Z AND W PHYSICS AT CEPC

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The prospect of CEPC electroweak physics in pre-CDR study

Table 4.1 The expected precision in a selected set of EW precision measurements and the comparison with the precision from LEP experiments. The current precisions for $\sin^2\theta_W^{\rm eff}$ and R_b include the measurements at the SLC.

Observable	LEP precision	CEPC precision	CEPC runs	$\int \mathcal{L}$ needed in CEPC
m_Z	2 MeV	0.5 MeV	Z lineshape	> 150 fb^{-1}
m_W	33 MeV	3 MeV	ZH (WW) thresholds	> 100 fb^{-1}
A^b_{FB}	1.7%	0.15%	Z pole	> 150 fb^{-1}
$\sin^2\theta_W^{\rm eff}$	0.07%	0.01%	Z pole	> 150 fb^{-1}
R_b	0.3%	0.08%	Z pole	> 100 fb^{-1}
N_ν (direct)	1.7%	0.2%	ZH threshold	> 100 fb^{-1}
N_ν (indirect)	0.27%	0.1%	Z lineshape	> 150 fb^{-1}
R_μ	0.2%	0.05%	Z pole	> 100 fb^{-1}
R_τ	0.2%	0.05%	Z pole	> 100 fb^{-1}

Status of CEPC electroweak analysis

Observable	Pre-CDR status	Current status
$A_{FB\ (b)}$	Extrapolation from LEP	Full simulation analysis on going
$Sin^2\theta_W$	Extrapolation from LEP	Full simulation analysis on going
R^b	Extrapolation from LEP	Full simulation sample ready Need manpower
R^{mu}	Extrapolation from LEP	Need full simulation samples
R^{tau}	Extrapolation from LEP	Need a robust tau finder
Alpha_QCD	Not covered	a new full simulation analysis
W boson mass	Extrapolation	Full simulation sample ready Need manpower

From pre-CDR study to CDR study

- Pre-CDR:
  - Extrapolation from LEP, no full simulation study
- CDR :
  - Must have full simulation study for a few key measurements.
    - A_{FB} , $Sin^2\theta_W$ and W boson mass.
  - Good to have Fast simulation or full simulation
    - Alpha_QCD
    - Z boson mass
    - Z Branching ratio : R^{mu} , R^{b} ,
  - Performance study in Z-pole full simulation
    - What can we learn of object calibration in Z-pole running
    - TPC performance and tracking performance in Z-pole running

Forward-backward asymmetry $A_{FB\ (b)}$

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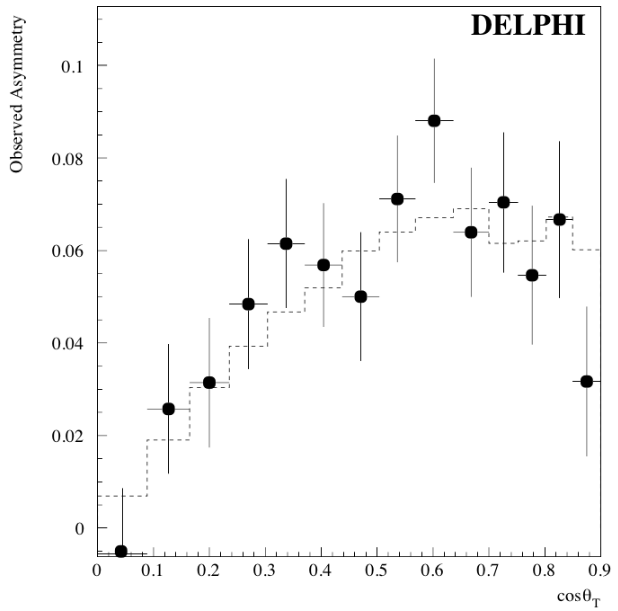
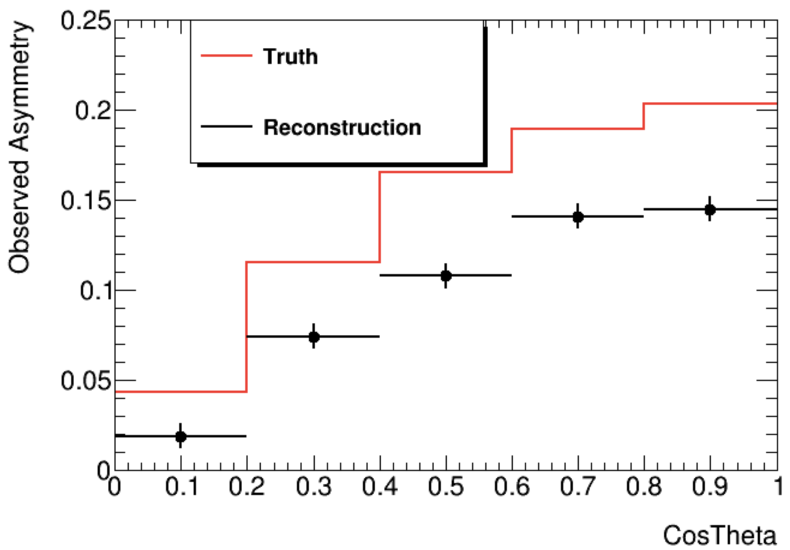
  - Pre-CDR : focus Z->bb inclusive semi-leptonic decay with jet charge method.
  - Current study with full simulation MC samples: focus on Z->bb fully leptonic decay.
  - Advantage : Lepton charge is measured more precise compared to jet charge.
  - Dis-Advantage: Lower branching ratio compared to semi-leptonic decay.
  - Manpower : Zhijun Liang, Gang Li, Manqi Ruan



CEPC full simulation



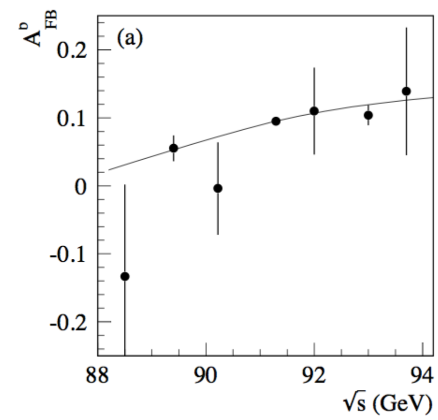
Backward-forward asymmetry measured from b jet

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

- LEP measurement : 0.1000+-0.0017 (Z peak)
- Pre-CDR study
  - focused on inclusive b jet measurement , semi-leptonic decay (Extrapolation from LEP)
    - Method : jet charge method using Inclusive b jet (~0.15%)
    - Expected Stat error (0.04%) (>100 times of LEP stat)
    - Expected Systematics (0.12%) :
      - B-tag efficiency (0.1%)
      - charge correlations due to B tag/ jet charge (0.05%)
      - Jet charge systematics (have not considered)
- Toward CDR
  - Plan to focus more on fully semi-leptonic decay mode with full simulation study
    - Method : Soft lepton from b/c decay
    - Expected Systematics (0.07%) :
      - Sample statistics in light/heavy flavor jet sample (0.74%)
    - Expected Systematics (0.18%) :
      - Branching rate of b/c decay into lepton (0.15%)
      - Lepton scale systematics and lepton Identification (0.1%)

Weak mixing angle

$\sin^2\theta_{eff}^{lept}$



LEP/SLD measurement : 0.23153 ± 0.00016

- 0.1% precision.
- Stat error in off –peak runs dominated.

CEPC Pre-CDR expected precisoin (0.01%):

- off-Z peak runs is key issue.
- Need at least 10 fb^{-1} for off-peak runs
- Toward CDR:
- Need to re-optimize off-peak runs statistics
- Try to reduce number of off-peak runs
    - Try 2 off-peak runs instead of 7 runs
- Optimize the off-peak runs energy
- plan to use Gfitter for electroweak combined fit
- collaborate with Gfitter experts Matthias Schott
- Manpower:
- Joao Guimaraes da Costa, Zhijun Liang

Sqrt(s) GeV	LEP lumi (fb-1)	Proposed CEPC lumi
88.2	0.05fb-1	10 fb-1
89.2	~0.4fb-1	10 fb-1
90.2	0.05fb-1	10 fb-1
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92.2	0.05fb-1	10 fb-1
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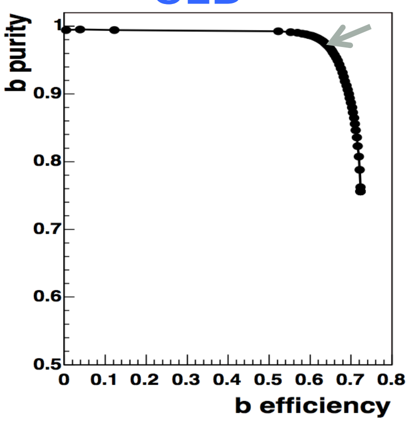
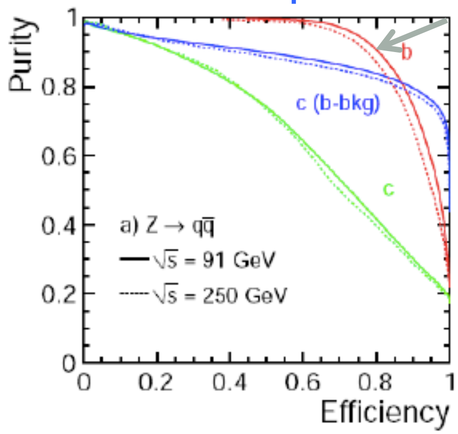
Branching ratio (R^b)

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

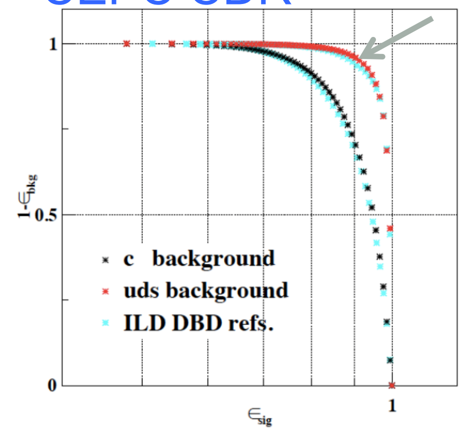
SLD



CEPC pre-CDR



CEPC CDR



- SLD/LEP measurement 0.21594 ±0.00066
- From PreCDR toward CDR
  - Expect ~10% higher B tagging efficiency than pre-CDR performance
    - In 95% B jet purity working
    - Reduce charm mistag and light jet mistag and hemi corrections systematics
  - Stat error (0.04%)
  - Syst error (0.07%)
    - Charm mistag : from 0.05%(pre-CDR) to 0.02% (CDR)
    - Light jet mistag : from 0.05% %(pre-CDR) to 0.02% (CDR)
    - Gluon radiation (g->bb , g->cc) (0.05%)

Number of neutrino generation (N_ν)

- LEP measurement :
  - Indirect measurement (Z line shape method): 2.984+-0.008
  - Direct measurement (neutrino counting method): 2.92+-0.05
    - Stat error (1.7%), Syst error (1.4%)
- CEPC measurement :

$$e^+e^- \to \nu\bar{\nu}\gamma.$$

    - Stat error (0.1%), Syst error (0.15%)
  - expected better granularity in calorimeter can help photon identification
  - Should focus on direct measurement
    - Need to consider photon trigger in early stage
    - Photon Trigger performance is key for this measurement
    - Toward CDR
      - Understand photon performance with full simulation

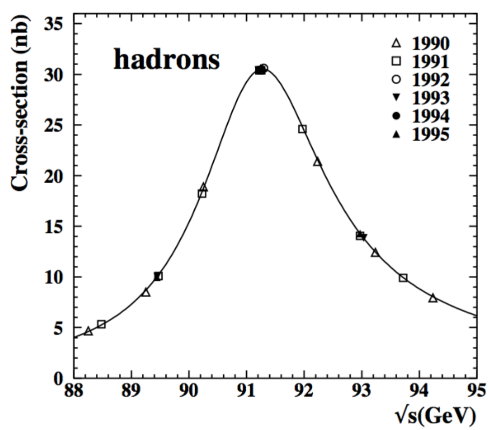
Systematics source	LEP	CEPC
Photon Trigger efficiency	0.5%	0.1%
Photon Identification efficiency	0.5%	0.1%
Calorimeter energy scale	0.5%	<0.05%

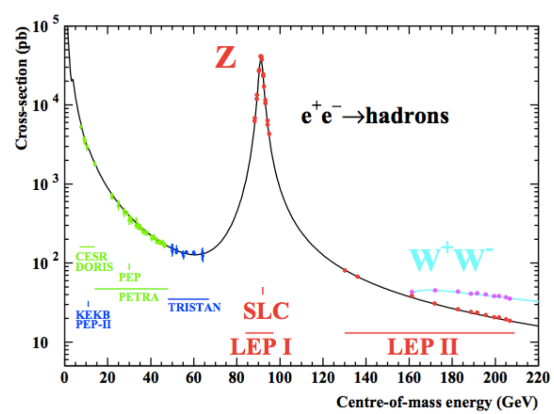
Branching ratio (R^{mu})

- LEP result: 0.2% total error
  - Stat : 0.15%
  - Syst : 0.1%
- CEPC : 0.05% total error expected
  - Better EM calorimeter is the key
  - Stat: 0.01%
  - Syst: 0.05%
    - Toward CDR
      - Understand photon energy scale and radiative events modelling systematics with full simulation.

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%

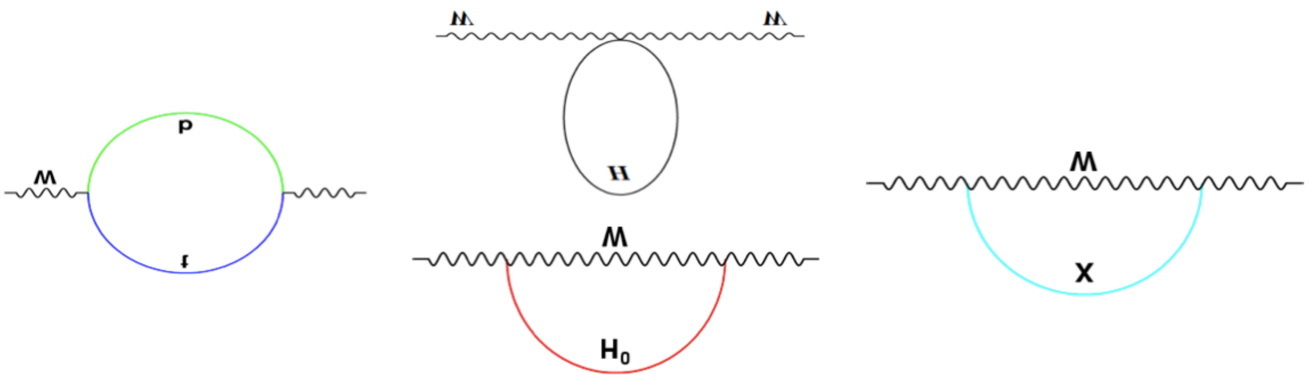
Z mass measurement

- LEP measurement : 91.1876±0.0021 GeV
- CEPC possible goal: 0.5 MeV
  - Stat uncertainty : 0.2MeV
  - Syst uncertainty: ~0.5 MeV
    - beam energy uncertainty
    - lepton momentum scale uncertainty
- Z mass threshold scan is needed to achieve high precision.
  - Precision in direct measurement in ZH runs is much lower
  - Z threshold scan is very important for lepton energy scale calibration
  - Towards CDR :
    - understand letpon momentum resolution with full simulation
    - Understand Tracking performance with TPC detector in high occupancy
    - Optimize the statistics of off-peaks runs for threshold scan.
  - 

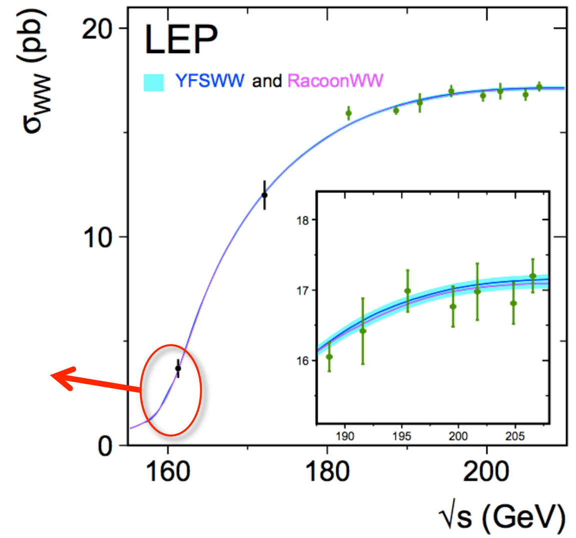


W mass measurement : motivation

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



W mass measurement(1)

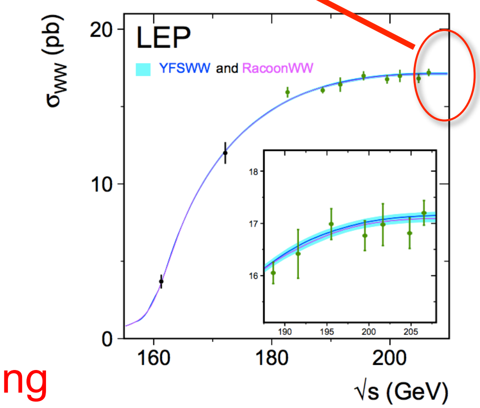


- Current PDG precision : 80.385±0.015 GeV
  - Possible goal for CEPC : ~2 MeV
- Two methods: Threshold scan, direct measure
  - 1.Threshold scans of W+W- cross section (√s=160GeV)
    - Disadvantage:
    - Higher cost
      - Require dedicated runs 100fb^{-1} on WW threshold (~160GeV)
    - Low statistics: low cross section below threshold
    - high requirement on beam momentum uncertainty
      - LEP (~50ppm)
      - Require CEPC to be less than 10ppm
    - Advantage:
      - Very robust method, can achieve high precision (2MeV precision).

    - Towards CDR : need to answer these questions for WW threshold scan.
    - Whether we need WW threshold scan runs ?
      - Improvement of W mass precision
    - How many runs we need and the run energy
    - How much statistics for each WW threshold scan runs ?

W mass measurement

- Method 2: direct measurement in ZH runs ($\sqrt{s}$=240GeV)
  - Decays model : WW-> lvqq , WW->lvlv
  - Advantage :
    - No additional cost :measured in ZH runs
    - Higher statistics: 10 times larger than WW threshold region
    - Lower requirement on beam energy uncertainty.
  - Disadvantage :
    - Larger uncertainty due to initial/final state photon radiation modeling
    - Towards CDR: need to understand detecor systematics with full simulation



	LEP	CEPC ($100fb^{-1}$)	CEPC ($100fb^{-1}$)
	lvqq	lvqq	lvlv
Statistical error	30 MeV	1.5 MeV	~3MeV
Beam energy	17 MeV	0.5 MeV	0.5MeV
Detector resolution	14MeV	3~4 MeV	2~4 MeV
Hadronisation	19MeV	2~3 MeV	-
QED	20MeV	1MeV	2~3 MeV

Summary of W and Z physics

- Toward CDR :
  - Must have full simulation study for a few key measurements.
    - A_{FB} , $Sin^2\theta_W$ and W boson mass.
  - Good to have Fast simulation or full simulation
    - Alpha_QCD
    - Z boson mass
    - Z Branching ratio : R^{mu} , R^{b} ,
  - Performance study in Z-pole full simulation
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  - Stat error: ~1.2% (4 experiments)
  - Systematics: ~1.4% (combination of three methods)
    - Method 1: Soft lepton from b/c decay (~2%)
      - Branching rate of b/c decay into lepton (1.5%)
      - B-tag and jet charge (1.1%)
      - Lepton pT and lepton Identification (0.9%)
    - Method 2: jet charge method using Inclusive b jet (~1.2%)
      - B-tag efficiency (0.4%)
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      - Sample statistics in light/heavy flavor jet sample (0.74%)
    - Method 3: D meson method (>8%, less important method)
- CEPC
  - Should focus on inclusive b jet measurement
    - Expected Stat error (0.1%) (>100 times of LEP stat)
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Manpower and activity update

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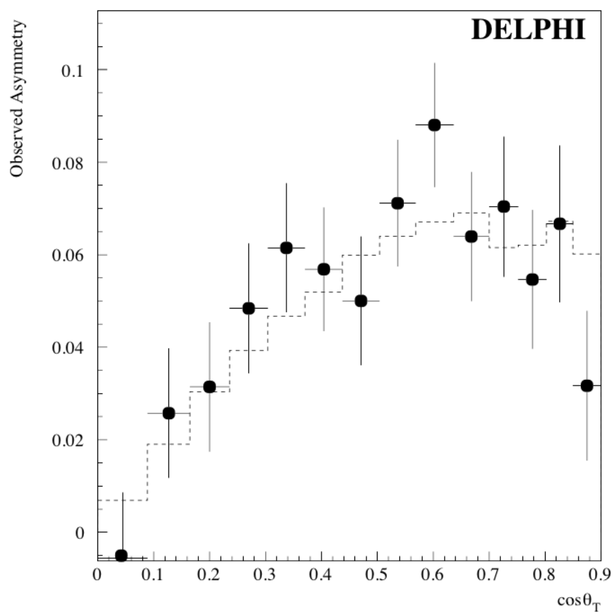

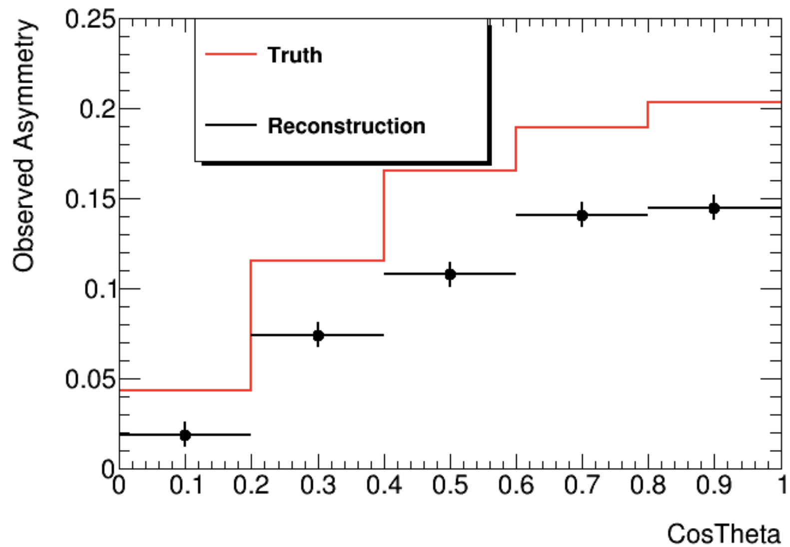

Manpower and activity update (2)

- Electroweak mixing angle: $\mathrm{Sin}^2\theta_W$
  - Pre-CDR : Extrapolation from LEP, using Zfitter for electroweak combined fit.
  - Current plan: plan to use Gfitter for electroweak combined fit
    collaborate with experts Matthias Schott.
  - Manpower: Joao Guimaraes da Costa, Zhijun Liang
- Alpha_QCD
  - collaborate with ATLAS Alpha_QCD measurement team
  - Manpower: Joao Guimaraes da Costa, Javier Llorente Merino

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Proposal for Z Mass scan

- The statistics in Off-peak runs was the bottleneck
- Propose 10 fb-1 integrated luminosity for off-peak runs in CEPC
- 7 mass scan runs

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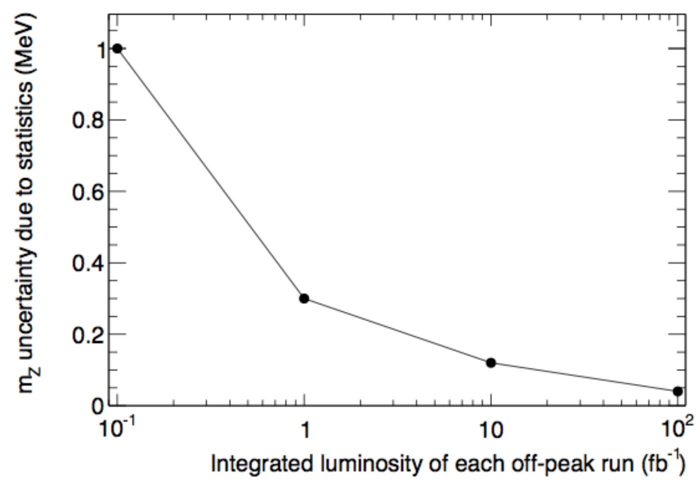

Branching ratio (R^b)

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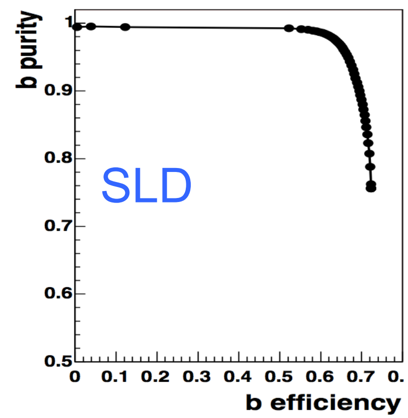
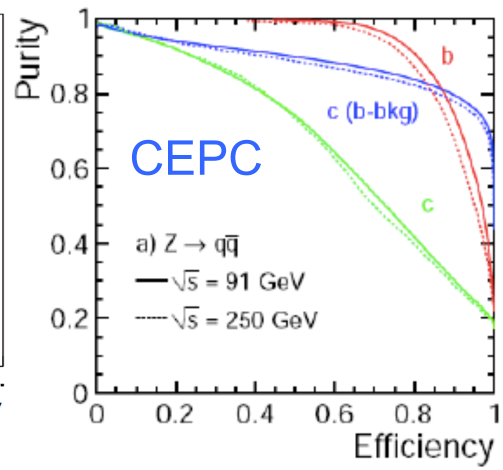
  - Syst error : 0.35%
    - Charm mistag   (0.2%)
    - Light jet mistag rate (0.2%)
    - Gluon radiation (g->bb , g->cc) (0.15%)

B working point in SLD





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