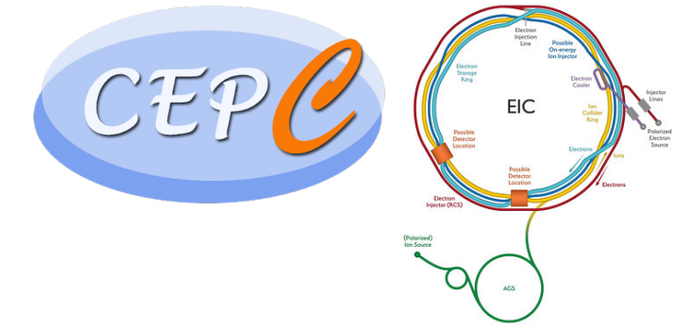
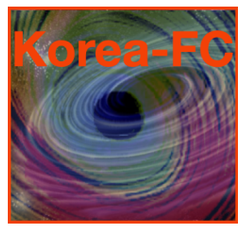
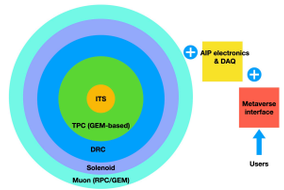






Future Collider Activities in Korea

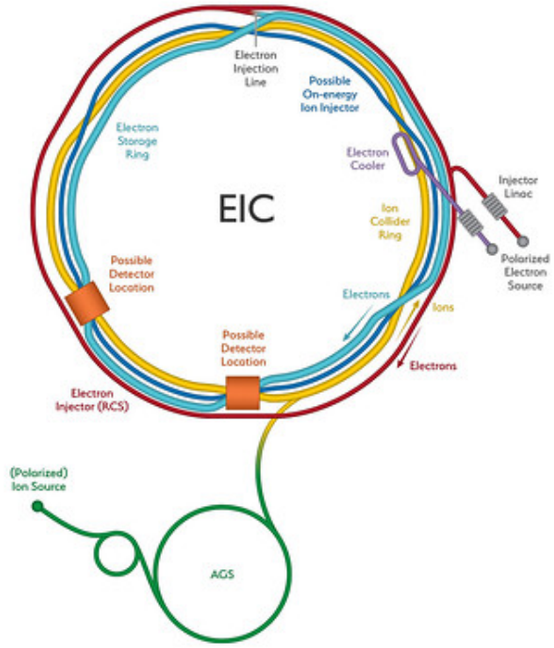
Hwidong Yoo (Yonsei Univ.)

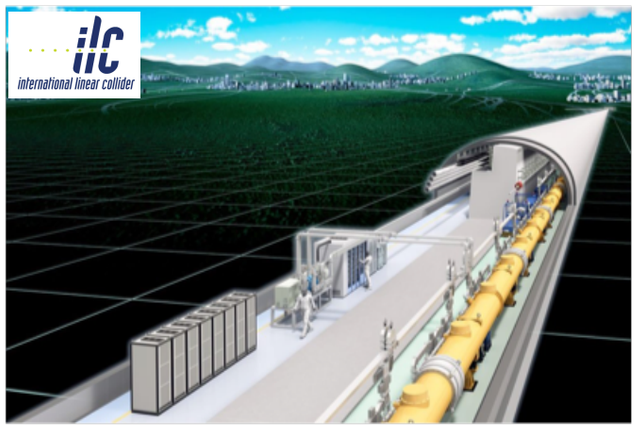
On behalf of
the Korea Future Collider Consortium

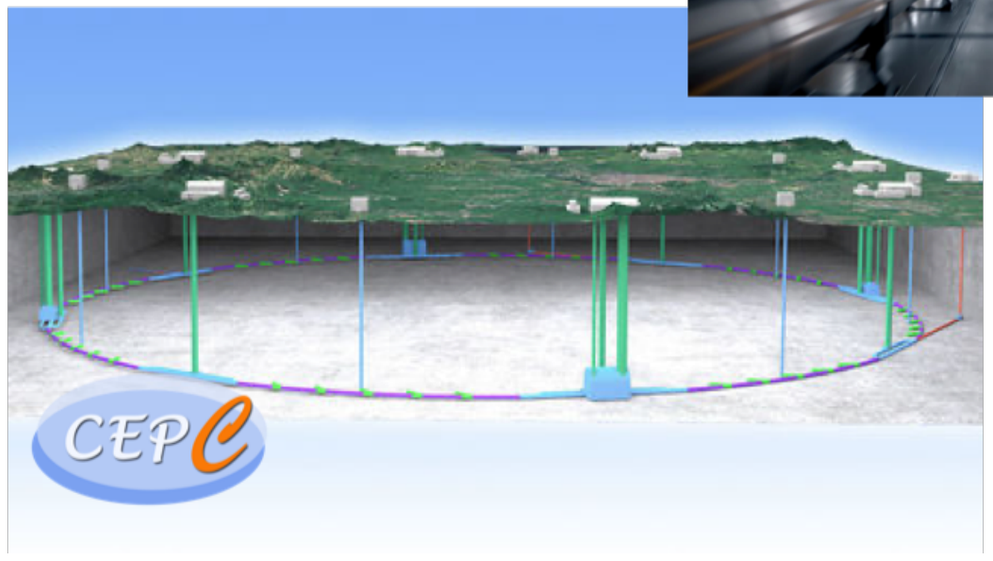
KPS DPF workshop,
December 17, 2021

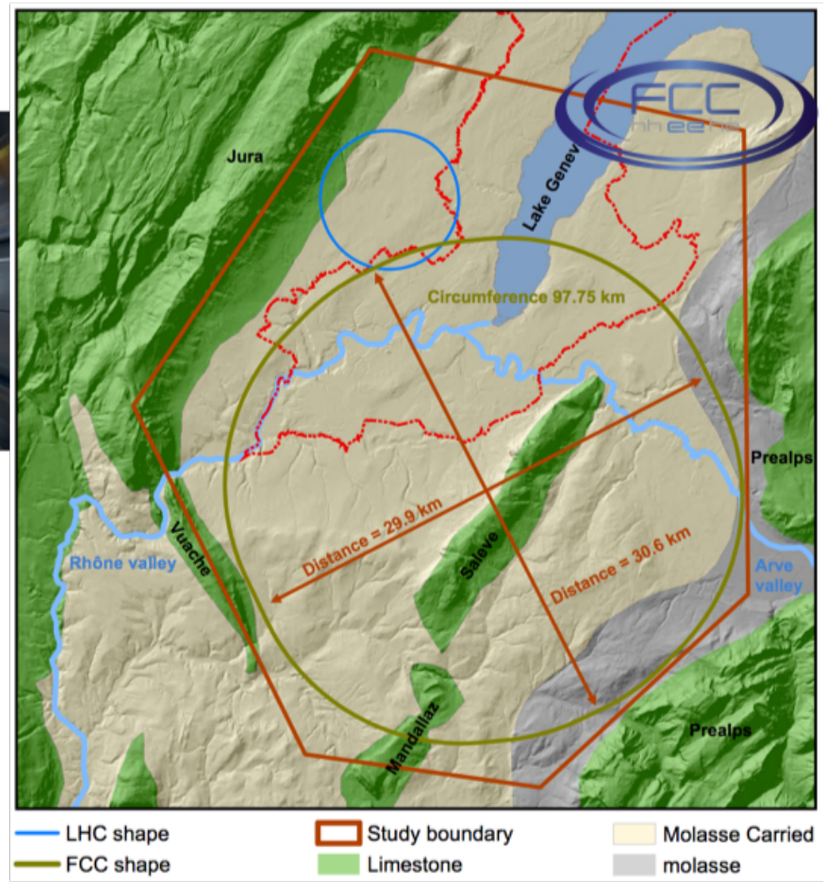
Future Collider Projects in HEP

- Many next generation experiments are under discussion
  - Linear colliders: ILC (Japan), CLIC (CERN)
  - Circular colliders: FCC-ee/eh/hh (CERN), CEPC/SPPC (China)
  - HI colliders: EIC (US)









Updated News: ILC

- https://agenda.linearcollider.org/event/9211/contributions/49147/attachments/37382/58558/ILCX_Oct.2021.pdf

Message from MEXT (March 2021)

Message given by the MEXT Minister

- The ILC project needs to resolve its various challenges including its international cost sharing and technical feasibility, as well as to obtain broad internal and external cooperation not for its pre-laboratory but for the ILC project itself.

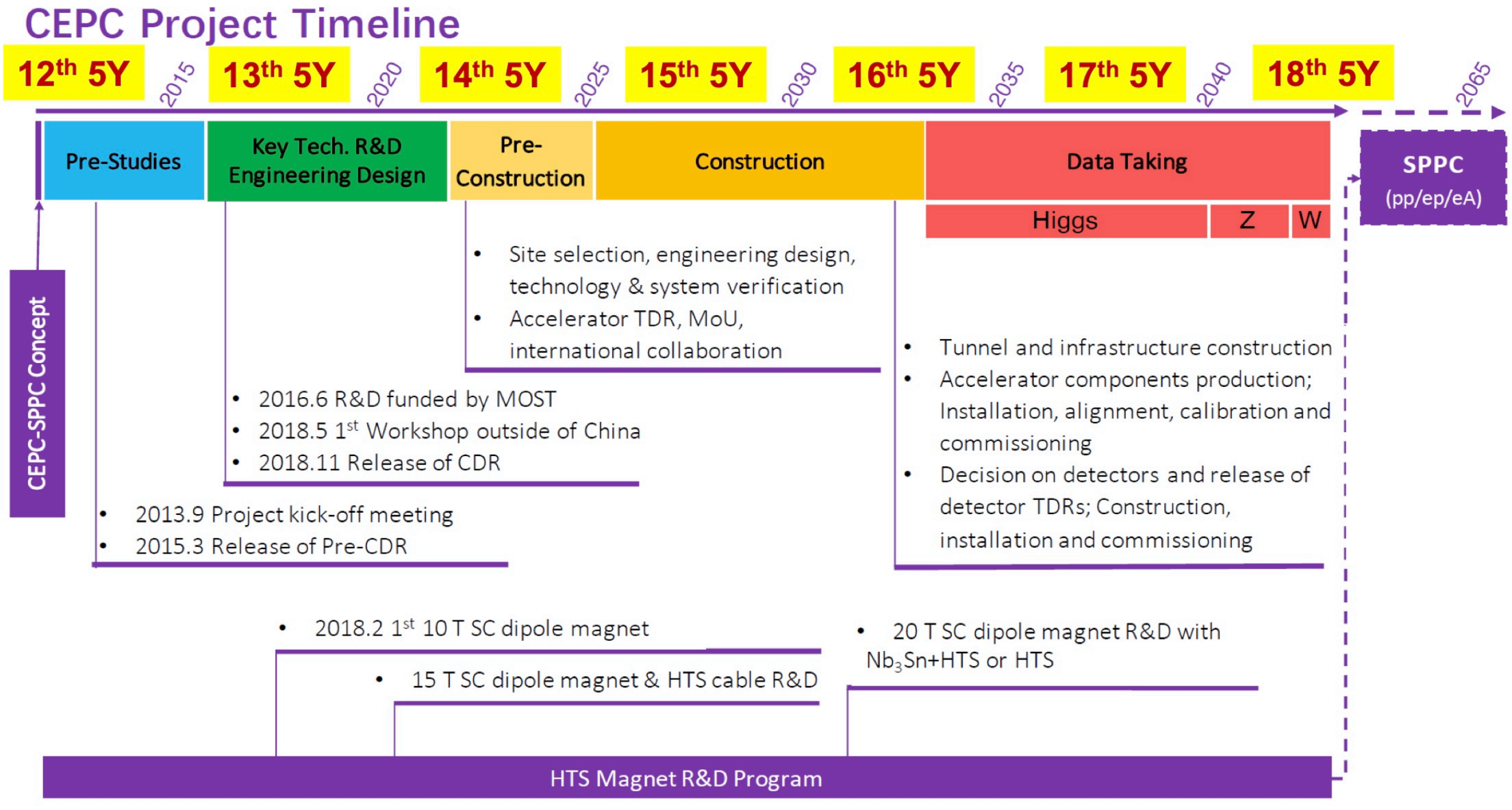
- Under the current situation that the perspective of broad internal and external cooperation for the ILC project itself as well as its pre-laboratory is not promised, it is difficult to obtain the people's understanding in Japan for investing the pre-laboratory. It is necessary to obtain the clear perspectives on financial contributions to the ILC project itself from the US and European countries in prior considering the pre-laboratory."

Three keys to move ILC forward given by MEXT:
1. Technical feasibility (← Prelab)
2. International cost sharing (← Governments, IDT, Phys. community)
3. Broad consensus in Japan (← Japanese phys. community)

Updated News: CEPC

- https://indico.ihep.ac.cn/event/15229/other-view?view=standard

- **2013-2025： Key technology R&D， from CDR to TDR, Site selection, Intl. Collab.**
- **Ideal situation: Approval in the 15th Five-Year Plan, schedule will be shifted accordingly**

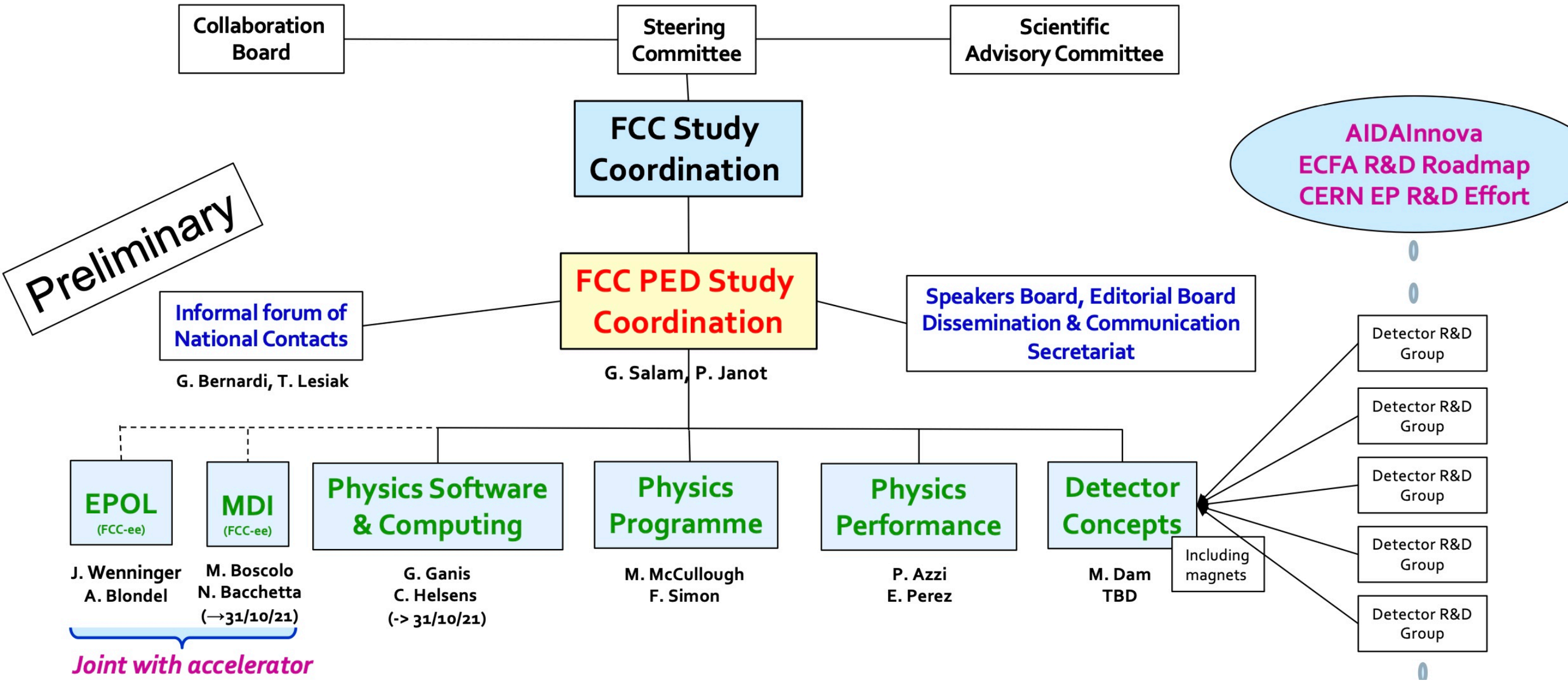


5

Updated News: FCC

- FCC feasibility study organization

The PED Pillar Organisation - preliminary



Updated News: FCC

The PED Pillar Objectives in 2025

- **Mostly defined by the general (tight) timeline of the FCC project**

Infrastructure and accelerator **Physics, Experiments, and Detectors**

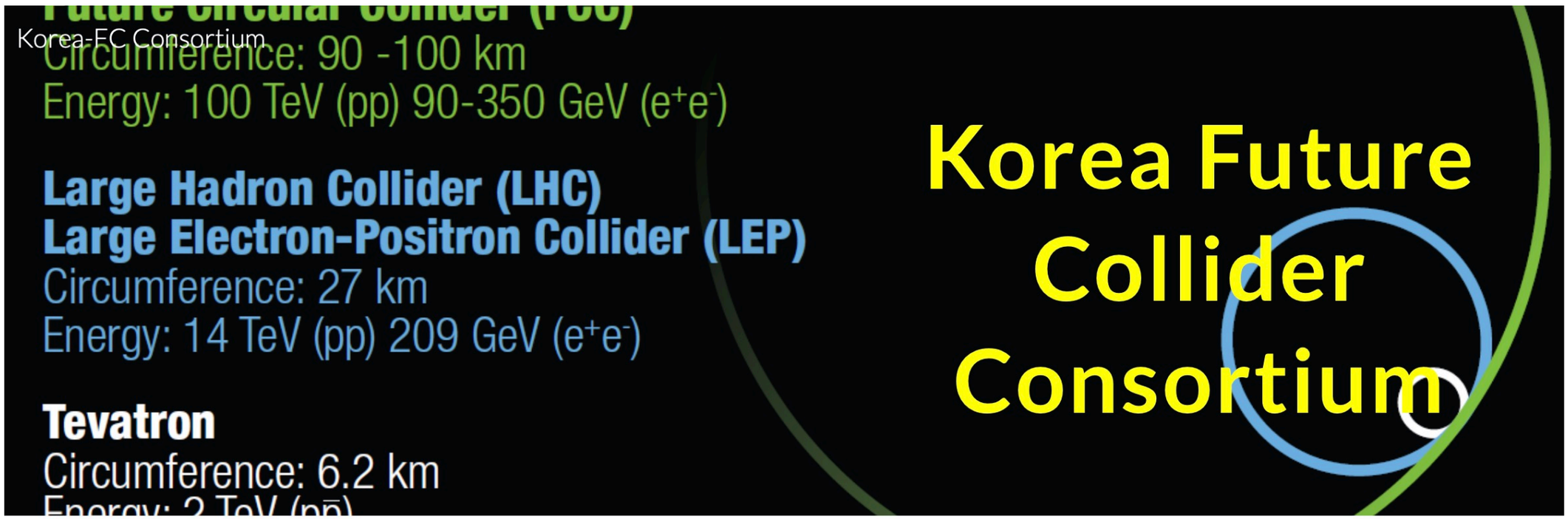
Milestone / activity	Target date	Possible timeline
First e^+e^- collisions in FCC-ee	Early 2040's	FCC-ee detector commissioning
Start machine installation	2037	Start FCC-ee detector installation
Tunnel completion	2035/36	
Start tunnel construction	2030	Start FCC-ee detector construction
Project approval	2028/29	FCC-ee Detector TDR's and approvals
Next European Strategy Update	2026/27	Next European Strategy Update (ESU)
Key prototypes (feasibility proof)	2026	FCC-ee Proto-collaborations and EoI's
FSR(*) (feasibility proof)	End 2025	PED FSR, includes enough common material and knowledge for FCC-ee proto-collaborations

(*) FSR = Feasibility Study Report

Adapted from schedule in M. Benedikt's presentation

Korea Future Collider Consortium

- Participants from various fields: accelerator, computing science, experiment, phenomenology etc.



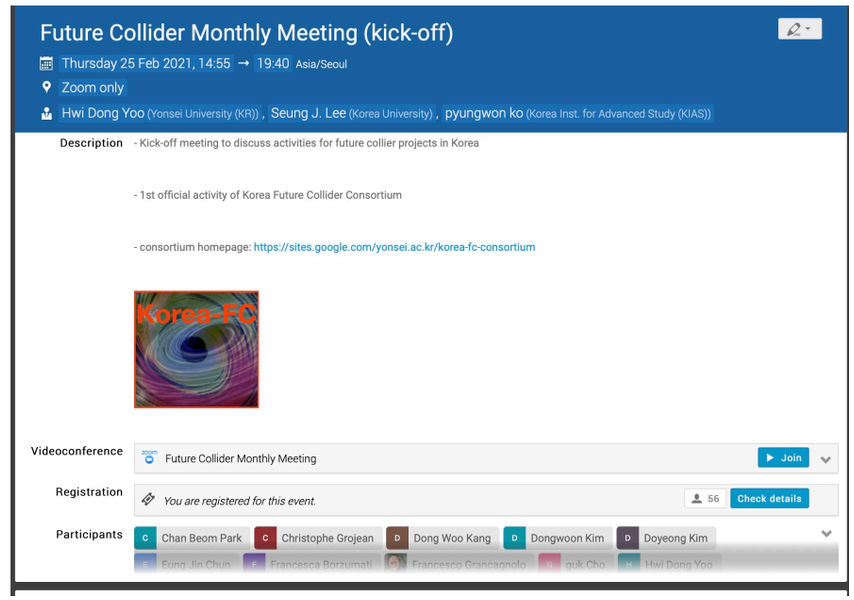
The Standard Model in particle physics has successfully explained all the experimental data up to now. Nevertheless, our minds do not rest in satisfaction because of the baffling questions such as the naturalness problem, the origin of CP violation, the baryogenesis, the non-zero neutrino masses, and the identity of dark matter. We should carry on our journey to the final theory. One essential measure for one step forward is studying future colliders, pushing the energy and intensity frontiers of particle colliders. In this regard, we put our minds together and launch the **Korea Future Collider Consortium**.

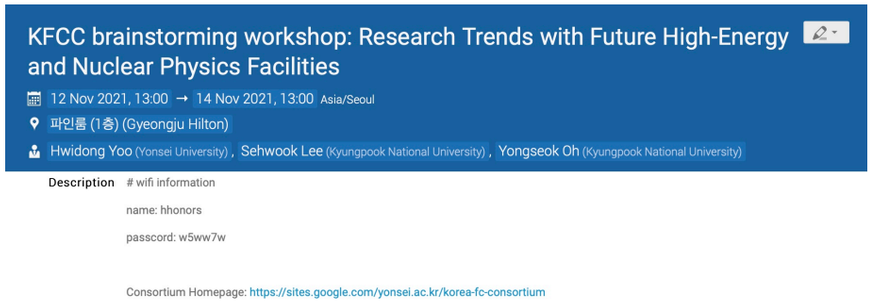
Goal: collaborate scientific activities for future collider projects in Korea such as theoretical approaches, detector R&D, accelerator R&D, communication etc.

https://sites.google.com/yonsei.ac.kr/korea-fc-consortium (contact to hdyoo@cern.ch if interested)

KFCC Activities: Workshop

- Kick-off workshop: Feb. 25
  - https://indico.cern.ch/event/1003237/
- Summer workshop: Aug. 26 - 27
  - https://indico.cern.ch/event/1063839/
- Informal meeting with CERN management: Sep. 3
  - https://indico.cern.ch/event/1065948/
- Fall workshop: Nov. 12 - 14 (invited only)
  - https://indico.knu.ac.kr/event/528/timetable/
- Many talks and discussions were recorded and available on the indico agenda!





During last summer

KFCC Activities: LoI v0

Letter of Intent from the Korea Future Collider Consortium

송정현 (건국대학교)

김홍주, 문창성, 박환배, 이세욱 (경북대학교)

이강영 (경상대학교)

고정환 (경희대학교)

원은일, 유재혁, 이승준, 최수용, 최준곤 (고려대학교)

임상훈 (부산대학교)

강신규, 박명훈 (서울과학기술대학교)

양운기, 정성훈 (서울대학교)

이상훈 (서울시립대학교)

김범규 (성균관대학교)

김용선 (세종대학교)

권영준, 박성찬, 유희동 (연세대학교)

문동호, 이재식 (전남대학교)

최성렬 (전북대학교)

이현민 (중앙대학교)

김정한 (충북대학교)

손민호 (한국과학기술원)

김태정 (한양대학교)

요약문

CERN 연구소의 Future Circular Collider (FCC) 프로젝트

- LHC 실험의 후속 프로그램으로 2030년대 후반 가동 시작을 목표로 함
- 건설비용만 수십 조 원으로 예측되는 금세기 최대 국제 공동연구 프로젝트
- 주요 연구 주제로 힉스 입자의 정밀 관측 및 새로운 물리현상 탐사
- 2020년부터 HL-LHC 업그레이드와 함께 CERN 연구소의 최우선 순위 연구주제로 선정됨
- CERN 연구소의 FCC 가속기 및 검출기 R&D 프로그램이 시작되어 관련 연구가 본격적으로 진행되고 있음 (2021 – 2025)
- 예상 일정: 가속기, 검출기 디자인 제출 (2025), 국제 공동연구단 구성 (2026), 프로젝트 승인 (2028), 건설 시작 (2030), 가동 시작 (2040)

한국 차세대 가속기 컨소시움 (Korea Future Collider Consortium)

- 차세대 가속기 관련 연구에 대하여 한국 물리학자들이 전 세계 입자물리 커뮤니티에서 **선도적 역할**을 위하여 구성
- FCC 실험에 사용될 주요 검출기에 대한 디자인, 프로토타입 R&D, 제작을 통한 **검출기 오너십**을 한국 연구진이 획득하는 것을 주요 목표로 함
- 이론, 실험, 빅데이터, 인공지능 등 다양한 분야의 전문가들이 모여 차세대 기초과학 연구의 방향성 설립 및 새로운 아이디어로 확장
- 차세대 가속기 관련 국내외 전문가 커뮤니티와의 협업체계 구축

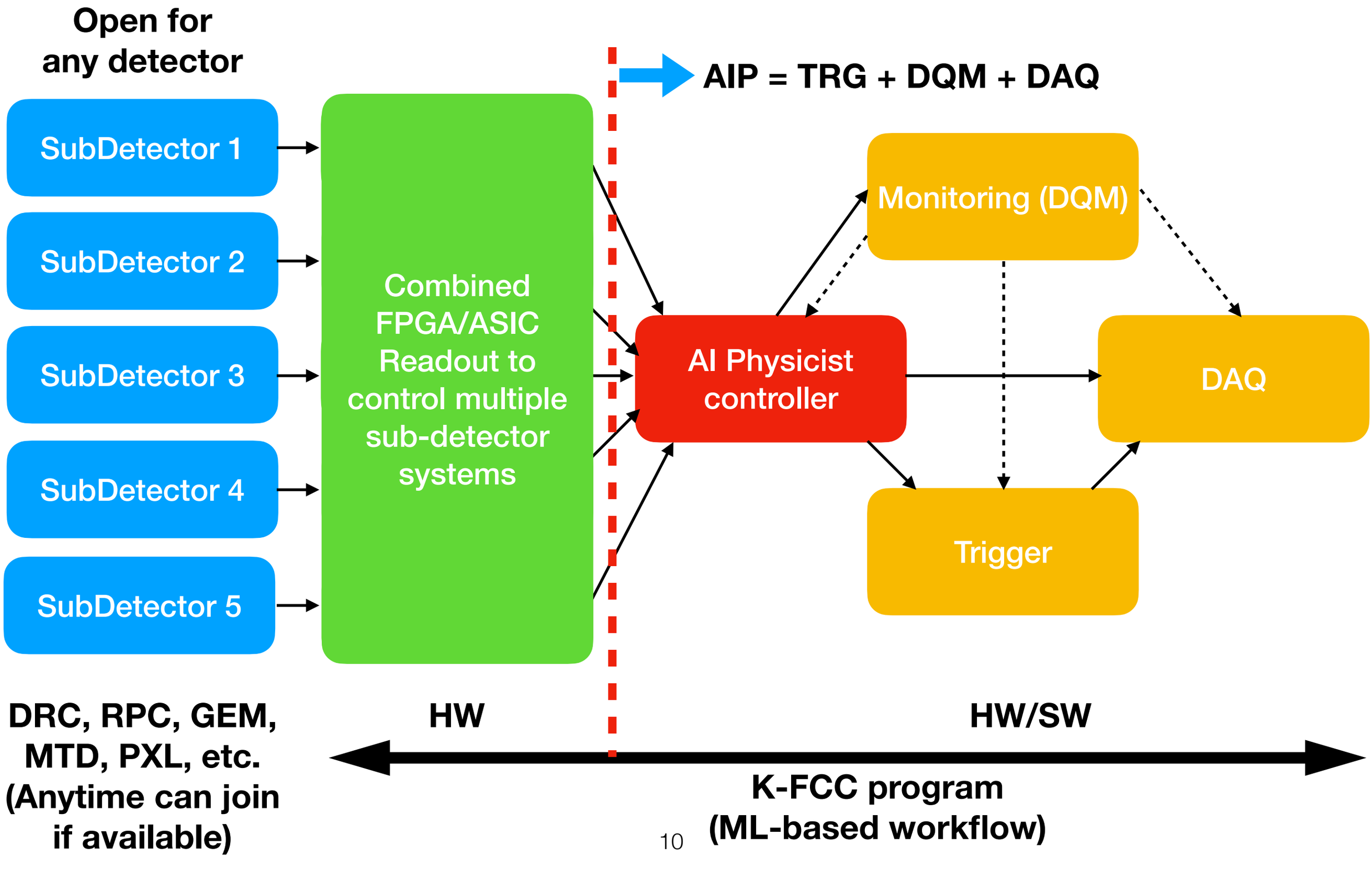
연구계획

- 인공지능을 기반으로 하는 차세대 검출기에 대한 개념 설계, 디자인, 프로토타입 R&D 수행을 목표로 함
- 인공지능 성능 가속화를 위하여 하드웨어와 소프트웨어를 결합한 하이브리드형 인공지능 플랫폼 개발
- 하위 검출기 시스템을 유기적으로 작동시켜 최적화하는 **인공지능 물리학자** 개발
- FCC 실험에서 수행 가능한 표준모형 및 새로운 물리이론에 대한 현상론적 연구
- 슈퍼컴퓨터, 양자컴퓨터를 이용한 양자머신러닝 등 첨단 미래 기술 활용

Anyone interested, please join us in next version!

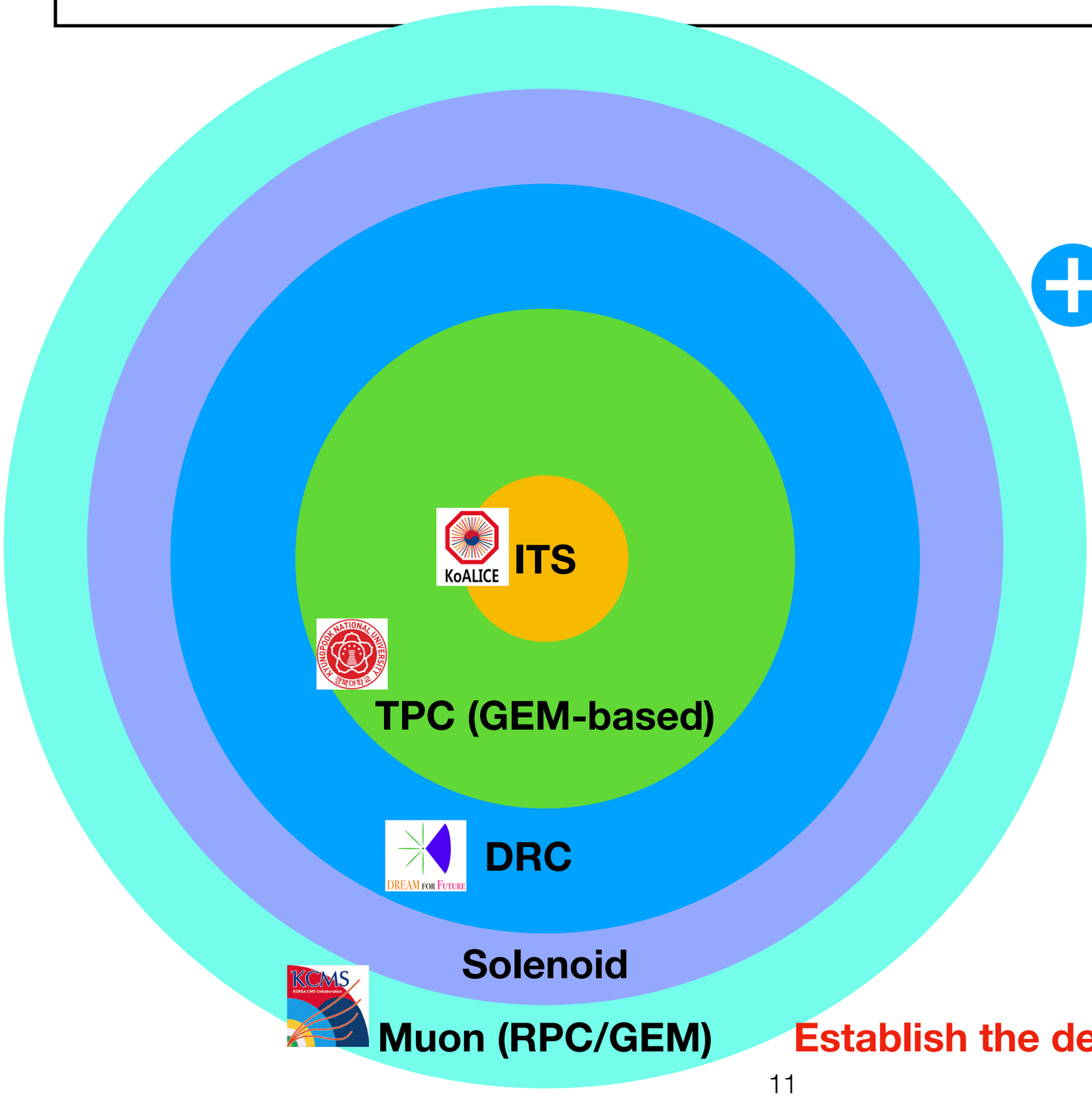
During last summer

KFCC Activities: AI Physicist



During last fall

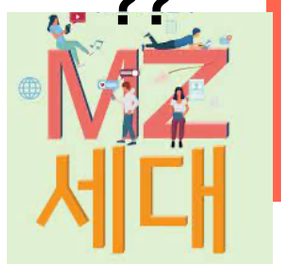
KFCC Activities: Detector Design



AIP electronics & DAQ

Belle II

??



Metaverse interface

Users

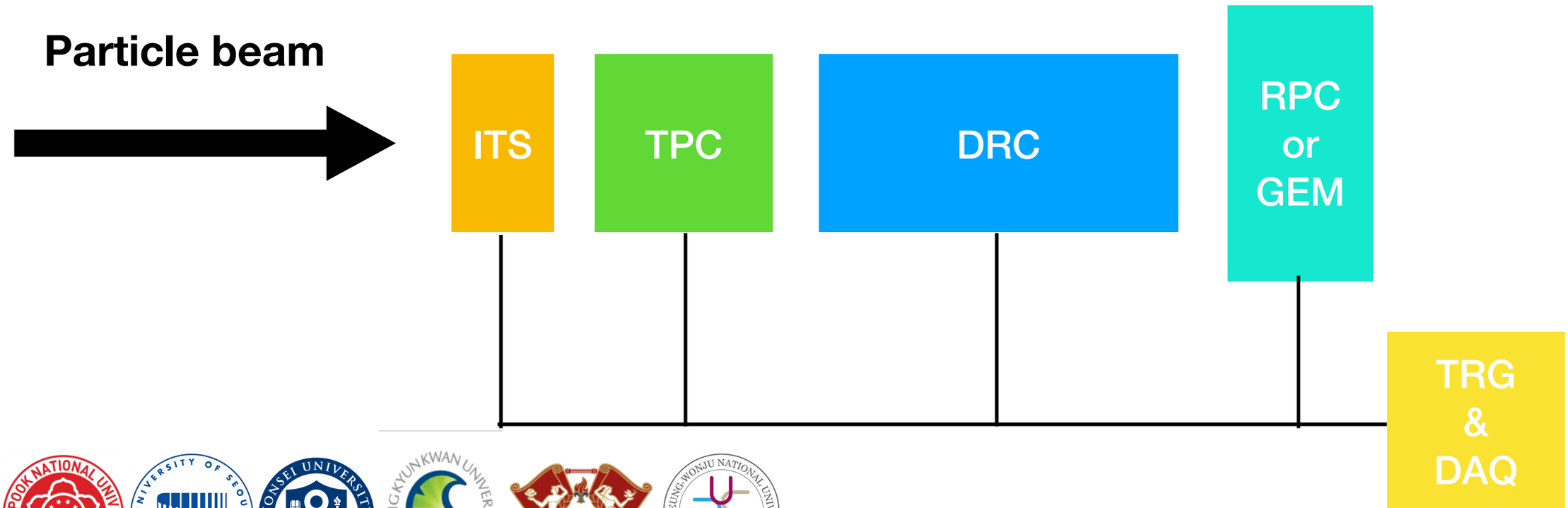
Establish the detector design requirement

KFCC Activities: Integration

In 2022

- (Experimental side) prepare at least one module for each subsystem and try “test-beam” together in “local facility”
    - Strategic partnership with accelerator community
- Define the AIP detector concept
    - Several guideline sentences for the definition
    - Reality with more details

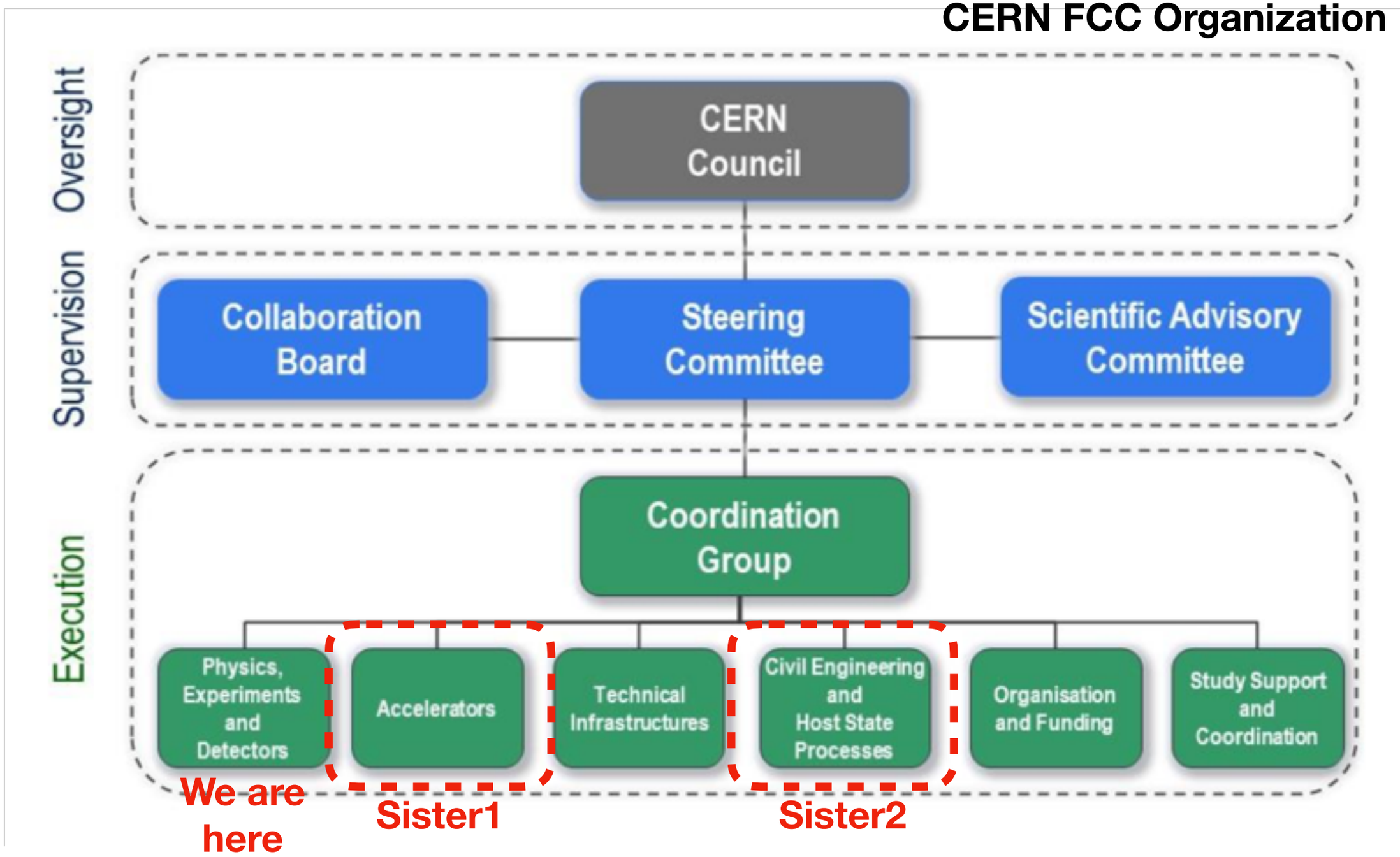
Anyone interested, please join us!



Extension of Collaboration

- Accelerator, civil engineering

CERN FCC Organization



Integration → Incubation

4년마다

지난 30 여년간 축적해온 연구역량의 집대성

40여년만의 빅 이벤트

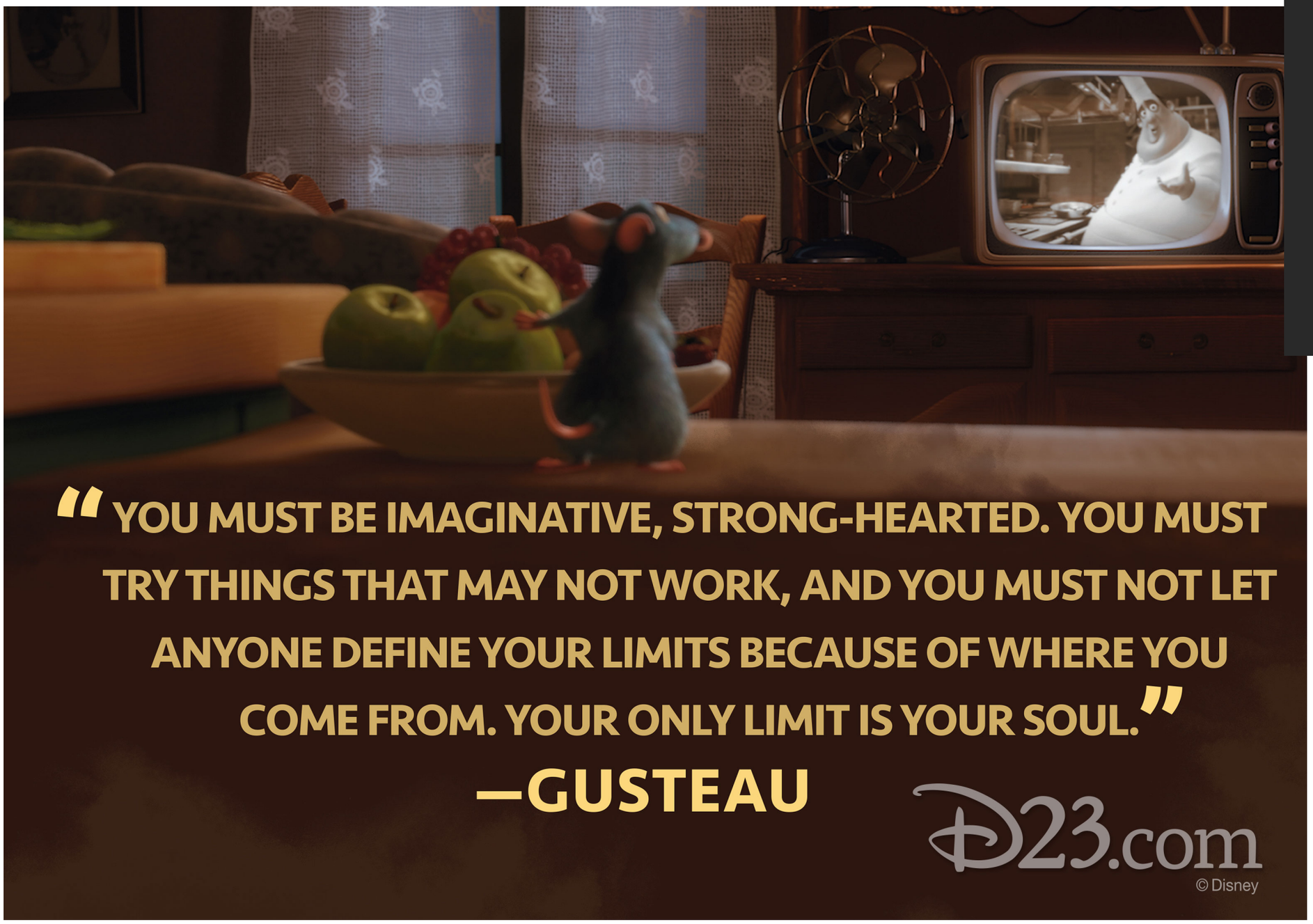
차세대 가속기 프로젝트에서 한국 연구진이 세계 최고 수준의 선도적 역할을 수행

차세대 가속기 프로젝트를 통해 업그레이드 된 젊은 연구 인력 양성

몇 단계 업그레이드 된 입자물리 연구 생태계 구축

Summary: KFCC

- Time to imagine!



Summary: KFCC

- Time to imagine!

Dual-Readout Calorimeter R&D in Korea

On behalf of
the Korea Dual-Readout Calorimeter Team

NP

Prof. Hyonsuk Jo (KNU)
Prof. Yongsun Kim (Sejong U.)
Prof. Sanghoon Lim (PNU)

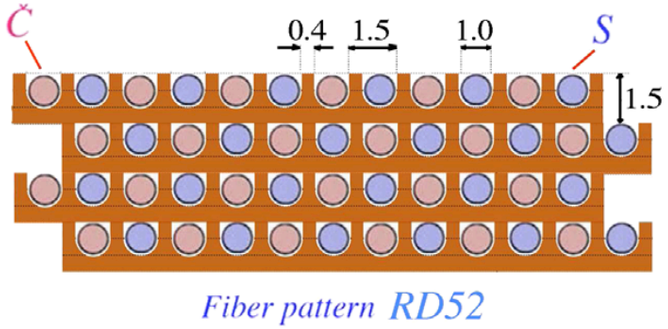
PP

Prof. Jason Lee (UoS)
Prof. Sehwook Lee (KNU)
Prof. Hwidong Yoo (YU)

Supported by KiSTi www.kisti.re.kr

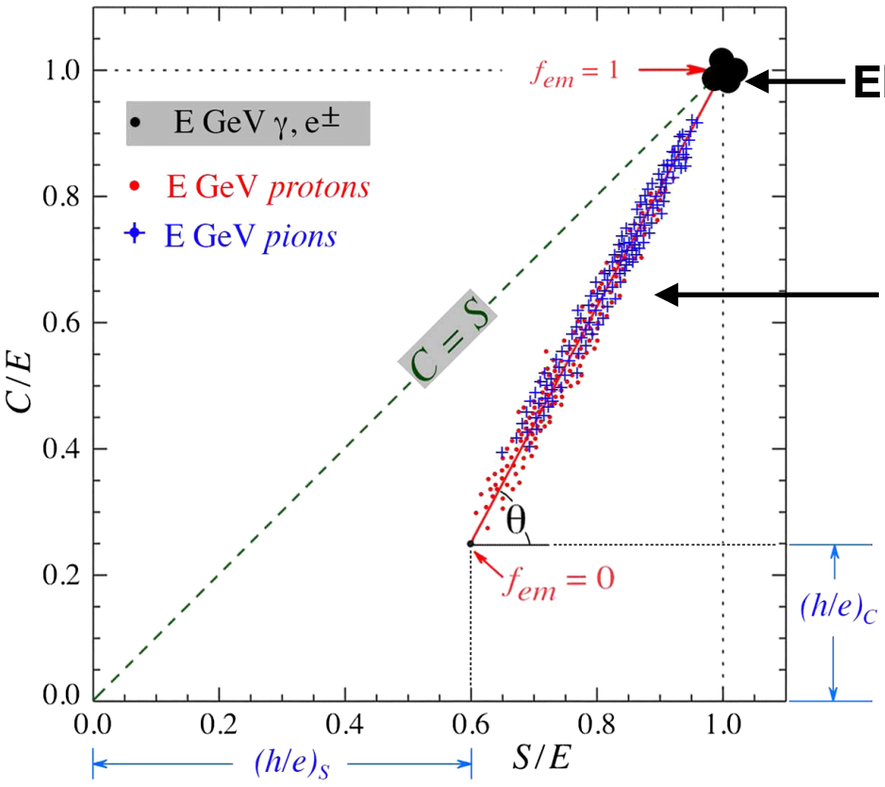
Intro: Dual-Readout Calorimeter (DRC)

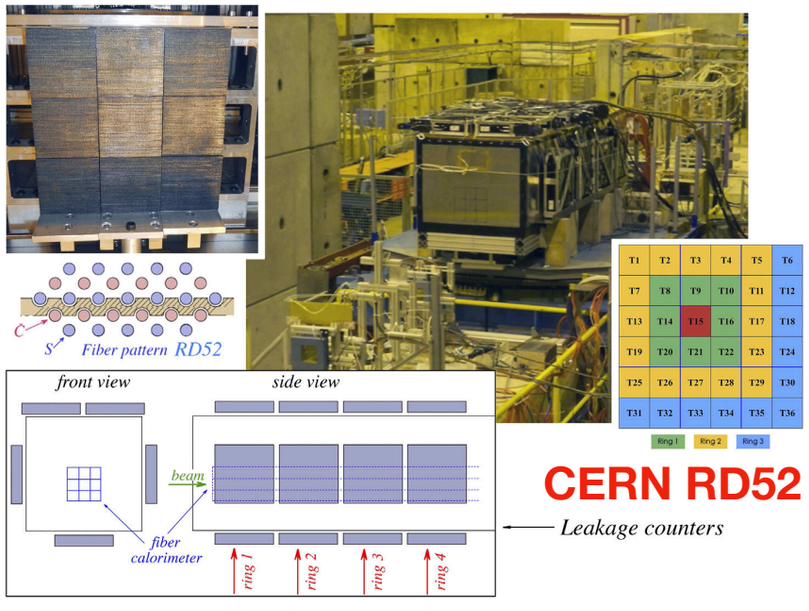
- DRC offers high-quality energy measurement for both EM particles and hadrons
  - DRC consists of two different optical fibers (S, C) in a single component
  - The main culprit of poor hadronic energy resolution is fluctuations of the EM shower components of hadron showers (f_{em})
  - f_{em} can be determined using the measured values of scintillation and Cerenkov signals
- Excellent hadron energy resolution can be achieved by correcting the energy of hadron event-by event



Fiber pattern RD52

$$S = E\left[f_{\rm em} + \frac{1}{(e/h)_S}(1 - f_{\rm em})\right],$$
$$C = E\left[f_{\rm em} + \frac{1}{(e/h)_C}(1 - f_{\rm em})\right],$$
$$f_{\rm em} = \frac{(h/e)_C - (C/S)(h/e)_S}{(C/S)[1 - (h/e)_S] - [1 - (h/e)_C]}.$$

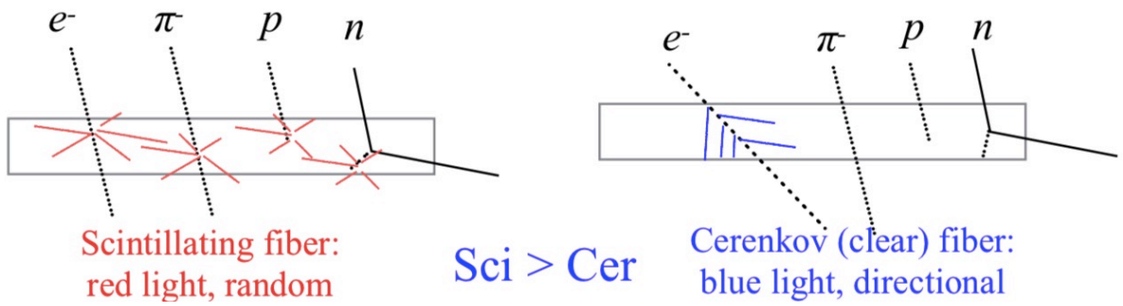




CERN RD52 experiment

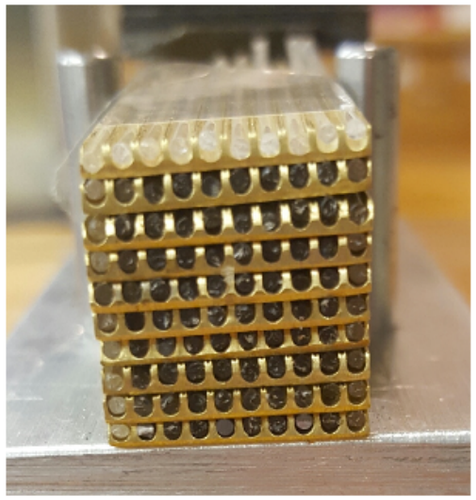
$$E = \frac{S - \chi C}{1 - \chi}.$$
$$\cot\theta = \frac{1 - (h/e)_S}{1 - (h/e)_C} = \chi,$$

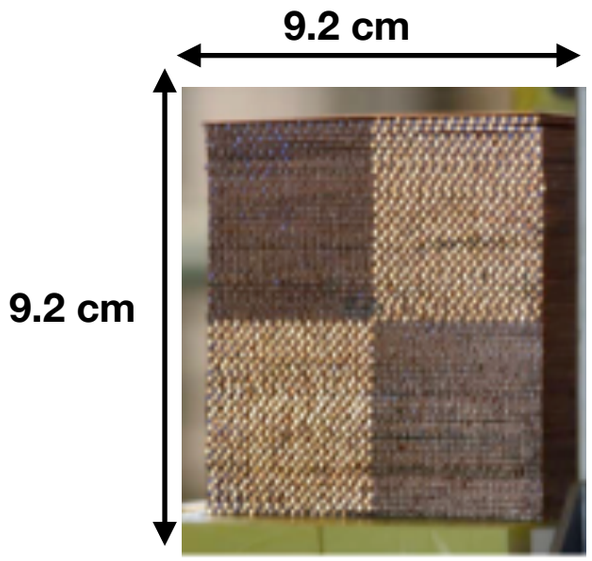
Signal generation: Scintillating & Cerenkov fibers



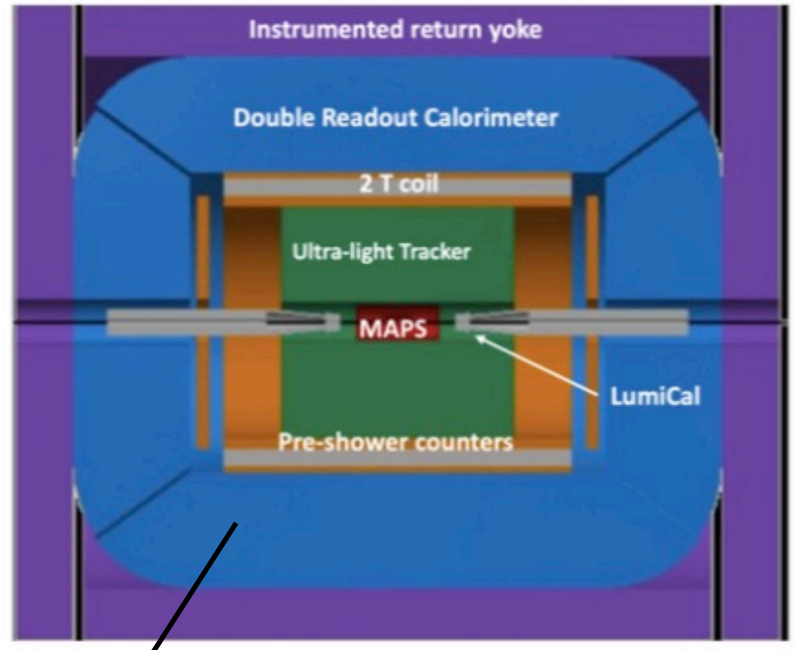
Intro: DRC Geometry and Module

- Korean team led the design of the Dual-Readout Calorimeter (DRC) for IDEA detector
  - Included in the CDRs of both FCC-ee and CEPC, published at the end of 2018

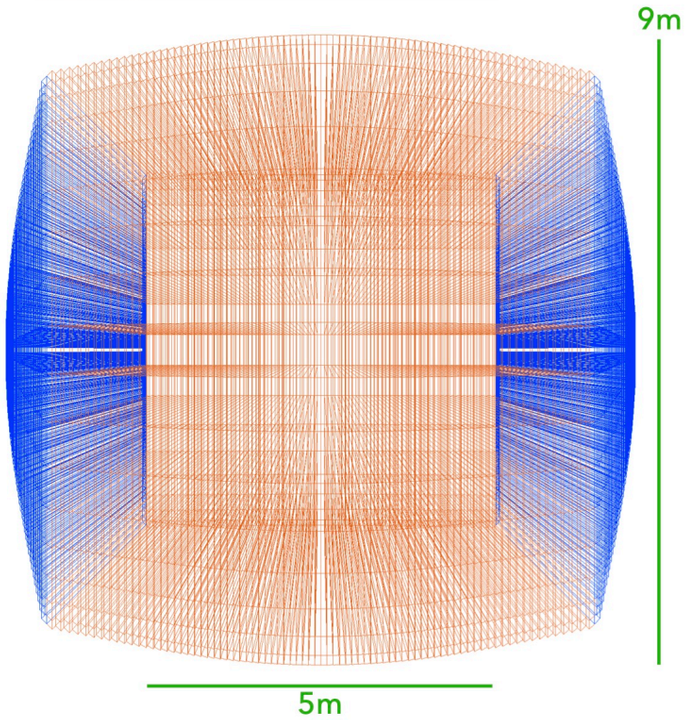


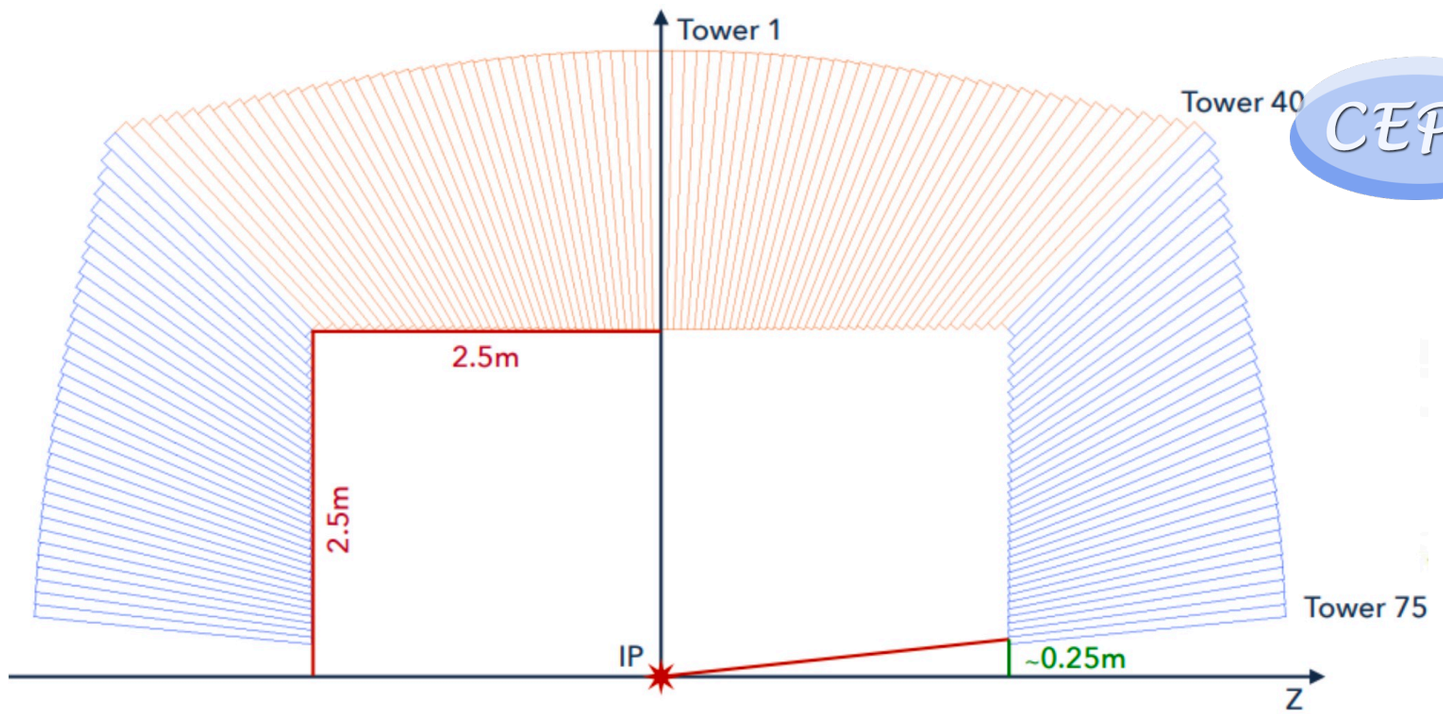


Size of unit module



IDEA





Intro: DRC International Collaboration

Prof. Hyonsuk Jo (KNU)
Prof. Yongsun Kim (Sejong U.)
Prof. Sanghoon Lim (PNU)
Prof. Jason Lee (UoS)
Prof. Sehwook Lee (KNU)
Prof. Hwidong Yoo (YU)

Prof. Rong-Shyang Lu

Prof. Chia Ming Kuo

Taiwan

Korea

Japan

Prof. Yuji Enari

USA

Prof. Sarah Eno

Prof. Chris Tully

Prof. Richard Wigmans

Prof. John Hauptman

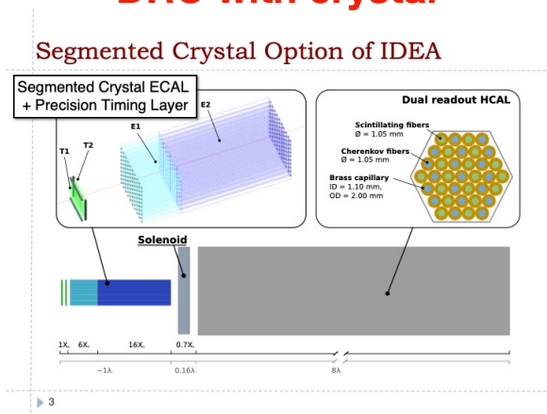
Europe

Prof. Paolo Giacomelli (Bologna)
Prof. Romualdo Santoro (Insubria)
Prof. Roberto Ferrari (Pavia)
Prof. Franco Bedeschi (Pisa)

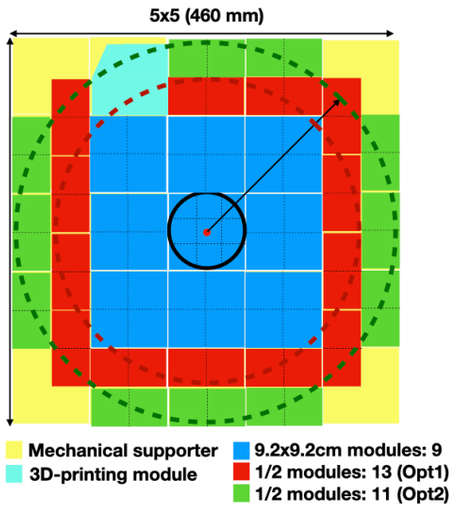
Prof. Iacopo Vivarelli

Prof. Valery Chmill

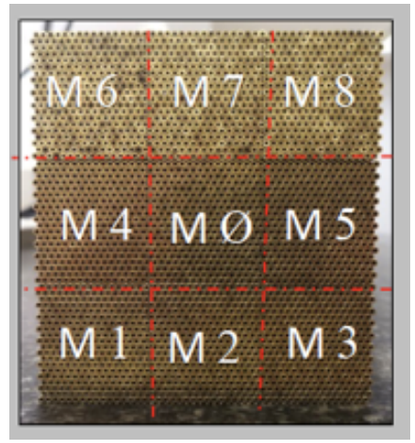
DRC with crystal



Full-size prototype detector



Bucatini prototype

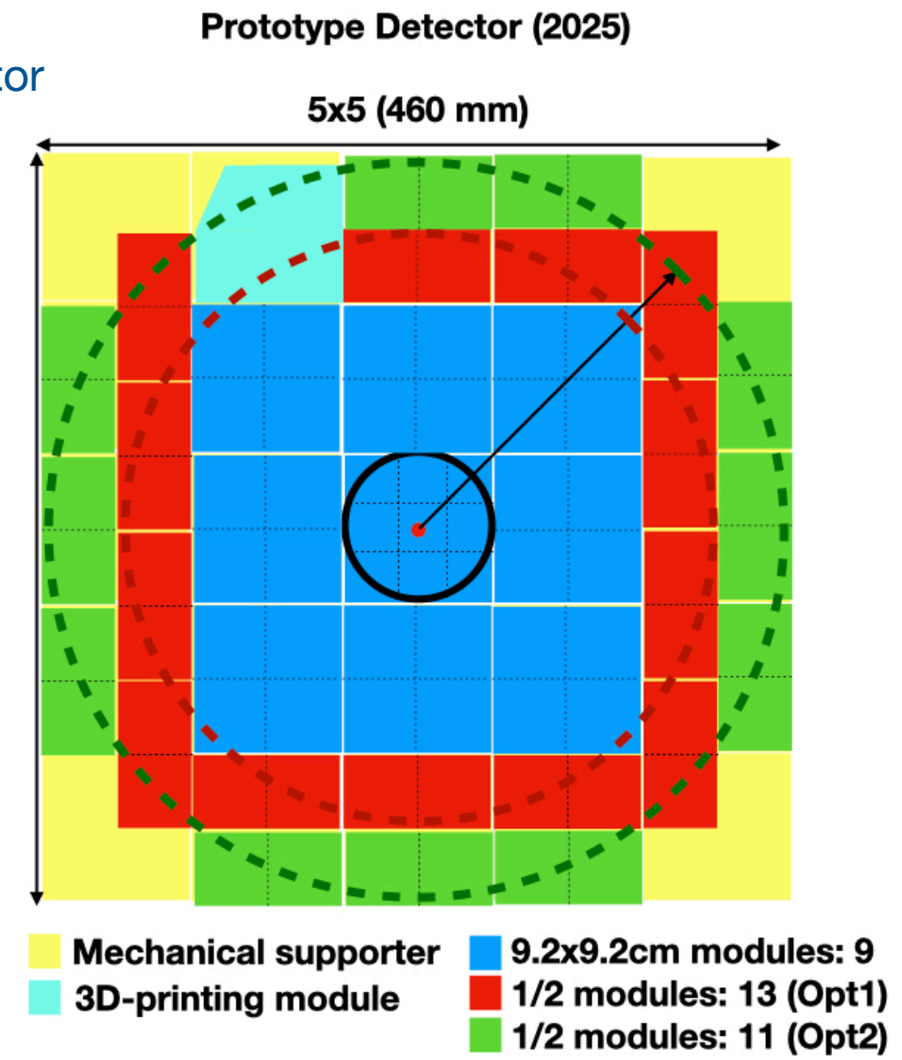


Intro: Korea Prototype Detector

- Primary goal: build a prototype detector for the detector design of future collider projects
  - **5 year (2020.Mar. - 2025.Feb.) R&D funding** supported by Korea NRF ($~0.4M/year, total **$~2M** for 5 years) => 2nd year in this program
  - Contain almost (97.5%) full hadronic shower energy
  - Demonstrate engineering aspects for full geometry detector
- Secondary goal: train next generations as experts of the (DRC) detector

2017-9	2020-1	2022-5	TBD
Design	R&D	Prototype	Production

Stage	Topic
Design	Propose a design of Dual-Readout Calorimeter to IDEA detector concept
R&D	Perform R&D (including engineering aspects) based on HW & SW
Prototype	Build 4x4 detector and perform test beams
Production	TBD



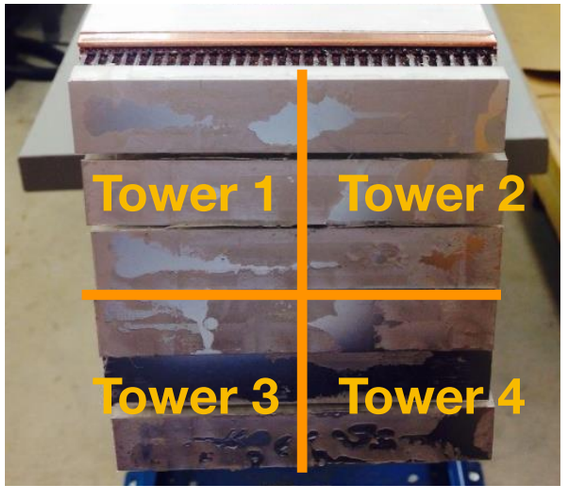
1. Two Module Production

- Two module buildings for initial R&D and upcoming test-beam experiment are on-going
- Various assembly steps are precisely being visited
  - Optical fiber treatments
  - PMT and electronics R&D
  - Housing and assembly kit design

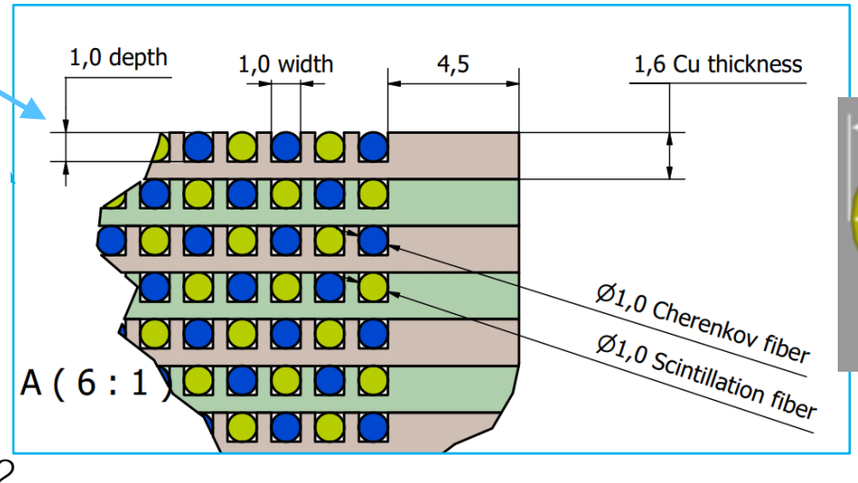
Test-beam plan

Goal	Details
Measurements	Time resolution, shower depth, longitudinal shower profile, light attenuation length etc.
	Position resolution, EM energy resolution, lateral shower profile, uniformity etc.
R&D	Readout test (MCP vs. SiPM)
	Time resolution (< 50 ps)
	Optical fibers (various types)
Training	Next generation experts for DRC HW

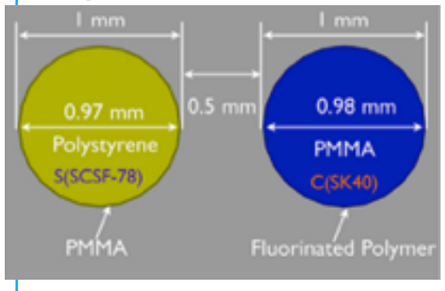
Module #1 (2x2)



Module #2 (3x3)



Specification of fibers



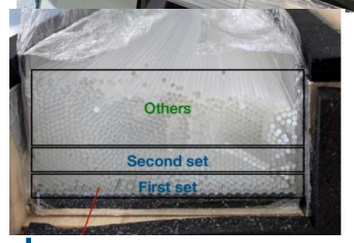
NIM A 762 (2014) 100, N. Akchurin et al.

Optical Fiber Treatment

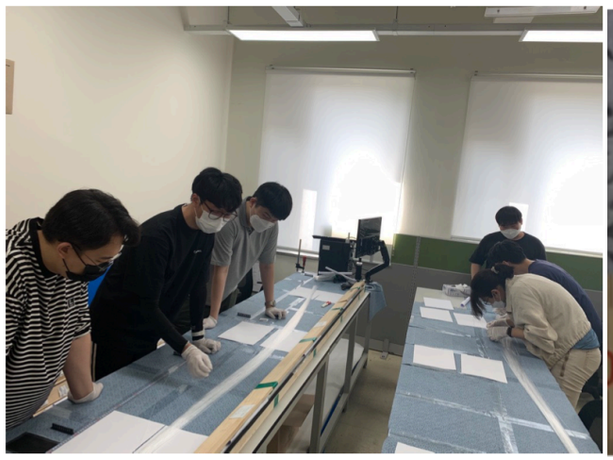
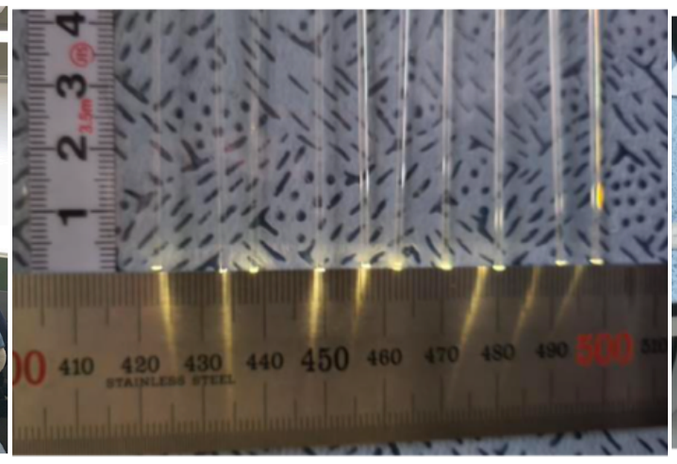
- Fibers delivered at early spring
  - From Kuraray (S) and Mitshbishi (C)



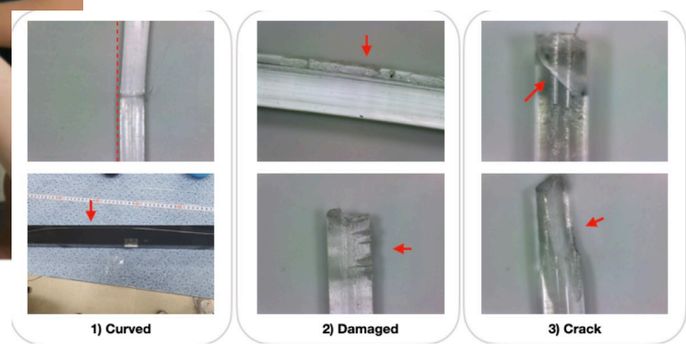




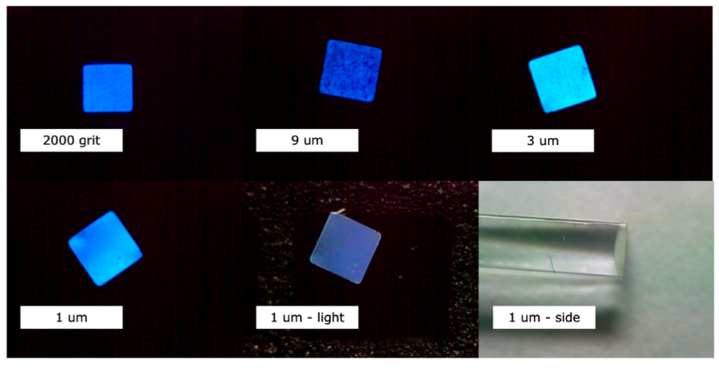
- Check the quality of fibers in details: check 1-by-1 and make a database

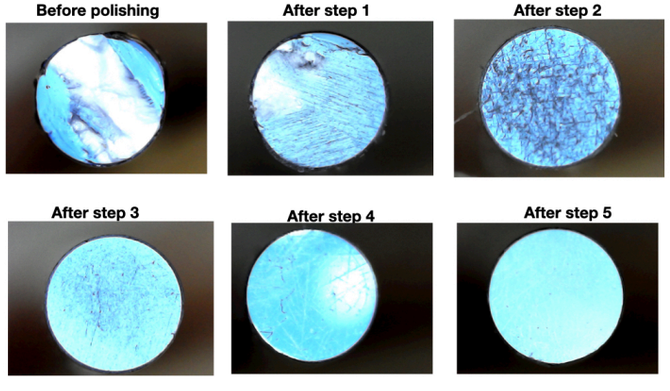



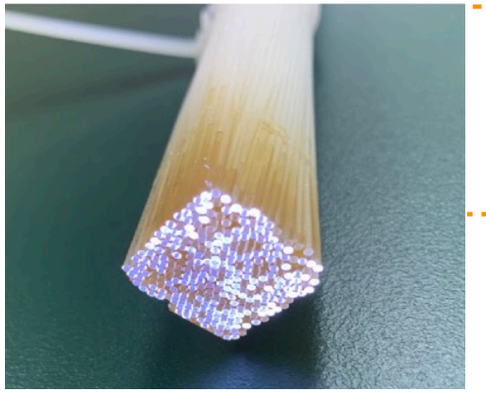
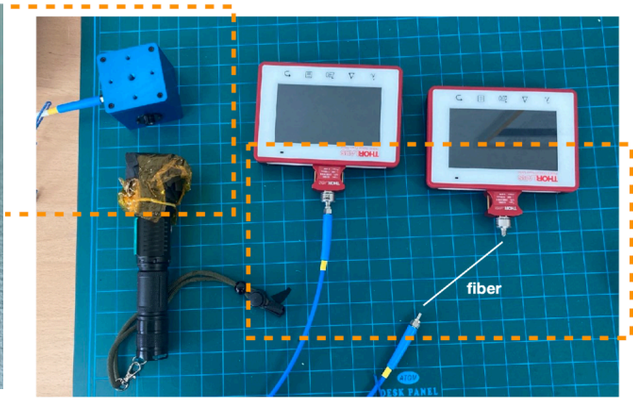




- Straightening, polishing, bundling, Inserting, light yield test etc.

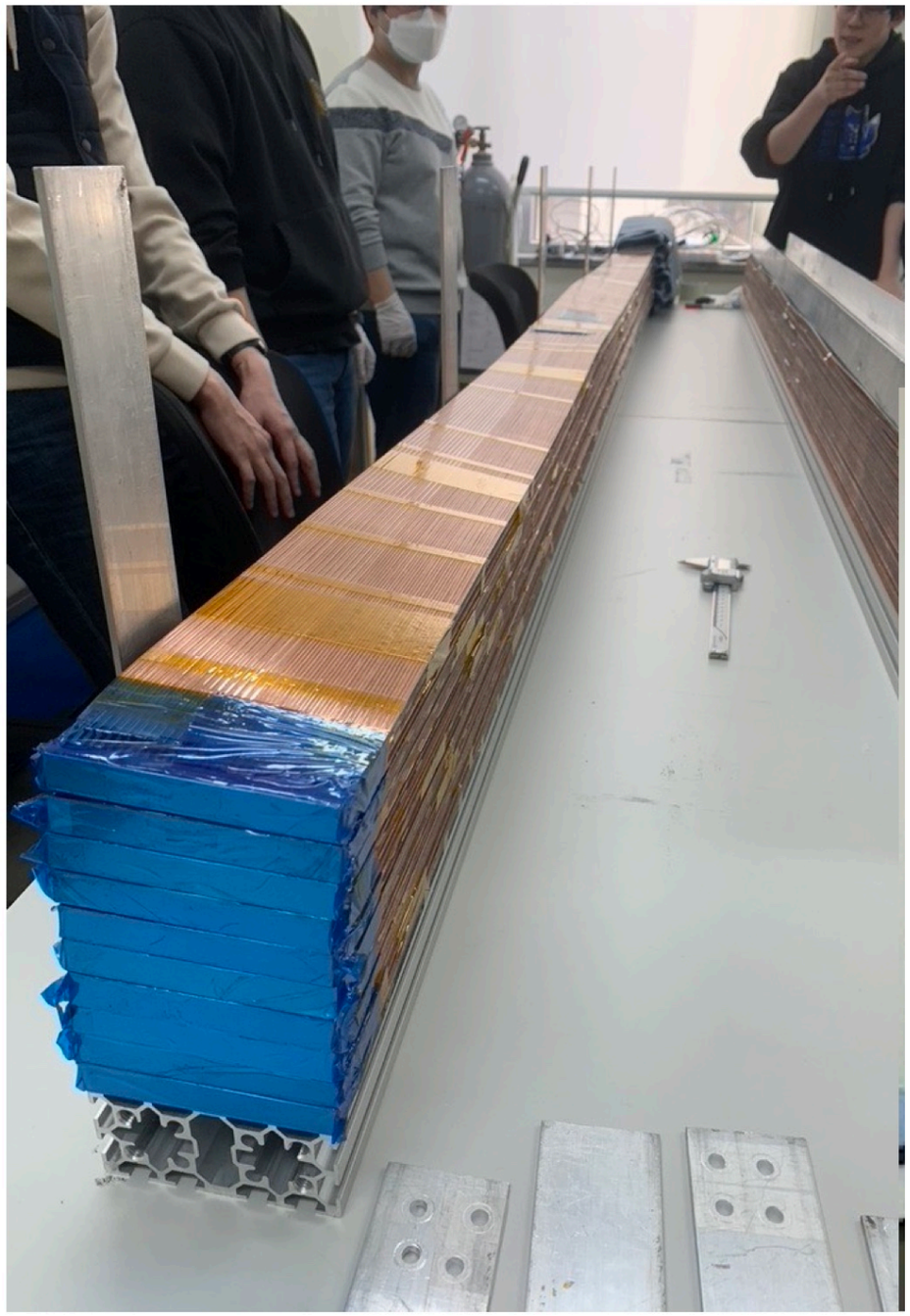


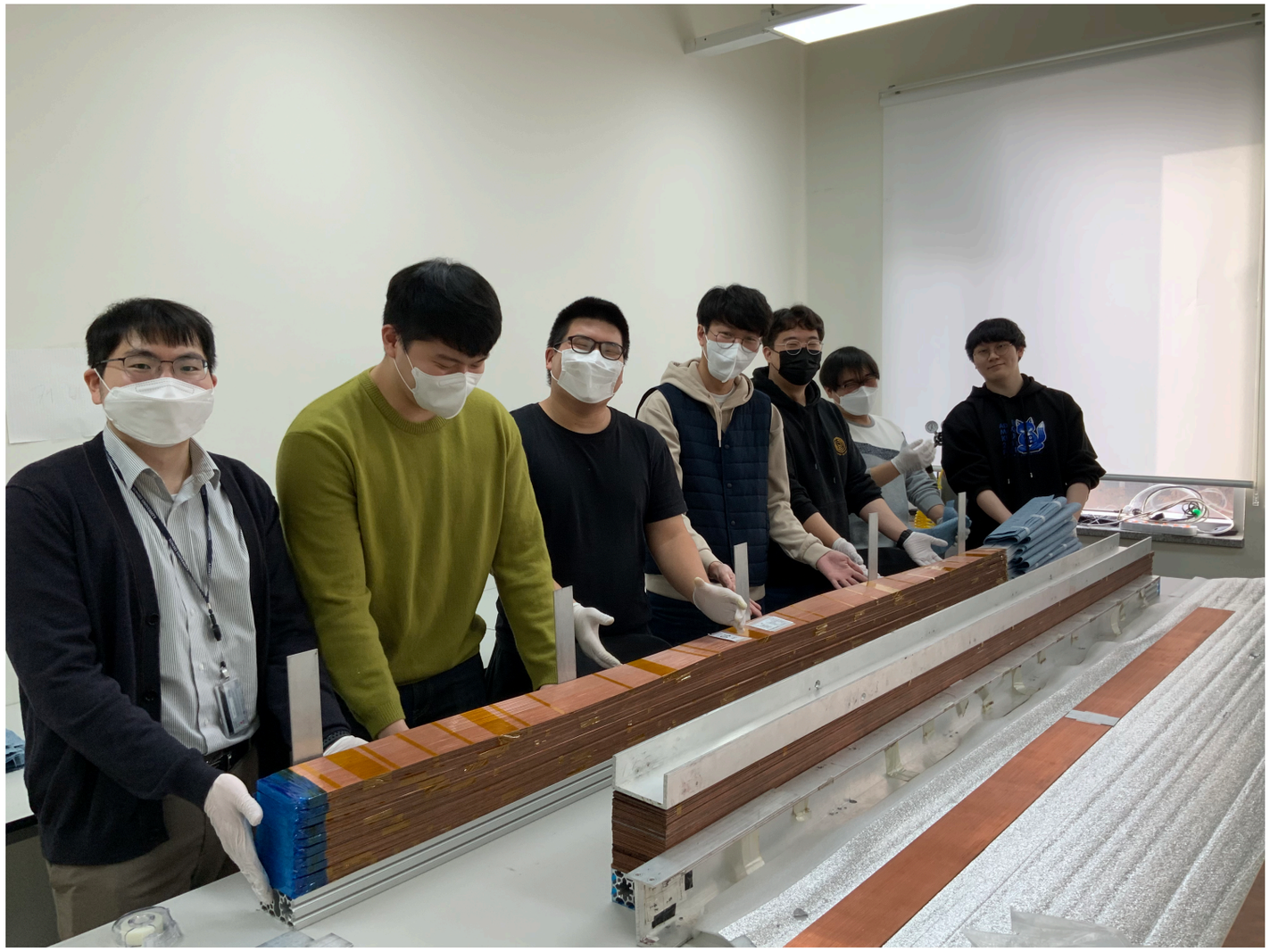


1st Module Assembly

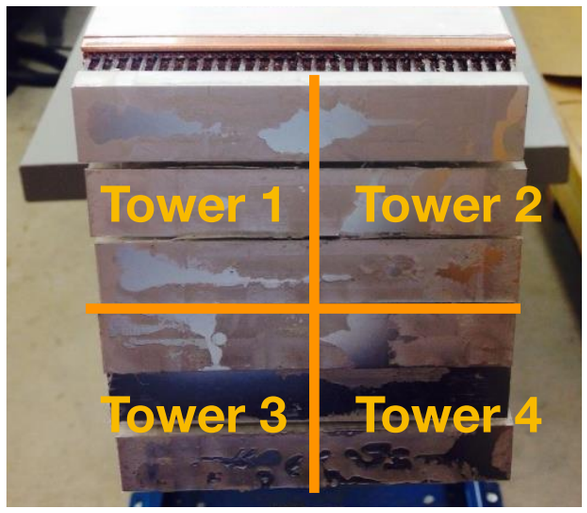
- We stacked copper plates which optical fibers were inserted for 1st module successfully!





Electronics R&D

Module #1 (2x2)

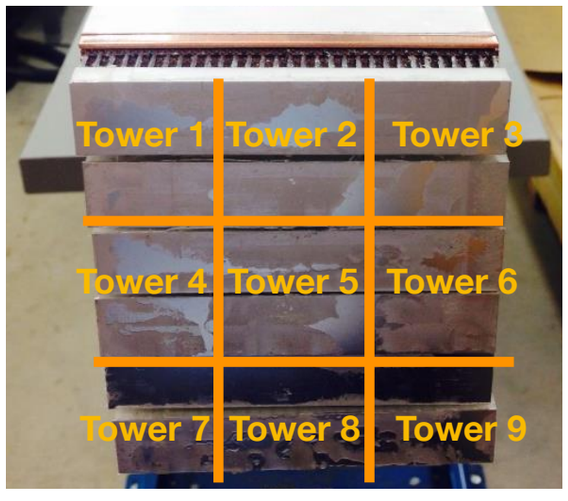


Tower#1	Tower#2
Tower#3	Tower#4

Combination of fibers for Module#1

	Tower #1	Tower #2	Tower #3	Tower #4
Scintillation fibers	Round / Single cladding	Round / Single cladding	Round / Double cladding	Square / Single cladding
Cherenkov fibers	Round / Single cladding			
Readout detector (2*4 ch)	2 PMTs	2 MCP-PMTs	2 PMTs	2 PMTs

Module #2 (3x3)



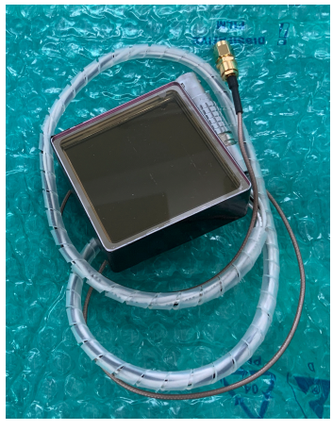
Tower#1	Tower#2	Tower#3
Tower#4	Tower#5	Tower#6
Tower#7	Tower#8	Tower#9

Combination of fibers for Module#2

	Tower #1~4 and #6~9	Tower #5
Scintillation fibers	Round / Single cladding	
Cherenkov fibers	Round / Single cladding	
Readout detector (400+16 ch)	16 PMTs	400 SiPMs

Electronics R&D

- 3 types of PMTs will be tested



The biggest number of pixels (16675) have been chosen
to avoid the saturation effect of photon counting for the scintillation lights.

SiPM	Photo-sensitive area	pixel size	Photo detection eff. (Silicone resin)		number of pixels	photo
S14160-1310PS	1.3x1.3 (1.69 mm²)	10 μm	~15% at 400 nm	~17% at 550 nm	16675	

MCP-PMT: excellent timing performance

MCP-PMT	Window size	Light / pour size	Q.E. (Bialkali)	max. HV (V)	Rise time (ns)	photo
PLANACON XP85012	53x53 mm²	scintillation / 25 um	~7% at 550 nm	2400	0.6	
PLANACON XP85112		Cerenkov / 10 um	~21% at 400 nm	2800	0.5	

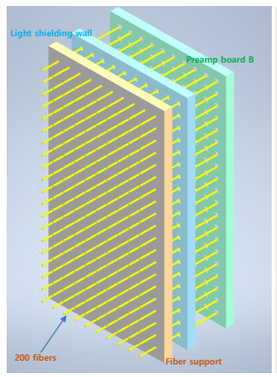
https://www.photonis.com/products/planacon

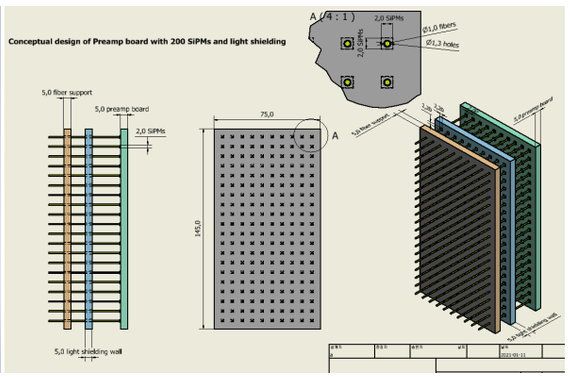
PMT: window size and timing performance

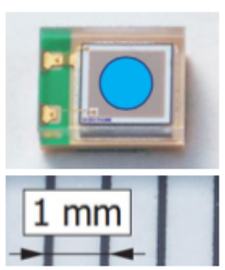
PMT	Window size	Q.E. (Super bialkali, SBA)		max. HV (V)	rise time (ns)	photo
		Ck.	Sc.			
R11265-100	23x23 mm²	~35% at 400 nm	~7% at 550 nm	1000	1.3	

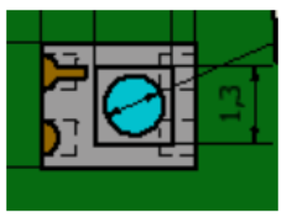
https://www.hamamatsu.com

- Electronics are under production

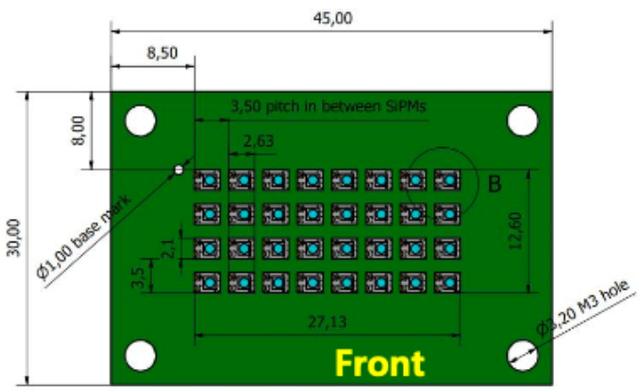






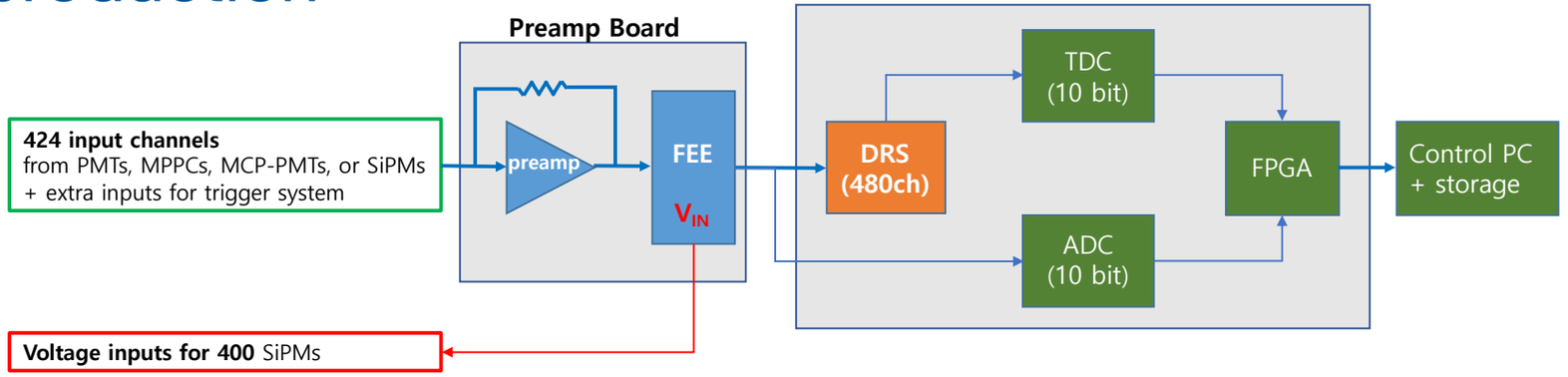


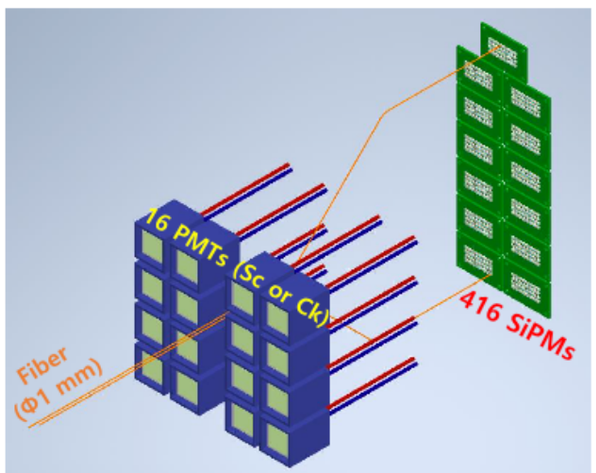
Single SiPM



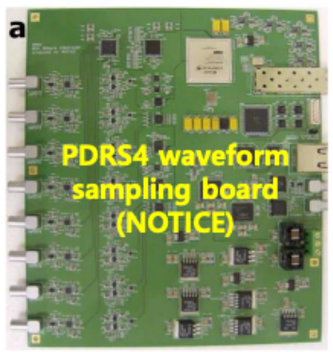
424 input channels
from PMTs, MPPCs, MCP-PMTs, or SiPMs
+ extra inputs for trigger system

Voltage inputs for 400 SiPMs





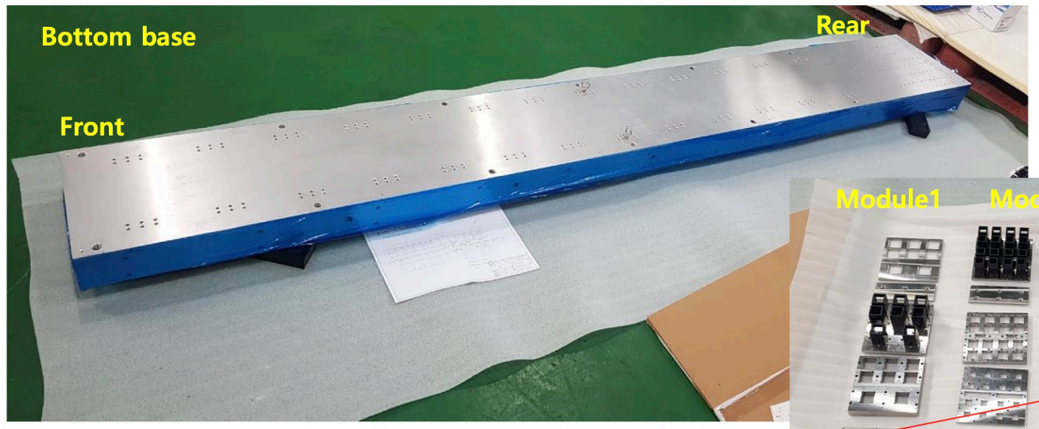
Preamp board based on DRS4

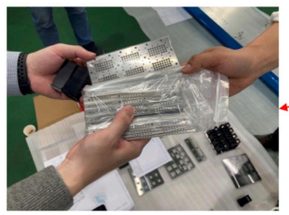


NIM A830 (2016) 119 H. Kim et al.

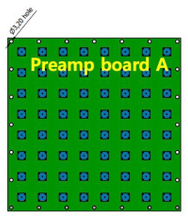
Will be delivered in next week

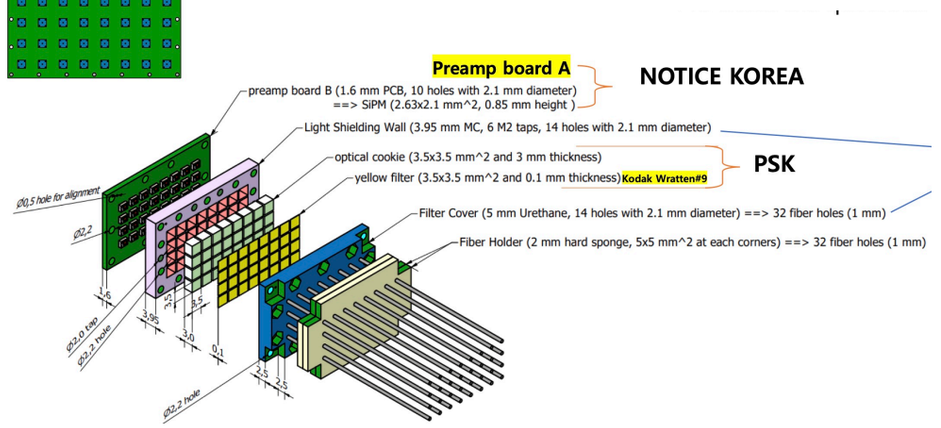
Supporter & Assembly Kit Design

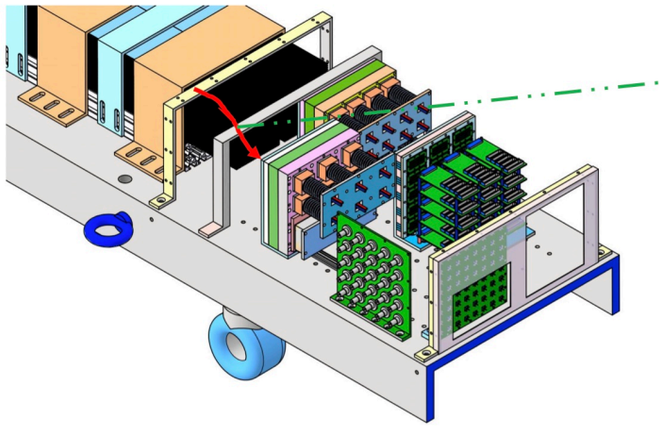


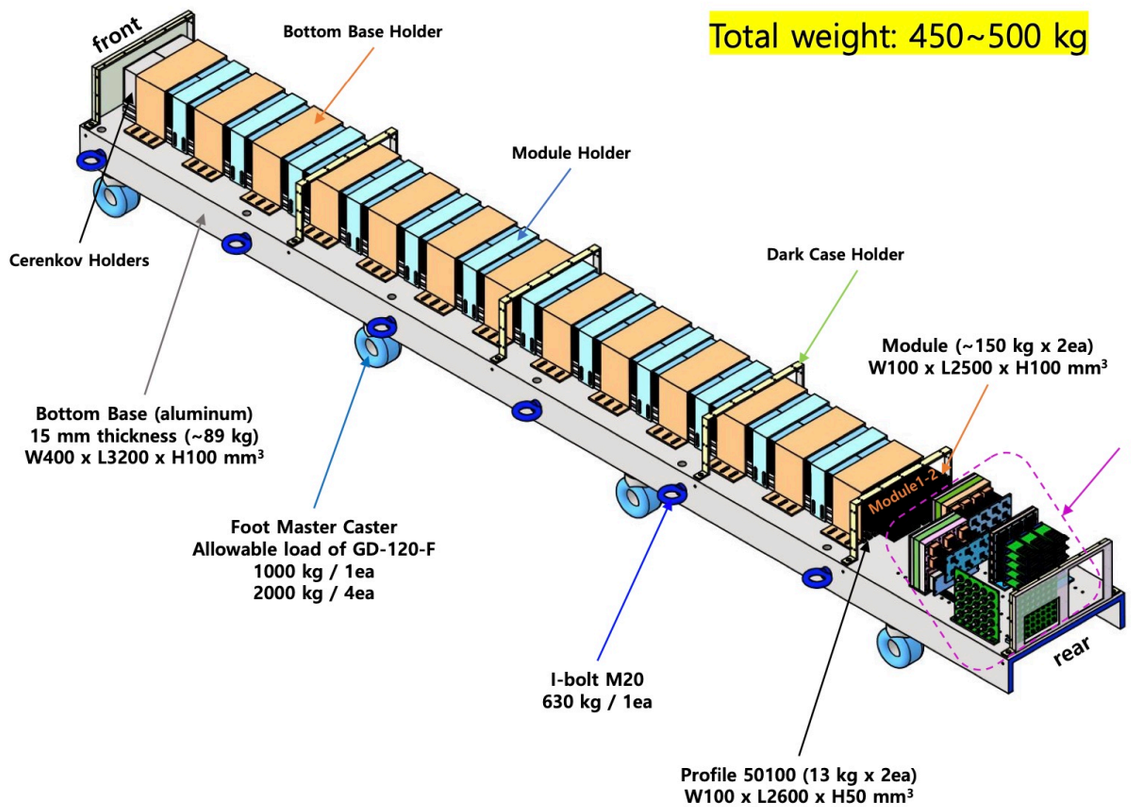


Dr. Ha brought some pieces. (11/19)
- Fiber Frames for SiPM
- Two Fiber Bundle Cases for each modules

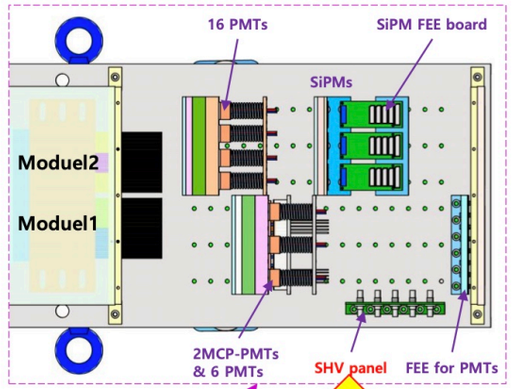




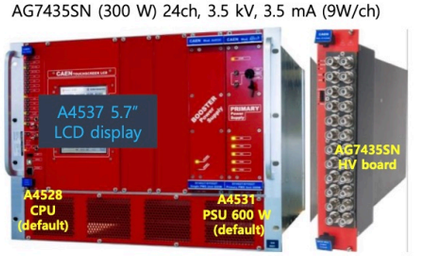




Total weight: 450~500 kg



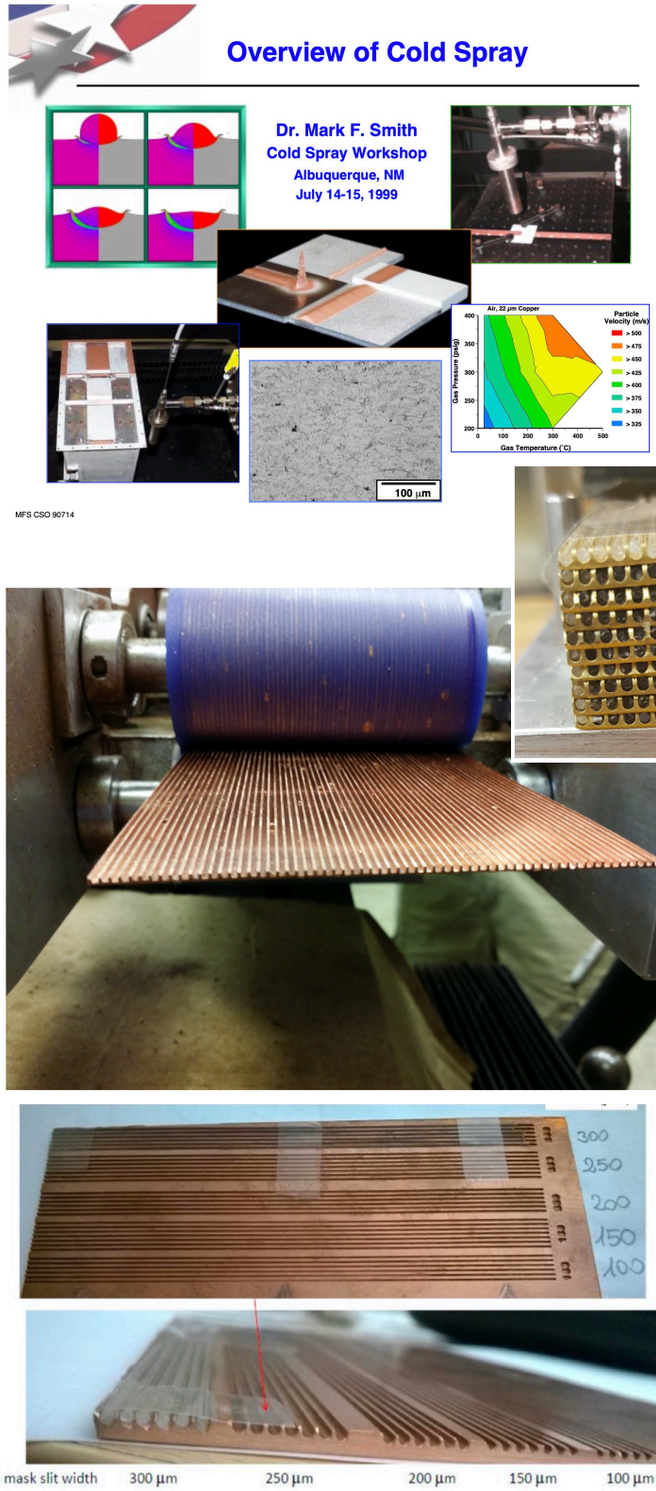
Universal Multichannel Power Supply System
SY4527Full (600W) 8U, 16 slots
AG7435SN (300 W) 24ch, 3.5 kV, 3.5 mA (9W/ch)

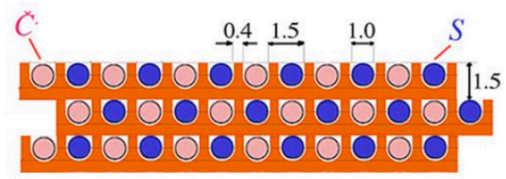


Delivery today!

2. Copper Forming

- We tried many options (by John Hauptman et al in CERN RD52)





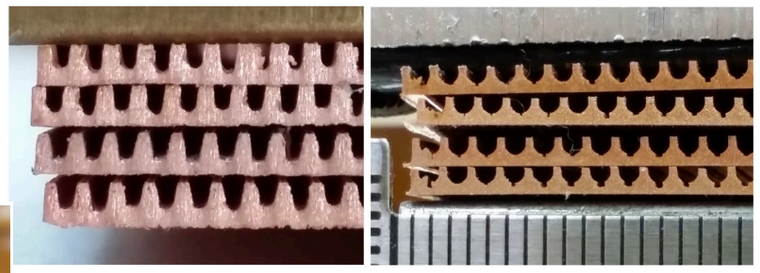
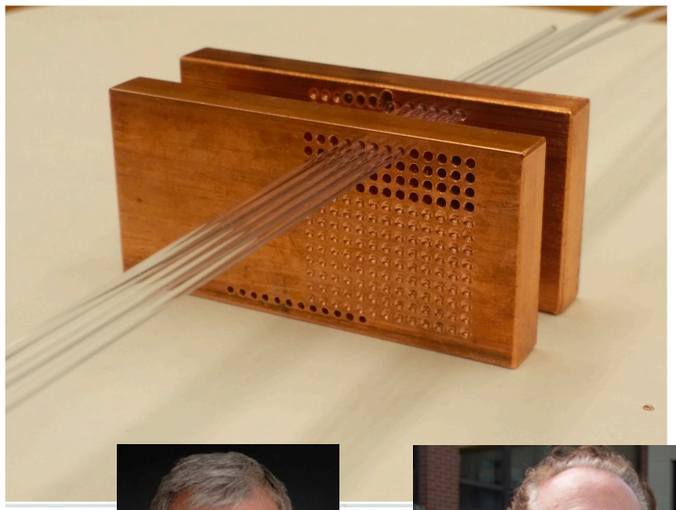
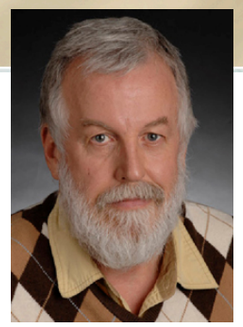


Figure 25: Water-jet grooved plates on the left (2.5 meters long) and the precision rolled corresponding grooves on the right.





R. Wigmans

J. Hauptman

RD52 Copper Forming (draft)

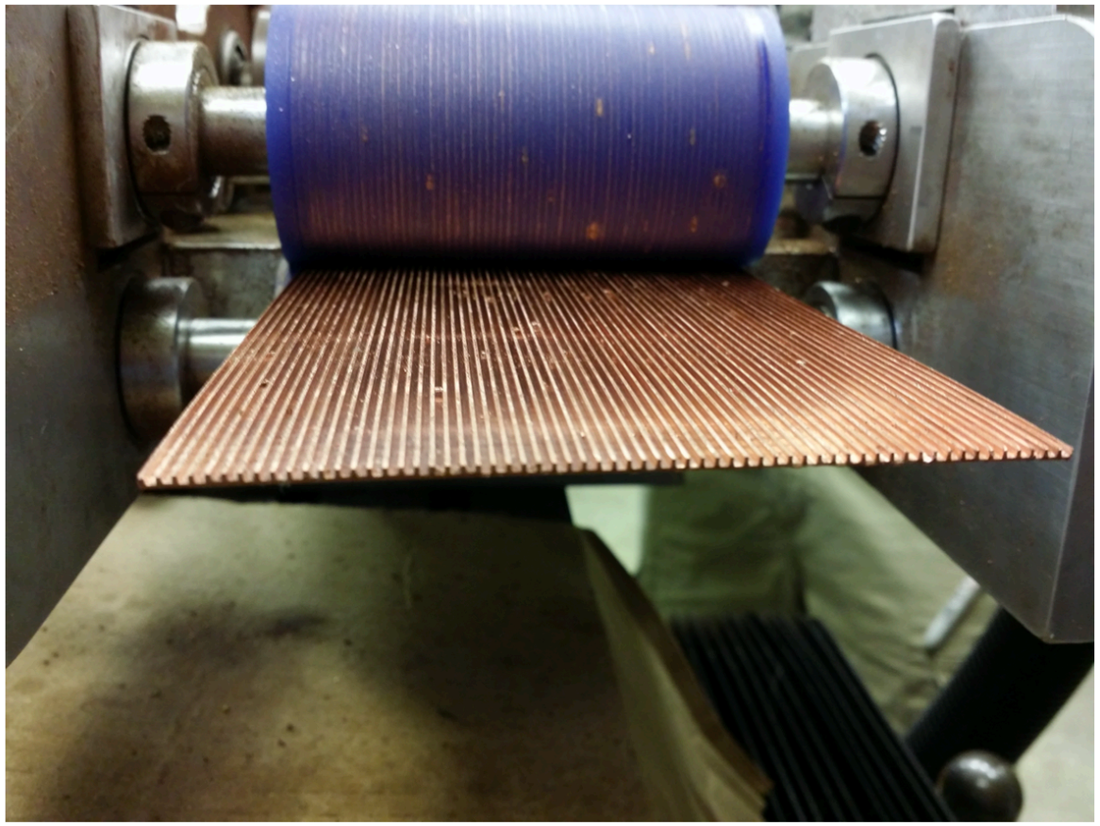
distribution

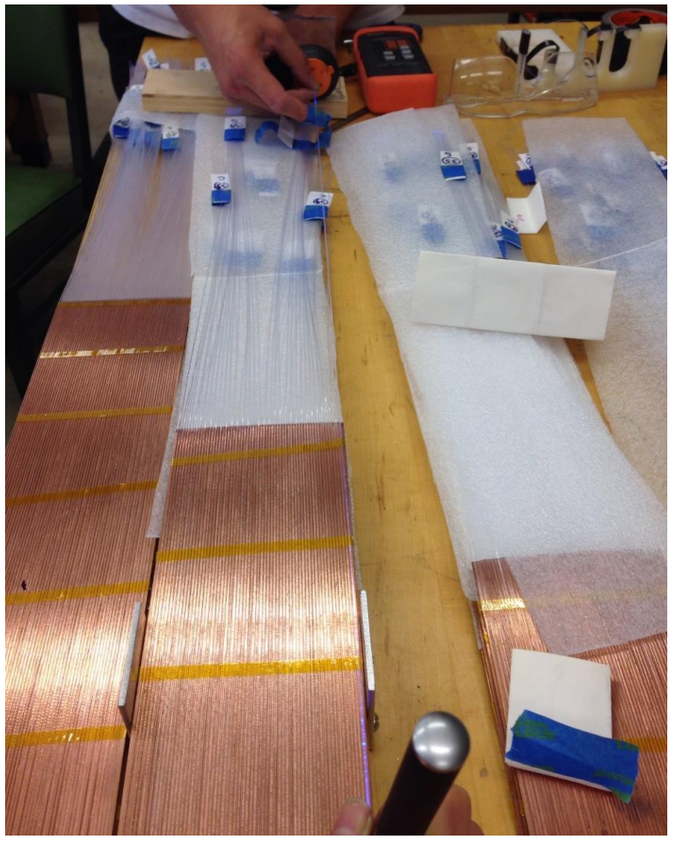
John Hauptman, Sehwook Lee, Fabrizio Scuri, Silvia Franchino,
Bobae Kim, Ryonghae Ye, Hyunsuk Jo, Richard Wigmans

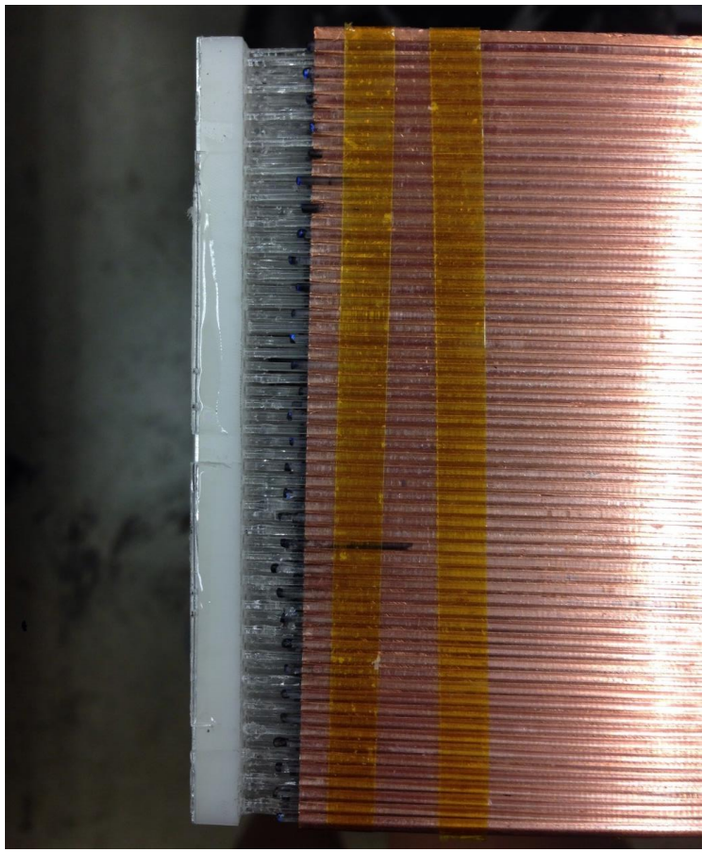
15 March 2018

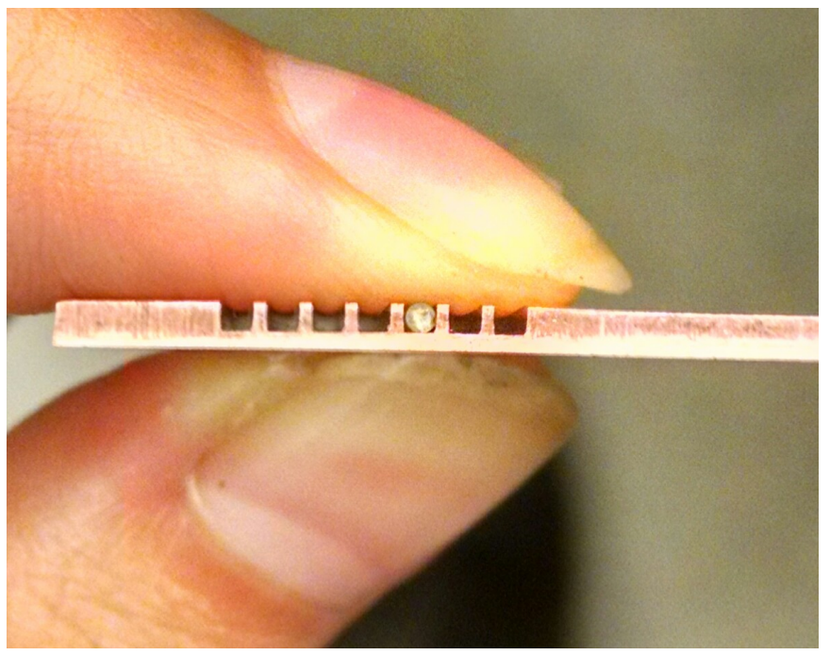
Contents

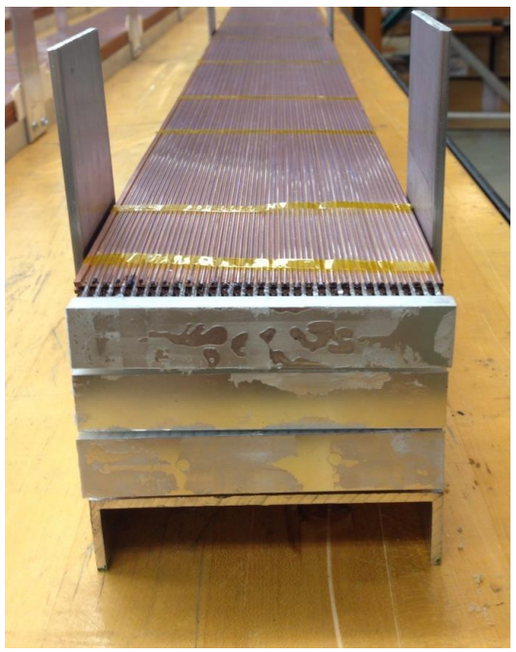
Cutting



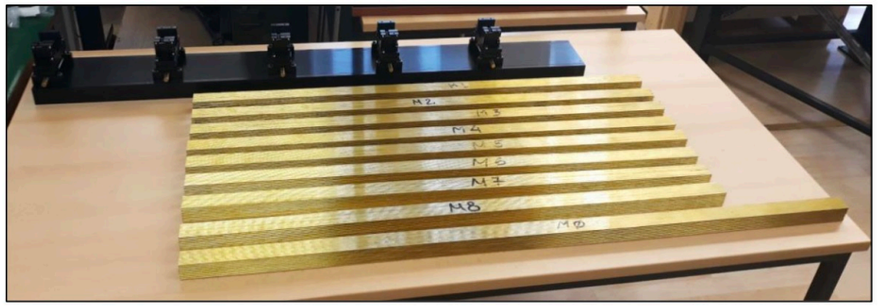


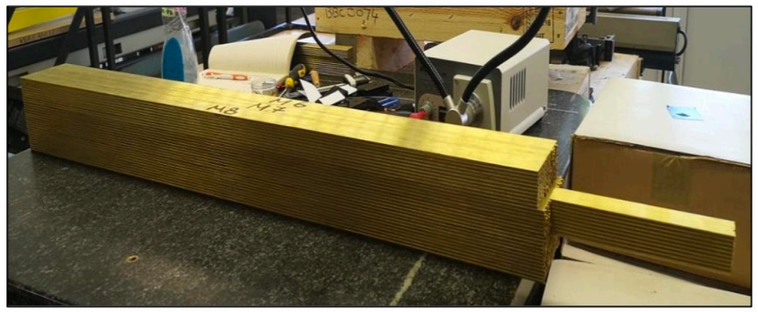


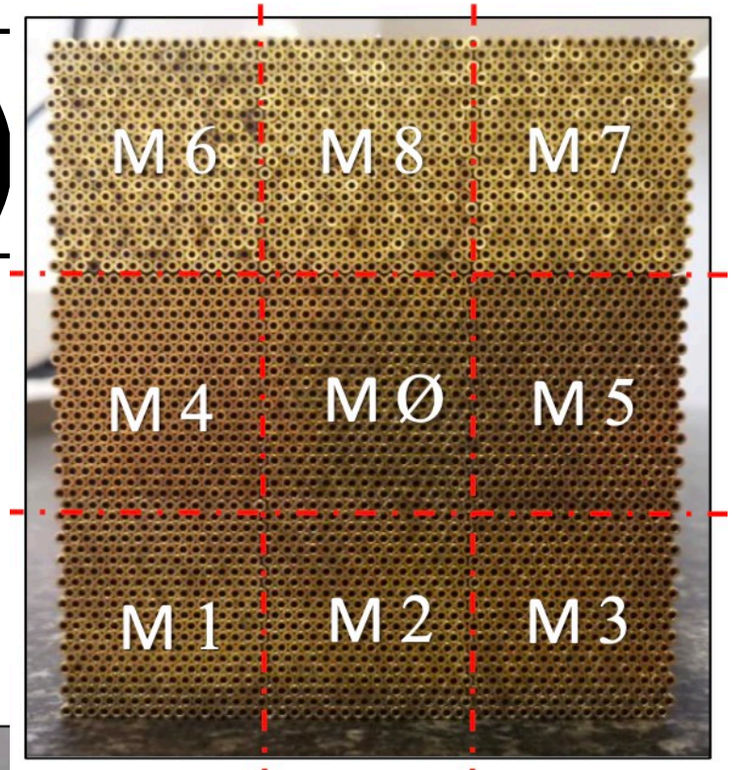


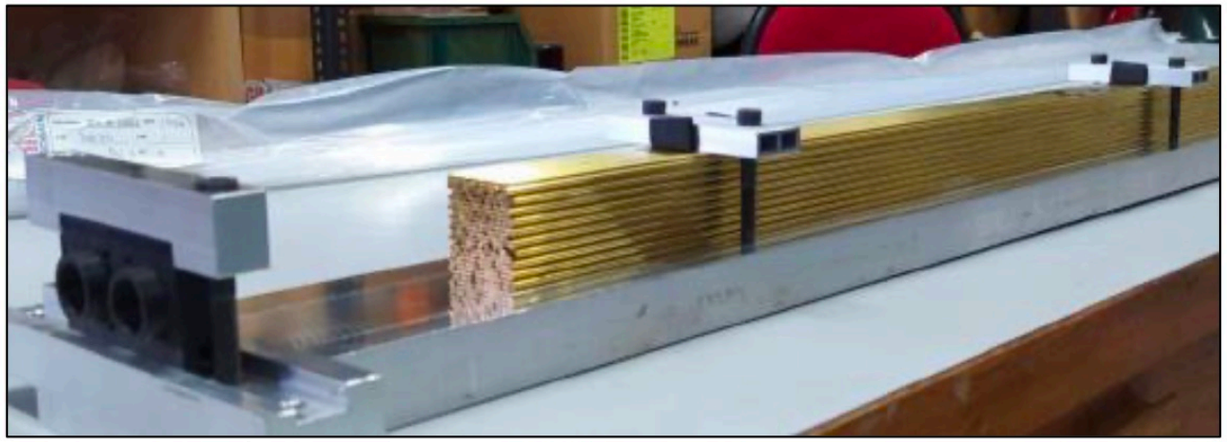


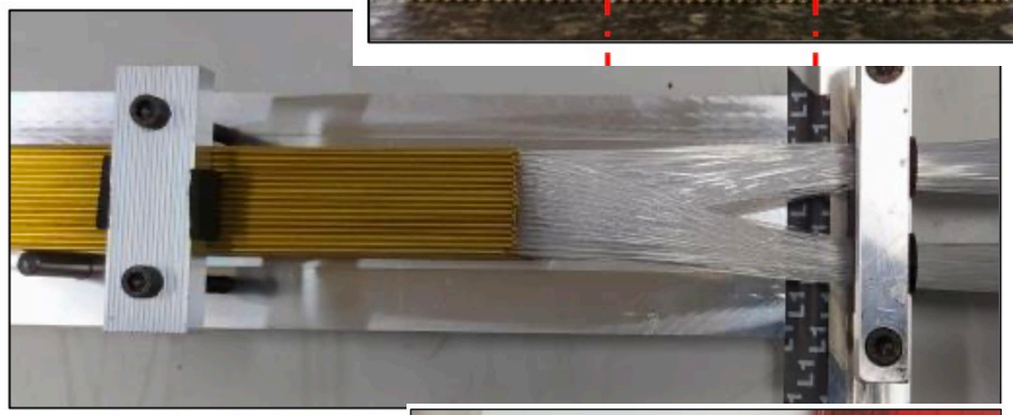
Bucatini (INFN)

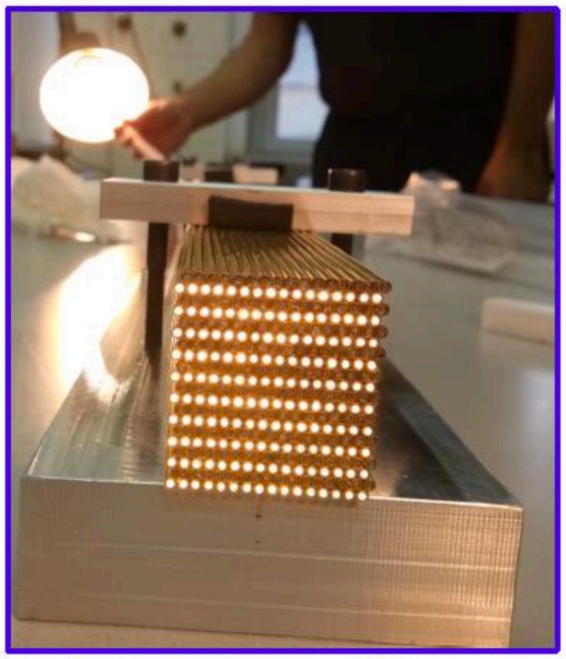




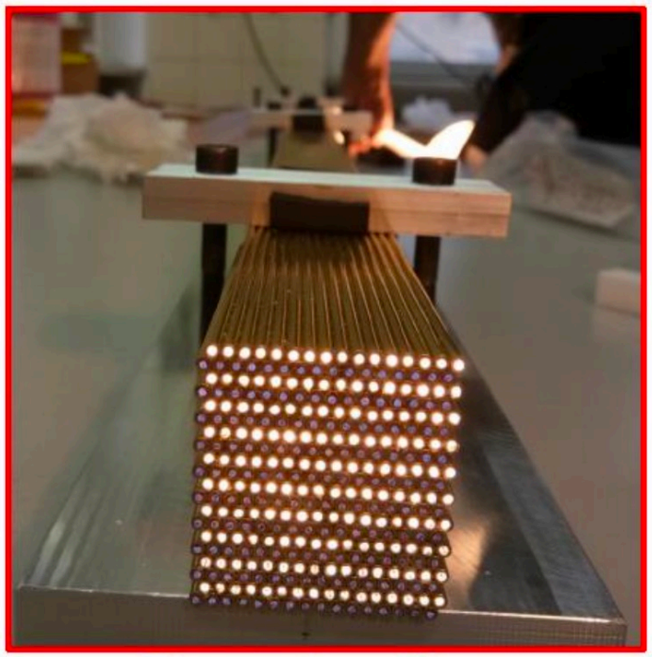




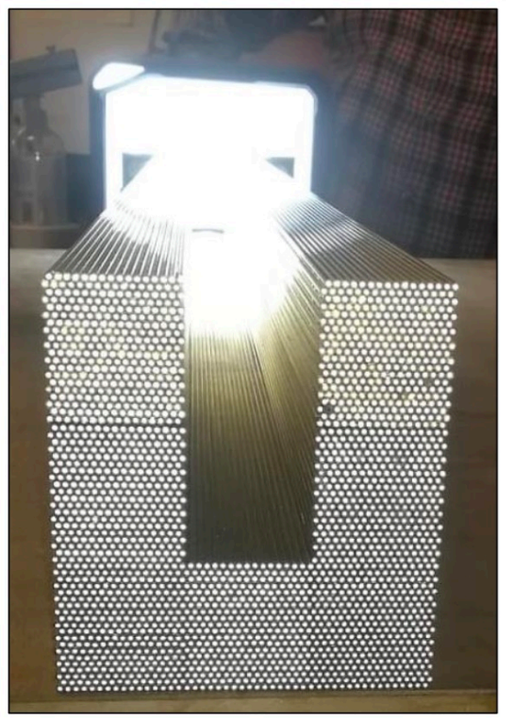


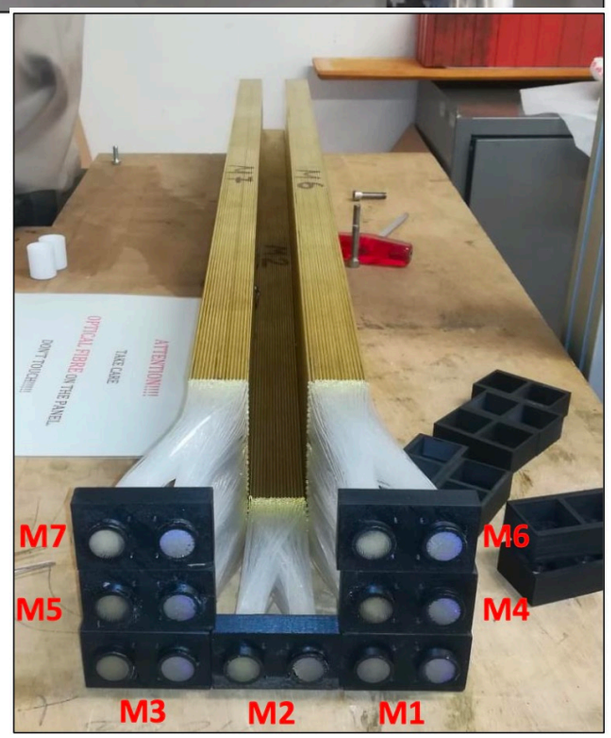


Scintillation fibers



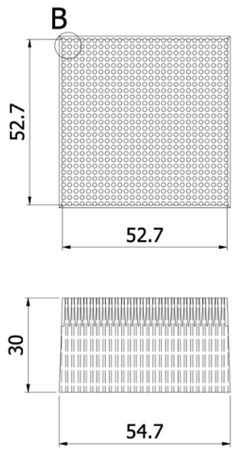
Cherenkov fibers

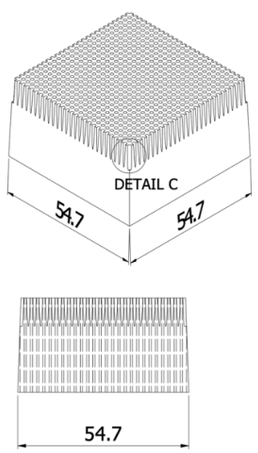


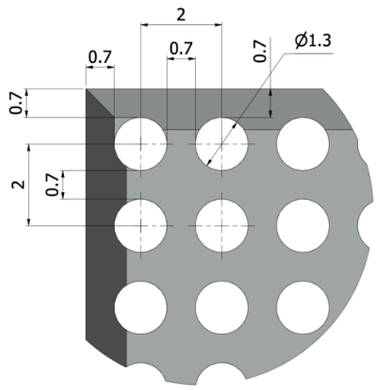


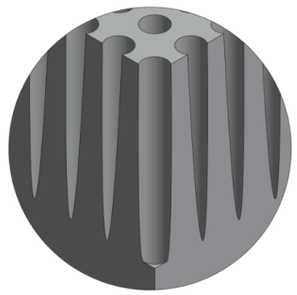
Cu Forming R&D in Korea

- Precise forming with innovative technology: 3D metal printer

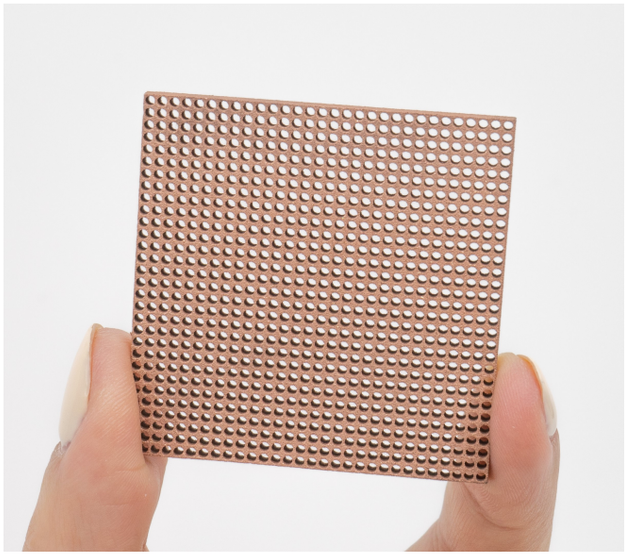








DETAIL C (10 : 1)



- Easy and cost-effective forming: Lego-like

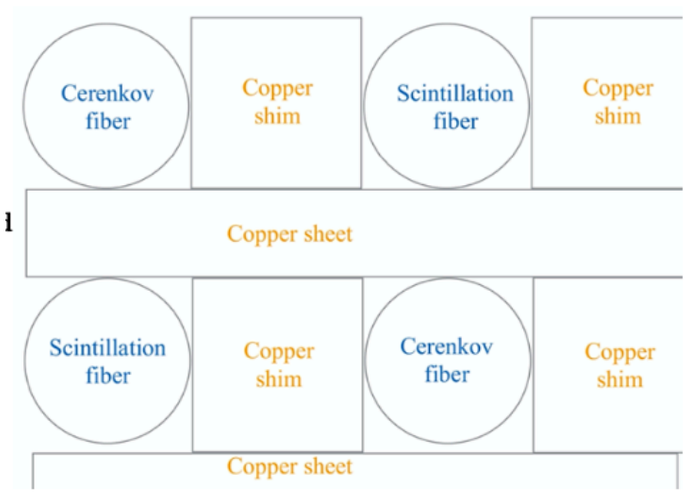


Figure 27: Direct stacking of copper shims and fibers. The shims bear the load.

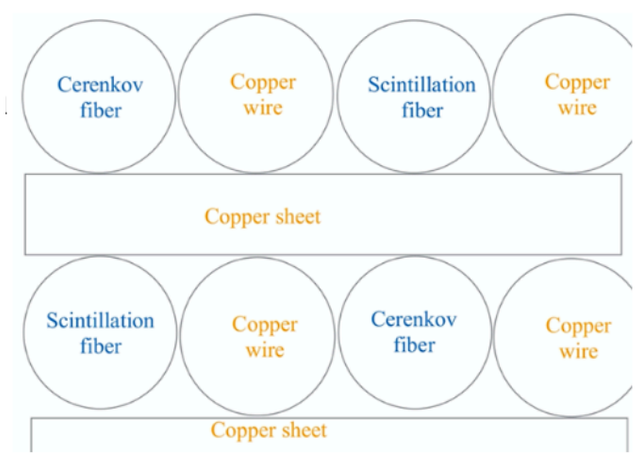
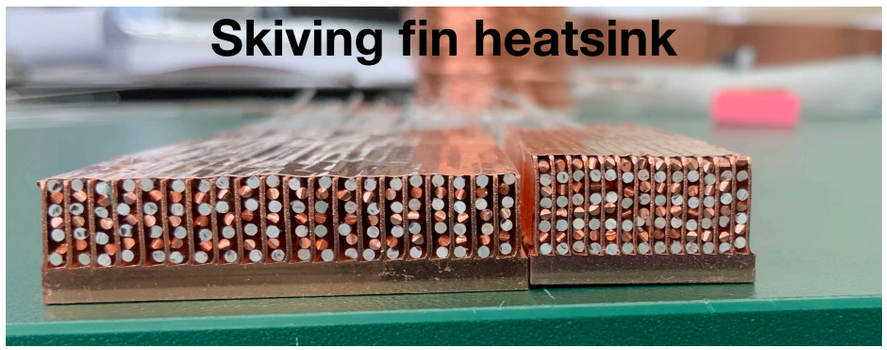
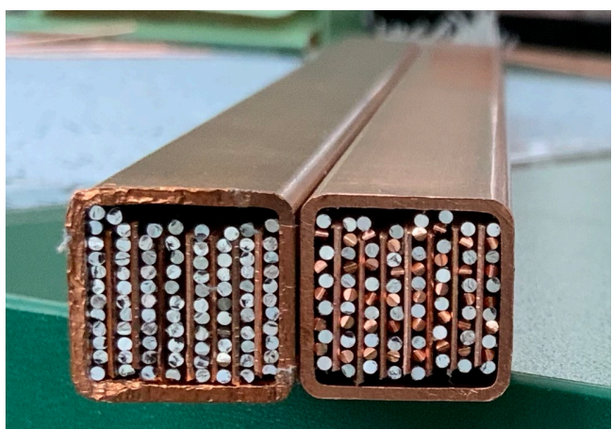


Figure 28: Direct stacking of copper wires (1.05mm diameter) and fibers on 0.5mm copper sheets. The slightly oversized copper wires carry the load.

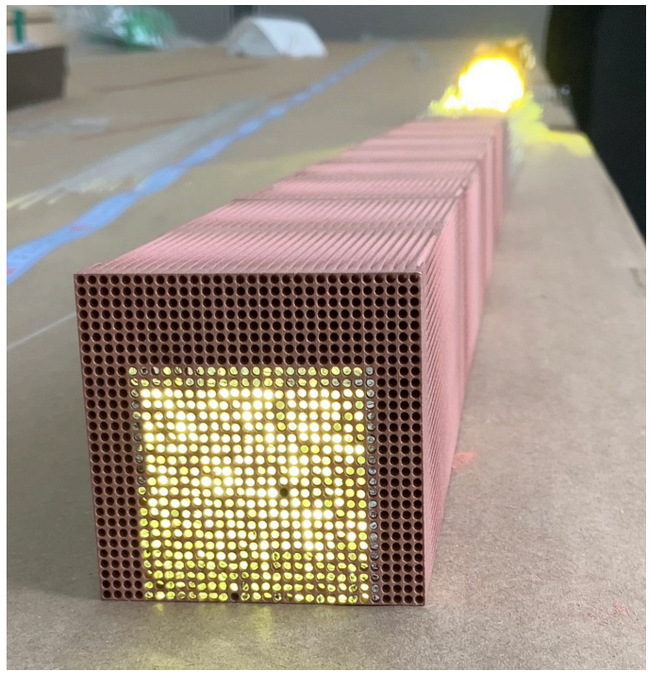


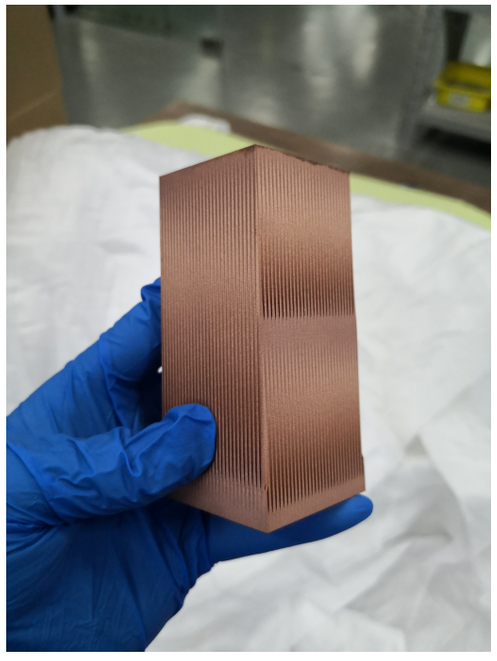


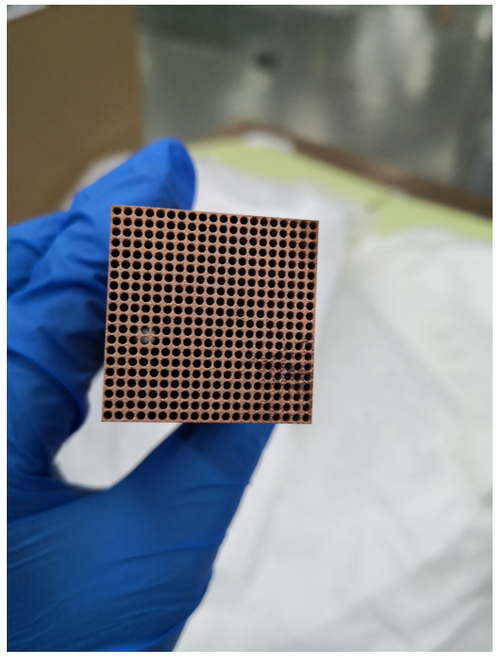
3D Metal Printing

with Harvestance
We will be your left hand

- 1st projective DRC module!

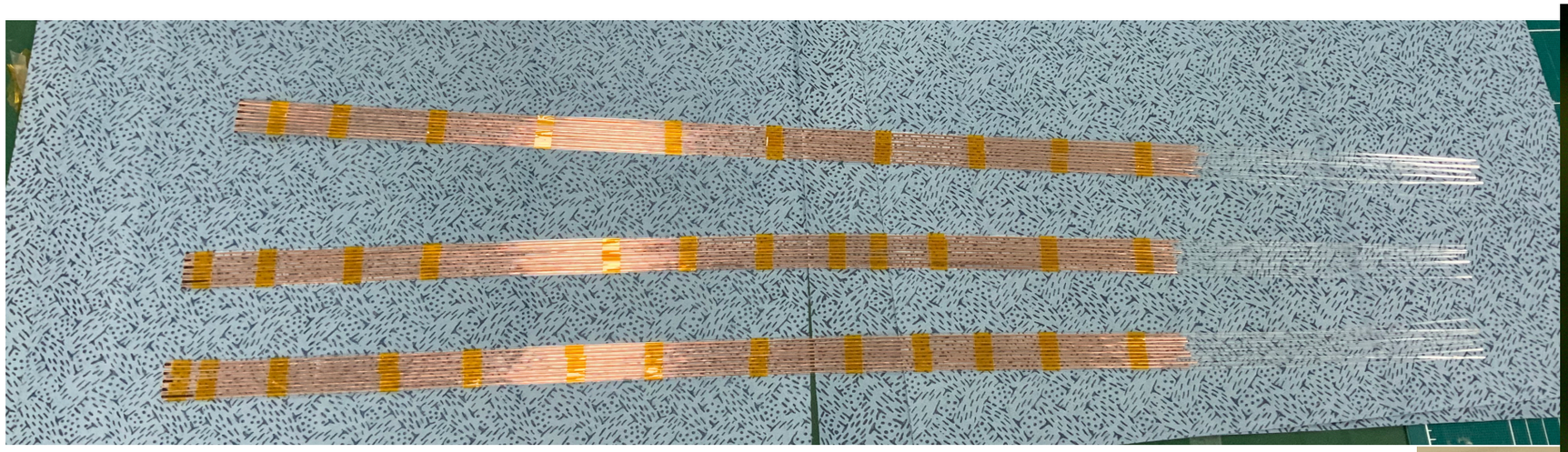


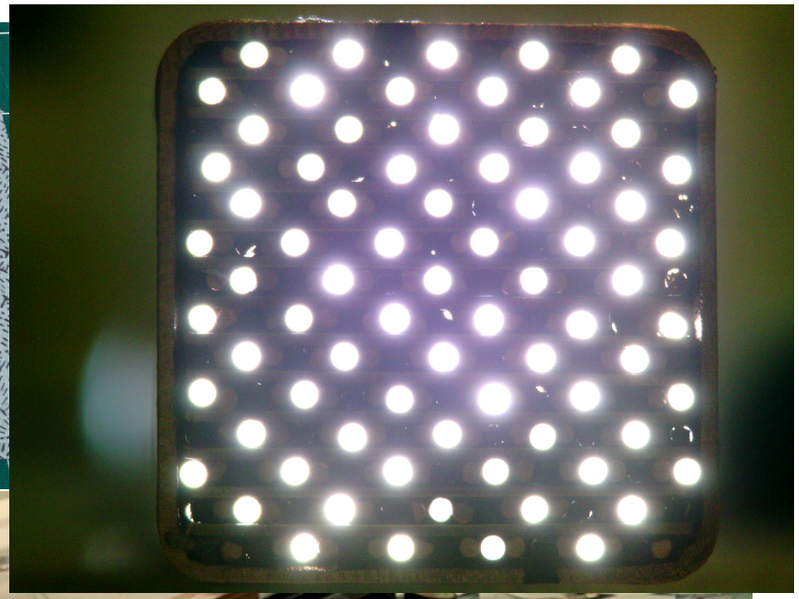


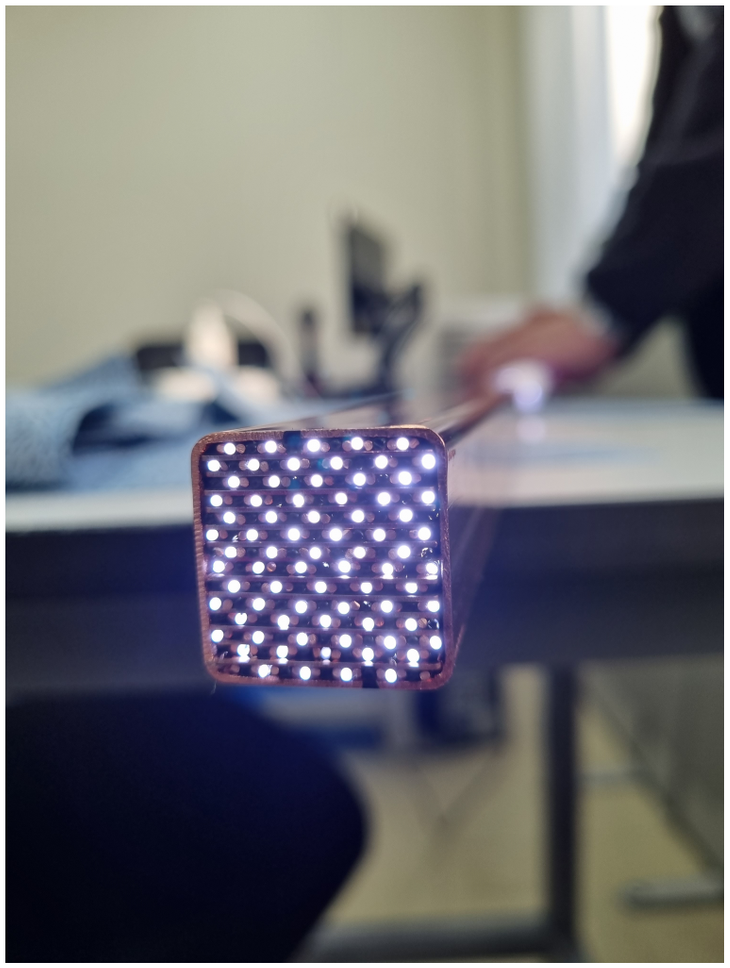


INSIDE 3D PRINTING SEOUL
CONFERENCE & EXPO

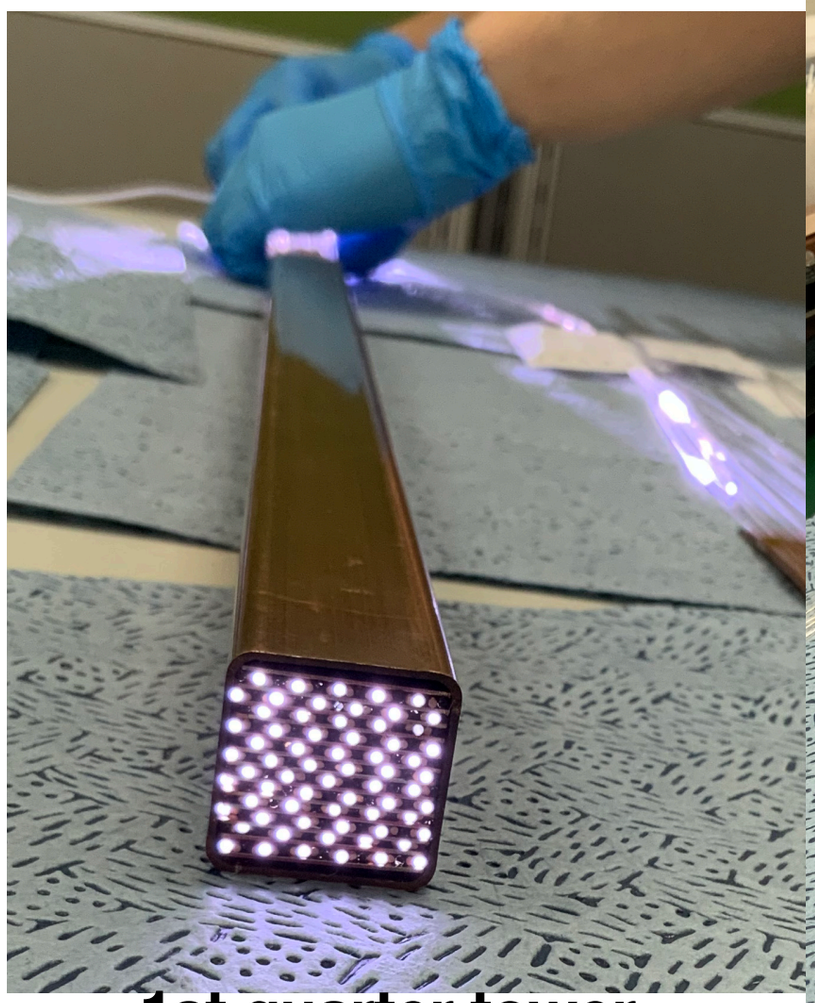
LEGO-like: Quarter Tower



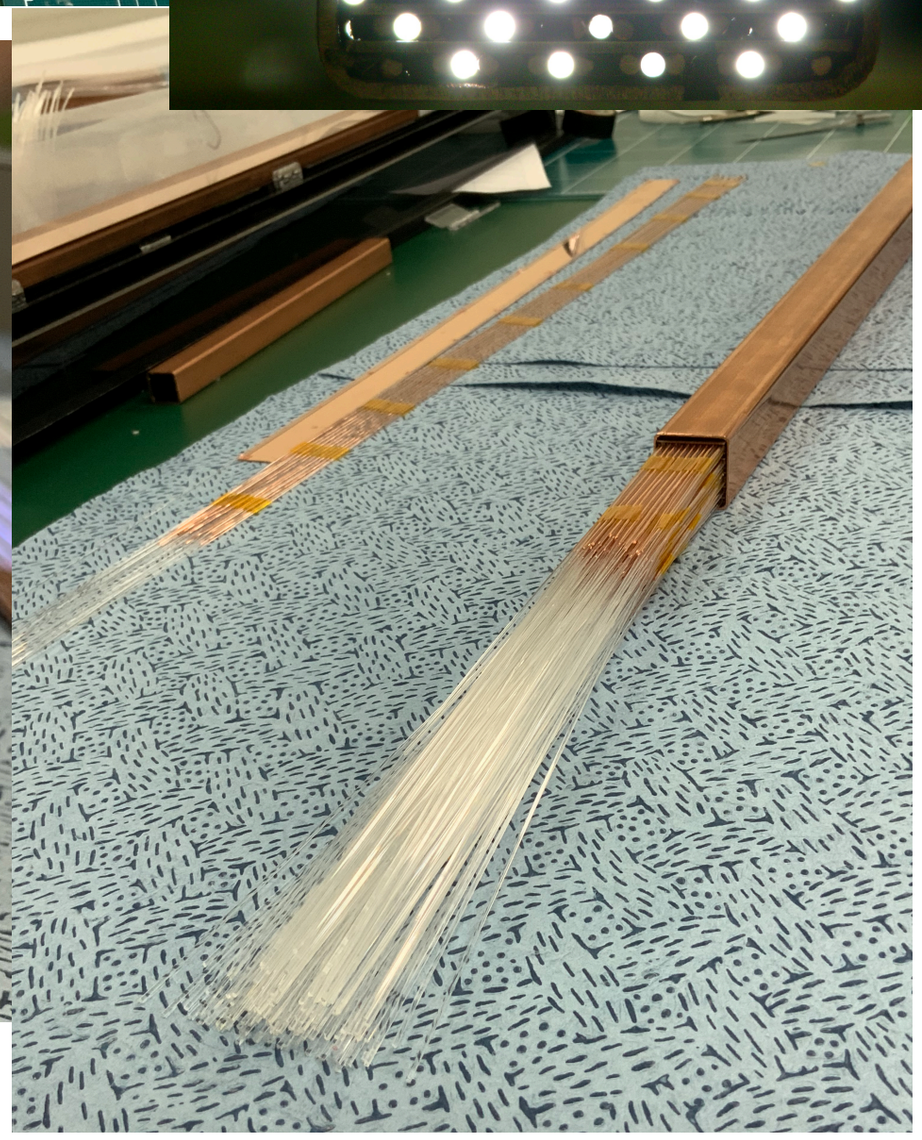




2nd quarter tower

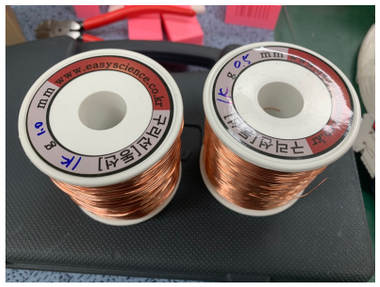


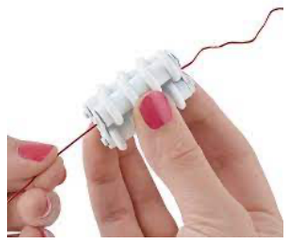
1st quarter tower



Nowadays What I have done …

- Straightening copper wires for lego-like module (produced 300 wires for two quarter-tower modules by myself)





Toward Detector Construction

- For TDR, need to demonstrate feasibility of detector construction in engineering aspects

	Cost	Forming	Assembly	Accuracy
		Production rate		**Performance**
Cutting	Moderate	Difficult	Difficult	Fair
Bucatini	Low	Moderate	Easy	Excellent
3D printing	Ultra high	Easiest	Easiest	Perfect
LEGO-like	Very low	Easy	Easy	Good

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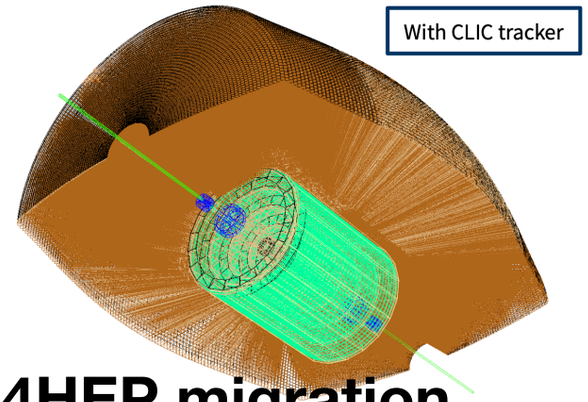
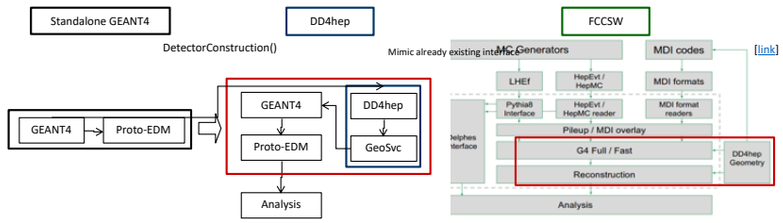
3. Software Development

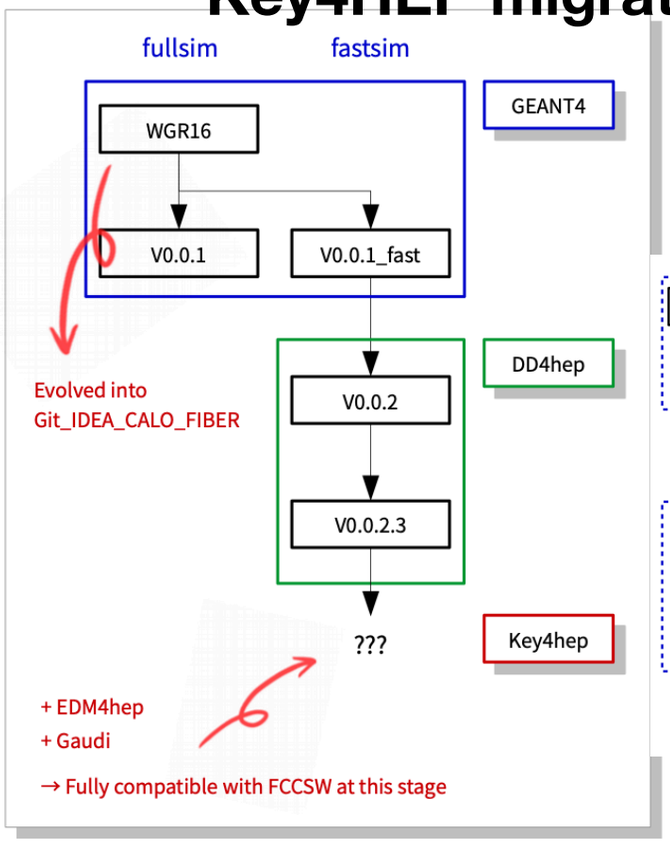
- Many SW development are on-going!
  - Migration to DD4HEP framework
  - Faster simulation: developing optical photon transport in GEANT4 => O(100) times faster
  - Migration to Key4HEP framework
    - Add digitization, reconstruction, calibration, etc.



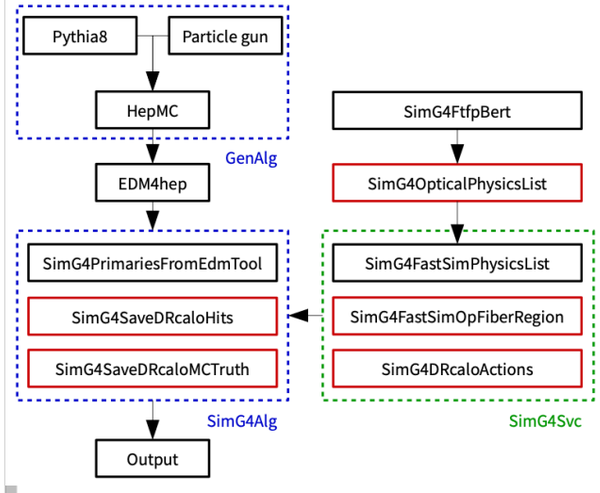
DD4HEP migration



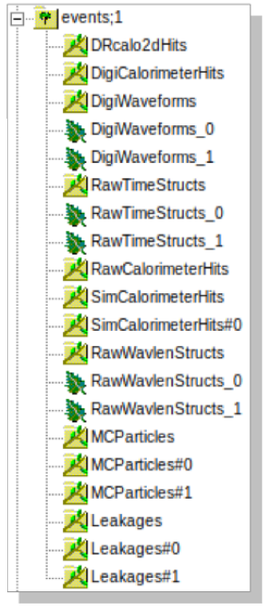
Key4HEP migration



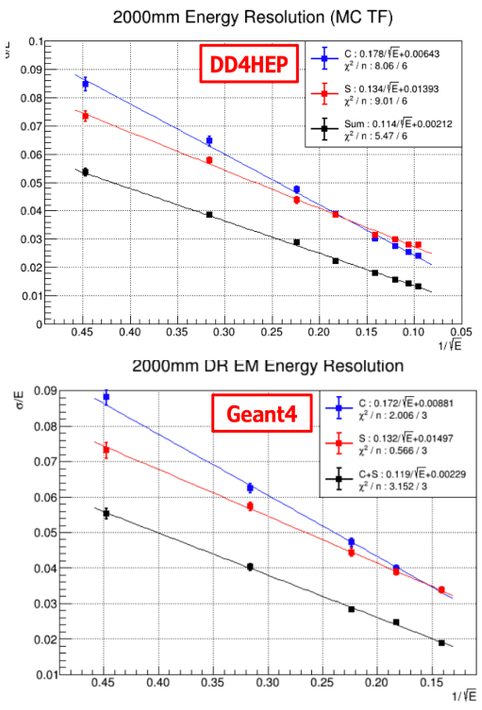
Simulation flow

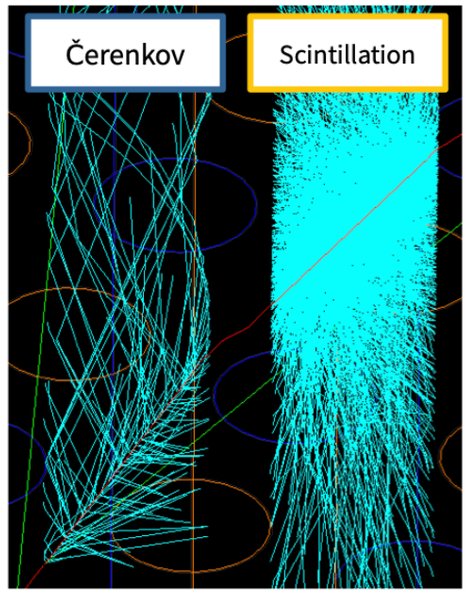


EDM4hep



Faster simulation





Important for a longitudinally unsegmented calorimeter

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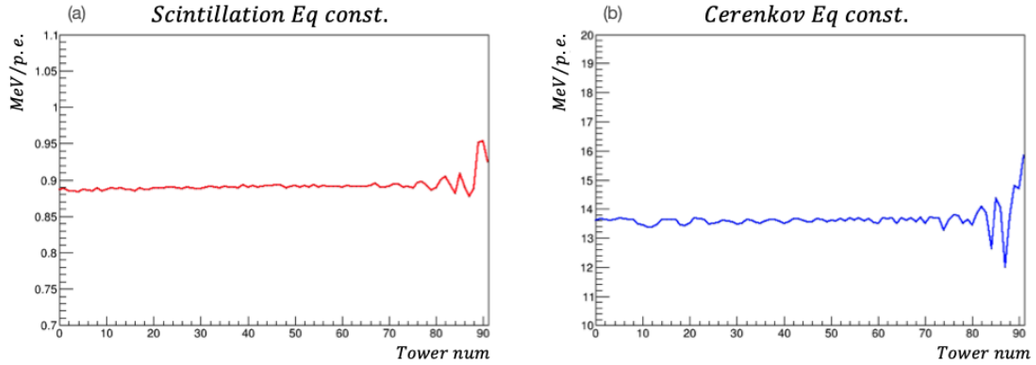
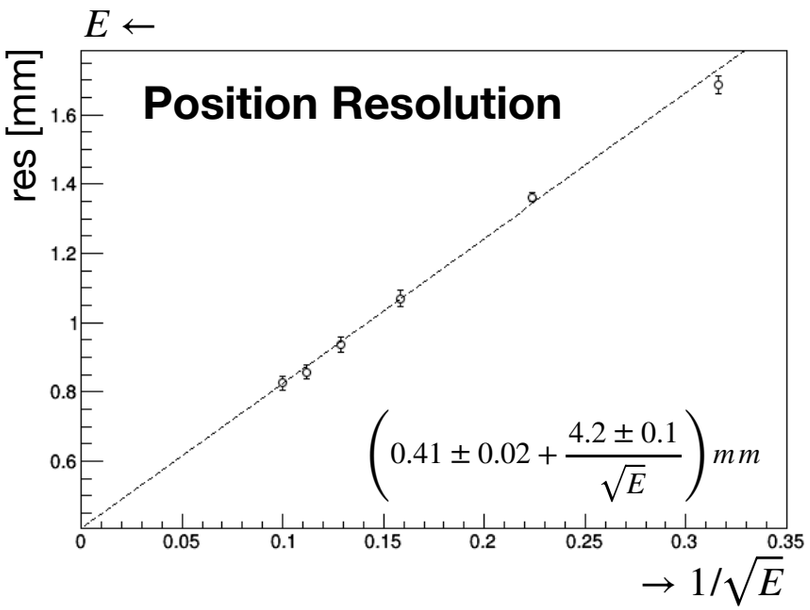
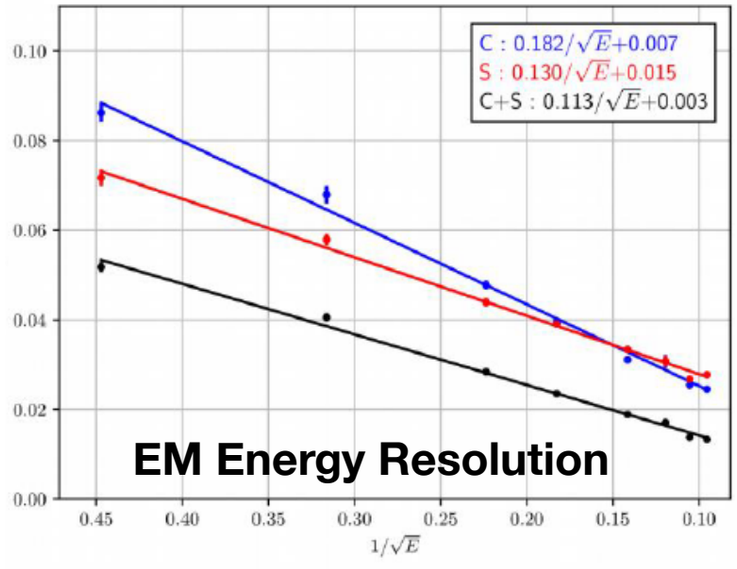
Simulation Studies

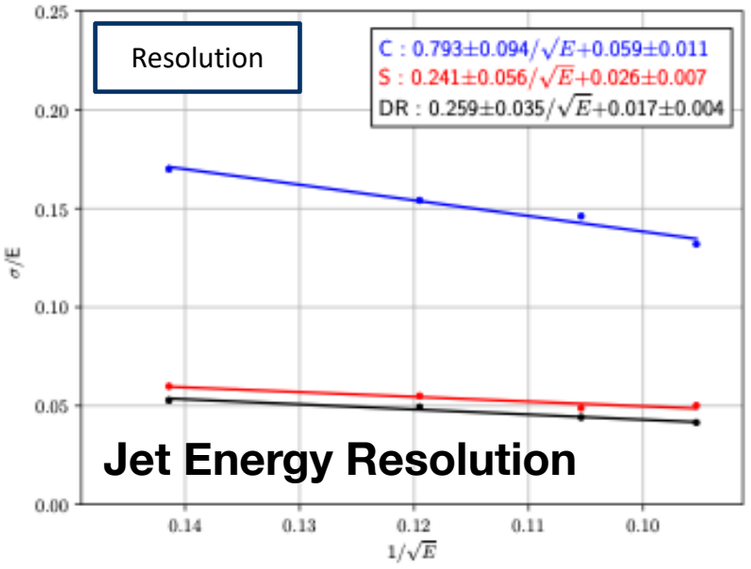
- Many simulation studies are on-going
  - First full GEANT4 based simulation performance
  - Using various benchmark physics process (W, Z, Higgs)

Calibration Constant

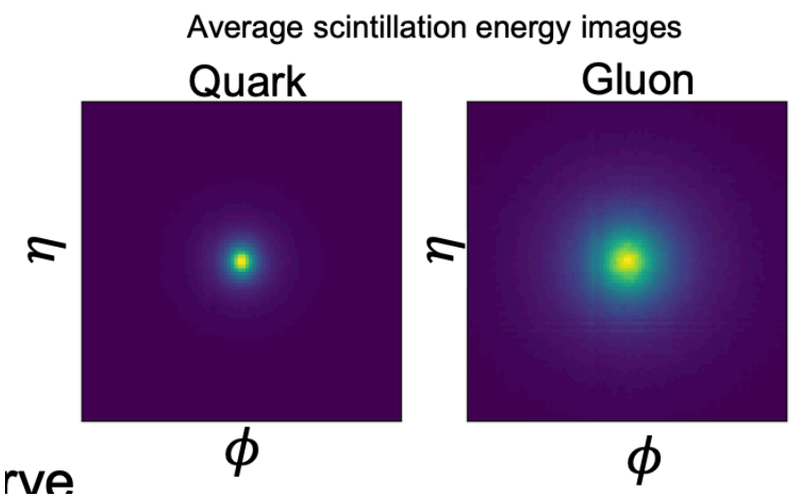


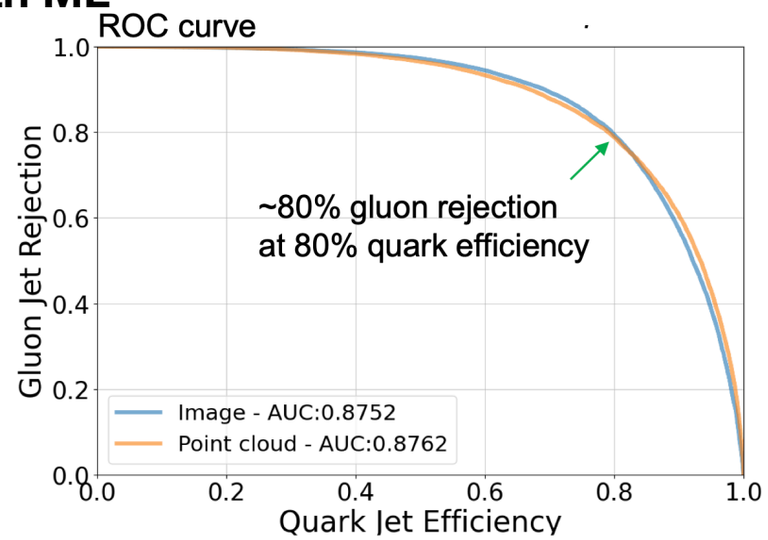




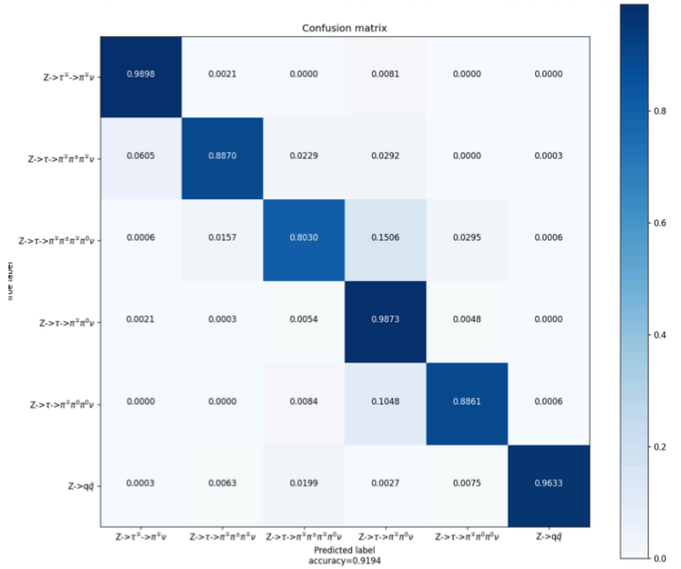


Jet identification with ML





Tau identification with ML



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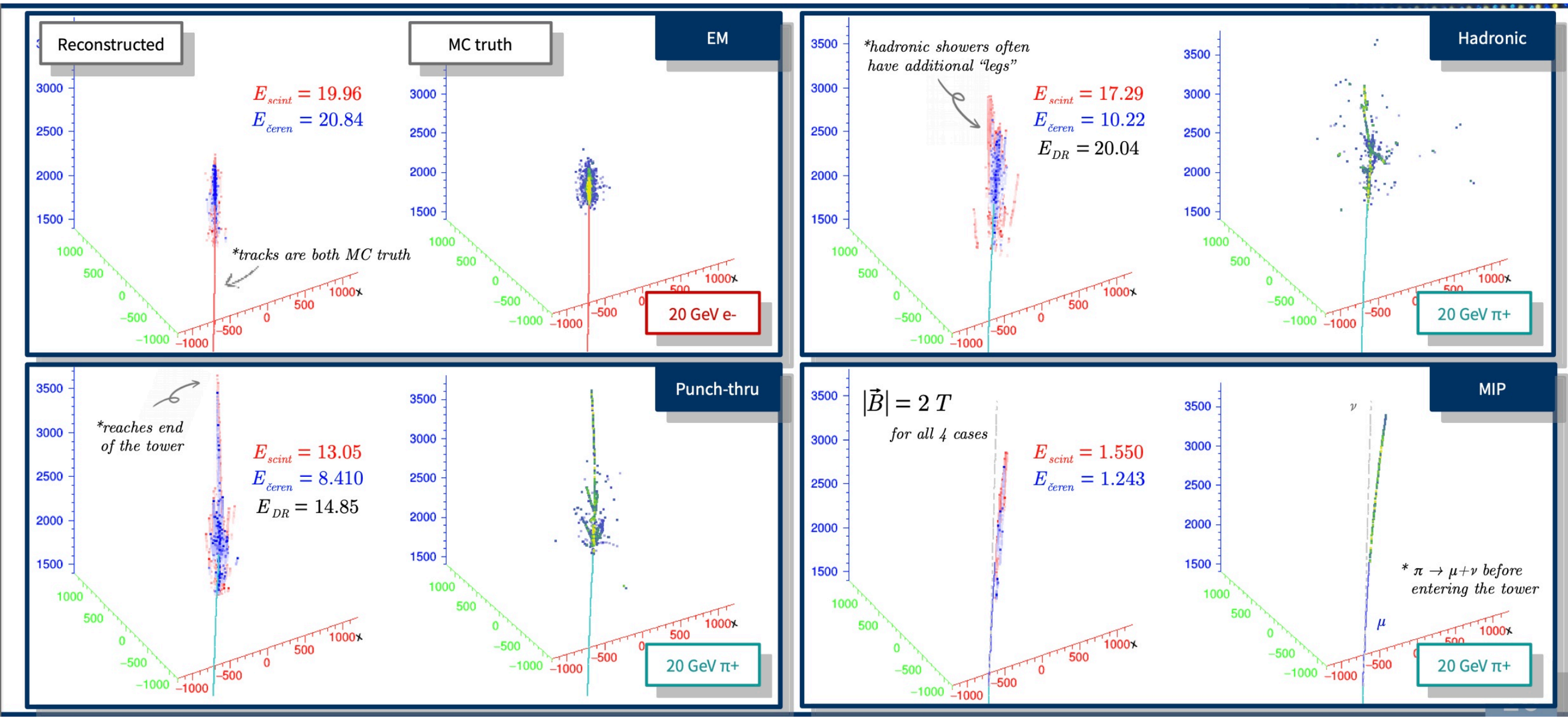
3D Shower Profile

- Develop novel ideas to exploit timing for longitudinal & 3D reconstruction



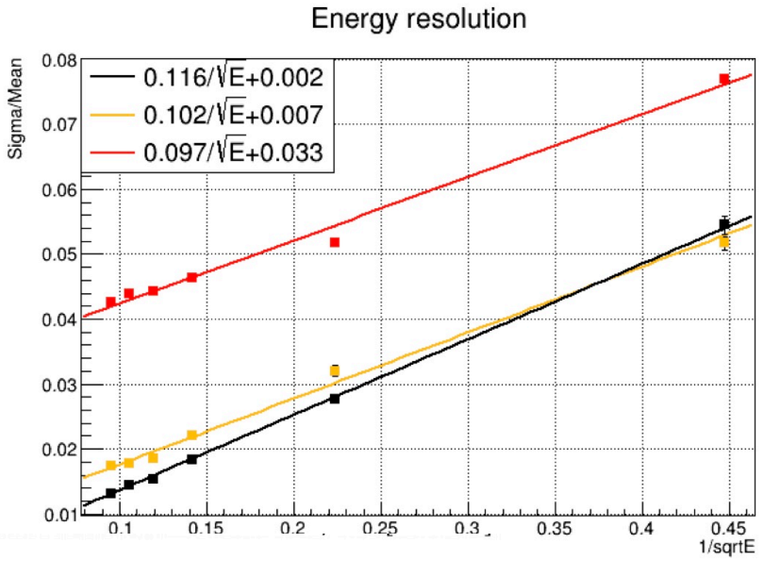
Bonus: Forward Detector for EIC

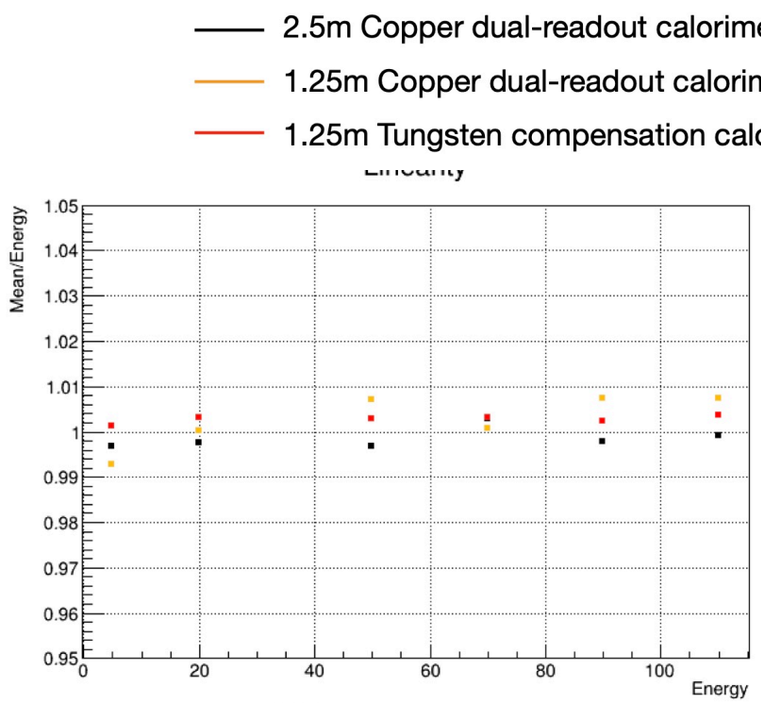
- Initial design and feasibility study for ECCE is on-going

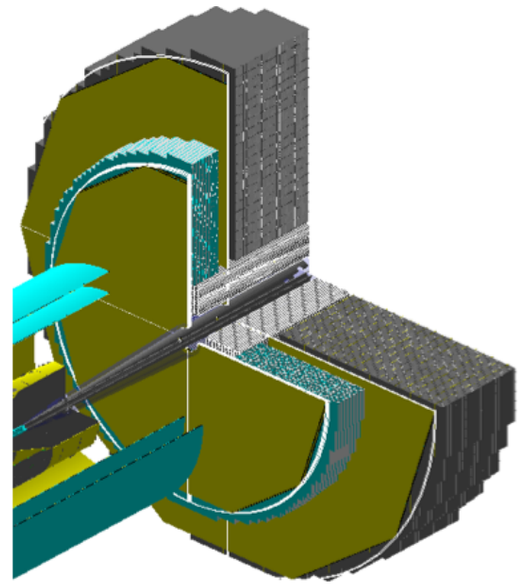
Collaboration with nuclear physicists in Korea

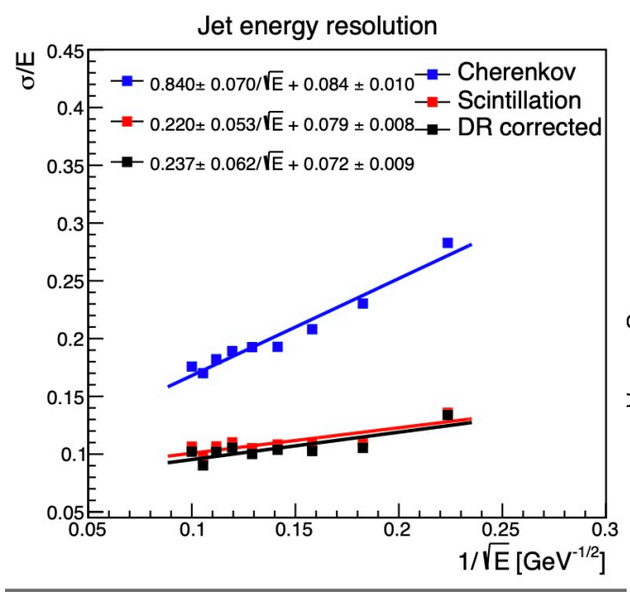
  - DRC pre-design is implemented in Fun4All framework

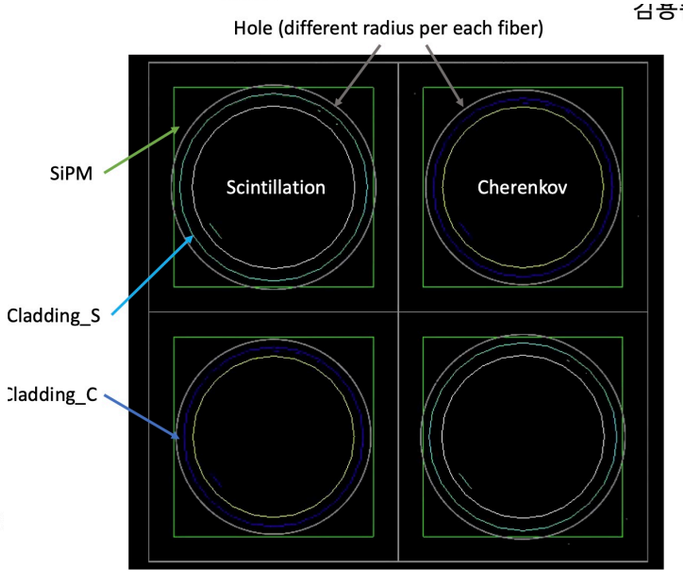
  - Absorber type: Cu vs. W

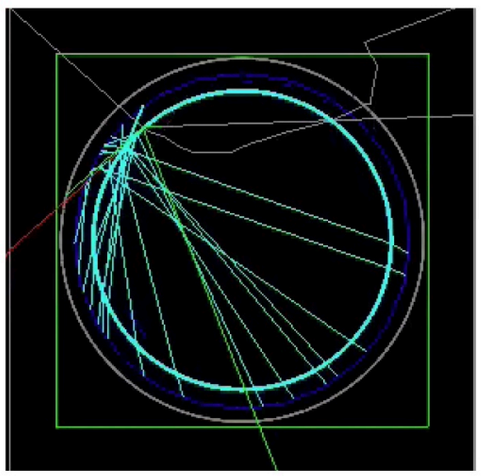


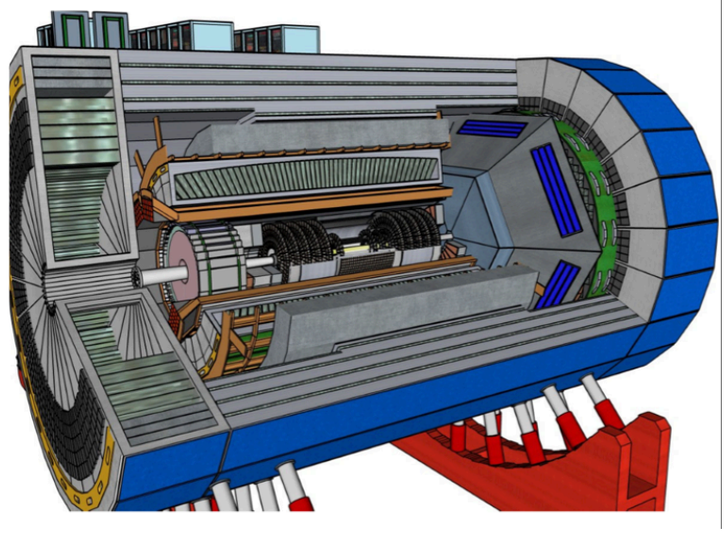












Breaking News!

- US DRC collaboration rises!

CALVISION

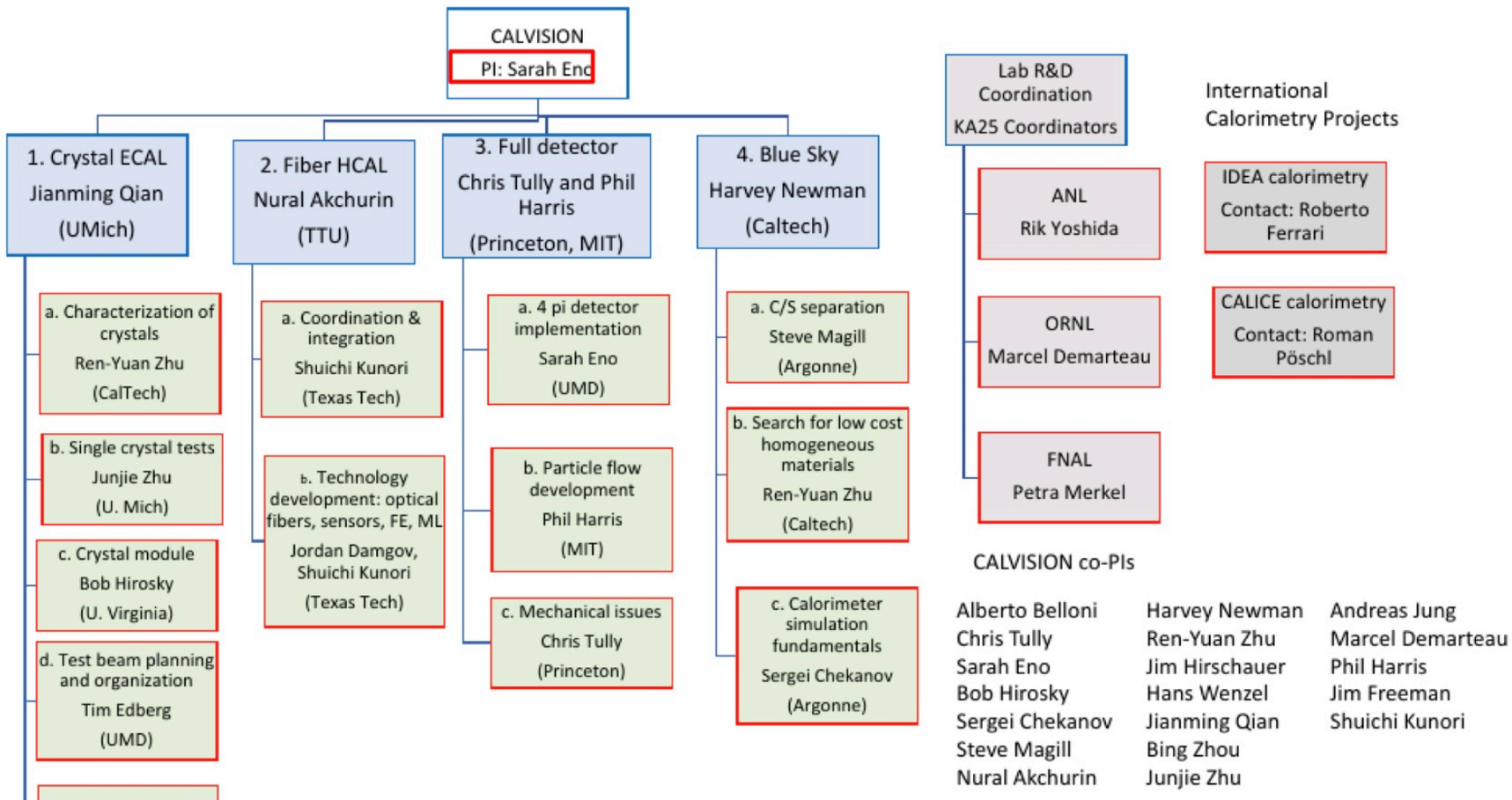
Organization of effort

CALVISION Collaboration formed to pursue calorimetry efforts on multiple fronts:

- Crystal DRO Ecal
- Fiber DRO HCAL
- Full Detector studies
- BlueSky R&D

Multi-year efforts proposed in each area.

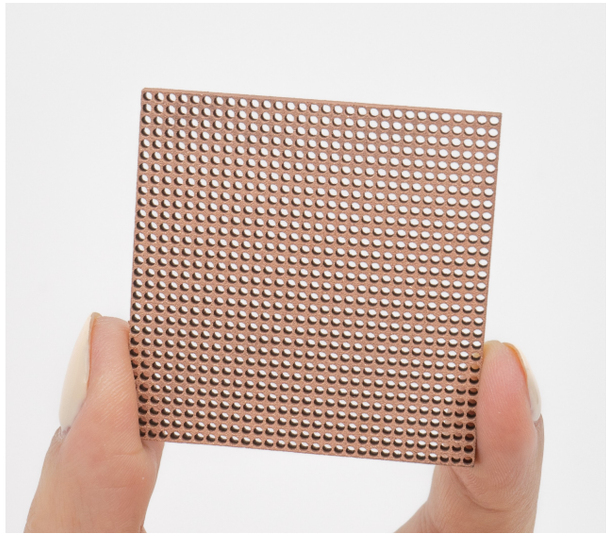
1st phase is spring '22--'25
- Lower level R&D
- Single modules, small arrays
- materials/technology evaluations
- Scale up modules in next phase



A very high-level overview of planned activities follows

Summary: DRC R&D

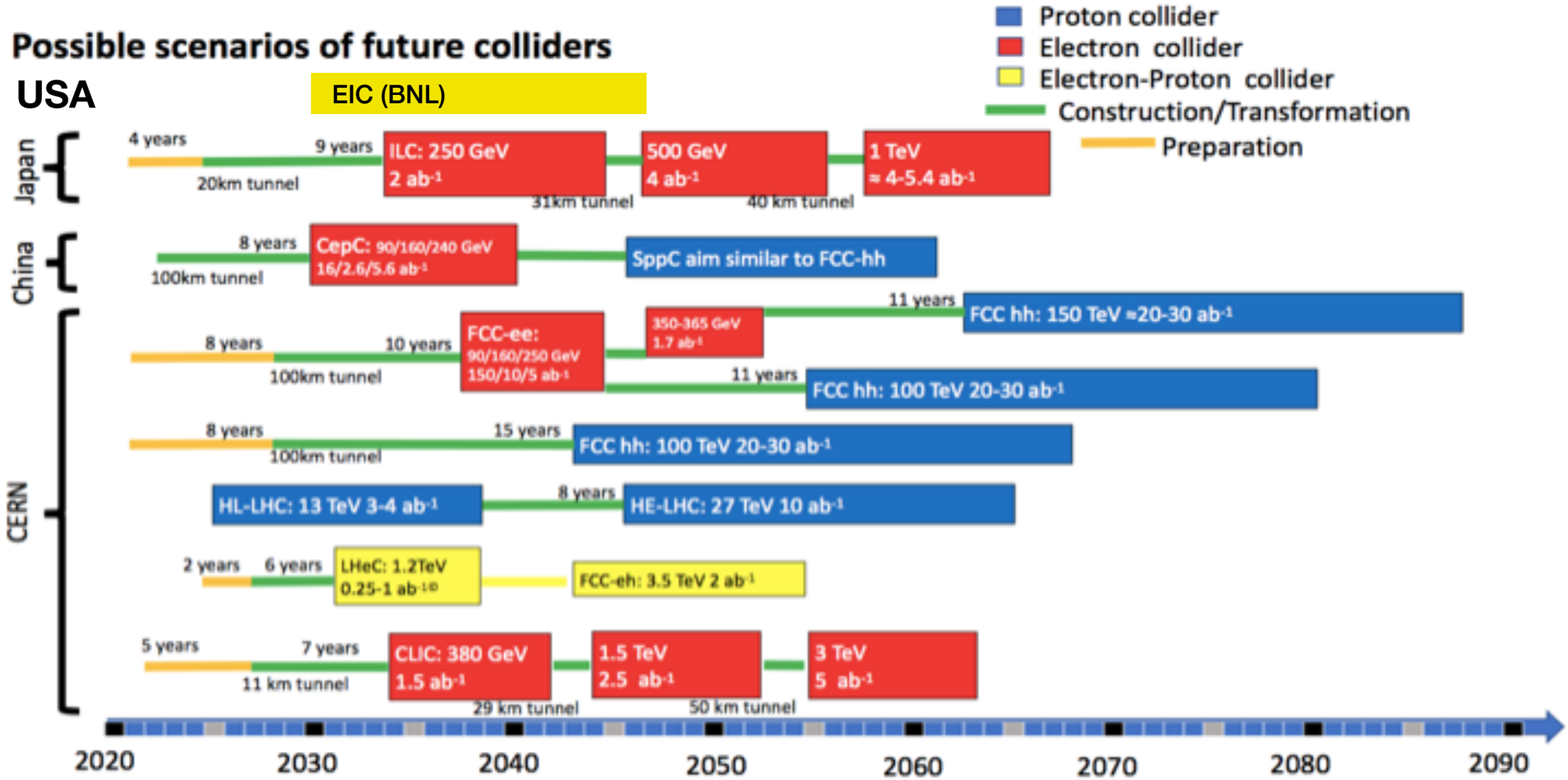
- Dual-Readout Calorimeter R&D project for future colliders in Korea is very active
  - Build and test full size prototype DRC detector by 2025
  - Collaborate with EU and US teams
- Both HW and SW R&D with all aspects are going well
  - Build two modules with various R&D goals
  - Design new electronics readout system and assembly kit
  - Perform copper forming R&D with 3D metal printing and mechanical stacking methods
  - Develop new SW framework to migrate DD4HEP and Key4HEP with fast GEANT4 simulation
  - Study GEANT4 simulation and wide particle identification with ML technique
- **Stay tune more interesting achievements in 2022!**



Back Up

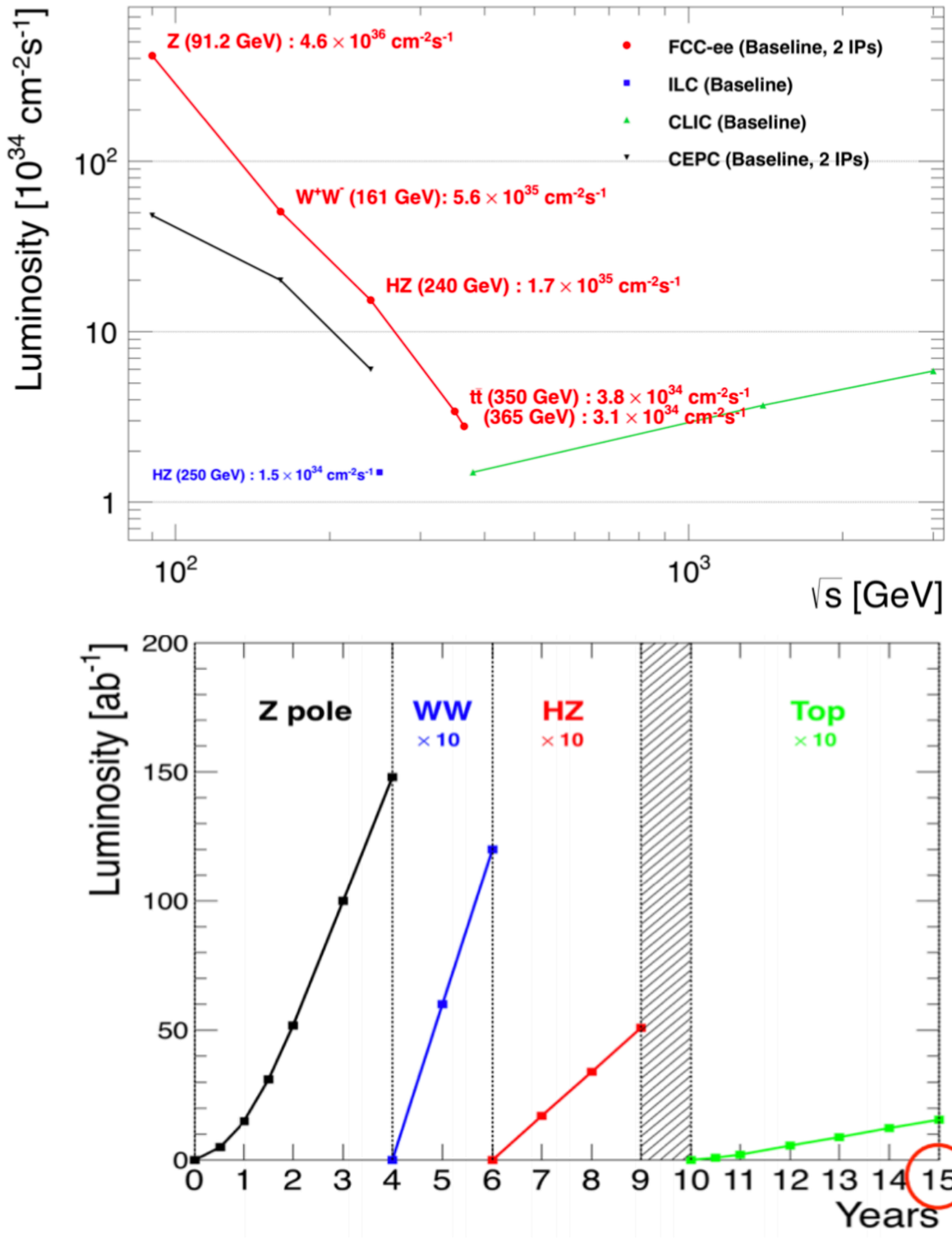
Roadmap of FC Projects

- Time flies very fast!



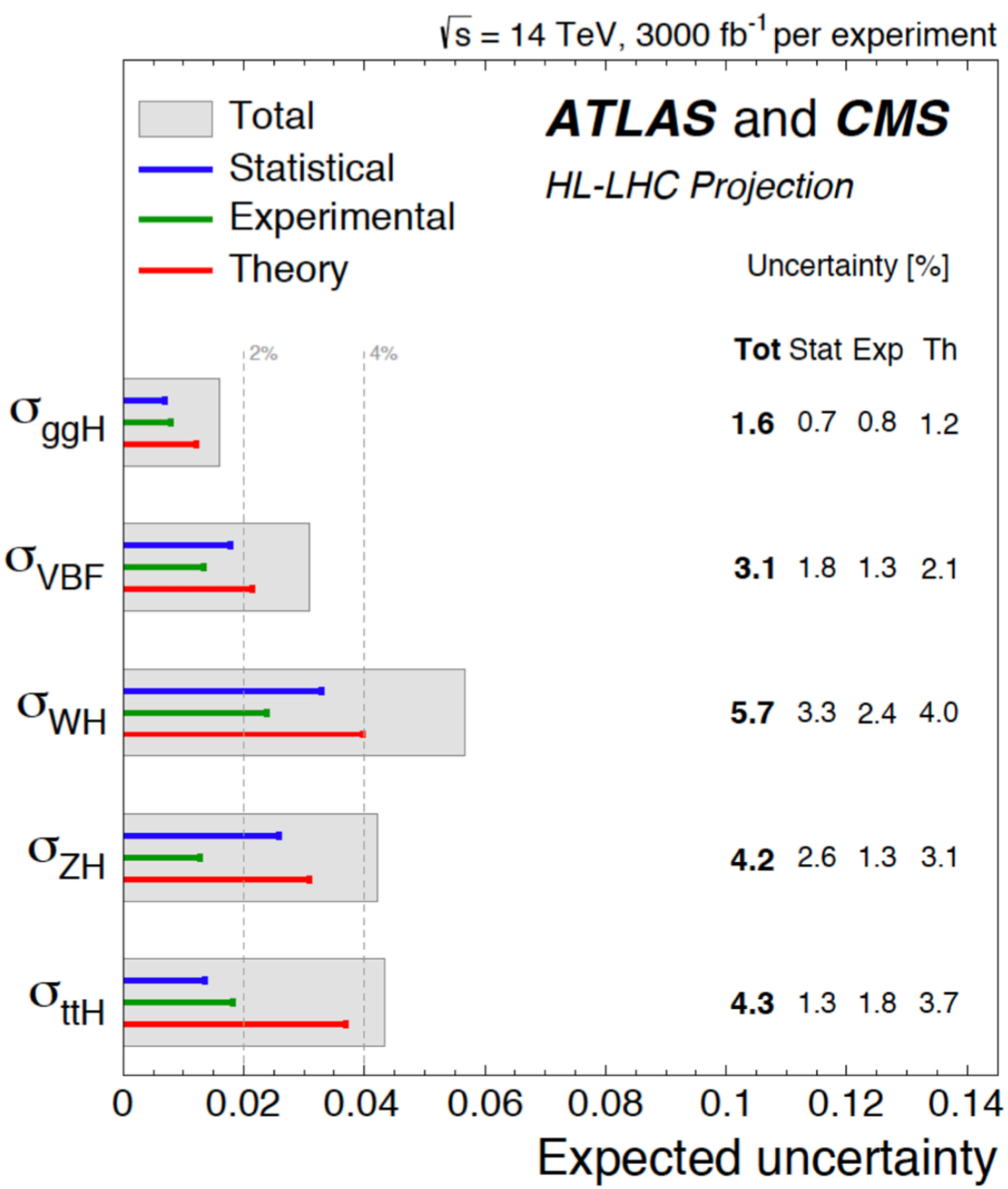
Physics of Future e^+e^- Colliders

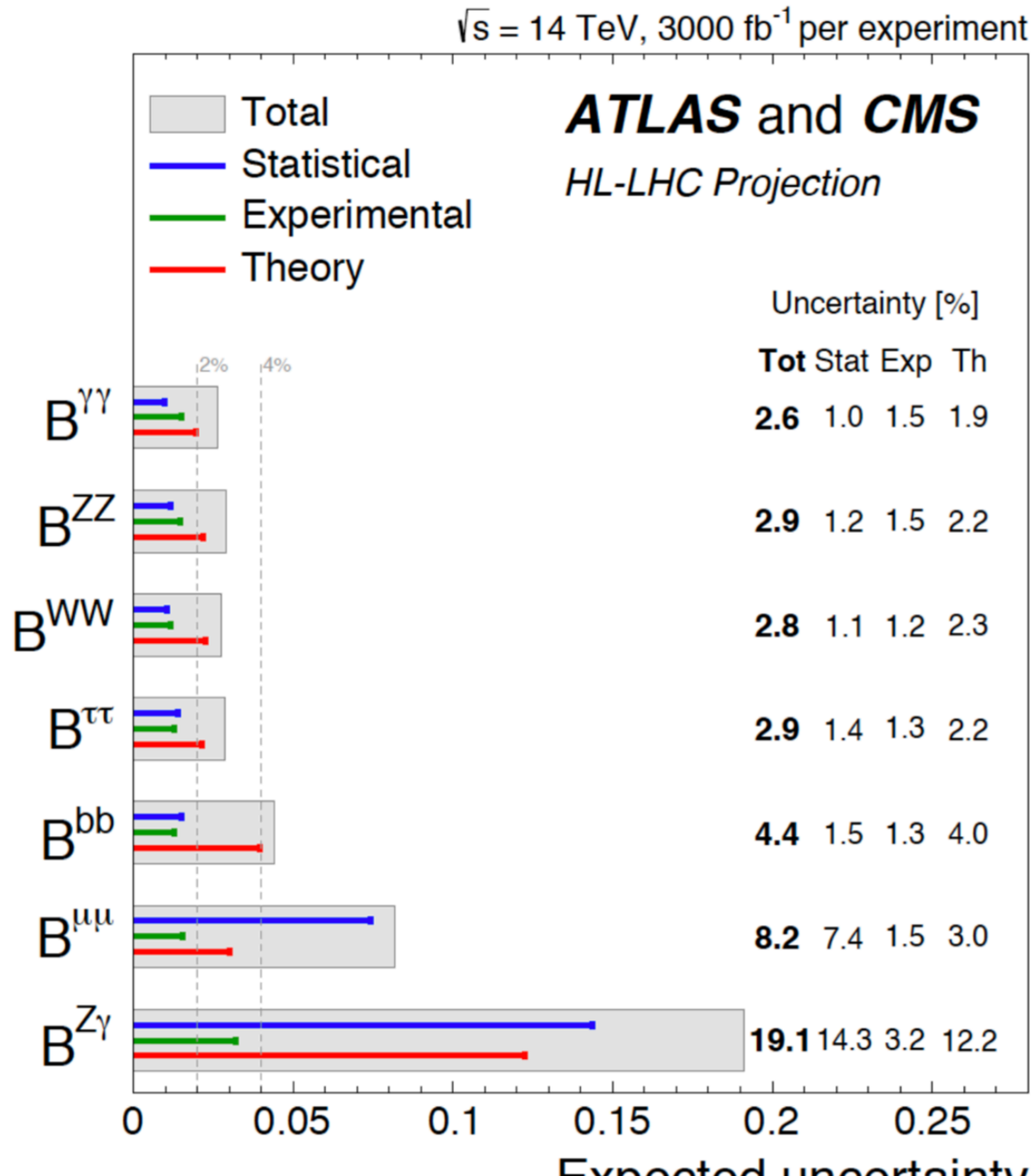
- Precision measurements!
  => Higgs factory!
  - Higgs factory (HZ): 10^6
  - EW & Top factory
    - $5x10^{12}$ (Z), 10^8 (WW), 10^6 (tt)
  - Flavour factory
    - $5x10^{12}$ (Z->bb, cc, tautau)
  - QED, QCD, BSM, etc.



Higgs x-sec & BR at HL-LHC

- Extrapolation from current Run2 results





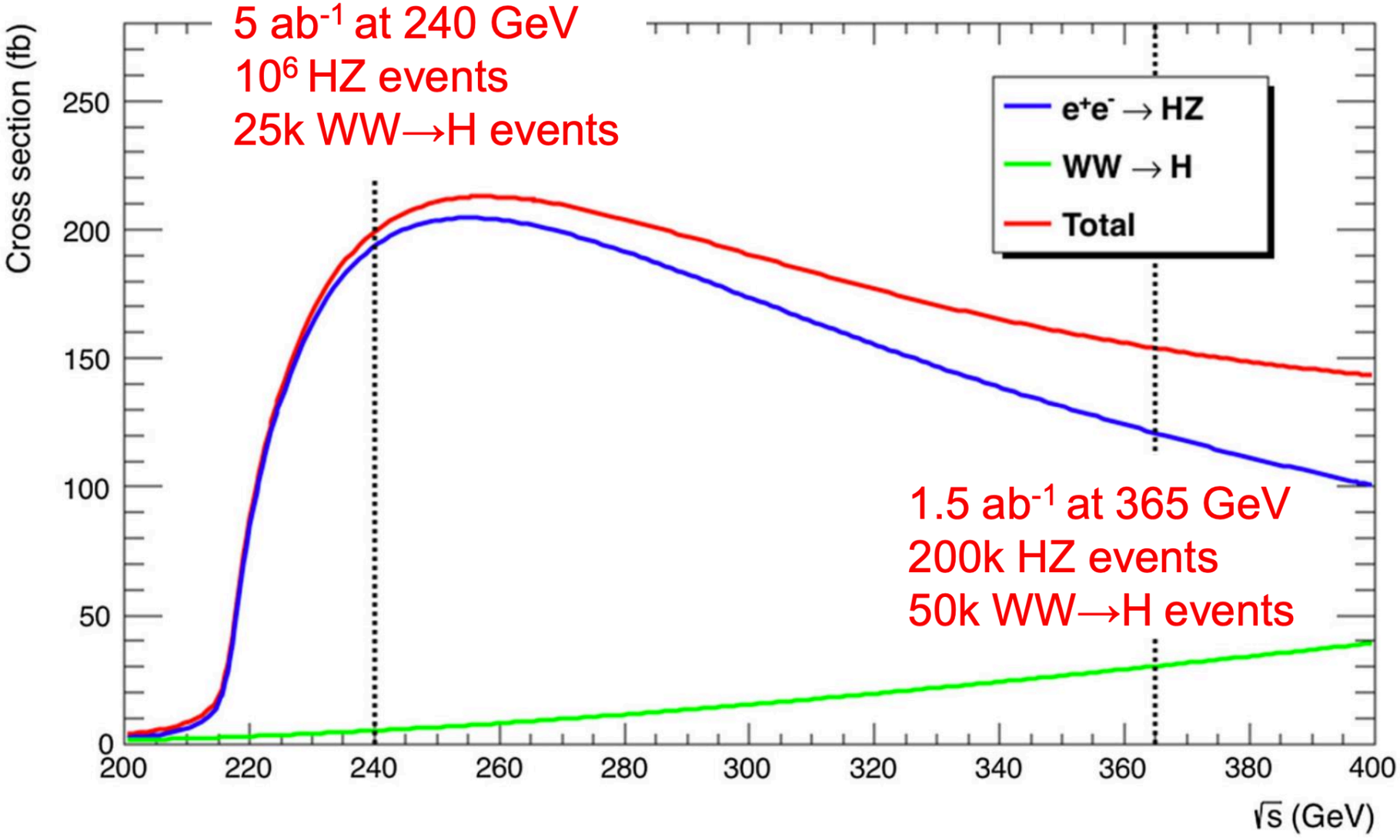
Higgs Couplings at FCC

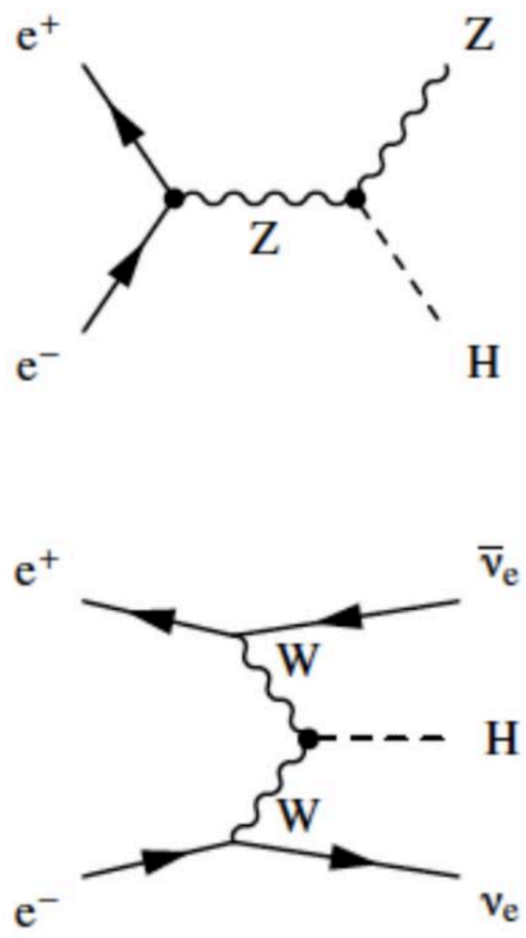
- Goal is < 1% precision

Collider	HL-LHC	ILC_{250}	$CLIC_{380}$	$LEP3_{240}$	$CEPC_{250}$	FCC-$ee_{240+365}$		
Lumi (ab^{-1})	3	2	1	3	5	5_{240}	$+1.5_{365}$	+ HL-LHC
Years	25	15	8	6	7	3	+4	
$\delta\Gamma_H/\Gamma_H$ (%)	SM	3.6	4.7	3.6	2.8	2.7	**1.3**	1.1
$\delta g_{HZZ}/g_{HZZ}$ (%)	1.5	0.3	0.60	0.32	0.25	0.2	**0.17**	0.16
$\delta g_{HWW}/g_{HWW}$ (%)	1.7	1.7	1.0	1.7	1.4	1.3	**0.43**	0.40
$\delta g_{Hbb}/g_{Hbb}$ (%)	3.7	1.7	2.1	1.8	1.3	1.3	**0.61**	0.56
$\delta g_{Hcc}/g_{Hcc}$ (%)	SM	2.3	4.4	2.3	2.2	1.7	**1.21**	1.18
$\delta g_{Hgg}/g_{Hgg}$ (%)	2.5	2.2	2.6	2.1	1.5	1.6	**1.01**	0.90
$\delta g_{H\tau\tau}/g_{H\tau\tau}$ (%)	1.9	1.9	3.1	1.9	1.5	1.4	**0.74**	0.67
$\delta g_{H\mu\mu}/g_{H\mu\mu}$ (%)	4.3	14.1	n.a.	12	8.7	10.1	**9.0**	3.8
$\delta g_{H\gamma\gamma}/g_{H\gamma\gamma}$ (%)	1.8	6.4	n.a.	6.1	3.7	4.8	**3.9**	1.3
$\delta g_{Htt}/g_{Htt}$ (%)	3.4	–	–	–	–	–	–	3.1
BR_{EXO} (%)	SM	<1.7	<2.1	<1.6	<1.2	<1.2	**<1.0**	**<1.0**

Why Higgs at Two Energies?

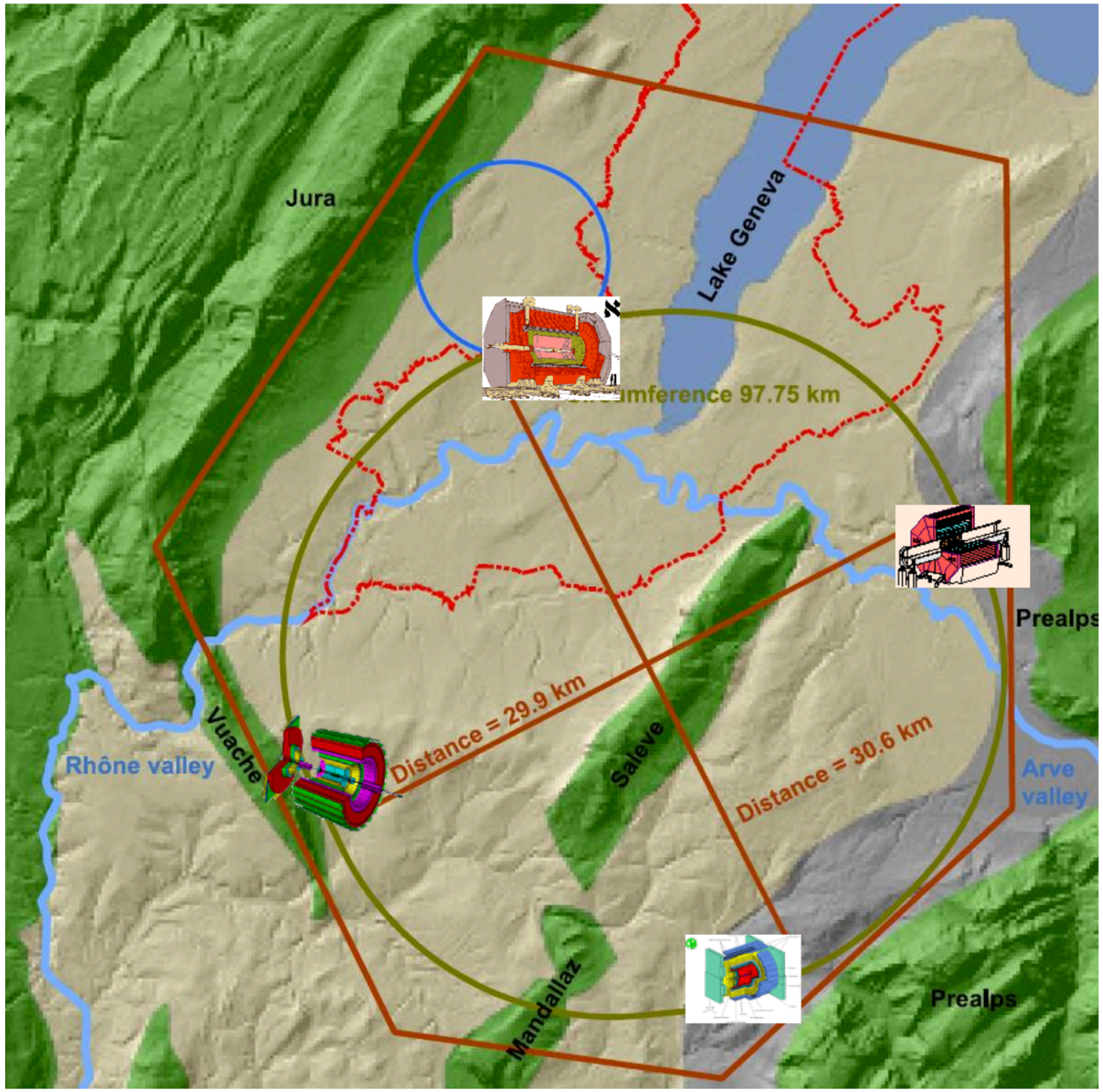
- Sensitivity to both processes very helpful improving the precision





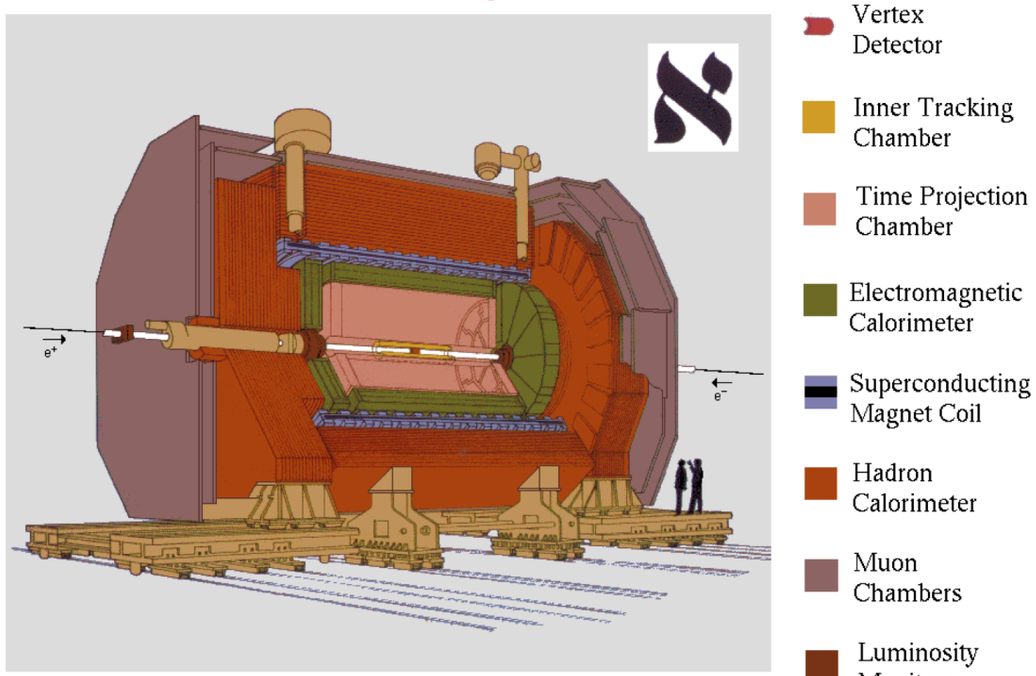
How Many IPs?

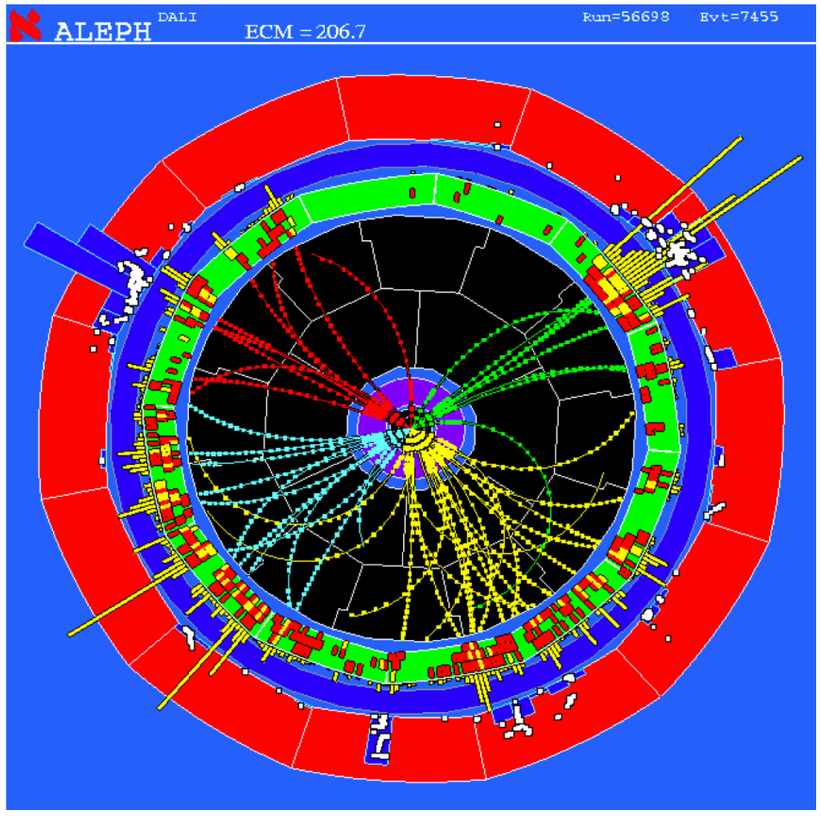
- Initial studies (in CDRs) are based on two IPs
- Strong physics driven arguments for evolving to 4 IPs
  - More data, sooner
  - Systematic robustness with redundancy
  - Better physics coverage



Particle Flow Detector

- For particle flow, design requirement:
  - Simplicity
  - 3D granularity for all sub-detectors
  - Large magnetic field (and large tracking volume)
  - Little material in front of the calorimeters
  - Redundancy of the measurements
- Full power (including future development) of computing should be considered for FCC
  - Including HPC and QC

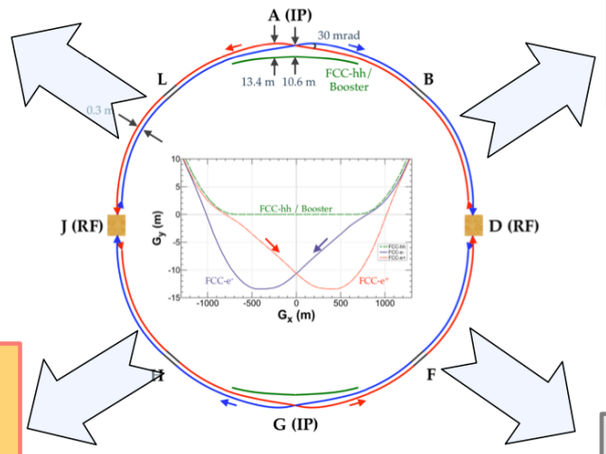




Detector Challenges

"Higgs Factory" Programme

- At two energies, 240 and 365 GeV, collect in total
  - 1.2 M HZ events and 75 k WW → H events
- Higgs couplings to fermions and bosons
- Higgs self-coupling (2-4 σ) via loop diagrams
- Unique possibility: measure electron coupling in s-channel production $e^+e^- \rightarrow H$ @ $\sqrt{s}$ = 125 GeV



Ultra Precise EW Programme

Measurement of EW parameters with factor ~300 improvement in *statistical* precision wrt. current WA

- 5×10^{12} Z and 10^8 WW
  - m_Z, Γ_Z, Γ_{inv}, $\sin^2\theta_W^{eff}$, R^Z_ℓ, R_b, α_s, m_W, Γ_W, …
- 10^6 tt
  - m_{top}, Γ_{top}, EW couplings

Indirect sensitivity to new phys. up to Λ=70 TeV scale

Heavy Flavour Programme

- Enormous statistics: 10^{12} bb, cc; 1.7×10^{11} ττ
- Extremely clean environment, favourable kinematic conditions (boost) from Z decays
- CKM matrix, CP measurements, "flavour anomaly" studies, e.g. b → sττ, rare decays, cLFV searches, lepton universality, PNMS matrix unitarity

Feebly Coupled Particles - LLPs

Intensity frontier: Opportunity to directly observe new feebly interacting particles with masses below m_Z:

- Axion-like particles, dark photons, Heavy Neutral Leptons
- Signatures: long lifetimes - LLPs