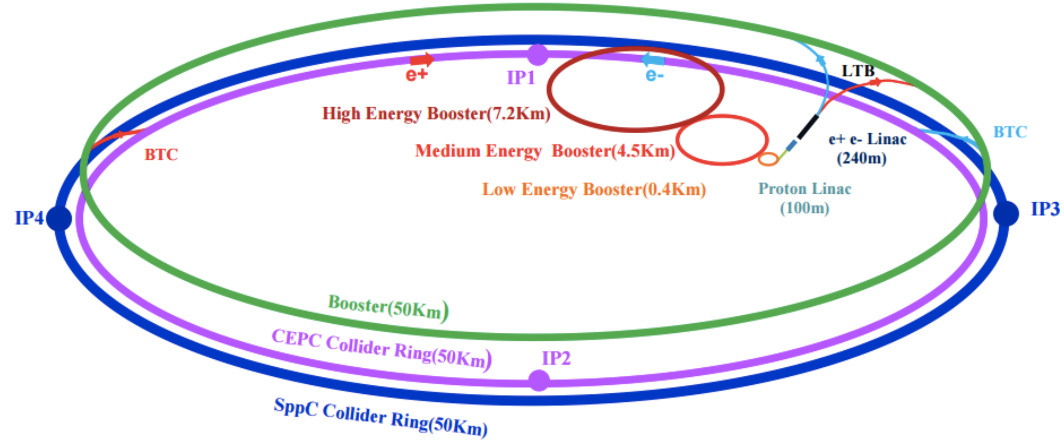
中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

ELECTROWEAK PHYSICS TOWARDS THE CDR

Zhijun Liang (IHEP)

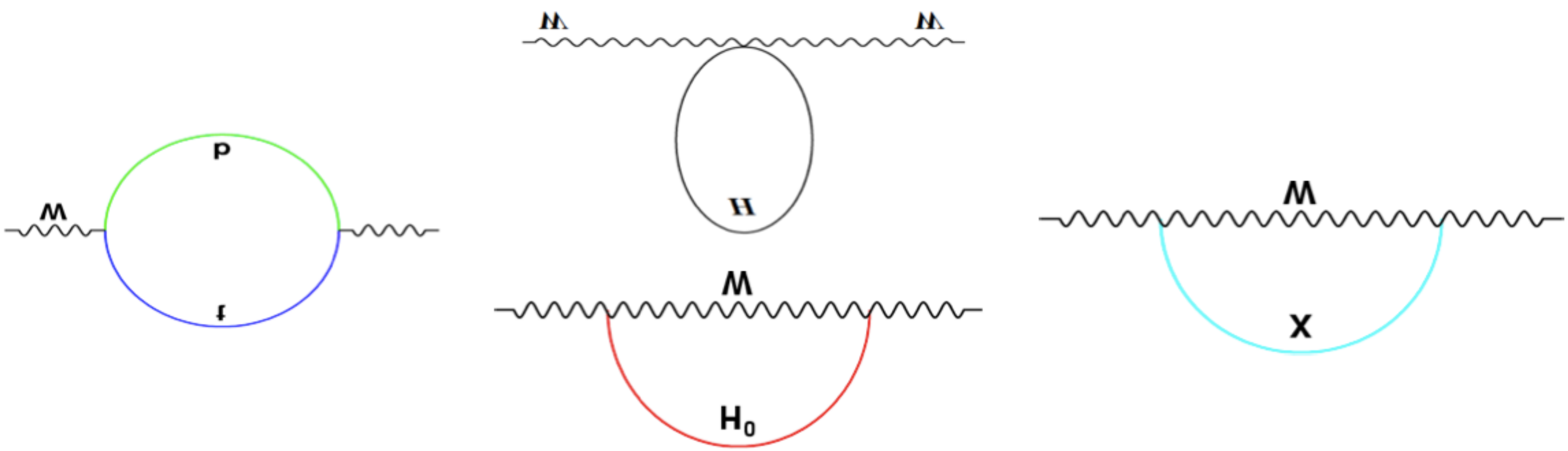
CEPC electroweak



- 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)

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



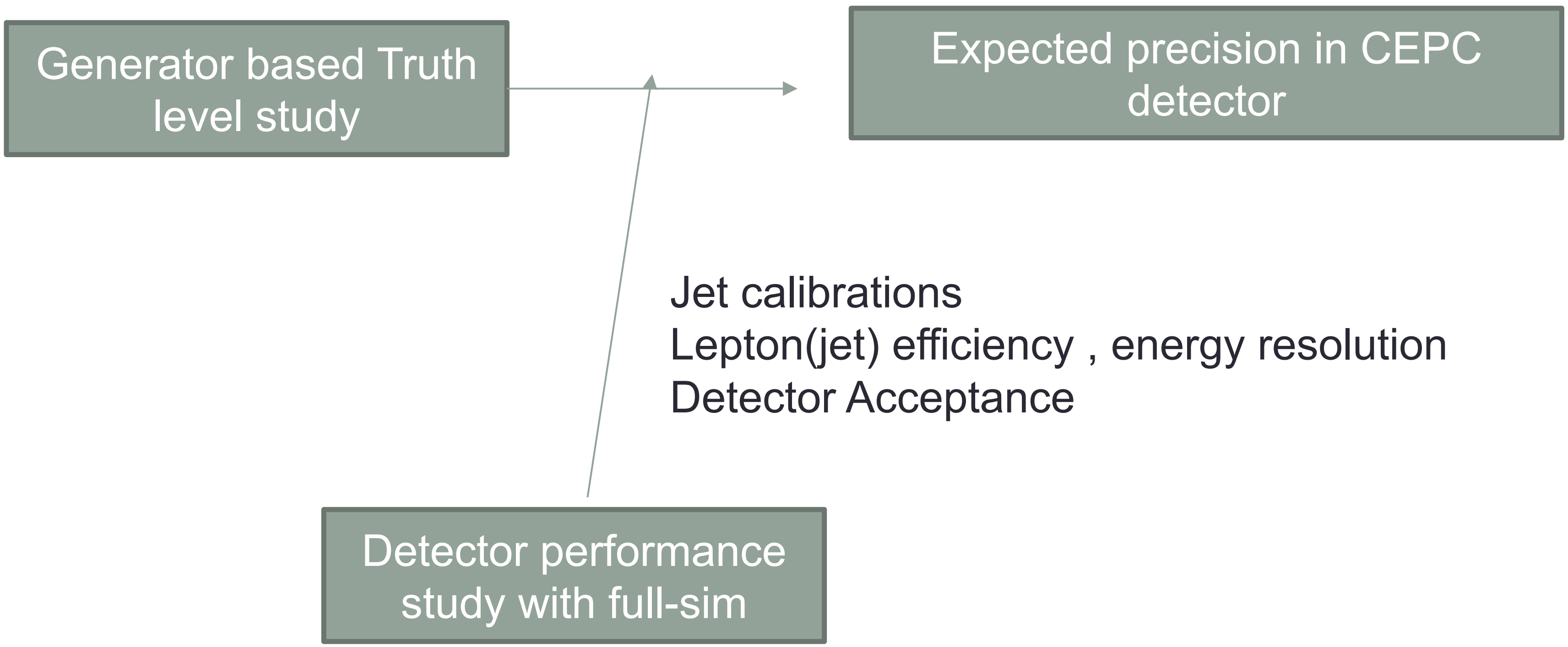
The prospect of CEPC electroweak physics in pre-CDR study

- 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
$\sin^2\theta_W^{\text{eff}}$	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

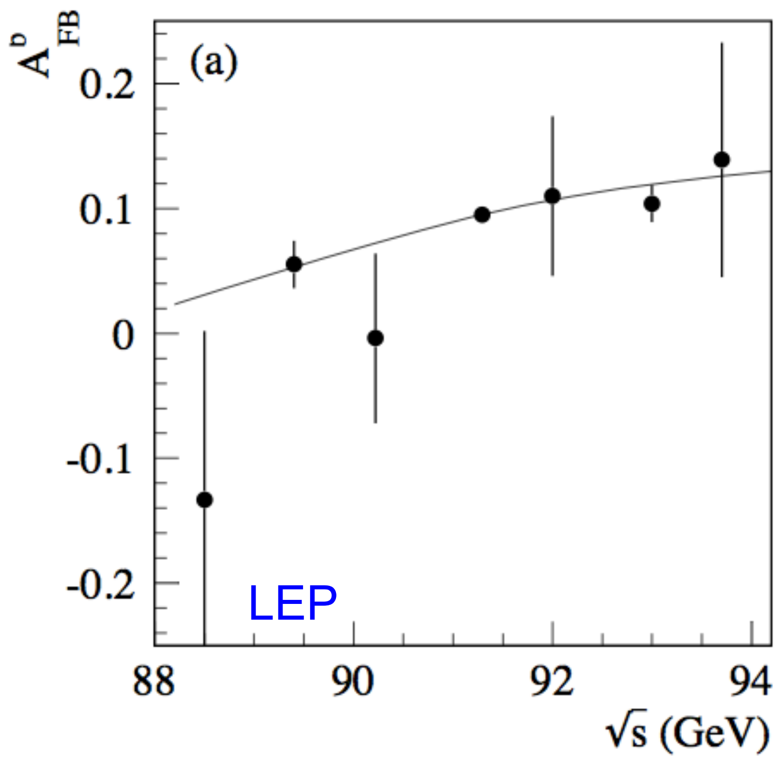
Toward CDR

- Some key experimental systematics study in full-sim MC samples.
  - Get jet energy resolution , lepton acceptance, b tagging efficiency …
- Expected precision for electroweak measurements can be done
  - In generator level with key detector performance input from fullsim



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

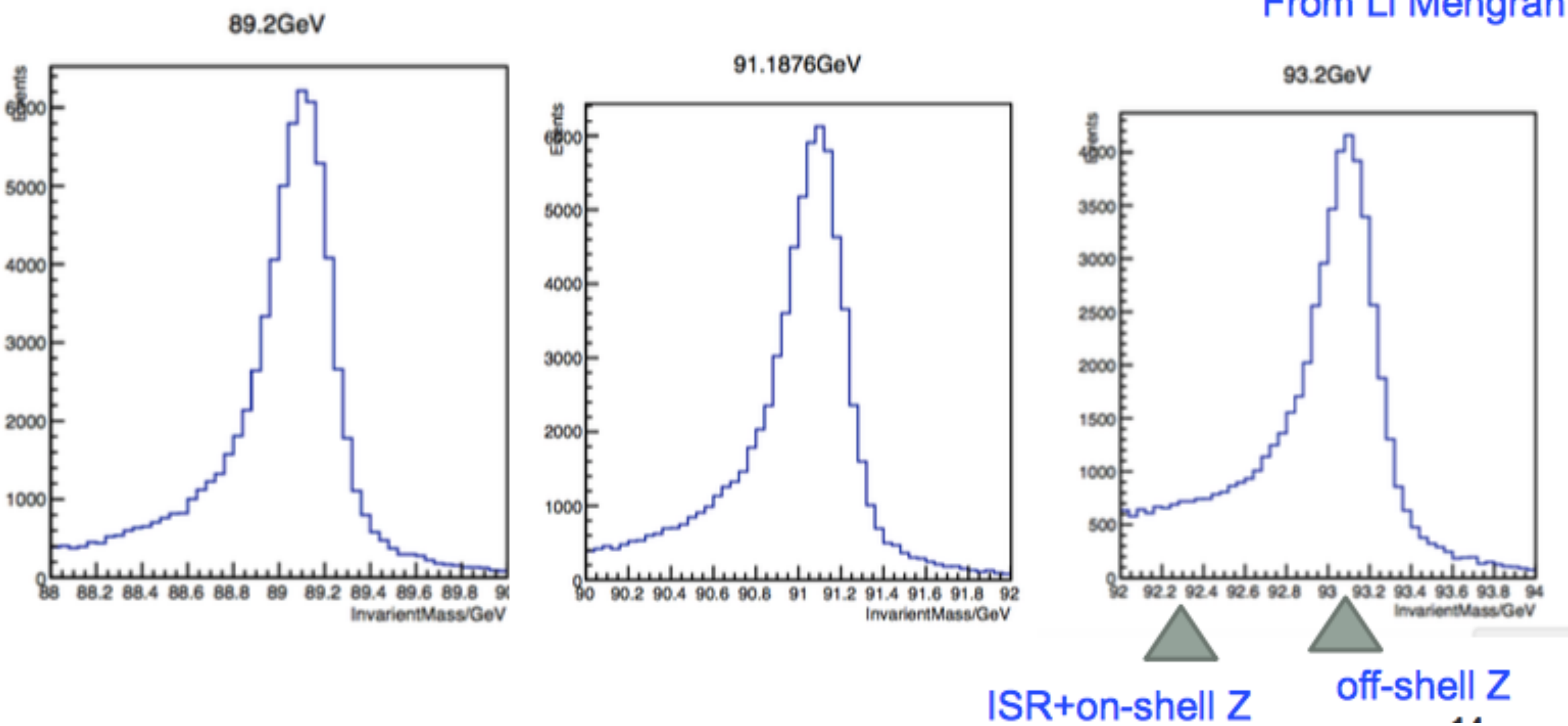
- LEP/SLD: 0.23153 ± 0.00016
  - 0.1% precision.
  - Stat error is one of limiting factor.
- CEPC
  - systematics error : 0.01%
    - Input From Backward-forward asymmetry measurement in Z pole Z->μμ events
    - Lepton efficiency and acceptance is one of the major systematics



$m_{\mu\mu}$ distribution in Z pole runs

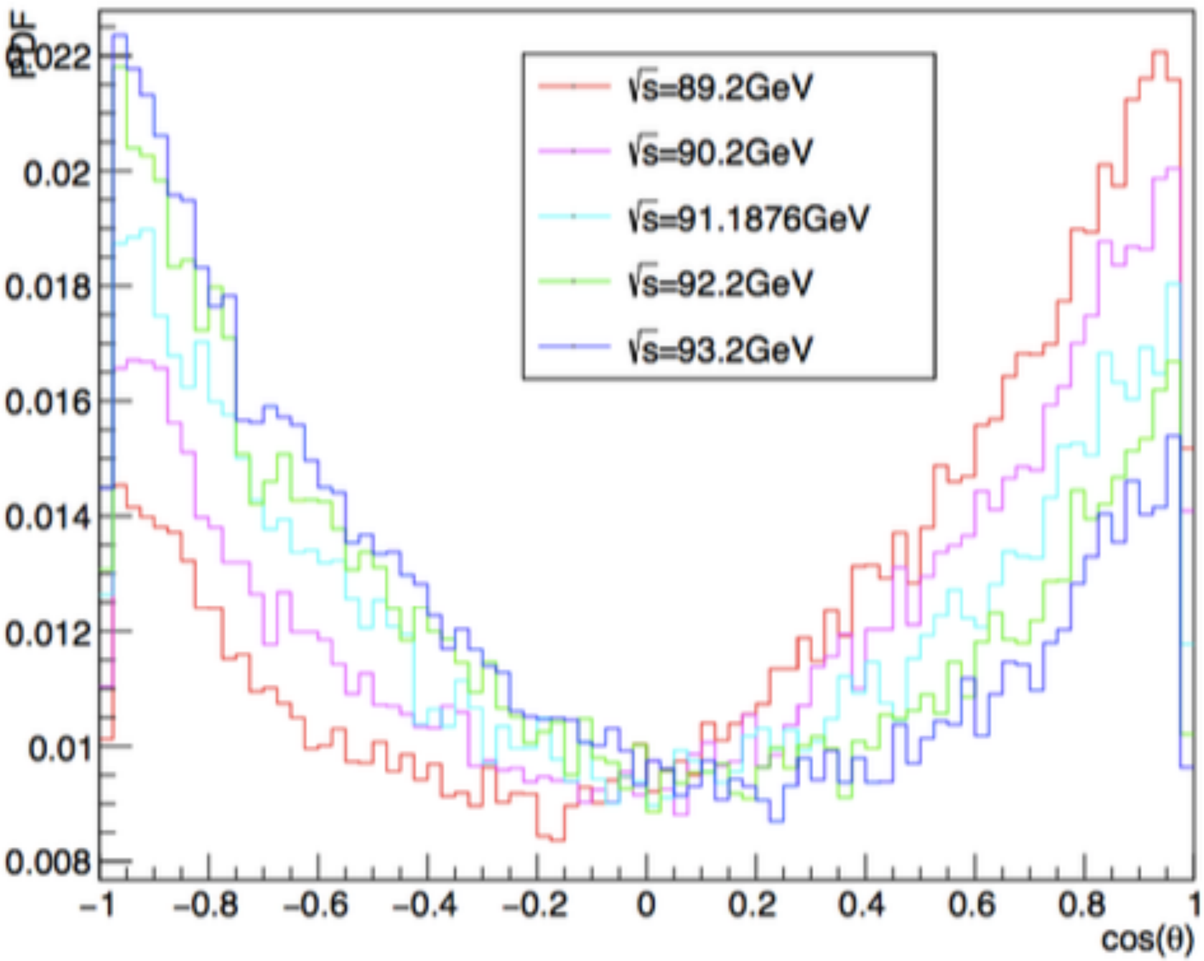
- Backward-forward asymmetry from Z->μμ in Z pole
- Generate full simulation with sqrt(s)=89.2 … 93.2GeV
- Resolution of m(μμ) is from detector resolution

From Li Mengran



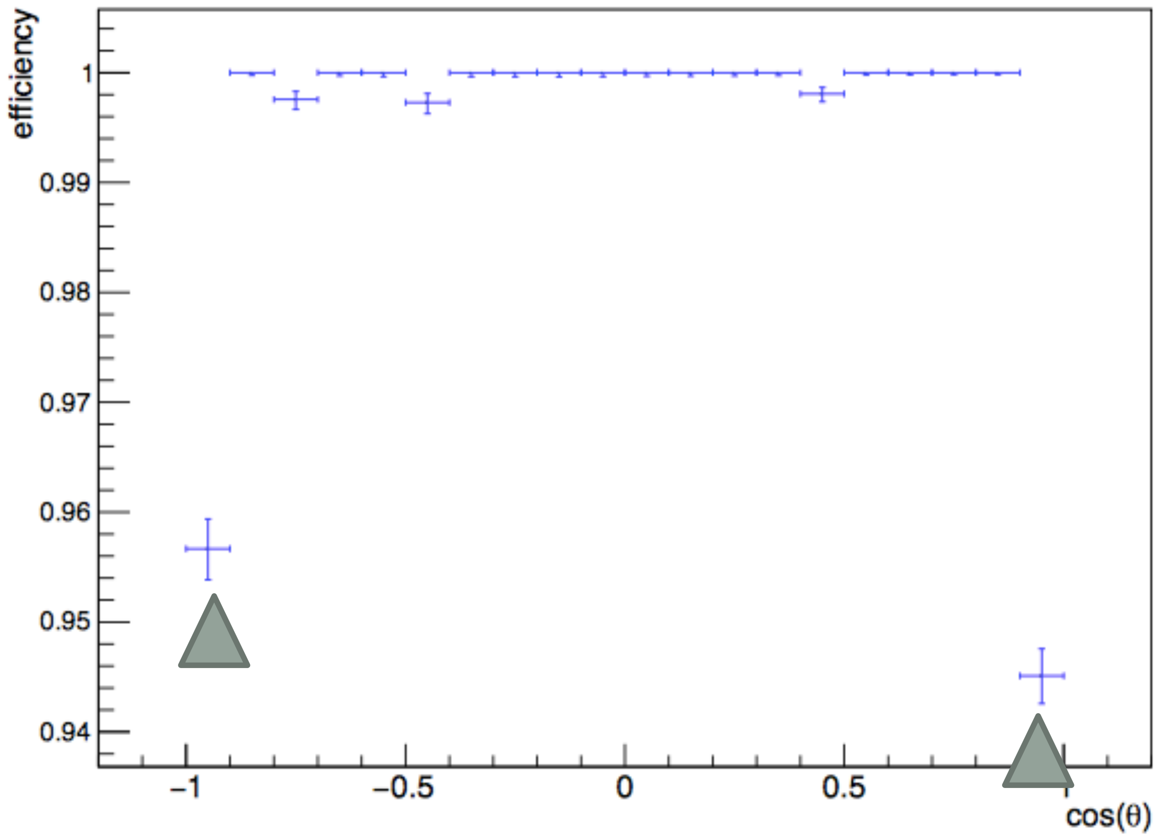
Cos (θ) of μ+ in Z-> $\mu^+ \mu^-$ events

Backward-forward asymmetry in Z pole runs



Muon reconstruction efficiency in CEPC $Z \to \mu^+ \mu^-$ full simulation

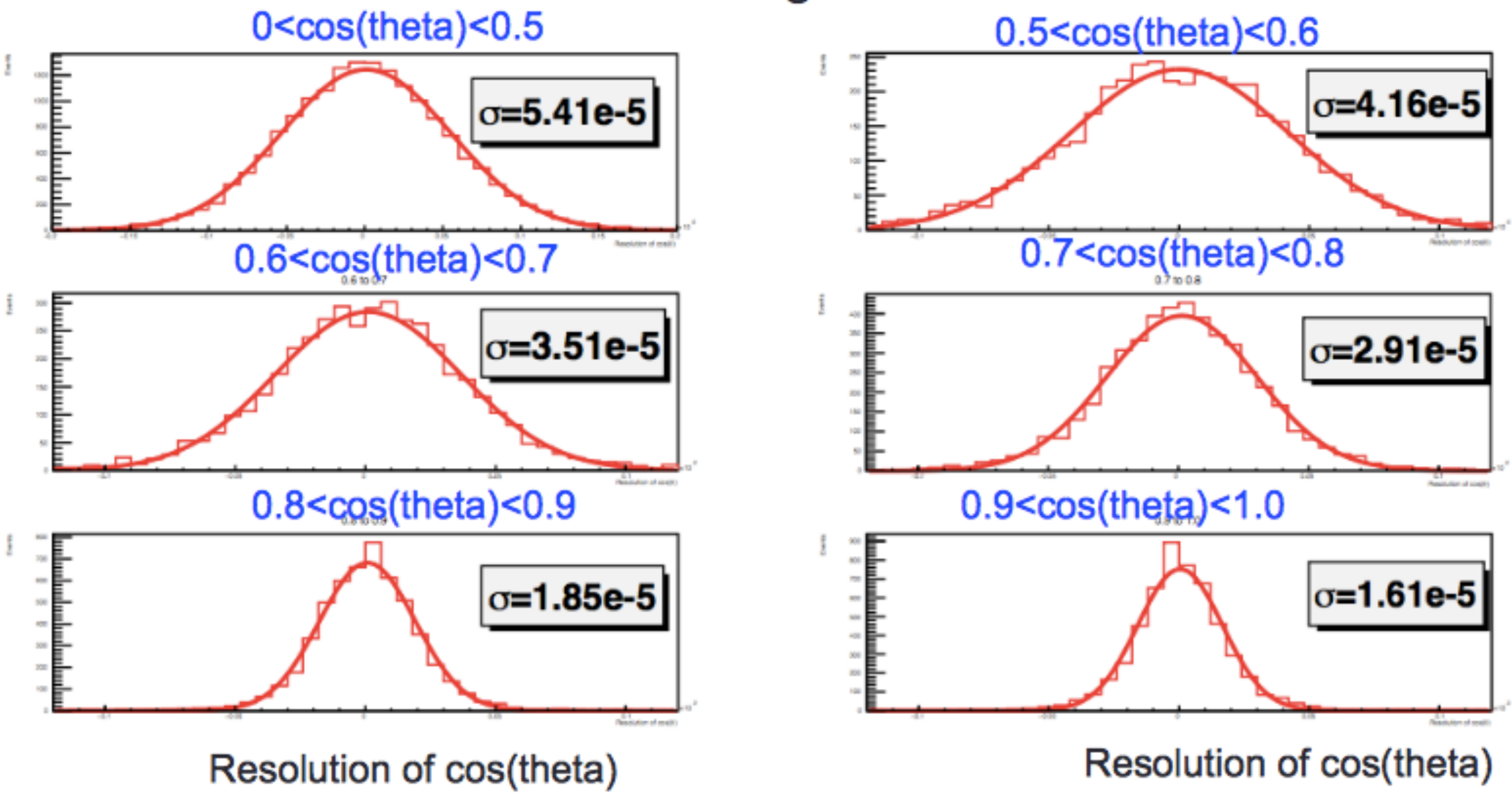
- In-efficiency in forward regions is the key of Afb measurement.



Detector resolution on cos(theta)

From Li Mengran

- Resolution from full simulation Z->μμ events
- Better resolution in forward regions.



Weak mixing angle analysis toward CDR

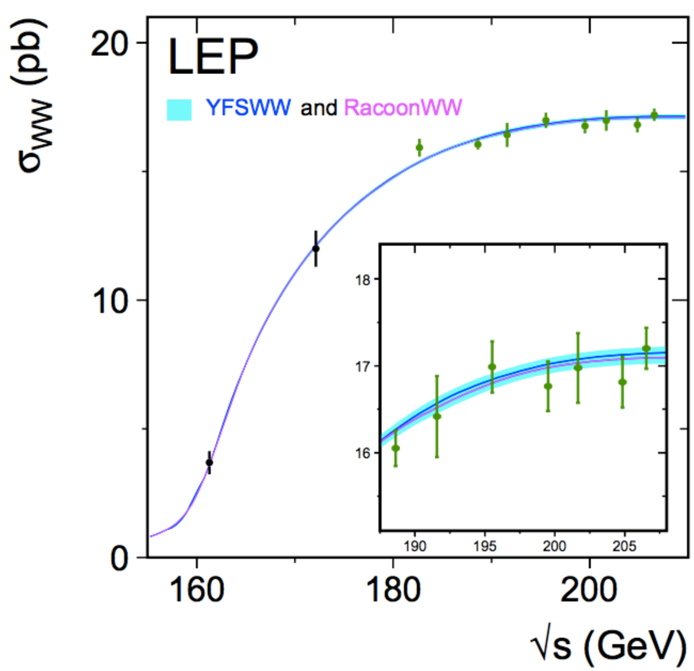
- Key detector performance inputs are almost ready
  - Lepton acceptance and efficiency map obtained
- Towards CDR
  - Estimate the expected precision using Gfitter framework with lepton performance inputs.

Update in W mass measurement

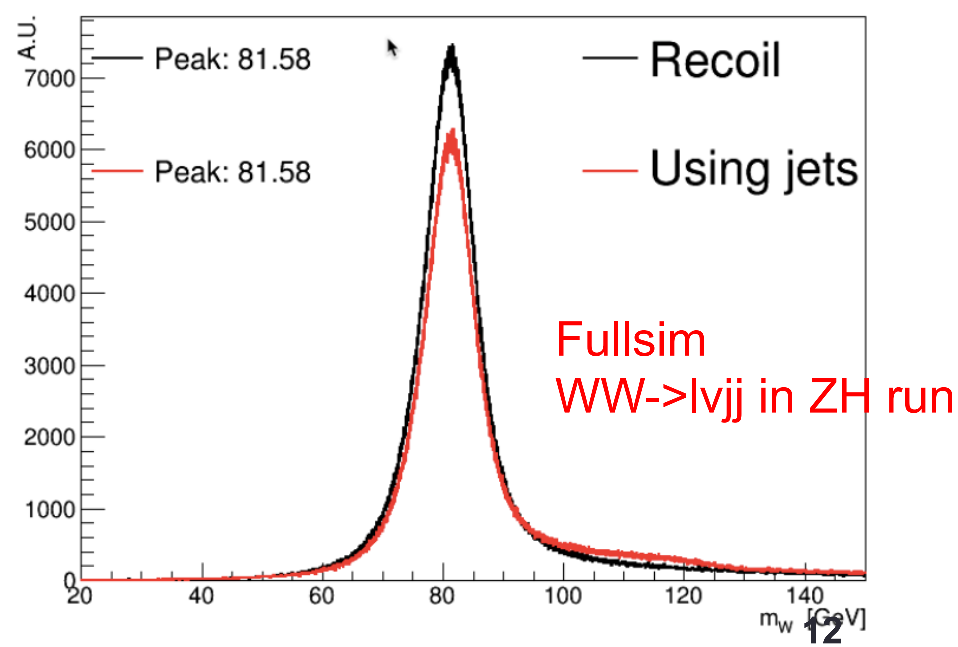
From Bo and Lesya

- Threshold scan method
  - Optimize off-peak runs statistics
  - Check selection efficiency in different off-peak runs
- Direct measurement of the hadronic mass (method for pre-CDR)
  - Optimize W mass direct reconstruction method in ZH runs
  - Jet energy calibration

Threshold scan



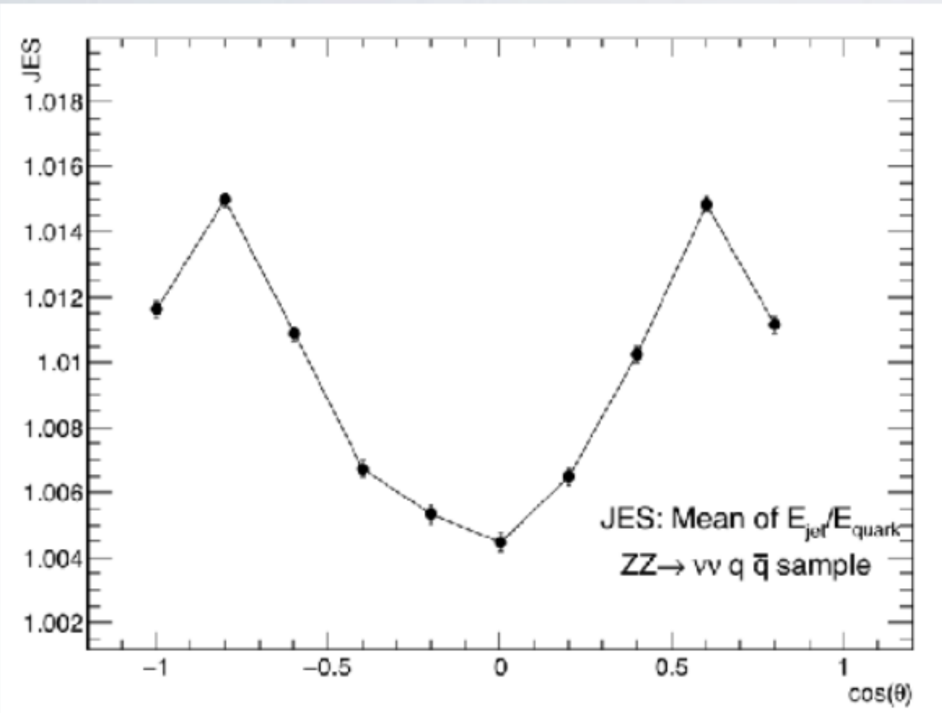
Direct reconstruction

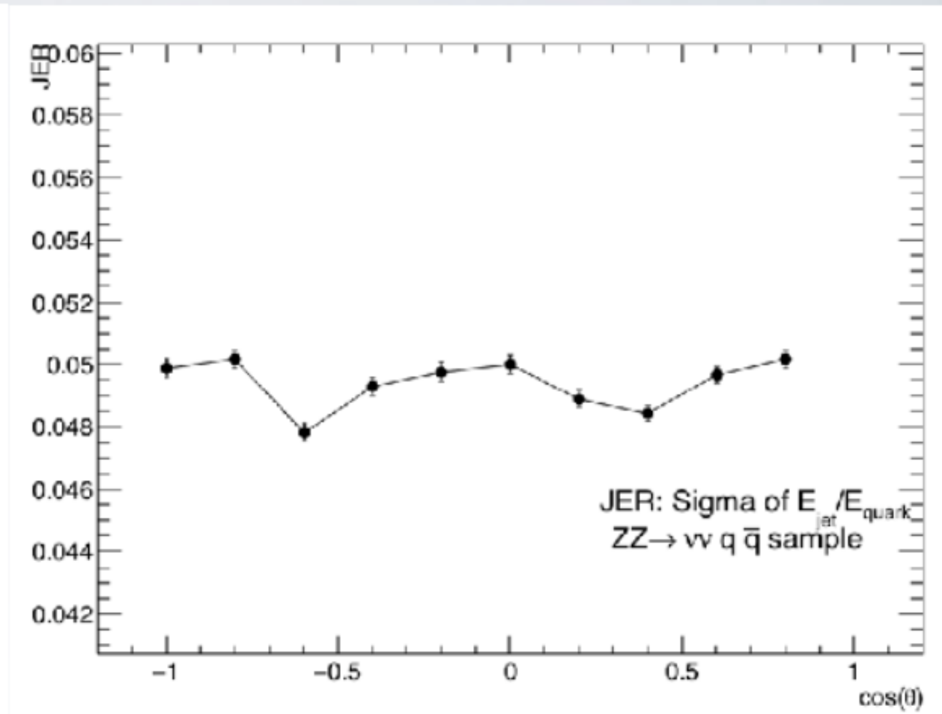


Jet energy scale and resolution

From Bo and Lesya

- Precision of Direct measurement depends strongly on
  - Jet energy calibration
- CEPC can collect 10^{11} Z->qq events
  - can obtain a good jet energy calibration

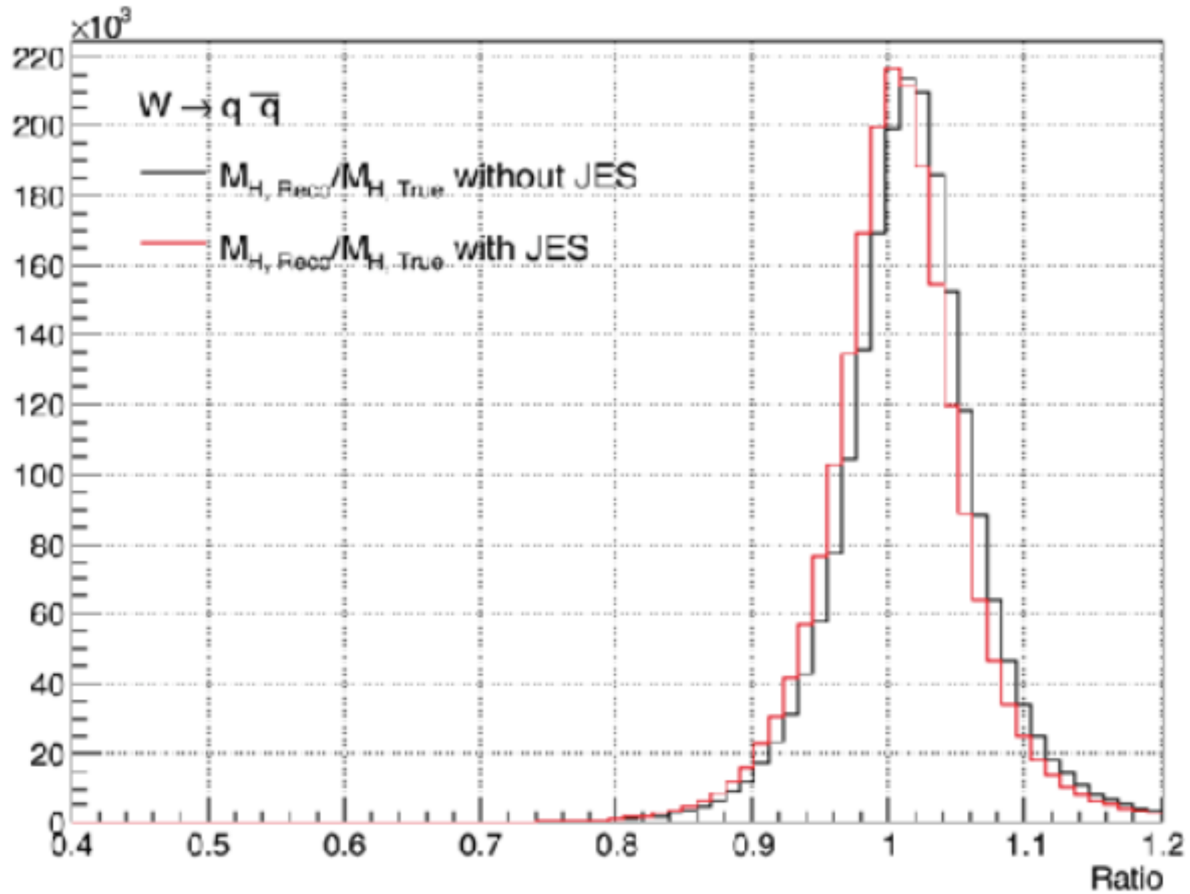




W boson mass

From Bo and Lesya

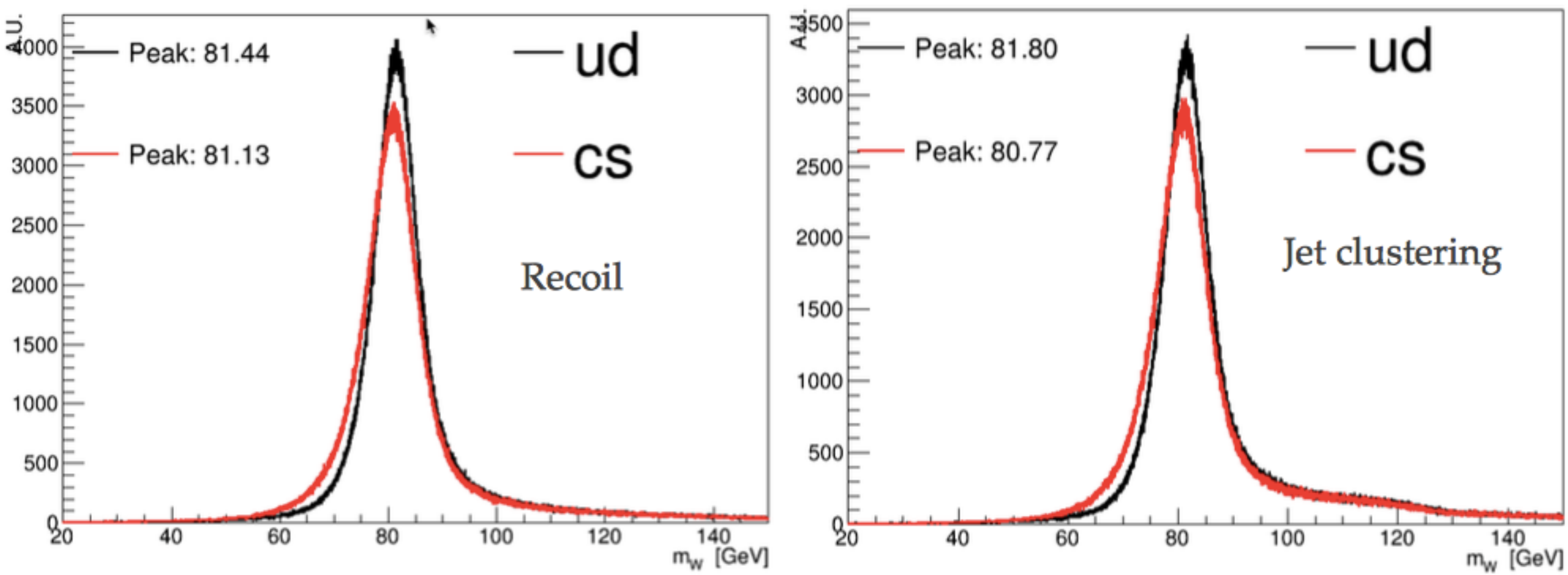
- Reconstructed the W boson mass from dijet can be improved a few percent after calibrations



W mass and
flavor dependence of jet energy scale

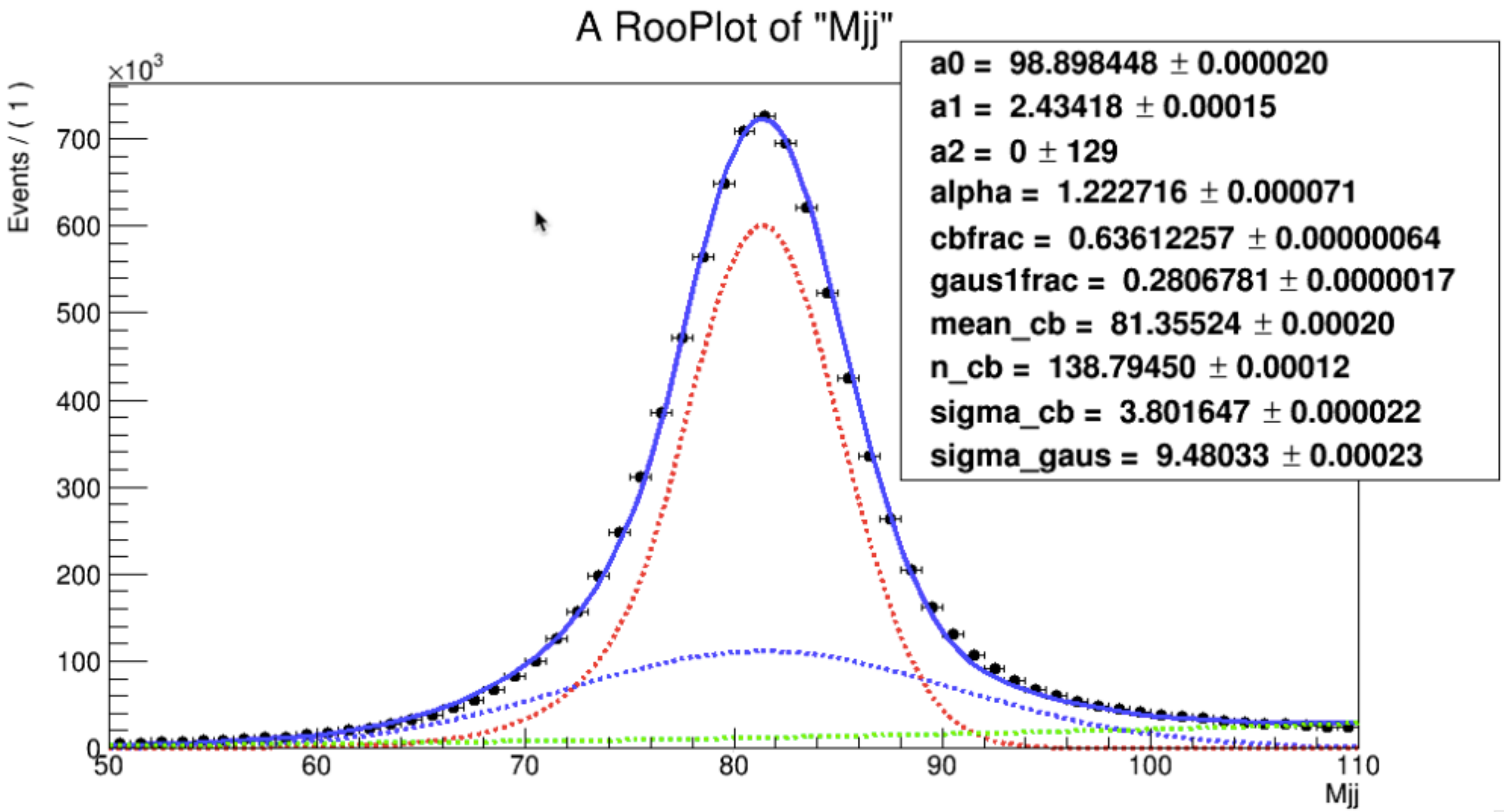
From Bo and Lesya

- Found flavor dependence on jet energy scale.
- Need to refine jet calibration, considering this dependence.



W mass reconstructed from dijet mass in semi leptonic decay

From Bo and Lesya



CB+Gaussian+3-order Polynomial

W mass analysis toward CDR

- Finalize Z->qq jet calibrations.
  - Quantify the jet energy resolution and jet angular resolution
- Apply jet energy calibration on WW->lvjj events
  - Quantify the uncertainty due to jet resolution

Major systematics in EWK measurement

	Major systematics	Other systematics
m_Z	Beam energy (10^{-5} ~ 10^{-6})	Luminosity measurement (10^{-4})
A_{FB}(lepton)	Beam energy (10^{-5} ~ 10^{-6})	Track Alignment in forward region Track angular resolution (<0.05%)
R_b	flavor tagging (light jet Bkg).	Gluon splitting modeling
A_{FB}(b)	flavor tagging (light jet and c jet background).	Jet charge
m_W (direct measurement)	Jet energy scale and resolution (<3% JER)	
m_W (threshold can)	Beam energy	Luminosity measurement
α_{QCD}	To be study	
α_{QED}	To be study	
TGC	Lepton angular resolution	

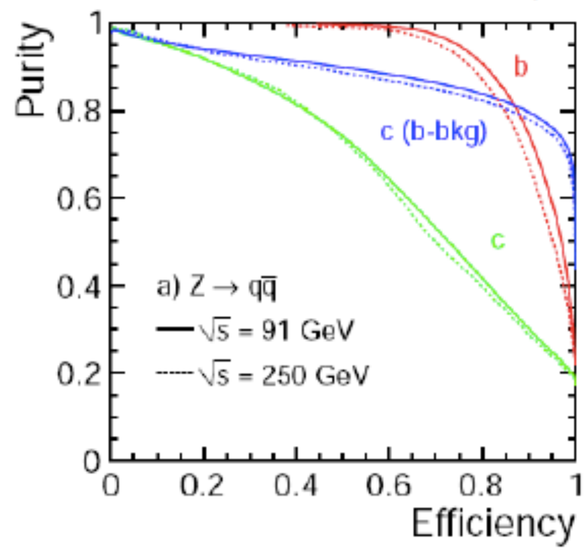
Summary

- Expected precision for electroweak measurements can be done
  - In generator level with key detector performance input from full simulation
- Updates in understanding key detector performance in precision electroweak measurements .
  - Jet energy calibration
  - Lepton accetance in CEPC detector
- Similar study can be done for other EWK topics.
  - Eg: triple-gauge coupling (TGC) from WW events
  - Lepton performance and jet energy resolutions in place.
- Welcome to join this effort

B tagging performance in Branching ratio (R^b)

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

- Major systematics is from light jet and c jet background
- can be reduced by improving the b tagging performance
- Need fullsim to validate its performance



Uncertainty	LEP	CEPC	CEPC improvement
hemisphere tag correlations for b events	0.2%	0.1%	Higher b tagging efficiency

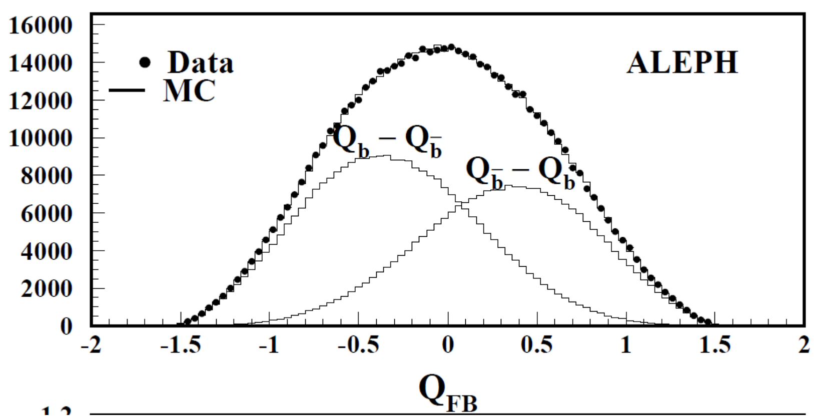
Backward-forward asymmetry measured from b jet

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

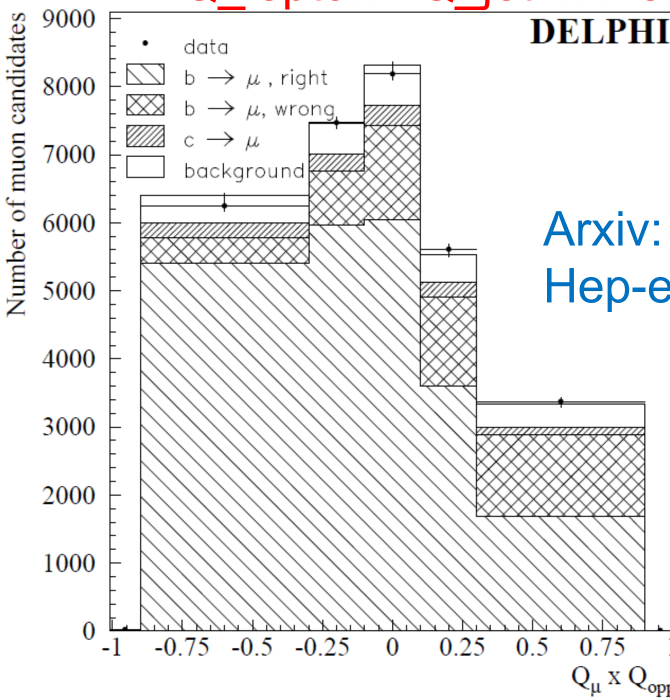
- LEP measurement : 0.1000+-0.0017 (Z peak)
  - Method 1: Soft lepton from b/c decay (~2%)
    - Select one lepton from b/c decay, and one b jets
    - Select lepton charge (Q_lepton) and jet charge (Q_jet)
  - Method 2: jet charge method using Inclusive b jet (~1.2%)
    - Select two b jets
    - use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

Arxiv:
Hep-ex/0107033

Q_F - Q_B in method 2



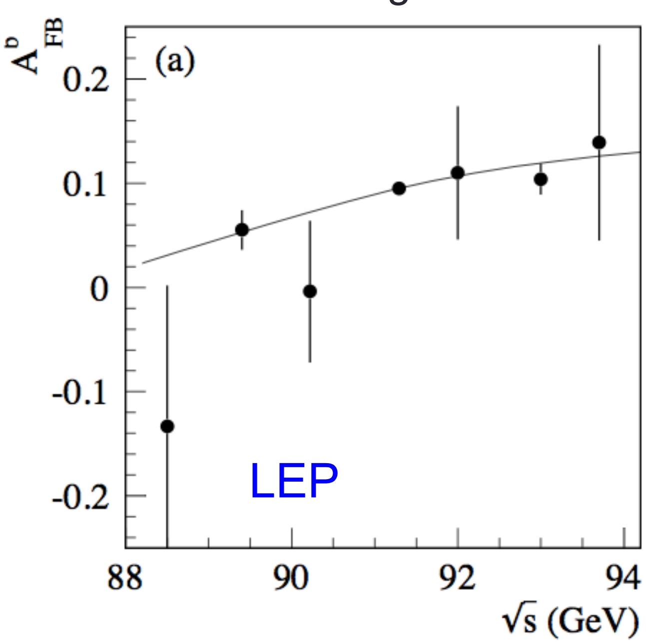
Q_lepton - Q_jet in method 1



Arxiv:
Hep-ex/0403041

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})
  - If mZ is not well measured in CEPC ,
    - We need a large statistics of off-Z peak runs for weak mixing angle

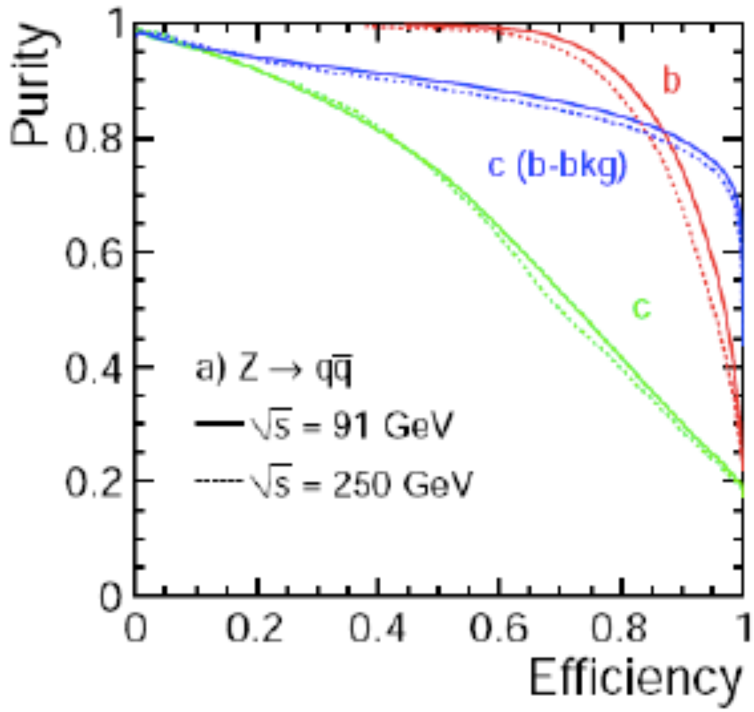


CEPC off-peak runs stat

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

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)
        - 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

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 a few key measurements.
    - m_W
    - Weak mixing angle
    - mZ

- Welcome to join this effort

Urgent open task

- 1. W mass measurement
  - Try to understand the precision with direct measurement approach
  - Design dedicated runs for WW threshold scan approach
- 2. Detector optimization using Z->bb R(b) measurement as benchmark model.
  - Pixel size optimization:
    - Baseline 16x16μm
    - Whether we need high resolution both direcction
    - Is 16x32 μm OK ?
  - Momentum resolution requirement
  - Impact parameter requirement

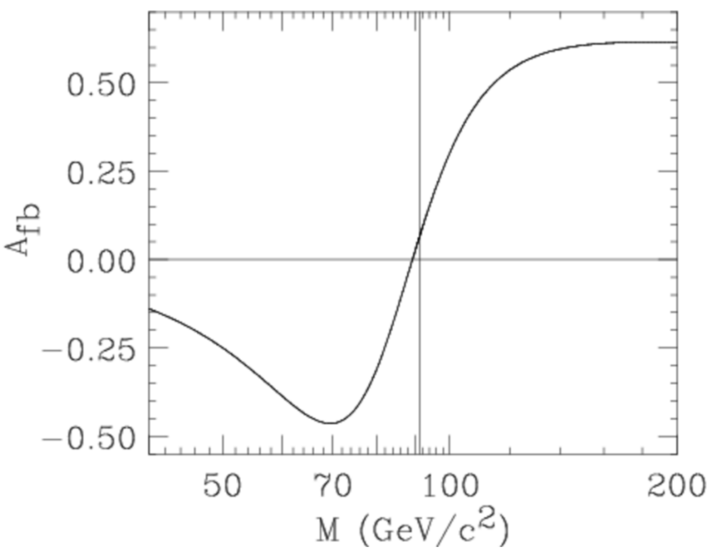
From Pre-CDR to CDR

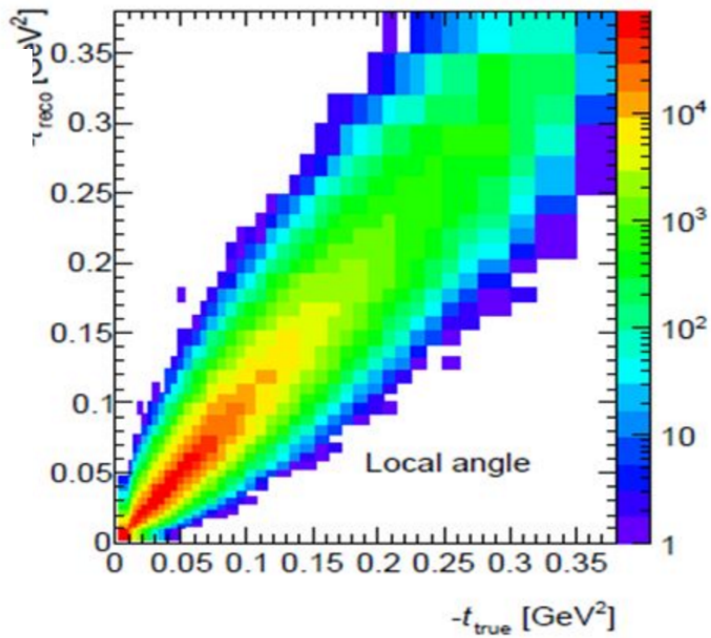
- Propagate beam momentum scale uncertainty to all EW measurement.
- Give a clear physics requirement to accelerator

		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				
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

Plan for Weak mixing angle

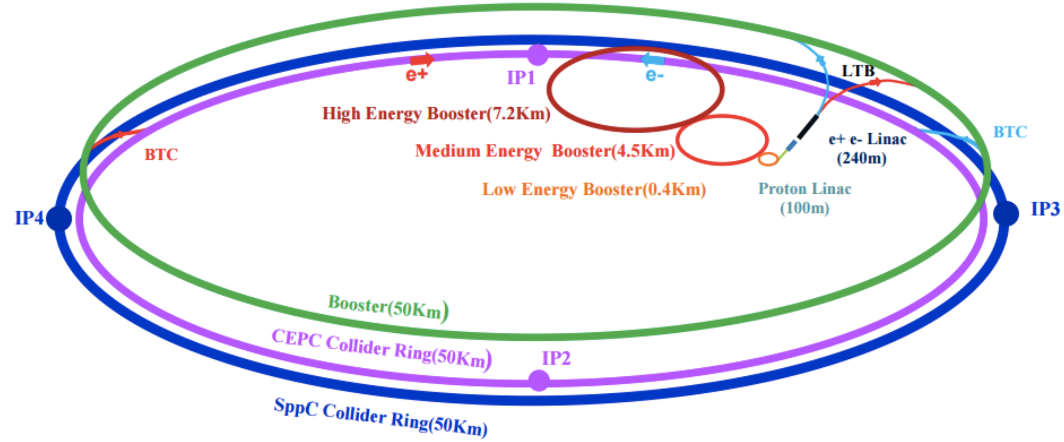
- More details in Mengran's talk





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

CEPC accelerator



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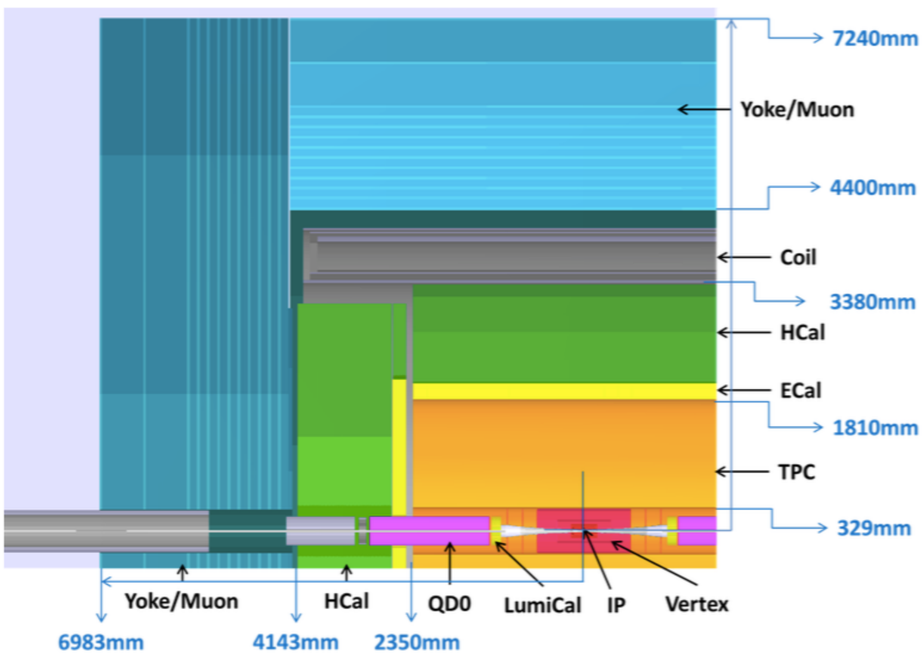
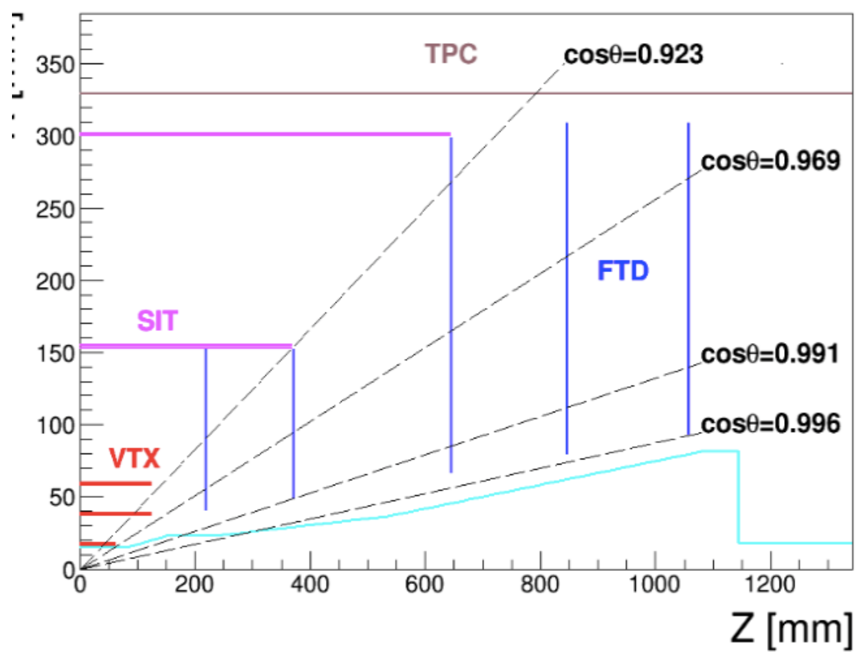
    - **Major focus of this talk**
- Preliminary Conceptual Design Report(Pre-CDR) available :
  - http://cepc.ihep.ac.cn/preCDR/volume.html
- Aiming to finalize Conceptual Design Report (CDR) next year

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 Pixel size in vertex detector : less than 16x 16μm
  - Expected Impact parameter resolution: less than 5μm
  - Expected Tracking resolution : $\delta(1/P_t) \sim 2*10^{-5}(GeV^{-1})$





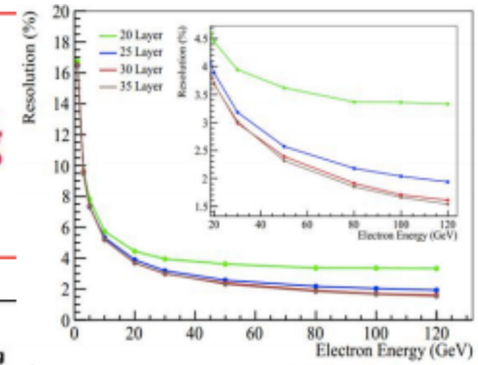
CEPC detector (2)

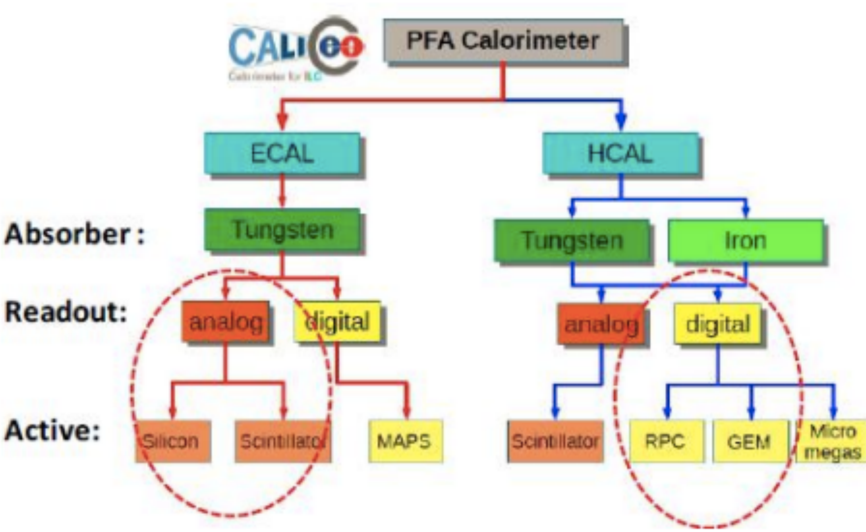
- Calorimeters:
  - Concept of Particle Flow Algorithm (PFA) based
  - EM calorimeter energy resolution: $\sigma_E/E \sim 0.16/\sqrt{E}$
  - Had calorimeter energy resolution: $\sigma_E/E \sim 0.5/\sqrt{E}$
  - Expected jet energy resolution : $\sigma_E/E \sim 0.3/\sqrt{E}$

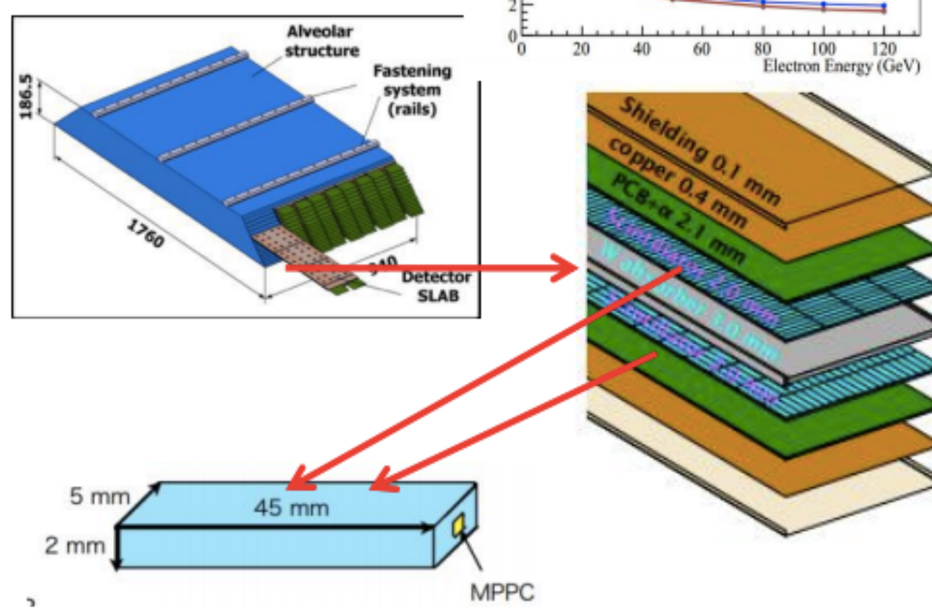
- Jet energy (Higgs self-coupling, W/Z separation)
  - ~1/2 resolution (wrt LHC)

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

less demanding at CEPC





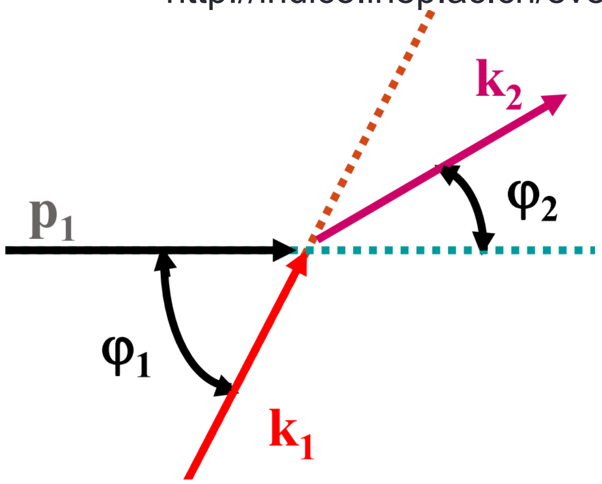


ECAL: Scintillator + W + Scintillator

Task 1 : Beam energy measurement

- Resonant depolarization method. (LEP approach)
  - Urgently need Beam polarization design in CEPC
  - Whether CEPC can have bunch with polarization and how long it lasts
  - Polarization fraction in Z and WW threshold

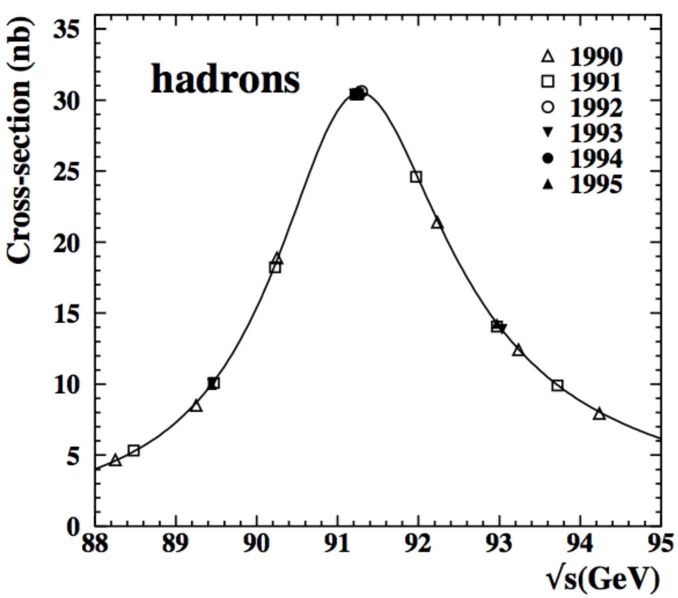
- compton scattering approach
  - Whether it can reach 1MeV precision from this approach
    - preliminary study in G-Y. Tang's talk http://indico.ihep.ac.cn/event/6495/session/4/contribution/29/material/slides/0.pdf



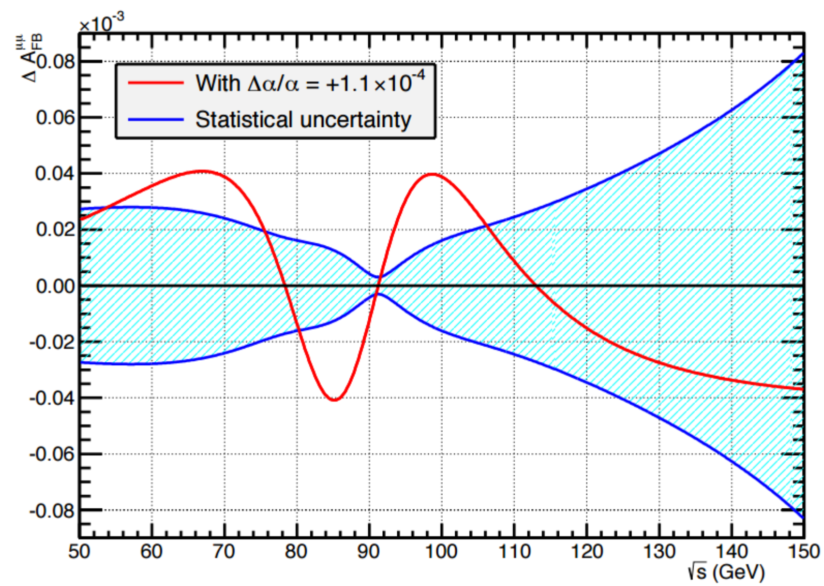
Task 2: optimizing Z threshold scan

- Optimize off-peak runs statistics for Z line shape and α_{QED} shape
  - Check event selection efficiency as a function of beam energy
- Fcc-ee colleague proposed to take more data around 87 and 94 GeV off-peak runs for α_{QED} shape

☐ Need fastsim study to check α_{QED} measurement

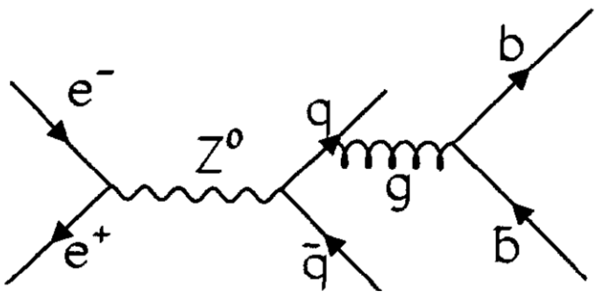


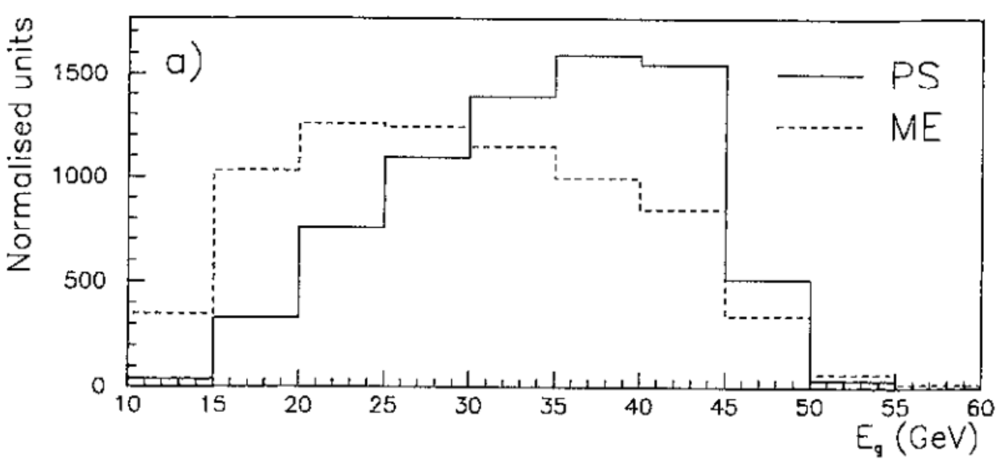
P. Janot, JHEP 1602 (2016) 053



Branching ratio (R^b): task : gluon splitting measurements

- To reduce the R_b systematics
- One of the task is to measure gluon splitting





Phys Lett B 405 (1997) 202