



第十六届TeV物理工作组学术研讨会 暨邝宇平院士学术思想研讨会

Opportunities at the electron-muon collider

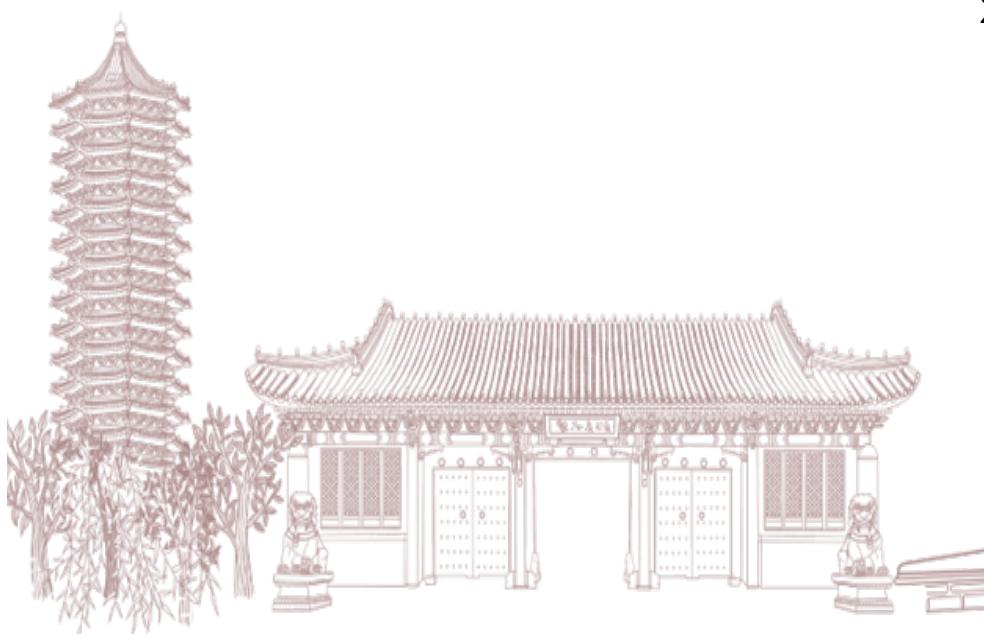
Xiaorui Wong (王晓锐)

Peking University

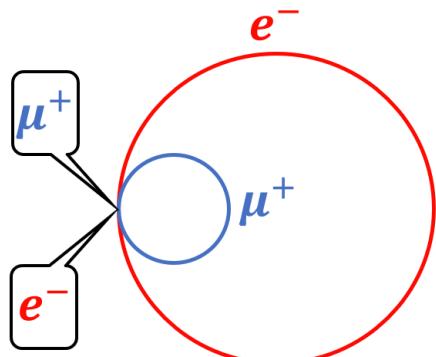
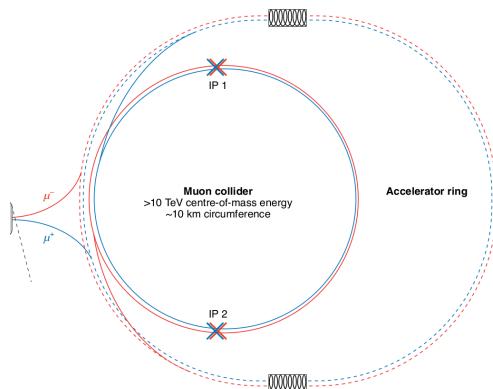
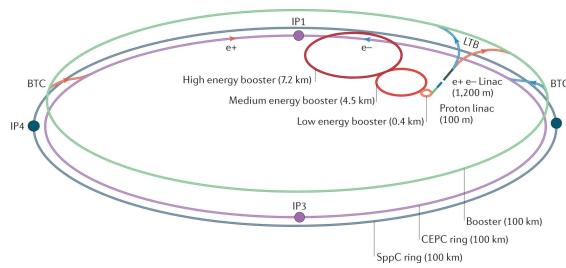
2022/11/09

In collaboration with:

Qing-Hong Cao, Yandong Liu,
Kun Cheng, and Yu Meng



Motivation



Electron collider

- Clean
- High synchrotron radiation
- Cost: ~4B\$

$$P \propto \frac{E_{\text{cm}}^2}{m^4}$$

Muon collider

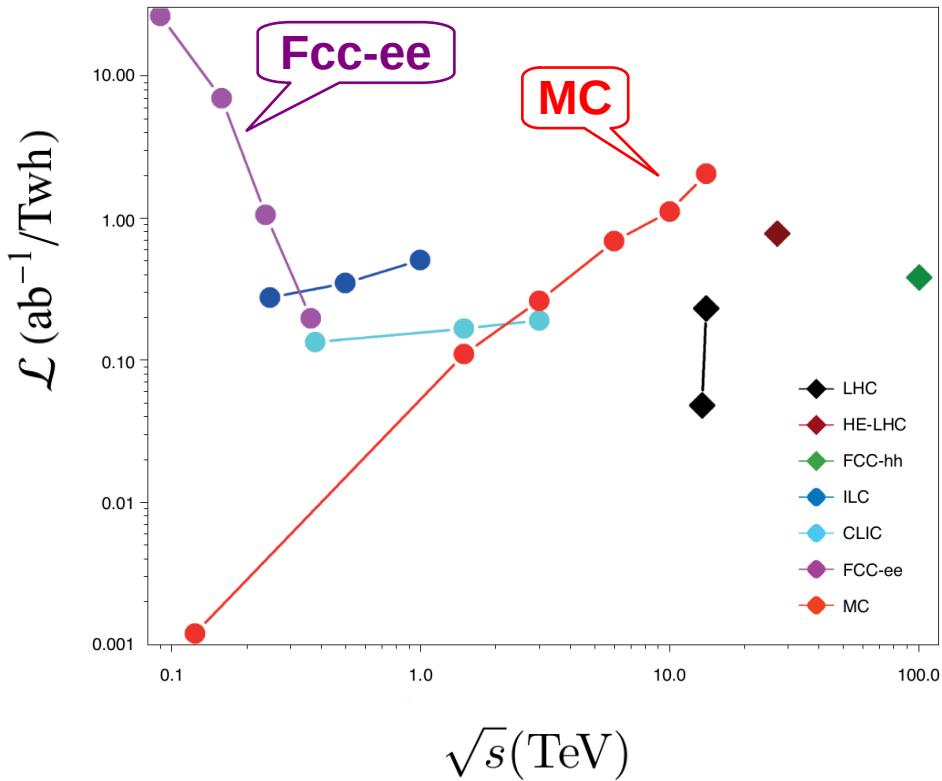
- Clean
- High energy
- Technology immature
- High cost
- Cost: ~9B\$ (in LHC tunnel)

Electron-muon collider

- Clean
- High energy
- High luminosity
- Defected detection efficiency
- Cost: ~0.1 to a few B\$
(corresponding to different stages)

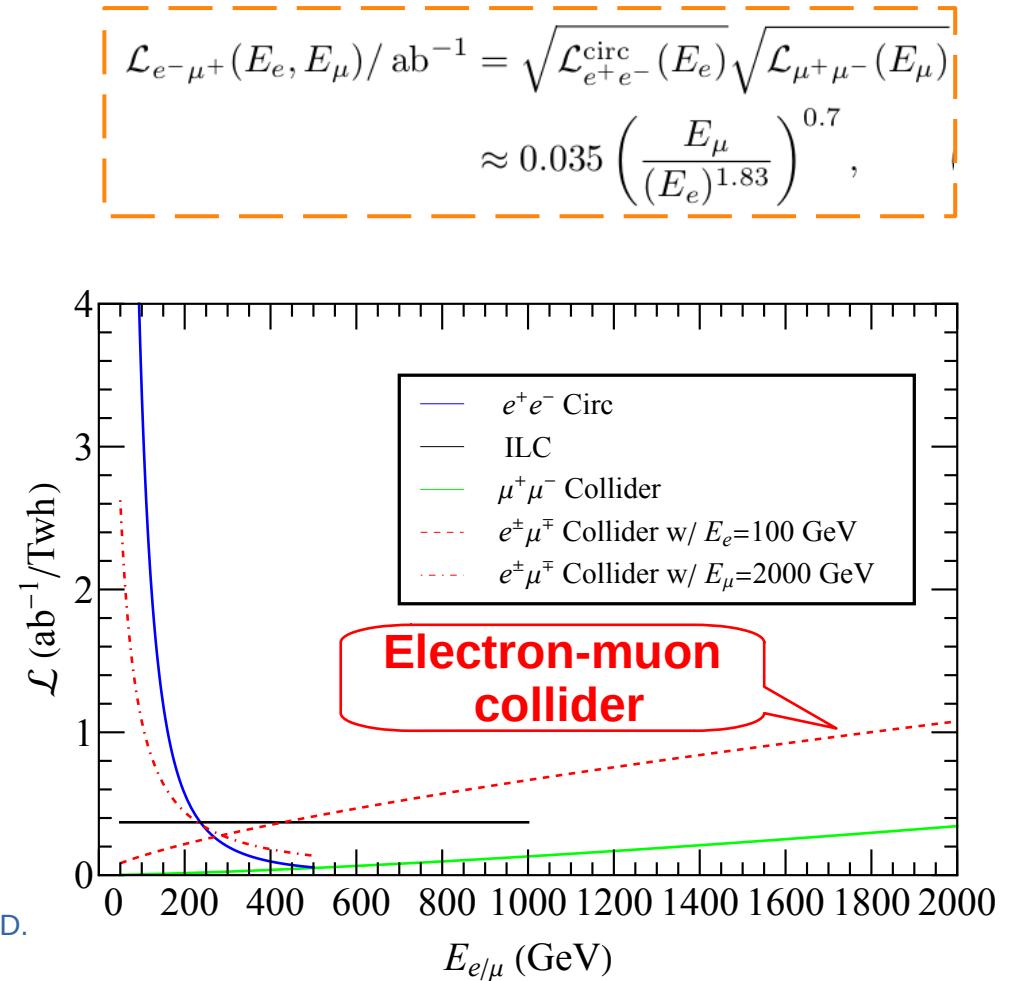
Meng Lu, Qiang Li et al.
Adv.High Energy Phys. 2021 (2021), 2010.15144

Integrated luminosity per energy

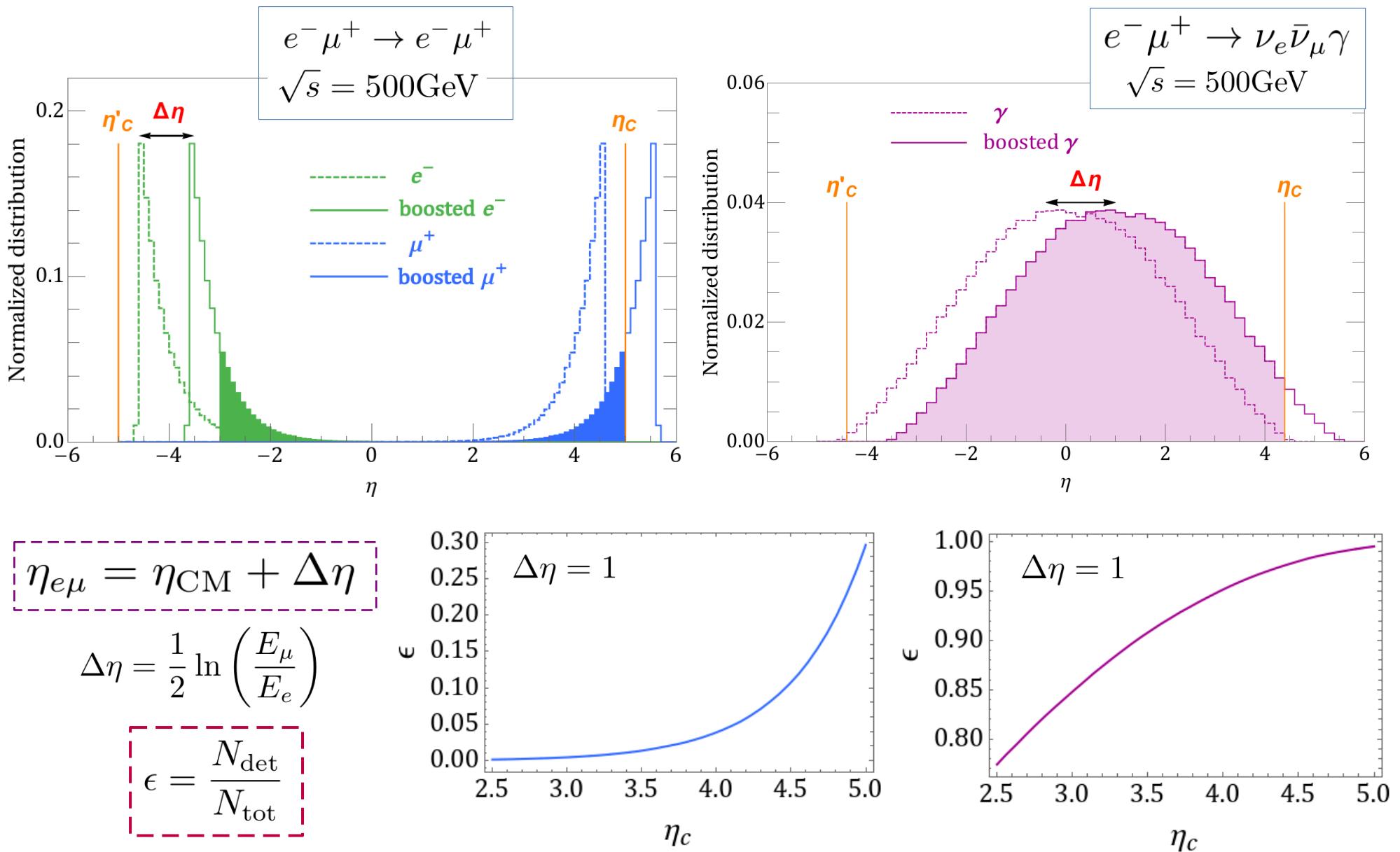


Twh^{-1} : per Terawatt-hour

K. Long, D. Lucchesi, M. Palmer, N. Pastrone, D. Schulte et al.
Nature Phys. 17 (2021) 3, 289-292



Detection efficiency

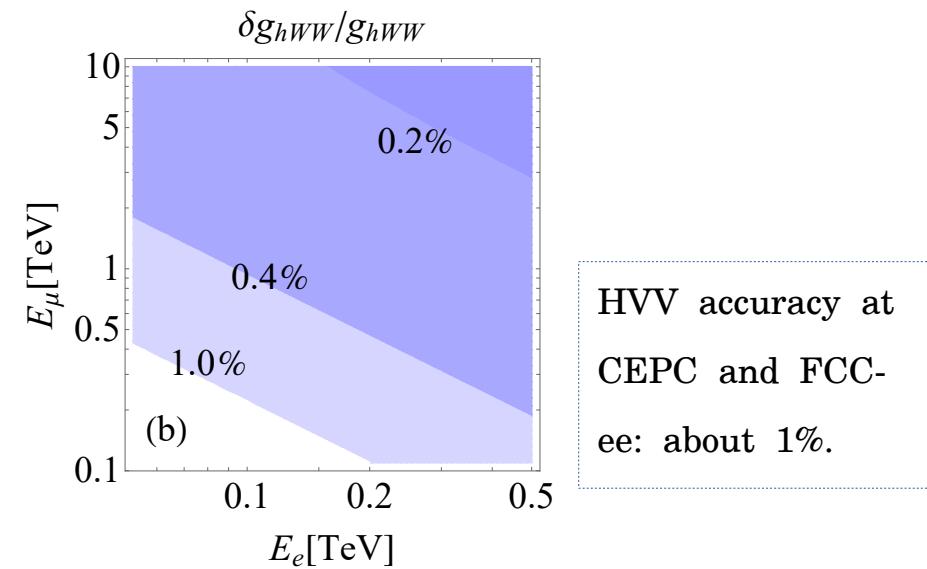
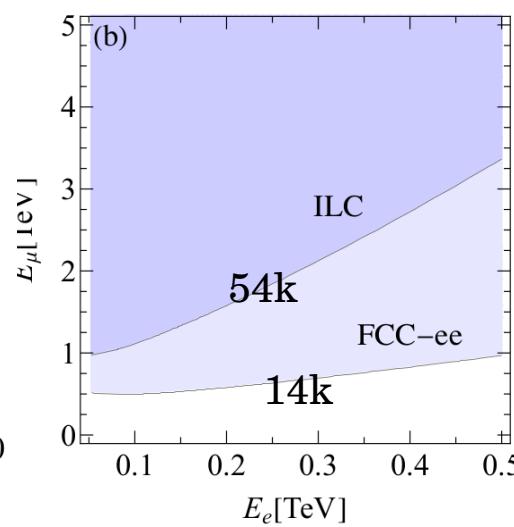
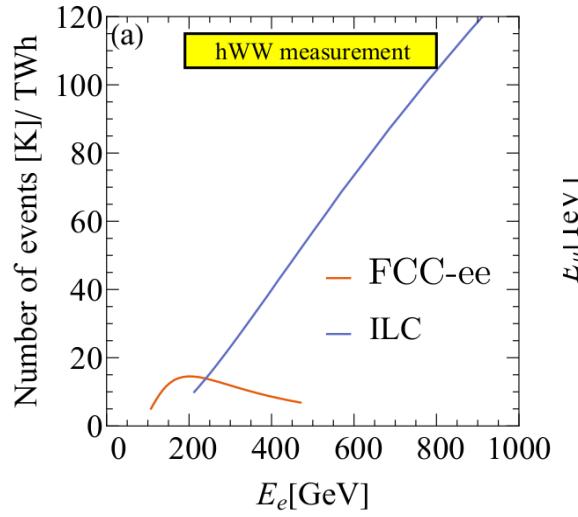
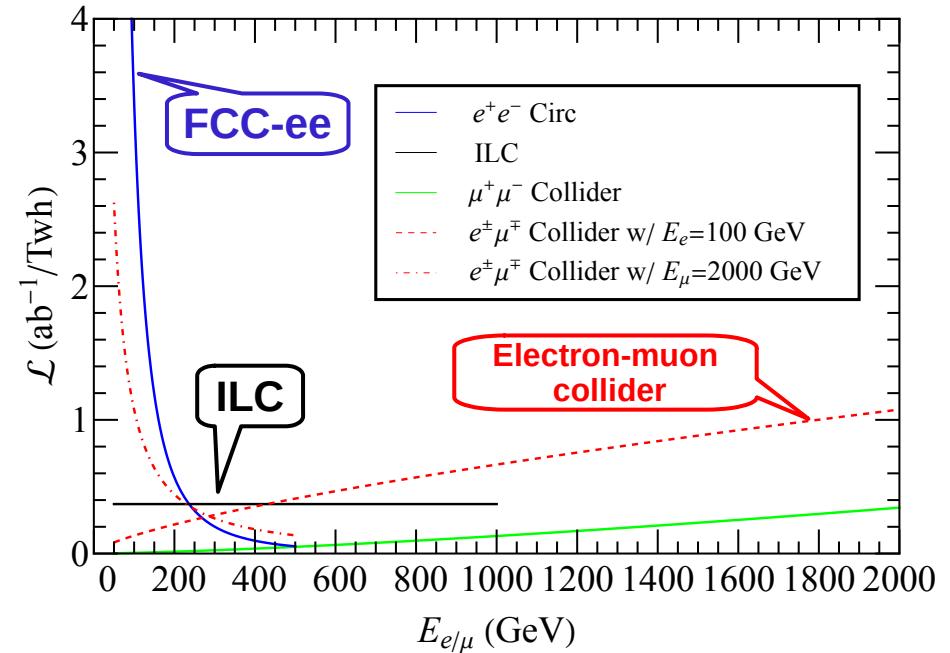
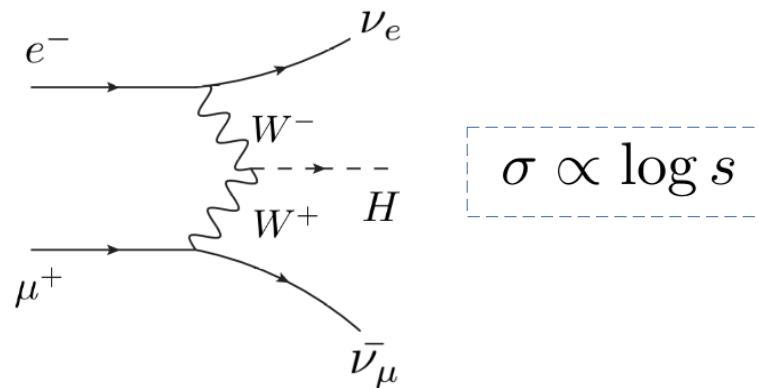




SM precision measurement

HWW measurement

$$N = \sigma \times \mathcal{L}_{\text{int}} \times \epsilon$$

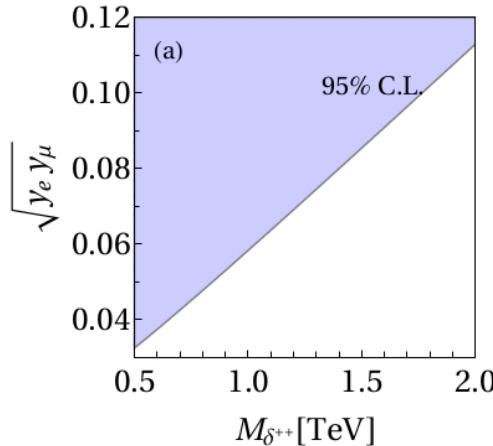
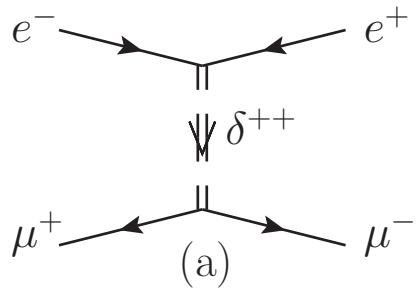




New physics

LNV & LFV

Lepton number violating(LNV) interaction



Precious constraint:

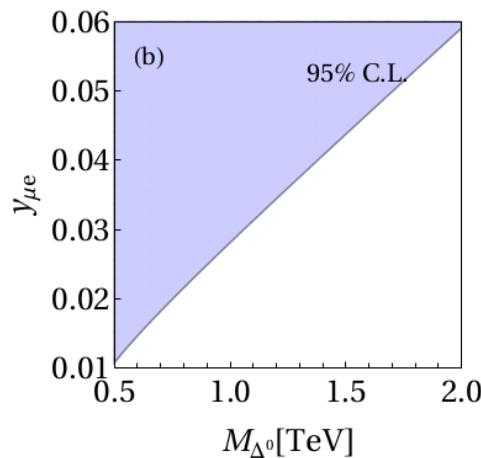
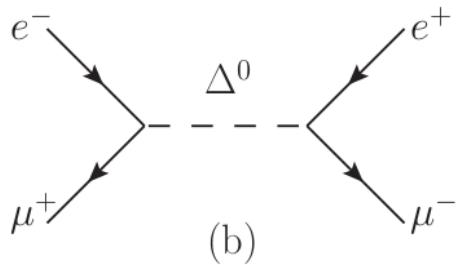
$$\delta^{\pm\pm} \rightarrow l^\pm l^\pm \Rightarrow m_{\delta^{\pm\pm}} \geq 1 \text{ TeV}$$

ATLAS Collaboration (2022)

$$\delta^{\pm\pm} \rightarrow W^\pm W^\pm \Rightarrow m_{\delta^{\pm\pm}} \geq 300 \text{ GeV}$$

2101.11961

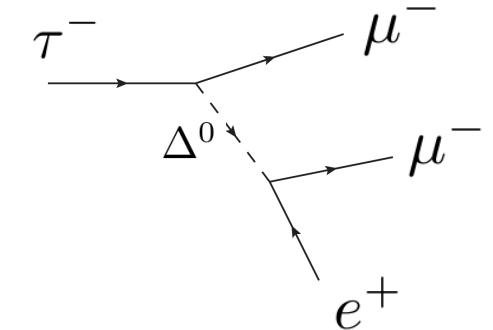
Lepton flavor violating(LFV) interaction



Precious constraint:

By decay process

$$y_{\mu e} < 0.116$$

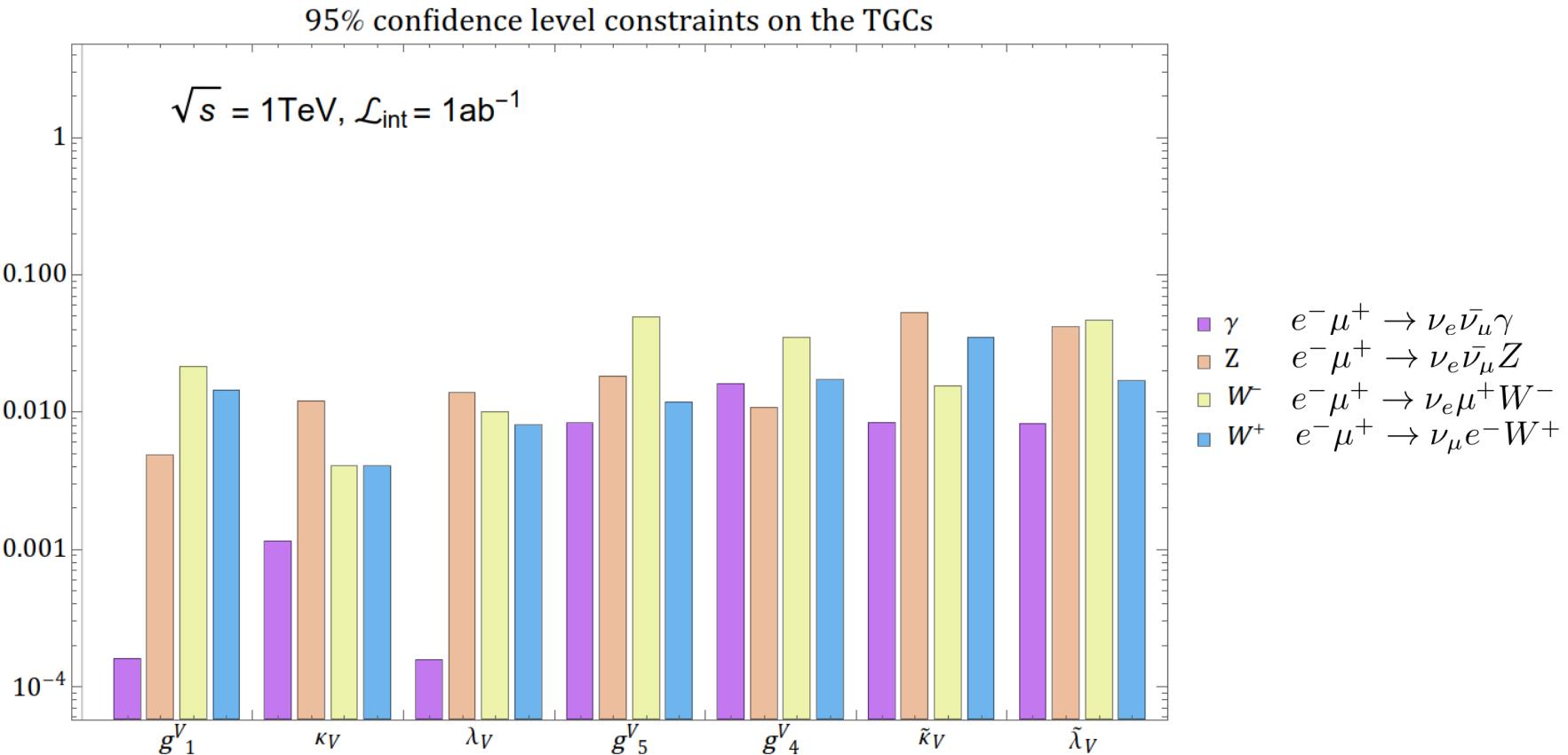


Rodolfo A. Diaz, R. Martinez, Carlos E.
Sandoval
e-Print: hep-ph/0311201

Constraint on triple gauge couplings

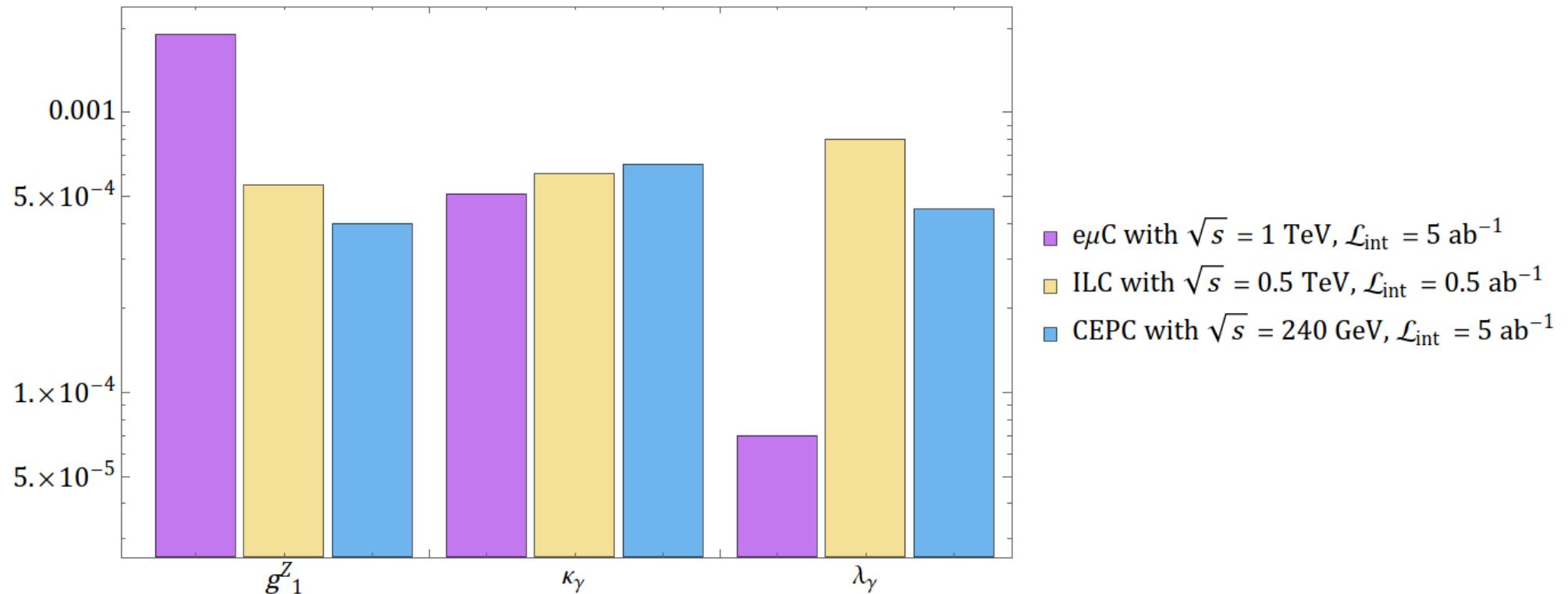
$$\begin{aligned}
i\mathcal{L}_{eff}^{WWV} = & g_{WWV} \left[g_1^V V^\mu (W_{\mu\nu}^- W^{+\nu} - W_{\mu\nu}^+ W^{-\nu}) + \kappa_V W_\mu^+ W_\nu^- V^{\mu\nu} + \right. \\
& \frac{\lambda_V}{m_W^2} V^{\mu\nu} W_\nu^{+\rho} W_{\rho\mu}^- + ig_5^V \varepsilon_{\mu\nu\rho\sigma} ((\partial^\rho W^{-\mu}) W^{+\nu} - W^{-\mu} (\partial^\rho W^{+\nu})) V^\sigma \\
& \left. + ig_4^V W_\mu^- W_\nu^+ (\partial^\mu V^\nu + \partial^\nu V^\mu) - \frac{\tilde{\kappa}_V}{2} W_\mu^- W_\nu^+ \varepsilon^{\mu\nu\rho\sigma} V_{\rho\sigma} - \frac{\tilde{\lambda}_V}{2m_W^2} W_{\rho\mu}^- W^{+\mu}{}_\nu \varepsilon^{\nu\rho\alpha\beta} V_{\alpha\beta} \right]
\end{aligned}$$

G. Gounaris, J.L. Kneur, D. Zeppenfeld, Z. Ajaltouni, A. Arhrib et al.,
hep-ph/9601233



Comparison with ILC and CEPC

Comparison with ILC and CEPC



What's more

- WW scattering
- Lepto-quark induced operators
- Higgs self-interaction
- Higgs anomalous coupling
- Leptophilic dark matter
- Weinberg operator
-

Summary

- Asymmetric energy configuration
- High luminosity, SM precision measurement
- High energy, NP searching
- Non-zero initial lepton number, LNV & LFV searching

Thanks for your attention!

Backup

Total project cost

$$TPC \approx 2B\$ \times \sqrt{\frac{\text{Length}}{10\text{km}}} + 10B\$ \times \sqrt{\frac{\text{Energy}}{1\text{TeV}}} + 2B\$ \times \sqrt{\frac{\text{Power}}{100\text{MW}}}$$

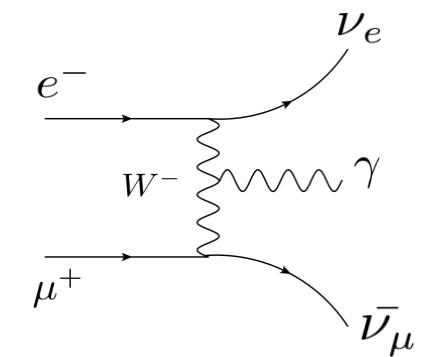
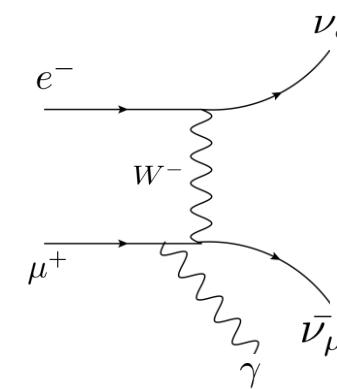
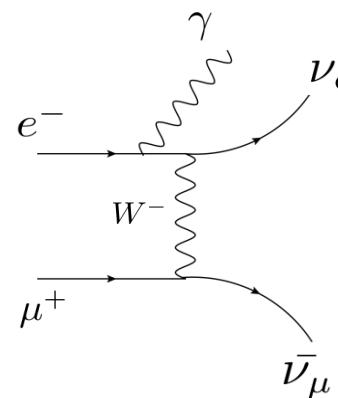
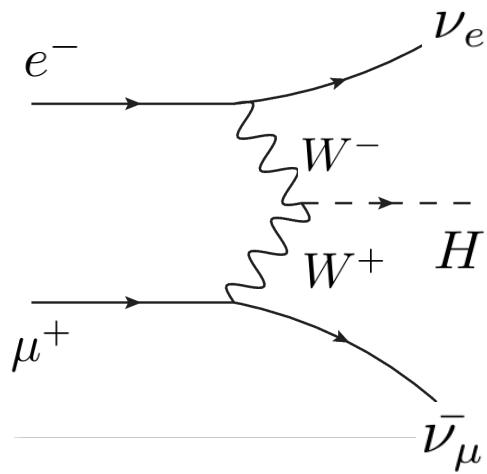
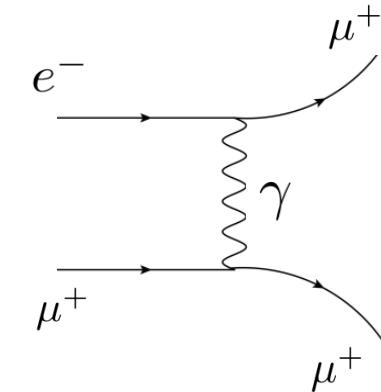
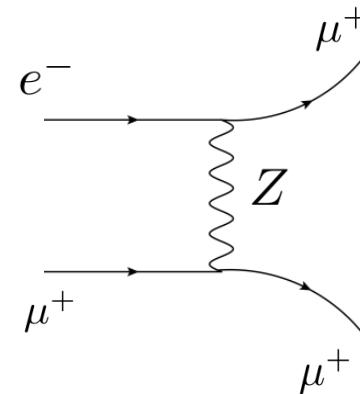
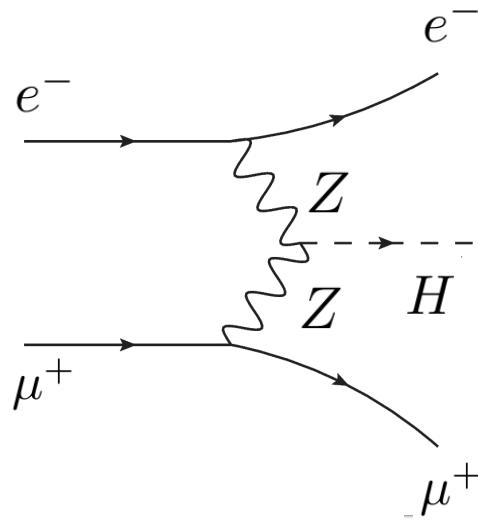


Vladimir Shiltsev
1705.02011

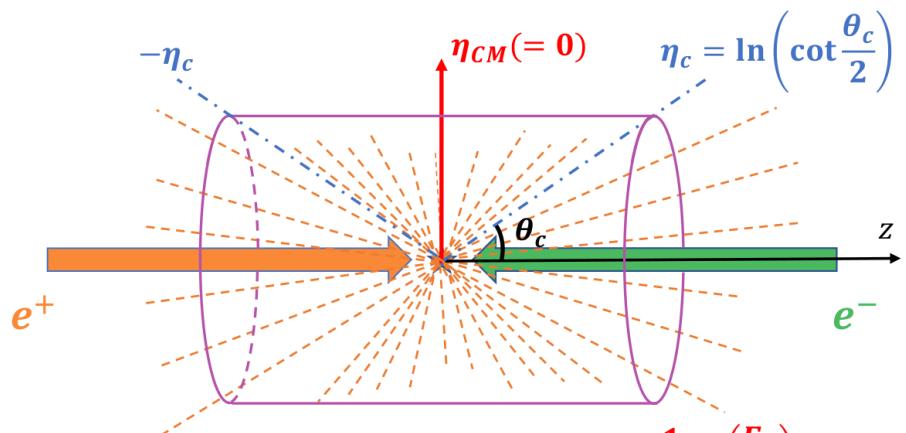
- 10B\$ for super conducting(SC) radio frequency(RF)
- 8B\$ for normal conducting(NC) RF
- 2B\$ for SC magnets
- 1B\$ for NC magnets

Let's take the LHC as an example. The first component of the " $\alpha\beta\gamma$ -model" is the cost of some 40 km of LHC tunnels (including 27 km of the LEP tunnel, 7 km of SPS, injectors and beamlines) which can be estimated as $2B\$ \times (40/10 \text{ km})^{1/2} = 4B\$$. The estimate of the second component is dominated by the cost of SC magnets for 14 TeV com collider, i.e., $2B\$ \times (14)^{1/2} = 7.5B\$$. Finally, the estimate of the 150 MW power infrastructure piece is $2B\$ \times (150 \text{ MW}/100\text{MW})^{1/2} = 2.5B\$$, that makes the TPC range of the LHC – if built from scratch - equal to $4B\$ + 7.5B\$ + 2.5B\$ = 14B\$ \pm 4.5B\$$. The CERN LHC

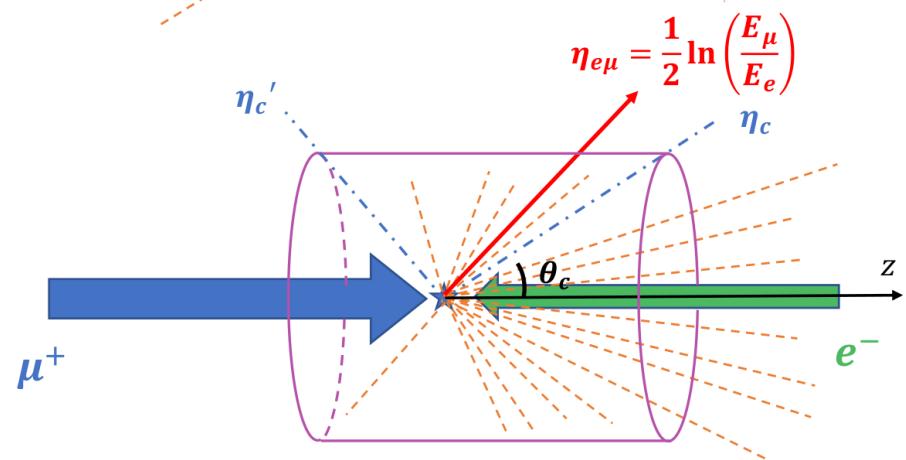
Higgs physics

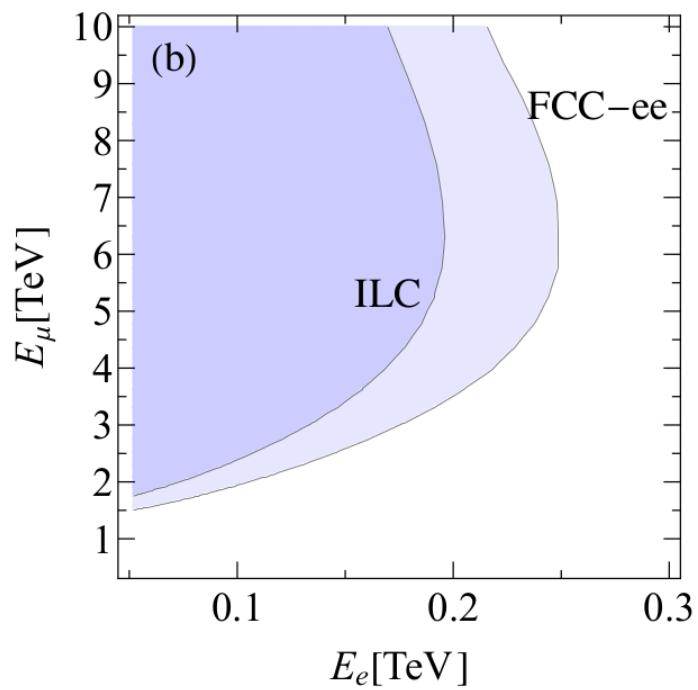
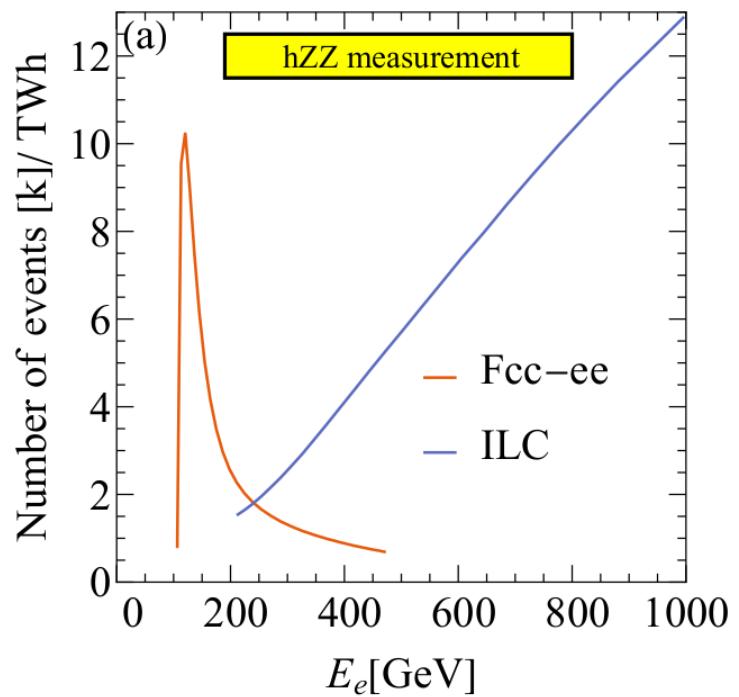


a)



b)

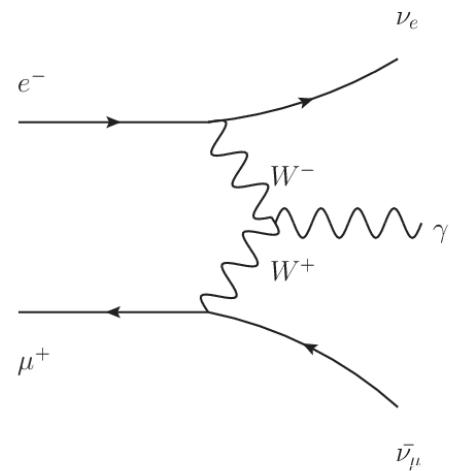




$$\sqrt{s} = 1000 \text{GeV}, \mathcal{L} = 1 \text{ab}^{-1}$$

signal

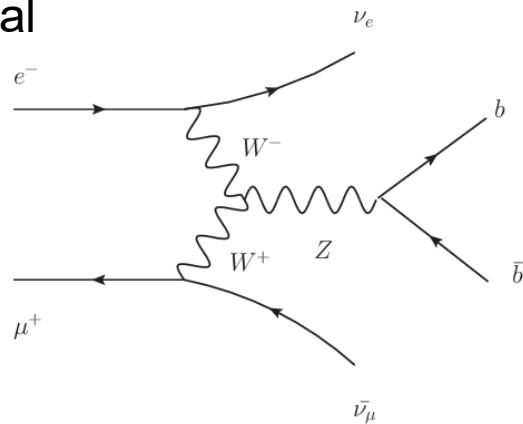
	$e^- \mu^+ \rightarrow \nu_e \bar{\nu}_\mu \gamma$
g_1^V	$-1.589 \times 10^{-4} \sim 1.589 \times 10^{-4}$
κ_V	$-1.14 \times 10^{-3} \sim 1.14 \times 10^{-3}$
λ_V	$-1.56 \times 10^{-4} \sim 1.56 \times 10^{-4}$
g_5^V	$-8.28 \times 10^{-3} \sim 8.28 \times 10^{-3}$
g_4^V	$-1.6 \times 10^{-2} \sim 1.6 \times 10^{-2}$
$\tilde{\kappa}_V$	$-8.34 \times 10^{-3} \sim 8.34 \times 10^{-3}$
$\tilde{\lambda}_V$	$-8.2 \times 10^{-3} \sim 8.2 \times 10^{-3}$



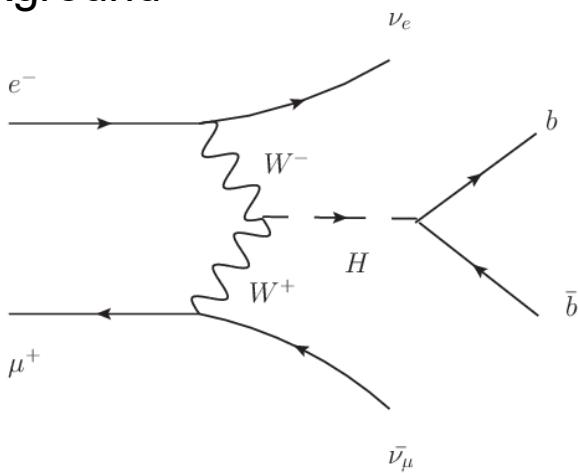
$\sqrt{s} = 1000\text{GeV}$, $\mathcal{L} = 1\text{ab}^{-1}$

$e^- \mu^+ \rightarrow \nu_e \bar{\nu}_\mu Z$	
g_1^V	$-4.8 \times 10^{-3} \sim 4.8 \times 10^{-3}$
κ_V	$-1.198 \times 10^{-2} \sim 1.198 \times 10^{-2}$
λ_V	$-1.37 \times 10^{-2} \sim 1.37 \times 10^{-2}$
g_5^V	$-1.82 \times 10^{-2} \sim 1.82 \times 10^{-2}$
g_4^V	$-1.078 \times 10^{-2} \sim 1.078 \times 10^{-2}$
$\tilde{\kappa}_V$	$-5.26 \times 10^{-2} \sim 5.26 \times 10^{-2}$
$\tilde{\lambda}_V$	$-4.14 \times 10^{-2} \sim 4.14 \times 10^{-2}$

signal



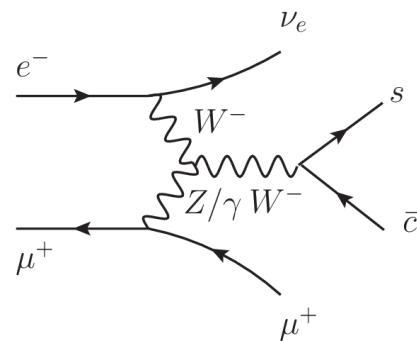
background



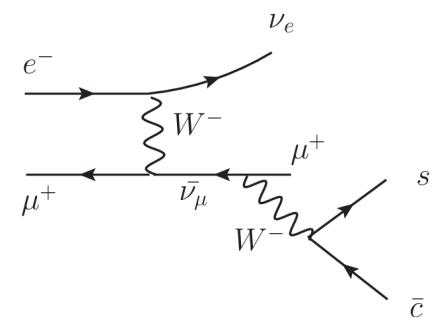
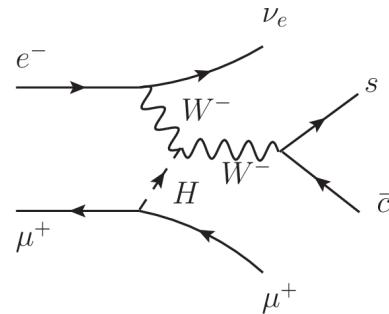
$$\sqrt{s} = 1000 \text{GeV}, \mathcal{L} = 1 \text{ab}^{-1}$$

	$e^- \mu^+ \rightarrow \nu_e \mu^+ W^-$
g_1^V	$-2.13 \times 10^{-2} \sim 2.13 \times 10^{-2}$
κ_V	$-4 \times 10^{-3} \sim 4 \times 10^{-3}$
λ_V	$-1 \times 10^{-2} \sim 1 \times 10^{-2}$
g_5^V	$-4.9 \times 10^{-2} \sim 4.9 \times 10^{-2}$
g_4^V	$-3.48 \times 10^{-2} \sim 3.48 \times 10^{-2}$
$\tilde{\kappa}_V$	$-1.54 \times 10^{-2} \sim 1.54 \times 10^{-2}$
$\tilde{\lambda}_V$	$-4.6 \times 10^{-2} \sim 4.6 \times 10^{-2}$

signal



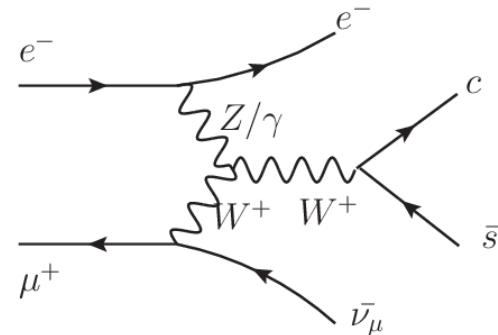
background



$$\sqrt{s} = 1000 \text{GeV}, \mathcal{L} = 1 \text{ab}^{-1}$$

	$e^- \mu^+ \rightarrow \bar{\nu}_\mu e^- W^+$
g_1^V	$-1.44 \times 10^{-2} \sim 1.44 \times 10^{-2}$
κ_V	$-4 \times 10^{-3} \sim 4 \times 10^{-3}$
λ_V	$-8 \times 10^{-3} \sim 8 \times 10^{-3}$
g_5^V	$-1.176 \times 10^{-2} \sim 1.176 \times 10^{-2}$
g_4^V	$-1.7 \times 10^{-2} \sim 1.7 \times 10^{-2}$
$\tilde{\kappa}_V$	$-3.47 \times 10^{-2} \sim 3.47 \times 10^{-2}$
$\tilde{\lambda}_V$	$-1.68 \times 10^{-2} \sim 1.68 \times 10^{-2}$

signal



background

