CEPC Status and Prospects

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Institute of High Energy Physics
Chinese Academy of Sciences

UK Tracker meeting
June 1, 2020

Can be downloaded from
http://cepc.ihep.ac.cn/

IHEP-CEPC-DR-2018-01
IHEP-AC-2018-01

CEPC
Conceptual Design Report

Volume I - Accelerator

The CEPC Study Group
August 2018

IHEP-CEPC-DR-2018-02
IHEP-EP-2018-01
IHEP-TH-2018-01

CEPC
Conceptual Design Report

Volume II - Physics & Detector

The CEPC Study Group
October 2018

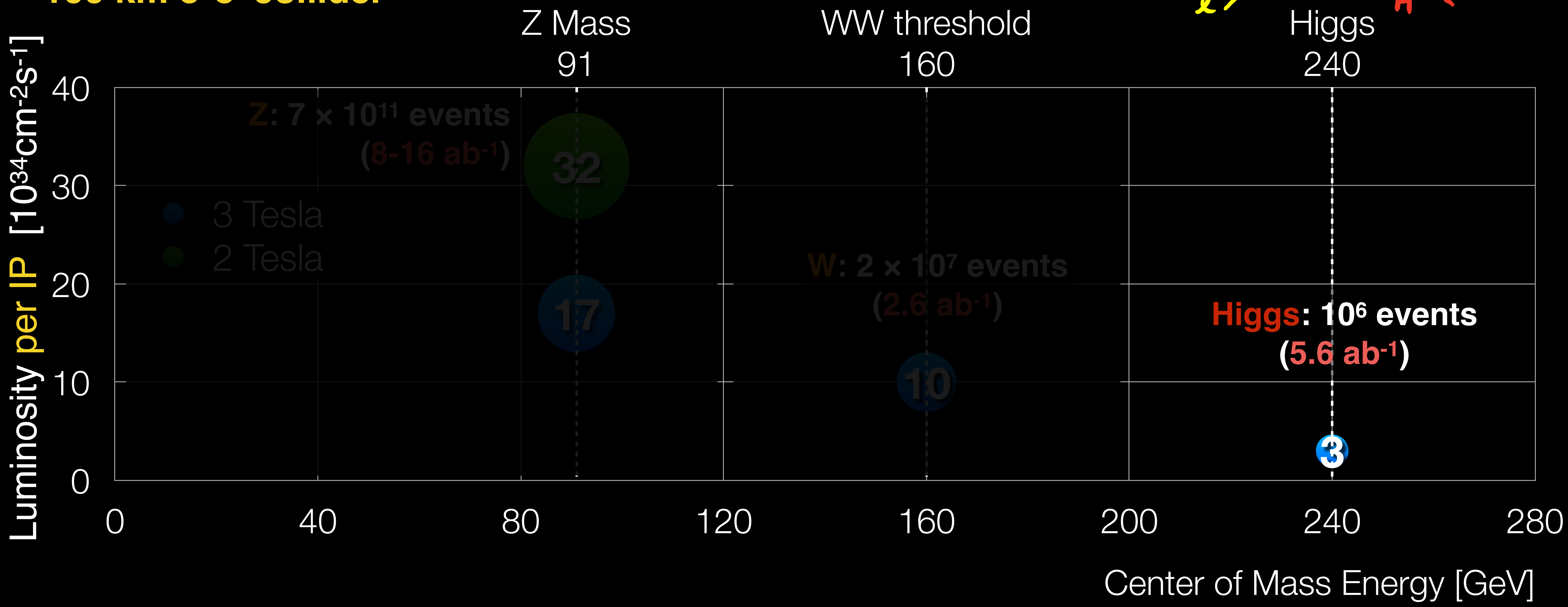
1143 authors
222 institutes (140 foreign)
24 countries

Editorial Team: 43 people / 22 institutions/ 5 countries

The Circular Electron Positron Collider (CEPC)
Physics Program

The CEPC Program

100 km e^+e^- collider



2 IPs planned

The CEPC Program

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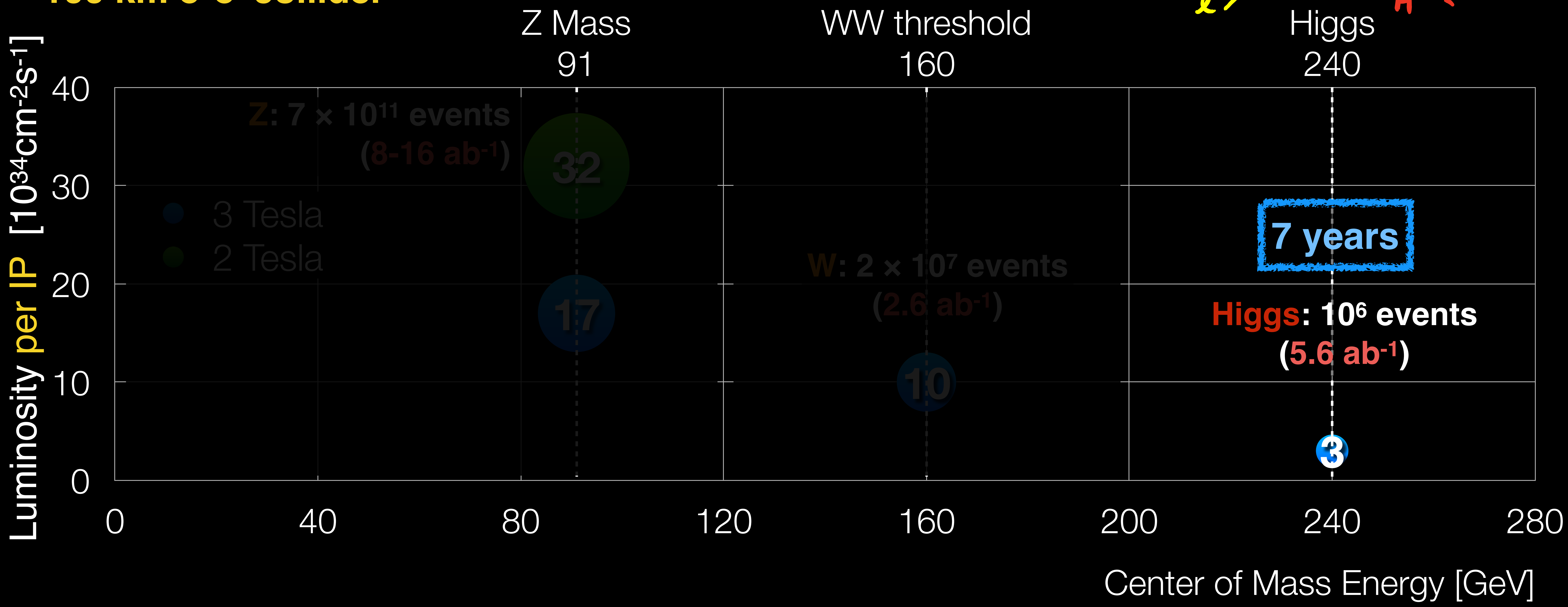

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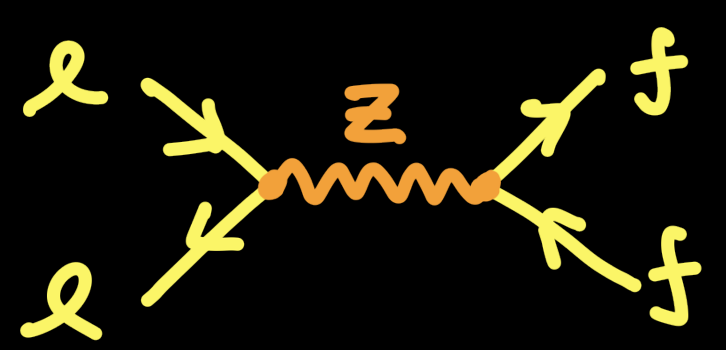
The CEPC Program



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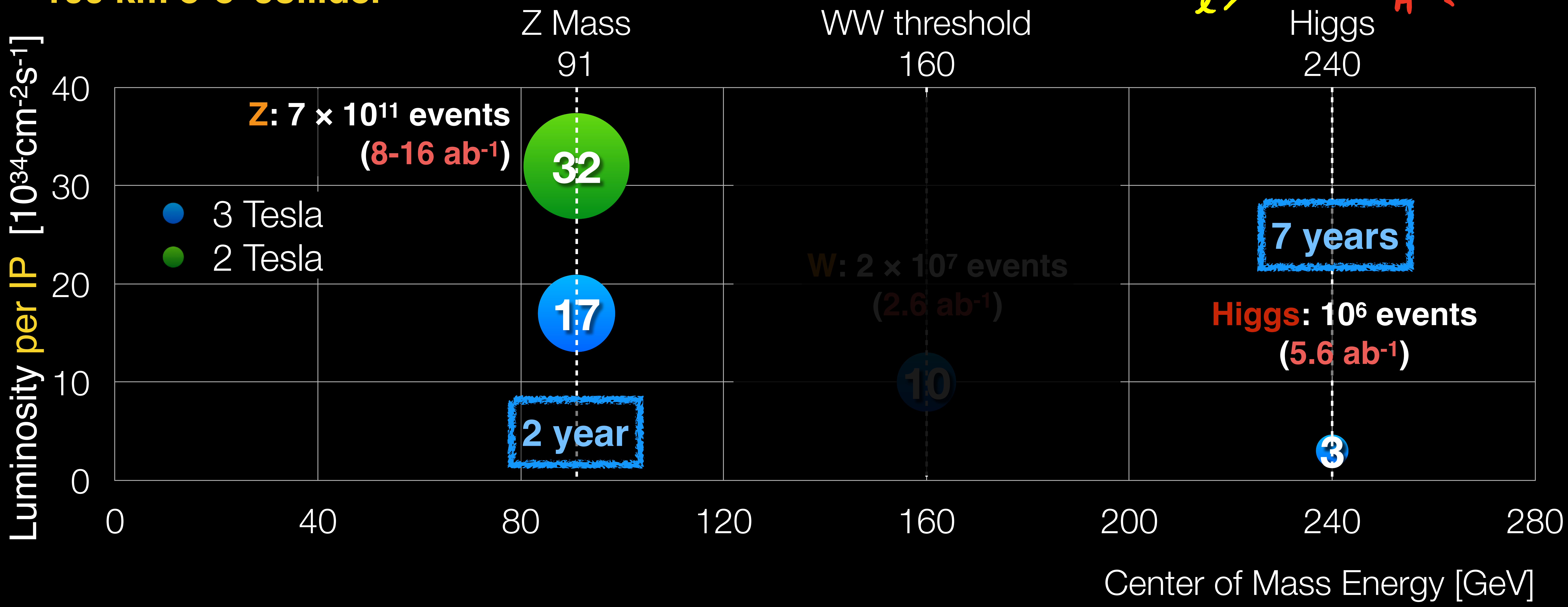
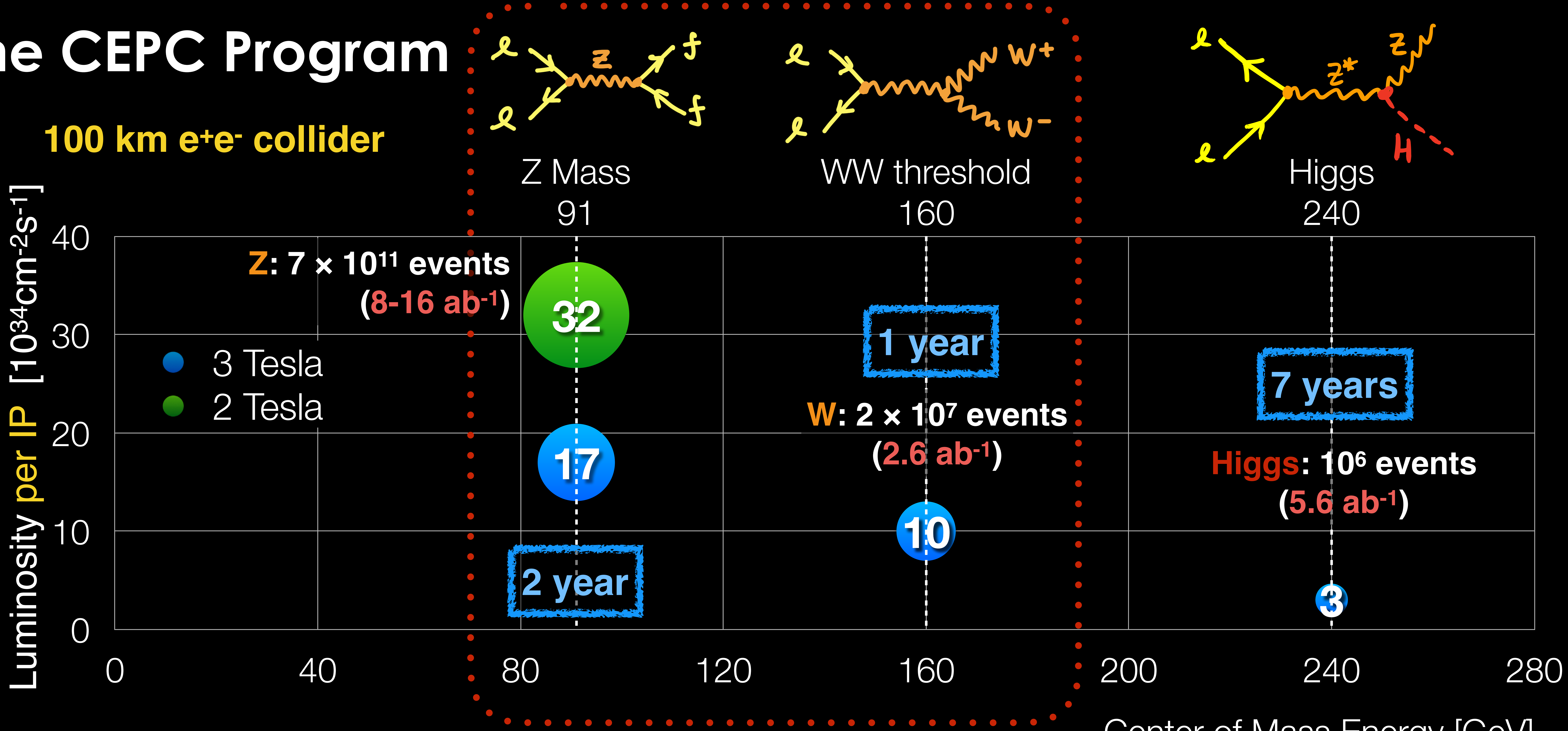


2 IPs planned

The CEPC Program

100 km e+e- collider



Also, Z and W factory

2 IPs planned

Updated Parameters of Collider Ring 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 (Higgs) × 3.2 (Z)

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These possible luminosity increases have not yet been absorbed into physics and detector studies

Luminosity increase factor: × 1.8 × 3.2

The Physics Goals — Shopping List

Precision tests of Standard Model (Higgs, W and Z) → **Potential to find new physics**

Higgs boson and electroweak symmetry breaking

Directly exploring new physics

- Exotic Higgs boson decays
- Exotics Z boson decays
- Dark matter and hidden sectors
- Extended Higgs sector

QCD precision measurements

- Precision α_S determination
- Jet rates at CEPC
- QCD dynamics, soft QCD effects
- QCD event shapes and light-quark Yukawa couplings

Flavor physics at the *Z* pole

- Rare B decays
- Tau lepton decays
- Flavor violating *Z* decays

Current CEPC Organization

Institutional Board
YN GAO
J. GAO

Steering Committee
Y.F. WANG (IHEP),….

Project Director
XC LOU
Q. QIN
N. XU

Theory
HJ HE(TH)
JP MA(ITP)
XG HE(SJTU)

Accelerator
J. GAO (IHEP)
CY Long (IHEP)
SN FU (IHEP)

Detector
J. Costa (IHEP)
S. JIN (NJU)
J. Wang(IHEP)

Meets yearly

International Advisory Committee

Young-Kee Kim, U. Chicago (Chair)
Barry Barish, Caltech
Hesheng Chen, IHEP
Michael Davier, LAL
Brian Foster, Oxford
Rohini Godbole, CHEP, Indian Institute of Science
David Gross, UC Santa Barbara
George Hou, Taiwan U.
Peter Jenni, CERN
Eugene Levichev, BINP
Lucie Linssen, CERN
Joe Lykken, Fermilab
Luciano Maiani, Sapienza University of Rome
Michelangelo Mangano, CERN
Hitoshi Murayama, UC Berkeley/IPMU
Katsunobu Oide, KEK
Robert Palmer, BNL
John Seeman, SLAC
Ian Shipsey, Oxford
Steinar Stapnes, CERN
Geoffrey Taylor, U. Melbourne
Henry Tye, IAS, HKUST
Yifang Wang, IHEP
Harry Weerts, ANL

International Expert Review Committees

Recommended by the International Advisory Committee in 2018

Accelerator Review Committee

Advises on all matters related to accelerator design and R&D including the Machine-Detector interface and upgrade capabilities

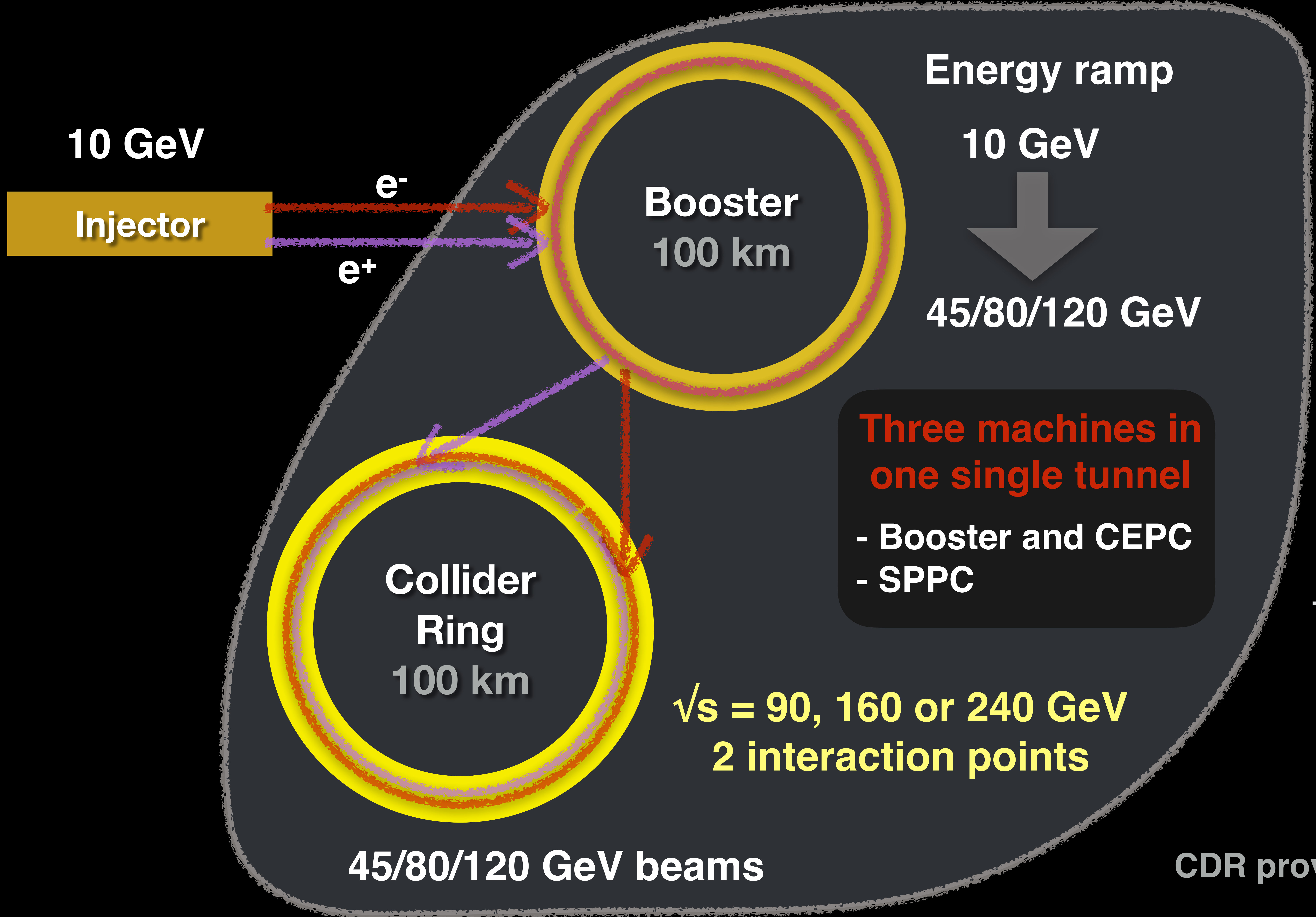
Detector R&D Review Committee

Reviews and endorses the Detector R&D proposals from the international community, such that international participants can apply for funds from their funding agencies and make effective and sustained contributions

First meetings happened in November 2019

The Circular Electron Positron Collider (CEPC) Accelerator and Detectors

CEPC Accelerator Chain and Systems



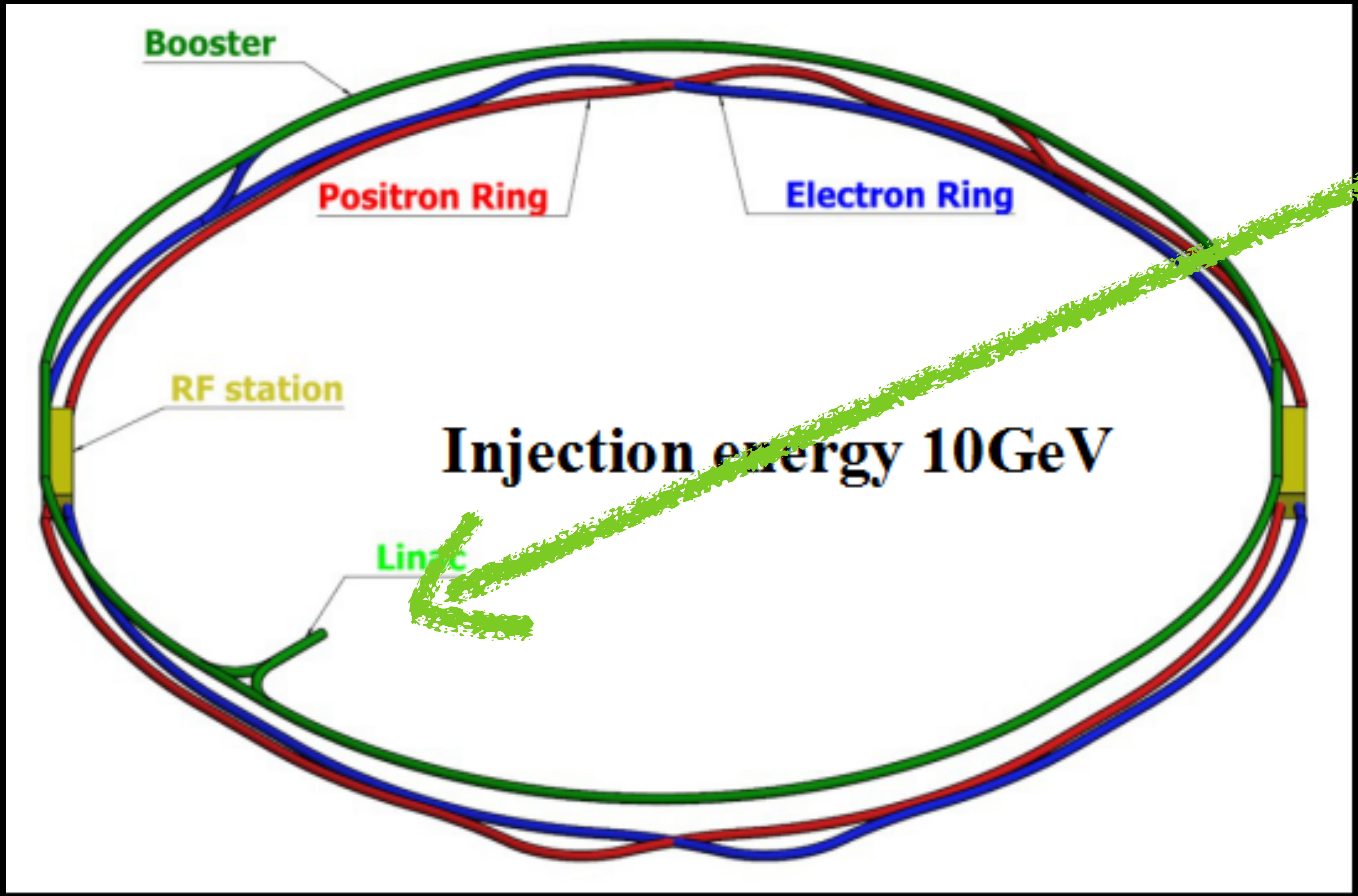
The key systems of CEPC:
1) Linac Injector
2) Booster
3) Collider ring
4) Machine Detector Interface
5) Civil Engineering

CDR provides details of all systems

The CEPC Baseline: LINAC Injector

LINAC: 1.2 km

Positron target



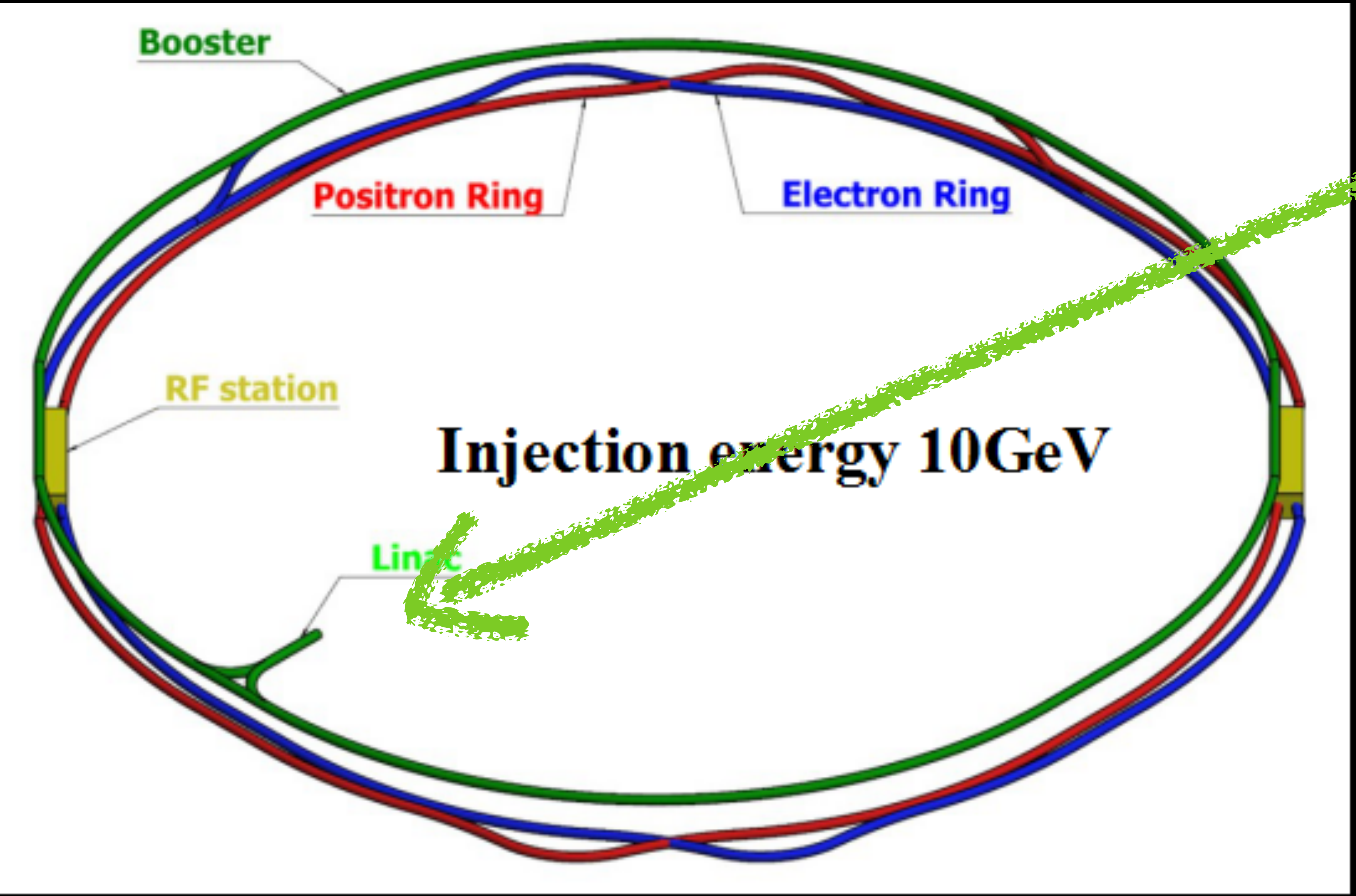
e+/e- beam energy:
10 GeV

Total beam transfer efficiency: 90%

The CEPC Baseline: LINAC Injector

LINAC: 1.2 km

Positron target



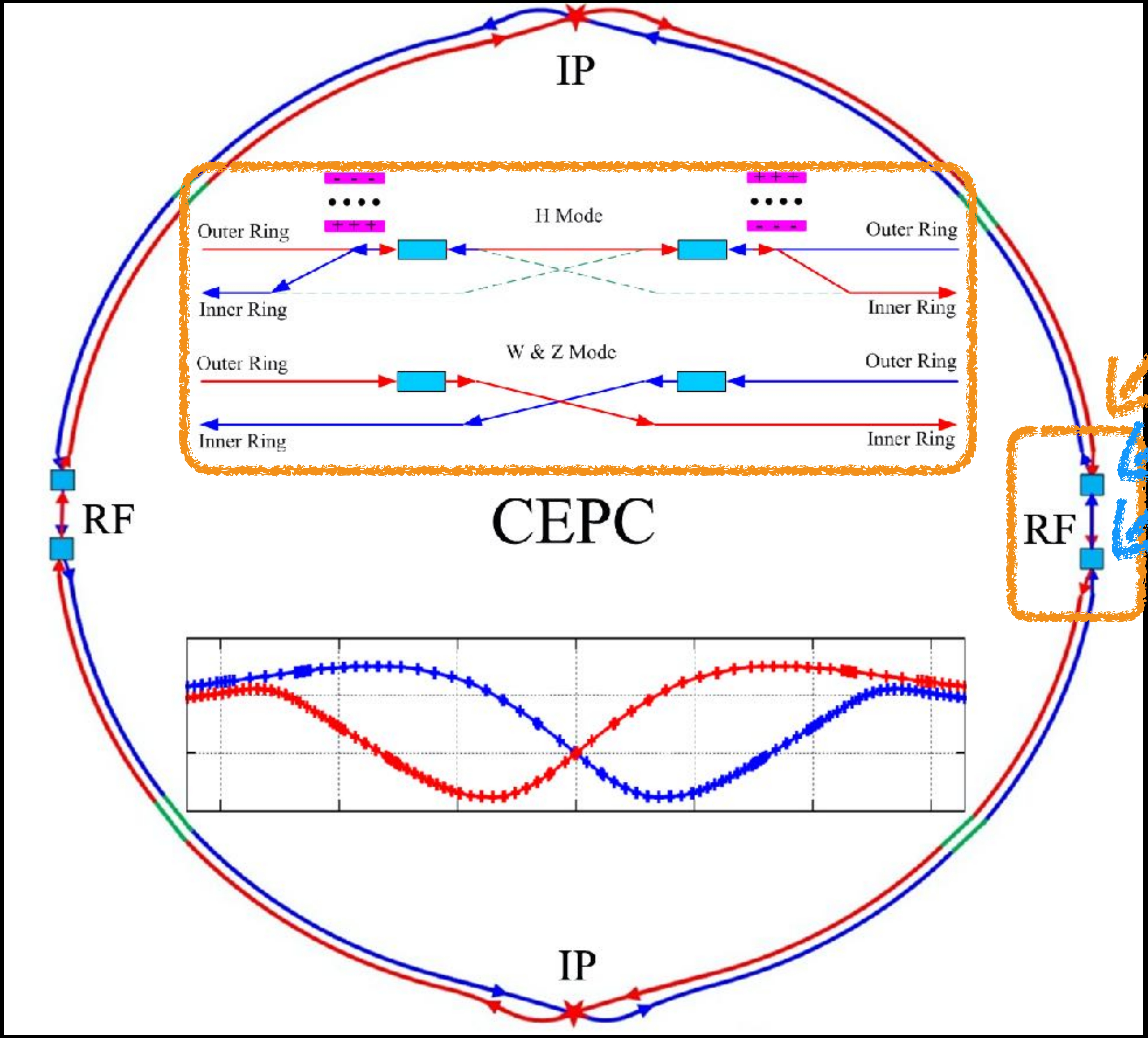
e+/e- beam energy: **10 GeV**

Total beam transfer efficiency: 90%

45 GeV **Plasma Wakefield Accelerator** considered as an alternative

To be tested in Shanghai's Soft XFEL Facility and SLAC FACET-II

The CEPC Baseline Collider Design



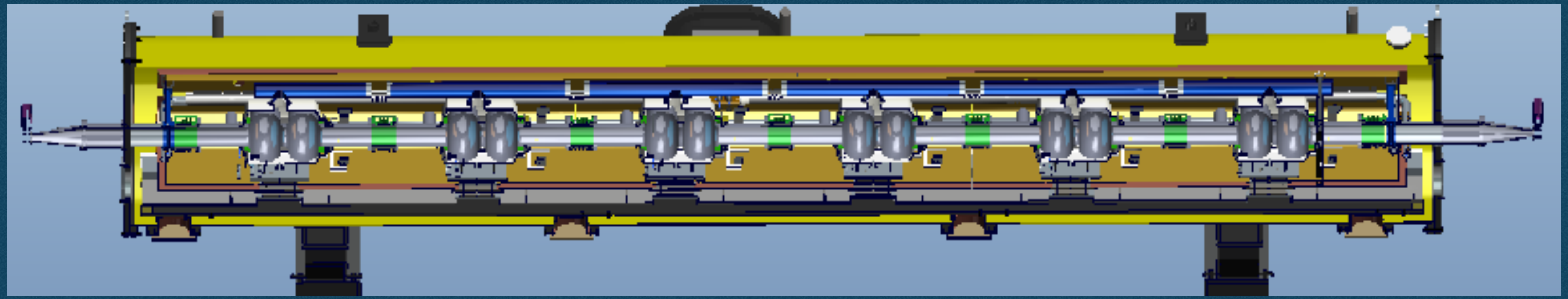
Double ring

Common RF cavities for Higgs

Two RF sections in total

Two RF stations per RF section

10 x 2 = 20 cryomodules



Six 2-cell cavities per cryomodule

CEPC TDR Technology Demonstration Platforms

J. Gao

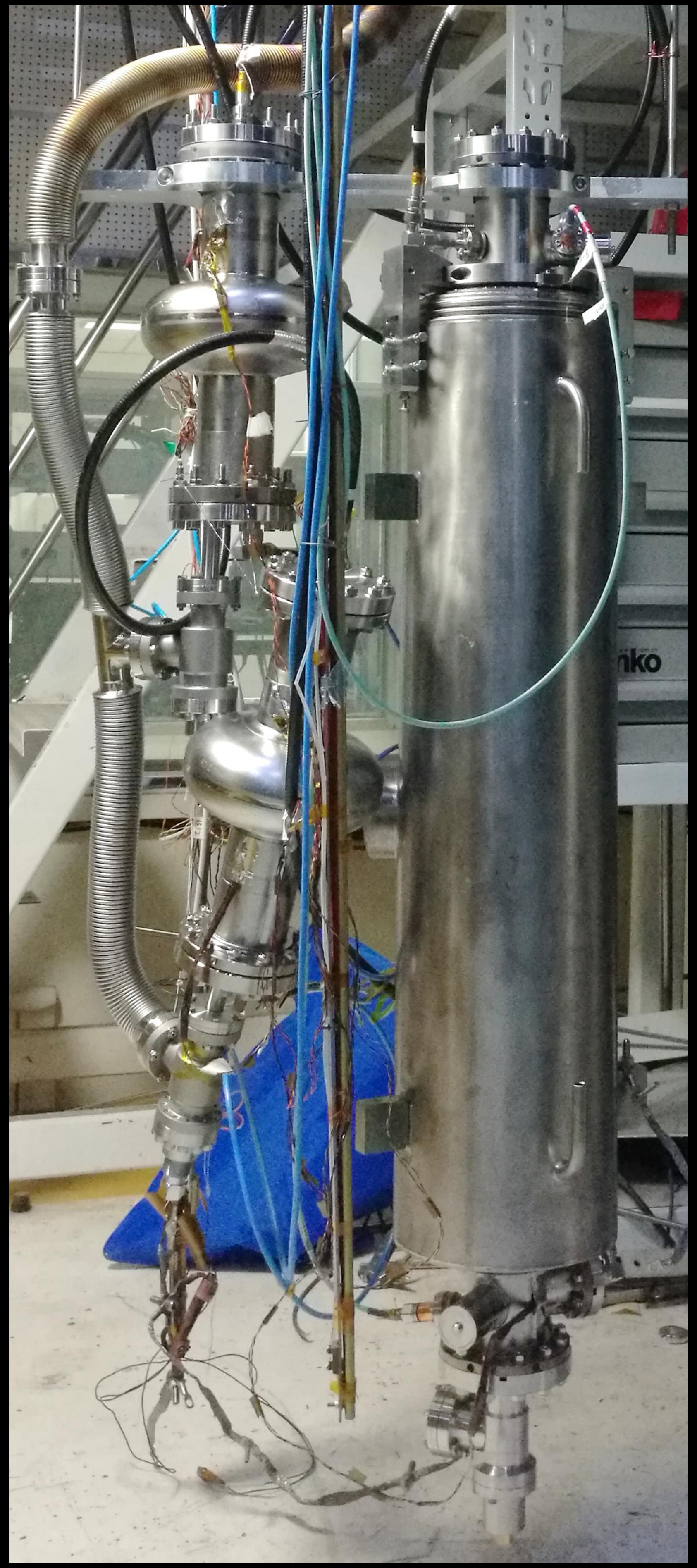
1) CEPC injector technology demonstration platform (including damping ring)
2) CEPC booster and collider ring magnets technology demonstration platform
3) CEPC booster and collider ring vacuum system technology demonstration platform
4) CEPC booster and collider ring SCRF accelerator technology demonstration platform
5) CEPC MDI technology demonstration platform (including SC magnets, installation, alignment)
6) CEPC tunnel components alignment and installation technology demonstration platform (40m long Mockup)
7) CEPC plasma accelerator injector technology demonstration platform (alternative to conventional injector)

Accelerator key technologies R&D — prototypes

CEPC 650 MHz Cavity

Collaboration with Photon Source projects in Shanghai and Beijing (1.3 GHz cavities)

IHEP SHINE 1.3 GHz 9-cell cavities (BCP) reached design goal

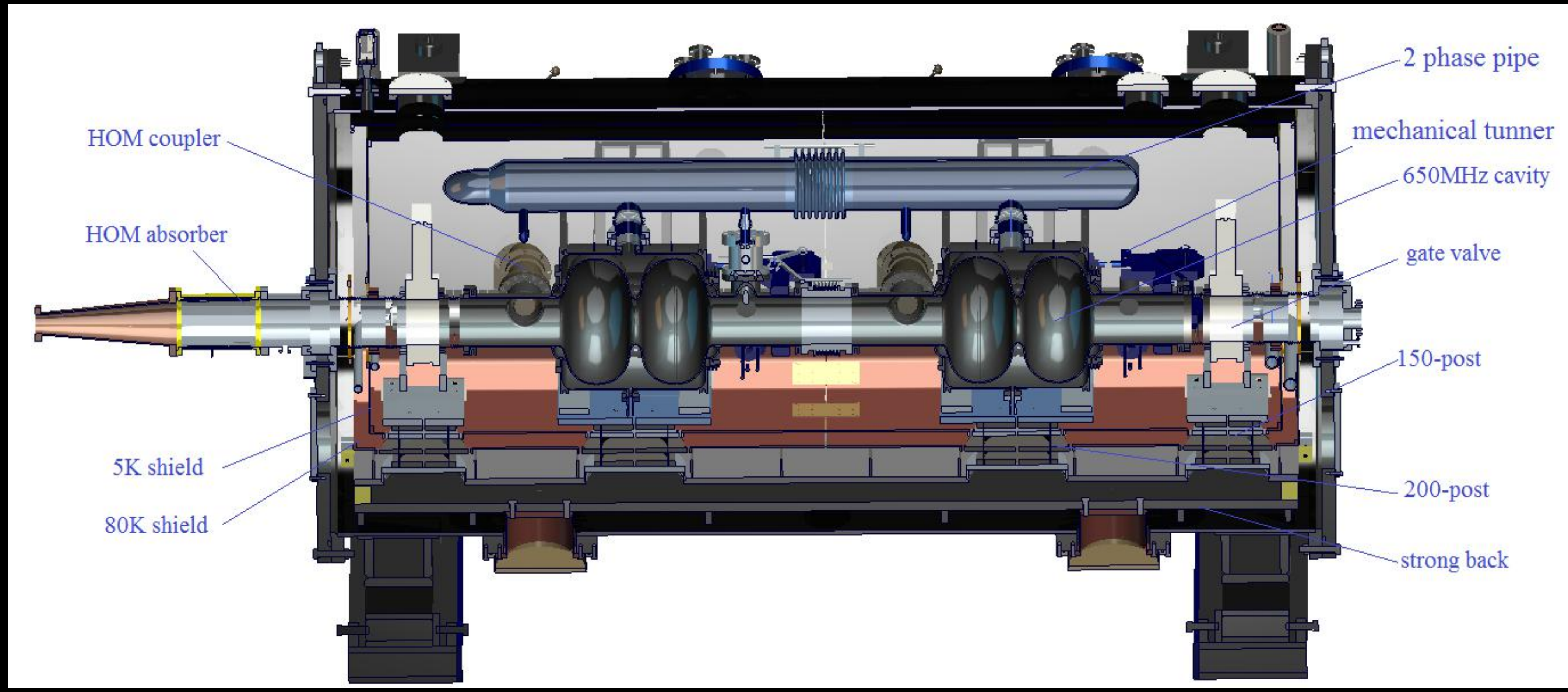


Accelerator key technologies R&D — prototypes

CEPC 650 MHz Cavity

Collaboration with Photon Source projects in Shanghai and Beijing (1.3 GHz cavities)

CEPC 650 MHz Cryomodule(2 x 2-cell Model)



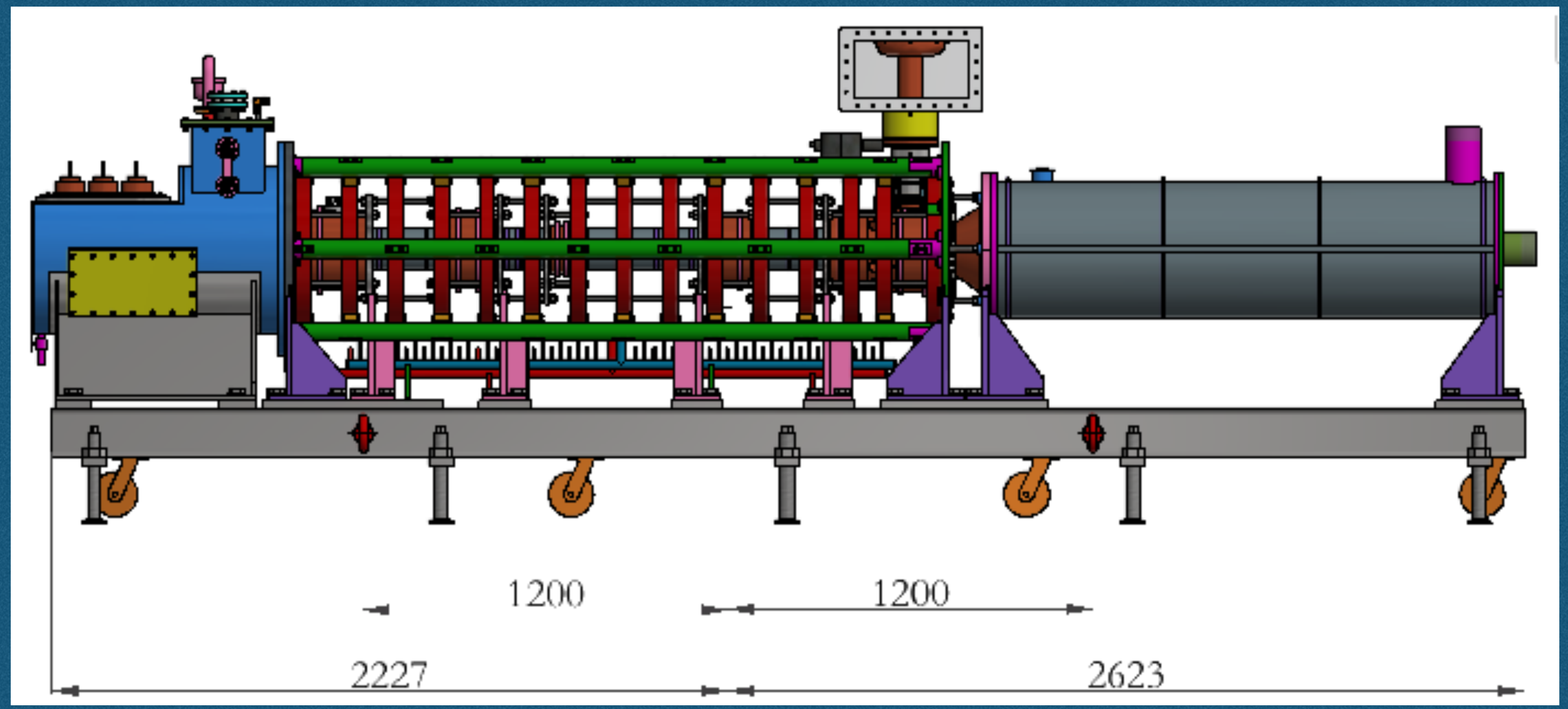
Accelerator key technologies R&D — prototypes

1st CEPC 650MHz Klystron Prototype Manufacture

2019/11: Bake-out

High Efficiency Klystron

"High efficiency klystron collaboration consortium", including IHEP, Institute of Electronic) of CAS, and Kunshan Guoli Science and Tech.



3 high-efficiency klystron (up to 80%) prototypes to be built by 2021

2019/12: Delivered to IHEP

2020/1-3: High-power test at IHEP

Accelerator key technologies R&D — prototypes

CEPC 650 MHz Cavity

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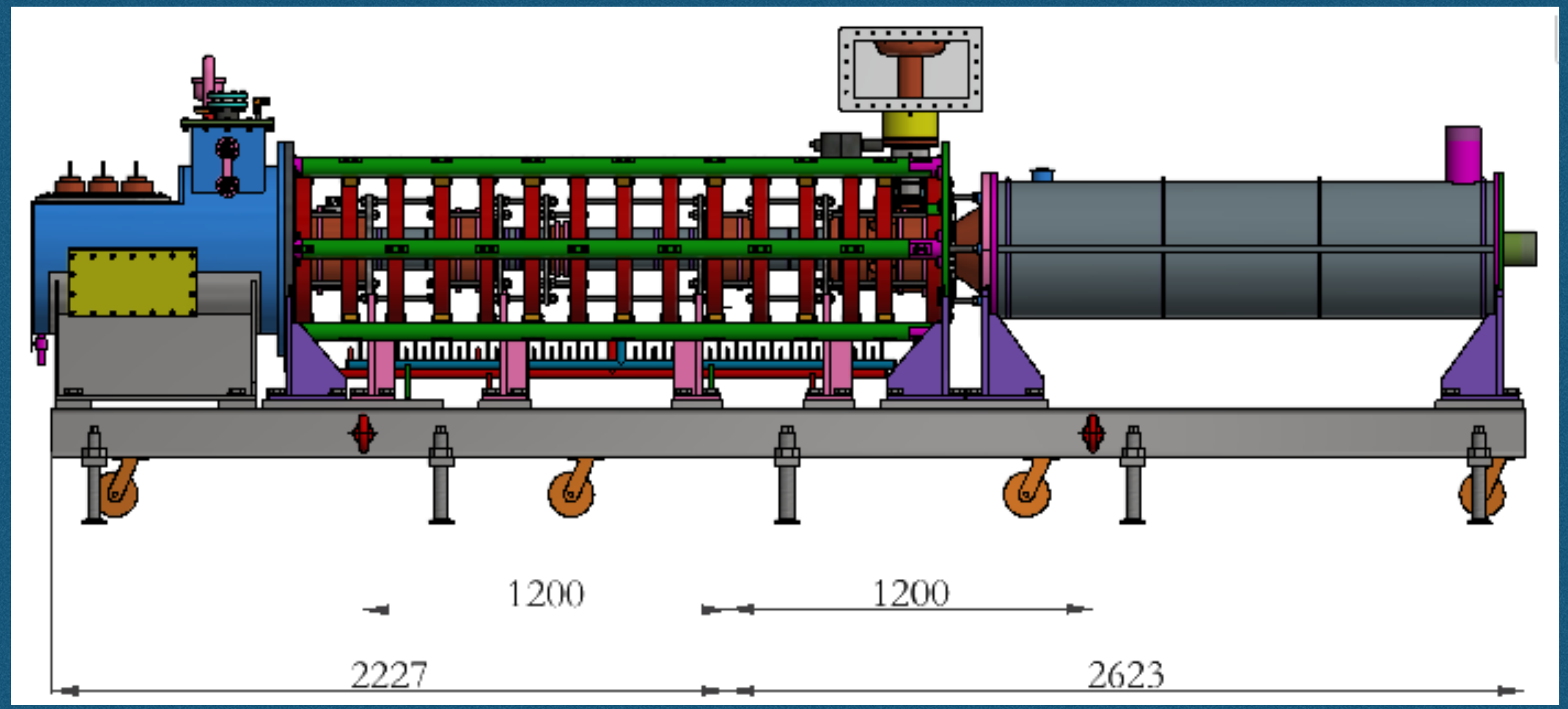

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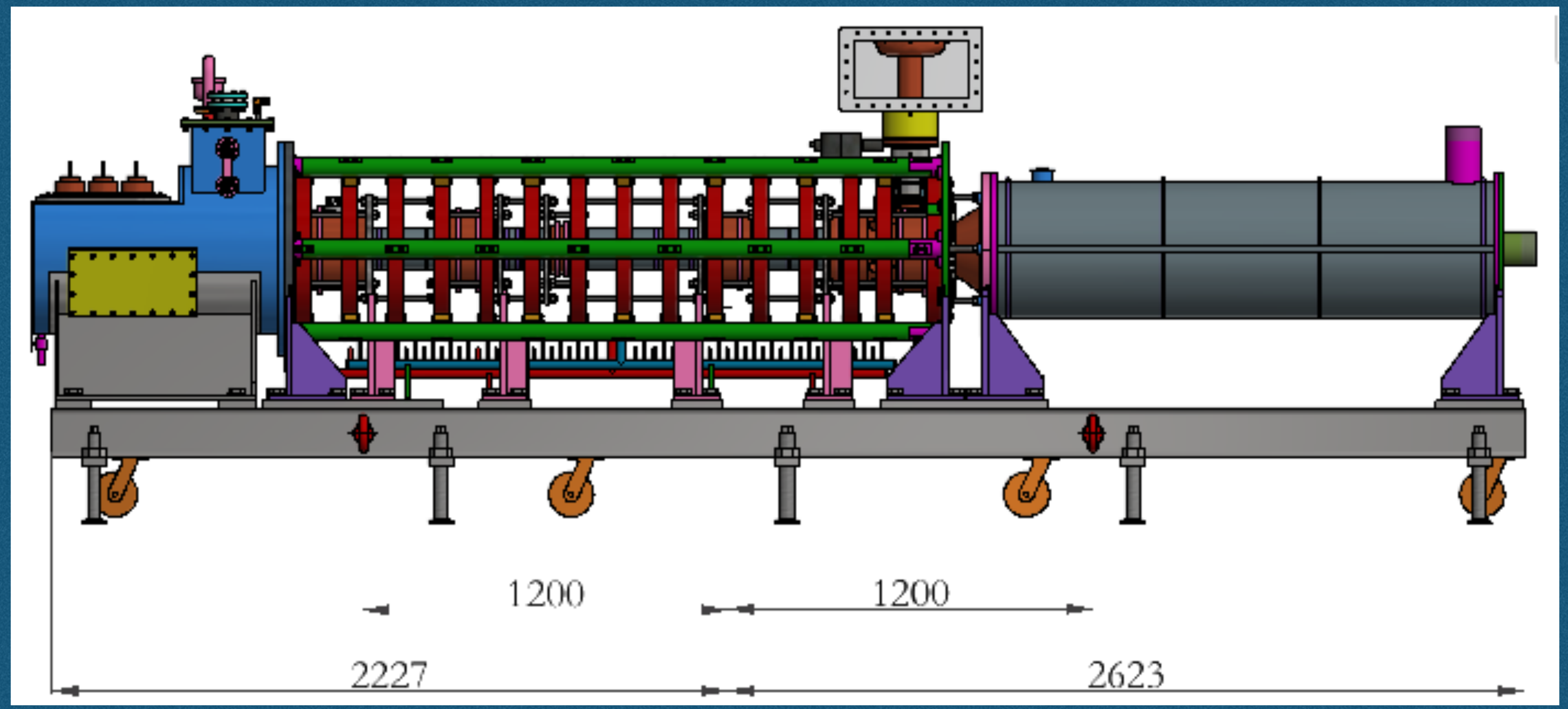

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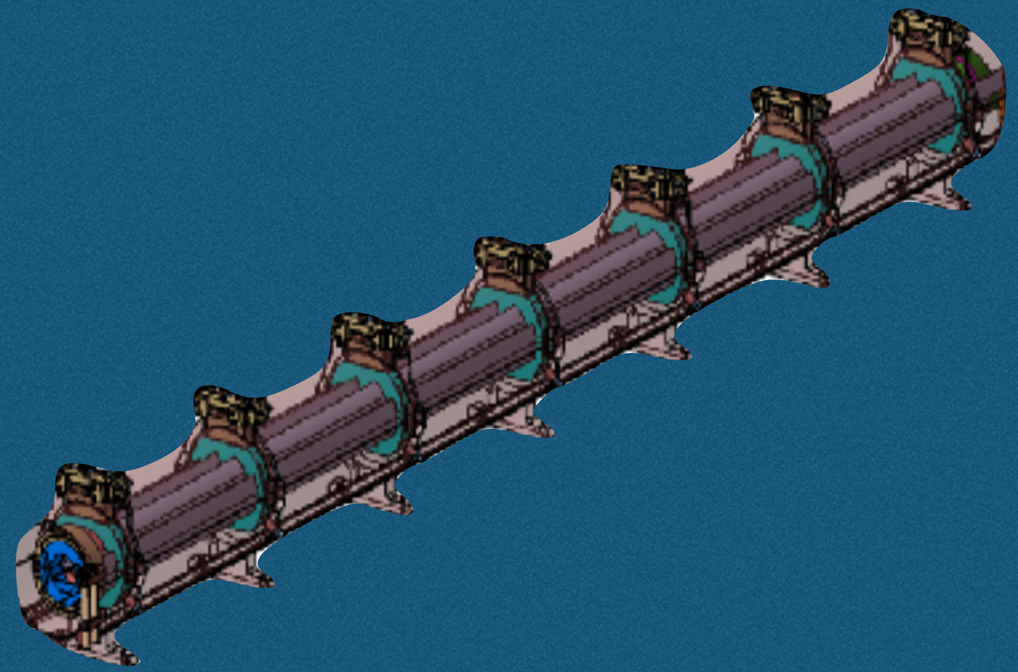
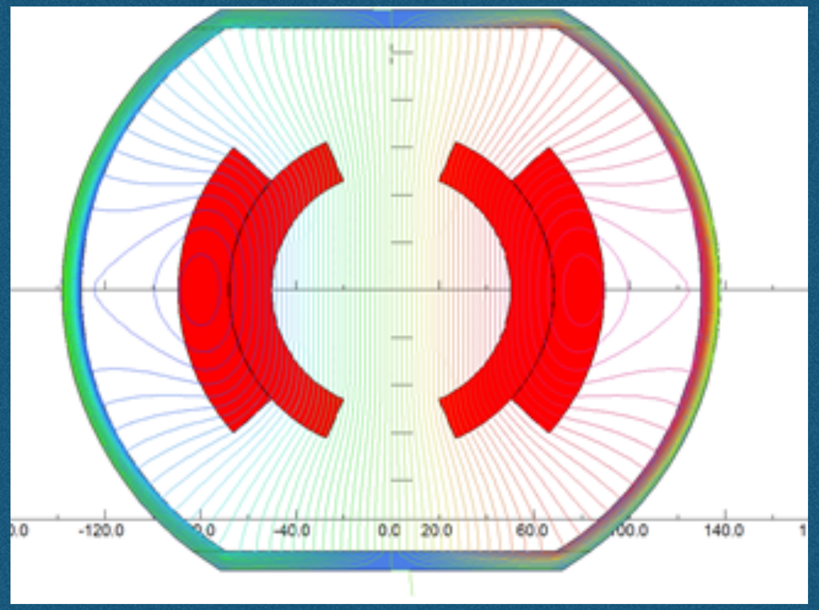
Booster low-field dipole magnets



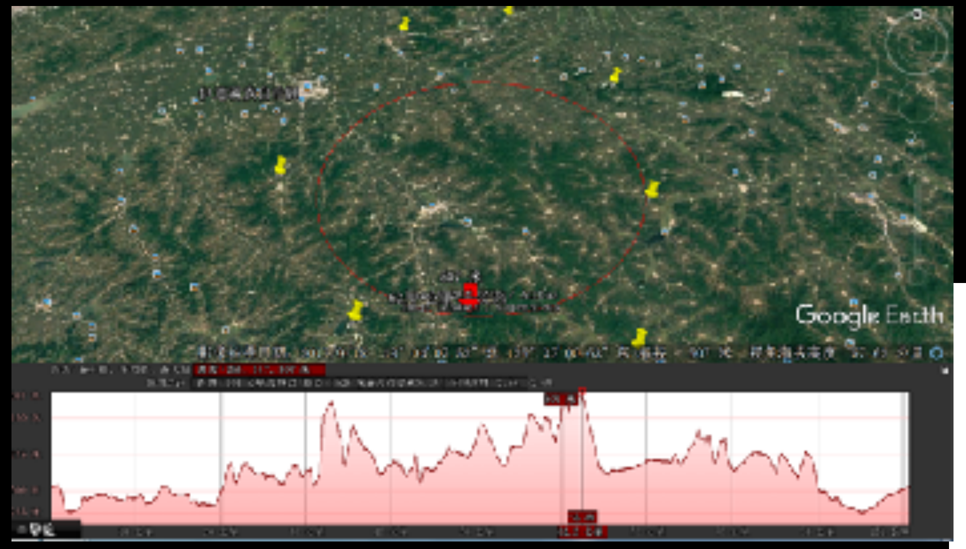
L_{mag} = 5 m, B_{min} = 30 Gs, Errors $<5\times10^{-4}$

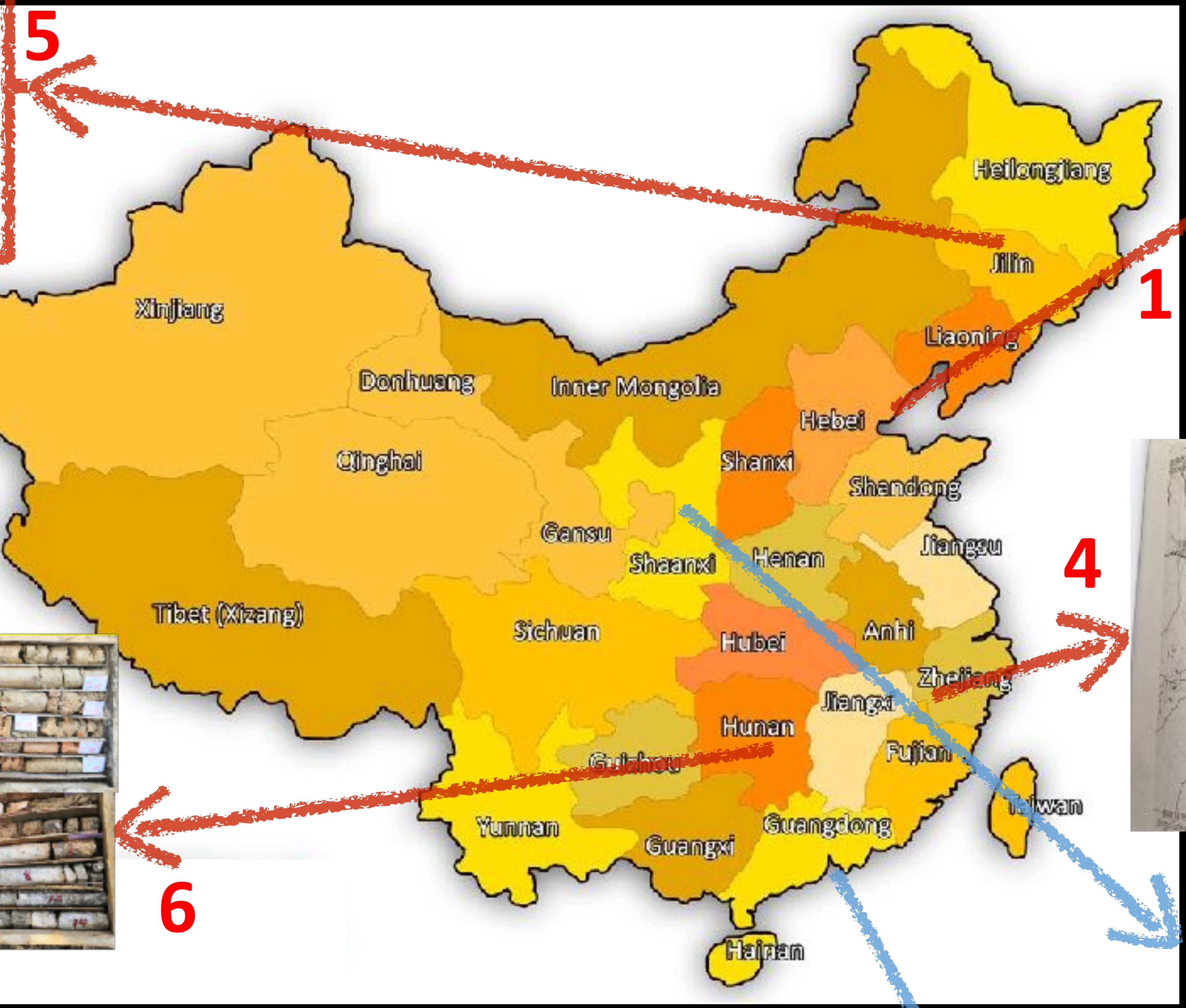
1m long prototype

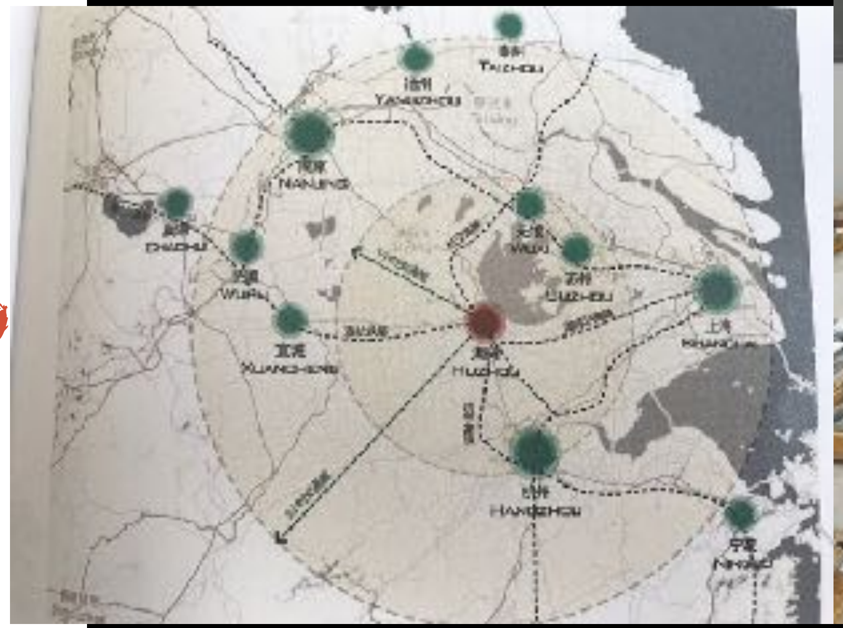


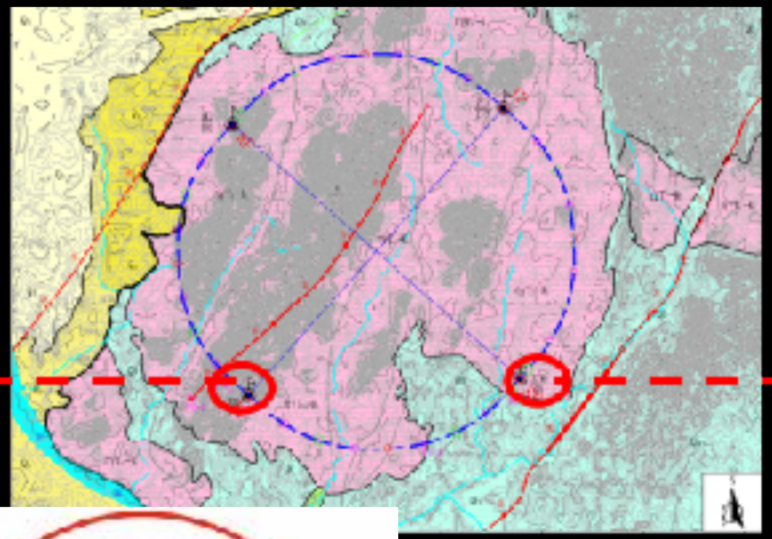
CEPC Site Selection

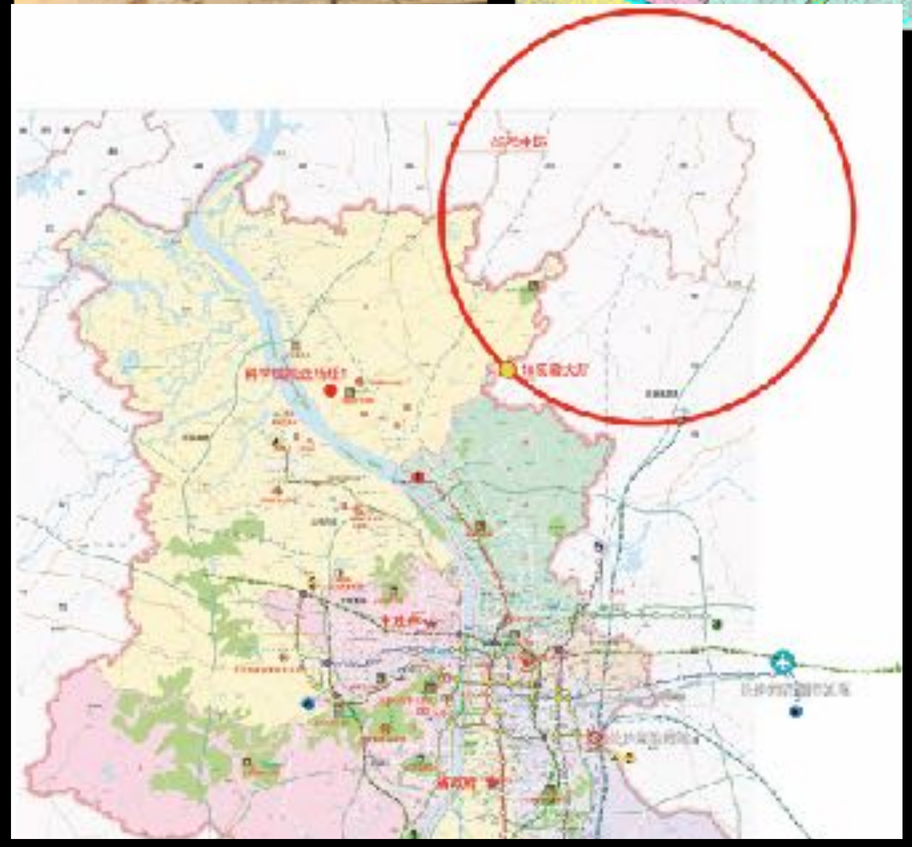
(Red are actively progressing forward)





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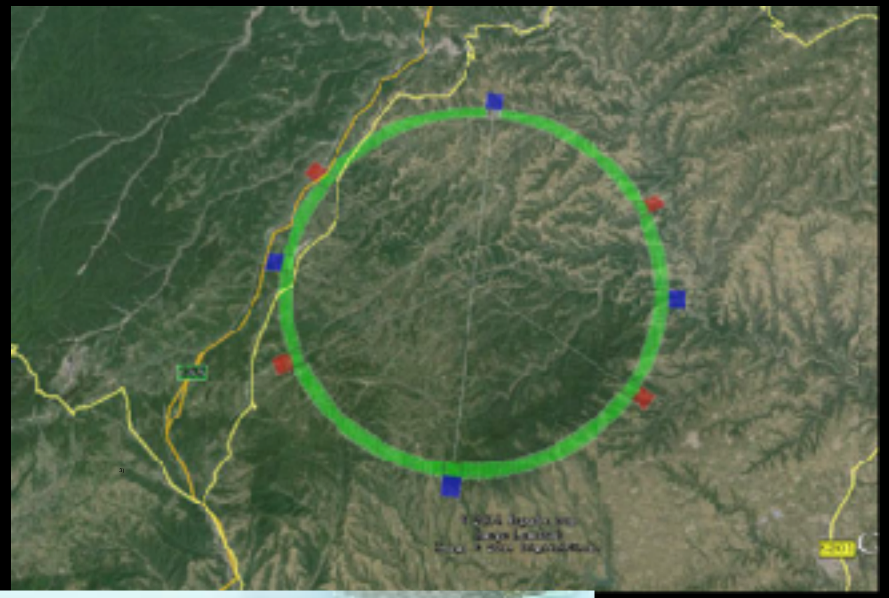


3

1) Qinhuangdao, Hebei Province

2) Huangling, Shanxi Province

3) Shenshan, Guangdong Province

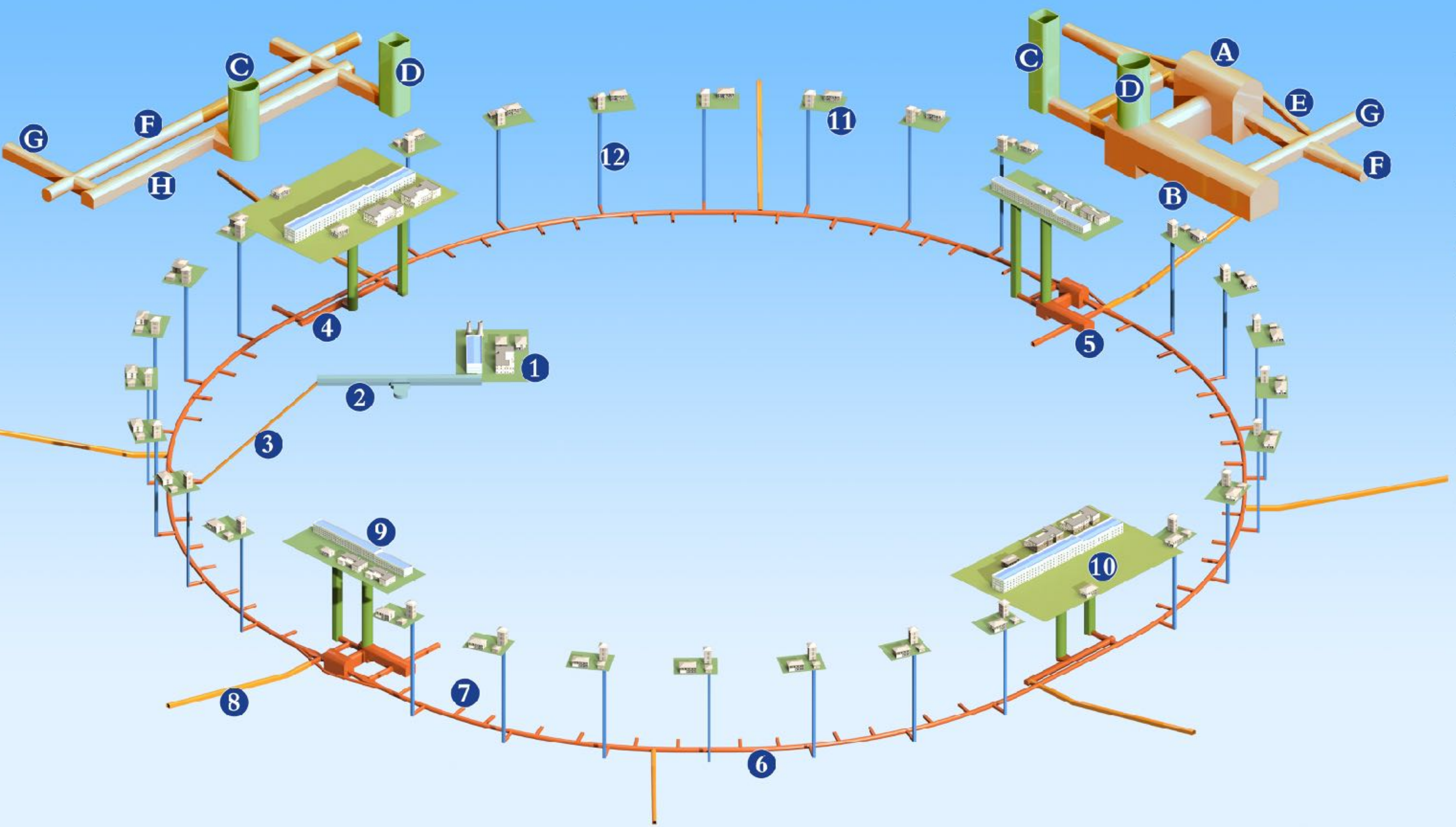
4) Huzhou, Zhejiang Province

5) Chuangchun, Jilin Province

6) Changsha, Hunan Province

Civil engineering

Civil engineering design very advanced



Accelerator Region Caverns:

1. Surface Buildings of Linac Segment
2. Linac Segment
3. Transfer Line
4. Tunnel Complex of RF Region
5. Detector Region Caverns
6. Main Ring Tunnel
7. Auxiliary Tunnel
8. Access Tunnel
9. Surface Buildings of Experiment Hall
10. Surface Buildings of RF Region
11. Surface Buildings of Shaft for Access and Cable
12. Shaft for Access and Cable

Detector Region Caverns:

A. Experiment Hall
B. Service Cavern
C. Transport Shaft
D. Shaft for Access, Cable and HVAC
E. Booster Bypass Tunnel
F. Main Ring Tunnel
G. Traffic Tunnel
H. Auxiliary Tunnel of RF Region

CEPC International Science City Concept

CEPC International Science City Concept

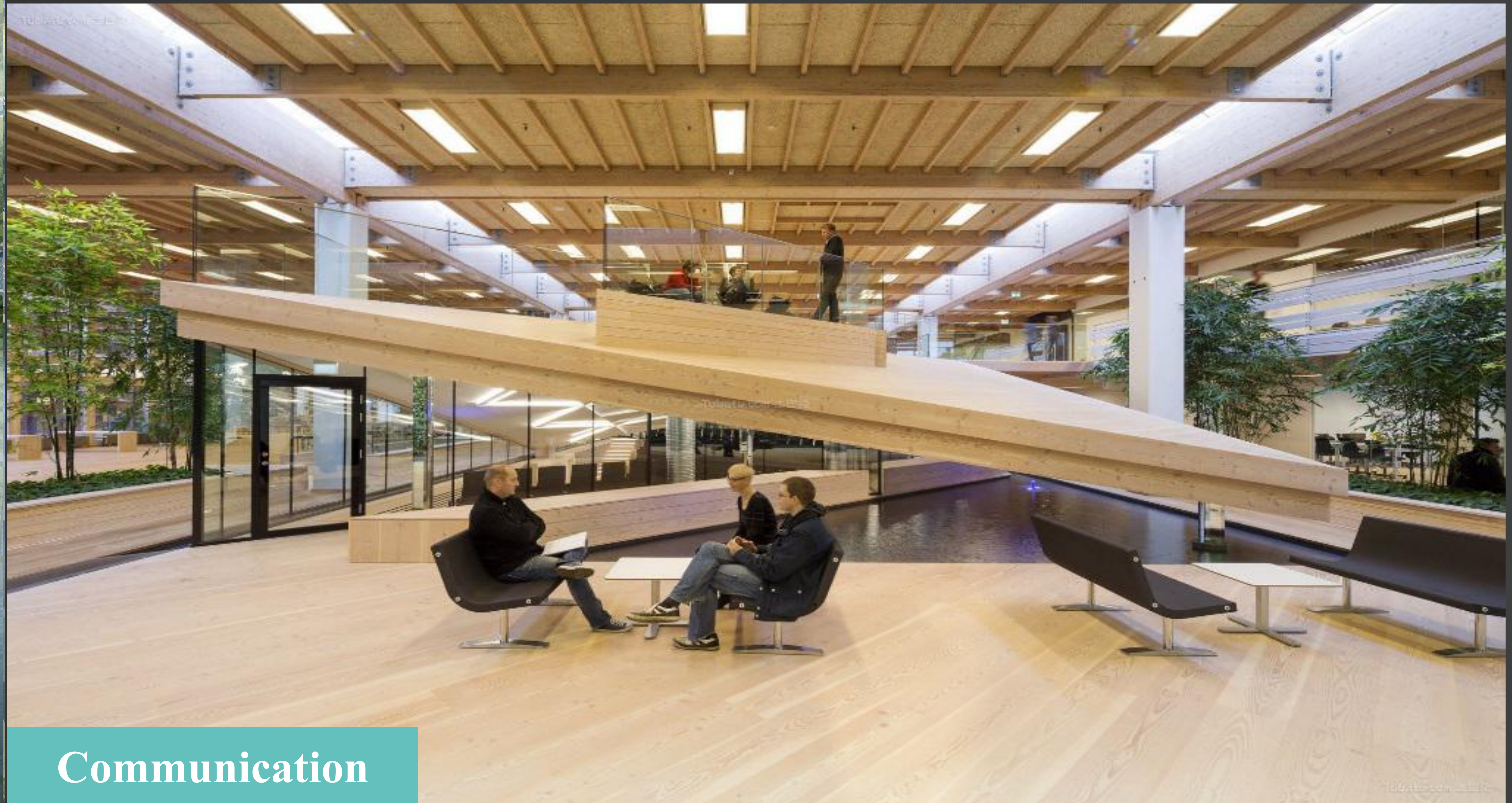
CEPC International Science City Concept

Working Space

Office

Meeting room

Luxary



Communication

Auditorium

CEPC International Science City Concept

xperimental labs

Experimental hall

Cafeteria

Functional Space

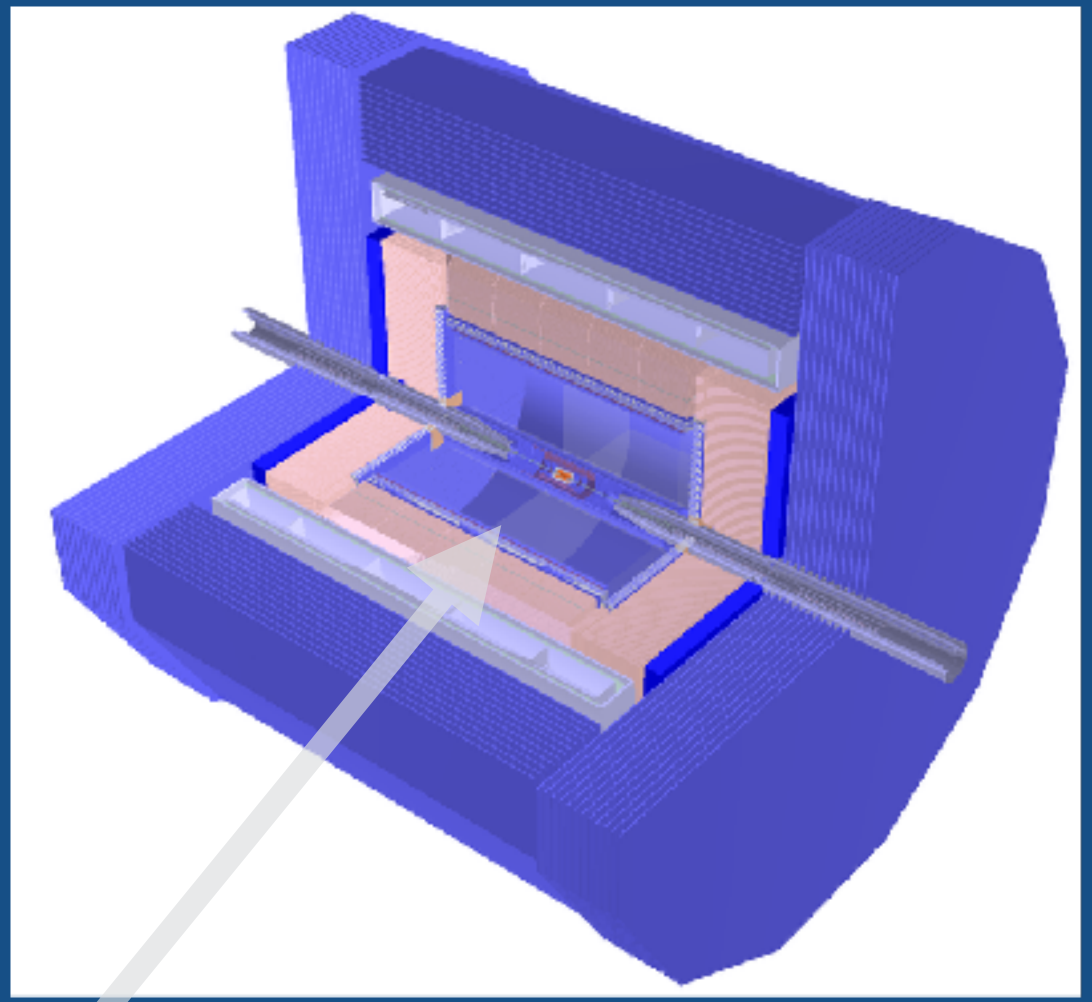
Exibition hall

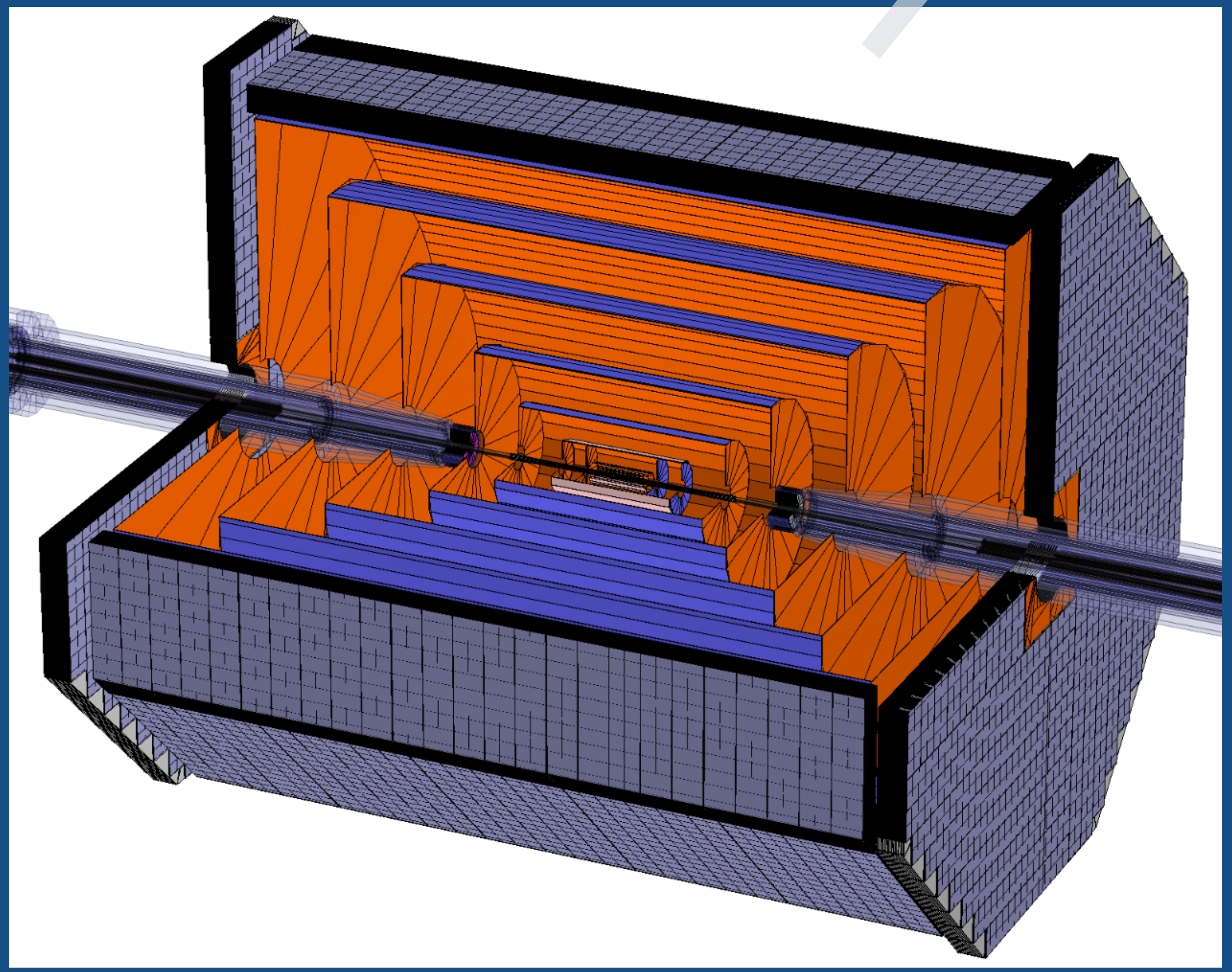
Sport facility

CEPC: These are NOT detector collaborations

Particle Flow Approach

High magnetic field concept (3 Tesla)

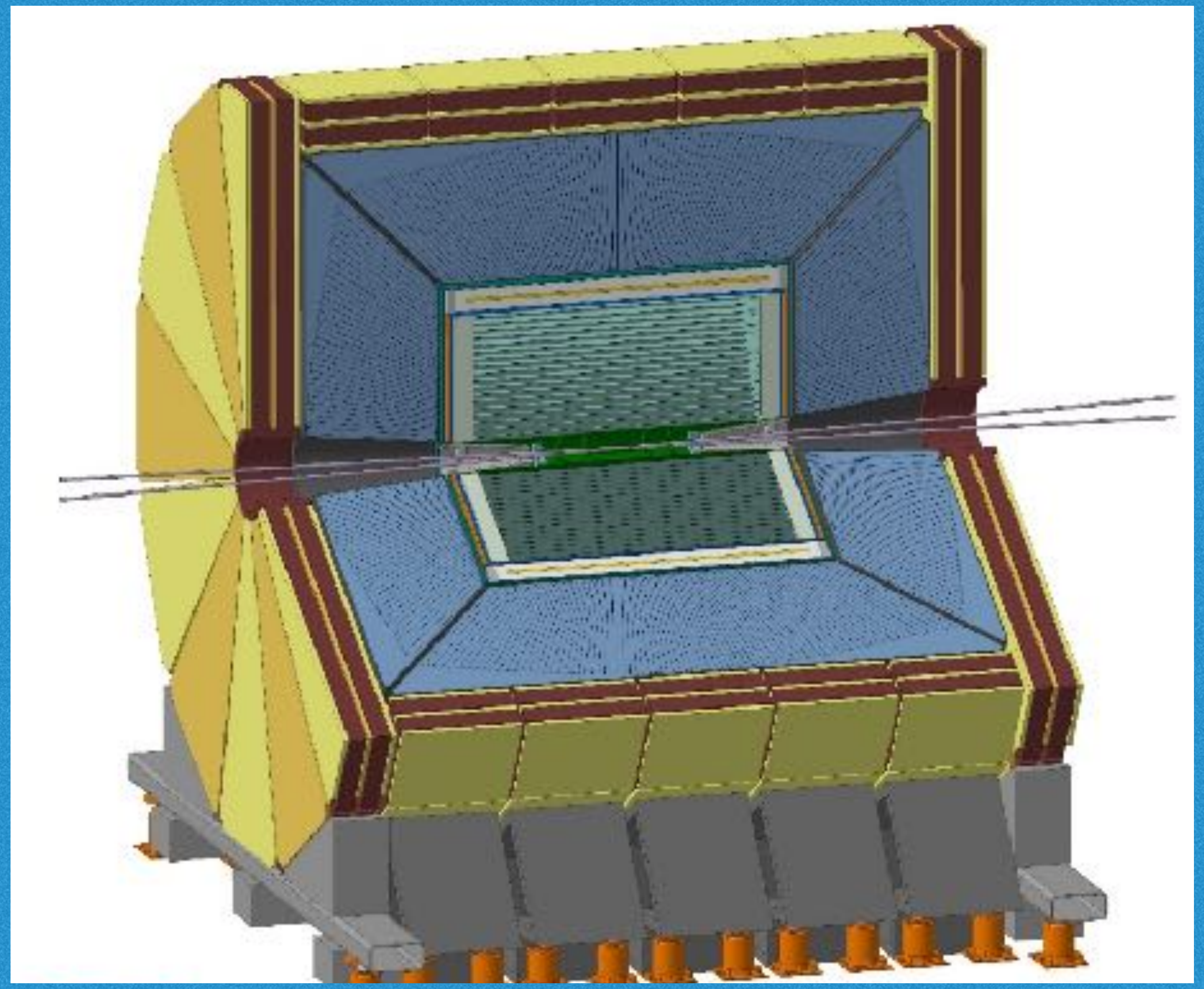




Full silicon tracker concept

CEPC plans for 2 interaction points

Low magnetic field concept (2 Tesla)



IDEA Concept

also proposed for FCC-ee

Final two detectors WILL be a mix and match of different options

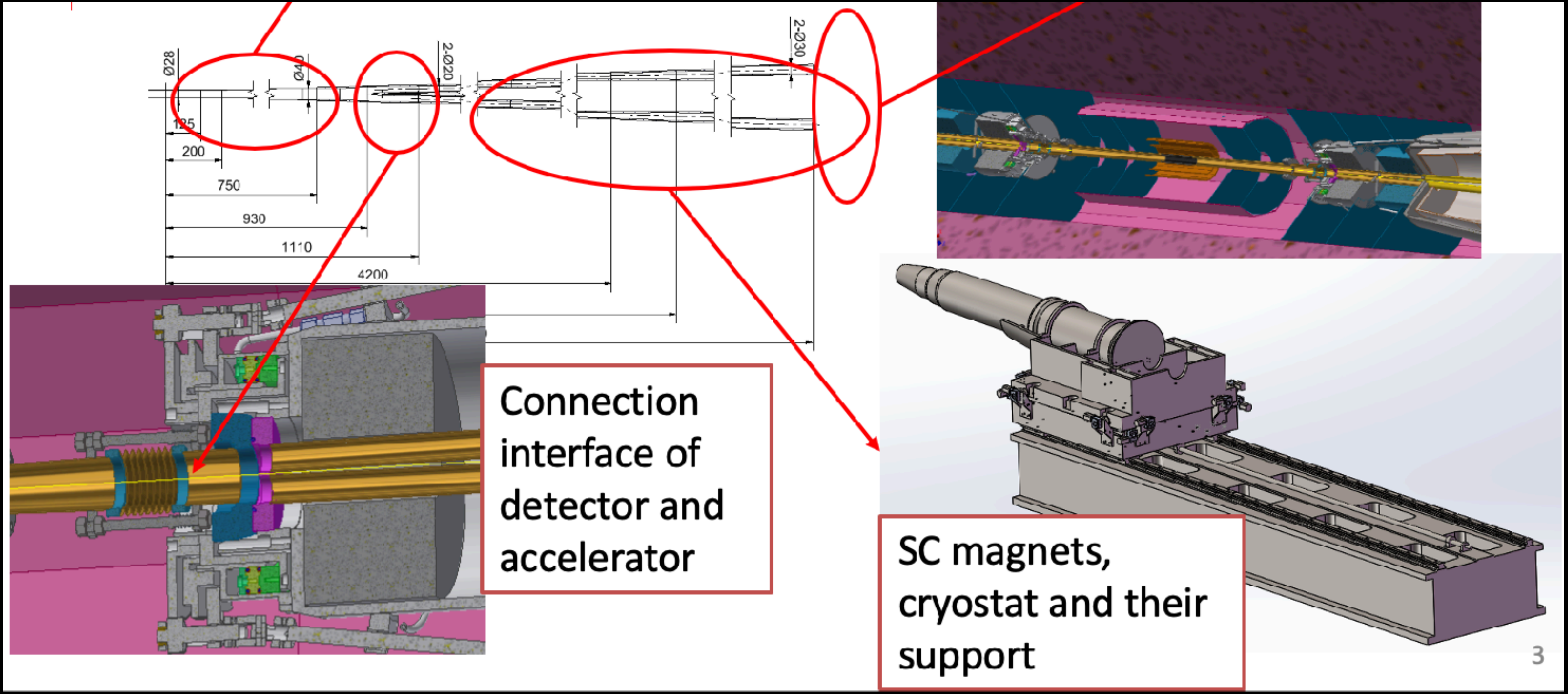
Machine-detector interface (**MDI**) in CEPC

Rates at the inner layer (16 mm):
Hit density: ~2.5 hits/cm^2/BX
TID: 2.5 MRad/year
NIEL: 10^{12} 1MeV n_{eq}/cm^2
(Safety factors of 10 applied)

Final focusing quadrupoles (QD0) need to be very close to IP

Detector acceptance:
> ± 150 mrad

Solenoid magnetic field limited:
2-3 Tesla
due to beam emittance blow up



Cooling of beampipe needed → increases material budget near the interaction point (IP)

Workshop last week: https://indico.ihep.ac.cn/event/11801/

Detector R&D Major R&D Breakdown

17 documents

1. Vertex
   - 1.1. Pixel Vertex Prototype
   - 1.2. ARCADIA/LFoundry CMOS
2. Tracker
   - 2.1. TPC
   - 2.2. Silicon Tracker
   - 2.3. Drift Chamber
3. Calorimeter
   - 3.1.ECAL Calorimeter
     - 3.1.1. Crystal Calorimeter
     - 3.1.2. Scintillator-Tungsten
   - 3.2. HCAL PFA Calorimeter
     - 3.2.1. DHCAL
     - 3.2.2. Sci AHCAL
   - 3.3. DR Calorimeter
4. Muon Detectors
   - 4.1. Muon Scintillator Detector
   - 4.2. Muon and pre-shower MuRWell Detectors
5. Solenoid
   - 5.1. LTS Solenoid
   - 5.2. HTS Solenoid
6. MDI
   - 6.1. LumiCal Prototype
   - 6.2. Mechanics
7. TDAQ
8. Software and Computing

Projects overview

Total subtasks: 95

17 documents, total: 80 pages

PBS	Task Name	Page	Subtasks	Context	Team	Document Responsible
	CEPC Detector R&D Project					
1	**Vertex**					
1.1	**Vertex Prototype**	5	9	CEPC	China+ international collaborators	Zhijun, Ouyang
1.2	**ARCADIA CMOS MAPS**	6	6	Generic	INFN, Italy	Manuel Rolo
2	**Tracker**					
2.1	**TPC Module and Prototype**	6	12	CEPC	IHEP, Tsinghua	Huirong
2.2	**Silicon Tracker Prototype**	6	8	Generic	China, UK, Italy	Harald Fox, Meng Wang
2.3	**Drift Chamber Activities**	4	3	FCC-ee/CEPC	INFN, Novosibirsk	Franco Grancagnolo
3	**Calorimetry**					
3.1	**ECAL Calorimeter**					
3.1.1	Crystal Calorimeter	5	6	CEPC	IHEP, Princeton + others	Yong Liu
3.1.2	PFA Sci-ECAL Prototype	3	3	CEPC	USTC, IHEP	Jianbei Liu
3.2	**HCAL Calorimeter**					
3.2.1	PFA Digital Hadronic Calorimeter	4	5	CEPC	SJTU, IPNL, Weizmann, IIT, USTC	Haijun Yang, Imad Laktineh, Shikma Bressler
3.2.2	PFA Sci-AHCAL Prototype	4	4	CEPC	USTC, IHEP, SJTU	Jianbei Liu
3.3	**Dual-readout Calorimeter**	5	5	FCC-ee/CEPC	INFN, Sussex, Zagreb, South Korea	Roberto Ferrari
4	**Muon Detector**					
4.1	Scintillator-based Muon Detector	4	5	CEPC	Fudan, SJTU	Xiaolong Wang, Liang Li
4.2	Muon and pre-shower µRWELL-	5	4	FCC-ee/CEPC	INFN, LNF	Paolo Giacomelli
5	**Solenoid**					
5.1	LTS solenoid magnet	4	4	CEPC	IHEP+Industry	Zhu Zian
5.2	HTS solenoid magnet	4	4	CEPC	IHEP+Industry	Zhu Zian
6	**MDI**					
6.1	LumiCal Prototype	4	2	ILC/CEPC	AC, IHEP	Suen Hou
6.2	Interaction Region Mechanics	3	4	CEPC	IHEP	Hongbo Zhu
8	**Software and Computing**	7	11	CEPC	IHEP, SDU	Li Weidong, Ruan Manqi, Sun Shengseng, Li Gang

Projects overview: Schedule

PBS	Task Name	Finish
	CEPC Detector R&D Project	**26/12/31**
1	**Vertex**	**23/12/29**
1.1	Vertex Prototype	23/12/29
1.2	ARCADIA CMOS MAPS	23/12/29
2	**Tracker**	**24/12/31**
2.1	TPC Module and Prototype	23/12/29
2.2	Silicon Tracker Prototype	23/10/31
2.3	Drift Chamber Activities	24/12/31
3	**Calorimetry**	**24/12/31**
3.1	**ECAL Calorimeter**	**24/12/31**
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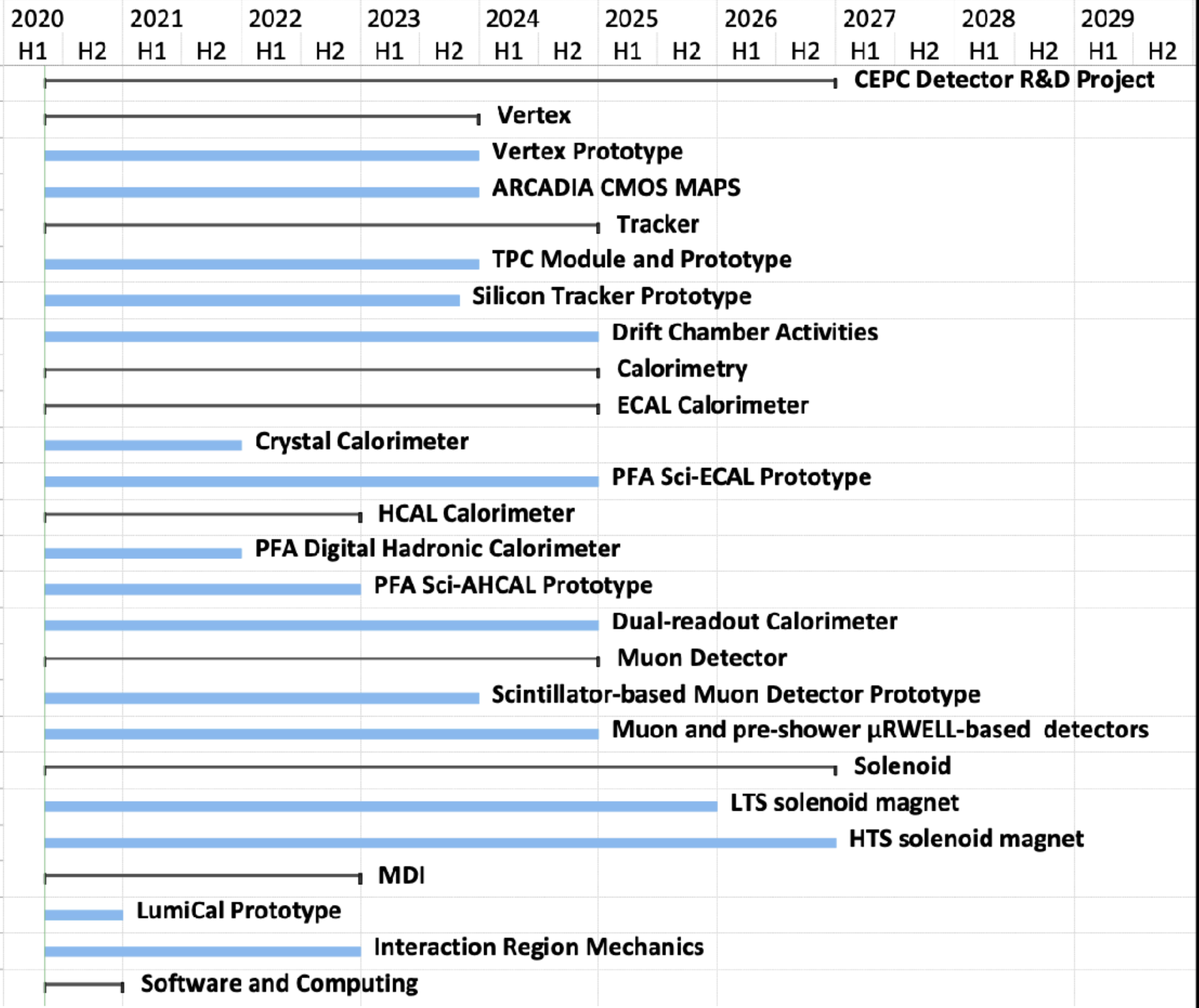
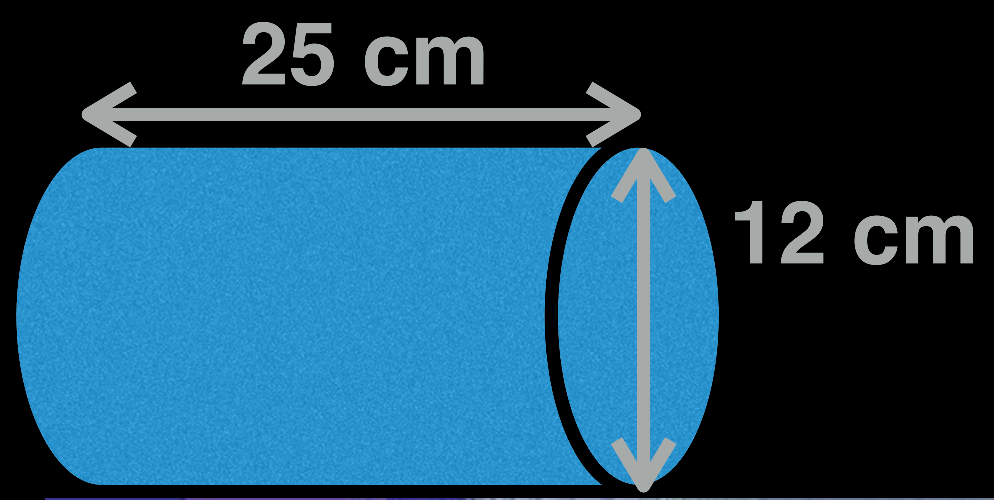
3.1.2	PFA Sci-ECAL Prototype	24/12/31
3.2	**HCAL Calorimeter**	**22/12/30**
3.2.1	PFA Digital Hadronic Calorimeter	21/12/31
3.2.2	PFA Sci-AHCAL Prototype	22/12/30
3.3	**Dual-readout Calorimeter**	**24/12/31**
4	**Muon Detector**	**24/12/31**
4.1	Scintillator-based Muon Detector Prototype	23/12/29
4.2	Muon and pre-shower µRWELL-based detectors	24/12/31
5	**Solenoid**	**26/12/31**
5.1	LTS solenoid magnet	25/12/31
5.2	HTS solenoid magnet	26/12/31
6	**MDI**	**22/12/30**
6.1	LumiCal Prototype	20/12/31
6.2	Interaction Region Mechanics	22/12/30
8	**Software and Computing**	**20/12/31**

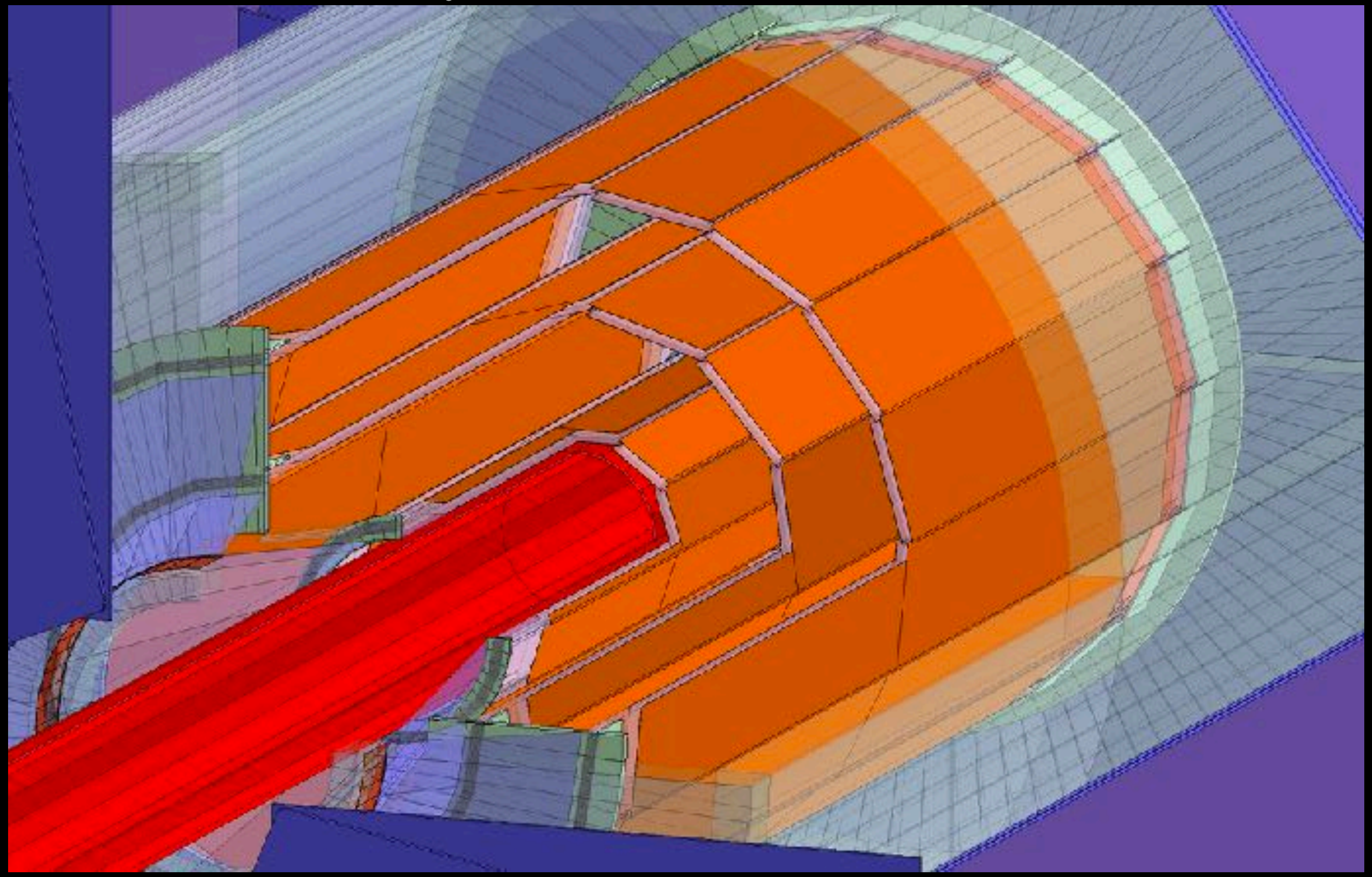


Baseline Pixel Detector



3 double ladders of silicon pixel sensors

✦ Innermost layer: σ_{SP} = 2.8 μm

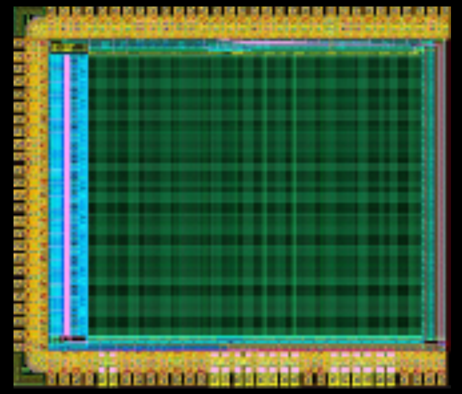


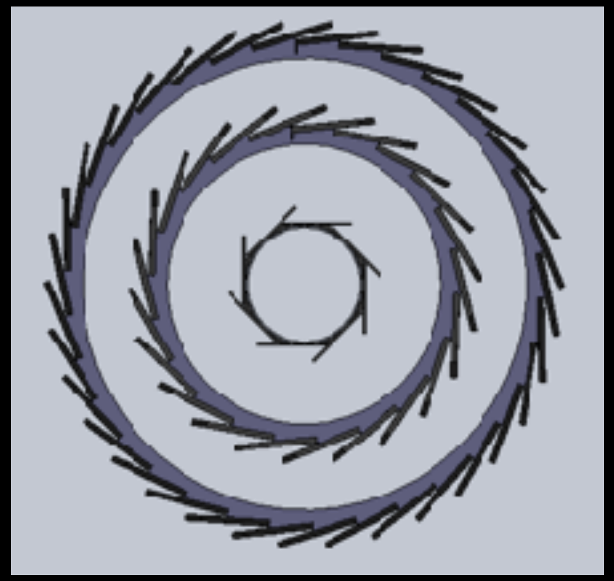
Low material budget
~ 0.15%X_0 per layer

CMOS { Integrated sensor and readout electronics on the same silicon bulk with "standard" CMOS process:
- low material budget,
- low power consumption,
- low cost …

Pixel Detector prototype: (by 2023)

Towerjazz





Collaborating with:
- Barcelona, IFAE
- Liverpool
- Oxford
- RAL
- QMU
- UMass, US

- Developing full size CMOS sensor for use in real size prototype, with good radiation hardness

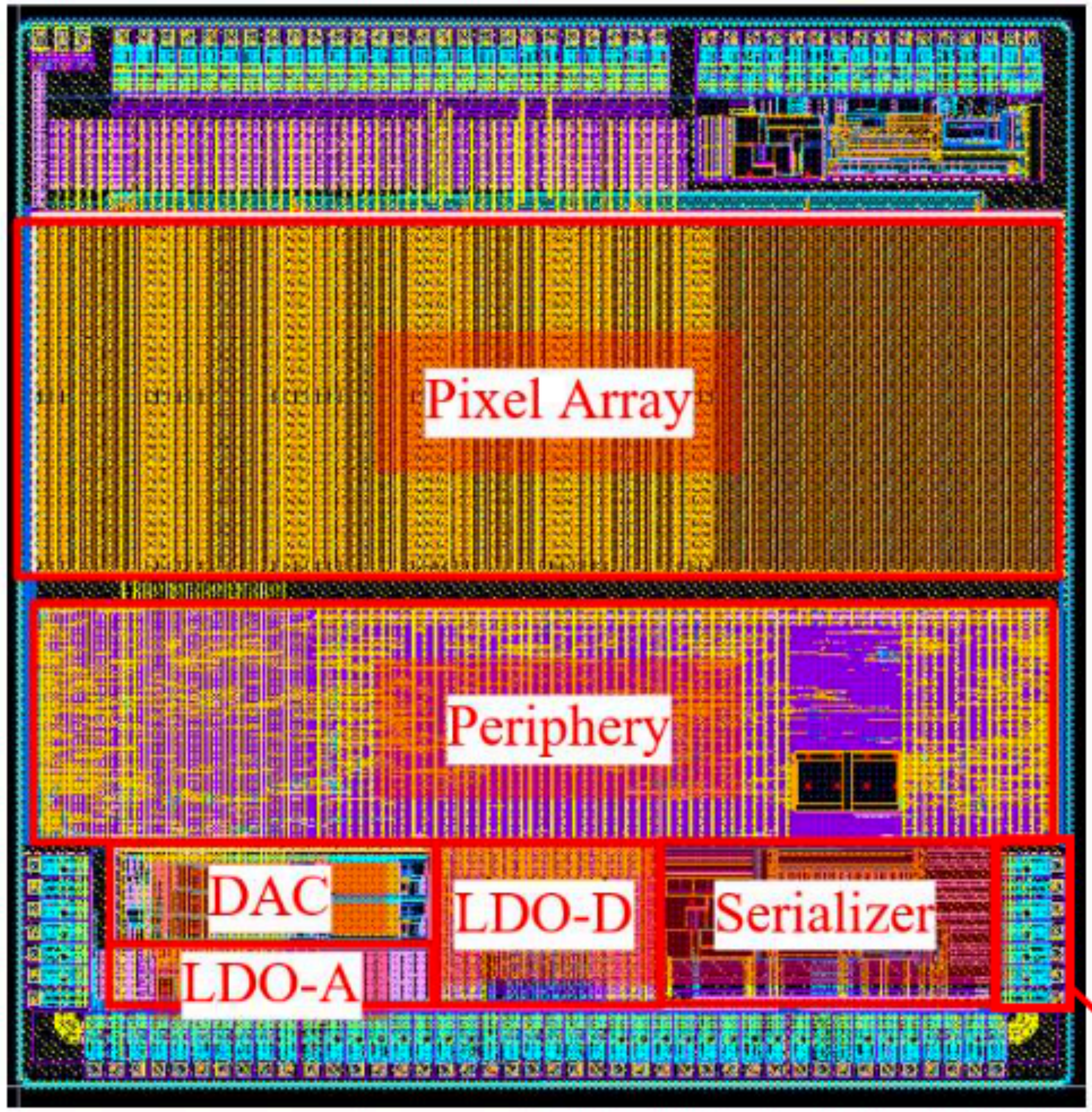
Second Version submitted in February

Collaboration with IFAE

Integrates:
FE-I3-like
and
ALPIDE-like
readout architecture

TaichuPix1 Chip received in Nov 19 and tested

Design Status of TaichuPix2



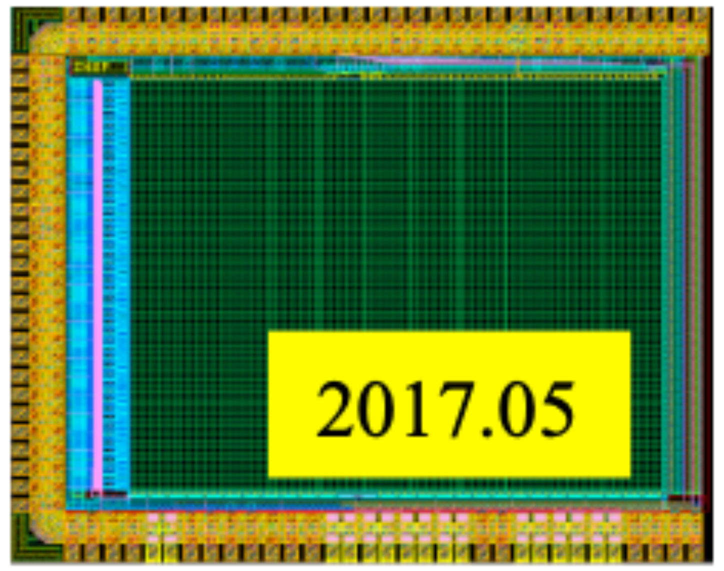
Pixel size: 24× 25 μm^2

- Submitted on Feb 18, 5*5mm
- All blocks fully integrated, as the final chip
- New features
  - A 64*192 pixel array with the same dimension as Tcpx1
    - 32 + 32 double column modified FE-I3 readout, 32 dblcol modified ALPIDE readout
    - 6 variations of pixel analog, each for 16 columns
  - Newly integrated blocks: Two LDOs for power supplies
  - 8b10b encoder added for Triggerless output and balanced datastream
  - X-chip buses added for multiple chip interconnections

Development path of CMOS Pixel Sensors:

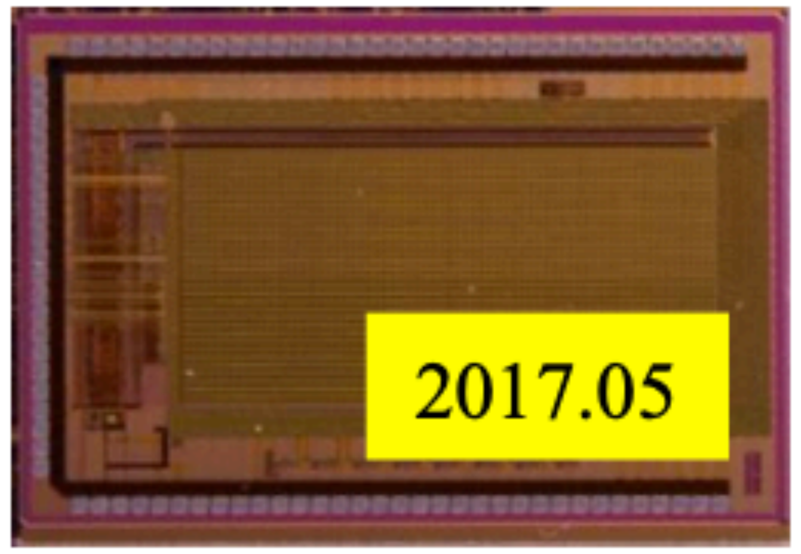
Prototype	Pixel size (μm^2)	Collection diode bias (V)	In-pixel circuit	R/O architecture	Main goals	Status
JadePix2	22 × 22	< 10 V (ac-coupled)	amp., discriminator, binary output	Rolling shutter	Small pixel, Power < 100 mW/cm^2	Electrical functionality verified
MIC4	25 × 25	reverse bias	Low power front-end, address encoder	Data-driven, Asynchronous	Small pixel, fast readout	Electrical functionality verified
JadePix3	16 × 26 16 × 23.11	reverse bias	Low power front-end, binary output	Rolling shutter with end of col. priority encoder	Small pixel, low power	Production finished

All prototypes in TowerJazz 180 nm CIS process



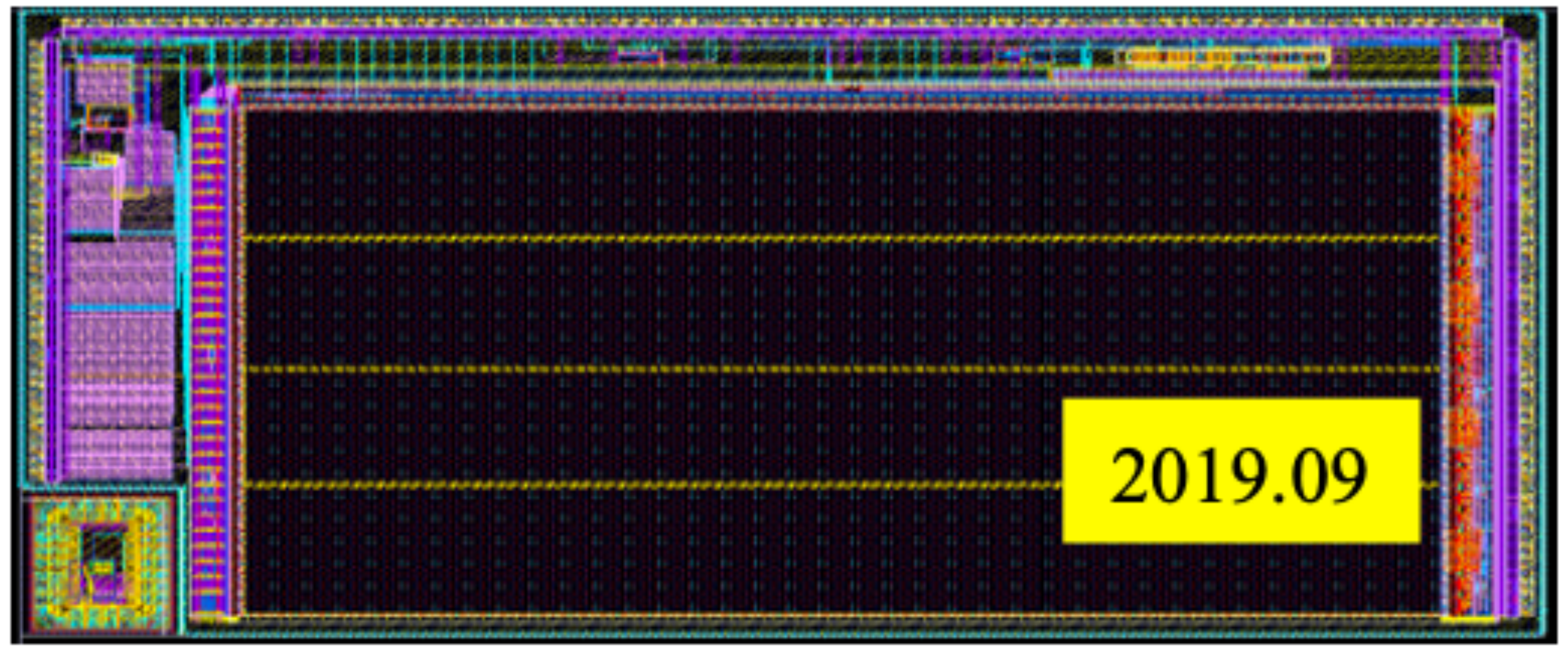
JadePix2 (IHEP)

3 × 3.3 mm^2



MIC4 (CCNU & IHEP)

3.2 × 3.7 mm^2



JadePix3(IHEP, CCNU, Dalian Minzu Unv., SDU)

10.4 × 6.1 mm^2

3

SOI Pixel Sensor Development at IHEP

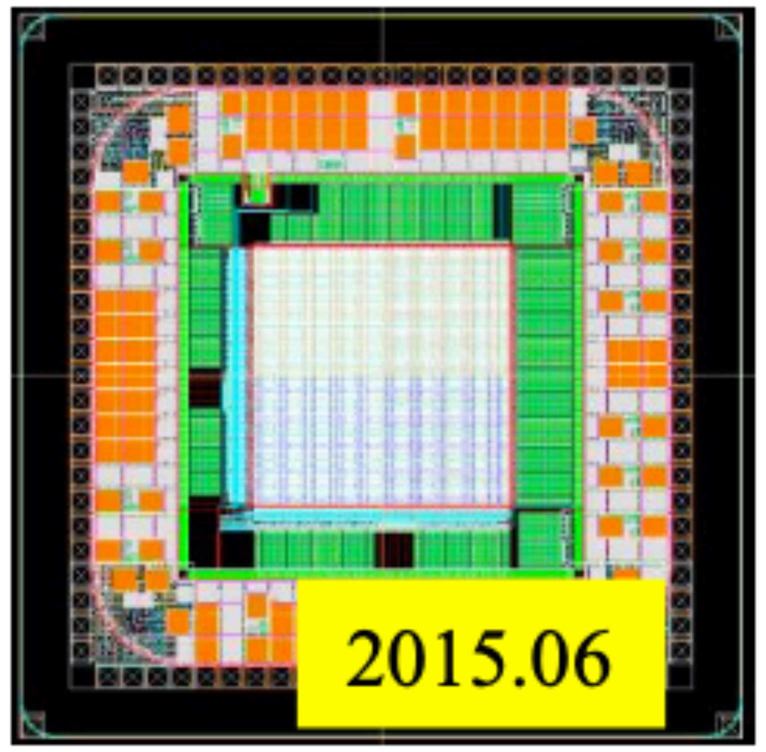
Prototypes in LAPIS 200nm Double-SOI process

LAPIS 200nm Pinned Depleted Diode process

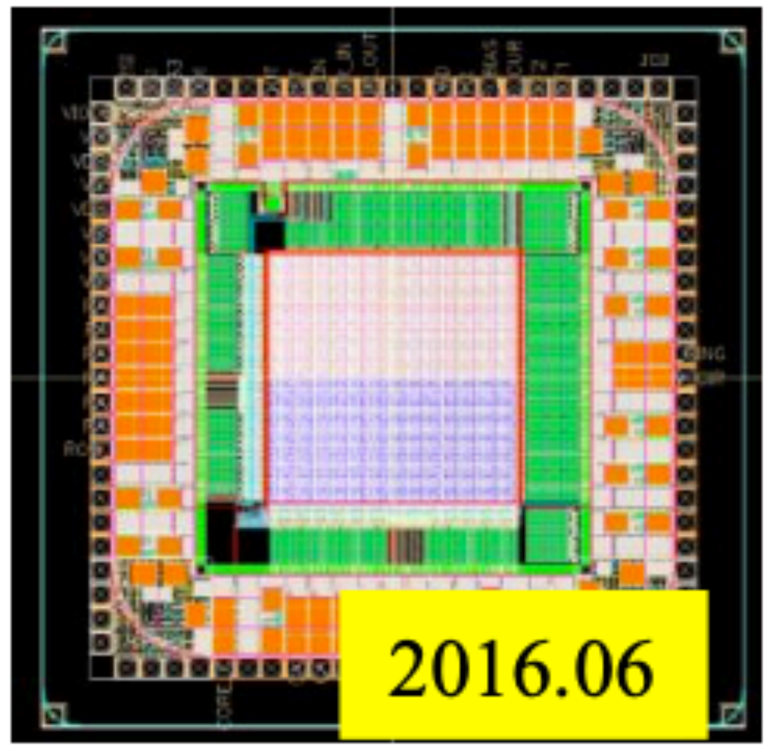
- 16μm *16μm with in-pixel discrimination
- Double-SOI process for shielding and radiation enhancement

- Thinned down to 75μm thick
- Temporal noise ~6e⁻
- Threshold dispersion (FPN) ~114e⁻
- Single point resolution ~2.3μm measurement under infrared laser beam

- Dedicated bias scheme to minimize capacitance
- Optimized for low FPN 12e⁻
- Pixel matrix divided as 45 regions, to verify design options

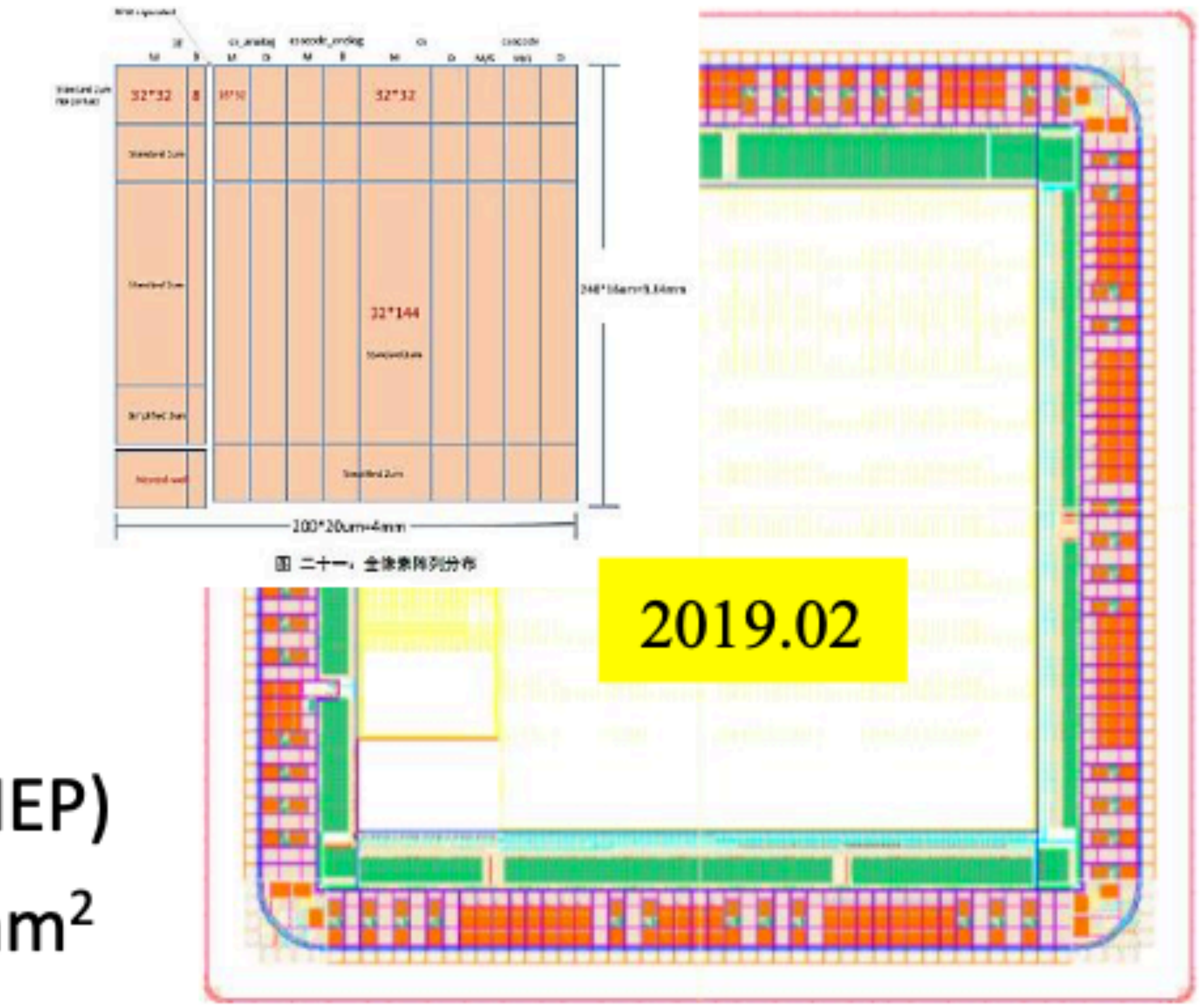


CPV1 (IHEP)
3 × 3 mm²



CPV2 (IHEP)
3 × 3 mm²

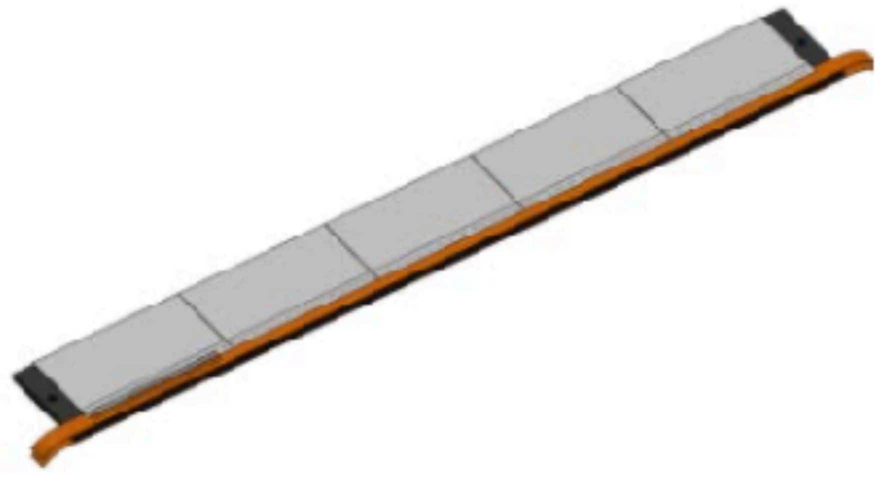
CPV3 (IHEP)
6 × 6 mm²



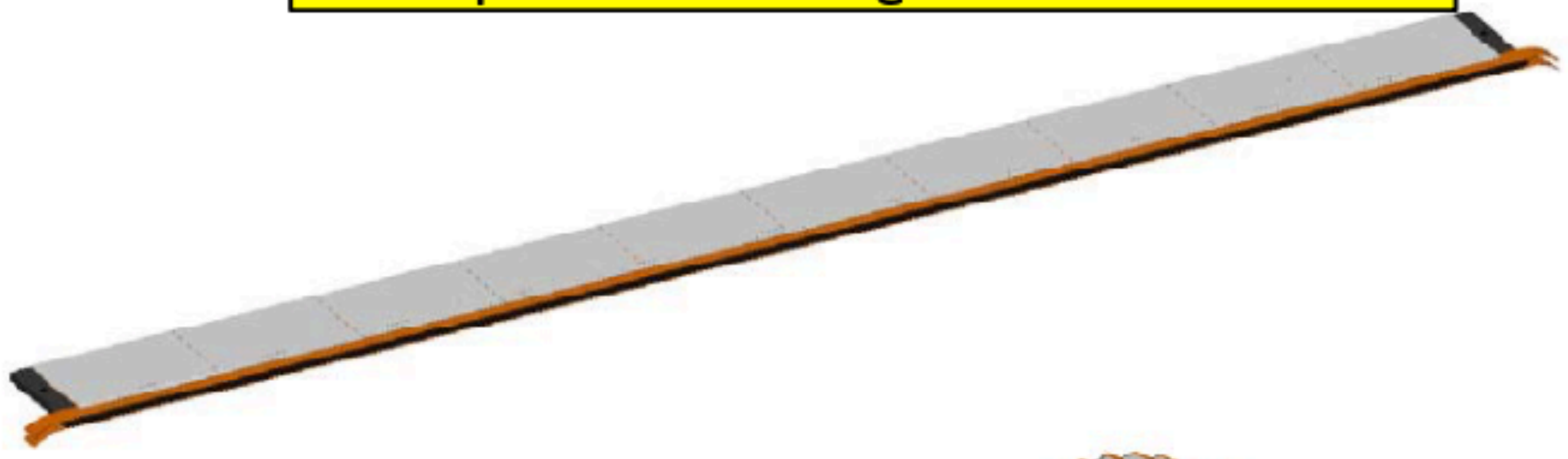
Mechanical Design

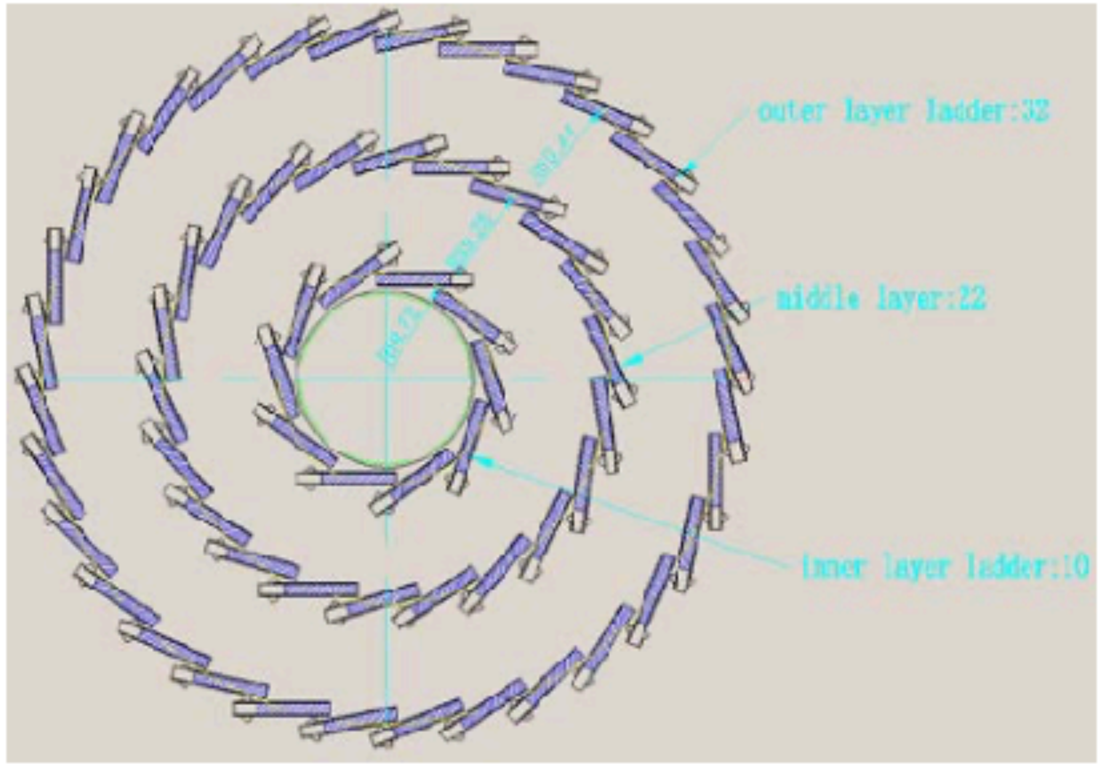
Studying different layouts, and materials

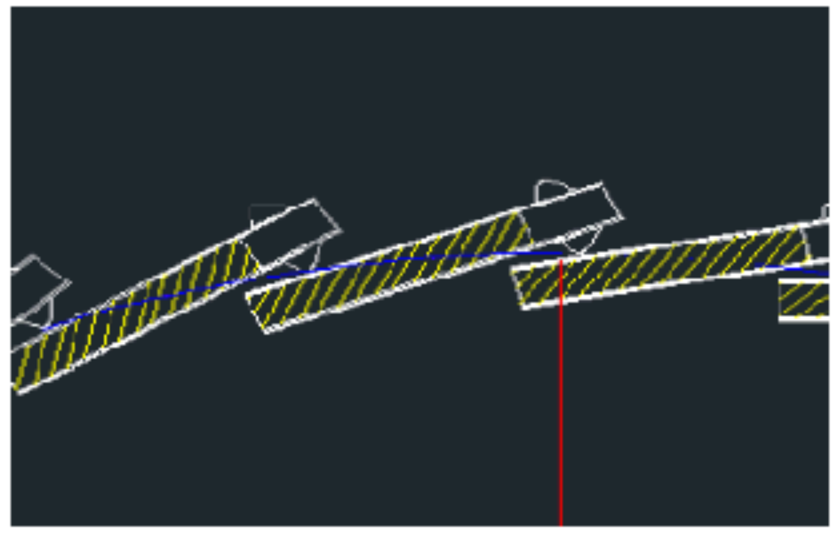
Ladder of inner layer(16.8 x 131 mm):
10 chips total including both sides

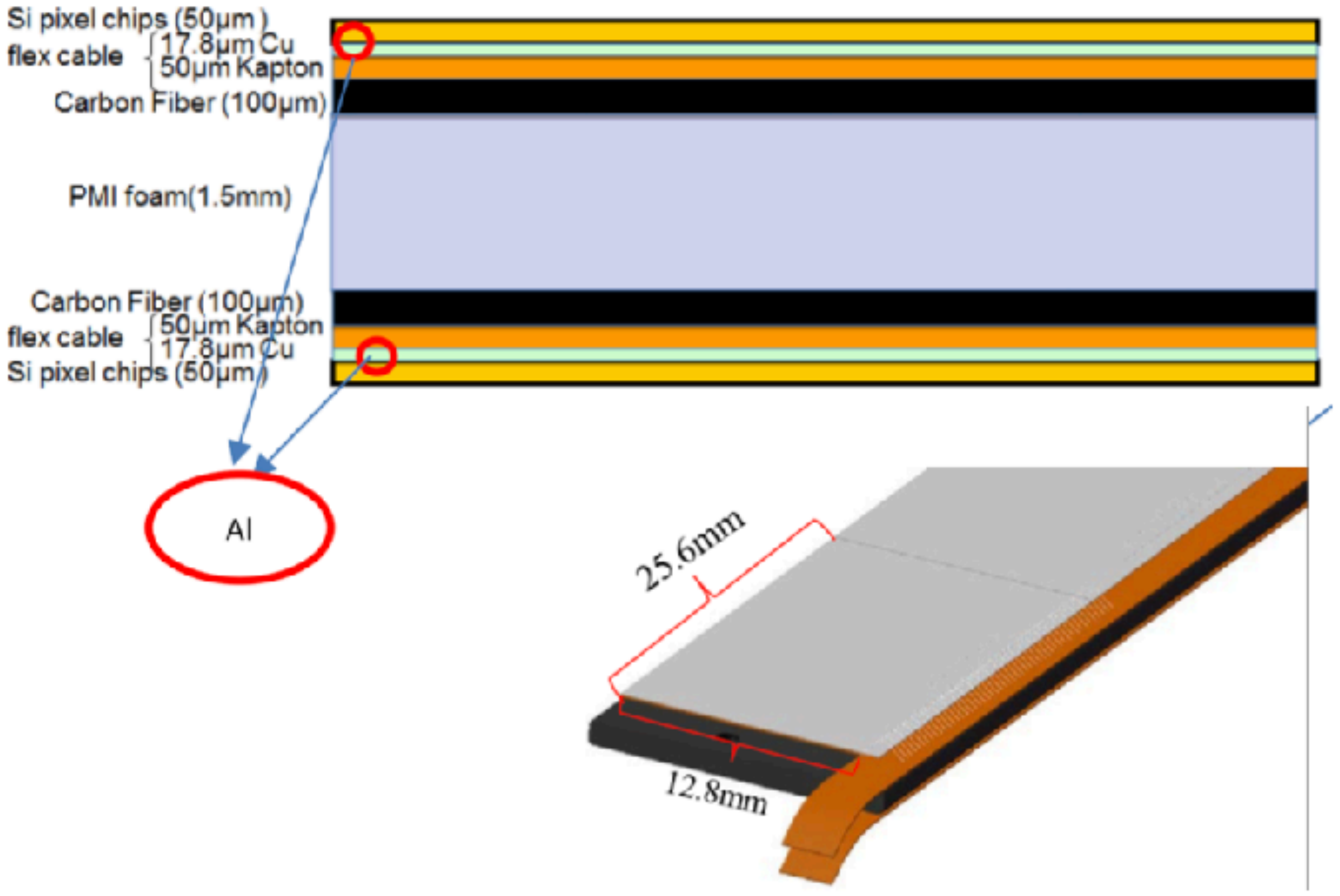


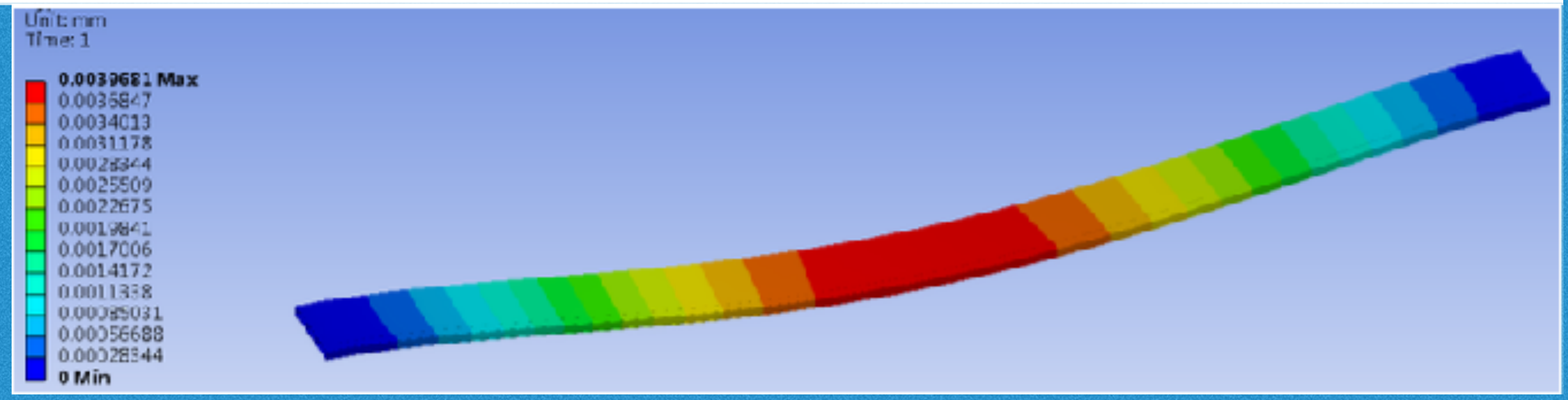
Ladder of outer two layers(16.8 x 264 mm):
20 chips total including both sides



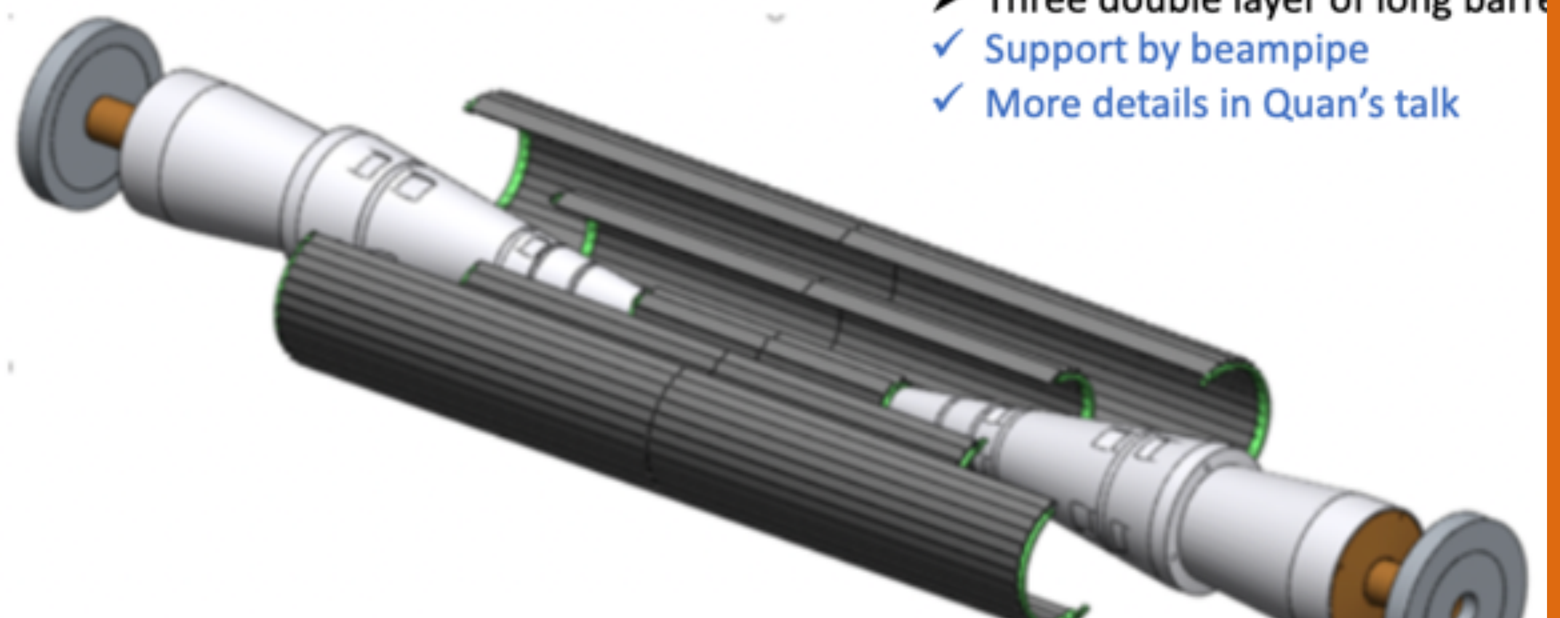




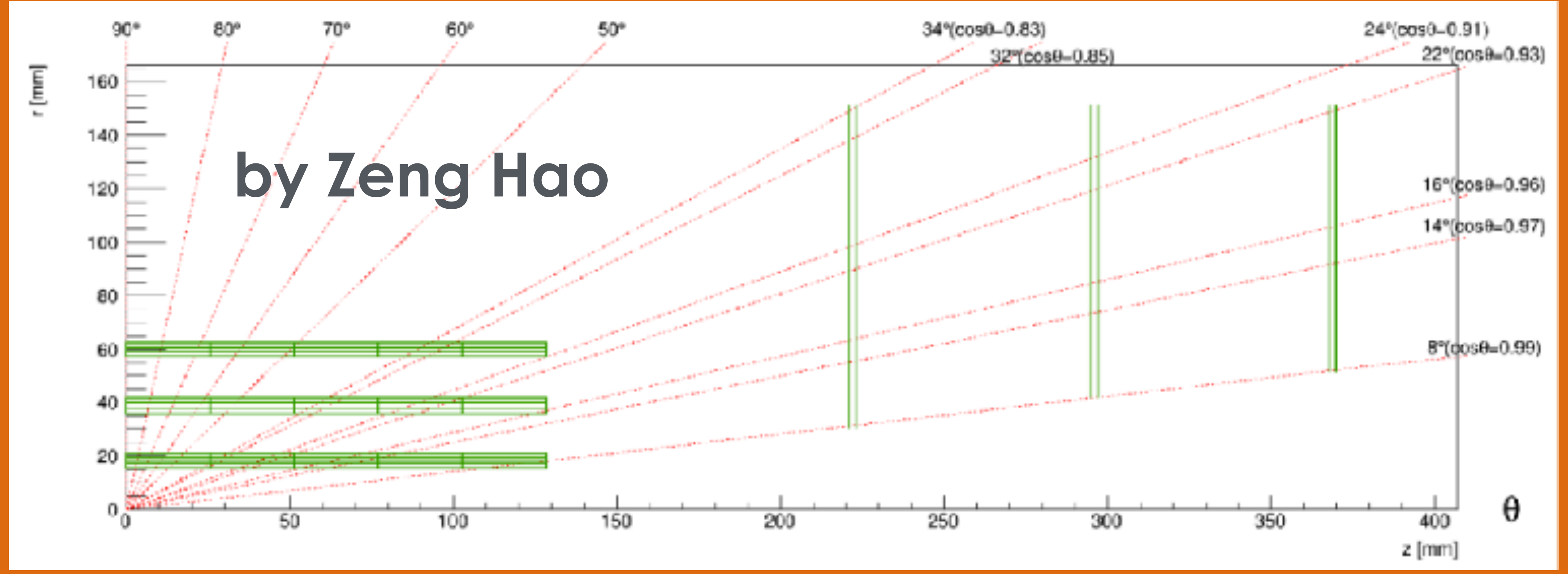


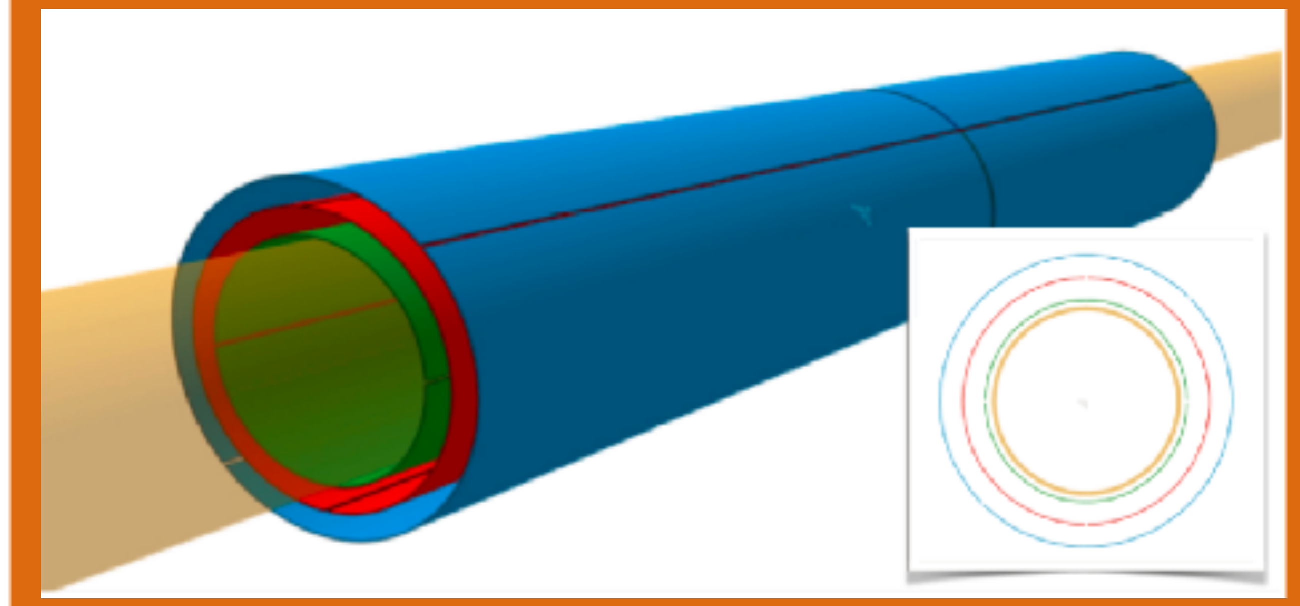


- ➢ Three double layer of long barre
- ✓ Support by beampipe
- ✓ More details in Quan's talk

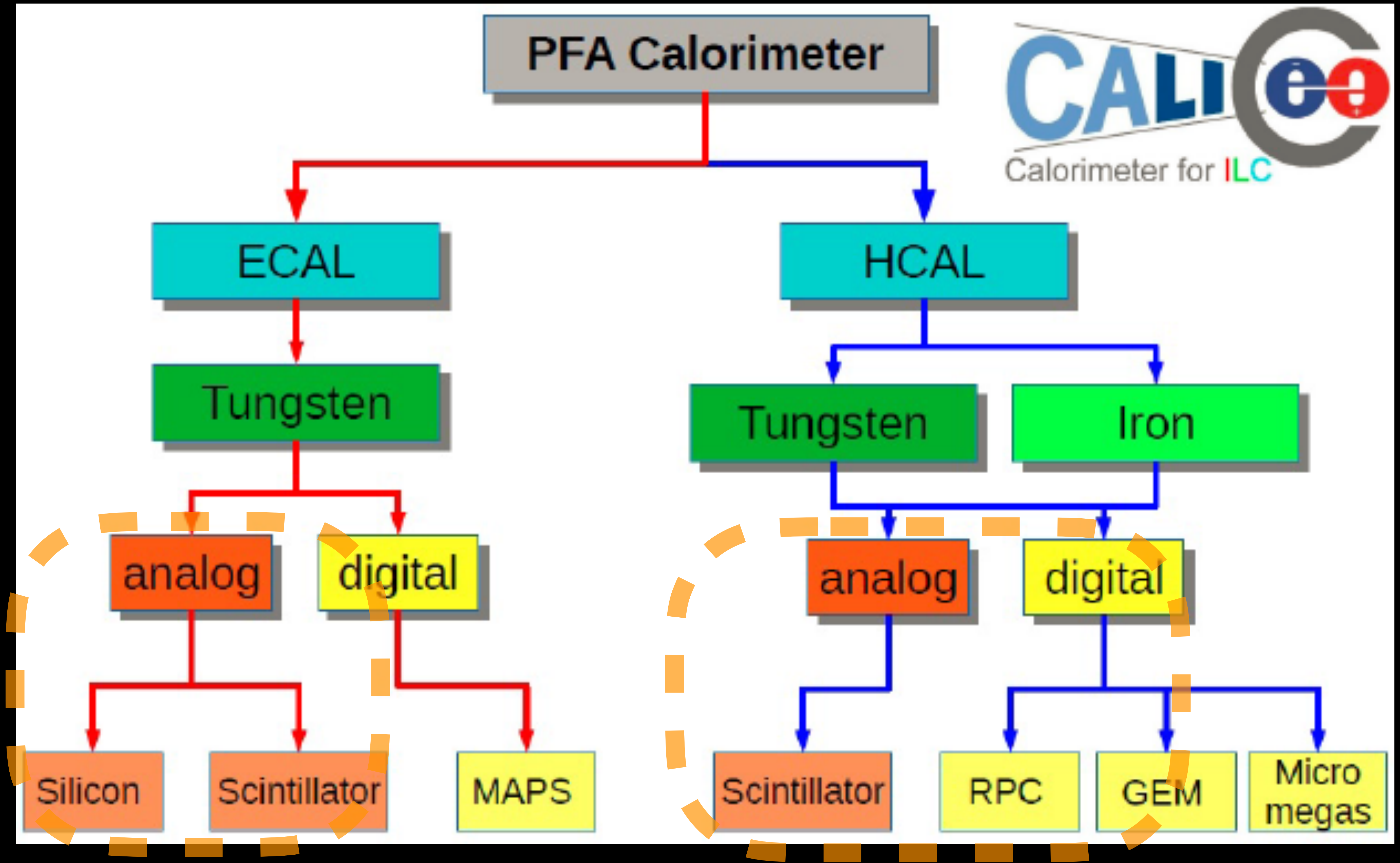


By Quan Ji





Calorimeter options

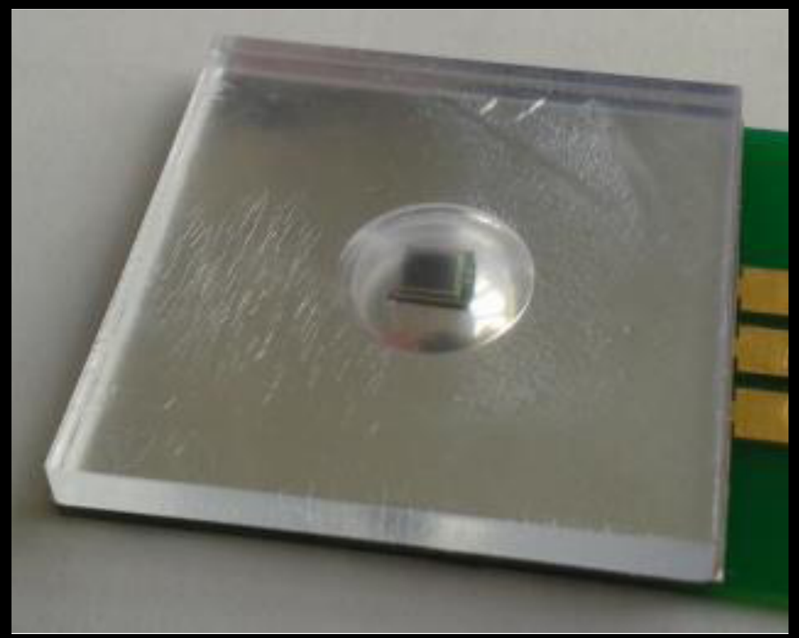


Chinese institutions have been focusing on Particle Flow calorimeters

Detector challenges:

- Compact design
- Calibration of channels
- Cooling
- Cost

Scintillator tiles/strips (here 3 × 3 cm²) + SiPMs



International collaboration with several institutes (Italy, France, USA)

Prototypes of up to ~1 m³ to be produced by 2023

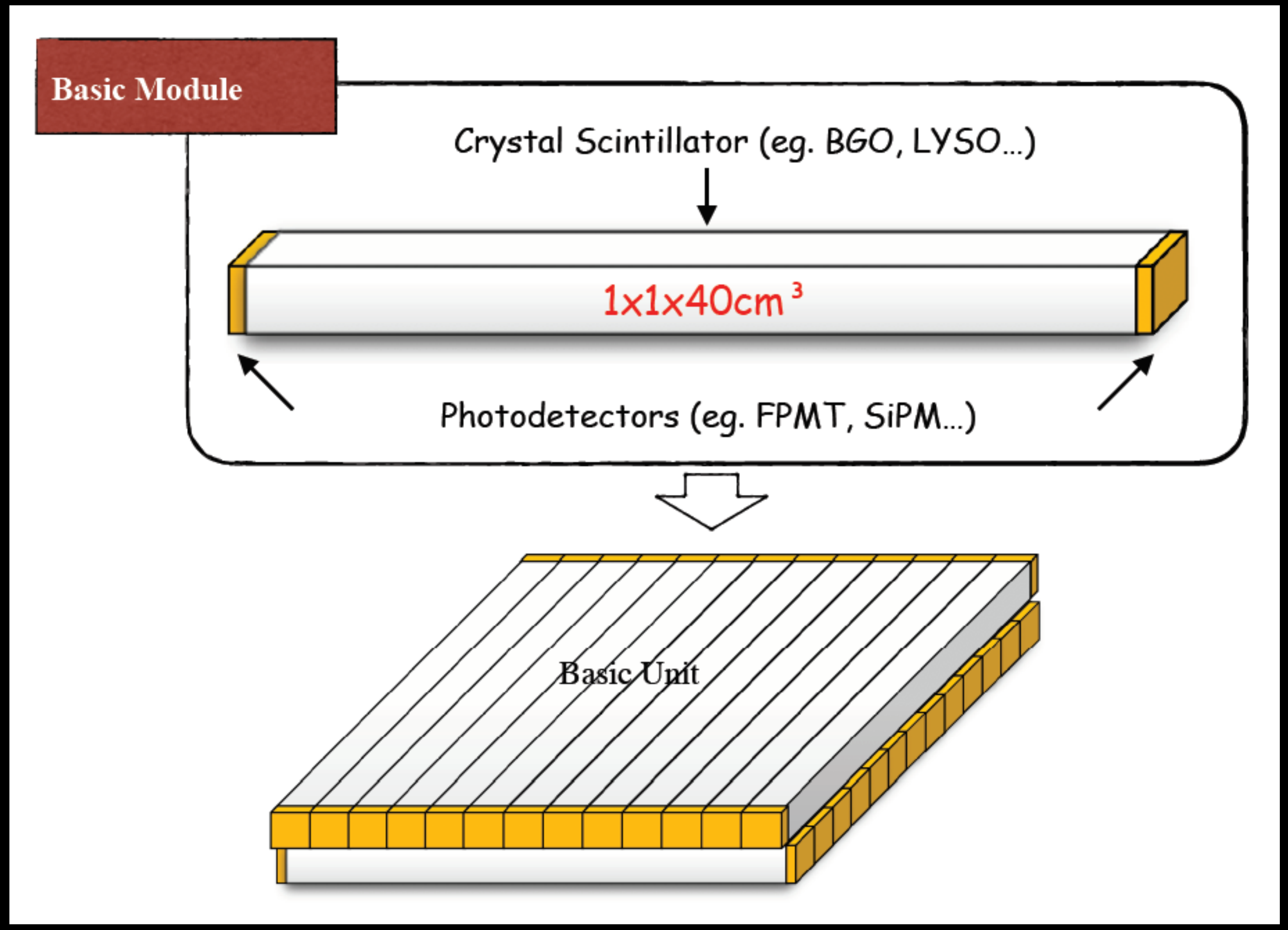
Studies started on a Crystal (LYSO:Ce + PbWO) ECAL/ Dual readout calorimetry

New Ideas: Crystal Calorimeters

Three new segmented calorimeter proposals based on crystals

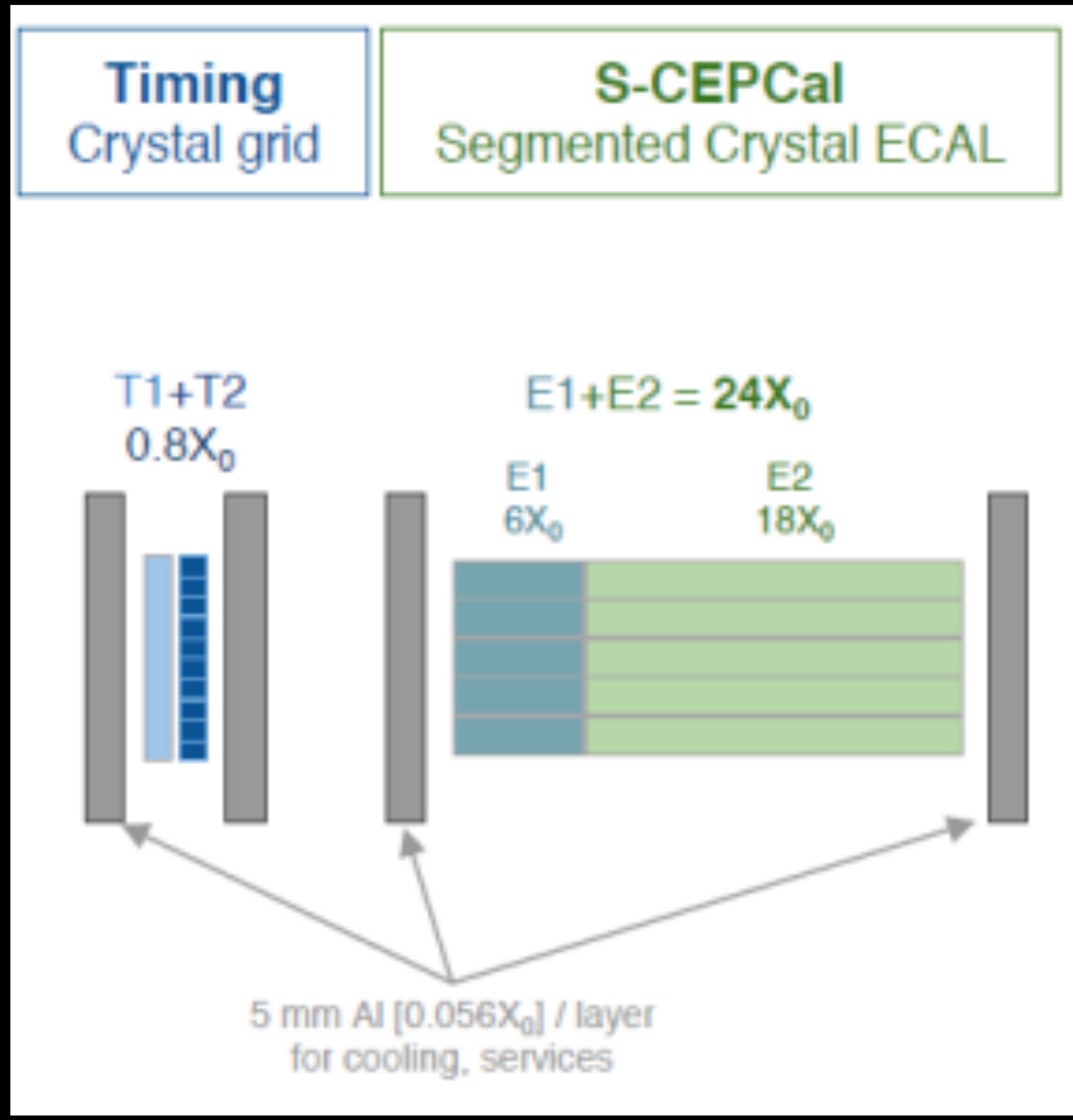
Long crystal bars with optical readout at both ends

Yuexin Wang (IHEP), et al



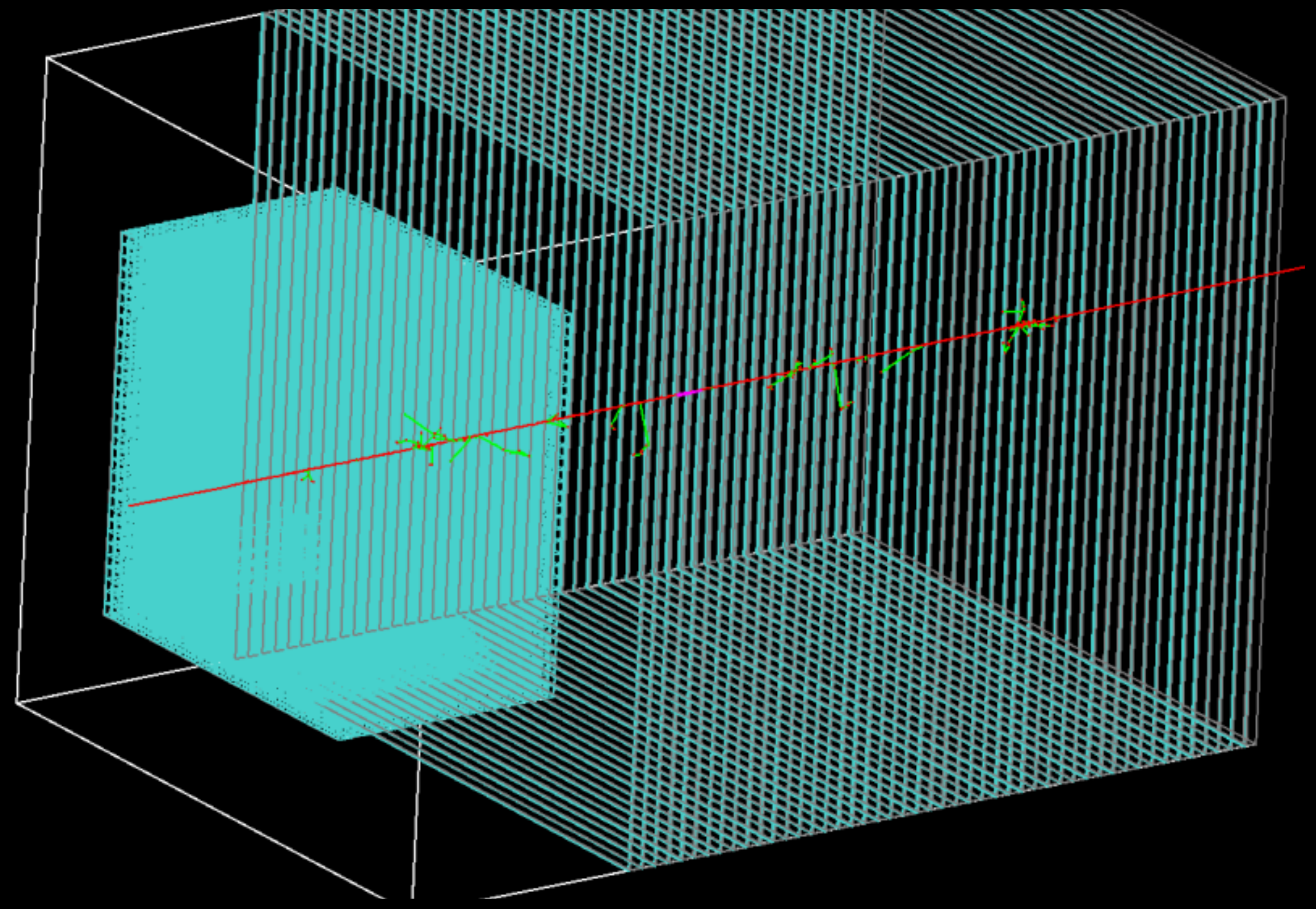
Long crystal bars with optical readout at single ends

Tully (Princeton), Eno (UMD), et al



Thin crystal tiles with optical readout at single ends

Yong Liu (IHEP), et al



ECAL: 30 layers

Crystals: LYSO:Ce, PbWO, BGO

Cost is an issue

Software and Reconstruction algorithms

After the CDR it is a good time to re-evaluate our software tools

Improve simplicity, flexibility, efficiency and collaborative nature

Important to use common tools as much as possible

Simulation Software

Based on standard tools

Root data format
DD4hep
Geant4

New hit-based Fast Simulation

FATRAS
(Fast ATLAS TRAck Simulation)

Reconstruction Software

Considering new tracking tool

ACTS
(A Common Tracking Software)

Porting of PFA tools:
Pandora and Arbor

Developing other algorithms:
vertex, long-lived charged particles, particle identification in jets

Workshop in Bologna, June 12-13, 2019 (FCC, CEPC, ILC): https://agenda.infn.it/event/19047/
with follow up in Hong Kong, Jan 17, 2020 (http://iasprogram.ust.hk/hep/2020/workshop_experiment.php)

Converged to a Turnkey Software Stack (Gaudi)

International Effort (key4hep-sw@cern.ch) started last year

Most Immediate Path for the CEPC Realization

March, 2018: Chinese Government New Plan

”actively initiating major-international science project…”

http://www.gov.cn/zhengce/content/2018-03/28/content_5278056.htm

focuses on

“frontier science, large-fundamental science, global impact, international collaboration”

Plan Goals

By 2020: 3-5 projects will be chosen into “preparatory stage”, among which 1-2 projects will later be selected

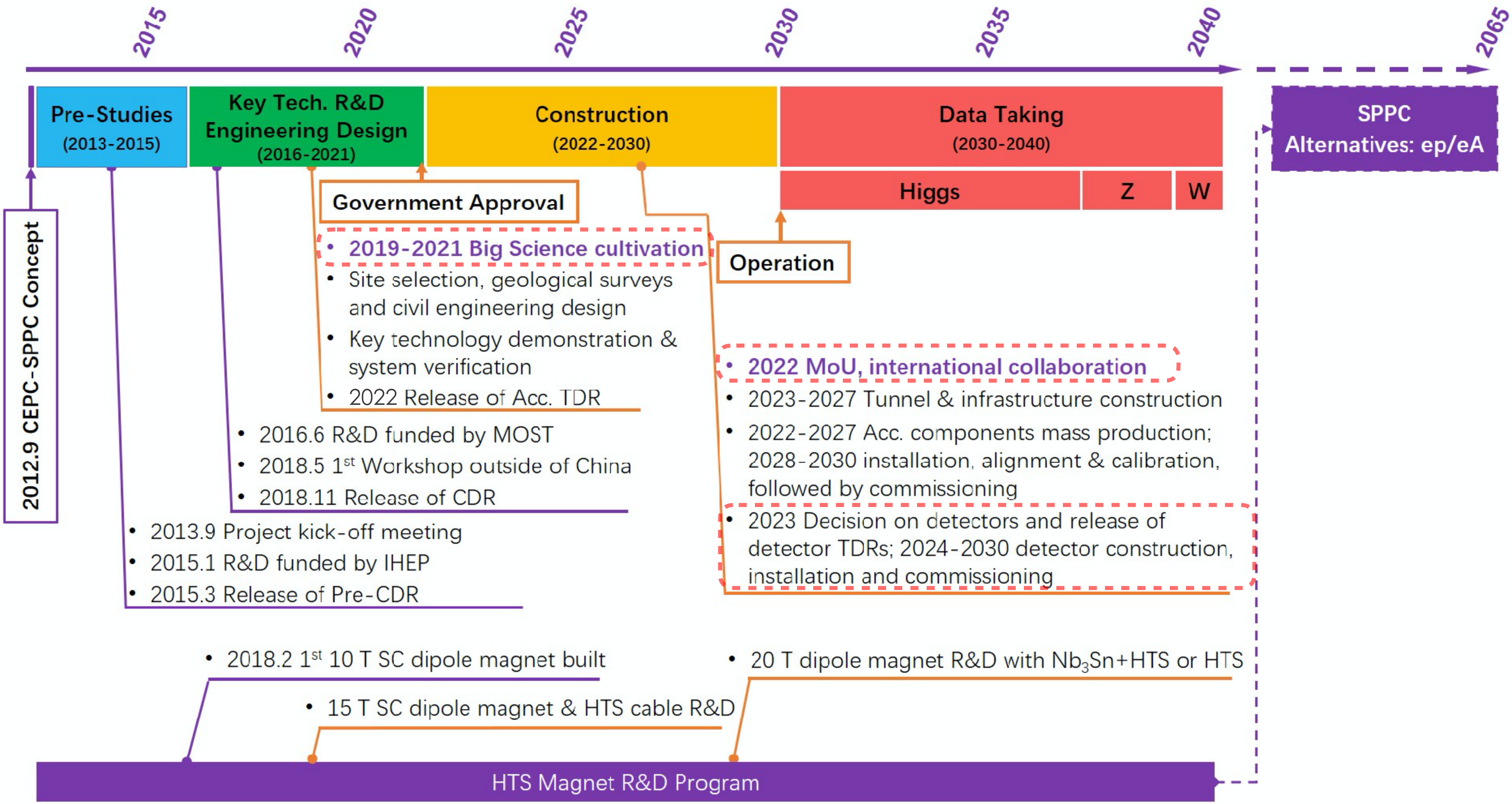
By 2035: 6-10 projects will be cultivated

The Ministry of Science and Technology (MOST) will select and develop the projects

Cultivation proposal submitted in 2019

Key task (4): Actively participate in large scientific projects initiated by other countries

CEPC Project Timeline



Main International Workshops

US meetings

Chicago: September 16-18, 2019

https://indico.cern.ch/event/820586/

"Washington": April 22, 2019 (FEPC)

https://indico.cern.ch/event/896263/

CEPC Yearly International Workshop

Shanghai: October 26-28

https://indico.ihep.ac.cn/event/11444/

2020 European Edition

postponed to next year

Marseille, France

US Snowmass, 2021 and CEPC

- Letters of Intent
  - CEPC will submit four overview Letters of Interest (LOI) to Snowmass that cover four main CEPC-SppC areas (each of the LOIs is 2 pages in length)
    - CEPC e^+e^- Detector R&D and experiment
    - CEPC Physics and simulation
    - CEPC e^+e^- Accelerator
    - SppC accelerator superconducting magnet R&D
  - Planning to submit others LoI focused on specific R&D or scientific questions
    - Everyone is welcome to join these according to their interests
- Contributed papers
  - Will work in the context of the Snowmass process and plan to submit several contributed papers in physics and/or R&D. These will have to come from individuals interested in contributing
  - Deadline: July 31, 2021

Meanwhile, …

Look forward to hear about the outcome of the European Strategy Process

Final remarks

CEPC CDR: http://cepc.ihep.ac.cn/

The Higgs at 125 GeV makes e+e- circular machines an exciting possibility

CEPC accelerator studies well advanced

Two significantly different detector concepts developed but
final detectors are to be defined by International Collaborations and they are likely to incorporate a mixture of the technologies explored so far

Key accelerator and detector technologies R&D continues and are being prototyped

2022: CEPC Accelerator TDR expected
2023: CEPC International Detectors TDRs
2030: Data-taking ideal starting date

Large synergies between needed R&D and already approved projects

CEPC aims to be an International Global project
At least one future high-energy e^+e^- collider should be built
Continued world-wide coordination effort is crucial to realize such project

Extra Slides

CEPC web site

http://cepc.ihep.ac.cn/

SCAN ME

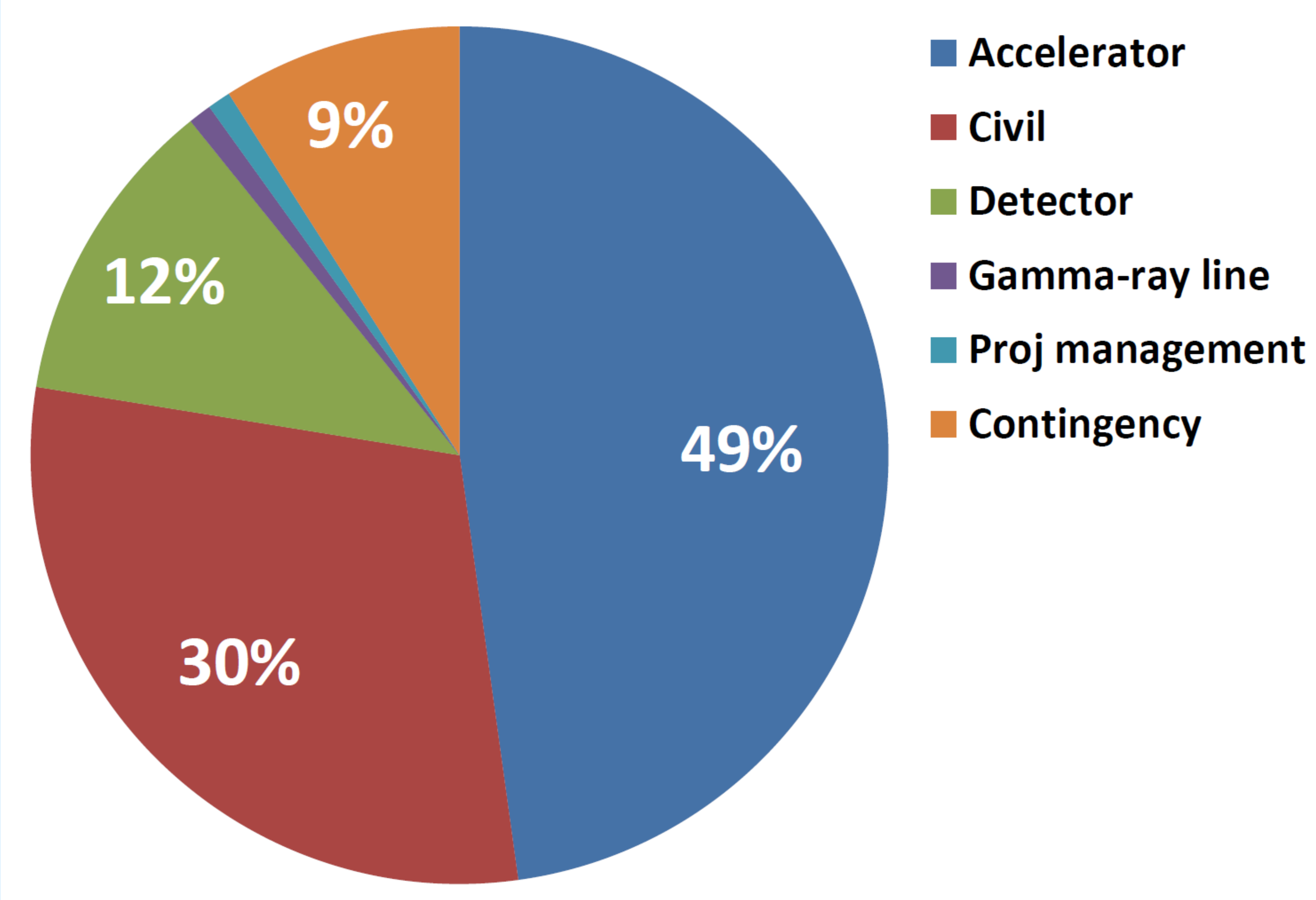
CDR Download

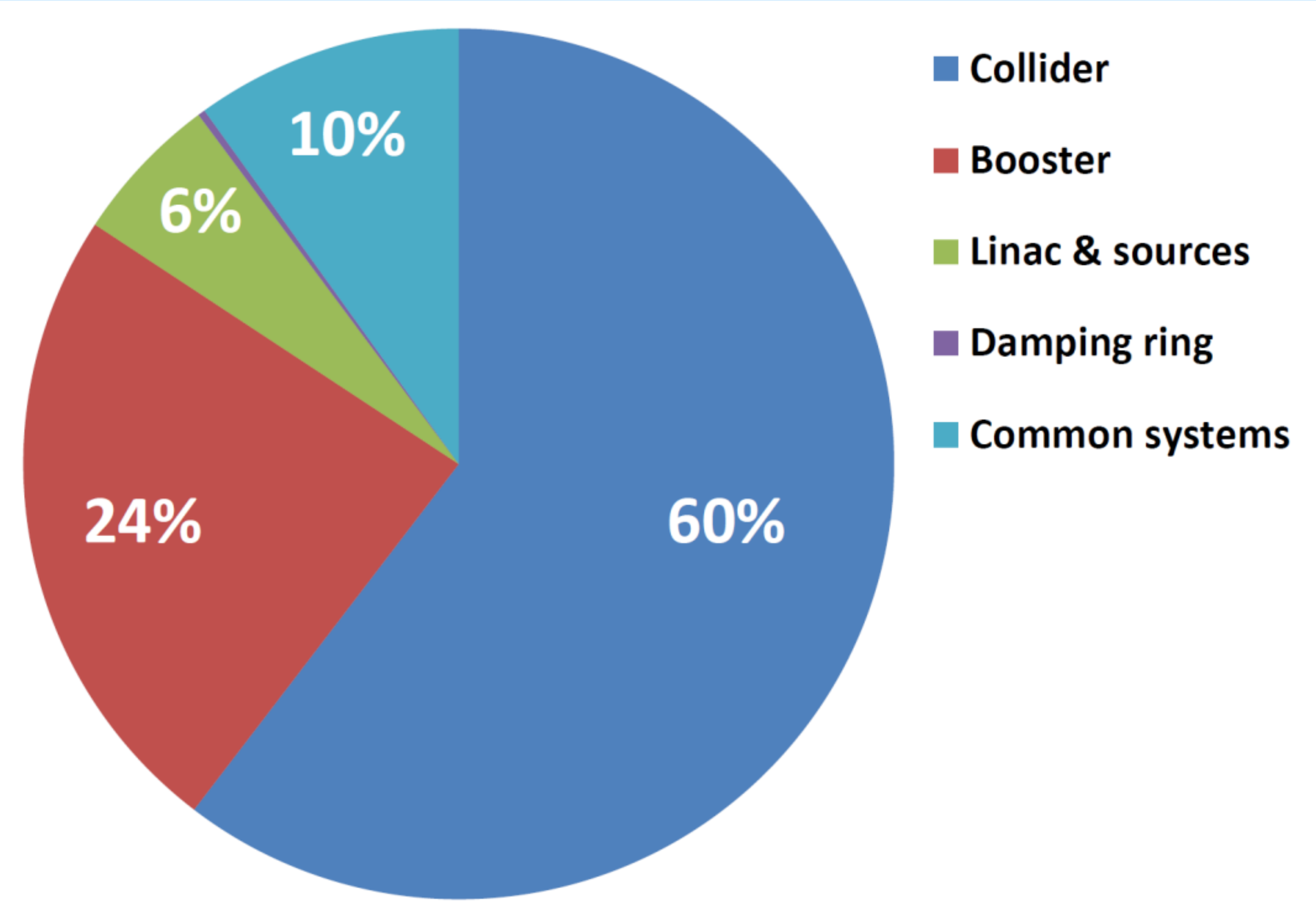
Possible scenarios of future colliders

Cost of project

Total cost of CEPC: $US 5 Billion

General evaluation of the relative cost of the project provided in the accelerator CDR





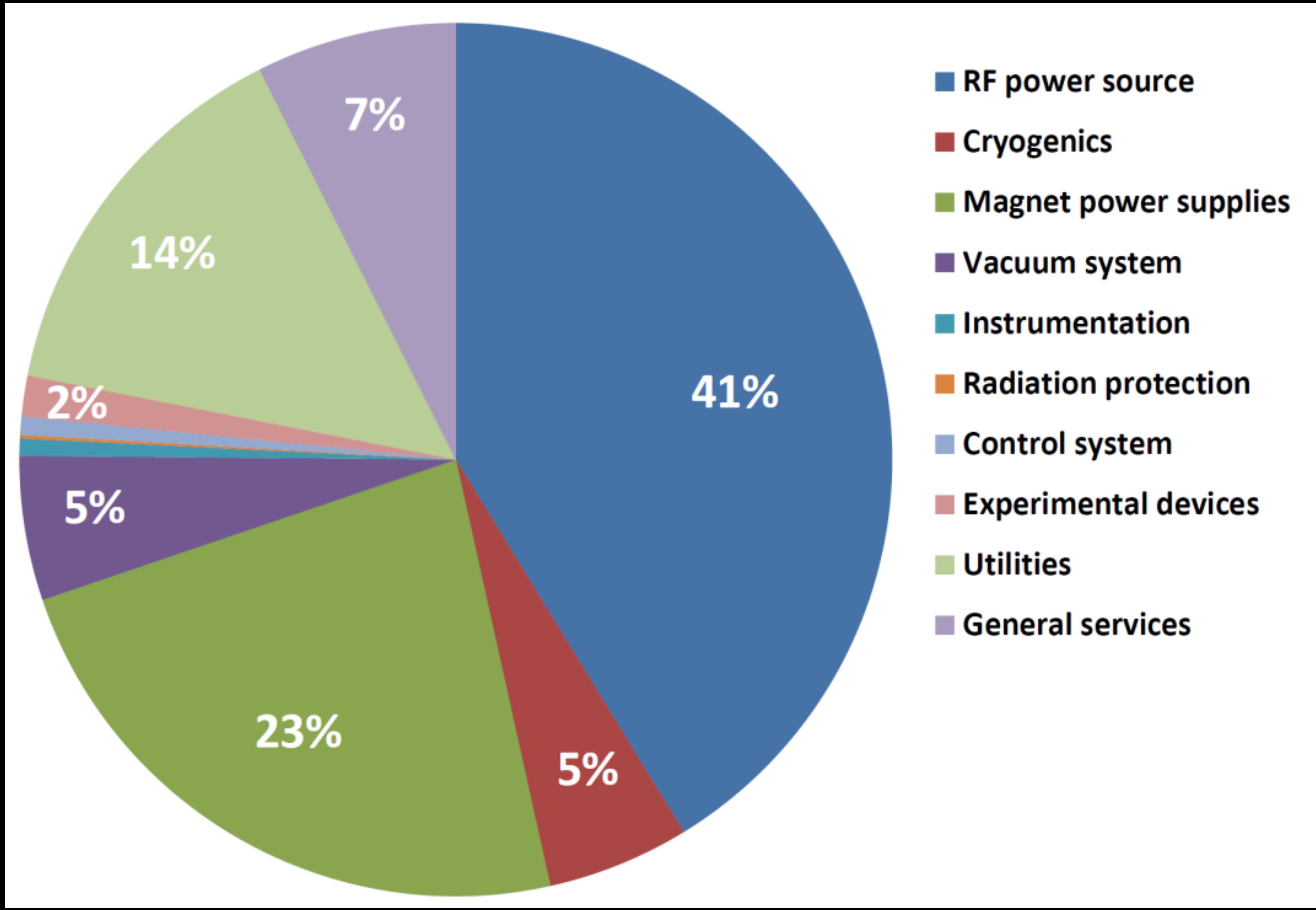
Cost of detectors not evaluated in detail and not part of the Conceptual Design Report

Careful costing estimates will be done moving forward towards the TDR

Power consumption evaluation

Power consumption during Higgs running: 266 MW

22% efficiency (larger than other projects): 60 MW beam → 266 MW total



Power consumption mitigating measures

Limit synchrotron radiation power to 30 MW per beam

Use superconducting RF cavities

Use high efficiency klystrons

Use permanent magnets in the 1 km Linac to Booster transport lines

Use a 2-in-1 structure for Collider dipoles and quadrupoles

Combine dipole and sextupole functions in the Collider bending magnets

Use a large coil cross section in the quadrupoles

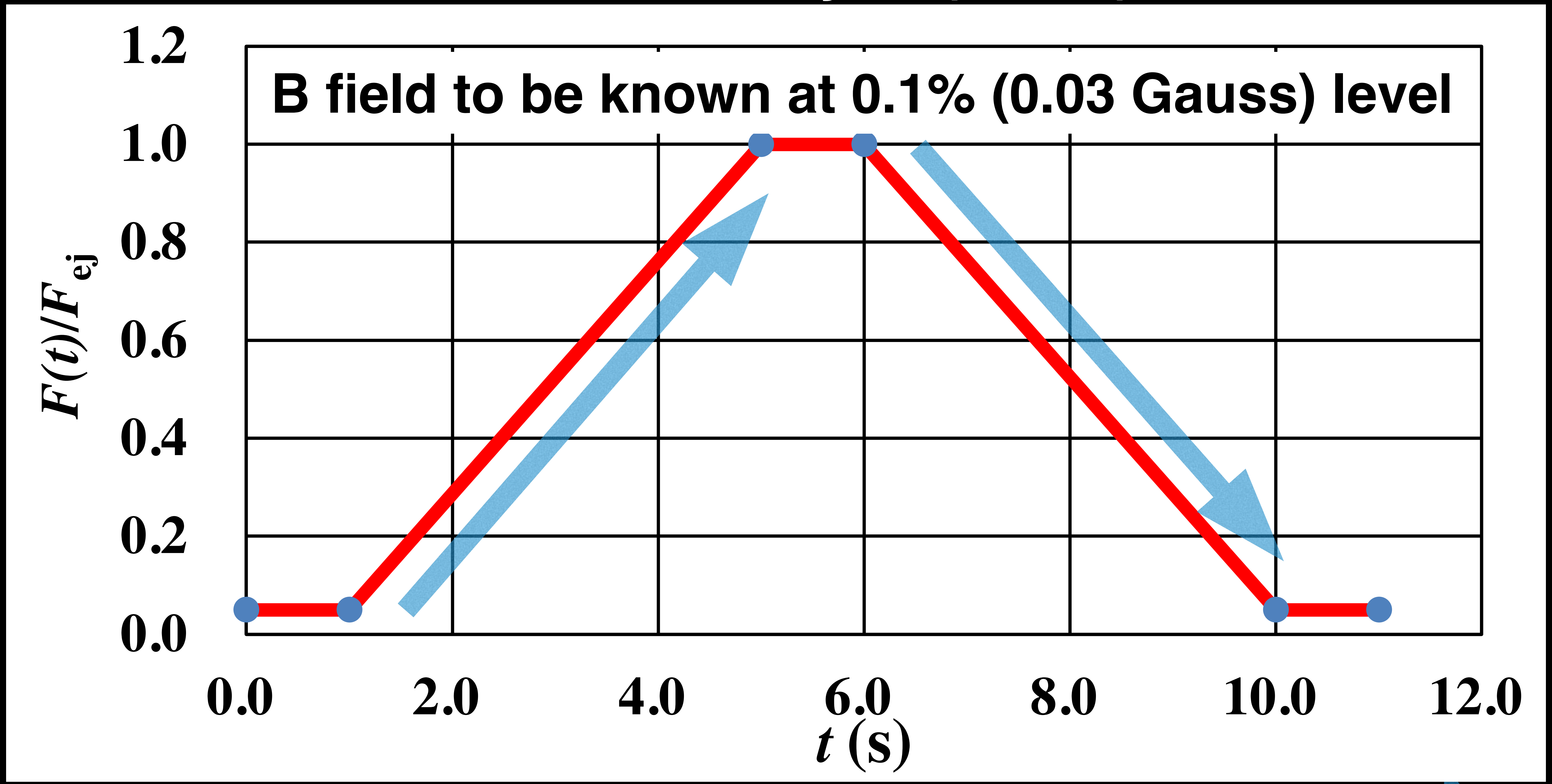
Tevatron: 58 MW; LHC, 7 TeV: ~180 MW

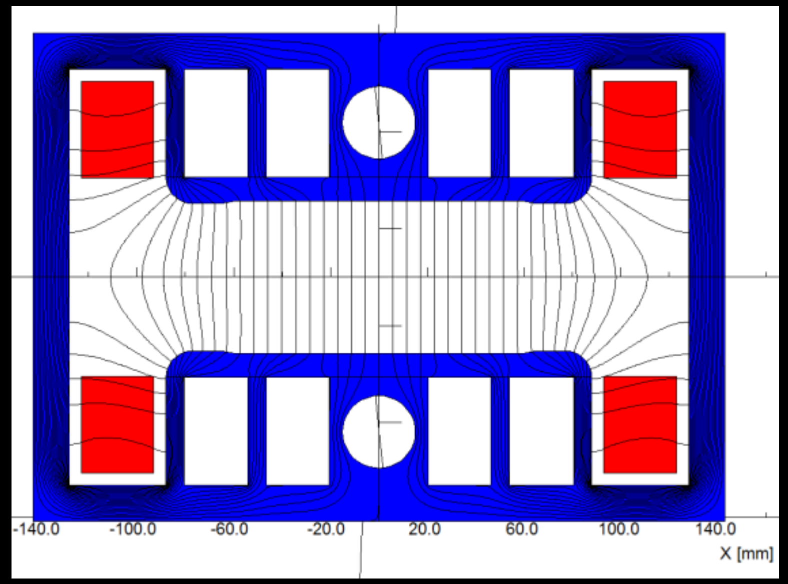
Main Parameters of Collider Ring (CDR)

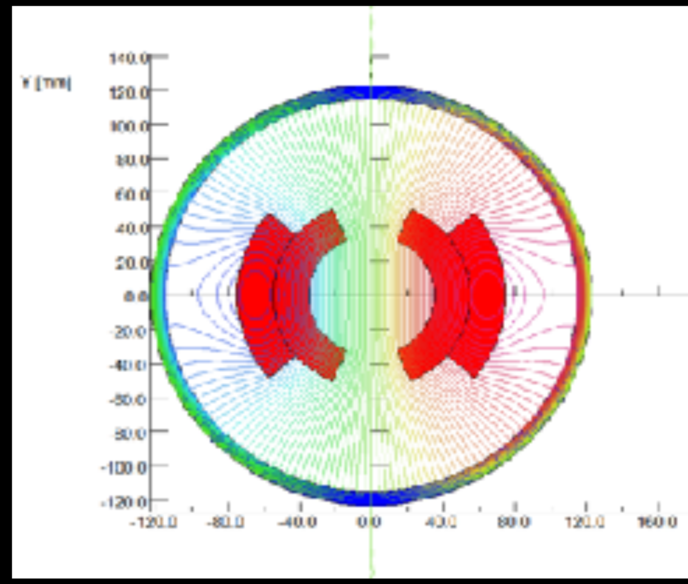
	Higgs	W	Z (3T)	Z (2T)
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (bunch spacing)	242 (0.68μs)	1524 (0.21μs)	12000 (25ns+10%gap)	
Beam current (mA)	17.4	87.9	461.0	
Synchrotron radiation power /beam (MW)	30	30	16.5	
β function at IP β_x^* / β_y^* (m)	0.36/0.0015	0.36/0.0015	0.2/0.0015	0.2/0.001
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Bunch length σ_z (mm)	3.26	5.9	8.5	
Photon number due to beamstrahlung	0.29	0.35	0.55	
Lifetime (hour)	0.67	1.4	4.0	2.1
Luminosity/IP L (10^{34} $cm^{-2}s^{-1}$)	2.93	10.1	16.6	32.1

Challenge: Low–field dipole magnets in Booster ring

Booster Cycle (0.1 Hz)

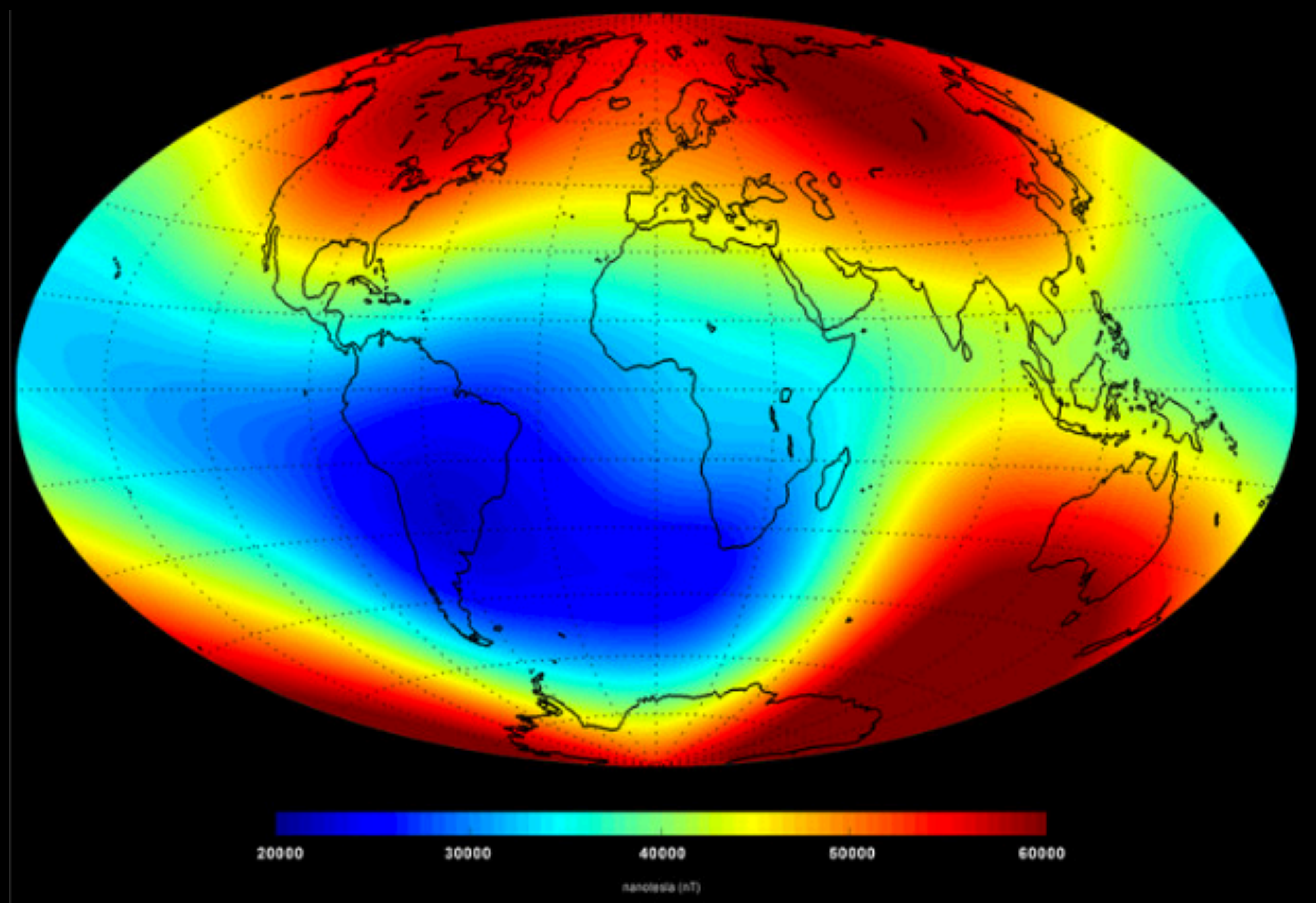






29 Gauss	338 Gauss	29 Gauss
10 GeV from Linac	120 GeV injection to collider	10 GeV from Linac

Earth magnetic field:
0.25 to 0.65 Gauss



On-going R&D program

High luminosities in circular colliders

Property	FCC-ee (100 km)				CEPC (100 km)		
Beam energy (GeV)	**45.6**	**80**	**120**	**175**	**45.6**	**80**	**120**
Luminosity/IP ($10^{34}cm^{-2}s^{-1}$)	230	28	8.5	1.5	32	10	3
Bunches/beam	16640	2000	393	48	12000	1524	242
Bunch separation (ns)	20	160	830	8300	25	260	680

Luminosity up to ~ 10^{36} $cm^{-2}s^{-1}$

Large number of bunches

Consequences for detector design

Crossing angle at IP
Bunch separation impacts overall designs
No power pulsing of detectors