Physics at CEPC future electron-positron collider

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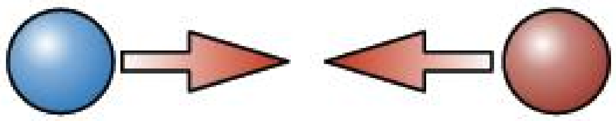
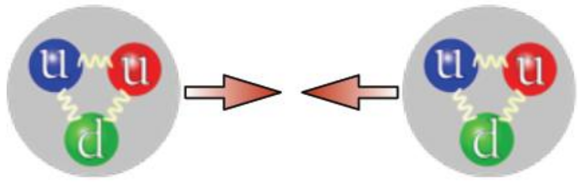
Workshop “Physics at future ee colliders”
Dubna June 2025

Choice of colliding particles



- e^+e^- collisions
- Point-like particles
- Total annihilation: initial state known
- Decent background
- Limited in energy, but – precision!

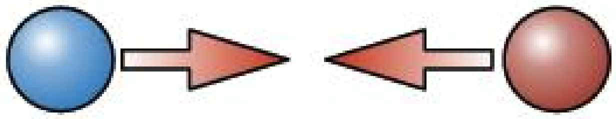


- pp(bar) collisions
- Composite particles
- Random energy of the hard interaction
- High background
- Highest energy frontier – discovery!

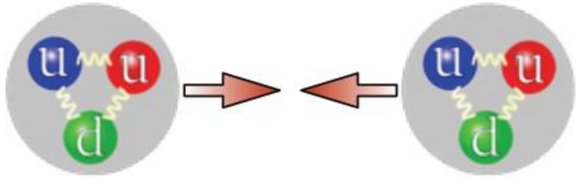
Choice of acceleration scheme

- e^+e^- circular colliders are limited in energy by the synchrotron radiation due to the beam curvature
- Either you build a tunnel of enormous size…
- Or you build a linear collider with enormous acceleration gradient
- Linear collider: advantage in energy
- Circular collider: re-use for a next pp-collider

Future collider candidates



- CEPC: 100 km, 240 GeV, Higgs physics (+350 GeV)
- FCC: 100 km, 360 GeV, Higgs + Top
- ILC: 30 km, 250/500/1000 GeV, Higgs, Top, discoveries
- CLIC: 50 km, 3000 GeV, Higgs, Top, discoveries



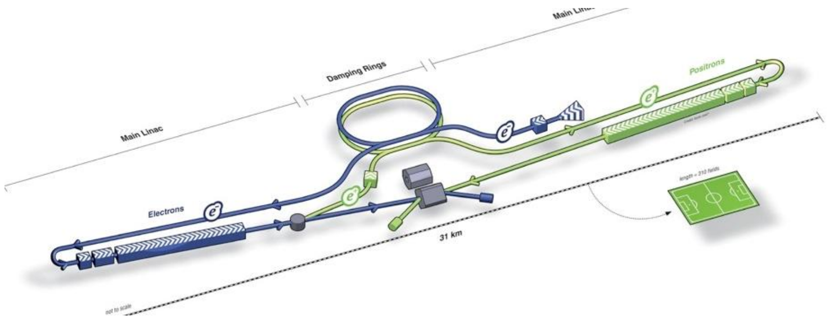
- HL LHC:
  14 TeV, 3 ab^{-1}
- HE-LHC:
  33 TeV, 2 ab^{-1}
- CEPC:
  70 TeV, 10 ab^{-1}
- FCC:
  100 TeV, 5 ab^{-1}

Next e+e$^-$ collider?

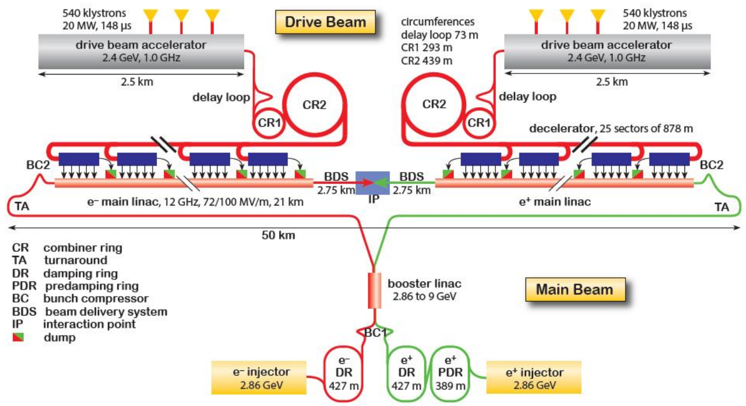
- Linear collider
  - ILC (Japan)
  - CLIC (CERN)
- Energy
  - 91/250 GeV (ILC)
  - 380/3000 GeV (CLIC)
- Luminosity
  - L≈2x10^{-34} cm^{-2}s^{-1}
  - Stat.error: better than 10^{-3}
- Beam polarization:
  - 80%(e$^-$), 30%(e+)

- Circular collider
  - CEPC (China)
  - FCC (CERN)
- Energy
  - 91/160/240/360 GeV (CEPC)
  - 91/160/250/360 GeV (FCC)
- Luminosity
  - L≈10^{-36} cm^{-2}s^{-1} (4 exps)
  - Stat.error: 10^{-3} .. 10^{-5}
- Tera-Z
  - 1 or few trillions (10^{12}) Z-bosons at 91 GeV

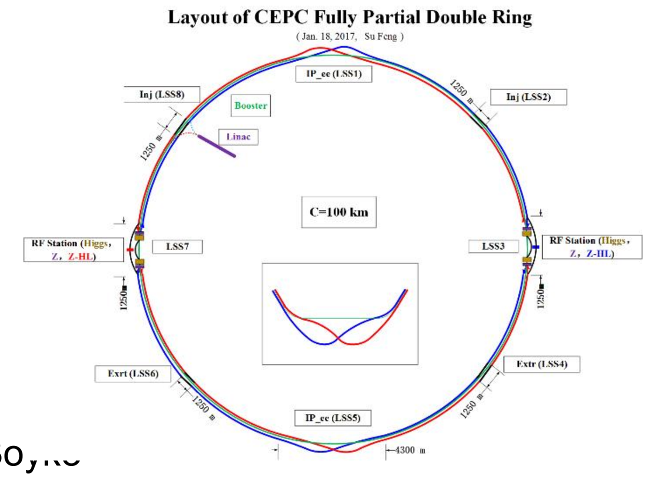
ILC (2035) **$ 4.5-5G**



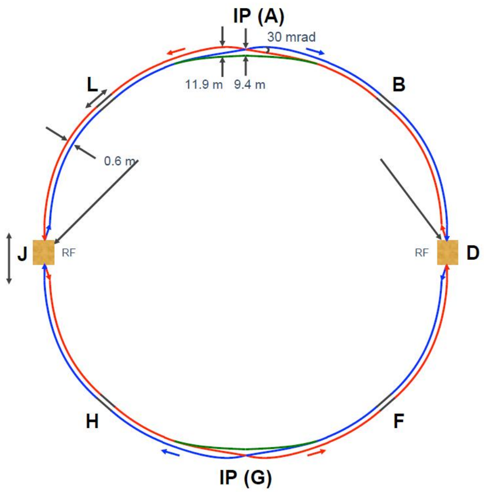
CLIC (2035) **$ 6.7G (380 GeV)**
$13G (3000 GeV)



CEPC (2035) **$ 5.5G**

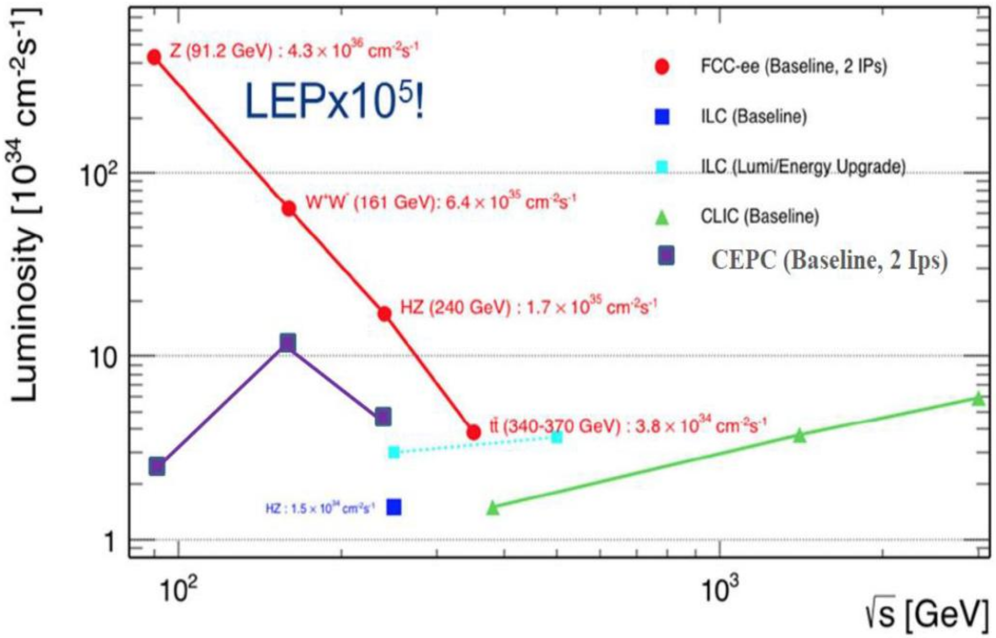


FCC-ee (2045) **$ 12G + 9G**



Luminosity vs Energy

~ 2017



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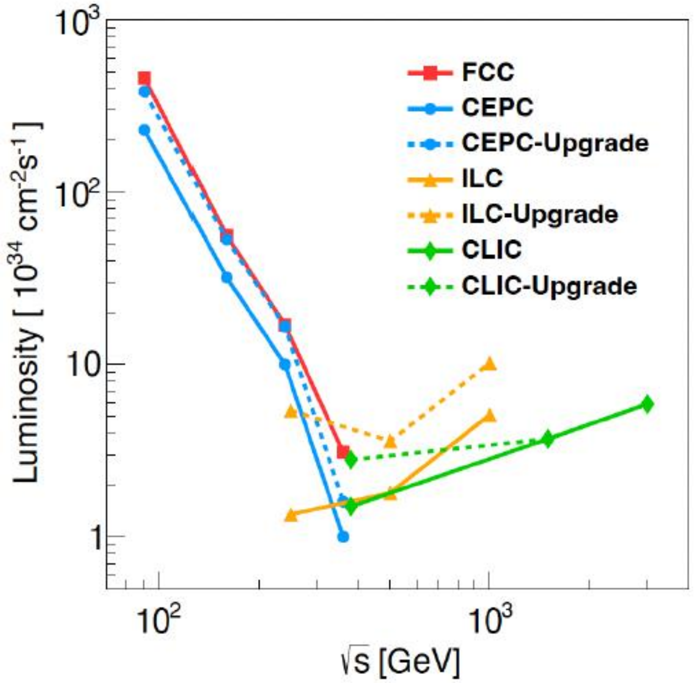
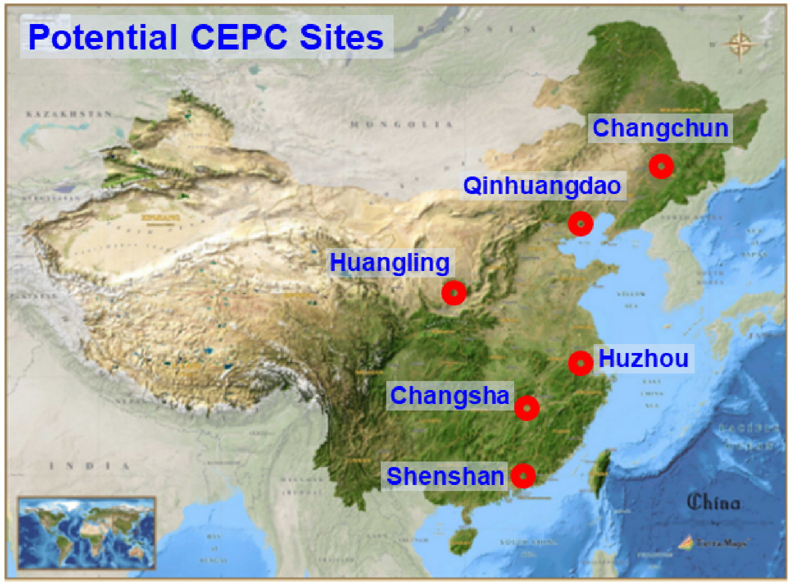
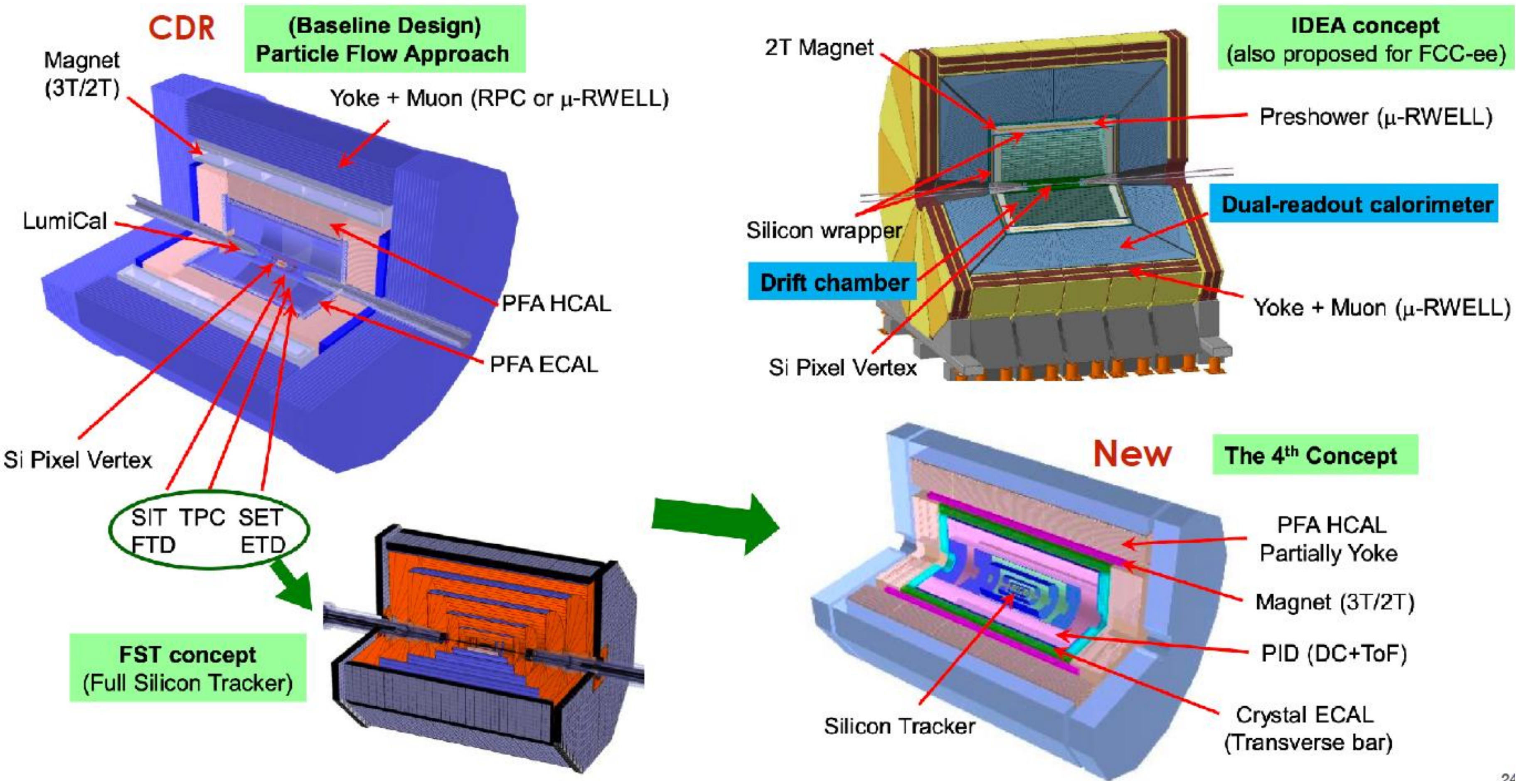


Possible CEPC location



CEPC detector studies

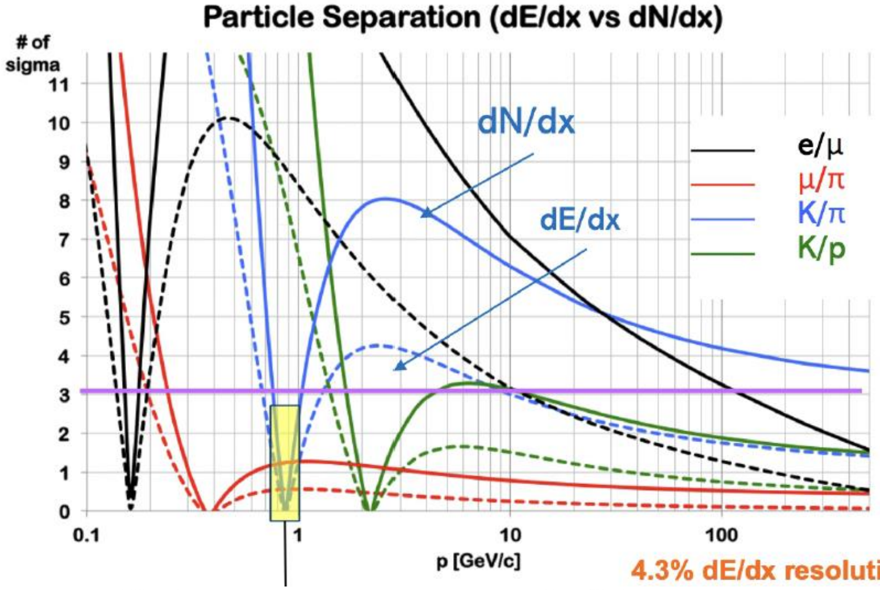
Detector concepts

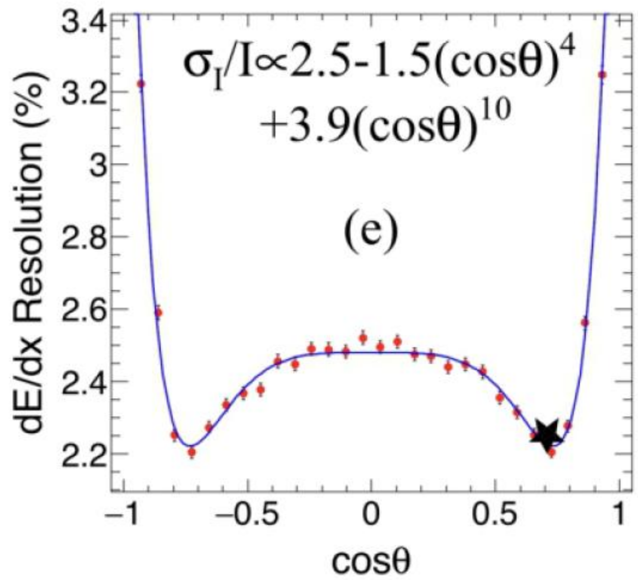


Detector R&D

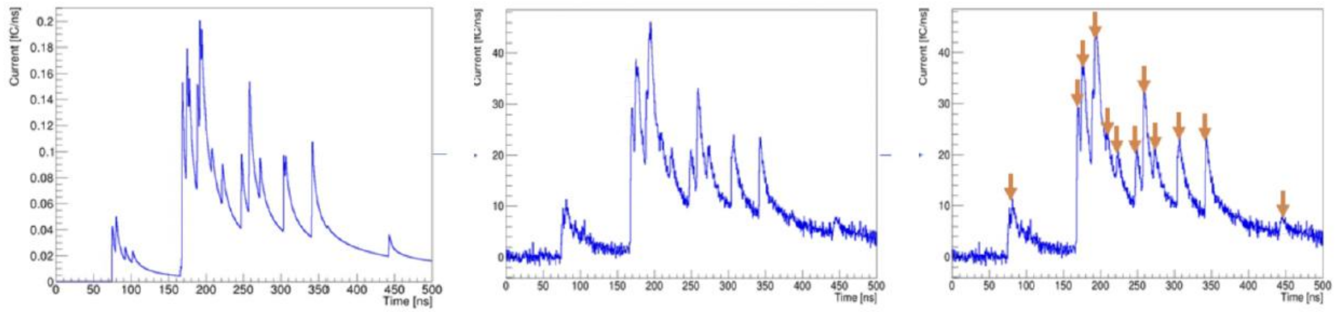
Sub-detector	Specification	Requirement	World-class level	CEPC prototype
Pixel detector	Spatial resolution	$\sim 3\ \mu m$	$3-5\ \mu m$ [12, 13]	$3-5\ \mu m$ [14–16]
TPC/drift chamber	dE/dx (dN/dx) resolution	$\sim 2\%$	$\sim 4\%$ [17, 18]	$\sim 4\%$ [19–21]
Scintillator-W ECal	Energy resolution Granularity	$< 15\%/\sqrt{E(\mathrm{GeV})}$ $\sim 2 \times 2\ \mathrm{cm}^2$	12.5% [22]	Prototype built to be measured $0.5 \times 0.5\ \mathrm{cm}^2$
4D crystal ECal	EM energy resolution 3D Granularity	$\sim 3\%/\sqrt{E(\mathrm{GeV})}$ $\sim 2 \times 2 \times 2\ \mathrm{cm}^3$	$2\%/\sqrt{E(\mathrm{GeV})}$ [23, 24] N/A	Prototyping [25] $\sim 3\%/\sqrt{E(\mathrm{GeV})}$ $\sim 2 \times 2 \times 2\ \mathrm{cm}^3$
Scintillator-Steel HCal	Support PFA, Single hadron σ_E^{had}	$< 60\%/\sqrt{E(\mathrm{GeV})}$	$57.6/\sqrt{E(\mathrm{GeV})}\%$ [26]	Prototyping
Scintillating glass HCal	Support PFA Single hadron σ_E^{had}	$\sim 40\%/\sqrt{E(\mathrm{GeV})}$	N/A	Prototyping $\sim 40\%/\sqrt{E(\mathrm{GeV})}$
Low-mass Solenoid magnet	Magnet field strength Thickness	$2\ \mathrm{T} - 3\ \mathrm{T}$ < 150 mm	$1\ \mathrm{T} - 4\ \mathrm{T}$ [27–29] > 270 mm	Prototyping

Particle Identifiction with dE/dx





4.3% dE/dx resolution



Simulation Digitization Reconstruction

Money

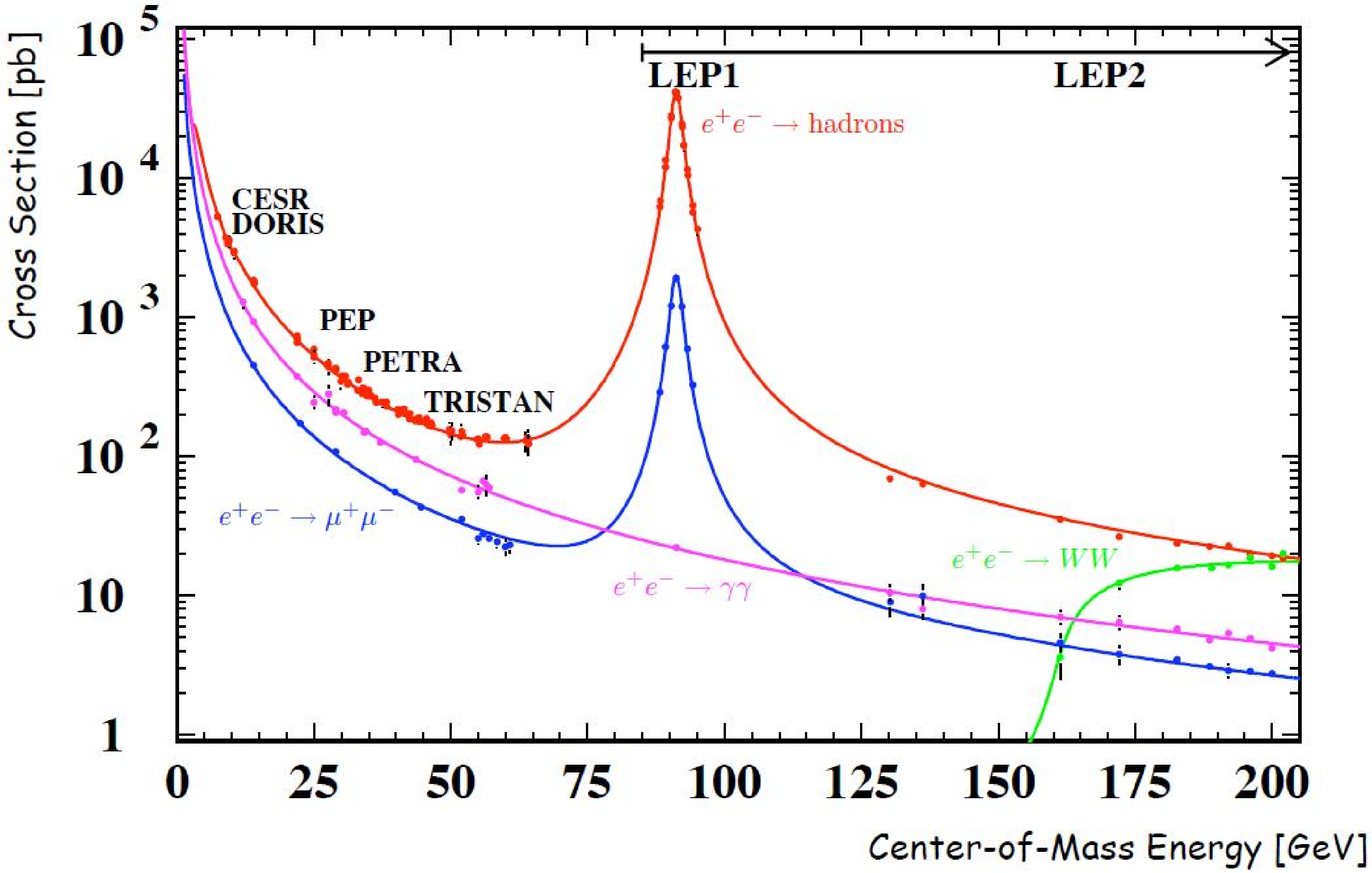
Total required funding: 36 Billion RMB (5 Billion CHF at today's exchange rate)

Funding Sources	Funding Model #1 (B RMB)	Funding Model #2 (B RMB)
Central Government	25	10
Local Government	5	20
International contributions	6	6
Donations	0-3.5	0-3.5

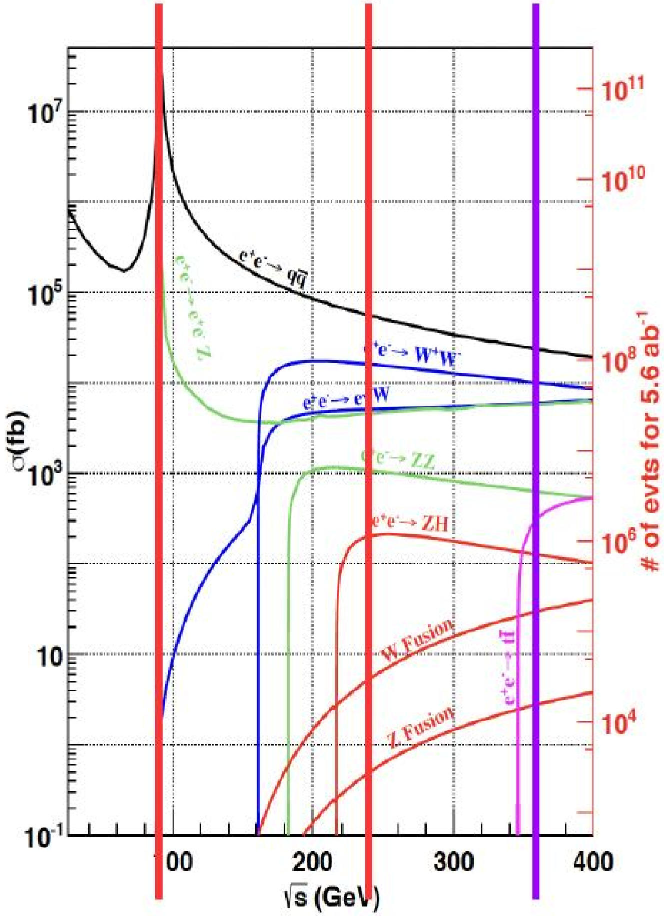
40 M$ received for R&D so far

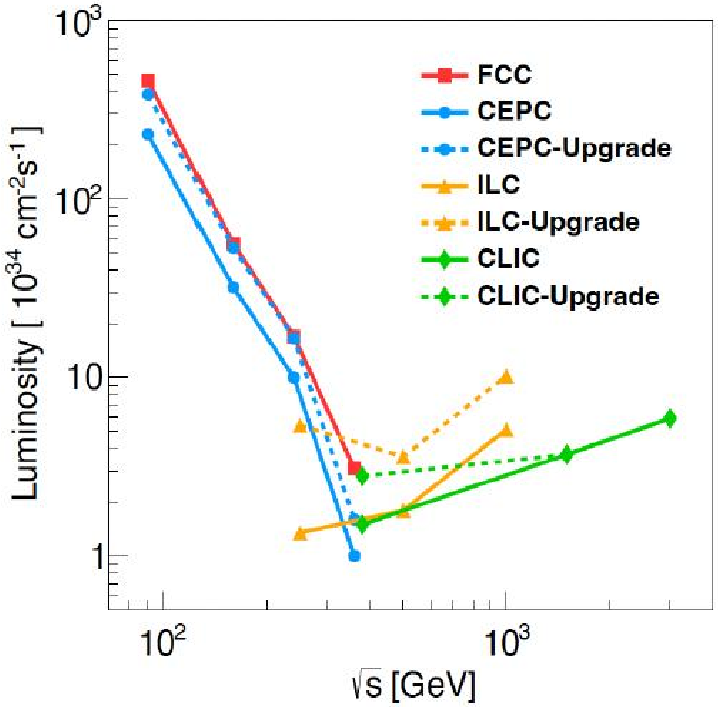
Physics at CEPC

e^+e^- annihilation at LEP and before



e+e- annihilation at CEPC





- 4 Million Higgs (10 years)
- ~ 1 Giga W (1 year) + 4 Tera Z (2 years)
- Upgradable: Top factory (500 k ttbar)

Physics topics at CEPC

- Precision Higgs boson physics (4M ee→ZH)
- Precision top quark physics (500K tt)
- Tera-Z: 4T Z^0
  - Ultra-precise EW measurements
  - QCD measurements
  - Flavour physics (b/c/τ/CKM/…)
- Gamma-gamma collisions
- Searches for the new physics
  - Limited by energy, but possible indirect signals from high-precision measurements

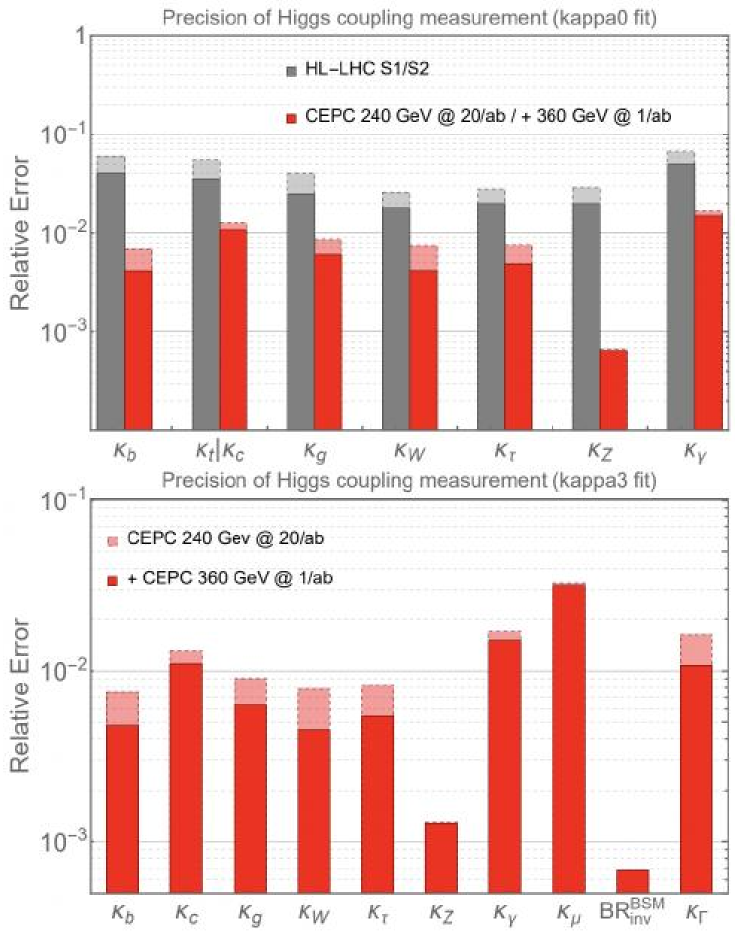
CEPC physics program

CEPC Operation mode		ZH	Z	W^+W^-	ttbar
		~ 240	~ 91.2	~ 160	~ 360
Run time [years]		7	2	1	-
CDR (30MW)	*L* / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	3	32	10	-
	[ab^{-1}, 2 IPs]	5.6	16	2.6	-
	Event yields [2 IPs]	**1×10^{6}**	**7×10^{11}**	**2×10^{7}**	-
Run time [years]		10	2	1	5
Latest (50MW)	***L* / IP [$\times 10^{34}$ cm^{-2}s^{-1}]**	8.3	192	27	0.83
	[ab^{-1}, 2 IPs]	20	96	7	1
	Event yields [2 IPs]	**4×10^{6}**	**4×10^{12}**	**5×10^{7}**	**5×10^{5}**

Large physics samples: ~10^6 Higgs, ~10^{12} Z, ~10^8 W bosons, ~10^6 top quarks

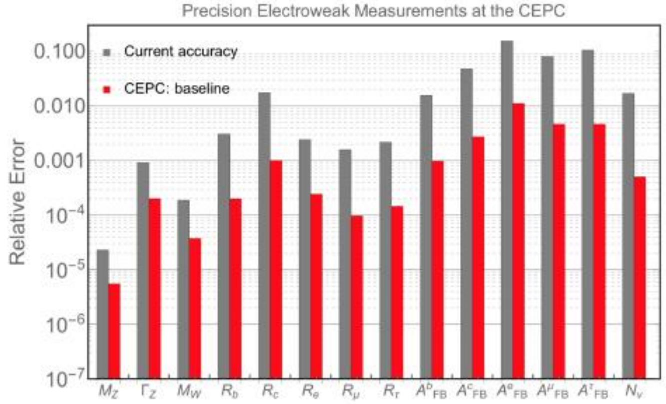
Higgs physics

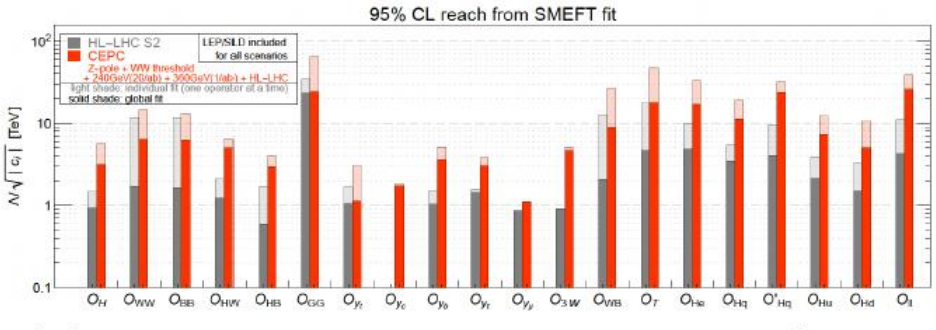
	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	vvH	ZH	vvH	eeH
inclusive	0.26%		1.40%	\	\
H→bb	0.14%	1.59%	0.90%	1.10%	4.30%
H→cc	2.02%		8.80%	16%	20%
H→gg	0.81%		3.40%	4.50%	12%
H→WW	0.53%		2.80%	4.40%	6.50%
H→ZZ	4.17%		20%	21%	
$H \to \tau\tau$	0.42%		2.10%	4.20%	7.50%
$H \to \gamma\gamma$	3.02%		11%	16%	
$H \to \mu\mu$	6.36%		41%	57%	
$H \to Z\gamma$	8.50%		35%		
$\mathrm{Br}_{upper}(H \to inv.)$	0.07%				
Γ_H	1.65%		1.10%		

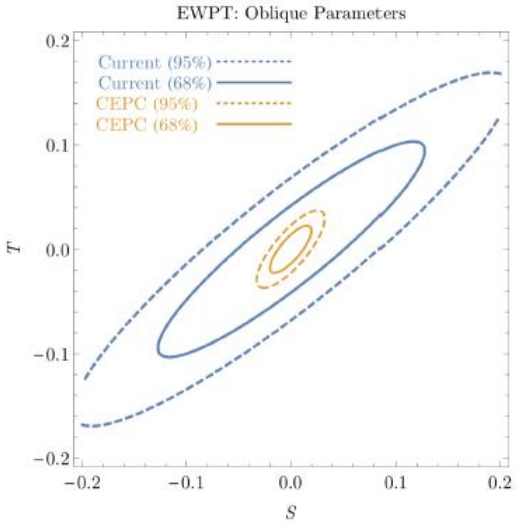


Electroweak measurements

Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta \Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta \Gamma_W$	49 MeV [46–49]	2.0 MeV (1.8 MeV)	WW threshold	E_{beam}
Δm_t	0.76 GeV [50]	$\mathcal{O}(10)$ MeV[a]	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [37, 51–55]	1.5×10^{-5} (1.5×10^{-5})	Z pole ($Z \to \tau\tau$)	Stat. Unc.
ΔA_μ	0.015 [37, 53]	3.5×10^{-5} (3.0×10^{-5})	Z pole ($Z \to \mu\mu$)	point-to-point Unc.
ΔA_τ	4.3×10^{-3} [37, 51–55]	7.0×10^{-5} (1.2×10^{-5})	Z pole ($Z \to \tau\tau$)	tau decay model
ΔA_b	0.02 [37, 56]	20×10^{-5} (3×10^{-5})	Z pole	QCD effects
ΔA_c	0.027 [37, 56]	30×10^{-5} (6×10^{-5})	Z pole	QCD effects
$\Delta \sigma_{had}$	37 pb [37–41]	2 pb (0.05 pb)	Z pole	lumiosity
δR_b^0	0.003 [37, 57–61]	0.0002 (5×10^{-6})	Z pole	gluon splitting
δR_c^0	0.017 [37, 57, 62–65]	0.001 (2×10^{-5})	Z pole	gluon splitting
δR_e^0	0.0012 [37–41]	2×10^{-4} (3×10^{-6})	Z pole	E_{beam} and t channel
δR_μ^0	0.002 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δR_τ^0	0.017 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δN_ν	0.0025 [37, 66]	2×10^{-4} (3×10^{-5})	ZH run ($\nu\nu\gamma$)	Calo energy scale







Summary

- CEPC will be a gigantic step for the HEP future
- Clean signals with unprecedented statistics will be detected
- Detector design is at a very advanced stage, many novel technologies are already prototyped and beamtested
- JINR group plans wide participation in CEPC project – see talk by Yu.Davydov