Search for Sub-millicharged Particles at J-PARC

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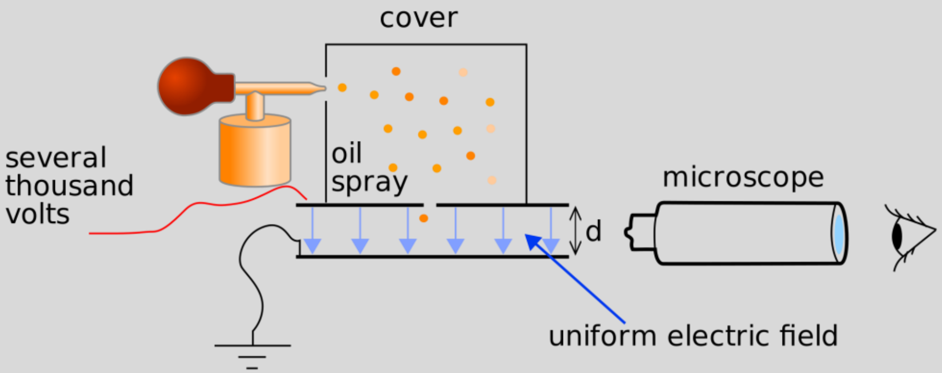
ICHEP 2022 Bologna

Motivation

Oil drop experiment apparatus

Robert Millikan



Simplified scheme of Millikan's oil drop experiment

From https://en.wikipedia.org/wiki/Oil_drop_experiment

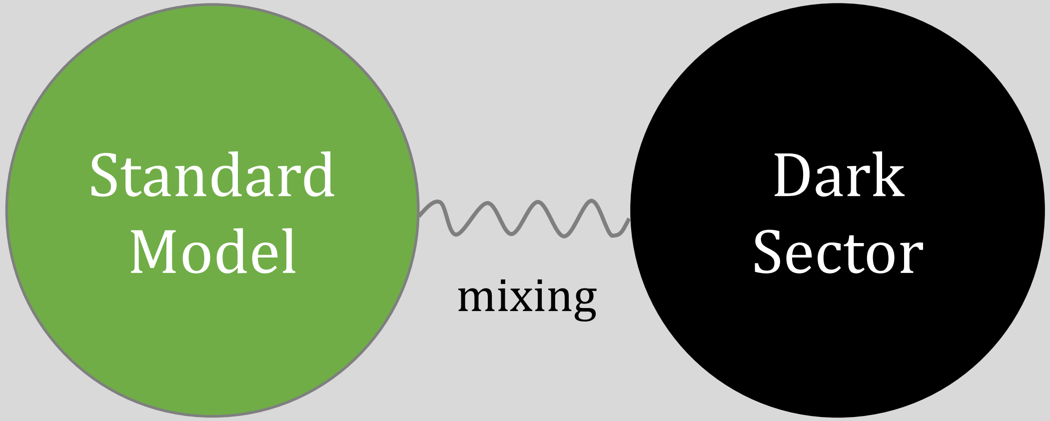
- Since its discovery in Robert Millikan's oil drop experiment, electric charge quantization is a longstanding question in particle physics.

Q. Should be electric charge quantized?

- Existence of millicharged particles (mCPs, χs) $\rightarrow$ BSM

How to understand mCPs in the SM paradigm?

Millicharged Particles

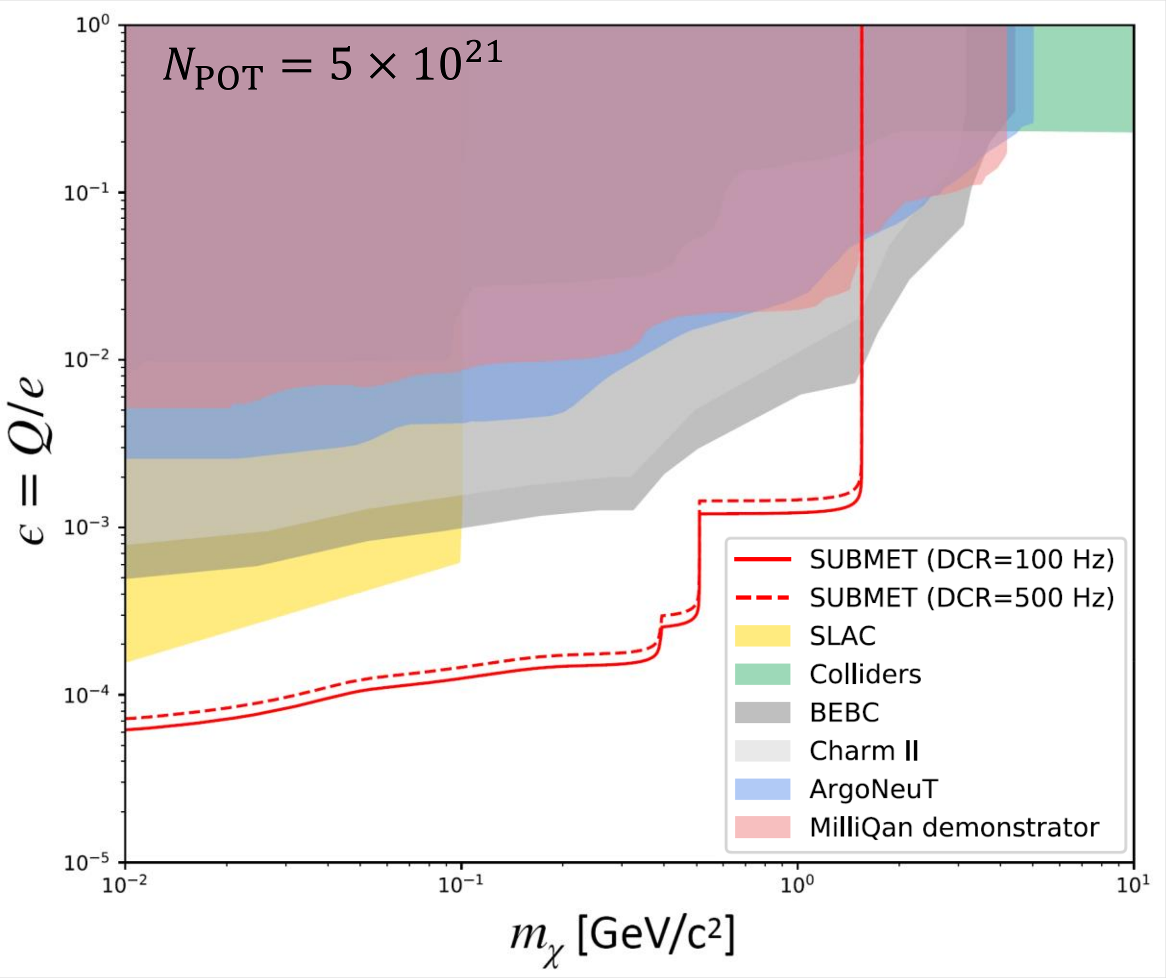


- One of the simple models: introducing an extra U(1) in dark sector. It allows arbitrary charge.
- A new U(1) with massless dark-photon (A') and dark-fermion (ψ)
- A' and B can kinetically **mix** (size of mixing κ)
- Charge of ψ is proportional to mixing (κ)

$$\mathcal{L}_{\text{dark sector}} = -\frac{1}{4}A'_{\mu\nu}A'^{\mu\nu} + i\bar{\psi}(\not{\partial} + ie'\not{A}' + iM_{\text{mCP}})\psi - \frac{\kappa}{2}A'_{\mu\nu}B^{\mu\nu}$$

$$\mathcal{L} = \mathcal{L}_{\text{SM}} - \frac{1}{4}A'_{\mu\nu}A'^{\mu\nu} + i\bar{\psi}(\not{\partial} + ie'\not{A}' + i\boldsymbol{\kappa e'}\not{B} + iM_{\text{mCP}})\psi$$

Current Reach

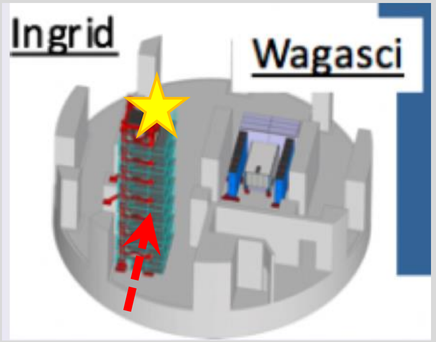


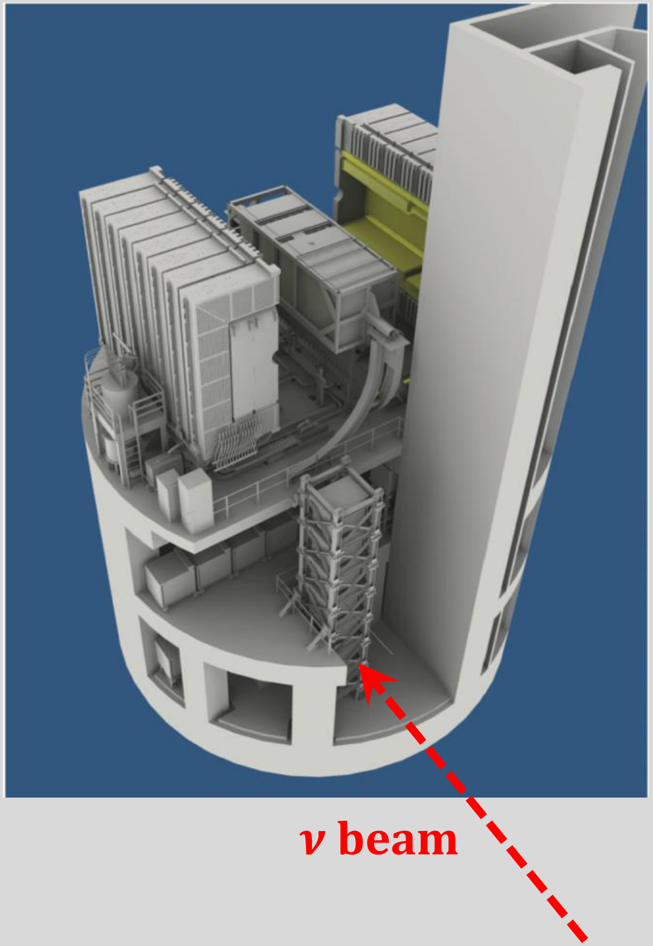
- Various searches for millicharged particles (χs) so far.
- $Q < 2 \times 10^{-4} e$ and $Q < 10^{-3} e$, $m_\chi > 0.1$ GeV/c^2 largely not probed yet.
- **SUB-M**illicharge **E**xperimen**T** (SUBMET): new experiment targeting small charge & low mass region.

Q. Where & how?

J-PARC

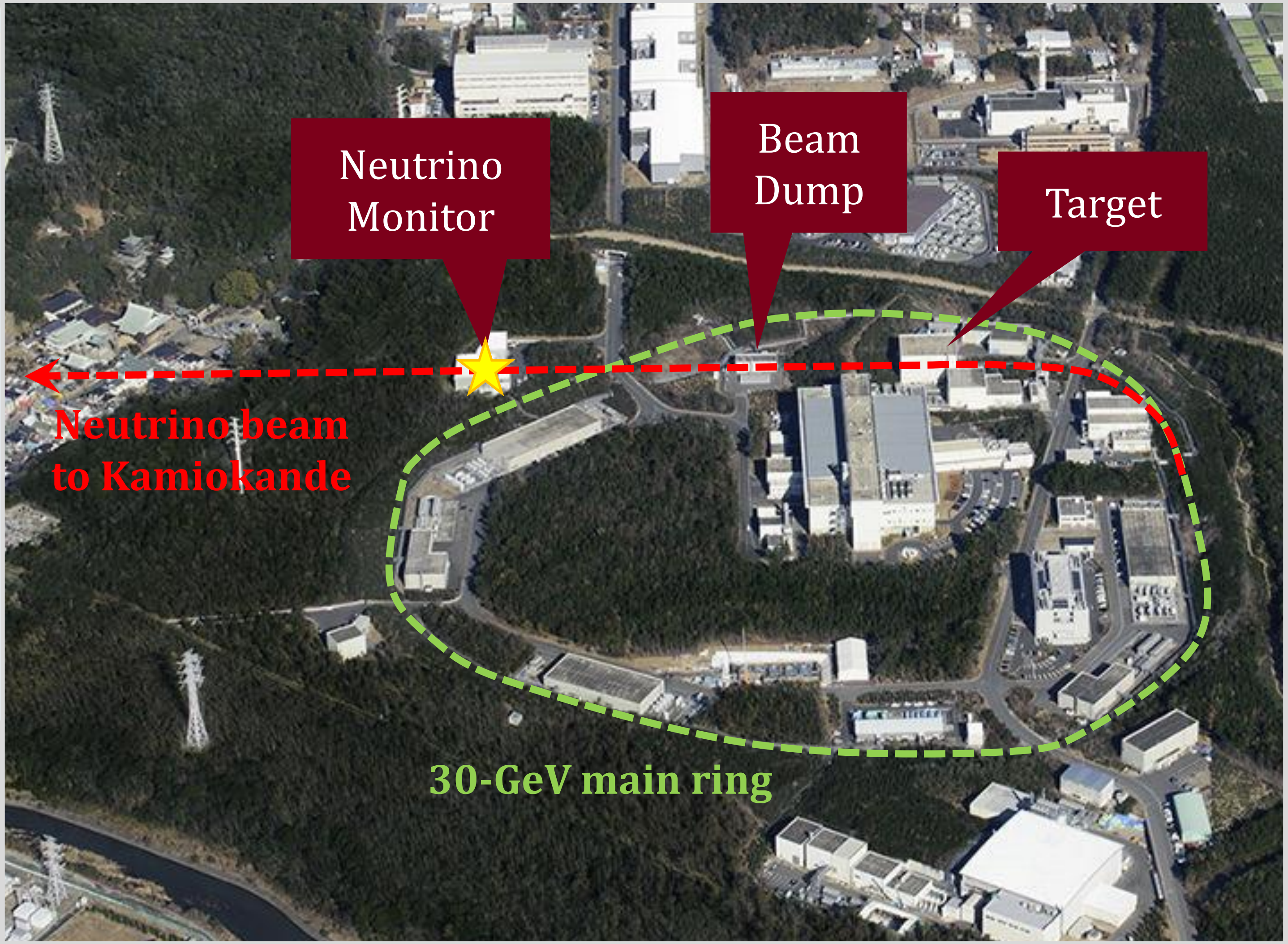
From PTEP 2012, 02B005





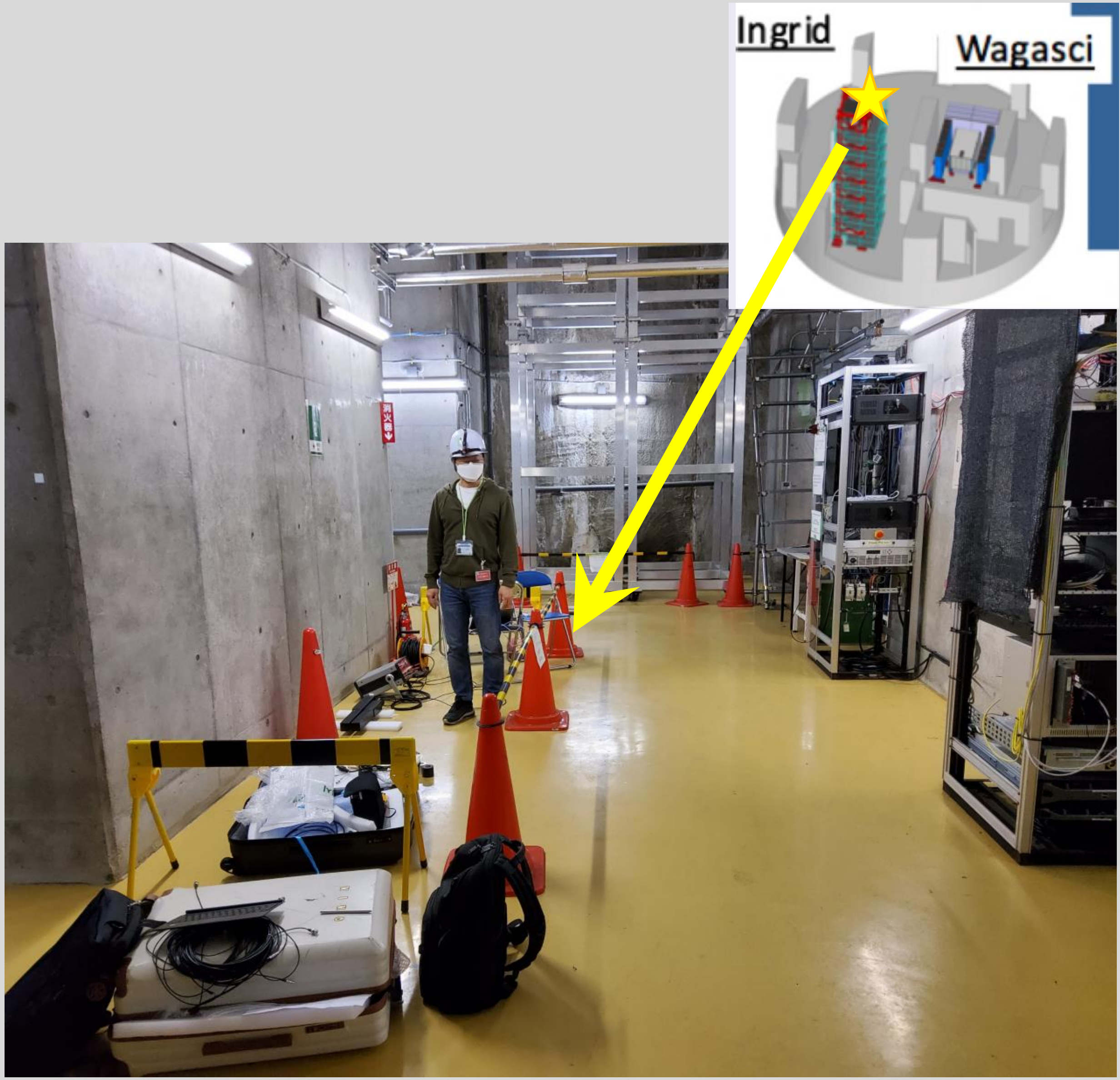
From
https://indico.phys.vt.edu/event/34/contributions
/708/attachments/581/746/HallsjoMIND.pdf

From https://j-parc.jp/c/en/about/outline.html

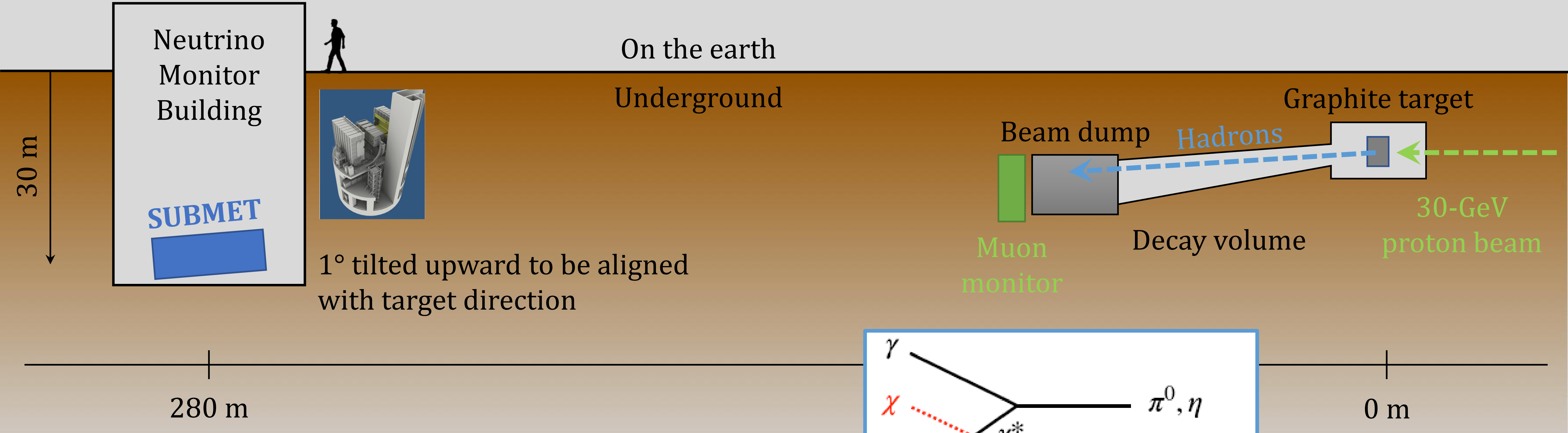


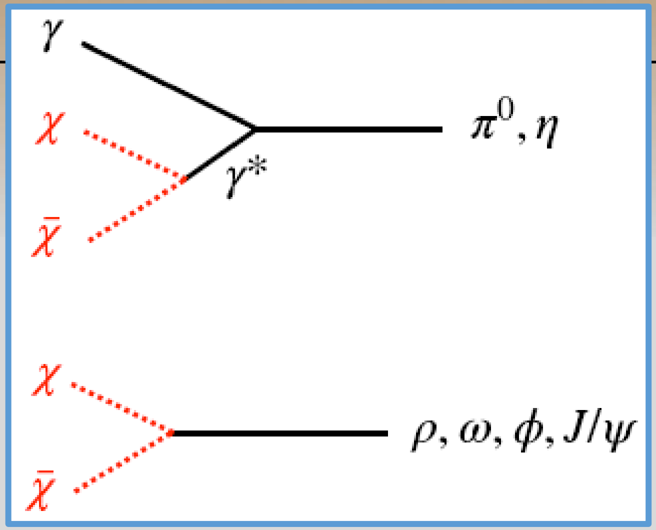
Experimental Site

- Our experimental site is on the bottom floor (~ 30 m underground) of the Neutrino Monitor (NM) building.
- **1 m × 4 m** for the detector itself
- Power, network, and beam-related trigger signal are available.
- We visited the site and checked environment in May 2022.



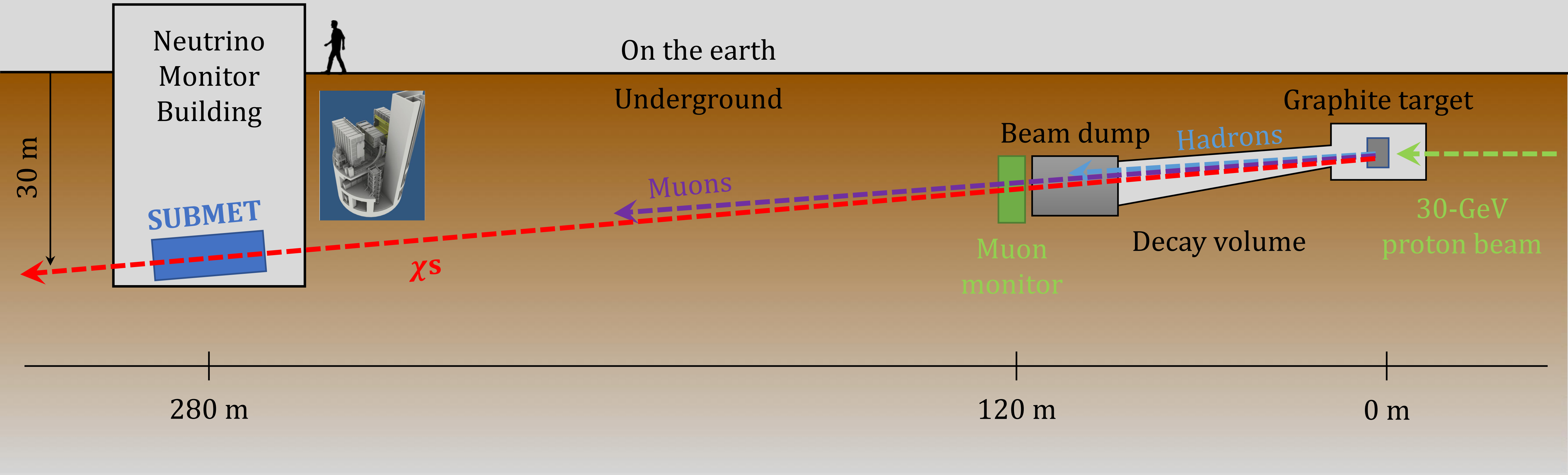
Basic Idea of χ Detection





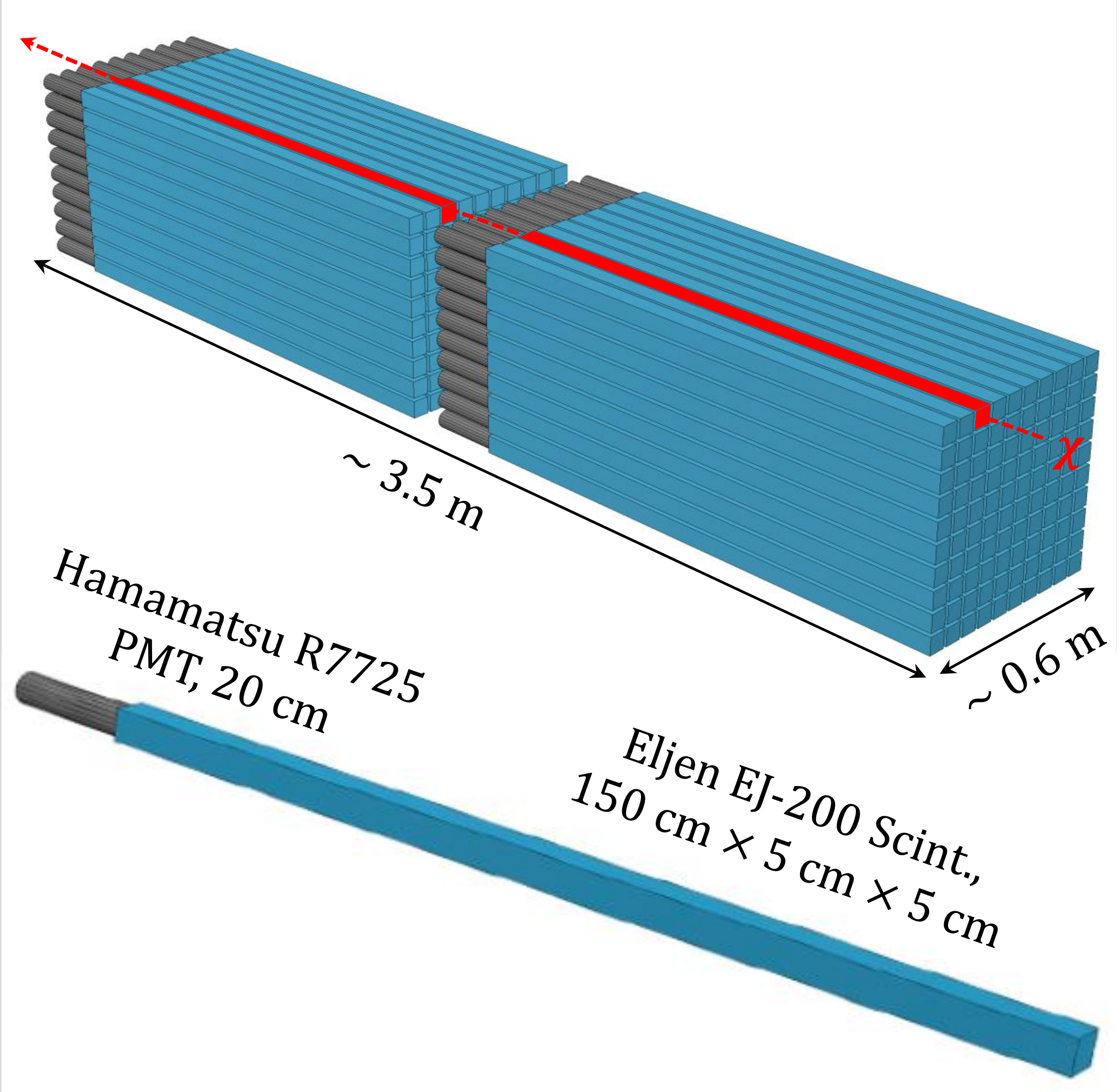
- Protons hit the target and produce hadrons.

Basic Idea of χ Detection



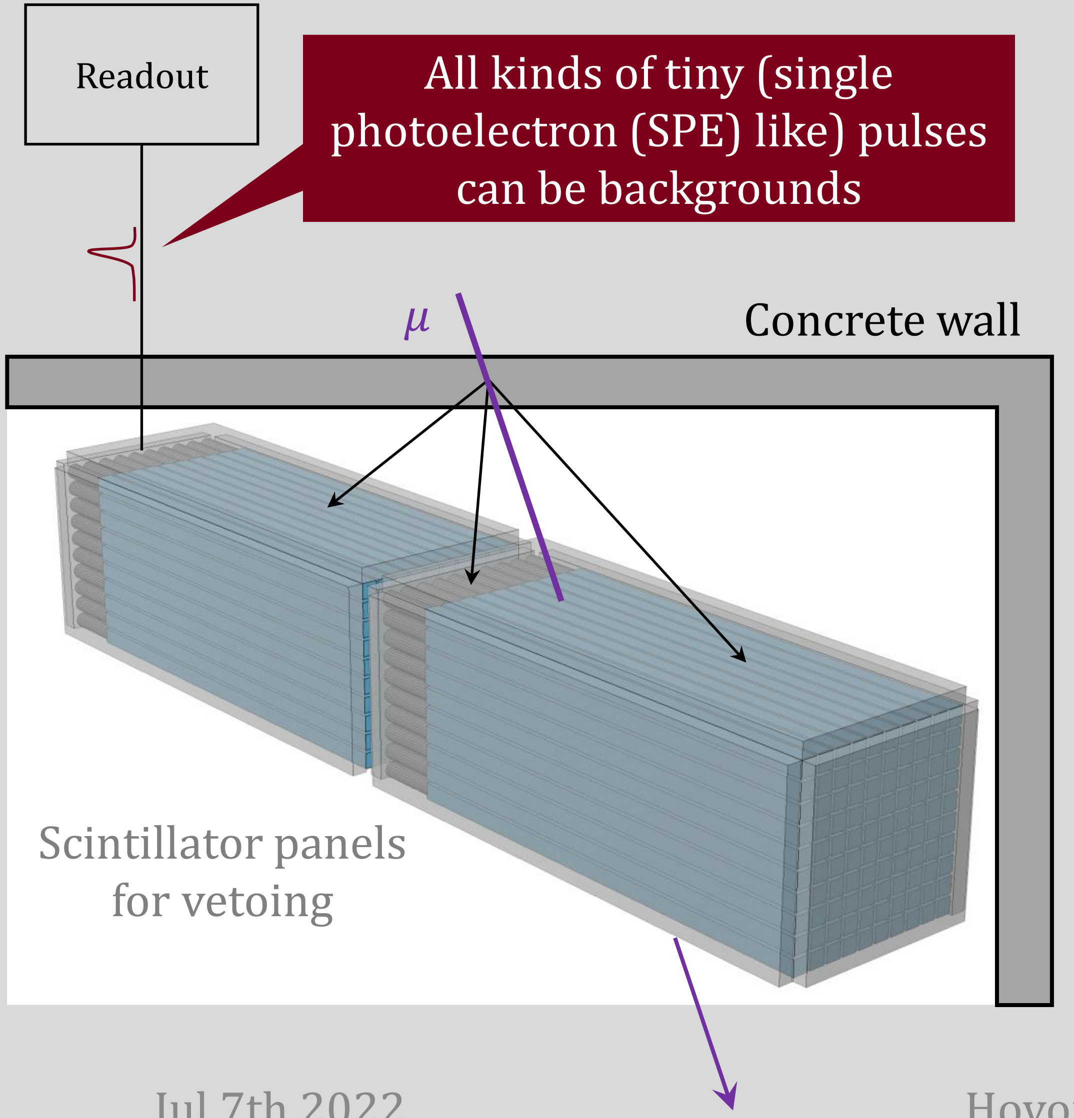
- Hadrons stop in the Beam Dump.
- Muons lose the entire energy in sand (5 MeV/cm) before reaching NM building.
- χs reach the detector. (Energy loss for χs with $q = 10^{-3}e$ is < 0.1 MeV.)

Detector Concept



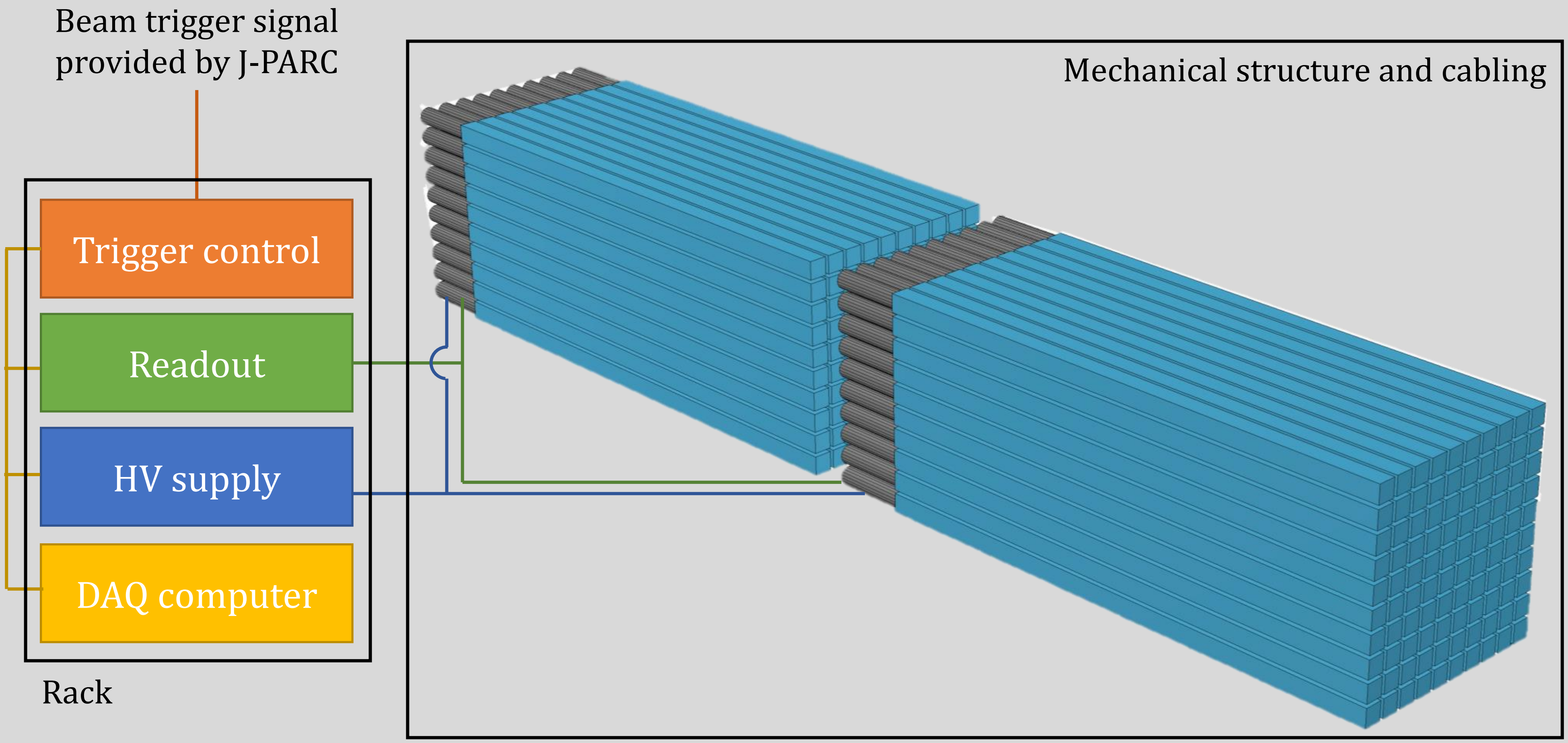
- Use **long scintillator bars** to enhance the production of photons by χs inside.
  - For small Q, it becomes single-photon detection.
- Stack scintillators to increase areal coverage and use **two layers** to control backgrounds.
- Align the two layers such that a χ goes through them for a short period of time.
- Require small time interval between hits ($\Delta t \sim 10$ ns) in the two layers and use the timing of proton beam
  - They help reduce backgrounds significantly

Expected Background Sources

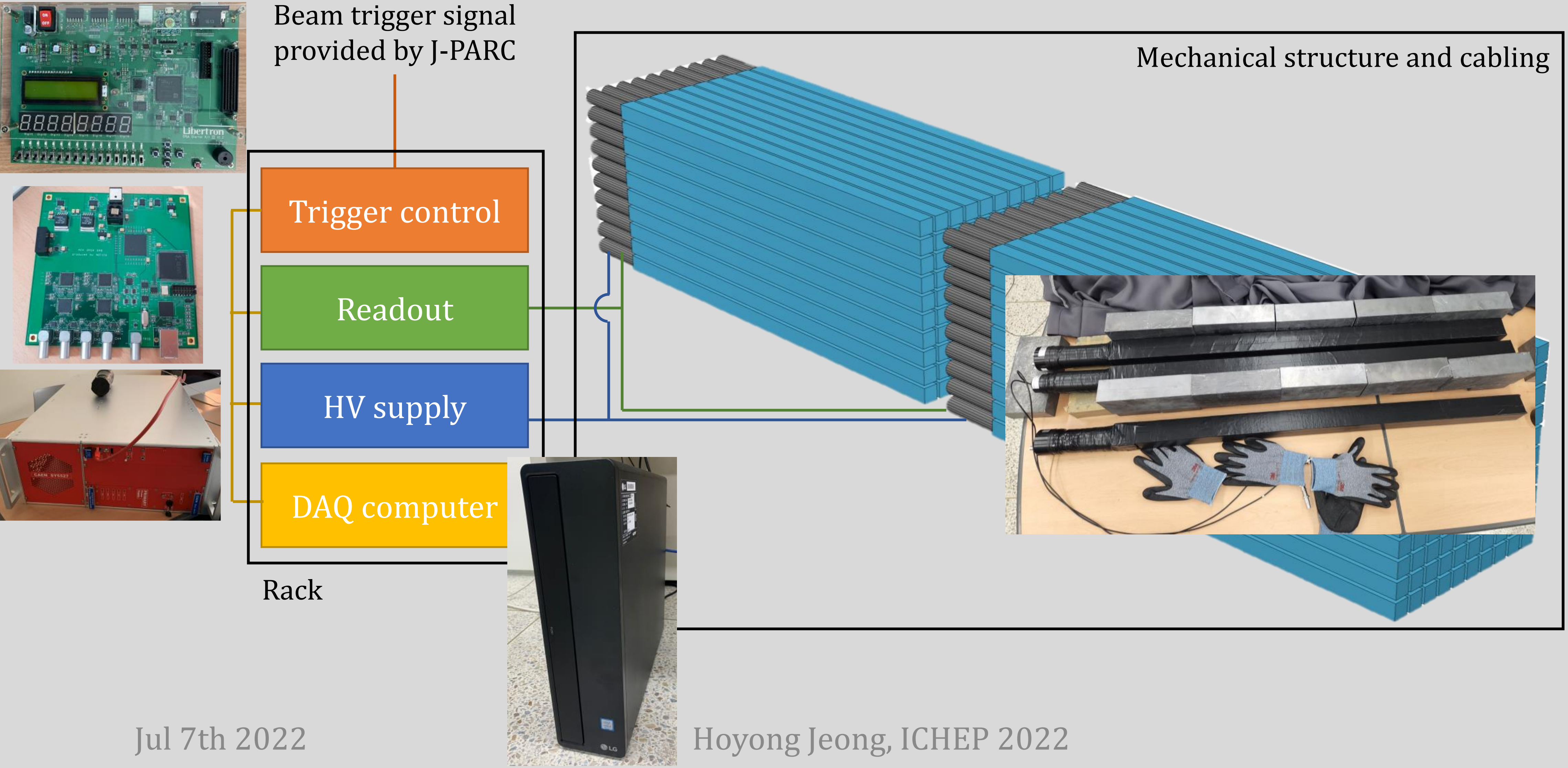


- Detector backgrounds
  - Random coincidence due to PMT dark current is expected to be the main background source ($O(10)$/year for dark count rate (DCR) = 500 Hz)
- Beam-induced backgrounds
  - Neutrino interactions with scintillator: negligible
  - Muons from neutrino-building interaction: scintillator plates
- Other sources
  - Cosmic shower, neutrons from surrounding structure, etc
- Running Geant4 simulation to understand background situation better
  - **Ex) $O(10^{-2})$ events per year in case of cosmic background**
- Non-beam-induced backgrounds can be estimated using no-beam data

Detector System

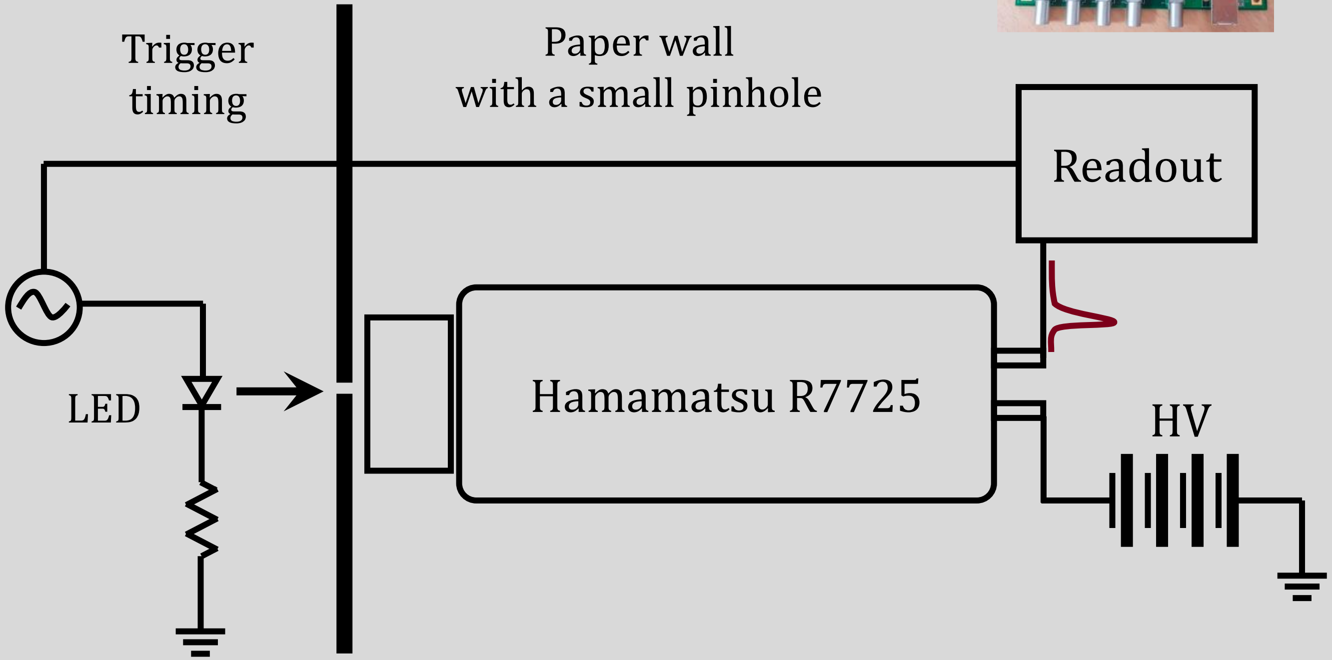


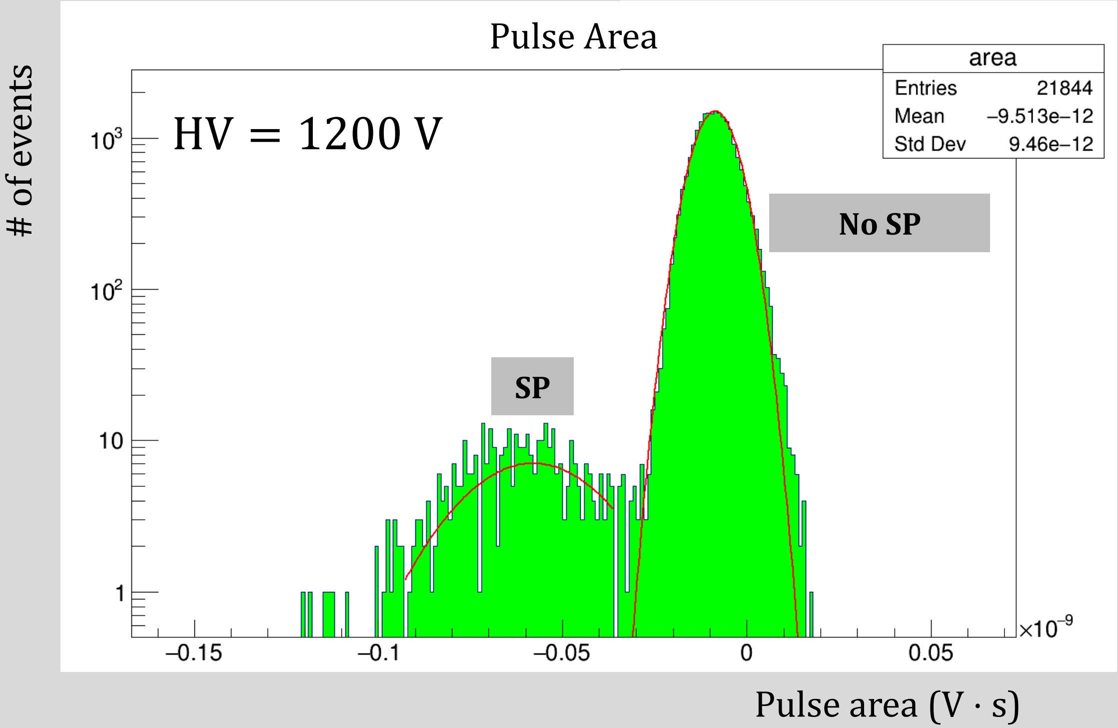
Detector System: Prototype



Study w/ Prototype: SP

Homemade (NOTICE Korea)
DRS4-based readout board ▶

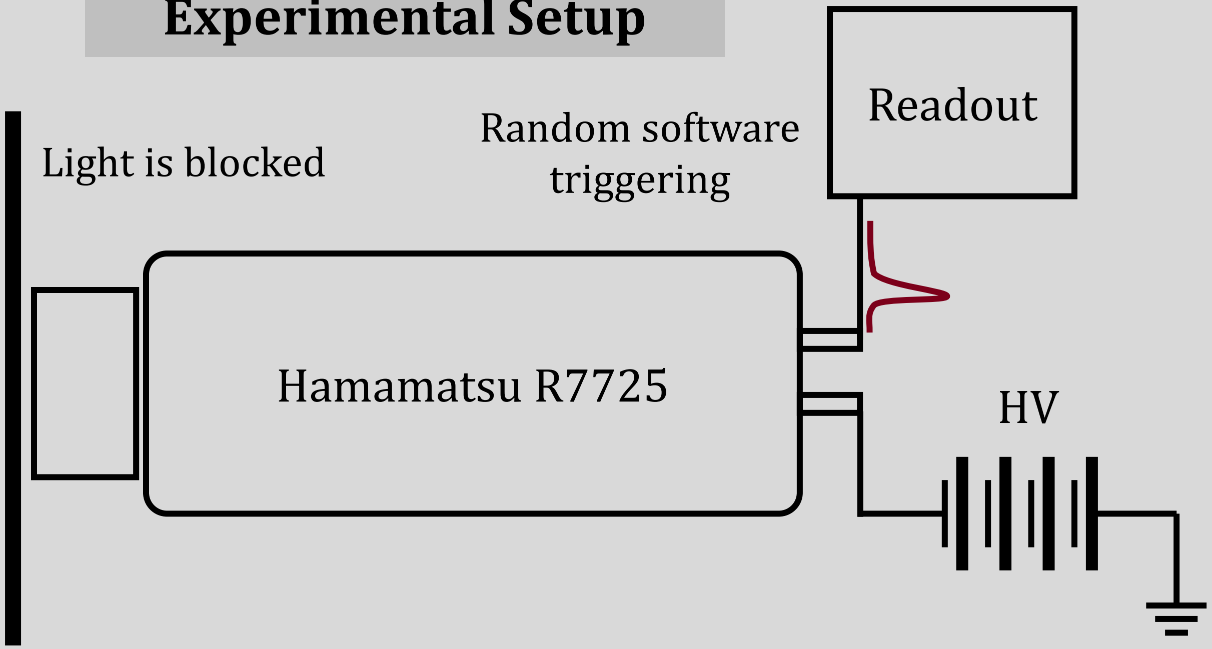


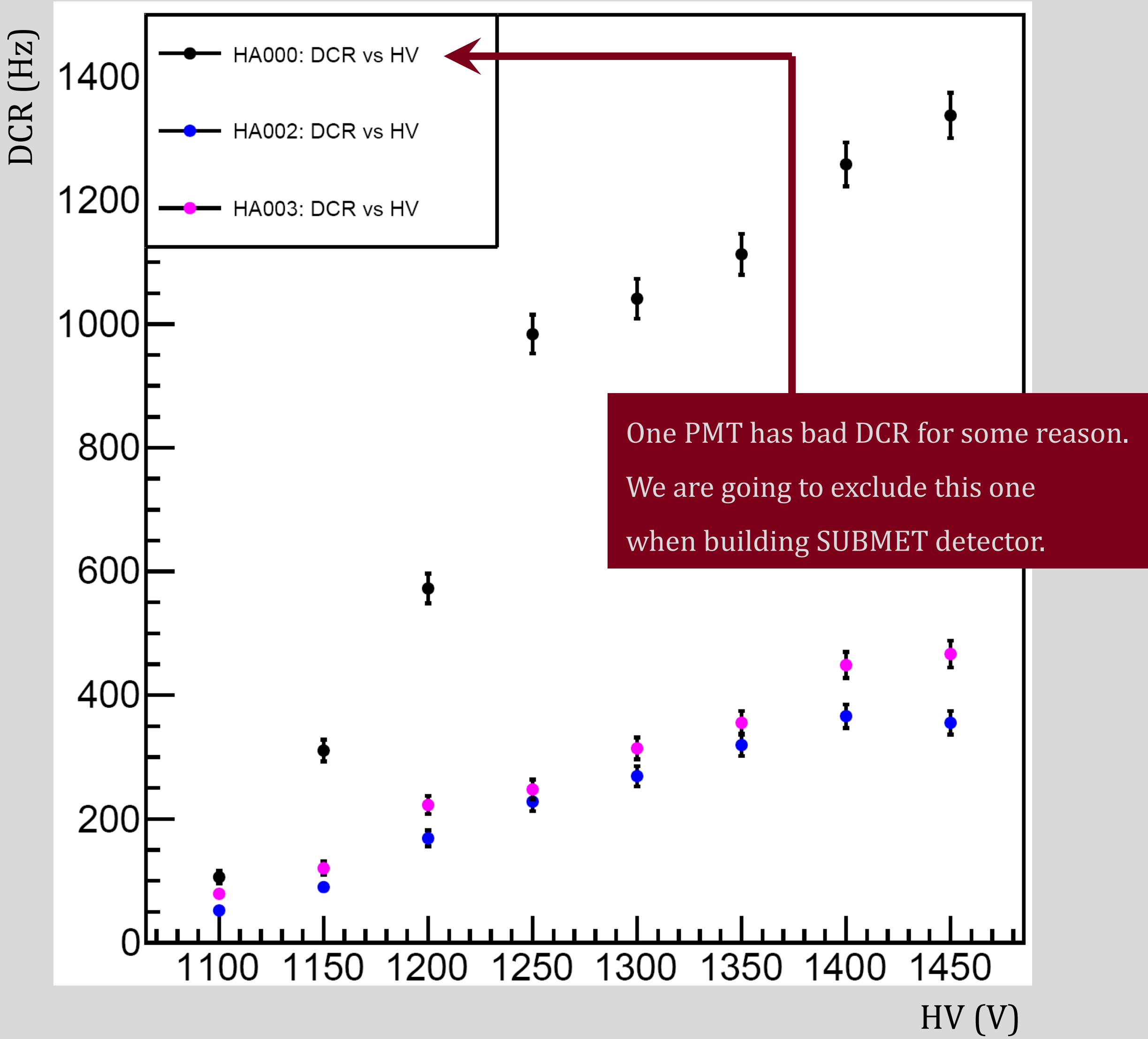


PMT can detect single-photon (SP) signal and 1200 ~ 1300 V is enough to distinguish the signal.

Study w/ Prototype: DCR

Experimental Setup



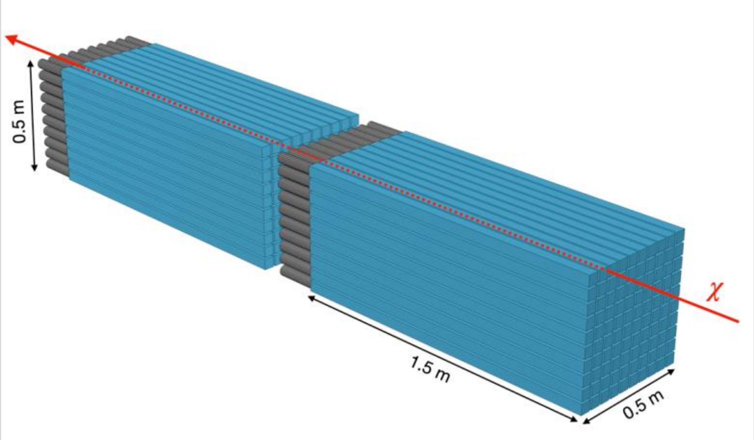


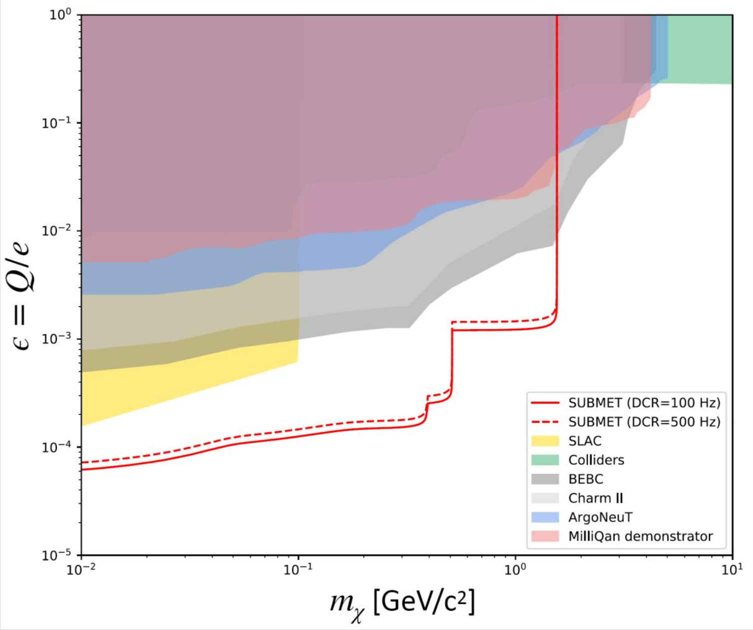
▶ Measurement result vs. HV. Three PMTs (Hamamatsu R7725) have been tested. The measurement was done in **room temperature**.

Each run has **100,000 triggered events**.

Number of pulses has been counted and converted to the unit of rate.

Summary and Outlook





- Proposal to search for millicharged particles using 30-GeV proton beam at J-PARC
  - Unique opportunity to probe small charge ($\sim 10^{-3}\ e$) & low mass ($m_\chi <$ 1.6 GeV/c^2) millicharged particles
- Received stage-I status in April 2022, and aim to get stage-II next winter
- Testing prototype to understand/optimize detector system
- Visited J-PARC in May 2022 to understand the experimental environment better

Plan	2022	2023	2024
Module assembly	Stage-I approved		
Detector installation			
Data-taking			

The Team

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Martin Gastal

Other Proposals/experiments

➢ There are proposals at LHC (milliQan, FORMOSA) and at FNAL (FerMINI), which are sensitive to higher mass regime
  → complimentary