EF04: EW Precision Physics and constraining new physics

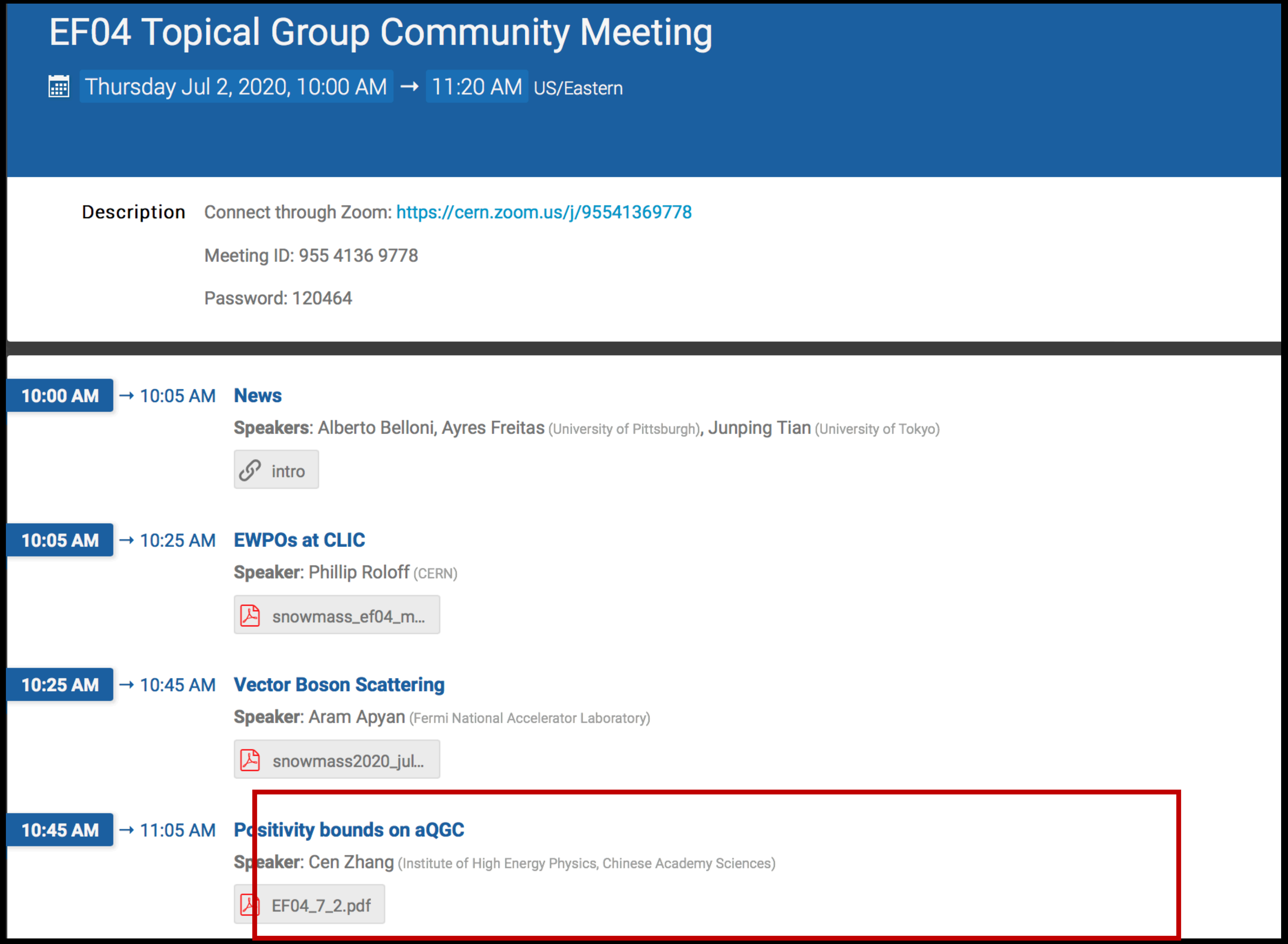
Zhijun Liang
(IHEP, Chinese Academy of Sciences)

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

EF04: status

- ➢ Two internal meetings.
- ➢ Presented two talks in snowmass EF04
  - ➢ https://indico.fnal.gov/category/1138/

Talk in EF04 snowmass meeting



- ➢ **https://indico.fnal.gov/category/1138/**

Internal meeting (July 03)

https://indico.ihep.ac.cn/category/719/

Plan for Snowmass EF04 LOIs contribution

- More detailed study of 2~3 benchmark electroweak observables (Siqi …)
  - Eg: weak mixing angle from Z->bb,Z->ll backward-forward asymmetry
  - More study with more realistic simulations
  - More detailed study on experimental and theory systematics
- Z->bb branching ratio (Bo Li)
- High order EWK calculation (NNLO EWK corrections)
  - Already setup connection between Zhao Li and EF04 conveners
- aTGCs/QGCs in WW events (Jiayin,LingFeng, Dan …)
- Unitarity bounds in aQGCs (Cen Zhang)
- Please consider to join us and write down your topics in QQ docs

https://docs.qq.com/sheet/DR1NXTXp6V2JkR1NH?tab=m0d77k

EF04	EW Precision Physics and constraining new physics	
EF04.1	WW process	Junmou Chen
EF04.2	TGC (remark: Jet can be measured to energy resolution of 4%, direction resolution of 1%)	
EF04.3	Afb(b) — sin^2(theta_W) (remark: Jet Charge Measurement)	
EF04.4	NNLO EW correction to HZ production	Zhao Li

Measuring Higgs couplings with longitudinal external states.

- Measure Higgs coupling by probing longitudinal polarization of W/Z boson
- Mainly in HL-LHC and may look into CPEC ZH->WW

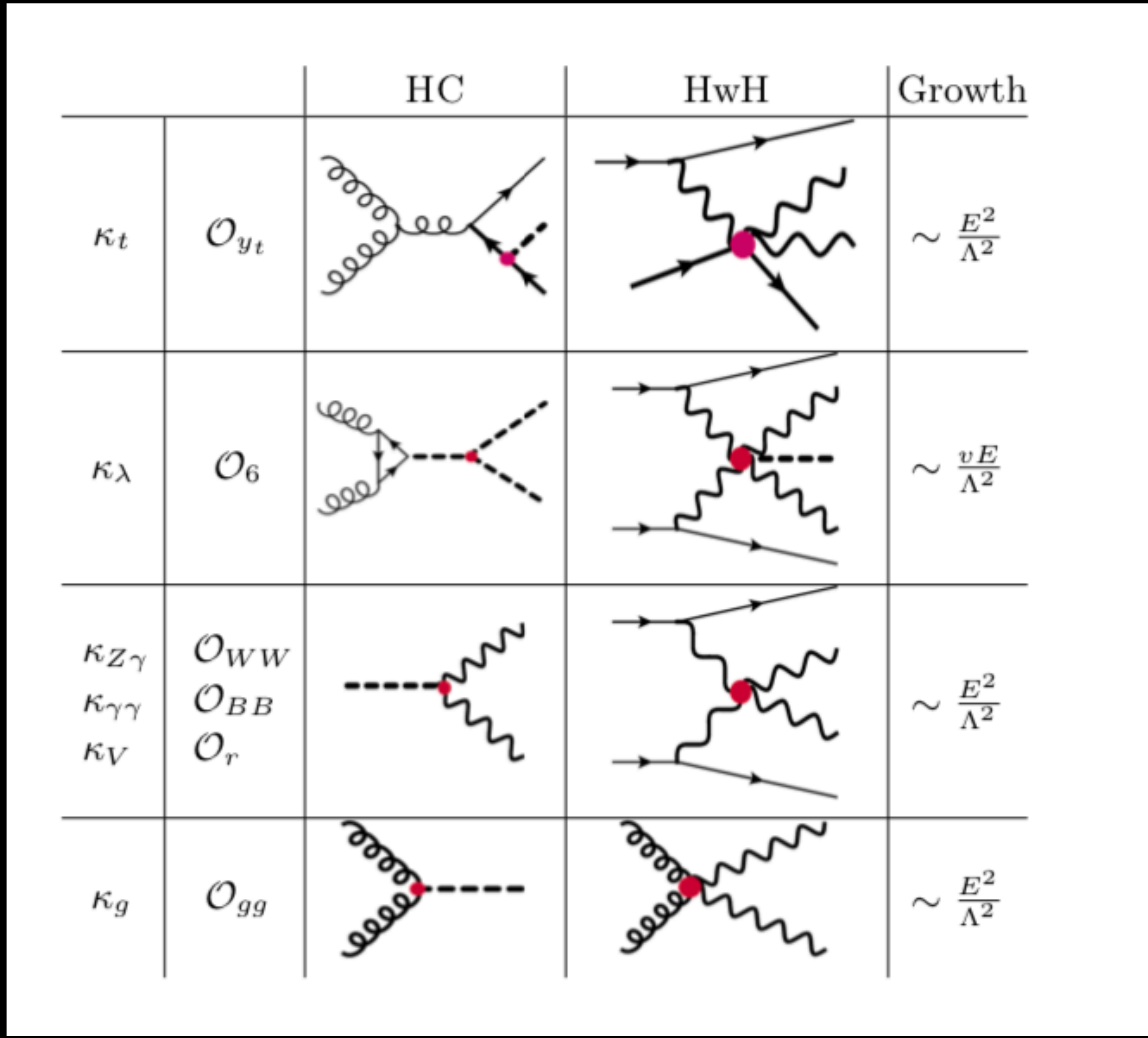
By Dr. Junmou Chen (KIAS)

1812.09299

Higgs Couplings without the Higgs

Brian Henning, Davide Lombardo, Marc Riembau, and Francesco Riva
Départment de Physique Théorique, Université de Genève,
24 quai Ernest-Ansermet, 1211 Genève 4, Switzerland

$$\kappa_t : pp \to jt + V_L V_L' \quad (4)$$
$$(e^+e^- \to ll + \{tbW_L, tbZ_L, ttW_L, ttZ_L\})$$
$$\kappa_\lambda : pp \to jjh + V_L V_L', \ (e^+e^- \to llhV_L V_L') \quad (5)$$
$$pp \to jj + 4V_L, \ (e^+e^- \to ll\,4V_L) \quad (6)$$
$$\kappa_{\gamma\gamma, Z\gamma} : pp \to jj + V'V, \ (e^+e^- \to llV'V) \quad (7)$$
$$\kappa_V : pp \to jj + V_L V_L', \ (e^+e^- \to llV_L V_L') \quad (8)$$
$$\kappa_g : pp \to W_L^+ W_L^-, Z_L Z_L, \ (e^+e^- \to lljj) \quad (9)$$



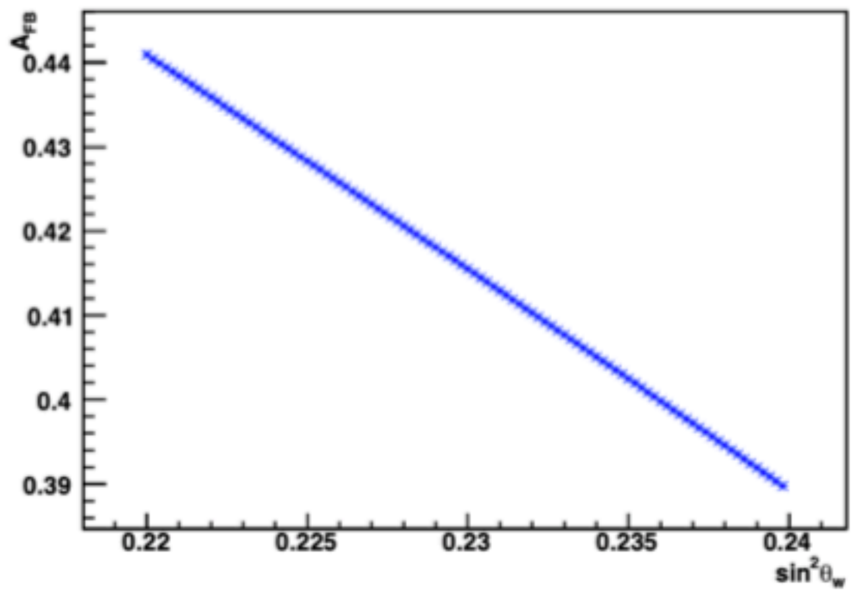
Weak mixing angle measurement at Z pole $\sin^2\theta_{eff}$ and A_{FB}

A first estimation on CEPC asymmetry measurement

- Total uncertainty of $\sin^2\theta_{eff}$ can easily be at 0.00001 level, for each single final state (except light quar finals)
- Which means an accurate flavor comparison is possible
- Energy-running $\sin^2\theta_W$ measurement can be achieved at heavy quark channels (uncertainty / running effect ~ 1/3 or 1/4)
- Better give more time running on off Z pole point

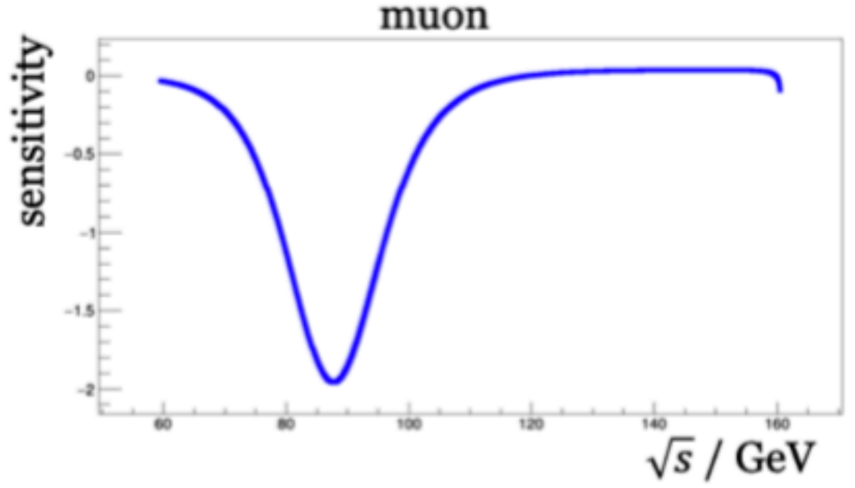
By Dr. Siqi Yang (USTC)

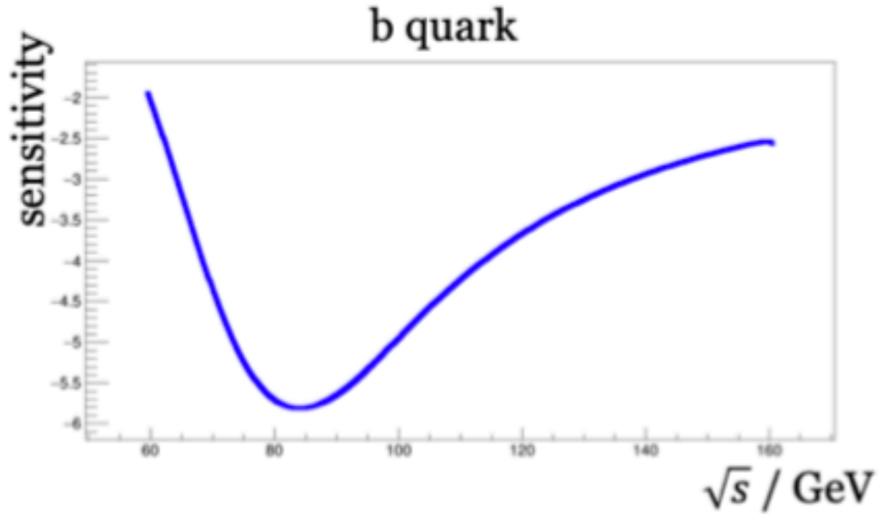
A_{FB} has roughly a linear relationship to $\sin^2\theta_{eff}$. Right plot is the average A_{FB} at Z pole, as a function of $\sin^2\theta_{eff}$ for e+e- → Z → uubar events, for example.



This relationship, or sensitivity of AFB to $\sin^2\theta_{eff}$, depends on collision energy and particle flavors

$$\text{sensitiviy} = \frac{\Delta \sin^2 \theta^{\ell}_{\text{eff}}}{\Delta A_{FB}}$$





Systematics

Collision Energy	70 GeV	75 GeV	91.18 GeV	115 GeV	130 GeV	155 GeV
$\sin^2\theta_{eff}$ in prediction	0.23140	0.23136	0.23123	0.23128	0.23136	0.23152
statistical uncertainty	0.00042	0.00019	0.00001	0.00328	0.00636	0.00796

Weak mixing angle measurement at Z pole $\sin^2\theta_{eff}$ and A_{FB}

Snowmass2021 - Letter of Interest

Measurement of the leptonic effective weak mixing angle at CEPC

Thematic Areas: (check all that apply □/■)

- □ (EF01) EW Physics: Higgs Boson properties and couplings
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- □ (Other) *[Please specify frontier/topical group]*

Contact Information:
Name (Institution) [email]: Siqi YANG (University of Science and Technology of China)
Collaboration (optional):

Authors:
Manqi Ruan, Siqi Yang, Zhenyu Zhao, Liang Han

Abstract:
We present a study of the measurement of the leptonic effective weak mixing angle, $\theta^{\ell}_{\text{eff}}$, at CEPC. Taking the advantage of the CEPC's high luminosity, the relative precision of $\sin^2\theta^{\ell}_{\text{eff}}$ can be at least one order of magnitude better than $\mathcal{O}(0.1\%)$ which has been achieved at LEP, SLC and Tevatron. It will be the first time that experimental observation and the standard model theoretical calculation on the Z pole electroweak symmetry breaking can be directly compared at two-loop level. CEPC can also provide a $\mathcal{O}(0.1\%)$ precision on the comparison between $\sin^2\theta^{\ell}_{\text{eff}}$ from different decay channels, including muon and electron, τ, heavy quarks (b and c), and light quarks (u and d). Besides, $\sin^2\theta^{\ell}_{\text{eff}}$ can be measured at off-pole energy points, providing direct observations on the running effect of $\sin^2\theta^{\ell}_{\text{eff}}$.

I. Motivation and introduction

The leptonic effective weak mixing angle is the key parameter in the electroweak global fitting. It is important not only to the standard model global fitting, but also predictions in potential new physics. It is defined as an effective parameter which could absorb standard model or beyond standard model higher order effects. The experimental precisions of the $\sin^2\theta^{\ell}_{\text{eff}}$ measurements at the Z mass pole region are at $\mathcal{O}(0.1\%)$ level, including 0.23221 ± 0.00029 from the LEP combined $e^+e^- \to b\bar{b}$ results, 0.23098 ± 0.00026 from the SLC $e^+e^- \to e^+e^-$ polarization asymmetry observation, and 0.23179 ± 0.00033 from the combined D0 and CDF measurements, dominated by the light quark $q\bar{q} \to \ell^+\ell^-$ processes [1;2]. The theoretical uncertainty on $\sin^2\theta^{\ell}_{\text{eff}}$ can be reduced to 0.00005 around Z pole by performing complete two-loop level calculations [3]. As a conclusion, the $\sin^2\theta^{\ell}_{\text{eff}}$ related global fittings are now limited by the experimental precision in the past two decades. By the discovery of the Higgs boson in 2012, all parameters in the standard model predictions are experimentally fixed. As direct new physics searches have been going on for almost 10 years at the Large Hadron Collider but no obvious clue found, precise comparison between experiment and theoretical results in the global fitting becomes important. This requires significant improvements on the experimental measurements on $\sin^2\theta^{\ell}_{\text{eff}}$.

CEPC is an ideal collider to provide high precision measurements on $\sin^2\theta^{\ell}_{\text{eff}}$. It is planning a two-year run period around the Z pole, which can generate $3\sim6\times10^{11}$ single Z boson events. With such a large data sample, the statistical uncertainty, which is the dominant uncertainty in the LEP and SLC measurement, we can easily reduce the statistical uncertainty around 0.00001 on $\sin^2\theta^{\ell}_{\text{eff}}$. High precisions can be achieved independently in different decay channels, including muon and electron, τ, light quarks (u and d), and heavy quarks (b and c). The comparison channels is part of the standard model global test. The running effect on the translated $\sin^2\theta_W$ as a function of the energy scale is another physics interest. By now, there is no direct weak mixing angle measurement at an energy scale higher than the Z pole region. It would be very important to experimentally test the theoretical prediction that $\sin^2\theta_W$ would run to a higher value as the energy scale goes up.

LHC also has possibility to achieve a high precision on $\sin^2\theta^{\ell}_{\text{eff}}$, but would be very difficult. Uncertainties from parton distribution functions which models the initial state quark momentum are at $\mathcal{O}(0.1\%)$ level with respect to the $\sin^2\theta^{\ell}_{\text{eff}}$ value. Systematic uncertainties under high instantaneous luminosity collisions are expected to be same large with that from PDFs. In general, trying to measure $\sin^2\theta^{\ell}_{\text{eff}}$ at hadron colliders requires a series of long term studies. Besides, hadron colliders could not provide direct observations on τ and heavy quark couplings.

As a conclusion, CEPC could bring a relative precision of $\sin^2\theta^{\ell}_{\text{eff}}$ at $\mathcal{O}(0.01\%)$ level, and at $\mathcal{O}(0.1\%)$ level for comparison between different channels and for observation on the energy running effect.

II. Measurements and Expected precisions

The effective weak mixing angle can be observed from the forward-backward asymmetry (A_{FB}) via the $e^+e^- \to Z/\gamma^* \to f\bar{f}$ process. A_{FB} is defined as:

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B} \tag{1}$$

Weak mixing angle measurement at Z pole $\sin^2\theta_{eff}$ and A_{FB}

where N_F and N_B represent the number of forward events, defined as those events having final state fermions along the direction of the e^- beam, and the number of backward events, defined as those having final state fermions along the direction of the e^+ beam. Around Z pole, $\sin^2\theta^{\ell}_{\text{eff}}$ and A_{FB} has approximately a linear relationship. The statistical uncertainty of the $\sin^2\theta^{\ell}_{\text{eff}}$ extracted from A_{FB} can be expressed as:

$$\Delta \sin^2\theta^{\ell}_{\text{eff}}(\text{stat.}) = \sqrt{\frac{1 - A_{FB}^2}{N \times \epsilon}} \times \frac{\sqrt{1 - 2f + f^2}}{1 - 2f} \times S \qquad (2)$$

where S is the slope of the $\sin^2\theta^{\ell}_{\text{eff}}$-$A_{FB}$ linear relationship representing the sensitivity, N is the total number of forward and backward events, ϵ is the overall efficiency of observing an event, and f is the probability of wrongly identifying the charge of the final state fermions. Systematics comes from the determination on ϵ and f, which could be very precision at lepton colliders. Even for those LEP measurements including both lepton and b quark channels, such uncertainties are negligible compared to the statistical uncertainty. Theoretical uncertainties comes from the calculation of S.

By the above discussions, we provide a preliminary estimation on the Z pole region in Table. 1. Note that the uncertainty corresponds to a one month data sample at CEPC.

channels	low mass measurement at 75 GeV	Z pole measurement at 91.19 GeV	high mass measurement at 130 GeV
lepton decay channel uncertainty	0.00017	0.00001	0.006
b quark channel uncertainty	0.00009	<0.00001	0.00016

Table 1: Expected uncertainty on $\sin^2\theta^{\ell}_{\text{eff}}$ with 1 month data collection in different channels and at different energy points.

R^b measurements

- R^b measurement is sensitive to New physics models (SUSY)
  - Very interesting about physics implication from Z->bb measurements
  - Ayres Freitas would like to follow up on that
- Systematics: b tagging efficiency hemisphere correlationshigh
  - Feedback: Need input from QCD experts
  - Feedback: better to avoid extrapolation from LEP, try standalone estimation from CEPC simulation.

The R_b measurement in the Z hadronic decay on the CEPC*

Bo Li(李波)[1;1)] Zhi-Jun Liang(梁志均)[2;2)] Bo Liu(刘波)[2]

[1] College of Nuclear Equipment and Nuclear Engineering, Yantai University, Yantai, Shandong 264005, China
[2] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China

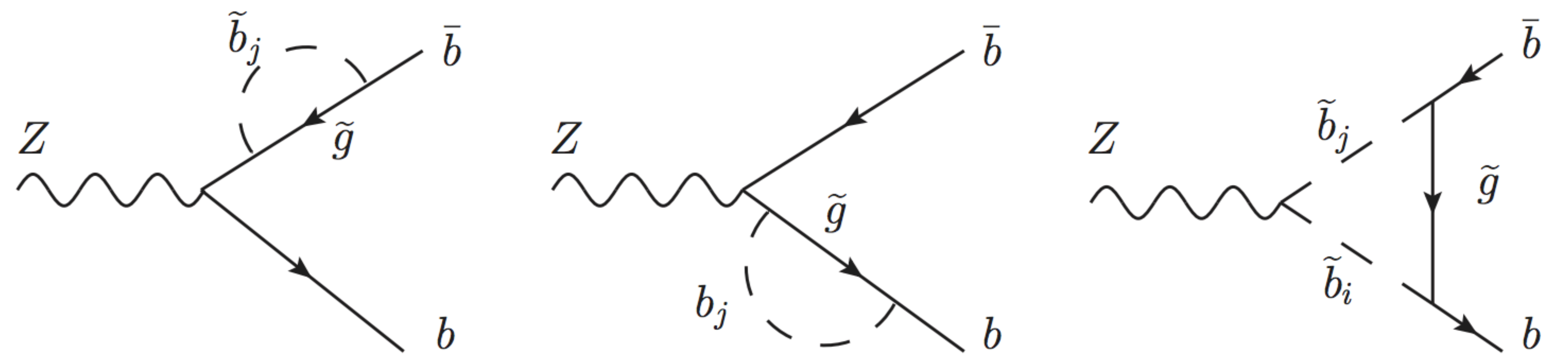

FIG. 1: One-loop Feynman diagrams of gluino correction to $Z \to \bar{b}b$

Bo Li (Yantai U.)
Zhijun, Bo Liu(IHEP)

Arxiv:1601.07758v2

R^b measurements

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[Measurement of R_b in hadronic Z decays at the CEPC]

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Contact Information:
Name (Institution) [email]: Bo Li (Yantai University) [boli@ytu.edu.cn]
Collaboration (optional):

Authors: Zhijun Liang, Bo Li, Bo Liu

Abstract: With an integrated luminosity of 45 ab^{-1} at $\sqrt{s} = 91.2\text{GeV}$, more than 10^{12} Z bosons will be produced at the Circular Electron Positron Collider (CEPC). As a real Z boson factory, the precise study of Z boson physics can be achieved. The relative partial width, R_b, of Z boson into b quarks is measured on the CEPC Monte Carlo (MC) level. Based on the latest CEPC detector concept, the Z hadronic decay channel is simulated and reconstructed by the CEPC software framework. By using the double-tagging method, R_b can be solved from several equations referring to the ratios of b-tagged jet hemispheres in Z hadronic events. With the high performance of the b-tagging algorithm for CEPC, the precision of R_b measurement can be improved accordingly.

1 Introduction

The Circular Electron Positron Collider (CEPC) is one of the next-generation e^+e^- colliders, that have been proposed to perform precision measurements of the Higgs boson properties. The CEPC will be hosted in China with a circumference of 100 km and two interaction points(IP)[1]. By operating at $\sqrt{s}$ = 240GeV, the CEPC is expected to produce approximately 10^6 Higgs bosons with an integrated luminosity of 5.6 ab^{-1} in about 7 years. The CEPC will also produce about more than 10^{12} Z bosons in about 2 years with an expected integrated luminosity of 45 ab^{-1} at $\sqrt{s} = 91.2\text{GeV}$[1]. With the high statistics of Z bosons, high-precision electroweak measurements of the Z boson properties can be achieved, such as the R_b measurement.

The relative decay width of $Z \to b\bar{b}$ in hadronic Z decays, $R_b = \Gamma(Z \to b\bar{b})/\Gamma(Z \to \text{hadrons})$, is a sensitive electroweak parameter to test the Standard Model (SM) and find new physics[2–4]. For example, the existence of stop-quarks or charginos in supersymmetry can result in a deviation between the measured R_b and the one in the SM[5]. The LEP and SLD collaborations have made accurate measurements of the R_b[6–10] with a combined value of $R_b = 0.21629 \pm 0.00066$[11]. The measurement of R_b at the CEPC is expected to be more precise owing to its high statistics of the Z boson and high performance of the b-tagging.

2 Monte Carlo simulation

The CEPC conceptual detector, following the Particle Flow Algorithm (PFA)[16], is composed of a silicon pixel vertex detector, a silicon tracking system, a TPC, an electromagnetic calorimeter and a hadronic calorimeter. The latest version of the conceptual detector is CEPC_v4[1], which has been updated and optimized from the preliminary conceptual detector CEPC_v1[17]. More information about the studies on the conceptual detector can be found in Ref.[18–22].

The Monte Carlo particles are generated from physics models by using Whizard[12] at the parton level and then interfaced with Pythia[13] for hadronization simulation. The MC particles are simulated by the detector simulation framework MokkaPlus[14] based on Geant4[15]. MokkaPlus is a simulation framework used for linear colliders and has been updated to match the CEPC detector concept.

The final physics objects, such as the lepton, photon and jet, are reconstructed by using a dedicated particle flow reconstruction framework Arbor[23;24]. A final state classification framework, FSClasser[25], is used for the reconstruction of the final physics events.

3 Analysis method

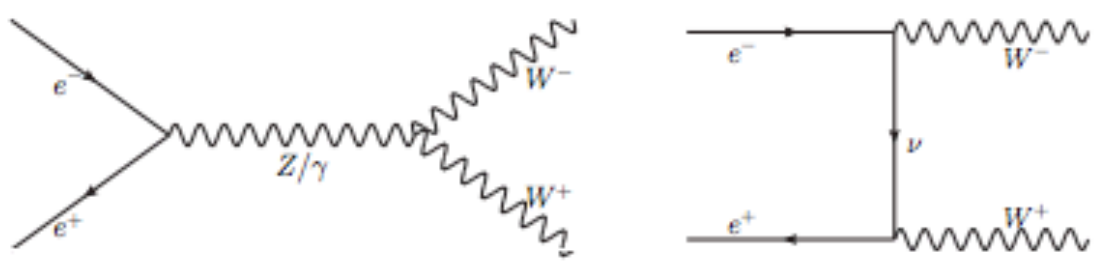
The R_b measurement is based on the double-tagging method. The procedure of the method is described as follows: The jets in the hadronic decay events are divided into two kinds of hemispheres, namely, hemisphere I and hemisphere J, according to the plane perpendicular to the thrust axis. By applying the b-tagging cuts on the two hemisphere samples separately, we can then retrieve two b-tagged hemispheres. The number of b-tagged hemisphere I samples is named N_t^I. For the opposite hemisphere J, the number of tagged samples is named N_t^J. For the two kinds of hemispheres, the b-tagging cut points can be applied differently. The number of events in which both hemispheres are tagged can be counted as $N_{tt}^{I,J}$. Three equations can

TGC with optimal observables

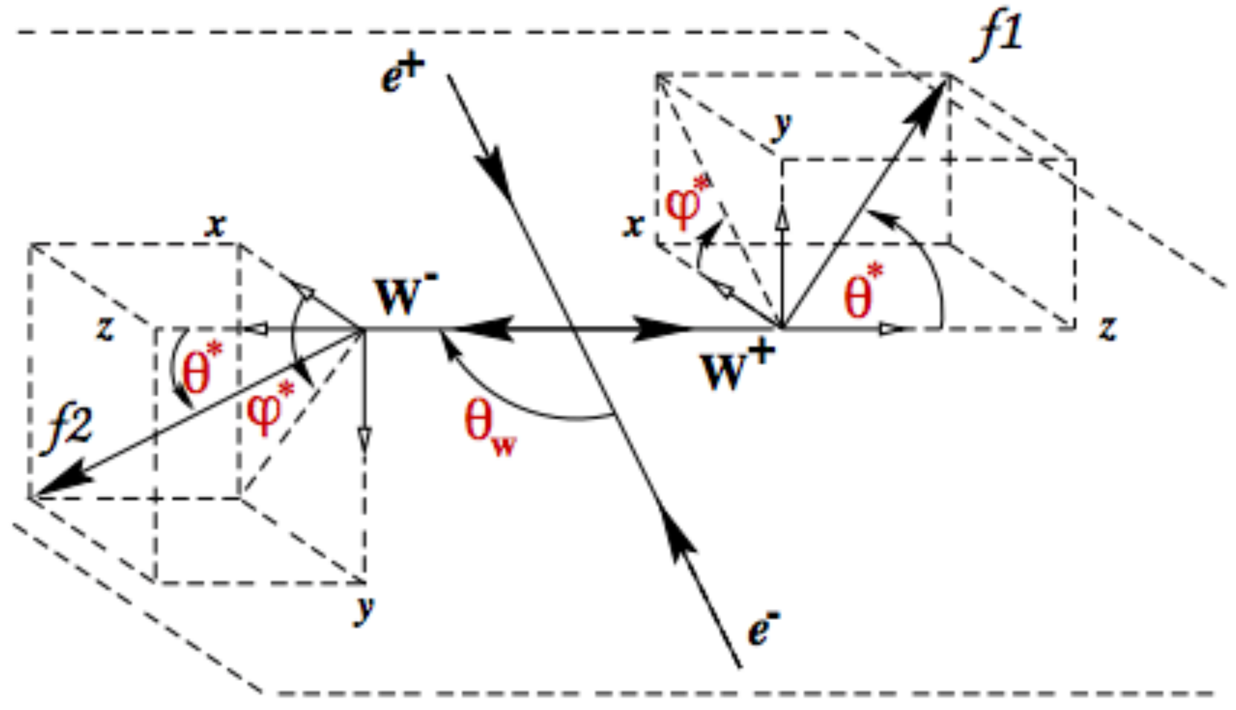
By jiaYing Gu,lingfeng Li
Dan Yu, Shuqi Li, Manqi, Zhijun

A refined TGC analysis using Optimal Observables

- TGCs are sensitive to the differential distributions!
  - Current method: fit to binned distributions of all angles.
  - Correlations among angles are ignored.

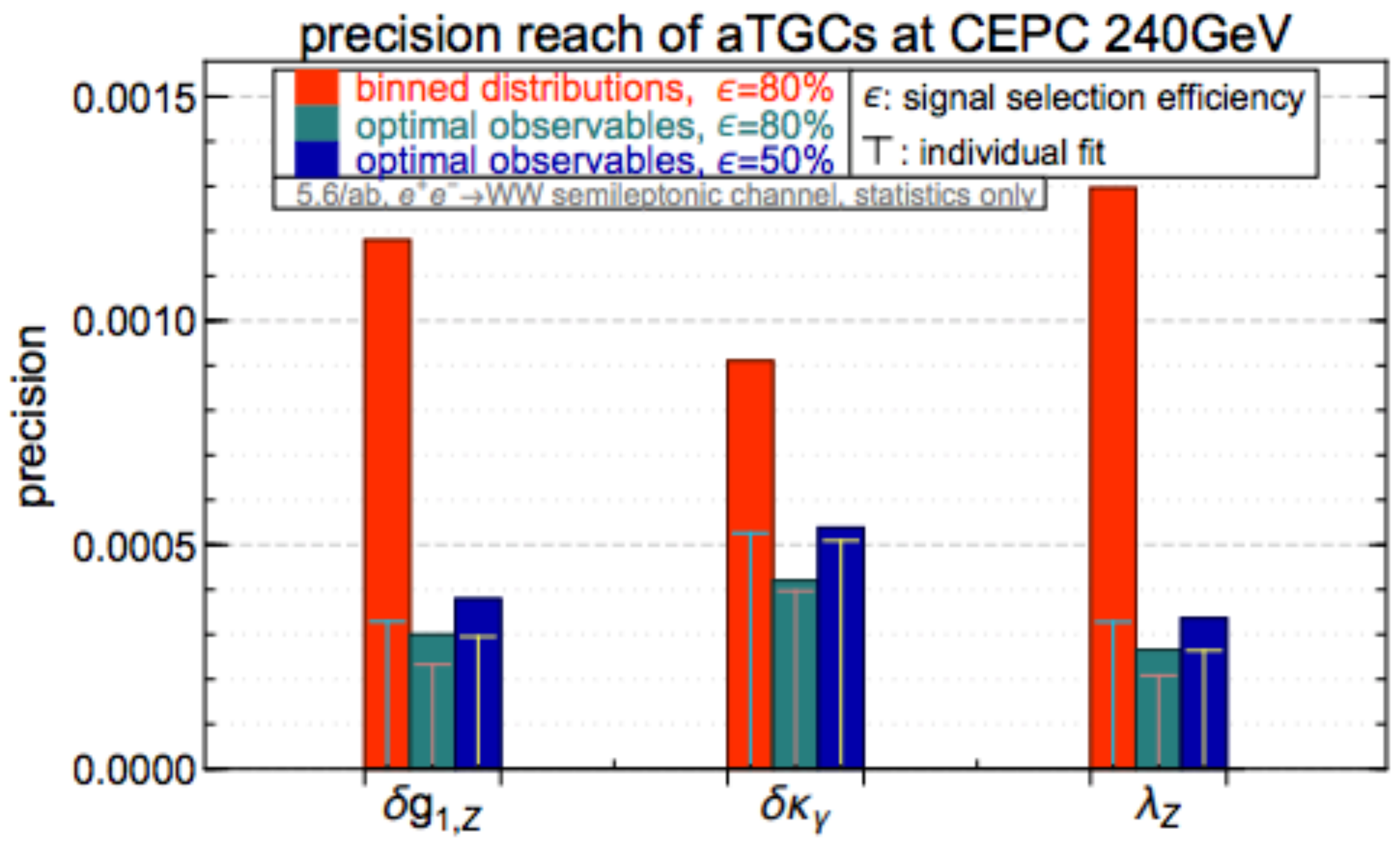


- What are optimal observables?
  (See *e.g.* Z.Phys. C62 (1994) 397-412 Diehl & Nachtmann)
  - For a given sample, there is an upper limit on the precision reach of the parameters.
  - In the limit of large statistics (everything is Gaussian) and small parameters (leading order dominates), this "upper limit" can be derived analytically!



$$\frac{d\sigma}{d\Omega} = S_0 + \sum_i S_{1,i}\, g_i\,,$$

- The optimal observables are given by $\mathcal{O}_i = \frac{S_{1,i}}{S_0}$, and are functions of the 5 angles.



TGC with optimal observables

Probing new physics with the measurements of $e^+e^- \to W^+W^-$ at CEPC with optimal observables

Thematic Areas: (check all that apply □/■)

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Contact Information:
Name (Institution) [email]:
Collaboration (optional):

Authors: (long author lists can be placed after the text)

Jiayin Gu [a], **Lingfeng Li** [b], **Shuqi Li** [c], **Zhijun Liang** [c], **Manqi Ruan** [c], **Dan Yu** [c], **Yudong Wang** [c]

jiagu@uni-mainz.de

[a] *PRISMA+ Cluster of Excellence, Institut für Physik, Johannes Gutenberg-Universität, Staudingerweg 7, 55128 Mainz, Germany*

[b] *Jockey Club Institute for Advanced Study, The Hong Kong University of Science and Technology, Hong Kong S.A.R., P.R.China*

[c] *Institute of High Energy Physics, CAS, China*

Abstract: (maximum 200 words)

We propose to study the prospectives of the diboson ($e^+e^- \to W^+W^-$) measurements at the CEPC in the effective-field-theory framework. We plan to implement the method of optimal observables to extract useful information in the differential distributions and obtain the best possible reach on the coefficients of the corresponding dimension-six operators. The impact of systematic uncertainties due to detector resolutions and beamstrahlung effects will be thoroughly investigated.

1 Background

The Circular Electron Positron Collider (CEPC) is a proposed future lepton collider based in China[1]. With runs at the Z-pole, WW threshold and around 240 GeV, it can reach unprecedented precisions for the measurements of the Higgs boson and the electroweak gauge bosons. For the electroweak gauge boson, the future prospectives of the measurements at the Z-pole and the WW threshold have already been studied in the conceptual design report[1]. Meanwhile, there is no projection for the set of observables in the diboson process, $e^+e^- \to W^+W^-$, at the CEPC. These observables are conventionally parameterized in terms of the anomalous triple Gauge couplings (aTGCs), and can be well measured at energies above the WW threshold, such as 240 GeV. They contain important information on the properties of the electroweak gauge bosons and provide crucial inputs for global effective-field-theory (EFT) analyses. A recent study[2] pointed out the importance of implementing the full EFT parameterization instead of the conventional three aTGC parameterization for the diboson process at future lepton colliders, and demonstrated the usefulness of the so-called *optimal observables*[3] for extracting information in the differential distributions of the diboson events. However, due to the absence of experimental inputs, Ref.[2] only performed a simplified diboson analyses based on statistical uncertainties. A more realistic analysis, which takes account of the systematics and detector effects, is desired to fully understand the potential of CEPC in probing the EFT parameters in the diboson measurements.

2 Proposed Study

We plan to focus on the semi-leptonic decay channel of the $e^+e^- \to W^+W^-$ process, which has a sizable branching fraction and good event reconstructions. While the optimal observable analysis in Ref.[2] gives an estimation on the precision reaches of the corresponding EFT parameters, our main focus will be on the investigation of the impacts of systematic uncertainties. This is a nontrivial task given the complicated nature of the optimal observables and their sensitivity to the differential distributions. In particular, the optimal observables at the parton level may be significantly different from those at detecter level, if the 4-momenta of the final state particles are not very well reconstructed. As such, it is important to understand the impacts of the resolutions of the jet energy and momentum, as well as the reconstruction of the missing momentum of the neutrino.

Our first step would be to compare the parton level and detector level results of the optimal observable analyses and understand the impact of systematics in terms of both the reconstructed central values of the EFT parameters (*i.e.* whether a bias can be induced by the systematics) and their uncertainties. In this comparison, we will also study the impacts of the selection cuts, such as the requirements on invariant mass that ensures the correct reconstruction of the W boson, on reducing the systematic uncertainties on the optimal observables. If the impacts of systematics are large and difficult to remove with selection cuts, we will also explore on the use of more sophisticated methods, such as machine learning techniques to estimate the precision reach on the EFT parameters and compare those with the ideal reach from the optimal observables.

3 Outlook

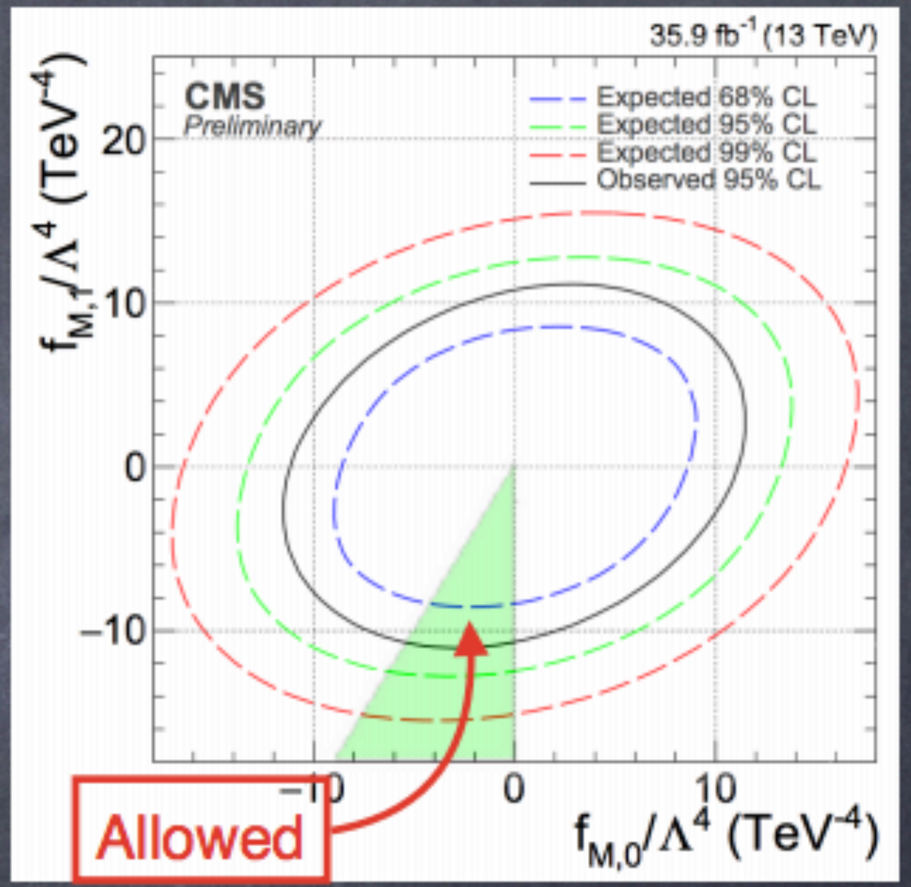
Our results on the optimal observable analyses of the diboson measurements will serve as a crucial component of a realistic global EFT analyses at the CEPC. It is also possible to generalize our analysis to include

Unitarity bounds in aQGCs

- However, SMEFT is meant to connect EXP data with concrete UV models. Therefore it does not make much sense to study the EFT space which cannot be UV-completed (if we know in advance).
- Particularly relevant at dim-8: positivity bounds tell us which part of the parameter space **cannot** be UV-completed. (e.g. if dim-8 coefficients have wrong signs).
- Currently affects the aQGC parametrization.
- However, **in the future, more dim-8 effects may become accessible.**

  (e.g. new observable proposed for DY process [Alioli, Boughezal, Mereghetti, Petriello, 2003.11615])

[CMS-PAS-SMP-18-001]



Relevant even for improved EXP precision

- These bounds need to be studied, to identify the meaningful parameter space, to form a consistent interpretation of data within the SMEFT framework, and also to help focus the EXP search.

Cen Zhang (IHEP)

Unitarity bounds in aQGCs

Positivity bounds on quartic-gauge-boson couplings

Snowmass letter of intent

Cen Zhang[1,2,3,*] and Shuang-Yong Zhou[4,5,†]

[1]*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China*
[2]*School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100049, China*
[3]*Center for High Energy Physics, Peking University, Beijing 100871, China*
[4]*Interdisciplinary Center for Theoretical Study, University of Science and Technology of China, Hefei, Anhui 230026, China*
[5]*Peng Huanwu Center for Fundamental Theory, Hefei, Anhui 230026, China*

Dim-8 Wilson coefficients in the Standard Model Effective Field Theory (SMEFT) are not allowed to take arbitrary values. By assuming that the SMEFT admits a UV completion that satisfies the fundamental principles of quantum field theory (QFT), including analyticity, unitarity, crossing symmetry, locality and Lorentz invariance, the so-called positivity bounds can be derived [1], determining the signs of certain linear combinations of dim-8 coefficients. Since the ultimate goal of the SMEFT is to determine its UV completion, one should restrict the search for operators only within these bounds, and optimize the search strategy accordingly. Alternatively, one might also use these bounds to experimentally test the fundamental principles of QFT [2]. In either case, as the LHC has started to probe the dim-8 SMEFT operators in many occasions, it has become increasingly important to understand the positivity bounds on their coefficients. A particular relevant topic at the LHC is the vector boson scattering (VBS) and the measurement of the quartic-gauge-boson couplings (QGCs). Searching for possible beyond the SM physics in the form of anomalous QGCs is one of the main goals of the current as well as the future electroweak program at the LHC and HL-LHC. These couplings can be measured in the VBS or the triboson production channels. Knowing their bounds from positivity will undoubtedly provide guidance for relevant future theoretical and experimental studies.

The conventional approach to derive positivity bounds makes use of the elastic 2-to-2 forward scattering amplitude. One can show that its second derivative w.r.t. s, the Mandelstem variable, is positive, and this leads to, at the tree level, a set of linear homogeneous inequalities for dim-8 coefficients. This approach has been adopted in Refs. [3–5], and the allowed parameter space of the Wilson coefficients has been reduced to only about 2%. However, these results are still far from complete. The reason is that the notion of elasticity depends on the particle basis, and therefore the scattering amplitudes between arbitrary superpositions of particle states should be explored, in order to obtain the full set of elastic positivity bounds. So far, this procedure has not been done systematically, and only a limited set of superposed states have been investigated in the literature.

Recently, we have proposed a new approach to extract positivity bounds [6]. This approach has the advantage that one is guaranteed to obtain the best bounds allowed by the fundamental QFT principles. Indeed, bounds tighter than the full set of elastic positivity bounds can be obtained in certain cases, and an explicit example has been presented in [6]. In this approach, instead of using elastic channels to probe the bounds, one essentially

* cenzhang@ihep.ac.cn
† zhoushy@ustc.edu.cn

describes the allowed parameter space as a convex cone via the *extremal representation* of cones, and thus we will call it the extremal positivity approach. This approach is efficient because the extremal rays of the cone can be directly written down via group theoretical considerations. So far, this approach has been applied to the 4-W and the 4-H operator sets in Ref. [6]. More general applications of this approach are yet to be explored.

For Snowmass 21, we propose to study the full set of positivity bounds on aQGC operators in the SMEFT framework, by applying the new extremal positivity approach. We expect these results to unify and supersede all previous results in the literature. While providing guidance for future theoretical and experimental studies on VBS and relevant SMEFT fits, we also hope that this study will establish the general methodology for obtaining complete positivity bounds for dim-8 SMEFT operators.

[1] A. Adams, N. Arkani-Hamed, S. Dubovsky, A. Nicolis, and R. Rattazzi, JHEP **10**, 014 (2006), arXiv:hep-th/0602178 [hep-th].
[2] J. Distler, B. Grinstein, R. A. Porto, and I. Z. Rothstein, Phys. Rev. Lett. **98**, 041601 (2007), arXiv:hep-ph/0604255.
[3] C. Zhang and S.-Y. Zhou, Phys. Rev. **D100**, 095003 (2019), arXiv:1808.00010 [hep-ph].
[4] Q. Bi, C. Zhang, and S.-Y. Zhou, JHEP **06**, 137 (2019), arXiv:1902.08977 [hep-ph].
[5] G. N. Remmen and N. L. Rodd, JHEP **12**, 032 (2019), arXiv:1908.09845 [hep-ph].
[6] C. Zhang and S.-Y. Zhou, (2020), arXiv:2005.03047 [hep-ph].

Summary of LOI topic in EF04

- Weak mixing angle measurements at Z pole
  - Eg: weak mixing angle from Z->bb, Z->ll backward-forward asymmetry
  - More study with more realistic simulations
  - More detailed study on experimental and theory systematics
- High order EWK calculation (NNLO EWK corrections)
- aTGCs/QGCs in WW events
- Unitarity bounds in aQGCs
- Z->bb branching ratio

https://docs.qq.com/sheet/DR1NXTXp6V2JkR1NH?tab=m0d77k

EF04	EW Precision Physics and constraining new physics	
EF04.1	WW process	Junmou Chen
EF04.2	TGC (remark: Jet can be measured to energy resolution of 4%, direction resolution of 1%)	
EF04.3	Afb(b) — sin^2(theta_W) (remark: Jet Charge Measurement)	
EF04.4	NNLO EW correction to HZ production	Zhao Li