J-PARC KOTO II
silicon detector opportunities

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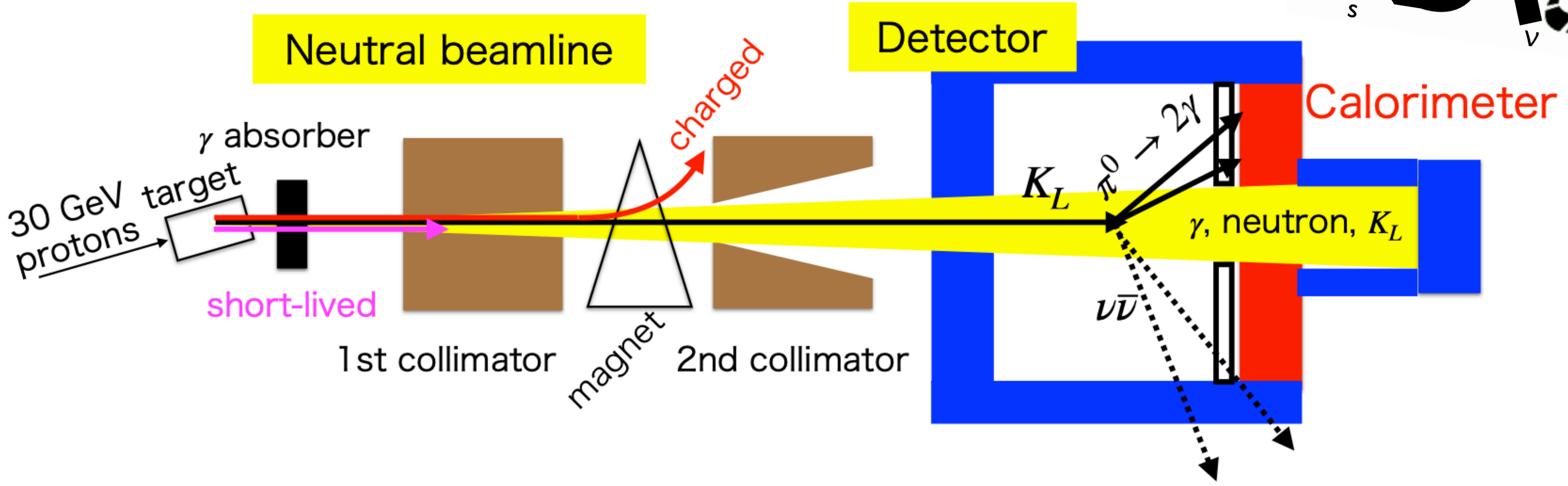
Discussion on Silicon detector projects

Measure $K_L \to \pi^0 \nu\nu$ (and $K_L \to \pi^0 \ell^+ \ell^-$)



Long narrow beamline + magnet. Long lived neutrals (γ, neutrons, K_L)

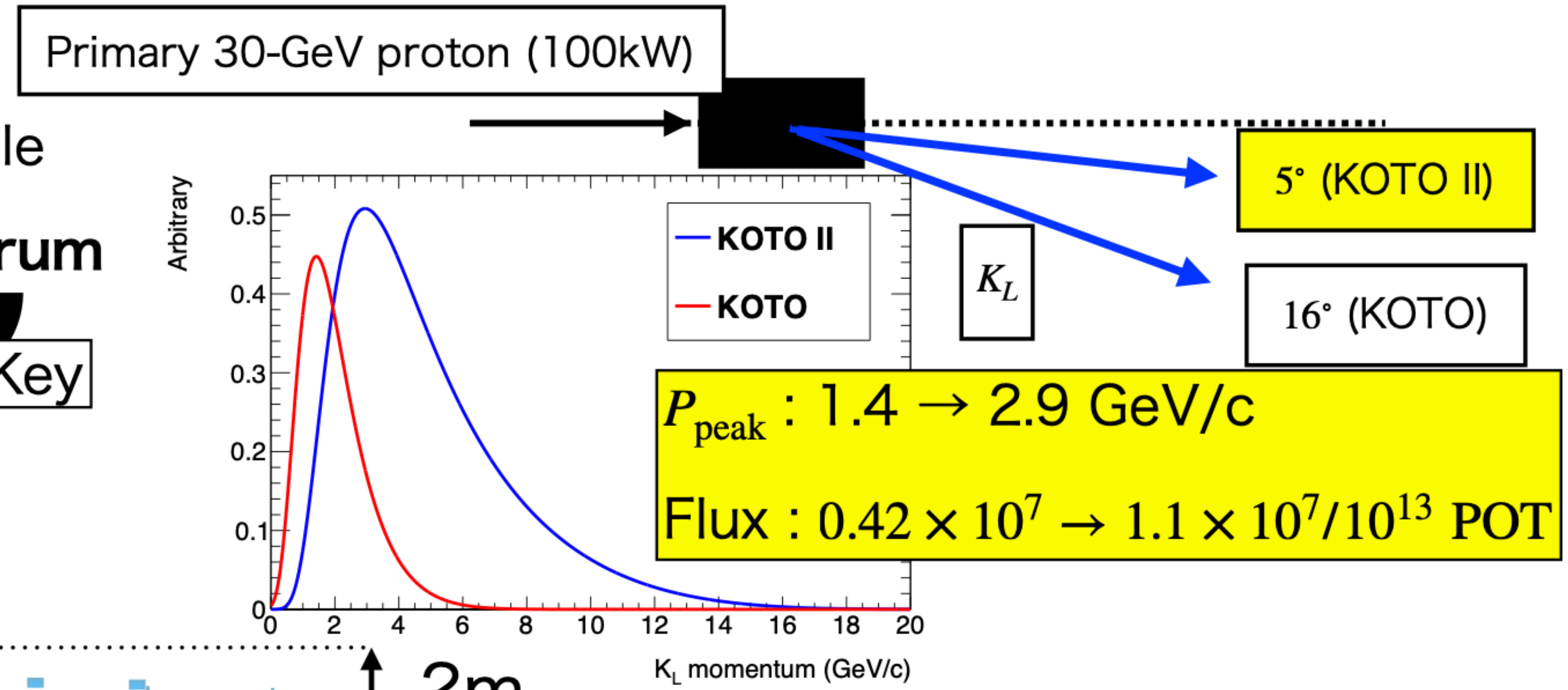
Signal: $\pi^0(\gamma\gamma)$ + nothing else. Use calorimeter and assume z vertex on beam axis.

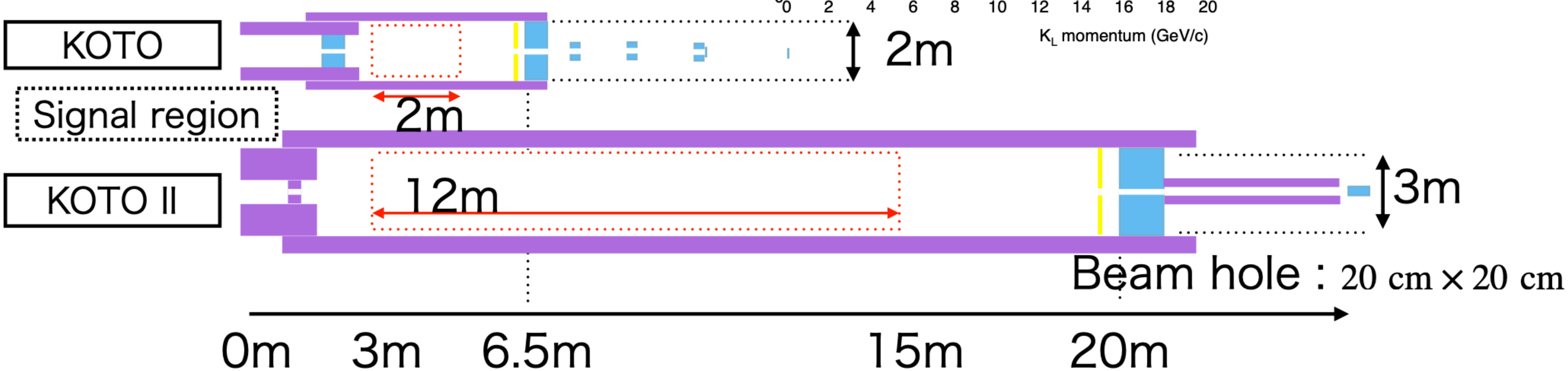
Veto counters to detect extra particles, suppress bkgs. Difficult to cover beam hole.

KOTO II proposal

- More K_L
  - Use forward production angle
    - $\times 2.6$ flux + **harder spectrum**
- More signal acceptance
  - Longer decay volume
  - Larger calorimeter

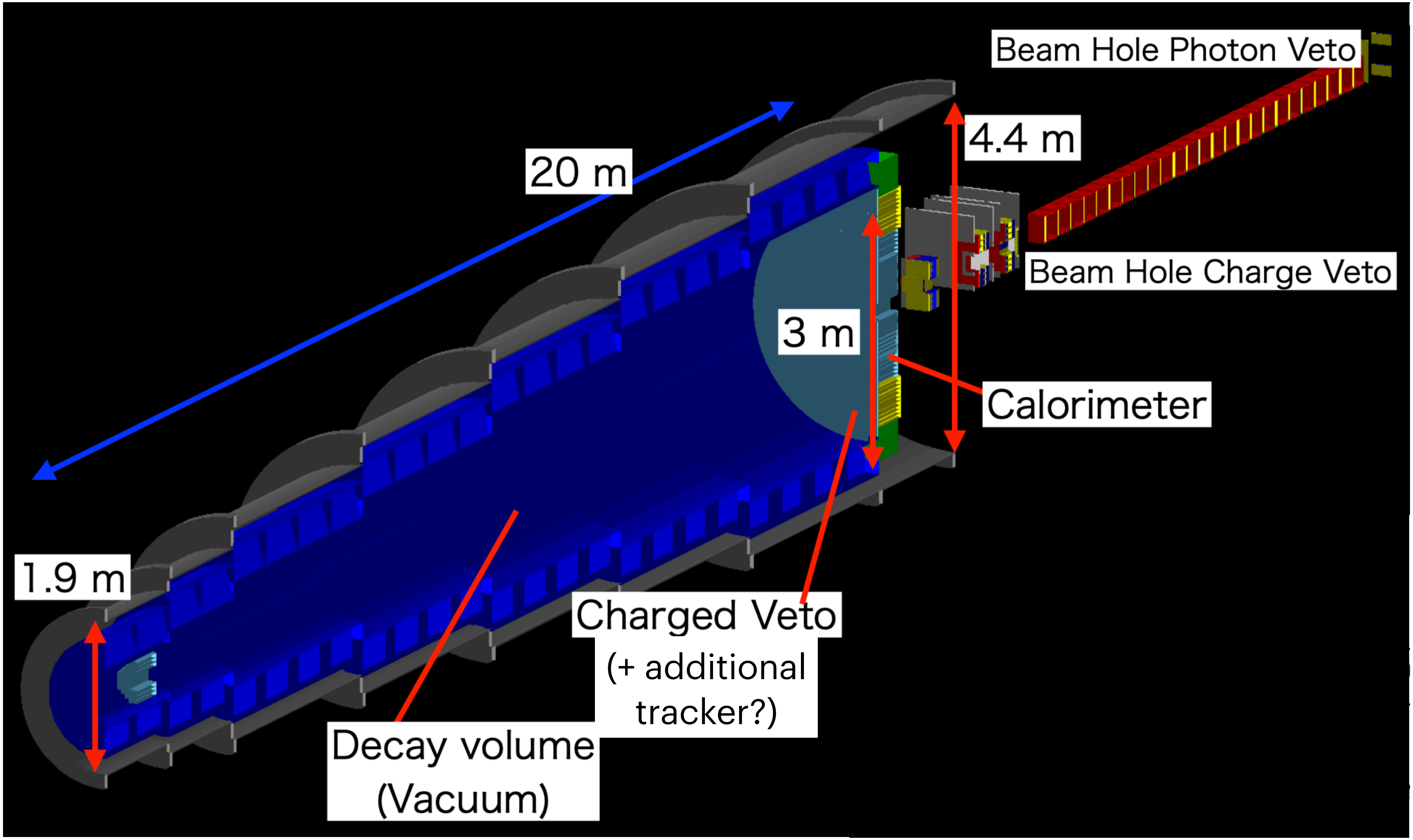
Key



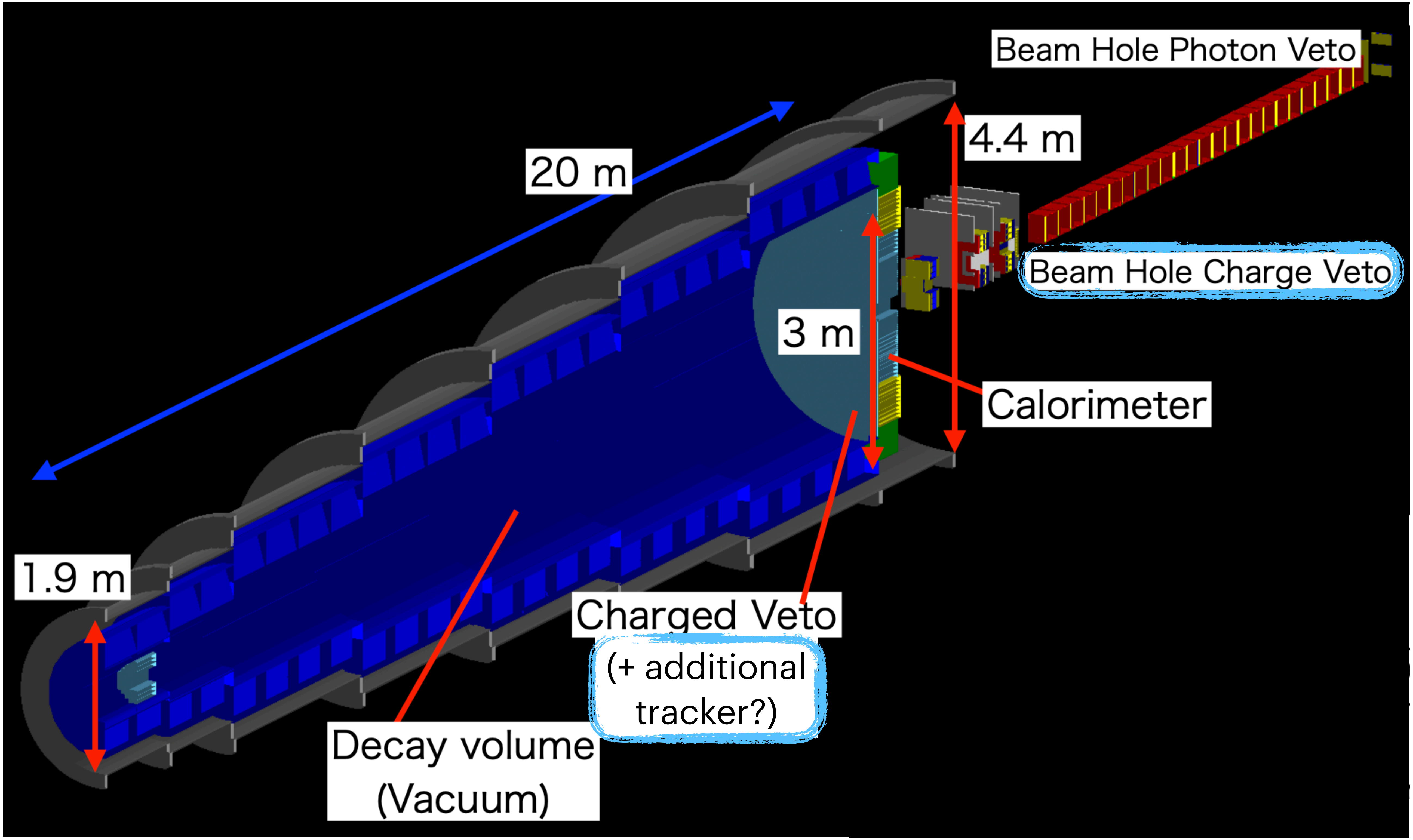


https://arxiv.org/pdf/2501.14827

Tentative plan



Tentative plan



Beam hole charge veto counter

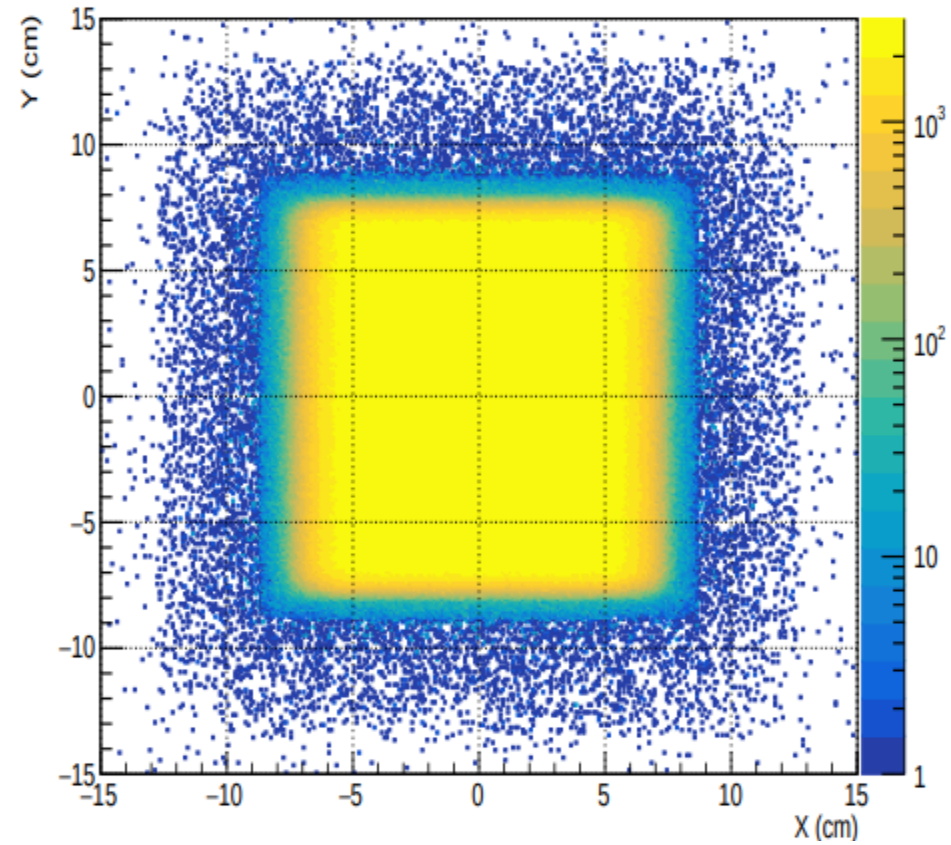
Neutral beams pass through the detector in 20x20cm beam hole. Essential to veto in-time photons/charged particles.

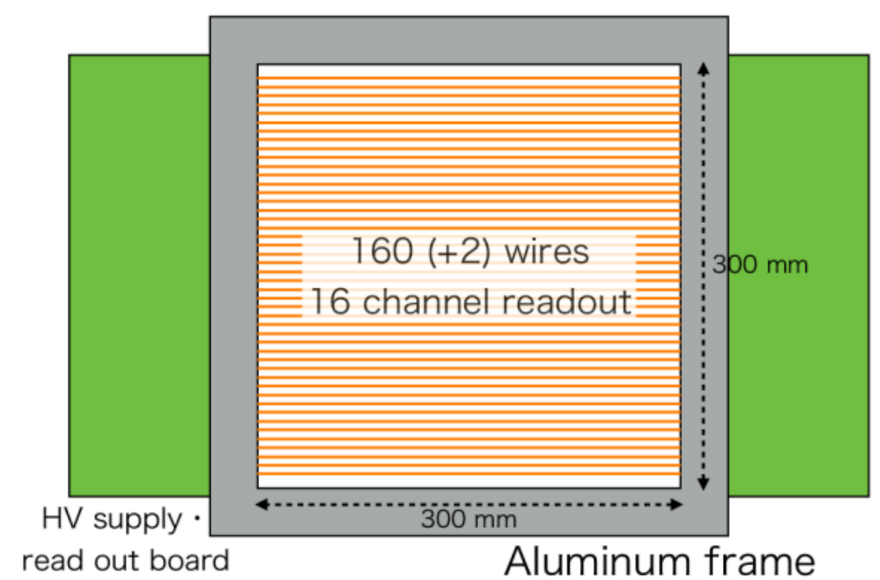
KOTO charged veto counter: thin gap chamber (poor timing resolution — 20 ns) → loss due to accidental event overlap.

KOTO II: considering silicon pixel detector with 2 planes, 200 μm each:
- Dose: 10^{13} 1 MeV neutron/cm^2,
- Charged particle hit rate: 0.2 MHz,
- Total hit rate (charged, neutrons, photons): 40 MHz,
- Time resolution: < 1 ns,
- Detection efficiency: > 99.5%.

Random veto (signal loss) 8.3% → <4%.

Other possibilities: thinner sensors — 50μm (MAPS) or faster timing (LGAD).





Tracker in forward region

Considering inclusion of tracker in forward region to increase $K_L \to \pi^0 \ell^+ \ell^-$ sensitivity.

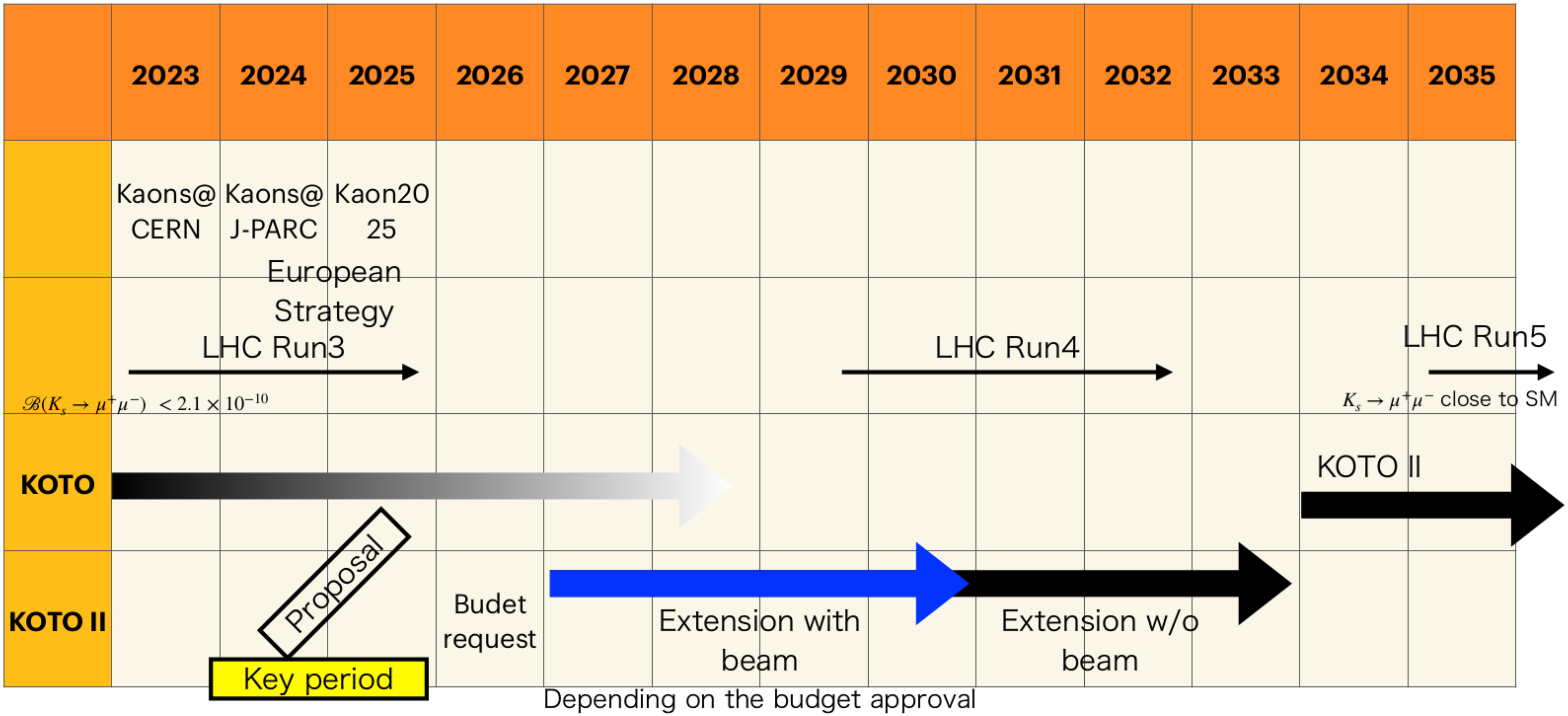
Two main scenarios:

- Simultaneous measurement of both channels — combine charged veto counter and additional thin tracker;
- Different data takings for $K_L \to \pi^0 \nu\nu$ and $K_L \to \pi^0 \ell^+ \ell^-$ — add new tracker (after ~8 years).

Two possible solutions (for now):

- Light-material tracking device in vacuum, based on evolution of Straw Tracker in NA62 (low material budget — < $0.5X_0$);
- Silicon pixels in inner region and scintillating fibers in outer region as in Mighty Tracker from LHCb Upgrade 2 (good time resolution — O(100ps)).

Timeline


2023
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Kaons@ CERN
Kaons@ J-PARC
Kaon20 25
European Strategy
LHC Run3
LHC Run4
LHC Run5
$\mathcal{B}(K_s \to \mu^+\mu^-) < 2.1 \times 10^{-10}$
$K_s \to \mu^+\mu^-$ close to SM
KOTO
KOTO II
KOTO II
Proposal
Key period
Budet request
Extension with beam
Extension w/o beam
Depending on the budget approval

Summary

KOTO: small collaboration, busy with data taking. KOTO II open to new members.

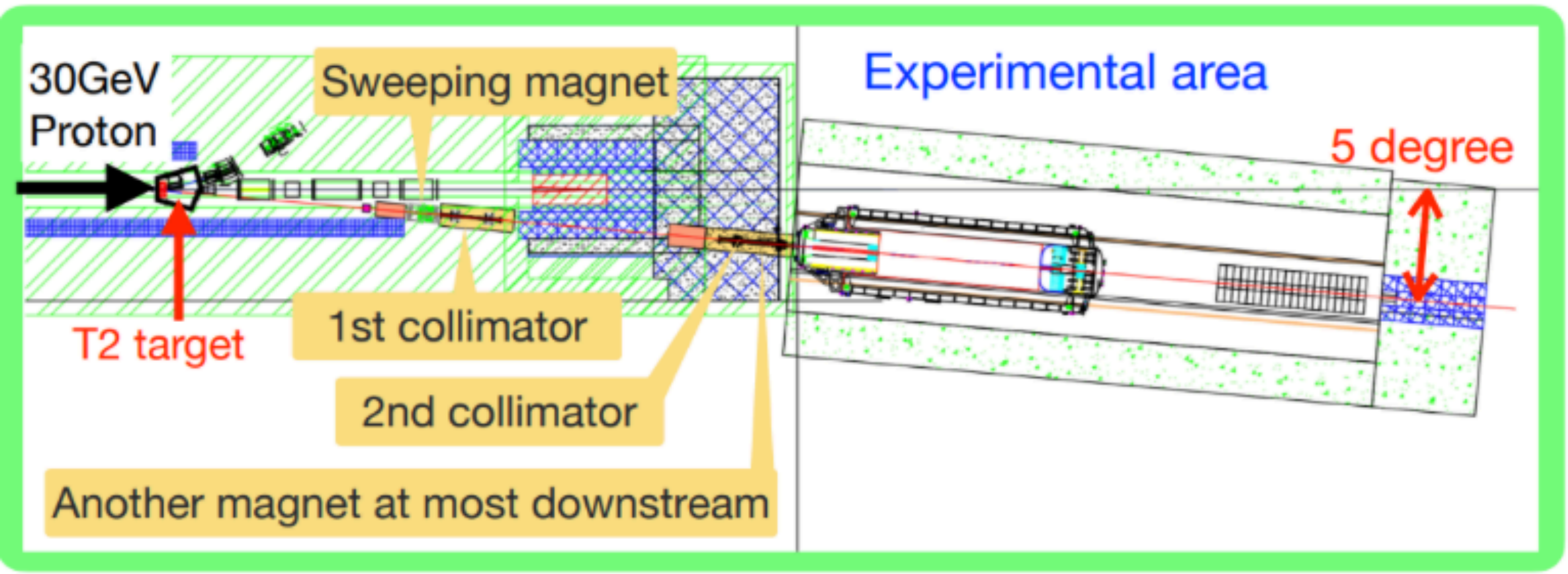
Two main open opportunities for silicon detectors:
- beam hole charge veto counter
- main forward tracker (still in discussion)

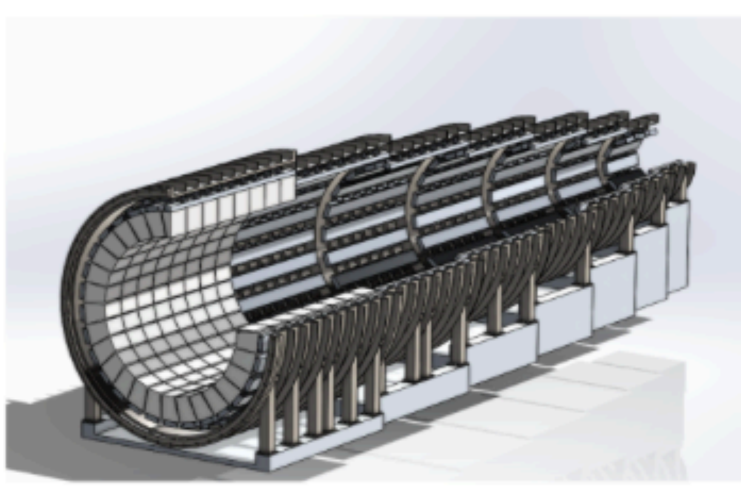
Birmingham and Pusan also interested — will form subgroup for discussion.

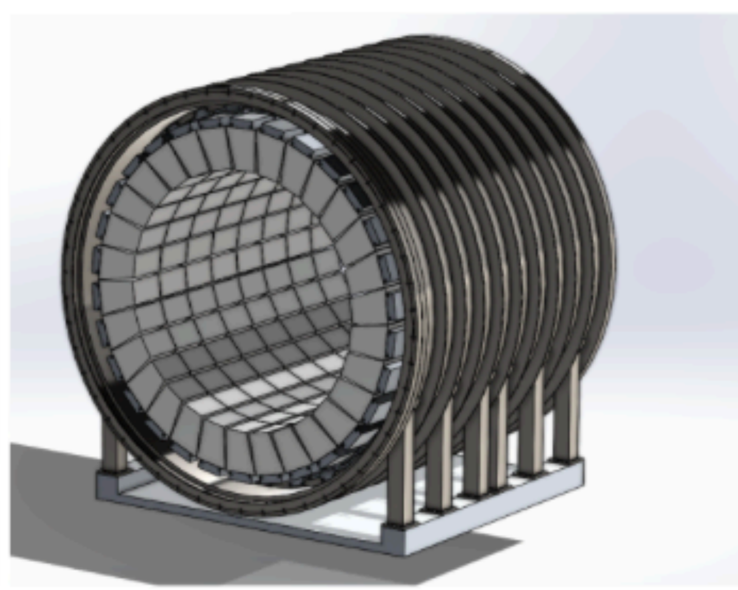
Other detector opportunities: https://indico.desy.de/event/48014/contributions/183739/subcontributions/8989/attachments/96005/131561/KOTO%20II.pdf

Backup

Design of the vacuum tank and beamline





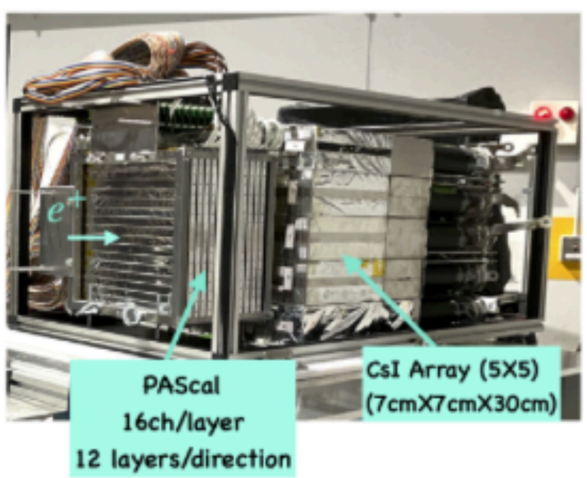


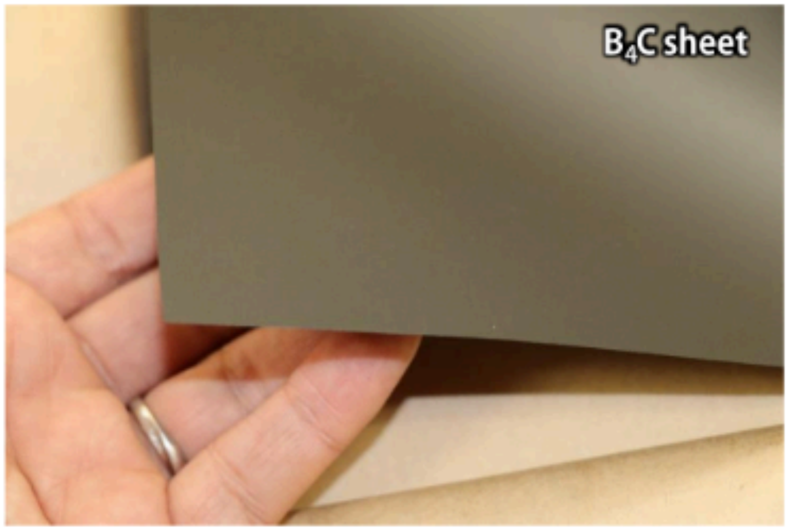
- KOTO II requires new beamline with 5 degree extraction angle.
- Much larger vacuum decay vessel with options to access detector components during shutdown periods (couple of months each year)

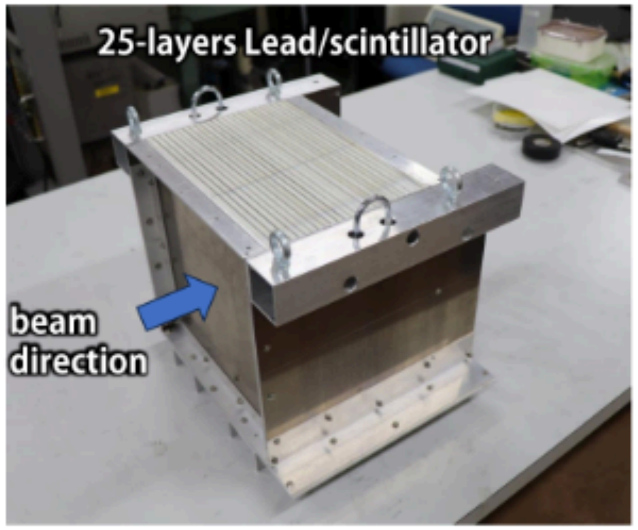
→Engineering opportunities

Main calorimeter upgrade

Technology (Experiment)	Depth	Energy resolution	Timing resolution
CsI (KOTO)	$27X_0$	$2\%/\sqrt{E} \oplus 1\%$	115 ps$/\sqrt{E} \oplus 5$ ps$/E$ $\oplus 130$ ps
Scintillator/Pb (KOPIO)	$16X_0$	$3\%/\sqrt{E}$	90 ps$/\sqrt{E}$
Scintillator fiber/Pb spaghetti (KLOE)	$15X_0$	$5.7\%/\sqrt{E} \oplus 0.6\%$	54 ps$/\sqrt{E} \oplus 140$ ps







- Larger vacuum vessel radius →twice larger calorimeter area
- Options to reconstruct photon angles using preshower calorimeter
- New CsI crystals outside existing or brand new calorimeter.
- Discussion of thermal neutron blind calorimeter with B_4C sheets inserted

Barrel counters with tracking, forward tracking

- Existing KOTO lead-scintillator counters are sufficient, however many more must be built . The end part of the Barrel Counter can be finely segmented in scintillating strips to for tracking (potential contribution from Mainz).
- Discussions of possible scenarios for main forward tracking (3 m diameter)
  - Light-material tracking device in vacuum, based on an evolution from the Straw Tracker in the NA62
  - Silicon pixels in the inner region and scintillating fibers in the outer region as in the Mighty Tracker from the LHCb Upgrade 2