

Physics studies and detector R&D towards the TDR Report from the review of the CEPC physics and detector CDR

CEPC workshop Beijing, November 2018

Marcel Vos, IFIC (UVEG/CSIC),

On behalf of the CDR review committee



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CEPC review committee

Mogens Dam (NBI)

Sasha Glazov (DESY)

Hitoshi Yamamoto (Tohoku University)

Bill Murray (Warwick/STFC)

Liang Han (USTC)

Marcel Vos (Valencia)

Marcel Stanitzki (DESY)

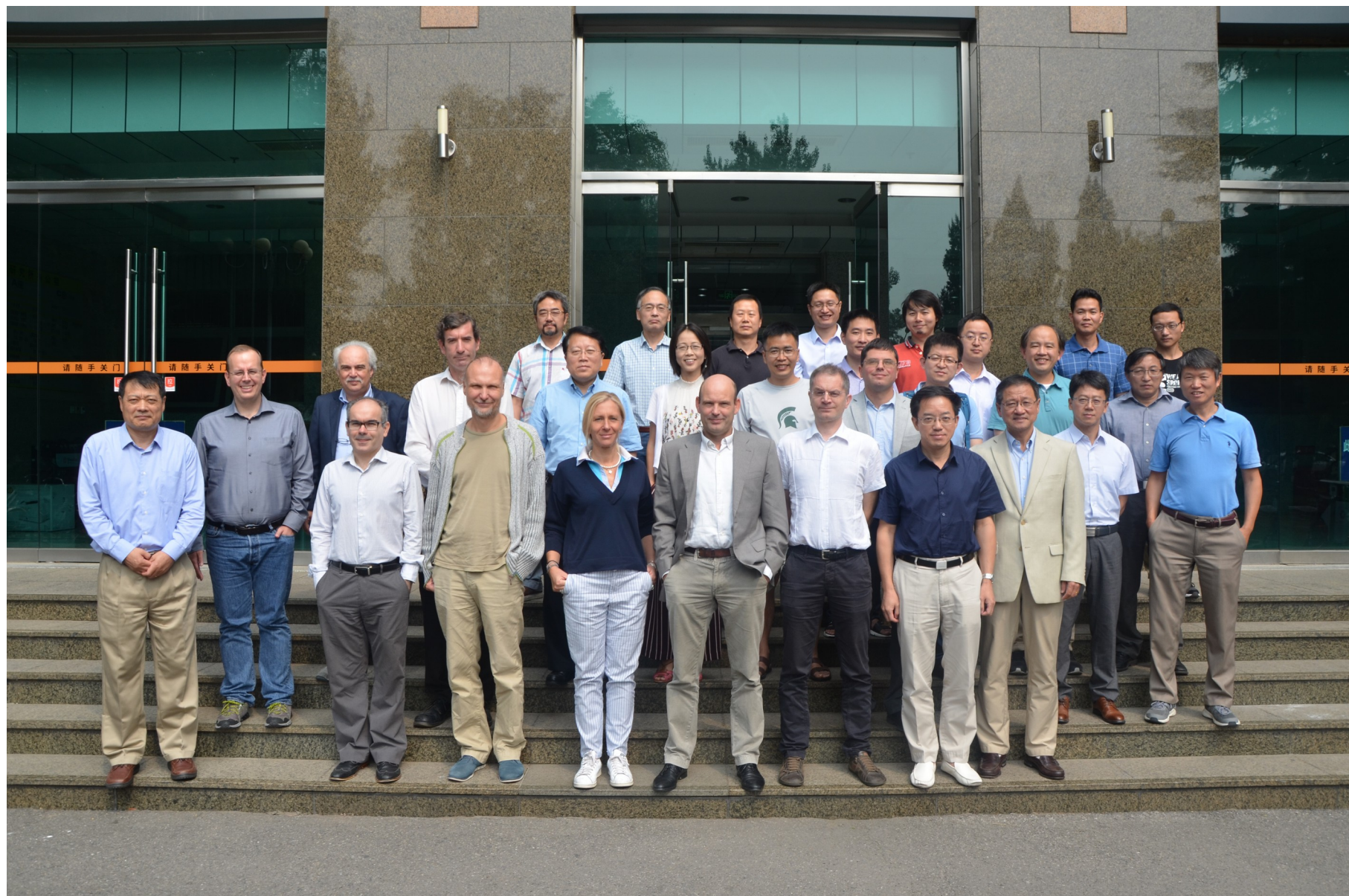
Claudia Cecchi (INFN/Perugia)

Maxim Perelstein (Cornell)

Tao Han (Pittsburgh)

Christophe Grojean (DESY/Humboldt)

CDR review face-to-face meeting (IHEP 13-15 September)



CEPC review

I would like to thank the editors for delivering a very readable draft of the CDR

I would like to thank the committee members for reading a complex and long document very carefully, on relatively short notice.

I would like to thank all those present at the review for very constructive discussions.

Thanks to the local organizers

We thank the local organization of the event for creating the boundary conditions for a very efficient and pleasant review process, for help with practical issues, such as visas, local transportation, etc., and for their great hospitality



Thanks to the local organizers



Charge

The International Review Committee of the CEPC Physics and Detector Conceptual Design Report (CDR) is to consider **the physics program goals of the CEPC and the detector concepts** presented.

Charge

The committee is asked to assess if the CEPC physics program is well motivated and aligned with the worldwide program for the future of High Energy Physics, and if the detector concepts presented in the CDR, as a whole, are adequate to carry out the physics program, and if there is a sufficient understanding of the detector subsystems to start working towards the TDR and produce detectors on the CEPC timescale. The Committee is requested to suggest mitigating measures in case of potential technological concerns on specific detector subsystems.

Charge

With regard to the site and cost no specific comments are solicited at this time.

The committee is invited to issue comments or suggestions on any aspect of this CDR draft beyond those specifically included in this charge.

Indeed, the committee did not venture into site selection, cost estimates, or the organization, governance, or internationalization of the project.

Another personal remark: it's encouraging to see the plans of the Chinese government to prepare large-scale, *international* projects (see X. Lou talk). Incorporating international contributions and establishing international collaborations takes time, but enhances the benefits of the project.

Overall appreciation

The report from the committee is available under the INDICO agenda:

<https://indico.ihep.ac.cn/event/8706/other-view?view=standard>

Report: “The review committee congratulates the CEPC study team with the succesful completion of the conceptual design report. The document provides a complete, and very readable, description of the project.”

M.V.: One more, big thank you to the CEPC editorial team for making the review a very enjoyable experience

Evaluation of the physics case

Report, executive summary: *“The CEPC is an ambitious project that can bring China to the first ranks of global particle physics.”*

A Higgs factory

Even more W-bosons

More Z-bosons than we know how to process

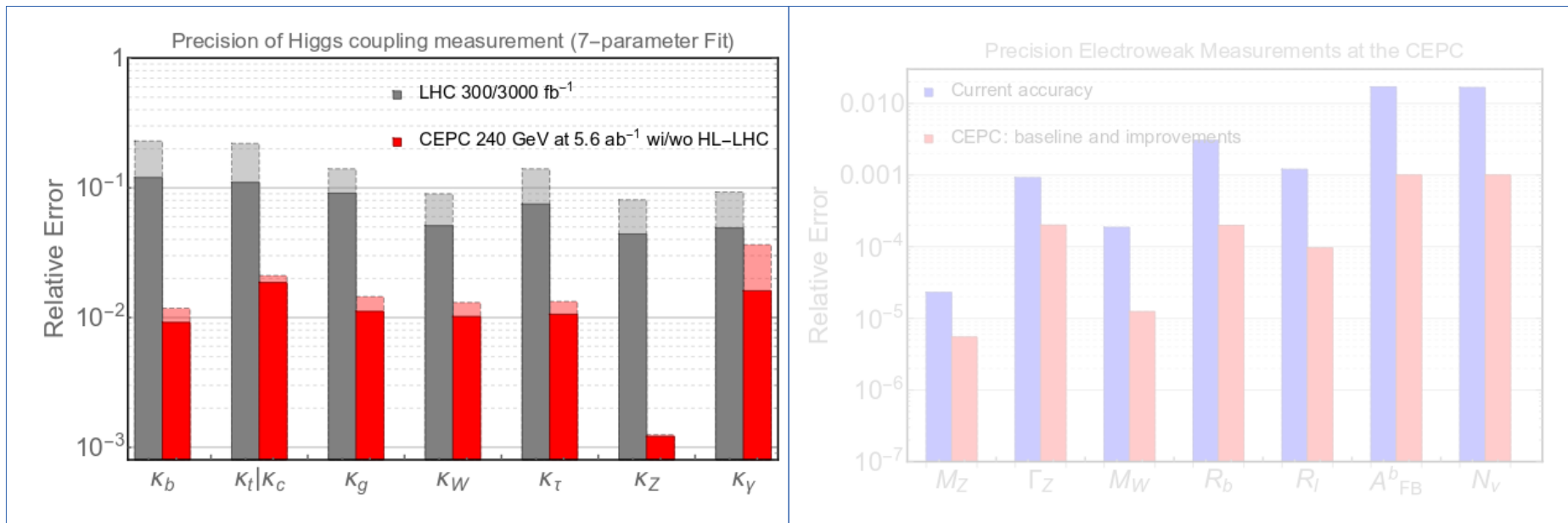
Operation mode	\sqrt{s} (GeV)	L per IP ($10^{34} \text{ cm}^{-2} \text{ s}^{-1}$)	Years	Total $\int L$ (ab^{-1} , 2 IPs)	Event yields
H	240	3	7	5.6	1×10^6
Z	91.2	32 (*)	2	16	7×10^{11}
W^+W^-	158–172	10	1	2.6	2×10^7 (†)

Table 1.1: CEPC operation plan at different center-of-mass energies (\sqrt{s}), and corresponding anticipated instantaneous luminosity (L), total integrated luminosity ($\int L$) and event yields. (*) The maximum instantaneous luminosity achievable at the Z factory operation is dependent on the detector solenoid magnet field. The value reported here assumes a 2 Tesla solenoid. (†) Additional 9.4×10^7 W^+W^- events will be produced during the Higgs factory operation.

Evaluation of the physics case: Higgs factory

Report: *“The central piece of the programme sees the CEPC operated as a Higgs boson factory at a centre-of-mass energy of 240 GeV, where the CEPC experiments will measure the Higgs boson couplings. The CEPC program offers a more precise and more model-independent characterization of the Higgs boson than can be performed at the LHC, and allows to measure several couplings that are not accessible at the LHC at all.”*

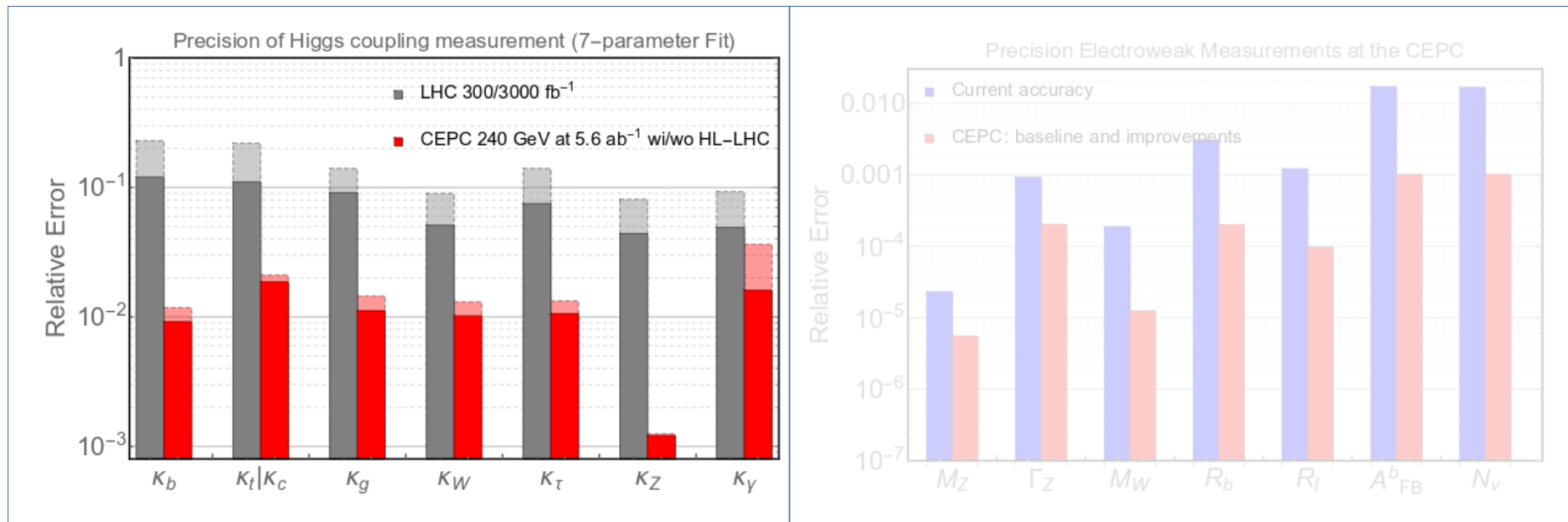
See also: N. Craig’s talk this workshop
CEPC Higgs paper: arXiv:1810.09037



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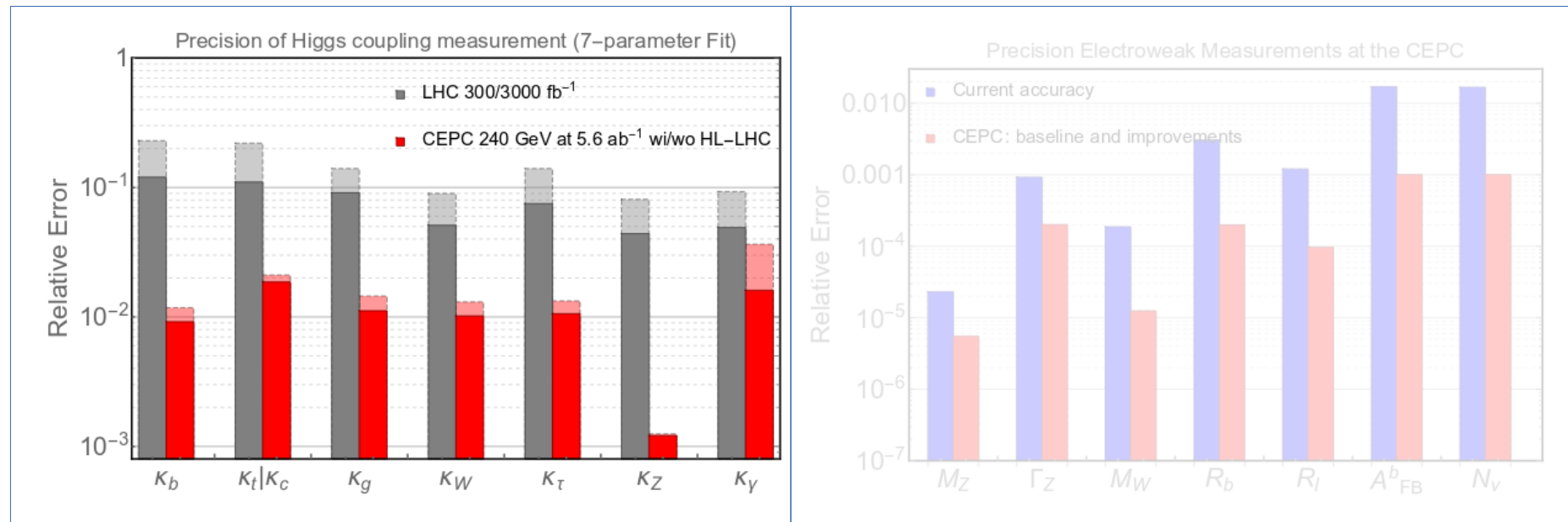
Corroborated by Japanese and European plans for e^+e^- colliders



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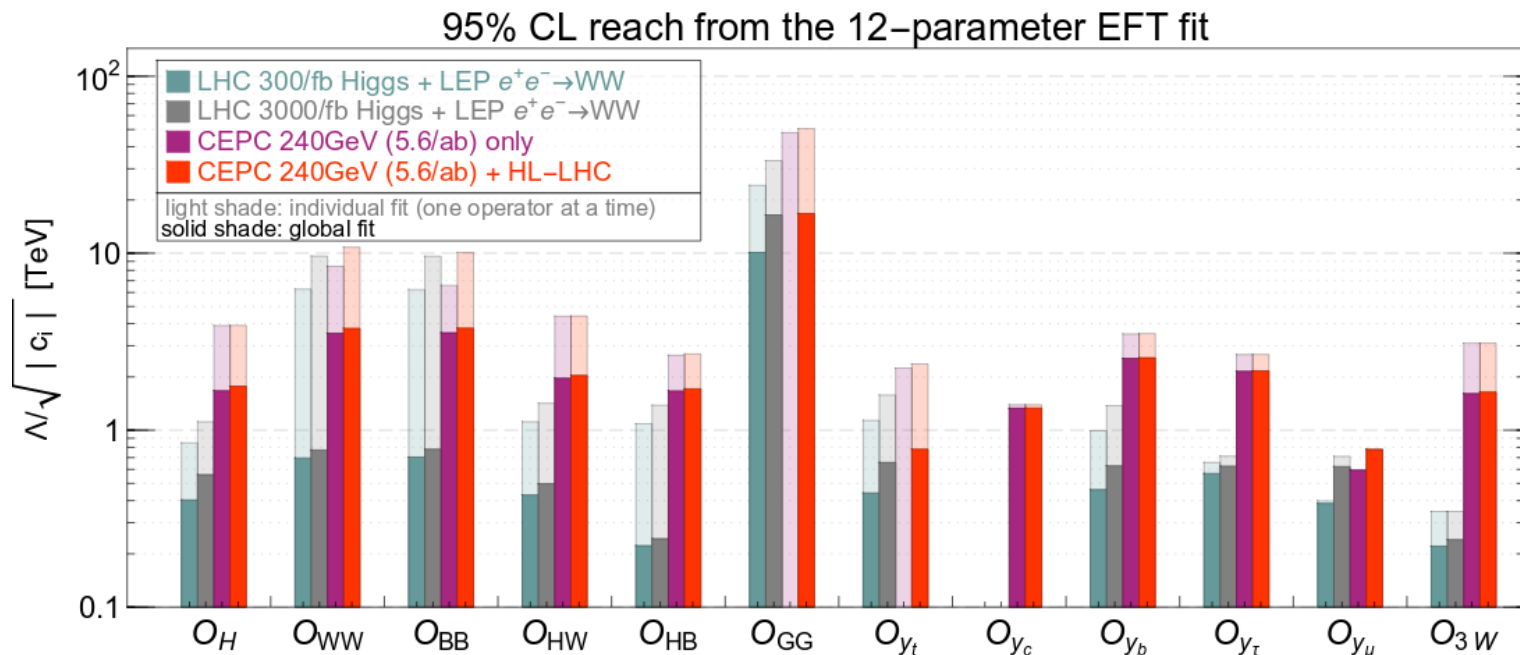
New – more aggressive - prospects to appear in HL-LHC yellow report



Evaluation of the physics case: Higgs factory

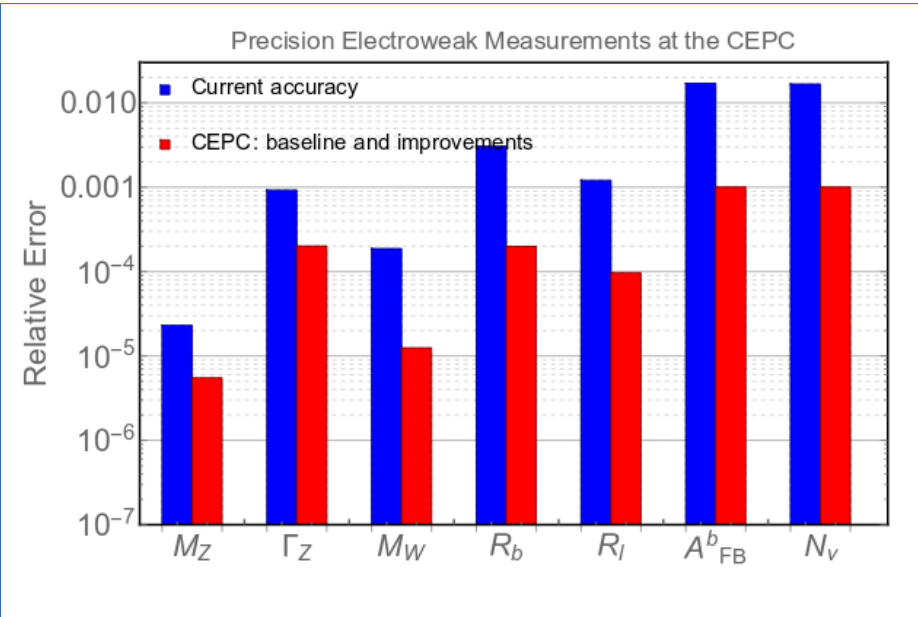
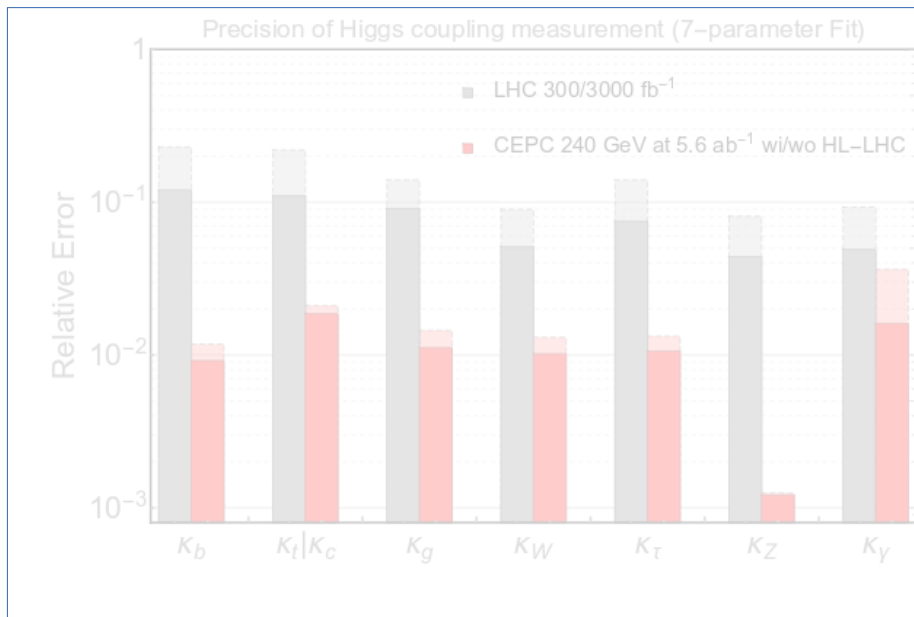
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Recommendation: use global EFT fits to assess model discrimination and indirect sensitivity to top quark Yukawa coupling and trilinear Higgs self-coupling



Evaluation of the physics case: EW physics

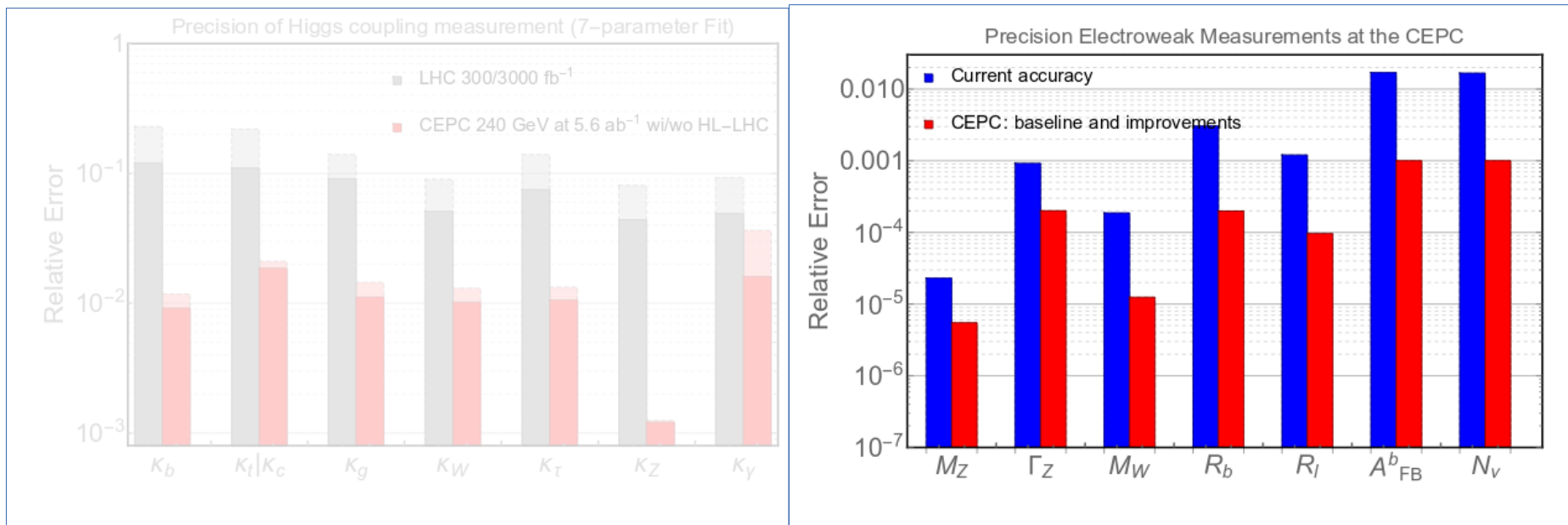
Report: *“The conceptual design report also provides a convincing case for electroweak precision measurements made possible by high-luminosity runs at the Z-pole and the W-pair production threshold.”*



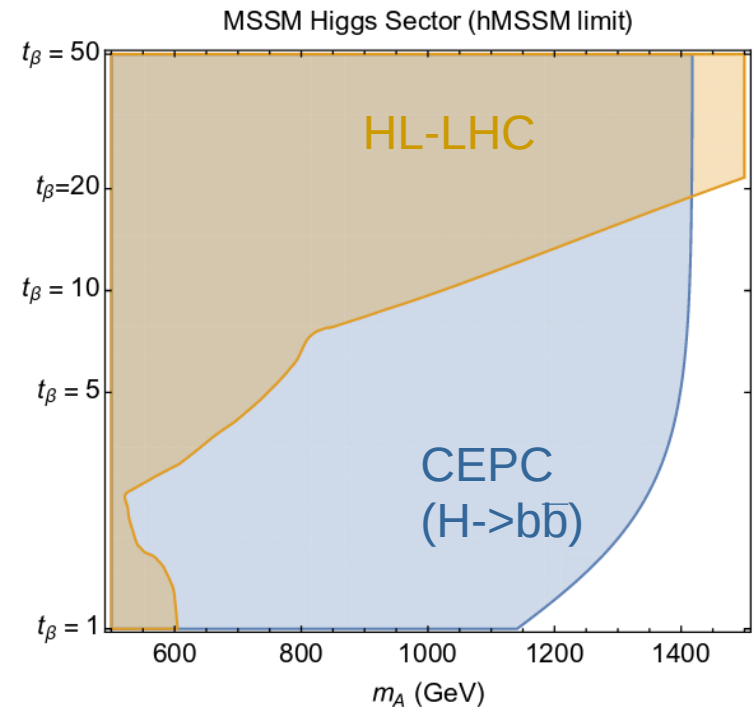
Evaluation of the physics case: EW physics

Report: *“The conceptual design report also provides a convincing case for electroweak precision measurements made possible by high-luminosity runs at the Z-pole and the W-pair production threshold.”*

Points of discussion: FCCee stresses Z precision-physics more strongly
Parametric and theory limitations to be exposed more clearly



Physics case: Higgs & EW



“These landmark precision measurements in the Higgs and electroweak sectors, with exquisite indirect sensitivity to physics beyond the Standard Model, yield a compelling physics case. The scientific potential of the CEPC project is supported by solid studies and is widely recognized by the international particle physics community.”

Rare decays

Rare Higgs and Z-boson decays are explored in detail

“Complementary to the precision program, the large samples of Higgs and Z-bosons yield an unrivalled discovery potential for searches for rare decays”

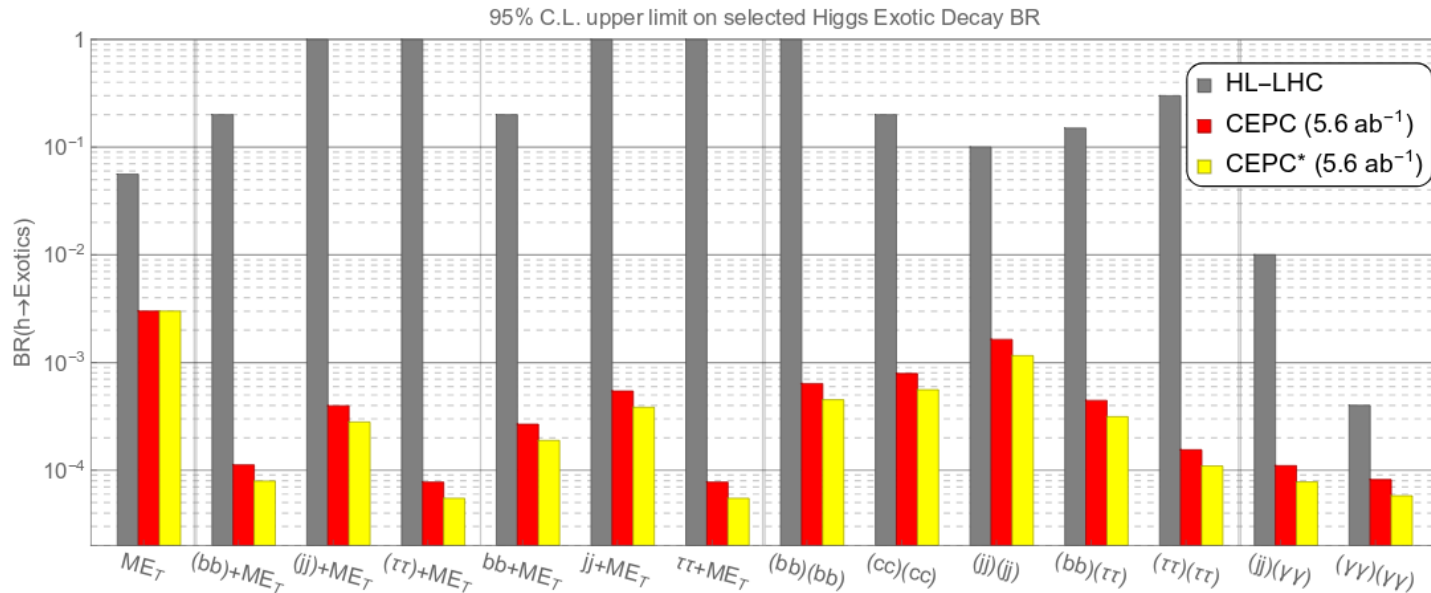


Figure 2.18: The 95% CL upper limit on selected Higgs exotic decay branching fractions at HL-LHC and CEPC, based on Ref. [117]. The benchmark parameter choices are the same as in Table 2.1. The red bars correspond to the results using only leptonic decays of the spectator Z-boson. The yellow bars further include extrapolation with the inclusion of the hadronic decays of the spectator Z-boson. Several vertical lines are drawn in this figure to divide different types of Higgs boson exotic decays.

[117] Z. Liu, L.-T. Wang, and H. Zhang, *Exotic decays of the 125 GeV Higgs boson at future e+e-lepton colliders*, Chin. Phys.C41(2017) no. 6, 063102, arXiv:1612.09284 [hep-ph]

Physics case: top

Top physics is absent in the CDR, but the top quark casts a long shadow

- precision EW is strongly affected by uncertainty on the top mass
- Higgs BR to gg , $\gamma\gamma$ and $Z\gamma$ are affected by top EW couplings in loops

Do not forget about the top.

If a linear collider is approved → study the potential of combined LC/CC fits

If CEPC is the only e^+e^- project → study the upgradability to $> 2 m_t$

Physics case: QCD

CEPC produces a large number of jets in a clean environment

The QCD chapter presents an appetizer for many potentially interesting studies

- measurement of α_s at higher scale/with reduced non-perturbative corrections
- measurement of non-global logs in the jet substructure observables
- light-quark Yukawa couplings using event shapes in ZH with $Z \rightarrow l^+l^-$ and $H \rightarrow jj$

A whole new tool box has developed since LEP, see [ArXiv:1704.04464](#)/[ArXiv:1803.06991](#)

Further work is highly encouraged to derive solid QCD prospects for the TDR

Physics case: flavour

CEPC produces a large number of bottom and charm and τ 's in the Z-pole run

The flavour physics chapter presents an appetizer for many interesting studies

- potentially competitive BR measurements for $B_s \rightarrow l^+ l^-$ (especially $\tau^+ \tau^-$)
- competitive results for $B \rightarrow K^{(*)} l^+ l^-$ analysis (especially $\tau^+ \tau^-$)
- $B \rightarrow K^{(*)} \nu \bar{\nu}$ and $\Lambda_b \rightarrow \Lambda \nu \bar{\nu}$
- LFV in τ decays similar to Belle II
- flavour-violating Z decays

This exploration (scaling LEP and Belle II results) is appreciated; turn into solid prospects for TDR

Further work is encouraged to explore the flavour physics potential for the TDR

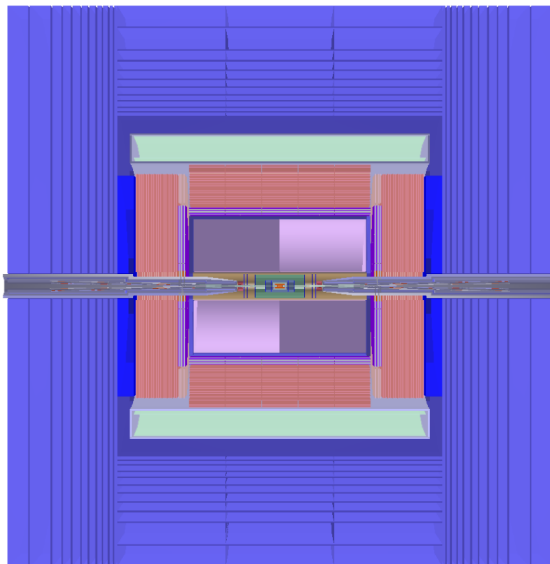
Physics case: summary of recommendations

“The review committee encourages the CEPC study group to extend the studies presented in the conceptual design report in several directions, keeping a close eye on new developments. A deeper understanding is needed of the synergy with the LHC and possible new hadron collider facilities, as well as the inter-relations between precision measurements in e^+e^- collisions at different center-of-mass energies. We encourage the CEPC study group to investigate the potential of the CEPC project for QCD, flavour and neutrino physics in greater depth.”

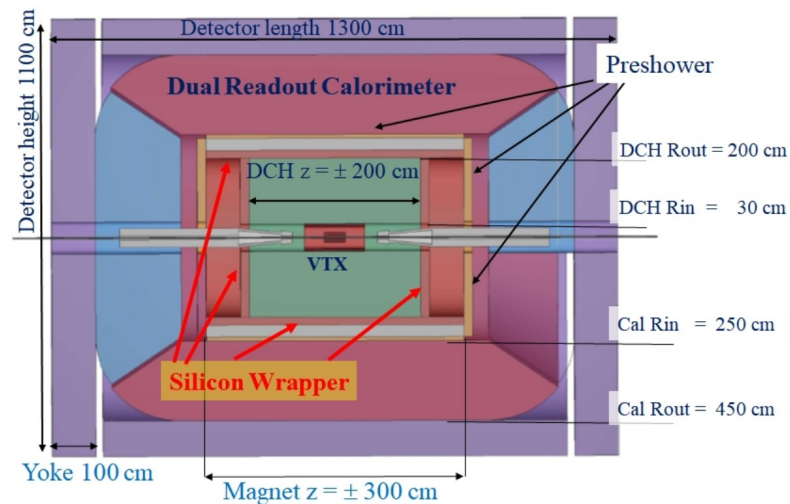
CEPC experiments: conceptual design

“The conceptual design of the CEPC experiments presents several solutions for the main detector subsystems. [...] It is plausible that the presented suite of subdetector technologies satisfy the stringent requirements of the CEPC precision physics programme.”

ILC-inspired “baseline”



Alternative “IDEA” detector



MV: I’m impressed by the speed at which Chinese groups, helped by int’l R&D collaborations and CEPC groups outside China, have set up the design and R&D effort

Detector R&D

The conceptual design of the experiment is based on a long-term, global detector R&D and design effort

CEPC needs to adapt the detector requirements and technologies to its specific environment (several examples later)

Detector R&D is never finished: continue to improve as long as possible

Detector R&D

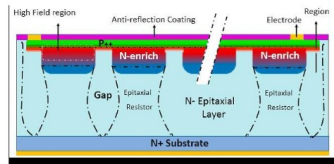
The conceptual design of the experiment is based on a long-term, global detector R&D and design effort

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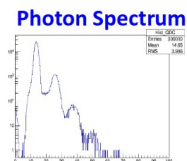
Detector R&D is never finished: continue to improve as long as possible

Hamamatsu MPPC vs NDL EQR SiPM
(epitaxial quenching resistors)

- Short recovery time
- High counting rate capability



NDL-SiPM 11-1010C (domestic)



NDL EQR-SiPM VS Hamamatsu MPPC

	NDL SiPM		Hamamatsu MPPC	
Effective Active Area	11-3030 B-S 3.0×3.0 mm ²	22-1414 B-S 1.4×1.4 mm ² (2×2 Array)	S13360-3025PE 3.0×3.0 mm ²	S13360-1325PE 1.3×1.3 mm ²
Effective Pitch	10 μm	10 μm	25 μm	25 μm
Micro-cell Number	90000	19600	14400	2668
Fill Factor	40%	40%	47%	47%
Breakdown Voltage (V _b)	23.7 ± 0.1V	23.7 ± 0.1V	53 ± 5V	53 ± 5V
Measurement Overvoltage (V)	3.3	3.3	5	5
Peak PDE	27% @ 420nm	35% @ 420nm	25% @ 450nm	25% @ 450nm
Max. Dark Count (kcps)	< 7000	< 1500	1200	210
Gain	2×10 ⁵	2×10 ⁵	7.0×10 ⁵	7.0×10 ⁵
Temp. Coef. For V _b	17mV/°C	17mV/°C	54mV/°C	54mV/°C

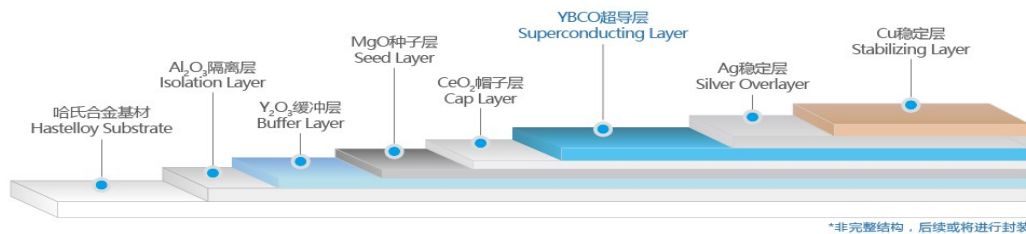
“It is very good to see active R&D in collaboration with Chinese industry to develop novel SiPMs.”

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Detector R&D is never finished: continue to improve as long as possible



From: Wei Zhao, CEPC CDR review

“The development of coils based on high-temperature superconductor in China is very relevant” [and not only for the IDEA detector concept...]

Detector concepts: towards the TDR

“The international experimental collaborations that are to design and build two competitive experiments for the CEPC must down-select the available sub-detector designs and integrate them into an integrated and coherent design that is optimized for overall performance. At this stage, the current, conceptual designs must be taken to the level of an engineered, technical design and the viability of key technologies must be demonstrated in large-scale prototypes.”

MV: this is a huge task, both at the technological and organizational level; on a time line that assigns 4 years to produce the TDR it becomes a truly heroic effort

Detector requirements

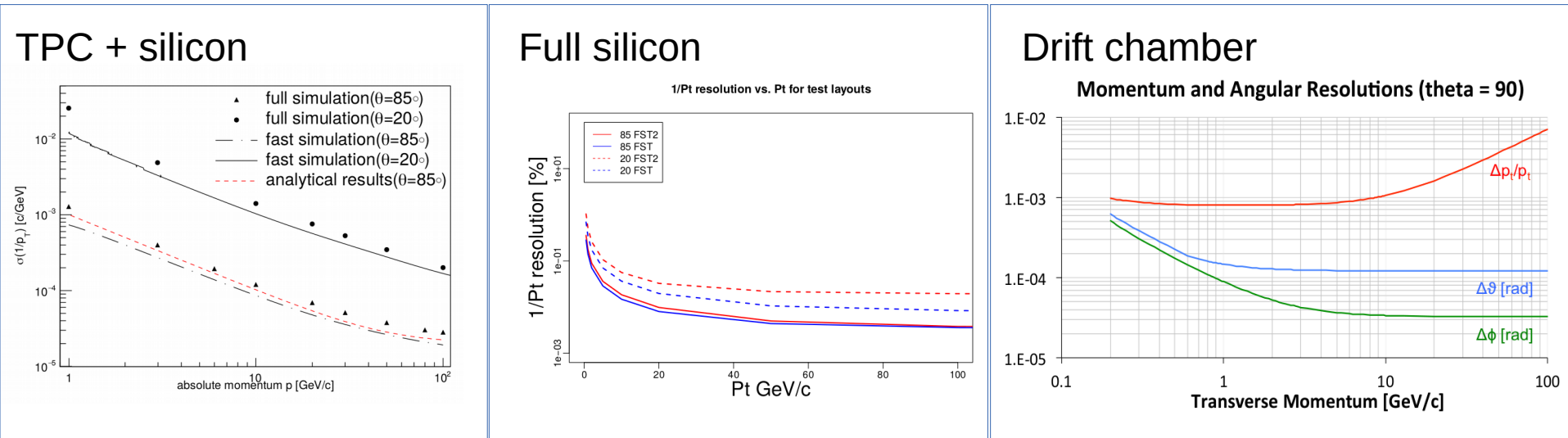
“We recommend that the benchmark studies for the detector performance be intensified, such that decisions are informed by a thorough understanding of the impact of the design on the scientific return of the project.”

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \rightarrow e^+e^-, \mu^+\mu^-$ $H \rightarrow \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\text{BR}(H \rightarrow \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\text{GeV}) \sin^{3/2} \theta}$
$H \rightarrow b\bar{b}/c\bar{c}/gg$	$\text{BR}(H \rightarrow b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\text{GeV}) \times \sin^{3/2} \theta} (\mu\text{m})$
$H \rightarrow q\bar{q}, WW^*, ZZ^*$	$\text{BR}(H \rightarrow q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\text{jet}}/E =$ $3 \sim 4\% \text{ at } 100 \text{ GeV}$
$H \rightarrow \gamma\gamma$	$\text{BR}(H \rightarrow \gamma\gamma)$	ECAL	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\text{GeV})}} \oplus 0.01$

Table 3.3: Physics processes and key observables used as benchmarks for setting the requirements and the optimization of the CEPC detector.

MV: the table shows, of course, that you are well aware of this. Implement this work flow fully and uniformly across the different sub-system options.

Detector performance: example



Momentum resolution offered by three solutions for the main tracker

Do they provide the required resolution? Which is the best tracker? Not easy to tell!

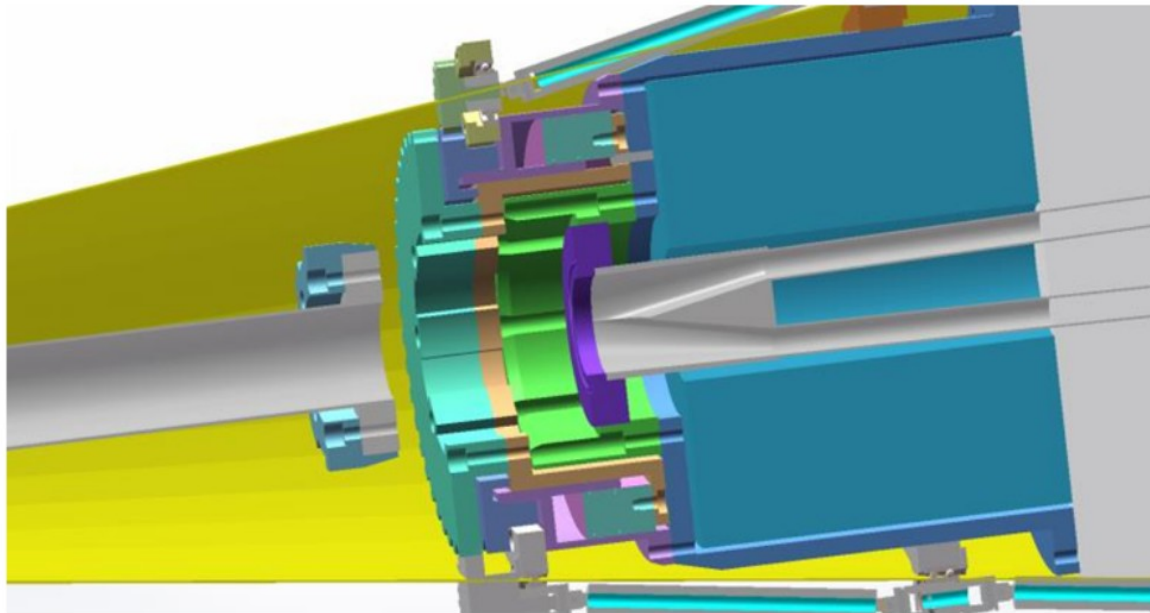
Underlying problem: a common full-simulation code does not exist yet

Report: "A comparison on an equal footing should be possible of all sub-detector options, using a detailed Monte Carlo simulation including the relevant background processes"

CEPC: specific 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

CEPC specific challenges

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

(1.5) “The machine-detector-interface issues pose severe challenges on the overall design of CEPC. In particular, the beam-induced backgrounds are notoriously difficult to predict and could impose limits on the luminosity and detector performance.”

It is crucial that the MDI group ensures an efficient communication between the machine and detector design groups.

CEPC: specific 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

CEPC: specific challenges

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

(3) “With the 100% duty cycle of the machine the power management of the subdetectors becomes a priority.”

Power-pulsing cannot be used to reduce average power consumption

The ILC designs must be revised thoroughly to deal with this additional challenge

Conceptual designs exist for CALO, but VXD and tracker need more work

Summary, in my own wording

CEPC is an exciting option; possibly even contiguous with HL-LHC?

- not much time to decide on governance and international contributions

The physics case:

- case for Higgs and EW precision physics is clear:

"CEPC has the opportunity and capability to make **landmark** measurements within the SM" (C. Grojean)

- good work on BSM potential through rare decays
- first exploration of QCD and flavour physics
- don't forget about the top quark!

The detector concept:

- all the pieces are in place: plausible sub-detector options
- experimental design to be fully adapted to CEPC environment
- extend full-simulation infrastructure to all options for fair comparisons
- it's not done yet: encourage CEPC-specific detector R&D

I wish CEPC the best of luck in the preparation of the TDR!