Dark Sector search at KOTO experiment

H. Nanjo
(Osaka U.)

Target topology

X: invisible (scaler, axion, massive/massless dark photon)

# of cluster	1	2	3	4	5
Mode	γX	$\pi^0 X$	$\pi^0\gamma X$	$\pi^0\pi^0 X$	$\pi^0\pi^0\gamma X$
		$\gamma\gamma X$			

X: Decay into e^+e^- : depends on X lifetime

X: Decay into two γ

# of cluster	3	4	5	6	7
Mode	γX	$\pi^0 X$	$\pi^0\gamma X$	$\pi^0\pi^0 X$	$\pi^0\pi^0\gamma X$
		$\gamma\gamma X$			

On-going analysis

X: invisible (scaler, axion, massive/massless dark photon)

Dedicated

By-product

By-product (main mode finished)

# of cluster	1	2	3	4	5
Mode	γX	$\pi^0 X$	$\pi^0\gamma X$	$\pi^0\pi^0 X$	$\pi^0\pi^0\gamma X$
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X: Decay into e^+e^- : depends on X lifetime

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# of cluster	3	4	5	6	7
Mode	γX	$\pi^0 X$	$\pi^0\gamma X$	$\pi^0\pi^0 X$	$\pi^0\pi^0\gamma X$
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$K_L \to \gamma X$

Wu Tong (National Taiwan U.)

- X : massless dark photon
  - Meaningful : $\mathscr{B} < 10^{-3}$ Eur. Phys. J. C (2020) 80:824
- Took single cluster data : $\sim 7 \times 10^{16}$ POT
- Cluster energy > 800 MeV
- Acceptance : 3.6×10^{-3} including decay.
- Main background : neutron cluster
  - $10^{-3} - 10^{-4}$ reduction with cluster/pulse shape.
- Sensitivity to signal $\mathscr{B}$: $O(10^{-6})$

$K_L \to \pi^0 X, \gamma\gamma X$

- Analysis of 2015 data for invisible X
  - No update on the 90% CL upper limit.
- Lifetime dependence of X assuming e^+e^- decay is studied with 2016-18 data.

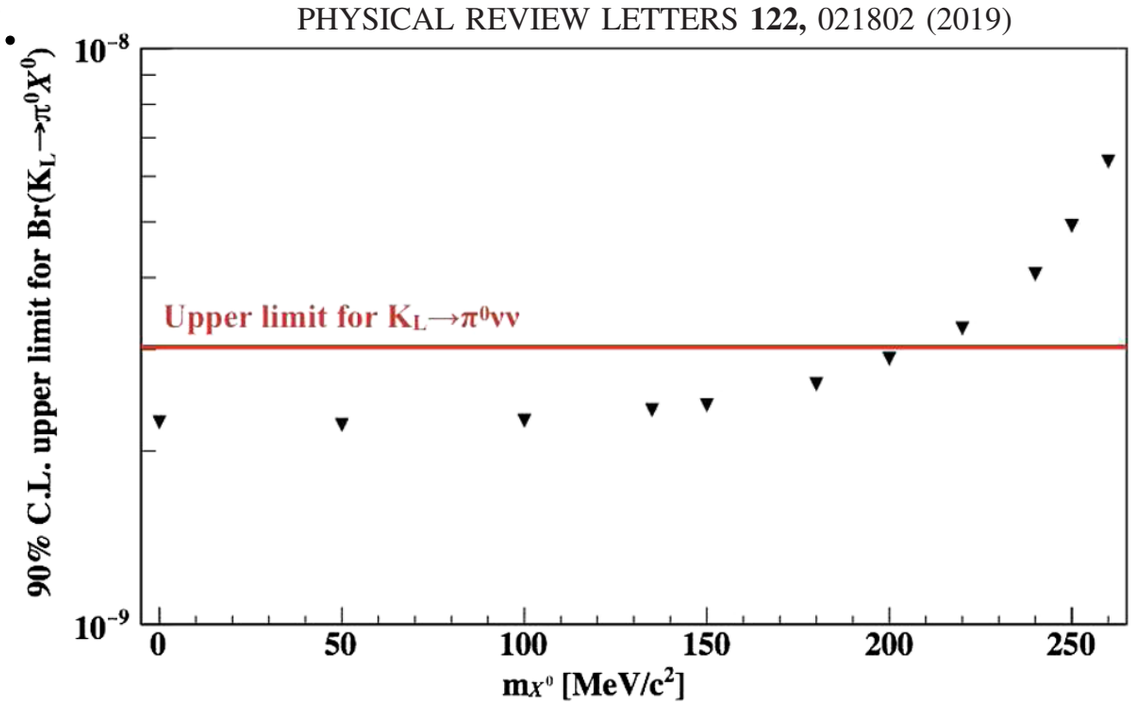
C. Lin (National Taiwan U.)

  - $\tau : 0.1\text{ns} - \infty$
  - No significant change for $m_X \sim 0$, upper limit increase for $m_X \gg 0$
  - Will be open soon.
- Interpretation with $\gamma\gamma X$ is not done yet.

Axiflavon model discussed for $K^+ \to \pi^+ X$

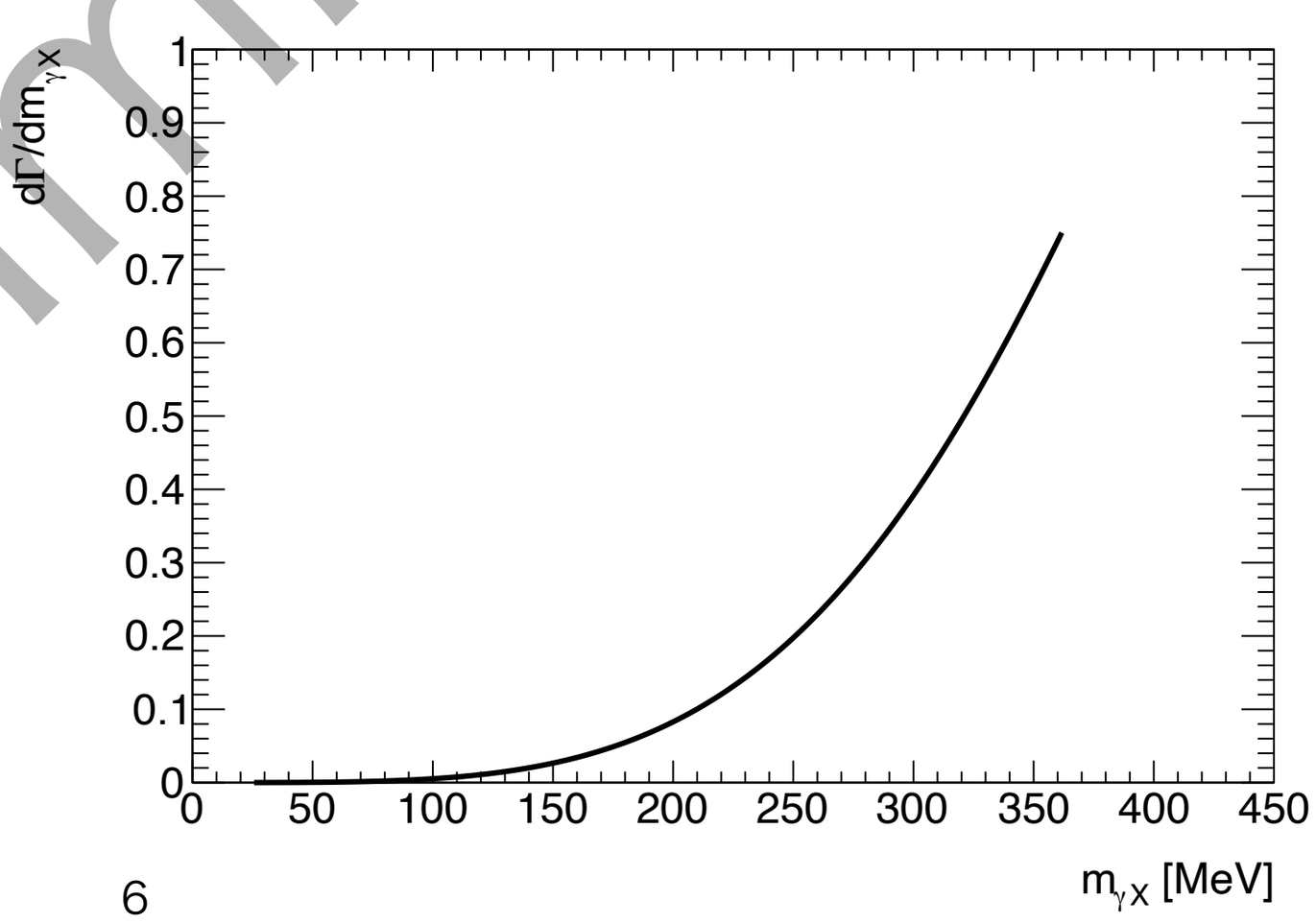
[7] T. Alanne *et al.*, arXiv:1905.07285 [hep-ph]

[8] L. Calibbi *et al.*, arXiv:1612.08040 [hep-ph]



$K_L \to \pi^0 \gamma X$

- X: massless dark photon
  - Meaningful $\mathscr{B} < 10^{-6}$
- Took 3 cluster data : $\sim 2.8 \times 10^{18}$ POT
- Combinatorial error of π^0 with 2 out of 3 clusters is < 10% with kinematic selection.
  - Heavier $m_{\gamma X}$ system
- SES of $O(10^{-7})$ is expected.
  - $K_L \to 2\pi^0$ background



$K_L \to \pi^0\pi^0 X$

Yuting Luo(U. Of Chicago)

- By-product for $K_L \to \pi^0\pi^0\nu\nu$ search
  - Not mentioned in Eur. Phys. J. C (2020) 80:824
  - SES : $O(10^{-9})$

$K_L \to \pi^0\pi^0\pi^0(\to \gamma X)$

- 5 cluster analysis
- $O(10^{-3})$ or better is expected due to γ inefficiency
  - Background from $K_L \to 3\pi^0$

$K_L \to \gamma X(\to \gamma\gamma)$

- By-product for $K_L \to \pi^0\gamma$ search

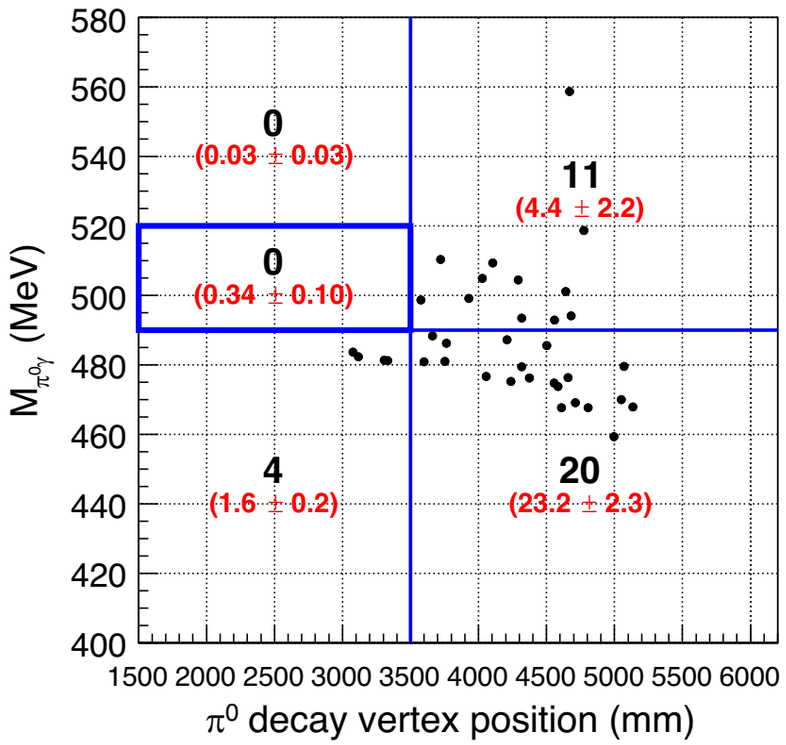
N. Shimizu(Osaka)

  - 90% CL upper limt : 1.7×10^{-7} PHYSICAL REVIEW D **102,** 051103(R) (2020)

    - The same upper limit for the prompt decay with $m_X \sim m_\pi^0$

  - K_L reconstruction and π^0 reconstruction with good vertex consistency.

- BG : 0.34 mainly from $K_L \to 2\pi^0$



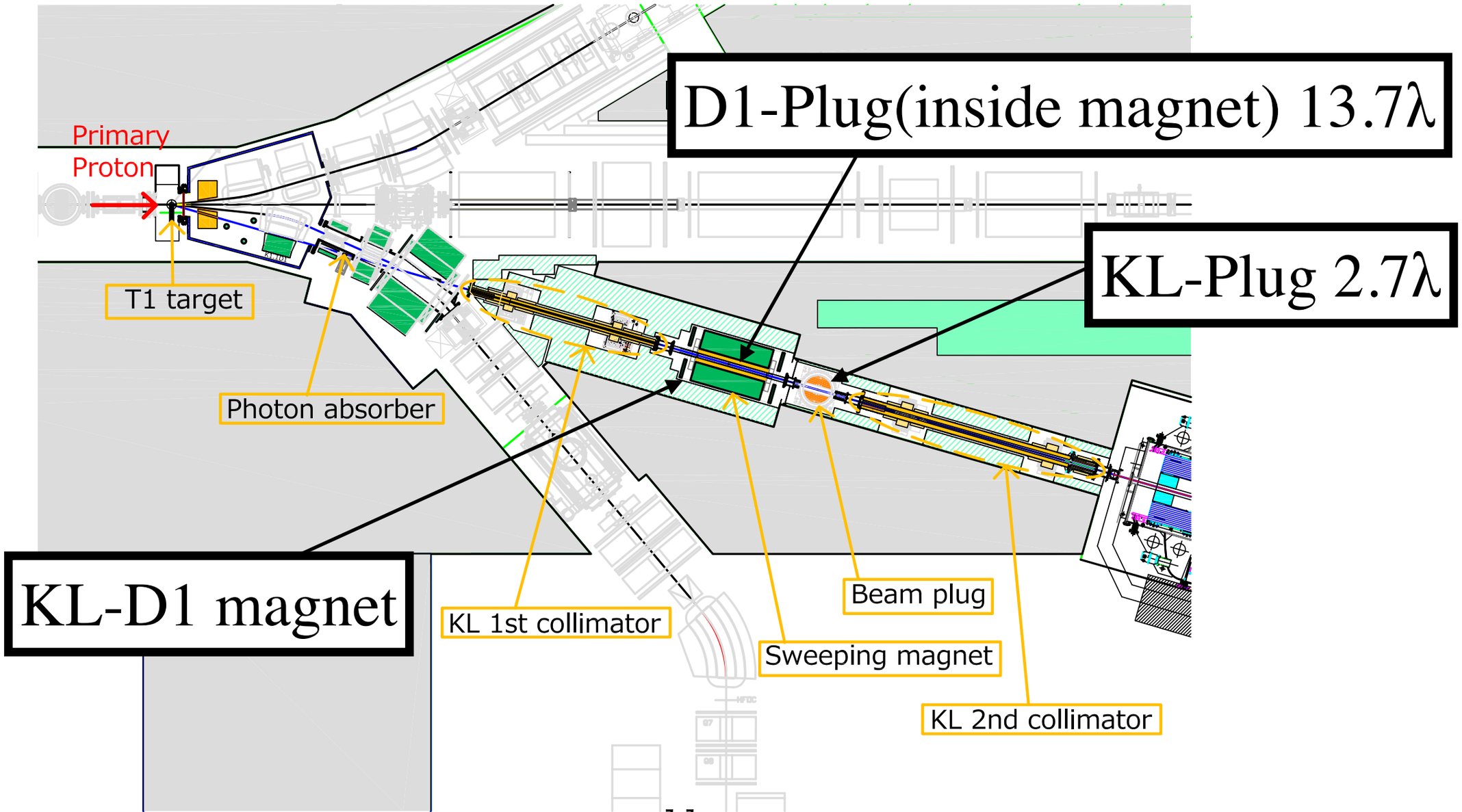
Source	Number of events
$K_L \to 2\pi^0$	0.32 ± 0.10
$K_L \to 3\pi^0$	<0.5
$K_L \to 2\gamma$	<0.06
Neutron	<0.02
$K_L \to \pi^0\gamma\gamma$	0.020 ± 0.002
Other K_L decays	<0.04
Total	$0.34 \pm 0.10 (<1.0)^{a}$

$K_L \to \pi^0 X(\to \gamma\gamma)$

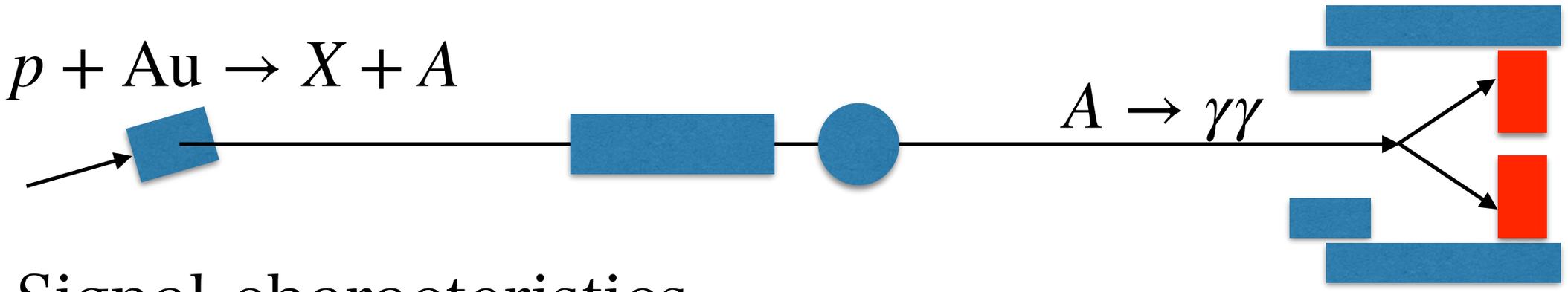
- By-product of $K_L \to \pi^0\gamma\gamma$ C. Lin (National Taiwan U.)
  - K_L reconstruction, π^0 reconstruction.
  - Upper limit on 4×10^{-5} (90%CL)
    - Limited from $K_L \to 3\pi^0$ background so far.
- The similar situation is expected.

Analysis of special beam-dump run

- Data taking with physics trigger with beam plugs closed.
- This data was taken when sweeping magnet was not functional.



Axion-like particle search

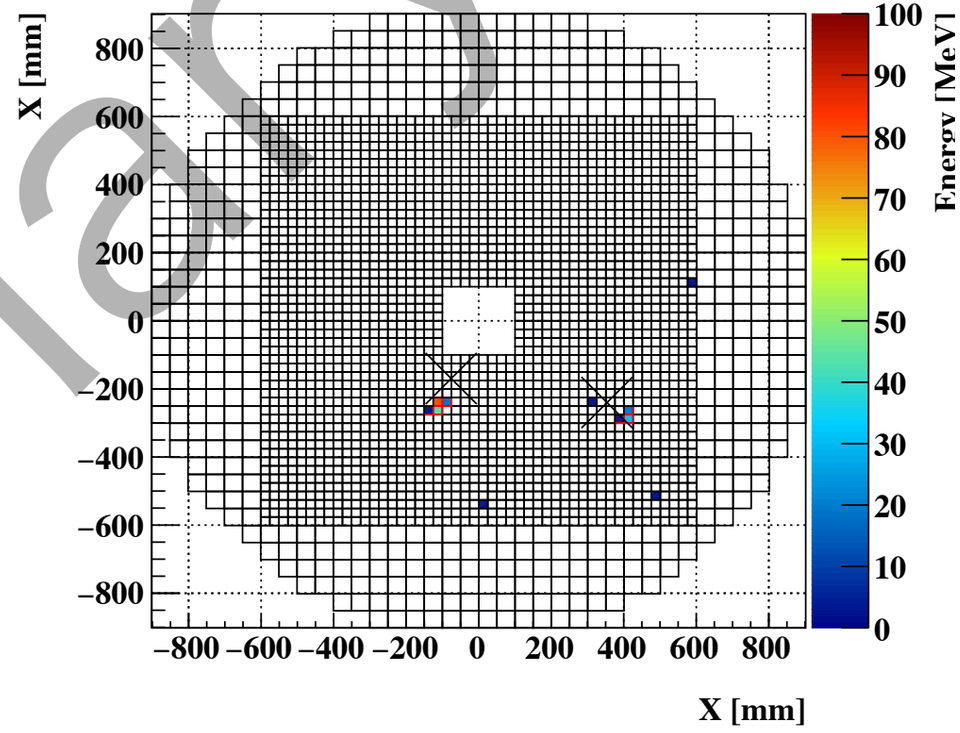


- Signal characteristics
  - 2 clusters in calorimeter
  - Small radius of center of energy.
  - Photon-like cluster
- Backgrounds
  - BG from KL→ flux evaluate with $3\pi^0$ decay
  - BG from π^0 → vertex distribution with π^0 assumption
  - BG from neutron → cluster shape information

Analysis status

- We took data for 2.2×10^{17} pot
- No 6-cluster events
  (No contribution from K_L decay)
- 2-cluster analysis

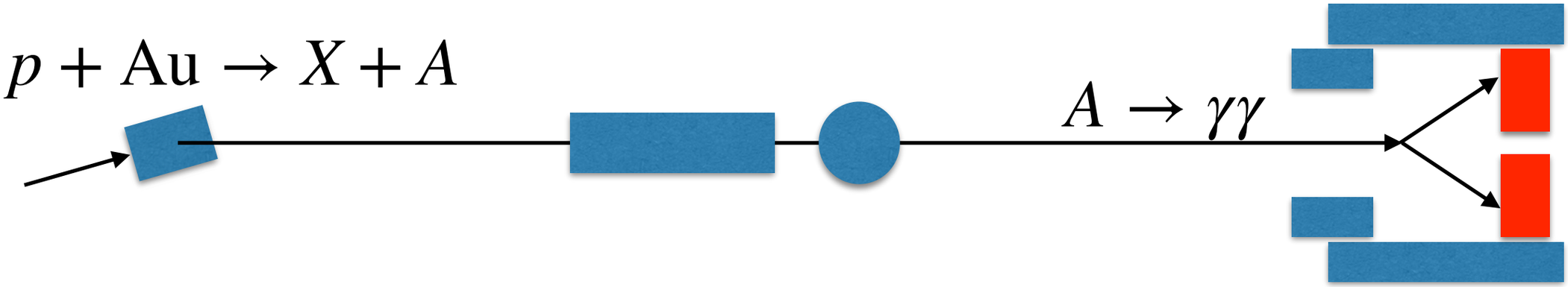
	# of events
Two cluster	569
COE radius<200	145
Veto detector	81
Calorimeter fiducial	37
Cluster shape	1



~50,150 MeV clusters

Dominant background spruce : neutron from primary Beamline
Signal acceptance should be evaluated with some models
(Momentum distribution, mass, lifetime,…)

Worth proceed?



- We took data for 2.2×10^{17} pot
- Assume Axion-like particle production : 1 ALP / POT
- Assume Solid angle : 7.8 μsr
- Assume no loss in beamline
- Decay probability: $\sim \frac{2\ \mathrm{m}}{\beta\gamma c\tau}$

prodcution × decay

- Geometrical acceptance 30%
- Assume $\beta\gamma = 3$ →SES for $c\tau \sim 10^{10}\mathrm{m} \rightarrow \tau \sim 30$ sec

Summary

- 1-4 cluster analysis are on-going.
- Analysis for beam dump mode is on-going.
- Will study possibility on 5-7 cluster analysis