CEPC Detector, Physics, Software: R&D, Collaboration and Future

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(for the Physics and Detector Working Group)

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Institute of High Energy Physics
Chinese Academy of Sciences

International Advisory Meeting Committee
Beijing, October 29, 2020

Physics progress

Re-evaluation of physics requirements

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E =$ $3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

under discussion → started at the workshop last year

Physics requirements

- **Jan 16-17, 2020: Mini-workshop: Software and Physics Requirements for e+e- Colliders**
  - http://iasprogram.ust.hk/hep/2020/workshop_experiment.php

Jan 16 (Thu) | Jan 17 (Fri)

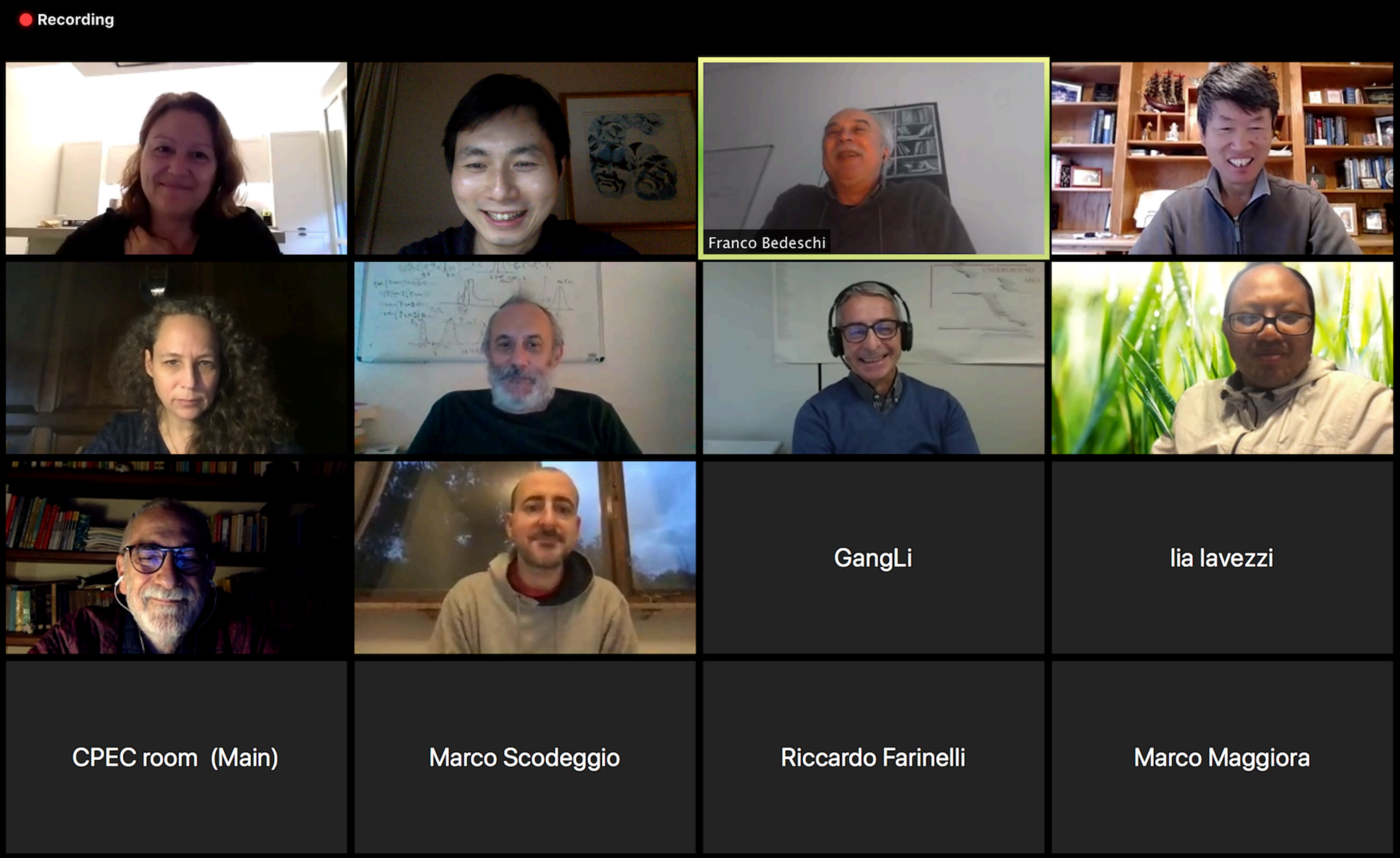
Time	Event
Session 1	**Chairs: Paolo GIACOMELLI and Joao GUIMARAES DA COSTA**
09:00 - 10:00	**Physics at a Circular Collider (sqrt(s) = 91-365 GeV) [Slides]** **Jiayin GU** *Johannes Gutenberg University Mainz*
10:00 - 10:30	**Discussion**
10:30 - 11:00	Group Photo and Coffee Break (Venue: Open Area, 1/F)
11:00 - 11:45	**Theoretical Tools [Slides]** **Alessandro VICINI** *University of Milan*
11:45 - 12:30	**ILC Detector Requirements [Slides]** **Jim BRAU** *University of Oregon*
12:30 - 14:00	Lunch (Self-arranged)
Session 2	**Chairs: Paolo GIACOMELLI and Joao GUIMARAES DA COSTA**
14:00 - 14:45	**CLIC Detector Requirements [Slides]** **Andre SAILER** *CERN*
14:45 - 15:25	**Tracking Requirements [Slides]** **Zhijun LIANG** *Institute of High Energy Physics, Chinese Academy of Sciences*
15:25 - 16:05	**Calorimeter Requirements [Slides]** **Yong LIU** *Institute of High Energy Physics, Chinese Academy of Sciences*
16:05 - 16:25	Coffee Break (Venue: Open Area, 1/F)
16:25 - 16:55	**Future Activities at FCC [Slides]** **Paolo GIACOMELLI** *National Institute for Nuclear Physics (INFN, Bologna)*
16:55 - 17:40	**Future Activities and Discussion [Slides]** **Moderators: Paolo GIACOMELLI, Joao GUIMARAES DA COSTA and Manqi RUAN**

Jan 16 (Thu) | **Jan 17 (Fri)**

Time	Event
Session 3	**Chairs: Paolo GIACOMELLI and Joao GUIMARAES DA COSTA**
09:00 - 09:10	**Introduction: Towards a Common Software for Future HEP Projects [Slides]** **Paolo GIACOMELLI** *National Institute for Nuclear Physics (INFN, Bologna)*
09:10 - 10:00	**The Turnkey Software Stack: Where Are We and Where We Want to Go? [Slides]** **Gerri GANIS** *CERN*
10:00 - 10:30	**EDM4hep: A Common Event Data Model [Slides]** **Frank GAEDE** *DESY*
10:30 - 11:00	Coffee Break (Venue: Open Area, 1/F)
11:00 - 11:50	**DD4hep and Shareable Detector Geometry Description [Slides]** **Andre SAILER** *CERN*
11:50 - 12:30	**CEPC Software Prototype [Slides]** **Jiaheng ZOU** *Institute of High Energy Physics, Chinese Academy of Sciences*
12:30 - 14:15	Lunch (Self-arranged)
Session 4	**Chairs: Paolo GIACOMELLI and Joao GUIMARAES DA COSTA**
14:15 - 14:50	**CEPC Simulation [Slides]** **Tao LIN** *Institute of High Energy Physics, Chinese Academy of Sciences*
14:50 - 15:20	**A Worldwide Software Collaboration? [Slides]** **David LANGE** *Princeton University*
15:20 - 15:50	Coffee Break (Venue: Open Area, 1/F)
15:50 - 16:45	**Future Software Implementations [Slides]** **Gerri GANIS, Xingtao HUANG and All**
16:45 - 17:15	**Wrap Up and Next Goals [Slides]** **Paolo GIACOMELLI and All**

Physics requirements

- Followed up at CEPC Workshop with a dedicated talk and discussion at Performance Session
  - https://indico.ihep.ac.cn/event/11444/session/10/contribution/199/material/slides/0.pdf



Work still to continue

Physics requirements: Higgs Factory

Manqi

- Jets (Hadronic system), Tracks, Isolated Lepton/Tau, Flavor Tagging
  - Hadronic system
    - The majority of Higgs events has jet final states; many important EW measurements relies on multi-jet processes.
    - BMR < 4%: to separate qqH signal from qqX background with recoil mass
      - Benchmarked with signal strength measurements at qqH, H→invisible, H→tautau, and vvH, H→bb (hadronic)
    - To investigate innovative color singlet identification algorithm (optimize jet clustering-matching or beyond)
      - Benchmarked with WW/ZZ separation with full hadronic final state
      - Benchmarked with signal strength measurements of H→hadronic final states (bb, cc, gg, WW/ZZ→4 jet) at qqH processes
  - Relative track momentum resolution ~ 0.1%:
    - Benchmarked with H→mumu signal strength, and Higgs mass measurement via Higgs recoil analysis with llH channel.
  - Isolated Leptons and taus;
    - Many benchmarks: Isolated leptons eff*purity > 99% (eff > 0.995%, mis-id < 1%);
    - Benchmarked with H→tautau: Isolated Tau finding eff*purity > 70%.
  - VTX: efficiently separate the b, c, and light jets.
    - eff*purity of c-tagging at H→jj events. Aim for eff*purity >> 10% (i.e. 25%?)
    - Benchmarked with H→cc & H→gg measurements;

Physics requirements: Z Factory

Manqi

- Z factory has extremely rich physics program, where a better detector is always better. More benchmark studies are needed, to quantify the Z factory potential & requirements.
- Detector acceptance: |cos(theta)| < 0.99, ... or better
- Tracks
  - Momentum threshold: ~o(100) MeV to find pions generated in D* decay (D*→D + pi)
  - Momentum resolution < 0.1%: Benchmarks? Narrow resonance generated at IP?
- Photons
  - Photons: ~o(100) MeV to find photons decay from low energy pi-0
  - Energy resolution < 5%/sqrt(E):
    - π^0 reco. Eff*purity ~50% at Z→qq events
    - Benchmarks: Bs→2π^0, what else?
- Separation: to count number of π^0 in the Z→ττ event
  - Separate photons from π^0 decay, with the energy of π^0 up to 30 GeV
  - Benchmark with tau decay Branching ratio measurements

- Separation: find objective particles inside jets
  - Tracks are usually well separated, while clusters can easily overlap with each other.
  - Jet lepton: identification performance usually degrades w.r.t. Isolated leptons. the detector separation capability should ensure the degrading is marginal.
  - Benchmark: measurement with neutral hadron (Klong, Neutron) in the final state
- Identification:
  - Leptons (in jet): benchmark with R_K & R_D, and LFV measurements.
  - Tau (in jet): i.e. Bc→τν, b→sττ analysis
  - Pion, Kaon&Proton: reco. eff*purity of objective particles decays into Kaon & proton final states (at IP, or decay from 2nd vertexes...).
    - D, Lambda_c, Lambda, Ds reconstruction require 3σ pi-kaon separation
    - Need dedicated benchmark analyses
  - Jet charge measurements for c/b-jets

20/10/2020

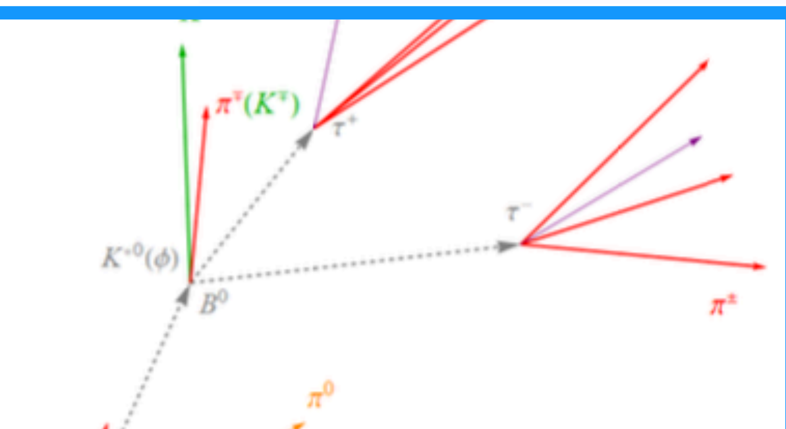
$$R_{D^{(*)}} \equiv \frac{\mathrm{BR}(B \to D^{(*)}\tau\nu)}{\mathrm{BR}(B \to D^{(*)}\ell\nu)}, \quad \ell = e,\, \mu$$

$$R_{K^{(*)}} \equiv \frac{\mathrm{BR}(B \to K^{(*)}\mu^+\mu^-)}{\mathrm{BR}(B \to K^{(*)}e^+e^-)}$$

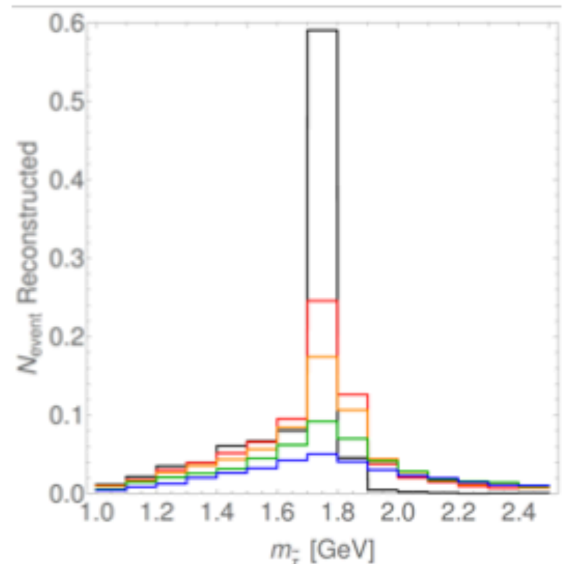
7

Vertex —>

- Understand the correlation between
  - VTX intrinsic performance
  - 2nd/3rd vertex reconstruction performance: efficiency/purity, and position resolution as a function of the vertex charge multiplicity & polar angle
  - Flavor tagging performance
  - Detailed performance study is needed!
- Distinguish different vertexes
  - b→B*(PV)→B→D*(2nd V)→D(3rd V)→...
  - b→τ+X, π+X
- Reconstruct accurately the decay vertex, such that the tau mass can be reconstructed in b→sττ event



Reconstructed tau mass
With VTX position resolution
Of 1, 2, 5, 10 μm



Physics at near the top threshold

Led by Yaquan Fang

Physics potential for top threshold run at e+e- collider

chaired by Yaquan FANG Yaquan (高能所)

from Tuesday, December 17, 2019 at **21:00** to Wednesday, December 18, 2019 at **00:15** (Asia/Shanghai)

Vidyo Info

Room Name	videocepc
Link	http://vidyo.ihep.ac.cn/flex.html?roomdirect.html&key=v5kJiddnOG5xmy1Ipns1iccuxo
Extension	
PIN	1234

Tuesday, December 17, 2019

21:00 - 21:20 introduction *20'*
Speaker: Prof. Yaquan FANG Yaquan (高能所)
Material: Slides

21:20 - 21:40 top measurement at LHC *20'*
Speaker: Jin Wang (IHEP)
Material: Slides

21:40 - 22:00 top mass measurement *20'*
Speaker: Prof. Zhijun Liang (IHEP)
Material: Slides

22:00 - 22:20 top coupling measurement et al. *20'*
Speaker: Dr. Zhen Liu (University of Maryland)
Material: Slides

22:20 - 22:40 top EFT *20'*
Speaker: Cen Zhang
Material: Slides

22:20 - 22:40 top EFT *20'*
Speaker: Cen Zhang
Material: Slides

22:40 - 23:00 Higgs measurement with top run *20'*
Speaker: Kaili Zhang (IHEP)
Material: Slides

23:00 - 23:20 Higgs EFT at top run *20'*
Speaker: Dr. Jiayin Gu (JGU Mainz)
Material: Slides

23:20 - 23:40 2HDM related new physics at 360 GeV *20'*
Speaker: Prof. Shufang Su (University of Arizona)
Material: Slides

23:40 - 00:00 GM model at 360 GeV run *20'*
Speaker: Dr. Yongcheng Wu (Carleton University)
Material: Slides

Scan top threshold for top mass/width measurement
Run at higher energy ~360 GeV for Higgs and new Physics

Physics at near the top threshold

Led by Yaquan Fang

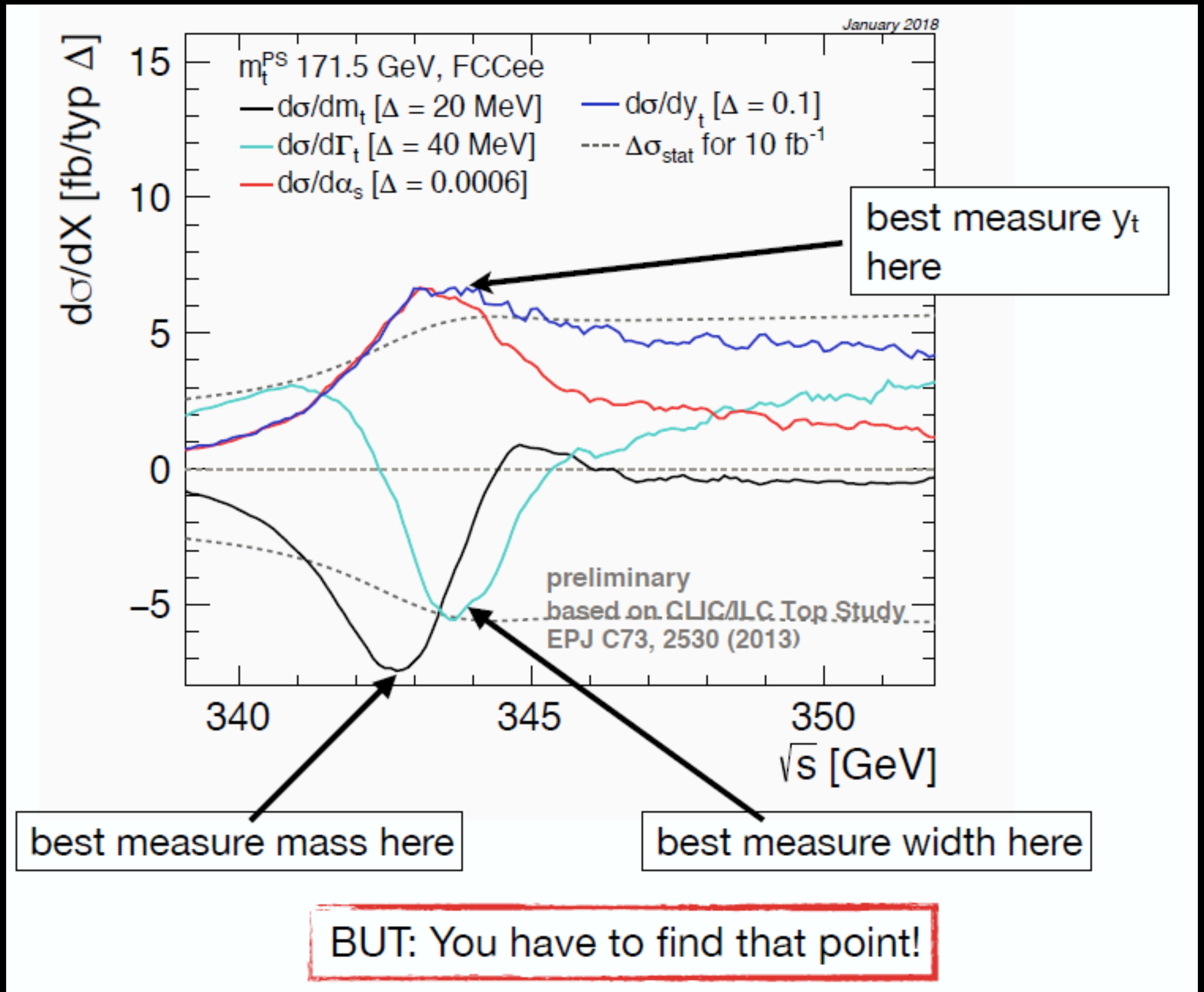
- The target accuracy of e^+e^- for top mass measurement is O(10) MeV and in a model independent way with luminosity around 200-400 fb^{-1}
  - with optimized setup: ~ 1 year of running (~480 fb^{-1}/year)

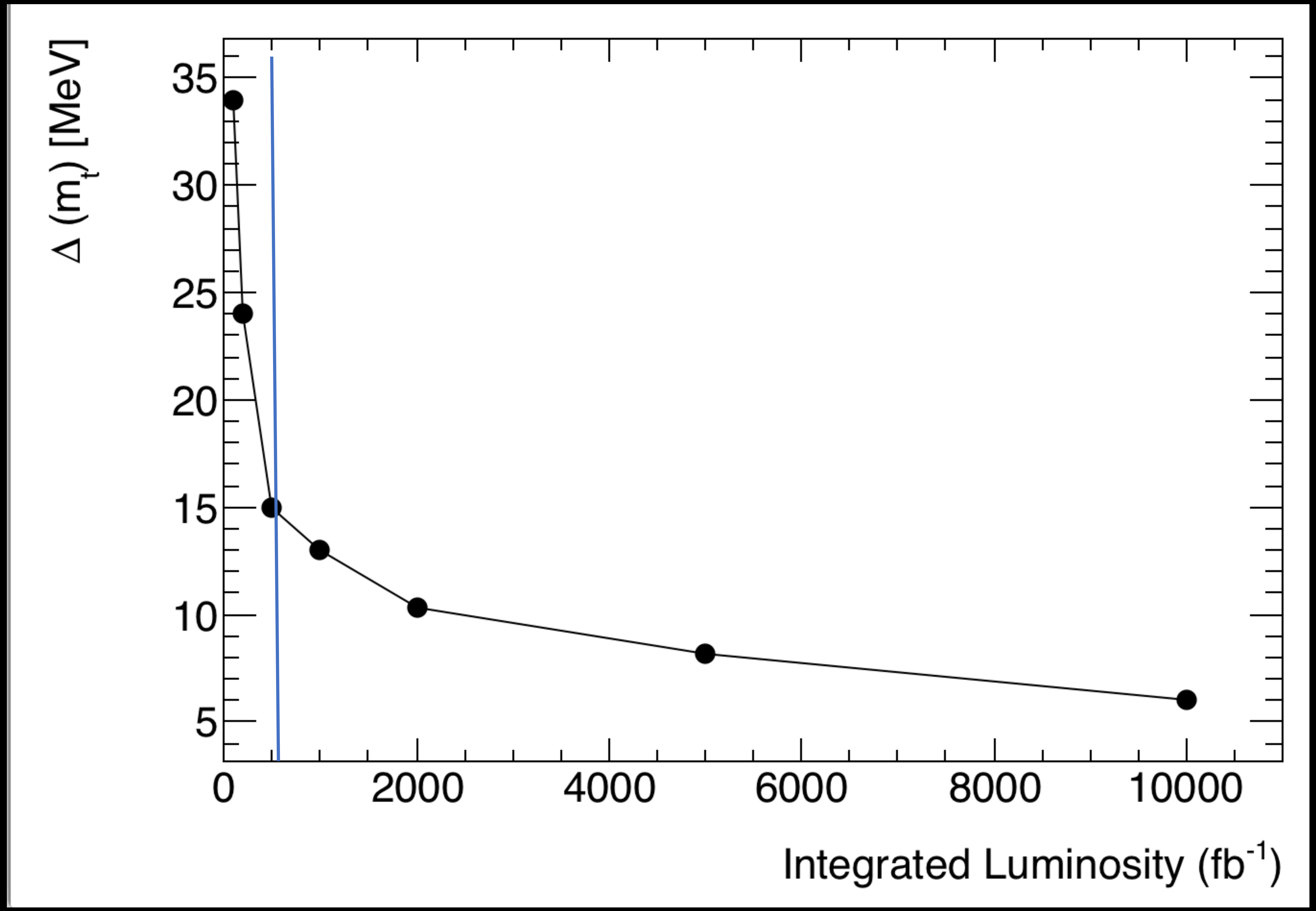
- Considering the run for top coupling measurement at CEPC, 360 GeV should be enough
  - Need to investigate the feasibility of running with a lower energy
  - The expected precision for the coupling is much better than LHC
  - 2 ab^{-1} luminosity corresponds to 4-5 years with optimized setup

- 360 GeV run is helpful for the Higgs width measurement
  - The results are not much different from the running at 365 GeV

- Some thoughts on new physics with 360 GeV have been addressed
  - 2HDM, Georgi-Machacek (GM) models, H—>sh (2HDM+S)

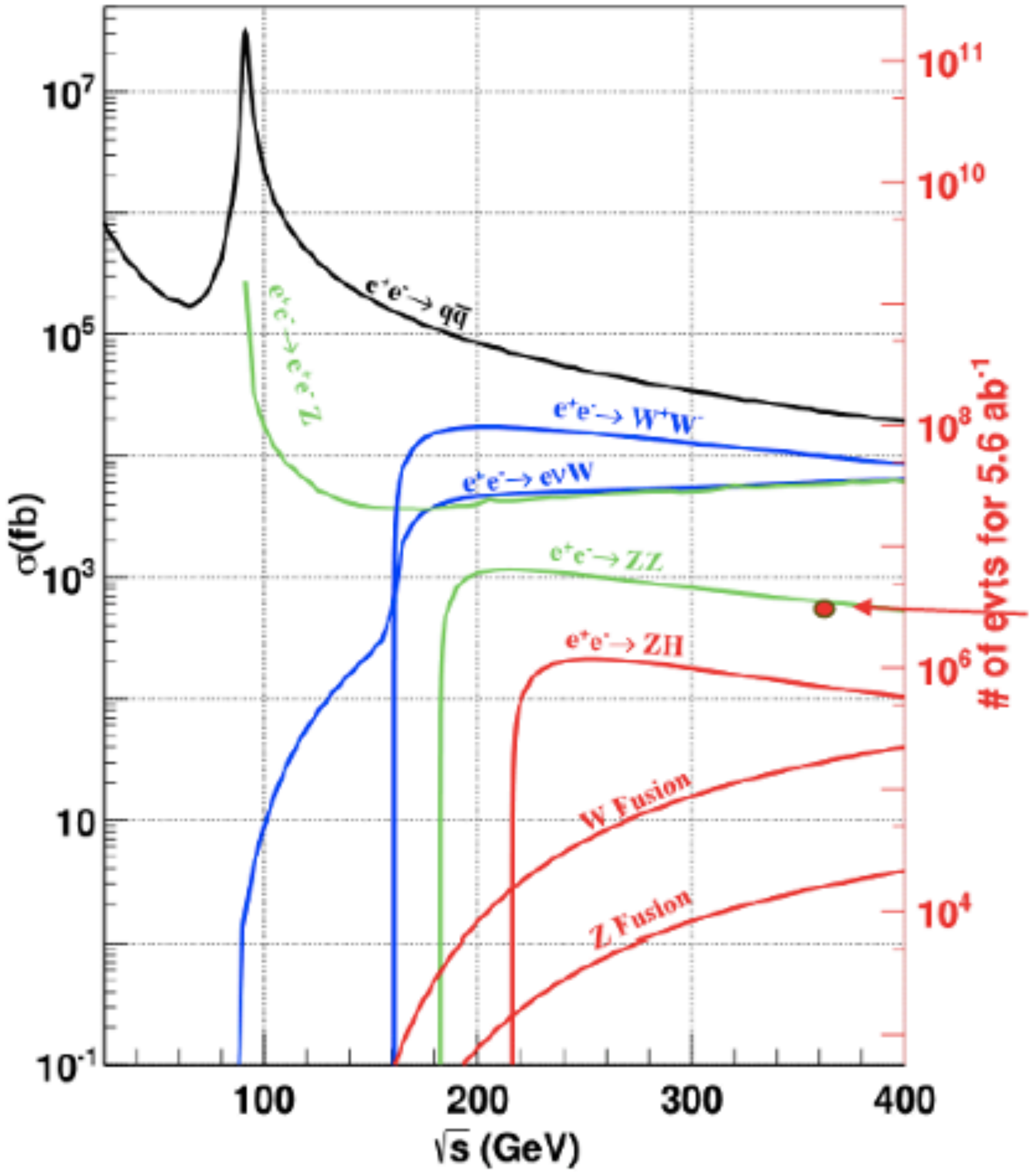
Top mass measurements





- Typically: 10 points (1 GeV step) are scanned with a global fit to measure top mass
- More aggressively, 4 energy points can be scanned to fit the mass
  - A pre-scan (e.g. 30% of data) can help determine the central point
  - Need to study which scanning points are the most sensitive

Additional sensitivity on Higgs measurements



	240GeV, 5.6ab^{-1}	360GeV, 2ab^{-1}	
	ZH	ZH	vvH
any	**0.50%**	**1%**	\
$H \to bb$	**0.27%**	**0.63%**	**0.76%**
$H \to cc$	**3.3%**	**6.2%**	**11%**
$H \to gg$	**1.3%**	**2.4%**	**3.2%**
$H \to WW$	**1.0%**	**2.0%**	**3.1%**
$H \to ZZ$	**5.1%**	**12%**	**13%**
$H \to \tau\tau$	**0.8%**	**1.5%**	**3%**
$H \to \gamma\gamma$	**5.4%**	**8%**	**11%**
$H \to \mu\mu$	**12%**	**29%**	**40%**
$\mathrm{Br_{upper}}(H \to \mathrm{inv.})$	**0.2%**	\	\
$\sigma(ZH) * \mathrm{Br}(H \to Z\gamma)$	**16%**	**25%**	\
Width	**2.9%**		
Combined Width 240/360	**1.4%**		

Fcc-ee 240 GeV/365 GeV:
CERN-ACC-2018-0057

$\sqrt{s}$ (GeV)	240		365	
Luminosity (ab^{-1})	5		1.5	
$\delta(\sigma BR)/\sigma BR$ (%)	HZ	$\nu\bar{\nu}$ H	HZ	$\nu\bar{\nu}$ H
$H \to$ any	±0.5		±0.9	
$H \to b\bar{b}$	±0.3	±3.1	±0.5	±0.9
$H \to c\bar{c}$	±2.2		±6.5	±10
$H \to gg$	±1.9		±3.5	±4.5
$H \to W^+W^-$	±1.2		±2.6	±3.0
$H \to ZZ$	±4.4		±12	±10
$H \to \tau\tau$	±0.9		±1.8	±8
$H \to \gamma\gamma$	±9.0		±18	±22
$H \to \mu^+\mu^-$	±19		±40	
$H \to$ invisible	< 0.3		< 0.6	

combined width: 1.3%

No significant difference between 360 GeV and 365 GeV

Flavor Physics

Some progress since CDR — 2 sessions at workshop — 9 talks

Particle	@ Tera-Z	@ Belle II		@ LHCb
$\boldsymbol{b}$ **hadrons**				
B^+	2×10^{10}	3×10^{10}	$(50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S))$	3×10^{13}
B^0	2×10^{10}	3×10^{10}	$(50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S))$	3×10^{13}
B_s	7×10^{9}	3×10^{8}	$(5\,\mathrm{ab}^{-1}$ on $\Upsilon(5S))$	8×10^{12}
b baryons	3×10^{9}			1×10^{13}
Λ_b	3×10^{9}			1×10^{13}

vs Belle II: b baryons, Λ_b, 100x B_s
vs LHCb: low bkg→neutrals (γ, π_0,…)

Unique sensitivity to processes unavailable at LHCb or Belle II: flavor-violating Z decays*, lepton universality in Z decays*, rare b→sττ decays, rare b→sνν decays, B_c decays*, semi-tauonic b→cτν decays, τ decays, FCNC single top.

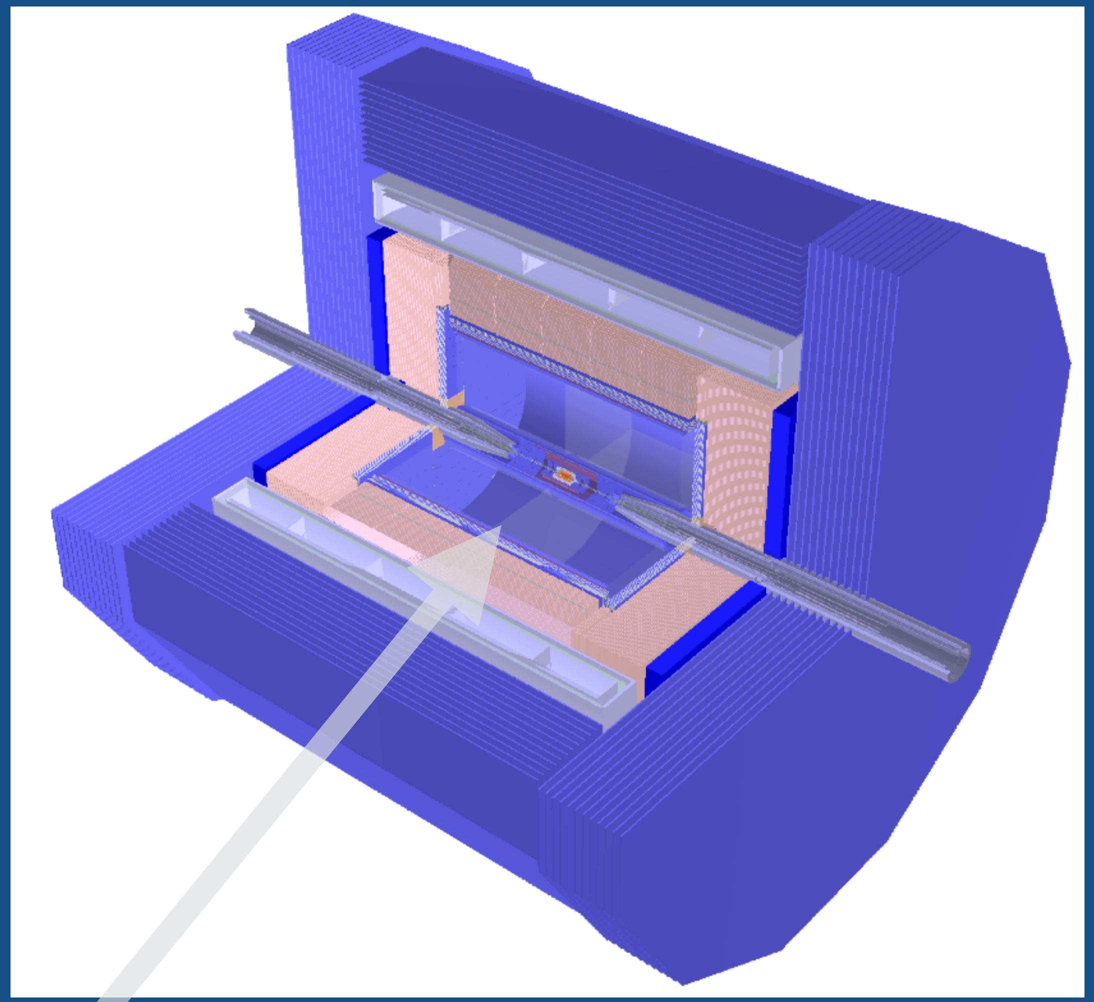
Detector prototypes progress

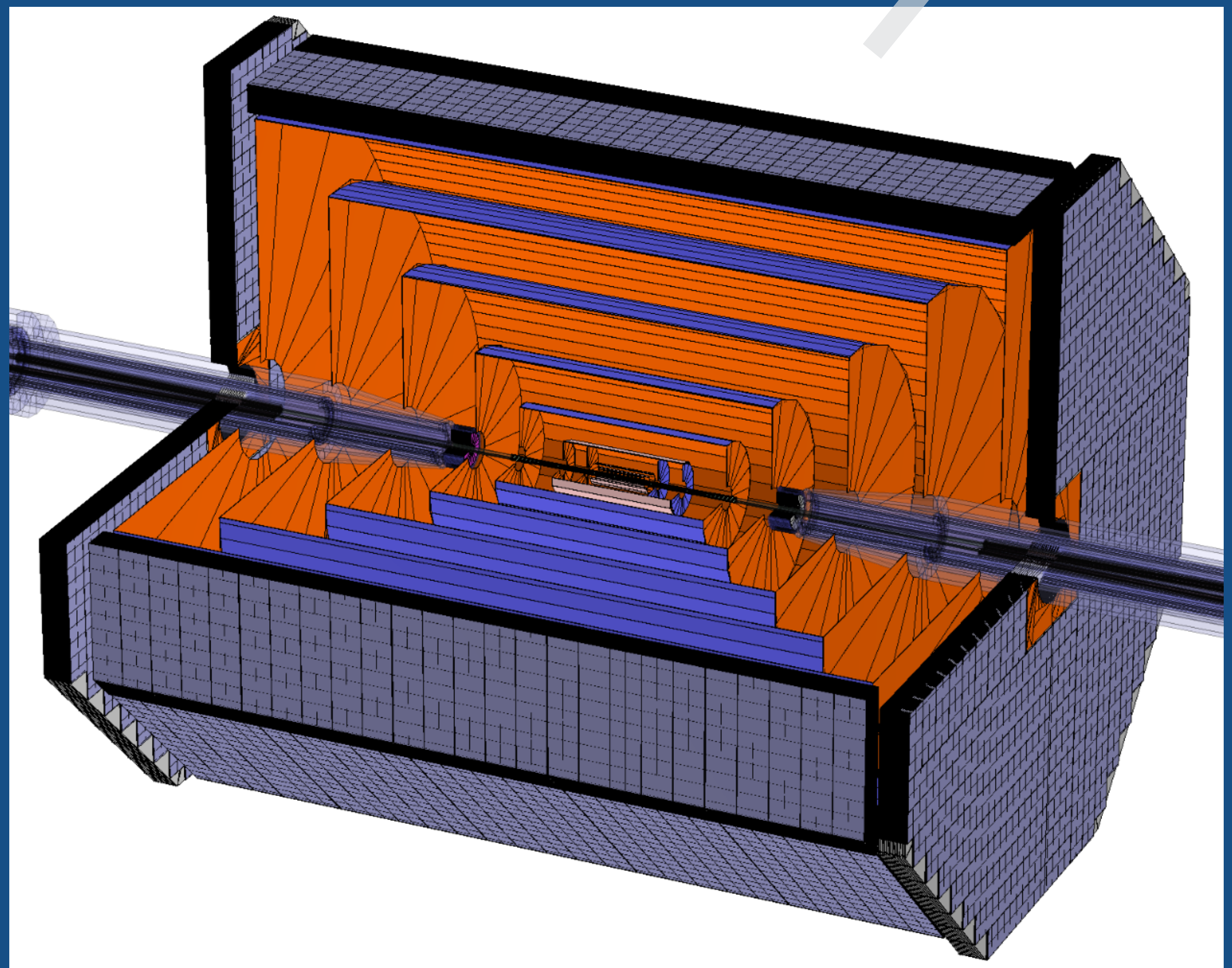
CEPC Detector Concepts studied

2 interaction points

Particle Flow Approach

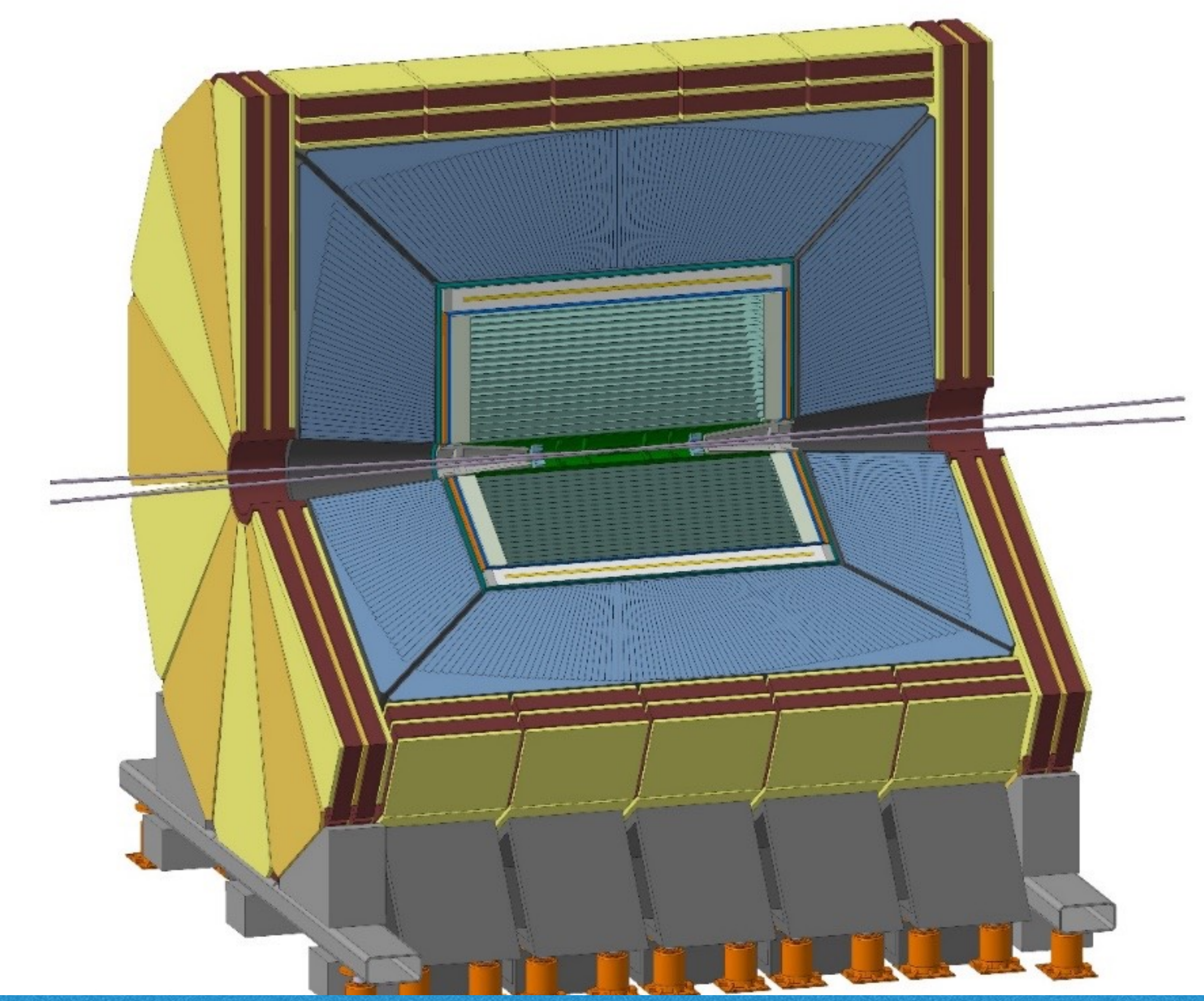
High magnetic field concept (3 Tesla)





Full silicon tracker concept

Low magnetic field concept (2 Tesla)



IDEA Concept

also proposed for FCC-ee

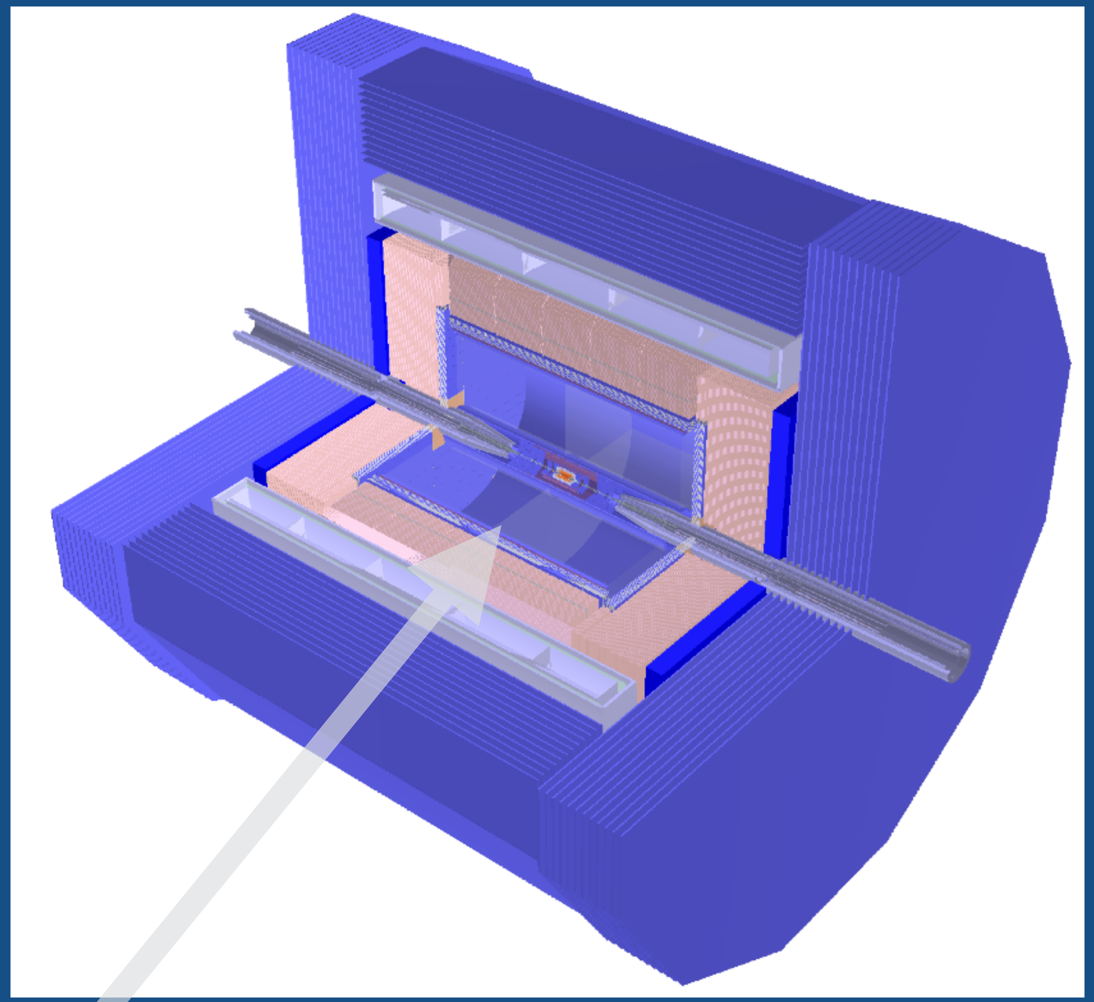
Final two detectors WILL be a mix and match of different options

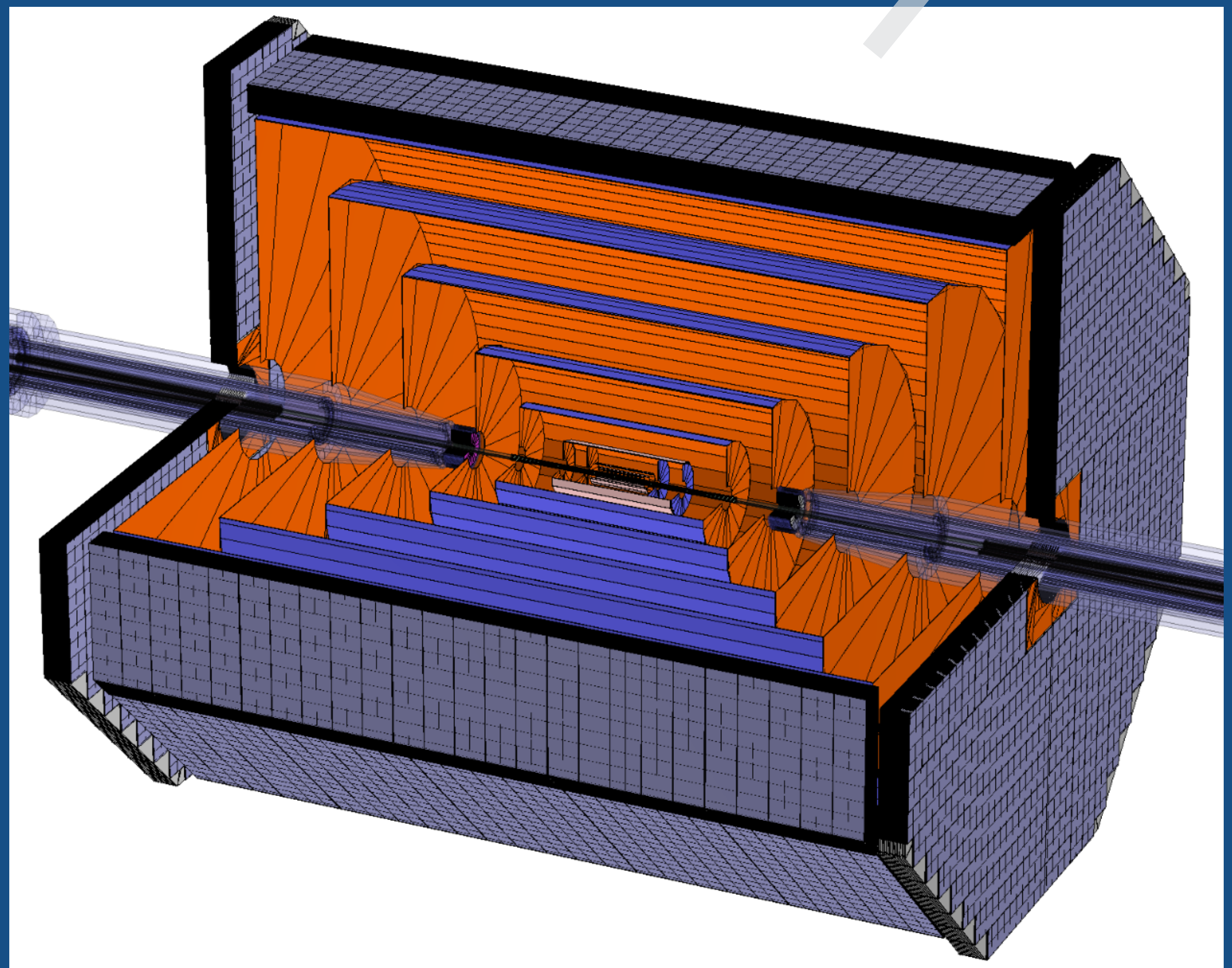
CEPC Detector Concepts studied

2 interaction points

Particle Flow Approach

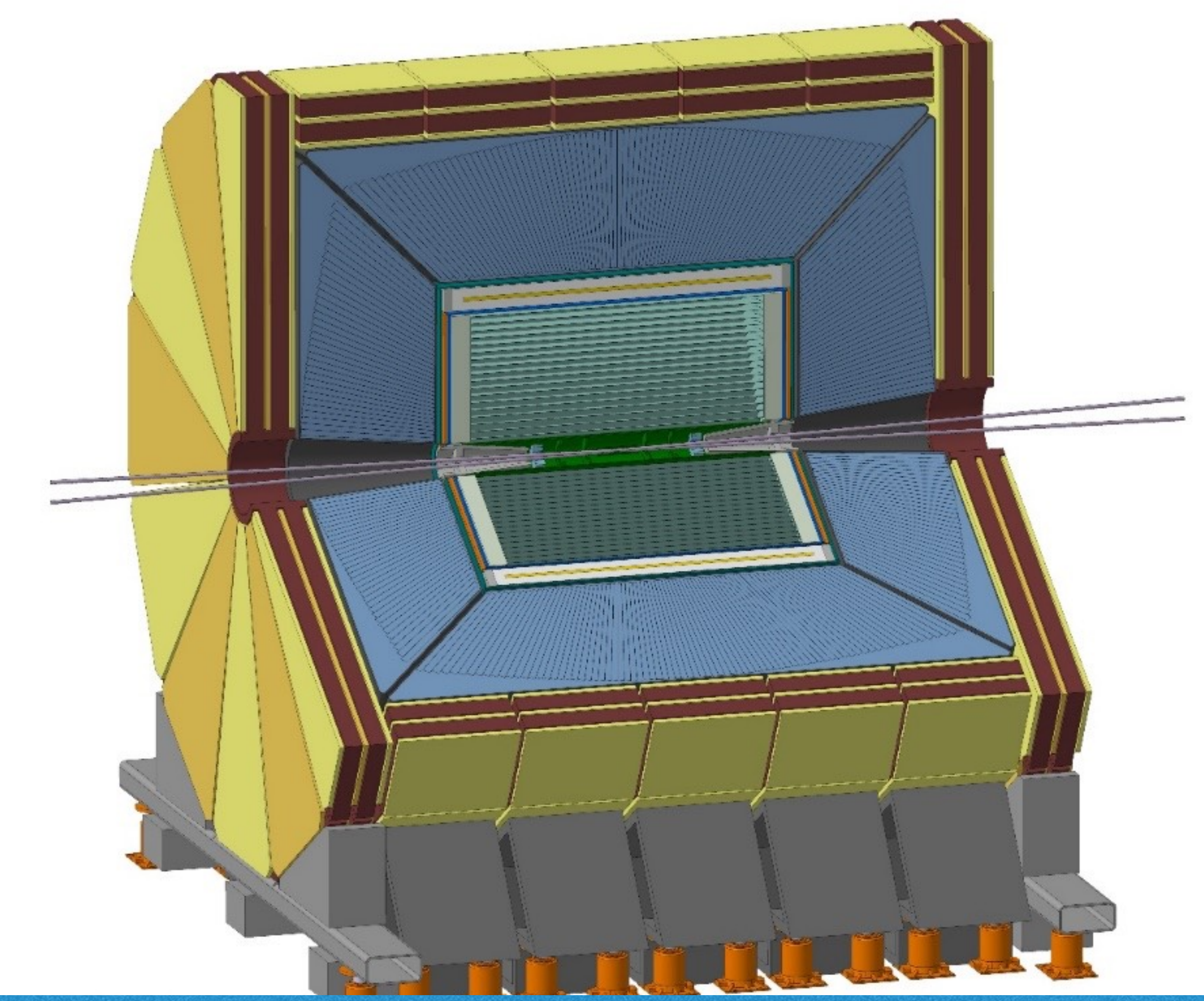
High magnetic field concept (3 Tesla)





Full silicon tracker concept

Low magnetic field concept (2 Tesla)



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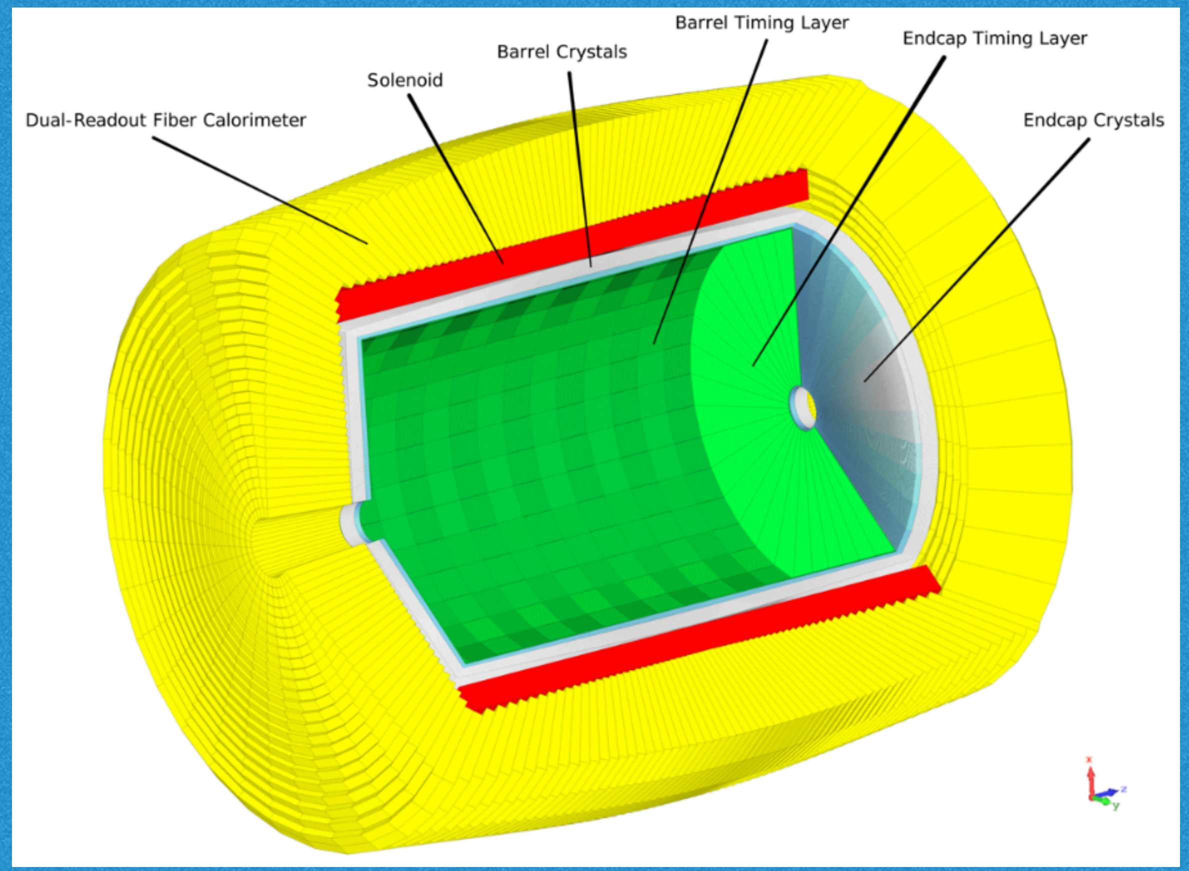


Crystal Calorimeter based detector (2-3 Tesla)

News reported at this conference

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

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

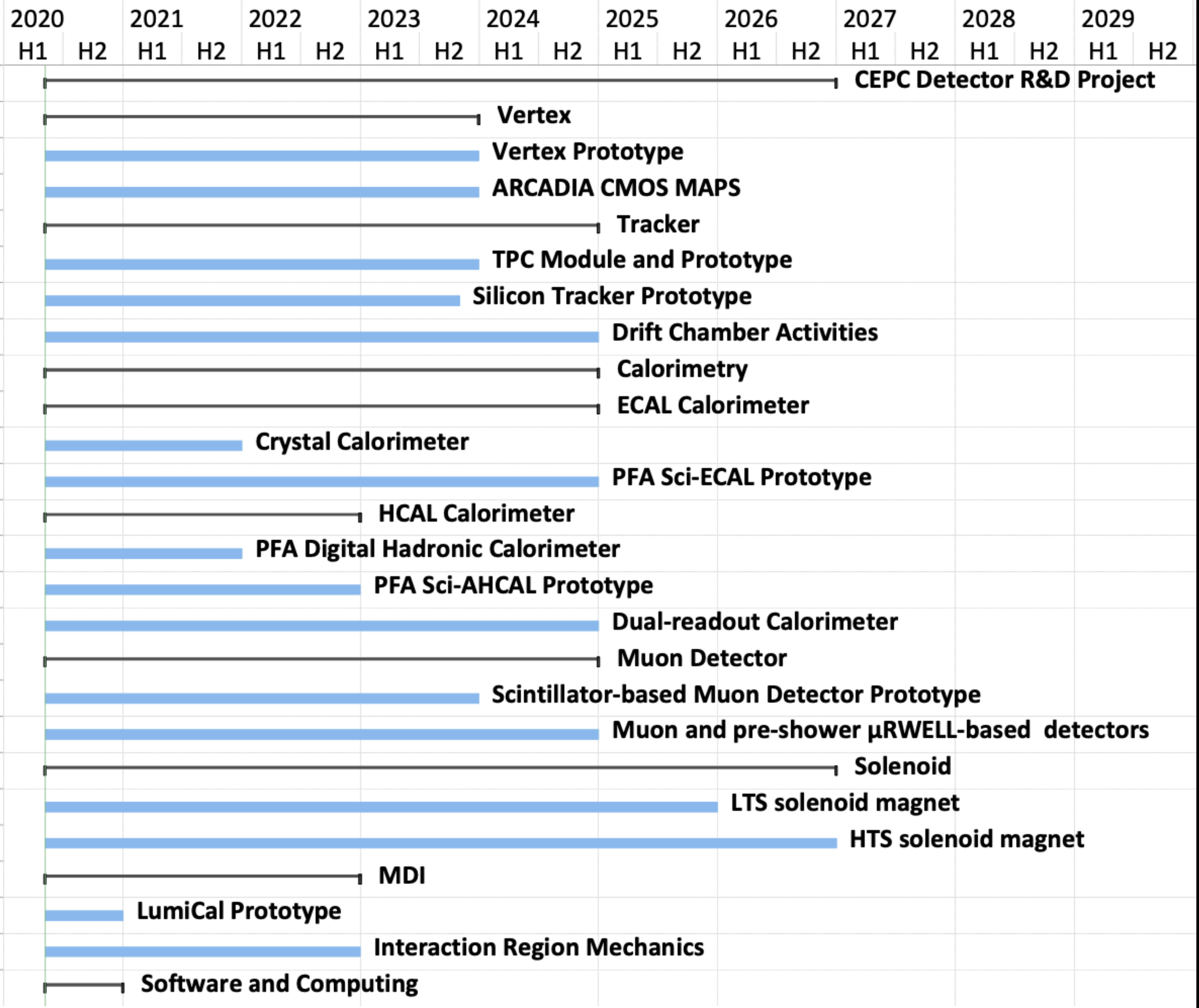
Total subtasks: 95

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**
3.1.1	Crystal Calorimeter	21/12/31
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**

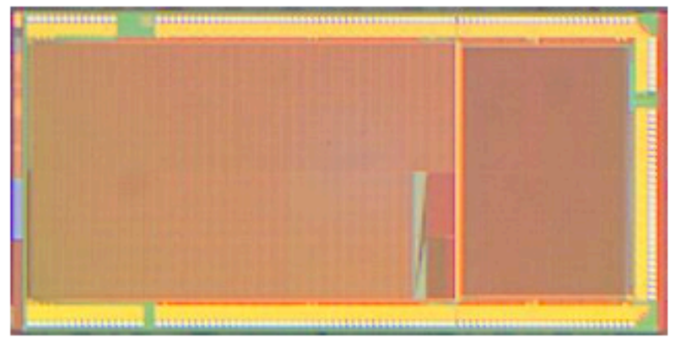


CEPC CMOS Pixel Sensor Development

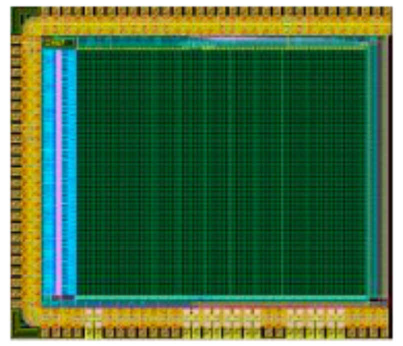
	JadePix1 (2015)	JadePix2 (2017)	MIC4	JadePix3 (2019)
Architecture	Roll. Shutter + Analog output	Roll. Shutter + In pixel discri.	Data-driven r.o. + In pixel discri.	Roll. shutter + end of col. priority encoder
Pitch (μm^2)	33 × 33 /16 × 16	22 × 22	25 × 25	16 × 26 16 × 23.11
Power con. (mW/cm^2)	--	--	150	~ 55*
Integration time (μs)*	--	40-50	~3	~100
Prototype size (mm^2)	3.9 × 7.9 (36 individual r.o)	3 × 3.3	3.1 × 4.6	10.4 × 6.1
Main goals	Sensor optimization	Small binary pixel	Small pixel + Fast readout+ nearly full functional	Smaller pixel + Low power + fully functional

* Assuming a matrix of 512 ×1024 pixels

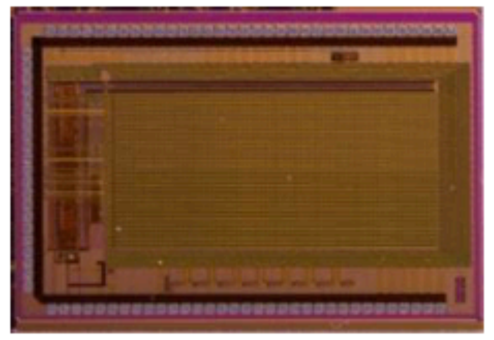
All prototypes in TowerJazz 180 nm process



JadePix1 (IHEP)



JadePix2 (IHEP)



MIC4 (CCNU & IHEP)

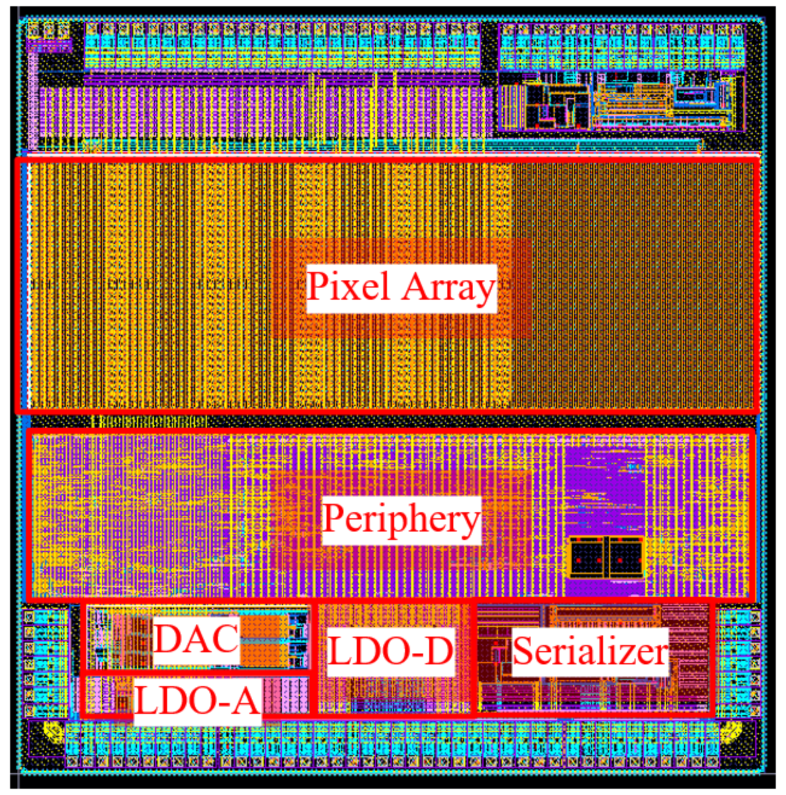
JadePix3 (IHEP, CCNU, Dalian Minzu Unv., SDU)

TaichuPix-1 tested

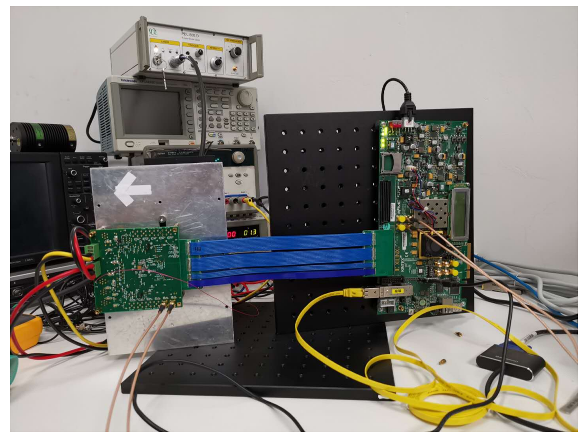
TaichuPix-2 produced

Pitch: 24 × 25 μm^2

Power: 130 mW/cm^2

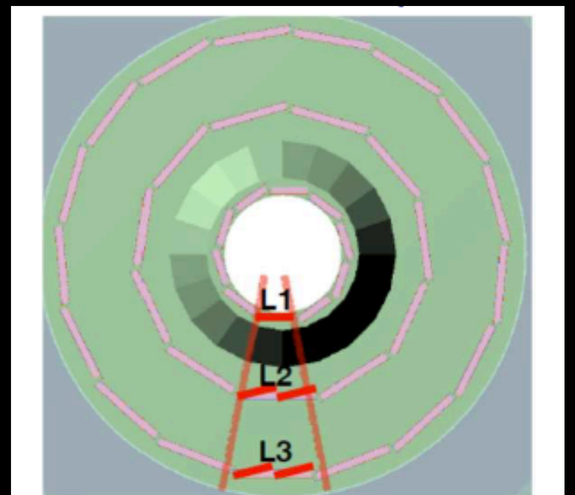


- 64×192 pixel array with the same dimension as TaichuPix-1
  - 32 double column modified FE-I3 readout, 32 modified ALPIDE readout
  - 6 variations of pixel analog design, each with 16 columns
- New features added to TaichuPix-2
  - Two LDOs for power supplies
  - 8b10b encoder added for Triggerless output and balanced data stream
  - X-chip buses added for multiple chip interconnections



- Test status: functional verification completed (I/O, bandgap, PPL …), more detailed tests on-going

IHEP, SDU, NWPU, IFAE & CCNU

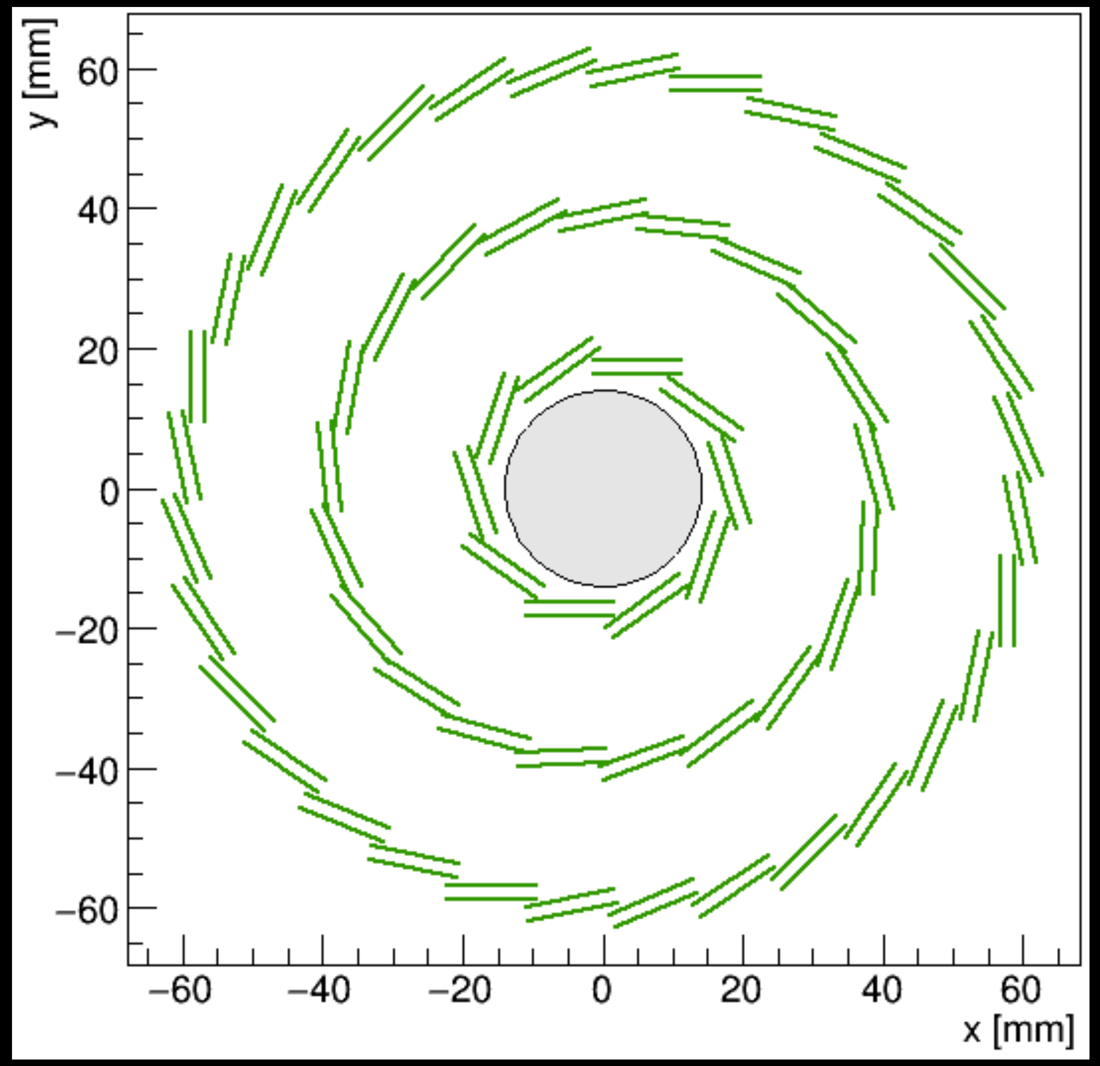


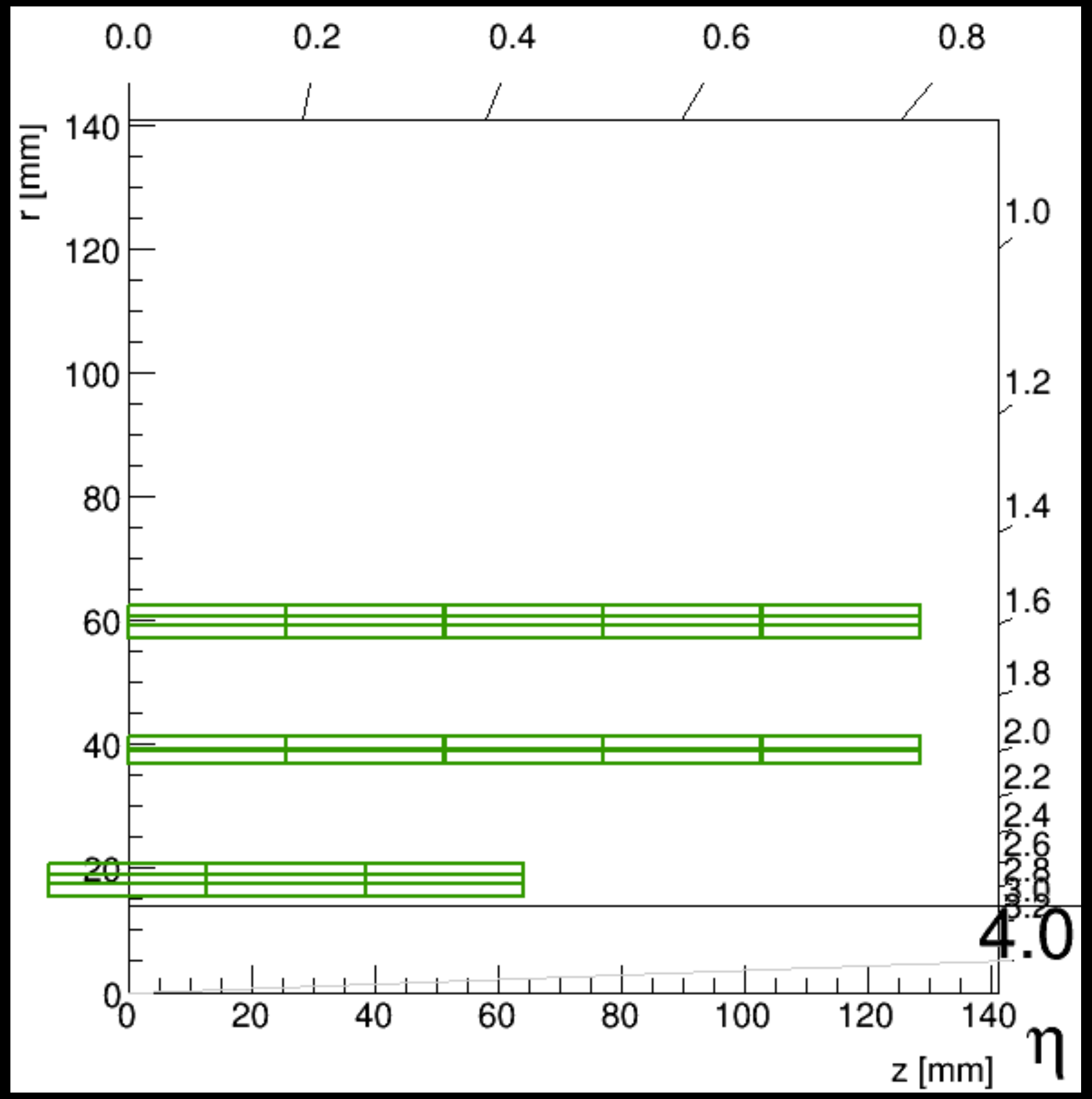
Full size prototype to be built

All required functionality already included

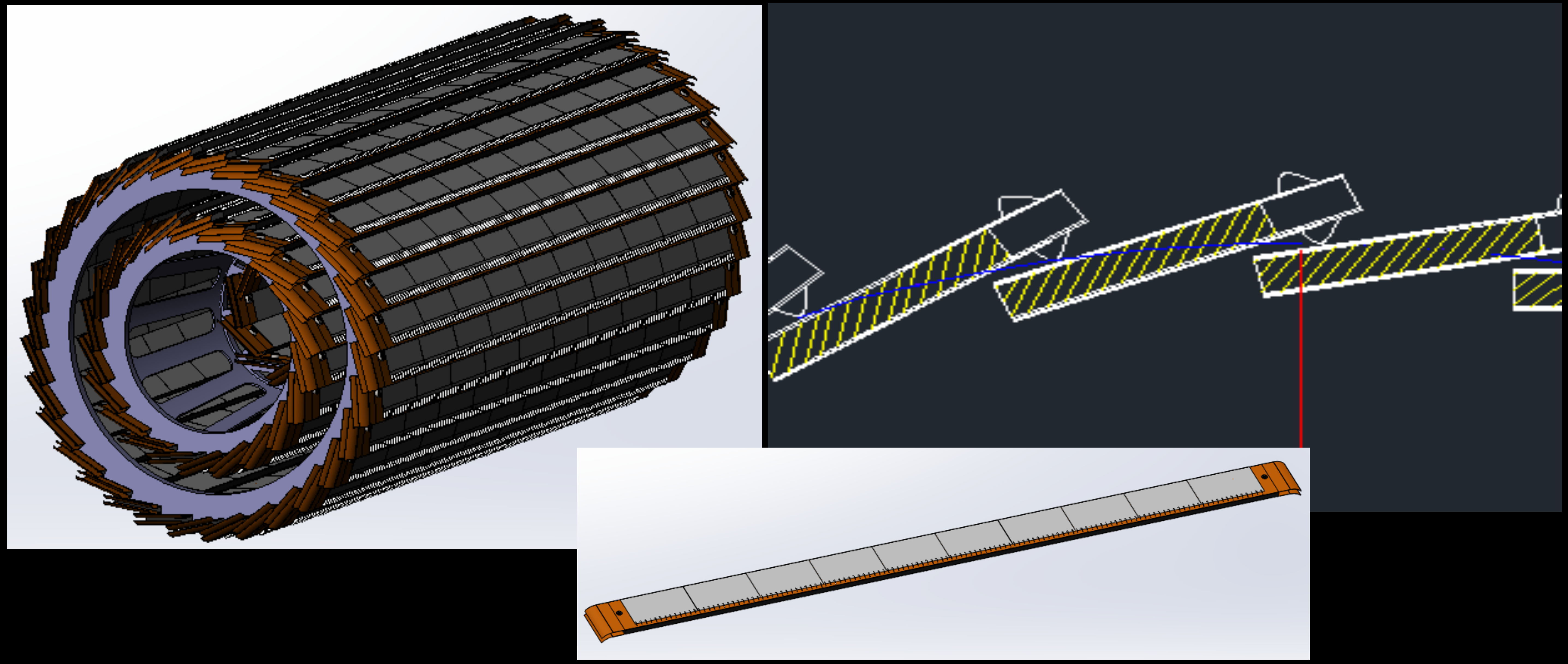
Pixel Vertex Detector Prototype

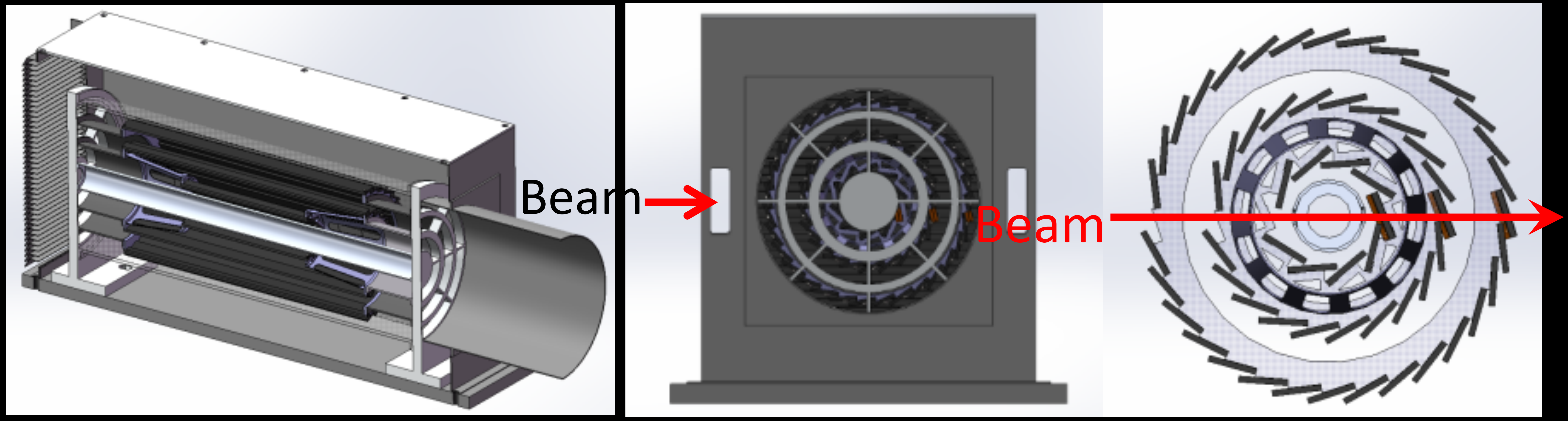
Layout optimization finalized





Engineering design on-going





Beampipe design

Ruiqiang Zhang, et al

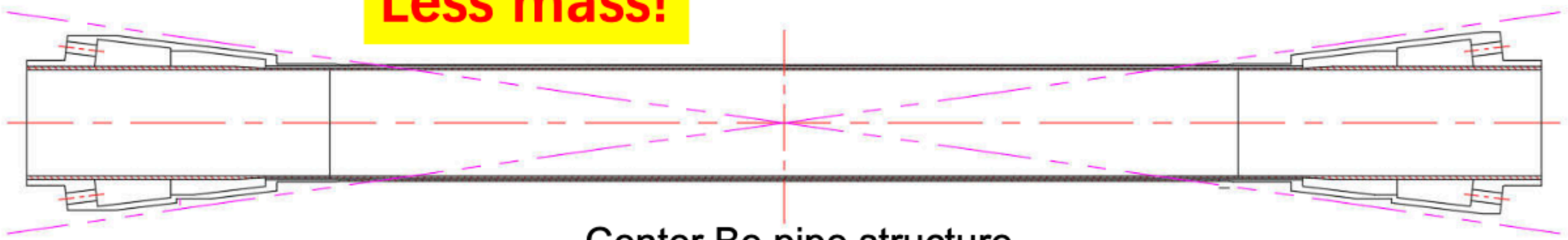
2.1 Be pipe

Based on the current domestic manufacturing capability, it is possible to manufacture the thin-wall beryllium pipe with wall thickness of **0.15mm and inner diameter of 20mm.**

Less mass!

Difficulties of manufacturing:

To meets the requirements of length(150mm), strength, stiffness and ultra-high vacuum.



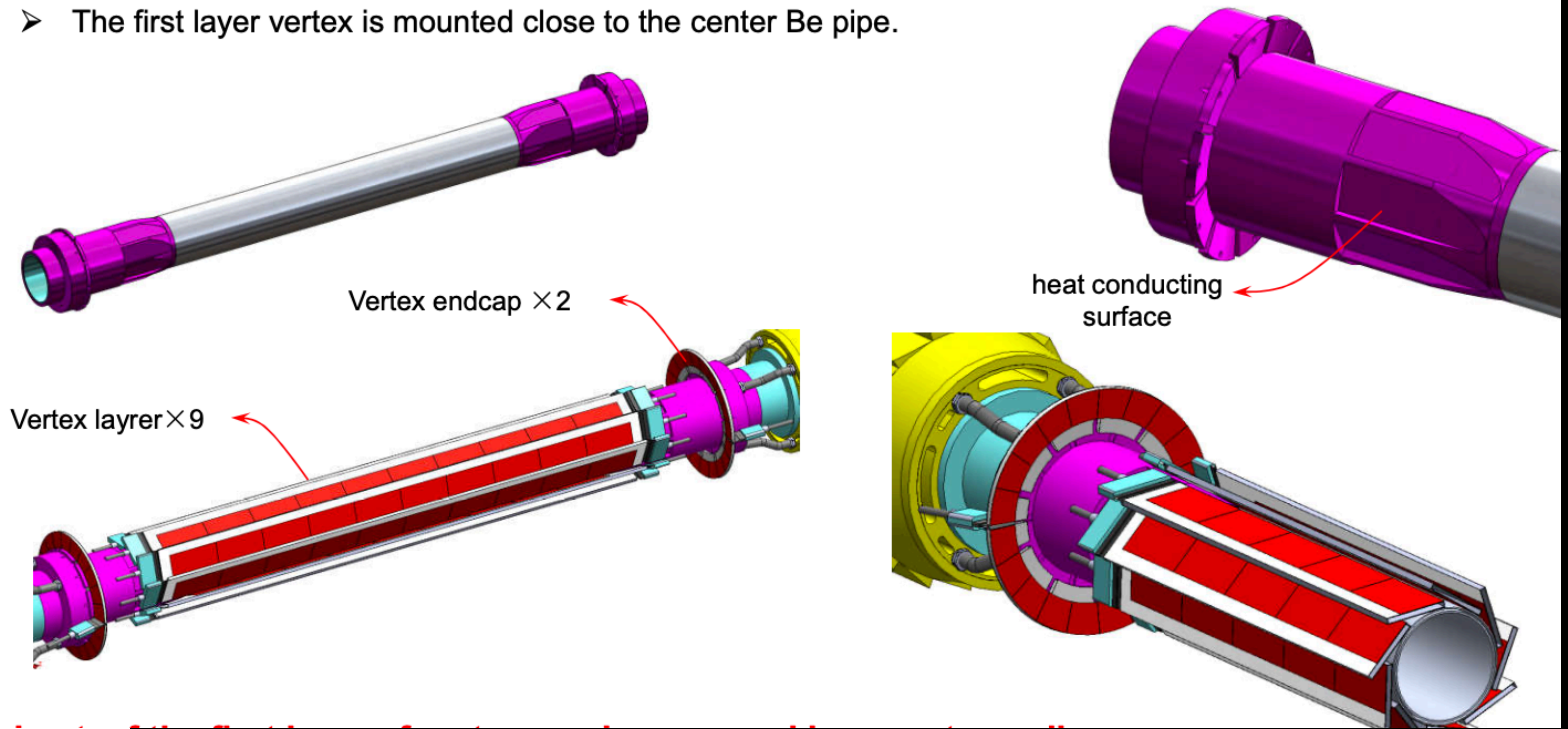
Center Be pipe structure

The critical pressure contrast of Be pipe with different wall thickness

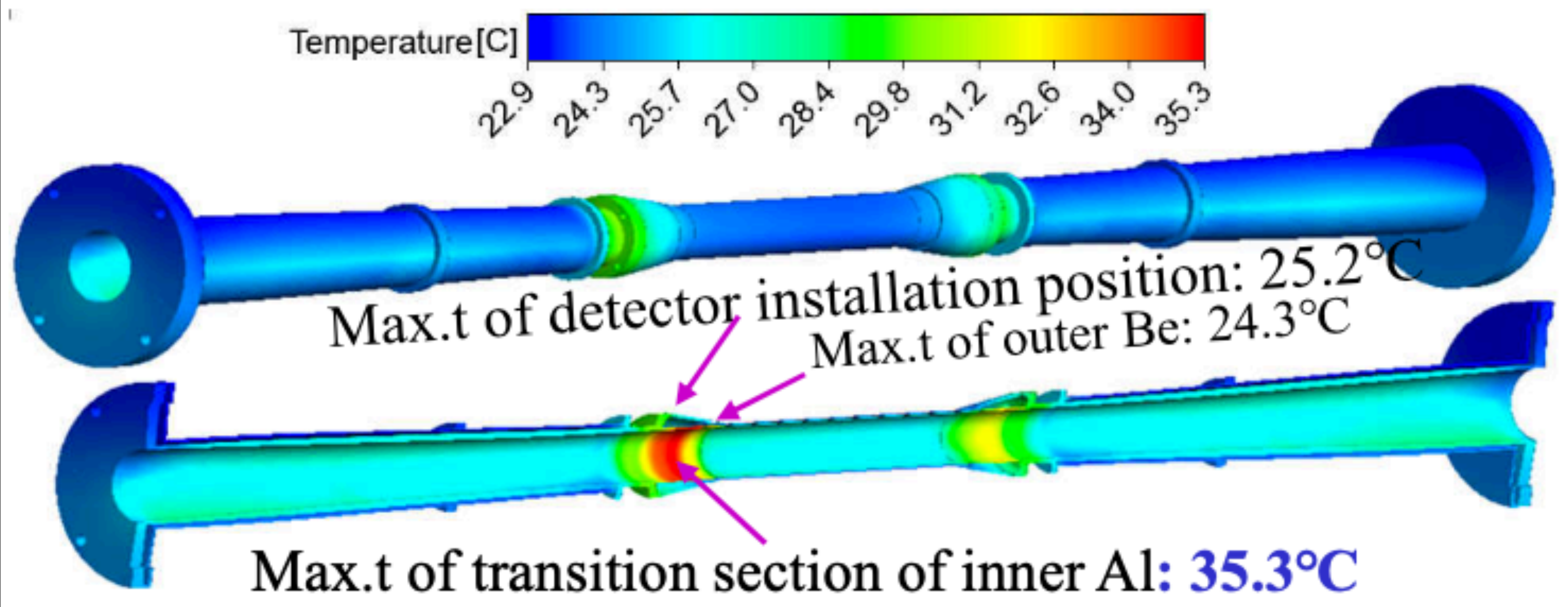
Version	Name	Wall thickness (mm)	Inside radius (mm)	External radius (mm)	Critical pressure (MPa)	Gap(coolant)
Previous design	Inner Be pipe	0.5	14	14.5	3.3053	0.5mm (Between inner and outer Be pipe)
	Outer Be pipe	0.35	15	15.35	0.9388	
New design	Inner Be pipe	0.2	10	10.2	0.5941	
	Outer Be pipe	0.15	10.7	10.85	0.2064	

2.2 Structure for detectors installation and cooling ---Vertex

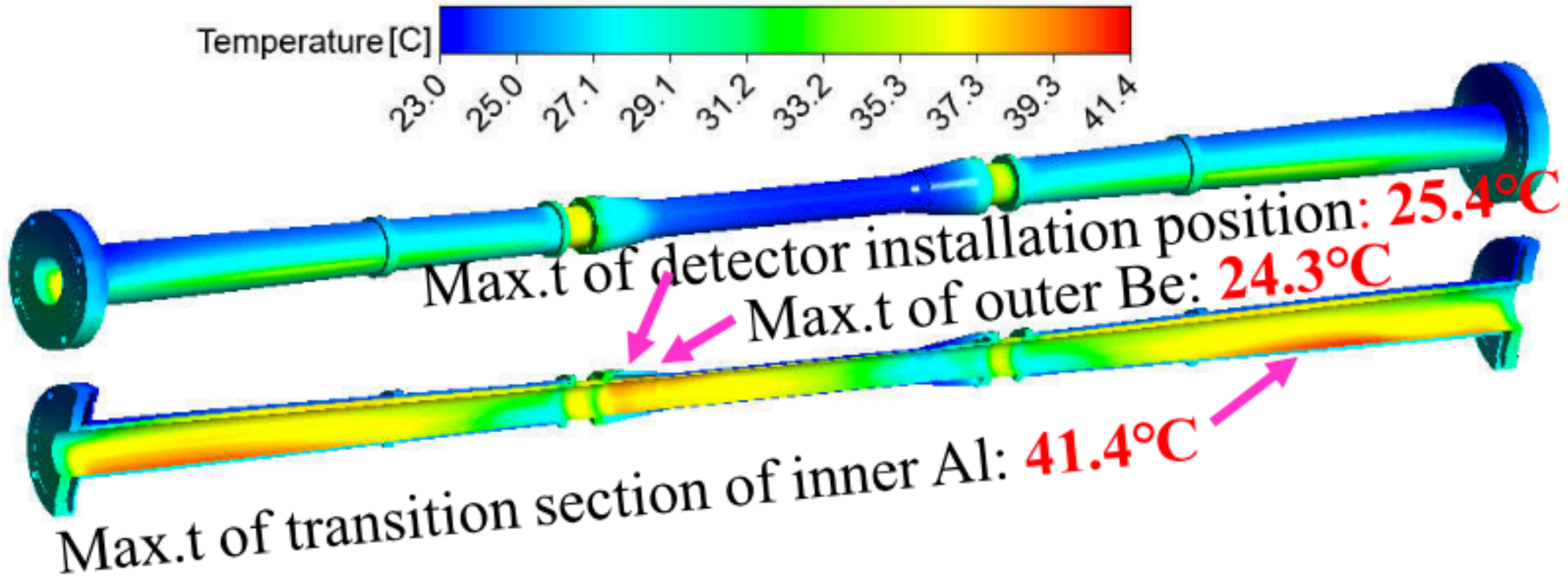
- The first layer vertex is mounted close to the center Be pipe.



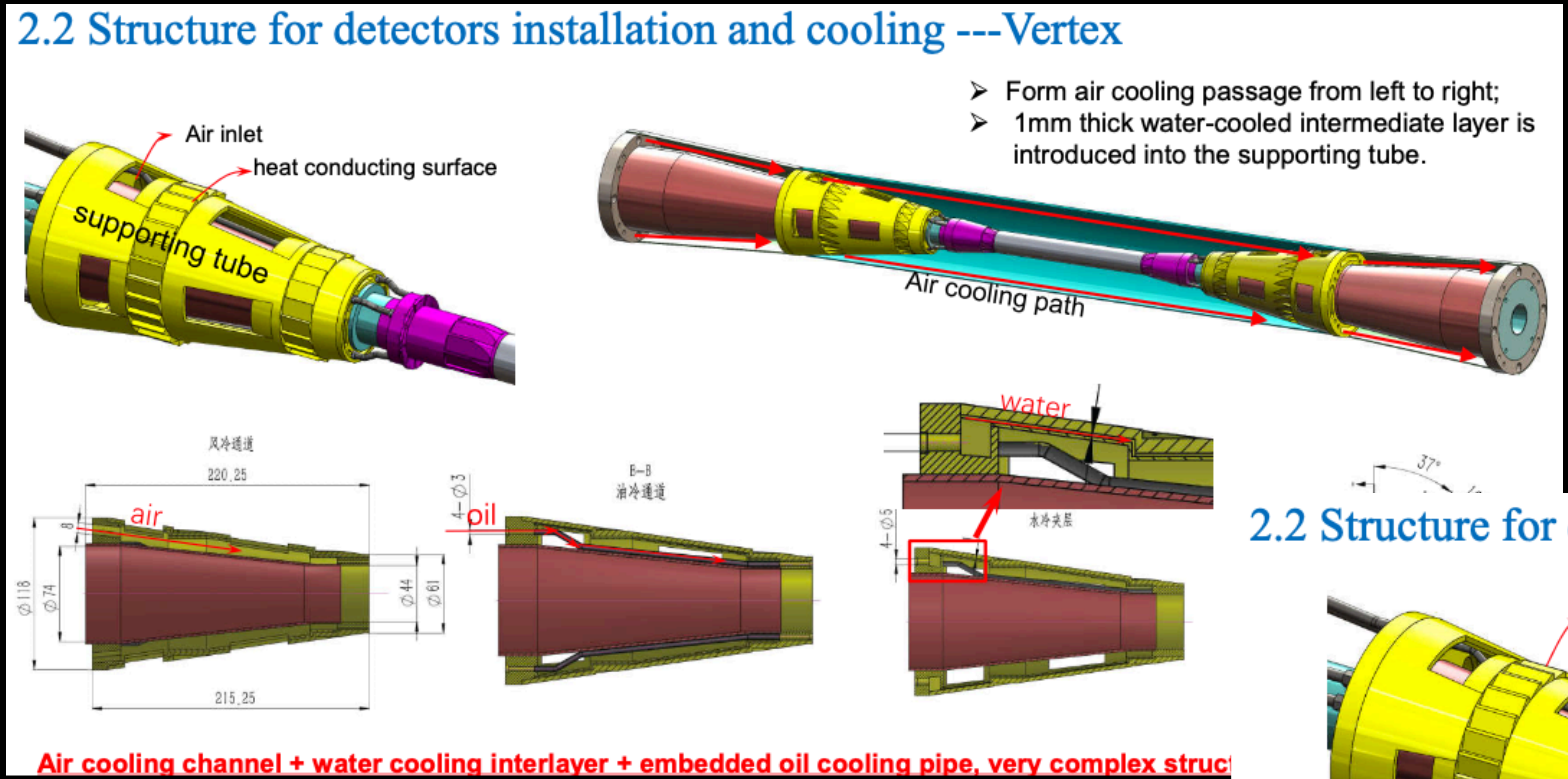
Temperature distribution in Z model

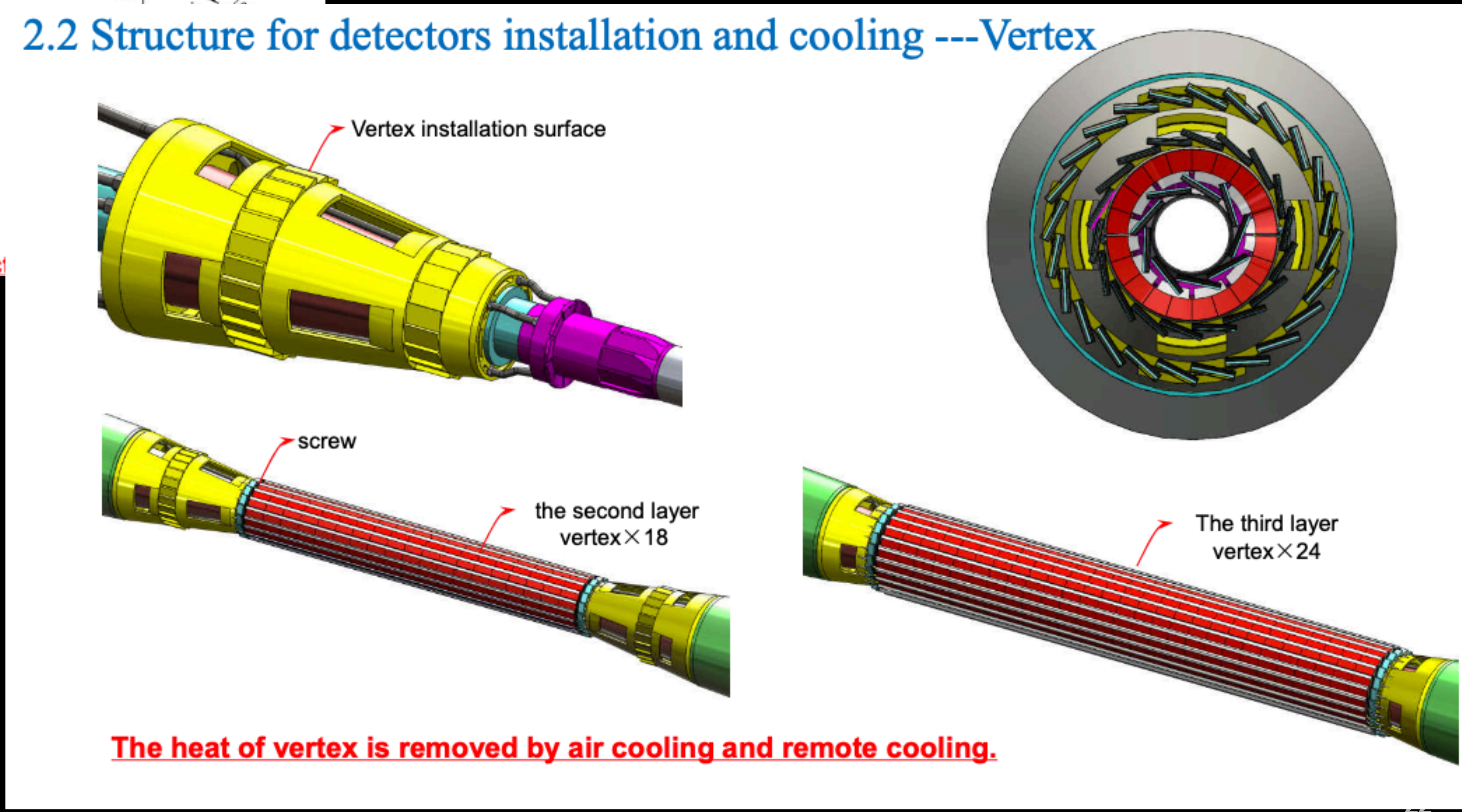


Temperature distribution in High Luminosity Z model



Silicon vertex supporting structure





MDI: CEPC beam background estimations

Higgs Run

Backgrounds on first layer of VTX

Background Type	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($krad \cdot yr^{-1}$)	1 MeV equivalent neutron fluence ($n_{eq} \cdot cm^{-2} \cdot yr^{-1}$)
Pair production	1.91	526.11	1.05×10^{12}
Synchrotron Radiation	0.026	15.65	
Radiative Bhabha	0.34	592.66	1.44×10^{12}
Beam Gas	0.9607	1235.9	3.37×10^{12}
Beam Thermal Photon	0.02	22.31	6.20×10^{10}
Total	3.2567	2392.63	5.922×10^{12}

Safety factor 10

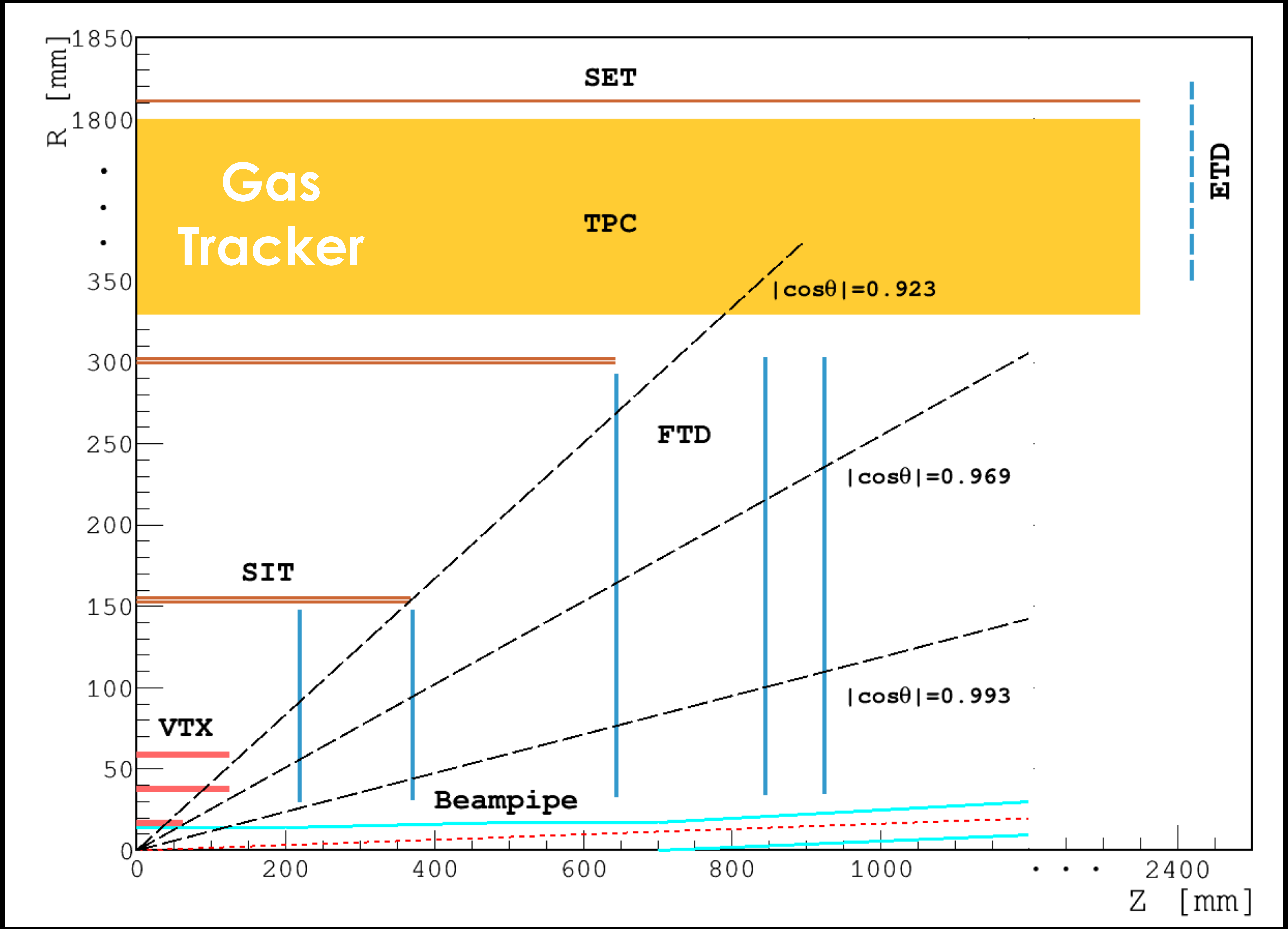
Previous results:

Rates at the inner layer (16 mm):

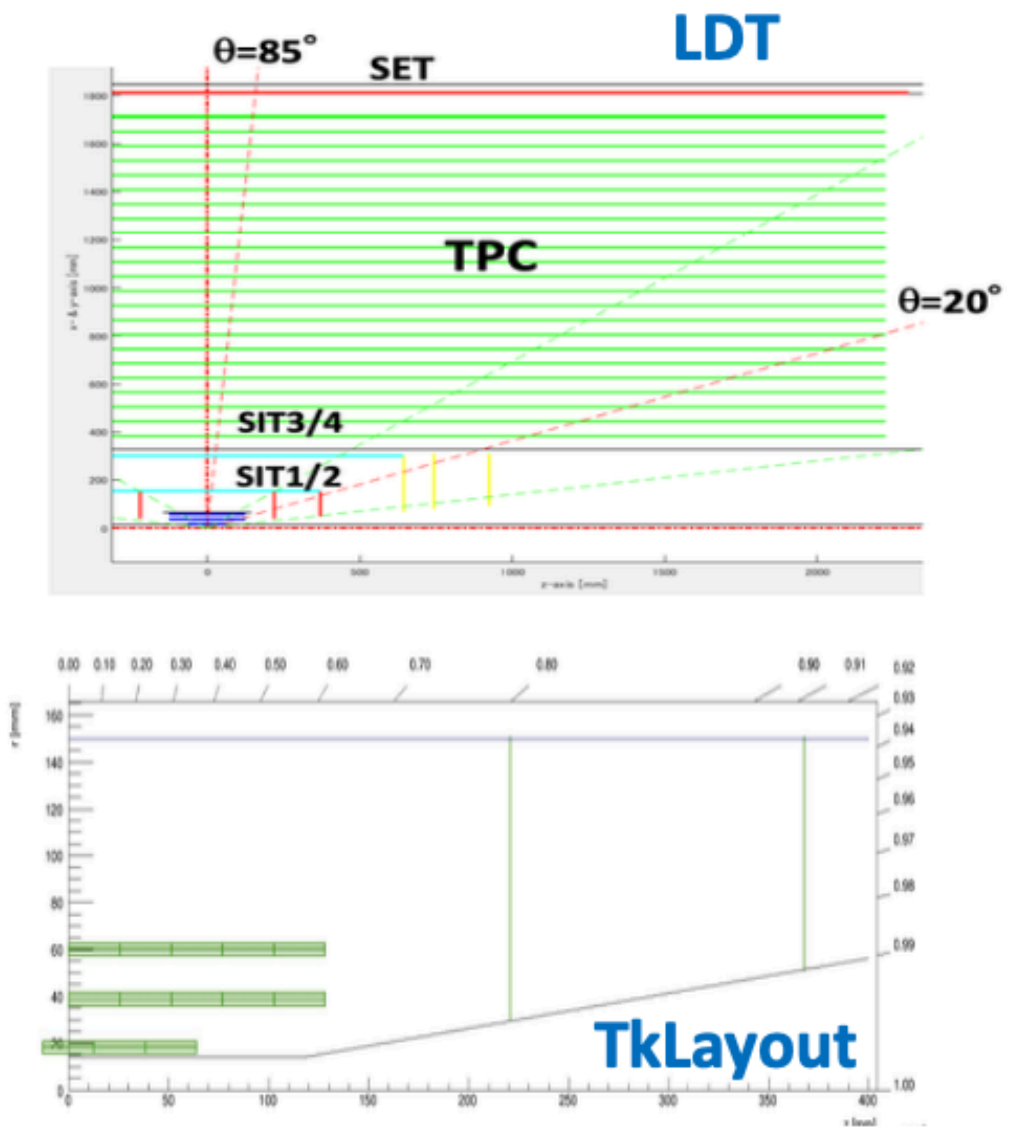
Hit density: ~2.5 hits/cm^2/BX
TID: 2.5 MRad/year
NIEL: 10^{12} 1MeV n_{eq}/cm^2
(Safety factors of 10 applied)

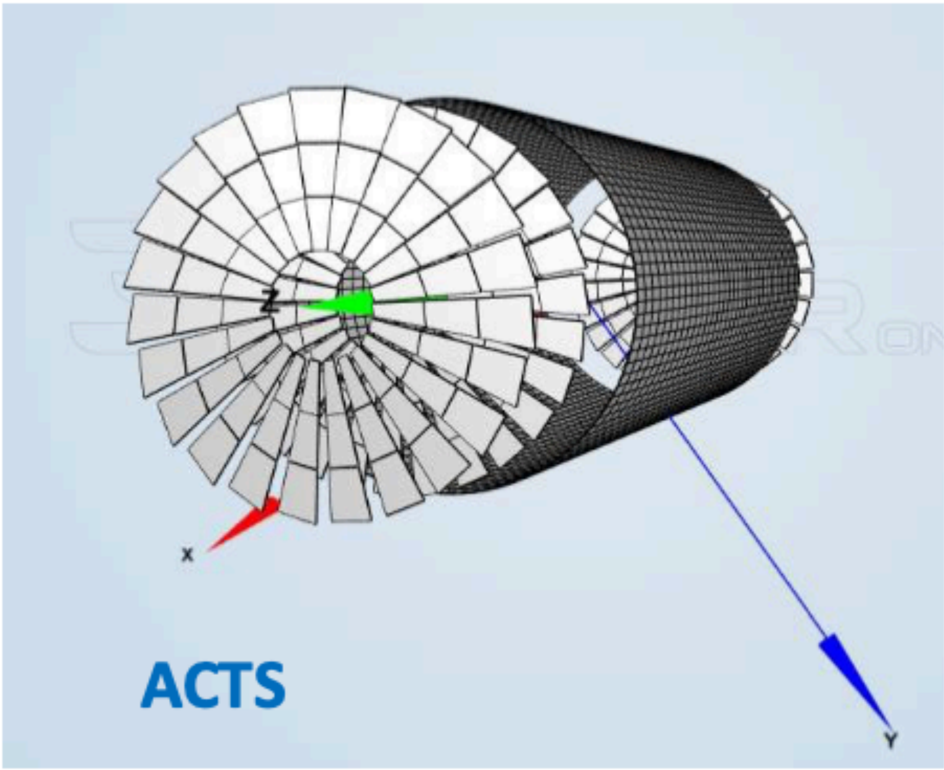
- Work for the Z run on-going
- Validating beam background simulations with real data: Belle II, BES III
  - Many results from Belle II presented at workshop

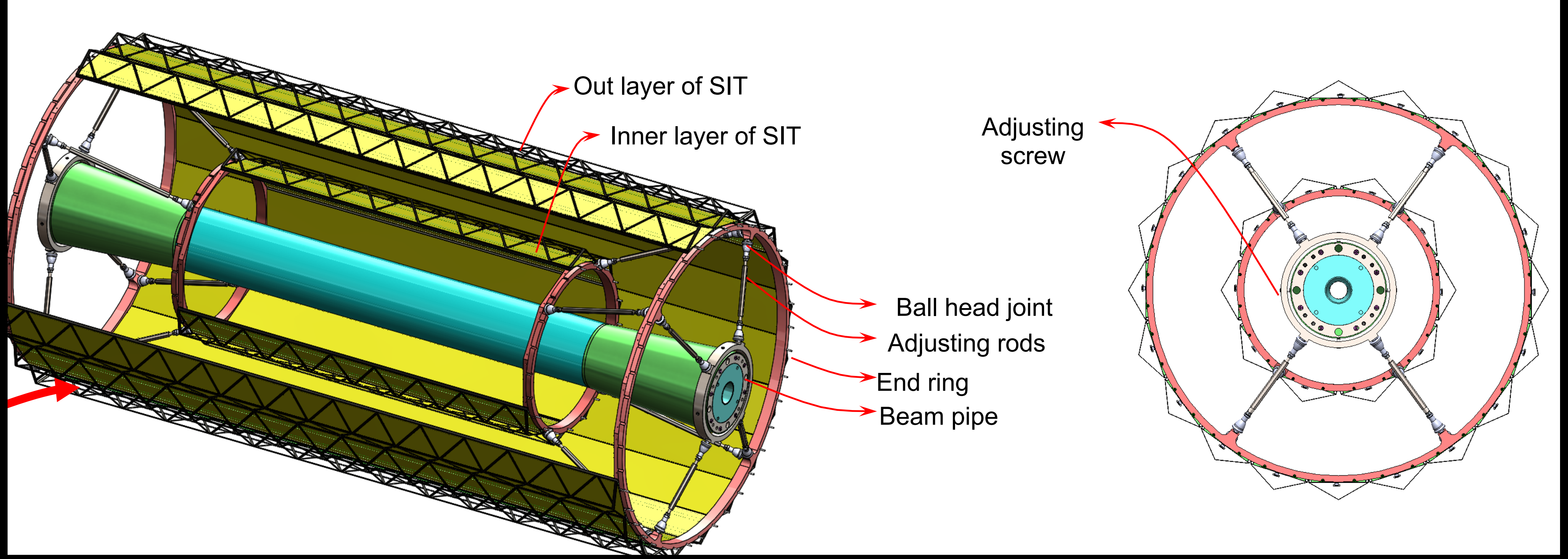
Silicon Tracker design



- **LDT** or **TkLayout** to validate basic tracking performance before implementing detailed geometry in **ACTS**



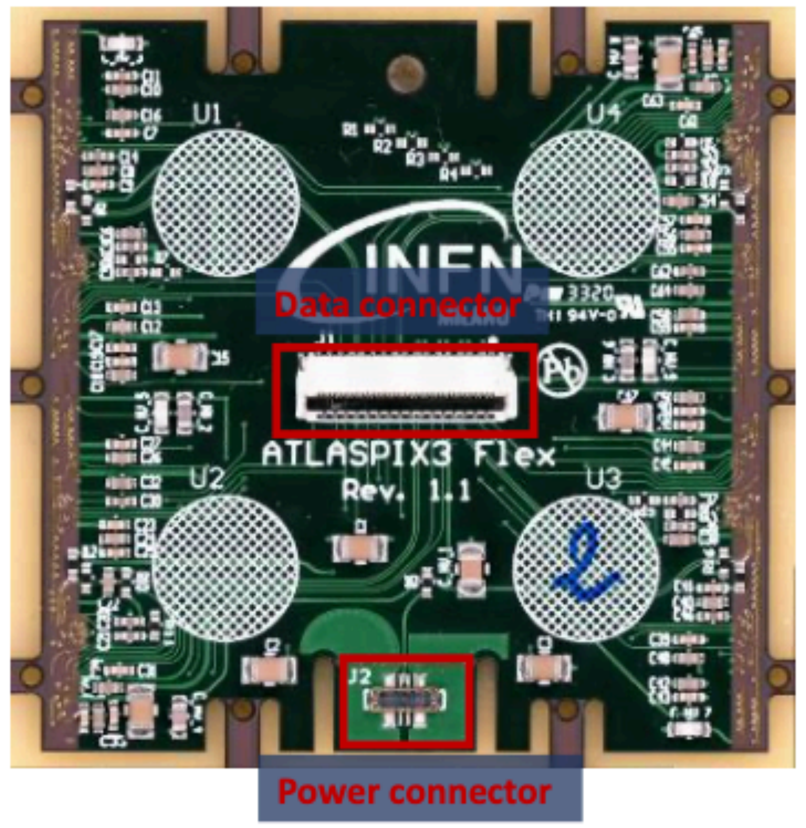




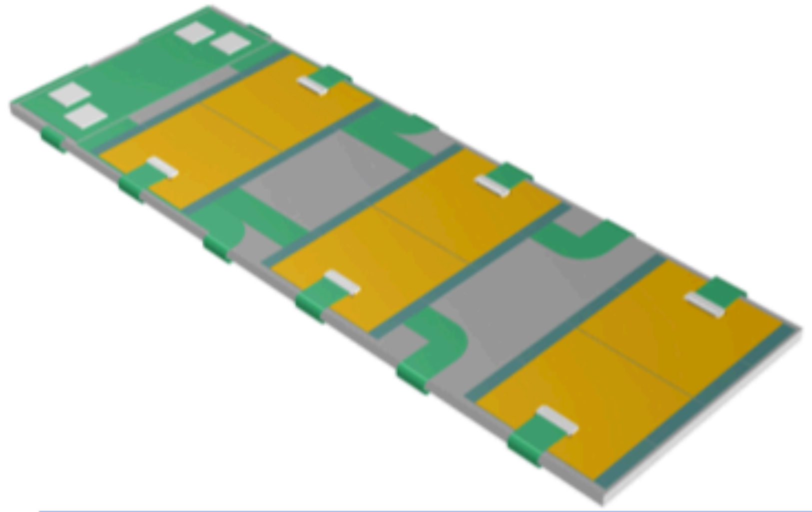
Silicon tracker demonstrator with international partners

DEMONSTRATOR (SHORT STAVE)

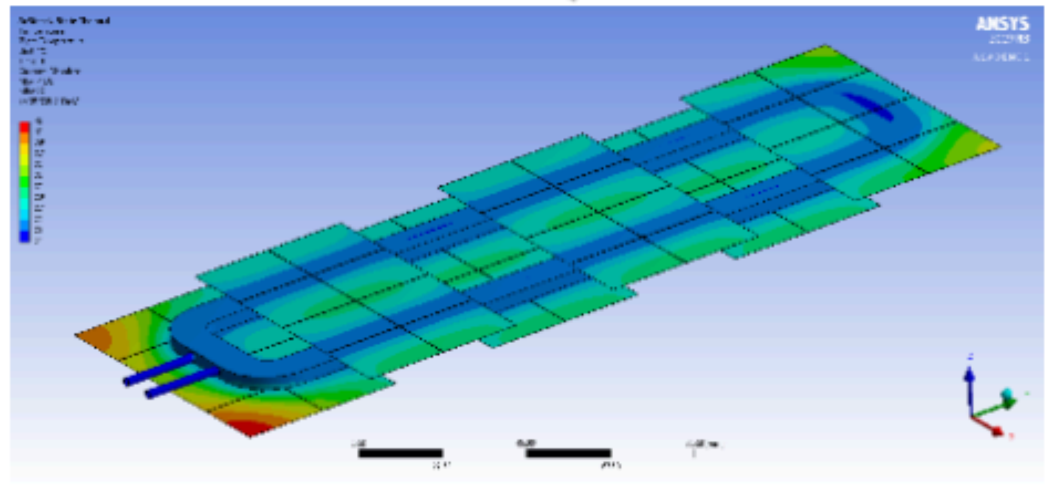
QuadModule Concept

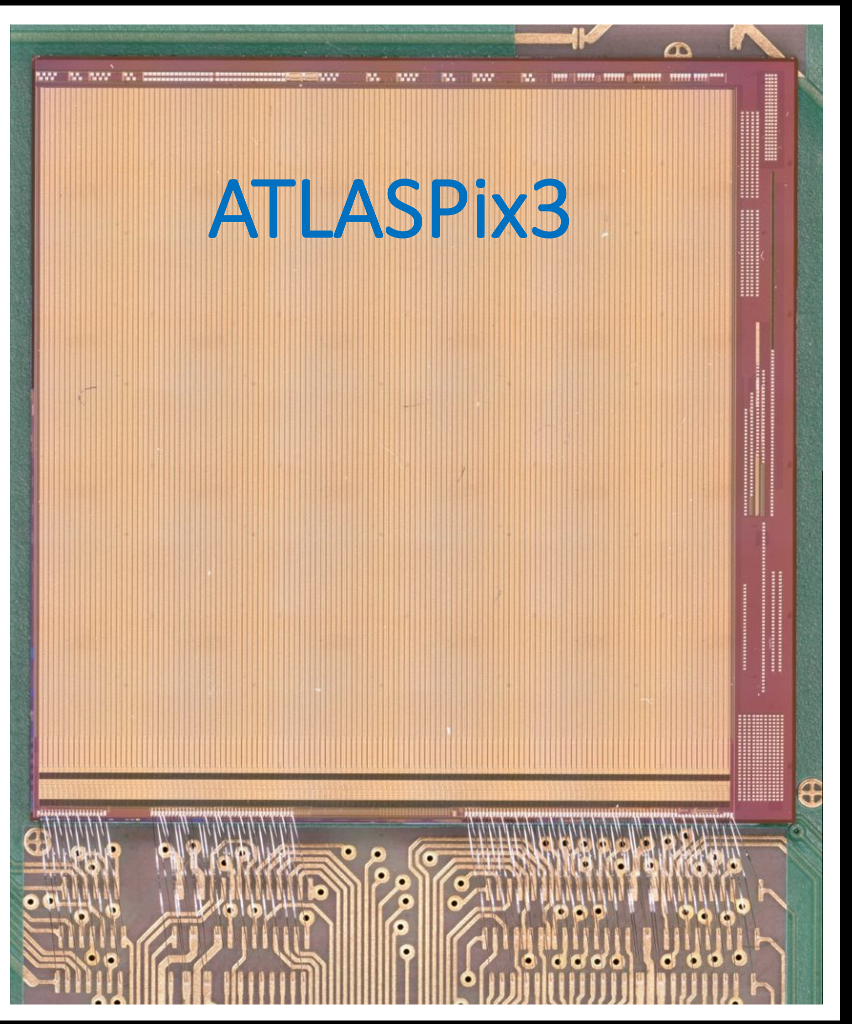


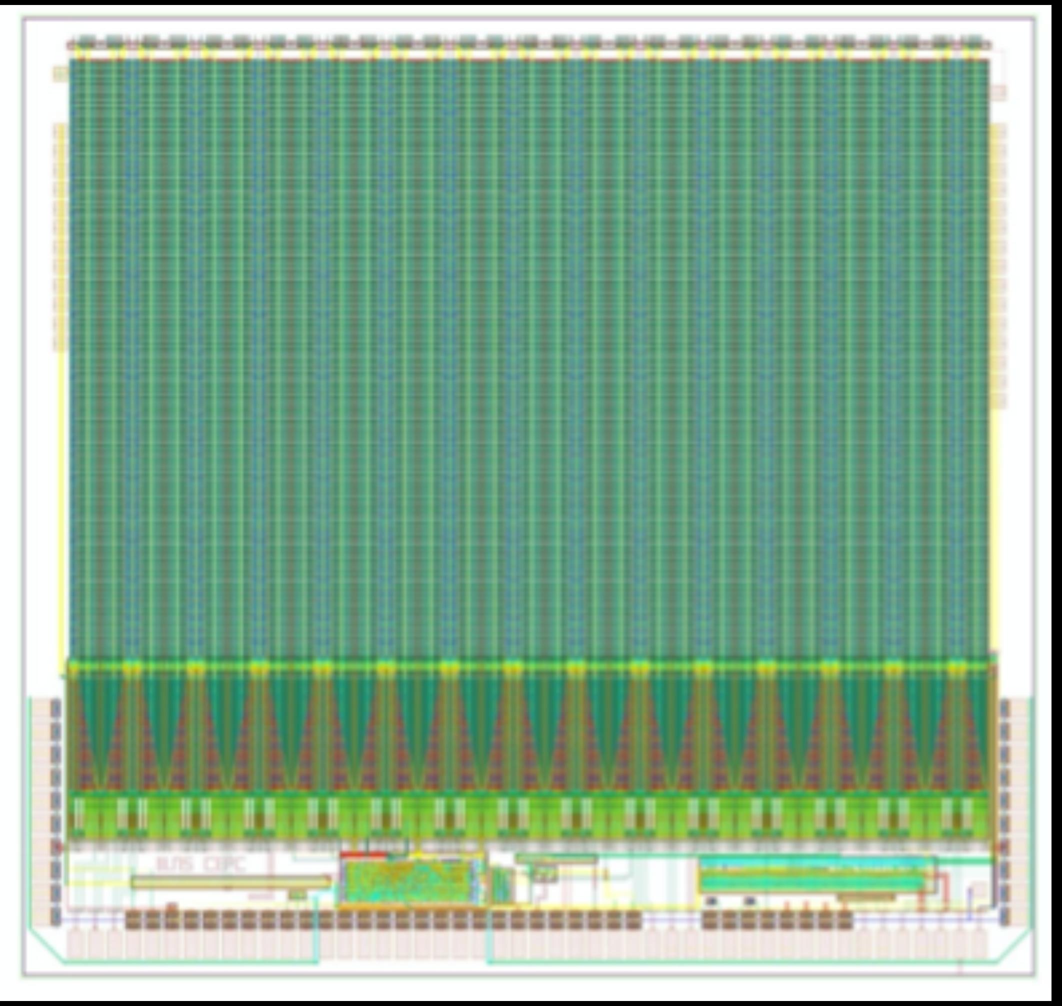
- Multiple modules on light composite support
  - Alternate tile pattern for hermeticity
  - Aggregation of data/optical conversion at the end-of-stave; serial powering



- Readout unit based on 4 chips
  - Shared services among 4 sensors by common power connections and configuration lines
  - Benefits of in-chip regulators to reduce connections







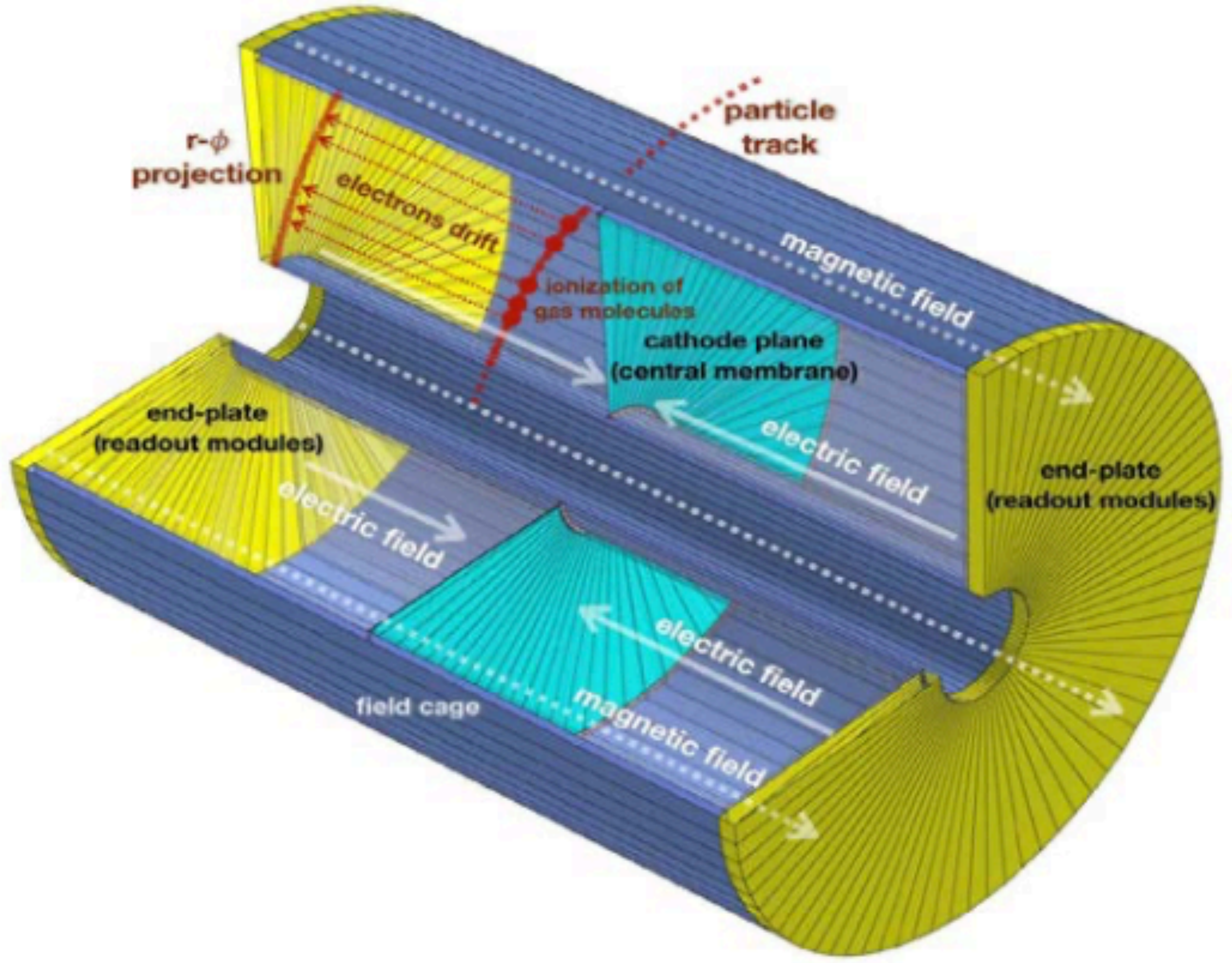
Ivan Peric, KIT

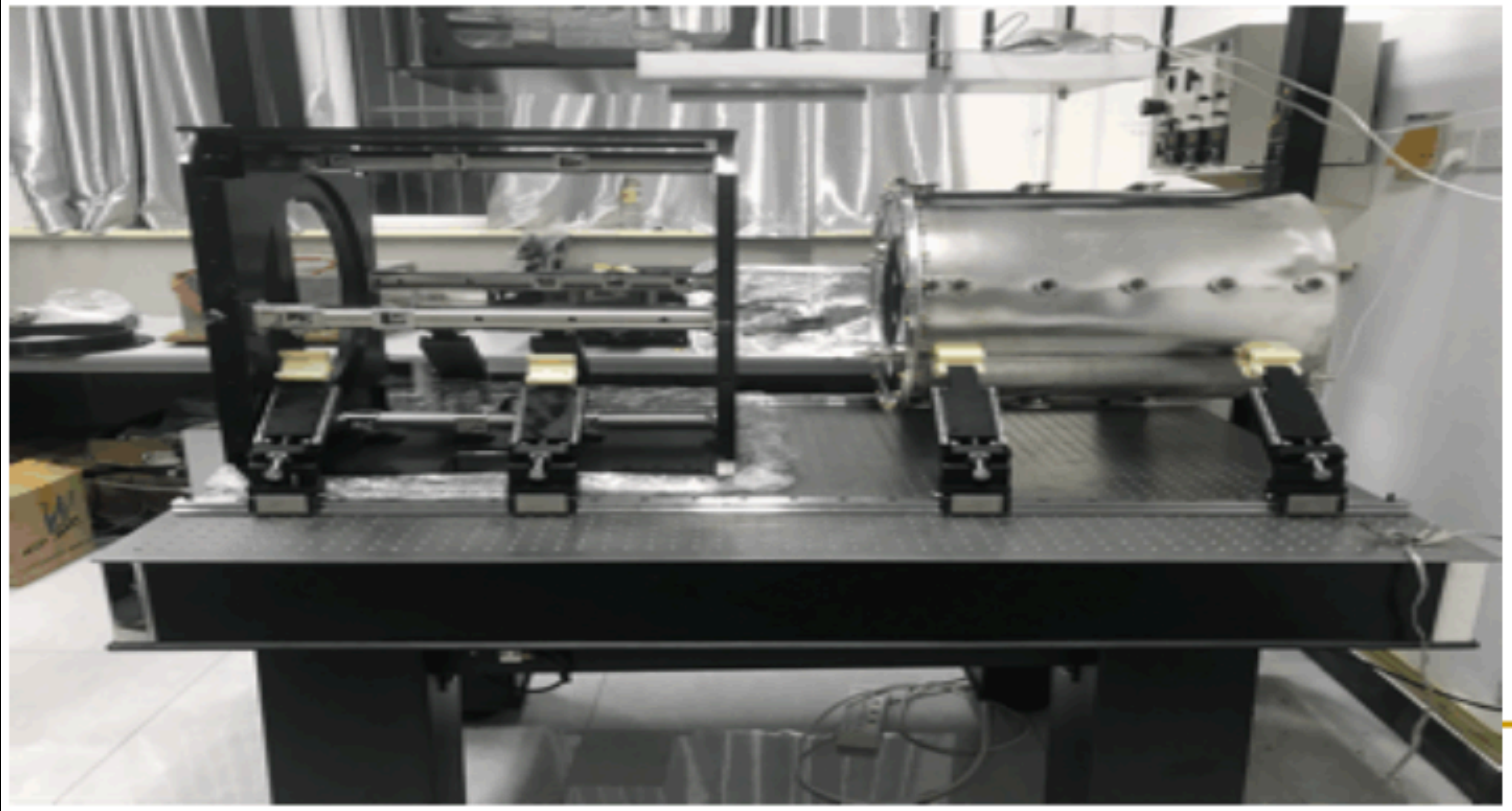
- **China**
  - Institute of High Energy Physics, CAS
  - Shangdong University
  - Tsinghua University
  - University of Science and Technology of China
  - Northwestern Polytechnical University
  - T.D. Lee Institute – Shanghai Jiao Tong University
  - Harbin Institute of Technology
  - University of South China
- **Italy**
  - INFN Sezione di Milano, Università di Milano e Università dell'Insubria
  - INFN Sezione di Pisa e Università di Pisa
  - INFN Sezione di Torino e Università di Torino
- **Germany**
  - Karlsruhe Institute of Technology
- **UK**
  - University of Bristol
  - STFC – Daresbury Laboratory
  - University of Edinburgh
  - Lancaster University
  - University of Liverpool
  - Queen Mary University of London
  - University of Oxford
  - University of Sheffield
  - University of Warwick

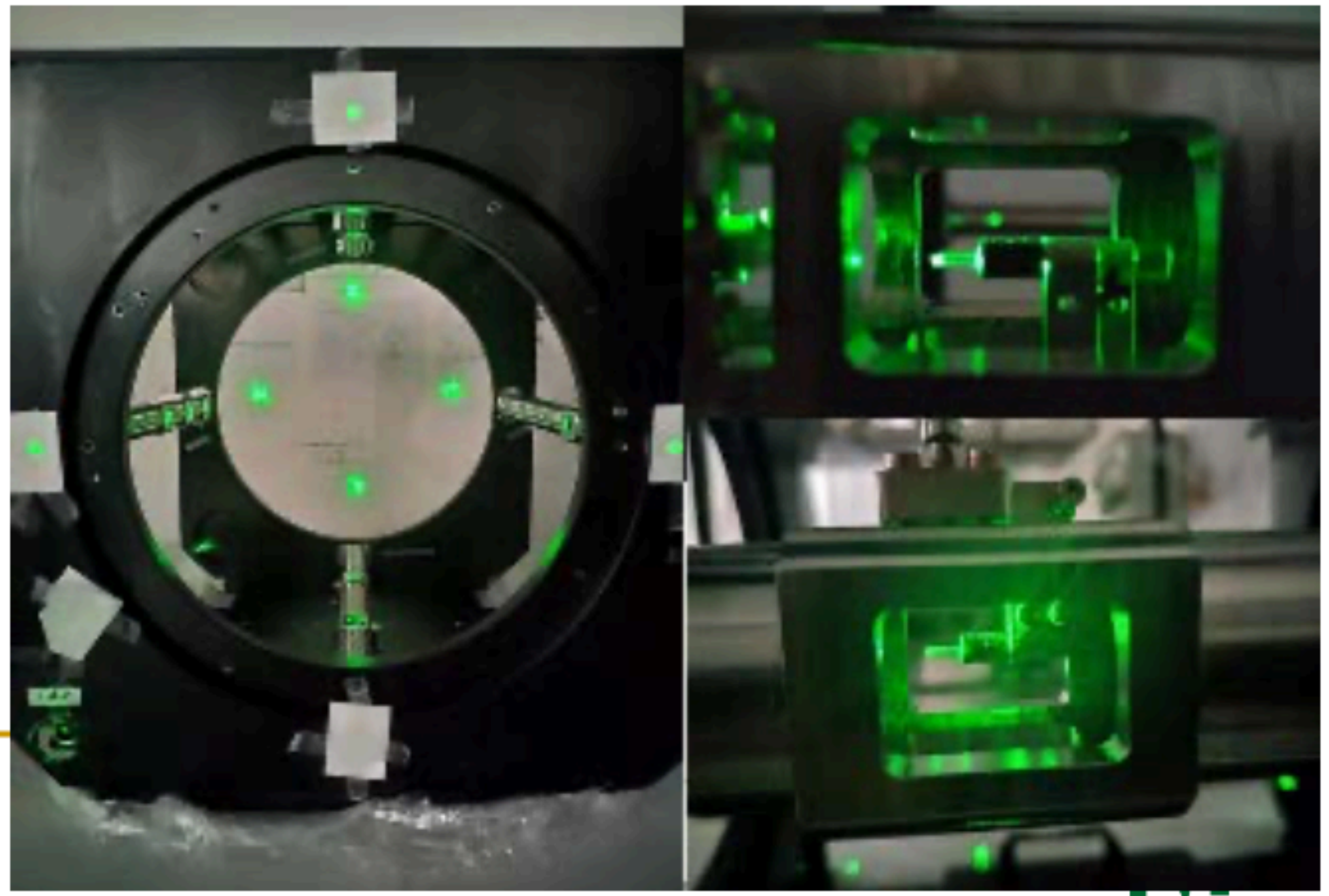
Time Projection Chamber at CEPC

TPC technology R&D

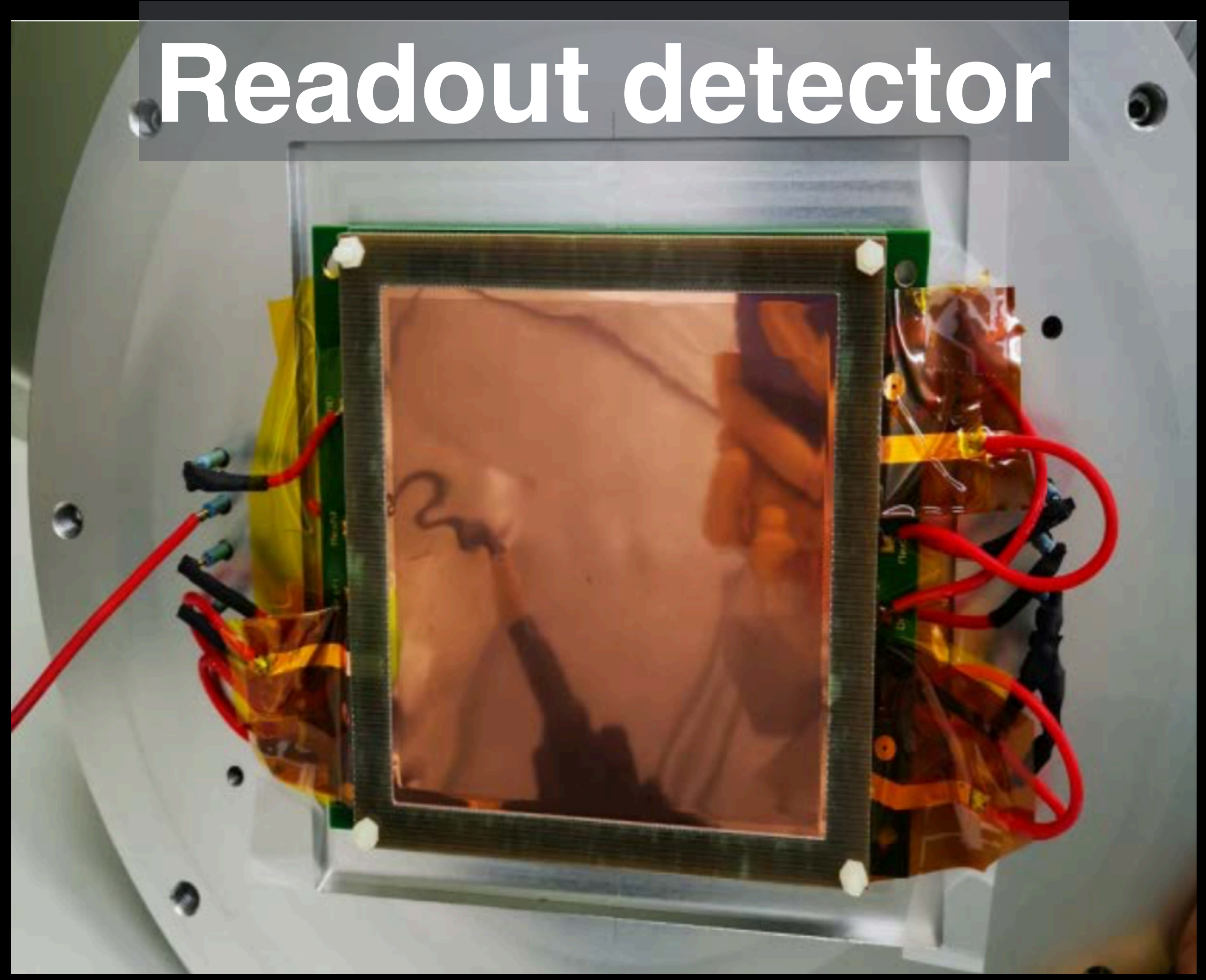
- TPC track technology is as one the baseline options in CEPC CDR
  - TPC limitation items under the high luminosity
  - Ions back flow in chamber (MOST1 funding)
  - Calibration and alignment using UV lasers(NSFC funding)
  - Low power consumption FEE ASIC chip(MOST1)
- Pixel readout R&D as one possible option for circular collider

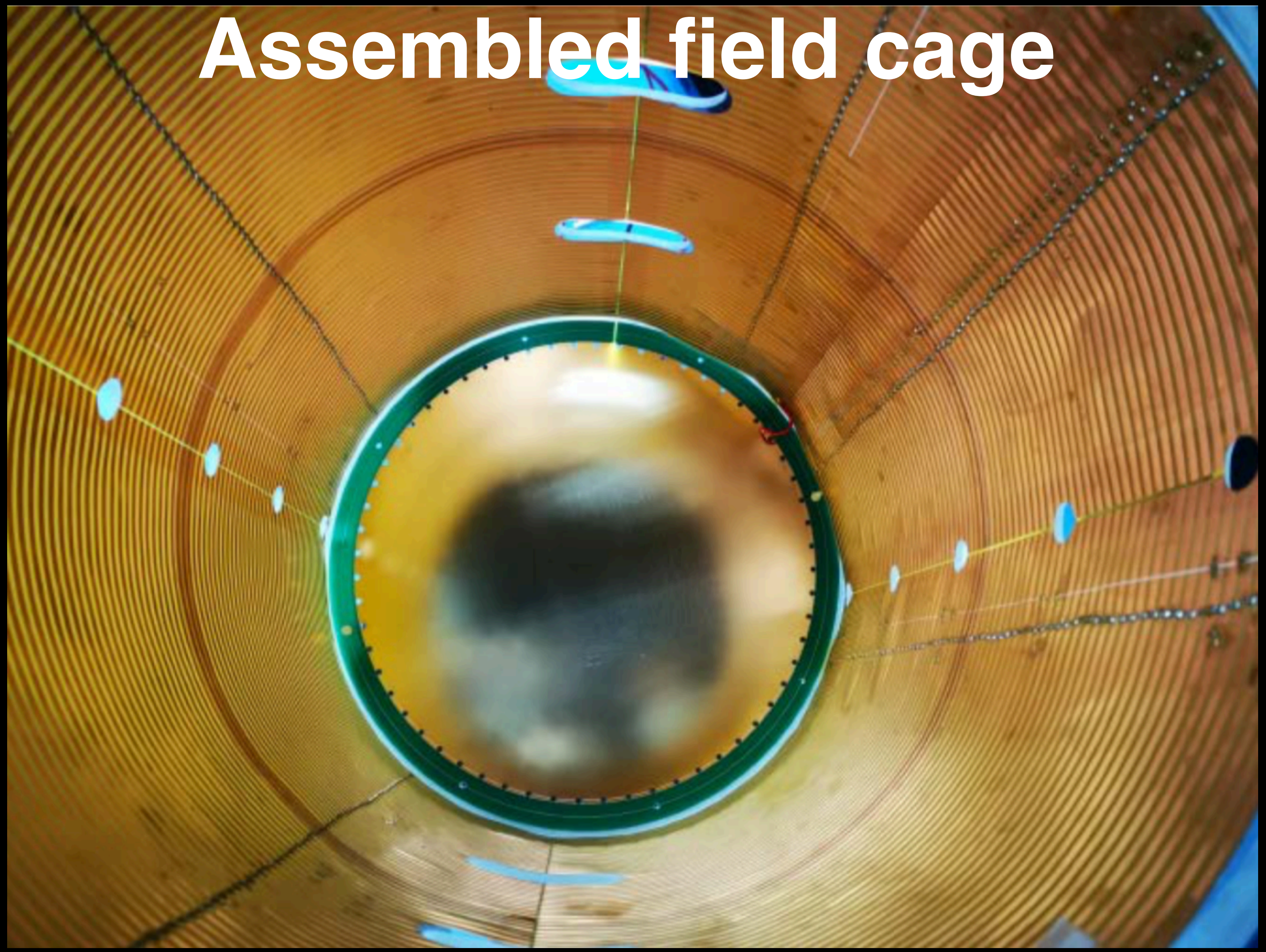




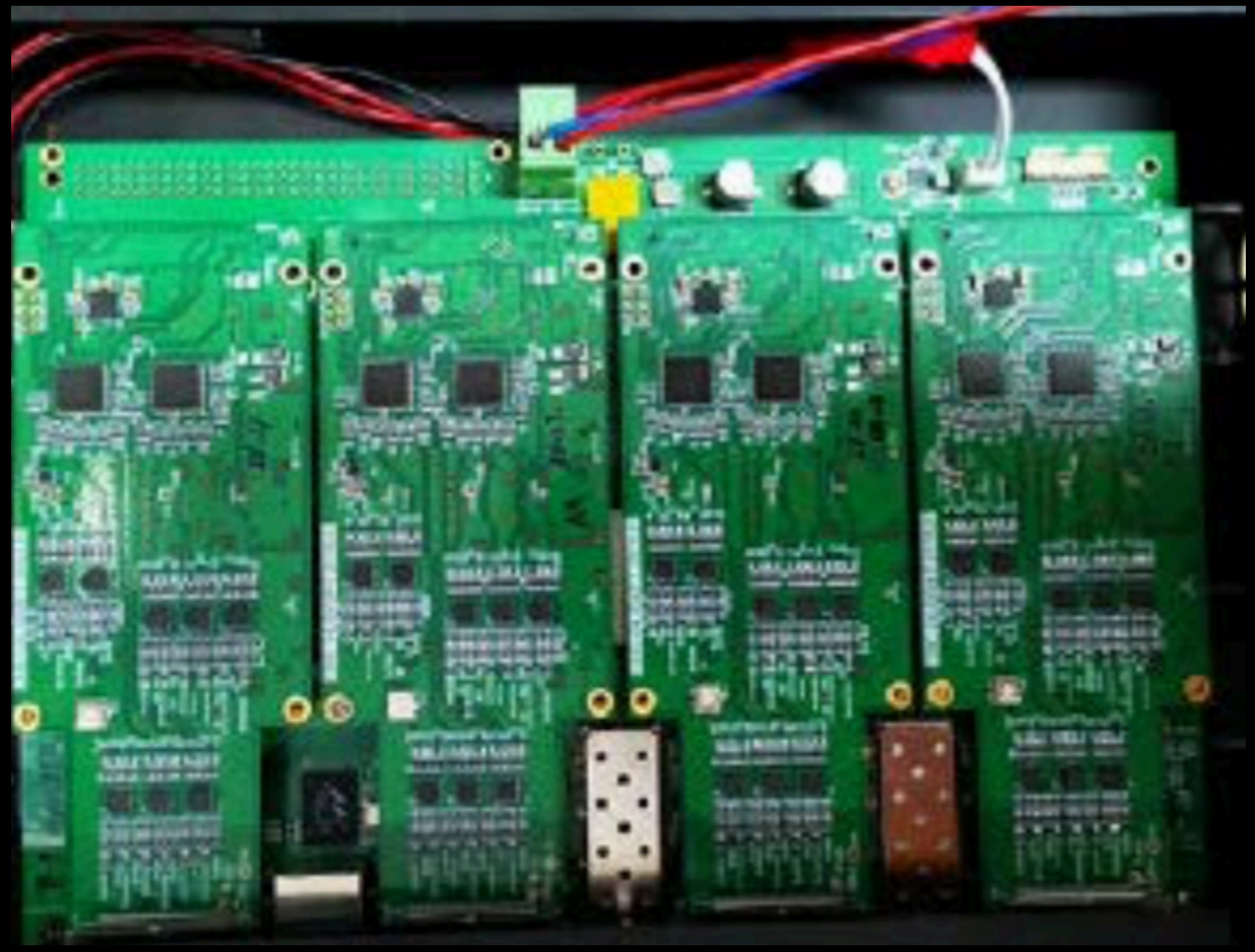


TPC Prototype



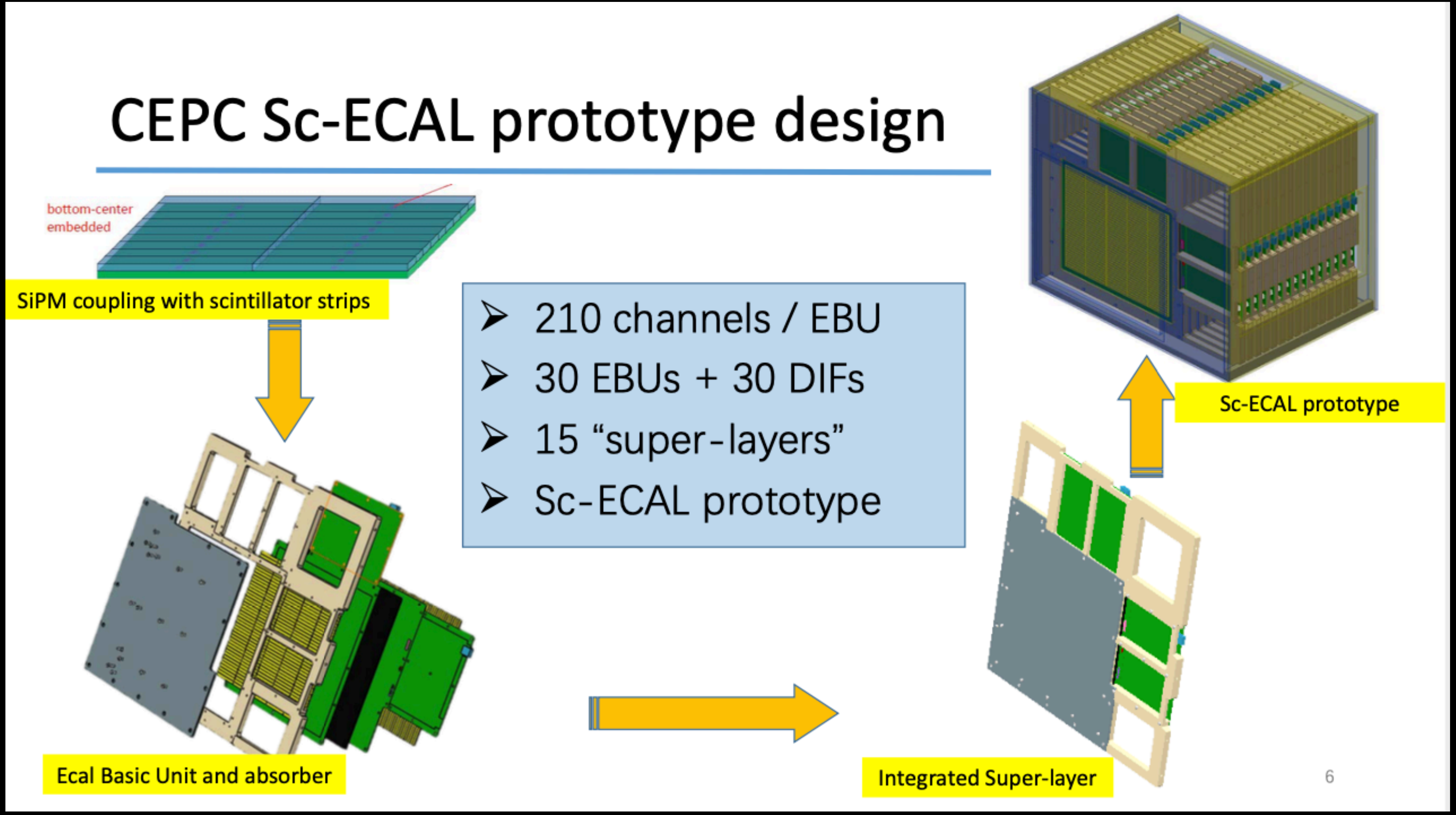


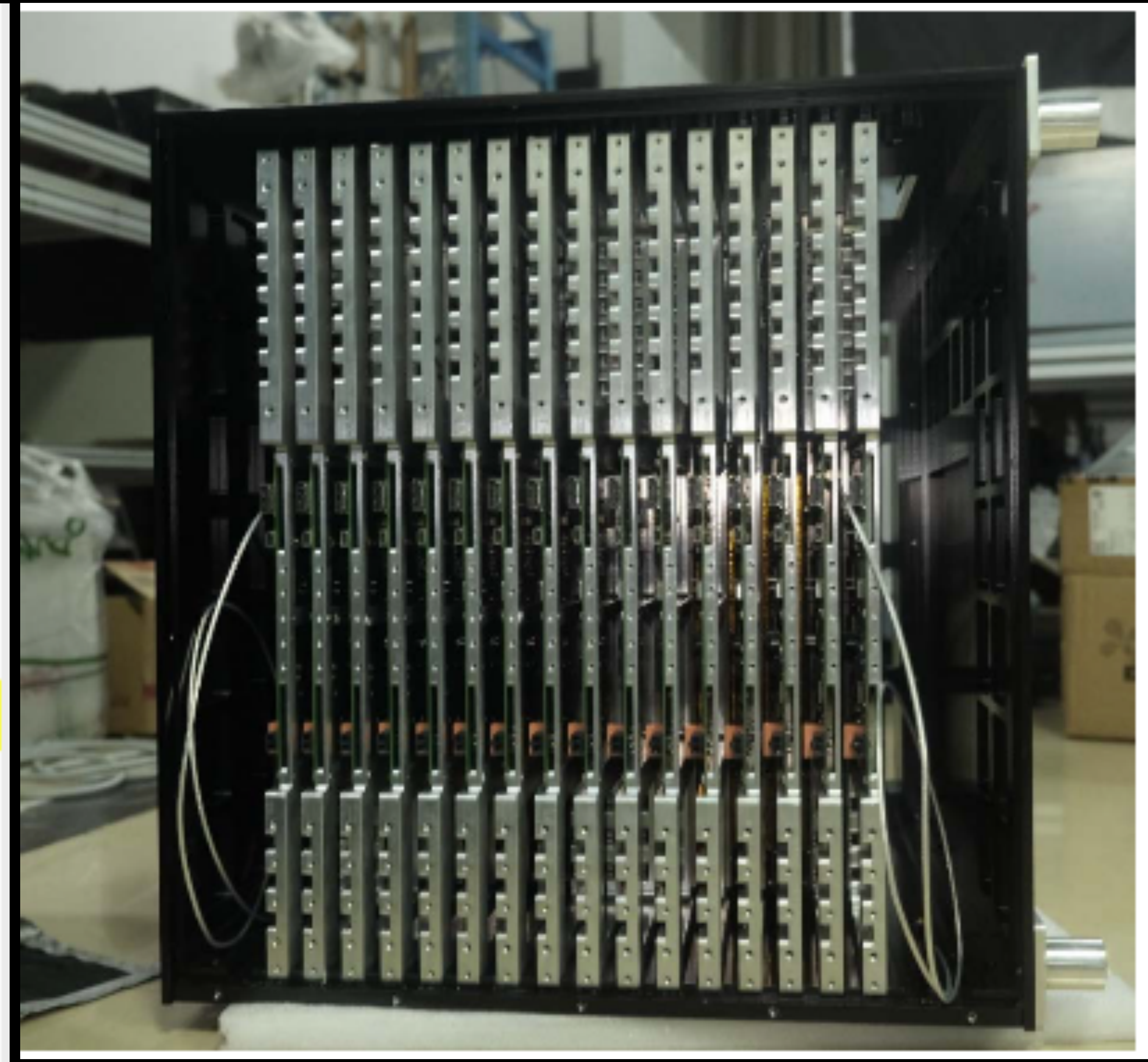
Readout electronics and DAQ



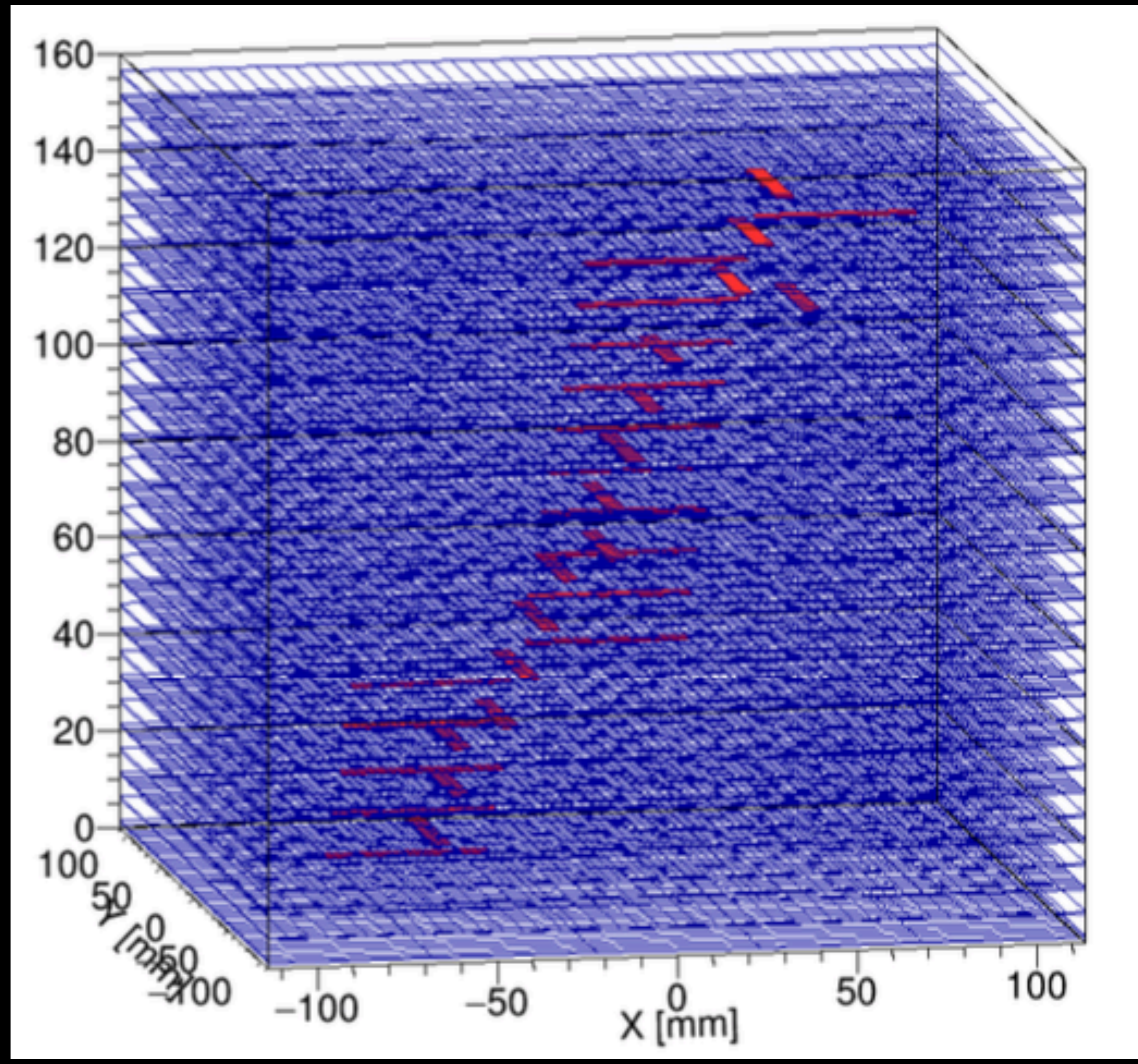
Scintillator ECAL Prototype

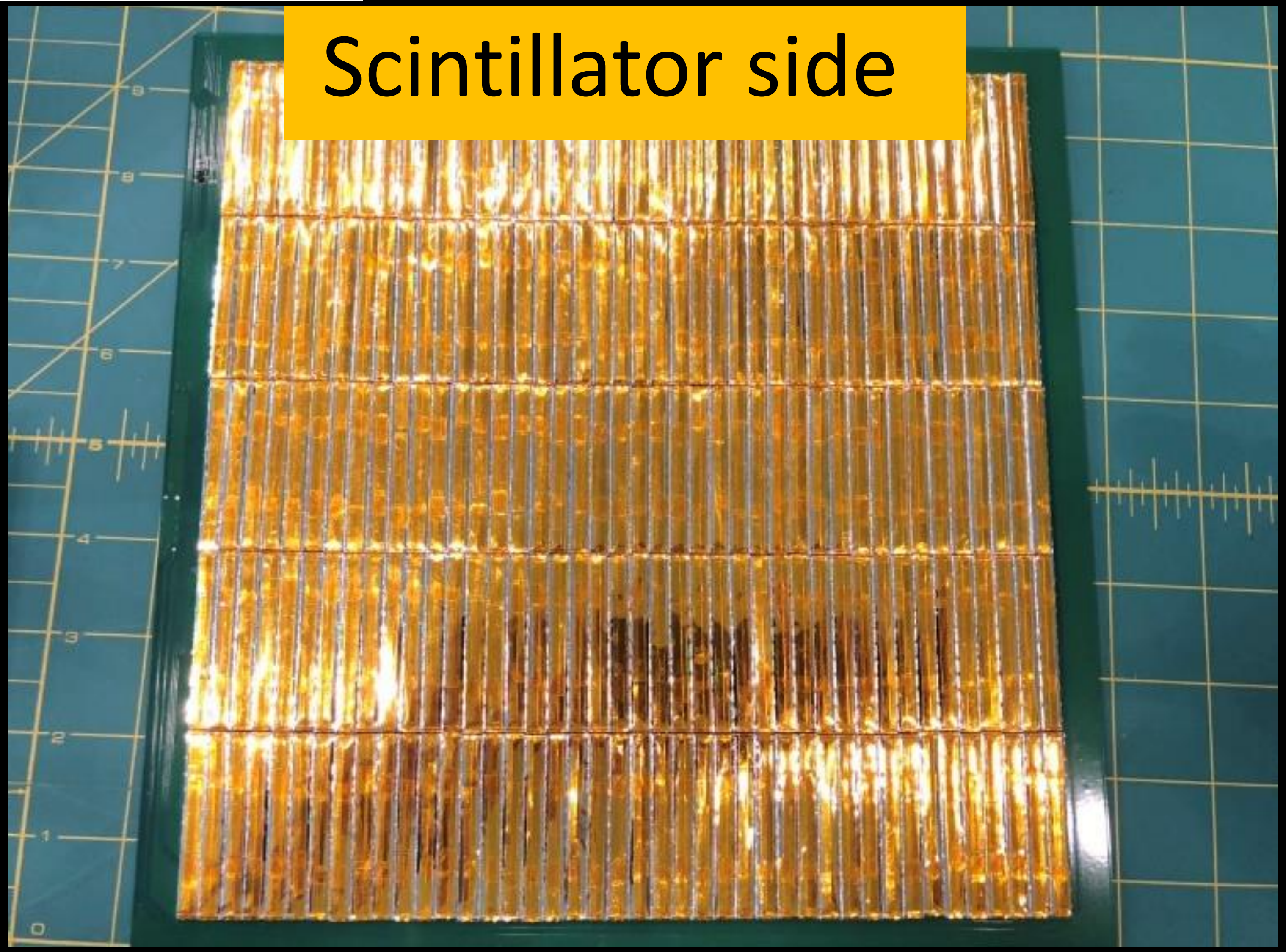
Scintillator-Tungsten Sandwich ECAL





Cosmic ray





30 full layers prepared in China-Japan collaboration

Test beam in China in next two weeks

Test beam planned for February 2021 at DESY

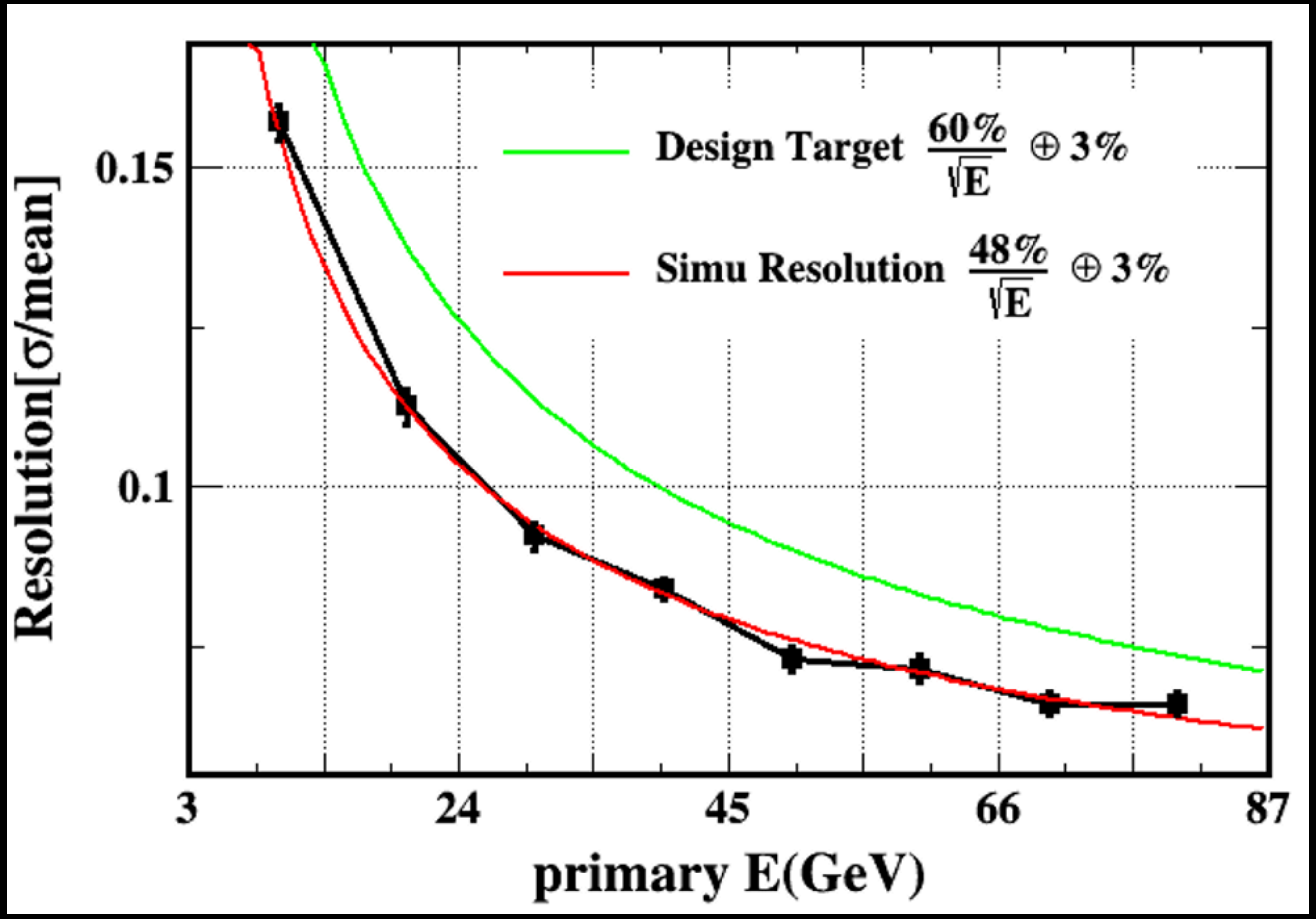
HCAL Calorimeter — Particle Flow Calorimeter

Scintillator and SiPM HCAL (AHCAL)

Design optimization finalized

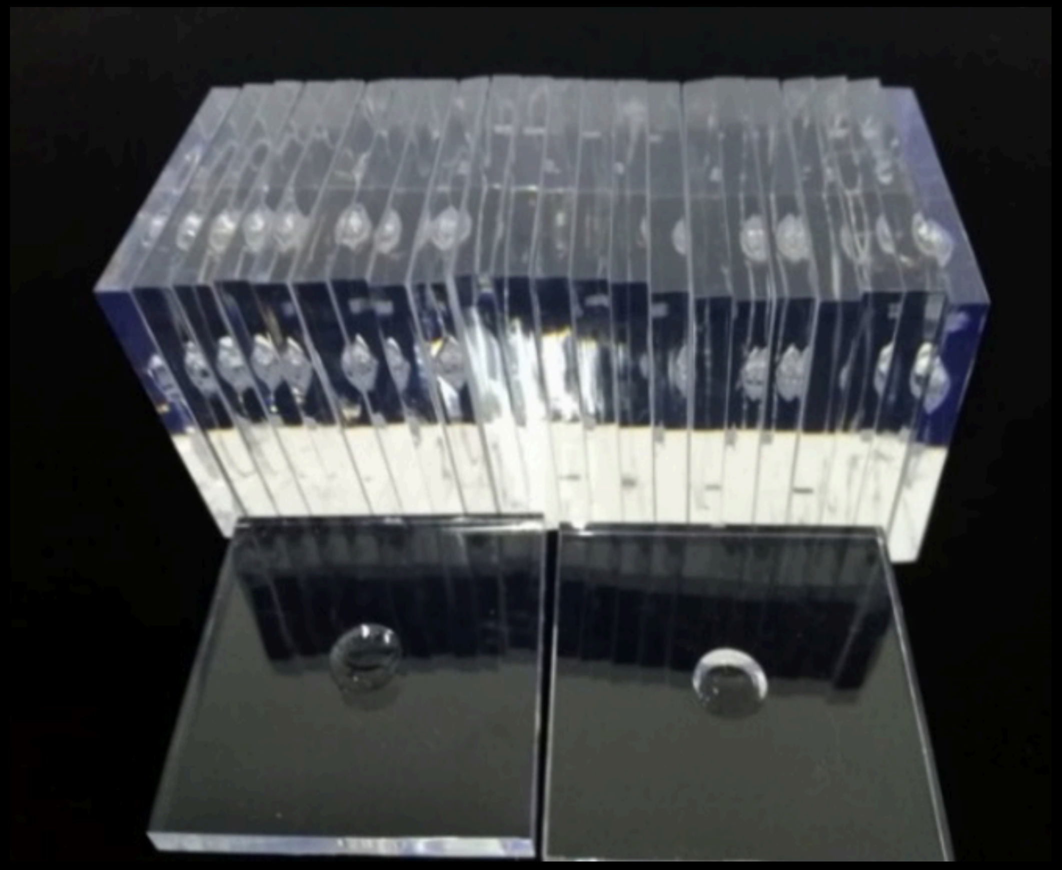
40 layers of 20 mm steel
+ 3 mm scintillator
+ 2 mm PCB
Cell size: 4 cm × 4 cm²
Transverse size: 72 × 72 cm²

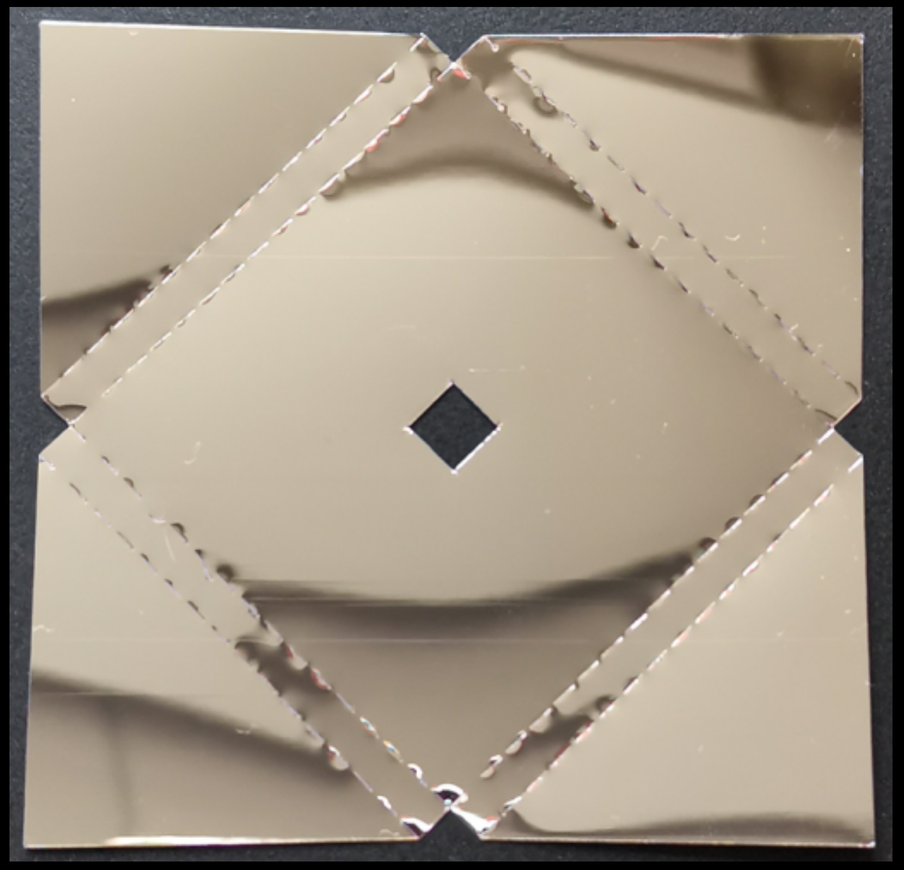
based on simulation studies

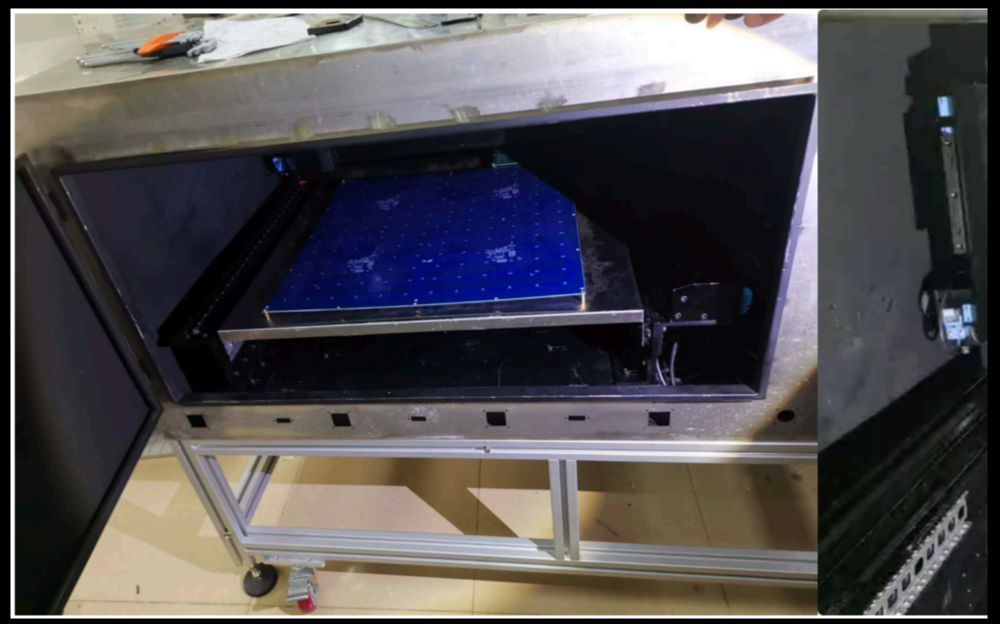


Optimized tile geometry production method

Injection molding technique to produce titles in large quantities







Automatic wrapping and batch testing

New Ideas: Crystal Calorimeters

Topical Workshop on CEPC Calorimetry at IHEP • March 2019

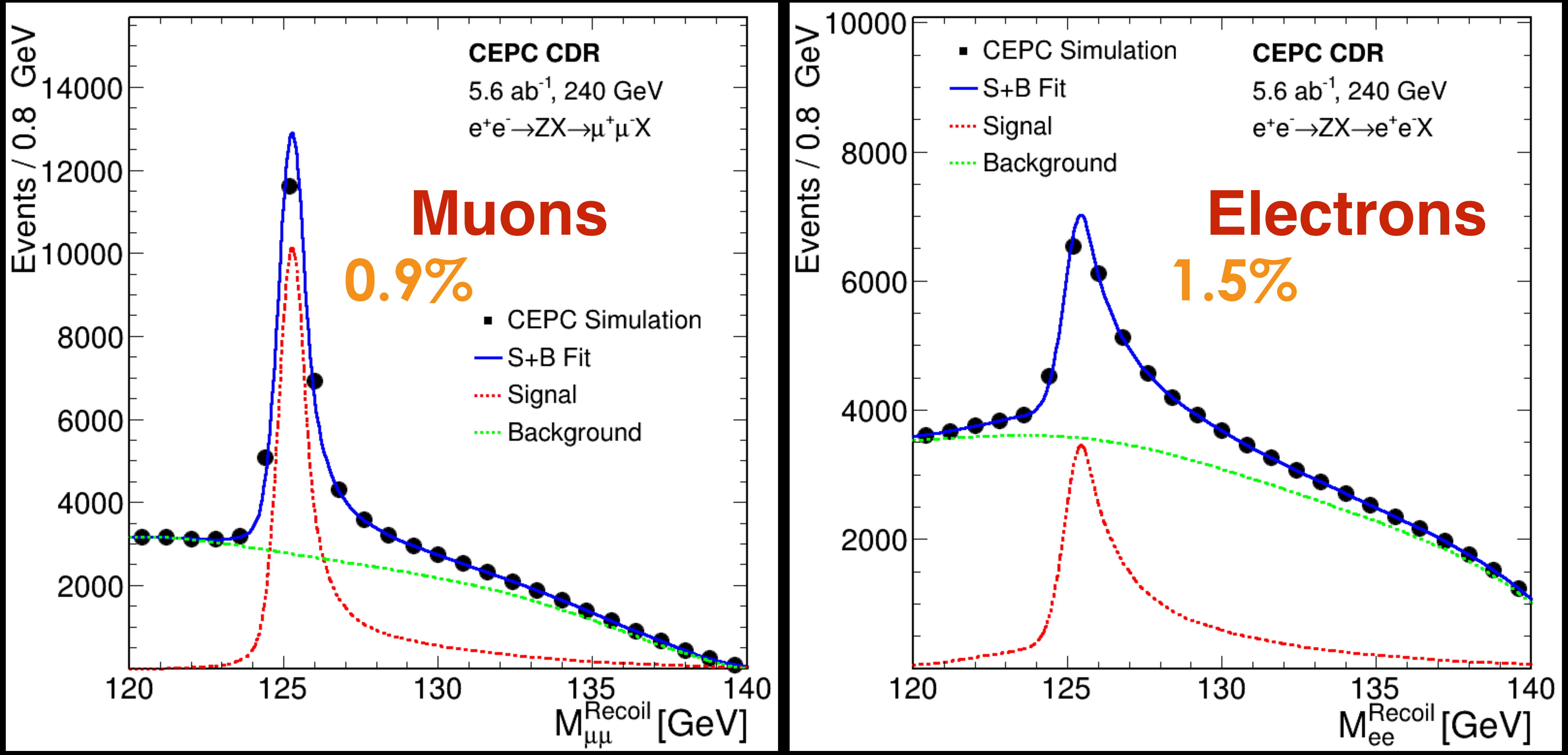
Follow up: Online mini-workshop on a detector concept with a crystal ECAL, July 2020

Concern: Electromagnetic resolution of PFA calorimeter not optimal

Physics motivations:

- Electrons' Bremsstrahlung: energy recovery
- Improve angular resolution, and gamma counting
- Recoil photons: new physics and neutrino counting

Z boson recoil mass

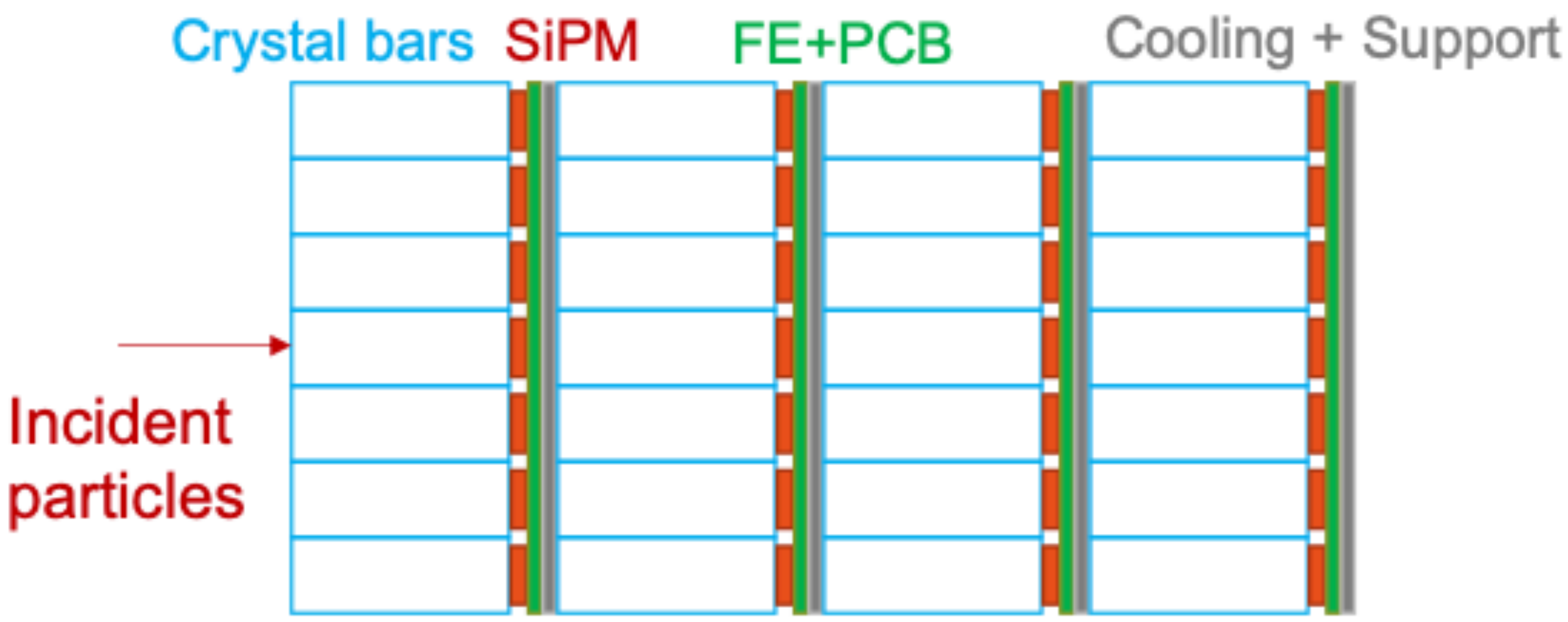


New Ideas: Crystal Calorimeters

Yong Liu

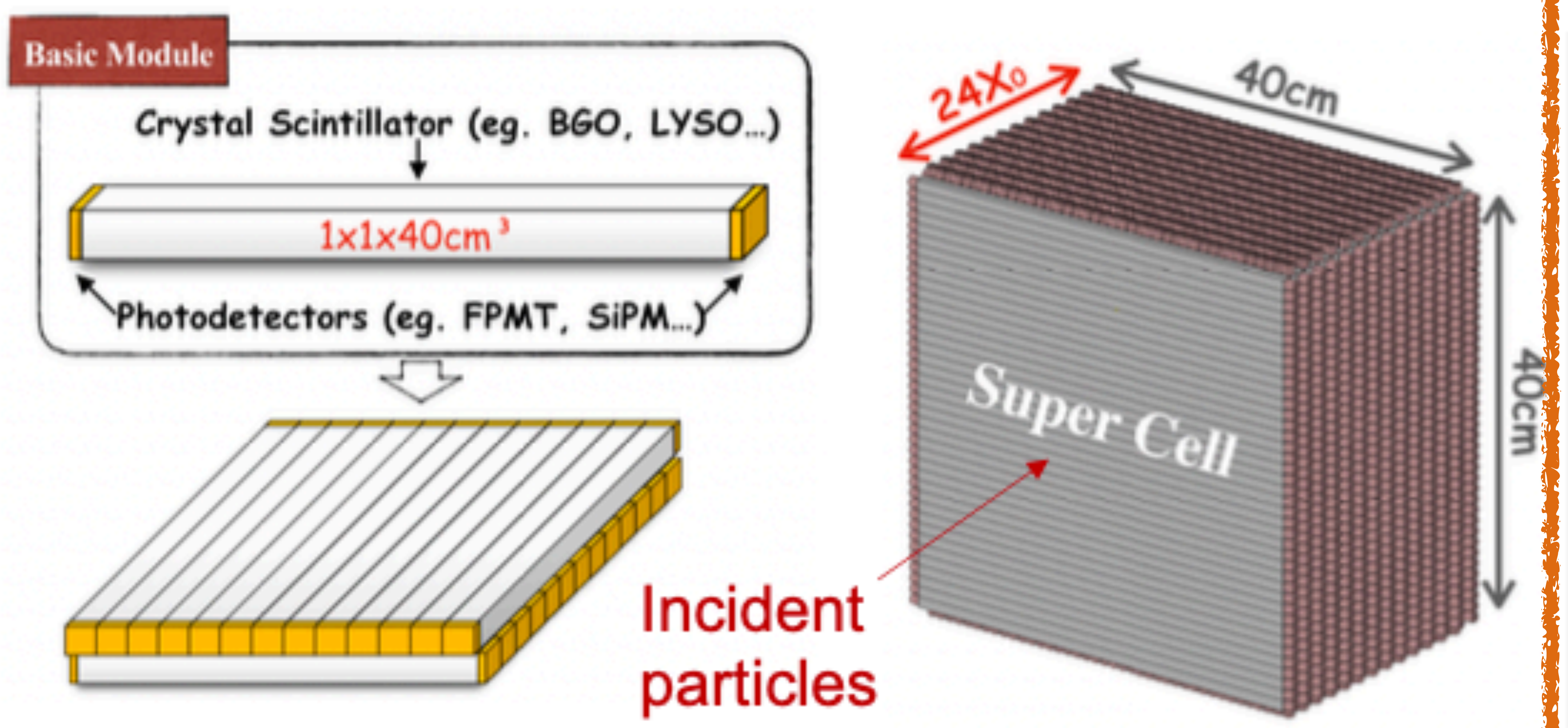
Two new segmented ECAL designs based on crystals

Design 1



- Longitudinal segmentation
- Fine transverse segmentation
  - 1×1cm or 2×2cm cells
- Single-ended readout with SiPM
- Potentials with PFA

Design 2



- Long bars: 1×40cm, double-sided readout
  - Super cell: 40×40cm cube
- Crossed arrangement in adjacent layers
- Significant reduction of #channels
- Timing at two sides: positioning along bar

Crystals: LYSO:Ce, PbWO, BGO? **SiPM: HPK, NLD?**

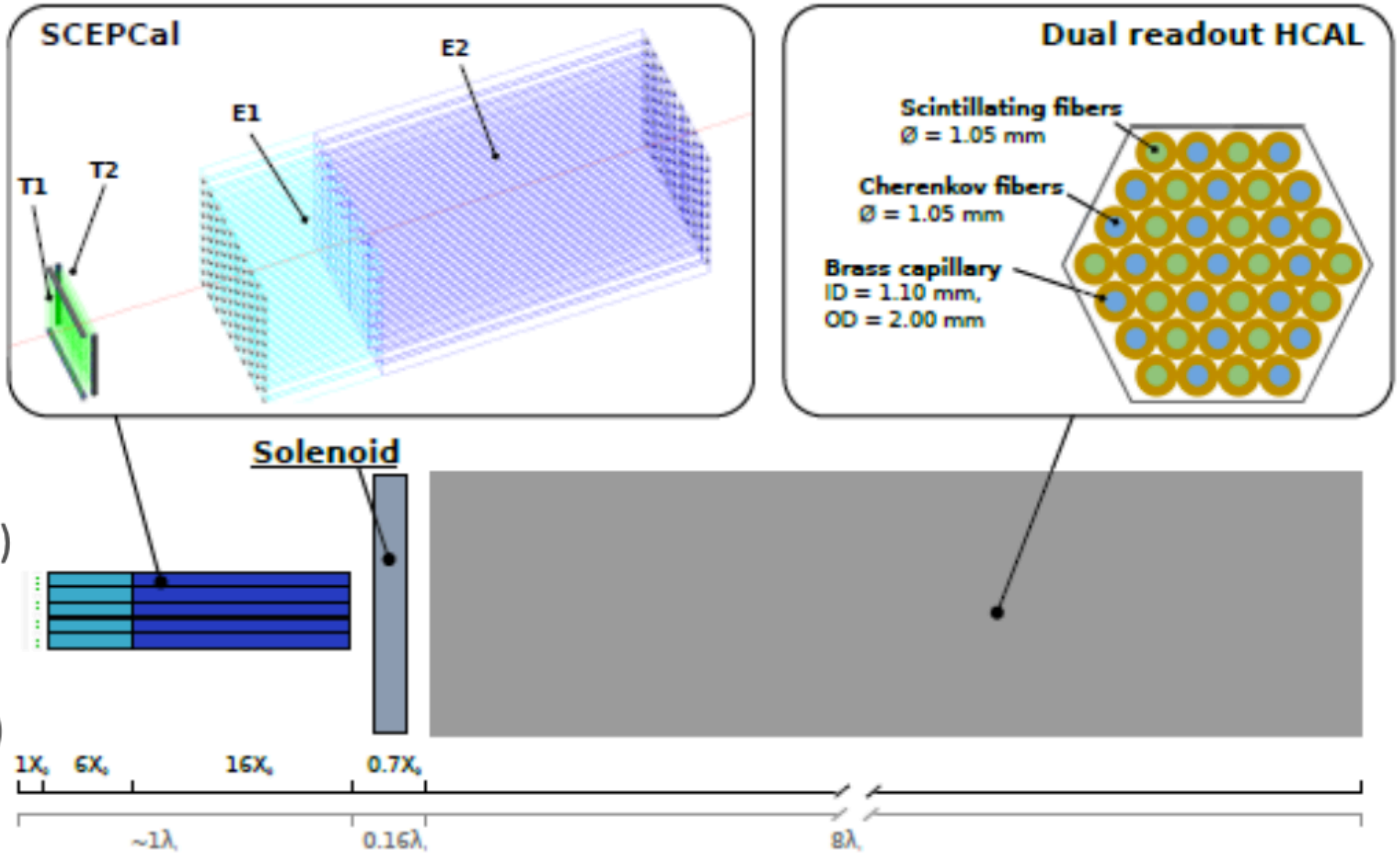
Being incorporated into CEPC Software

Cost is an issue

Dual Readout Crystal Calorimeter

Drawing from the pioneering work of RD52, but upgrading for new developments in inexpensive, high-QE, tailored-wavelength sipmms See: https://arxiv.org/abs/2008.00338 Also see Snowmass LOI: SNOWMASS21-IF6-008.pdf

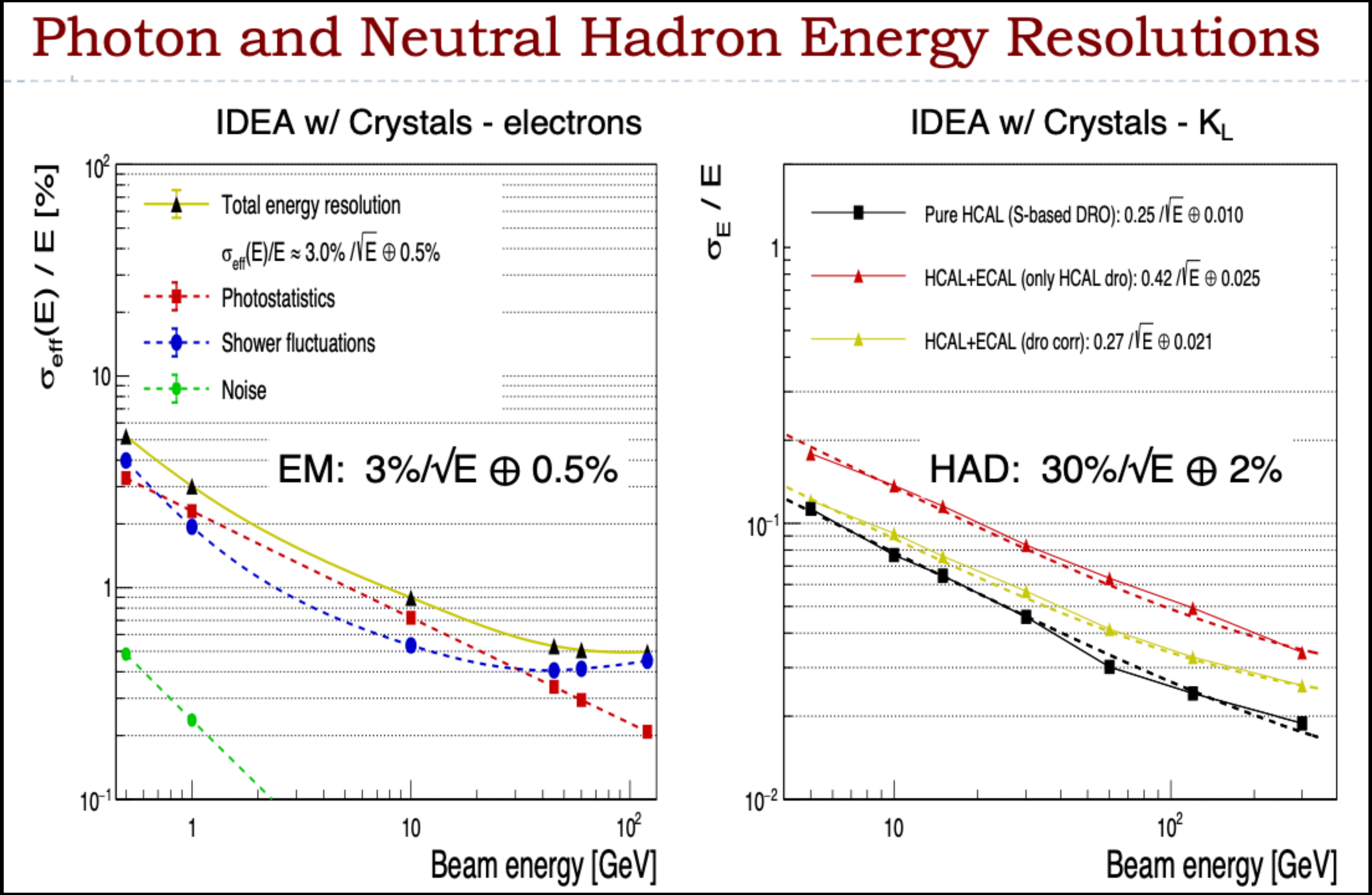
- **Timing layer** $\sigma_t \sim 20$ ps
  - LYSO:Ce crystals (~$1X_0$)
  - 3x3x54 mm³ active cell
  - 3x3 mm² SiPMs (15-20 um)
- **ECAL layer** $\sigma_E/E \sim 3\%/\sqrt{E}$
  - PbWO crystals
  - Front segment (~$6X_0$,~0.2λ,~50 mm)
  - Rear segment (~$16X_0$,~0.7λ,~140 mm)
  - 10x10 mm² crystal
  - 5x5 mm² SiPMs (10-15 um)
  - 3 SiPMs (one on entrance, two on exit)
- Thin solenoid between ECAL and HCAL
- IDEA HCAL



CMS ECAL crystals are 22x22x230 mm

Chris Tully, Sarah Eno, et al

Dual Readout Crystal Calorimeter



TDAQ

Working on expanding the Trigger and DAQ requirements for the CEPC from the CDR into a better understanding of the overall situation

Triggerless running has impact on detector design, power consumption and cooling

TDAQ and Online

Conveners: Prof. Zhen An LIU (IHEP), David Newbold (UKRI), Chris Bee (CERN)

Location: Grand Ballroom C (Online Meeting Room:https://weidijia.zoom.com.cn/j/66965146553)

10:30 **Introduction of the TDAQ requirements** *10'*
Speaker: Prof. Zhen An LIU (IHEP)
Material: Slides

10:40 **Requirements from the LumiCal, Suen Hou** *10'*
Speaker: Suen Hou (IPAS)
Material: Slides

10:50 **Requirements from the Vertex Dedector** *10'*
Speaker: Mr. Wei WEI (IHEP)
Material: Slides

11:00 **Requirements from the TPC** *10'*
Speaker: Dr. Huirong Qi (IHEP)
Material: Slides

11:10 **Requirements from the ECAL & HCAL** *10'*
Speaker: Dr. Yong Liu (IHEP)
Material: Slides

11:20 **Pixel readout technologies and the challenges for the future** *20'*
Speaker: Garcia-Sciveres Maurice (LBNL)
Material: Slides

TDAQ and Online

Conveners: Prof. Zhen An LIU (IHEP), David Newbold (UKRI), Chris Bee (CERN)

Location: Grand Ballroom C (Online Meeting Room:https://weidijia.zoom.com.cn/j/66965146553)

14:00 **Requirements from the Drift Chamber** *10'*
Speaker: Francesco Grancagnolo (INFN-Lecce)
Material: Slides

14:10 **Requirements from DR Calorimeter** *10'*
Speaker: Roberto Ferrari (INFN)
Material: Slides

14:20 **Requirements from the Muon Detector** *10'*
Speaker: Paolo Giacomelli (INFN-Bo)
Material: Slides

14:30 **Requirements from the Silicon Tracker** *10'*
Speaker: Jens Dopke (STFC Rutherford Appleton Laboratory)
Material: Slides

14:40 **LHCb software-only trigger** *15'*
Speaker: Dorothea vom Bruch (LPNHE)

14:55 **ATLAS HLT tracking optimisation** *15'*
Speaker: Mark Sutton (Sussex)
Material: Slides

15:10 **High-Precision Timing Distribution Systems for LHC experiments** *15'*
Speaker: Eduardo Mendes (CERN)
Material: Slides

Series of discussions culminated in the workshop, to continue to followup, led by Zhen An Liu

Software and Reconstruction algorithms

Last year reported that we had started developing a new CEPC software platform (moving away from iLCSoft)

Workshop in Bologna (June 12-13) (FCC, CEPC, ILC, CLIC) kicked-off collaboration: https://agenda.infn.it/event/19047/

Consensus:
- Develop a Common Turnkey Software Stack (Key4hep) for future collider experiments
- Maximize the sharing of software components between experiments

CEPCSW is now fully integrated with Key4hep, and supports application development

See Xingtao Huang’s talk during workshop for details

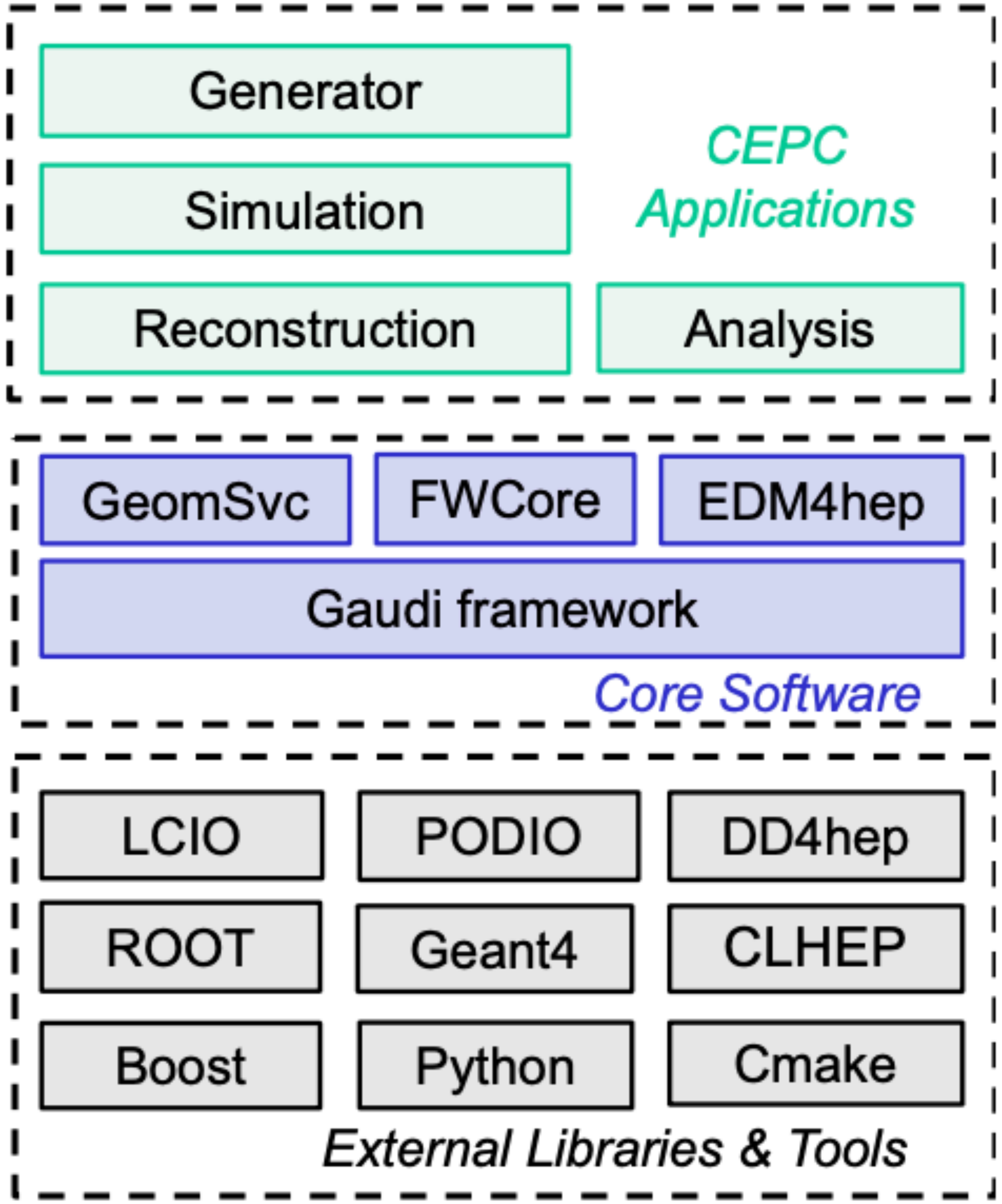
CEPCSW and Core Software

Architecture of CEPCSW

- External libraries
- Core software
- CEPC applications for simulation, reconstruction and analysis

Core software

- Gaudi framework: defines interfaces to all software components and controls their execution.
- EDM4hep: generic event data model for HEP collider experiments
- FWCore :manage event objects defined by EDM4hep.
- GeomSvc :a DD4hep-based geometry service to provide a unified way to access detector geometry data.
- Both FWCore and EDM4hep are Key4hep packages.



4

CEPCSW Progress and Plans

- Further progress made since last CEPC workshop
  - Detector simulation framework was developed and used for the study of CEPC_v4 detector and reference detector
  - ECAL fast simulation with the frozen shower method was developed to speed up the simulation of electromagnetic shower
  - Finished porting of digitization and reconstruction algorithms for trackers and ECAL from Marlin to CEPCSW
  - k4Pandora package was developed to integrate Pandora with CEPCSW and became part of Key4hep software stack
- CEPCSW is managed with Github, deployed with CVMFS, and available for all CEPC Sites

- Plan
  - Adding more components from Key4hep when they are available
  - Non-uniform magnetic field and pile-up of beam backgrounds
  - Development of simulation and reconstruction algorithms for the reference detector (SiTrk+DC, Crystal bar ECal)
  - Add algorithms for building reconstructed particles

Detector International Collaboration

Speakers at CEPC Workshop — Detector Parallel Sessions

** Sessions **	Talks **
Silicon	12
Gaseous	11
Calorimeter	10
MDI	10
TDAQ/online	13
Offline/Software	9
Performance	8

73

Speakers

CEPC workshop

Strasbourg
Karlsruher
Birmingham
Padova
Santa Cruz
IHEP ×3
Pisa
CERN ×2
Milano

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CERN
BNL
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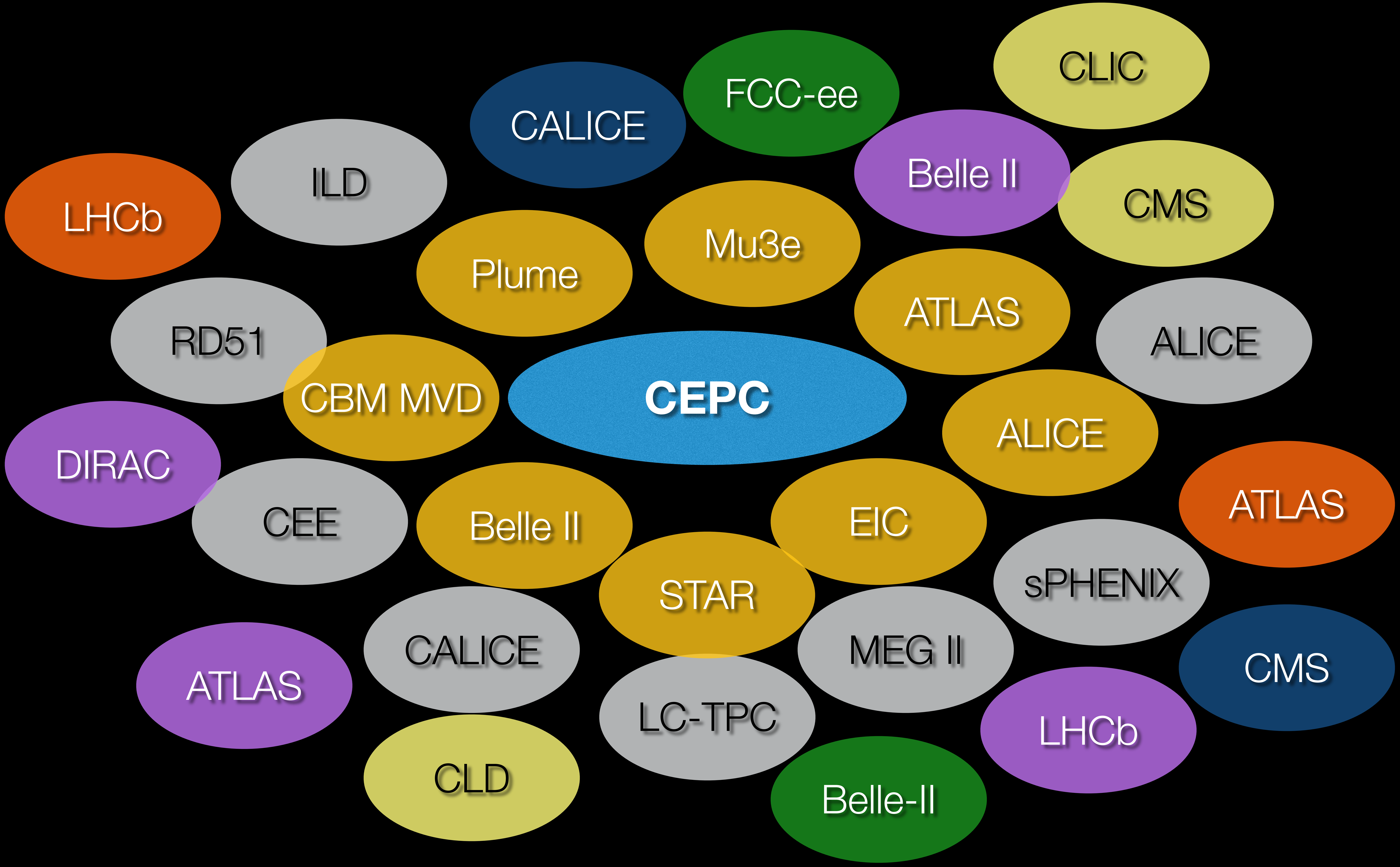
Collaborations

**** Sessions ****

- Silicon
- Gaseous
- Calorimeter
- MDI
- TDAQ/online
- Offline/Software
- Performance



Main Detector and Physics Workshops in 2020

- Jan 18, 2020: Physics Potential Study for Future e+e- Higgs Factories
  - http://iasprogram.ust.hk/hep/2020/meeting_20200118.php
- Jan 16-17, 2020: Mini-workshop: Software and Physics Requirements for e+e- Colliders
  - http://iasprogram.ust.hk/hep/2020/workshop_experiment.php
- Jan 16-17, 2020: Mini-Workshop: Machine Detector Interface for Future Colliders:
  - http://iasprogram.ust.hk/hep/2020/workshop_accelerator.php
- May 28-29, 2020: CEPC MDI Workshop
  - https://indico.ihep.ac.cn/event/11801/
- July 22-23, 2020: Online mini-workshop on a detector concept with a crystal ECAL
  - https://indico.ihep.ac.cn/event/11938/other-view?view=standard
- Aug 28-29, 2020: Workshop on Detector & Accelerator Mechanics
  - https://indico.ihep.ac.cn/event/12324/

Snowmass — Letters of Intent

https://indico.ihep.ac.cn/event/12410/

Detector
14 LoI

Detector R&D
Conveners: Joao Guimaraes Costa, WANG Jianchun, Mr. Manqi Ruan (IHEP)

15:00 **CEPC Detectors Overview LoI** *1'*
CEPC Detector Overview LOI
SNOWMASS21-EF1_EF4-IF9_IF0-260.pdf
Speakers: Joao Guimaraes Costa, Mr. Manqi Ruan (IHEP), WANG Jianchun
Material: Paper | Slides

15:02 **IDEA Concept** *1'*
Speaker: Franco Bedeschi (INFN-Pisa)
Material: Paper

15:03 **Dual Readout Calorimeter** *1'*
Speaker: Roberto Ferrari (INFN)
Material: Paper

15:04 **Drift Chamber** *1'*
Speaker: Franco Grancagnolo
Material: Paper

15:06 **mu-RWELL (muons, preshower)** *1'*
Speaker: Paolo Giacomelli (INFN-Bo)
Material: Paper

15:08 **Time Detector LoI** *1'*
Speaker: Prof. Zhijun Liang (IHEP)
Material: Slides

15:09 **Key4hep** *1'*
Speakers: Dr. Weidong Li (高能所), Dr. Tao LIN (高能所), Prof. Xingtao Huang (Shandong University), Wenxing Fang (Beihang University)
Material: Slides

15:10 **PFA Calorimeter** *1'*
Speakers: Haijun Yang (Shanghai Jiao Tong University), Dr. Jianbei Liu (University of Science and Technology of China), Dr. Yong Liu (Institute of High Energy Physics)
Material: Slides

15:11 **High Granularity Crystal Calorimeter** *1'*
Speaker: Dr. Yong Liu (Institute of High Energy Physics)
Material: Paper | Slides

15:12 **Muon Scintillator Detector** *1'*
Speaker: Dr. Xiaolong Wang (Institute of Modern Physics, Fudan University)
Material: document

15:13 **Vertex LoI** *1'*
Speaker: Prof. Zhijun Liang (IHEP)
Material: Slides

15:15 **MDI LoI** *1'*
Speaker: Dr. Hongbo ZHU (IHEP)
Material: Slides

15:16 **TPC LoI** *1'*
Speaker: Dr. Huirong Qi (Institute of High Energy Physics, CAS)
Material: Slides

15:17 **Solenoid R&D LoI** *1'*
Speaker: Dr. Feipeng NING (IHEP)
Material: Slides

Physics
17 LoI

Open Physics Questions
Convener: Mr. Manqi Ruan (IHEP)

16:00 **EF01-Higgs boson CP properties at CEPC** *3'*
Speakers: Meng Xiao, Xin Shi
Material: Slides

16:03 **EF01-Measurement of branching fractions of Higgs hadronic decays** *3'*
Speaker: Yanping Huang
Material: Slides

16:06 **EF02-Study of Electroweak Phase Transition in Exotic Higgs Decays with CEPC Detector Simulation** *3'*
Speaker: Shu Li
Material: Slides

16:09 **EF03-Feasibility study of CP-violating Phase ϕs measurement via Bs → J/Ψϕ channel at CEPC** *3'*
Speaker: Mingrui Zhao
Material: Slides

16:12 **EF03-Probing top quark FCNC couplings tqγ, tqZ at future e+e- collider** *3'*
Speaker: Peiwen Wu
Material: Slides

16:15 **EF03-Searching for Bs → ϕvv and other b → svv processes at CEPC** *3'*
Speaker: Lingfeng Li
Material: Slides

16:18 **EF04-Measurement of the leptonic effective weak mixing angle at CEPC** *3'*
Speaker: Siqi Yang
Material: Slides

16:21 **EF04-Probing new physics with the measurements of e+e- → W+W- at CEPC with optimal observables** *3'*
Speaker: Jiayin Gu
Material: Slides

16:24 **EF05-Exlusive Z decays** *3'*
Speaker: Qin Qin
Material: Slides

16:27 **EF05-NNLO electroweak correction to Higgs and Z associated production at future Higgs factory** *3'*
Speaker: Zhao Li
Material: Slides

16:30 **EF08-SUSY global fits with future colliders using GAMBIT** *3'*
Speaker: Peter Athron
Material: Slides

16:33 **EF08-Probing Supersymmetry and Dark Matter at the CEPC, FCCee, and ILC** *3'*
Speaker: Tianjun Li
Material: Slides

16:36 **EF09-Search for Asymmetric Dark Matter model at CEPC by displaced lepton jets** *3'*
Speaker: Mengchao Zhang
Material: Slides

16:39 **EF09-Search for t + j + MET signals from dark matter models at future e+e- collider** *3'*
Speaker: Peiwen Wu
Material: Slides

16:42 **EF0910-Dark Matter via Higgs portal at CEPC** *3'*
Speaker: Xin Shi
Material: Slides

16:45 **EF0910-Lepton portal dark matter, gravitational waves and collider phenomenology** *3'*
Speaker: Ke-Pan Xie
Material: Slides

16:48 **RF1-Exploring new physics with Bc →τ v_τ** *3'*
Speaker: Taifan Zheng
Material: Slides

CEPC Physics and Detector Meetings

https://indico.ihep.ac.cn/category/214/

Physics and Detector Meetings

Physics and Simulations	416 events
Vertex	12 events
Tracker	128 events
Calo&Muon	160 events
MDI	52 events
General	138 events
100 TeV Simulation	12 events
Pure Silicon Detector	8 events
Offline Software	1 event
Mechanics	3 events

Regular International Participation to the Plenary Meetings

CEPC Day meeting every month

October 2020

- 21 Oct CEPC Physics and Detector Plenary Meeting
- 14 Oct CEPC Physics and Detector Plenary Meeting

September 2020

- 30 Sep CEPC Physics and Detector Plenary Meeting
- 16 Sep CEPC Physics and Detector Plenary Meeting

August 2020

- 31 Aug CEPC Physics and Detector Snowmass Letters of Intent
- 19 Aug CEPC Physics and Detector Plenary Meeting

July 2020

- 22 Jul CEPC Physics and Detector Plenary Meeting
- 15 Jul CEPC Physics and Detector Plenary Meeting
- 01 Jul CEPC Physics and Detector Plenary Meeting

June 2020

- 10 Jun CEPC Physics and Detector Plenary Meeting
- 03 Jun CEPC Physics and Detector Plenary Meeting

May 2020

- 27 May CEPC Physics and Detector Plenary Meeting
- 20 May CEPC Physics and Detector Plenary Meeting
- 06 May CEPC Physics and Detector Plenary Meeting

April 2020

- 29 Apr CEPC Physics and Detector Plenary Meeting
- 15 Apr CEPC Physics and Detector Plenary Meeting

March 2020

- 25 Mar CEPC Physics and Detector Plenary Meeting

January 2020

- 08 Jan CEPC Physics and Detector Plenary Meeting

Particle Flow Calorimeter Collaborations

- **CEPC HCAL:**
  - **Imad Laktineh**, IPNL, University of Lyon, France (SDHCAL based on GRPC)
  - **Shikma Bressler**, Weizmann Institute of Science, Israel (SDHCAL based on RPWELL)
  - **Enrique Kajomovitz**, Israel Institute of Technology, Israel (SDHCAL based on RPWELL)
  - **Hans-Christian Schultz-Coulon and Wei Shen**, University of Heidelberg, Germany (Scintillator+Steel HCAL)

- **CEPC ECAL:**
  - **Vincent Boudry, Jean-Claude Brient**, LLR, France (Silicon+W ECAL)
  - **Tohru Takeshita, Shinshu University**, Japan (Scintillator+SiPM ECAL)
  - **Wataru Ootani**, University of Tokyo, Japan (Scintilator+W ECAL)
  - **Christoph Tully**, Princeton University, USA (Crystal ECAL)
  - **Sarah Eno**, University of Maryland, USA (Crystal ECAL)

  - **Christophe de la taille**, CNRS/IN2P3 Micro-Electronics Design Lab, Ecole Polytechnique Palaiseau, France (Readout electronics)

Silicon Vertex Detector

- CMOS pixel sensor development:
  - Marc Winter, Christine Hu-Guo, IPHC Strasburg, France
  - Sebastian Grinstein, Raimon Casanova, IFAE, Barcelona, Spain
  - ALICE, indirectly through CCNU

- SOI pixel sensor development
  - KEK, Japan

- Vertex Detector Prototype (MOST2):
  - CMOS Pixel Sensor development
    - Barcelona, IFAE
  - Mechanics and services
    - Liverpool, Oxford, RAL, QMU (UK)
    - Univ. Massachusetts (USA)

Trackers

- **Time Projection Chamber**
  - Paul Colas, Aleksan Roy, Stephan Anne., CEA-Saclay IRFU group, France (FCPPL)
  - Keisuke Fujii's group, KEK, Japan
  - Joined LC-TPC in Dec 2016
    - DESY test beam in 2018
- **Silicon Tracker**
  - Full Silicon Tracker Design
    - Weiming Yao, Berkeley (USA)
    - Sergei Chekanov, Argonne (USA)
  - Tracker Demonstrator
    - Harald Fox (Lancaster), Yanyan Gao (Edinburgh), Roy Lemmon (Daresbury), Tim Jones (Liverpool)
    - Ivan Peric (KIT)
    - Based on ALICE and ATLAS technology

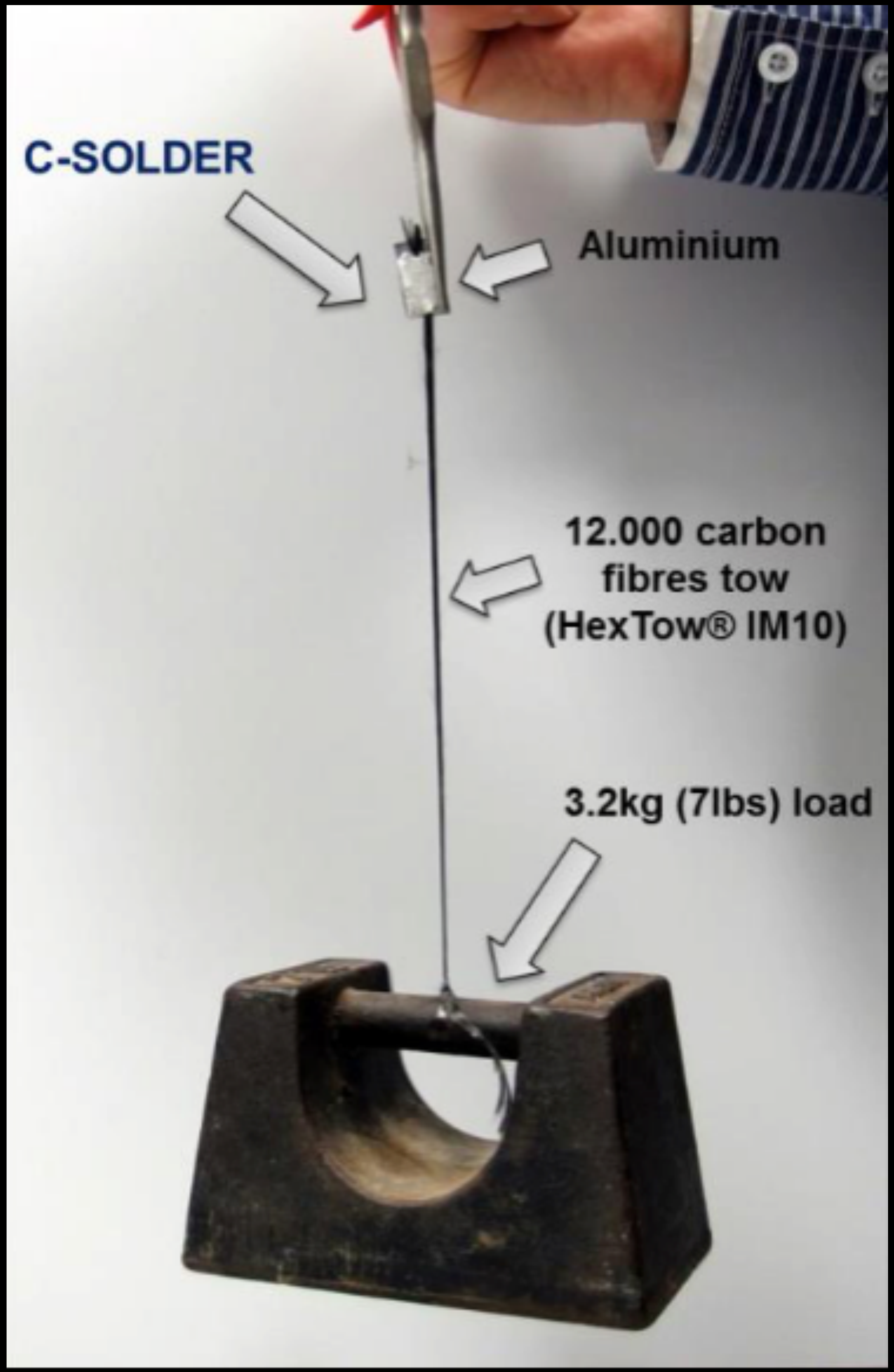
- **China**
  - Institute of High Energy Physics, CAS
  - Shangdong University
  - Tsinghua University
  - University of Science and Technology of China
  - Northwestern Polytechnical University
  - T.D. Lee Institute – Shanghai Jiao Tong University
  - Harbin Institute of Technology
  - University of South China
- **Italy**
  - INFN Sezione di Milano, Università di Milano e Università dell'Insubria
  - INFN Sezione di Pisa e Università di Pisa
  - INFN Sezione di Torino e Università di Torino
- **Germany**
  - Karlsruhe Institute of Technology
- **UK**
  - University of Bristol
  - STFC – Daresbury Laboratory
  - University of Edinburgh
  - Lancaster University
  - University of Liverpool
  - Queen Mary University of London
  - University of Oxford
  - University of Sheffield
  - University of Warwick

IDEA: Silicon

- Active pixel detectors (INFN: Milano, Torino)
  - SEED and ARCADIA (1 M€ INFN grant)
    - Low power, high resolution, stitching
    - First prototypes by late 2020 → test on beam
  - DAQ development for test beam
    - Potential collaboration with China (FEST grant supports travel to China)
- Active and passive CMOS for Si wrapper (INFN: Milano)
  - Continuation of ATLAS phase 2 upgrade work
- EU grants:
  - FEST (travel 4 yr), AIDA++ (applied)
- International collaboration:
  - UK-Oxford, ETH, Zurich university, (IHEP-China?)

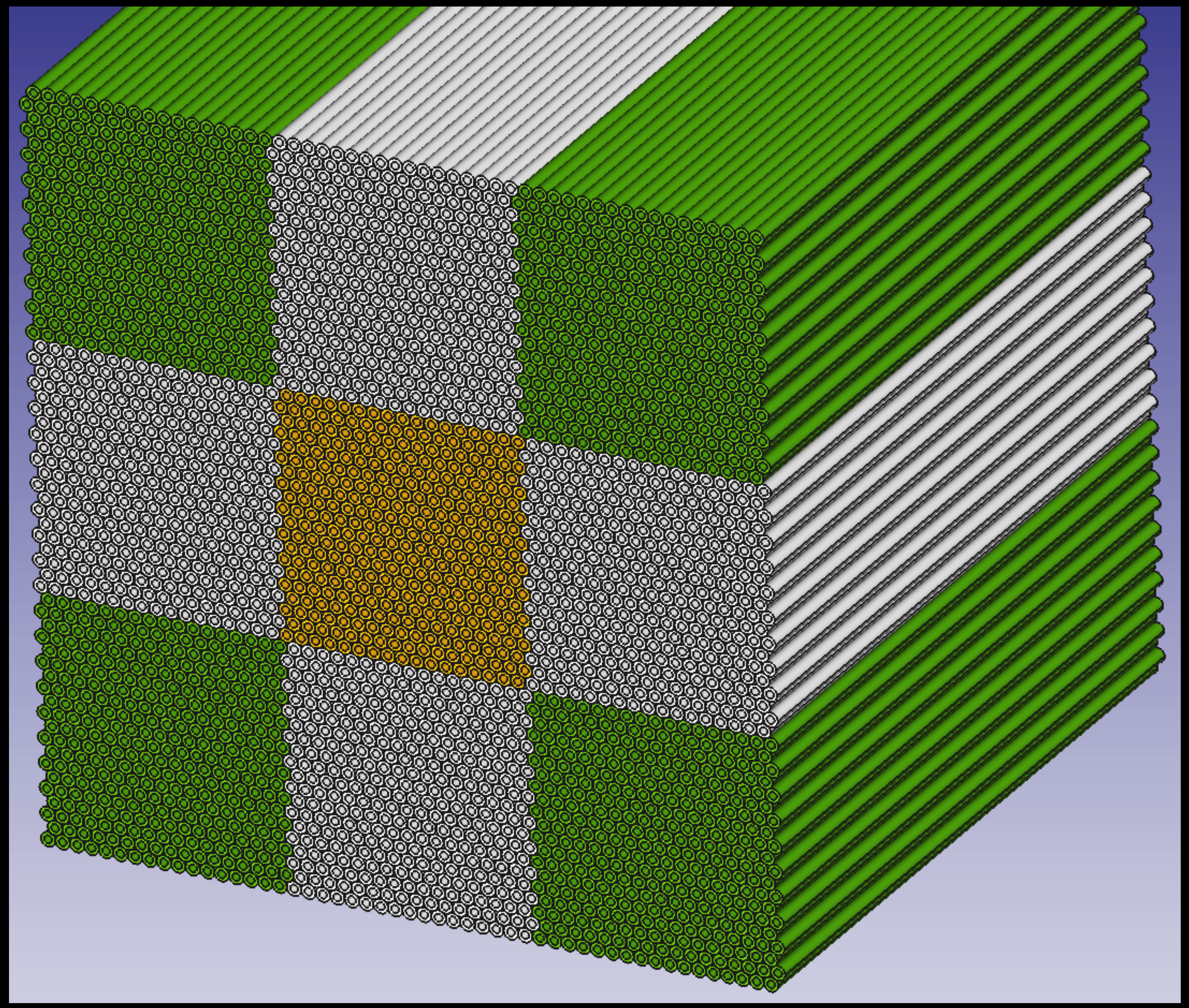
IDEA: Drift Chamber

- Drift chamber (INFN: Lecce, Bari)
  - Full length prototype
    - C-fiber wires
    - Cluster counting electronics
    - Non-flammable gases
- EU grants:
  - CREMLIN2, AIDA++ (Applied)
- International collaboration:
  - (BINP, Novosibirsk)



IDEA: DR calorimeter

- Full EM containment prototype (INFN: Pavia, Milano, Pisa)
  - 10 cm x 10 cm x 100 cm
    - Mechanics with metal capillaries 2 mm OD, 1.1 mm ID
    - 9 towers. Central tower read out with SiPM. Remaining with PMT.
    - Alpha-tester compact CAEN electronics (FERS system)



- EU grants:
  - AIDA++ (applied)
- Cofunded by INFN, UK, Croatia
- International collaboration:
  - UK: University of Sussex, RBI - Croatia, South Korea

IDEA: μRwell chambers

INFN Istituto Nazionale di Fisica Nucleare

- Development of large area chambers with industrial partners ELTOS and TECHTRA (INFN: Bologna, Ferrara, Frascati)
  - μRwell technology
  - Test μRwell 2D readout
  - R&D on DLC+Cu sputtering with USTC (China)
- EU grants:
  - ATTRACT, CREMILN2, AIDA++(Applied)
- International collaboration:
  - USTC – China, BINP-Novosibirsk

Key R&D Issues Moving Forward

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	1.8	0.036	-
Number of particles/bunch N_e (10^{10})	15.0	16.3	8.0	16.1
Bunch number (bunch spacing)	242 (0.68μs)	214 (0.7 μs)	12000	10870 (27ns)
Beam current (mA)	17.4	16.8	461.0	841.0
Synchrotron radiation power /beam (MW)	30	-	16.5	30
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	0.15/0.001
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.00[illegible]	0.68/0.0014	[illegible]18/0.[illegible]016	0.52/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	15.0/0.037	6.0/0.04	8.8/0.04
Bunch length σ_z (mm)	[illegible]	[illegible]	[illegible]	[illegible]
Lifetime (hour)	0.67	0.35	2.1	[illegible]
Luminosity/IP L (10^{34} cm^{-2}s^{-1})	2.93	5.0	32.1	101.1

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

Luminosity increase factor: × 1.8 × 3.2

Some key R&D topics moving forward

- Machine Detector Interface
- Luminosity meter (LumiCal)
- Silicon Vertex (continue work on material budget versus resolution versus cooling)
  - Services design and integration

Some key R&D topics moving forward

- Machine Detector Interface
- Luminosity meter (LumiCal)
- Silicon Vertex (continue work on material budget versus resolution versus cooling)
  - Services design and integration
- Tracker

Trade off: Transparency <—> reliability/resolution

  - Time Projection Chamber
    - Finalize investigation of Ion back flow and field distortion at the Z pole and 2 Tesla
    - Follow up on the Pixel TPC possibility
  - Drift Chamber
    - Can it cope with the high rates at the Z pole? Enough resolution?
    - Can provide PID with dE/dx measurement
  - Full silicon tracker → need manpower increase to exploit this option
    - Are we adding too much material?
    - Need to add detector for particle identification

Some key R&D topics moving forward

- Calorimetry
  - ECAL, HCAL, DR
    - Finalize evaluation of the crystal calorimeter option
    - Cost versus physics performance
    - Cooling of PFA calorimeter? versus performance?

Some key R&D topics moving forward

- Calorimetry
  - ECAL, HCAL, DR
    - Finalize evaluation of the crystal calorimeter option
    - Cost versus physics performance
    - Cooling of PFA calorimeter? versus performance?

- Muon System optimization
  - Optimize number of layers

Optimization of detectors

Not an easy task without definite detectors/collaborations target

- Use a mixture of fast simulation and full simulation
- Need to consider engineering aspects
- Need to consider costing issues

Final remarks

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

Now considering new ideas and developing new tools

Need more time to explore alternatives and test new ideas

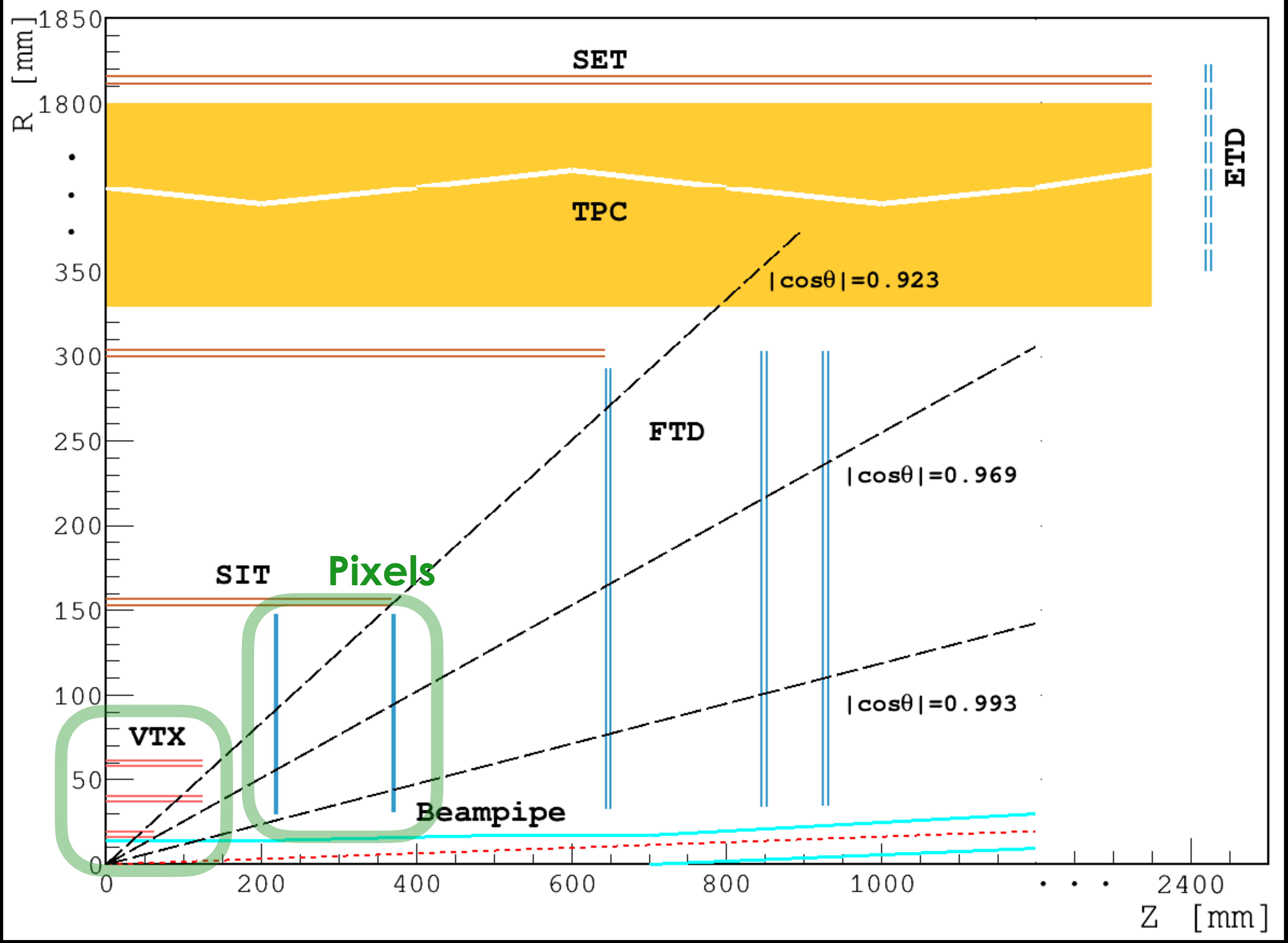
Key accelerator and detector technologies R&D continues and are put to prototyping

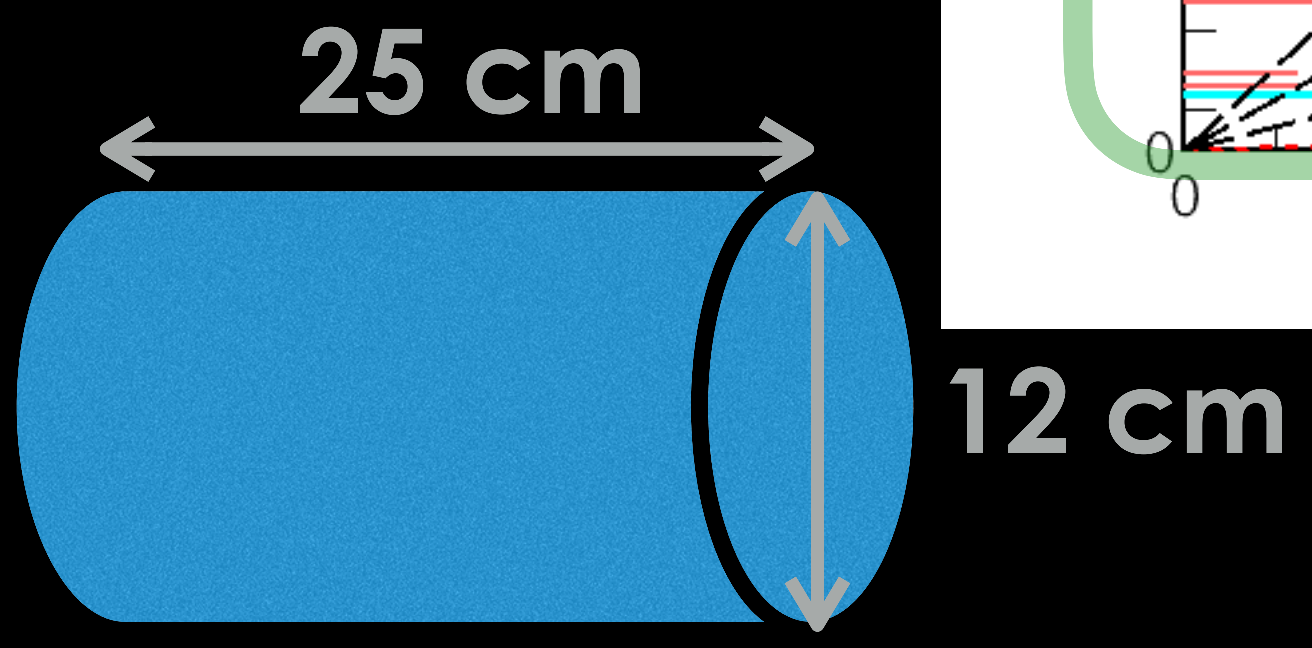
Need to coordinate with engineers to study real detector feasibility

Need to expand international collaboration

Tracker Detector – PFA Detector

Tracker material budget/layer: ~0.50-0.65% X/X_0





Required resolution

$\sigma_{SP} < 7\ \mu m$

Sensor technology

1. Microstrip sensors double layers:
   - stereo angle: 5°-7°
   - strip pitch: 50 μm
2. Large CMOS pixel sensors (CPS)

HV-CMOS research on-going: SUPIX-1 / -2 sensor prototypes

Power and Cooling

1. DC/DC converters
2. Investigate air cooling

Total Silicon area ~ 68 m²

Extensive opportunities for international participation

CEPC CDR: Particle Flow Conceptual Detector

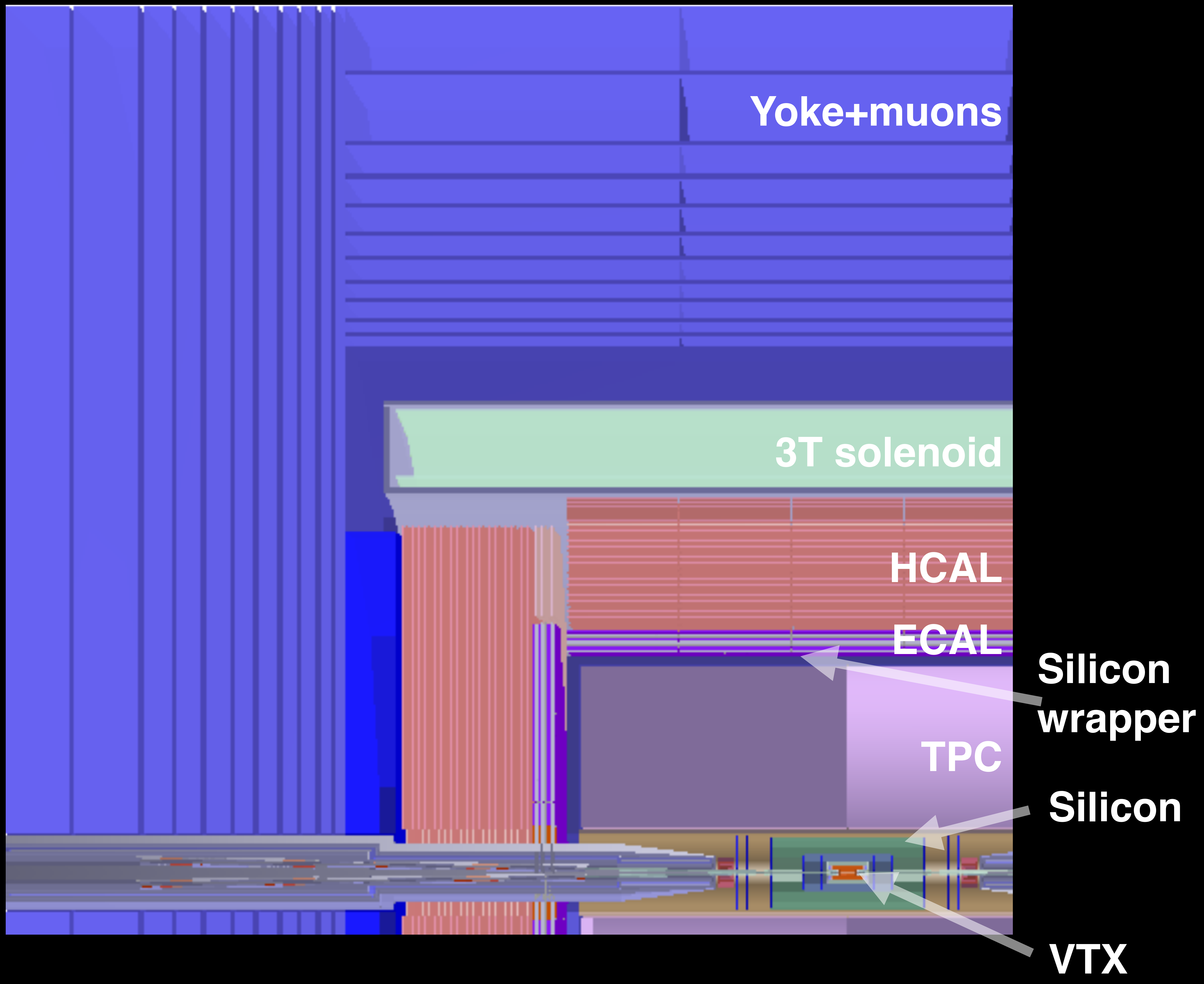
Major concerns being addressed

1. **MDI region highly constrained**
   L* = 2.2 m
   Compensating magnets

2. **Low-material Inner Tracker design**

3. **TPC as tracker in high-luminosity Z-pole scenario**

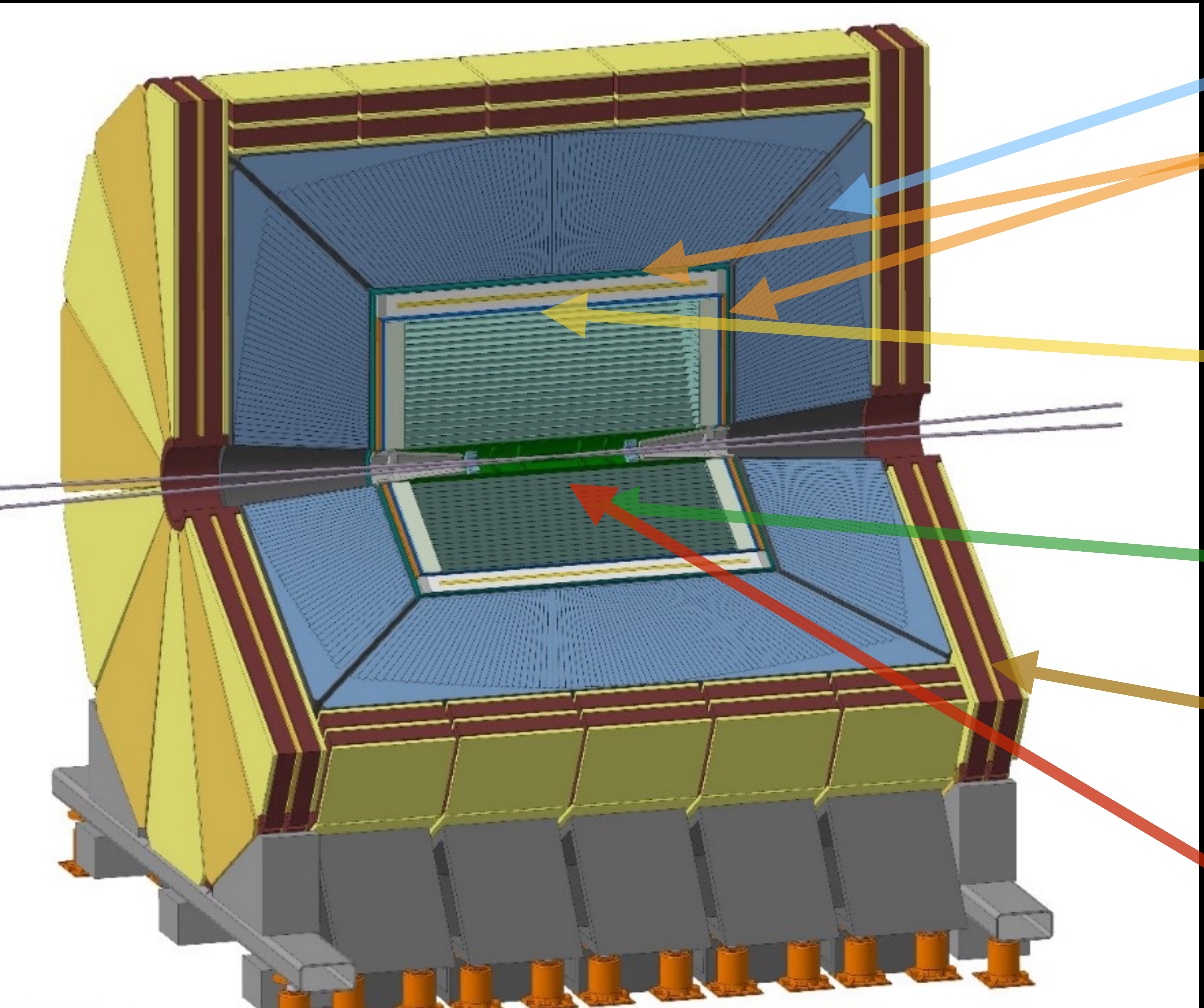
4. **ECAL/HCAL granularity needs**
   Passive versus active cooling
   Electromagnetic resolution



Magnetic Field: 3 Tesla

CEPC CDR: IDEA Conceptual Detector (CEPC + FCC-ee)

Inspired on work for 4th detector concept for ILC



Calorimeter outside the coil

* Dual-readout calorimeter: 2 m/8 λ_{int}
* Preshower: ~1 X_0

Magnet: 2 Tesla, 2.1 m radius

Thin (~ 30 cm), low-mass (~0.8 X_0)

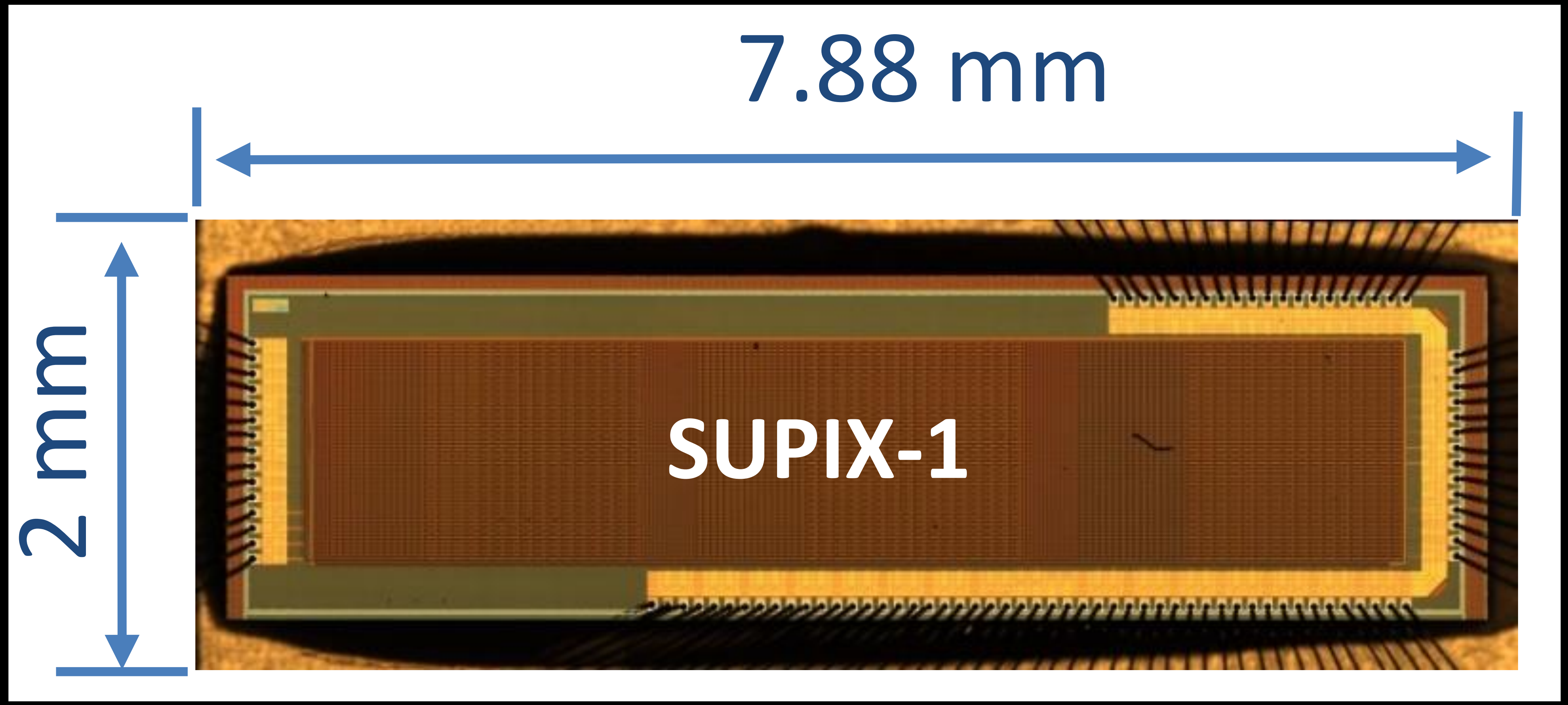
* Drift chamber: 4 m long; Radius ~30-200 cm, ~ 1.6% X_0 , 112 layers
* (yoke) muon chambers

Vertex: Similar to CEPC default

CMOS Large-Pixel Sensors for Tracker

SUPIX1 (Shandong University PIXel)

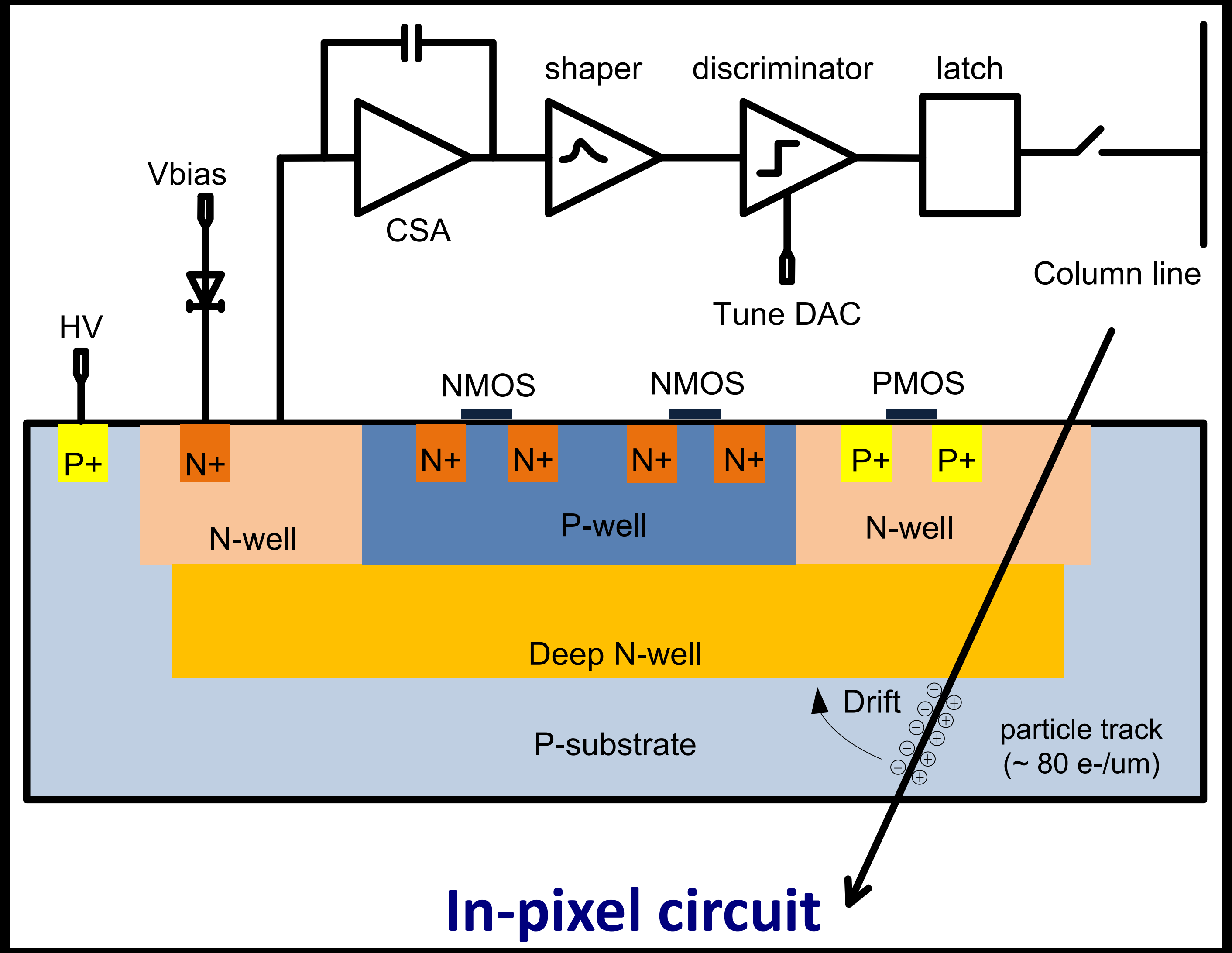
Produced and under test



- Matrix: 64 × 16
- Rolling shutter readout mode
- 16 parallel analog outputs
- Sensitive area: 2 × 7.88 mm²

SUPIX2

Submitted to SMIC in November



- Matrices: 32 × 16
- Rolling shutter readout mode
- 16 parallel analog outputs
- Pixel sizes: 60×60 μm², 60×180 μm²

MDI Assembly and Installation

Engineering studies started | **Different scenarios under study**

Silicon tracker assembly pushed from one side

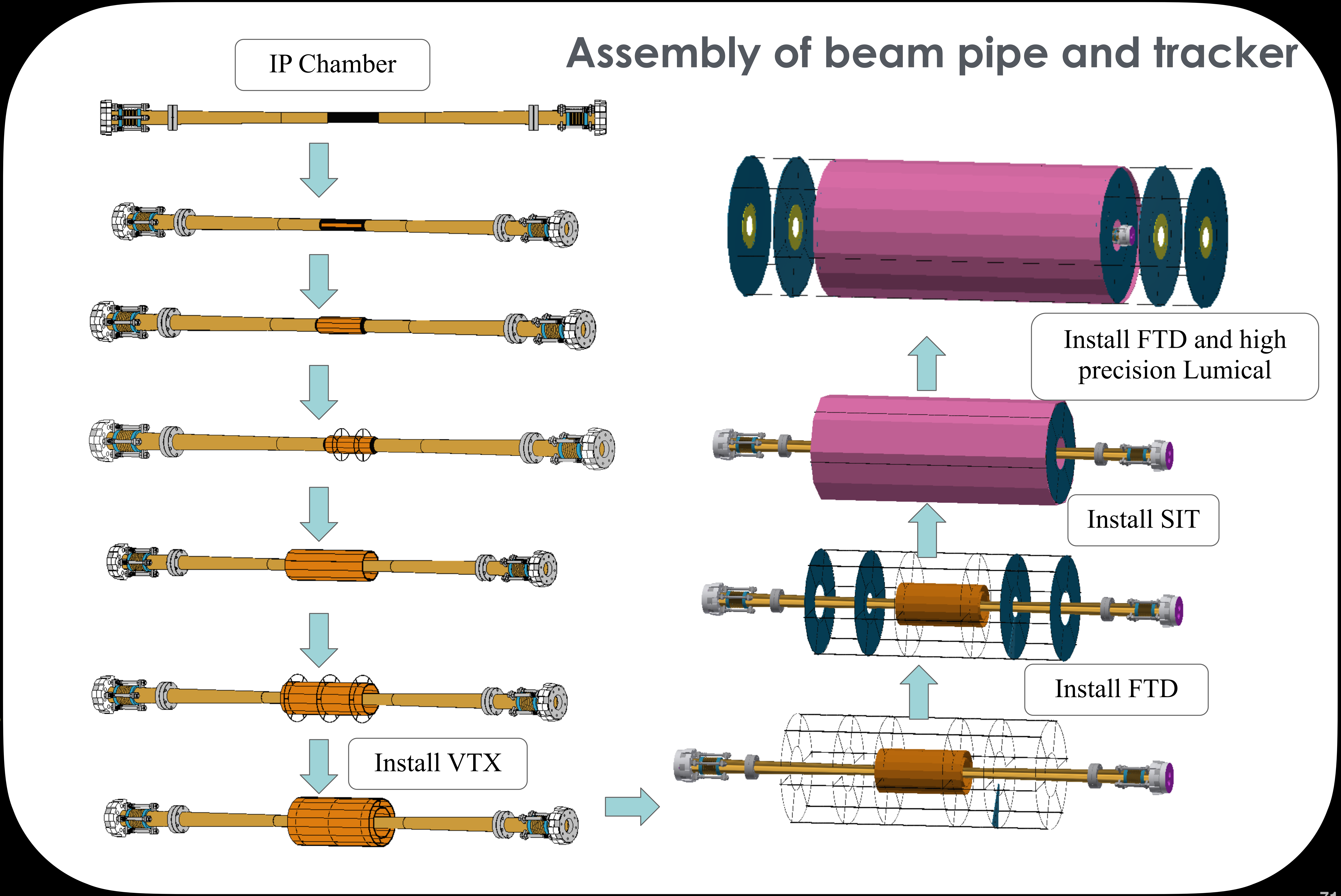
Vacuum connections closed remotely

MDI Assembly and Installation

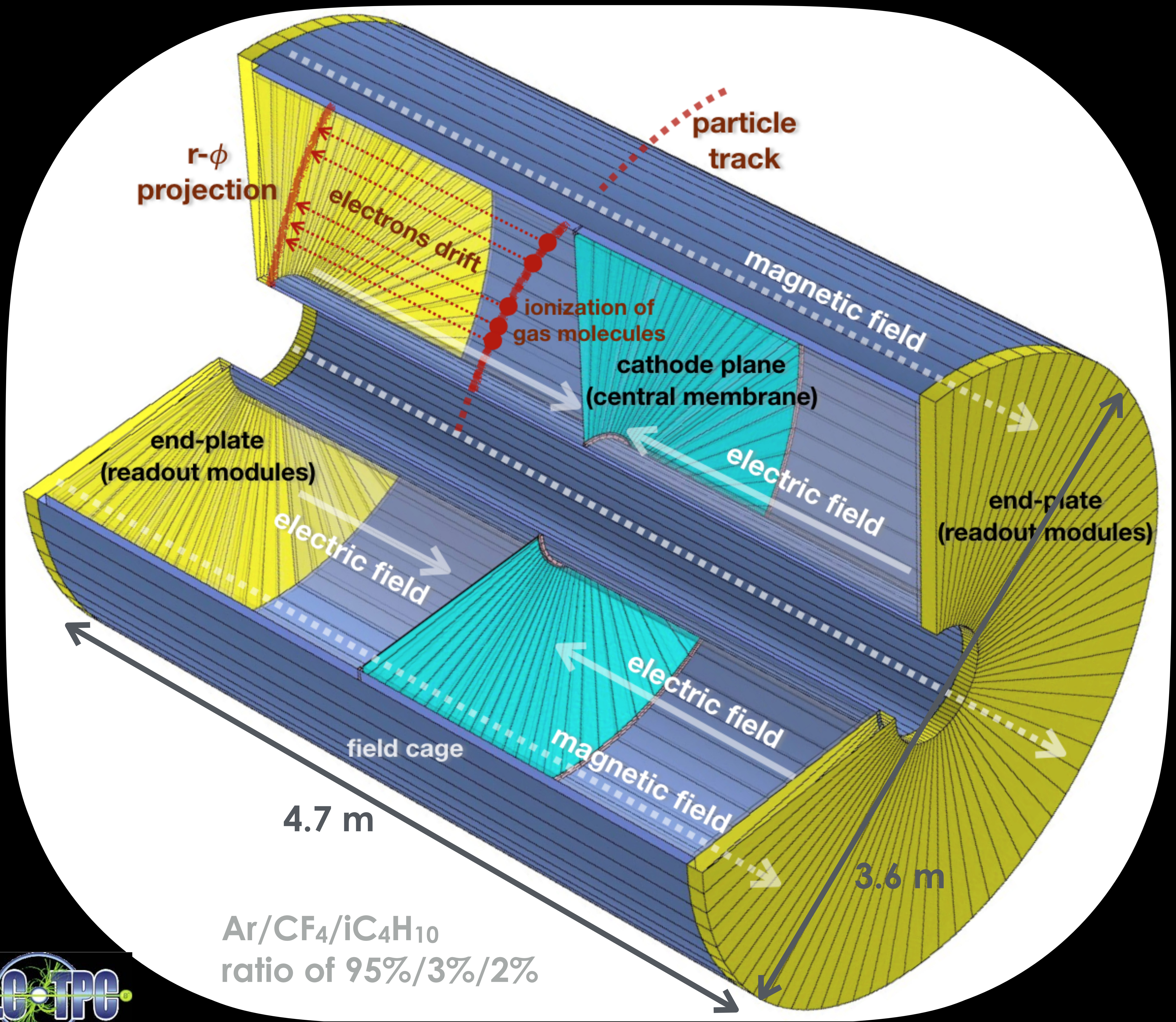
Engineering studies started

Different scenarios under study

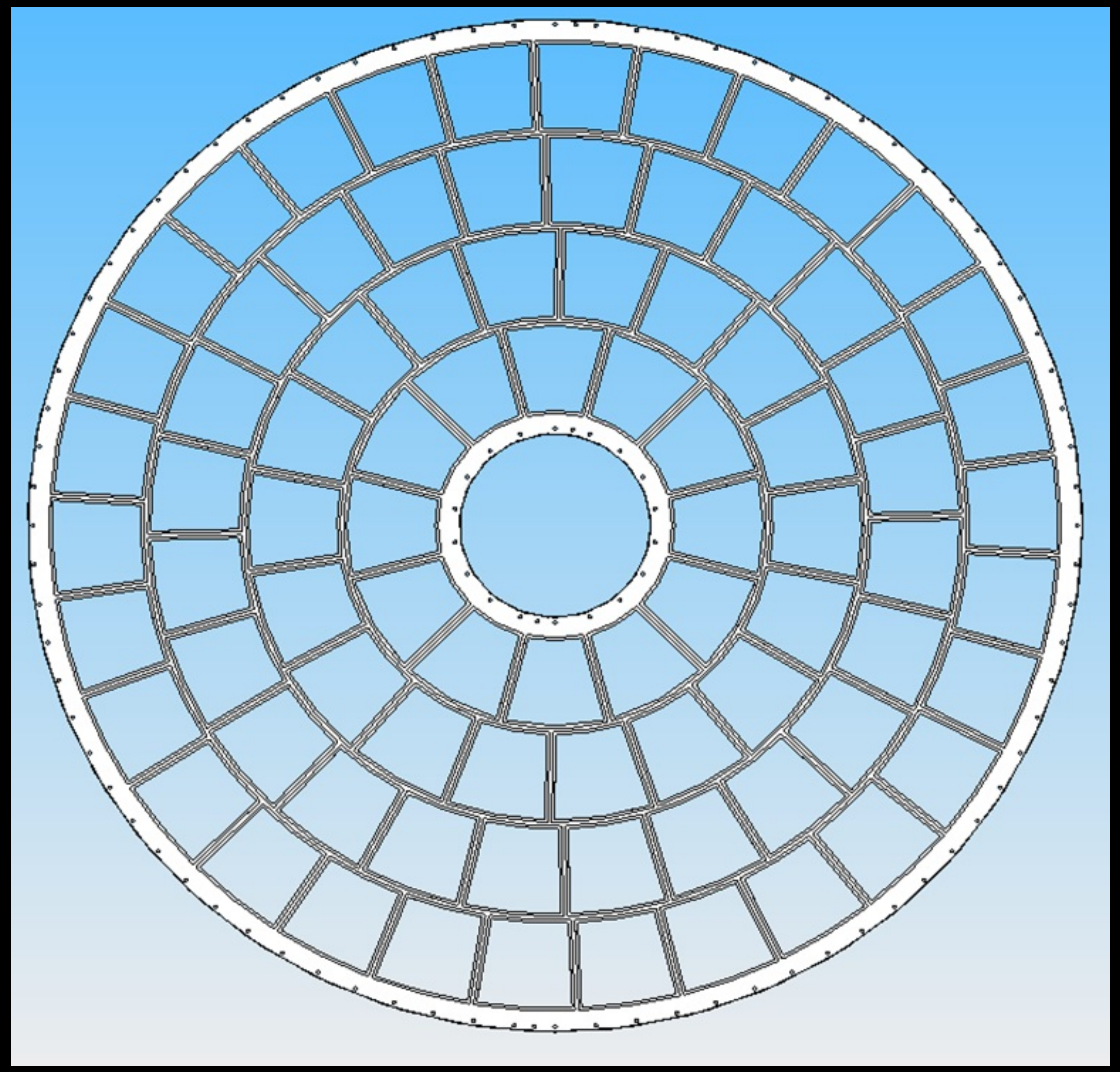
Needs close collaboration between detector designers and MDI engineers



Time Projection Chamber (TPC)

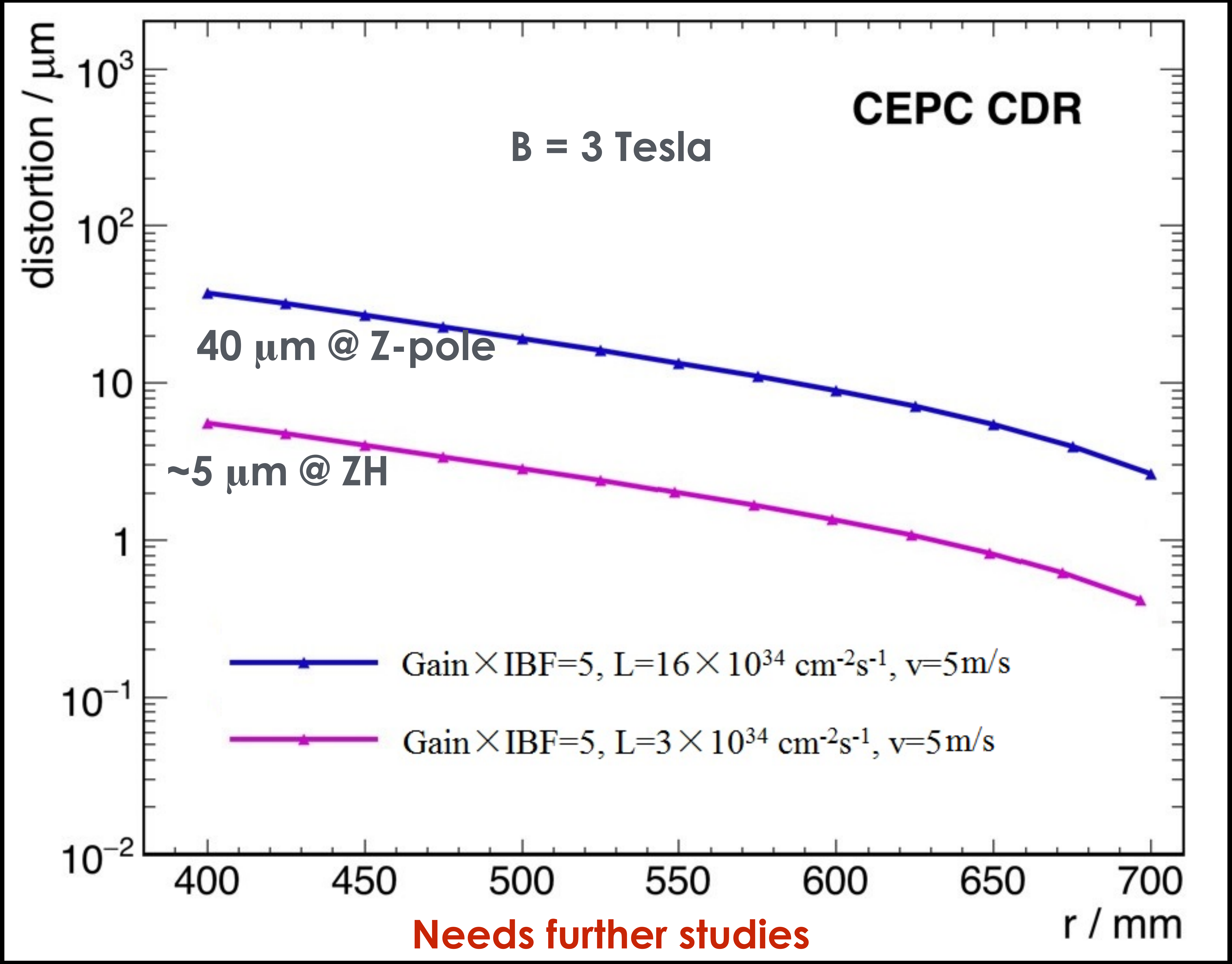


- **Allows for particle identification**
- **Low material budget:**
  - <1% X_0 in r
  - 10% X_0 for readout endcaps in Z



Readout by: Micro-Pattern Gas Detector (MPGD)

Time Projection Chamber (TPC) – Challenges



- Position resolution: ~100 μm in rϕ
- dE/dx resolution: 5%

- 3 Tesla magnetic field —> reduces diffusion of drifting electrons
- Problem: Ion Back Flow —> track distortion

Assumes, for each primary ionization, 5 ions backflow from readout into main gas system

Hybrid: GEM and Micromegas readout

Mini-workshop, Hong Kong, IAS Jan 2019: http://iasprogram.ust.hk/hep/2019/workshop_cc.php

Drift Chamber Option – IDEA Concept

Lead by Italian Colleagues

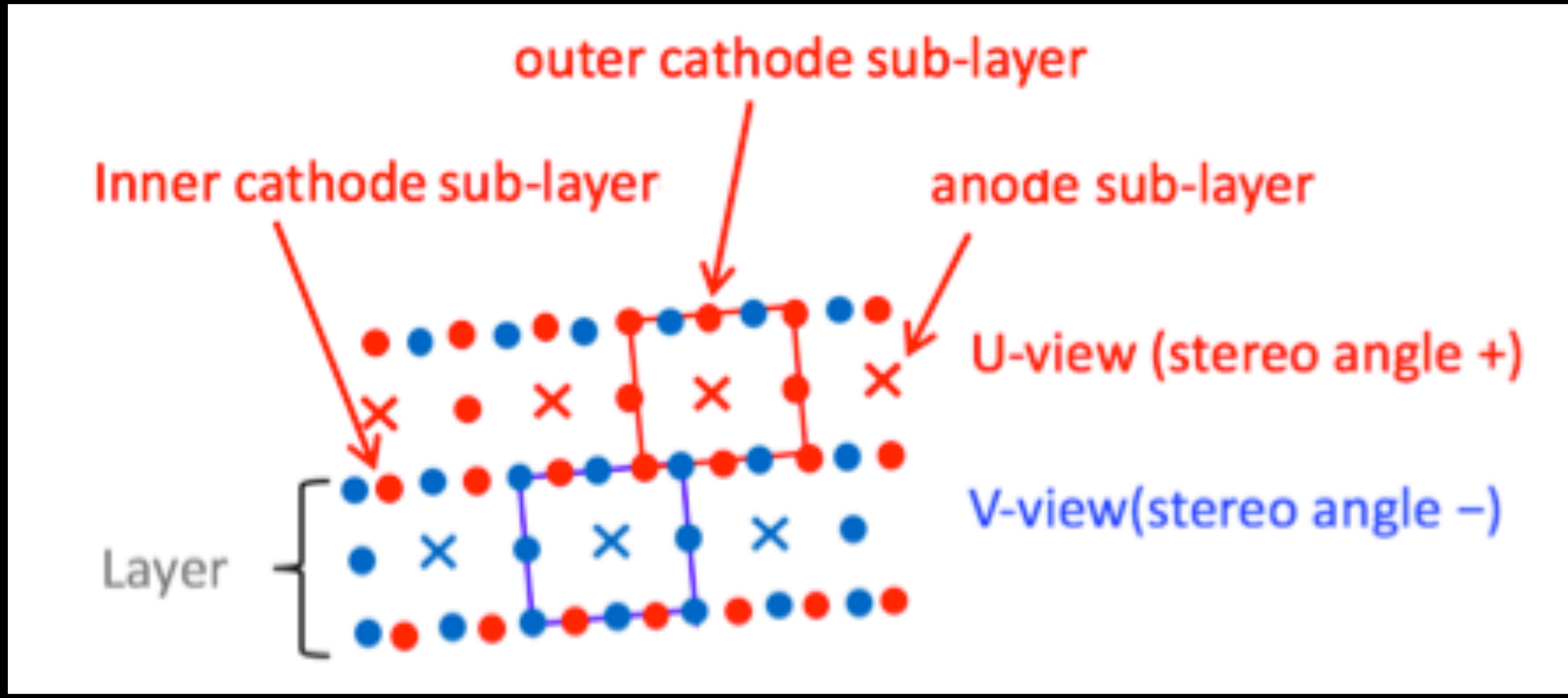
Low-mass cylindrical drift chamber

Follows design of the KLOE and MEG2 experiments

- Length: 4 m
- Radius: 0.35- 2m
- Gas: 90%He – 10%iC_4H_{10}
- Material: 1.6% X_0 (barrel)

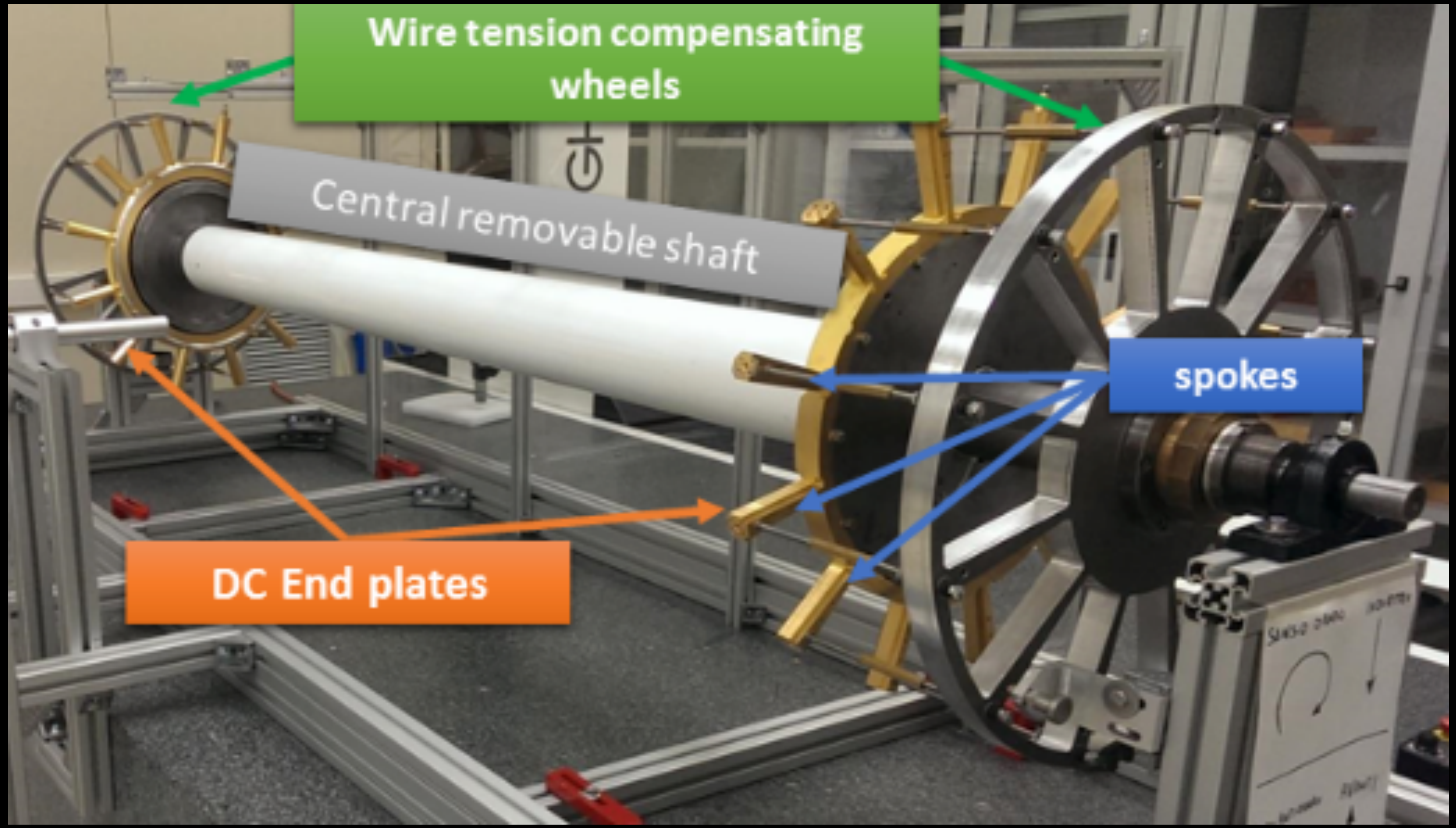
- Spatial resolution: < 100 μm
- Max drift time: ~350 nsec
- Cells: 56,448

Layers: 14 SL × 8 layers = 112
Cell size: 12 - 14 mm



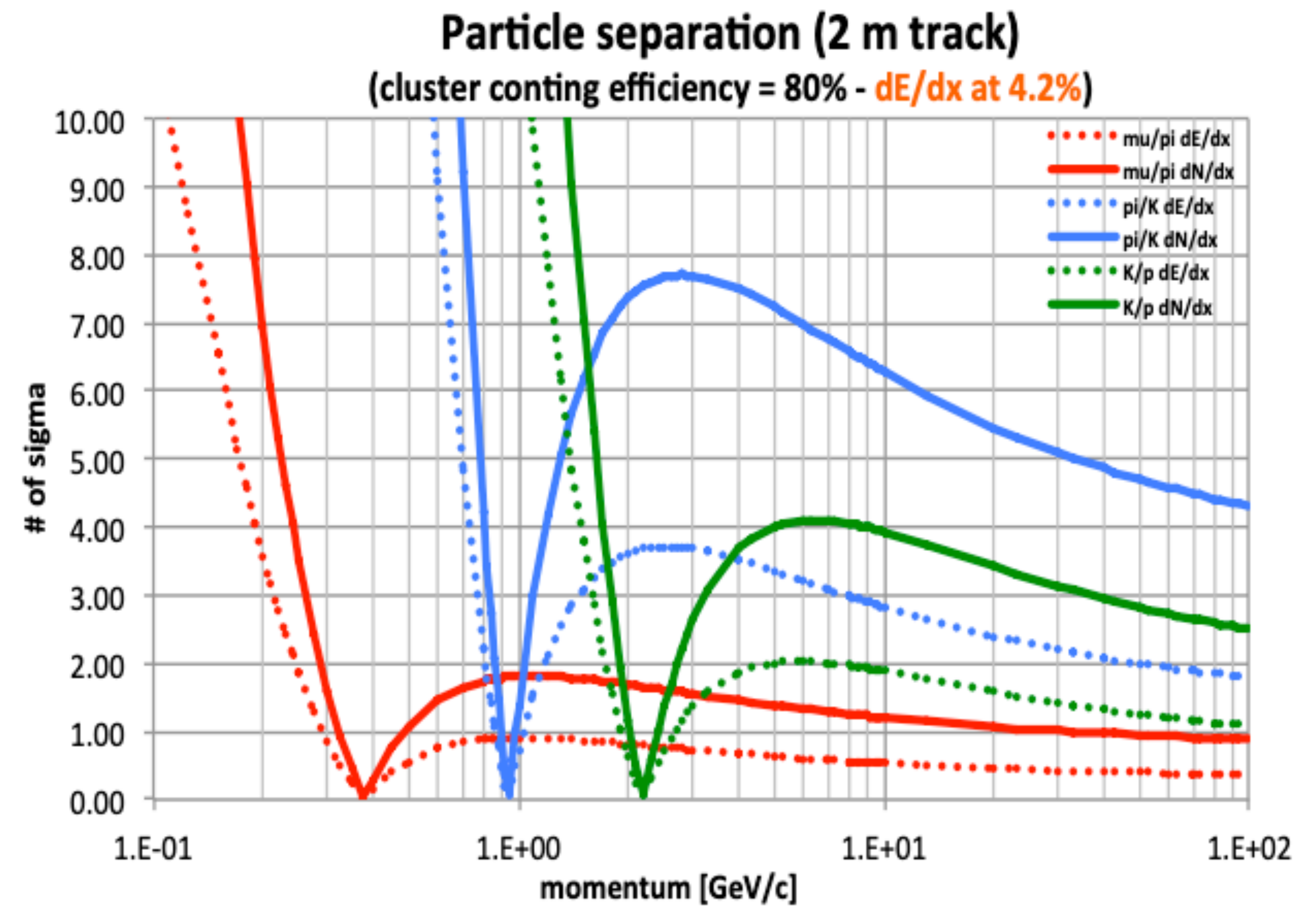
Stereo angle: 50-250 mrad

MEG2 chamber (naked)



Drift Chamber Considerations

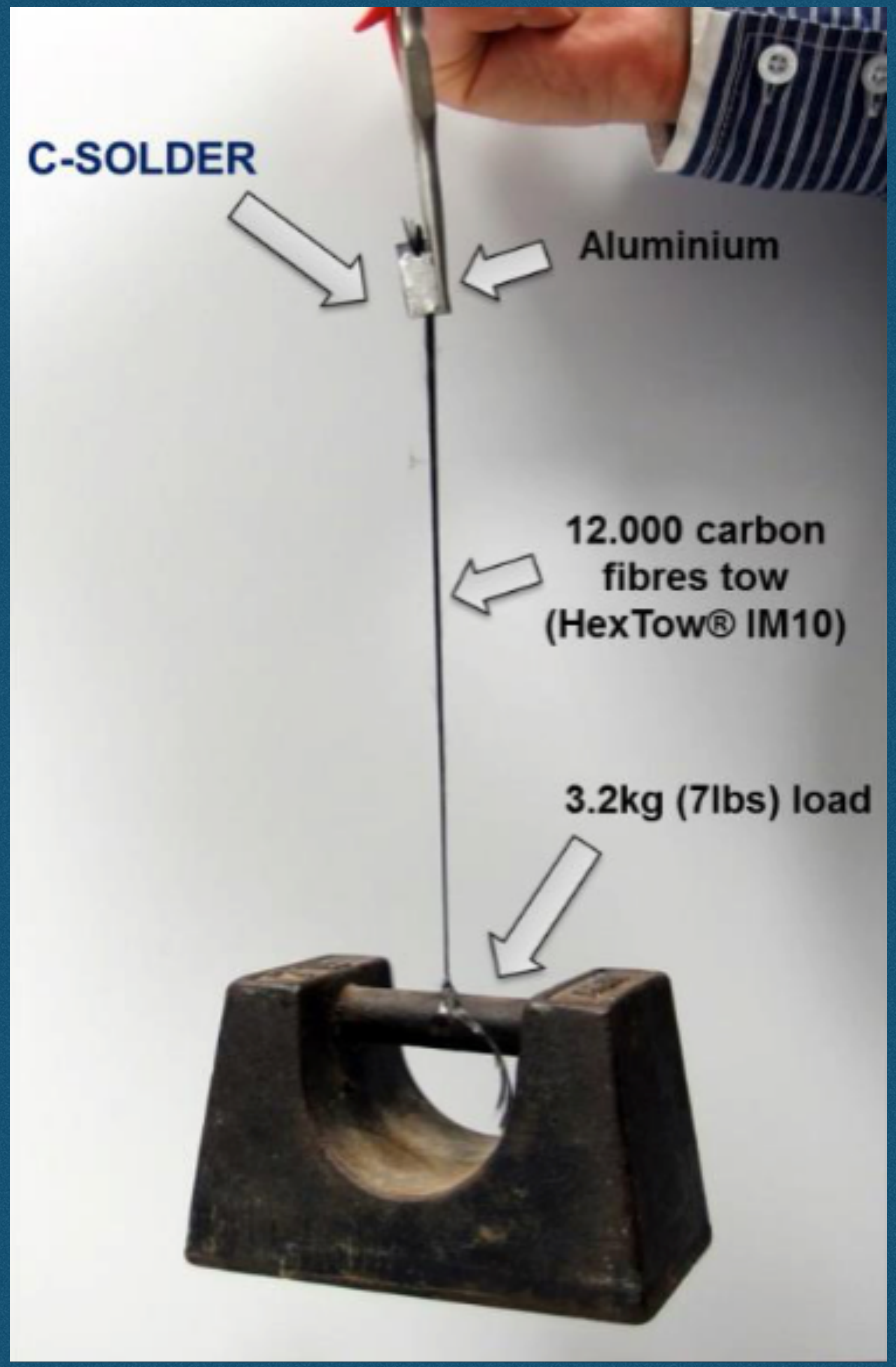
Particle Identification



Wire tension, 25 g, $T > 0.32$ N

Aluminium and Tungsten wires marginal

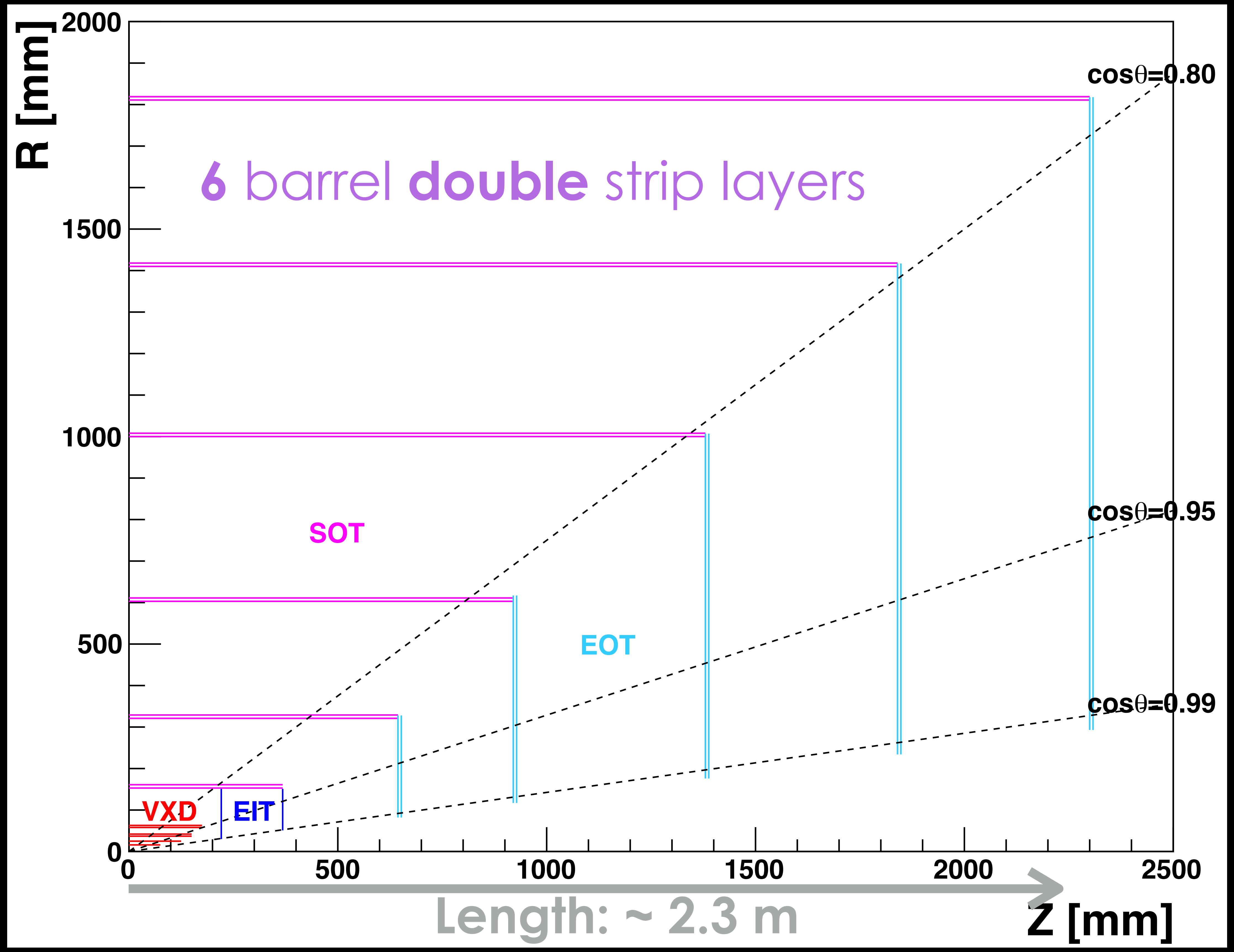
Exploring 35 μm Carbon monofilaments



Full Silicon Tracker Concept

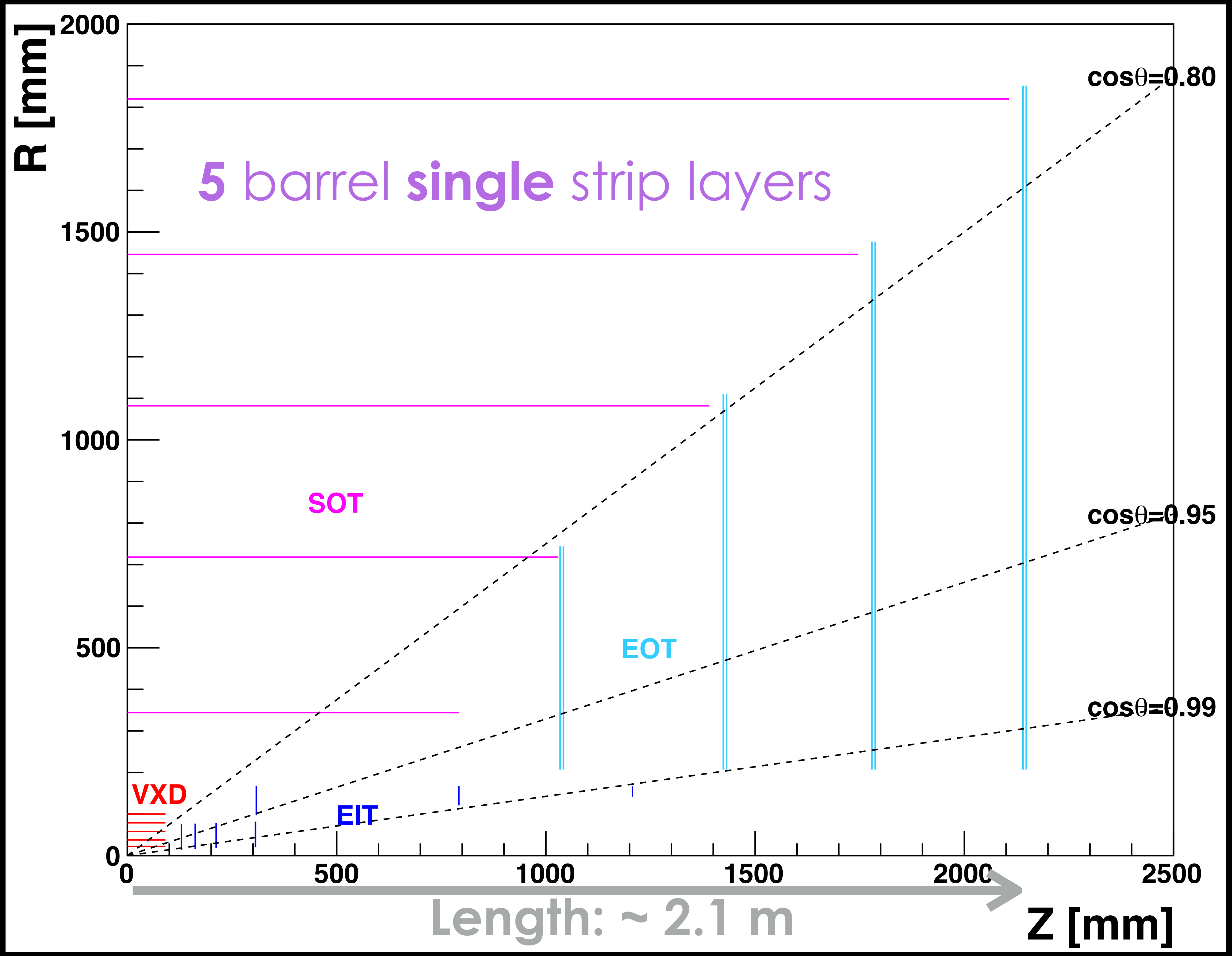
Replace TPC with additional silicon layers

FST layout: Rad length up to 7%



Radius ~ 1.8 m

FST2 layout: Rad length up to 10%



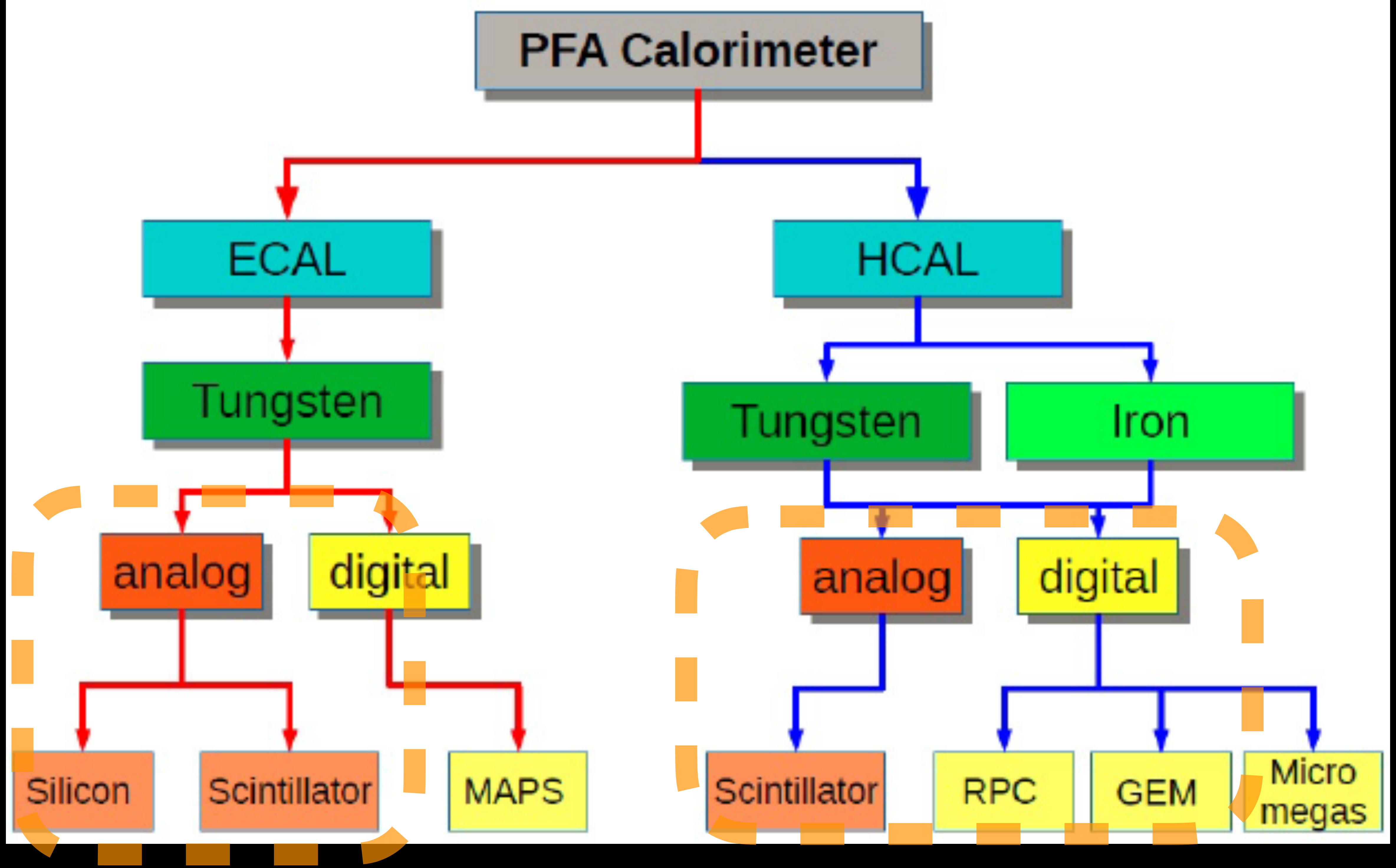
Proposed by Berkeley and Argonne

Drawbacks: higher material density and limited particle identification (dE/dx)

Calorimeter options

Chinese institutions have been focusing on Particle Flow calorimeters

R&D supported by MOST, NSFC and IHEP seed funding



High Granularity

Electromagnetic	ECAL with Silicon and Tungsten (LLR, France) ECAL with Scintillator+SiPM and Tungsten (IHEP + USTC)
Hadronic	SDHCAL with RPC and Stainless Steel (SJTU + IPNL, France) SDHCAL with ThGEM/GEM and Stainless Steel (IHEP + UCAS + USTC) HCAL with Scintillator+SiPM and Stainless Steel (IHEP + USTC + SJTU)

Newer Options

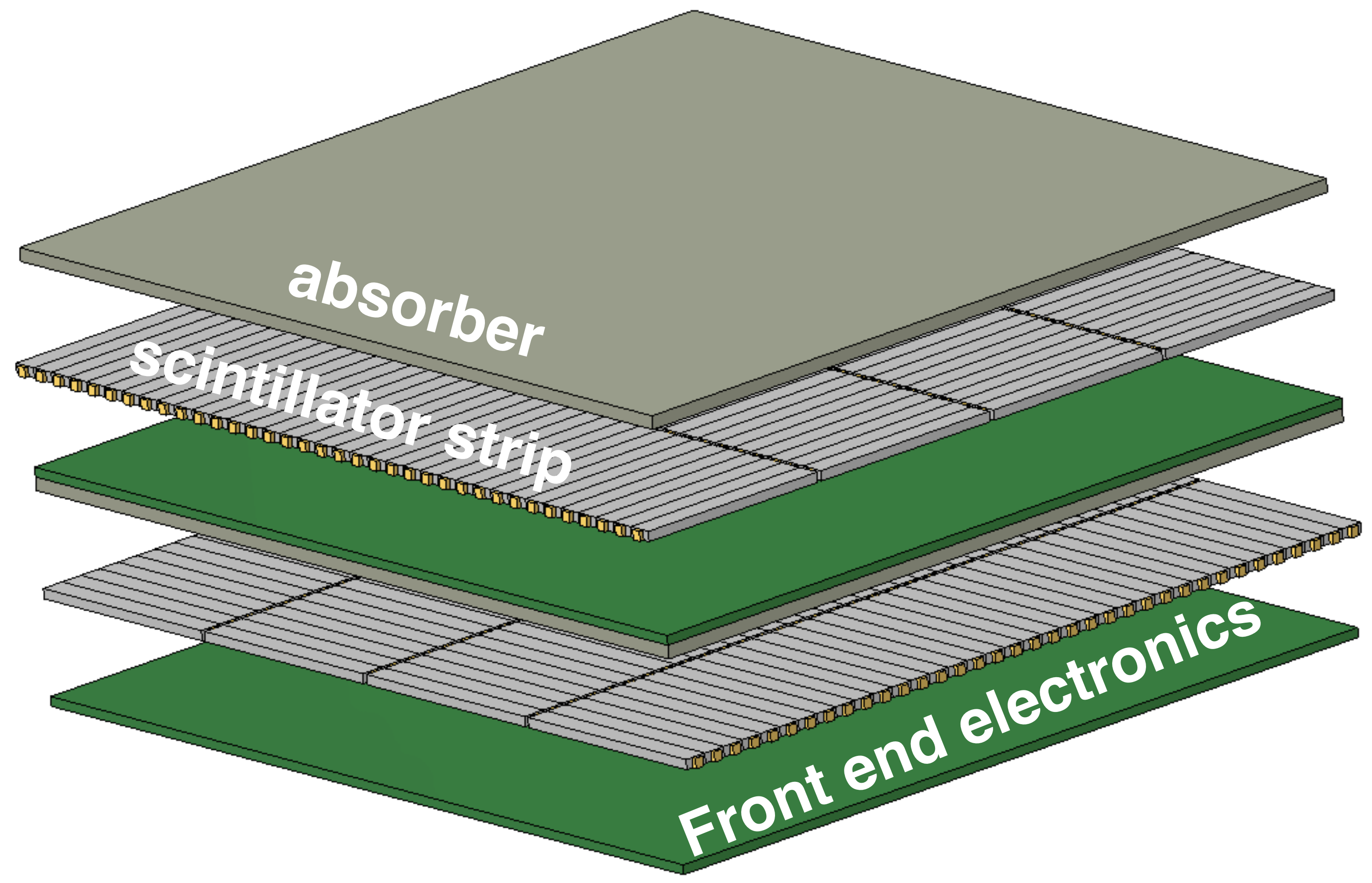
Some longitudinal granularity	Crystal Calorimeter (LYSO:Ce + PbWO) Dual readout calorimeters (INFN, Italy + Iowa, USA) — RD52

ECAL Calorimeter — Particle Flow Calorimeter

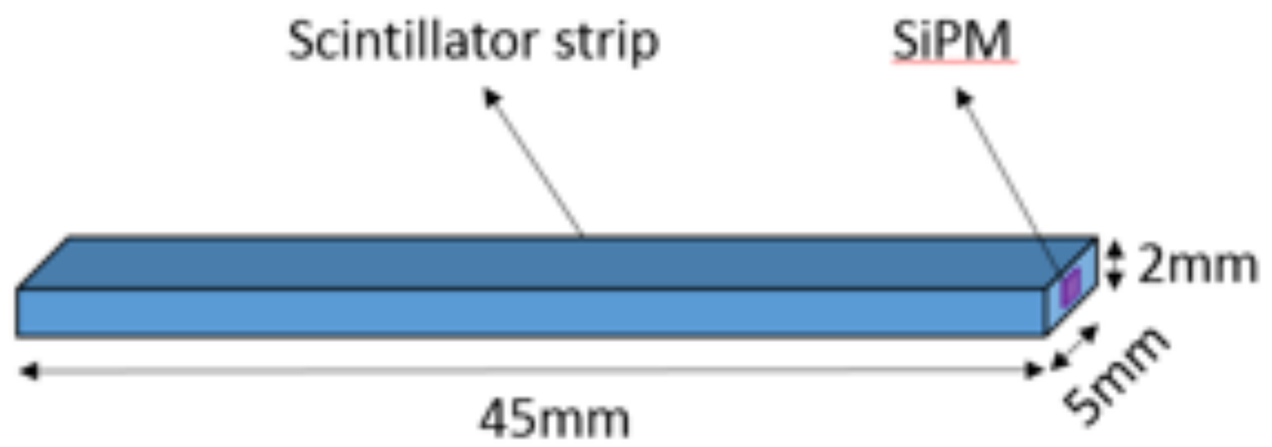
Scintillator-Tungsten Sandwich ECAL

Crucial parameters
- Absorber thickness: 24 X_0
- Layer number: 30 layers
- Cell size: < 10 mm × 10 mm

Superlayer (7 mm) is made of:
- 3 mm thick: Tungsten plate
- 2 mm thick: Scintillator 5 x 45 mm²
- 2 mm thick: Readout/service layer



Cell size: 5 x 5 mm²
(with ambiguity)

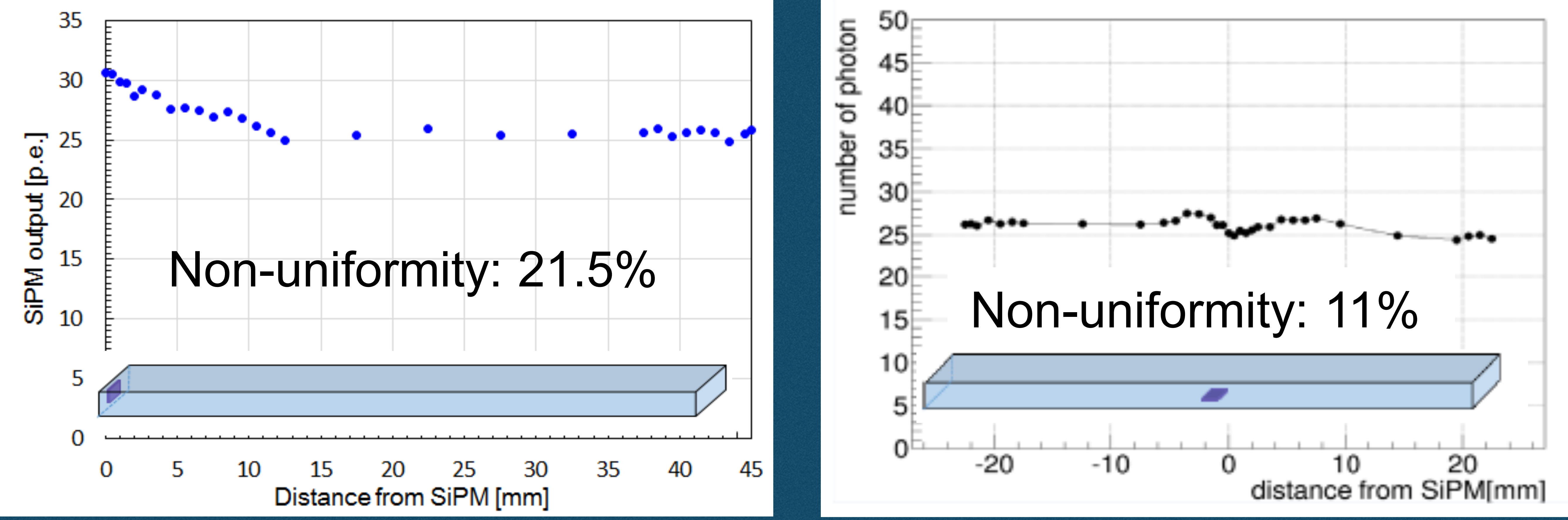


SiPM studies

Determined the optimal dynamic range of SiPM for both Sci-ECAL and AHCAL

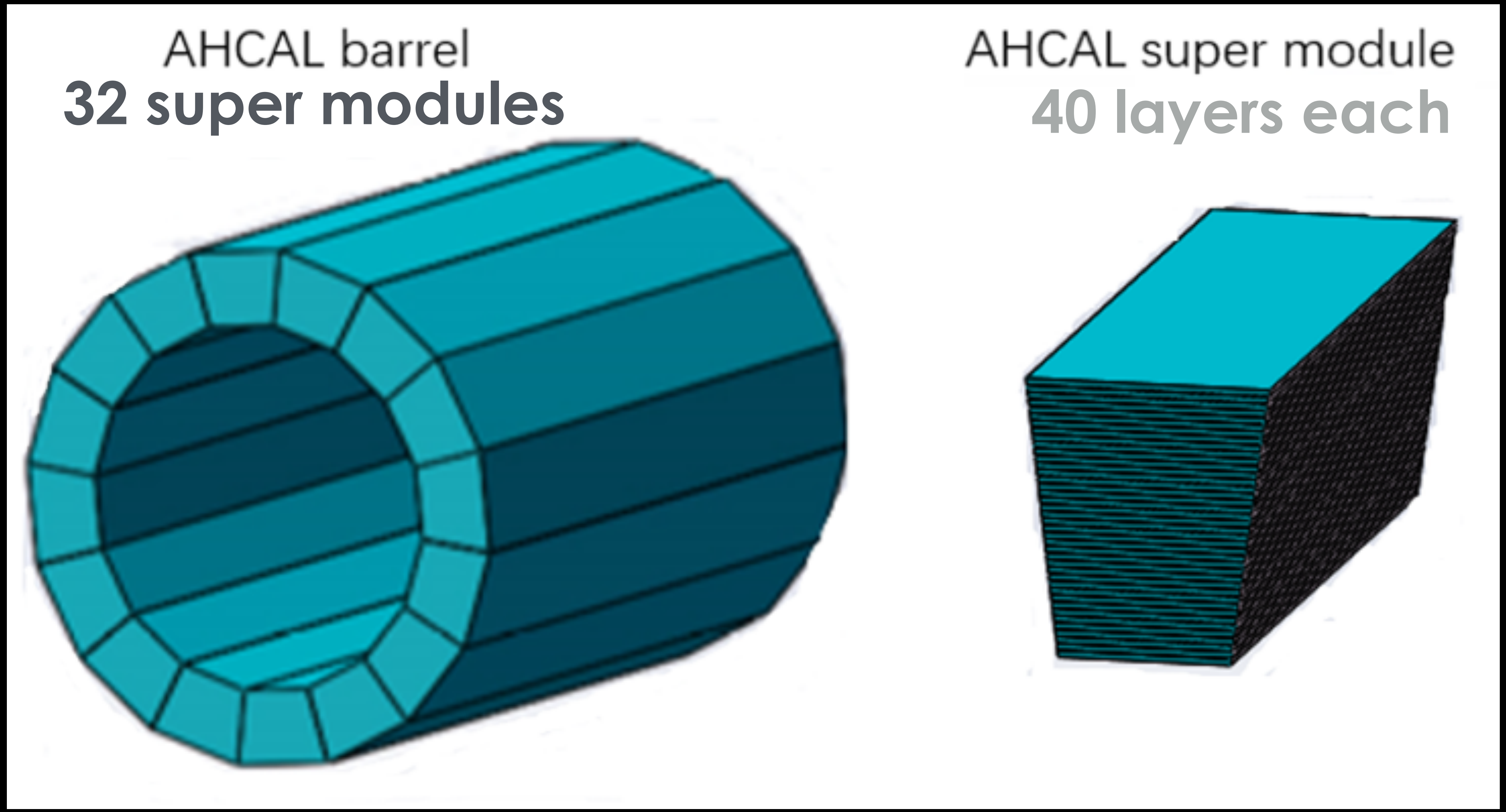
1. SiPM with more than 10000 pixels are not required

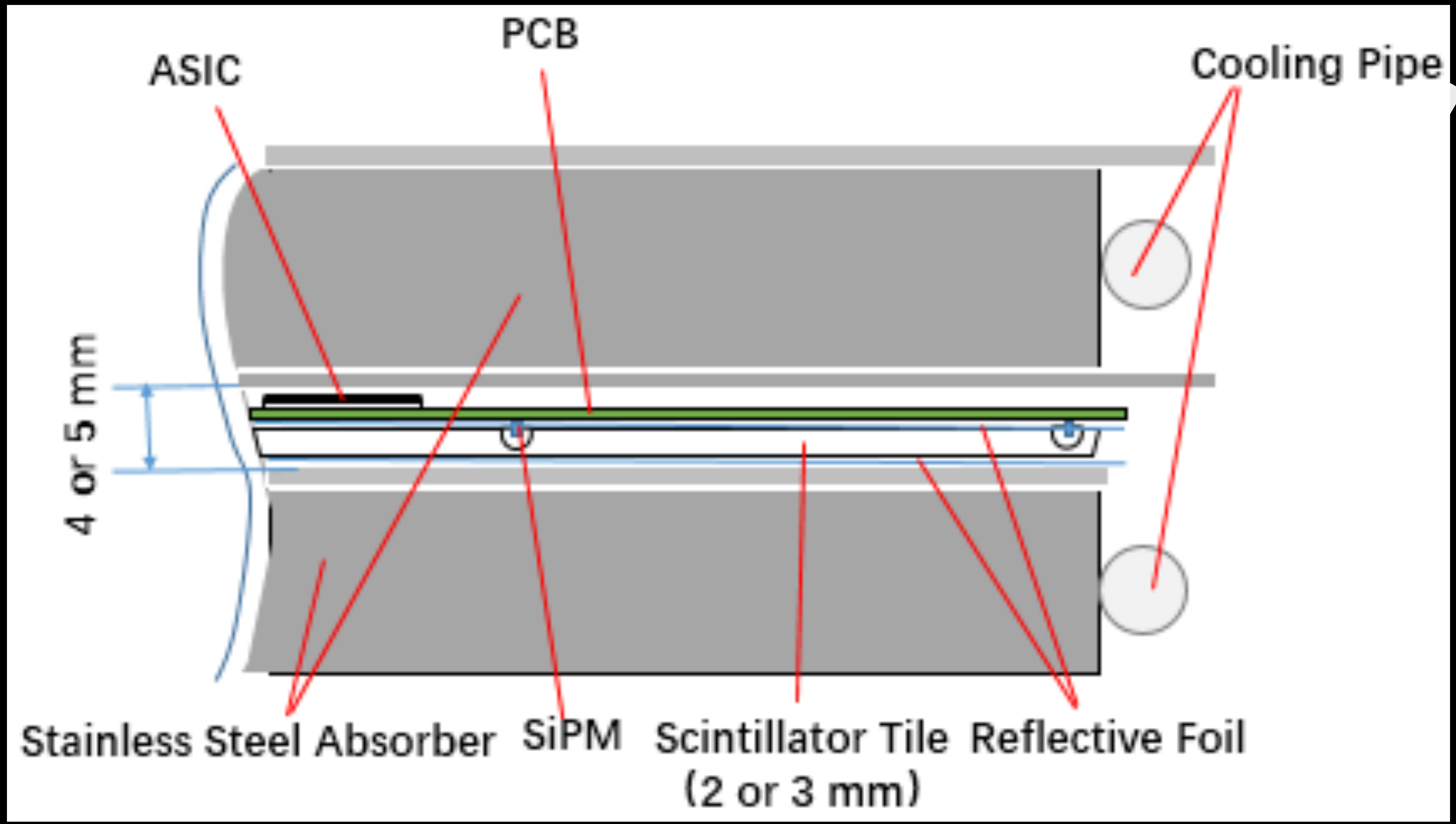
2. SiPM to be located in center of strip

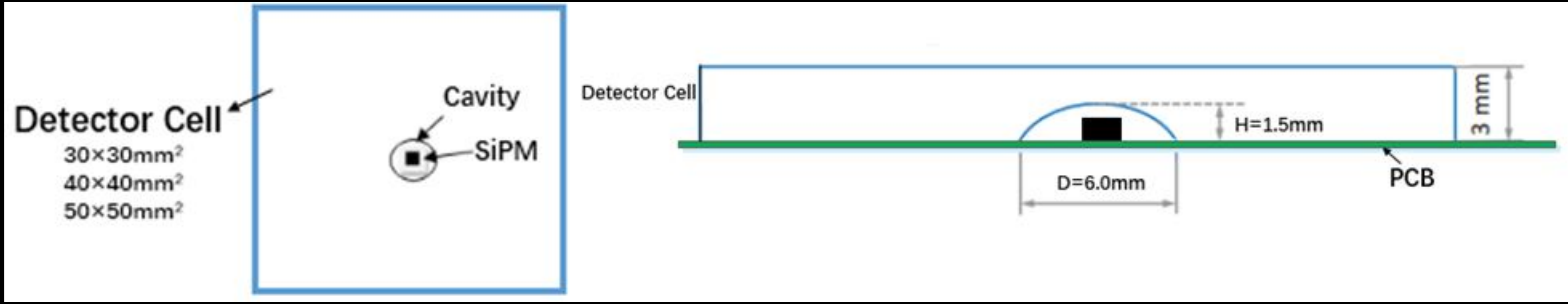


HCAL Calorimeter — Particle Flow Calorimeter

Scintillator and SiPM HCAL (AHCAL)





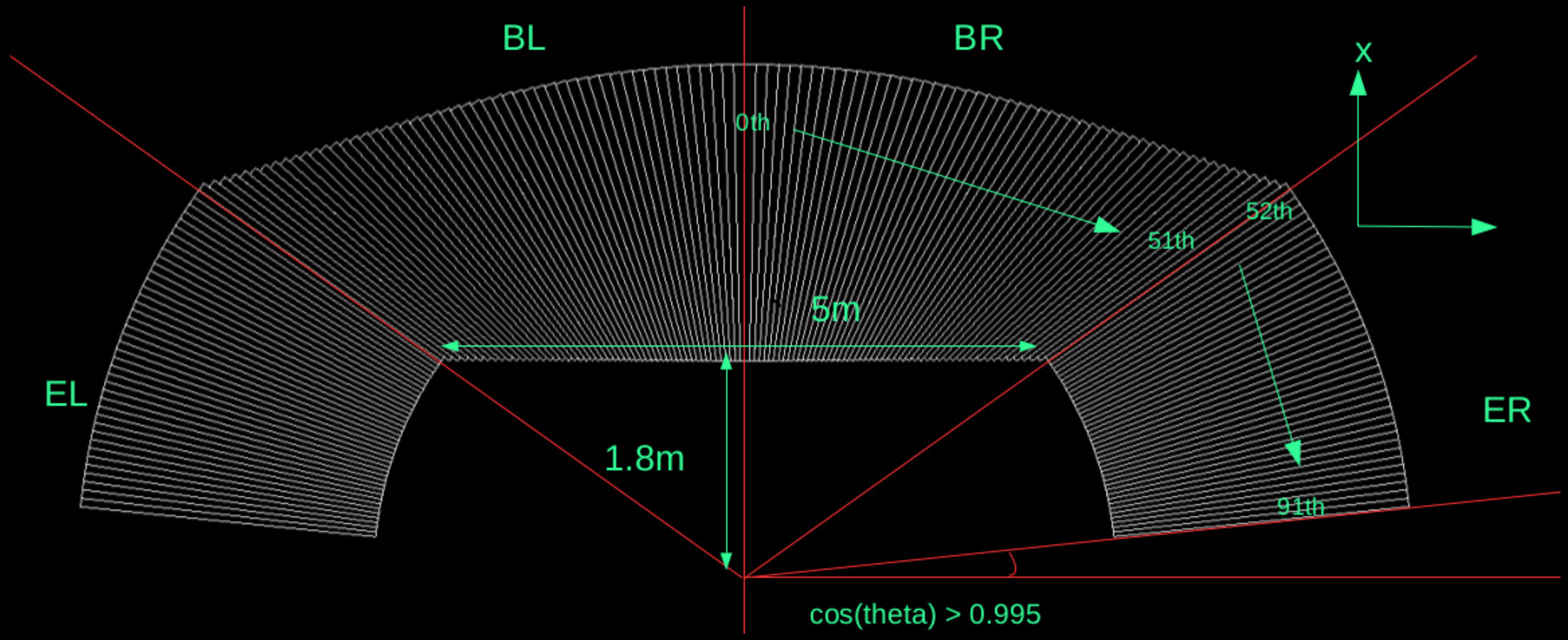


Readout channels:
~ 5 Million (30 x 30 mm²)
~ 2.8 Million (40 x 40 mm²)

Dual Readout Calorimeter

Lead by Italian colleagues: based on the DREAM/RD52 collaboration

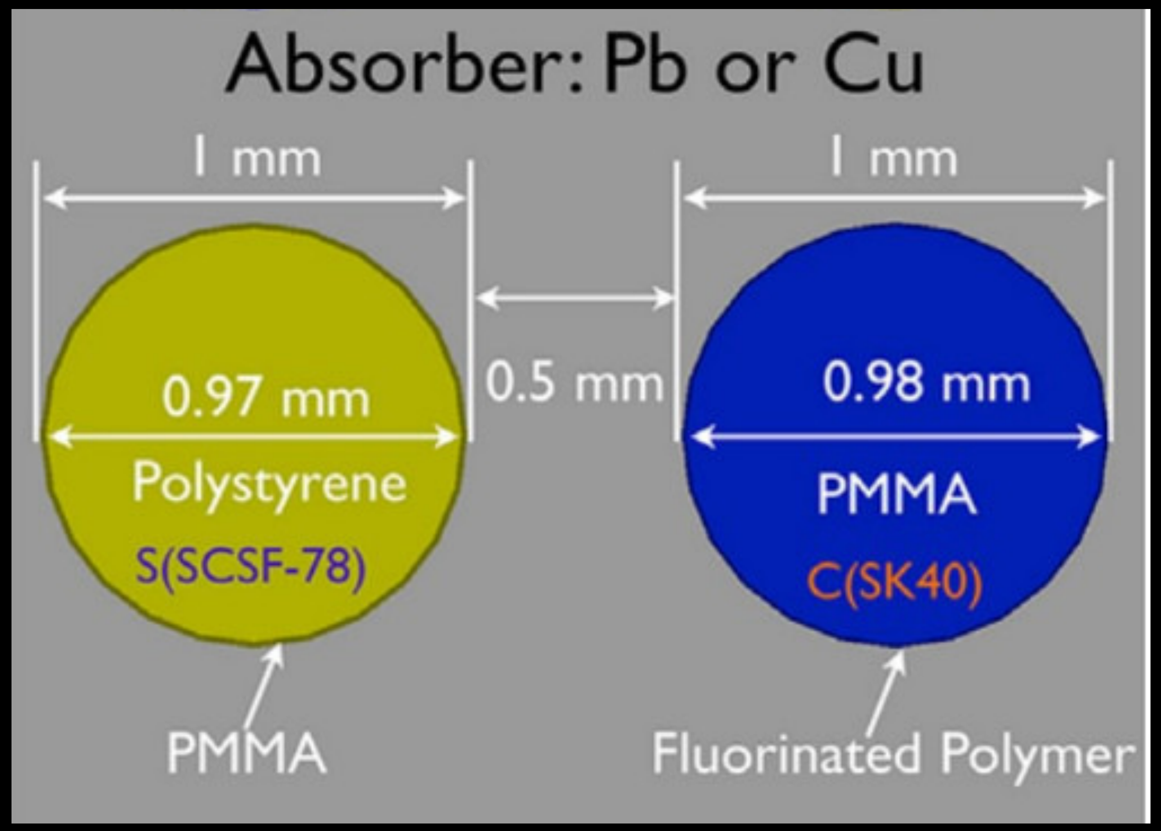
Projective 4π layout implemented into CEPC simulation
(based on 4th Detector collaboration design)



Covers full volume up to |cos(θ)| = 0.995
with 92 different types of towers (wedge)

4000 fibers (start at different depths
to keep constant the sampling fraction)

Performance in G4 simulation:
EM resolution: 10.3%/√E + 0.3%
Had resolution : ~34%/√E

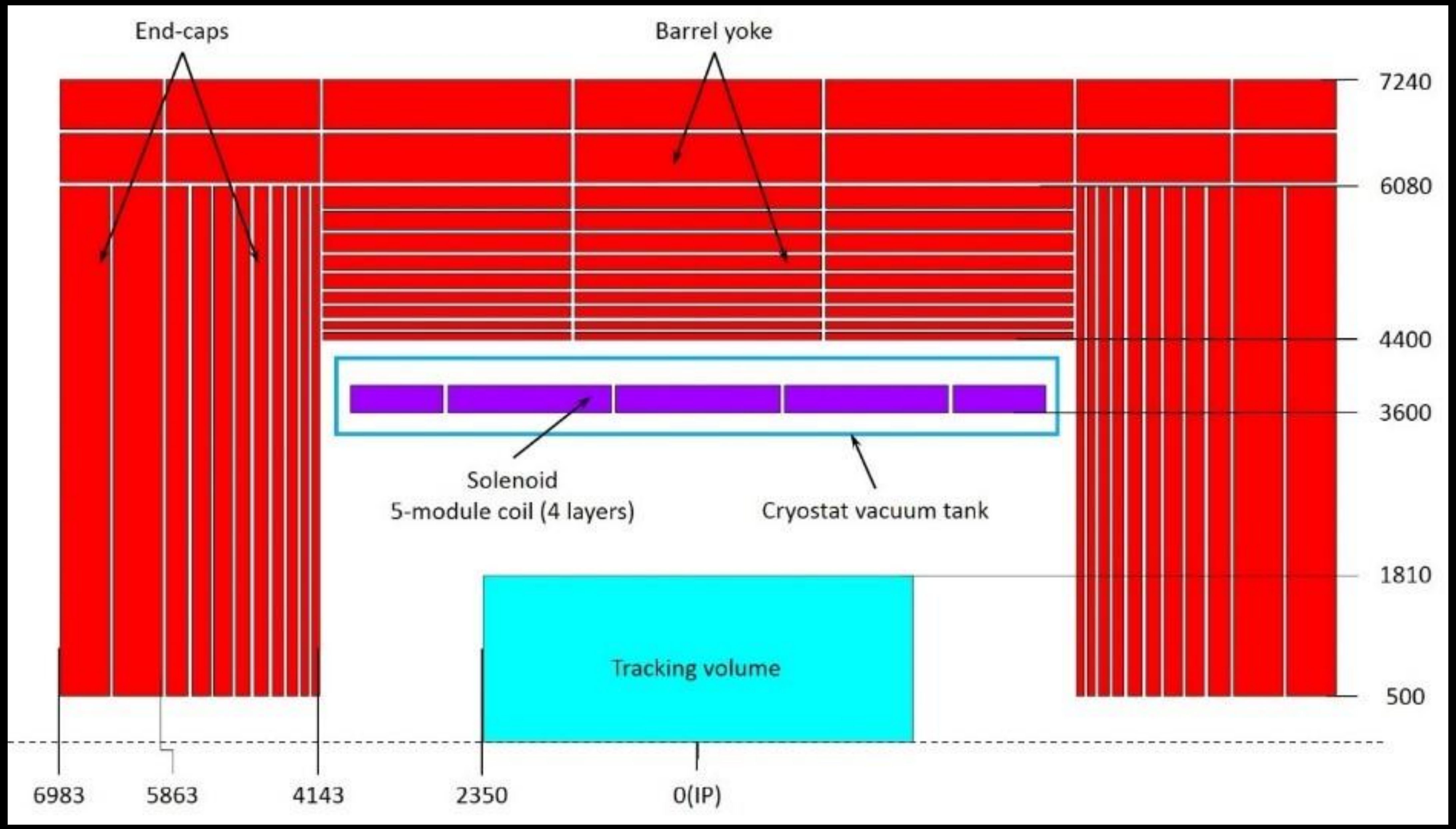


Studying different readout schemes
PMT vs SiPM

Several prototypes from RD52
have been built

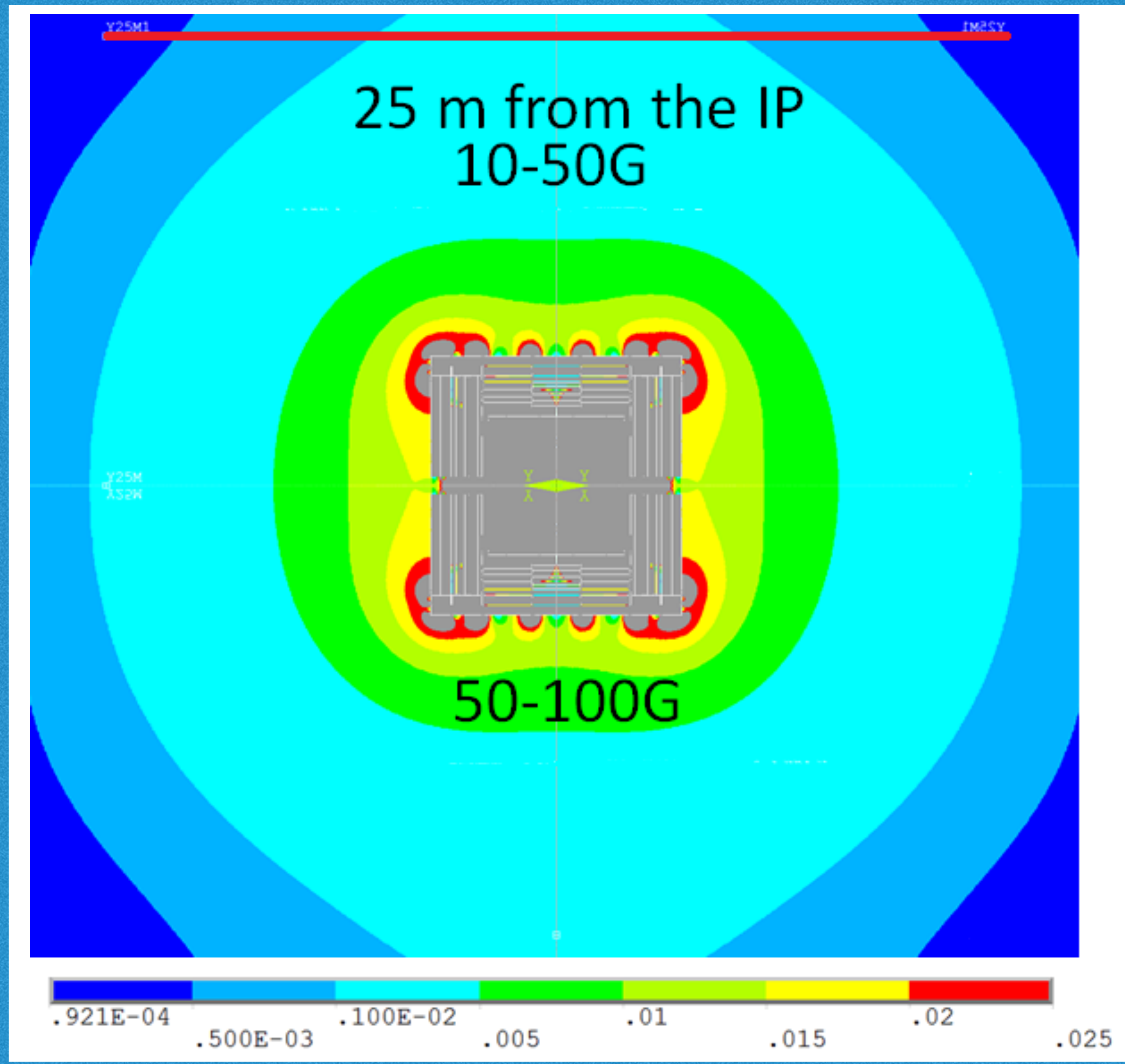
Superconductor solenoid development

3 Tesla Field Solenoid

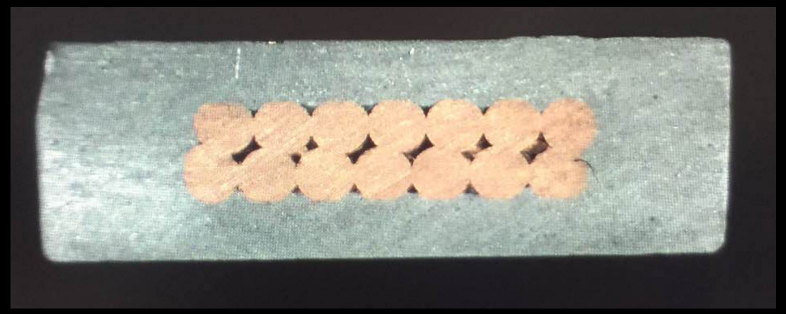


Operating current	15.8 A	Cable length	30.1 km

Stray field map of magnet



Default is NbTi Rutherford SC cable (4.2K)
High-Temperature SC cable is also being considered (YBCO, 20K)

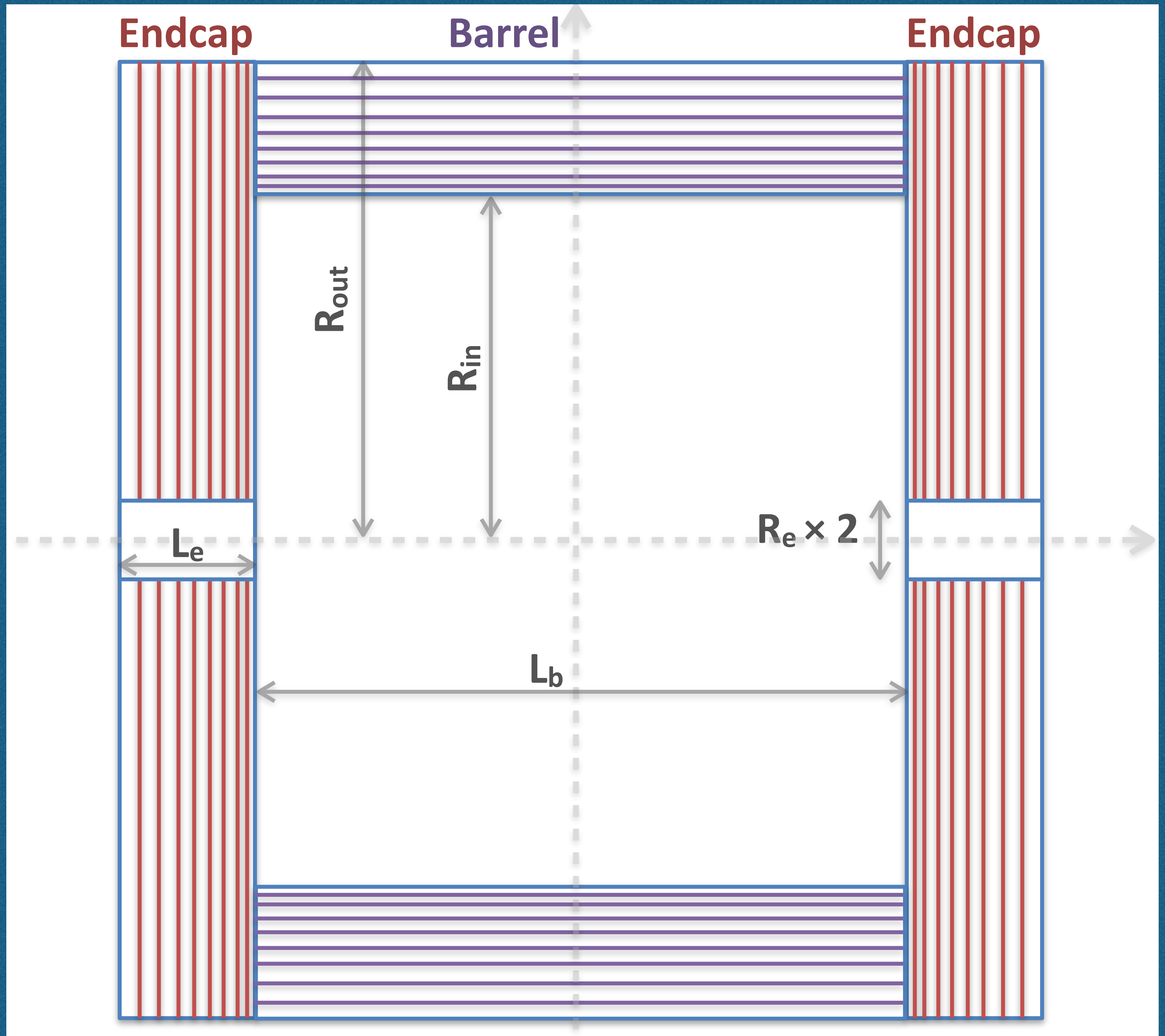


Design for 2 Tesla magnet presents no problems
Thin HTS solenoid being designed for IDEA concept
Double-solenoid design also available

Muon Detector System

Baseline Muon detector

- 8 layers
- Embedded in Yoke
- Detection efficiency: > 95%

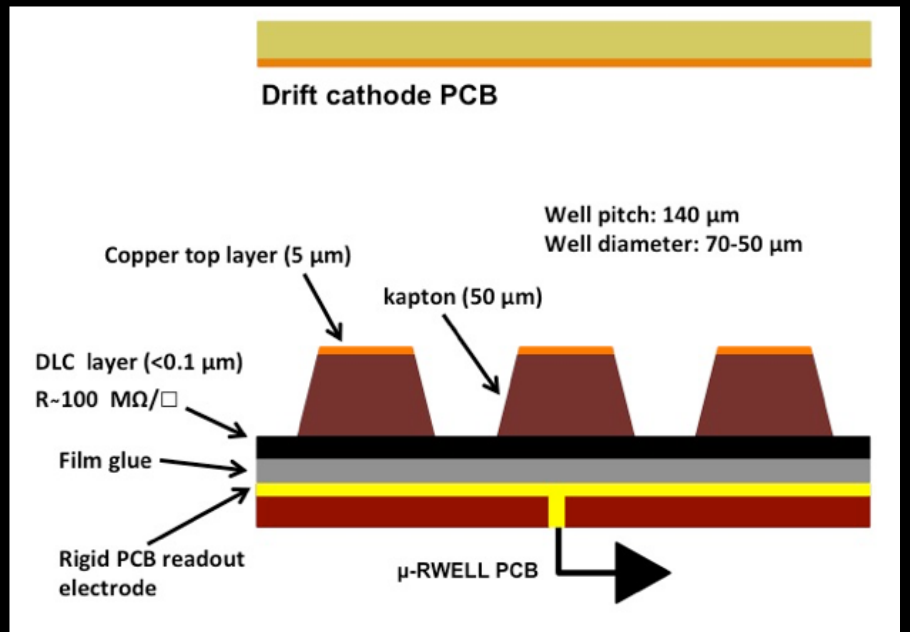


Baseline: Bakelite/glass RPC

Other technologies considered

Monitored Drift Tubes
Gas Electron Multiplier (GEM)
MicroMegas

New technology proposal (INFN): µRwell



Better resolution (200-300 µm) at little extra cost (?)

Muon system: open studies

Good experience in China on gas detectors but currently little strong direct R&D on CEPC — rather open for international collaboration

- **Layout optimization**:
  - Visit the requirements for number of layers
    - Implications for exotic physics searches
  - Use as a tail catcher / muon tracker (TCMT)
    - Jet energy resolution with/without TCMT
- **Detector industrialization**