Precision measurements: sensitivity to new physics scenarios

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IF-UNAM

Workshop on

Physics Behind Precision

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Introduction

Motivation to look for physics beyond the SM
☛ talk by *Paul Langacker*

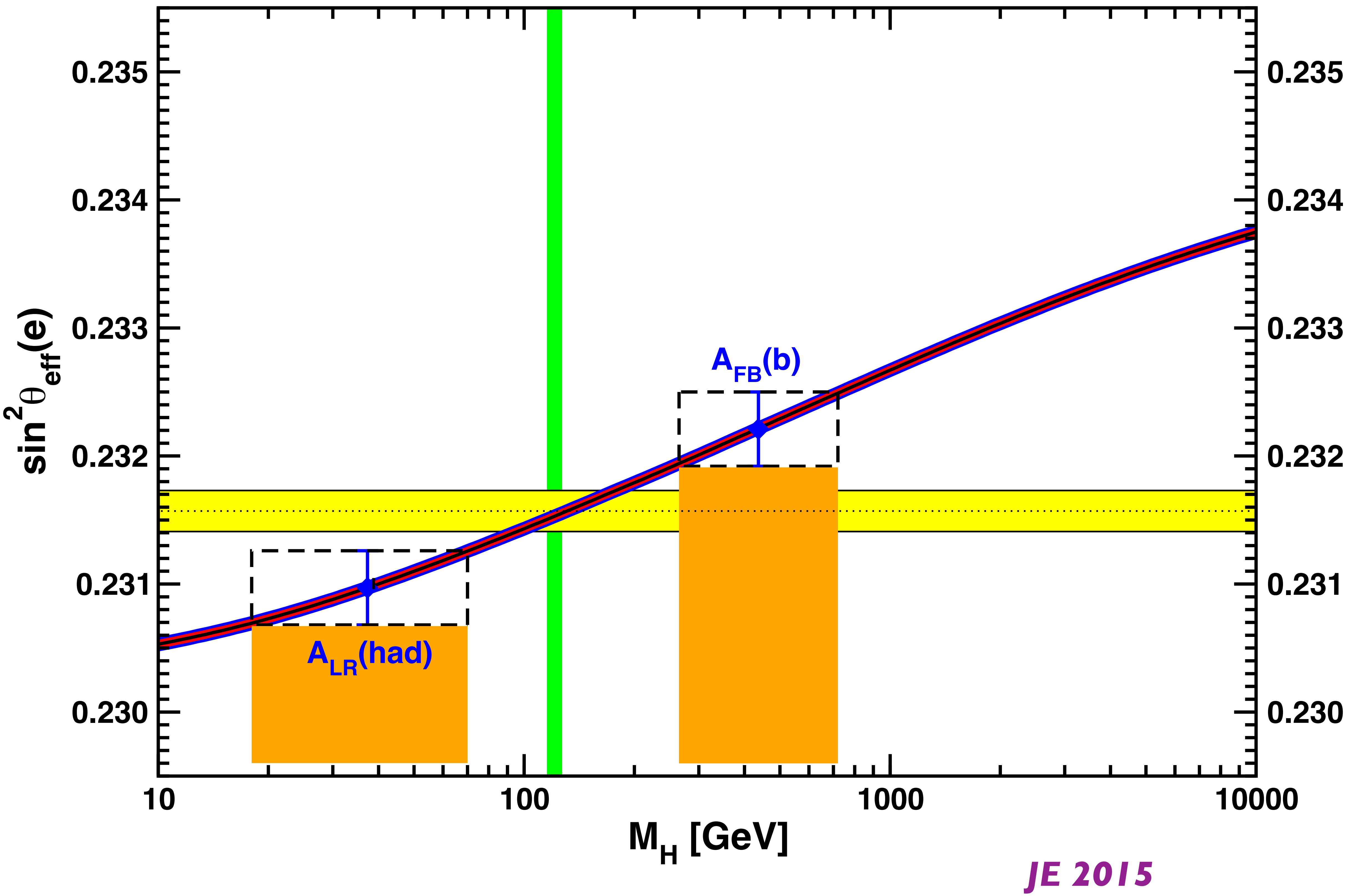
In this talk, I will assume the very optimistic case, where the theory uncertainties from unknown higher orders will <u>not</u> be dominant. Progress has been steady in the past.

Example: leading m_t^2 corrections to ρ-paramter

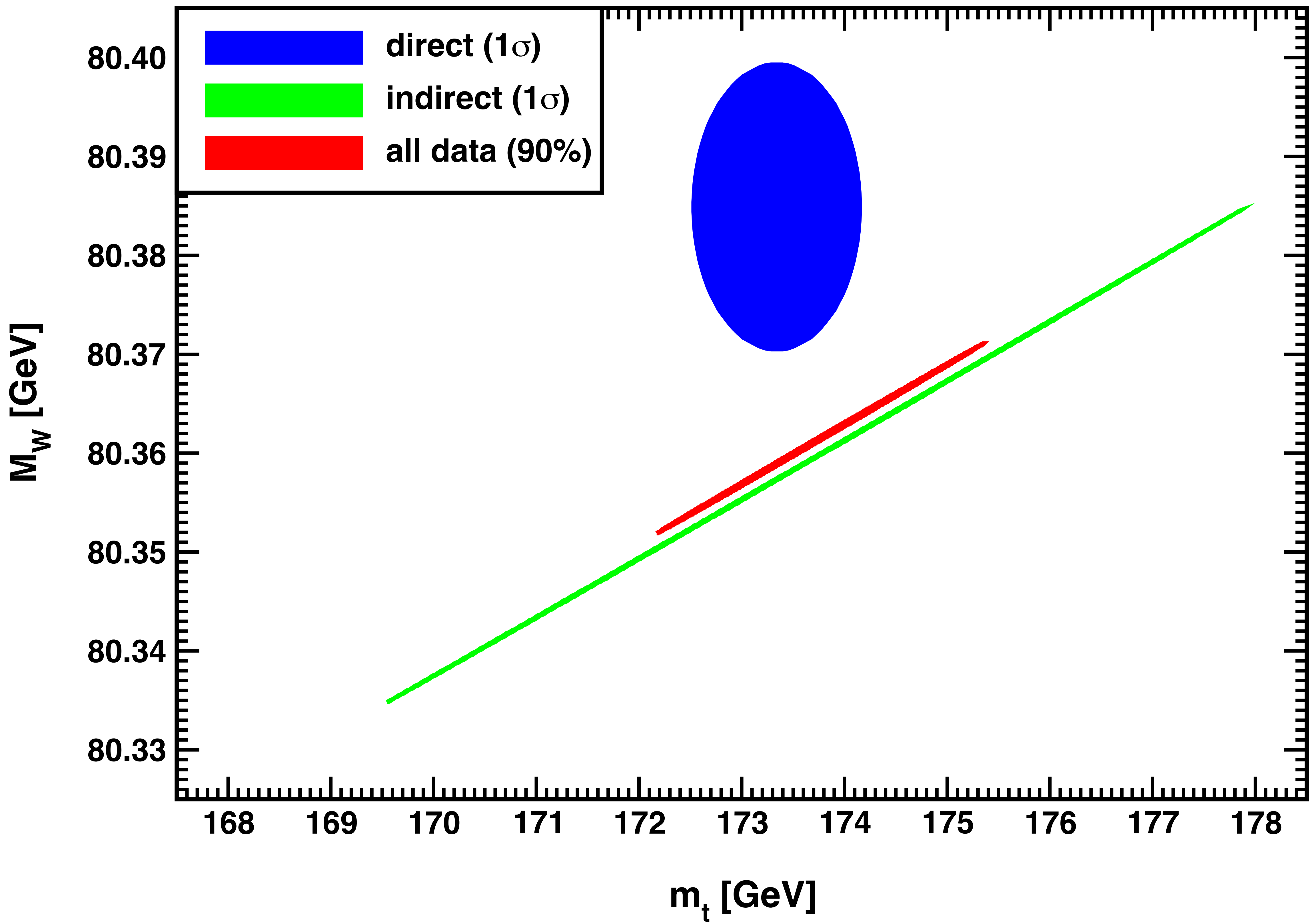
1-loop ***Veltman 1977***

2-loop (M_H = 0) ***van der Bij, Veltman 1984***
M_H arbitrary ***Barbieri et al. 1992, Fleischer, Tarasov, Jegerlehner 1993***

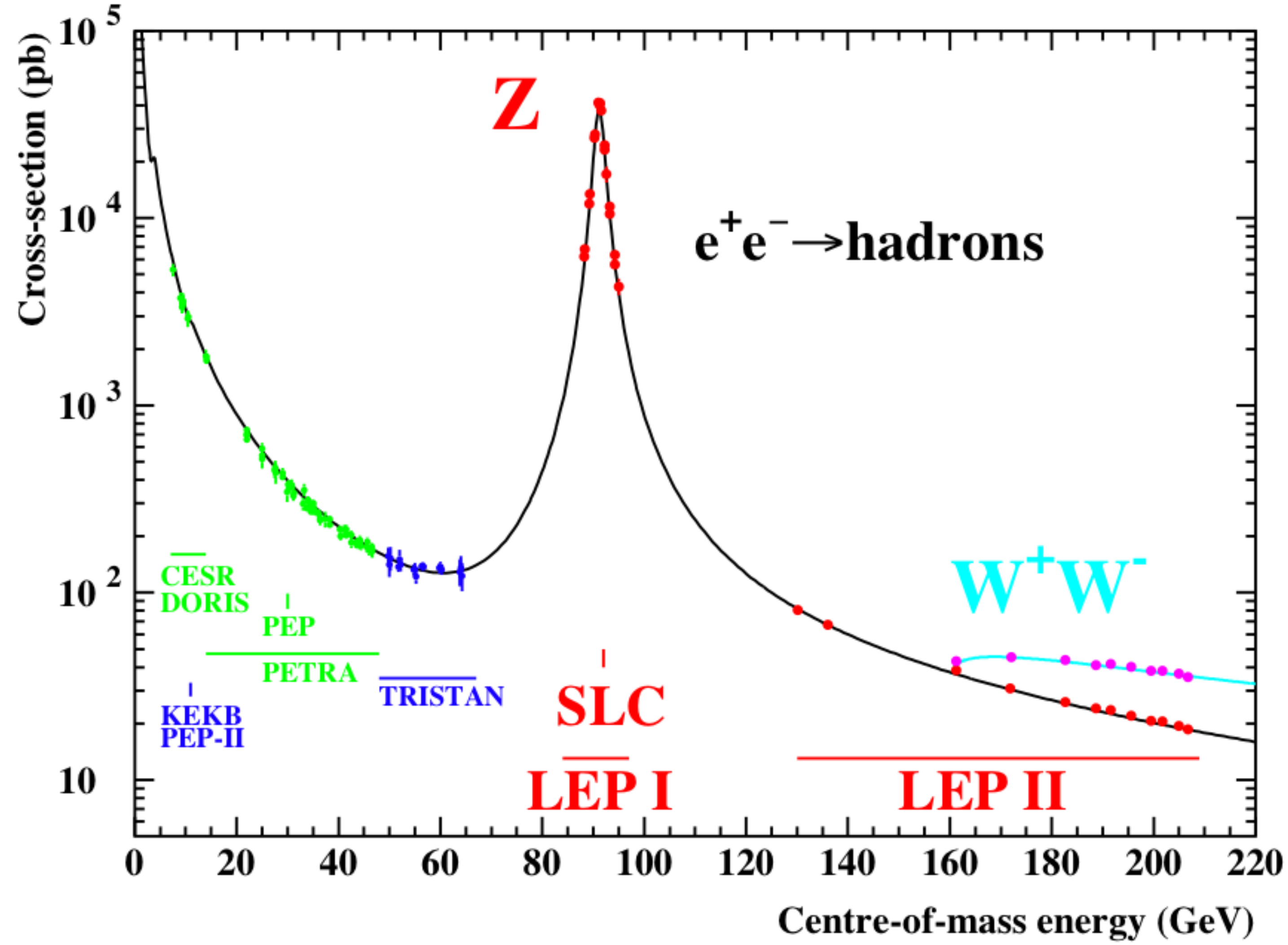
3-loop ($M_H \to \infty$) ***Boughezal, Tausk, van der Bij 2004***



0.235
0.234
0.233
0.232
0.231
0.230
$\sin^2\theta_{eff}(e)$
$A_{FB}(b)$
$A_{LR}(had)$
10
100
1000
10000
M_H [GeV]
JE 2015


direct (1σ)
indirect (1σ)
all data (90%)
80.40
80.39
80.38
80.37
80.36
80.35
80.34
80.33
M_W [GeV]
168
169
170
171
172
173
174
175
176
177
178
m_t [GeV]

Key EW observables



M_Z ± 2.1 MeV ➨ < 100 keV

Γ_Z ± 2.3 MeV ➨ < 100 keV

R_μ ± 0.025 ➨ < 0.001

R_b ± 0.00066 ➨ < 6×10^{-5}

m_t ± 810 MeV (incl. QCD) ➨ ± 15 MeV

σ_{had} ± 37 pb ➨ ± 4 pb (assumes 0.01% luminosity error)

A_{LR} ± 0.0022 ➨ ± 2×10^{-5} (needs 3-loop EW to be useful, 4-loop to match exp.)

A_{LR}^{FB}(b) ± 0.020 ➨ ± 0.001 (using similar b-tagging improvements as for R_b)

M_W ± 33 MeV (LEP); ± 16 MeV (Tevatron) ➨ ± 0.6 MeV ☛ talk by *Graham Wilson*

Γ_W ± 42 MeV ☛ talk by *Paolo Azzurri* (1st + 2nd row CKM unitarity test)

α_S

source	α	uncertainty	FCC
Z decays	0.1203	0.0028	0.00012
W decays	0.117	0.043	0.00018
τ decays	0.1174	+0.0019	
deep inelastic scattering	0.1156	0.0023	0.00018
jet-event shapes in e	0.1169	0.0034	< 0.001
lattice	0.1187	0.0012	
world average	0.1181	0.0013	0.00009

top threshold scan
precision gauge coupling unification

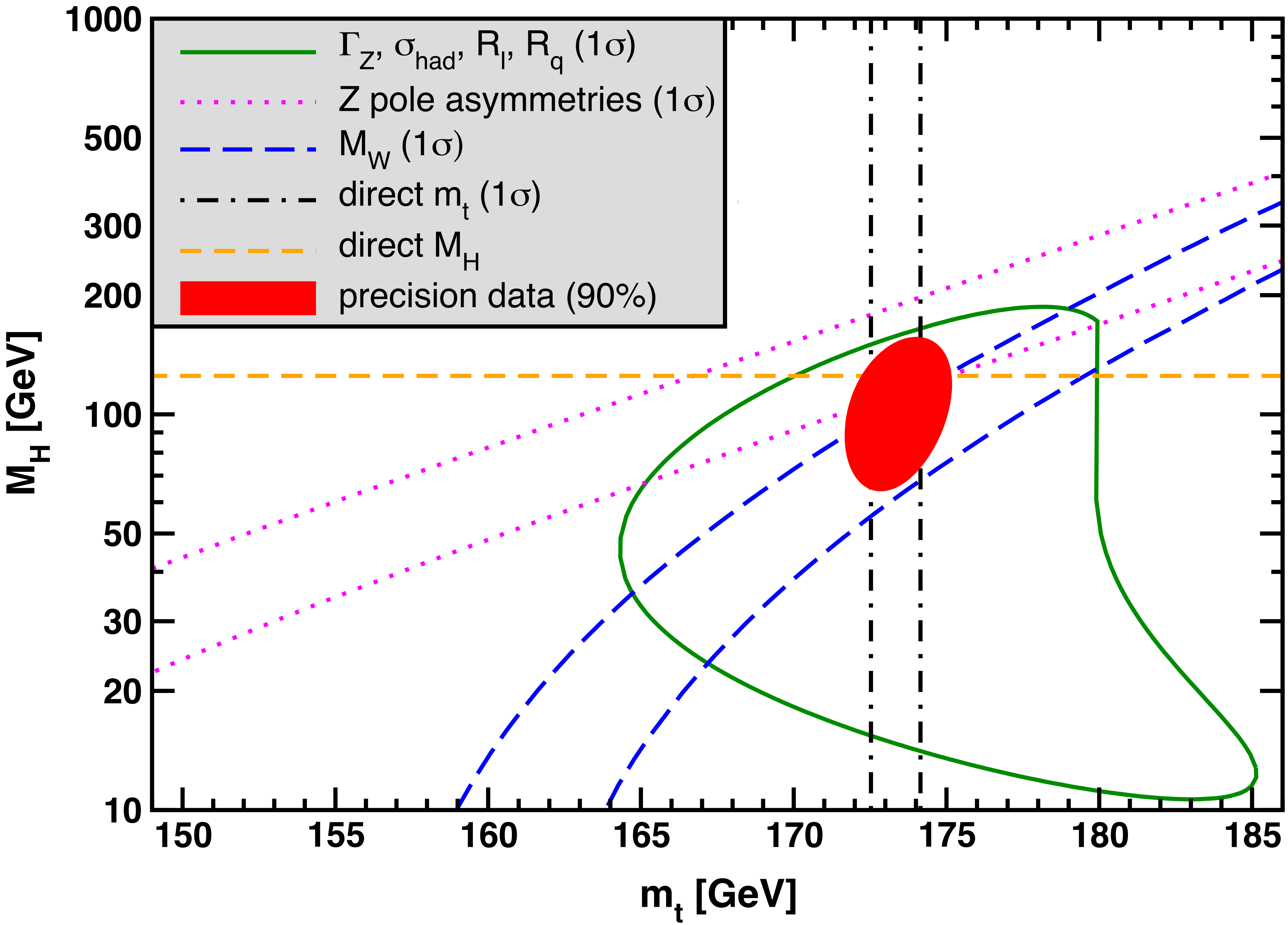
Bethke, Dissertori, Salam 2015
JE, Ayres 2015
PDG 2016

Number of active neutrinos

currently: $N_\nu = 2.992 \pm 0.007$

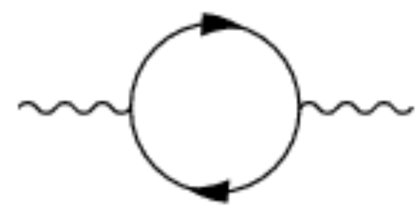
FCC-ee @ 91 GeV:
N_ν can be constrained to within $\pm$ 0.0006

FCC-ee @ 161 GeV:
the Zγ final state would provide an additional constraint on N_ν of better than $\pm$ 0.0015



Γ_Z, σ_{had}, R_l, R_q (1σ)
Z pole asymmetries (1σ)
M_W (1σ)
direct m_t (1σ)
direct M_H
precision data (90%)
1000
500
300
200
100
50
30
20
10
150
155
160
165
170
175
180
185
M_H [GeV]
m_t [GeV]

Vacuum Polarization



$g_\mu - 2$

Δr

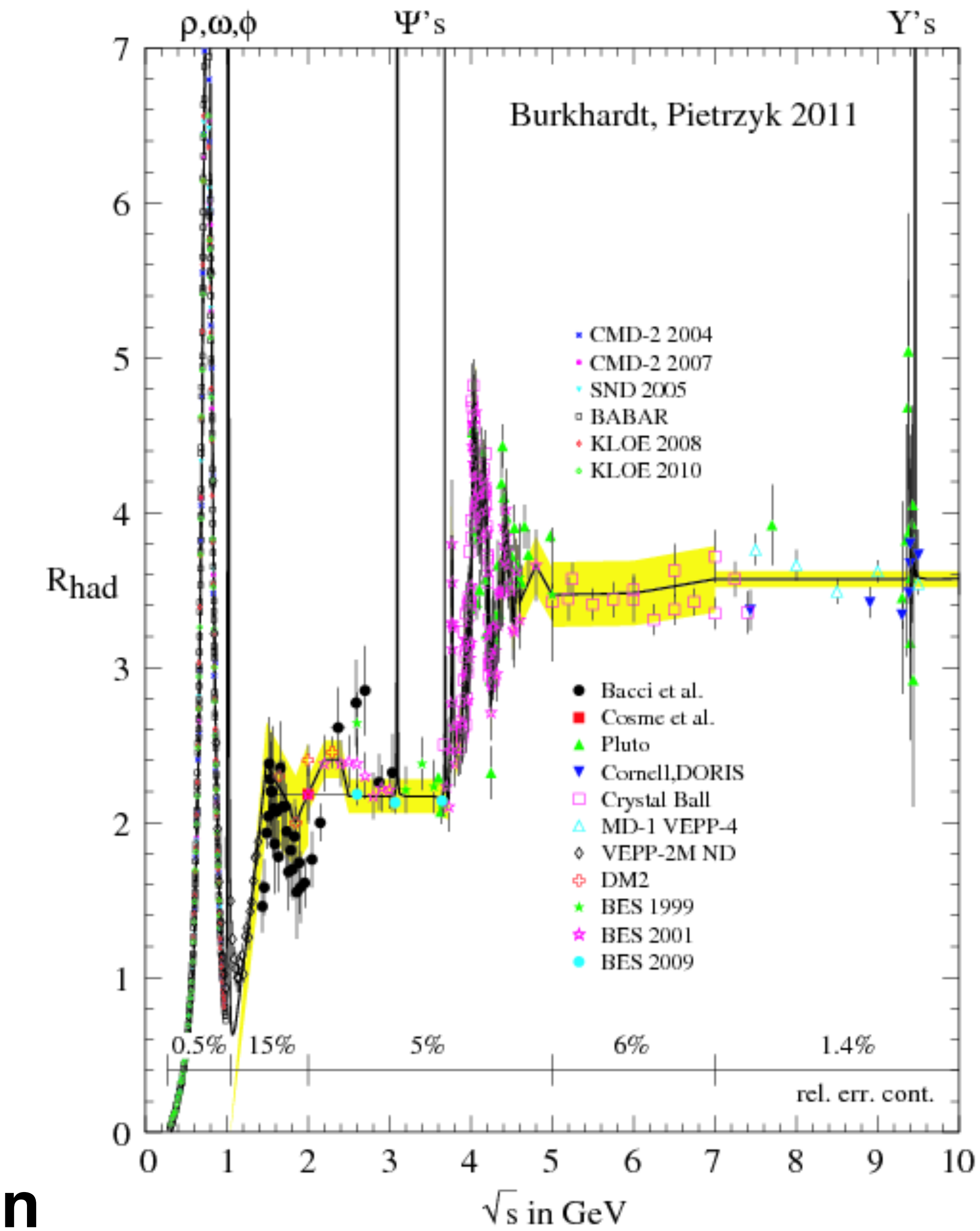
$\sin^2\theta_W(0)$

σ_{had} (if luminosity is determined through Bhabba scattering)

strong correlation — can be advantage in

assume $\Delta\alpha_{had}$ to 1.8×10^{-5} (from $\sigma_{\mu\mu}$ and $A^{FB}_{\mu\mu}$)
☛ talks by Fred Jegerlehner and Patrick Janot

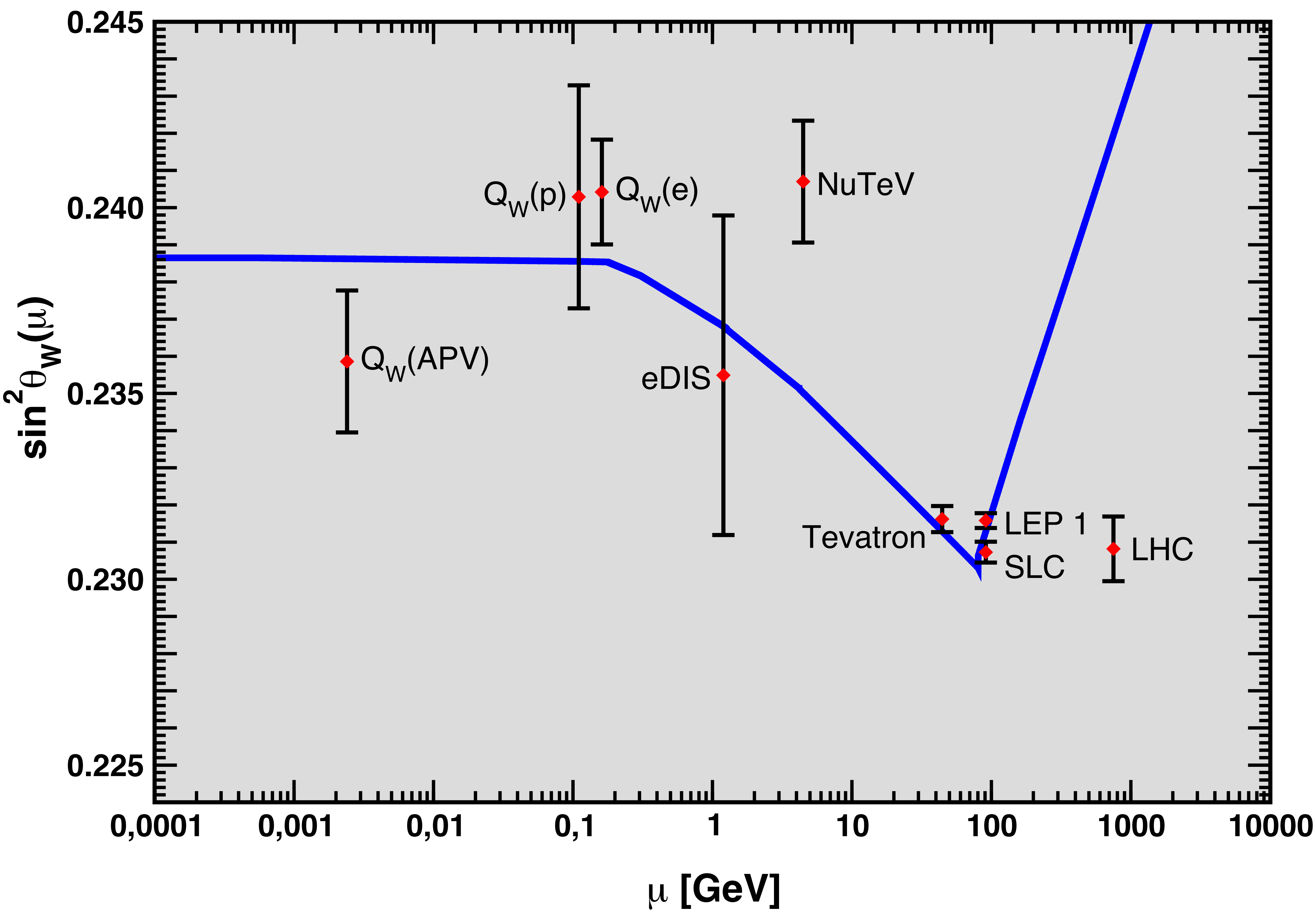
and $m_b = \pm$ 9 MeV, $m_c = \pm$ 8 MeV from Higgs BRs @ FCC-ee



M_H

source	M	uncertainty	FCC-ee
radiative corrections	96	$^{+22}$	1.3
Higgs branching ratios	126.1	1.9	
direct	125.09	0.24	0.007
global fit	125.11	0.24	0.007

JE, Ayres 2015
PDG 2016



0.245
0.240
0.235
0.230
0.225
$\sin^2\theta_W(\mu)$
$Q_W(p)$
$Q_W(e)$
NuTeV
$Q_W(APV)$
eDIS
Tevatron
LEP 1
SLC
LHC
0,0001
0,001
0,01
0,1
1
10
100
1000
10000
μ [GeV]

Complementarity: Need EW precision measurements on and off the Z pole

on pole:

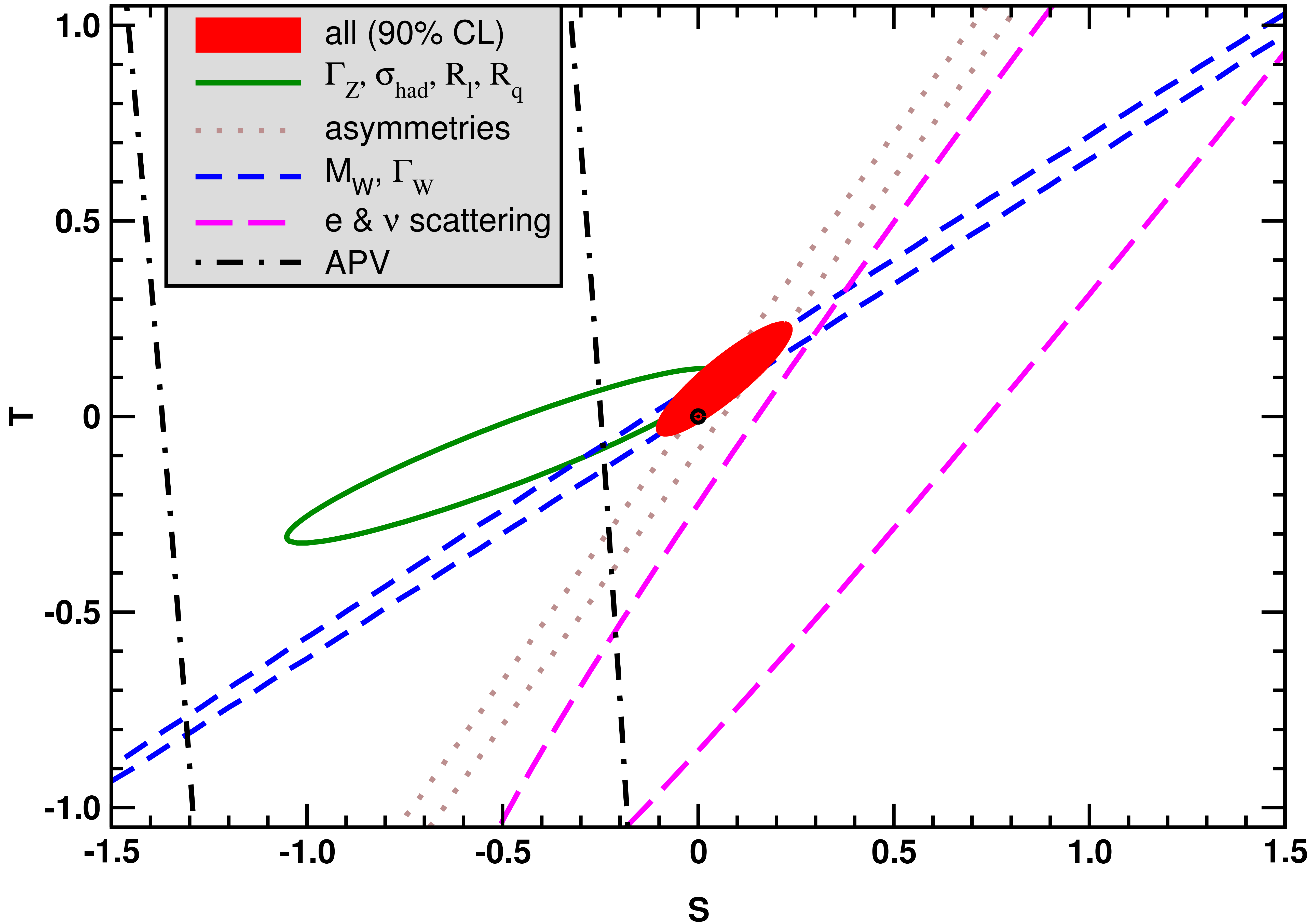
$\sin^2\theta_W$
STU
RPC SUSY
ZZ′

below pole (interference amplitude):

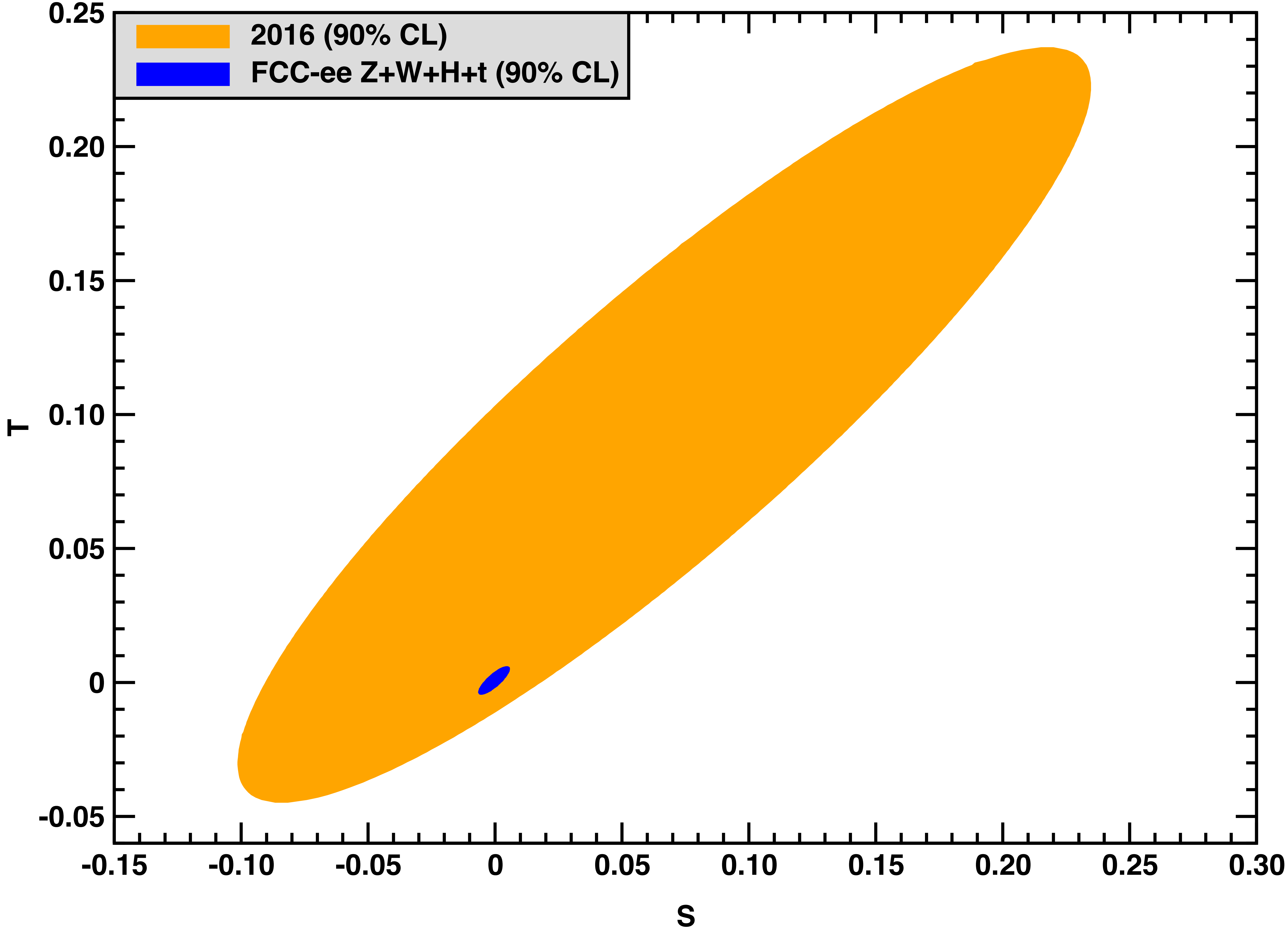
running $\sin^2\theta_W$ (“dark Z”)
X parameter
RPV SUSY
vvee, vvuu, vvdd 4-Fermi operators
parity-violating eeee, eeuu, eedd 4-Fermi operators

above pole:

eeff operators
incl. 2nd/3rd generation f and parity-conserving



all (90% CL)
Γ_Z, σ_{had}, R_l, R_q
asymmetries
M_W, Γ_W
e & ν scattering
APV
T
S
1.0
0.5
0
-0.5
-1.0
-1.5
-1.0
-0.5
0
0.5
1.0
1.5



2016 (90% CL)
FCC-ee Z+W+H+t (90% CL)
0.25
0.20
0.15
0.10
0.05
0
-0.05
T
-0.15
-0.10
-0.05
0
0.05
0.10
0.15
0.20
0.25
0.30
S

STU

	current	FCC-ee
S	± 0.099	± 0.005
T	± 0.116	± 0.007
U	± 0.095	± 0.005
S	± 0.078	± 0.003
T	± 0.066	± 0.003
T	± 0.030	± 0.002

Implications of T (ρ_0) parameter

ρ_0 would constrain VEVs of higher dimensional Higgs representations to ≲ 1 GeV

Sensitivity to degenerate scalar EW doublets up to 2 TeV (using results based on EFT approach *Henning, Lu, Murayama 2014*)

Non-degenerate multiplets of heavy fermions or scalars ☛

Non-degenerate multiplets of heavy fermions or scalars

$\Delta\rho_0 = G_F \Sigma_i C_i / (8 \sqrt{2} \pi^2) \Delta m_i^2$ [$\Delta m_i^2 \geq (m_1 - m_2)^2$]

despite appearance <u>there is</u> decoupling
(see-saw type suppression of Δm_i^2)

currently: $\Sigma_i C_i / 3 \Delta m_i^2 \leq (49 \text{ GeV})^2$

assuming no SM deviation ($\rho_0 = 1 \pm 0.000012$) $\Longrightarrow$
FCC-ee: $\Sigma_i C_i / 3 \Delta m_i^2 \leq (8 \text{ GeV})^2$

assuming central value unchanged from today
($\rho_0 = 1.00037 \pm 0.000012$) $\Longrightarrow$
FCC-ee: $\Sigma_i C_i / 3 \Delta m_i^2 = (34 \pm 1 \text{ GeV})^2$

Other oblique parameters

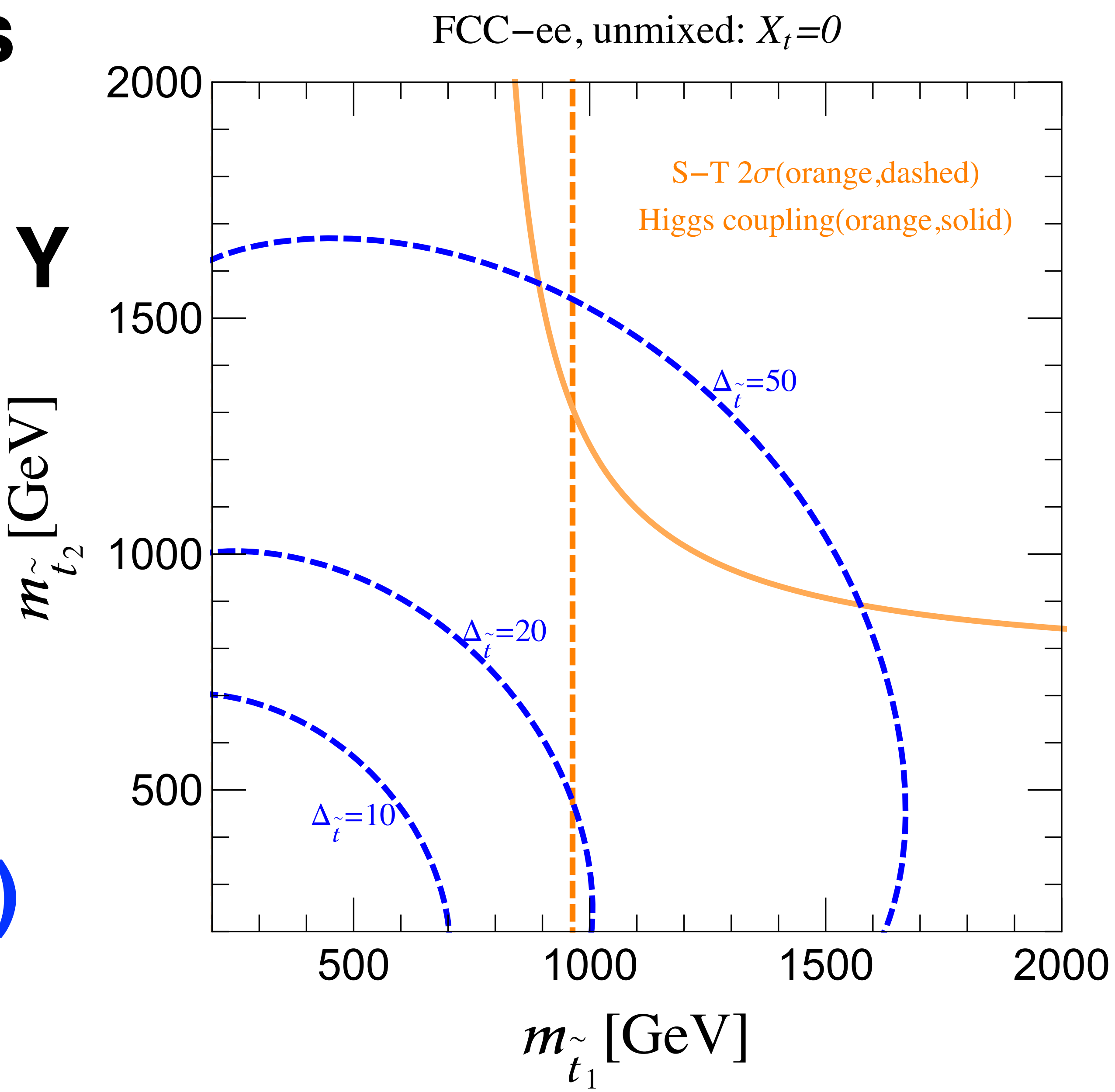
At dimension 6 and at first order in the new physics $\Longrightarrow$ 4 bosonic operators.

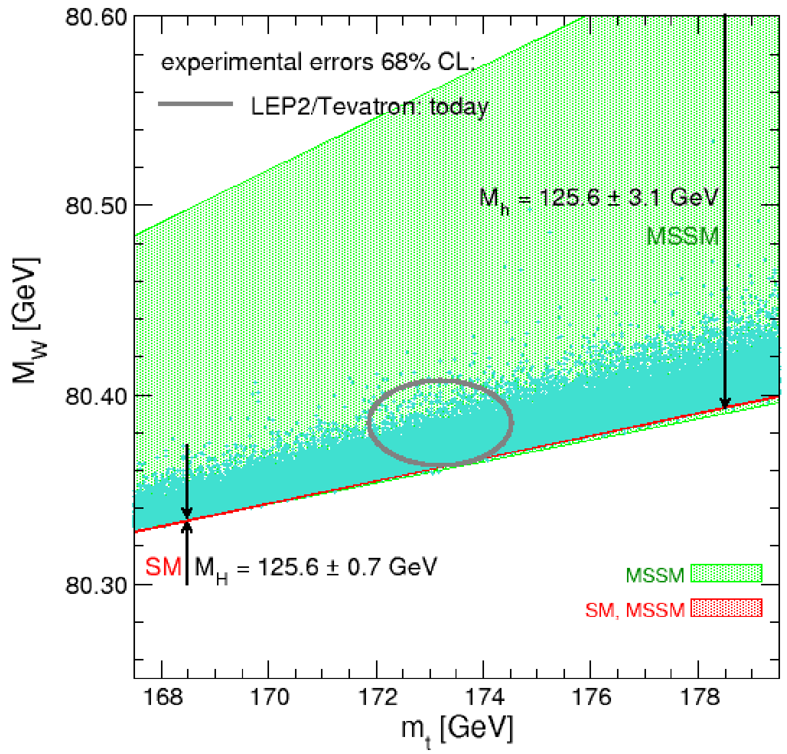
Can be mapped onto S, T, W, Y

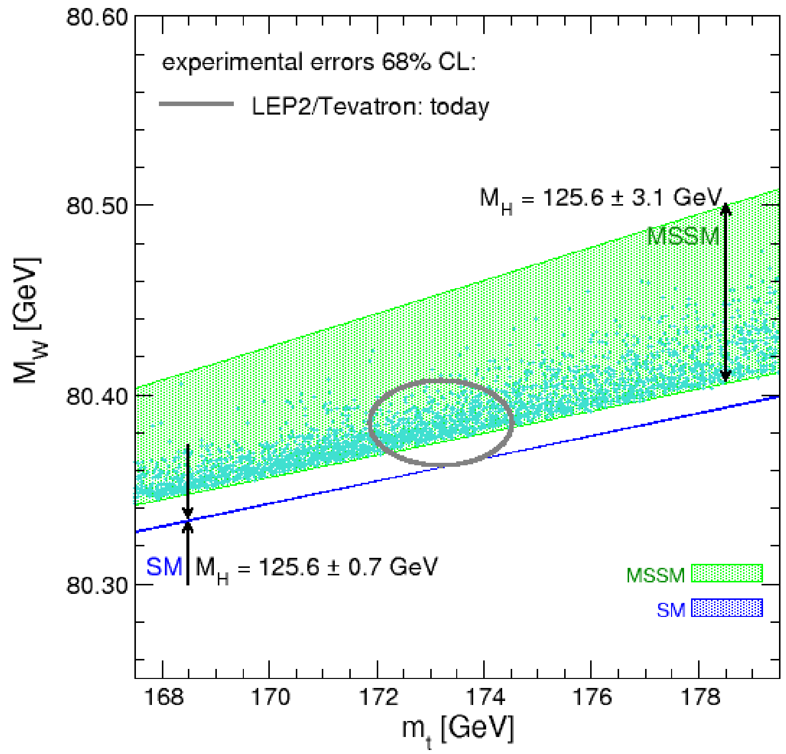
Henning, Lu, Murayama 2014
Fan, Reece, Wang 2014

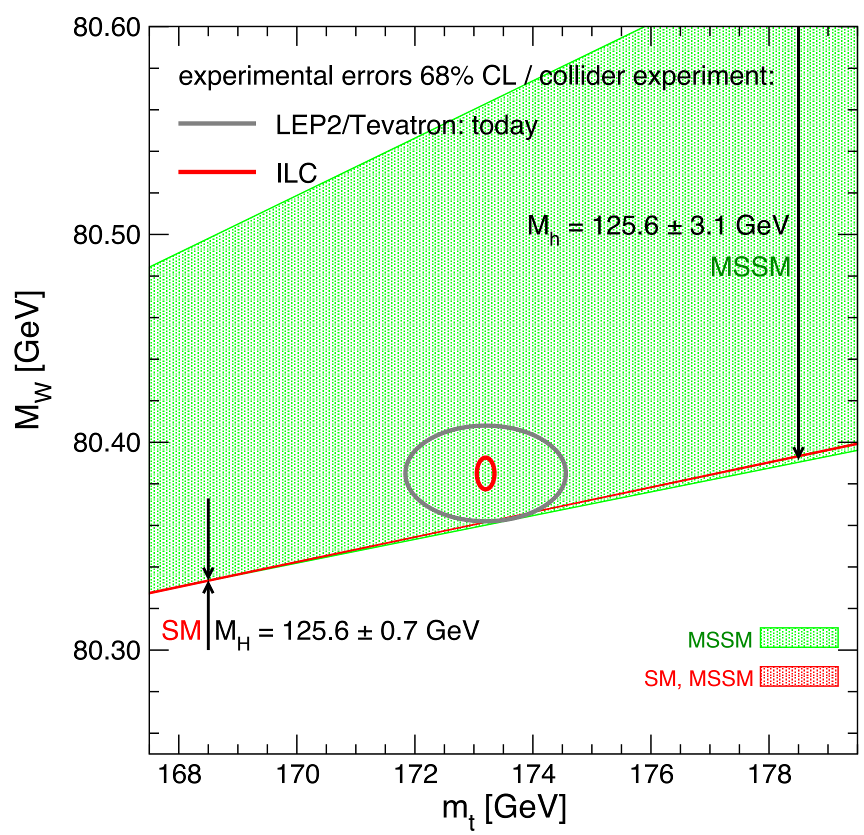
E.g., a stop doublet of degenerate soft mass M contributes

$$S \sim -\, m_t^2 / (6\pi M^2) + O(M^{-4})$$









Heinemeyer, Hollik, Weiglein, Zeune 2013

Non-oblique parameters

long-standing deviation in $A_{FB}(b)$ from LEP 1

currently:

ρ_b = 0.056 ± 0.020

κ_b = 0.182 ± 0.068 (2.7 σ)

difficult to explain without affecting / tuning R_b

FCC-ee: ρ_b ± 0.002 and κ_b ± 0.007

or better when including $A_{FB}(b)$ in addition to $A_{FB}^{LR}(b)$

These results are virtually independent of STU (fixed or floating)

Conclusions

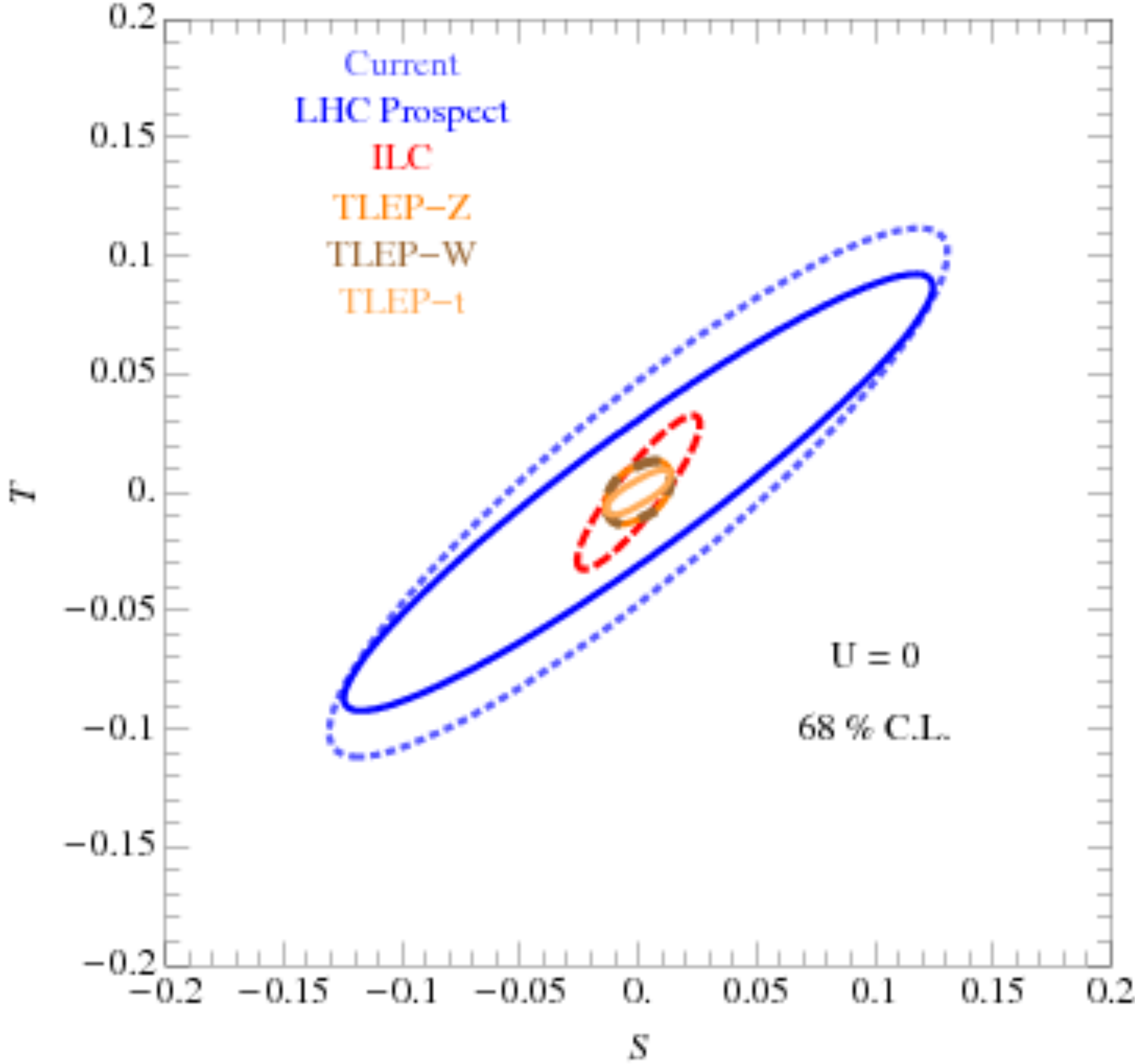
Unprecedented precision possible at FCC-ee — *assuming <u>major</u> advancements in higher order perturbative calculations to keep the theory uncertainties <u>below</u> the experimental ones.*

Many results may even be included after the end of the FCC-ee.

E.g., the T parameter is sensitive to new physics with O(1) couplings up to

$$\Lambda \sim v / \sqrt{\Delta\rho} \sim 70 \text{ TeV}$$

BACKUP



Fan, Reece, Wang 2014