DIAGNOSTICS AND BUNKER DESIGN FOR A HIGH-PERFORMANCE CRYOMODULE TEST FACILITY AT KEK

[FJPPN-A_RD_28]

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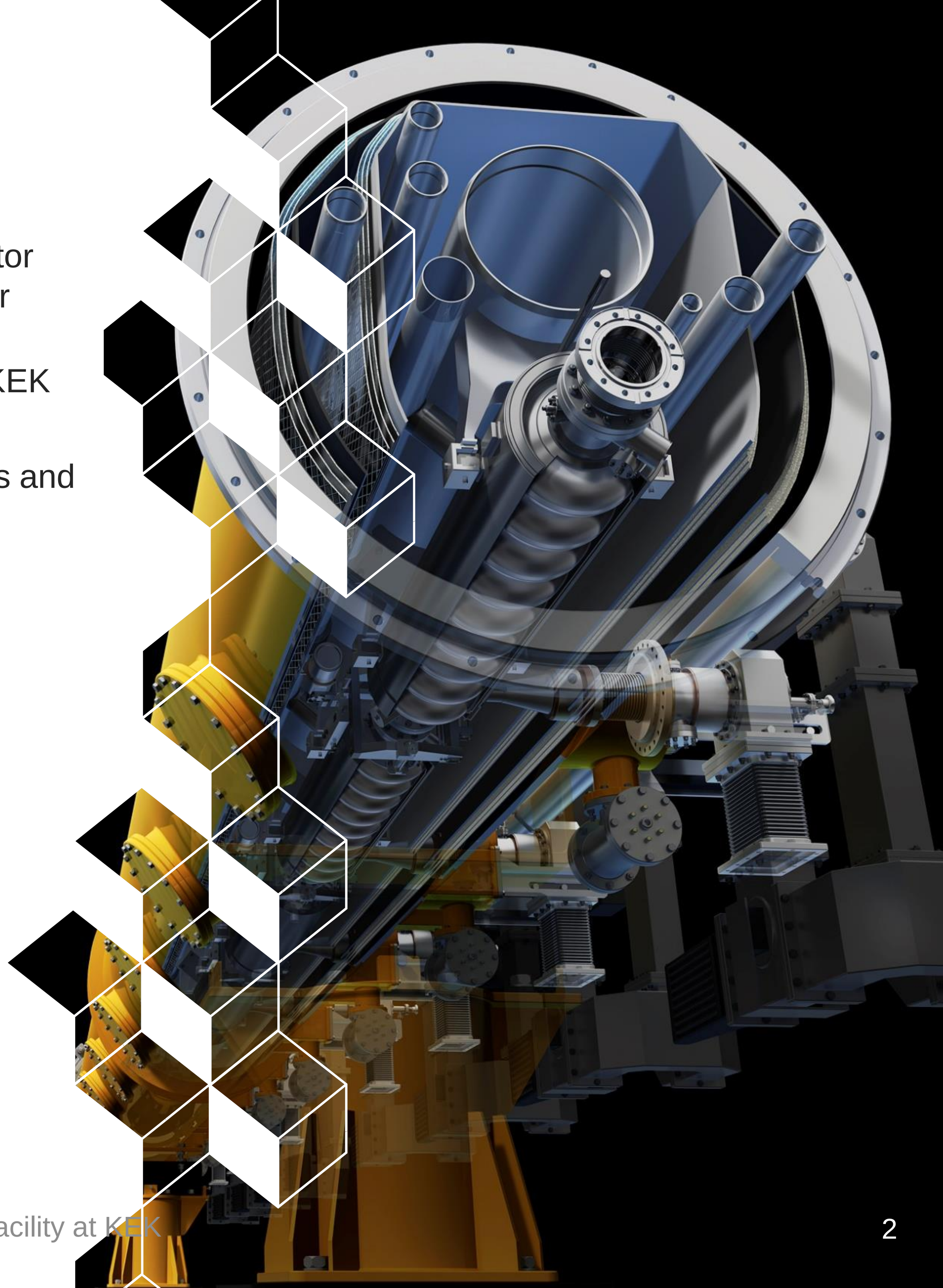
Motivation and collaboration overview

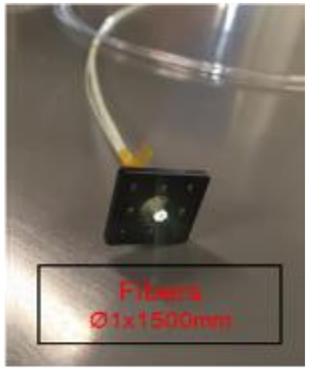
- ILC Technology Network Framework
  - An ILC prototype cryomodule (CM) will be constructed at KEK until 2027
  - Plan of test and operation under the same conditions as in the future accelerator (vacuum, cryogenic temperatures, high power radio frequency, etc.), except for beam acceleration
  - A test facility for high-performance CMs is being designed and will be built at KEK
- Field emission
  - Main cause for the degradation of the quality factor of superconducting cavities and the final machine performance
  - Mostly originates from dust particle contamination
- Gamma-ray diagnostics are paramount for cryomodule performance evaluation and radiation protection

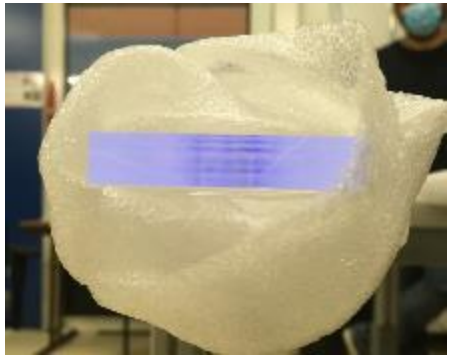
CEA	*Collaboration members*	Dr. E. Cenni (PI), Dr. J. Plouin, L. Maurice,
	Requested funding	**3.75 k€** (15 days, 1 travels, material shipment)
KEK	*Collaboration members*	Dr. M. Omet (PI), Dr. Y. Yamamoto, Dr. A. Kumar, Dr. H. Ito, Dr. T. Yamada, Dr. H. Iwase, Dr. T. Oyama, K. Tsugane
	Requested funding	**1440 k¥** (20 days, 2 travels, material shipment)

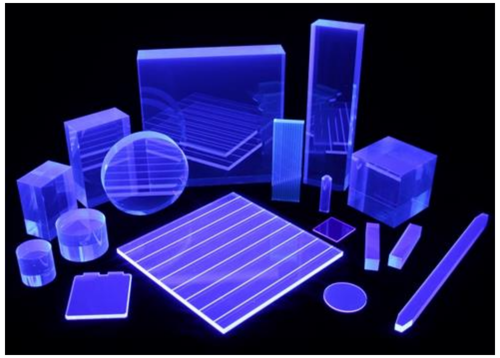


γ–Diagnostic system for high performance cavities and CMs

- We are interested in versatile and large-area coverage detectors:
  - Plastic scintillators can be shaped in different forms
  - Reasonably cheap with respect to the area coverage
  - Largely used in particle physics (e.g. Sci-Fi Tracker in LHCb)
- We started by testing a plastic bars (10x50x1500mm) and fibers (Ø1x1500mm) as a proof of concept
- <u>Detectors are at room temperature (easy to install and change configuration)</u>
- <u>Possibility to study field emission radiation pulse by pulse, with time resolution within the pulse</u>
- We are developing dedicated Geant4 applications for cryomodule and cavity testing allowing us to optimize detectors with respect to the radiation emerging from the cavities

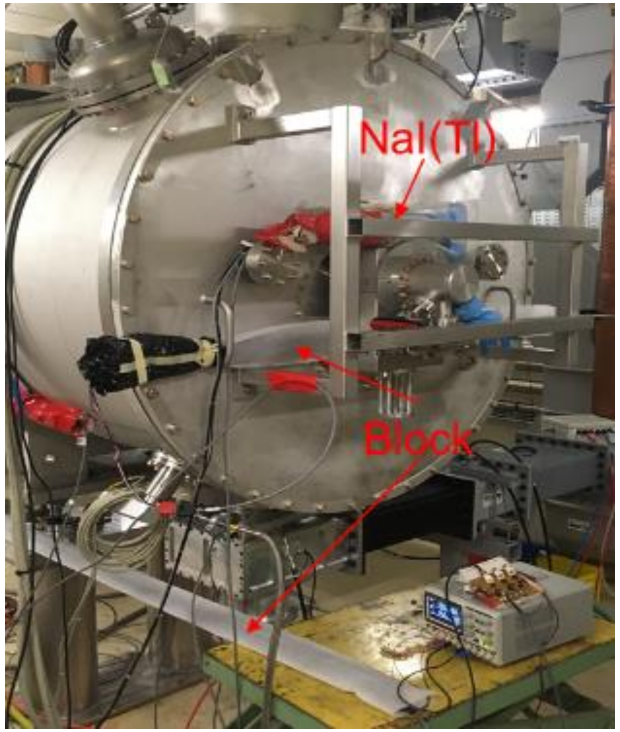






Base plastic is Polyvinyl toluene (PVT)

ESS cryomodule installed in the test stand at <u>Saclay</u>



Scintillator block installed on ESS cryomodule during power test in Saclay, close to a NaI(Tl) scintillator.

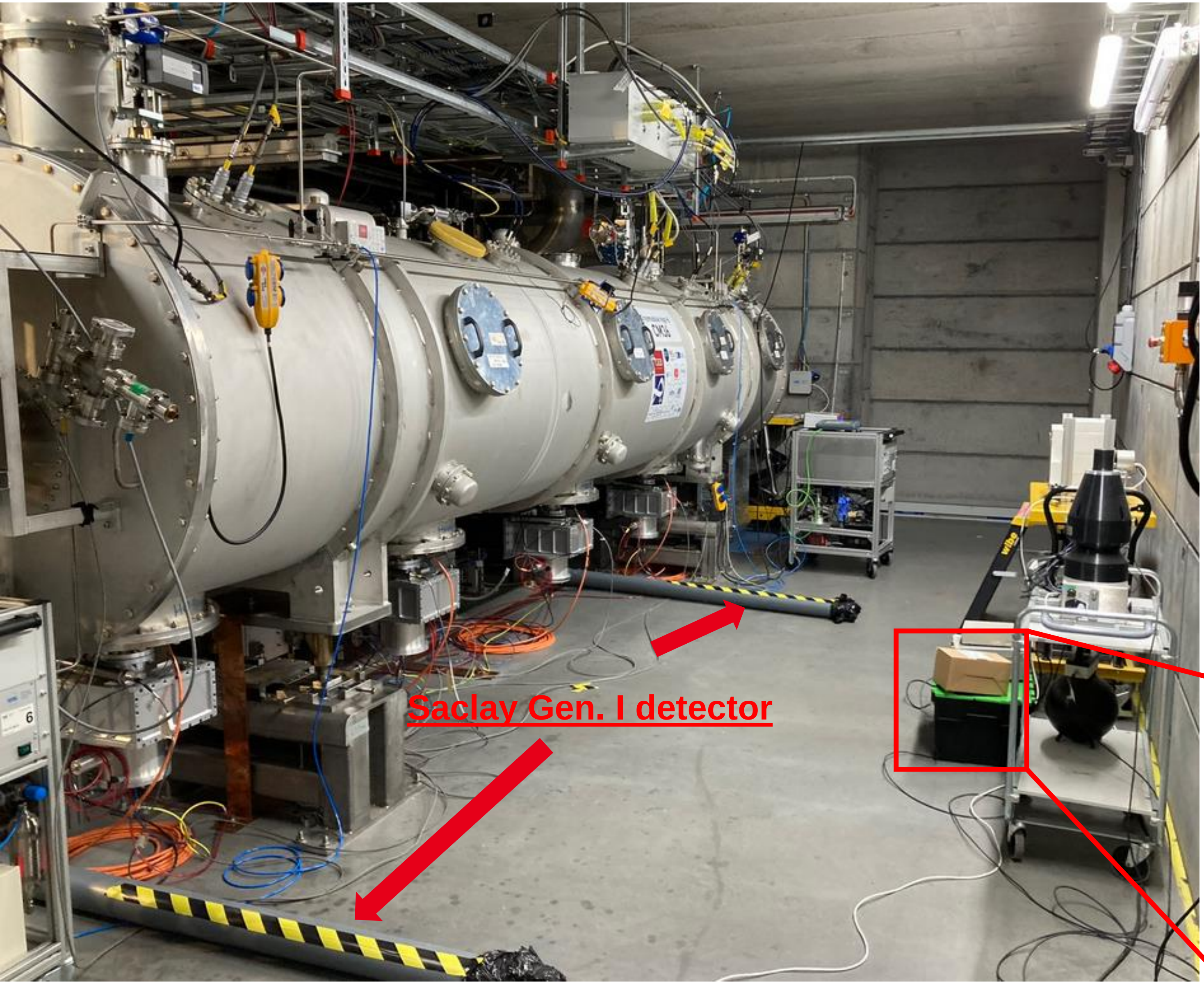
Detector development (Generation overview)

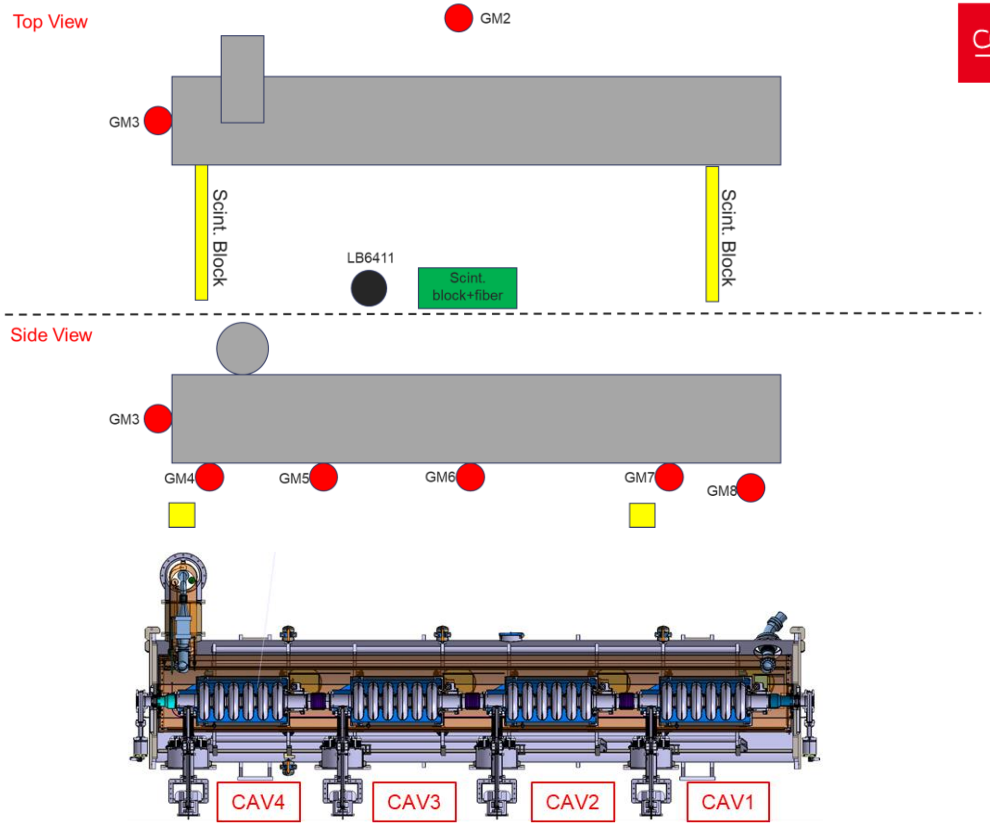
Generation	Set up	Time resolution	Pros	Cons
I	Photomultiplier + LPS	~10 µs	Implementation	"Slow"
II	Photomultiplier + fast amplifier	~1ns	Response speed	Cost per detector, read out speed (scope)
III	MPPC* + dedicated readout	~1ns	Cheaper cost per detector, fast acquisition/analysis	Need dedicated ASIC

**Multi-Pixel Photon Counter, Silicon Photomultiplier*

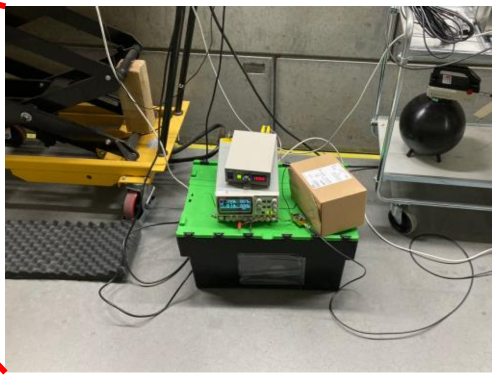
- We have collected data for **Gen. I** at CEA and ESS
- **Gen. II** is ongoing, we have some preliminary data from ESS (TS2)
- **Gen. III** is under development

Test Stand 2 @ESS



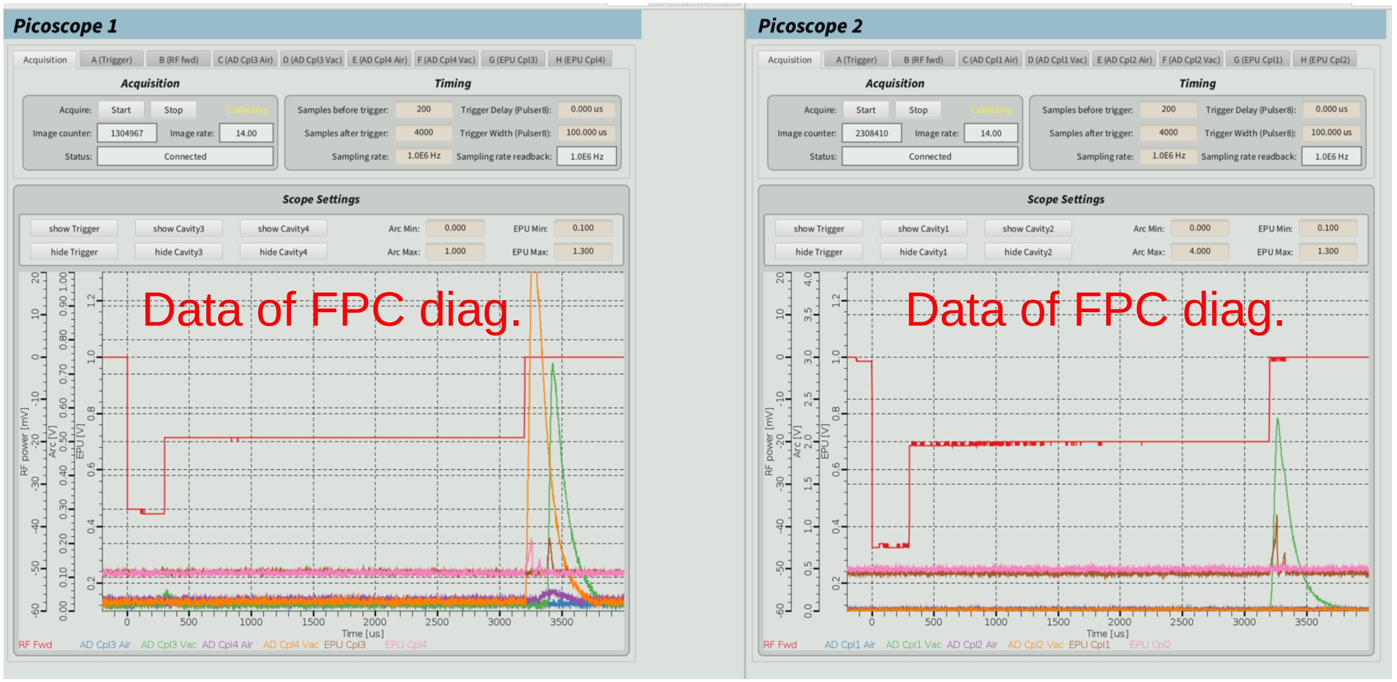


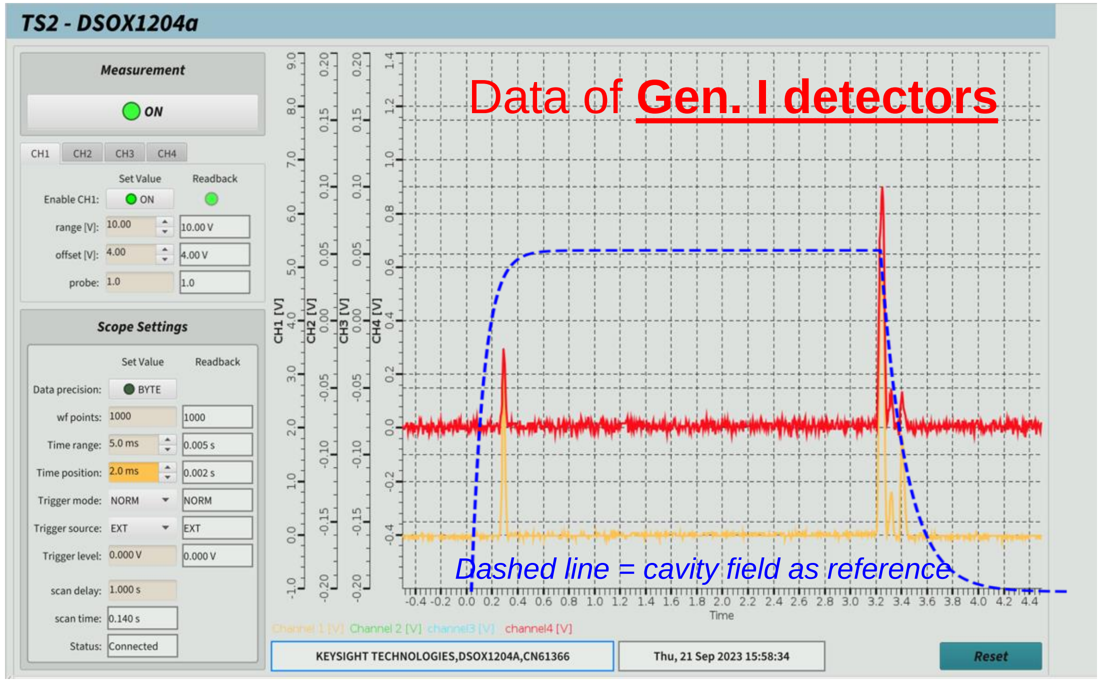
Saclay Gen. II detector

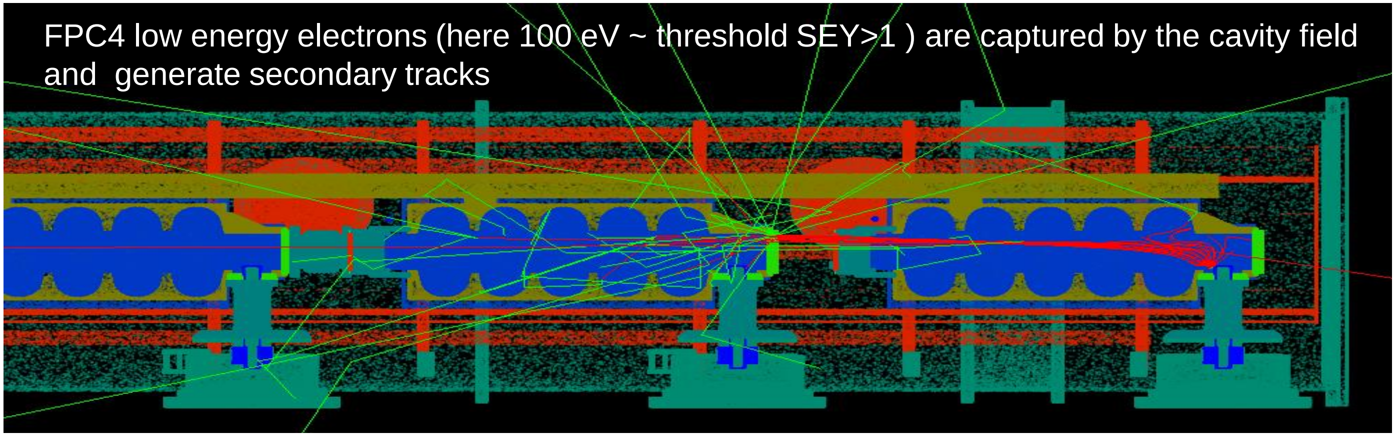


- For the first time the comparison of data from different detectors generations is possible

Fundamental power coupler (FPC) electron emission

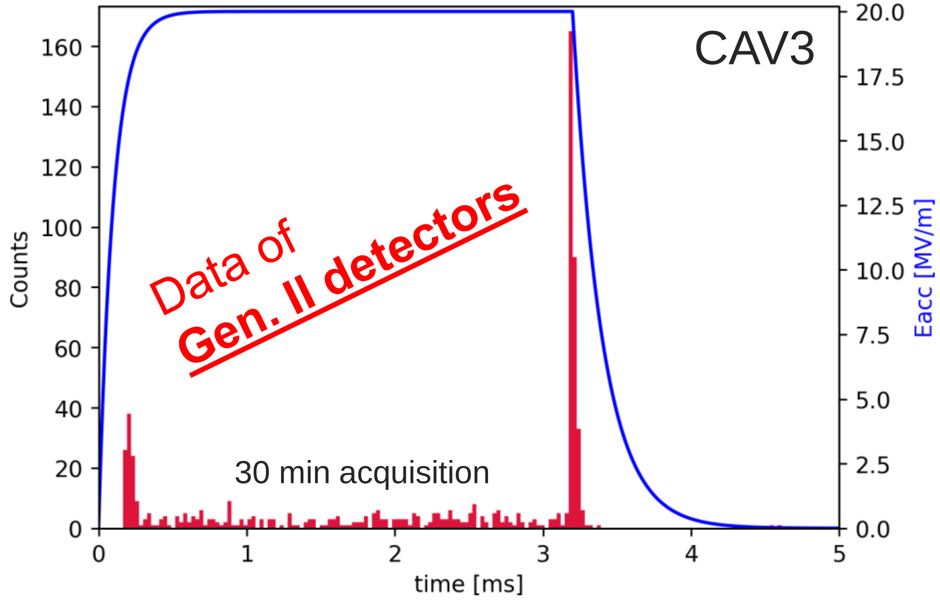


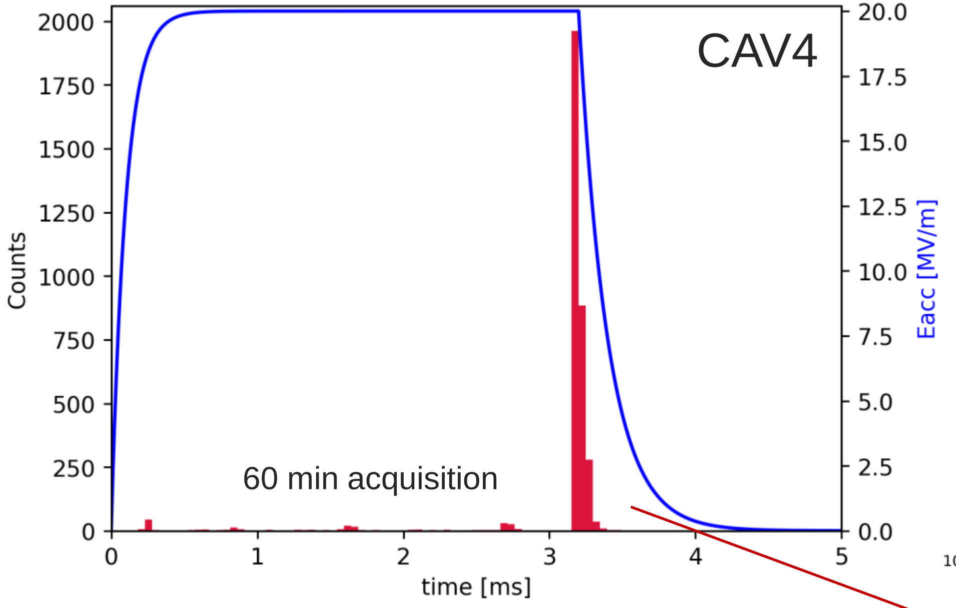




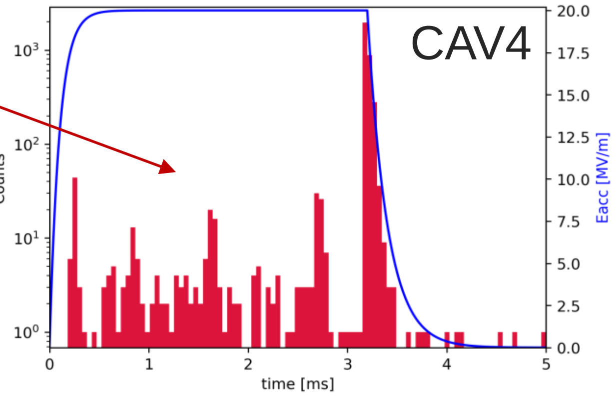
- Due to the 10µs time resolution, we can distinguish between FE and FPC electron emission

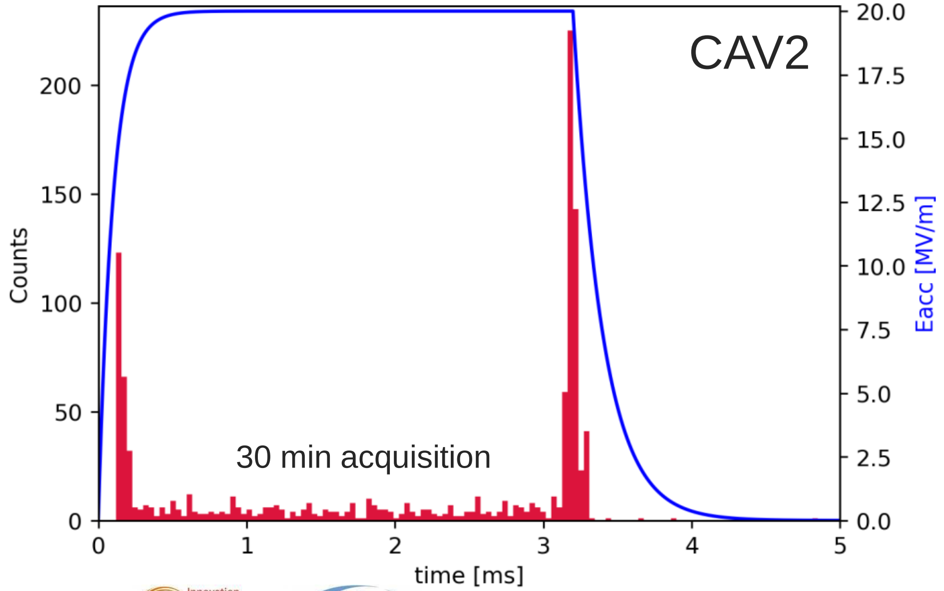
Data taken during CM test at ESS (light pulse count wrt time)

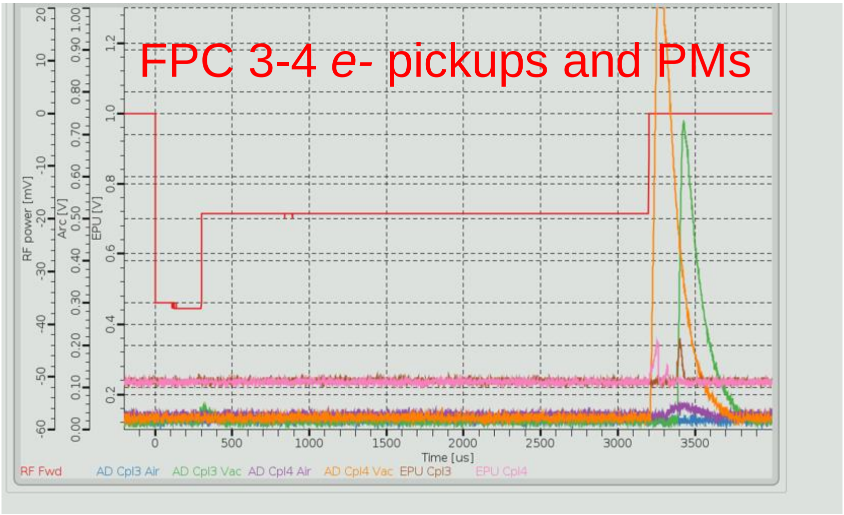




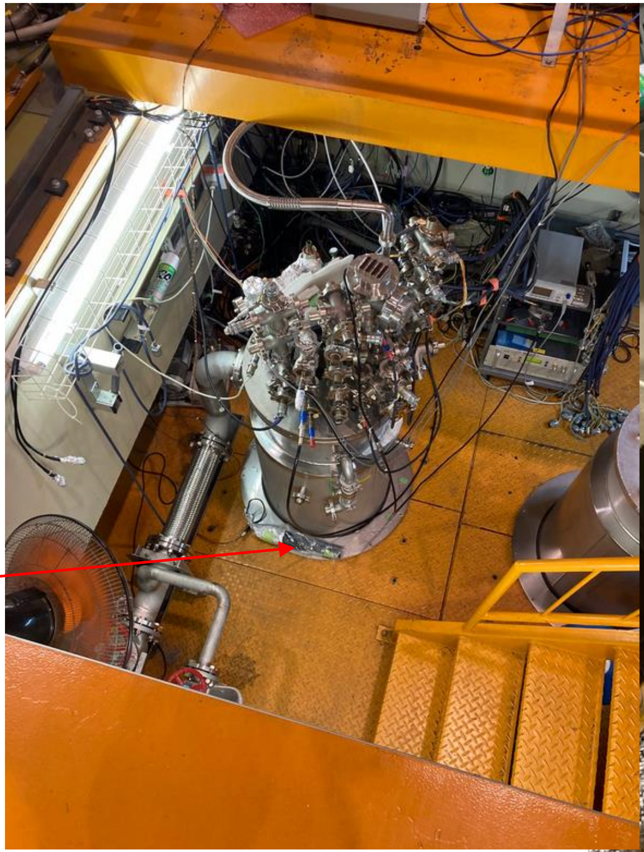
log scale

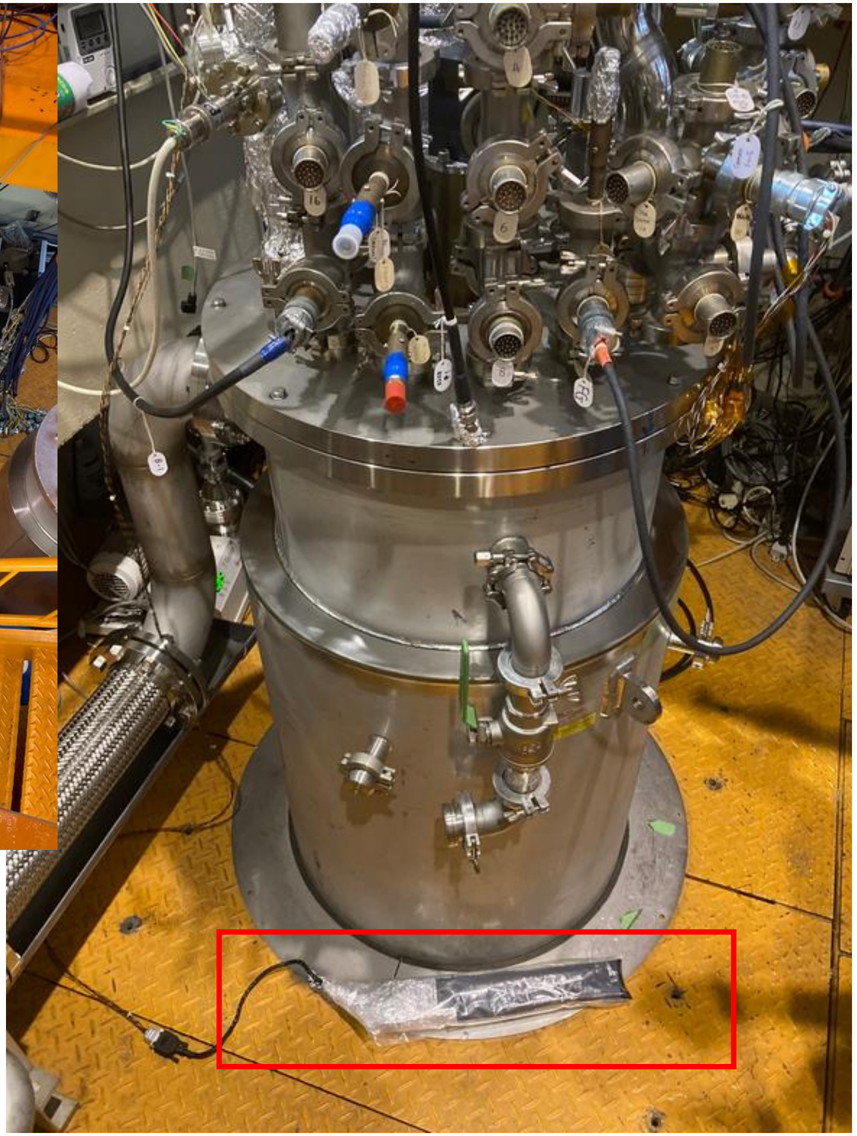






Detector test in STF @KEK





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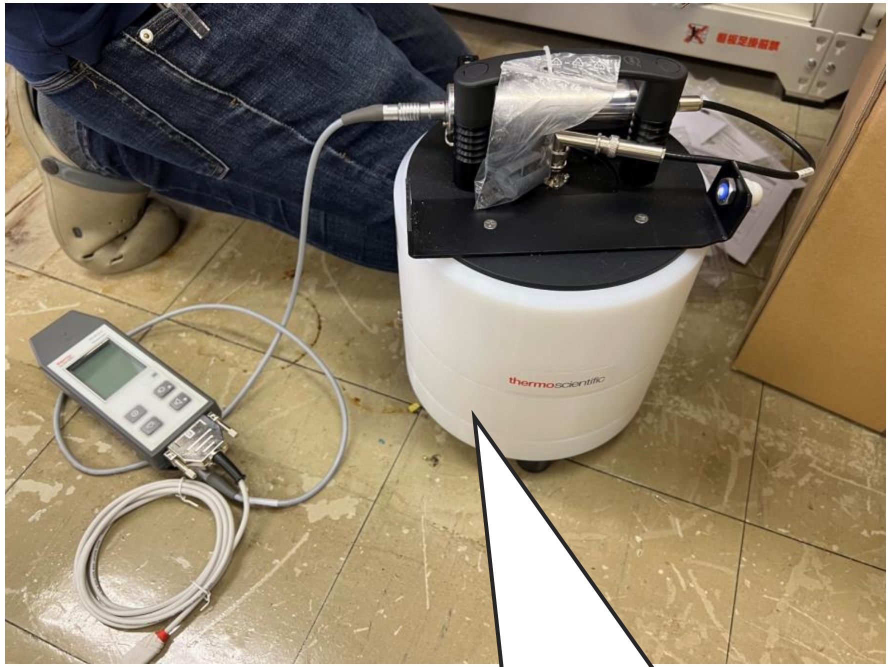
EAJADE
Europe-America-Japan Accelerator Development Exchange Programme

Radiation study at KEK during cavity vertical tests using additional neutron monitors

FHT 762 Wendi-2
(Wide Energy Neutron Detector)



Used for HL-LHC (<~GeV)

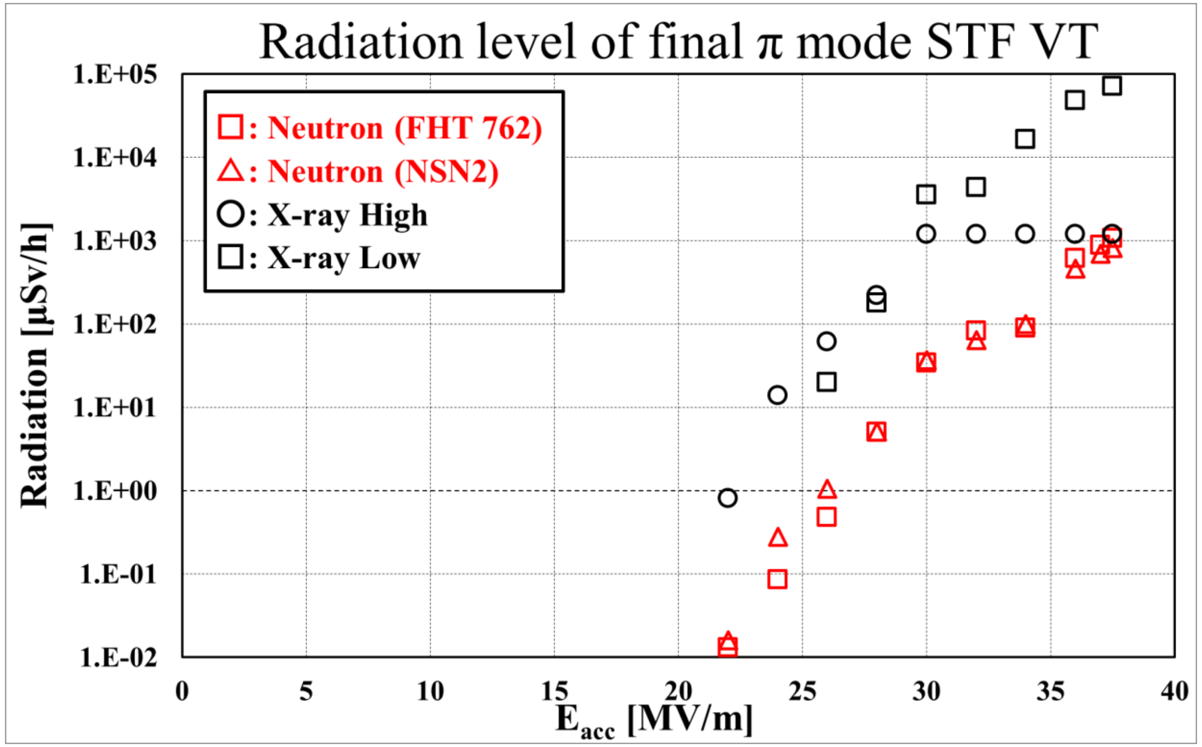
NSN2
(Neutron REM Counter)

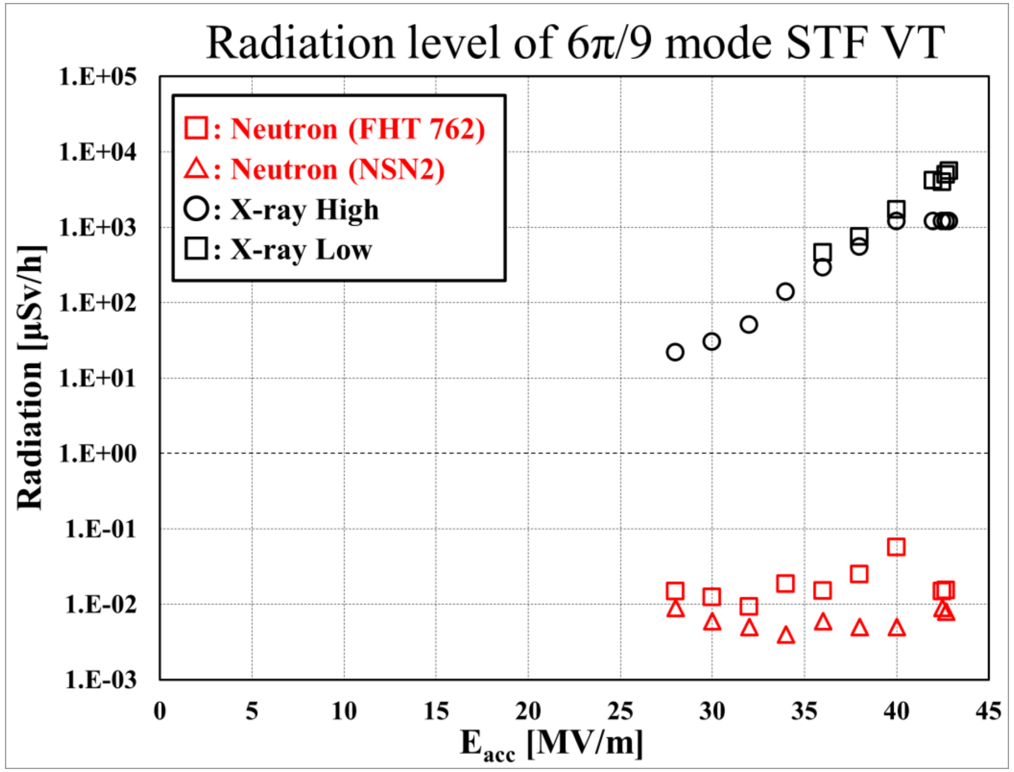
Used by the KEK radiation group (<20MeV)

They were installed beside the VT cryostat

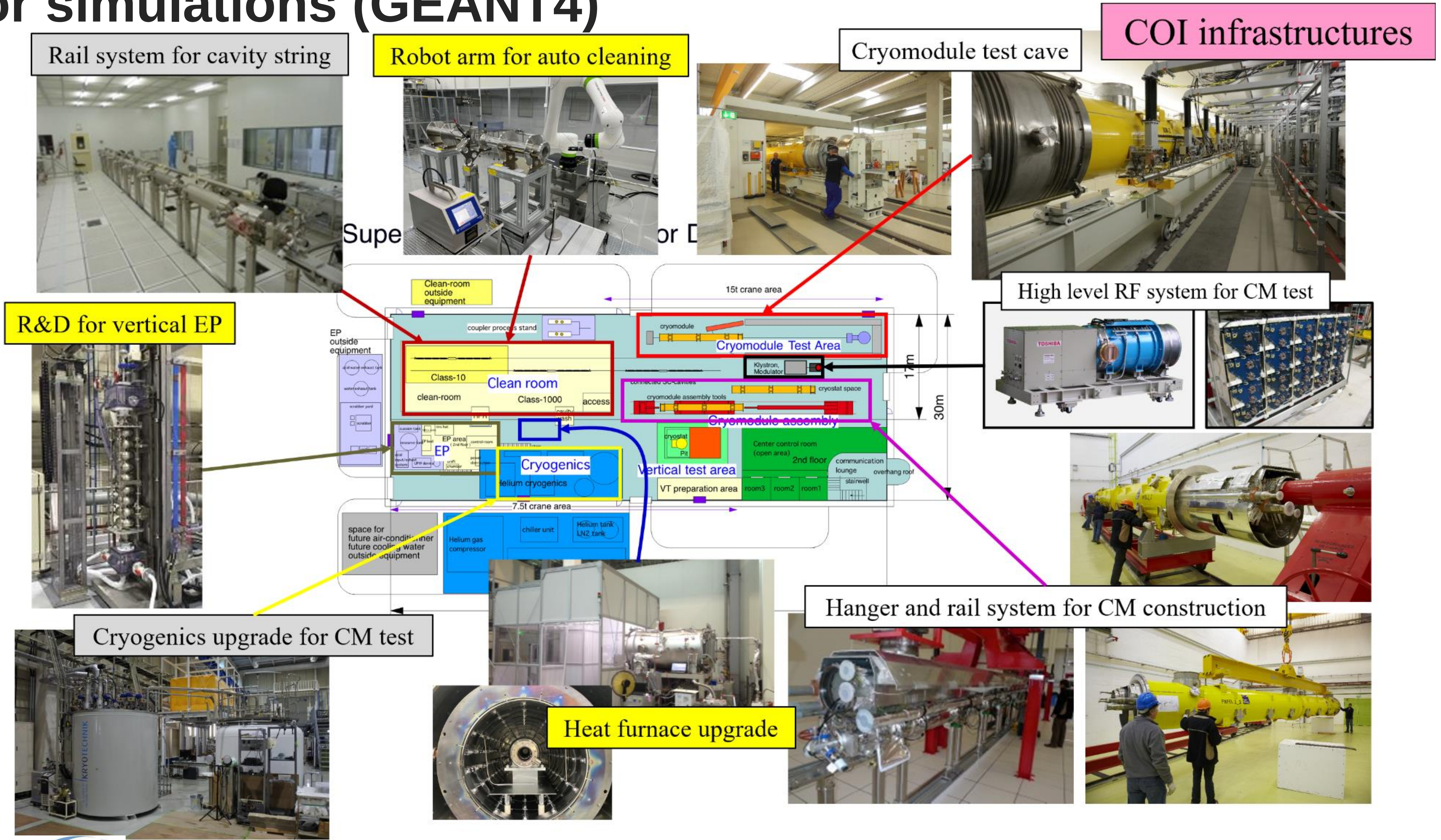
Radiation study during cavity vertical tests using additional neutron monitors

- During a vertical test of 1.3 GHz 9-cell TESLA-type SRF cavity
- Both instruments are in good agreement. In the case of π mode, the number of neutrons is about 1/100 of the amount of gamma rays.





Design of CM test bunker at COI and providing data for simulations (GEANT4)



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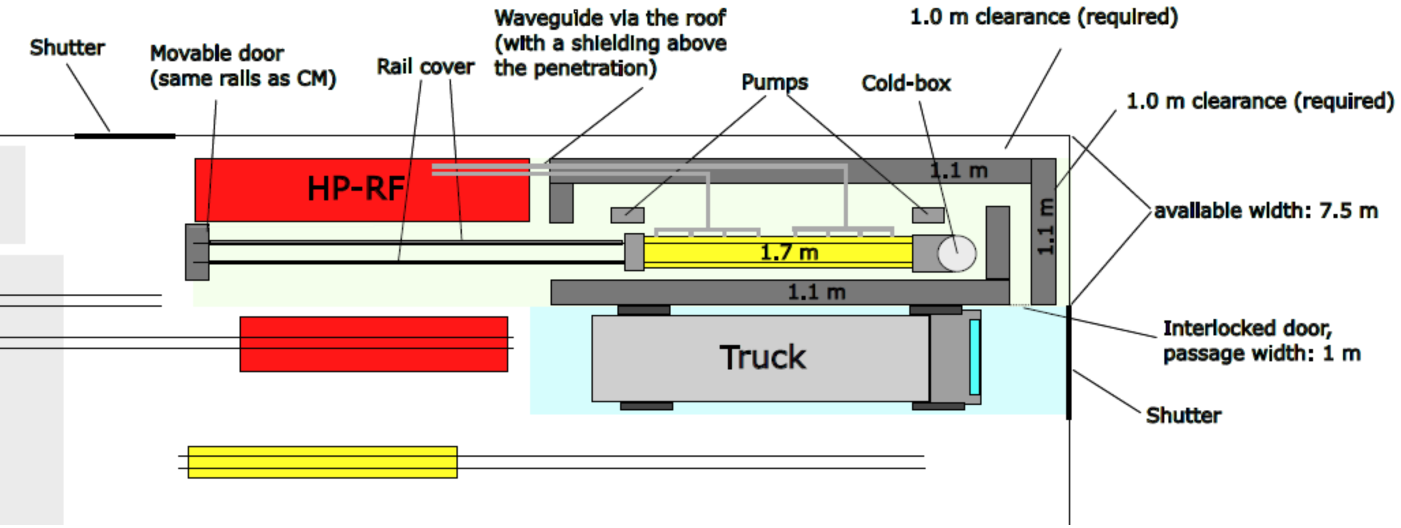
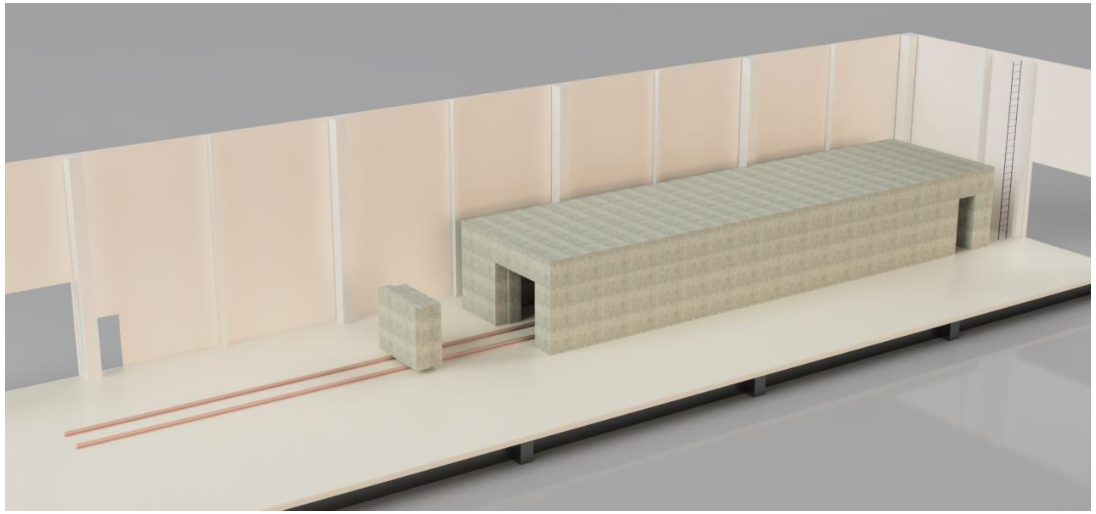
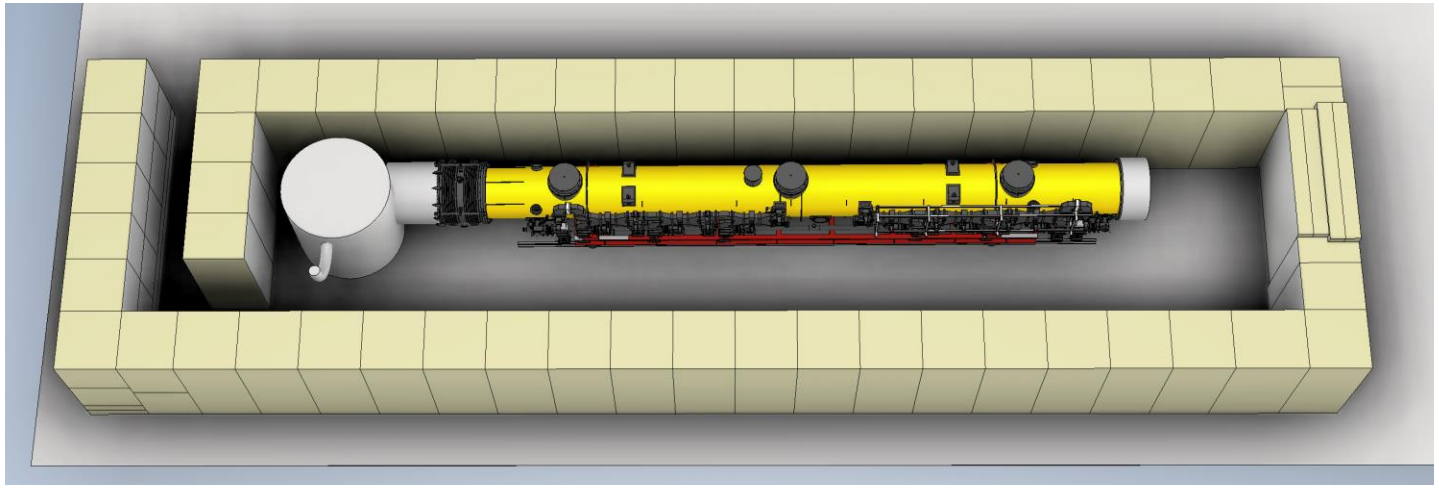
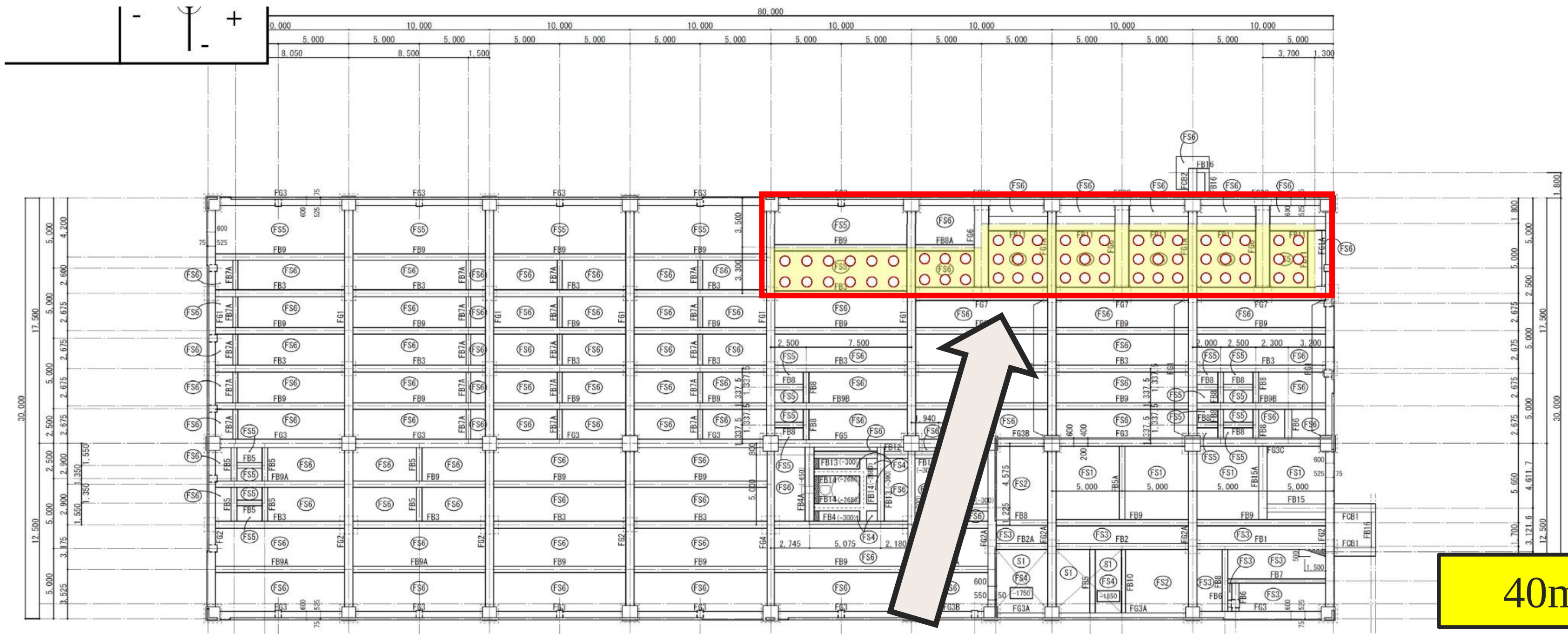






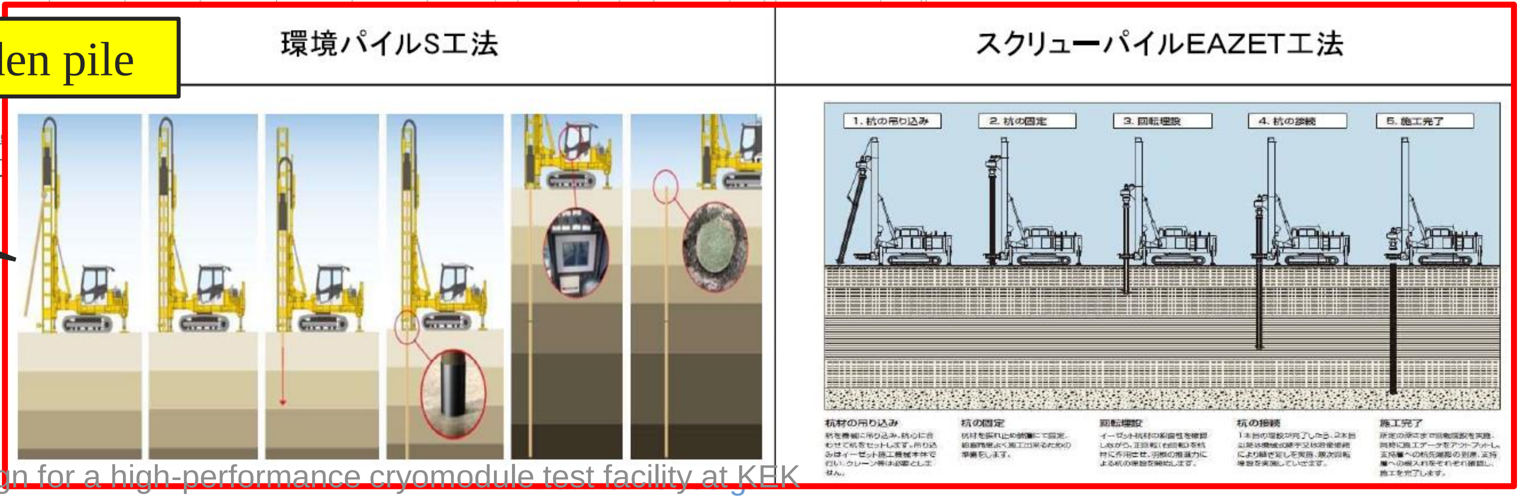
Reinforcement of floor



40m length iron pile

5m length wooden pile

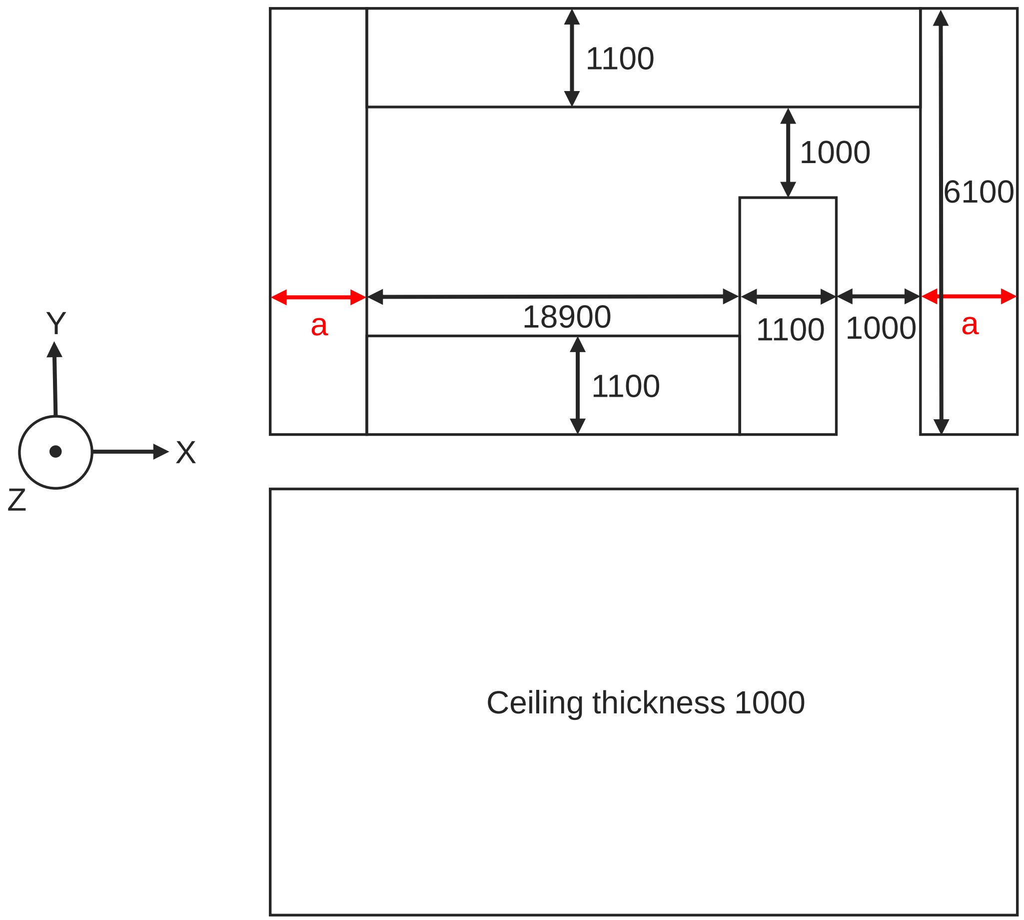
Proposed method



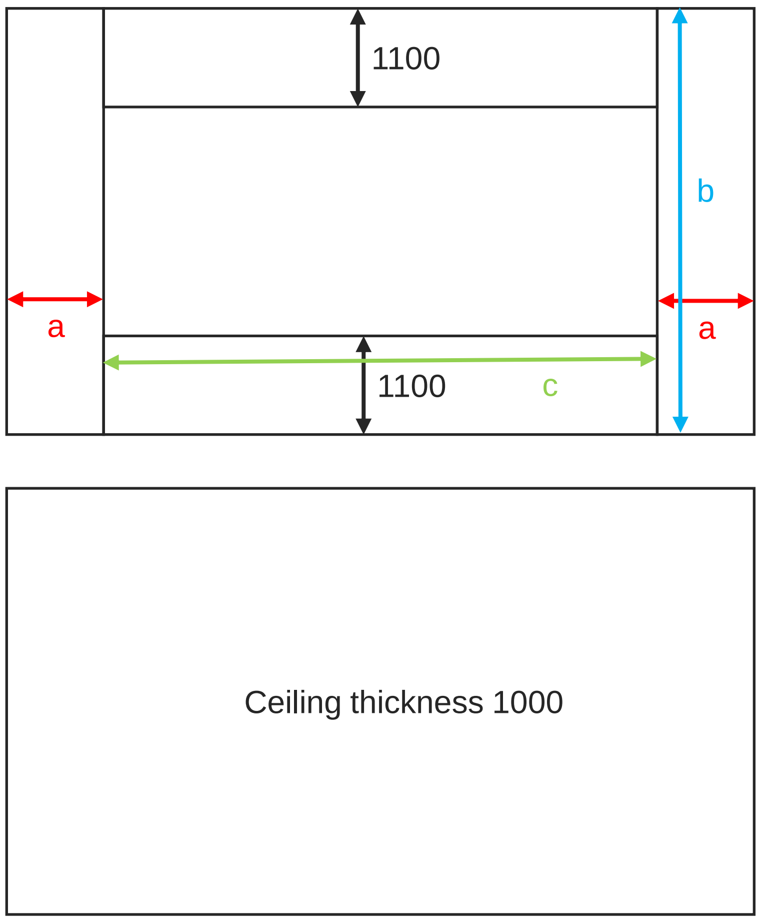
Parameter for different posibilities

Courtesy from M. Omet

Layout with labyrinth



Layout without labyrinth

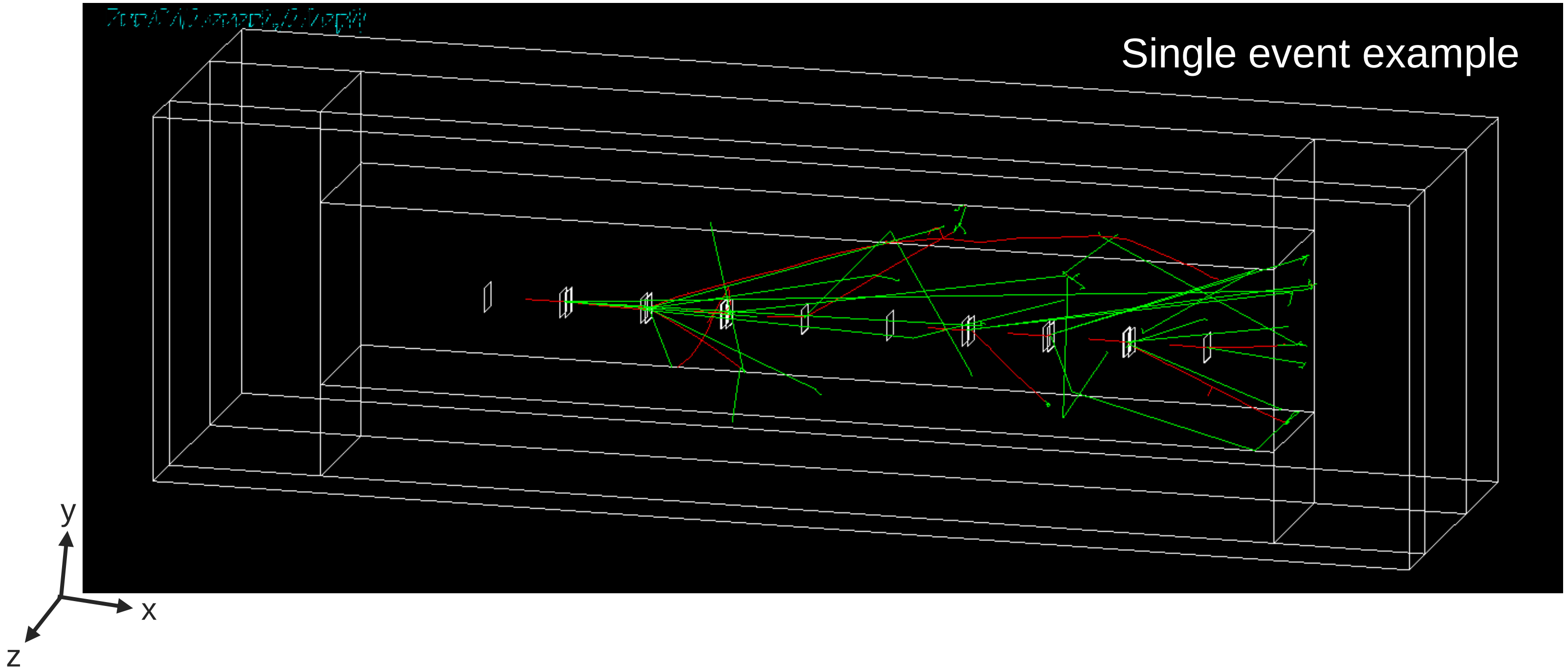


Simulations using Geant4 during stay at CEA (under FJPPN budget)

Courtesy from M. Omet

Activities
- Learn how to use Geant4
- Reproduce results presented by KEK radiation department
- Change bunker design and find optimal layout

Simulation conditions
- 35 MeV e⁻ on 2 mm Niobium plates
  - No energy distribution, thus more severe condition compared to KEK radiation department simulations
  - Upstream and downstream cases
  - 10.000 particles each
- Shielding material
  - Concrete
  - 2.35 g / cm^3
  - O 49.68%, Si 25.11%, Ca 18.30%, C 4.10%, Al 1.30%, Fe 0.7%, K 0.7%, Mg 0.04%, Cl 0.03%, Na 0.02%, S 0.02%
  - Box around bunker to visualize dose (90 x 30 x 30 surfaces)
  - Slice through bunker at cavity height to visualize dose (90 x 30 surfaces)

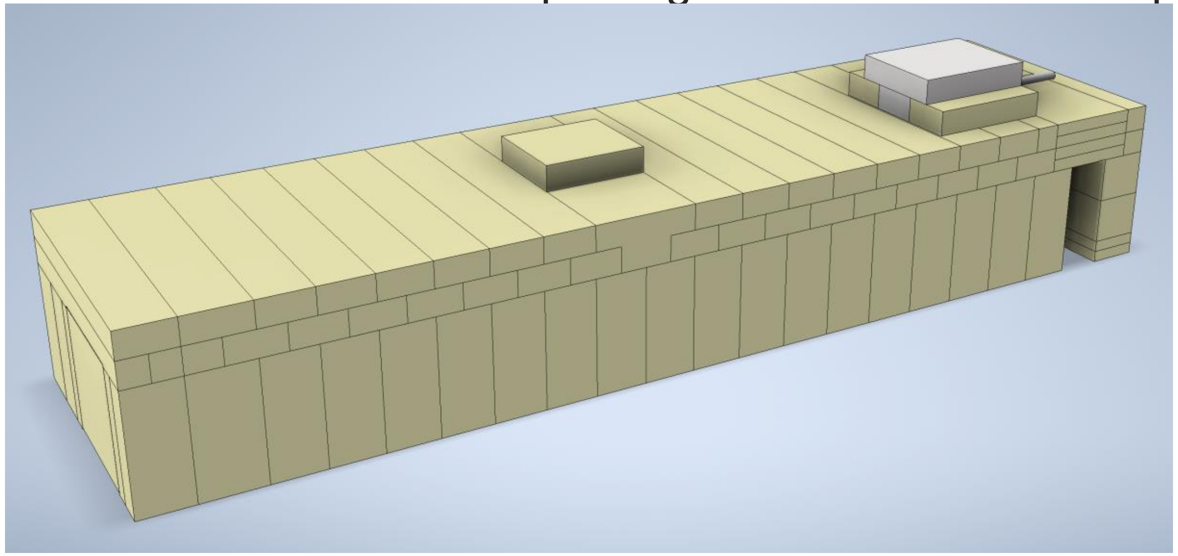


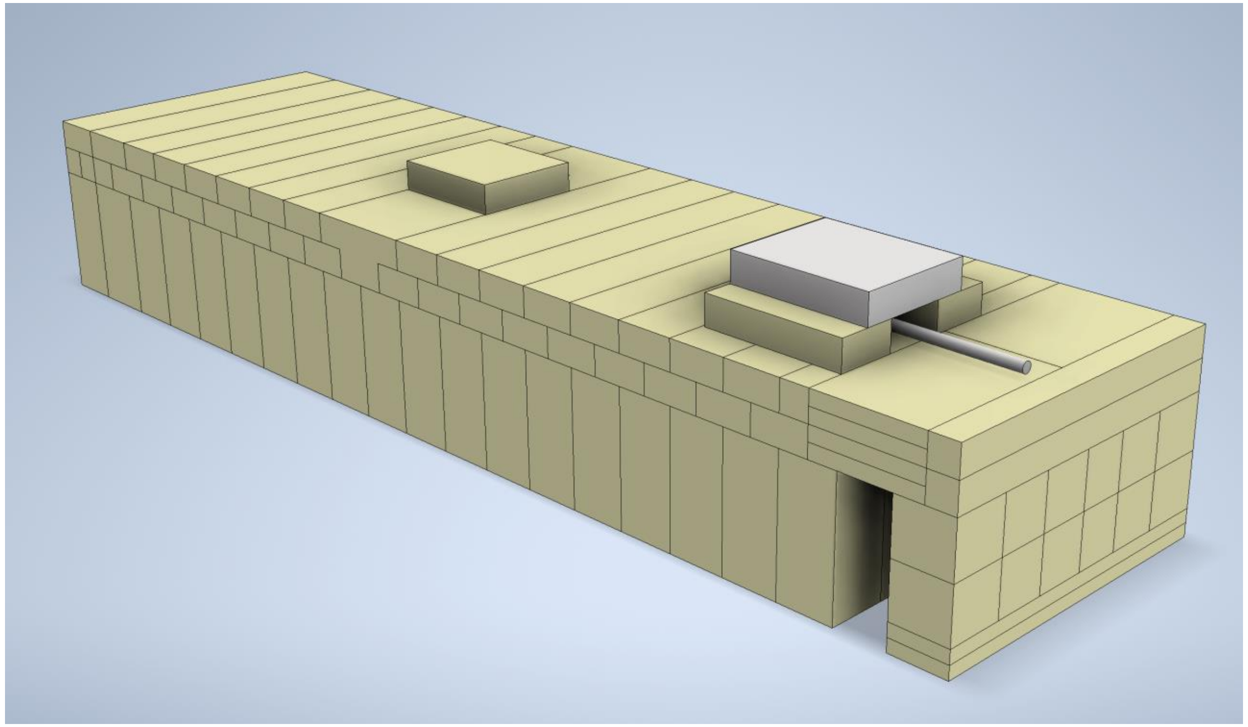
Current status as of 2025/05/15

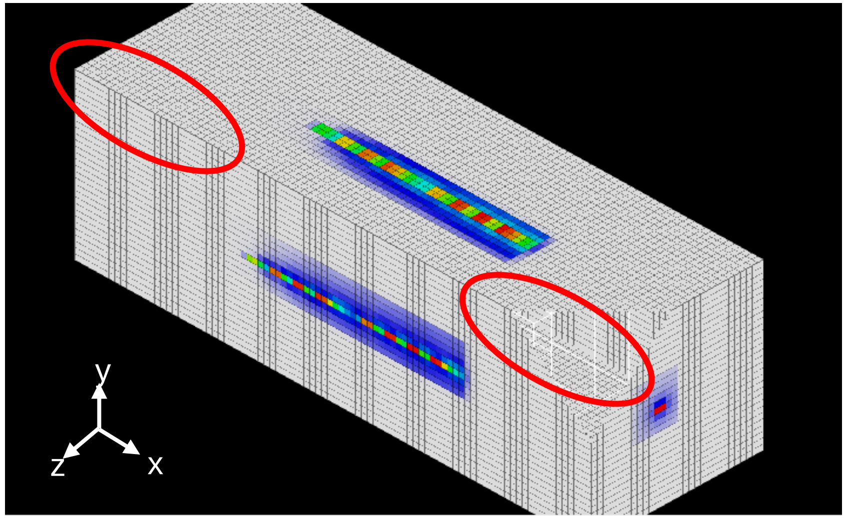
Courtesy from M. Omet

Decided for design featuring labyrinth

Under consideration: Replacing rails with air cushion pads







One idea from CEA bunker:

Feedthroughs are located in the upper corners, since radiation is the lowest there

Remaining holes are closed with shielding material (e.g. lead)

Very simple and flexible design

Can we use the same approach?

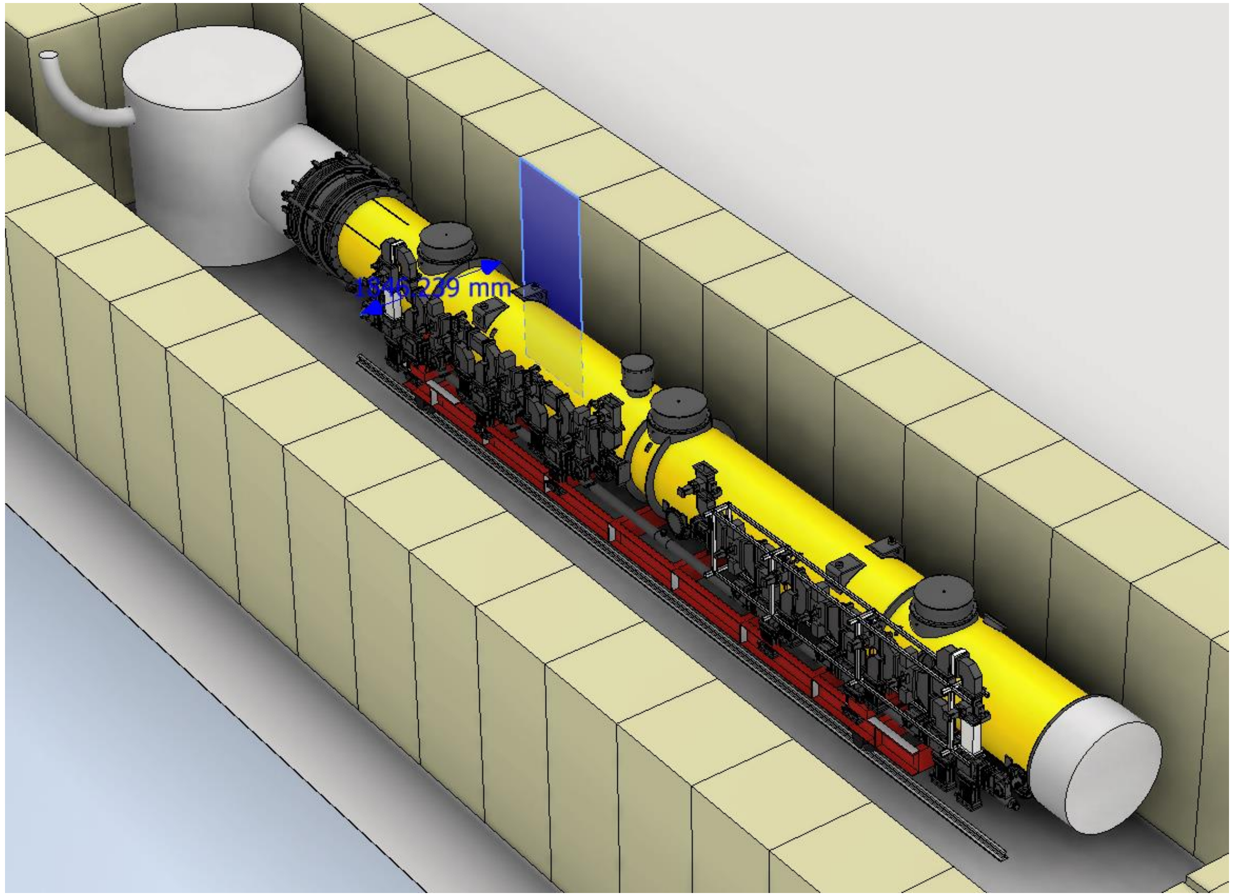
Simulations using Geant4 during stay at CEA (under FJPPN budget)

Result

- Recommended wall thicknesses based on simulation
  - East / west: 2500 mm
  - North / south: 1500 mm
  - Case: New 14 (lowest average pressure)
- Dose estimation within Geant4 simulation has to be reevaluated

Bunker width considerations

Courtesy from M. Omet



Summary and outlook

CEA activities

- Simulation with particle tracking codes and electro-magnetic shower code (GEANT4) for the interaction of electrons with the SRF cavities and cryomodule materials
- Detector development (time-resolved gamma detection)
- Measuring campaign during cryomodule and cavity tests

KEK activities

- Radiation study during cavity vertical tests using additional neutron monitors
- Measurement device preparation
- Design of CM test bunker at COI and providing data for simulations (GEANT4)

Collaboration outlook

- The CEA team would like to extend their detector application to TESLA-type cavities tested in the vertical cryostat and the CM at KEK as well as participate in the design of the new CM test facility and study the best solution for radiation protection with conventional radiation dose monitors (gamma and neutrons)
- The KEK team would like to gaining first-hand experience during radiation measurement campaigns (especially involving PIP-II CMs) at CEA

Detector development (time-resolved gamma detection): In the second year, we will continue with data acquisition and further software development to enhance the detector's capabilities. A new detector is currently in development, and we aim to have it deployed by the end of this year. In the next year, we plan to design and start developing a new detector for the operation within the ITN CM. Build the first prototype and test it within a VT cryostat, and cryocooler cryostat at KEK.

Thank you very much for your attention!

[1] *Framework for the ILC Technology*, KEK, 2023.
[2] *The International Linear Collider - Technical Design Report - Volume 1: Executive Summary*, CERN, FNAL, KEK, 2013.
[3] *ILC-Japan homepage*, 2024, https://ilc-japan.org/en/ .
[4] Y. Yamamoto, *SRF 5-year plan in Japan for ILC*, Presentation at the International Workshop on Future Linear Colliders (LCWS2023), SLAC, 2023.
[5] E. Cenni, *Presentation at TTC workshop*, (TTC 2023), Fermilab 2023
[6] Devanz, G., Cenni, E., Piquet, O., Baudrier, M., & Maurice, L. (2023). Instrumentation for High-Performance Cavities and Cryomodule Field Emission Analysis. *In 21st International Conference on Radio-Frequency Superconductivity*.

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