Higgs couplings projections at the FCC-hh

Part of WIP with T. Armadillo, E. Celada, J. t. Hoeve, F. Maltoni, L. Mantani, J. Rojo,
A. N. Rossia, ST, M. Thomas, E. Vryonidou

Simone Tentori

FCC Workshop, CERN, 16/01/25

Kappa Framework – I

- Scale each Higgs interaction with a kappa modifier

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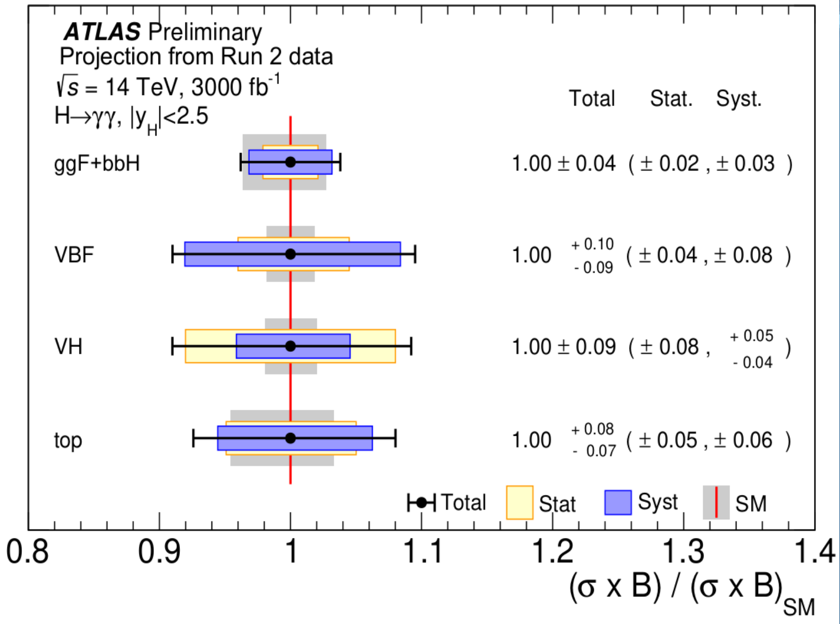
$$\sigma(i \to H \to f) = \frac{\sigma(i \to H)\Gamma_f}{\Gamma_H}$$

$$\sigma(i \to H \to f) = \sigma^i_{\mathrm{SM}} \mathrm{Br}_{\mathrm{SM}} \cdot \left(\frac{\kappa_i^2 \kappa_f^2}{k_H^2}\right)$$



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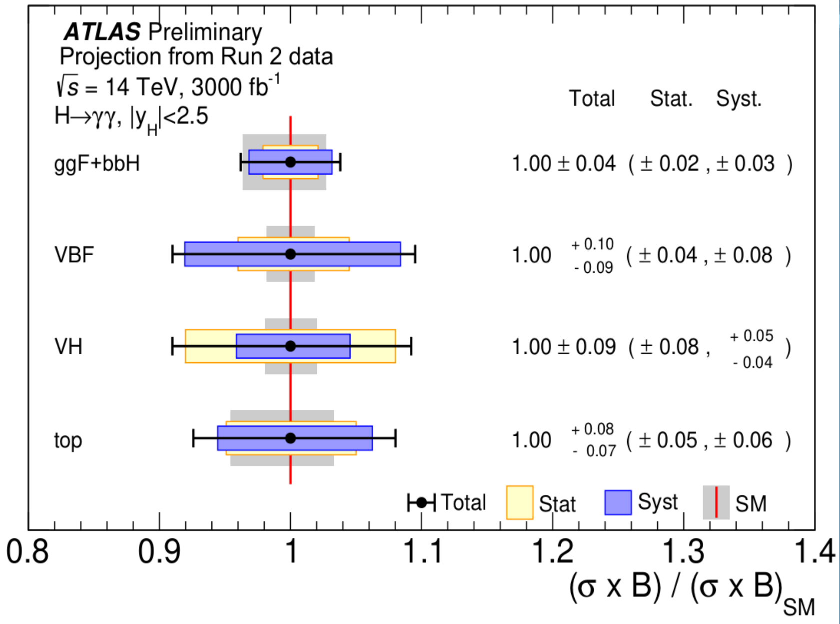

- Easy comparison between colliders, easy interpretation (BSM)

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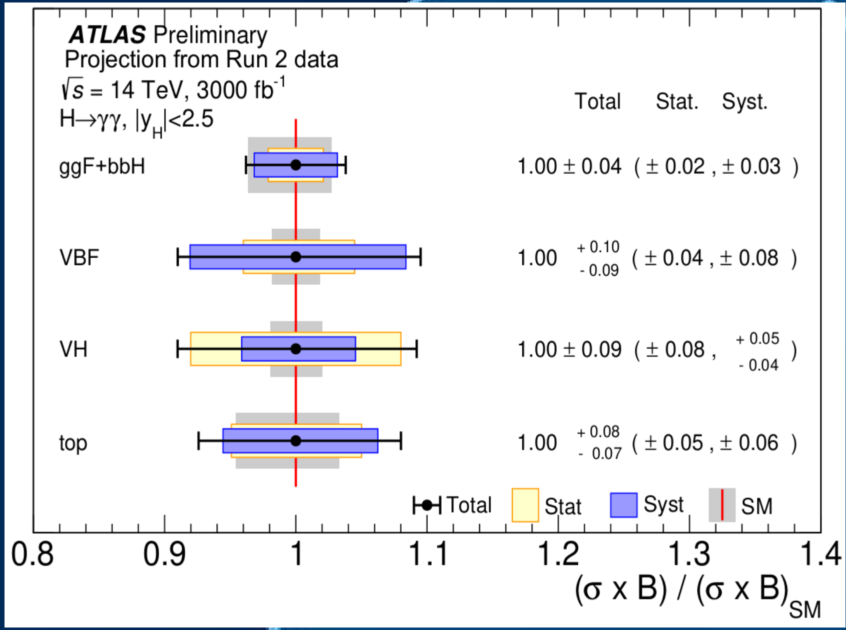

- Easy comparison between colliders, easy interpretation (BSM)
- Not fully exploiting kinematics & beam polarization

Kappa Framework III

κ_H expression depends on the BSM Physics

The kappa-0 framework:

- $(\kappa_H^0)^2 = \sum_f \kappa_f^2 \, Br_f^{SM}$
- No new Higgs decay channels
- Testable in any collider

The kappa-1(2) framework:

- $(\kappa_H)^2 = (\kappa_H^0)^2 / (1 - Br_{BSM})$
- New BSM light states or Higgs decays

Following Granada 2019 naming scheme [1905.03764]

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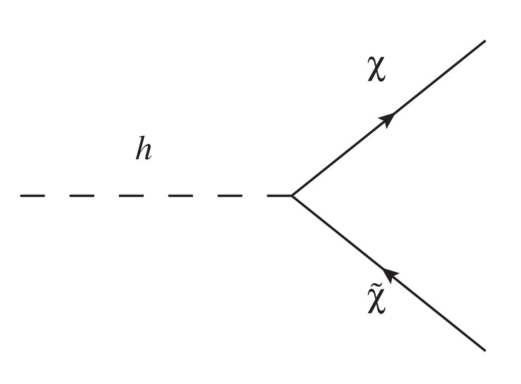
The kappa-3 framework:

- $(\kappa_H)^2 = (\kappa_H^0)^2 / (1-Br_{BSM})$
- New BSM light states or Higgs decays
- HL-LHC AS FIT BASELINE

Following Granada 2019 naming scheme [1905.03764]

Kappa Framework IV



Br_{inv}: Invisible Branching ratio

- Can be measured
- Target for HL-LHC (2.5% at 95% C.L.)

BSM Branching ratio

kappa-1 framework

*More in the Backup

Kappa Framework IV

BSM Branching ratio

kappa-2 framework

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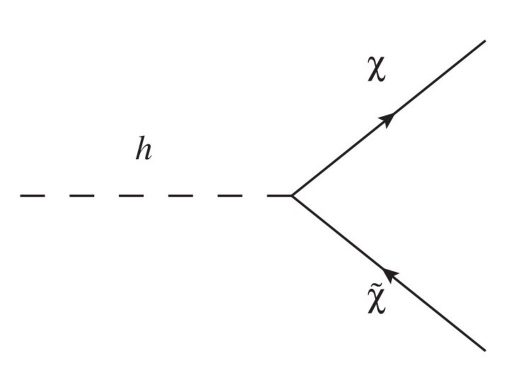
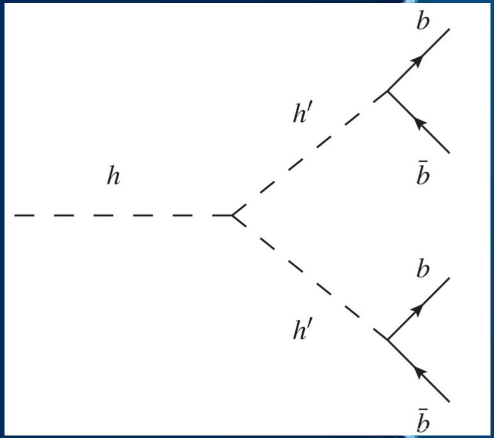


Br_{und}: Undetected Branching ratios
- Cannot be targeted
- Free in the fit
- Needs proxy for Γ_H or additional conditions



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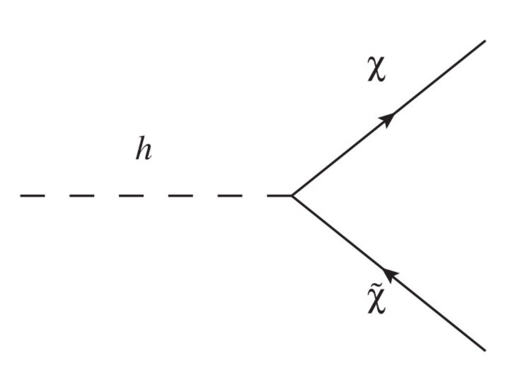

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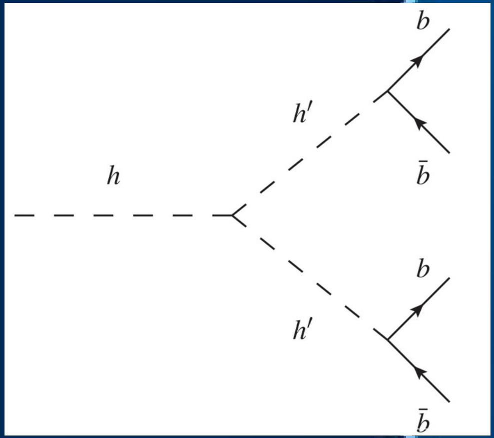


In future $\ell^+\ell^-$ colliders synergy between:
- ZH inclusive
- $H \rightarrow ZZ$

*More in the Backup

For more SMEFiT take a look at Jaco Ter Hoeve talk on Tuesday!

Methodology

SMEFiT

- New functionalities to implement kappa framework
- Input based on recent SnowMass2022 projection
- Validated against HEPfit 2019 results (big thanks to Jorge de Blas, for helping with the validation)

	FCC-ee 240		LHeC	
	HepFit	SMEFIT	HepFit	SMEFIT
κ_W	1.3	1.3	0.994*	0.994*
κ_Z	0.21	0.2	0.988*	0.988*
κ_g	1.7	1.6	3.9	3.9
κ_γ	4.8	4.7	7.8	7.7
$\kappa_{Z\gamma}$	71	75	-	-
κ_c	1.8	1.7	4.3	4.2
κ_t	-	-	-	-
κ_b	1.3	1.3	2.3	2.3
κ_μ	10	9.9	-	-
κ_τ	1.4	1.4	3.6	3.6
$\mathrm{Br}_{\mathrm{inv.}}$	0.22	0.27	2.2	2
$\mathrm{Br}_{\mathrm{und.}}$	1.2	1.2	2.2	2.2

FCChh input

For more FCChh input look at previous talk by Birgit Stapf

Observable	Fit Input	δ_{stat}	δ_{tot}	κ-dependence
$\mu_{gg}^{\gamma\gamma}$	$\delta\mu/\mu$	0.1%	1.5%	$\frac{\kappa_g^2\kappa_\gamma^2}{k_H^2}$
$\mu_{gg}^{\mu\mu}$	$\delta\mu/\mu$	0.28%	1.2%	$\frac{\kappa_g^2\kappa_\mu^2}{k_H^2}$
μ_{gg}^{ZZ}	$\delta\mu/\mu$	0.18%	1.9%	$\frac{\kappa_g^2\kappa_Z^2}{k_H^2}$
$\mu_{gg}^{Z\gamma}$	$\delta\mu/\mu$	0.55%	1.6%	$\frac{\kappa_g^2\kappa_{Z\gamma}^2}{k_H^2}$
$\mu_{tt}^{b\bar{b}}$	$\delta\mu/\mu$	1.05%	1.9%	$\frac{\kappa_t^2\kappa_b^2}{k_H^2}$
$R_{ZZ}^{\mu\mu}$	$\delta R/R$	0.33%	1.3%	$\frac{\kappa_\mu^2}{\kappa_Z^2}$
$R_{ZZ}^{\gamma\gamma}$	$\delta R/R$	0.17%	0.8%	$\frac{\kappa_\gamma^2}{\kappa_Z^2}$
$R_{\mu\mu}^{\gamma\gamma}$	$\delta R/R$	0.29%	1.4%	$\frac{\kappa_\gamma^2}{\kappa_\mu^2}$
$R_{\mu\mu}^{Z\gamma}$	$\delta R/R$	0.58%	1.8%	$\frac{\kappa_{Z\gamma}^2}{\kappa_\mu^2}$
$\text{Br}_{\text{inv.}}$	$\text{Br}_{\text{inv.}}$	0.01 %	0.01 %	$\text{Br}_{\text{inv.}}$
$\tilde{\mu}_{WH}^{\gamma\gamma}(*)$	$\delta\sigma/\sigma$	1.4%	1.4%	$\frac{\kappa_W^2\kappa_\gamma^2}{k_H^2}$
$\tilde{\mu}_{WH}^{\tau\tau}(*)$	$\delta\sigma/\sigma$	1.6%	1.6%	$\frac{\kappa_W^2\kappa_\tau^2}{k_H^2}$
$\tilde{\mu}_{WH}^{b\bar{b}}(*)$	$\delta\sigma/\sigma$	1.1%	1.1%	$\frac{\kappa_W^2\kappa_b^2}{k_H^2}$
$R_{\gamma\gamma}^{WW}(**)$	$\delta R/R$	1.5%	1.5%	$\frac{\kappa_W^2}{\kappa_\gamma^2}$

Original 2019 ESPPU Input
[Eur. Phys. J. C (2019) 79:474]

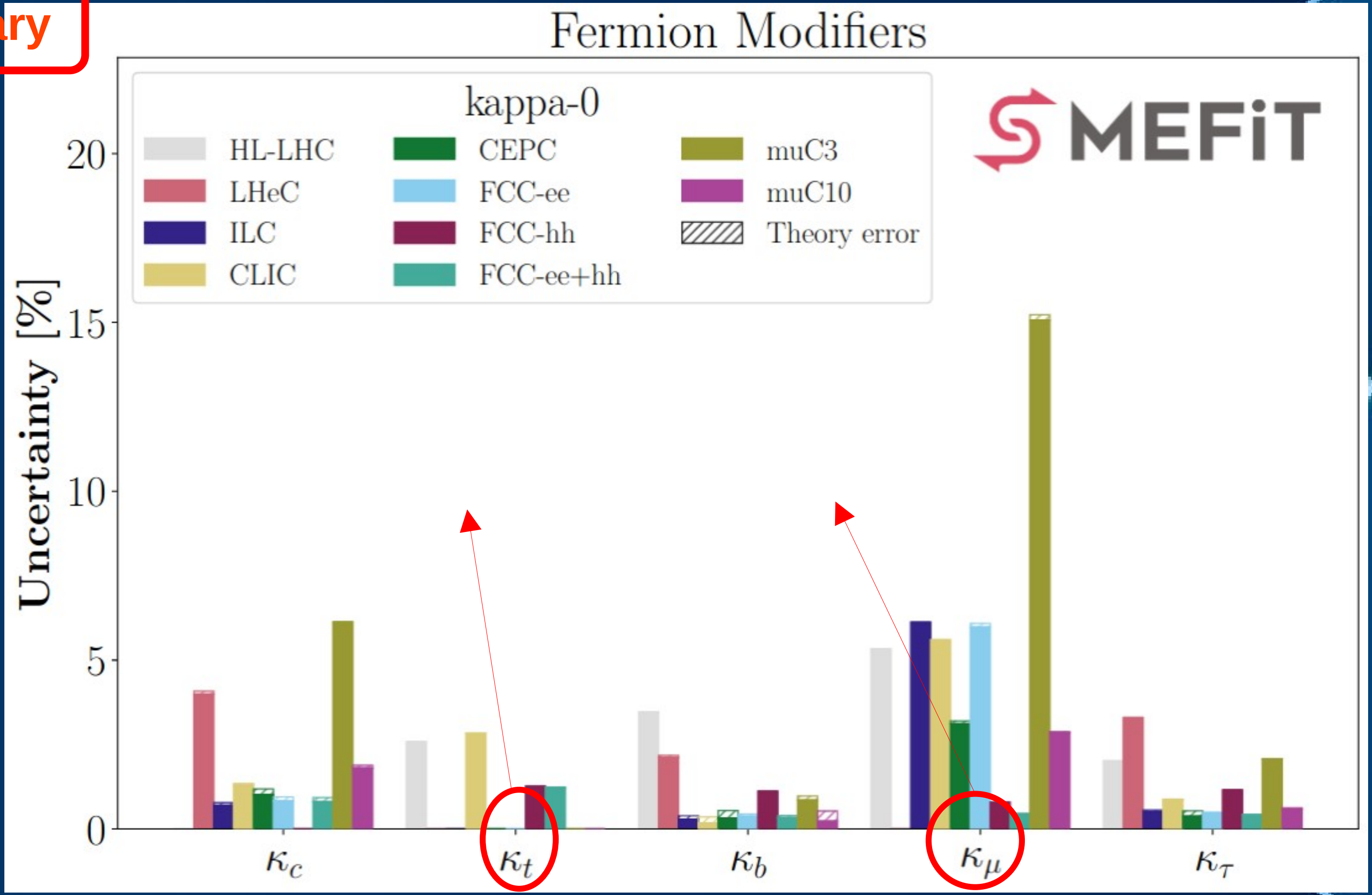
- K_g
- K_γ
- K_μ
- K_Z
- $K_{Z\gamma}$
- K_t
- K_b

[Mangano, CERN-FCC-PHYS-2019-0002]

- K_W
- K_τ
- K_b, K_γ (already present, reduce correlations)

Kappa-0 framework

Preliminary



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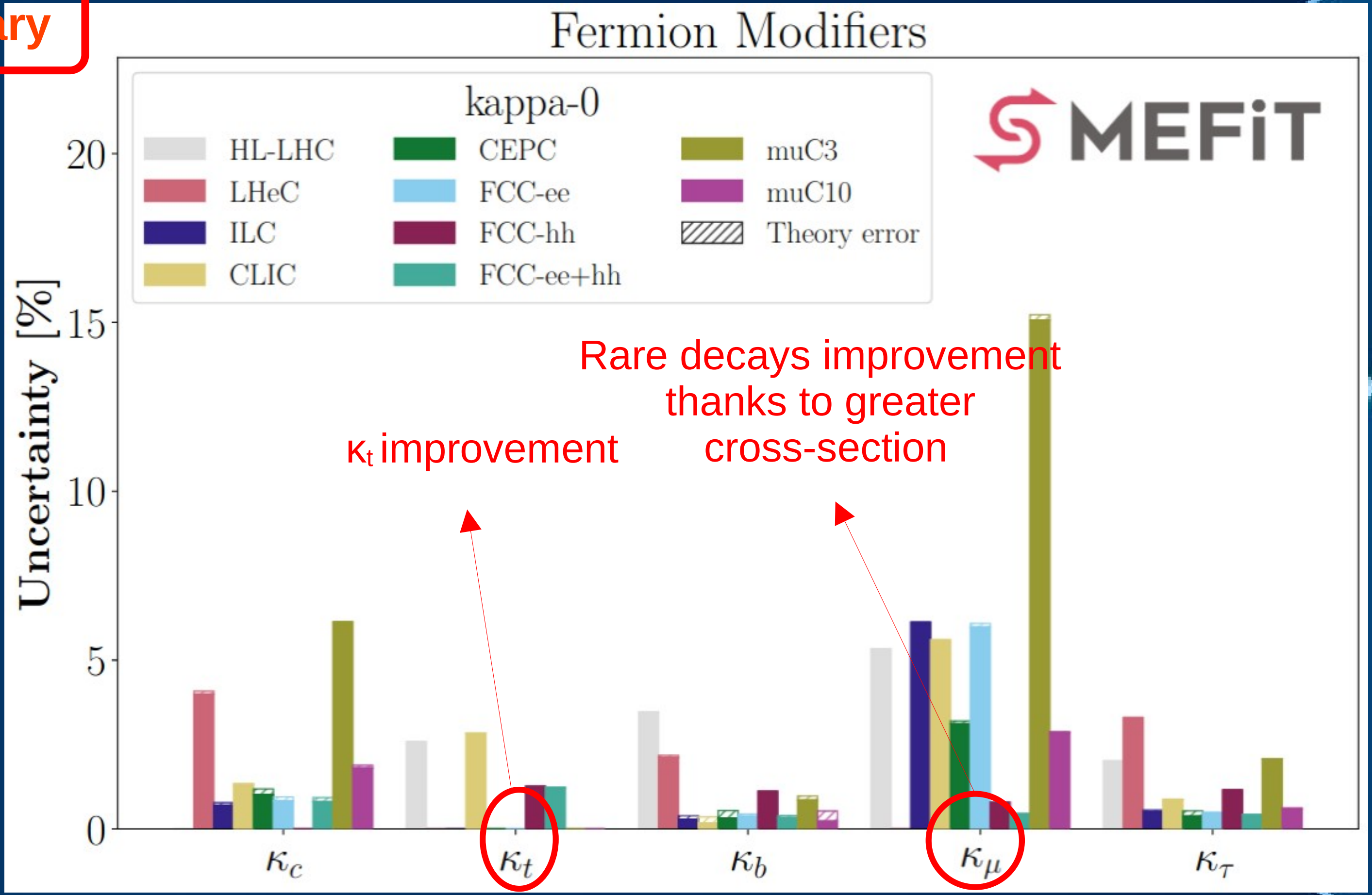

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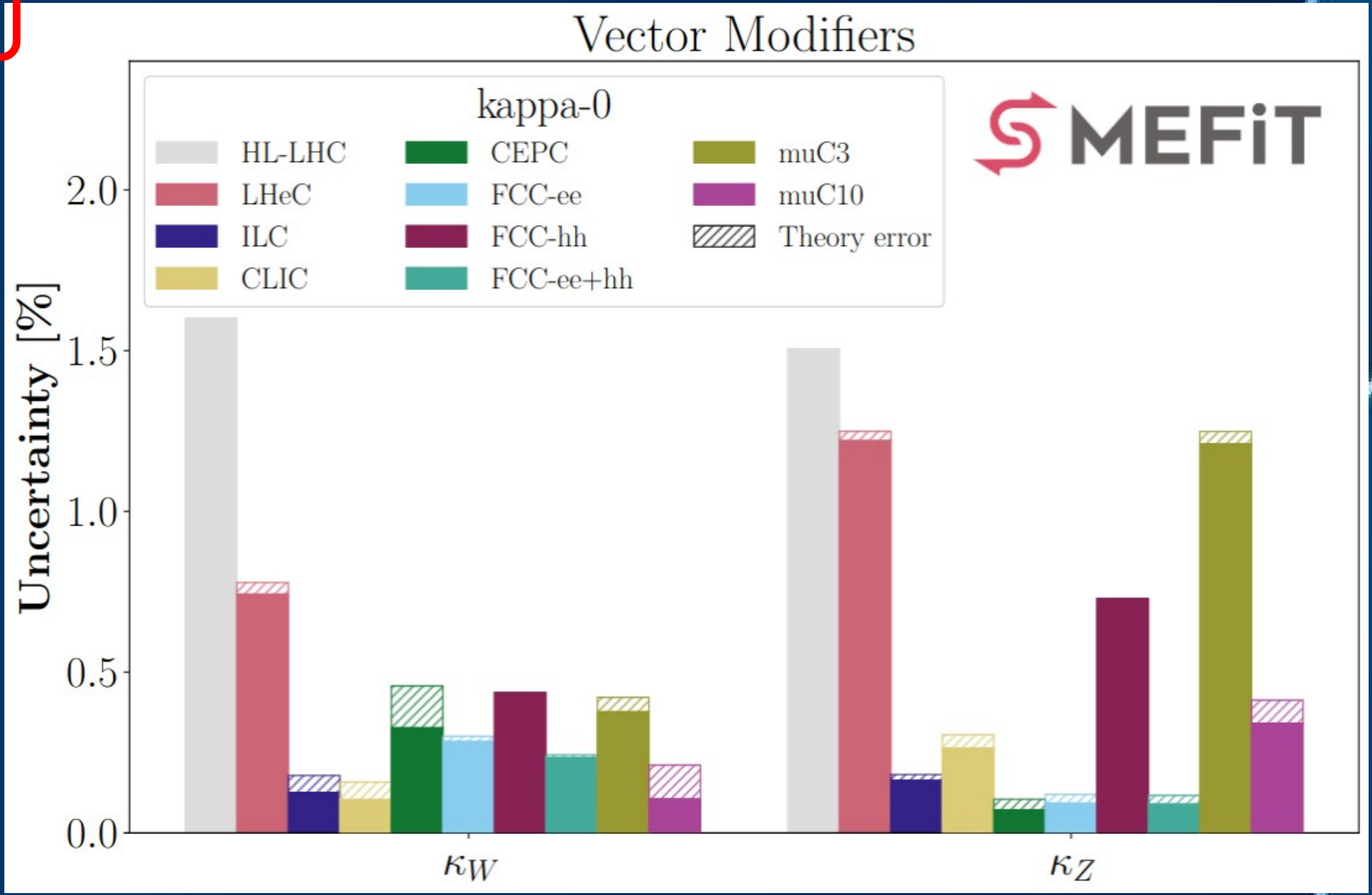

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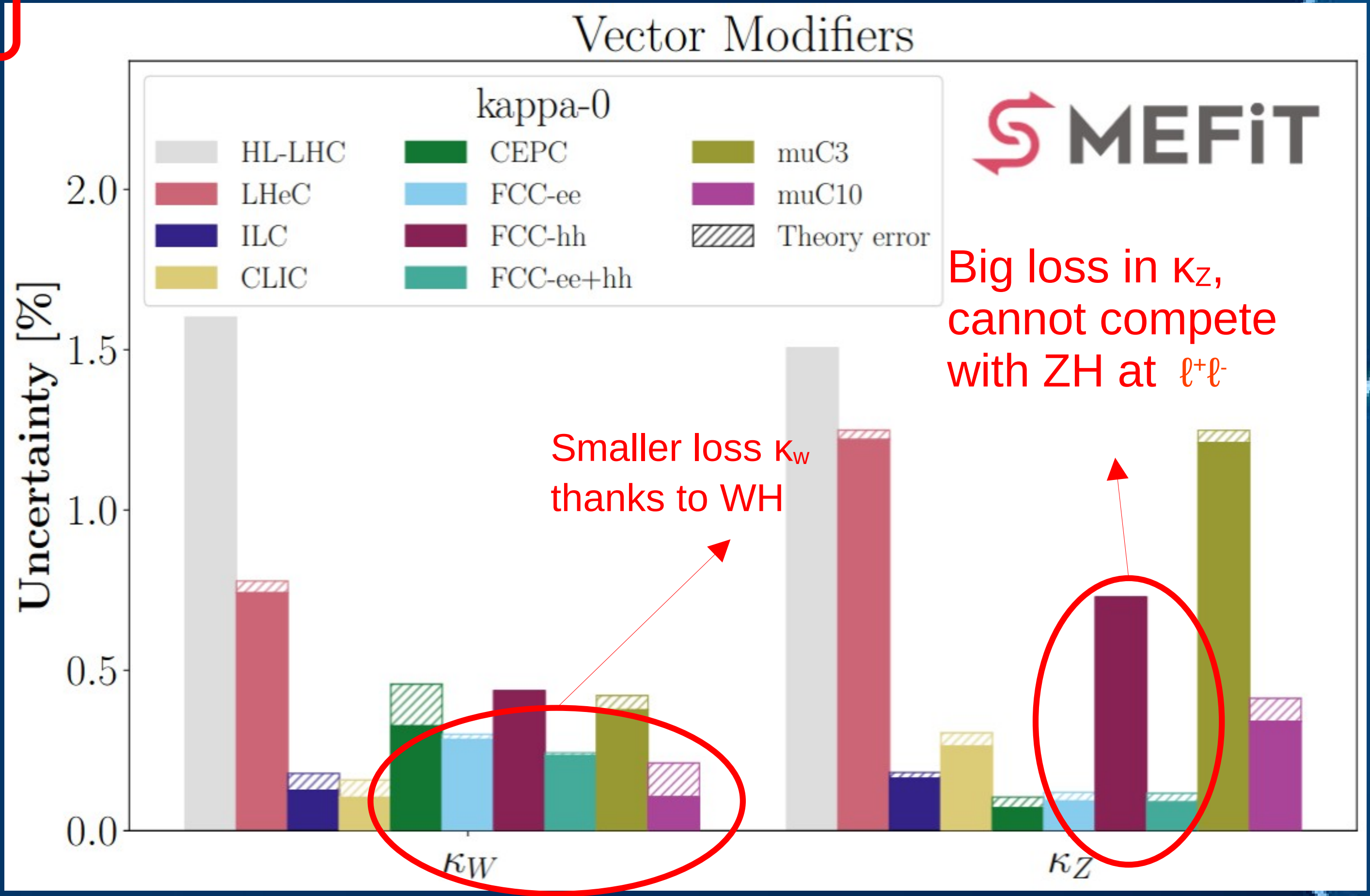

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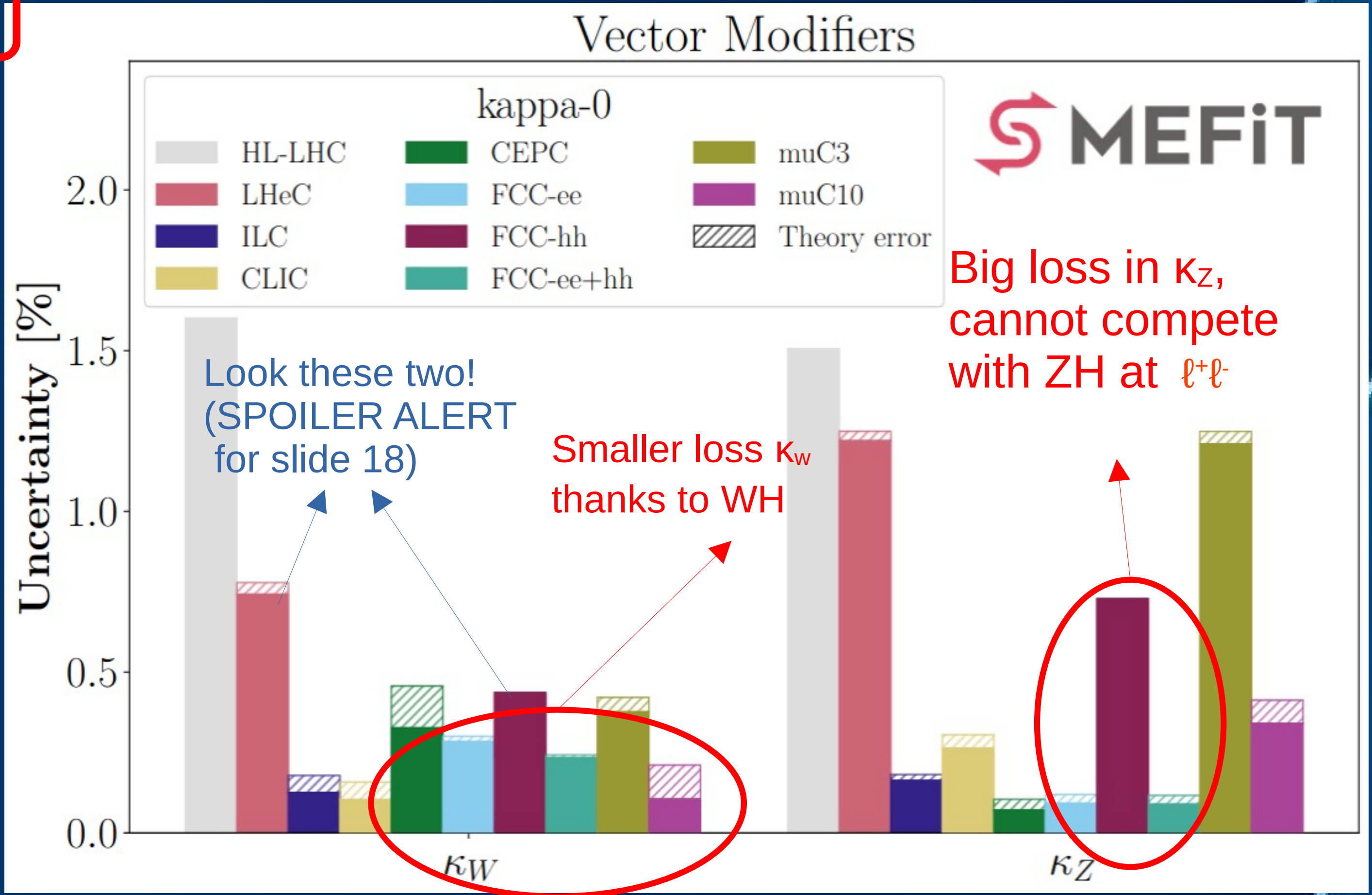

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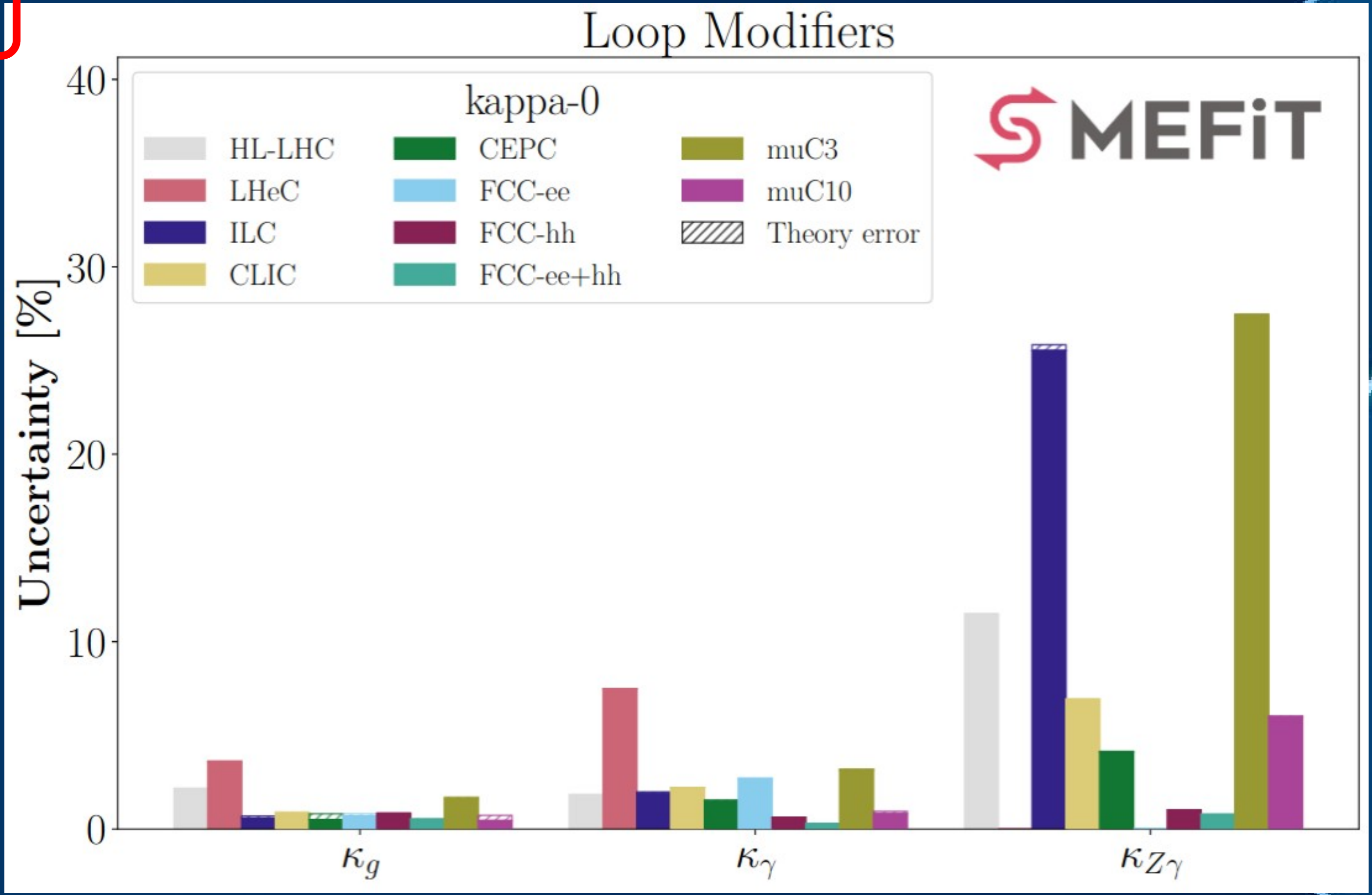

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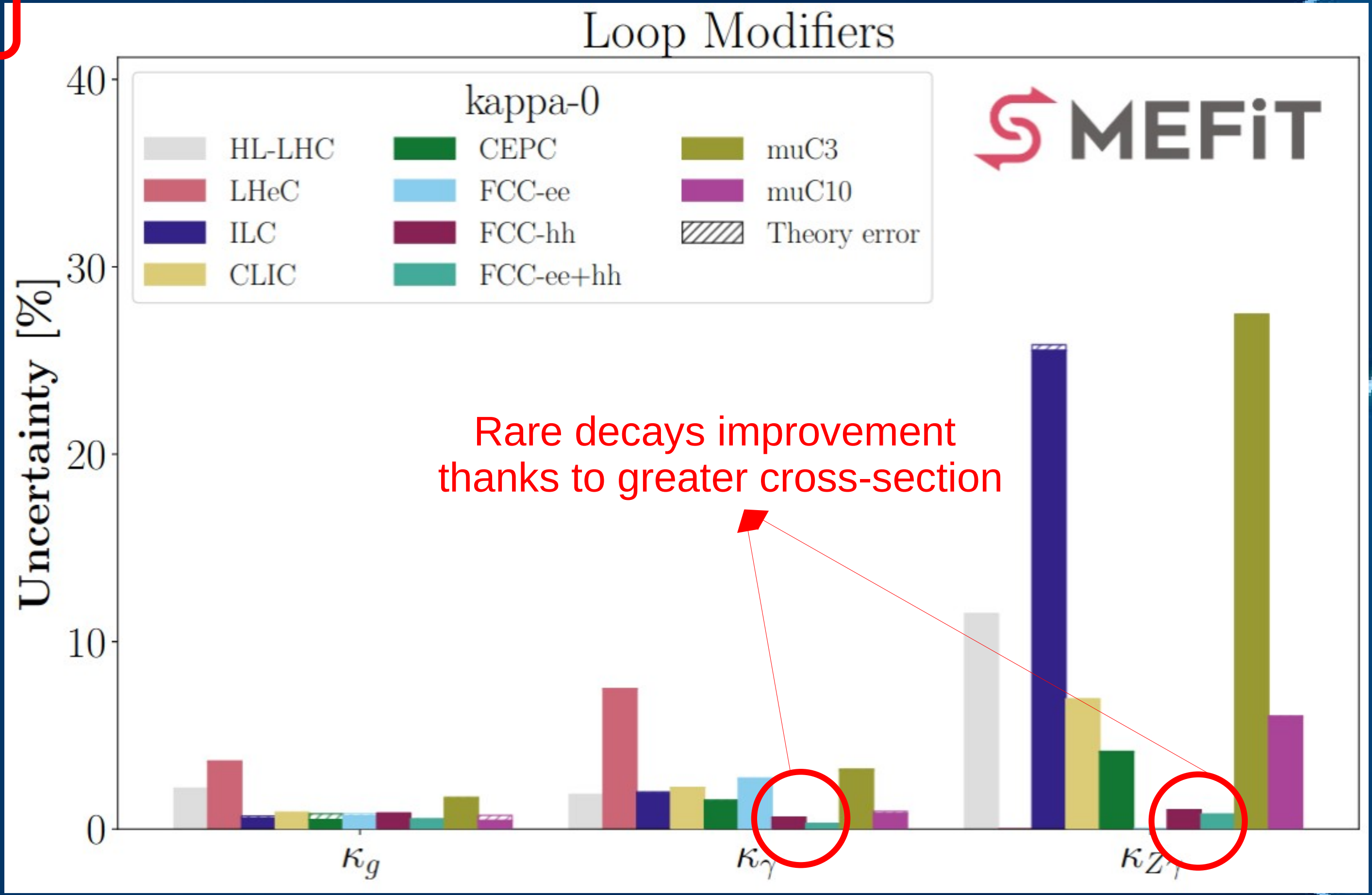
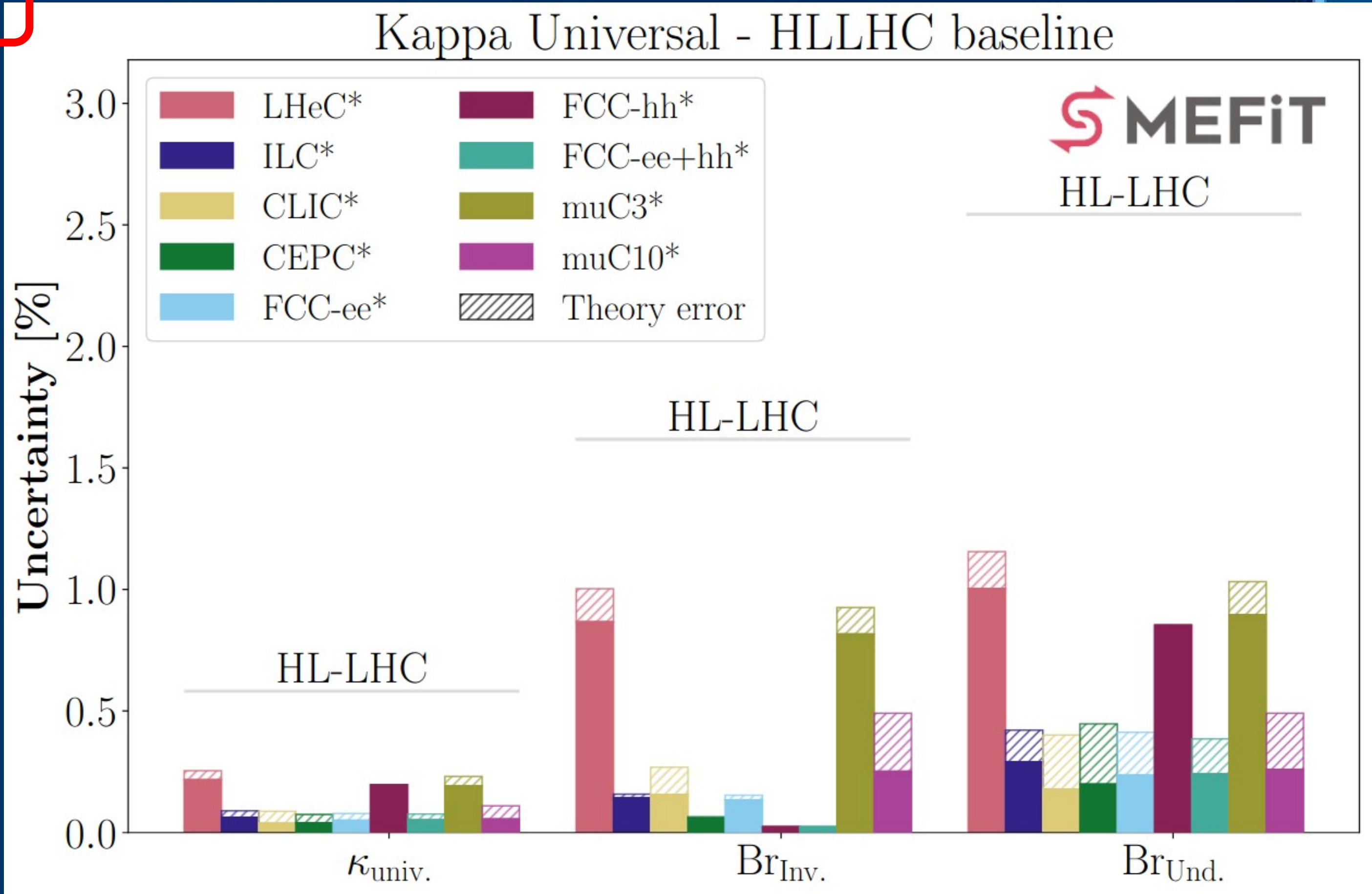


Kappa universal

- Unique kappa modifier: $\kappa_{univ.}$
- HLLHC as baseline
- $Br_{inv.}$ and $Br_{und.}$ turned on
- $\kappa_{univ.} \leq 1$: needed due to $Br_{und.}$
- UV Case: Minimal Scalar Extension

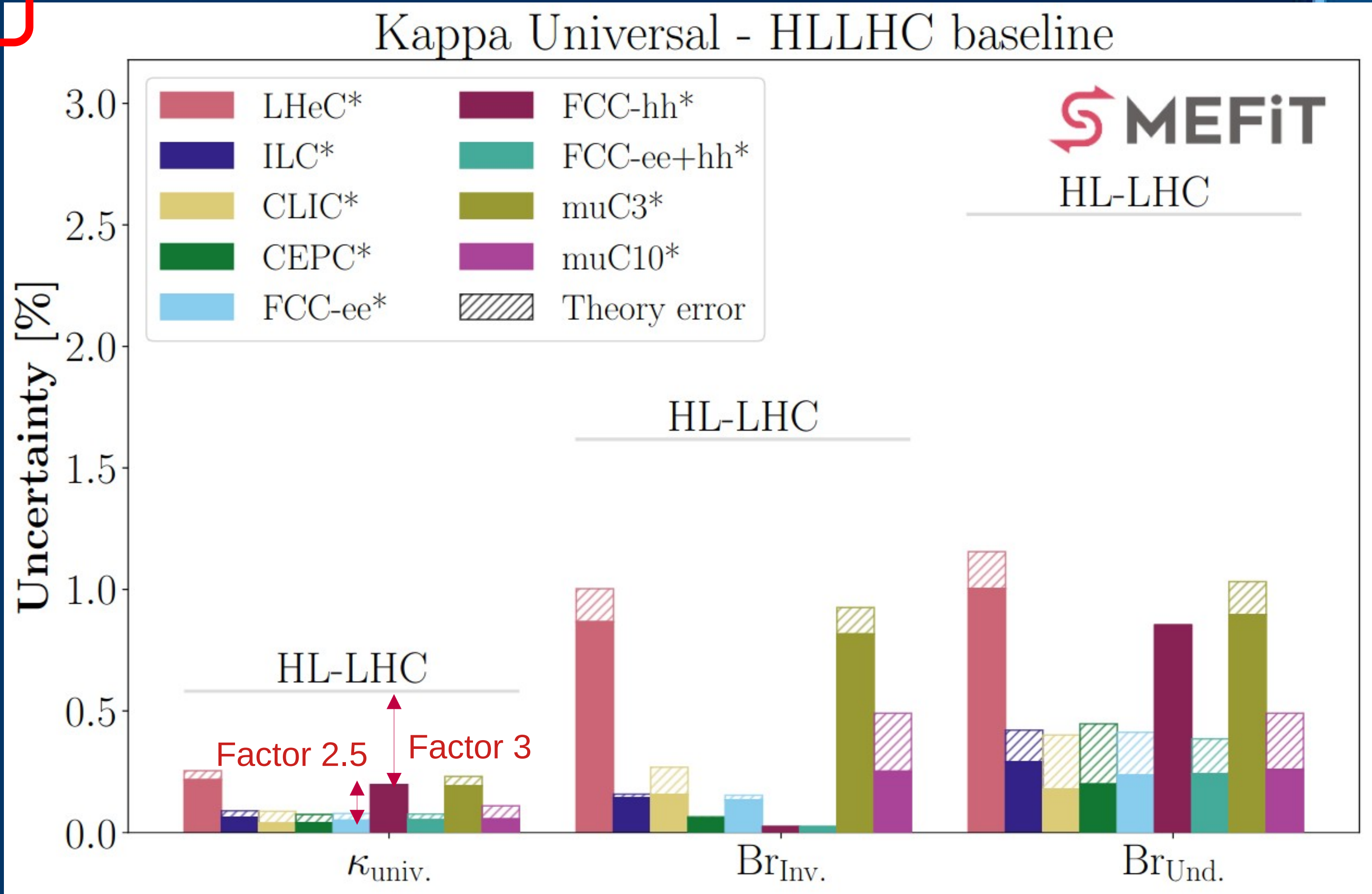
Kappa universal

Preliminary



Kappa universal

Preliminary

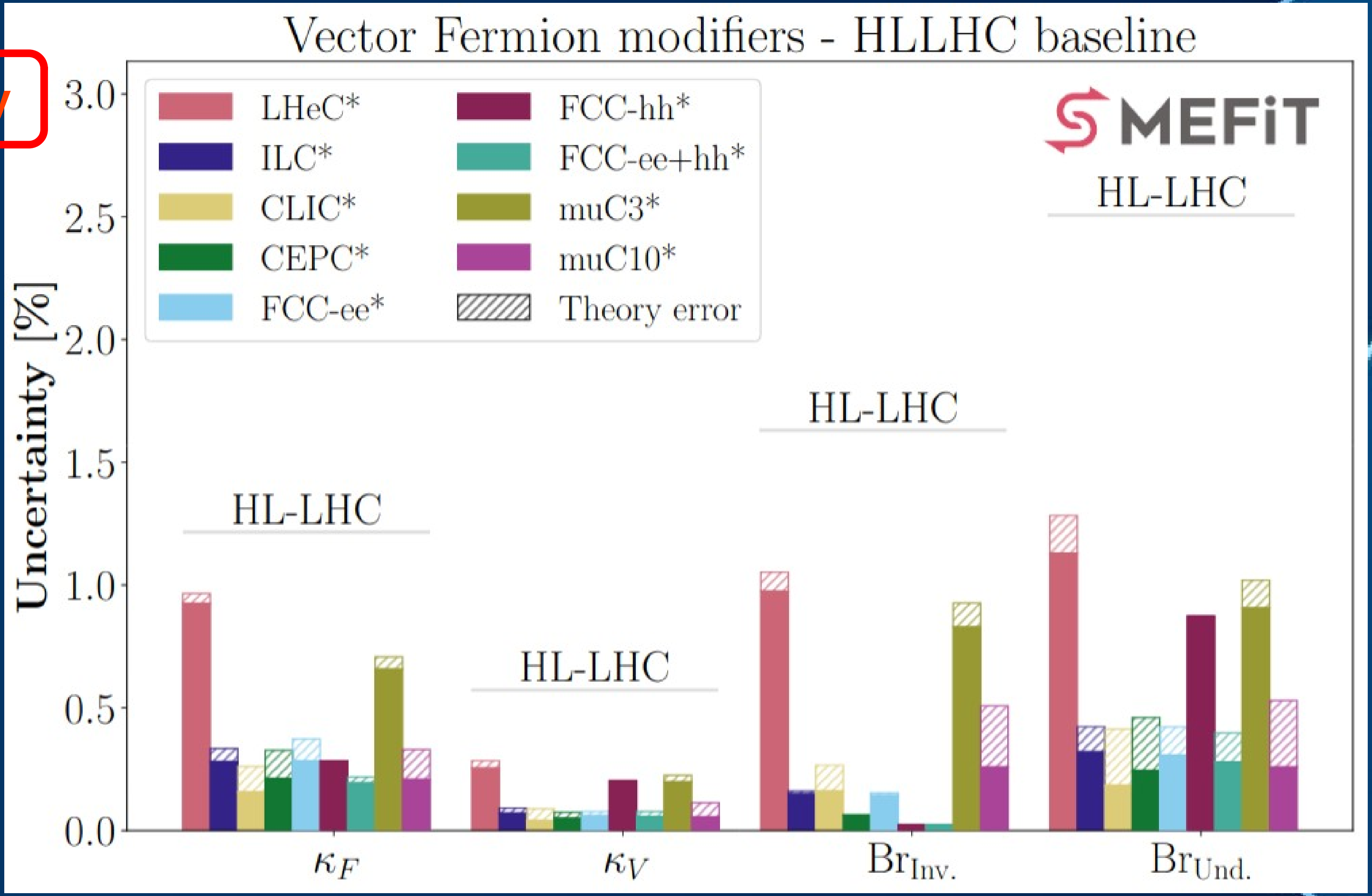


Fermion Vector modifiers

- Two kappa modifiers: κ_f, κ_V
- HLLHC as baseline
- $Br_{inv.}$ and $Br_{und.}$ turned on
- $\kappa_V \leq 1$: needed due to $Br_{und.}$
- UV Case: Type I 2HDM

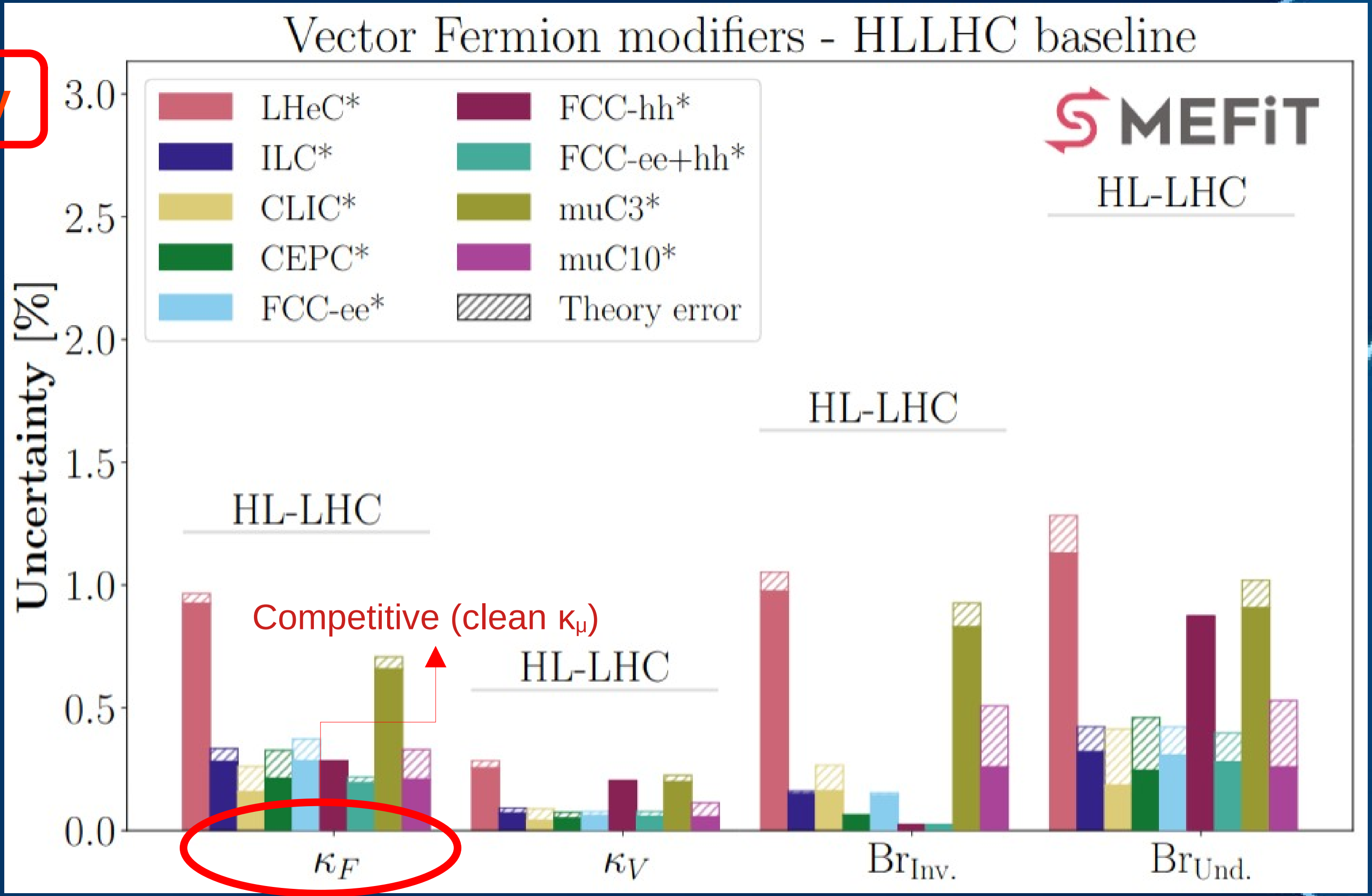
Fermion Vector modifiers

Preliminary



Fermion Vector modifiers

Preliminary

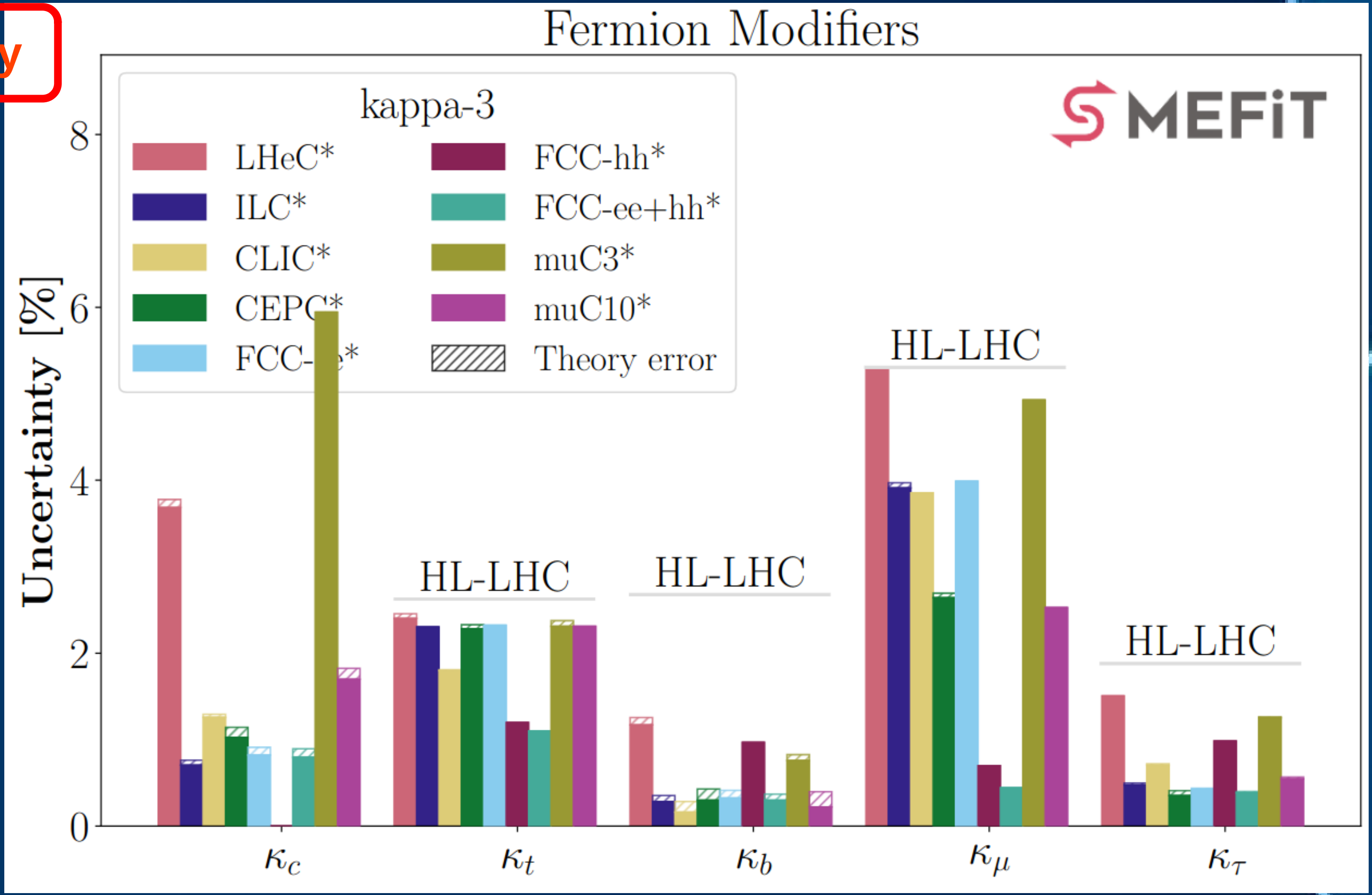


Kappa-3 framework

- Ten kappa modifiers
- HLLHC as baseline
- $Br_{inv.}$ and $Br_{und.}$ turned on
- $\kappa_Z \leq 1$, $\kappa_W \leq 1$: needed due to $Br_{und.}$

Kappa-3

Preliminary



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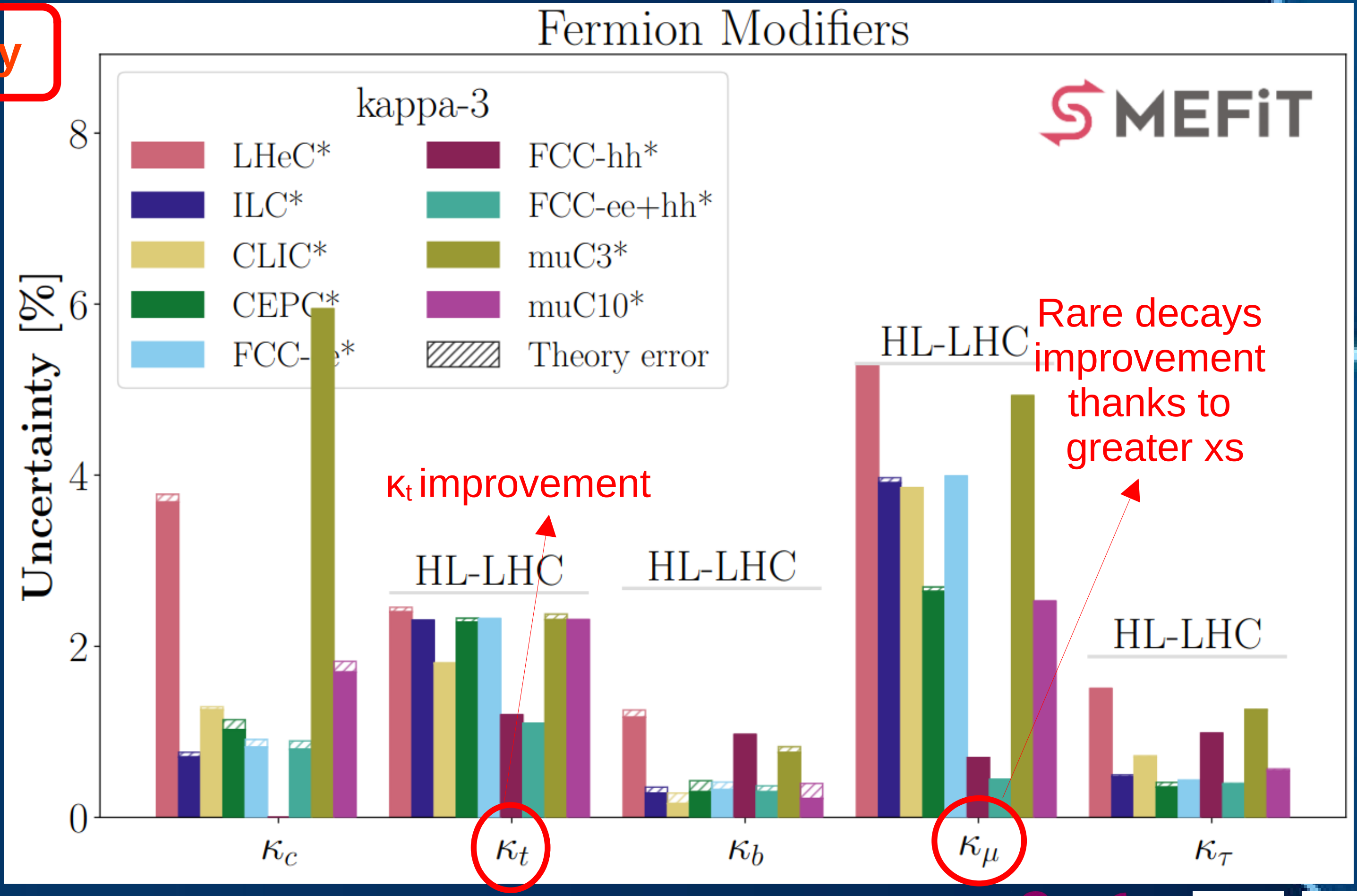
Preliminary



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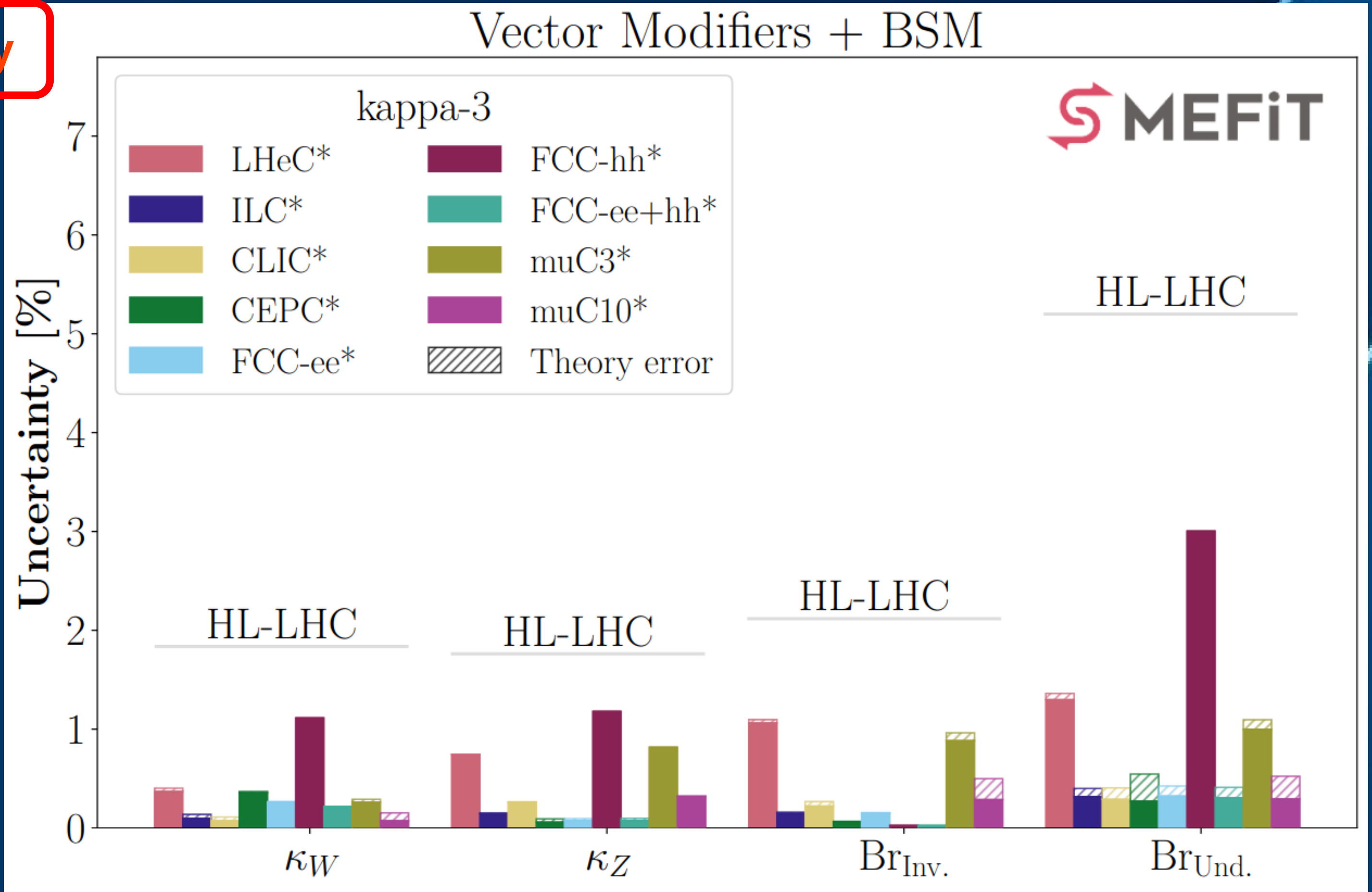

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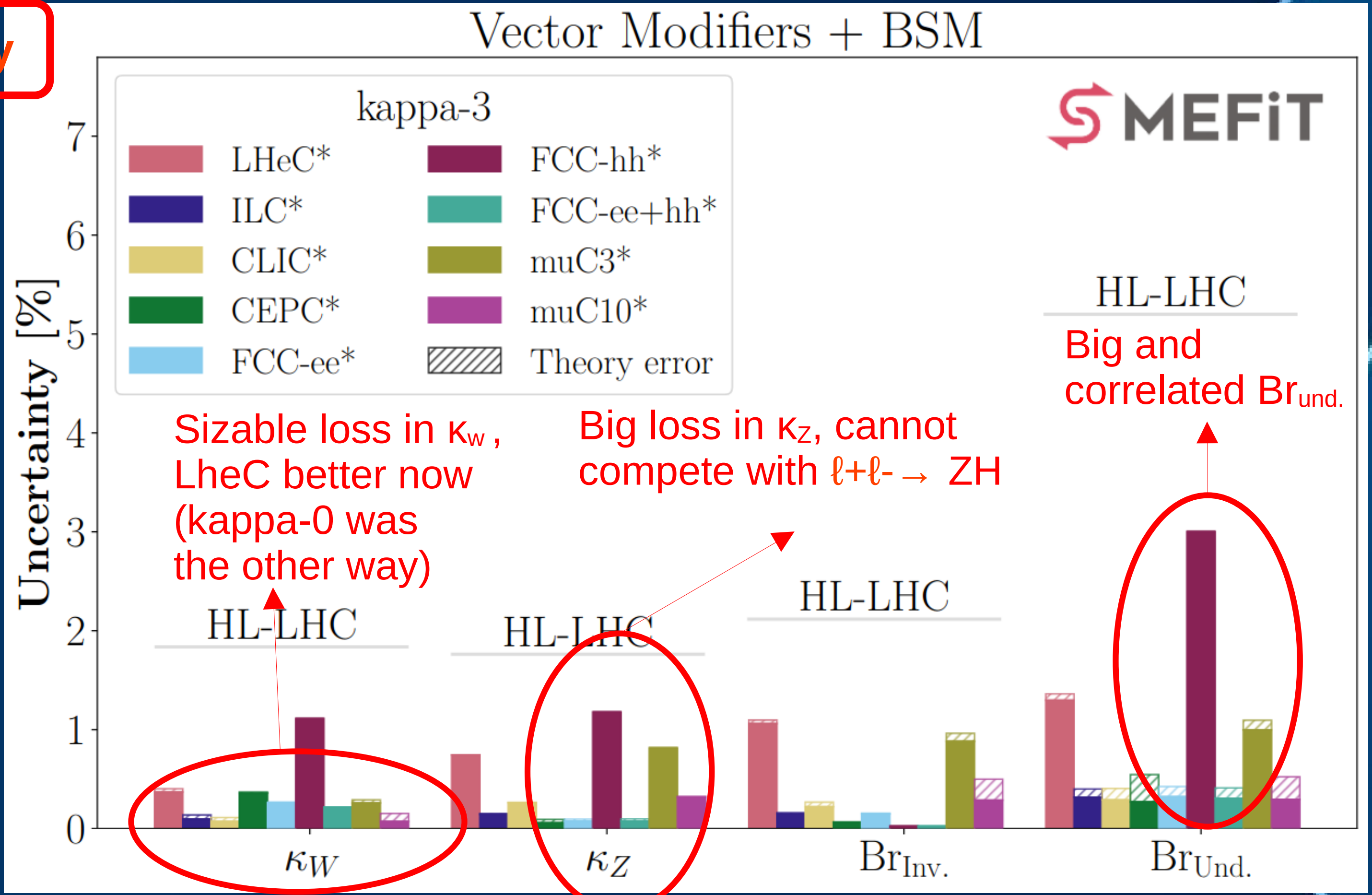


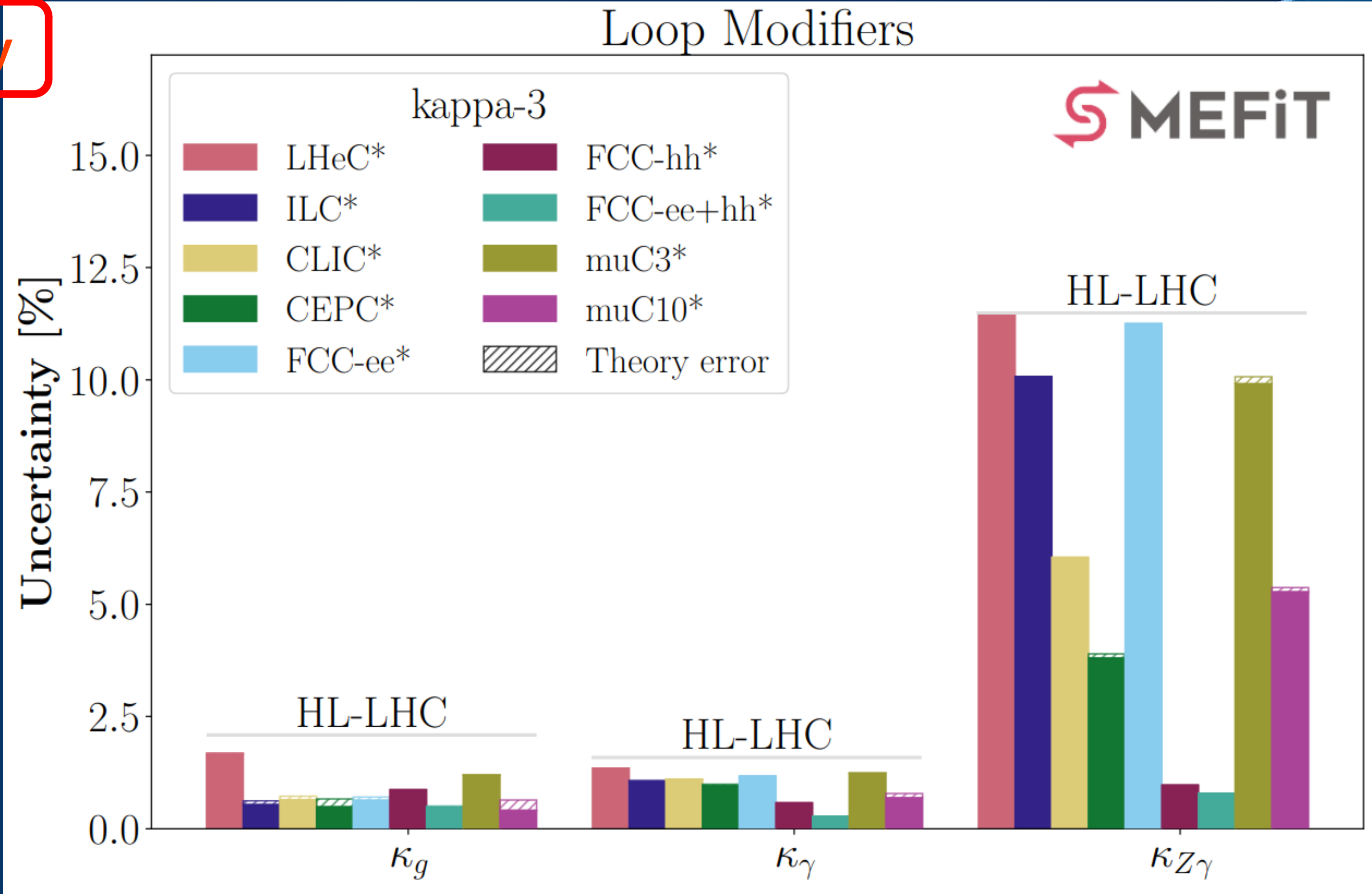
Sizable loss in κ_W, LheC better now (kappa-0 was the other way)

Big loss in κ_Z, cannot compete with $\ell^+\ell^- \to ZH$

Big and correlated $\mathrm{Br}_{\mathrm{und.}}$

Kappa-3

Preliminary



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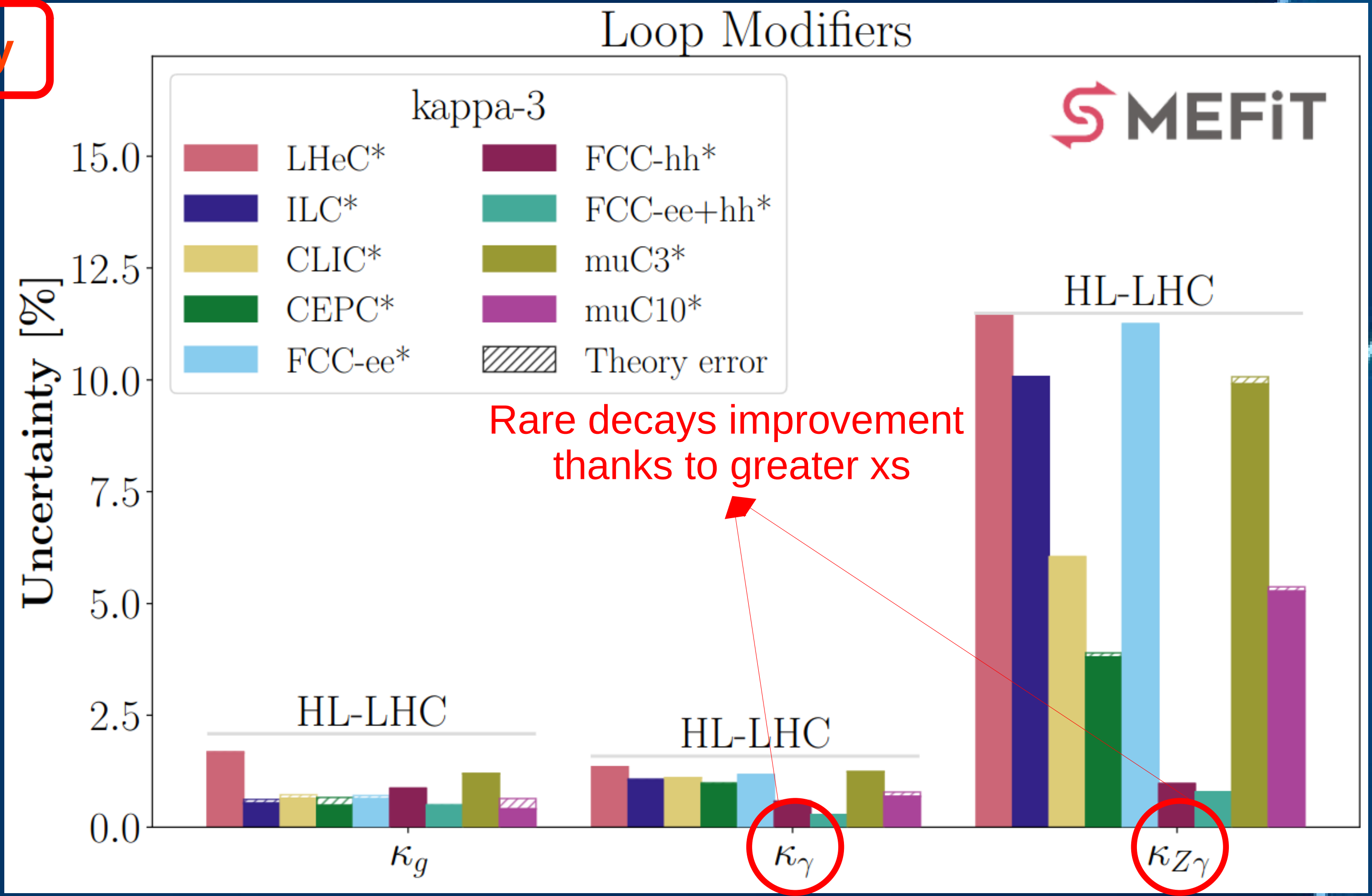
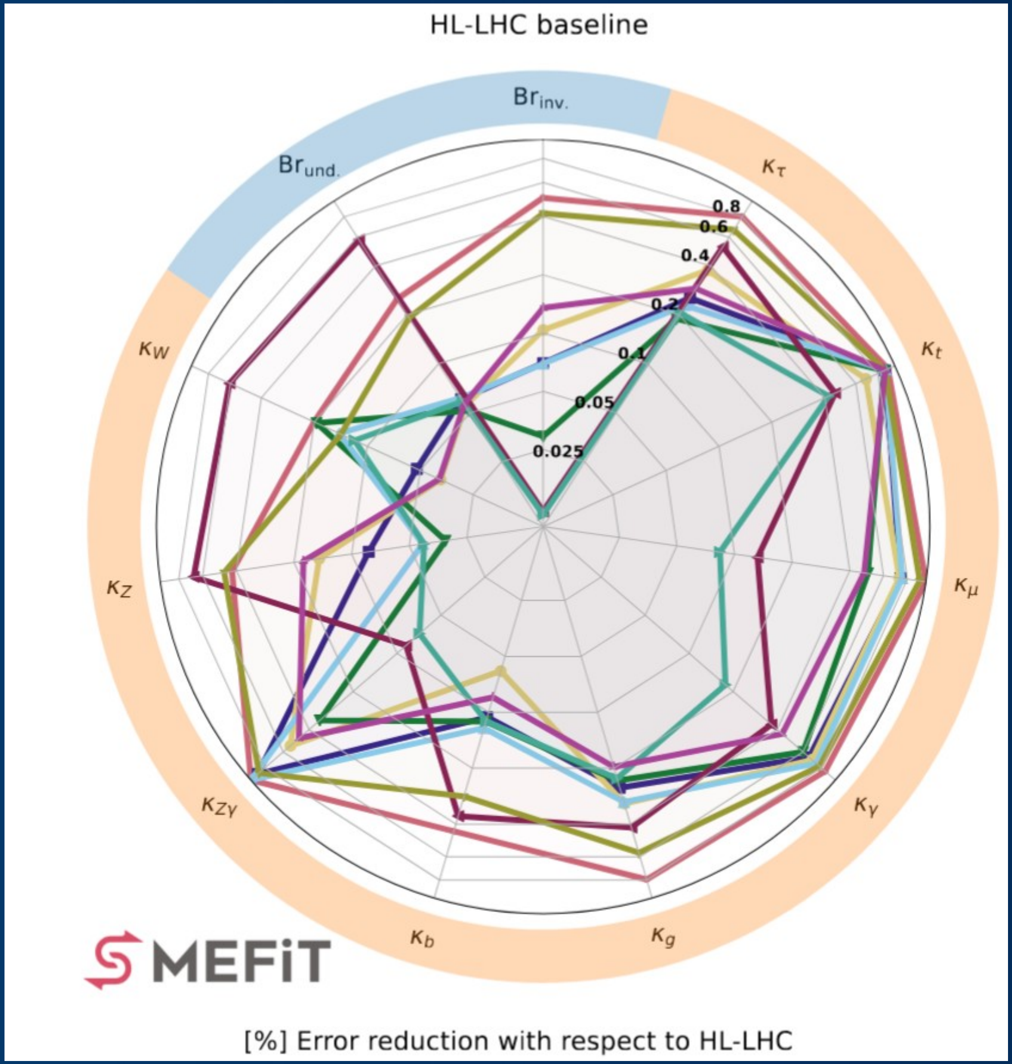
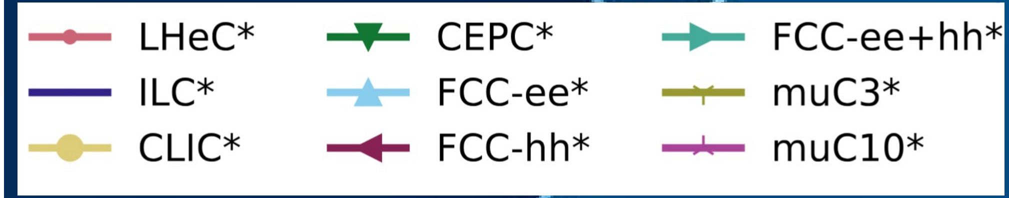
Kappa-3

Preliminary



LHeC effects





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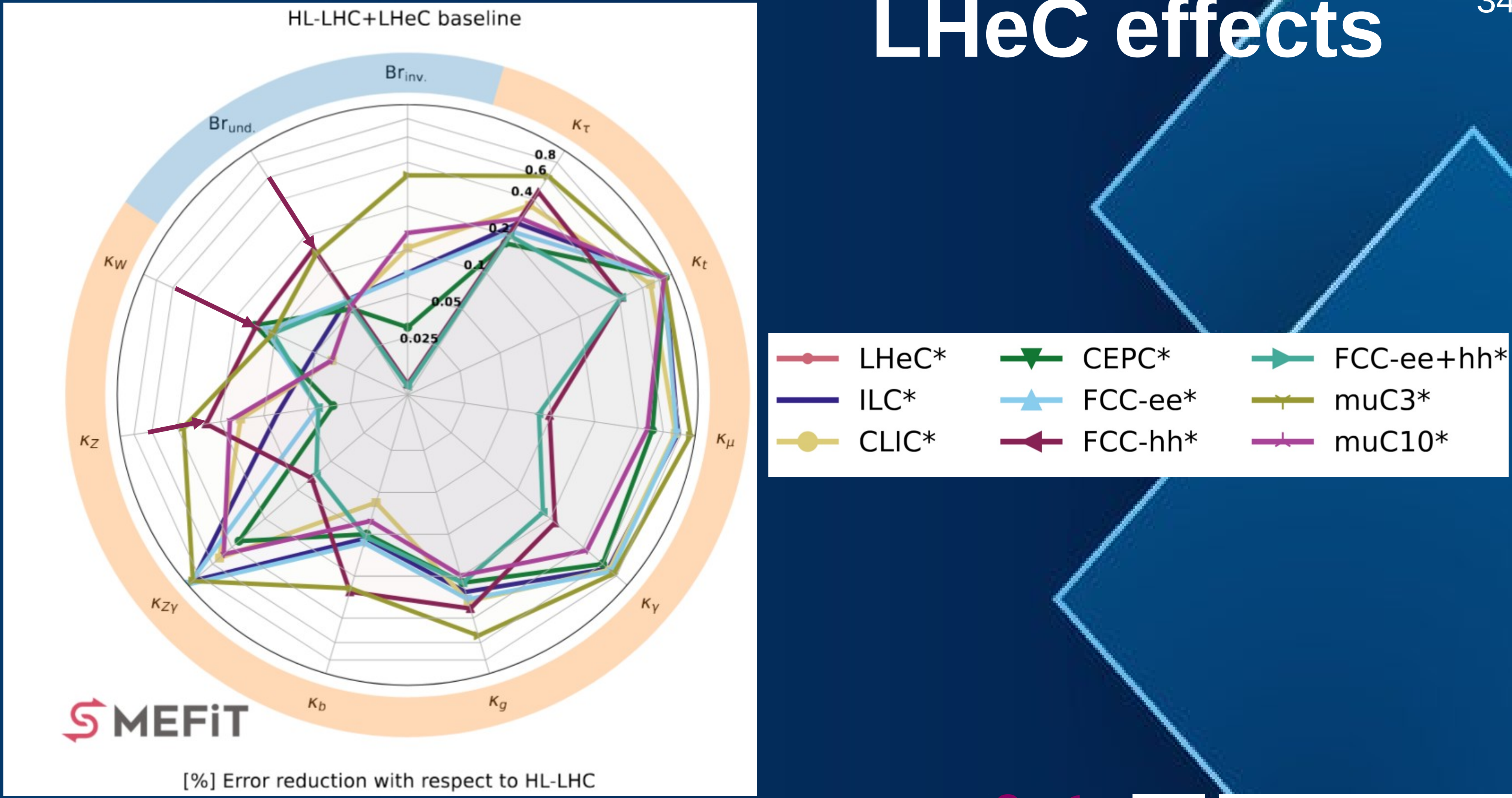

Summary and Conclusions

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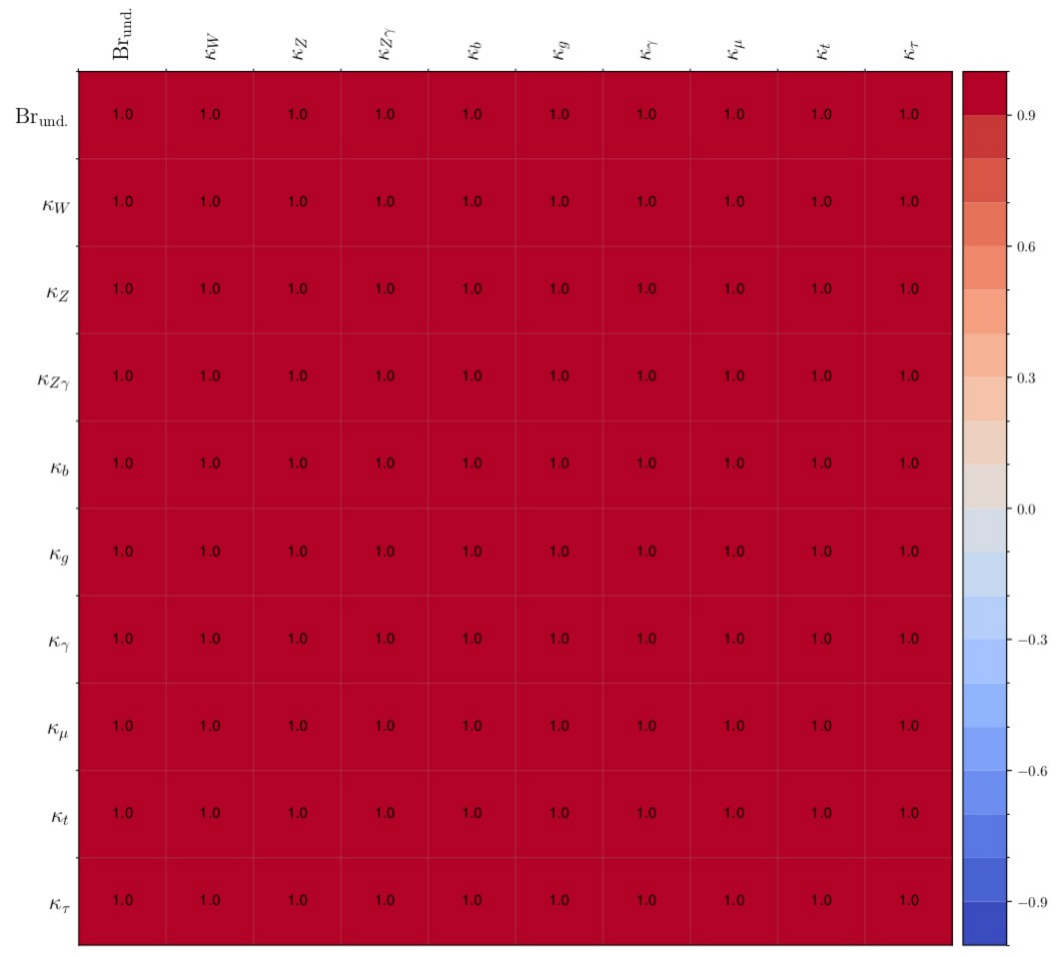
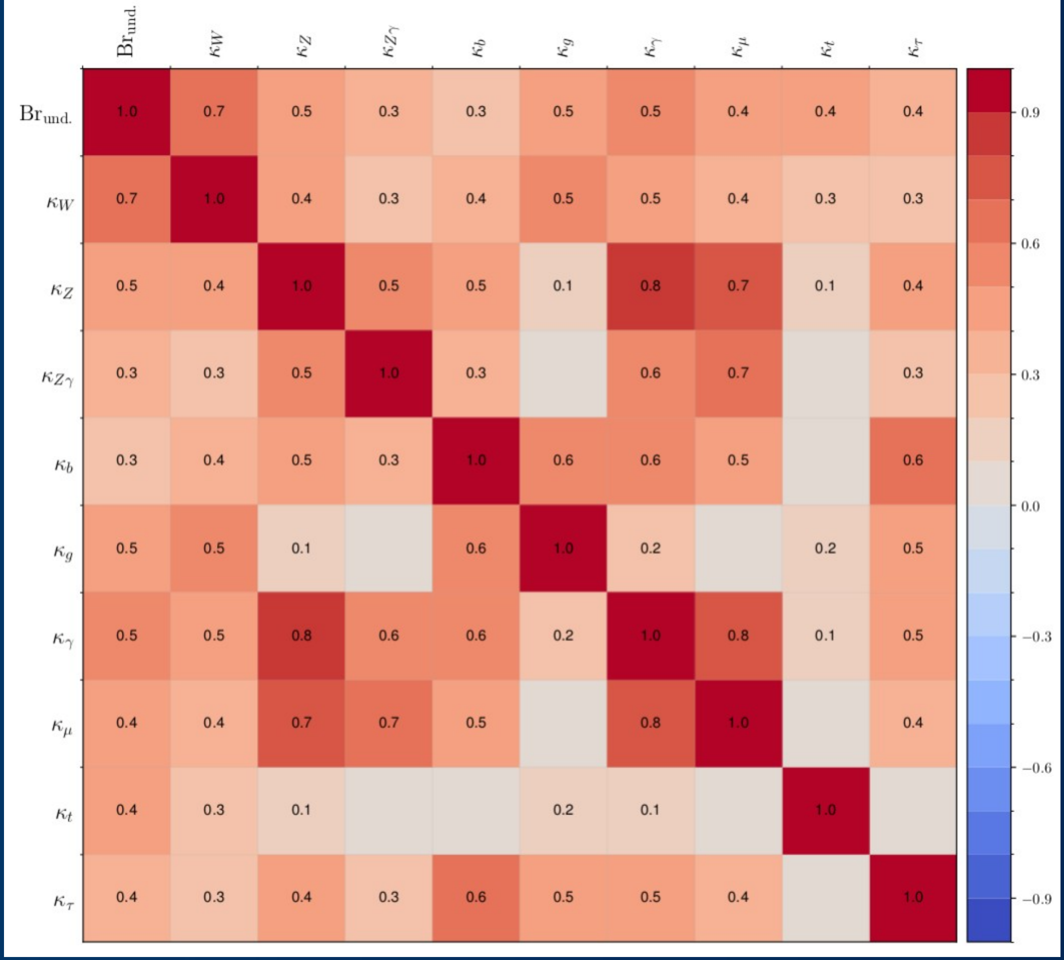
Thanks for the attention!

Backup

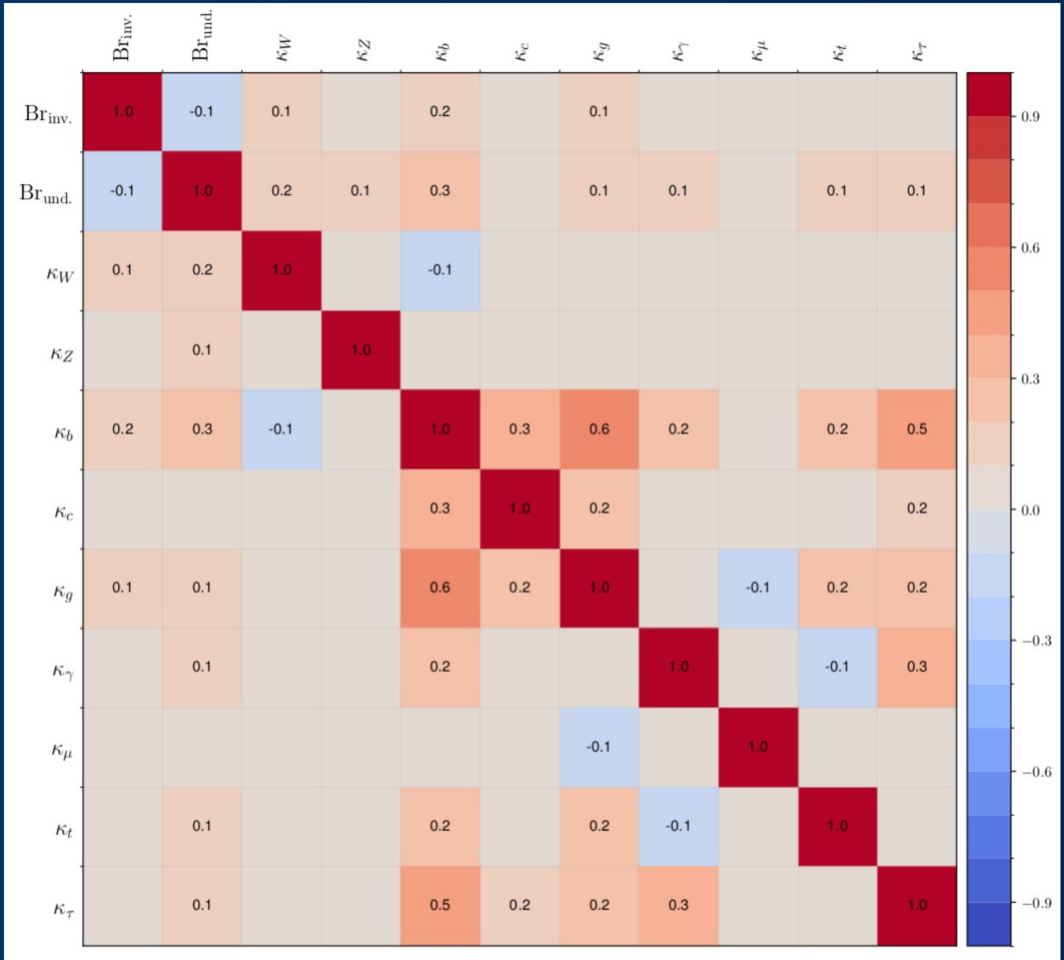
FCChh unconstrained



FCChh constrained



LheC correlations



Kappa0

			κ_W[%]	κ_Z[%]	κ_g[%]	κ_γ[%]	$\kappa_{Z\gamma}$[%]	κ_c[%]	κ_t[%]	κ_b[%]	κ_μ[%]	κ_τ[%]
HL-LHC		exp+th	1.6	1.5	2.2	1.8	11	-	2.6	3.5	5.3	2
LHeC		exp	0.74	1.2	3.6	7.5	-	4	-	2.1	-	3.3
		exp+th	0.78	1.2	3.6	7.5	-	4.1	-	2.2	-	3.3
ILC	250	exp	1.8	0.22	2.3	6.5	26	2.4	-	1.8	14	1.9
		exp+th	1.8	0.24	2.3	6.6	25	2.4	-	1.8	14	1.9
	500	exp	0.21	0.17	0.92	3.4	26	1.1	-	0.43	9.4	0.65
		exp+th	0.28	0.19	1	3.4	26	1.2	-	0.53	9.3	0.71
	1000	exp	0.13	0.16	0.58	1.9	26	0.7	-	0.29	6.1	0.51
		exp+th	0.18	0.18	0.69	2	26	0.78	-	0.39	6.1	0.56
CLIC	380	exp	0.77	0.43	2.1	-	-	4.6	-	1.6	-	2.9
		exp+th	0.83	0.45	2.2	-	-	4.5	-	1.6	-	2.9
	1500	exp	0.16	0.28	1.1	4.9	15	1.8	2.9	0.33	12	1.3
		exp+th	0.24	0.32	1.2	4.9	15	1.9	2.8	0.53	12	1.3
	3000	exp	0.1	0.26	0.82	2.2	6.9	1.3	2.8	0.18	5.6	0.87
		exp+th	0.16	0.31	0.91	2.2	6.9	1.3	2.8	0.36	5.6	0.88
CEPC	240	exp	0.57	0.074	0.7	1.6	4.3	1.1	-	0.56	3.3	0.6
		exp+th	0.77	0.11	1.1	1.8	4.2	1.4	-	0.83	3.3	0.82
	360	exp	0.33	0.071	0.5	1.5	4.1	1	-	0.33	3.1	0.38
		exp+th	0.46	0.1	0.81	1.6	4.1	1.2	-	0.54	3.2	0.54
FCC-ee	240	exp	0.9	0.11	1.1	3.2	-	1.2	-	0.88	6.8	0.93
		exp+th	0.93	0.14	1.3	3.3	-	1.3	-	0.96	6.9	0.97
	365	exp	0.28	0.091	0.7	2.7	-	0.82	-	0.37	6	0.47
		exp+th	0.3	0.12	0.81	2.7	-	0.95	-	0.45	6.1	0.49
FCC	hh	exp+th	0.44	0.73	0.84	0.63	1	-	1.3	1.1	0.79	1.2
	hh+ee	exp	0.23	0.089	0.51	0.28	0.78	0.81	1.2	0.33	0.44	0.41
		exp+th	0.24	0.12	0.55	0.3	0.8	0.93	1.2	0.4	0.46	0.43
muC 3000		exp	0.38	1.2	1.6	3.1	27	6.1	-	0.85	15	2.1
		exp+th	0.42	1.2	1.7	3.2	27	6.1	-	0.98	15	2.1
muC 10000		exp	0.11	0.34	0.45	0.82	6	1.8	-	0.23	2.8	0.59
		exp+th	0.21	0.41	0.73	0.94	6	1.9	-	0.53	2.9	0.63

Kappa universal

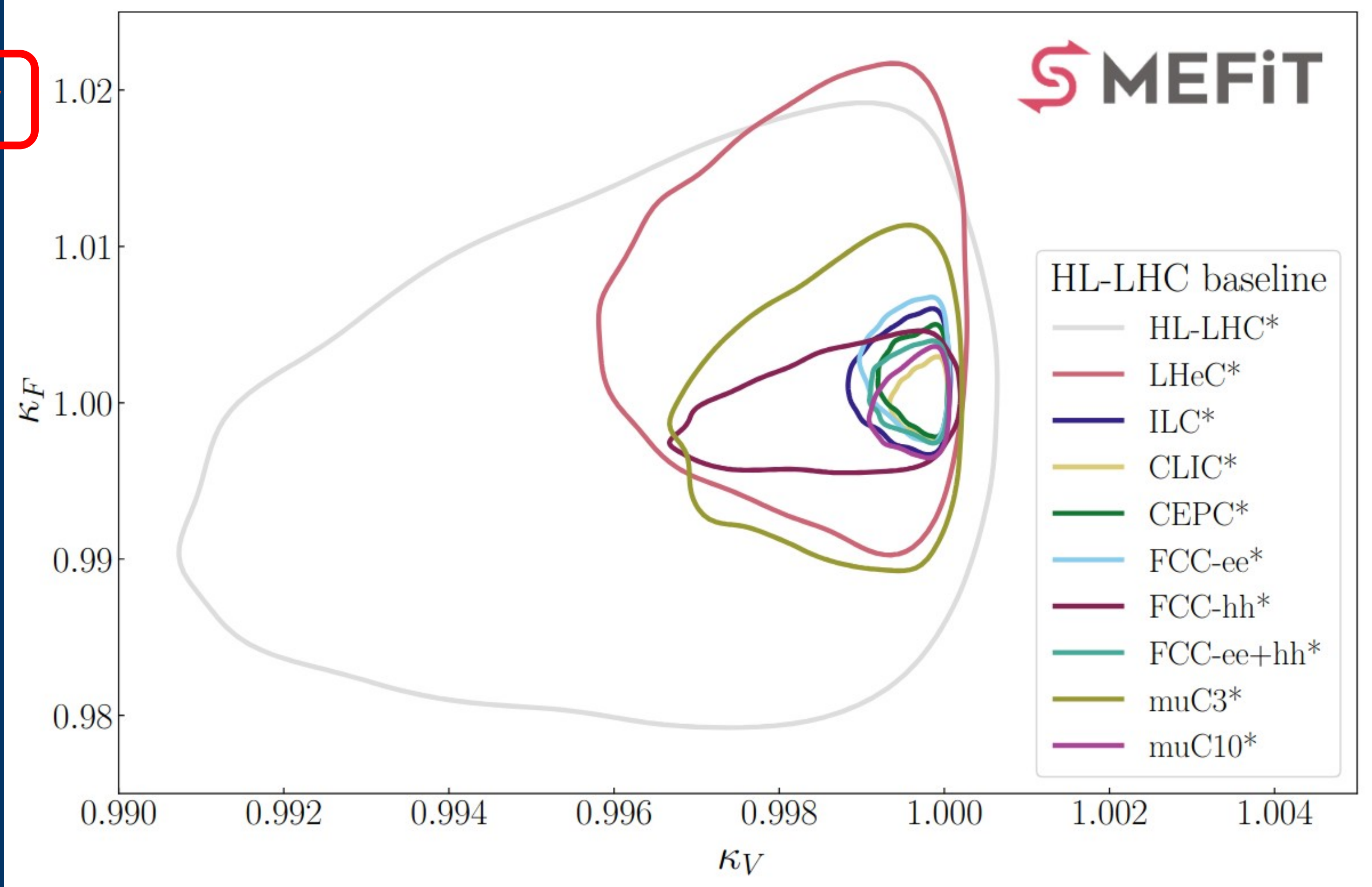
	$\kappa_{\text{univ.}}$ [%]		$\text{Br}_{\text{inv.}}$ [%]		$\text{Br}_{\text{und.}}$ [%]	
	Exp	Exp+Th	Exp	Exp+Th	Exp	Exp+Th
HL-LHC*	0.58		1.6		2.5	
LHeC*	0.22	0.25	0.87	1	1	1.2
ILC*	0.063	0.09	0.14	0.16	0.29	0.42
CLIC*	0.039	0.087	0.16	0.27	0.18	0.4
CEPC*	0.041	0.075	0.059	0.065	0.2	0.45
FCC-ee*	0.05	0.078	0.13	0.15	0.24	0.41
FCC-hh*	0.2		0.025		0.85	
FCC*	0.052	0.076	0.025	0.025	0.24	0.39
muC 3000*	0.19	0.23	0.82	0.93	0.9	1
muC 10000*	0.056	0.11	0.25	0.49	0.26	0.49

Fermion Vector modifiers

	$\kappa_F [\%]$		$\kappa_V [\%]$		$\mathrm{Br}_{\mathrm{inv.}} [\%]$		$\mathrm{Br}_{\mathrm{und.}} [\%]$	
	Exp	Exp+Th	Exp	Exp+Th	Exp	Exp+Th	Exp	Exp+Th
HL-LHC*	1.2		0.57		1.6		2.5	
LHeC*	0.93	0.96	0.25	0.28	0.97	1.1	1.1	1.3
ILC*	0.28	0.33	0.07	0.091	0.15	0.16	0.32	0.42
CLIC*	0.16	0.26	0.04	0.089	0.16	0.27	0.18	0.41
CEPC*	0.21	0.33	0.049	0.074	0.062	0.066	0.24	0.46
FCC-ee*	0.29	0.37	0.061	0.078	0.14	0.15	0.31	0.42
FCC-hh*	0.28		0.2		0.025		0.87	
FCC*	0.19	0.22	0.058	0.078	0.025	0.025	0.28	0.4
muC 3000*	0.66	0.71	0.2	0.23	0.83	0.93	0.91	1
muC 10000*	0.21	0.33	0.056	0.11	0.26	0.51	0.26	0.53

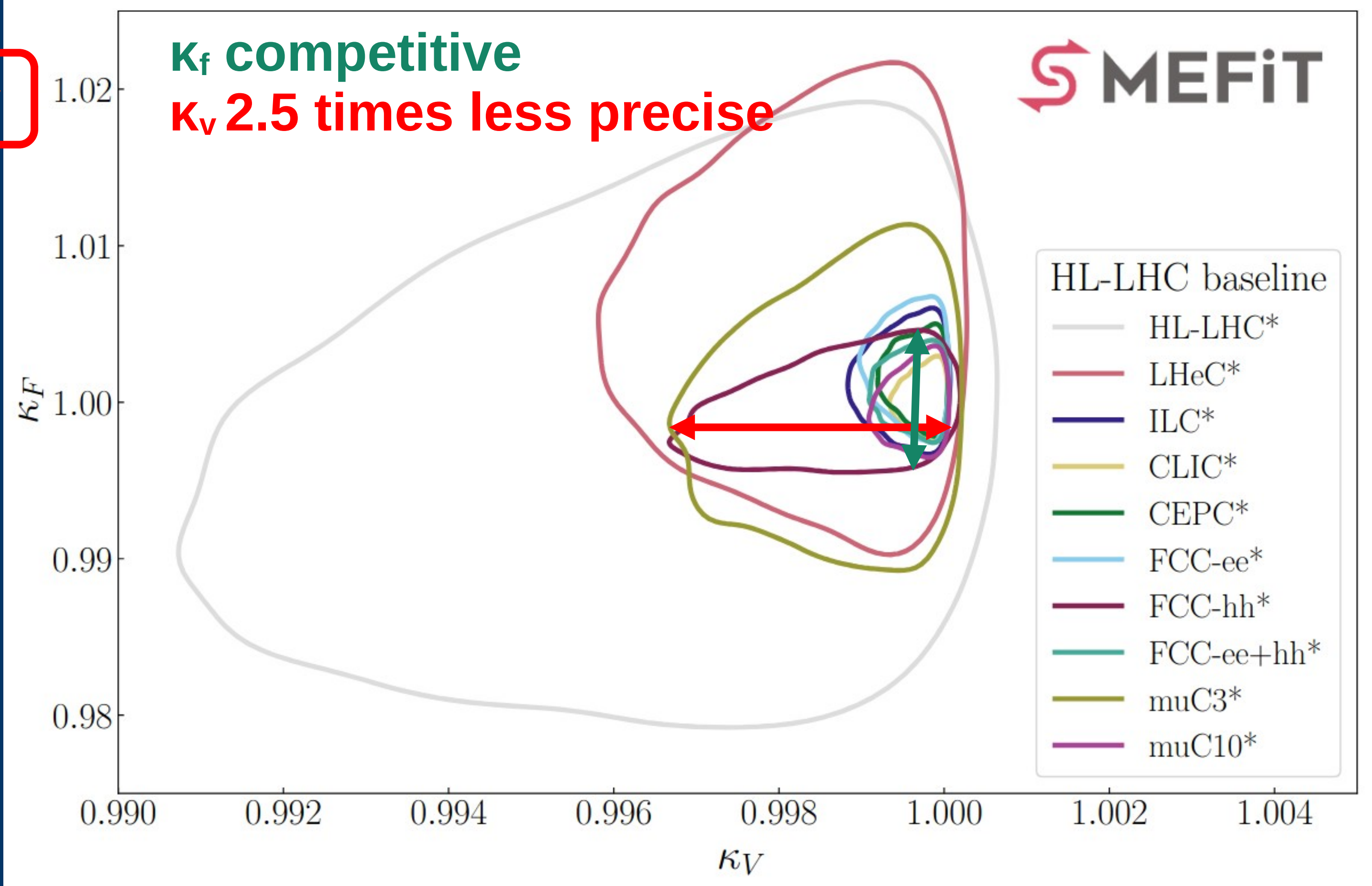
Fermion Vector modifiers

Preliminary



Fermion Vector modifiers

Preliminary



kappa3

			κ_W	κ_Z	κ_g	κ_γ	$\kappa_{Z\gamma}$	κ_c	κ_t	κ_b	κ_μ	κ_τ	$\mathrm{Br}_{\mathrm{inv.}}$	$\mathrm{Br}_{\mathrm{und.}}$
HL-LHC*		exp+th	1.8	1.8	2.1	1.6	11	-	2.6	2.7	5.3	1.9	2.1	5.2
LHeC*		exp	0.37	0.74	1.7	1.4	11	3.7	2.4	1.2	5.3	1.5	1.1	1.3
		exp+th	0.4	0.74	1.7	1.3	11	3.8	2.5	1.3	5.5	1.5	1.1	1.4
ILC*	250	exp	0.89	0.17	1.2	1.3	10	1.8	2.4	0.85	4.9	0.93	0.19	0.8
		exp+th	0.9	0.19	1.2	1.3	9.9	1.8	2.3	0.9	5	0.93	0.19	0.9
	500	exp	0.17	0.15	0.8	1.2	10	1.1	2.3	0.41	4.5	0.59	0.16	0.45
		exp+th	0.23	0.16	0.85	1.2	10	1.2	2.3	0.49	4.7	0.62	0.17	0.54
	1000	exp	0.096	0.14	0.53	1.1	10	0.7	2.3	0.28	3.9	0.48	0.15	0.32
		exp+th	0.14	0.15	0.62	1.1	10	0.76	2.3	0.35	4	0.5	0.16	0.4
CLIC*	380	exp	0.56	0.31	1.4	1.3	11	4.4	2.4	1.1	5.3	1.5	0.37	1.3
		exp+th	0.57	0.32	1.4	1.3	11	4.4	2.4	1.1	5.3	1.4	0.37	1.3
	1500	exp	0.12	0.26	0.88	1.2	8.8	1.8	1.8	0.32	4.8	0.95	0.27	0.45
		exp+th	0.16	0.27	0.93	1.3	8.9	1.8	1.8	0.45	4.8	0.97	0.31	0.56
	3000	exp	0.07	0.26	0.65	1.1	6	1.3	1.8	0.16	3.9	0.71	0.22	0.29
		exp+th	0.11	0.26	0.72	1.1	5.8	1.3	1.8	0.28	3.8	0.72	0.27	0.4
CEPC*	240	exp	0.54	0.057	0.55	1	4	1.1	2.3	0.39	2.8	0.43	0.064	0.28
		exp+th	0.57	0.095	0.75	1	4	1.2	2.3	0.52	2.8	0.48	0.067	0.66
	360	exp	0.36	0.057	0.49	0.95	3.8	1	2.3	0.3	2.6	0.35	0.062	0.27
		exp+th	0.37	0.091	0.67	0.99	3.9	1.1	2.3	0.43	2.7	0.41	0.067	0.55
FCC-ee*	240	exp	0.67	0.079	0.79	1.2	11	0.93	2.3	0.49	4.1	0.56	0.17	0.4
		exp+th	0.66	0.12	0.9	1.2	11	1.1	2.3	0.62	4.1	0.61	0.19	0.72
	365	exp	0.26	0.075	0.64	1.2	11	0.82	2.3	0.33	4	0.43	0.15	0.32
		exp+th	0.24	0.095	0.7	1.2	11	0.91	2.3	0.41	3.9	0.44	0.15	0.42
FCC*	hh	exp+th	1.1	1.2	0.87	0.58	0.98	-	1.2	0.97	0.7	0.99	0.025	3
	hh+ee	exp	0.22	0.074	0.47	0.28	0.79	0.8	1.1	0.3	0.45	0.39	0.024	0.31
		exp+th	0.21	0.096	0.51	0.28	0.77	0.89	1.1	0.37	0.44	0.4	0.025	0.41
muC 3000*		exp	0.26	0.82	1.2	1.2	9.9	5.9	2.3	0.76	4.9	1.3	0.88	1
		exp+th	0.29	0.81	1.2	1.2	10	5.9	2.4	0.83	4.9	1.3	0.96	1.1
muC 10000*		exp	0.071	0.32	0.41	0.69	5.3	1.7	2.3	0.22	2.5	0.54	0.29	0.29
		exp+th	0.15	0.32	0.64	0.78	5.4	1.8	2.3	0.4	2.5	0.57	0.5	0.52