E14 Status

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For E14 collaboration

E14 experiment (in Phase 1)

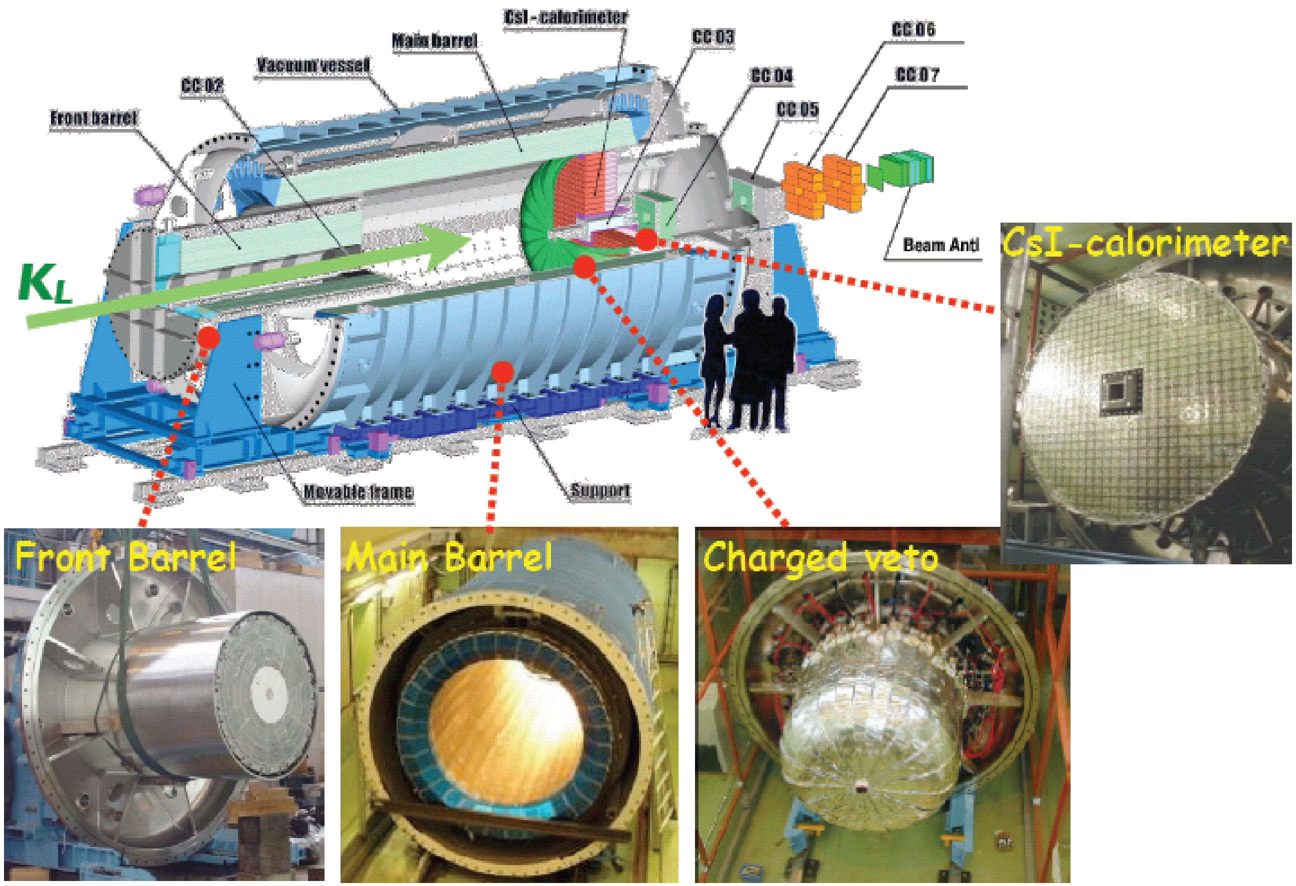
- Measurement of $K_L \rightarrow \pi^0 \nu\nu$ decay with the sensitivity of SM prediction $O(10^{-11})$ using modified KEK-E391a detector
  - To "touch" SM events
  - To discover or exclude physics beyond the SM
  - To understand and control backgrounds down to the level of 10^{-11}

    ➔ Step to next phase (in Phase 2) : to design 100-events-observation experiment with dedicated target and new detector

Contents

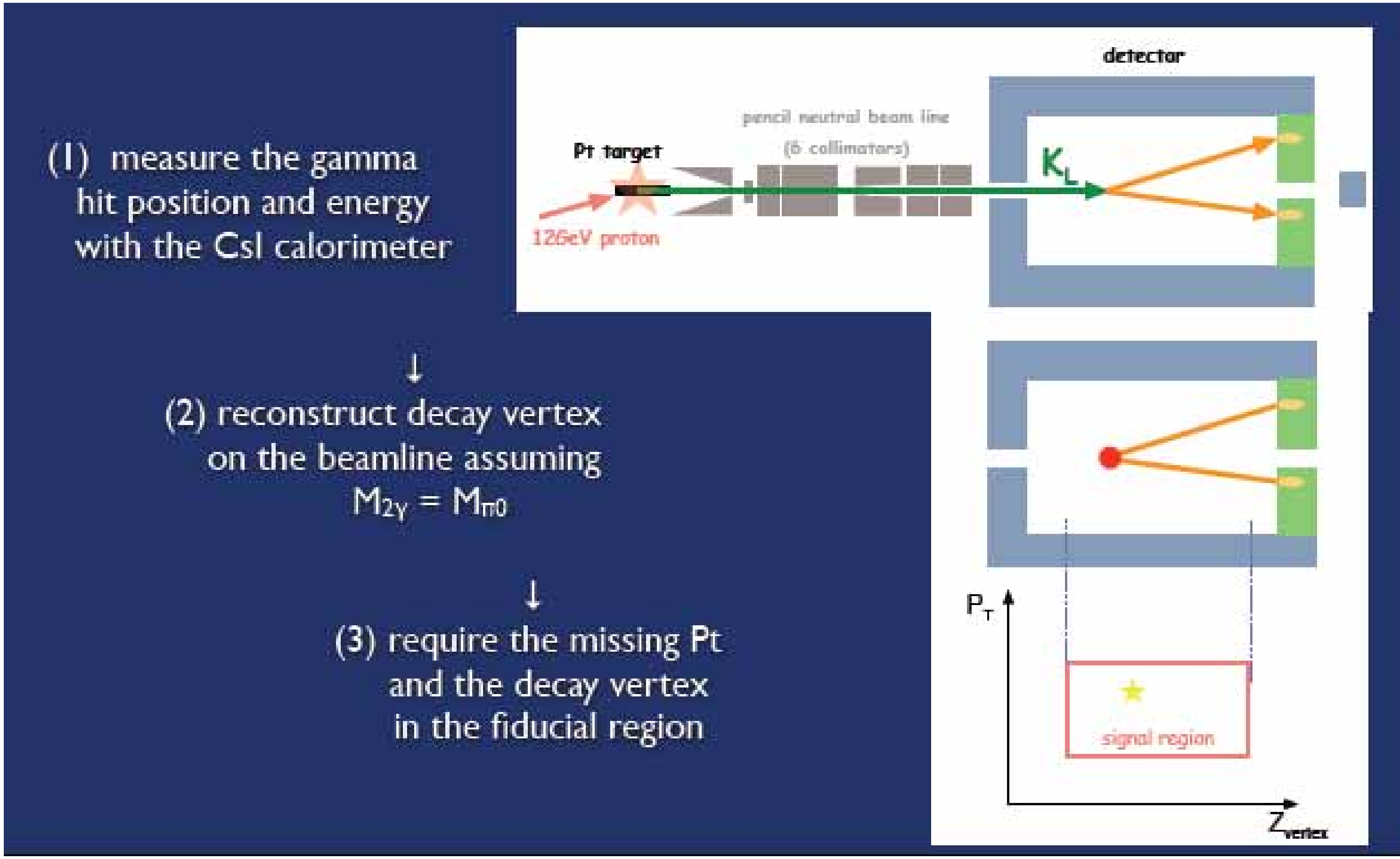
- KEK E391a Result
- E14 progress
  - Beam-line design
  - Updated signal / background estimation
  - Preparation of CsI calorimeter
- Plan
  - Schedule and funding

KEK E391a experiment



- Analysis using Run2 full data (Feb-Mar in 2005)
  - Accumulate 1.4×10^{18} POT, equivalent to ~30 days

E391a analysis method

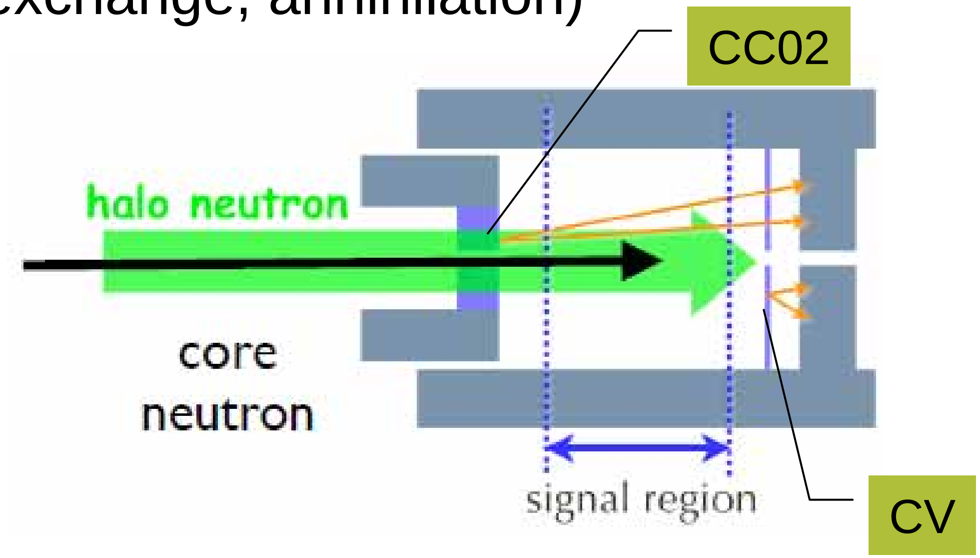


+ Develop analysis cuts with the signal region being masked.

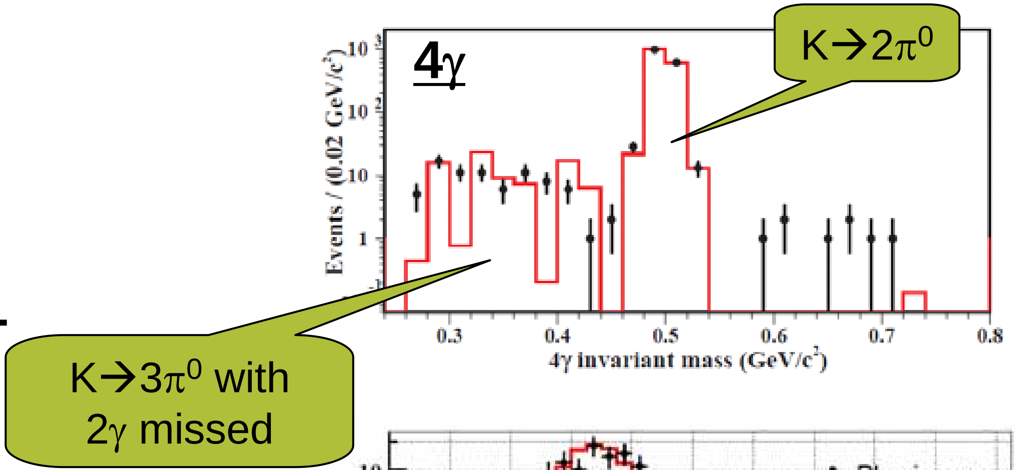
➔ Completely blind manner in this analysis!

Source of Background

- Kaon Decay
  - $K_L \rightarrow \pi^0\pi^0$ (2γ missed; due to inefficiency or fusion)
  - $K_L \rightarrow \pi^+\pi^-\pi^0$ (2 charged pion missed)
  - $K_L \rightarrow \pi^- e^+ \nu$ (charge exchange, annihilation)
- Halo neutron
  - Interact with "CC02","CV"
  - Produce π^0, η



E391a BGs



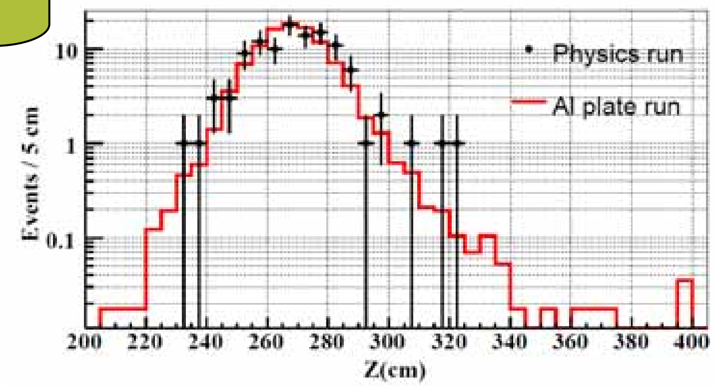
- BG estimation: 0.41

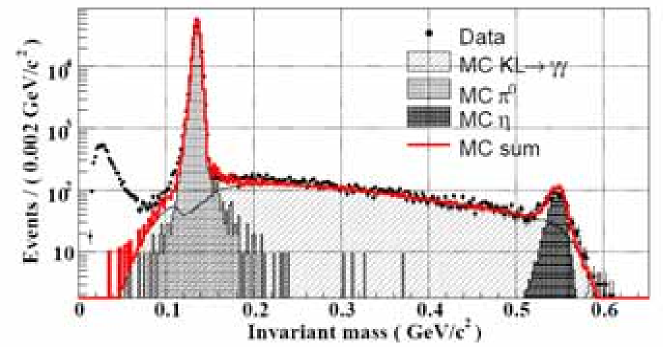
KL decay

  - Kπ2 BG: 0.11
    - MC (x11 statistics)
      - Photo veto examined by 4γ data

Halon

  - CC02 BG: 0.16
    - Tail evaluated by “Al plate” data
  - CV BG: 0.08
    - bifurcation
  - CV-η BG: 0.06
    - X-section eval’d by “Al plate run”



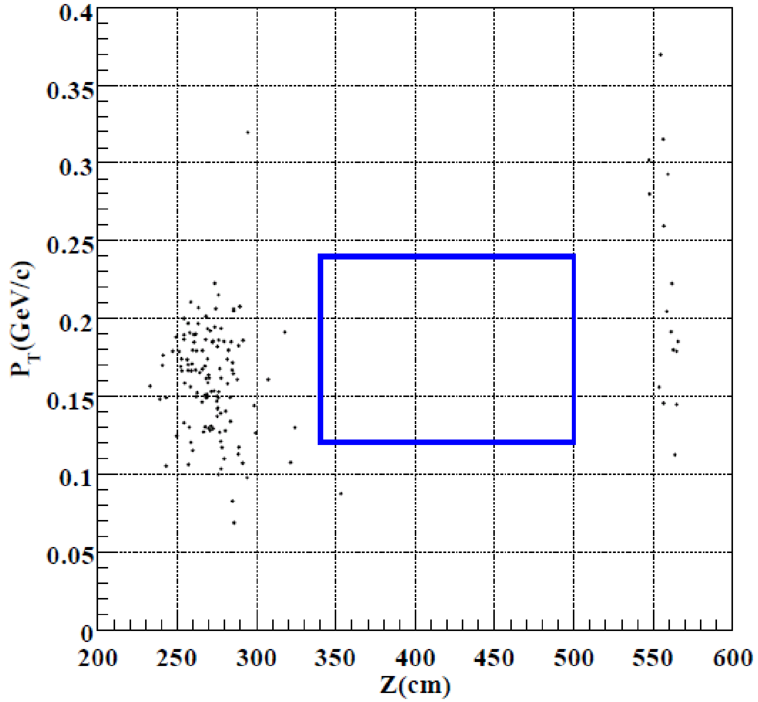


E391a Run-2 Result

- No events inside the box
- Sensitivity
  - N(K decay)=5.1×10^9
  - Acceptance=0.67%
    - Geometrical + Efficiency + Accidental loss
  - SES = 2.9×10^{-8}
- BR < 6.7×10^{-8} (90%CL)

➔ Submitted to PRL

(arXiv:0712.4164)



Seminar @ KEK 4-#345
on Jan 16 (Wed)

What we learned from E391a

- Understand BG sources and mechanisms
  - Found effective cuts
  - Find out effective upgrades to reduce BGs
    - Beam line, calorimeter, and “key” veto counters
- Best sensitivity estimation for E14
  - Need 10^3 better sensitivity for E14
    - KL yield (x40) x run time (x10)
    - Acceptance improvement
      - Can reduce loss due to “cluster shape cut” with finer CsI
      - Must reduce self-vetoing acceptance loss

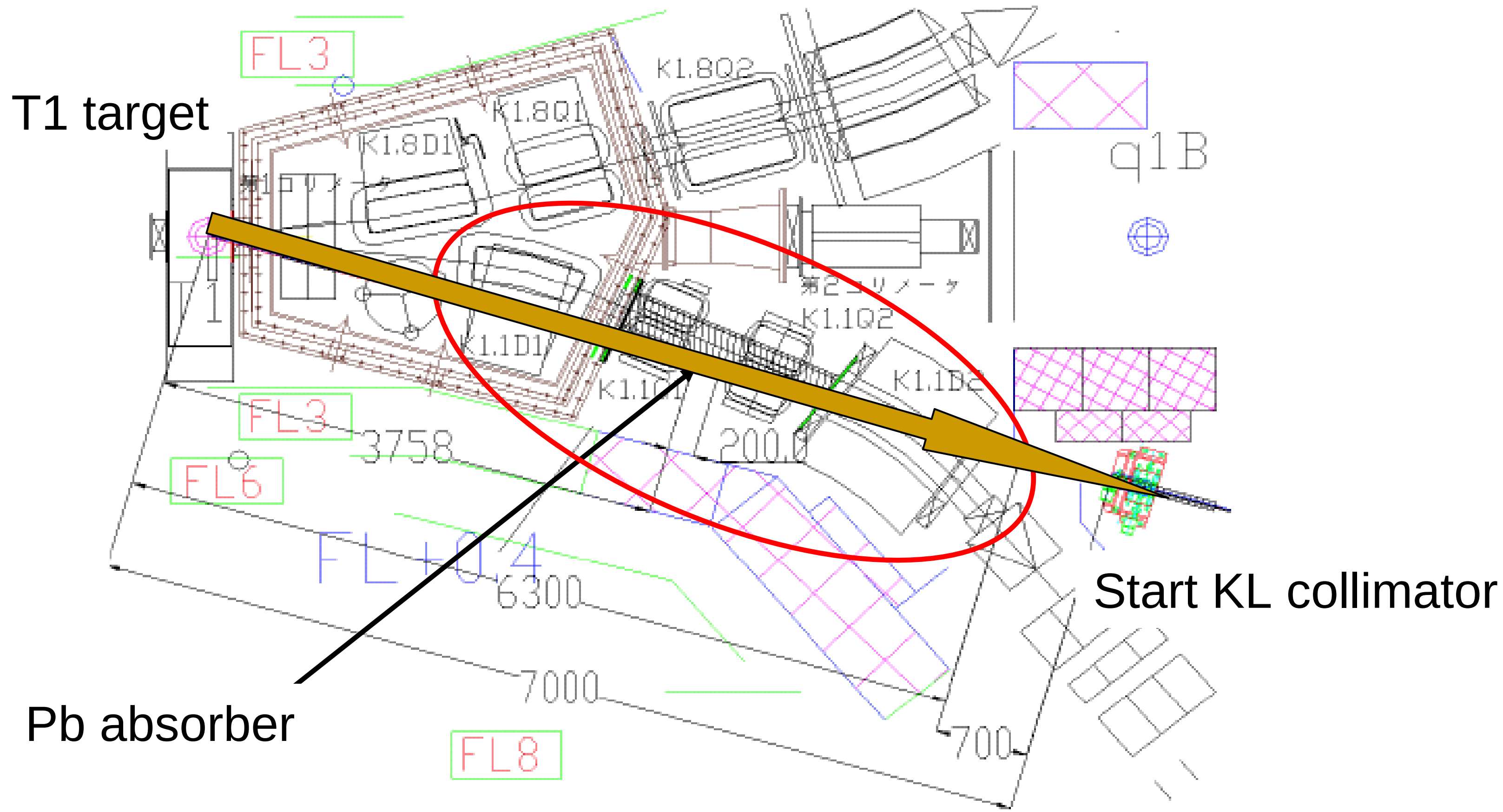
E14 progress (1)

Beam-line design

Status of Beam line design

- Design concept has been almost fixed
  by using GEANT-based simulation
- We have (at least) one design
  to improve halo/core ratio of E391a
- Further optimization in progress

Effect of upstream (K1.1) materials



Effect of K1.1 materials

- At least, modification of K1.1 materials are needed to retain K_L yield
- "KL alone" is most preferable from the view point of halo neutron flux

Table 3: Number of the core neutrons, halo neutorns and K_L's per spill (2×10^{14} protons) at the three different configurations.

	Core neutron ($E_n > 100MeV$)	halo neutron ($R > 8cm$ at CsI Surface, $P_n > 2GeV/c$)	K_L (At the exit of beam line)
KL line alone	3.21×10^8	$(0.72 \pm 0.15) \times 10^4$	$(7.79 \pm 0.11) \times 10^6$
modified K1.1	3.15×10^8	$(1.17 \pm 0.19) \times 10^4$	$(7.77 \pm 0.11) \times 10^6$
original K1.1	1.53×10^8	$(1.38 \pm 0.20) \times 10^4$	$(4.56 \pm 0.08) \times 10^6$

KL yield

- Depends on MC package
  - G4 / G3 / FLUKA

E391a

	K_L Yield per POT
Run-II data	$(1.36 \pm 0.08)\times10^{-7}$
GEANT3	$(1.32 \pm 0.03)\times10^{-7}$
GEANT4(QGSP)	$(1.31 \pm 0.11)\times10^{-7}$
GEANT4(QBBC)	$(1.54 \pm 0.12)\times10^{-7}$
FLUKA	$(1.40 \pm 0.02)\times10^{-7}$

E14

	K_L Yield per POT
GEANT3	$(3.8 \pm 0.1)\times10^{-8}$
GEANT4(QGSP)	$(2.3 \pm 0.1)\times10^{-8}$
GEANT4(QBBC)	$(2.7 \pm 0.3)\times10^{-8}$
FLUKA	$(8.3 \pm 0.2)\times10^{-8}$

→ We use G4 result as a default

← FLUKA may reproduce data according to production experiment (BNL-E802)

Further studies

- Round beam or Square beam?
  - No reason to keep axially symmetric shape in E14
    - Common T1 target, with production angle of 16 degree
      → Effective target image is horizontally long
  - Reason to consider square-shape:
    - Beam hole of the calorimeter is square (easy to construct)
    - Easier to fabricate long collimator with high accuracy
    - KL yield increases
    - Improve halo/core
- Collimator material (heavy metal or Fe?)

Plan of optimization

I. decision of "default setup"
   - square beam-hole + upstream material (without K1.1)

II. Size of Pb absorber

III. Collimator line
   - Front wedge (650~700 cmのsection)
   - Trimming line

IV. Position and length of collimator

V. To γ enhance & for K^0_L B.G.

-> allocate active collimator in end of collimator. (ex.sandwich)

-> allocate W in end of collimator.

VI. Determine collimator design (~08.Mar)

E14 progress (2)

Signal / background estimation updated

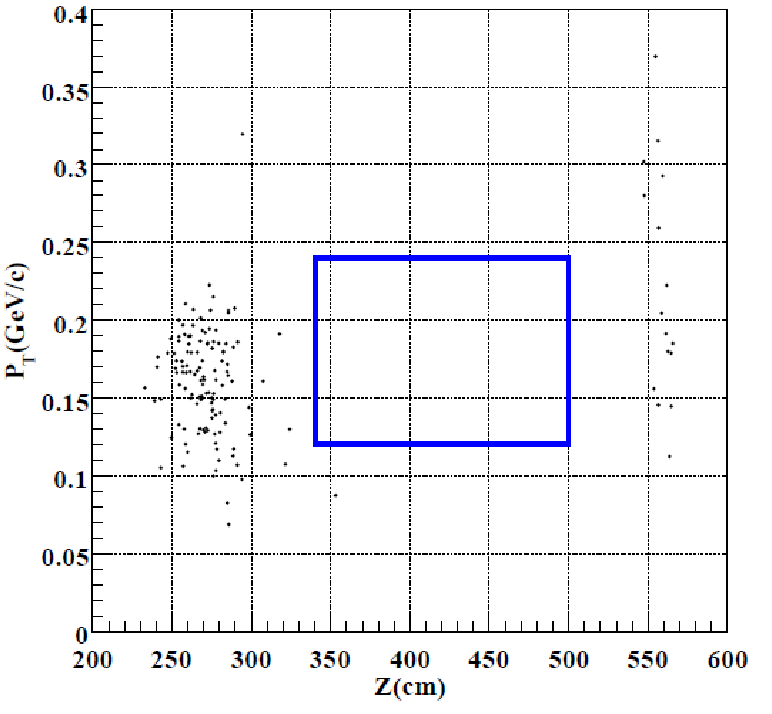
Signal / BG update summary

- Use KL / halo n yield
  from beam line simulation

- On the way to full simulation
  - Basically, we used "fast simulation"
    - Model functions for detector response
  - ➔ Partially, we used "full simulation"
    - Shower shape, extra particles in interactions, …

Again, E391a result

- E391a final plot
  - Upstream
    "CC02 BG" near the box
  - Downstream
    "CV BG"
  - Middle Z, from Low P_T
    likely "CV-η BG"
  - No Kaon BG at this level



Improvement E391a → E14

- Better beam line
  - Reduce halo neutron/KL ratio
  - Larger production angle (16 deg.), softer neutron
- Better reconstruction
  - Main calorimeter with longer and finer CsI crystals
- Improved photon vetoes
  - Longer CsI crystals for calorimeter
  - Thicker Main Barrel
  - New Beam Hole Photon Veto (BHPV)
  - Newly developed collar counters (NCC: made of CsI crystal)
- Charged veto reconfigured

Signal / Background Summary

- 3 snowmass years
- “KL alone” beamline

(KL yield based on GEANT4/QGSP)

		standard cuts	CsI cluster shape cut	acceptance loss (50%)
Signal	$K_L \to \pi^0 \nu \overline{\nu}$	6.0 ± 0.1	5.4 ± 0.1	2.70 ± 0.05
K_L BG	$K_L \to \pi^0 \pi^0$	3.7 ± 0.2	3.3 ± 0.2	1.7 ± 0.1
	$K_L \to \pi^+ \pi^- \pi^0$	0.18 ± 0.08	0.16 ± 0.07	0.08 ± 0.04
	$K_L \to \pi^- e^+ \nu_e$	0.13 ± 0.01	0.03 ± 0.003	0.02 ± 0.001
halo n BG	CV	—	—	0.08
	η	8.1	0.6	0.3

Note:
Detailed simulation of CV/CC02 BG in progress

$K_L \rightarrow \pi^0\pi^0$

Keys:
- Photon veto function
- Fusion function

- 3 categories
  - Even (2γ from 1π^0)
  - Odd (2γ from both π^0)
  - Fusion (at least 1γ fused with others)

Table 6: $K_L \rightarrow \pi^0\pi^0$ background with different fusion separation functions after the standard cuts.

	even	odd	fusion	total
KAMI function(default)	2.5 ± 0.1	0.03 ± 0.004	0.25 ± 0.06	2.8 ± 0.1
7×7-block χ^2	2.5 ± 0.1	0.03 ± 0.004	1.2 ± 0.1	3.7 ± 0.2
RMS	2.5 ± 0.1	0.03 ± 0.004	2 ± 0.2	4.5 ± 0.2

Numbers before “cluster shape cut” and acceptance loss correction

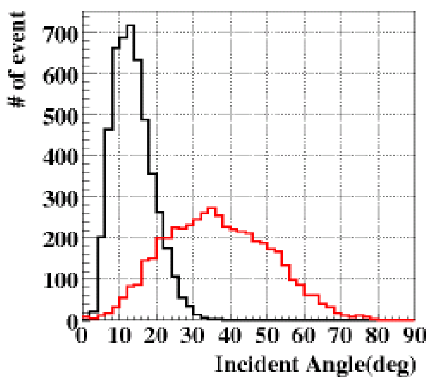
➔ Accounting these, 3.7 goes to 1.7

Kπ2 BG: 1.7

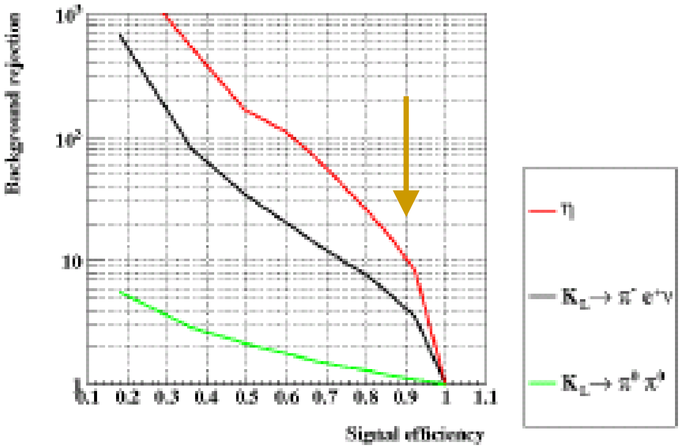
CV-η BG

- Effective cuts
  - Consistency of angle and shower shape
    “cluster shape cut” ➔ introduce ANN (Artificial Neural Net)

Cf.) Similar method $\chi^2(\theta)$ cut successfully reduce “η background” in E391a



True incident angle of signal (black) and η (red)



ANN :
BG Rejection
vs
signal acceptance

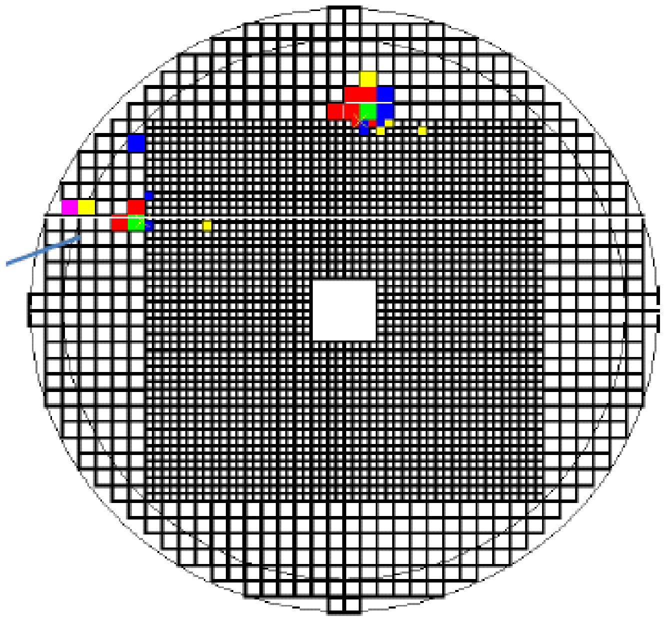
At inner CV x/y=12cm and outer CV z=50cm

η BG: 0.3

CC02 BG

- Based on G4 MC
  - x100 statistics
  - Photo-nuclear interaction included
- Reconstruction tail to signal box
  - Shower leakage (from front of CsI)
    ← Vetoed by MB
  - Photo-nuclear interaction
    ← "shower shape cut" is effective
- 0.01 event, in case of NCC

  Note: ~1 event in case of E391a CC02



CC02 BG: 0.01

Further effort to reduce BG

- MB upgrade
  - Original : Add layers outside of E391a MB
    ➔ Add finer sampling layers **<u>inside</u>** of E391a MB
    - To improve efficiency in low energy

  ← Effective to reduce $K\pi 2$ even BG

- Optimization of CV
  - Position, thickness, or even configuration

  ← Effective to reduce CV-π^0 and CV-η BG

E14 progress (3)

Preparation of CsI calorimeter

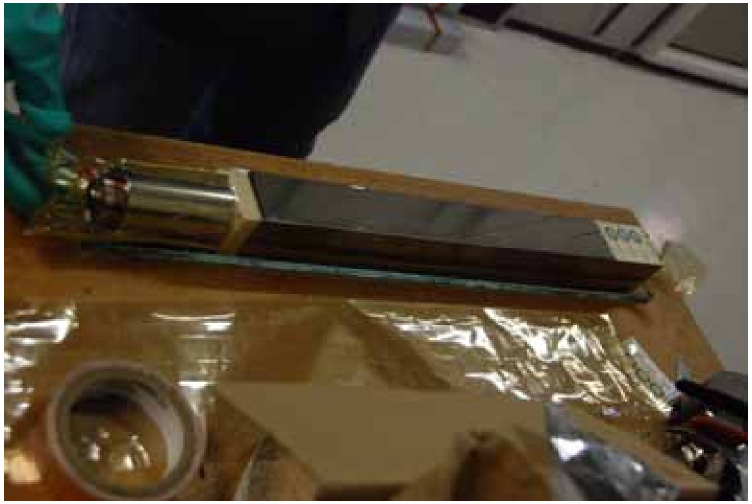
Preparation of CsI calorimeter

- CsI transfer
  - Procedure established
  - Phase 1 (~120 5cmx5cm blocks) in Feb 2008
- Readout R&D
  - 125MHz FADC
  - Beam test in Dec 2007
- Cockcroft-Walton PMT base
  - 1st prototype in Jan 2008

Rehearsal of CsI unstacking

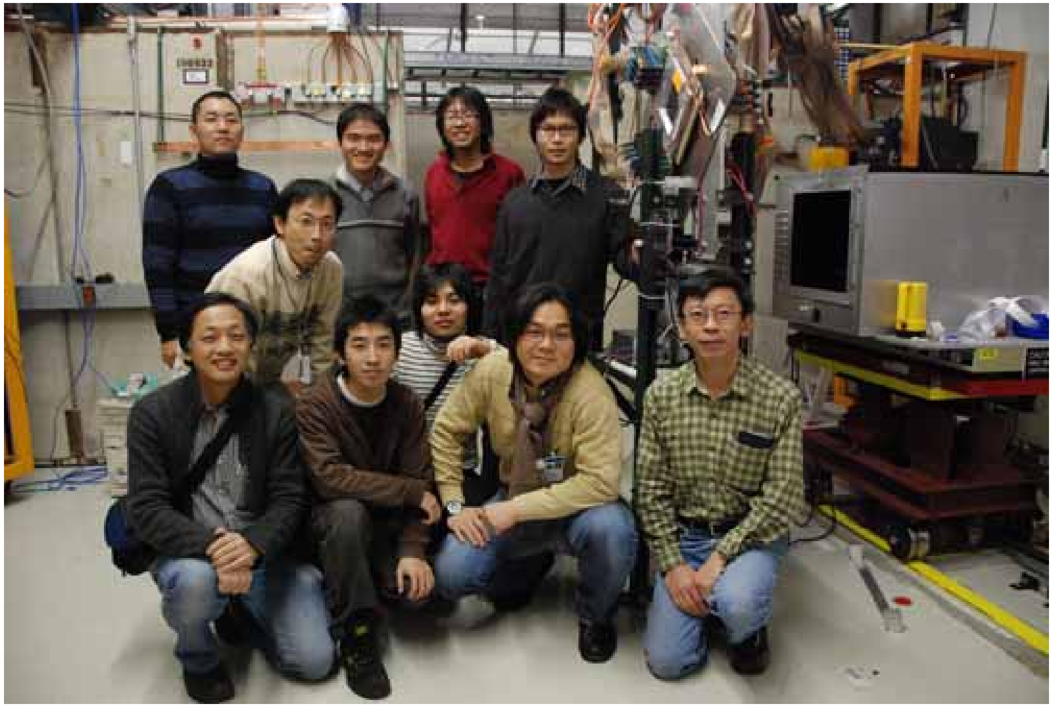
- At FNAL-KTeV hall in Dec 2007

And CsI packing



Test of CsI Readout

- Beam test at FNAL in Dec 2007
  - Using M-Test line
- 125MHz FADC
  - 16ch VME module
  - FPGA control

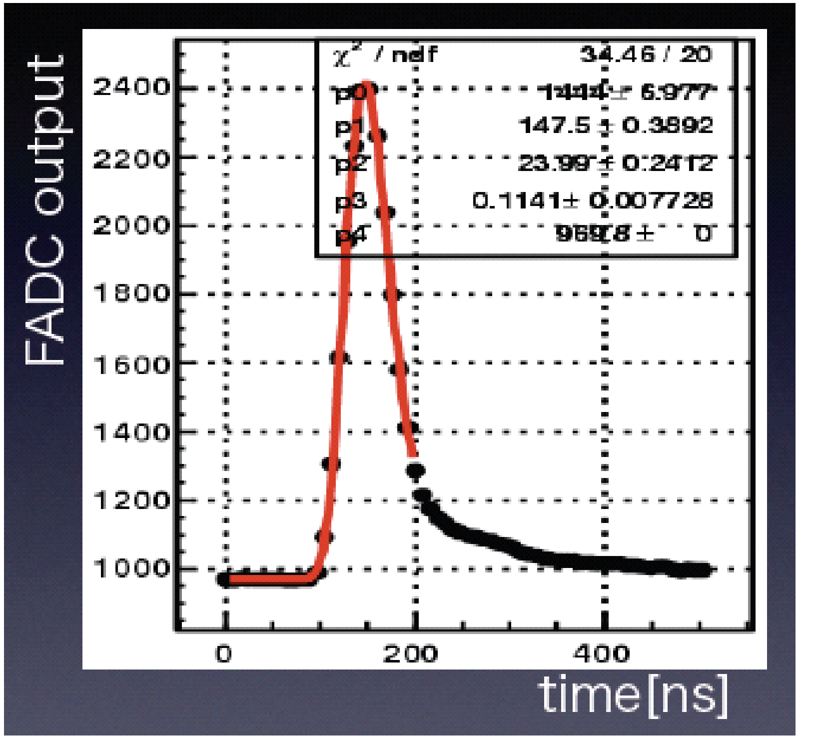


← Debugging

← Synchronization with usual DAQ system

Test of CsI Readout

- Prompt look at FADC output



The readout worked successfully.

Plan

Schedule & funding

Important milestone

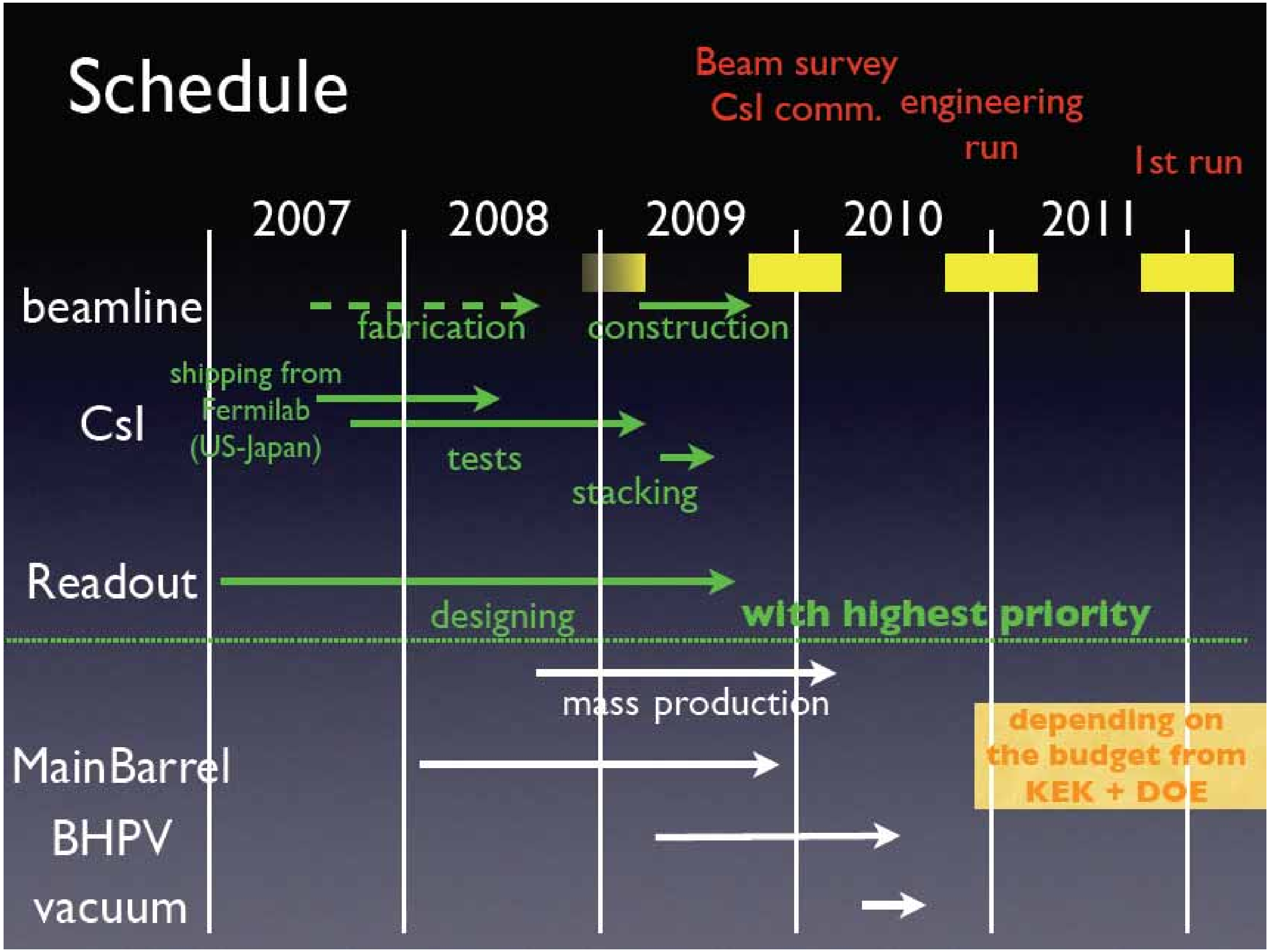
- Beam survey in autumn 2009

  ← Originally, we planned to do it early 2009,
  but consulting with beam channel group,
  we decide to delay it for half an year.

  - Not to conflict with K1.8 preparation
  - Realistic working schedule

- Purpose of the survey is to measure …
  - beam profile ← to know counting rate
  - KL yield ← to solve the ambiguity in MC packages
  - halo neutron ← to find out requirement to upstream K1.1 materials

Schedule digest



Funding scenario

Funding Scenario

2007-09: 2.29 Oku-yen in total

beamline w/ sweeping magnet
full experimental area

Unit: 10K yen~$0.1K

	sum	2007	2008	2009	2010	2011
sum	67109	6070	24036	21779	14244	980
Tokutei	27370	5120	10930	6890	3450	980
US/J	2450	950	1000	500		
KEK	17060		3880	8080	5100	
DOE	18229		7726	5309	5194	
G.in Aid	2000		500	1000	500	

CsI crystals
from Fermilab

Amounts in yellow are allocated

Summary

- E391a finished the analysis of Run2 data
  - No serious problem
  - BG well understood
- E14 steadily making progress in preparation
  - Beam-line design, as a first priority
  - Signal / background estimation,
    studied by fast simulation, step to full simulation
  - CsI preparation, in progress in this FY
- Plan
  - Important milestone: Beam survey in autumn 2009

End of my talk

Thank you for your attention.