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)

Outline

- Z->bb branching ration measurement in Z pole (Li bo, Yantai University)
- W mass measurement in ZH runs (Liu bo, IHEP)
- Afb measurement in Z pole (Li Mengran , IHEP)

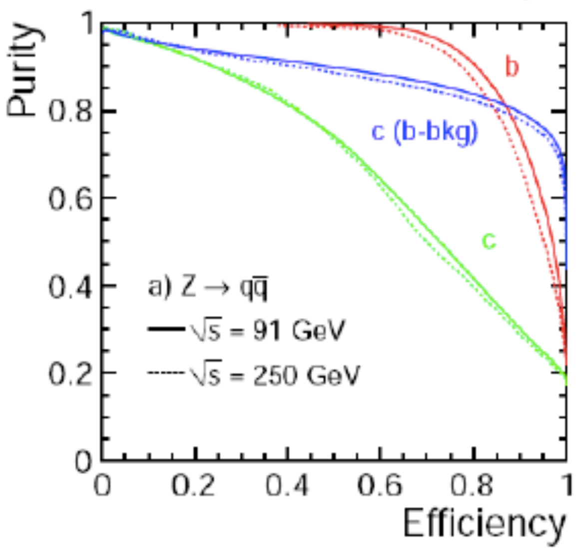
Major systematics in EWK measurement

	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 and c jet background).	Gluon splitting modeling
A_{FB}(b)	flavor tagging (light jet and c jet background).	Jet charge
m_W (direct reconstruction)	Jet energy scale and resolution (<3% JER)	Beam energy
m_W (threshold scan)	Beam energy	Luminosity measurement
α_{QCD} , α_{QED}	To be study	

Part I: B tagging performance in Branching ratio (R^b)

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

- 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

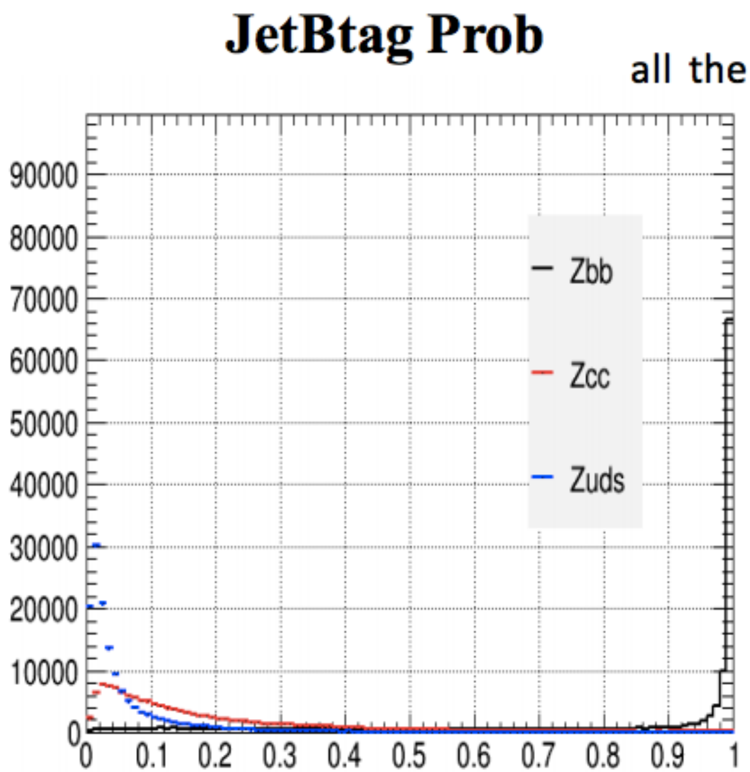


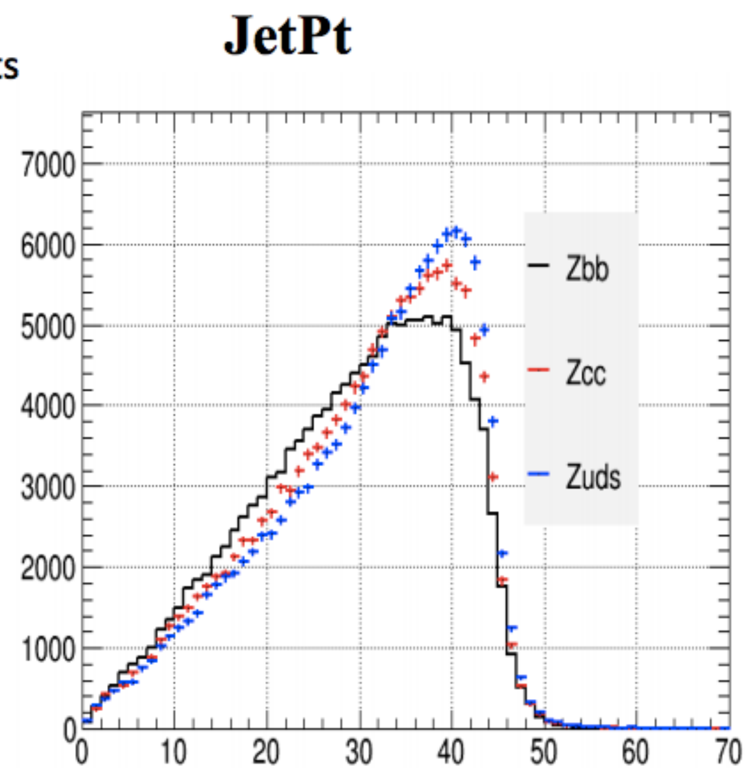
Uncertainty	LEP	CEPC	CEPC improvement
hemisphere tag correlations for b events	0.2%	0.1%	Higher b tagging efficiency

R_b status (from Li Bo)

- Full simulation study to understand the impact of b tagging performance to c jet /light jet background systematics

all the 2jets





- The BtagProb are different for Zbb, Zcc and Zll
- Four BtagProb Work Point are used :
  - The BtagProb>0.6 , BtagProb>0.7, BtagProb>0.8, BtagProb>0.9

Matrix method of RB measurement

(from Li Bo)

Rb method

简介

Get From Mixed MC Sample

$$\frac{N_t}{2N_{had}} = R_b\varepsilon_b + R_c\varepsilon_c + (1 - R_b - R_c)\varepsilon_{uds}$$

$$\frac{N_{tt}}{N_{had}} = C_b R_b \varepsilon_b^2 + C_c R_c \varepsilon_c^2 + C_{uds}(1 - R_b - R_c)\varepsilon_{uds}^2$$

R_c, ε_c, ε_{uds}
C_b, C_c, C_{uds}
Get from MC

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

1.015 1.021 1.026 1.033

Following this procedure, we can measured the R_b , ε_b

The Z hadronic **'DATA'** is mixed by MC samples: Zbb **sample1**, Zcc **sample1**, Zll sample1
We set Rb=0.3, Rb=0.5, Rb=0.7 as the Input Rb to mix the 'DATA'

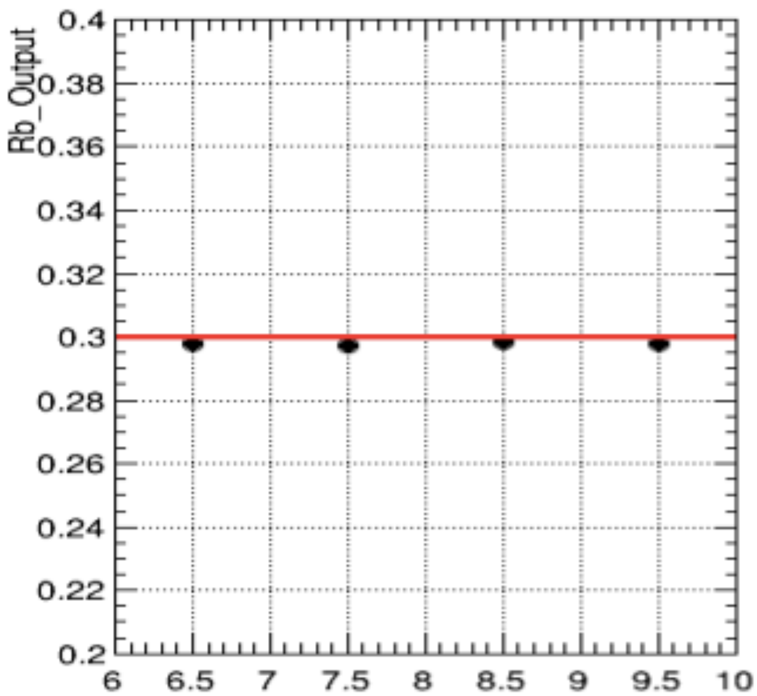
The R_c, ε_c, C_b, C_c, C_{uds} is gotten by MC samples: Zbb sample2, Zcc sample2, Zllsample2
So if **sample1≠** sample2, which means the MC R_c, ε_c, C_b, C_c, C_{uds} are different from the Truth in 'DATA'

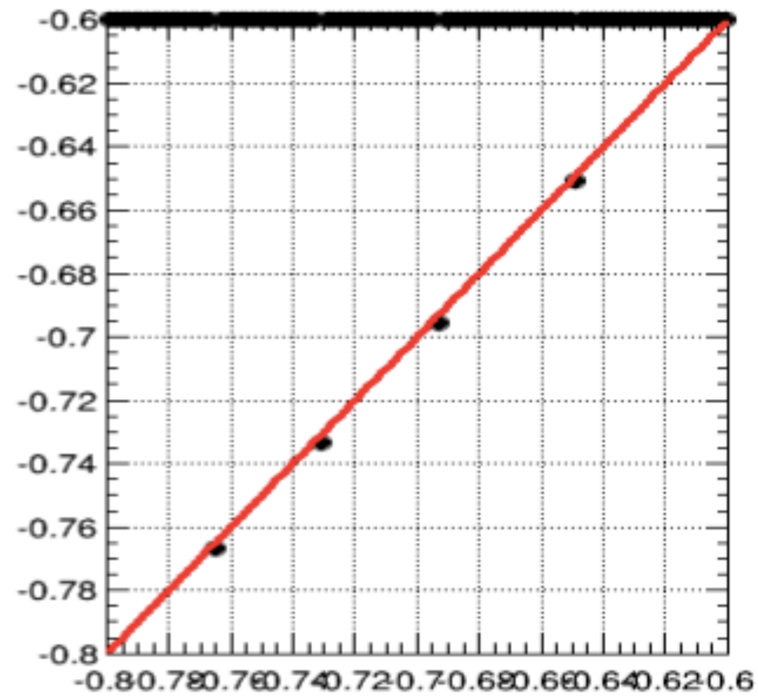
Closeure of matrix method

(from Li Bo)

- Check closure of matrix method.
- We get back back what the input R_B value
- Next step: quantify the impact of b tagging performance on R_b measurement

Input Rb=0.3, Four BtagProb work point: Prob>0.6, >0.7, >0.8, >0.9



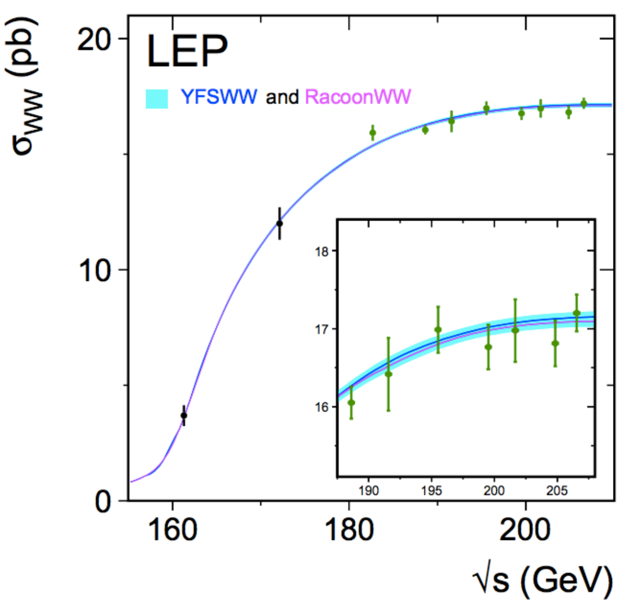


PartII: W mass measurement

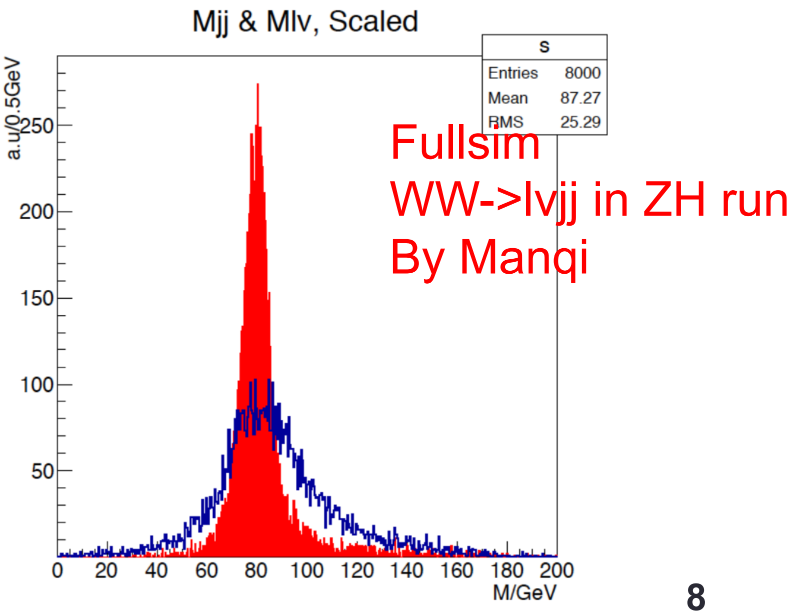
Liu bo

- 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



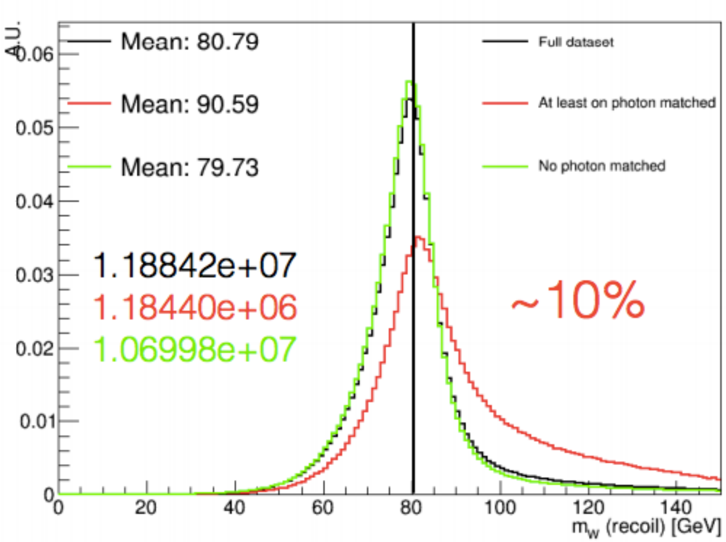
Direct reconstruction



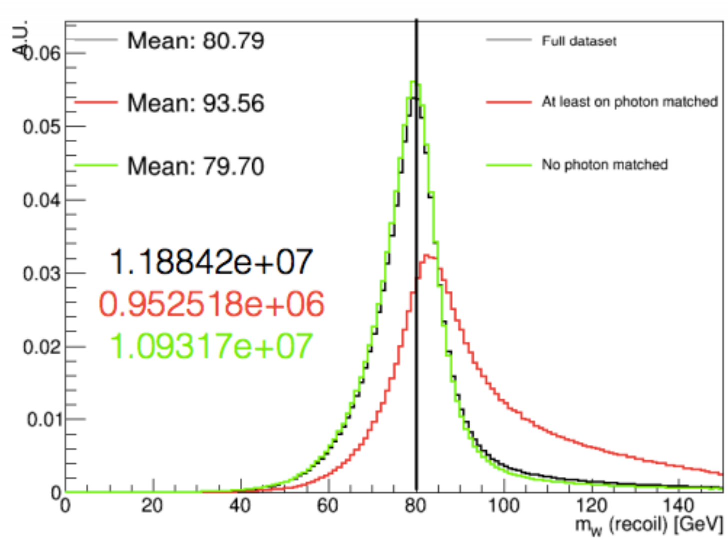
Update in direct reconstruction approach

- Using WW->μvjj channel in sqrt(s)=240GeV e+e- collision
- M_W is reconstructed by
  - Sum of four vector of all reconstructed PFO objects. (S)
  - Subtract the four vector of the muon (M)
  - The mass of the remaining four vector (S-M)

Liu bo



At one matched photon



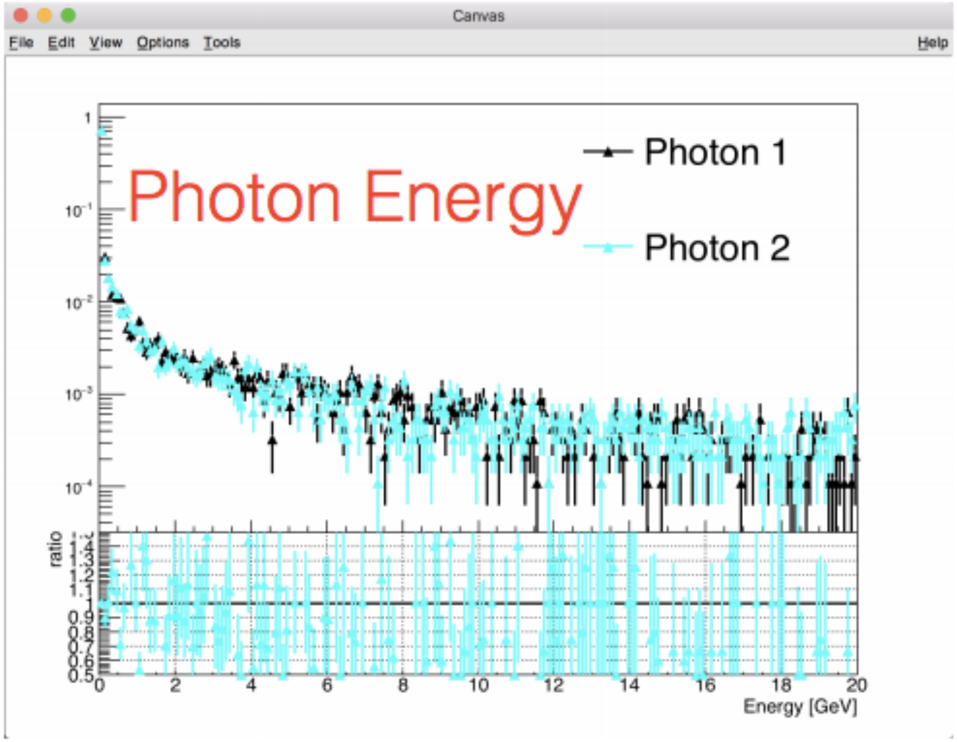
At one matched photon with E>0.5 GeV

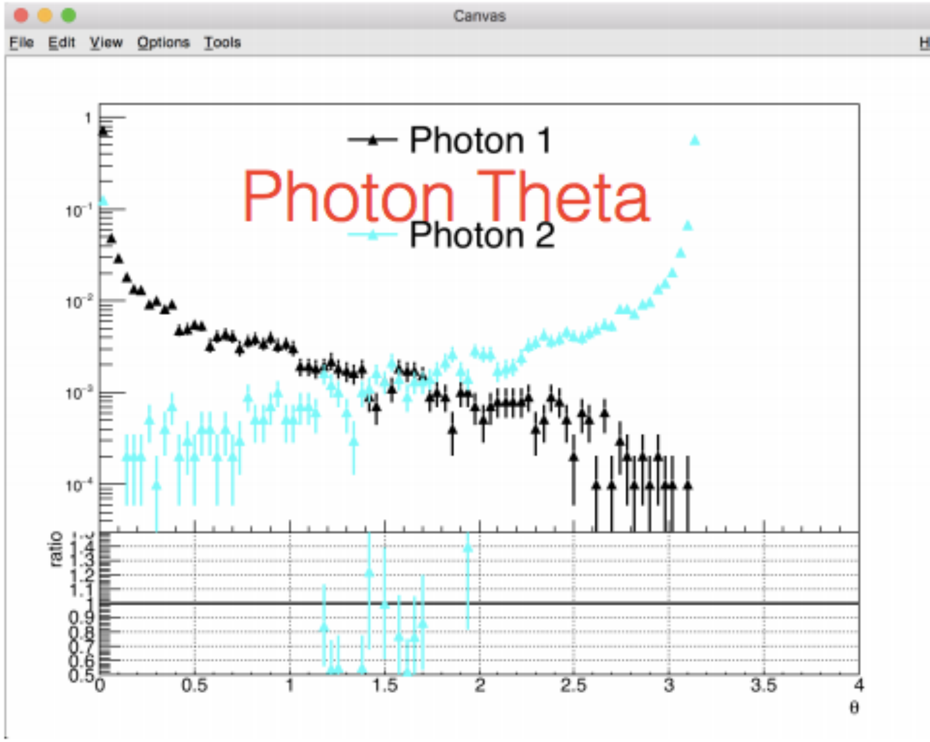
use dR<0.05 and dE/E<0.5 to do match

To develop method to deal with photons in Mjj

Impact of ISR photons

From Liu bo

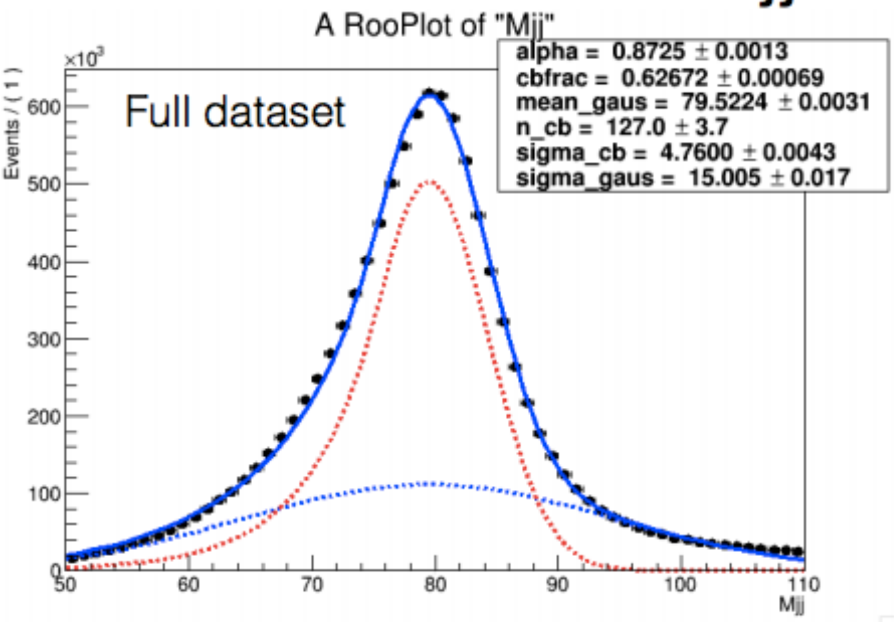


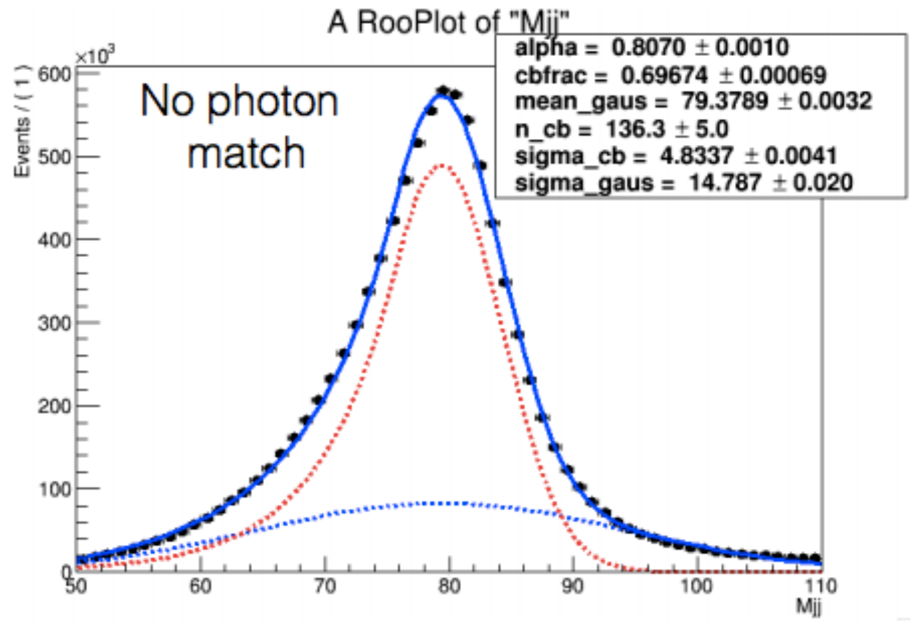


Most of ISR photons are in forward region with small energy
Can these photon be reconstructed?

Fit mjj distribution

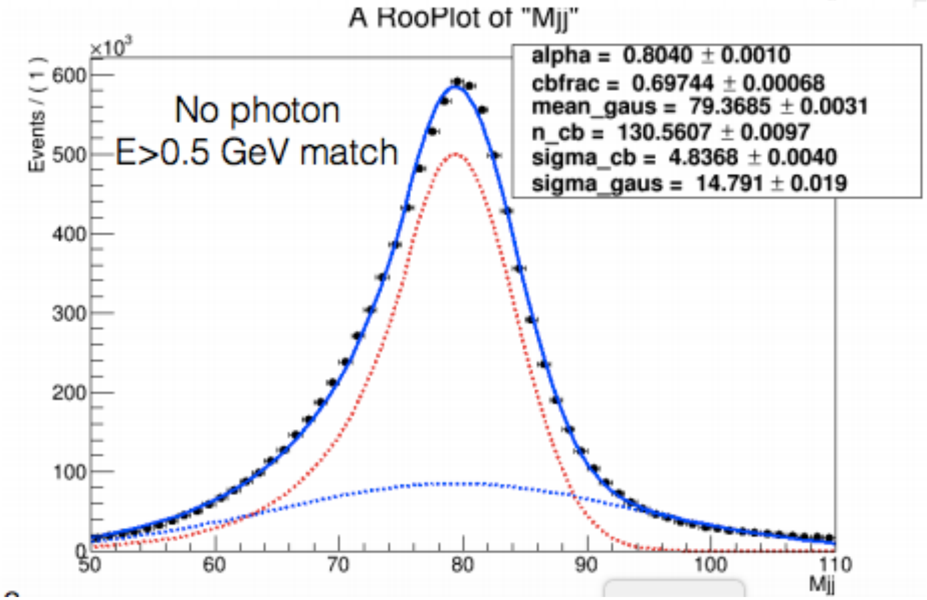
From Liu bo



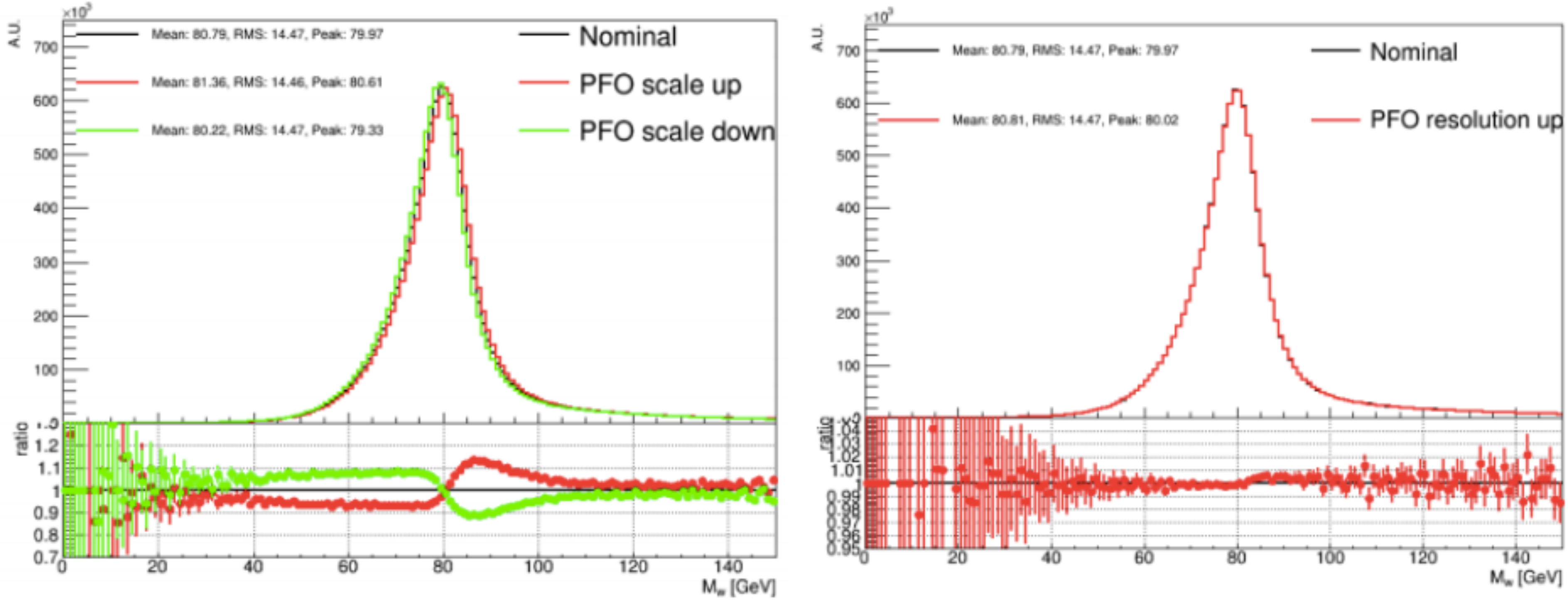


No big different for three cases,
Fit still to be tuned

PDF: cbfrac*RooCBShape("cb", "cb", Mjj, mean, sigma_cb, alpha, n_cb) +(1-cbfrac)*RooGaussian("gaus", "gaus", Mjj, mean, sigma_gaus)



Machinery to test JES uncertainty



Caveat: Use same map for scale and resolution for now. Just for machinery test.

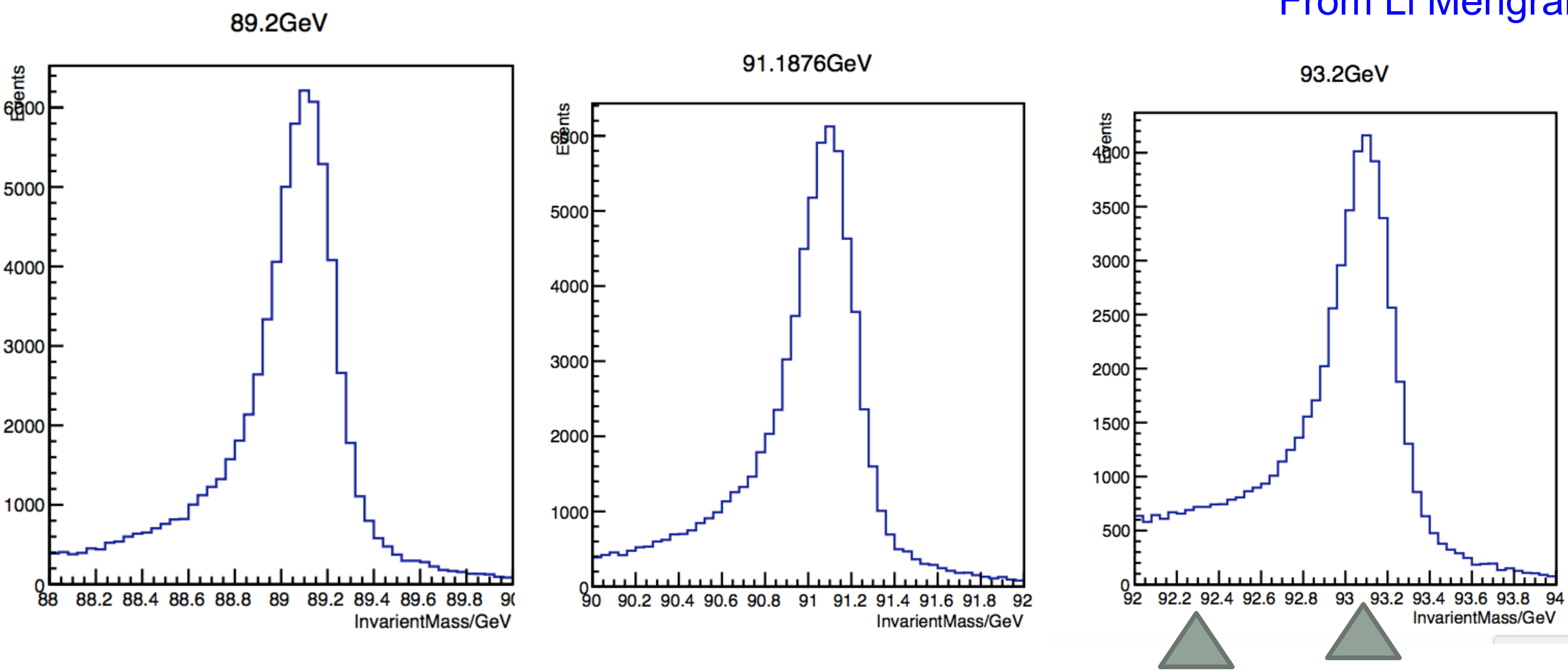
Next step on W mass

- Try to understand the impact of JES uncertainty
- Understand the impact due to beam energy

partIII: Backward-forward asymmetry

- 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



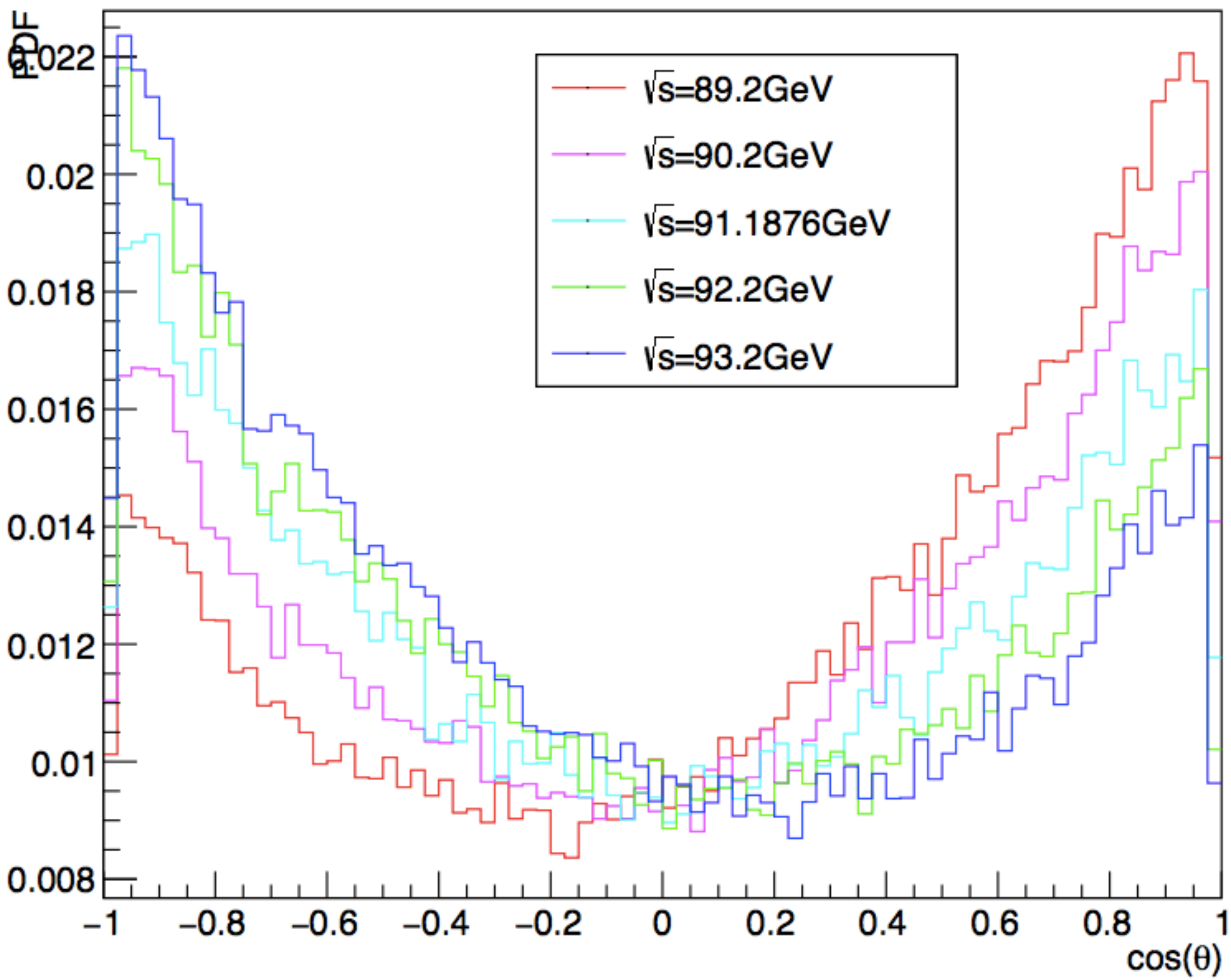
ISR+on-shell Z

off-shell Z

Cos(theta) of μ+ in Z->μμ events

- Some in-efficiency in forward regions.

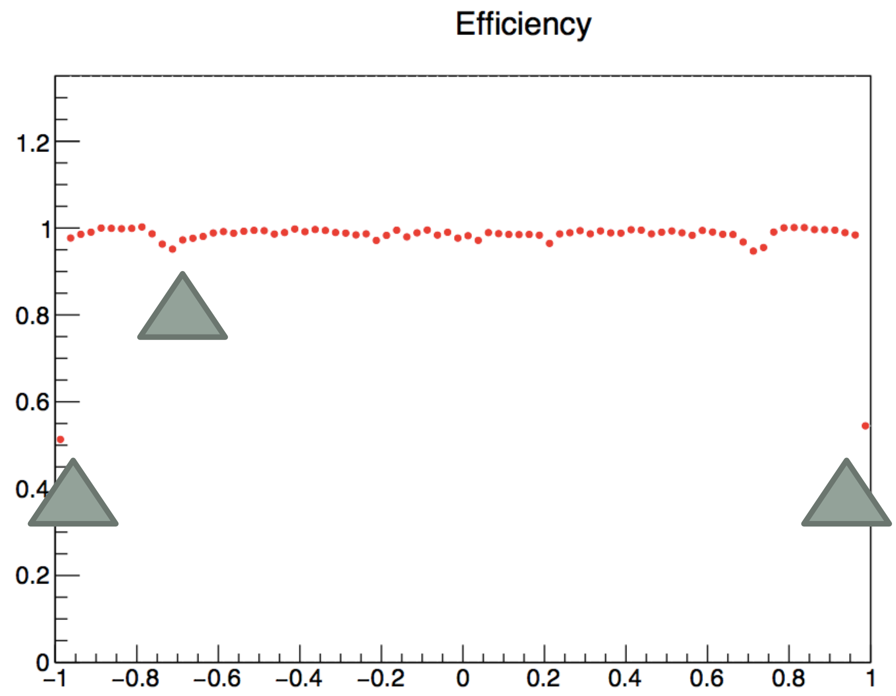
From Li Mengran



muon efficiency

- Total efficiency of muon reconstruction and muon ID efficiency.
- understanding Efficiency loss in forward region is important.
- Inefficiency in cos(theta)=0.7
- due to transition regions between barrel and endcap ?

From Li Mengran

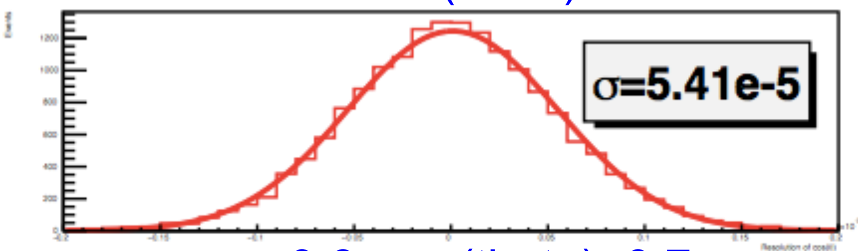


Detector resolution on cos(theta)

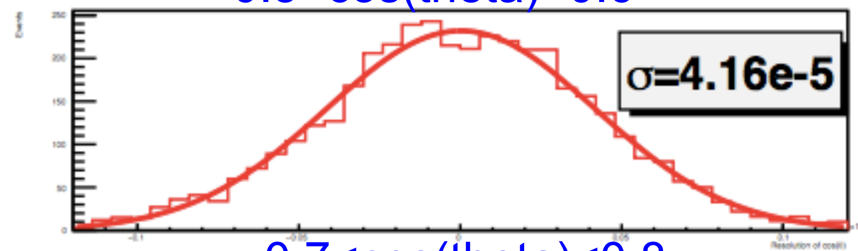
From Li Mengran

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

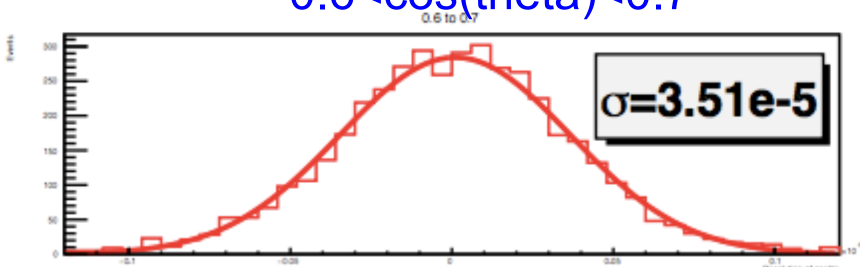
0<cos(theta)<0.5



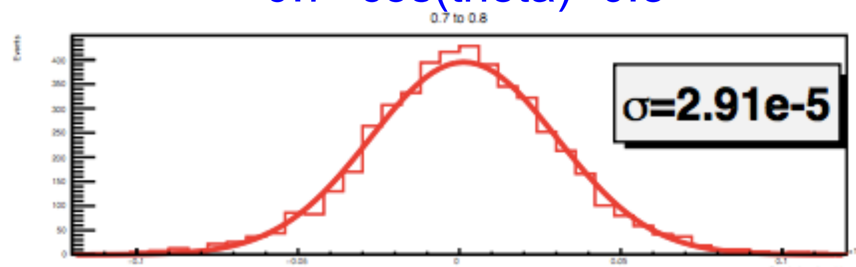
0.5<cos(theta)<0.6



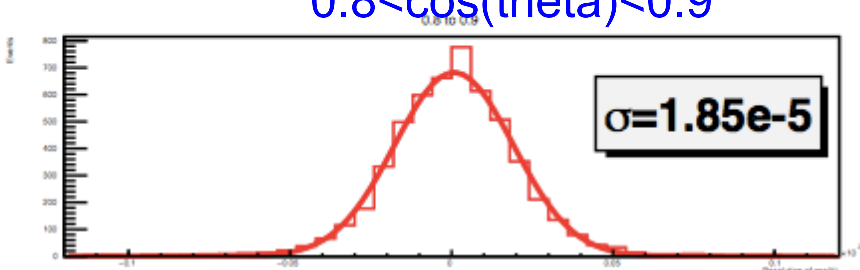
0.6<cos(theta)<0.7



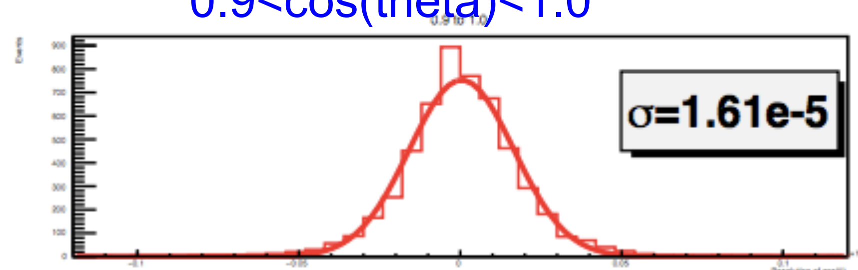
0.7<cos(theta)<0.8



0.8<cos(theta)<0.9



0.9<cos(theta)<1.0



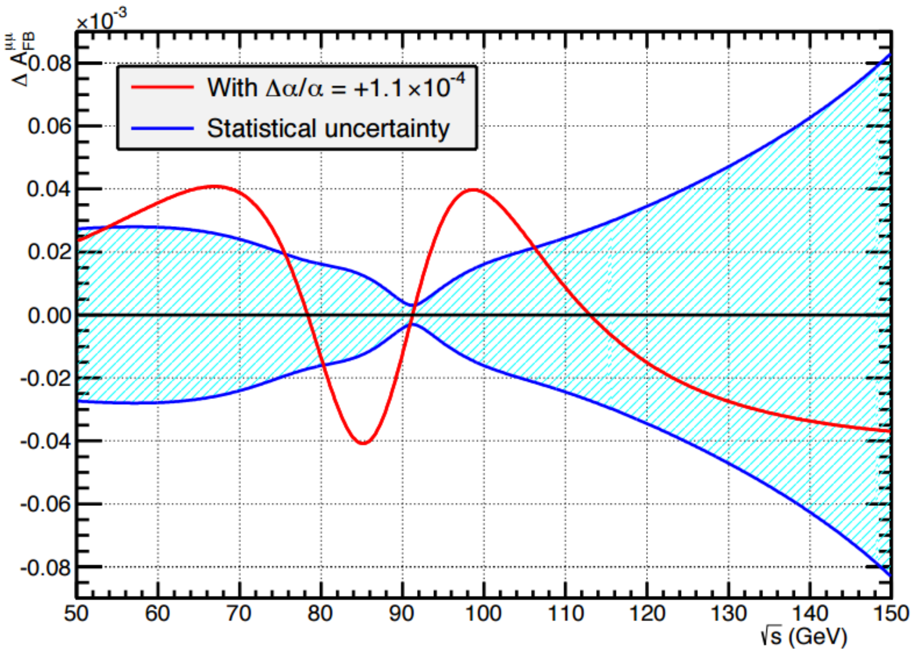
Resolution of cos(theta)

Resolution of cos(theta)

Next step for Afb

- Understand the impact resolution and efficiency effect to AFB systematics
- Fcc-ee colleague proposed to take more data around 87 and 94 GeV off-peak runs for α_{QED} shape
- Use AFB analysis for α_{QED} measurement

P. Janot, JHEP 1602 (2016) 053



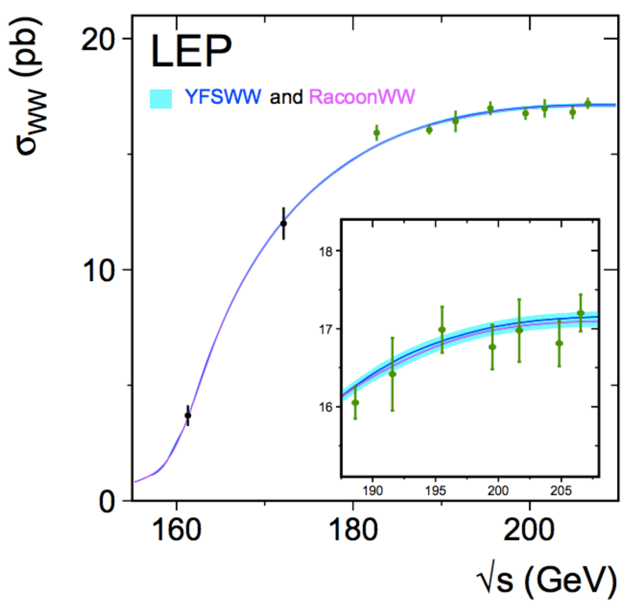
Summary

- Toward CDR:
  - In physics potential/motivation section:
    - Give expected precision of each EWK measurement in Physics motivation
  - In physics case section :
    - Plan to study the impact of leading exponential systematics of EWK measurement. (fullsim or fastsim)

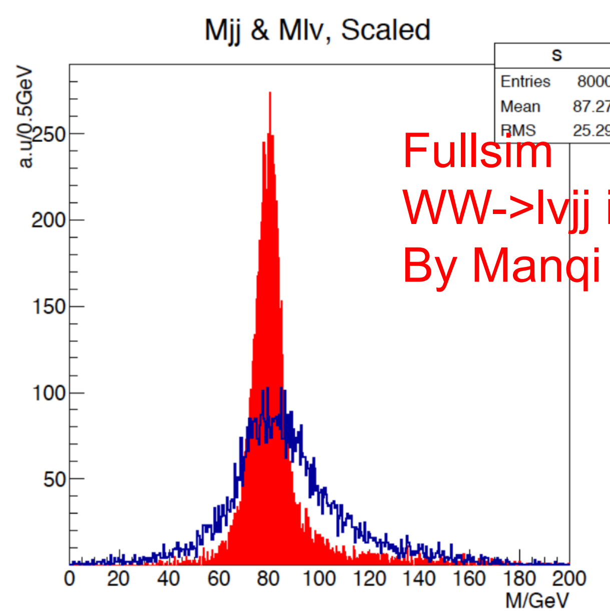
Tasks in W mass measurement

- 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



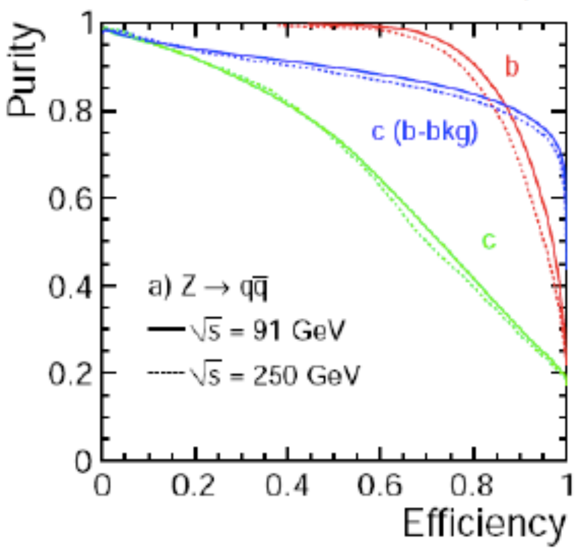
Direct reconstruction



B tagging performance in Branching ratio (R^b)

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

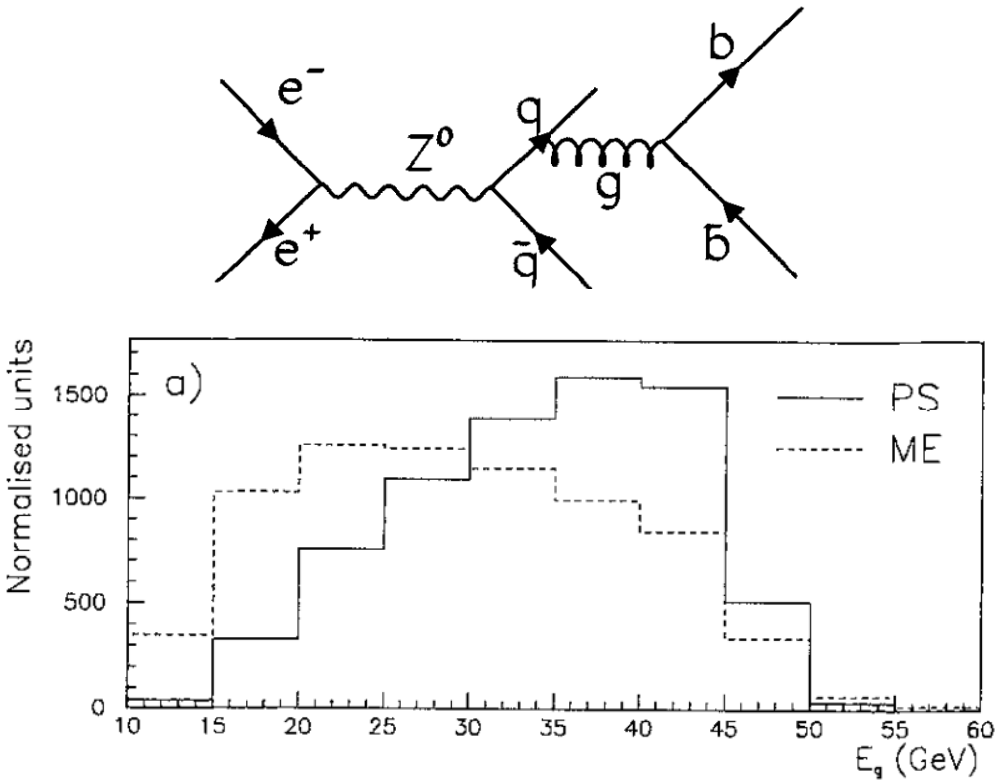
- Major systematics is from light jet and c jet background
- can be reduced by improving the b tagging performance
- Need fullsim to validate its performance



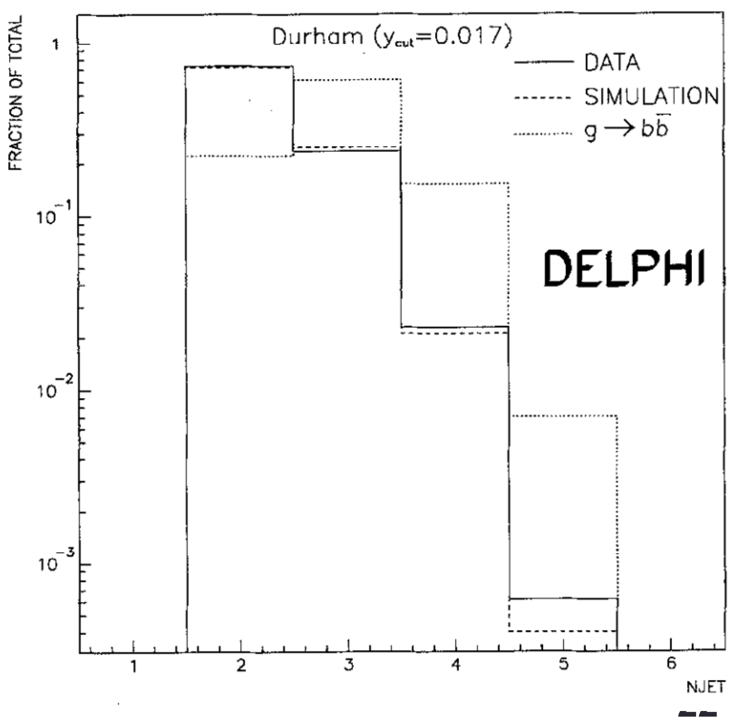
Uncertainty	LEP	CEPC	CEPC improvement
hemisphere tag correlations for b events	0.2%	0.1%	Higher b tagging efficiency

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



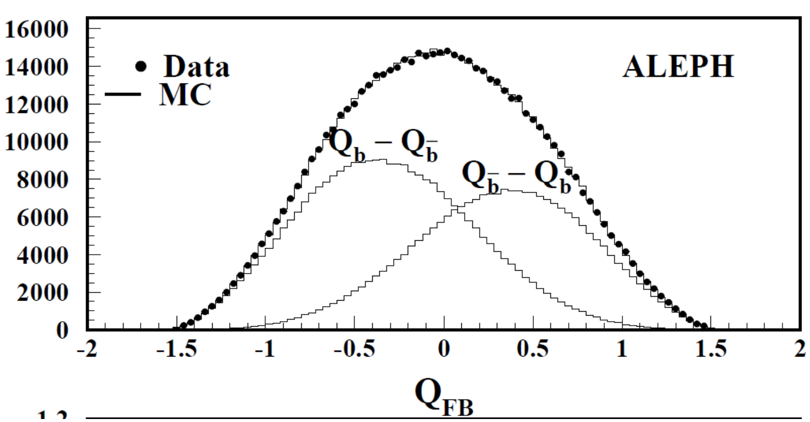
Backward-forward asymmetry measured from b jet

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

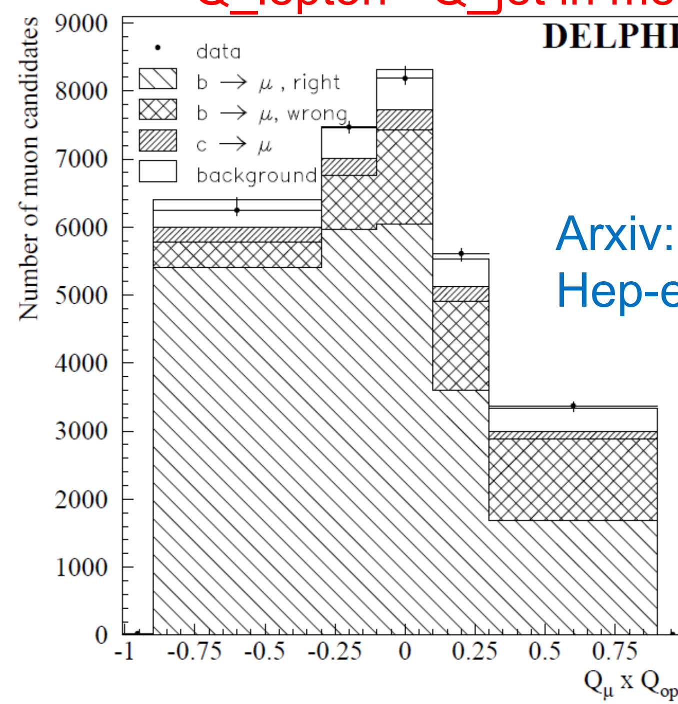
- LEP measurement : 0.1000+-0.0017 (Z peak)
  - Method 1: Soft lepton from b/c decay (~2%)
    - Select one lepton from b/c decay, and one b jets
    - Select lepton charge (Q_lepton) and jet charge (Q_jet)
  - Method 2: jet charge method using Inclusive b jet (~1.2%)
    - Select two b jets
    - use 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

Tasks in EWK measurements

	Task	samples
m_Z	Resonant depolarization and Compton scattering method on beam energy	
mZ , α_{QED}	Optimize off-peak runs statistics and selection	fastsim
R_b	Validate B/c tagging performance in R_b Measurement	Fullsim
A_{FB}(b) semi-leptonic	Jet charge reconstruction	Fullsim
A_{FB}(b) leptonic	Lepton reconstruction in jets	Fullsim
m_W (direct reconstruction)	Optimize W mass reconstruction and jet energy calibration	Fullsim
m_W (threshold scan)	Optimize off-peak runs statistics and selection	fastsim
A_{FB}(lepton)	Detector acceptance , forward detector alignment precision	fastsim

Manpower status

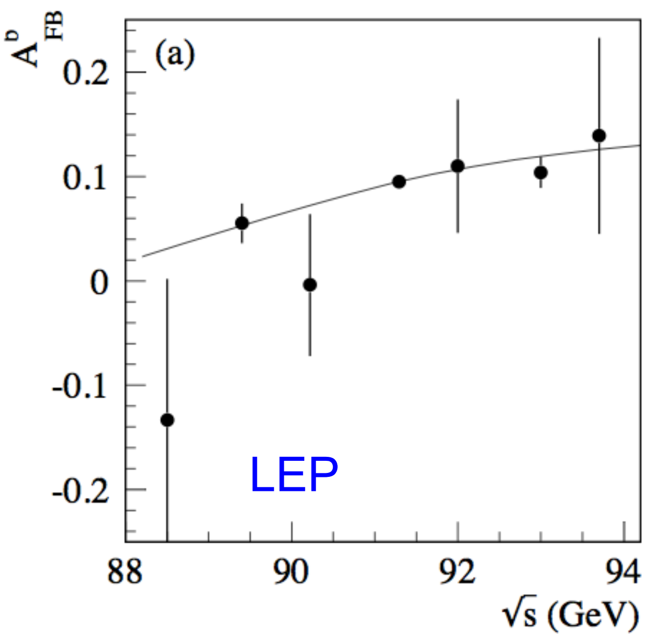
	manpower	Availability
Resonant depolarization and Compton scattering method on beam energy		
Optimize off-peak runs statistics and selection	-	
Validate B/c tagging performance in R_b Measurement	Bo Li	Just joint
Jet charge reconstruction	-	
Lepton reconstruction in jets	-	
Optimize W mass reconstruction and jet energy calibration		
Optimize off-peak runs statistics and selection	-	
Detector acceptance , forward detector alignment precision	Mengran	Till middle of 2017

Summary

- EWK study in Pre-CDR is mainly based on extrapolation from LEP
- Would like to do fast or full simulation study for CEPC CDR.
- Need more manpower to complete these study
- Welcome to join this effort

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

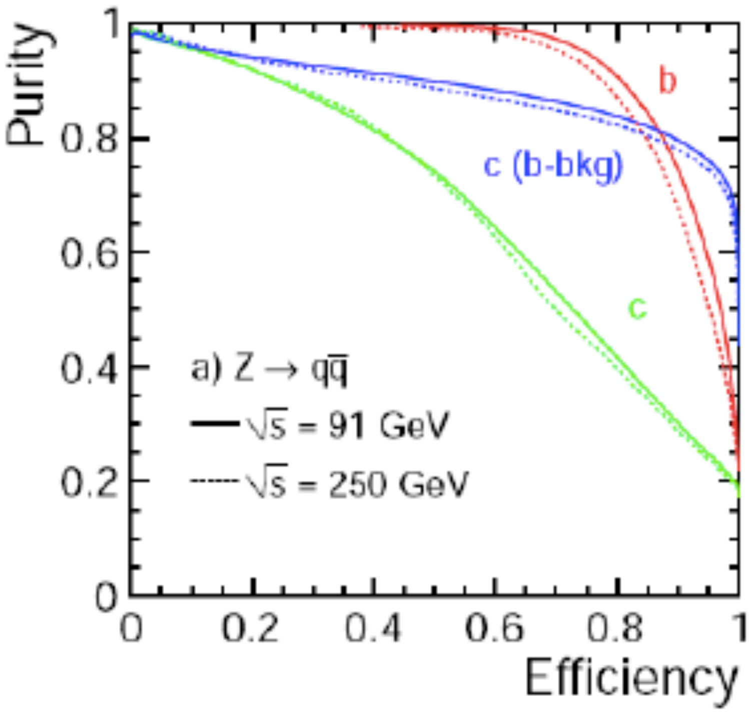


CEPC off-peak runs stat

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

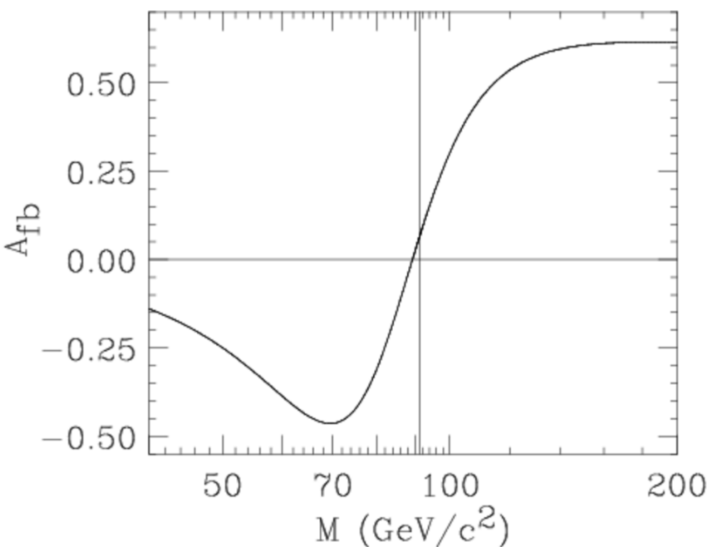
From Pre-CDR to CDR

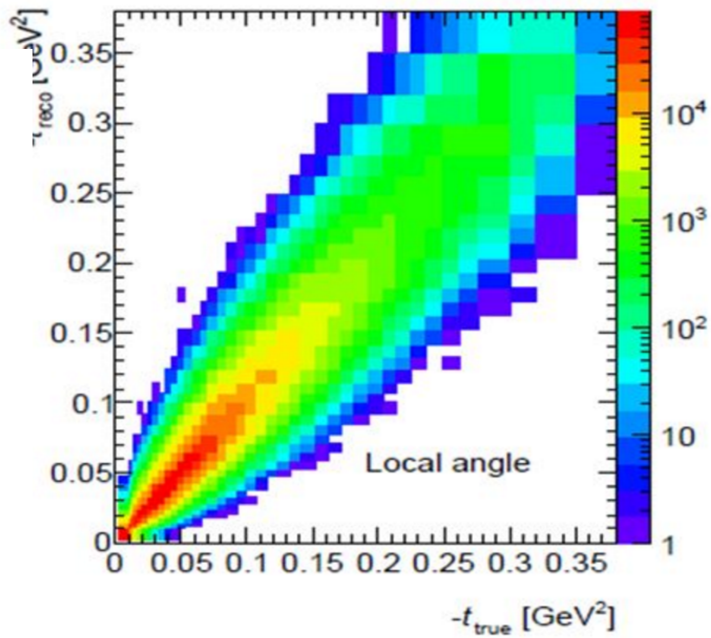
- Propagate beam momentum scale uncertainty to all EW measurement.
- Give a clear physics requirement to accelerator

		Correlations				
		m_Z	Γ_Z	σ^0_{had}	R^0_ℓ	$A^{0,\ell}_{FB}$
$\chi^2/\text{dof} = 172/180$		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

Plan for Weak mixing angle

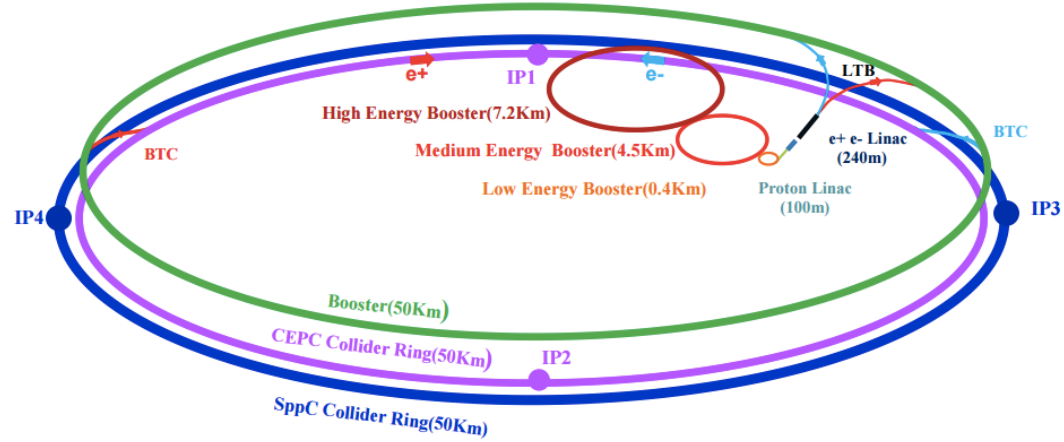
- More details in Mengran's talk





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

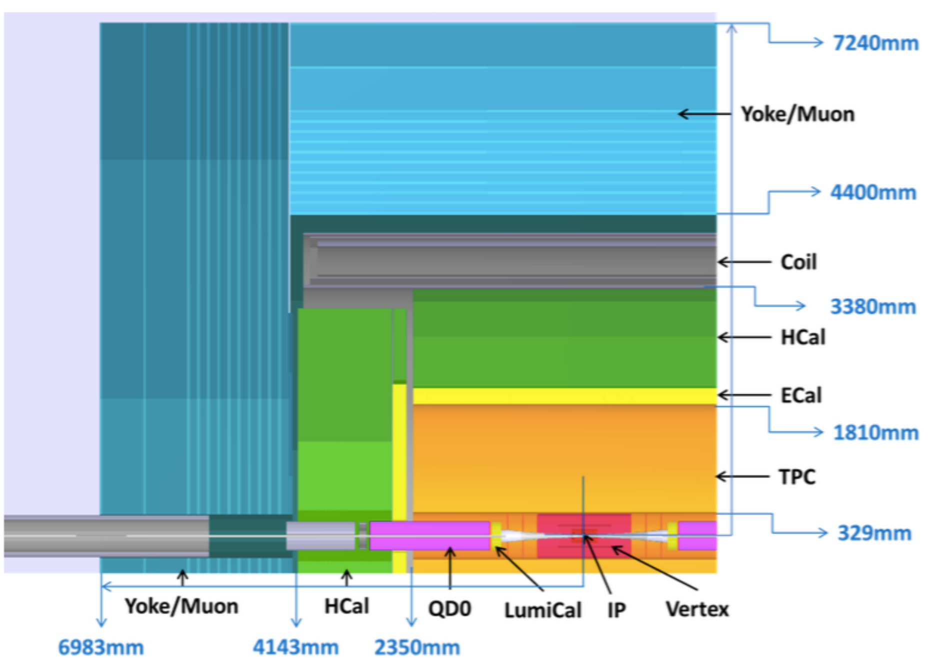
CEPC accelerator

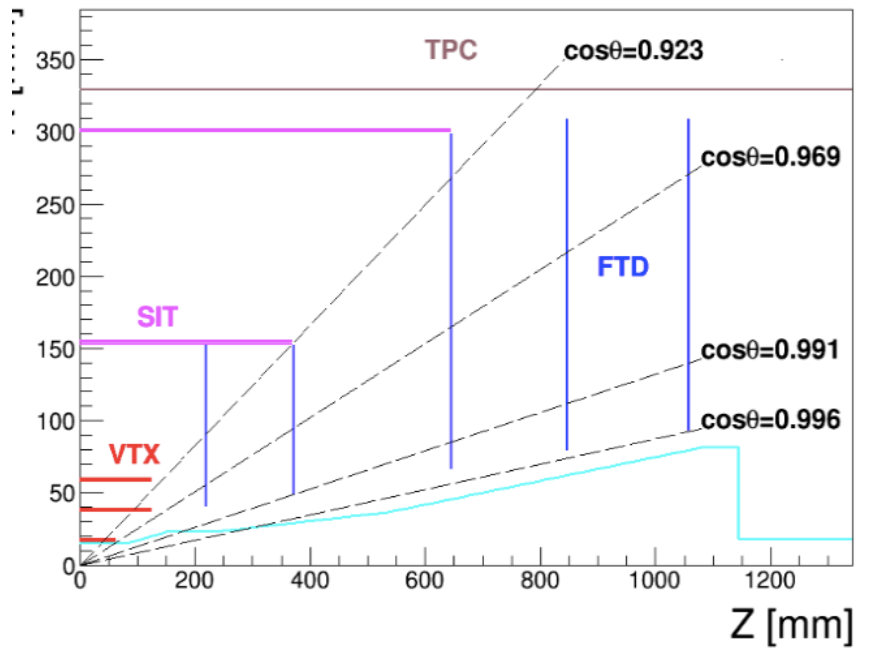


- Electron-positron circular collider
  - Higgs Factory（E_{cms}=250GeV , 10^6 Higgs)
    - **Precision study of Higgs coupling in ZH runs**
    - **complementary to ILC**
    - **See Manqi and Gang's talk this morning in Higgs section for more details**
  - Z factory（E_{cms}=91 GeV, 10^{10} Z Boson）:
    - **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 Pixel size in vertex detector : less than 16x 16μm
  - Expected Impact parameter resolution: less than 5μm
  - Expected Tracking resolution : $\delta(1/Pt) \sim 2*10^{-5}(GeV^{-1})$





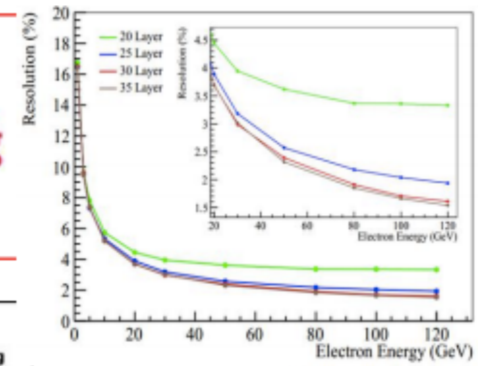
CEPC detector (2)

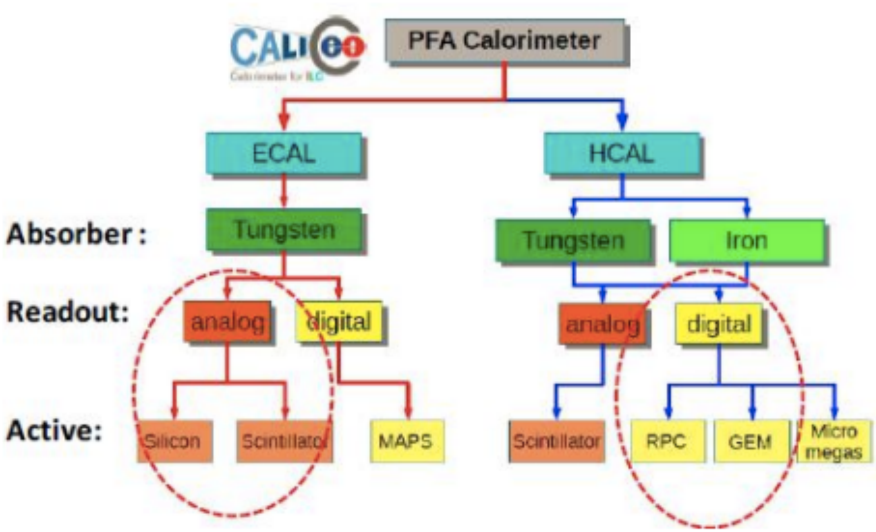
- Calorimeters:
  - Concept of Particle Flow Algorithm (PFA) based
  - EM calorimeter energy resolution: $\sigma_E/E \sim 0.16/\sqrt{E}$
  - Had calorimeter energy resolution: $\sigma_E/E \sim 0.5/\sqrt{E}$
  - Expected jet energy resolution : $\sigma_E/E \sim 0.3/\sqrt{E}$

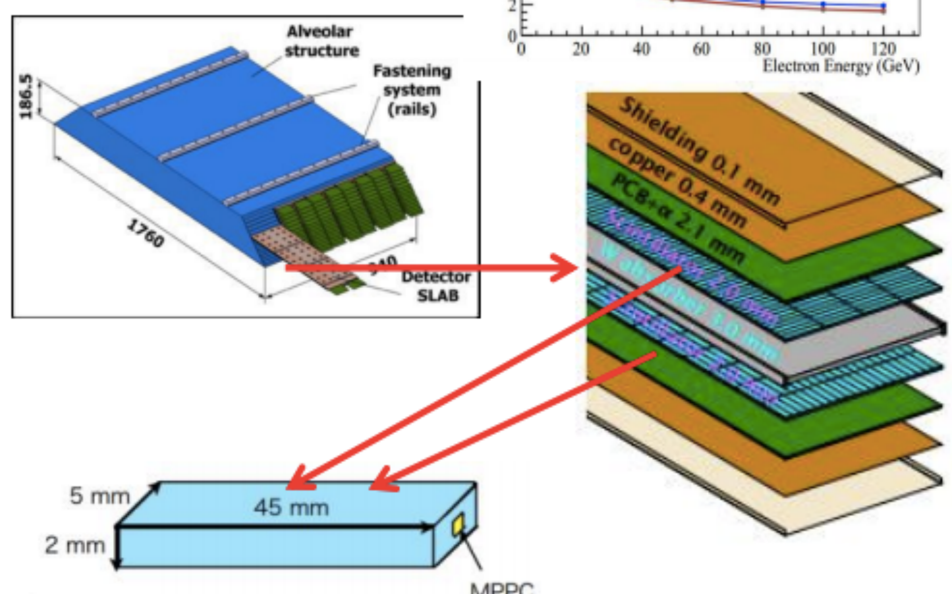
- Jet energy (Higgs self-coupling, W/Z separation)
  - ~1/2 resolution (wrt LHC)

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

less demanding at CEPC





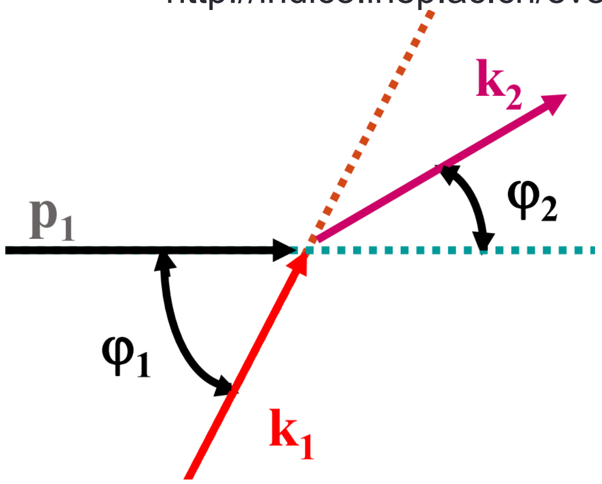


ECAL: Scintillator + W + Scintillator

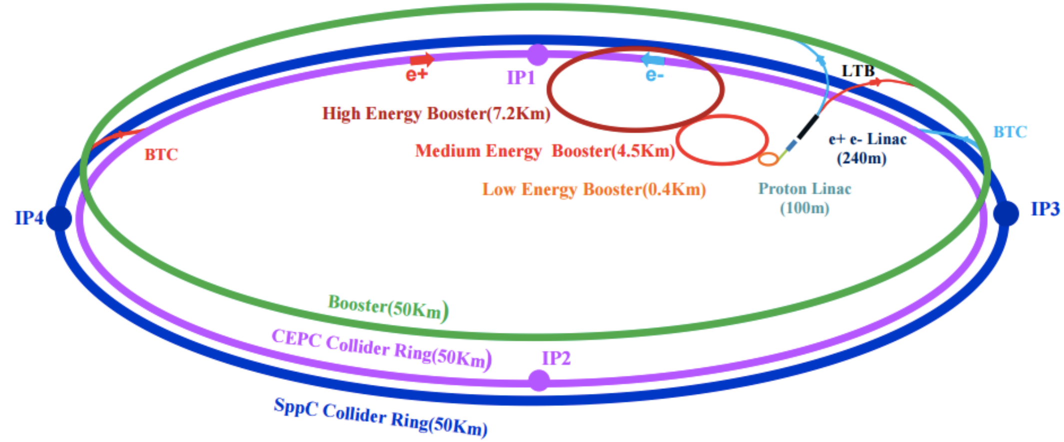
Task 1 : Beam energy measurement

- 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



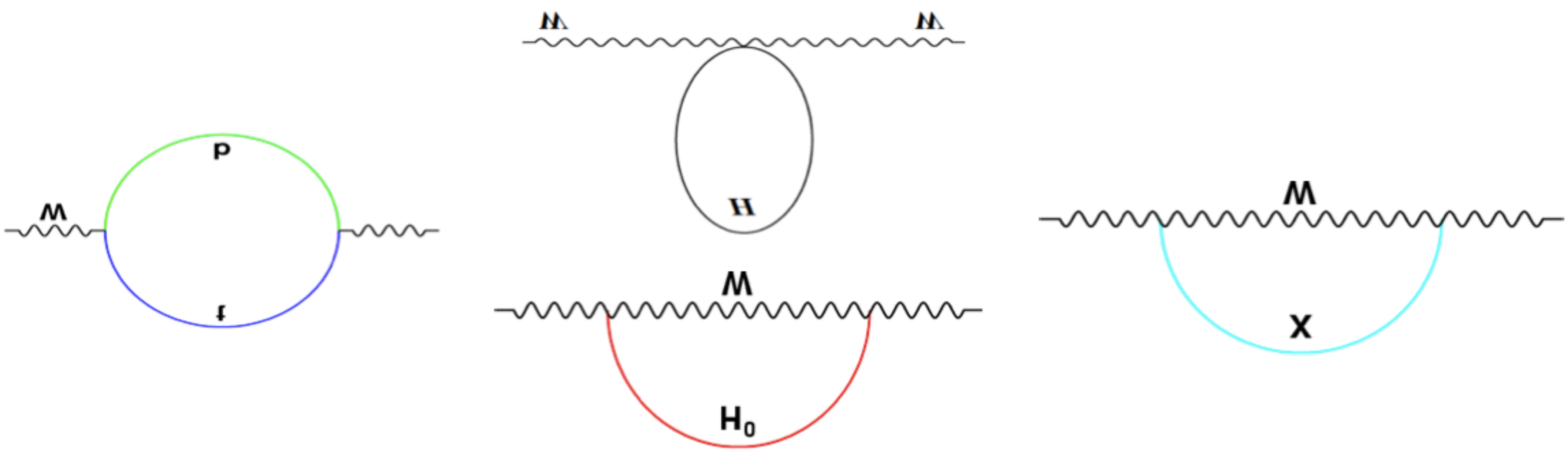
CEPC accelerator



- 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

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^b_{FB}	1.7%	0.15%	Z pole
$\sin^2\theta^{\text{eff}}_W$	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