High granularity readout TPC selected in CEPC Phy.&Det. TDR

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- **Main track detector choiced: TPC option**
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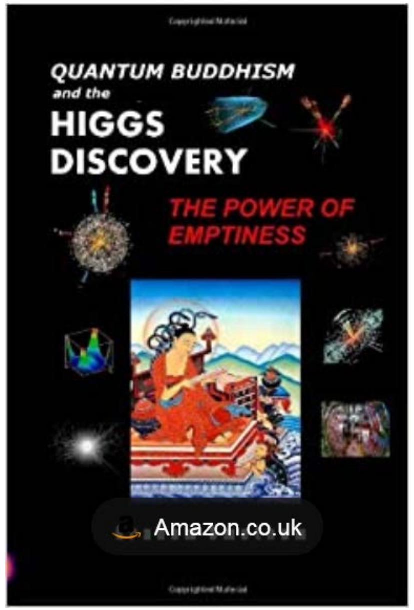
Brief reminder about CEPC

- CEPC proposal R&D from 2013-2024, over ten years
- The CEPC accelerator TDR (**released**) and phy./det. TDR (**preparation**).



2012
discovery of the
Higgs boson

Kick-off on Sept. 13, 2013
inspired by the discovery of the Higgs boson at the LHC
CEPC study group formed in Beijing
Accelerator, Physics and Detector groups

PreCDR released , March 2015
CDR released , November 2018
1st Funding from MOST in 2016
2nd Funding from MOST in 2018
3rd Funding from MOST in 2023
Accelerator TDR released in 2023.
Phy.&Det. TDR was prepared and will be released in 2025.

Brief reminder about CEPC

- CEPC operation stages: **10-years Higgs → 2-years Z pole → 1-year W**
- CEPC phy./det. TDR (**preparation**)
  - Physics and detector concept designed under the principle.
  - **Requirements may be with regard to runs of Higgs and Z-pole separately**.
    - Mandatory requirements MUST be met.
    - Auxiliary requirements, if any, are optional.

Chapter 3 of this report outlines that the CEPC is planned to be in operation for 8 months annually, totaling 6,000 hours. This operational schedule is used to calculate the cumulative absorbed doses for magnet coil insulations, as illustrated in Figure 4.2.4.16, considering a 10-year Higgs operation, 2-year Z operation, and 1-year W operation. Figure 4.2.4.17 displays the absorbed doses when an additional 5-year $t\bar{t}$ operation is included. These plots also include the upper limit for absorbed dose in epoxy resin, which is measured at 2×10^7 Gy [11].

CEPC- TDR p116

Physics requirements on future circular e+e- collider

- Performance & Physics benchmarks: defined
- PFA is essential:
  - BMR < 4% & pursue 3%
  - Highly relevant – and even as the pre-request for excellent JOI & Pid (in jets)

	Processes @ c.m.s.	Domain	Total Det. Performance	Sub-D
H->ss/cc/sb	vvH @ 240 GeV	Higgs	PFA + JOI (Jet origin id)	All sub-D, especially VTX
Vcb	WW@ 240/160 GeV	Flavor	JOI + Particle (lepton) id	All
W fusion Xsec	vvH @ 360 GeV	Higgs	PFA + JOI	All
α_S	Z->tautau @ 91.2 GeV	QCD	PFA: Tau & Tau final state id	ECAL + Tracker material
B->DK	91.2 GeV	Flavor	PFA + Particle (Kaon) id	All, especially Tracker & ToF
Weak mixing angle	Z	EW	JOI	All
Higgs recoil	llH	Higgs	Leptons id, track dP/P	Tracker, All
H->bb, cc, gg	vvH	Higgs	PFA + JOI	All
	qqH	Higgs	PFA + JOI + Color Singlet id	All
H->inv	qqH	Higgs/NP	PFA	All
H->di muon	qqH	Higgs	PFA, Leptons id	Calo, All
H->di photon	qqH	Higgs	PFA, Photons id	ECAL, All
W mass & Width	WW@160 GeV	EW	Beam energy	NAN
Top mass & Width	ttbar@360 GeV	EW	Beam energy	NAN
Bs->vvPhi	Z	Flavor	Object in jets; MET	All
Bc->tauv	Z	Flavor	-	All
B0->2 pi0	Z	Flavor	Particle/pi-0 in jets	ECAL

Table from Manqi's talk on IAS2024 conference in January

Physics requirements of the track detector

- TPC can provide hundreds of hits with high spatial resolution compatible, with PFA design (**low X_0**)

Differential Efficiency.

Requirement: Pt threshold ~ o(100) MeV, |cos(theta)| < 0.99

Ref: CDR baseline design

Differential Material Budget.

Requirement: < 10%/50% X0 in Barrel/endcap

Ref: CDR baseline design + BMR & Material Dependence

Differential Resolution of 5 track parameters.

Requirement: In the barrel

δ(D0/Z0) ~ < 3 micro meter at 20 GeV

δ(Pt)/Pt ~ o(0.1%)

Ref: CDR baseline performance

Differential Pid Capability: eff*purity of Kaon id @ Z pole.

Requirement: eff*purity > 90% for all charged Kaon (@ Z pole)

~ relative resolution of dE/dx (or dN/dx) be better than 3%

ToF of 50 ps

Ref: Nuclear Inst. and Methods in Physics Research, A 1047 (2023) 167835

Sep. power: On 3 prong tau decay @ Z pole.

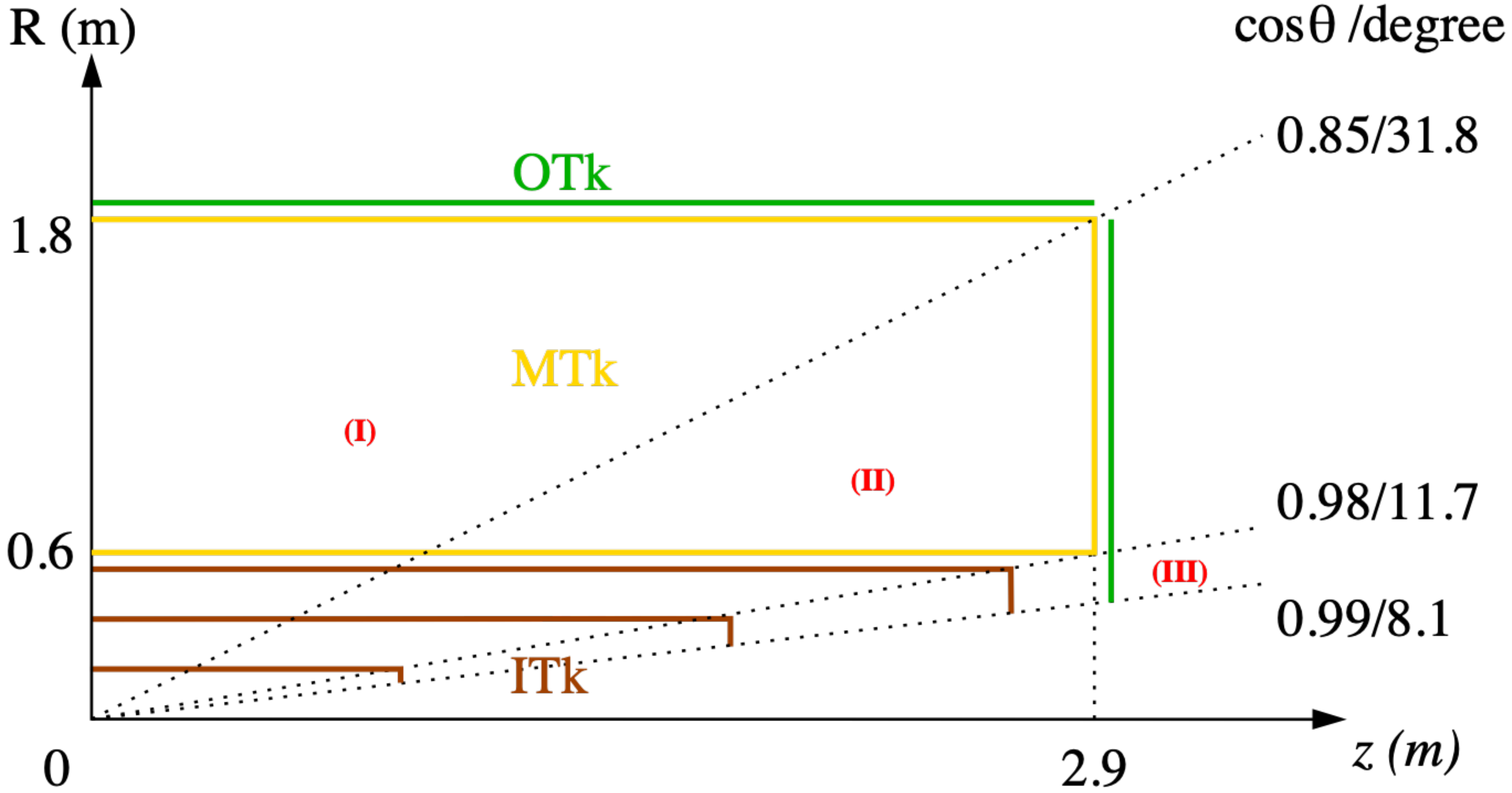
Requirement: efficiency > 99% at 3-prong tau

Ref: CDR baseline performance

- TPC **SELECTED** as the baseline track detector in TDR

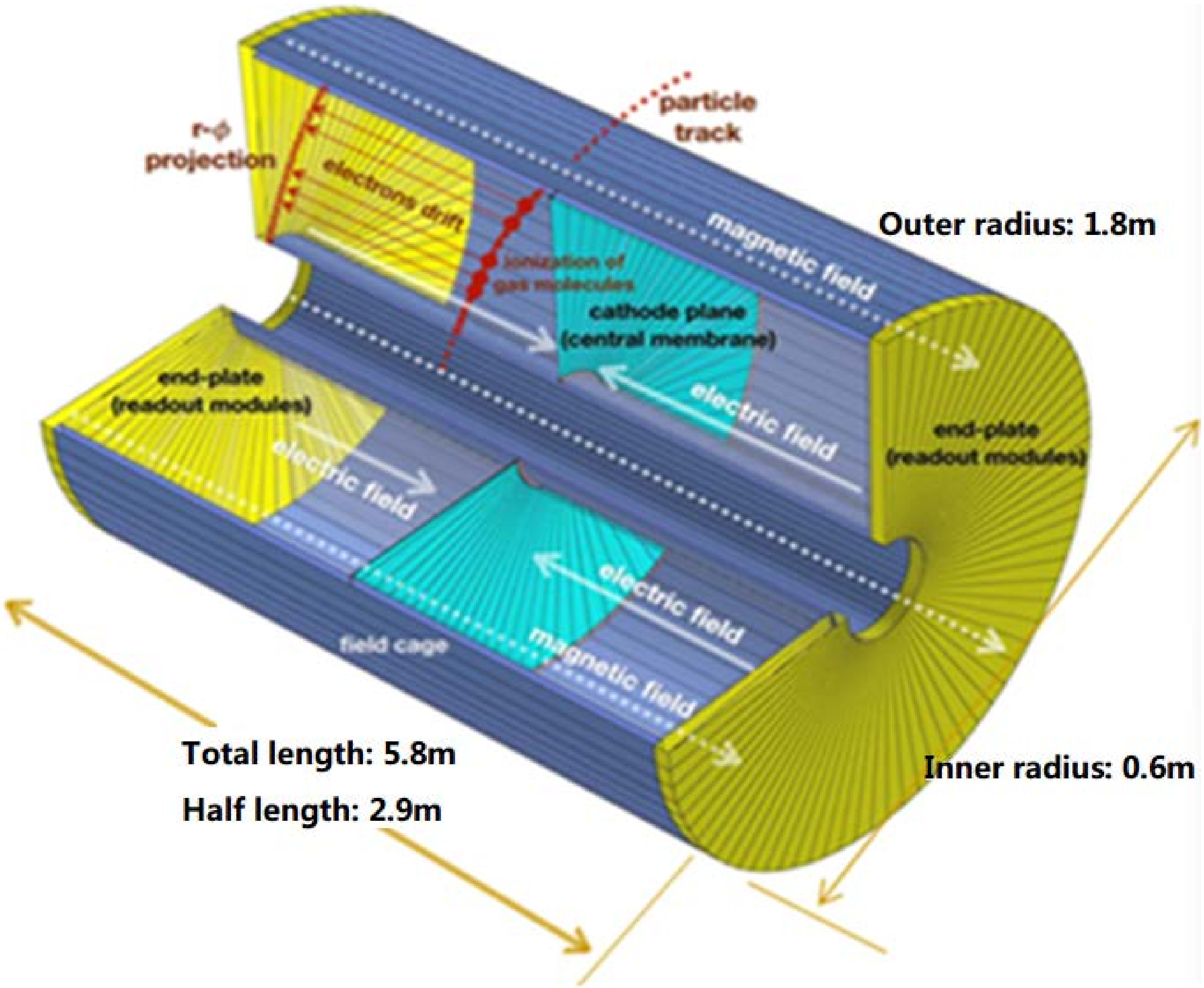
Track detector system (**Finalized Geometry** in CEPC Phy.&Det. TDR)

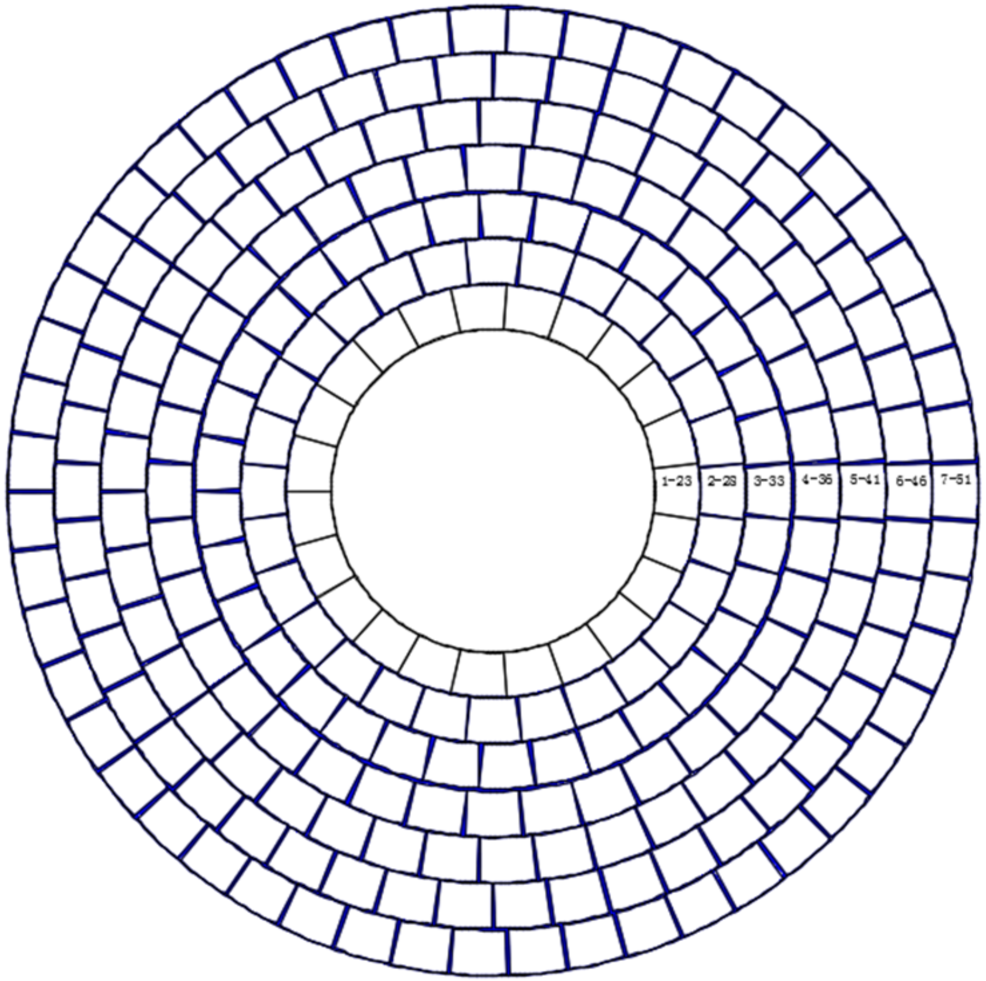
- The track detector system's geometry was finalized.
    - The limited schedule for TDR preparation
    - Converging geometries as quickly as possible in preparation for physics simulation



Almost finalized Geometry of the track detector system

TPC detector (**Finalized Geometry** in CEPC Phy.&Det. TDR)





Almost finalized Geometry of TPC detector and the Endplate

High granularity readout -1 @cosθ≃0.85

Parameters4	Higgs run	Z pole run
B-field	3.0T	2.0T
Pad size (mm)/All channels	1.0mm × 6.0mm /2 × 10^6	1.0mm × 6.0mm /2 × 10^6
Material budget barrel	≃ 0.012 X_0	≃ 0.012 X_0
Material budget endcap	< 0.17 X_0	< 0.17 X_0
Points per track in rφ	200	200
σ_{point} in rφ	≤ 100µm (full drift)	? (full drift)
σ_{point} in rz	≃ 0.4 – 0.8 mm (for zero – full drift)	? (for zero – full drift)
2-hit separation in rφ	< 2mm	< 2mm
dE/dx	≤ 3.6%	≤ 3.6%
Momentum resolution normalized: $\sigma_{1/pT} = \sqrt{a^2 + (b/pT)^2}$	a = 1.82 e -5	a = 3.32 e -5
	b = 0.60 e -3	b = 0.92 e -3

High granularity readout -3 @cosθ≃0.85

Parameters4	Higgs run	Z pole run
B-field	3.0T	2.0T
Pad size (mm)/All channels	0.110mm×0.110mm /2×6×10^8 (TPX4)	0.110mm×0.110mm /2×6×10^8 (TPX4)
Material budget barrel	≃ 0.012 X_0	≃ 0.012 X_0
Material budget endcap	< 0.20 X_0	< 0.20 X_0
Points per track in rφ	22000	22000
σ_{point} in rφ	≤ 100µm (full drift)	? (full drift)
σ_{point} in rz	≃ 0.1 – 0.5 mm? (for zero – full drift)	? (for zero – full drift)
2-hit separation in rφ	< 0.5mm?	< 0.5mm?
K/π separation power @20GeV	≤ 3σ	≤ 3σ
Momentum resolution normalised: $\sigma_{1/pT} = \sqrt{a^2 + (b/pT)^2}$	a = 1.82 e -5	a = 3.32 e -5
	b = 0.60 e -3	b = 0.92 e -3

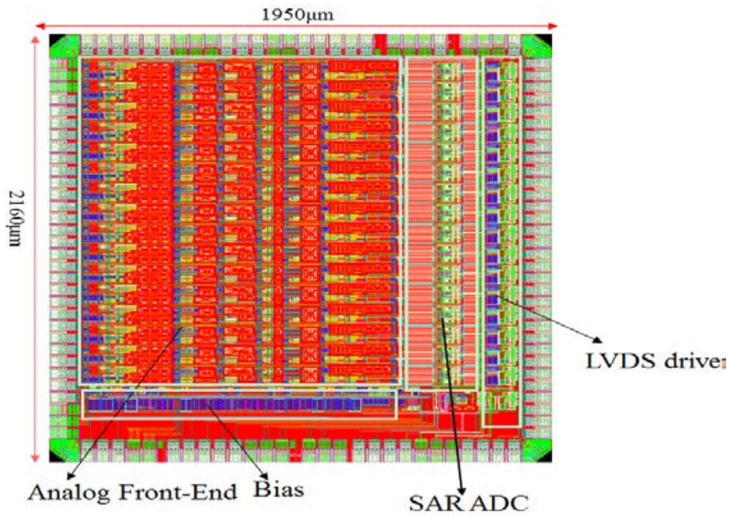
High granularity readout -3 @cosθ≃0.85

Parameters4	Higgs run	Z pole run
B-field	3.0T	2.0T
Pad size (mm)/All channels	0.5mm×0.5mm /2×3×10^7	0.5mm×0.5mm /2×3×10^7
Material budget barrel	≃ 0.012 X_0	≃ 0.012 X_0
Material budget endcap	< 0.20 X_0	< 0.20 X_0
Points per track in rφ	2200	2200
σ_{point} in rφ	≤ 100μm (full drift)	? (full drift)
σ_{point} in rz	≃ 0.1 – 0.5 mm? (for zero – full drift)	? (for zero – full drift)
2-hit separation in rφ	< 0.5mm?	< 0.5mm?
K/π separation power @20GeV	≤ 3σ	≤ 3σ
Momentum resolution normalised: $\sigma_{1/pT} = \sqrt{a^2 + (b/pT)^2}$	a = 1.82 e -5	a = 3.32 e -5
	b = 0.60 e -3	b = 0.92 e -3

Power Consumption – TPC

- **Power consumption relative with the high granularity readout**
  - Pad readout TPC@1mm×6mm@IHEP
  - Total channels: **10^6**
    - WASA ASIC chip: 3.5mW/ch@40 MS/s
  - High granularity readout TPC： **3×10^7**
  - Total power: **<10 kW**
    - **<100mW/cm^2**

	AGET	PASA+ALTRO	Super-ALTRO	SAMPA
TPC	T2K	ALICE	ILC	ALICE upgrade
Pad尺寸	6.9x9.7 mm^2	4x7.5 mm^2	1x6 mm^2	4x7.5 mm^2
通道数	1.25 x 10^5	5.7x 10^5	1-2 x 10^6	5.7 x 10^5
读出结构	MicroMegas	MWPC	GEM/MicroMegas	GEM
增益	0.2-17 mV/fC	12 mV/fC	12-27 mV/fC	20/30 mV/fC
成型方式	CR-(RC)^2	CR-(RC)^4	CR-(RC)^4	CR-(RC)^4
达峰时间	50 ns-1us	200 ns	30-120 ns	80/160 ns
ENC	850 e @ 200ns	385 e	520 e	482 e @ 180ns
波形采样方式	SCA	ADC	ADC	ADC
采样率	1-100 MSPS	10 MSPS	40 MSPS	10 MSPS
精度	12 bit(external)	10 bit	10 bit	10 bit
功耗	<10 mW/ch	32 mW/ch	47.3 mW/ch	17 mW/ch
CMOS工艺	350 nm	250 nm	130 nm	130 nm



Discussion

- Is it necessary to optimize the readout pad size to reach a reasonable readout number?
  - Power consumption relative with the high granularity readout
  - Amount output detector data relative with the high granularity readout
- Optimization performance of the reasonable readout TPC
  - PID requirements for both Higgs physics and Z-physics
  - All estimates should be based on available pixelated readout TPC techniques
    - Peter, Jochen, Jan …
  - How to contribute from LCTPC collaboration to CEPC Phy.&Det. TDR?

- Any comments or suggestions are welcomed.
- Discussion…

Many thanks!