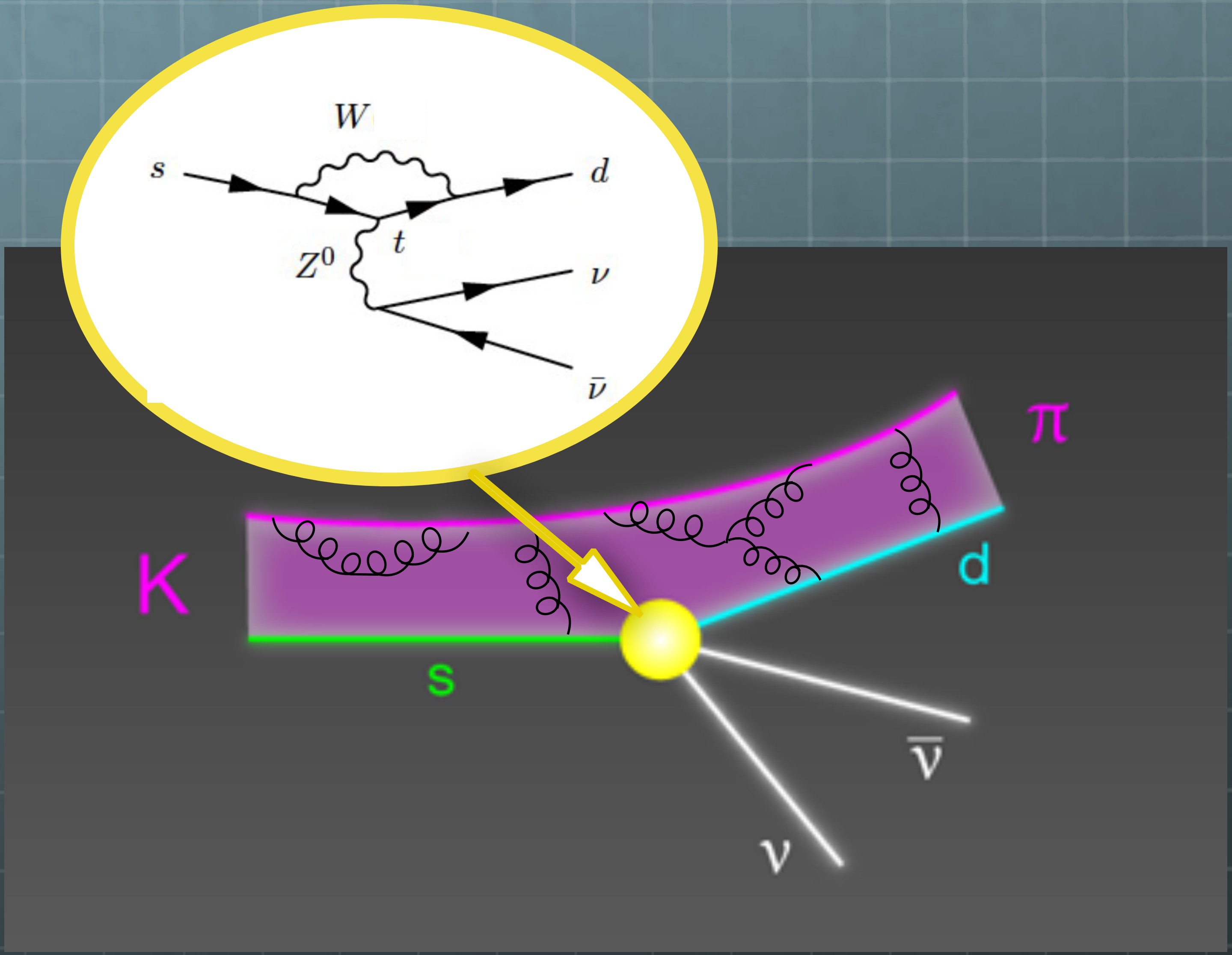
KOTO 국제공동실험의 형성과정과 각기관별 역할

GeiYoub Lim
IPNS, KEK

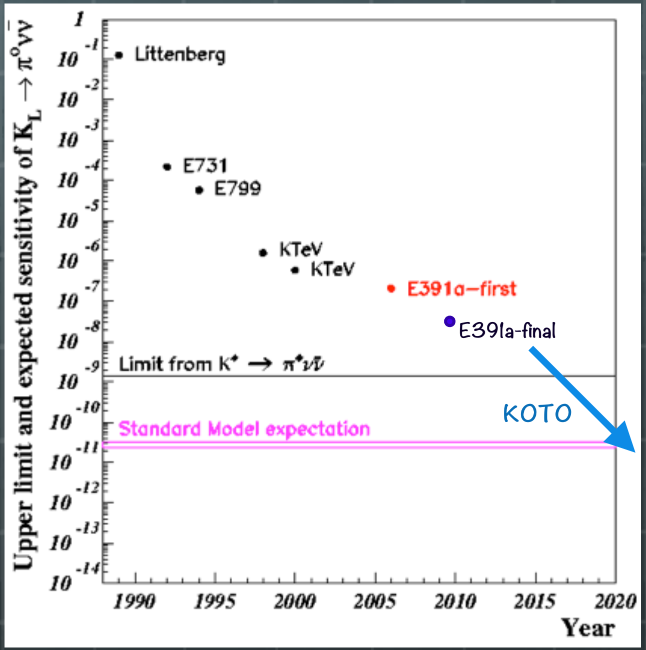
12th Oct. 2018 @ LAMPS Meeting

Flavor Changing neutral current



Signal of the $K_L \to \pi^0 \nu \bar{\nu}$ Decay

- No information of incident K_L
  - Only decaying particle is K_L in the neutral beam.
  - Momentum distribution can be obtained by using monitoring modes such as $K_L \to \pi^0 \pi^0 \pi^0$
- One clear π^0 and only one
  - Properly reconstruct π^0
    - $\pi^0 \to e^+ e^- \gamma, \ \pi^0 \to \gamma\gamma$
  - No any other decay products
    - Hermetic veto detector



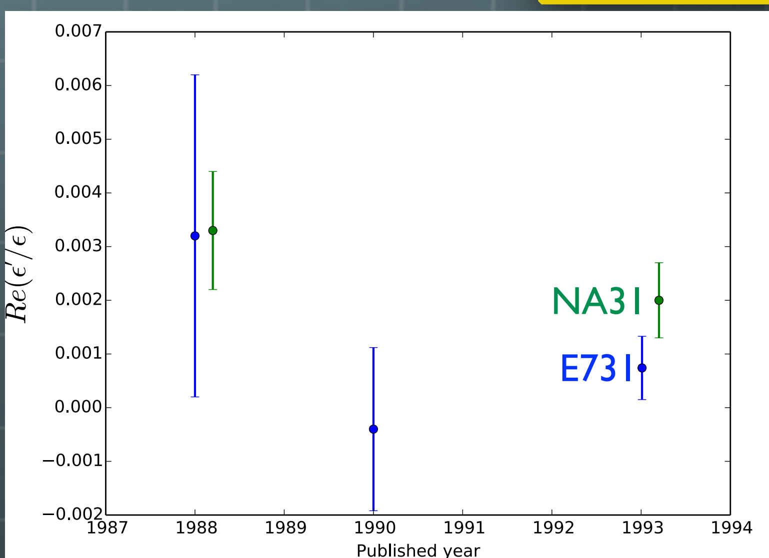
PHYSICAL REVIEW D VOLUME 39, NUMBER 11 1 JUNE 1989

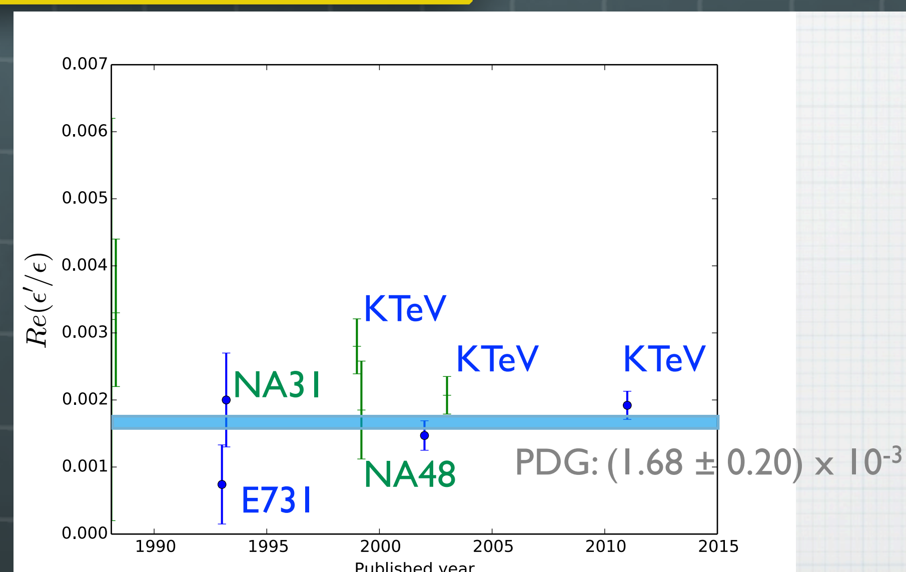
CP-violating decay $K_L^0 \to \pi^0 \nu\bar{\nu}$

Laurence S. Littenberg
Department of Physics, Brookhaven National Laboratory, Upton, New York 11973
(Received 6 January 1989)

The process $K_L^0 \to \pi^0 \nu\bar{\nu}$ offers perhaps the clearest window yet proposed into the origin of *CP* violation. The largest expected contribution to this decay is a direct *CP*-violating term at $\approx$few$\times 10^{-12}$. The indirect *CP*-violating contribution is some *3 orders of magnitude* smaller, and *CP*-conserving contributions are also estimated to be extremely small. Although this decay has never been directly probed, a branching ratio upper limit of $\sim 1\%$ can be extracted from previous data on $K_L^0 \to 2\pi^0$. This leaves an enormous range in which to search for new physics. If the Kobayashi-Maskawa (KM) model prediction can be reached, a theoretically clean determination of the KM product $\sin\theta_2 \sin\theta_3 \sin\delta$ can be made.

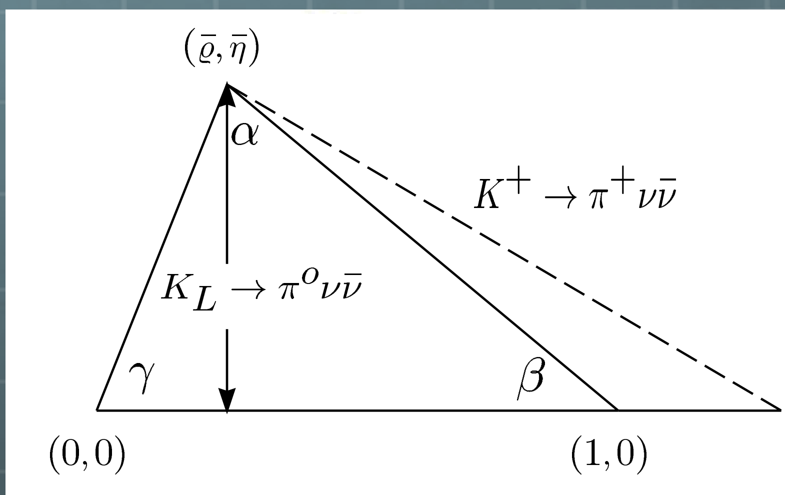
Searching for Direct CP-violation



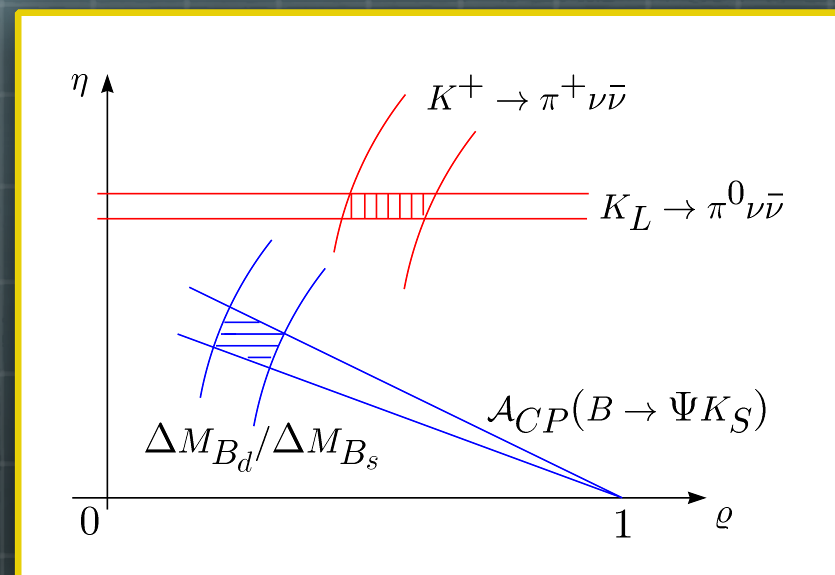


T. Yamanaka , 50 Years of CP Violation

Unitarily Triangles and New physics beyond SM



$$B(K_L^0 \to \pi^0 \nu\bar{\nu}) = 1.94 \cdot 10^{-10} \eta^2 A^4 X^2(x_t)$$



G. Buchalla arXiv:0110313

The most suppressed FCNC

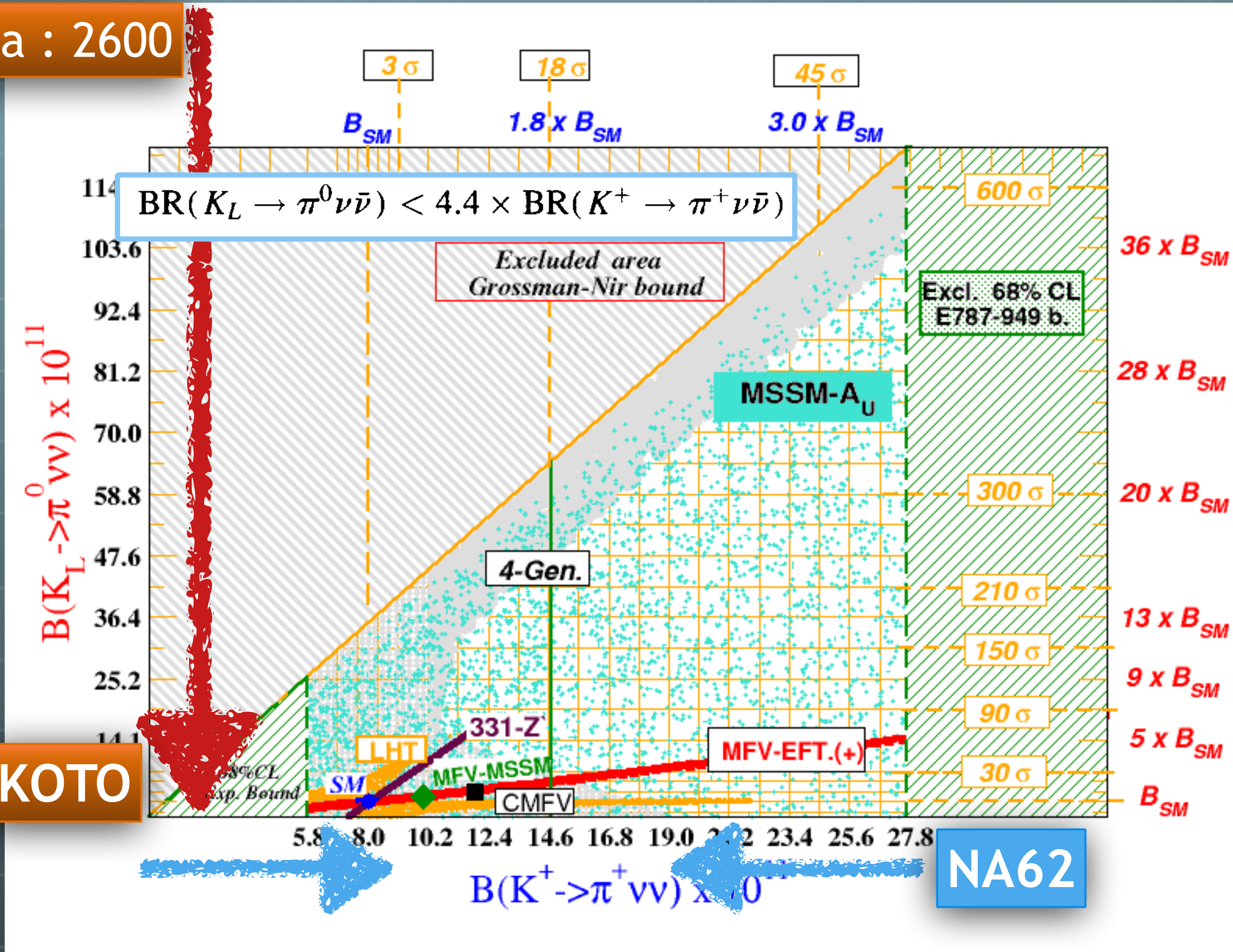
$$\underbrace{|V_{ts}^* V_{td}|}_{K \text{ system}} \sim 5 \cdot 10^{-4} \ll \underbrace{|V_{tb}^* V_{td}|}_{B_d \text{ system}} \sim 10^{-2} < \underbrace{|V_{tb}^* V_{ts}|}_{B_s \text{ system}} \sim 4 \cdot 10^{-2},$$

The largest deviations from the SM prediction in Kaon sector.

$$\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

M. Blanke, arXiv:1305.5671v1

E391a : 2600



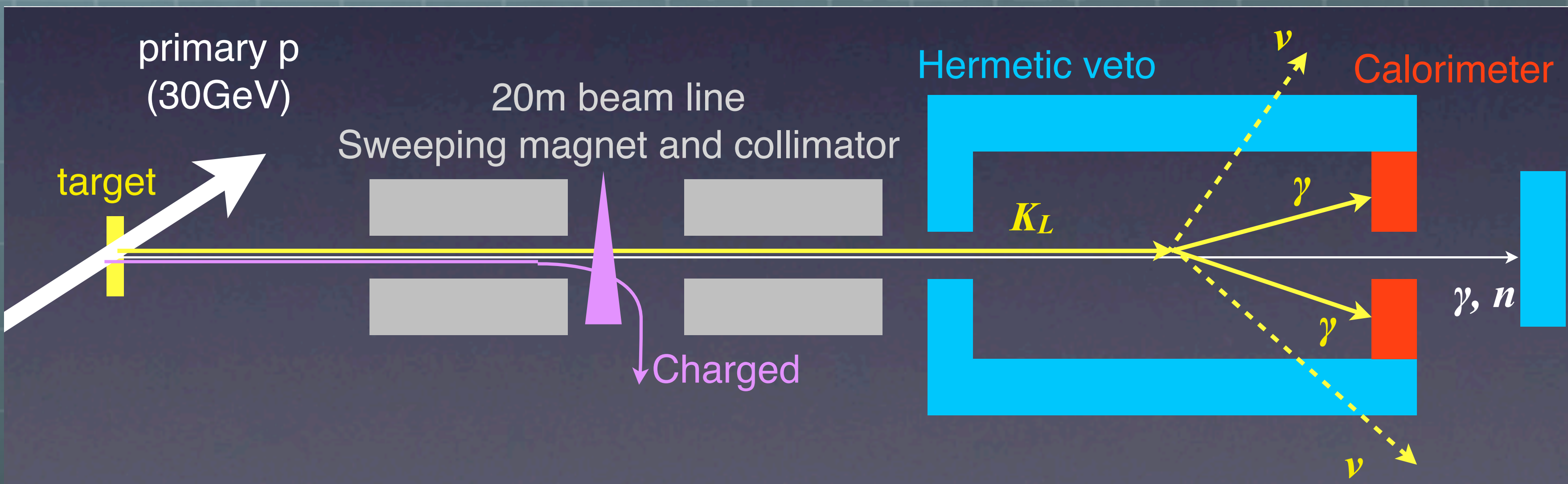
$$\mathrm{BR}(K_L \to \pi^0 \nu\bar{\nu}) < 4.4 \times \mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu})$$

KOTO

NA62

http://www.lnf.infn.it/wg/vus/content/Krare.html

Experimental Method



2γ+ Nothing

Signal of the $K_L \rightarrow \pi^0 \nu \bar{\nu}$ Decay

- No information of incident K_L
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  - Momentum distribution can be obtained by using monitoring modes such as $K_L \rightarrow \pi^0\pi^0\pi^0$
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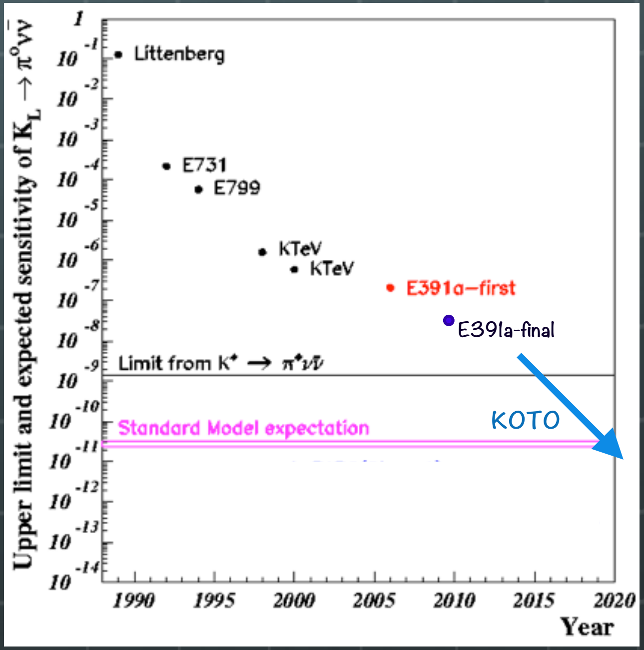
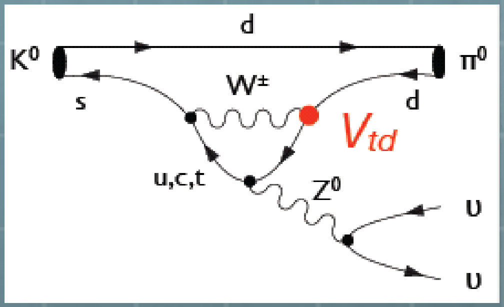
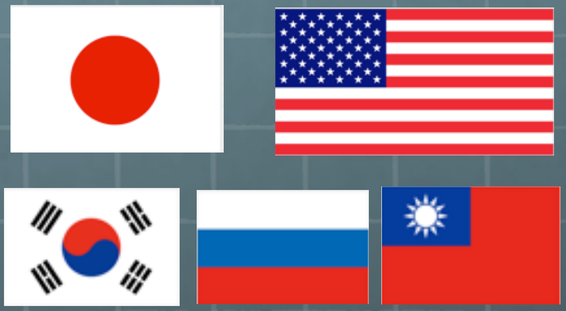




K0 at TOkai



PTEP

Prog. Theor. Exp. Phys. **2017**, 021C01 (11 pages)
DOI: 10.1093/ptep/ptx001

Letter

A new search for the $K_L \to \pi^0 \nu\bar{\nu}$ and $K_L \to \pi^0 X^0$ decays

J-PARC KOTO Collaboration
J. K. Ahn[1], K. Y. Baek[2], S. Banno[3], B. Beckford[4], B. Brubaker[5,19], T. Cai[5,20], M. Campbell[4], C. Carruth[4,21], S. H. Chen[6], S. Chu[5], J. Comfort[7], Y. T. Duh[6], T. Furukawa[8], H. Haraguchi[3], T. Hineno[9], Y. B. Hsiung[6], M. Hutcheson[4], T. Inagaki[10], M. Isoe[3], E. Iwai[3,22], T. Kamibayashi[11], I. Kamiji[9], N. Kawasaki[9], E. J. Kim[12], Y. J. Kim[13], J. W. Ko[13], T. K. Komatsubara[10,14], A. S. Kurilin[15,†], G. H. Lee[12], H. S. Lee[16], J. W. Lee[3,23], S. K. Lee[12], G. Y. Lim[10,14], C. Lin[6], J. Ma[5], Y. Maeda[9,24,*], T. Masuda[9,25], T. Matsumura[17], D. Mcfarland[7], J. Micallef[4,26], K. Miyazaki[3], K. Morgan[5,27], R. Murayama[3], D. Naito[9,28], K. Nakagiri[9], Y. Nakajima[9,29], Y. Nakaya[3,†] H. Nanjo[9,30], T. Nomura[10,14], T. Nomura[11], Y. Odani[8], R. Ogata[8], H. Okuno[10], T. Ota[8], Y. D. Ri[3], M. Sasaki[11], N. Sasao[18], K. Sato[3,29], T. Sato[10], S. Seki[9], T. Shimogawa[8,28], T. Shinkawa[17], S. Shinohara[9], K. Shiomi[3,31], J. S. Son[12], J. Stevens[7,32], S. Su[4], Y. Sugiyama[3,28], S. Suzuki[8], Y. Tajima[11], G. Takahashi[9], Y. Takashima[3], M. Tecchio[4], I. Teo[5,33], M. Togawa[3], T. Toyoda[3], Y. C. Tung[6,34], T. Usuki[9], Y. W. Wah[5], H. Watanabe[10,14], N. Whallon[4,35], J. K. Woo[13], J. Xu[4], M. Yamaga[3,36], S. Yamamoto[8], T. Yamanaka[3], H. Yamauchi[8], Y. Yanagida[3], H. Yokota[17], H. Y. Yoshida[11], and H. Yoshimoto[3]

Proposal of an Experiment at the KEK 12GeV Proton Synchrotron

Measurement of the $K_L^0 \to \pi^0 \nu \overline{\nu}$ decay

Takao Inagaki, Nobuhiro Ishihara, Takahiro Sato,
Takao Shinkawa, Junpei Shirai and Yoshio Yoshimura

Physics Department,

National Laboratory for High Energy Physics (KEK)

Shuhei Ajimura and Takashi Nakano

Physics Department,

Osaka University

7 June, 1996

only 8 members from 2 institutes

Approved at July, 2001.

Two issues

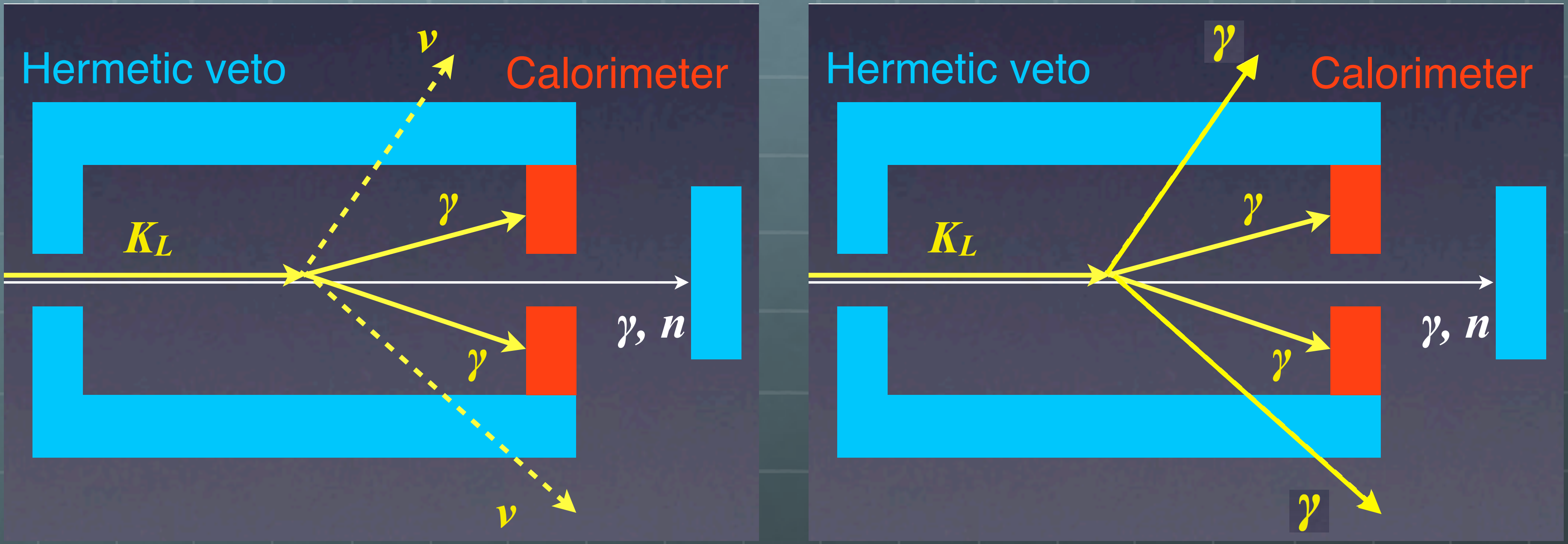
$$K_L \to \pi^0 \nu \bar{\nu}$$

- Photon detection inefficiency
- Pencil beam

5 years to get approval !

KEK-PS E391a

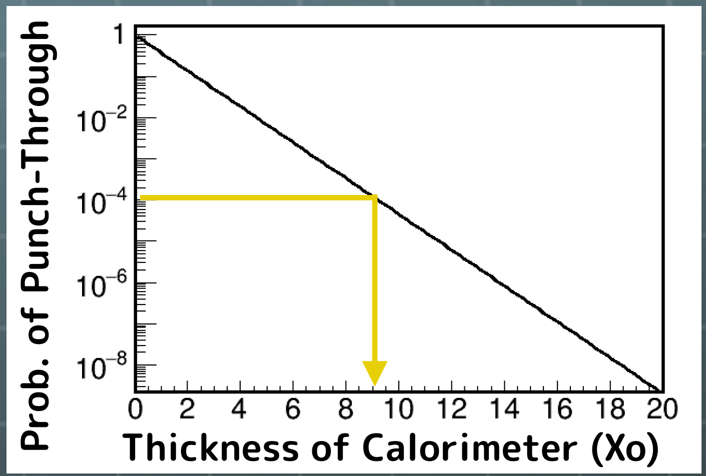
$K_L \to \pi^0 \pi^0$ Background ?



- When we miss 2 gammas among 4 gammas generated at the $K_L \to \pi^0 \pi^0$ decay.
- $Br(K_L \to \pi^0 \pi^0)/Br(K_L \to \pi^0 \nu\bar{\nu}) = 2.6 \times 10^7$
- We have to detect gamma with inefficiency less than 10^{-4}

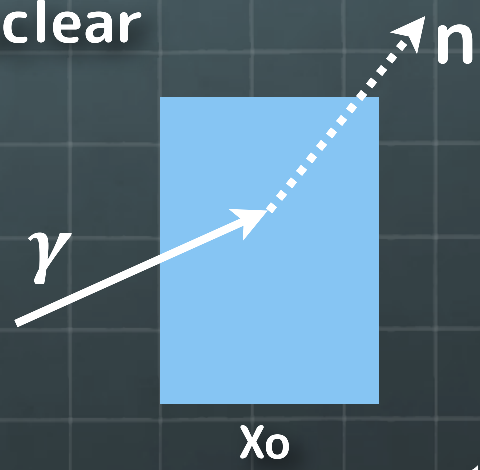
Why we miss the gamma ?

- Punch-through



Detailed study using M.C.

- Photo-nuclear



Energy dependent

(GDR and Delta resonate)

Doubtable M.C. calculation

Inefficiency measurement

Electron beam from INS 1.3-GeV ES

Photon tagging system,

32 +8 (backing) counters,

detects recoil electrons after

bremsstrahlung.)

Samples were placed behind a shield

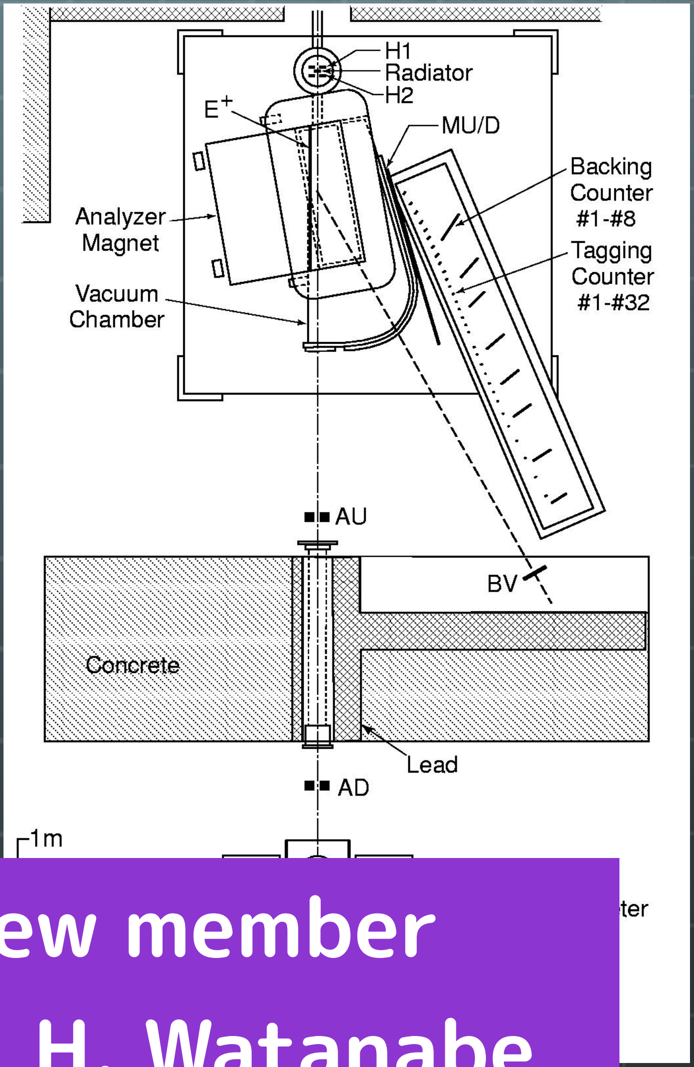
through active collimation.

Still not so perfect photon-tagging to

make a direct measurement of

inef

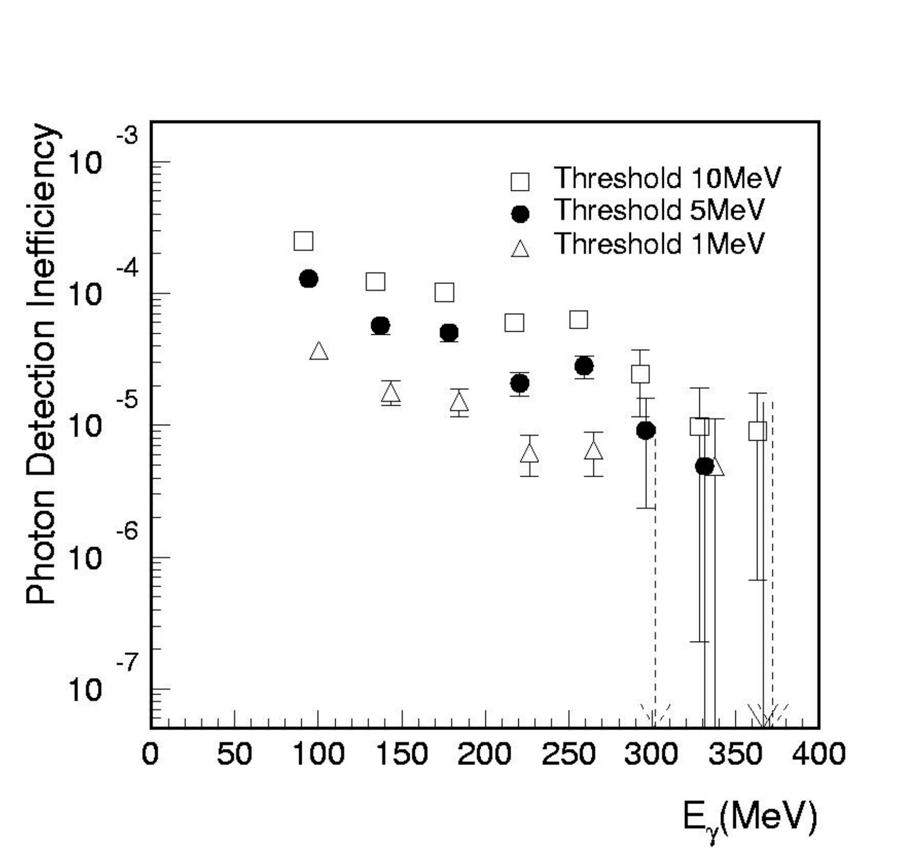
exis



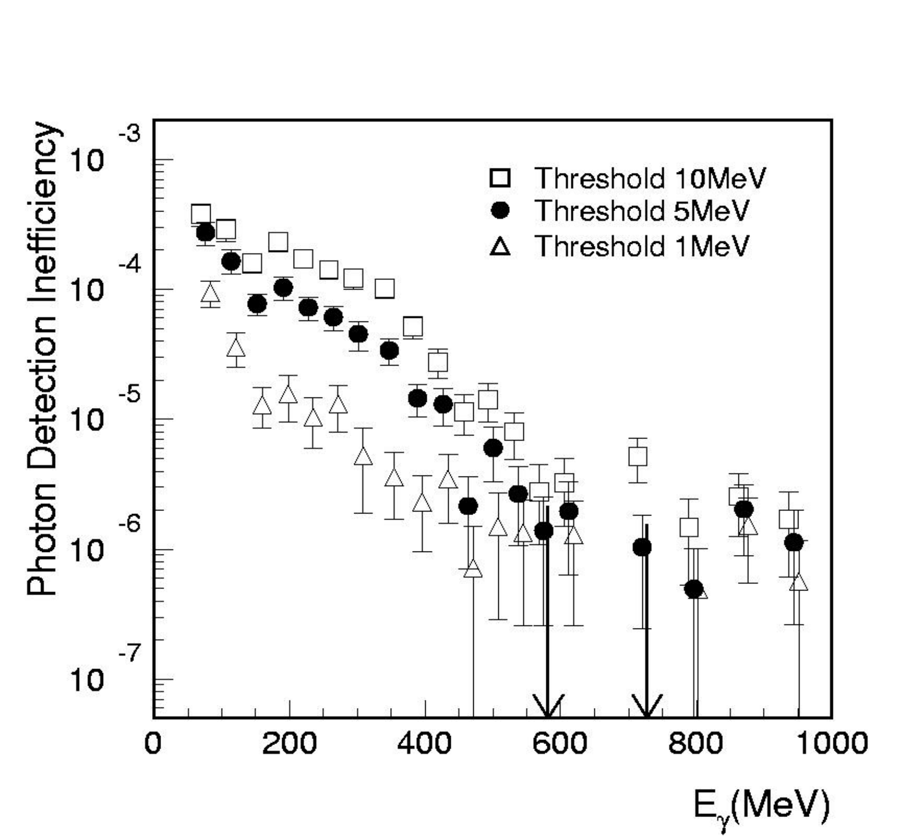
Important to invite new member

-> Saga Univ. joint : H. Watanabe

CsI Calorimeter



Lead-Scin. Sampling calorimeter



Two issues

- Photon detection inefficiency
- Pencil beam ←—— My participation

5 years to get approval !

Request a young staff:
—> real start of the experiment

KAON'99
June 22, 1999
Univ. of Chicago

Transverse Muon Polarization (P_T) in $K^+ \rightarrow \pi^o \mu^+ \nu$ ($K_{\mu 3}$) Decay

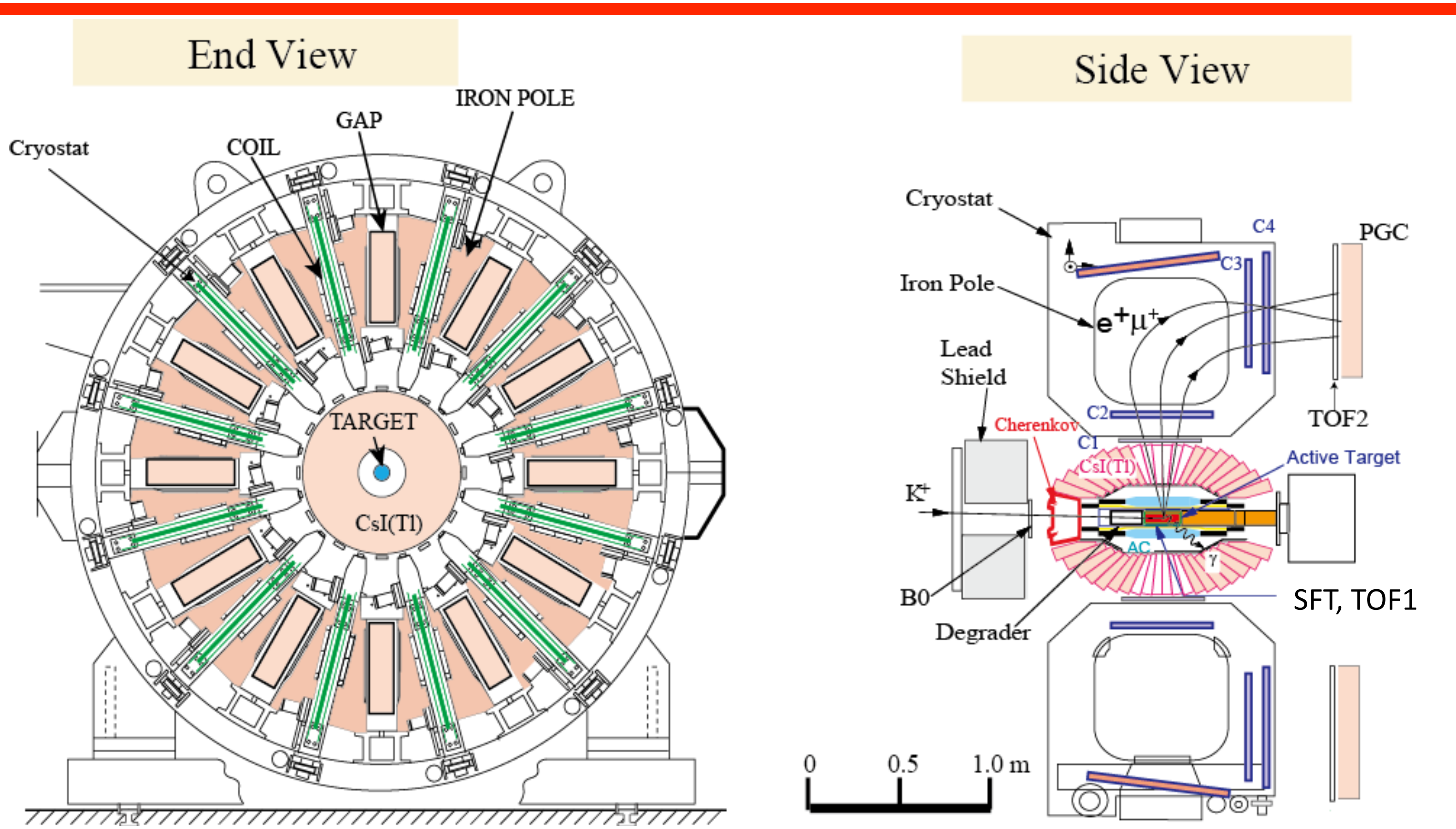
(KEK-PS E246 Collaboration)

Introduction
Experiment
Analysis
Systematics
First results from 1996-97 data

Gei-Youb Lim
IPNS, KEK

Dec. 1995 Post-doc.

The TREK apparatus for E36



Reasonable upgrade of KEK-PS E246

Stopped K method
- K1.1BR beamline
- Fitch Cherenkov
- K^+ stopping target

Tracking
- MWPC (C2, C3, C4)
- Spiral Fiber Tracker(SFT)

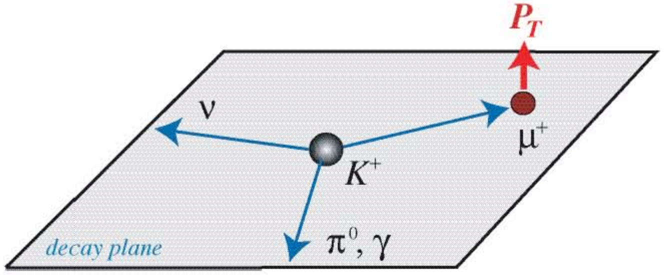
PID
- TOF1,2
- Aerogel Cherenkov (AC)
- Pb glass counter (PGC)

Gamma ray
- CsI(Tl)

Transverse μ^+ polarization in $K_{\mu 3}$

$K^+ \to \pi^0 \mu^+ \nu$ decay

$$P_T = \frac{\sigma_\mu \cdot (p_{\pi^0,\gamma} \times p_{\mu^+})}{|(p_{\pi^0,\gamma} \times p_{\mu^+})|}$$



- P_T is T-odd, and spurious effects from final state interaction are small: $P_T(\mathrm{FSI}) < 10^{-5}$

  Non-zero P_T is a signature of T violation.

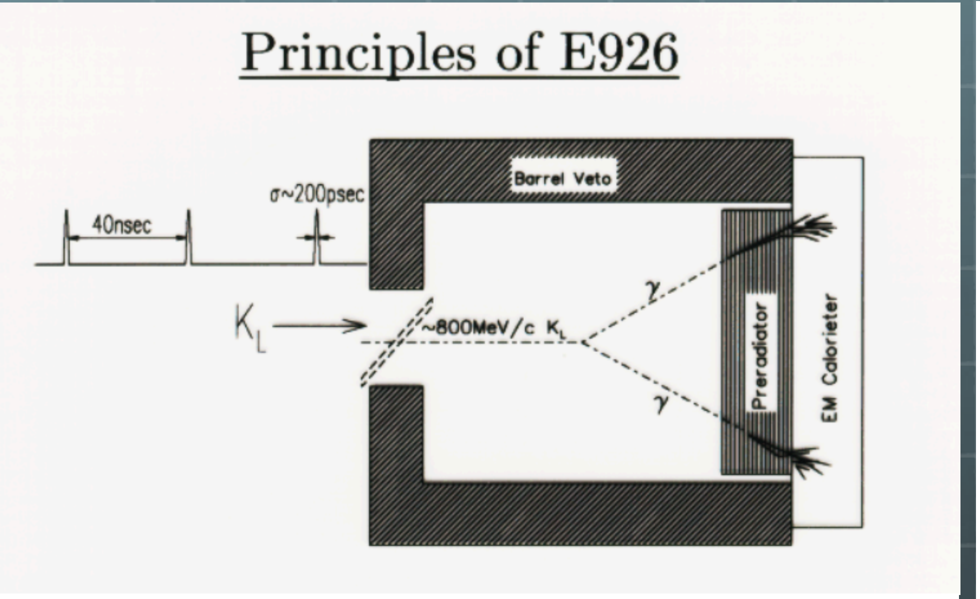
- Standard Model (SM) contribution to P_T : $P_T(\mathrm{SM}) < 10^{-7}$

  P_T in the range 10^{-3}~10^{-4} is a sensitive probe of CP violation beyond the SM.

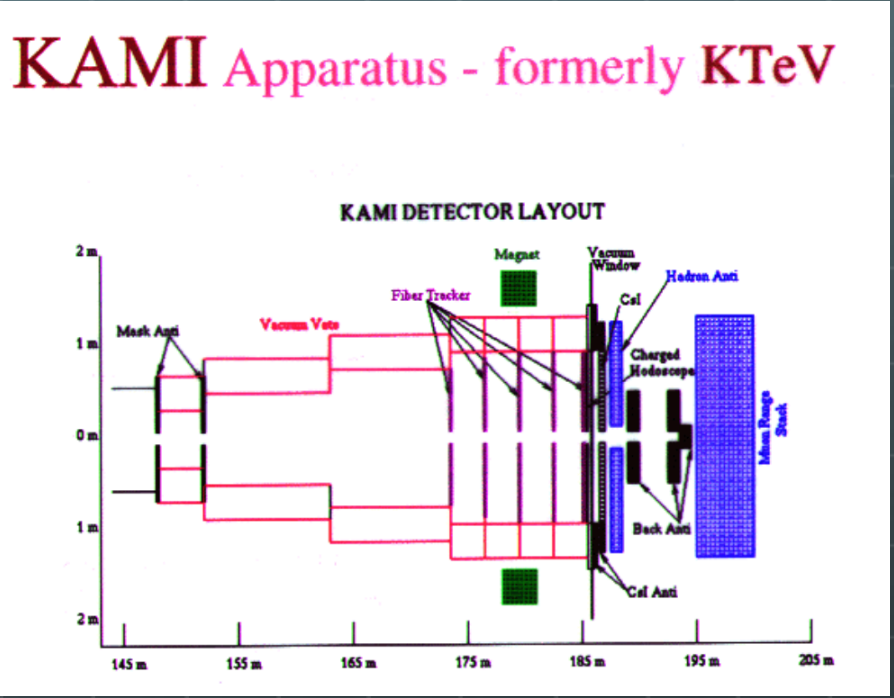
- There are theoretical models of new physics which allow a sizable P_T without conflicting with other experimental constraints.

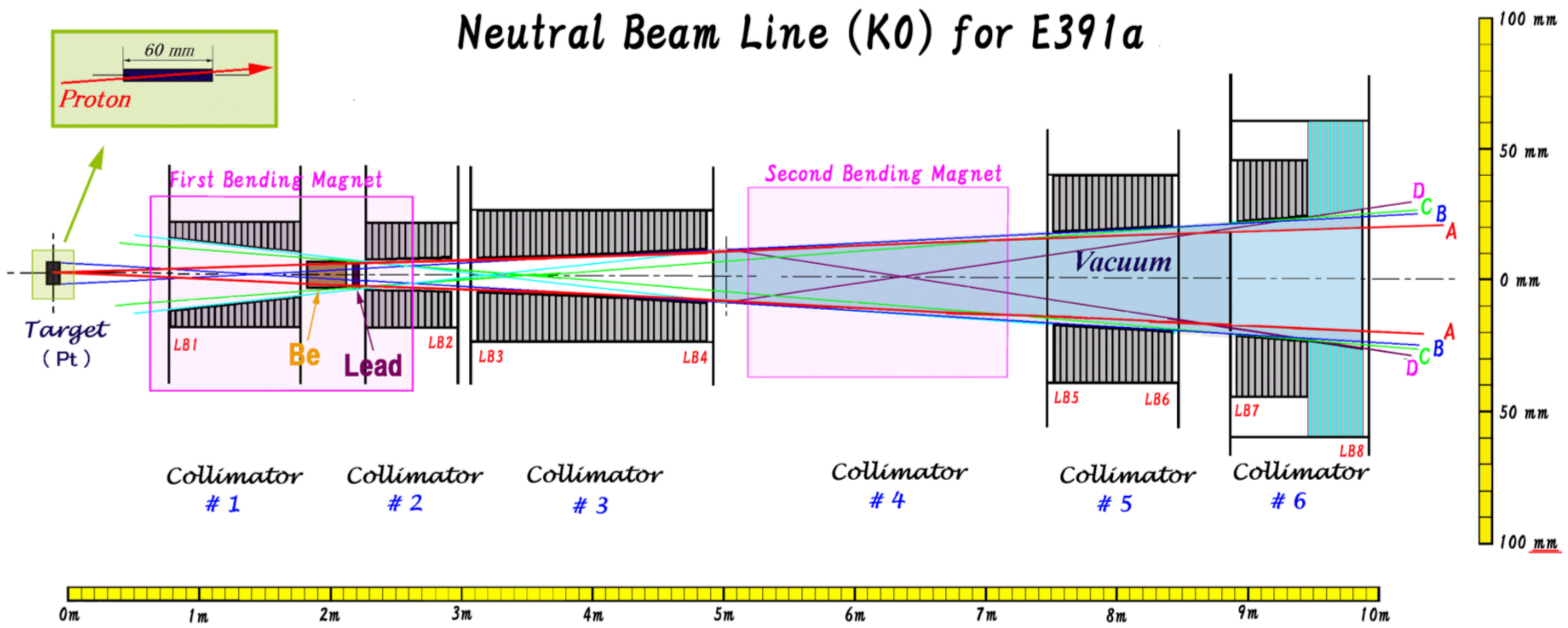
4

Plans @ USA



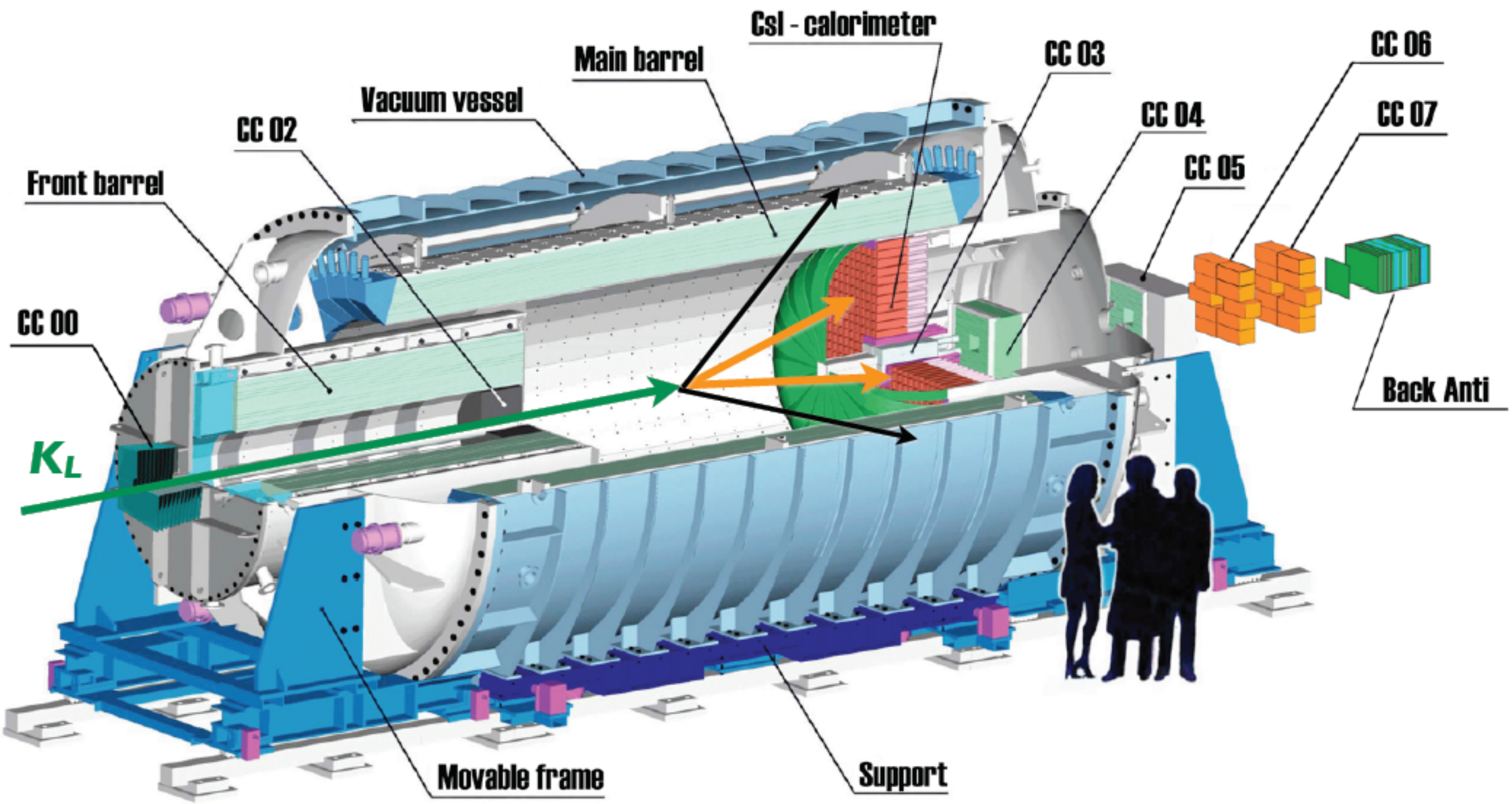
KOPIO @ BNL



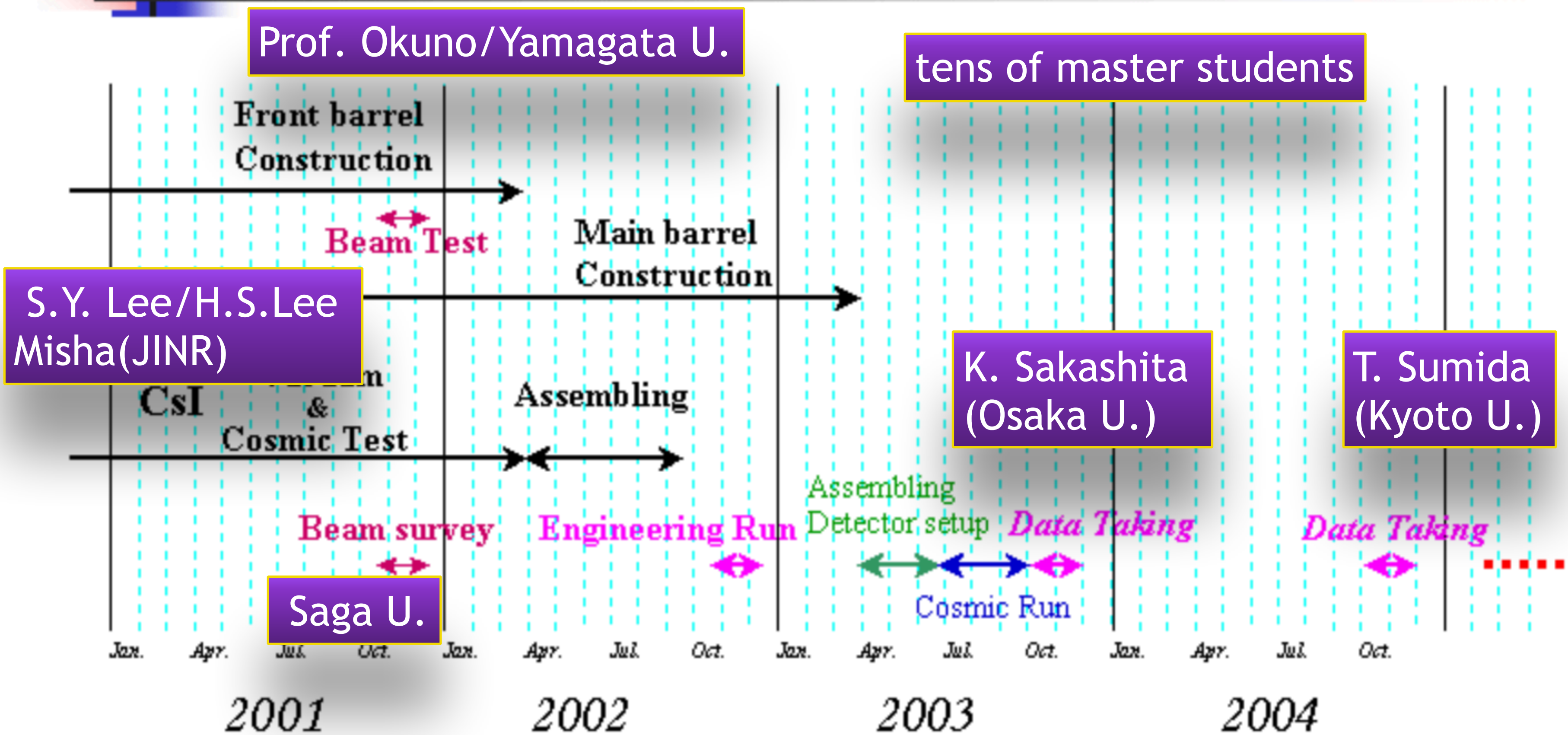


- ~ 2 years work
- Every things are new experience
  - Interesting period to study many things!

The E391a Detector



Schedule



G.Y.Lim @ Oct. 2001

図 3　積み上げ完成記念写真（2002 年 9 月 20 日）

Neutral beam line to study $K_L^0 \to \pi^0 \nu \bar{\nu}$ decay at the KEK 12-GeV proton synchrotron

H. Watanabe[a,*], K. Abe[i], Y. Aikawa[i], Y. Akune[i], M. Doroshenko[c], E. Harada[i], Y. B. Hsiung[b], T. Ikei[g], Y. Ikemoto[g], S. Inoue[i], T. Inagaki[c], N. Kawakubo[i], S. Kobayashi[i], T. Kojima[i], A.S. Kurilin[e], S.Y. Lee[h], G.Y. Lim[c], J. Nix[a], I. Ogawa[i], H. Okuno[c], K. Omata[c], T. Oba[g], G. N. Perdue[a], K. Sakashita[g], T. Sato[c], T. Shinkawa[f], Y. Sugaya[g], T. Sumida[d], Z. Tsamalaidze[e] T. Tsukamoto[i], Y. W. Wah[a], M. Yamaga[c], T. Yamanaka[g], Y. Yoshimura[c]

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69 authors

PHYSICAL REVIEW D **81,** 072004 (2010)

Experimental study of the decay $K_L^0 \to \pi^0 \nu \bar{\nu}$

J. K. Ahn,[1] Y. Akune,[2] V. Baranov,[3] K. F. Chen,[4] J. Comfort,[5] M. Doroshenko,[6,*] Y. Fujioka,[2] Y. B. Hsiung,[4] T. Inagaki,[6,7] S. Ishibashi,[2] N. Ishihara,[7] H. Ishii,[8] E. Iwai,[8] T. Iwata,[9] I. Kato,[9] S. Kobayashi,[2] S. Komatsu,[8] T. K. Komatsubara,[7] A. S. Kurilin,[3] E. Kuzmin,[3] A. Lednev,[10,11] H. S. Lee,[1] S. Y. Lee,[1] G. Y. Lim,[7] J. Ma,[11] T. Matsumura,[12] A. Moisseenko,[3] H. Morii,[13] T. Morimoto,[7] Y. Nakajima,[13] T. Nakano,[14] H. Nanjo,[13] N. Nishi,[8] J. Nix,[11] T. Nomura,[13,†] M. Nomachi,[8] R. Ogata,[2] H. Okuno,[7] K. Omata,[7] G. N. Perdue,[11,¶] S. Perov,[3] S. Podolsky,[3] S. Porokhovoy,[3] K. Sakashita,[8,†] T. Sasaki,[9] N. Sasao,[13] H. Sato,[9] T. Sato,[7] M. Sekimoto,[7] T. Shimogawa,[2] T. Shinkawa,[12] Y. Stepanenko,[3] Y. Sugaya,[8] A. Sugiyama,[2] T. Sumida,[13,‡] S. Suzuki,[2] Y. Tajima,[9] S. Takita,[9] Z. Tsamalaidze,[3] T. Tsukamoto,[2,§] Y. C. Tung,[4] Y. W. Wah,[11] H. Watanabe,[11,†] M. L. Wu,[4] M. Yamaga,[7,8,||] T. Yamanaka,[8] H. Y. Yoshida,[9] Y. Yoshimura,[7] and Y. Zheng[11]

(E391a Collaboration)

[1]*Department of Physics, Pusan National University, Busan 609-735, Republic of Korea*
[2]*Department of Physics, Saga University, Saga 840-8502, Japan*
[3]*Laboratory of Nuclear Problems, Joint Institute for Nuclear Research, Dubna, Moscow Region 141980, Russia*
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[5]*Department of Physics, Arizona State University, Tempe, Arizona 85287, USA*
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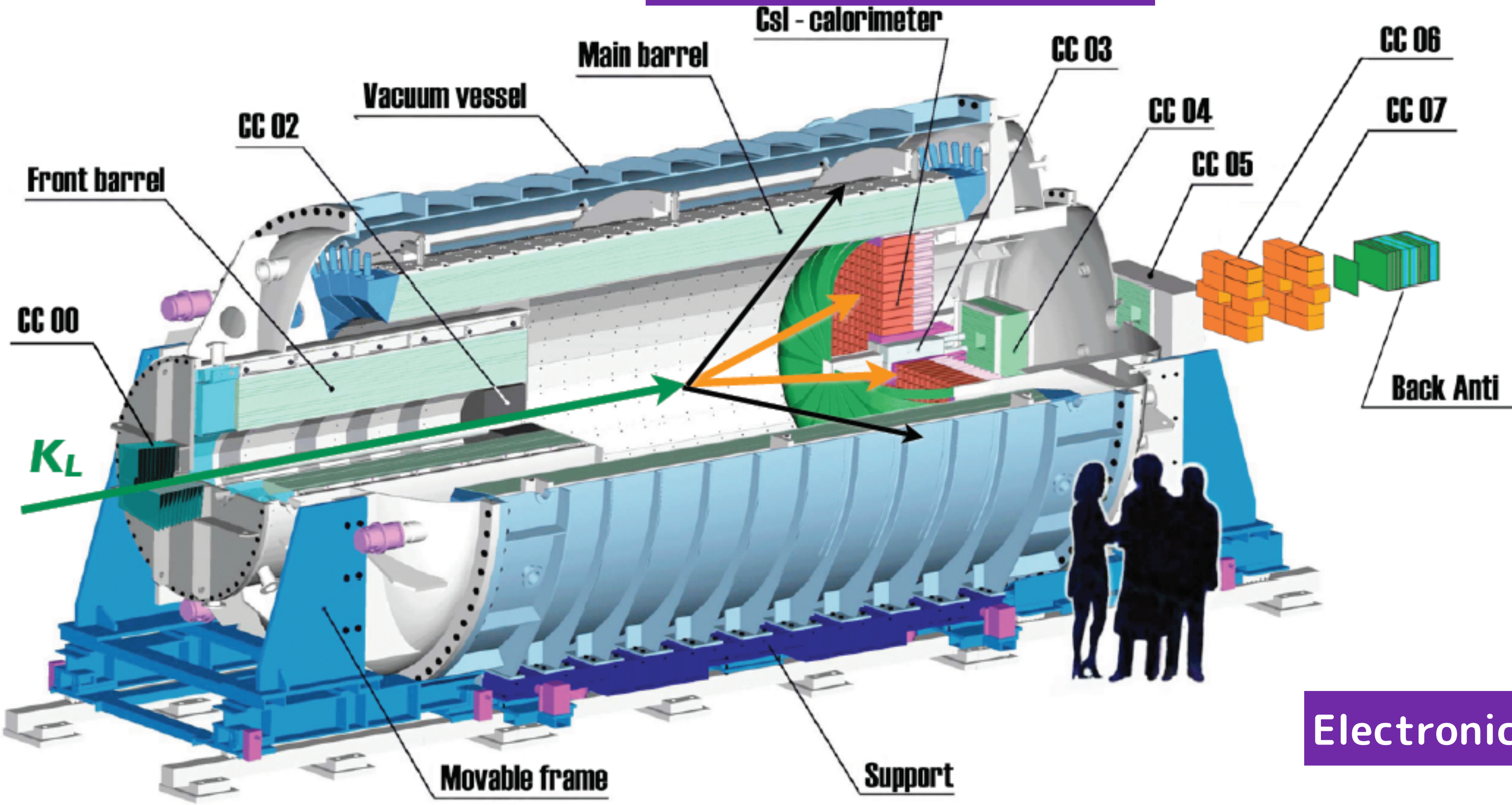
(Received 25 November 2009; published 29 April 2010)

The first dedicated search for the rare neutral-kaon decay $K_L^0 \to \pi^0 \nu \bar{\nu}$ has been carried out in the E391a experiment at the KEK 12-GeV proton synchrotron. The final upper limit of 2.6×10^{-8} at the 90% confidence level was set on the branching ratio for the decay.

DOI: 10.1103/PhysRevD.81.072004 PACS numbers: 13.20.Eb, 11.30.Er, 12.15.Hh

The E391a Detector

The most expensive part

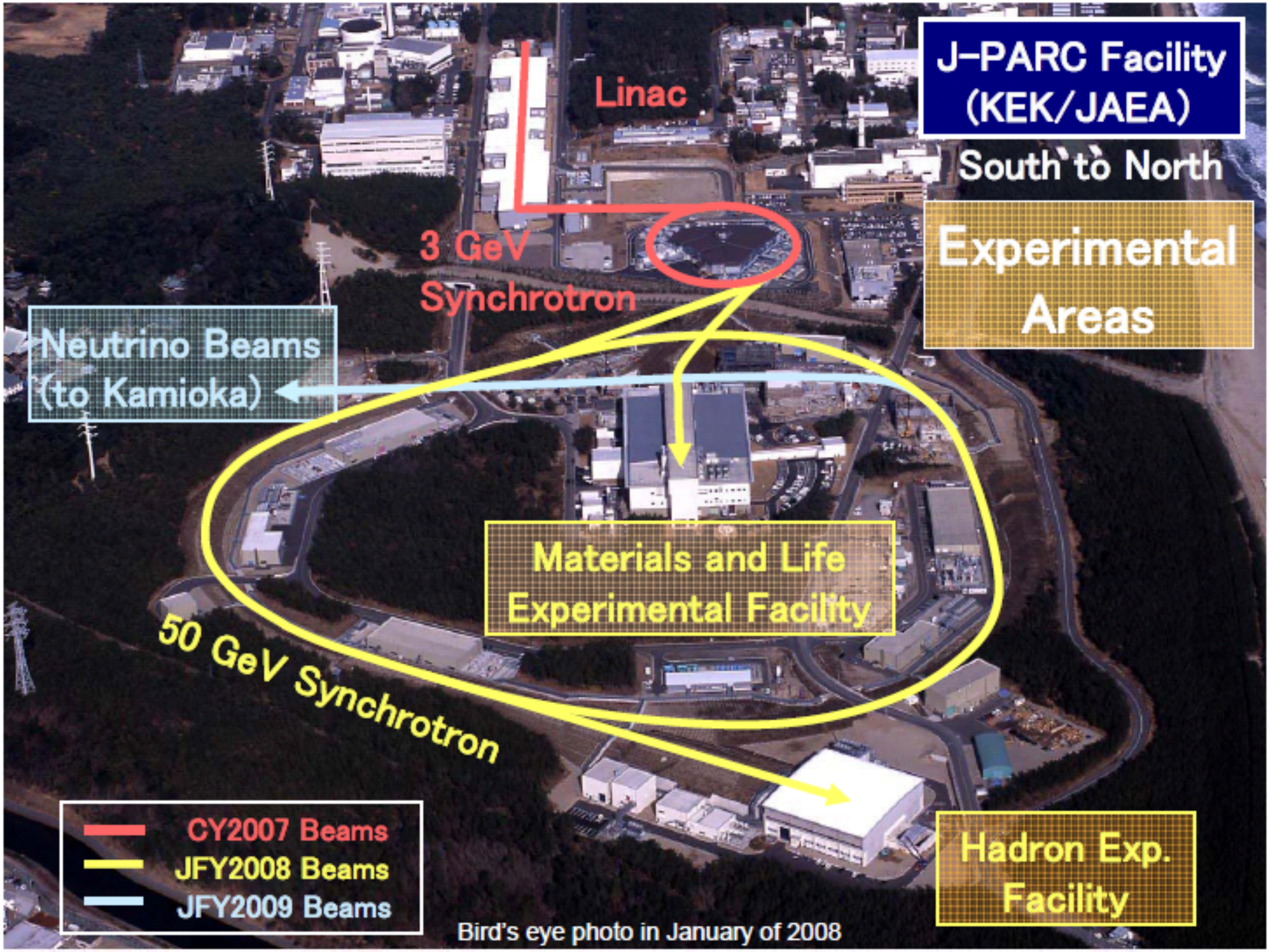


Electronics

Re-use existing resources

Full-time workers

- T. Inagaki, H. Okuno, G.Y.Lim, M.Yamaga, Y. Tajima
- H.Watanabe,S.Y.Lee,M. Dorochenko, H.S.Lee,K.Sakashita,T.Sumida
- Leading role of spokesman
  - To make ongoing project
  - Increasing many collaborators
- Concentrating 3~4 physicists is essential


J-PARC Facility
(KEK/JAEA)
South to North
Linac
3 GeV
Synchrotron
Experimental
Areas
Neutrino Beams
(to Kamioka)
Materials and Life
Experimental Facility
50 GeV Synchrotron
Hadron Exp.
Facility
CY2007 Beams
JFY2008 Beams
JFY2009 Beams
Bird's eye photo in January of 2008

E391a @ JPARC(A-line)

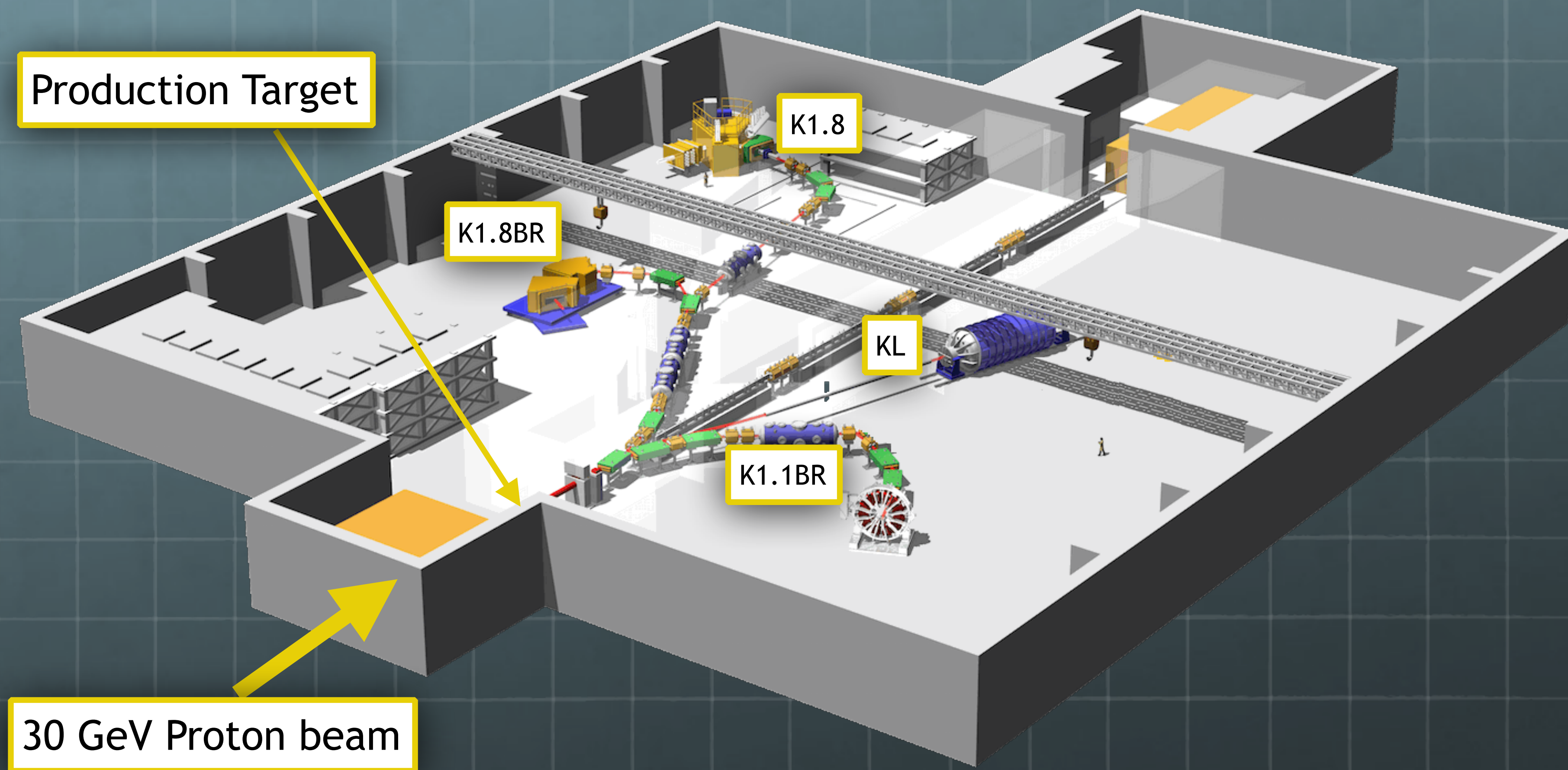
- From the 1-day data analysis (E391a)
  - Expected S.E.S. : (2.5-5)X10^{-8}/day
- We can expect
  - Under assumption of
    - Same acceptance with that of the E391a
    - 2X10^{14} (30 GeV) Protons /3.4 sec
      - Same beam size at the calrimeter
      - 1.6X10^{7} K_L/spill (H. Watanabe's M.C.)
    - 10^{7} sec data taking / year
  - We could expect (5.7-11.3)X10^{-12} S.E.S / year
- More reliable results f E391a (soon later)
- Rate effects / Operation of accelerator (have to check)

(16 - 8) events for 3 years data taking

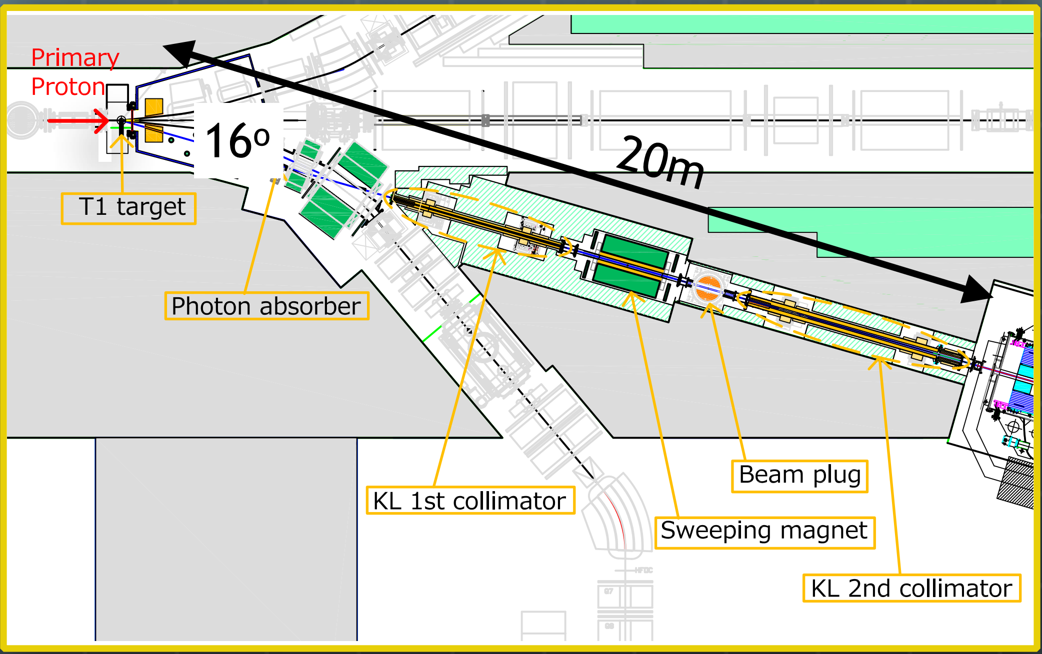
Phase transition

- Morden collaboration
- Each institutes have clear responsibility
  - KEK : E391a detector transportation
    Beam line
  - Osaka U. : CsI calorimetern (KTeV)
  - U. of Chicago : Flash ADC
  - Michigan : DAQ
  - Kyoto U.: Additional detectors

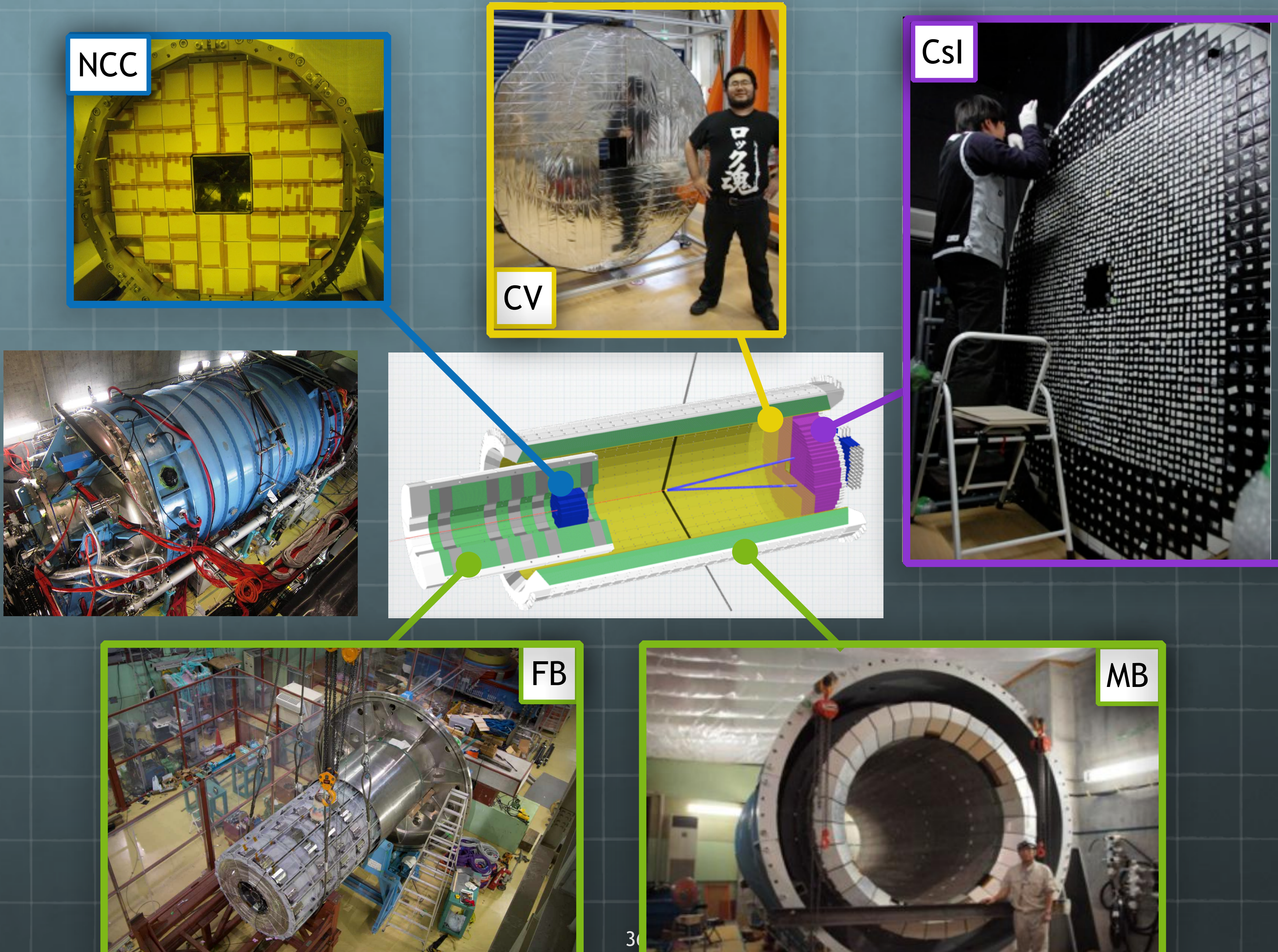
Hadron Hall so far



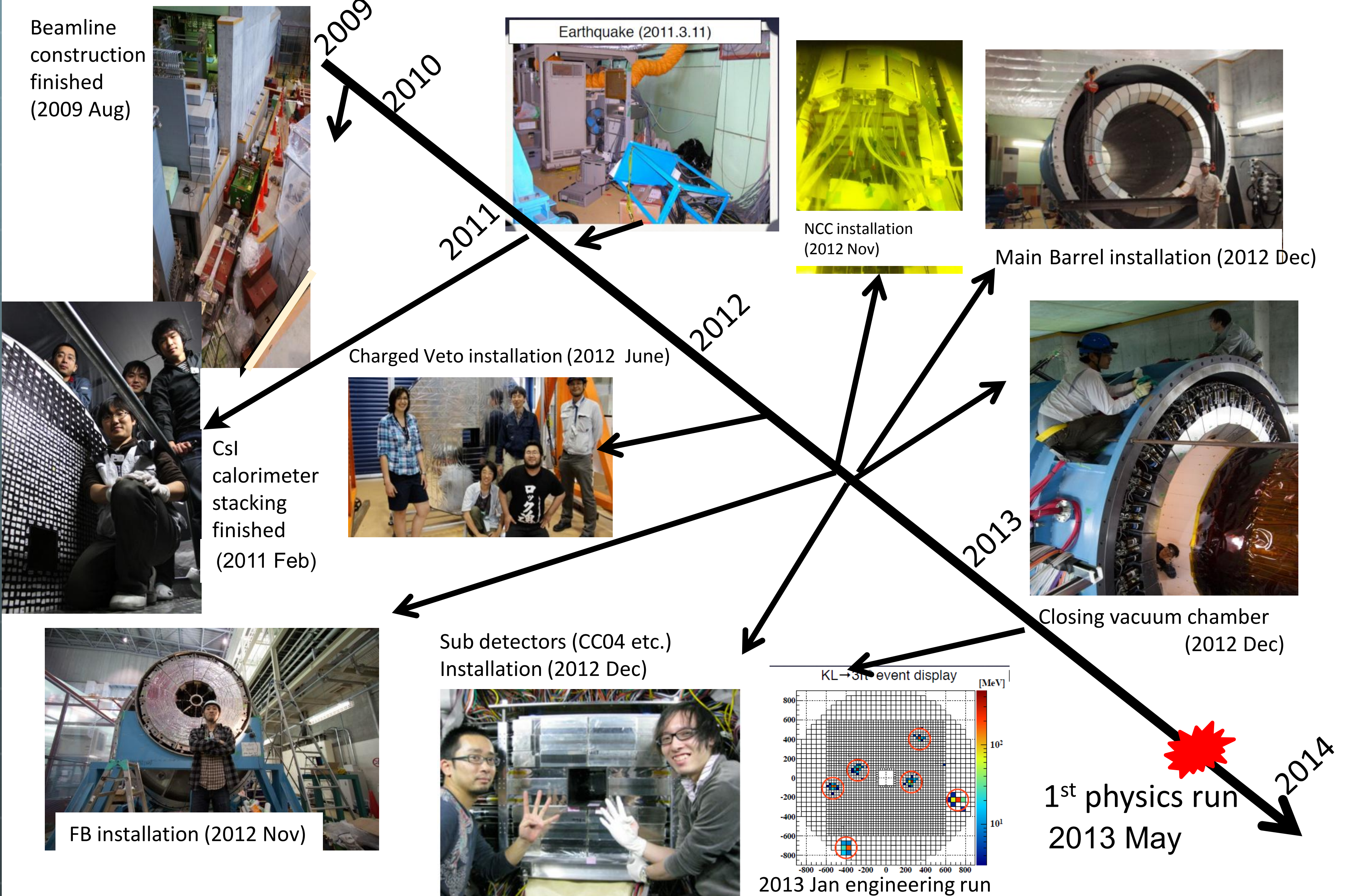
KL Beam Line



Primary
Proton
16°
20m
T1 target
Photon absorber
KL 1st collimator
Sweeping magnet
Beam plug
KL 2nd collimator

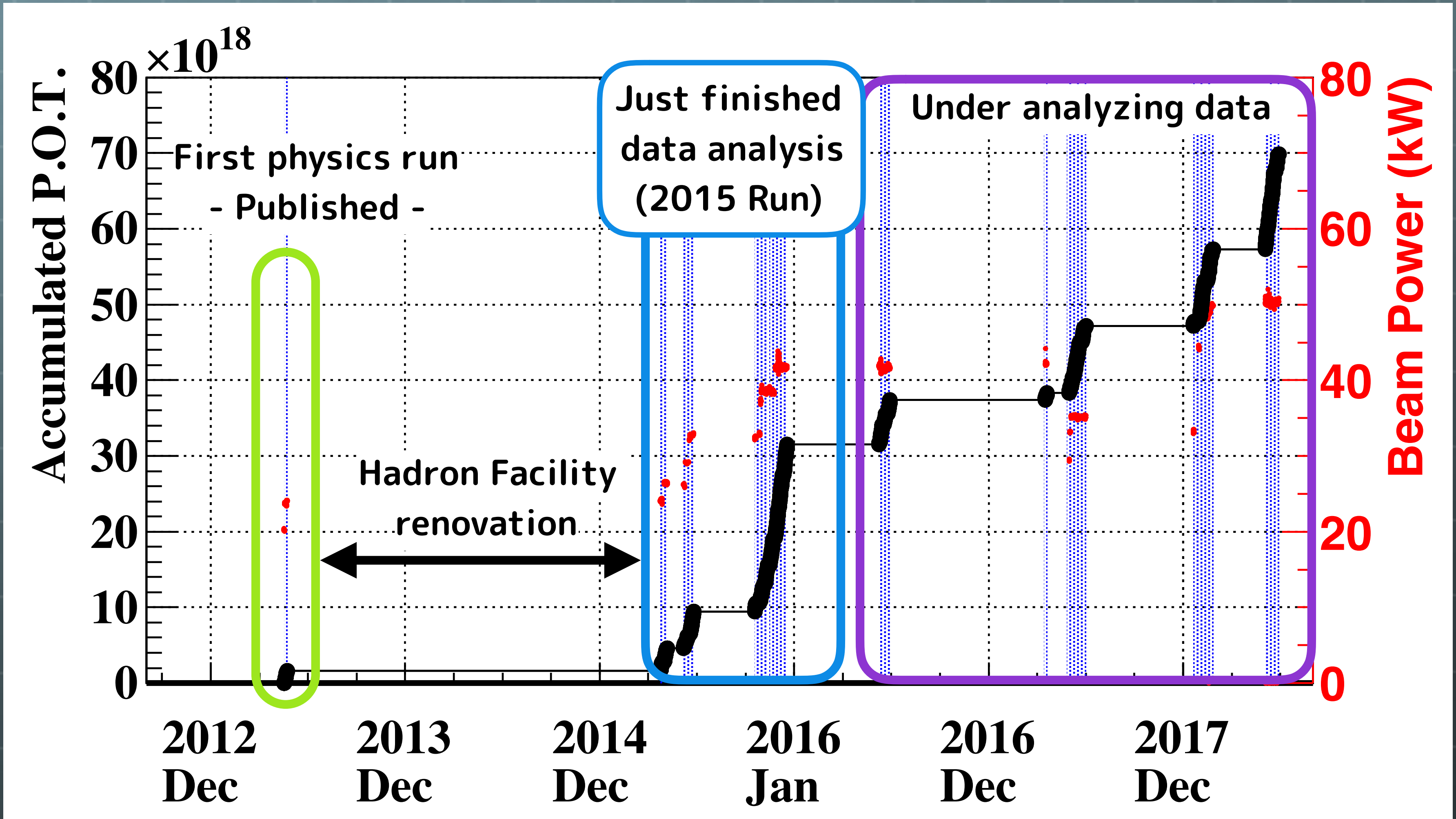

NCC
CV
CsI
FB
MB

Timeline of KOTO



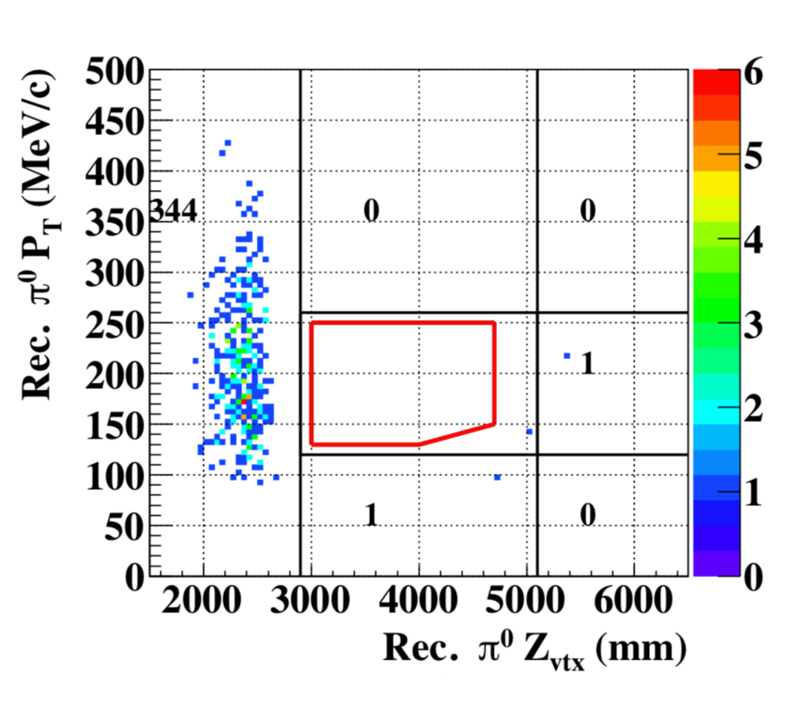

Installed
April 1, 2016

History of data taking

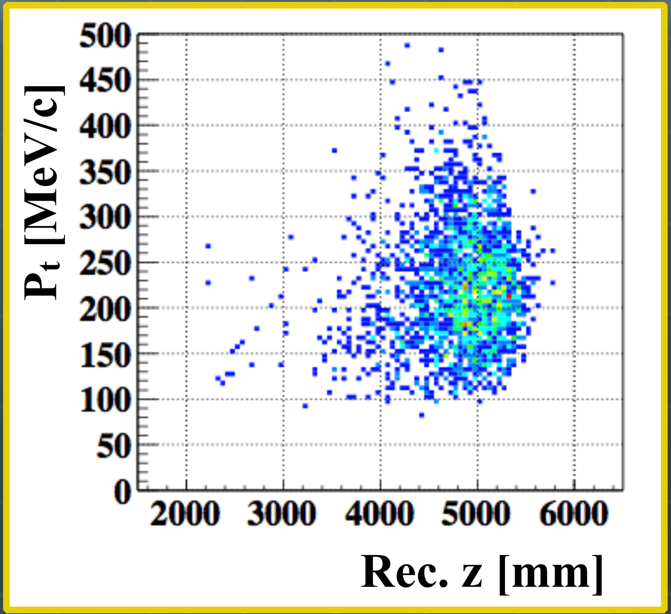


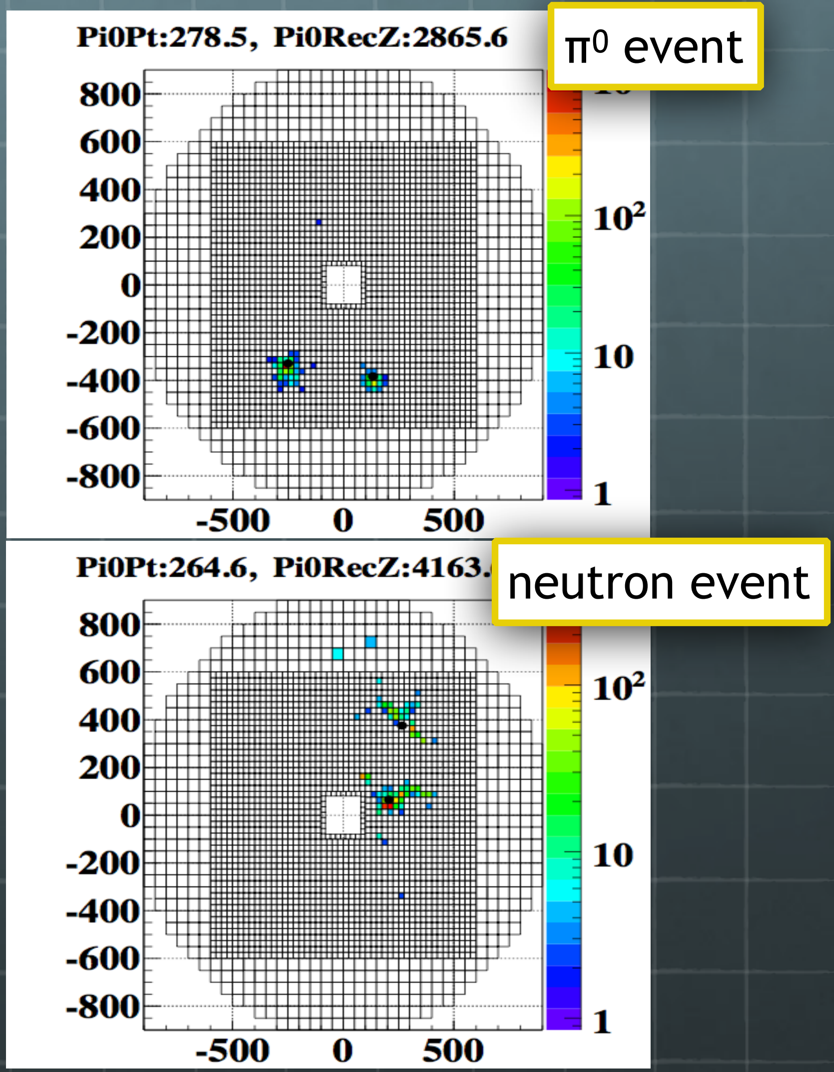
Result of 2015 Run

- Several detector upgrades to reject background events observed the first physics run
- Background estimation with blinded signal region
- Opened Box in June 2018
- No signal candidate
- BR<3.0×10-9 @90%C.L.



Enhanced neutron events

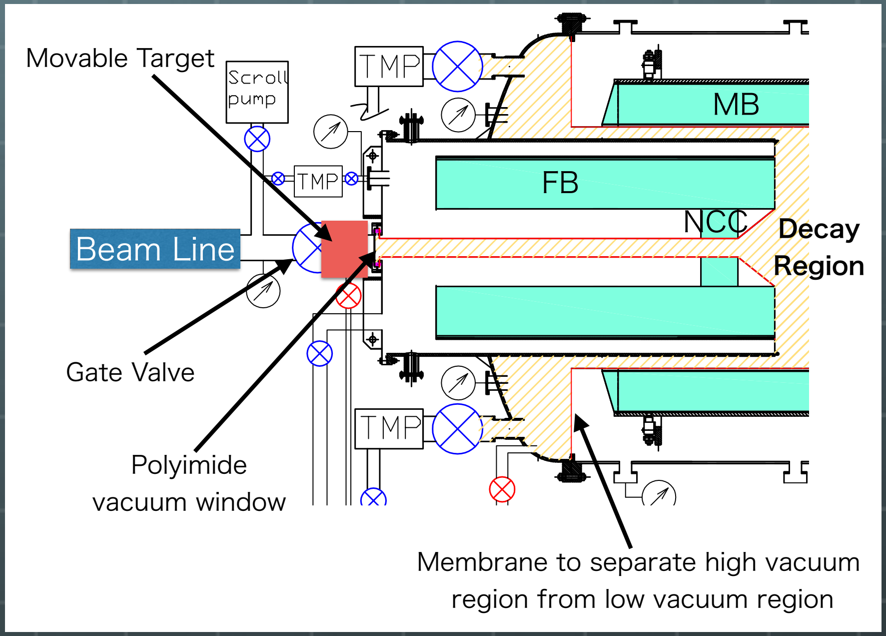


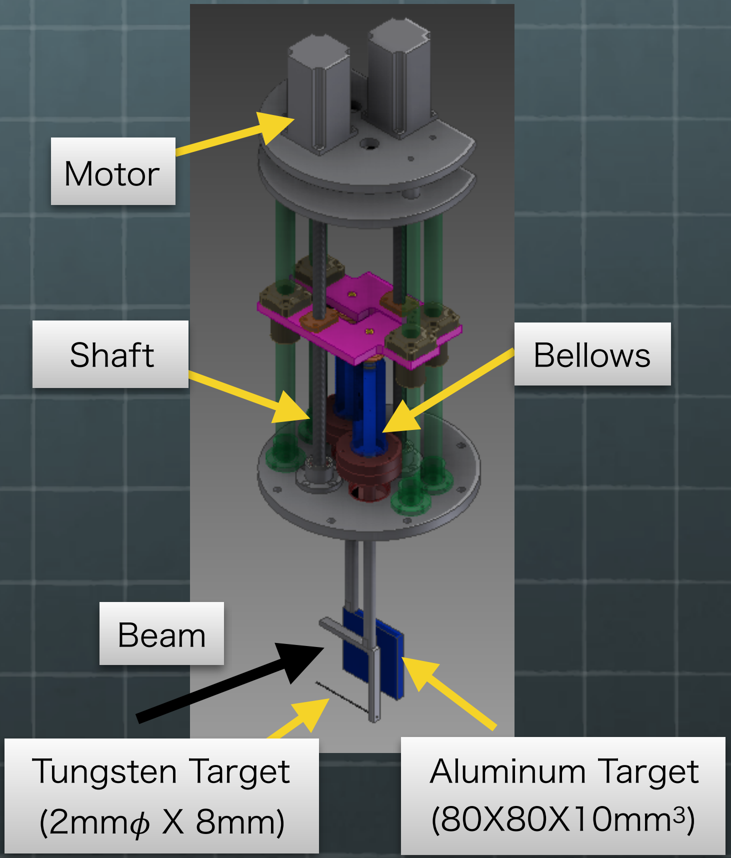


- 70-hour data taking with Al-target (>15 times more than May 2013)
- To study cluster and pulse shape in the calorimeter
- To develop a method to discriminate neutron induced events from the π^0 events

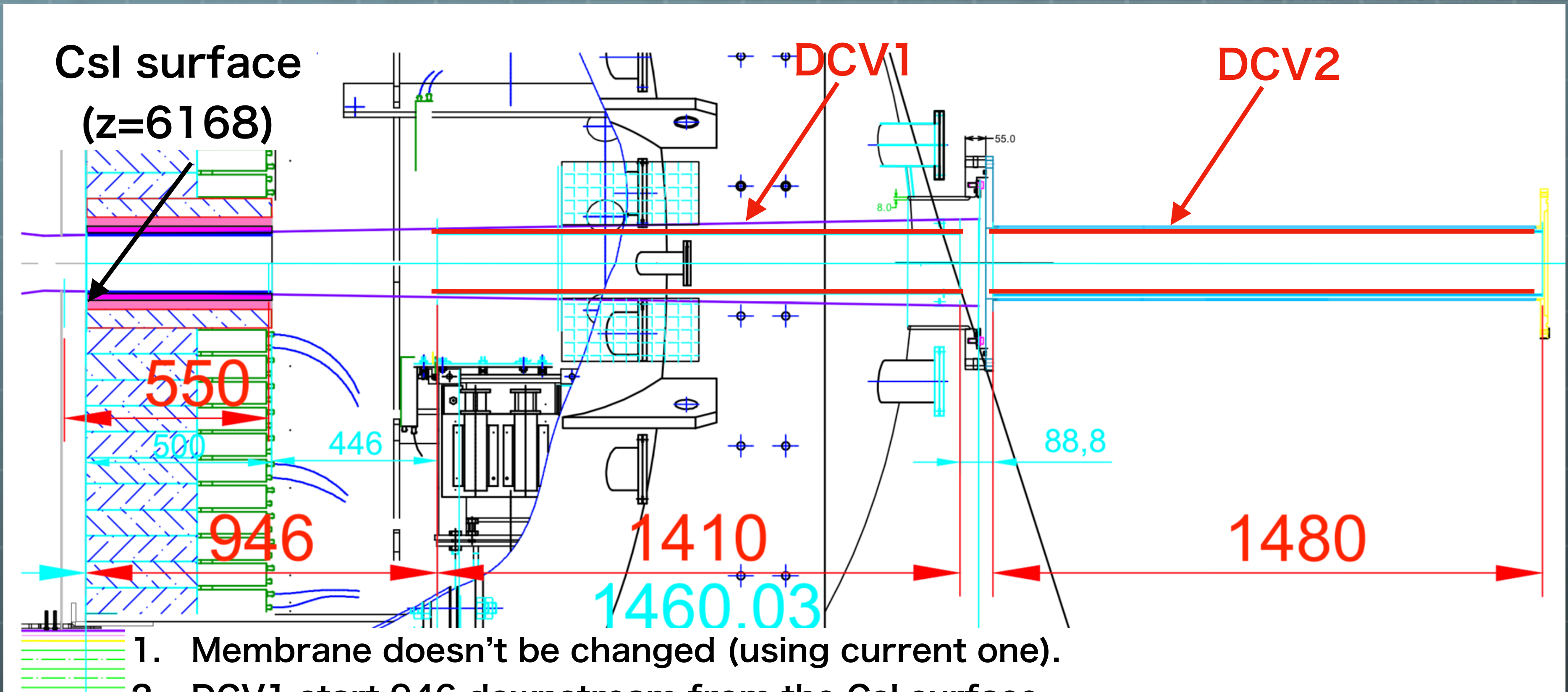
Halo neutron events

- To reduce scattering source
- To take data for enhanced neutron events





Downstream Charged Veto



1. Membrane doesn't be changed (using current one).
2. DCV1 start 946 downstream from the CsI surface.
    1. Cross section is 166mmX166mm and length of 1410mm
3. DCV2 start 89mm downstream from the DCV1 rare edge.
    1. Cross section is 176mmX176mm and length of 1480mm
4. Thickness of DCV1 and DCV2 is 5mm
5. CsI G-10 : change length 900 ->550
    1. start 50mm in front of the CsI

Summary

- KOTO searching for new physics with K-decay.
- It takes long time to start an experiment.
    - Long-term plan, working plan is important
- Successful collaboration needs core members.
    - Need not so many, but fully concentrate (at least 3).
    - Proper appraisal.
- Searching for existing resources. Step-by-setp approach.
- Self-motivation collaborator is important.
    - Not always contributing, but needed time.
    - Develop their contributing items.