High granularity readout TPC technology in CEPC TDR stage

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On behalf of the CEPC gaseous tracker R&D group

LCTPC Collaboration Meeting, 29-31 January 2025, Bonn

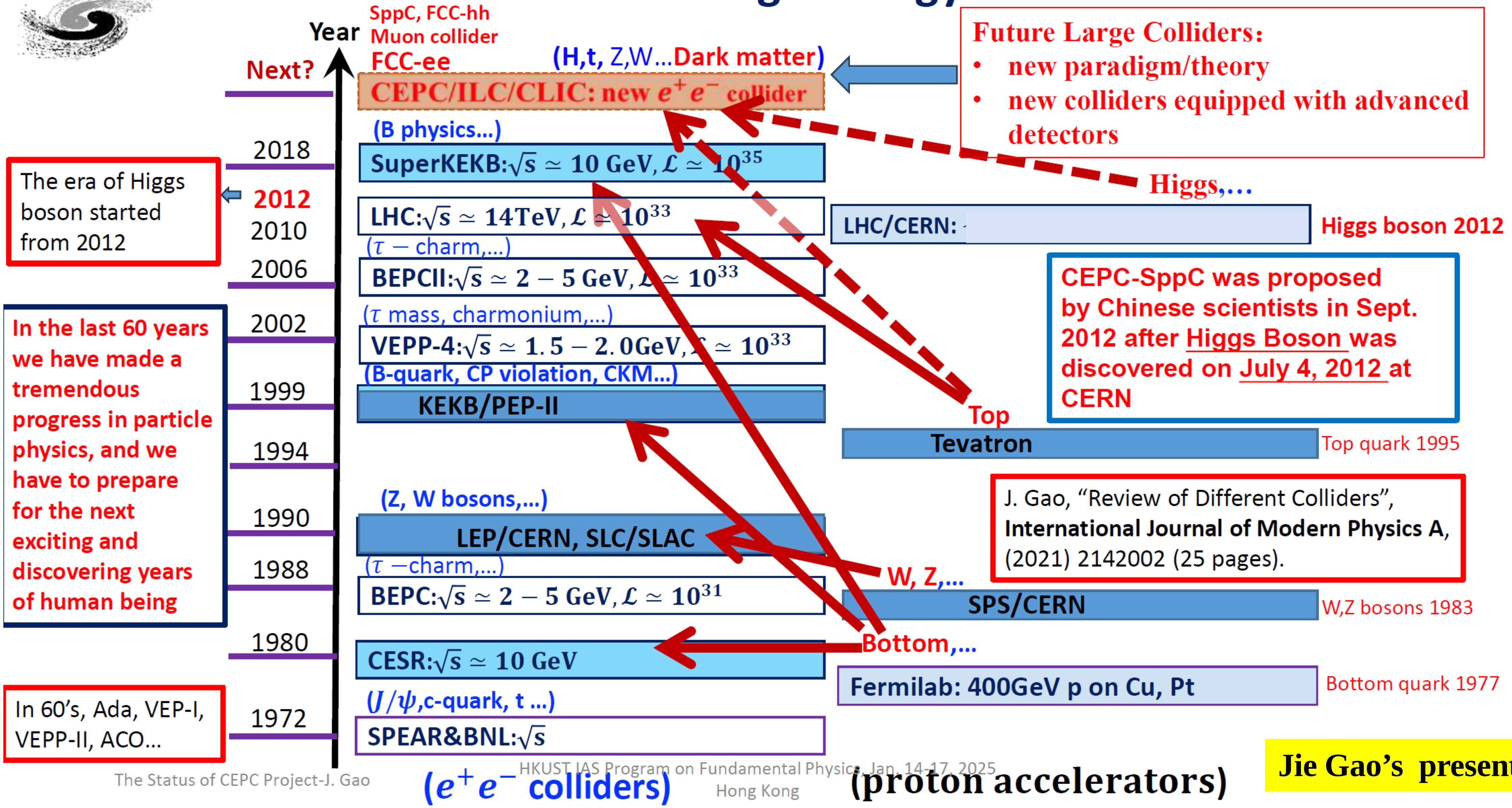
Content

- Some inputs from IAS FP2025 meeting
- Motivation and physics requirements
- Status of TPC in CEPC TDR
- Simulation and prototype preparation
- Work plan and Summary

First Question: What does TPC technology need to face?

- **Some inputs from IAS FP2025 meeting**
  - **Update CEPC and FCCee**

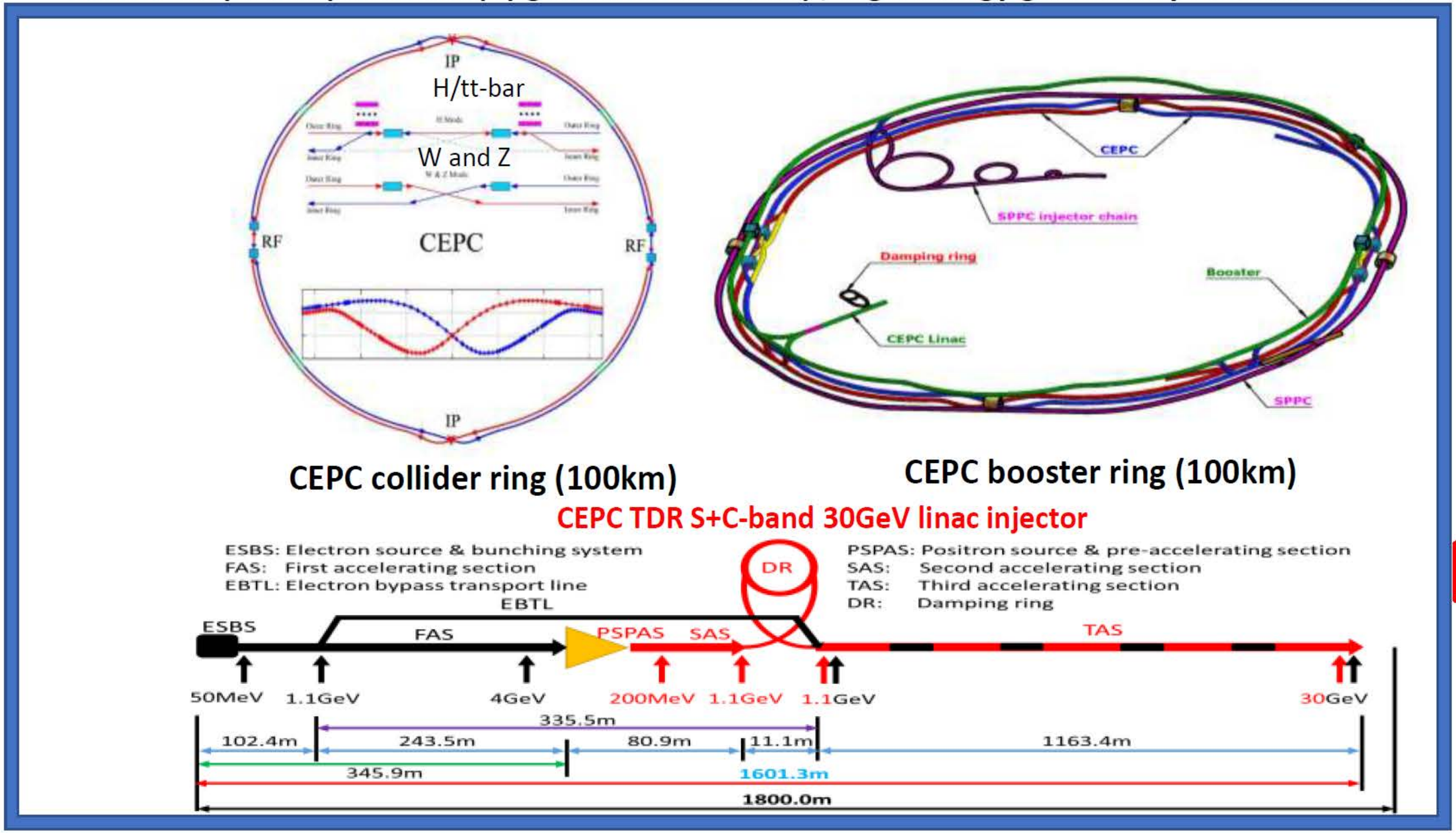
A Brief Historical Recall: High Energy Colliders and Factories

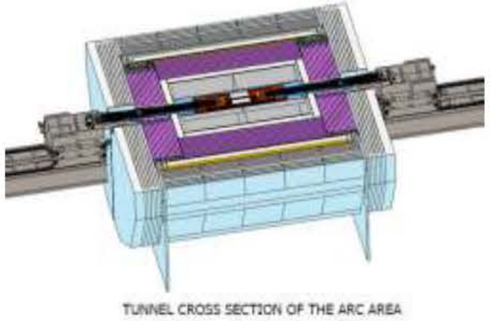


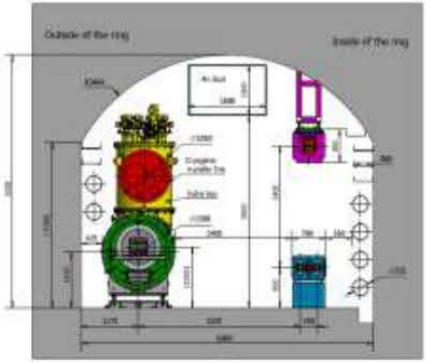
Jie Gao's presentation

CEPC Higgs Factory and SppC Layout in TDR/EDR

CEPC as a Higgs Factory： H, W, Z, upgradable to ttbar, followed by a SppC (a Hadron collider) ~125TeV
30MW SR power per beam (upgradable to 50MW) , high energy gamma ray 100Kev~100MeV







CEPC/SppC in the same tunnel

The Status of CEPC Project-J. Gao

HKUST IAS Program on Fundamental Physics, Jan. 14-17, 2025 Hong Kong

Jie Gao's presentation

CEPC Operation Plan and Goals in TDR/EDR

Operation mode		ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]		~240	~91	~160	~360
Run Time [years]		10	2	1	5
30 MW	L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	**5.0**	**115**	**16**	**0.5**
	$\int L\,dt$ [ab^{-1}, 2 IPs]	13	60	4.2	0.65
	Event yields [2 IPs]	2.6×10^6	2.5×10^{12}	1.3×10^8	4×10^5
50 MW	L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	**8.3**	**192**	**26.7**	**0.8**
	$\int L\,dt$ [ab^{-1}, 2 IPs]	21.6	100	6.9	1
	Event yields [2 IPs]	4.3×10^6	4.1×10^{12}	2.1×10^8	6×10^5

* Higgs is the top priority. The CEPC will commence its operation with a focus on Higgs.

** Detector solenoid field is 2 Tesla during Z operation, 3Tesla for all other energies.

*** Calculated using 3,600 hours per year for data collection.

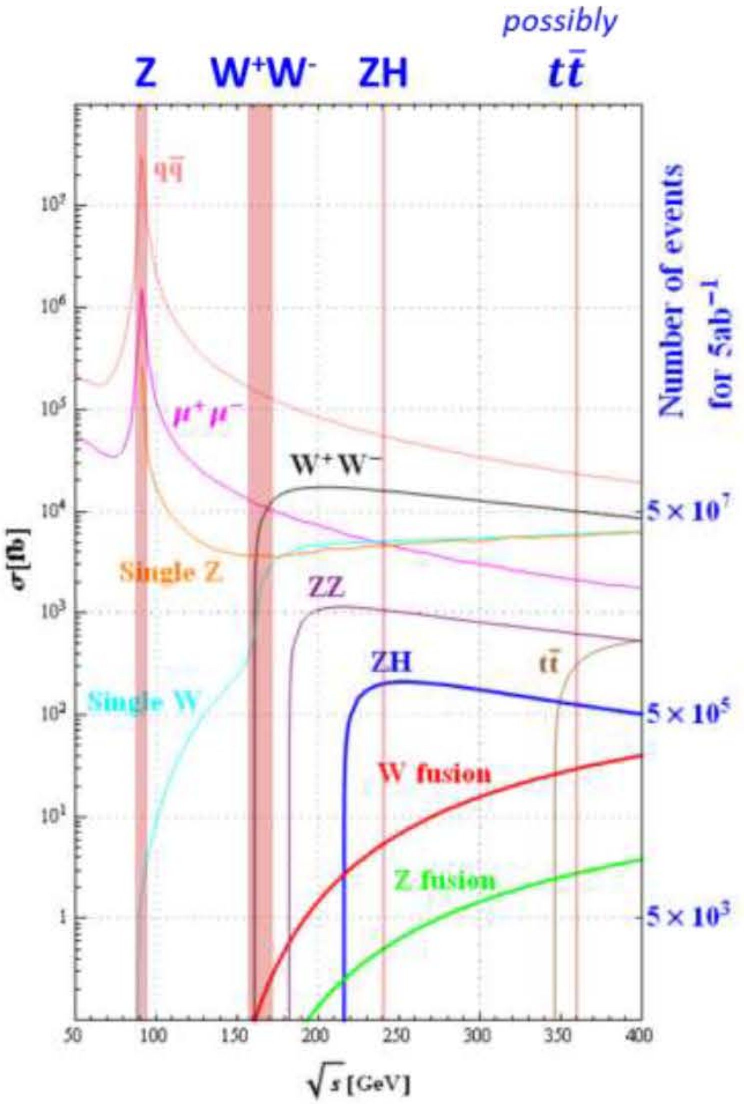
CEPC physics white papers:

1: Higgs physics, Chinese Physics C Vol. 43, No. 4 (2019) 043002
https://arxiv.org/pdf/1810.09037

2: Flavor physics, https://arxiv.org/pdf/2412.19743 (2024)

3: New physics, to be published

4: QCD, to be published



Jie Gao's presentation

CEPC Accelerator System Parameters in TDR/EDR

Linac

Parameter	Symbol	Unit	Baseline
Energy	E_{e-}/E_{e+}	GeV	30
Repetition rate	f_{rep}	Hz	100
Bunch number per pulse			1 or 2
Bunch charge		nC	1.5 (3)
Energy spread	σ_E		1.5×10^{-3}
Emittance	ε_r	nm	6.5

Booster

		tt	*H*		*W*	*Z*	
		Off axis injection	Off axis injection	On axis injection	Off axis injection	Off axis injection	
Circumfer.	km	100					
Injection energy	GeV	30					
Extraction energy	GeV	180	120		80	45.5	
Bunch number		35	268	261+7	1297	3978	5967
Maximum bunch charge	nC	0.99	0.7	20.3	0.73	0.8	0.81
Beam current	mA	0.11	0.94	0.98	2.85	9.5	14.4
SR power	MW	0.93	0.94	1.66	0.94	0.323	0.49
Emittance	nm	2.83	1.26		0.56	0.19	
RF frequency	GHz	1.3					
RF voltage	GV	9.7	2.17		0.87	0.46	
Full injection from empty	h	0.1	0.14	0.16	0.27	1.8	0.8

Collider

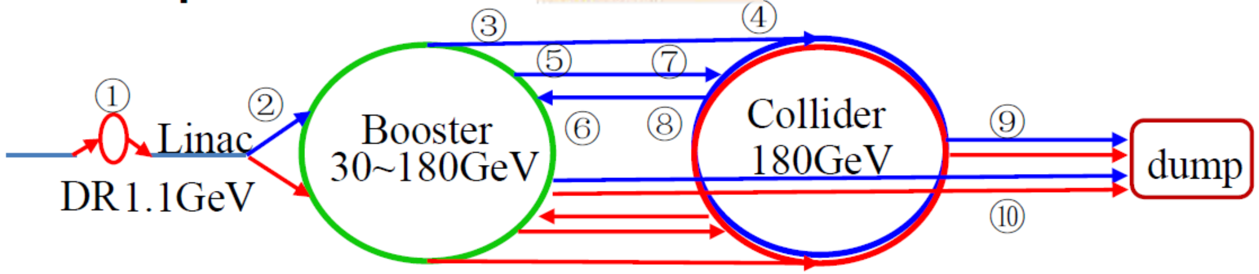
	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	100.0			
SR power per beam (MW)	30			
Energy (GeV)	120	45.5	80	180
Bunch number	268	11934	1297	35
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Beam size at IP σ_x/σ_y (um/nm)	14/36	6/35	13/42	39/113
Bunch length (natural/total) (mm)	2.3/4.1	2.5/8.7	2.5/4.9	2.2/2.9
Beam-beam parameters ξ_x/ξ_y	0.015/0.11	0.004/0.127	0.012/0.113	0.071/0.1
RF frequency (MHz)	650			
Luminosity per IP (10^{34} cm^{-2} s^{-1})	5.0	115	16	0.5
Luminosity per IP (10^{34} cm^{-2} s^{-1}) From J. Gao's formula below	5	115	12	0.59

Running scenarios: Higgs 10 years, Z 2 years, W 1 year, ttbar 5 years

$$L_{max}\,[cm^{-2}\,s^{-1}] = 0.158\times10^{34}\,\frac{(1+r)}{\beta_y[mm]}\sqrt{\frac{R[m]}{C_\gamma[mGeV^3]N_{IP}}}\,(P_b[MW]/E[GeV]^2)\,e^{\frac{\sqrt{\Phi_p}}{3.22}}\,(1+0.000505*\Phi_p^2)$$ (J. Gao's formula)

Factory of
4 Million Higgs
4 Trillion Z bosons
200 Million W+W- pairs
600K $t\bar{t}$ pairs

Transport lines



CEPC Technical Design Report (TDR) includes:
1) CEPC Accelerator TDR released on Dec. 25, 2023
2) CEPC Detector TDRrd (rd=reference design) will be completed by June 2025

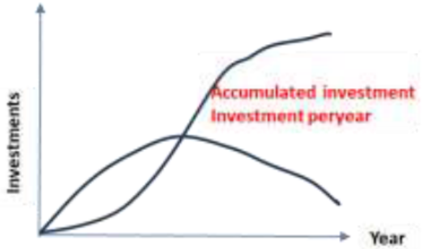
Jie Gao's presentation

CEPC Milestones, Timeline and Human Resources

https://indico.global/event/12247

Year	2012	2013	2015	2017	2018	2023	2025	2027	2030	2035
Human resources			~50		~100	~200	~300	~500	~2800	~2500

Year	Accelerator human resource	Accumulated accelerator spending Billion RMB
2015	50	-
2018	100	-
2023	200	0.2
2025	300	0.3
2027	500	0.4
2031	2800	9
2035	2500	20



CEPC kickoff meeting in Sept. 2013

Proposal (2025) for CEPC entering 15th five year plan

2025

36.4B RMB
Total construction

CEPC detector reference design will be completed by June 2025

CEPC EDR site study and civil engineering design

2012.9	2013.9	2015.3	2017.4	2018.11	2023.12	2024 ~ 2027		~2035
CEPC proposed		Pre-CDR	Progress report	CDR	TDR	EDR	start of construction	Completion

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CEPC IDRC and IAC Meeting in Oct. 2024

- The IDRC report is positive.

Our initial evaluation of the information that we have received has not shown any showstoppers, but R&D remains to be completed, and the industrialization of some of the more novel technologies has yet to be demonstrated. Furthermore, full-size prototypes are essential to confirm that the required performance can be achieved. The integration of services with the mechanical design will also require further work. In addition the interfaces between detectors require special attention. A key challenge is the development of multiple Front-End ASICs, a process that demands long-term investment and has proven difficult during upgrades of LHC experiments for the HL-LHC.

The International Detector Review Committee (IDRC) held its inaugural meeting at IHEP, Oct 21-23, 2024, to review the status and plan of Ref-TDR.

https://indico.ihep.ac.cn/event/23265/ access key: cepcidrc

CEPC IAC meeting in 2024 was held from Oct. 29-30, 2024, IHEP
IAC listened also the reports from IARC and IDRC on CEPC EDR progresses
https://indico.ihep.ac.cn/event/23450/timetable/

Final IAC report will come soon

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CEPC in Synergy with other Accelerator Projects in China

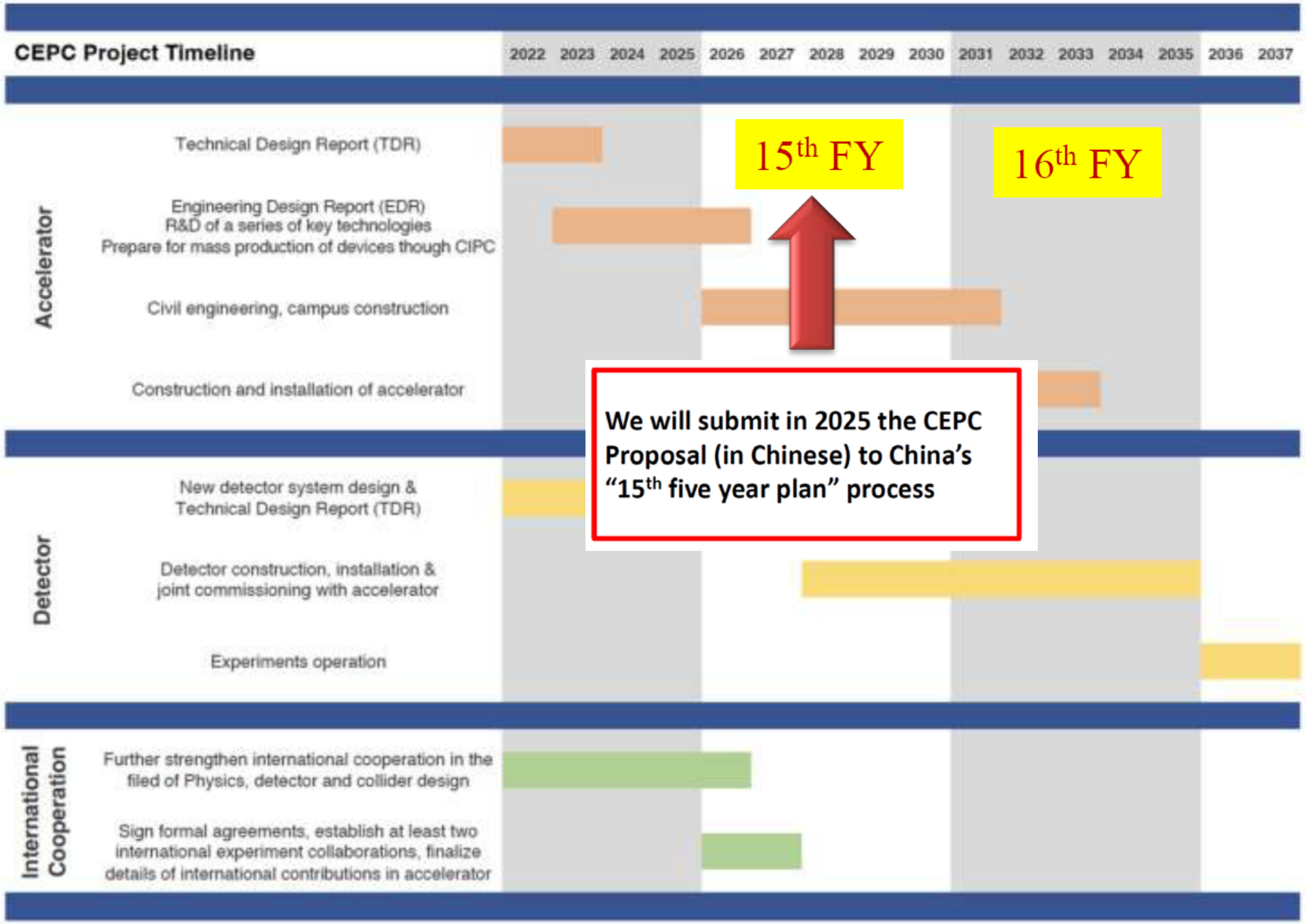
Project name	Machine type	Location	Cost (B RMB）	Completion time
CEPC	Higgs factory Upto ttar energy	Led by IHEP, China	**36.4 (where accelerator 19)**	Around 2035 (starting time around 2027)
BEPCII-U	e+e-collider 2.8GeV/beam	IHEP (Beijing)	**0.15**	2025
HEPS	4th generation light source of 6GeV	IHEP (Huanrou)	**5**	2025
SAPS	4th generation light source of 3.5GeV	IHEP (Dongguan)	**3**	2031 (in R&D, to be approved)
HALF	4th generation light source of 2.2GeV	USTC (Hefei)	**2.8**	2028
SHINE	Hard XFEL of 8GeV	Shanghai-Tech Univ., SARI and SIOM of CAS (Shanghai)	**10**	2027
S3XFEL	S3XFEL of 2.5GeV	Shenzhen IASF	**11.4**	2031
DALS	FEL of 1GeV	Dalian DICP	-	(in R&D, to be approved,)
HIAF	High Intensity heavy ion Accelerator Facility	IMP, Huizhou	**2.8**	2025
CIADS	Nuclear waste transmutation	IMP, Huizhou	**4**	2027
CSNS-II	Spallation Neutron source proton injector of 300MeV	IHEP, Dongguan	**2.9**	2029

The total cost of the accelerator projects under construction:39B RMB more than CEPC cost of 36.4B RMB

Jie Gao’s presentation

CEPC Planning, Schedule and Teams

TDR (2023), EDR(2027), start of construction (~2027)



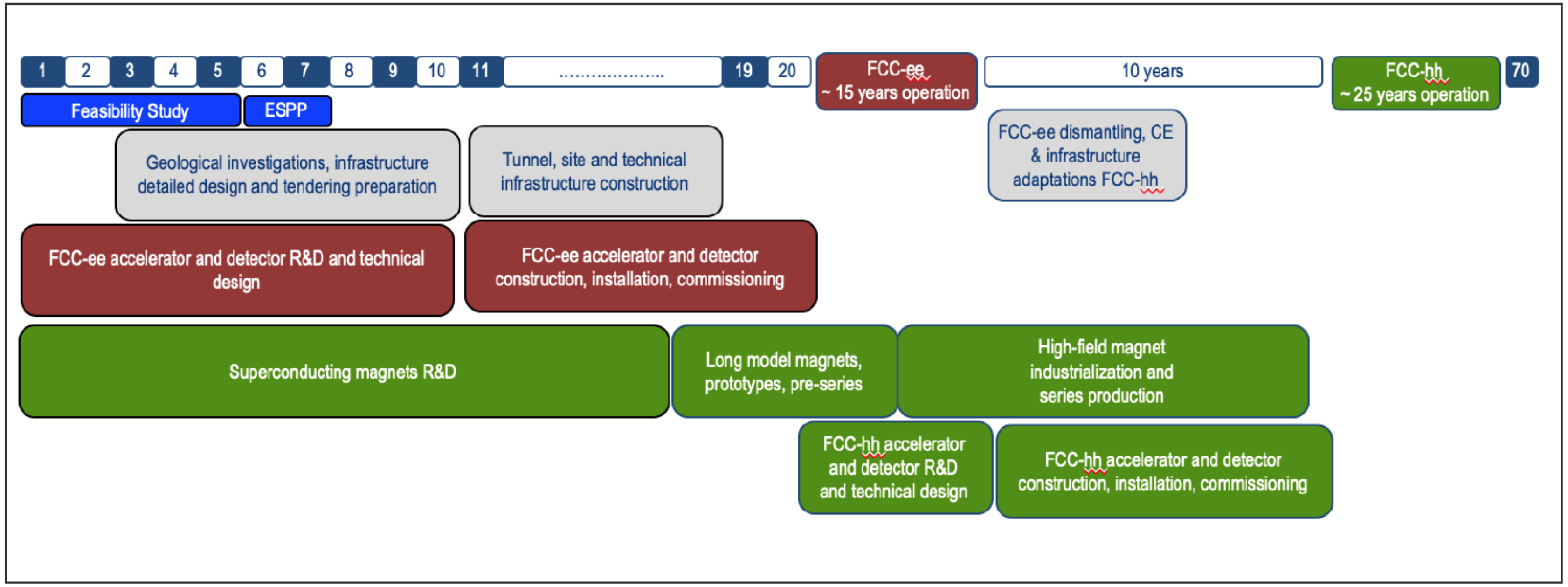
-CEPC team (domestic)

CEPC accelerator and detector/experiments/theory group is an highly **experienced** team with strong international collaboration experiences. It has demonstrated its **expertise** and **achievements** in the following relevant projects, both domestic and international ones, such as: **BEPC-BEPCII (BES-BESIII)， BFELP，CSNS， ADS， HEPS， LEP, LHC, LHCb, ILC, EXFEL, HL-LHC, BELLE, BELLE-II, CLEO, Daya Bay, JUNO, LHAASO, etc.**

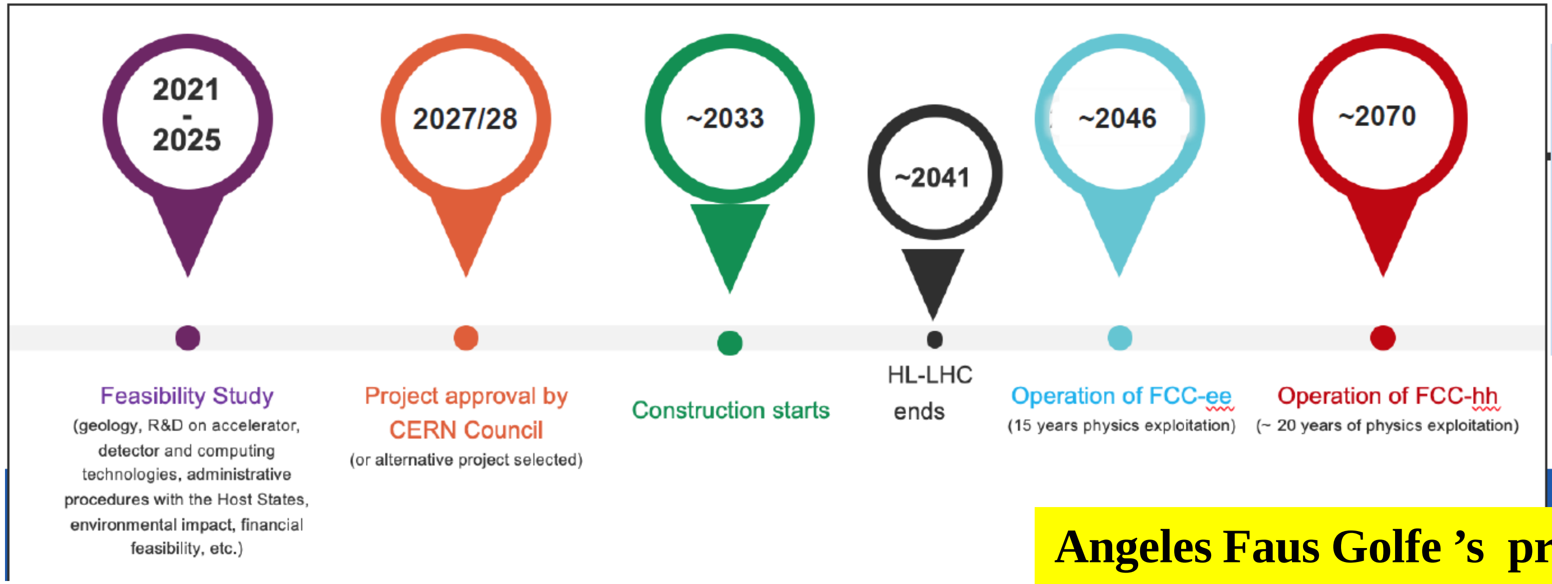
-CEPC international partners and collaborators

Jie Gao's presentation

FCC integrated program -timeline



Note: FCC Conceptual Design Study started in 2014 leading to CDR in 2018



Ambitious schedule taking into account:
- ❑ past experience in building colliders at CERN
- ❑ approval timeline: ESPP, Council decision
- ❑ that HL-LHC will run until 2041
- ❑ **project preparatory phase with adequate resources immediately after Feasibility Study**

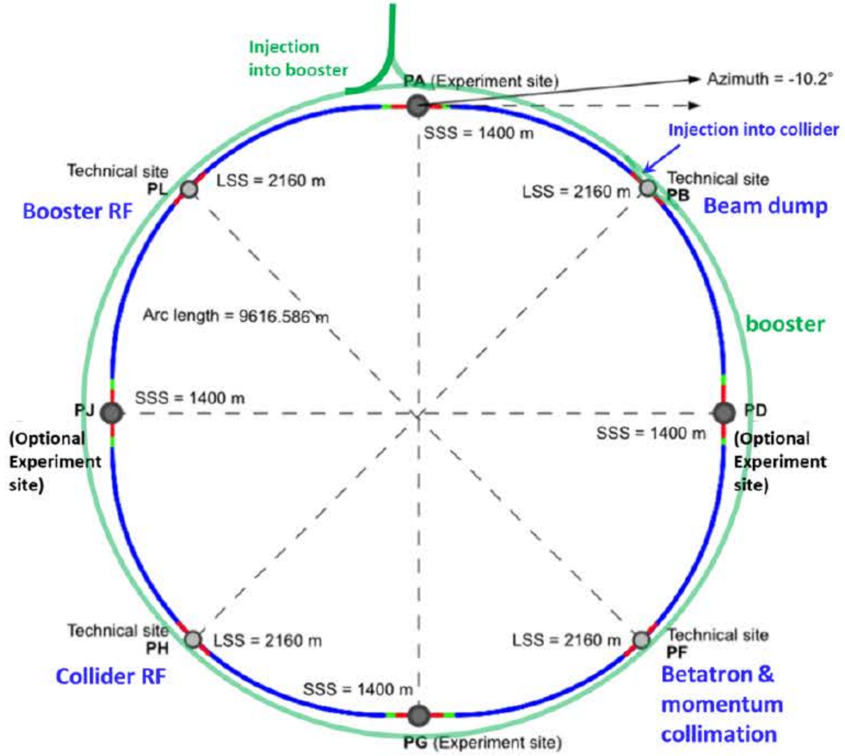
Angeles Faus Golfe 's presentation

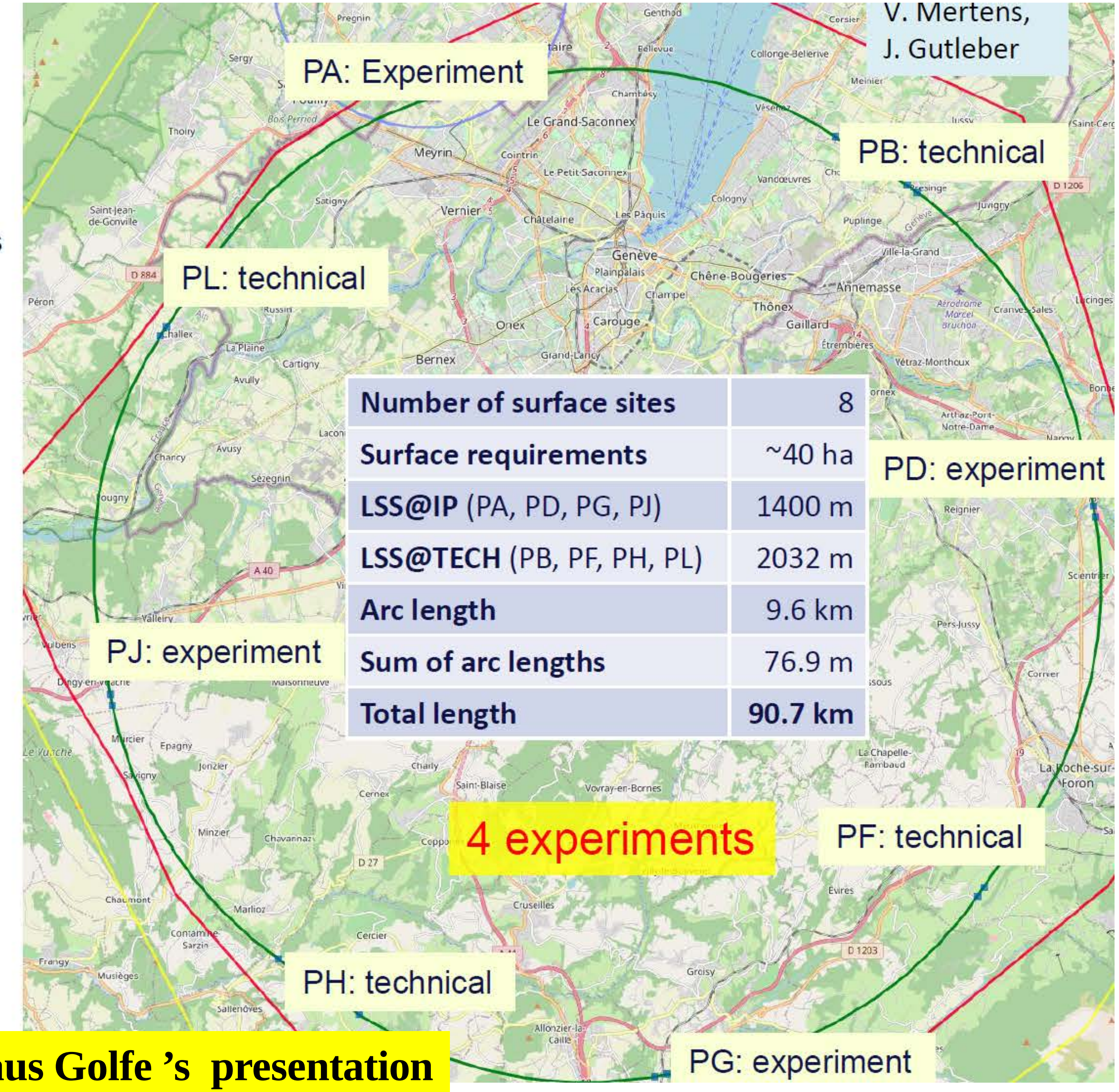
Reference layout and implementation:PA31 -90.7 km

Layout chosen out of ~ 100 initial variants, based on **geology** and **surface constraints** (land availability, access to roads, etc.), **environment,** (protected zones), **infrastructure** (water, electricity, transport), **machine performance** etc.

“Avoid-reduce-compensate” principle of EU and French regulations

Overall lowest-risk baseline: 90.7 km ring, 8 surface points, 4-fold symmetry

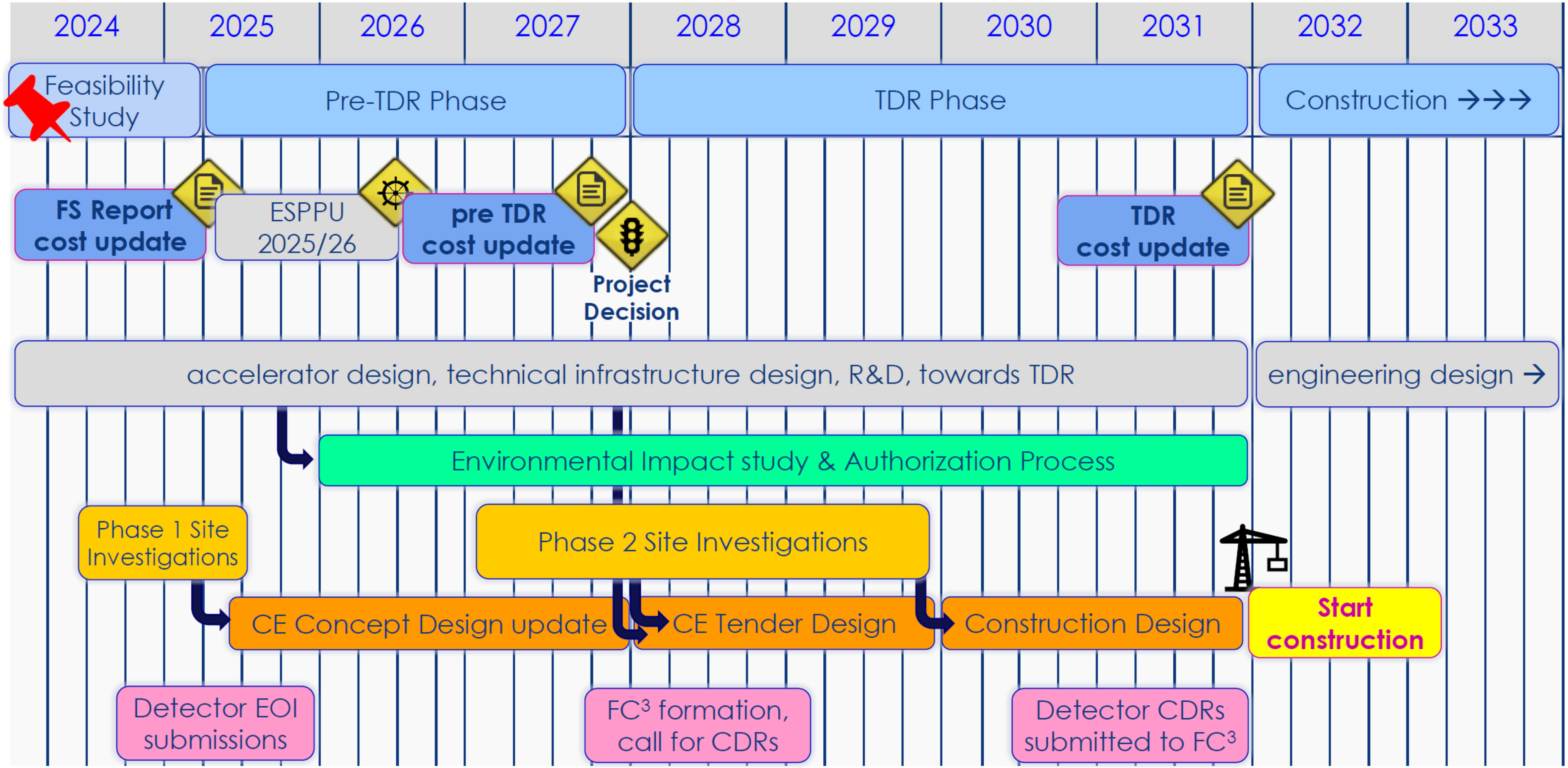




Number of surface sites	8
Surface requirements	~40 ha
LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2032 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	**90.7 km**

Angeles Faus Golfe ’s presentation

Possible timeline till start of construction



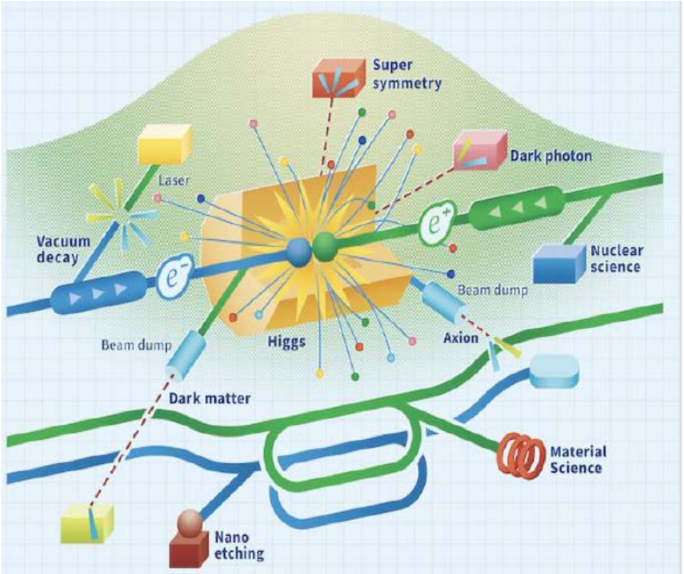
Angeles Faus Golfe 's presentation

7) Comments on the Japanese community approach

The first stage of the process, i.e. Starting first general discussion on a global project at a government level would be very useful, or even mandatory, for the other future very large projects in general. Since the initial decision will be made globally, it can access the global resources and responsibilities are shared in a fair way.

In the current situation in Europe, where the coming update of the European Strategy for Particle physics, 2025 to early 2026, will highly focus on the next CERN flagship project, it is not likely for Europe to take a lead in initiating a consensus building of a global Higgs factory project. China is also busy with the CEPC.

Could Japan take an initiative to invite other countries to exchange their view on the global project to start? What can we do to help this to happen?



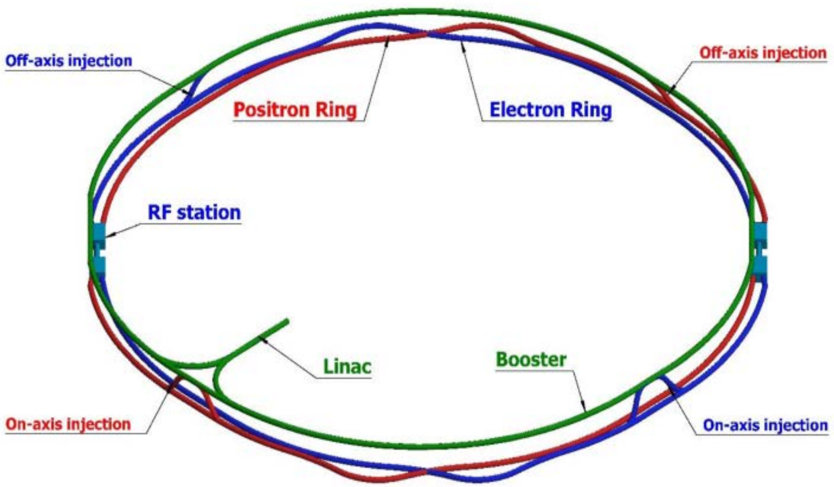
Tatsuya Nakada 's presentation

Second Question: What does TPC technology need to solve?

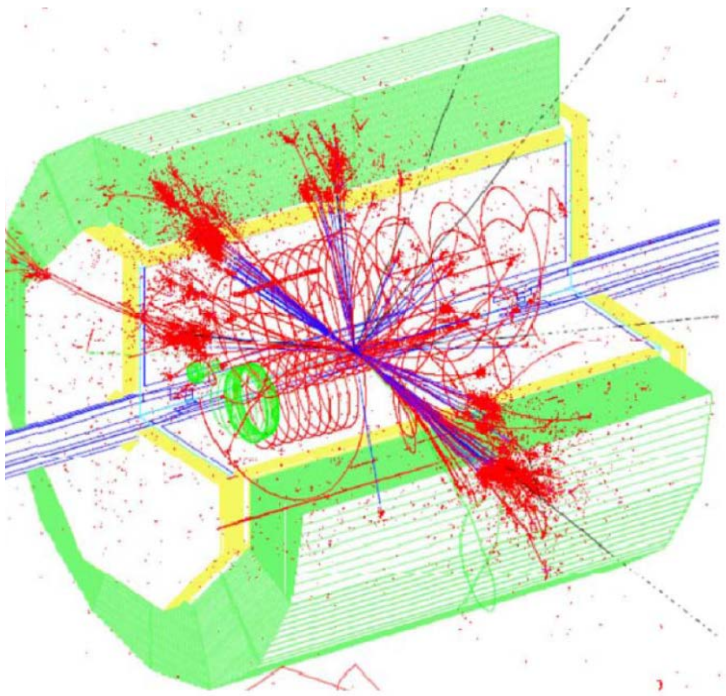
- **Motivation and physics requirements**

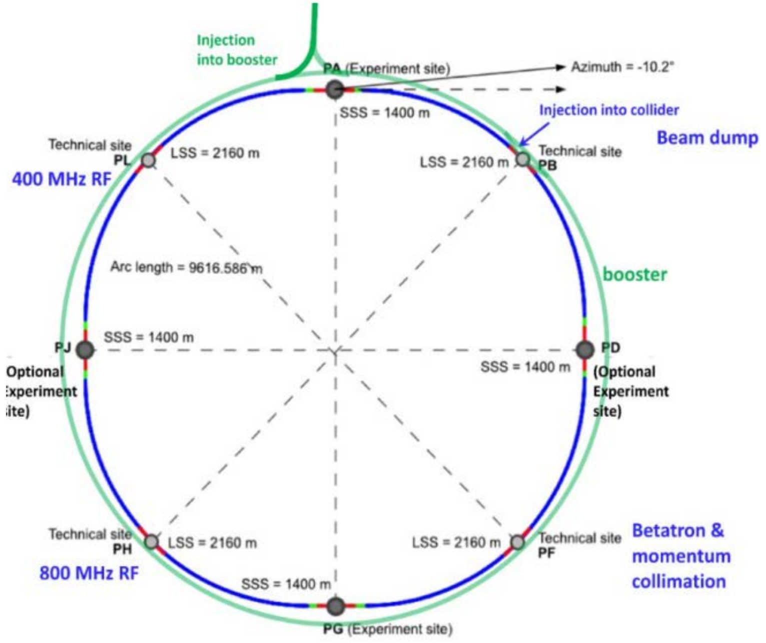
Motivation and physics requirements

- A TPC is the main track detector for some candidate experiments at future e+e- colliders.
  - **Baseline detector concept** of ILD at ILC and CEPC
- TPC technology can be of interest for other future colliders (EIC, FCC-ee)
- Pixelated readout TPC can improve **PID requirements of Flavor Physics at e+e- collider**.



Circular Electron Positron Collider (CEPC)





Future Circular Collider (FCCee)

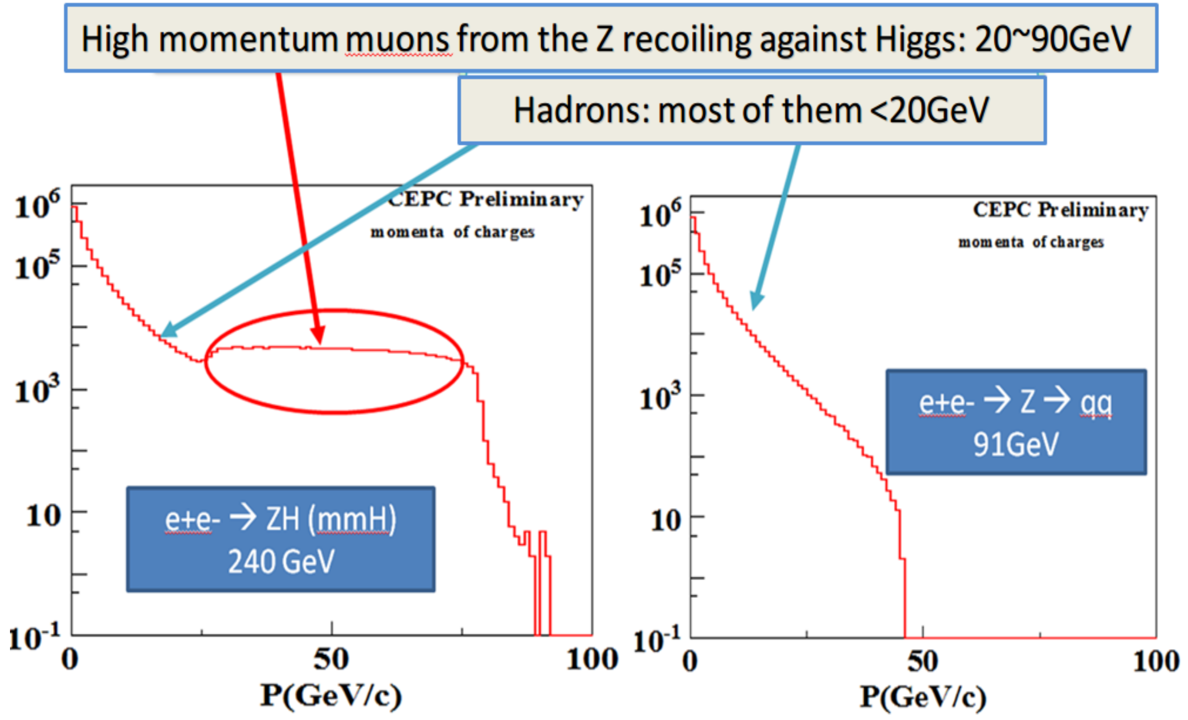
https://arxiv.org/abs/1811.10545

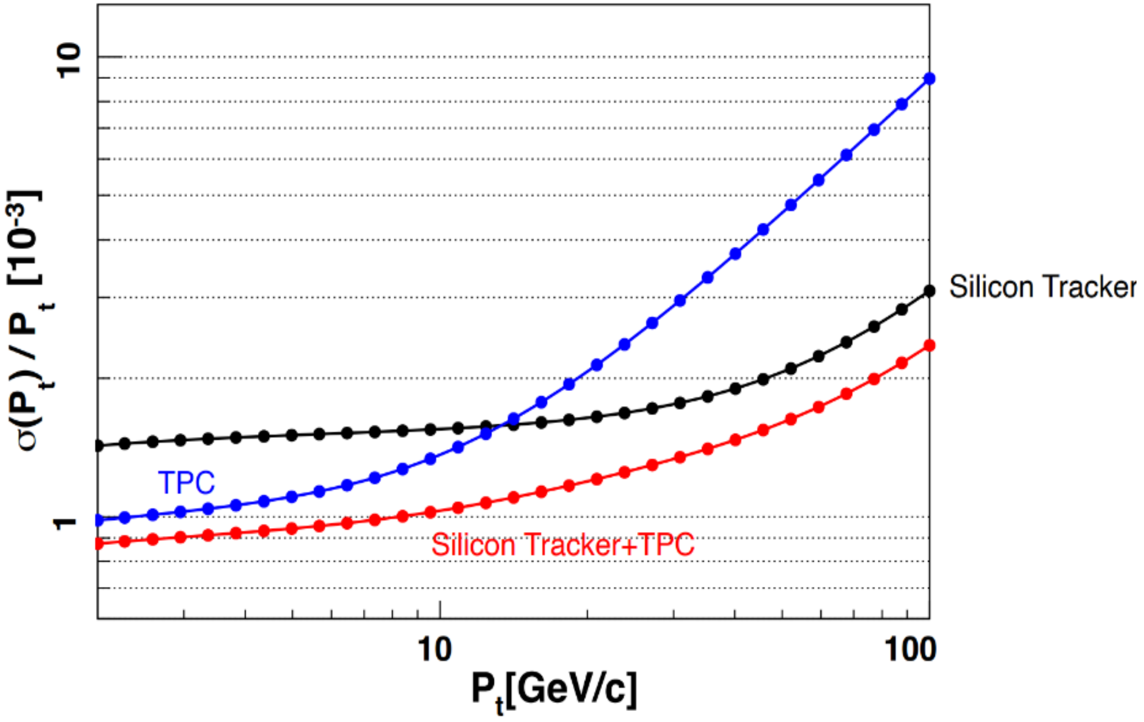
https://arxiv.org/abs/2203.08310

Motivation and physics requirements

- Circular e+e- collider operation stages in TDR: **10-years Higgs @3T → 2-years Z pole → 1-year W**
- Physics Requirements of the tracker
  - High momentum resolution for Higgs and Z
  - PID for the flavor physics and jet substructure

Calibration: Low luminosity Z at 3T
Approximately $10^{35}cm^{-2}s^{-1}$
1%-20% of high luminosity Z



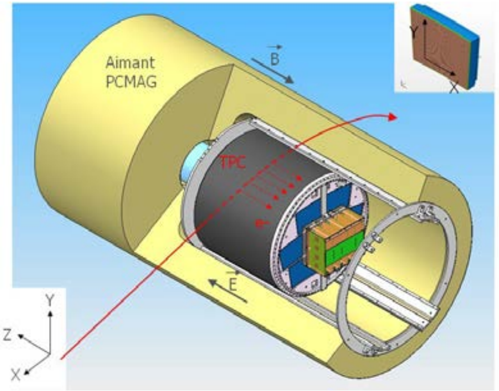


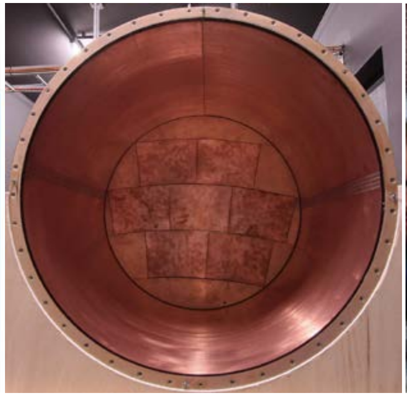
https://doi.org/10.1140/epjc/s10052-018-5876-z

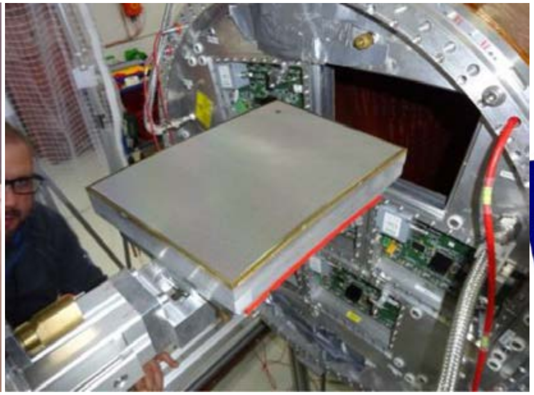
Readiness and status of TPC in LCTPC

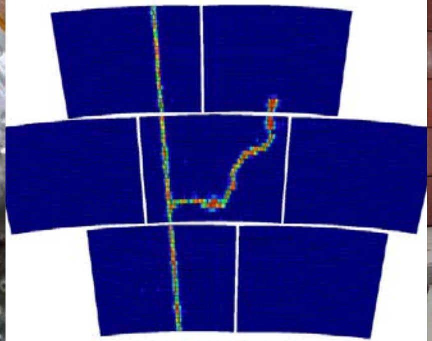
- **Large Prototype** setup has been built to compare different detector readouts under identical conditions and to address integration issues.
  - PCMAG: B < 1.2T, bore Ø: 85cm
  - Two end plates for the LP made from Al with 7 module window
- **LP Field Cage Parameter**
  - Length = 61cm, inner Ø = 72cm drift field up to E ≈ 350V/cm
  - Made of composite materials: 1.24 % X_0

JINST 5: P10011, 2010
JINST 16: P10023, 2021





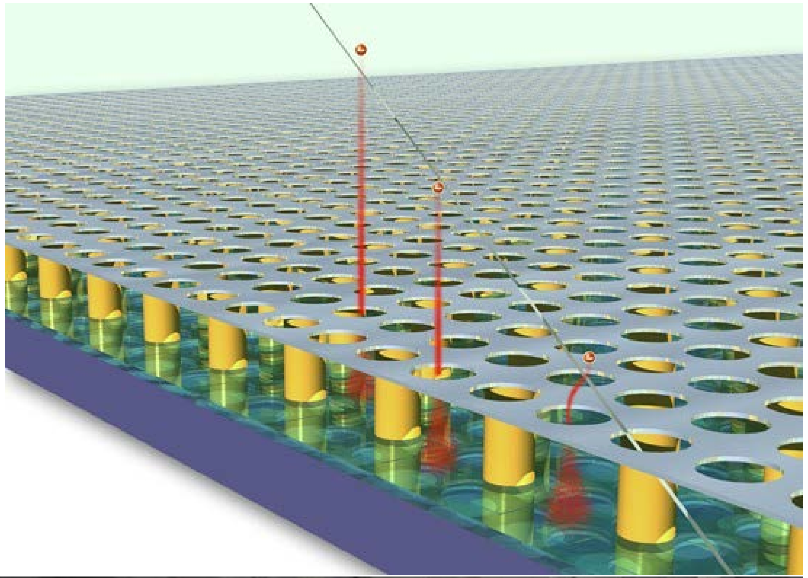


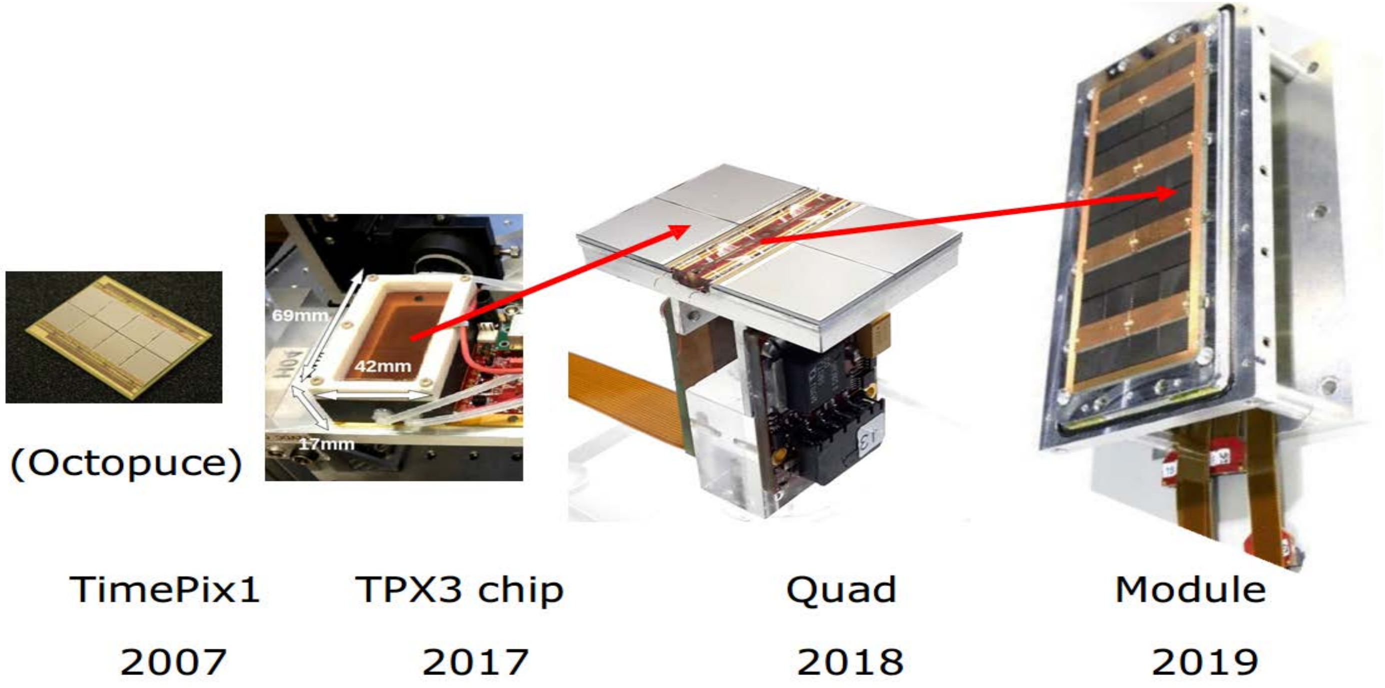


https://doi.org/10.48550/arXiv.2006.08562

Readiness and status of TPC in LCTPC

- GridPix detector have moved from Timepix to Timepix3 ASICs. Tests with quad devices have been successfully done under B=1.0T at DESY in 2021 and 2022.
- Very high detection efficiency results in **excellent tracking and dE/dx performance.** Timepix4 development is ongoing.
  - All results showed that **a pixel TPC is realistic.(**~10^6 events **)**



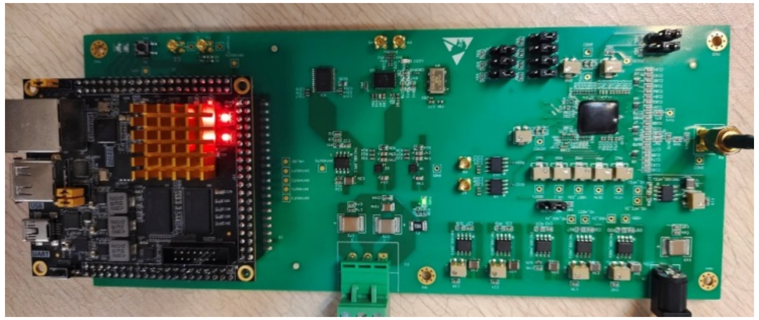


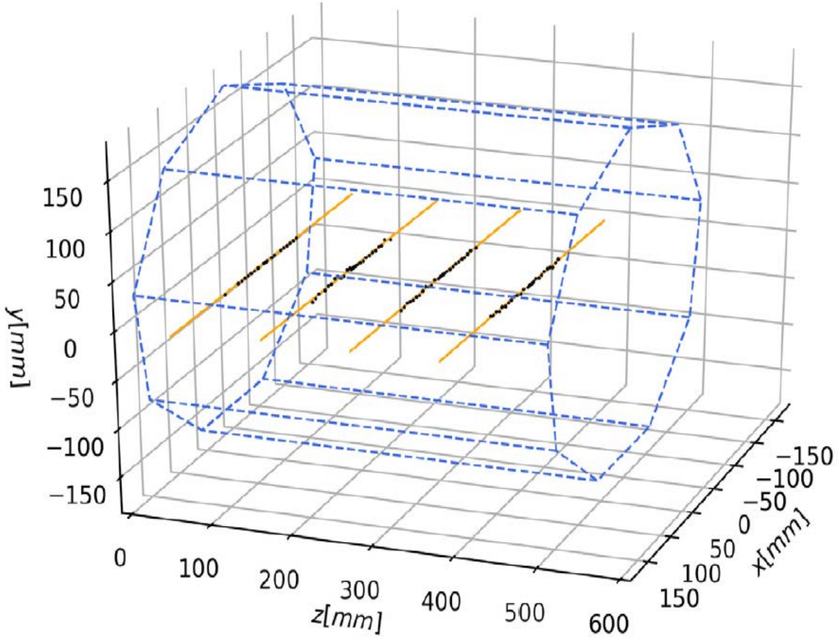
NÌM A535 (2004) 506-510
NIM A845 (2017) 233-235

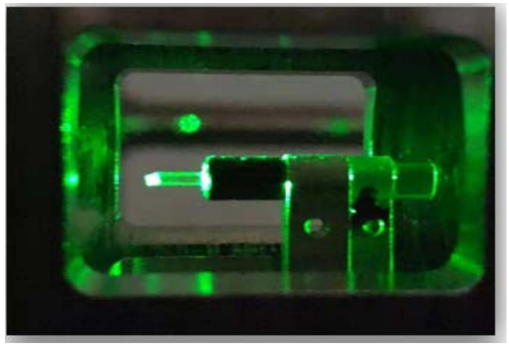
https://arxiv.org/abs/1902.01987

Readiness and status of TPC in LCTPC

- **CEPC TPC detector prototyping roadmap:**
  - From TPC module to TPC prototype R&D for Higgs and Tera-Z
- **Achievement so far:**
  - **IBF×Gain ~1 @ G=2000** validation with a hybrid TPC module
  - Spatial resolution of **$\sigma_{r\varphi} \leq 100$ μm and dE/dx resolution of 3.6%**
  - FEE chip: reach ~**3.0mW/ch with ADC** and the pixelated readout R&D

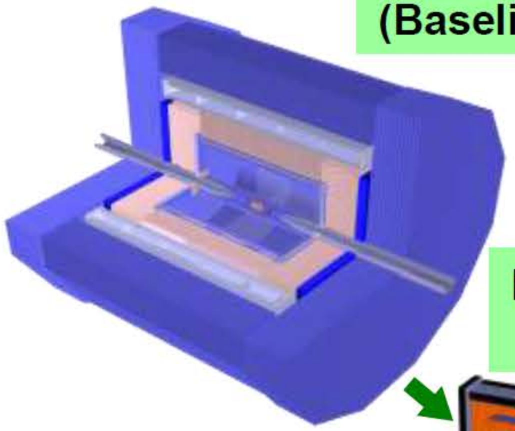


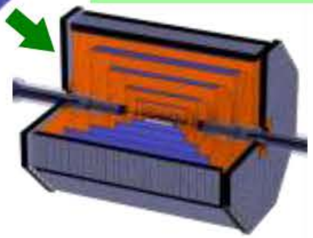


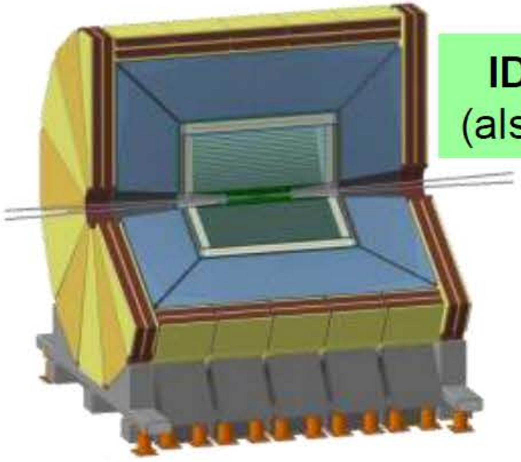


- **Status of TPC in CEPC TDR**

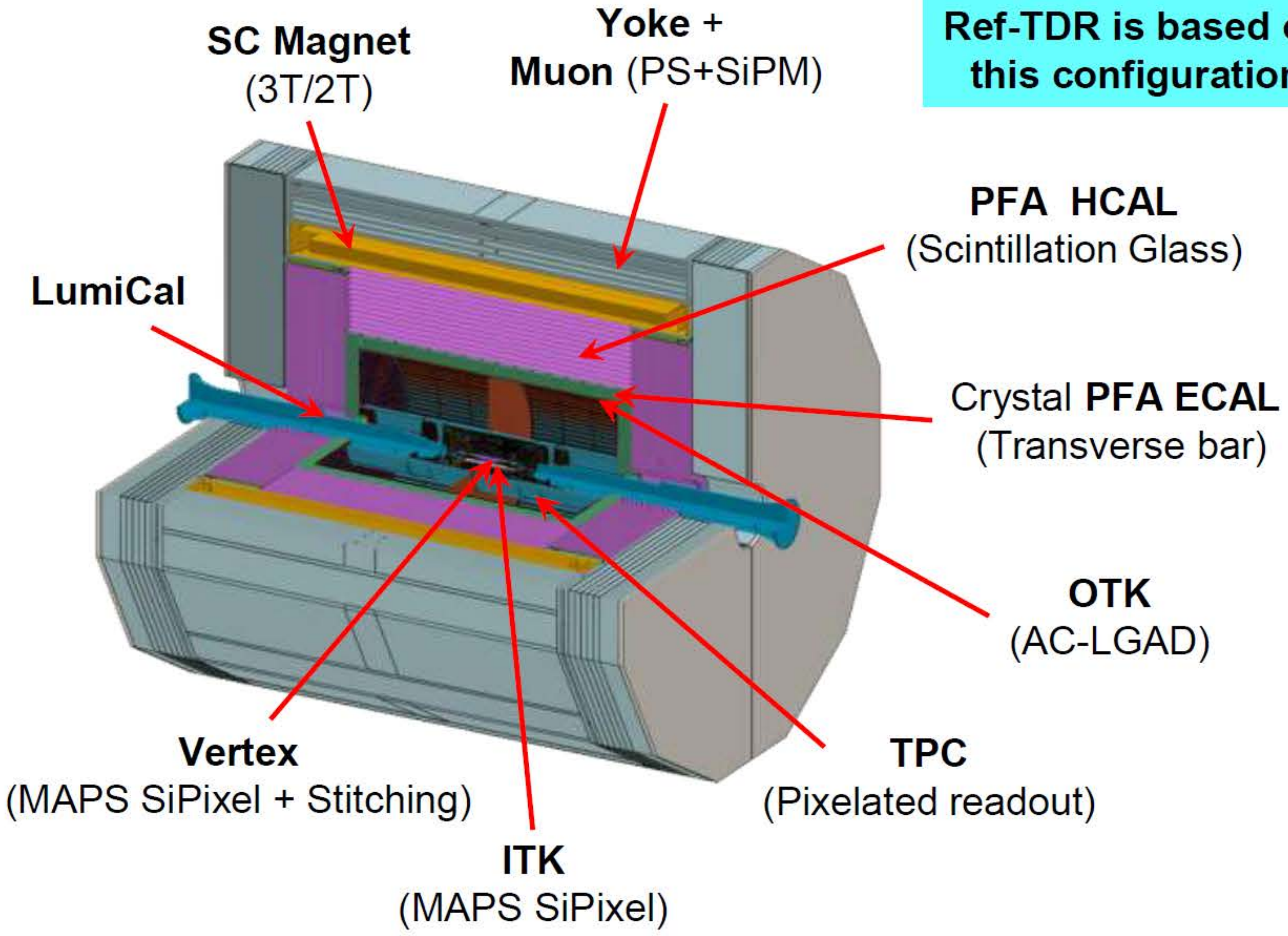
CEPC Detector Progresses







The 4th Concept



Ref-TDR is based on this configuration

CEPC TDR-ref Detector Specifications

Sub-system	Key technology	Key Specifications
Vertex	6-layer CMOS SPD	$\sigma_{r\phi}$ ~ 3 μm, X/X_0 < 0.15% per layer
Tracking	CMOS SPD ITK, AC-LGAD SSD OTK, TPC + Vertex detector	$\sigma\left(\frac{1}{P_T}\right) \sim 2\times10^{-5} \oplus \frac{1\times10^{-3}}{P\times \sin^{3/2}\theta}(GeV^{-1})$
Particle ID	dN/dx measurements by TPC Time of flight by AC-LGAD SSD	Relative uncertainty ~ 3% σ(t) ~ 30 ps
EM calorimeter	High granularity crystal bar PFA calorimeter	EM resolution ~ $3\%/\sqrt{E(GeV)}$ Effective granularity ~ 1×1×2 cm^3
Hadron calorimeter	Scintillation glass PFA hadron calorimeter	Support PFA jet reconstruction Single hadron $\sigma_E^{had} \sim 40\%/\sqrt{E(GeV)}$ Jet $\sigma_E^{jet} \sim 30\%/\sqrt{E(GeV)}$

- ❖ Design of the CEPC detector evolves with the R&D progressing and our better understanding of the physics reach.
- ❖ The key specifications continue to be optimized.

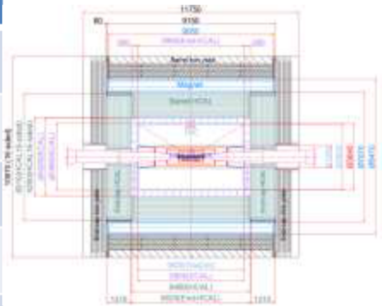
Status of TPC in CEPC ref-TDR

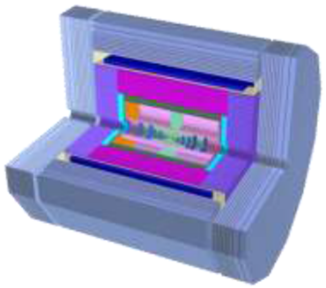
- From January 2024, the CEPC community initiated the technical comparison and selection, balancing factors including **R&D efforts, detector performance, cost, power consumption and construction risks**.

System	Technologies	
	Baseline	For comparison
Beam pipe	Φ20 mm	
LumiCal	SiTrk+Crystal	
Vertex	CMOS+Stitching	CMOS Pixel
Tracker	CMOS SiDet ITrk	
	Pixelated TPC	PID Drift Chamber
	AC-LGAD OTrk	SSD / SPD OTrk
		LGAD ToF
ECAL	4D Crystal Bar	PS+SiPM+W, GS+SiPM, etc
HCAL	GS+SiPM+Fe	PS+SiPM+Fe, etc
Magnet	LTS	HTS
Muon	PS bar+SiPM	RPC
TDAQ	Conventional	Software Trigger
BE electr.	Common	Independent

Radius

Subsystem	Supported By
Barrel Yoke	Base
Magnet	Barrel Yoke
Barrel HCAL	Barrel Yoke
Barrel ECAL	Barrel HCAL
TPC+ Barrel OTK	Barrel ECAL
ITK	TPC
Beampipe+VTX+LumiCal	ITK
Endcap Yoke	Base
Endcap HCAL	Barrel HCAL
Endcap ECAL+OTK	Barrel HCAL





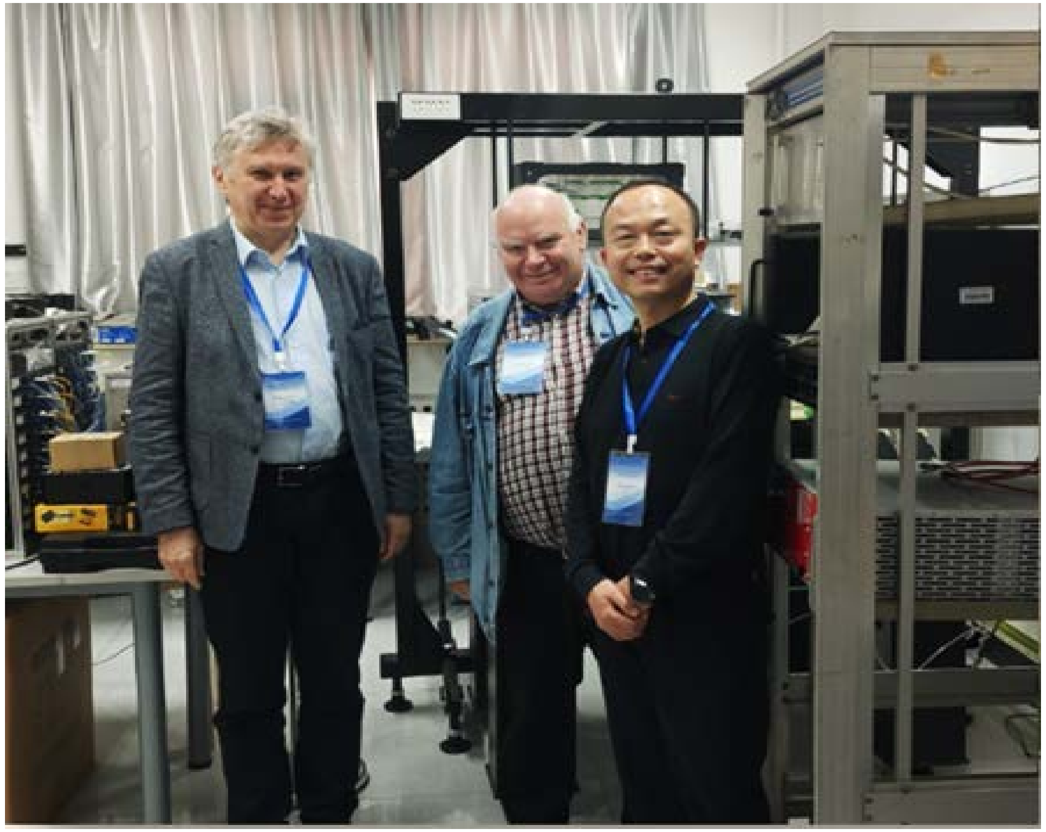
- The CEPC study group started to compare different technologies in January, 2024
- By the end of June, 2024 the baseline technologies were chosen.
- Multiple factors were considered in the process: performance, cost, R&D efforts, technology maturity, …

Timeline of CEPC TRD-ref Detector

Date	Actions and/or Expectations
Jan 1, 2024	Start the ref-TDR process by comparing different technologies
Jul 1, 2024	Baseline technologies are chosen; start to write TDR and address key issues
Aug 7, 2024	Report to the IDRC chair Prof Daniela Bortoletto
Oct 21-23, 2024	Review of the Ref-TDR plan by the IDRC
Oct 23-27, 2024	Report at the CEPC workshop
Oct 29-30, 2024	Report progresses to the CEPC IAC
~January 2025	The first draft of the ref-TDR is ready for internal reviews
~April 2025	Finish international reviews
Jun 30, 2025	The ref-TDR is ready to release

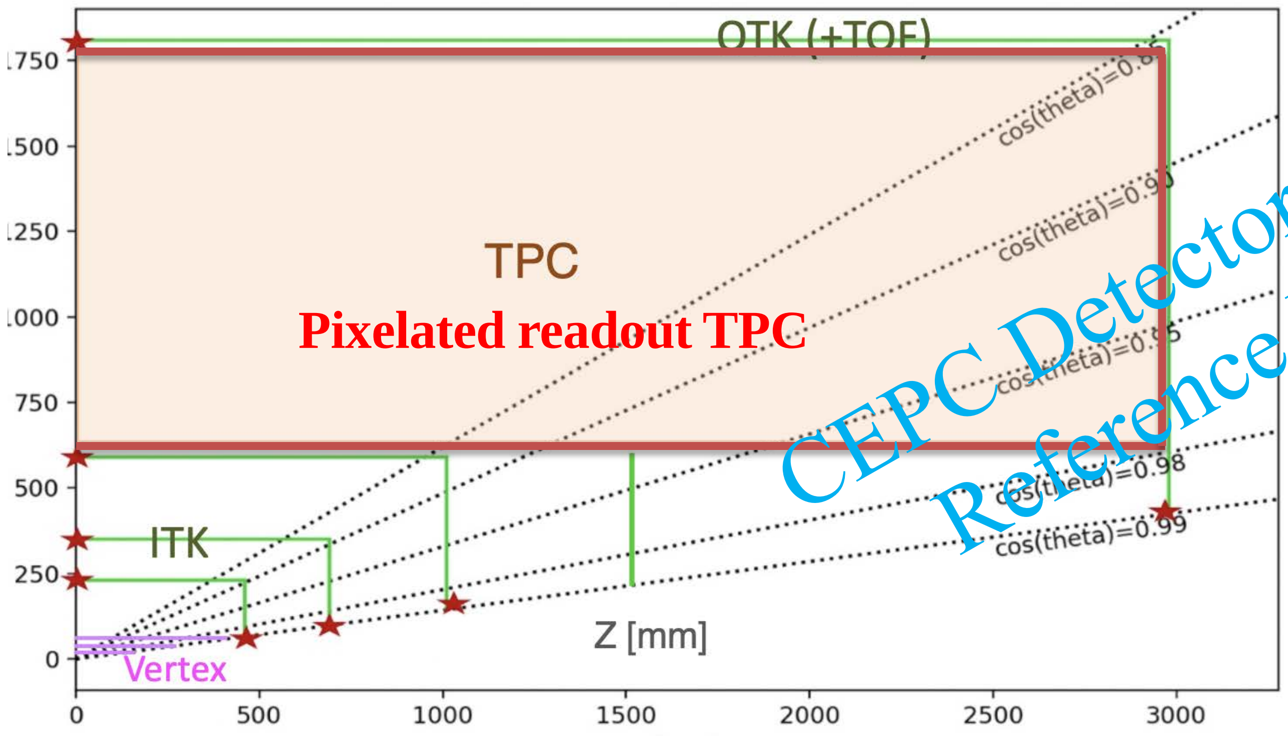
Some contributions from LCTPC in 2024

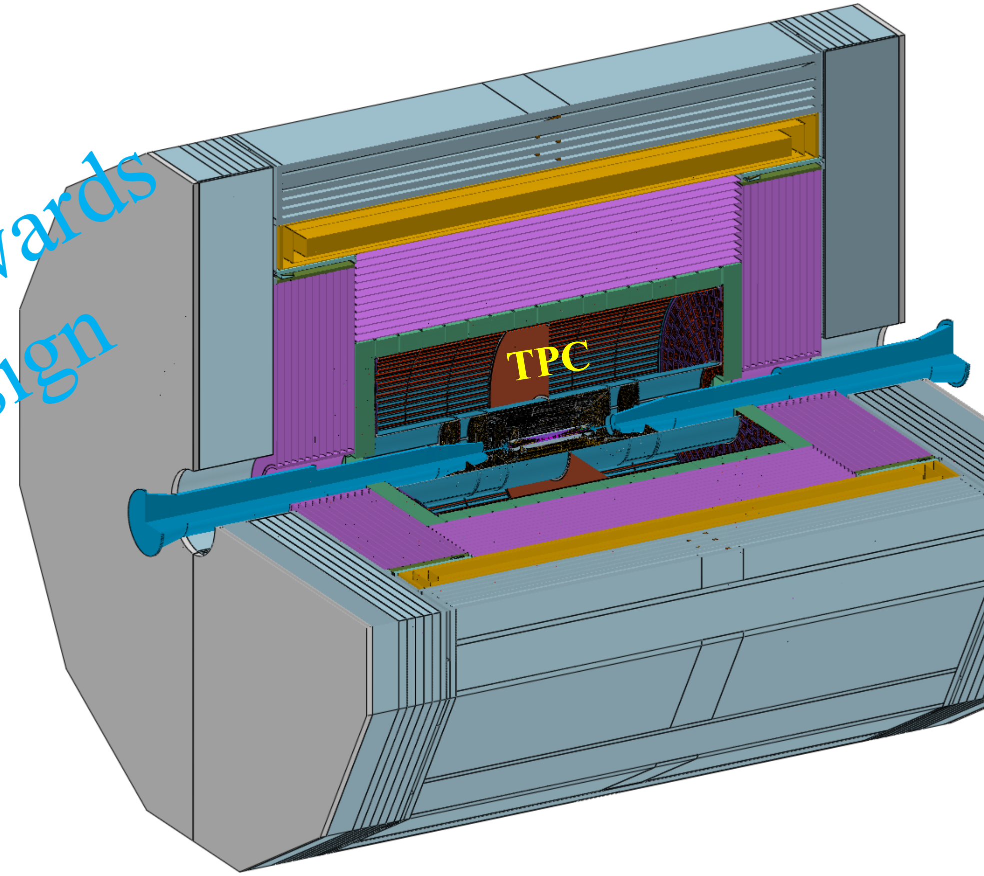
- Discussion of a bi-weekly meeting has been raised to toward TDR preparation in LCTPC.
- Paul and Maxim joined the IDRC meeting as the TPC experts.
  - Pixelated readout TPC successfully has been selected as a benchmark detector in TRD stage.
- In ILD monthly meeting, Jochen gave a talk to indicate the status of TPC in TDR.



Baseline design of TPC technology in CEPC ref-TDR

- Tracking system: Silicon combined with gaseous chamber for the tracking and PID
  - Pixelated readout TPC as the **baseline gaseous detector** in the CEPC ref-TDR
    - Radius of TPC from 0.6m to 1.8m



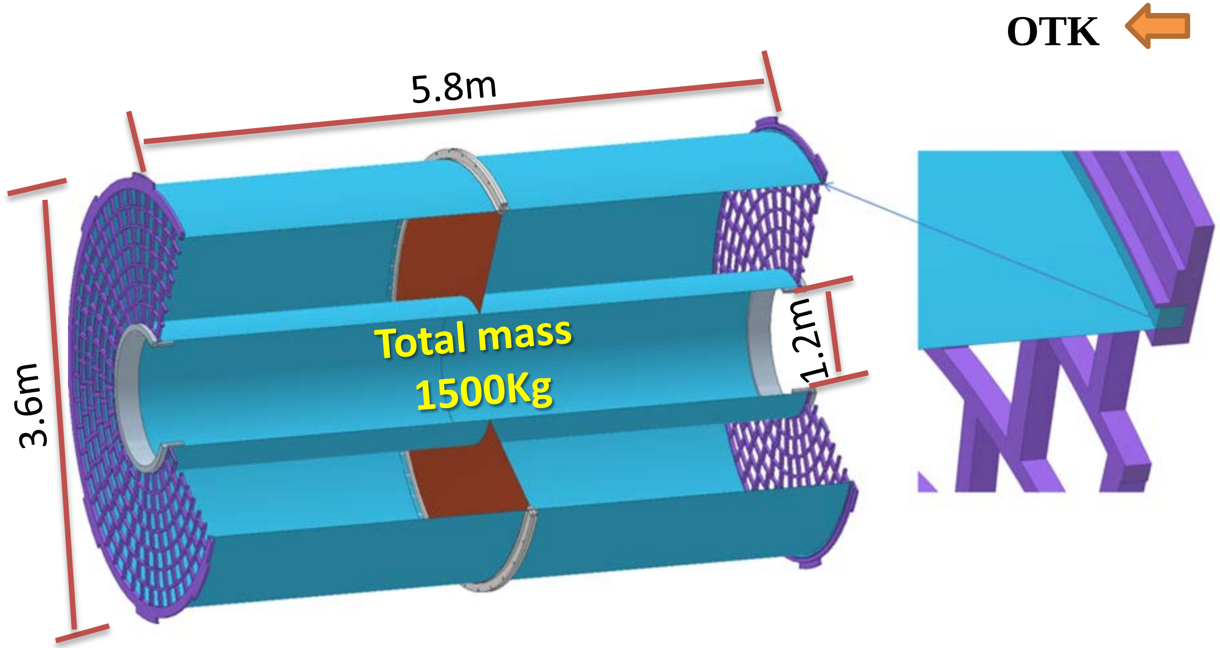


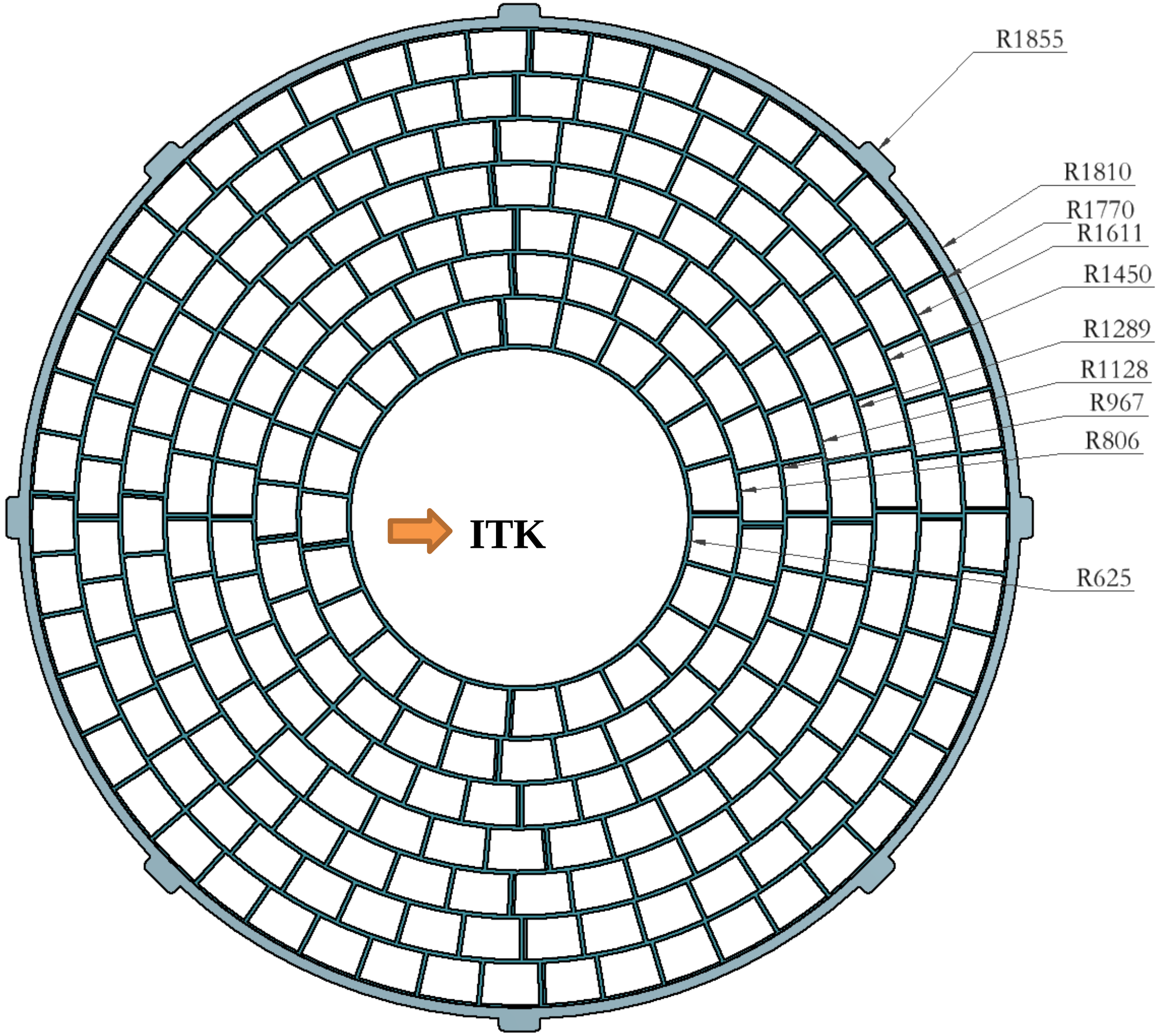
CEPC Detector towards Reference Design

Geometry of the tracking detector system of the CEPC TDR

Parameters of TPC technology in CEPC ref-TDR

TPC detector	Key Parameters
Modules per endcap	248 modules /endcap
Module size	206mm×224mm×161mm
Geometry of layout	Inner: 1.2m Outer: 3.6m Length: 5.9m
Potential at cathode	- 62,000 V
Gas mixture	T2K: Ar/CF4/iC4H10=95/3/2
Maximum drift time	34μs @ 2.75m
Detector modules	Pixelated Micromegas





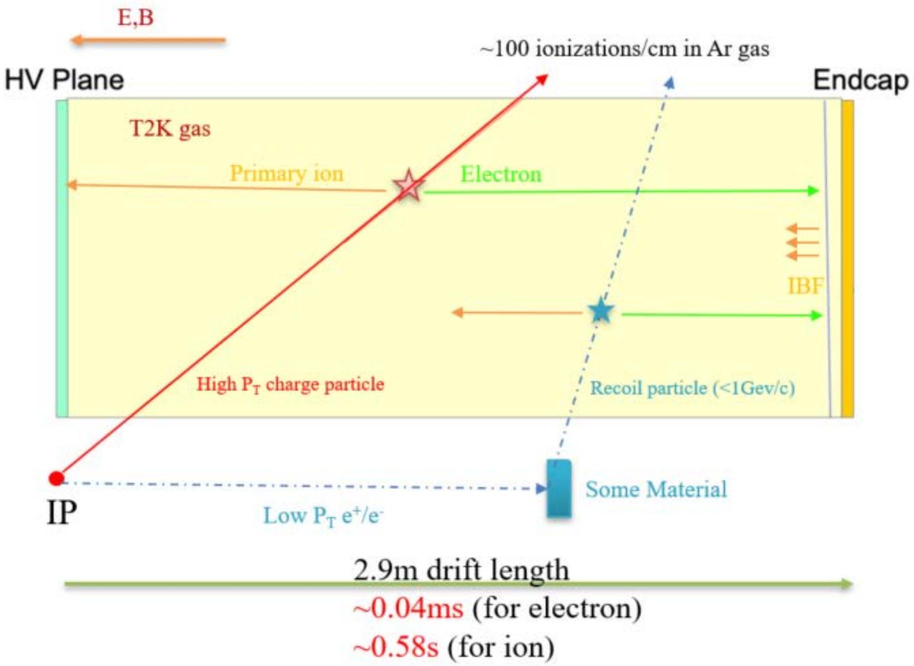
Detailed design of TPC detector in ref-TDR

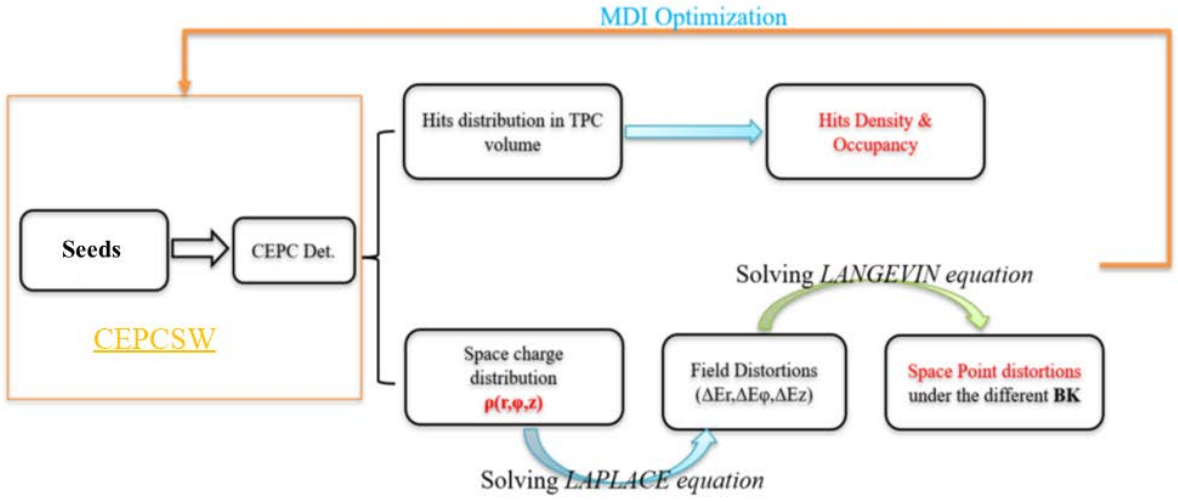
- **Pixelated readout TPC R&D for Higgs and Z**

Pixelated readout TPC for Higgs and Z

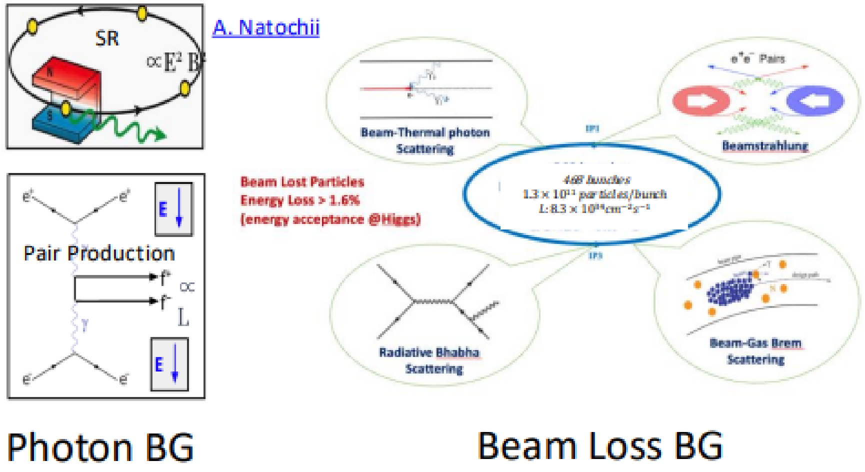
Xin She's talk

- Space charge in TPC chamber
  - Physics events: H→ss/cc/sb, Z→qq…(High P_T)
- Higgs/Z background sources
  - I. Pair production (Luminosity related)
  - II. Single Beam (BGB, BGH,Touschek Scatter…)
  - III. Synchrotron Radiation
  - IV. Injection background
- Simulation framework

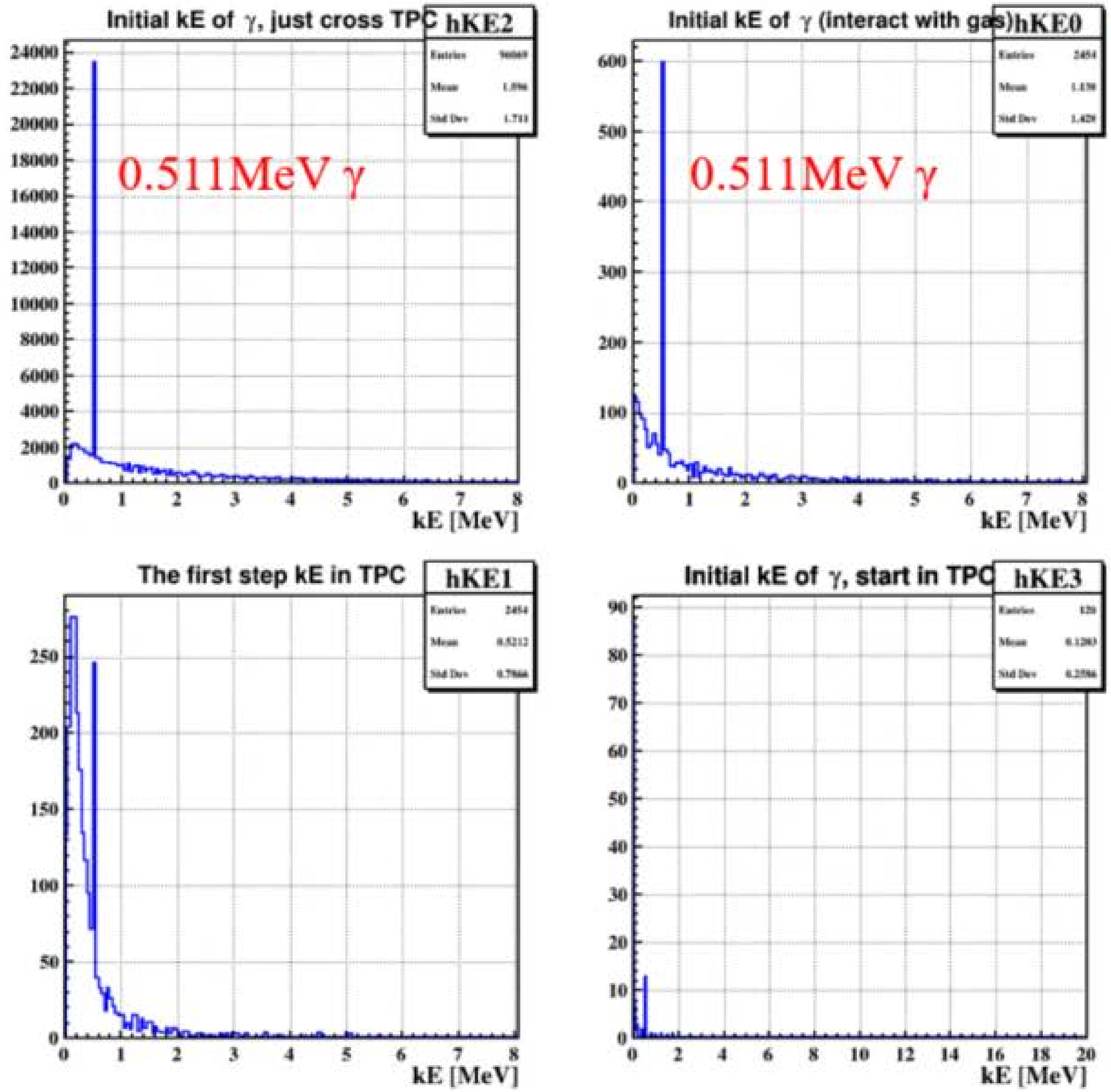




Simulation flow of CEPC Beam Backgrounds



Gamma (<10MeV) events at low luminosity Z @3T



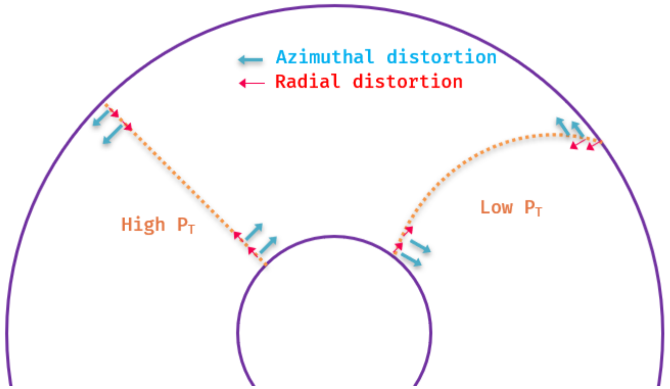
- γ energy distribution (10BX WholeLZ241204 log)
  - 1.2e+7 tracks (γ,e-,e+...) in total
  - 8.4e+6 γ tracks (~70.0%)
  - 9.9e+4 γ will cross TPC and ~2454 γ will interact with T2K gas through "compt, phot, conv" process, 96096 γ just cross TPC without energy deposit
  - ~1.3% γ energy > 10 MeV
  - Large number of 0.511 MeV γ (through e+ annihilation)
  - Average energy deposit： 27.12 MeV/BX by sum all secondary e- dE, small less than the result from .root file (32.3 MeV/BX)
  - **So, low energy γ is the main contributions of beam background for TPC, similar to Higgs mode.**

TPC distortion caused by primary ions

- Radial distortion (Δ_r) is much smaller than azimuthal distortion, almost imperceptible when along the track for most P_T track

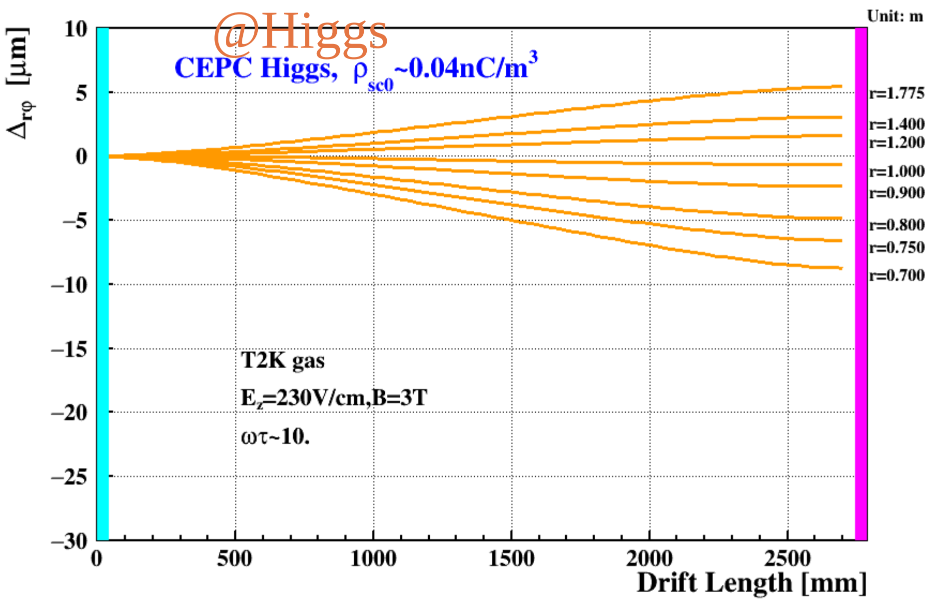
IBF×Gain=1, same primary ion level

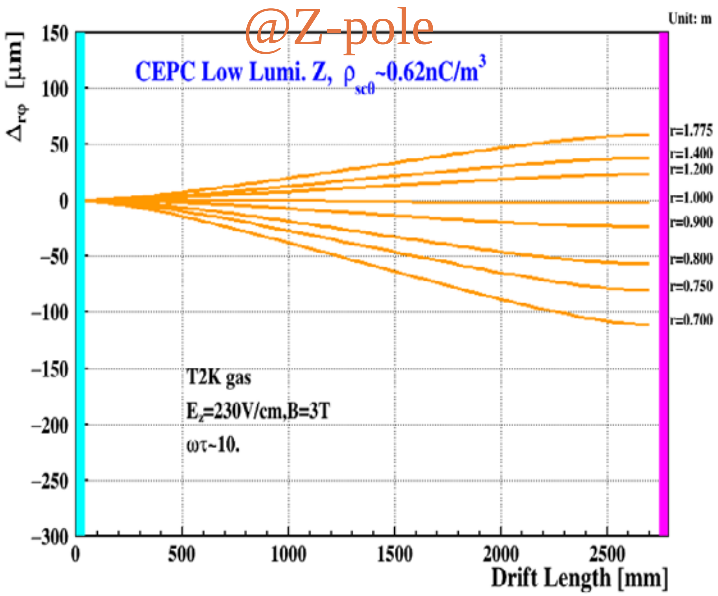
  - Azimuthal distortion ($\Delta_{r\varphi}$) has much serous impact both on high/low P_T tracks
  - The maximum $\Delta_{r\varphi}$ is $10\mu m$@Higgs (**acceptable**)
  - The maximum $\Delta_{r\varphi}$ can be reduced to $<100\mu m$@Z-pole (**optimization of MDI**)
    - Including Pair + Single Beam

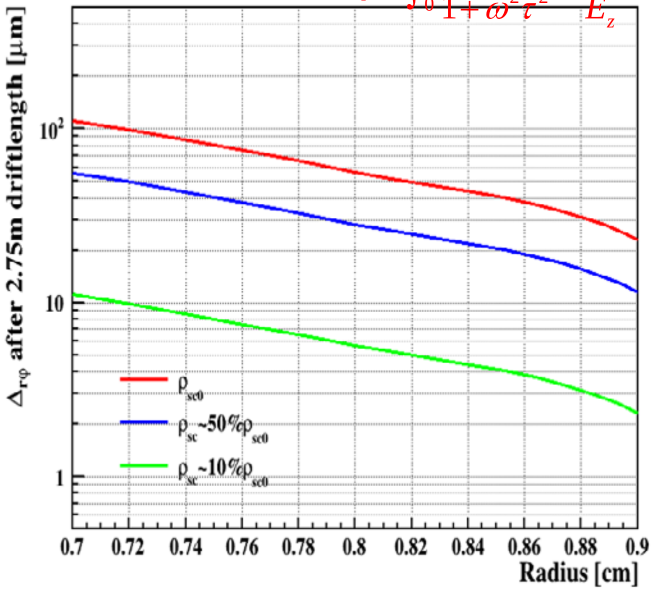


$$\Delta_{r\varphi} = \int_0^L \frac{\omega\tau}{1+\omega^2\tau^2} \times \frac{E_r}{E_z} dz$$

$$\Delta_r = \int_0^L \frac{1}{1+\omega^2\tau^2} \times \frac{E_r}{E_z} dz$$







Numerical calculation results of TPC distortion

Full Simulation of Pixelated readout TPC

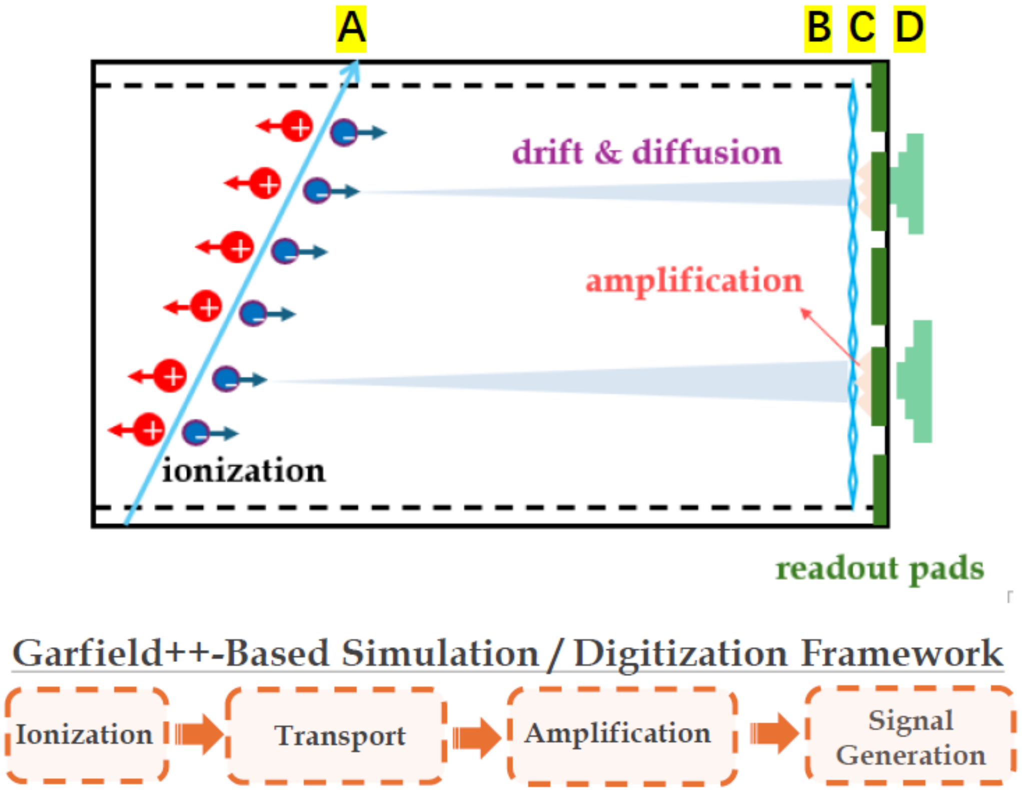
Guang Zhao's talk in 3rd DRD1 meeting
https://indico.cern.ch/event/1442324/contributions/6262871/attachments/2984481/5255933/DRD1_CM3_TPC_SIM_Guang.pdf

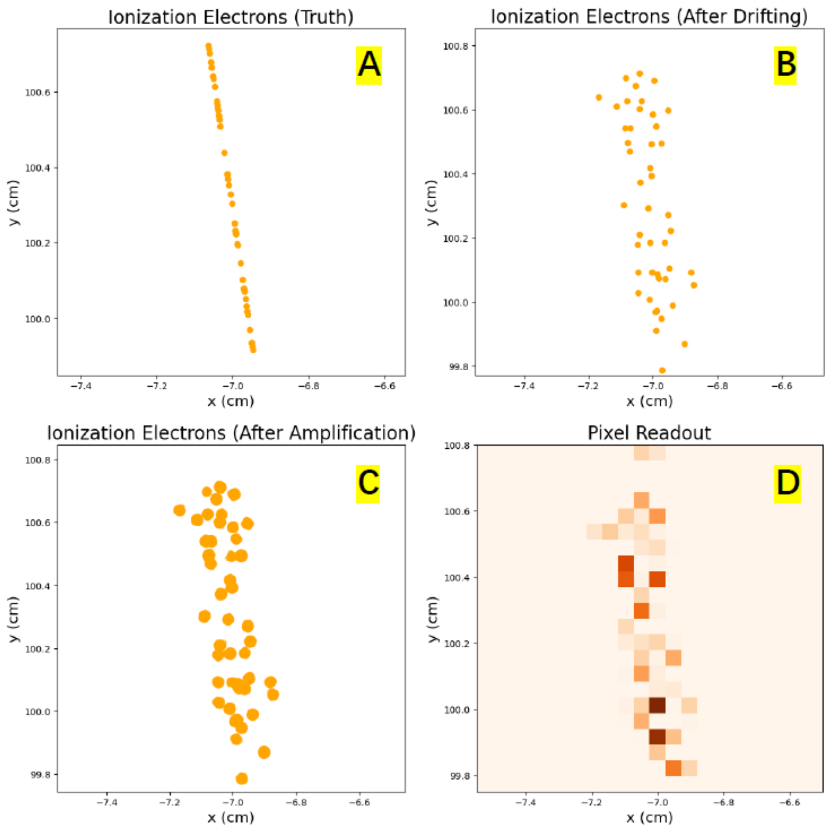
Simulation:

- With the full TPC geometry
- Ionization simulated with Garfield++
- Drift and diffusion from parameterized model based on Garfield++

Digitization (Refer to the TPC module and prototype):

- Electronic noise: 100 e-
- Amplification:
  - Number of electrons: 2000
  - Profile of signal size : 100μm





Simulation of TPC detector under 3T/2T and T2K mixture gas

Full Simulation of Pixelated readout TPC – Readout size

- Simulation of the readouts in pixel sizes
  - Actually, TPX3/4 option existing and the power consumption will be optimized.
  - Optimization started in this ref-TDR at IHEP to meet **Higgs/Z at 3T**.

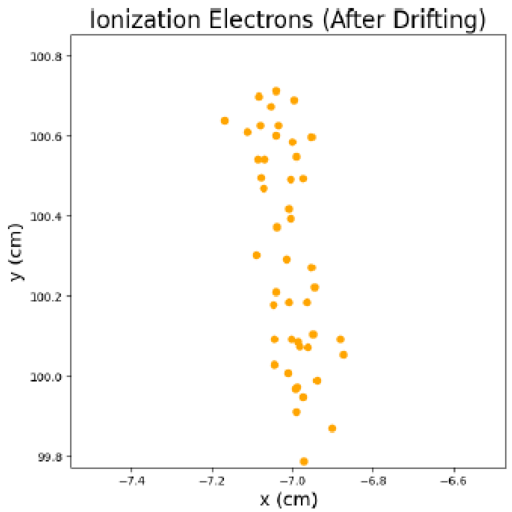
- Concerning pixel sizes for a TPC
  - A pixel size of 55 (110) microns is optimal; one can profit from cluster counting and high precision tracking
  - Larger pixel/pad sizes have larger occupancies and one should question whether they can handle the very high beam-beam rate

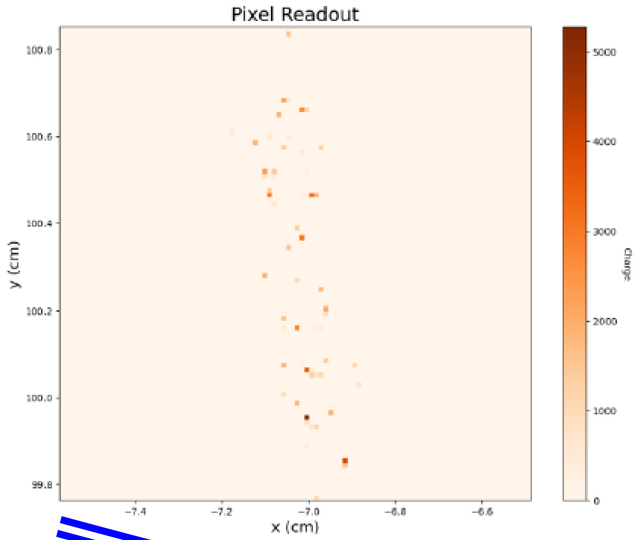
Peter's comment
in CEPCWS at Hangzhou.

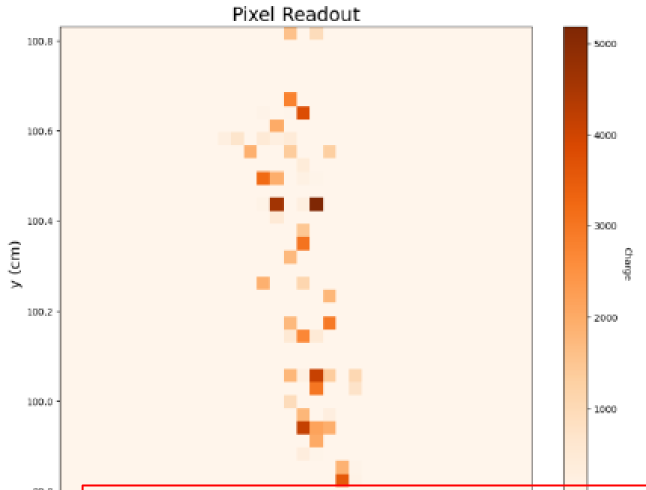
Pixel size = 110 um

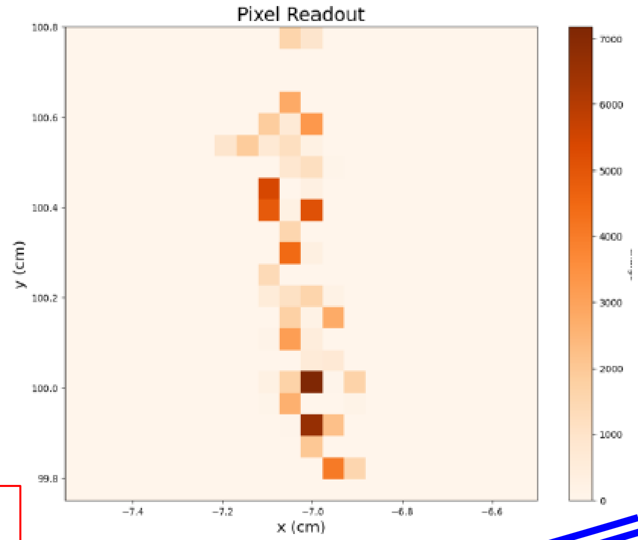
Pixel size = 300 um

Pixel size = 500 um









Optimization of readout size
Balancing of performance, cost power consumption, etc.

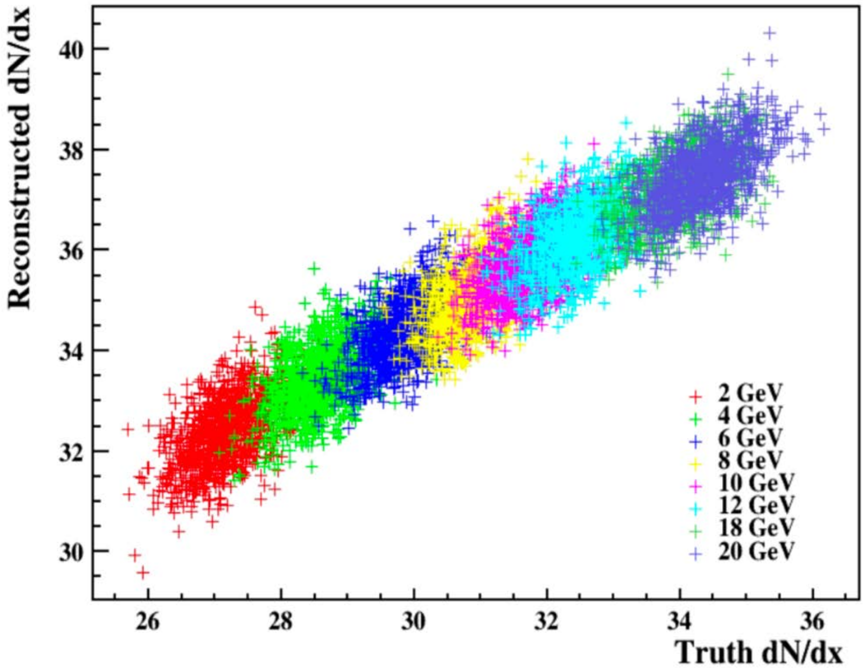
Reconstruction:

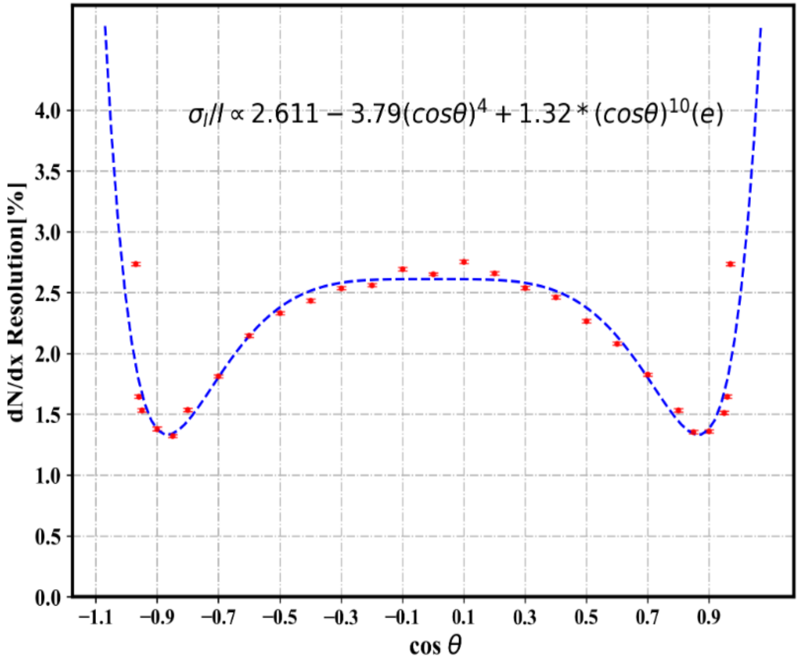
- Reconstruction by counting the number of fired pixels over threshold
- **Reconstruction with good linearity and reliability**

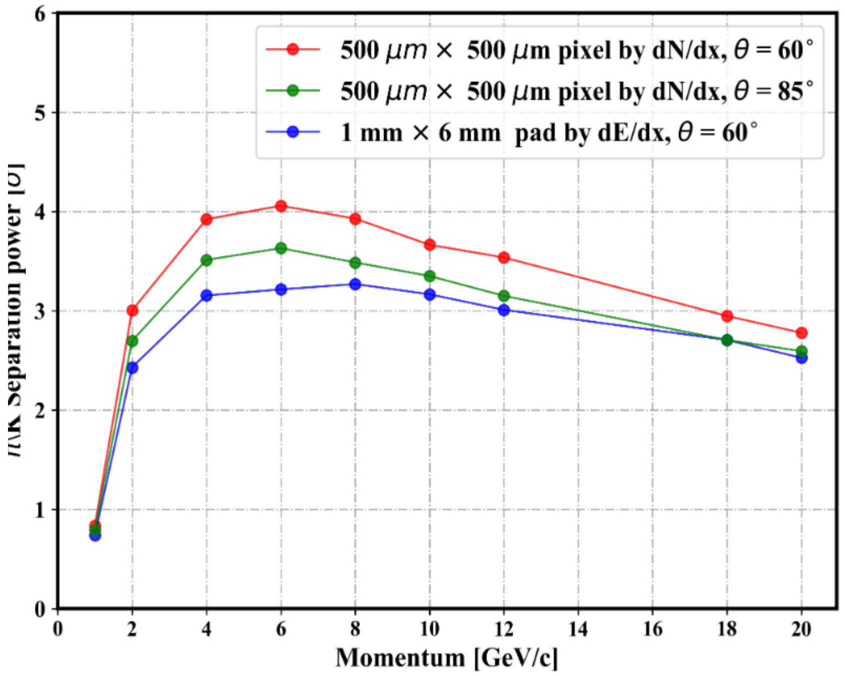
Preliminary PID performance:

- π/k separation power simulation with different momentum

$$\text{Separation power: } \frac{|\mu_A - \mu_B|}{\frac{\sigma_A + \sigma_B}{2}}$$

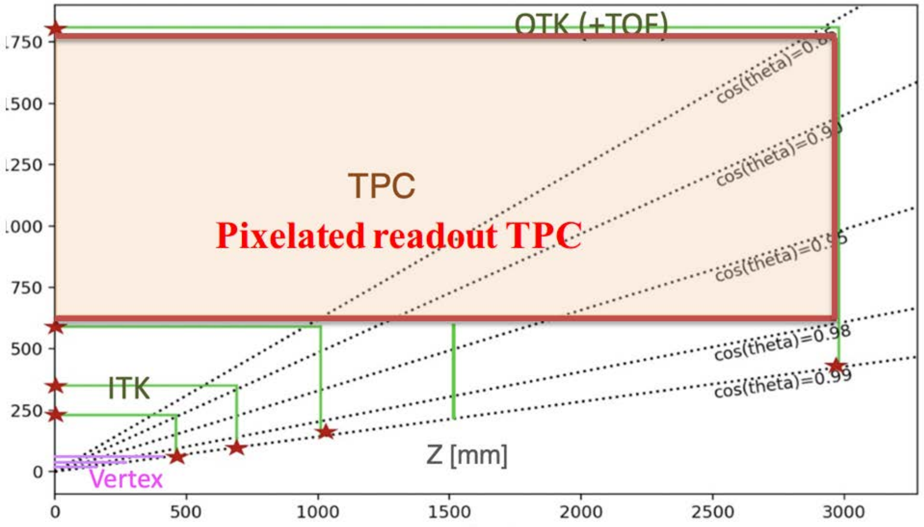


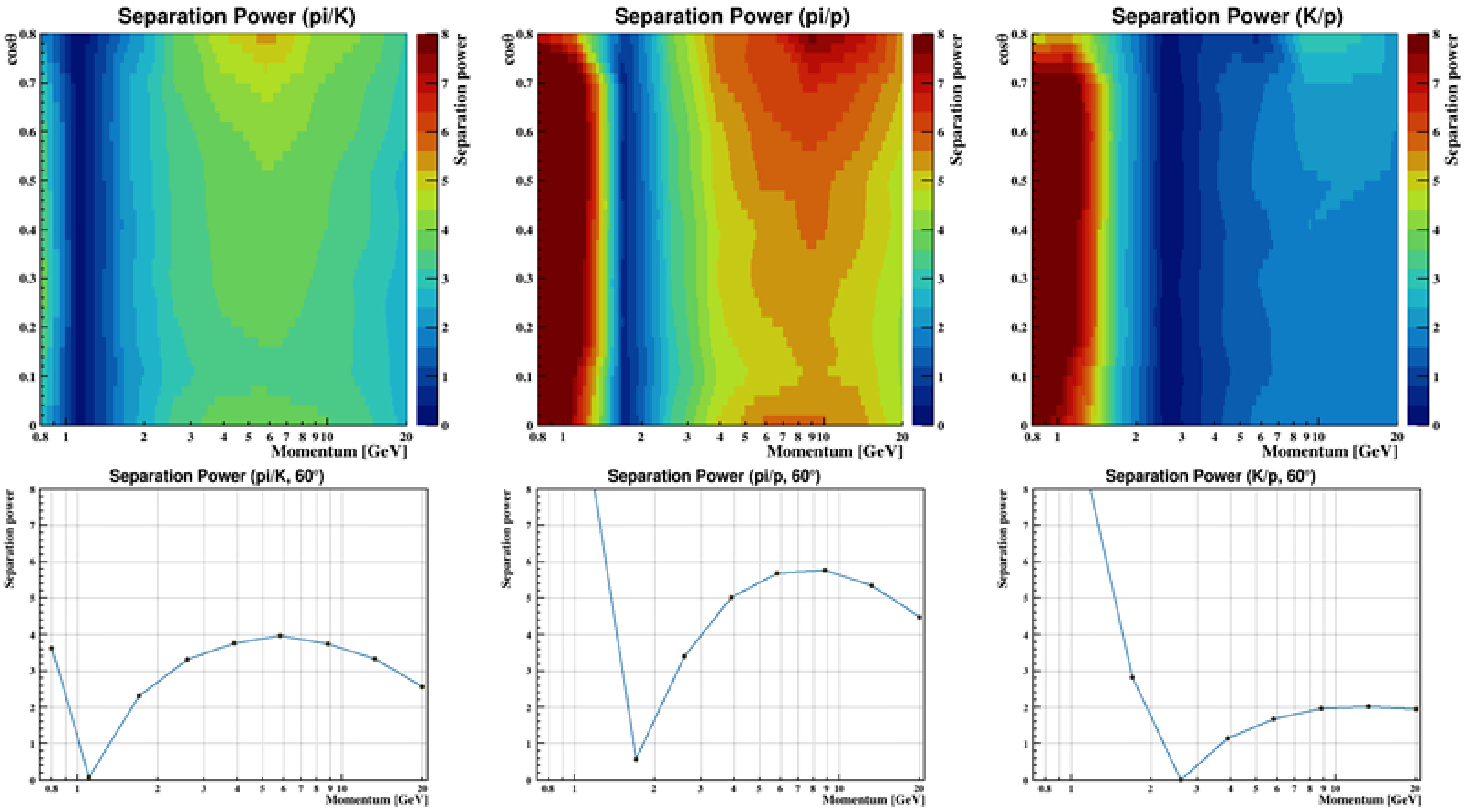




Full Simulation of Pixelated readout TPC – PID performance

- Performance of the pixelated readout TPC
  - Simulation of π/K, π/p, and K/p separation power with varying momentum and cosθ

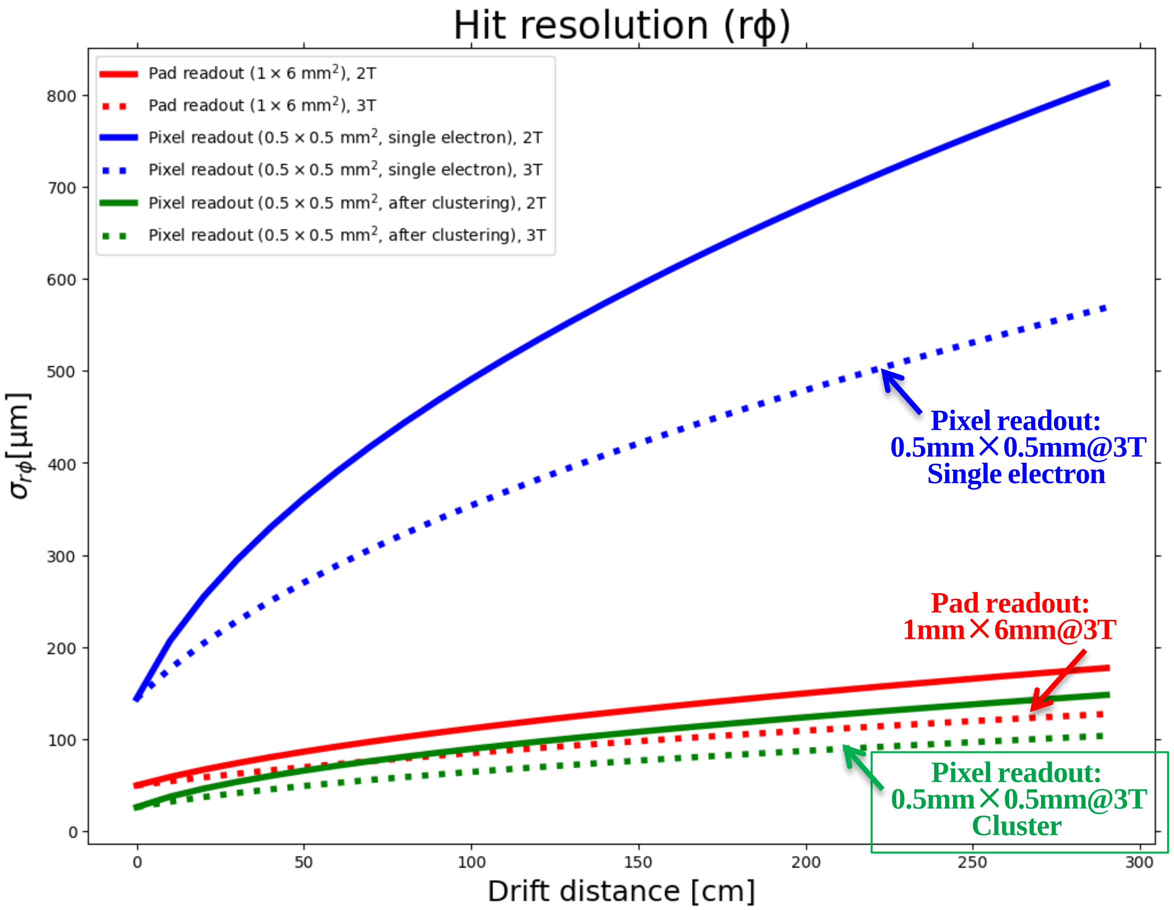




Full Simulation of Pixelated readout TPC – Spatial resolution

Estimation of the **spatial resolution using pixelated readout**.

- The granularity readout and the transverse diffusion are also taken into consideration..
- TPC can operates effectively at 3T B-field.
- Pixelated readout TPC can achieves superior spatial resolution at 3T compared to 2T.



Pad readout:

$$\sigma_{r\phi}^{\text{pad}} = \sqrt{(\sigma_{r\phi 0}^{\text{pad}})^2 + \sigma_{\phi 0}^2 \sin^2(\phi_{\text{track}}) + L\frac{D_{r\phi}^2}{N_{\text{eff}}}\sin(\theta_{\text{track}})}$$

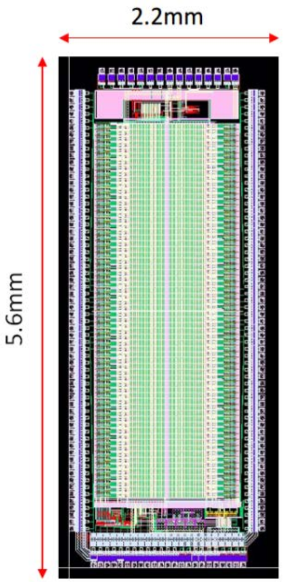
Pixel readout:

$$\sigma_{r\phi}^{\text{pixel}} = \sqrt{(\sigma_{r\phi 0}^{\text{pixel}})^2 + LD_{r\phi}^2}$$

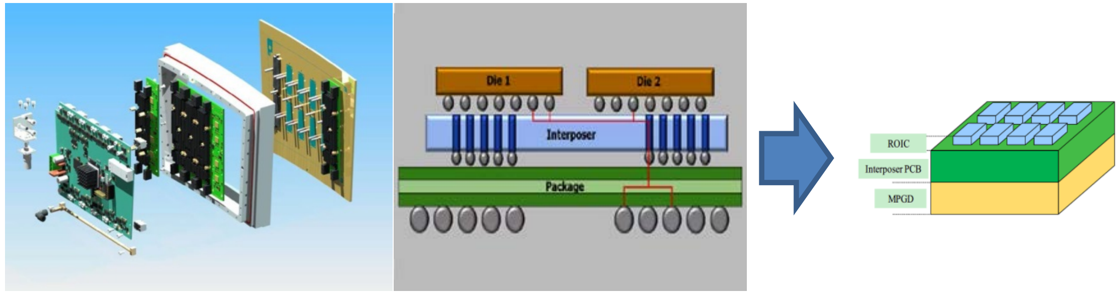
Full Simulation of Pixelated readout TPC – TEPix with 500μm×500μm

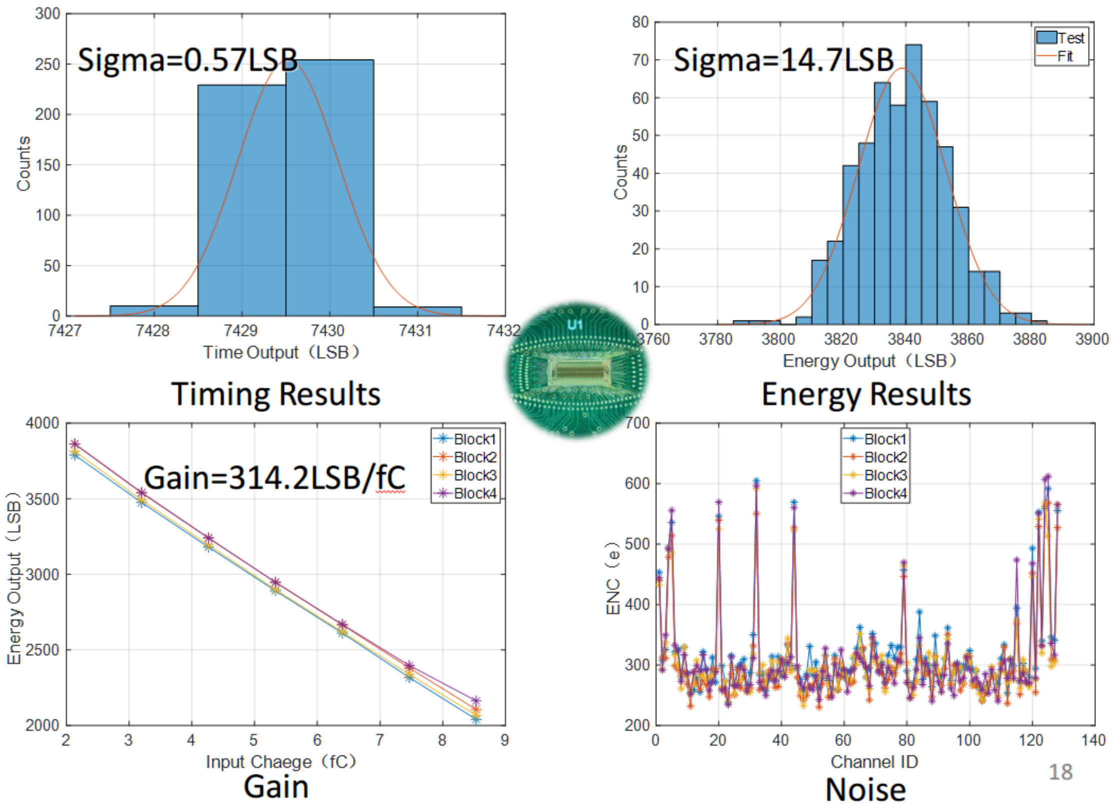
Zhi Deng's talk

- Pixelated Readout Electronics: TEPix development
  - Multi-ROIC chips + Interposer PCB as RDL
  - Four-side bootable
- TEPix: Low power Energy/Timing measurement
  - Low power consumption: 0.5mW/ch@2nd Chip
  - Timing: 1 LSB(<10ns)
  - Noise: 300e- (high gain)



Parameter		Spec
Number of channels		128
Power Consumption		Analog<30mW
		Digital<30mW
ENC		~300 e(high gain)
Dynamic Range		25fC(high gain)
		150fC(low gain)
INL		<1%
Time Resolution		<10ns

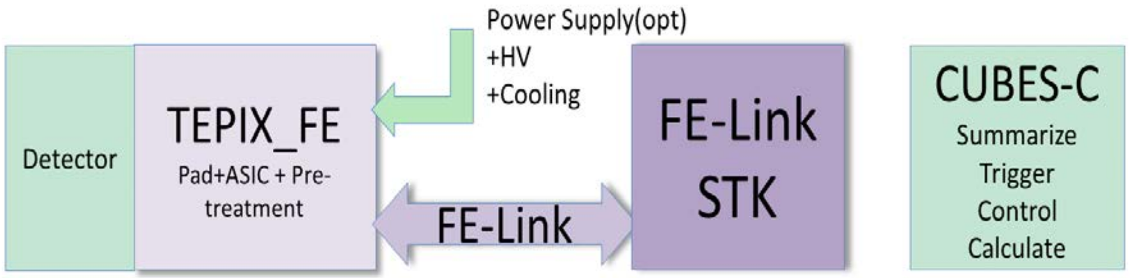


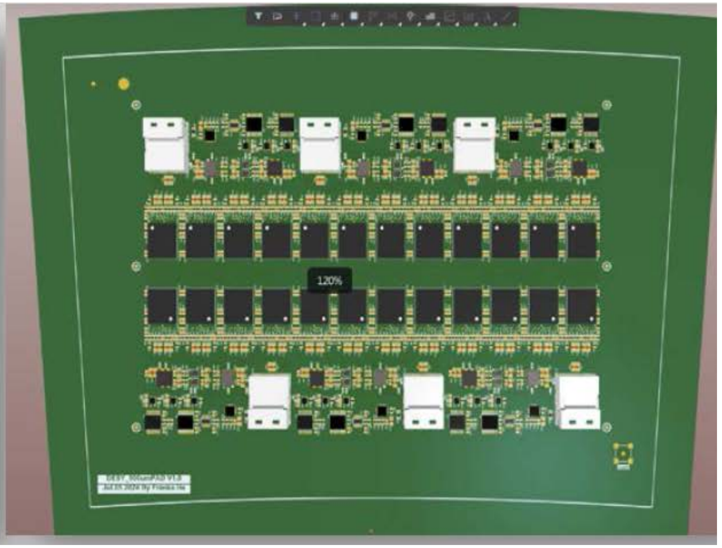


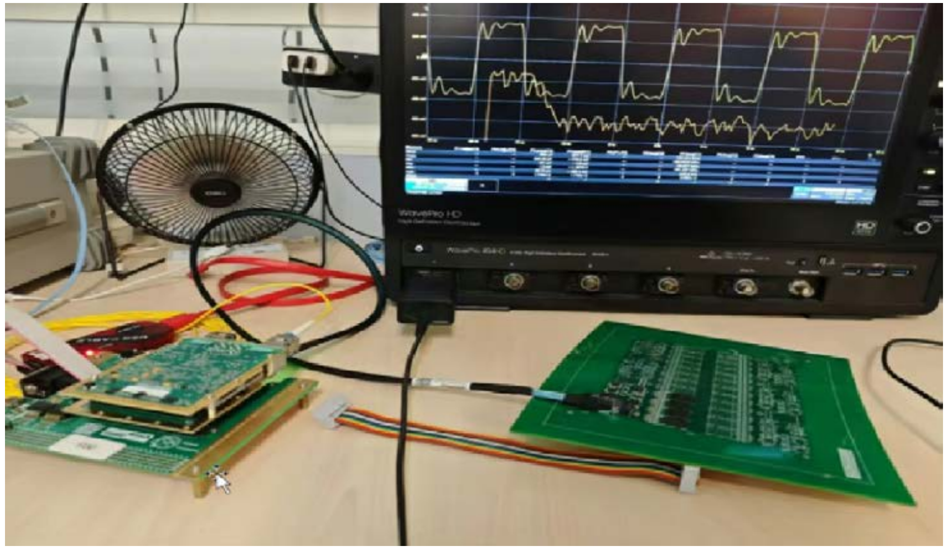
FEE ASIC: TEPIX—Test Results in May

Validation and commissioning of TPC prototype

- **R&D on Pixelated TPC readout for CEPC TDR.**
  - ASIC chip developed and **2nd prototype wafer has been done** and tested.
  - The TOA and TOT can be selected as the initiation function in the ASIC chip
- **Beam test of the pixelated readout TPC prototype in preparation. (May , 2025 at DESY)**



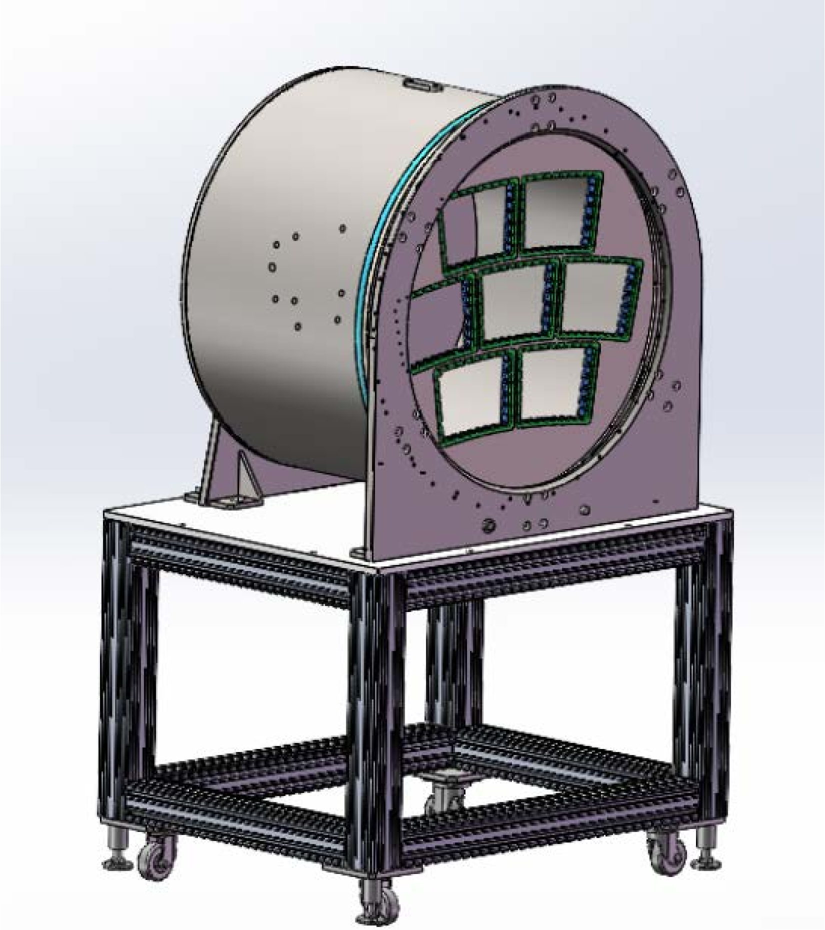




Photos TPC modules assembled for the beam test

Work plan in CEPC stage

- Short term work plan (**before June, 2025**)
  - Optimization of TPC detector for CEPC ref-TDR
  - Prototyping R&D and validation with the test beam
    - mechanics, manufacturing, beam test, full drift length prototype
  - Performance of the simulation and Machine Learning algorithm
- Long term work plan (**next 3-5 years**)
  - Development of TPC prototype with low power consumption FEE
    - Collaboration with LCTPC collaboration on beam test
  - Development of the full drift length prototype
    - Drift velocity. Attachment coefficient, T/L Diffusion, etc.



Milestones achieved	Before June, 2025	Beyond TDR
Ion backflow suppression	IBF×Gain<1 (Gain=2000)	Graphene technology
Pixelated readout prototype	Validation with beam test	Prototype with Multi-modules
Power consumption ASIC	~100mW/cm^2 (60nm ASIC)	Optimization 330µm - 500µm
PID resolution	3% (dN/dx)	<3% (dN/dx)
Material budget (barrel)	Carbon Fiber	Full size prototype

Third Question: What’s the critical issues and how to R&D?

We would like to discuss the critical issues we are facing and outline potential R&D strategies to address them in this LCTPC CM.

- **Low luminosity Z pole (ALICE TPC)**
- **Pixelated TPC (Peter’s R&D)**
- **ILD detector concept (FCCee and CEPC)**

Summary

- In LCTPC collaboration, TPC detection technology R&D using the pad readout towards the pixelated readout for Higgs and Z run at the future e+e- collider.
- Pixelated TPC is chosen as the baseline gaseous tracker in CEPC ref-TDR. The simulation results show that both of PID performance and the momentum resolution are good. Validation with TPC prototype in preparation before TDR.
- Synergies with CEPC/DRD1/FCCee/EIC/LCTPC allow us to continue R&D and ongoing with the significant international collaboration. All of contributions will input to CEPC ref-TDR in next few months.

CEPC2025 workshop to be held in May in Barcelona.
All information will be announced soon.

Many thanks!