CEPC Workshop and Reviews Postmortem

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Physics and Detector Working Group
Beijing, November 27, 2019

CEPC International Detector R&D Committee (IDRC)

Committee proposed by CEPC IAC

Detector R&D Committee that reviews and endorses the **Detector R&D proposals** from the **international community**, such that the international participants could apply for funds from their funding agencies and make effective and sustained contributions.

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Later, this committee is expected to evolve to

evaluate the Letters of Intent for the CEPC Detectors

submitted by the proponents of the International Detector Collaborations

(Expected timescale 2022-23)

CEPC International Detector R&D Committee (IDRC)

Committee: 16 members

In Beijing

Dave Newbold, UK, RAL (chair)
Jim Brau, USA, Oregon
Brian Foster, UK, Oxford
Liang Han, China, USTC
Andreas Schopper, CERN, CERN
Steinar Stapnes, CERN, CERN
Hitoshi Yamamoto, Japan, Tohoku

By Vidyo

Valter Bonvicini, Italy, Trieste
Ariella Cattai, CERN, CERN
Cristinel Diaconu, France, Marseille
Abe Seiden, USA, UCSC
Laurent Serin, France, LAL
Roberto Tenchini, Italy, INFN
Ivan Villa Alvarez, Spain, Santader

Excused

Harvey Newman, USA, Caltech
Marcel Stanitzki, Germany, DESY

CEPC International Detector R&D Committee (IDRC)

First meeting happened on Tuesday, Nov 19

https://indico.ihep.ac.cn/event/10941/

Organizational Meeting:

Key tasks of this inaugural meeting were:

- To establish the remit and working mode of the panel
- To review the current catalogue of R&D activities
- To provide initial feedback to the project leadership on the shape and scale of the R&D programme, and on short-term priorities
- To identify further information the committee will need in the future.

Highlights for discussion at IDRC Meeting

Machine Detector Interface 5'
Speaker: Dr. Hongbo ZHU (IHEP)
Material: Slides

Luminometer 5'
Speaker: Suen Hou (高能所)
Material: Slides

Silicon vertex detector 5'
Speakers: Prof. Qun OUYANG (IHEP), Prof. Zhijun Liang (IHEP)
Material: Slides

Silicon tracker 5'
Speakers: Prof. Meng Wang (Shandong University), Dr. Hongbo ZHU (IHEP)
Material: Slides

Time Projection Chamber 5'
Speaker: Dr. Huirong Qi (Institute of High Energy Physics, CAS)
Material: Slides

Drift Chamber 5'
Speakers: Franco Grancagnolo, Franco Bedeschi (INFN-Pisa)
Material: Slides

Electromagnetic Calorimetry 5'
Speakers: Dr. Yong Liu (Institute of High Energy Physics), Dr. Jianbei Liu (University of Science and Technology of China)
Material: Slides

Hadronic Calorimetry 5'
Speakers: Haijun Yang (Shanghai Jiao Tong University), Dr. Jianbei Liu (University of Science and Technology of China)
Material: Slides

Dual Readout Calorimeter 5'
Speakers: Dr. gabriella gaudio (INFN-PV), Franco Bedeschi (INFN-Pisa), Prof. Sehwook Lee (Kyungpook National University)
Material: Slides

Solenoid Magnet 5'
Speaker: Dr. Feipeng NING (IHEP)
Material: Slides

Muon detector 5'
Speaker: Paolo Giacomelli (INFN-Bo)
Material: Slides

Software 5'
Speaker: Dr. Weidong Li (高能所)
Material: Slides

Trigger and DAQ 5'
Speakers: Mr. Jingzhou ZHAO Jingzhou (高能所), Prof. Zhen An LIU Zhenan (IHEP)
Material: Slides

https://indico.ihep.ac.cn/event/10941/

Findings

- Requirements on sub-detectors should not be viewed in isolation, but increasingly in the context of studies of global detector performance, since there are strong interactions between sub-detector design choices. One example is the interplay between calorimetry, precision timing, and tracking in achieving the overall particle ID performance goals.

- In light of the above, the requirements on, and potential of, the proposed precision timing detector should be determined as a matter of urgency.

- A clear chain of argument, starting with physics requirements and culminating in detailed sub-detector specifications, should be maintained during the optimisation of the detector concepts. This will allow the impact of design changes to be assessed in terms of their effect on overall physics performance.

- The requirements on the muon sub-detector should be clarified, specifying the minimum performance needed for the core physics programme, as well as desirable additional features to allow a wider range of physics. The justification for a stand-alone muon spectrometer should be carefully examined.

Findings

- Regardless of choices regarding a precision timing detector, a common timestamping strategy should be defined, capable of dealing with 25ns running at the Z pole.

- There is no clear overarching trigger and readout strategy for the CEPC detectors. Decisions on architecture may have strong effects on the design of sub-detector electronics, and one or more clear options for triggering need to be rapidly established. The feasibility of operation in 'triggerless mode' should also be evaluated.

- There are a number of overlapping proposals for calorimetry, with a wide range of cost and performance. A clear set of requirements and a path to a baseline design choice need to be established.

- Global detector studies will require, at a minimum, a coherent and flexible fast simulation tool, capable of supporting parallel studies of several evolving integrated detector concepts. This should continue to be a priority in experiment software development, though it is also important to begin the process of designing the experiment data model and base software framework. It is likely that software tools are on the critical path for detector design.

Findings

- The CEPC software suite builds upon common tools used for studies of several different machines. The strategy to continue co-development of common tools with other experiments is correct, and divergence between projects should be avoided in view of the limited available effort.

- The machine-detector interface and LumiCAL are complex and challenging aspects of the overall detector design. Close cooperation between accelerator and detector teams must be reinforced and maintained.

- In general, the process of transition from generic R&D to concrete optimised CEPC detector designs is not yet fully mapped out. Adherence to an aggressive overall project plan will require this process to be understood in the coming year, and for a clear strategy for optimisation and technology selection criteria to be defined well in advance of the collaboration-building stage.

- A wide-ranging R&D programme should be maintained for the time being, though with the recognition that not all concepts under development will be mature on the time scale dictated by the overall CEPC schedule.

Recommendations:

1. The project leadership and IDRC should assemble a coherent list of R&D activities, such that the presence of gaps and overlaps can be determined and addressed

2. Each current R&D project should provide, before the end of 2019, key information to the IDRC:
   - The objectives of the project
   - The anticipated schedule on which the objectives will be met
   - The funding available to the project, and the leadership arrangements within it
   - The extent to which the project is a CEPC-specific development

3. As a step in the transition from R&D to detector choices and TDRs, the project should aim to complete an update to the CDR within 12-18 months. This should take into account machine parameter changes, any new or modified physics requirements, and the availability of new sub-detector systems. This process should happen in parallel with sub-system R&D, and form the focal point for global detector optimisation studies

Preliminary Recommendations

4. A conservative full-detector concept, potentially deliverable on an aggressive time scale, should be specified by the CEPC Management and adopted as the baseline for the CDR update. This should then act as a comparator for alternative concepts, that can fit within a less aggressive schedule, with a different balance of risk, cost and performance

5. A set of short-term requirements on simulation and reconstruction tools should be established, serving the needs of detector optimisation studies, and informing the plans for software and data management development in the pre-TDR period

6. Ways to increase the rate of progress should be found for certain R&D areas, such that they do not hold up the overall detector design process. These include:
   - The precision timing detector
   - The trigger and readout strategy
   - The machine-detector interface and LumiCal

7. Sufficient time should be allocated during CEPC workshops for IDRC discussions, not conflicting with other events requiring the attendance of project leadership or IDRC members

CEPC Project Timeline

CEPC International Advisory Committee

Young-Kee Kim (Chair), University of Chicago
Barry Barish, Caltech
Hesheng Chen, IHEP
Michel Davier, LAL
Brian Foster, DESY/U. Hamburg
Rohini Godbole, CHEP, Bangalore
David Gross, UC Santa Barbara
George Hou, Taiwan U.
Peter Jenni, CERN & Albert-Ludwigs-University Freiburg
Eugene Levichev, BINP
Lucie Linssen , CERN
Joe Lykken, Fermilab
Luciano Maiani, U. Rome
Michelangelo Mangano, CERN
Hitoshi Murayama, IPMU/UC Berkeley
Tatsuya Nakada, EPFL
Katsunobu Oide, KEK
Robert Palmer, BNL
John Seeman, SLAC
Ian Shipsey, Oxford
Steinar Stapnes, CERN
Geoffrey Tayler, U. Melbourne
Henry Tye, IAS, HKUST
Hendrik J. (Harry) Weerts, ANL

Committee met on Thursday and Friday last week

Recommendations

The machine-detector interface is a complex and challenging aspect of the overall accelerator and detector design. For instance, the 2T/3T choice of the detector solenoid requires a speedy resolution. The length of the solenoid iron yoke is another crucial parameter. Close coordination and communication between accelerator and detector teams are crucial and will be even more important to finalize the TDR.

Recommendation 13: Set up a high-level executive working group between accelerator and detector teams to define a workable scenario for the machine-detector-interface area.

MDI Recommendations:

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Detector Recommendations:

4. Is the overall detector R&D, and design enhancement on track? What should be improved and how to achieve the improvement?

The detector technology R&D is reasonably well on track on several fronts and well in line with the current overall stage of the CEPC project. The IAC supports the notion of a baseline detector as it allows key aspects (e.g. impact of background on the detector, relation between detector performance features and physics capabilities) to be studied. The baseline detector also serves as a general basis for studying the CEPC physics potential. It allows all processed physics and background samples to be produced in a single detector and software version, thereby making efficient use of computing resources. This does not imply that this baseline corresponds to a detector that will be proposed for construction.

Detector Recommendations:

Among the detector optimization and detector R&D activities, a few items were flagged as critical and should be tackled with high priority:

Recommendation 15:

- *Engage engineering expertise to assess various engineering aspects of the detector options under study (supports, low mass aspects of the vertex and tracking detectors, heat dissipation and integration of cooling, low-mass services and service routing, influence of the magnetic field on the design, etc.). Engineering expertise helps also to enhance the credibility of the cost estimates.*
- *Reinforce detector studies in the forward region at the interface of the accelerator. Optimize the luminosity measurement, compatible with expected statistical errors on the physics, through optimal design, integration and alignment of LumiCal. Perform advanced engineering studies on the overall design of the complex forward MDI region, taking all constraints into account.*

Detector Recommendations:

- *Study whether the TPC is compatible with the high rates expected for operation at the Z-peak, including ion backflow, electronics readout and DAQ schemes.*
- *Study the impact of the choice of the solenoid field (2T or 3T) at all foreseen CEPC center-of-mass energies. Draw conclusions on the detector design and performance (in particular the TPC), taking the impact on the beams and the CEPC luminosity performance into account. Preferably make a final choice of the recommended magnetic field for both CEPC detectors at the earliest possible time.*
- *Continue to pursue studies of the solenoid yoke in view of magnetic stray fields and their influence on the booster beams and on other surrounding equipment.*
- *Reinforce efforts towards an engineering design of the IDEA detector (including engineering details of the dual readout calorimeter) and implement the corresponding design in the event simulation and reconstruction software.*

Detector Recommendations:

Other recommended detector and physics studies:

Recommendation 16:

- *Perform detailed simulation studies to better understand the physics needs from the detector at the various CEPC energy stages; draw consequences about the corresponding detector performance requirements (e.g. photon resolution, jet resolution, added value of PID) and study how this influences the detector design.*
- *Study the physics case for performing flavor physics including the tau lepton at the Z-peak. Draw conclusions on a possible impact on the detector design.*
- *Given that time-of-flight detectors with a time resolution in the 30-50 ps are becoming available, study their potential added value for a CEPC detector by assessing a few key physics benchmarks.*
- *Assess the added value of dE/dx capabilities in the tracker.*
- *Assess the added value of the muon detector system. As a result, define the number of muon detection layers to include, together with their required performance.*

Other General Recommendations:

In addition to the above, the IAC recommends that further improvements in the structuring of the CEPC detector and physics study be implemented. In this context, the IAC makes the following suggestions:

Recommendation 17:

- *Set up a logical structure in Indico for specialized meetings (e.g. for specific sub-detectors, software development, detector design and engineering, physics studies, etc.). Schedule regular meetings among experts.*
- *Set up a system of internal technical notes, as well as a corresponding internal reviewing process.*
- *Set up a system for reviewing/rehearsing public CEPC presentations.*
- *Set up a (simple) structured public web page / work space where links to working groups, meetings, technical documents, software documentation, public presentations etc. can be found. Include instructions for joining the corresponding mailing lists.*

Some, important near future steps:

Detector Technical Design Report (TDR)

The Detector Technical Design Report (TDR) is not of the responsibility of the current CEPC Working Group

This is to be taken by the International Collaborations that will be formed circa 2022-23

Our job is to promote detector R&D in key technologies applicable to circular e^+e^- collisions:

- **Taking into account the CEPC timescale**
- **Keeping an open mind to more challenging emerging technologies**

Updated Parameters of Collider Ring since CDR

	Higgs		Z (2T)	
	CDR	Updated	CDR	Updated
Beam energy (GeV)	120	-	45.5	-
Synchrotron radiation loss/turn (GeV)	1.73	1.68	0.036	-
Piwinski angle	2.58	3.78	23.8	33
Number of particles/bunch N_e (10^{10})	15.0	17	8.0	15
Bunch number (bunch spacing)	242 (0.68μs)	218 (0.68μs)	12000	15000
Beam current (mA)	17.4	17.8	461.0	1081.4
Synchrotron radiation power /beam (MW)	30	-	16.5	38.6
Cell number/cavity	2	-	2	1
β function at IP β_x^* / β_y^* (m)	0.36/0.0015	0.33/0.001	0.2/0.001	-
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.89/0.0018	0.18/0.0016	-
Beam size at IP σ_x/σ_y (μm)	[illegible]	[illegible]	[illegible]	-
Bunch length σ_z (mm)	3.26	3.93	8.5	11.8
Lifetime (hour)	[illegible]	0.22	2.1	1.8
Luminosity/IP L (10^{34} $cm^{-2}s^{-1}$)	2.93	5.2	32.1	101.6

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

Luminosity increase factor: × 1.8 × 3.2

Re-evaluation of physics requirements

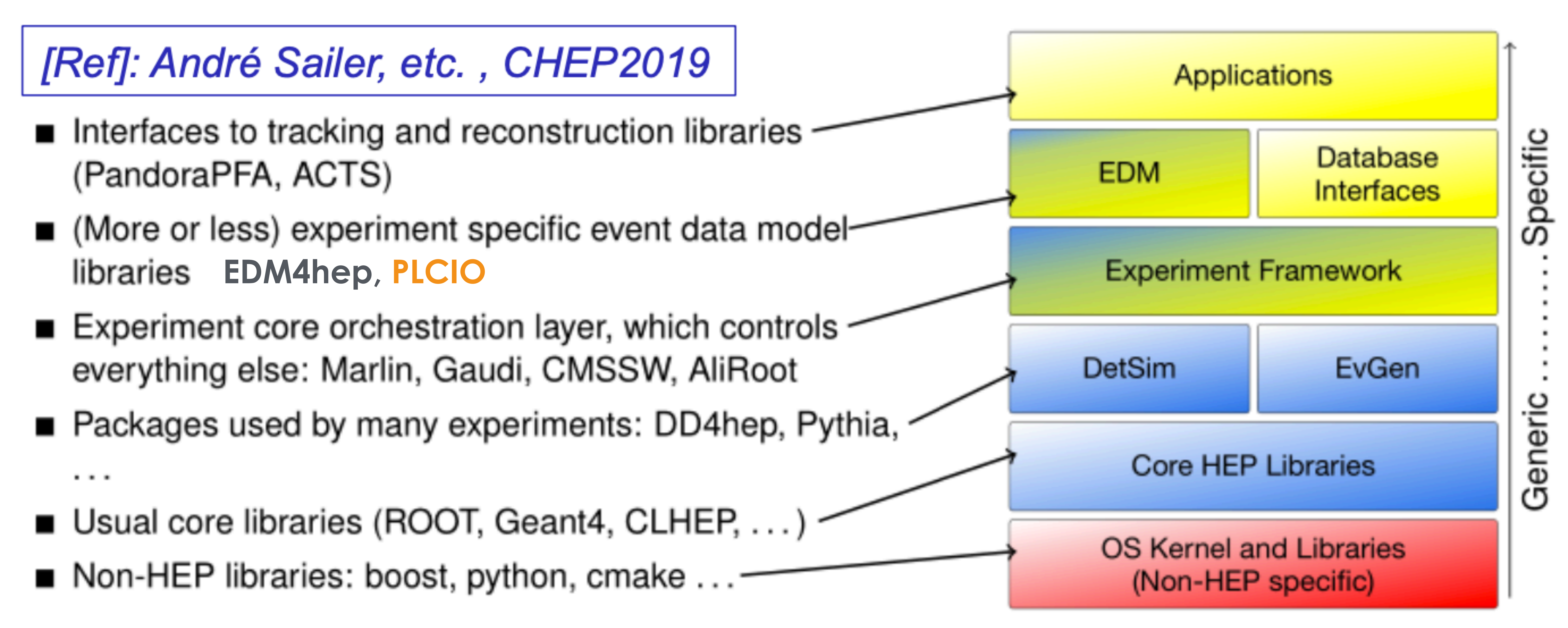
Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	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 this meeting → aim at workshop in Hong Kong

Software and Reconstruction algorithms

Developing a Common Software Stack (Key4HEP)

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



CEPCSW prototype has been developed using Gaudi, DD4hep, Geant4 and PLCIO
Vertex tracking ported to new framework

See Weidong's talk during workshop

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 (if we are going to be ready for TDR in such short timescale)
- Need to consider costing issues

Work needs to be shared and coordinated at common Detector Plenary Meeting

Aiming for a document sometime before collaborations are proposed is reasonable

First, integrate better detector and physics performance people to study different options

Some key R&D topics moving forward

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

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Transparency <—> reliability/resolution

  - Time Projection Chamber
    - Ion back flow and field distortion is a major problem to operate at the Z pole and 2 Tesla
  - Drift Chamber
    - Can it cope with the high rates at the Z pole? Enough resolution?
  - Full silicon tracker → need manpower increase to exploit this option
    - Are we adding too much material?
    - What about particle identification? Does it really matter?

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    - Are we adding too much material?
    - What about particle identification? Does it really matter?
- Need a decision on 3 Tesla solenoid soon
  - Trade-off of luminosity versus resolution and particle identification needed
  - Can the same physics goals be achieved some other way?

Some key R&D topics

- Calorimetry
  - ECAL, HCAL, DR
    - Cost versus physics performance
    - Cooling of PFA calorimeter? versus performance?
    - PFA ECAL photon resolution rather poor
      - Do we need to improve it for physics purposes?
      - Does it make sense to pay for such expensive detector with poor photon resolution
    - DR: Timescale for large prototype?

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- Muon system optimization
  - Why so many muon layers?
  - What do we really need?

ATLAS Detector Involvement

Number of institutions involved in Phase II Upgrades in ATLAS

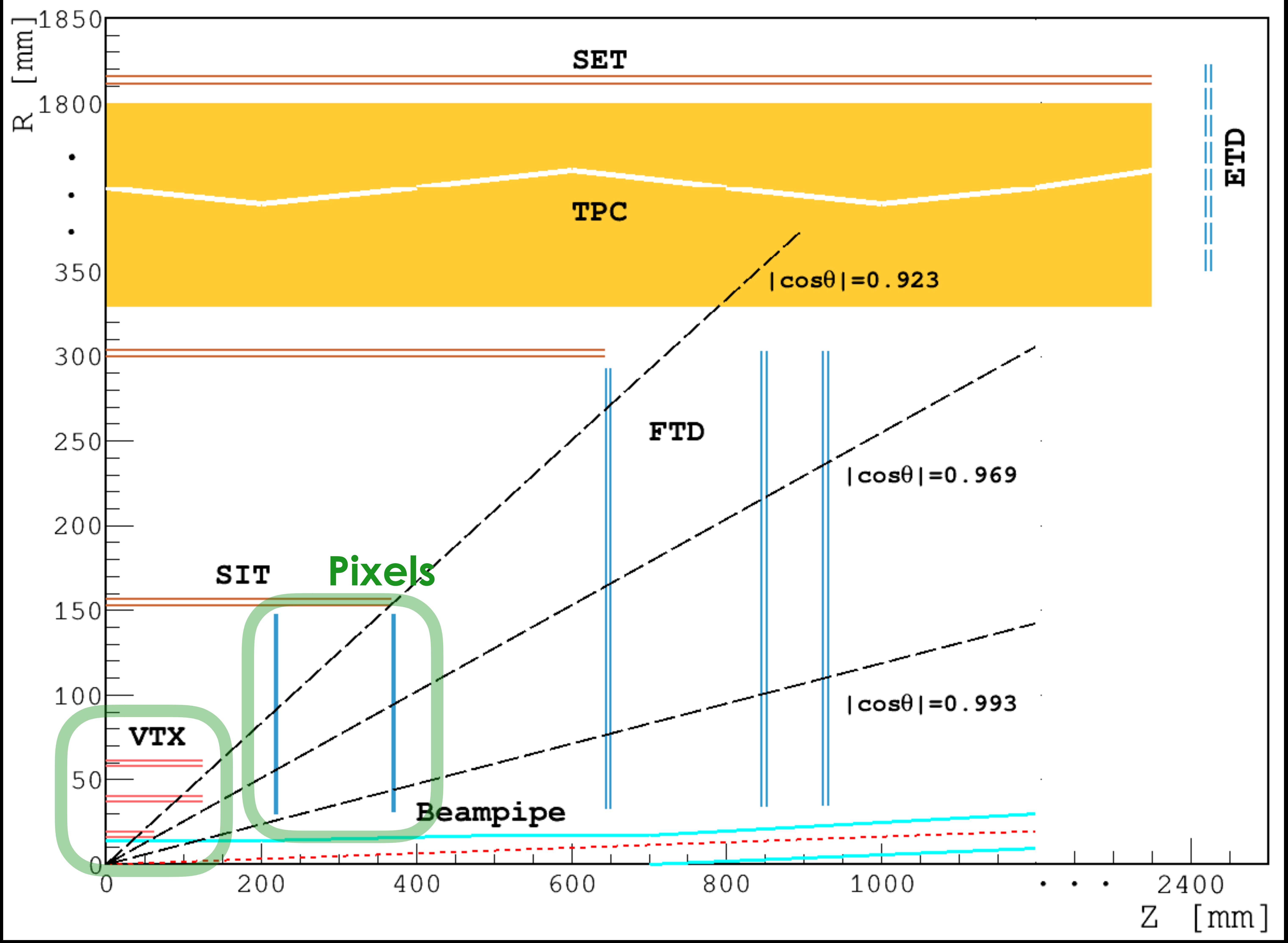
	Institutions
ITK Pixel	65
ITK Strip	62
Muon	60
Tile Calorimeter	34
LAr Calorimeter	29
Trigger/DAQ	101
New Small Wheel	59
HGTD	18

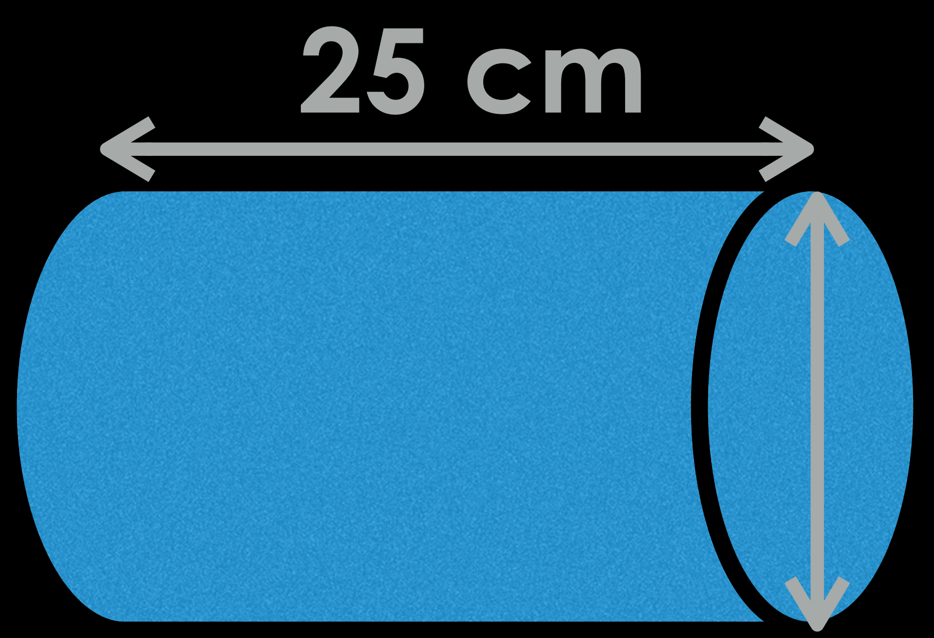
Expanding the collaboration is essential!!

Tracker Detector – PFA Detector

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

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





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

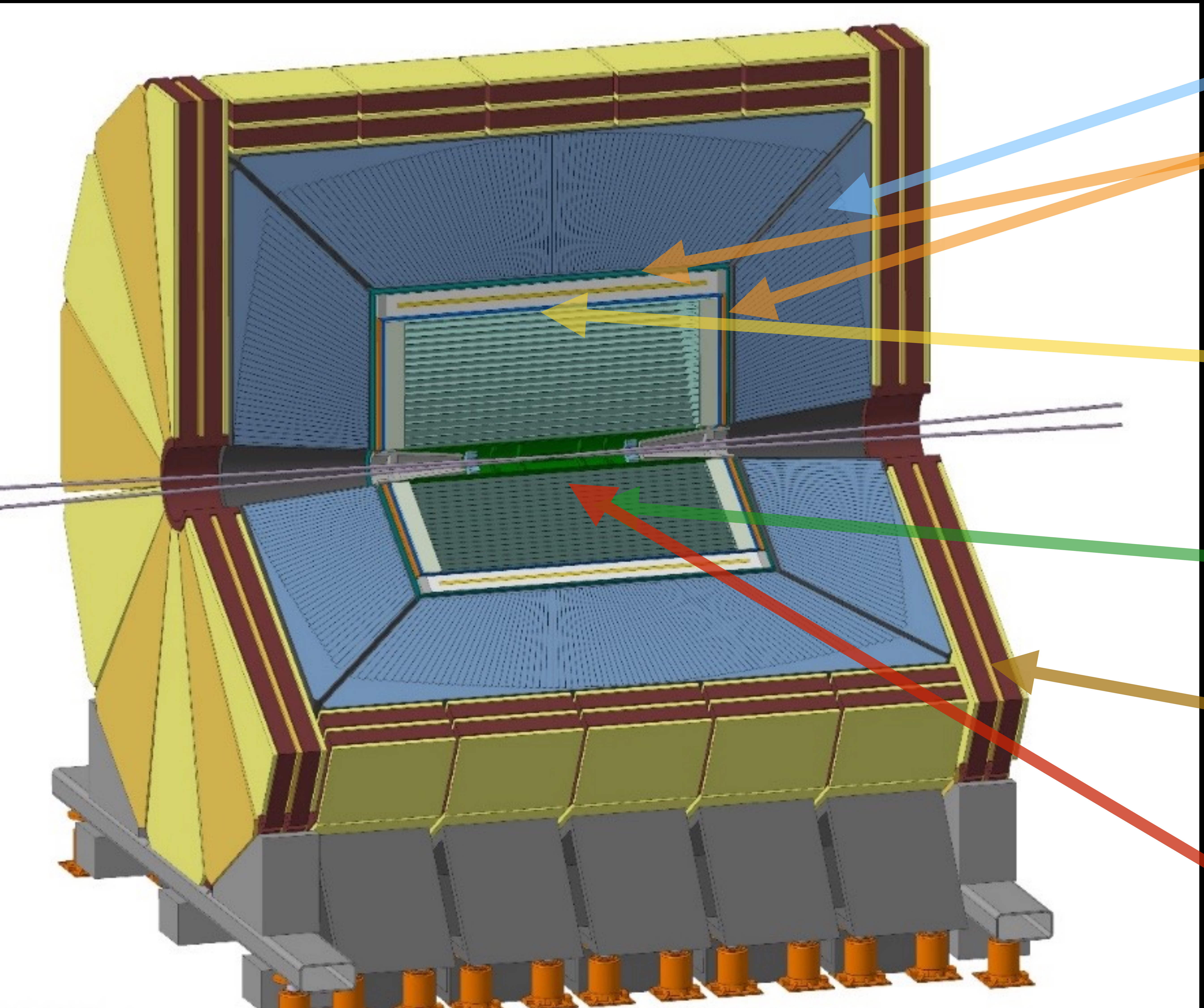
1. DC/DC converters
2. Investigate air cooling

Total Silicon area ~ 68 m²

Extensive opportunities for international participation

CEPC CDR: 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