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

Electroweak and top threshold physics update

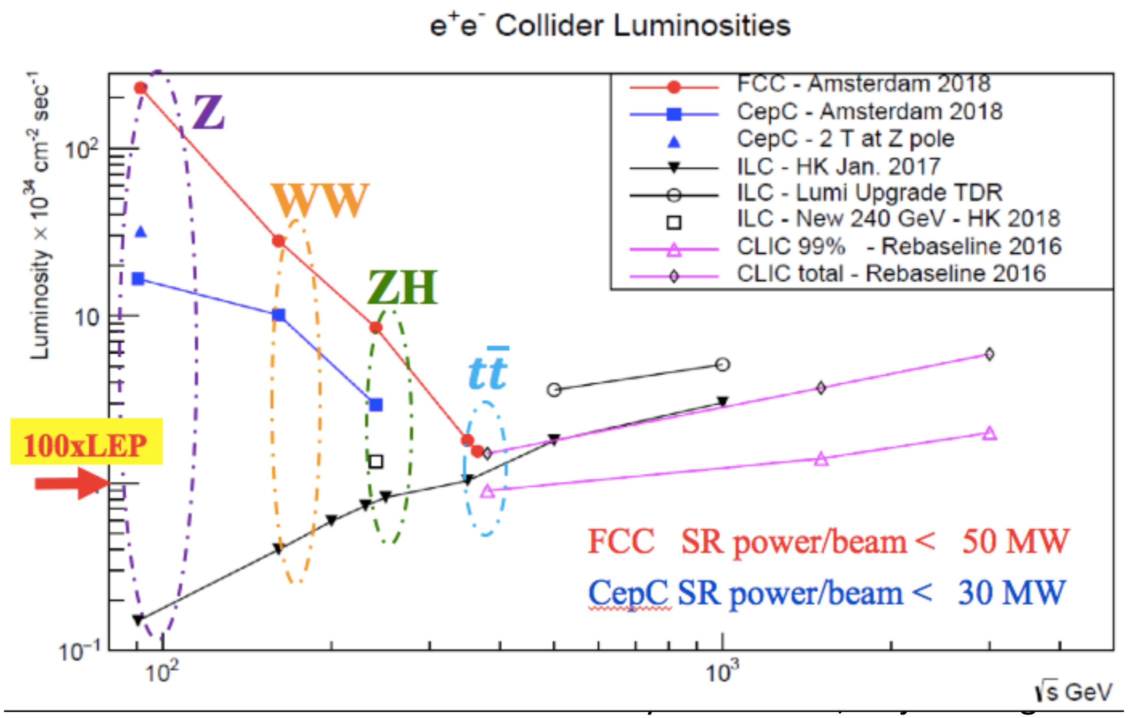
Zhijun Liang

Institute of High Energy Physics ,
Chinese Academy of Science

CEPC day meeting

Introduction

- CEPC is Higgs Factory （E_{cms}=240GeV，10^6 Higgs)
- CEPC is Z factory(E_{cms}~91GeV) ,electroweak precision physics at Z pole.
  - baseline **L=1.6 X 10^{35} cm^{-2}s^{-1} , Solenoid =3T, 3X10^{11} Z boson, two years**
  - **L= 3.2 X 10^{35} cm^{-2}s^{-1} , Solenoid =2T , 6X10^{11} Z boson**
- WW threshold scan runs (~160GeV) are also expected.
  - One year, Total luminosity 2.6 ab^{-1} **14M WW events**



From F. Bedeschi

Electroweak global fit status

- Review of the key electroweak constant

Fundamental constant	$\delta x/x$	measurements	
$\alpha = 1/137.035999139\ (31)$	1×10^{-10}	$e^{\pm}\ g_2$	Z pole
$G_F = 1.1663787\ (6) \times 10^{-5}\ \text{GeV}^{-2}$	1×10^{-6}	$\mu^{\pm}$ lifetime	
$M_Z = 91.1876 \pm 0.0021\ \text{GeV}$	1×10^{-5}	LEP	Z pole
$M_W = 80.379 \pm 0.012\ \text{GeV}$	1×10^{-4}	LEP/Tevatron/LHC	WW run
$\sin^2\theta_W = 0.23152 \pm 0.00014$	6×10^{-4}	LEP/SLD	Z pole
$m_{top} = 172.74 \pm 0.46\ \text{GeV}$	3×10^{-3}	Tevatron/LHC	ttbar runs
$M_H = 125.14 \pm 0.15\ \text{GeV}$	1×10^{-3}	LHC	ZH runs

From PDG2018

Outline

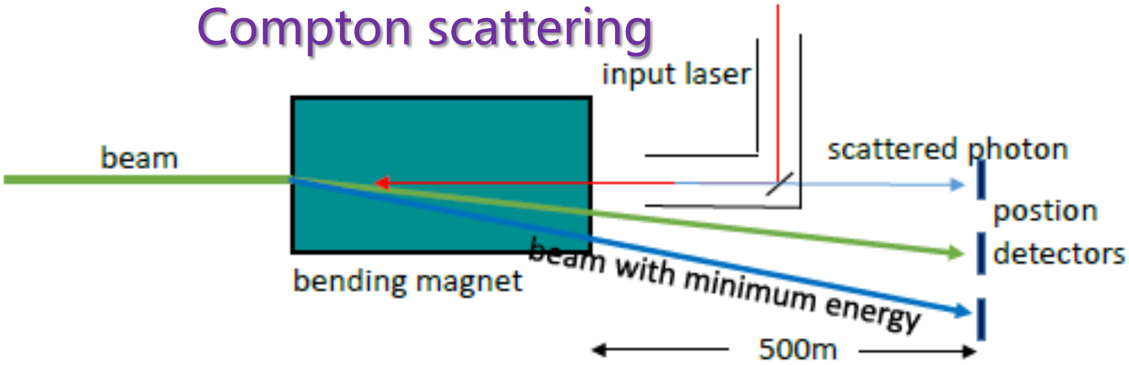
- Introduction to CEPC
- Z pole physics
- W physics
- Top physics

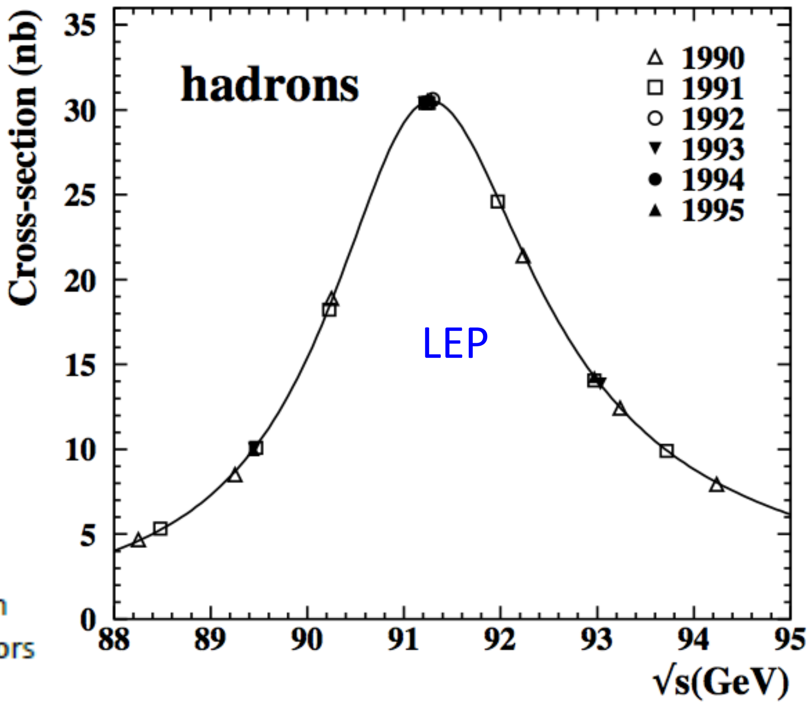
Z mass measurement

- LEP precision : 91.1876±0.0021 GeV
- CEPC goal : 0.5 MeV (CDR) → 0.1MeV (TDR)
  - Beam energy uncertainty is major systematics
    - 5~10% transverse beam polarization is the key
    - Resonant depolarization approach by LEP → <0.1MeV
    - Compton scattering → <0.3 MeV

	Z pole (91GeV)	WW (160GeV)	ZH (240GeV)
Resonant Depolarization	0.1MeV	0.5 MeV	NA
Compton Scattering	0.3MeV	0.6MeV	1.0 MeV

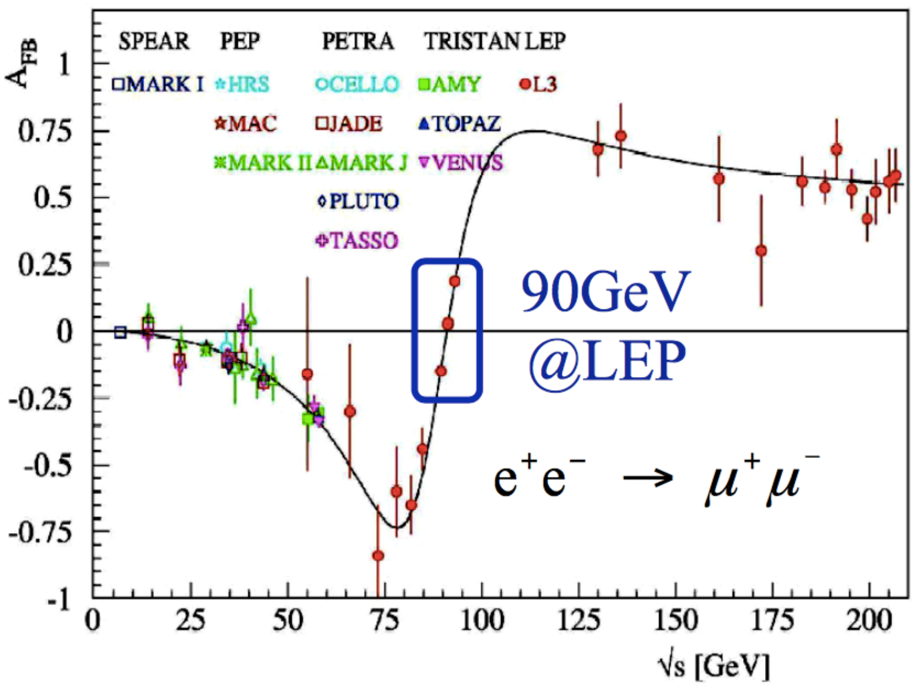
Compton scattering

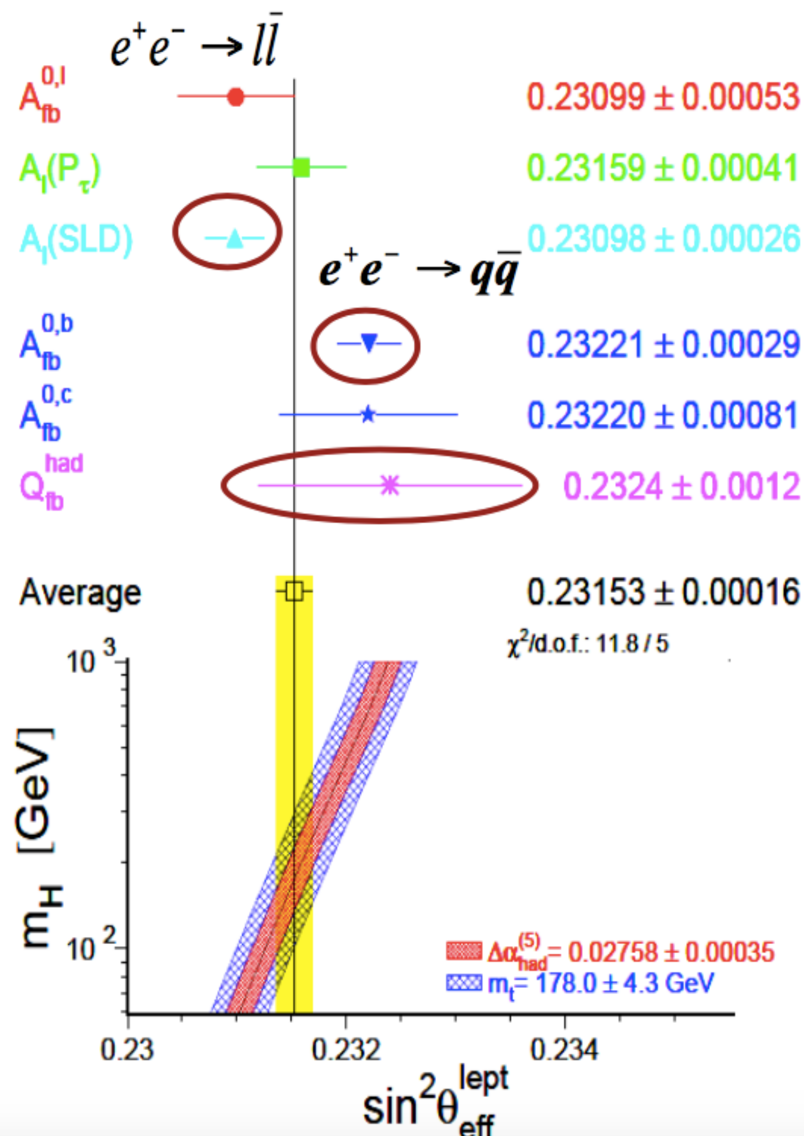




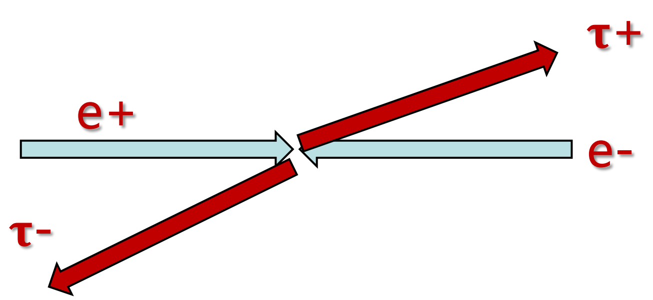
Weak mixing angle $\sin^2\theta_{eff}^{lept}$

- Some tension between SLD and LEP results (~3σ)
  - Remain a puzzle for ~10 years





A_e and A_τ: tau polarization



$$A_{\rm FB} = \frac{\sigma_{\rm F}-\sigma_{\rm B}}{\sigma_{\rm F}+\sigma_{\rm B}}$$

$$A_{\rm LR} = \frac{\sigma_{\rm L}-\sigma_{\rm R}}{\sigma_{\rm L}+\sigma_{\rm R}}\frac{1}{\langle|\mathcal{P}_{\rm e}|\rangle}$$

$$A_{\rm LRFB} = \frac{(\sigma_{\rm F}-\sigma_{\rm B})_{\rm L}-(\sigma_{\rm F}-\sigma_{\rm B})_{\rm R}}{(\sigma_{\rm F}+\sigma_{\rm B})_{\rm L}+(\sigma_{\rm F}+\sigma_{\rm B})_{\rm R}}\frac{1}{\langle|\mathcal{P}_{\rm e}|\rangle}$$

- Weak mixing angle
  - extracted from A_e and A_τ using tau polarization: more precise

τ decay mode	Number selected decays	Purity of the samples (%)
$\tau\to e\nu_e\nu_\tau$	18434	89.4 ± 0.1
$\tau\to\mu\nu_\mu\nu_\tau$	19811	94.3 ± 0.1
$\tau\to\pi/K\nu_\tau$	14850	73.2 ± 0.1
$\tau\to\rho\nu_\tau$	26548	75.4 ± 0.1
$\tau\to a_1\nu_\tau$	9446	53.2 ± 0.2

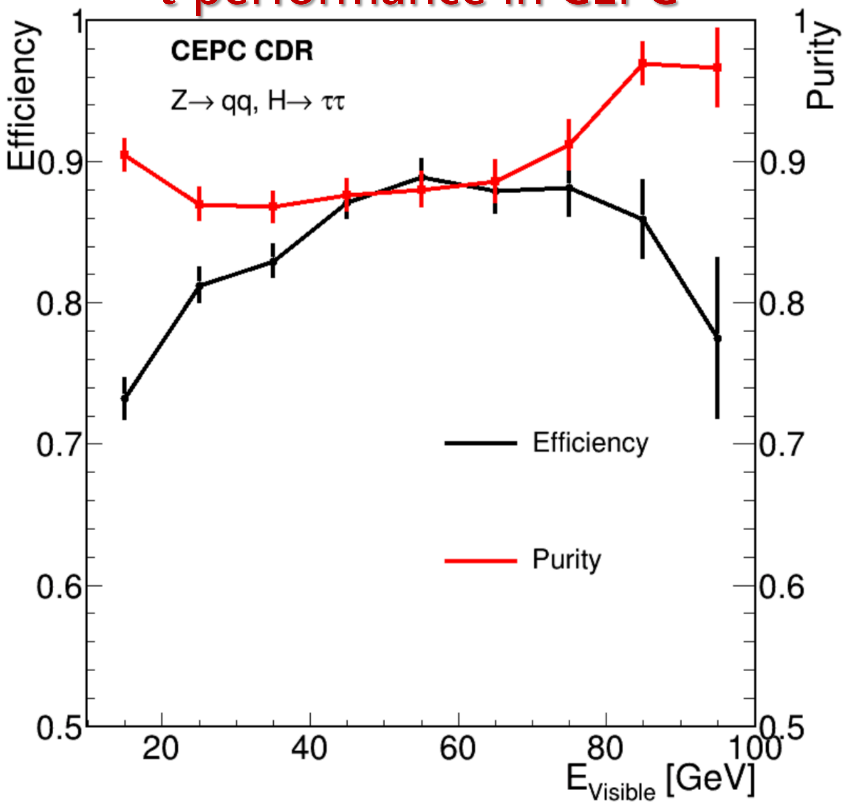
$A_{\rm LRFB}$, $P_\tau(\cos\theta)$ → A_e and A_τ

A_e and A_τ in $Z \rightarrow \tau\tau$: systematics

- Current precision
  - A_e : **0.1515±0.0019 (PDG)**
  - A_τ : **0.143±0.004 (PDG)**
- CEPC:
  - A_τ : Key systematics is from EM scale, and **τ** identification
  - A_e limited by statistics

CEPC precision	Rel stat unc.	Rel total unc.
A_τ	$2X10^{-4}$	$5X10^{-4}$
A_e	$3X10^{-4}$	$3X10^{-4}$

τ performance in CEPC



CEPC EWK input to ECFA

	Γ_Z	σ_{had}		A_e (τ pol)	A_τ (τ pol)
CEPC	0.5 MeV	0.005 nb		0.0003	0.0005
FCC-ee	0.1 MeV	0.005 nb		–	–
	R_e	R_μ	R_τ	R_b	R_c
CEPC	0.0003	0.0001	0.0002	0.0002	0.001
FCC-ee	0.0003	0.00005	0.0001	0.0003	0.0015
	$A_{\text{FB}}^{0,e}$	$A_{\text{FB}}^{0,\mu}$	$A_{\text{FB}}^{0,\tau}$	$A_{\text{FB}}^{0,b}$	$A_{\text{FB}}^{0,c}$
CEPC	0.005	0.003	0.005	0.001	0.003
FCC-ee	–	–	–	–	–
(fitted)	A_e	A_μ	A_τ	A_b	A_c
CEPC	0.0003	0.003	0.0005	0.001	0.003
FCC-ee	0.0001	0.00015	0.0003	0.003	0.008

Table 1: A comparison of CEPC and FCC-ee Z-pole inputs. All uncertainties are relative **(normalized to 1)** except for Γ_Z and σ_{had}. "τ pol" denotes that the measurement is from τ polarization in $Z \to \tau^+\tau^-$. The 5 fitted asymmetry observables ($A_{e,\mu,\tau,b,c}$) are derived from a simutanous fit of all the $A_{\text{FB}}^{0,}$ observables as well as the A_e and A_τ from τ polarization.

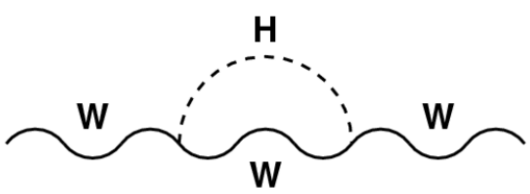
Discrepancy Due to statistics

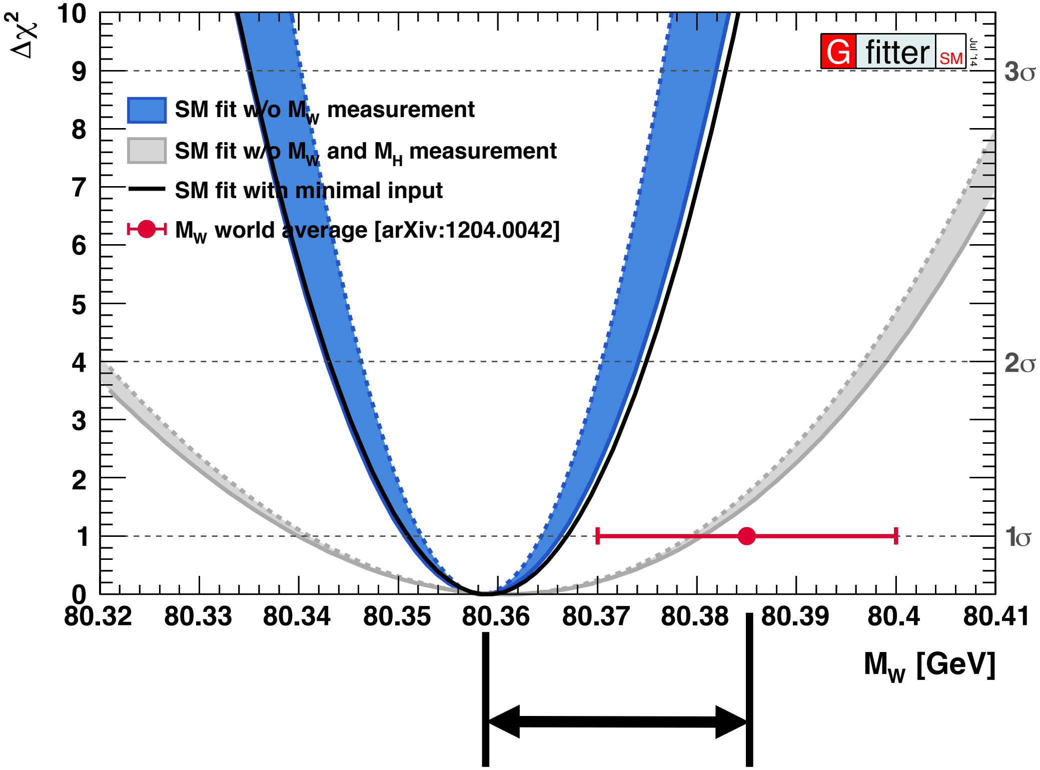
doing check on systematics (tracker alignment …)
Plan to work with USTC

- Introduction to CEPC
- Z pole physics
- W physics
- Top physics

Motivation

- Small tension in weak mixing angle and W mass.(2σ)
  - Between direct measurement and EWK fit prediction
  - Indirect search for new physics





W mass measurement in lepton collider

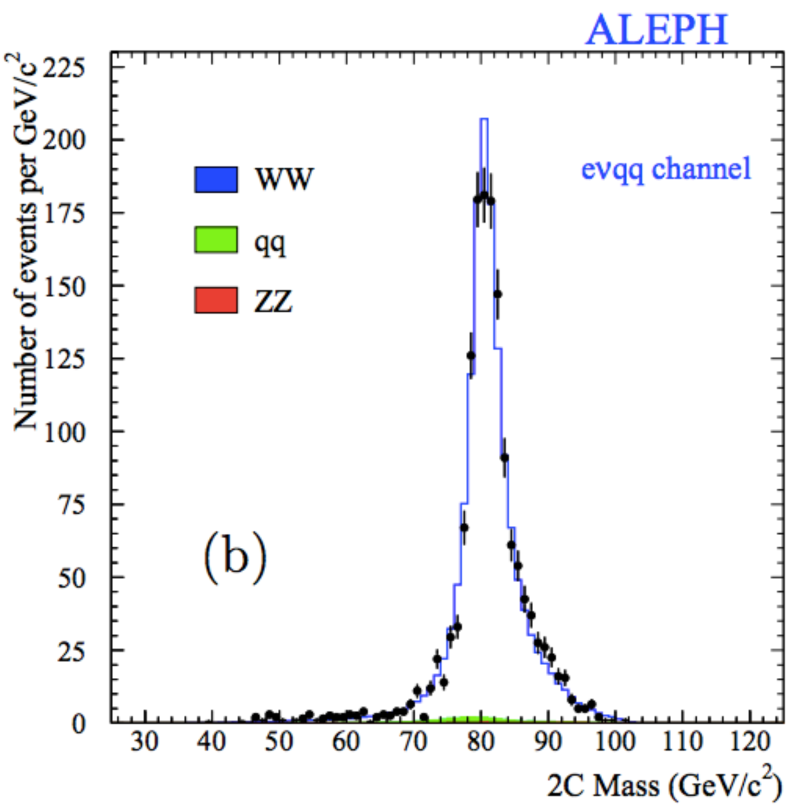
- Two approaches to measure W mass at lepton collider:

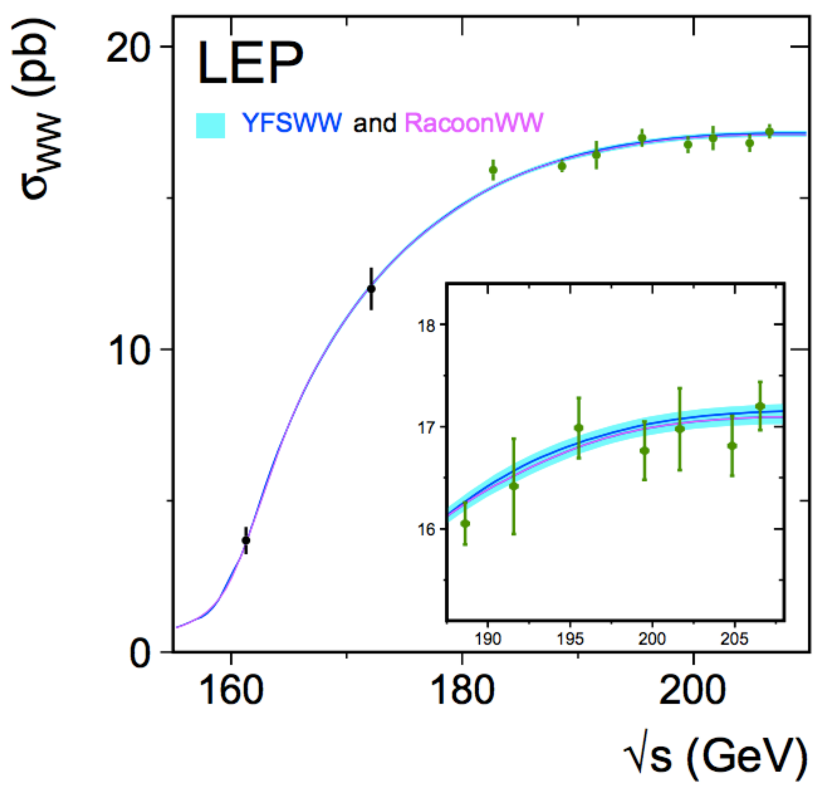
Direct measurement

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

WW threshold scan

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



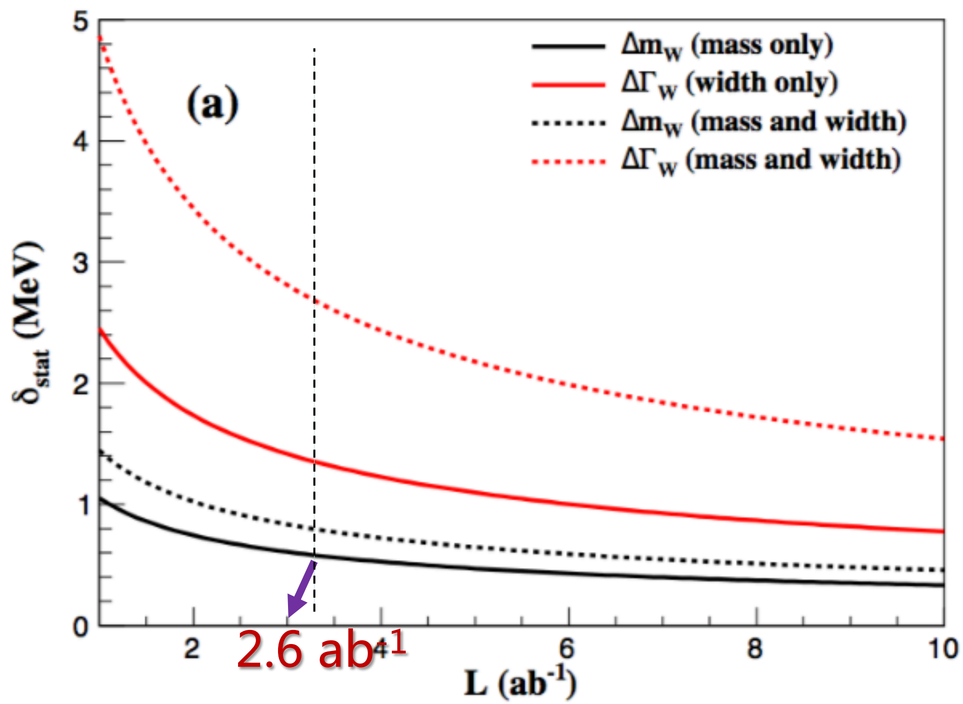


WW threshold scan-systematics unc.

- Expected 1MeV precision in W mass measurement
  - Dominated by statistics uncertainty.
    - Would benefitted if extend WW runs by three more years
  - Leading syst. (0.4MeV): beam energy syst.

Observable	m_W	Γ_W
Source	Uncertainty (MeV)	
Statistics	0.8	2.7
Beam energy	0.4	0.6
Beam spread	–	0.9
Corr. syst.	0.4	0.2
Total	1.0	2.8

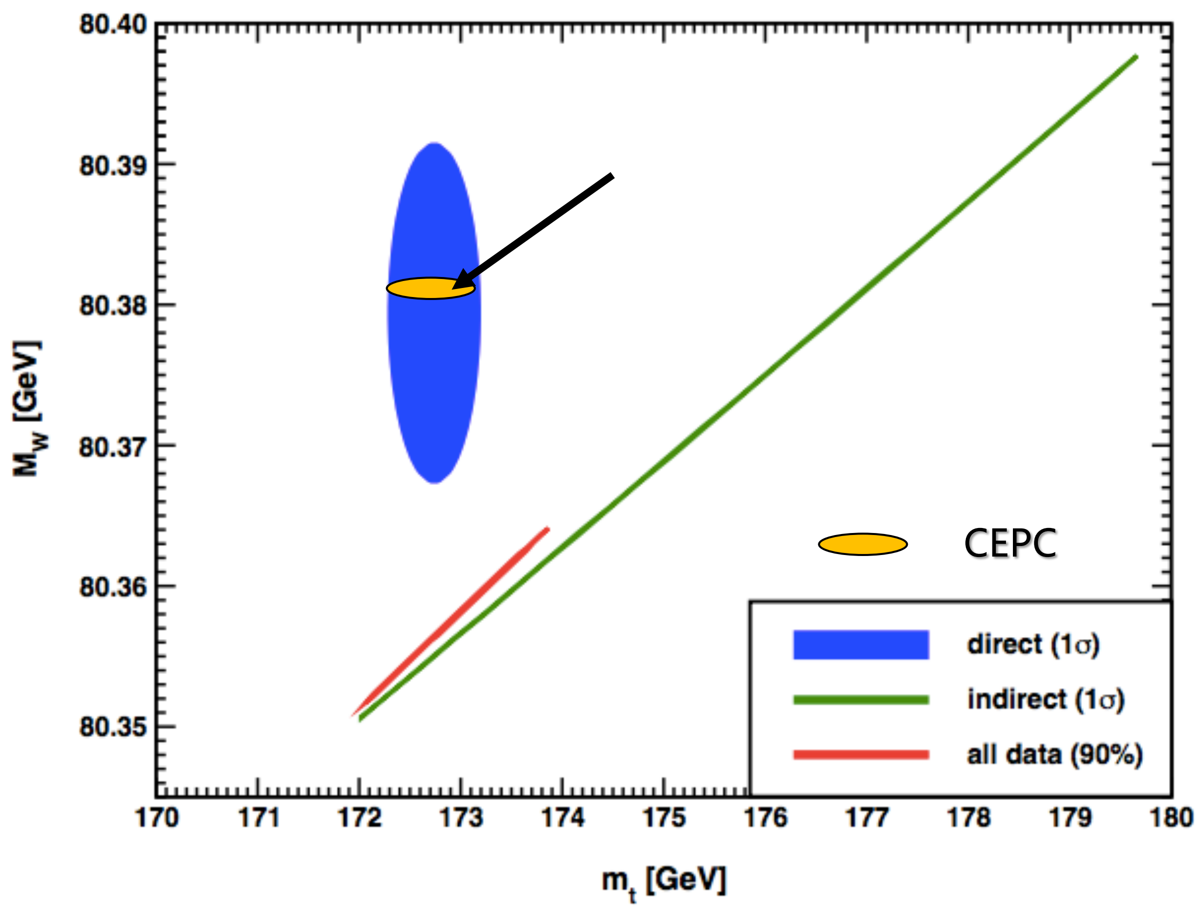
Statistics unc. on W mass Vs Luminosity



Idea from Paolo Azzuri et al. arxiv: 1703.01626v1

Prospect of CEPC W mass measurement

- CEPC can improve current precision of W mass by one order of magnitude
  - Good physics potential for BSM physics from indirect search



Freitas & JE (PDG 2018)

Joint CEPC-FCC W mass paper

- Joint CEPC-Fcc W mass paper submitted to EPJC
  - Weekly meeting with Fcc side to converge on this paper
  - Paolo Azzurri collected comments from FCC side
  - Gang and I have preliminary review
  - Joao did final review for paper draft before submitting to Arxiv
- To Do
  - Clarify experimental systematics estimation to EPJC referee

arXiv.org > hep-ex > arXiv:1812.09855

High Energy Physics – Experiment

Data-taking strategy for the precise measurement of the W boson mass with threshold scan at circular electron positron colliders

P. X. Shen, P. Azzurri, M. Boonekamp, P. Z. Lai, B. Li, G. Li, H. N. Li, Z. J. Liang, B. Liu, J. M. Qian, L. S. Shi, C. X. Yu

Outline

- Introduction to CEPC
- Z pole physics
- W physics
- Top physics

Top threshold scan

- Review of the key electroweak constant

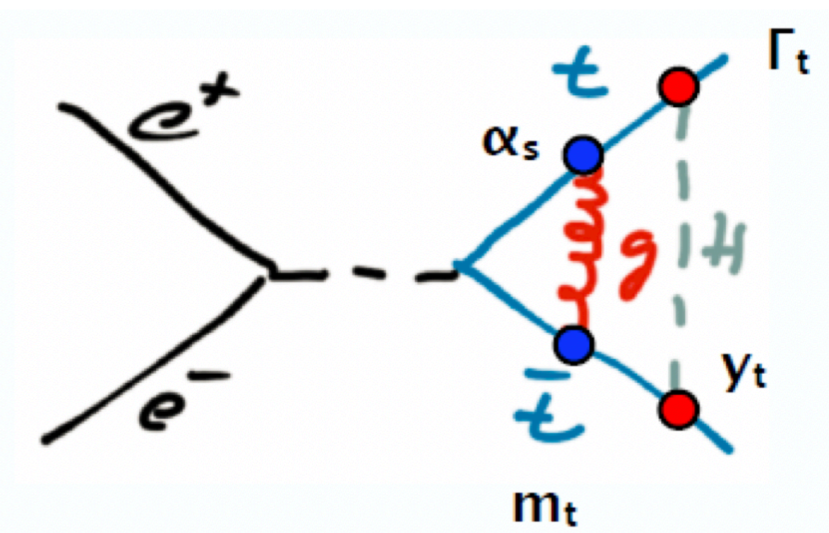
Fundamental constant	δx/x	measurements
$\alpha = 1/137.035999139\ (31)$	1×10^{-10}	$e^{\pm}\ g_2$
$G_F = 1.1663787\ (6) \times 10^{-5}\ \text{GeV}^{-2}$	1×10^{-6}	$\mu^{\pm}$ lifetime
$M_Z = 91.1876 \pm 0.0021\ \text{GeV}$	1×10^{-5}	LEP
$M_W = 80.379 \pm 0.012\ \text{GeV}$	1×10^{-4}	LEP/Tevatron/LHC
$\sin^2\theta_W = 0.23152 \pm 0.00014$	6×10^{-4}	LEP/SLD
$m_{top} = 172.74 \pm 0.46\ \text{GeV}$	3×10^{-3}	Tevatron/LHC
$M_H = 125.14 \pm 0.15\ \text{GeV}$	1×10^{-3}	LHC

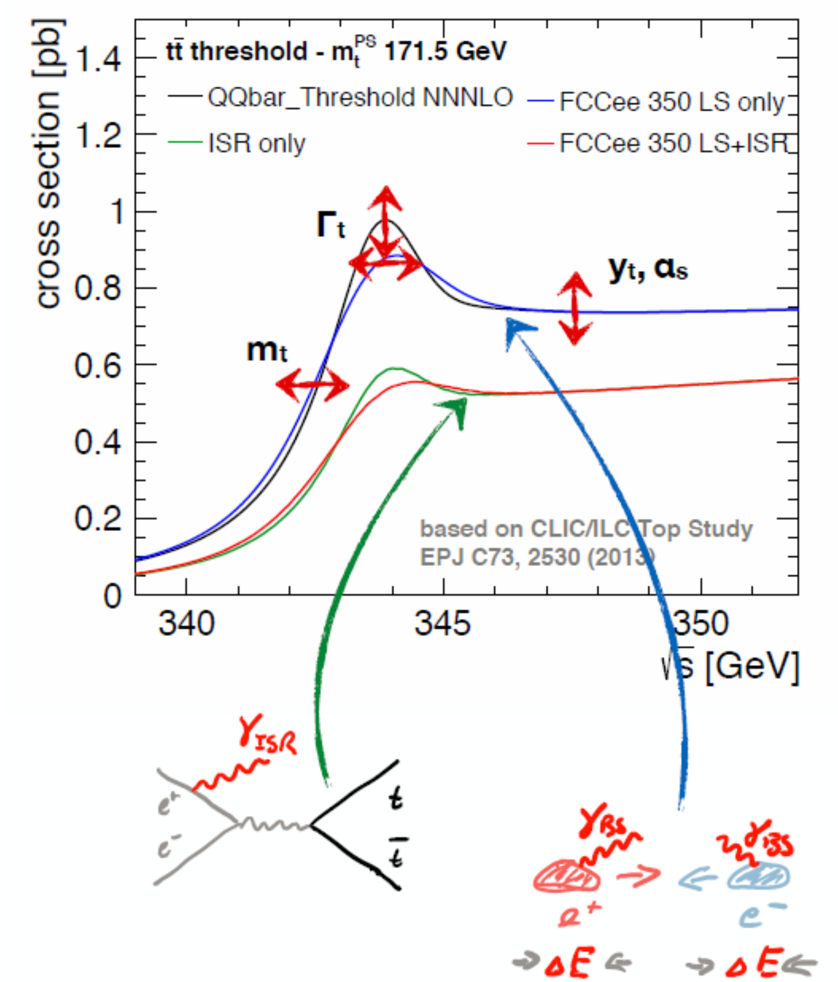
Top scan Runs

From PDG2018

top threshold scan

- Top threshold cross-section depends on:
  - top mass
  - top width (lifetime)
  - top-Higgs coupling
  - αQCD



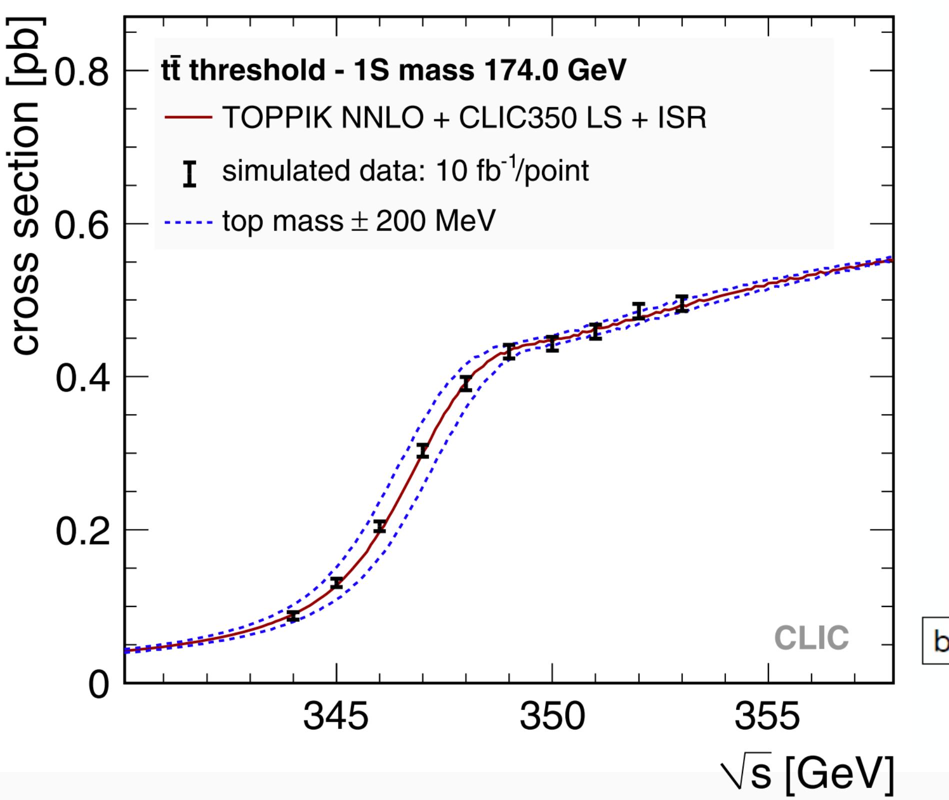


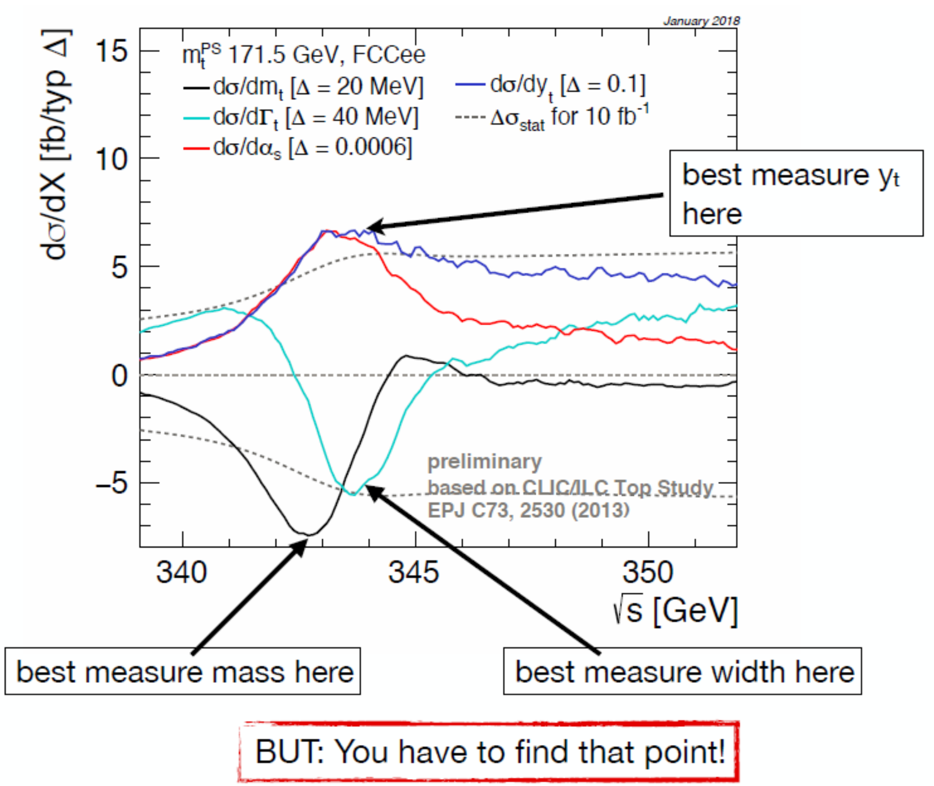
Thanks to discussion and slides from Alain Blondel

Study by Frank Simon (CLIC/ILC study, EPJC 73,(2013)2530)

Top threshold scan

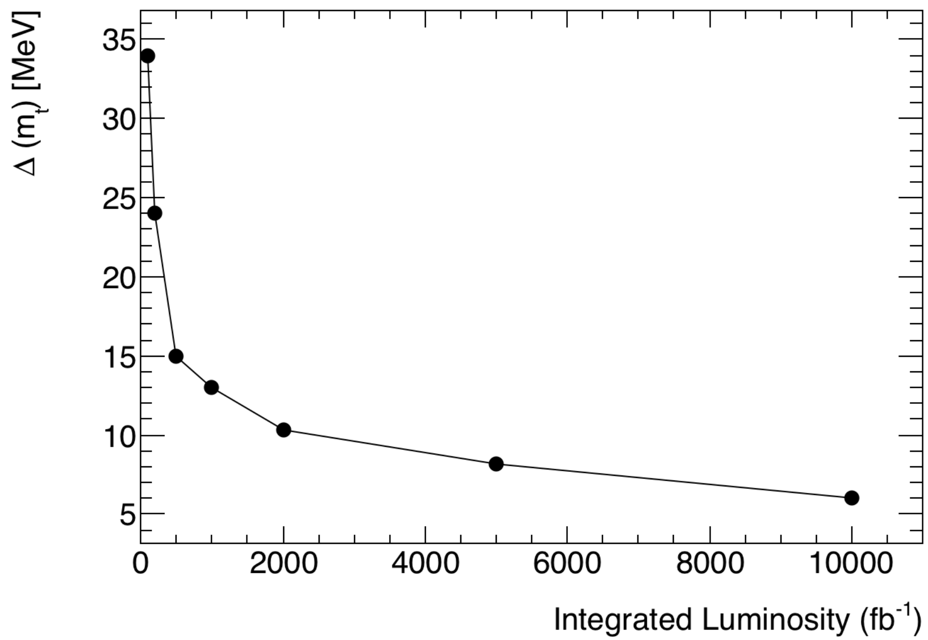
- Strategy:
  - Need a rough scan to measure the top mass to 100 MeV. (5-10 fb^{-1})
  - Fix the final scan points
  - since there are four parameters to fix, need at least 4 scan points
    - Scanning range 340GeV ~355GeV





Top threshold scan

- If CEPC decided to have top threshold scan
  - Better to have integrated Lumosity larger than $2ab^{-1}$
  - Aim for 10MeV precision

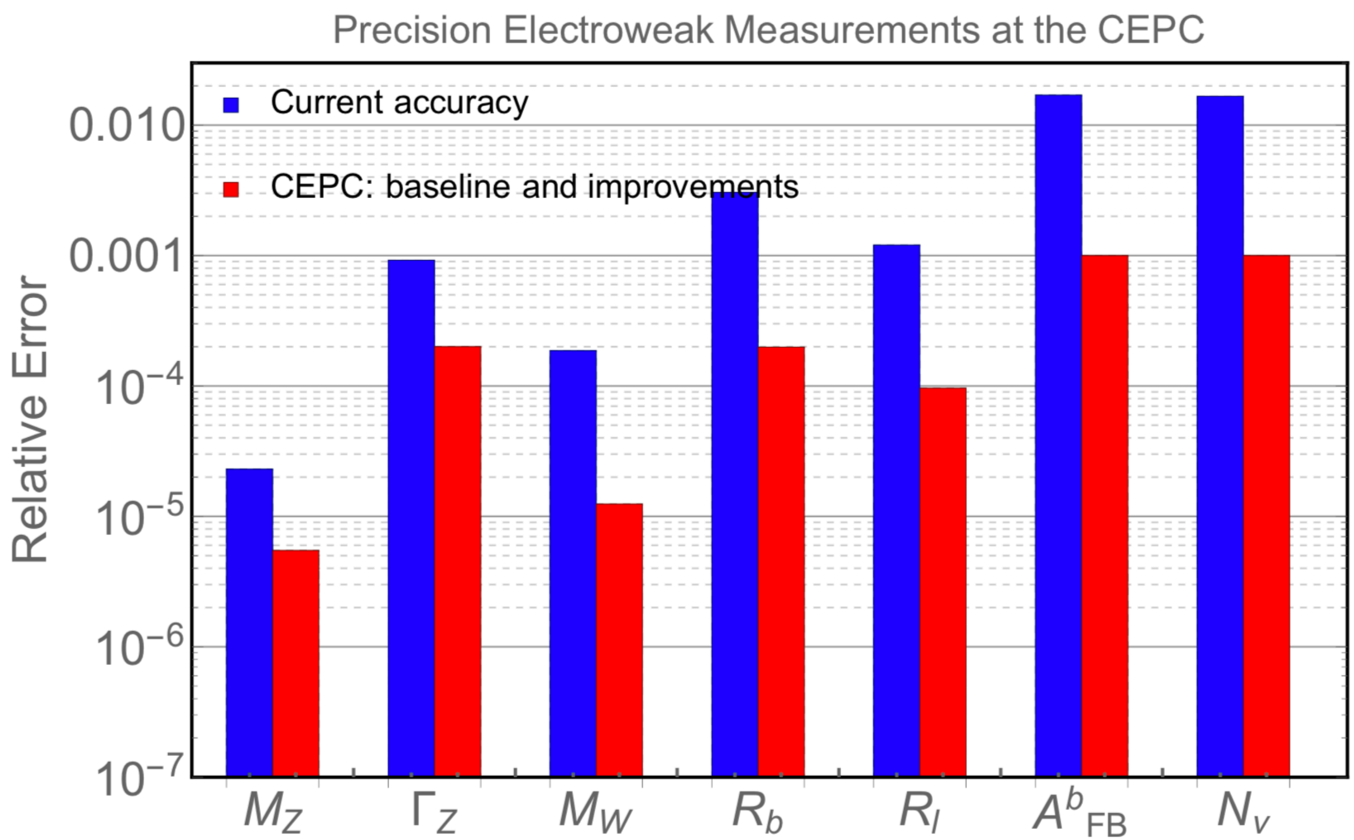


ILC/CLIC estimation with 100 fb^{-1}

m_t stat. error	34 MeV
m_t theory syst. (1 %/3 %)	5 MeV/8 MeV
α_s stat. error	0.0009
α_s theory syst. (1 %/3 %)	0.0008/0.0022

Summary

- Potential of electroweak measurement at CEPC
  - W mass precision (1MeV) is expected to be limited by statistics
  - Possible target for top mass precision (10MeV) for CEPC
    - With 2ab^{-1} integrated Luminosity scanning 345GeV ~353GeV



Backup

Beam polarization

- **What is Polarized beam collision ?**
  - Usually mean longitudinal polarized beam for physics

Type	Polarized beam collision	Beam energy measurement
Polarized Type	Longitudinal polarized	Transverse polarized
Fraction of polarization	>30% (50%)	5~10% is enough

Type	Longitudinal polarized e-	Longitudinal polarized e+	Transverse polarized Beam
CEPC	To be discussed	To be discussed	Yes (Z,WW)
Fcc-ee	No	NO	Yes (Z,WW)
ILC	yes	yes	-

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

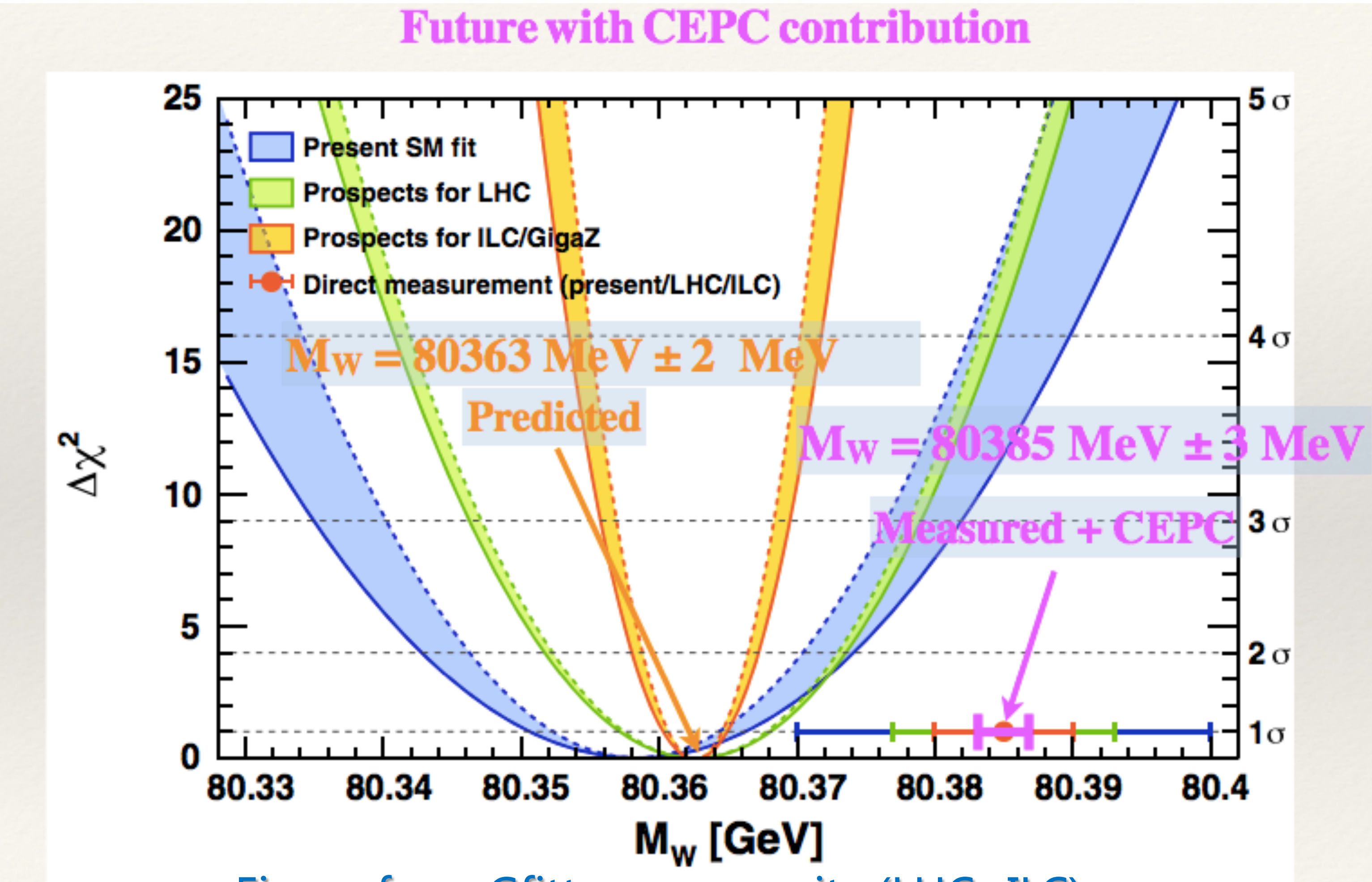
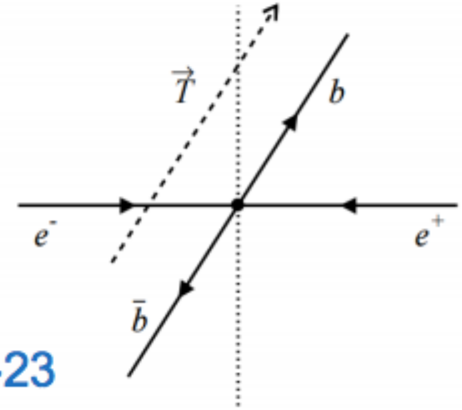


Figure from Gfitter community (LHC+ILC)

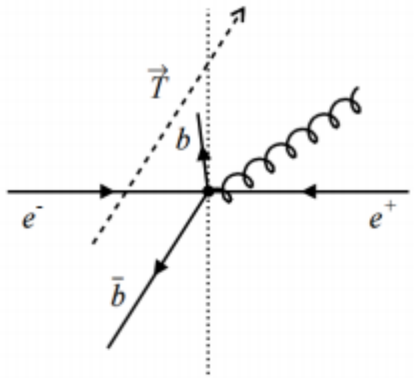
Backward-forward asymmetry $A_{FB}^{b\bar{b}}(0)$

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

CERN-EP/98-23



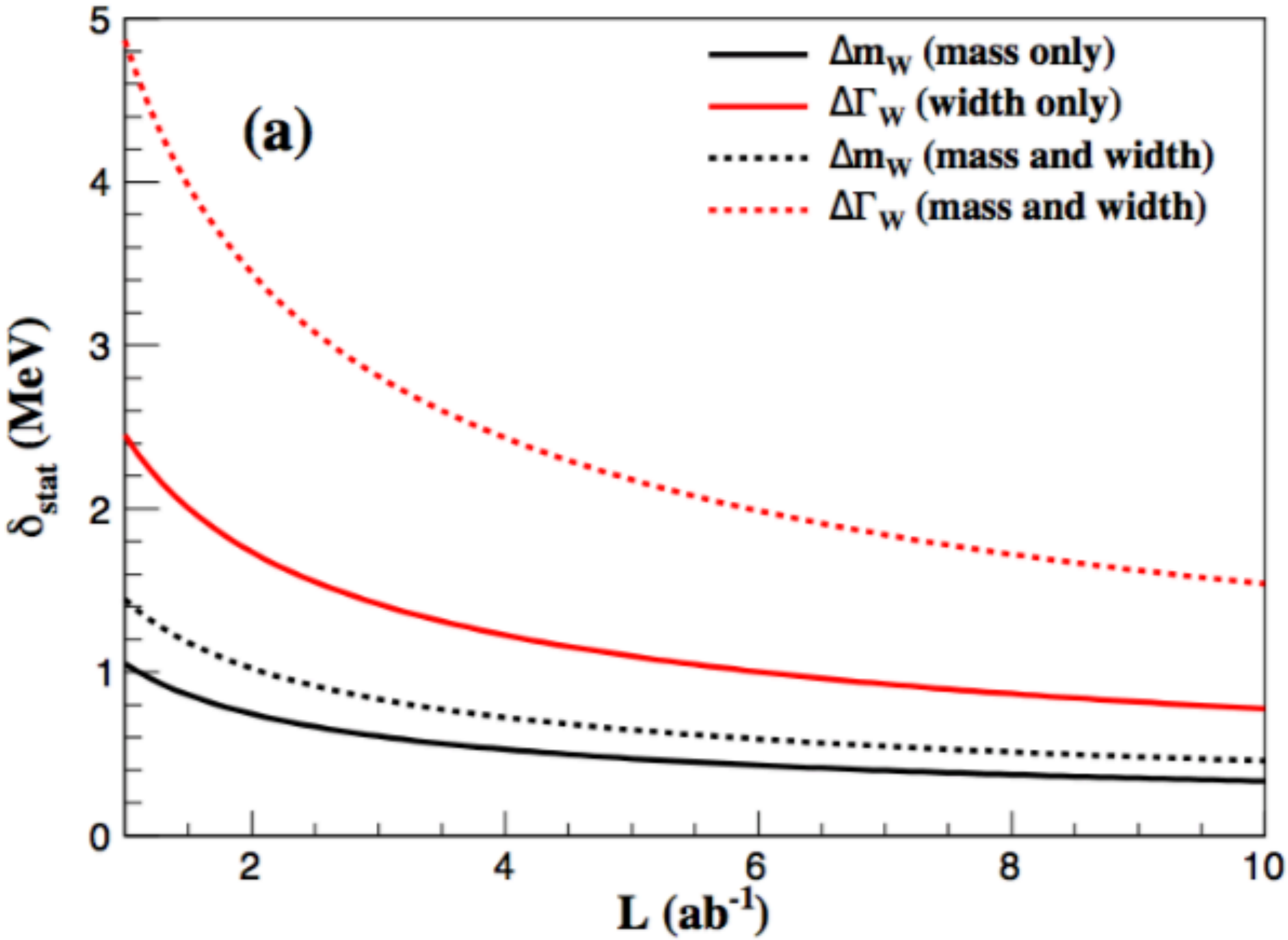
(a) No gluon



(d) Thrust forward, quark backward

Error source	$C_{\mathrm{QCD}}^{\mathrm{quark}}$ (%)		$C_{\mathrm{QCD}}^{\mathrm{part,T}}$ (%)	
	$b\bar{b}$	$c\bar{c}$	$b\bar{b}$	$c\bar{c}$
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

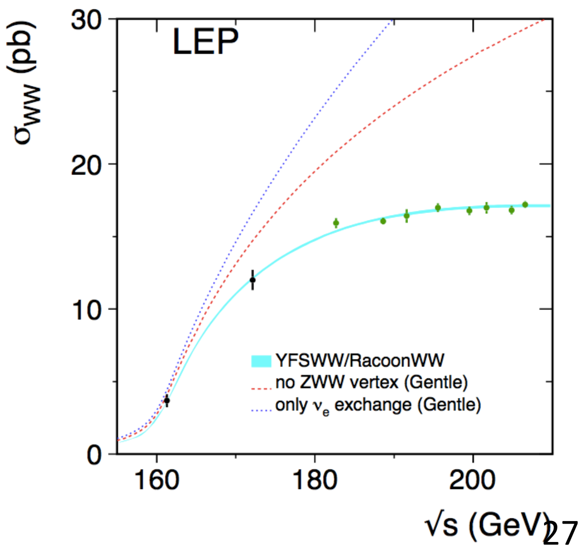
Statistics error on W mass Vs Luminosity



WW threshold scan – CEPC plan

- WW threshold scan running proposal
  - Assuming one year data taking in WW threshold (2.6 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|)
    - 14M 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

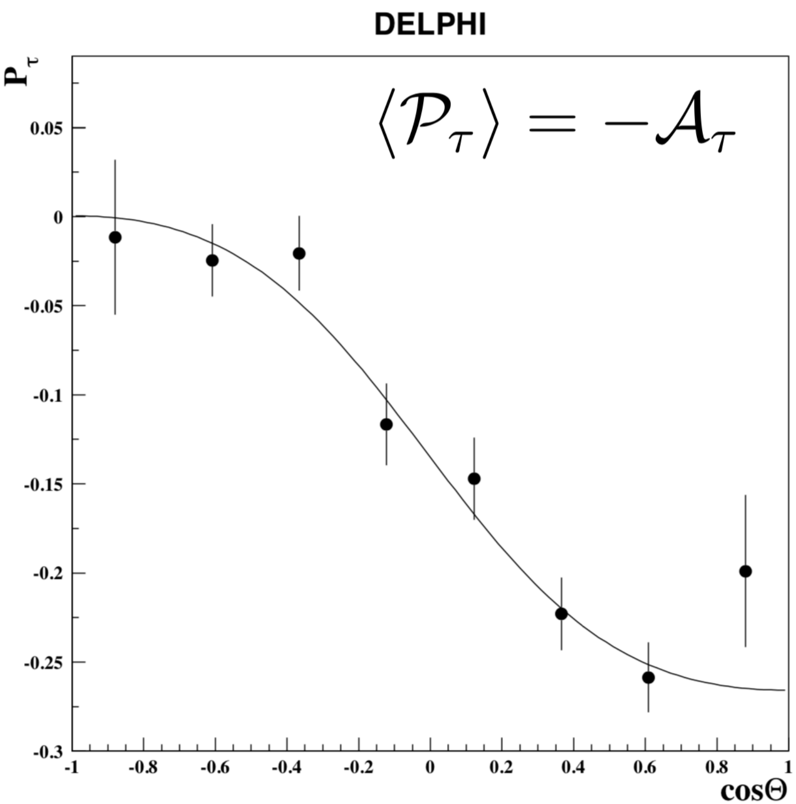


A_e and A_τ in $Z \rightarrow \tau\tau$

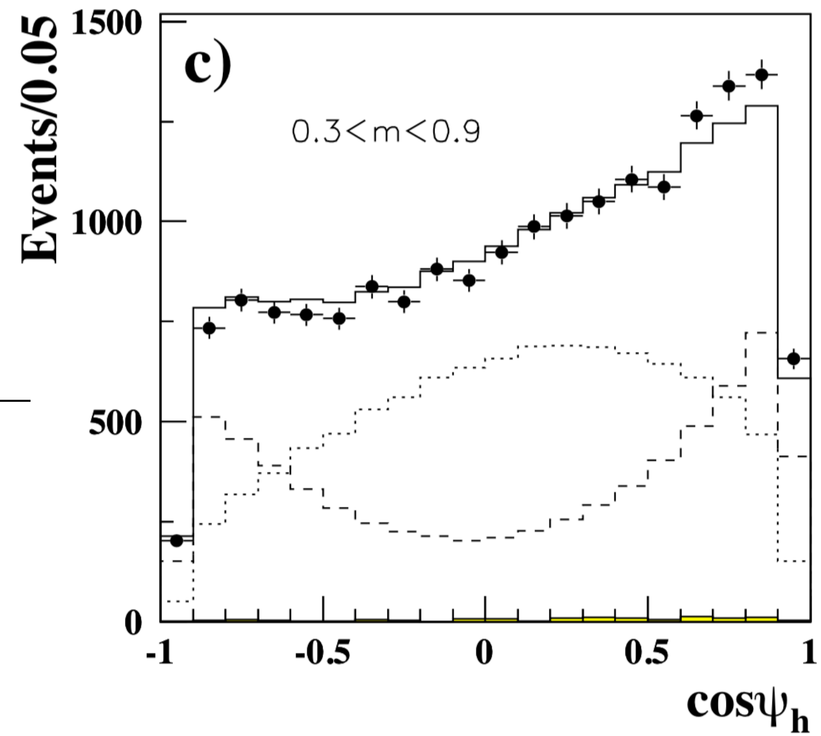
- Tau polarization can be measured through its decay product

$$P_\tau(\cos\theta) = -\frac{\mathcal{A}_\tau(1+\cos^2\theta) + \mathcal{A}_e(2\cos\theta)}{(1+\cos^2\theta) + \frac{4}{3}\mathcal{A}_{fb}(2\cos\theta)}$$

A_{LRFB}, $P_\tau(\cos\theta)$ → A_e and A_τ



From DELPHI

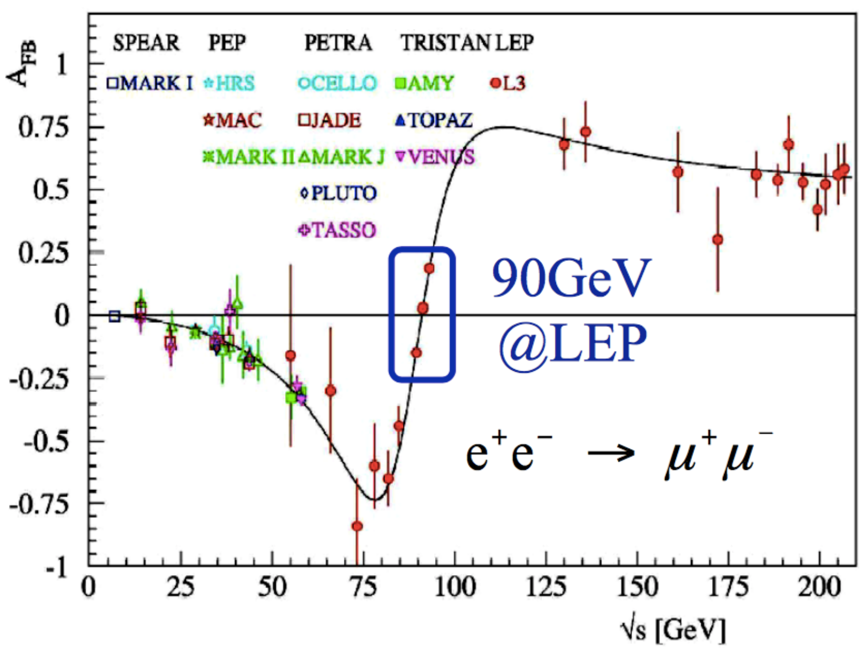


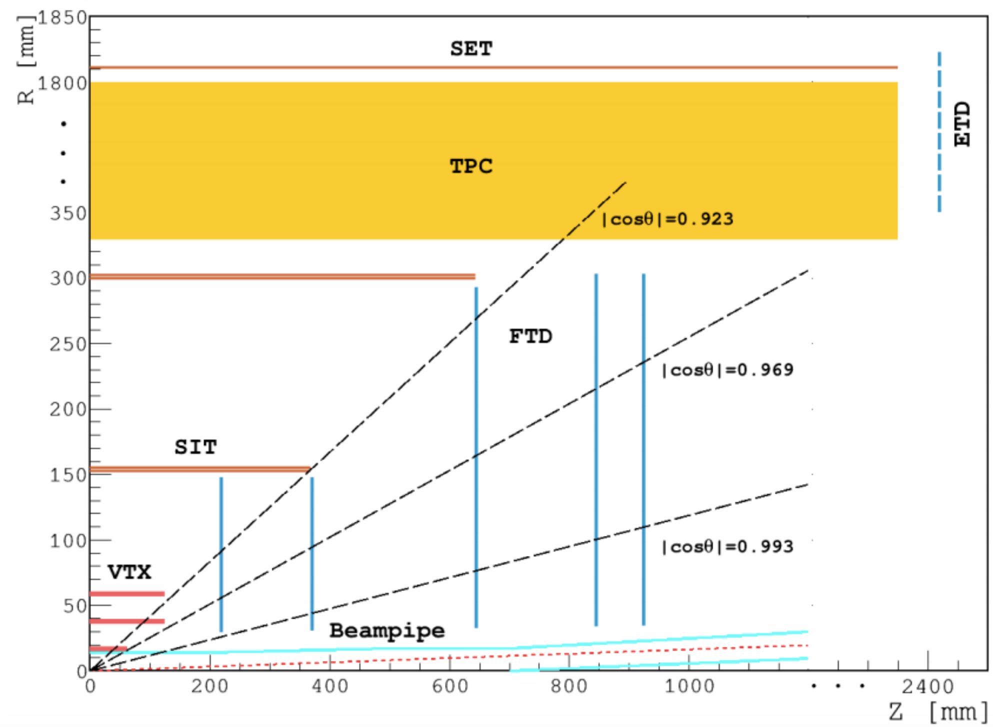
Eur. Phys. J. C 14, 585-611 (2000)

Backward-forward asymmetry in Z->μμ

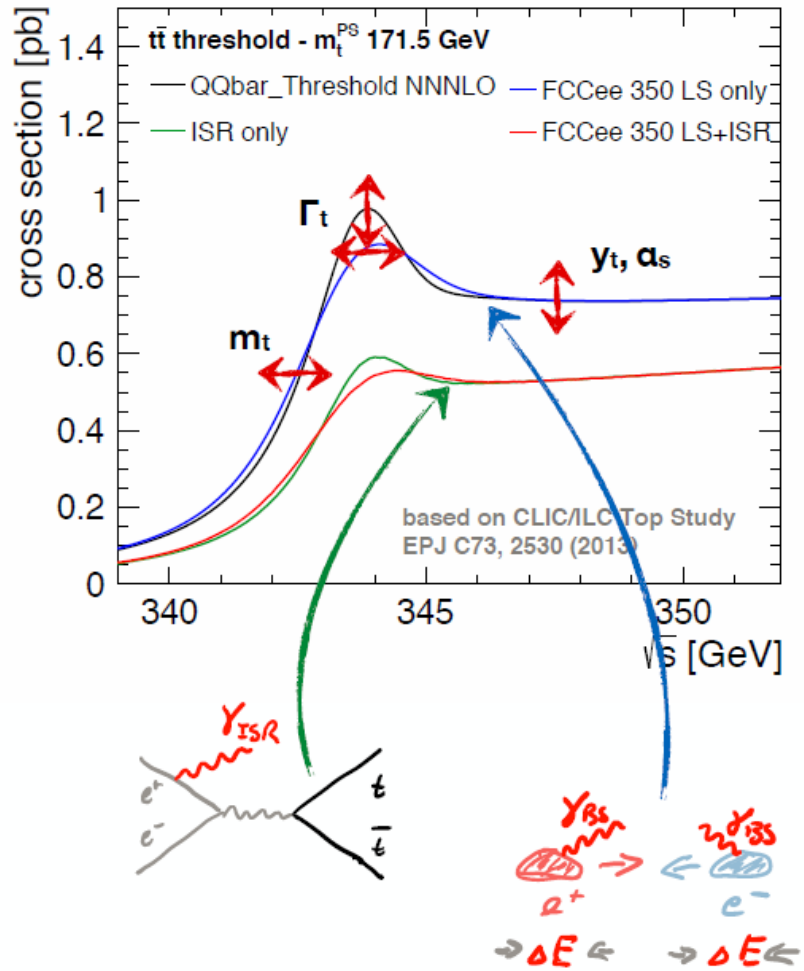
$$A_{FB}^{(0,\mu)}$$

- LEP measurement : 0.0169 +-0.00130
- CEPC expected: +-0.00005
  - CEPC has potential to improve it by a factor of 20~30 .
    - Acceptance systematics (larger detector coverage, smaller syst.)
- Major systematics (absolute value.)
  - Beam energy systematics ($5e^{-5}$, assuming 500keV E_{beam} unc.)
  - Muon angular resolution ($1e^{-5}$ level)



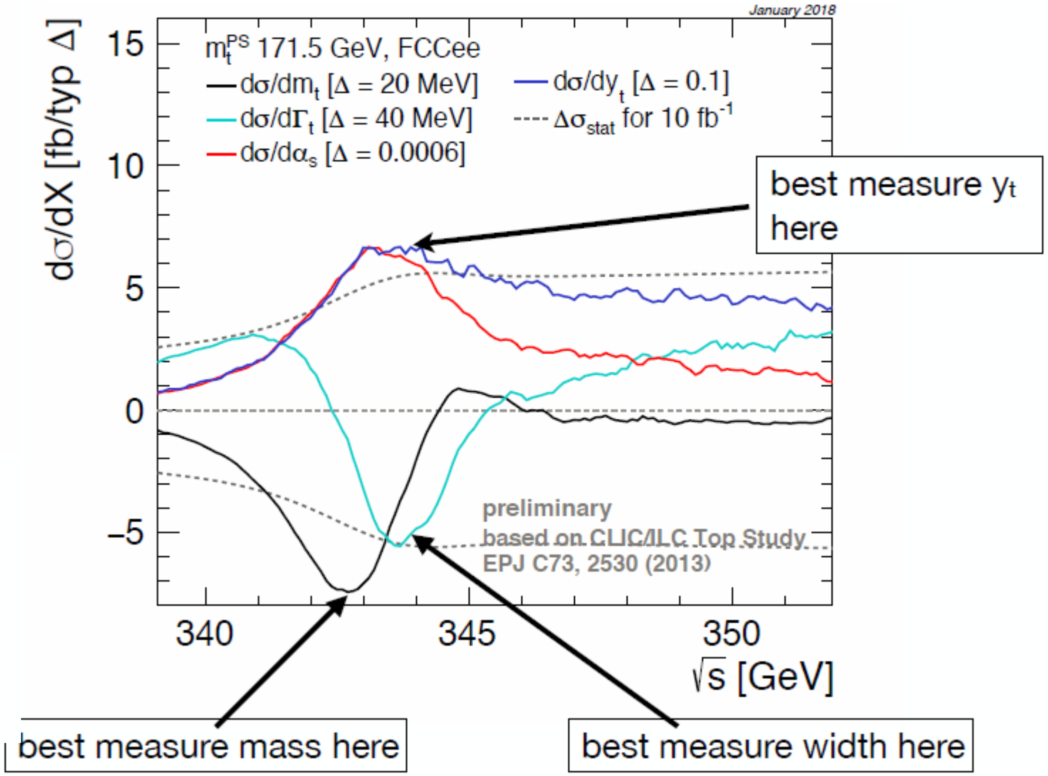


Top threshold scan



Top threshold cross-section depends on

- -- top mass
- -- top width (lifetime)
- -- top Higgs coupling
- -- α_{QCD}



BUT: You have to find that point!

Slide by Alain Blondel

Study by Frank Simon (CLIC/ILC study, EPJC 73,(2013)2530)