SUBMET: Search for millicharged particles in J-PARC

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Outline

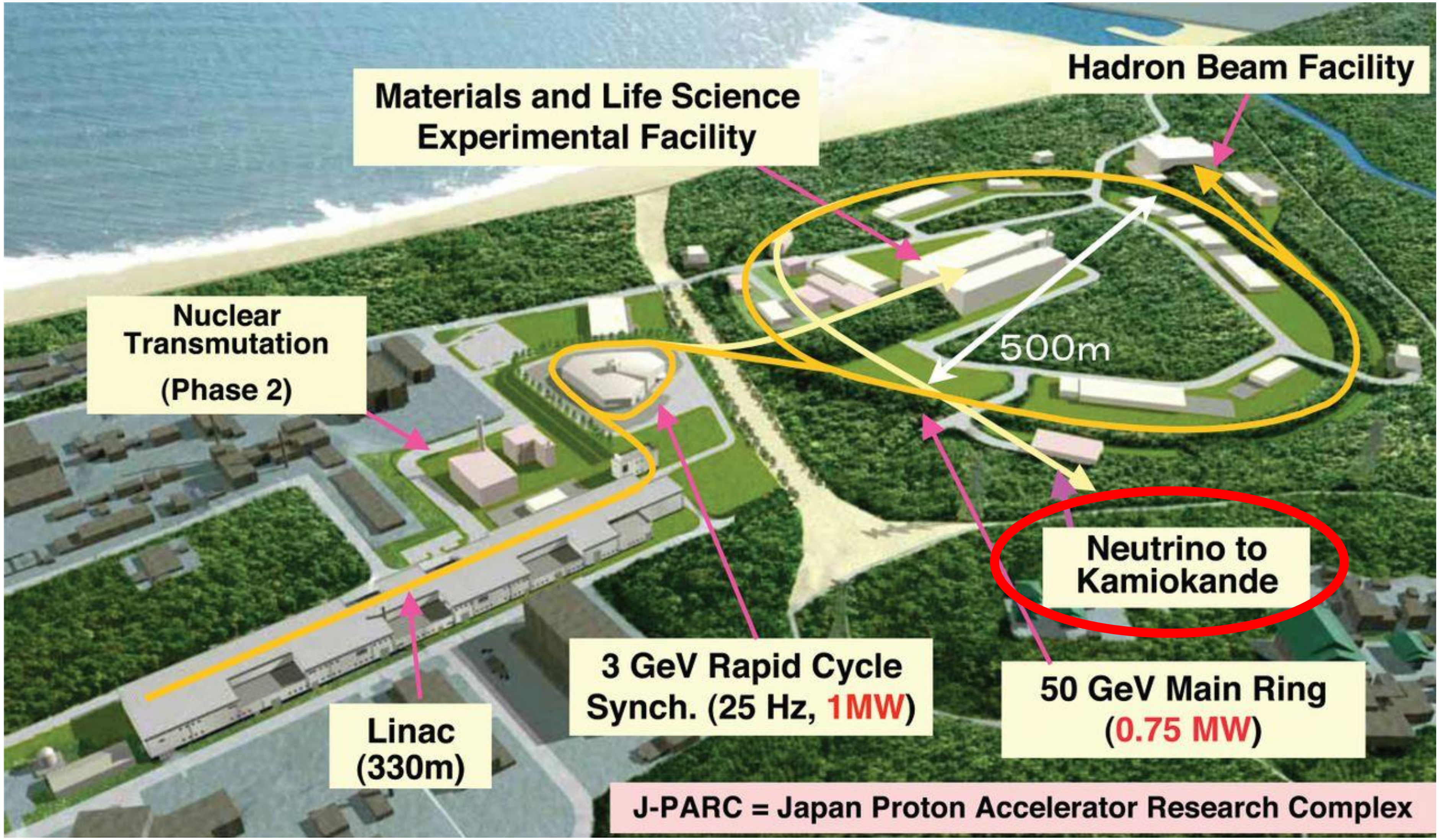
- Scintillator-based detector in pp fixed target experiments at J-PARC
  - Inspired by MilliQan and FerMINI experiment
  - Similar to FerMINI with lower beam energy and larger N_POT

    (120 GeV -> 30 GeV ($\sqrt{s}$=7.6 GeV), 6*10^20 -> 10^22)

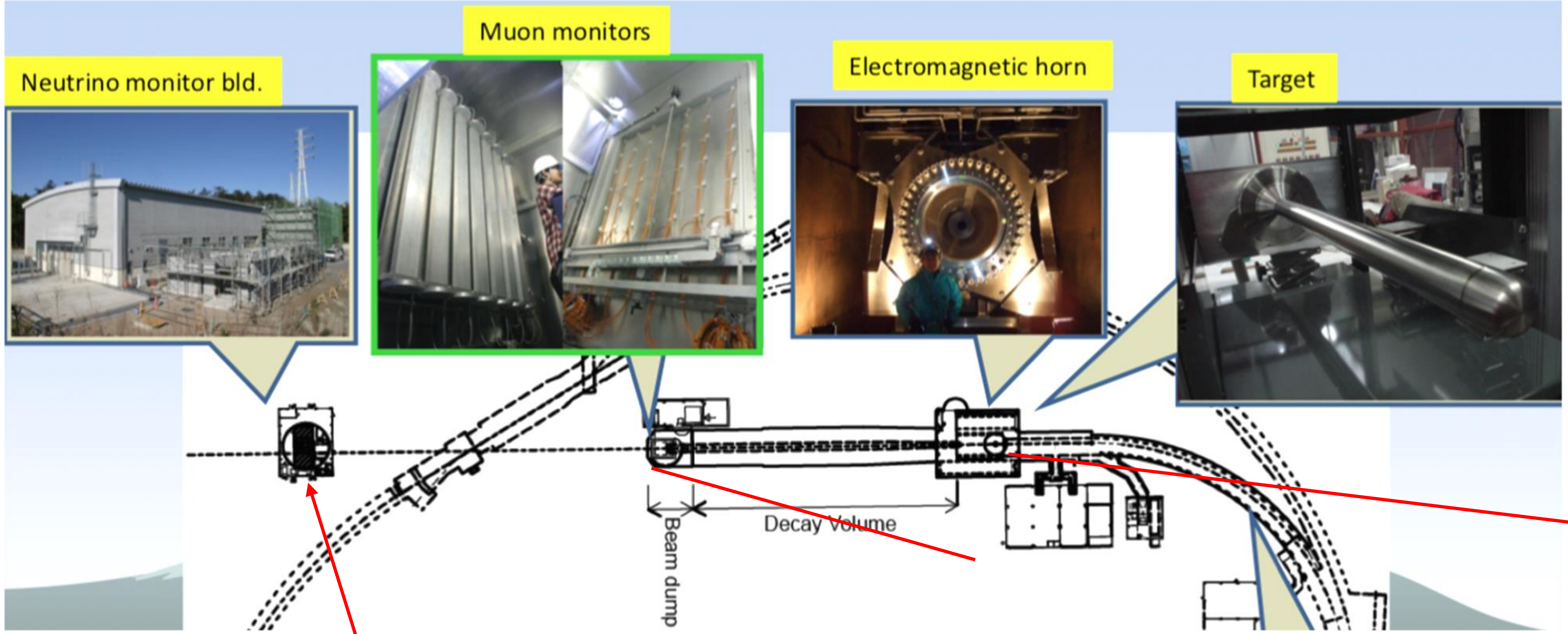
- Candidate site 280m from the target

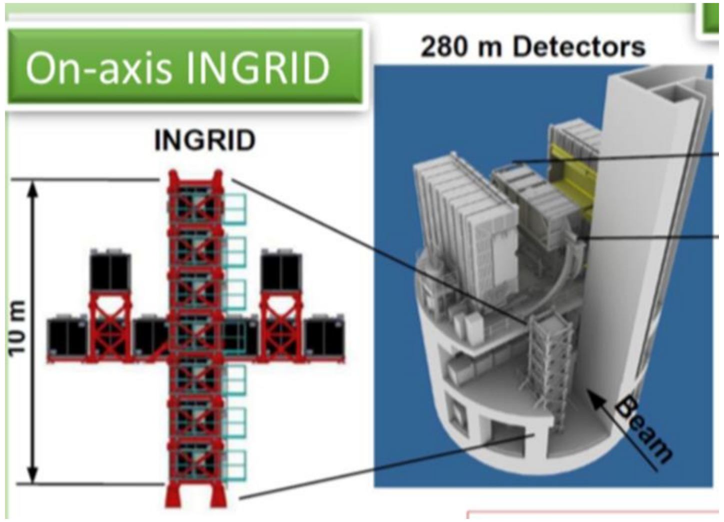
- Explored different detector designs

J-PARC proton beam

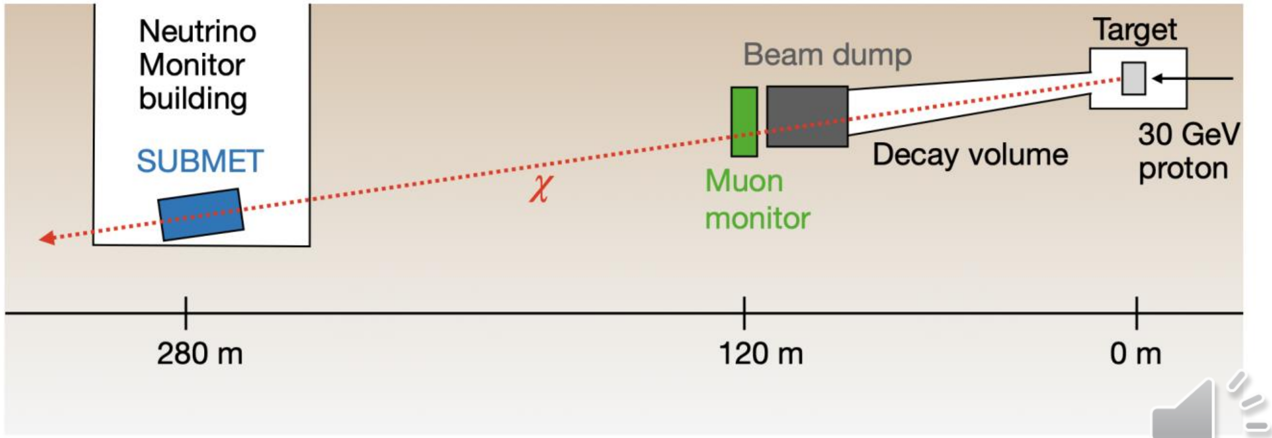


Detector site



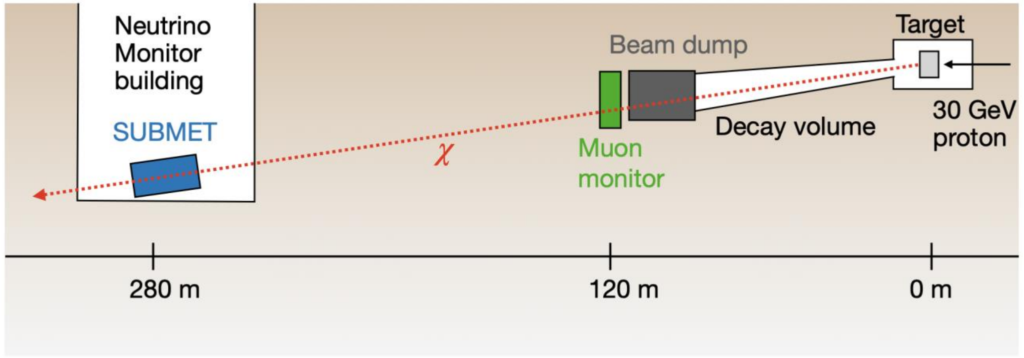


Potential detector site (280 m from the target)

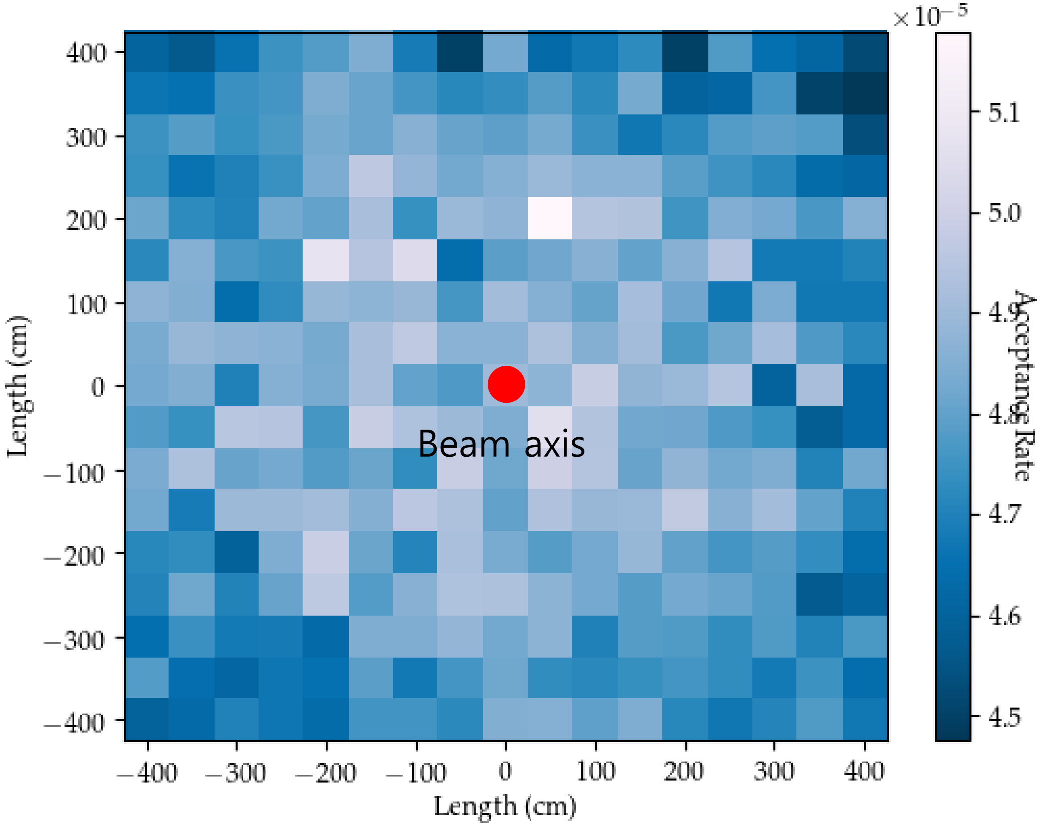


Signal acceptance

- Detector ~280 m away from the target

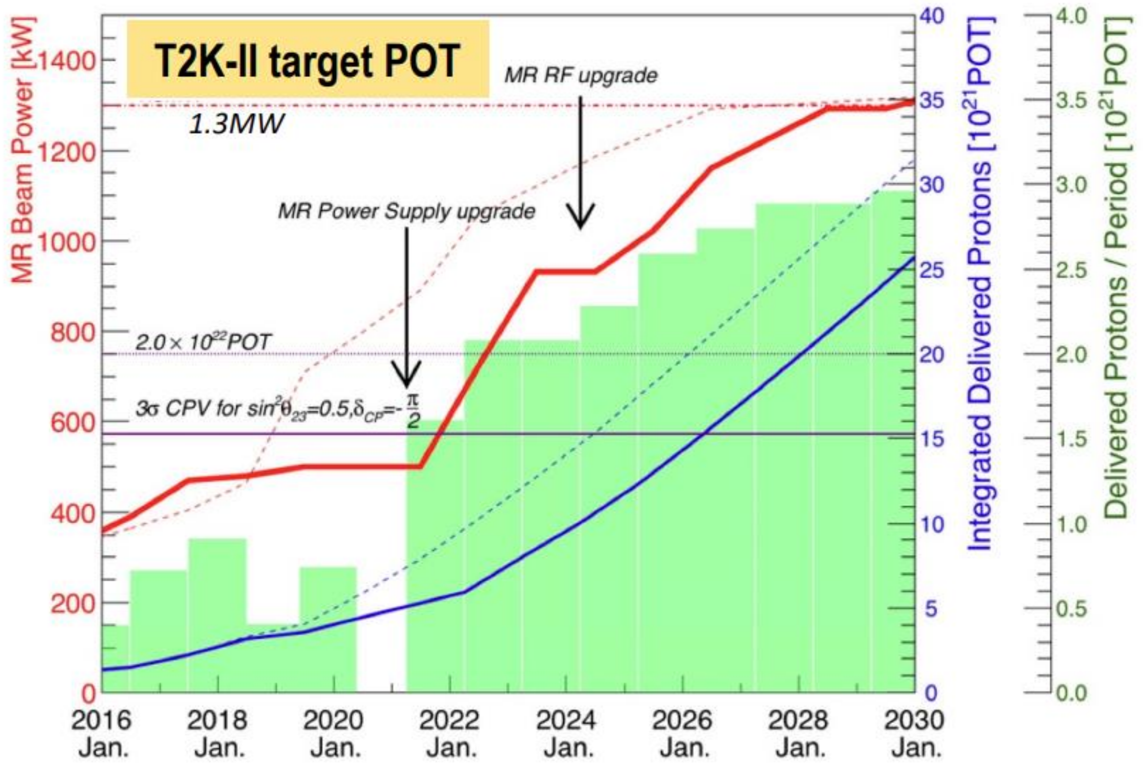


- We expect an acceptance rate of about $O(10^{-4})$
  - Calculated by Pythia using photons from pi0 (assuming mCPs and photons are moving in the same direction)
- Does not need to be right on axis
  - Roughly equal within 8x8 m^2
  - Ample space to install detector



One box is 50x50 cm^2

J-PARC operation plan



- Projection of integrated POT taken f rom https://pos.sissa.it/369/054/pdf
- From 2023-2027, ~3x10^{21} POT/year is expected
- We used 10^{22} POT as a benchmark

Production of mCP

Production via π^0, η and J/ψ neutral meson decays

$\pi^0, \eta \to \gamma\chi\bar{\chi}$ $\quad J/\psi \to \chi\bar{\chi}$

$$N_\chi \propto c_{\mathfrak{m}} \epsilon^2 N_{POT} \times f(\frac{m_\chi^2}{m_{\mathfrak{m}}^2})$$

Calculations done with PYTHIA8

$$c_{\pi_0} \simeq 1.9,\ c_\eta \simeq 0.21,\ c_{J/\psi} \simeq 5 \times 10^{-9}$$

(Upsilons are irrelevant due to low √s)

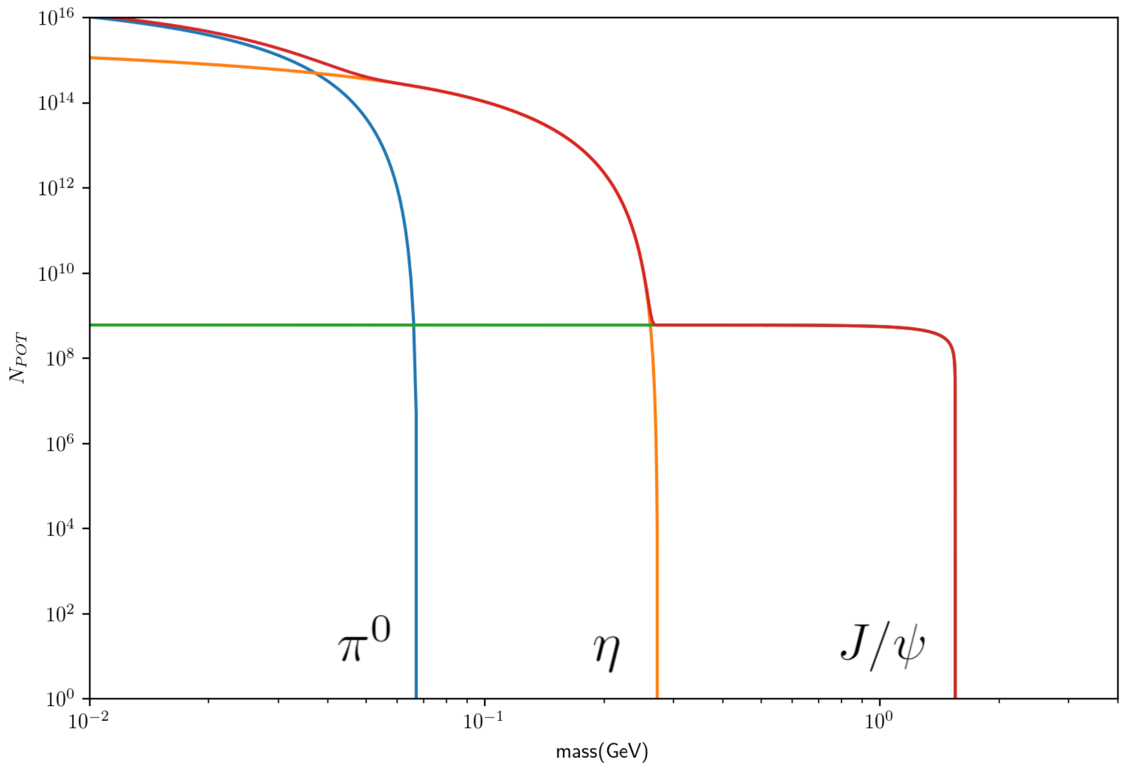
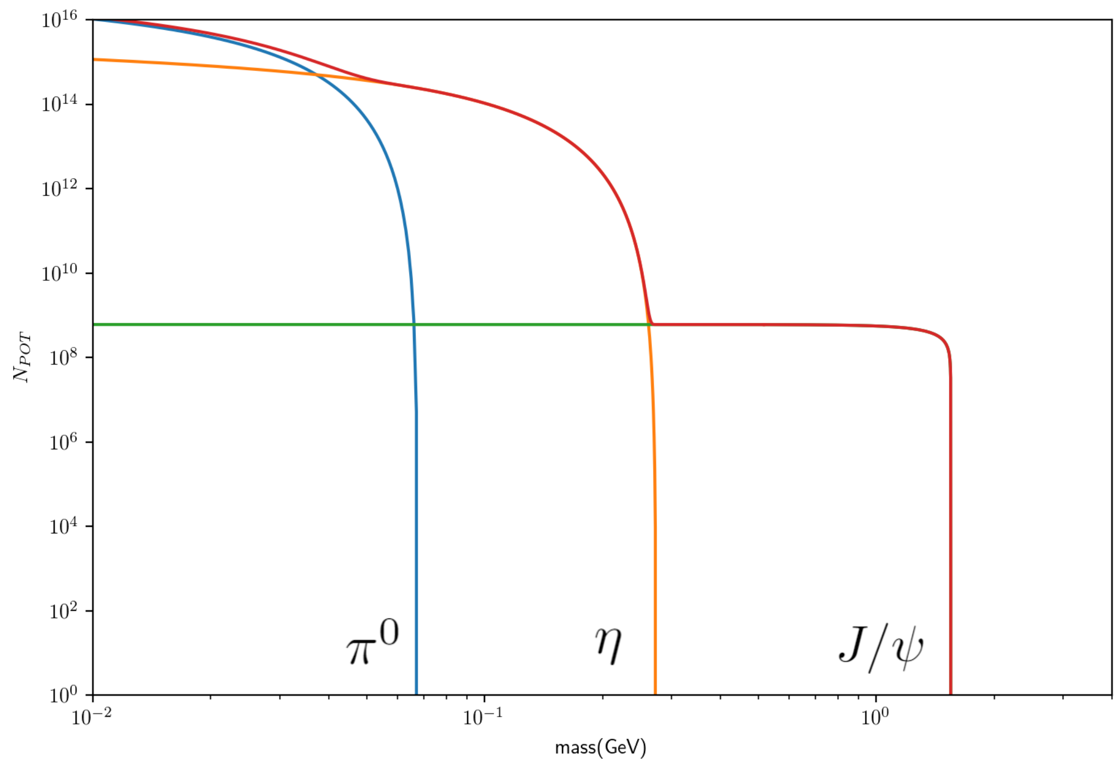
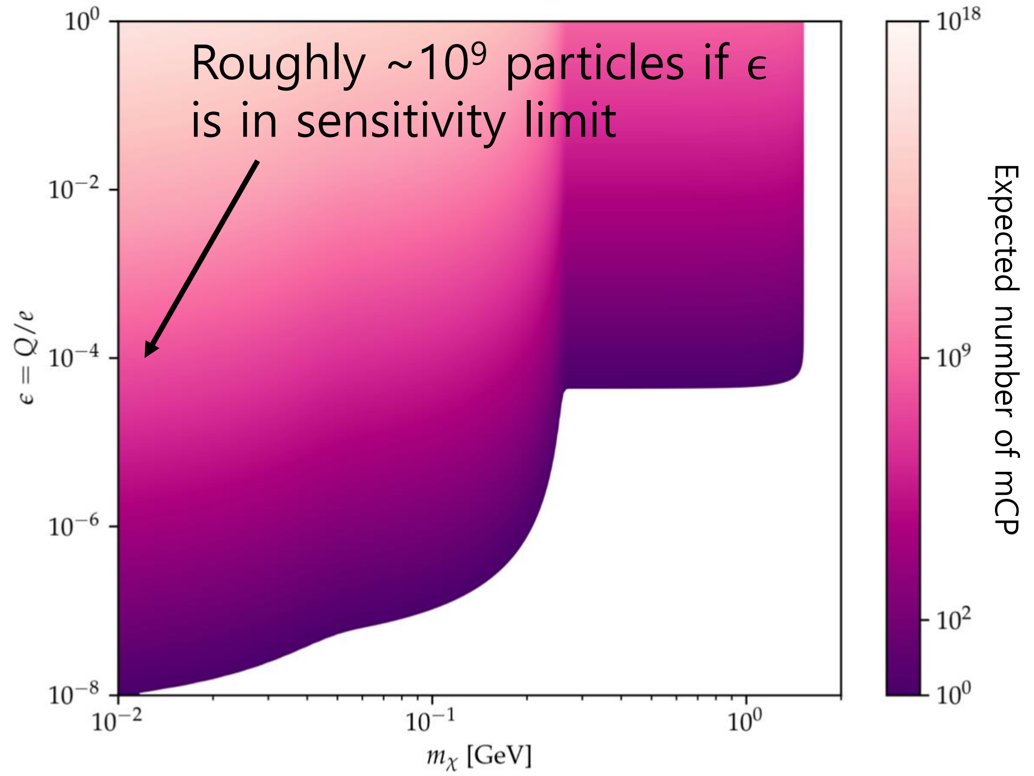


Figure 1: Expected number of MCP to reach a $0.5\mathrm{m}^2$ detector in J-PARC, assuming an accumulated POT of 10^{22}.

Production of mCP





Detector design

- 4-layer milliqan detector with 0.5 m^2
  - Smaller detector face given the distance between the target and the detector is s horter than FerMINI case
  - Bumping acceptance by factor of two d oes not change the sensitivity that much (will be discussed later)

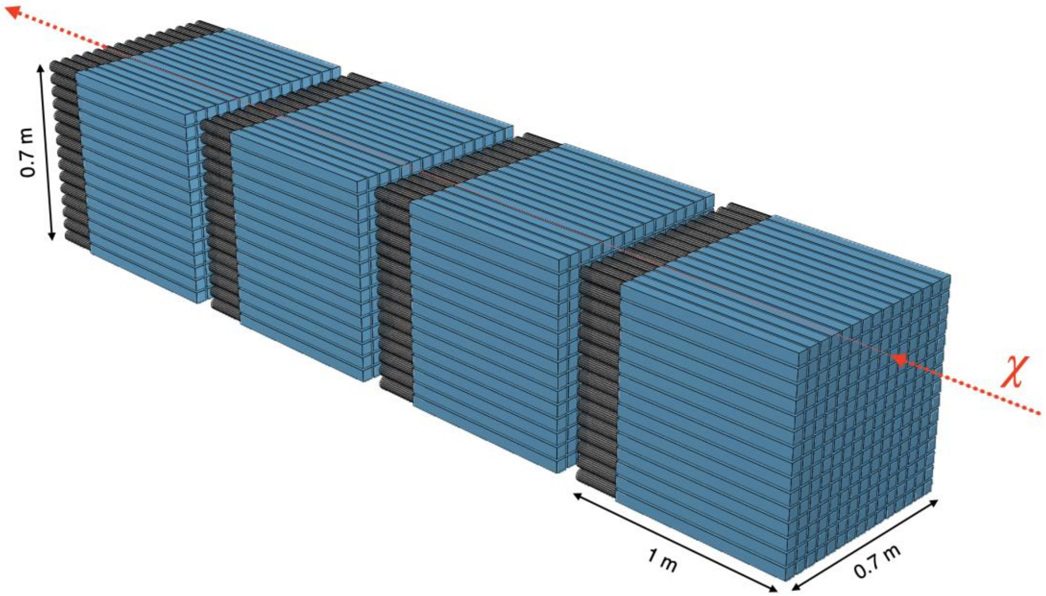
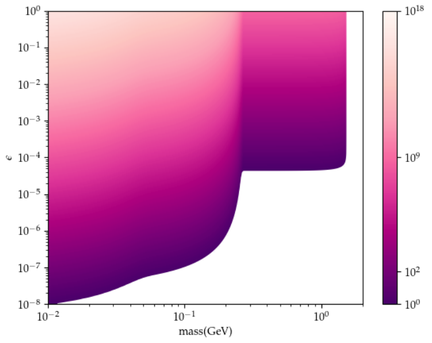


Figure 3: Demonstration of the SUBMET detector. There are four layers of scintillator bars (blue). At one end of each bar a PMT (black) is attached A χ will penetrate 4 layers in a narrow time window.

Backgrounds

- Beam-induced backgrounds
  - Muons from pion/kaon decay do not reach the detector (dE/dx = 4 MeV/cm for s oil => 60 GeV for 150 m)
  - Neutrino interactions: $O(10^7)$/layer for $N_{POT}=10^{22}$ gives ~0 bkg
  - Overlap with muons from neutrino interaction: ~5% of collisions will have produce muons in the detector
- Detector backgrounds
  - Random coincidence expected to be negligible
- Other sources
  - Cosmic shower (need in situ measurement)
- Assume N_{bkg} ~ O(1) for sensitivity study

Sensitivity

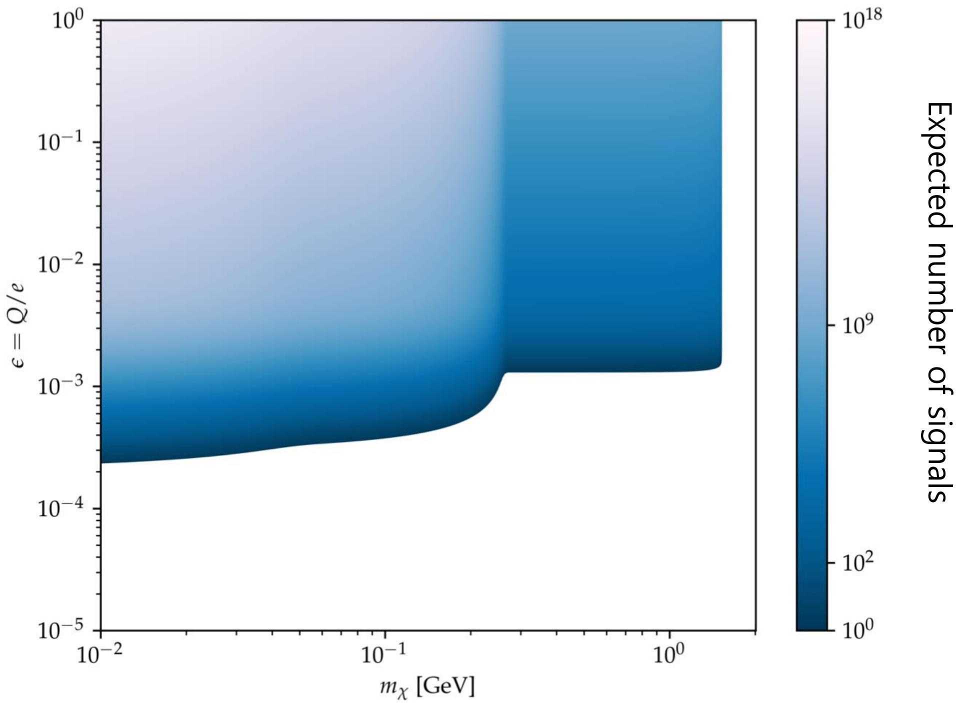


Production

× $P = (1 - e^{-N_{PE}})^n$ =

Probability to emit a photon in a single layer

Detector efficiency (n: number of layers)



Signal (n=4)

Sensitivity

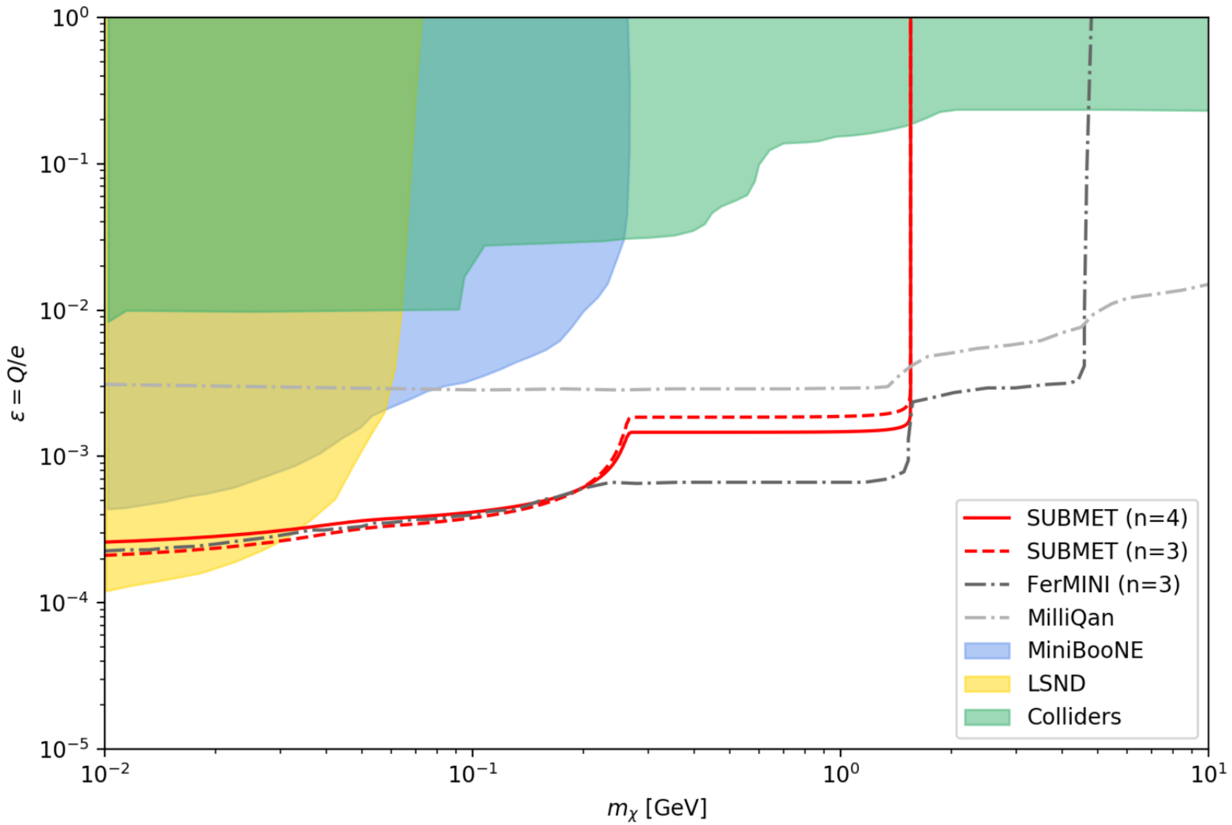


Figure 6: Exclusion at 95% CL for $N_{POT} = 10^{22}$. For comparison, the constraints from previous experiments are shown as shaded area and the expected sensitivity of the proposed experiments are drawn in gray dotted line. Note that FerMINI curve is from 3-layer detector design.

Sensitivity (alternative designs)

N_χ(relative)	N_{PE}(relative)	b	Exclusion limit on ϵ for $m_\chi = 10$ MeV/c^2
1	1	1	2.6×10^{-4}
2	1	1	2.4×10^{-4}
1	1	100	3.0×10^{-4}
1	2	1	1.9×10^{-4}
1	3	1	1.7×10^{-4}

- Not too sensitive to specific configurations
- The most sensitive is the scintillator yield

Summary

- P-P fixed target experiments such as J-PARC are better suited for mCP searches up to low GeV mass range.
- SUBMET provides sensivity down to $\epsilon \simeq 3 \times 10^{-4}$ for $m_\chi < 0.2$ GeV and to $\epsilon \simeq 1.5 \times 10^{-3}$ for $m_\chi < 1.5$ GeV.
- Increasing scintillator yield offers better sensitivity.

Thank you