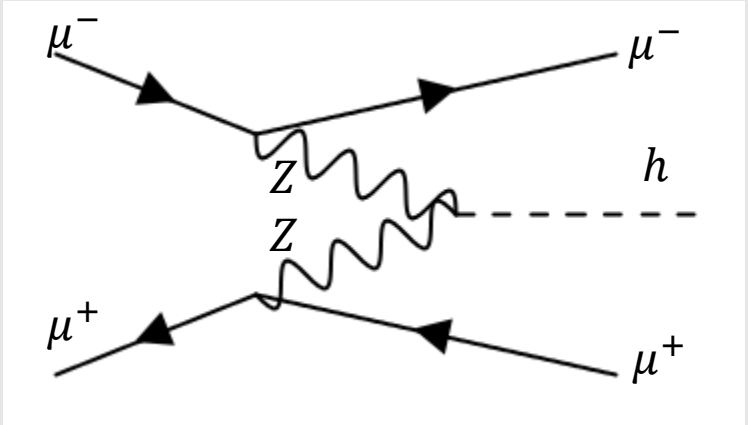
PARTICLE PHYSICS on the PLAINS
UNIVERSITY OF KANSAS

Inclusive Higgs Rate with Forward Detection at High Energy Muon Collider



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10/15/2023

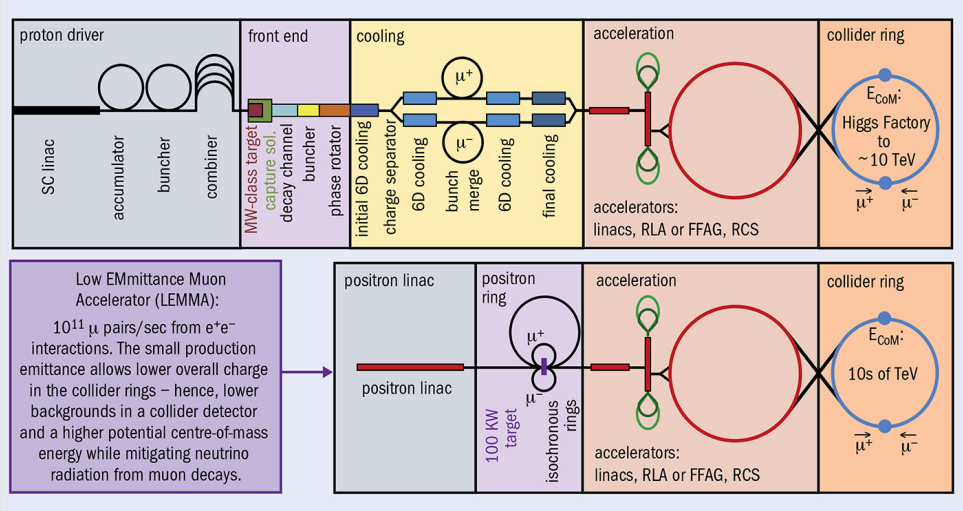
Collaborate with Zhen Liu, Kun-Feng Lyu

Outline

- Muon Collider (MuC)
- Motivation
- Higgs productions at TeV Muon Collider
- Inclusive Higgs rate from ZZ fusion ($\sqrt{s} = 10\ \mathbf{TeV}$)
  - Motivation
  - Signal vs. Background
  - Cutflow analysis
- Higgs coupling global fit combining with other studies

Why considering muon collider?

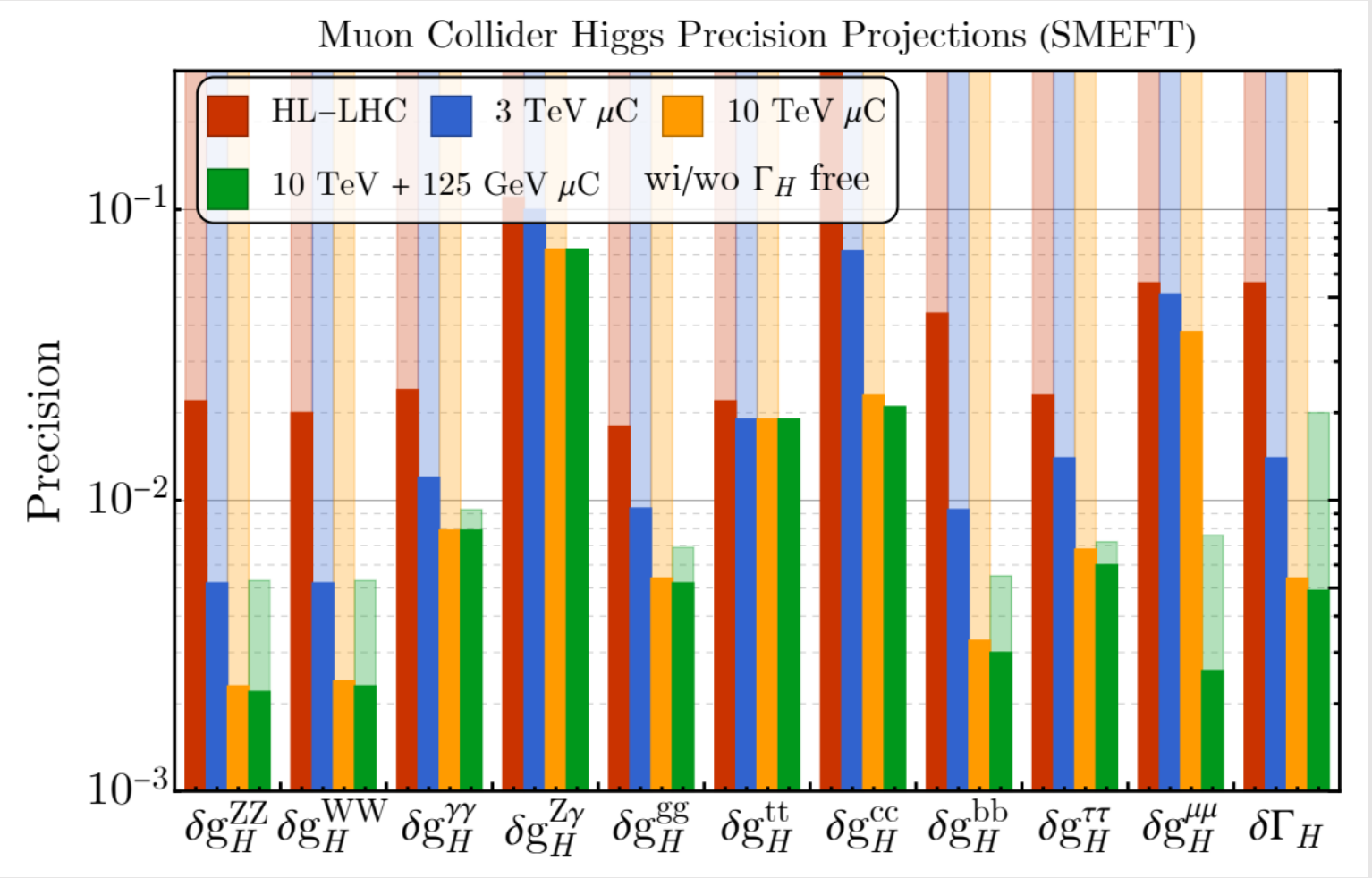
- High energy (3,10 TeV):
  - High mass (low synchrotron radiation)
  - Fundamental particle: full energy collision
- Clean environment:
  - Known initial state
  - Clean background



Expect to have great sensitivity on various studies.

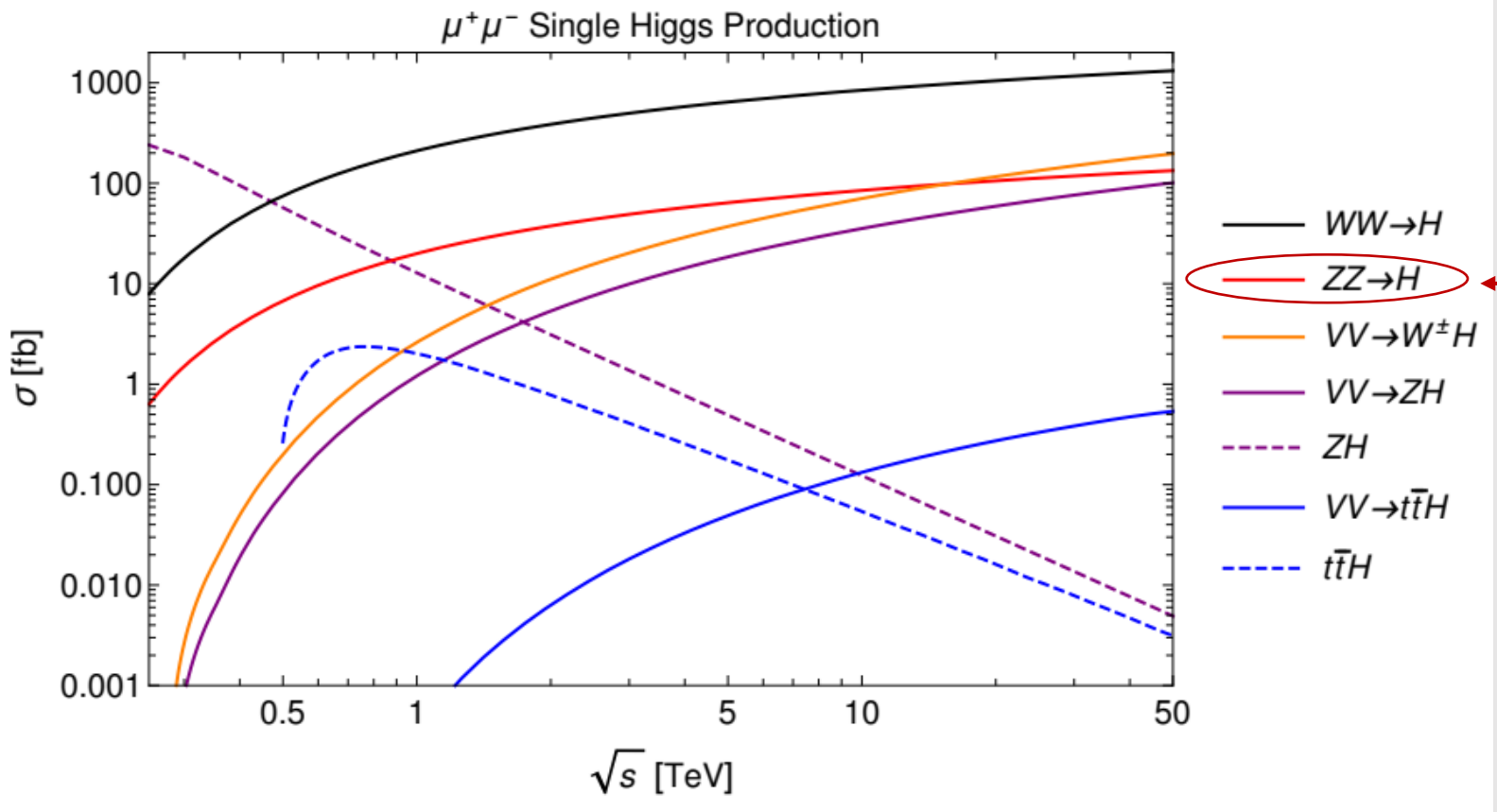
Motivation

- Previous Higgs studies at MuC do not have constraint on Higgs total width.
- Our study will be directly sensitive to g_H^{ZZ}, which combining with other channel will be able to constraint on Γ_H

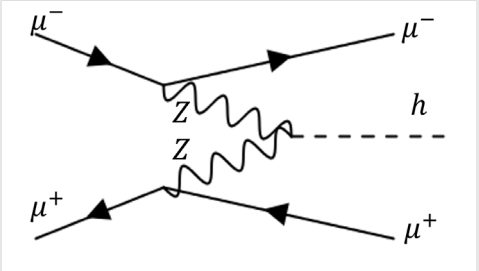


[2209.01318] Muon Collider Forum Report

Higgs productions at Muon Collider



Our study



Matthew Forslund, Patrick Meade, [2203.09425]

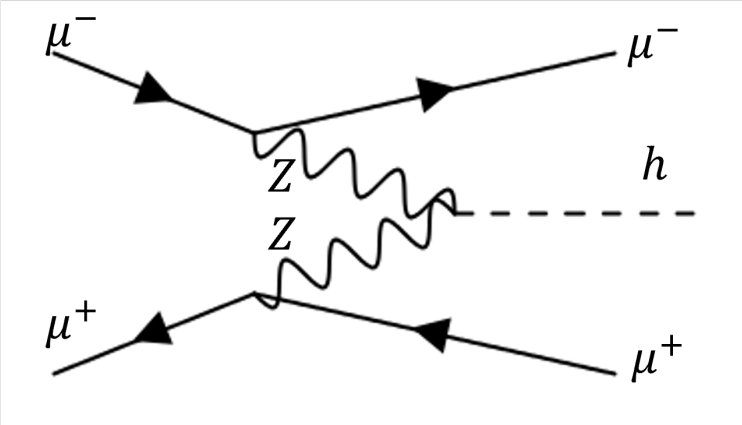
Inclusive Higgs rate from ZZ fusion ($\sqrt{s} = 10$ TeV)

Forward muon detector: $2.5 < \eta(\mu) < 4, 6, 8$

$$p_h = (\sqrt{s}, 0,0,0) - p_{\mu^+} - p_{\mu^-}$$

$$m_h^2 = \left[(\sqrt{s}, 0,0,0) - p_{\mu^+} - p_{\mu^-}\right]^2$$

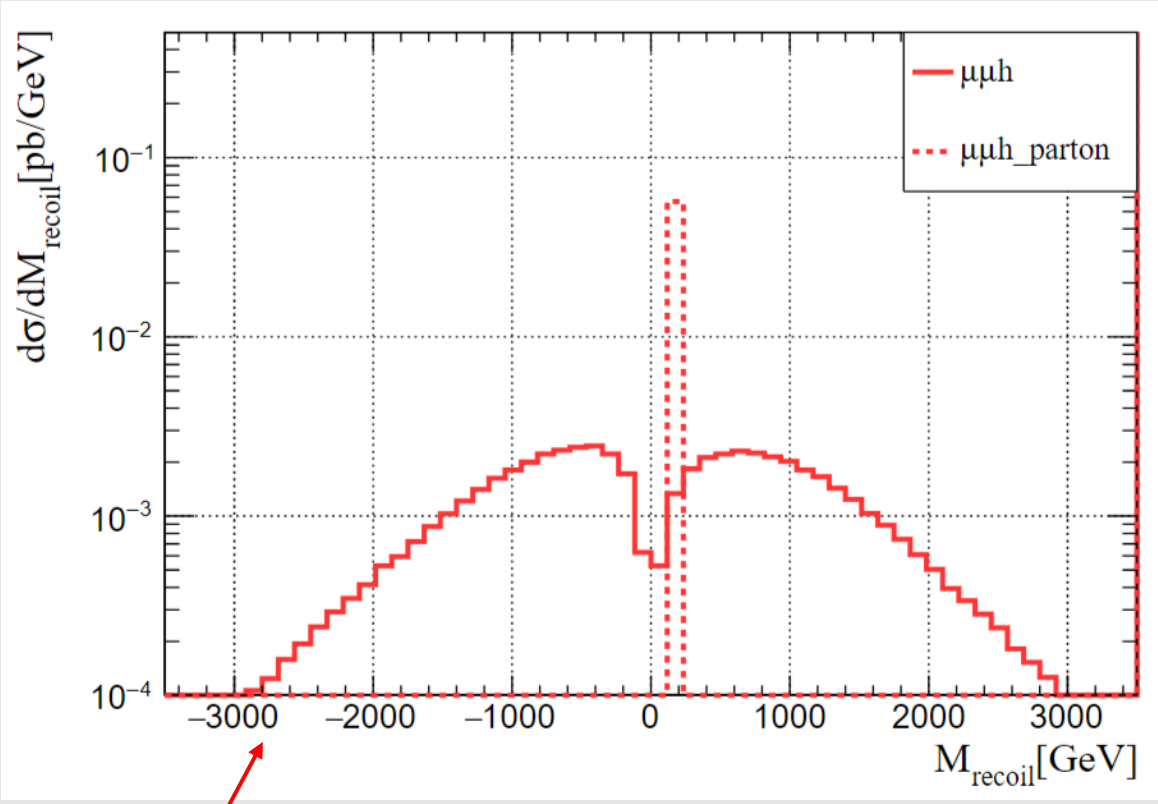
Recoil mass of dimuon



Does not rely on the detection of Higgs decay product.

Inclusive Higgs rate from ZZ fusion ($\sqrt{s} = 10$ TeV)

Due to the uncertainty of high energy measurement, the smearing effect dominate the recoil mass distribution.



$[(\sqrt{s},0,0,0) - p_{\mu^+} - p_{\mu^-}]^2 < 0$

Fast detector simulation using Delphes.

Signal vs. Background ($\sqrt{s} = 10$ TeV)

Only tag 2 forward muons

Do not have any requirements on other stuff.

Type	Scattering process	cross section σ (pb)
VBF	$\mu^+\mu^- \to \mu^+\mu^- h$	0.0867
t-channel	$\mu^+\mu^- \to \mu^+\mu^-$	1.12×10^4
t-channel	$\mu^+\mu^- \to \mu^+\mu^-\gamma$	754.8
VBS	$\mu^+\mu^- \to \mu^+\mu^-\ell^+\ell^-$	3.96
VBS	$\mu^+\mu^- \to \mu^+\mu^- jj$	2.06
VBS	$\mu^+\mu^- \to \mu^+\mu^-\nu_\ell\bar{\nu}_\ell$	1.68
VBS	$\mu^+\mu^- \to \mu^+\mu^- W^+W^-$	0.939

Cross section for both signal and background after parton-level pre-selection.

Pre-selection at parton-level:

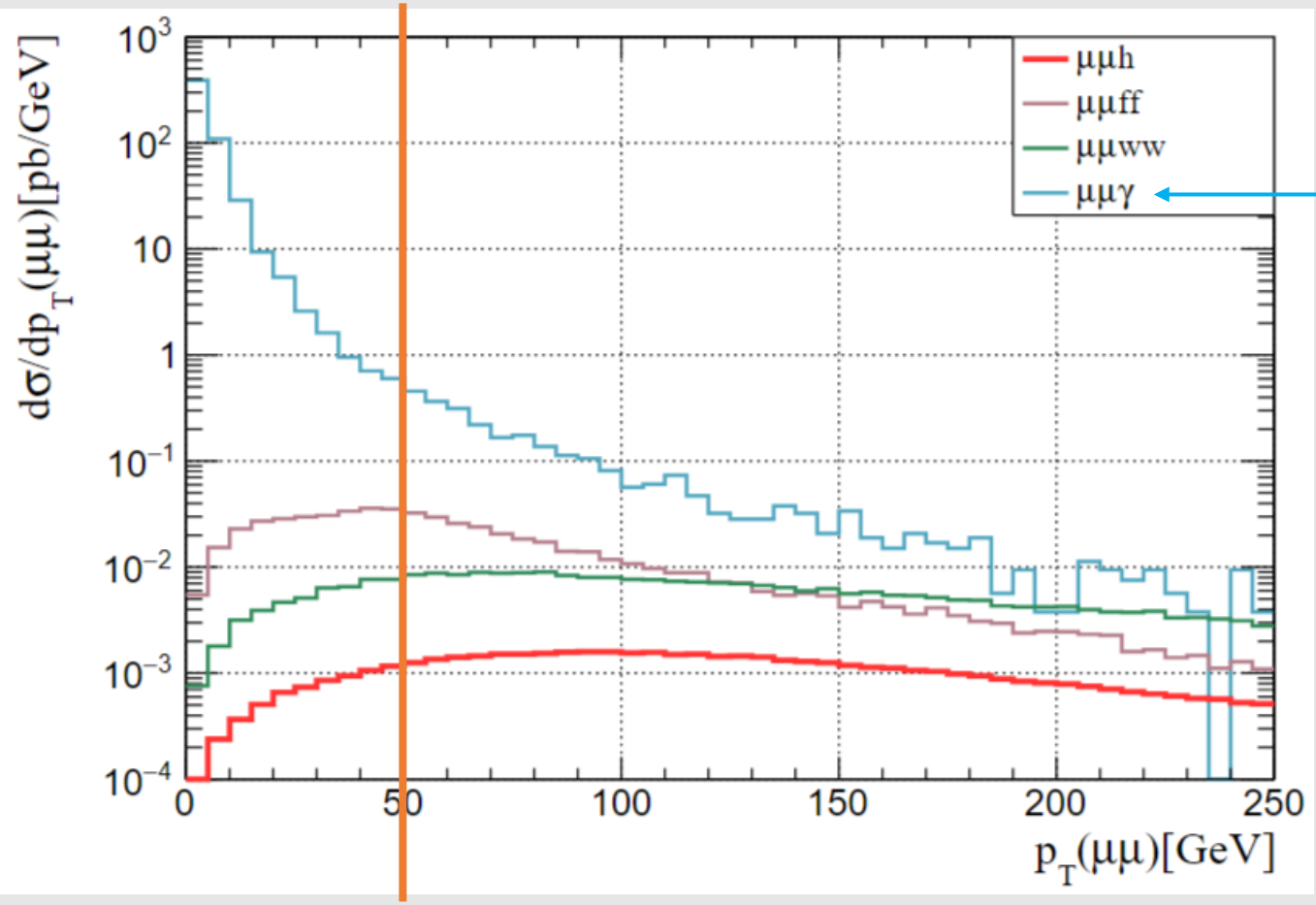
$p_T(l, j) > 5$ GeV,
$p_T(\gamma) > 1$ GeV,
$|\eta(l)| < 10$,
$\Delta R(ll, lj, jj) > 0.2$

3 types of background

- $\mu\mu \to \mu\mu(\gamma)$
- $\mu\mu \to \mu\mu + ff$
- $\mu\mu \to \mu\mu + WW$

Signal vs. Background ($\sqrt{s} = 10$ TeV)

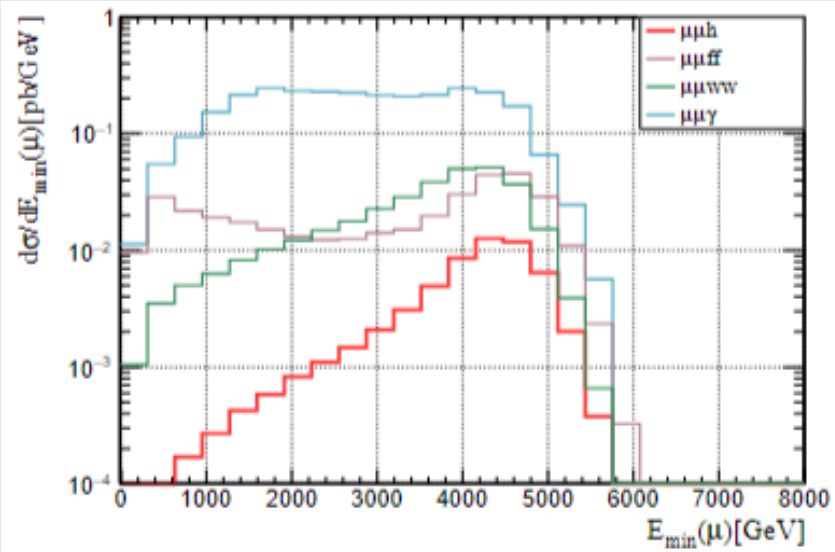
Require $p_T(\mu\mu) > 50$ GeV

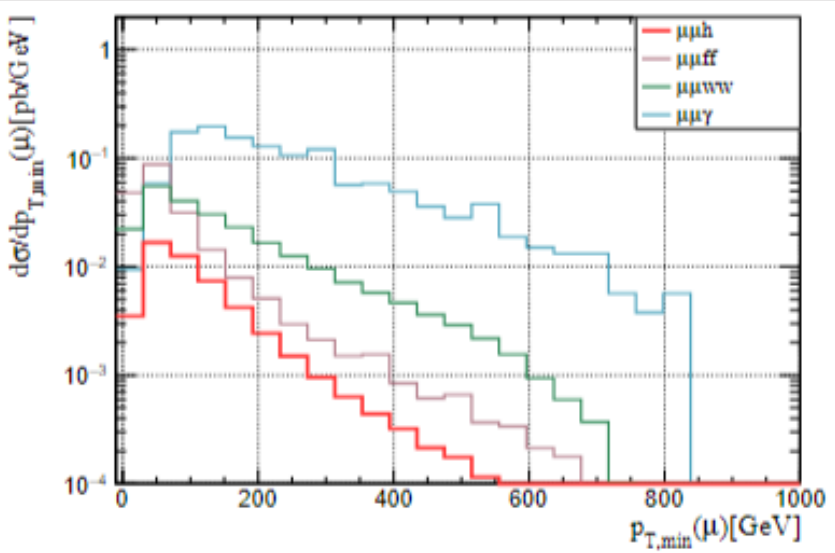


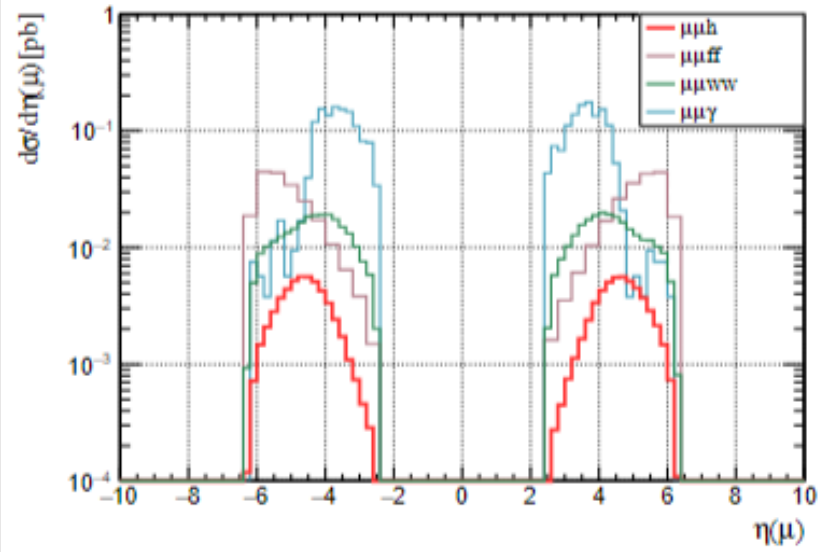
Merging $\mu\mu \to \mu\mu$ and $\mu\mu \to \mu\mu\gamma$

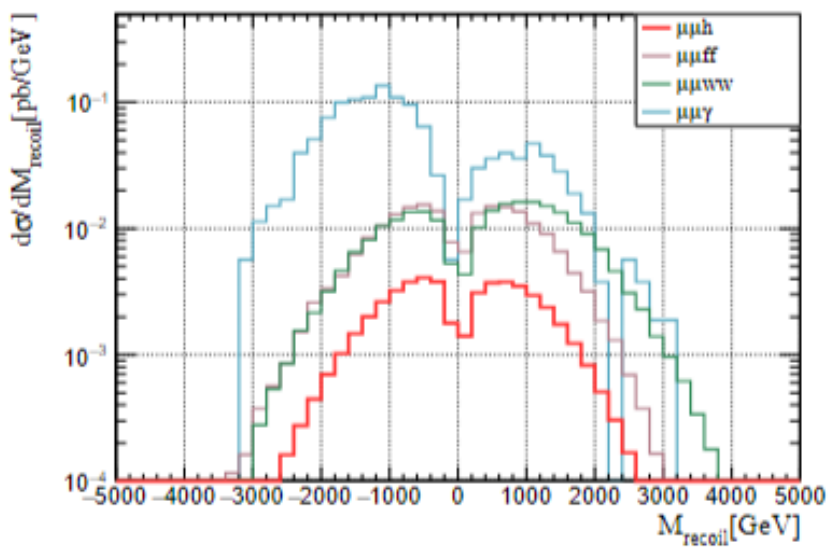
Cutflow analysis

Checking other kinematics and applying a few cuts.









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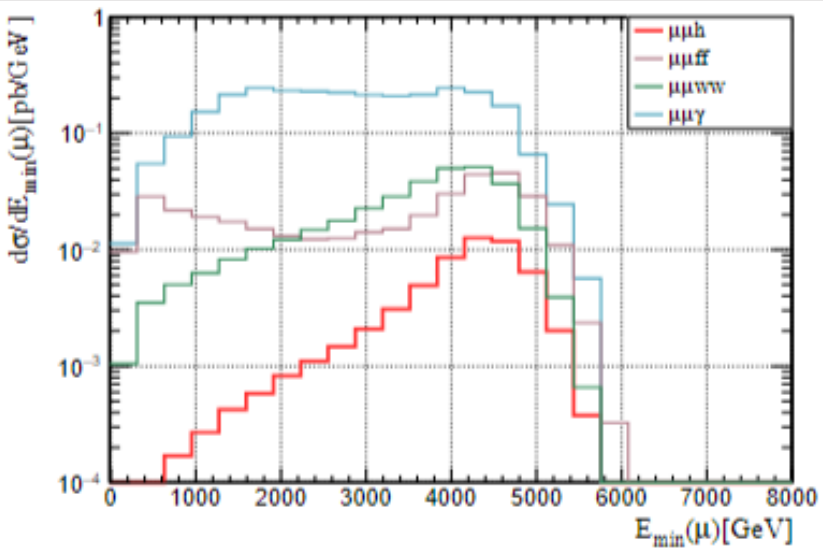
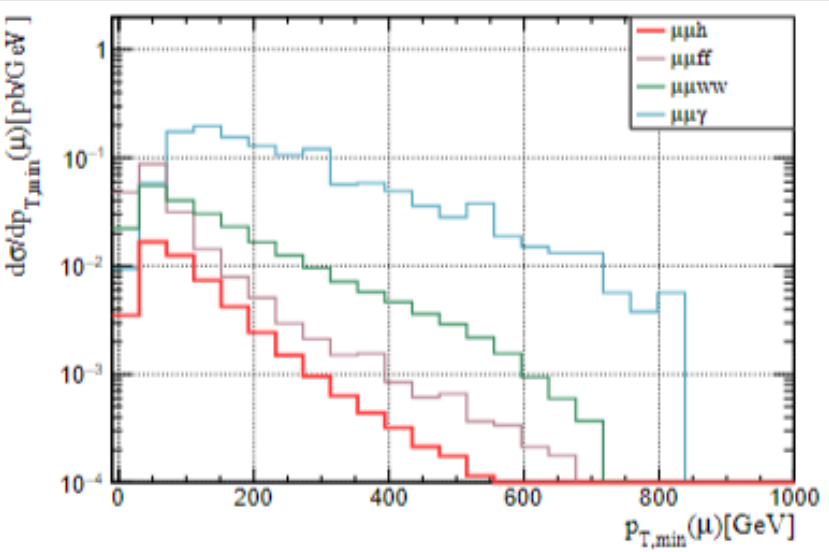
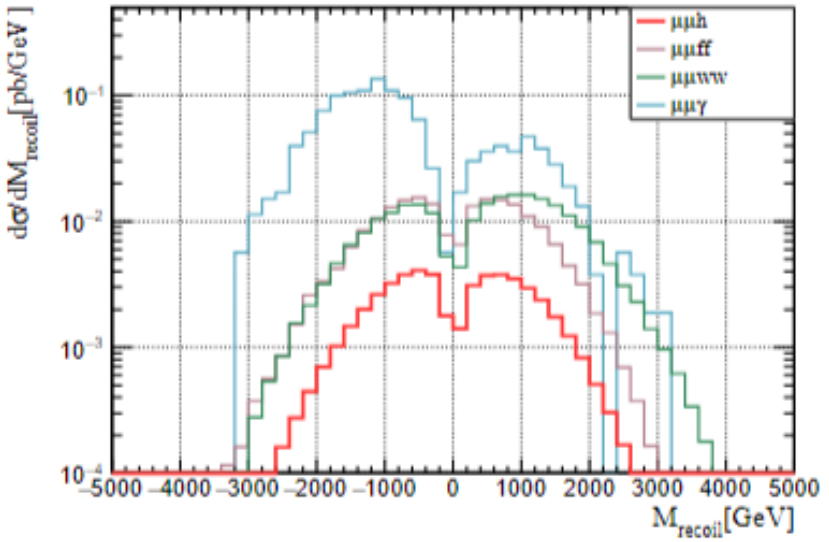




Process	Pre-selection	$p_T(\mu\mu) > 50$ GeV	$E(\mu) > 3000$ GeV & $p_{T,min}(\mu) < 300$ GeV
$\mu^+\mu^- \to \mu^+\mu^- h$	73.3%	65.7%	56.4% (0.0489 pb)
$\mu^+\mu^- \to \mu^+\mu^- \gamma$	13.1%	0.38%	0.12% (0.906 pb)
$\mu^+\mu^- \to \mu^+\mu^- f\bar{f}$	8.13%	4.69%	2.58% (0.199 pb)
$\mu^+\mu^- \to \mu^+\mu^- W^+W^-$	40.0%	34.9%	22.0% (0.207 pb)

TABLE II. Cutflow table for both signal and background events. All processes before the pre-selection cuts are set to 100%.



Detector level pre-selection:

- Only two visible muons in forward region $(2.5 < \eta(\mu) < 8.0)$.
- Back-to-back muons: $\eta(\mu^-) \cdot \eta(\mu^+) < 0$.
- Sufficient transverse momentum: $p_T(\mu) > 20$ GeV.

Sensitivity

3 TeV

Benchmark	$\eta(\mu) < 4$	$\eta(\mu) < 6$	$\eta(\mu) < 8$
$\Delta\sigma/\sigma$	6.2%	3.94%	3.94%

TABLE V. The 68% projected sensitivity on the Higgs inclusive rate from ZZ fusion at 3 TeV muon collider.

10 TeV

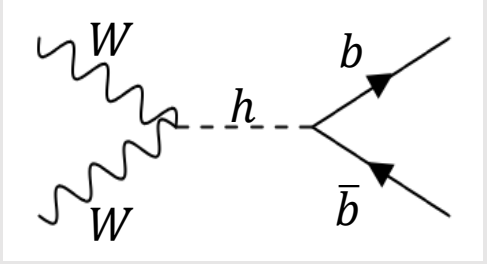
Benchmark	$\eta(\mu) < 4$	$\eta(\mu) < 6$	$\eta(\mu) < 8$
$\Delta\sigma/\sigma$	15.2%	0.75%	0.74%

TABLE III. The 68% projected sensitivity on the Higgs inclusive rate from ZZ fusion at 10 TeV muon collider.

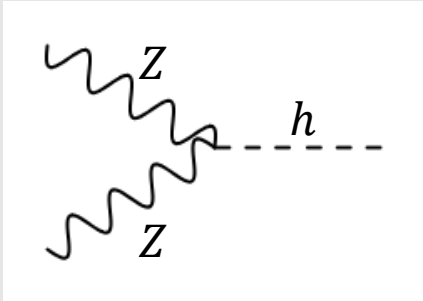
Higgs coupling global fit

- Kappa framework
  - $\kappa_i = \frac{g_{hii}}{g_{hii}^{SM}}$
  - $\kappa_\Gamma = \sum \frac{\kappa_i^2 \Gamma_i^{SM}}{\Gamma^{SM}} + \frac{\Gamma^{BSM}}{\Gamma^{SM}}$

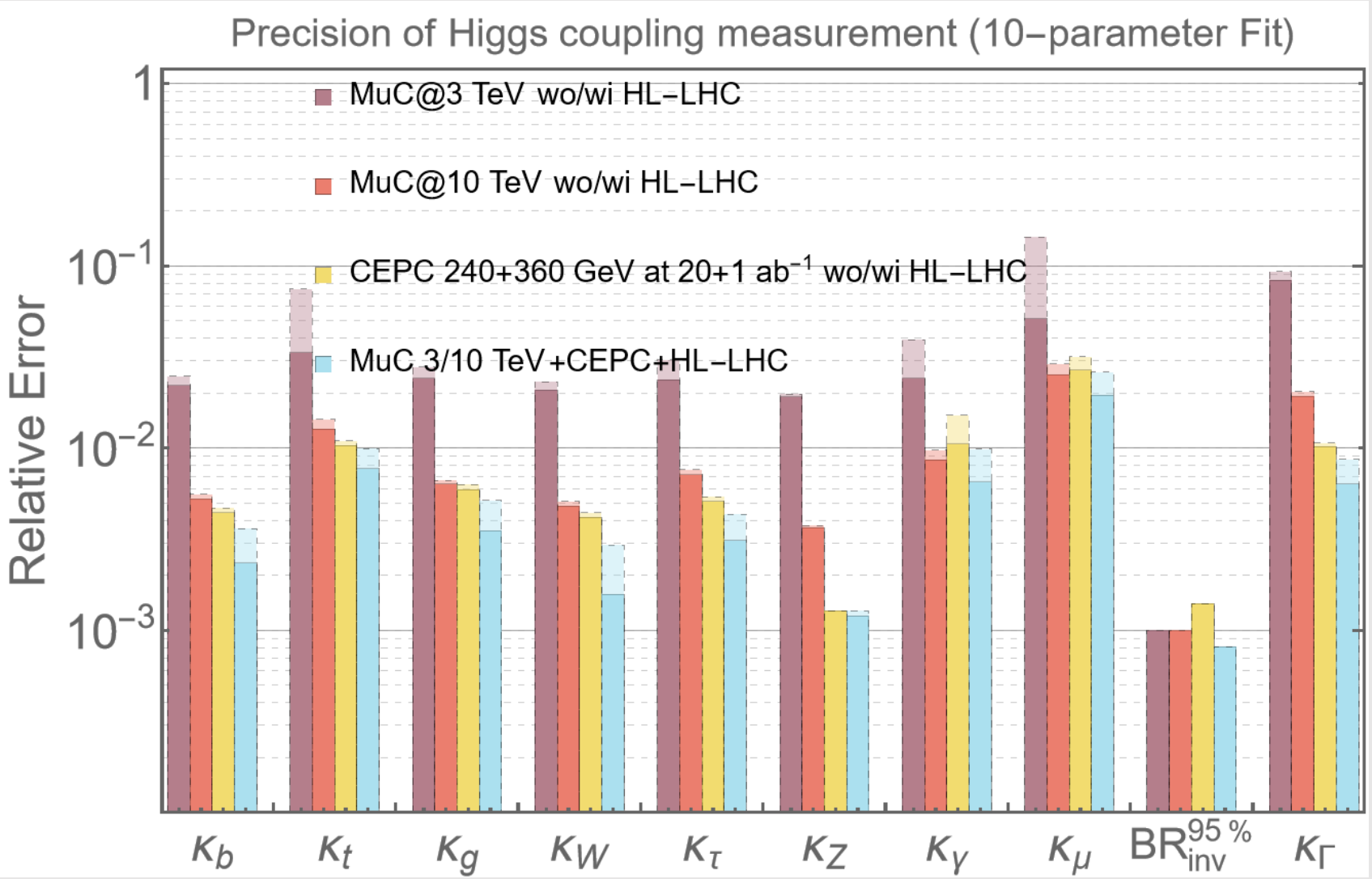
- Sensitivity under kappa framework
  - $\mu_{WW}^{bb} = \frac{\kappa_W^2 \kappa_b^2}{\kappa_\Gamma}$ ←



  - $\mu_{ZZ} = \kappa_Z^2$ ←



Higgs coupling global fit



$$\eta(\mu) < 6$$

1. Matthew Forslund and Patrick Meade. [2203.09425] High Precision Higgs from High Energy Muon Colliders (arxiv.org)
2. M. Ruhdorfer, E. Salvioni, A. Wulzer. [2303.14202] Invisible Higgs from forward muons at a muon collider (arxiv.org)
3. Zhen Liu, Kun-Feng Lyu, Ishmam Mahbub, Lian-Tao Wang. [2308.06323] Top Yukawa Coupling Determination at High Energy Muon Collider (arxiv.org)
4. Our inclusive Higgs rate result.

Conclusion

- $ZZ \rightarrow h$ inclusive rate channel only using forward muon detection.
- Only sensitive to κ_Z
- With forwarded detection $2.5 < \eta(\mu) < 6$, the cross-section precision is ~0.75%
- Combining with other studies, we can constraint on Γ_H~2%

Back up

Merging $\mu\mu \to \mu\mu$ and $\mu\mu \to \mu\mu\gamma$

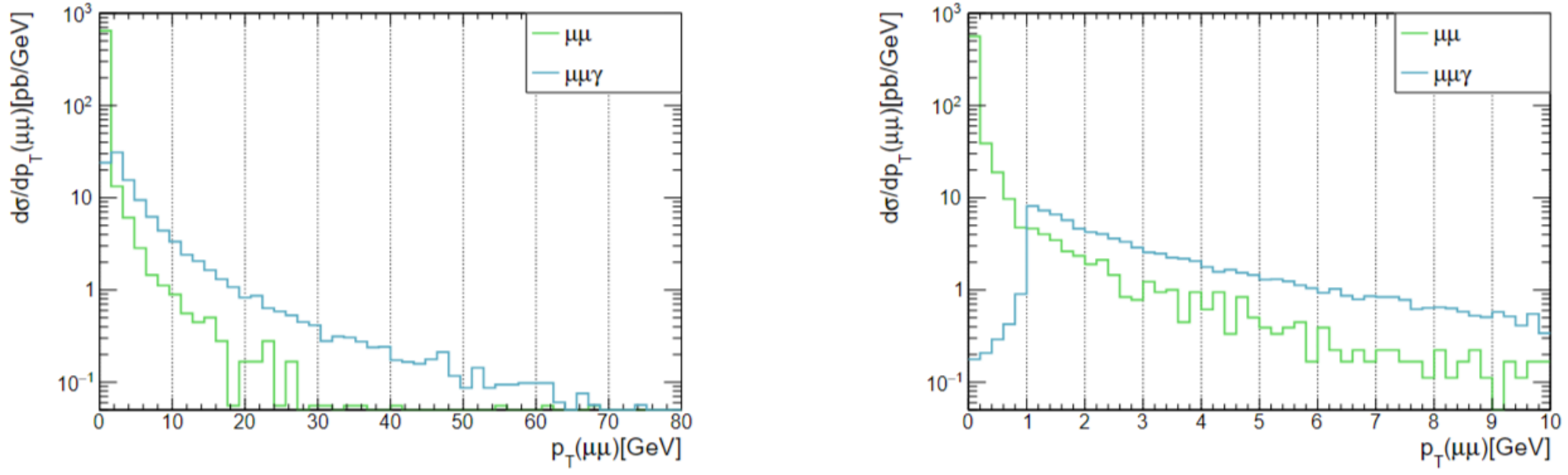
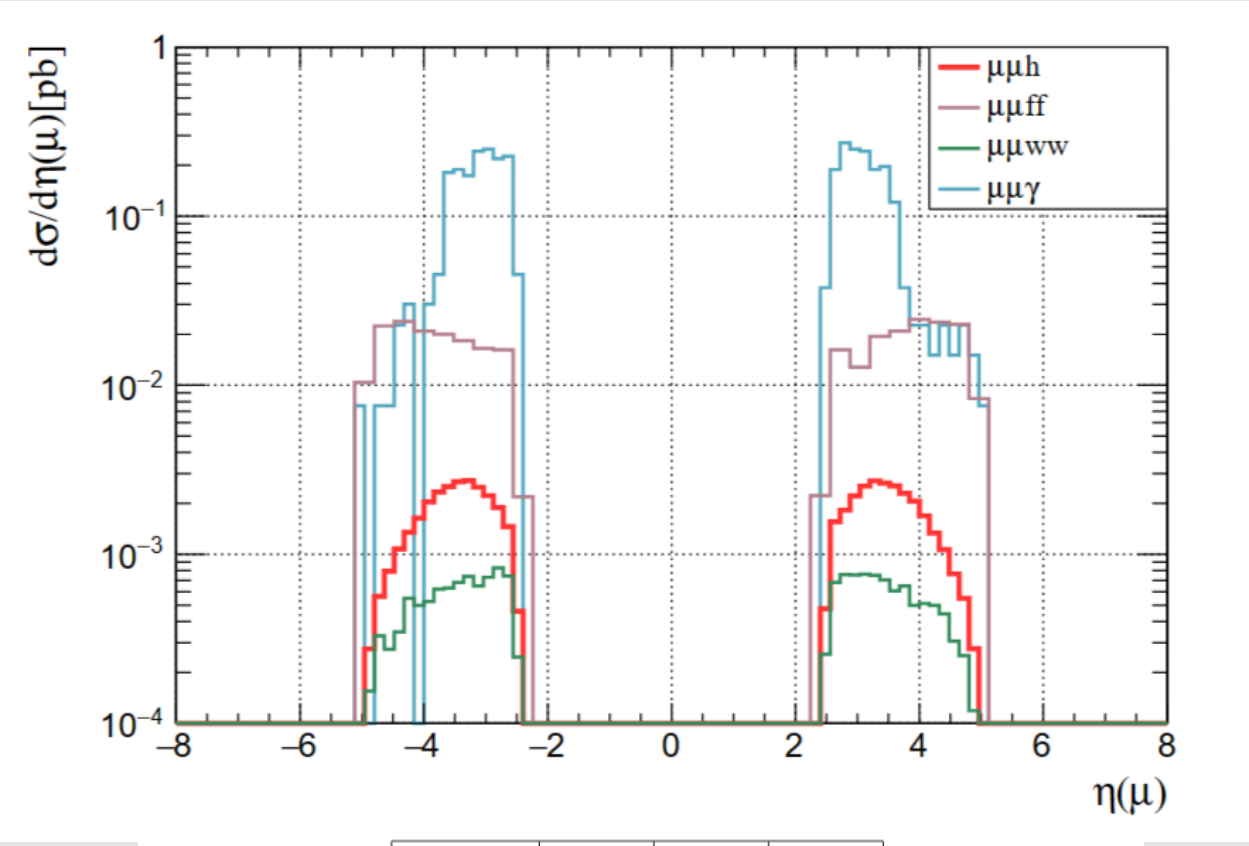


FIG. 4. The truth level $p_T(\mu\mu)$ distribution after QED parton shower, under the cuts of $2.5 < \eta(\mu) < 8$, $\eta(\mu^+) \cdot \eta(\mu^-) < 0$ and $p_T(\mu) > 20$ GeV. The right panel is a zoom-in version of the left. The sharp cliff around 1 GeV is caused by a $p_T(\gamma) > 1$ GeV cut.

3/10 TeV muon collider

After $p_T(\mu\mu) > 50$ GeV :

3 TeV



Benchmark	$\eta(\mu) < 4$	$\eta(\mu) < 6$	$\eta(\mu) < 8$
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TABLE V. The 68% projected sensitivity on the Higgs inclusive rate from ZZ fusion at 3 TeV muon collider.

10 TeV

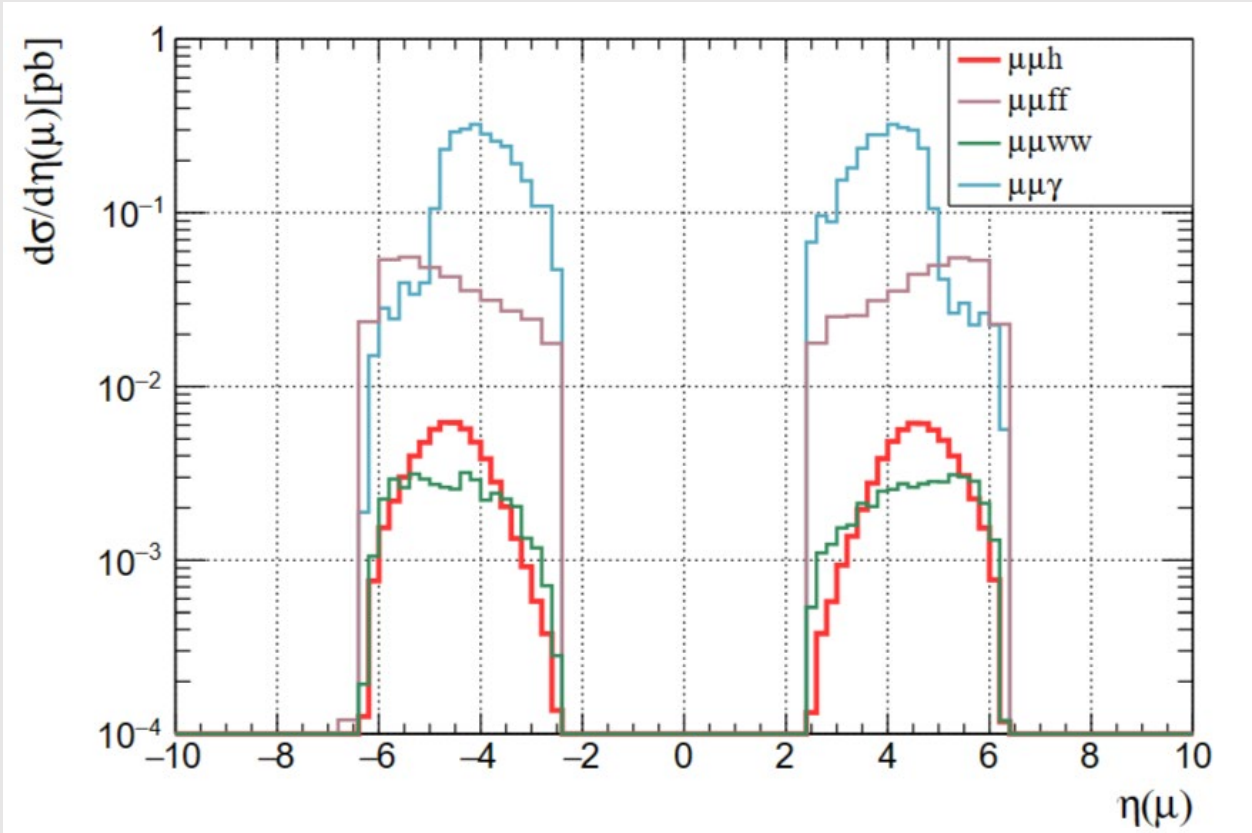

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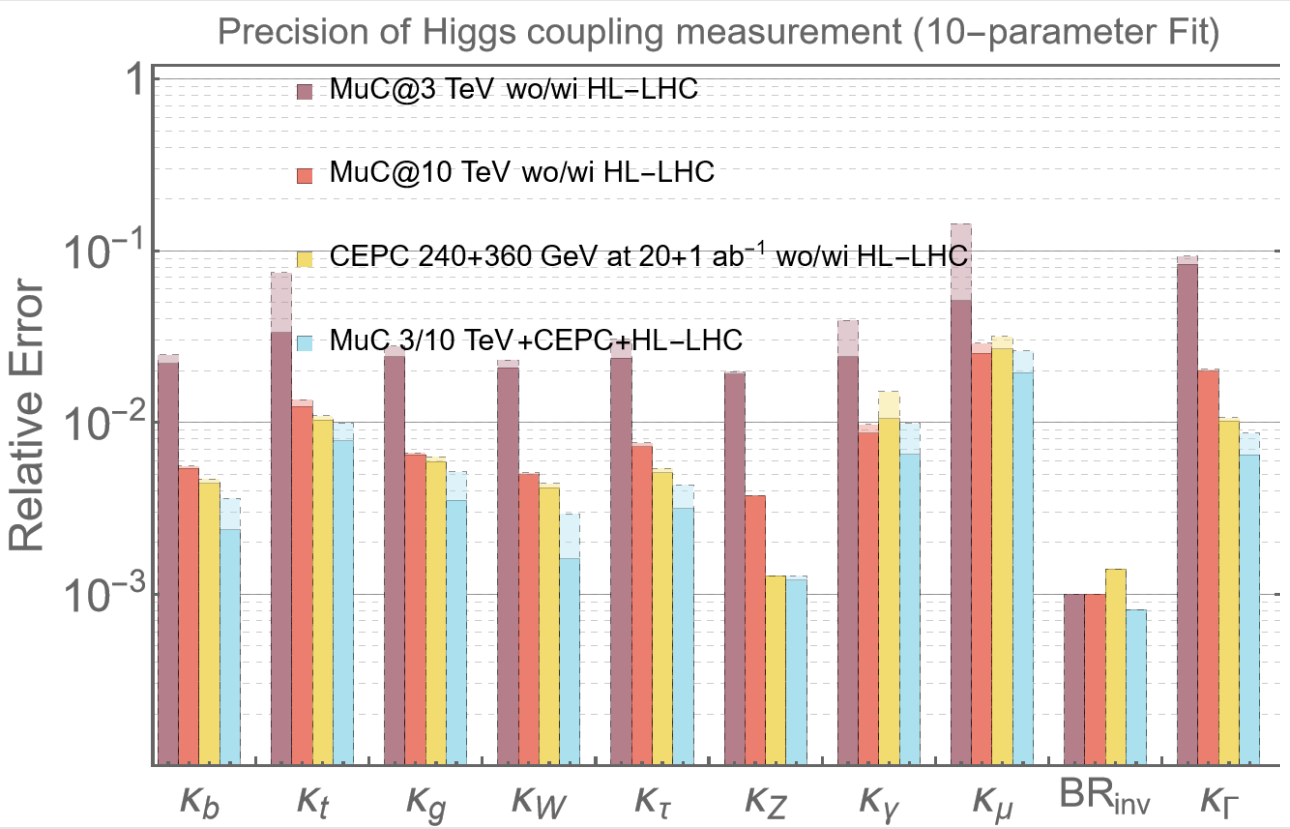
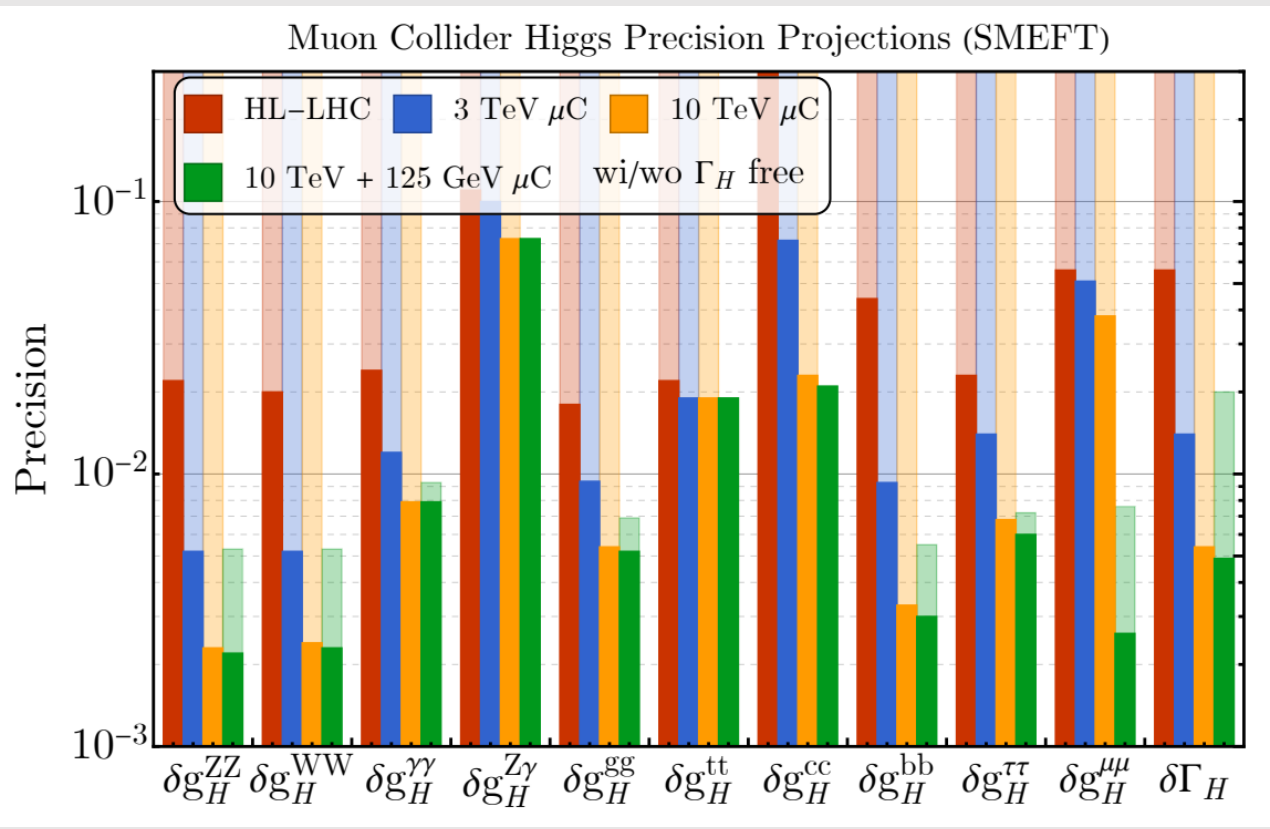
TABLE III. The 68% projected sensitivity on the Higgs inclusive rate from ZZ fusion at 10 TeV muon collider.

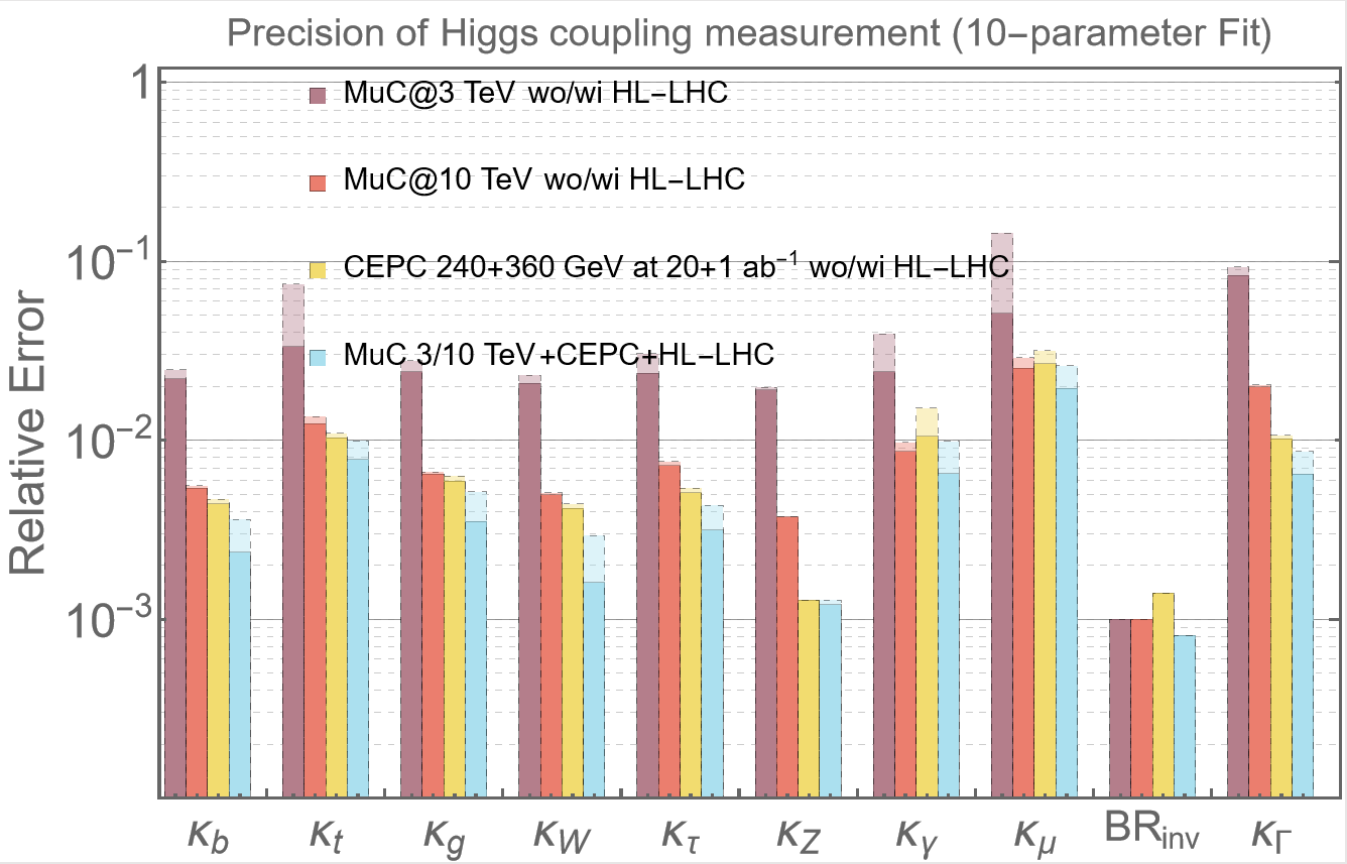
Our result vs. previous studies



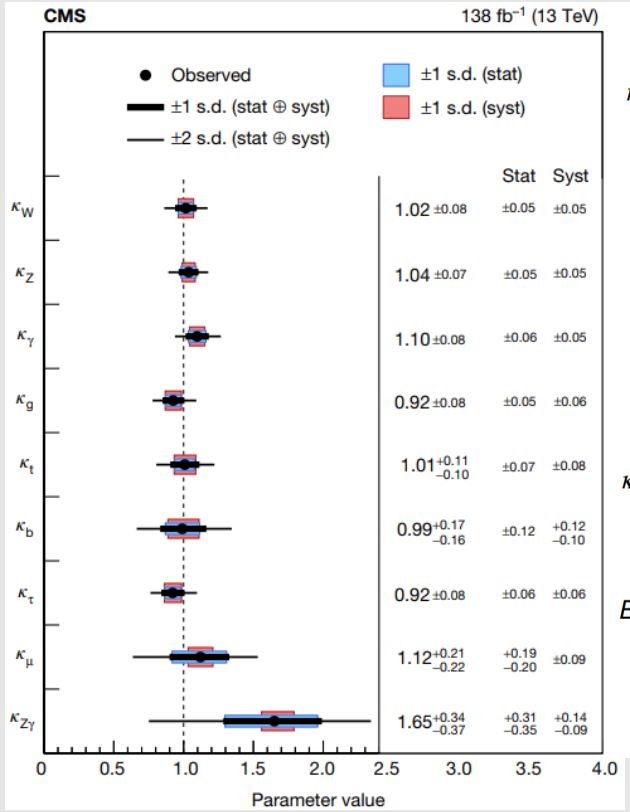


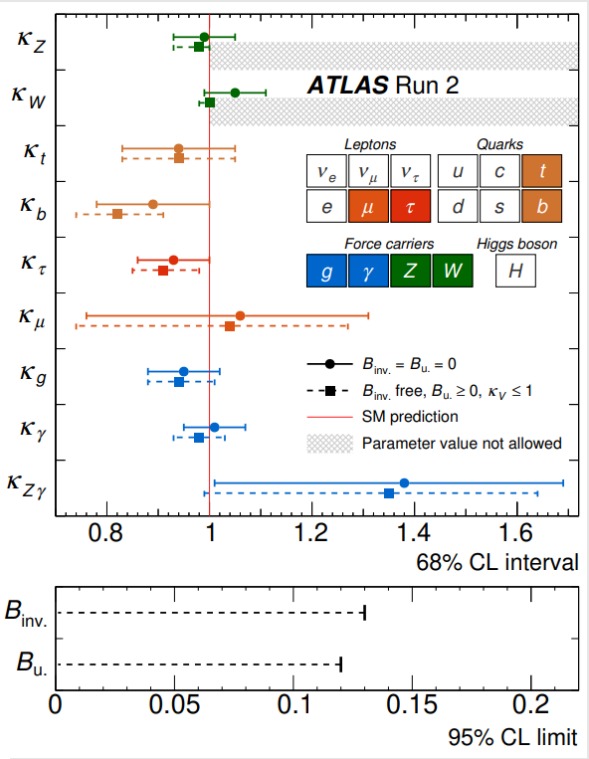
Global fit

MuC and other future collider performance



LHC run-2 result

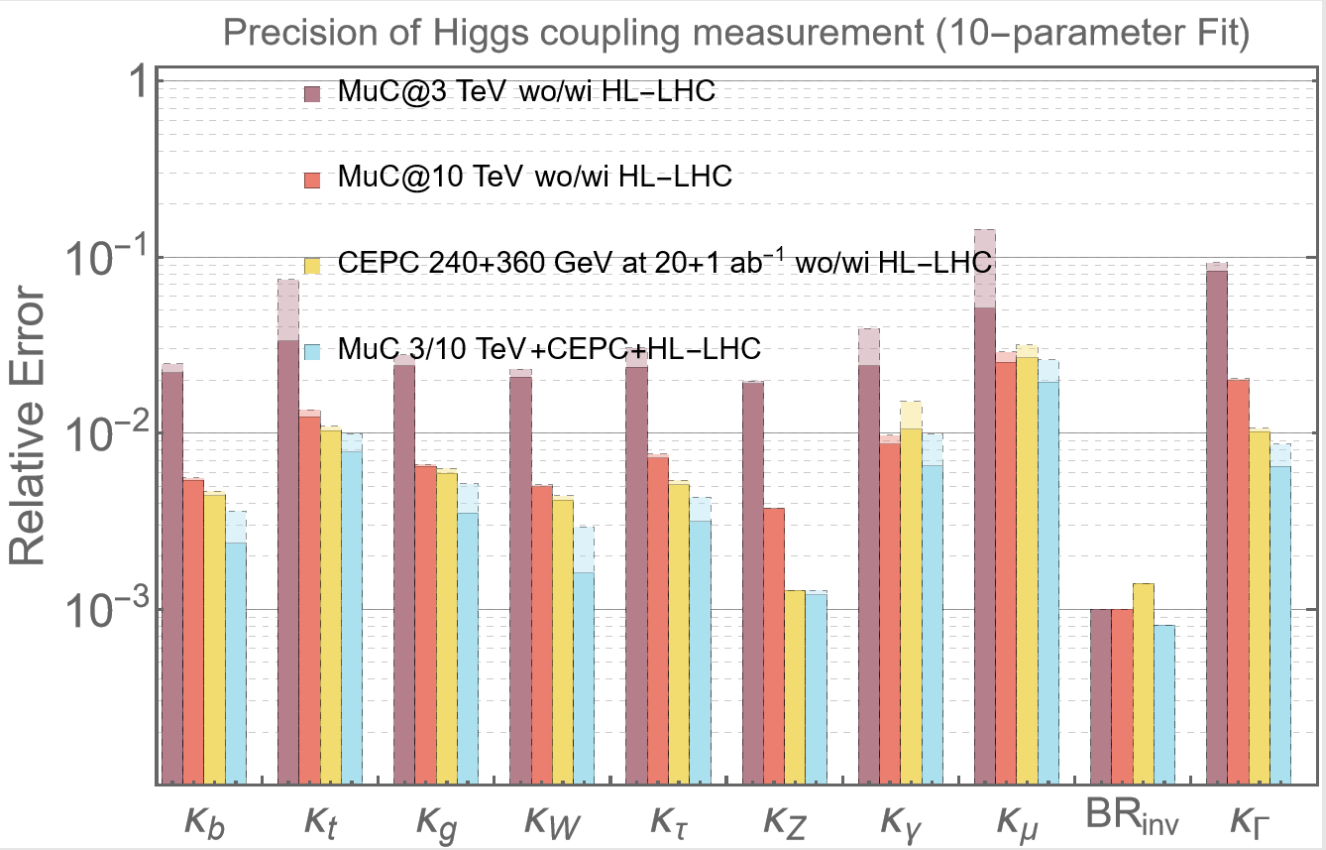


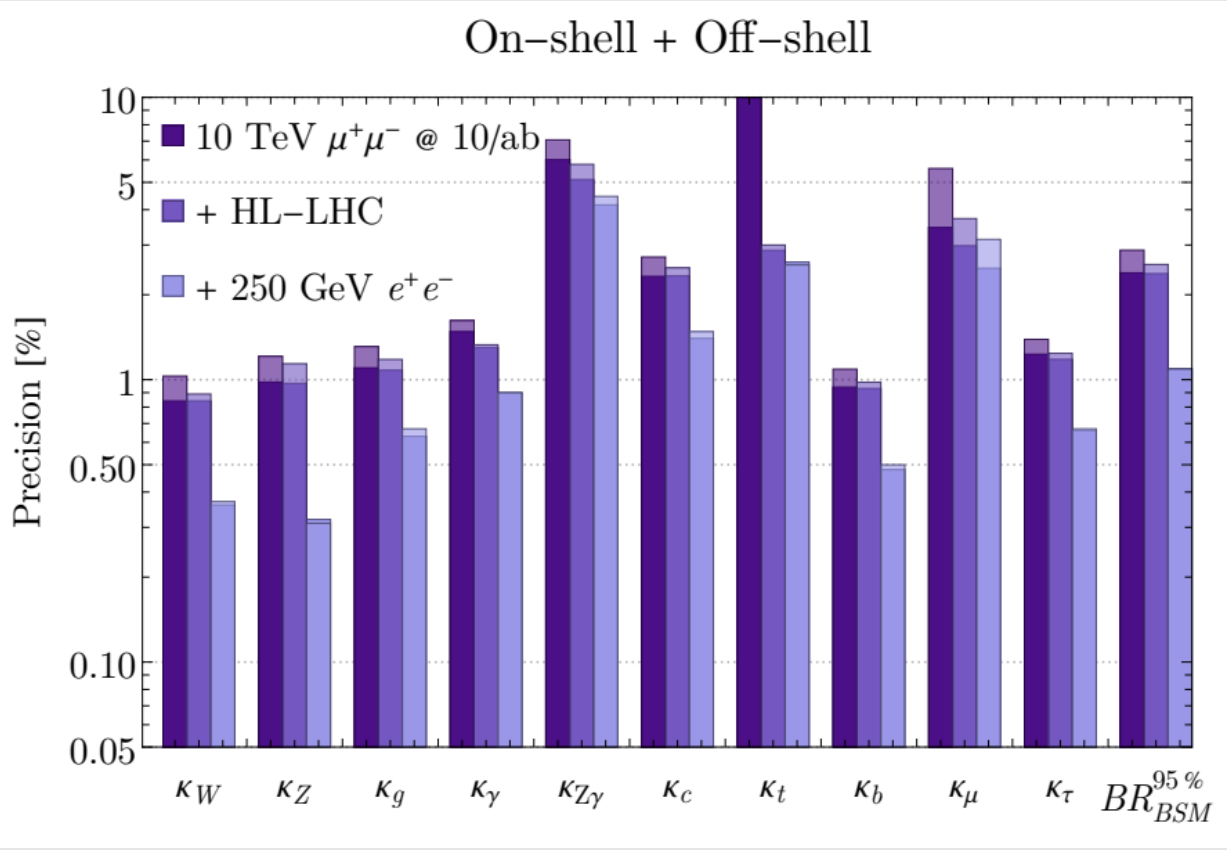


[2207.00043] A portrait of the Higgs boson by the CMS experiment ten years after the discovery

[2207.00092] A detailed map of Higgs boson interactions by the ATLAS experiment ten years after the discovery

Our result comparing with the other group





Matthew Forslund, Patrick Meade
[2308.02633] Precision Higgs Width and Couplings with a High Energy Muon Collider

Correlation matrix

	1	2	3	4	5	6	7	8	9	10
1	1.00	−0.333	0.801	0.919	0.697	0.674	0.558	0.179	0	0.967
2	−0.333	1.0	−0.276	−0.362	−0.240	−0.263	−0.193	−0.0616	0	−0.355
3	0.801	−0.276	1.00	0.762	0.579	0.565	0.464	0.149	0	0.803
4	0.919	−0.362	0.762	1.00	0.664	0.739	0.533	0.170	0	0.982
5	0.697	−0.240	0.579	0.664	1.0	0.493	0.403	0.130	0	0.699
6	0.674	−0.263	0.565	0.739	0.493	1.0	0.385	0.129	0	0.736
7	0.558	−0.193	0.464	0.533	0.403	0.385	1.0	0.104	0	0.560
8	0.179	−0.0616	0.149	0.170	0.130	0.129	0.104	1.00	0	0.180
9	0	0	0	0	0	0	0	0	1.00	0
10	0.967	−0.355	0.803	0.982	0.699	0.736	0.560	0.180	0	1.00

{kb, kt, kg, kw, ktau, kz, kgamma, kmu, brinv, ktotal}