J-PARC KOTO実験における $K_L \to \pi^0 \nu \bar{\nu}$ 崩壊探索

上路　市訓（京都大学）

Flavor Physics Workshop 2018 @ Kavli IPMU

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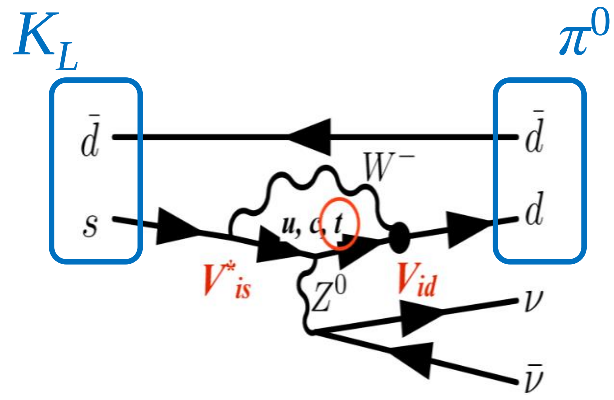
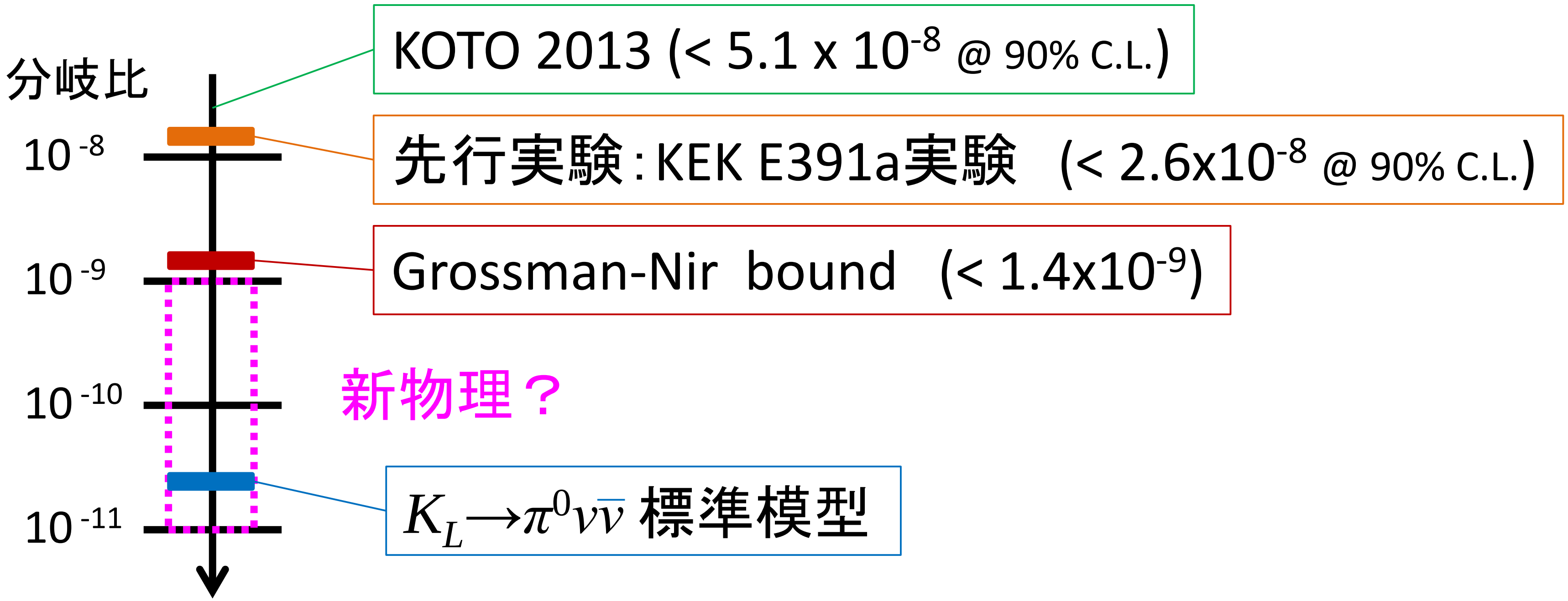
Introduction

$K_L \to \pi^0 \nu \bar{\nu}$ 崩壊



- Direct CP violation
- Flavor Changing Neutral Current
- 標準模型の分岐比　**~ 3 x 10^-11^**
  - small theoretical uncertainty: **~1%**

→ Sensitive to New Physics



$K_L \to \pi^0 \nu \bar{\nu}$ 崩壊

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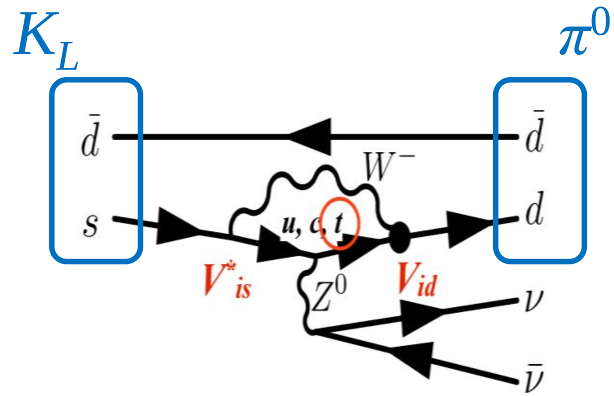
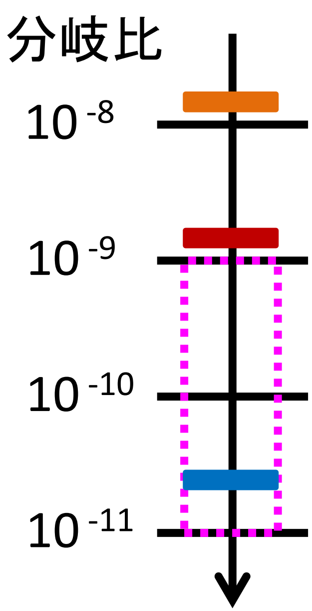
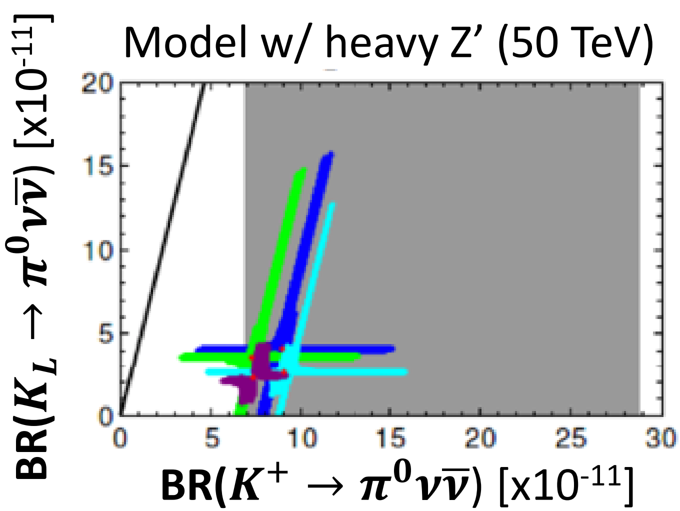


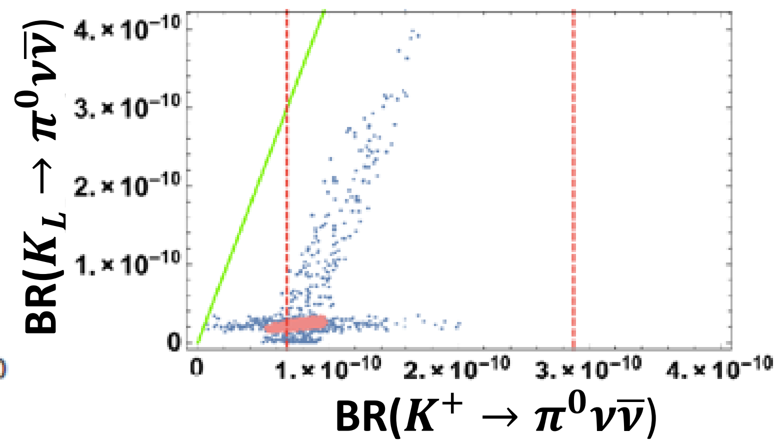


Model w/ heavy Z' (50 TeV)



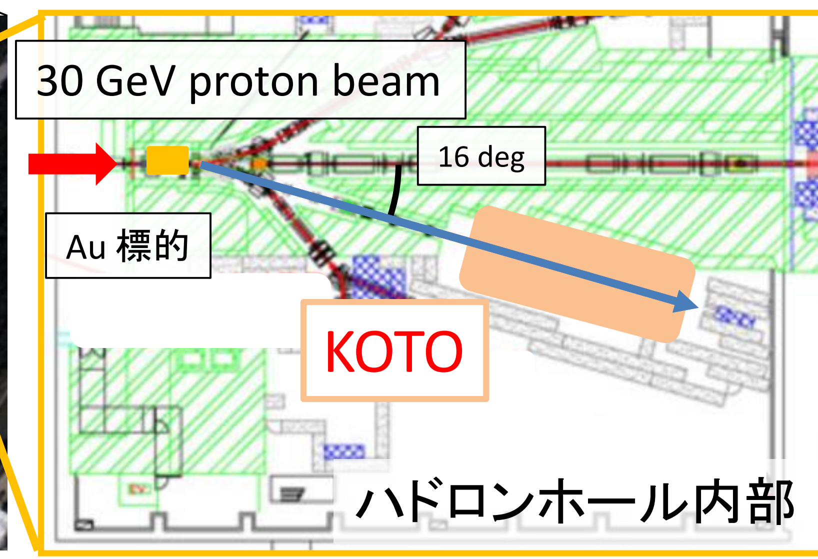
A.J.Buras, et al. JHEP11(2014)121

Model w/ O(10TeV) SUSY

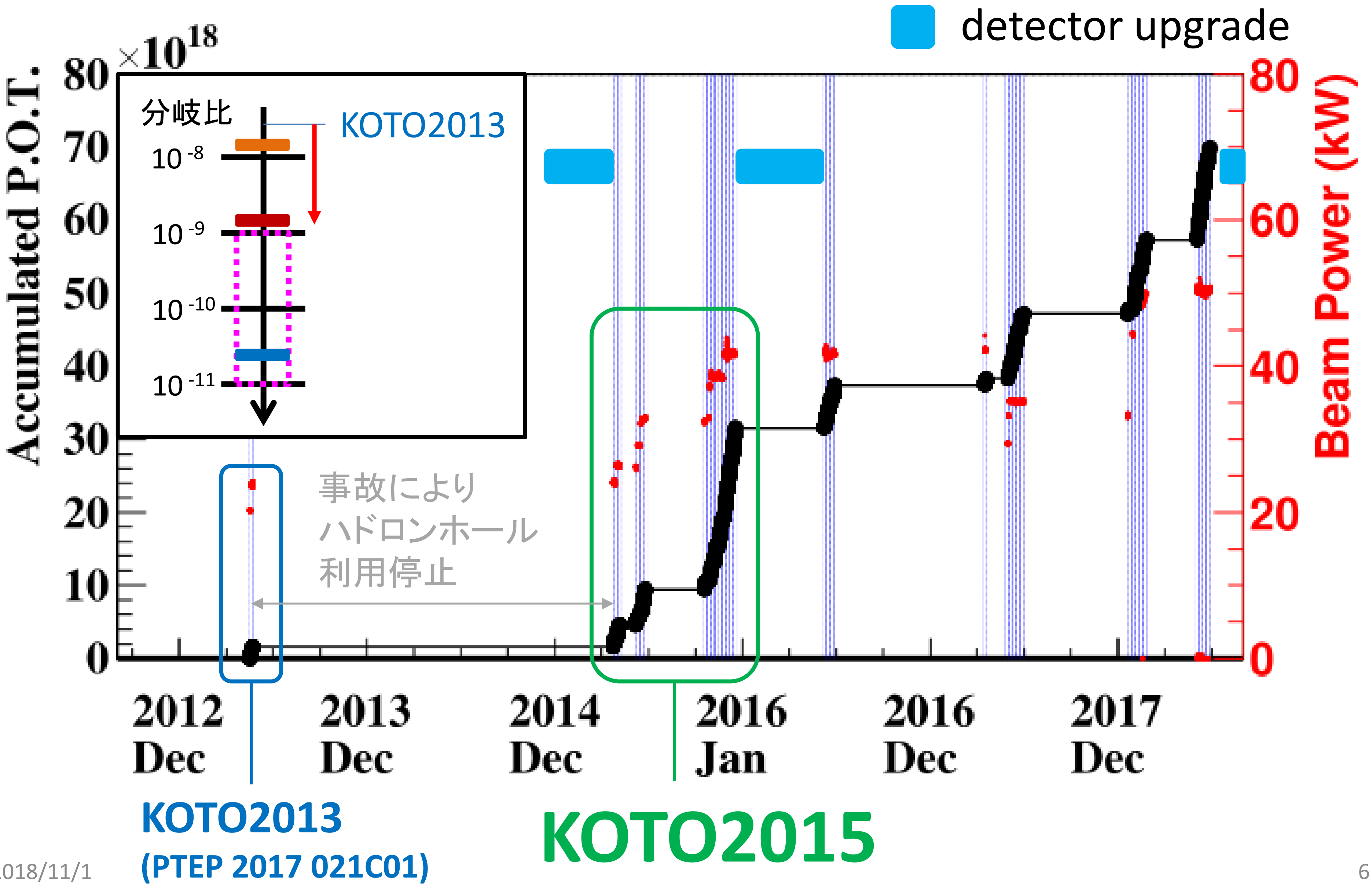


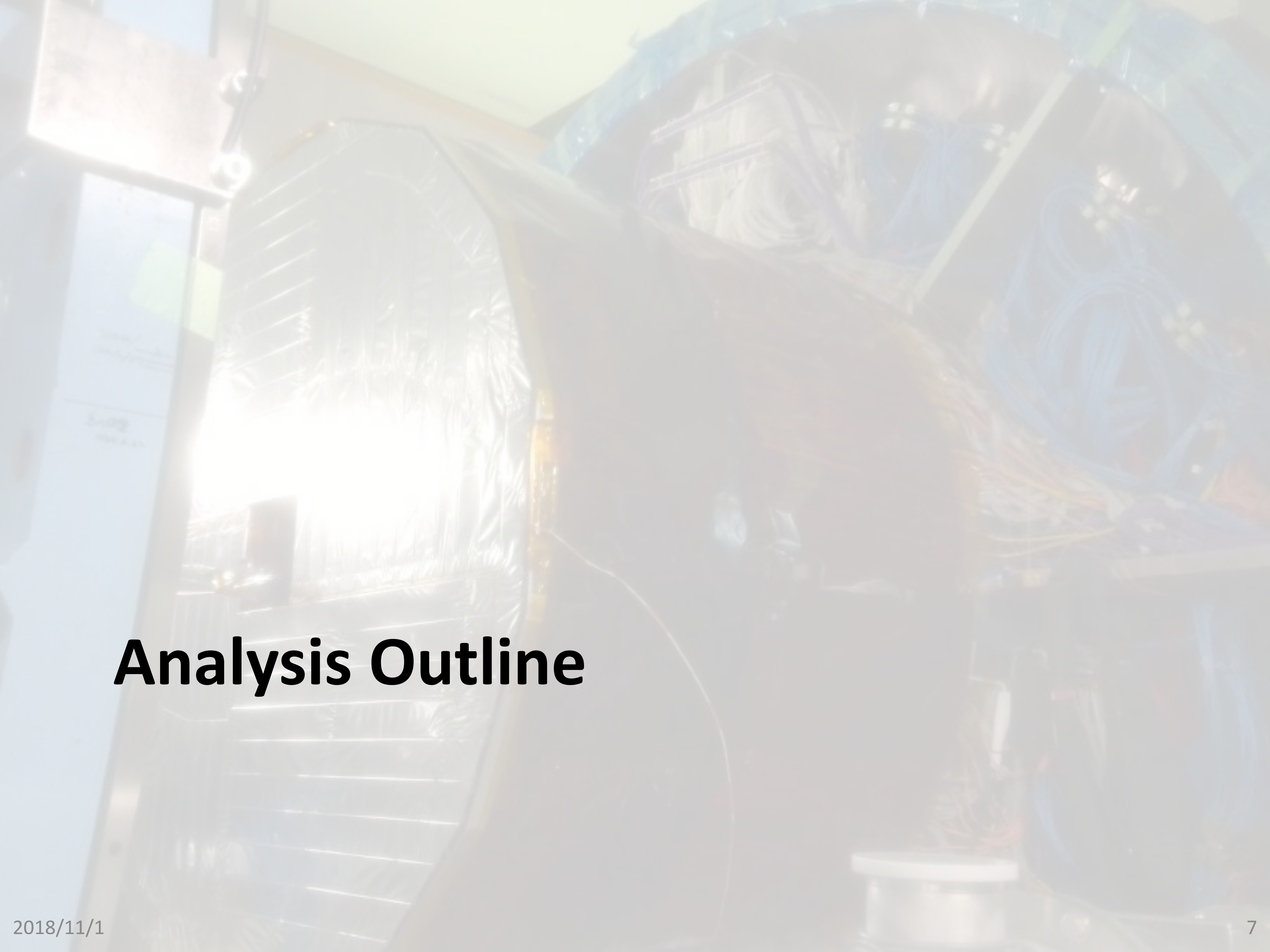
M.Tanimoto, K.Yamamoto, PTEP2016,12,123B02

J-PARC KOTO 実験



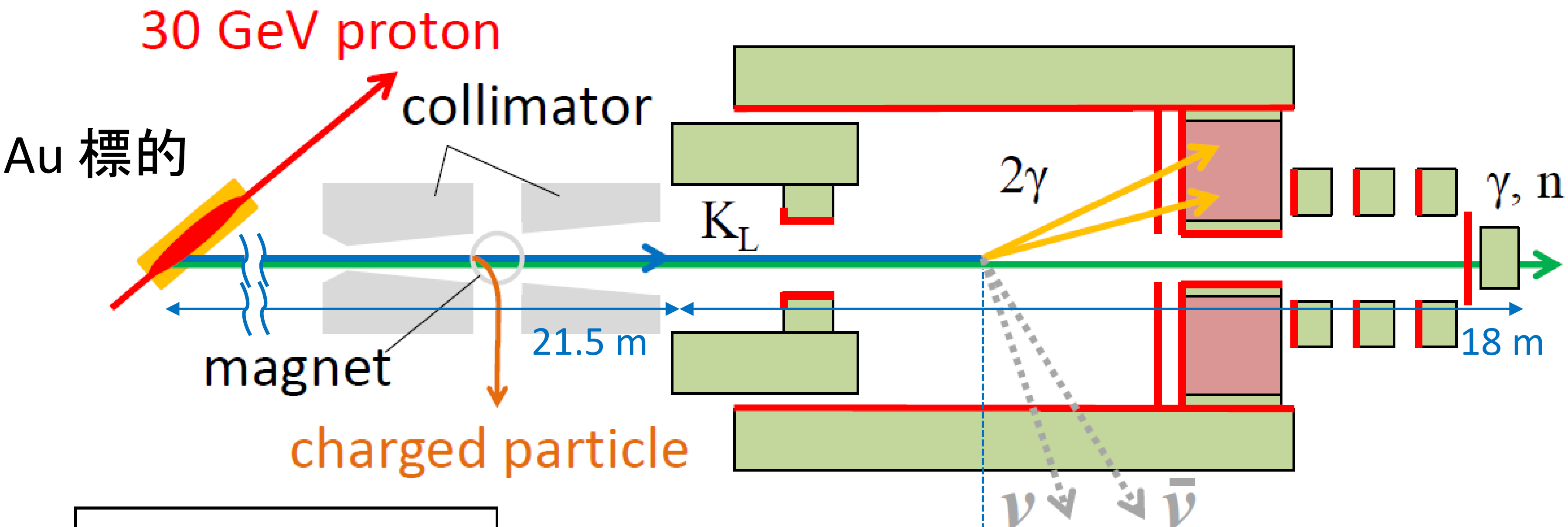
KOTO実験の軌跡


detector upgrade
×10^18
Accumulated P.O.T.
80
70
60
50
40
30
20
10
0
Beam Power (kW)
分岐比
KOTO2013
10^-8
10^-9
10^-10
10^-11
事故により
ハドロンホール
利用停止
2012 Dec
2013 Dec
2014 Dec
2016 Jan
2016 Dec
2017 Dec
KOTO2013
(PTEP 2017 021C01)
KOTO2015



Analysis Outline

実験原理

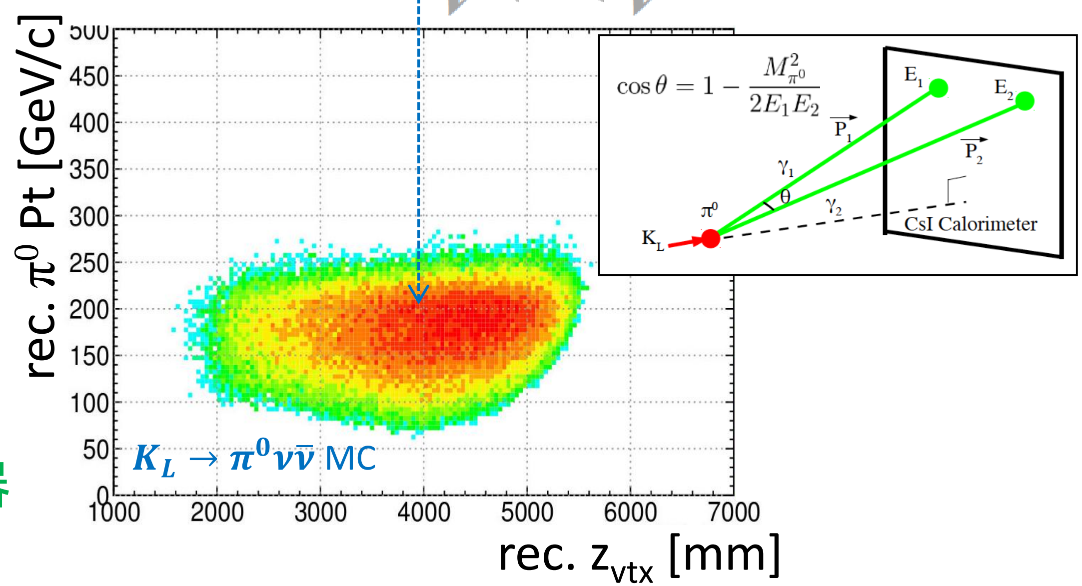


- 電磁カロリメータ
- 光子検出器
- 荷電粒子検出器

2γ (+Pt≠0) + nothing

↓

崩壊領域を光子・荷電粒子検出器（Veto 検出器）で囲む



Analysis Outline

Blind Analysis

Background Estimation

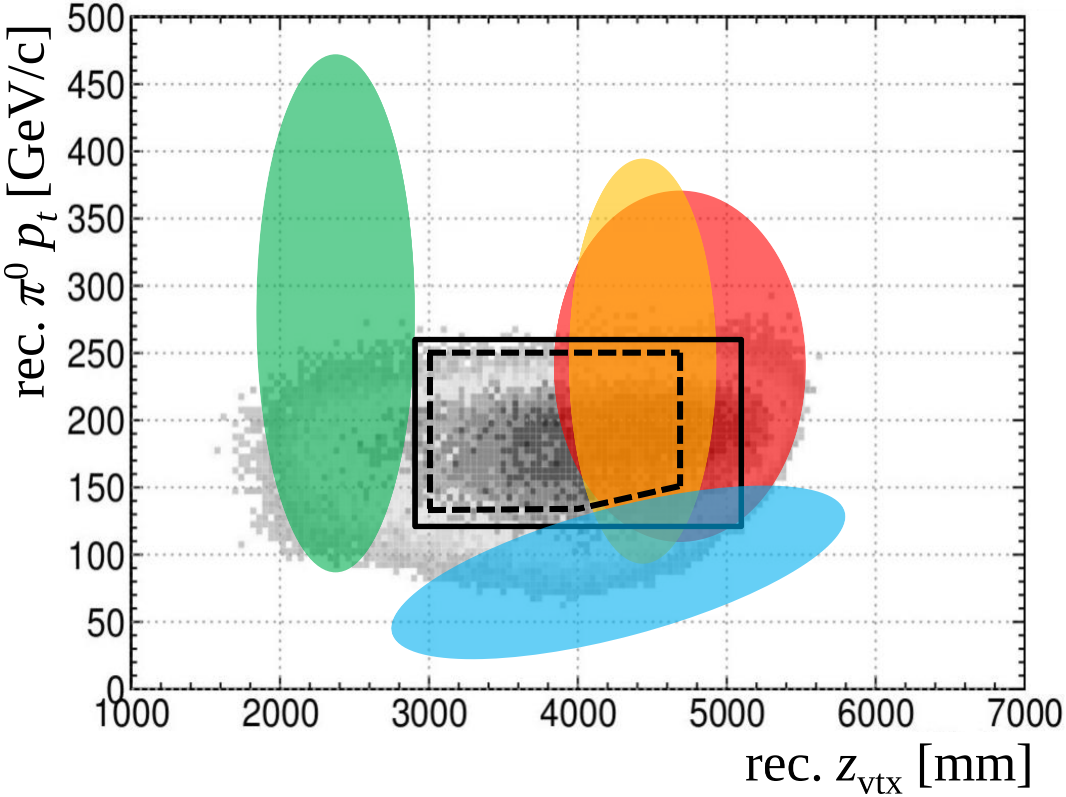
Number of Background Events
← MC simulation & control samples

Single Event Sensitivity

K_L flux
← normalization mode analysis ($\boldsymbol{K_L \rightarrow 2\pi^0}$)
Signal Acceptance
← MC simulation ($\boldsymbol{K_L \rightarrow \pi^0 \nu \bar{\nu}}$)

After fixing all the analysis configuration
→ ***open signal box***

Background Sources



signal box

blinded region

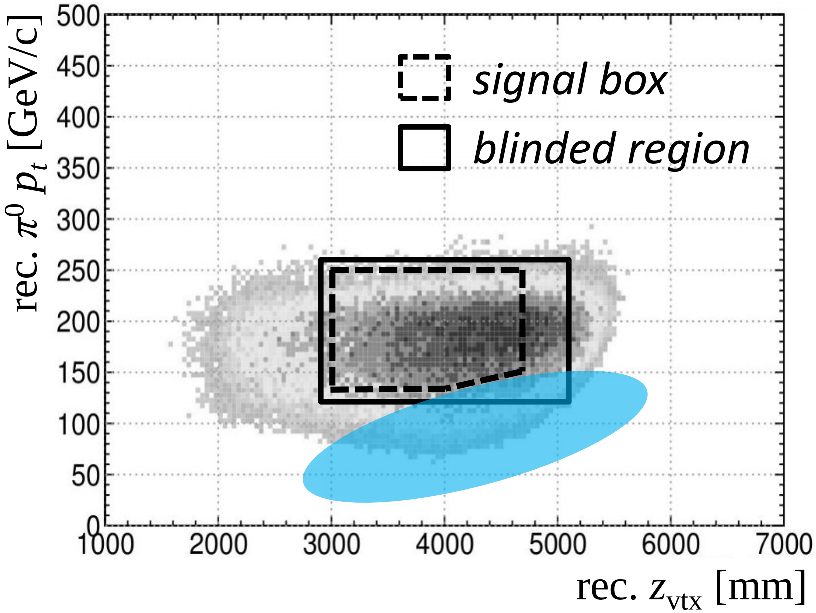
K_L Decays

Hadron Cluster Background

Upstream-π^0 Background

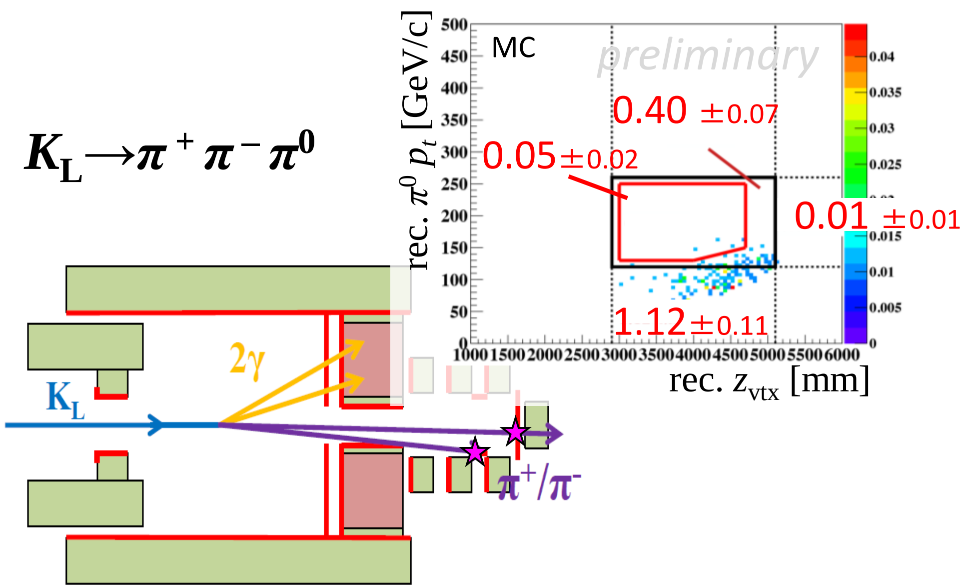
CV-η Background

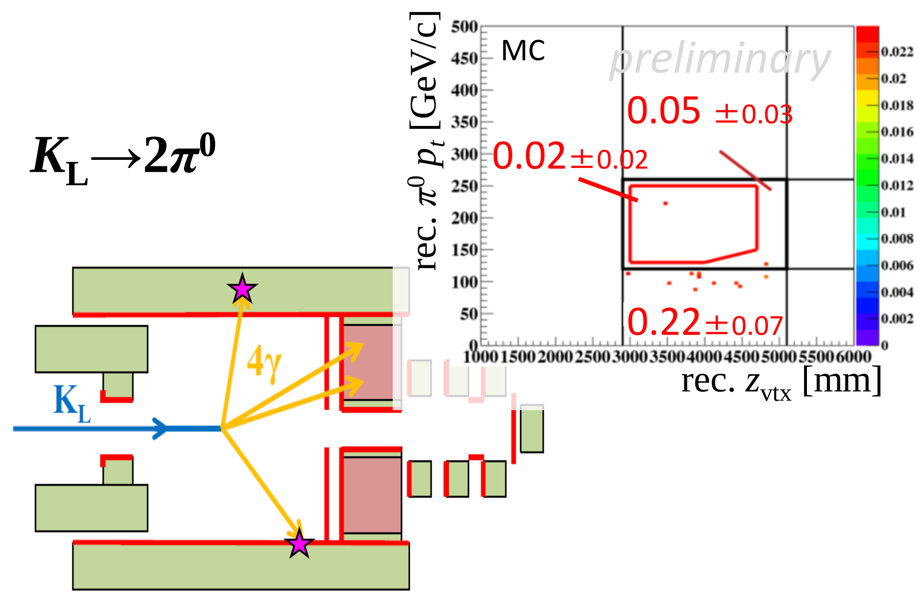
K_L Decays



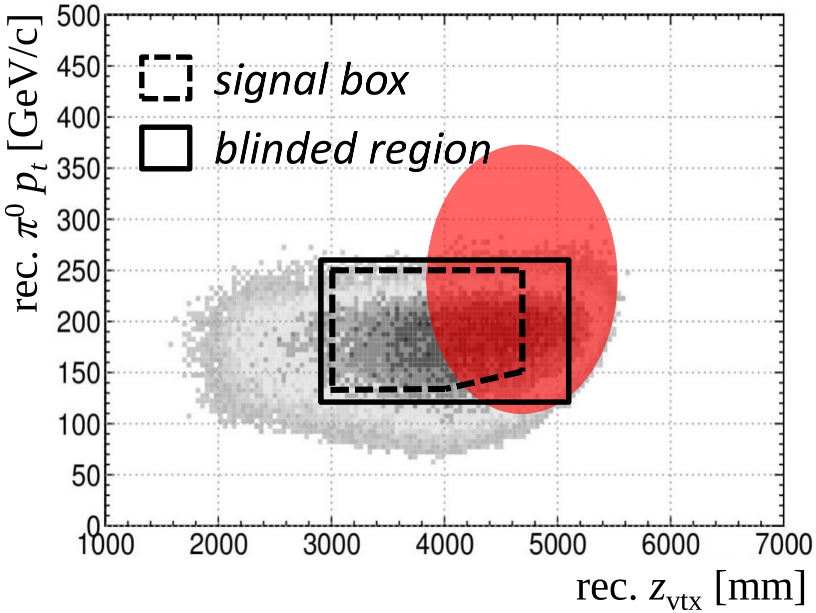
#BG inside *signal box*

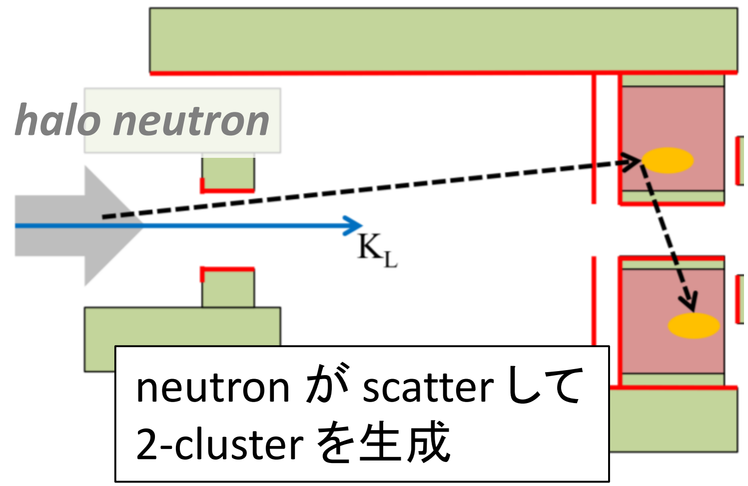
$K_L \to \pi^+\pi^-\pi^0$	0.05 +/- 0.02
$K_L \to 2\pi^0$	0.02 +/- 0.02
other K_L decays	0.03 +/- 0.01

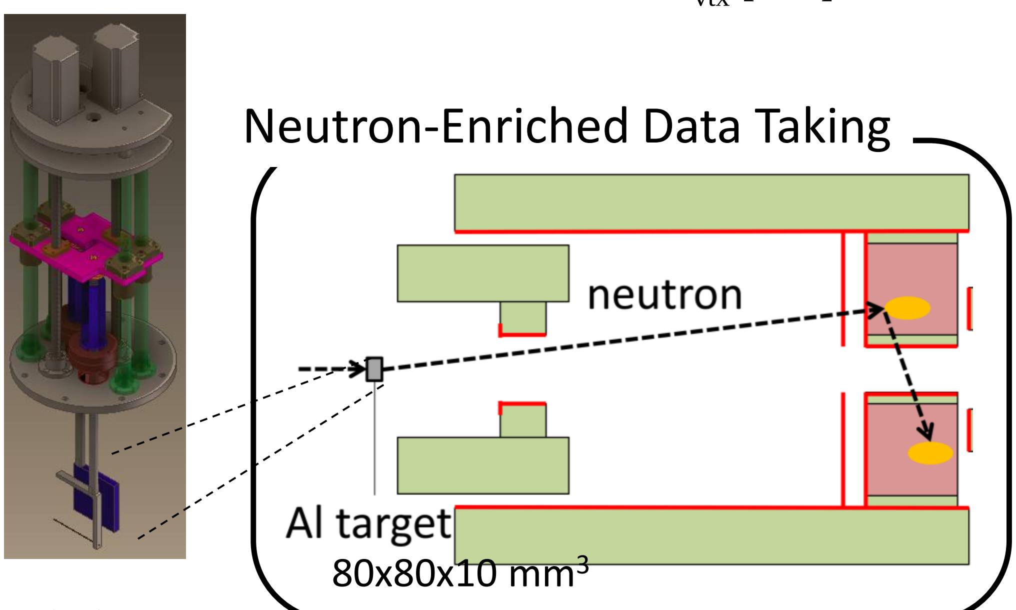


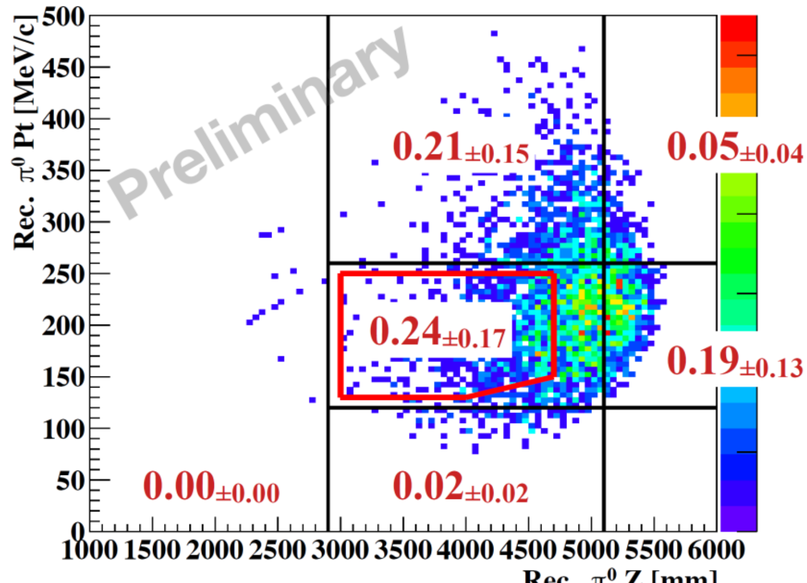


Background Sources: Hadron Cluster Background

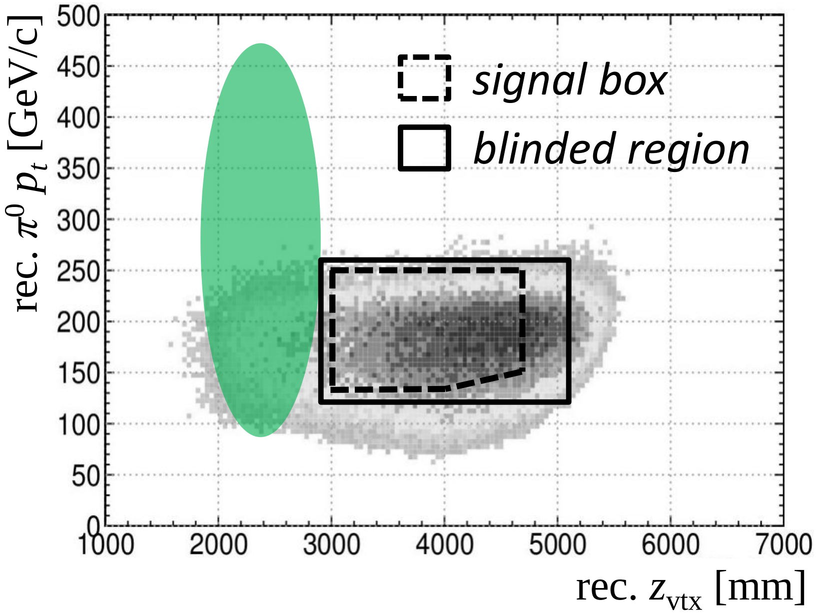


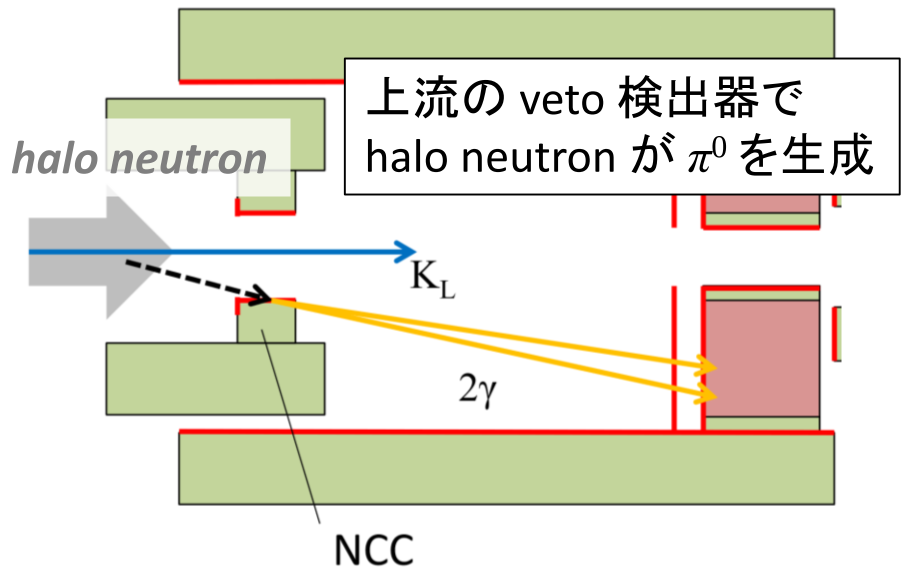






Background Sources: Upstream-π^0 Background



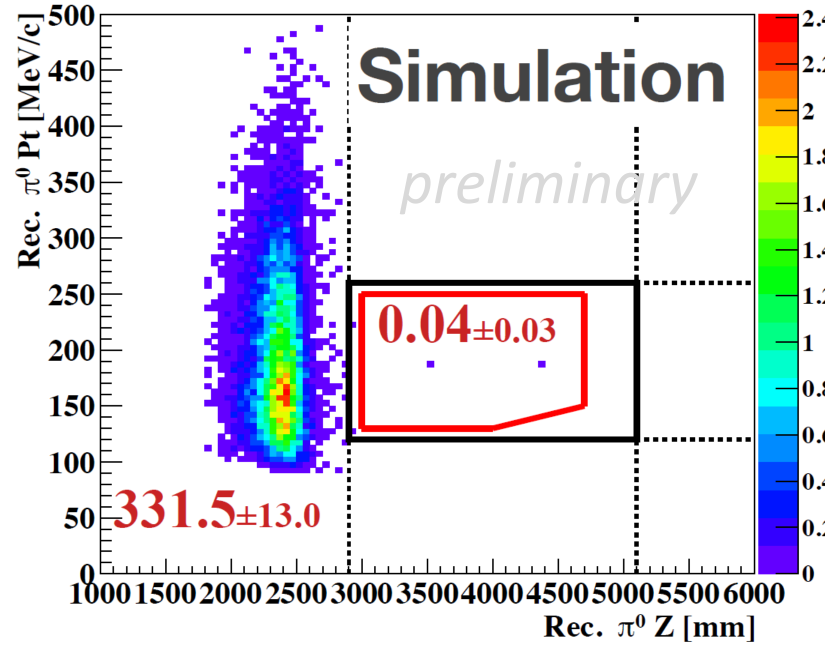


Background になる理由

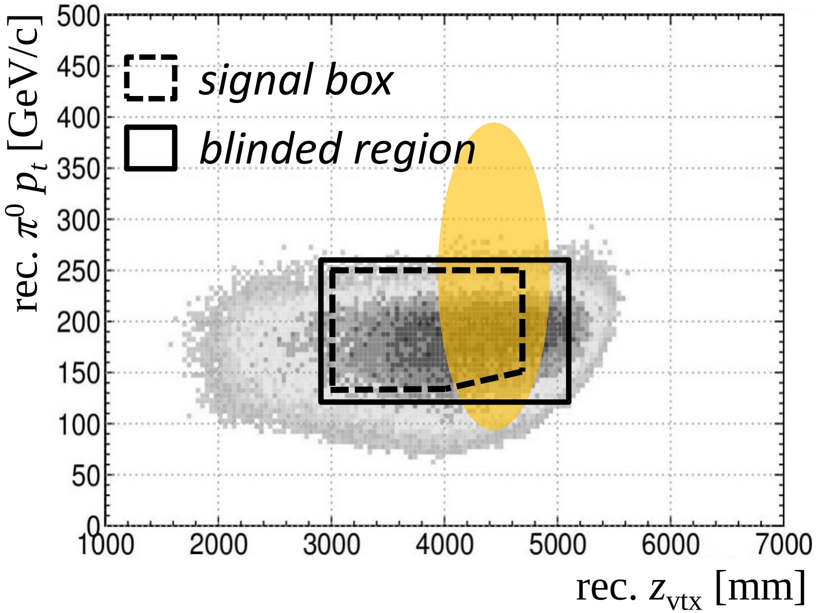
☆ small visible energy on calorimeter
(photo-nuclear interaction)

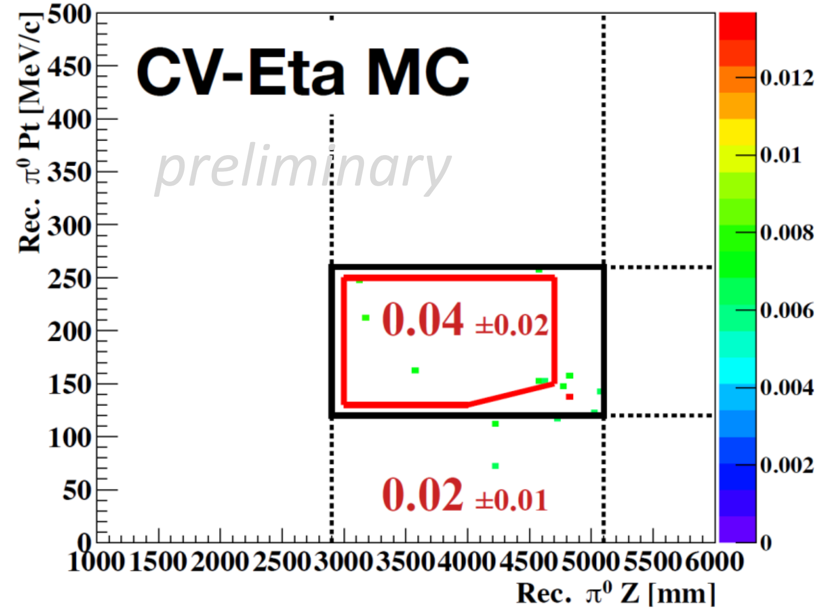
☆ "γ + n" cluster pair

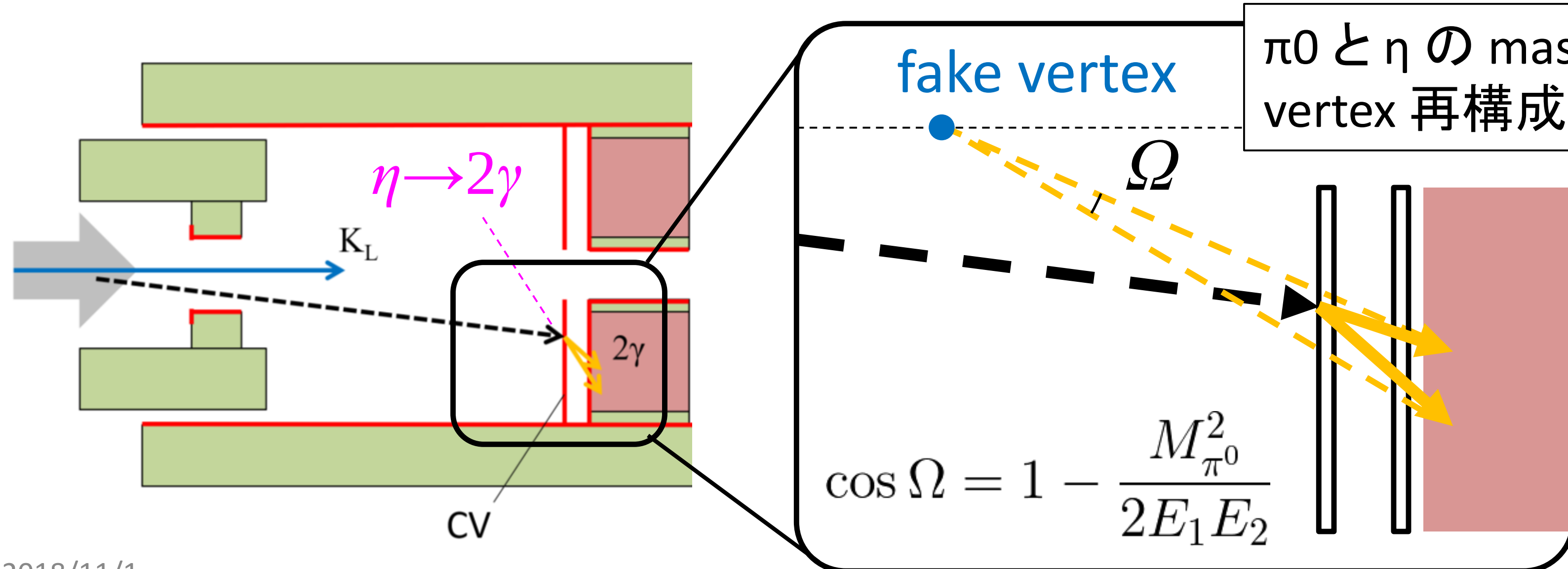
-> vertex の再構成を間違える



Background Sources: CV-η Background



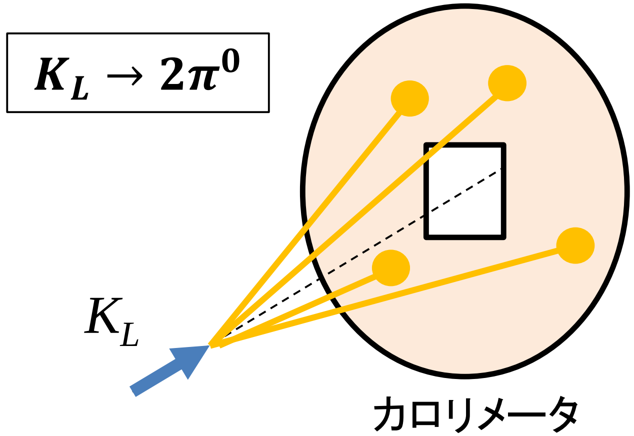


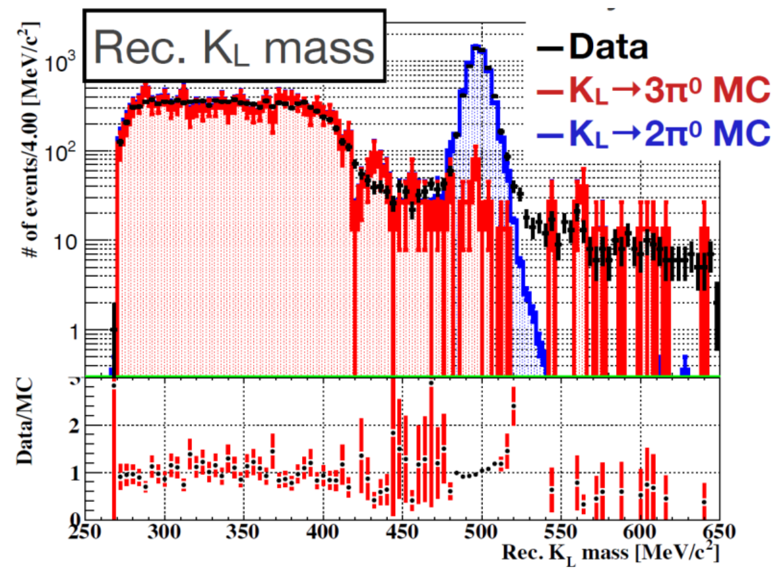


π0 と η の mass の差で
vertex 再構成を間違える

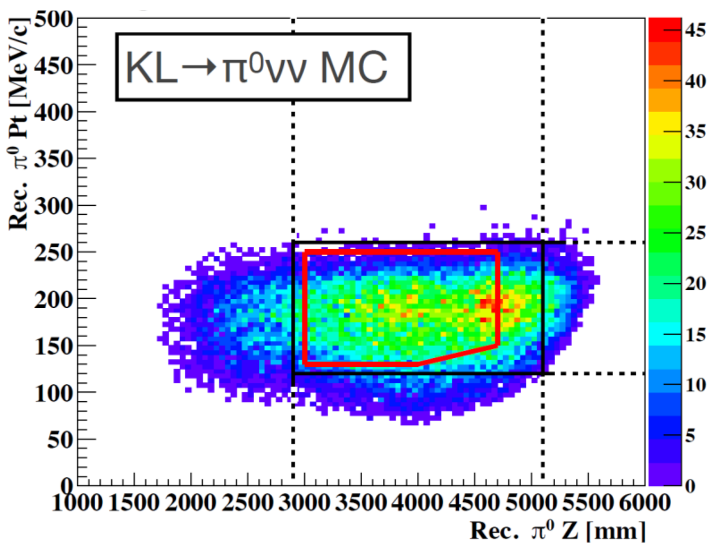
実験感度の算出：Single Event Sensitivity

☆ K_L Flux Measurement





☆ Signal Acceptance



Single Event Sensitivity (S.E.S.)

= [(KL yield) x (signal acceptance)]$^{-1}$

= $\mathbf{(1.30 \pm 0.01_{stat.} \pm 0.14_{syst.}) \times 10^{-9}}$

Result of 2015 Data Analysis

Summary of Physics Data Reduction

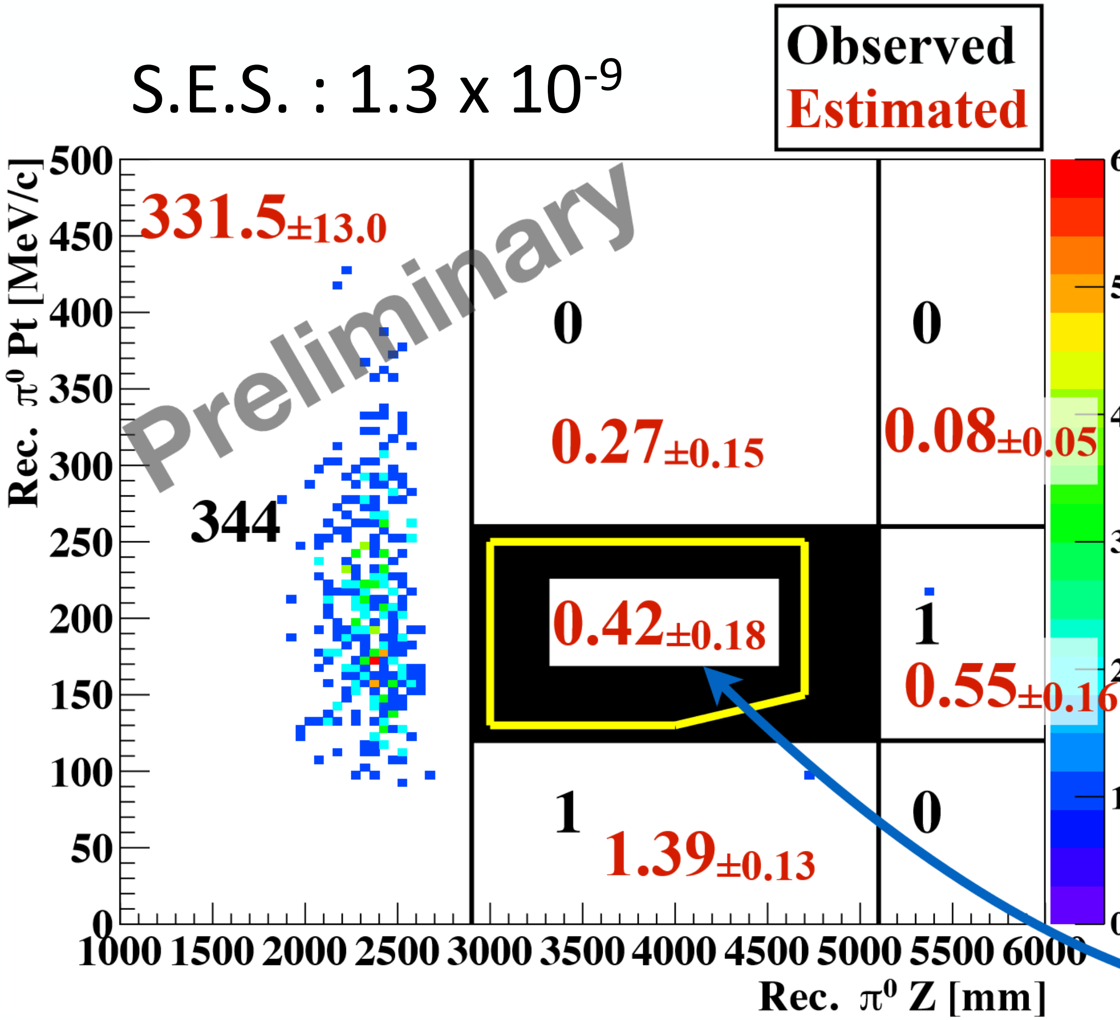
Selection Criteria	number of remaining events
triggered events	4.31×10^9
two-cluster	8.74×10^8
trigger-related cuts	2.50×10^8
photon selection cuts	1.75×10^8
kinematic cuts	3.59×10^7
veto cuts	3.83×10^4
shape-related cuts	347

kinematical selection (two-cluster, trigger-related cuts, photon selection cuts, kinematic cuts)

further BG suppression (veto cuts, shape-related cuts)

Summary of Background Estimation

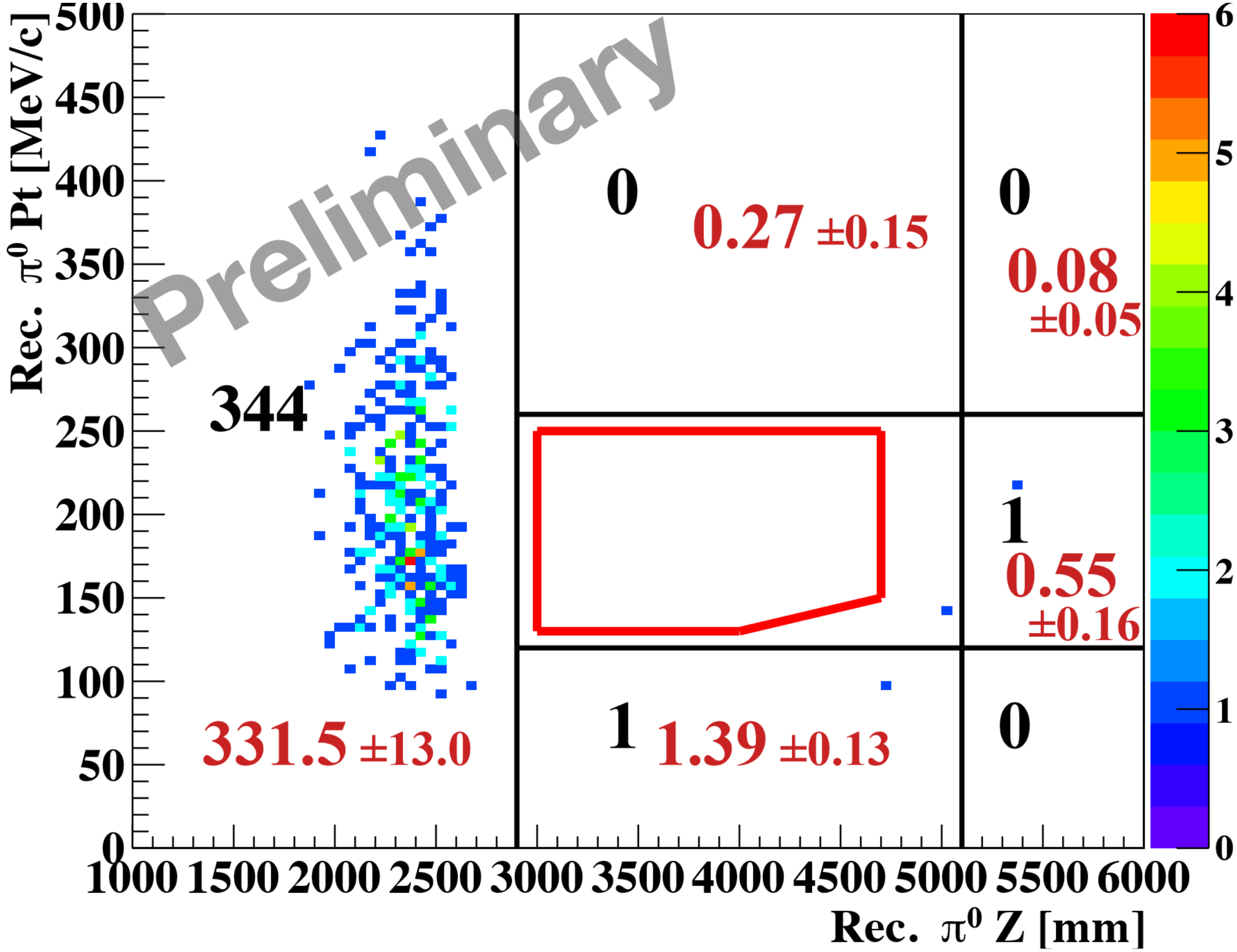
S.E.S. : 1.3×10^{-9}



BG source	# of BG
$K_L \rightarrow 2\pi^0$	0.02 ± 0.02
$K_L \rightarrow \pi^+\pi^-\pi^0$	0.05 ± 0.02
other K_L decays	0.03 ± 0.01
Hadron Cluster	0.24 ± 0.17
Upstream-π^0	0.04 ± 0.03
CV-η	0.04 ± 0.02
Total	0.42 ± 0.18

Opening Signal Box

S.E.S. : 1.3 x 10^{-9}



NO Event Observed: **BR($K_L \to \pi^0 \nu \bar{\nu}$) < 3.0 x 10^{-9} (90% C.L.)**

Summary

- KOTO実験 2015年データ解析結果

$BR(K_L \to \pi^0 \nu \bar{\nu})$ < 3.0 x 10^{-9} (90% C.L.)

先行実験 (KEKPS E391a) が記録した上限値を1桁更新

～これからのKOTO実験～

○ 2016年以降のデータを順次解析中

✓ データ量が2015年の約2倍になる見込み

○ background rejection 強化に向けた検出器増強

✓ カロリメータのアップグレード（Hadron Cluster BG）

✓ 新 veto 検出器の導入（$K_L \to \pi^+ \pi^- \pi^0$）

○ 実験感度向上に向けた解析手法のアップグレード

✓ 波形解析の強化による時間精度向上

arXiv:1810.09655 submitted for publication (2018.Oct.23)

Search for the $K_L \to \pi^0 \nu \overline{\nu}$ and $K_L \to \pi^0 X^0$ decays at the J-PARC KOTO experiment

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(Dated: October 24, 2018)

A search for the rare decay $K_L \to \pi^0 \nu \overline{\nu}$ was performed. With the data collected in 2015, corresponding to 2.2×10^{19} protons on target, a single event sensitivity of $(1.30 \pm 0.01_{\mathrm{stat.}} \pm 0.14_{\mathrm{syst.}}) \times 10^{-9}$ was achieved and no candidate events were observed. We set an upper limit of 3.0×10^{-9} for the branching fraction of $K_L \to \pi^0 \nu \overline{\nu}$ at the 90% confidence level (C.L.), which improved the previous limit by almost an order of magnitude. An upper limit for $K_L \to \pi^0 X^0$ was also set as 2.4×10^{-9} at the 90% C.L., where X^0 is an invisible boson with a mass of 135 MeV/c^2.

PACS numbers: 13.20.Eb, 11.30.Er, 12.15.Hh

Introduction. The $K_L \to \pi^0 \nu \overline{\nu}$ decay is a CP-violating process and is highly suppressed in the Standard Model (SM) due to the $s \to d$ flavor-changing neutral current transition [1, 2]. The branching fraction for this decay can be accurately calculated, and is one of the most sensitive probes to search for new physics beyond the SM (see

where X^0 is an invisible light boson. The upper limit for this decay was set, for the first time in [19], as 3.7×10^{-8} (90% C.L.) for the X^0 mass of 135 MeV/c^2.

Experimental methods and apparatus. A 30-GeV proton beam extracted from the J-PARC Main Ring with