Probing light milli-charged particles at the BESIII

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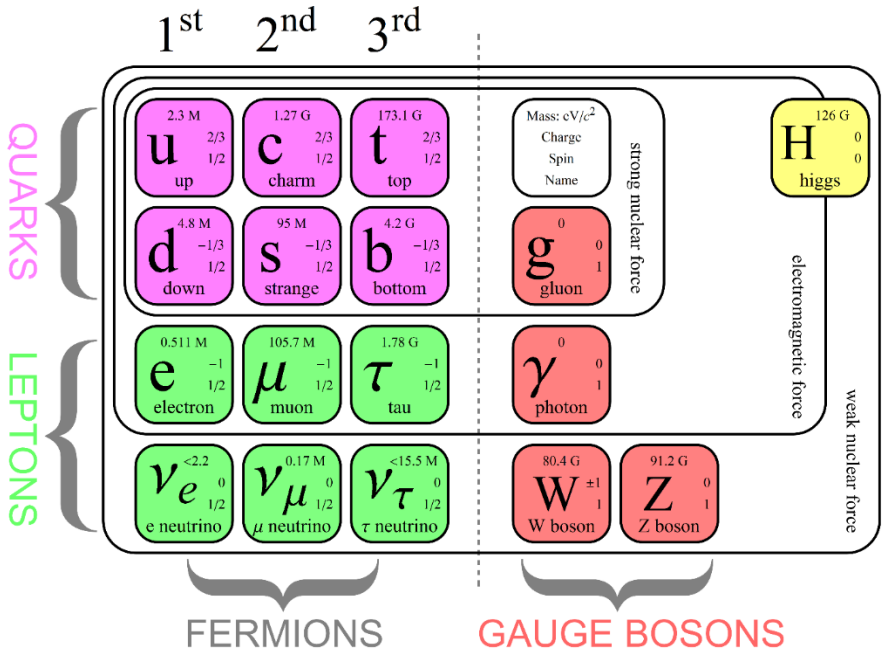
3rd CLHCP, Nanjing
2017-12-23

Outline

- Introduction
- Phenomenology at BESIII detector
- Summary

Introduction

The puzzle of electric charge



About 1910 Robert Millikan and Harvey Fletcher "oil drop" experiment elucidated the magnitude of the electron charge *e*. And by the early 1920s there was consensus that *e* was the smallest electric charge.

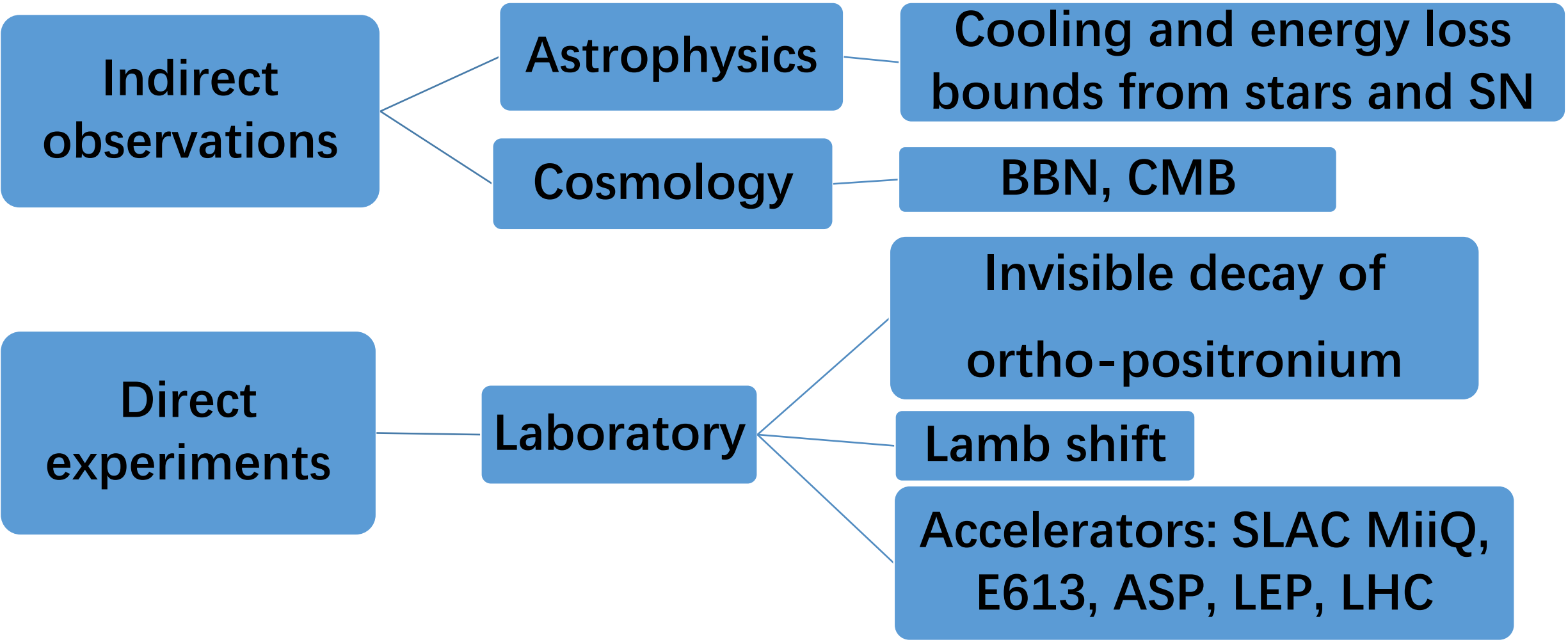
This was not challenged until the 1960s when physicists adopted the view of quarks as real elementary particles. *e*/3 or *2e*/3

Any other charges such as 1.001*e*, 0.005*e*, π*e*?

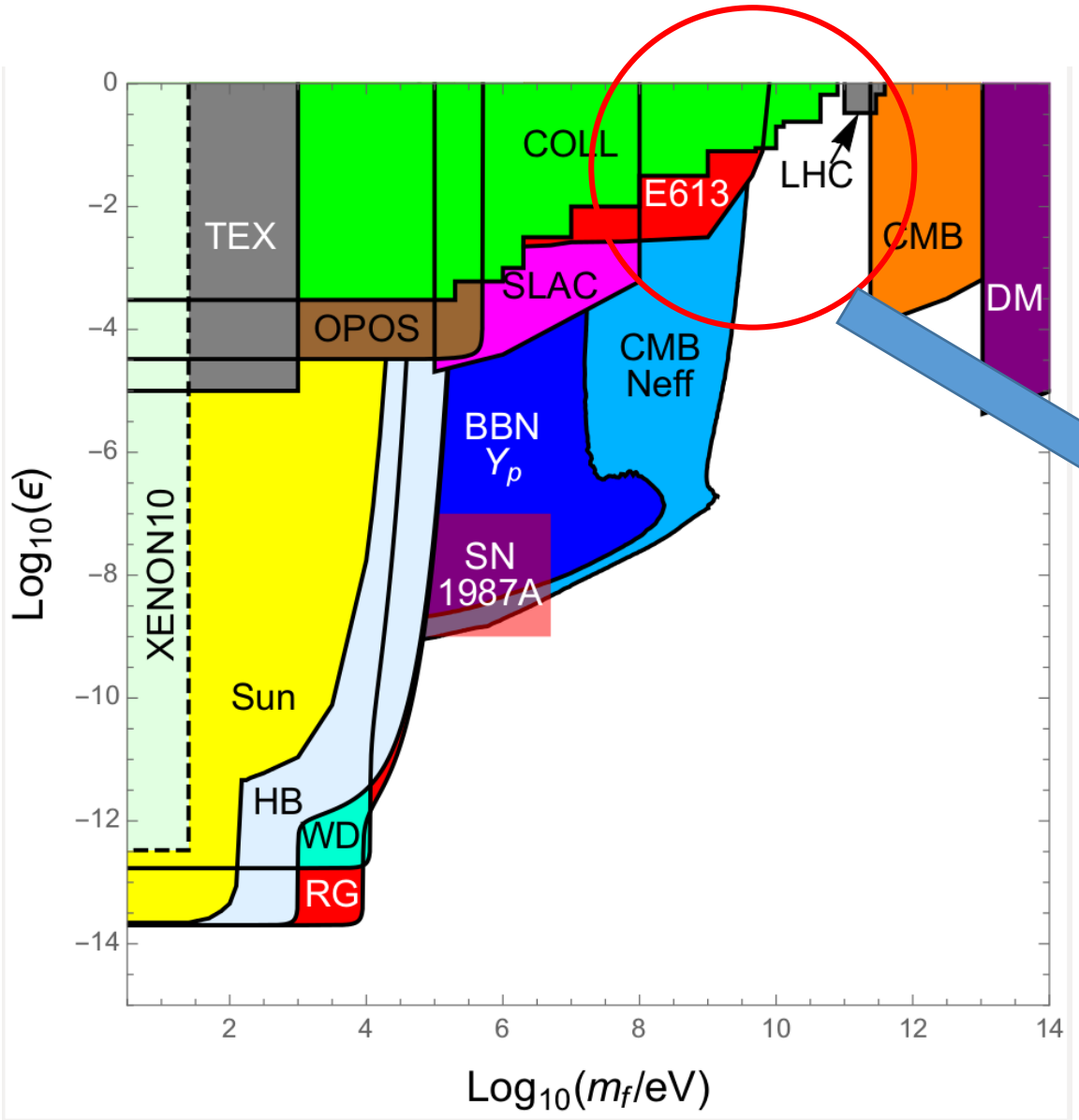
Milli-charge

- εe: ε is any real number
- $\varepsilon < 1$ milli-charged particle (MCP)
- Dark matter candidate?

Status on searches for milli-charged particles

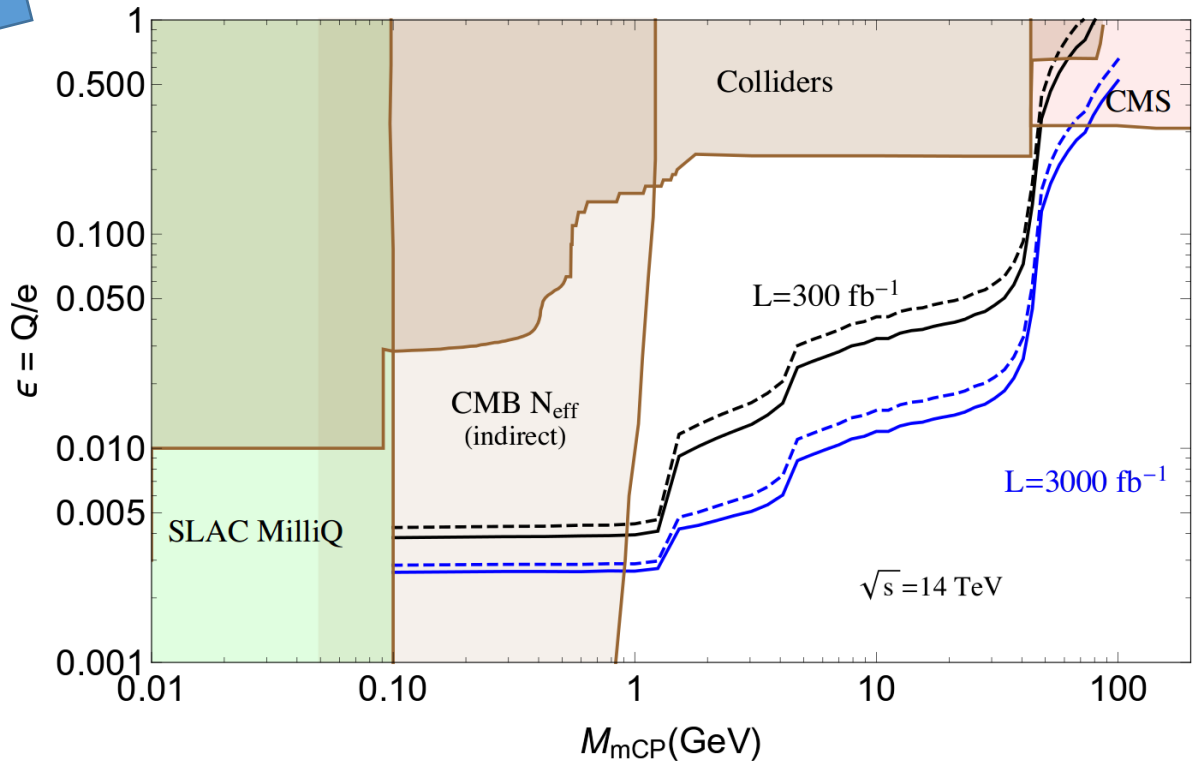


Existing Constraints



1511.01122

1410.6816



Phenomenology at BESIII detector

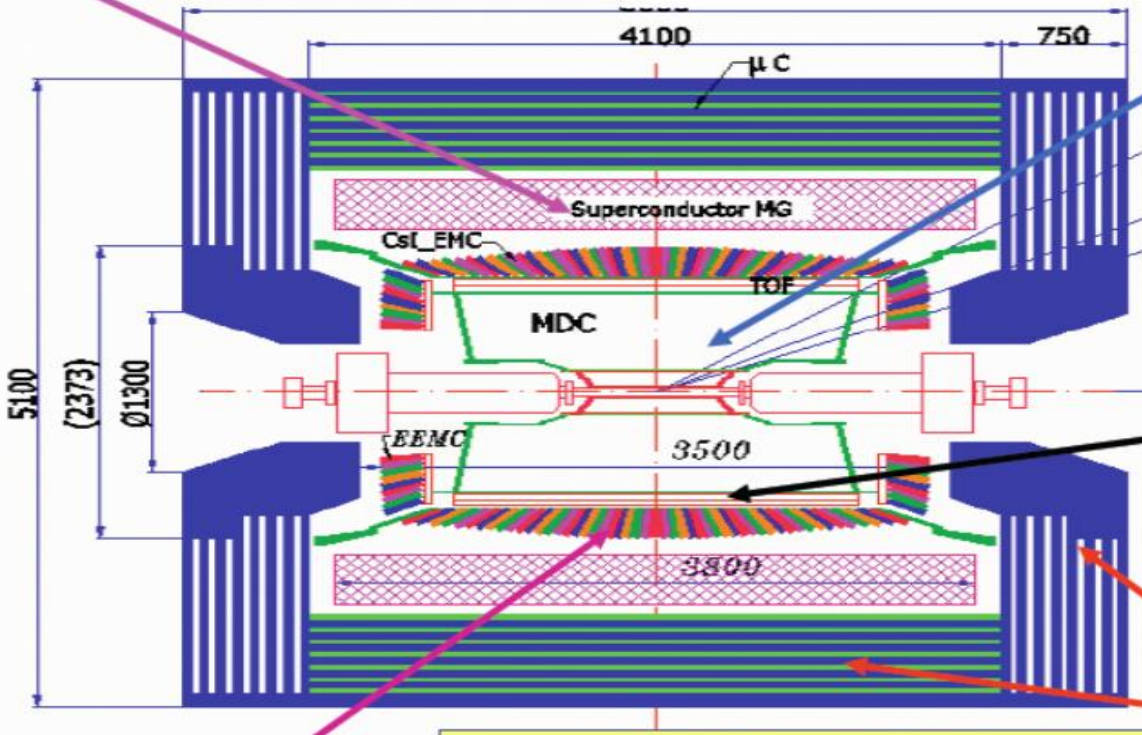
BEPCII: high luminosity double-ring collider

From H. L. Ma's slide

BESIII detector

Nucl. Instr. Meth. A614, 345 (2010)

Magnet: 1 T Super conducting



MDC: small cell & Gas:
He/C_3H_8 (60/40), 43 layers
σ_{xy}=130 μm
σ_p/p = 0.5% @1GeV
dE/dx=6%

TOF:
σ_T = 100 ps Barrel
110 ps Endcap

Muon ID: 9 layers RPC
8 layers for endcap

EMC: CsI crystal, 28 cm
ΔE/E = 2.5% @1 GeV
σz = 0.6 cm/√E

Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

From H. L. Ma's slide

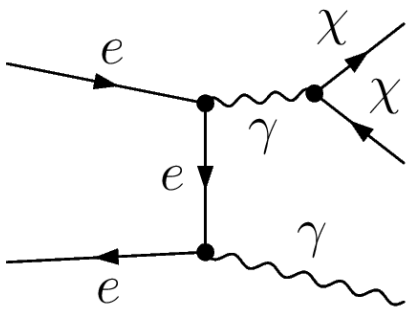
Lagrangian

$$\Delta\mathcal{L} \sim -\varepsilon e \bar{\chi} \gamma^{\mu} A_{\mu} \chi$$

χ is a massive Dirac fermion

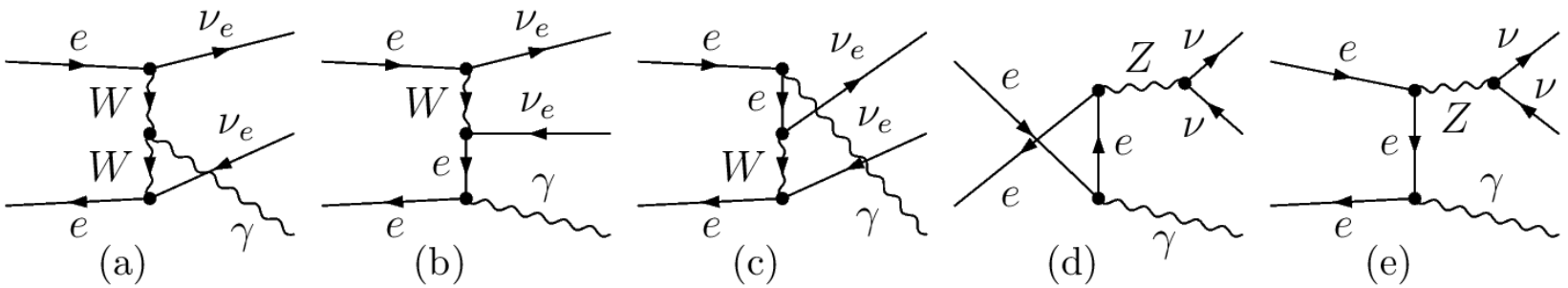
Phenomenology at BESIII detector

Mono-photon signature



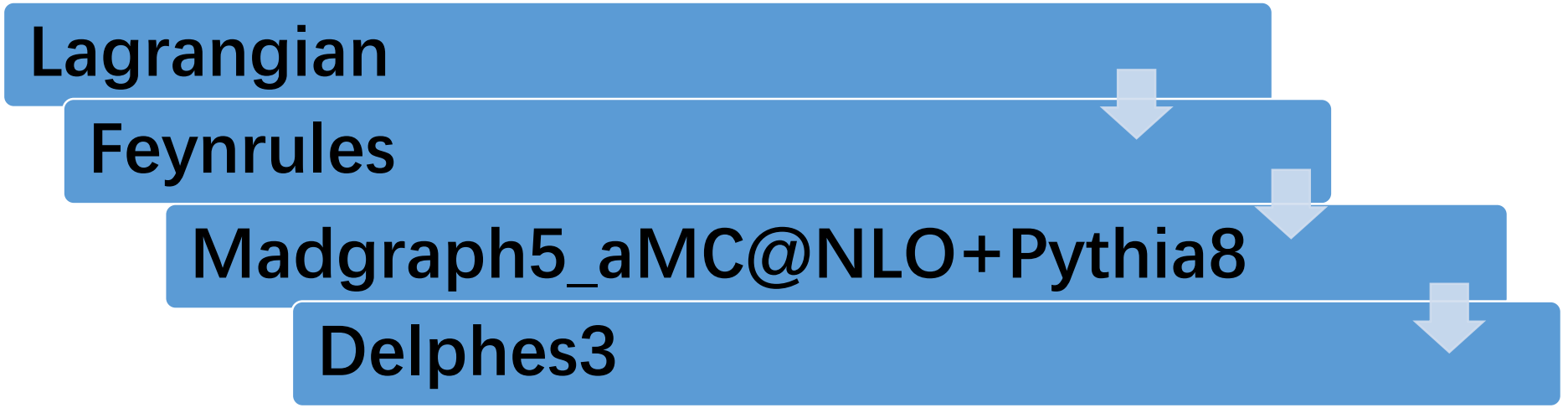
$$e^+e^- \to \gamma^*\gamma \to \chi\bar{\chi}\gamma$$

$$\frac{d\sigma}{dE_\gamma d\cos\theta_\gamma} = \frac{4\varepsilon^2\alpha_{em}^3}{3E_\gamma s^{5/2}(\sqrt{s}-2E_\gamma)^2}(2E_\gamma\sqrt{s}-2m_\chi^2-s)\sqrt{1-\frac{4m_\chi^2}{s-2E_\gamma\sqrt{s}}} \times [\cos\theta_\gamma E_\gamma^2 - \mathrm{arctanh}(\cos\theta_\gamma)(2E_\gamma^2-2E_\gamma\sqrt{s}+s)]$$



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

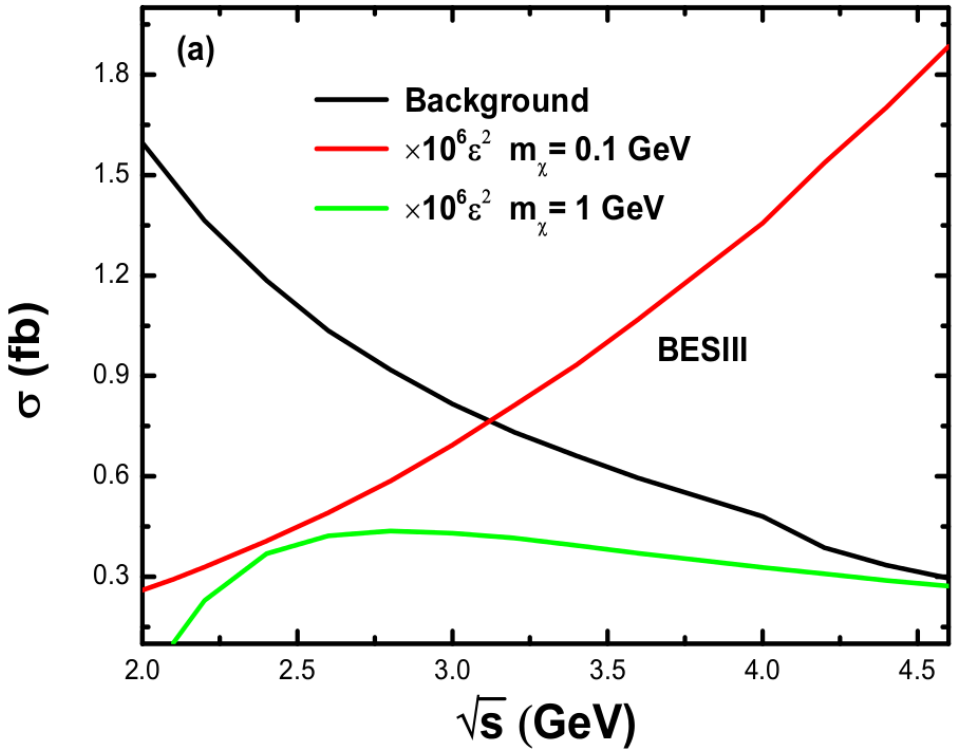
Event simulation

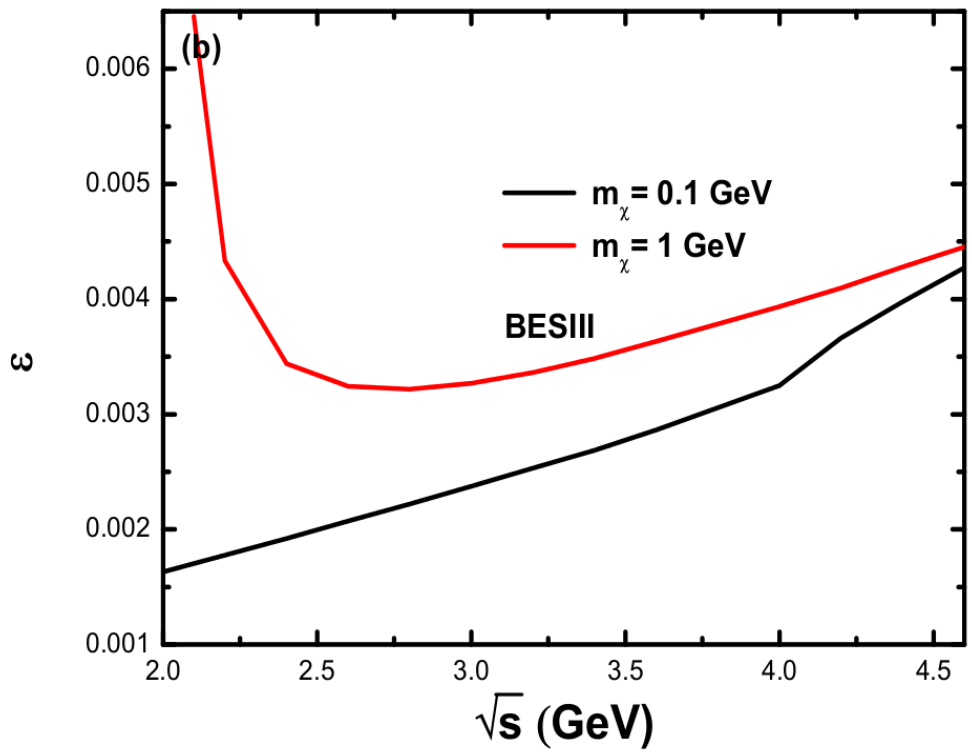


Energy resolution: $\frac{2.3\%}{\sqrt{E/\mathrm{GeV}}} \oplus 1\%$ from 20 MeV to 2 GeV for BESIII

$E^{\gamma} > 25$ MeV in the EMC barrel ($|\cos\theta^{\gamma}| < 0.8$) or
$E^{\gamma} > 50$ MeV in the EMC end-caps ($0.86 < |cos\,\theta^{\gamma}| < 0.92$)

Cross section and 2σ lower limit of ε as a function of $\sqrt{s}$ with 1 fb^{-1} luminosity





$$S(\varepsilon)/\sqrt{S(\varepsilon)+B} > 2$$

Data samples were collected by BESIII

2.9 fb^{-1} psi(3770) at 3.773 GeV, 2010 + 2011
0.5 fb^{-1} psi(4040) at 4.009 GeV, 2011
0.024 fb^{-1} tau mass scan at around 3.554 GeV, 2011
1.3x10^9 J/psi at Ecm=3.097 GeV, 2009 (0.225x10^9) + 2012
0.5x10^9 psi(3686) at Ecm=3.686 GeV, 2009 (0.106x10^9) + 2012
1.9 fb^{-1} Y(4260) at 4.23 and 4.26 GeV, 2013
0.5 fb^{-1} Y(4360) at 4.36 GeV, 2013
0.5 fb^{-1} Y(4260) and Y(4360) scan, 2013
0.8 fb^{-1} R scan, 104 energy points between 3.85 and 4.59 GeV, 2014
0.5 fb^{-1} at 4.60 GeV, 2014
0.1 fb^{-1} at 4.47 and 4.53 GeV for line shape, 2014
0.04 fb^{-1} around the threshold of Lambda charm, 2014
1.0 fb^{-1} at 4.42 GeV, 2014
0.5 fb-1 data for R scan from 2.0 to 3.08 GeV, 2015
0.1 fb-1 data @ 2.125 GeV, 2015
3.1 fb-1 data at 4.18 GeV, 2016

http://bes3.ihep.ac.cn/datasets/datasets.htm

Combine results of different $\sqrt{s}$

Test Statistic (TS)

$$\chi^2(S,B) \equiv S(\varepsilon)/\sqrt{S(\varepsilon)+B}$$

$$\Delta\chi^2 = \chi^2(m_\chi,\varepsilon) - \chi^2(m_\chi,\varepsilon=0) = 2.71$$

ε_{95} corresponding to 95% upper limit

$$\chi^2(S,B) = -2\ln\mathcal{L}(S,B)$$

$$\chi^2 = -2\ln\mathcal{L} = -2\ln\left(\prod_i \mathcal{L}_i\right) = \sum_i(-2\ln\mathcal{L}_i) = \sum_i \chi_i^2 = \sum_i \frac{S_i(\varepsilon)}{\sqrt{S_i(\varepsilon)+B_i}}$$

$$\Delta\chi^2 = \sum_i\left(\frac{S_i(\varepsilon)}{\sqrt{S_i(\varepsilon)+B_i}} - \frac{S_i(\varepsilon=0)}{\sqrt{S_i(\varepsilon=0)+B_i}}\right) = 2.71$$

Combine results of different $\sqrt{s}$

- 2.9 fb^{-1} psi(3770) at 3.773 GeV, 2010 + 2011
- 0.5 fb^{-1} psi(4040) at 4.009 GeV, 2011
- 0.024 fb^{-1} tau mass scan at around 3.554 Ge
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- 0.8 fb^{-1} R scan, 104 energy points between 3
- 0.5 fb^{-1} at 4.60 GeV, 2014
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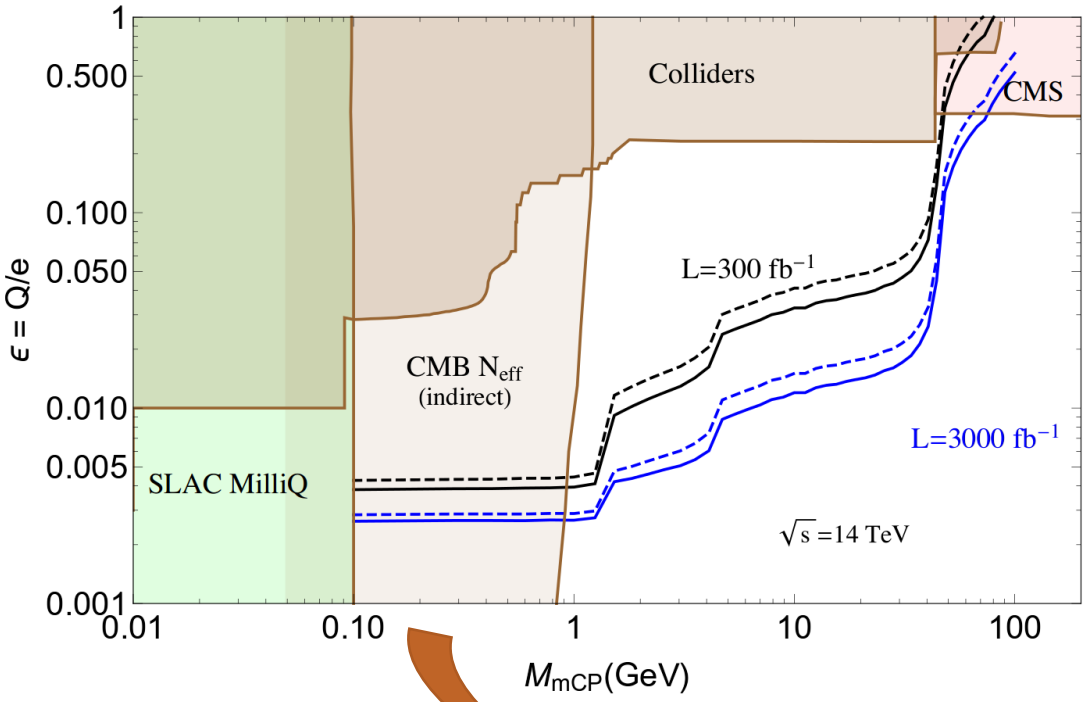
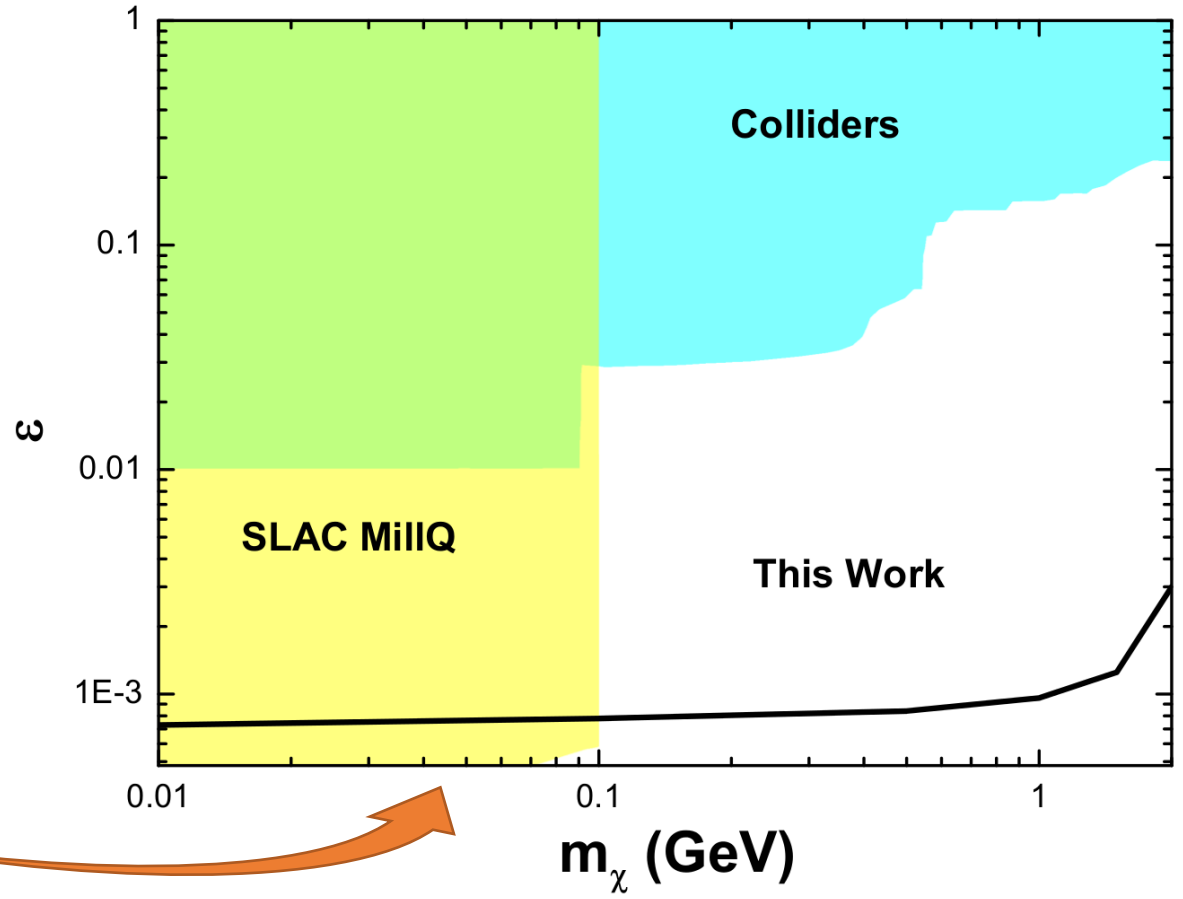
- 1.0 fb^{-1} at 4.42 GeV, 2014
- 0.5 fb-1 data for R scan from 2.0 to 3.08 GeV
- 0.1 fb-1 data @ 2.125 GeV, 2015
- 3.1 fb-1 data at 4.18 GeV, 2016

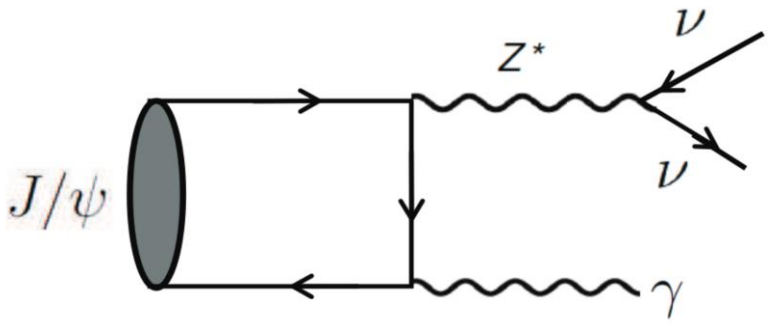
$\sqrt{s}$ (GeV)	Luminosity (fb^{-1})	B	$\varepsilon_{95}(m_\chi = 0.1\,\mathrm{GeV})$	$\varepsilon_{95}(m_\chi = 1\,\mathrm{GeV})$	$\varepsilon_{95}(m_\chi = 2\,\mathrm{GeV})$
2.125	0.1	0.03	0.0062	0.020	–
3.097	0.8	0.60	0.0032	0.0043	–
3.554	0.024	0.02	0.019	0.025	–
3.686	1	1.13	0.0034	0.0043	–
3.773	2.9	3.46	0.0023	0.0029	–
4.009	0.5	0.69	0.0051	0.0062	–
4.18	3.1	4.68	0.0027	0.0031	0.0084
4.23	1.9	2.96	0.0034	0.0037	0.0088
4.26	1.9	3.01	0.0034	0.0038	0.0084
4.36	0.5	0.83	0.0061	0.0066	0.013
4.42	1	1.72	0.0047	0.0050	0.0090
4.6	0.5	0.94	0.0066	0.0069	0.011
Combine results			0.00078	0.00096	0.0030

Combine results of different $\sqrt{s}$

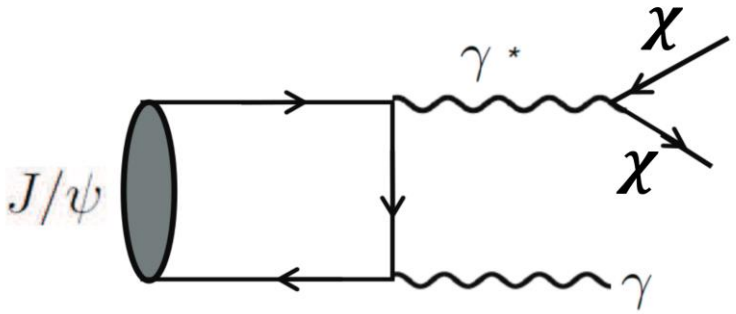




Something worthy of note



$$\mathrm{Br}(J/\psi \to \gamma\nu\bar{\nu}) = 0.7 \times 10^{-10}$$



C-parity violate

Summary

Summary

- We propose a search for milli-charged particles via mono-photon signature at BESIII detector at BEPCII in a simplified extended model.
- We present the cross section of signal and background and 2σ lower limit of ε as a function of $\sqrt{s}$ with 1 fb^{-1} luminosity.
- Using the collected data luminosity at BESIII, we present the constrains on the charge of milli-charged particle for $7.8 \times 10^{-4}e \sim 3.0 \times 10^{-3}e$ over the its mass range of 0.1 GeV ~ 2 GeV, which can be by up to two orders of magnitude over previous direct experiments.

Thanks