Electroweak physics at CEPC

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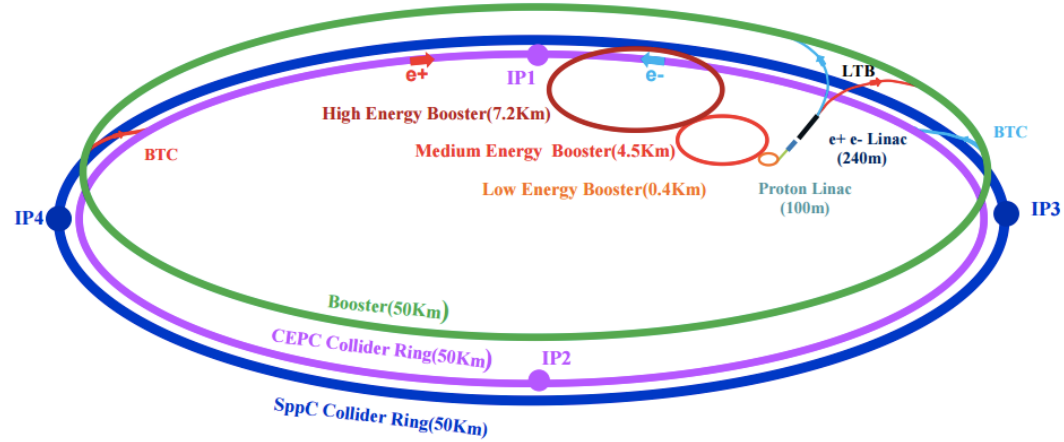
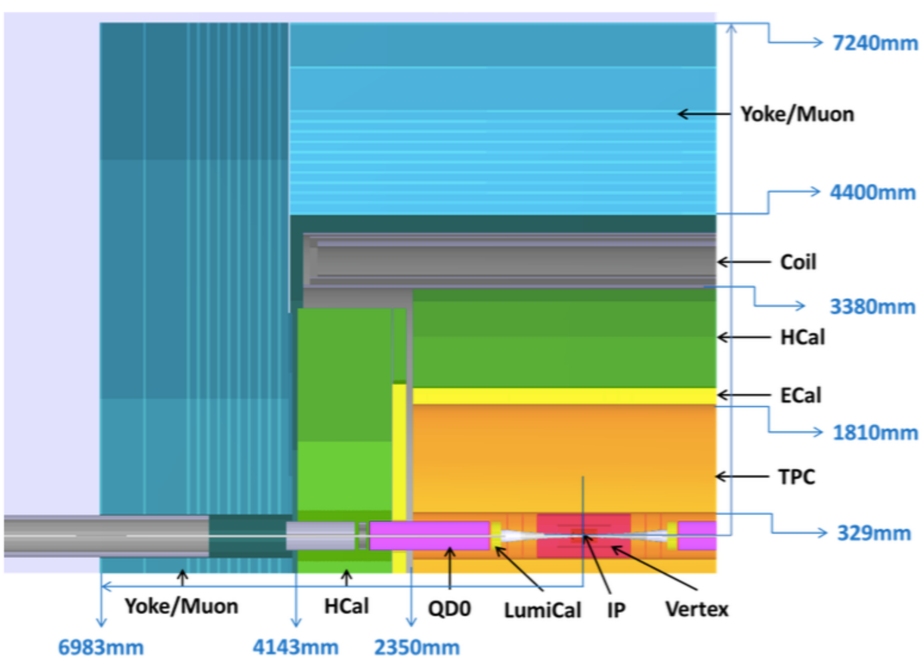
CEPC accelerator

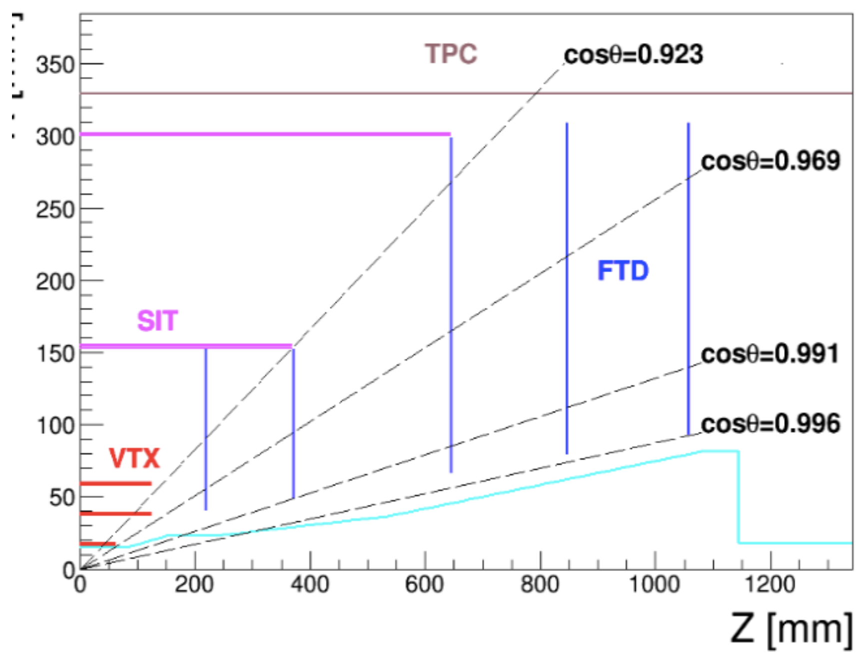


- Electron-positron circular collider
  - Higgs Factory（E_{cms}=250GeV , 10^6 Higgs)
    - **Precision study of Higgs coupling in ZH runs**
    - **complementary to ILC**
    - **See Manqi and Gang's talk this morning in Higgs section for more details**
  - Z factory（E_{cms}=91 GeV, 10^{10} Z Boson）:
    - **Precision Electroweak measurement in Z pole running**
    - **Major focus of this talk**
- Preliminary Conceptual Design Report(Pre-CDR) available :
  - http://cepc.ihep.ac.cn/preCDR/volume.html
- Aiming to finalize Conceptual Design Report (CDR) next year

CEPC detector (1)

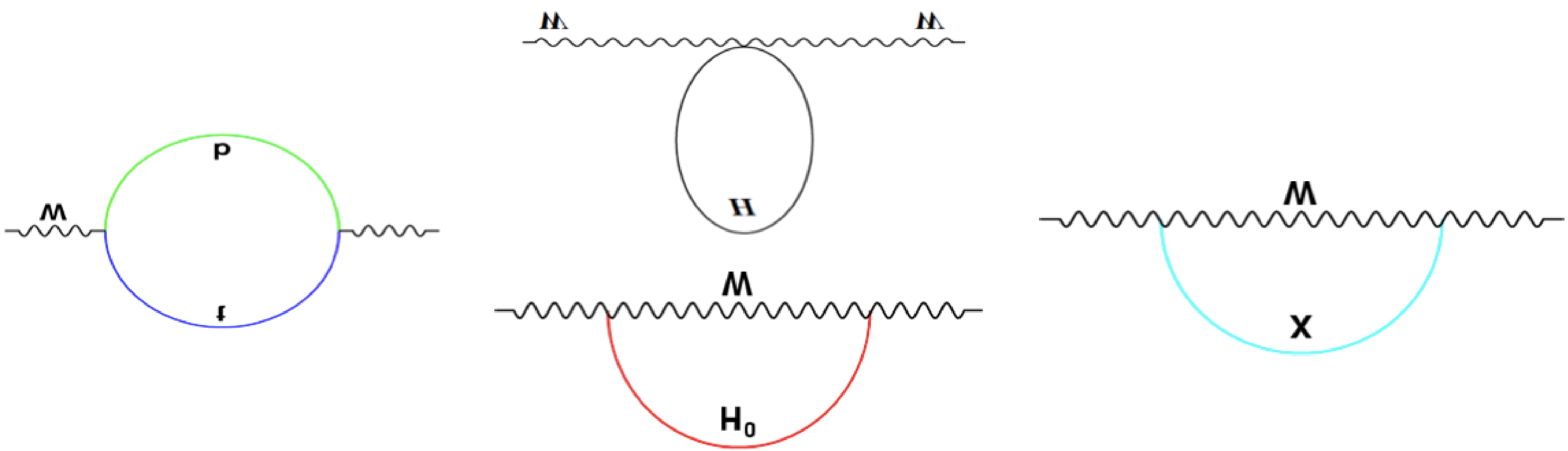
- ILD-like design with some modification for circular collider
  - No Power-pulsing
- Tracking system (Vertex detector, TPC detector , 3.5T magnet)
  - Expected Impact parameter resolution: less than 5μm
  - Expected Tracking resolution : $\delta(1/P_t) \sim 2*10^{-5}(GeV^{-1})$
- Calorimeters: Concept of Particle Flow Algorithm (PFA) based
  - Expected jet energy resolution : $\sigma E/E \sim 0.3/\sqrt{E}$





Motivation

- 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



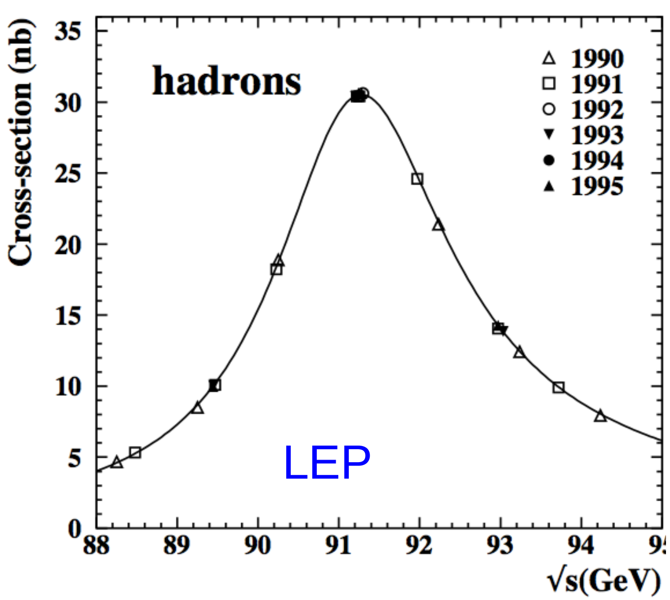
The prospect of CEPC electroweak physics in pre-CDR study

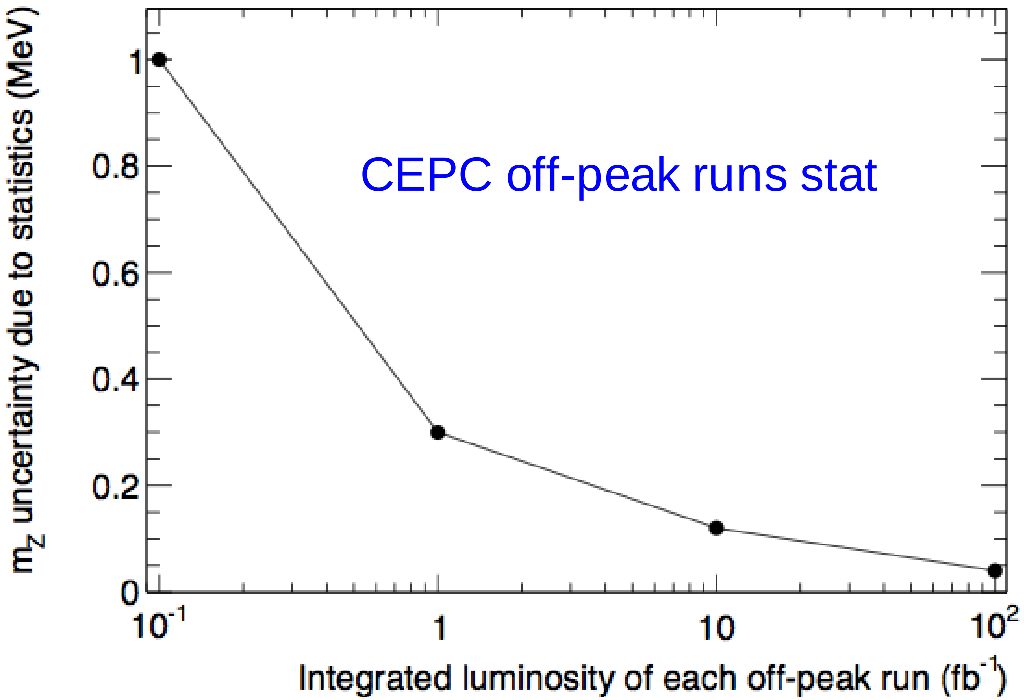
- Expected precision on some key measurements in CEPC Pre-CDR study based on projections from LEP and ILC.
  - http://cepc.ihep.ac.cn/preCDR/volume.html
- From now to next year, plan to update the study for Conceptual Design Report (CDR) with full detector simulation

Observable	LEP precision	CEPC precision	CEPC runs
m_Z	2 MeV	0.5 MeV	Z lineshape
m_W	33 MeV	3 MeV	ZH (WW) thresholds
A_{FB}^b	1.7%	0.15%	Z pole
$\sin^2\theta_W^{\rm eff}$	0.07%	0.01%	Z pole
R_b	0.3%	0.08%	Z pole
N_ν (direct)	1.7%	0.2%	ZH threshold
N_ν (indirect)	0.27%	0.1%	Z lineshape
R_μ	0.2%	0.05%	Z pole
R_τ	0.2%	0.05%	Z pole

Z mass measurement

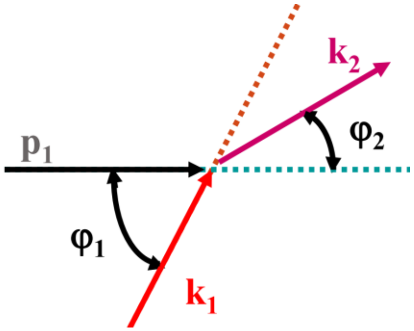
- LEP measurement : 91.1876±0.0021 GeV
- CEPC possible goal: 0.5 MeV
  - Z threshold scan runs is needed to achieve high precision.
  - Stat uncertainty : 0.2MeV
    - Better to have more than $10fb^{-1}$ for off-peak runs (6 off-peaks runs)
  - Syst uncertainty: ~0.5 MeV
    - Beam energy uncertainty need to be better than 5ppm
    - start to Establishing a accelerator model relating the measured beam energy
    - Study of the resonant depolarization technique to measure beam energy (LEP approach)





Physics Requirement for accelerator

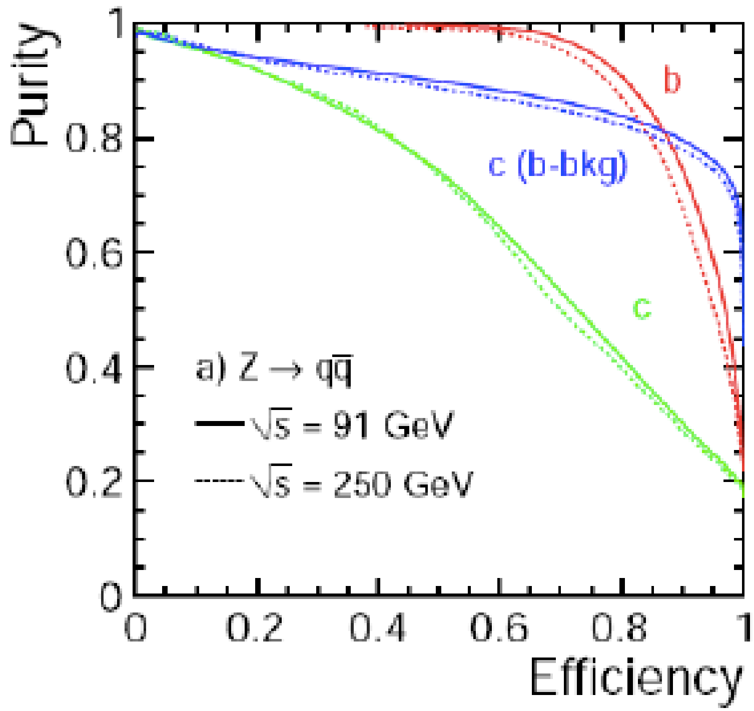
- Expected Beam momentum scale uncertainty
  - CEPC pre-CDR : 500keV precision (10^{10} -10^{11} Z)
  - FCC-ee : 100keV precision (10^{13} Z)
- Precision of beam energy measurement may have a big impact to Z pole running program.
  - Pre-CDR requirement: 5-10 ppm level uncertainty on P_{beam}
  - preliminary study with compton scattering (BEPC-II approach)
  - may be able to reach 1MeV precision from
    - preliminary study in G-Y. Tang's talk http://indico.ihep.ac.cn/event/6495/session/4/contribution/29/material/slides/0.pdf
  - Toward CDR : check scenario of 1ppm uncertainty on P_{beam}
    - Requested by FCC-ee experts to do more study
    - beam polarization issue and resonant depolarization method (LEP approach)



Branching ratio (R^b)

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

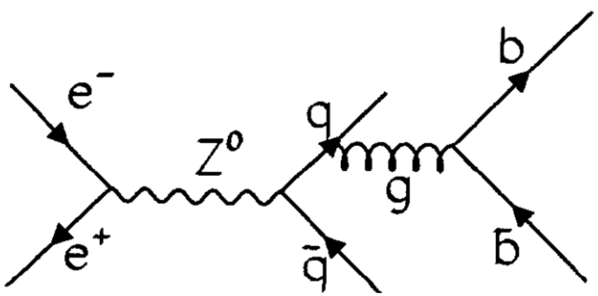
- LEP measurement 0.21594 ±0.00066
  - Stat error : 0.44%
  - Syst error : 0.35%
  - Typically using 65% working points
- CEPC pre-CDR
  - Expected Stat error (0.04%)
  - Expected Syst error (0.07%)
  - Expect to use 80% working points
    - 15% higher efficiency than SLD
    - 20-30% higher in purity than SLD

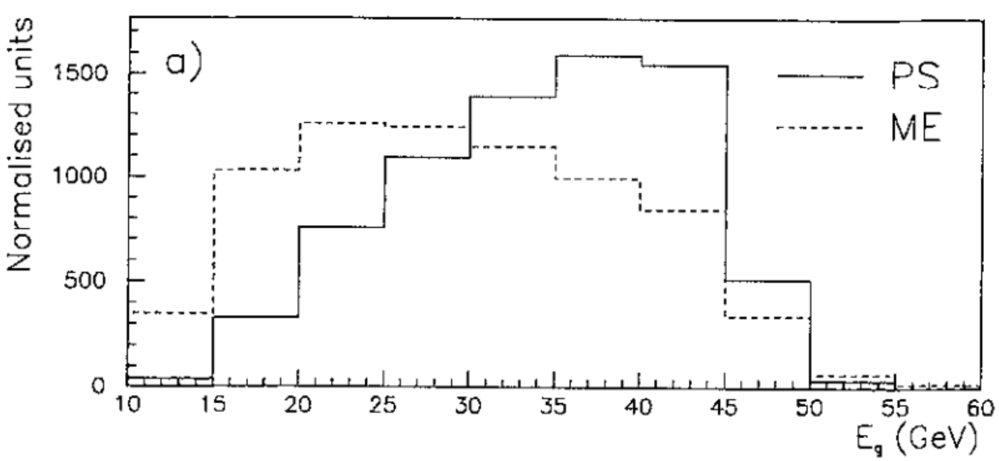


Uncertainty	LEP	CEPC	CEPC improvement
charm physics modeling	0.2%	0.05%	tighter b tagging working point
hemisphere tag correlations for b events	0.2%	0.1%	Higher b tagging efficiency
gluon splitting	0.15%	0.08%	Better granularity in Calo

Branching ratio (R^b): uncertainty in gluon splitting

- Discrepancy of parton shower (PS) and matrix element calculation.
- Data/MC discrepancy in high jet multiplicity





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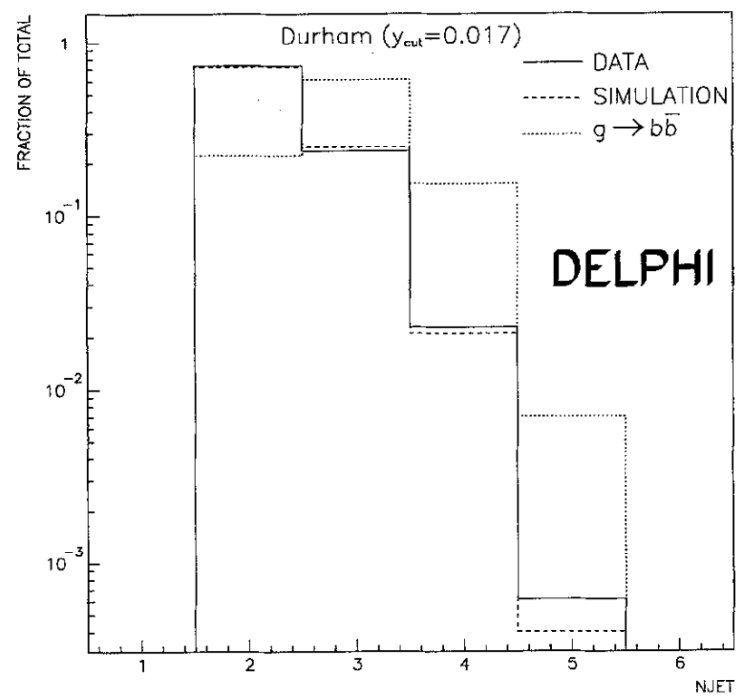
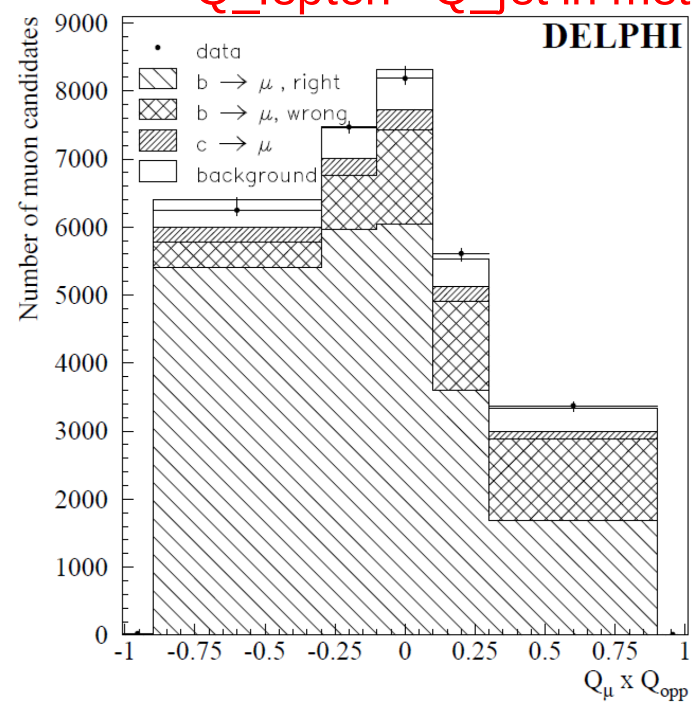


Backward-forward asymmetry measured from b jet

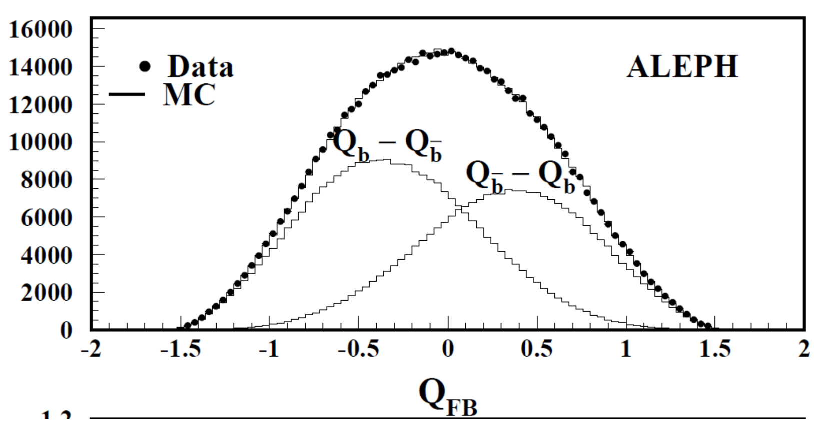
$$A_{FB}^{b\bar{b}}(0)$$

- 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



Q_F - Q_B in method 2



Backward-forward asymmetry measured from b jet

$$A_{FB}^{b\bar{b}}(0)$$

- 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%, less important method)
- CEPC pre-CDR
  - Focus more on method 2 (inclusive b jet measurement)
  - For CDR study, will try to find
    - Expected Systematics (0.15%) :

Uncertainty	LEP	CEPC	CEPC improvement
charm physics modeling	0.2%	0.05%	tighter b tagging working point
tracking resolution	0.8%	0.05%	better tracking resolution
hemisphere tag correlations for b events	1.2%	0.1%	Higher b tagging efficiency
QCD and thrust axis correction	0.7%	0.1%	Better granularity in Calo

QCD correction to Thrust

$A_{FB}^{b\bar{b}}(0)$

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

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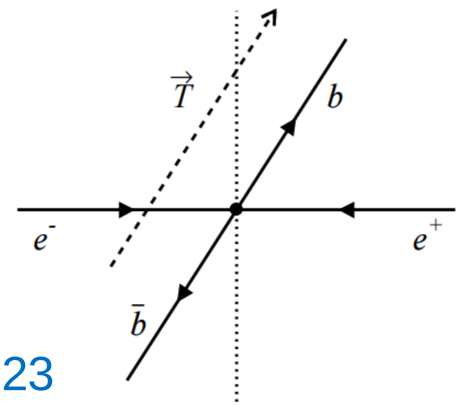
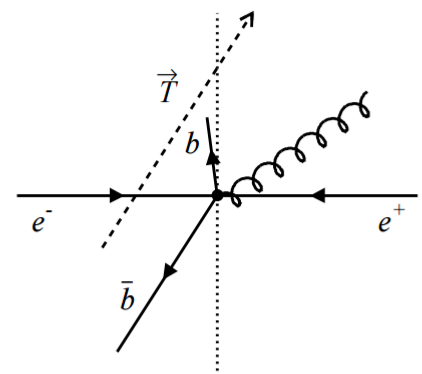


(a) No gluon



(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

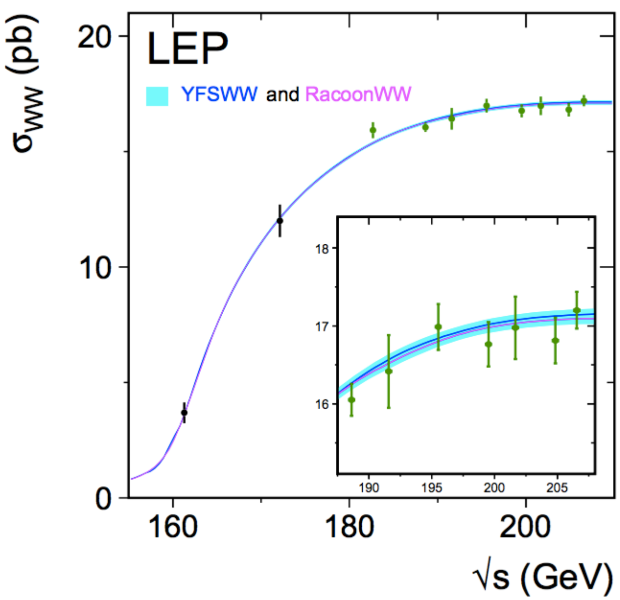
Weak mixing angle $\sin^2\theta_{eff}^{lept}$

- LEP/SLD: 0.23153 ± 0.00016
  - 0.1% precision.
  - Stat error is one of limiting factor.
- CEPC
  - systematics error : 0.01%
    - Input From Backward-forward asymmetry measurement
    - The precision mZ is another limiting factor (uncertainty on P_{beam})

		Correlations				
		m_Z	Γ_Z	σ^0_{had}	R^0_ℓ	$A^{0,\ell}_{FB}$
$\chi^2/\text{dof} = 172/180$		ALEPH				
m_Z [GeV]	91.1893 ± 0.0031	1.000				
Γ_Z [GeV]	2.4959 ± 0.0043	0.038	1.000			
σ^0_{had} [nb]	41.559 ± 0.057	−0.092	−0.383	1.000		
R^0_ℓ	20.729 ± 0.039	0.033	0.011	0.246	1.000	
$A^{0,\ell}_{FB}$	0.0173 ± 0.0016	0.071	0.002	0.001	−0.076	1.000

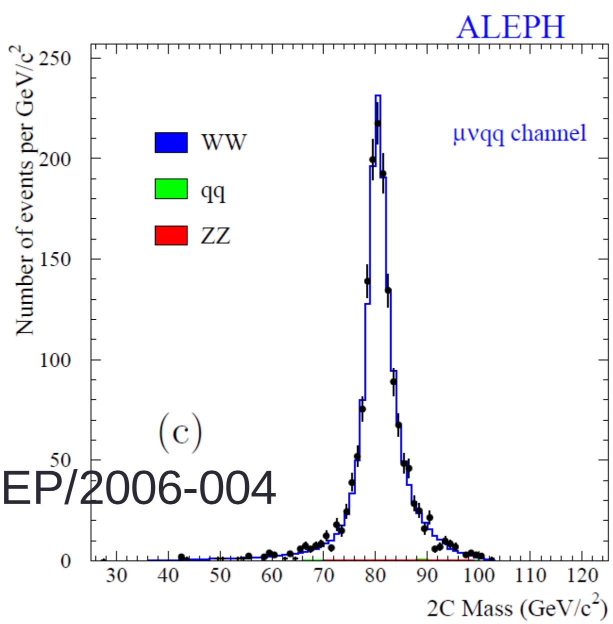
W mass measurement (1)

- PDG precision : 80.385±0.015 GeV
  - Possible goal for CEPC pre-CDR : 3 MeV
- Three methods for W mass measurements:
  - 1.WW Threshold scan ($\sqrt{s}$=160GeV):
    - Advantage: Very robust method, can achieve high precision.
    - Disadvantage
      - Higher cost , Require dedicated runs >1000fb^{-1} on WW threshold(~160GeV)



W mass measurement (2)

- Direct measurement of the hadronic mass (method for pre-CDR)
  - Based on 10^{10} Z->hadrons sample to calibrate jet energy scale (< 3MeV)
  - Advantage :
    - No additional cost :measured in ZH runs (sqrt(s)=250GeV)
    - Higher statistics: 10 times larger than WW threshold region
    - Lower requirement on beam energy uncertainty.
  - Disvantage:
    - Can not get better precision than 3MeV
    - Require Beam momentum measurement : 10ppm level on P_{beam}



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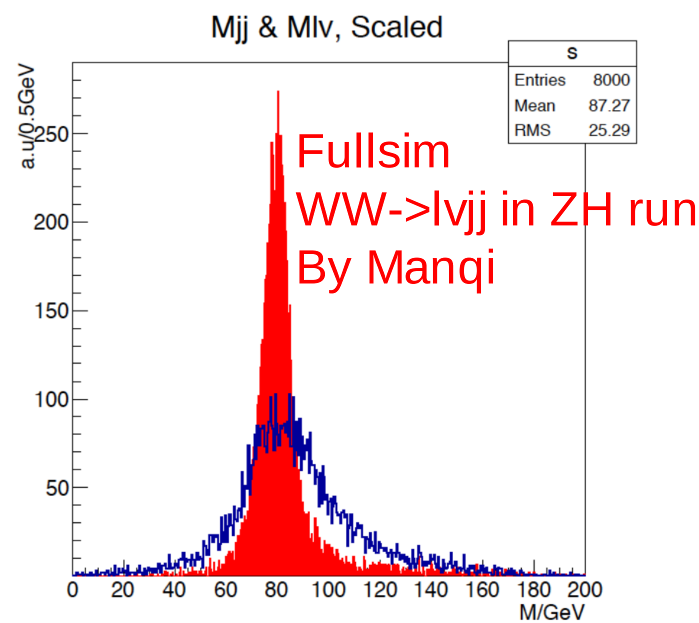

Summary

- CEPC electroweak physics in Preliminary Conceptual Design Report.
  - Expected precision based on projections from LEP and ILC.
- Aim for more realistic study with full simulation for CDR next year.
  - Mainly focus on fullsim study on key measurements.
  - Understand Detector requirements and accelerator requirements
    - m_W
    - Weak mixing angle
    - mZ
    - Afb_B
    - R_B
  - Short of manpower in Z/W physics
  - Need help from international collaborations
- Need input from theorists to improve the measurements !
  - Interpretations
  - Higher order calculations
  - New ideas
  - ......
- Welcome to join this effort

From Pre-CDR to CDR

- Propagate beam momentum scale uncertainty to all EW measurement.
- Give a clear physics requirement to accelerator

		Correlations				
		m_Z	Γ_Z	σ^0_{had}	R^0_ℓ	$A^{0,\ell}_{FB}$
$\chi^2/\mathrm{dof} = 172/180$		ALEPH				
m_Z [GeV]	91.1893 ± 0.0031	1.000				
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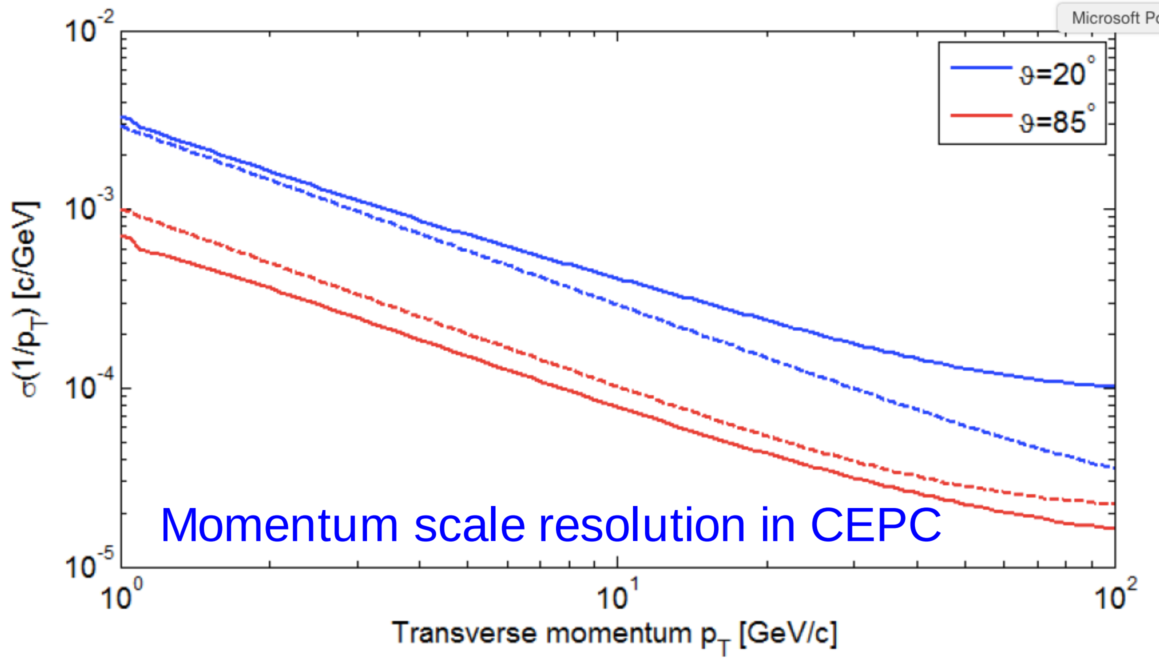
$A^{0,\ell}_{FB}$	0.0173 ± 0.0016	0.071	0.002	0.001	−0.076	1.000

Branching ratio (R^{mu})

- LEP result: 0.2% total error (Stat : 0.15%, Syst : 0.1%)
- CEPC : 0.05% total error expected
  - Better EM calorimeter is the key



Systematics source	LEP	CEPC
Radiative events (Z->μμγ)	0.05%	0.05%
Photon energy scale	0.05%	0.01%
Muon Momentum scale	0.009%	<0.003%
Muon Momentum resolution	0.005%	<0.003%

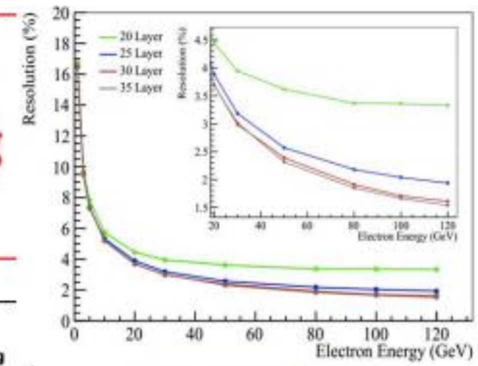
CEPC detector (2)

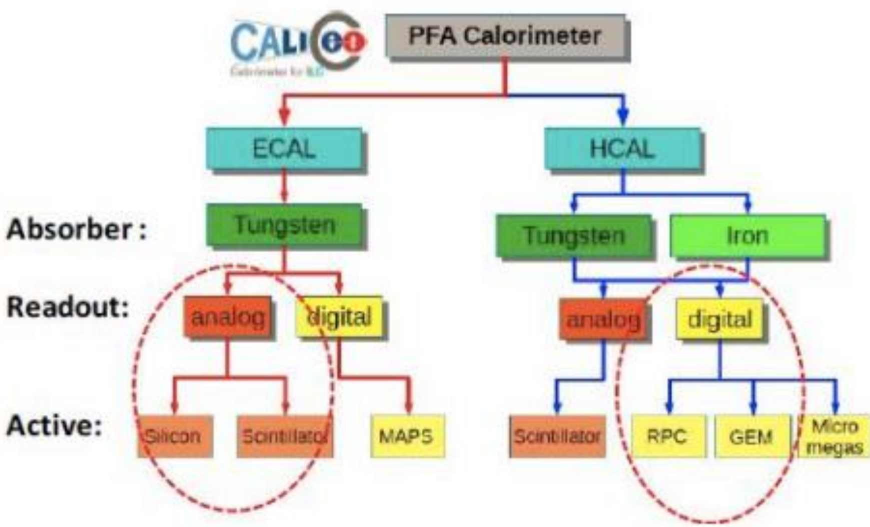
- Calorimeters:
  - Concept of Particle Flow Algorithm (PFA) based
  - EM calorimeter energy resolution: $\sigma_E/E \sim 0.16/\sqrt{E}$
  - Had calorimeter energy resolution: $\sigma_E/E \sim 0.5/\sqrt{E}$
  - Expected jet energy resolution : $\sigma_E/E \sim 0.3/\sqrt{E}$

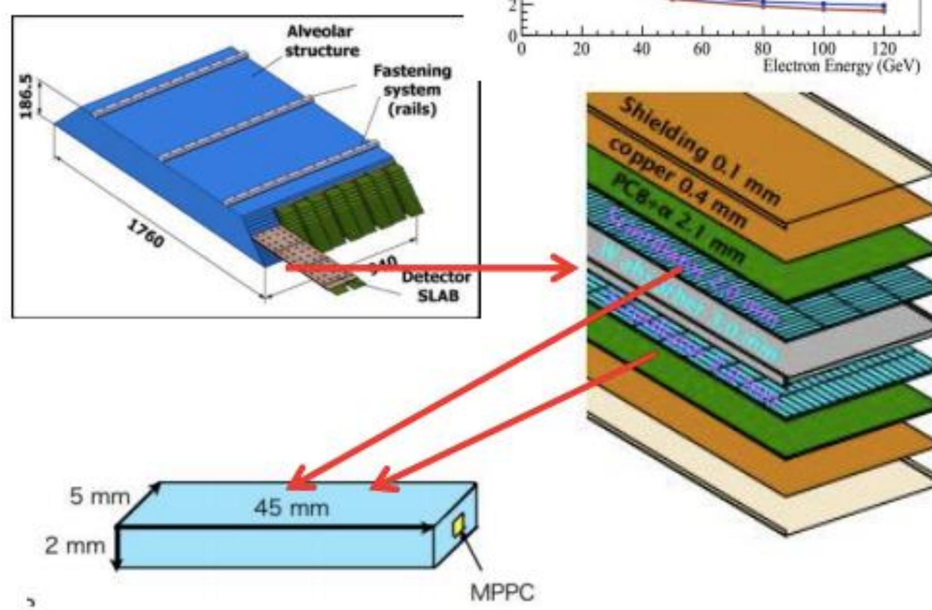
- Jet energy (Higgs self-coupling, W/Z separation)
  - ~1/2 resolution (wrt LHC)

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

less demanding at CEPC



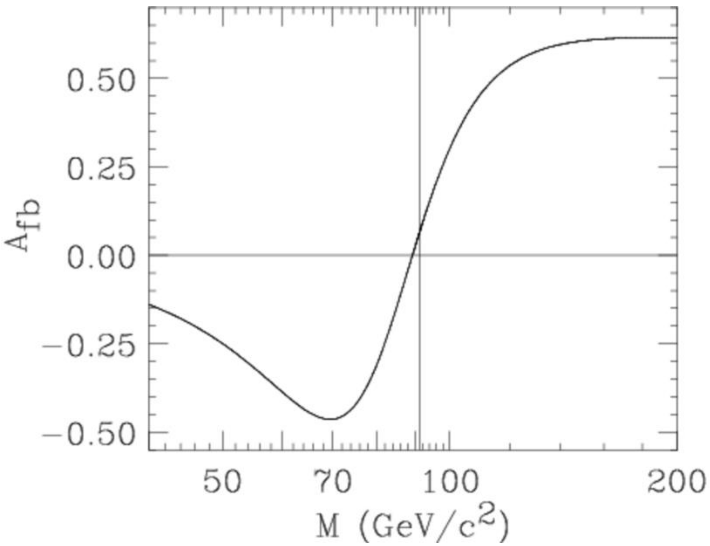


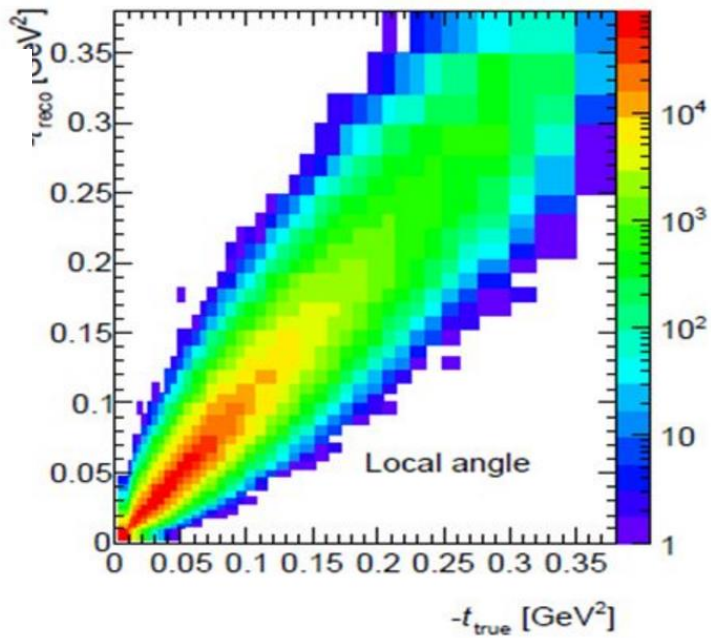


ECAL: Scintillator + W + Scintillator

Plan for Weak mixing angle

- More details in Mengran's talk





Truth distribution From Z fitter → unFolding matrix → Reco level distribution