中国科学院高能物理研究所

Institute of High Energy Physics Chinese Academy of Sciences

Physics motivation for beam energy measurement

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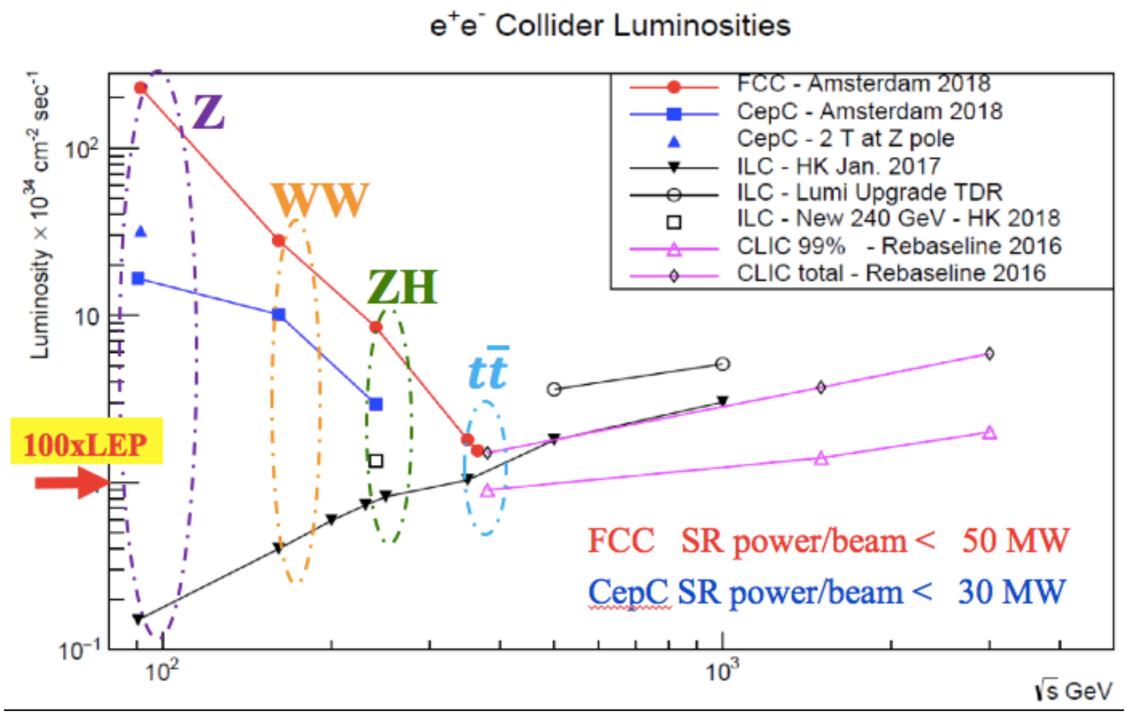
CEPC working day meeting

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
  - **Assuming Z cross section with ISR correction : 32 nb**
- 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

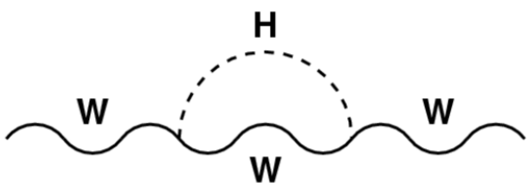
- Review of the key electroweak constant
  - Beam energy systematics is dominant systematics on M_Z, M_W
  - Beam energy measurement is the key to Z pole and WW physics

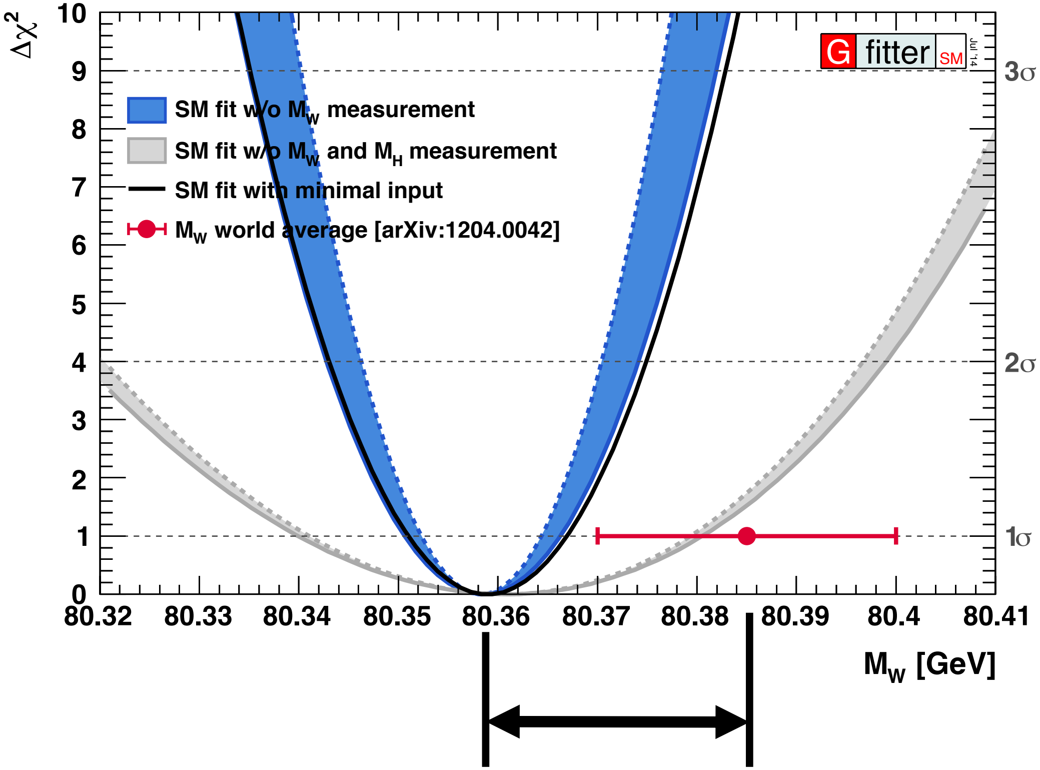
Fundamental constant	δx/x	measurements	
$\alpha = 1/137.035999139\ (31)$	1×10^{-10}	$e^{\pm}\ g_2$	Z pole
$G_F = 1.1663787\ (6) \times 10^{-5}\ \mathrm{GeV}^{-2}$	1×10^{-6}	$\mu^{\pm}$ lifetime	
$M_Z = 91.1876 \pm 0.0021$ GeV	1×10^{-5}	LEP	Z pole
$M_W = 80.379 \pm 0.012$ GeV	1×10^{-4}	LEP/Tevatron/LHC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

From PDG2018

Motivation

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

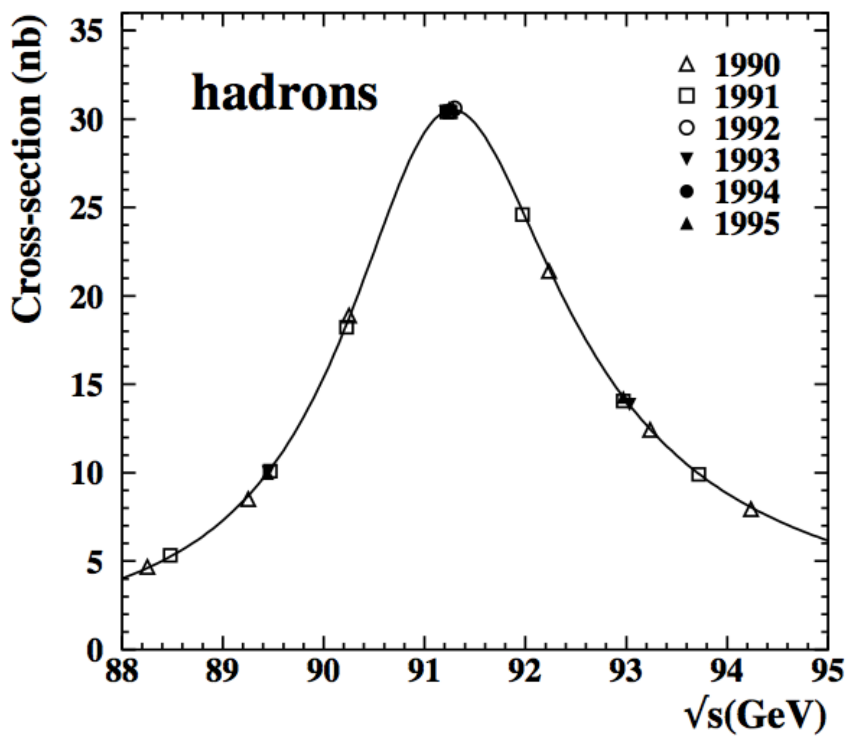


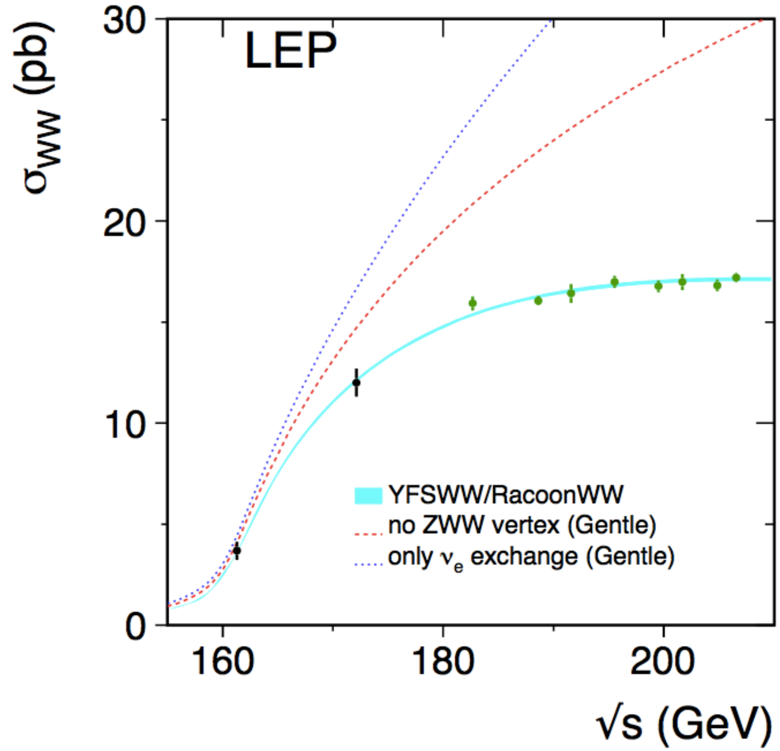


W mass and Z mass measurement

- Threshold scan method is used in LEP for Z/W mass measurement

	Current precision	CEPC goal	CPPC beam energy precision
M_Z	2MeV	0.1 MeV	0.1MeV
M_W	19MeV	1MeV	0.5 MeV





E_beam measurement method

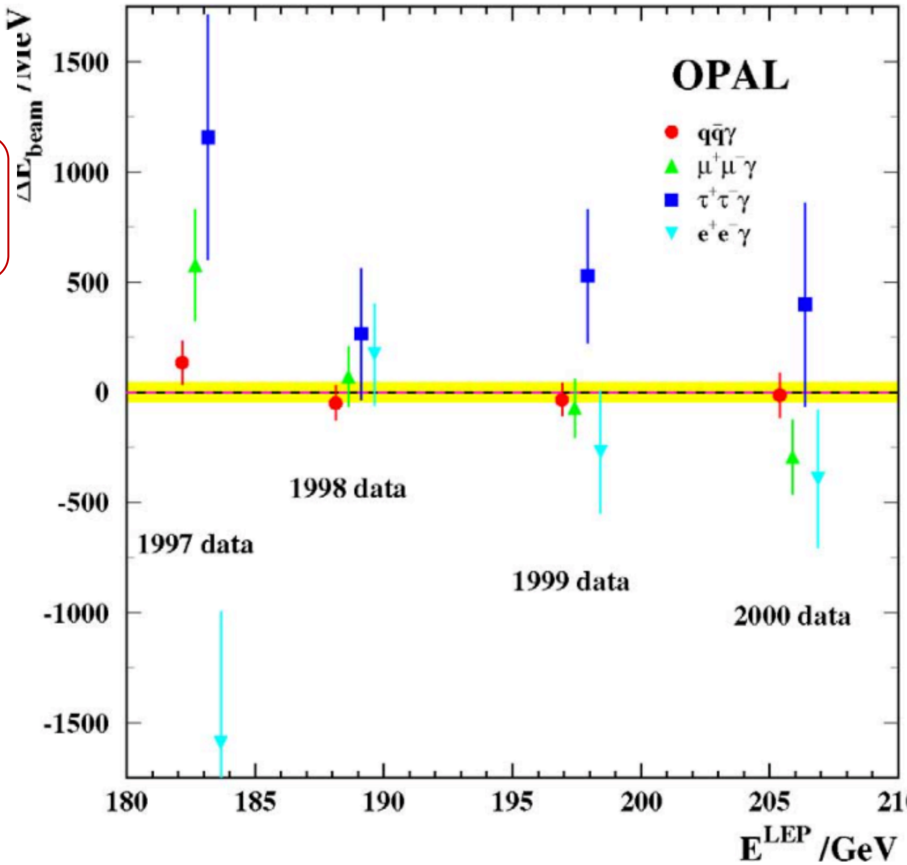
	Z pole	WW (160GeV)	ZH (240GeV)	ttbar (350GeV)
Resonant Depolarization (Zhe's talk)	0.1MeV	0.5 MeV	NA	NA
Compton scattering (Yongsheng)	0.3MeV	0.6MeV	1.0 MeV	1.8 MeV
Z->μμγ	-	1~2MeV	1~2MeV	1~2MeV

Z->llγ method

- Use Z pole data to calibrate lepton and photon momentum scale
  - Use this scale to measure beam energy in WW and ZH and ttbar runs
  - LEP precision with this method: ~20MeV (syst from lepton angular scale)
  - CEPC expected precision: 1~2 MeV (benefitting from granularity of detector)

Table 6
Systematic error contributions on ΔE_{beam} for leptonic events

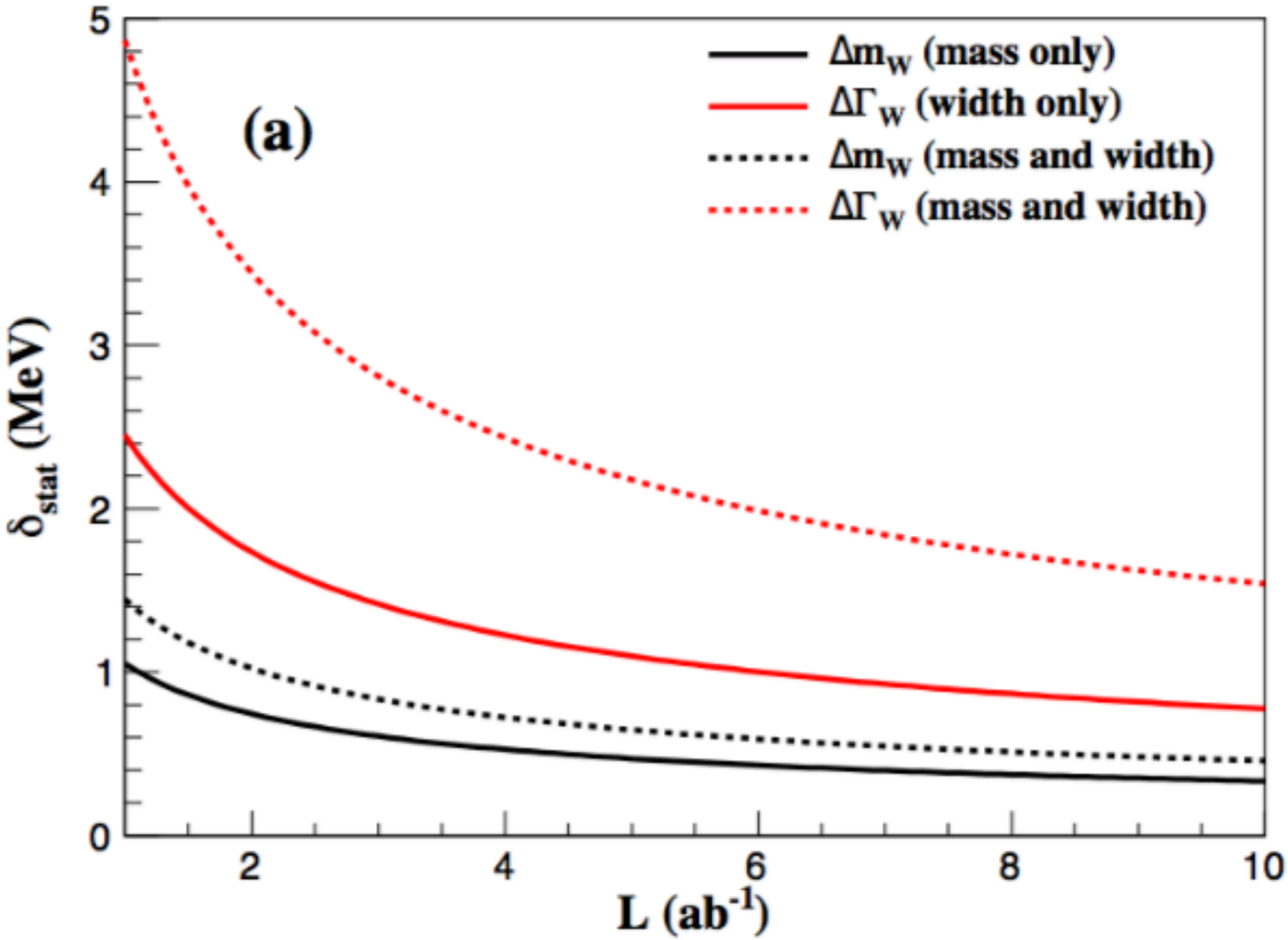
Effect	Systematic error/MeV		
	$\mu^+\mu^-\gamma$	$\tau^+\tau^-\gamma$	$e^+e^-\gamma$
Lepton angular scale	21	66	24
Lepton angular resolution	2	4	7
Fit parameters	1	4	10
Non-resonant background	< 1	6	4
Bhabha/t-channel	< 1	3	5
ISR modelling	1	7	10
Beam energy spread/boost	2	5	6
Total	21	67	30
Monte Carlo statistics	9	34	34
LEP calibration	11	11	11
Full total	25	76	46



Summary

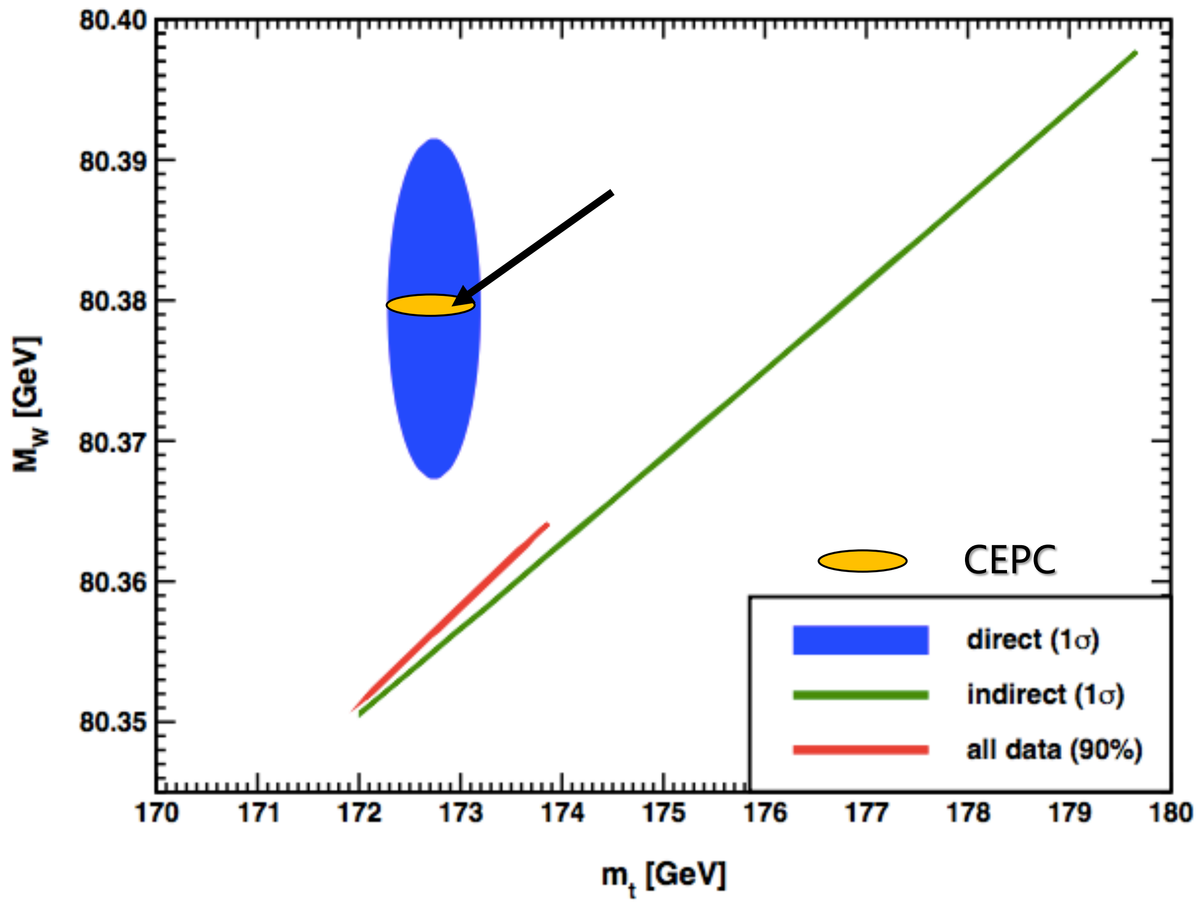
- Precise Beam energy measurement is the key
  - to CEPC Z pole and WW physics
- Three different methods
  - Resonant Depolarization method is more for Z and WW runs (Zhe' s talk)
  - Compton scattering method for WW, ZH and ttbar runs (Yongsheng's talk)
  - Z->μμγ method works for ZH and ttbar runs

Statistics error on W mass Vs Luminosity



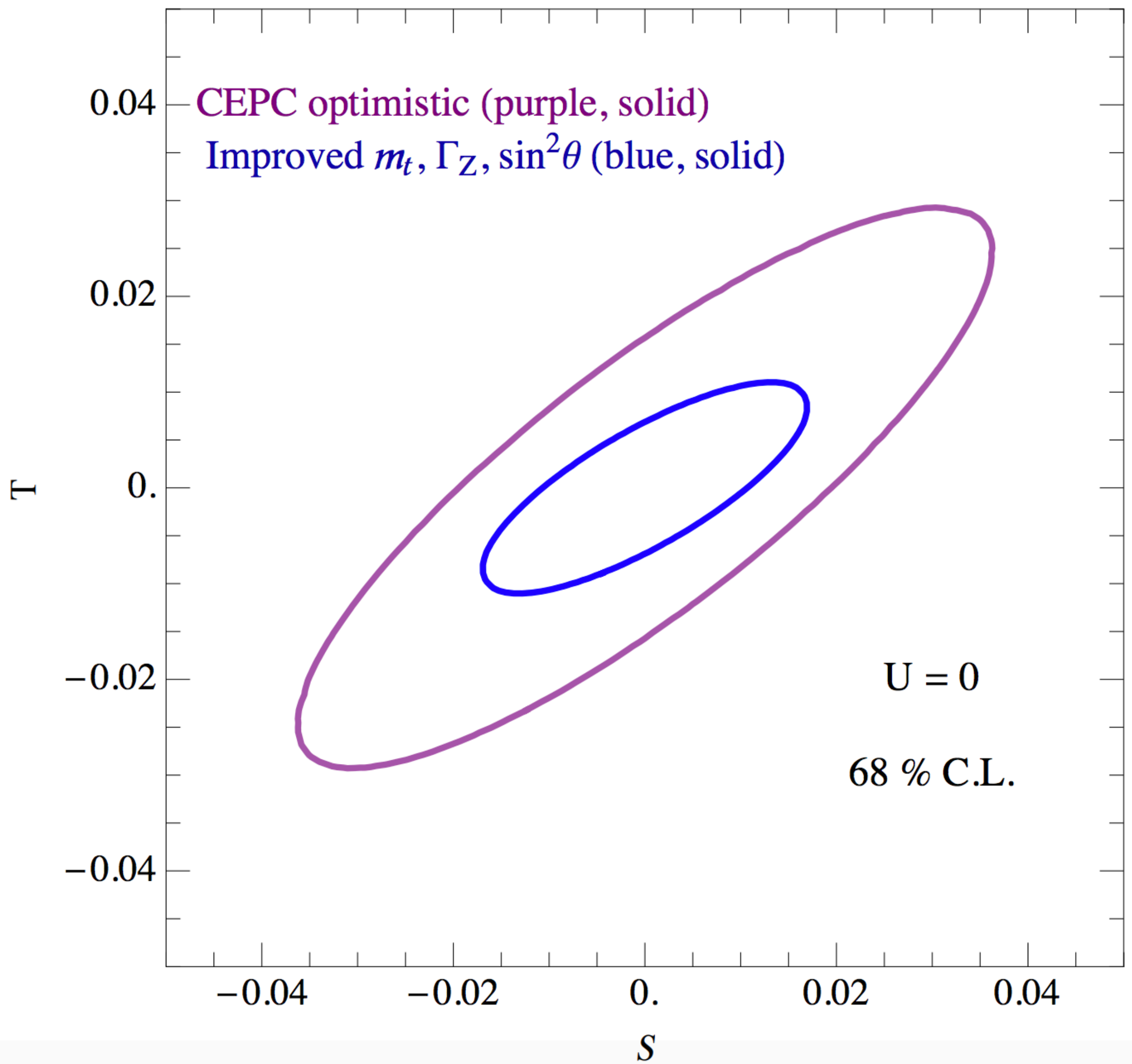
Prospect of CEPC W mass measurement

- CEPC can improve current precision of W mass by one order of magnitude
  - A possible BSM physics can be discovered in the future



Freitas & JE (PDG 2018)

CEPC physics potential

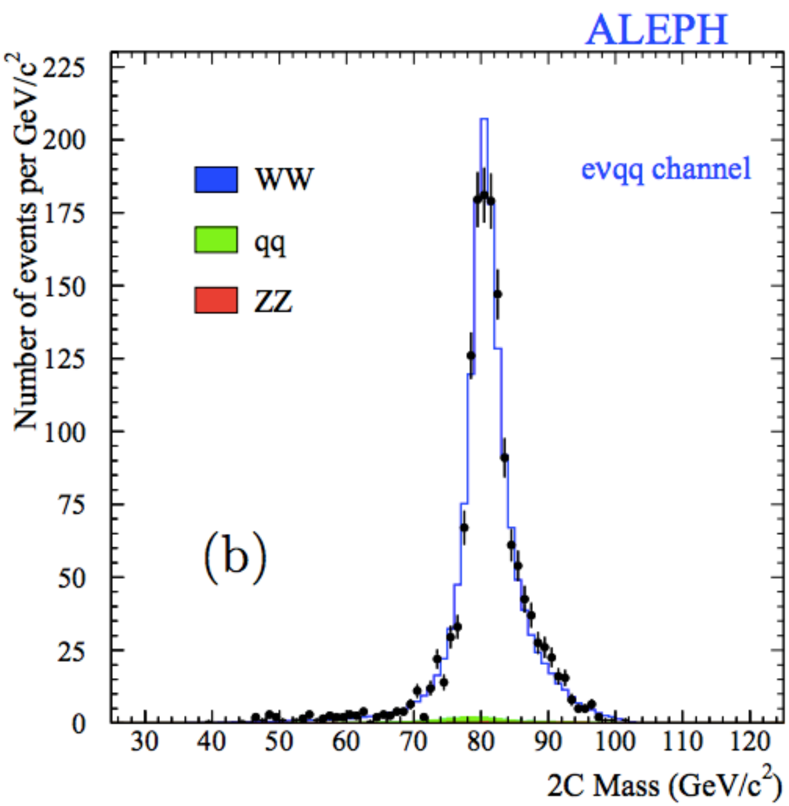


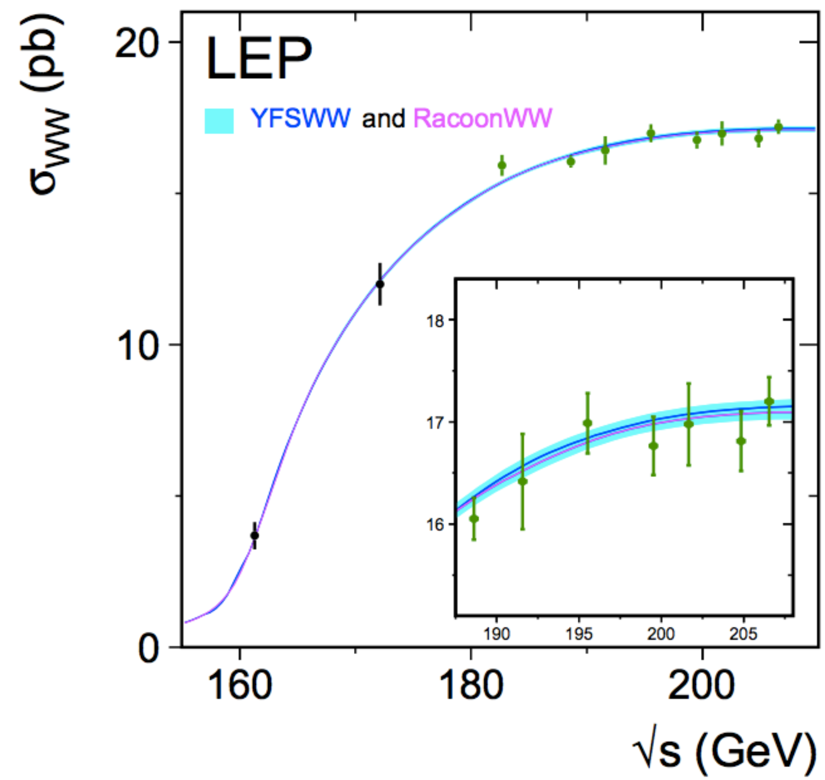
W mass measurement in lepton collider

- 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

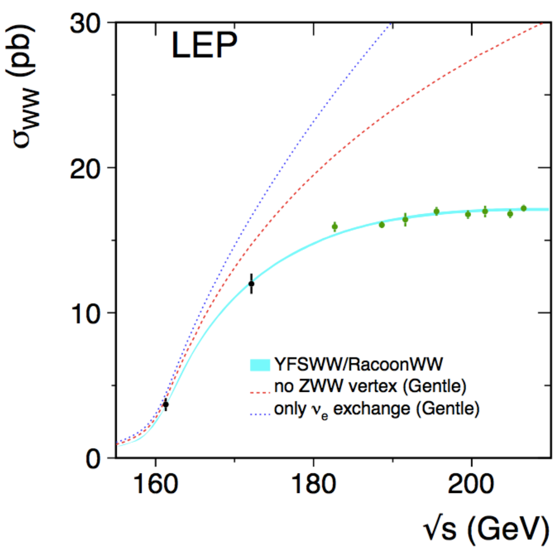




WW threshold scan – CEPC plan

- WW threshold scan running proposal
  - two points scan proposed by Paolo Azzuri (arxiv: 1703.01626v1)
  - 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 of LEP2)

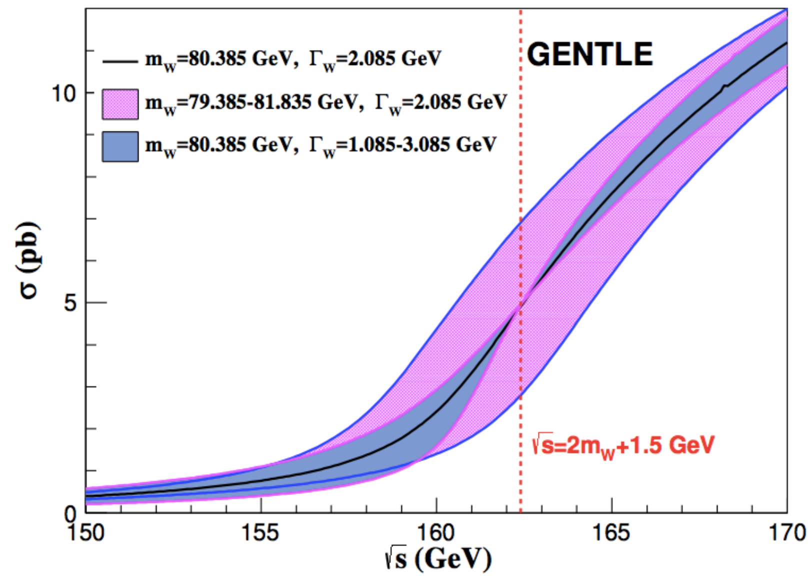
E_{cm} (GeV)	Lumiosity (ab^{-1})	Cross section (pb)	Number of WW pairs (M)
157.5	0.5	1.25	0.6
161.5	0.2	3.89	0.8
162.5	1.3	5.02	6.5
172.0	0.5	12.2	6.1



WW threshold scan-systematics unc.

- Consider the beam spread unc. (EBS),beam energy unc. , signal efficiency, cross section unc. and background
- Expected 1MeV precision in W mass
  - Dominated by statistics uncertainty: 1MeV
  - Leading syst. (0.5MeV): beam energy syst.
- Working with Paolo Azzuri and Maarten Boonekamp for systematics study
- Plan to have a joint CEPC-Fcc(ee) paper on WW threshold scan.

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



By Peixun

Backward-forward asymmetry in Z->μμ

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

- LEP measurement : 1.69% +-0.13% (PDG fit)
- CEPC has potential to improve it by a factor of 20~30 .
  - muon angular resolution(~0.1%)
  - Acceptance in forward region
- Full simulation studies to understand muon angular resolution
  - Muon angular resolution can reach 1e^{-5} level (by full sim)
  - Potential benchmark channel
    - TPC challenges in Z pole , forward region design in TDR

CEPC: specific challenges

TPC challenges

"Several challenges are identified, where more work is needed towards a TDR."

(2) "The Z-pole run, with a lower magnetic field and high event rate, represents a challenge for the tracker design and requires a detailed strategy for the data acquisition and processing capacity of the experiment."

Large ion clouds drift through the Time Projection Chamber; gating is impossible
M. Stanitzki: I doubt that a TPC will work at all

Z-events production rate is 30 kHz; need to be acquired, processed and stored
M.V.: the CDR v2.0 does not present this strategy

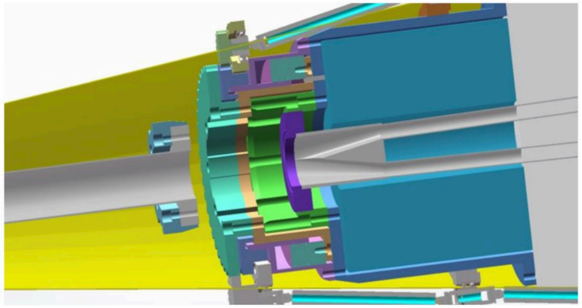
In Marcel 'talk

CEPC: specific challenges

Forward region challenges

"Several challenges are identified, where more work is needed towards a TDR"

(1) "The design of the forward region is highly conditioned by the presence of the focussing magnets and their compensating coils, while the requirements on mechanical alignment and stability are an order of magnitude more stringent than in previous experiments."



LumiCal weighs over 400 kg, sits on a structure that extends more than 1 m into the tracker, and must be aligned to better than 1 μm

Prospect of CEPC EWK physics

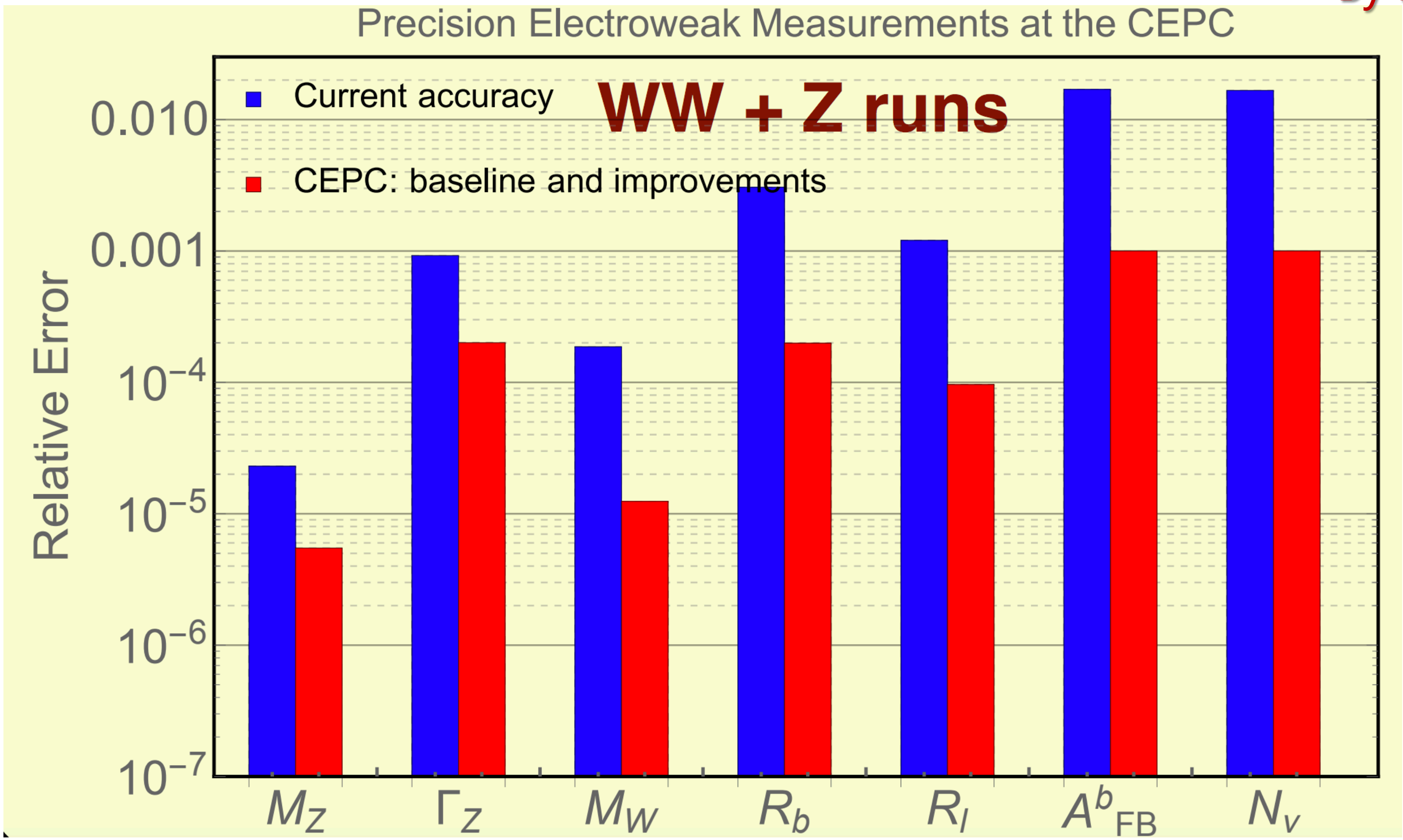
- Expect to have 1~2 order of magnitude better than current precision

Observable	LEP precision	CEPC precision	CEPC runs	CEPC $\int \mathcal{L}dt$
m_Z	2.1 MeV	0.5 MeV	Z pole	8 ab^{-1}
Γ_Z	2.3 MeV	0.5 MeV	Z pole	8 ab^{-1}
$A_{FB}^{0,b}$	0.0016	0.0001	Z pole	8 ab^{-1}
$A_{FB}^{0,\mu}$	0.0013	0.00005	Z pole	8 ab^{-1}
$A_{FB}^{0,e}$	0.0025	0.00008	Z pole	8 ab^{-1}
$\sin^2\theta_W^{\mathrm{eff}}$	0.00016	0.00001	Z pole	8 ab^{-1}
R_b^0	0.00066	0.00004	Z pole	8 ab^{-1}
R_μ^0	0.025	0.002	Z pole	8 ab^{-1}
m_W	33 MeV	1 MeV	WW threshold	2.6 ab^{-1}
m_W	33 MeV	2–3 MeV	ZH run	5.6 ab^{-1}
N_ν	1.7%	0.05%	ZH run	5.6 ab^{-1}

Prospect of CEPC EWK physics

- Expect to have 1~2 order of magnitude better than current precision

By Liantao



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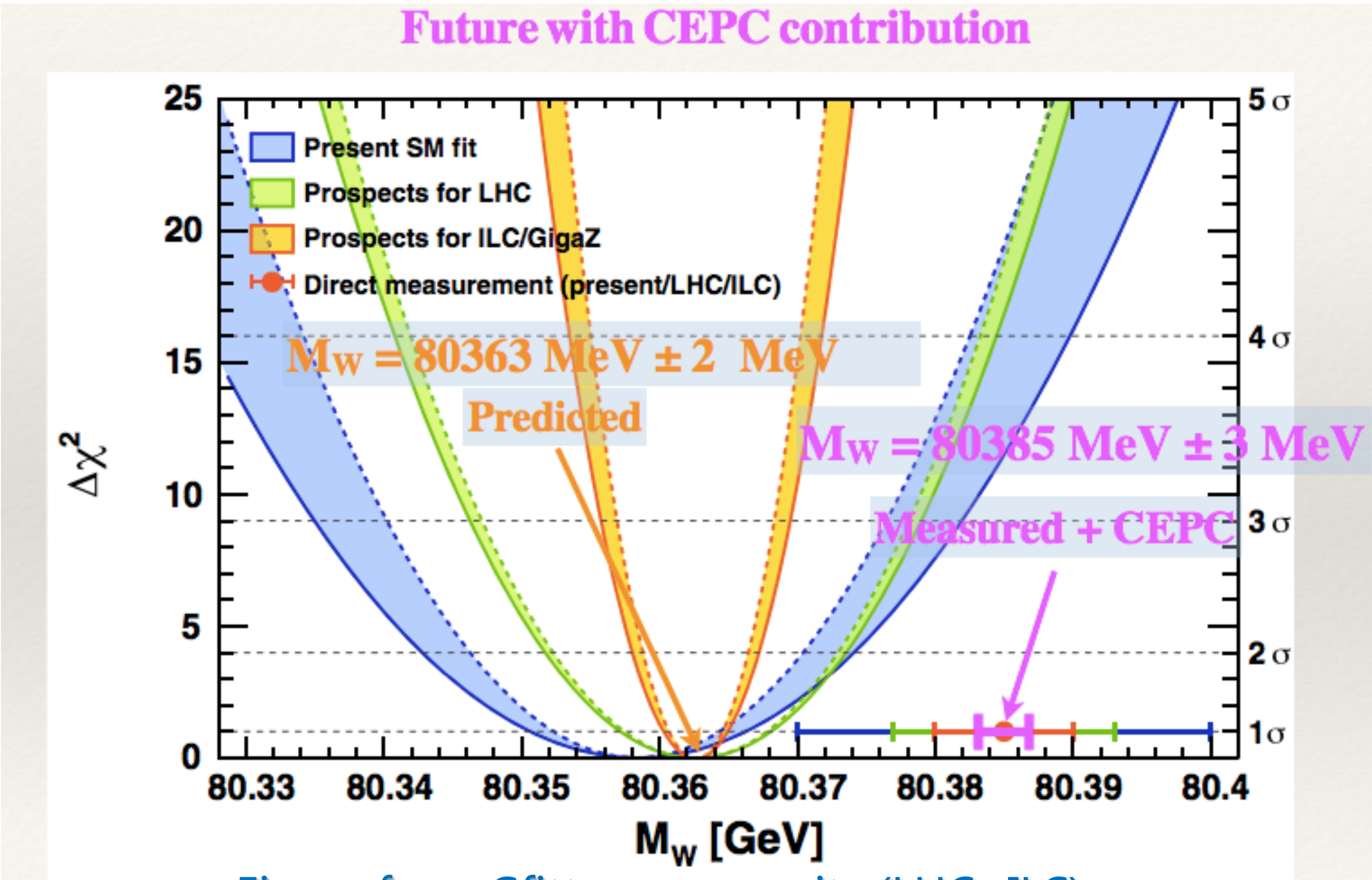
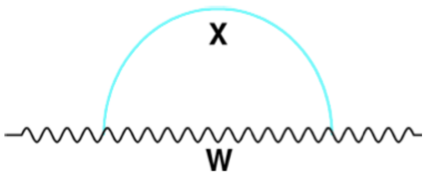
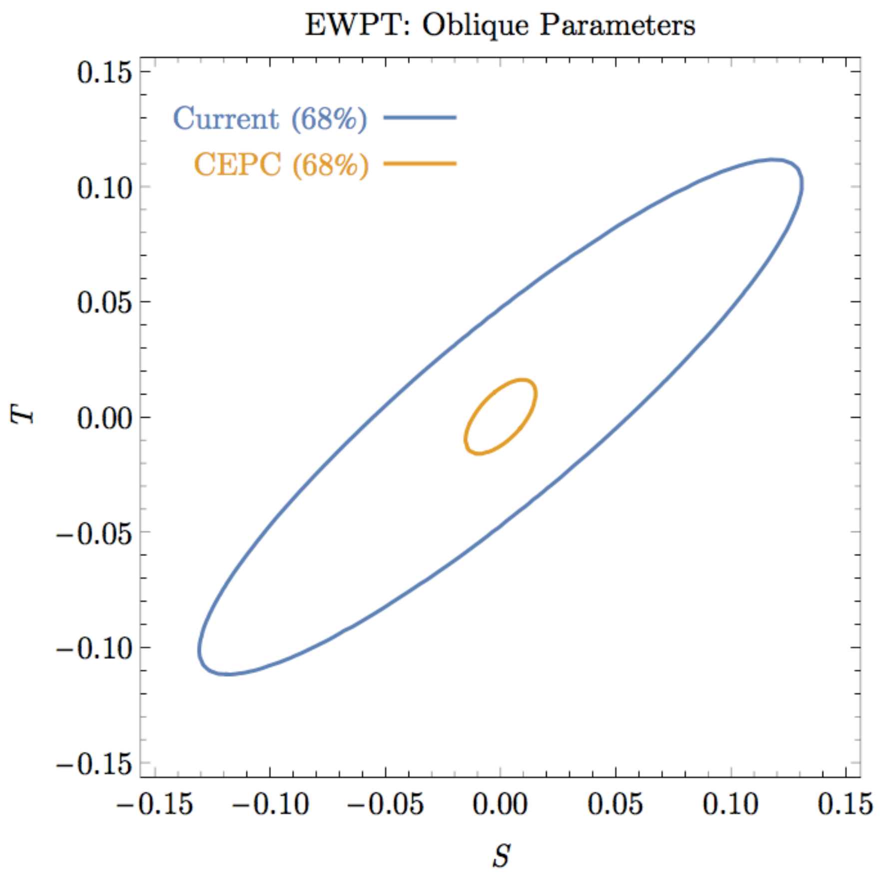


Figure from Gfitter community (LHC+ILC)

Constraint to new physics

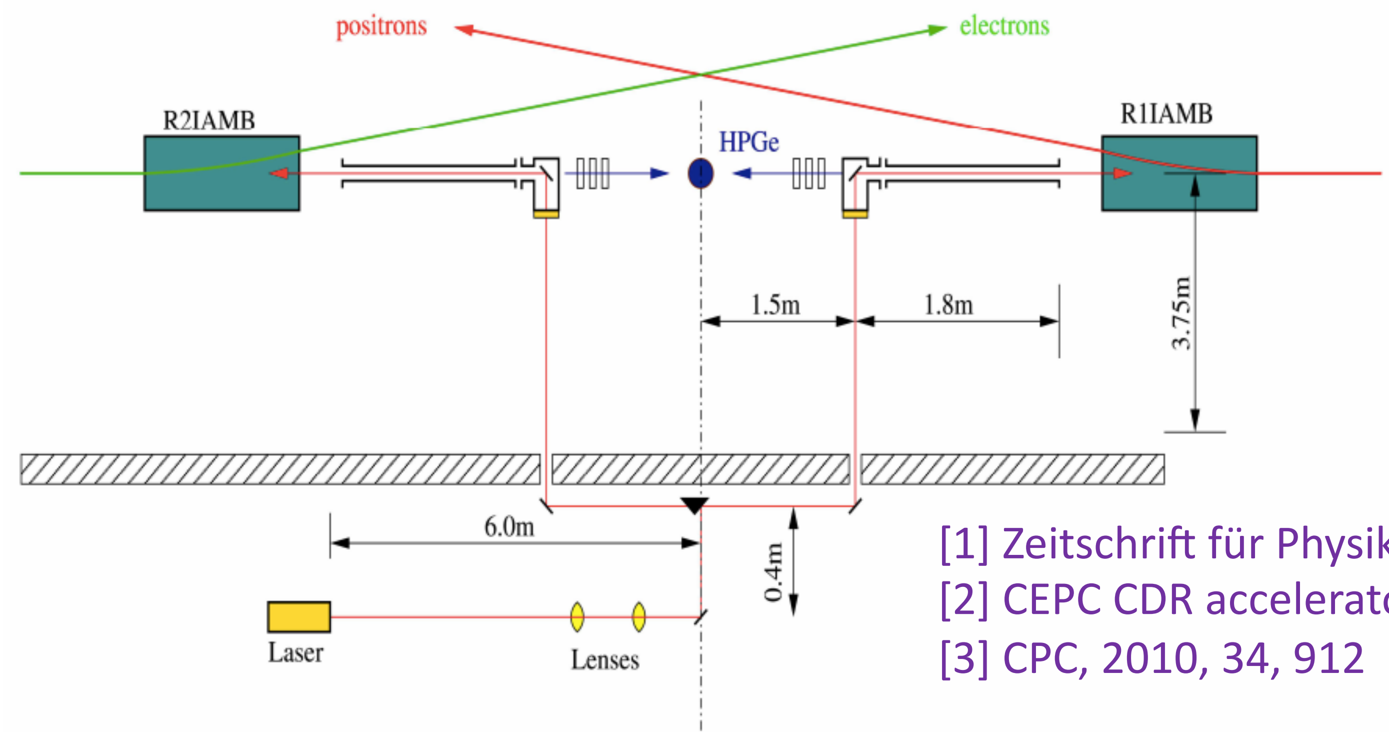
- Oblique parameter S,T,U : corrections to gauge-boson self-energies
  - S and T (U) correspond to dimension 6 (8) operators
- Constraint to Oblique parameter from CEPC EWK measurements will be about one order of magnitude better than current constraint.





Z mass measurement（2）

- Syst uncertainty: ~0.5 MeV
  - Beam energy uncertainty is major systematics
    - Resonant depolarization approach by LEP [1] → <0.5MeV
    - Compton backscattering [2] → 2~5 MeV
    - Radiation return , Z(μμ)γ events → 2~5MeV



[1] Zeitschrift für Physik C (1995) 45–62.
[2] CEPC CDR accelerator (volume I)
[3] CPC, 2010, 34, 912