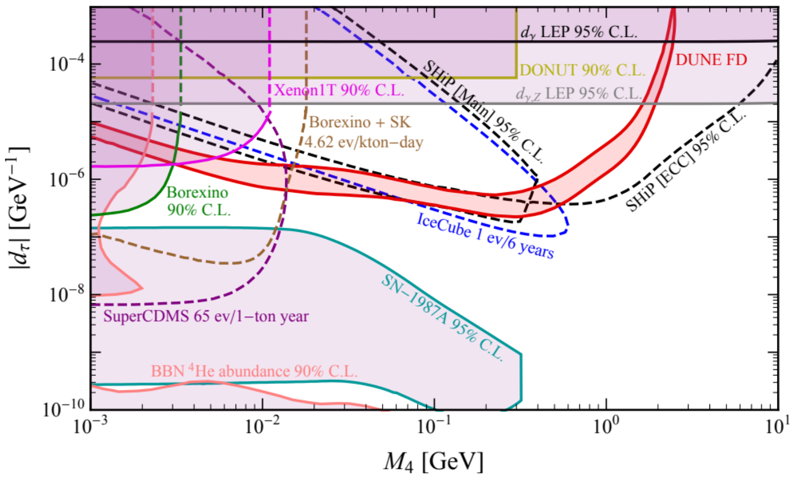
Current Limits



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





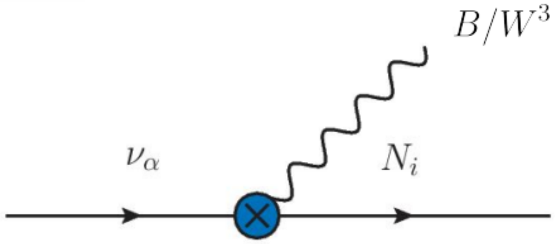


arXiv: 2105.09699

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

A EFT Model: Neutrino dipole portal

Above EW scale

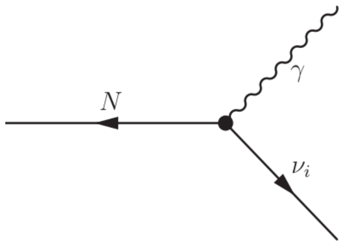


$$\mathcal{L} \supset \bar{L}(d_{\mathcal{W}}\mathcal{W}^a_{\mu\nu}\tau^a + d_B B_{\mu\nu})\tilde{H}\sigma_{\mu\nu}N_D + \text{H.c.}$$

↓ SSB

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

↓



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

$$d_\gamma = \frac{v}{\sqrt{2}}\left(d_B \cos\theta_w + \frac{d_{\mathcal{W}}}{2}\sin\theta_w\right)$$

$$d_Z = \frac{v}{\sqrt{2}}\left(\frac{d_{\mathcal{W}}}{2}\cos\theta_w - d_B \sin\theta_w\right)$$

$$d_W = \frac{v}{\sqrt{2}}\frac{d_{\mathcal{W}}}{2}\sqrt{2}.$$

$$\{m_N, d_{\mathcal{W}}, d_B\}$$

$$d_{\mathcal{W}} = a \times d_B$$

$$d_Z = \frac{d_\gamma(a\cos\theta_w - 2\sin\theta_w)}{2\cos\theta_w + a\sin\theta_w}$$

$$d_W = \frac{\sqrt{2}a d_\gamma}{2\cos\theta_w + a\sin\theta_w}.$$

$$\{m_N, d_\gamma, a\}$$

$$a = -2\cot\theta_w$$

HNL Decays

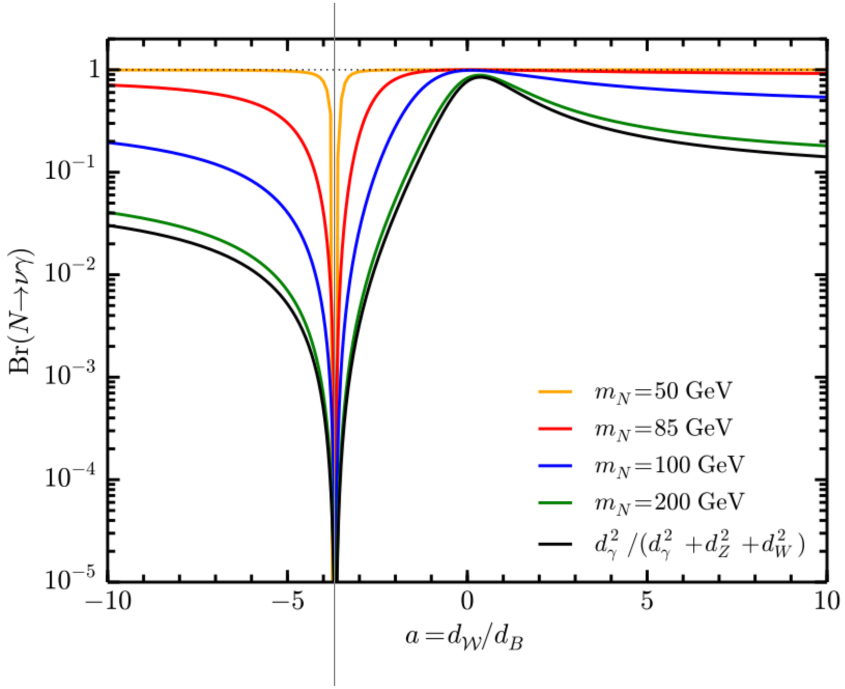
$$\Gamma_{N\to\nu\gamma} = \frac{d_\gamma^2 m_N^3}{4\pi},$$

$$\Gamma_{N\to\nu Z} = \frac{d_Z^2(m_N^2 - M_Z^2)^2(2m_N^2 + M_Z^2)}{8\pi m_N^3}\Theta(m_N > M_Z),$$

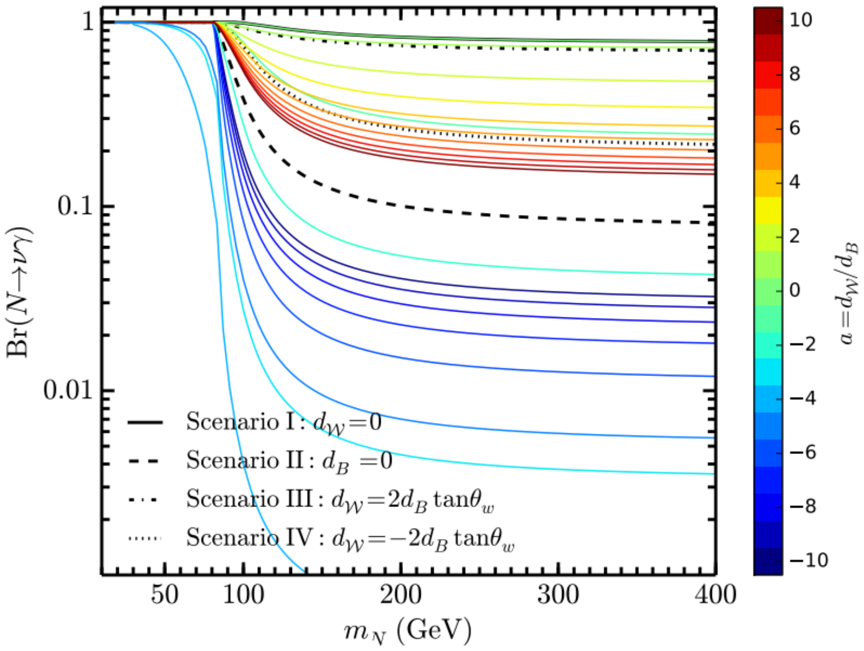
$$\Gamma_{N\to W\ell} = \frac{d_W^2}{8\pi m_N^3}\sqrt{(m_N^2 - (M_W - m_\ell)^2)(m_N^2 + (M_W - m_\ell)^2)}$$
$$\times \left(2m_\ell^2(2m_\ell^2 - 4m_N^2 - M_W^2) + (m_N^2 - M_W^2)(2m_N^2 + M_W^2)\right)\Theta(m_N > M_W + m_\ell).$$

$$N \to \nu Z^* \to \nu f\bar{f}$$

$$N \to W^*\ell \to \ell + ff'$$



$a = -2\cot\theta_w$



$$\mathrm{Br}(N\to\nu\gamma) \equiv \frac{\Gamma_{N\to\nu\gamma}}{\Gamma_{N\to\nu\gamma} + \Gamma_{N\to\nu Z} + \Gamma_{N\to W\ell} + \Gamma_{N\to\text{3-body}}}$$

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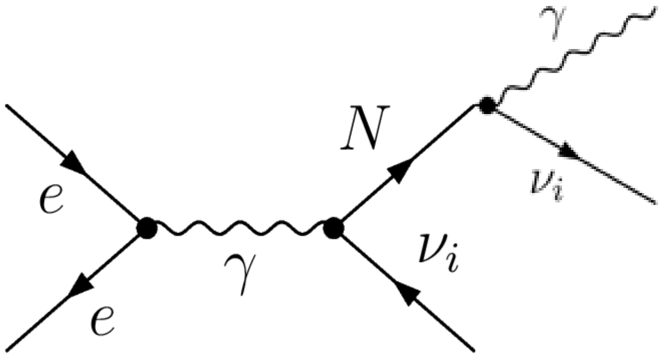
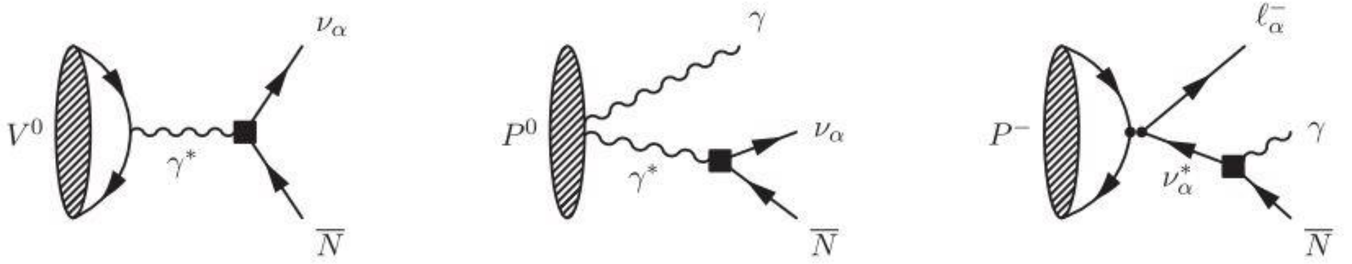
HNL production at low energy

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



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



$\rho^0 \to \nu_e + \overline{N}$

$\omega \to \nu_e + \overline{N}$

$\phi \to \nu_e + \overline{N}$

$J/\psi \to \nu_e + \overline{N}$

$\Upsilon(1S) \to \nu_e + \overline{N}$

$\pi^0 \to \gamma + \nu_e + \overline{N}$

$\eta \to \gamma + \nu_e + \overline{N}$

$\eta' \to \gamma + \nu_e + \overline{N}$

$\pi^- \to \gamma + e^- + \overline{N}$

$K^- \to \gamma + e^- + \overline{N}$

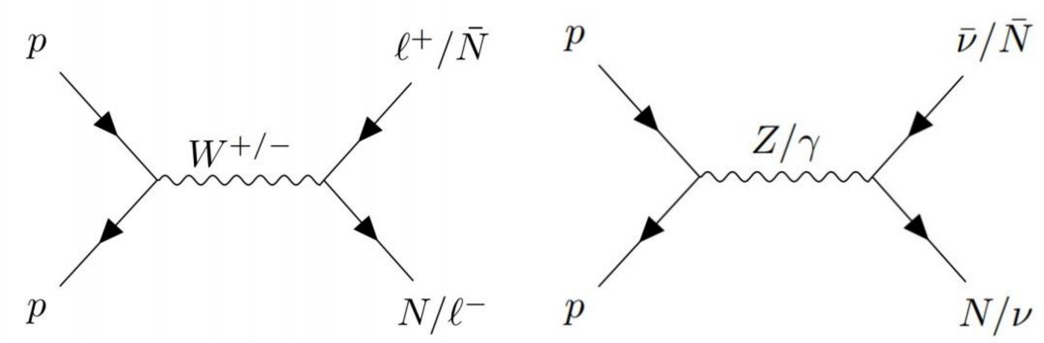
$D^- \to \gamma + e^- + \overline{N}$

$D_s^- \to \gamma + e^- + \overline{N}$

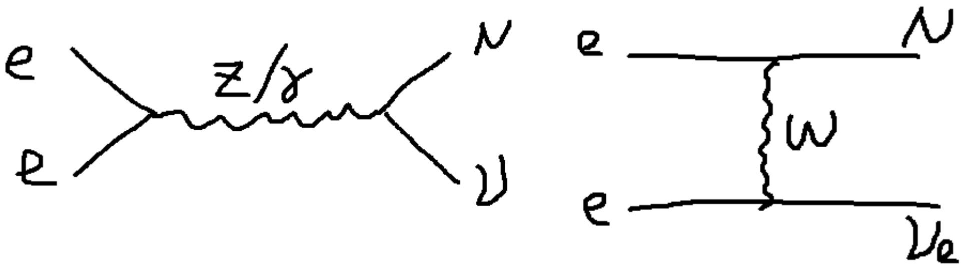
$B^- \to \gamma + e^- + \overline{N}$

HNL production at high energy

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

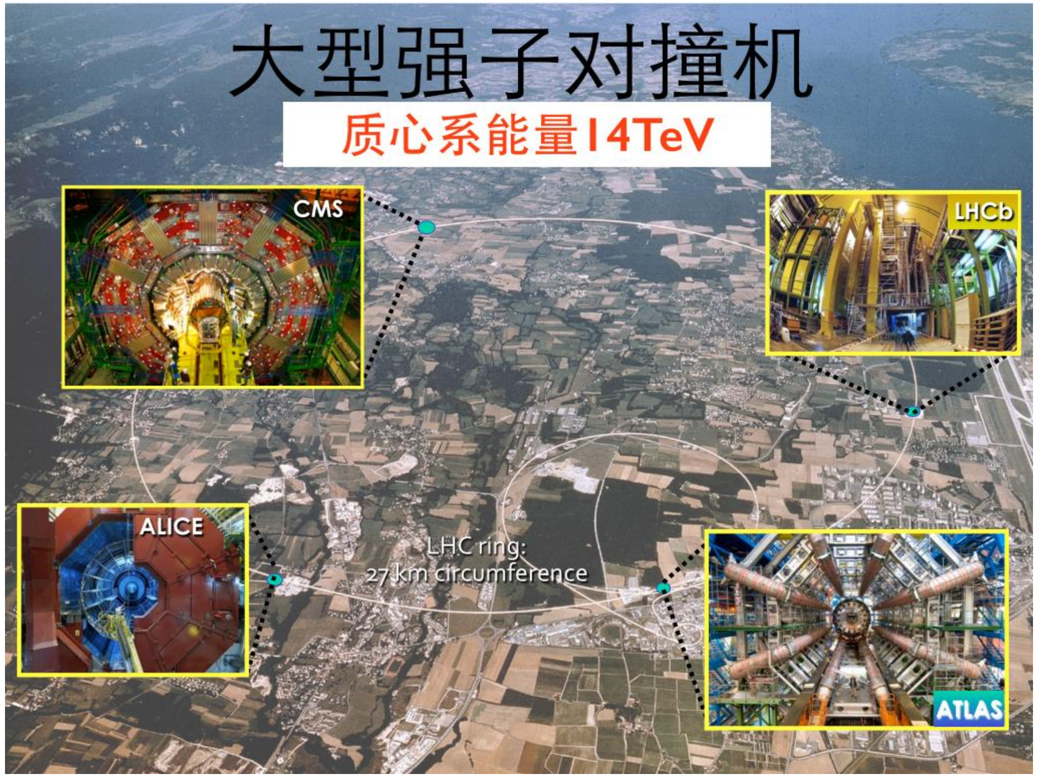


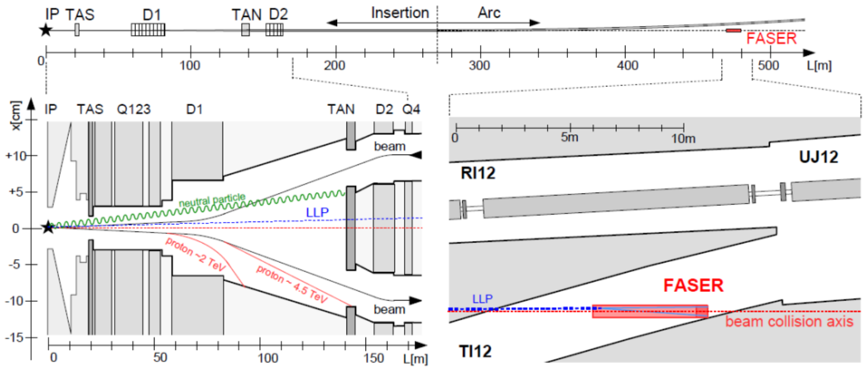
LHC



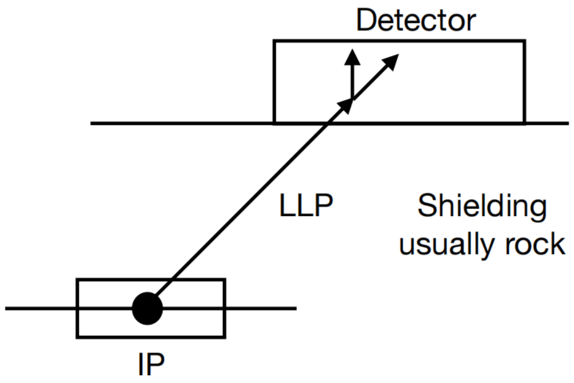
CEPC

Long Lived Particle Detectors



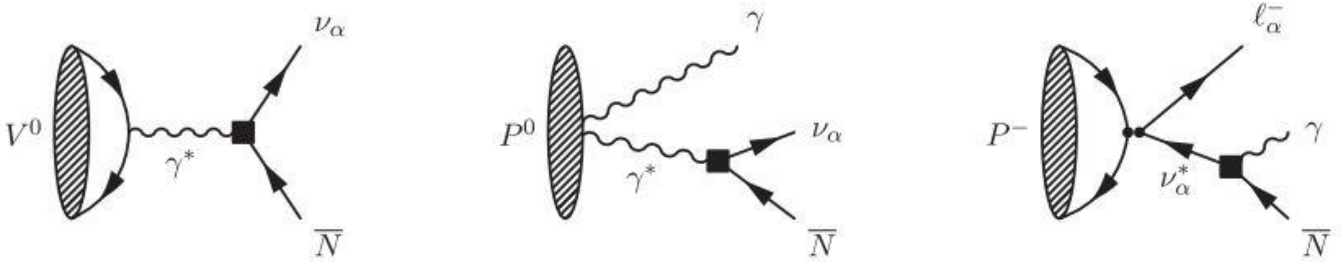


Approved experiment



Detectors	L_x [m]	L_y [m]	L_{xy} [m]	L_z [m]	Luminosity [fb^{-1}]
FASER-2	–	–	[0, 1]	[475, 480]	3000
MAPP-2	[3, 6]	[−2, 1]	–	[48, 61]	300
FACET	–	–	[0.18, 0.5]	[101, 119]	3000

Production at the LHC by Meson Decay



- We focus mainly via the on-shell decays of light meson

TABLE I. Production cross sections of mesons at the 14-TeV LHC in the forward hemisphere [102]. For the charged mesons, the given cross sections are only for one of the two charge-conjugated states.

Meson	Cross section [fb]	Meson	Cross section [fb]	Meson	Cross section [fb]
ρ^0	1.86×10^{14}	π^0	1.54×10^{15}	$\pi^\pm$	1.35×10^{15}
ω	1.74×10^{14}	η	1.69×10^{14}	$K^\pm$	1.57×10^{14}
ϕ	2.09×10^{13}	η'	1.81×10^{13}	$D^\pm$	8.48×10^{11}
J/ψ	3.93×10^{10}			$D_s^\pm$	2.70×10^{11}
$\Upsilon(1S)$	5.30×10^{8}			$B^\pm$	8.23×10^{10}

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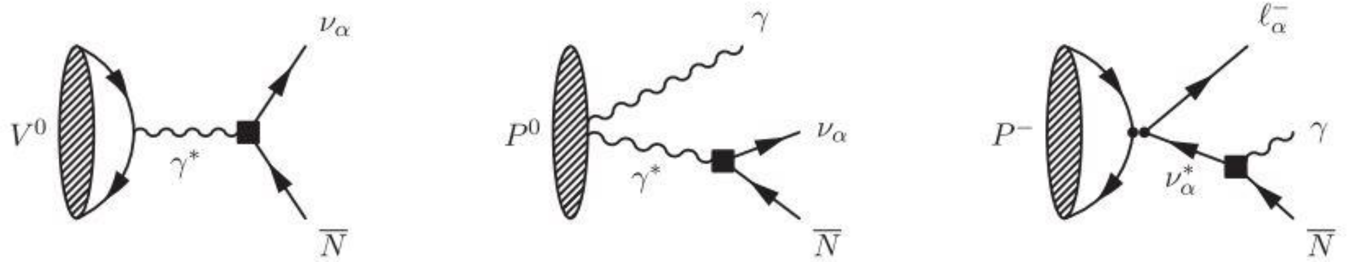
Production at the LHC by Meson Decay



- We focus mainly via the on-shell decays of light meson

$$\Gamma\left(V^0 \to \nu_\alpha \overline{N}\right) = \frac{f_V^2 m_V}{12\pi} e^2 Q_q^2 \left|d_\gamma^\alpha\right|^2 \left(1 - \frac{m_N^2}{m_V^2}\right)\left(1 + \frac{m_N^2}{m_V^2} - 2\frac{m_N^4}{m_V^4}\right)$$

$$\frac{\mathrm{d}\Gamma\left(P^0 \to \gamma \nu_\alpha \overline{N}\right)}{\mathrm{d}q^2\, \mathrm{d}\cos\theta} = \frac{1}{512\pi^3 m_P}\left(1 - \frac{q^2}{m_P^2}\right)\left(1 - \frac{m_N^2}{q^2}\right)\left|\mathcal{M}\left(P^0 \to \gamma \nu_\alpha \overline{N}\right)\right|^2$$

$$\frac{\mathrm{d}\Gamma\left(P^- \to \gamma \ell_\alpha^- \overline{N}\right)}{\mathrm{d}q^2\, \mathrm{d}\cos\theta} = \frac{\sqrt{\lambda\left(q^2, m_P^2, m_{\ell_\alpha}^2\right)}}{512\pi^3 m_P^3}\left(1 - \frac{m_N^2}{q^2}\right)\left|\mathcal{M}\left(P^- \to \gamma \ell_\alpha^- \overline{N}\right)\right|^2$$

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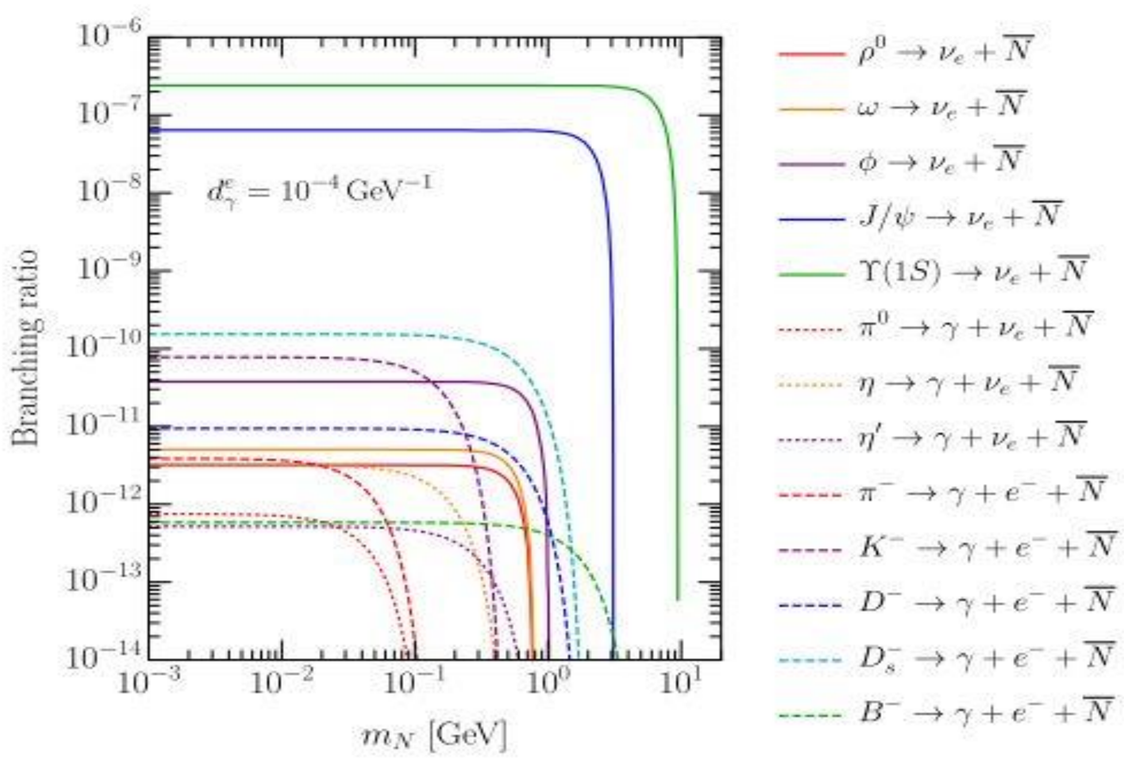
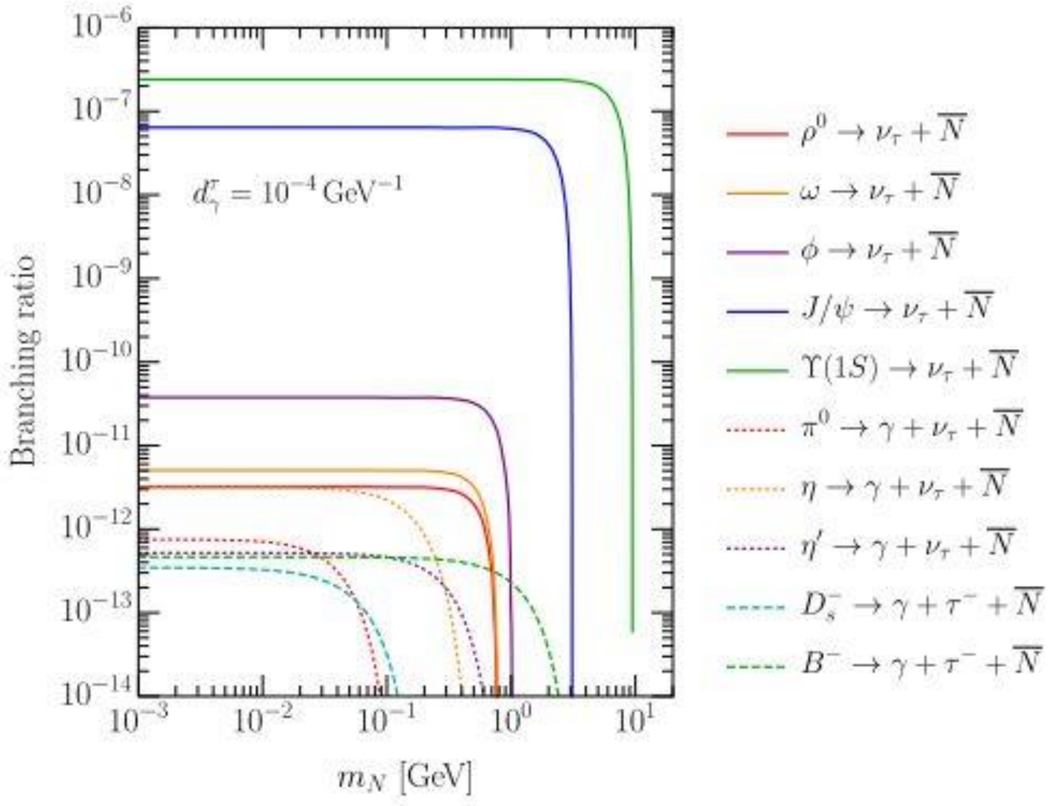
Production at the LHC by Meson Decay





- *J/φ* and ϒ decay branching ratio into N is large, but the number of them at the LHC is small
- The dominant production is from ρ^0, ϕ, ω, $\pi, \pi^\pm$, η decay

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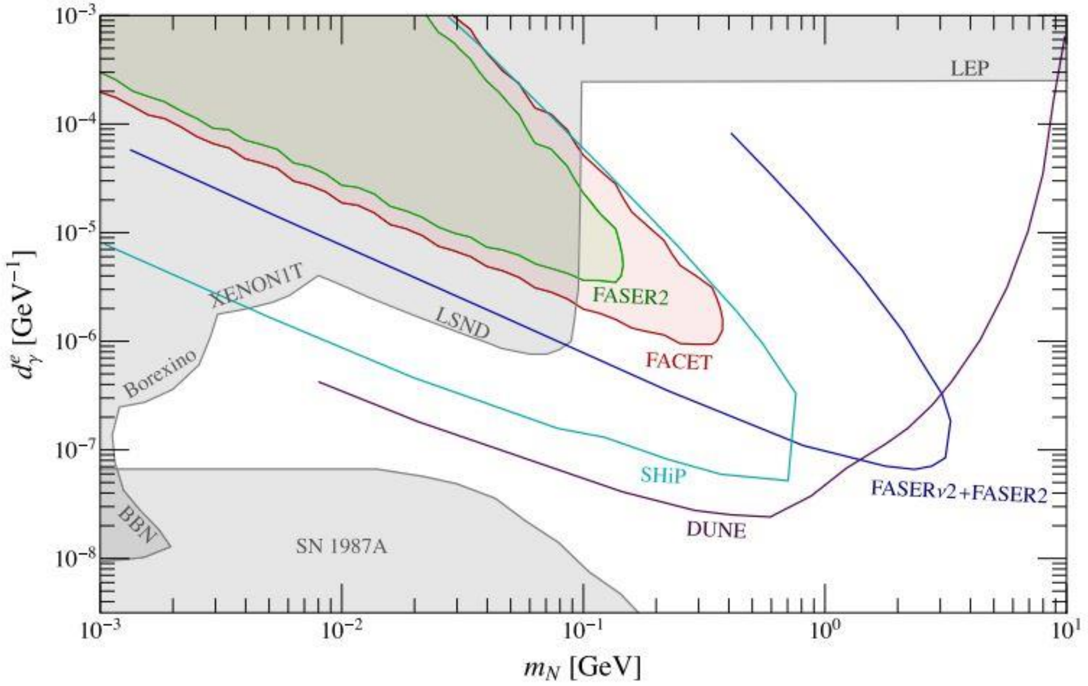
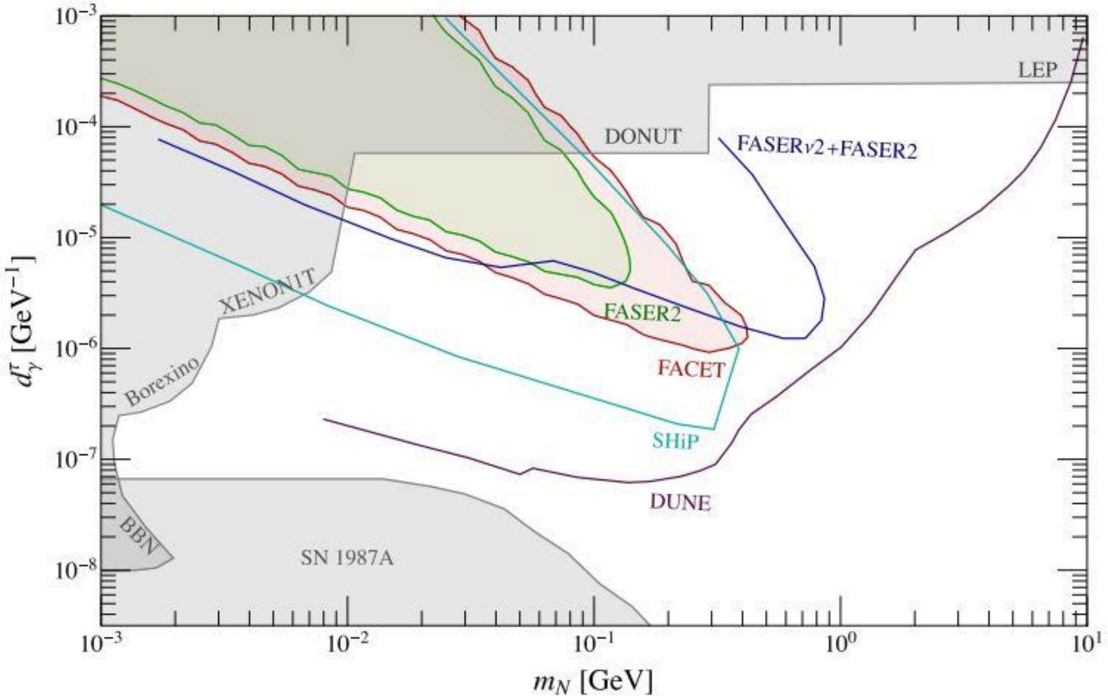
Results from Meson Decay





- Benefit from large number of meson produced at the LHC, the sensitivity can surpass the current limits
- Projection at the SHiP and DUNE can be even better see 1803.03262 and 2210.13141
- Usage of the FASERυ can extend the sensitivity, see 2011.04751

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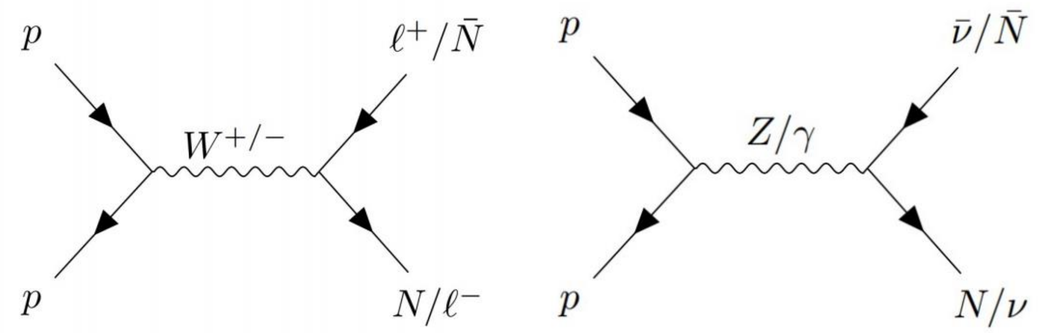
Production at the LHC by Bosons Decay



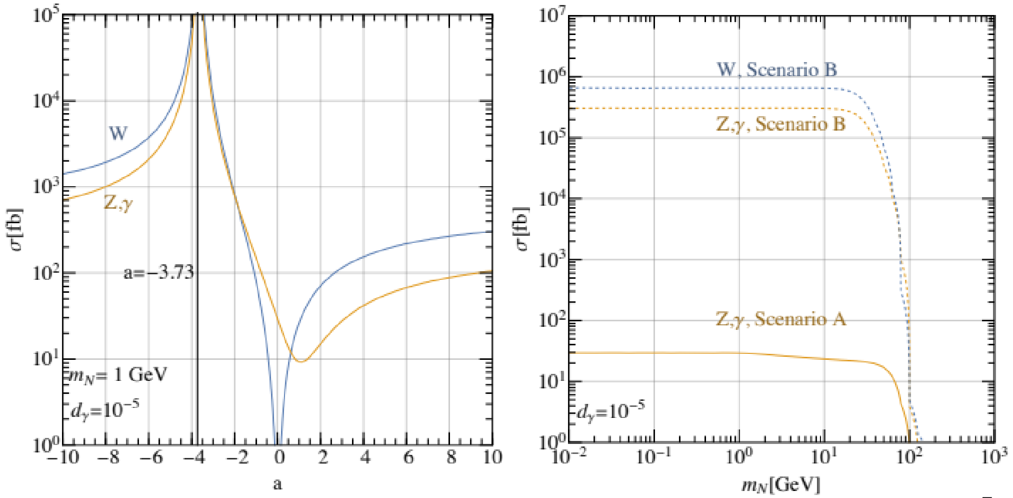
- We focus mainly via the on-shell decays of W/Z,
- the EFT should be valid with $\Lambda > M_{W,Z}$

$$d_{\mathcal{W}} = a \times d_B$$

$$d_Z = \frac{d_\gamma (a\cos\theta_w - 2\sin\theta_w)}{2\cos\theta_w + a\sin\theta_w}$$

$$d_W = \frac{\sqrt{2} a d_\gamma}{2\cos\theta_w + a\sin\theta_w}.$$

$$\{m_N, d_\gamma, a\}$$



Scenario	Assumptions	Relations
A	$d_{\mathcal{W}} = 0$	$d_Z = -d_\gamma \tan\theta_w$; $d_W = 0$
B	$d_{\mathcal{W}} = 2\tan\theta_w \times d_B$	$d_Z = 0$, $d_W = \sqrt{2} d_\gamma \sin\theta_w$
C	$d_{\mathcal{W}} = -3 \times d_B$	$d_Z \approx 11.250 \times d_\gamma$, $d_W \approx 13.258 \times d_\gamma$
D	$d_{\mathcal{W}} = -3.73 \times d_B$	$d_Z \approx 139.55 \times d_\gamma$; $d_W \approx 173.52 \times d_\gamma$

- The cross section can be high, and depend on $a = d_B/d_{\mathcal{W}}$

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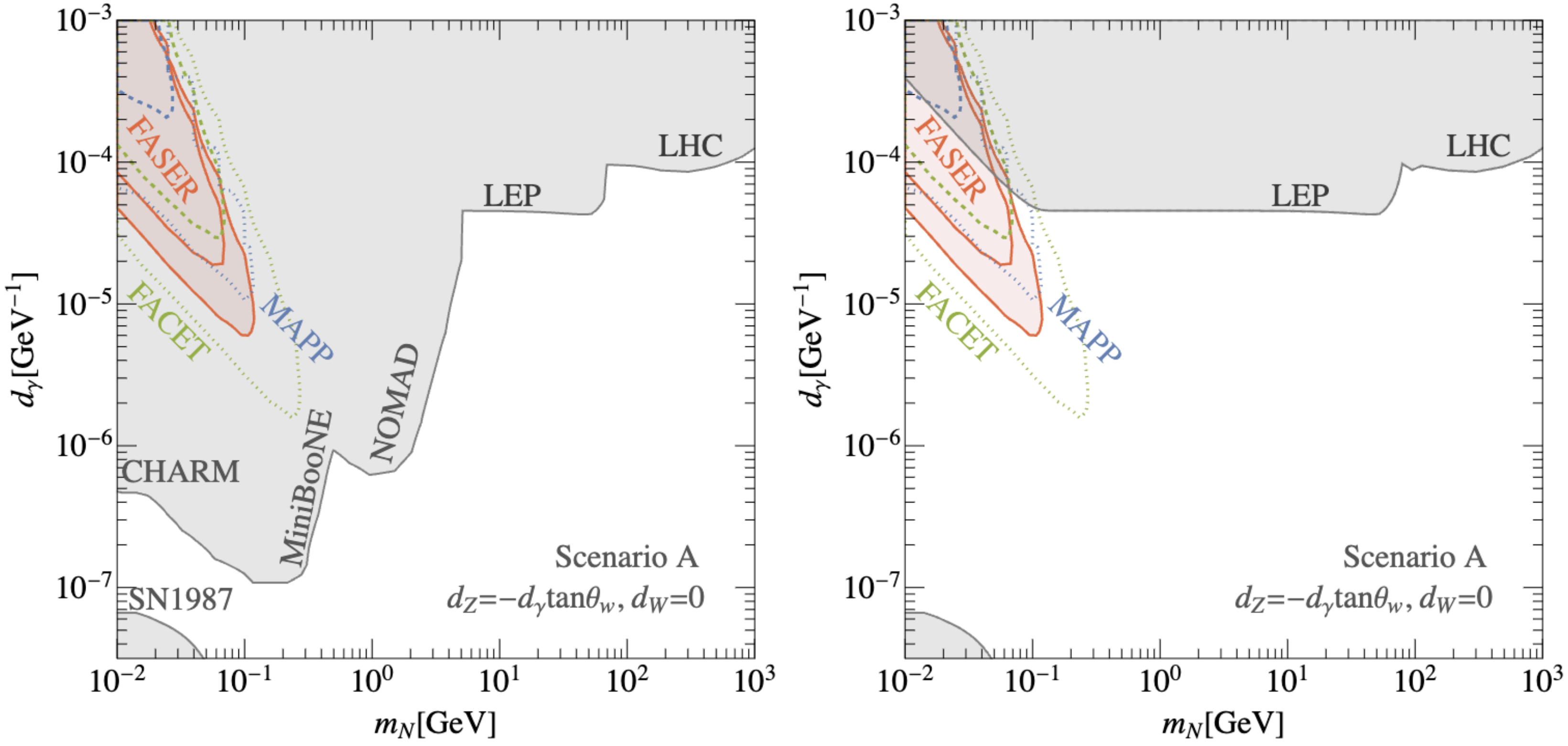
Results from Bosons Decay



- Left is the flavor universal coupling case, right for d_τ dominance
- The current limits from neutrino scattering are strong for e, μ flavor
- Less τ limits, since **hard to get υ_τ source**
- **Better sensitivity for d_τ** with LLP searches!

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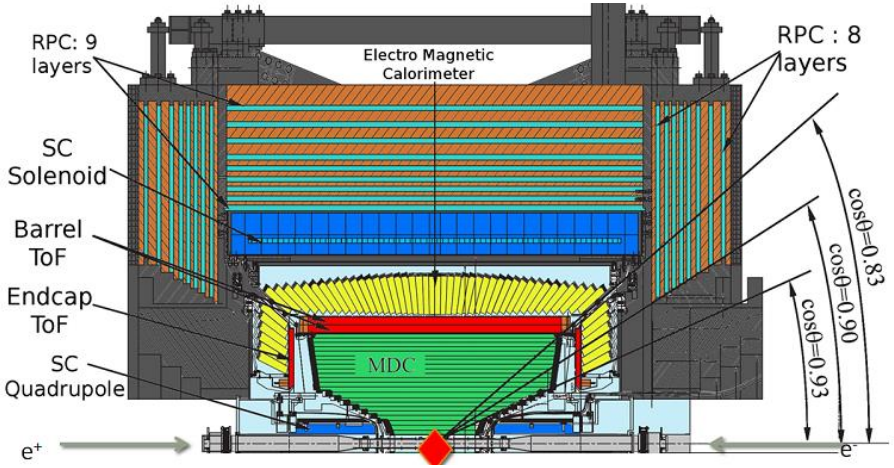
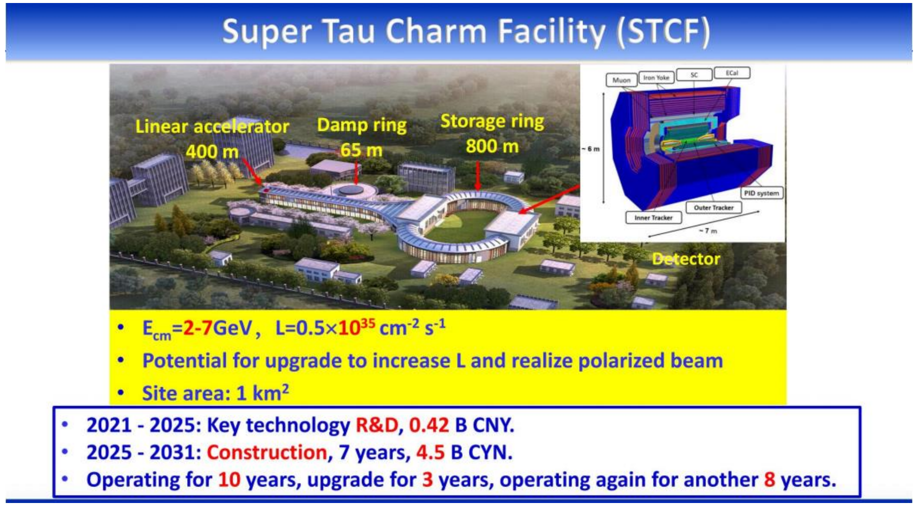
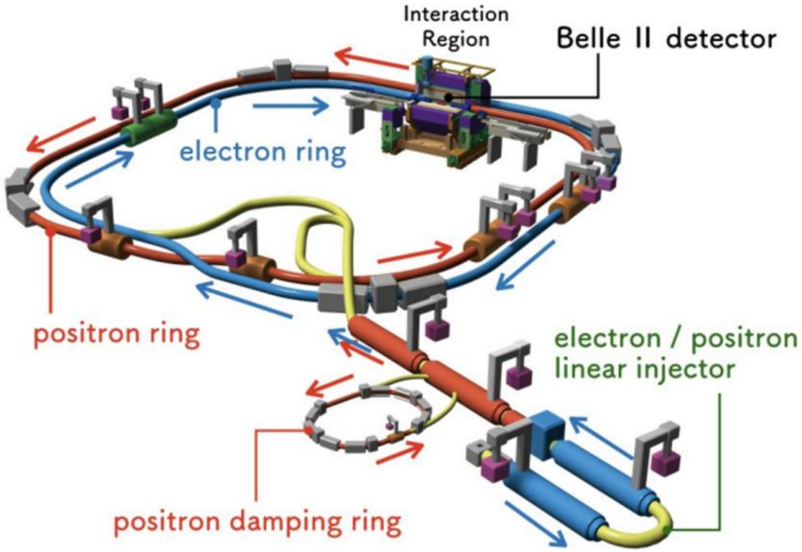
$e^+ e^-$ colliders

BESIII detector

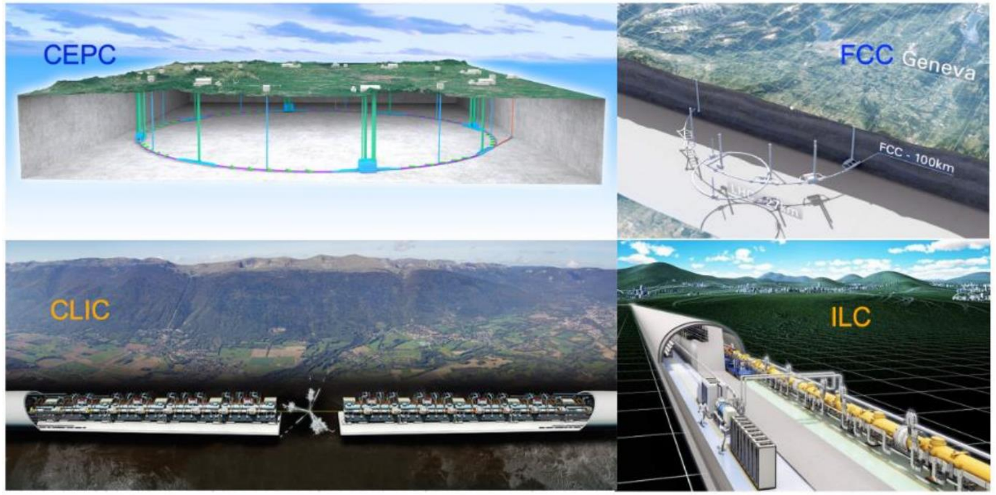




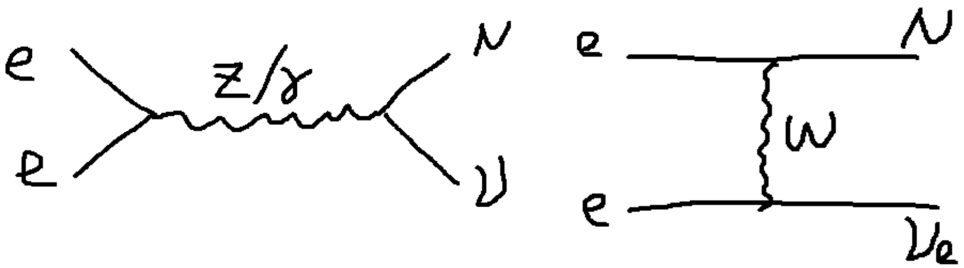


$\sqrt{s} \ll M_Z$

$\sqrt{s} \geq M_Z$



Production at electron colliders

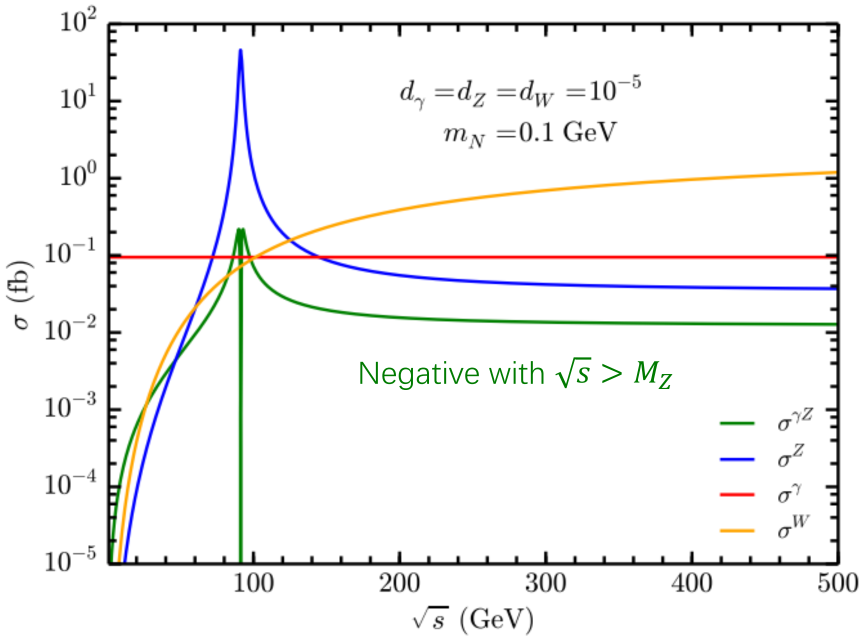


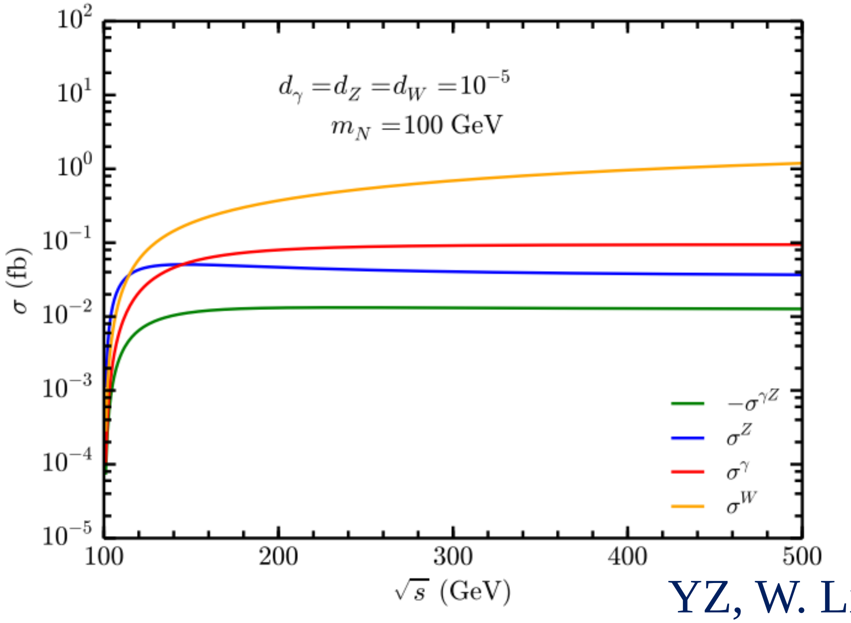
$$
\sigma^{\gamma}(e^+e^- \to N\bar{\nu}) = \frac{\alpha d_\gamma^2 (s-m_N^2)^2(s+2m_N^2)}{3s^3},
$$

$$
\sigma^{Z}(e^+e^- \to N\bar{\nu}) = \frac{\alpha d_Z^2 (s-m_N^2)^2(s+2m_N^2)}{24c_w^2 s_w^2 s\left(\Gamma_Z^2 M_Z^2 + (M_Z^2 - s)^2\right)}\left[\left(8s_w^2 - 4s_w + 1\right)\right],
$$

$$
\sigma^{\gamma Z}(e^+e^- \to N\bar{\nu}) = \frac{\alpha d_\gamma d_Z (s-m_N^2)^2(s+2m_N^2)}{6c_w s_w s^2\left(\Gamma_Z^2 M_Z^2 + (M_Z^2 - s)^2\right)}\left[(-4s_w + 1)\left(M_Z^2 - s\right)\right],
$$

$$
\sigma^{W}(e^+e^- \to N\bar{\nu}_e) = \frac{\alpha (d_W^e)^2}{2s_w^2 s}\Bigg[-2s - (2M_W^2 + s)\log\left(\frac{M_W^2}{-m_N^2 + M_W^2 + s}\right) + m_N^2\left(\frac{M_W^2}{-m_N^2 + M_W^2 + s} + 1\right)\Bigg],
$$

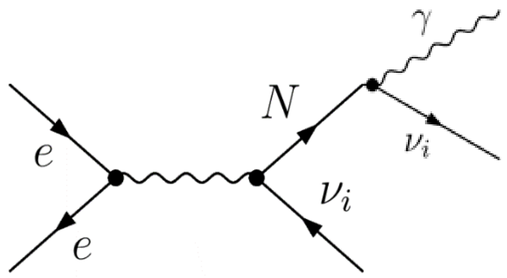


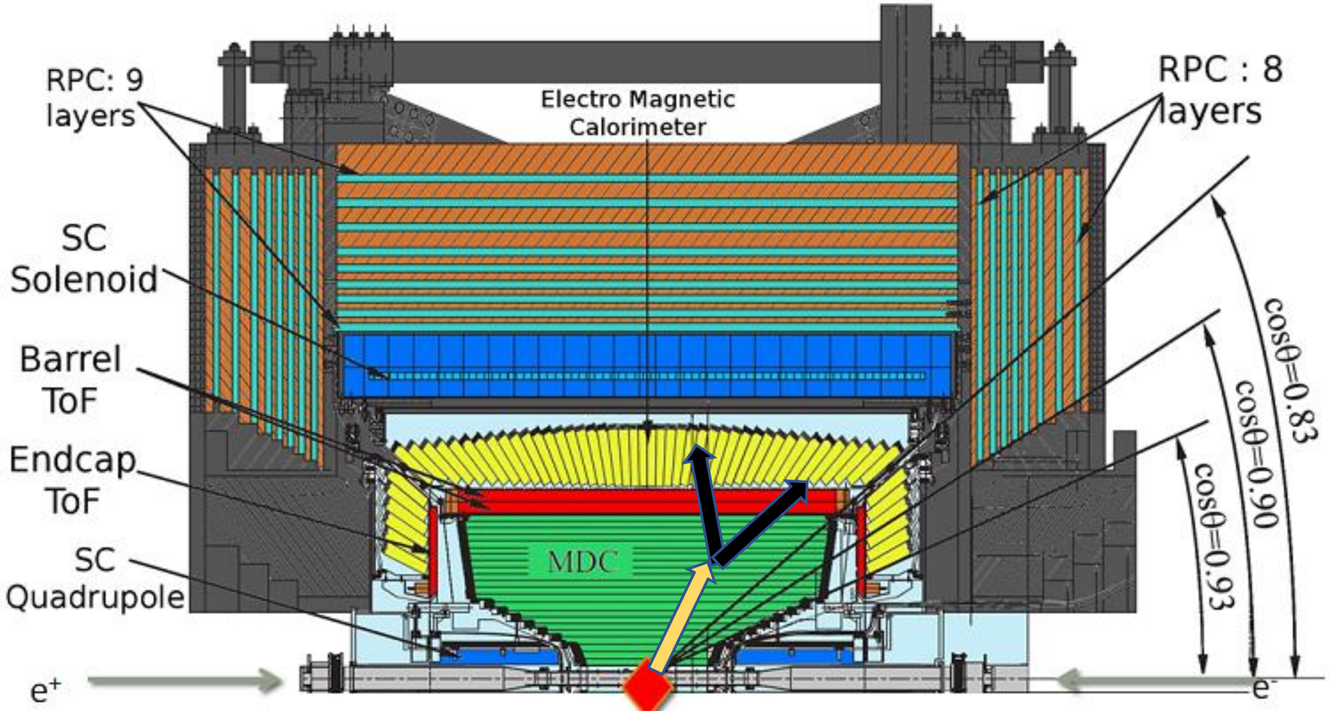


- With $\sqrt{s} \ll M_Z$ the contribution from Z or W can be neglected comparing with γ.
- σ^{γ} has little to do with the CM energy when $m_N \ll \sqrt{s}$.
- σ^{W} dominants when $\sqrt{s} \gg M_Z$ while can be ignored around Z-pole

YZ, W. Liu, Phys.Rev.D 107 (2023) 9, 095031

Decay Length





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

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

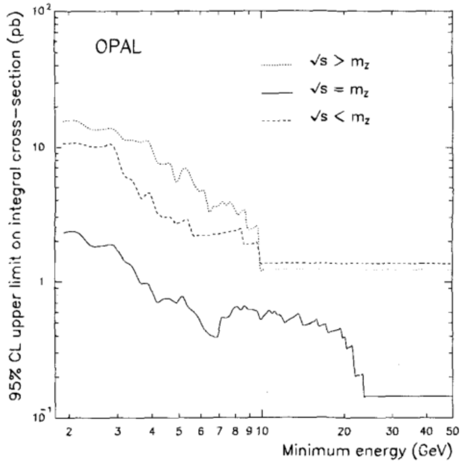
$$P_{dec}(l) = (1 - e^{-l/l_{dec}})\mathrm{Br}(N \to \nu\gamma).$$

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

Searches at LEP

LEP1

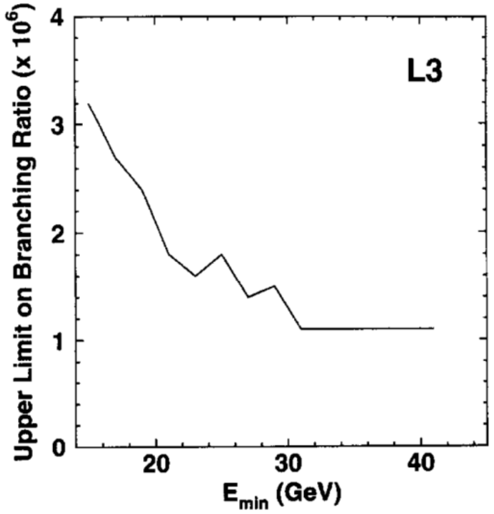
OPAL collaboration, Z. Phys. C 65 (1995) 47



scan-points. The 95 % CL upper limit on the cross-section at the Z^0 peak for production of a single photon with energy exceeding 23 GeV is found to be 0.15 pb. For models in

$Z \to \gamma +$invisible

L3 collaboration, Phys. Lett. B 412 (1997) 201



95% C.L. upper limit of 3.2×10^{-6} with $E_\gamma > 15$ GeV

LEP2

DELPHI collaboration, Eur. Phys. J. C 38 (2005) 395

	$\sqrt{s}$	200–209 GeV
	$<\sqrt{s}>$	205.4 GeV
	N_{observed}	190
HPC	$N_{\text{background}}$	0.1
$0.06 < x_\gamma < 1.1$	$N_{e^+e^-\to\nu\bar{\nu}\gamma}$	198.1±2.0
$45^\circ < \theta_\gamma < 135^\circ$	σ_{meas} (pb)	1.50±0.11
	$\sigma_{\nu\bar{\nu}\gamma(\gamma)}$ (pb)	1.61
	N_ν	2.71±0.30

$$\chi^2 = \left(\frac{\sigma^{\text{SM}} + \sigma^{N\nu} - \sigma^{\text{exp}}}{\delta\sigma^{\text{exp}}}\right)^2$$

$Z \to$invisible

Phys.Rept. 427 (2006) 257

new physics contributions $\Gamma^{\text{NP}}_{Z\to\text{invisible}} < 2.0$ MeV at 95% C.L.

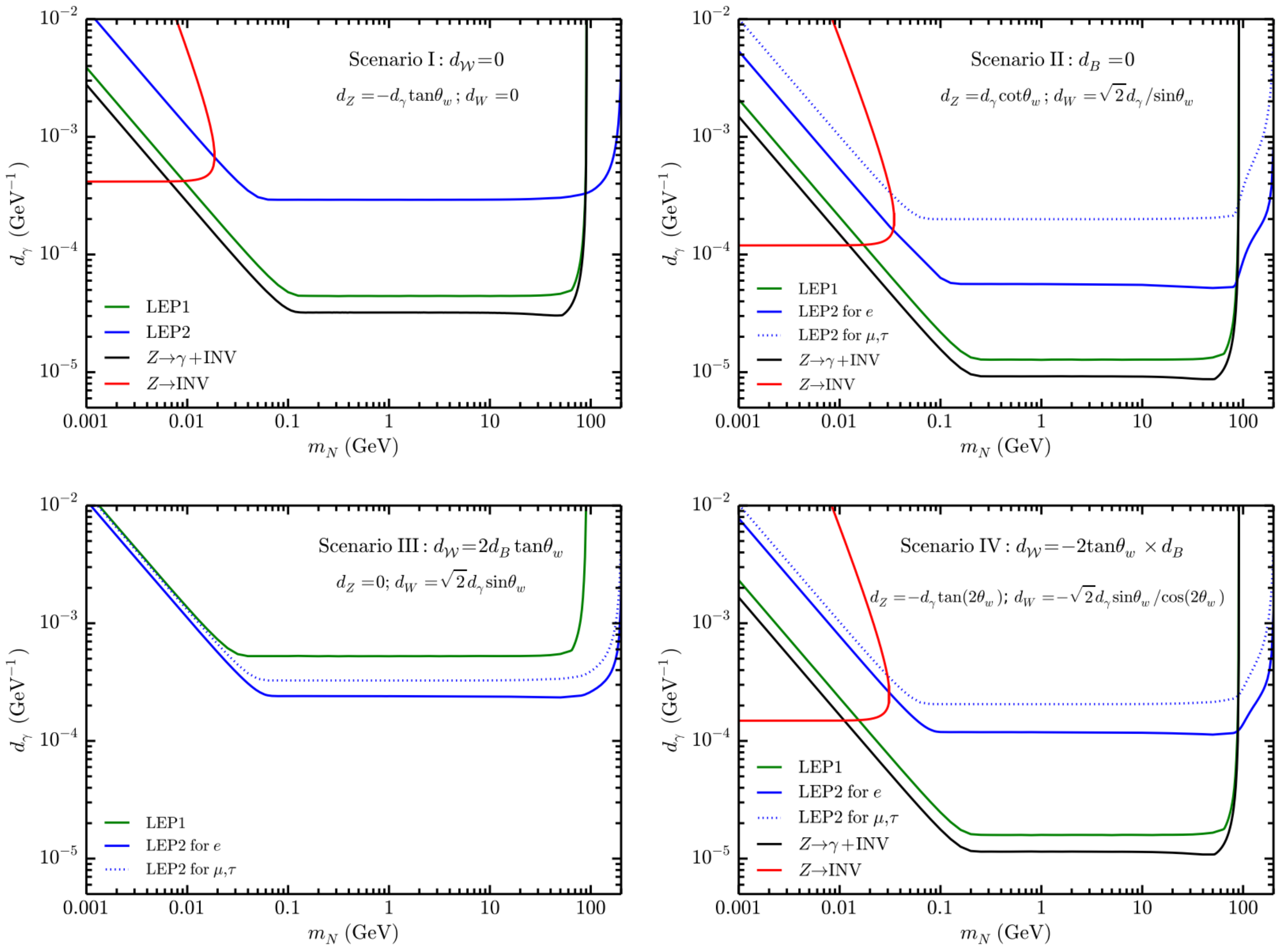
Four typical scenarios

Scenario	Assumptions	Relations
I	$d_{\mathcal{W}} = 0$	$d_Z = -d_\gamma \tan\theta_w;\ d_W = 0$
II	$d_B = 0$ ($a \to \infty$)	$d_Z = d_\gamma \cot\theta_w;\ d_W = \sqrt{2} d_\gamma / \sin\theta_w$
III	$d_{\mathcal{W}} = 2\tan\theta_w \times d_B$	$d_Z = 0;\ d_W = \sqrt{2} d_\gamma \sin\theta_w$
IV	$d_{\mathcal{W}} = -2\tan\theta_w \times d_B$	$d_Z = -d_\gamma \tan(2\theta_w);\ d_W = -\sqrt{2} d_\gamma \sin\theta_w / \cos(2\theta_w)$

$$d_{\mathcal{W}} = a \times d_B$$

$$\begin{aligned} d_Z &= \frac{d_\gamma (a\cos\theta_w - 2\sin\theta_w)}{2\cos\theta_w + a\sin\theta_w} \\ d_W &= \frac{\sqrt{2} a d_\gamma}{2\cos\theta_w + a\sin\theta_w}. \end{aligned}$$

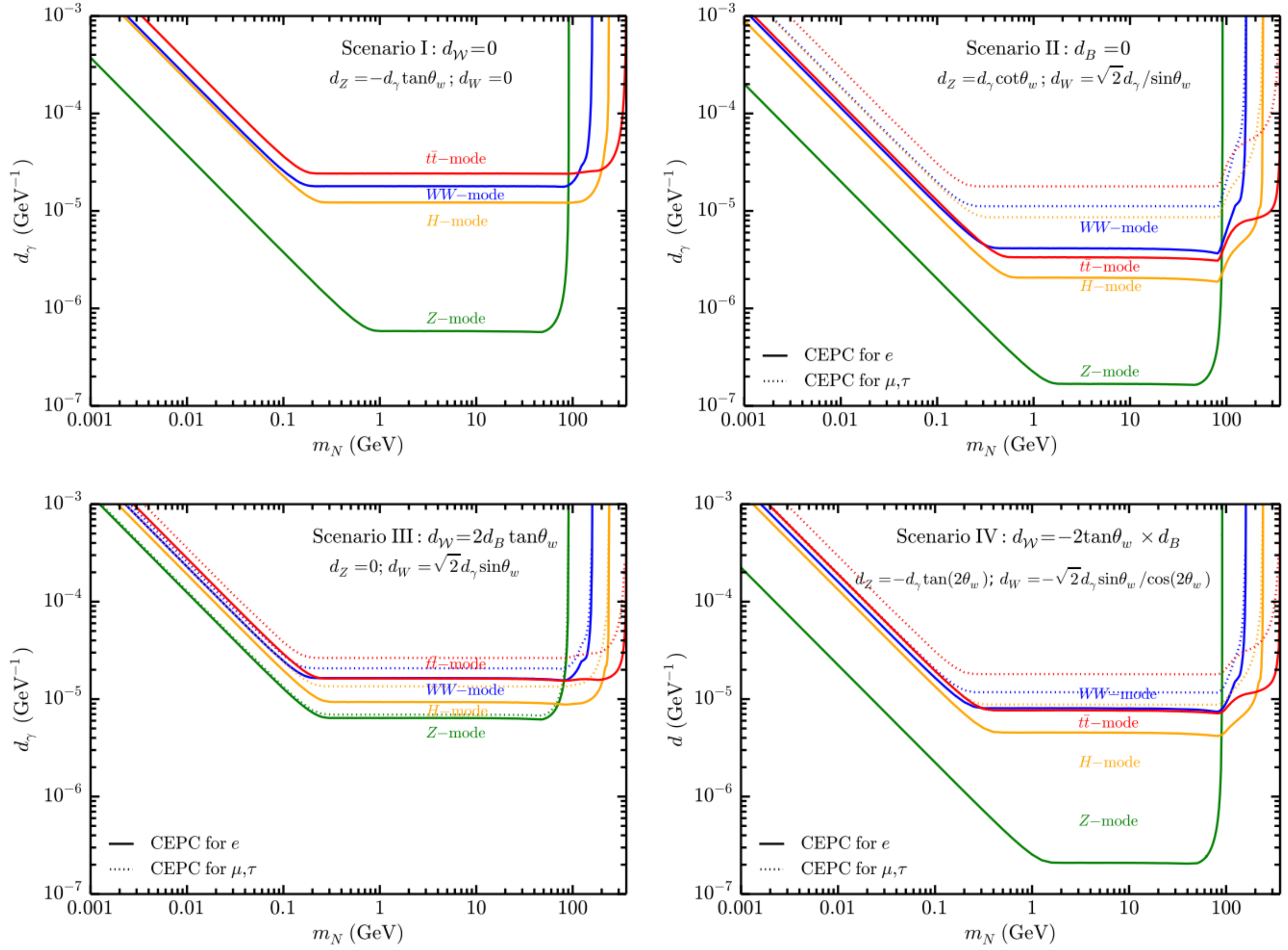
Results at LEP



- A characteristic “U” shape.
- The measurements of Z decay will derive same sensitivity for all the three lepton flavors, so almost do the monophoton searches at LEP1.
- the constraints on electron will be stricter than mu or tau from monophoton searches at LEP2.
- The constraints from the measurement of the branching ratio for Z → γ + invisible are always found to be most stringent.

YZ, W. Liu, Phys.Rev.D 107 (2023) 9, 09503

Results at CEPC

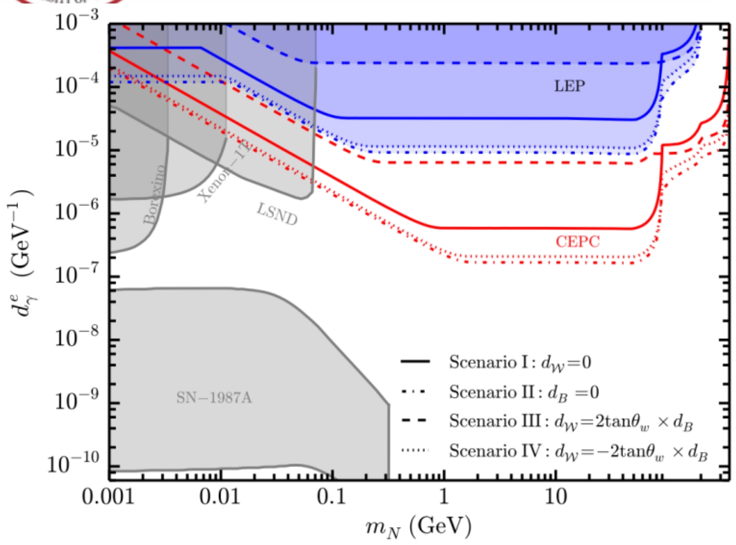


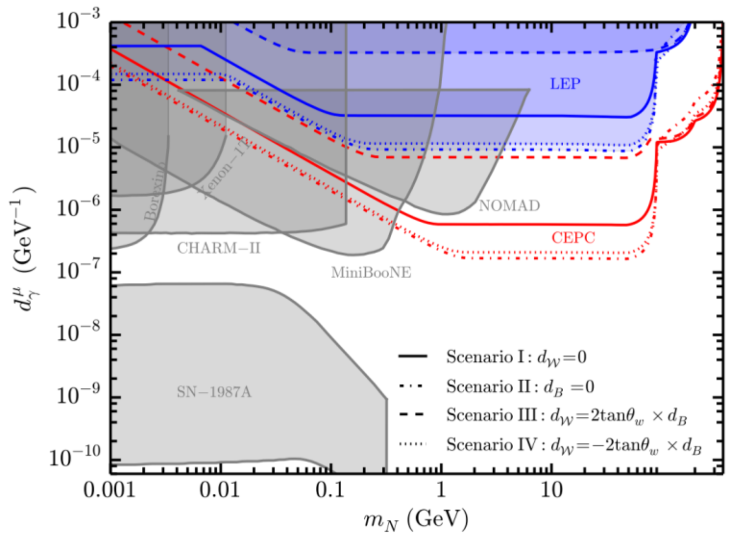
Operation mode	Z factory	WW threshold	Higgs factory	$t\bar{t}$
$\sqrt{s}$ (GeV)	91.2	160	240	360
Run time (year)	2	1	10	5
Instantaneous luminosity ($10^{34} cm^{-2} s^{-1}$, per IP)	191.7	26.6	8.3	0.83
Integrated luminosity (ab^{-1}, 2 IPs)	100	6	20	1
Event yields	3×10^{12}	1×10^{8}	4×10^{6}	5×10^{5}

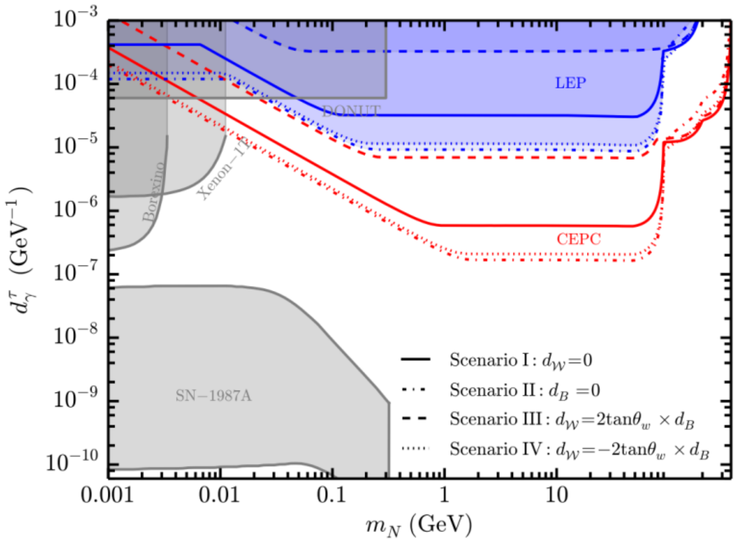
- Z-mode has the best sensitivity in all four scenarios for the HNL with small mass.
- Z-mode can give about two orders of magnitude of improvement over the other three running modes at CEPC in the sensitivity on d_mu/tau.

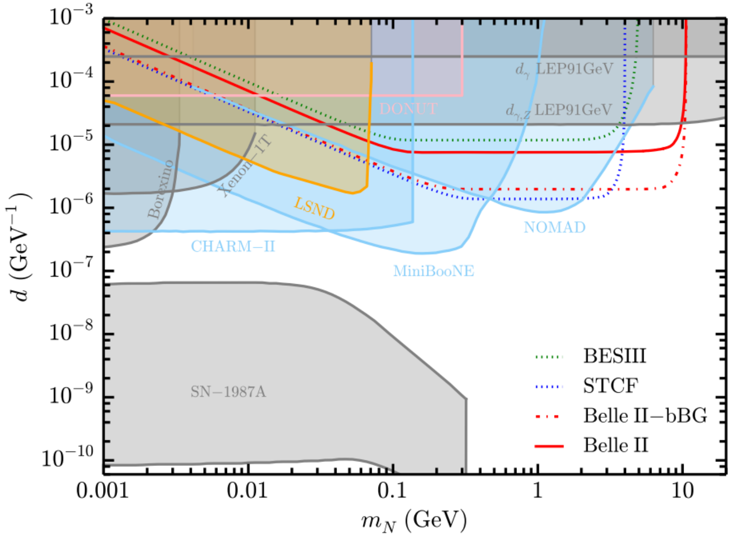
YZ, W. Liu, Phys.Rev.D 107 (2023) 9, 095031

Results at electron colliders









- The current constraints basically do not dependent on the ratio a, since the typical scattering energies are far less than the electroweak scale.

- 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)

YZ, W. Liu, Phys.Rev.D 107 (2023) 9, 095031

YZ, R. Ding, M. Song, L. Chen, Phys.Lett.B 829 (2022) 137116

Summary

- The more general dipole couplings to HNL which respect the full gauge symmetries of the SM are considering.
- We present the constraints on various electron colliders and LHC by Long-lived Particle Detectors.
- The constraints on active-sterile neutrino transition magnetic moments dependent on the model at high energy colliders.
- The current constraints basically do not dependent on the ratio a, since the typical scattering energies are far less than the electroweak scale.

谢谢观看

Thank you!

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HEFEI UNIVERSITY OF TECHNOLOGY