Search for millicharged particles at J-PARC

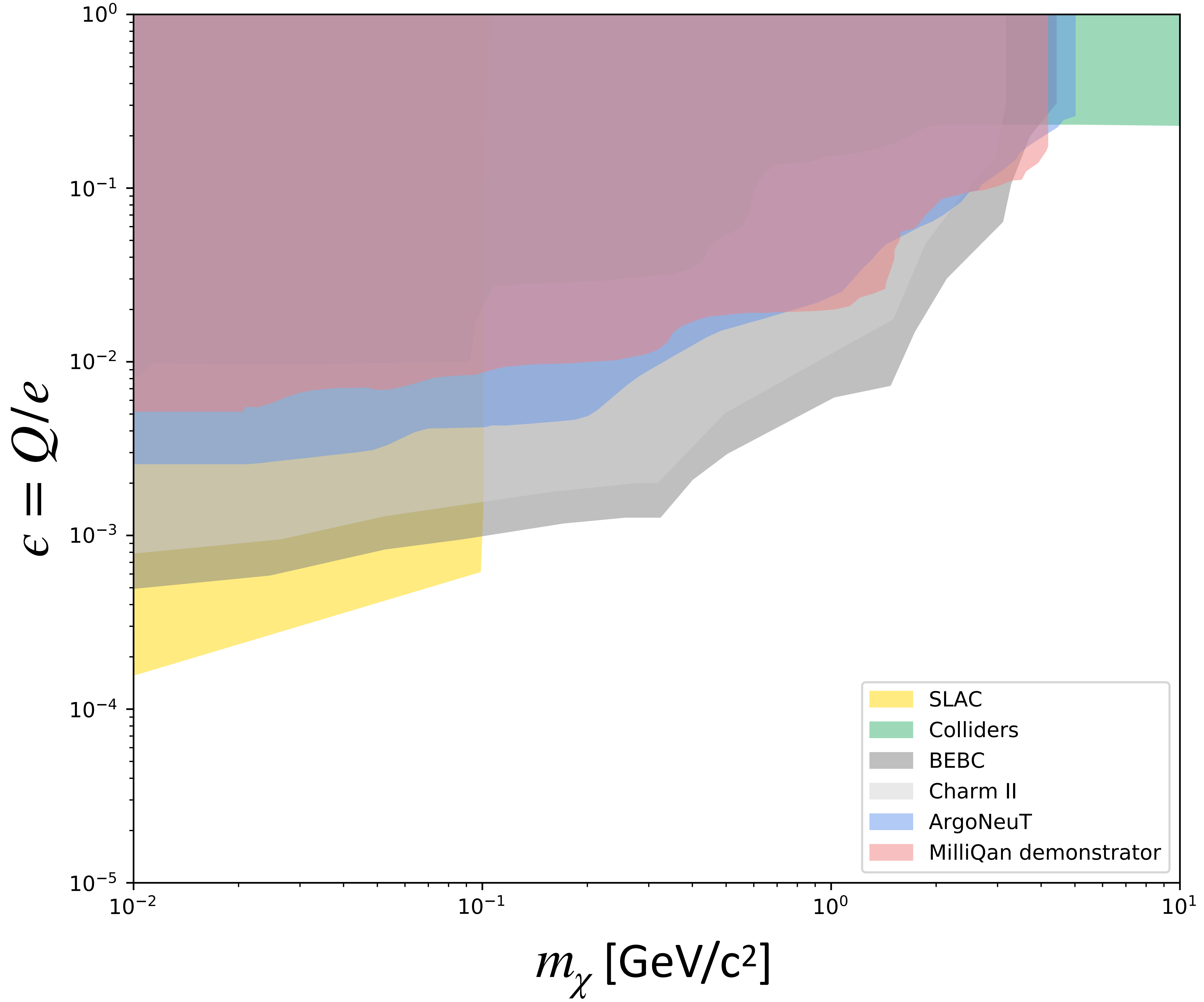
SUB-Millicharge ExperimenT (SUBMET)

Jae Hyeok Yoo (Korea University) on behalf of the SUBMET collaboration

11/09/2021

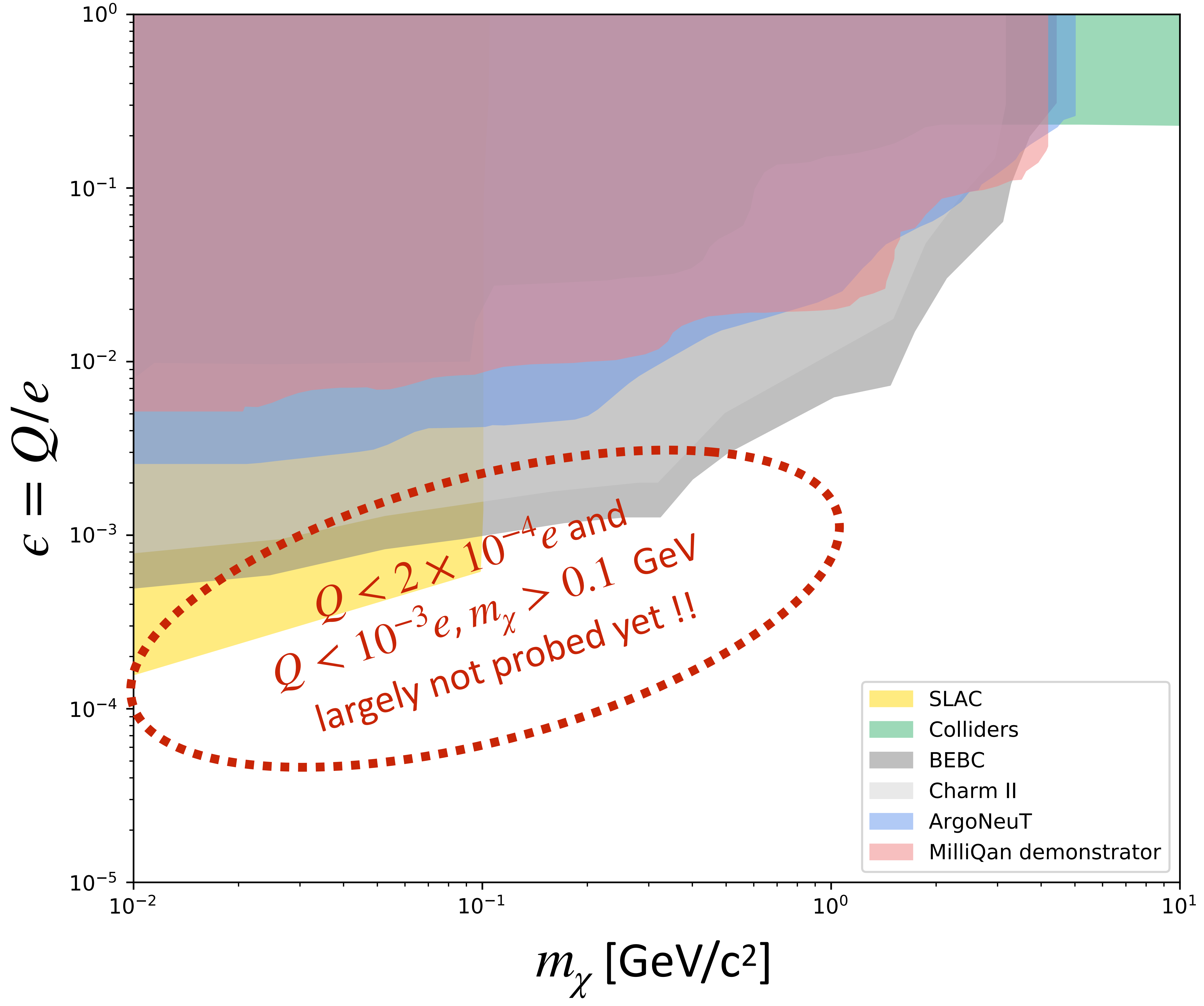
Tenth Workshop of Long-lived Particle Community

Motivation



- Since its discovery in Robert Millikan's oil drop experiment, electric charge quantization is a long-standing question in particle physics
- Well-motivated dark-sector models have been proposed to predict the existence of millicharged particles (χs) while preserving the possibility for unification
  - Such models can contain a rich internal structure, providing candidate particles for dark matter
- Results of EDGES experiment [*Nature* 555, 67–70 (2018)] can be explained if a fraction of DM is millicharged
- Various searches for χs so far

Motivation



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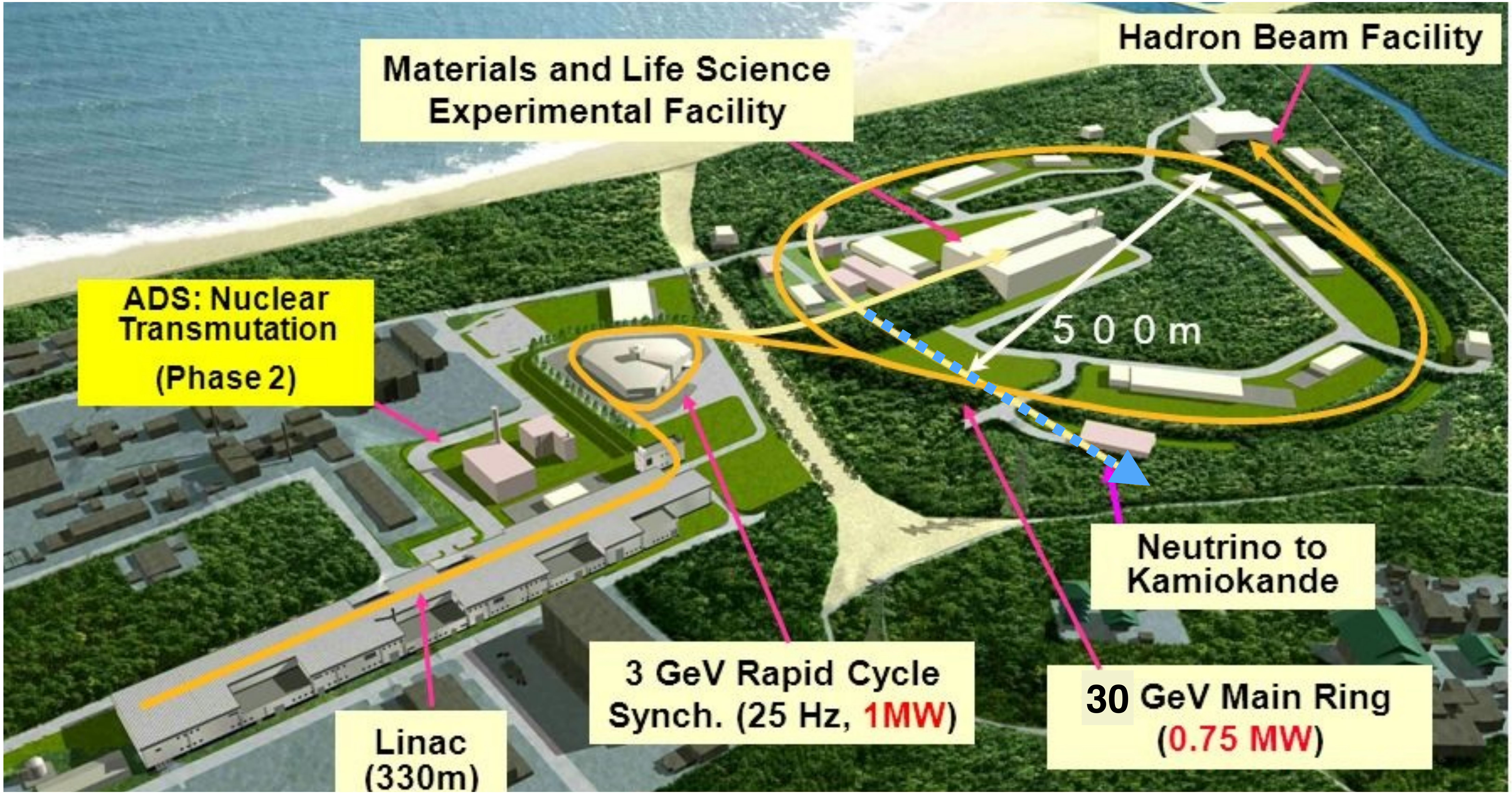
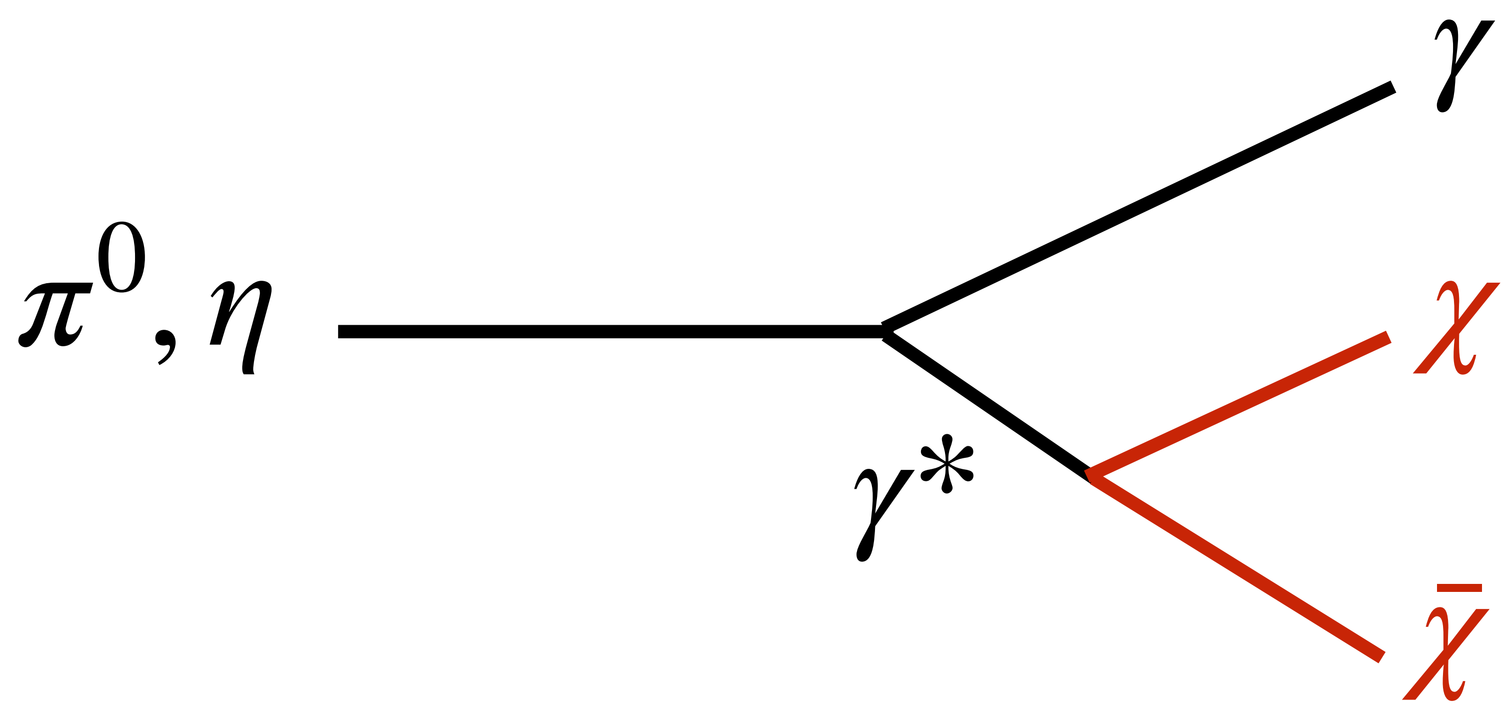
  - Such models can contain a rich internal structure, providing candidate particles for dark matter
- Results of EDGES experiment [*Nature* 555, 67–70 (2018)] can be explained if a fraction of DM is millicharged
- Various searches for χs so far
- **SUBMET**: new experiment targeting **small charge & low mass region**

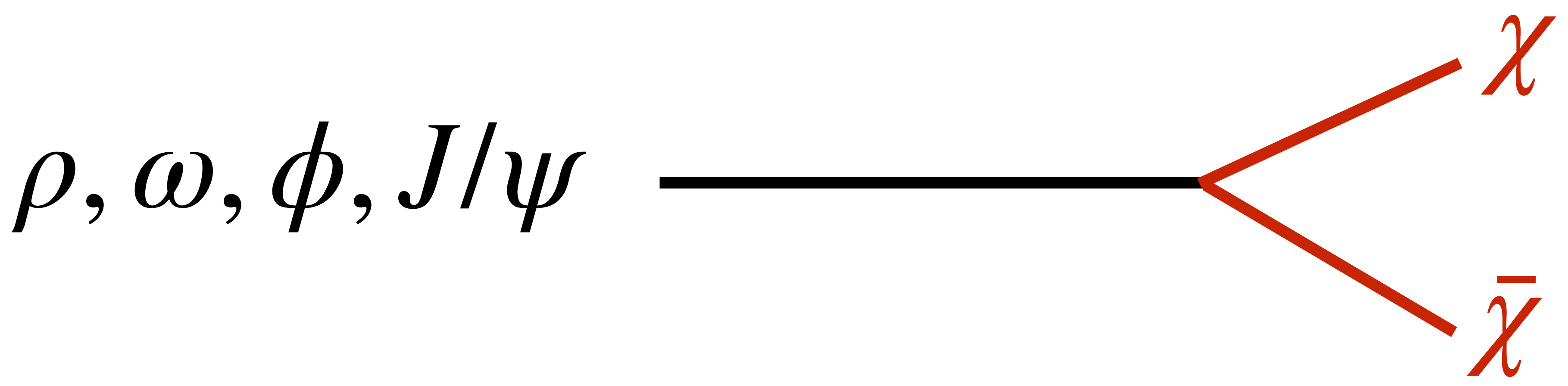
J-PARC complex



https://sciencesprings.files.wordpress.com/2018/01/j-parc-facility-new-japan-proton-accelerator-research-complex-j-parc-located-in-tokai-village-ibaraki-prefecture-japan.jpg

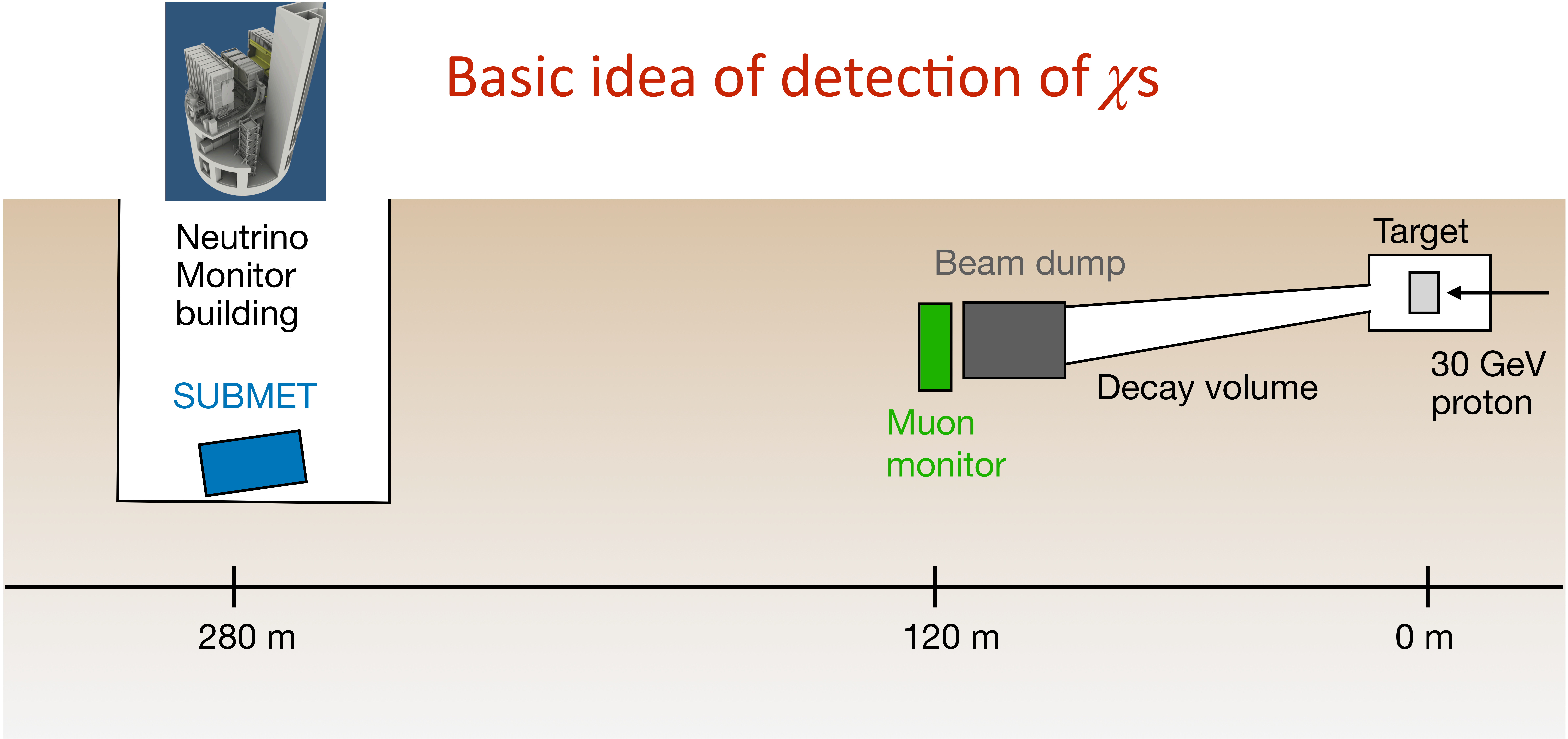
Production of χs





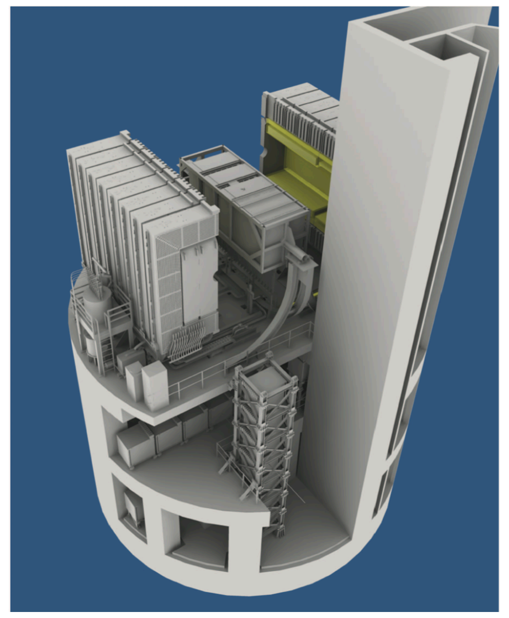
- A new U(1) in dark sector with massless dark-photon (A') and massive dark-fermion (χ)
  - A' and B (in SM) kinetically mix and charge of χ is proportional to mixing
- χs can be produced from the decay of neutral mesons
  - π^0, η through a photon ($\pi^0, \eta \rightarrow \gamma\gamma^* \rightarrow \gamma\chi\bar{\chi}$)
  - $\rho, \omega, \phi,$ and J/ψ directly to $\chi\bar{\chi}$ ($\rho, \omega, \phi, J/\psi \rightarrow \gamma^* \rightarrow \chi\bar{\chi}$)
- In both cases, m_χ up to $m_{meson}/2$ is allowed

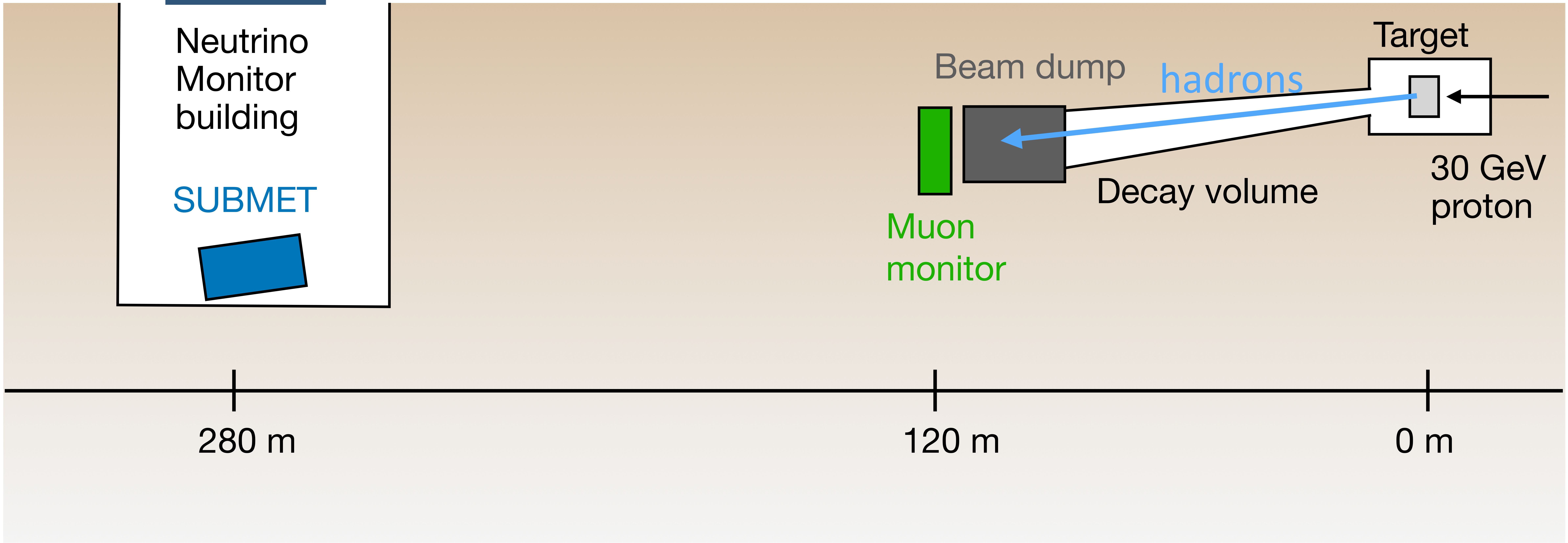
Basic idea of detection of χs



Protons hit the target and produce hadrons

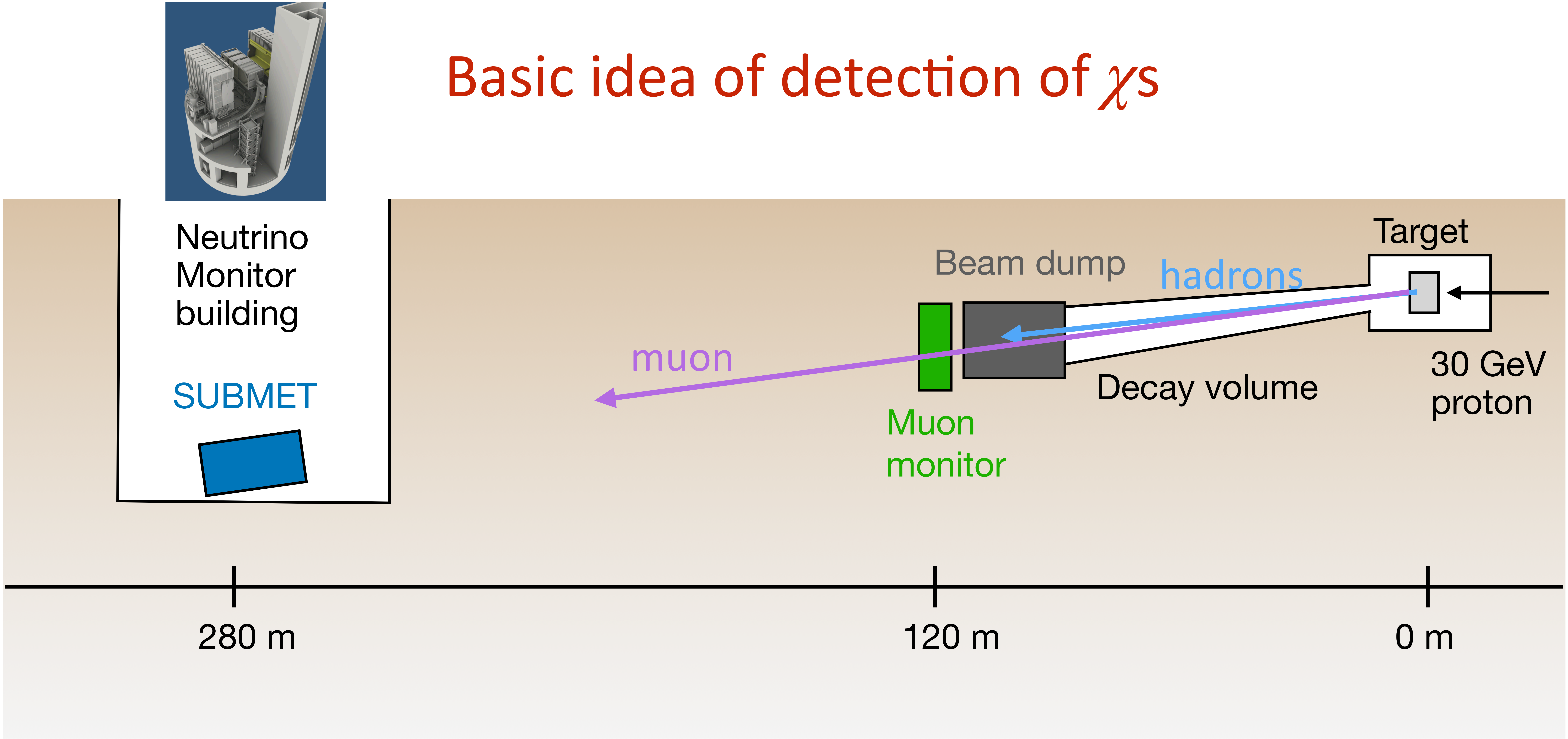
Basic idea of detection of χs





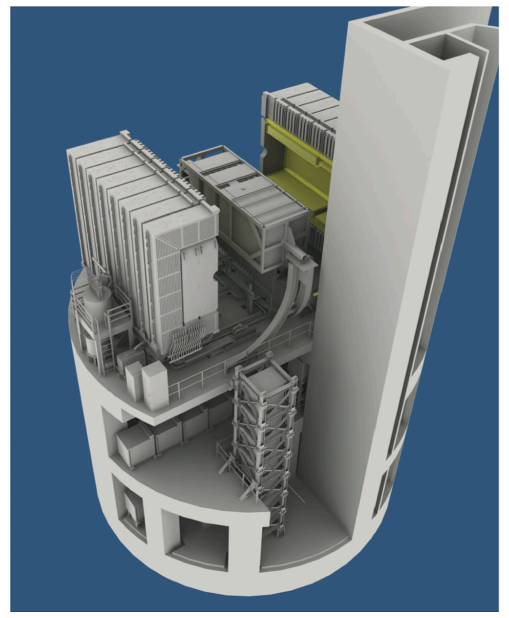
Hadrons are stopped in beam dump

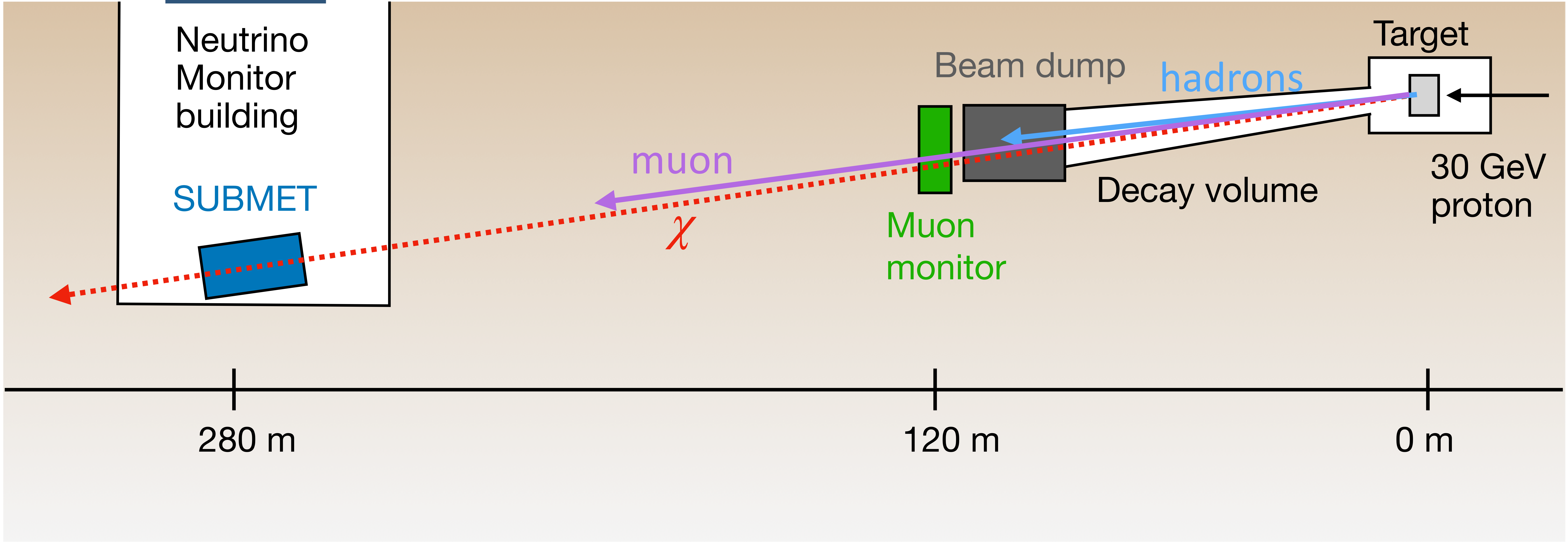
Basic idea of detection of χs



Muons pass the beam dump, but lose energy in sand (5 MeV/cm) before reaching the Neutrino Monitor building

Basic idea of detection of χs

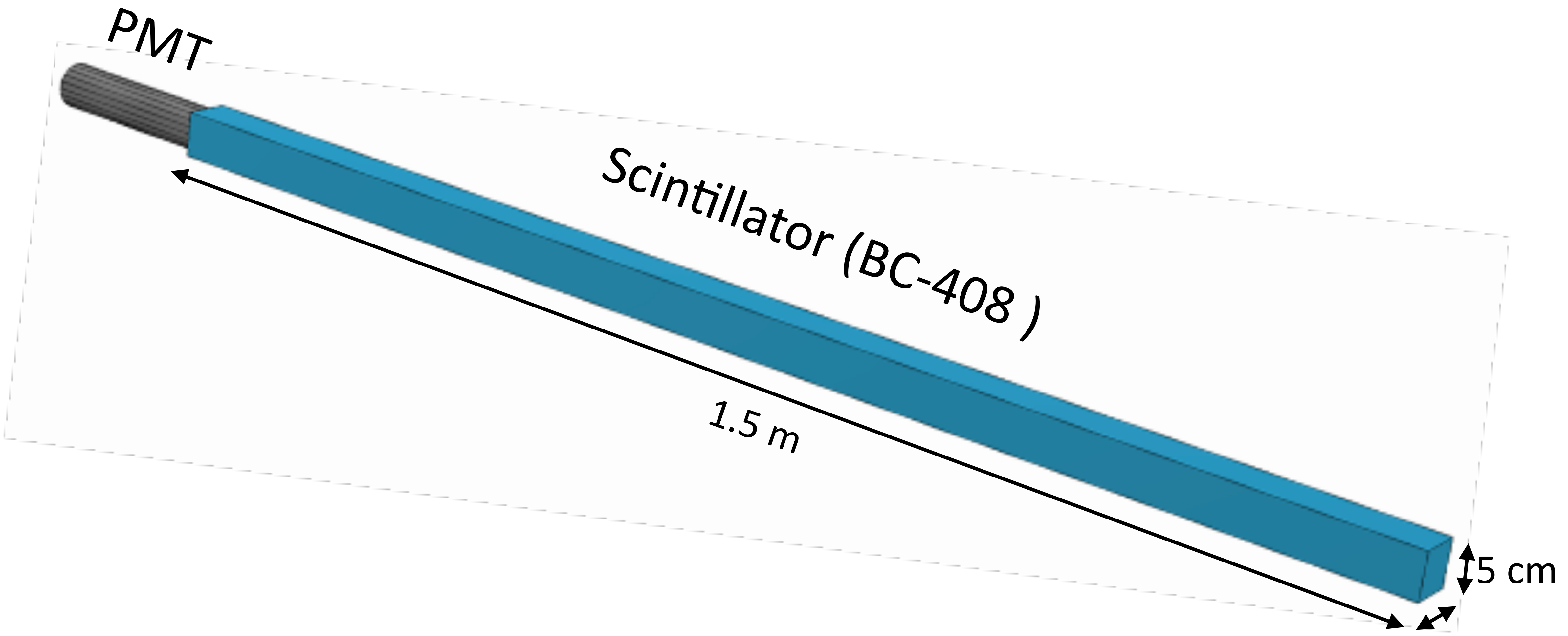




Only χs (and neutrinos) reach the detector

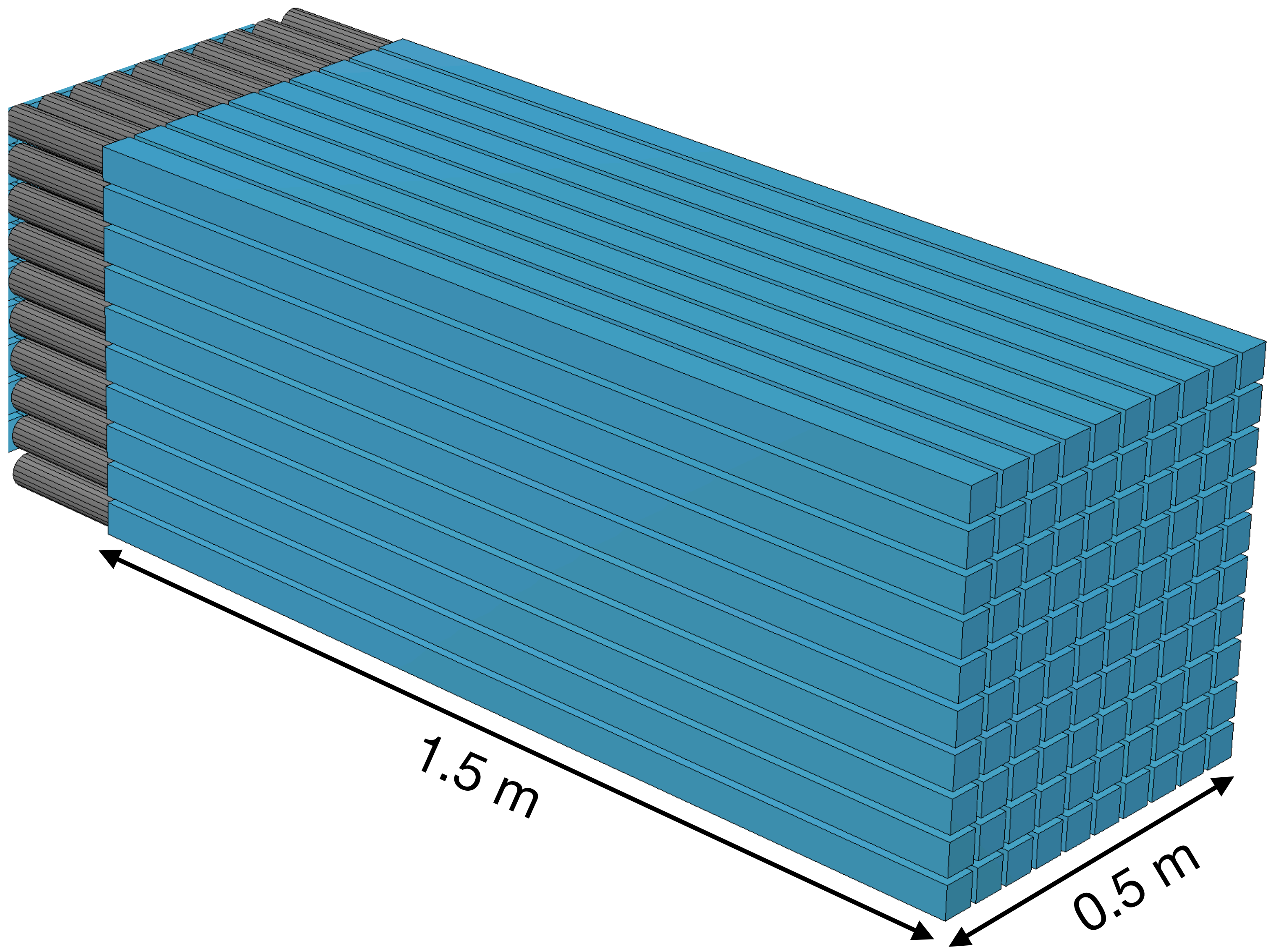
(energy loss for χs with $Q = 10^{-3}e$ is <0.1 MeV)

Detector design



- Inspired by the milliQan experiment, use long scintillator bars so that χs with small charge can produce photons
  - For small ϵ, detect single photons

Detector design



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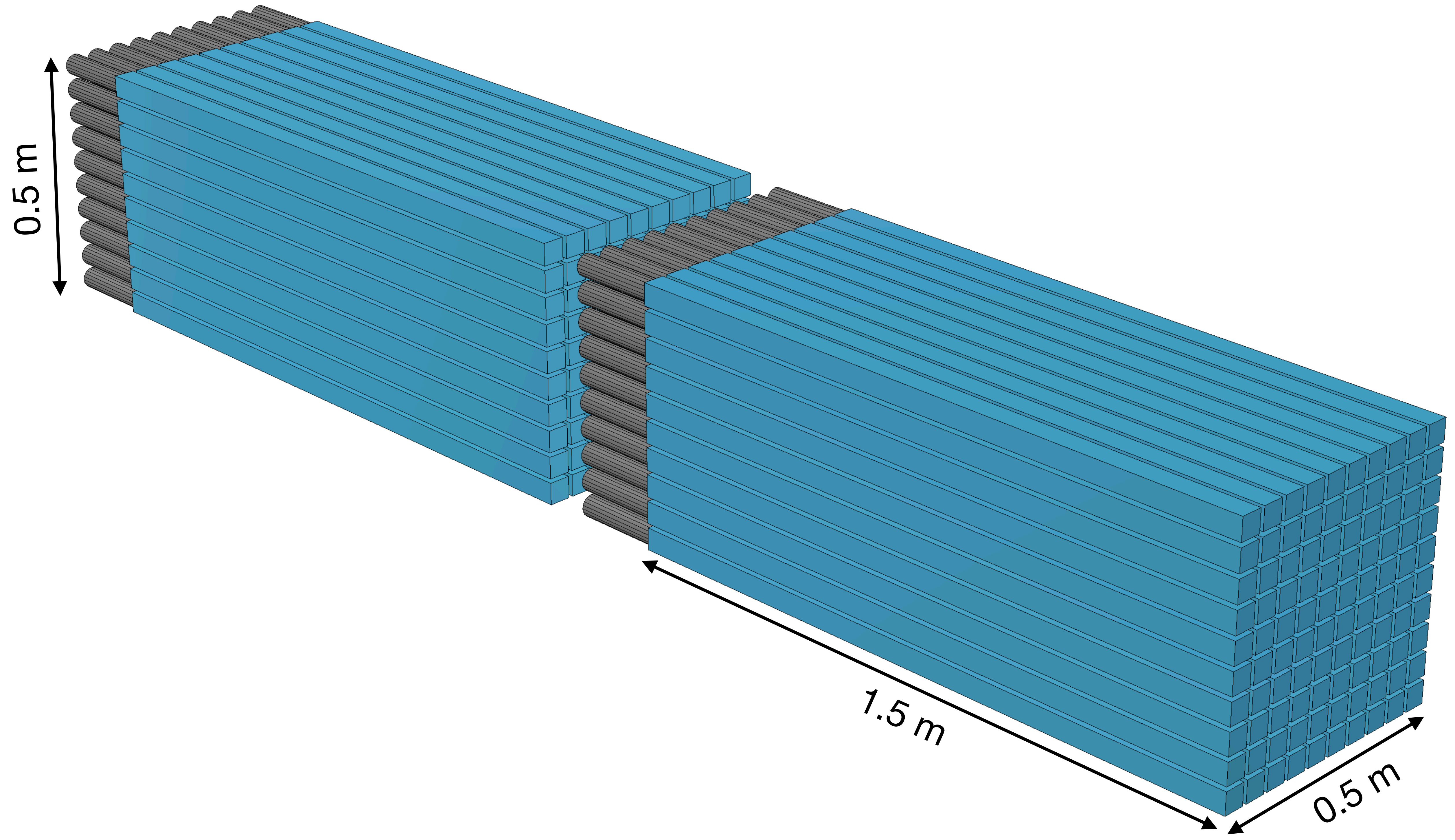

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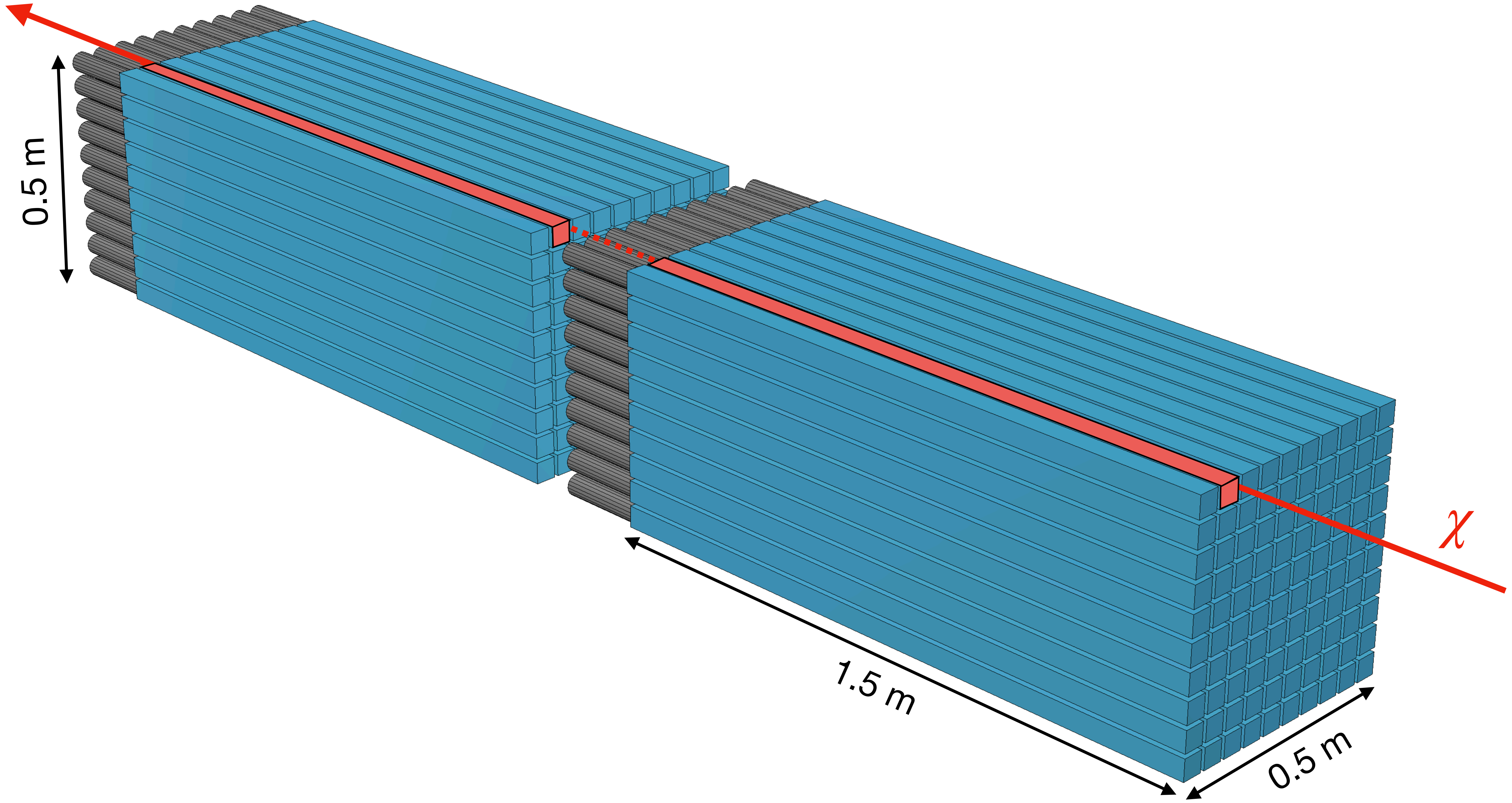
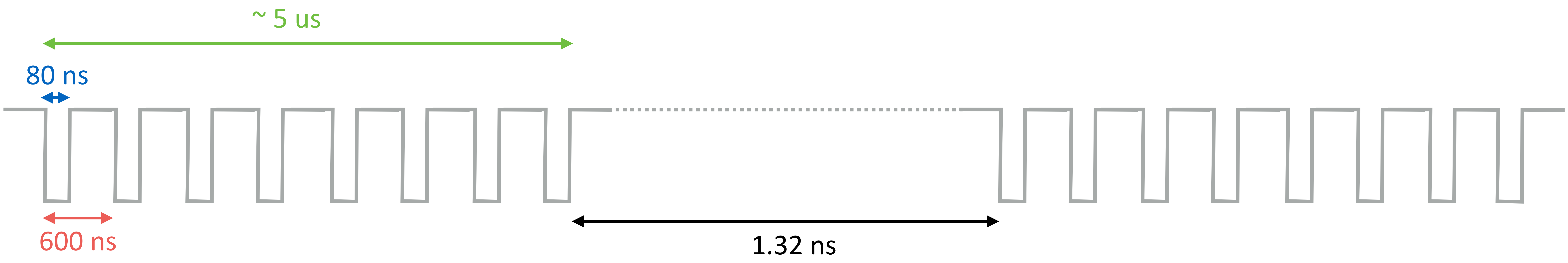


- Inspired by the milliQan experiment, use long scintillator bars so that χs with small charge can produce photons
  - For small ϵ, detect single photons
- Stack scintillators to increase total volume and use two layers to control backgrounds
- Align the two layers such that a χ goes through them
- Require small time difference ($\Delta t = 10 \sim 20$ ns) between hits in the two layers

Beam time

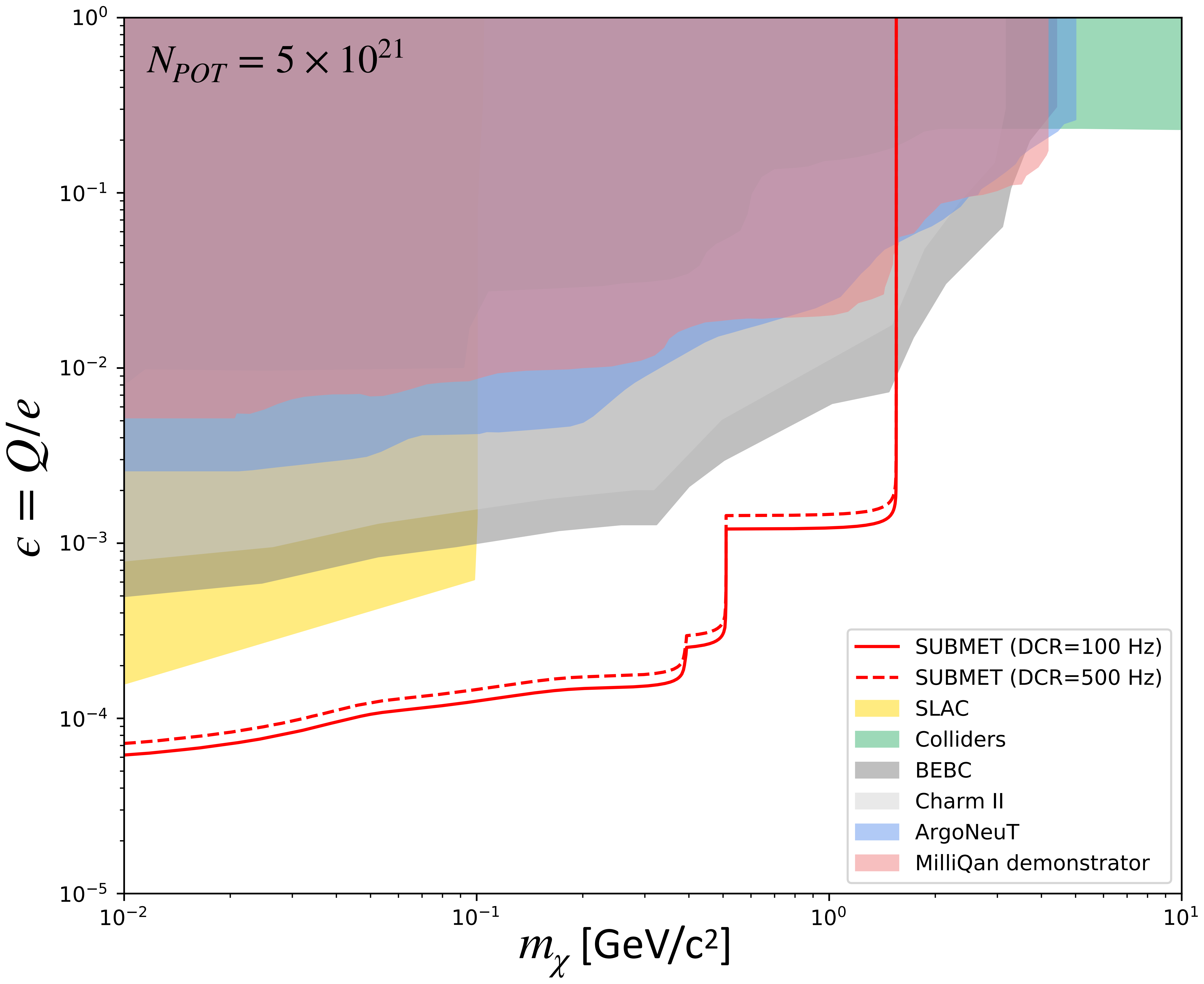


- A proton spill hits the target every 1.32 s
- Each spill contains 8 bunches (width ~ 80 ns) and they are ~600 ns apart
- Can use this info to get a significant reduction of acquisition time
  - Expect to achieve background rejection by $O(10^{-6})$

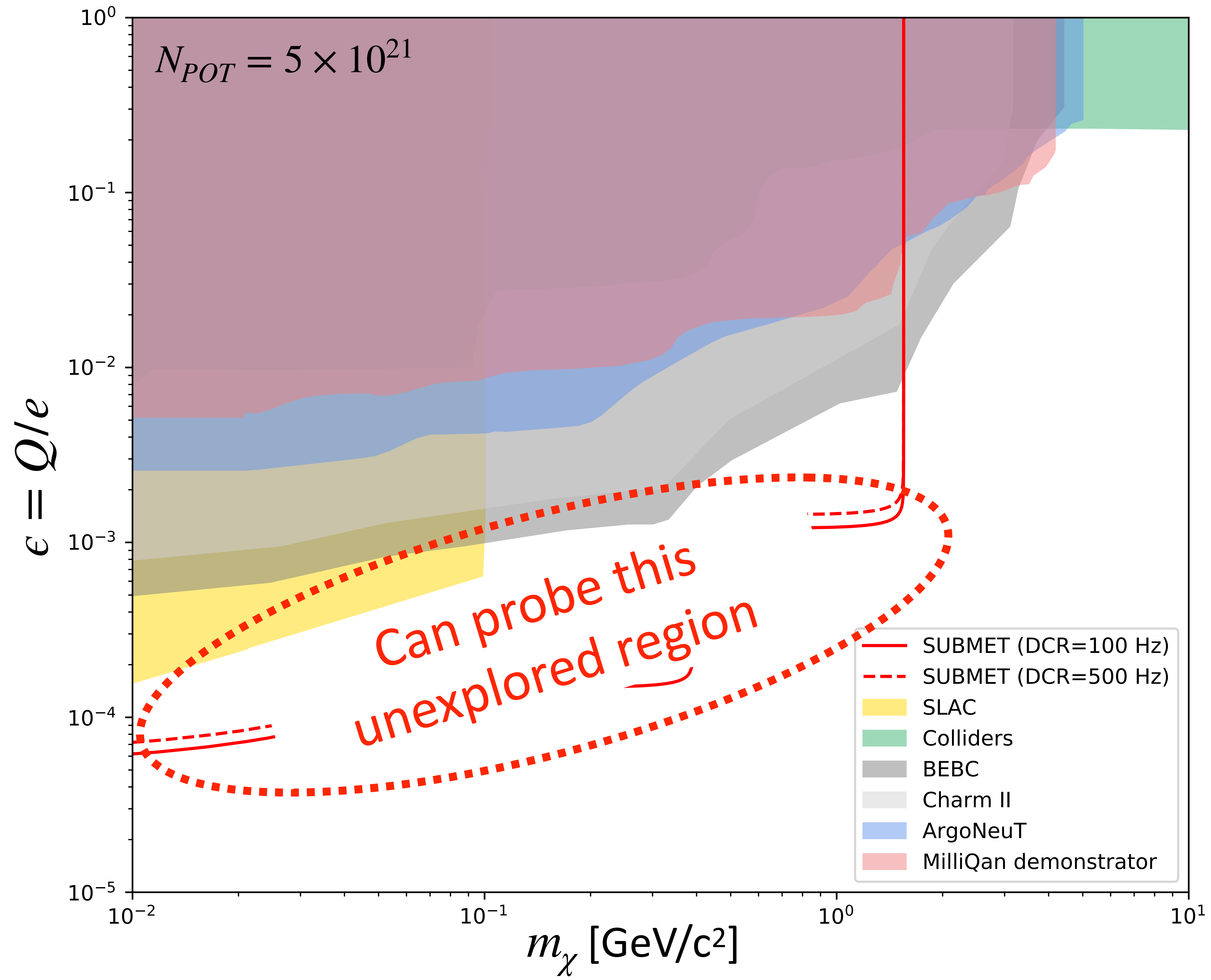
Backgrounds

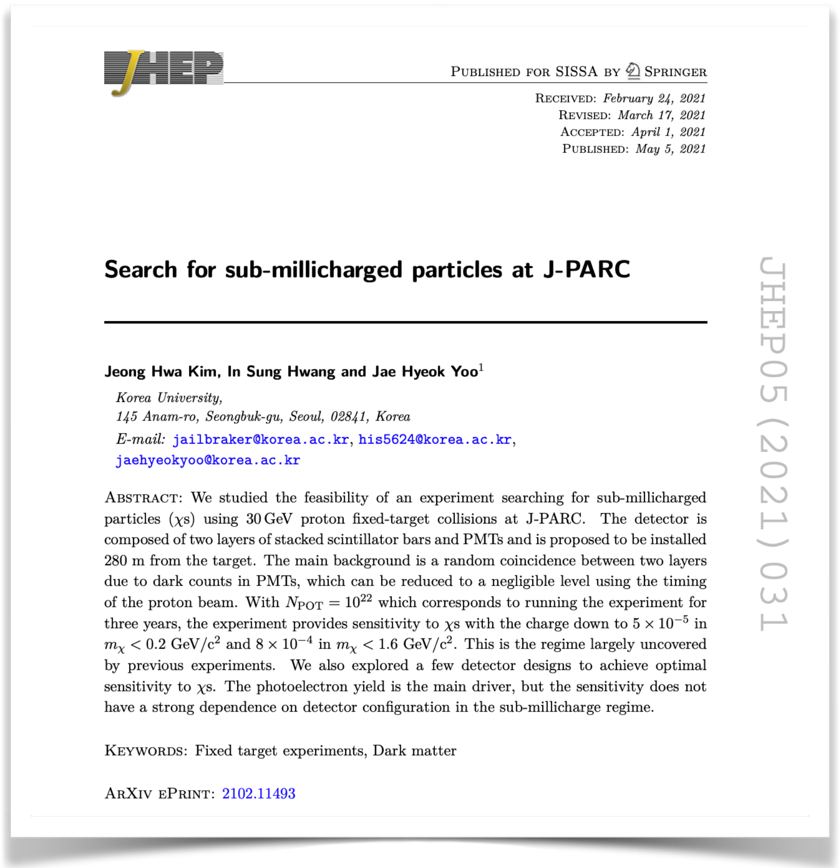
- Detector backgrounds
  - Random coincidence due to PMT dark counts is expected to be the main source (O(10)/year for DCR=500 Hz)
- Beam-induced backgrounds
  - Muons from hadron decays do not reach detector due to energy loss
  - Neutrino interactions with scintillator: estimated using INGRID measurements and found to be negligible
  - Muons from neutrino-building interactions can be identified/rejected by scintillator plates in front of detector
- Other sources
  - Cosmic shower: needs in situ measurement, but easy to control due to large energy deposit
  - Neutrons from surrounding structure: shields by outermost bars, scintillator panels
- Non-beam-induced backgrounds can be estimated using no-beam data

Sensitivity of SUBMET



Sensitivity of SUBMET





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Search for sub-millicharged particles at J-PARC

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Abstract: We studied the feasibility of an experiment searching for sub-millicharged particles (χs) using 30 GeV proton fixed-target collisions at J-PARC. The detector is composed of two layers of stacked scintillator bars and PMTs and is proposed to be installed 280 m from the target. The main background is a random coincidence between two layers due to dark counts in PMTs, which can be reduced to a negligible level using the timing of the proton beam. With $N_{POT} = 10^{22}$ which corresponds to running the experiment for three years, the experiment provides sensitivity to χs with the charge down to 5×10^{-5} in $m_\chi < 0.2$ GeV/c^2 and 8×10^{-4} in $m_\chi < 1.6$ GeV/c^2. This is the regime largely uncovered by previous experiments. We also explored a few detector designs to achieve optimal sensitivity to χs. The photoelectron yield is the main driver, but the sensitivity does not have a strong dependence on detector configuration in the sub-millicharge regime.

Keywords: Fixed target experiments, Dark matter

ArXiv ePrint: 2102.11493

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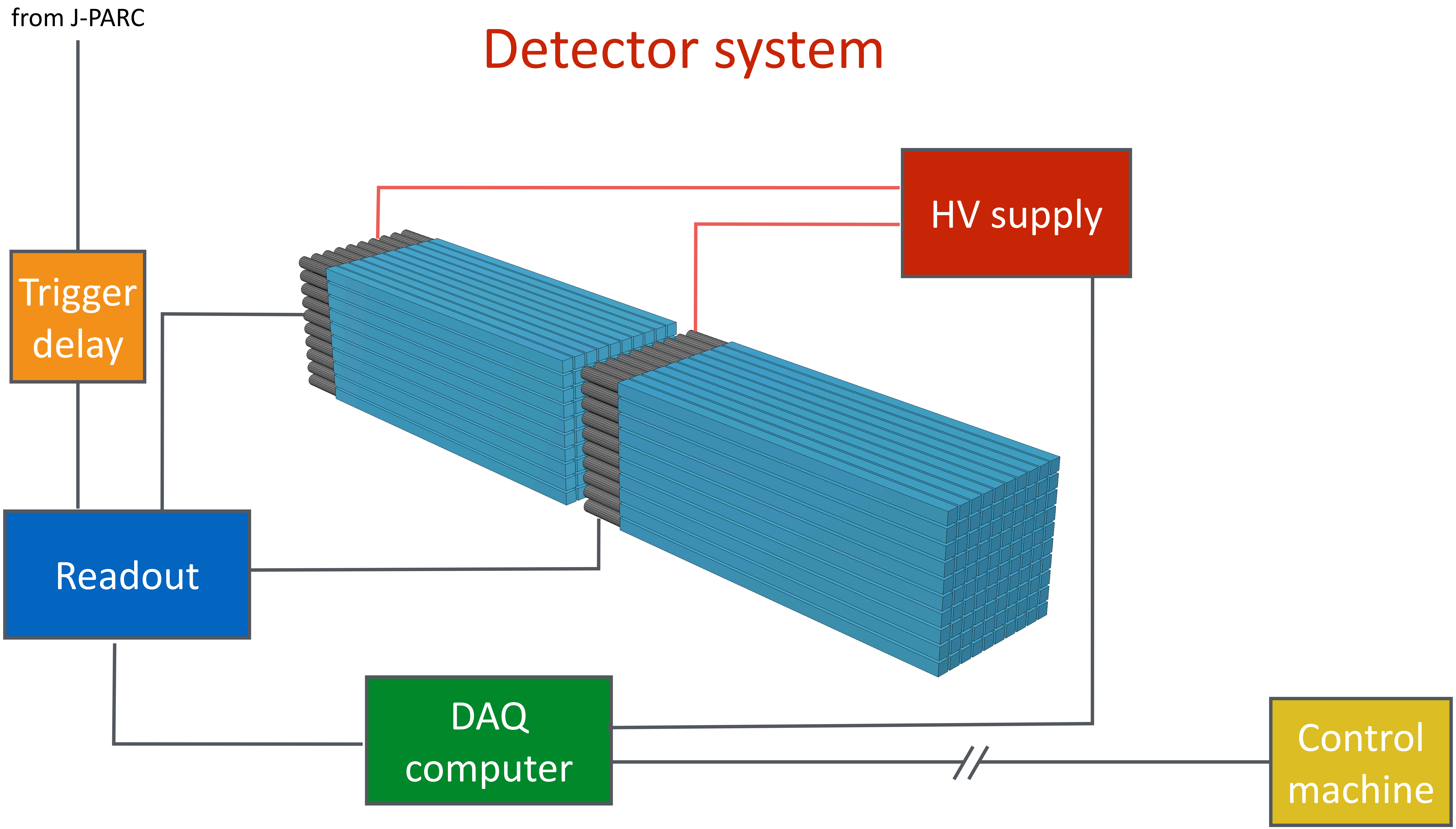
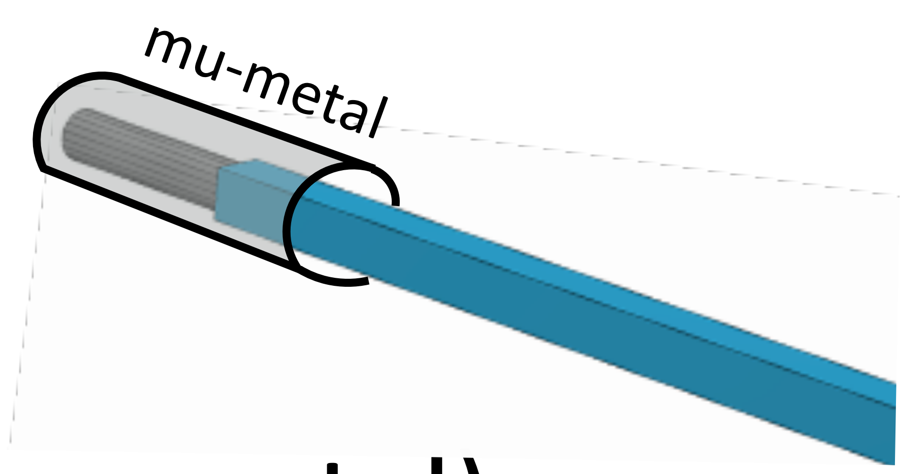
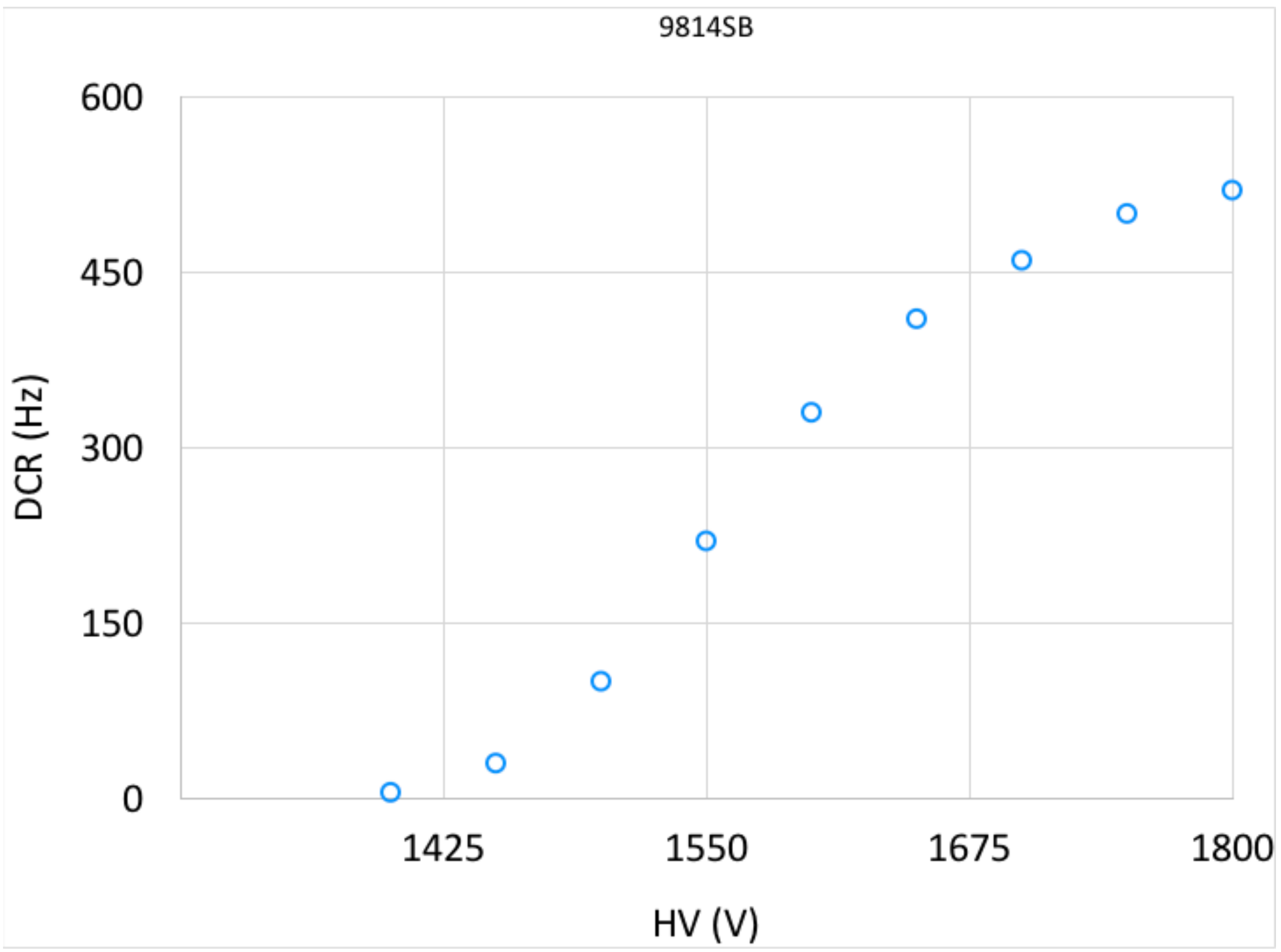
Detector system



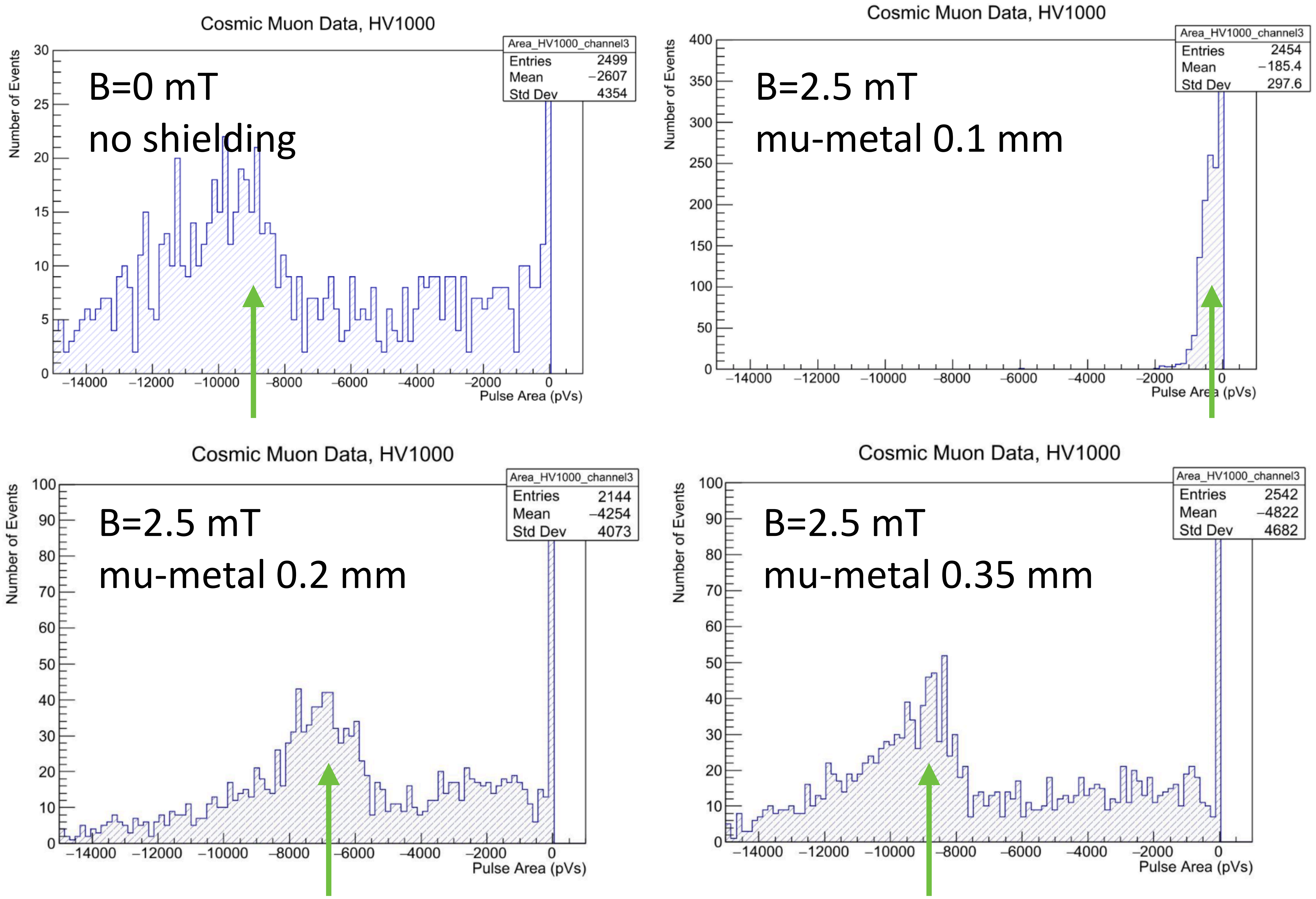
PMT



Dark count rate measurement

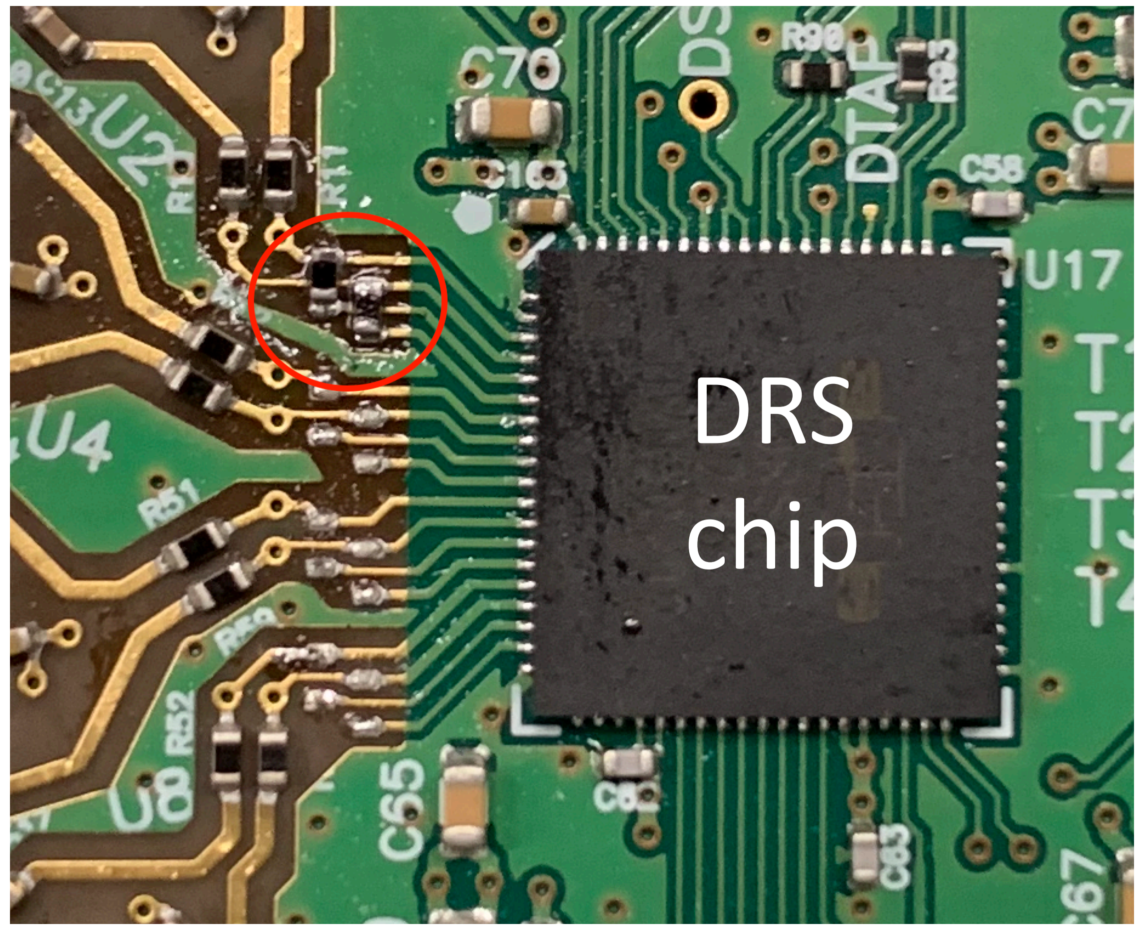


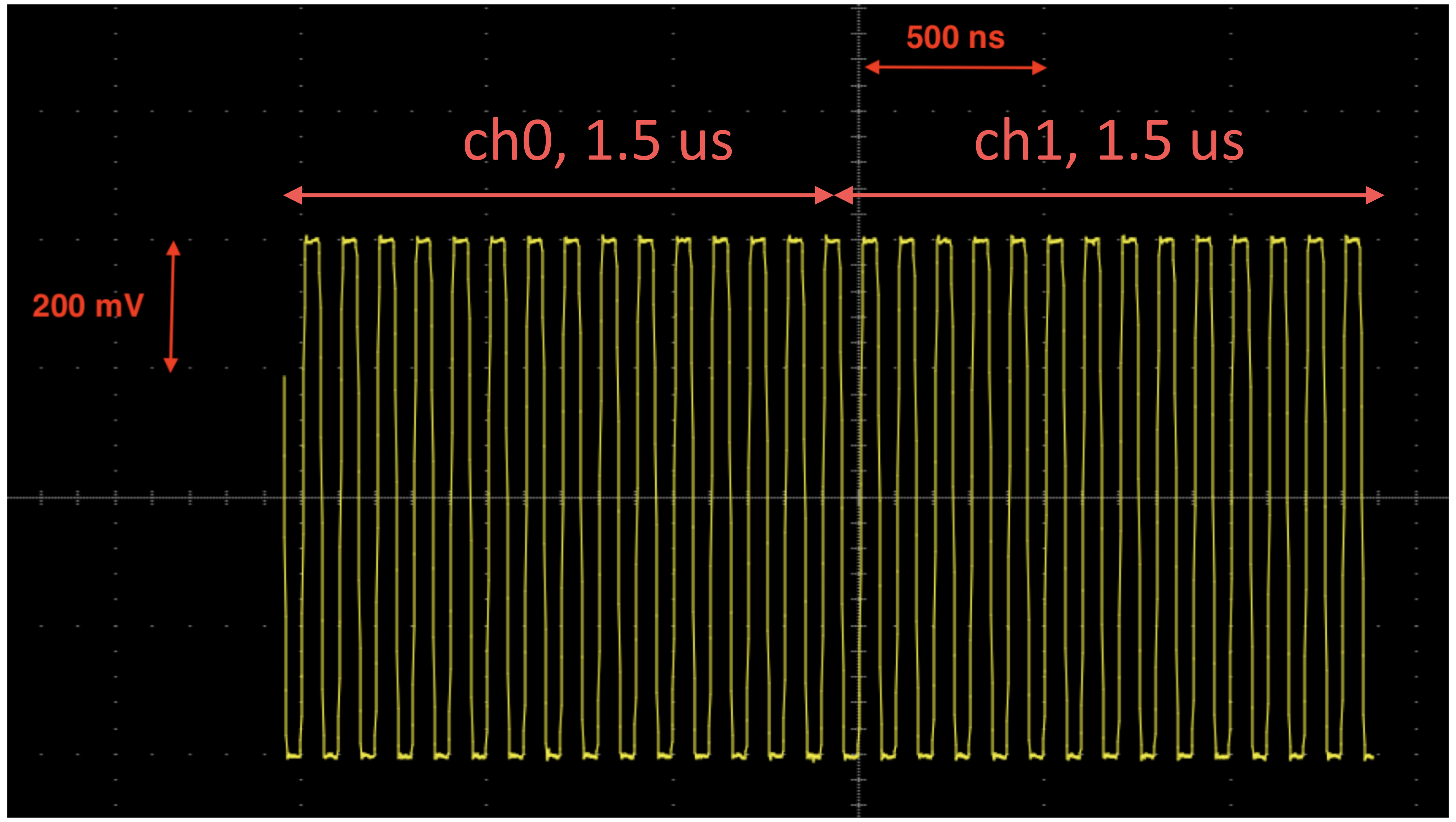
Magnetic shielding (mu-metal)



Readout

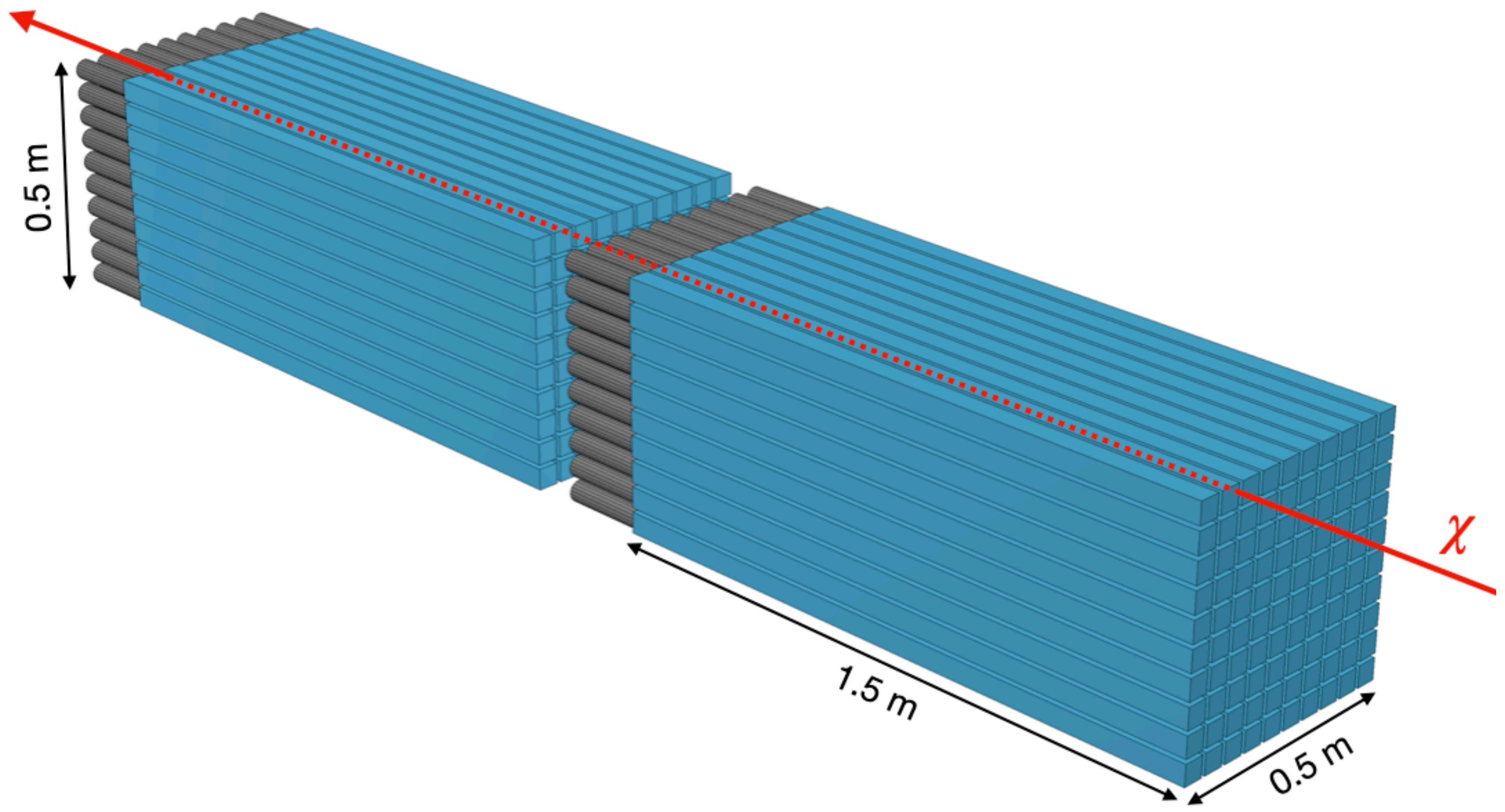
connected two inputs using 0 ohm resistors

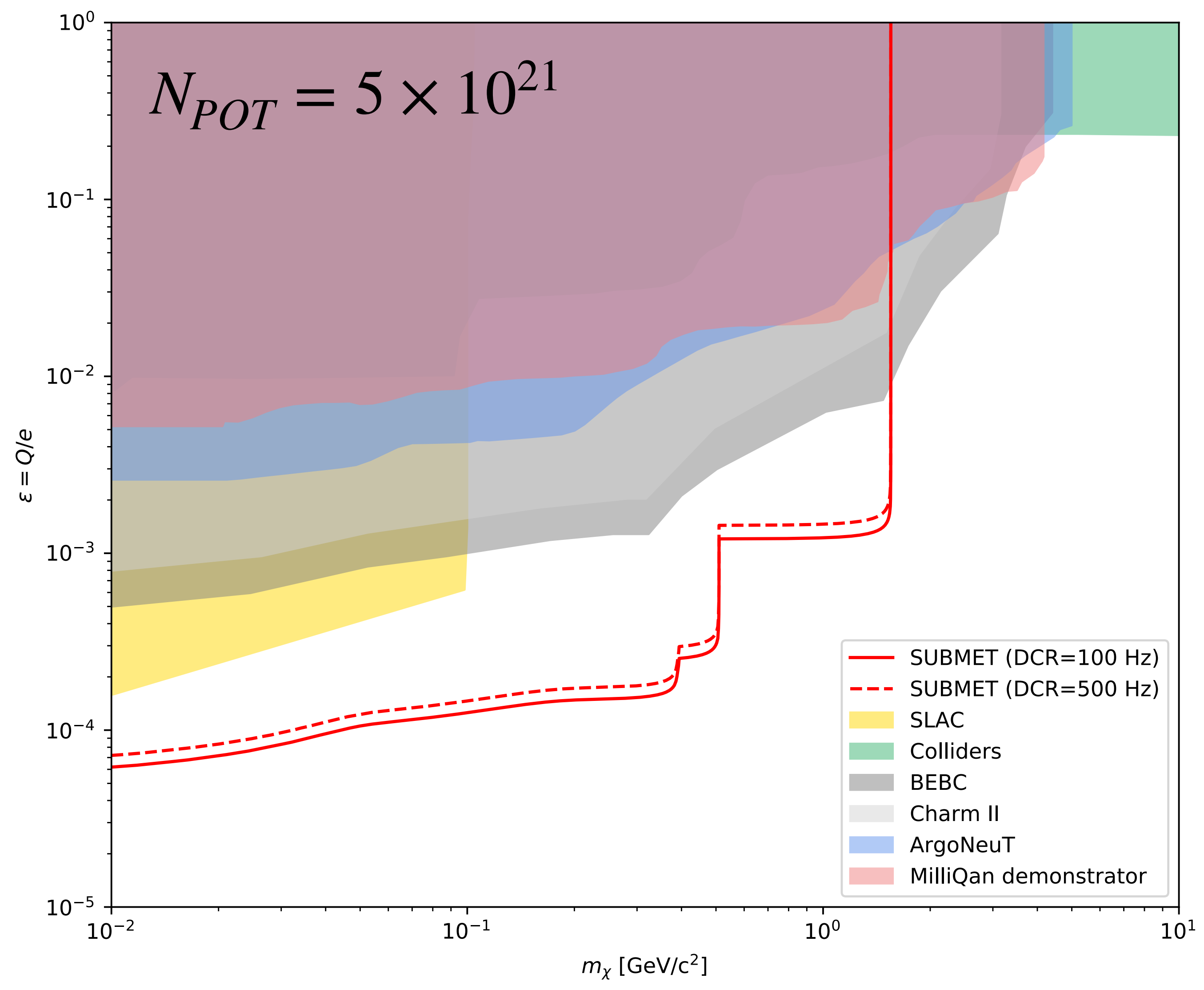




- Use Domino Ring Sampler (DRS) chip (1024 sampling depth, 0.7 GSPS)
- Each channel can read 1.5 us, but one can cascade 4 (actually up to 8) channels to extend the acquisition window to 6 us
  - Cascading two channels confirmed using DRS evaluation board
- Producing prototype readout board with a company (NOTICE Korea)
- Working on trigger delay board (FPGA) to control the readout time

Summary and outlook





- We proposed a **new experiment to search for millicharged particles** using 30 GeV proton beam at **J-PARC**
- Unique opportunity to probe **small charge & low mass** ($m_\chi < 1.6$ GeV) **millicharged particles**
- Using beam time allows for significant background reduction
- Submitted proposal to the 32nd J-PARC PAC this summer
  - Received very positive feedback
- Funding from the National Research Foundation of Korea (0.5M USD) is secured
- Looking forward to building and installing the detector in the coming year!

The team

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