Physics at Z pole and WW runs

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Outline

- Introduction to precision electroweak physics
- Z pole physics
- W physics

Introduction

- CEPC have good potential in electroweak precision physics at Z pole.
  - Latest design in CEPC Z pole accelerator
  - L=1.6 X 10^{35} $cm^{-2}s^{-1}$ (one order of magnitude larger than pre-CDR)
  - Aim to have 10^{11} Z boson for electroweak precision physics
- The accelerator design for WW threshold scan runs are also updated
  - Total luminosity 2.5 ab^{-1}
  - Aim to have 1 MeV level precision for W mass measurement
  - More details in Hengne and Peixun's talk

Status of W/Z physics study in CEPC

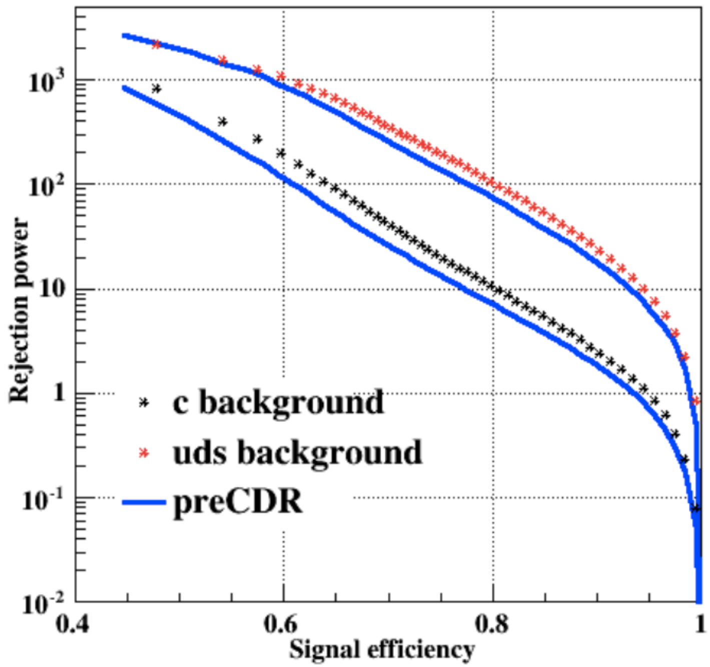
- The prospect of W/Z physics study in CEPC are under study
- Mainly based on projection from LEP

Observable	LEP precision	CEPC precision	CEPC runs	$\int \mathcal{L}$ needed in CEPC
m_Z	2 MeV	0.5 MeV	Z threshold scan	3.2ab^{-1}
$A_{FB}^{0,b}$	1.7%	0.1%	Z threshold scan	3.2ab^{-1}
$A_{FB}^{0,\mu}$	7.7%	0.3%	Z threshold scan	3.2ab^{-1}
$A_{FB}^{0,e}$	17%	0.5%	Z threshold scan	3.2ab^{-1}
R_b	0.3%	0.02%	Z pole	3.2ab^{-1}
R_μ	0.2%	0.01%	Z pole	3.2ab^{-1}
N_ν	1.7%	0.05%	ZH runs	5ab^{-1}
m_W	33 MeV	2-3 MeV	ZH runs	5ab^{-1}
m_W	33 MeV	1 MeV	WW threshold	2.5ab^{-1}

Branching ratio (R^b)

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

- LEP measurement 0.21594 ±0.00066 (~0.3%)
  - Stat unc and Systematics Unc. Have similar contribution
- CEPC
  - Expected Stat Unc. Is neglectable
  - Expected Syst error (0.02%)
  - Expect to use 80% working points
    - 15% higher efficiency than SLD
    - 20-30% higher in purity than SLD



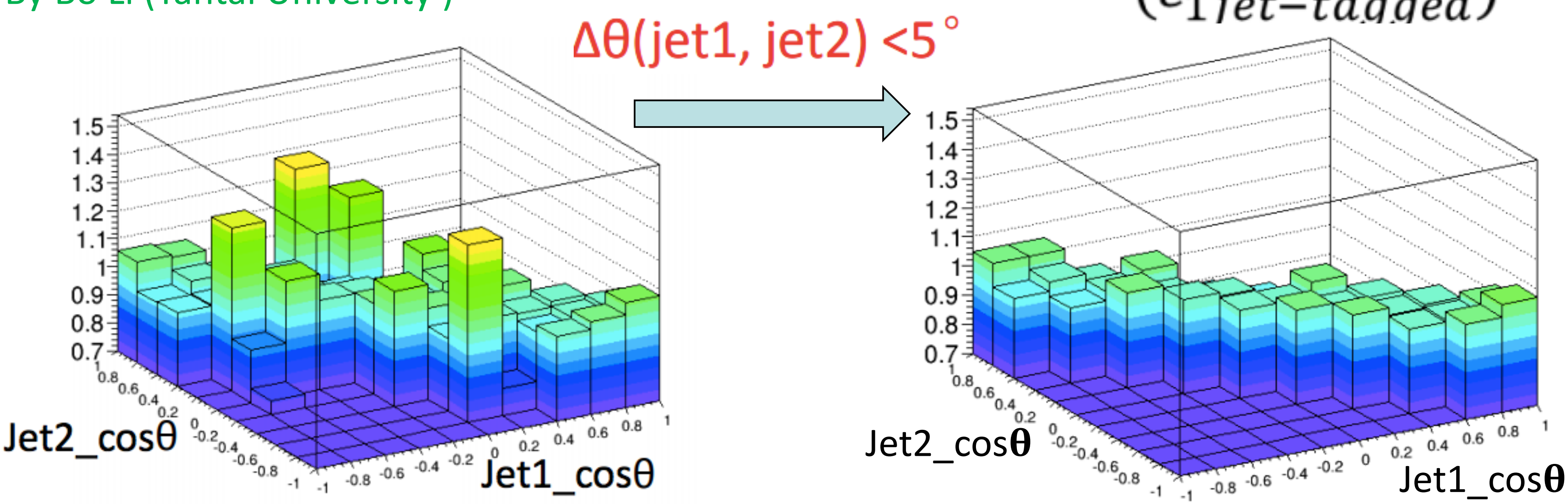
Uncertainty	LEP	CEPC	Thing to improve
hemisphere tag correlations for b events	0.2%	0.02%	B tagging performance, pixel
gluon splitting	~0.15%	0.01%	Better granularity in Calo

R^b : hemisphere tag correlations

- Study hemisphere b tag correlations systematics with full simulation
- Two ways to reduce correlations factor -> reducing systematics
  - Using tighter cuts to choose Z->bb events
  - Use different B jet tagger (soft muon tag Vs impact parameter/ 2nd vertex)
  - Correlations factors c_b need to be reduced below 0.01% (systematics 0.02%)

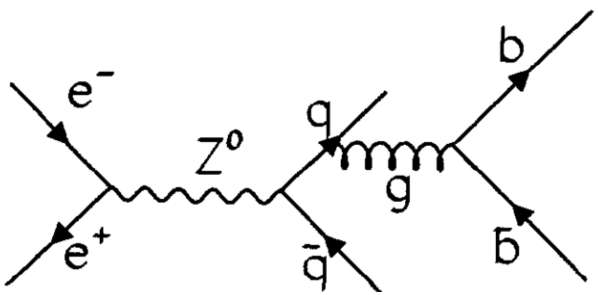
$$C_b = \frac{\varepsilon_{2\,jet-tagged}}{(\varepsilon_{1\,jet-tagged})^2}$$

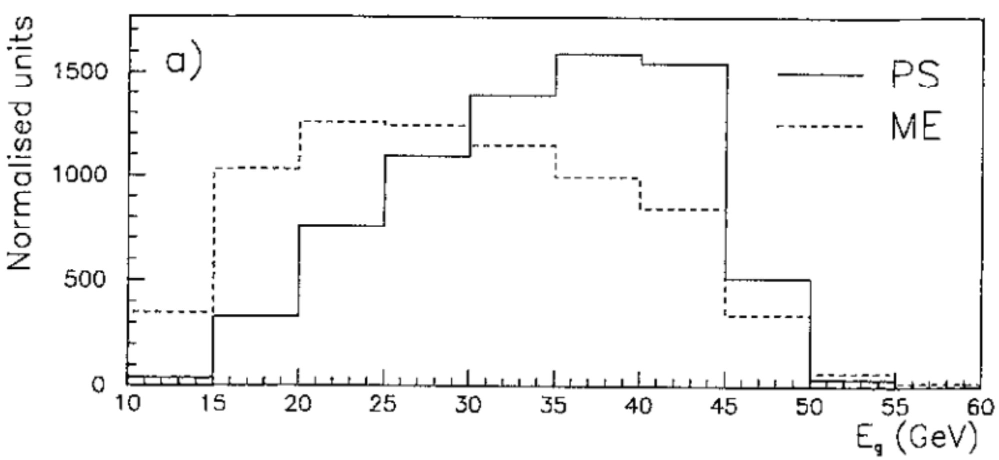
By Bo Li (Yantai University)



Branching ratio (R^b): gluon splitting

- To reduce the R_b systematics
  - Another task is to measure gluon splitting
  - plan to setup dedicated analysis for gluon splitting measurement





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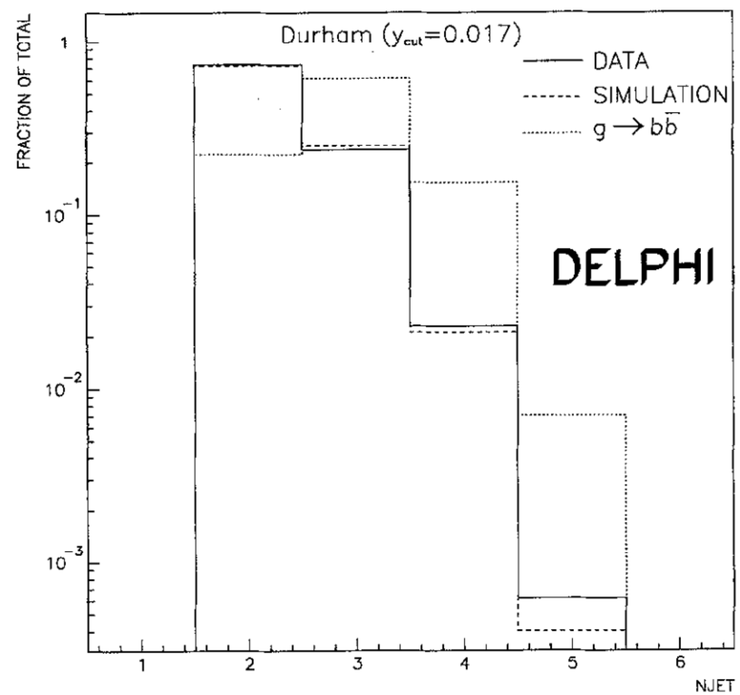
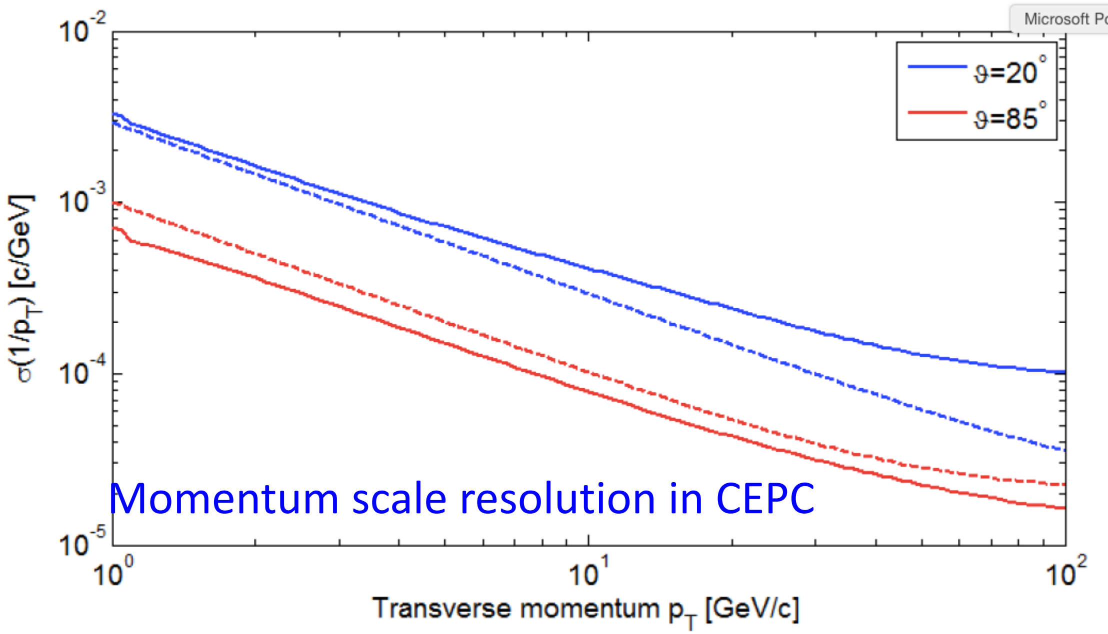


Branching ratio (R^{μ})

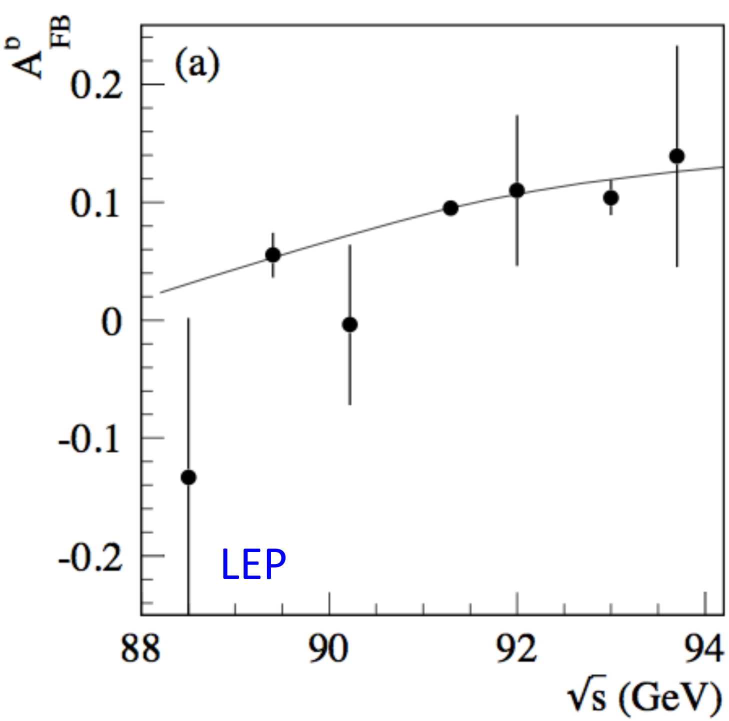
- LEP result: 0.2% total error (Stat : 0.15%, Syst : 0.1%)
- CEPC : 0.01% total error expected
  - Higher granularity and better resolution in EM calorimeter is the key

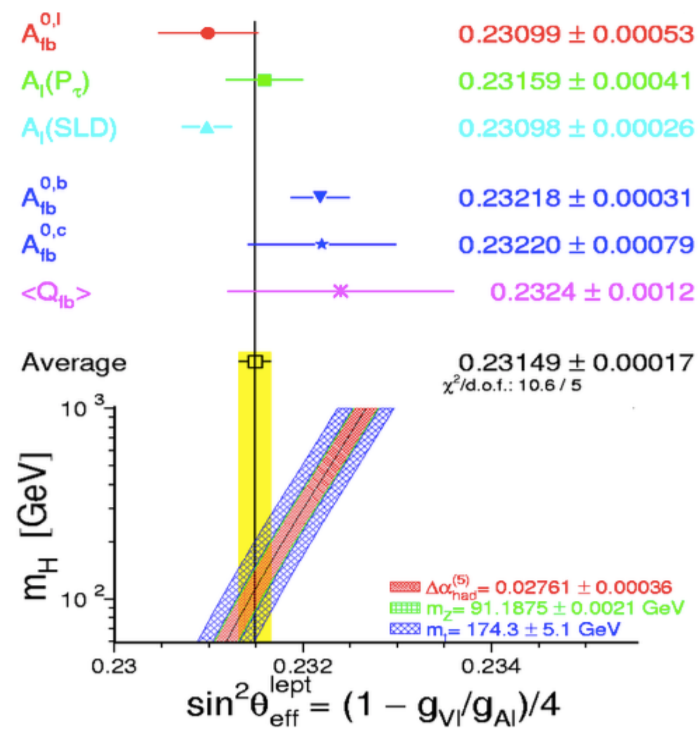


Systematics source	LEP	CEPC
Radiative events (Z->μμγ)	0.05%	0.01%
Muon Momentum scale	0.009%	<0.005%

Weak mixing angle $\sin^2\theta_{eff}^{lept}$

- LEP/SLD: 0.23153 ± 0.00016
  - ~0.07% precision. (Stat error is limiting factor.)
- CEPC
  - Aim for 0.002% precision
    - Input from Backward-forward asymmetry measurement of Z->bb and Z->μμ
    - Z->ee, Z->ττ have not been studied yet.



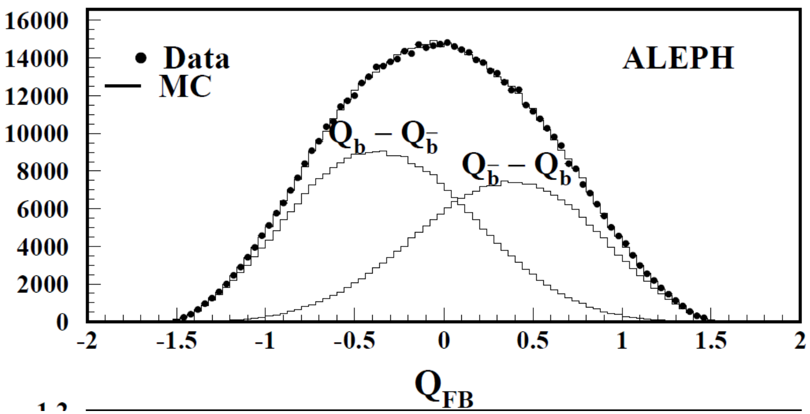


Backward-forward asymmetry

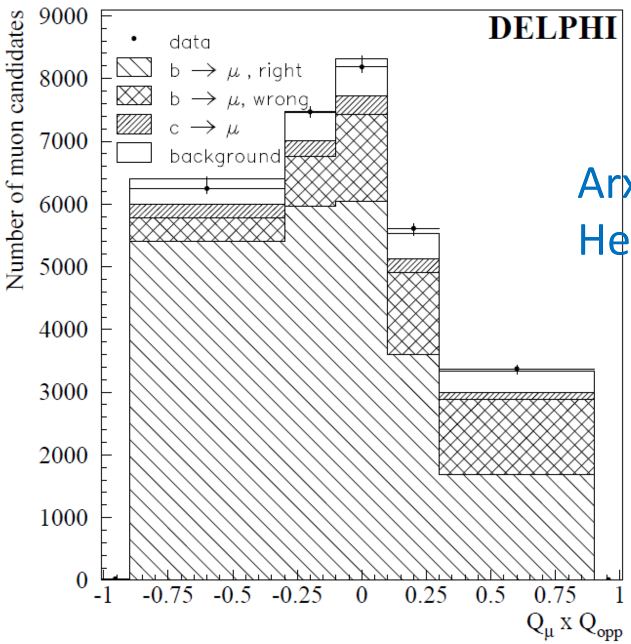
- LEP measurement : 0.1000+-0.0017 (Z peak)
  - Method 1: Soft lepton from b/c decay (~2%)
    - Select one lepton from b/c decay, and one b jets
    - Select lepton charge (Q_lepton) and jet charge (Q_jet)
  - Method 2: jet charge method using Inclusive b jet (~1.2%)
    - Select two b jets
    - use event Thrust to define the forward and background
    - Use jet charge difference (Q_F - Q_B)

Arxiv:Hep-ex/0107033

Q_F - Q_B in method 2



Q_lepton - Q_jet in method 1



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Backward-forward asymmetry $A_{FB}^{b\bar{b}}(0)$

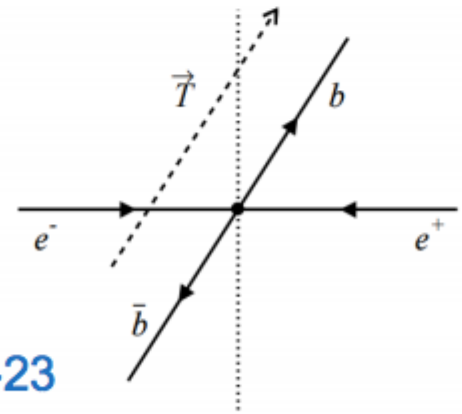
- LEP measurement : 0.1000+-0.0017 (Z peak)
    - Method 1: Soft lepton from b/c decay (~2%)
    - Method 2: jet charge method using Inclusive b jet (~1.2%)
    - Method 3: D meson method (>8%, method)
- CEPC
    - Focus more on method 2 (inclusive b jet measurement)
    - Expected Systematics (0.15%) :

Uncertainty	LEP	CEPC	Things to improve
hemisphere tag correlations for b events	1.2%	0.1%	Higher b tagging efficiency
QCD and thrust axis correction	0.7%	0.1%	

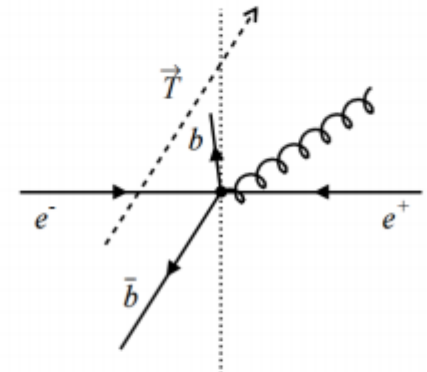
Backward-forward asymmetry $A_{FB}^{b\bar{b}}(0)$

- Uncertainty Afb_b due to QCD correction to Thrust
  - Higher order QCD effect is major systematics

CERN-EP/98-23



(a) No gluon



(d) Thrust forward, quark backward

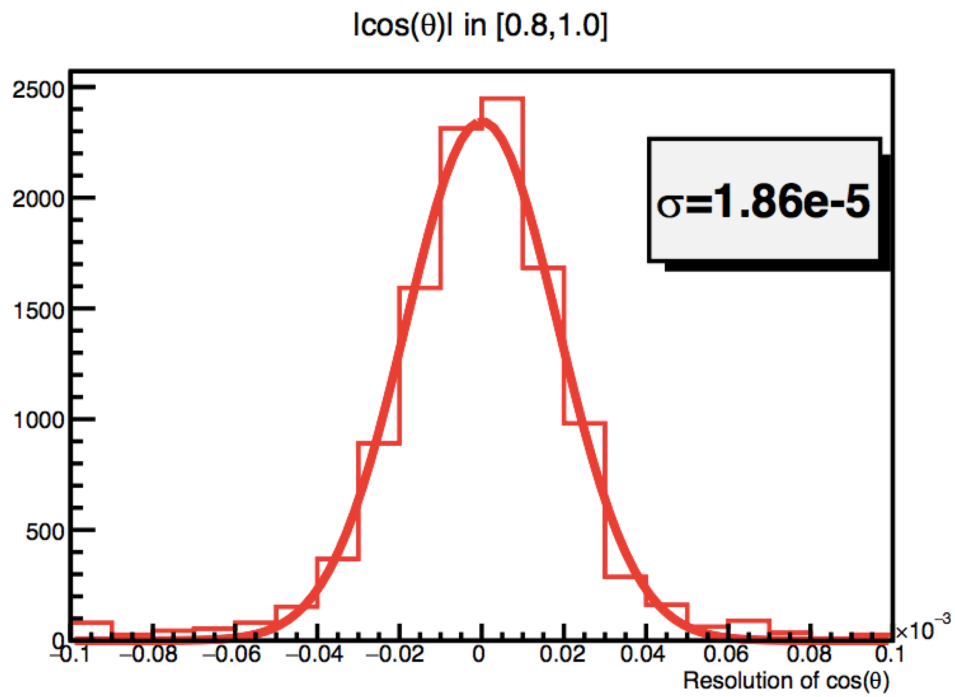
Error source	$C_{\mathrm{QCD}}^{\mathrm{quark}}$ (%)		$C_{\mathrm{QCD}}^{\mathrm{part,T}}$ (%)	
	$b\bar{b}$	$c\bar{c}$	$b\bar{b}$	$c\bar{c}$
Theoretical error on m_b or m_c	0.23	0.11	0.15	0.08
$\alpha_s(m_Z^2)$ (0.119 ± 0.004)	0.12	0.16	0.12	0.16
Higher order corrections	0.27	0.66	0.27	0.66
Total error	0.37	0.69	0.33	0.68

Backward-forward asymmetry in Z->μμ

$A_{FB}^{(0,\mu)}$

- LEP measurement : 1.69% +-0.13%(PDG fit)
- CEPC aim to improve it by a factor of 20~30 .
  - muon angular resolution and acceptance
  - the precision of beam energy measurement
- Full simulation studies to understand muon angular resolution
  - Muon angular resolution can reach 1e^{-4} to 1e^{-5} level

By Mengran Li (IHEP)



Weak mixing angle (2)

- Comparison with Fcc-ee on weaking mixing angle measurement
  - Expect 1~2 order magnitude better than LEP results

Improvement compared to LEP results	**CEPC**	**FCC-ee (from Paolo's talk)**
AFB (Z->ee)	30	50
AFB (Z->μμ)	20-30	30
AFB (Z->ττ)	NA	15
AFB (Z->bb)	10	5
Weak mixing angle	70	100

Outline

- Introduction to precision electroweak physics
- Z pole physics
- W physics

Motivation of W mass measurement

- CEPC have very good potential in electroweak physics.
- Precision measurement is important
  - It constrain new physics beyond the standard model.
  - Eg: Radiative corrections of the W or Z boson is sensitive to new physics

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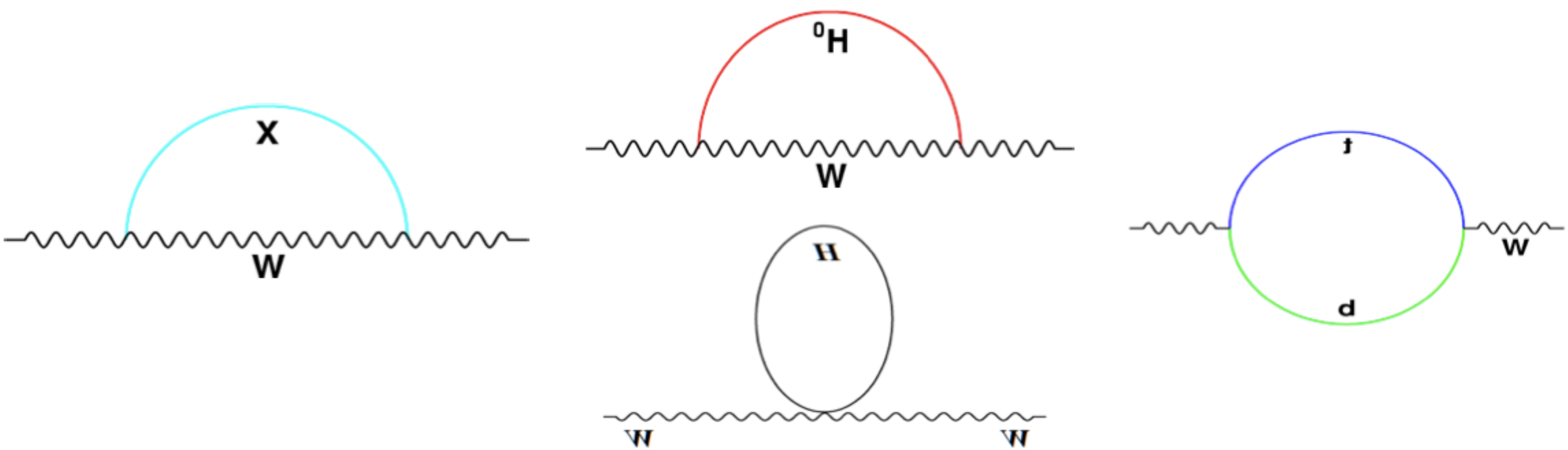
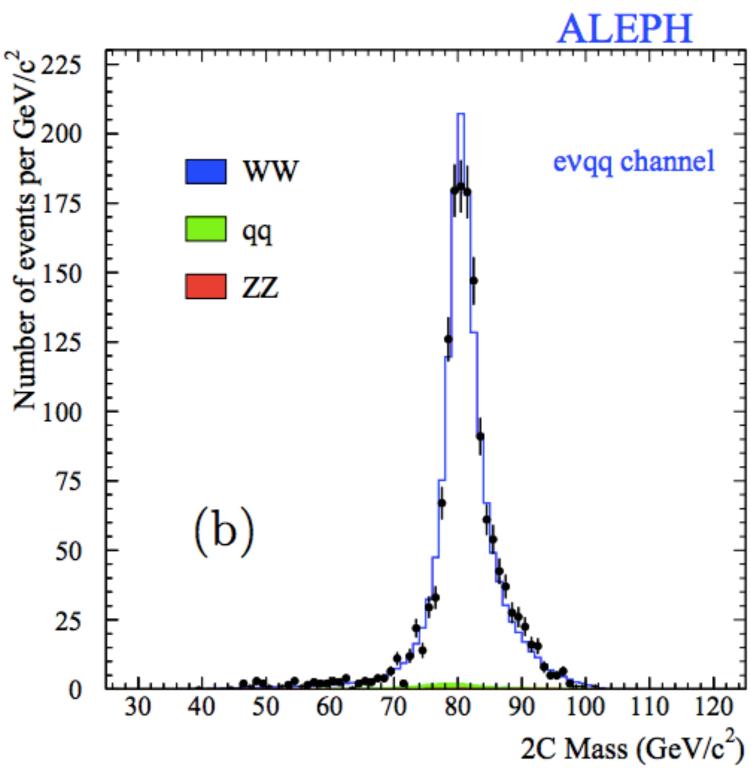


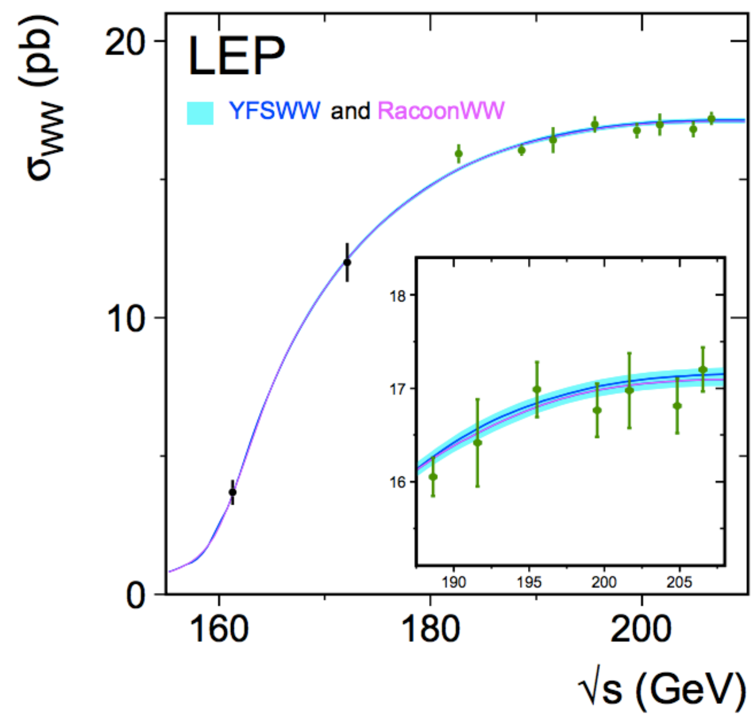
W mass measurement

- Two approaches to measure W mass

Direct measurement
ZH runs 240GeV
Precision 3MeV
PeiZhu's talk tomorrow

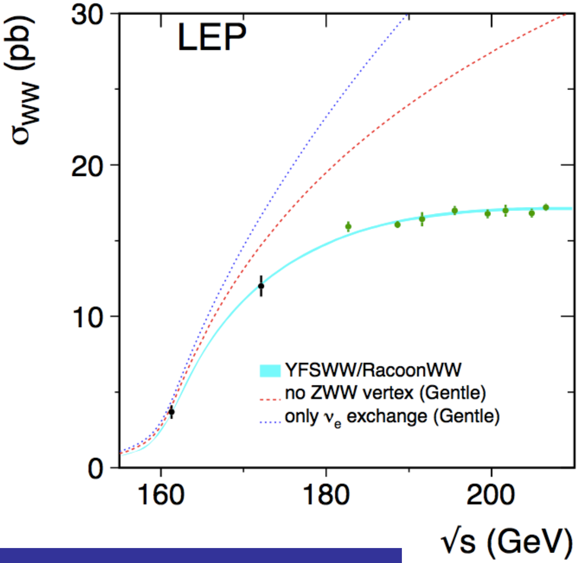


WW threshold scan
WW threshold runs (157~172GeV)
Precision 1MeV
PeiXun's talk tomorrow



WW threshold scan proposal

- Based on Peixun and Gang study :
  - Assuming one year data taking in WW threshold (2.5 ab^{-1})
  - Four energy scan points:
    - 157.5, 161.5, 162.5(W mass, W width measurements)
    - 172.0 GeV (α_{QCD} measurement, Br (W->had) , CKM $|V_{cs}|$)
    - 14M WW events in total (40k WW events in LEP2)
      - 400 times larger than LEP2 comparing WW r



E_{cm} (GeV)	Lumiosity(ab^{-1})	Cross section (pb)	Number of WW pairs (M)
157.5	0.5	1.25	0.6
161.5	0.2	3.89	0.8
162.5	1.3	5.02	6.5
172.0	0.5	12.2	6.1

Expected precision in WW scan

- Statistics is enough for Branching ratio measurement Br (W->had) and α_{QCD} (mW) measurements.
- Statistics uncertainty is one of the limiting factor for W mass and W width measurement in CEPC one year running plan (2.5 fb^{-1})

Energy (GeV)	Systematics	Statistics uncertainty	limiting factor
W mass	1MeV Beam energy	1.0 MeV	Statistics
W width	1 MeV	3.2 MeV	Statistics
Br (W->had) & α_{QCD} (mW)	10^{-4}	10^{-4}	/

Open issue

- Tools needed:
  - Soft muon b jet tagger is needed for R_b measurement
  - Jet charge reconstruction is need for Afb_b
- Analyses to be covered
  - Afb_b , Afb_e measurements
    - Key input to weak mixing angle measurement
  - W->jj branching ratio and alpha_QCD
  - Z->ll off-peak runs design and alpha_QED measurements

Summary

- CEPC electroweak physics community is working on in Conceptual Design Report.
  - updated in CEPC accelerator design on Z pole and WW threshold runs
  - one order of magnitude larger than pre-CDR
  - Prospect of CEPC W/Z physics improved benefitted from higher design luminosity
  - More details about W physics in Hengne and Peixun's talk
- Welcome to join this effort
  - Lots of work needed to understand the systematics