Kaon-Scatter Introduced Backgrounds in the KOTO Experiment

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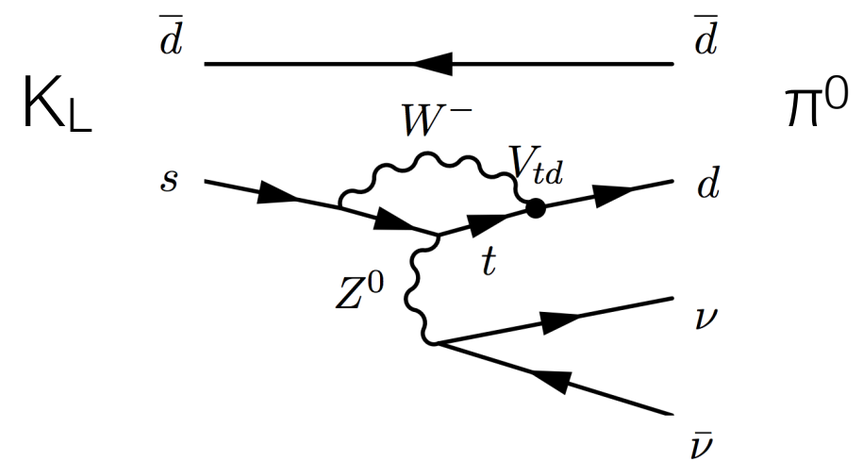
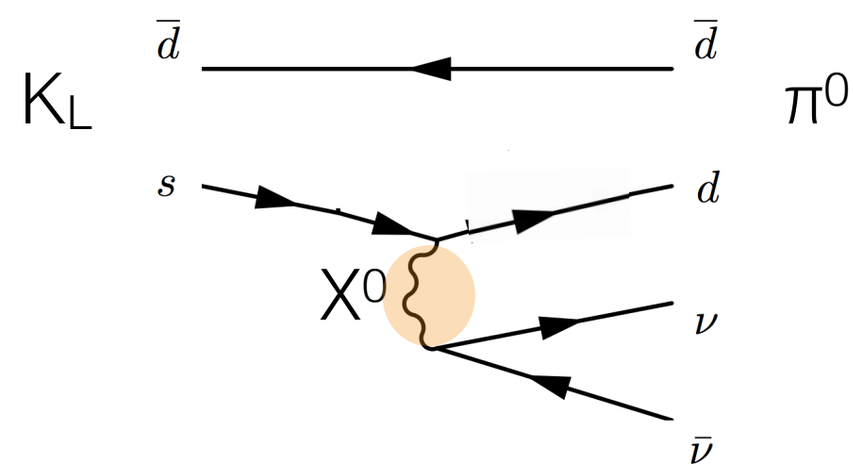
KOTO Experiment

- Study $K_L \to \pi^0 \nu\bar{\nu}$ decay
- Branching ratio (SM): $(3.0 \pm 0.3) \times 10^{-11}$
  - observe one event in ~300 billion events
  - 2013: 24 kW
    2015: 24 kW ~ 42 kW
    2016: 42 kW
    2017: 12 kW ~ 42 kW

SM

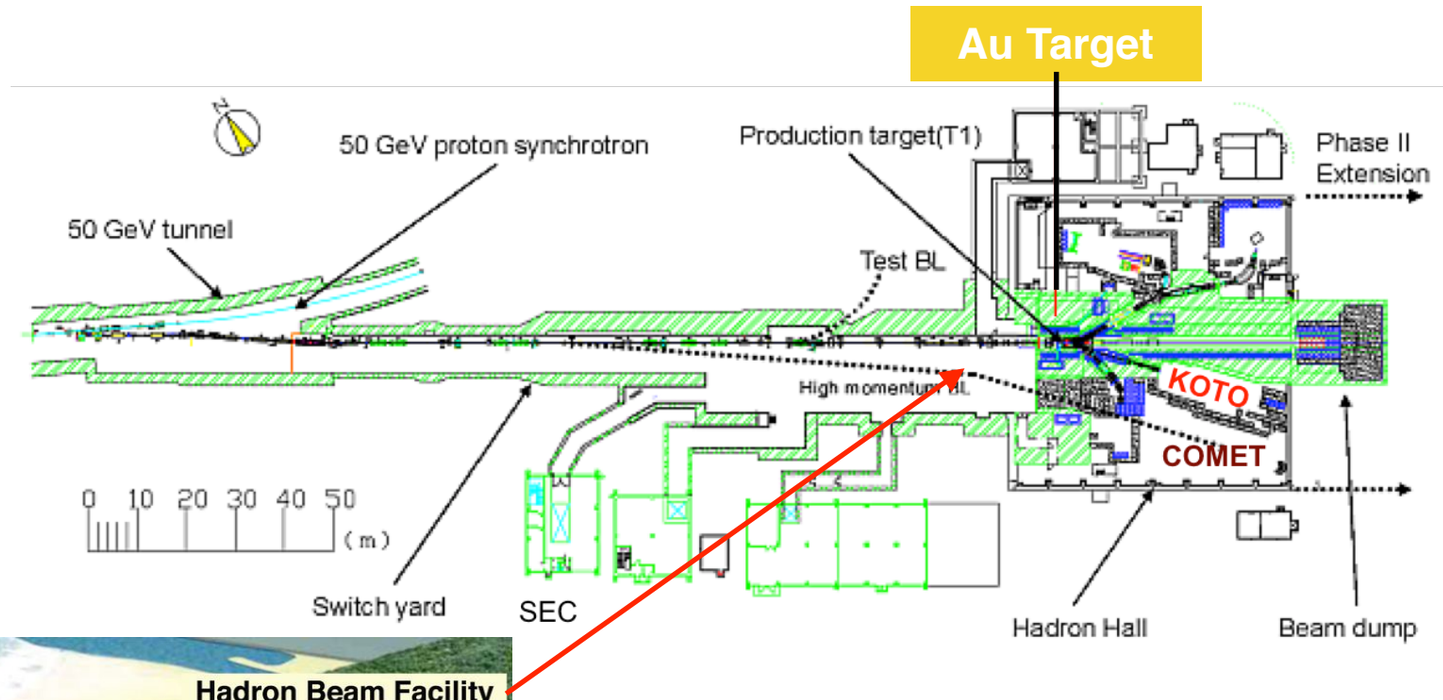


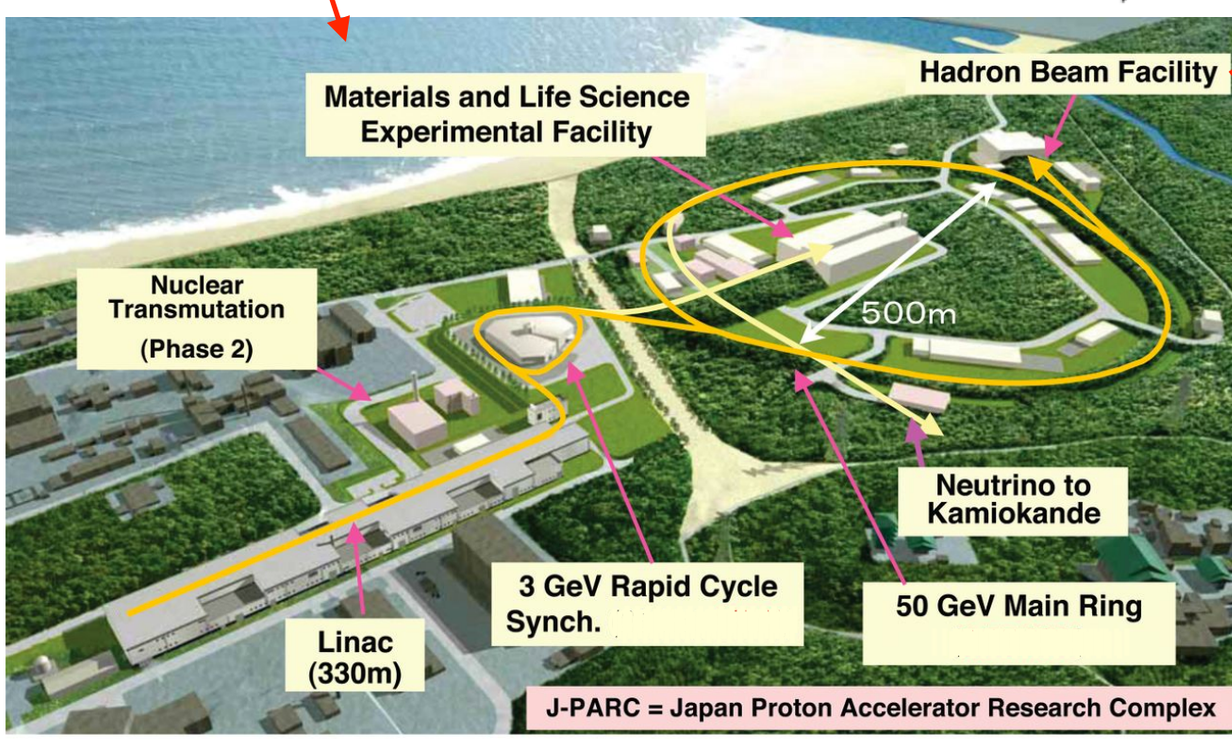
New Physics



KOTO Experiment at J-PARC

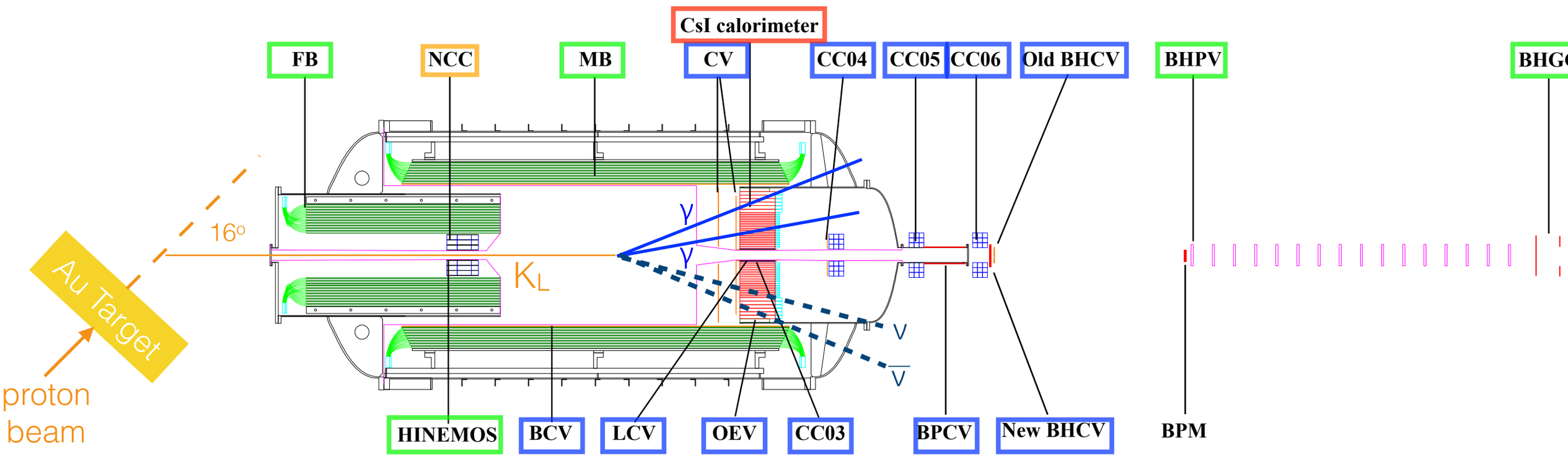
- Located at Tōkai, Ibaraki, Japan





KOTO Detectors

- $K_L \to \pi^0 \nu\bar{\nu}$ signal characteristics:
  - 2 photons on CsI calorimeter
  - large P_T



- CsI Photon Detector
- Photon Veto
- Neutron Counter
- Charged Particle Veto

KOTO Detectors

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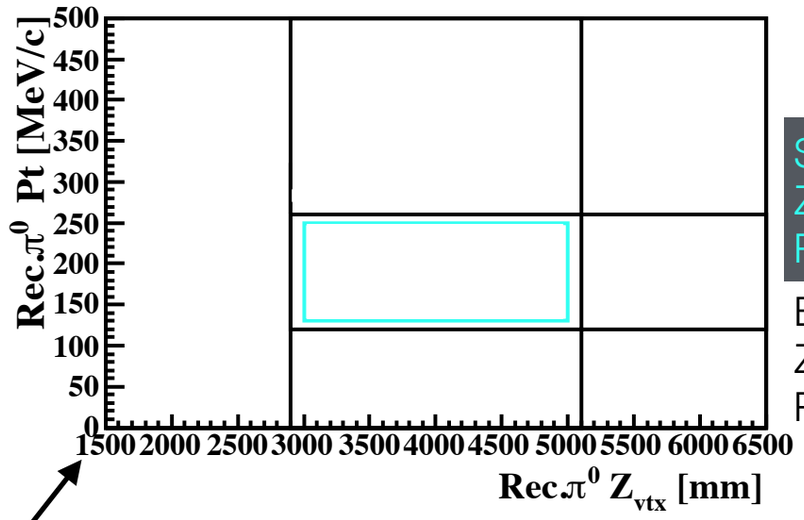
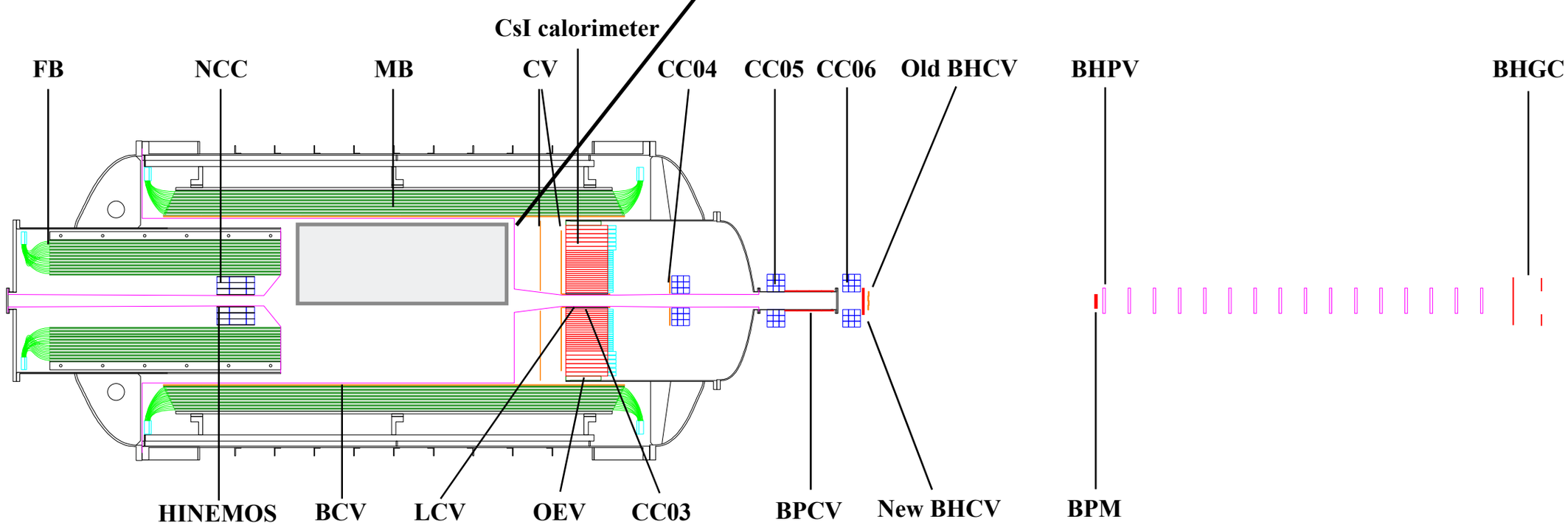
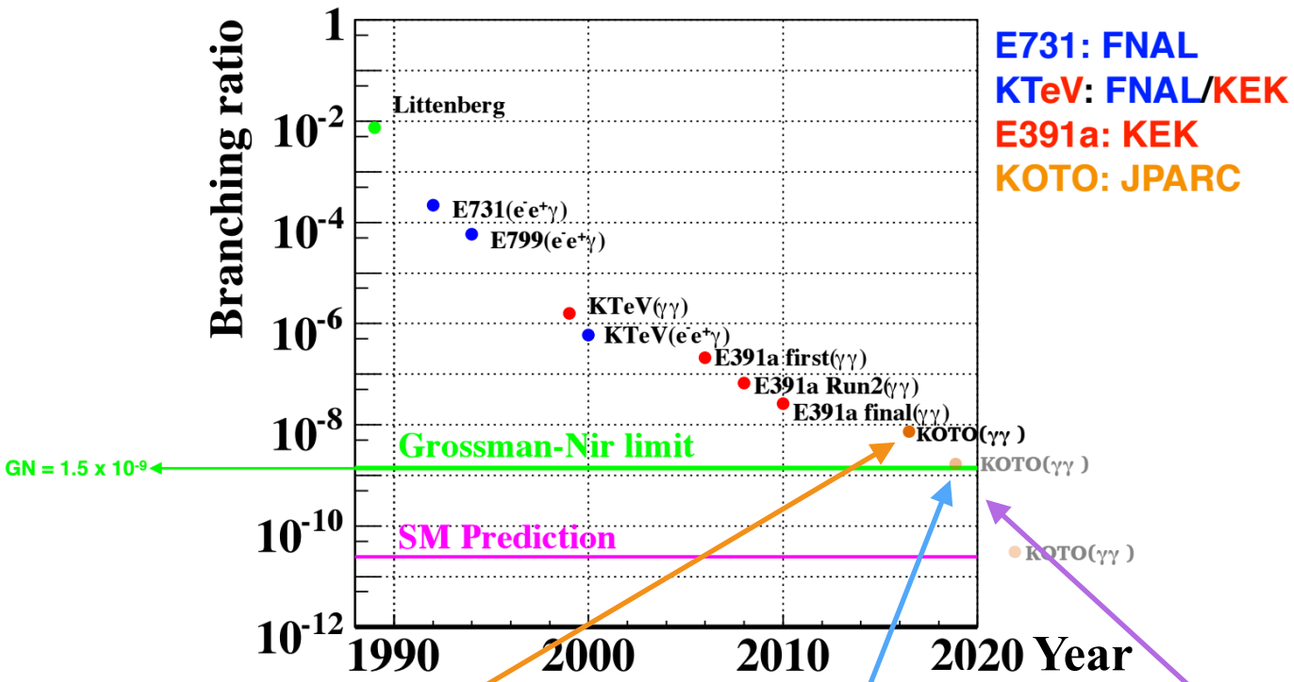


Signal region
Z_{vtx}: 3000~5000 mm
P_T:130~250 MeV/c

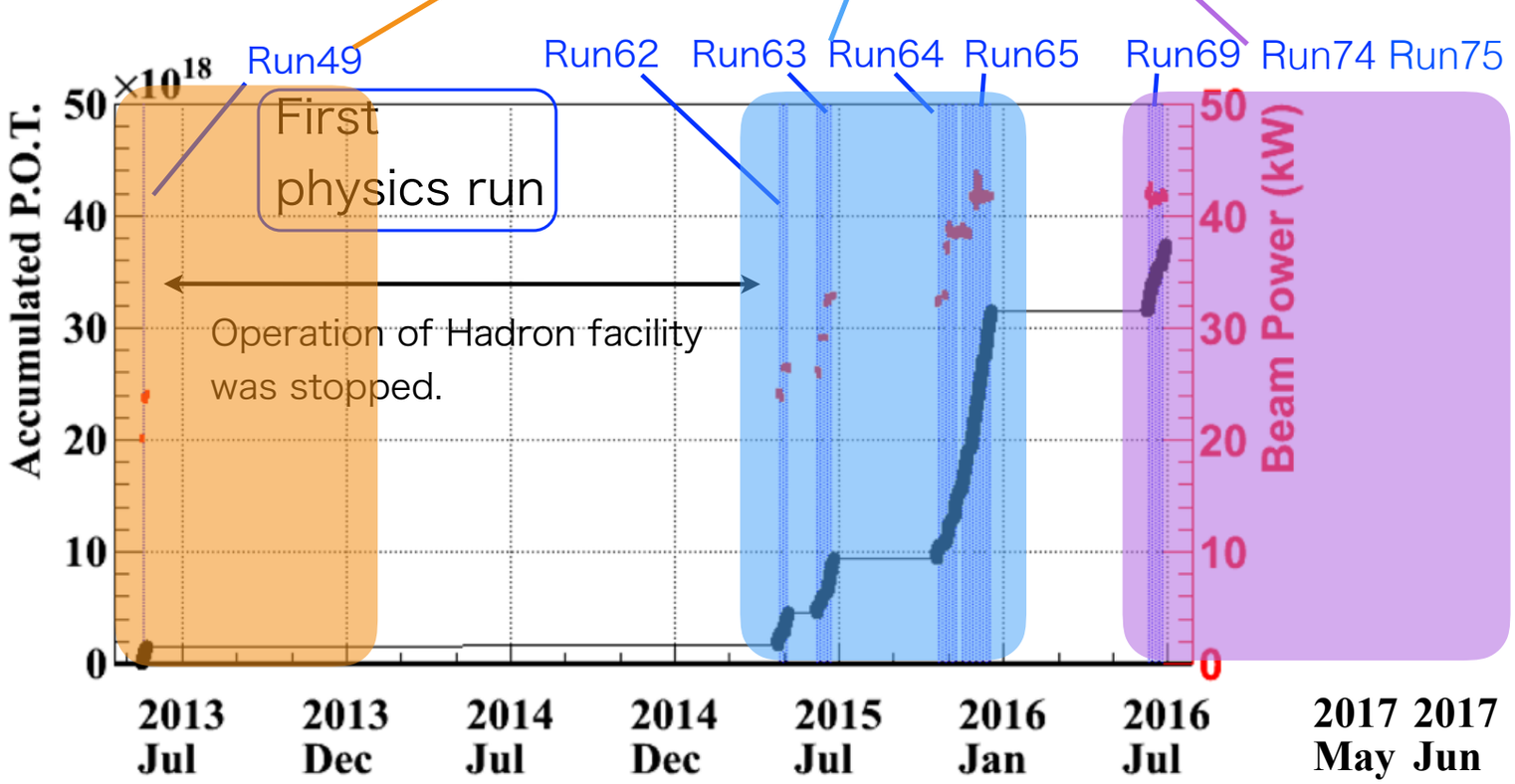
Blinded region
Z_{vtx}: 2900~5100 mm
P_T:120~260 MeV/c



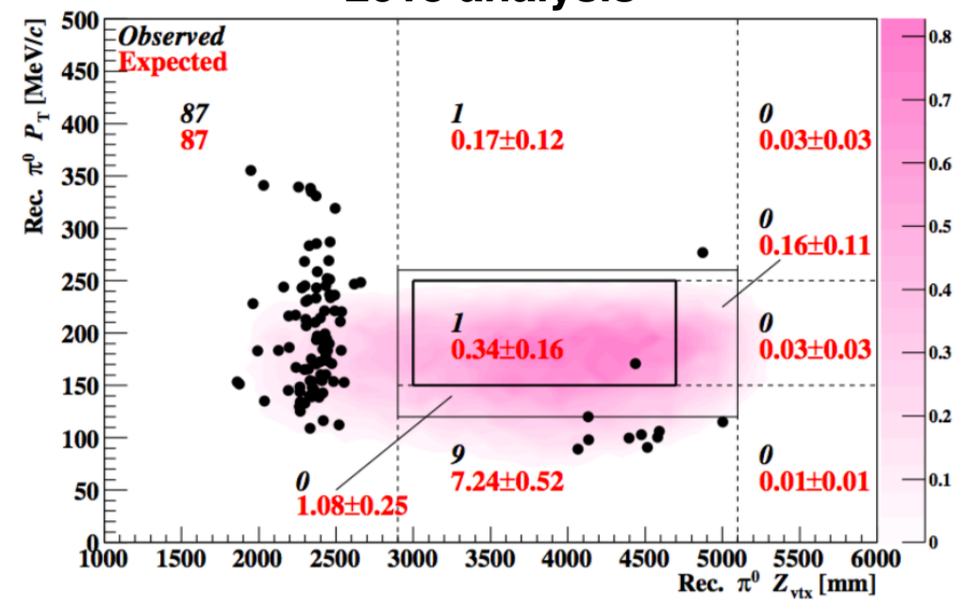
KOTO Analysis



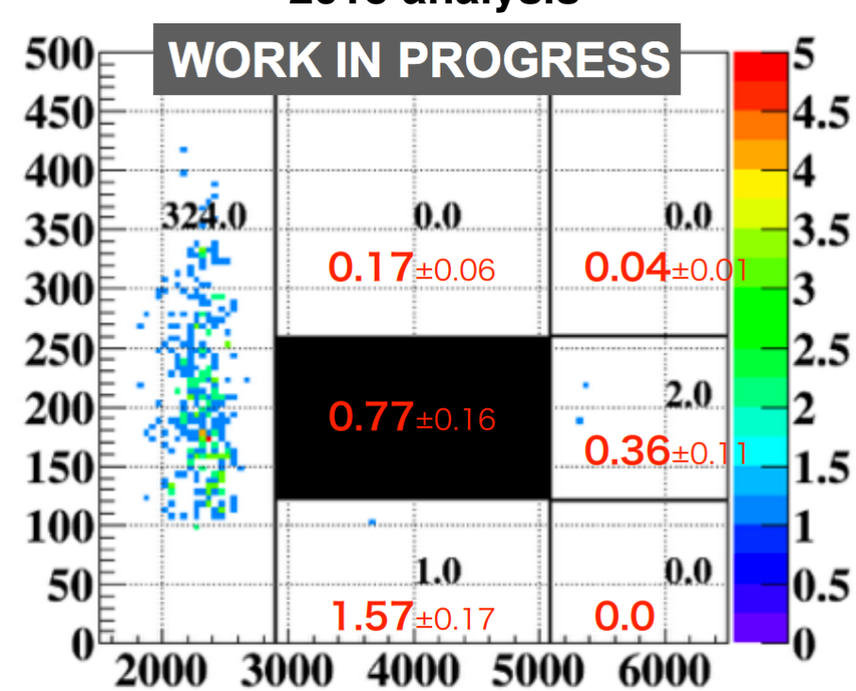
E731: FNAL
KTeV: FNAL/KEK
E391a: KEK
KOTO: JPARC



2013 analysis

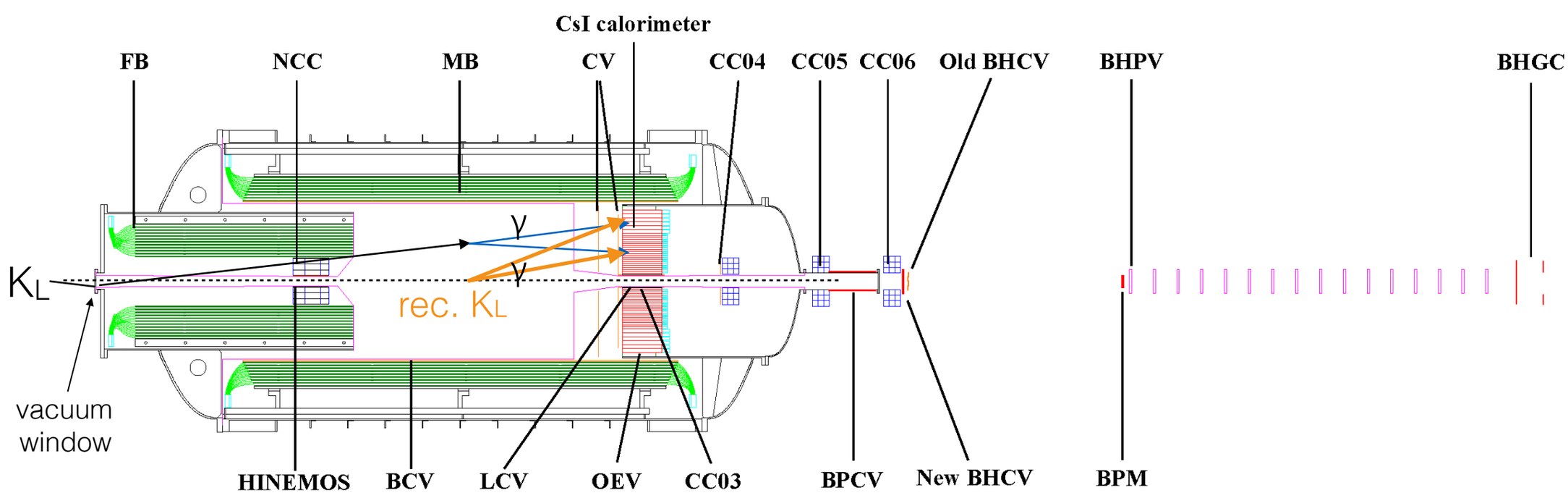


2015 analysis



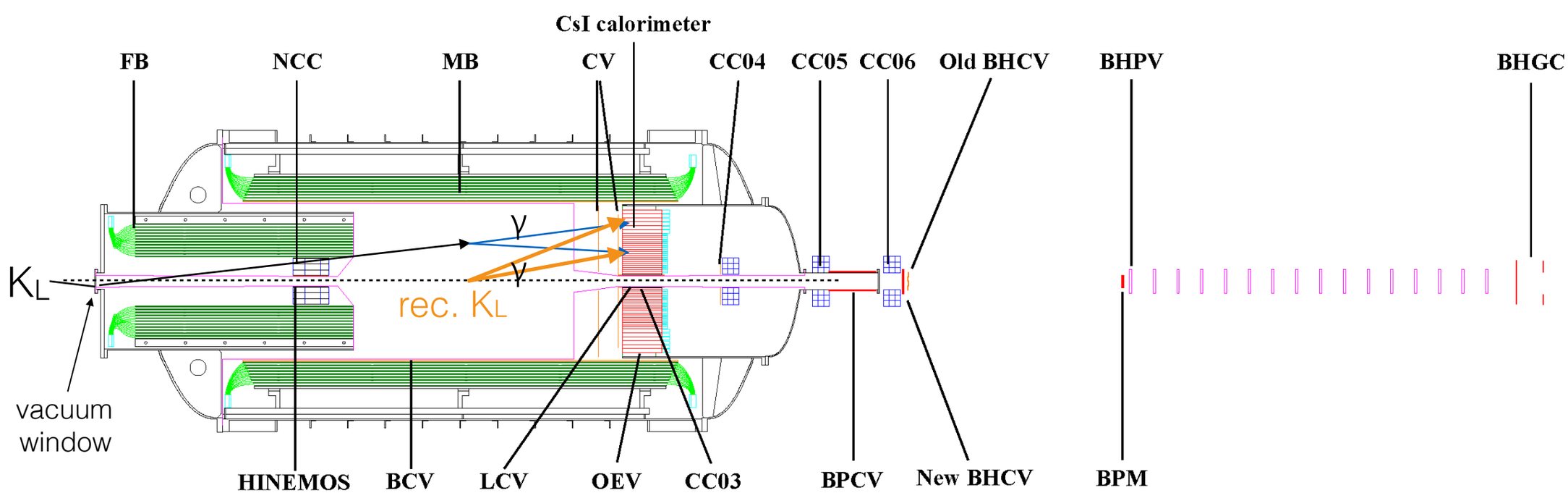
K_L Scattering

- Current reconstruction method reconstruct K_L onto the beam line
  - K_L scattered upstream of the detector (vacuum window) allows 2-photon decays appear to have large P_T
  - $K_L \to \pi^0 \nu\bar{\nu}$ background candidates with final production of 2-photon decays:
    - $K_L \to \gamma\gamma$
    - $K_L \to \pi^+\pi^-\pi^0$



K_L->γγ Background

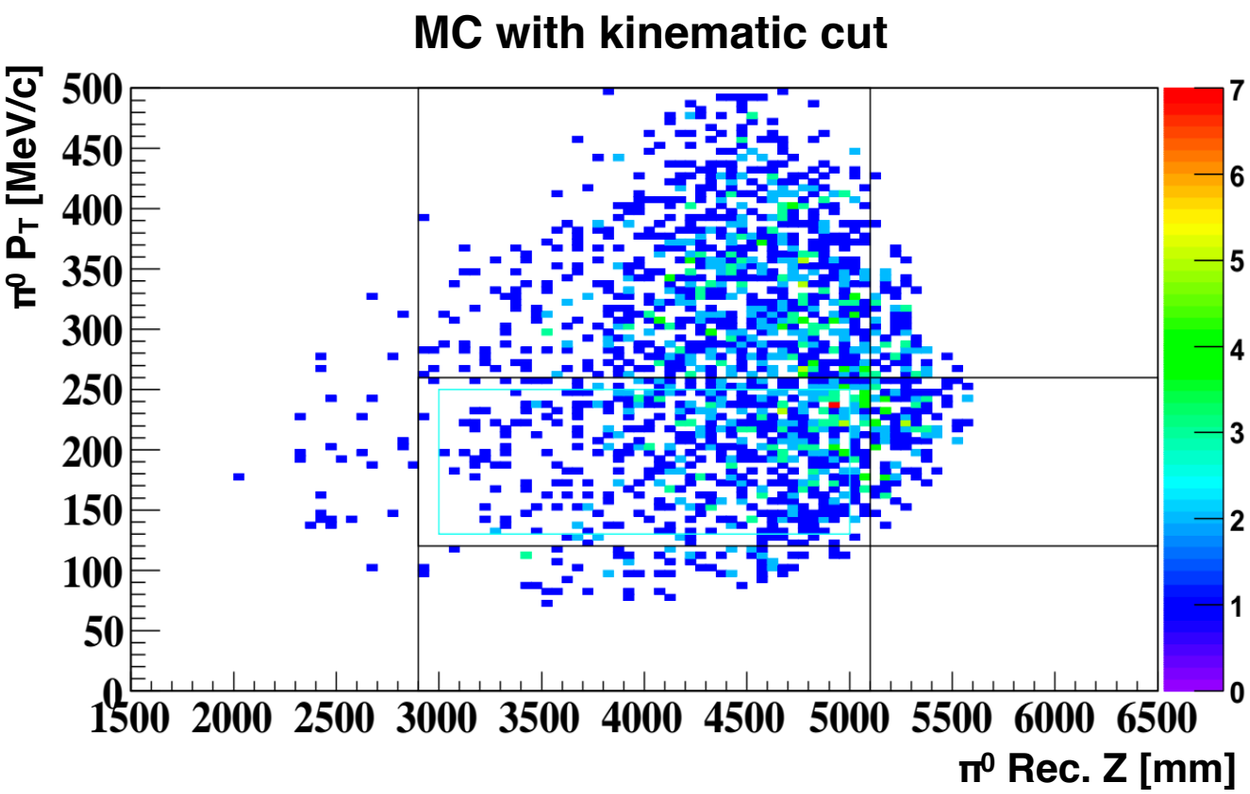
- Scattered K_L introduced K_L->γγ event

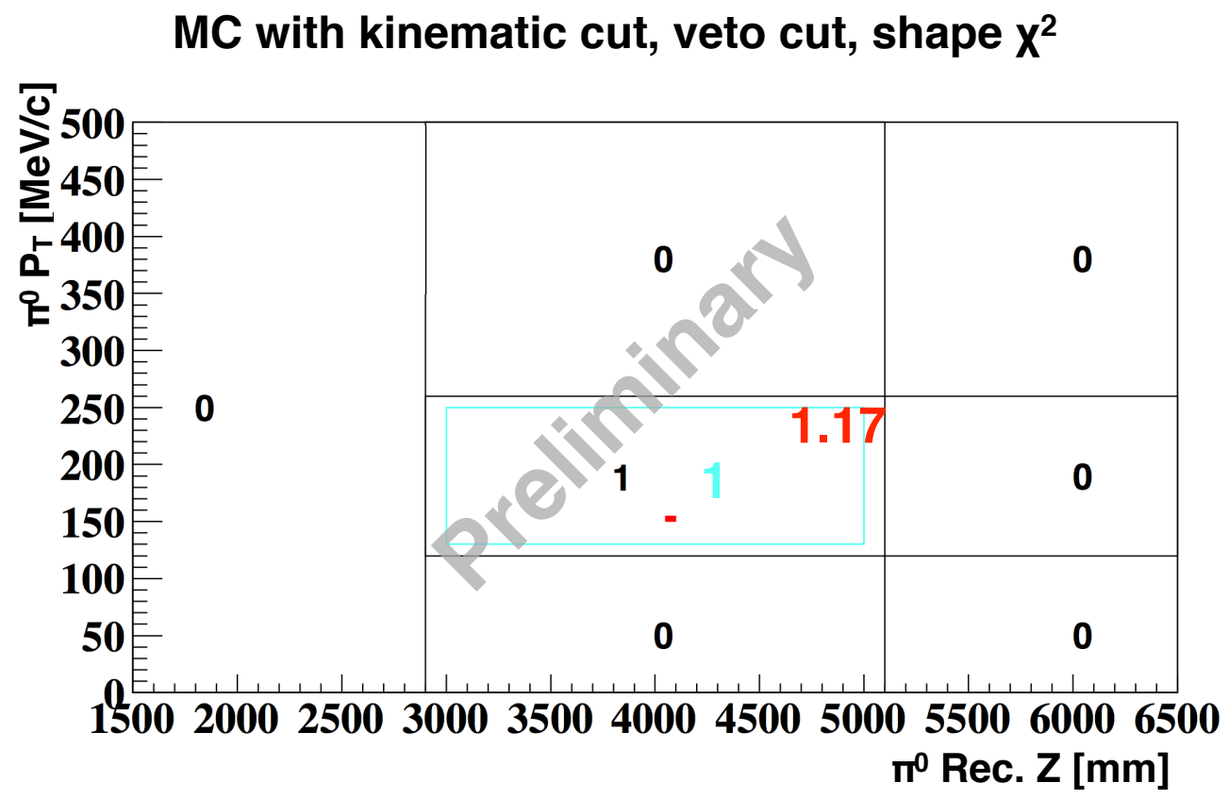


K_L->γγ Background

- $POT_{MC} = \dfrac{K_{L\ simulated}}{BR(K_L\text{->}\gamma\gamma) \times K_L\ flux}$
- $POT\ scale\ factor = \dfrac{POT_{Data}}{POT_{MC}}$
- $BG_{Data} = BG_{MC} \times POT\ scale\ factor$

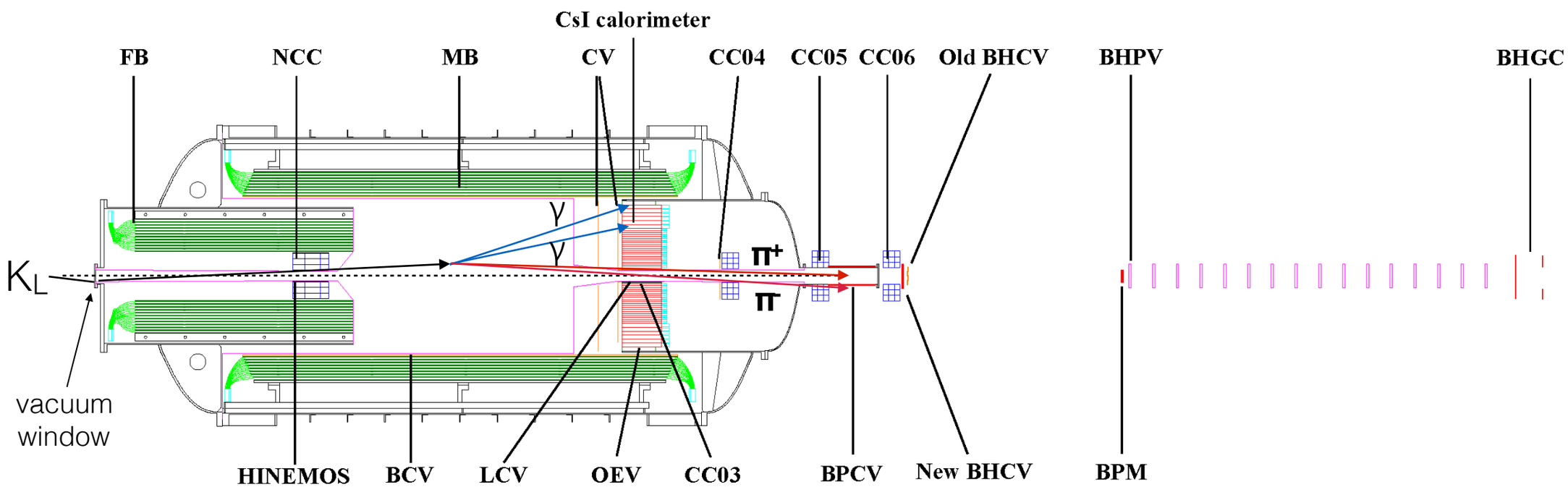
Mode	BR
$K_L \to 3\pi^0$	$(1.952 \pm 0.012) \times 10^{-1}$
$K_L \to \pi^+\pi^-\pi^0$	$(1.254 \pm 0.005) \times 10^{-1}$
$K_L \to 2\pi^0$	$(8.64 \pm 0.06) \times 10^{-4}$
$K_L \to 2\gamma$	$(5.47 \pm 0.04) \times 10^{-4}$





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

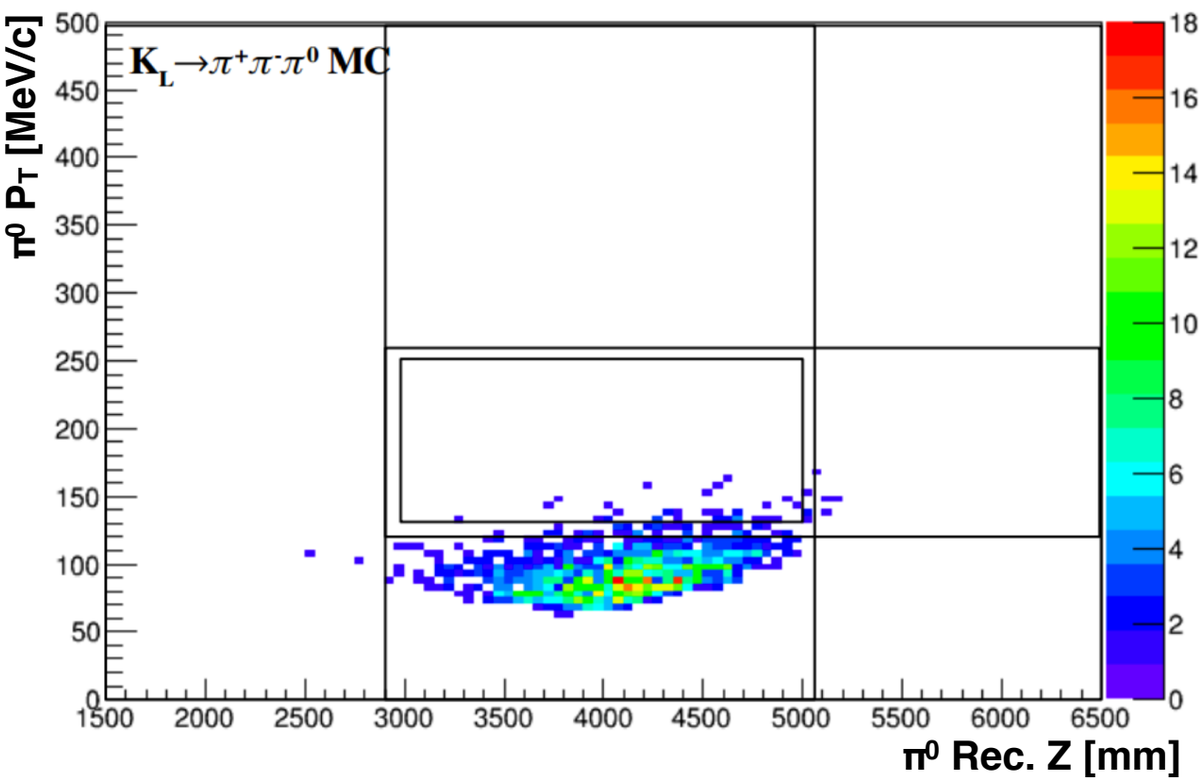
- Scattered K_L introduced $K_L \to \pi^+\pi^-\pi^0$ event with π^+ and π^- going down the beam line



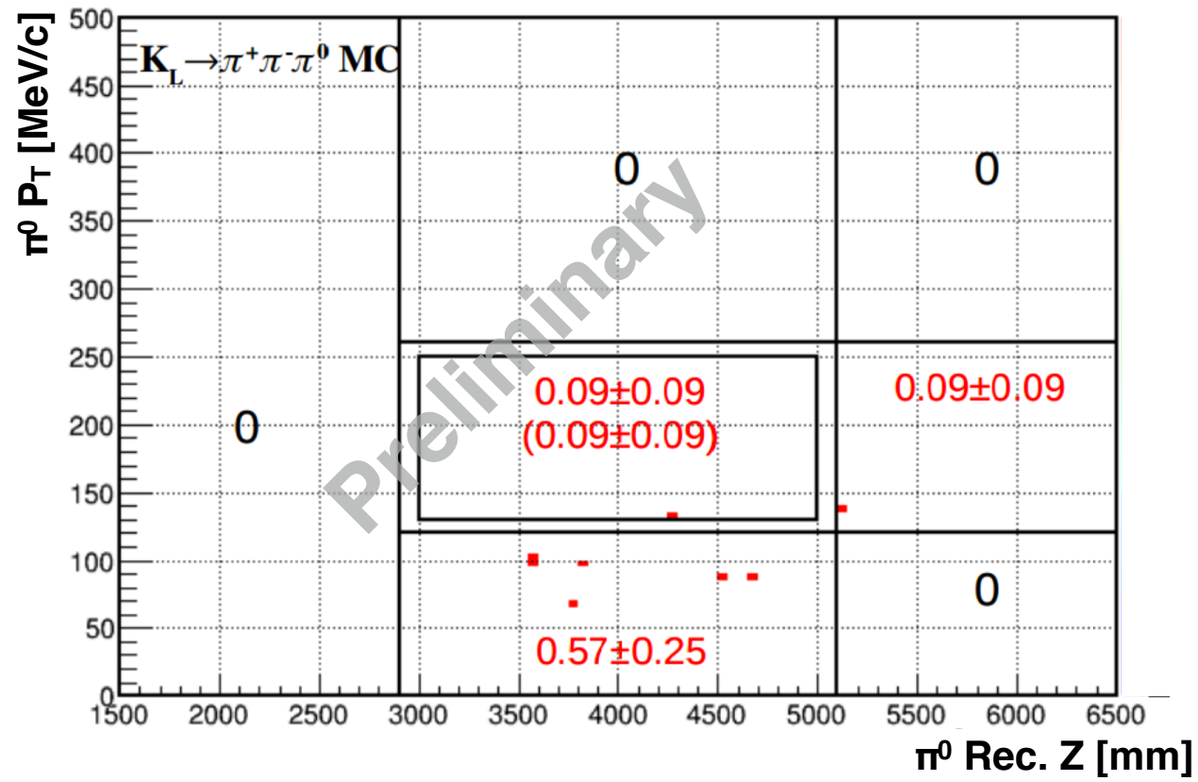
$K_L \to \pi^+\pi^-\pi^0$ Background

- $POT_{MC} = \dfrac{K_{L\ simulated}}{BR(K_L \to \pi^+\pi^-\pi^0) \times K_L\ flux}$
- $POT\ scale\ factor = \dfrac{POT_{Data}}{POT_{MC}}$
- $BG_{Data} = BG_{MC} \times POT\ scale\ factor$

MC with kinematic cut



MC with kinematic cut, veto cut, χ^2, and more

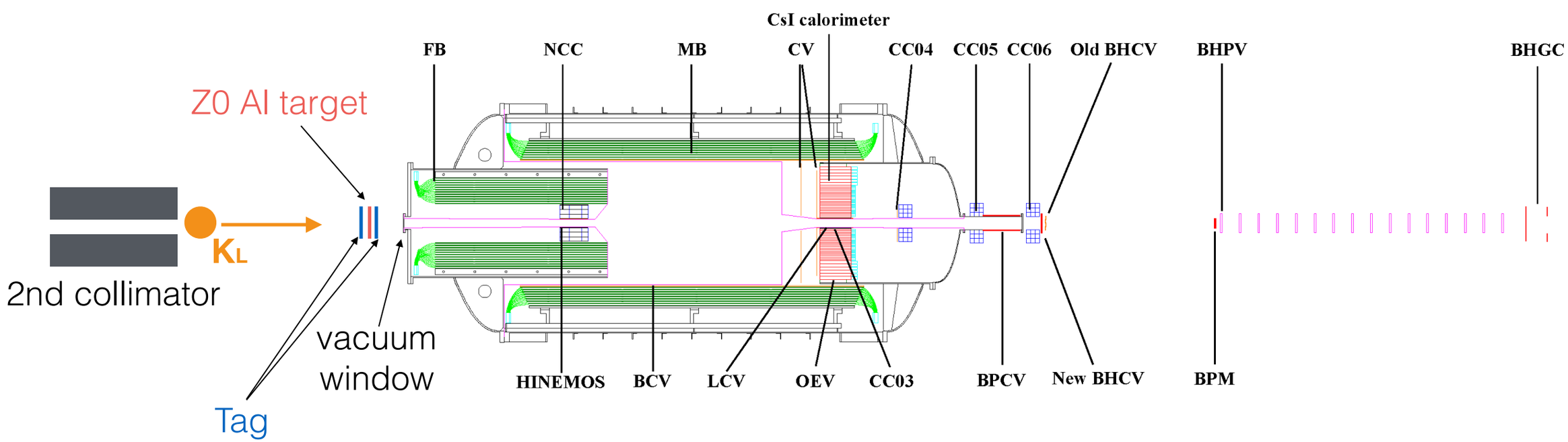


K_L Scattering - MC

- Tag K_L across the Z0 Al target and scale to vacuum window
  - Al target
    - thickness: 5 mm, ρ = 2.699 g/cm^3
  - vacuum window (Kapton)
    - thickness: 0.125 mm, ρ = 1.42 g/cm^3

$$\text{scattered } K_{L\,vac} = \text{scattered } K_{L\,Al} \times \frac{\rho_{vac} \times \text{thickness}_{vac}}{\rho_{Al} \times \text{thickness}_{Al}}$$

$$= 76.03 \times \text{scattered } K_{L\,Al}$$



K_L Scattering - MC

- Tag K_L across the Z0 Al target and scale to vacuum window
  - Al target
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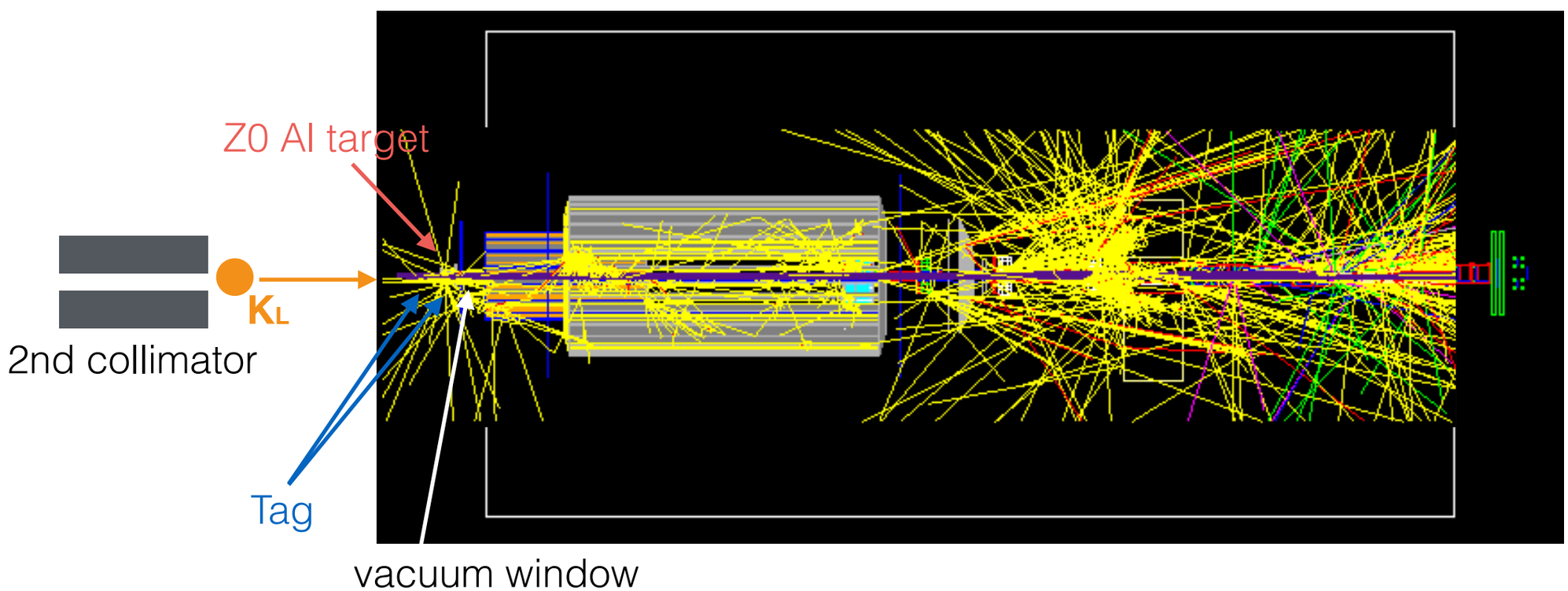
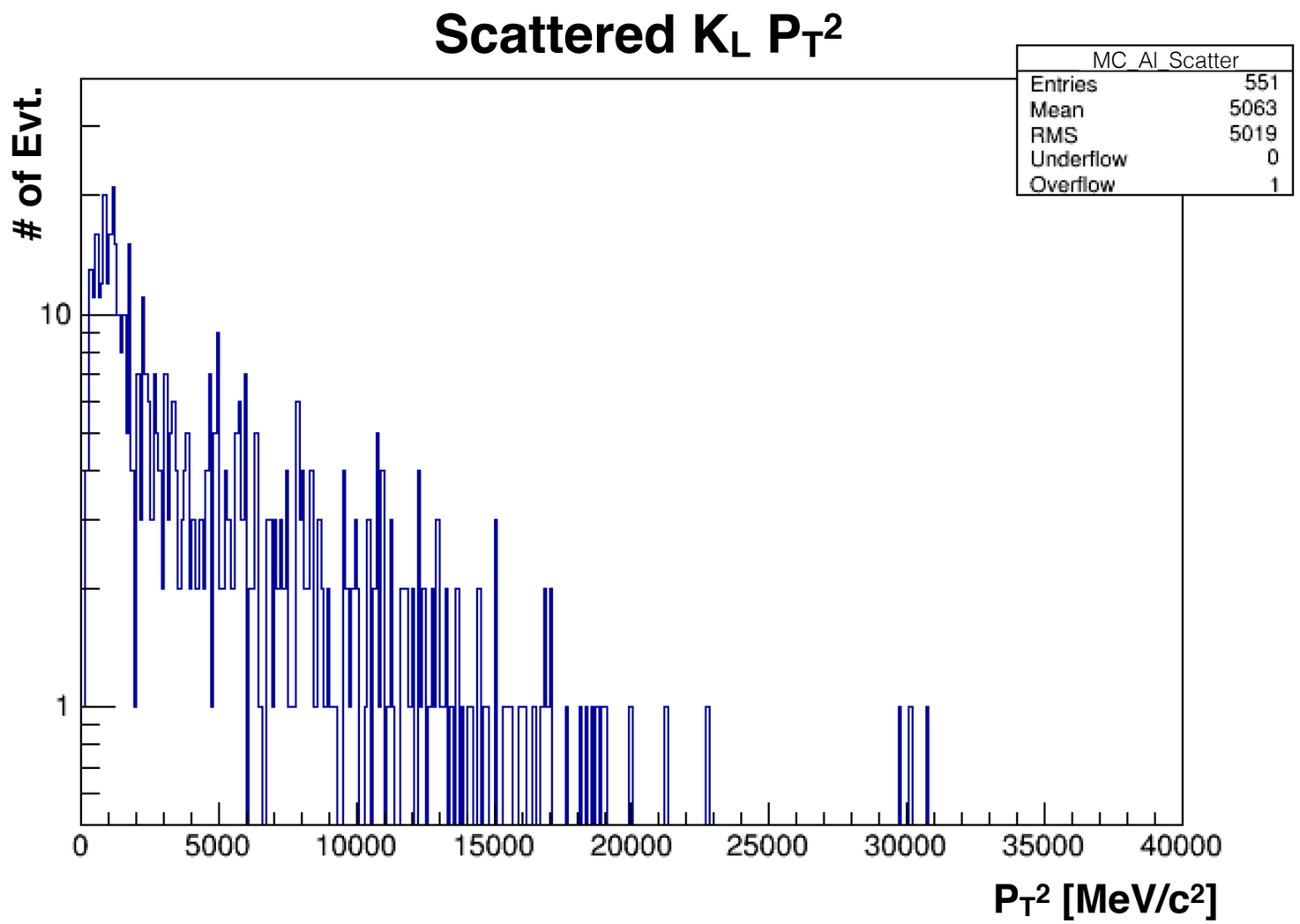


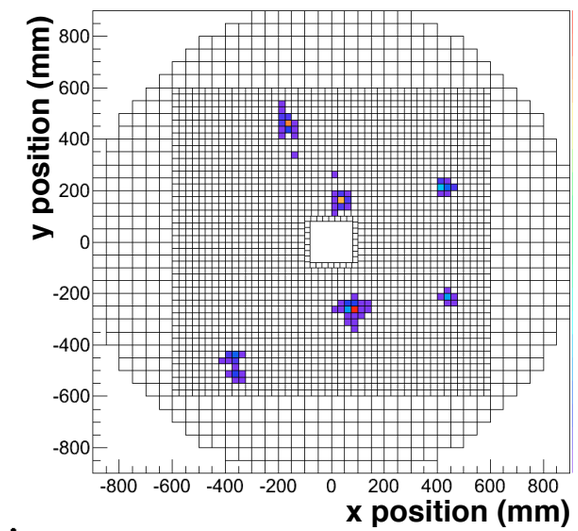
K_L Scattering - MC

- No cut
  - Scatter rate at Al target: 1.17%
  - Scatter rate after scaling to vacuum window: 0.022%
    - next: kinematic constraint

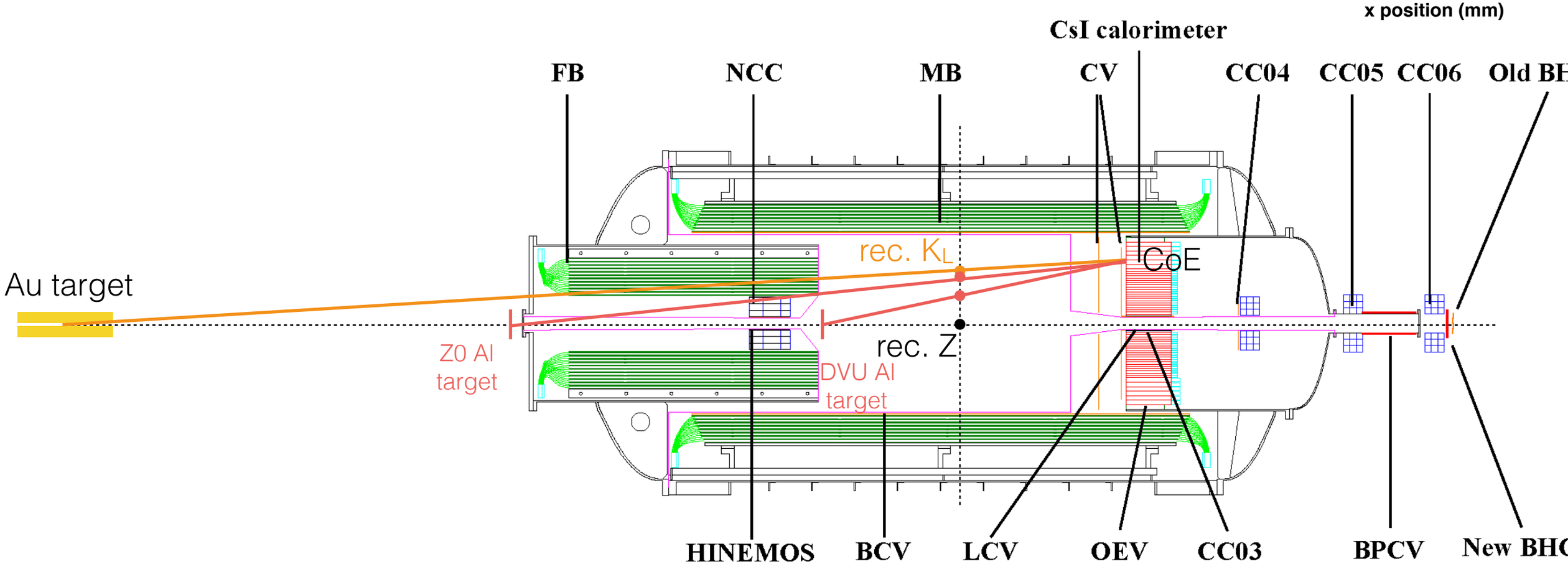


K_L Scattering - Data

- Use removable Al targets to obtain scattered K_L beam profile with $K_L \to \pi^0\pi^0\pi^0$ mode
  - Ideal P_T for $K_L \to \pi^0\pi^0\pi^0$ is expected to be 0 MeV/c

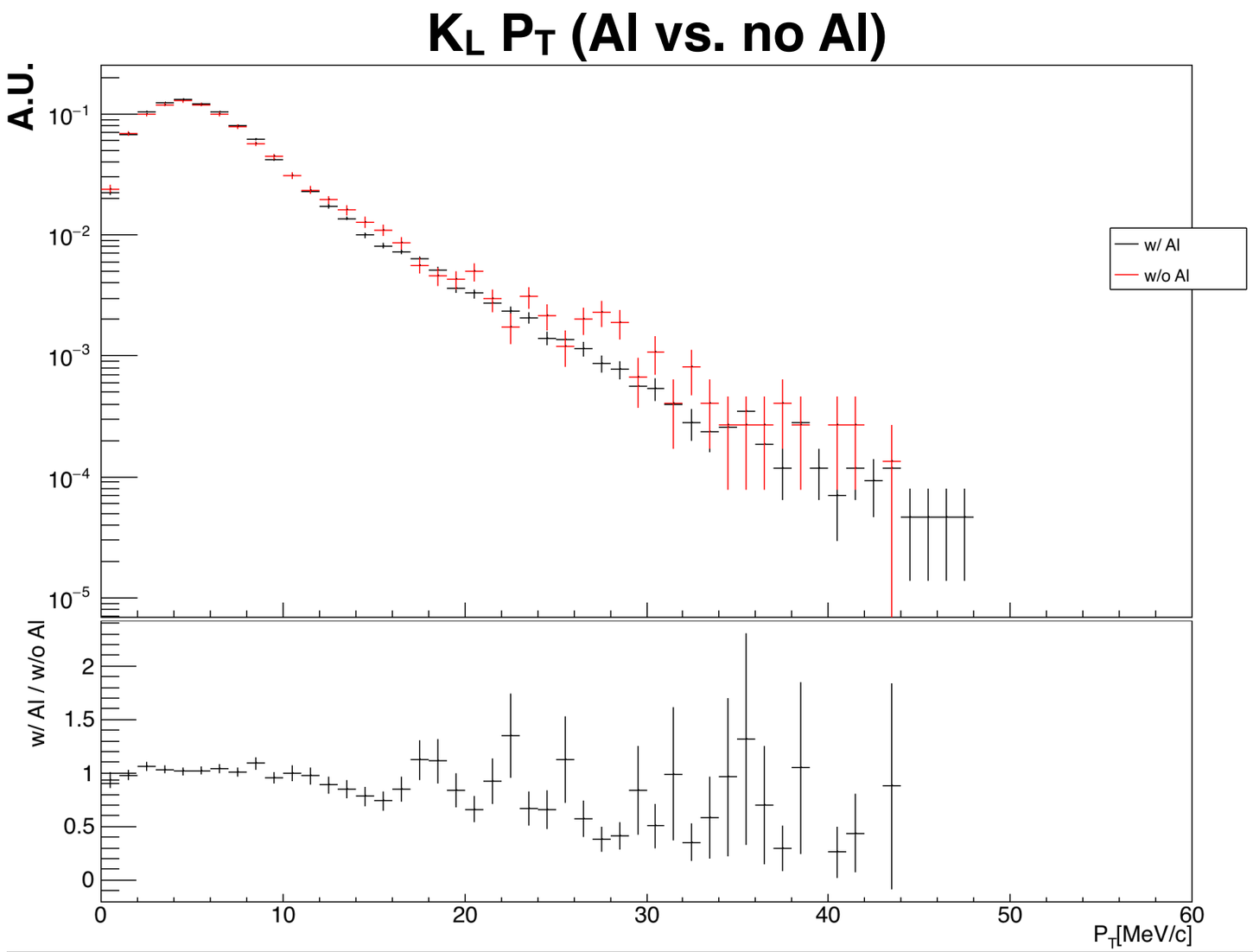


$$\text{CoE radius} = \frac{\sqrt{\left(\sum_i E_i x_i\right)^2 + \left(\sum_i E_i y_i\right)^2}}{\sum_i E_i}$$

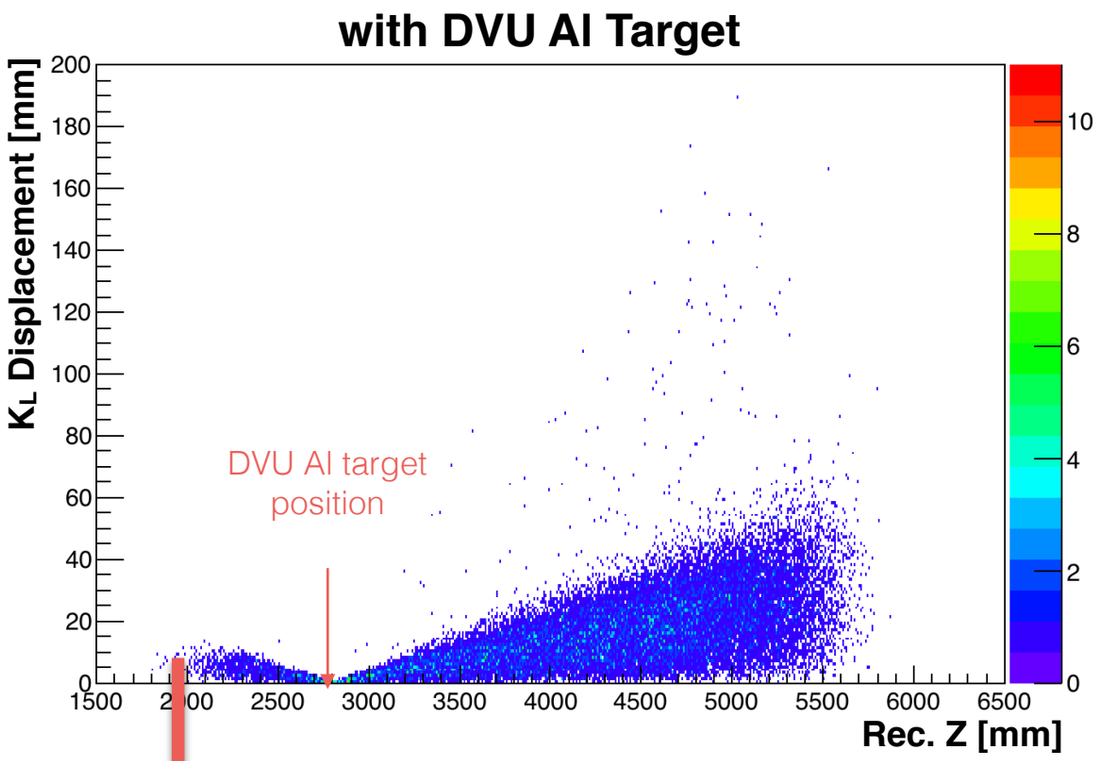


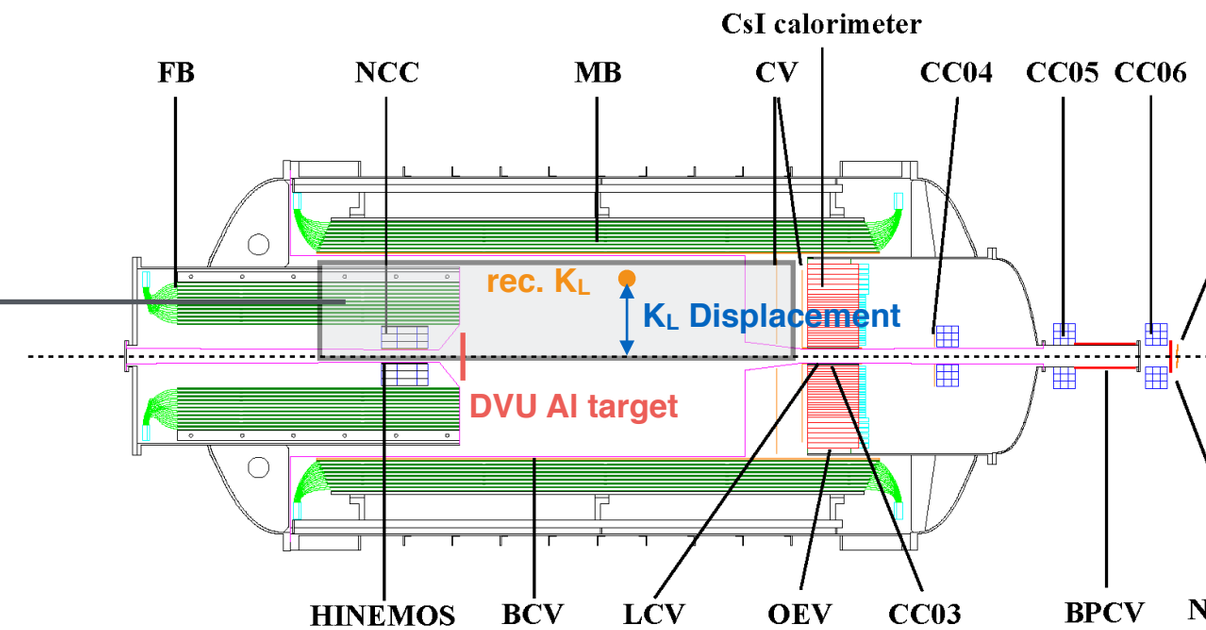
K_L Scattering - Data

- Apply kinematic cut on data
- The data agrees with the MC that small number of KL scatter
  - DVU Al target
  - without DVU Al target



K_L Scattering - Data

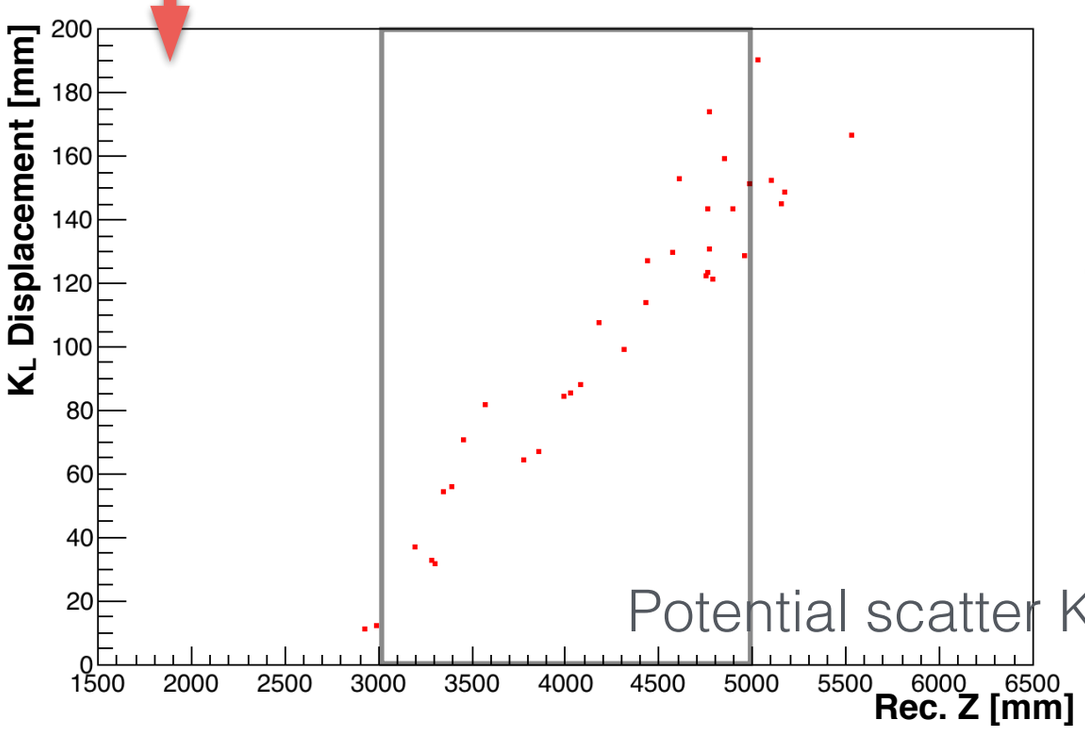




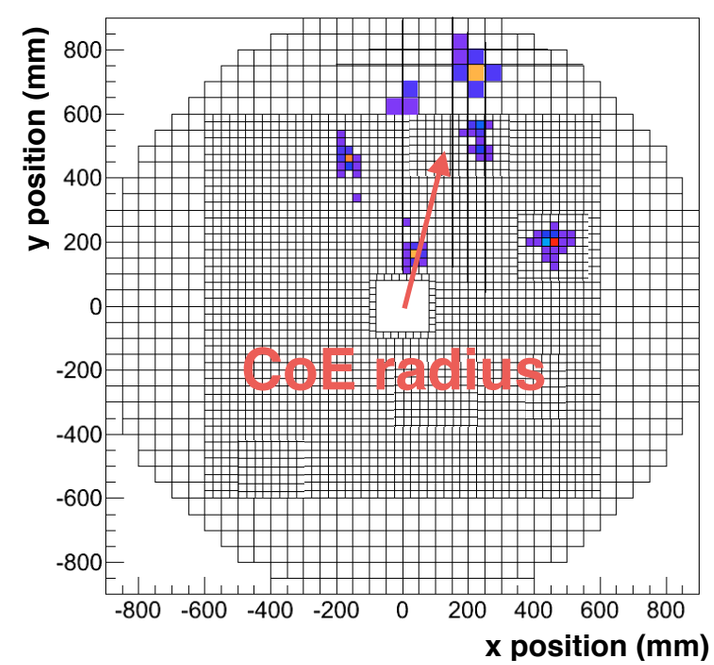
After CoE cut: CoE > 200 mm

$$\text{CoE radius} = \frac{\sqrt{(\sum_i E_i x_i)^2 + (\sum_i E_i y_i)^2}}{\sum_i E_i}$$

Large CoE —> Large P_T



Potential scatter K_L background



Summary

- Scattered K_L could allow 2-photon decays to have large apparent P_T and contribute to background of $K_L \to \pi^0 \nu\bar{\nu}$ signal
  - $K_L \to \gamma\gamma$
  - $K_L \to \pi^+\pi^-\pi^0$

- MC shows 1.17% of K_L scatter at Al target

- Preliminary study on Al target data verifies scattered K_L can produce large P_T

- Further study is ongoing