EWPOs at CEPC

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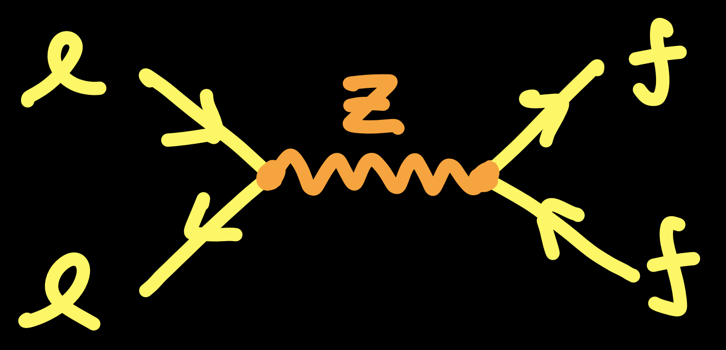
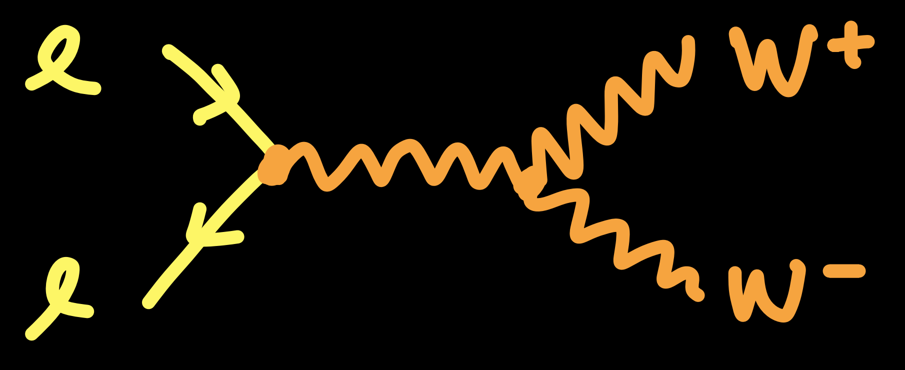
Updated CEPC collider parameters since CDR

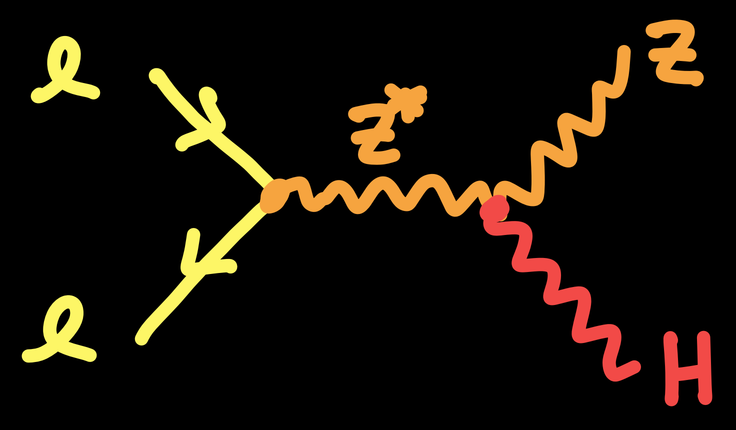
	Higgs		Z (2T)	
	CDR	Updated	CDR	Updated
Beam energy (GeV)	120	-	45.5	-
Synchrotron radiation loss/turn (GeV)	1.73	1.68	0.036	-
Piwinski angle	2.58	3.78	23.8	33
Number of particles/bunch N_e (10^{10})	15.0	17	8.0	15
Bunch number (bunch spacing)	242 (0.68μs)	218 (0.68μs)	12000	15000
Beam current (mA)	17.4	17.8	461.0	1081.4
Synchrotron radiation power /beam (MW)	30	-	16.5	38.6
Cell number/cavity	2	-	2	1
β function at IP β_x^* / β_y^* (m)	0.36/0.0015	0.33/0.001	0.2/0.001	-
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.89/0.0018	0.18/0.0016	-
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	17.1/0.042	6.0/0.04	-
Bunch length σ_z (mm)	3.26	3.93	8.5	11.8
Lifetime (hour)	0.67	0.22	2.1	1.8
Luminosity/IP L (10^{34} cm^{-2}s^{-1})	2.93	5.2	32.1	101.6

Luminosity increase factor: × 1.8 × 3.2

The CEPC Program

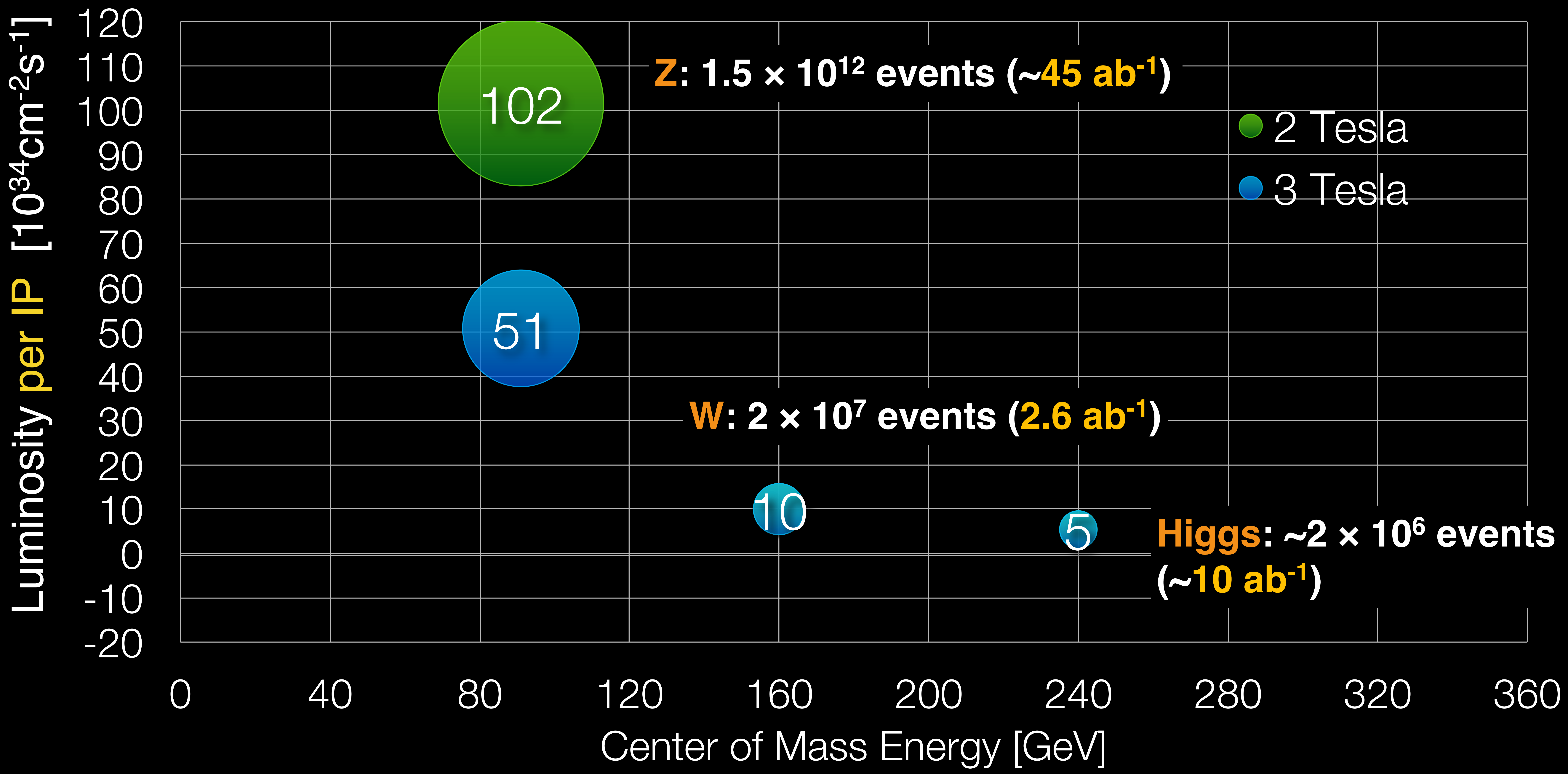






100 km e^+e^- collider

2 IPs



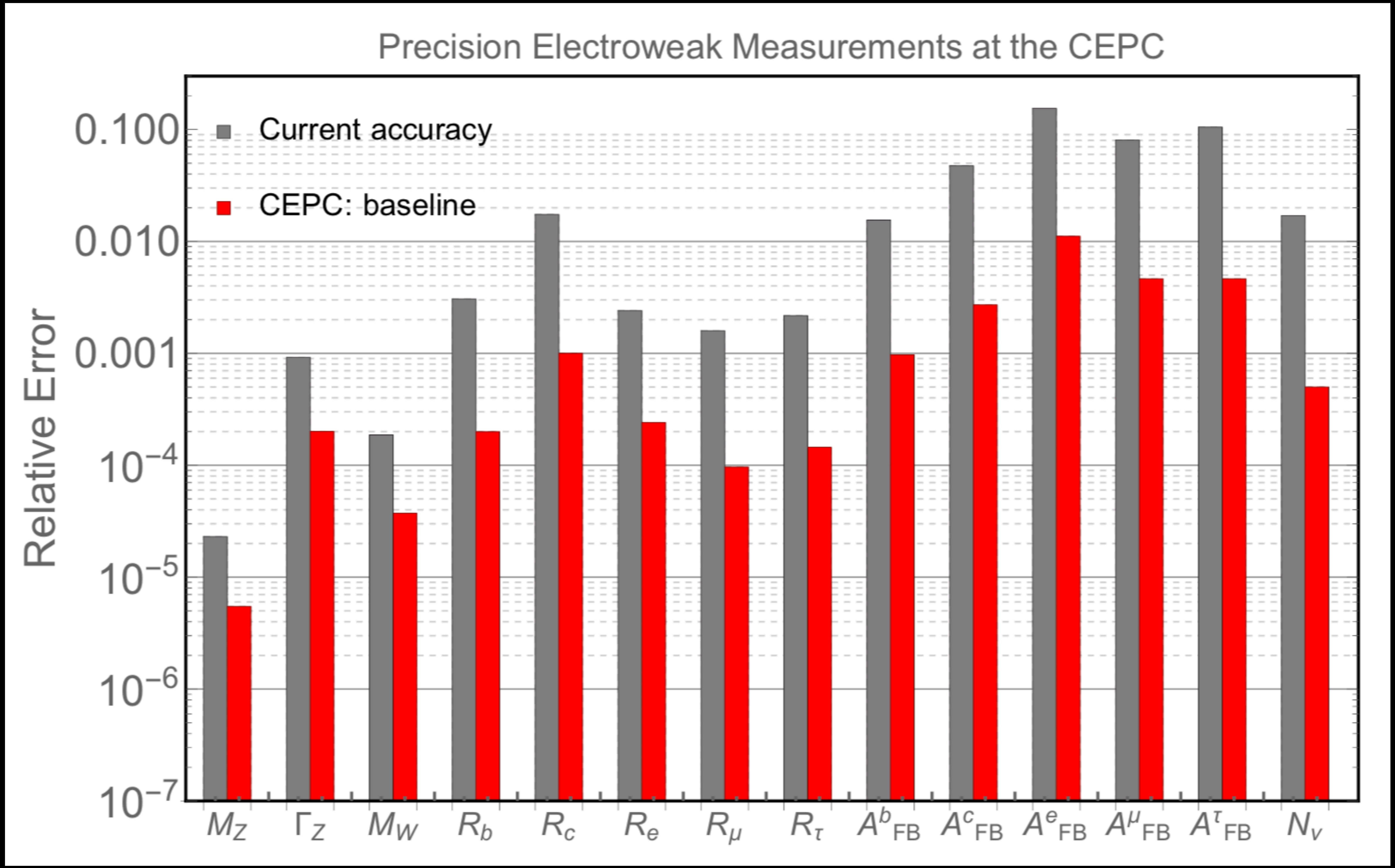
Motivation of electroweak

- key observables contributed to electroweak global fits

Fundamental constant	δx/x	measurements	
$\alpha = 1/137.035999139\ (31)$	1×10^{-10}	$e^{\pm}\ g_2$	**From PDG**
$G_F = 1.1663787\ (6) \times 10^{-5}\ \text{GeV}^{-2}$	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 threshold scan**
$\sin^2\theta_W = 0.23152 \pm 0.00014$	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**

Overview of CEPC electroweak physics

- expected precision of electroweak measurements in CEPC CDR
- Estimated by extrapolation from LEP experiments



observables
m_Z
Γ_Z
$\sigma_{\rm had}$
R_e
R_μ
R_τ
R_b
R_c
$A_{\rm FB}^{0,e}$
$A_{\rm FB}^{0,\mu}$
$A_{\rm FB}^{0,\tau}$
$A_{\rm FB}^{0,b}$
$A_{\rm FB}^{0,c}$
A_e (τ pol)
A_τ (τ pol)
BR($Z \to$ inv)
m_W
m_W
Γ_W
$\sigma^{\rm tot}_{\rm 240GeV}(WW)$
BR($W \to e\nu$)
BR($W \to \mu\nu$)
BR($W \to \tau\nu$)
BR($W \to jj$)*
derived quantiti
$\sin^2\theta_W^{\rm eff}$
N_ν
N_ν

Example 1: Branching ratio (R^b)

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

- At LEP measurement 0.21594 ±0.00066
- CEPC aim to improve the precision by a factor ~20
- R^b measurement is sensitive to New physics models (SUSY)
  - SUSY predicts corrections to Z→ bb vertex
  - Through gluino and chargino loop …

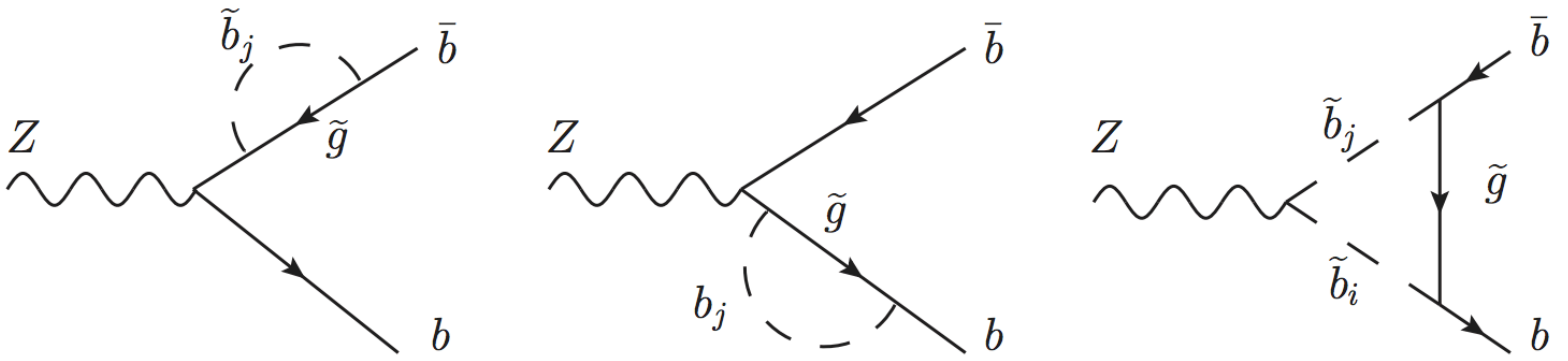


FIG. 1: One-loop Feynman diagrams of gluino correction to $Z \to \bar{b}b$

Arxiv:1601.07758v2

R^b: b tagging hemisphere correlations

- Hemisphere is taken to be tagged
  - if it is tagged by either one or both of the secondary vertex and lepton tags.
- Major systematics: hemisphere correlations
  - The tagging efficiency correlation between the two hemispheres in one event:
    - ➢ Angular effects : due to inefficient regions of detector
    - ➢ QCD effects (g->bb)
    - ➢ Vertex effects : due to vertex fitting

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

Single (N_t) and double tagged events (N_{tt})

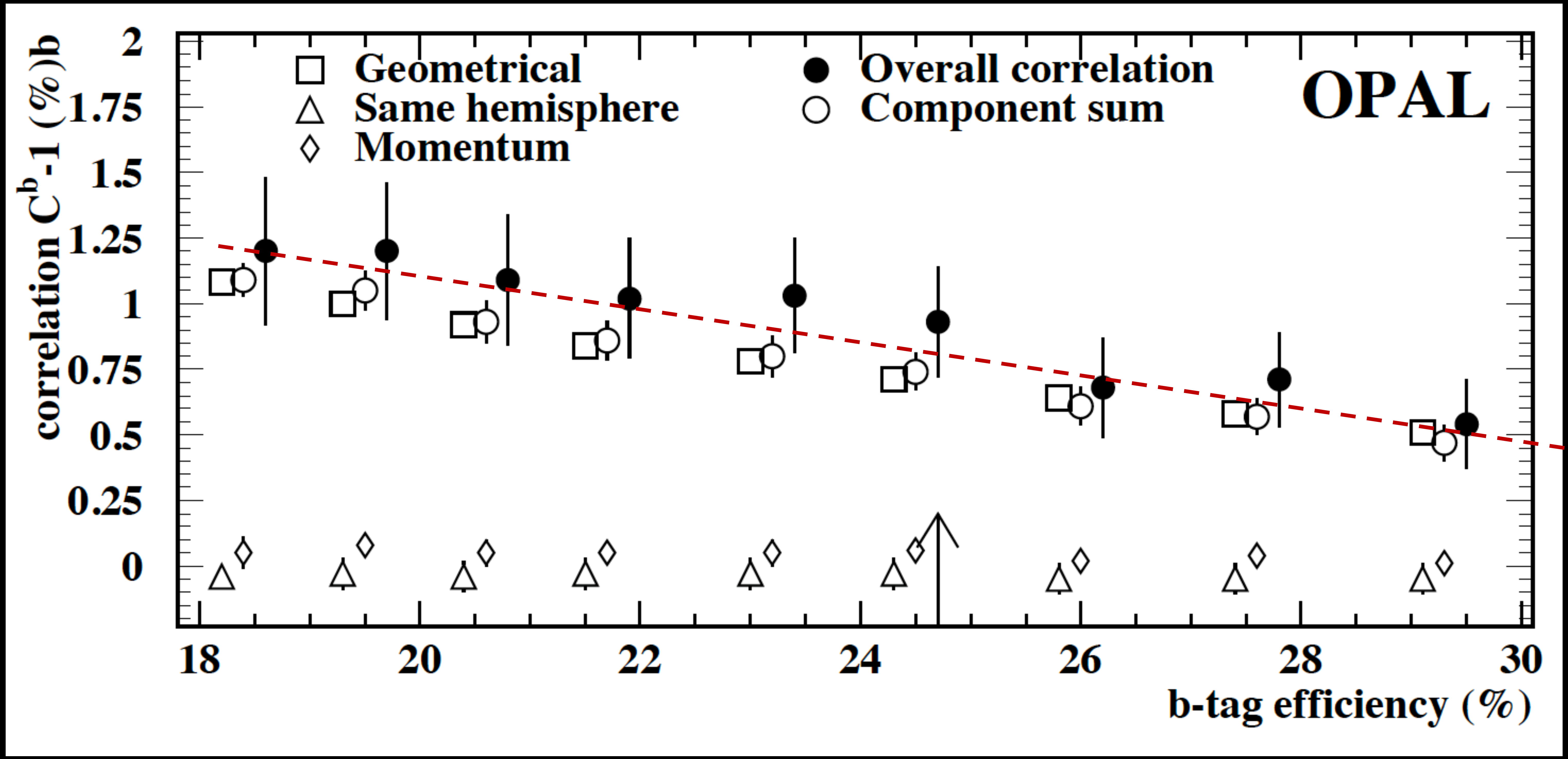
- $$\begin{aligned} N_t &= 2N_{had}\{\epsilon^b R_b + \epsilon^c R_c + \epsilon^{uds}(1 - R_b - R_c)\}, \\ N_{tt} &= N_{had}\{C^b(\epsilon^b)^2 R_b + C^c(\epsilon^c)^2 R_c + C^{uds}(\epsilon^{uds})^2 (1 - R_b - R_c)\}, \end{aligned}$$

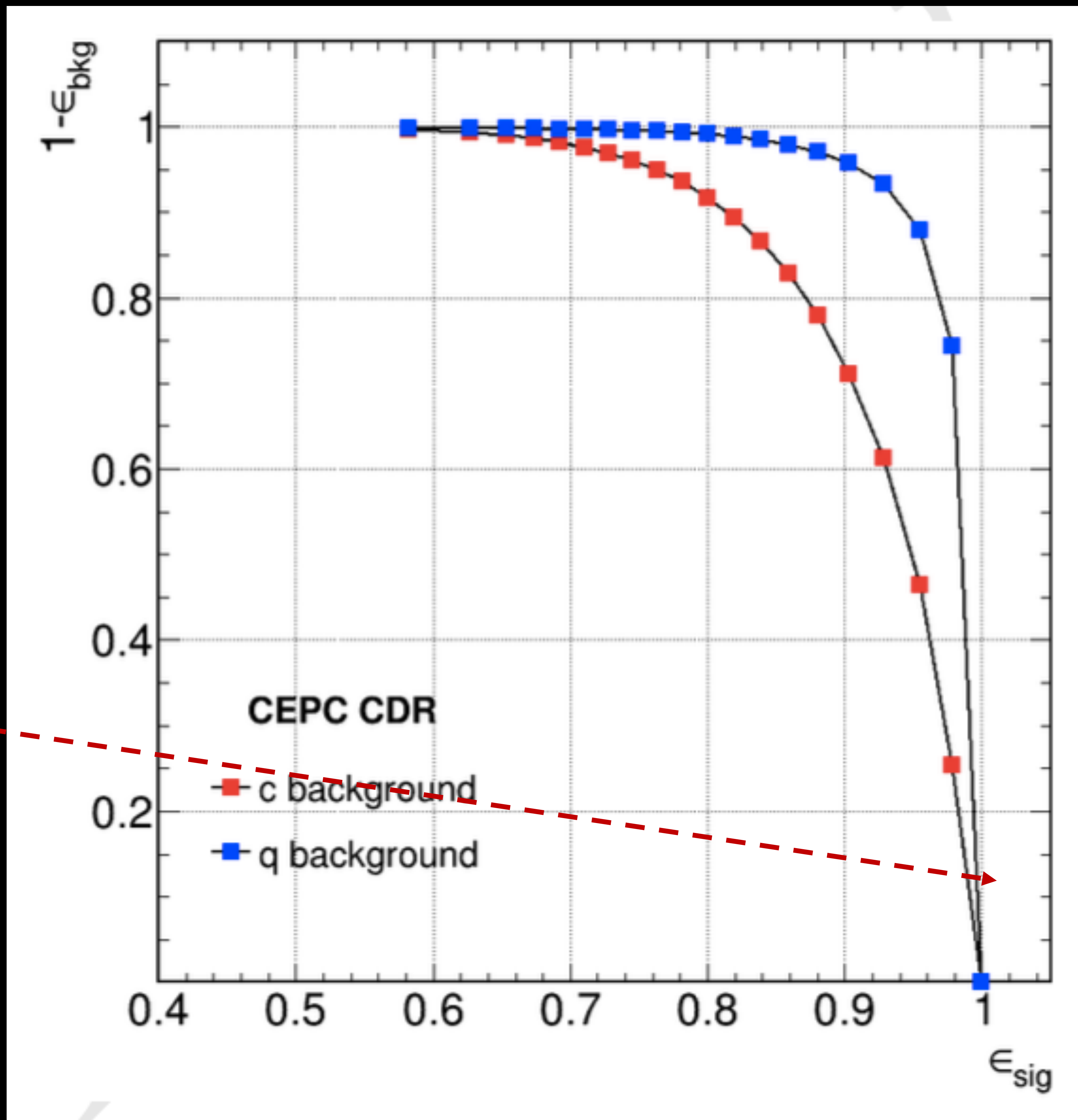
R^b: b tagging hemisphere correlations

- hemisphere correlations depends on b tagging efficiency
  - with 95% purity working points efficiency> 70%
  - This systematics will not be dominated

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

CEPC b tagging ROC curve

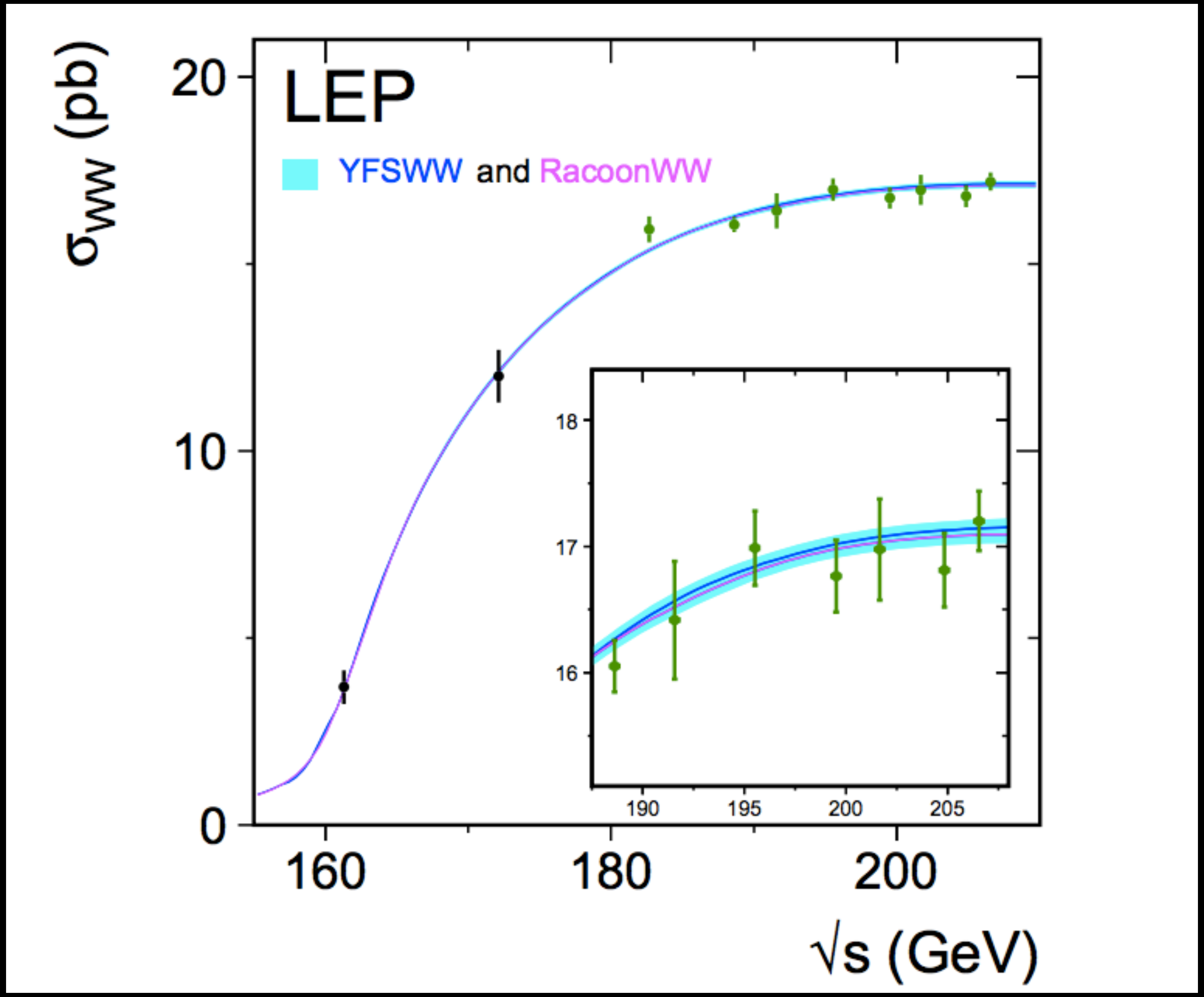


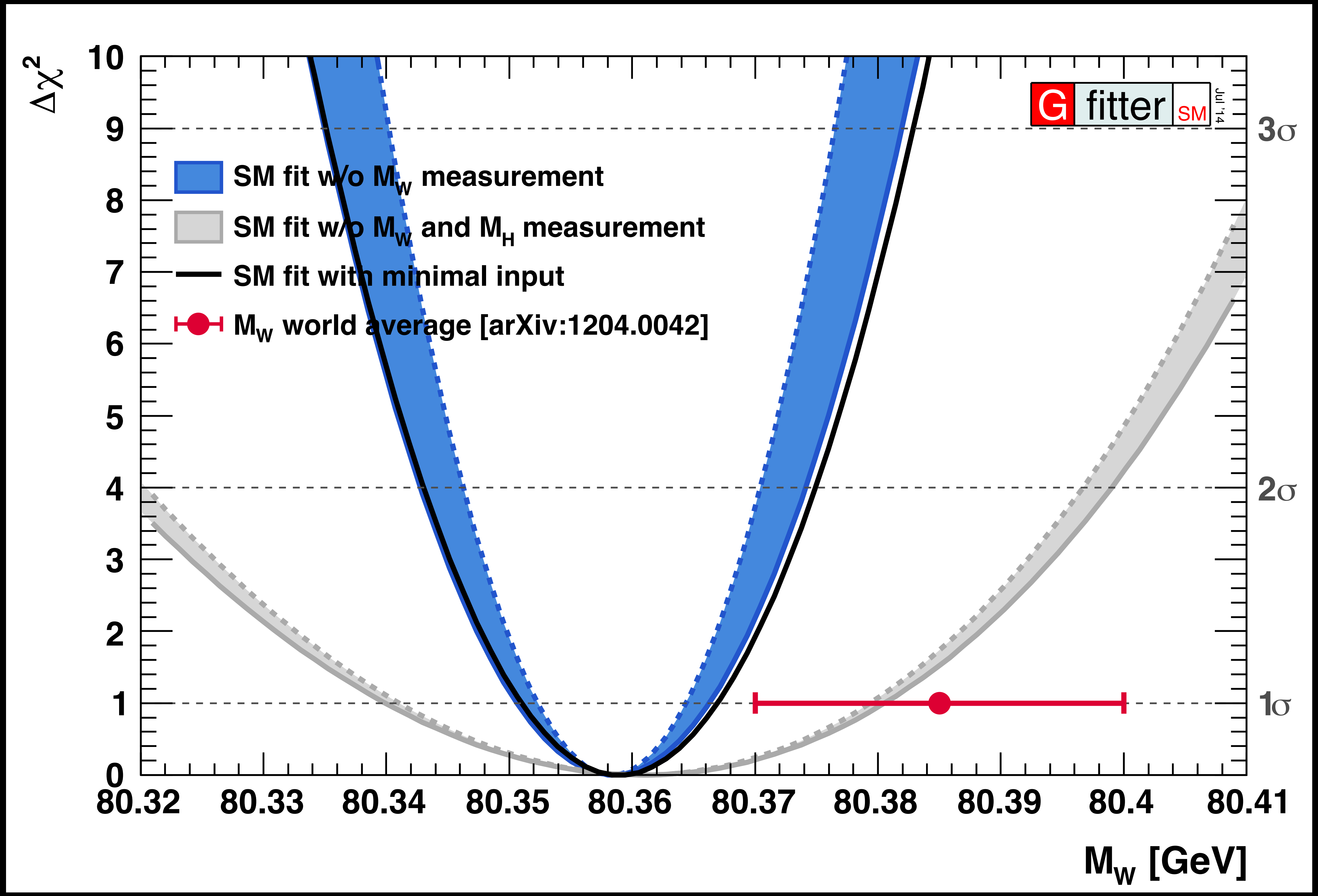


OPAL collaboration, Eur.Phys.J.C8:217-239,1999

Example 2: W mass measurements

- Small tension with 95% purity working points efficiency> 70%
  - This systematics will not be dominated



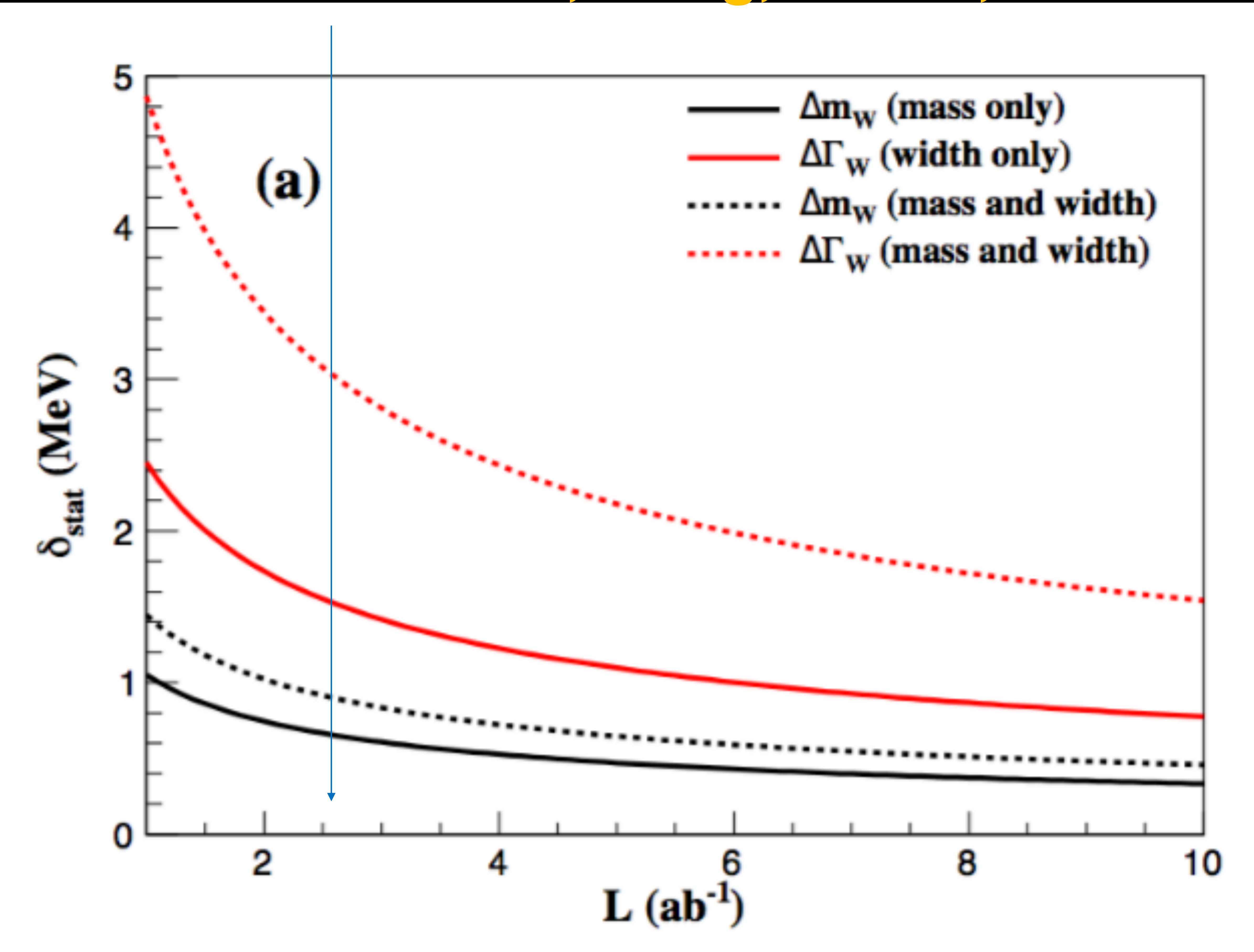


Example 2: W mass measurement in WW threshold

- Expected 1MeV precision in W mass measurement at CEPC
  - 2.6ab^{-1} in WW threshold)
  - Leading syst. (0.5MeV): Beam energy syst.
  - Stat uncertainty is about 0.5MeV

Eur. Phys. J. C (2020) 80:66
Peixun, Gang, Paolo , et al

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

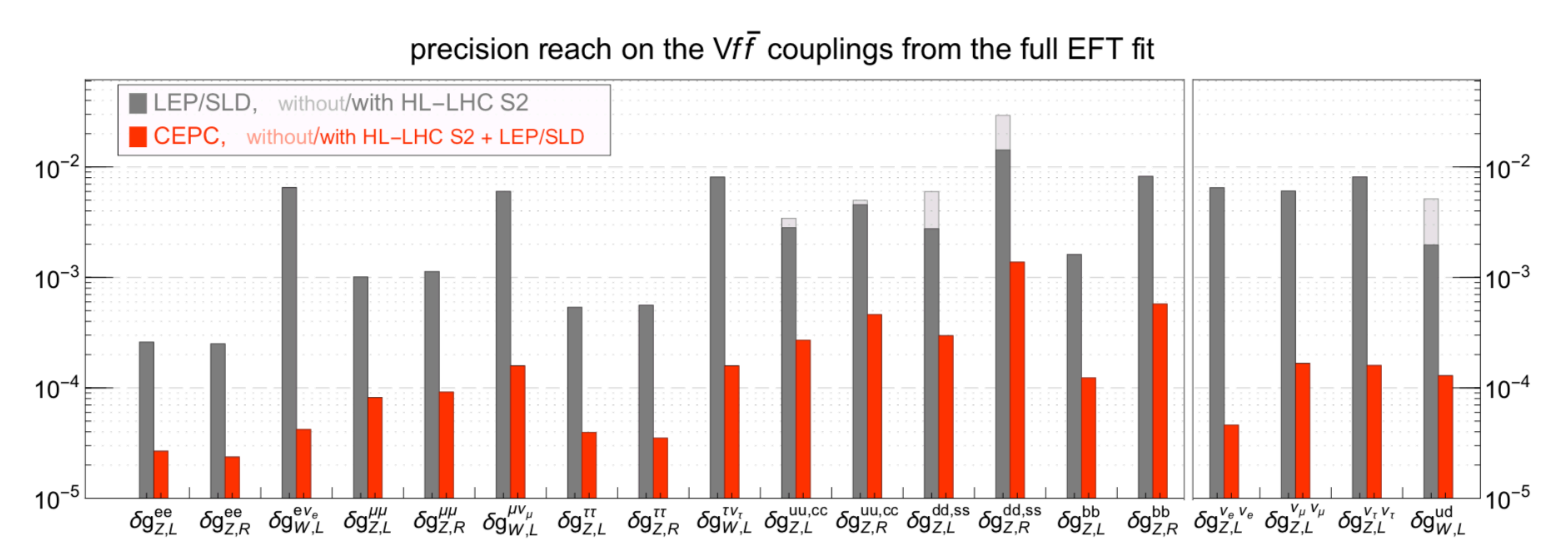


EFT fits

$$\mathcal{L}_{\rm eff}^{Vf\bar f} \supset \sqrt{g_L^2+g_Y^2}Z_\mu \left[\sum_{f=u,d,e,v}\bar f_L\gamma^\mu(T_f^3 - s_W^2 Q_f + \delta g_L^{Zf})f_L + \sum_{f=u,d,e}\bar f_R\gamma^\mu(-s_W^2 Q_f + \delta g_R^{Zf})f_R\right] + \frac{g_L}{\sqrt{2}}\left[W_\mu^+\bar u_L\gamma^\mu(V_{\rm CKM}+\delta g_L^{Wq})d_L + W_\mu \bar\nu_L\gamma^\mu(1+\delta g_L^{W\ell})e_L + {\rm h.c.}\right],$$

By jiaying Gu

One-sigma precision reaches on the V f f̄ couplings from the full EFT global fit.

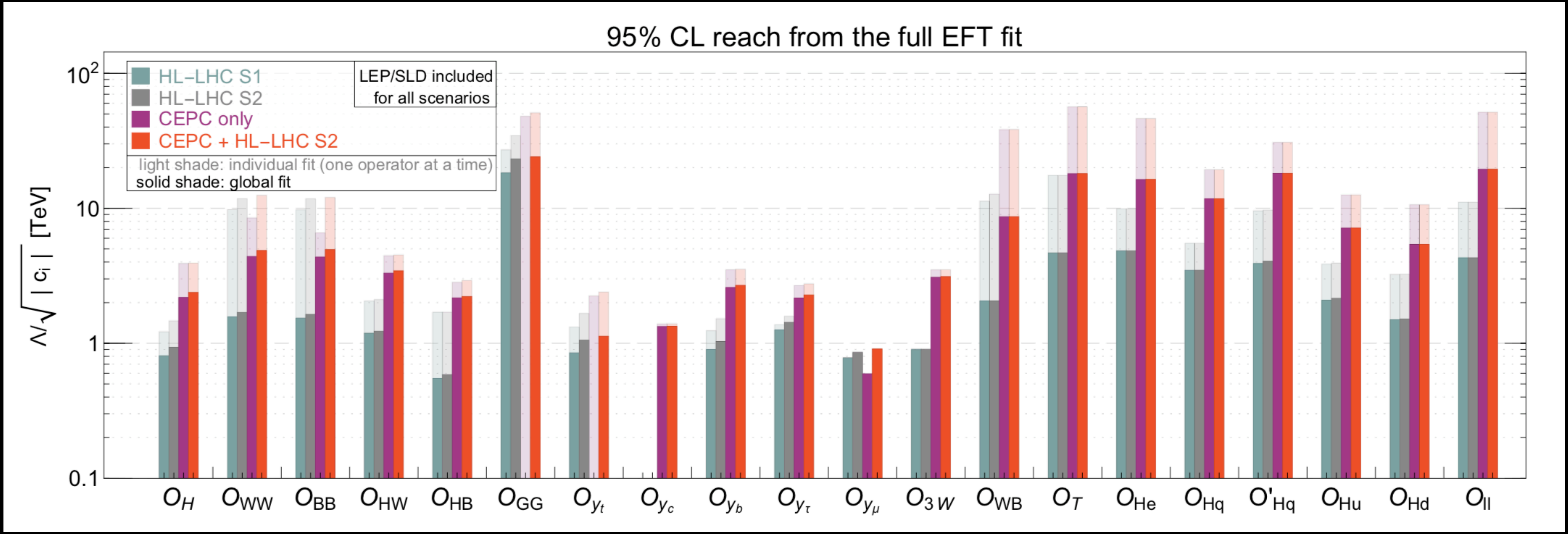


Plan for Snowmass EF04 contribution

- Some ideas about CEPC contributions (LOI and contributed paper)
- More detailed study of 2~3 benchmark electroweak observables
  - Eg: weak mixing angle from Z->bb backward-forward asymmetry
  - More study with more realistic simulations
  - More detailed study on experimental and theory systematics
- High order EWK calculation (NNLO EWK corrections)
  - One theorists are interested in NNLO EWK corrections for
- EFT fit from EWPOs
- aTGCs/QGCs in WW events
- …… (in middle of collecting more ideas)
- Plan to present more details in future EF04 meetings

Backup

EFT fits



95% CL reach from the full EFT fit
HL−LHC S1
HL−LHC S2
CEPC only
CEPC + HL−LHC S2
LEP/SLD included for all scenarios
light shade: individual fit (one operator at a time)
solid shade: global fit
$\Lambda/\sqrt{|c_i|}$ [TeV]
10^2
10
1
0.1
O_H O_{WW} O_{BB} O_{HW} O_{HB} O_{GG} O_{y_t} O_{y_c} O_{y_b} O_{y_τ} O_{y_μ} O_{3W} O_{WB} O_T O_{He} O_{Hq} O'_{Hq} O_{Hu} O_{Hd} O_{ll}

Branching ratio (R^b): systematics

Source	$\Delta\epsilon^c/\epsilon^c$ (%)	$\Delta\epsilon^{uds}/\epsilon^{uds}$ (%)	ΔR_b
Tracking resolution	1.24	4.0	0.00017
Tracking efficiency	0.80	4.0	0.00014
Silicon hit matching efficiency	0.82	2.8	0.00009
Silicon alignment	0.58	2.1	0.00008
Electron identification efficiency	1.11	0.5	0.00015
Muon identification efficiency	0.64	0.2	0.00009
c quark fragmentation	2.26	-	0.00028
c hadron production fractions	3.66	-	0.00046
c hadron lifetimes	0.55	-	0.00007
c charged decay multiplicity	1.09	-	0.00014
c neutral decay multiplicity	2.39	-	0.00030
Branching fraction $B(D \to K^0)$	1.20	-	0.00015
c semileptonic branching fraction	2.44	-	0.00031
c semileptonic decay modelling	2.34	-	0.00029
Gluon splitting to $c\bar{c}$	0.34	6.3	0.00018
Gluon splitting to $b\bar{b}$	0.50	9.3	0.00027
K^0 and hyperon production	-	0.3	0.00001
Monte Carlo statistics (c, uds)	0.66	2.5	0.00010
Subtotal $\Delta\epsilon^c$ and $\Delta\epsilon^{uds}$	6.65	13.3	0.00090
Electron identification background			0.00039
Muon identification background			0.00041
Efficiency correlation ΔC^b			0.00066
Event selection bias			0.00033
Total			0.00129

$$\frac{\Delta R_b}{R_b} = -0.059\frac{\Delta\epsilon^c}{\epsilon^c} - 0.010\frac{\Delta\epsilon^{uds}}{\epsilon^{uds}} + \frac{\Delta C^b}{C^b}$$

Tracker resolution and efficiency(~0.1%)

Lepton identification (~0.1%)

Charm modeling (~0.4%)

Gluon splitting (~0.1%)

Background (~0.2%)

b-tagging corrections (~0.3%)

OPAL collaboration, Eur.Phys.J.C8:217-239,1999

R^b: tracker systematics

- Alignment systematics:
  - LEP study : 20μm mis-alignment → 0.04% systematics
  - CEPC aim for 2um mis-alignment (at least 5μm) → <0.005% syst.
- Hit Efficiency :
  - LEP study 1% syst. → 0.007% syst. In R^b
  - CEPC aim for <0.2% hit efficiency syst. → 0.002% syst. In R^b
- Lepton efficiency
  - LEP: 3% syst. → 0.04% systematics in R^b
  - CEPC aim for 0.2% syst. → 0.003% syst. In R^b

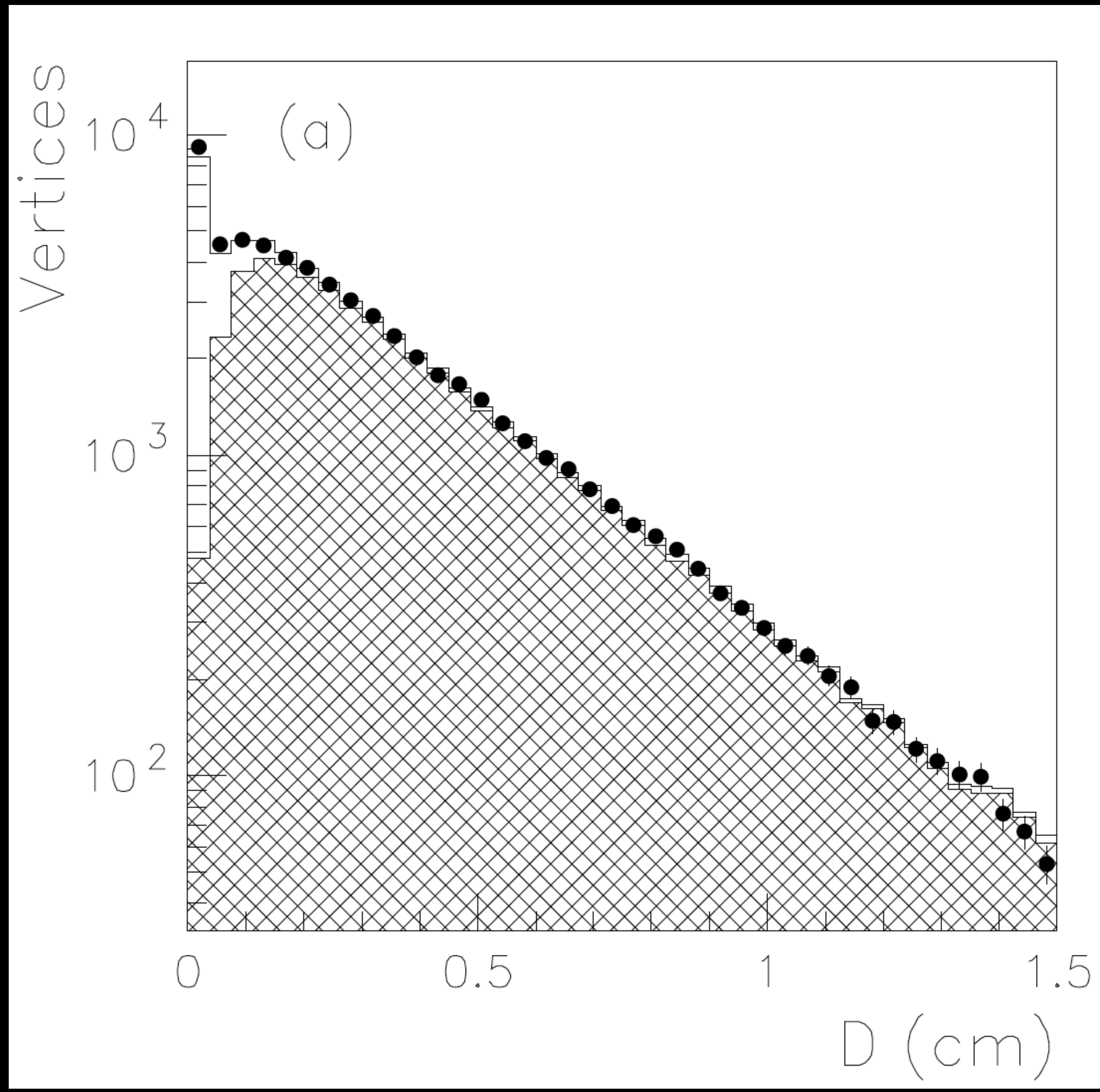
$\mathcal{O}_H = \frac{1}{2}(\partial_\mu \|H\|^2)^2$	$\mathcal{O}_{GG} = g_s^2 \|H\|^2 G_{\mu\nu}^A G^{A,\mu\nu}$
$\mathcal{O}_{WW} = g^2 \|H\|^2 W_{\mu\nu}^a W^{a,\mu\nu}$	$\mathcal{O}_{y_u} = y_u \|H\|^2 \bar{q}_L \widetilde{H} u_R + \text{h.c.} \quad (u \to t, c)$
$\mathcal{O}_{BB} = g'^2 \|H\|^2 B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{y_d} = y_d \|H\|^2 \bar{q}_L H d_R + \text{h.c.} \quad (d \to b)$
$\mathcal{O}_{HW} = ig(D^\mu H)^\dagger \sigma^a (D^\nu H) W_{\mu\nu}^a$	$\mathcal{O}_{y_e} = y_e \|H\|^2 \bar{l}_L H e_R + \text{h.c.} \quad (e \to \tau, \mu)$
$\mathcal{O}_{HB} = ig'(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$	$\mathcal{O}_{3W} = \frac{1}{3!} g \epsilon_{abc} W_\mu^{a\,\nu} W_{\nu\rho}^b W^{c\,\rho\mu}$
$\mathcal{O}_{WB} = gg' H^\dagger \sigma^a H W_{\mu\nu}^a B^{\mu\nu}$	$\mathcal{O}_{\ell\ell} = (\bar{\ell}_L \gamma^\mu \ell_L)(\bar{\ell}_L \gamma_\mu \ell_L)$
$\mathcal{O}_T = \frac{1}{2}(H^\dagger \overleftrightarrow{D}_\mu H)^2$	$\mathcal{O}_{He} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{e}_R \gamma^\mu e_R$
$\mathcal{O}_{Hq} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{q}_L \gamma^\mu q_L$	$\mathcal{O}_{Hu} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{u}_R \gamma^\mu u_R$
$\mathcal{O}'_{Hq} = iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H \bar{q}_L \sigma^a \gamma^\mu q_L$	$\mathcal{O}_{Hd} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{d}_R \gamma^\mu d_R$

Branching ratio (R^b): detector requirement

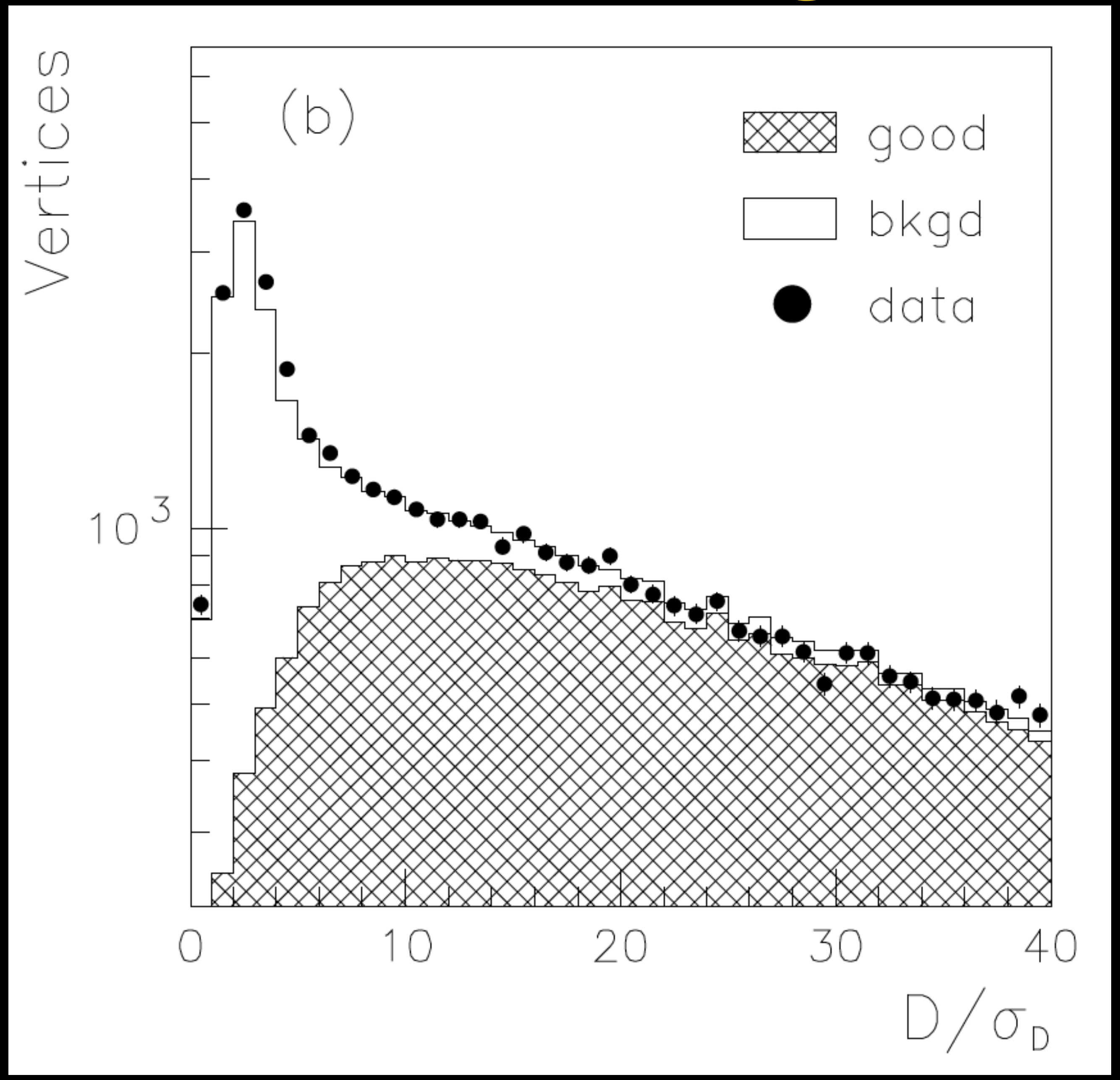
$$\frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to had)}$$

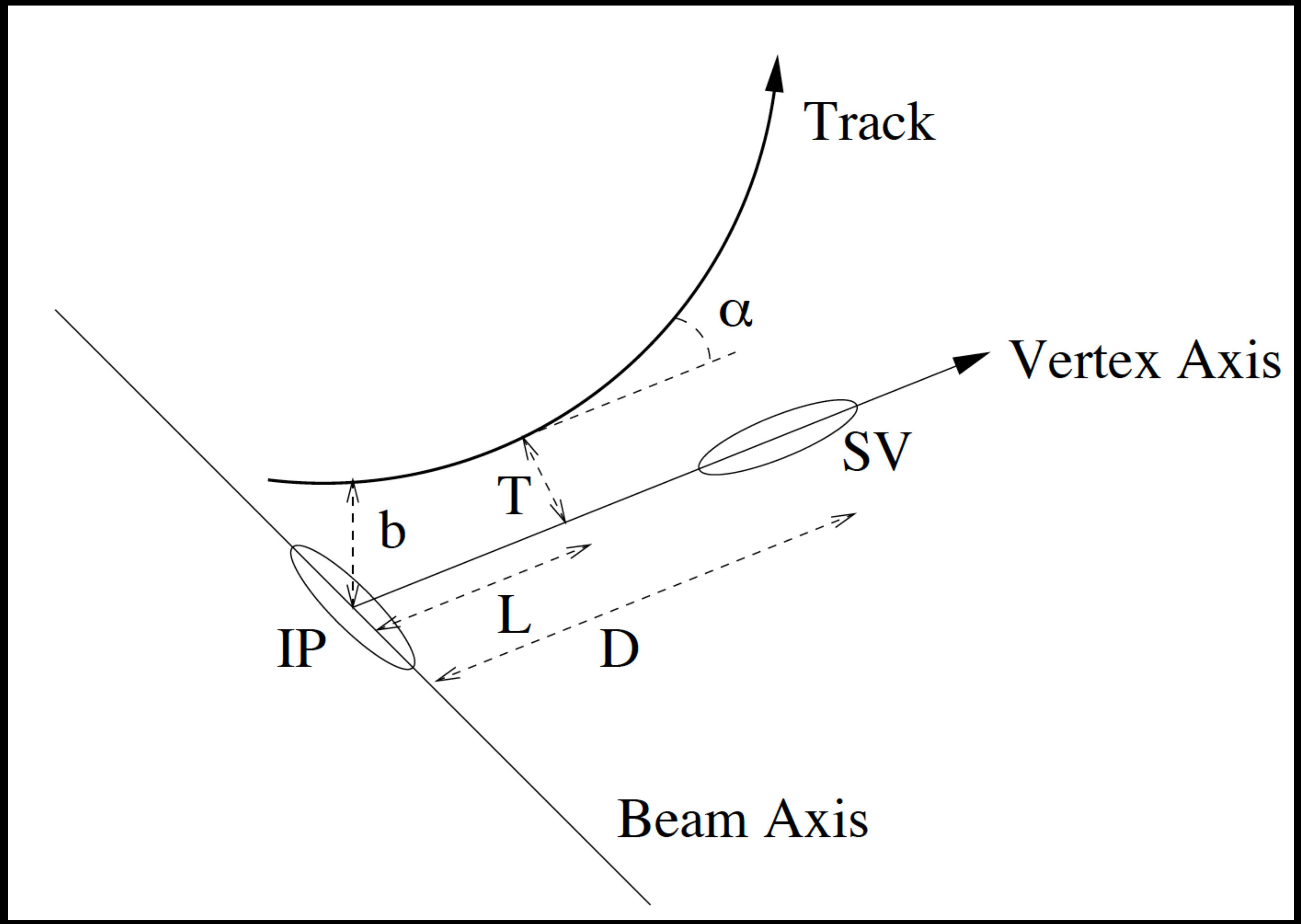
- Two ways to tag the b quarks in Z->qq events
  - Secondary Vertex tag (Average decay length of b meson of 2mm level at Z pole)
    - ➢ Multi-variant analysis : Impact parameter in R/φ and Z , mass of vertex …
  - Lepton tag
  - ➢ High momentum Electron and muon with pT>1GeV in a jet …

Vertex distance to IP



Vertex distance significance

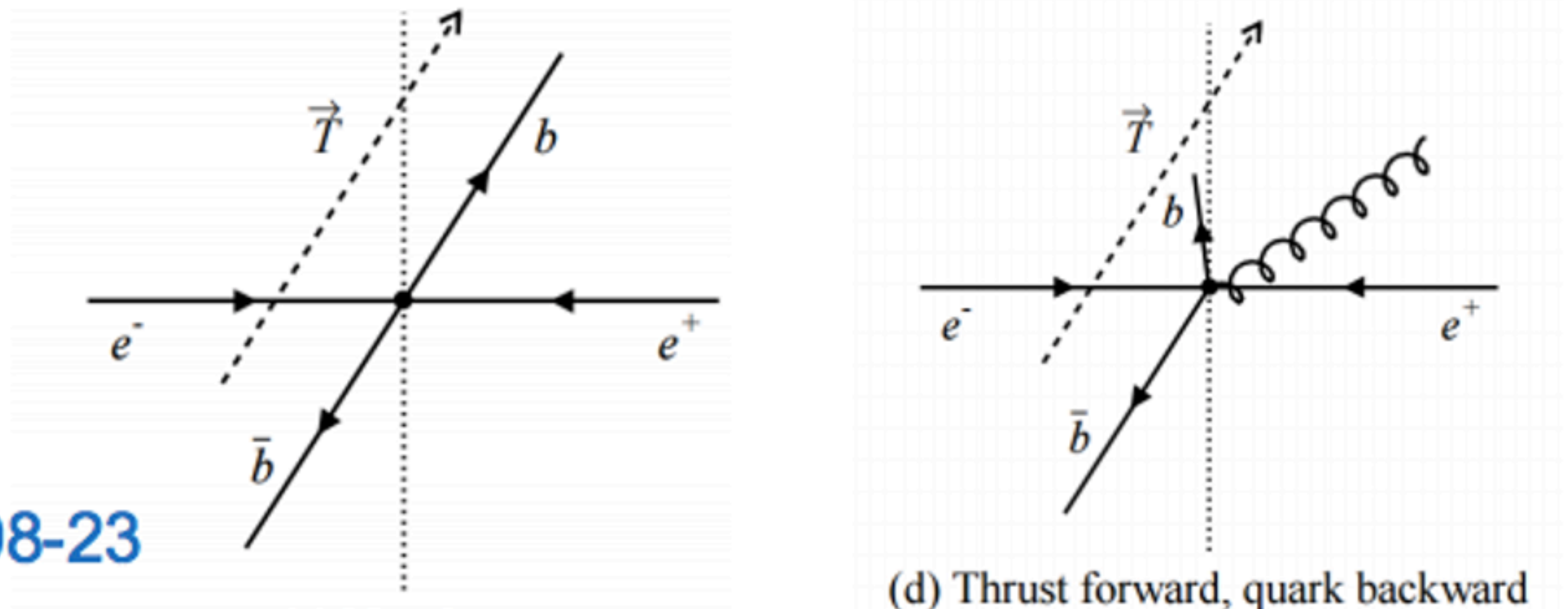




SLD, Ann.Rev.Nucl.Part.Sci.46:395–469,1996

Branching ratio (R^b): theory systematics

- QCD related systematics
  - High order QCD corrections gives impact to hemisphere correlations
  - Impact to Backward-forward asymmetry



CERN-EP/98-23

(a) No gluon

(d) Thrust forward, quark backward

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

R^b: charm modelling and lepton ID

- Charm modelling : depends on input from flavor experiments (BELLEII…)
  - C hadron fractions (factions of D^+, D^0, D^+_s) → 0.2% syst. In R^b
  - LEP: Tagging efficiency for D+ is three times higher than D0
  - Need more study to check D meson tagging efficiency in Fcc-ee/CEPC

Source	$\Delta\epsilon^c/\epsilon^c$ (%)	$\Delta\epsilon^{uds}/\epsilon^{uds}$ (%)	ΔR_b
c quark fragmentation	2.26	-	0.00028
c hadron production fractions	3.66	-	0.00046
c hadron lifetimes	0.55	-	0.00007
c charged decay multiplicity	1.09	-	0.00014
c neutral decay multiplicity	2.39	-	0.00030
Branching fraction $B(D \to K^0)$	1.20	-	0.00015
c semileptonic branching fraction	2.44	-	0.00031
c semileptonic decay modelling	2.34	-	0.00029