Development of FASER preshower detector to search for right-handed neutrinos

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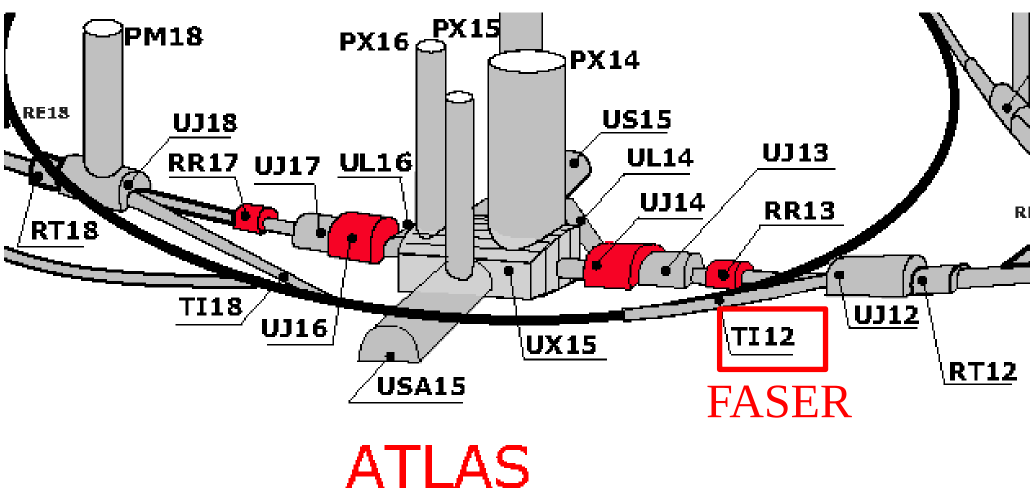
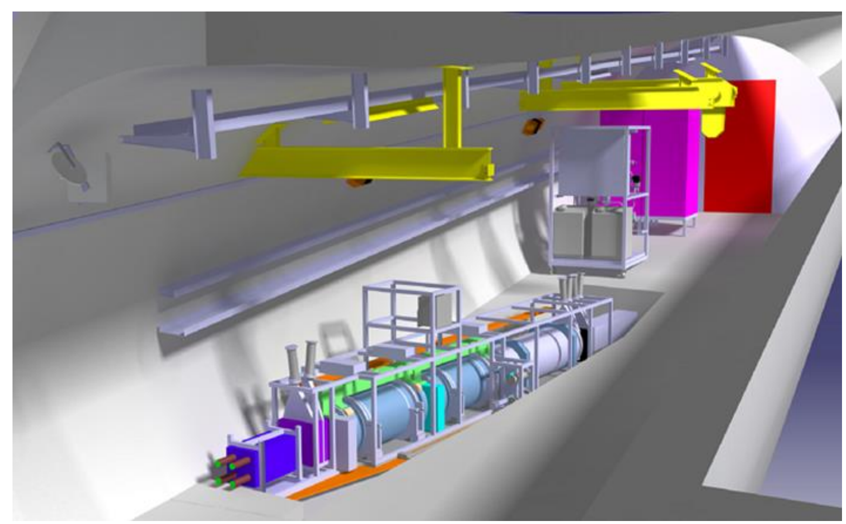
FASER experiment

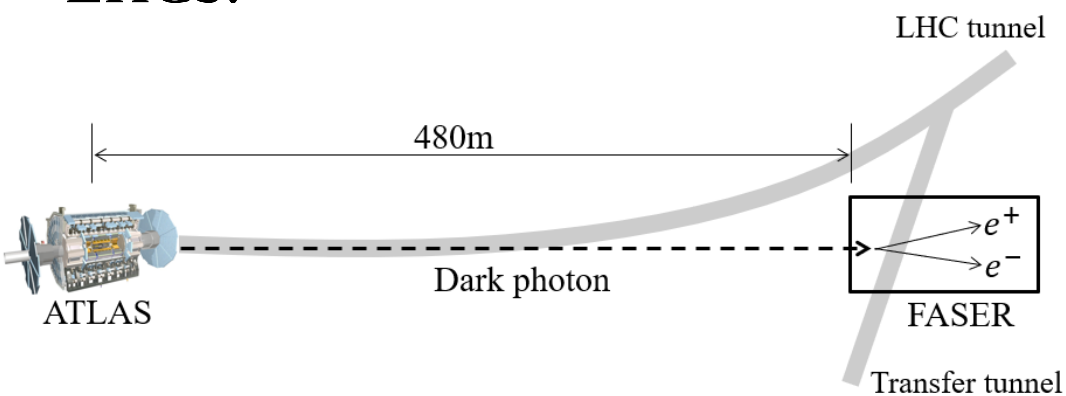
- FASER is a new experiment to "search for new long-lived particles" and "measure neutrino interactions", that are produced in pp collisions at ATLAS Interaction Point (IP), starting in 2022 (LHC Run 3).
- The detector is placed 480 m downstream of ATLAS IP, realizing the experiment in silent condition (only 500 Hz muon rate).
- This is the first experiment to utilize high cross-section of pp collisions in the forward region.



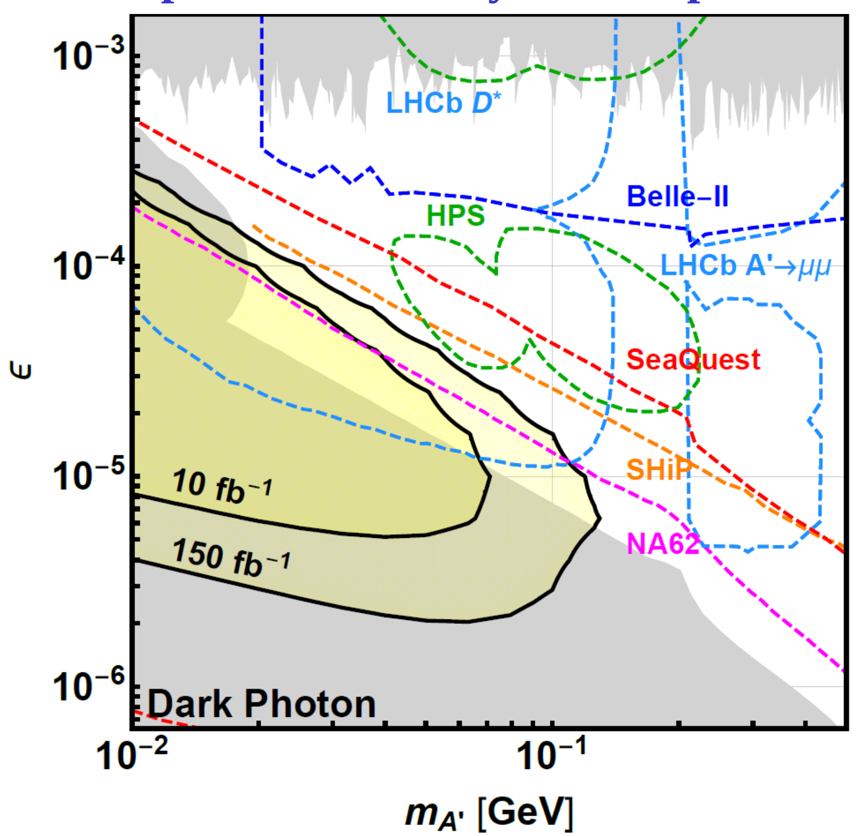


Search for new long-lived particles

- FASER searches for new long-lived particles with masses in MeV-GeV range (dark photon, ALP, right-handed neutrino, etc.).
- Benchmark search：Dark photon decaying into electron-position pairs
- New parameter region can be explored only with the first year in 2022 (~20 fb^{-1})
- Almost all region bellow 0.1 GeV can be covered together with Belle II and LHCb.

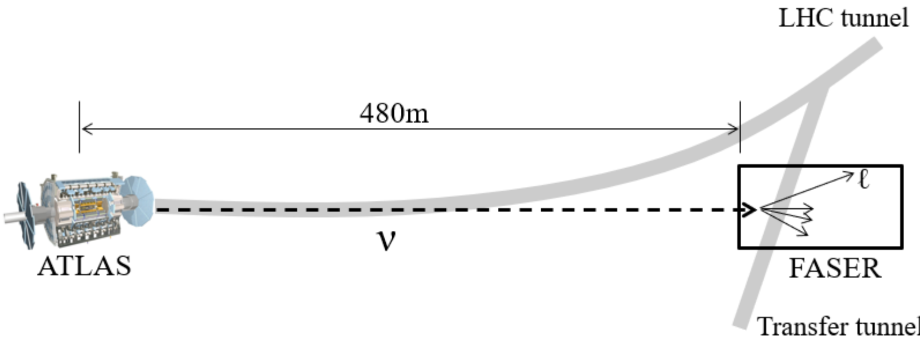


Expected sensitivity to dark photon



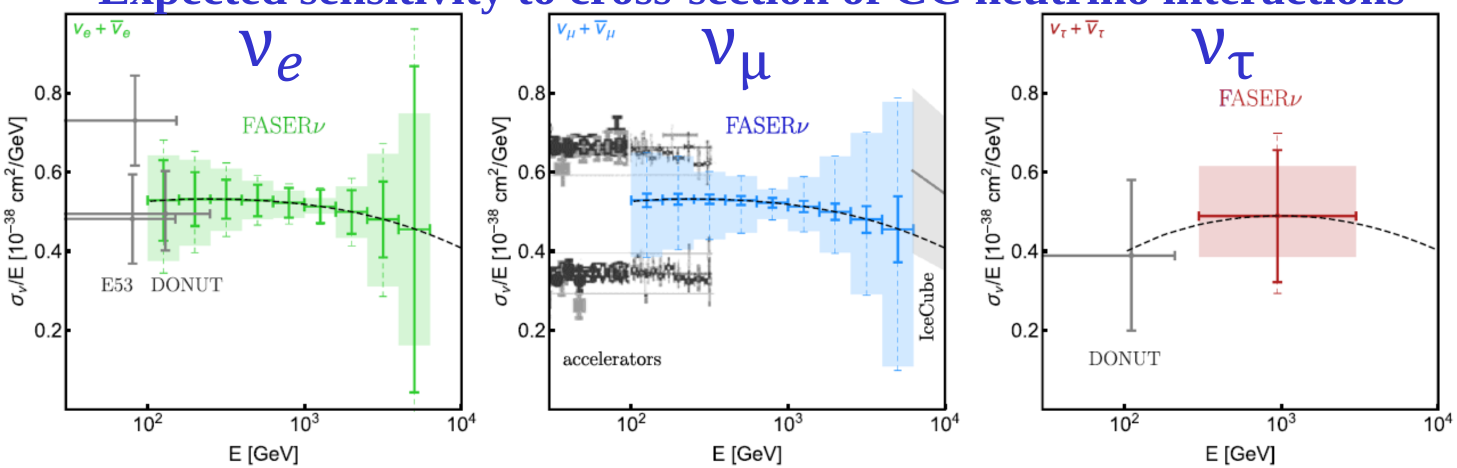
Measurement of CC neutrino interactions

- FASER measures neutrino interactions at TeV region not explored yet.
  - The first experiment to measure neutrinos created in beam collisions.
- All neutrino flavors can be identified in CC interaction.
- Cross-section of ν_μ and $\bar{\nu}_\mu$ will be measured separately with magnetic field of the spectrometer.



Expected sensitivity to cross-section of CC neutrino interactions

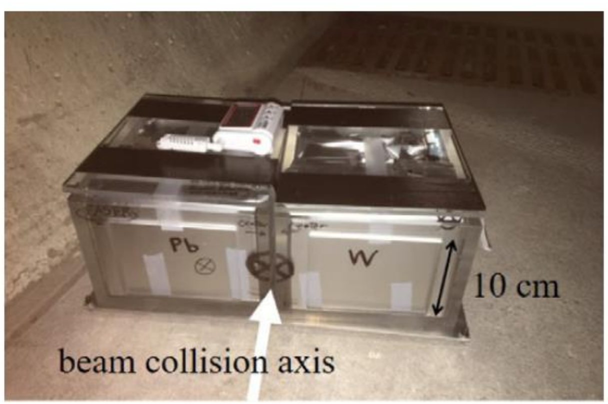
	CC events @150 fb^{-1}
$\nu_e + \bar{\nu}_e$	~1.3 x 10^3
$\nu_\mu + \bar{\nu}_\mu$	~2.0 x 10^4
$\nu_\tau + \bar{\nu}_\tau$	~20



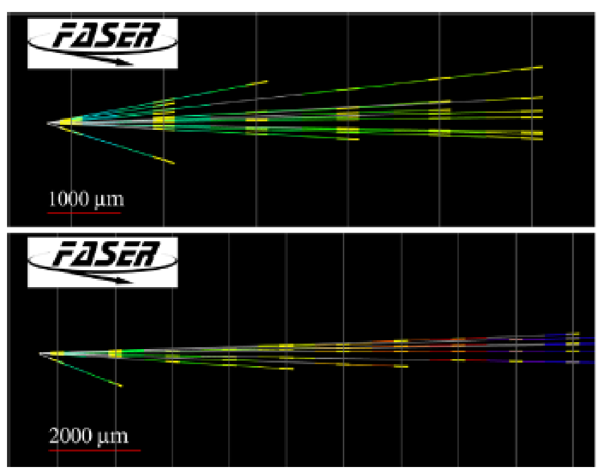
Neutrino measurement at pilot run

- Measurement of neutrino interactions was performed with 12.2 fb^{-1} of data, putting emulsion detector at the opposite side of FASER site with respect to ATLAS IP in 2018. [Phys. Rev. D 104, L091101 (2021)]
  - 101 1-mm thick tungsten (14 kg) and 120 0.5-mm thick Pb (15 kg)
- 6.1 CC neutrino event candidates (11.9 BG) with 2.7σ significance
  - First neutrino interaction candidate at LHC.

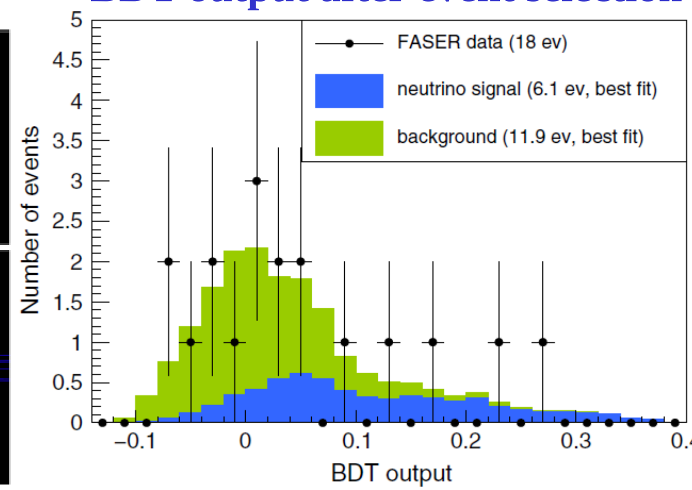
Pilot emulsion detector



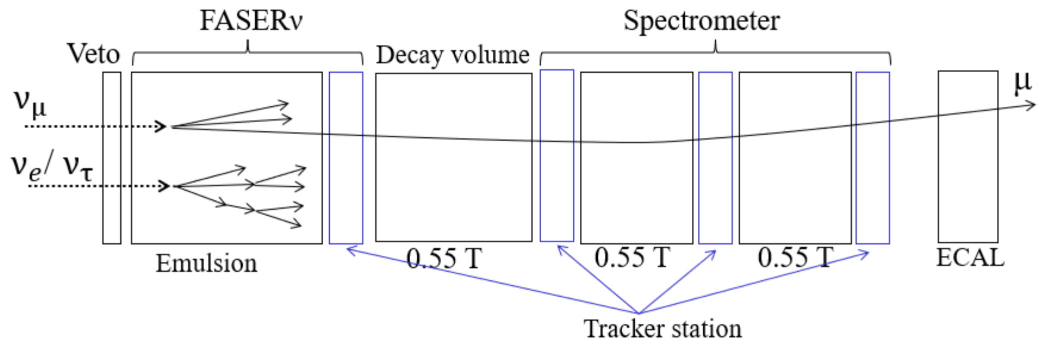
CC neutrino event candidates



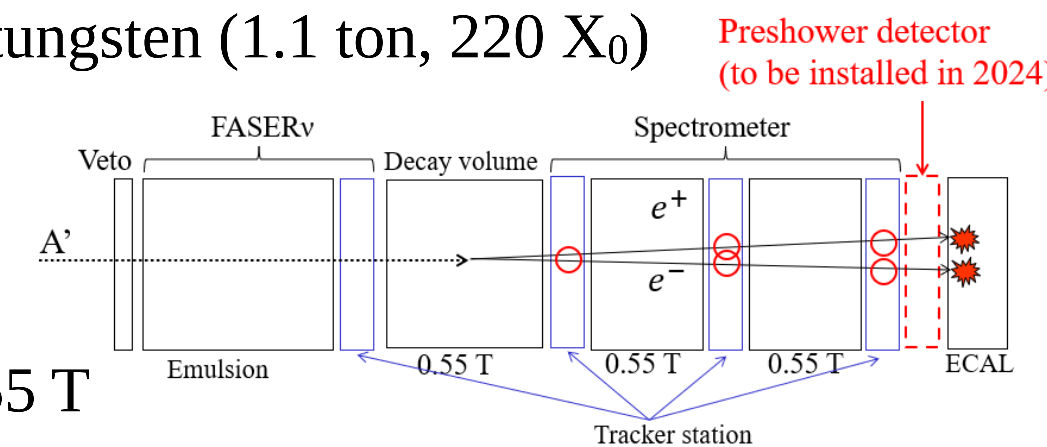
BDT output after event selection



FASER detector



- Scintillator veto/trigger
- FASERν (neutrino detector)
  - 770 emulsion + 1-mm thick tungsten (1.1 ton, 220 X_0)
  - Silicon strip tracker 0



- Decay volume with 1.5 m / 0.55 T
- 2-m spectrometer with 0.55 T
  - Silicon strip tracker 1/2/3
- Preshower detector (will be installed in 2024)

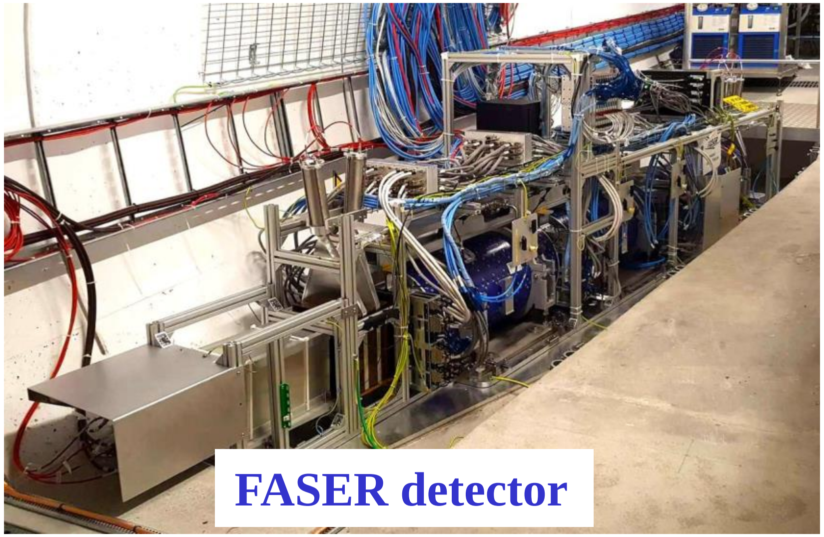
Today's topic

- ECAL (Electro-magnetic CALorimeter)

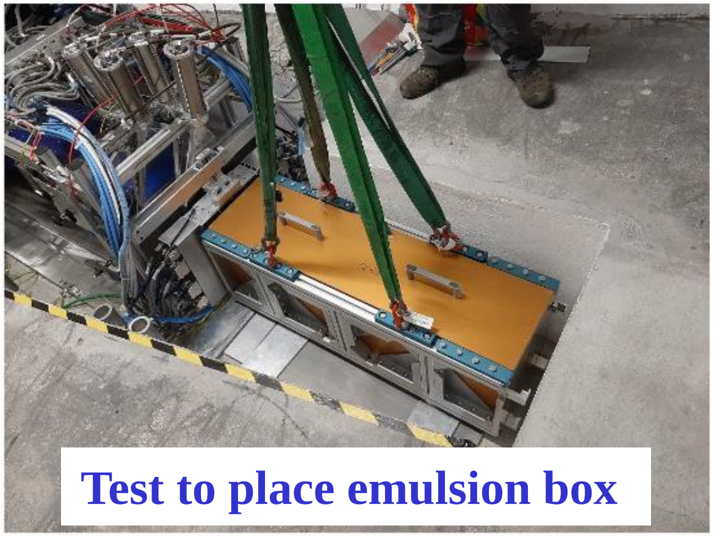
Installation of FASER detector

- Development of detector components started in the winter of 2018.
- The detector was assembled and test operation was performed on surface in the winter of 2020.
- The detector except for FASERν was installed in the experimental site in the spring of 2021.
- FASERν tracker was installed, and test to place the emulsion box was performed in November 2021.

The construction is ongoing rapidly!



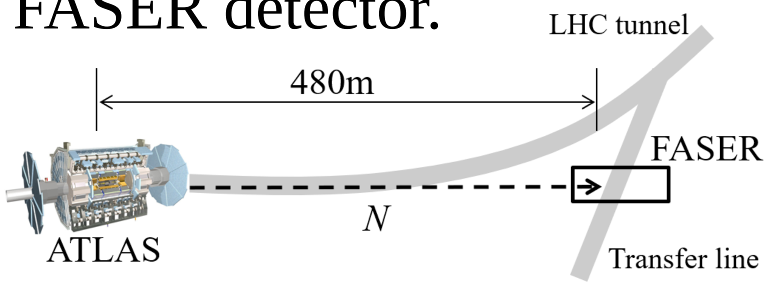
FASER detector



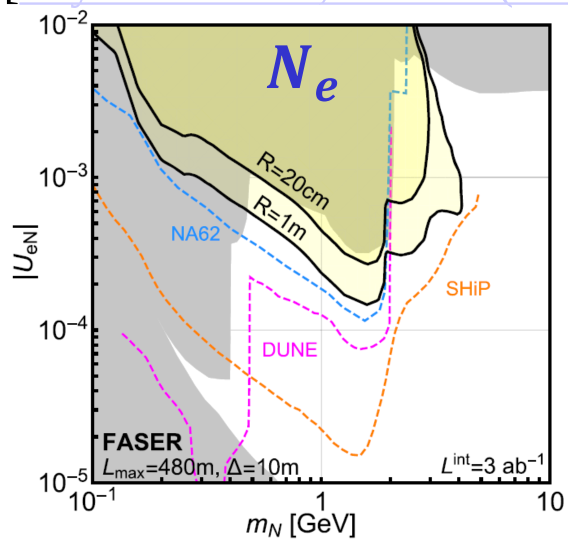
Test to place emulsion box

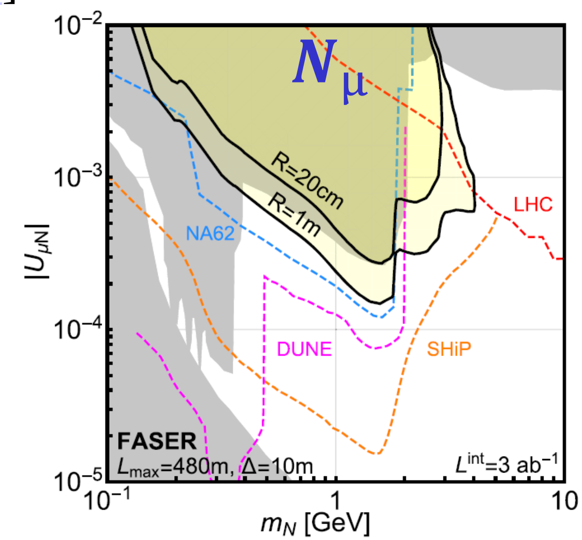
Search for right-handed neutrinos

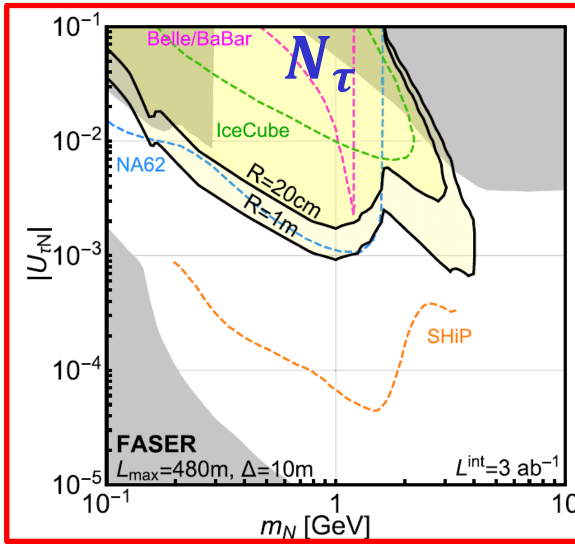
- Right-handed neutrino (N) can explain reason of small mass of neutrinos in Sea-Saw mechanism. → The search is strongly motivated.
- N's are produced from B/D meson decays, etc. created in pp collisions at LHC and their decays are detected with FASER detector.
- In FASER, N_τ has the largest sensitive region and is the most interest.



[Phys. Rev. D97, 095016 (2018)] **Expected sensitivity to right-handed neutrinos**



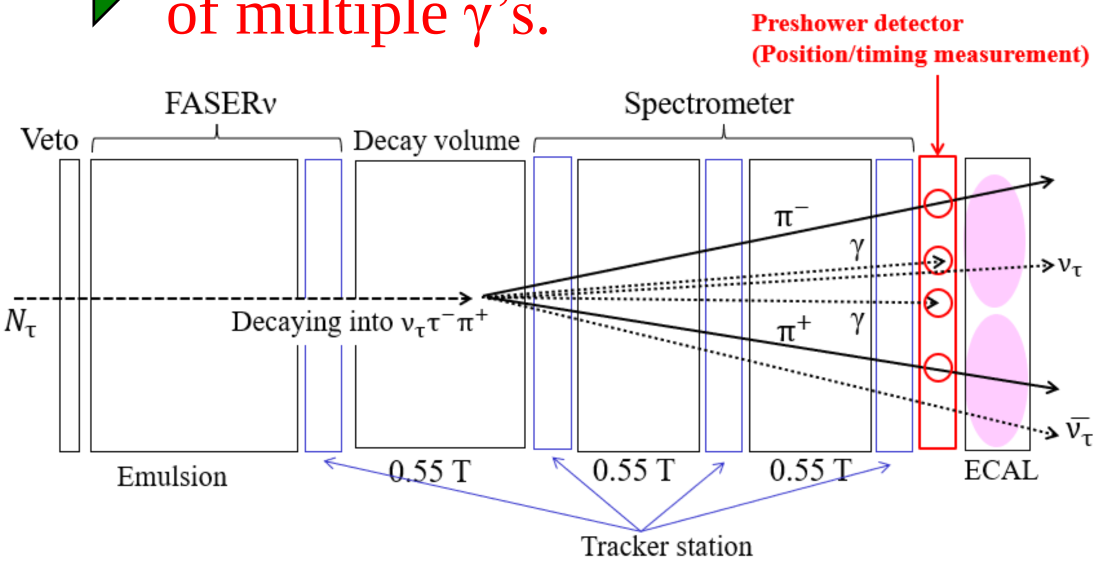


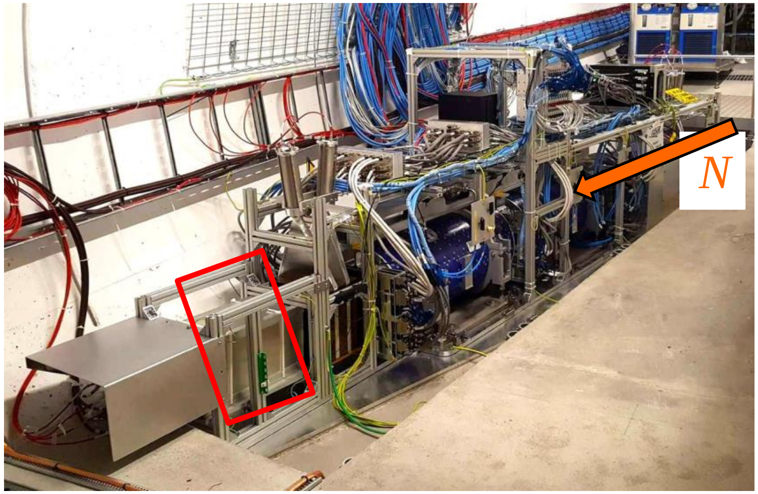


Detection of N_τ with preshower detector

- N_τ decays into different final states, depending on its mass.
  - 「$\tau^-\pi^+$」($>m_\tau + m_\pi$), 「$\tau^- K^+$」 ($>m_\tau + m_K$), 「$\tau^-\rho^+$」 ($>m_\tau + m_\rho$)
- τ in the final state has to be identified to know the neutrino flavor.
  - 「$\tau^- \rightarrow \bar{\nu}_\tau \pi^- \pi^0 (\pi^0 \rightarrow \gamma\gamma)$」 is the most promising decay mode.
- FASER-ECAL cannot separate multiple γ's without segmentation.

Preshower detector will be developed to enable detection of multiple γ's.



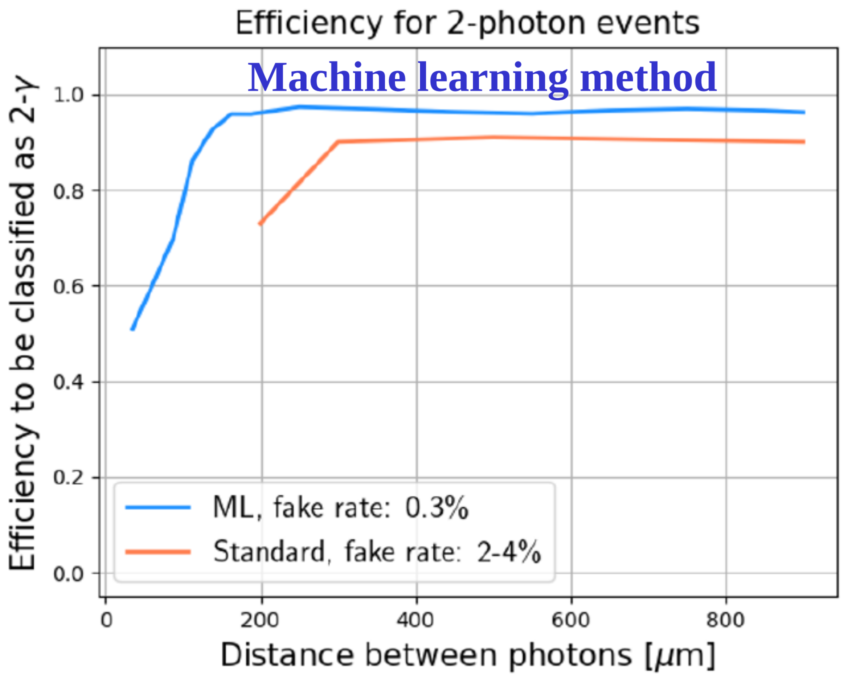


Requirement to preshower detector

- Requirements are determined to detect 2 γ's from ALP (Axion Like Particle) decay.
- The pixel size should be <200 um.
- The time resolution should be ~100 ps to separate the signal and BG back-scattered from ECAL.

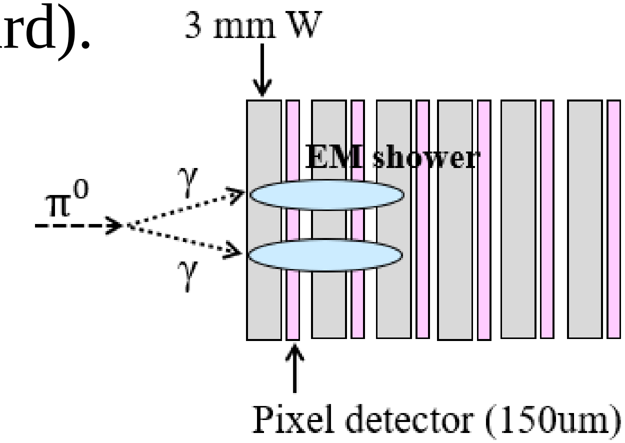
SiGe-BiCMOS pixel sensor will be used for preshower detector.

Detection efficiency of ALP v.s. 2-γ separation



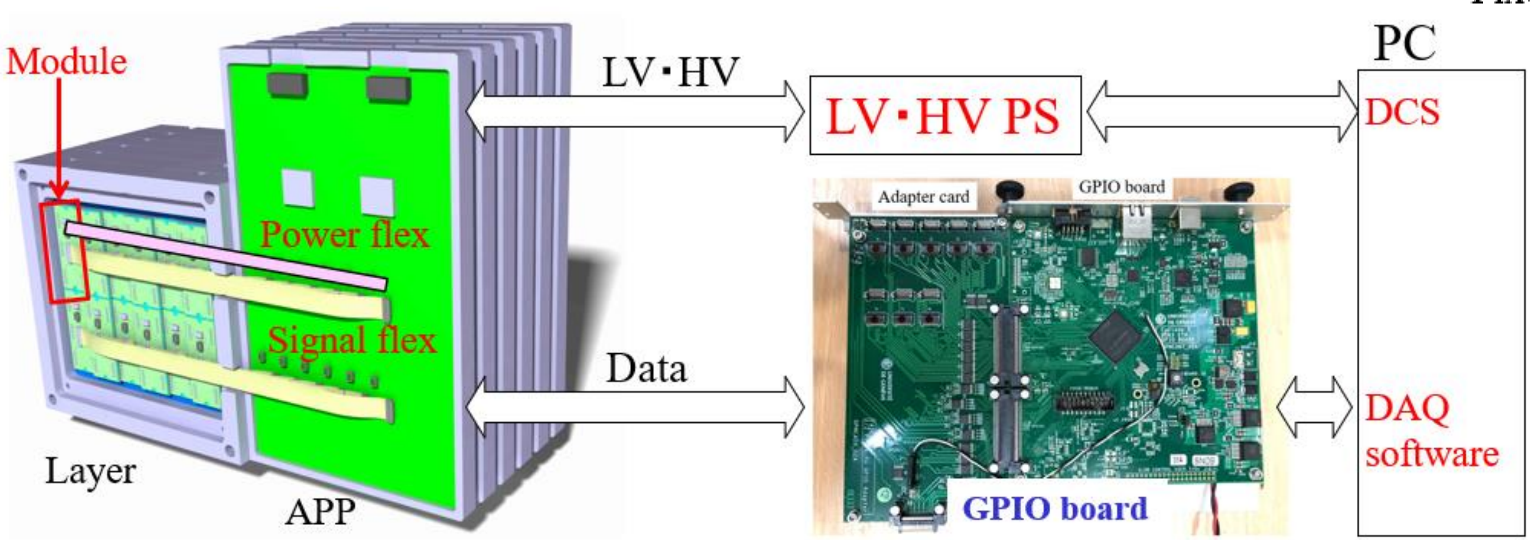
Preshower detector

- 6 layers of tungsten and SiGe-BiCMOS pixel sensors.
- Active Patch-Panel (APP) squeezes data from each layer with 12 pixel modules and sends it to DAQ board (GPIO board).



Japanese group

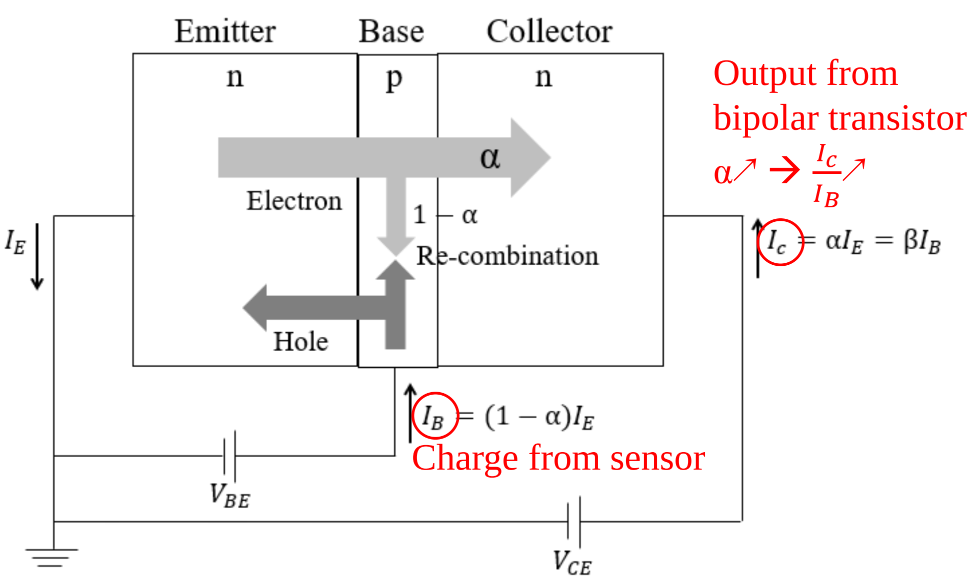
- Module flex, signal/power flex, APP
- DAQ software
- Power system (LV･HV PS and DCS)

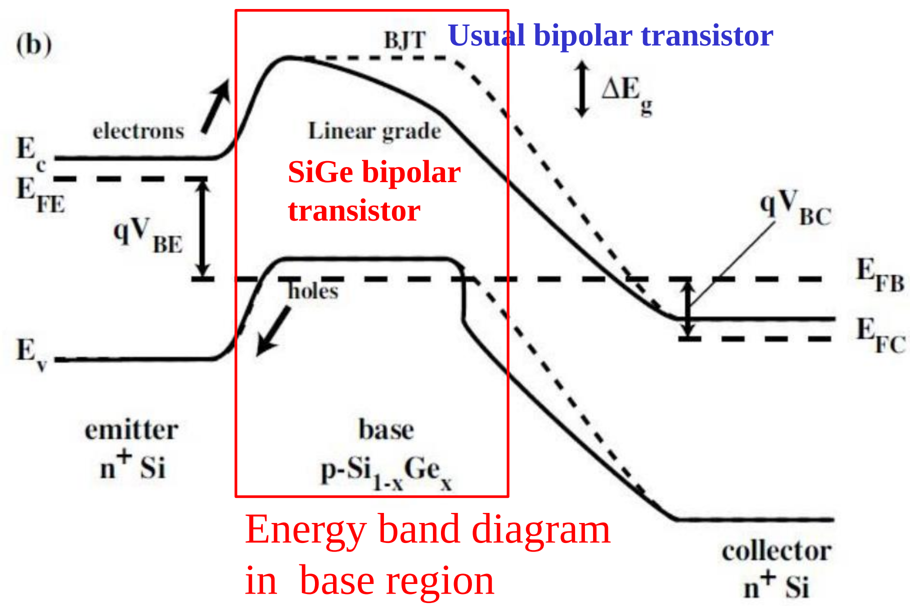


SiGe bipolar transistor

- Bipolar transistor works as amplifier whose gain (I_c/I_B) is proportional to transmission rate of electrons in the base region (α).
- SiGe heterojunction can create the electric field in the base and accordingly increase α (diffusion → drift). → Higher gain
  - Heterojunction: a junction of semiconductors with different band gap

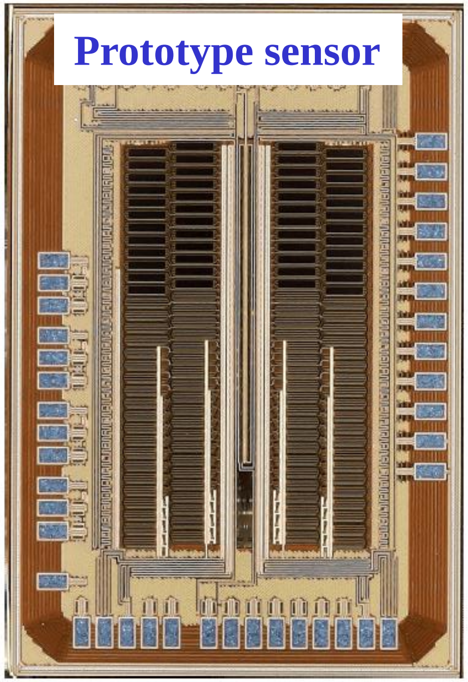
→ Higher gain of SiGe bipolar transistor realizes better time resolution.



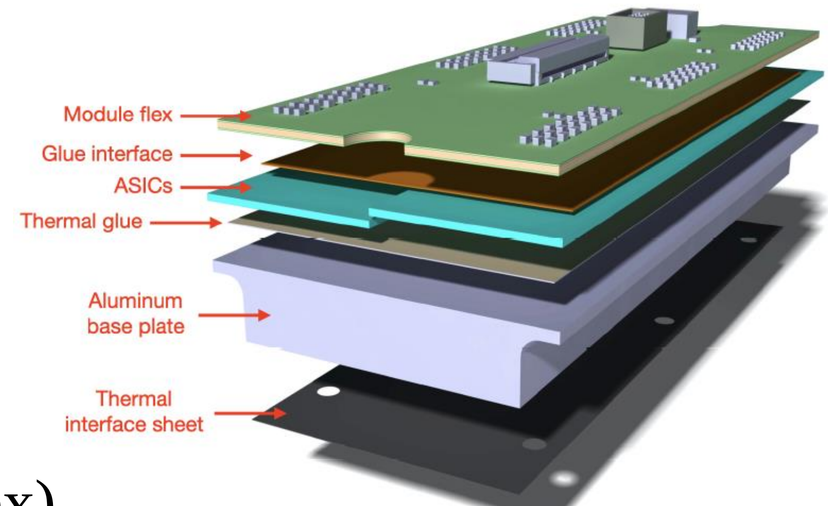


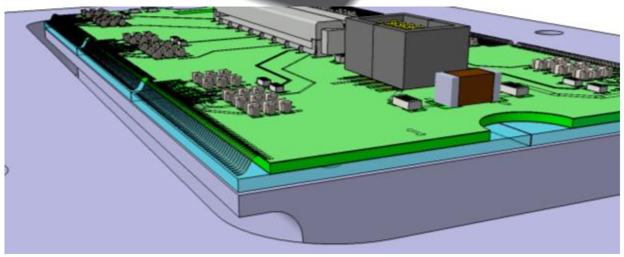
Pixel sensor for Preshower detector

- Preshower detecdtor uses a monolithic pixel sensor with SiGe-BiCMOS technology developed in University of Geneva.
  - Bump-bond is not necessary to connect a sensor and FE chips.
- SG14G2 130 nm IHP process (IHP Microelectronics)
- SiGe bipolar transistor is implemented in ASIC part with SiGe-BiCMOS technology.
- Sensor size：2.2 × 1.5 cm^2
- 208 × 128 pixels with 65 μm octagonal shape
- 4-bit flash-ADC for each 16 × 16 pixels (super-pixel)
- 7-bit TDC for each super-column (8 super-pixel)
- Expected time resolution：<300 ps

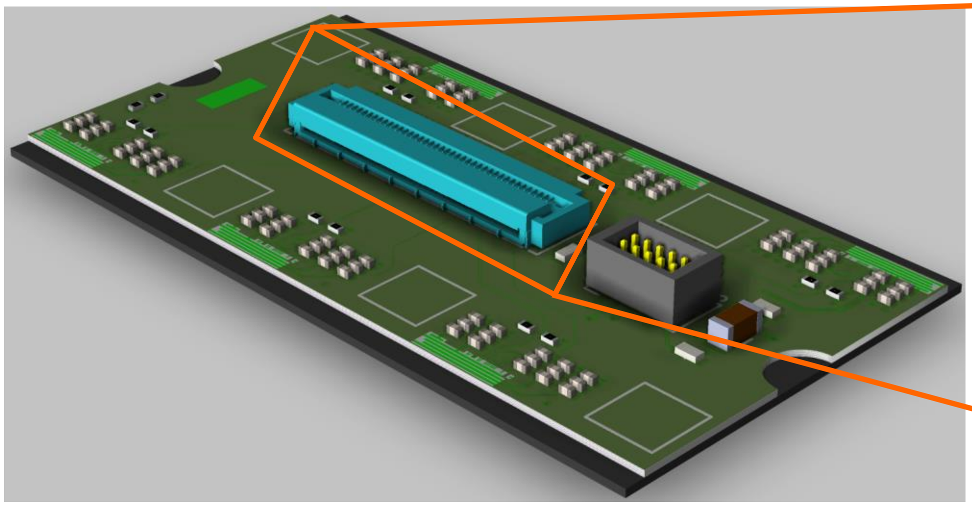


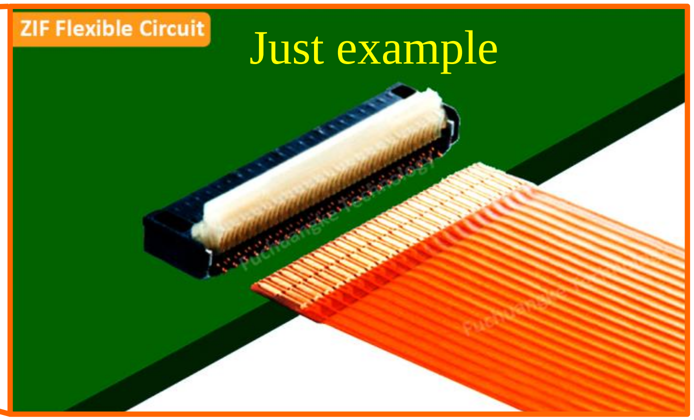
Pixel module



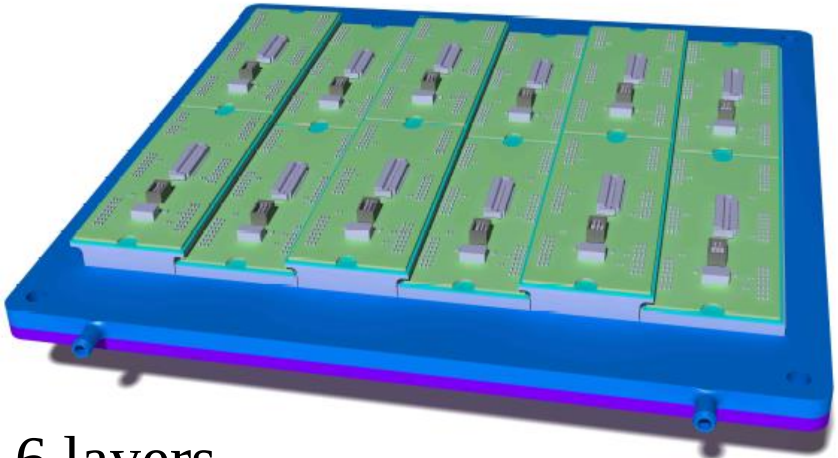


- 6 pixel sensors per module
- Size： 6.7 × 3.1 cm^2
- The sensor and 6-layer flex (module flex) are connected with wire-bonding.
  - UniGe and Japan develop the module flex.
- ZIF type connector is used for the signal connector to cope with the limited space between neighboring layers (~3 cm).



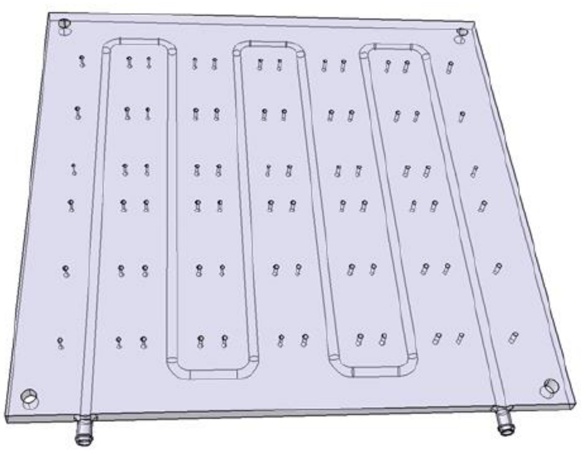


Pixel layer

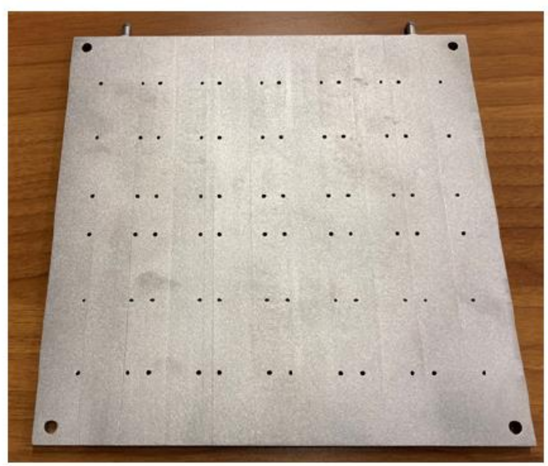


- 12 modules per layer
- Size : 20 × 20 cm^2 (5 mm thickness)
- The preshower detector will consist of 6 layers.
- Al alloy (AlSi10Mg) is used for water cooling with 15 degree.
  - The cooling pipe is embedded with 3D print.
  - Cooling capability per layer: 48W (including 30% contingency)

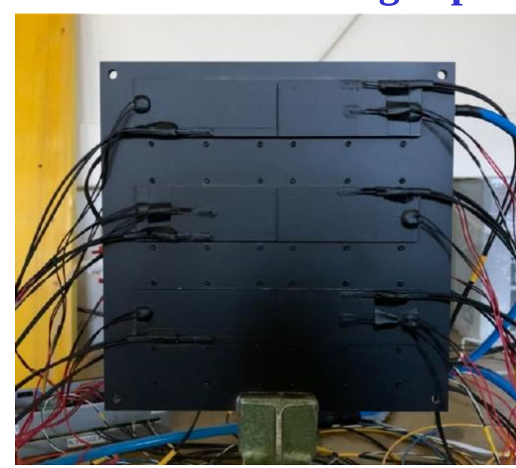
Conceptual design of cooling plate



Cooling plate prototype



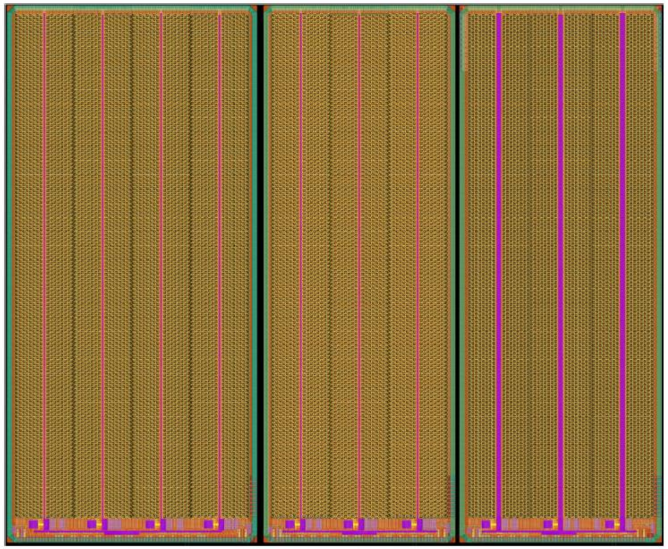
Test to evaluate cooling capability



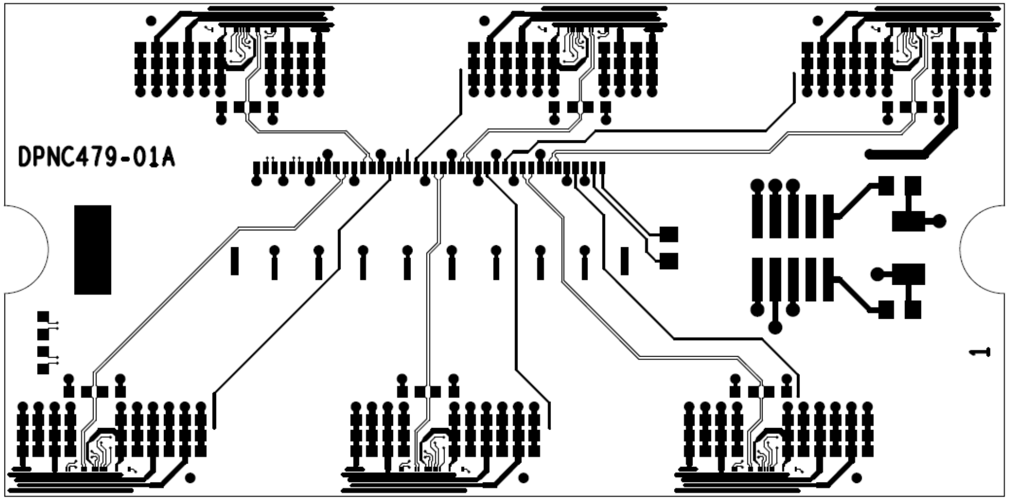
Pre-production & real detector

- About 5 pre-production modules will be developed in April 2022.
  - All PCBs are produced in Japan and will be delivered on March.
- Production of the sensors for the real detector will start in the winter of 2022.
- The detector will be assembled/constructed in 2023 and installed in the spring of 2024.

Layout of pre-production sensor



Layout of module flex for pre-production



Summary

- FASER is a new experiment to search for new long-lived particles and measure neutrino interactions, that are produced in pp collisions at ATLAS IP, starting in 2022.
  - All detector components except for emulsion was installed until November 2021.
  - The commissioning is ongoing to start the experiment at the beginning of LHC Run 3.
- The preshower detector with SiGe-BiCMOS monolithic pixel sensor will be installed in the spring of 2024 for identification of multiple γ's.
  - It will enable to search for right-handed neutrinos and ALP.
  - SiGe-BiCMOS technology can realize excellent time resolution with high amplifier gain.
- The prototype pixel module will be developed in April 2022
- The real detector will be constructed in 2023 and installed in 2024.