KOTO II prospects and plans

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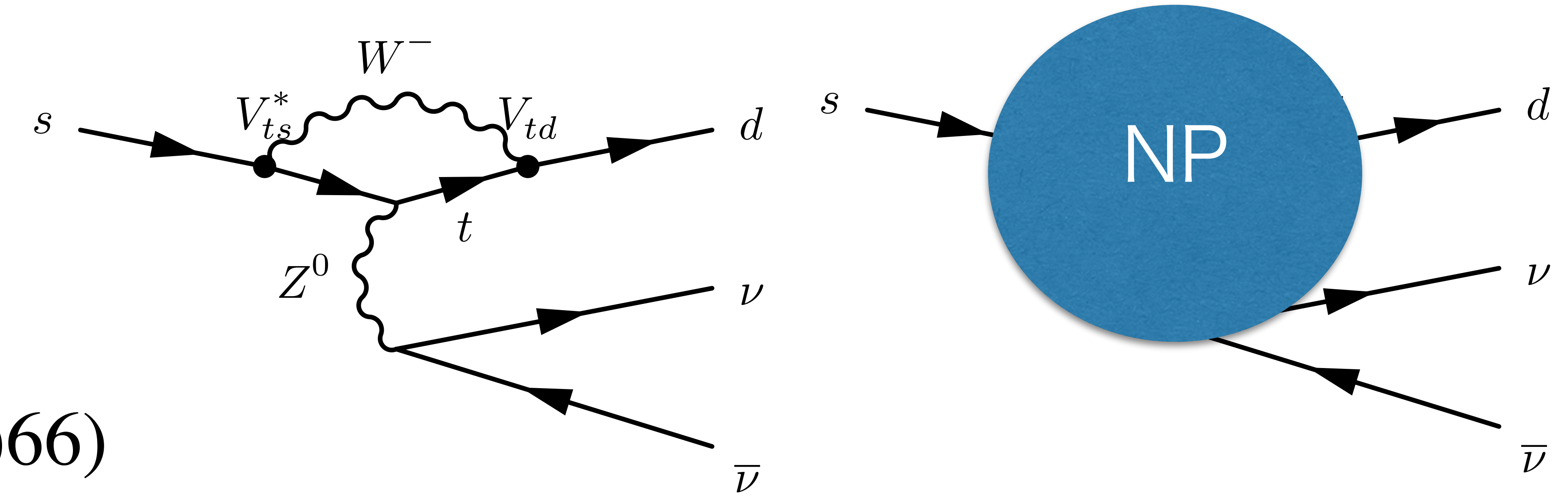
2023/9/13 Kaons@CERN 2023

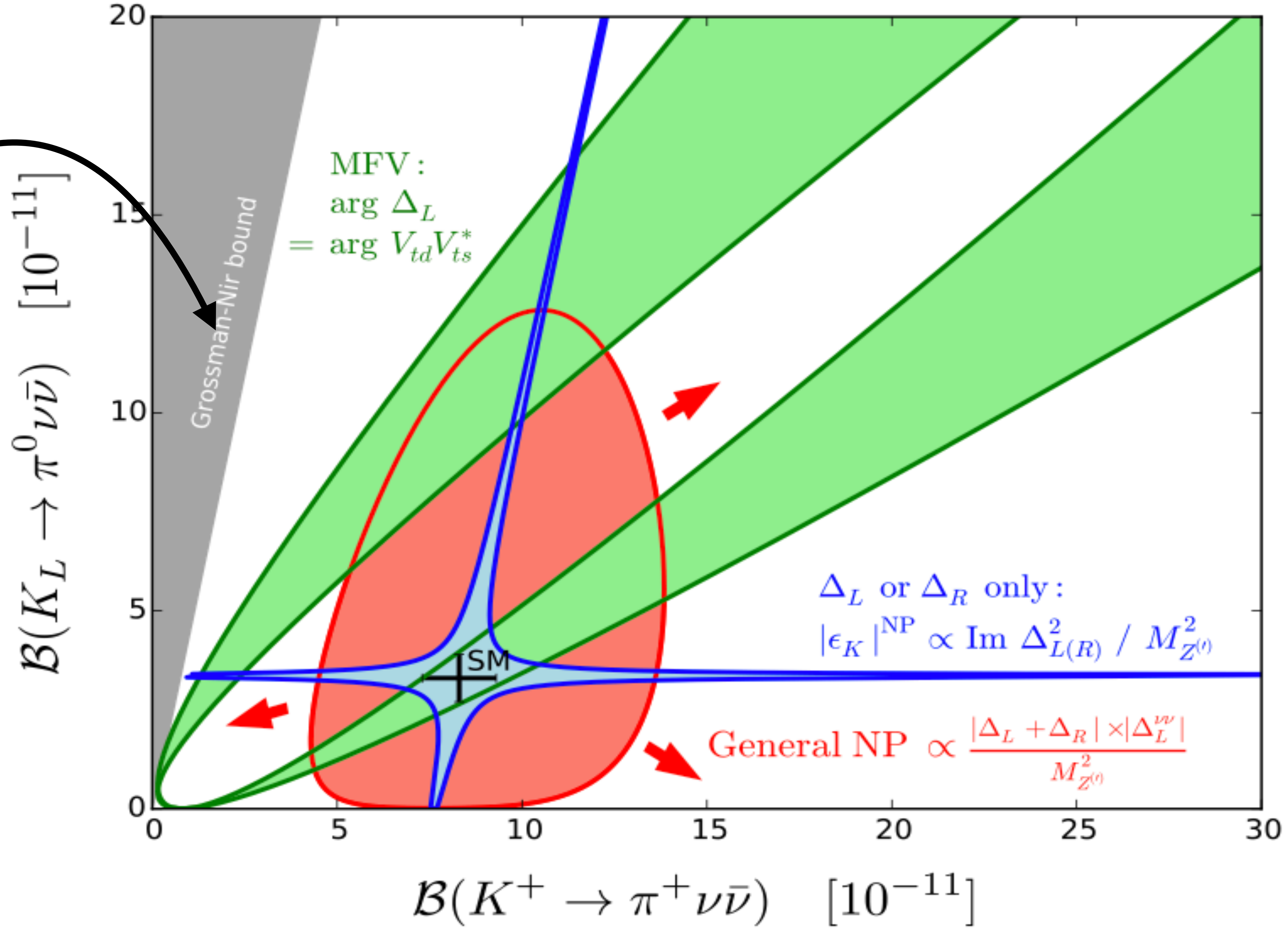
$K_L \to \pi^0 \nu\bar{\nu}$



- $\mathscr{B}_{\mathrm{SM}}(K_L \to \pi^0 \nu\bar{\nu}) = (3.4 \pm 0.6) \times 10^{-11}$ (JEHP11(2015)033)

  $(2.94 \pm 0.15) \times 10^{-11}$ (Eur.Phys.J.C 83 (2023)66)
  - Suppressed SM process
  - Theoretically clean
    - CKM parameter uncertainty
    - theoretical uncertainty ~2%
- Sensitive to new physics
  - High energy scale as large as 1000 TeV
  - Correlation to $\mathscr{B}(K^+ \to \pi^+ \nu\bar{\nu})$
    - Grossman-Nir bound

      $\mathscr{B}(K_L \to \pi^0 \nu\bar{\nu}) < 4.3 \mathscr{B}(K^+ \to \pi^+ \nu\bar{\nu})$



Sensitivity —Ultimate Grossman-Nir bound —

- Ultimate Grossman-Nir bound

  $\mathscr{B}(K^+)_{SM} = (8.4 \pm 1.0) \times 10^{-11}$

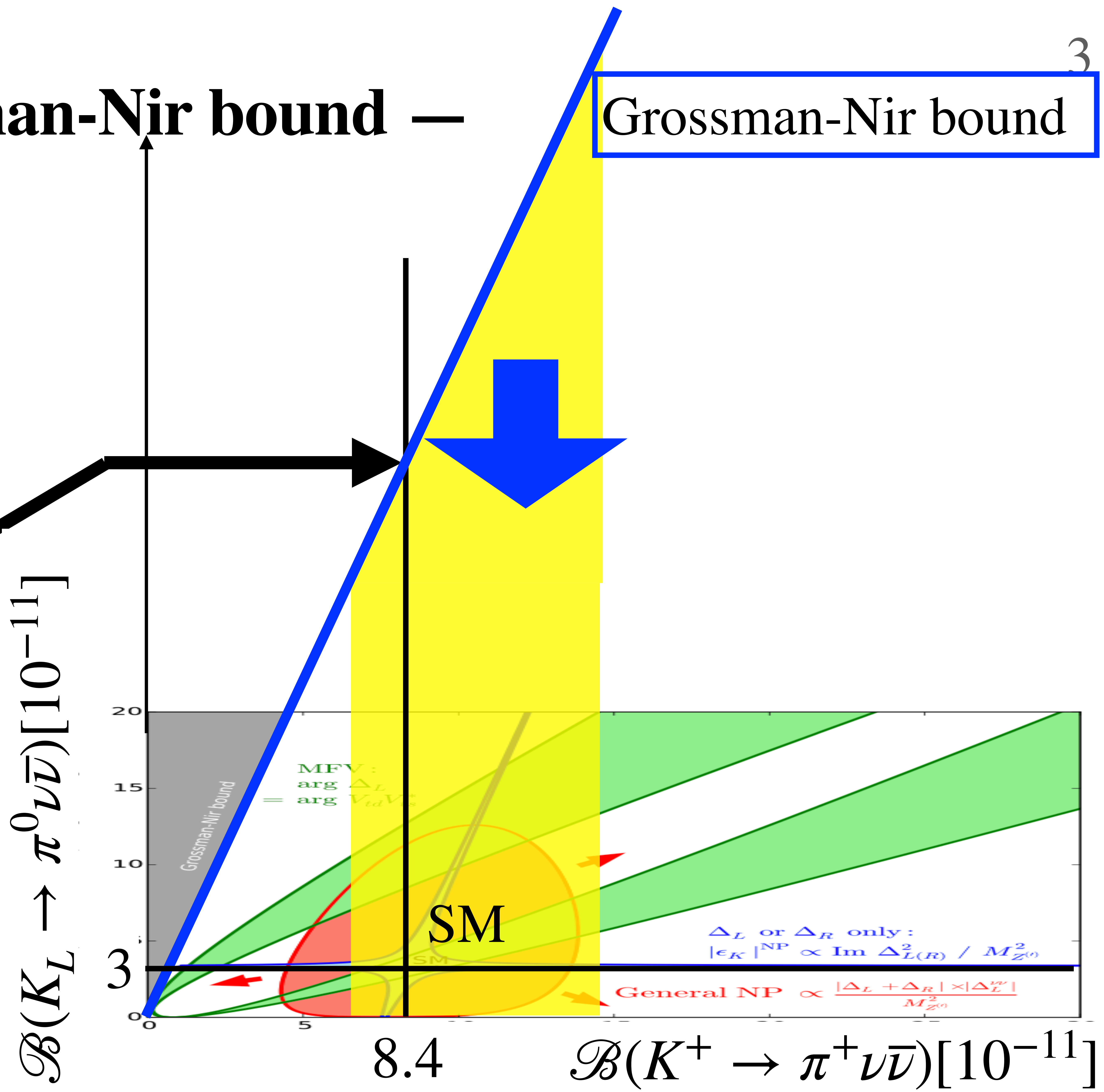
  $\rightarrow \times 4.3$: $(3.6 \pm 0.4) \times 10^{-10}$

  (bench mark of future bound)

- Goal of current KOTO experiment

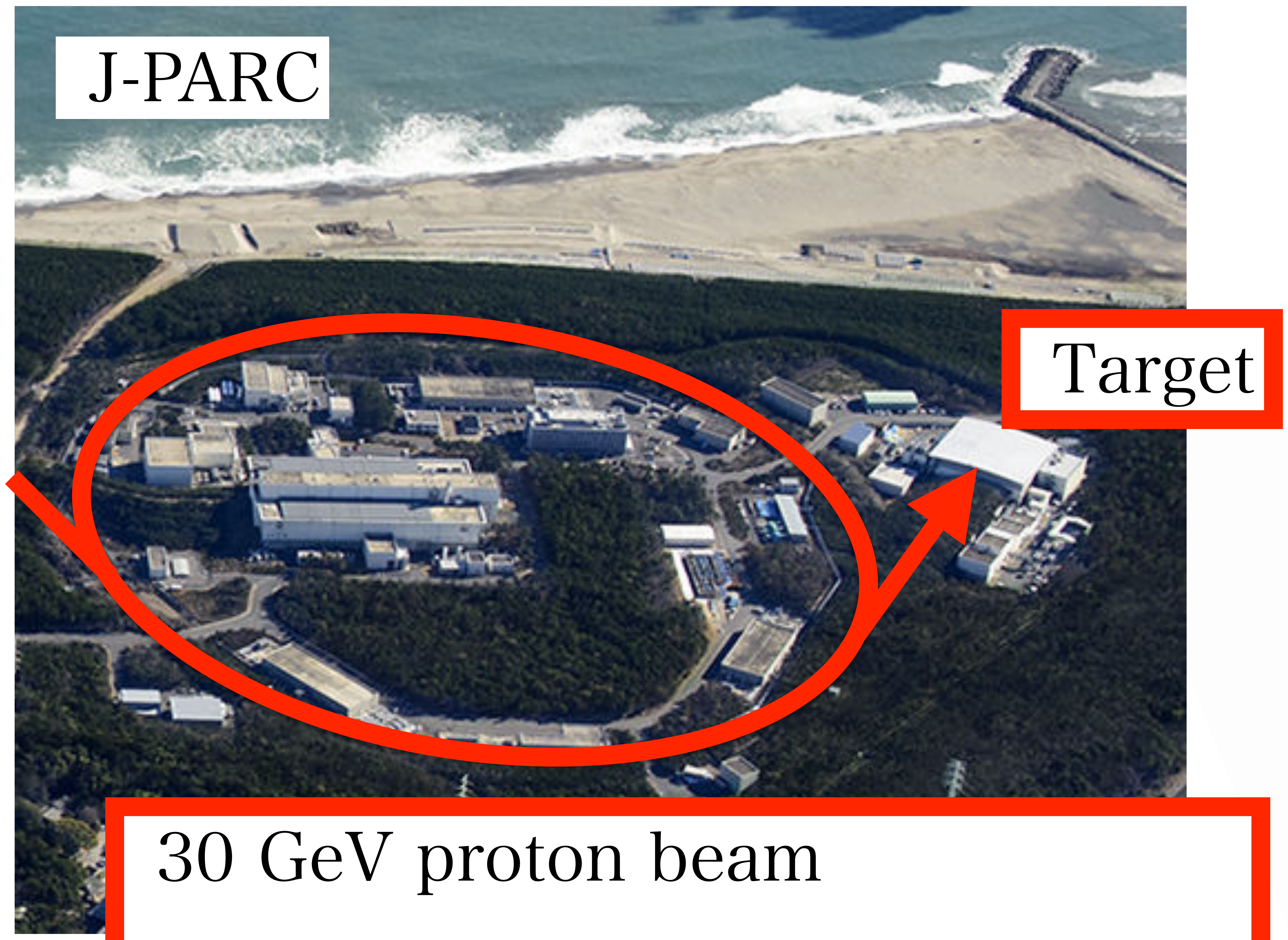
  SES: below 10^{-10}

  $\rightarrow$Upper limit$<3.6 \times 10^{-10}$



NA62 : $(10.6^{+4.0}_{-3.4} \pm 0.9) \times 10^{-11}$ (68 % CL) JHEP 06 (2021), 093

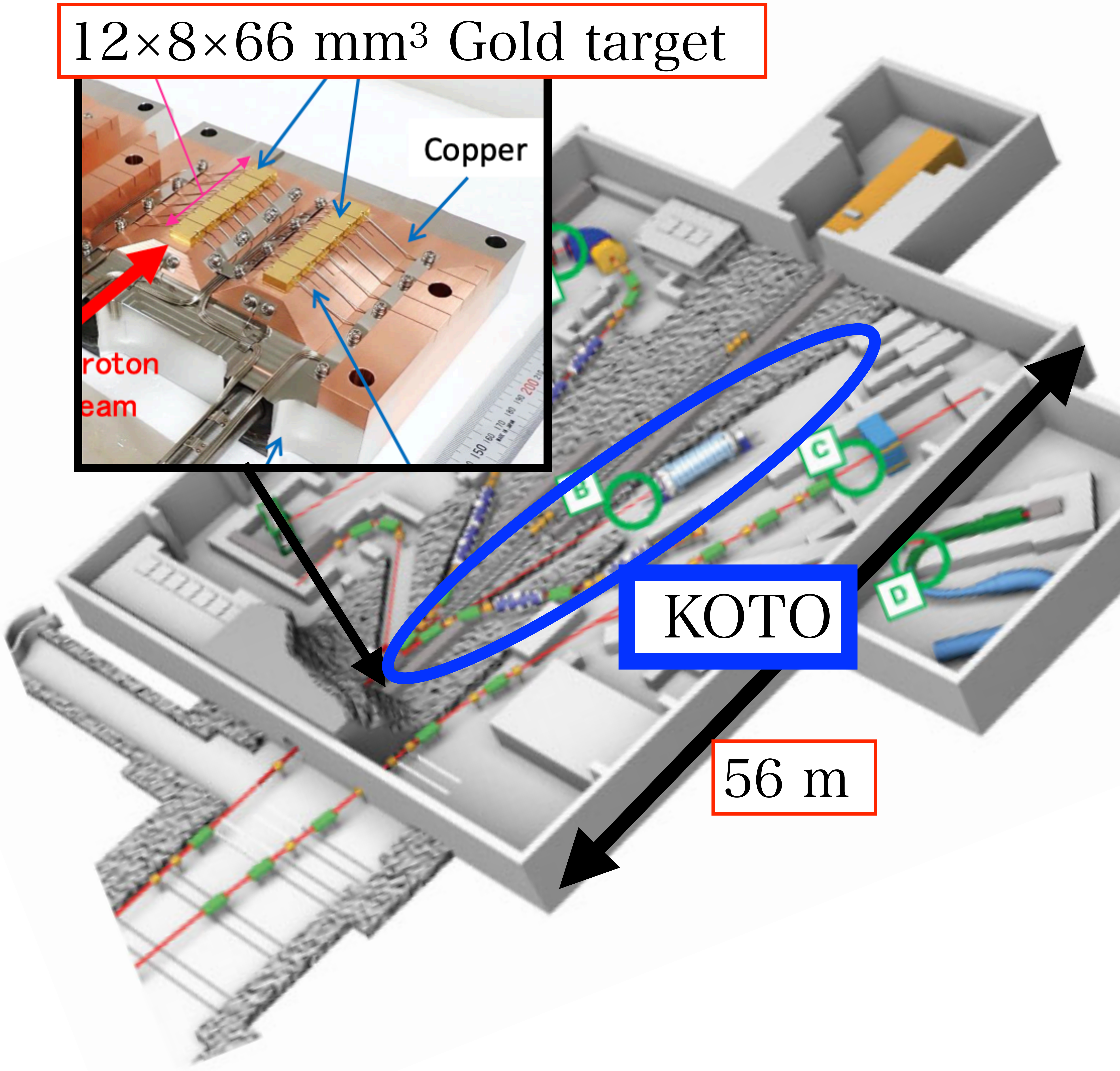
KOTO experiment in Hadron Experimental Facility at J-PARC



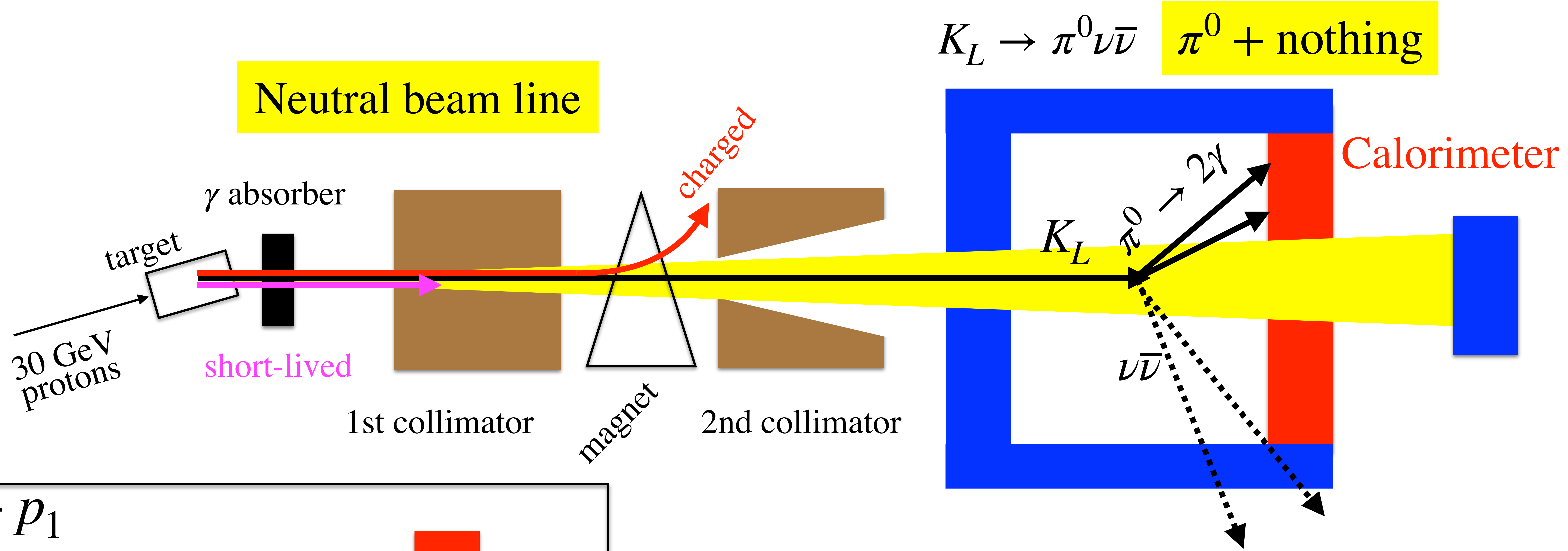
30 GeV proton beam

Slow extraction

65 kW, 2-s spill / 5.2-s spill (2021)

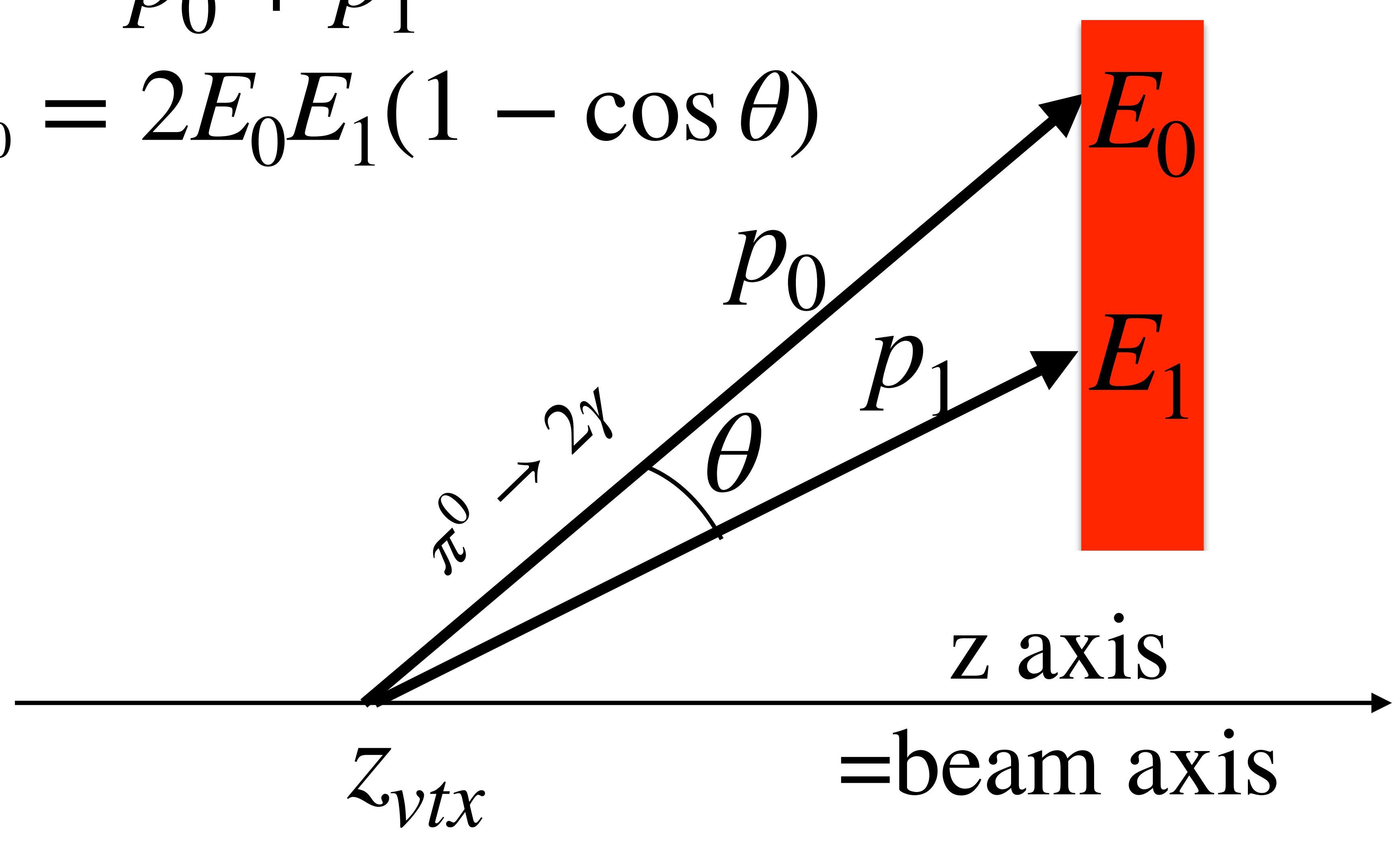


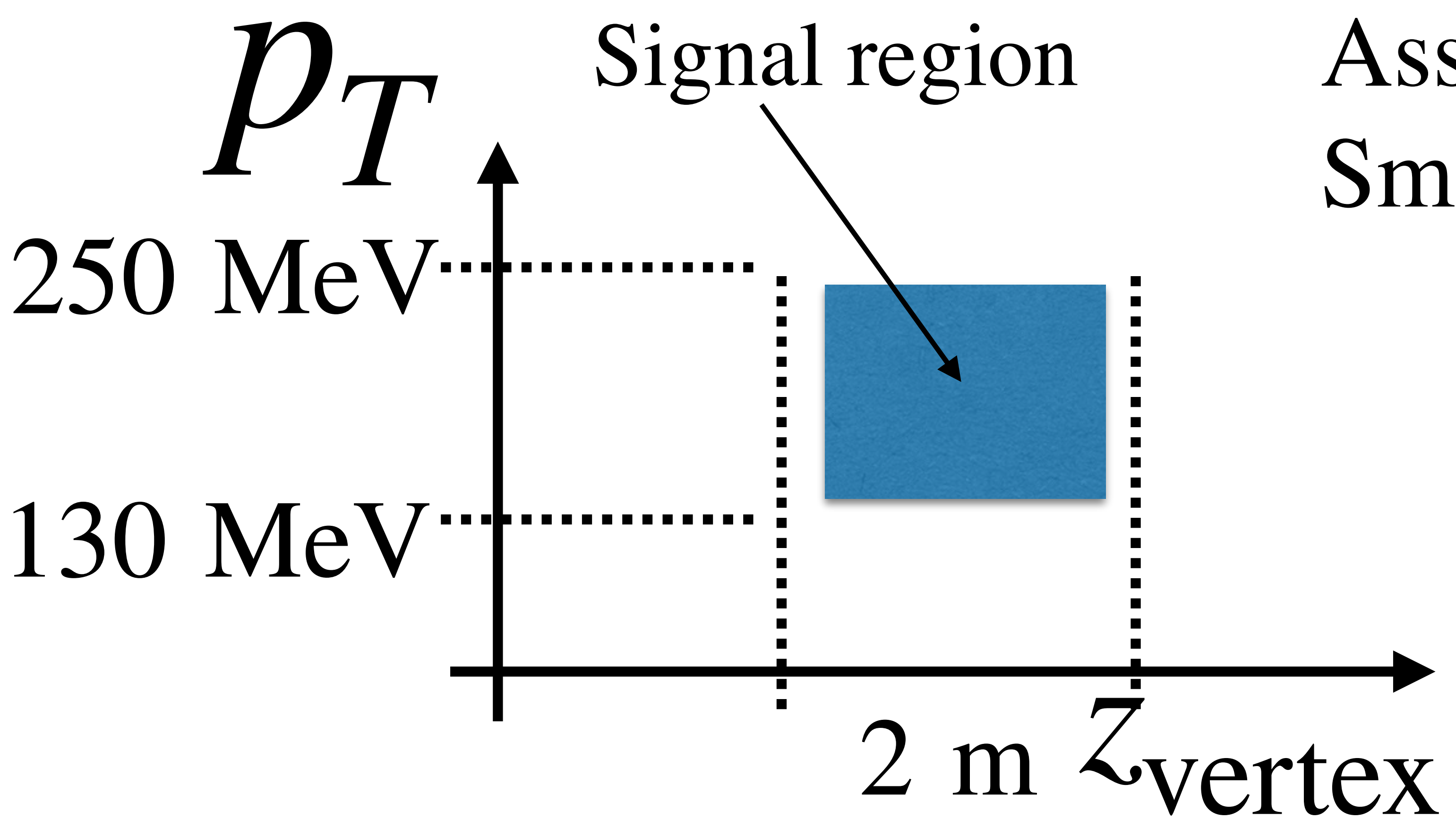
Concept of signal detection



$p_{\pi^0} = p_0 + p_1$

$m_{\pi^0}^2 = 2E_0E_1(1 - \cos\theta)$





Assume the vertex on beam axis
Small beam hole for veto

⇕

Narrow beam

Where are we? KOTO results of 2021 analysis

source	Current estimation
Upstream π^0	0.064±0.050(stat)±0.006(sys)
$K_L \to 2\pi^0$	$0.060 \pm (0.022)_{stat}(^{+0.051}_{-0.060})_{sys}$
K^+	$0.043 \pm (0.015)_{stat}(^{+0.004}_{-0.030})_{sys}$
Hadron cluster BG	0.024±0.004(stat)±0.006(sys)
Scattered $K_L \to 2\gamma$	0.022±0.005(stat)±0.004(sys)
Halo $K_L \to 2\gamma$	0.018±0.007(stat)±0.004(sys)
η production in CV	0.023±0.010(stat)±0.006(sys)
Sum	0.255±0.058(stat) $(^{+0.053}_{-0.068})_{sys}$

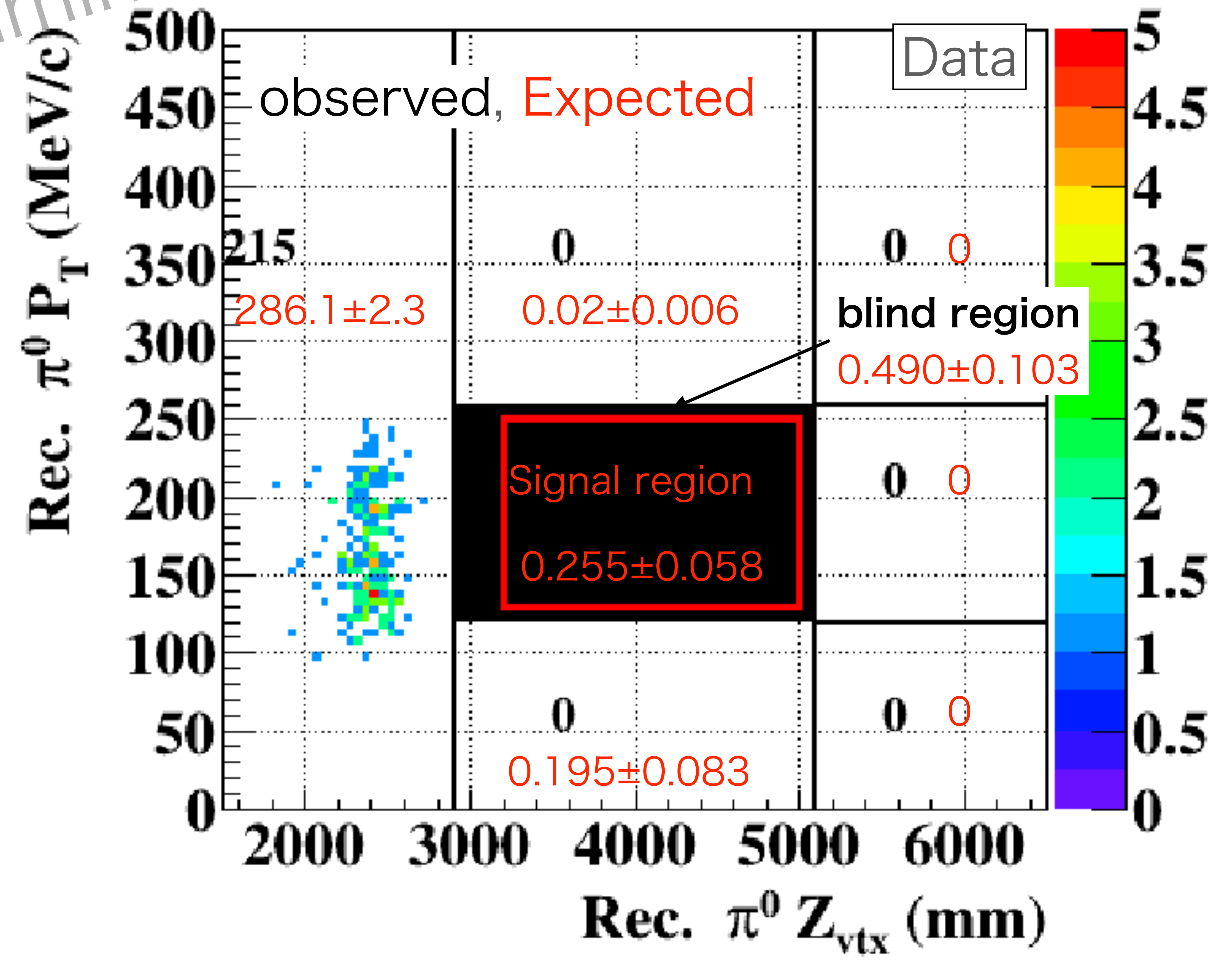
56

Single Event Sensitivity(S.E.S.):8.7×10^{-10}

c.f. 2016-2018 analysis:7.2×10^{-10}

BG Estimation

c.f. 2016-2018 analysis:1.23±0.26



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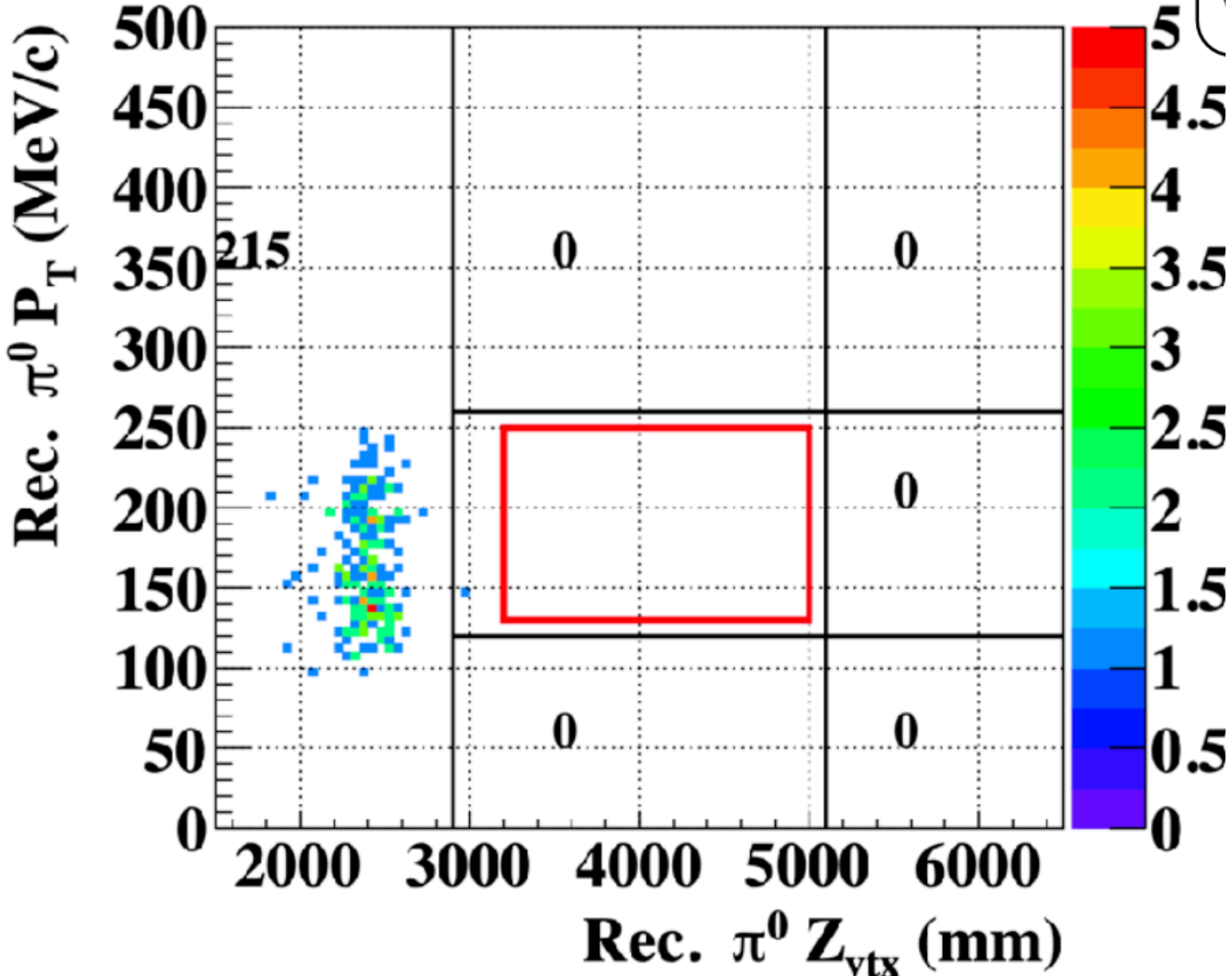
Single Event Sensitivity(S.E.S.):8.7×10^{-10}

c.f. 2016-2018 analysis:7.2×10^{-10}

- No signal candidate observed
  - $BR<2.0\times10^{-9}$@90% C.L.

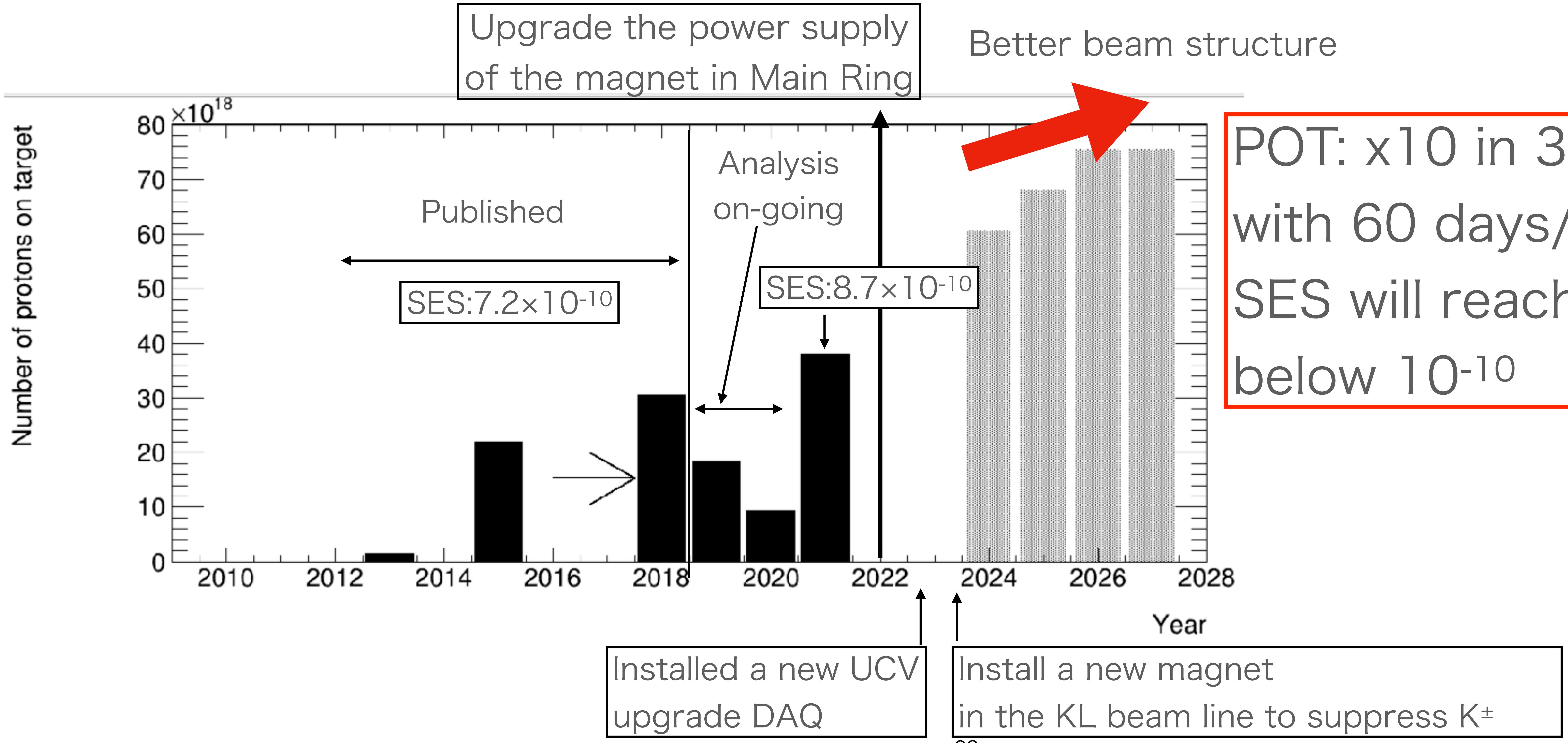


Prospects for future run

K. Shiomi
KEK IPNS seminar

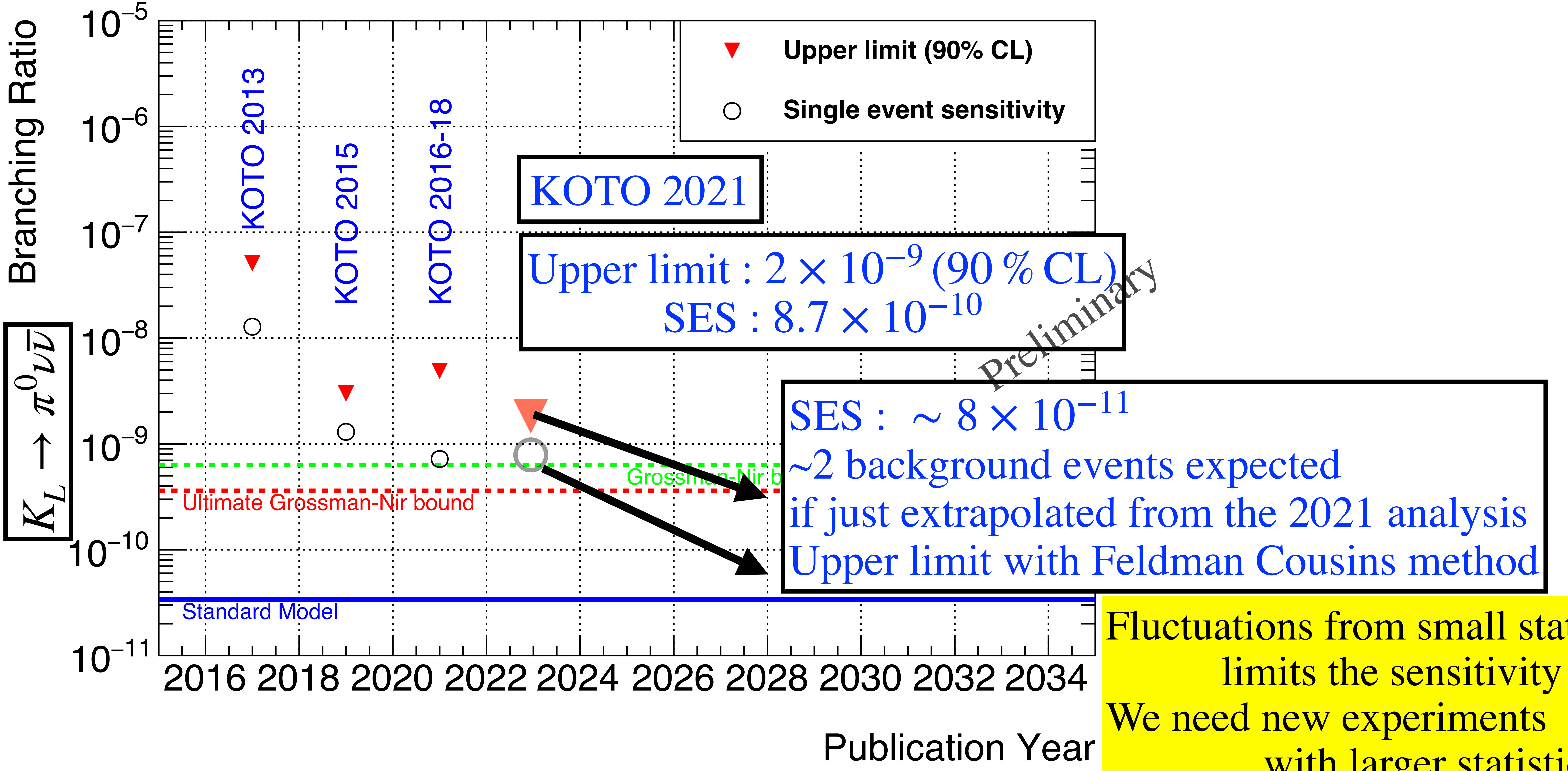
Beam Power :64kW→ 80-100kW

Better beam structure



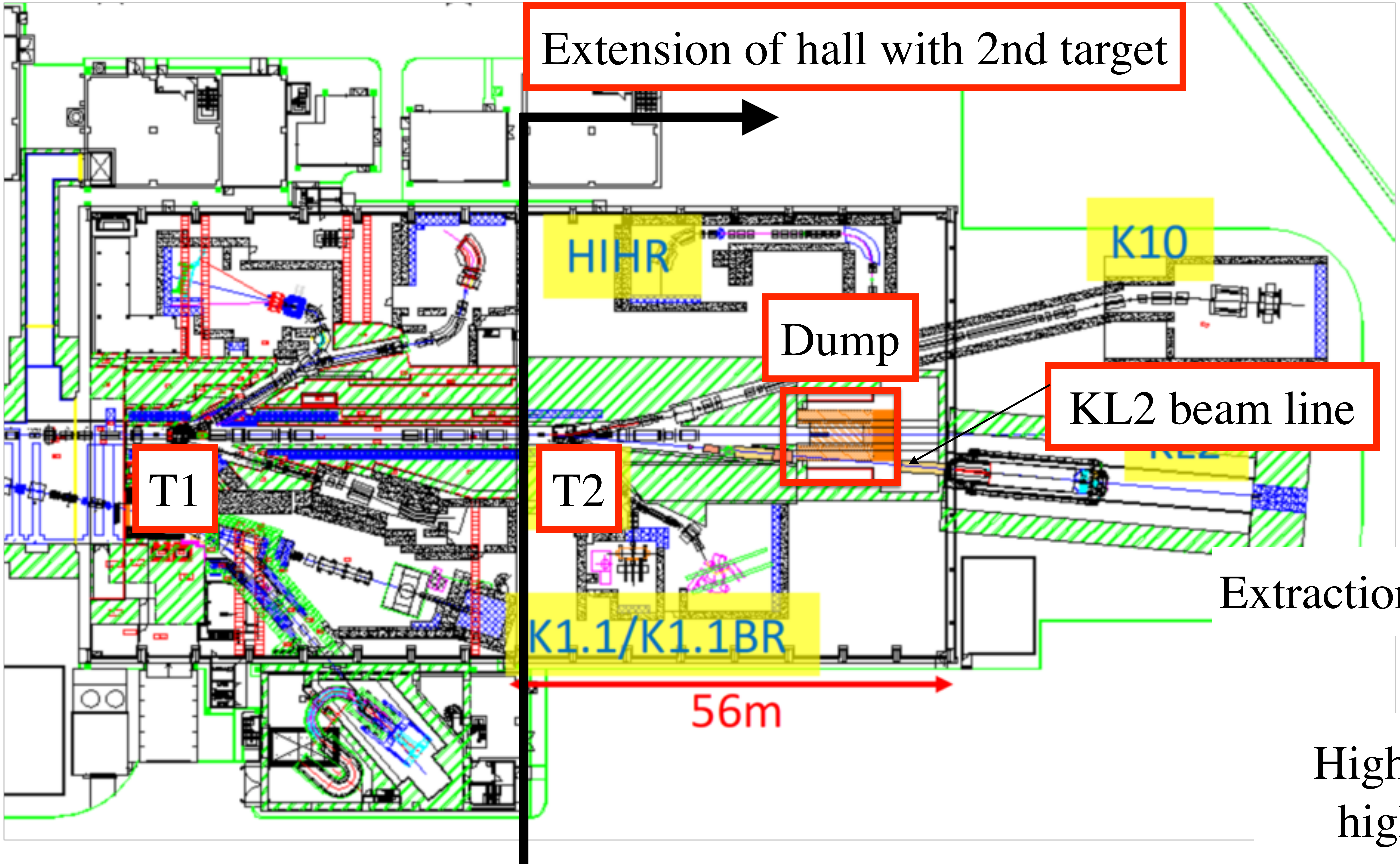
POT: x10 in 3-4 years
with 60 days/year data taking
SES will reach the sensitivity
below 10^{-10}

KOTO current status and prospects



Fluctuations from small statics limits the sensitivity
We need new experiments with larger statistics

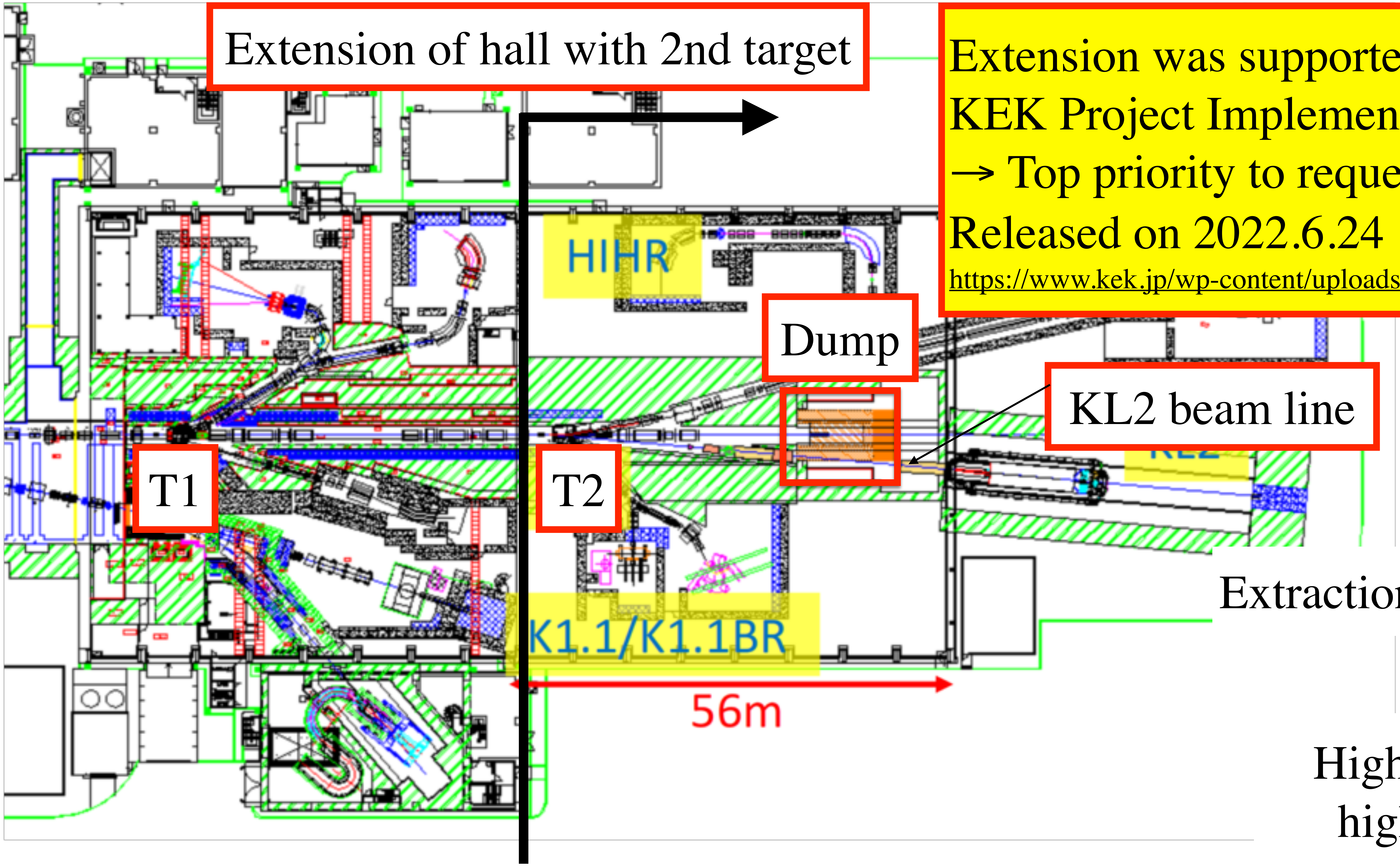
KOTO II with extension of hadron experimental facility



Extraction angle: 16° → 5°

Higher momentum & higher intensity K_L

KOTO II with extension of hadron experimental facility



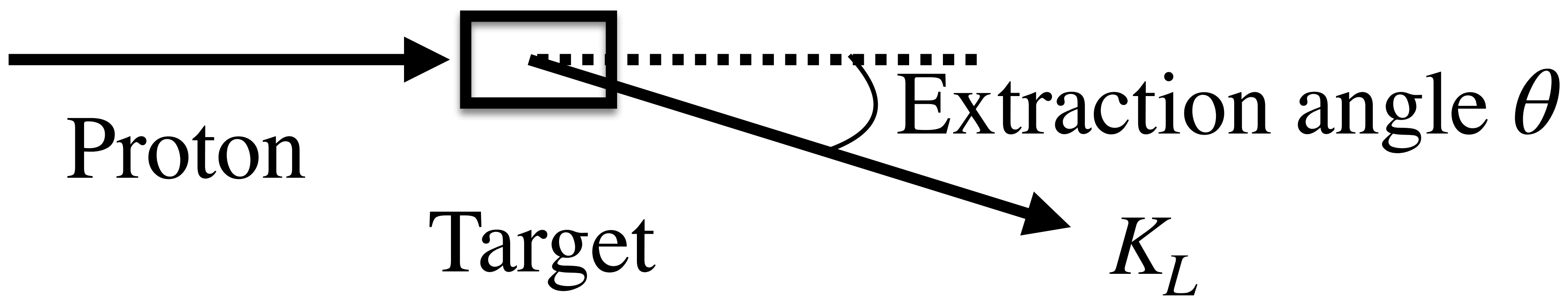
Extension was supported by
KEK Project Implementation Plan 2022
→ Top priority to request new budget
Released on 2022.6.24
https://www.kek.jp/wp-content/uploads/2022/07/KEK-PIP2022.pdf

Extraction angle: 16° → 5°

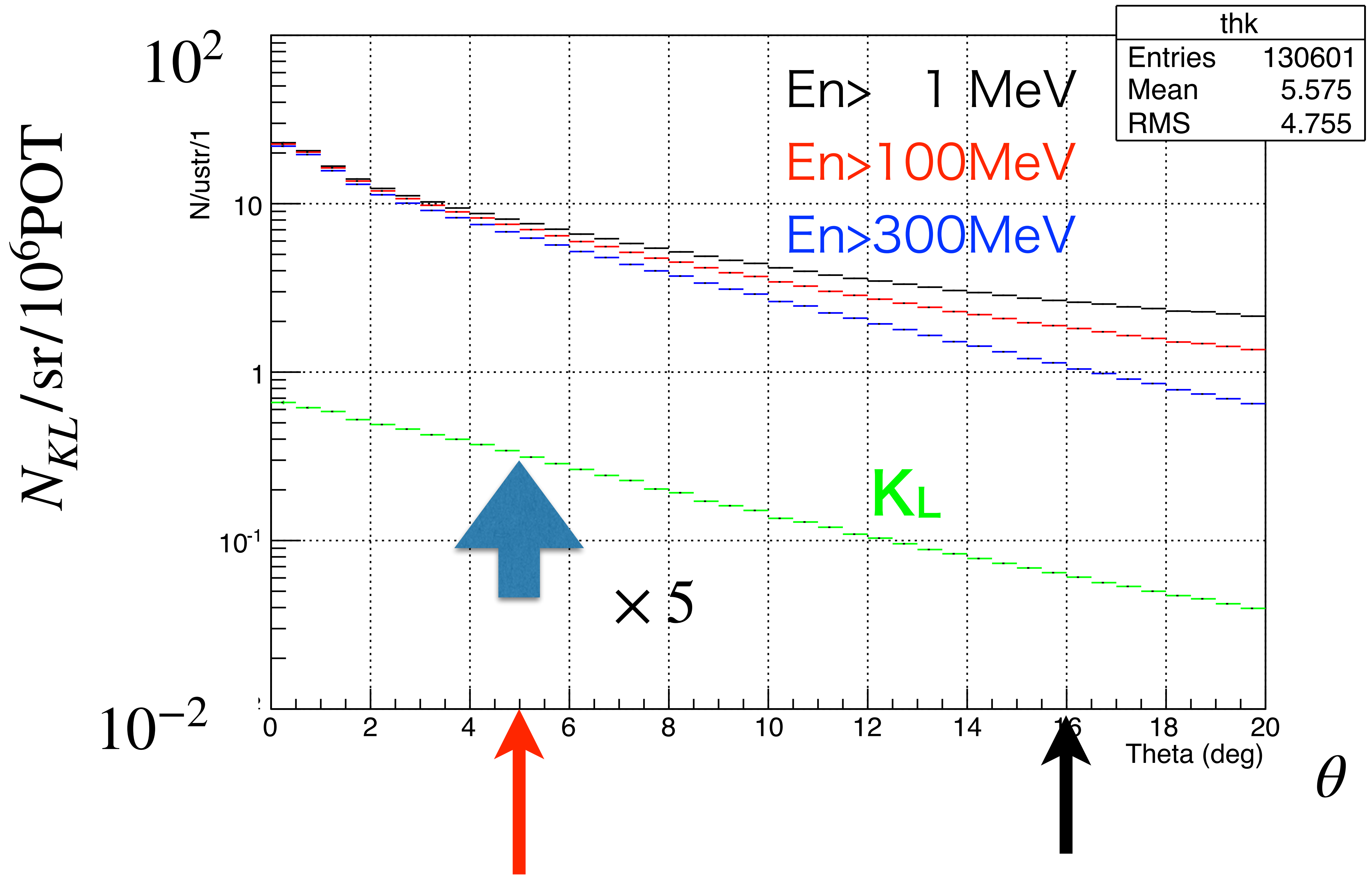
Higher momentum & higher intensity K_L

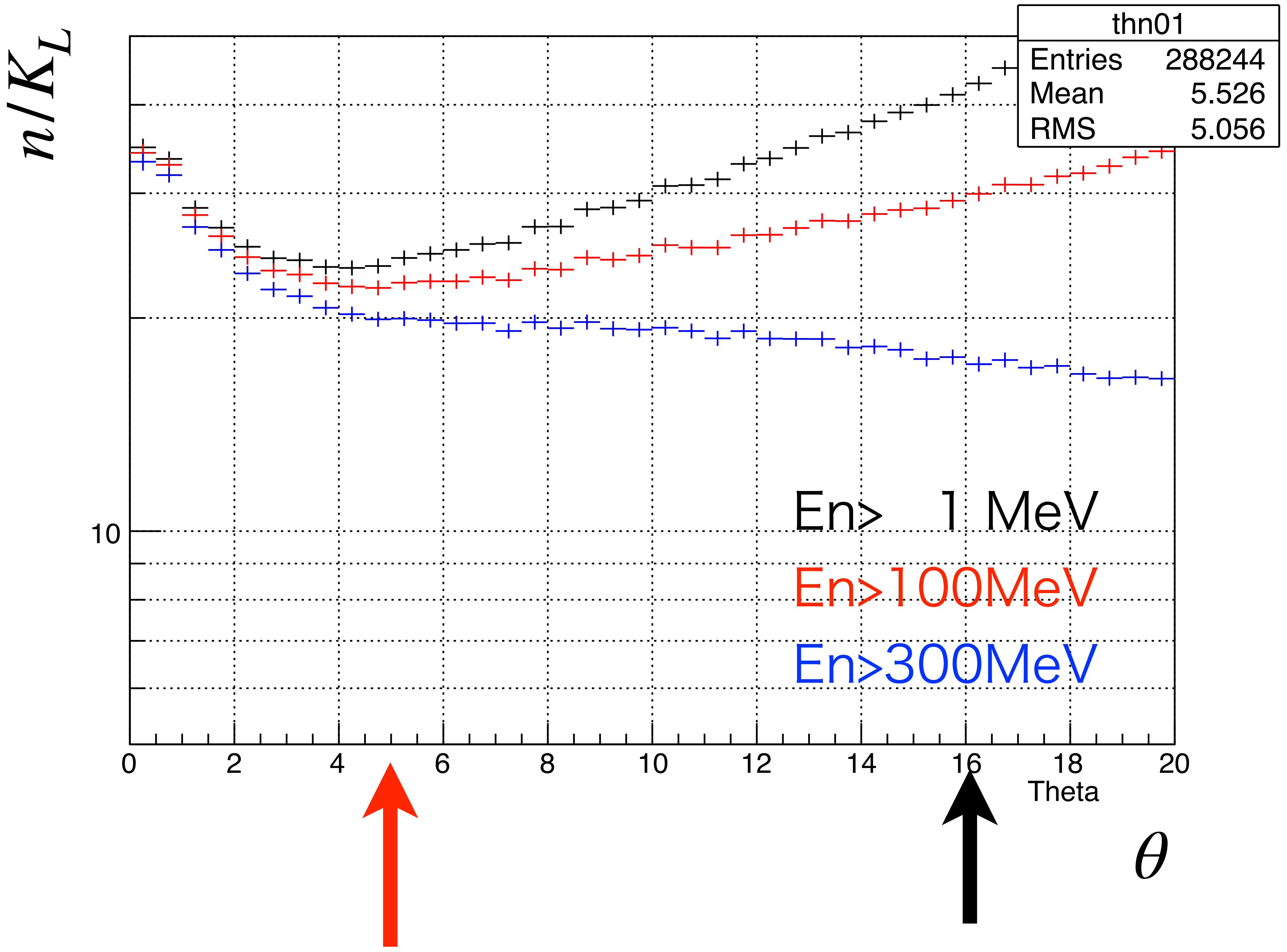
More K_L

Key to use long decay volume



Small extraction angle $\theta \rightarrow$ High flux, High momentum
$\rightleftarrows$ neutron background
$\rightarrow 5^\circ$ is optimal





5 degrees
KOTO II

16 degrees
KOTO

5 degrees
KOTO II

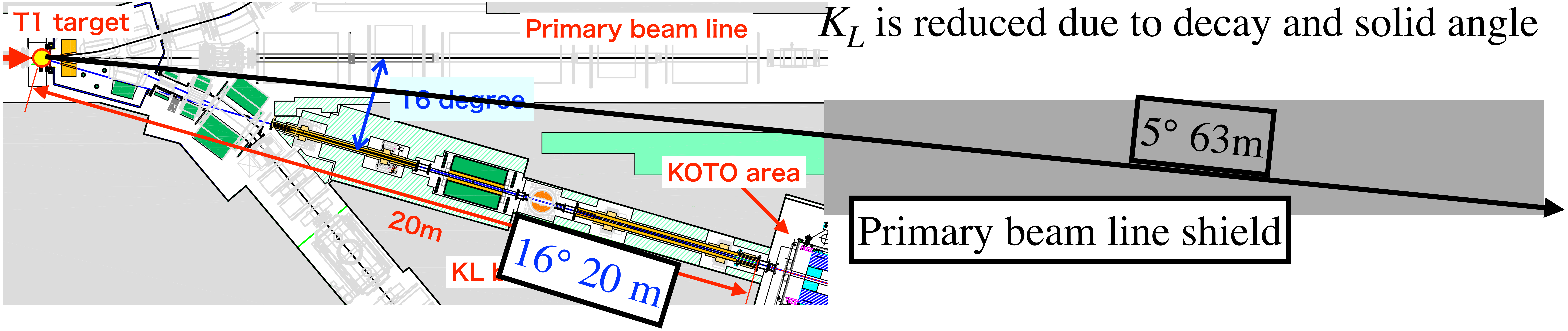
16 degrees
KOTO

Design of beam line

Current KOTO beam line

Extrapolate at 5° → too long

K_L is reduced due to decay and solid angle



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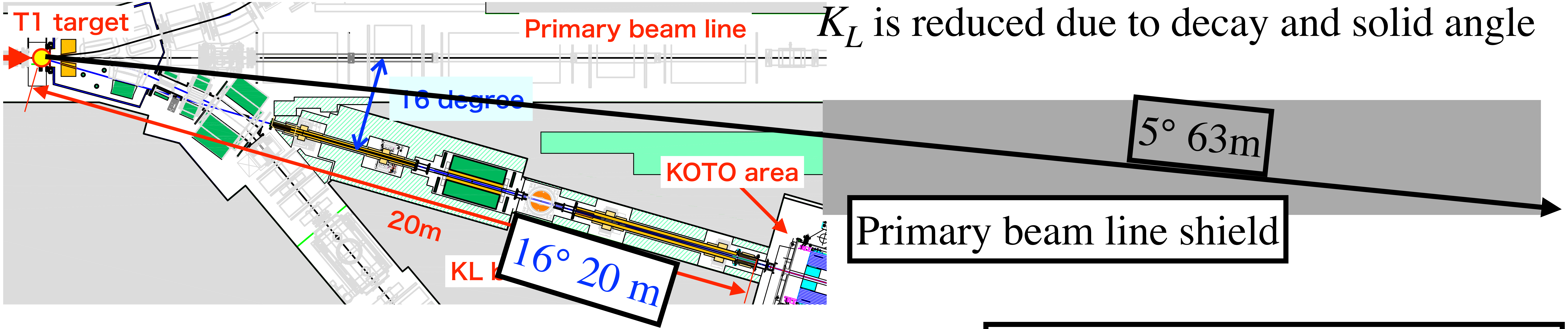
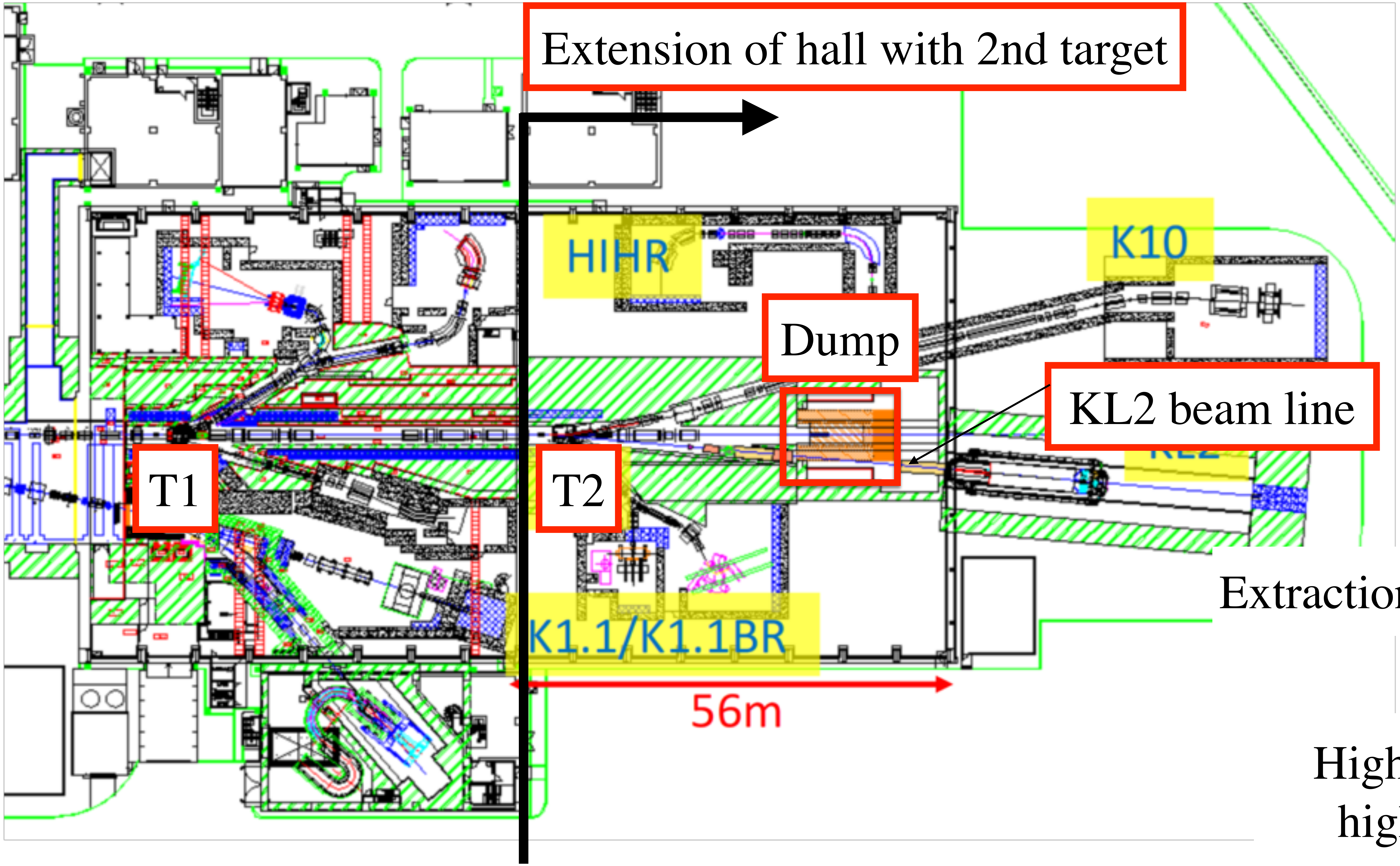


Current KOTO beam line

Detector behind the beam dump for shorter beam line

Not fit in the current hadron experimental hall

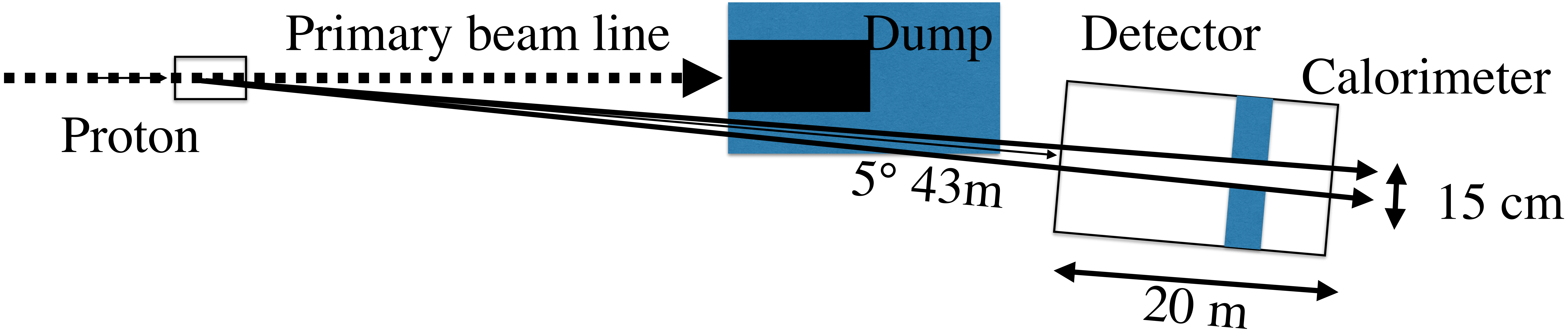
KOTO II with extension of hadron experimental facility



Extraction angle: 16° → 5°

Higher momentum & higher intensity K_L

Idea of experiment behind the dump



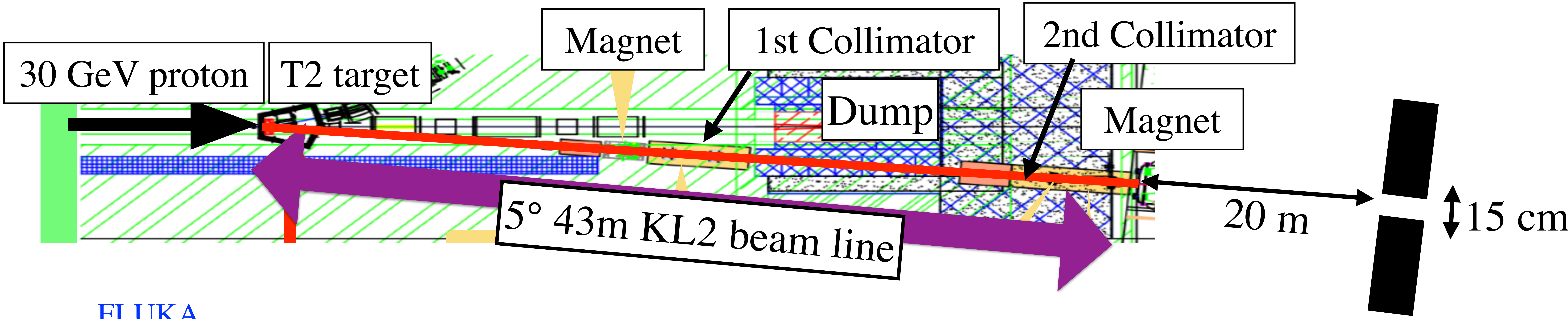
1. Narrow beam ⇄ Signal reconstruction (Beam width at calorimeter : 15 cm)
2. Longer decay volume to increase the decay → 20-m long detector
3. Shorter beam-line length is better
   to have larger solid angle
   to minimize the decay loss

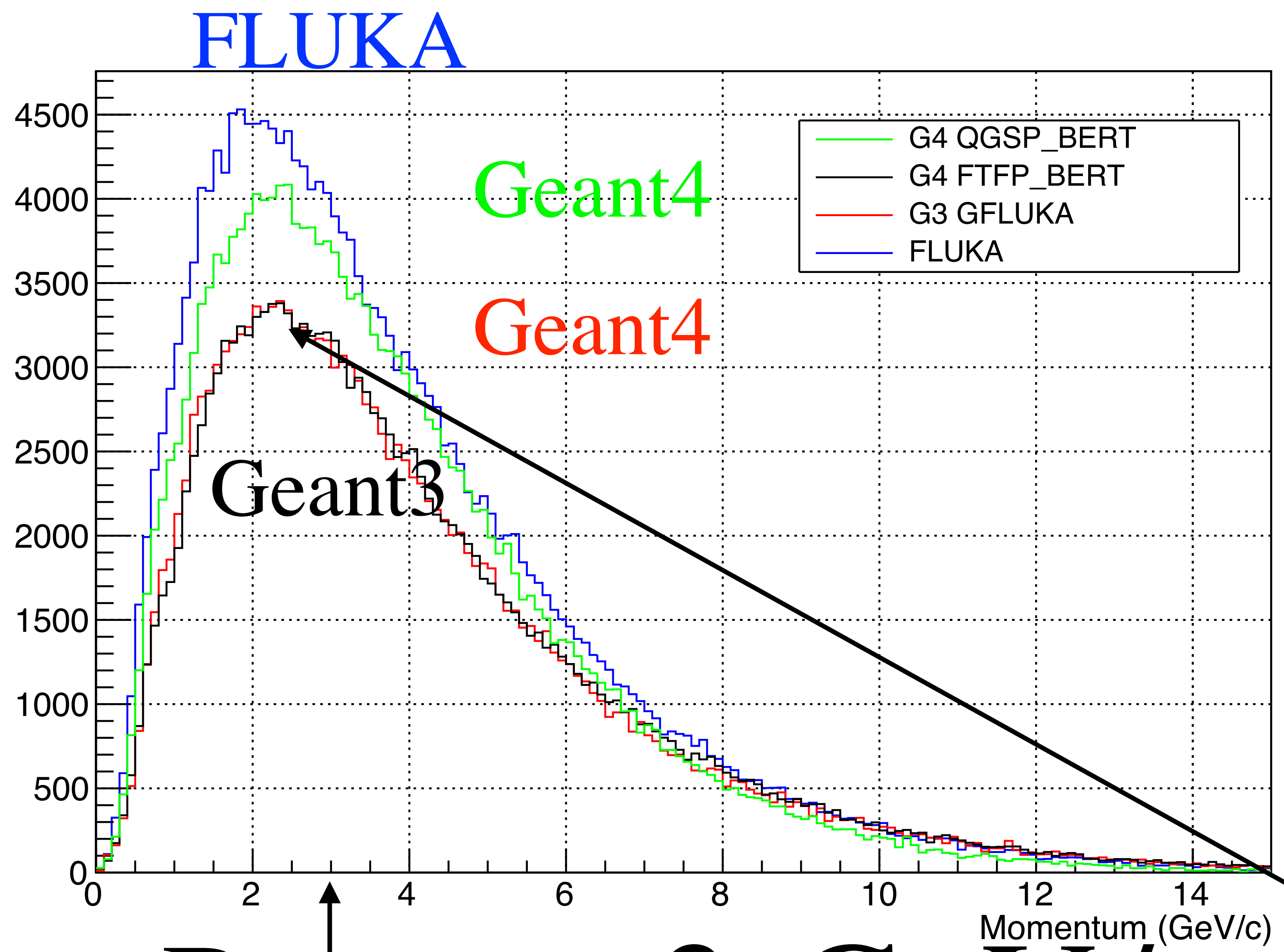
→ Minimize the distance between the target and the dump

⇔ Should keep the beam line away from the main body of the dump

Solid angle :4.8μsr

KL2 beam line





$P_{\text{peak}} = 3\ \text{GeV}/c$

	Production angle	Beam line	Solid angle
KOTO	16°	20 m	7.8 μsr
KOTO II	5°	43 m	4.8 μsr
Gain	× 5	× 0.8	× 0.6

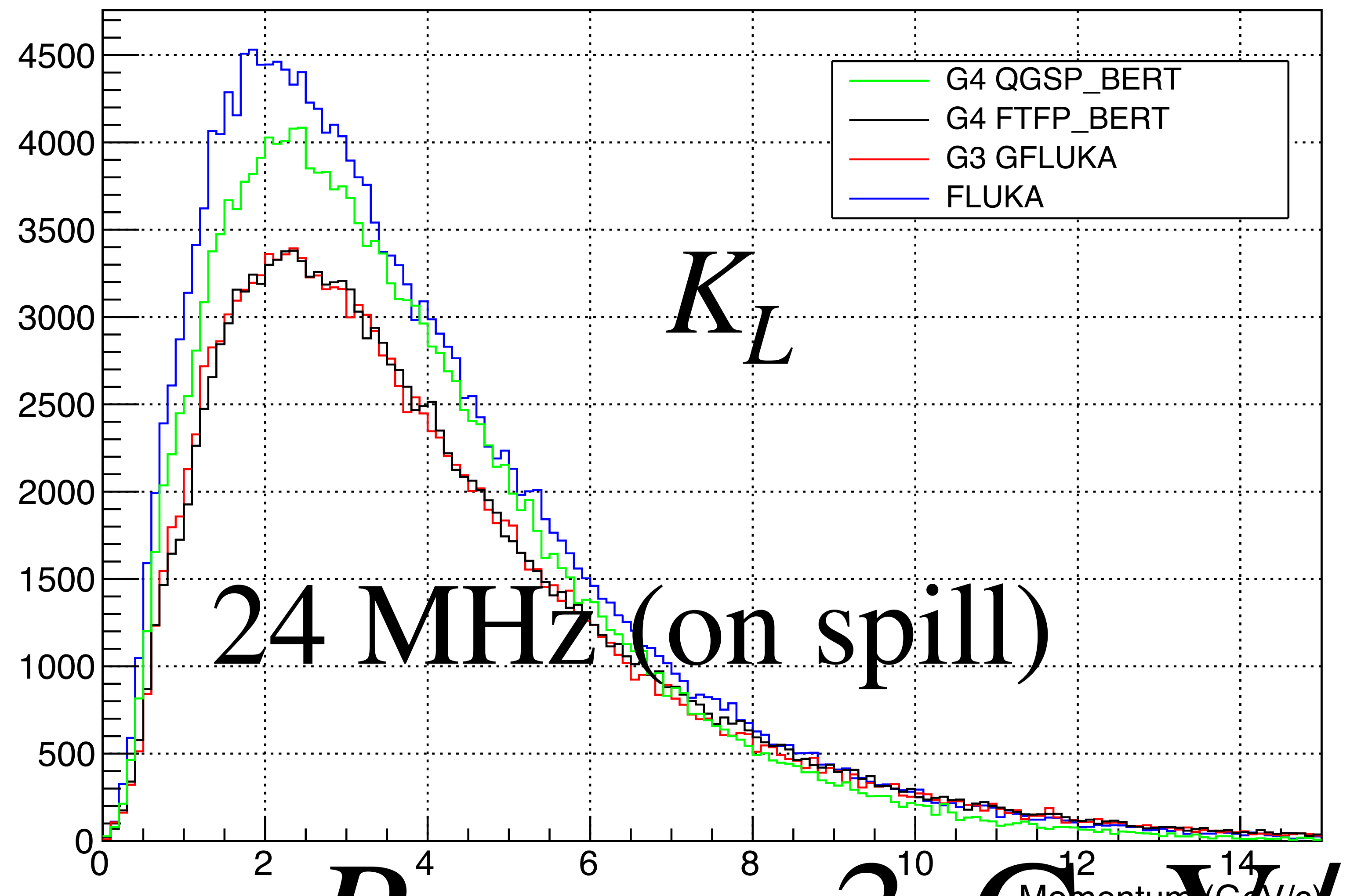
× 2.4 gain from KOTO

$1.1 \times 10^7 K_L/(2 \times 10^{13}\text{POT})$ at the entrance of detector for 100 kW beam on T2

K_L rate at the detector

- 100 kW beam on T2 target
- 1λ target length (63% loss)
- 2-s spill / 4.2-s reputation cycle

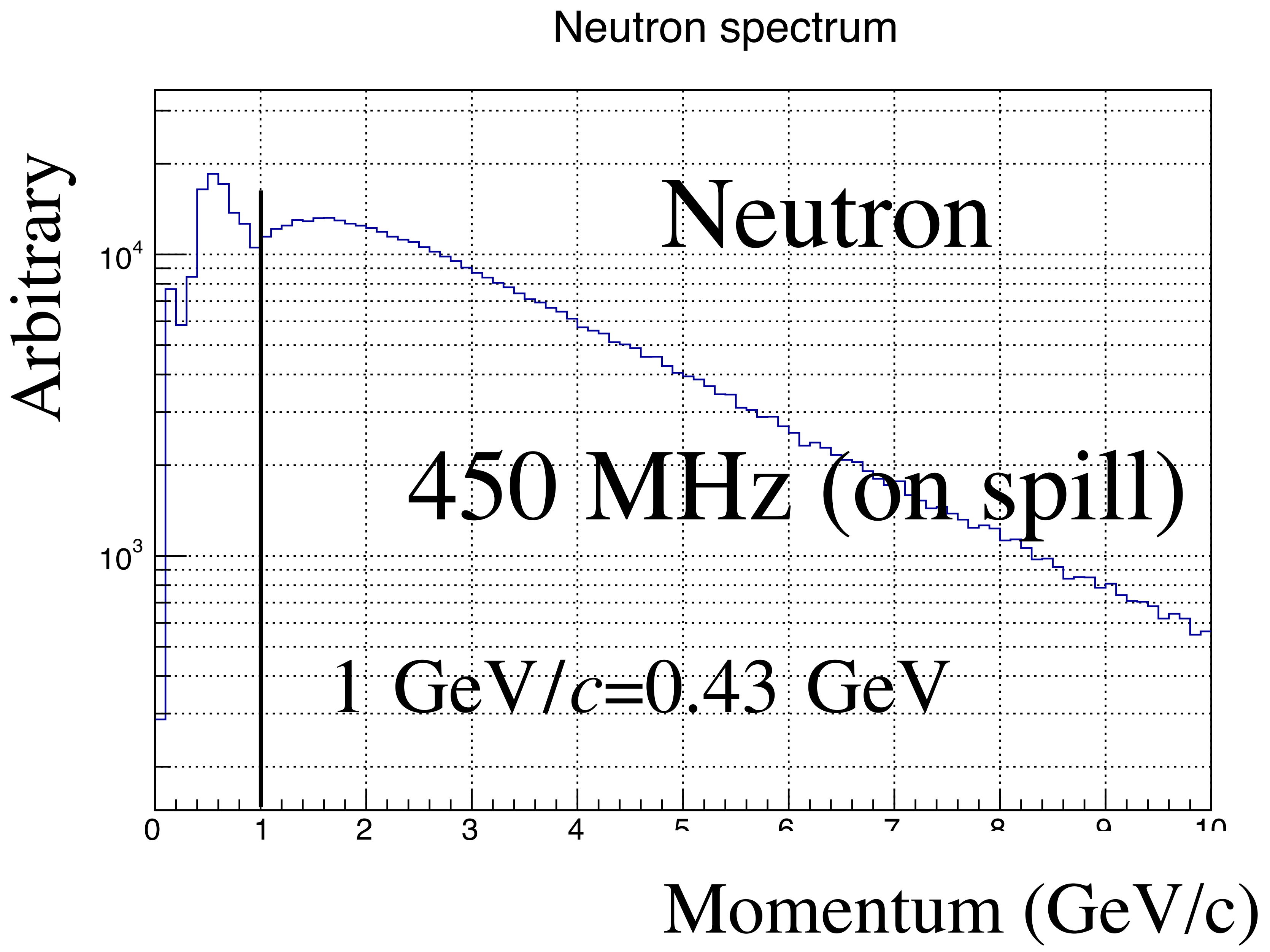
- 8.8×10^{13} POT /spill
- 24 MHz K_L incident in the dector during spill

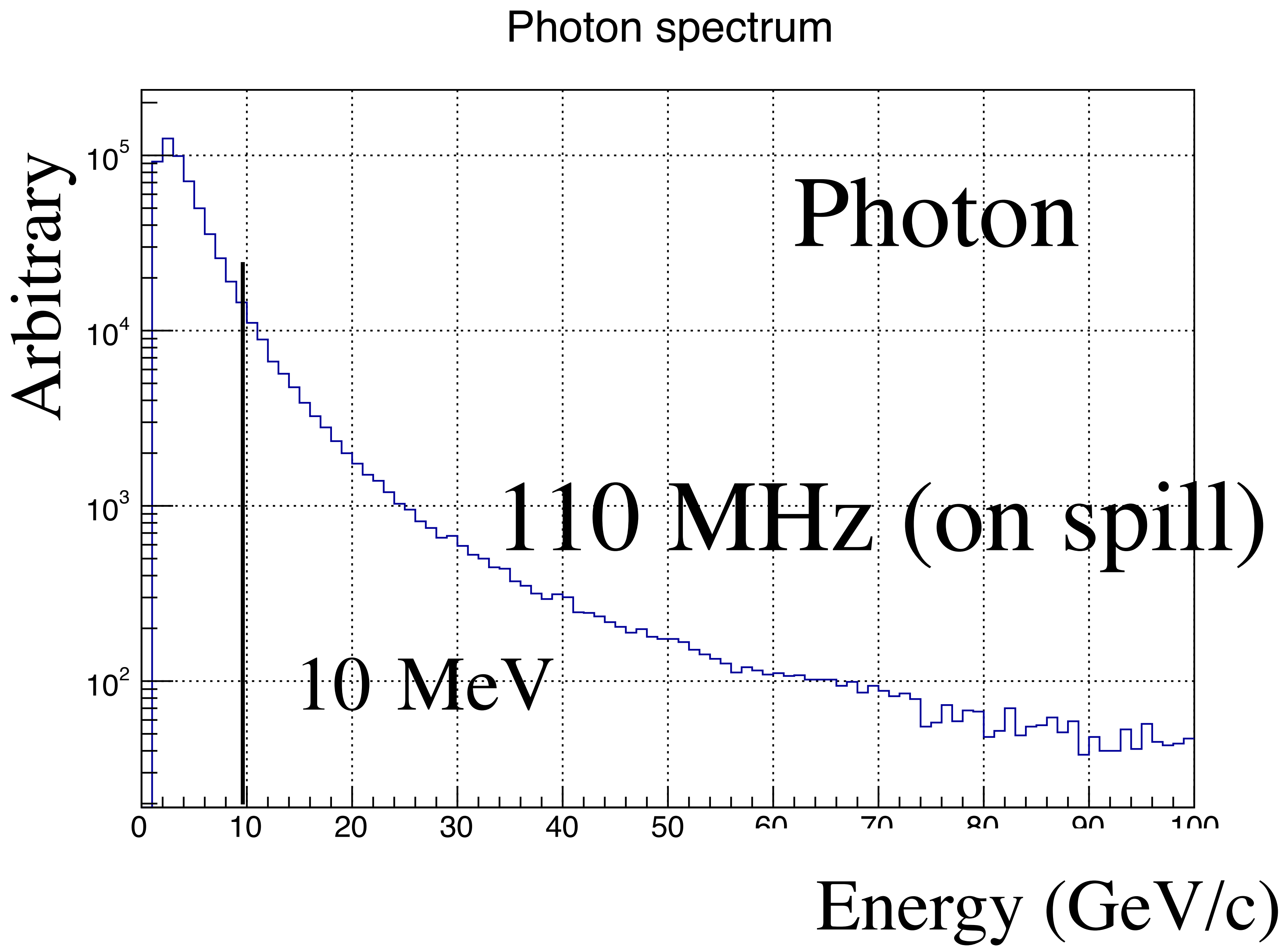


$P_{\text{peak}} = 3\ \text{GeV}/c$

$1.1 \times 10^7 K_L / (2 \times 10^{13}\text{POT})$

Beam core neutron and photon





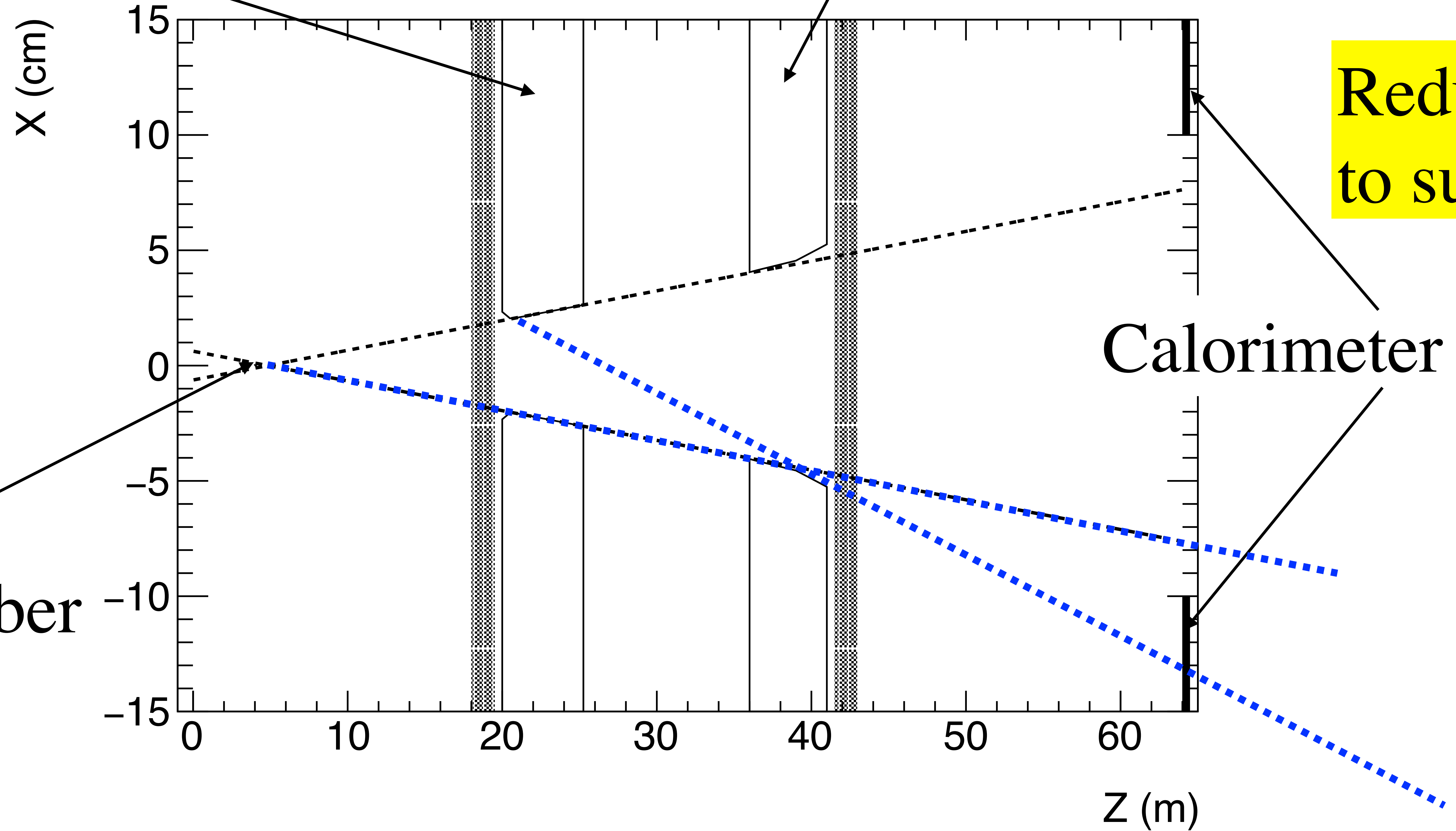
Particle	Energy range	On-spill rate (MHz)
K_L		24
Photon	>10 MeV	110
	>100 MeV	24
Neutron	>0.1 GeV	660
	>1 GeV	450

Harsh condition
for in-beam counters

Collimator design to suppress beam halo

1st collimator
Define the shape
→4.8 μsr

2nd collimator
Cut particles from Photon absorber
Cut particles from edge of 1st collimator
Hide inner surface from the target

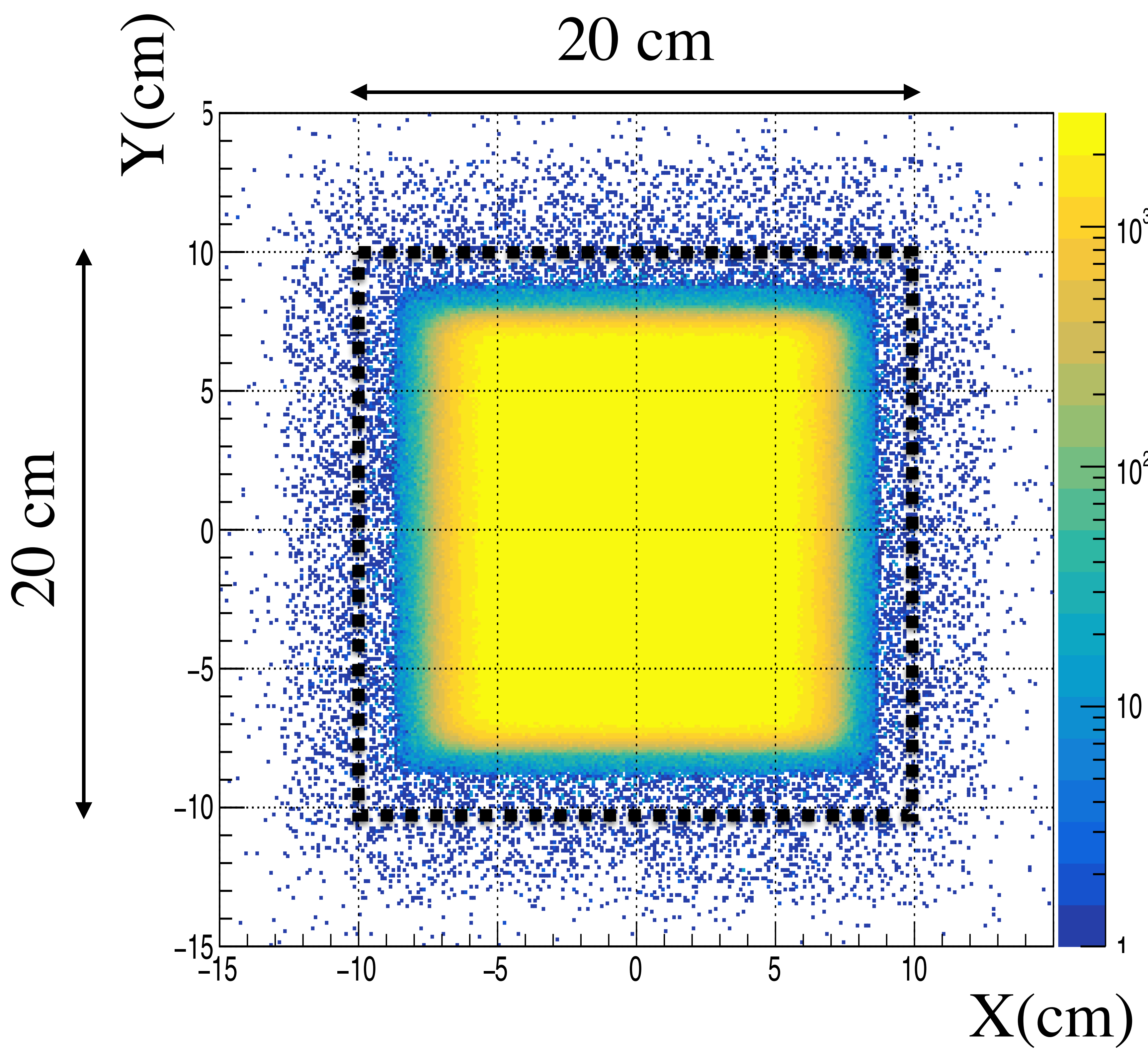


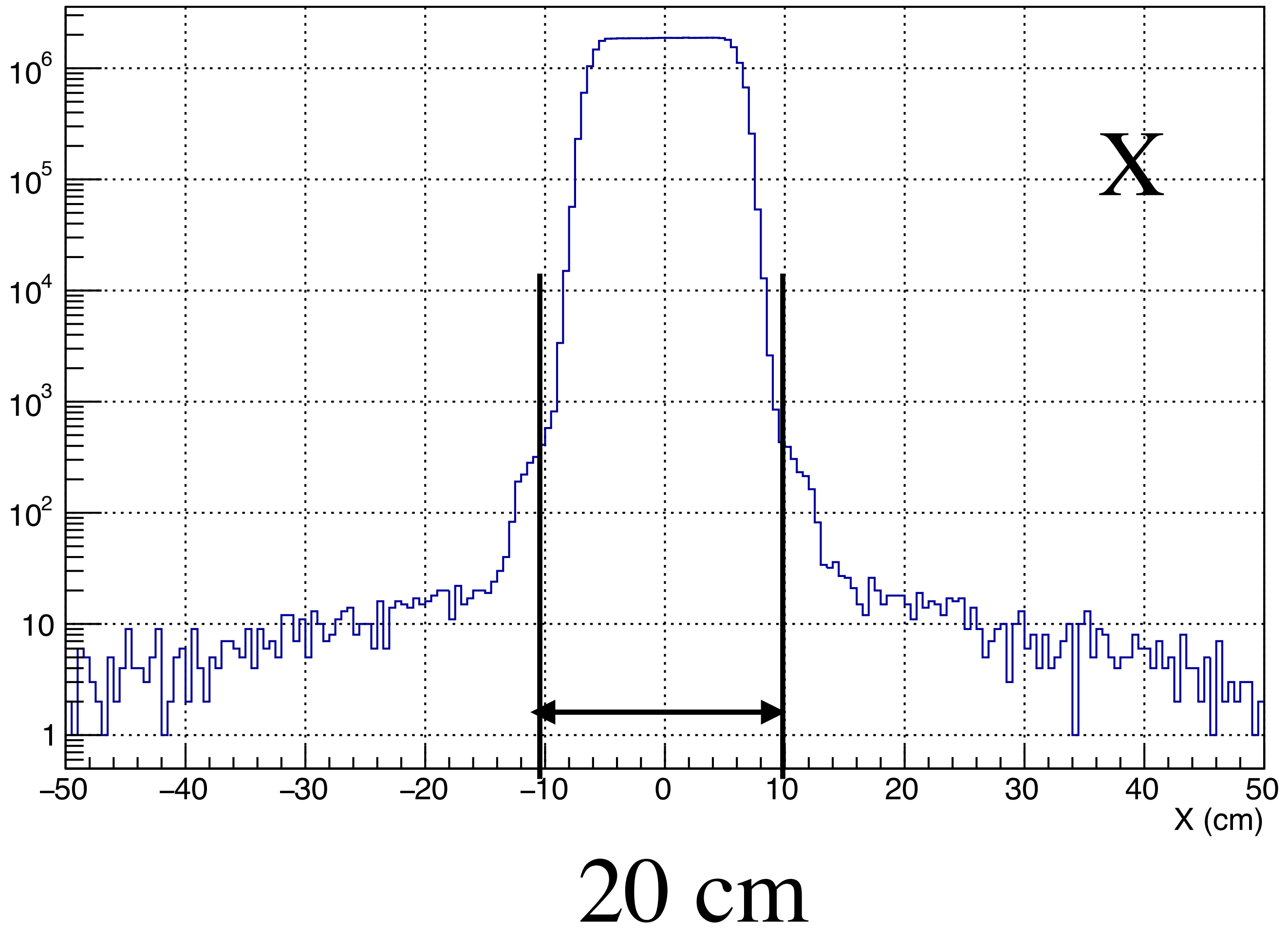
Reduce 2nd scattering points to suppress beam halo

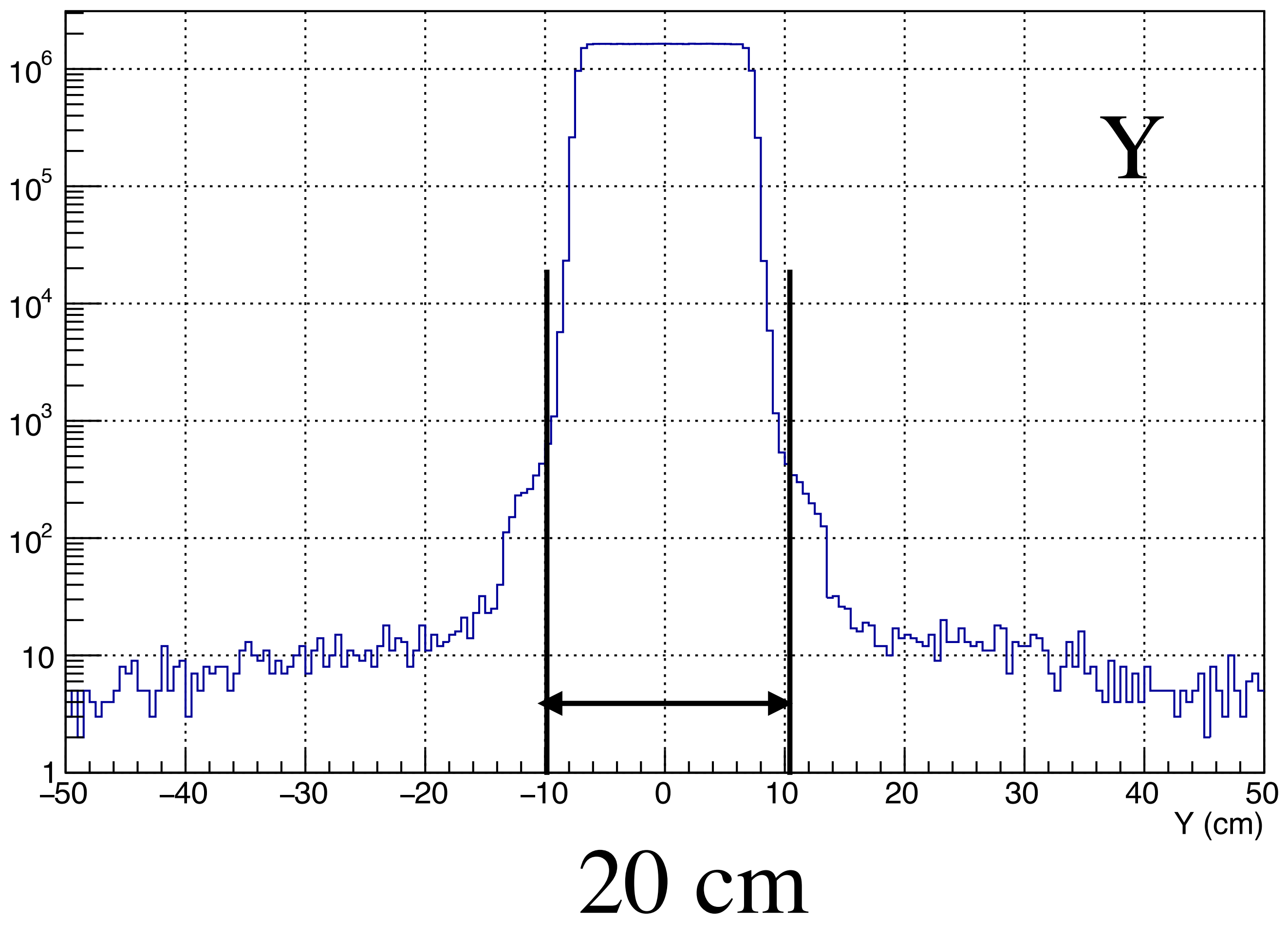
7-cm long
Pb photon absorber

Flux of beam halo neutron

XY profile of neutrons at 64 m downstream of T2 = Z@Calorimeter
20-cm square region=Calorimeter beam hole

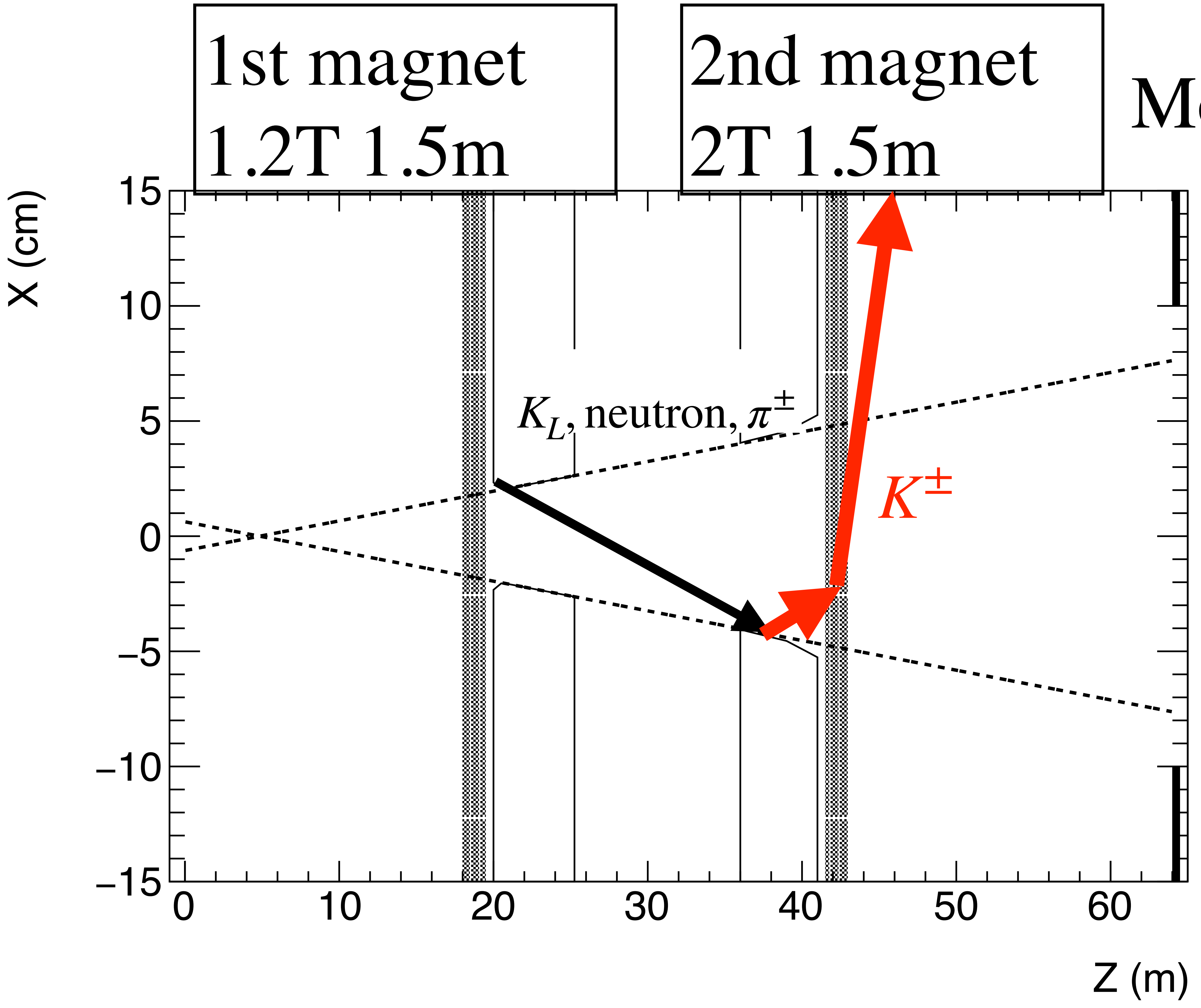






R(halo/core) = 1.8×10^{-4}
→ halo neutron background

Magnets to suppress charged particles



Momentum kick : 0.9 GeV/c

$R(K^+/K_L) = 4.1 \times 10^{-6}$ without 2nd magnet

$\rightarrow\ < 1.1 \times 10^{-6}$ with 2nd magnet

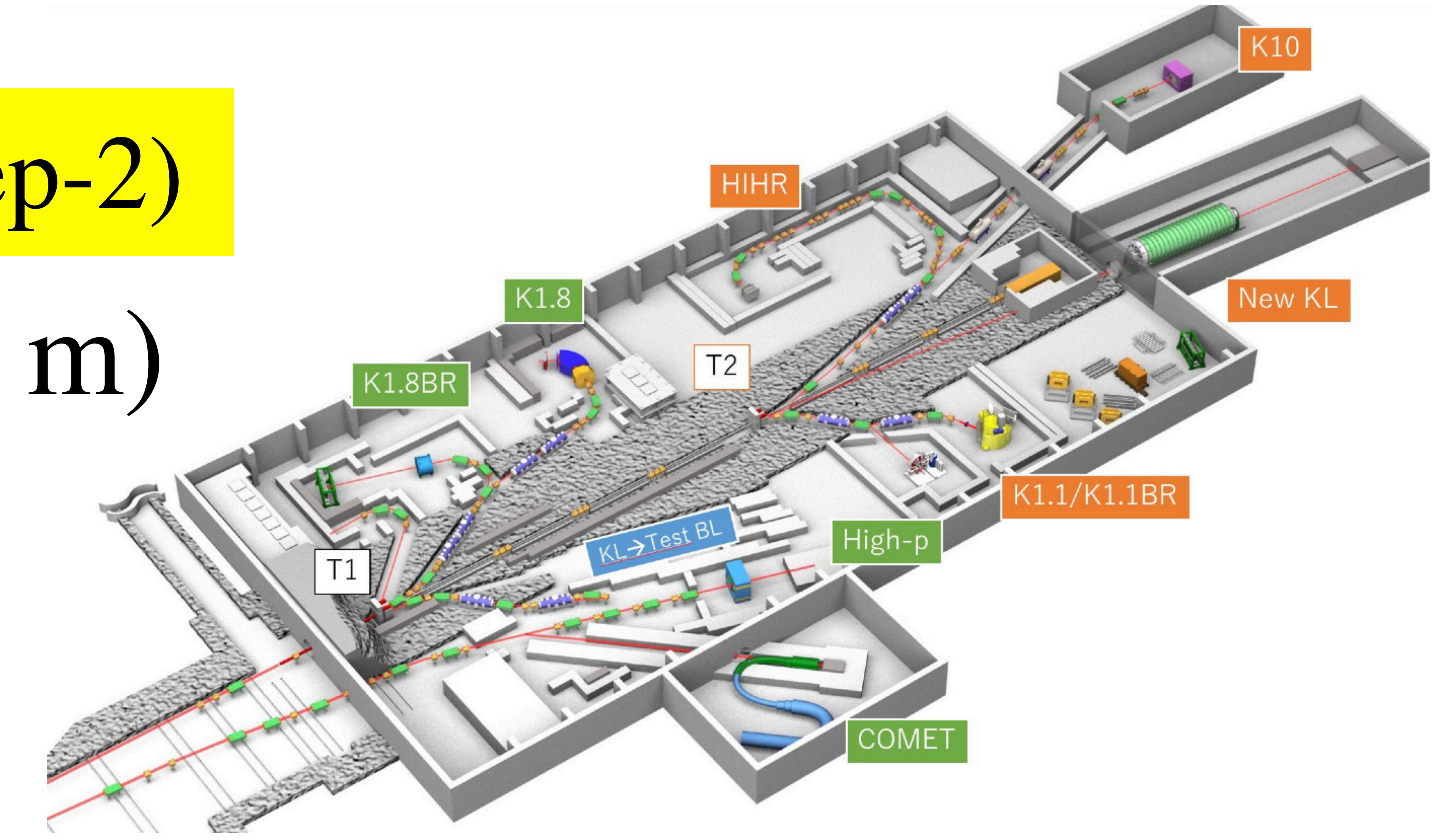
$R(K^+/K_L) = 0.41 \times 10^{-6}$ is assumed for background study

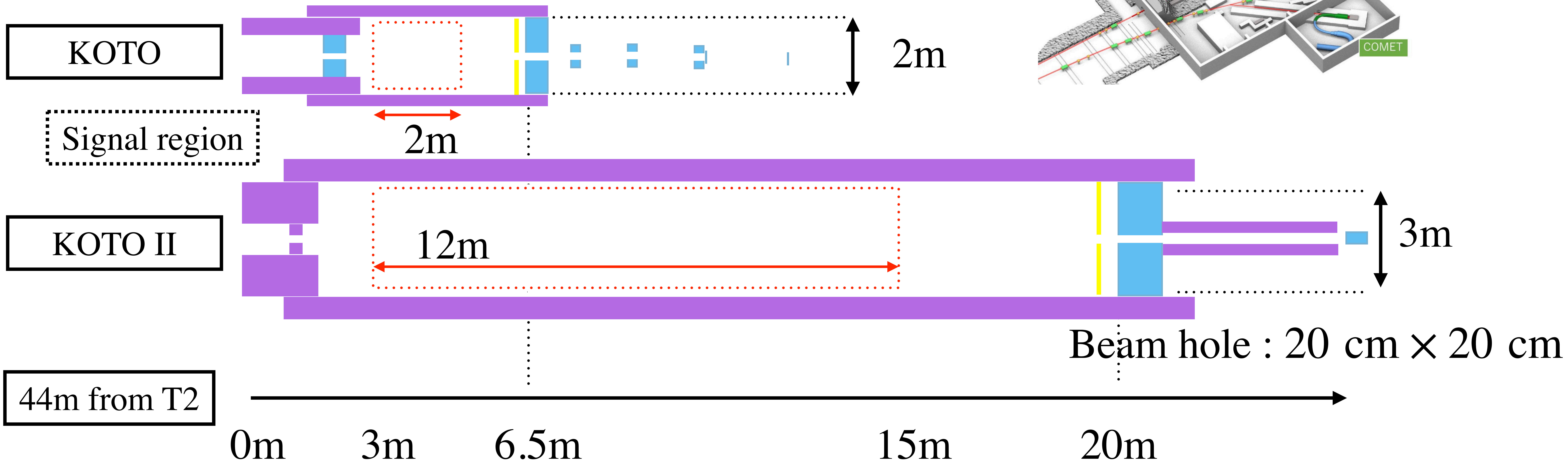
KOTO-II detector

Peak K_L momentum : 1.4 GeV/c (step-1) → 3 GeV/c (step-2)

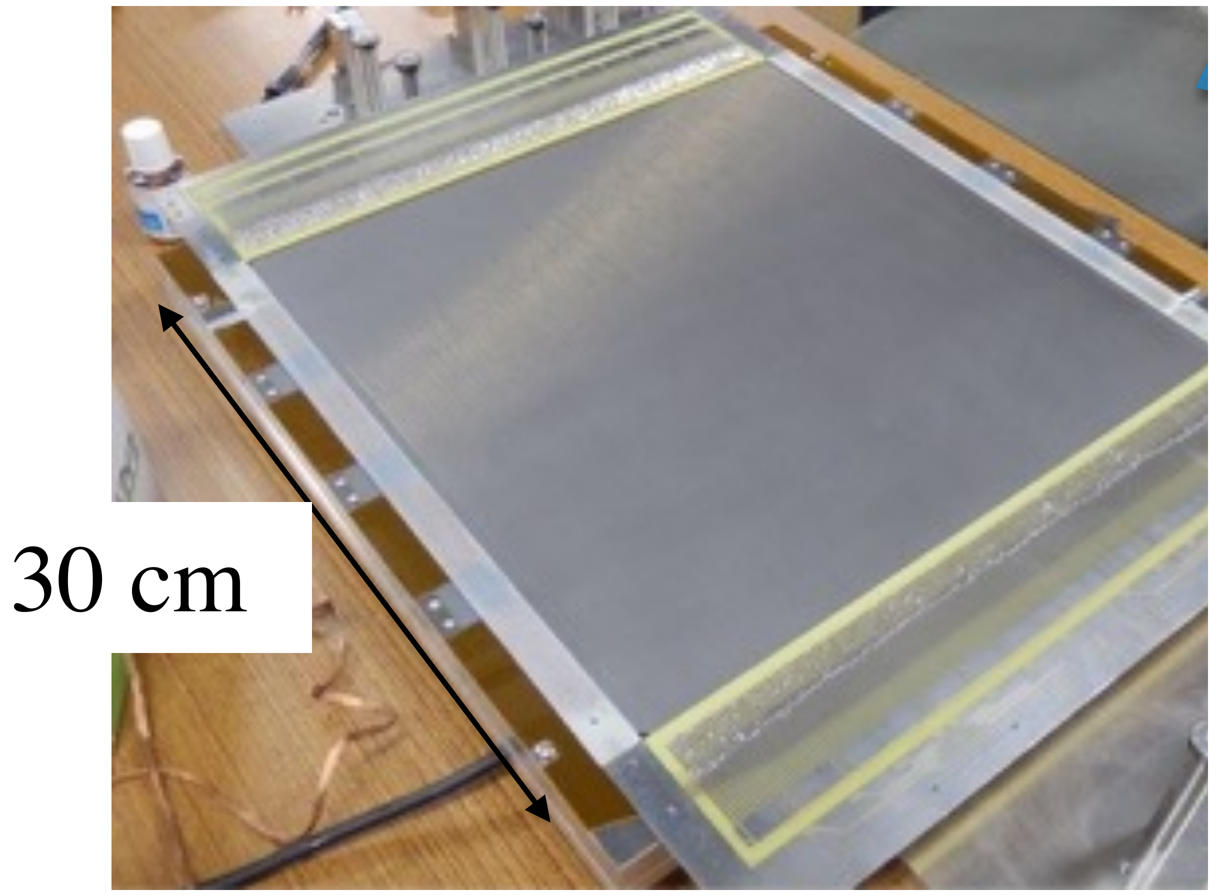
Possible to use longer decay volume (2 m → 12 m)

Larger diameter calorimeter (2 m → 3 m)





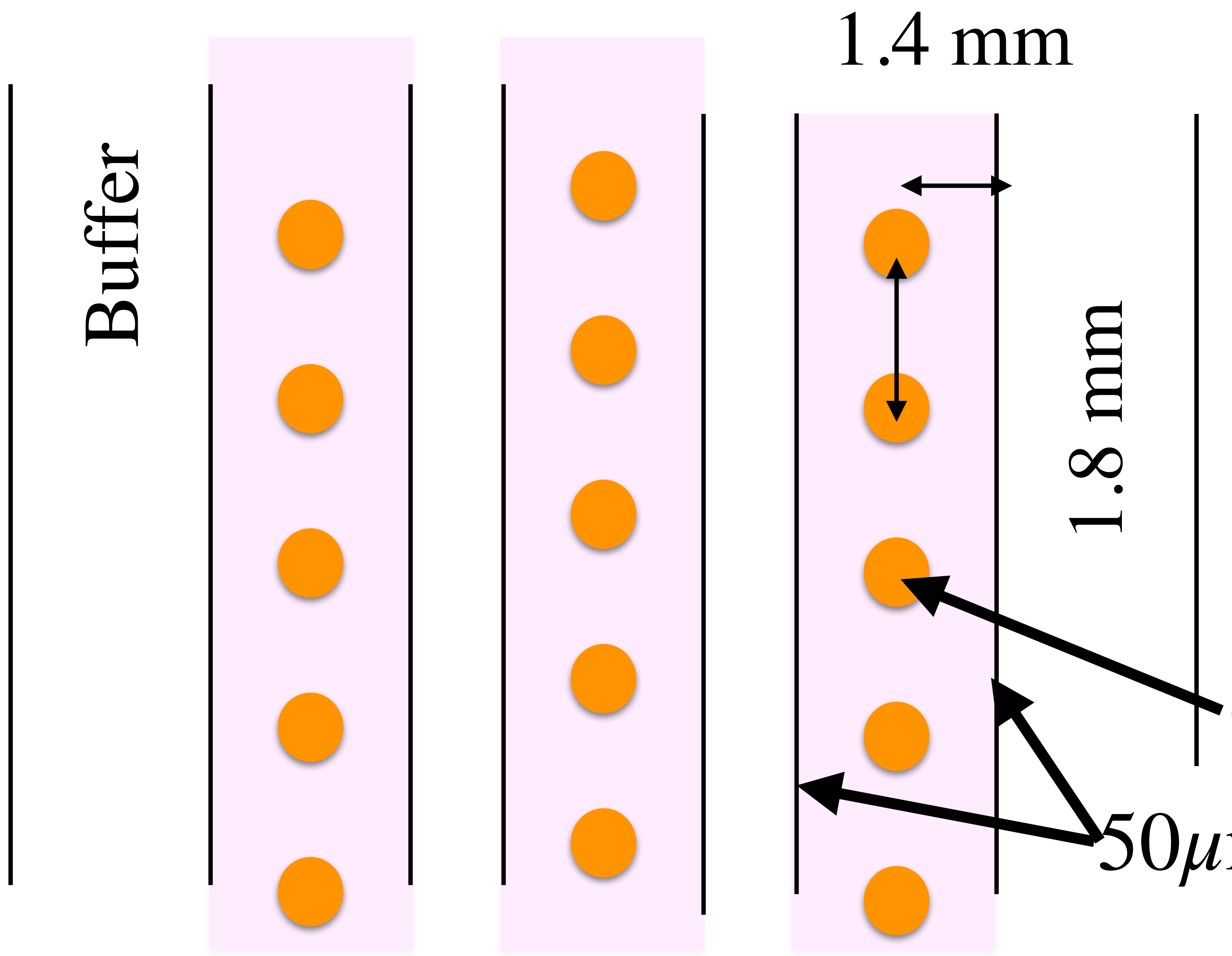
Candidate of in-beam charged veto



Gas : CF_4:n-pentane = 55:45

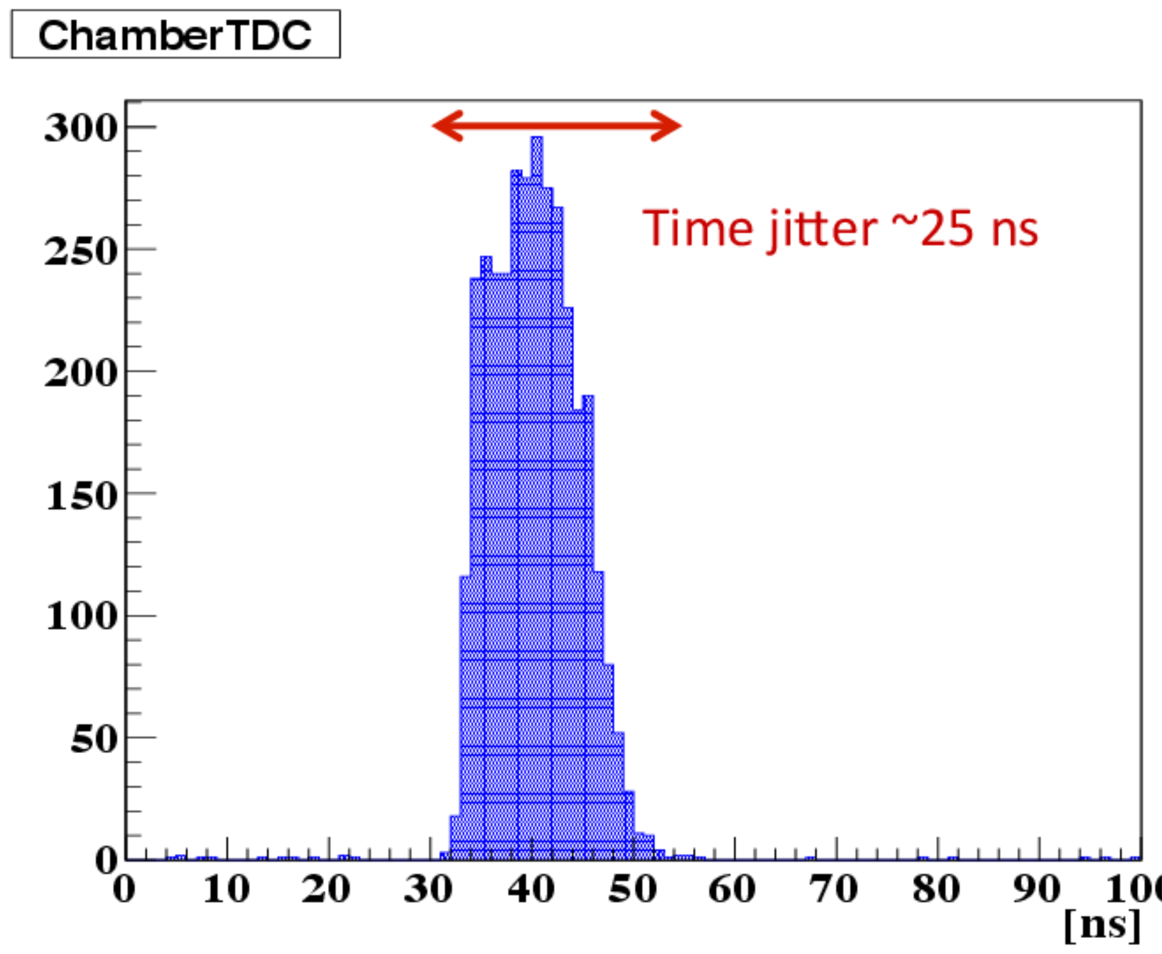
Thinner is better
→ Less hits due to γ/neutrons

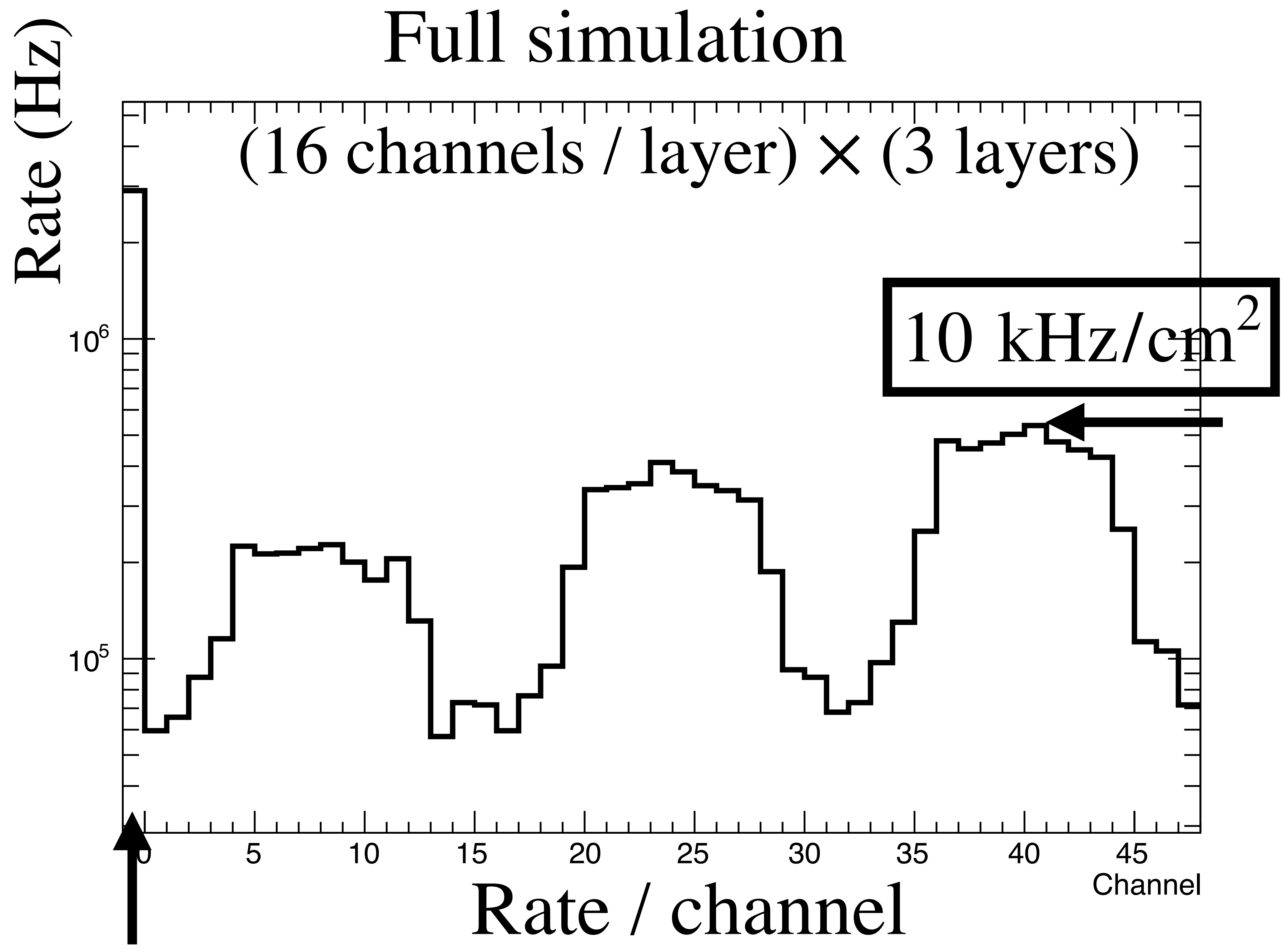
MWPC-type gas wire chamber
(Thin Gap Chamber)
Tolerable for 100kHz/cm² hit rate
99.9% efficiency with 2-out-of-3 logic
Used in KOTO



ϕ = 50 μm Au/W wire

50μm thick carbon-coated polyimide foil

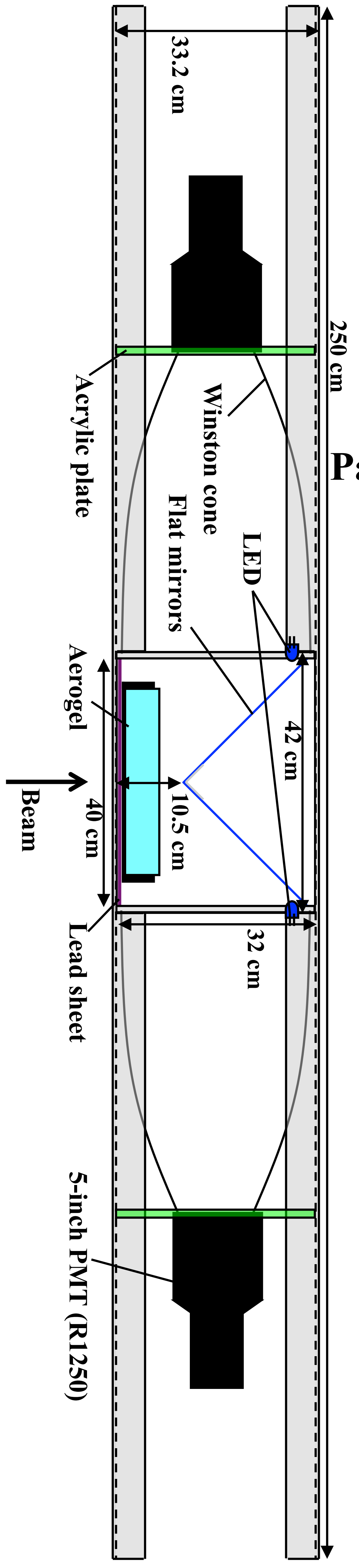


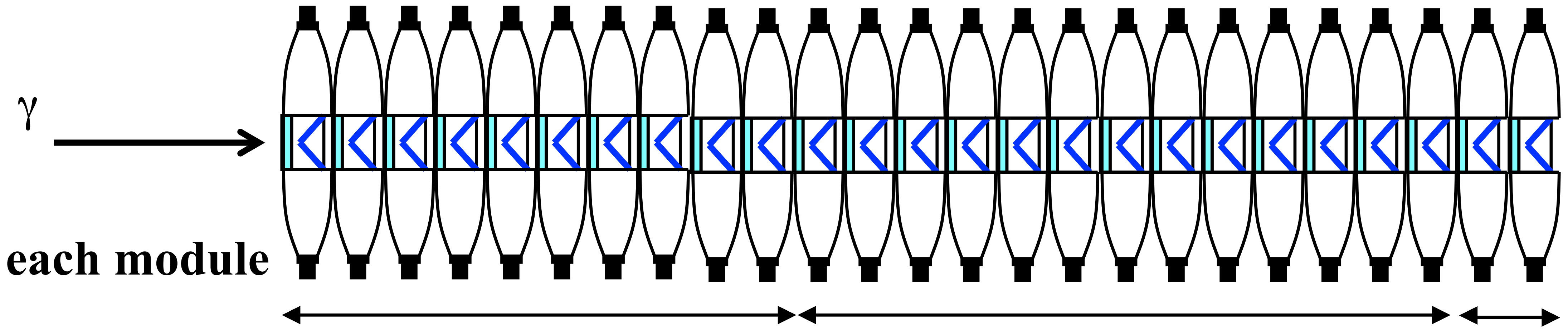


Counter rate with 2-out-of-3 logic

Operational
30-ns veto window
2.9 MHz hit
8.3% loss contribution

Candidate of in-beam photon veto





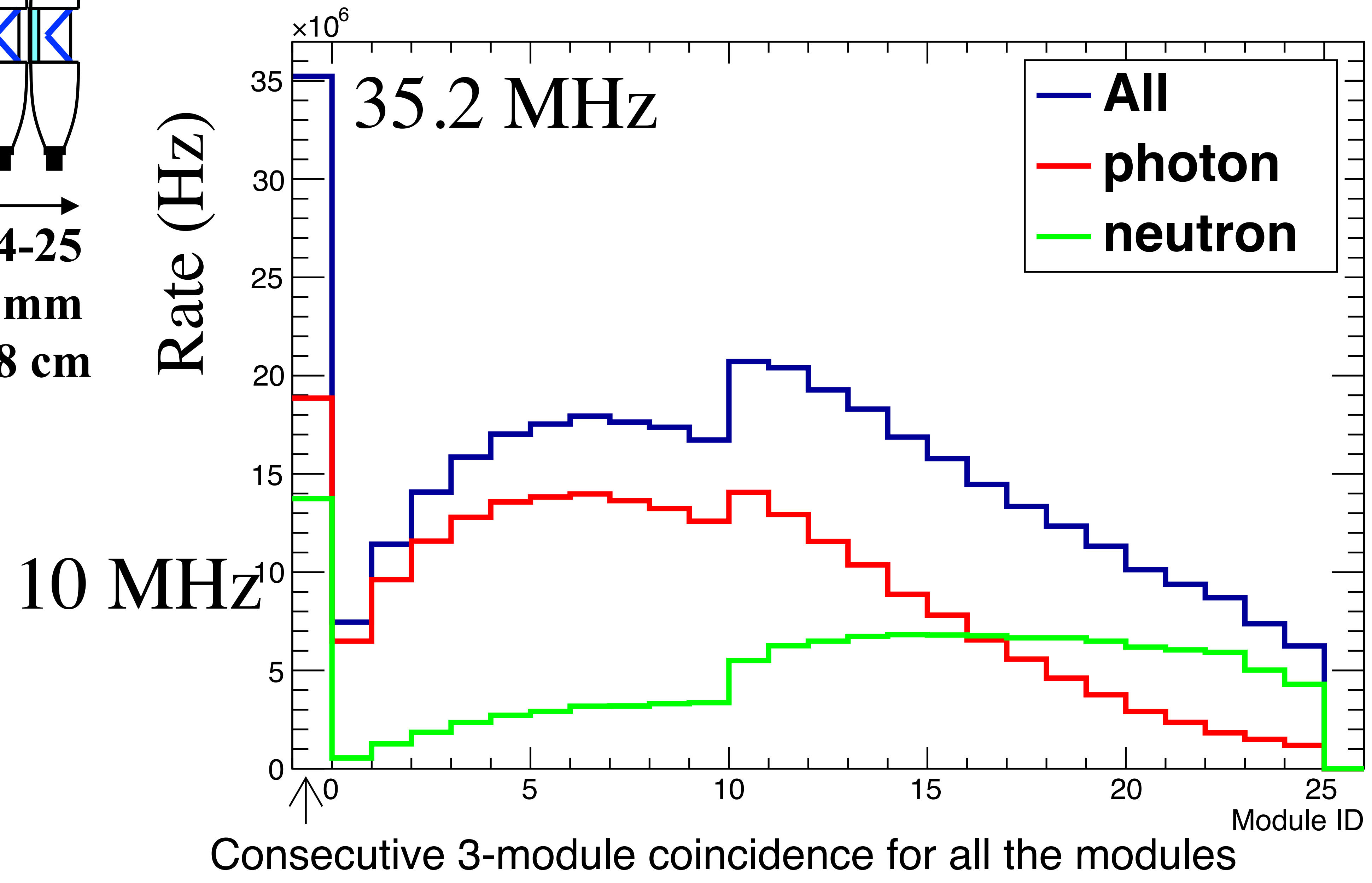
Parameters for each module

Module No.:	1-10	11-23	24-25
Thickness of lead sheets:	1.5 mm	3 mm	0 mm
Thickness of aerogel:	2.9 cm	5.8 cm	5.8 cm

- Lead : photon→e^+e^-
- Aerogel : Cherenkov radiator
- 3-consecutive hits

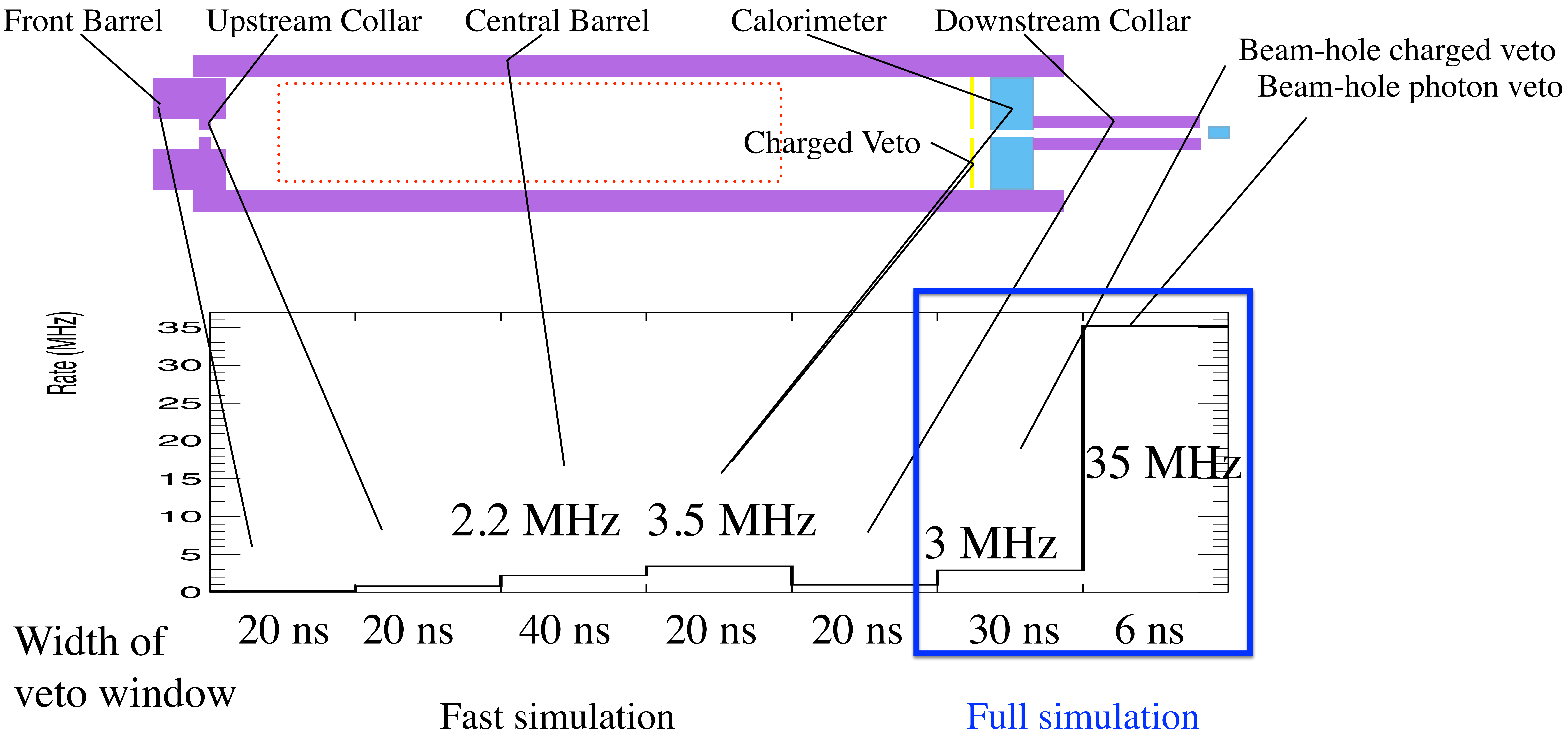
These reduce neutron / low energy γ hits
Used in KOTO

Full simulation



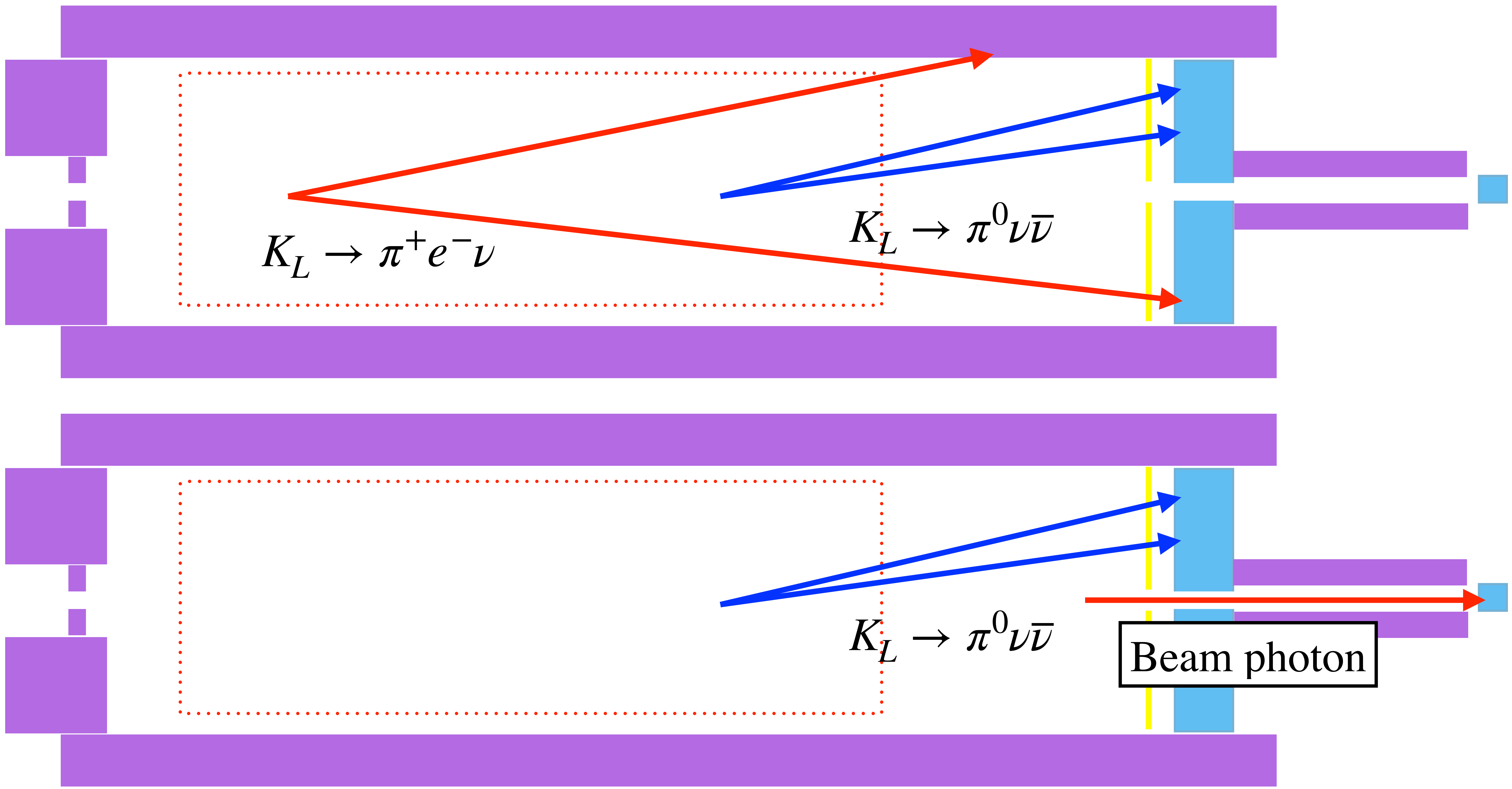
35.2 MHz, 6-ns veto window
→ 19% accidental loss contribution
→ PMT with moderate gain+ fast amplifier

Detector rate environment

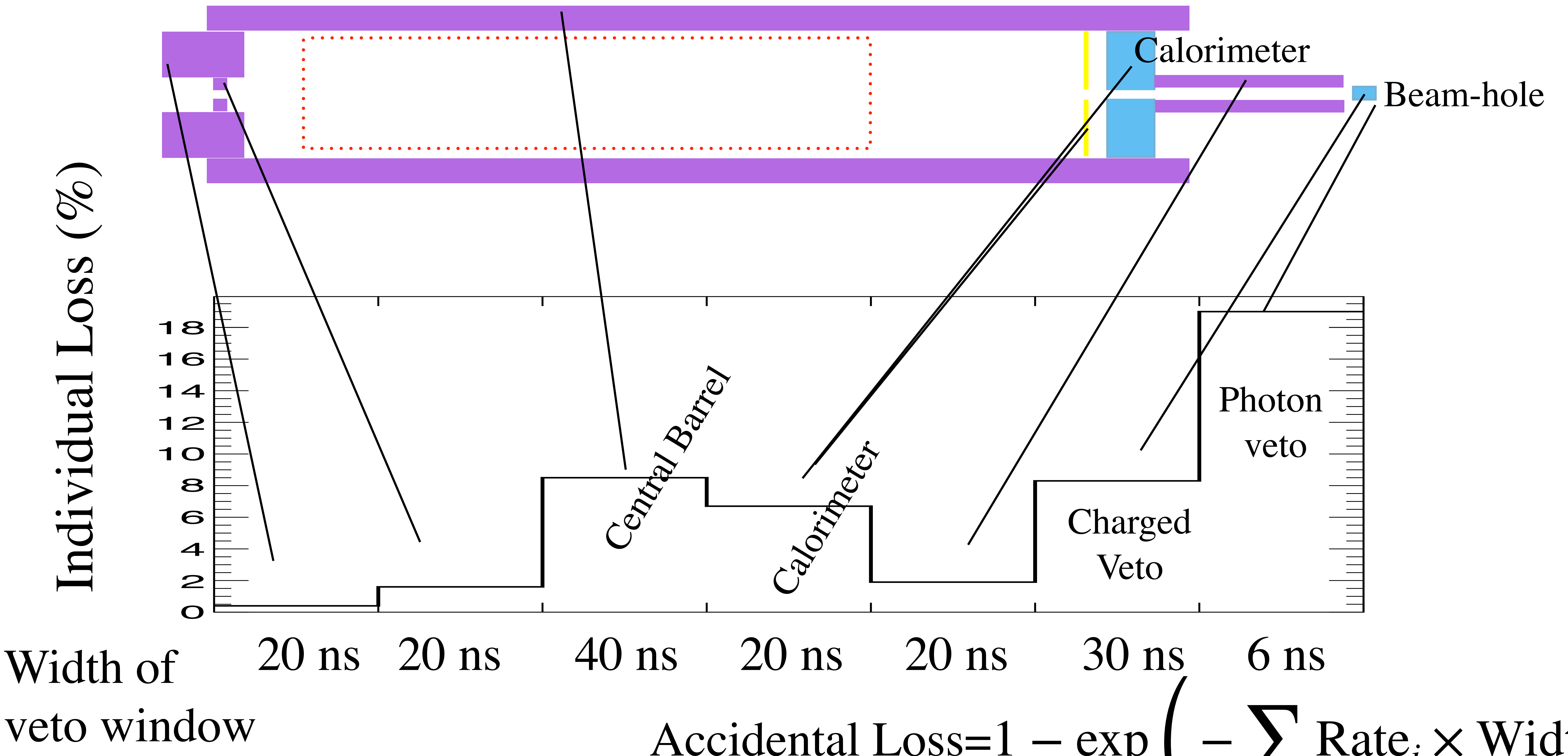


Accidental loss

Signal can be vetoed with accidental K_L decay or beam particle hits



Accidental loss

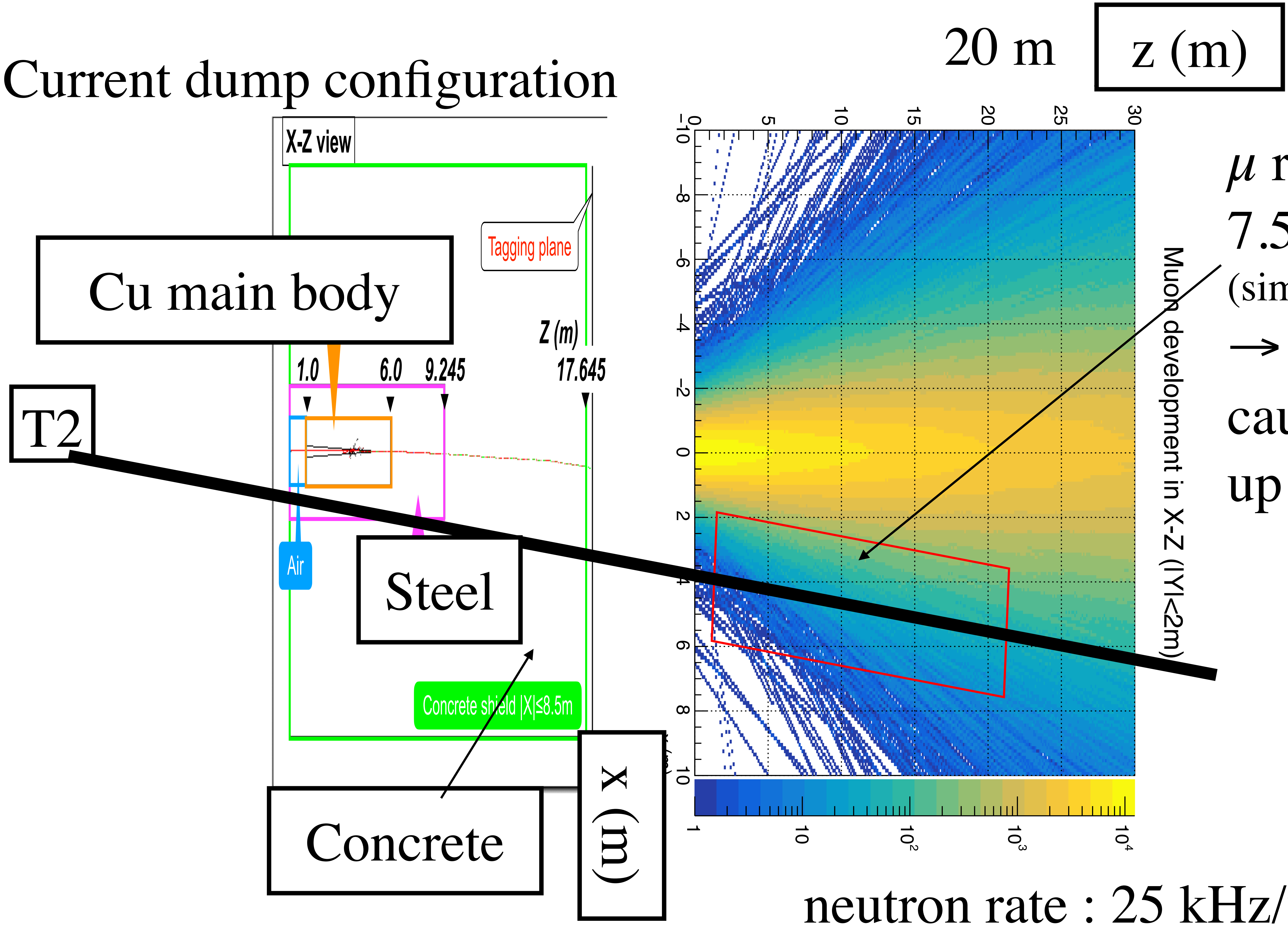


$$\text{Accidental Loss} = 1 - \exp\left(-\sum_i \text{Rate}_i \times \text{Width}_i\right) = 39\%$$

Radiation environment behind the dump

Current dump configuration

20 m



μ rate

7.5 MHz/detector

(simple dump model + Geant3 simulation)

→

cause accidental loss

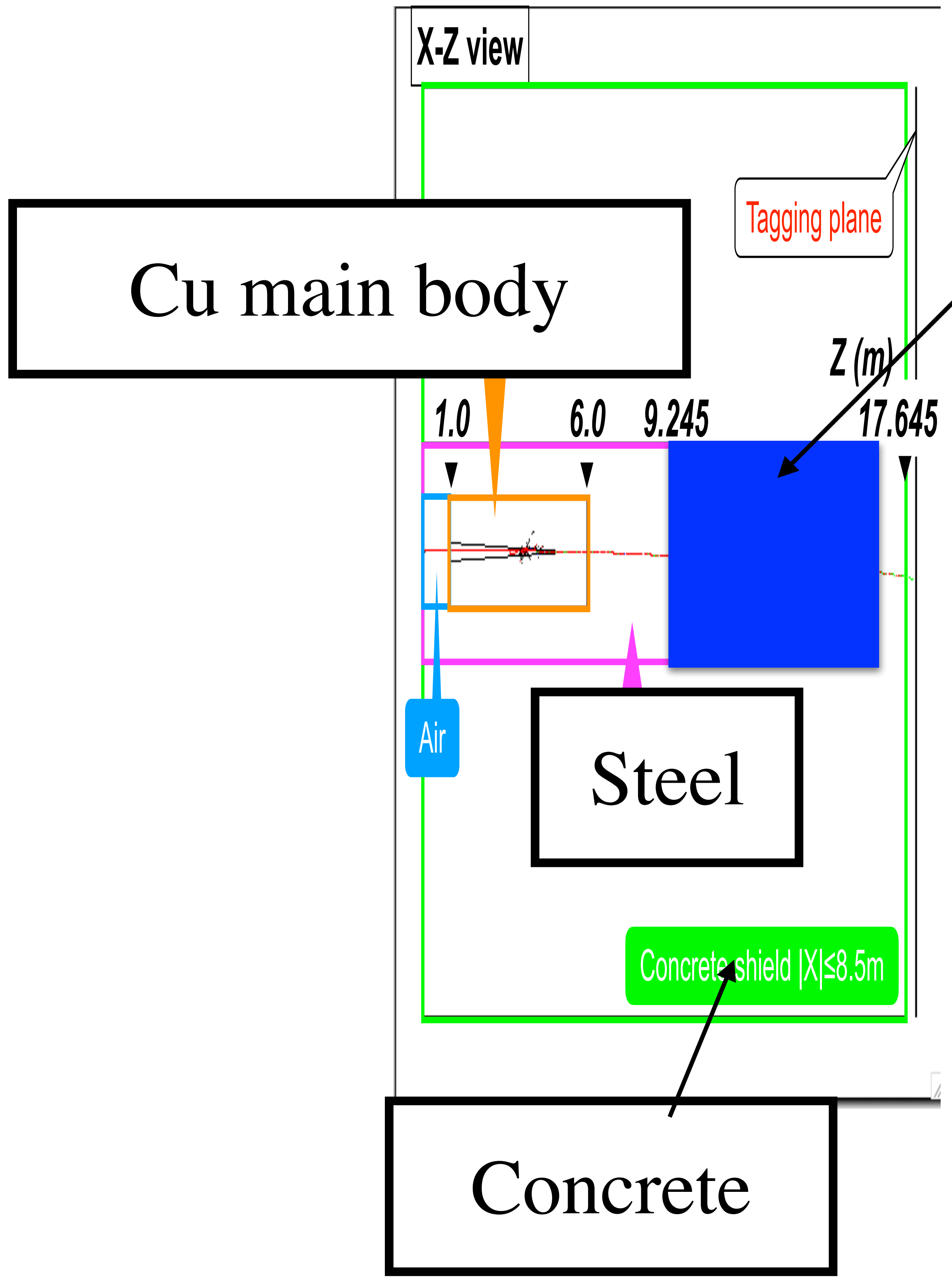
up to 60%.

neutron rate : 25 kHz/whole region

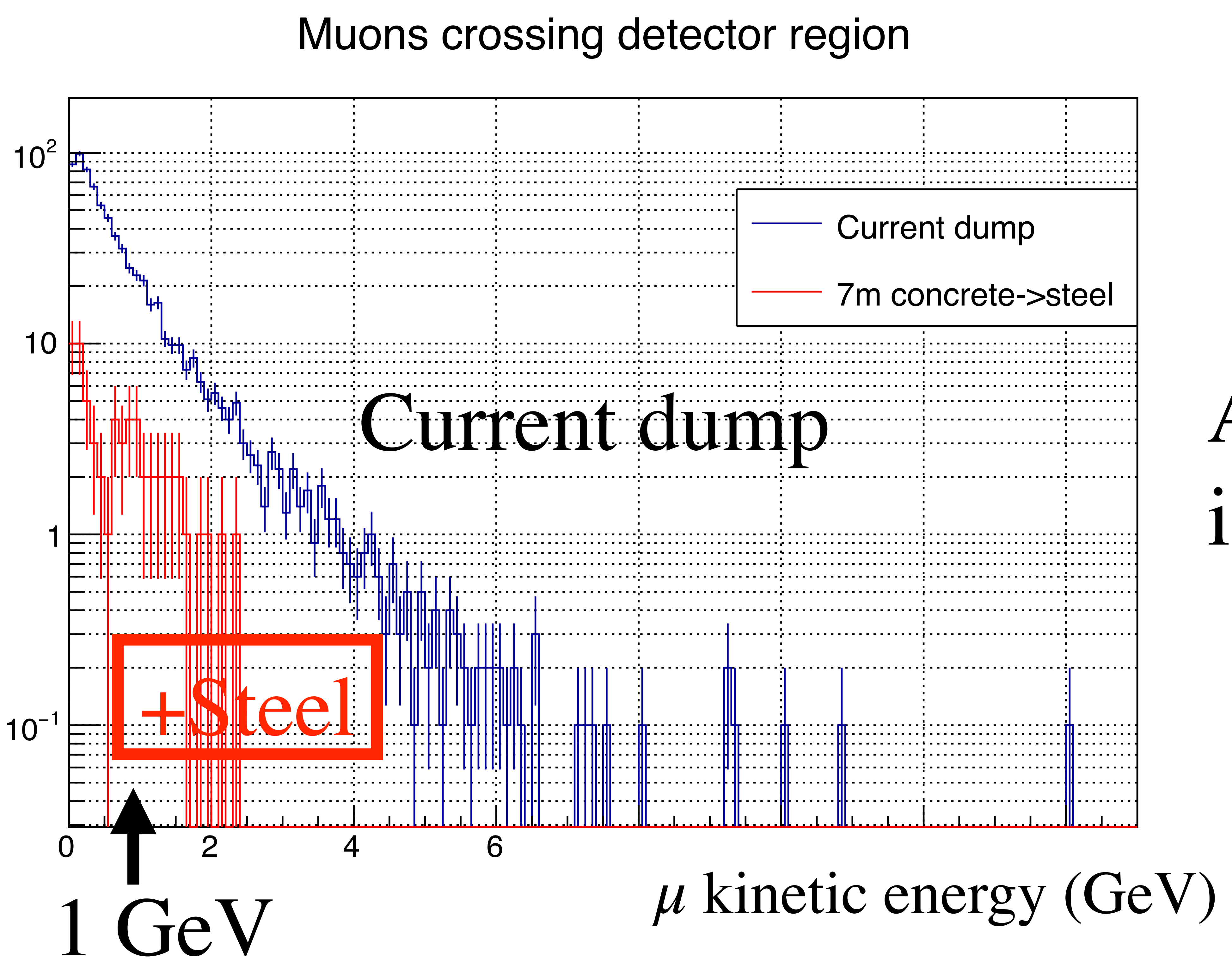
Radiation environment behind the dump

Proposed dump configuration

Additional steel $4 \times 3 \times 7\ m^3$



7.5 MHz → 0.7 MHz



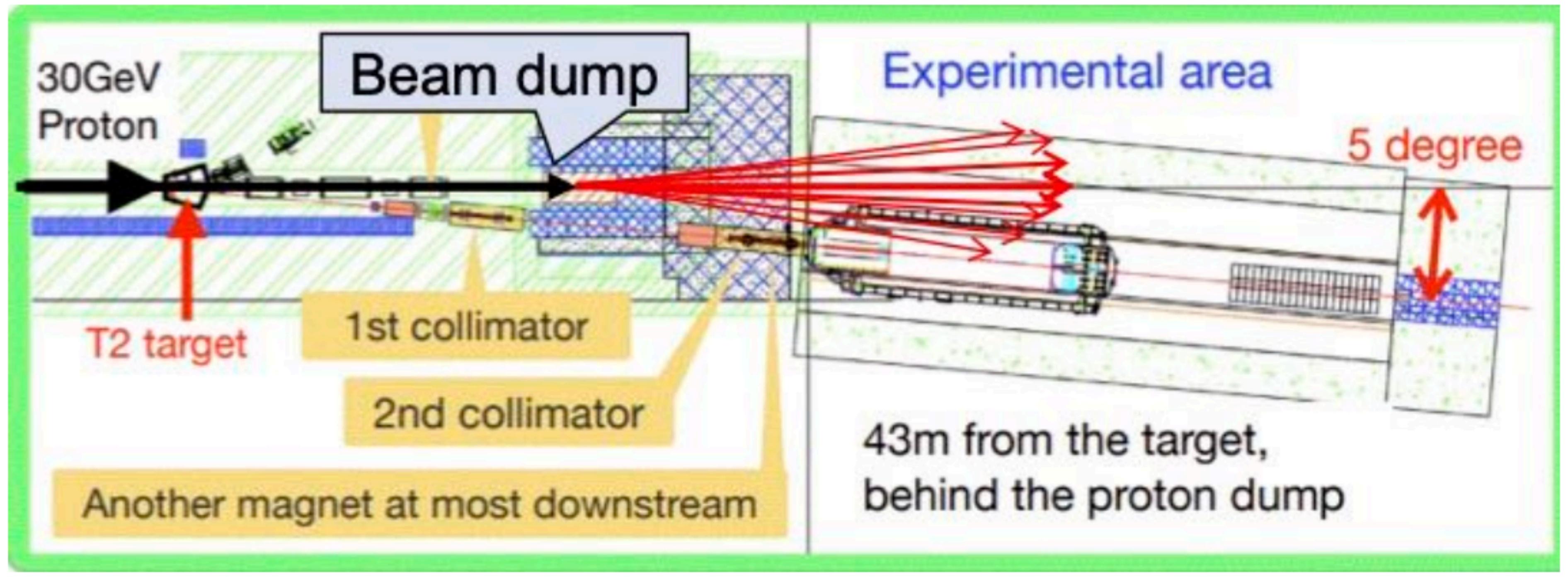
Additional steel is included in the budget request

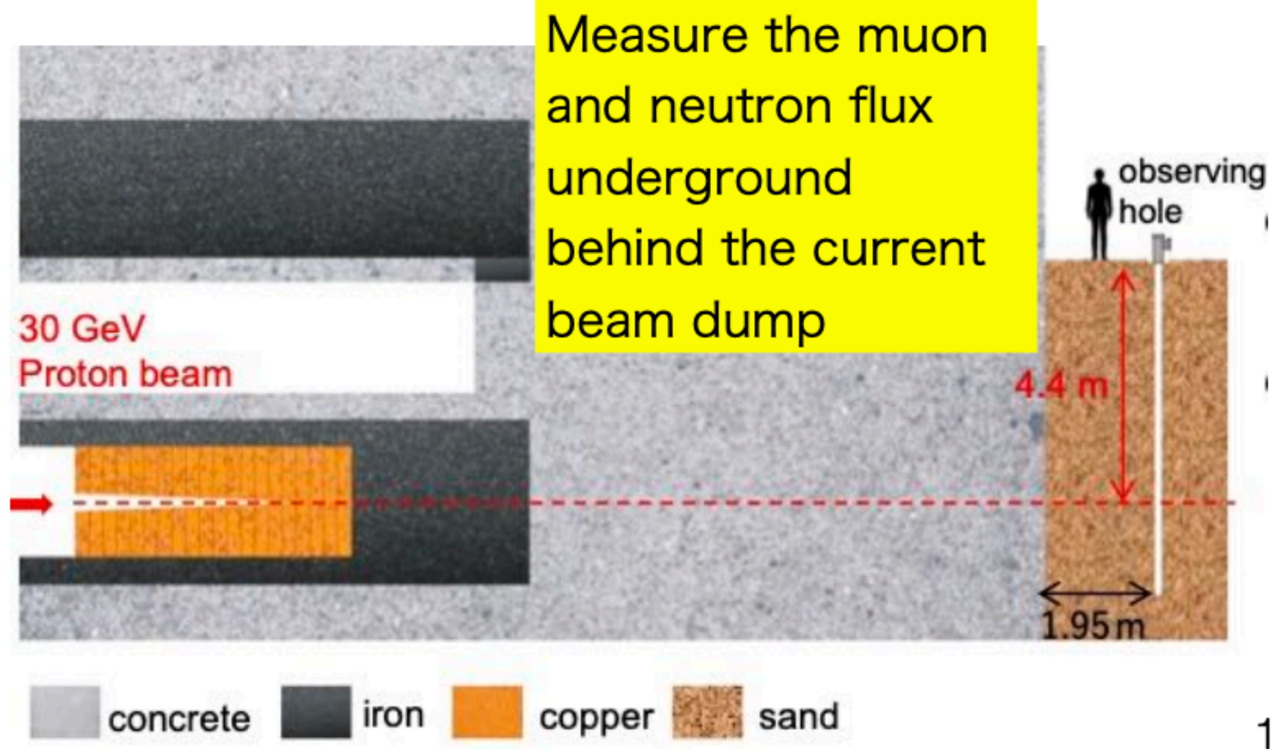
Measurement of muon flux behind the dump

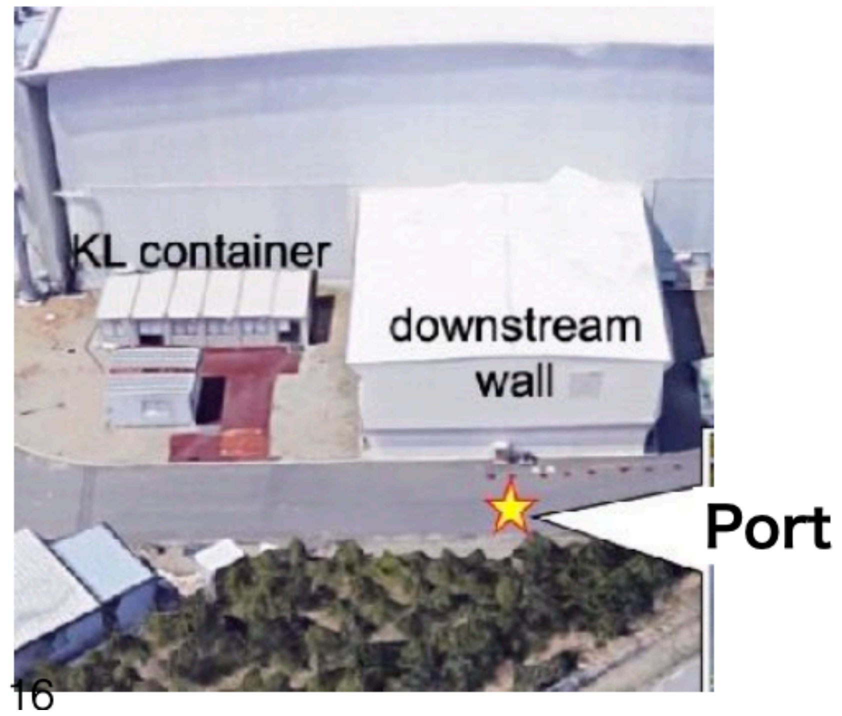
Update
Y.Hirayama,
T.Matsumura

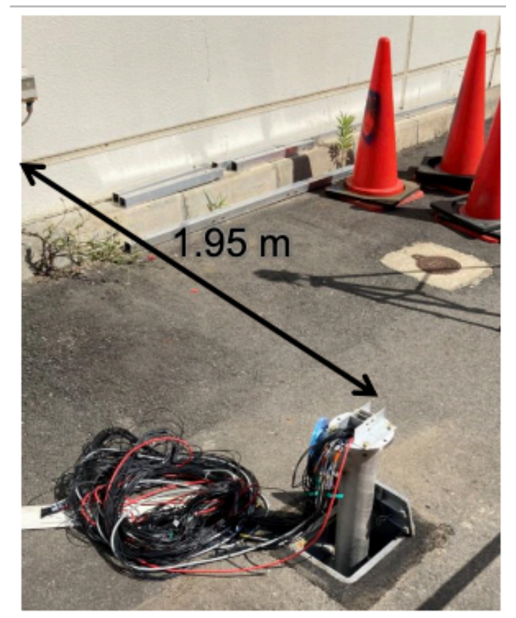
Muon flux measurement behind the beam dump in Run90

Motivation: to confirm the muon flux coming to KOTO II/KL2 area, which will be built behind the beam dump

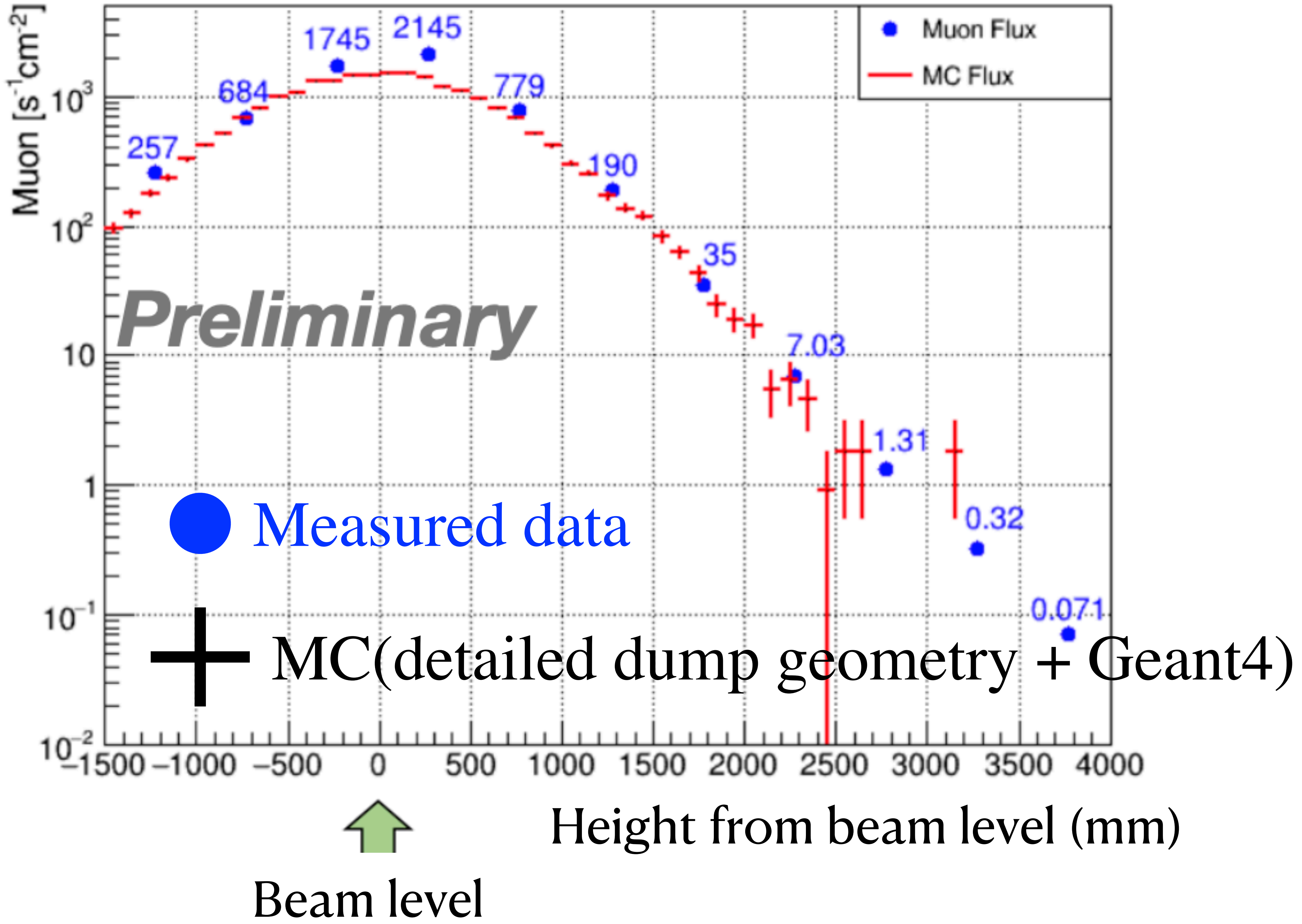








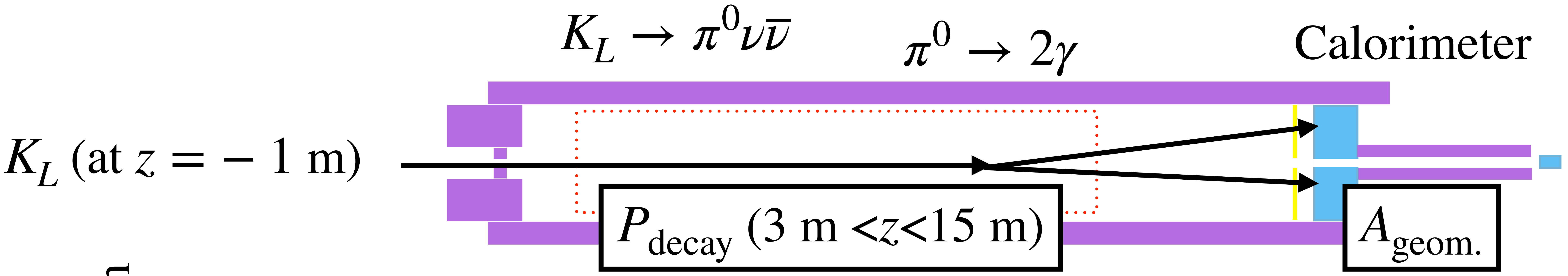
Measurement in June 2023 with beam

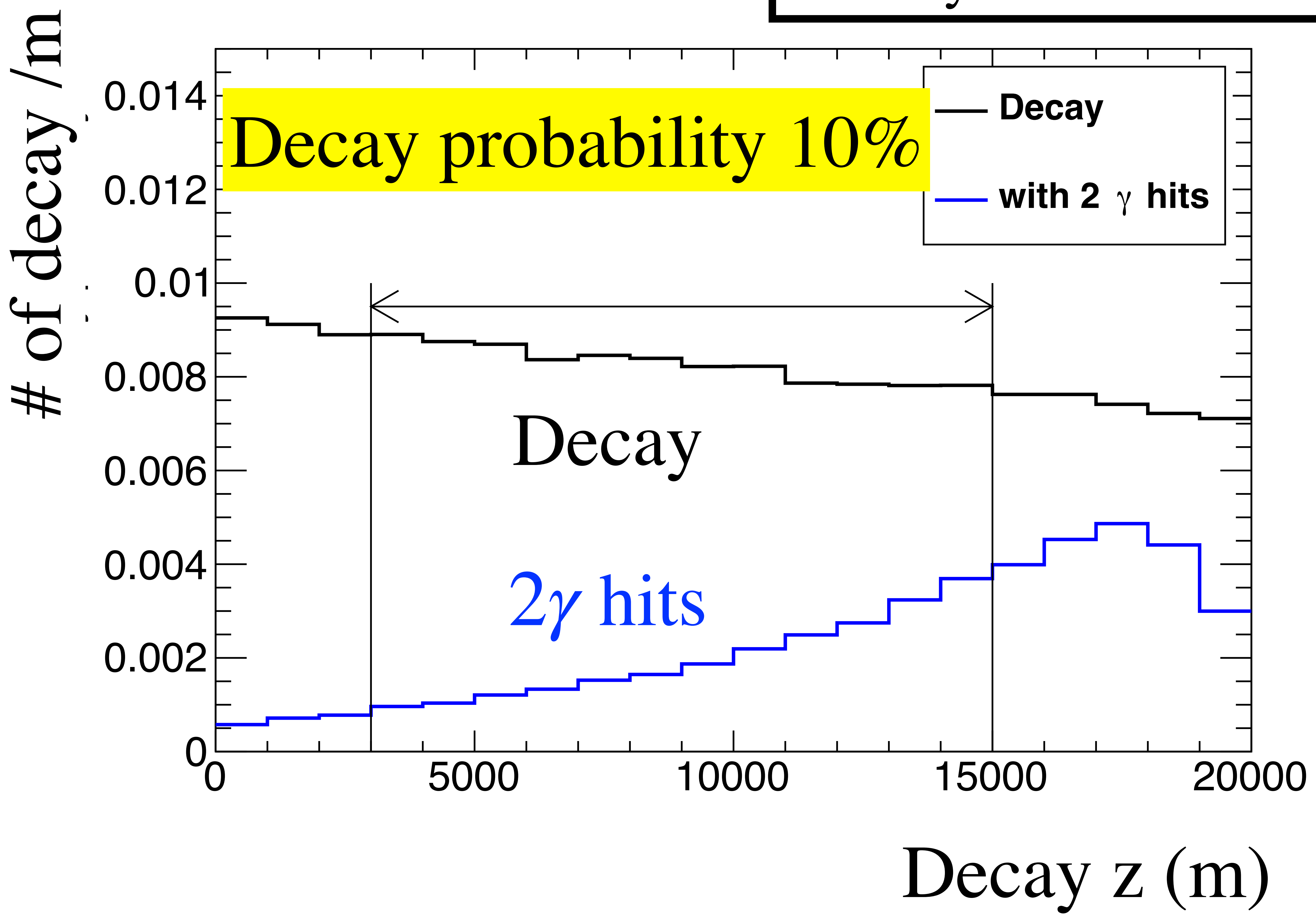


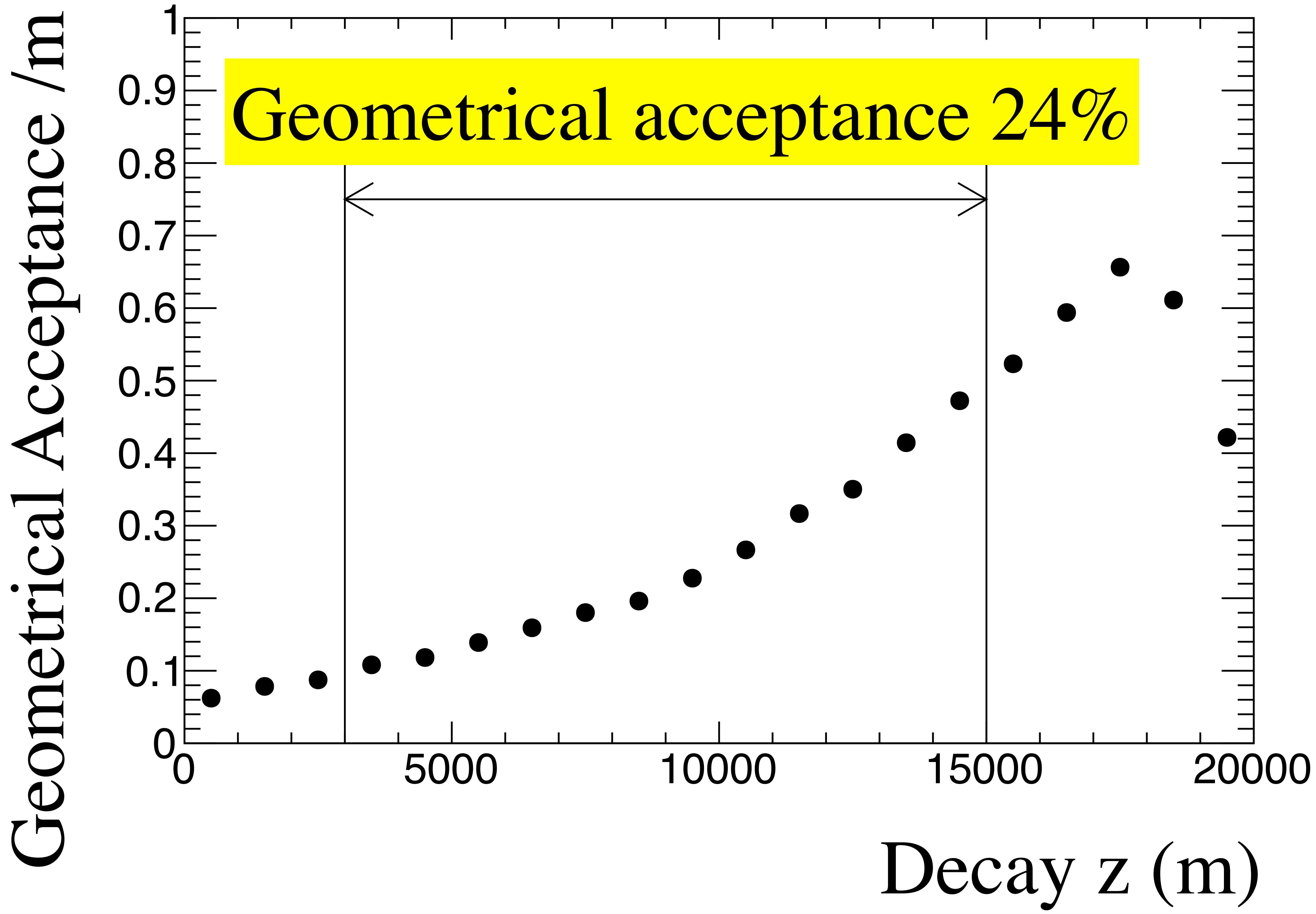
Detailed analysis in progress

Measurements are consistent to MC (detailed dump geometry + Geant4).
This MC gives 2.1 MHz for KOTO II detector rate without additional steel
→ 0.1 MHz with additional steel → contribution to accidental loss : 0.4%

Signal — 2γ in calorimeter —



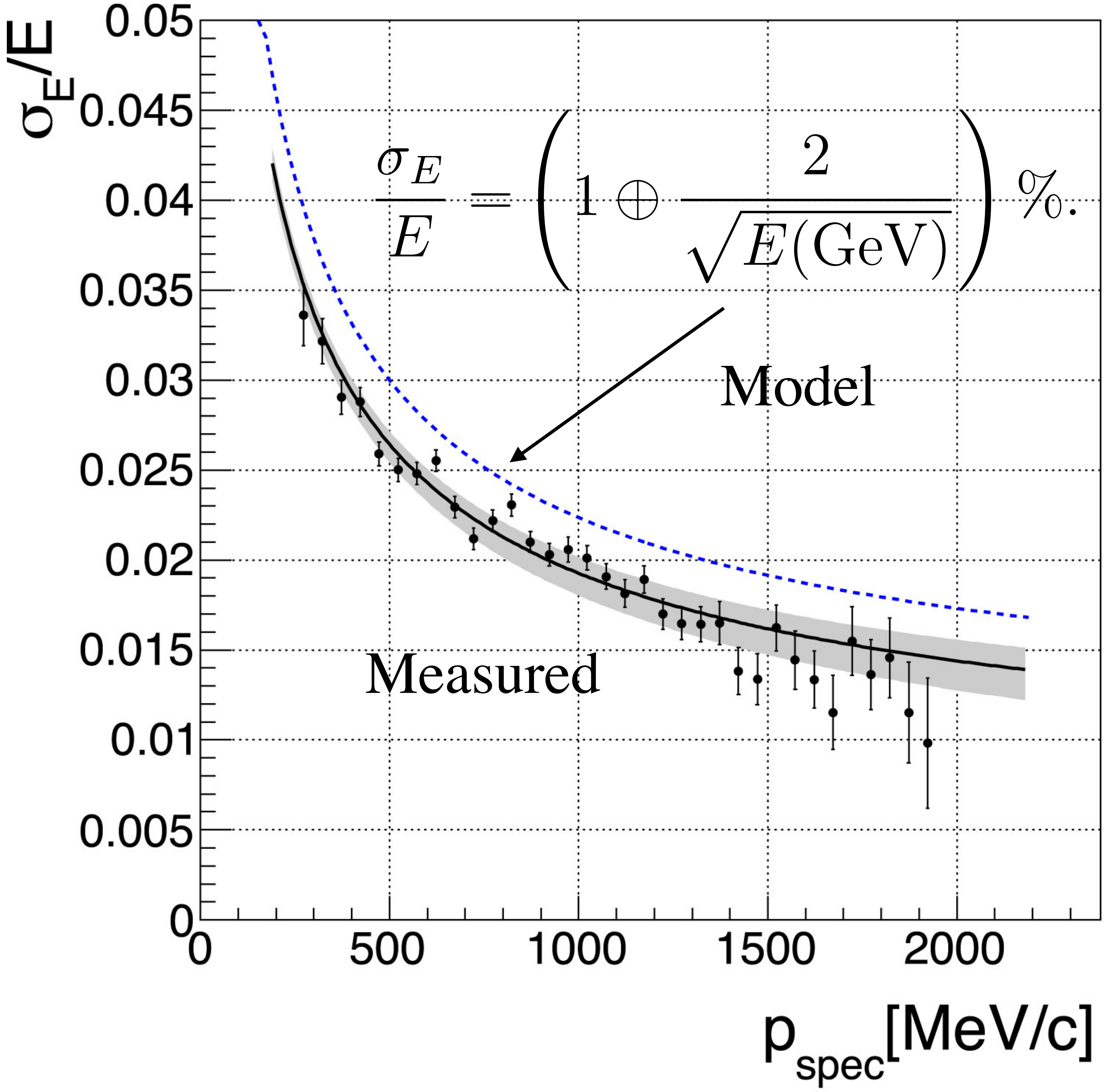


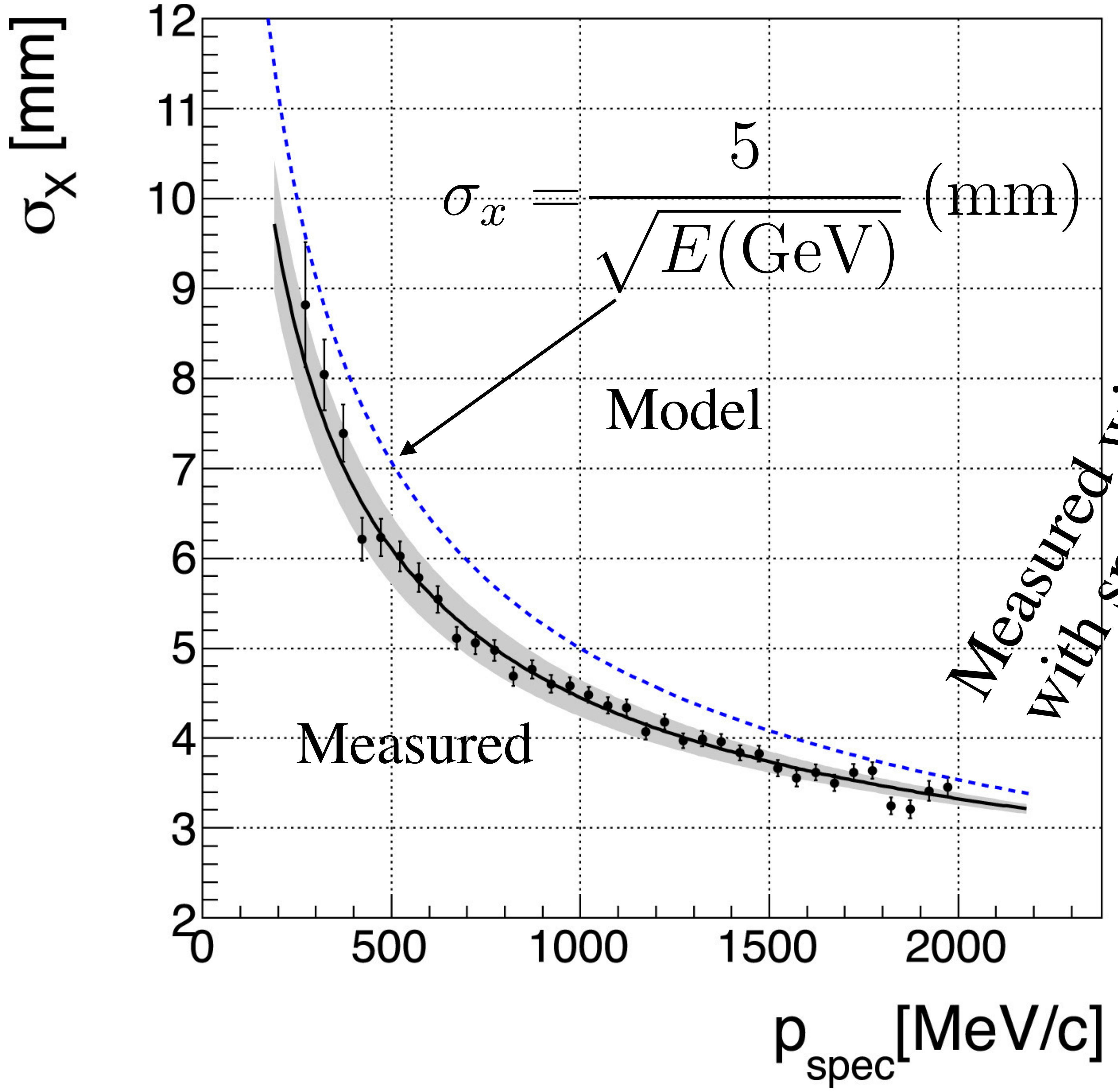


Signal — modeling of calorimeter —

Smearing energy and position

Model based on the performance of the current CsI calorimeter





Measured with $e^{\pm}$ in engineering run in 2012 with spectrometer in front of the calorimeter

Signal — event selections —

$E_0 + E_1 > 500$ MeV
$\sqrt{x_i^2 + y_i^2} < 1350$ mm
$\max(|x_i|, |y_i|) > 175$ mm
$E_i > 100$ MeV
$|\mathbf{r}_1 - \mathbf{r}_0| > 300$ mm

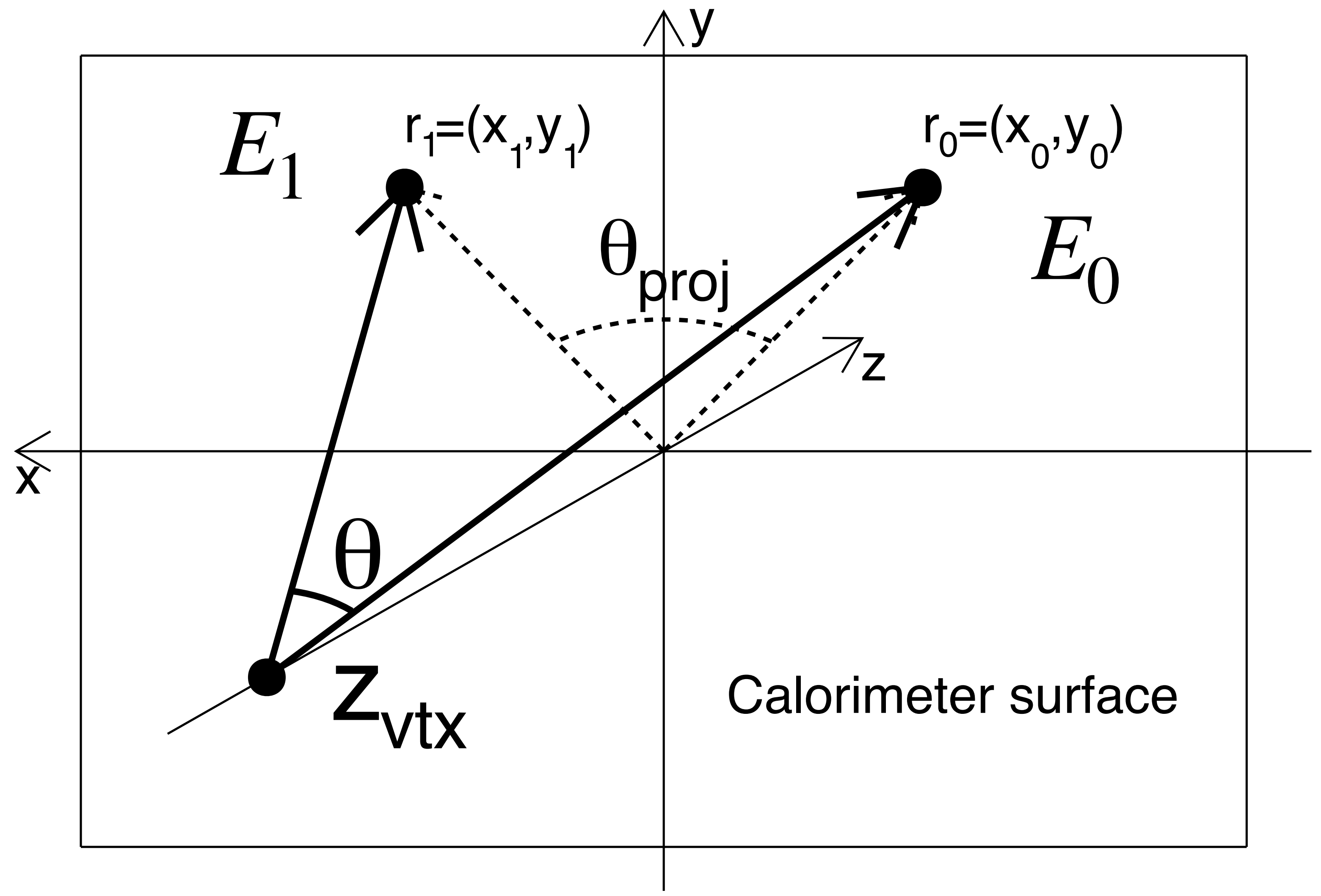
Quality cuts

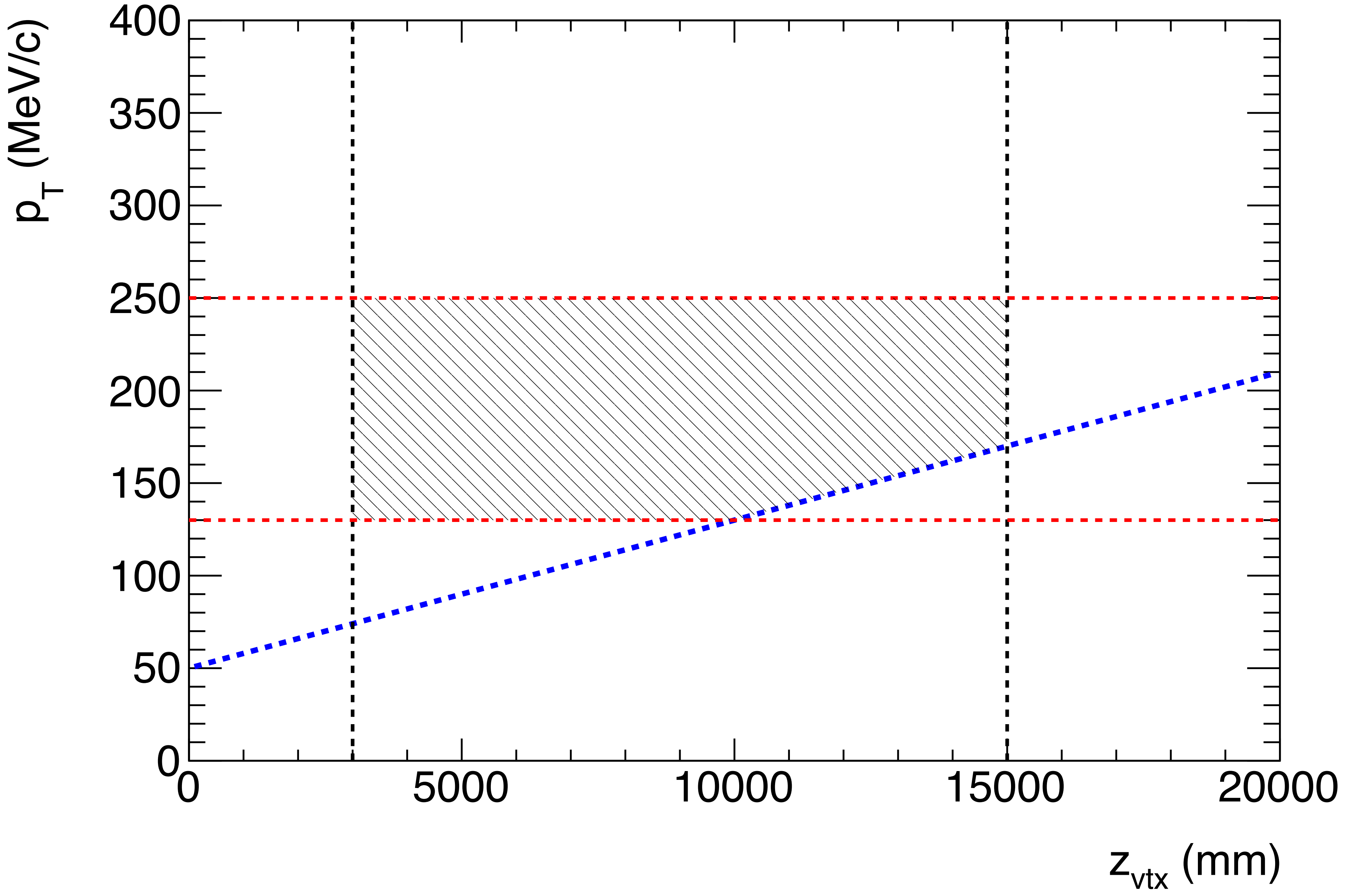
$\theta_{proj} < 150°$ ⟷ $K_L \to 2\gamma$

130 MeV/c < p_T < 250 MeV/c
Tight p_T at downstream

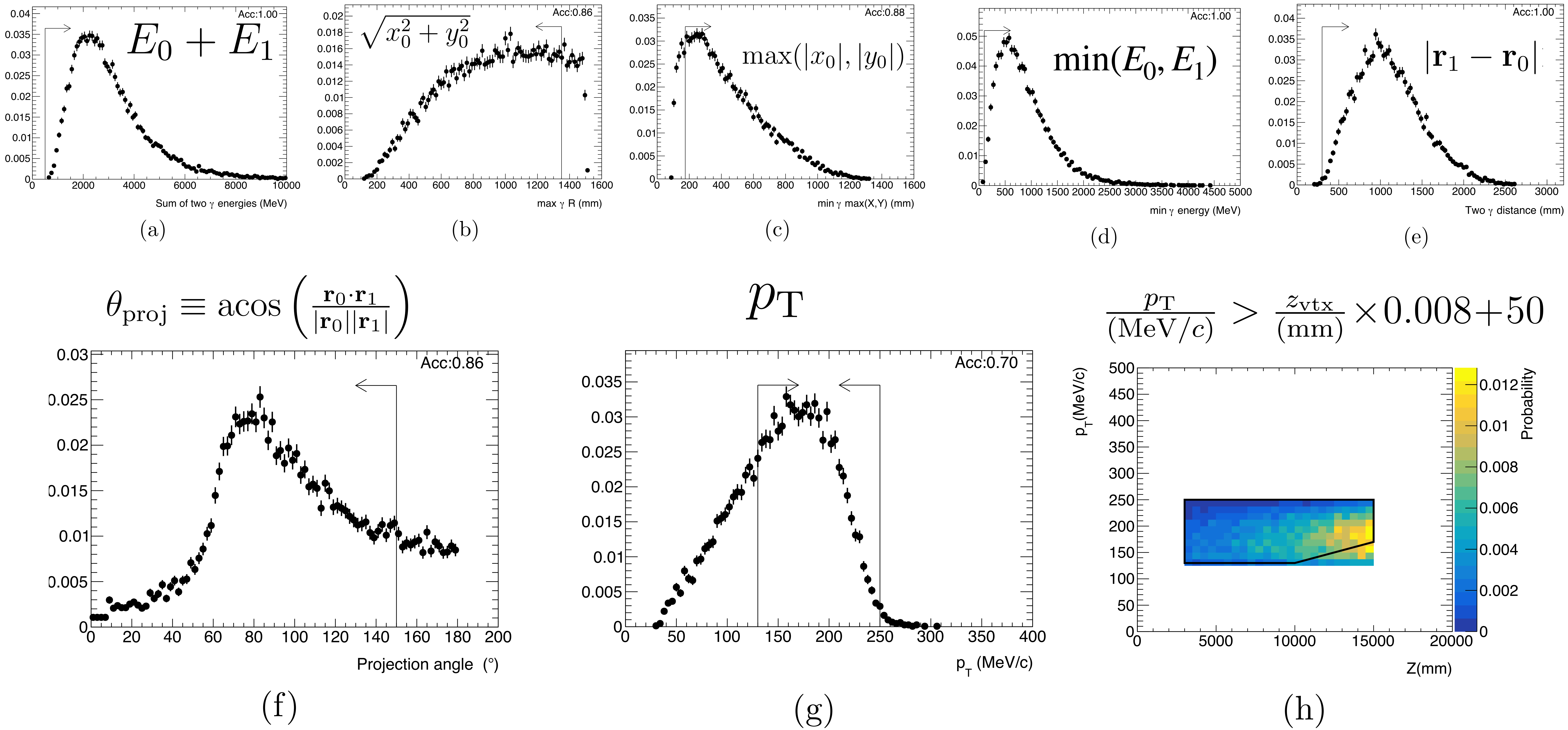
High p_T signal characteristics
Region with worse p_T resolution

selection with cluster shape and waveform
Discrimination of photon/neutron clusters
Discrimination of true/fake incident angle





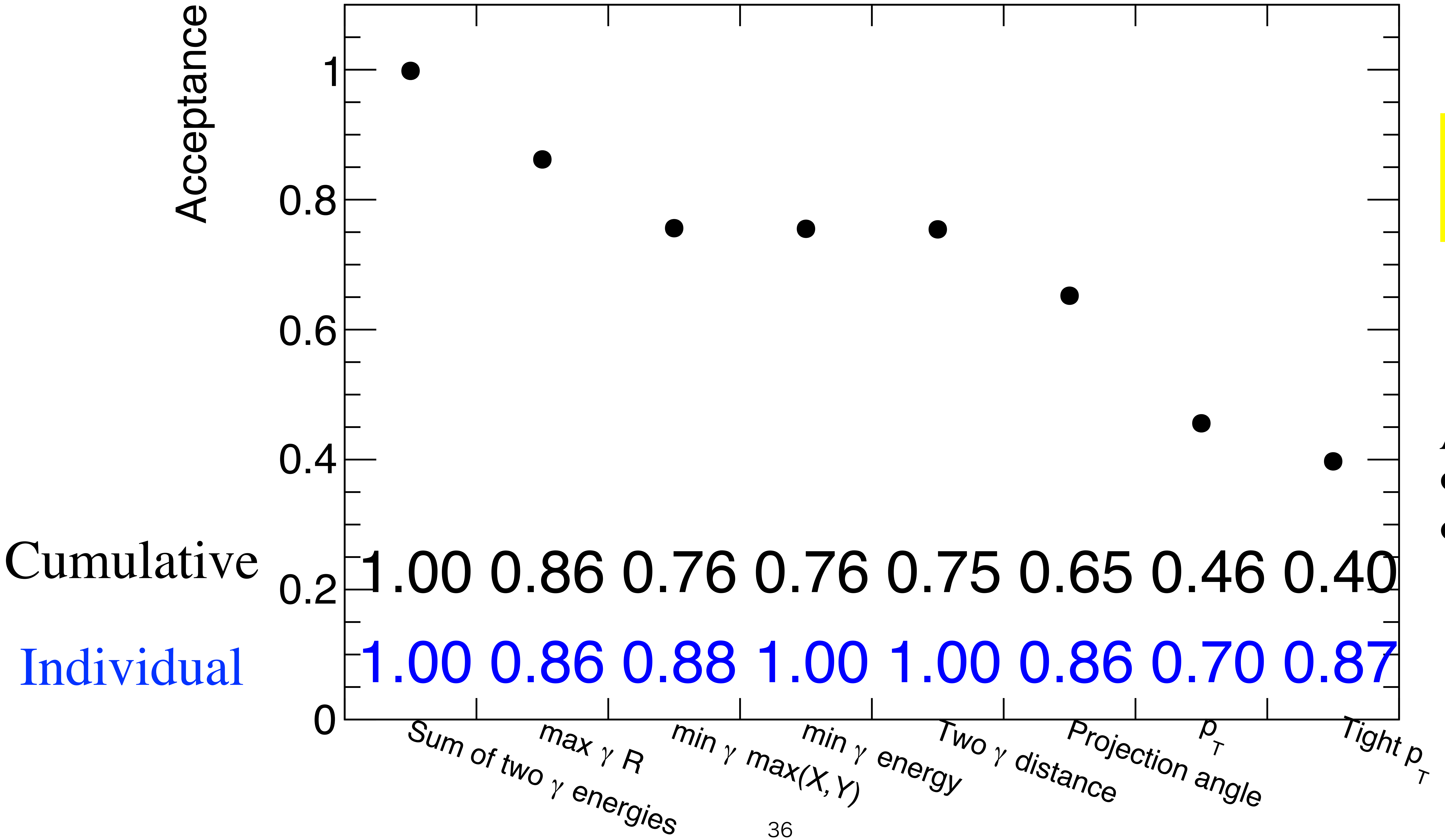
Signal— distributions —



(a) (b) (c) (d) (e)

(f) (g) (h)

Signal— cut acceptance —



Signal acceptance :
$0.4 \times (0.9)^4 = 0.26$ in total

Assumed signal efficiency

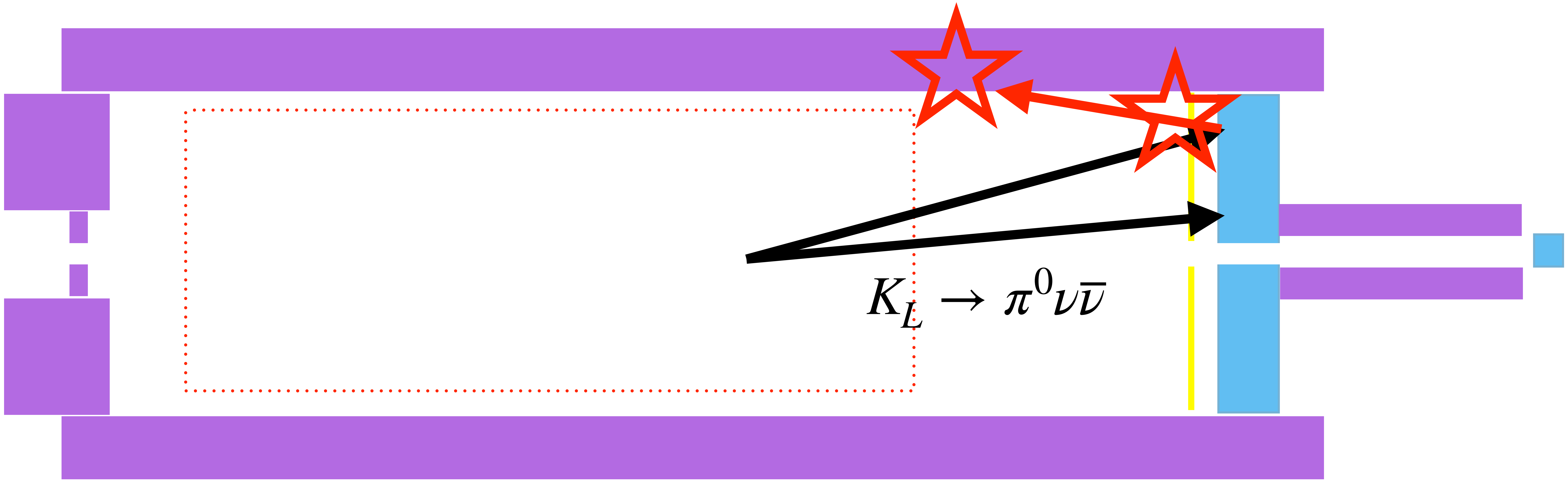
- n/γ discrimination (3 cuts) : 0.9^3
- Consistency between the reconstructed γ angle and the shower shape: 0.9

Signal loss

- Accidental loss : evaluated to be 39%
- Shower leakage loss

Single loss — shower leakage loss—

Gammas from π^0 decay in $K_L \to \pi^0 \nu \overline{\nu}$ sometimes cause shower-leakage to veto counters
$\to$ Signal happens to be vetoed.



Single loss — shower leakage to Central Barrel : backsplash—

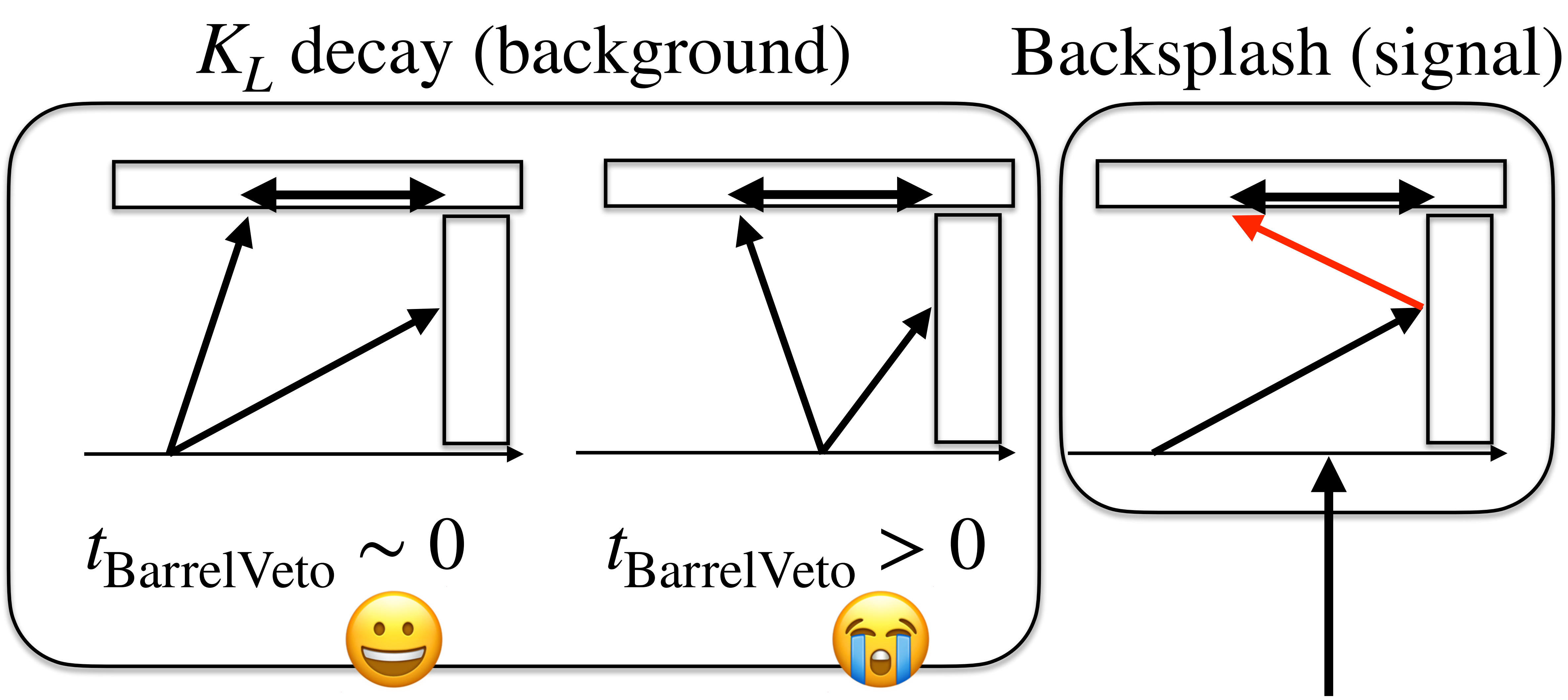
Background : Should veto

Signal : Should not veto

How to discriminate ?

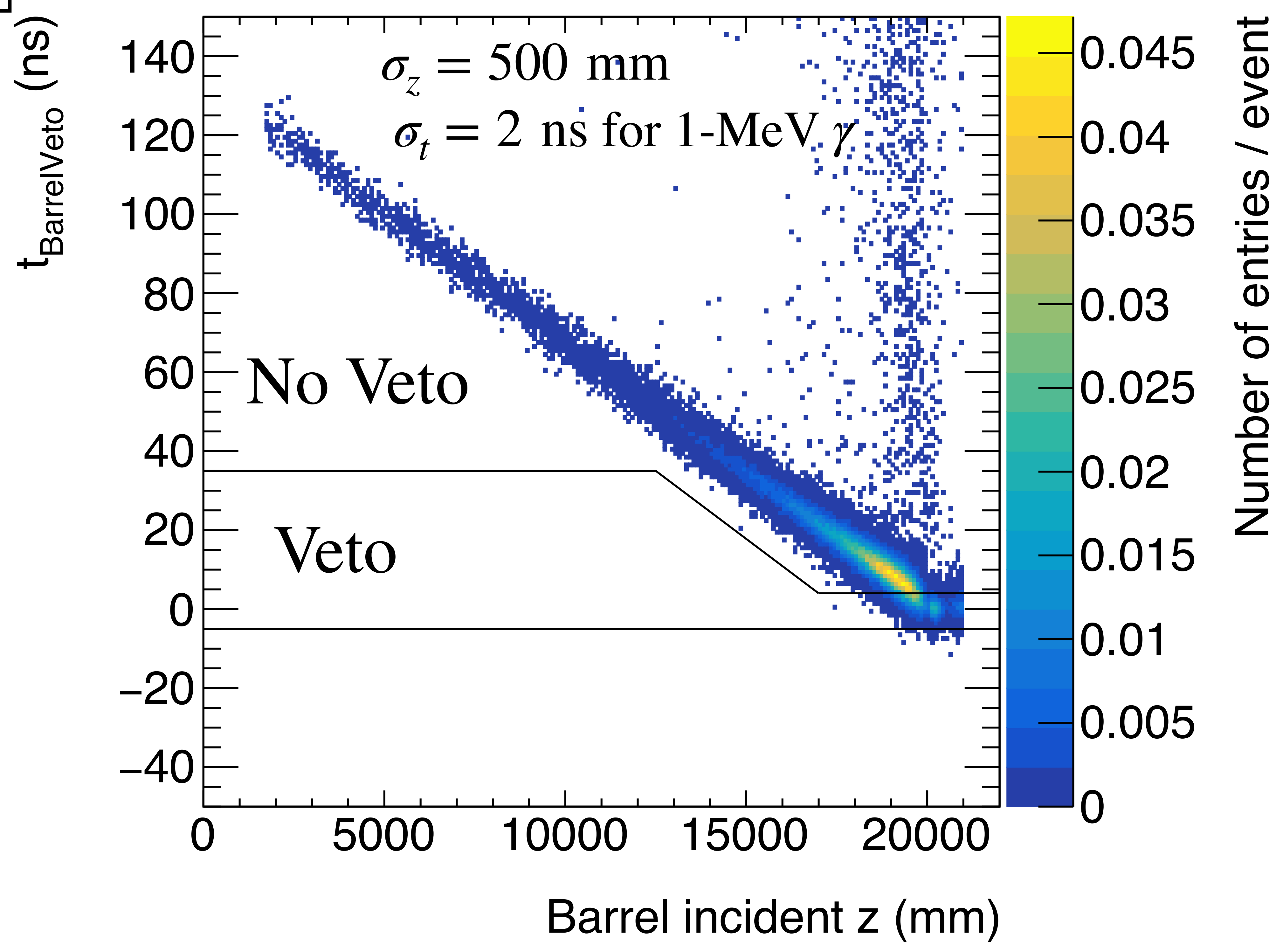
Signal loss — suppress backsplash loss—

$$t_{\mathrm{BarrelVeto}} = \left[t_{\mathrm{BarrelHit}} - t_{\mathrm{CalorimeterHit}}\right] + (z_{\mathrm{Caloriemter}} - z_{\mathrm{BarrelHit}})/c$$
$$= -\left[t_{\mathrm{CalorimeterHit}} - t_{\mathrm{BarrelHit}}\right] + (z_{\mathrm{Caloriemter}} - z_{\mathrm{BarrelHit}})/c$$



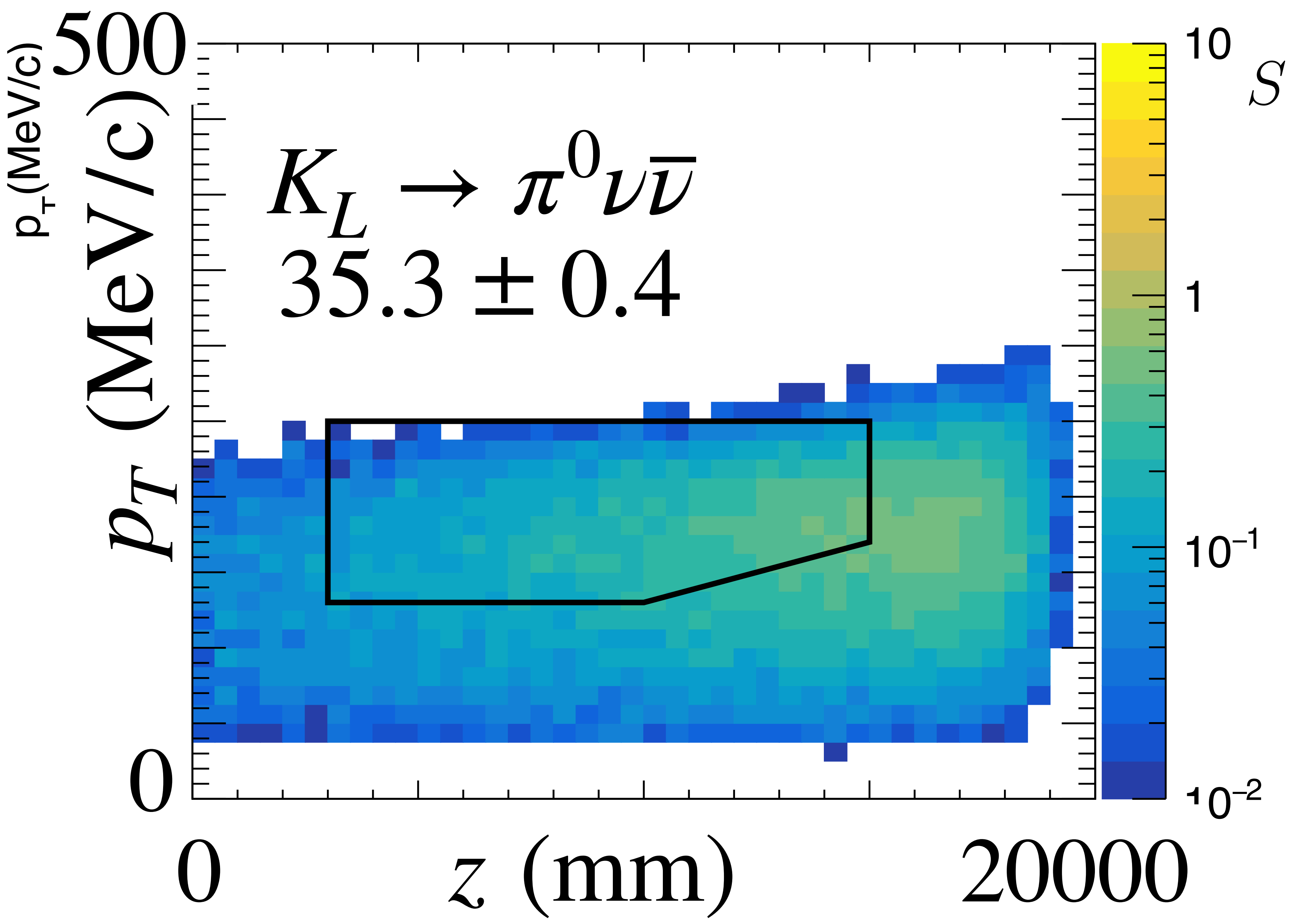
$t_{\mathrm{BarrelVeto}} \sim 2(z_{\mathrm{calorimeter}} - z_{\mathrm{BarrelHIt}}/c)$

Distribution for $K_L \to \pi^0 \nu \overline{\nu}$
(Shower simulation)



Shower-leakage loss=9%
Signal survival probability=91%

of signal events



$$S = \frac{(\text{beam power}) \times (\text{running time})}{(\text{beam energy})} \times (\text{number of } K_L/\text{POT})$$
$$\times P_{\text{decay}} \times A_{\text{geom}} \times A_{\text{cut}} \times (\text{1-accidental loss}) \times (\text{1-backsplash loss}) \times \mathcal{B}_{K_L \to \pi^0 \nu \bar{\nu}}$$
$$= \frac{(100 \text{ kW}) \times (3 \times 10^7 \text{ s})}{(30 \text{ GeV})} \times \frac{(1.1 \times 10^7 K_L)}{(2 \times 10^{13} \text{ POT})}$$
$$\times 9.9\% \times 24\% \times 26\% \times (1 - 39\%) \times 91\% \times (3 \times 10^{-11})$$
$$= 35.$$

Beam power : 100 kW at T2 target
Data taking : 3×10^7 s
# of events (SM) : 35 events

	KL yield	Decay Probability	Geometrical Acceptance	Cut efficiency	1- Accidental loss	1-Backsplash loss
KOTO		3.3%	26%	3%	36%	50%
KOTO II	×2.6	10%	24%	26%	61%	91%
Improvement factor	2.6	3	0.9	8.7	1.7	1.8

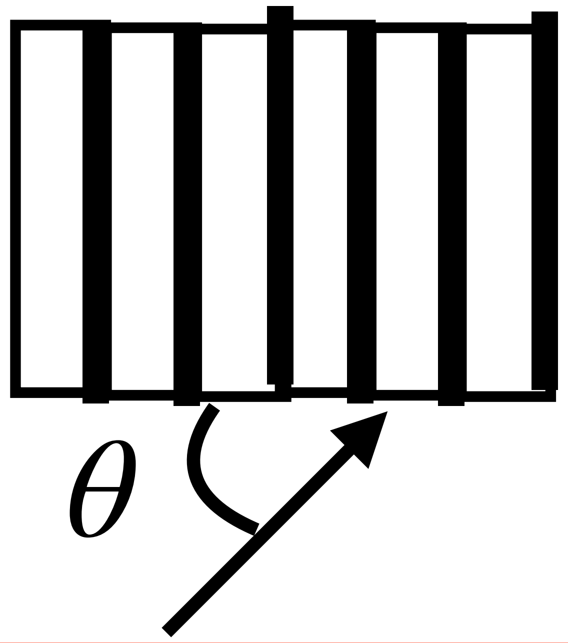
Improvement factor × 190 in total

Background evaluation

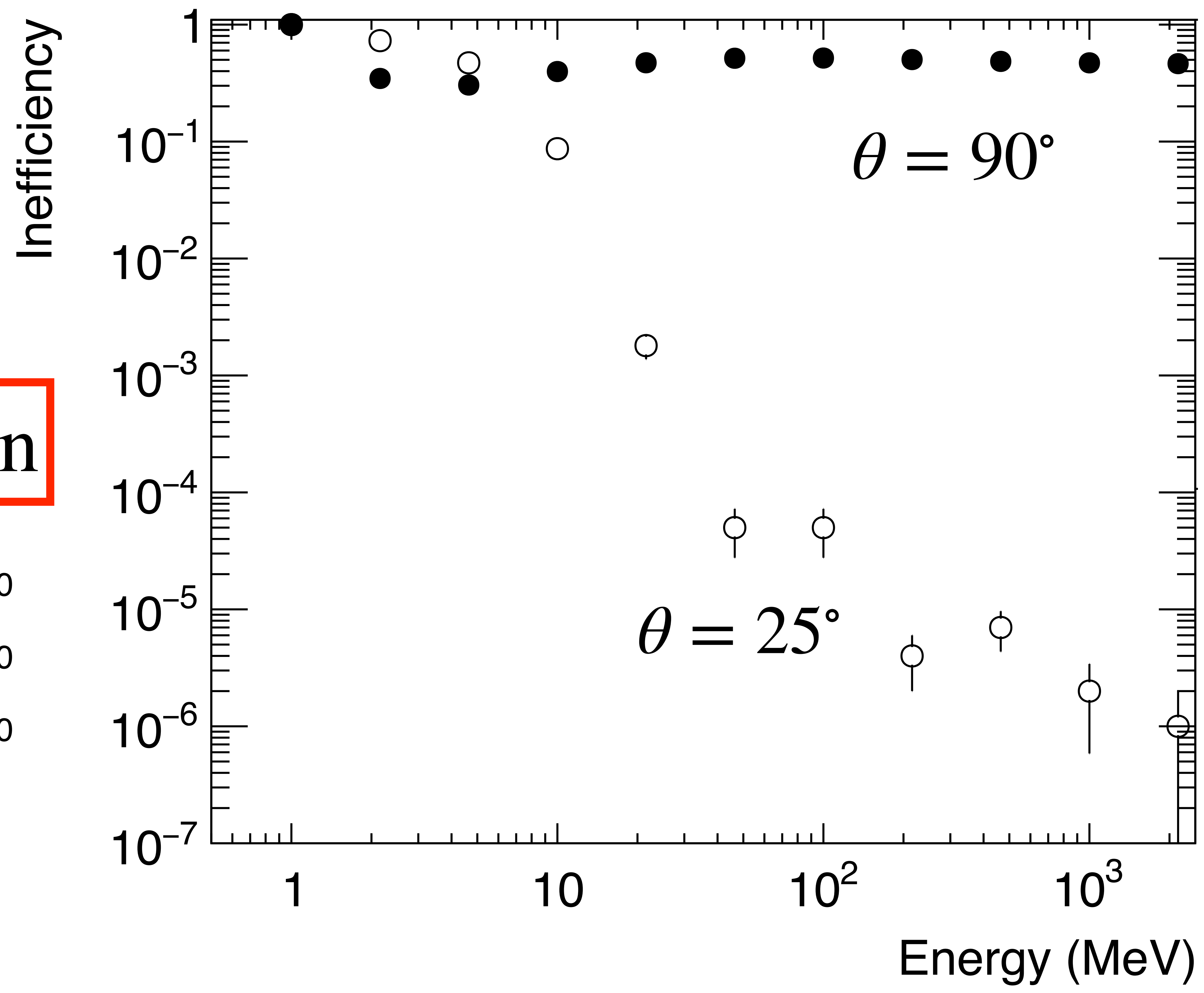
Beam power : 100 kW at T2 target
Data taking : 3×10^7 s

Background — Inefficiency modeling —

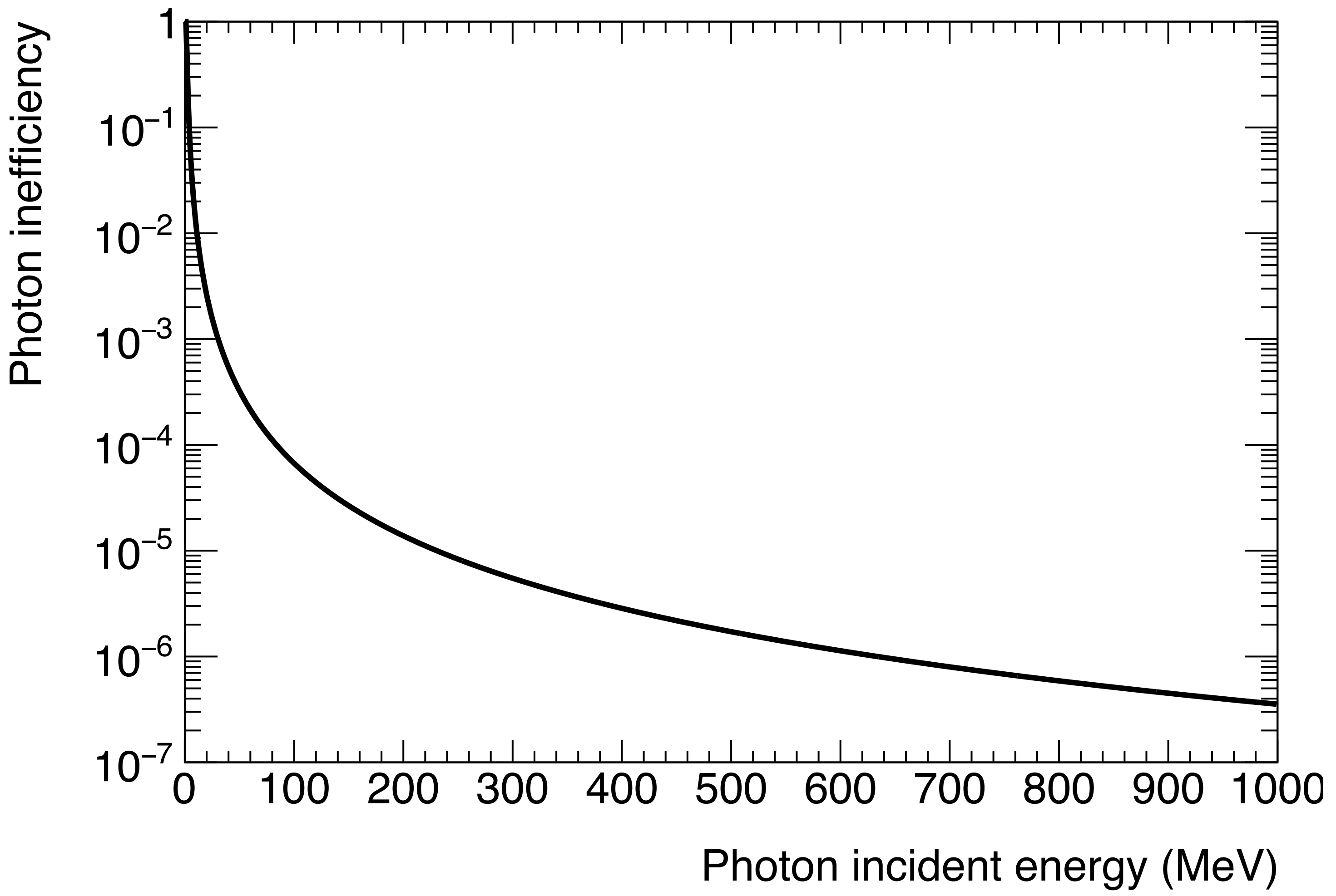
New Barrel
Lead (1 mm)
Scintillator(5 mm)
1-MeV threshold

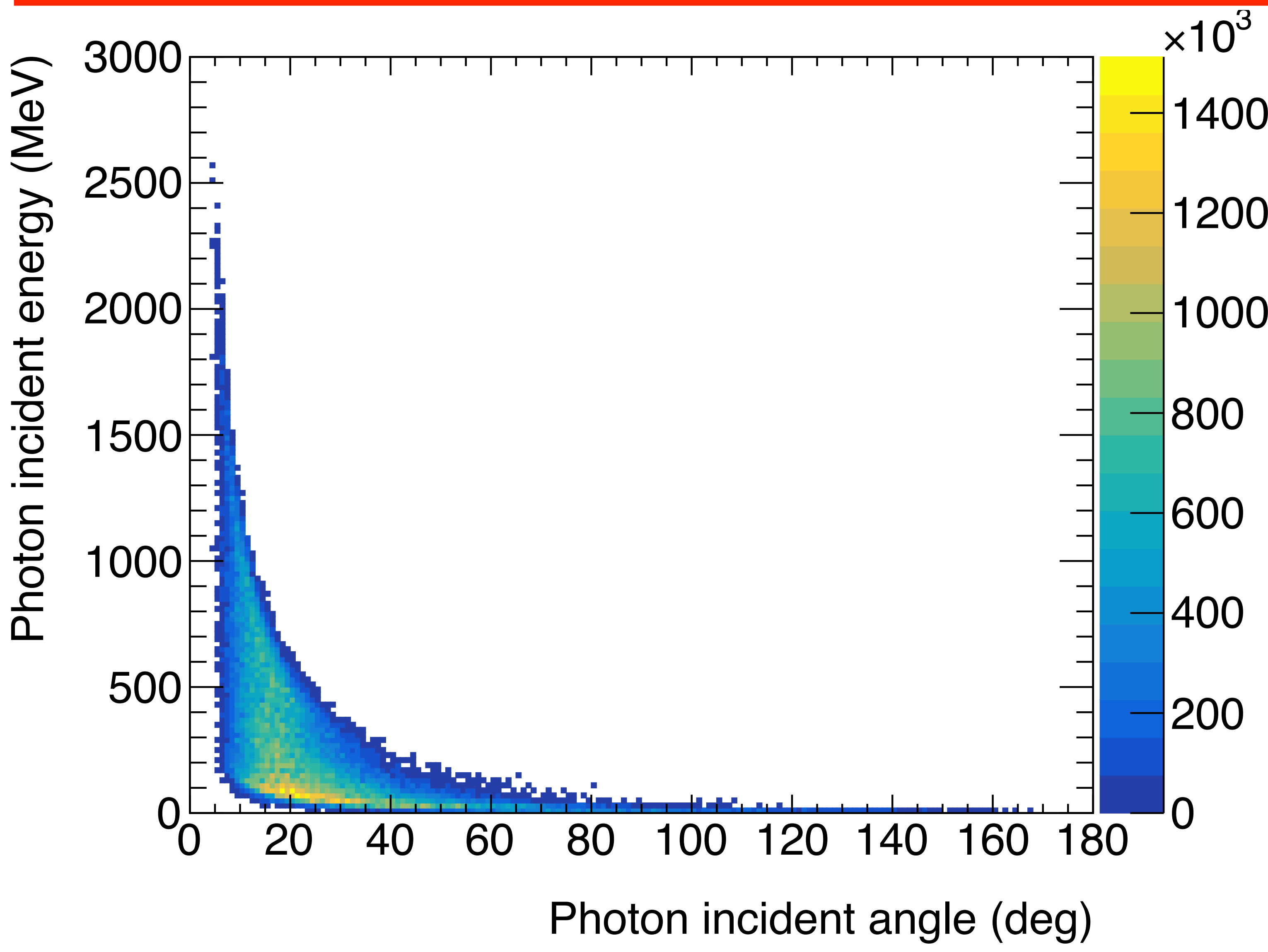


Layers stacked in z direction



Calorimeter
50-cm long CsI

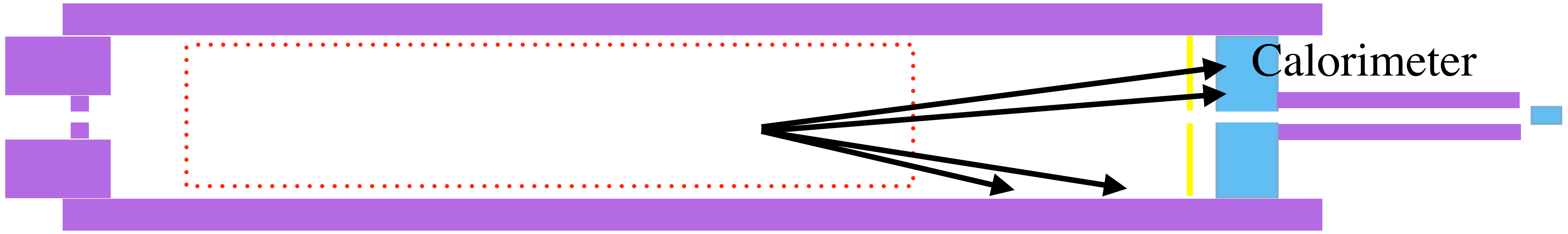




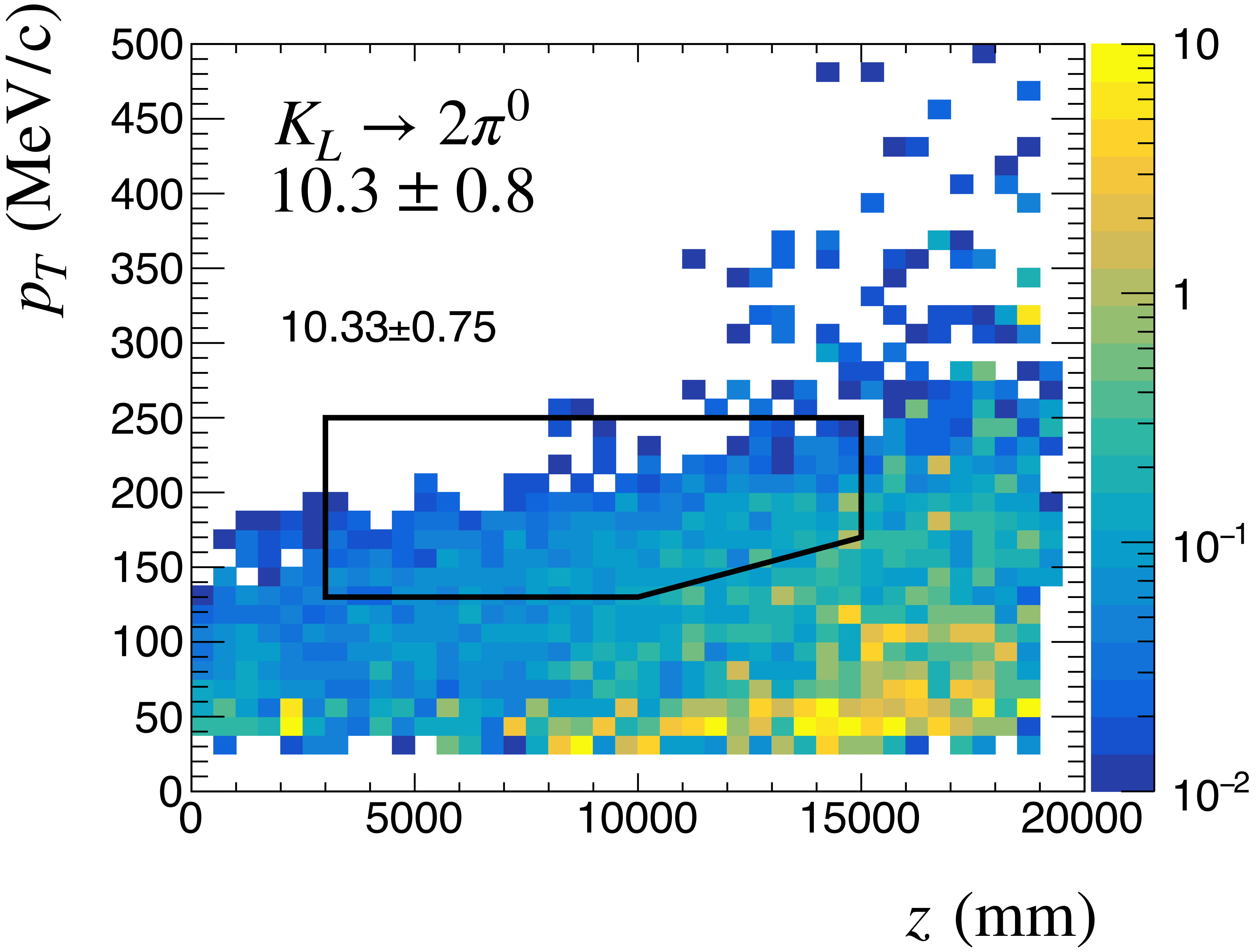
90 deg : inefficient
⇔Less photons, low energy

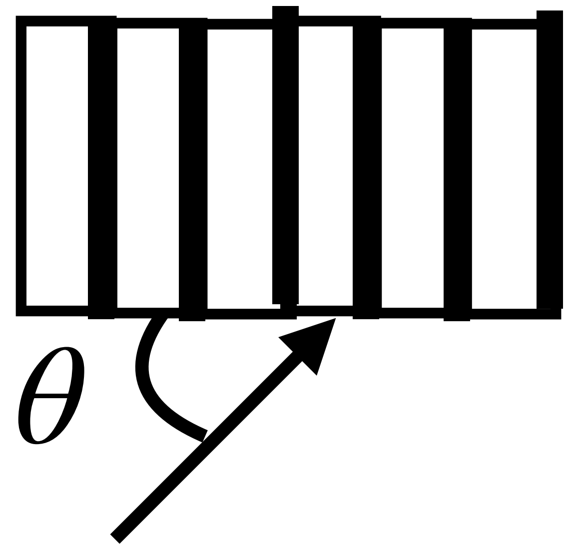
Background $-K_L \to 2\pi^0-$

$\sigma_z = 500$ mm
$\sigma_t = 2$ ns for 1-MeV γ

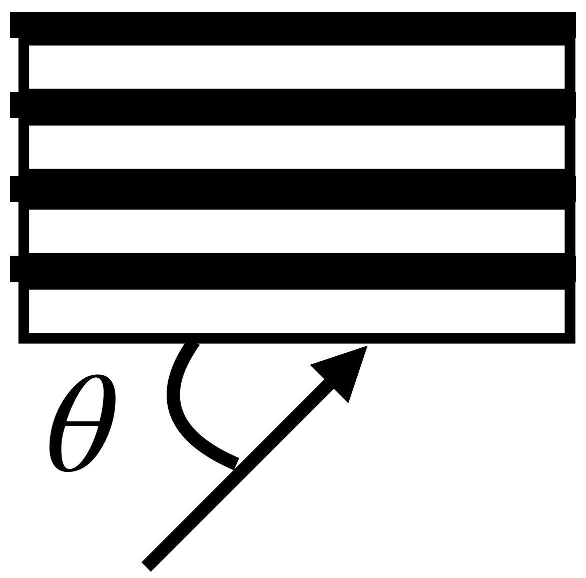


Update from KAON2022





10.3 events are expected.
layer in radial direction is better



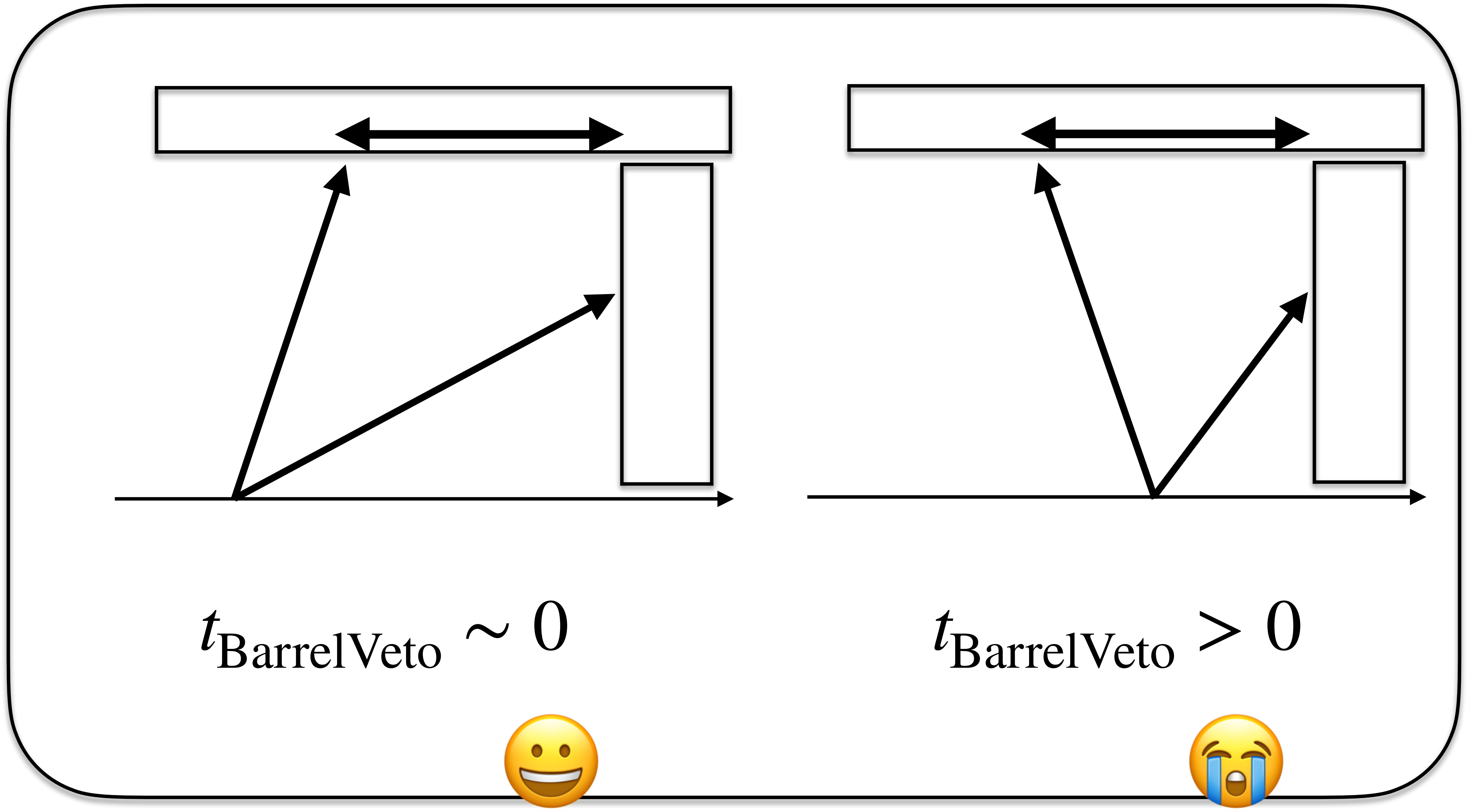
33.2 events are expected.
(KAON2022)

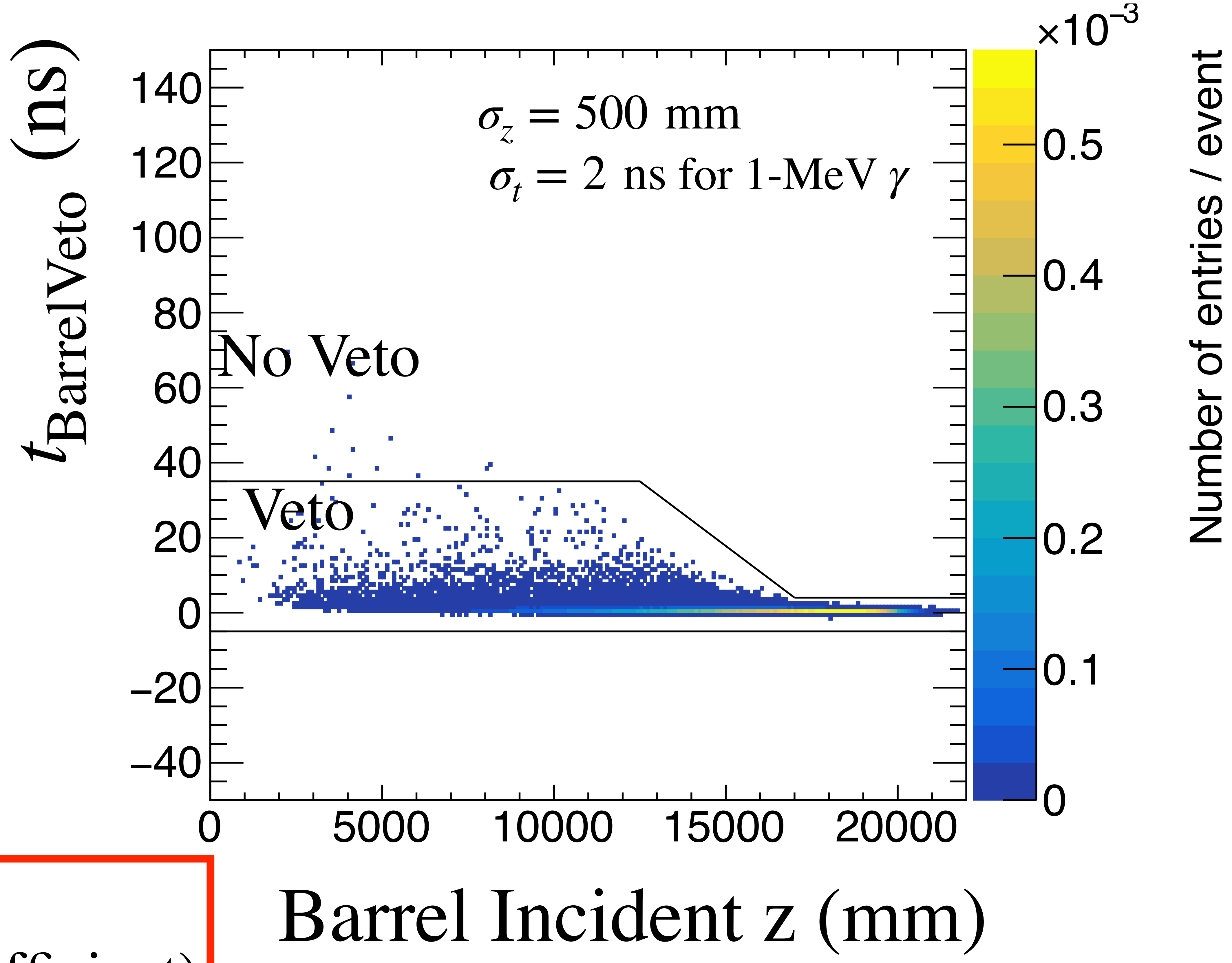
Background $-K_L \to 2\pi^0-$

$$t_{\text{BarrelVeto}} = \left[t_{\text{BarrelHit}} - t_{\text{CalorimeterHit}}\right] + (z_{\text{Caloriemter}} - z_{\text{BarrelHit}})/c$$
$$= - \left[t_{\text{CalorimeterHit}} - t_{\text{BarrelHit}}\right] + (z_{\text{Caloriemter}} - z_{\text{BarrelHit}})/c$$

Distribution for $K_L \to 2\pi^0$
(Shower simulation)

K_L decay (background)

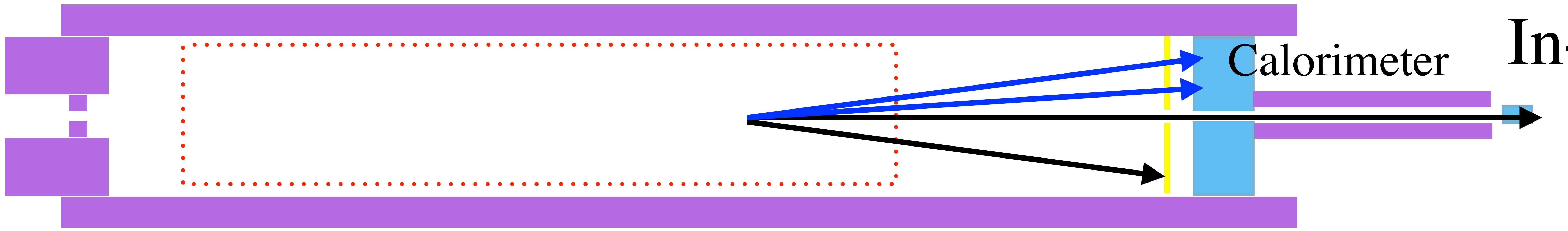




High momentum K_L
→ boost

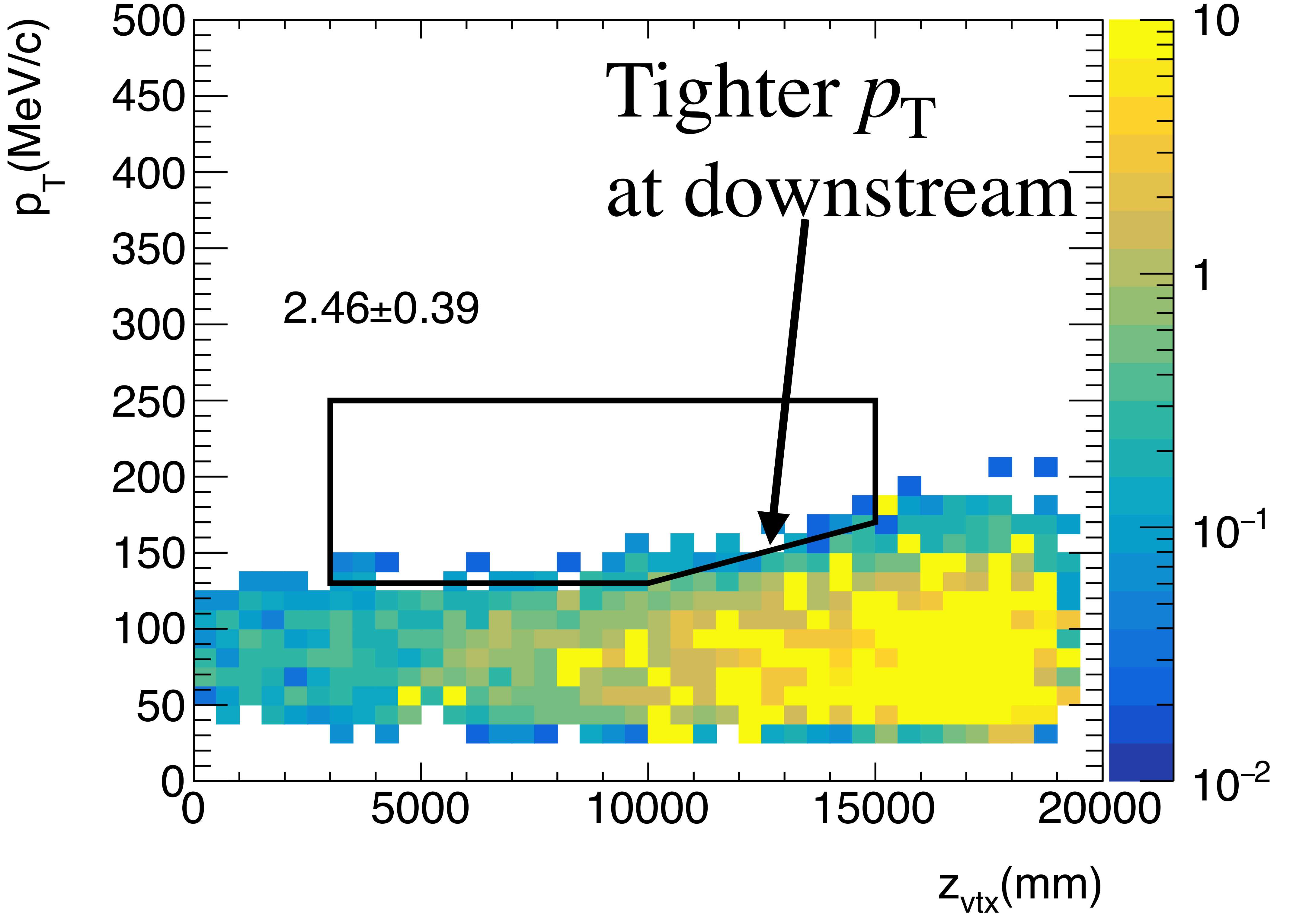
Backward γ tends to be low energy
→ negligible impacts (originally inefficient)

Background — $K_L \to \pi^+\pi^-\pi^0$ —



In-beam inefficiency : 5×10^{-3}

π^- Inefficiency: $4 \times 10^{-4} - 10^{-5}$ depending on momentum



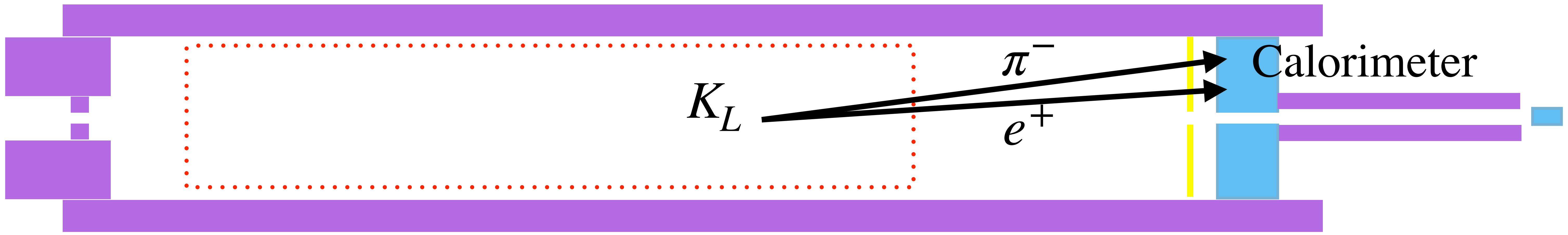
2.5 events are expected

π^0 p_T is limited with kinematics and resolution

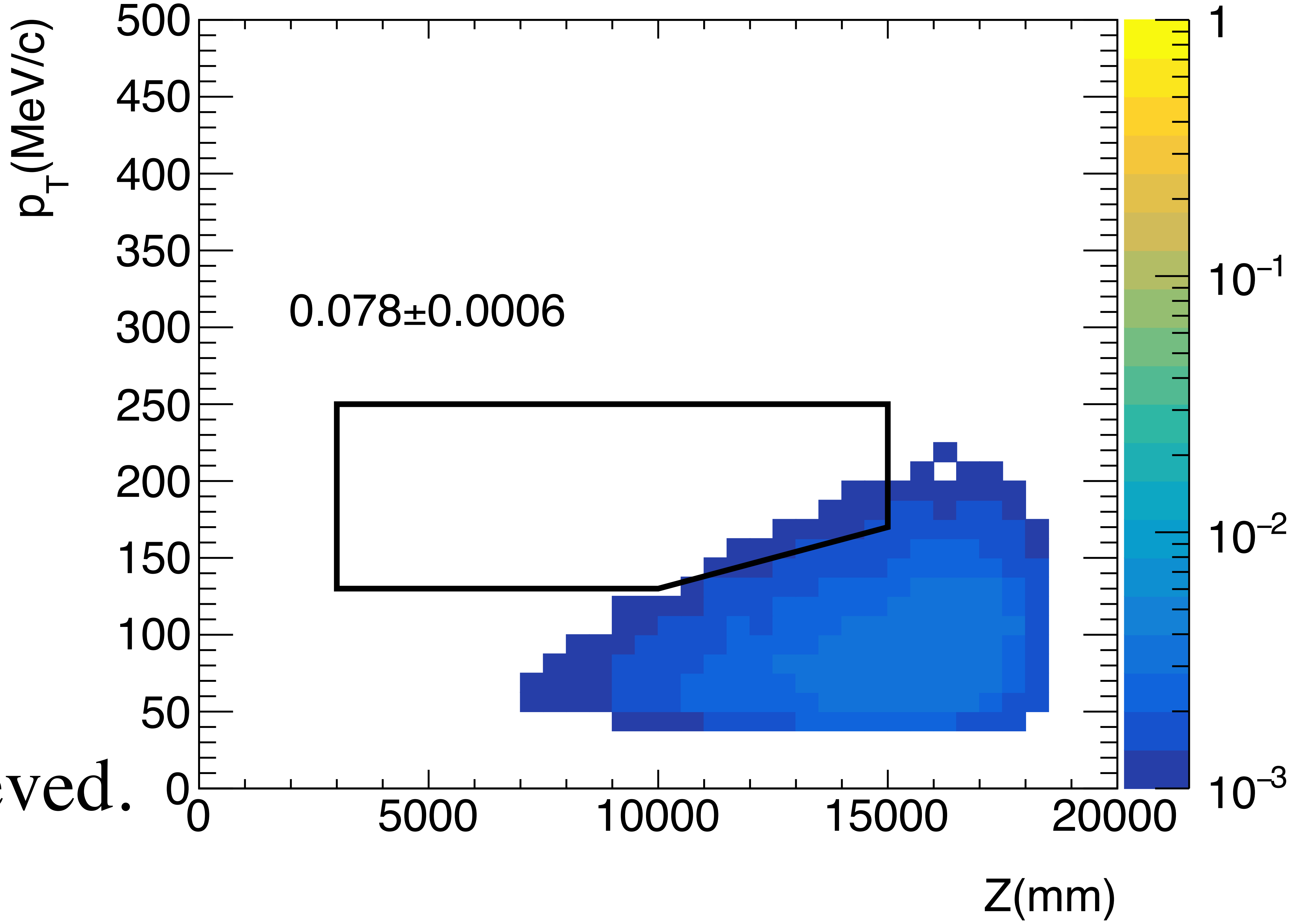
One charged pion is lost in Charged Veto

The other one is lost in Beam Hole Charged Veto

Background $-$ $K_L \to \pi^{\pm}e^{\mp}\nu$ $-$



Reduction to be $\times 10^{-12}$ for penetrating two charged particles

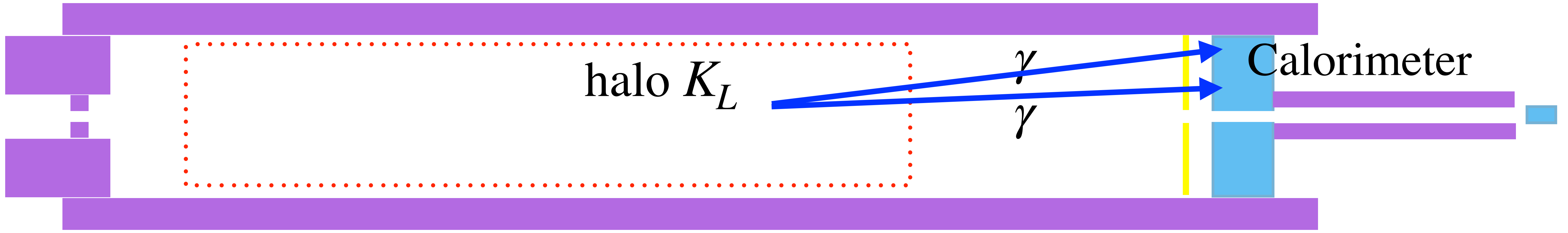


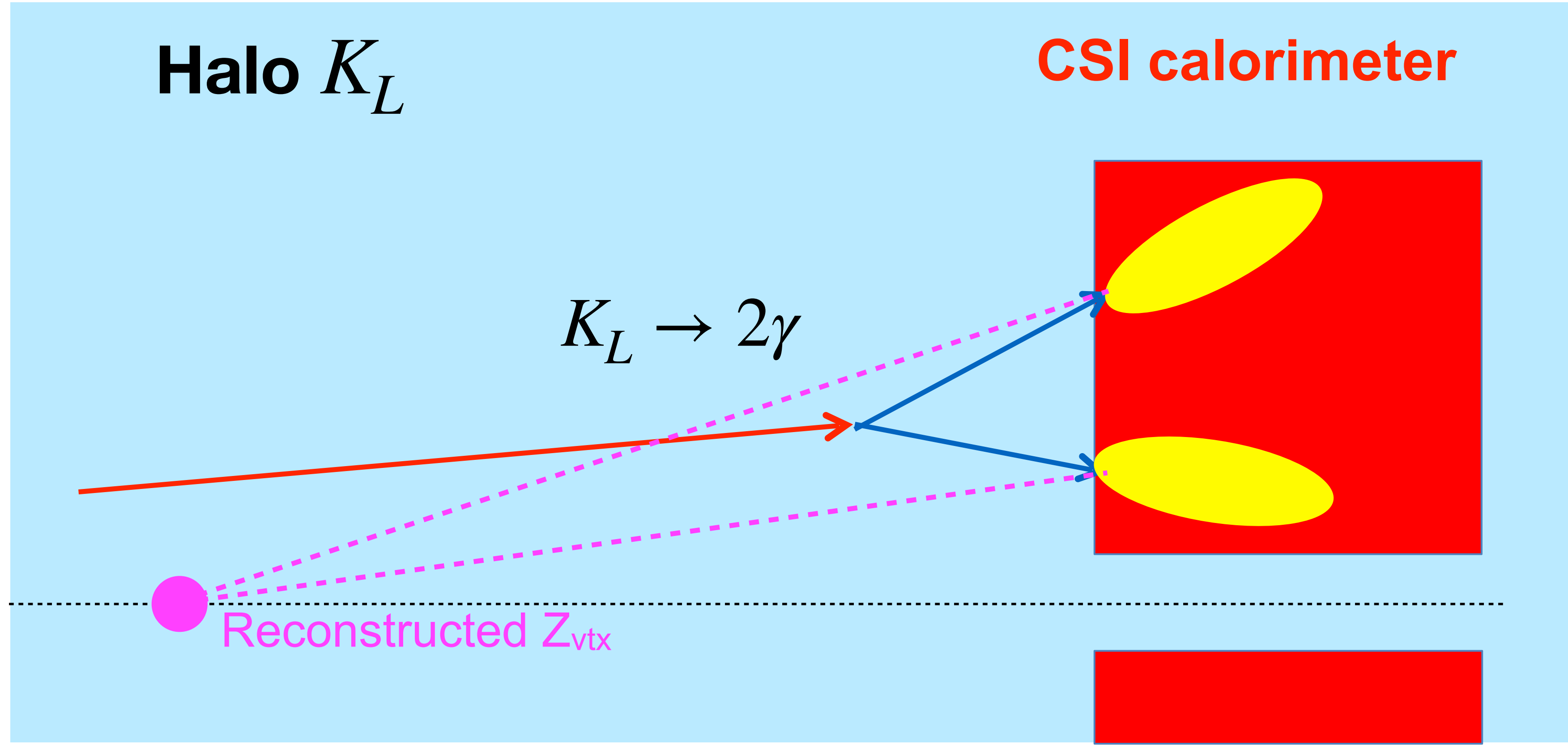
0.08 events are expected

Two layers with 10^{-3}/layer/charged particle

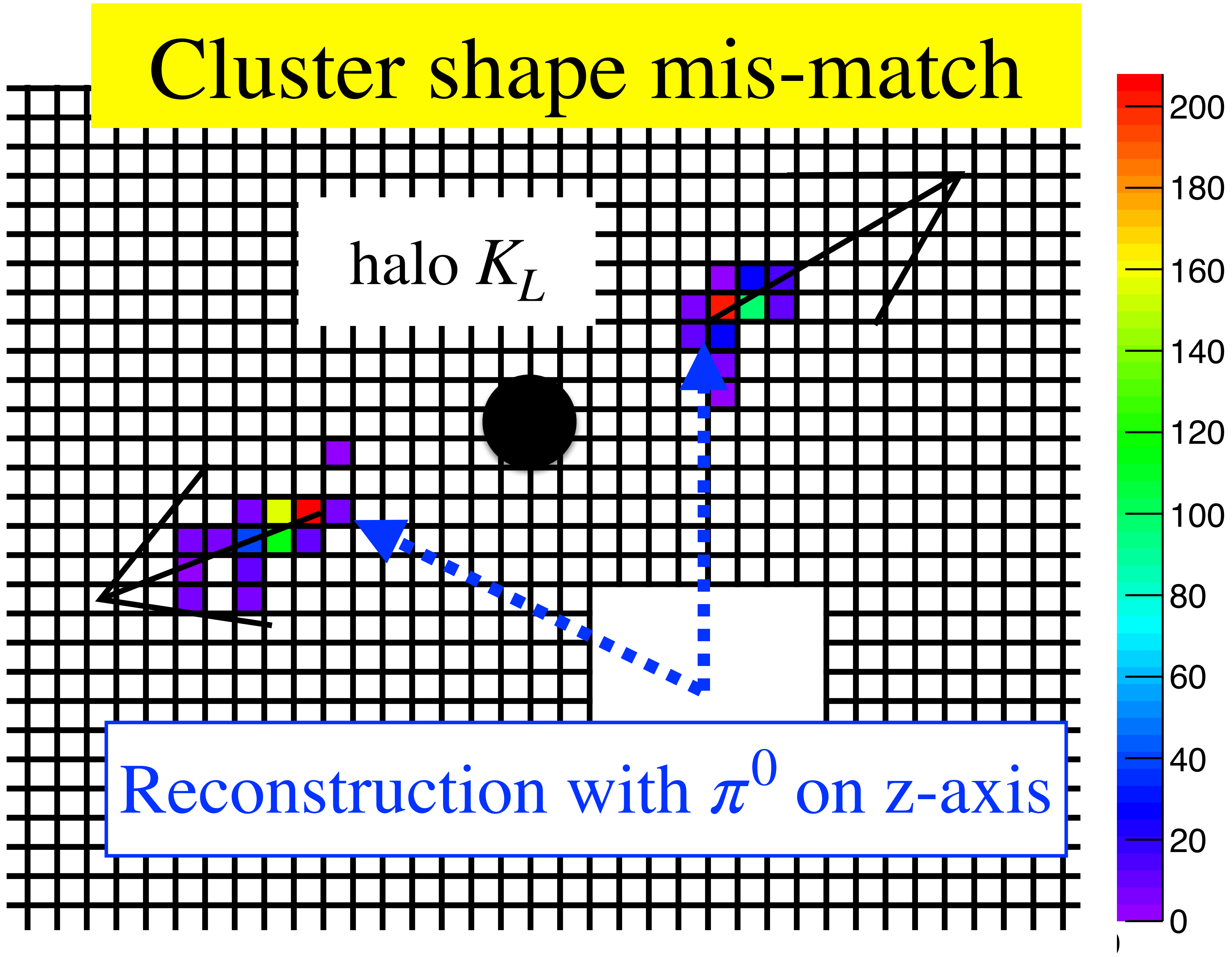
KOTO CV : 10^{-5} /layer/charged particle was achieved.

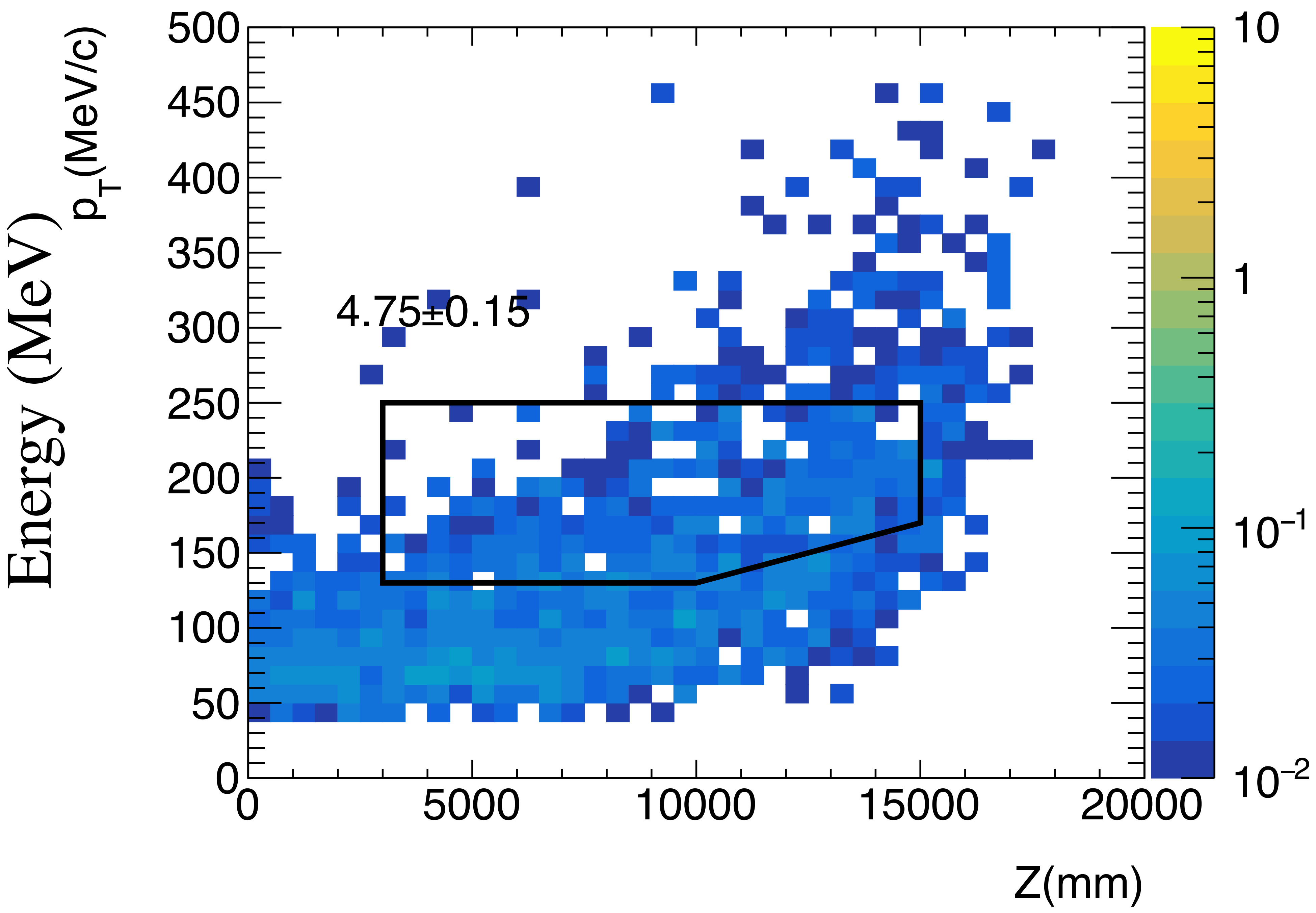
Background —halo $K_L \to 2\gamma$—





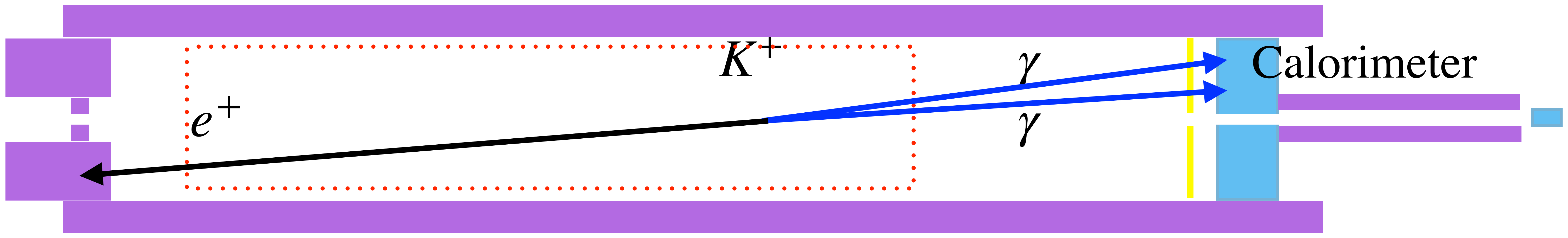
Larger p_T due to wrong reconstructed vertex

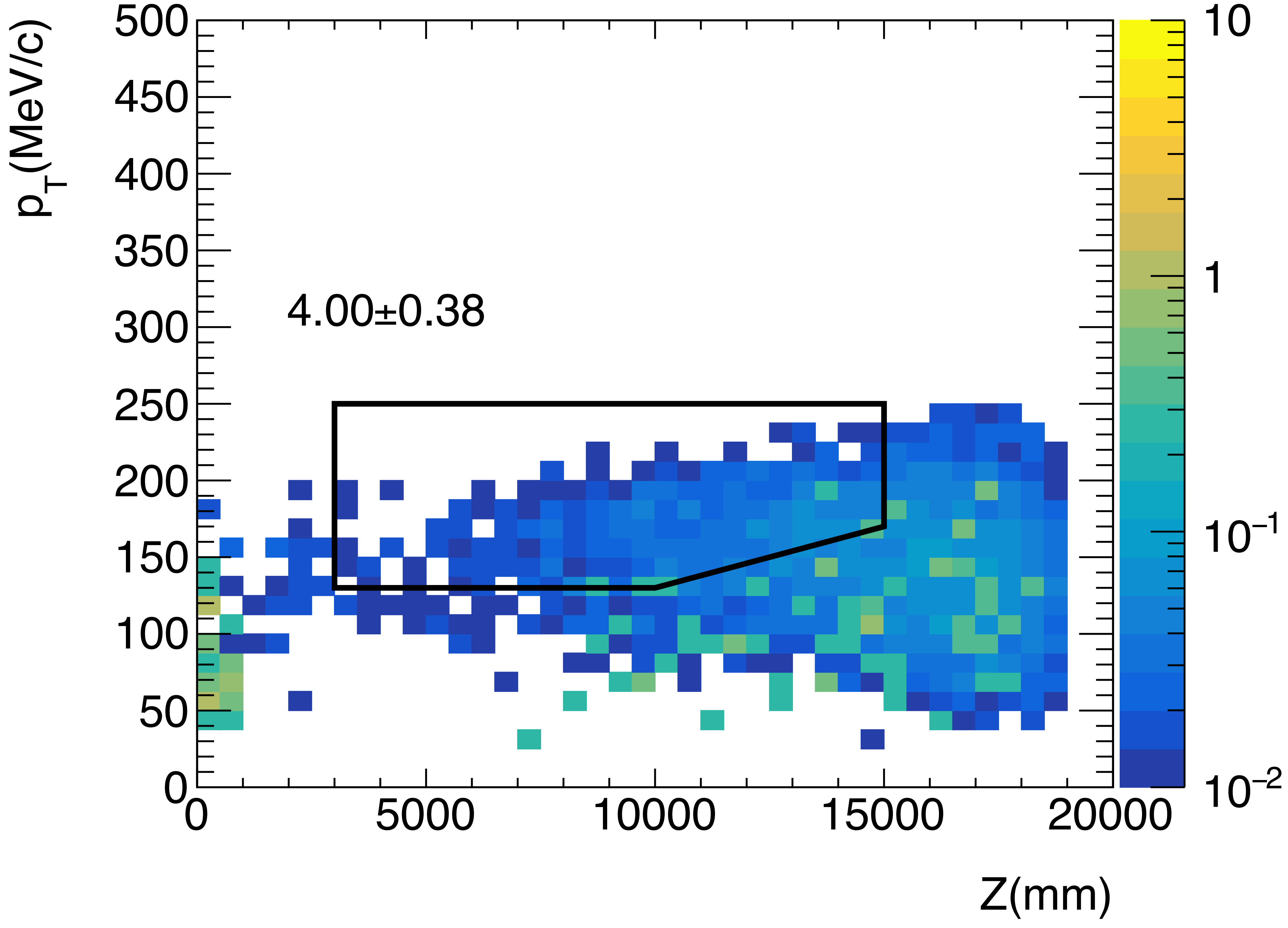




4.8 events expected with the assumption: × 1/100 reduction by requiring shower-shape consistency with the reconstructed incident angle

Background — $K^{\pm} \to \pi^0 e^{\pm} \nu$ —



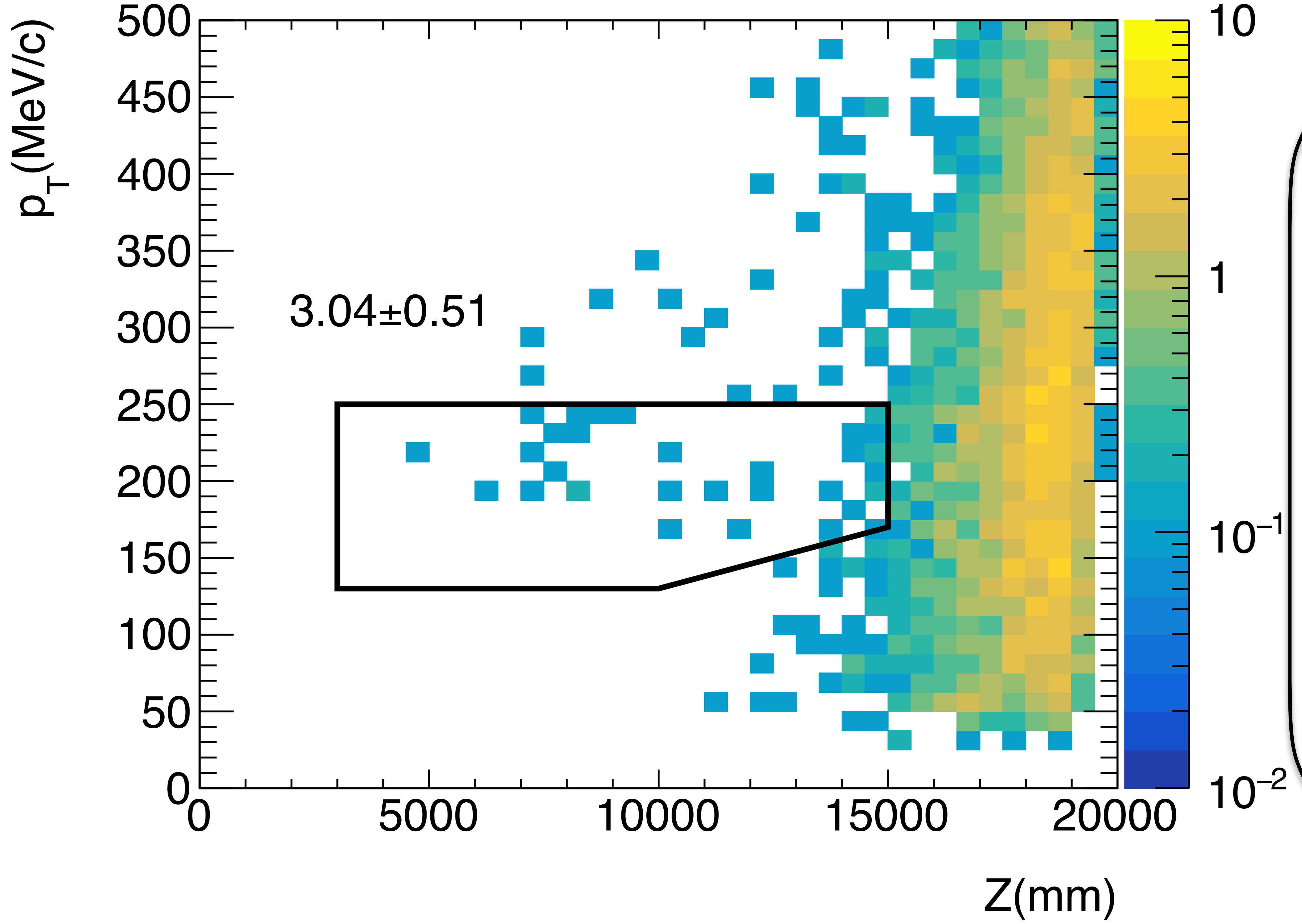


4.0 events are expected.
Second magnet is assumed to reduce it to be $\times 1/10$.

Background — hadron cluster background —

3 events are expected.

$\times 10^{-7}$ reduction with 73% signal efficiency (0.9^3) is assumed



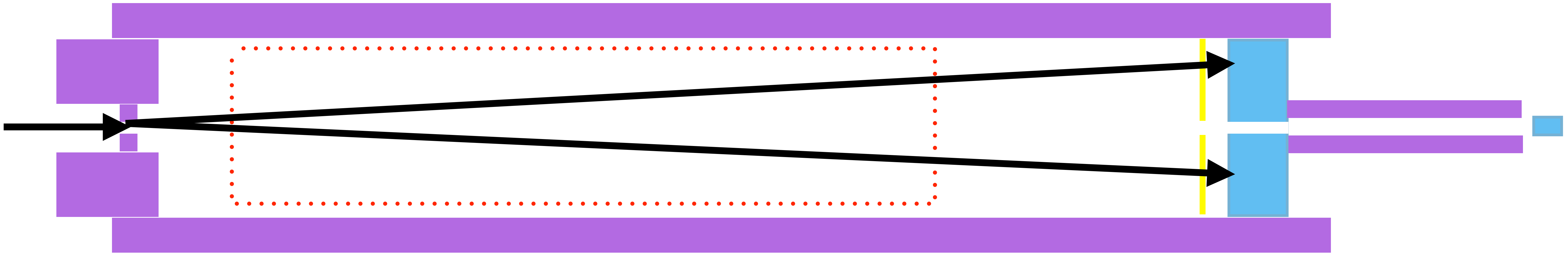
KOTO achieved $\sim 10^{-7}$ reduction
with 0.65 signal efficiency

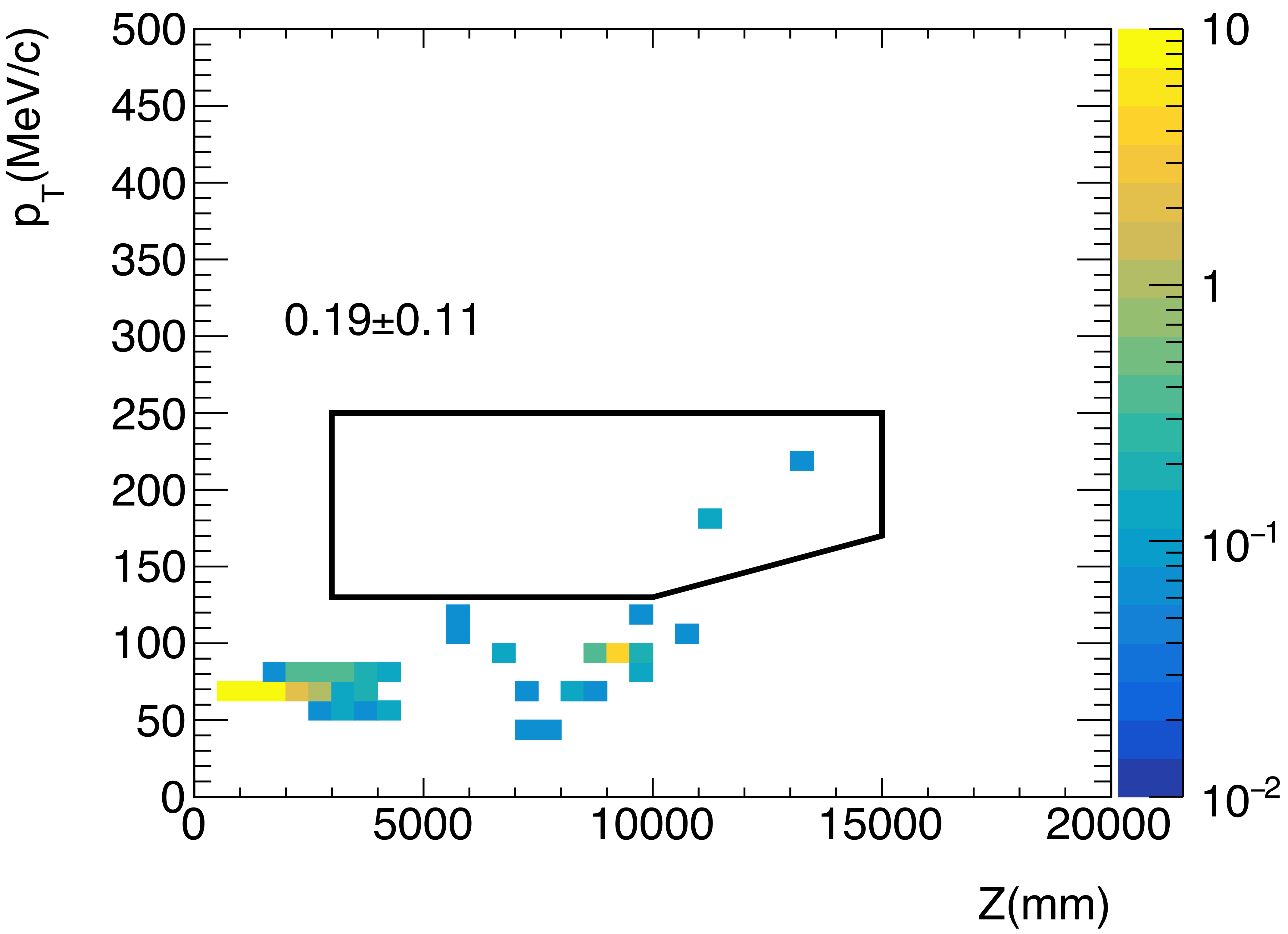
Cluster shape + Pulse shape
$\times (2.5 \times 10^{-6})$ with 72% signal efficiency

Shower depth
$\times (2.1 \times 10^{-2})$ with 90% signal efficiency

Background — Upstream π^0 —

Halo neutron $\rightarrow \pi^0$

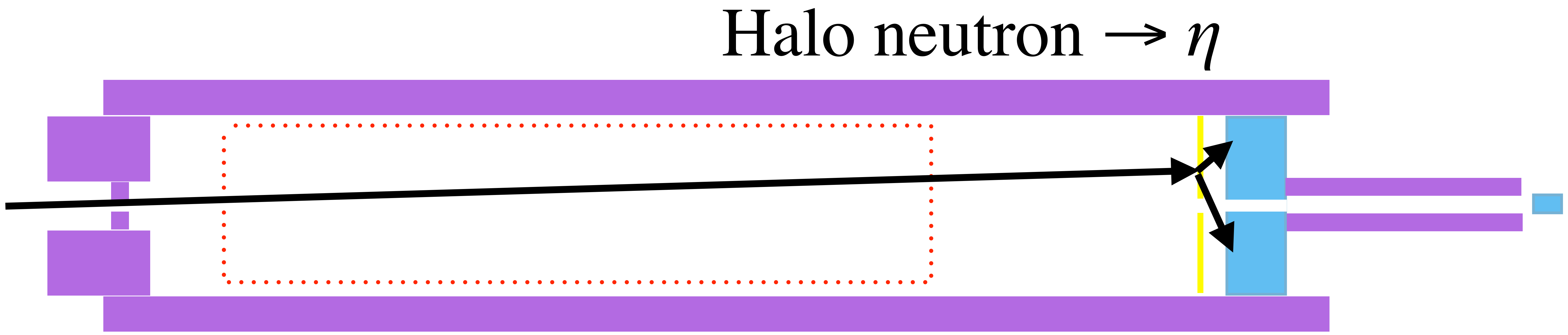


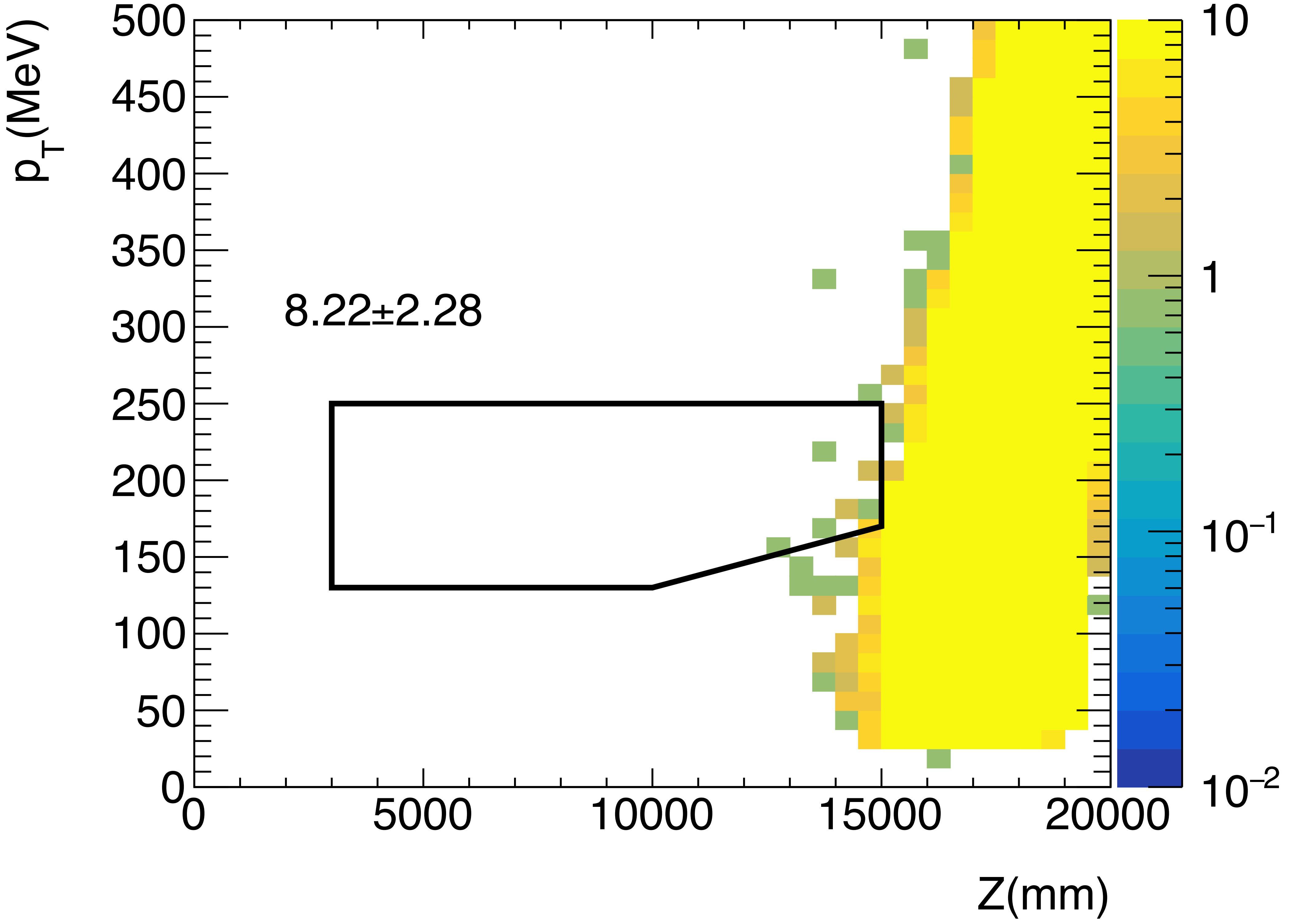


0.2 events are expected.

Fully active upstream collar counter is assumed.

Background — η production at CV —





8.2 events are expected.
3-mm thick plastic scintillator at 30-cm upstream of the calorimeter is assumed.
More reduction by using the cluster shape cuts can be expected.

Background summary

Update from KAON2022

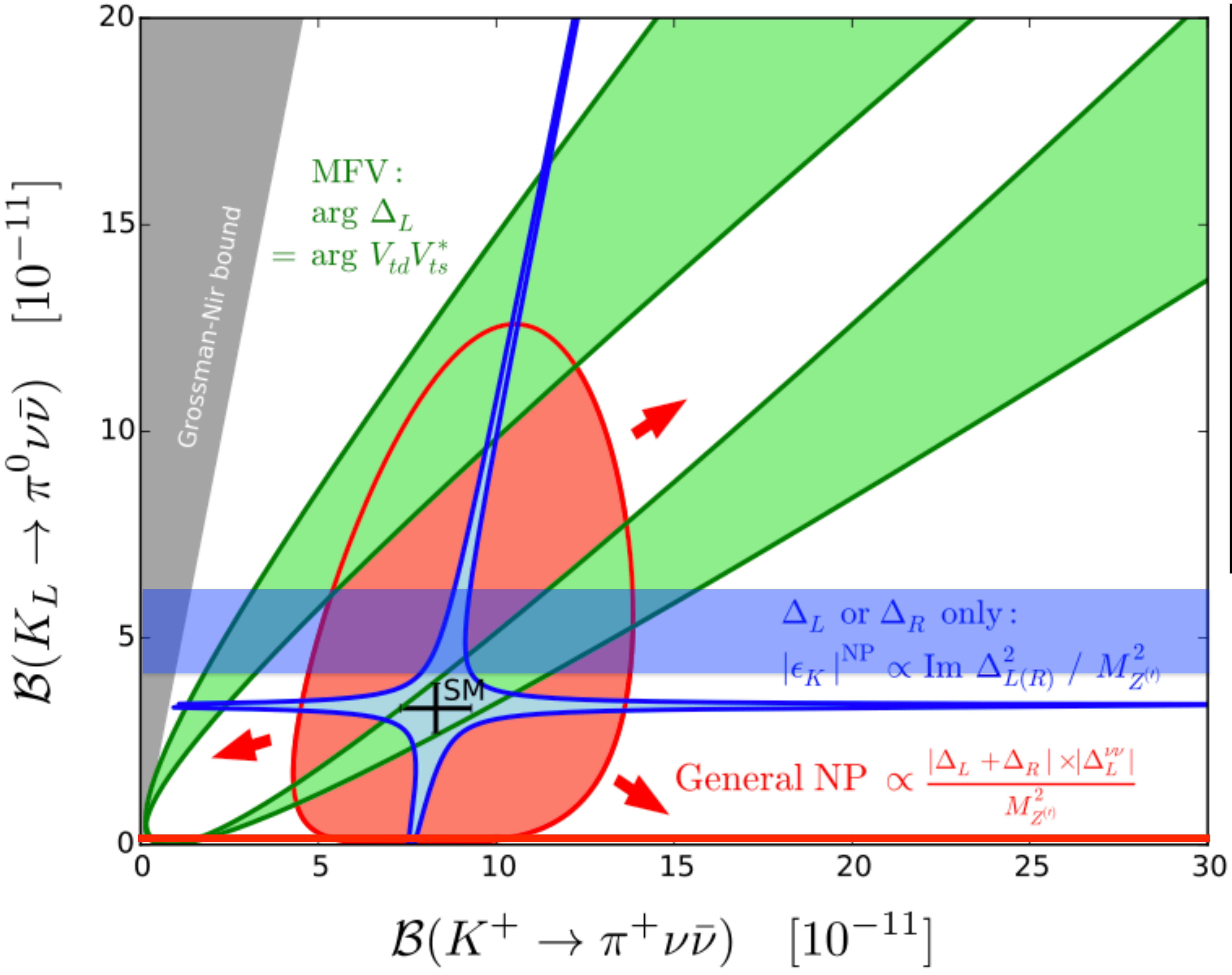
100 kW beam, 3×10^7s
$\rightarrow$ POT : 6.3×10^{20}

# of signal events (SM) : 35
# of background events : 33
S/N = 1.1 $\rightarrow$ 6.1σ observation

SES: 8.5×10^{-13}

Impact of KOTO II

Base design → better sensitivity with more studies



100 kW beam, 3×10^7 s $= 6.3 \times 10^{20}$ POT

SES: 8.5×10^{-13}, S/B=1.1

- 35 SM signal / 33 background events
  →6.1σ observation
- $\Delta\mathcal{B}/\mathcal{B} = 23\,\%$ →$\Delta\eta/\eta = 12\,\%$
- 38% deviation from SM→90%-CL indication of NP

Example
70% deviation from SM

May find NP effect

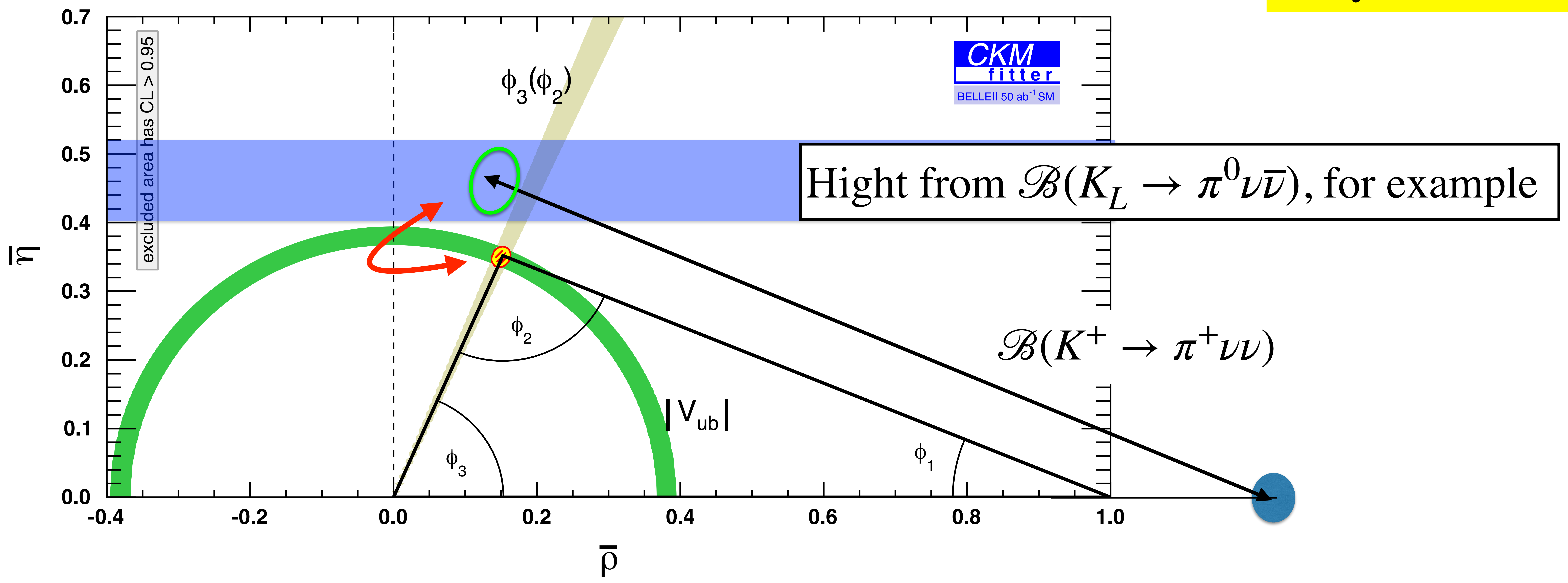
Impact of KOTO II

100 kW beam, 3×10^7 s $= 6.3 \times 10^{20}$ POT

- $\Delta\eta/\eta = 12\,\%$

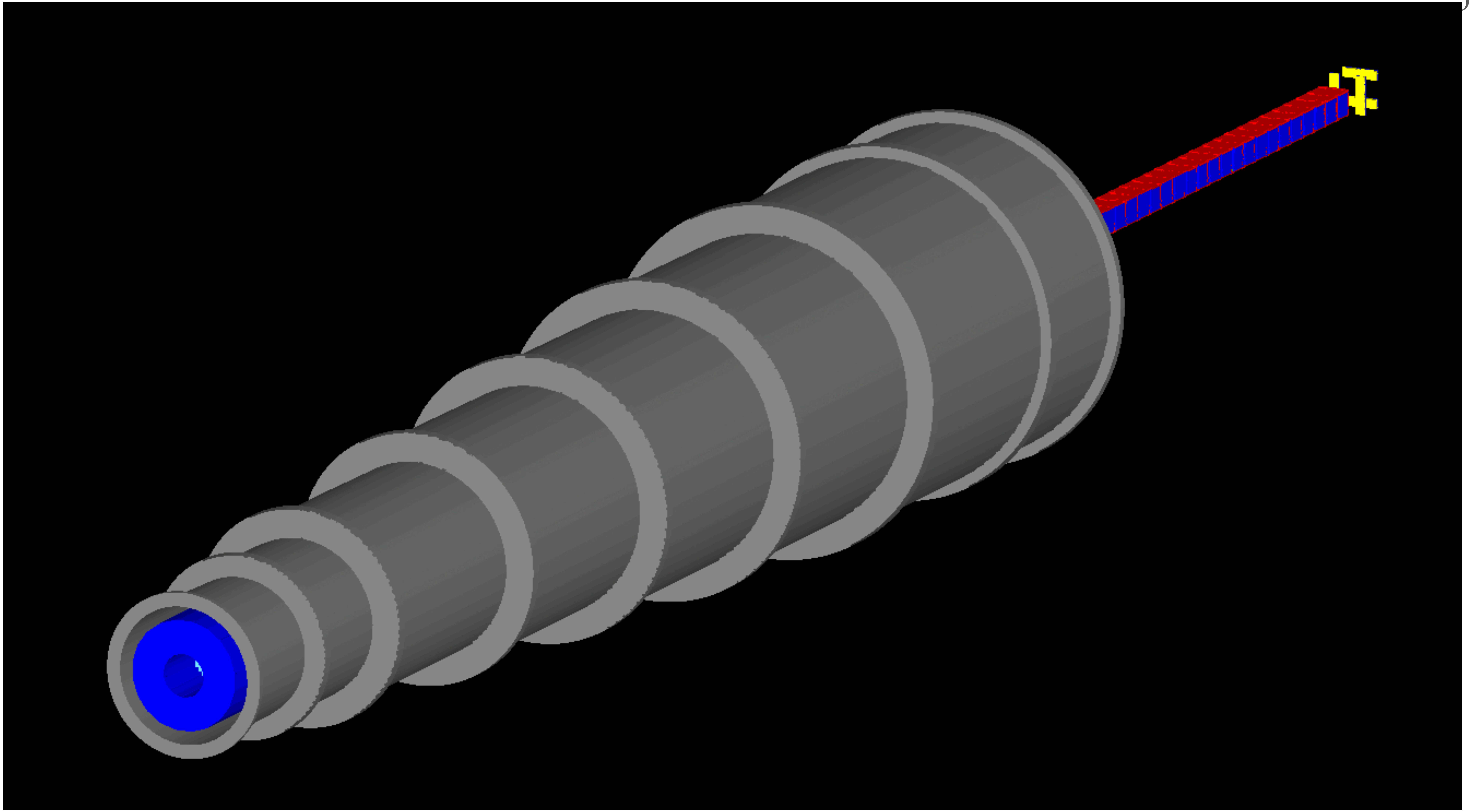
Belle II 50 ab^{-1} with only Tree contribution

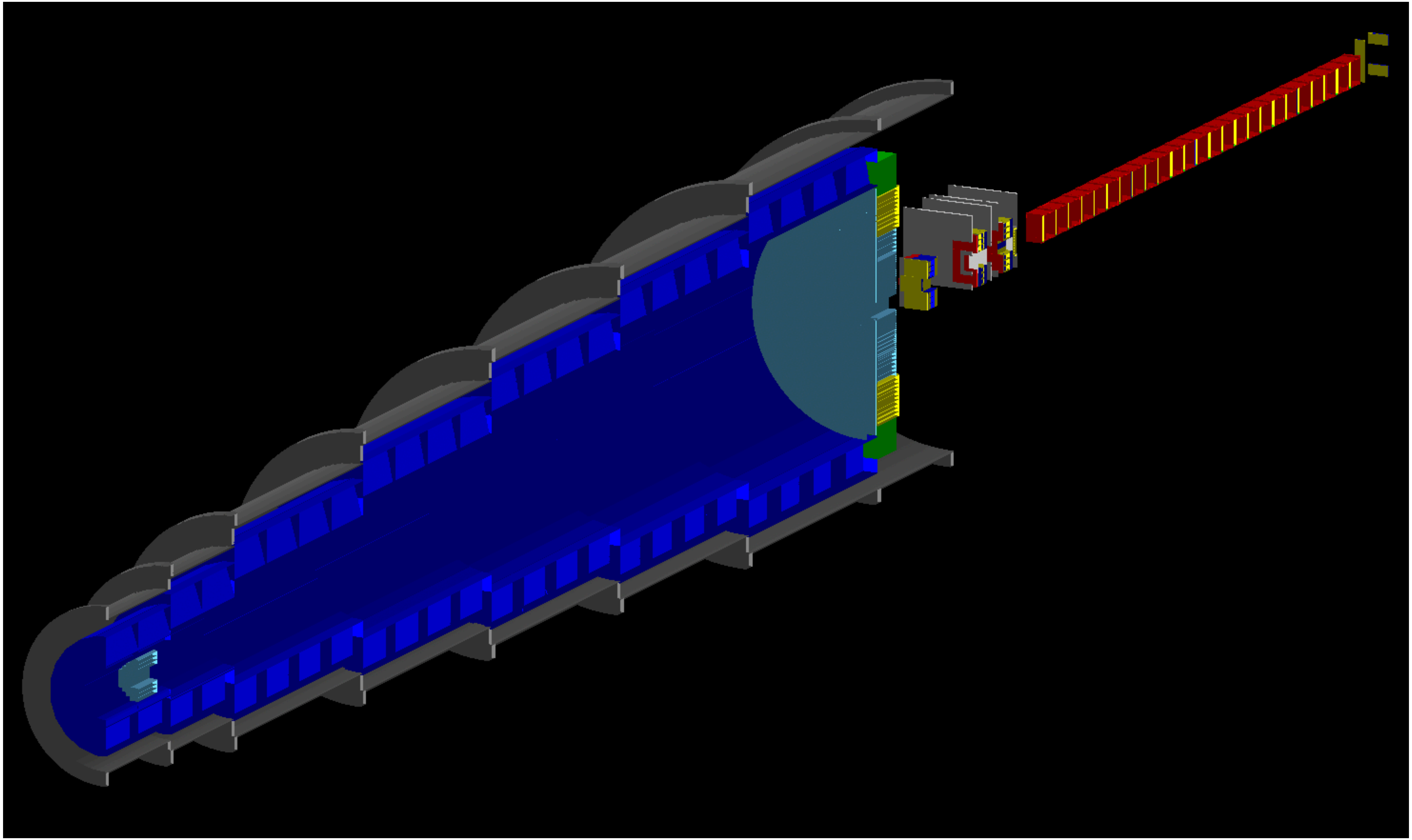
May find NP effect



Preparation of KOTO II — realistic detector —

- Realistic detector geometry → Weight / Cost evaluation
- Geant4 geometry → ready for full simulation

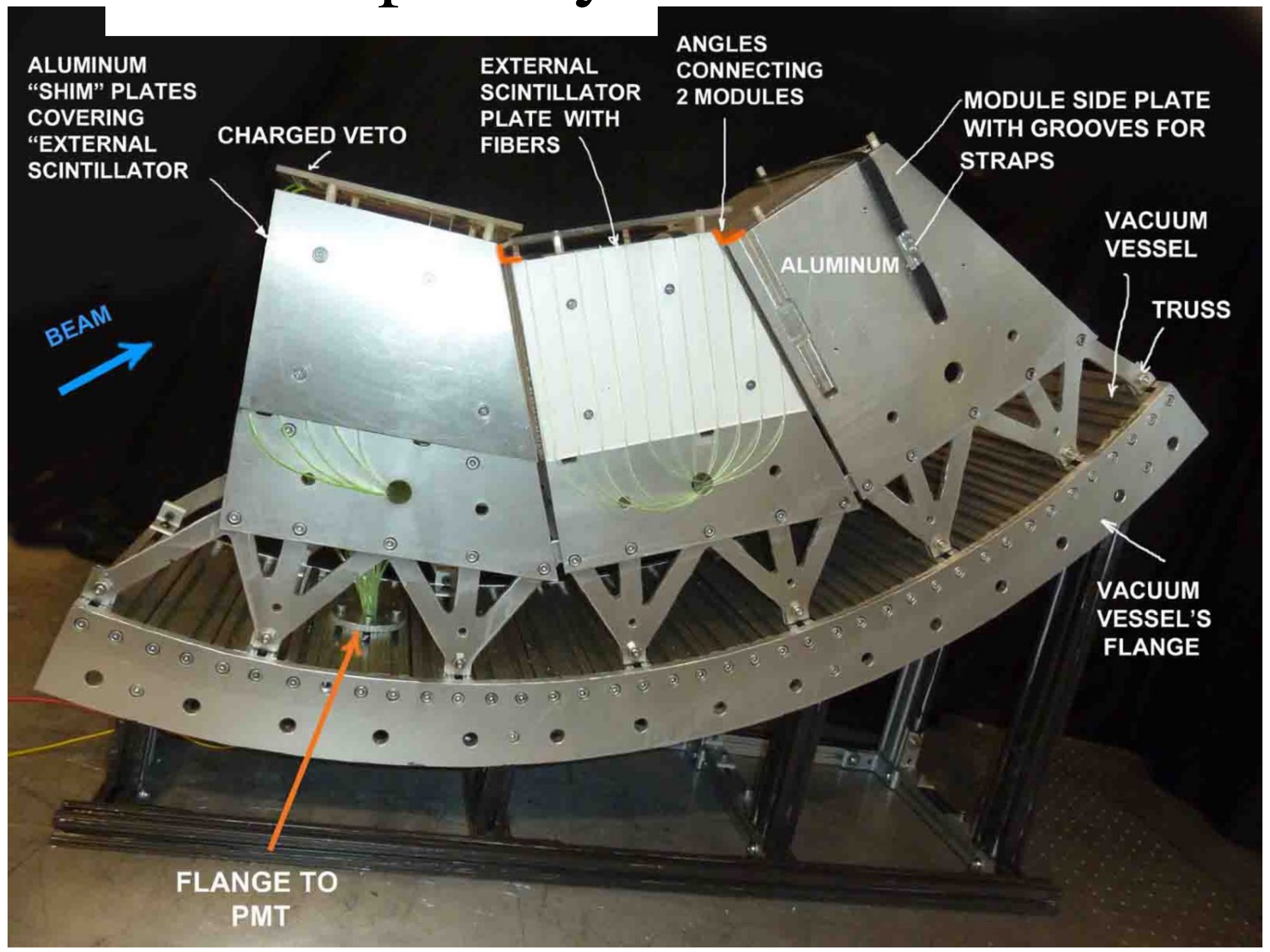


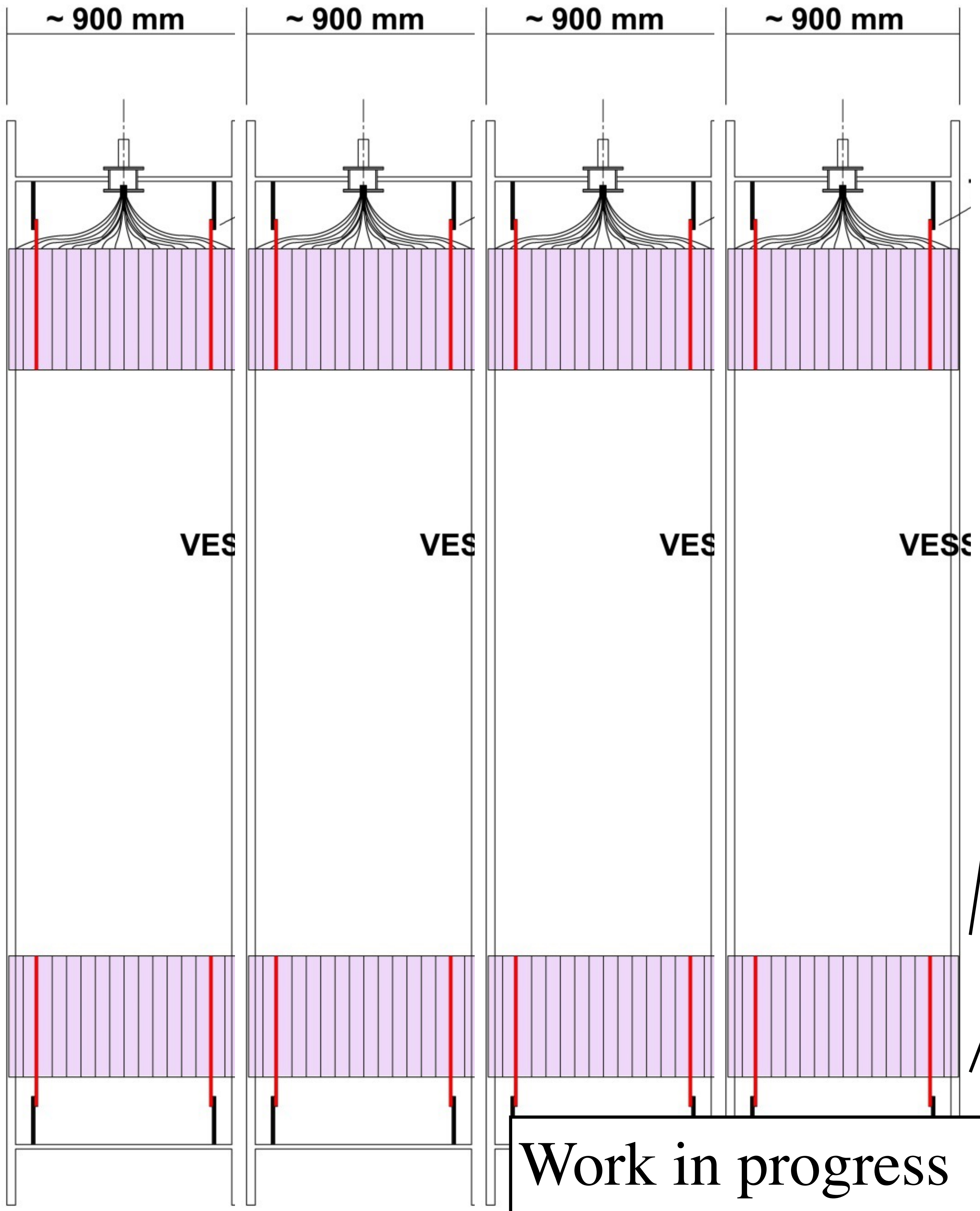


Preparation of KOTO II — barrel detector —

- 1 module : 135 layers of scintillator (1-mm thick) and lead (5-mm thick)
- Read out with PMT outside of the vacuum
- 32 modules in $\phi \times 4$ in z → 1 vacuum tank

Mockup study

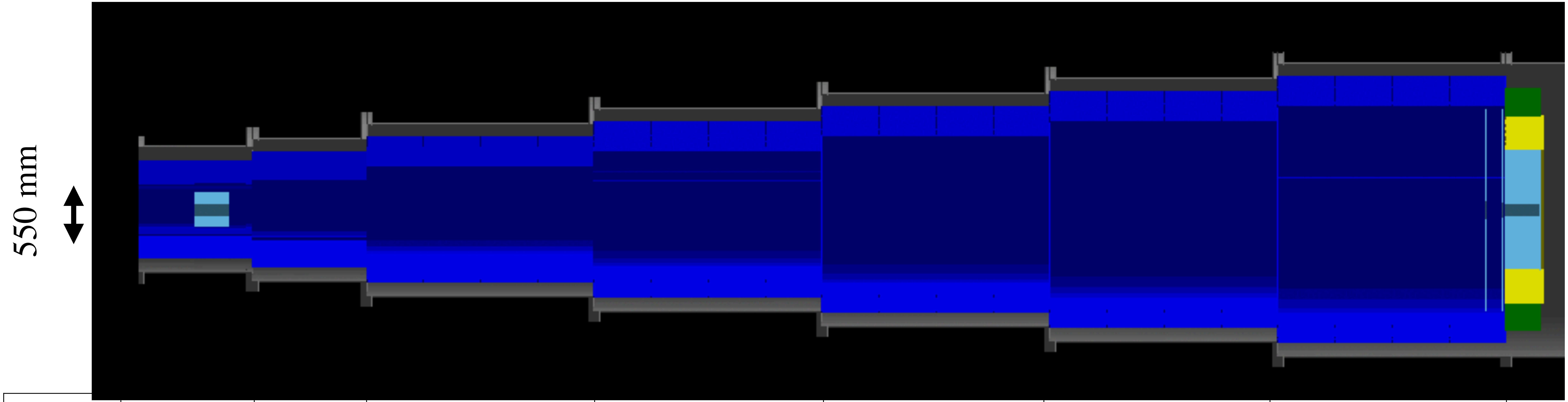




Work in progress
in U of Chicago

1st prototype

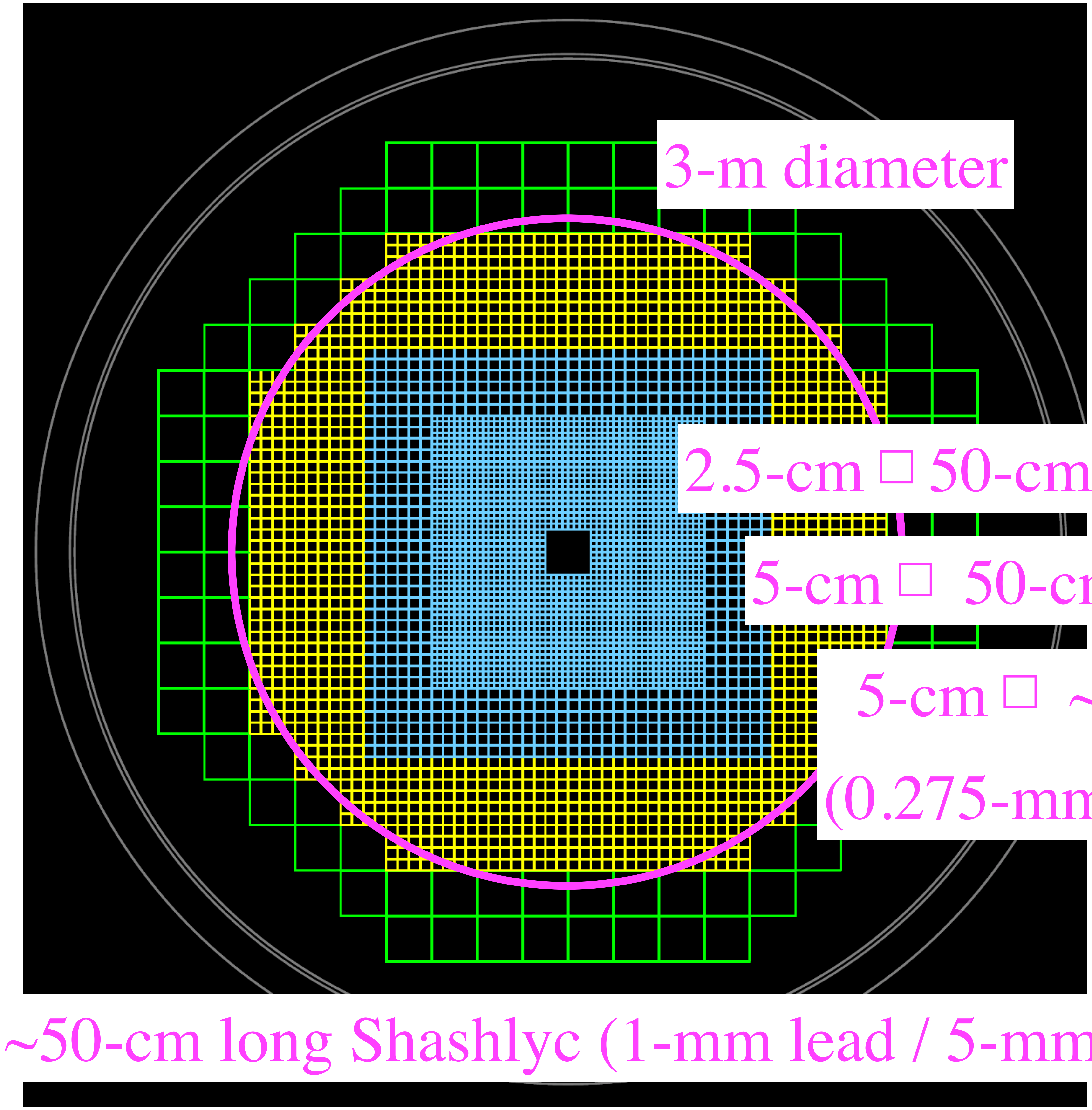
Preparation of KOTO II — barrel detector—



	0	1	2	3	4	5	6
# in Z	2	2	4	4	4	4	4
# in φ	20	20	24	32	32	32	32

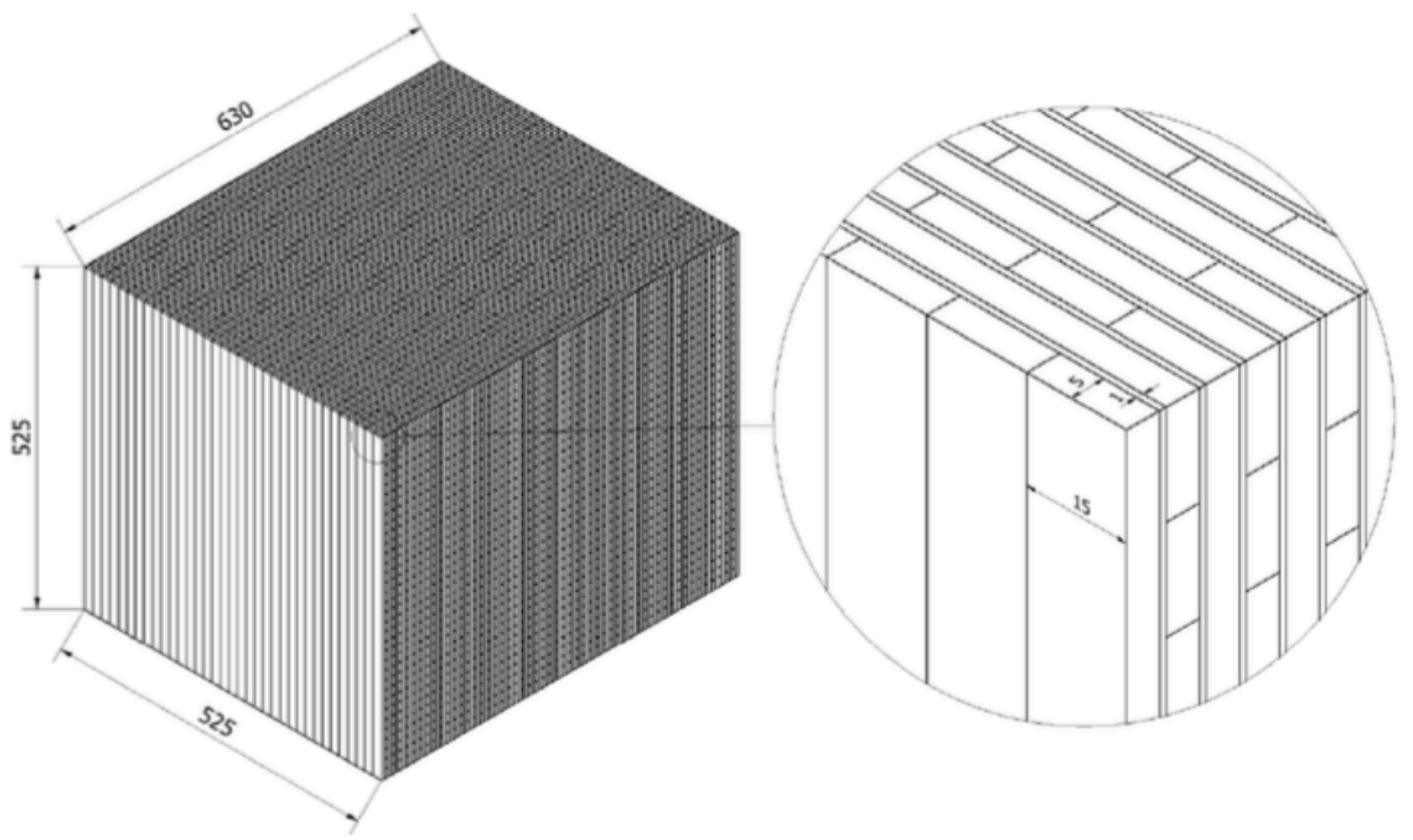
Preparation of KOTO II — Calorimeter —

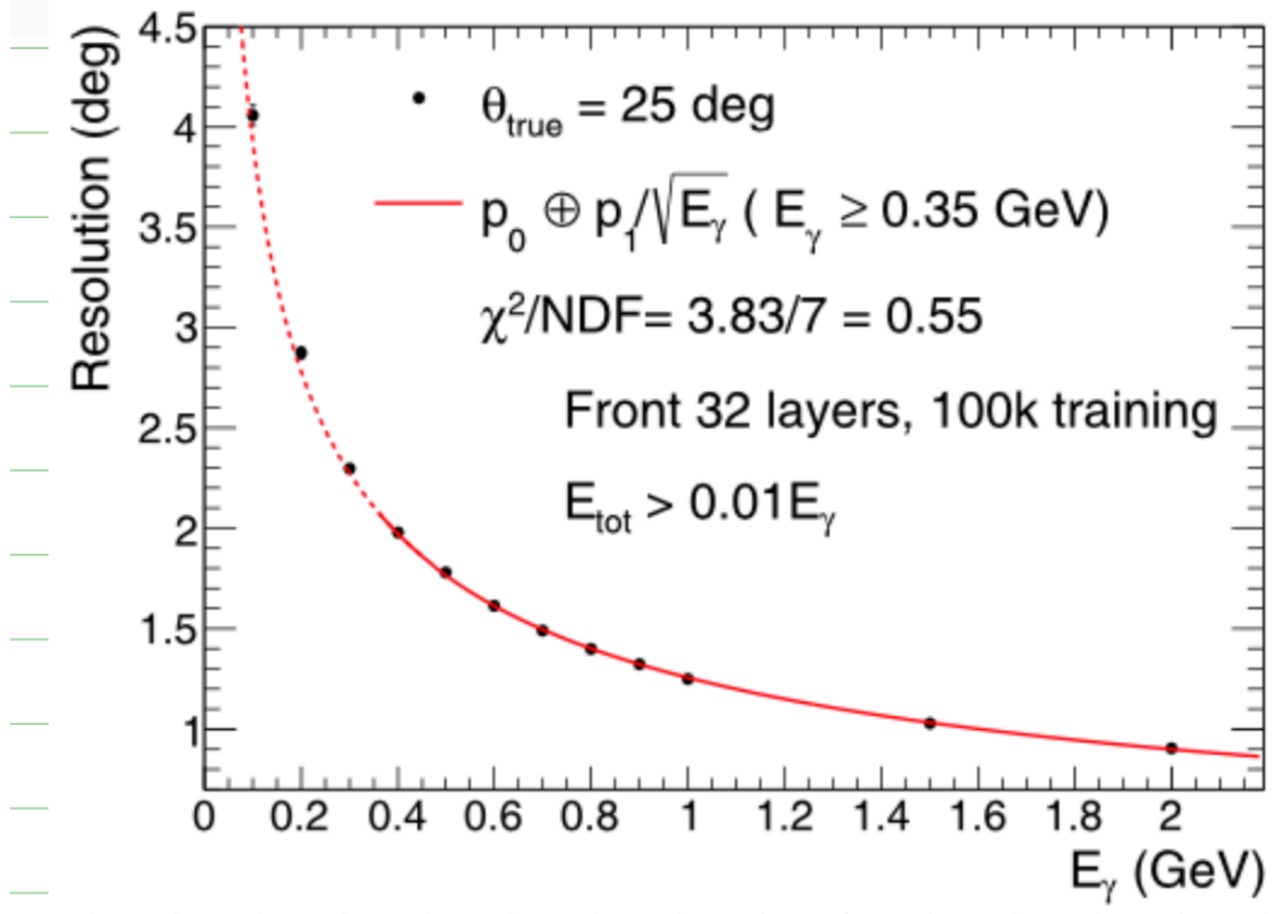
- An example configuration to study more.
- Idea of assembly
  - Stacking from the bottom.
  - Fix with pressure from side and top



Preparation of KOTO II
— Trial of photon angle measurement with Calorimeter —

G.Y. Lim



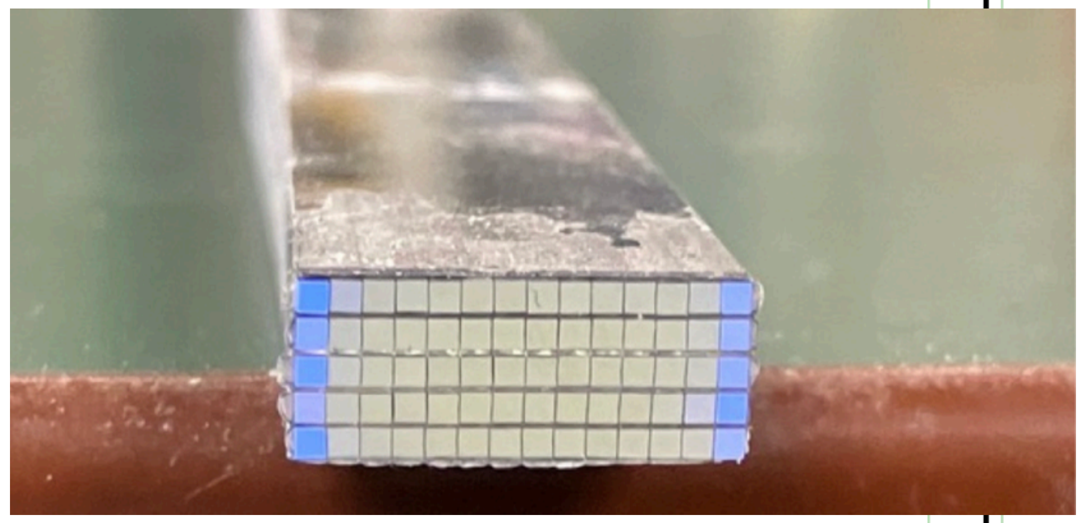


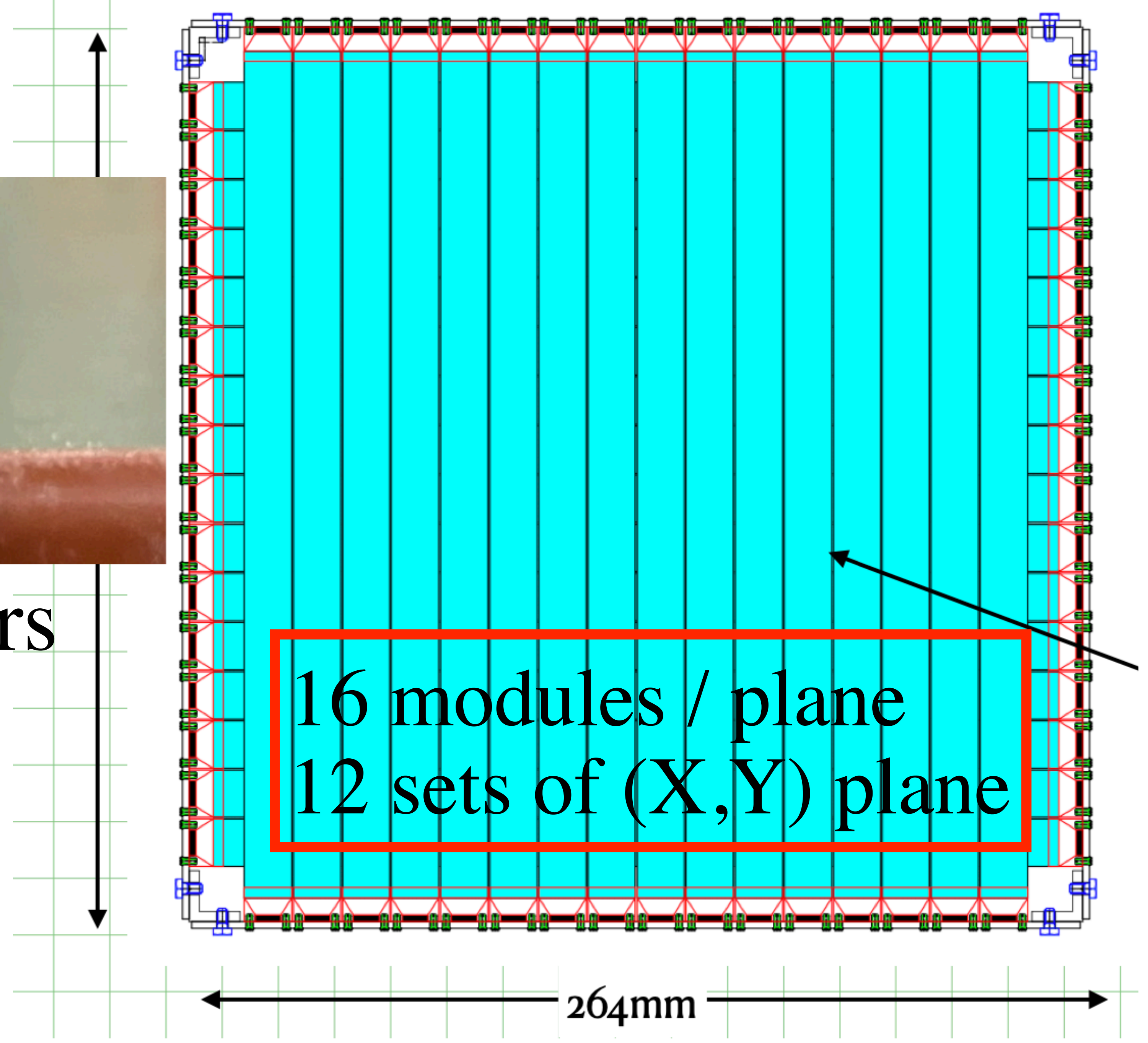
Lead/Scintilator sandwich
→ 15-mm-wide scintillator readout
→ Shower development

Photon incident angle resolution
a few degree for E_γ 0.2-2 GeV

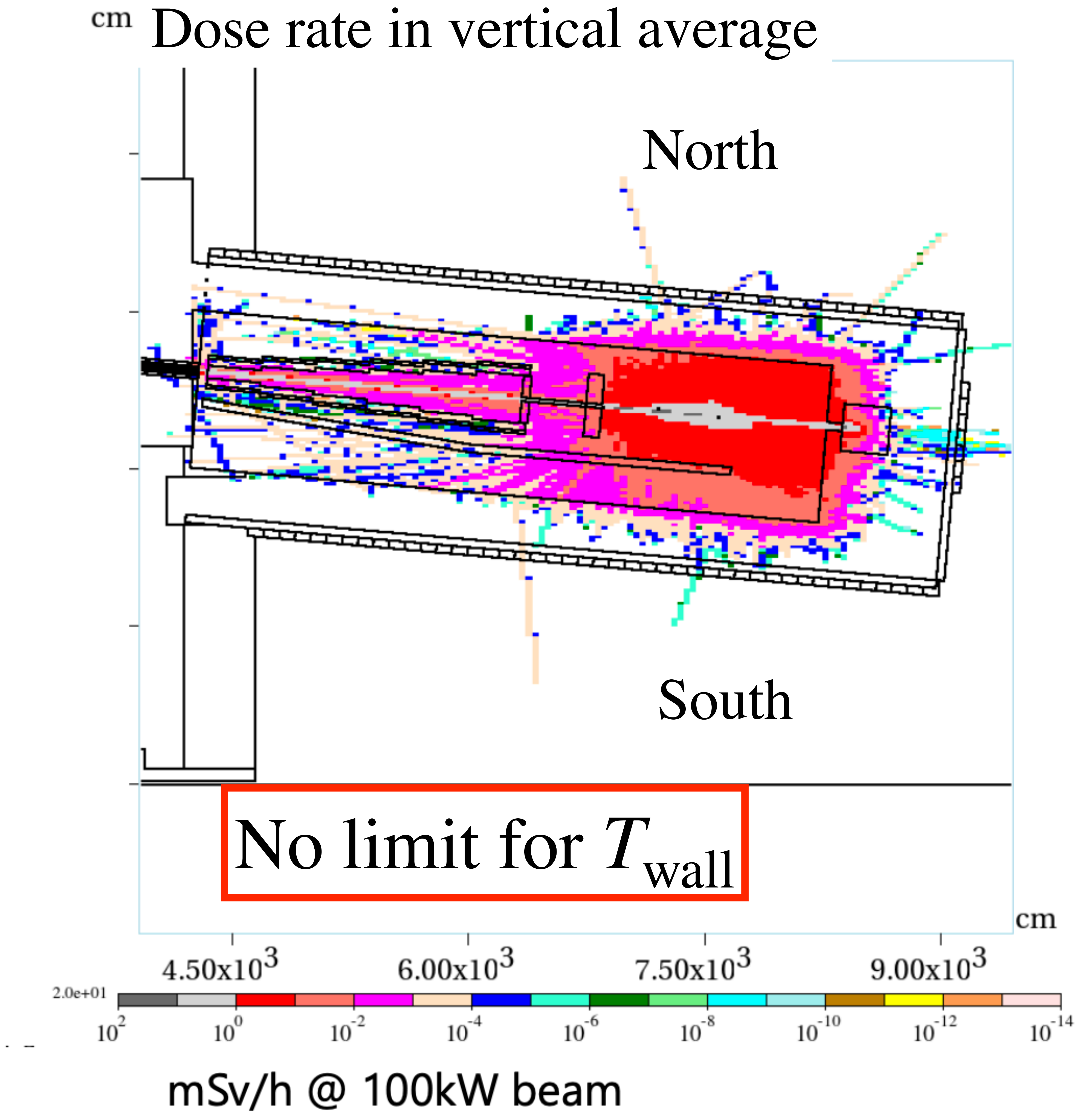
Simulation of angular resolution of new electromagnetic sampling calorimeter
(NIMA 1052 (2023)168261)

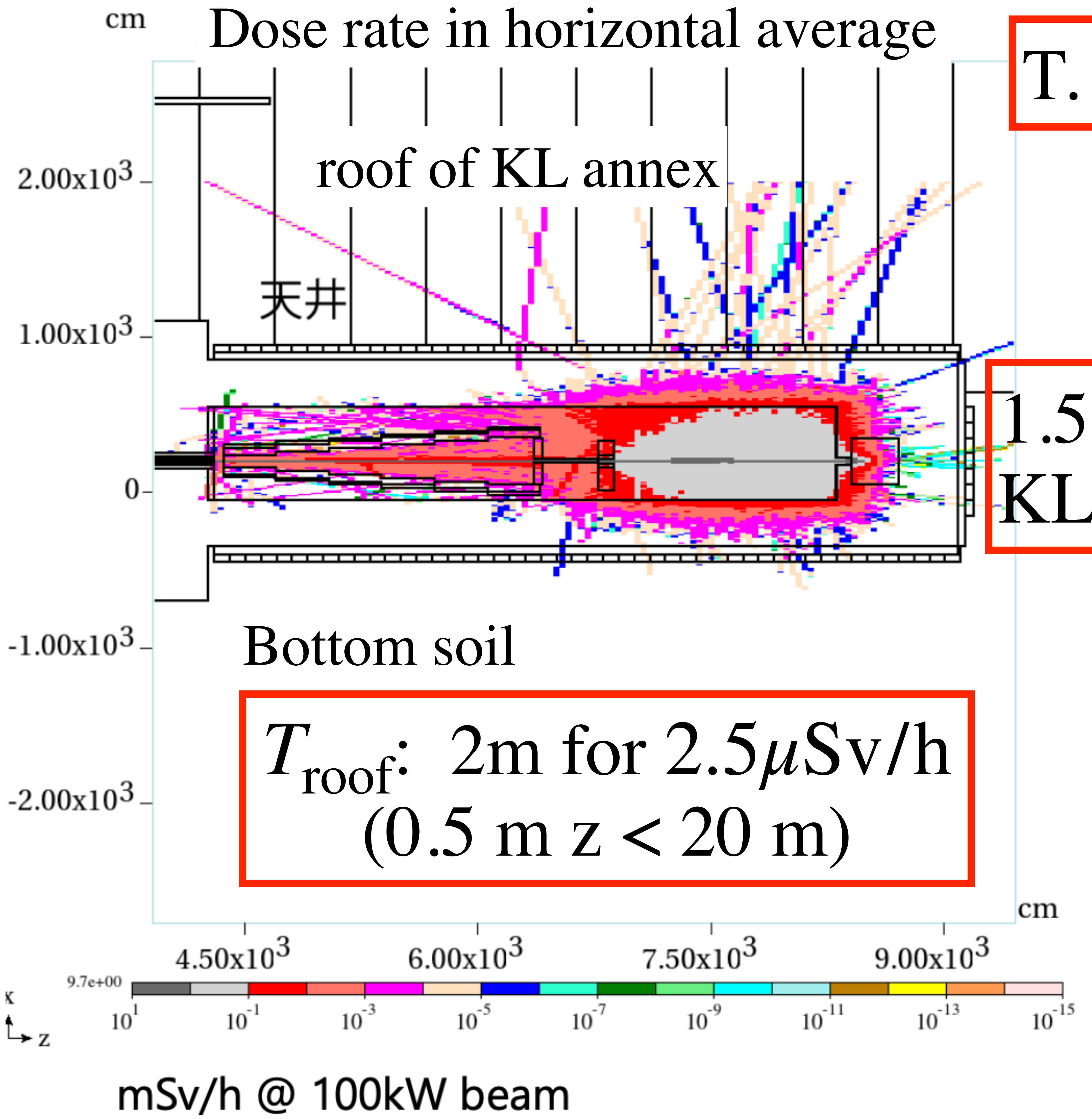
- Considering to use it in front of main calorimeter
- Construction of prototype modules
  - Lead : 0.15-mm-thick, Scintillator: 1-mm-square scintillating fibers
  - Read out with MPPCs
  - 5-layer 14-mm-wide module : Light yield : ~100 p.e./MeV





Design of KL annex —Radiation shielding—



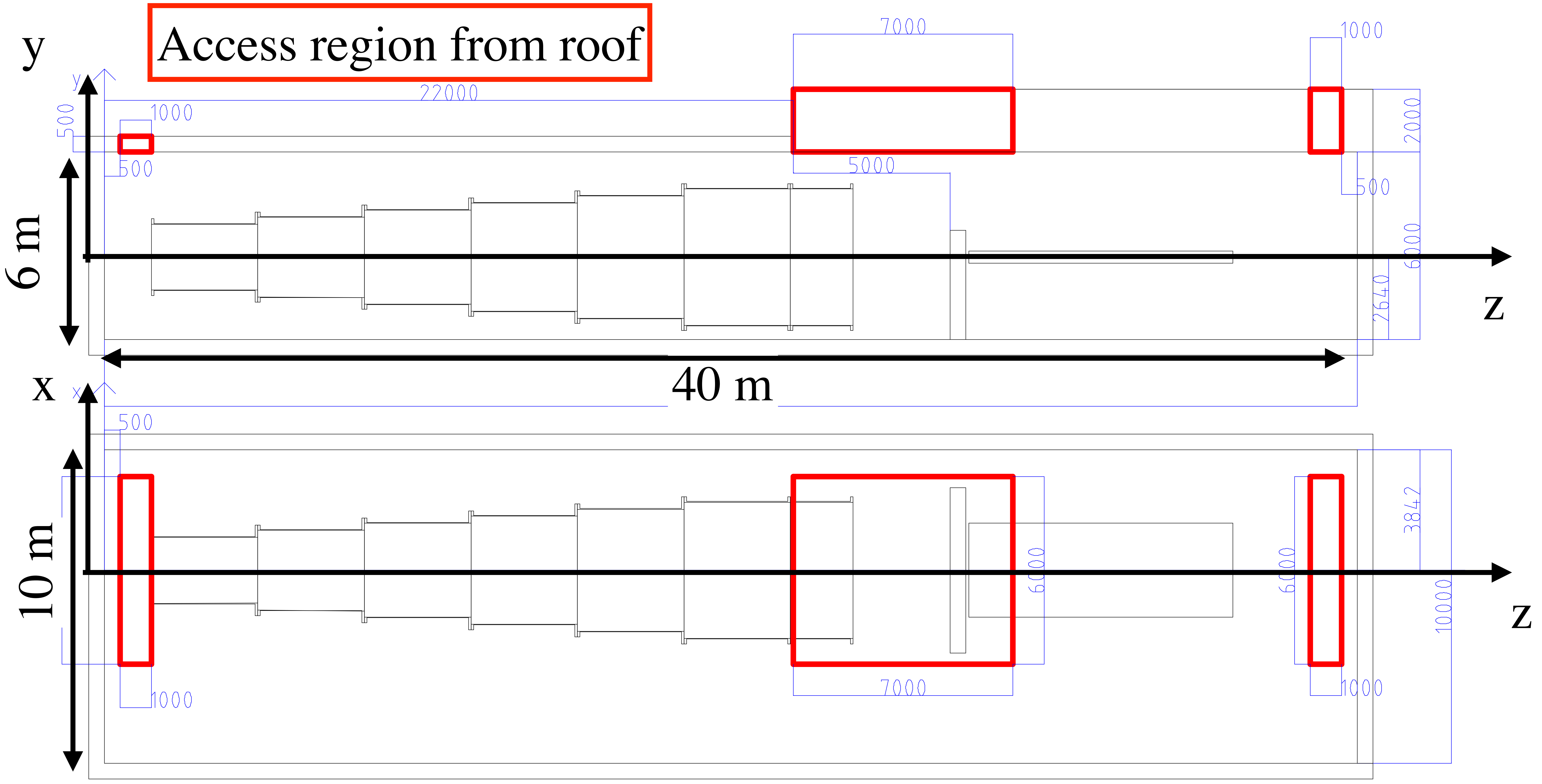


T. Matsumura

1.5 m iron
KL beam dump

Determined the minimum thickness of wall and roof → Realistic annex design by company

Preparation of KL Annex — Determination of roof access —

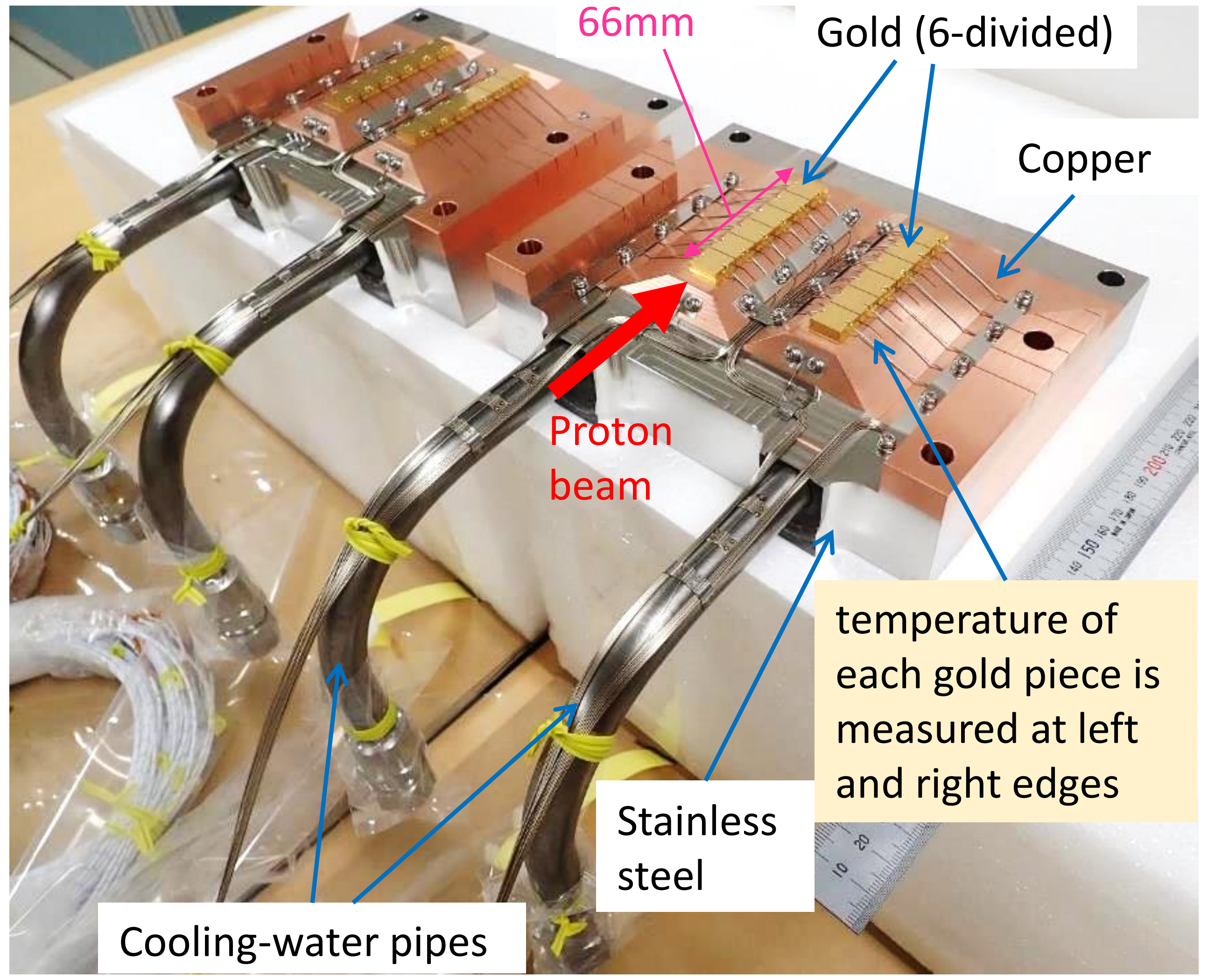


Determined the position / size of the roof open→Realistic annex design by company

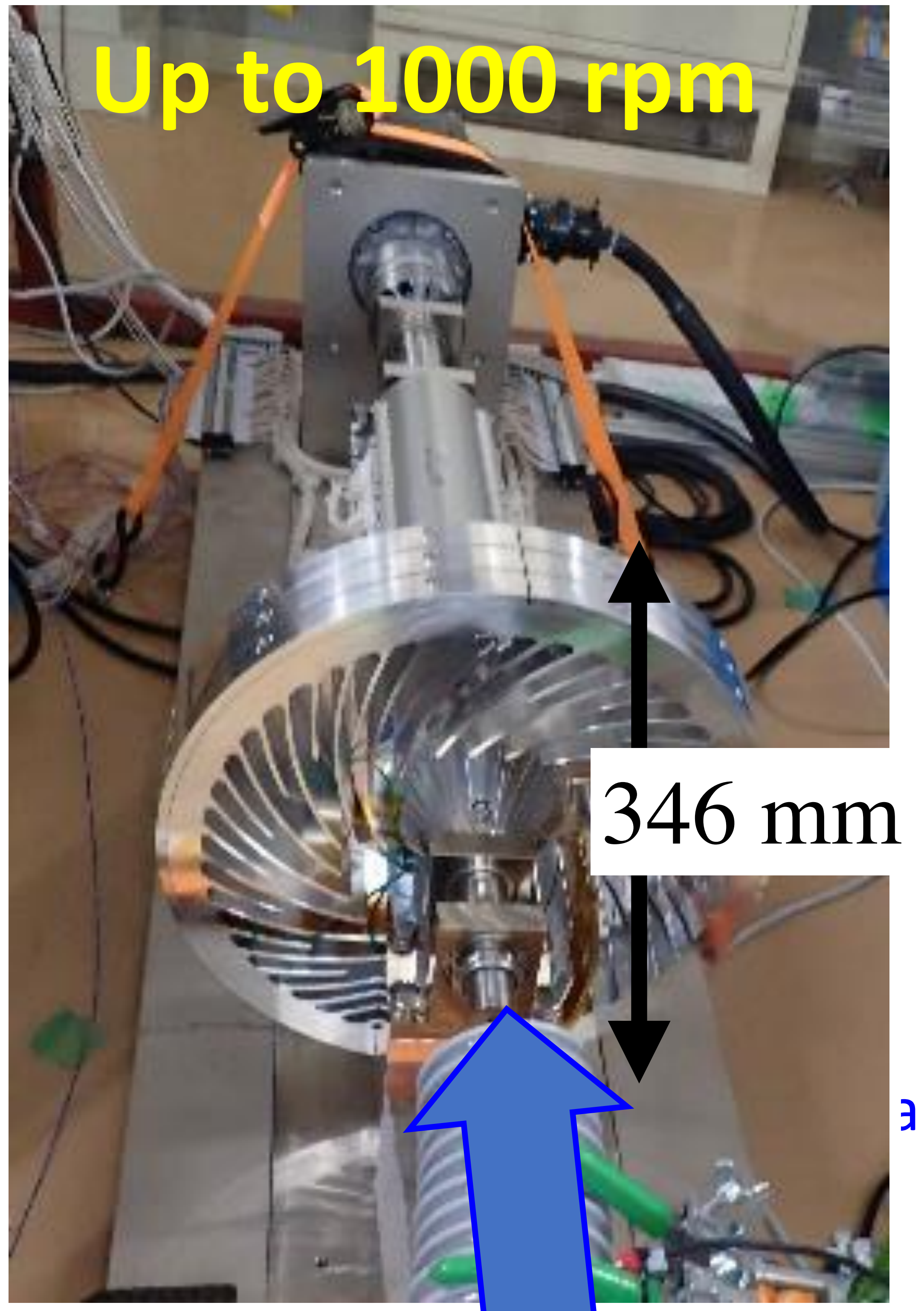
Hadron hall : Proton target

Current target
Up to 115 kW beam
2-sec spill / 4.2-s cycle

Gold + Cu with cooling water

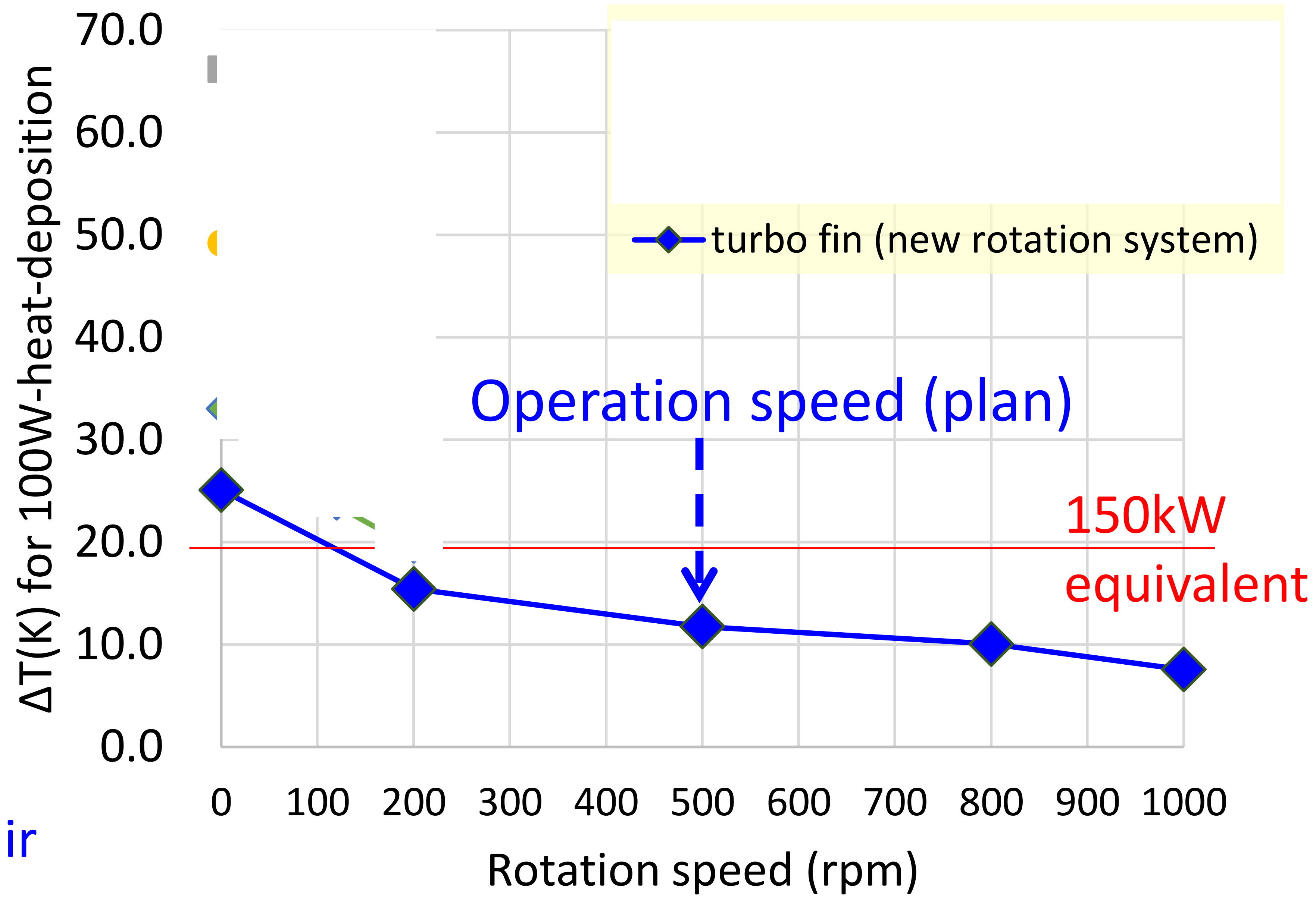


New target under development
Rotating target with turbo-fin (Cu, gas-jet drive)
Protons hit outer region (Au, etc)



Temperature-controlled air (newly installed)

Preliminarily result (in Air)

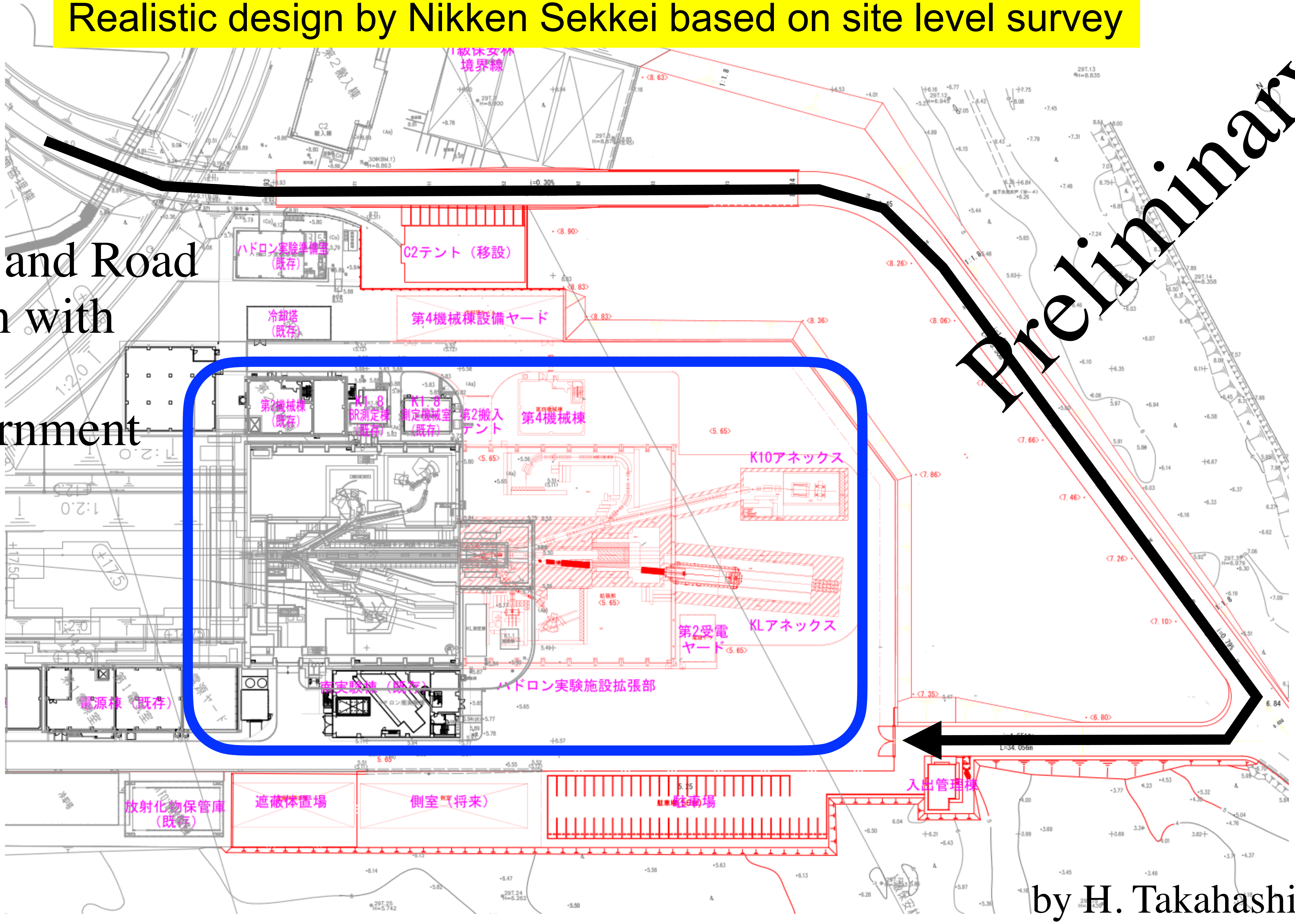


500 rpm → enough cooling performance

by H. Takahashi at 3rd HEF-ex WS

Architectural and Civil Engineering Design

Realistic design by Nikken Sekkei based on site level survey



Extended hall and Road in consultation with JAEA and the local government

by H. Takahashi at 3rd HEF-ex WS

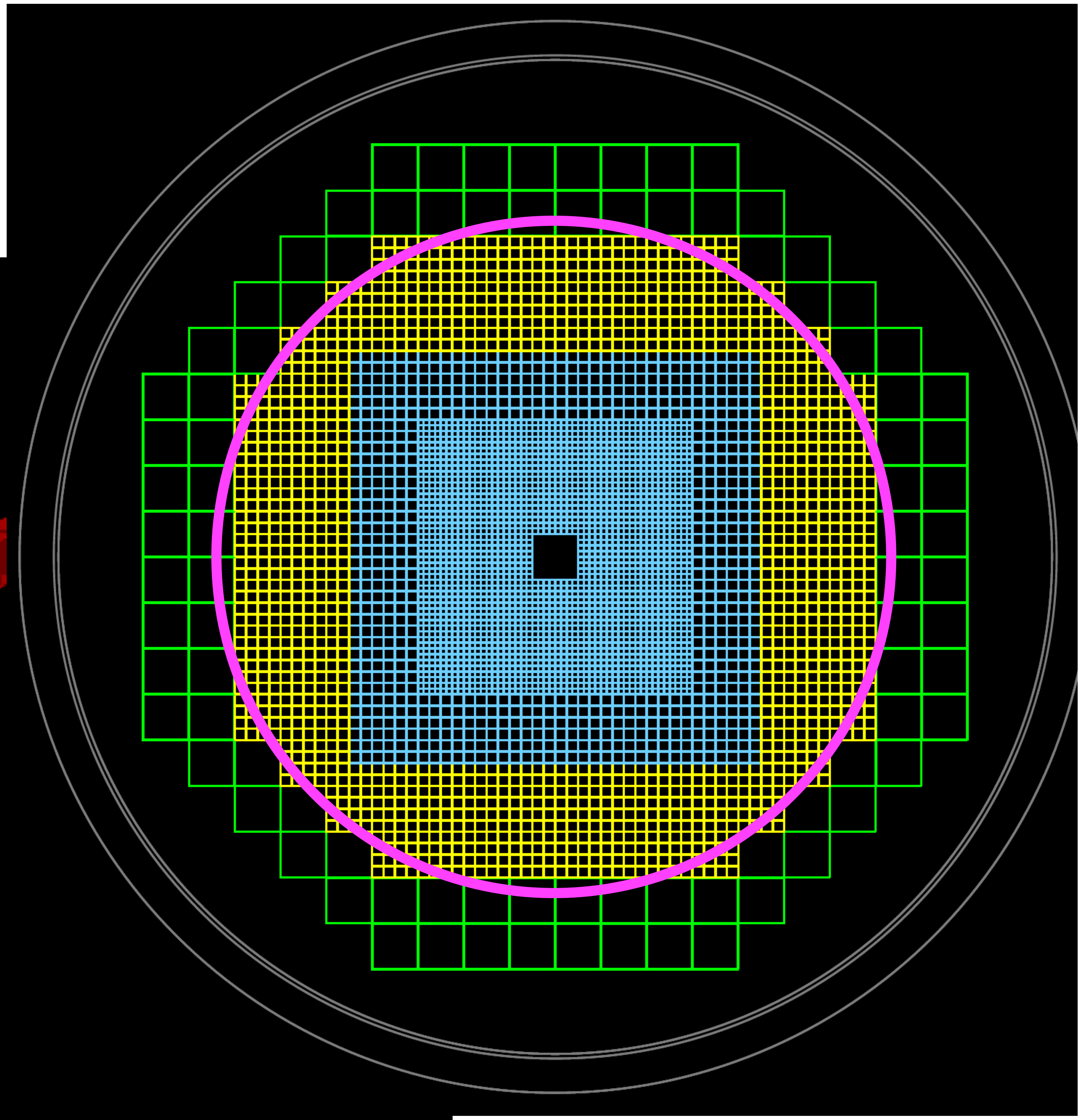
Time line of Hadron Experimental Facility extension

- Time line for the earliest case
  - 1st Priority to get budget on KEK PIP2020
  - Depends on the budget request (every one year)

Phasing

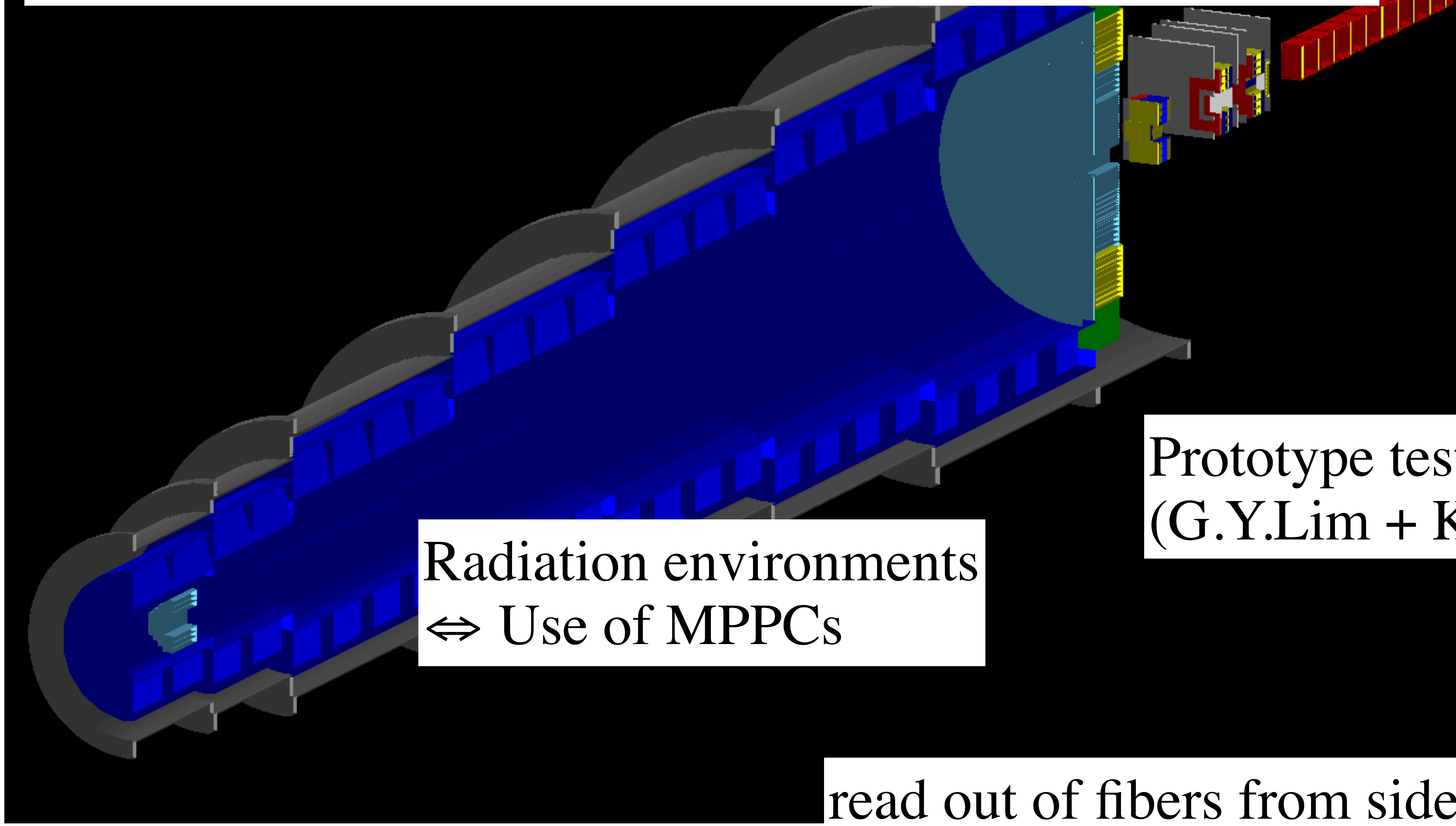
KOTO II Preparation group
KOTO II collaboration
Proposal submission
New design / Prototyping / Funding
Construction
Beam survey
FY2022
FY2023
FY2024
FY2025
FY2026
FY2027
FY2028
FY2029
FY2030
FY2031
FY2032
MR accelerator Upgrade
HK starts
BELLE2 LS2
construction parallel to beam operation in the first 4 years,
beam-suspension in the next 2.5 years
The Extension Project of Hadron Experimental Facility (7 years)
Hadron Hall
Current Programs with SX Power towards 100kW
Hall Extension
Expanded Programs with more beam lines

Current and future R&D items



Trial production and performance test of shashlyc counter for calorimeter candidate

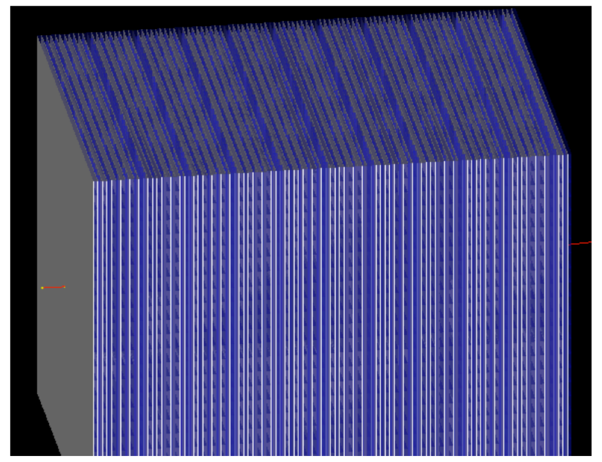
Energy, timing resolutions, neutron/γ discrimination

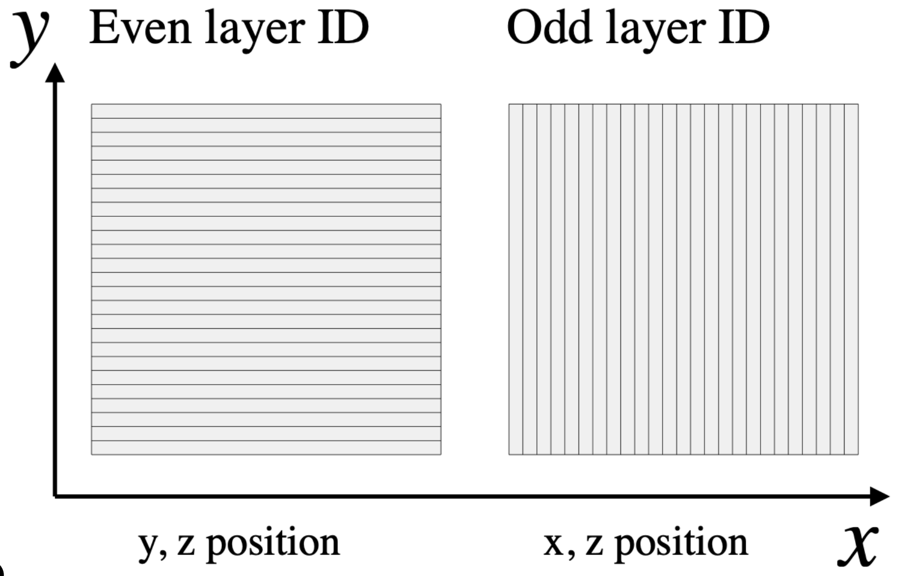


Radiation environments

⇔ Use of MPPCs

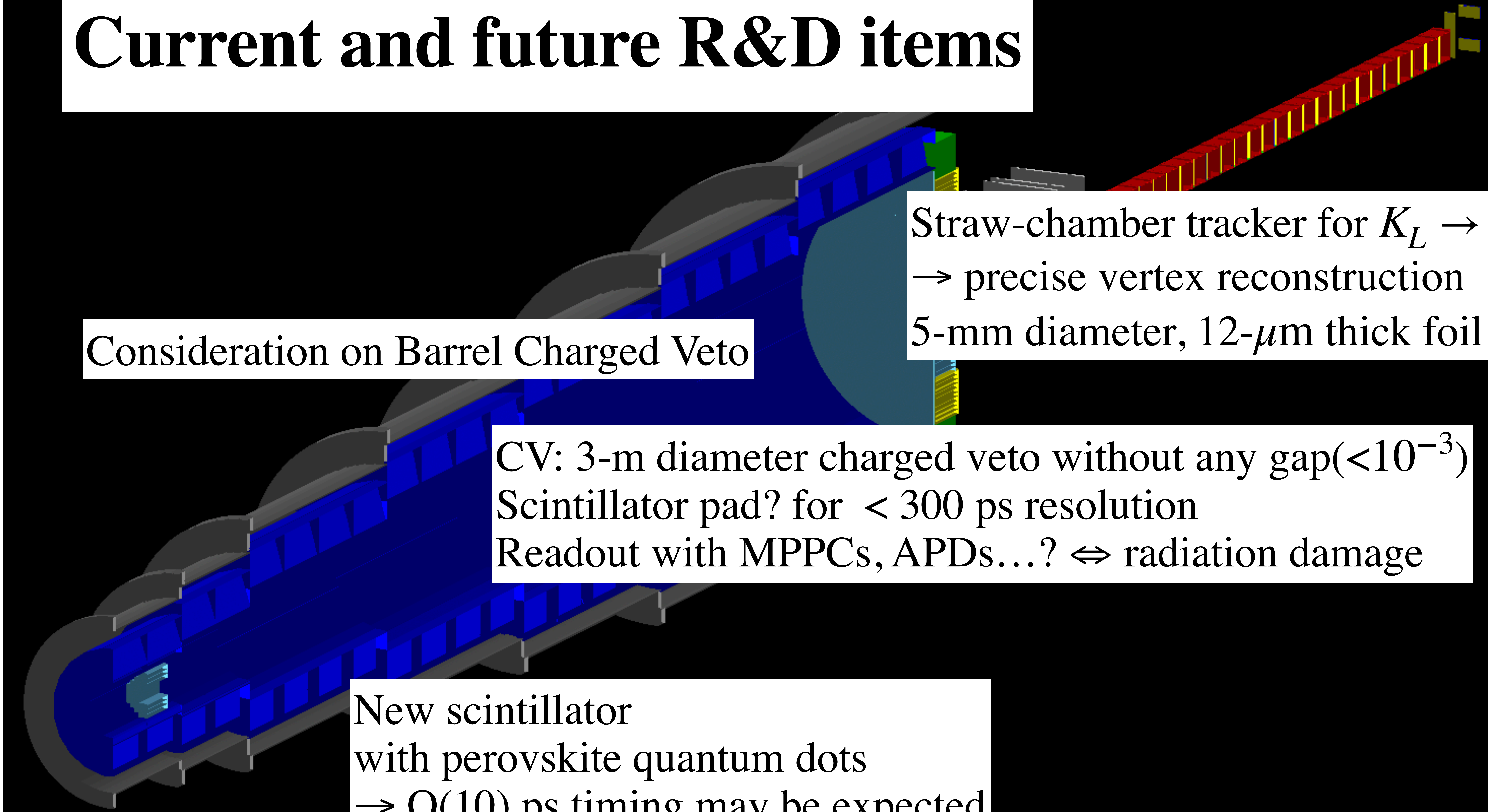
Prototype test of photon-angle measurement (G.Y.Lim + Korean group)





read out of fibers from side with MPPCs

Current and future R&D items



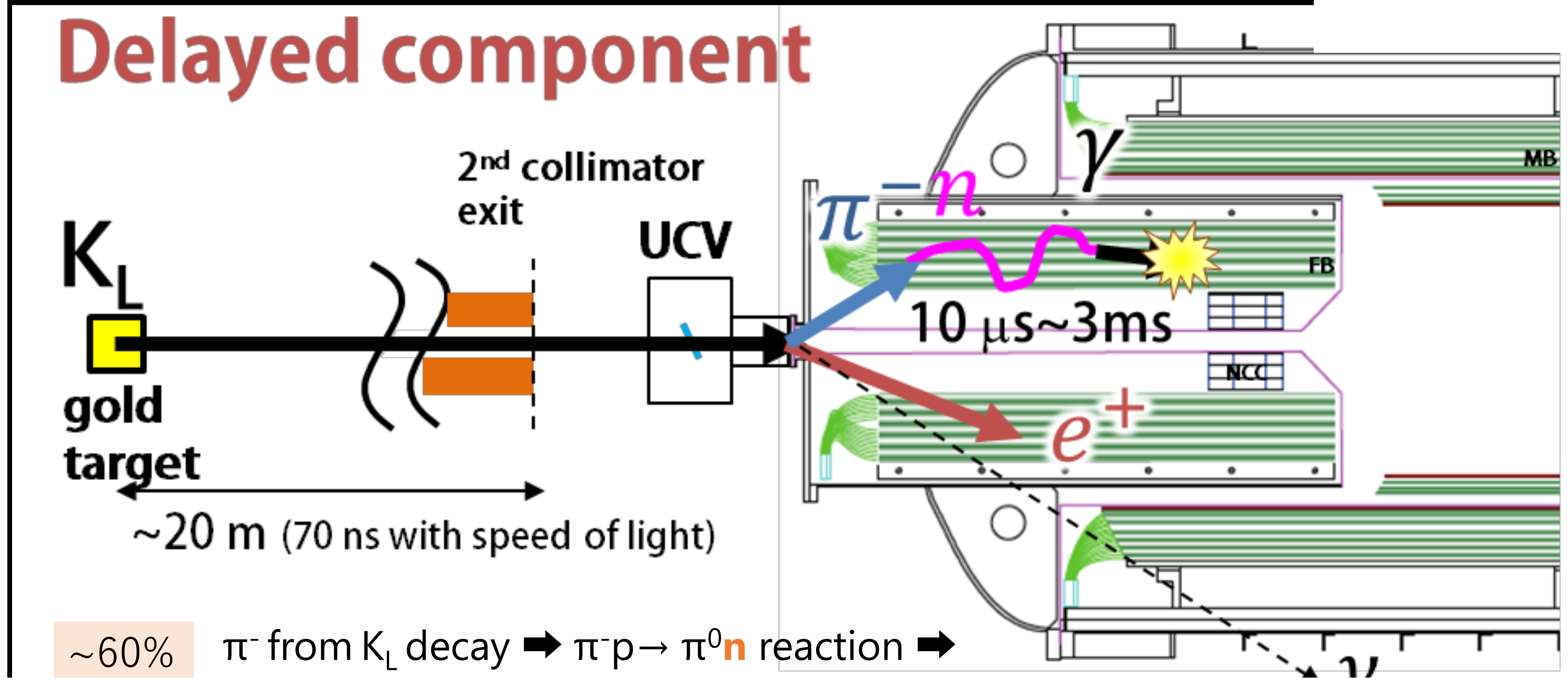
Straw-chamber tracker for $K_L \to \pi^0 l^+ l^-$
→ precise vertex reconstruction
5-mm diameter, 12-μm thick foil

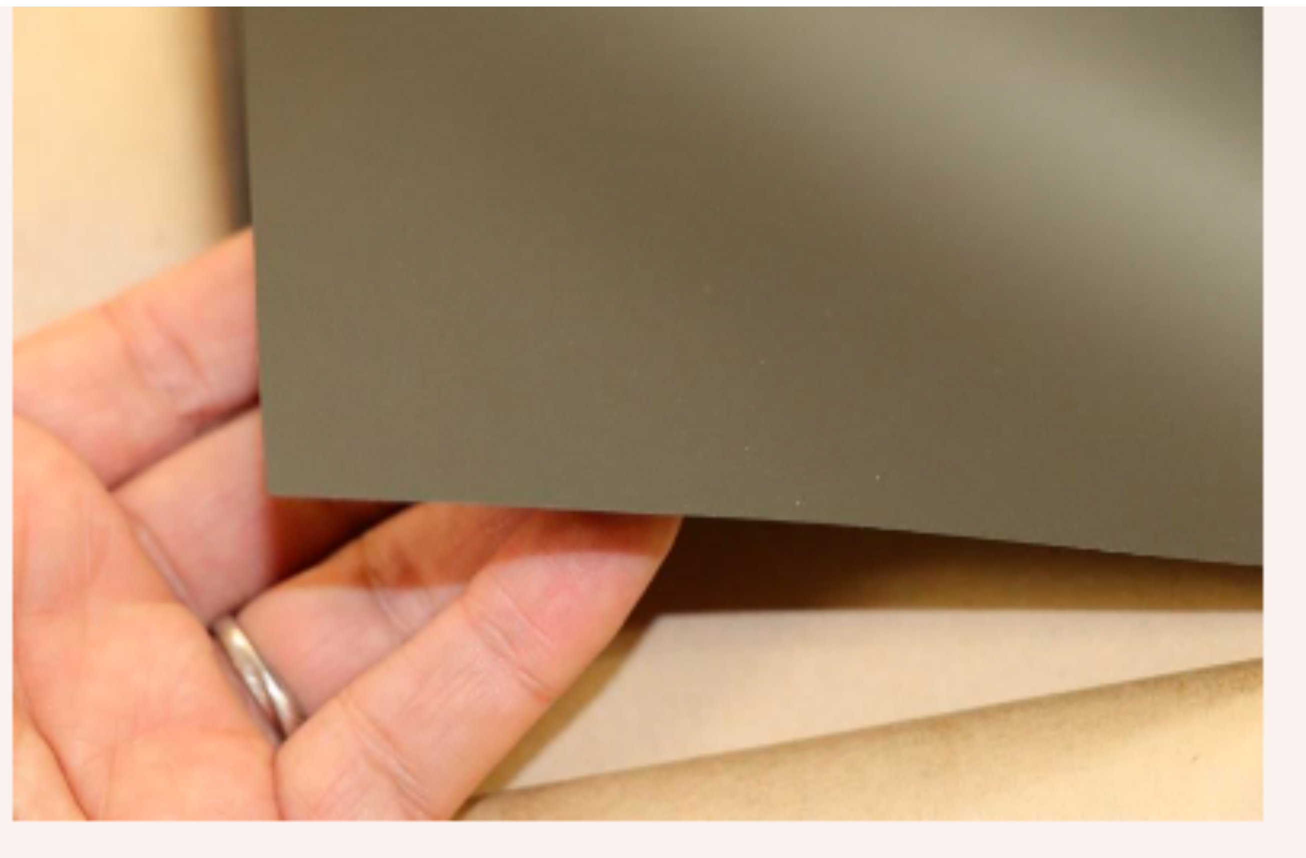
Consideration on Barrel Charged Veto

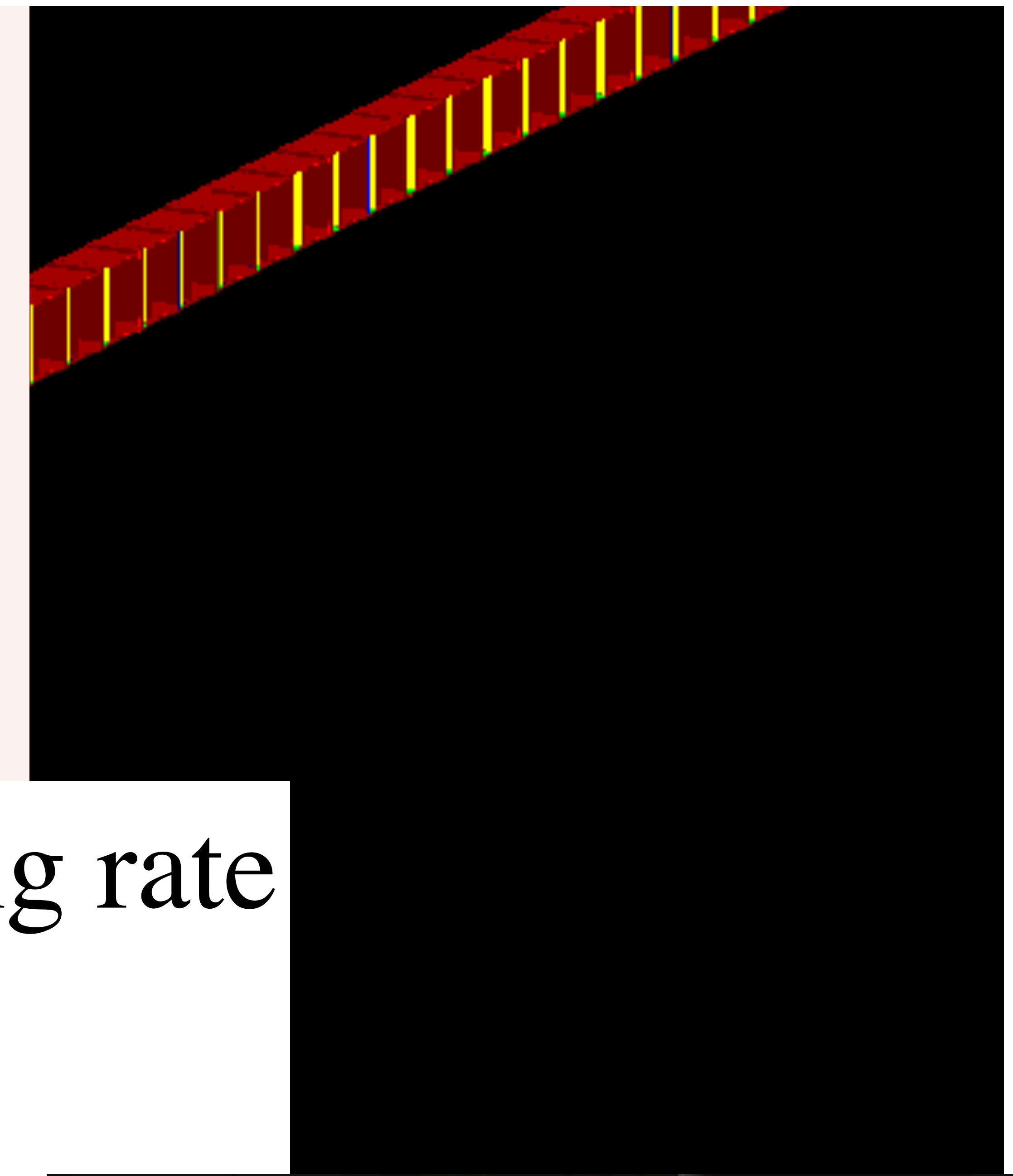
CV: 3-m diameter charged veto without any gap(<10^{-3})
Scintillator pad? for < 300 ps resolution
Readout with MPPCs, APDs…? ⇔ radiation damage

New scintillator
with perovskite quantum dots
→ O(10) ps timing may be expected

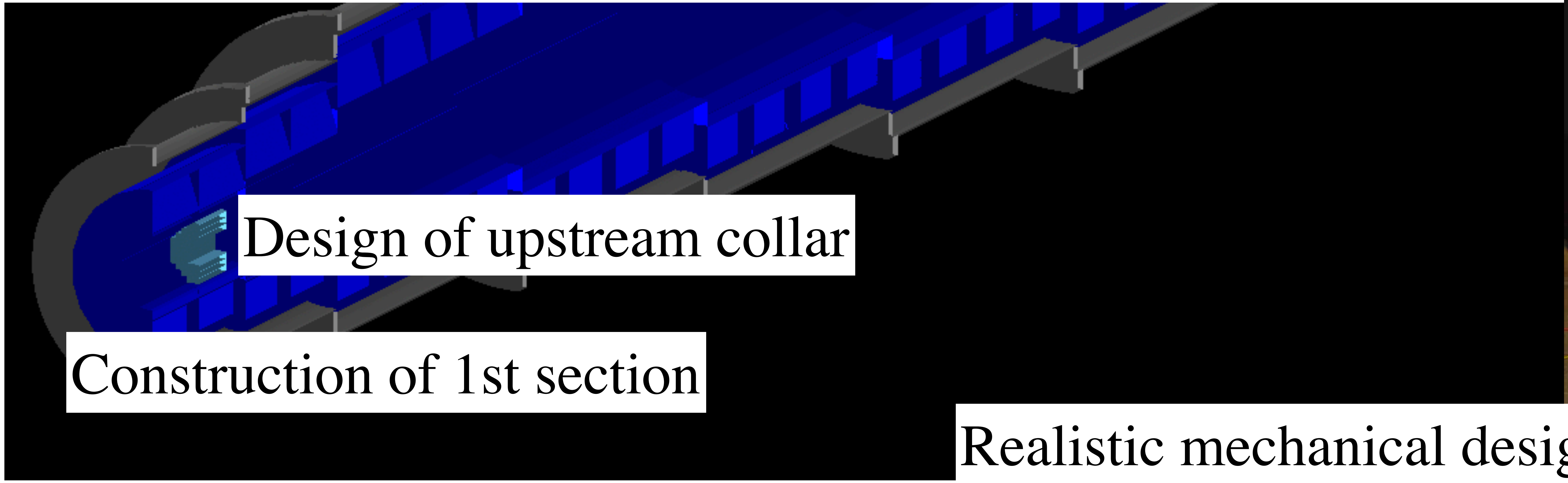
Current and future R&D items





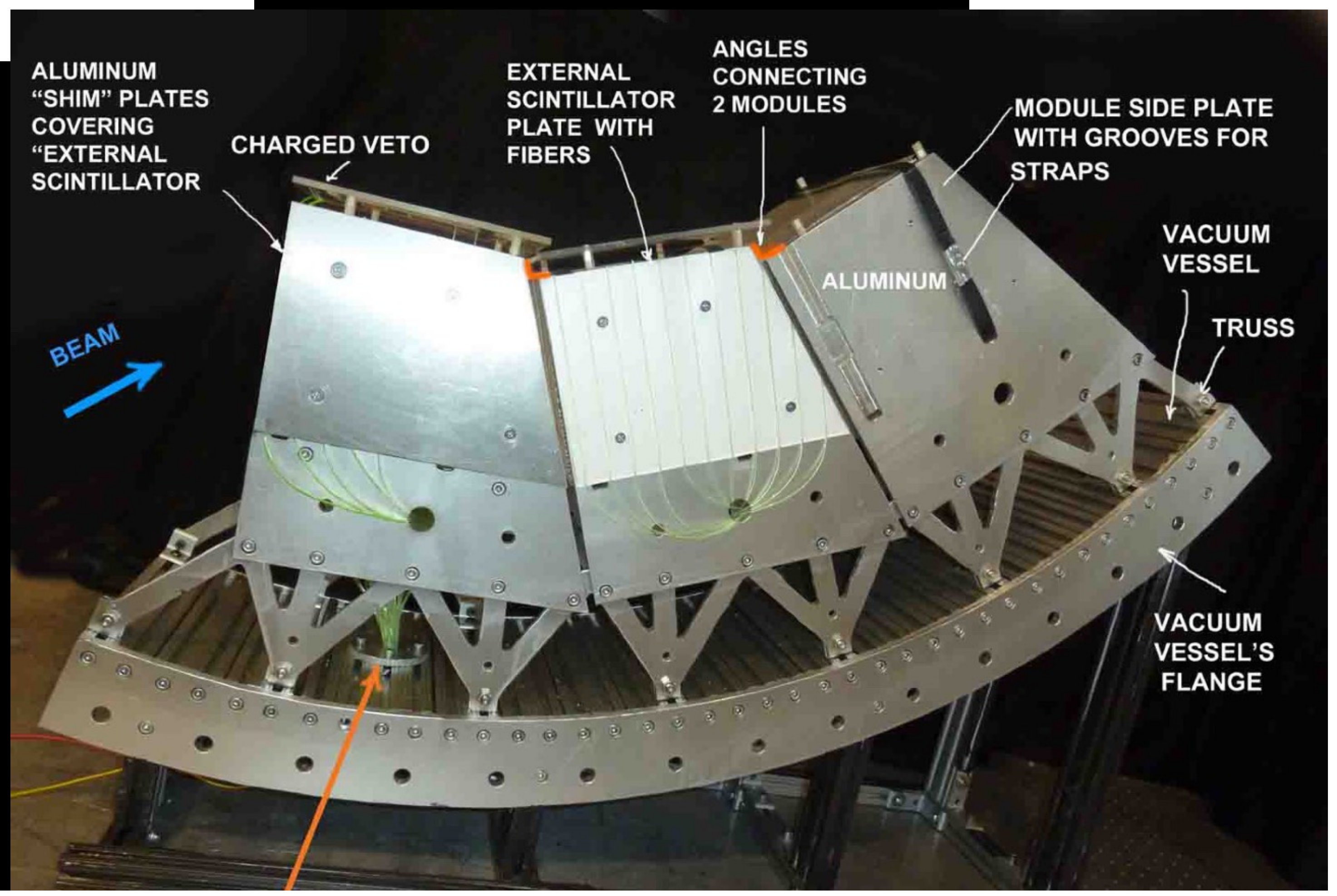


$\pi^{\pm}$ hits the detector → thermal neutron → capture →high counting rate
B_4C sheet for each lead layer will reduce the detector hit rate
→ Prepare a lead-B_4C-scintillator module → Test at J-PARC



Design of upstream collar

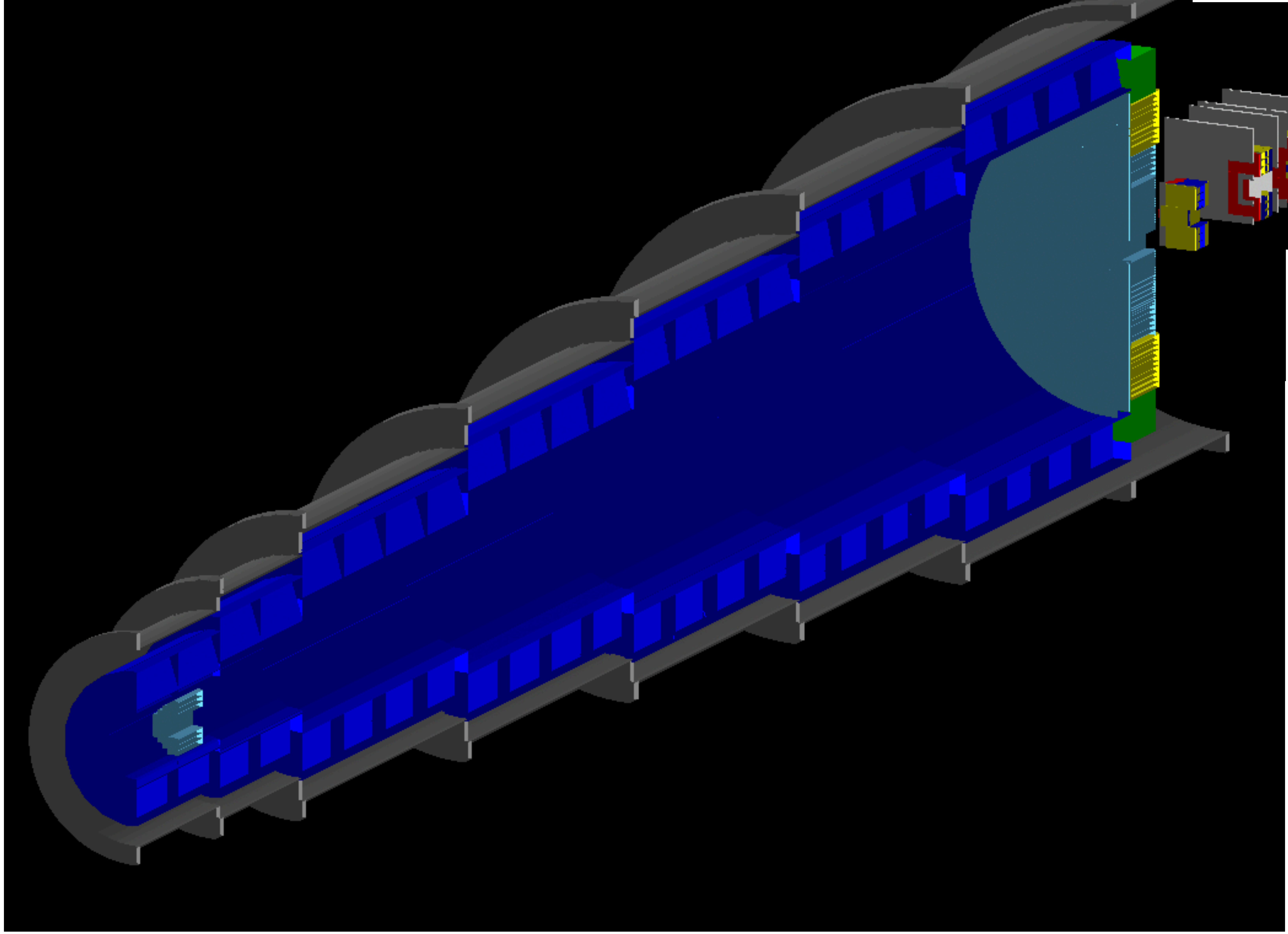
Construction of 1st section



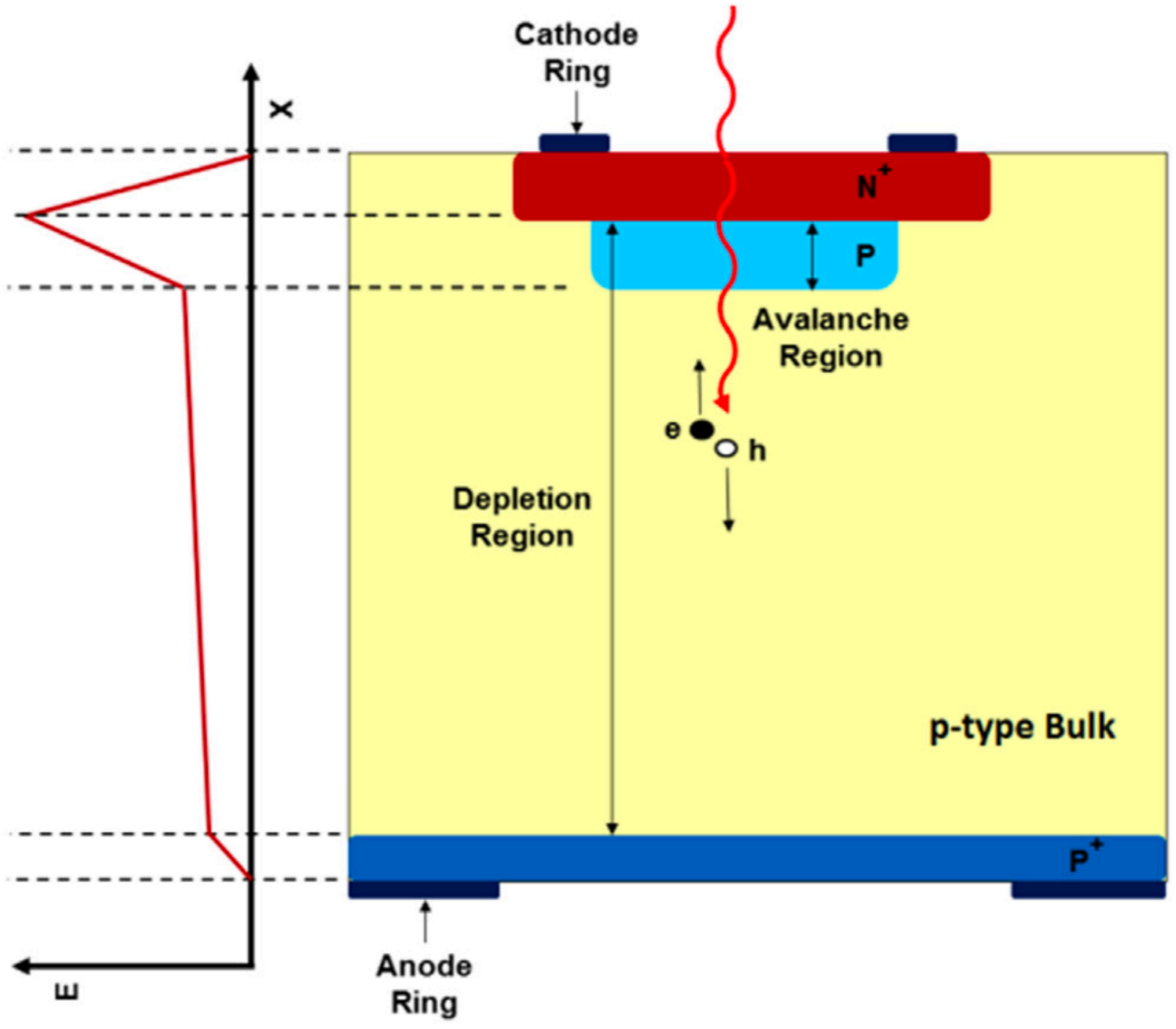
Realistic mechanical design of barrel (U of Chicago)

Current and future R&D items

In-beam photon veto
lead-aerogel module is considered
Any other ideas?



In-beam charged veto
Low Gain Avalanche Diode?



More study items and more collaboration

- Korea-Japan co-research (2023-2024)
  - Dual readout calorimeter, LGAD, … for KOTO II
- Mechanical design : will have supports from engineer group in U of Chicago.
- KEK detector R&D platform
  - Development of quantum-dot scintillator with fast timing
- Study with Full-simulation / Fast-simulation packages
  - Reduction of background using cluster shape : halo $K_L \to 2\gamma, \eta$ production in CV, …
  - Feasibility studies for other decay modes, $K_L \to \pi^0 e^+ e^-, K_L \to \pi^0 \mu^+ \mu^-, K_L \to \pi^0 X$ …
- Will prepare KOTO-II proposal in JFY2023.
  - Any suggestions, contributions are welcome.
  - More international collaboration is one of the keys.
  - Could you consider to join the KOTO-II preparation group to prepare a proposal?

Conclusion

- KOTO II at extended hadron experimental facility at J-PC will measure $\mathscr{B}(K_L \to \pi^0 \nu \bar{\nu})$
  - Extension of Hadron Experimental Facility
    → Supported by KEK PIP 2022
  - 40 events can be observation in SM with S/B=1.1 → 6σ discovery.
  - Deviation of 38% may give 90% indication of NP.
  - Preparation toward KOTO II is on-going.

- Many challenges in the detector / analysis → many chances of contributions.
- Will prepare our proposal in JFY2024.
- You are more than welcome to join us.
- Let's make a next generation experiment!