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Electroweak Physics at CEPC

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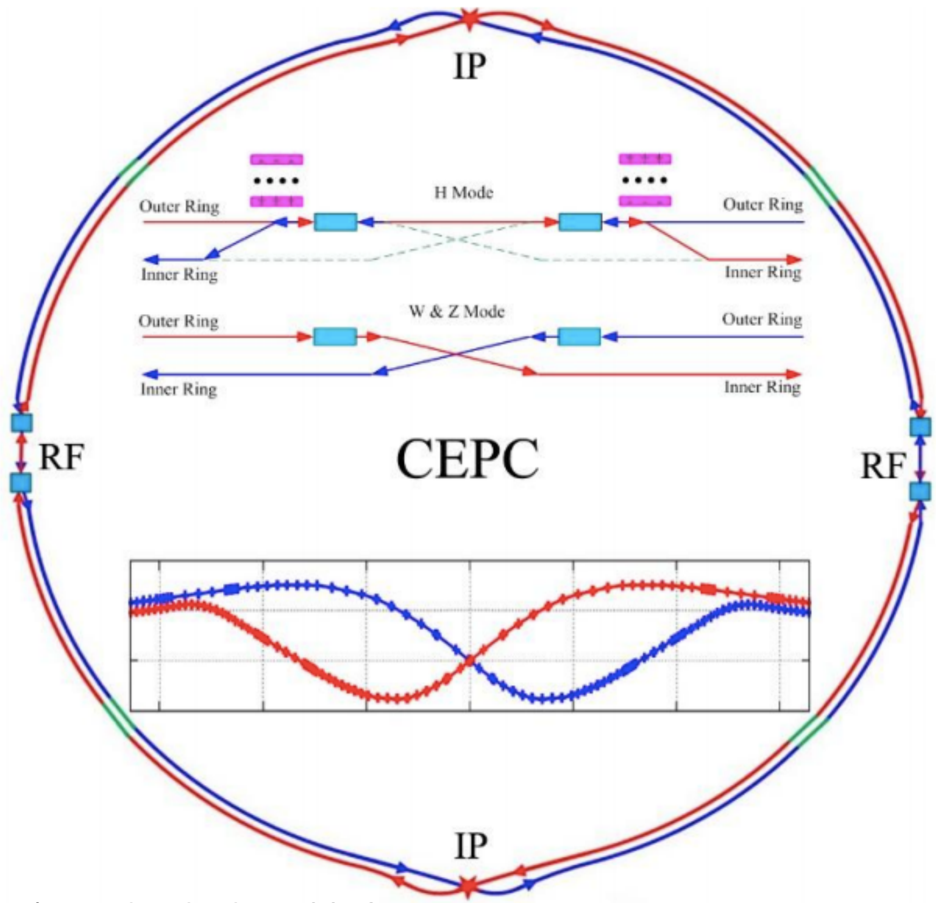
Outline

- Introduction to CEPC
- W physics
- Z pole physics

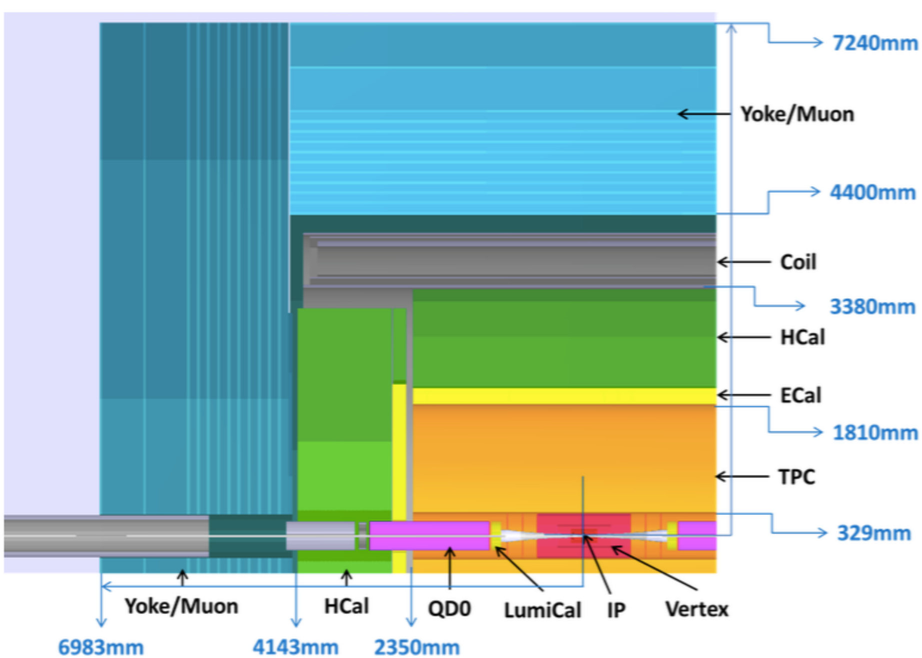
Introduction to CEPC

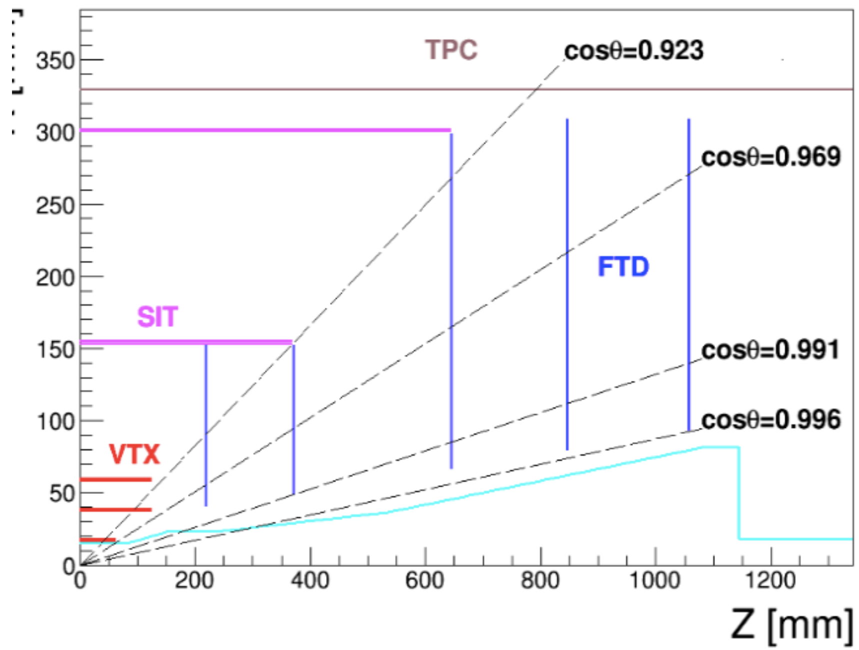
- CEPC is Higgs Factory (E_{cms}=240GeV , 10^6 Higgs)
- CEPC have good potential in electroweak precision physics at Z pole.
  - L=1.6 (3.2) X 10^{35} $cm^{-2}s^{-1}$, 10^{12} Z boson **(tera-Z)**
- WW threshold scan runs are also expected.
  - Total luminosity 2.5 ab^{-1} ,
  - **14M WW events**



CEPC detector

- ILD-like design with some modification for circular collider
  - No Power-pulsing
- Tracking system (Vertex detector, TPC detector , 3.0T magnet)
  - Expected Tracking resolution : δ(1/Pt) ~ 2*10-5(GeV-1)
- Particle Flow Algorithm (PFA) based
  - Expected jet energy resolution : σE/E ~ 0.3/√E





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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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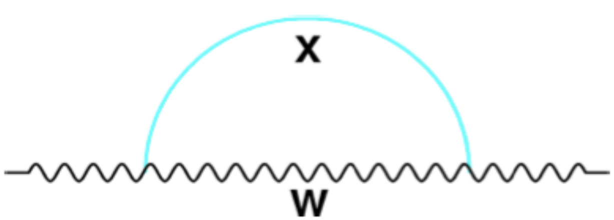
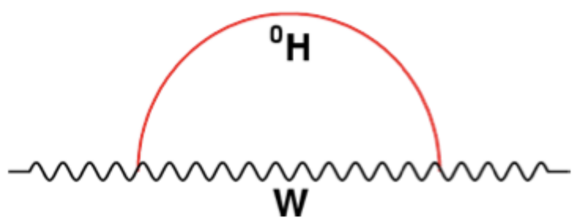
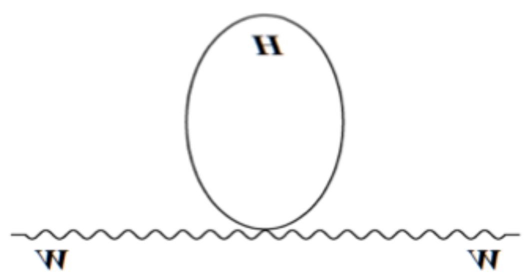
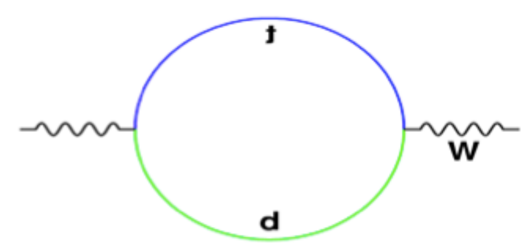








W mass measurement

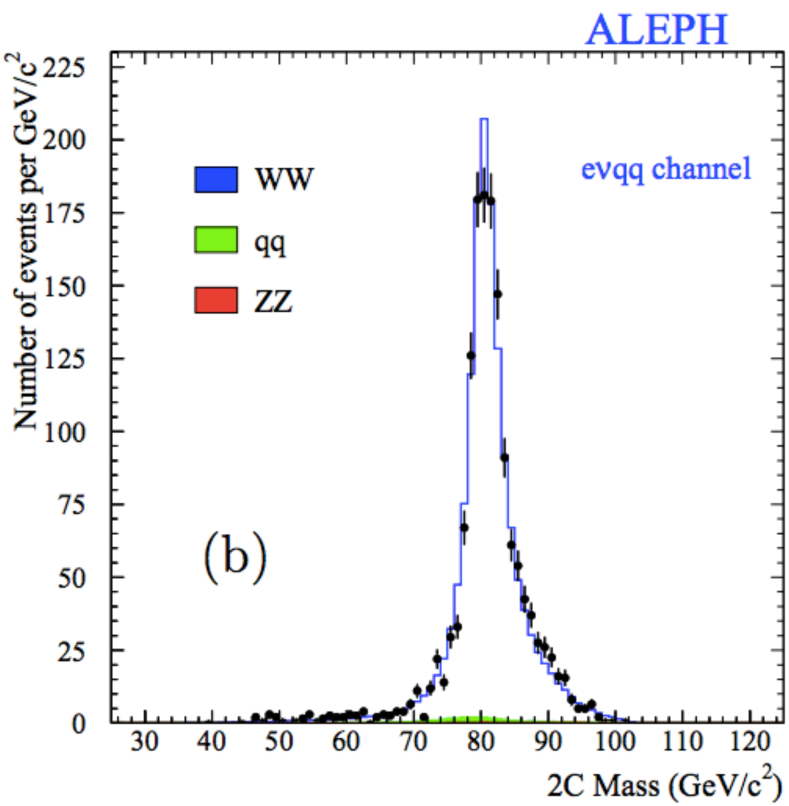
- Two approaches to measure W mass :

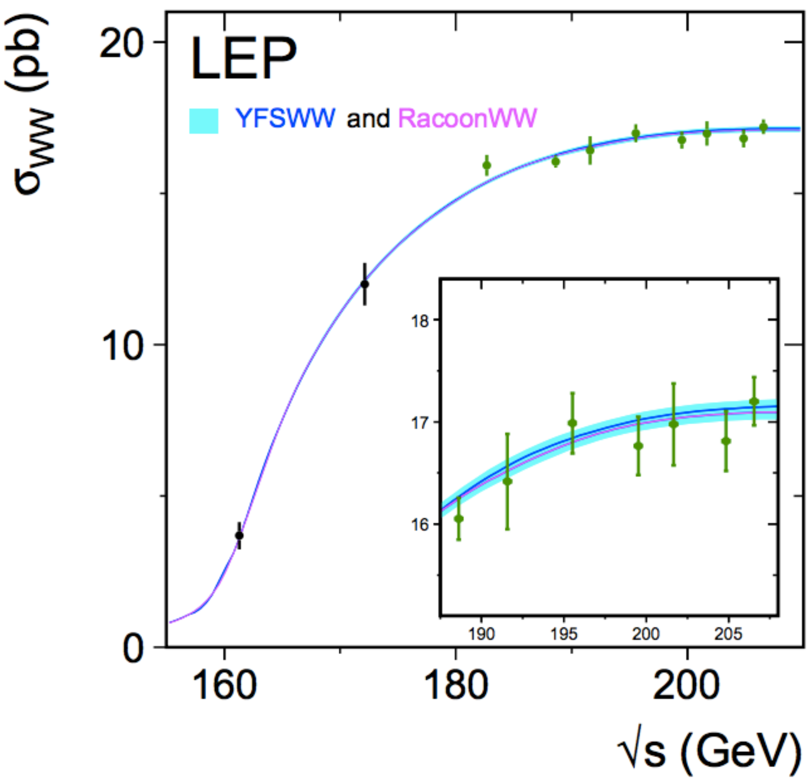
Direct measurement

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

WW threshold scan

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





WW threshold scan-systematics unc.

- Consider the beam spread unc. (E_{BS}),beam energy unc. , signal efficiency, cross section unc. and background uncertainty.

➢ With E_{BS}, the σ_{WW} becomes:

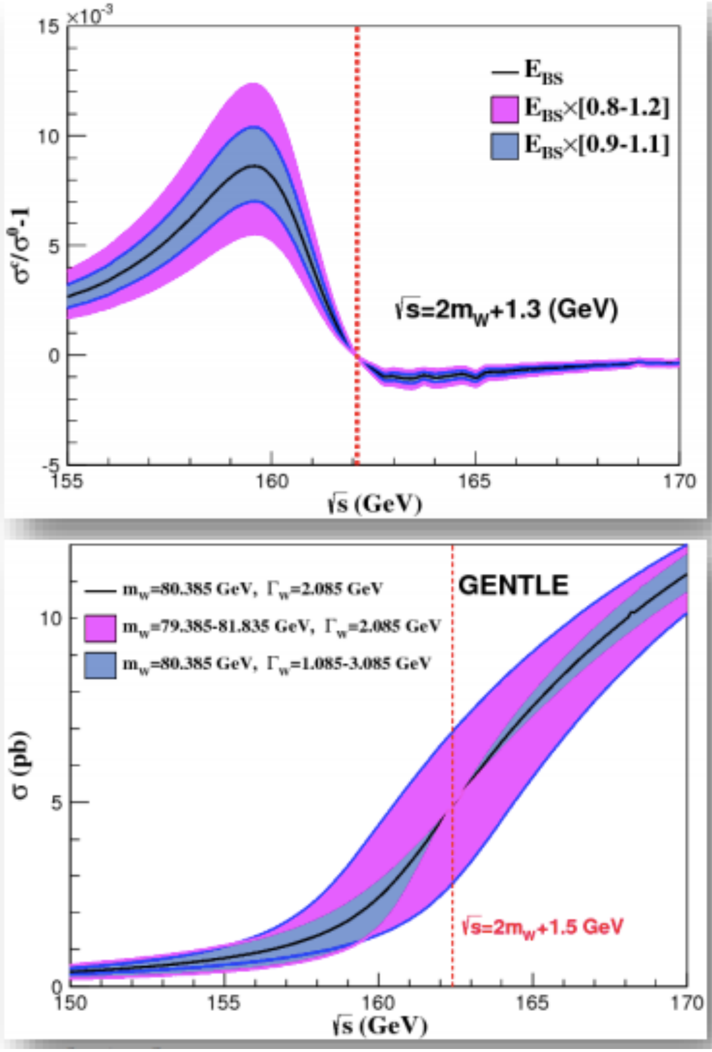
$$\sigma_{WW}(E) = \int_0^{\infty} \sigma_{WW}(E') \times G(E,E')dE'$$

$$\approx \int_{E-6\sqrt{2}\Delta E_{BS}}^{E+6\sqrt{2}\Delta E_{BS}} \sigma(E') \times \frac{1}{\sqrt{2\pi}\sqrt{2}E_{BS}} e^{\frac{-(E-E')^2}{2(\sqrt{2}E_{BS})^2}} dE'$$

➢ $E_{BS} + \Delta E_{BS}$ is used in the simulation, and E_{BS} is for the fit formula.

➢ The m_W insensitive to ΔE_{BS} when taking data around 162.1 GeV

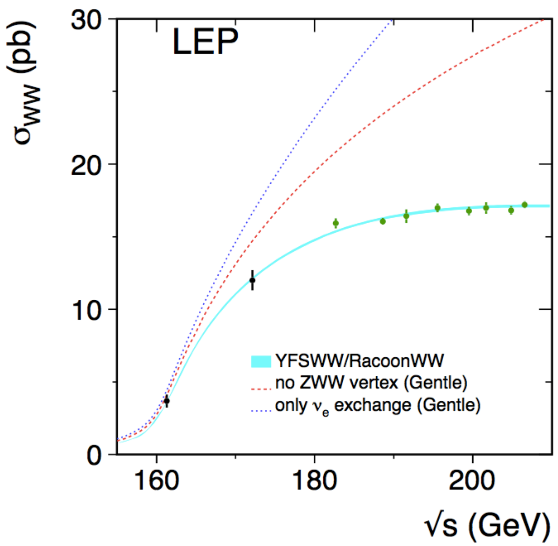
By Peixun Shen (Nankai University)



WW threshold scan – run plan

- WW threshold scan running proposal
  - 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} (m_W) measurement, Br (W->had) , CKM |Vcs|)
    - 16M 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
161.5	0.2	3.89	0.8
162.5	1.3	5.02	6.5
172.0	0.5	12.2	6.1



WW threshold scan – physics goal

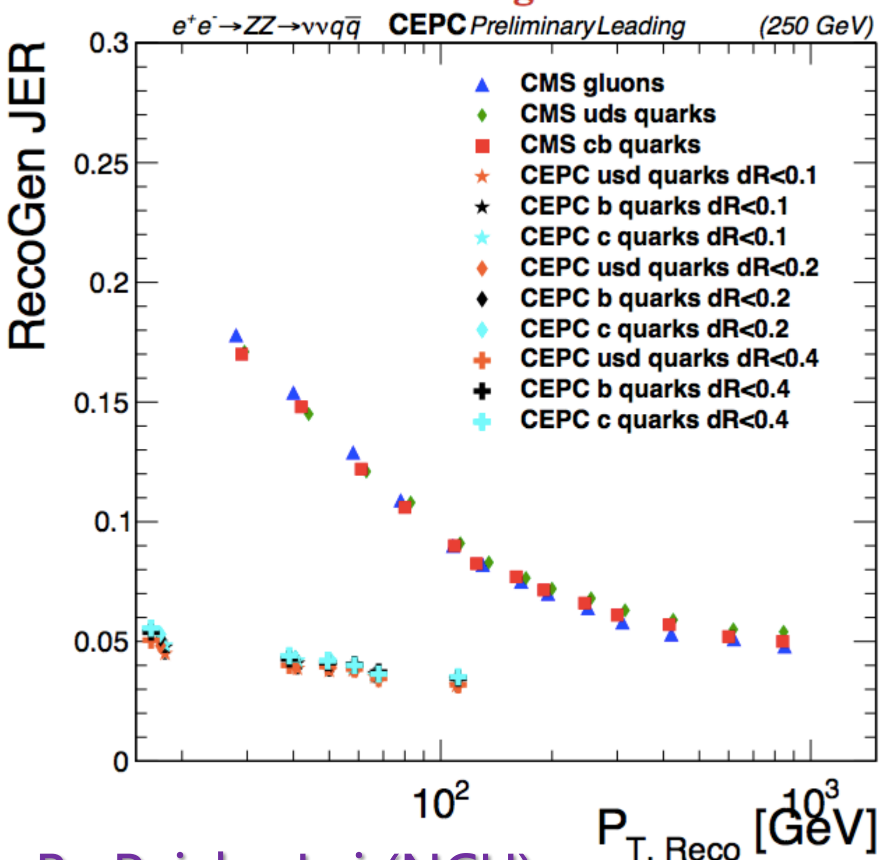
- Statistics is enough for Branching ratio measurement Br (W->had) and αQCD (mW) measurements.
- Statistics uncertainty is one of the limiting factor for W mass and W width measurement with CEPC one year running plan (2.5 fb^{-1})

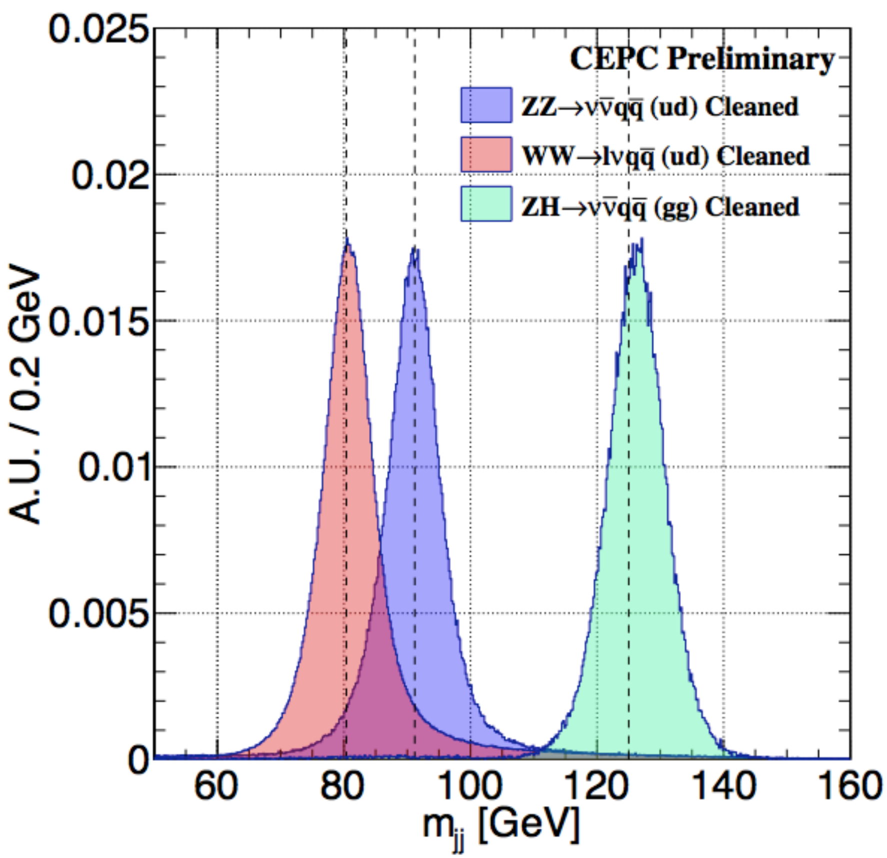
Energy (GeV)	Systematics	Statistics uncertainty	limiting factor
W mass	1MeV Beam energy	1.0 MeV	/
W width	1 MeV	3.2 MeV	Statistics
Br (W->had) & α_{QCD} (mW)	10^{-4}	10^{-4}	/

W mass direct measurement

- The Z, W, and Higgs bosons can be well separated in CEPC.
- Benefitted from excellent jet energy resolution and PFA based calorimeter
- Possible to measure W mass from direct di-jet mass reconstruction.

Leading

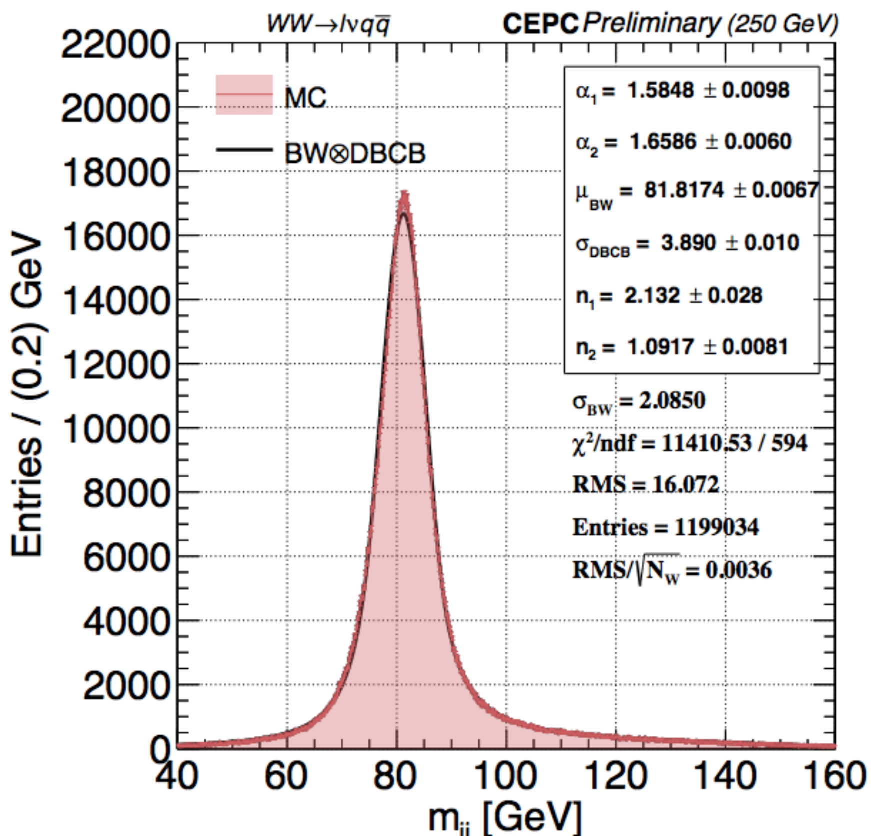




By Peizhu Lai (NCU)

W mass direct measurement

- Reconstruct di-jet mass from WW->lvqq events in ZH run
  - Not affect by beam energy uncertainty
  - Major systematics is Jet energy scale (JES) uncertainty (2~3 MeV)
  - Calibrate JES with Tera-Z (Z->jj)



By Peizhu Lai (NCU)

Prospect of CEPC W mass measurement

- CEPC can improve current precision of W mass by one order of magnitude
  - A possible BSM physics can be discovered in the future

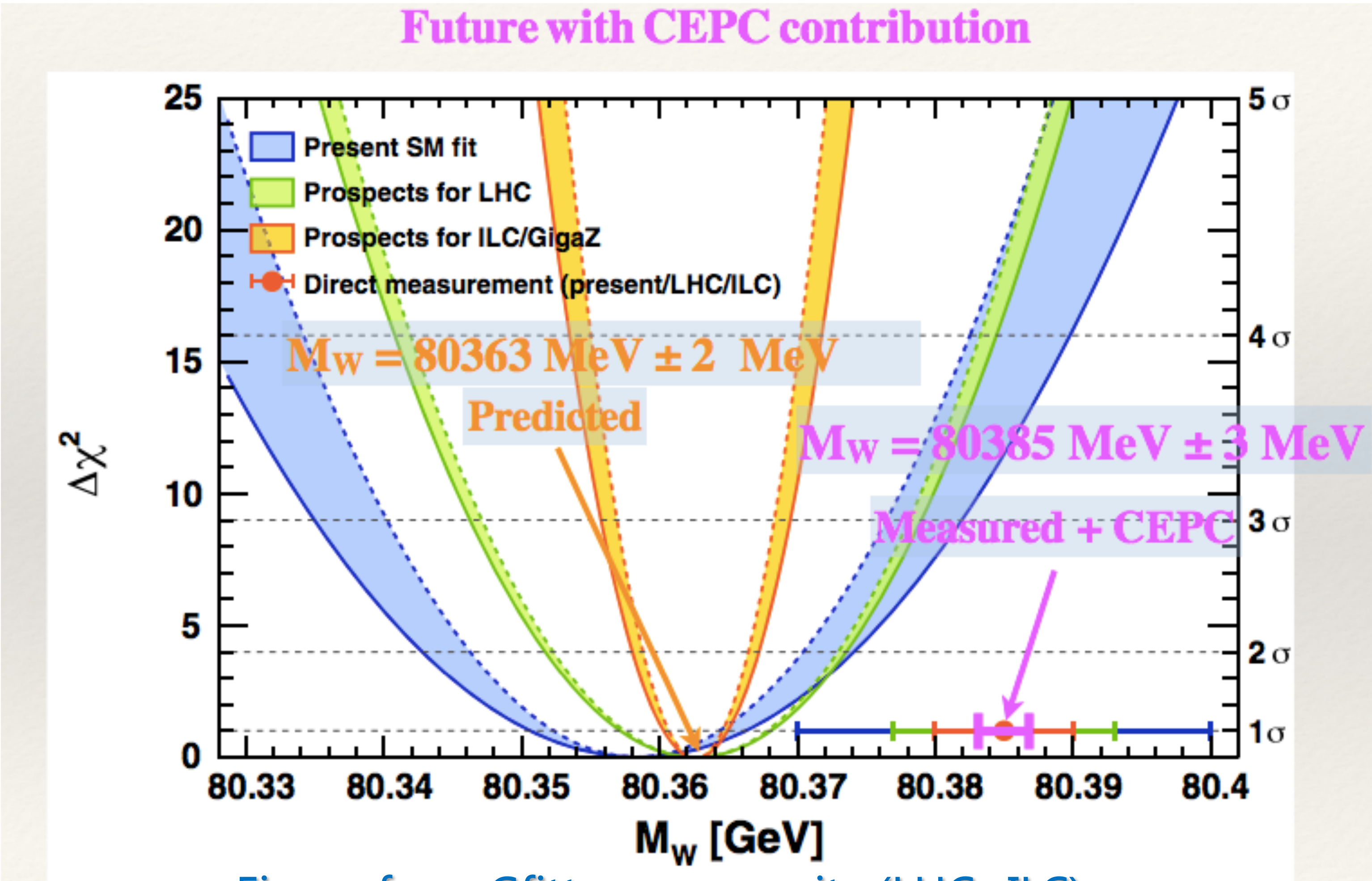


Figure from Gfitter community (LHC+ILC)

Outline

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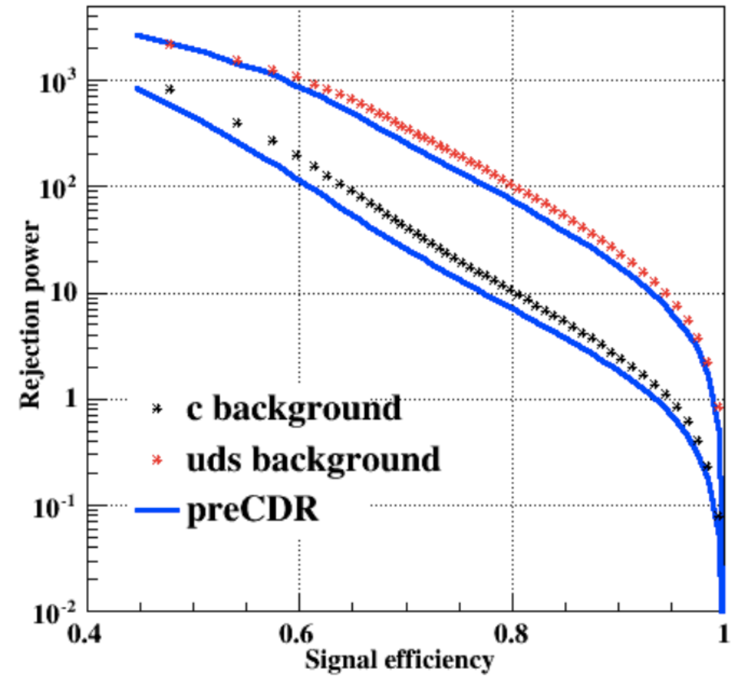
Branching ratio (R^b)

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

- 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



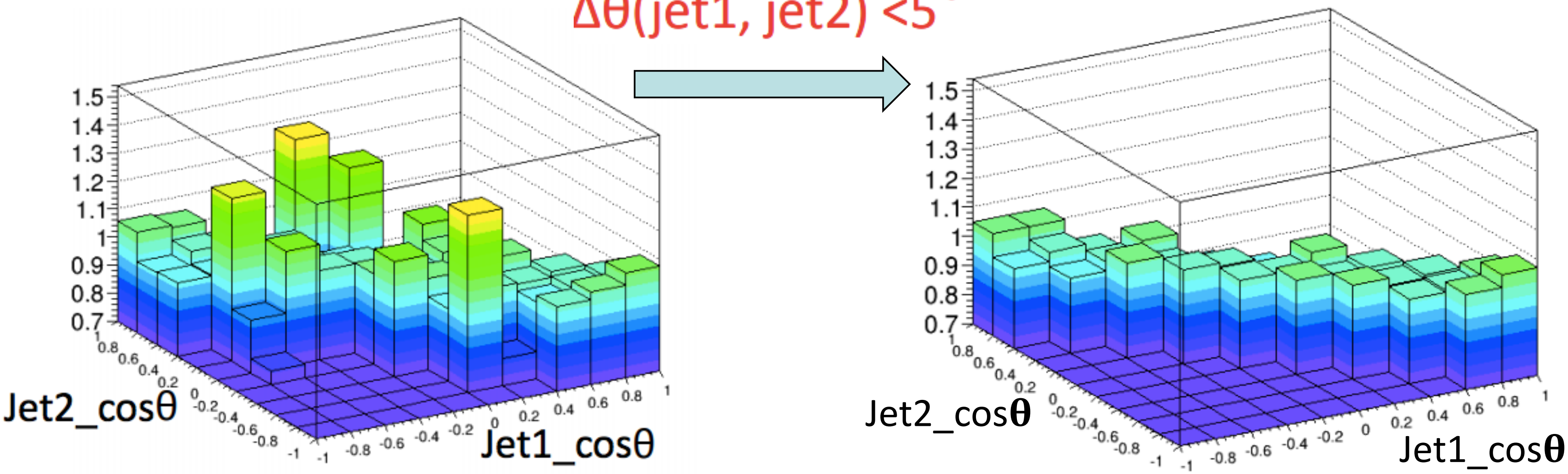
Uncertainty	LEP	CEPC	Thing to improve
hemisphere tag correlations for b events	0.2%	0.02%	B tagging performance, pixel
gluon splitting	~0.15%	0.01%	Better granularity in Calo

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)
  - Correlations factors c_b need to be reduced below 0.01%

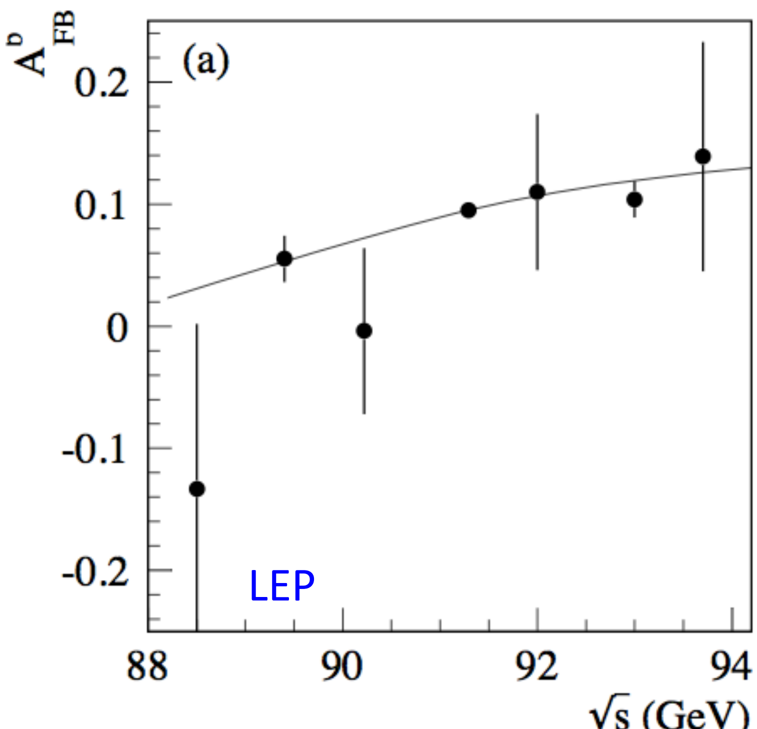
$$C_b = \frac{\varepsilon_{2jet-tagged}}{(\varepsilon_{1jet-tagged})^2}$$

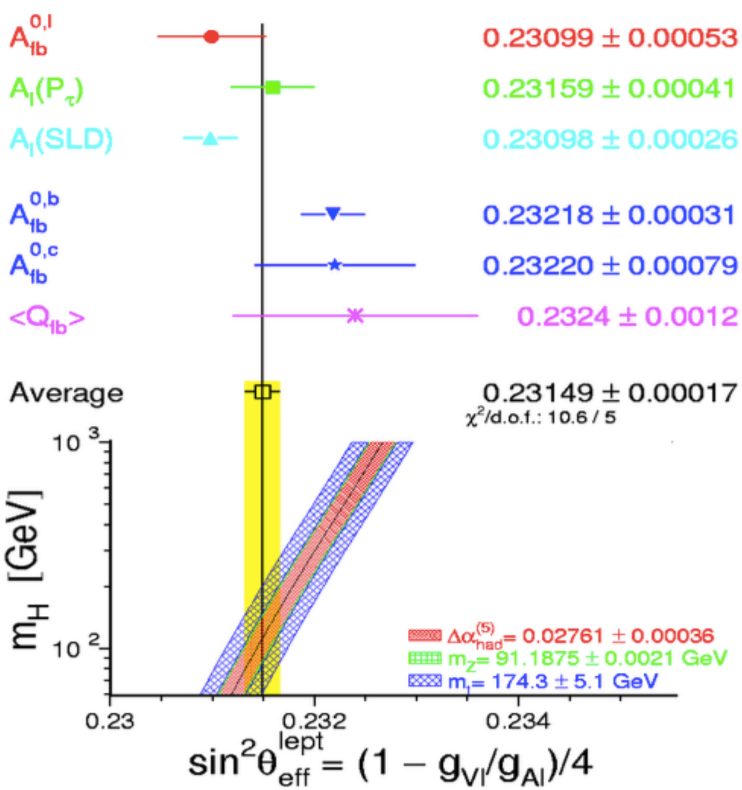
By Bo Li (Yantai University)



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



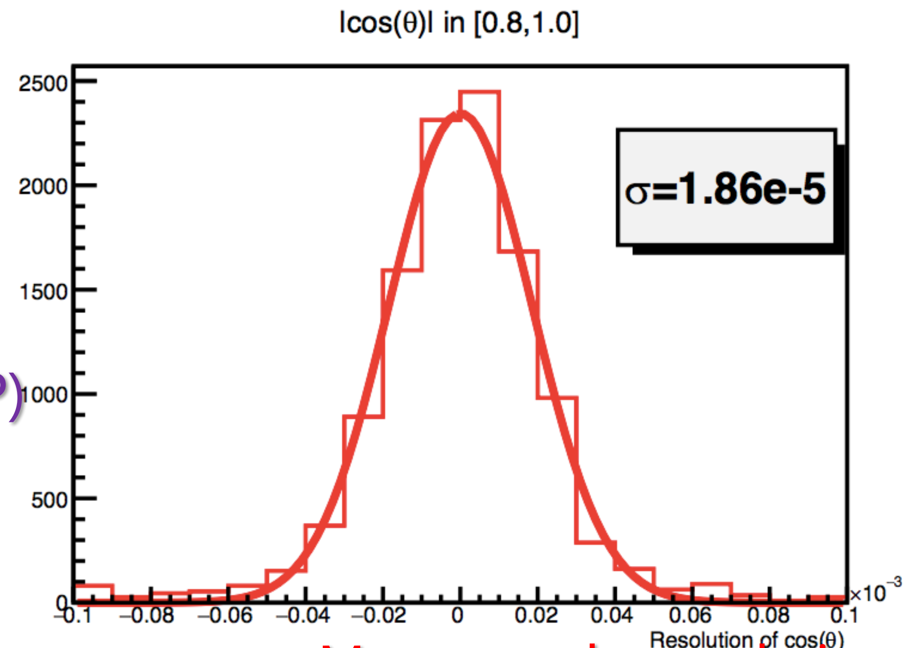


Backward-forward asymmetry in Z->μμ

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

- 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)



Muon angular resolution

Weak mixing angle (2)

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

Improvement compared to LEP results	CEPC	FCC-ee (Paolo's talk in CEPC Roma workshop)
A_{FB} (Z->ee)	30	50
A_{FB} (Z->μμ)	20-30	30
A_{FB} (Z->ττ)	NA	15
A_{FB} (Z->bb)	10	5
Weak mixing angle	70	100

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}

Summary

- CEPC community is working on in Conceptual Design Report.
  - updated CEPC accelerator design on Z pole and WW runs
  - order of magnitudes larger than pre-CDR
  - Prospect of CEPC W/Z physics improved benefitted from higher design luminosity
- Welcome to join this effort
  - Lots of work needed to understand the systematics

- Thanks for hard work from current team.
  - PhD Students, and who are practically working:
  - Peixun Shen (Nankai U.), Pei-Zhu Lai (NCU), Mengran Li (IHEP), Bo Li(Yantai U.)
  - Supervisors, Conveners, Experts, who are contributing ideas :
  - Gang Li (IHEP), Zhijun Liang (IHEP), Manqi Ruan (IHEP), Bo Liu (IHEP), Chai-Ming Kuo (NCU), Maarten Boonekamp (CEA Saclay), Hengne Li (SCNU/UVa), Fuivio Piccinini (INFN), Liantao Wang (Chigago), Joao Costa (IHEP)

Open issue

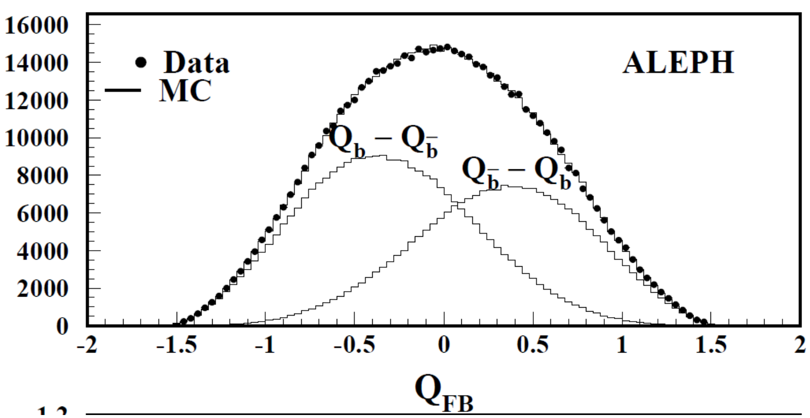
- Tools needed:
  - Soft muon b jet tagger is needed for R_b measurement
  - Jet charge reconstruction is need for Afb_b
- Analyses to be covered
  - Afb_b , Afb_e measurements
    - Key input to weak mixing angle measurement
  - W->jj branching ratio and alpha_QCD
  - Z->ll off-peak runs design and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

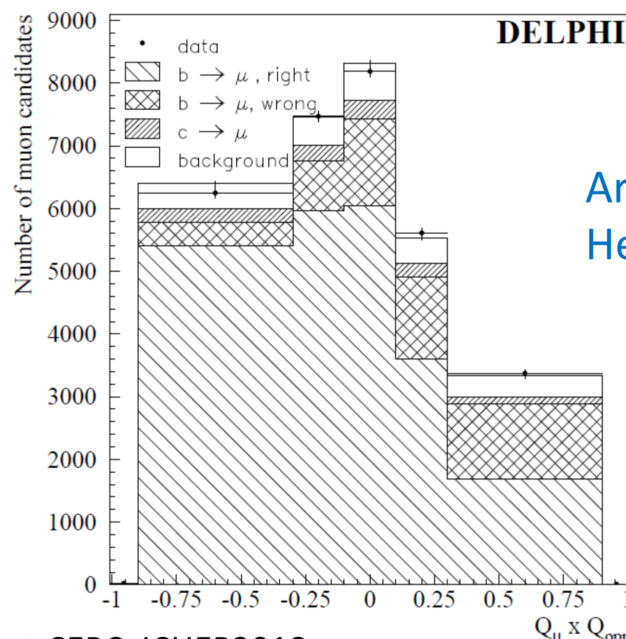
Backward-forward asymmetry

- 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) Q_lepton - Q_jet in method 1

Arxiv:Hep-ex/0107033

Q_F - Q_B in method 2





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

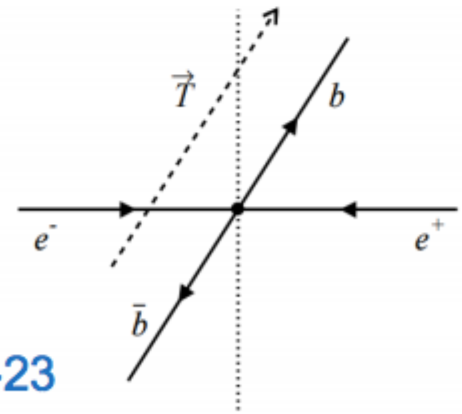
- LEP measurement : 0.1000+-0.0017 (Z peak)
  - Method 1: Soft lepton from b/c decay (~2%)
  - Method 2: jet charge method using Inclusive b jet (~1.2%)
  - Method 3: D meson method (>8%, method)
- CEPC
  - Focus more on method 2 (inclusive b jet measurement)
  - Expected Systematics (0.15%) :

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%	

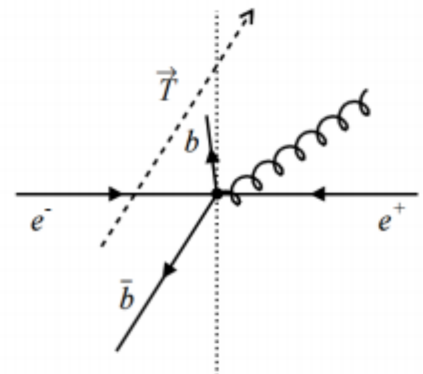
Backward-forward asymmetry $A_{FB}^{b\bar{b}}(0)$

- 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	$C_{\text{QCD}}^{\text{quark}}$ (%)		$C_{\text{QCD}}^{\text{part,T}}$ (%)	
	$b\bar{b}$	$c\bar{c}$	$b\bar{b}$	$c\bar{c}$
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

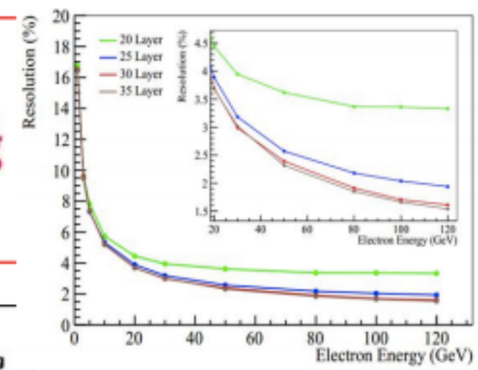
CEPC detector (2)

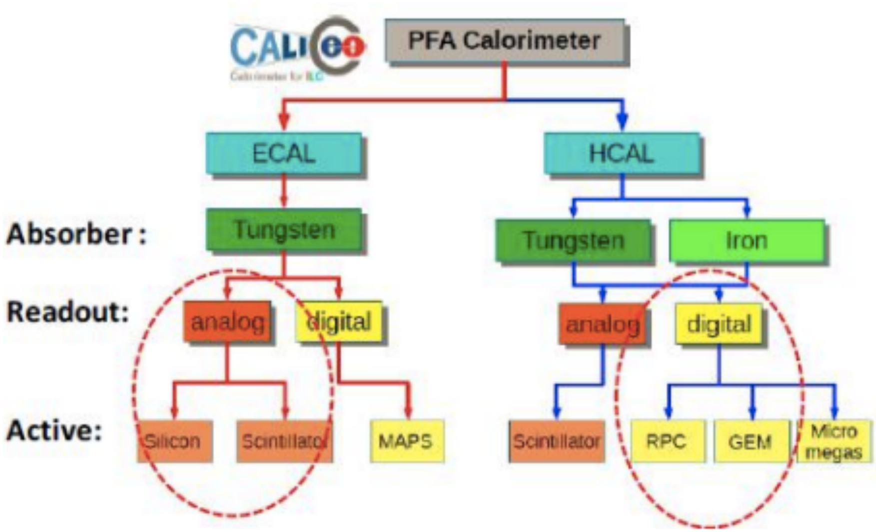
- Calorimeters:
  - Concept of Particle Flow Algorithm (PFA) based
  - EM calorimeter energy resolution: $\sigma_E/E \sim 0.16/\sqrt{E}$
  - Had calorimeter energy resolution: $\sigma_E/E \sim 0.5/\sqrt{E}$
  - Expected jet energy resolution : $\sigma_E/E \sim 0.3/\sqrt{E}$

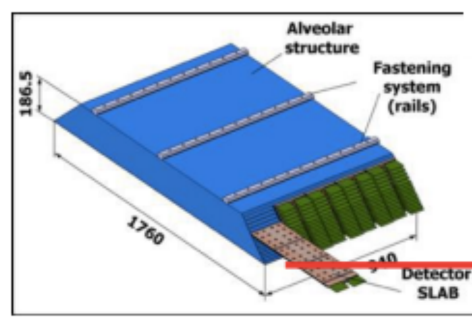
- Jet energy (Higgs self-coupling, W/Z separation)
  - ~1/2 resolution (wrt LHC)

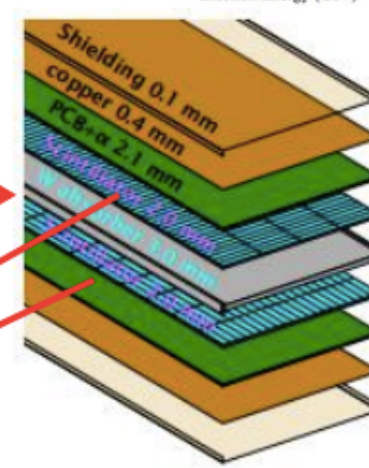
$$\sigma_E / E = 0.3 / \sqrt{E(GeV)}$$

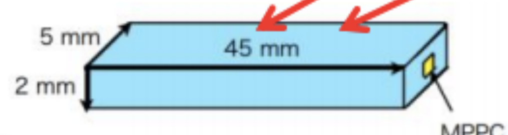
less demanding at CEPC











ECAL: Scintillator + W + Scintillator