J-PARC E14 K^OTO Experiment

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

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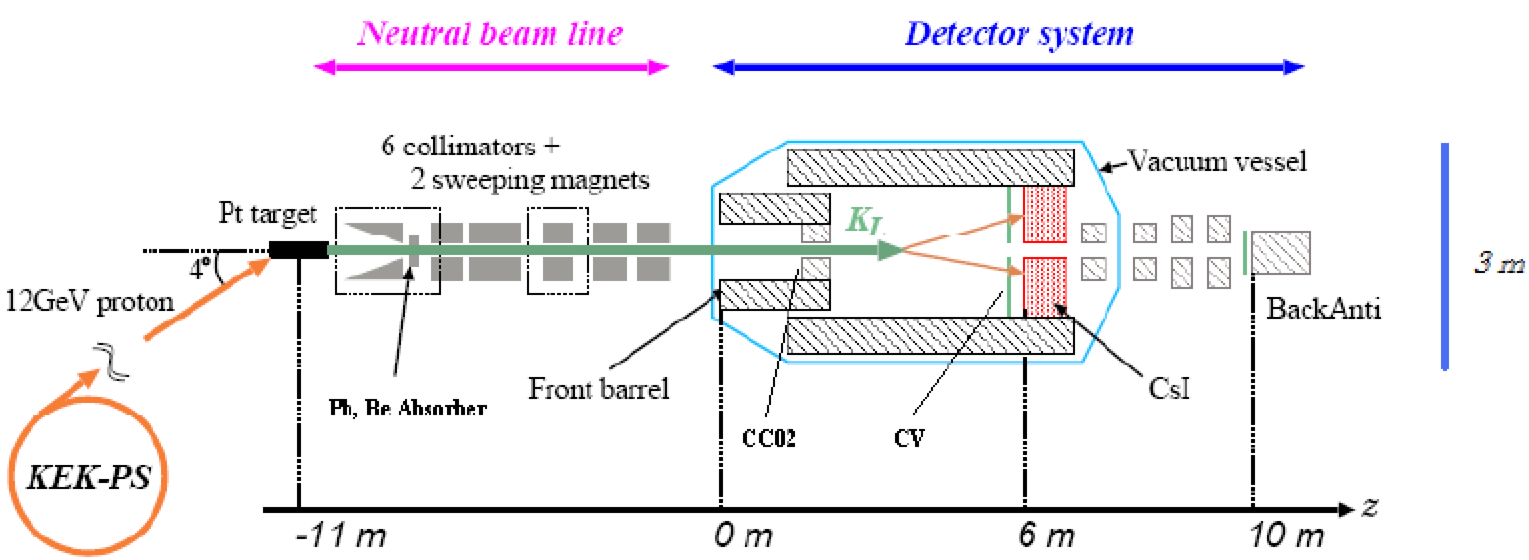
University of Chicago

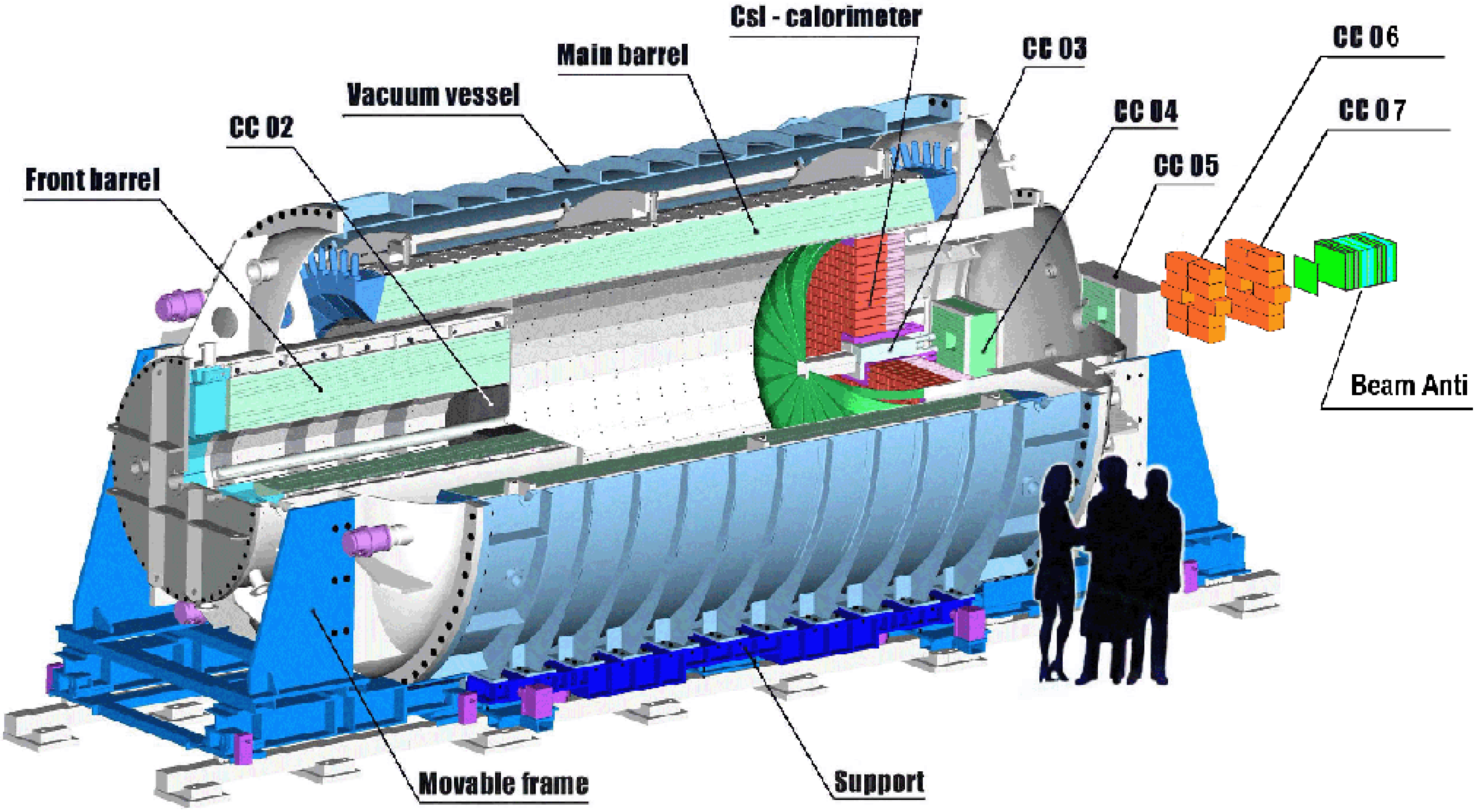
KoTO collaboration:
Japan:KEK,Kyoto,NDA,Osaka,Saga,Yamagata
Taiwan:National Taiwan
USA:Arizona State,Chicago,Michigan
*Russia:*JINR
Korea:Cheju,Chonbuk,Kyungpook,Pusan,National Seoul

Principles of the experiment

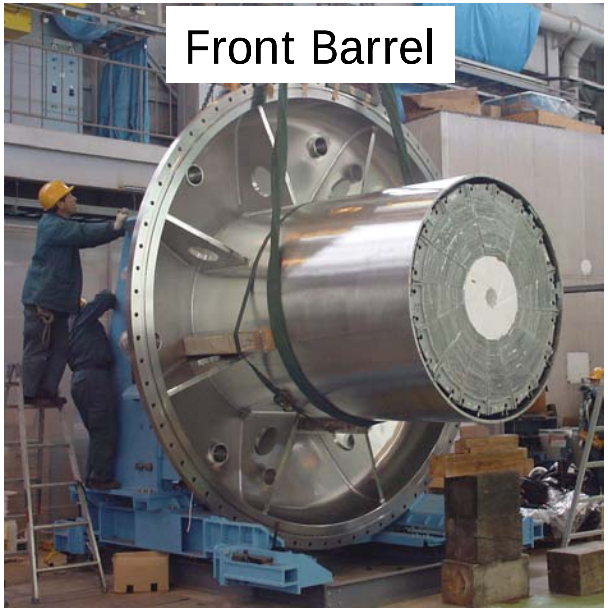
- To detect $K_L^0 \to \pi^0 \nu \bar{\nu}$ by looking for two photons with a missing transverse momentum(Pt).
- Events from the major neutral decays(Kl->3pi0, Kl->2pi0, and Kl->gg) were collected to calculate the total number of Klong.
- A pencil beam is critical for the Pt resolution and background reduction.
- The hermitic veto system is what sets this experiment apart from previous efforts

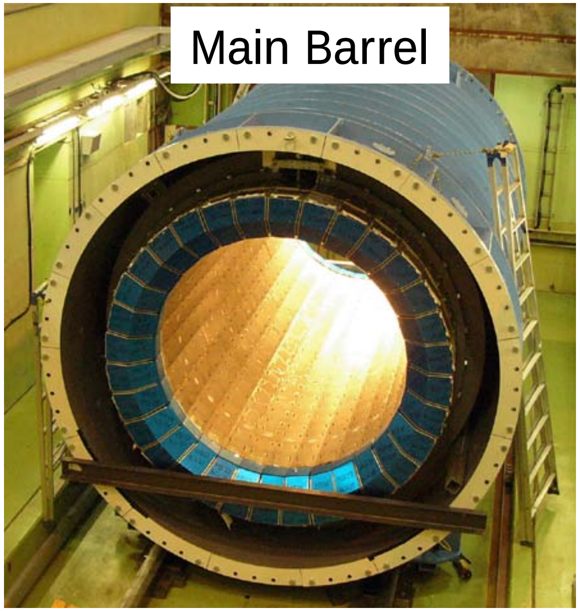


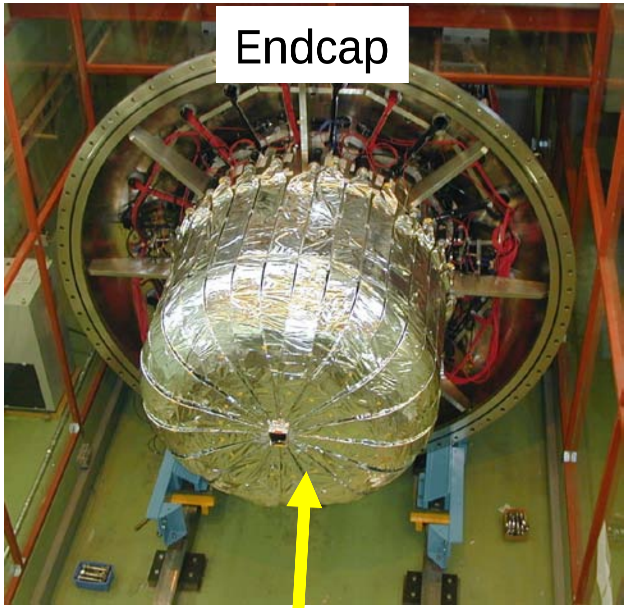
KEK E391a Detector
Upgrade to JPARC E14

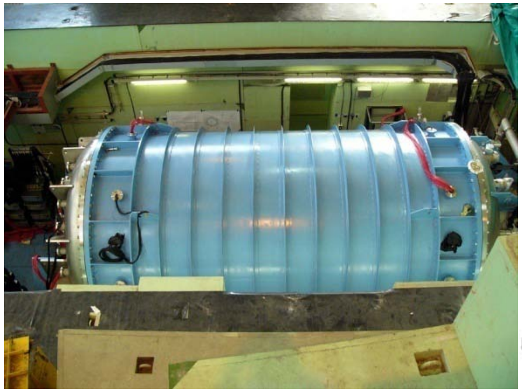


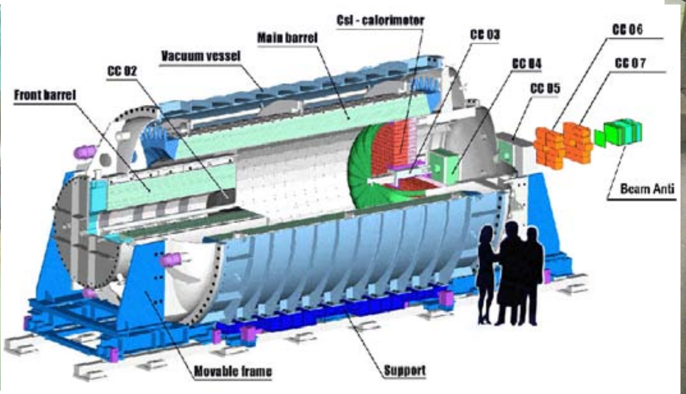
KEK-E391a Detector

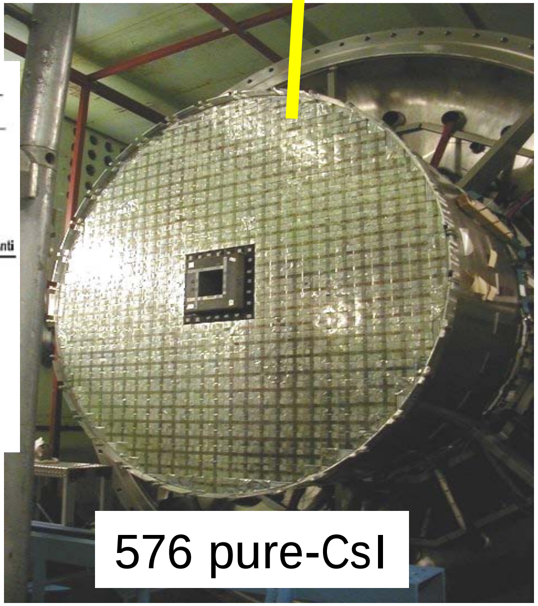








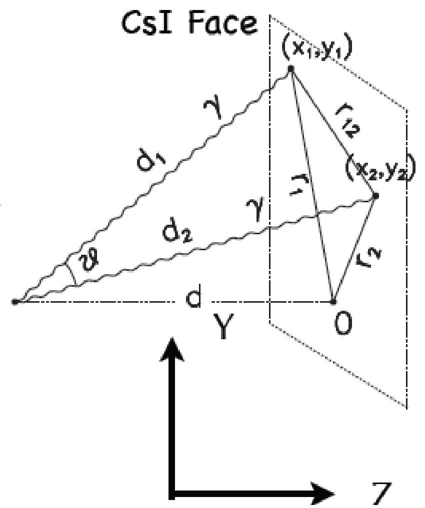




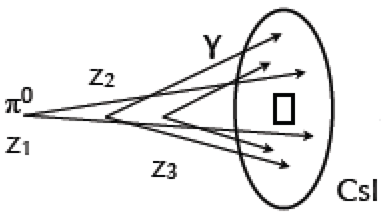
Detector Integration was finished on Jan 22, 2004
Date taking between 2004-2006

Reconstruction of Pion and Kaon

- Pi0 reconstruction:



- Select the correct combination by choosing the one with small vertex dispersion among the multiple Pi0s. And use the weighted average of Pi0 z vertex as Kaon vertex.



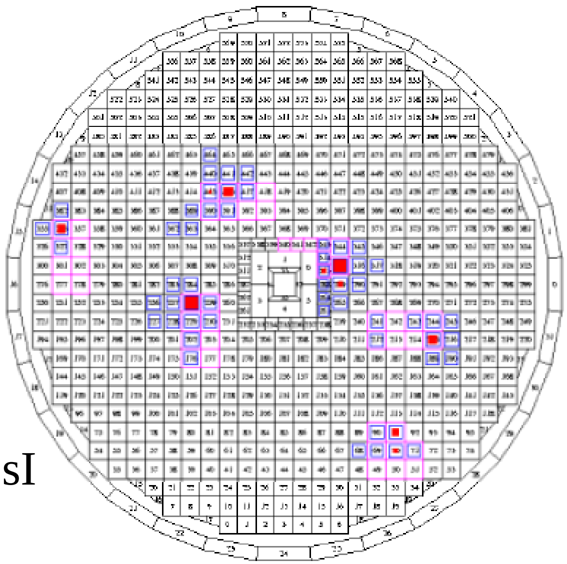
$K \rightarrow \pi^0\pi^0\pi^0$

$$\chi_z^2 = \sum_{i=1}^{n} \frac{(\bar{z} - z_i)^2}{\sigma_i^2}$$

$$m_\pi^2 = (p_{\gamma_1} + p_{\gamma_2})^2 = 2\,E_1\,E_2 \times (1 - \cos\,\theta)$$

$$r_{12}^2 = d_1^2 + d$$

- Draw a line from the center of energy in the CsI face to the target, and move the Kaon vertex in the XY plane to shift it to the line.



Six clusters in our CsI

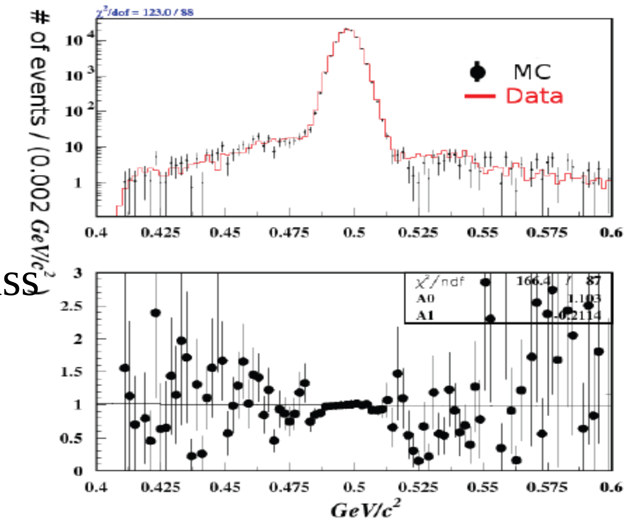
Kaon simulation and Flux

- The Kaon Monte Carlo simulation(MC) matches data well. The calculation of flux and acceptance depends on the simulation.
- Flux number:

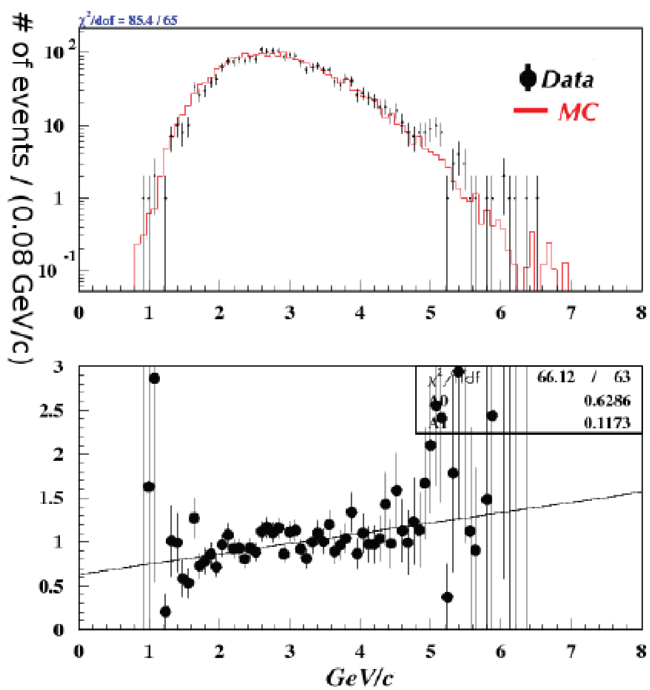
  Observed # of decays in data/(observed # of decays in MC/total # of Kaon decays)

  = (3.48+-0.25)*10^9

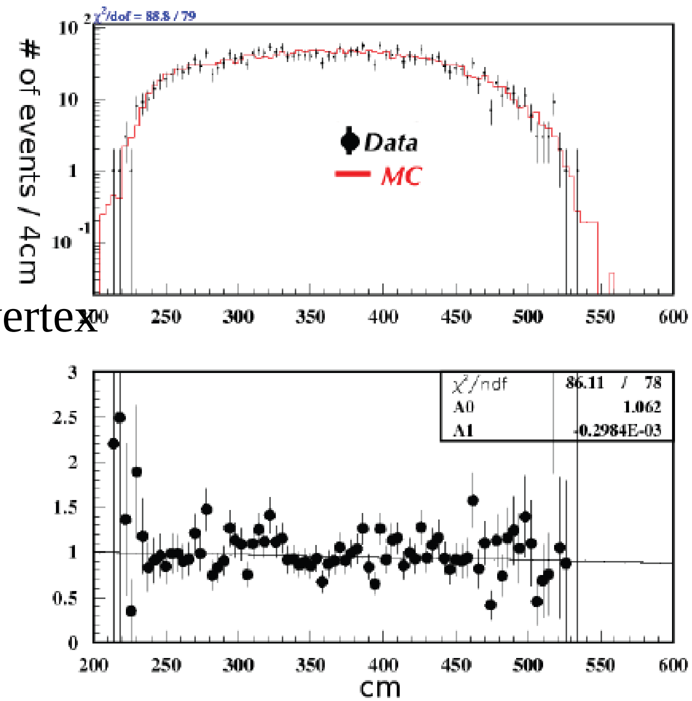
mass



Momentum

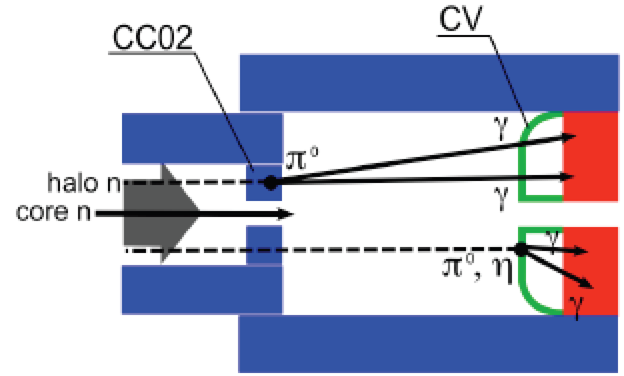


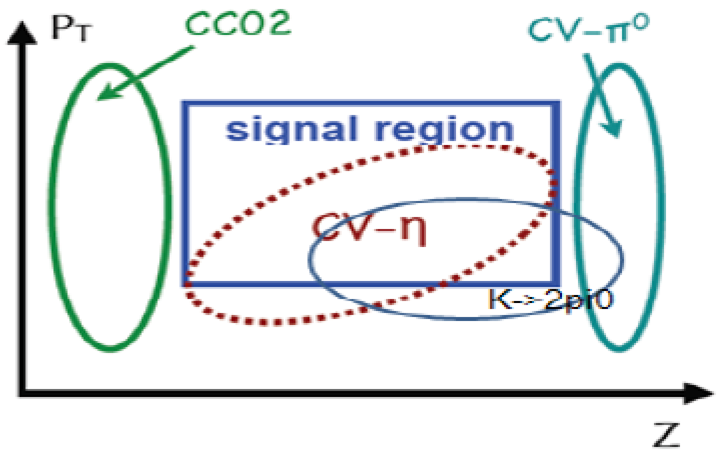
Decay z vertex

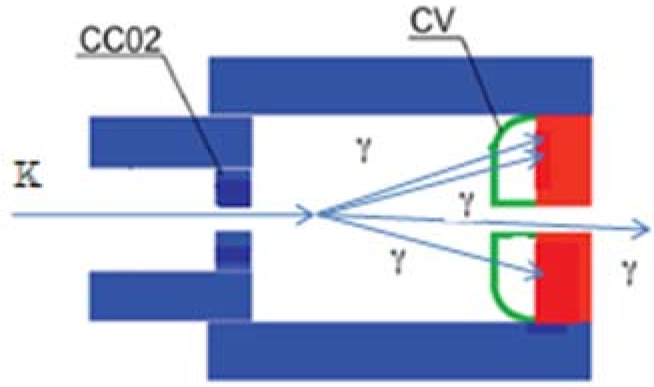


Possible Backgrounds

- We often use the transverse momentum(Pt) vs. z plot to display the events.
- The signal box is defined as a simple square on the Pt vs. z plane.
- Backgrounds can come from halo neutron interaction in detectors and kaon activities

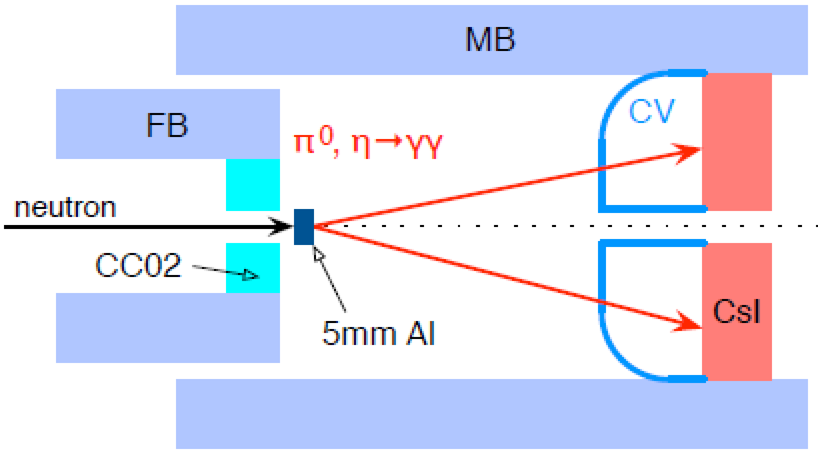


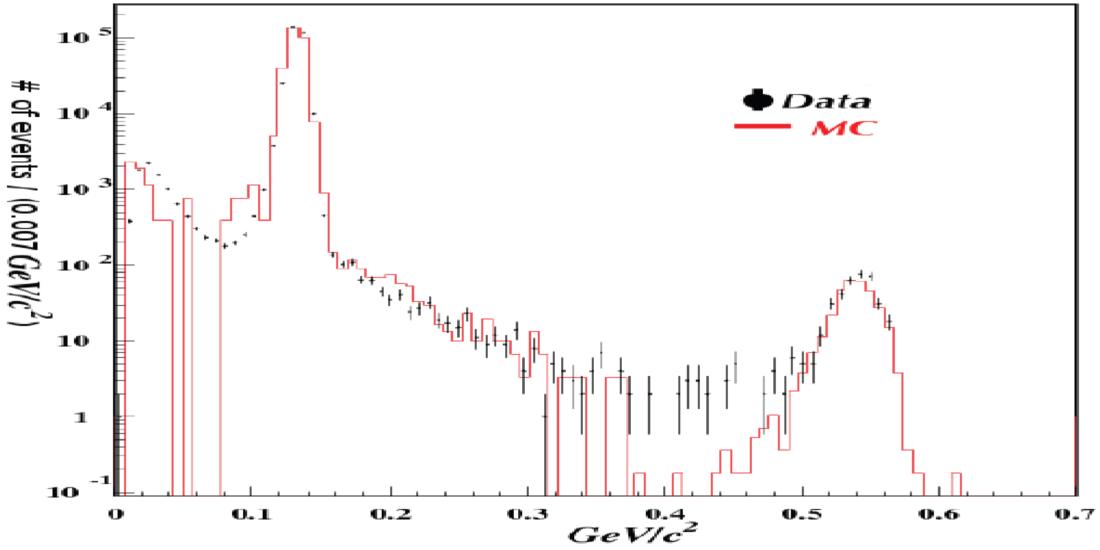




Special Al target data for neutron background validation

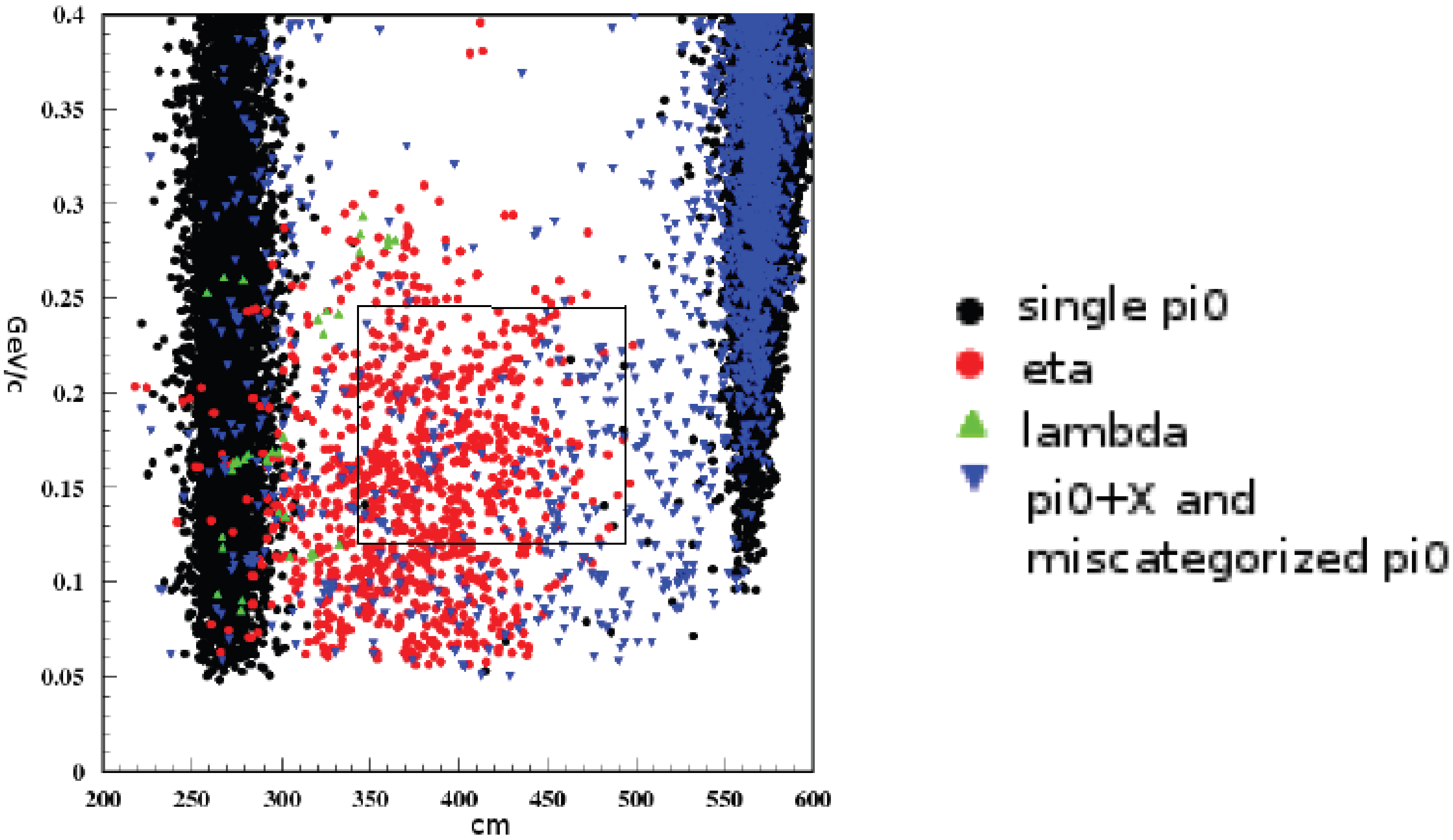
- An Aluminum plate is placed behind CC02
- The huge number of core neutron interaction makes this special run a calibration of the neutron interaction model in the background simulation





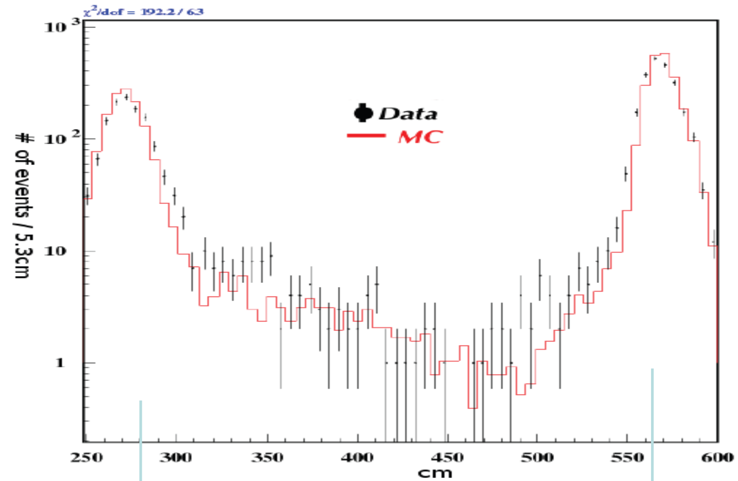
Events by Secondary Particle Types in the Neutron Interaction

- Eta background dominates and it's the only source after we tighten the cuts.

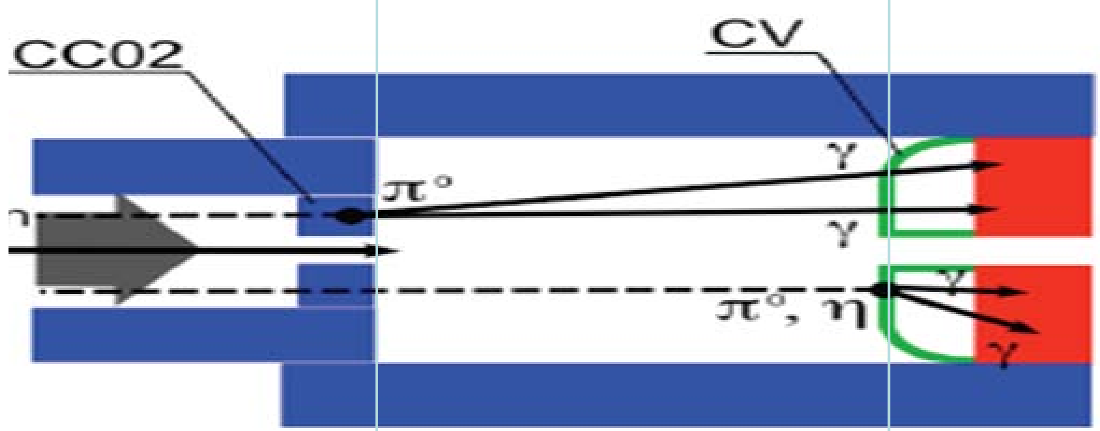


Comparison of data and MC for all events outside the signal box.

Absolute Normalized

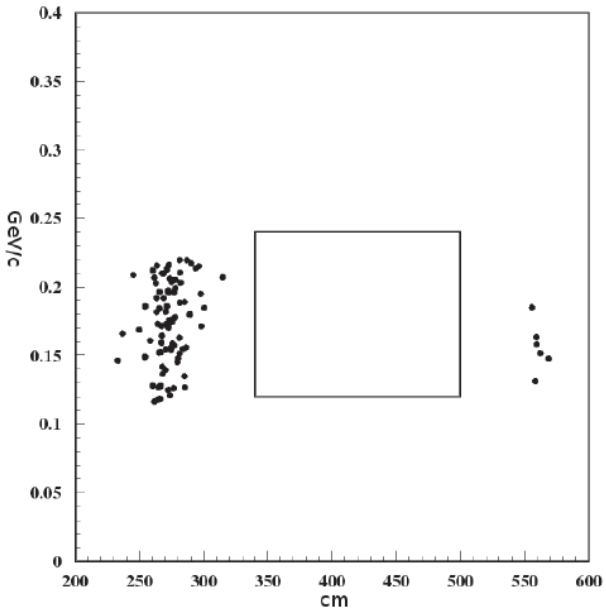


Reconstructed Pi0 z distribution

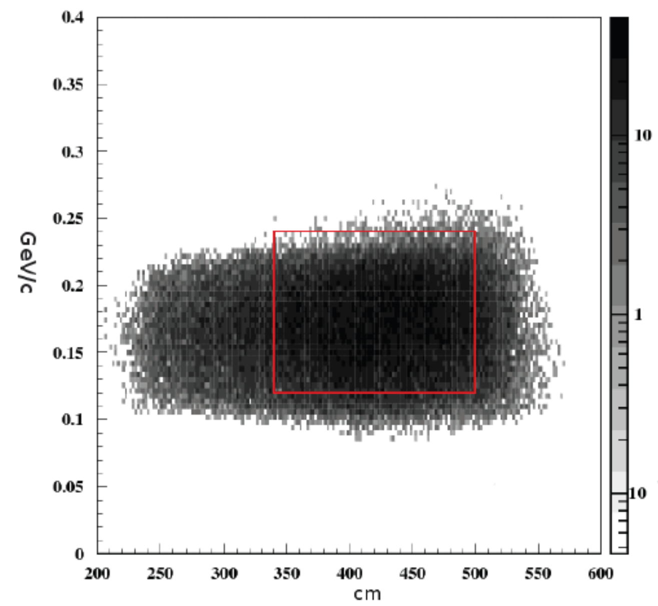


Opening the Signal Box:

Data:



MC:



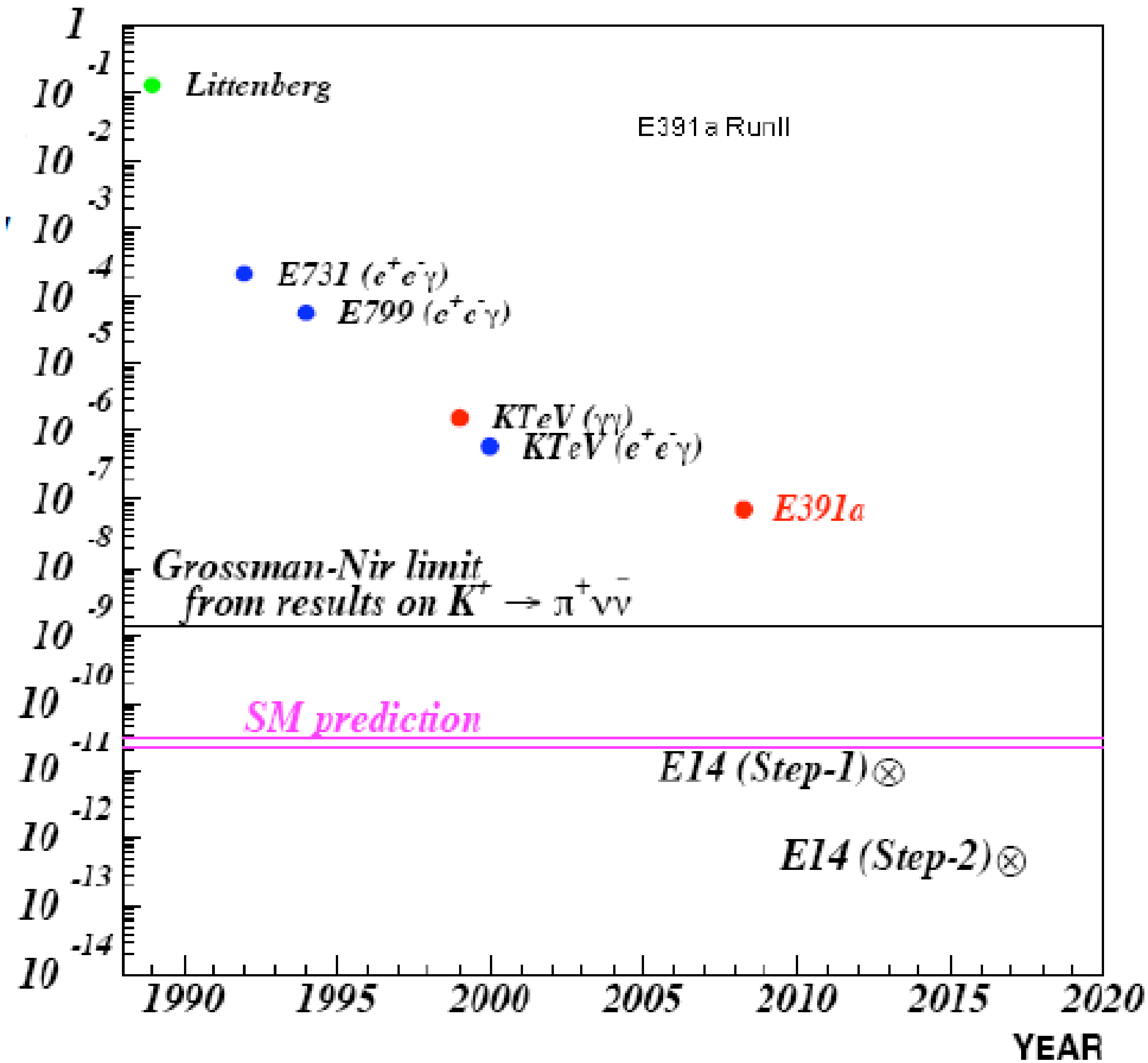
MC Acceptance: (0.94+/-0.06)%

Single Event Sensitivity = 1/(flux*acceptance)= $(2.8+/-0.3)x10^{-8}$

The combined 90% c.l. limit for all E391a data is $<2.6x10^{-8}$, or SES of

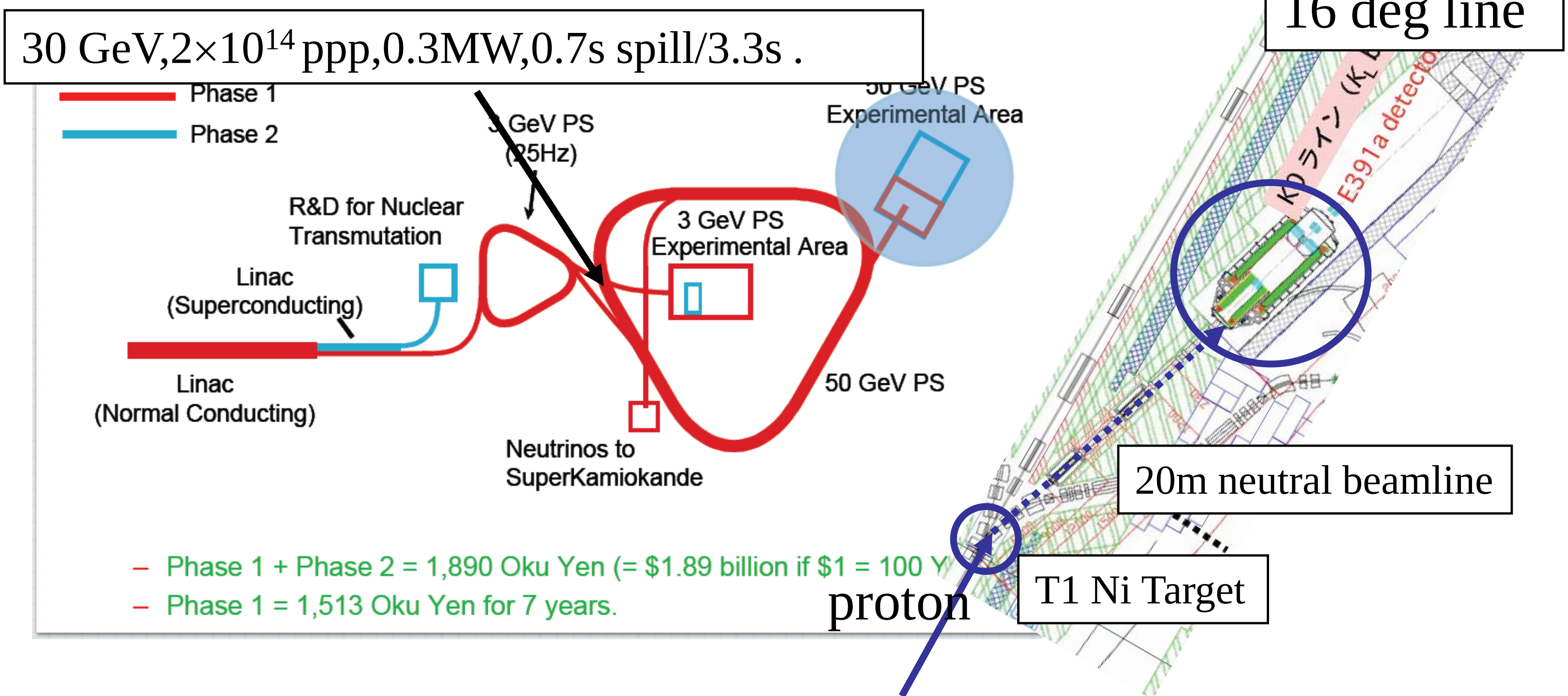
$1.1x10^{-8}$

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



Strategy from E391a to E14

- Requirement : 3 order improvement
  – (1)High intensity beam
  – (2)New beam line (suppress halo neutrons)
  – (3)Detector upgrade (suppress background)

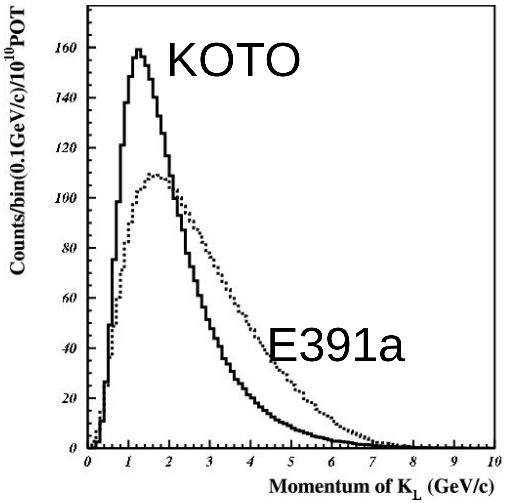


High intensity beam

– Flux x RunTime x Acceptance = 3000 x E391

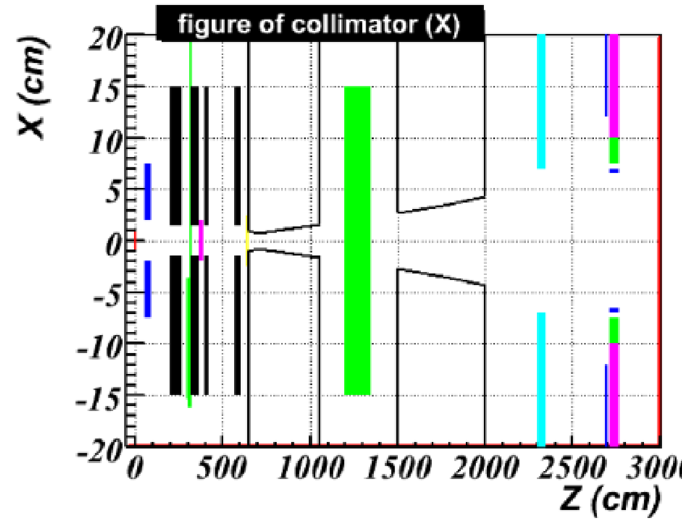
→ 2.8 SM events (3 order higher sensitivity than E391a)

	KOTO	E391a (Run2)	
Proton energy	30 GeV	12 GeV	
Proton intensity	2e14	2.5e12	
Spill/cycle	0.7/3.3sec	2/4sec	
Extraction Angle	16 deg	4 deg	
Solid Angle	9μStr	12.6μStr	
KL yield/spill	7.8e6	3.3e5	x30 /sec
Run Time	3 Snowmass years =12 months.	1 month	x10
Decay Prob.	4%	2%	x 2
Acceptance	3.6%*	0.67%	x5

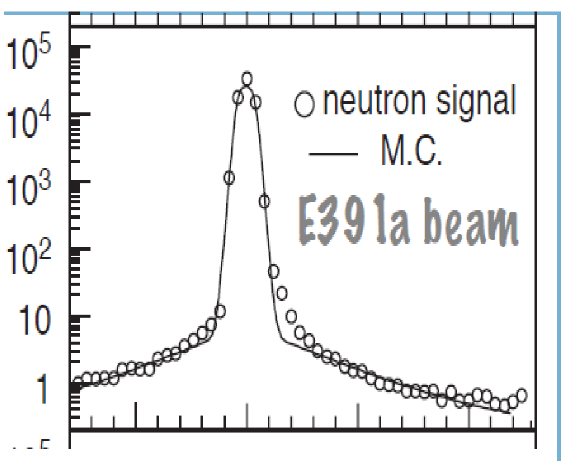


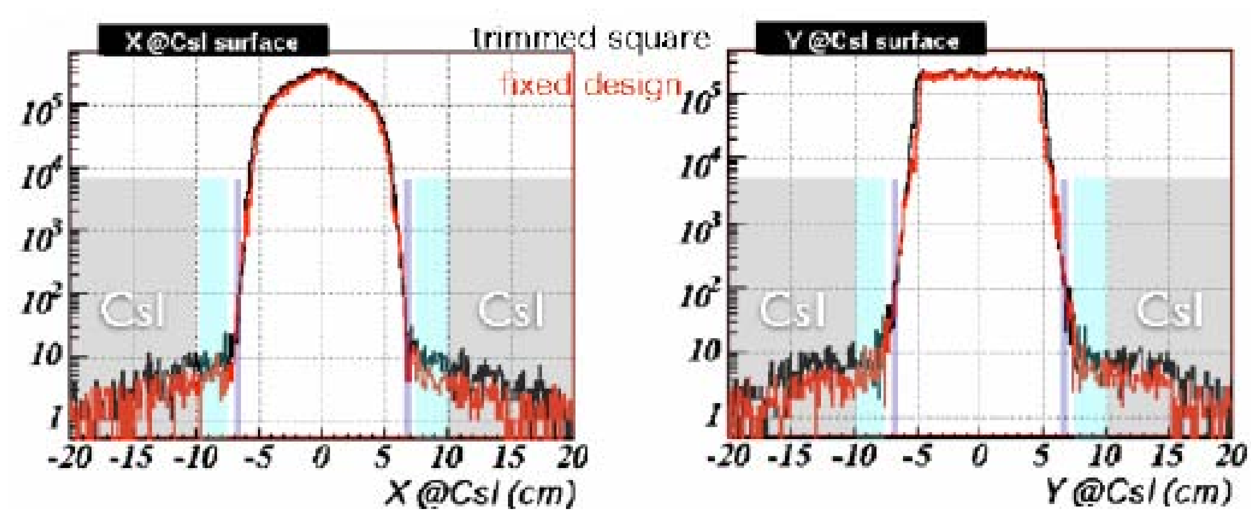
(2) New Beamline

	KOTO	E391a	
Halo neutron/spill (P>0.78GeV/c)	1.1×10^{4}	1.1×10^{5}	
KL/spill	7.8×10^{6}	3.3×10^{5}	
Halo neutron/KL	1.4×10^{-3}	3.3×10^{-1}	1/240

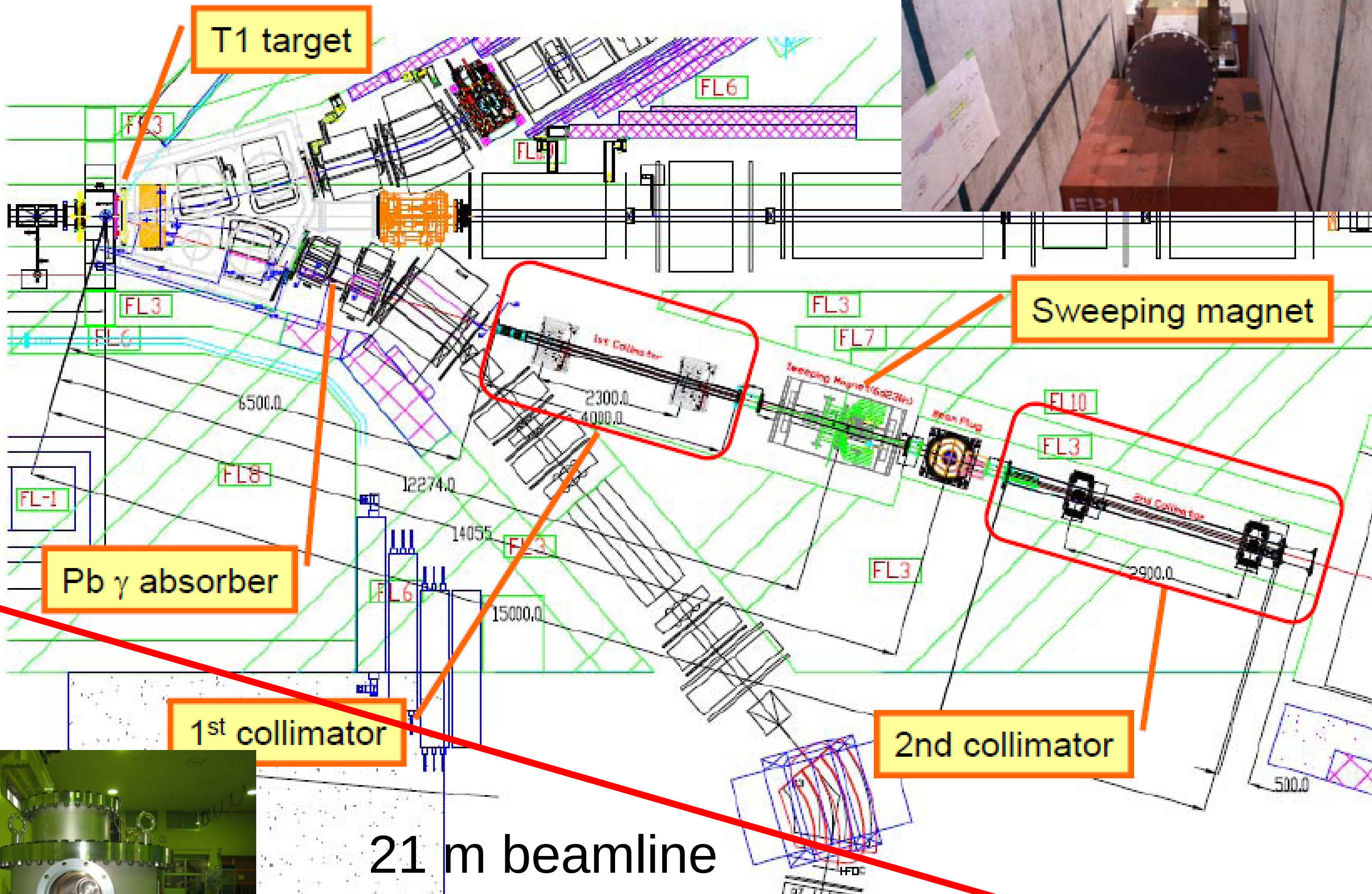


– halo-n/KL : 1/240 of E391a



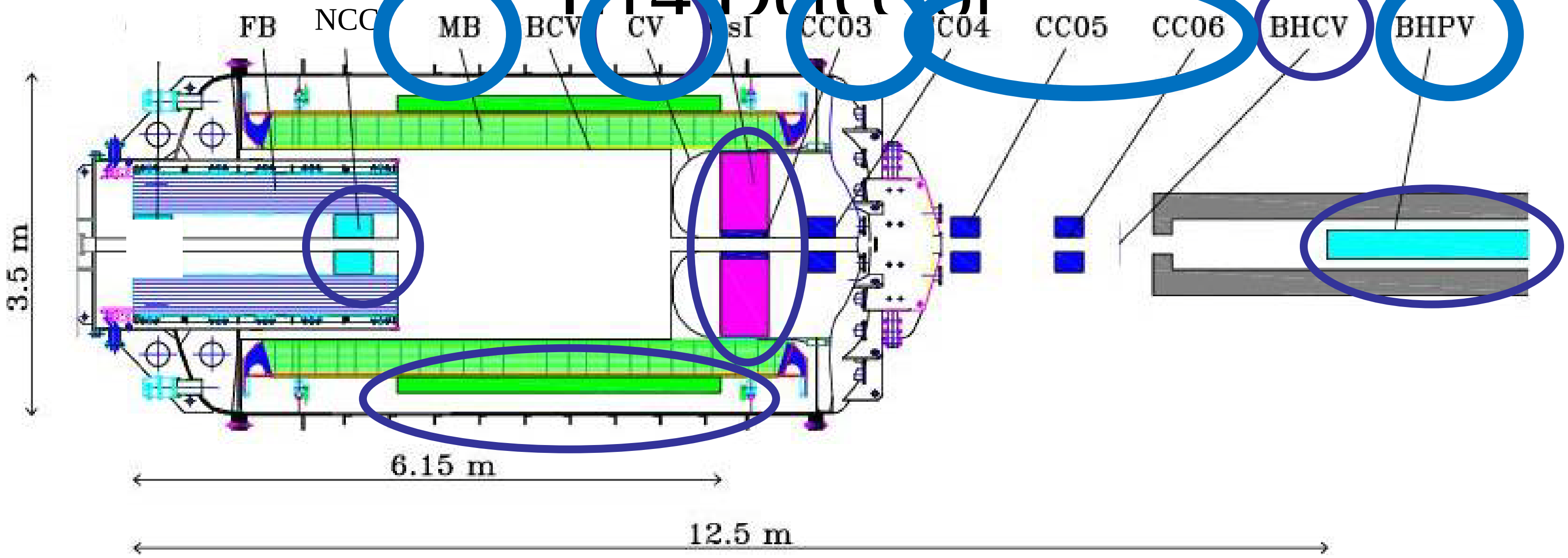


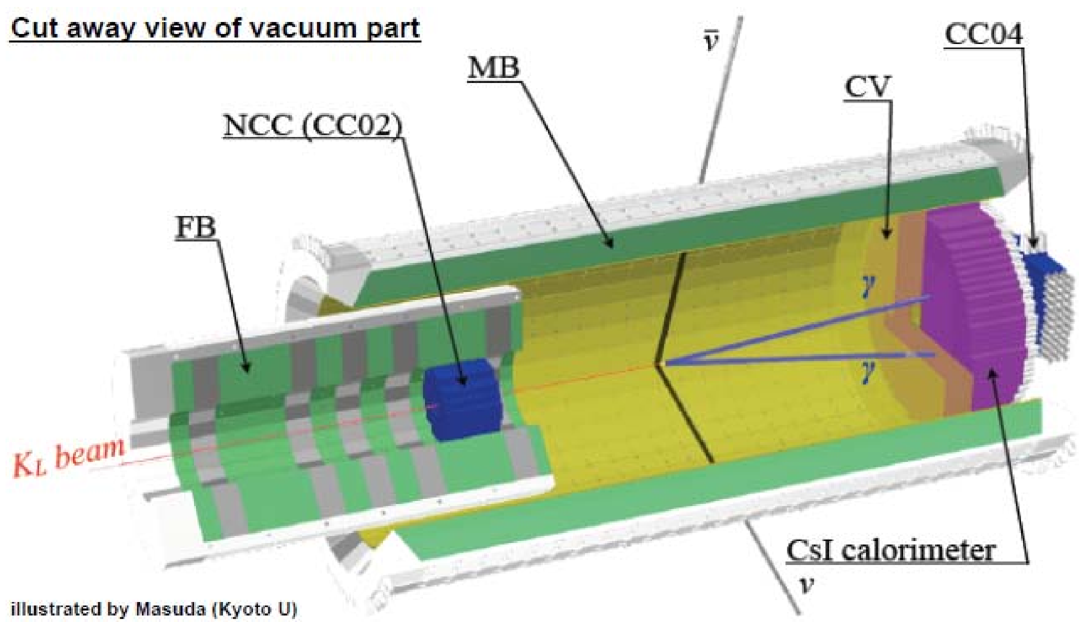
New Beamline



Finish the construction in this September including Shields

E14 Detector





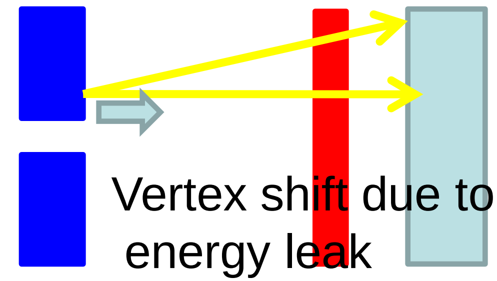
E14 Background estimation

- CsI shower including photonuclear effect is fully simulated.
- Inefficiency functions are used for other vetoes.

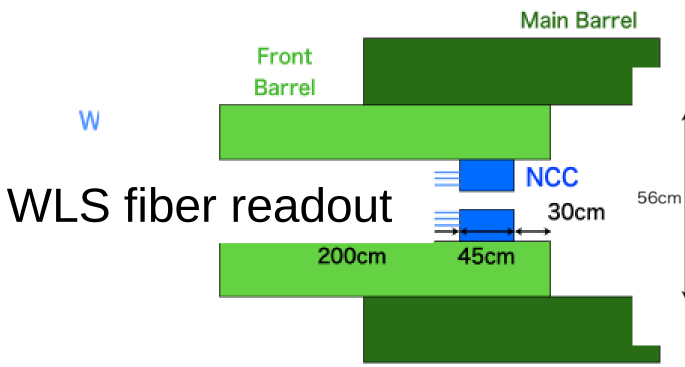
Signal	$K_L \pi\nu\nu$	2.7
	$K\pi 2$	1.7
K_L BG	ch$K\pi 3$	0.08
	$Ke^{+}3$	0.02
	CC02-π^0	0.01
halo-n BG	CV-π^0	0.08
	CV-η	0.3

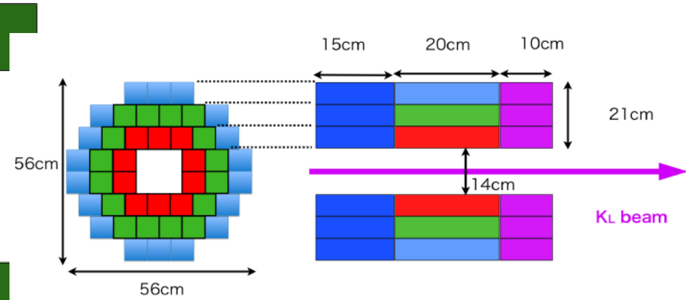
Factor 2-3 uncertainty on KL yield→ we will measure in this fiscal year.

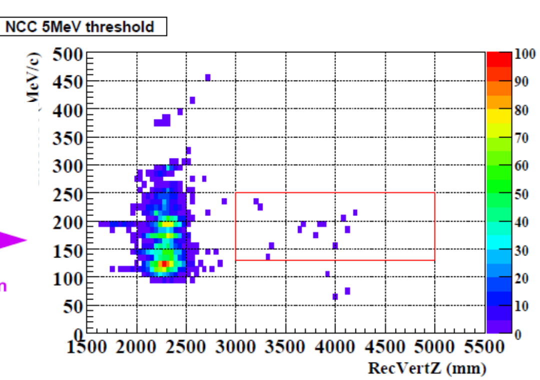
CC02 upgrade



- halo neutron/KL reduction : 1/240
- 50cm CsI → reduce shower leakage : 1/10
- Move upstream (30cm) :1/10←→halo neutron hit x10
- NCC: CsI full active. :1/10
  - long interaction length to suppress n interaction.
  - short radiation length to veto $\pi^0 \rightarrow \gamma\gamma$
  - Veto with extra particles in π^0 production.
    - Segmentation for halo-n monitor with n/γ separation.



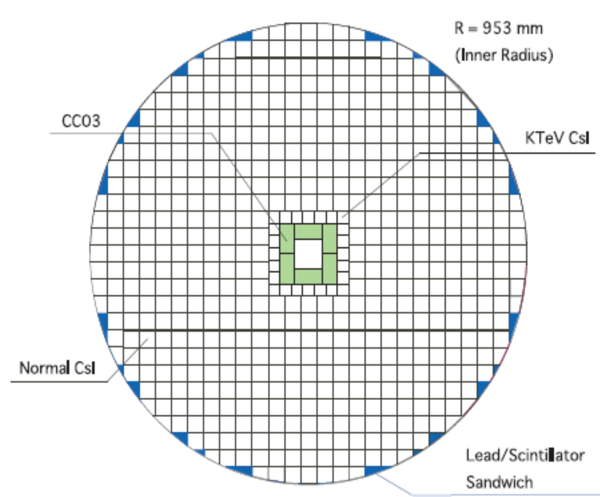




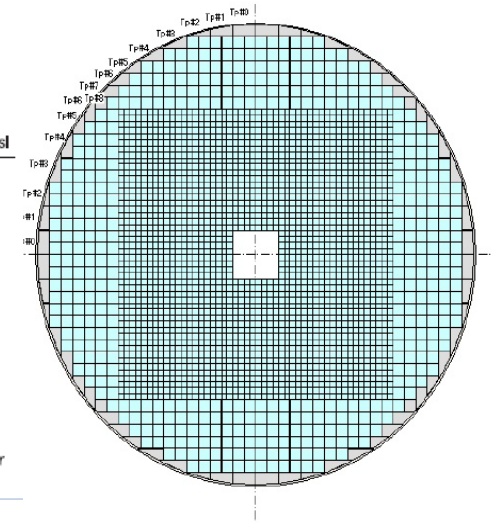
KTeV CsI Crystals:

- Highly Granular CsI
  - Fusion
- Longer blocks
  - 30cm→50cm
  - punch through

E391a

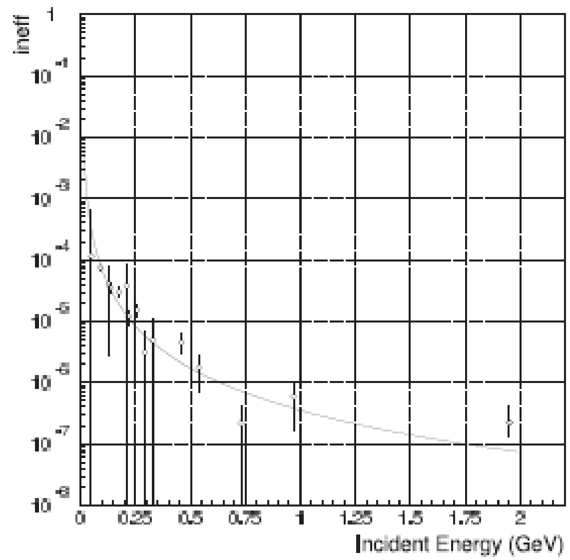


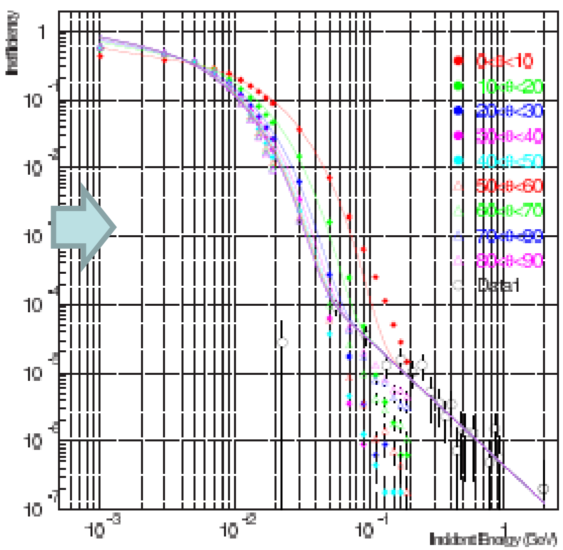
E14



Main Barrel Veto

- Thicker
  - $14X_0 \rightarrow 18.5X_0$
- Even and Fusion BG
  - 2 γ missed in MB

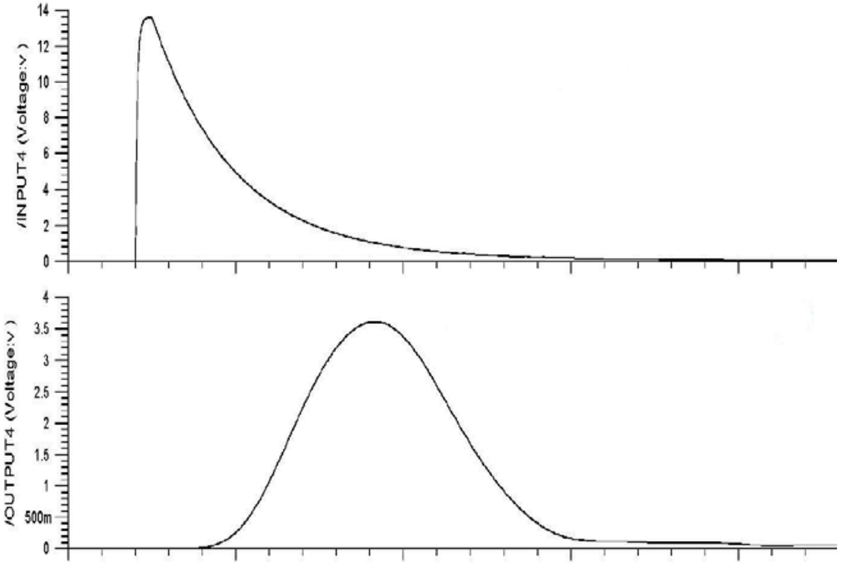




~3500 channels of photo-tube (CsI ~2800) signals + DAQ

Tradition: ADC charge; TDC time; multi-level triggers; multi computer readout.

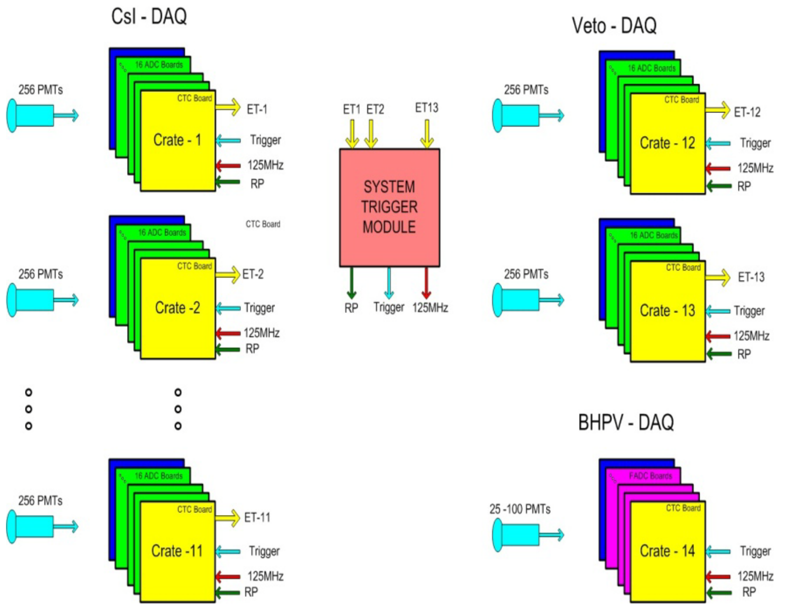
Go digital:



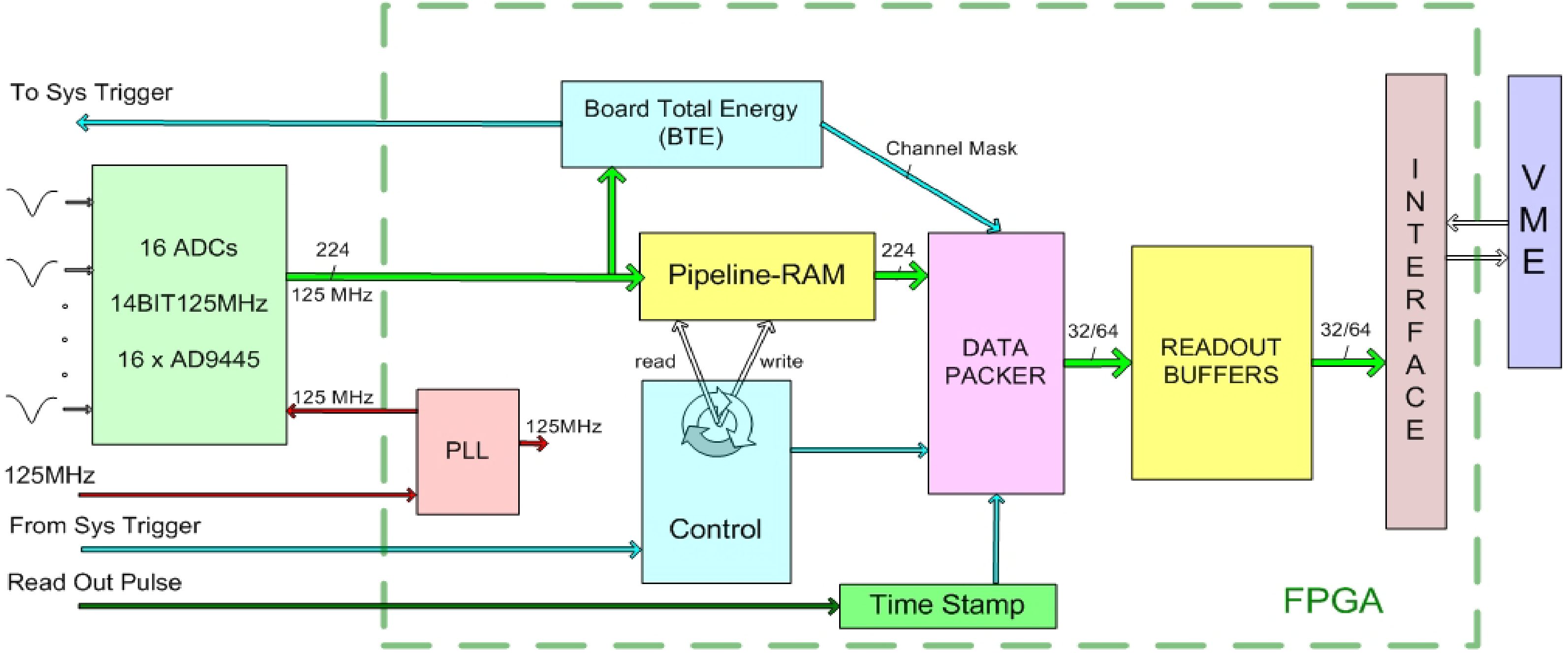
Each tic is 8 nsec

Brute force FADC :
Dynamic range (bits)
Speed (1GHz)
Cost ↑
Amount of storage ↑

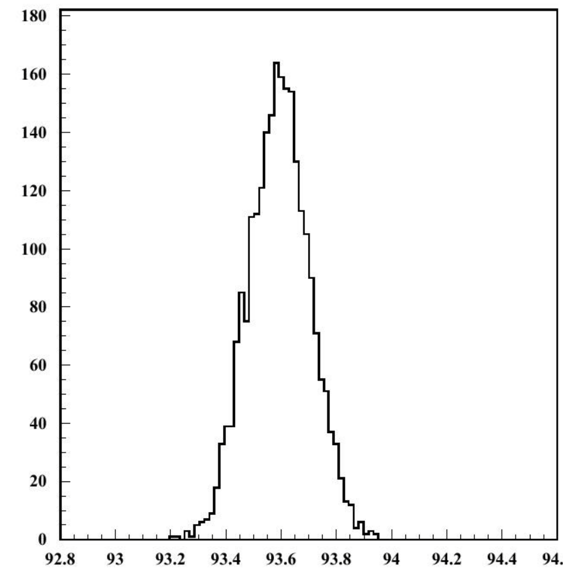
Spreading out the pulse:
Slower speed (~100 MHz)
Cost ↓
Amount of storage ↓



No delay cables !



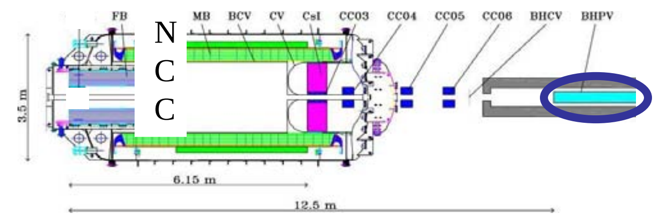
16 Channels, 10 poles Gaussian filter, 14 bit FADC
VME64 and two optical fiber readout.

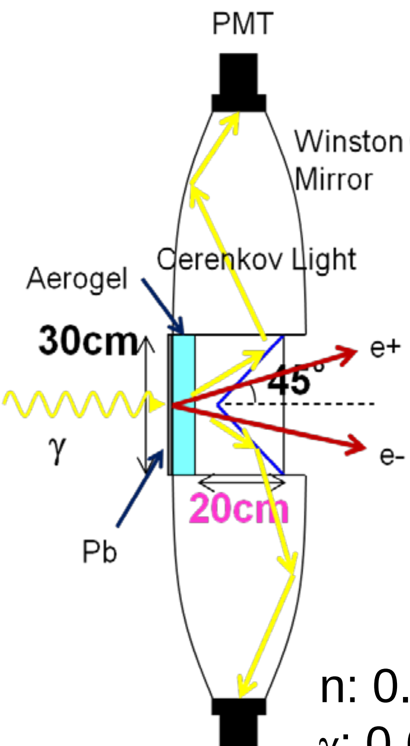


Fitted peak timing of Gaussian pulse
σ ~ 110 psec

Beam Hole Photon Veto

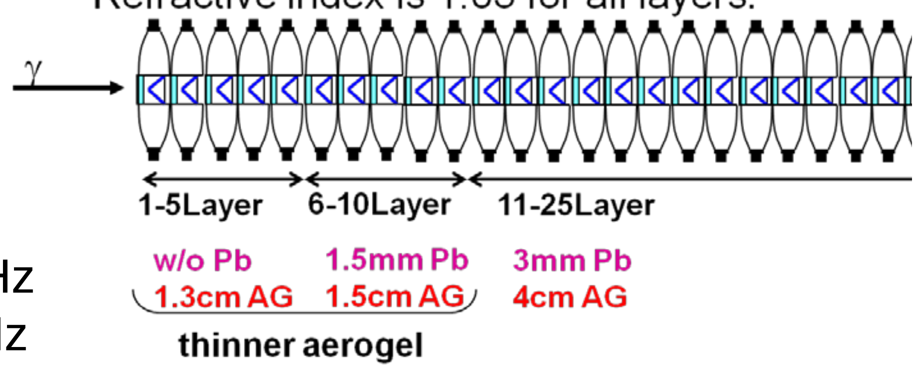
- Lead gamma converter + Aerogel Cerenkov radiator → insensitive to neutrons.

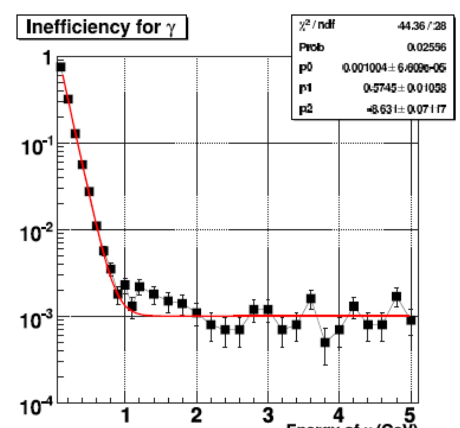




n: 0.4 GHz
γ: 0.6 GHz

Refractive index is 1.05 for all layers.





Main Ring Slow Extraction in October

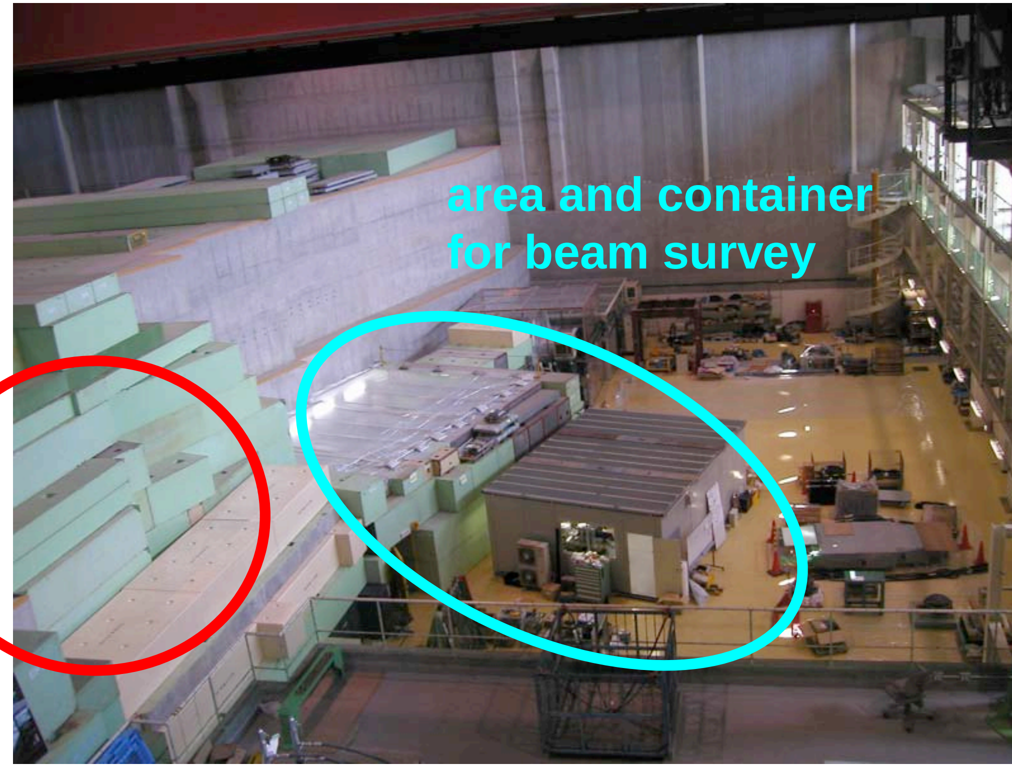
- <u>Oct.21 (Wed)</u>
  single-shot operation, 4shots
- <u>Oct.22 (Thu)</u>
  single-shot operation 4 x E11 pps
  <u>0.2% of design intensity</u>
  continuous operation 16:00～07:00AM
  0.17Hz (every 6sec)
  0.5 x E11 pps

radiation survey of experimental area

First beam to the KL experiment Oct 22, 23

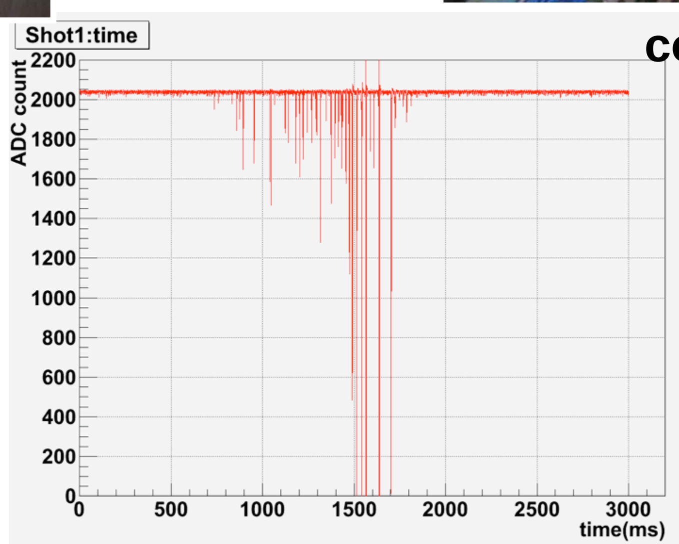
KL beamline（photo in Aug）

under shielding blocks



commissioning of the detectors

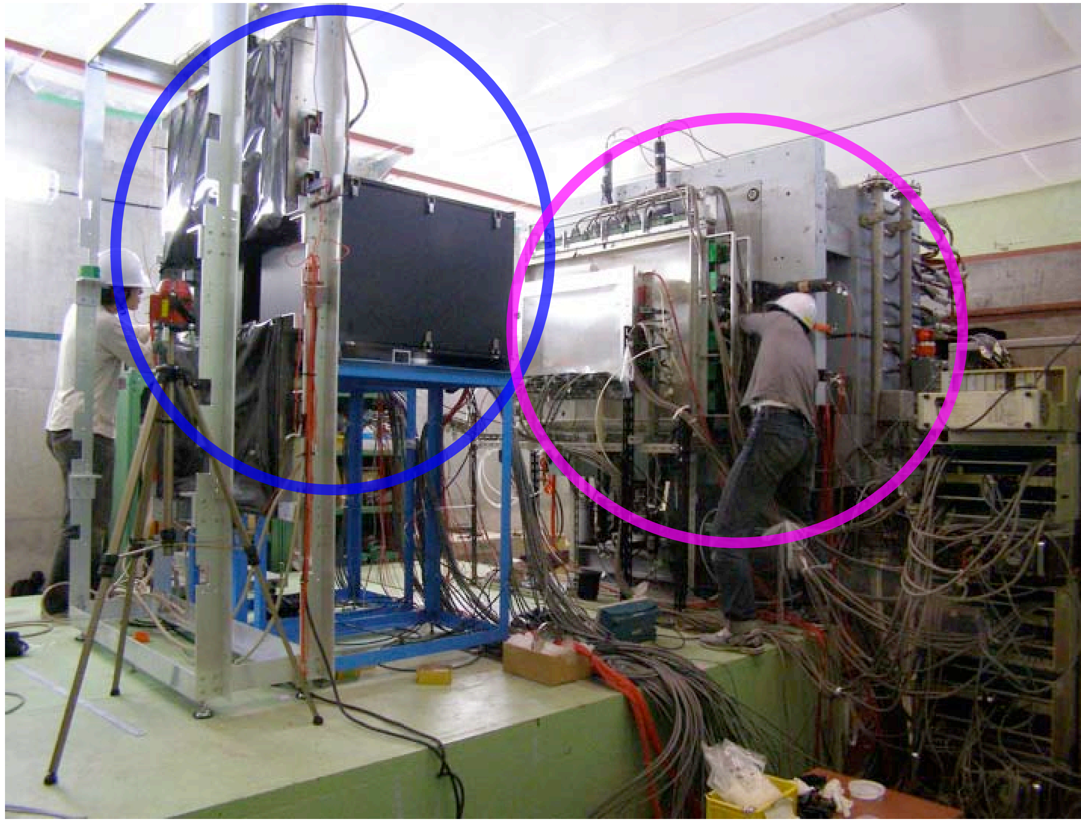
time structure of the extraction by KL beam monitor



KL beam survey (Oct/Nov/Dec)

upstream

downstream



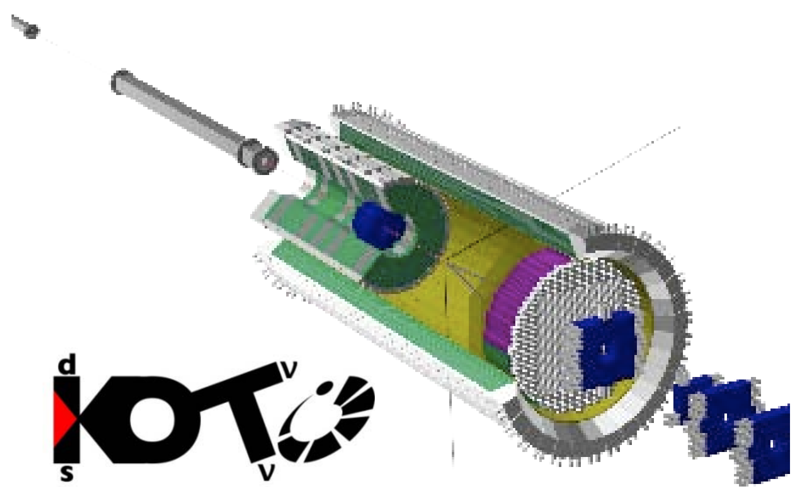
hodoscope
+ CsI crystals
for
$K_L \to \pi^+ \pi^- \pi^0$
measurement

spectrometer
for
$K_L \to \pi^+ \pi^-$
measurement

plan:

- **CsI calorimeter:**
  construction and commissioning
  (2010)

- **detector construction:**
  engineering run and first physics run
  (2011)



Summary

- E14: aim to discover $K_L \rightarrow \pi^0 \nu\nu$ with few events in Step1, and ~100 events measurement in Step 2.
- Understand all backgrounds from KEK E391a is key to new beamline and to upgrade detector elements.
- Detector upgrades are underway including KTeV CsI crystals, the Gaussian filter deadtime-less pipeline DAQ, Pb/aerogel high rate low inefficiency beam detector…
- Engineering run in 2010 and Physics run in 2011.

Backup

$K_L \to \pi^0 \nu \overline{\nu}$ "3 σ" discovery