Electroweak measurements at CEPC

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Chinese Academy of Sciences

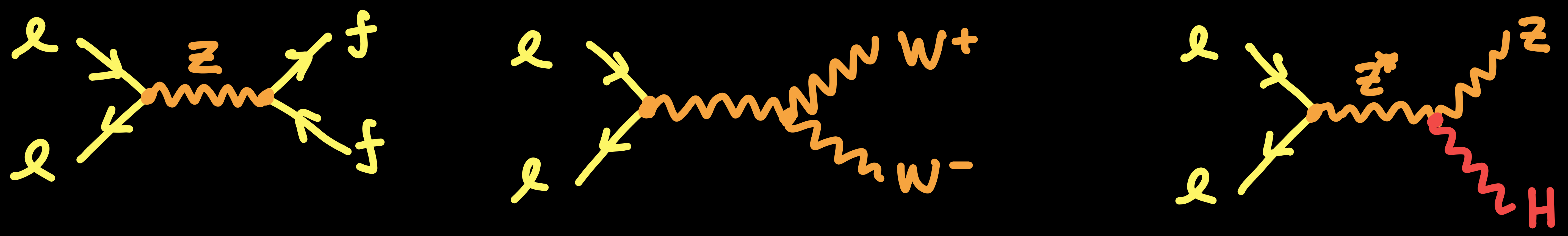
Updated CEPC collider parameters since CDR

	Higgs		Z (2T)	
	CDR	Updated	CDR	Updated
Beam energy (GeV)	120	-	45.5	-
Synchrotron radiation loss/turn (GeV)	1.73	1.68	0.036	-
Piwinski angle	2.58	3.78	23.8	33
Number of particles/bunch N_e (10^{10})	15.0	17	8.0	15
Bunch number (bunch spacing)	242 (0.68μs)	218 (0.68μs)	12000	15000
Beam current (mA)	17.4	17.8	461.0	1081.4
Synchrotron radiation power /beam (MW)	30	-	16.5	38.6
Cell number/cavity	2	-	2	1
β function at IP β_x^* / β_y^* (m)	0.36/0.0015	0.33/0.001	0.2/0.001	-
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.89/0.0018	0.18/0.0016	-
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	17.1/0.042	6.0/0.04	-
Bunch length σ_z (mm)	3.26	3.93	8.5	11.8
Lifetime (hour)	0.67	0.22	2.1	1.8
Luminosity/IP L (10^{34} $cm^{-2}s^{-1}$)	2.93	5.2	32.1	101.6

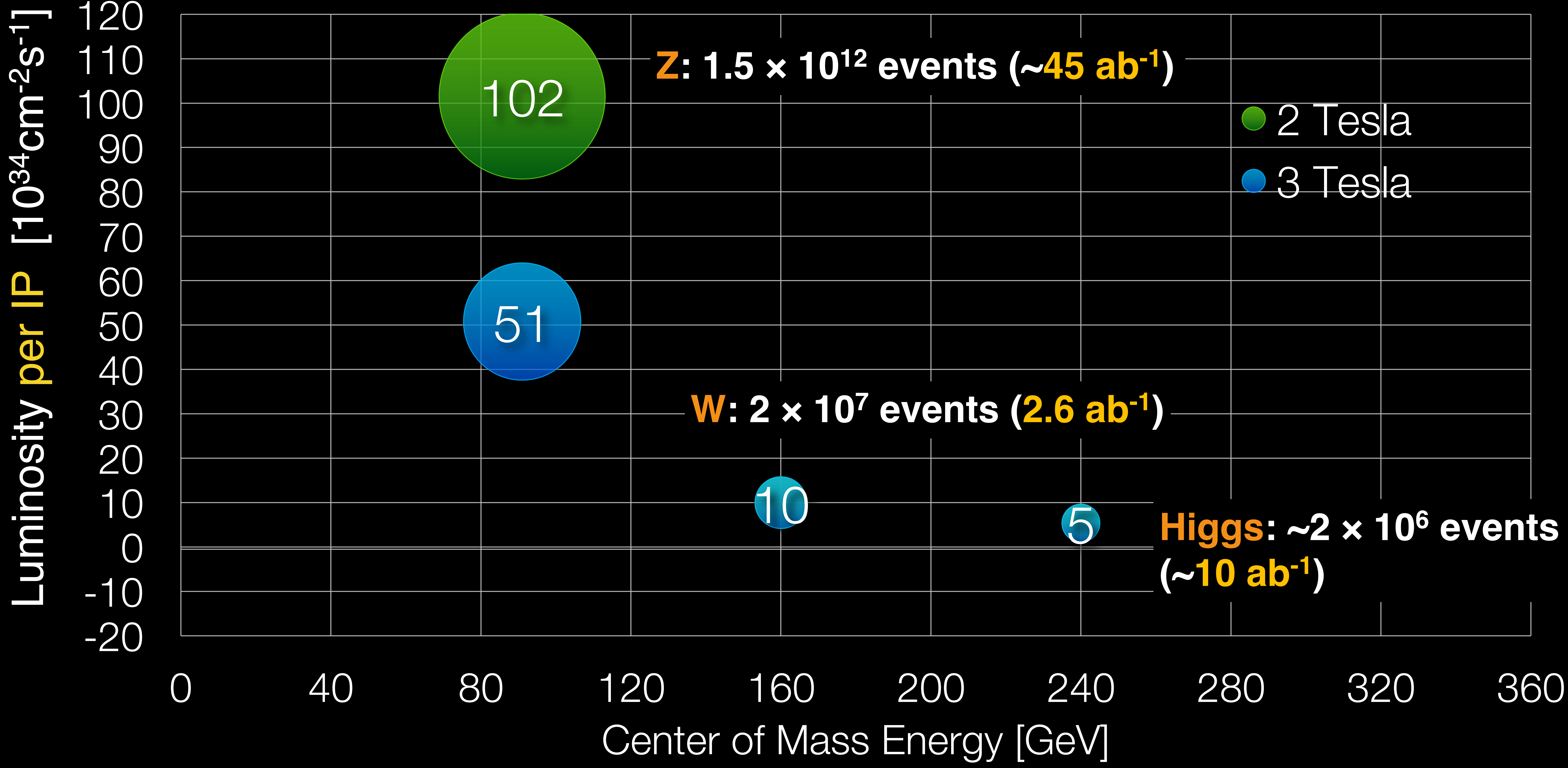
Luminosity increase factor: × 1.8 × 3.2

The CEPC Program

100 km e^+e^- collider

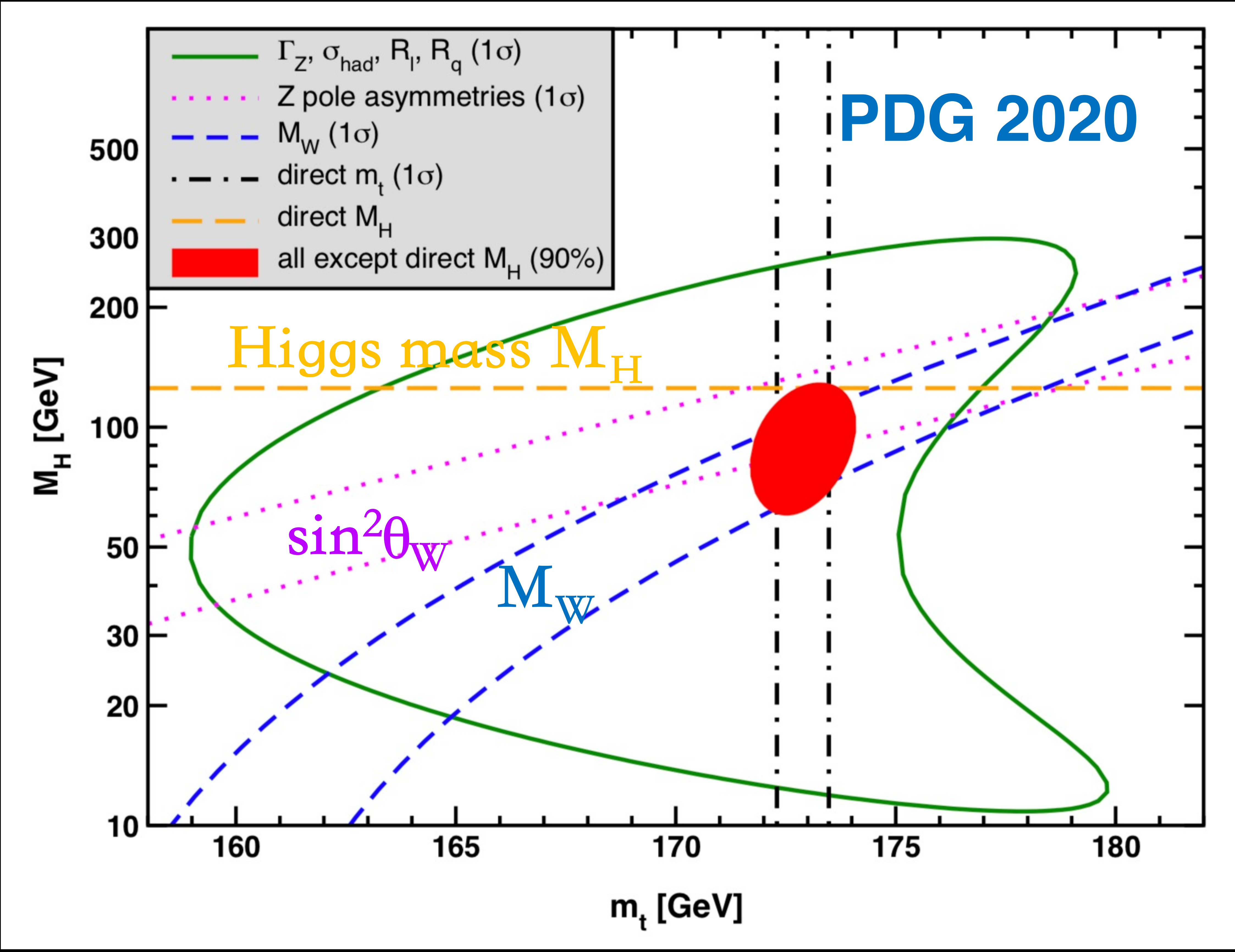


2 IPs



The status of electroweak global fit

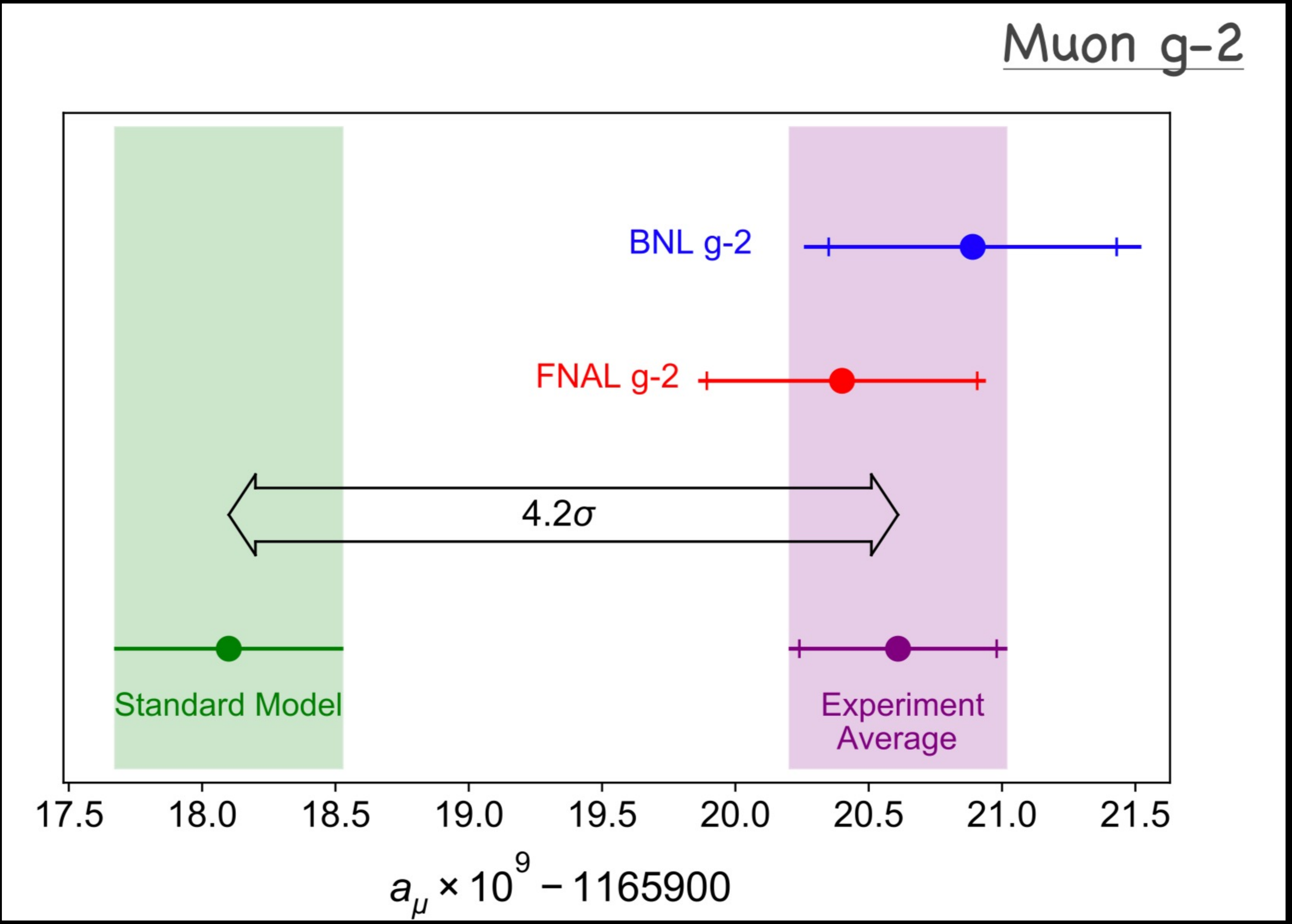
- 7 key observables in electroweak global fit
  - Consistency study of the standard model electroweak section
  - Small conflict in Higgs mass (2σ) between direct measurement and EWK fit.
  - Need CEPC Z pole and WW runs : Precise measurements on EWK observables.



Fundamental constant	δx/x	measurements
$\alpha = 1/137.035999139\ (31)$	1×10^{-10}	$e^{\pm}\ g_2$
$G_F = 1.1663787\ (6) \times 10^{-5}\ \mathrm{GeV}^{-2}$	1×10^{-6}	$\mu^{\pm}$ lifetime
$M_Z = 91.1876 \pm 0.0021$ GeV	1×10^{-5}	LEP
$M_W = 80.379 \pm 0.012$ GeV	1×10^{-4}	LEP/Tevatron/LHC
$\sin^2\theta_W = 0.23152 \pm 0.00014$	6×10^{-4}	LEP/SLD
$m_{top} = 172.74 \pm 0.46$ GeV	3×10^{-3}	Tevatron/LHC
$M_H = 125.14 \pm 0.15$ GeV	1×10^{-3}	LHC

Motivation of precision measurement

- Muon g-2 → in-direct search for new physics with precision measurement
- Liantao predicted that CEPC could probe the new physics behind muon g-2



From Liantao Wang (University of Chicago)

$$\mathscr{L} \supset \frac{e}{16\pi^2}\frac{m_\mu}{M_{\rm NP}^2} H\bar{L}\sigma_{\mu\nu}\mu_R F^{\mu\nu} \quad \rightarrow \quad \delta a_\mu \simeq \frac{e}{16\pi^2}\frac{m_\mu^2}{M_{\rm NP}^2}$$

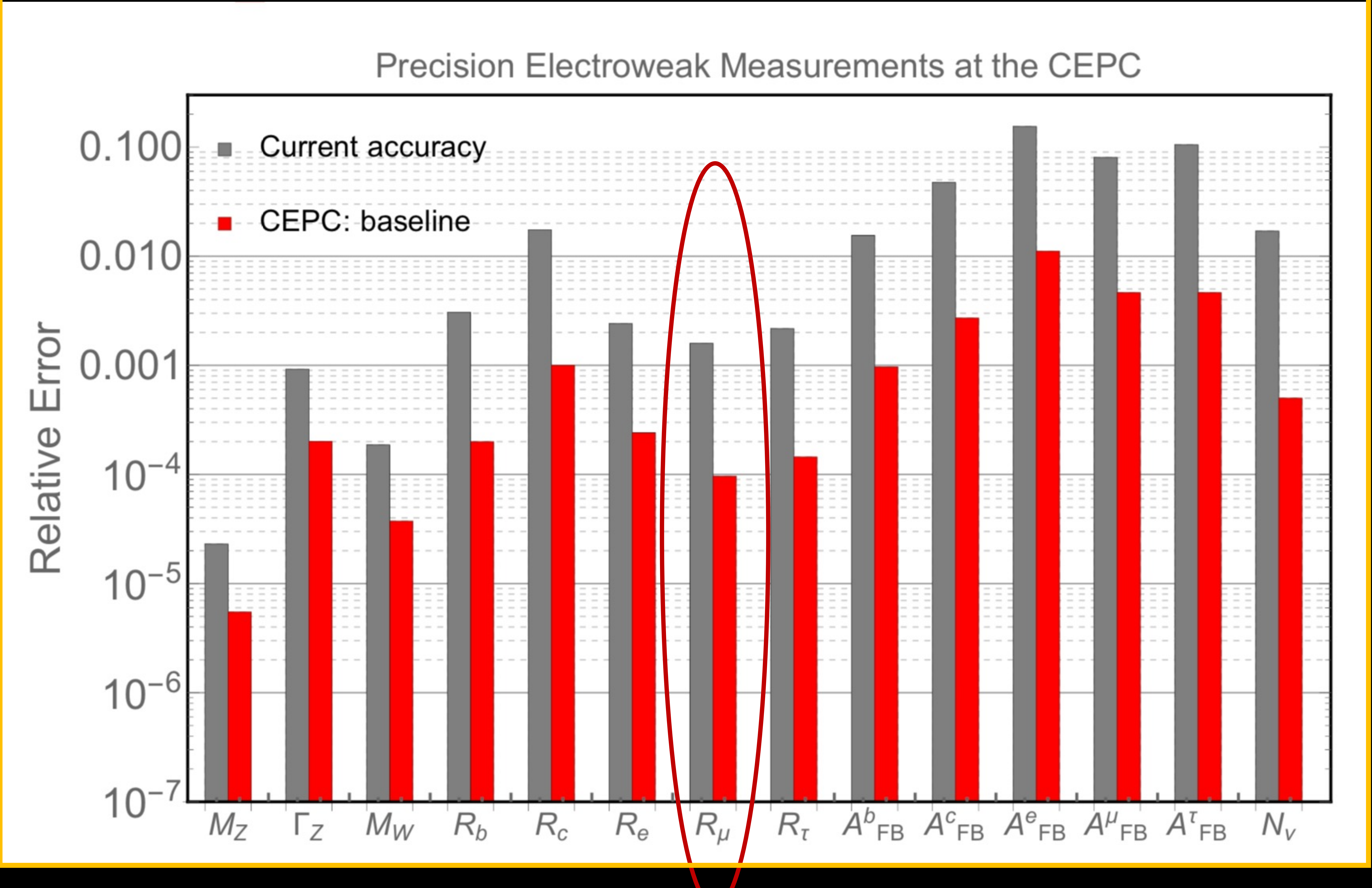
Disagreement with SM ⇒ (1-loop) $M_{NP} \sim 300$ GeV.

Or, with 2-loop contribution, $M_{NP} \sim 30$ GeV.

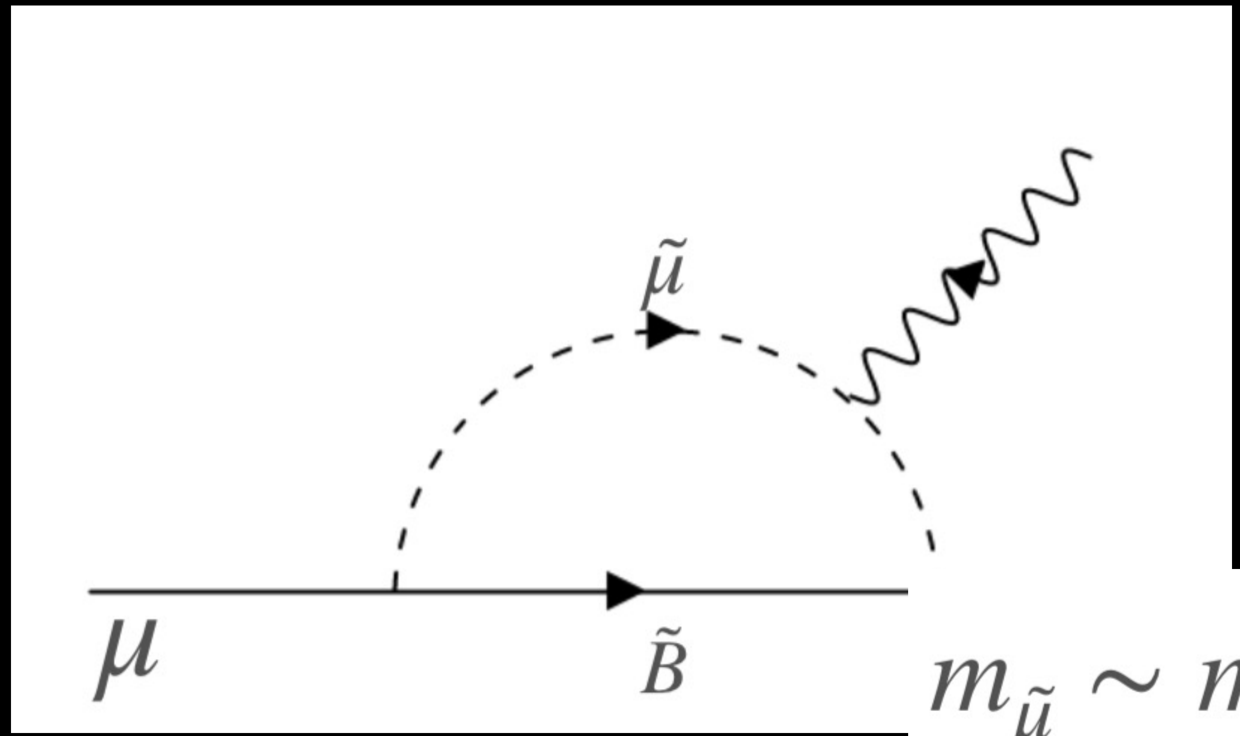
https://indico.ihep.ac.cn/event/13888/session/0/contribution/5/material/slides/0.pdf

Probing new physics behind muon g-2 at CEPC

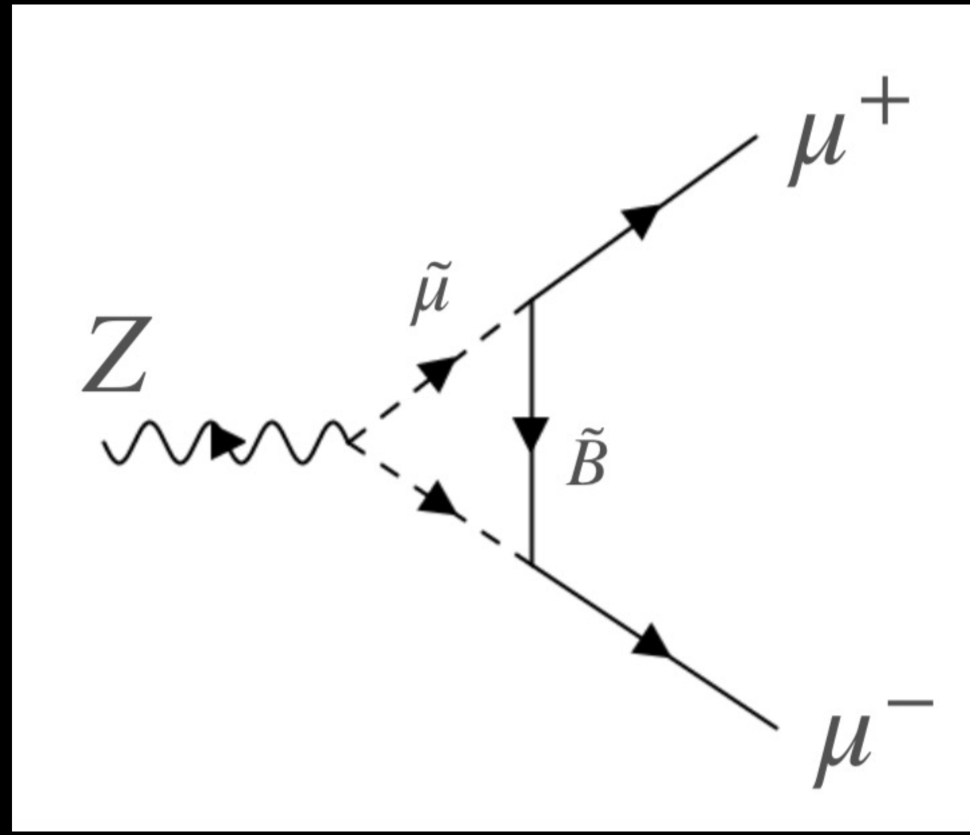
- From Liantao, if new physics behind muon g-2 @ one loop
- Expect to see disagreement with SM at Z->μ μ branching ratio at 10^{-4} to 10^{-5}
- Within the reach of CEPC Z pole physics



From Liantao Wang



$m_{\tilde{\mu}} \sim m_{\tilde{B}} \sim 100 - 500$ GeV



$$\frac{\delta\Gamma_\mu}{\Gamma_\mu} \sim 10^{-4} - 10^{-5}$$

Probing new physics behind muon g-2 at CEPC

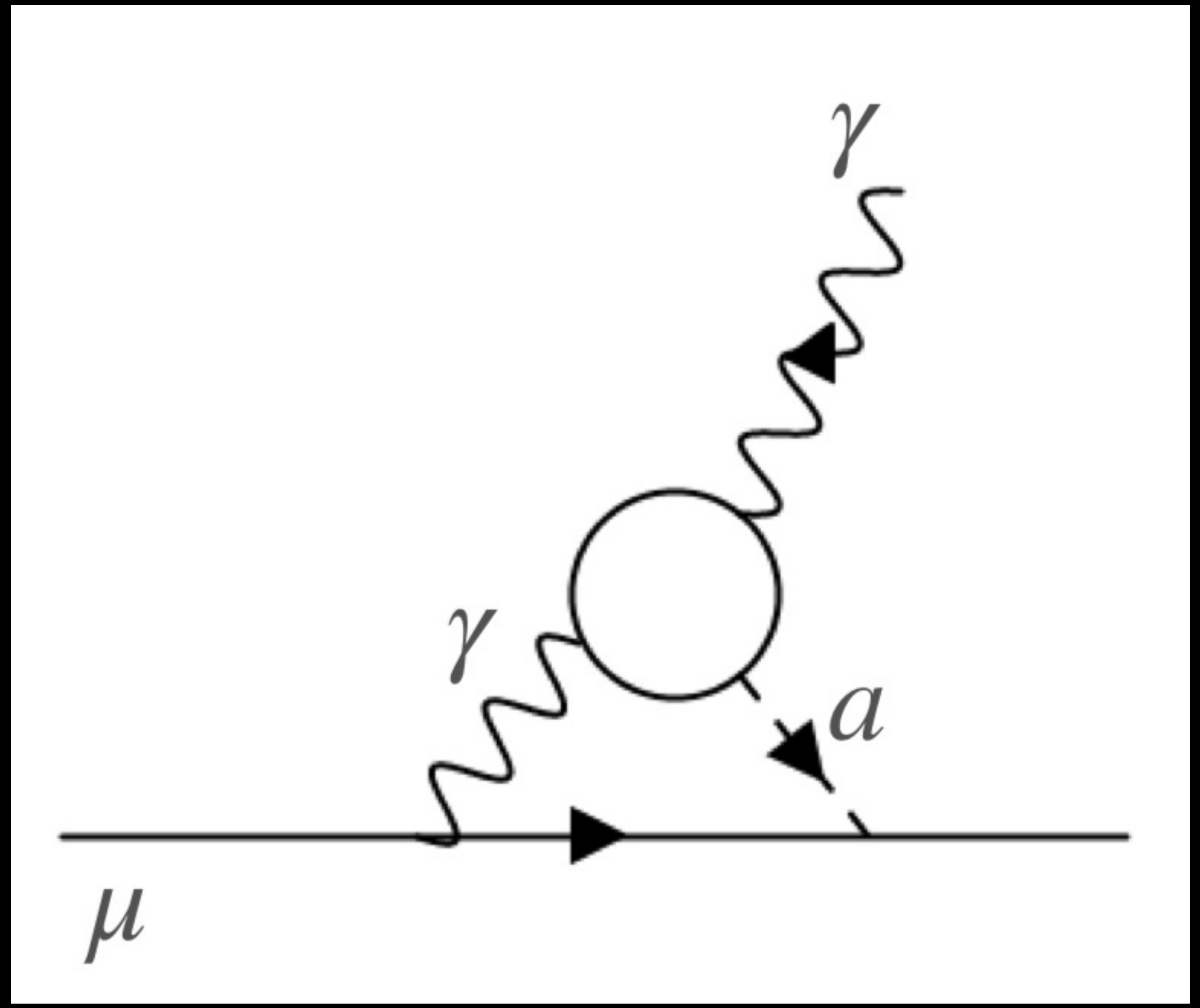
- From Liantao, if new physics behind muon g-2 @ two loop
- Expect to see disagreement with SM at Br(Z->4μ) and Br(Z->2μ2γ) at ~10^{-7}
- Within the reach of CEPC Z pole physics

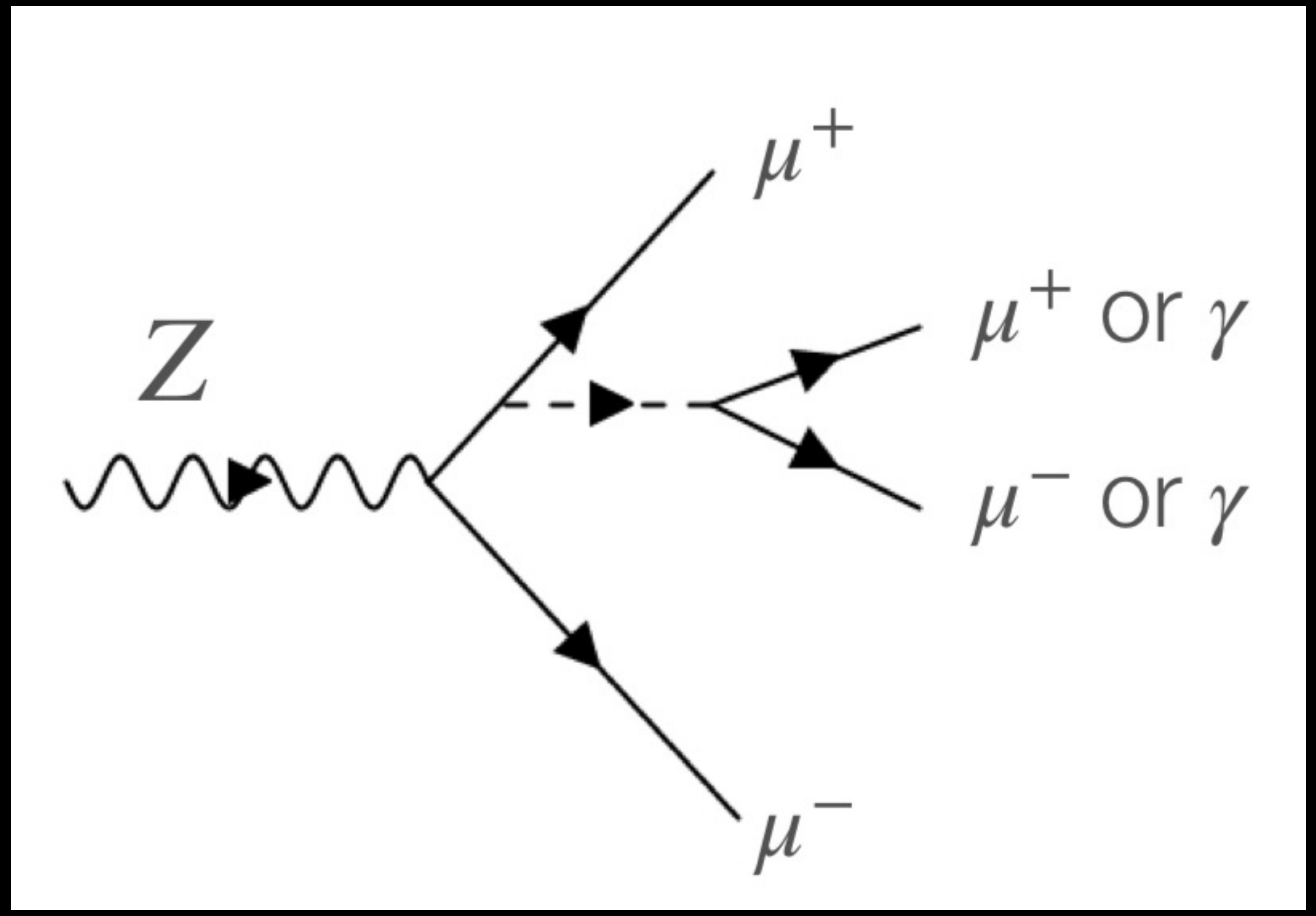
	Current precision	CEPC
Br(Z->4μ)	~3*10^{-7} ATLAS/CMS	~10^{-9}
Br(Z->2μ2γ)	< 6*10^{-7}@ 95% CL By LEP	<2*10^{-9}

Phys. Rev. Lett. 112, 231806 (2014)

Phys.Lett.B 311 (1993) 391-407

From Liantao Wang (University of Chicago)





a : axion-like particle, pseudo-scalar Higgs, …

$m_a < 100$ GeV

$BR(Z \to 4\mu$ or $2\mu 2\gamma) \sim 10^{-7}$

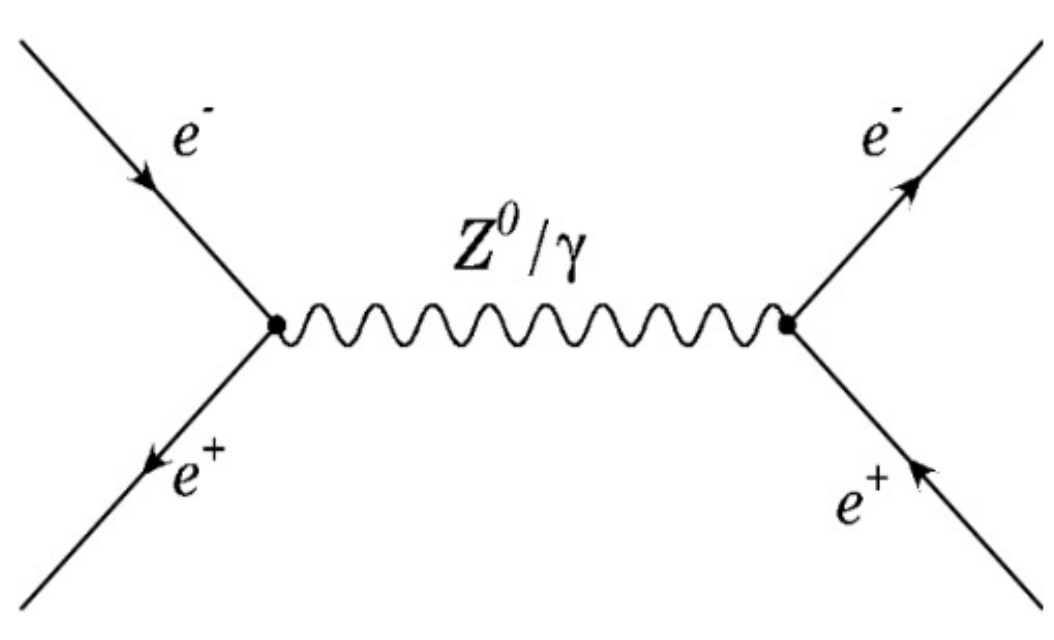
Within the reach of Tera Z.

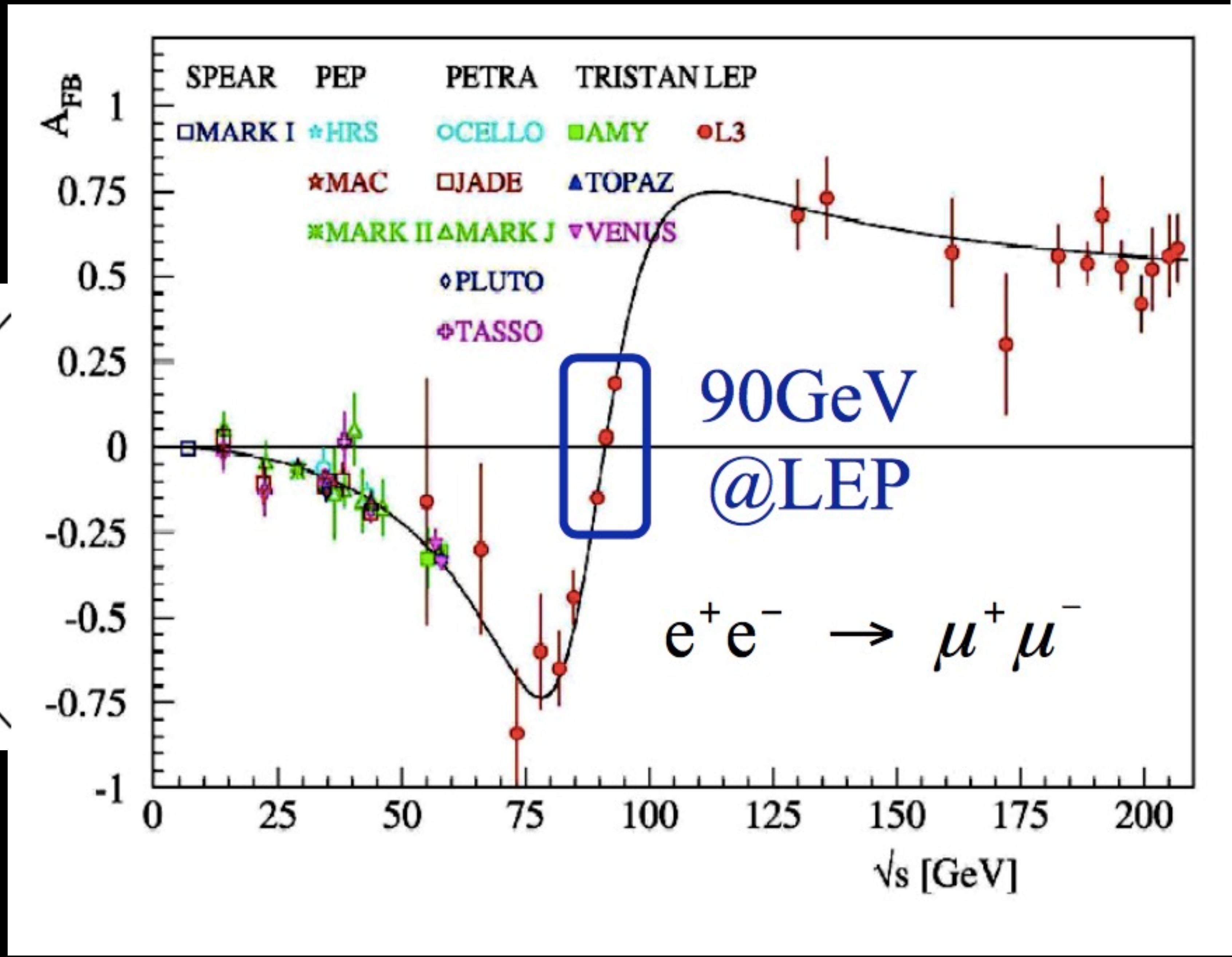
Weak mixing angle measurements ($Sin^2\theta_W$)

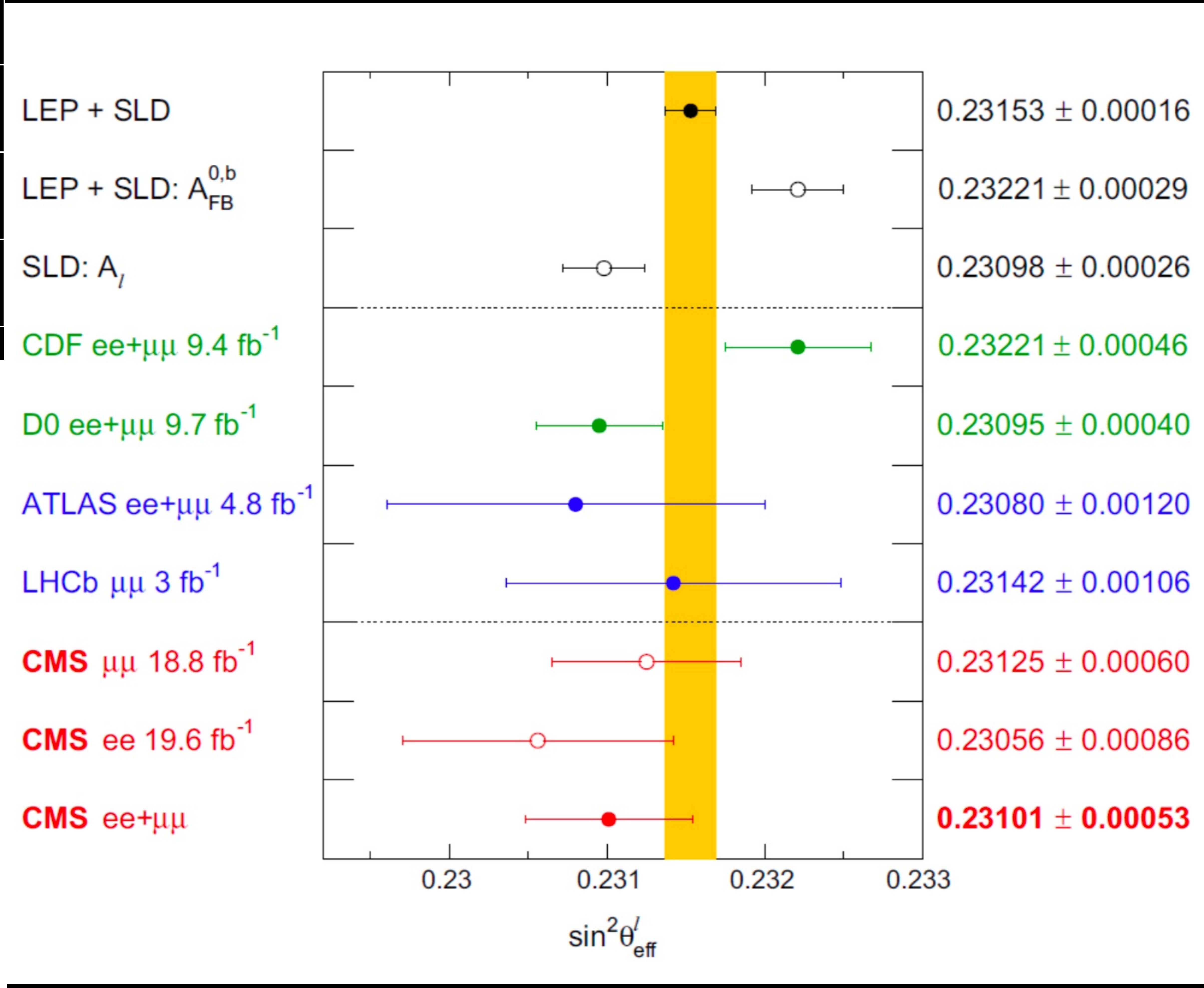
- Weak mixing angle measurement is well motivated
  - ~3σ tension between LEP and SLC measurements
  - Experimental syst. much larger than theory syst.

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} \neq 0$$

	$Sin^2\theta_W$
LEP	0.23221 ± 0.00029
SLC	0.23098 ± 0.00026
Theory	0.23121 ± 0.00004



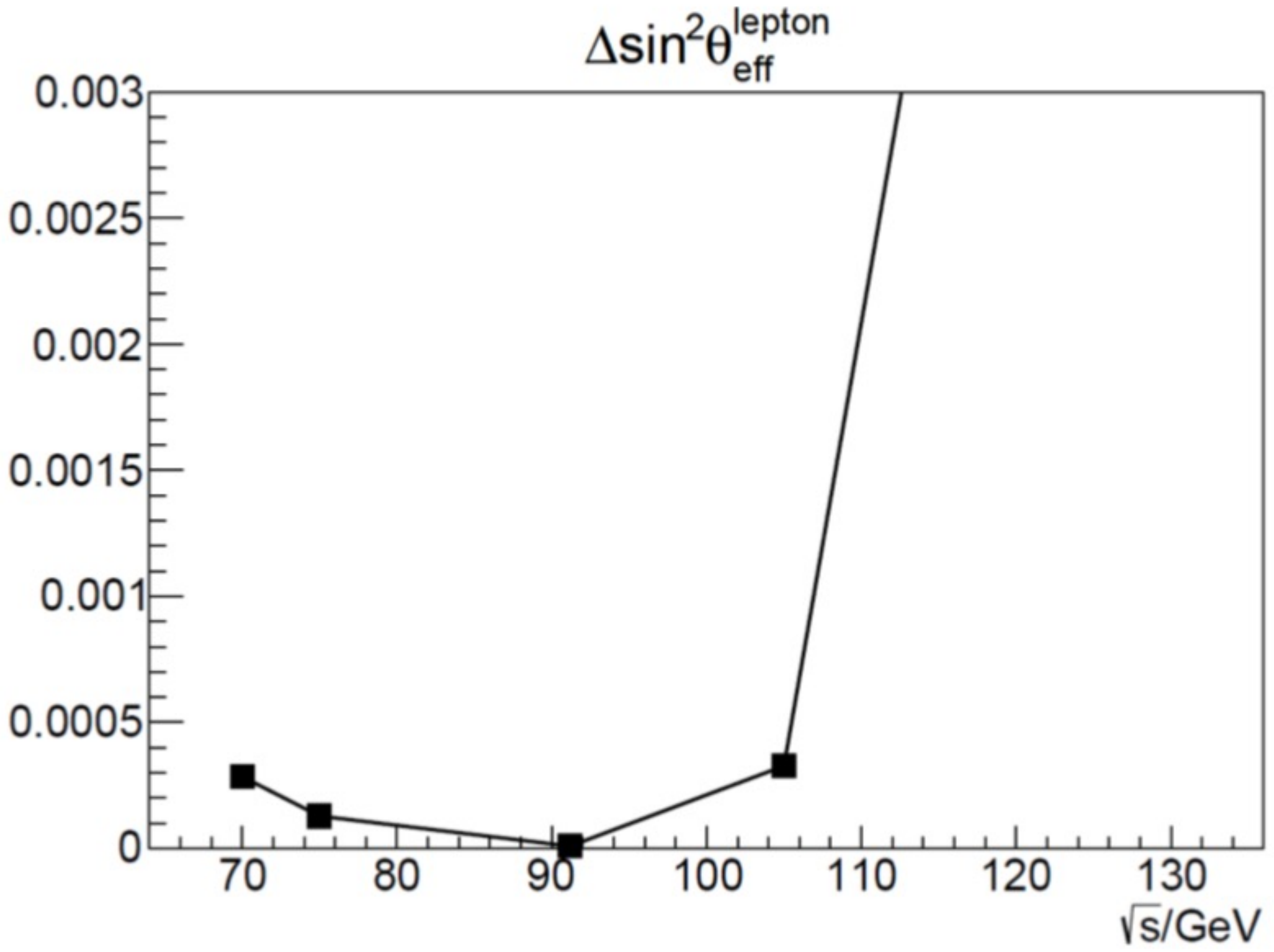




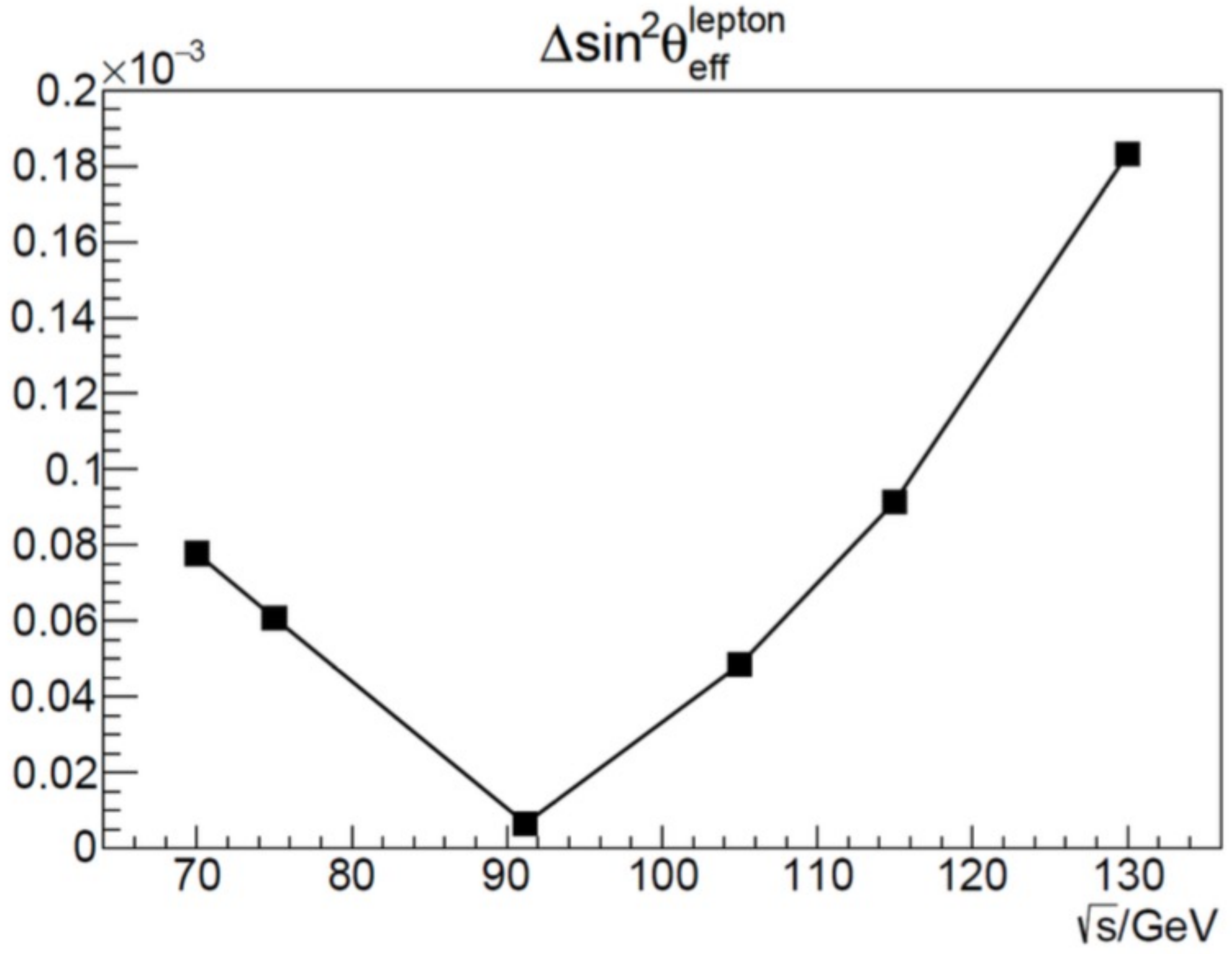
Weak mixing angle measurements ($\mathrm{Sin}^2\theta_W$)

By Siqi Yang（USTC）

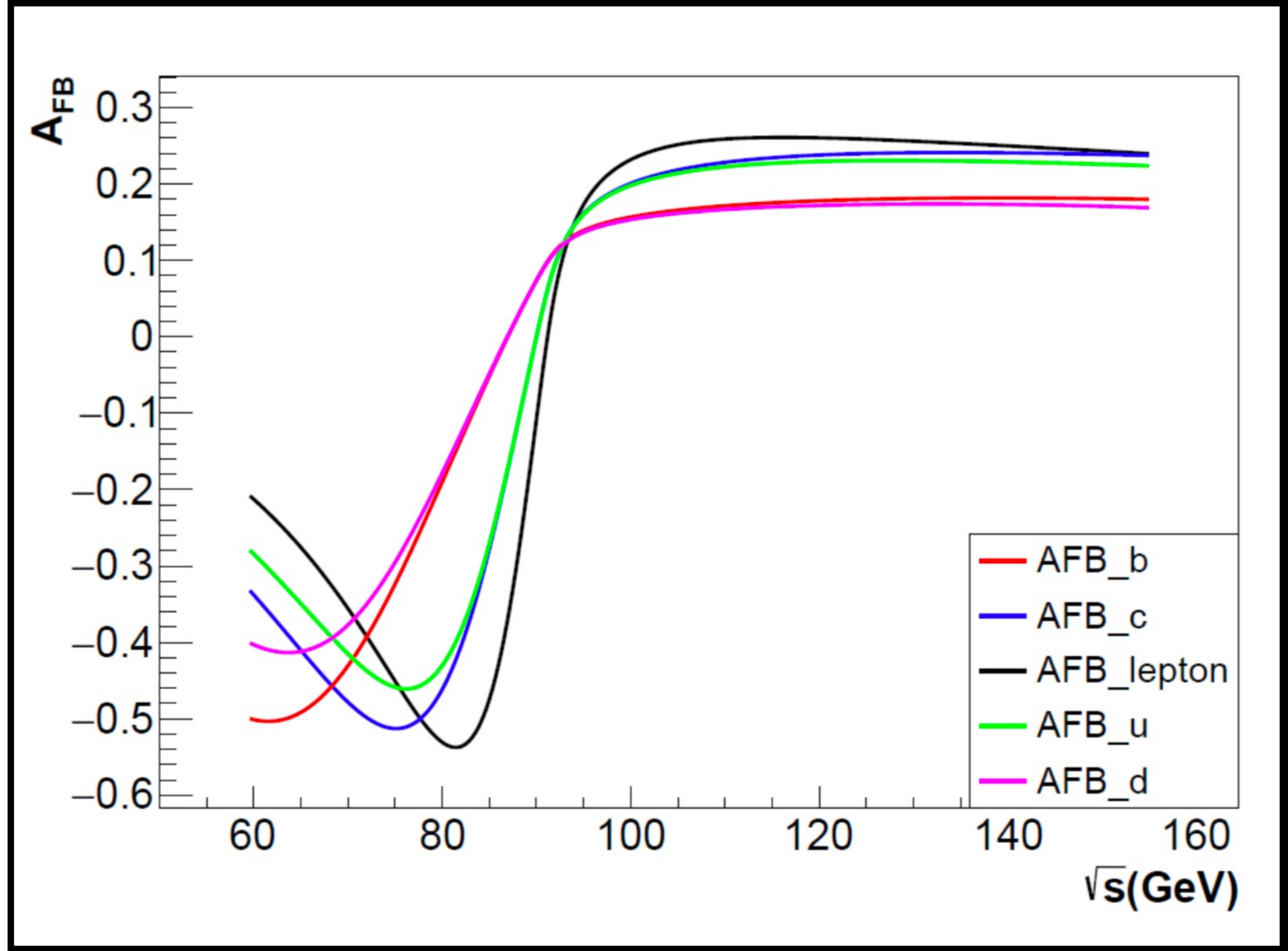
- Study of off-peak runs for weak mixing angle measurements.



lepton final state
$(ee + \mu\mu + \tau\tau)$



b quark final state



Energy scale	70 GeV	75 GeV	91.19 GeV	105 GeV	115 GeV	130 GeV
$\Delta\sin^2\theta_{eff}$ from lepton final state	0.00028	0.00013	0.00001	0.00033	0.00385	0.00766
$\Delta\sin^2\theta_{eff}$ from b quark final state	0.00008	0.00006	<0.00001	0.00005	0.00009	0.00018

Weak mixing angle measurements ($\sin^2\theta_W$)

- Stat. Unc. dominated in LEP and Tevatron measurements
- Syst. Unc. (PDF) will become dominated systematics for LHC measurements
- CEPC has potential to improve $\sin^2\theta_W$ by two order of magnitudes
- Theory unc. is about 4×10^{-5} level with two loop calculation

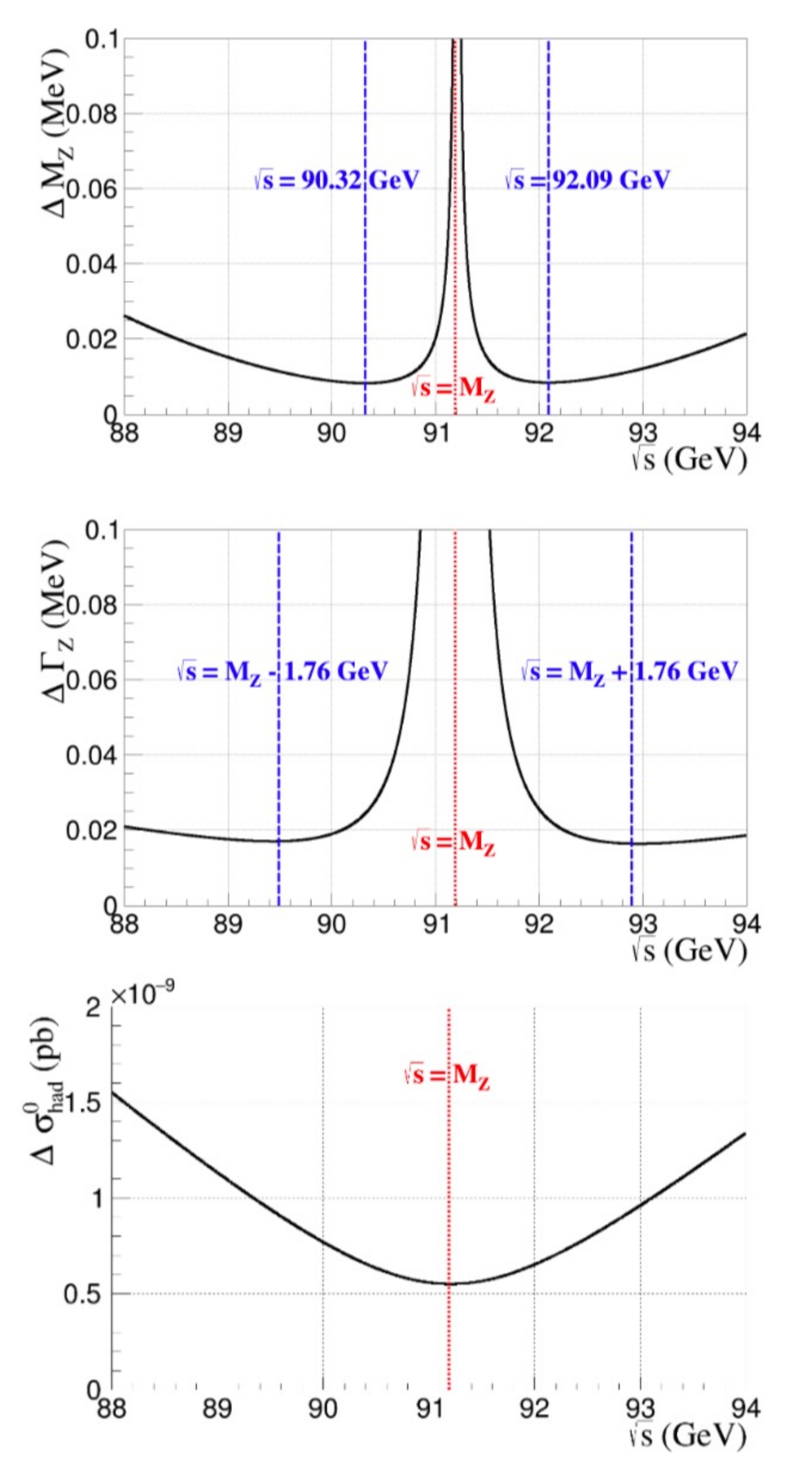
Experiment	Stat. (10^{-5})	Syst. (10^{-5})	Theory unc. (PDF+QCD) (10^{-5})	Total unc. (10^{-5}) $\delta\sin^2\theta_W$
LEP	29	~ 1	~0	29
Tevatron	27	5	18	33
LHC 8TeV	36	18	35	53
LHC 13TeV By Projection	~15	> 20	> 25	~ 20
CEPC	~0.2	~0.2	4 (Today)	~0.3

Z mass and Z width measurements

- ➢ TeraZ runs at Z pole in CEPC physics program
- ➢ Stat unc. is much lower than Syst Unc.
- ➢ Dominated systematics
- ● Beam energy scale
- ● Beam energy spread

By Shudong WANG

Parameter	δ_{stat}	δ_{total}
M_Z (KeV)	7	66
Γ_Z (KeV)	13	126
σ^0_{had} (pb)	0.09	1.73



Branching ratio (R^b): motivation

$$\frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to \text{had})}$$

- At LEP measurement 0.21594 ±0.00066
- CEPC aim to improve the precision by a factor 10~20 (0.02%)
- R^b measurement is sensitive to New physics models (SUSY)
  - SUSY predicts corrections to Z→ bb vertex
  - Through gluino and chargino loop …

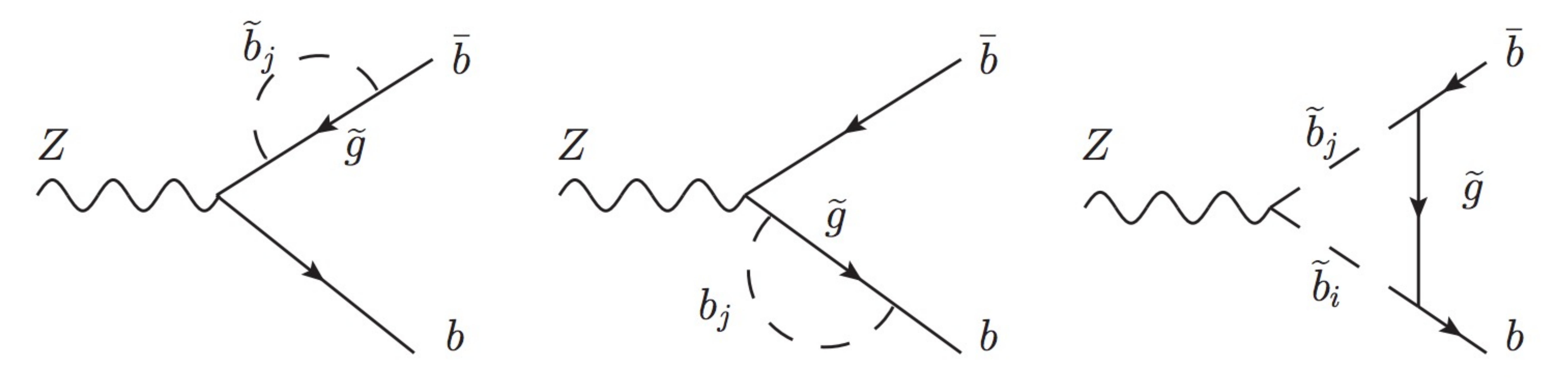


FIG. 1: One-loop Feynman diagrams of gluino correction to $Z \to \bar{b}b$

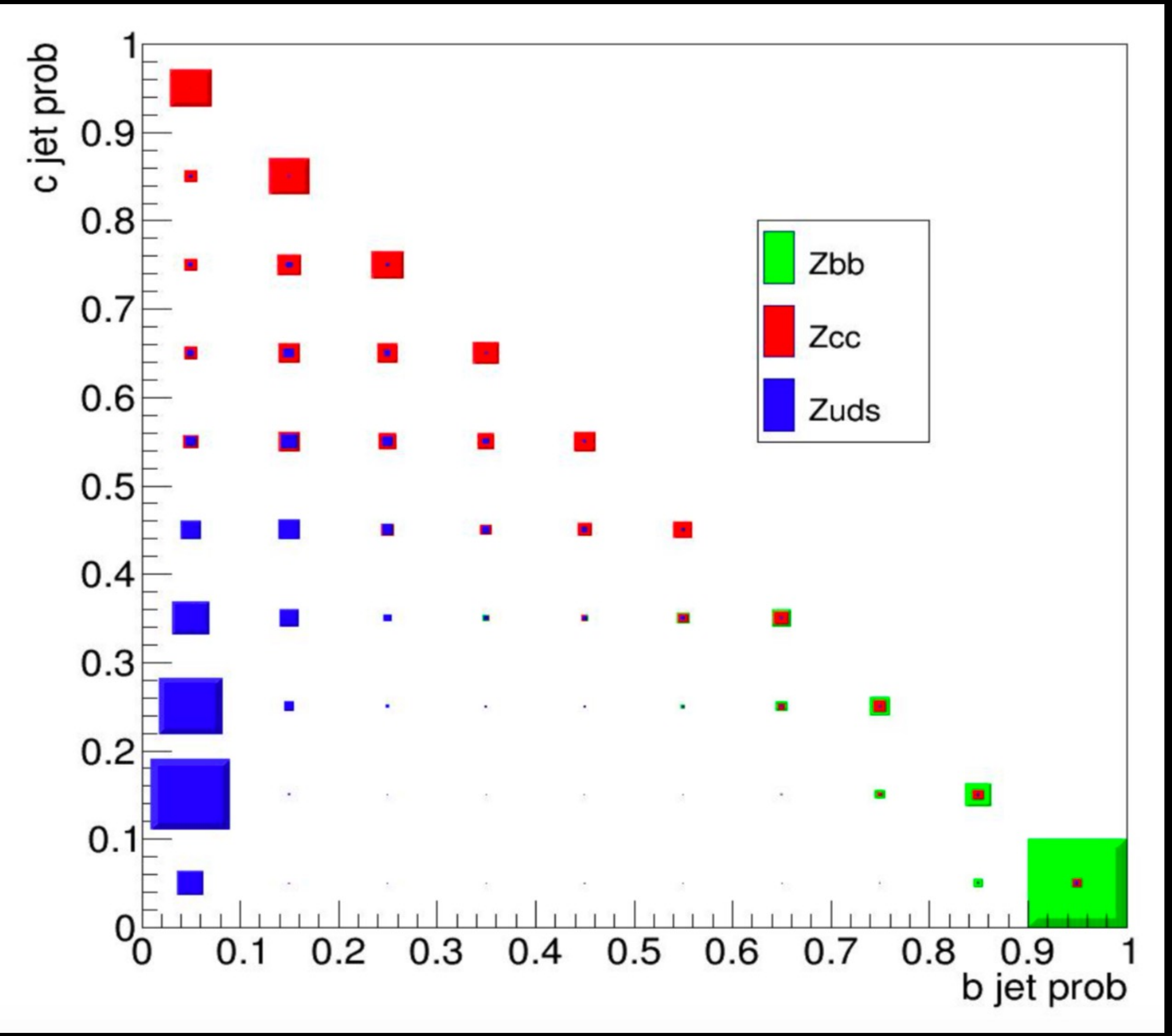
Arxiv:1601.07758v2

R^b: b tagging hemisphere correlations

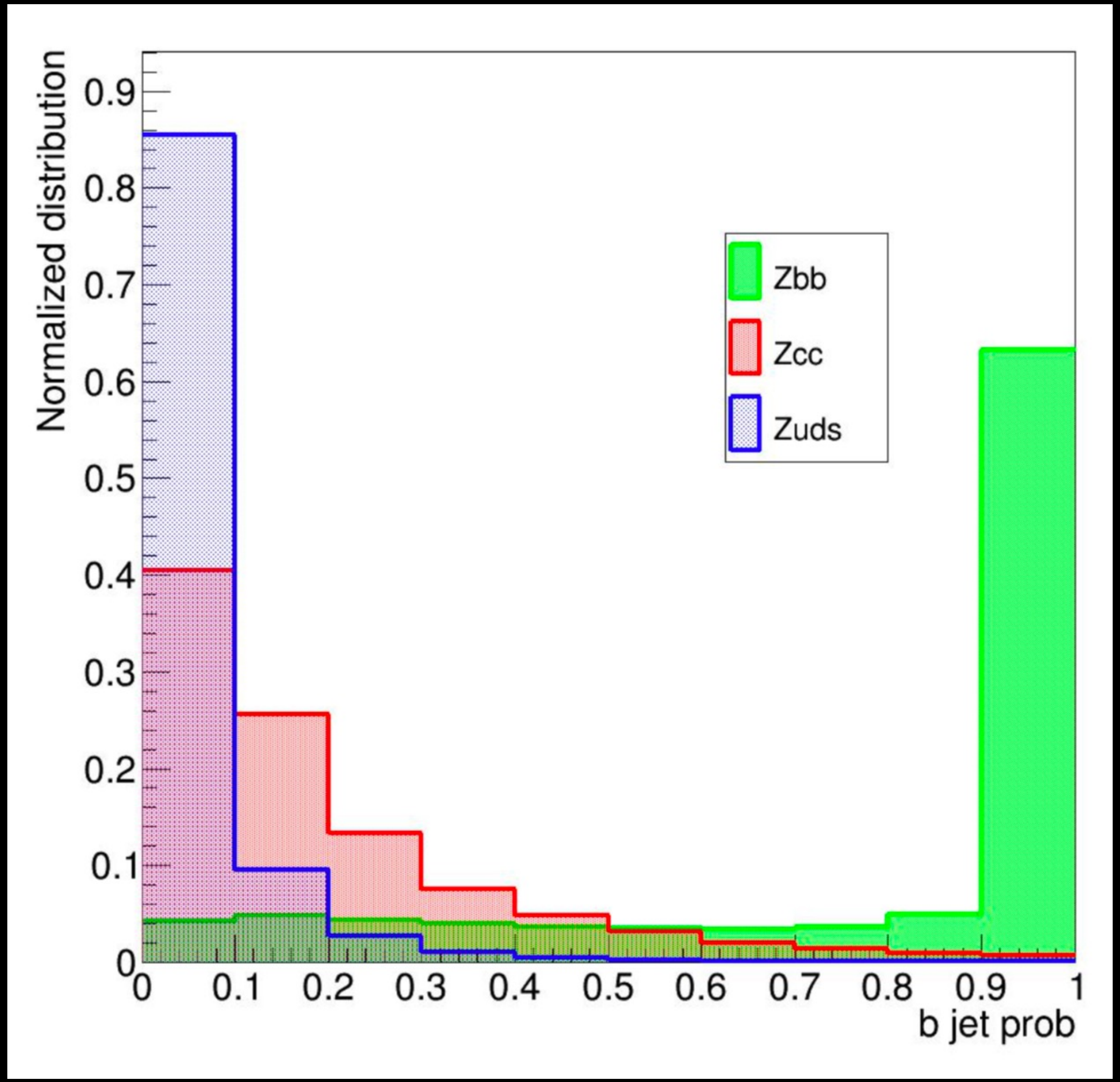
- Expected to be 20~50 times better than LEP measurements
  - with 95% purity working points, efficiency > 70% in CEPC (~30% for LEP)
  - 1D and 2D template fit for b tagging probability

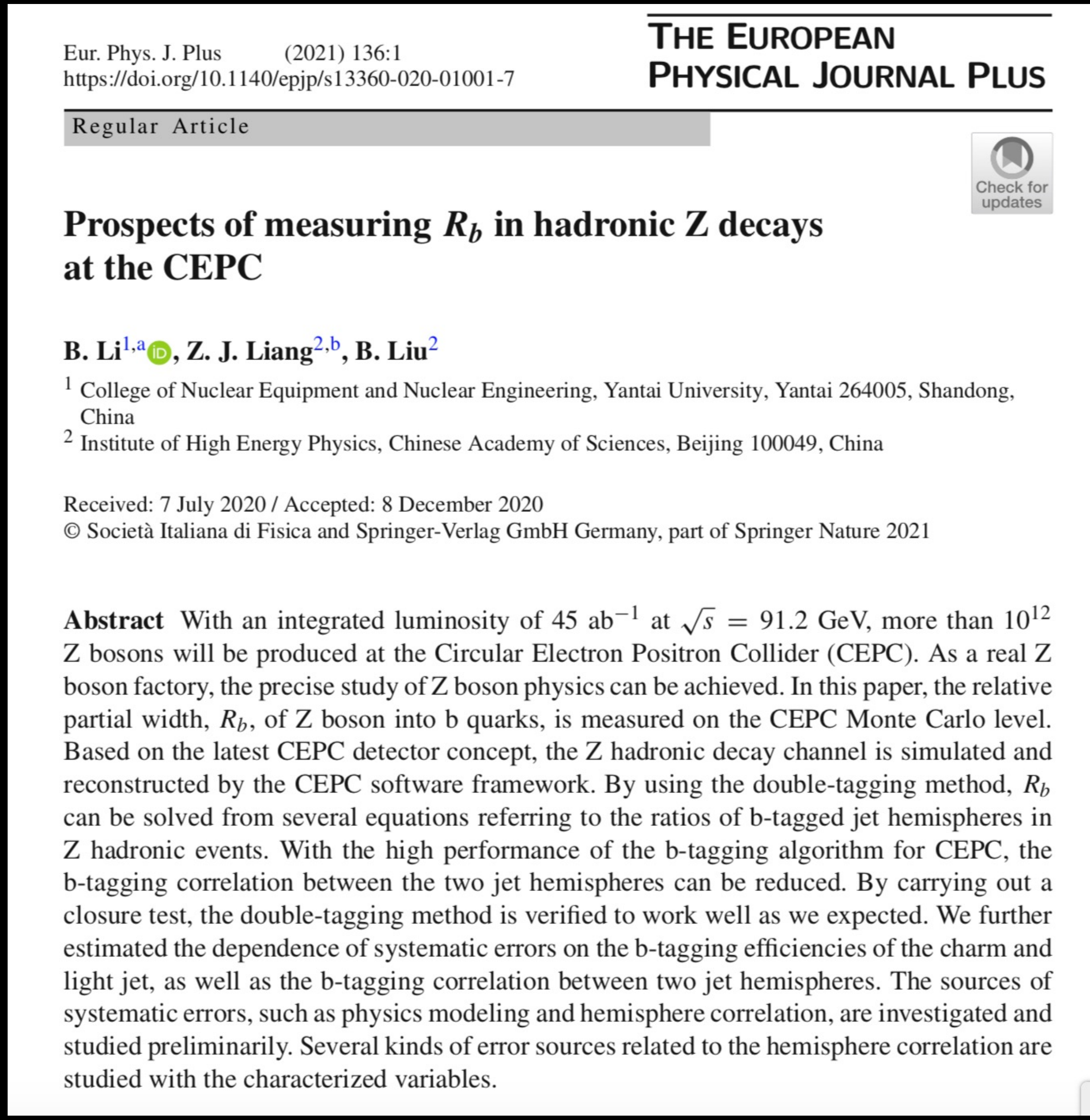
Published at EPJP
By Li Bo (Yantai University)

b tagging vs c tagging probability



b tagging probability





Eur. Phys. J. Plus (2021) 136:1
https://doi.org/10.1140/epjp/s13360-020-01001-7

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Regular Article

Check for updates

Prospects of measuring R_b in hadronic Z decays at the CEPC

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Received: 7 July 2020 / Accepted: 8 December 2020
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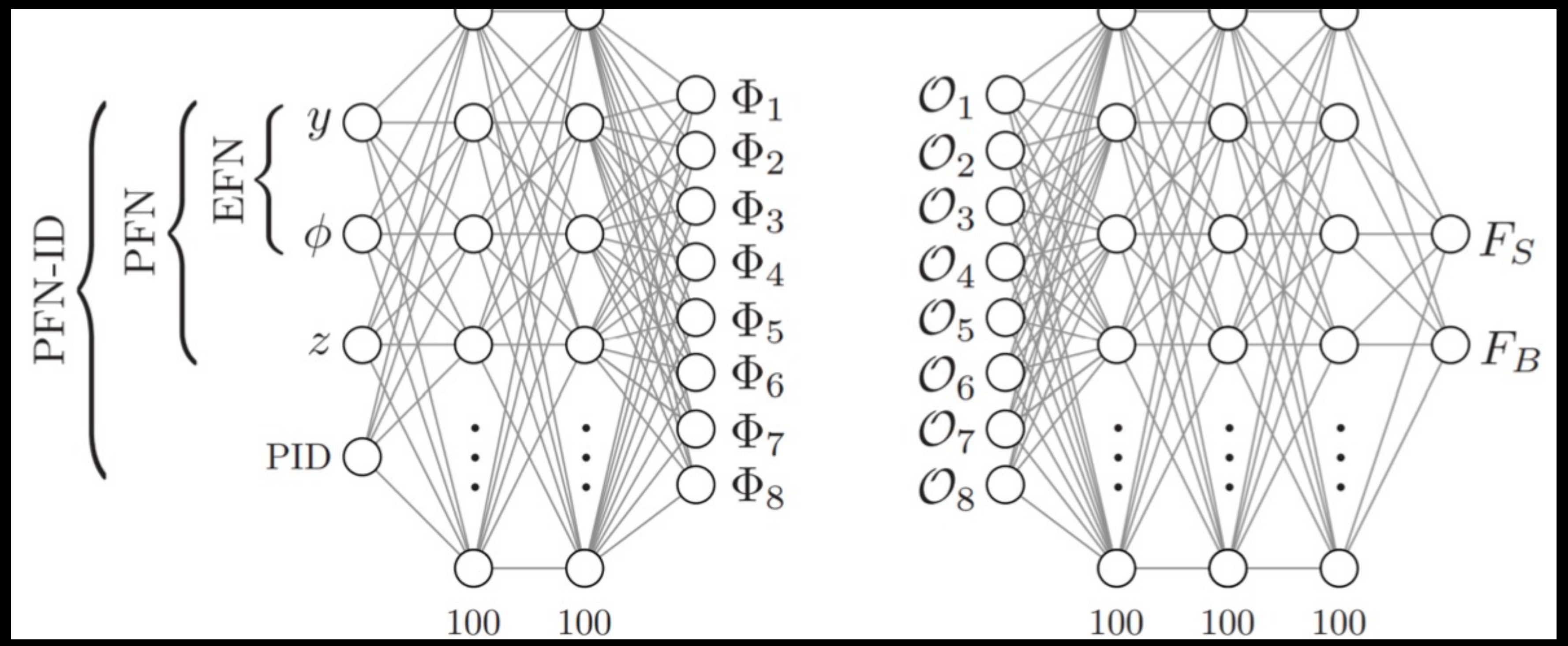
Abstract With an integrated luminosity of 45 ab^{-1} at $\sqrt{s}$ = 91.2 GeV, more than 10^{12} Z bosons will be produced at the Circular Electron Positron Collider (CEPC). As a real Z boson factory, the precise study of Z boson physics can be achieved. In this paper, the relative partial width, R_b, of Z boson into b quarks, is measured on the CEPC Monte Carlo 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 b-tagging correlation between the two jet hemispheres can be reduced. By carrying out a closure test, the double-tagging method is verified to work well as we expected. We further estimated the dependence of systematic errors on the b-tagging efficiencies of the charm and light jet, as well as the b-tagging correlation between two jet hemispheres. The sources of systematic errors, such as physics modeling and hemisphere correlation, are investigated and studied preliminarily. Several kinds of error sources related to the hemisphere correlation are studied with the characterized variables.

R^b: b tagging hemisphere correlations

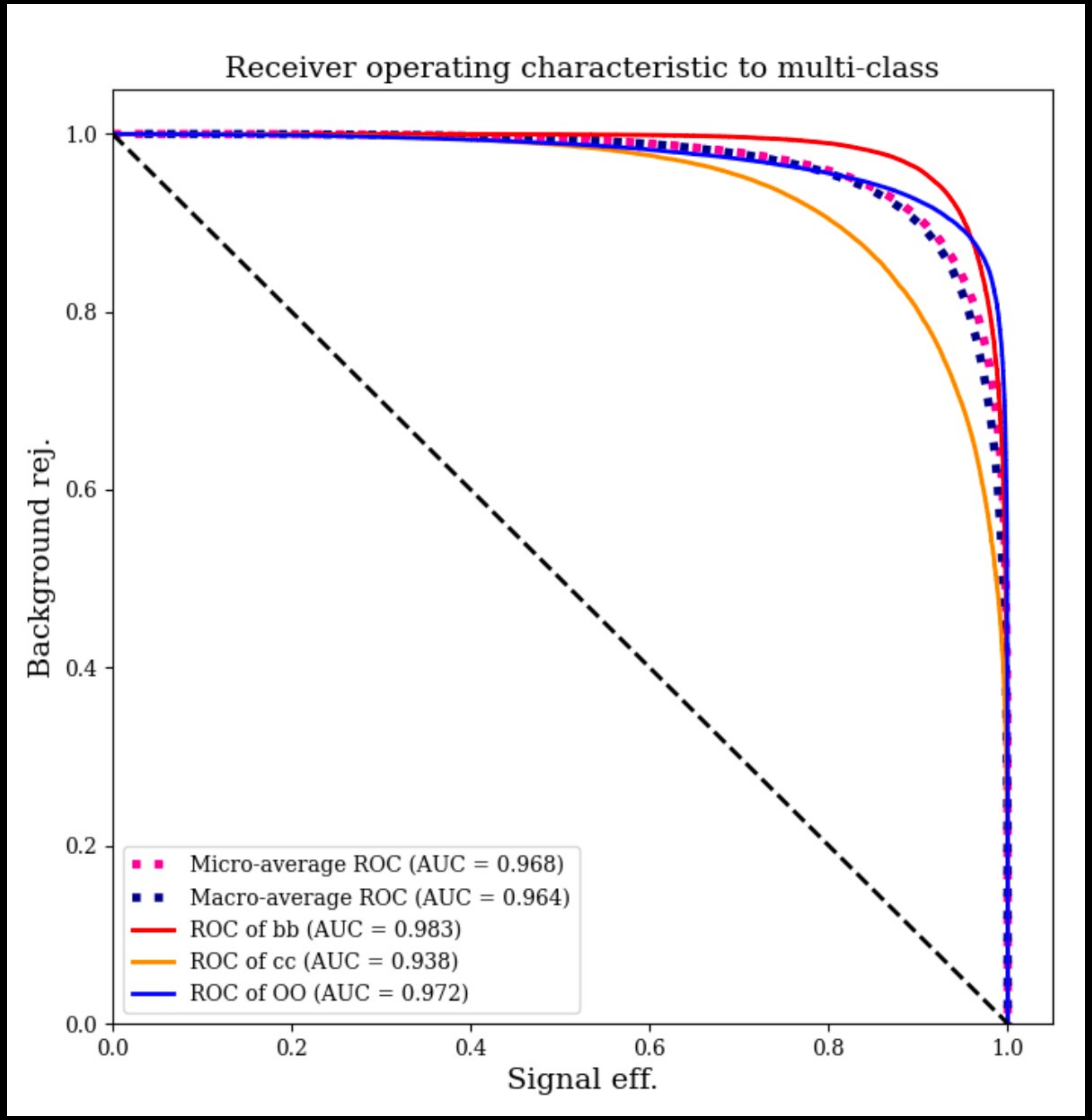
- Further optimization of b/c tagging with machine learning
  - b-tagging improved about 10%;
  - c-tagging improved significantly, about 40% at ε = 95%.

By Liao LiBo (wuzhou U.)

ParticleFlow Network (arXiv:1810.05165)



tag	ϵ_S	efficiency*purity	
		xgboost	PFN
b	50%	-	50%
	90%	79.7%	85.7%
	95%	72.8%	79.5%
c	50%	-	48.7%
	90%	58.5%	72.5%
	95%	50.3%	69.4%
uds	50%	-	48.7%
	90%	-	82.5%
	95%	-	68.7%

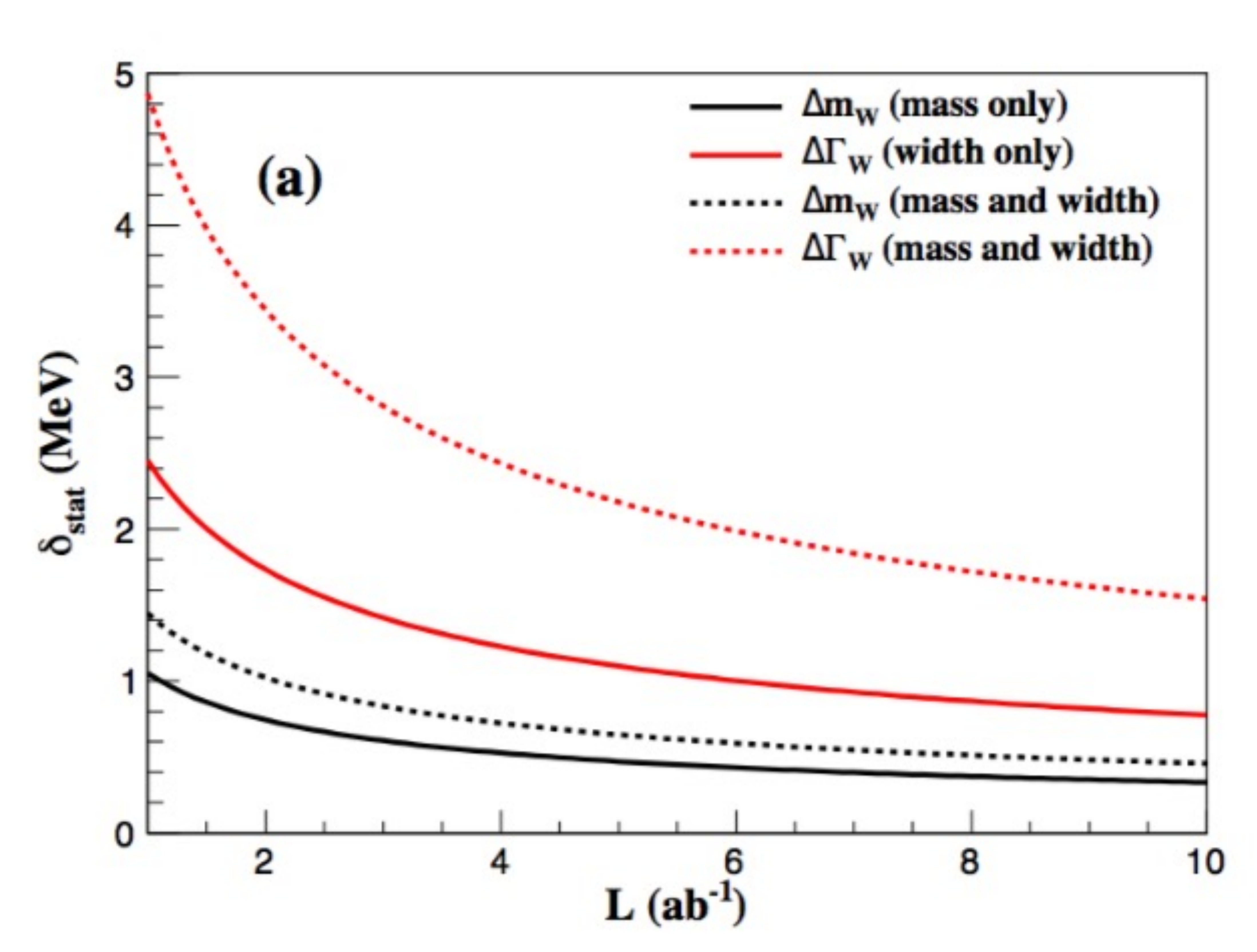


W mass measurements

- **Expect to reach 1MeV precision on W mass (12 MeV unc. in PDG fit in PDG2020)**
- **Four energy scan points:**
- 157.5, 161.5, 162.5(W mass, W width measurements)
- 172.0 GeV (α_{QCD} (m_W), Br (W->had) , CKM |Vcs|)
- 14M WW events in total
- 400 times larger than LEP2 WW runs)

P.X.Shen, P.Azzuri , G.Li et,al, Eur.Phys.J.C 80 (2020) 1, 66
Joint study of CEPC/Fcc-ee

Observable	m_W	Γ_W
Source	Uncertainty (MeV)	
Statistics	0.8	2.7
Beam energy	0.4	0.6
Beam spread	–	0.9
Corr. syst.	0.4	0.2
Total	1.0	2.8



Snowmass 2021

- **Submit five letter of intent (LOI) in snowmass 2021**
- **Weak mixing angle measurements at Z pole**
  - **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**
- **Bounds in aQGCs**
- **Z->bb branching ratio**

CEPC LOI of $Sin^2\theta_W$

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
□ (EF02) EW Physics: Higgs Boson as a portal to new physics
□ (EF03) EW Physics: Heavy flavor and top quark physics
□ (EF04) EW Precision Physics and constraining new physics
□ (EF05) QCD and strong interactions: Precision QCD
□ (EF06) QCD and strong interactions: Hadronic structure and forward QCD
□ (EF07) QCD and strong interactions: Heavy Ions
□ (EF08) BSM: Model specific explorations
□ (EF09) BSM: More general explorations
□ (EF10) BSM: Dark Matter at colliders
□ (Other) *[Please specify frontier/topical group]*

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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 $\sin^2\theta^{\ell}_{\text{eff}}$.

CEPC LOI : Z->bb

Snowmass2021 - Letter of Interest

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

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□ (EF05) QCD and strong interactions: Precision QCD
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□ (EF07) QCD and strong interactions: Heavy Ions
□ (EF08) BSM: Model specific explorations
□ (EF09) BSM: More general explorations
□ (EF10) BSM: Dark Matter at colliders
□ (Other) *[Please specify frontier/topical group]*

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Authors: Zhijun Liang, Bo Li, Bo Liu

Abstract: With an integrated luminosity of 45 ab^{-1} at $\sqrt{s} = 91.2$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.

CEPC LOI : TGC in WW

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

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

□ (EF01) EW Physics: Higgs Boson properties and couplings
□ (EF02) EW Physics: Higgs Boson as a portal to new physics
□ (EF03) EW Physics: Heavy flavor and top quark physics
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□ (EF10) BSM: Dark Matter at colliders
□ (Other) *[Please specify frontier/topical group]*

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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.

CEPC LOI : unitarity

Positivity bounds on quartic-gauge-boson couplings

Snowmass letter of intent

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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

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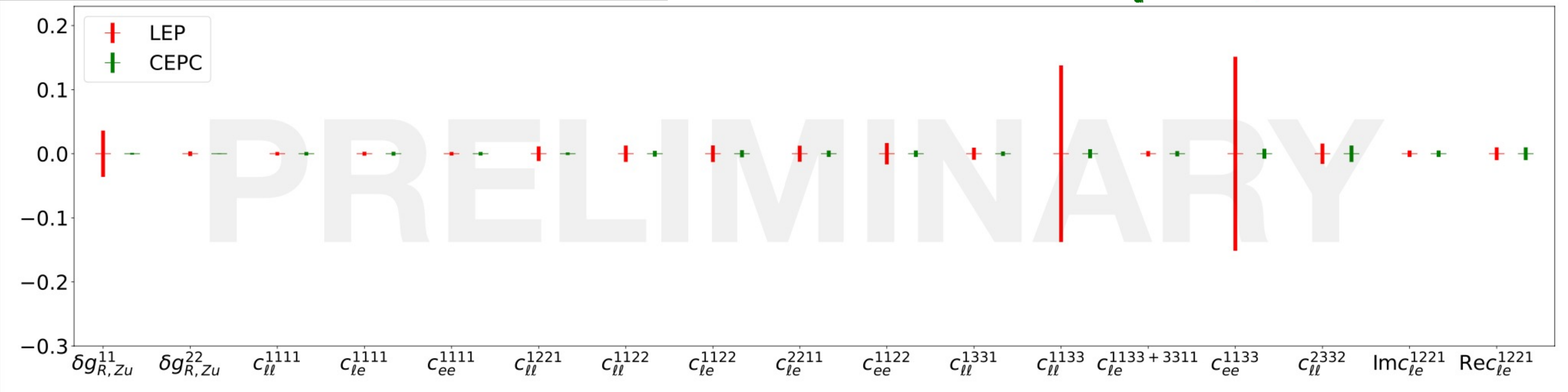
Probing new physics:

Search for new physics in CEPC
Z pole/ WW rus using 4-fermion operators

Yong Du (ITP, CAS)

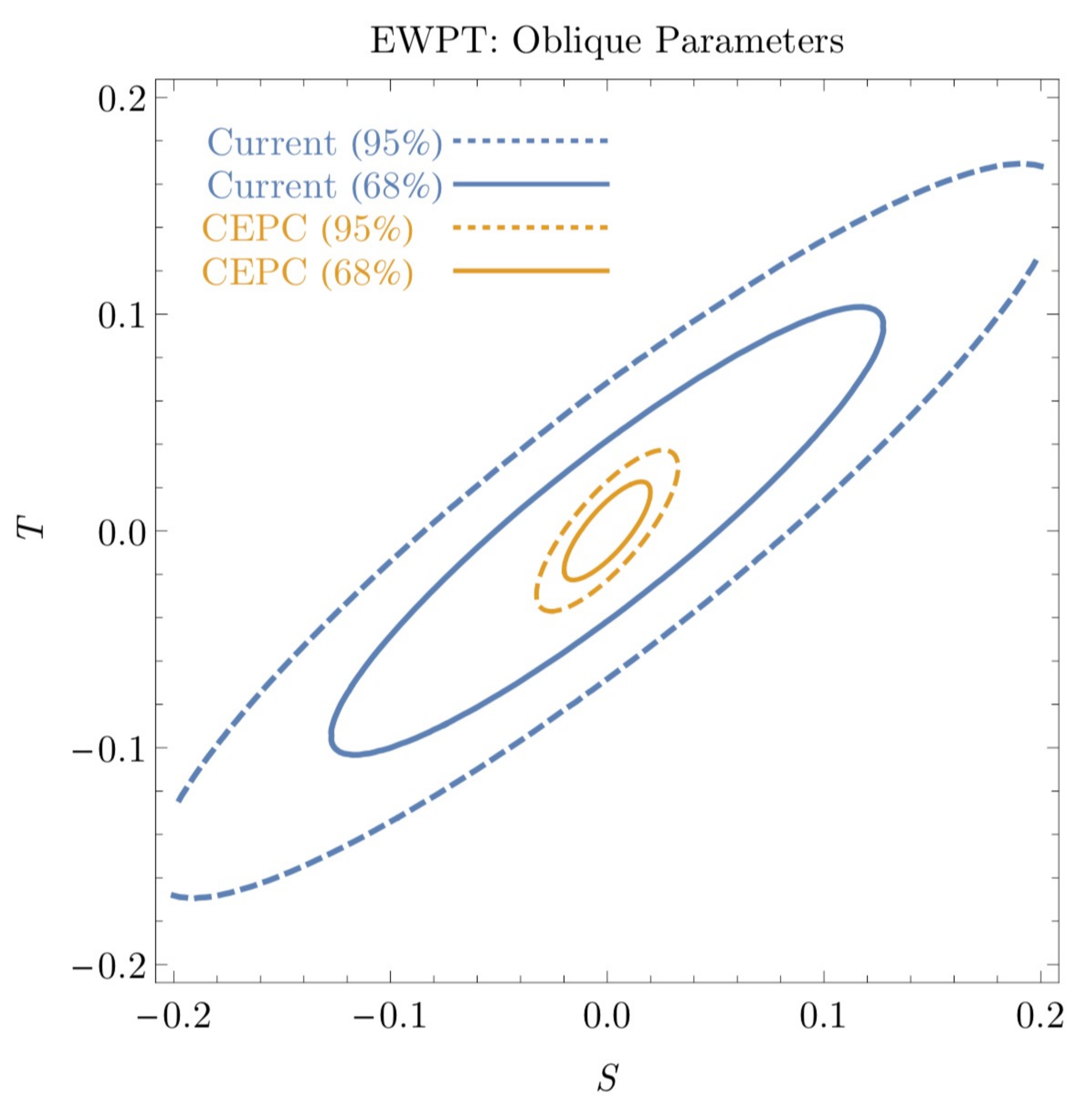
What in common for PVES and neutron decay? *4-fermion operators!*

<u>*PVES*</u>	<u>*Neutron decay*</u>
$\mathcal{O}_{le} = \frac{c_{\ell e}}{\Lambda^2}\left(\bar{\ell}\gamma_\mu \ell\right)\left(\bar{e}\gamma^\mu e\right)$	$\mathcal{O}_{lq}^{(3)} = \frac{c_{\ell q}^{(3)}}{\Lambda^2}\left(\bar{\ell}\gamma_\mu \tau^I \ell\right)\left(\bar{q}\gamma^\mu \tau^I q\right)$
Ignore flavor indices. Left-right symmetric model	Ignore flavor indices. Lepto-quark model
$\Lambda^{\text{Moller}} \gtrsim 10 \sim 50\,\text{TeV}$	$\Lambda^{\nu_\alpha \leftrightarrow \nu_\beta} \gtrsim \mathcal{O}(10)\,\text{TeV}$
The MOLLER collaboration, 1411.4088	YD, Li, Tang, Vihonen, Yu, 2011.14292

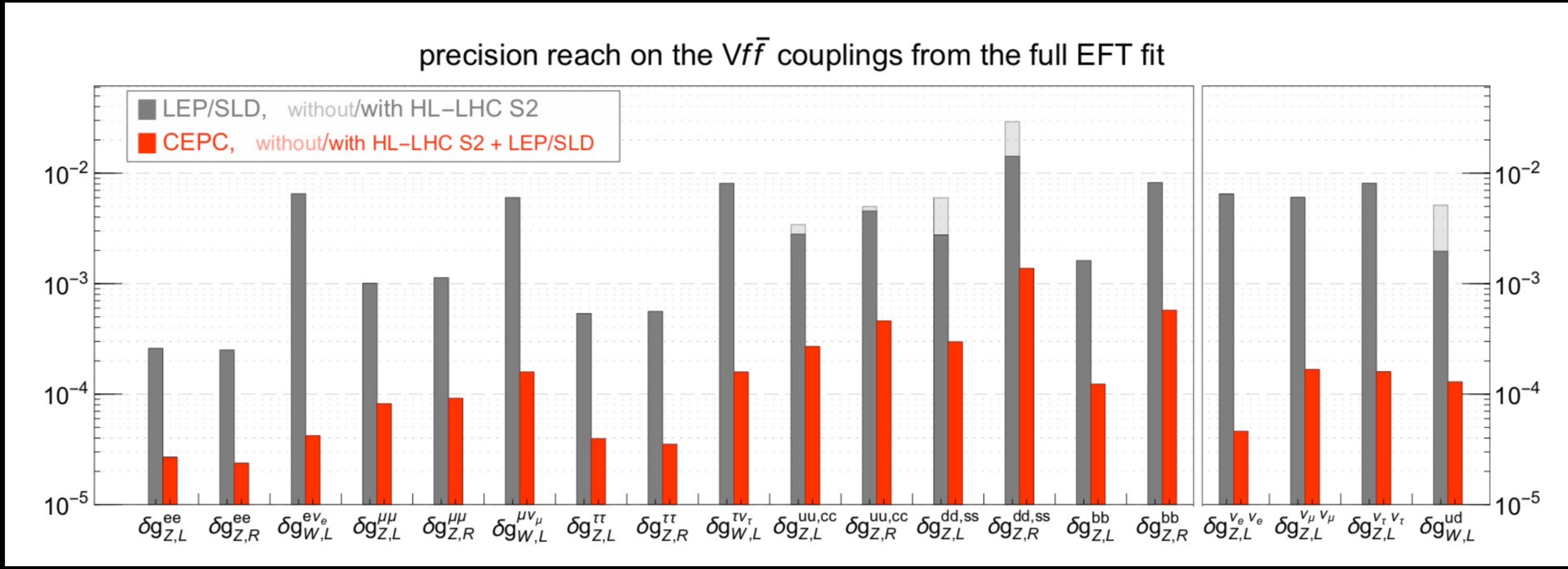


EWK white paper

- **Plan to have EWK white paper in one year , welcome for contributions**
  - **Prospects study of CEPC EWK precision measurements**
  - **implication study of EWK measurements.**
  - **Current draft on git.**
  - **http://cepcgit.ihep.ac.cn/CEPC-White-Paper/electroweak-physics.git/**

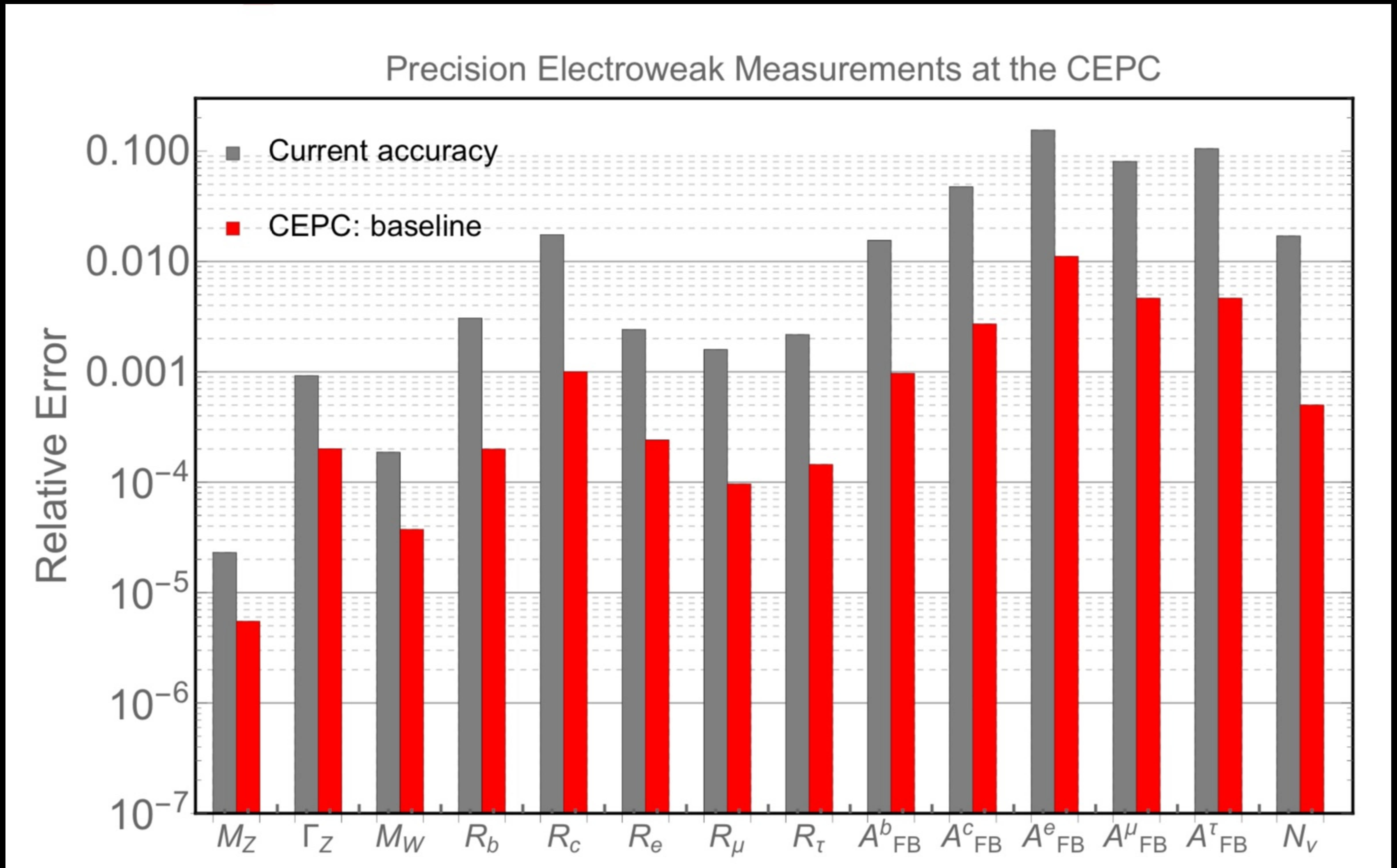


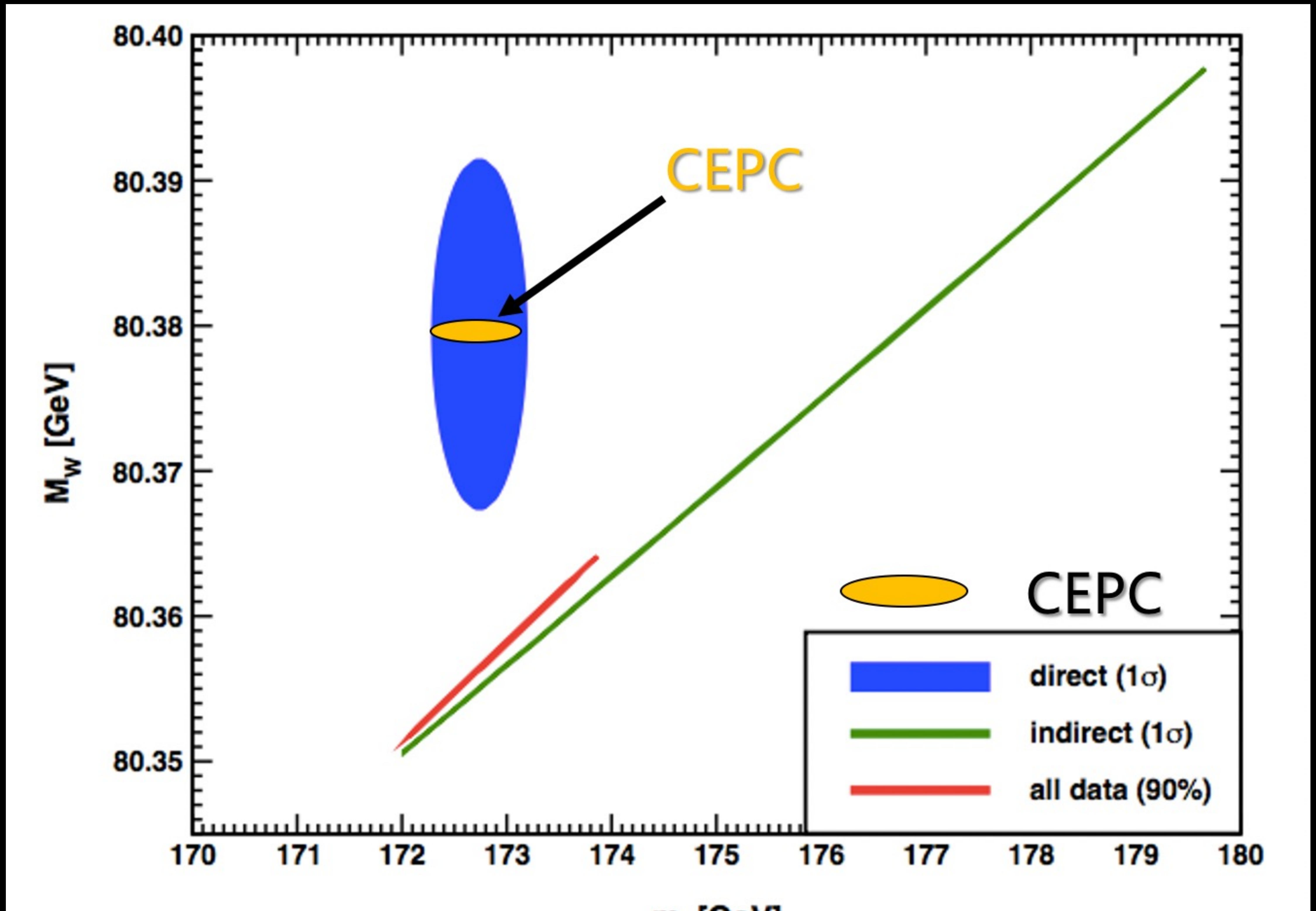
EFT with CEPC observable



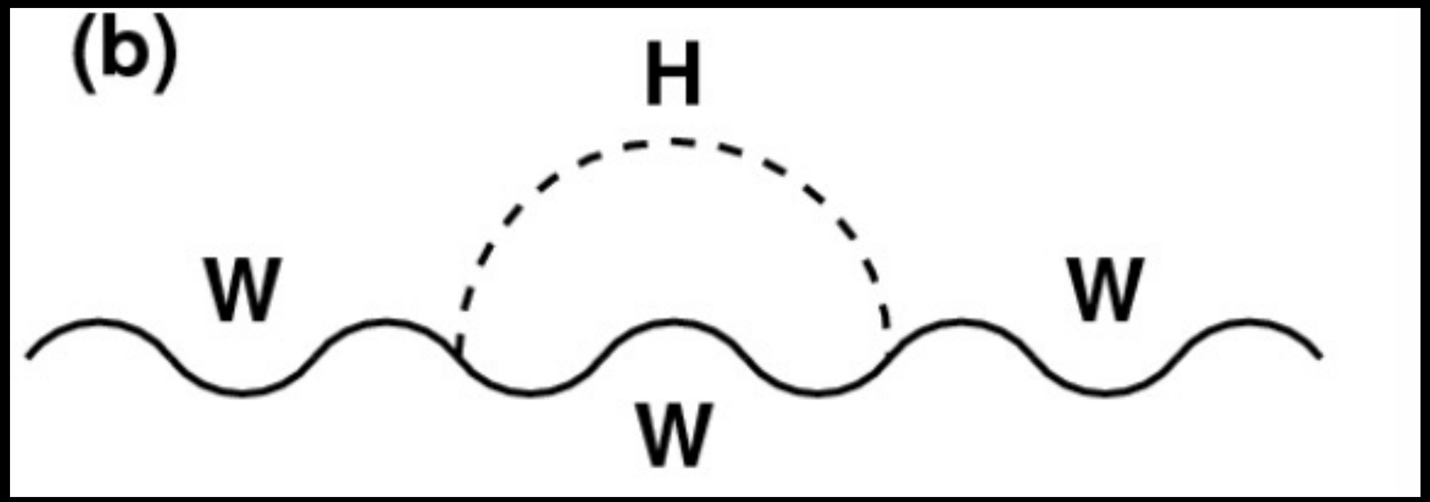
Summary

- Luminosity @ Z pole is now 3.2 times higher compared to CDR design
- ☐ Instant luminosity > $100*10^{34}cm^{-2}s^{-1}$
- ☐ >1.5 $X10^{12}$ Z boson (Two year Z pole running)
- Potential of electroweak measurement at CEPC
- ☐ 1~2 order of magnitude better than current precision
- ☐ May solve the puzzle in muon g-2, W mass and $Sin^2\theta_W$
- Please join us !



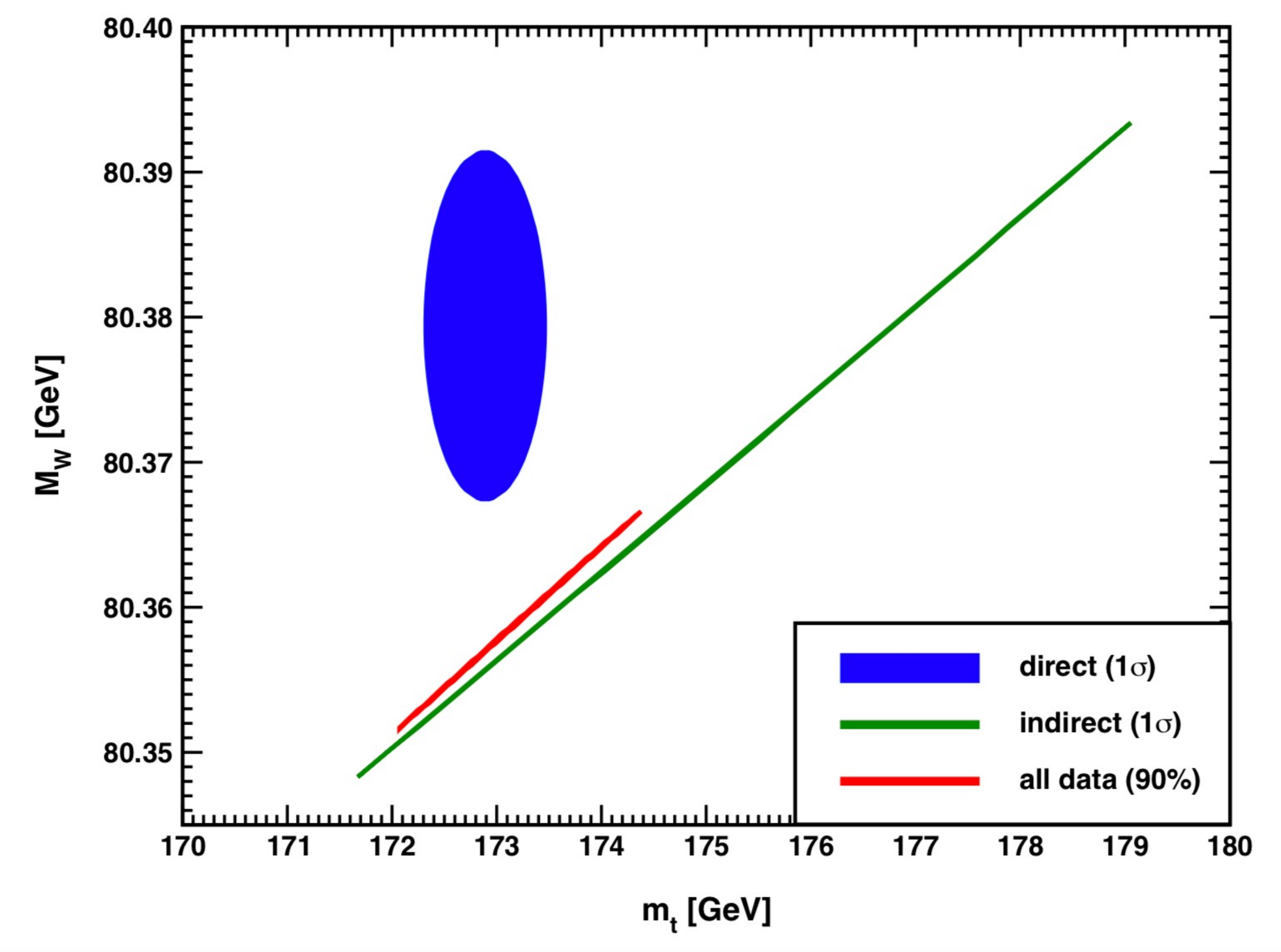


Backup:W mass measurements

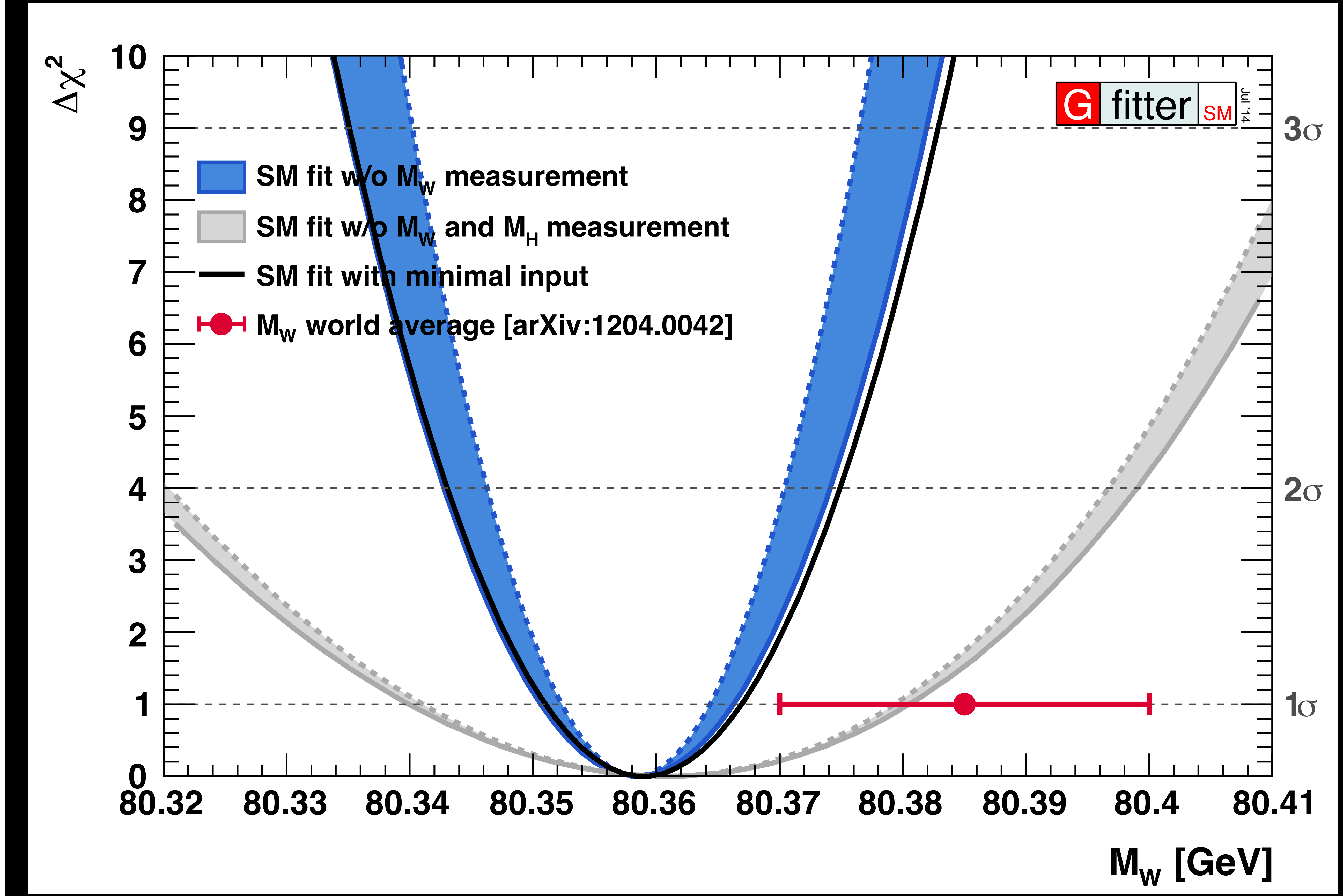


- W mass measurement is well motivated
  - ~2σ tension between direct measurements and EWK global fit
  - Indirect search for new physics

W mass (m_W) vs Top mass (m_t)



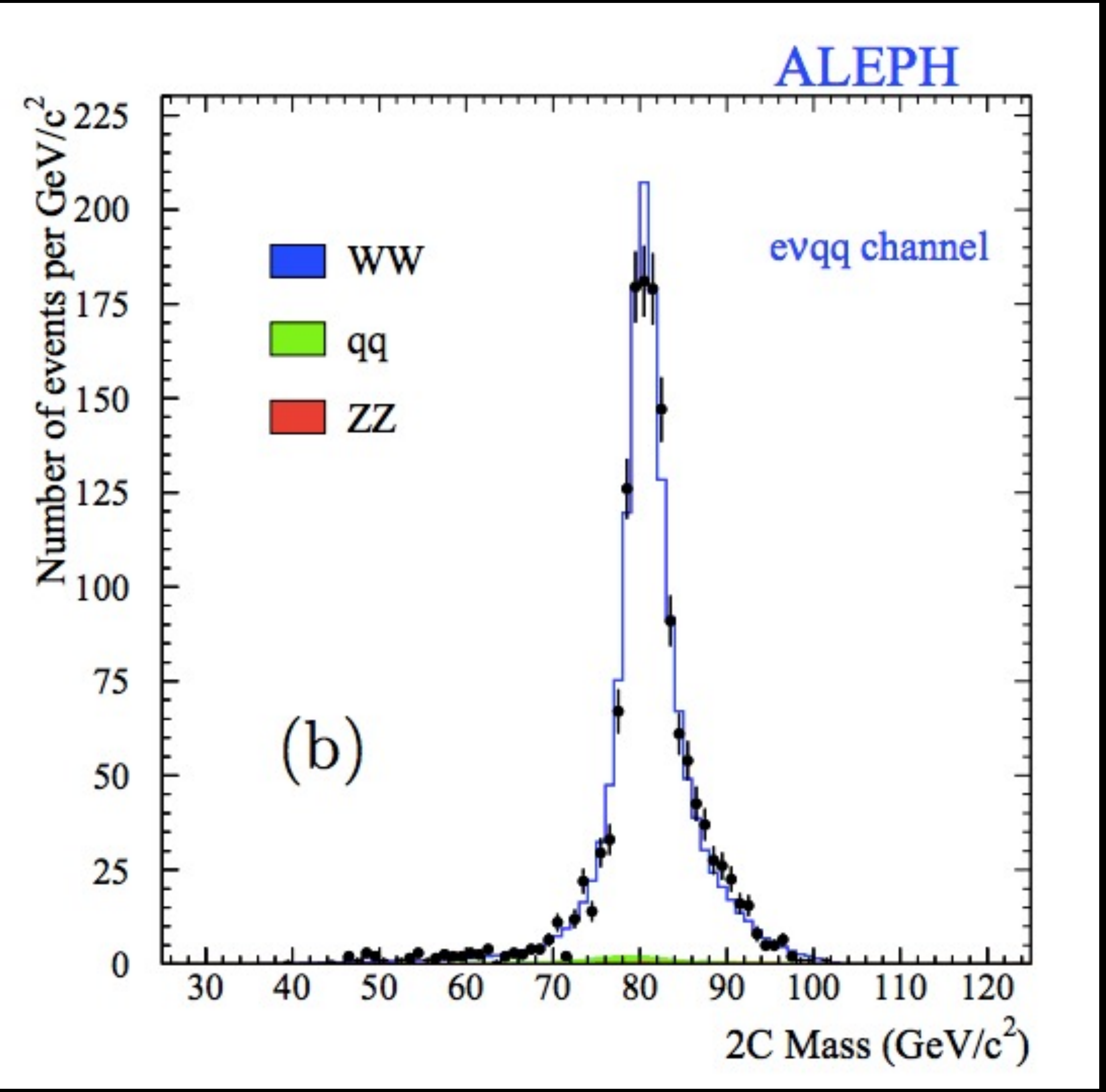
Chi2 distribution of W mass in EWK fit



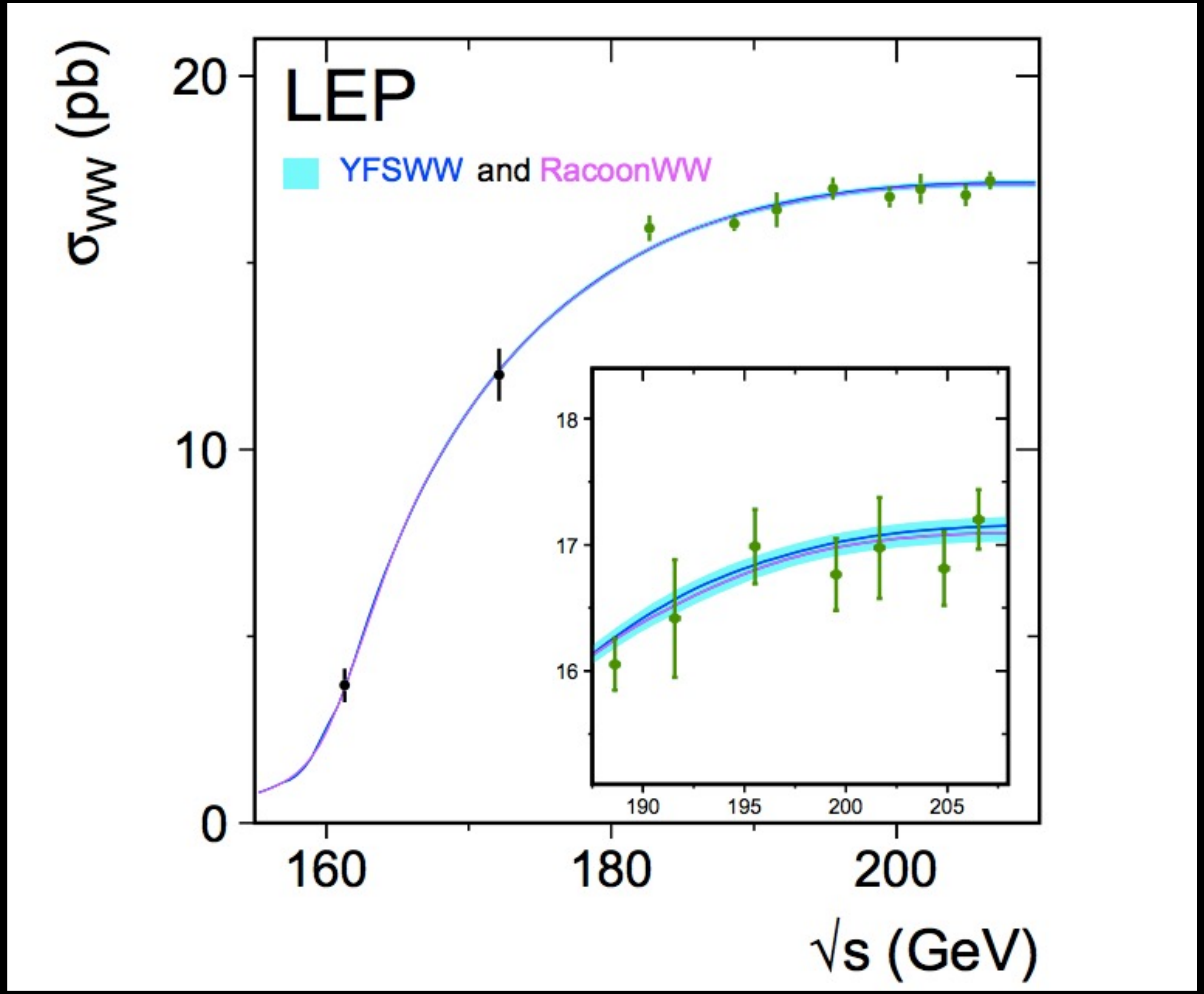
W mass measurement in lepton collider

- **Two approaches to measure W mass at lepton collider （developed by LEP)**

Direct measurement
performed in ZH runs (240GeV)
Precision 2~3MeV



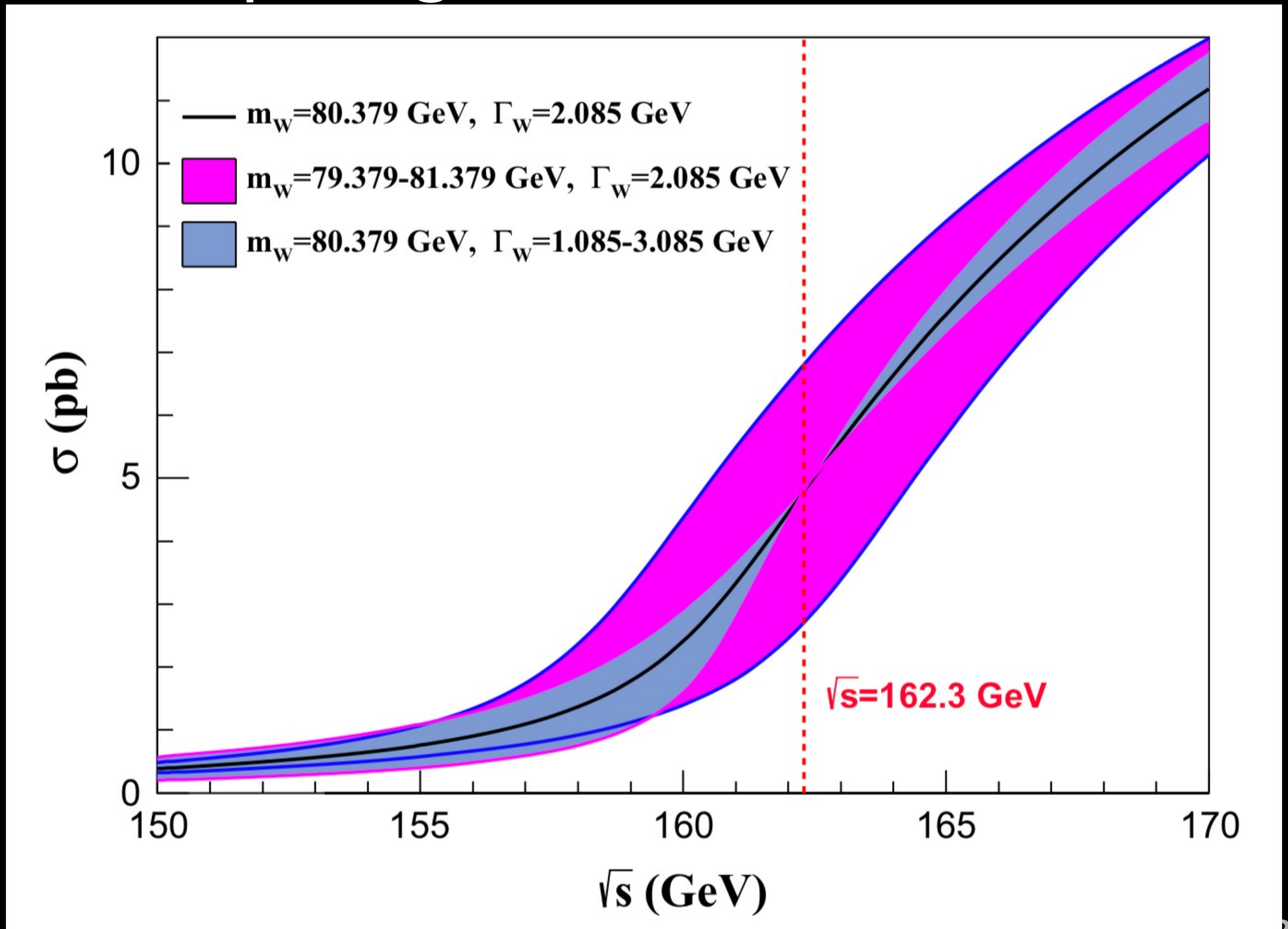
WW threshold scan
WW threshold runs (157~172GeV)
Expected Precision 1MeV level



W mass measurement in lepton collider

- **Optimization of data taking strategy in WW threshold scan**
- **Assuming one year data taking in WW threshold (2.6 ab^{-1})**
- **Four energy scan points:**
- 157.5, 161.5, 162.5(W mass, W width measurements)
- 172.0 GeV (α_{QCD} (m_W) measurement, Br (W->had) , CKM |Vcs|)
- 14M WW events in total(400 times larger than LEP2 comparing WW runs)

E_{cm} (GeV)	Lumiosity (ab^{-1})	Cross section (pb)	Number of WW pairs (M)
157.5	0.5	1.25	0.6
161.2	0.2	3.89	0.8
162.3	1.3	5.02	6.5
172.0	0.5	12.2	6.1

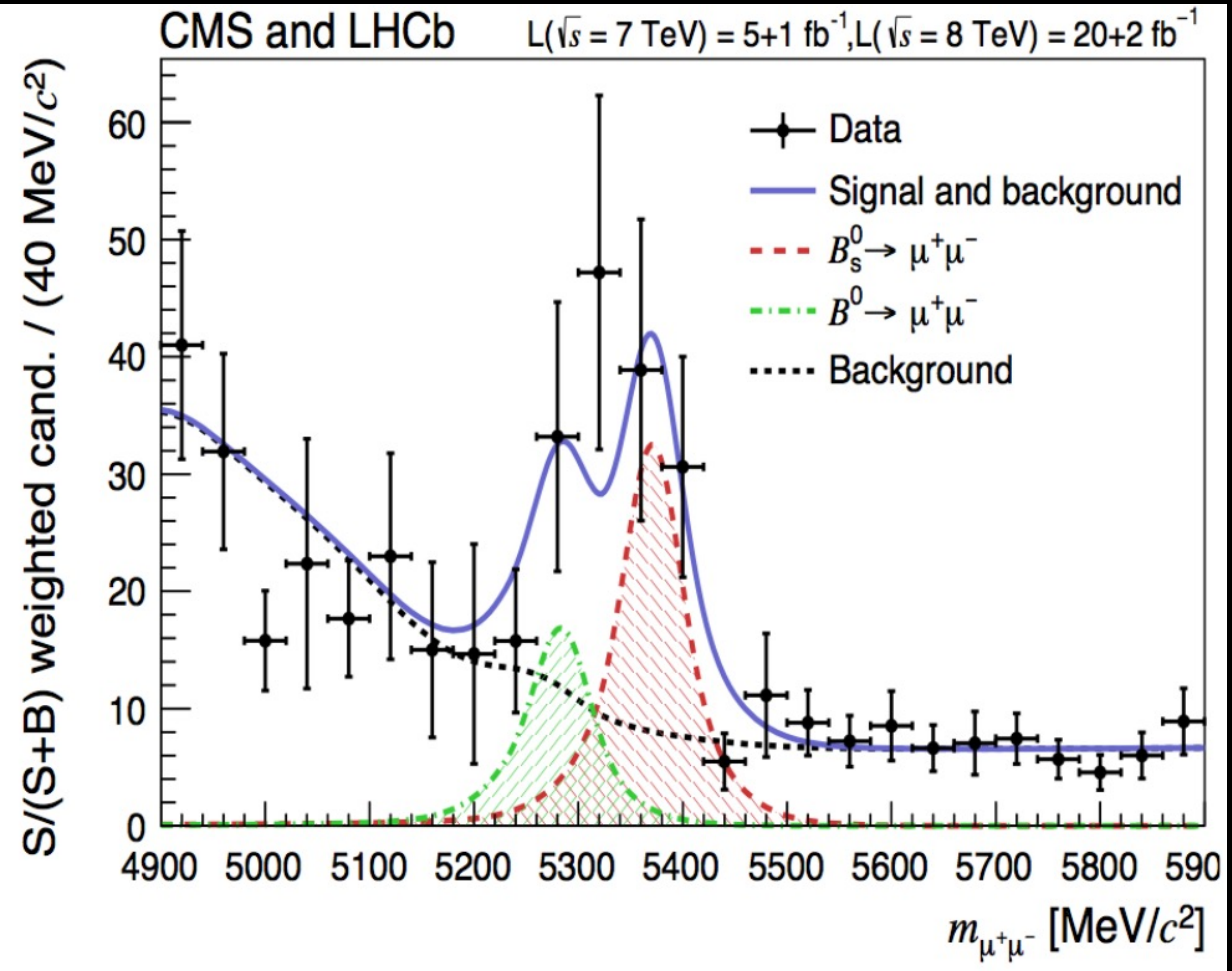


Backup: Track momentum resolution @ Z pole

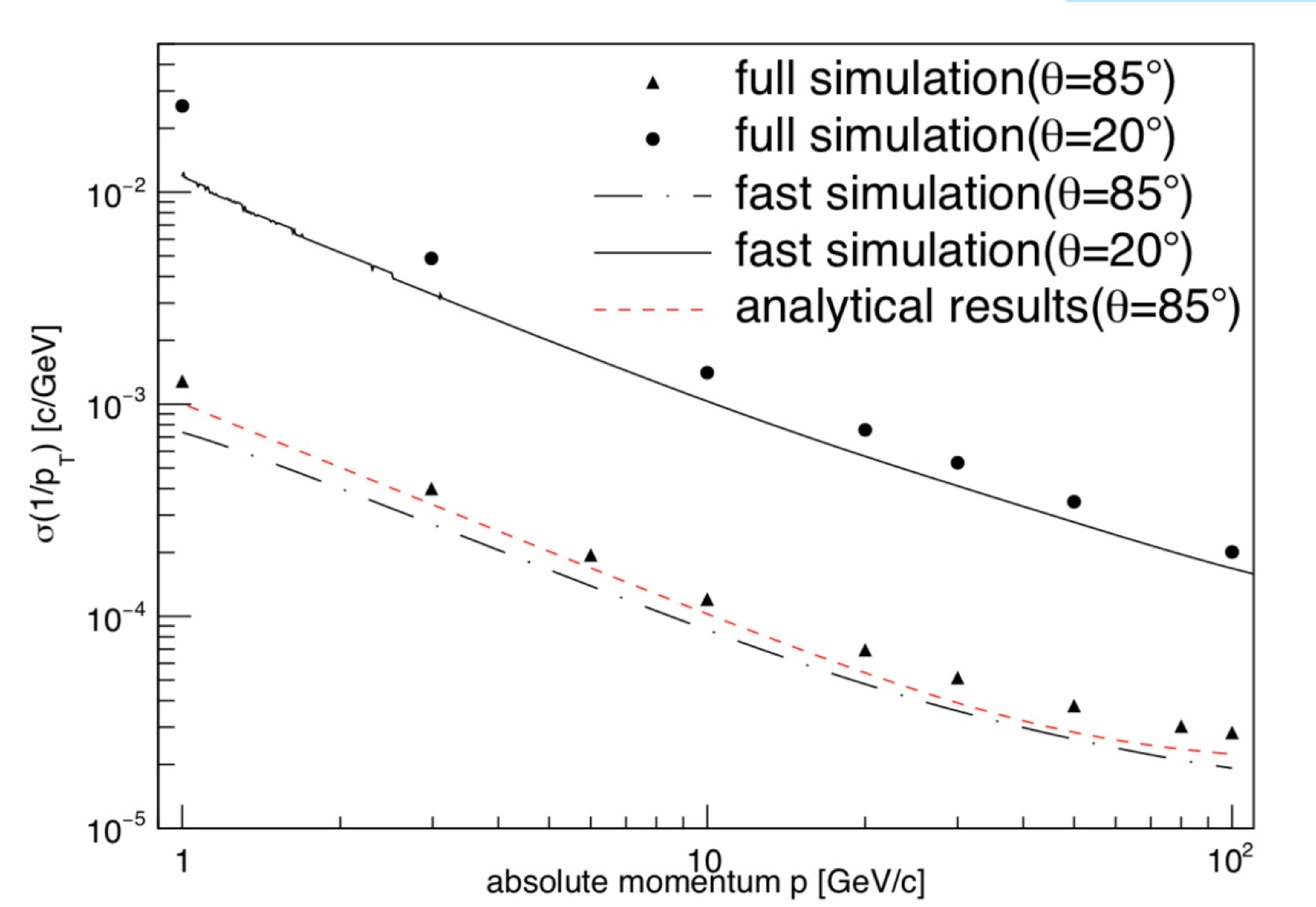
- Current optimization based on ZH runs @ 240GeV
- Most demanding case for low momentum track resolution is flavor physics
- Current design is good enough for EWK and flavor physics at Z pole

$$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$$

B_s / B^0 -> μ μ by CMS and LHCb



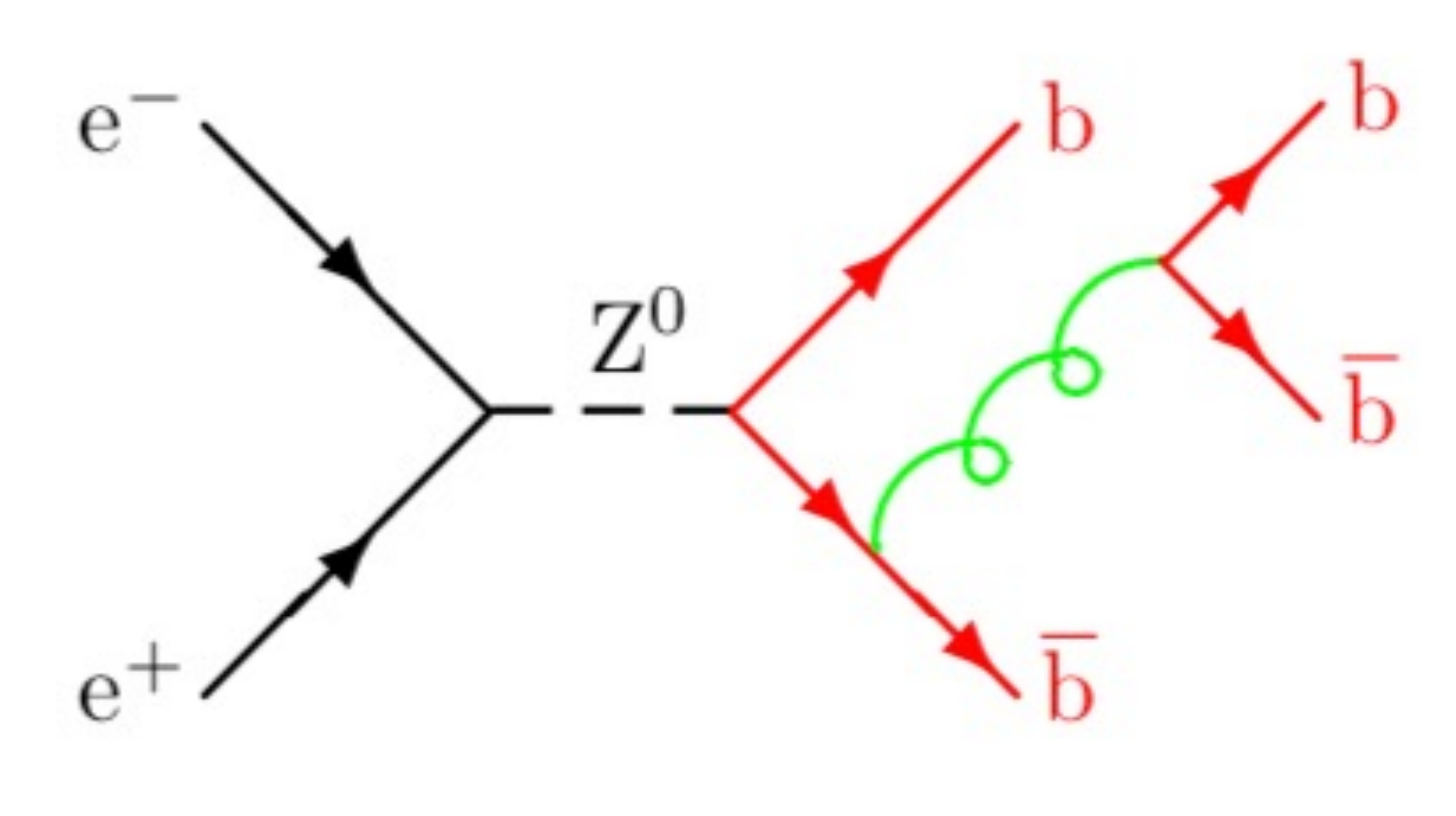
Momentum resolution in CEPC

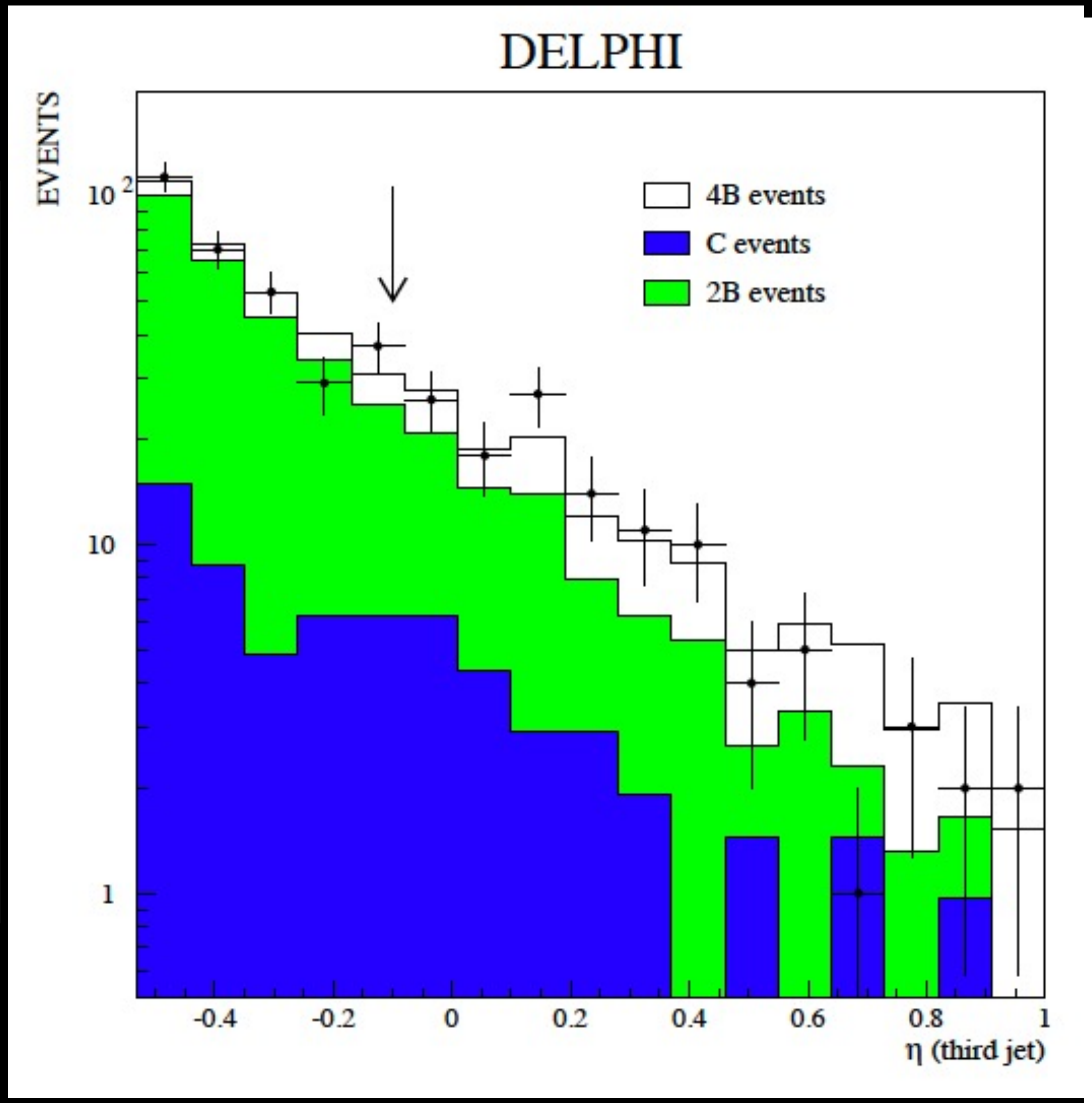


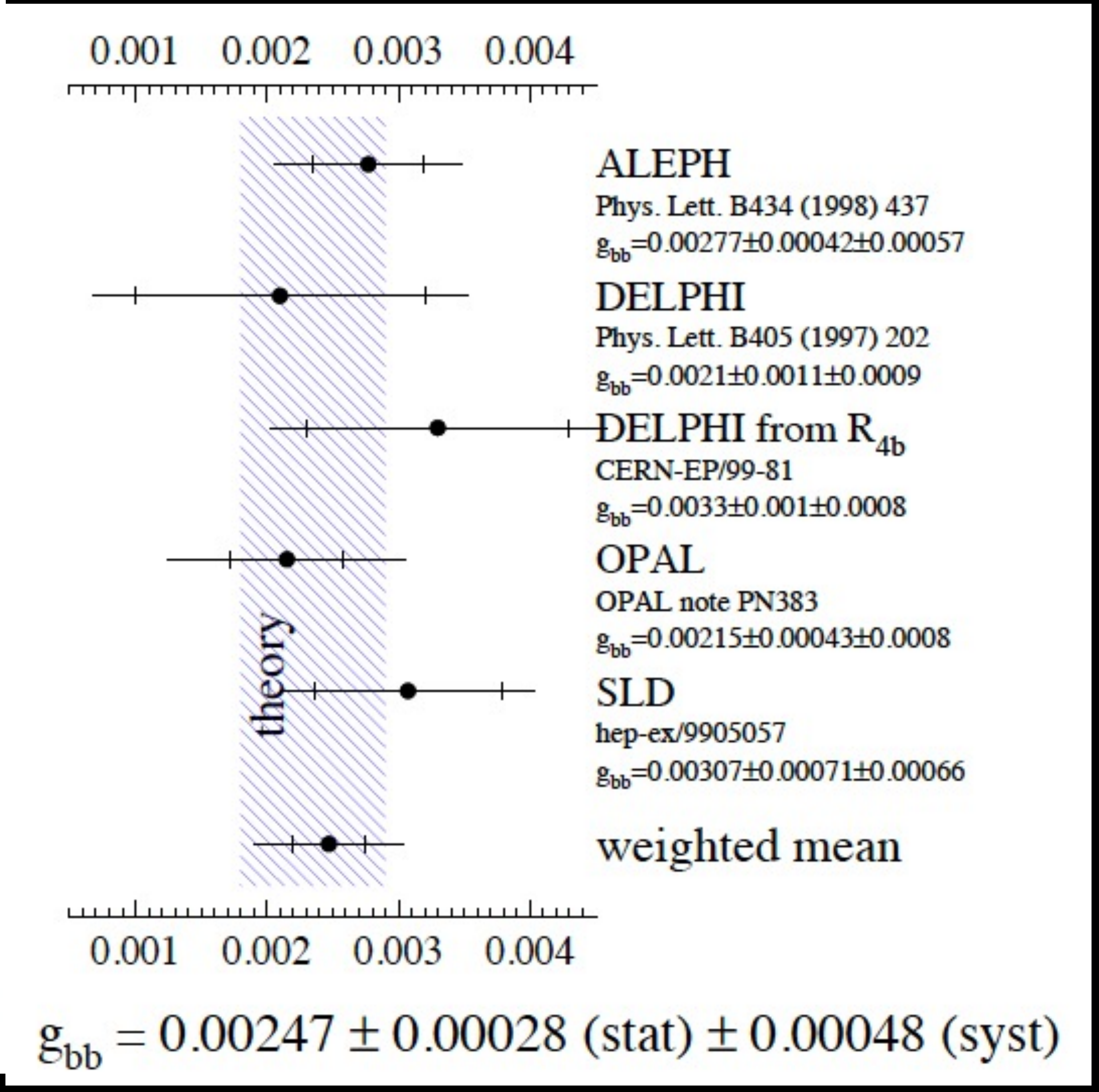
From CEPC CDR

R_b: gluon splitting

- Gluon splitting systematics is estimated by comparing data and MC simulation







DELPHI Z->4b analysis
Gluon splitting measurements

R^b: charm modelling and lepton ID

- Charm modelling : depends on input from flavor experiments (BELLEII…)
  - C hadron fractions (factions of D^+, D^0, D^+_s) → 0.2% syst. In R^b
  - LEP: Tagging efficiency for D+ is three times higher than D0
  - Need more study to check D meson tagging efficiency in Fcc-ee/CEPC

Source	$\Delta\epsilon^c/\epsilon^c$ (%)	$\Delta\epsilon^{uds}/\epsilon^{uds}$ (%)	ΔR_b
[illegible]	[illegible]	[illegible]	[illegible]
c hadron production fractions	3.66	-	0.00046
c hadron lifetimes	0.55	-	0.00007
c charged decay multiplicity	1.09	-	0.00014
c neutral decay multiplicity	2.39	-	0.00030
Branching fraction $B(D \to K^0)$	1.20	-	0.00015
c semileptonic branching fraction	2.44	-	0.00031
c semileptonic decay modelling	2.34	-	0.00029

Branching ratio (R^b): systematics

Source	$\Delta\epsilon^c/\epsilon^c$ (%)	$\Delta\epsilon^{uds}/\epsilon^{uds}$ (%)	ΔR_b
Tracking resolution	1.24	4.0	0.00017
Tracking efficiency	0.80	4.0	0.00014
Silicon hit matching efficiency	0.82	2.8	0.00009
Silicon alignment	0.58	2.1	0.00008
Electron identification efficiency	1.11	0.5	0.00015
Muon identification efficiency	0.64	0.2	0.00009
c quark fragmentation	2.26	-	0.00028
c hadron production fractions	3.66	-	0.00046
c hadron lifetimes	0.55	-	0.00007
c charged decay multiplicity	1.09	-	0.00014
c neutral decay multiplicity	2.39	-	0.00030
Branching fraction $B(D \to K^0)$	1.20	-	0.00015
c semileptonic branching fraction	2.44	-	0.00031
c semileptonic decay modelling	2.34	-	0.00029
Gluon splitting to $c\bar{c}$	0.34	6.3	0.00018
Gluon splitting to $b\bar{b}$	0.50	9.3	0.00027
K^0 and hyperon production	-	0.3	0.00001
Monte Carlo statistics (c, uds)	0.66	2.5	0.00010
Subtotal $\Delta\epsilon^c$ and $\Delta\epsilon^{uds}$	6.65	13.3	0.00090
Electron identification background			0.00039
Muon identification background			0.00041
Efficiency correlation ΔC^b			0.00066
Event selection bias			0.00033
Total			0.00129

$$\frac{\Delta R_b}{R_b} = -0.059\frac{\Delta\epsilon^c}{\epsilon^c} - 0.010\frac{\Delta\epsilon^{uds}}{\epsilon^{uds}} + \frac{\Delta C^b}{C^b}$$

Tracker resolution and efficiency(~0.1%)

Lepton identification (~0.1%)

Charm modeling (~0.4%)

Gluon splitting (~0.1%)

Background (~0.2%)

b-tagging corrections (~0.3%)

OPAL collaboration, Eur.Phys.J.C8:217-239,1999

R^b: b tagging hemisphere correlations

- Hemisphere is taken to be tagged
  - if it is tagged by either one or both of the secondary vertex and lepton tags.
- Major systematics: hemisphere correlations
  - The tagging efficiency correlation between the two hemispheres in one event:
    - ➢ Angular effects : due to inefficient regions of detector
    - ➢ QCD effects (g->bb)
    - ➢ Vertex effects : due to vertex fitting

$$C_b = \frac{\varepsilon_{2jet-tagged}}{(\varepsilon_{1jet-tagged})^2}$$

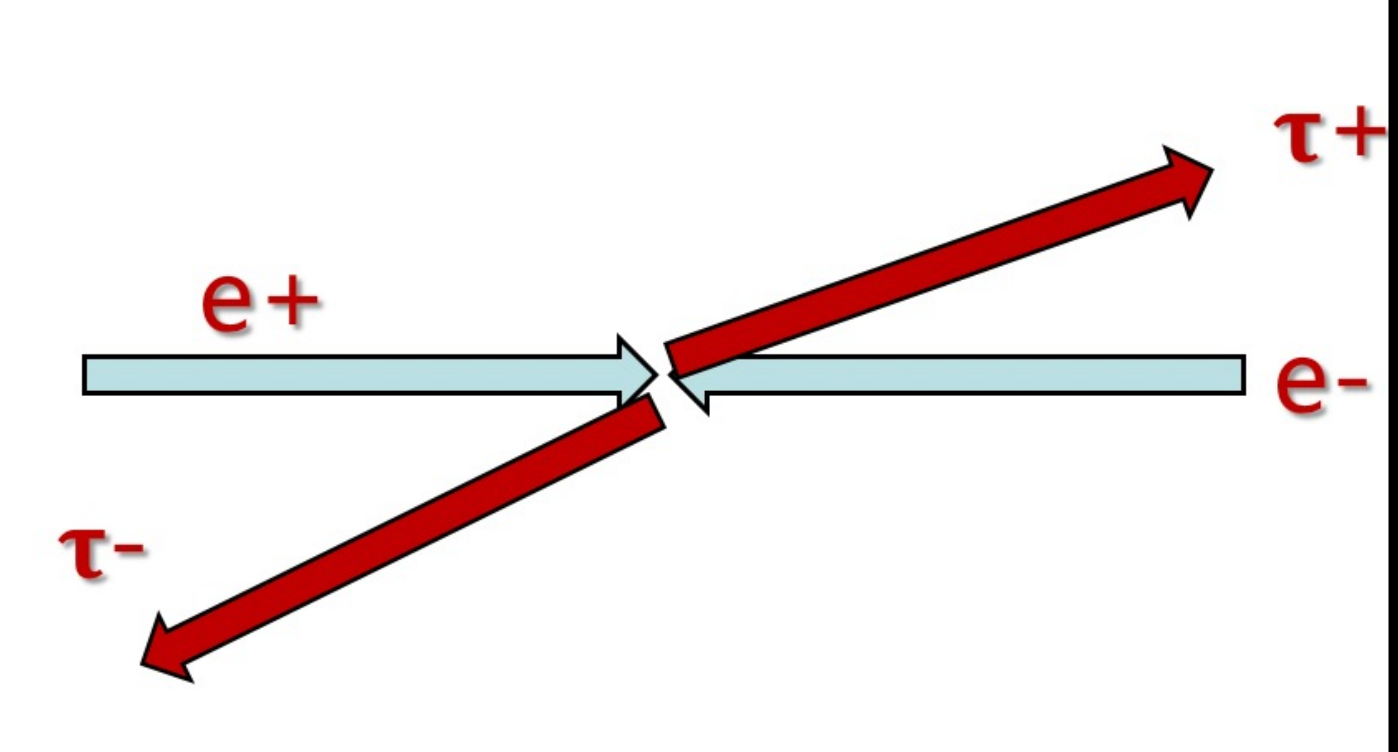
Single (N_t) and double tagged events (N_{tt})

- $$\begin{aligned} N_{\mathrm{t}} &= 2N_{\mathrm{had}}\{\epsilon^{\mathrm{b}}\ R_{\mathrm{b}} + \epsilon^{\mathrm{c}}\ R_{\mathrm{c}} + \epsilon^{\mathrm{uds}}\ (1-R_{\mathrm{b}}-R_{\mathrm{c}})\}, \\ N_{\mathrm{tt}} &= N_{\mathrm{had}}\{C^{\mathrm{b}}\ (\epsilon^{\mathrm{b}})^2\ R_{\mathrm{b}} + C^{\mathrm{c}}(\epsilon^{\mathrm{c}})^2\ R_{\mathrm{c}} + C^{\mathrm{uds}}(\epsilon^{\mathrm{uds}})^2\ (1-R_{\mathrm{b}}-R_{\mathrm{c}})\}, \end{aligned}$$

Weak mixing angle measurements

- $\sin^2\theta_W$ can be extracted very precisely from A_e and A_τ using tau polarization
- Major systematics of A_e precisely:

□ Tau ID efficiency and fake rate (expected to be comparable to stat. unc.)



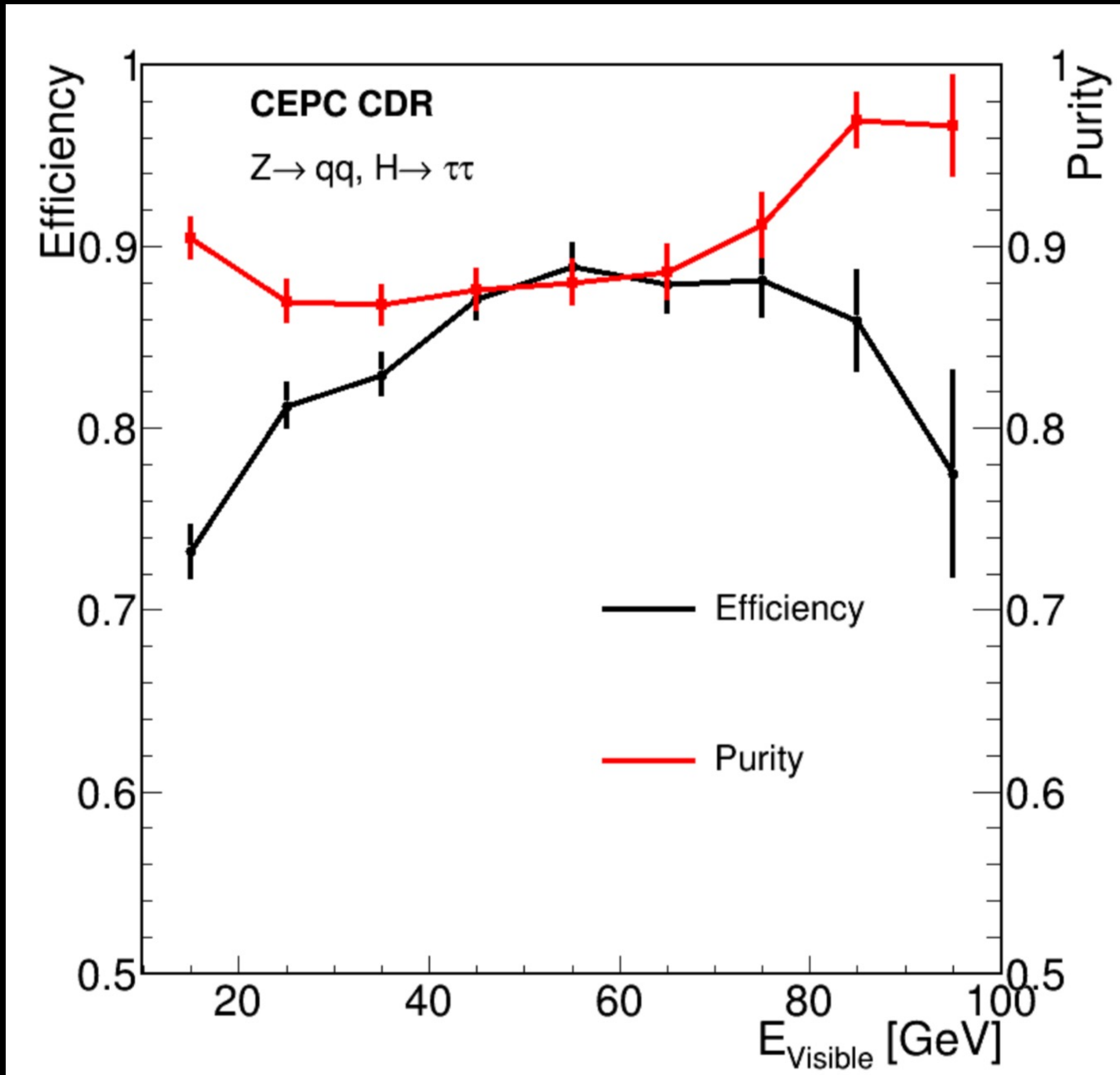
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \frac{1}{\langle|\mathcal{P}_e|\rangle}$$

$$A_{LRFB} = \frac{(\sigma_F - \sigma_B)_L - (\sigma_F - \sigma_B)_R}{(\sigma_F + \sigma_B)_L + (\sigma_F + \sigma_B)_R} \frac{1}{\langle|\mathcal{P}_e|\rangle}$$

Tau purity was already very good in LEP
even better at CEPC with better tau performance

τ decay mode	Number selected decays	Purity of the samples (%)
$\tau \to e\nu_e\nu_\tau$	18434	89.4 ± 0.1
$\tau \to \mu\nu_\mu\nu_\tau$	19811	94.3 ± 0.1
$\tau \to \pi/K\nu_\tau$	14850	73.2 ± 0.1
$\tau \to \rho\nu_\tau$	26548	75.4 ± 0.1
$\tau \to a_1\nu_\tau$	9446	53.2 ± 0.2

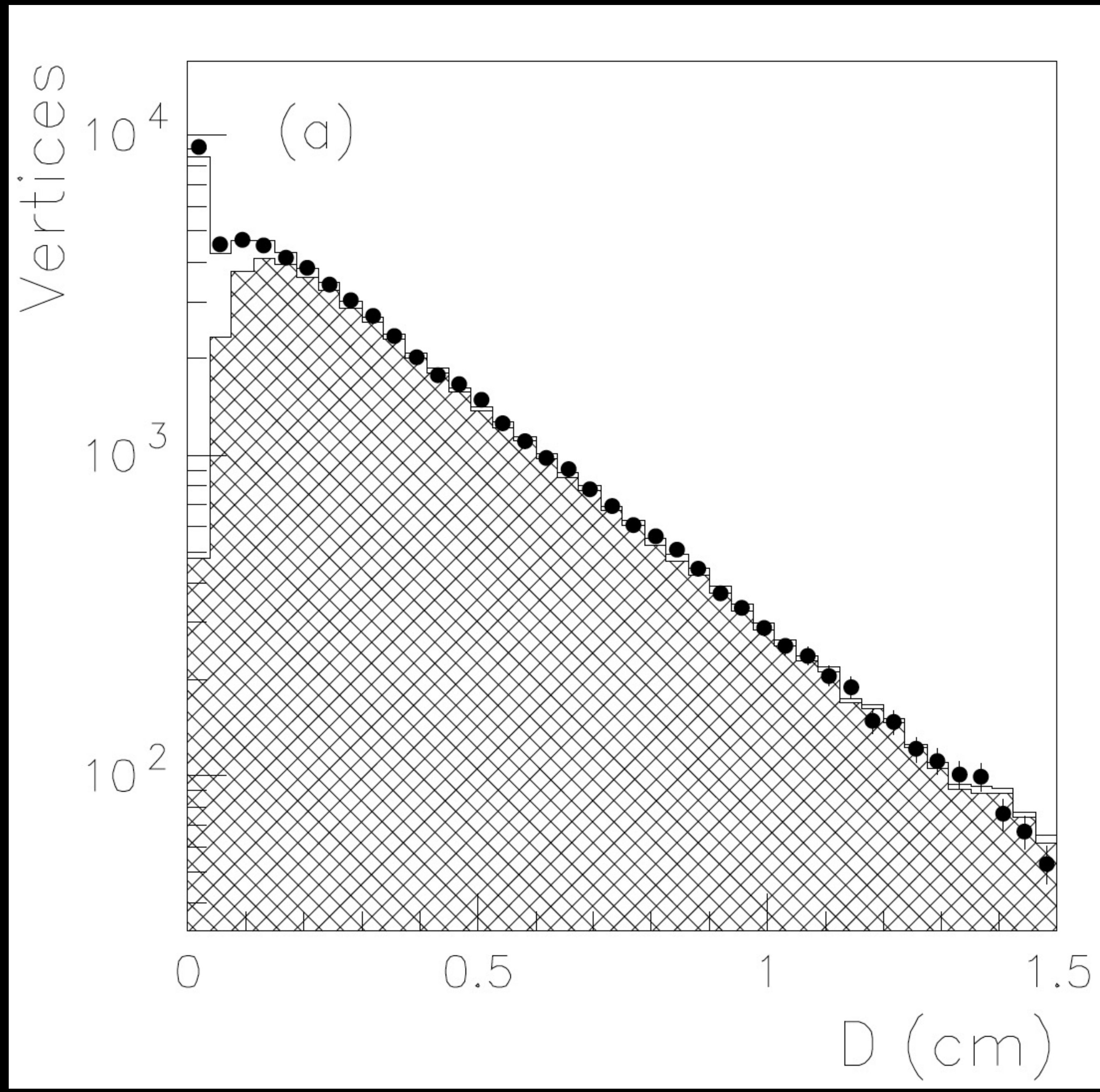


Branching ratio (R^b): detector requirement

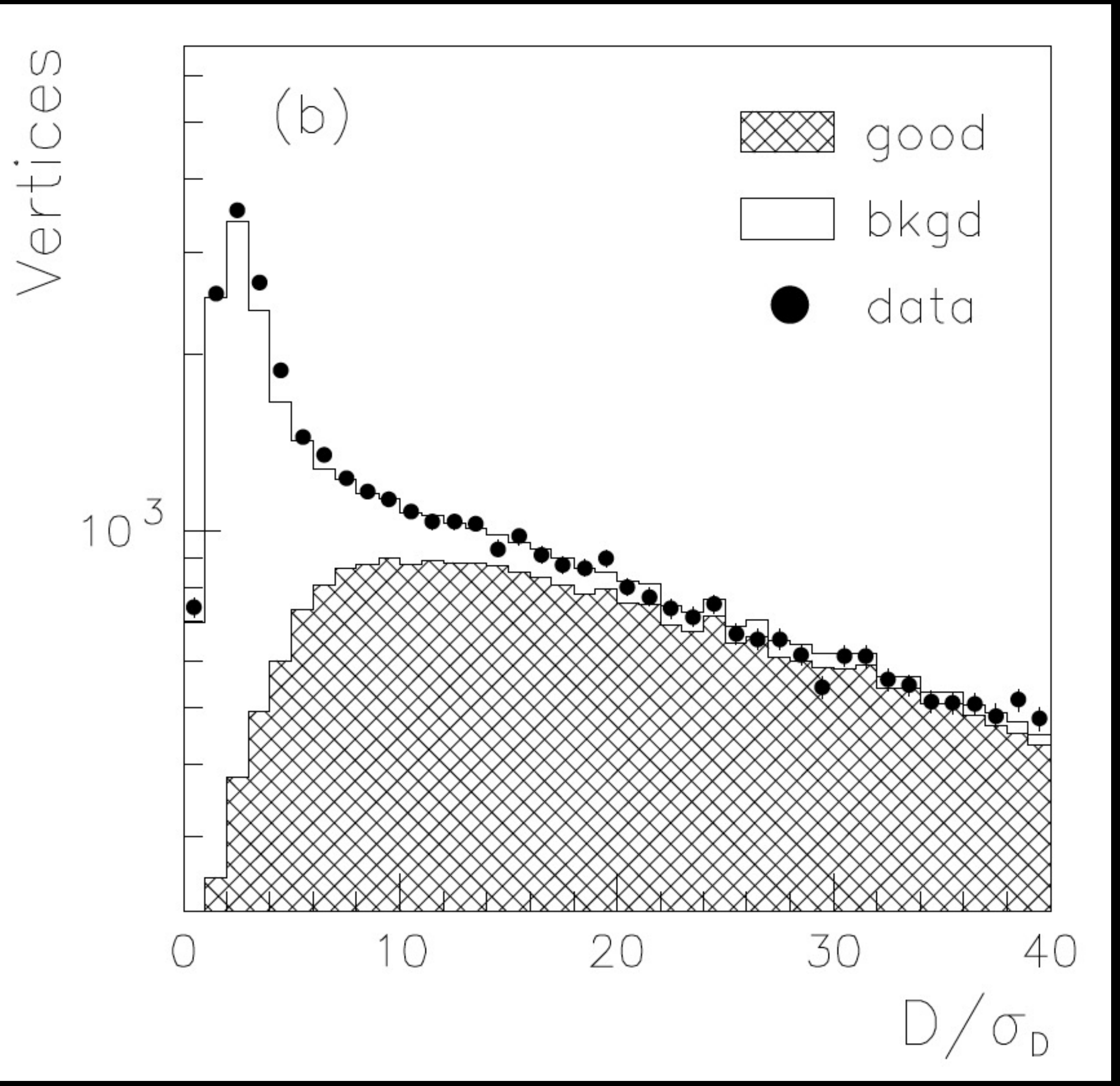
$$\frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to had)}$$

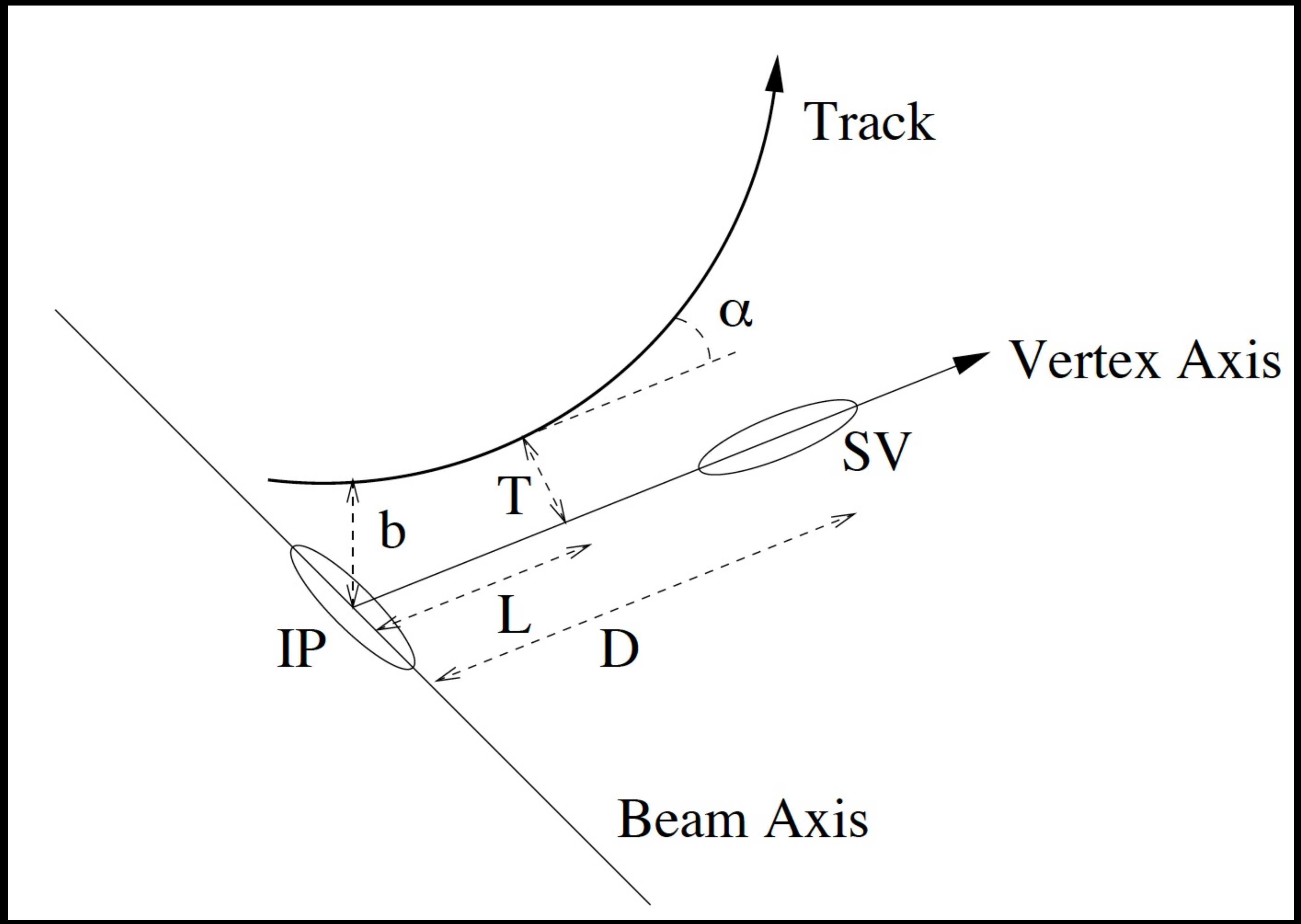
- Two ways to tag the b quarks in Z->qq events
  - Secondary Vertex tag (Average decay length of b meson of 2mm level at Z pole)
    - ➢ Multi-variant analysis : Impact parameter in R/φ and Z , mass of vertex …
  - Lepton tag
  - ➢ High momentum Electron and muon with pT>1GeV in a jet …

Vertex distance to IP



Vertex distance significance





SLD, Ann.Rev.Nucl.Part.Sci.46:395-469,1996

R^b: publication

Published at EPJP
By Li Bo (Yantai University)
B Tagging matrix approach

Eur. Phys. J. Plus (2021) 136:1
https://doi.org/10.1140/epjp/s13360-020-01001-7
THE EUROPEAN PHYSICAL JOURNAL PLUS

Regular Article

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Prospects of measuring R_b in hadronic Z decays at the CEPC

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Received: 7 July 2020 / Accepted: 8 December 2020

Abstract With an integrated luminosity of 45 ab^{-1} at $\sqrt{s}$ = 91.2 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. In this paper, the relative partial width, R_b, of Z boson into b quarks, is measured on the CEPC Monte Carlo 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 b-tagging correlation between the two jet hemispheres can be reduced. By carrying out a closure test, the double-tagging method is verified to work well as we expected. We further estimated the dependence of systematic errors on the b-tagging efficiencies of the charm and light jet, as well as the b-tagging correlation between two jet hemispheres. The sources of systematic errors, such as physics modeling and hemisphere correlation, are investigated and studied preliminarily. Several kinds of error sources related to the hemisphere correlation are studied with the characterized variables.

New study with template fit in preparation
By Li Bo (Yantai University)

Performance study of the relative decay width measurement in hadronic decays of Z boson at CEPC by using the template method

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Received: date / Revised version: date

Abstract. The Circular Electron Positron Collider (CEPC) was proposed by the Chinese particle physics scientists as a future Higgs factory and W/Z factory. It will produced more than 10^{12} Z bosons by operating at a centre-of-mass energy around 91.2GeV in two years. In this study, the measurement of the relative decay widths of Z bosons decaying to b quarks (R_b), c quarks (R_c) and light quarks(R_{uds}) in hadronic Z decays are studied on CEPC Monte Carlo (MC) samples. By using a template method, R_b, R_c and R_{uds} can be fitted from reconstructed data as the fractions of MC templates with different flavours. The distribution of a sensitive variable, b-tagging probability, is used as the template, because of its high performance in discriminating different flavours. Based on the expected statistics of 10^{12} Z bosons at CEPC, the statistical uncertainty is estimated to be approximately 10^{-6} by using the template method, which means that the measurement will no longer be limited by the statistics. Systematic errors arise directly from the difference in the b-tagging probability distribution between real data and template MC samples. By considering the bias of input variables used for b-tagging probability computing, the quantitative effect for each kind of input variable is investigated by using an ensemble test procedure.

Key words. CEPC – relative decay width – template method

PACS. 12.15.-y – 13.38.DG – 14.70.HP

Prospect of CEPC EWK physics

- Prospect of CEPC EWK physics was estimated by extrapolations from LEP
- Expect to have 1~2 order of magnitude better than current precision
- More study with simulation or more realistic estimation of systematics is needed