LumiCal Design for CEPC

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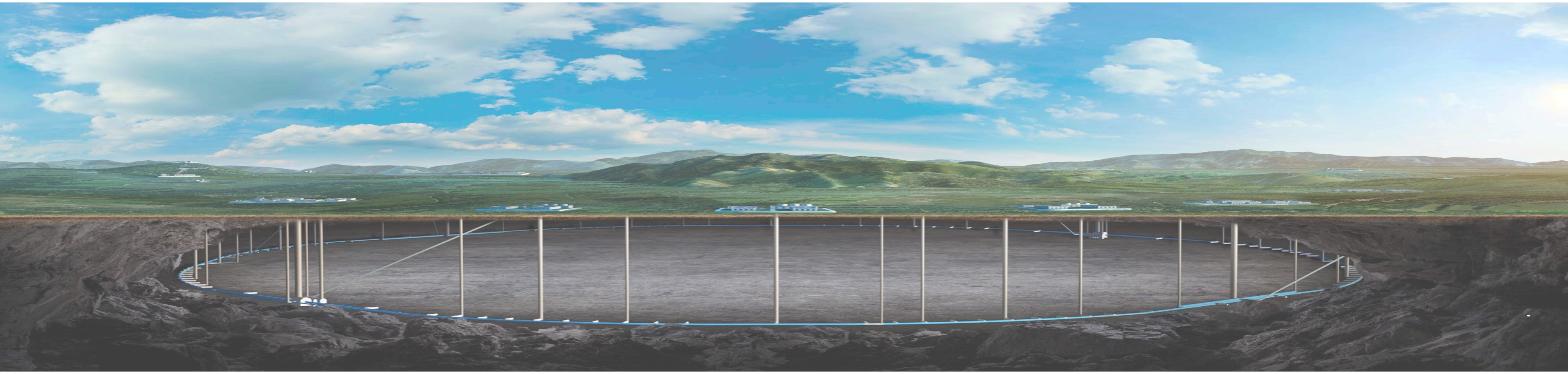
On behalf of the CEPC MDI Study Group



35th FCAL workshop on Forward Calorimetry at Future Linear Collider, 19 - 20 September 2019, Hamburg

OUTLINE

- Introduction to **CEPC**
- Luminosity measurement
- LumiCal design in CDR
- Revised LumiCal design
- Summary

CIRCULAR ELECTRON POSITRON COLLIDER (CEPC)

- Phase I: Circular Electron-Positron Collider (CEPC)
  - Higgs Factory, CM energy ~240 GeV (*ZH* threshold), peak luminosity >3 × 10^{34} $cm^{-2}s^{-1}$, 2 interaction points (IP)
    → Higgs precision measurements (mass, width, branching ratios, couplings, etc.)
  - Operation at 91/160 GeV → EW precision measurements

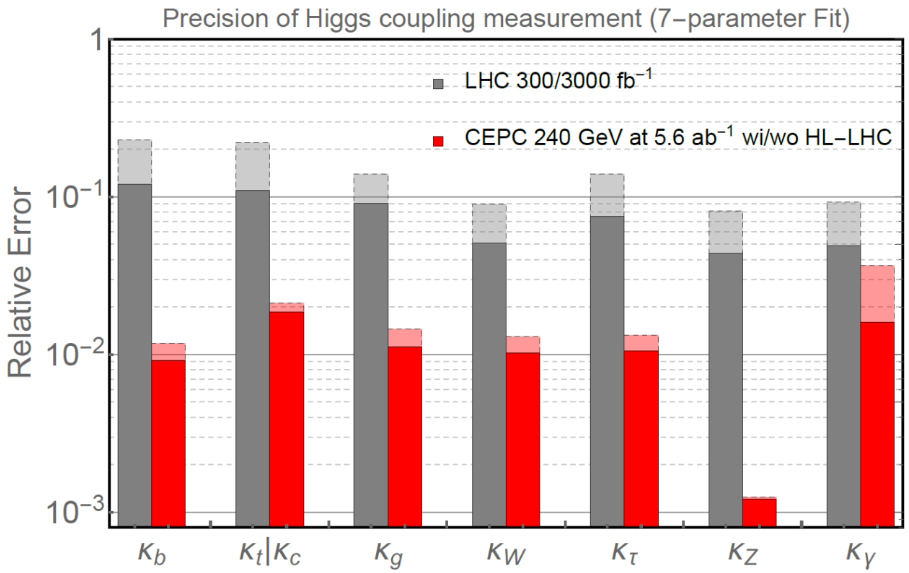
- Phase II: Super Proton-Proton Collider (SppC)
  - Discovery machine, center-of-mas energy 50 - 100 TeV, peak luminosity ~1 × 10^{35} $cm^{-2}s^{-1}$, 2 IP → energy frontier for New Physics
  - Other possible collision modes: *ep, eA, pA or AA*

Higgs Precision Measurement

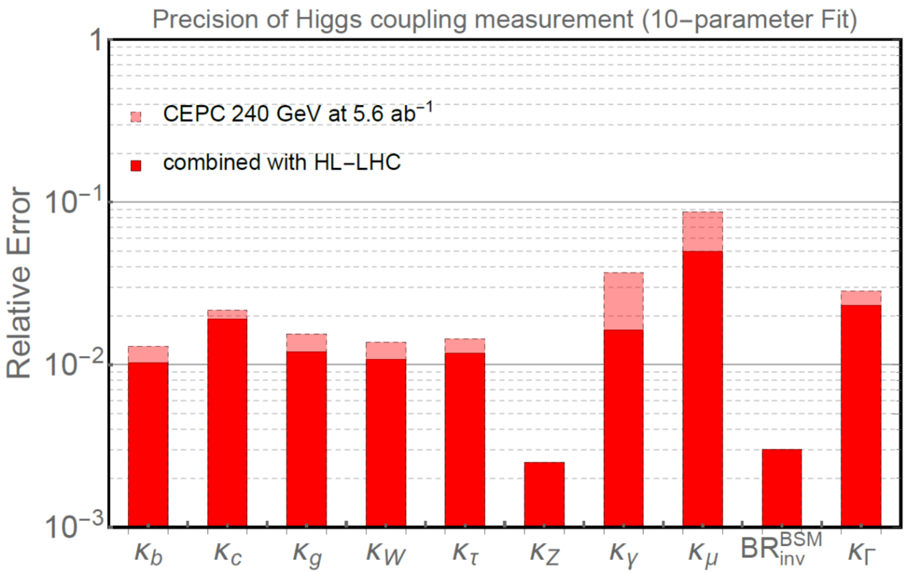
- Higgs coupling deviations from the Standard Model (SM) predictions parameterized as:

$$\kappa_f = \frac{g(hff)}{g(hff;\mathrm{SM})}, \kappa_V = \frac{g(hVV)}{g(hVV;\mathrm{SM})}$$

Model-dependent fit:



Model-independent fit:



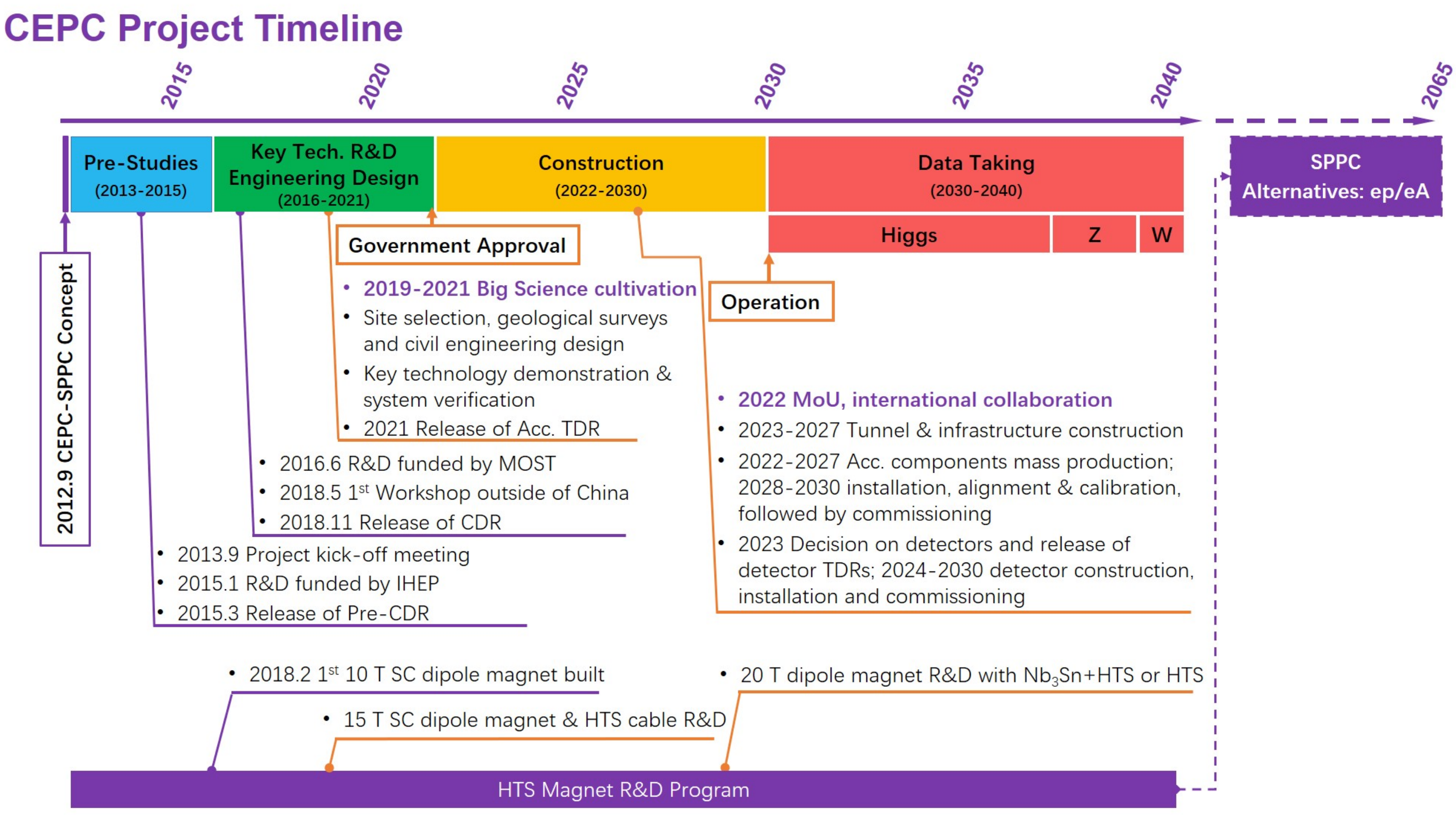
ELECTROWEAK PRECISION MEASUREMENTS

- Precision measurements with reduced uncertainties:

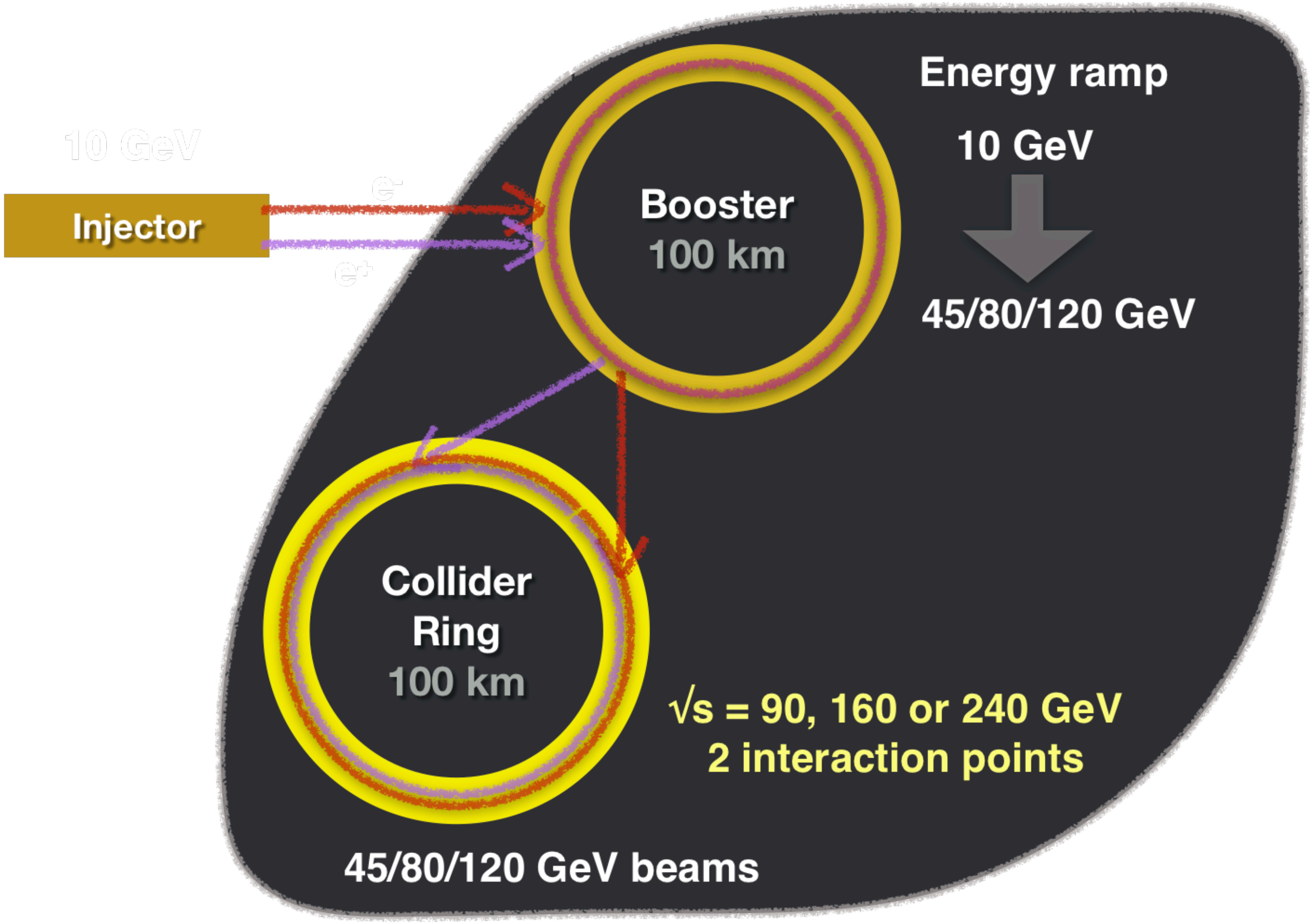
$$R_b, A_{FB}^b, \sin\theta_W^{eff}, m_Z, m_W, N_\nu \cdots$$

	Present data	CEPC fit
$\alpha_s(M_Z^2)$	0.1185 ± 0.0006 [23]	$\pm 1.0 \times 10^{-4}$ [24]
$\Delta\alpha_{\rm had}^{(5)}(M_Z^2)$	$(276.5 \pm 0.8) \times 10^{-4}$ [25]	$\pm 4.7 \times 10^{-5}$ [26]
m_Z [GeV]	91.1875 ± 0.0021 [27]	$\pm\mathbf{0.0005}$
m_t [GeV] (pole)	$173.34 \pm 0.76_{\rm exp}$ [28] $\pm 0.5_{\rm th}$ [26]	$\pm 0.2_{\rm exp} \pm 0.5_{\rm th}$ [29, 30]
m_h [GeV]	125.14 ± 0.24 [26]	$< \pm 0.1$ [26]
m_W [GeV]	$80.385 \pm 0.015_{\rm exp}$ [23] $\pm 0.004_{\rm th}$ [31]	$(\pm \mathbf{3}_{\rm exp} \pm 1_{\rm th}) \times 10^{-3}$ [31]
$\sin^2\theta_{\rm eff}^{\ell}$	$(23153 \pm 16) \times 10^{-5}$ [27]	$(\pm \mathbf{2.3}_{\rm exp} \pm 1.5_{\rm th}) \times 10^{-5}$ [32]
Γ_Z [GeV]	2.4952 ± 0.0023 [27]	$(\pm \mathbf{5}_{\rm exp} \pm 0.8_{\rm th}) \times 10^{-4}$ [33]
$R_b \equiv \Gamma_b/\Gamma_{\rm had}$	0.21629 ± 0.00066 [27]	$\pm \mathbf{1.7} \times 10^{-4}$
$R_\ell \equiv \Gamma_{\rm had}/\Gamma_\ell$	20.767 ± 0.025 [27]	$\pm\mathbf{0.007}$

Project Timeline (Ideal)

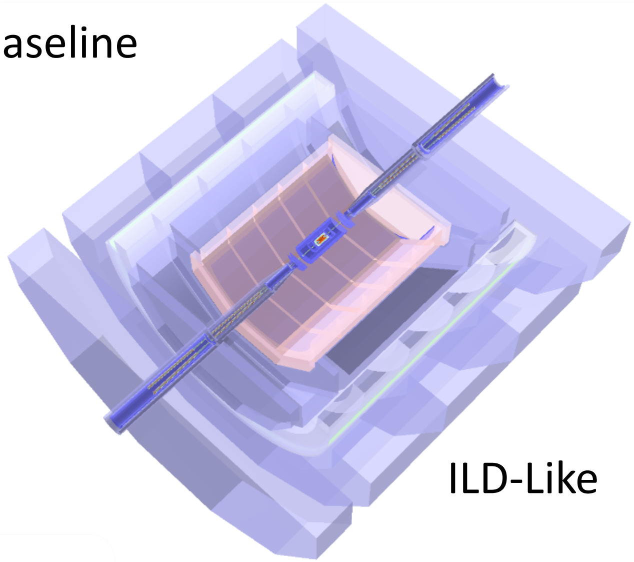


MACHINE DESIGN

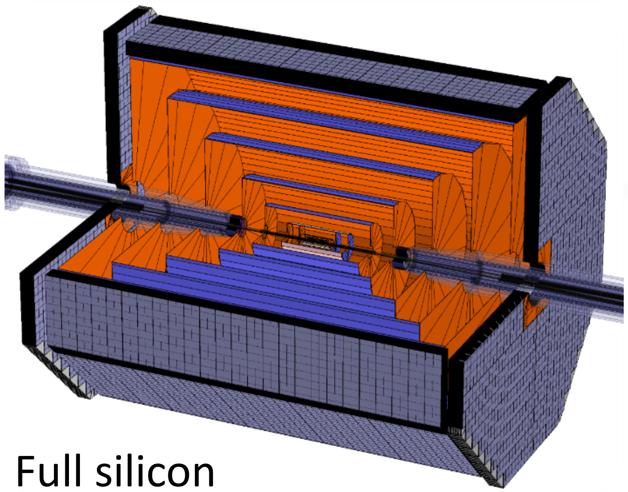


DETECTOR CONCEPTS

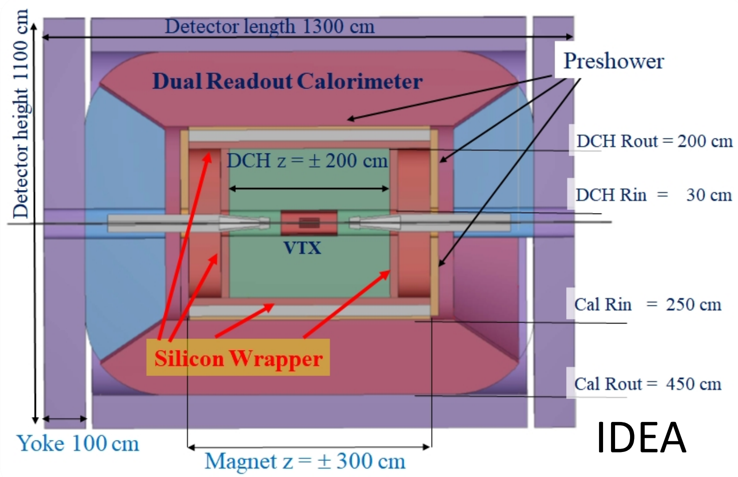
Baseline



ILD-Like



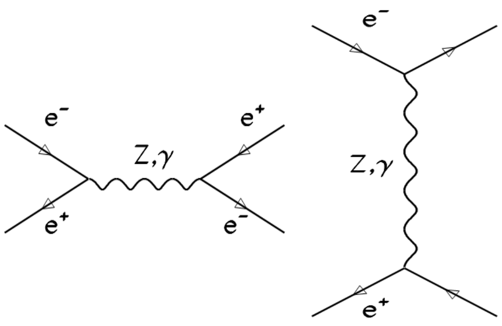
Full silicon



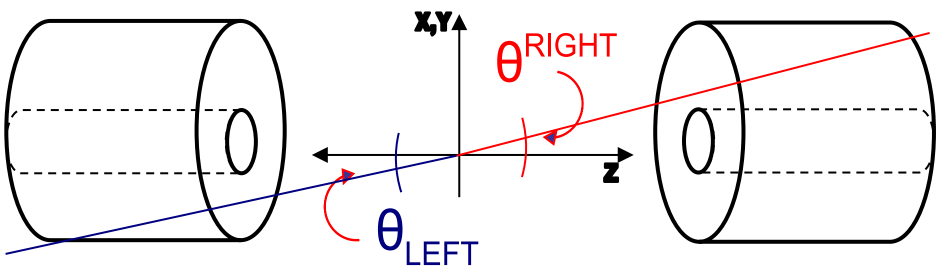
IDEA

Luminosity Measurement

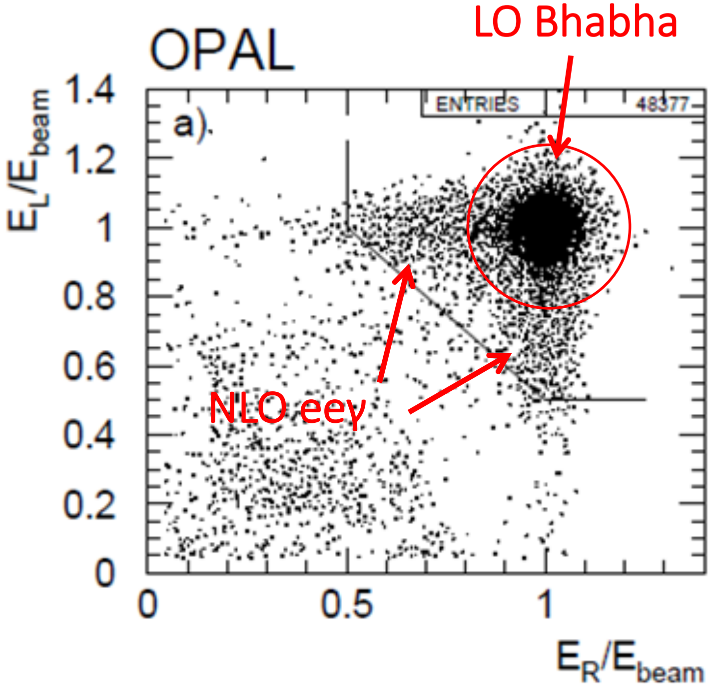
- High precision required for Higgs & EW precision measurements
- Detection of Bhabha elastics scattering
  - QED process, theoretical error to <0.1%
  - Triggering on a pair of scattered



$$\sigma = \frac{16\pi\alpha^2}{s}\left(\frac{1}{\theta^2_{min}} - \frac{1}{\theta^2_{max}}\right)$$



$\Delta\theta \equiv \theta_{RIGHT} - \theta_{LEFT}$



PRECISION REQUIREMENT

- Luminosity measurement by counting Bhabha events in a fiducial θ region

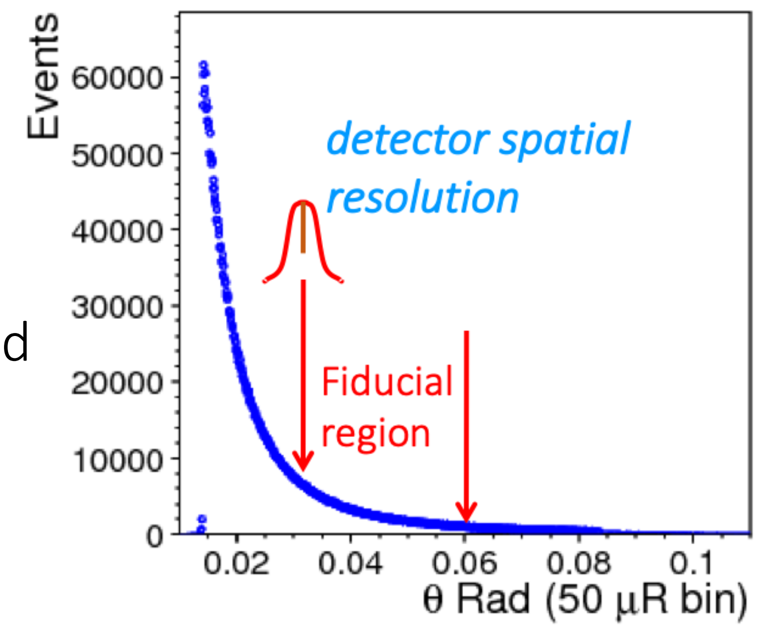
$$\sigma = \frac{16\pi\alpha^2}{s}\left(\frac{1}{\theta^2_{min}} - \frac{1}{\theta^2_{max}}\right)$$

$$\mathcal{L} = \frac{1}{\varepsilon}\frac{N_{\rm acc}}{\sigma^{\rm vis}}$$

- Dominant systematic uncertainty

$$\Delta L/L \sim 2\Delta\theta/\theta$$

- To achieve precision: $\Delta L/L < 10^{-3}$
  - LumiCal at z= ±1 m, θ_{min}= 30 mrad
    → Δθ = 15 μrad or Δ r = 15 μm
  - Error due to offset on Z → 0.1 mm on z or Δ r = Δ Rxθ = 3 μm



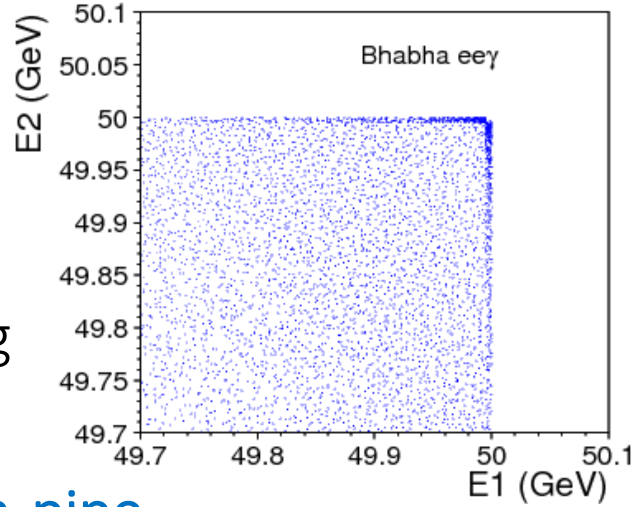
*Offset on the **mean of spatial resolution** = **offset on** θ_{min}*

*→dominant **luminosity error***

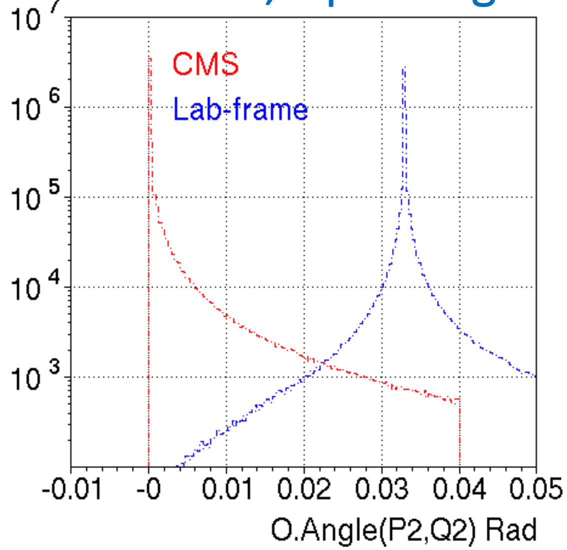
Beam Crossing Angle

- **BHLUMI theoretical precision <0.05%**
  - LO elastic e^+e^- scattering dominant
  - $E(e^+) = E(e^-) = E_{beam}$, Open Angle = π
- CMS(e^+e^-) boosted by the beam crossing
- $e^\pm$ boosted ~16.5 mrad off ring-center

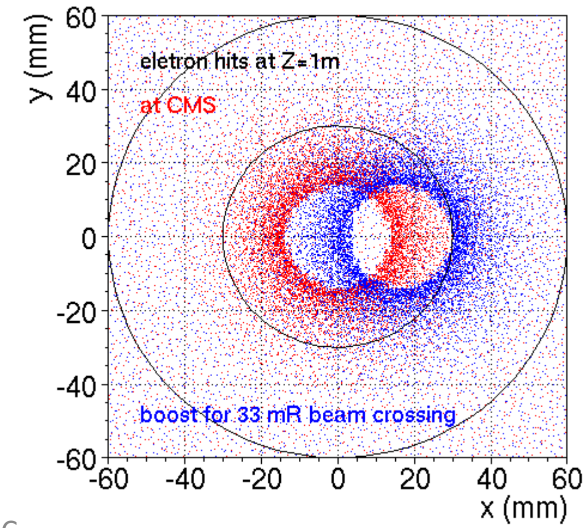
→back-to-back offset → $e^\pm$ lost into beam-pipe



Bhabha e^+e^-, Open angle $-\pi$



Bhabha e^- @detector r-ϕ, z=1m



Boosted Bhabha Events

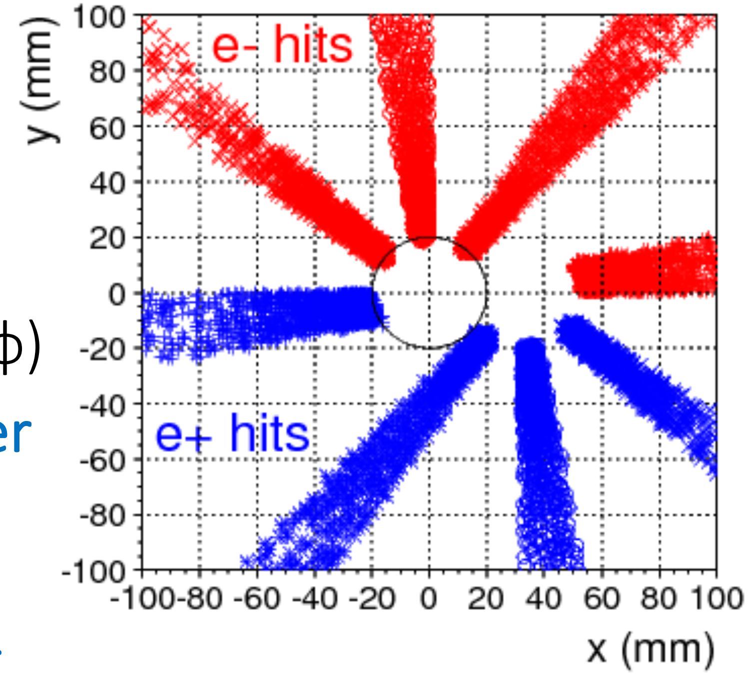
BHLUMI to simulate colliding e^+e^- back-to-back

Boost CEPC crossing angle of 33 mrad

Boost BHLUMI e^+, e^- to CEPC → *E is larger by ~0.01%*

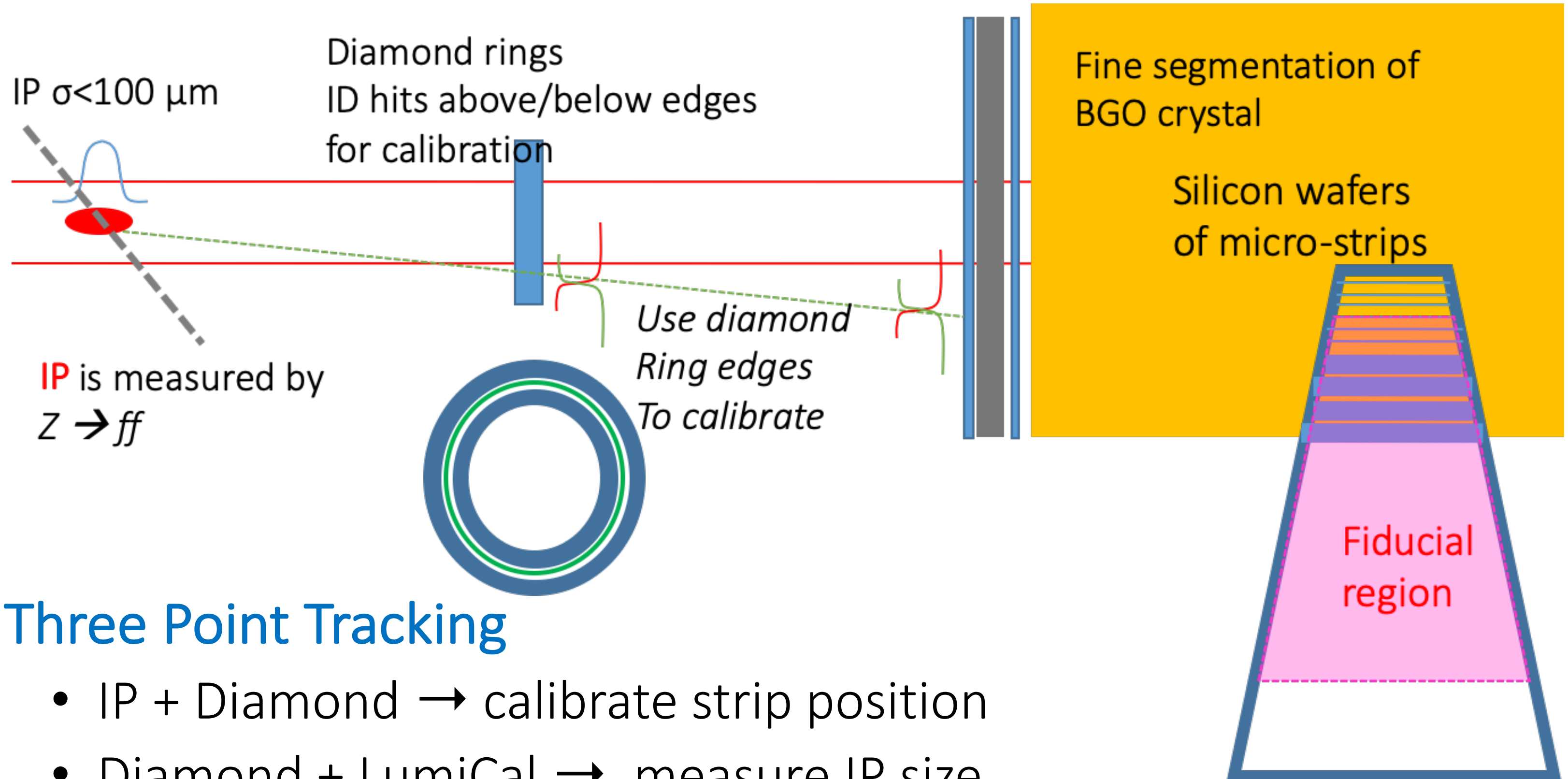
Ebeam = 50 GeV → boosted E = 50.0068 GeV

- Boosted LO Bhabha (e^+e^-, no γ)
- e^+ and e^- detected in fiducial acceptance of r > 20 mm
- r-ϕ plotted in bands (every 45 deg in ϕ)
- Event loss 163 nb → 98 nb (50 nb after selection)
    - Loss is SIGNIFICANT
    - LumiCal with a small inner r, in OVAL shape if feasible



Hits on detector x-y planes @z=1m

Tracking Ring

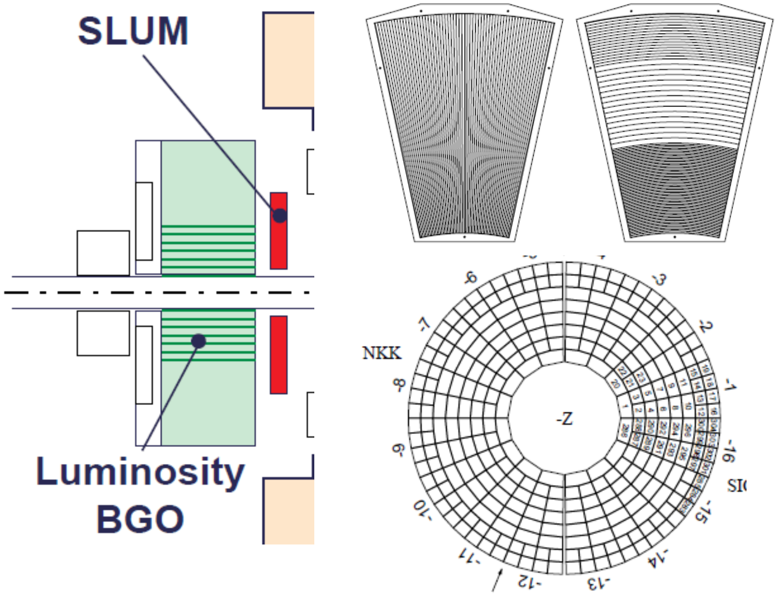


- Three Point Tracking
  - IP + Diamond → calibrate strip position
  - Diamond + LumiCal → measure IP size
- Calibrate offset of the mean of error at inner radius
  - Silicon strip resolution ~ 5 µm, error on mean much smaller to reach 1 µm → possible to reach $\Delta L/L$ ~ 0.01 % (challenging)

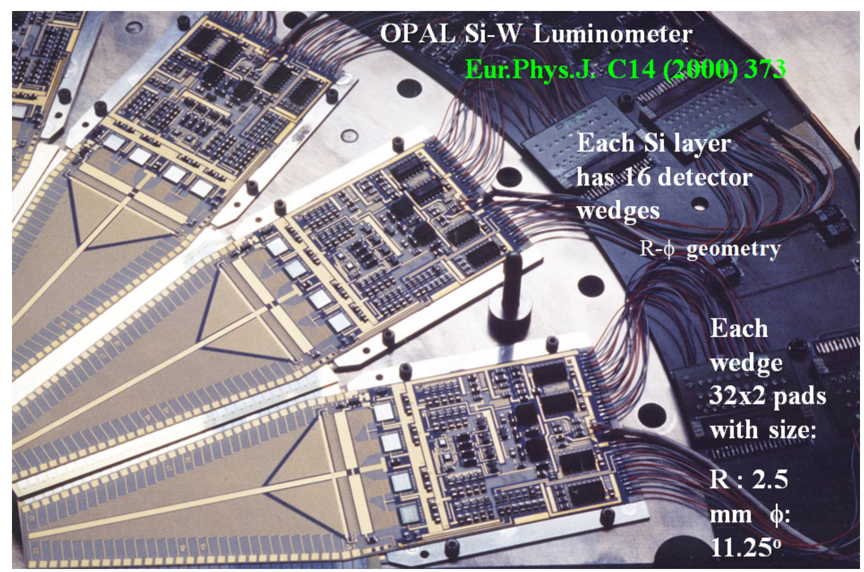
DETECTOR TECHNOLOGIES

- Luminosity precision~ $e^{\pm}$ detection at inner radius of fiducial
  - Silicon strip can reach required precision
  - Alignment precision difficult to reach 1 µm
  - Wide strip (~2mm) CAN NOT reach 10 µm resolution
  - A stand-alone LumiCal CAN NOT calibrate its offsets to IP

L3 Silicon layer + BGO

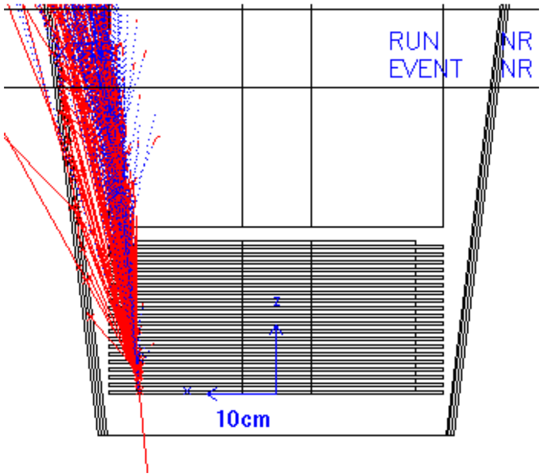


OPAL Si-W sandwich

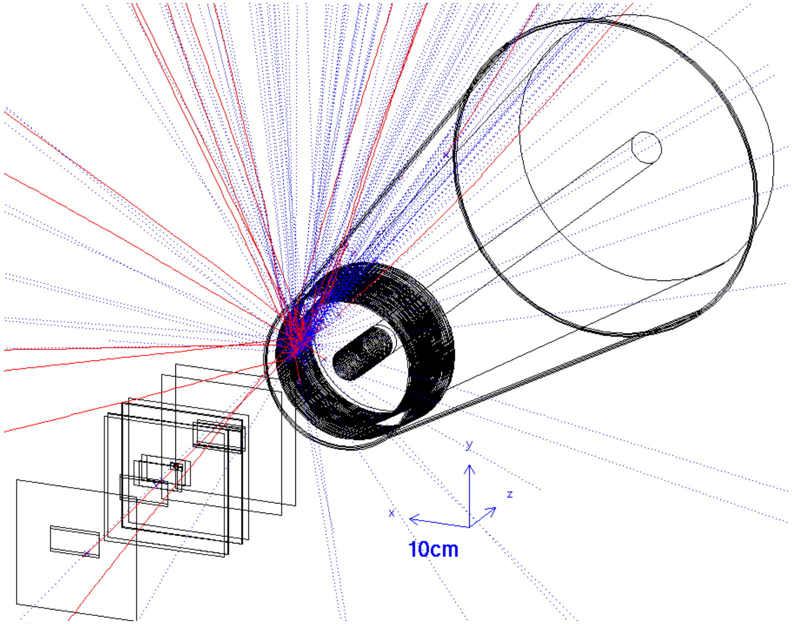


Silicon-Tungsten

- Detector assembly:
  - First layer: high resolution tracking for electron hit r, ϕ position
  - Energy resolution: Si-wafer detector for charged particles; MIP of Landau ionization charge; EM shower = # of charged particles



- $e^{\pm}/\gamma$ Identification:
  - Photon without hit on Si-wafer, fragmentation after ~1 X_0
  - Photon ID: EM shower without hit on 1st layer
  - photon spatial resolution: calorimeter segmentation



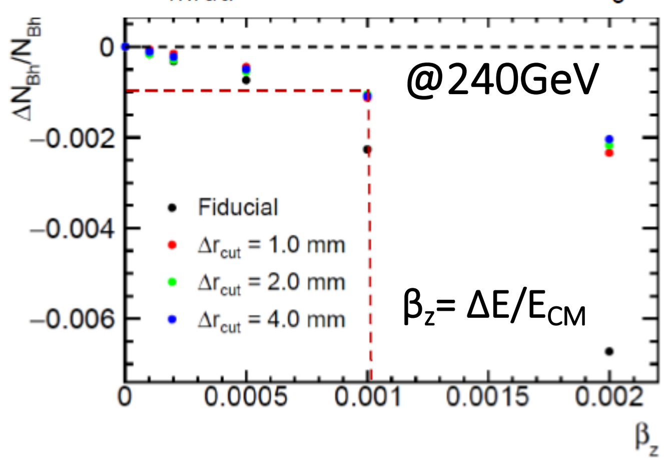
Systematic Uncertainties

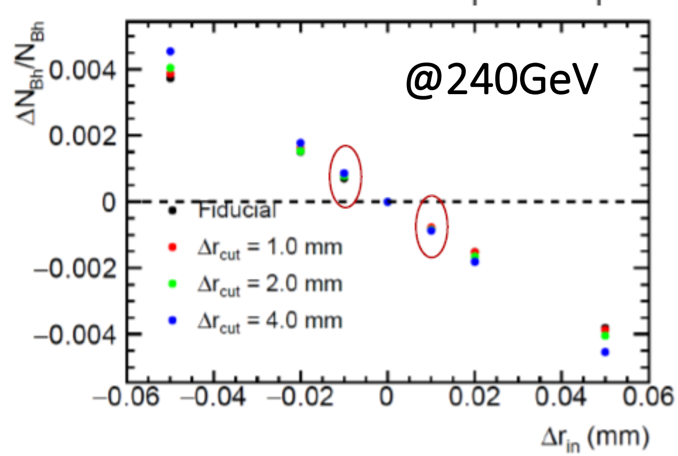
$\Delta L/L \sim 10^{-3}$ @ Higgs

Parameter	unit	limit (Fiducial)	limit (LEP style)
ΔE_{CM}	MeV	120	120
$E_{e^+} - E_{e^-}$	MeV	120	240
$\frac{\delta\sigma_{E_{beam}}}{\sigma_{E_{beam}}}$		20%	Effect cancelled
Δx_{IP}	mm	0.1	1
Δz_{IP}	mm	1.4	10
Beam synchronisation	ps	1	15
$\sigma_{x\,IP}$	mm	0.1	1
$\sigma_{z\,IP}$	mm	1	10
r_{in}	µm	13	10
$\sigma_{r_{shower}}$	mm	0.15	1
Δd_{IP}	mm	1	1
$\Delta\varphi_{tilt}$	mrad	6	6

$\Delta L/L \sim 10^{-4}$ @ Z-pole

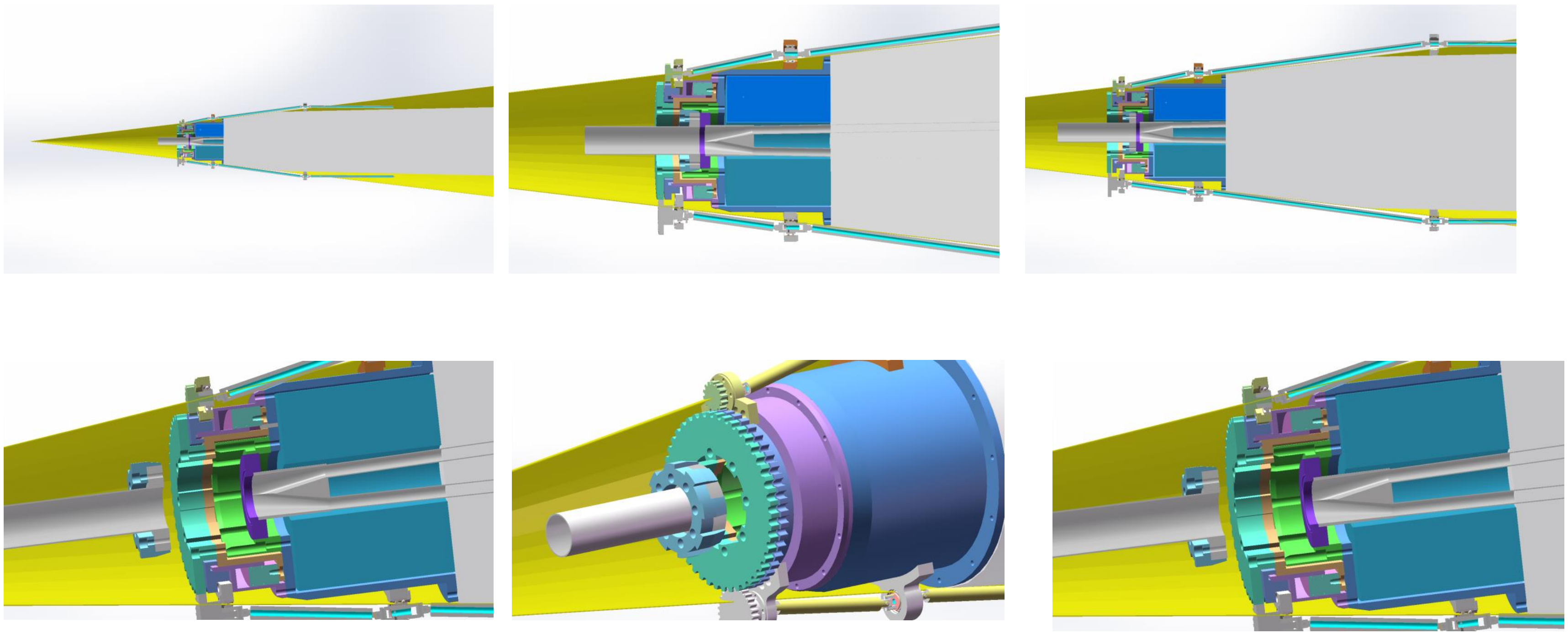
Parameter	unit	limit
ΔE_{CM}	MeV	4.5
$E_{e^+} - E_{e^-}$	MeV	11
$\frac{\delta\sigma_{E_{beam}}}{\sigma_{E_{beam}}}$		Negligible up to at least factor 2
Δx_{IP}	mm	0.5
Δz_{IP}	mm	2
Beam synchronisation	ps	3
$\sigma_{x_{IP}}$	mm	0.5
$\sigma_{z_{IP}}$	mm	7
r_{in}	µm	1
$\sigma_{r_{shower}}$	mm	0.2
Δd_{LC}	µm	80
$\Delta\phi$	mrad	0.8





Installation Scheme

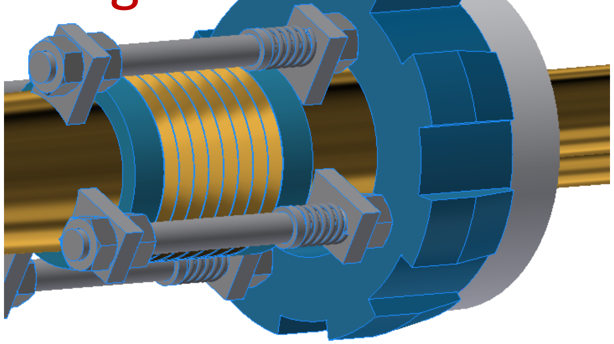
- No easy solution to install all the critical components in the interaction region with high precision; inspired by the Remote Vacuum Connection (RVC) developed by SuperKEKB

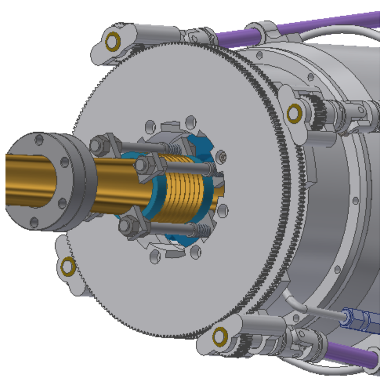


CAVEAT

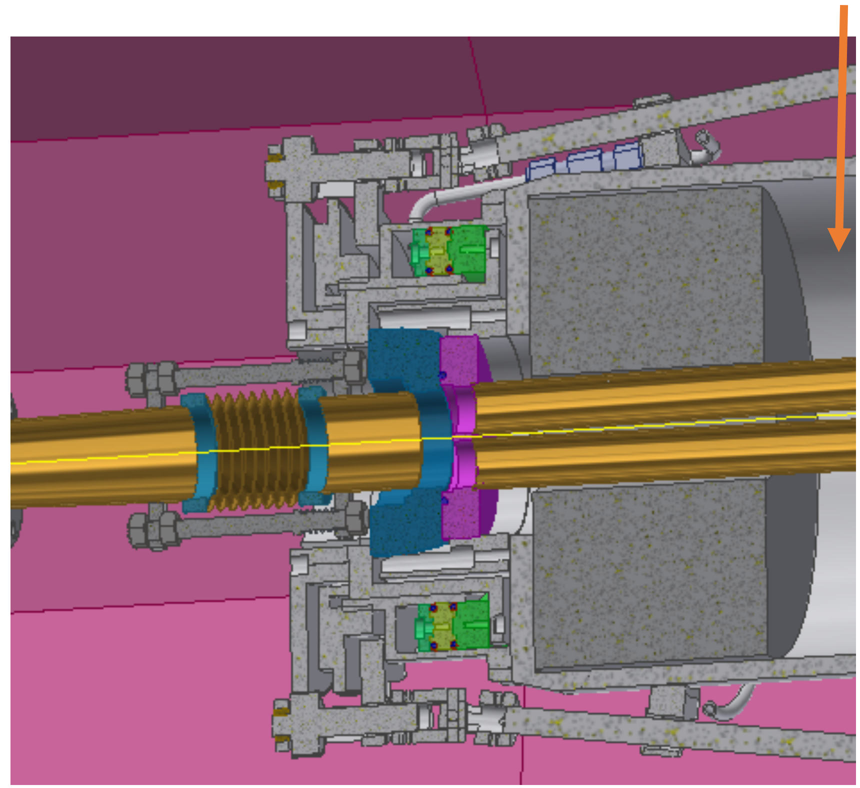
- LumiCal (20 cm long, radiation length of >20 X_0) mounted on the quadrupole and inserted together into the interaction region, BUT too much material in front

Flange

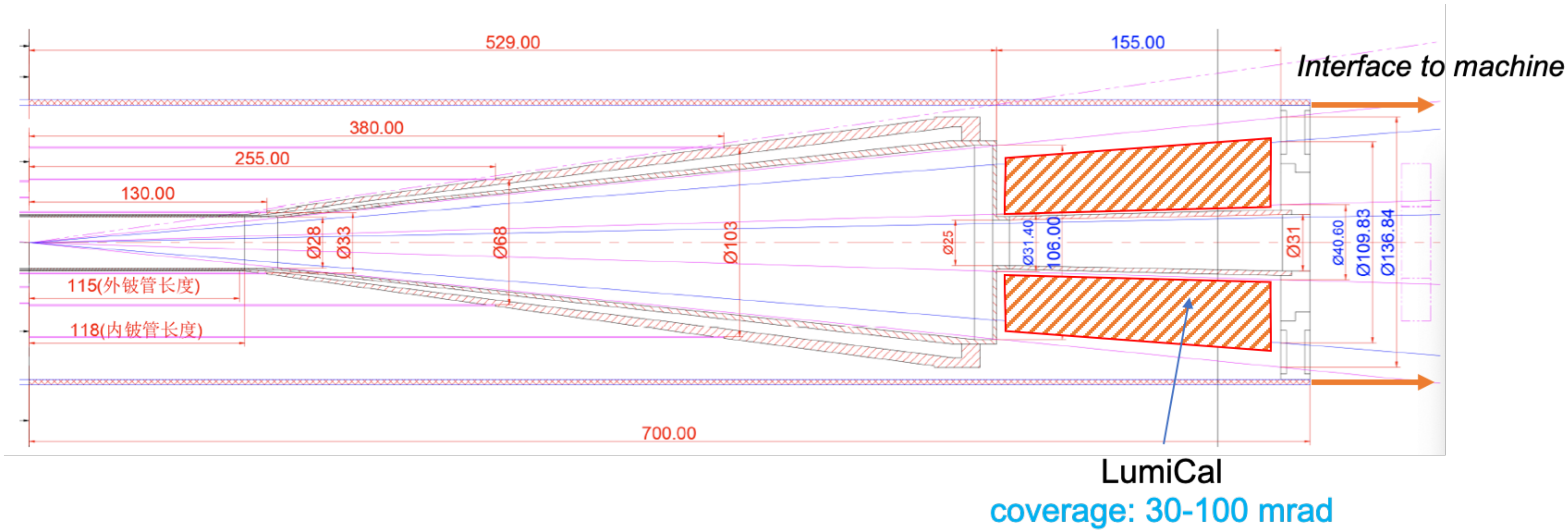




LumiCal position



MOVING LUMICAL CLOSER TO IP



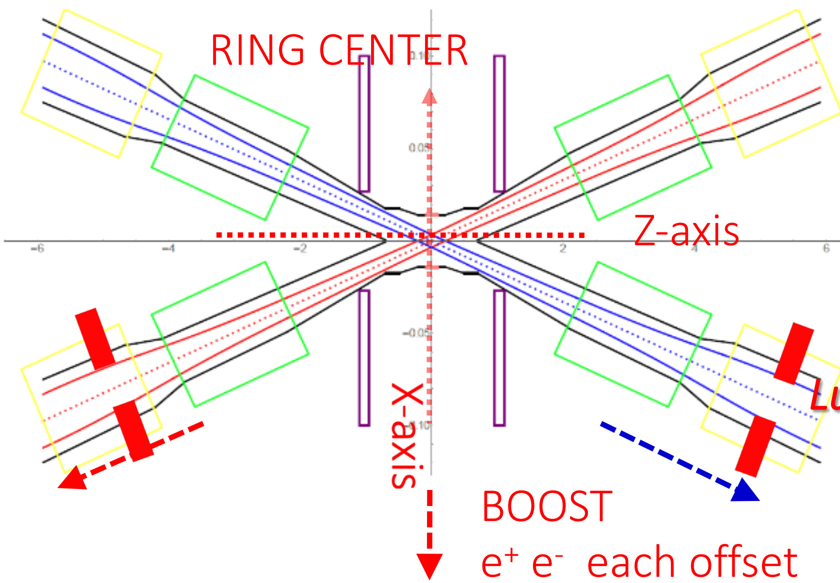
- **New**: LumiCal with reduced weight mounted on the beampipe instead, together with a supporting structure to mitigate the deformation of the central beryllium beampipe

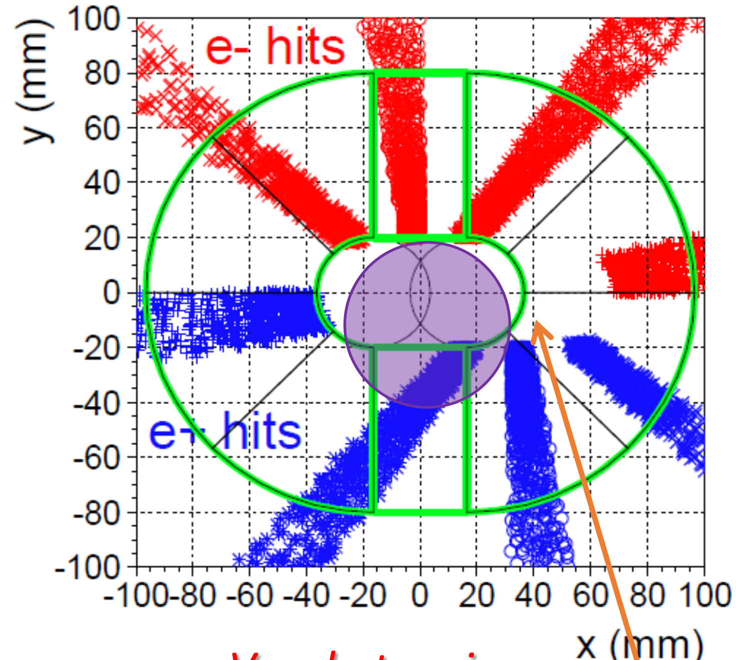
RE-ESTIMATION

Beam crossing: 33 mRad

→ Boost off ring center (+x axis)
→ offset 16.5 mrad maximum
(electrons on x-z plane)

LOW angle Bhabha on x-axis
one electron detected (+x side)
the other electron (-x side)
is boosted into beam-pipe
NOT counted for Lumi measurement





Very hot region,
Low angle Bhabha
boosted outward

Proposal:
Insert Crystal Scint. LumiMon on outgoing pipe
to trigger/back-to-back for Bhabha <50 mrad on x-axis
with one electron lost into beam pipe

SUMMARY

- **CEPC** proposed as a Higgs Factory for precision Higgs (& EW) measurements, with the possible upgrade to **SppC**
- HIGH LUMINOSITY PRECISION required for Higgs & EW precision measurements → challenges on LumiCal design (in the crowed interaction region)

- Revised LumiCal design toward TDR
  - Design evaluation, uncertainty re-estimation, detector R&D

- Currently involved institutions: IHEP, VINCA, SINCA, NCU …

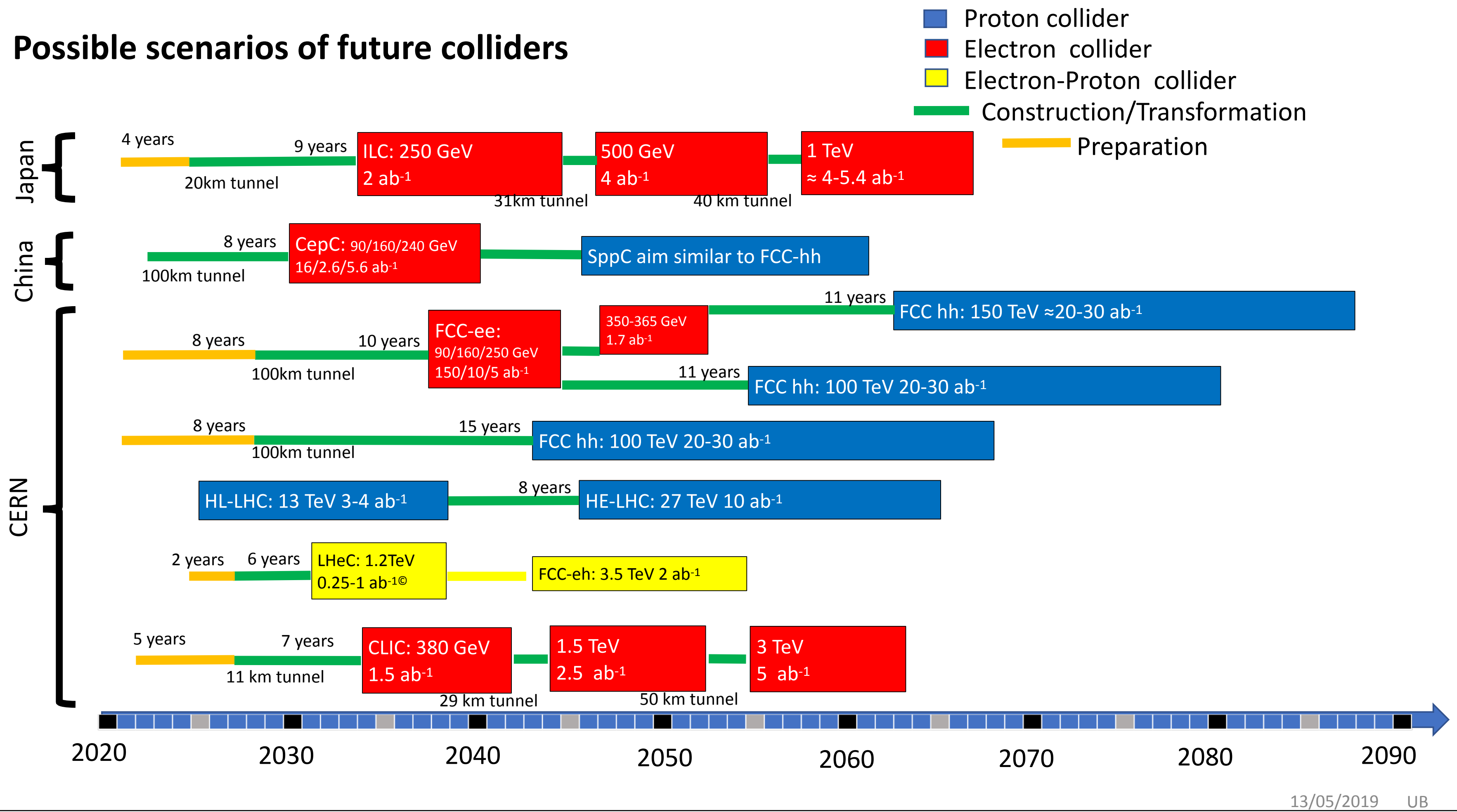
Any interest to join and help us?

CEPC November Workshop

IHEP, Beijing: November 18-20

https://indico.ihep.ac.cn/event/9960/

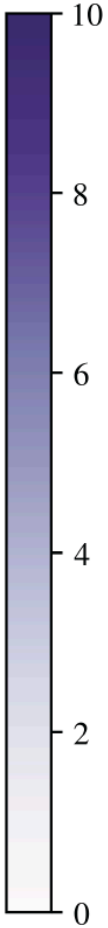
FUTURE COLLIDERS



PRECISION ON HIGGS COUPLINGS

	LHeC	HE-LHC	ILC_{250}	ILC_{500}	$CLIC_{380}$	$CLIC_{1500}$	$CLIC_{3000}$	CEPC	$FCCee_{240}$	$FCCee_{365}$	FCCee/eh/hh
g^{eff}_{HZZ}	1.7	1.2	7.7	≥ 10	5.5	≥ 10	≥ 10	6.9	7.7	≥ 10	≥ 10
g^{eff}_{HWW}	1.8	1.3	6.7	≥ 10	4.9	≥ 10	≥ 10	6.3	7.0	≥ 10	≥ 10
$g^{\text{eff}}_{H\gamma\gamma}$	1.7	1.3	2.8	3.4	2.6	3.1	3.4	3.1	3.1	3.1	≥ 10
$g^{\text{eff}}_{HZ\gamma}$	1.1	2.4	1.1	1.6	1.1	2.3	3.0	1.7	1.1	1.2	≥ 10
g^{eff}_{Hgg}	1.4	1.7	2.0	2.8	1.7	2.3	2.9	2.8	2.3	2.7	4.5
g^{eff}_{Htt}	1.1	1.7	1.1	1.2	1.1	1.4	1.4	1.1	1.1	1.1	1.8
g^{eff}_{Hcc}	⋆		⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆
g^{eff}_{Hbb}	2.7	1.5	6.1	9.8	5.1	≥ 10	≥ 10	7.6	7.3	9.1	≥ 10
$g^{\text{eff}}_{H\tau\tau}$	1.6	1.3	4.1	5.8	2.7	3.8	4.8	5.0	5.0	6.1	7.8
$g^{\text{eff}}_{H\mu\mu}$	1.2	1.8	1.3	1.4	1.3	1.4	1.6	1.4	1.4	1.4	≥ 10
$\delta g_{1Z}[\times 10^2]$	1.3	1.4	6.7	≥ 10	≥ 10	≥ 10	≥ 10	7.3	7.8	≥ 10	≥ 10
$\delta\kappa_\gamma[\times 10^2]$	1.3	1.2	≥ 10	≥ 10	≥ 10	≥ 10	$\geq 10^2$	≥ 10	≥ 10	≥ 10	≥ 10
$\lambda_Z[\times 10^2]$	1.1	1.0	≥ 10	$\geq 10^2$	≥ 10	$\geq 10^2$	$\geq 10^3$	≥ 10	≥ 10	≥ 10	≥ 10

SMEFT ND (⋆) not measured at HL-LHC



IAC RECOMMENDATIONS

Report:

The Second Meeting of
the CEPC (SppC) International Advisory Committee

November 20, 2016

- CEPC still looks like a Chinese project owned by China. It is important to find a mechanism that allows the international community to take some sense of ownership. In order to get international support and participation, the scope of the CEPC project must be clear, and its science case and future opportunities must be powerful and attractive to the international community.
- It is critical to get CEPC onto the regional strategic plans such as the European Strategy (ES) and the P5 in the U.S. through grassroots community support. LP 2017, LHCP 2017 and TIPP 2017, which will take place in China in 2017, will bring significant parts of the international community to China and will provide opportunities to build relationships with potential international partners.
- To enhance international participation, the IAC believes that CEPC working groups should be co-led by a Chinese and a foreign member, and advises to set up an International Steering Committee for the R&D phase.

China to initiate big science projects

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China to initiate big science projects

Updated: Mar 28,2018 6:57 PM english.gov.cn

China will play an active role in significant international scientific research projects, as planned by the State Council.

Since China is keen to enhance its innovation competence and have influence in the international arena, it regards organizing big science projects as a powerful tool to solve key global scientific issues and aggregate cutting-edge scientific resources, as well as to construct a global innovation governance system. In that, scientific diplomacy will help to enhance cooperation with other countries.

The short-term goal for the big science project plan is to cultivate three to five projects by 2020, and select and initiate one to two big science projects, then form a nascent mechanism of organizing big science projects.

By mid-century, a slew of such projects will be incubated, and China will play a big role in global scientific innovation governance system while continuing to make contributions to solving major global scientific issues.