Search for rare $K_L^0 \to \pi^0 \nu \bar{\nu}$ decay

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Outline

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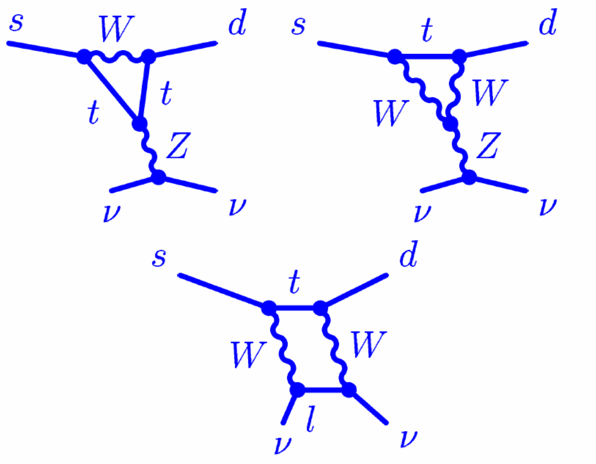
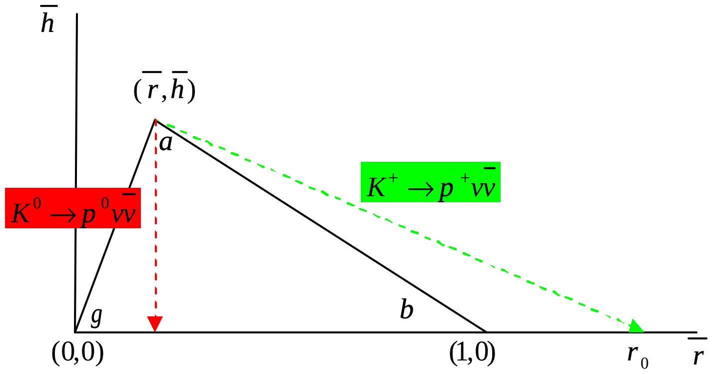
  - Principles
  - Background estimations
  - Recent result
- Future experiments
  - E14 (J-PARC)
  - KLOD (Protvino)
- Conclusion

Introduction

- $K_L^0 \to p^0 \nu\bar{\nu}$ decay
  - Direct CP violation: ΔS=1
  - Small theoretical uncertainties ~1.5%
  - Direct measurement of the height of Unitarity triangle: BR ~ η^2
  - Rare decay: BR~2.8x10^{-11}

- Strict test of SM, sensitive to new physics
  - Unitarity triangle
  - Check consistency with B physics

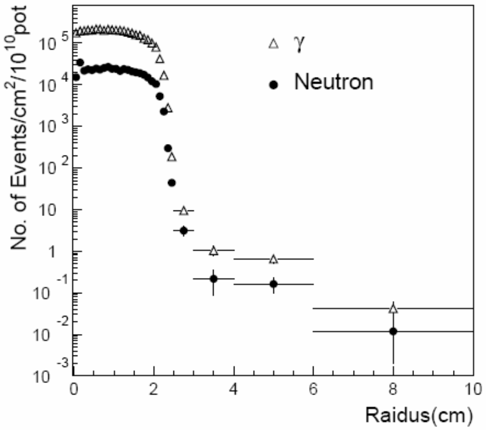




E391 experiment (KEK,Japan)

- Search for signature $\pi^0(\to\gamma\gamma)$ +nothing
- Measure energies and positions of γ`s
- Reconstruct decay vertex on beam axis on assumption of π^0 decay
  - Select events with high P_T

- Hermetic 4-π veto system
- Double decay chamber
- High vacuum
- Pencil beam

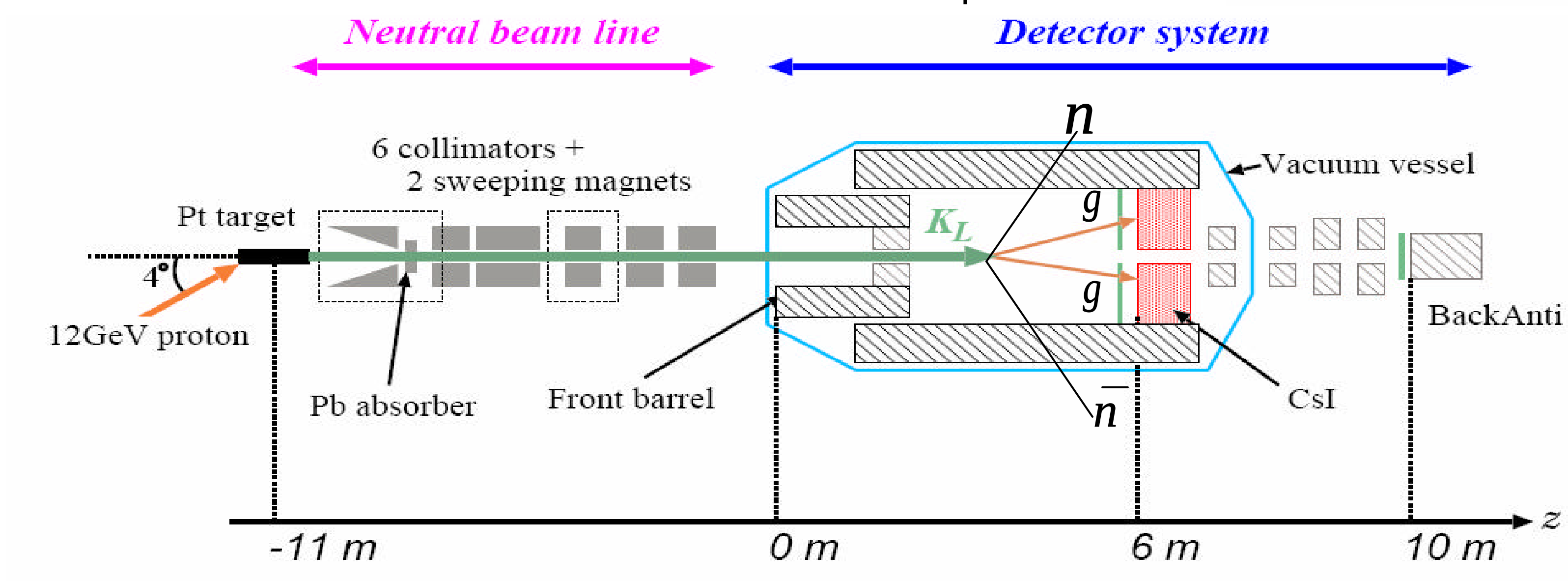


Data taking

RUN I: 2004: 3.4×10^{18} pot

RUN II: 2005: 1.9×10^{18} pot

RUN III: 2005: 1.5×10^{18} pot

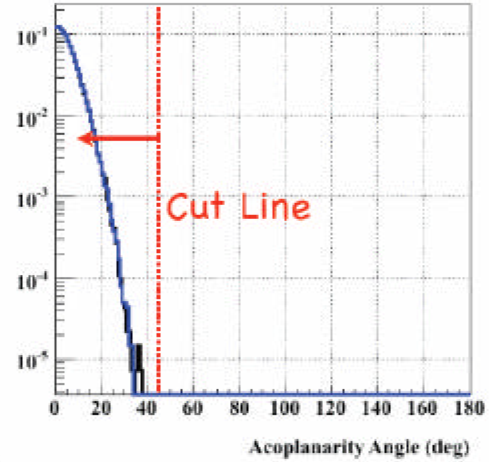


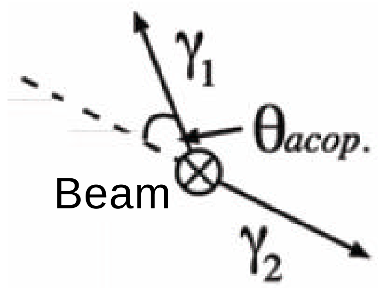
E391 data analysis

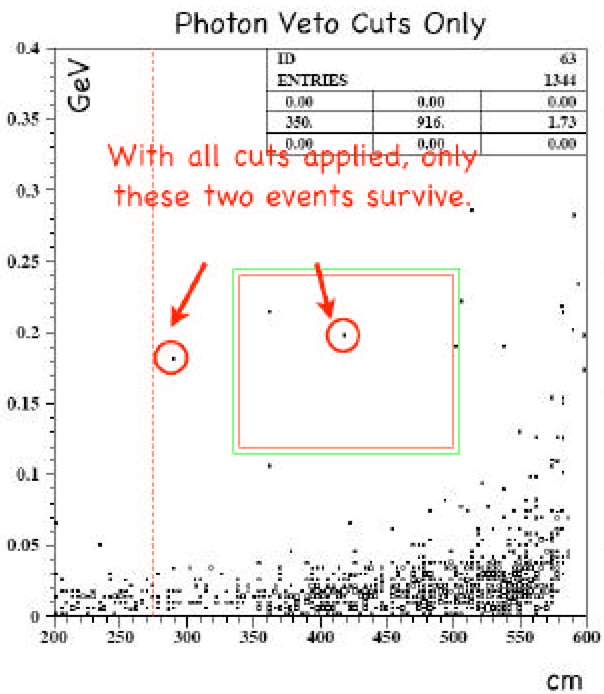
- Finished full RUN II analysis
  - RUN III analysis is going on
- Blind analyses method
  - Hide signal and control regions up to estimation of backgrounds
- Backgrounds sources
  - K->$\pi^0\pi^0$, K->$\gamma\gamma$,
  - π^0 production on CC02 by halo neutrons
  - π^0 and η production on CV by halo neutrons
  - Charge decays: Ke3,Kmu3
  -

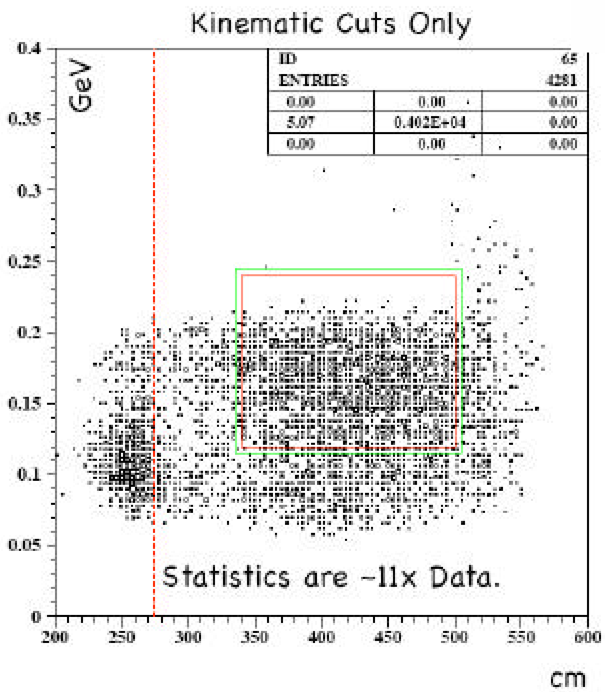
E391: background

- K->$\pi^0\pi^0$
  - Estimated from MC
    - Confirm by K–>$\pi^0\pi^0\pi^0$ study as bgr for K–>$\pi^0\pi^0$
  - Simulate x11 statistics of data
- K->$\gamma\gamma$ – negligible small
  - No additional particle
  - Balance P_T and acoplanarity angle

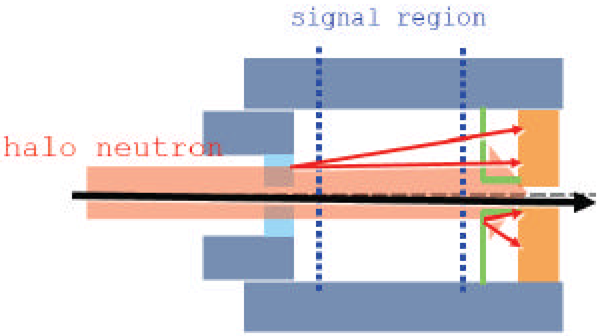




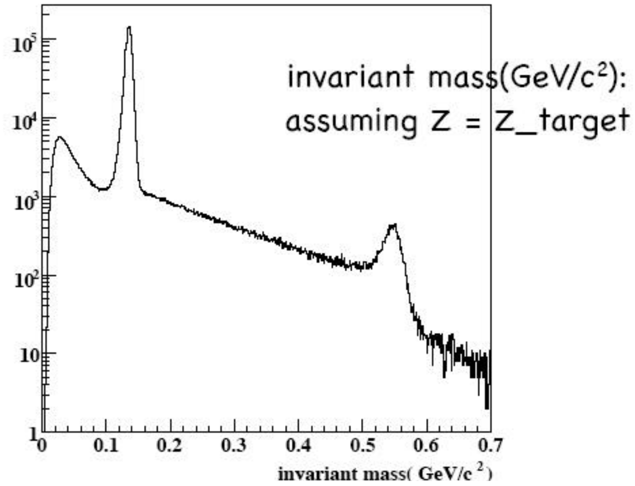


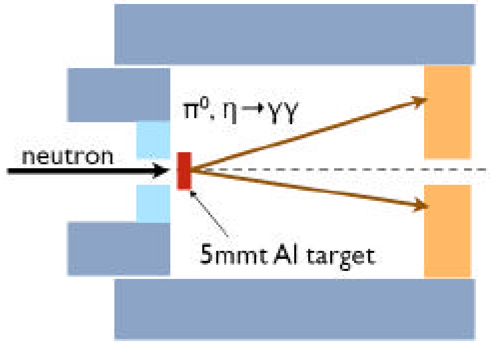


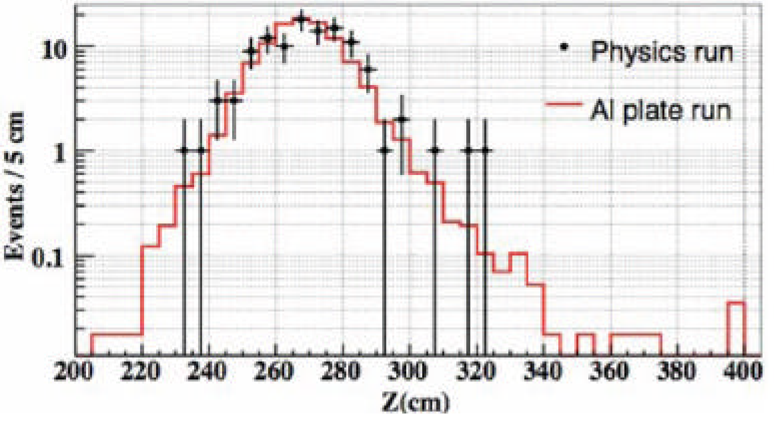
E391 background



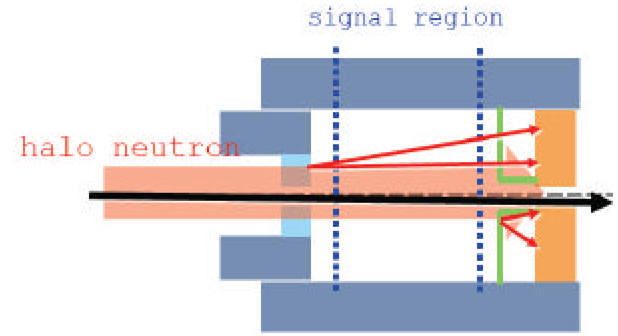
- π^0 production on CC02 by halo neutrons
  - Tail to signal region due to errors in energy and position reconstruction of γ's
  - Estimated from special run data normalized to CC02 events
    - Z position of left edge of signal region was optimized by S/N



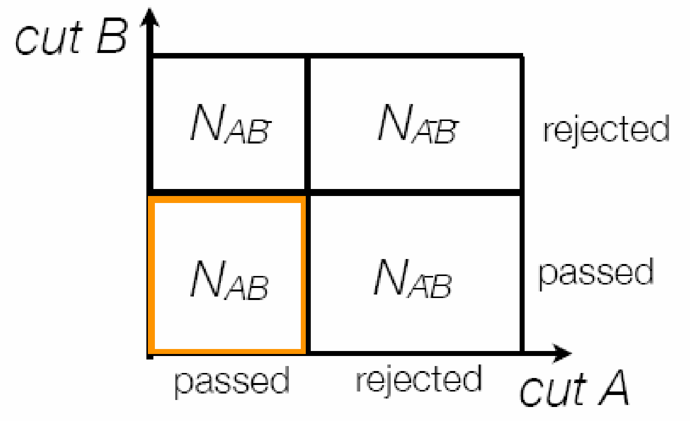




E391 background



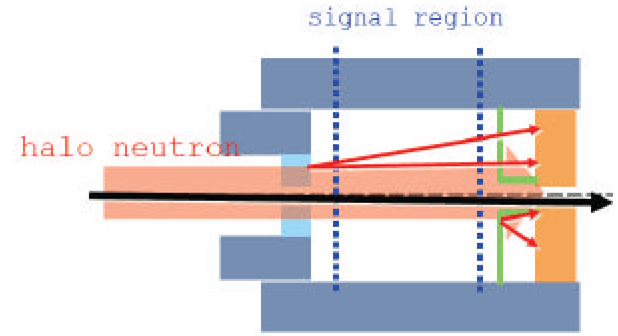
- π^0 production on CV by halo neutrons
  - Estimated from data using bifurcation method
    - Single background source
      - Confirm by MC
        - » Apply basic set of cuts: upstream+CsI veto
    - Independent sets of cuts
      - A=downstream detector veto
      - B=gamma selection

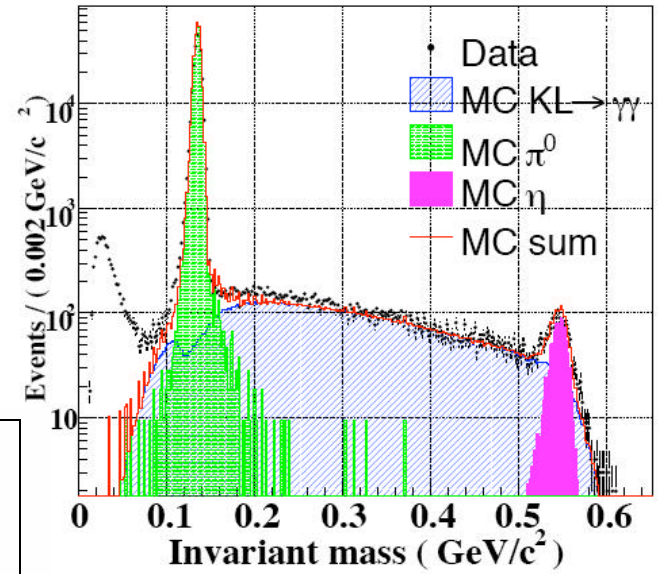


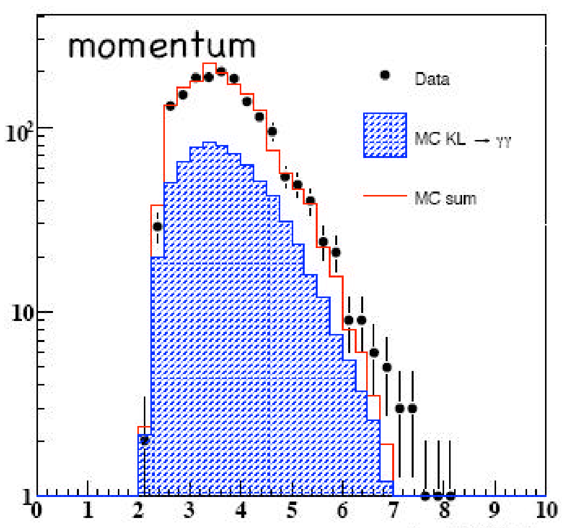
$$N_{AB} = (N_{\bar{A}B} \times N_{A\bar{B}}) / N_{\bar{A}\bar{B}}$$

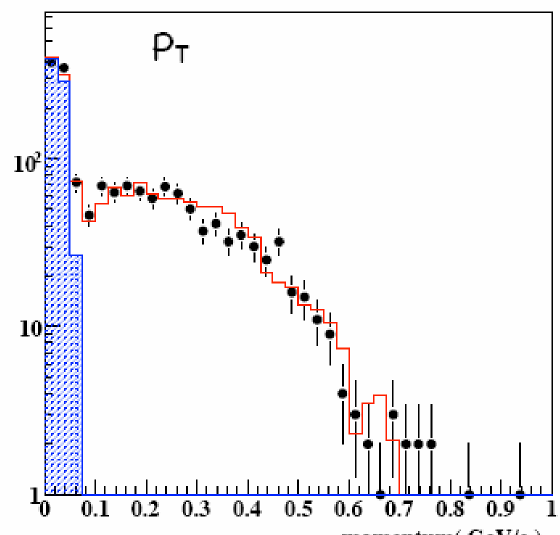
E391 background

- η production on CV by halo neutrons
  - Estimated from MC with x200 statistics
    - MC well reproduce spectrum of η production on Al target run data





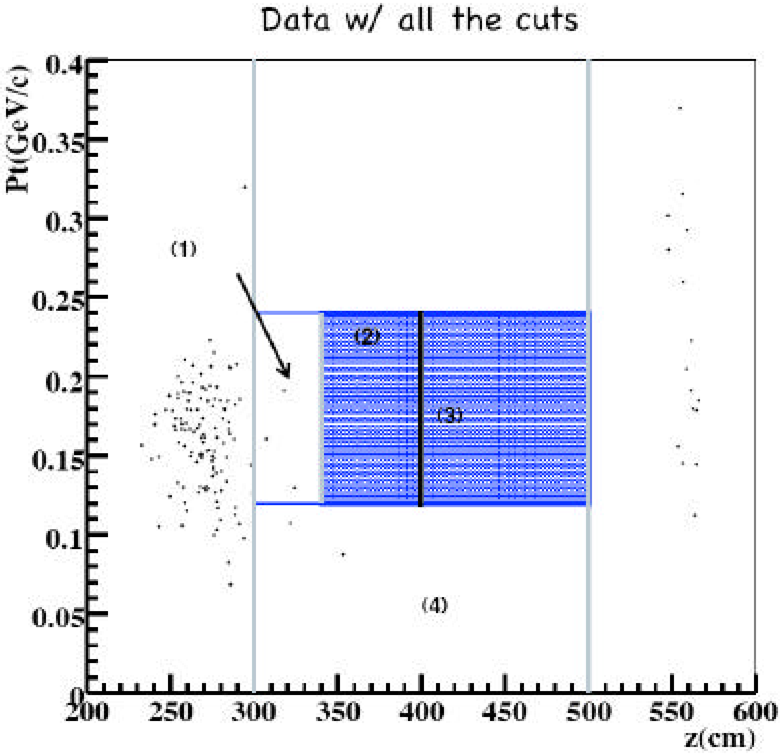




E391 background summary

- Control region
  - (1) =1.9±0.2
    - CC02: 1.9±0.2
    - Observed 3 events
  - (4) =0.39±0.08
    - CC02: 0.26±0.07
    - CV-η: 0.04±0.01
    - CV-π^0: 0.09±0.04
    - Observed 2 events

- Signal region
  - (2):=0.15±0.05
    - CC02: 0.11±0.04
    - CV-η: 0.04±0.02
  - (3):=0.26±0.11
    - CC02: 0.05±0.03
    - CV-η: 0.02±0.01
    - CV-π^0: 0.08±0.04
    - $K_L \to \pi^0\pi^0$:0.11±0.09
  - Total 0.41±0.11

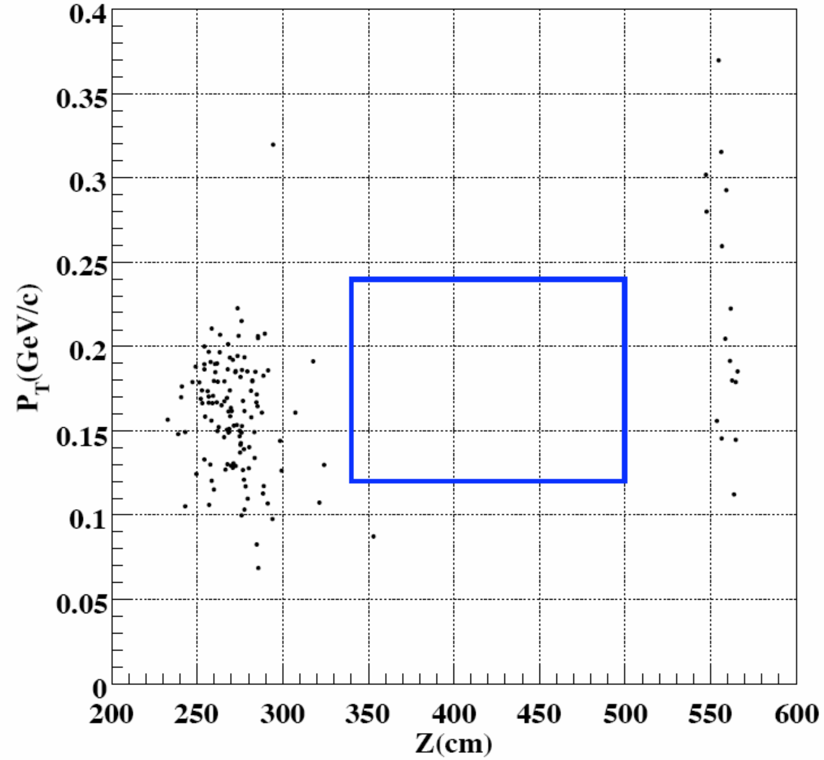


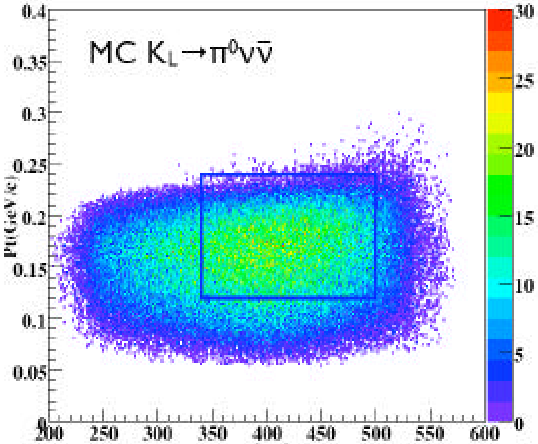
E391: Opening the signal box

- No event observed in the signal box

- Acceptance=0.67%
- $N(K_L)=(5.13\pm0.40)\times10^9$
- $SES=(2.93\pm0.25)\times10^{-8}$
- Upper limit
  - $BR(K_L^0\to\pi^0\nu\bar{\nu}) < 6.7\times10^{-8}$ (90%CL)

arXiv:0712.4164



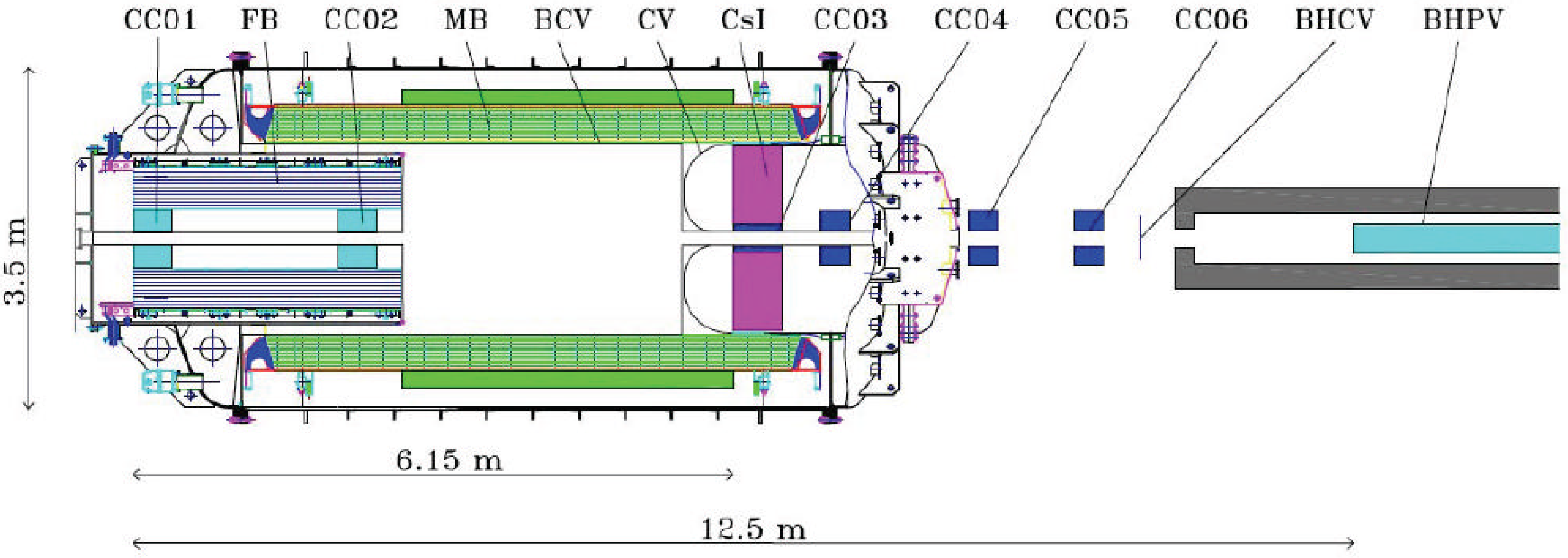


Run III, having ~70% of Run II statistics, is now analyzed

Future experiments
E14 (“KOTO”) on J-PARC

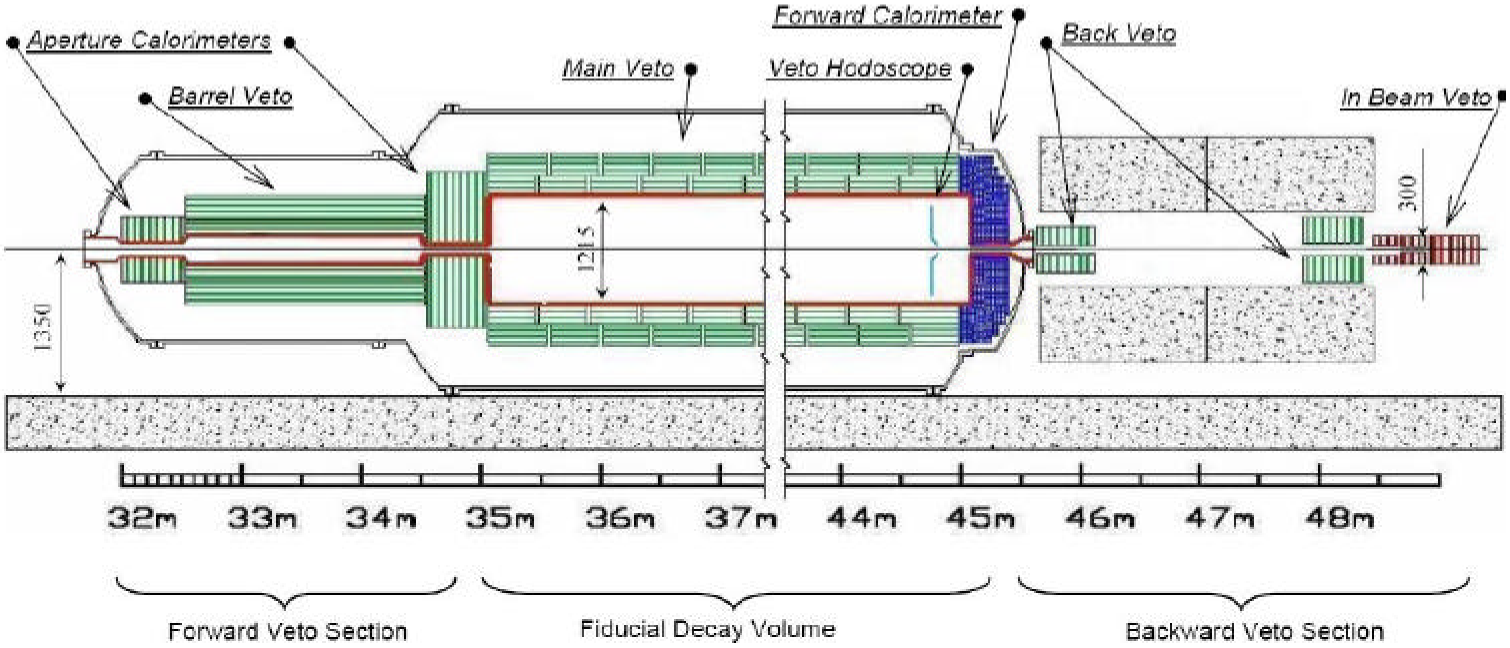
- Step-1: first observation ~3.5 SM events
- Step-2 in future: optimize detector and beam line for ~100 SM events.

- Modify E391 setup
  - Thick and fine granular calorimeter
  - Full active CC02
  - New electronics
  - New BHPV



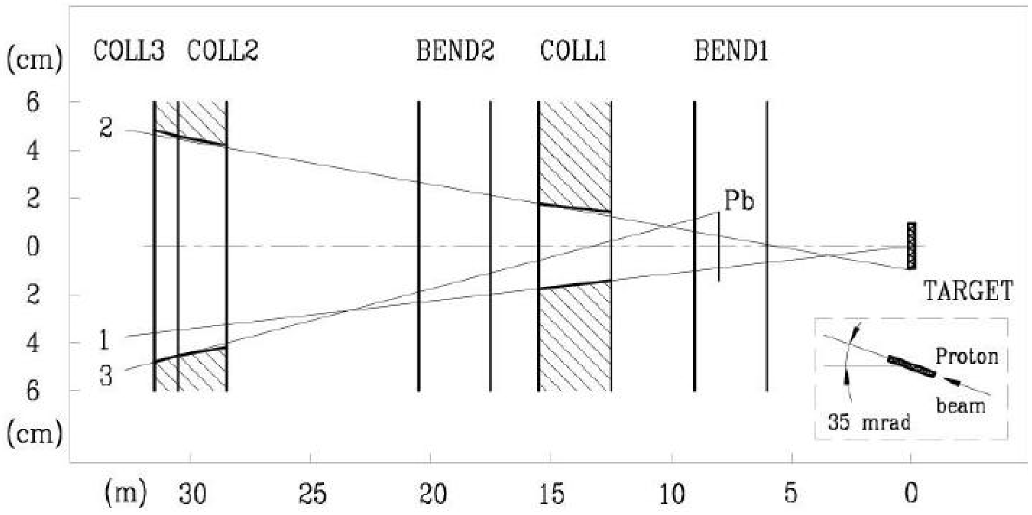
Future experiments
KLOD in Protvino

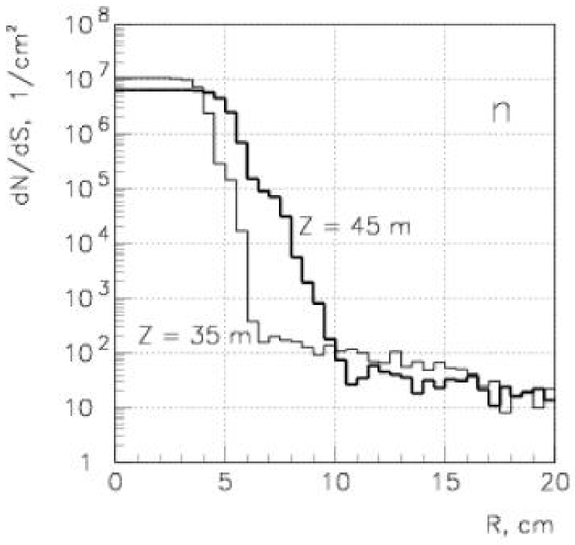
- Use the similar principles as E391 but different detector implementations
  - Small modules of main veto
  - Extendable decay region
  - Vacuum tank ~10^{-5}Pa
  - Calorimeter with possibility to measure the angle
  - High intensity K_L beam
    - Working accelerator
  - Possible to use micro-bunching to measure momentum of K_L by TOF



Future experiments
KLOD in Protvino

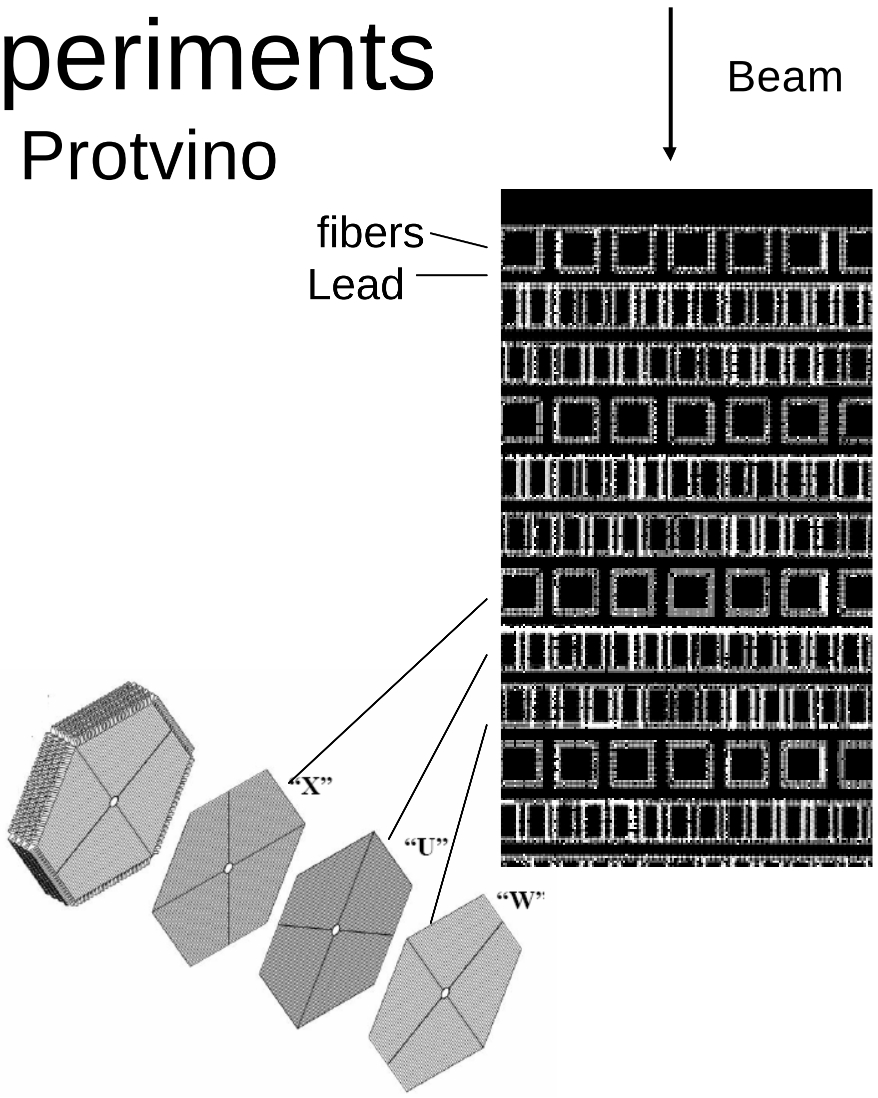
- Beamline
  - 10^{13} proton/spill @60GeV
  - Cu target 25cm (80% interactions)
  - Length = 31.5m
  - Pb absorber
- Parameters
  - $5.4x10^{7}$ K_L/spill
  - Mean KL momentum = 10GeV/c
  - n/K_L~10
  - Halo n is suppressed on more than 5 orders

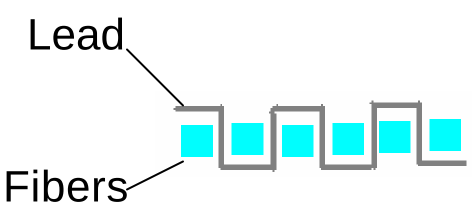




Future experiments
KLOD in Protvino

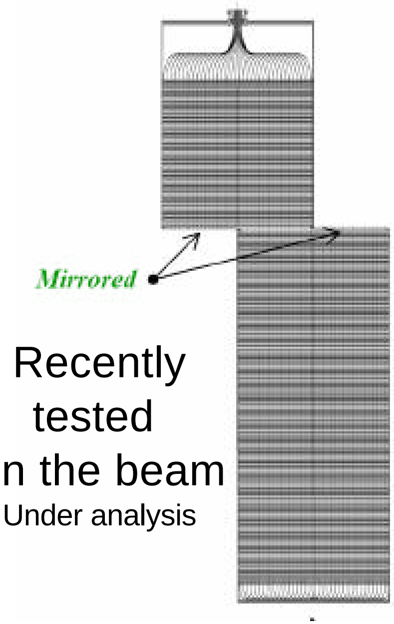
- <u>Calorimeter</u>
  - Measure energy, position and angle of gammas
  - Fast response
  - It can be made by set of blocks with enough X0
    - Block consists of 3 rotated (by 60^0) layers of fibers with lead
    - Energy resolution ~5% @ 1GeV
    - Position resolution ~2mm
    - Angle resolution ~ 25mrad @ 1GeV



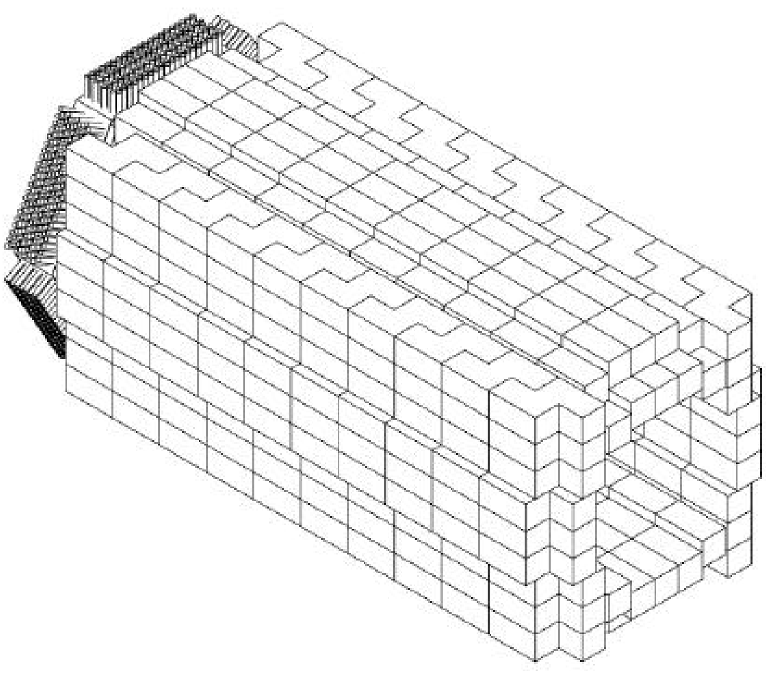


Future experiments
KLOD in Protvino

- Main veto
  - Shashluk type module (0.3Pb/1.5Sc)
  - 18 phe/1 MeV visible energy
  - σ_E/E~3% @ 1GeV
  - Or sandwich type modules located around beam axis
  - Extendable decay region



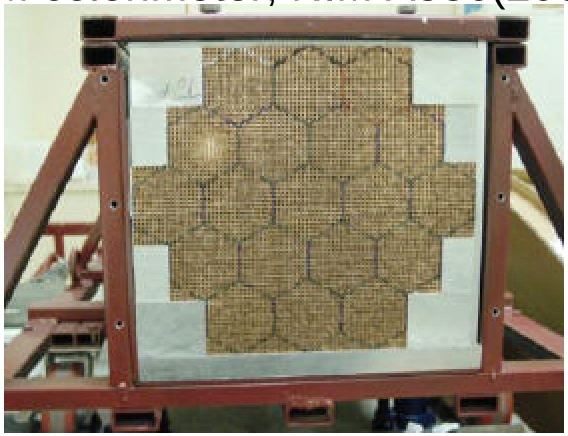
Recently tested on the beam
Under analysis

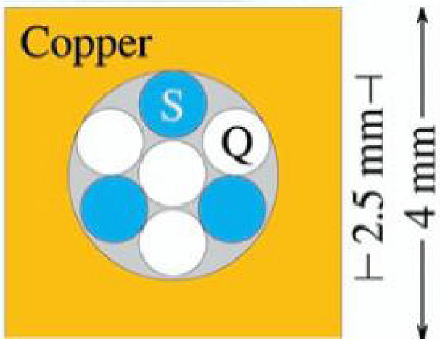


Future experiments
KLOD in Protvino

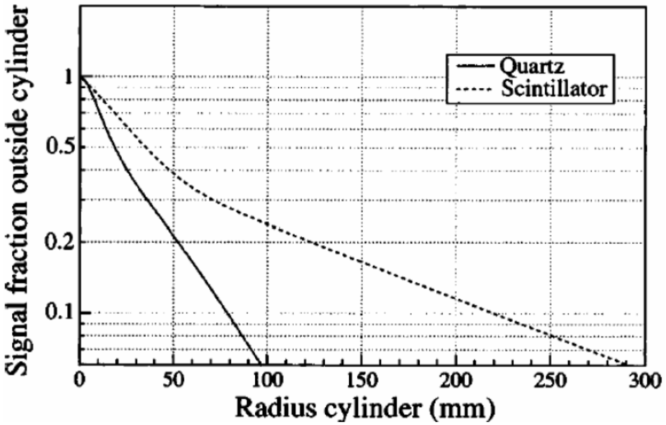
- Beam veto for gamma identification
  - Dual readout sci+quartz fibers
    - Ch/Sci ratio
    - transverse and longitudinal profile

DREAM colorimeter, NIM A536(2005),29





Transverse profile of 80GeV π shower
N.Akchurin, R.Wigmans, Rev.Sci.Instrum. Vol74,2003



Future experiments
KLOD in Protvino

- Main cuts
  - 0.15<Egamma<6 GeV
  - P_T>120MeV/c
  - Decay vertex inside fiducial volume
  - Dist(γ–γ)>15cm
  - Energy gravity center > 20 cm
  - γ's pointed to reconstructed vertex ±0.5m

Acceptance = 15%
4.8% decays in fiducial volume
5.4×10^7 KL/spill

- Backgrounds on level of 1 SM signal event
  - $K_L \to \pi^0\pi^0$ ~0.26
  - $K_L \to \gamma\gamma$ < 0.1
  - $K_L \to \pi^0\pi^0\pi^0$ < 0.1
  - Ke3 < 0.1

For 10 days beam time (~10^4 spill/day)
(10days x 10^4spill/day) x (5.4×10^7 KL/spill) x (0.048) x (0.15) x BR(2.8×10^{-11}) $\approx$1.1 event

Conclusion

- Interest for search for rear KL decays is increased
  - J-PARK (Japan), KLOD (Russia), Project-X(FNAL), CERN
- Recent (but not final) E391 result
  - Upper limit BR($K_L \to \pi^0 \nu \bar{\nu}$)<$6.8x10^{-8}$ (90%CL)
    - $5.9x10^{-7}$ KTeV (factor of 8.7 improvement) using Dalitz decay
  - Analysis of Run III data set is not finished yet
- E14 ("KOTO") experiment
  - Recommend for approval by J-PARC PAC
- KLOD experiment
  - Sensitivity of level ~1.1 SM events by 10 days with S/N~4
  - Possibility to get world level result in Russia

E391

Invariant mass of $2\pi^0$