K_L稀崩壊実験とビームライン

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RCNPワークショップ「J-PARCハドロンビームライン整備拡充に向けて」

2007年11月11日　大阪大学核物理研究センター

outline: $K_L \to \pi^0 \nu \overline{\nu}$ プロジェクト

- 物理の目的

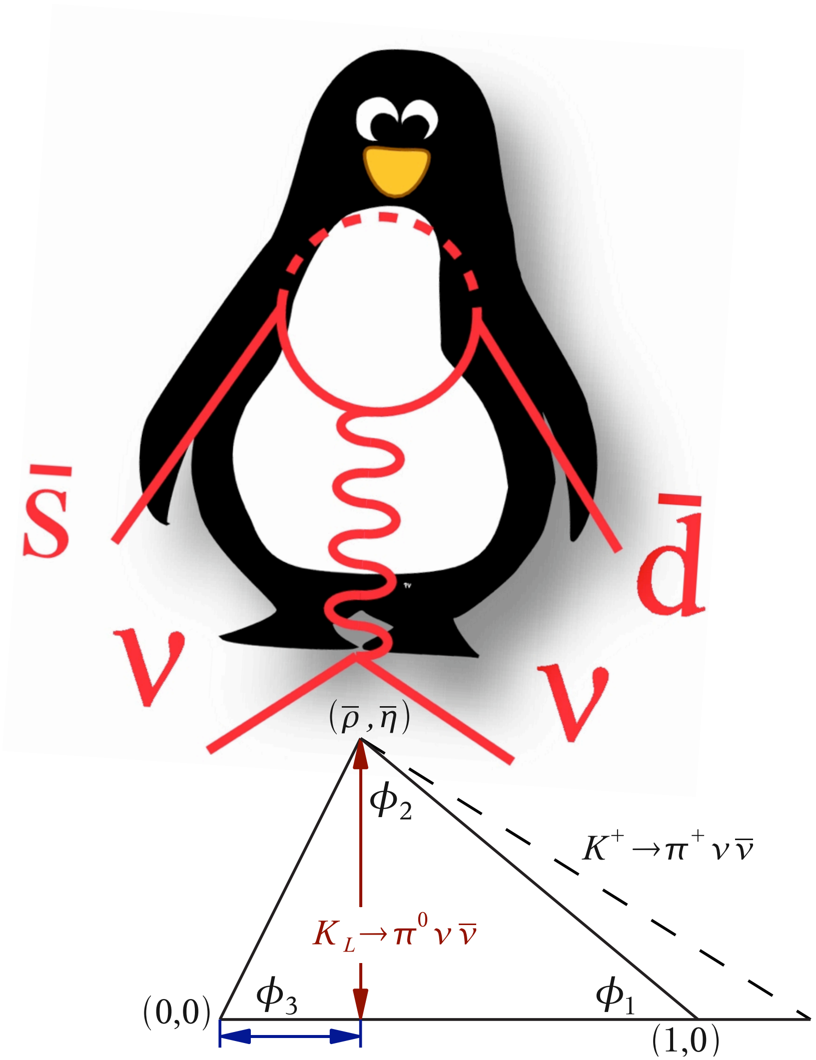
  (10/26 の 連絡会 での岡田さんのレビュー)

- E14実験の status

- E14のための中性ビームラインと測定器

  [スタディの最新結果]

- long-range plan



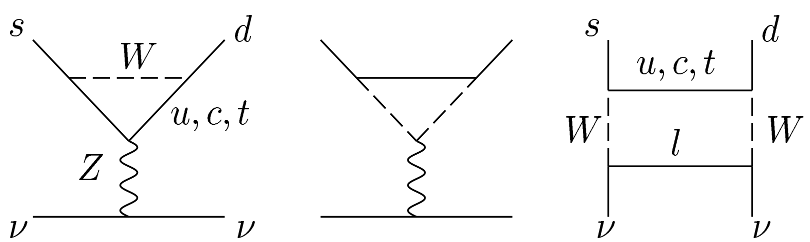
(24 slides in total)

物理の目的

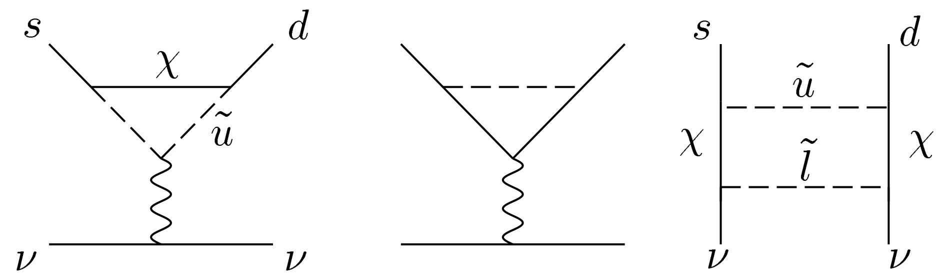
- $K_L \to \pi^0 \nu \bar{\nu}$ 崩壊の 分岐比 を測定して

3×10^{-11} in the SM

標準模型を越える物理の フレーバー構造 を探索する。

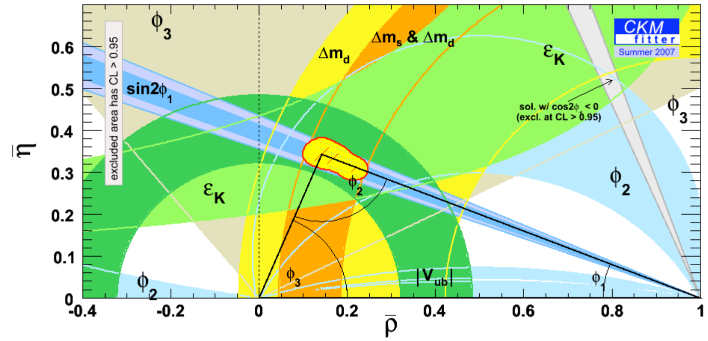


$$Q_\nu = (\bar{s}_L \gamma_\mu d_L)(\bar{\nu}_L \gamma^\mu \bar{\nu}_L)$$



- Direct CP violation - クォークフレーバー混合の 複素位相

標準模型での $K \to \pi\nu\bar{\nu}$



$$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) = (5.30 \times 10^{-11}) \cdot C_{\pi\nu\bar{\nu}} \times [(\rho_0 - \rho)^2 + \eta^2]$$

$$\mathcal{B}(K_L^0 \to \pi^0\nu\bar{\nu}) = (23.2 \times 10^{-11}) \cdot C_{\pi\nu\bar{\nu}} \times [\eta^2]$$

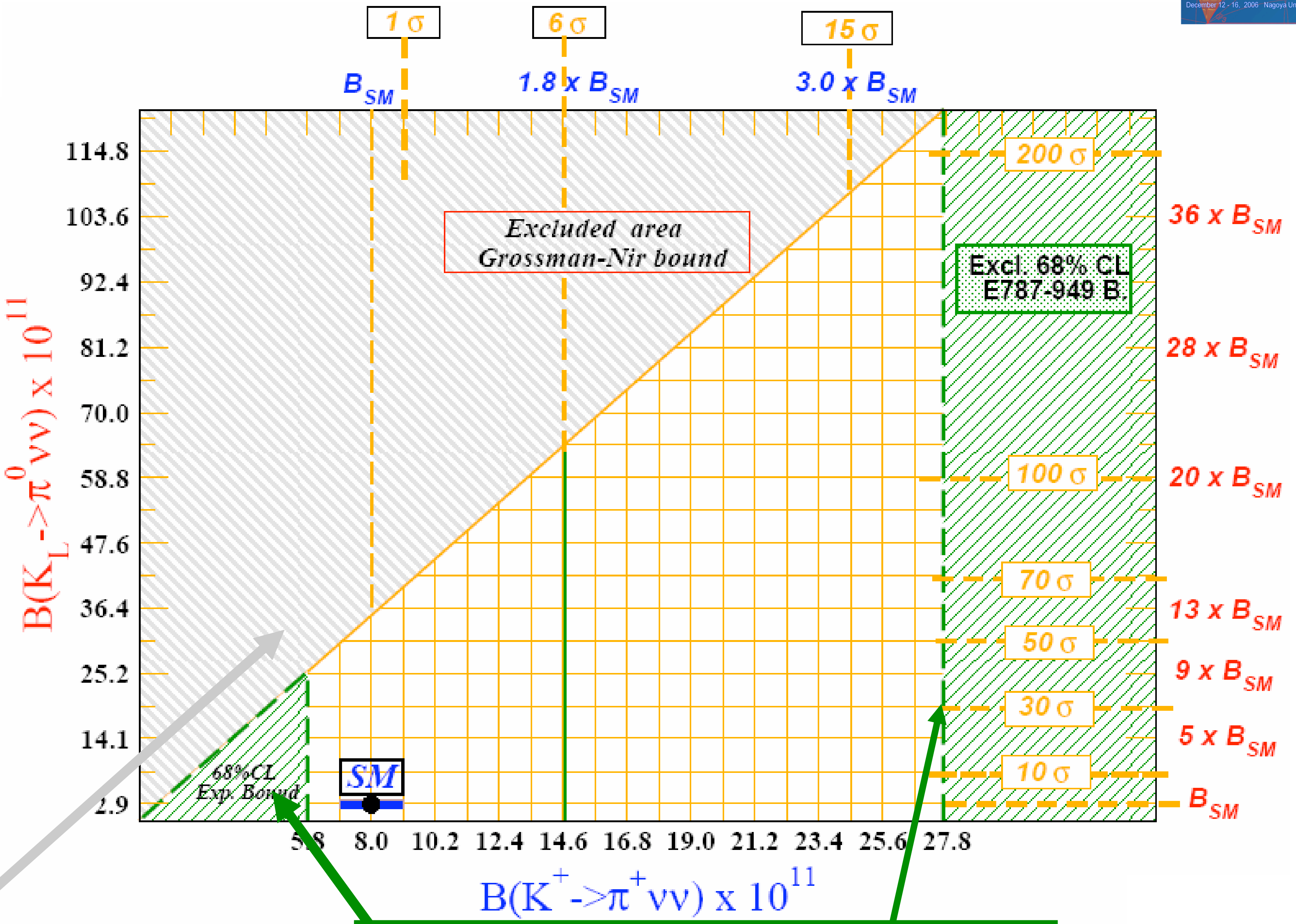
$$C_{\pi\nu\bar{\nu}} \equiv \left[\frac{\mathcal{B}(K^+ \to \pi^0 e^+ \nu)}{4.87 \times 10^{-2}}\right] \times \left[\frac{|V_{cb}|}{0.0415}\right]^4 \times \left[\frac{X(x_t)}{1.529}\right]^2$$

$\times 10^{-11}$

	2004	2007
K+	7.8 +- 1.2 (15%)	7.83 +- 0.82 (10%)
KL	3.0 +- 0.6 (20%)	2.49 +- 0.39 (16%)

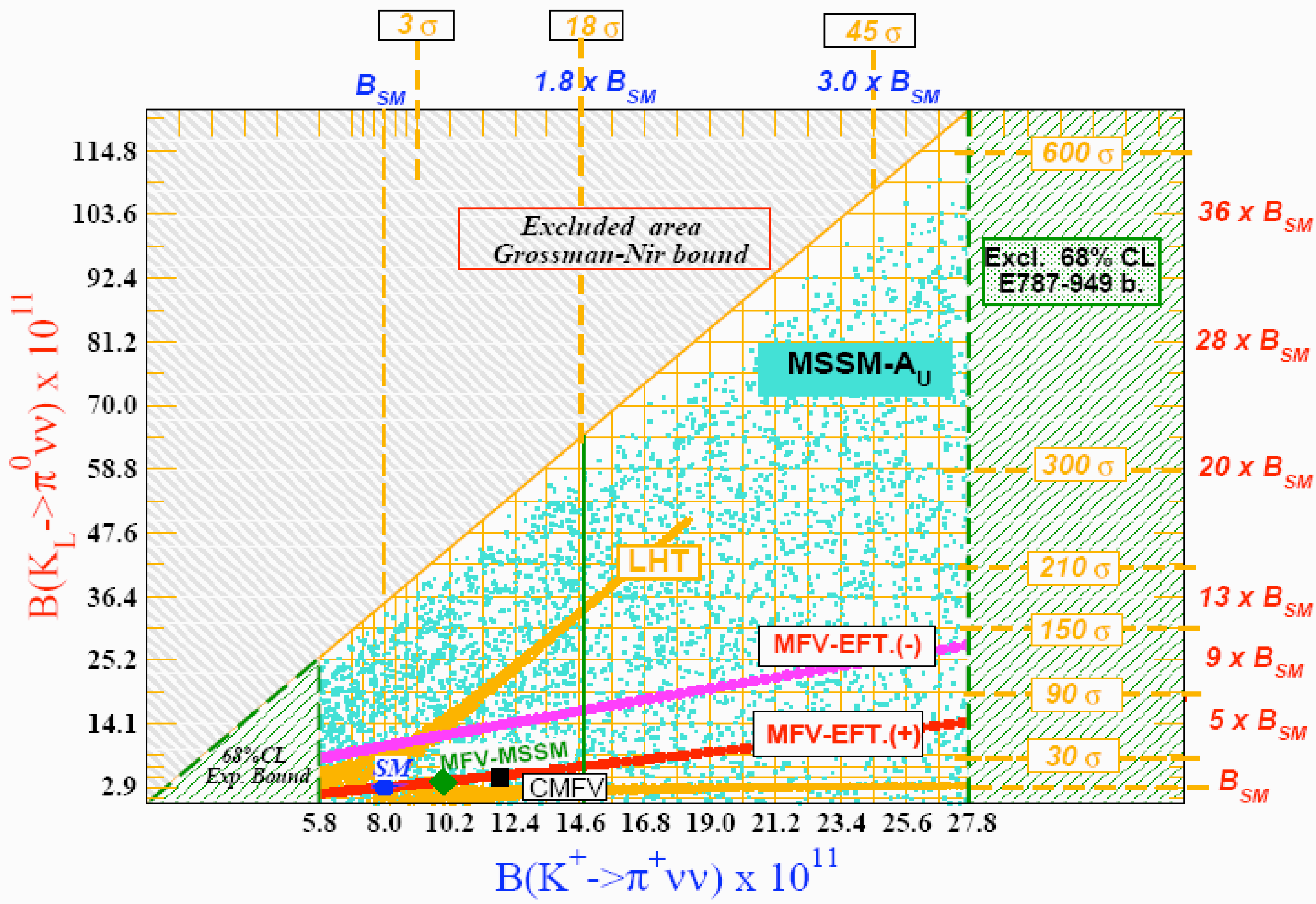
- NNLO QCD calculations (Buras et al. ’05, ‘06)
- non-perturbative effects due to charm&up (Isidori et al. ’05)
- Kl3 matrix elements (Mescia-Smith ‘07)

Federico Mescia @



$B(K^+ \to \pi^+ \nu\bar{\nu}) = 14.7^{+13.0}_{-8.9} \times 10^{-11}$ [E787-E949]

$B(K_L \to \pi^0 \nu\bar{\nu}) \leq 4.4 B(K^+ \to \pi^+ \nu\bar{\nu})$ [Grosmann - Nir Bound]


3 σ
18 σ
45 σ
B SM
1.8 x B SM
3.0 x B SM
Excluded area
Grossman-Nir bound
Excl. 68% CL
E787-949 b.
MSSM-A U
LHT
MFV-EFT.(-)
MFV-EFT.(+)
MFV-MSSM
SM
CMFV
68%CL
Exp. Bound
600 σ
300 σ
210 σ
150 σ
90 σ
30 σ
36 x B SM
28 x B SM
20 x B SM
13 x B SM
9 x B SM
5 x B SM
B SM
114.8
103.6
92.4
81.2
70.0
58.8
47.6
36.4
25.2
14.1
2.9
5.8
8.0
10.2
12.4
14.6
16.8
19.0
21.2
23.4
25.6
27.8
B(K+->π+νν) x 10^11
B(K_L->π0νν) x 10^11

J-PARC
E14 collaboration

- 日本
  - KEK
    - Inagaki, Komatsubara, Lim, Watanabe, ...
  - 京都大学
    - Nanjo, Nomura, Sasao, ...
  - NDA
    - Matsumura, Shinkawa, ...
  - 大阪大学
    - Yamaga, Yamanaka, ...
  - 佐賀大学
    - Suzuki, Kobayashi, ...
  - 山形大学
    - Iwata, Tajima, Yoshida, ...
- 米国
  - Arizona State Univ
  - Univ of Chicago
  - Univ of Michigan, Ann Arbor
- ロシア
  - JINR
- 台湾
  - National Taiwan Univ
- 韓国
  - Pusan National Univ
  - Univ of Seoul
  - CheonBuk National Univ

[new to the J-PARC experiment]

- Proposal [2006 April], 101 pages

Stage1 approval ← 1st PAC meeting (2006 July)

- Report to the 2nd J-PARC PAC meeting [2007 Jan], 23 pages

- Report to FIFC, beamline [2007 May], 52 pages
  Report to FIFC, detector [2007 June], 72 pages

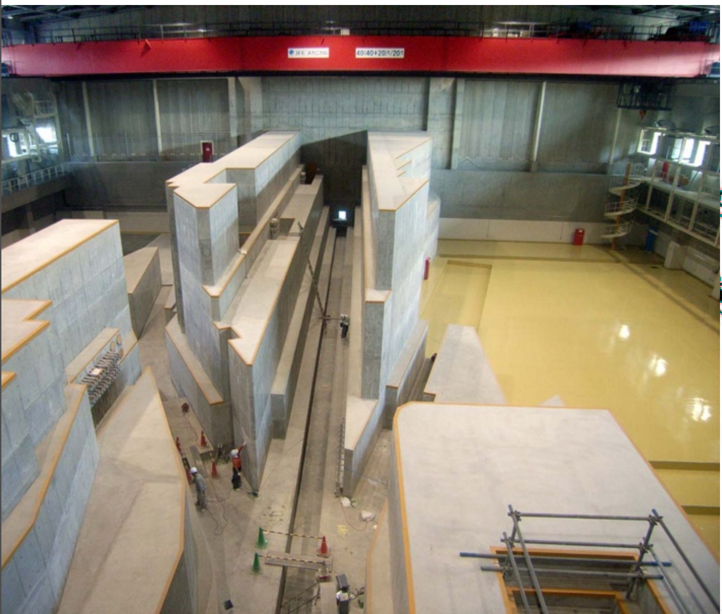
FIFC meeting (2007 June)

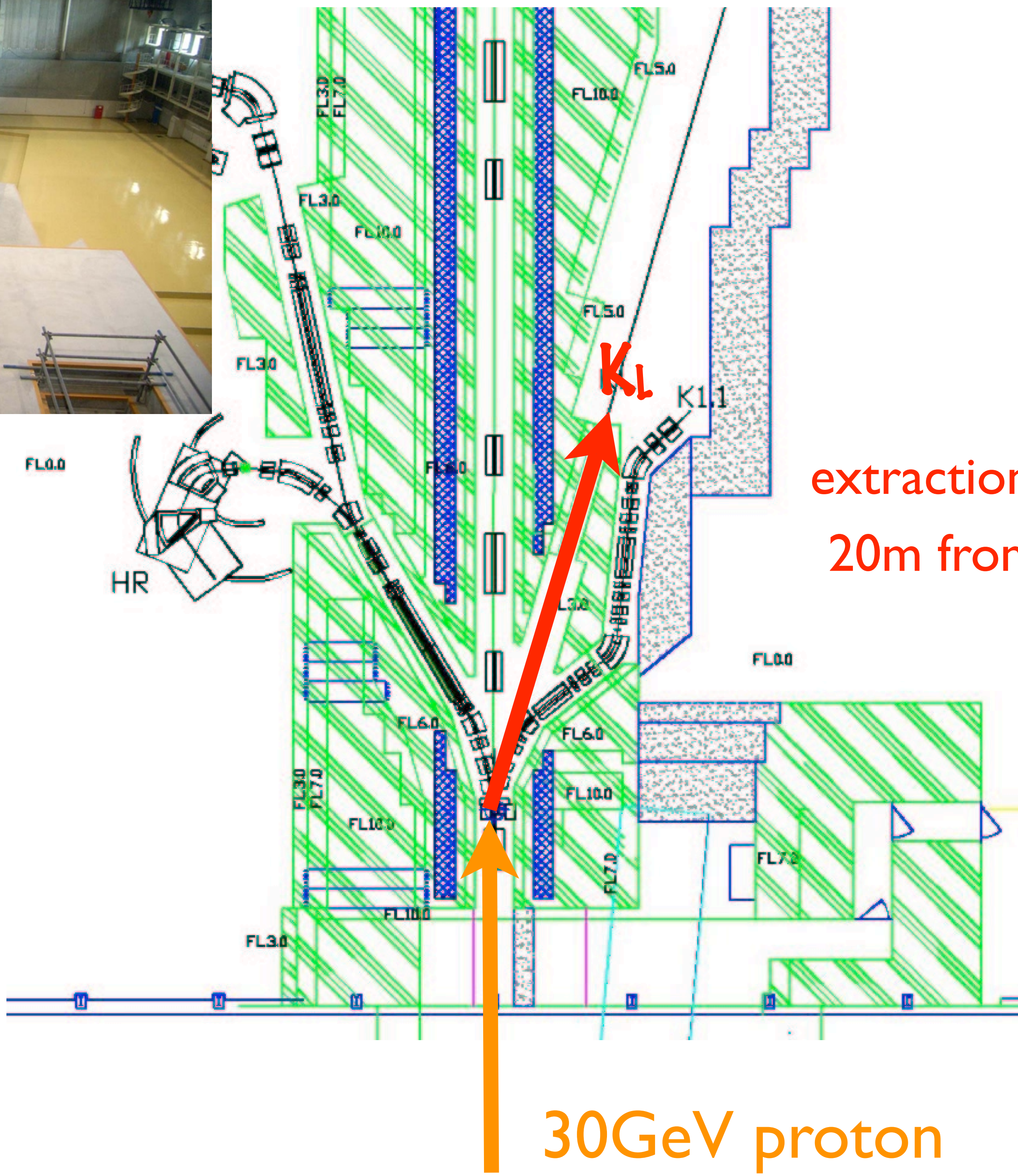
- Report to the 3rd J-PARC PAC meeting [2007 July], 28 pages

Stage2 recommendation ← 3rd PAC meeting (2007 July)

- Report to E14 Review/Planning Committee [2007 Oct], 42 pages

review committee (1st meeting: Nov 14 Wed)

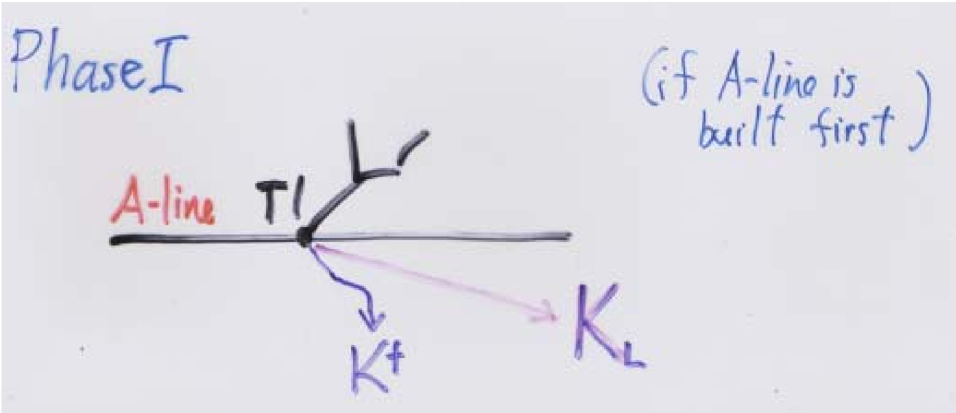


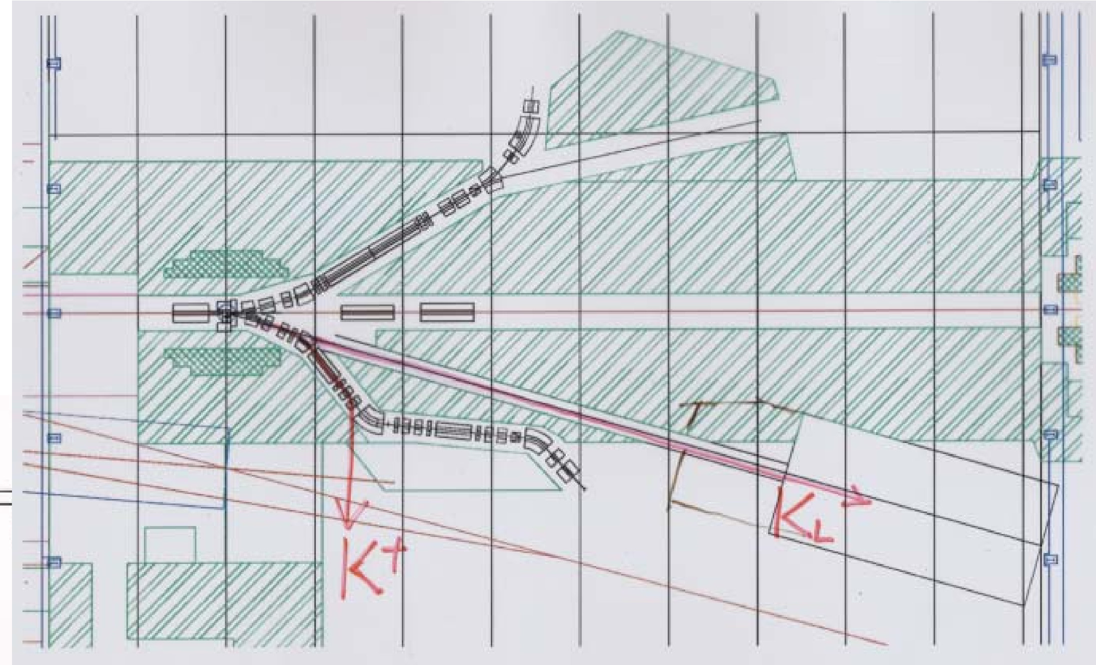


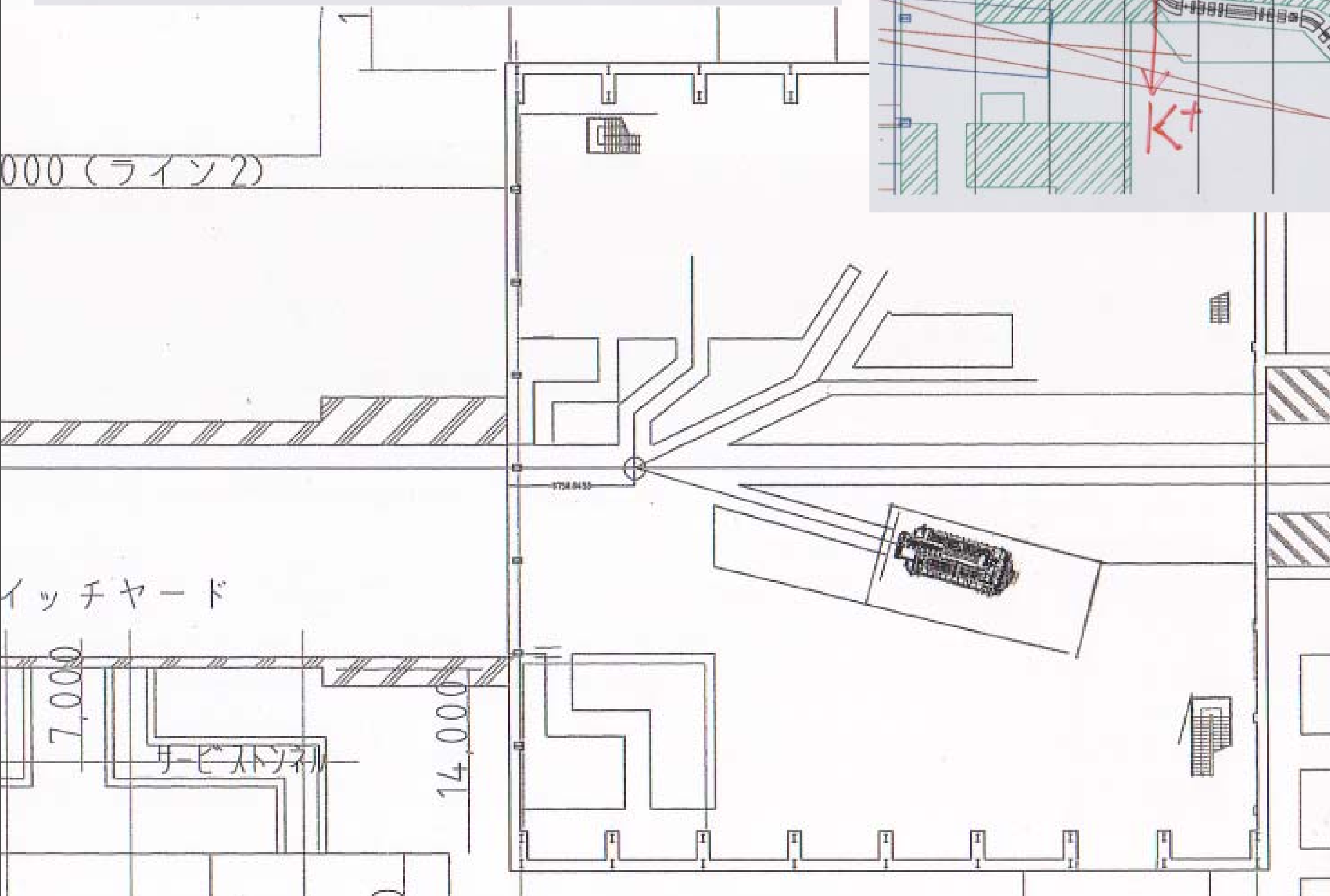
extraction: 16 degree

20m from T1 target

30GeV proton



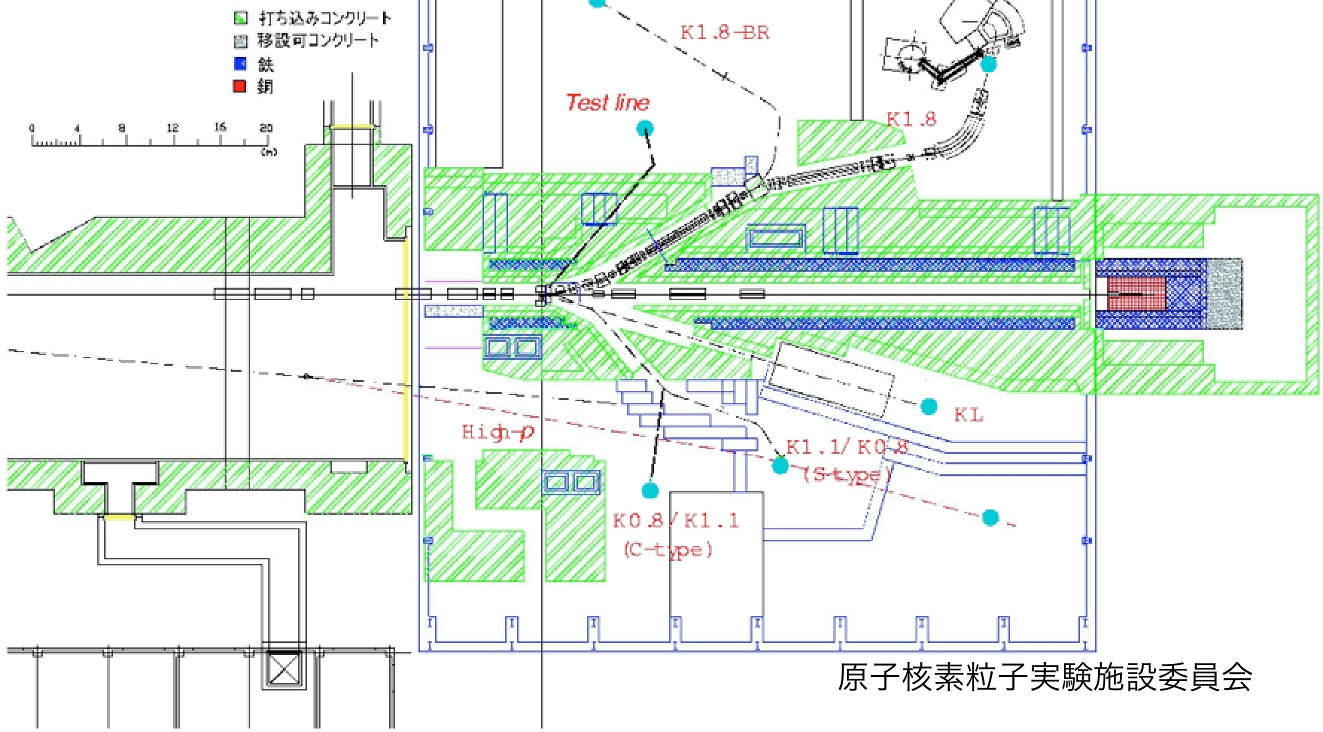




PLAN A-1 16 degree production 20m

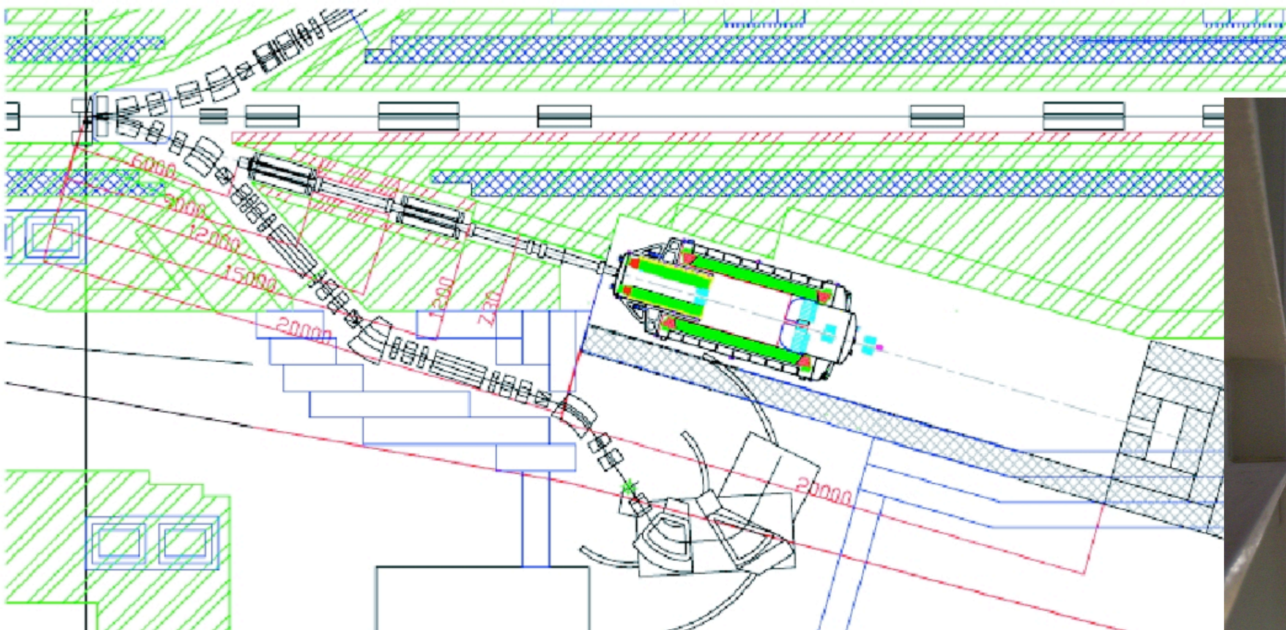
@NP02
(2002 Sept)

Fig.1
Hadron Hall Layout Plan



原子核素粒子実験施設委員会

Fig.2 Layout of K1.1 (S-type) and KL lines



原子核素粒子

実験施設委員会

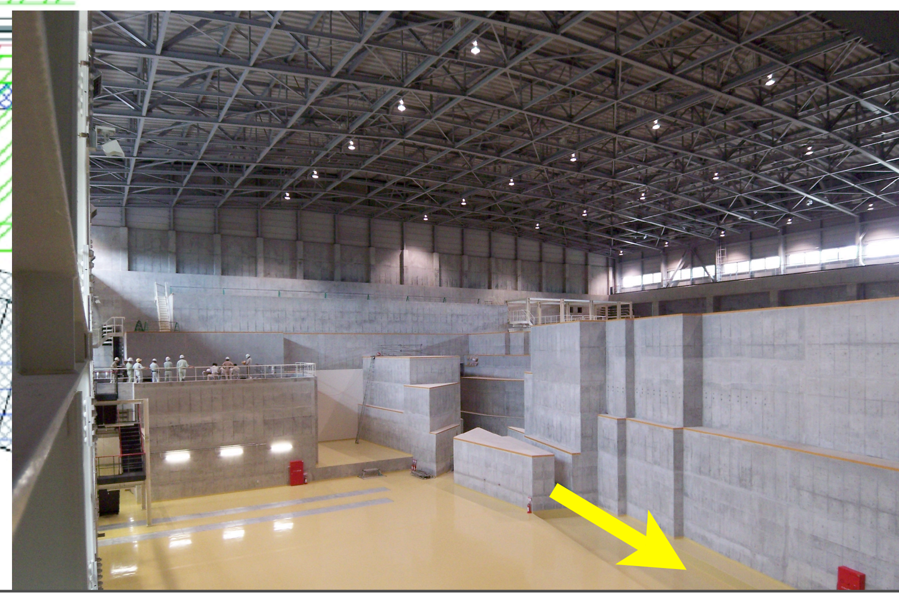
(NPFC)
2003-2004

↕

ビームライン

レイアウト案

2004 Feb



halo neutrons significantly made backgrounds in E391a

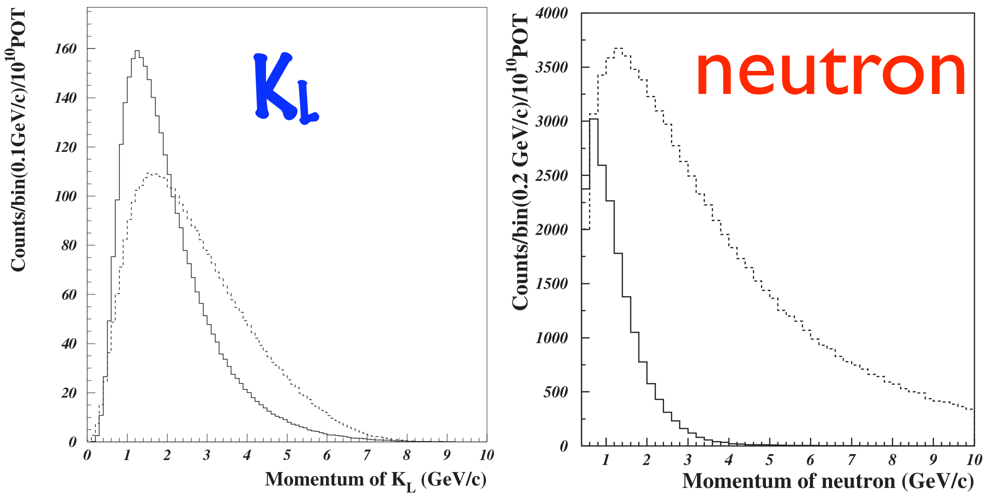
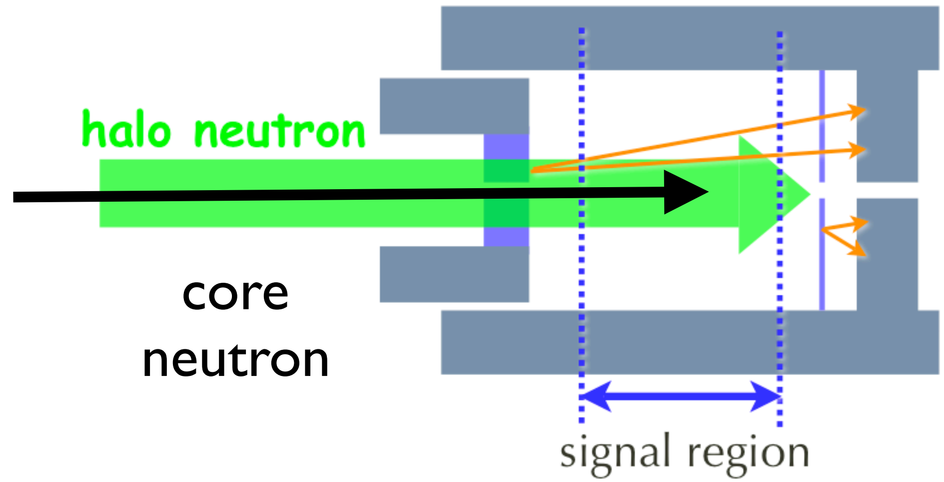
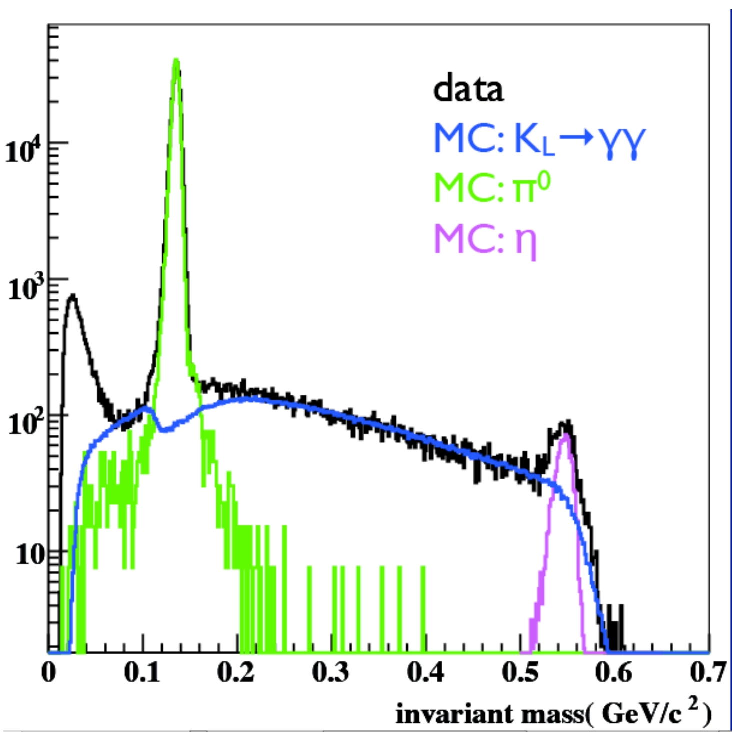
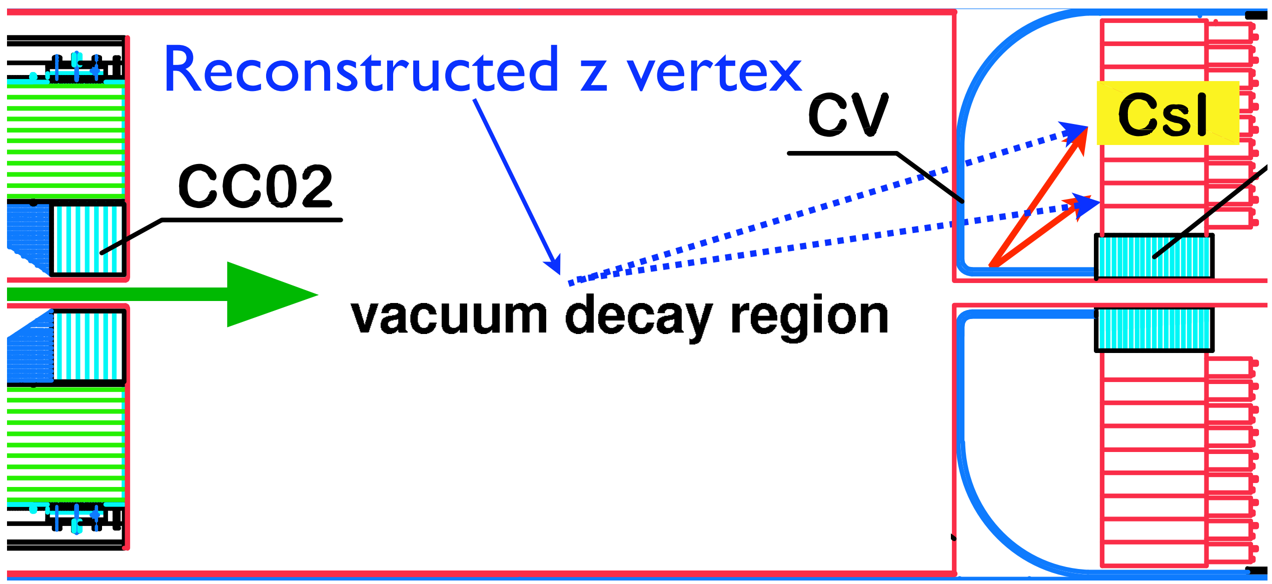


Figure 10: Momentum distribution of K_L (left) and neutron (right). The solid line is for the K_L beamline in Step 1, and the dashed line is for the PS-K0.



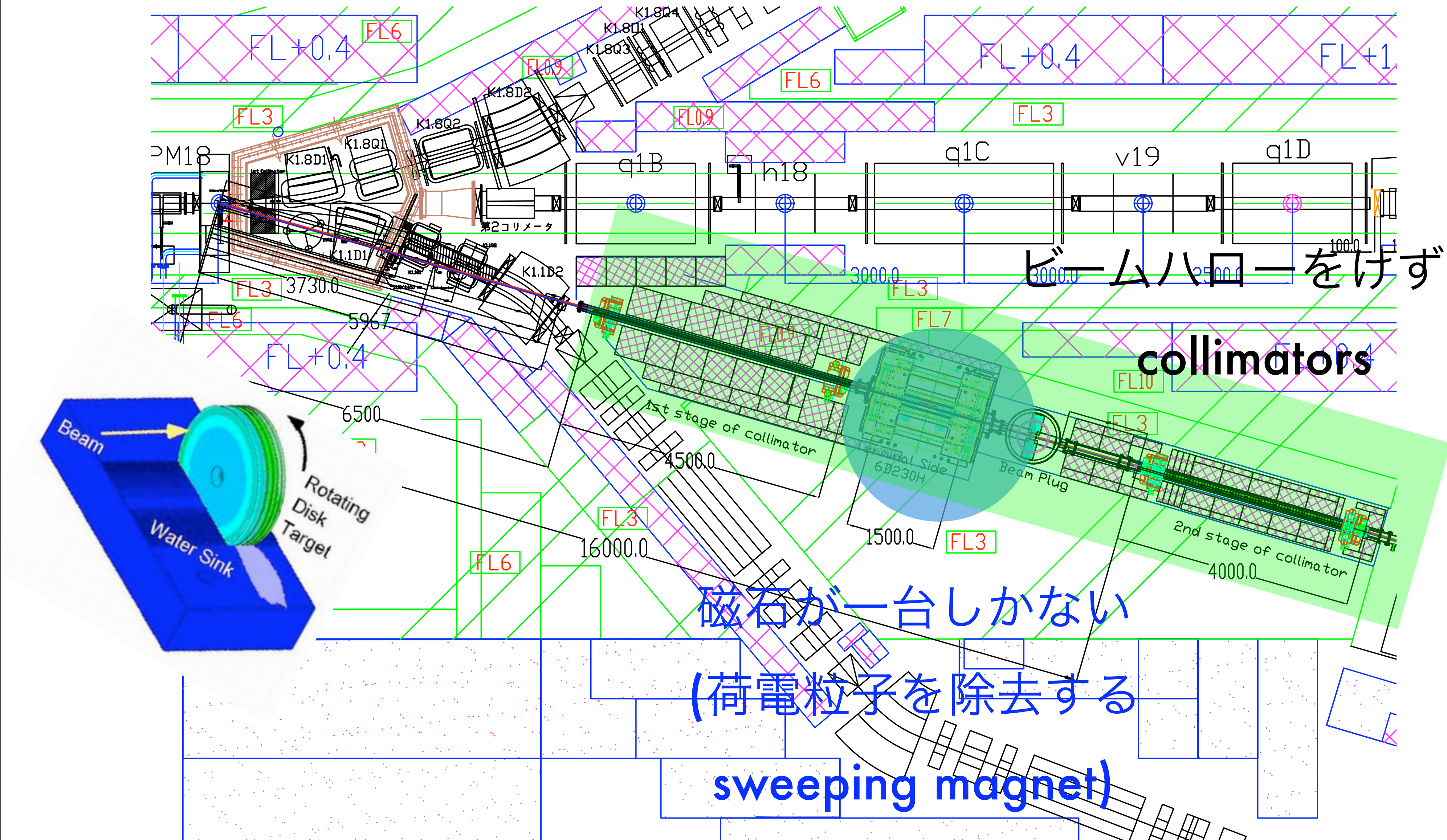




η background ?

m = 548MeV, $\eta \to \gamma\gamma$ (40%)

KLラインの特徴



ビームハローをけずる

collimators

磁石が一台しかない

(荷電粒子を除去する

sweeping magnet)

@KEKPS との違い

- 粒子生成ターゲットが”点”ではない（水平方向）
- ターゲット直後でcollimateできない
- γ absorber (Pb)はコリメータより前に設置する。

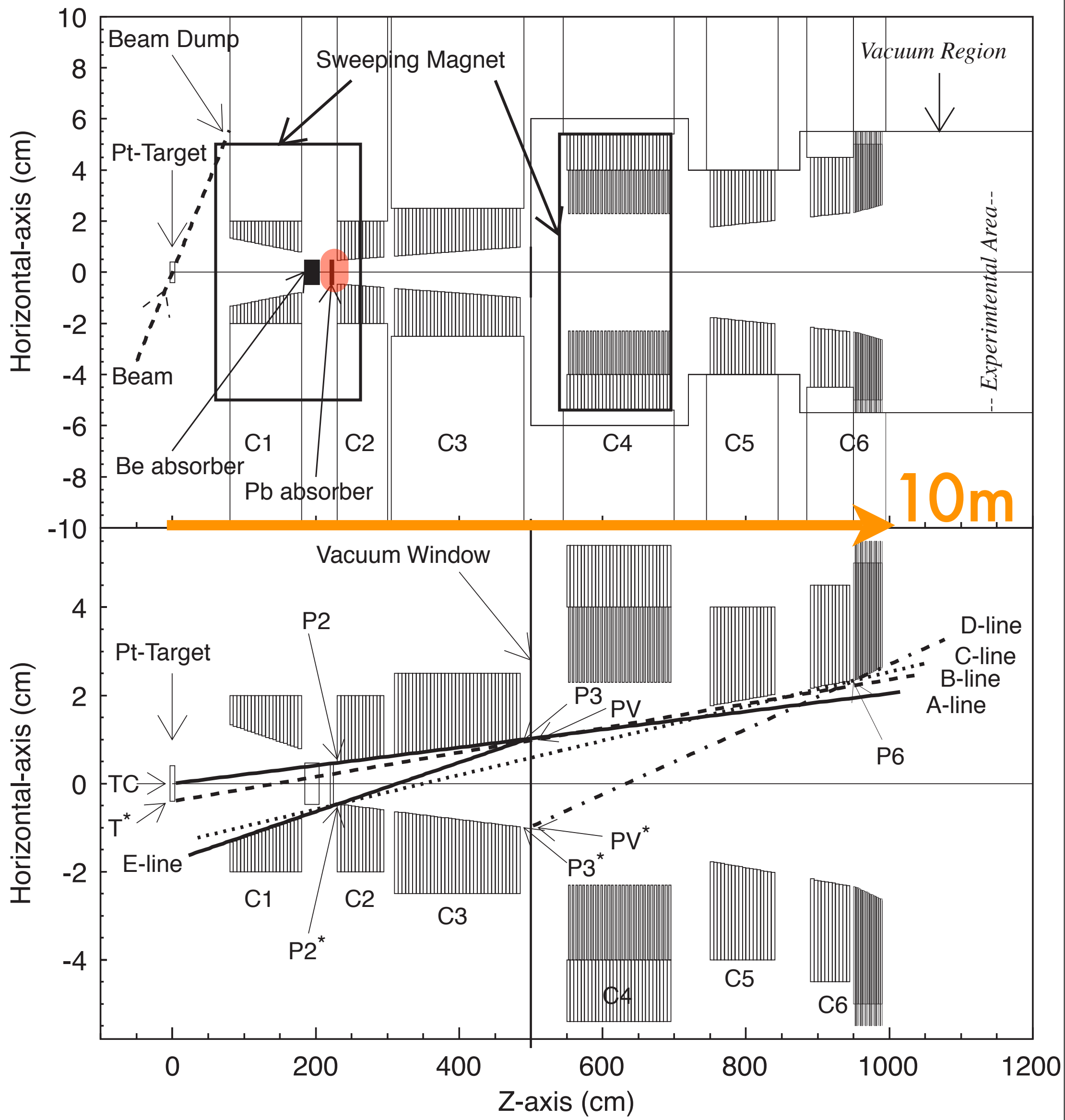


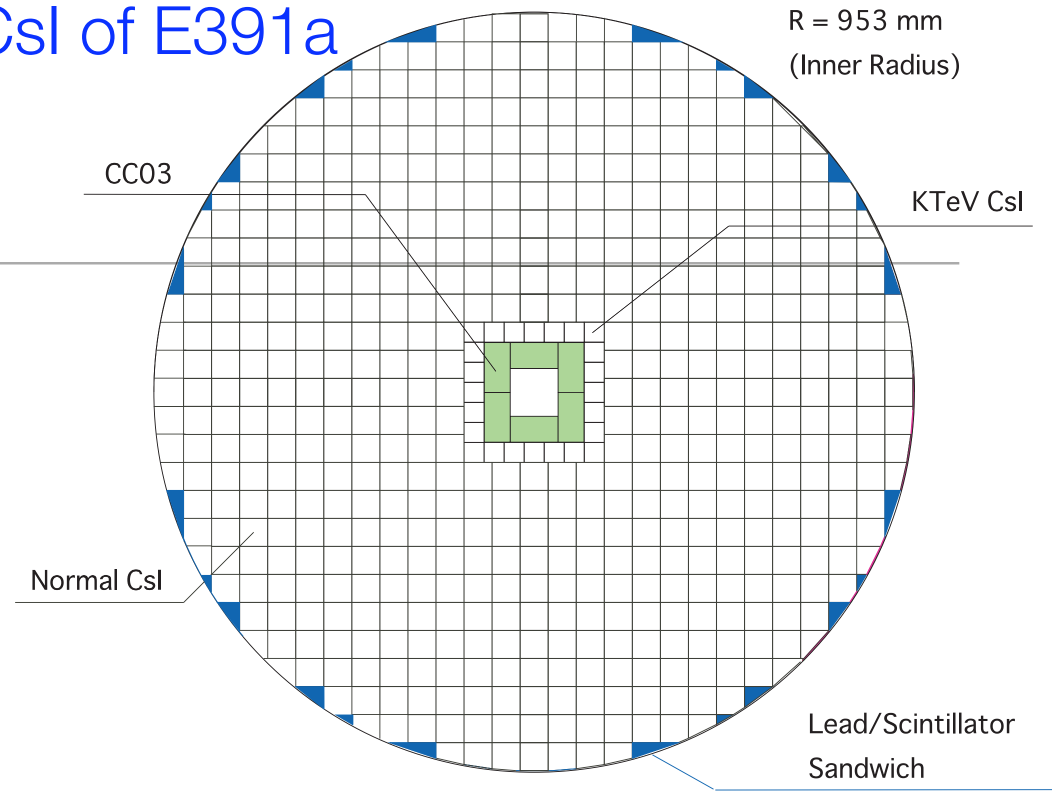
Table 2: Parameters of the K_L beamline for Step 1

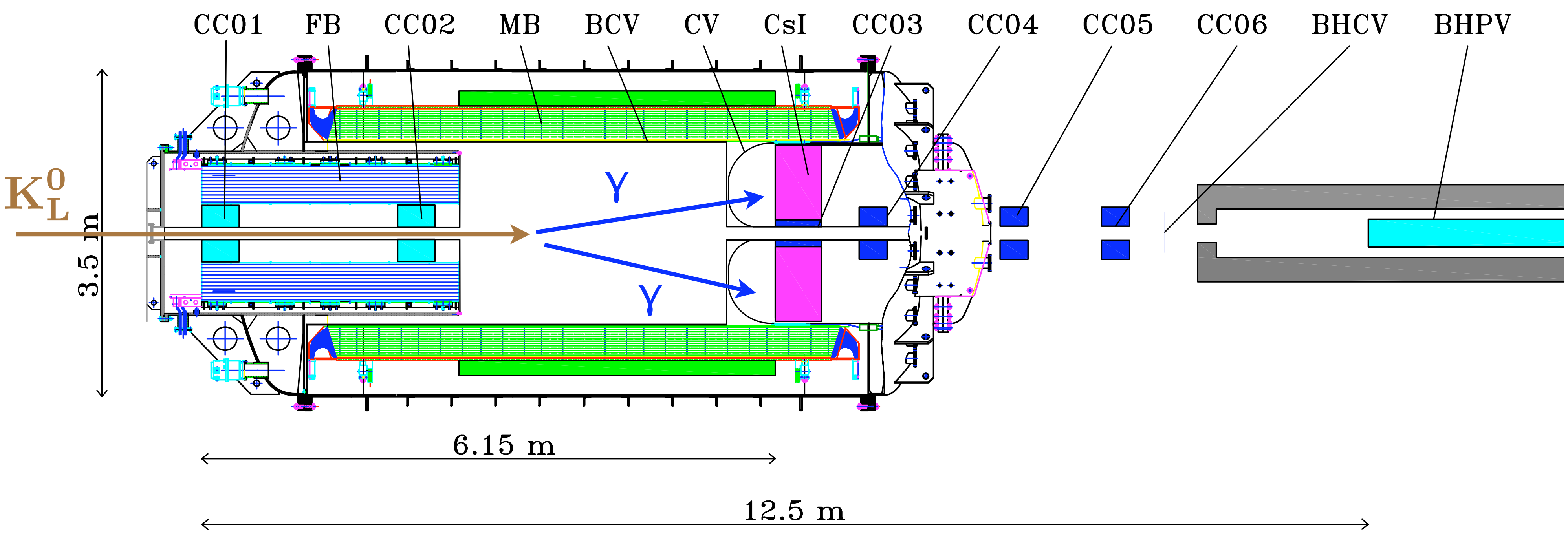
Item	J-Parc Step 1	KEK E391a
Primary proton energy	30 GeV	12 GeV
Proton intensity	2×10^{14}	2.5×10^{12}
Spill length / Beam repetition	0.7 s / 3.3 s	2 s / 4 s
Production Target	Common T1 target	Pt rod (L=60 mm, 8-mm ϕ)
Extraction angle	16°	4°
Solid angle	9 μsr	12.6 μsr
K_L yield/spill (beam exit)	8.1×10^6	3.3×10^5
Average momentum of K_L	2.1 GeV/c	2.6 GeV/c
Decay probability in $3 < z(m) < 5$	3.6%	2.7%
Core Neutrons/spill		
E_n >0.1 GeV	3.4×10^8	2.0×10^7
$E_n > 1$ GeV	6.9×10^7	1.4×10^7

測定器システム

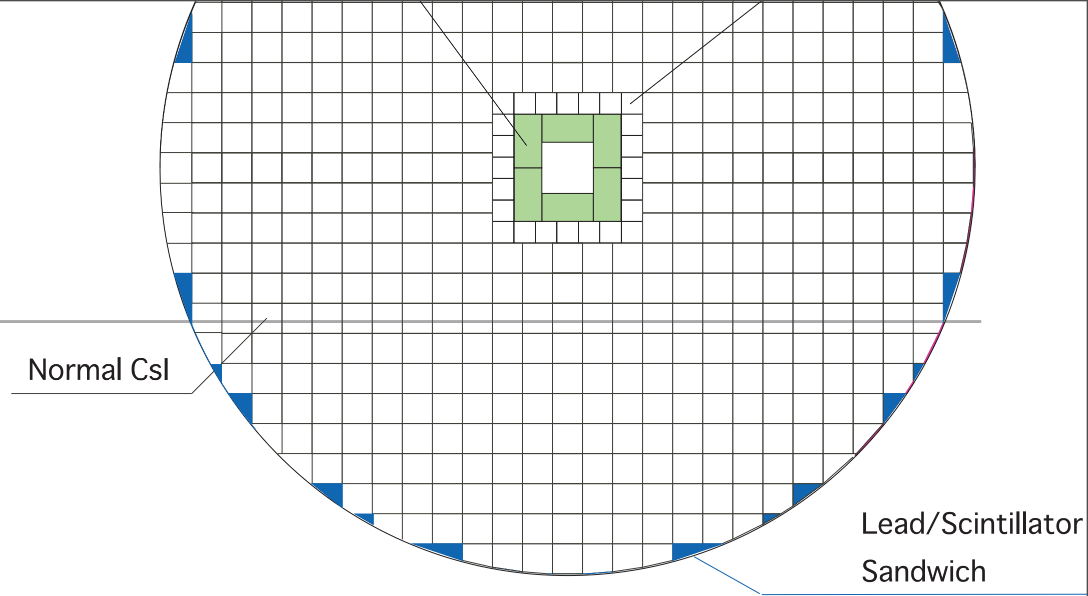
- E391a 測定器を移設／改造
  - CsI calorimeter
  - 読み出し: waveform digitization
  - photon veto in the beam

CsI of E391a



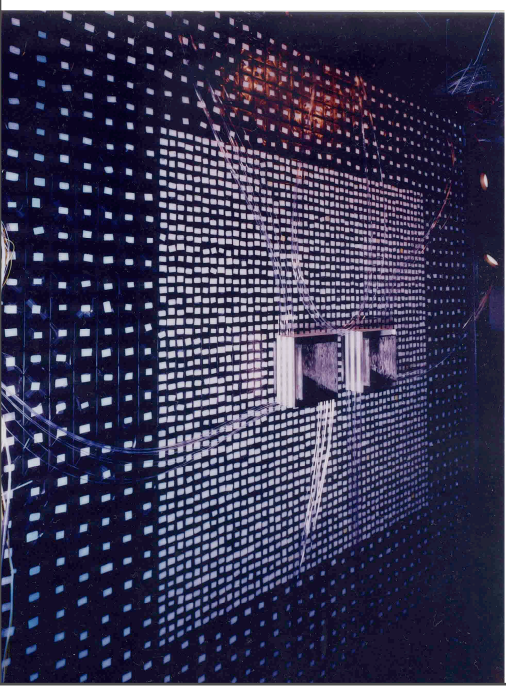


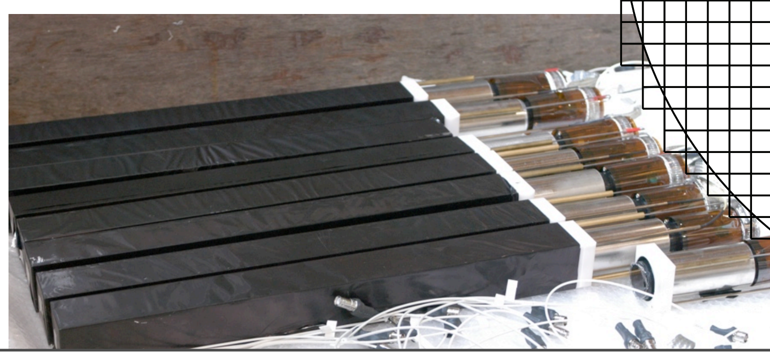
Calorimeter

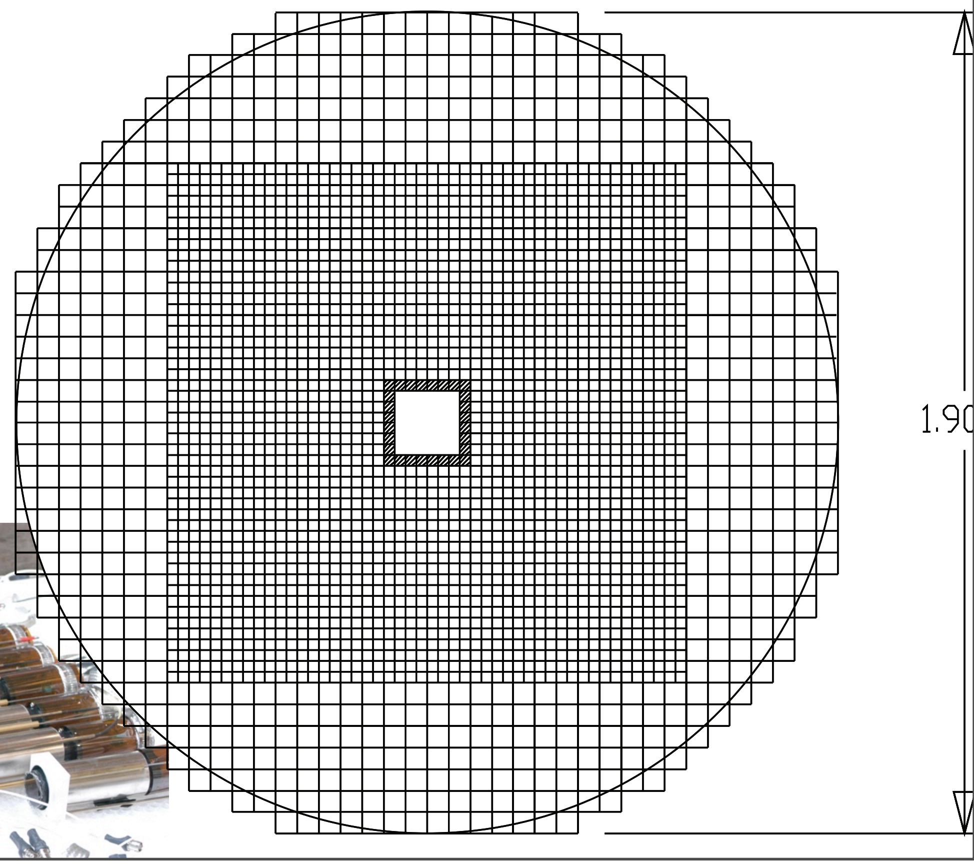


- 7cm x 7cm x 30cm (16 r.l.)
  CsI blocks for E391a (576 ch)

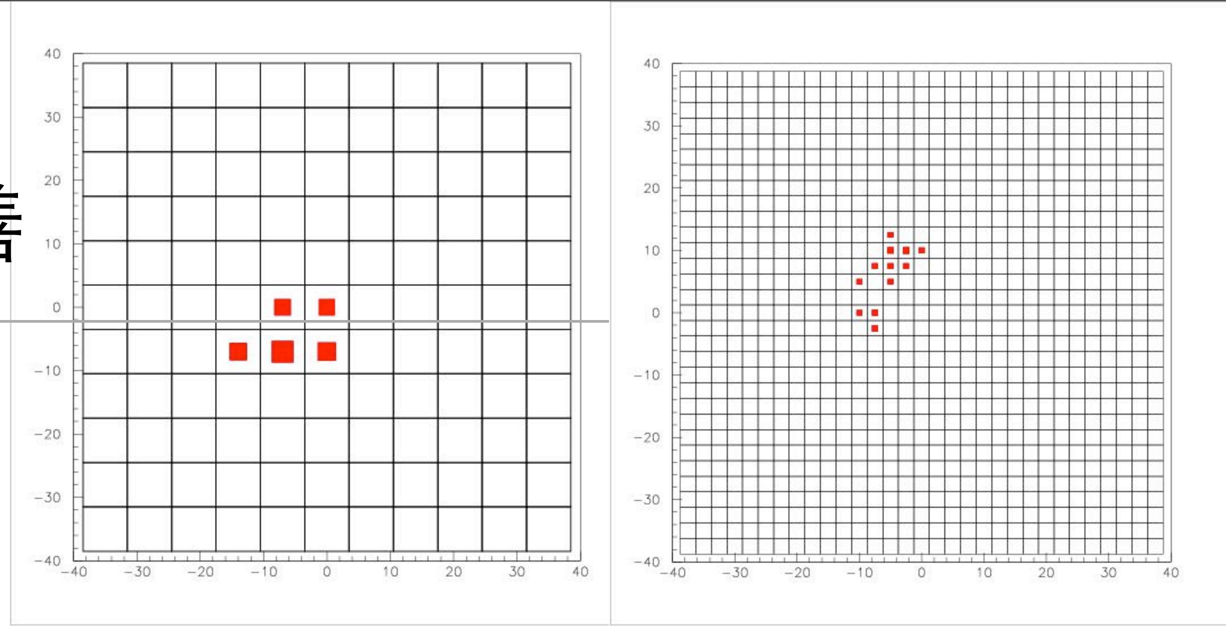
- 2.5cm x 2.5cm x 50cm (27 r.l.)
  or 5cm x 5cm x 50cm
  CsI blocks from KTeV (2816 ch)



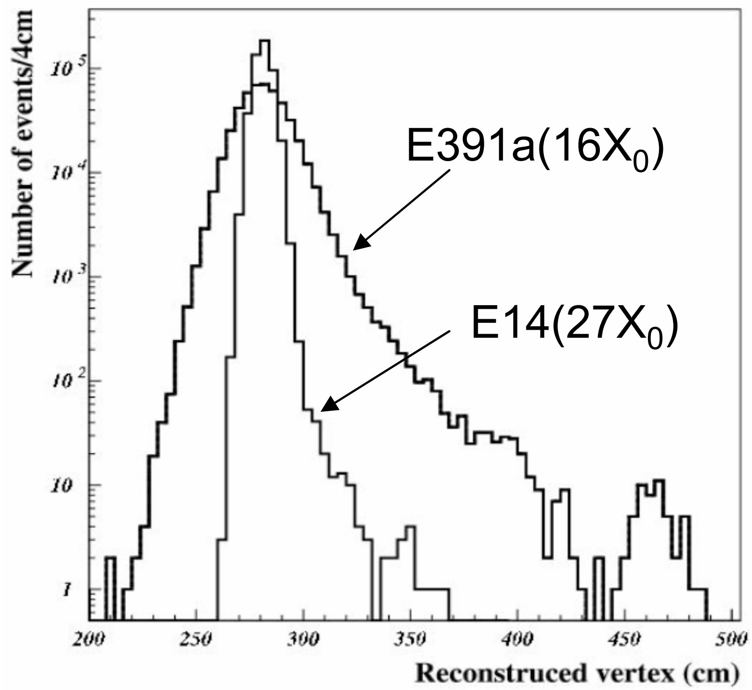


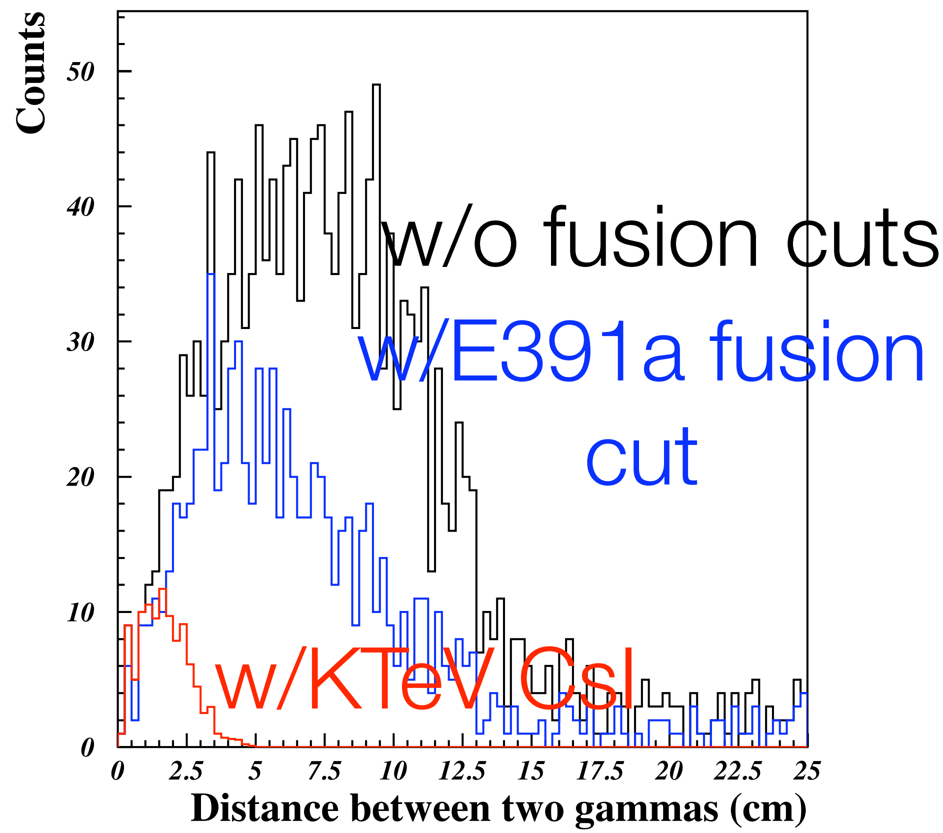


KTeV CsI による改善

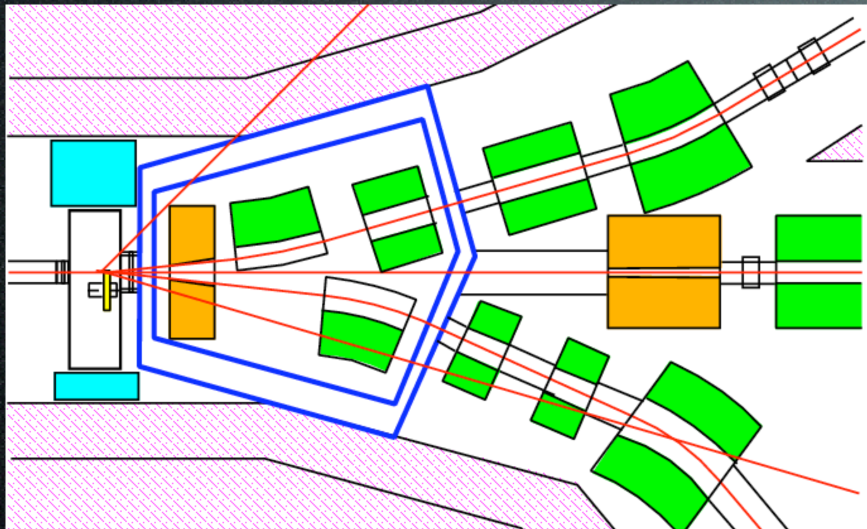


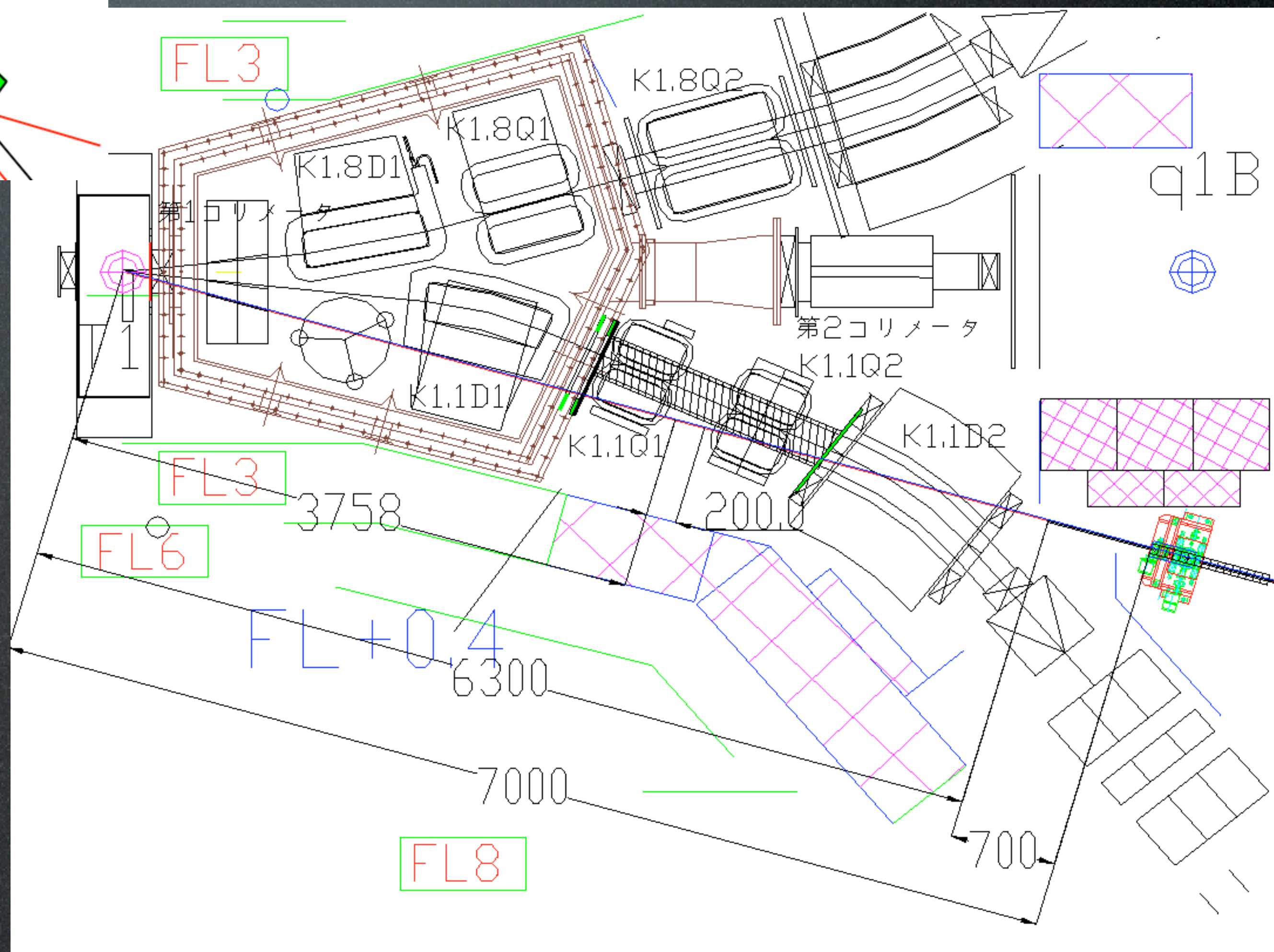
- photon isolation
    - x8 bkg reduction
- energy resolution (punch through)
    - suppress neutron background

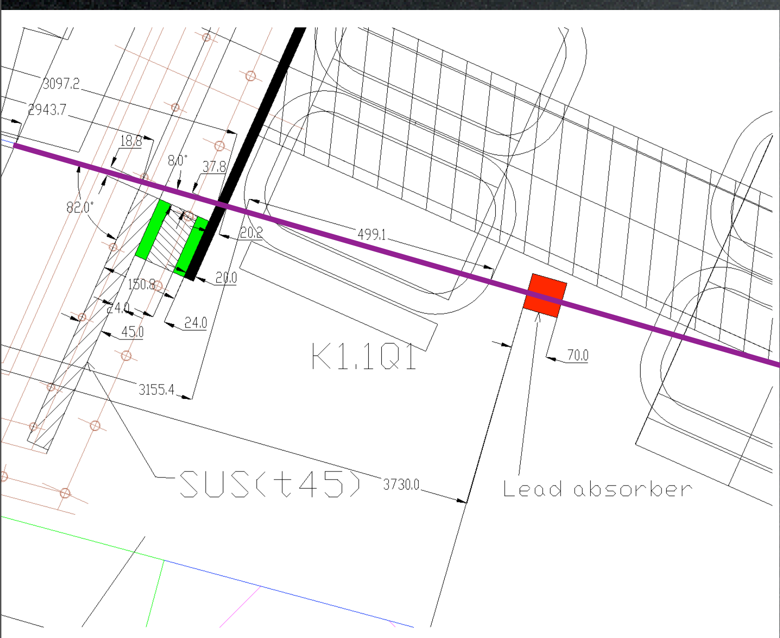




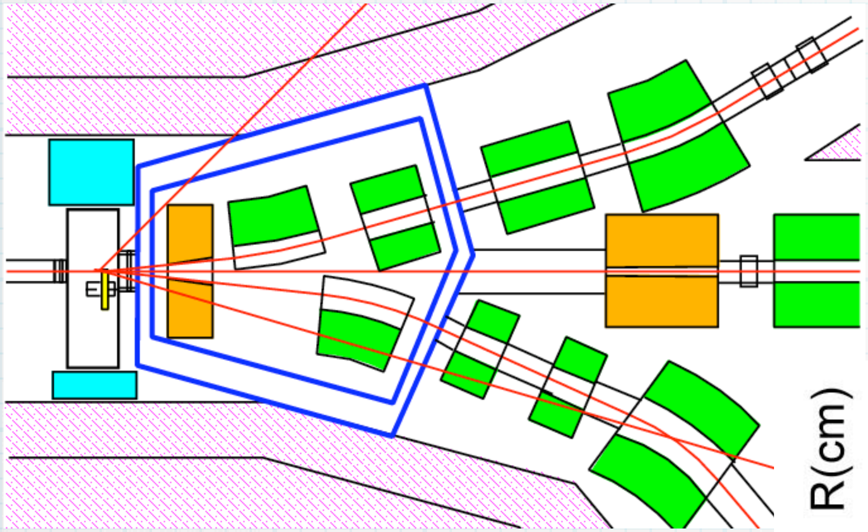
K1.1 componentsの効果



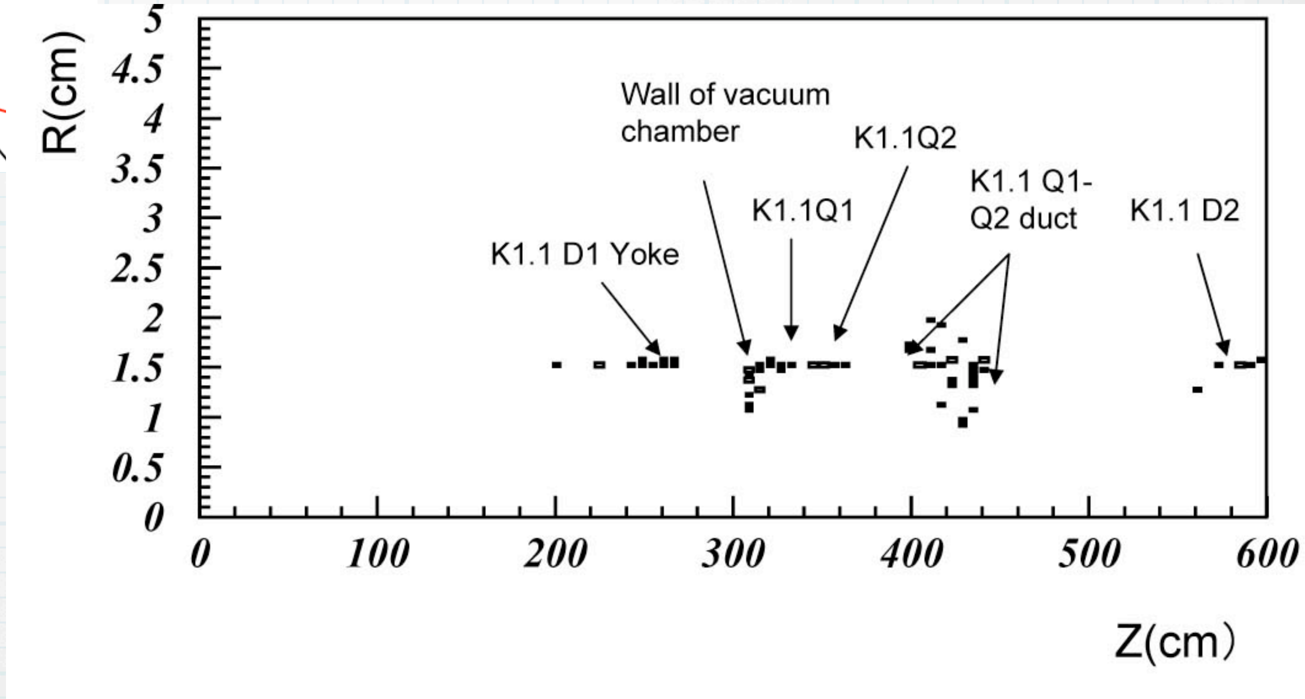




K1.1 componentsの効果

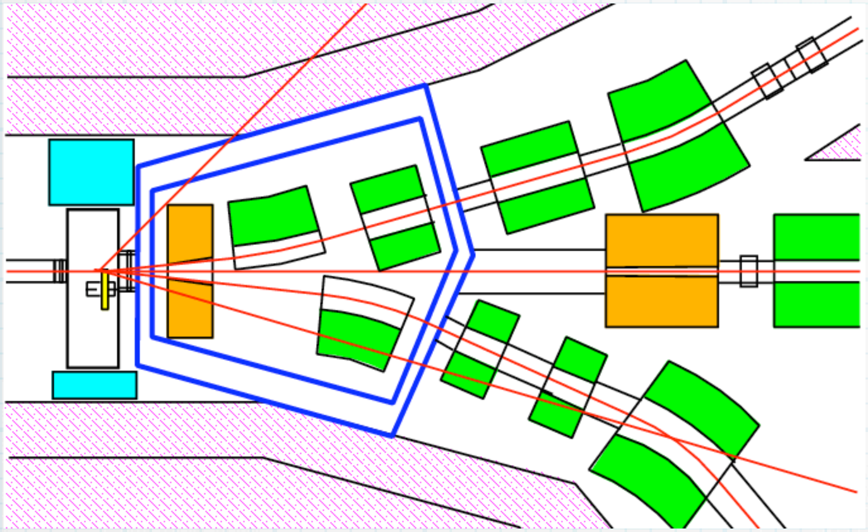


where in the upstream
do halo neutrons come from ?



	K1.1 D1	flange	K1.1 Q1, Q2	K1.1 duct	K1.1 D2
KL line alone	out	t=0.2mm	out	out	out
modified K1.1	in	t=0.2mm	in	t=0.2mm	in
original K1.1	in	t=20mm	in	t=5mm	in

K1.1 componentsの効果



"KL line alone" most preferable
KL x1.7
halo neutron x0.52

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	$(1.38 \pm 0.20)\ \times 10^4$	$(4.56 \pm 0.08) \times 10^6$

	K1.1 D1	flange	K1.1 Q1, Q2	K1.1 duct	K1.1 D2
KL line alone	out	t=0.2mm	out	out	out
modified K1.1	in	t=0.2mm	in	t=0.2mm	in
original K1.1	in	t=20mm	in	t=5mm	in

KL flux

Table 9: The K_L yields per incident proton on the target (POT) at E391a, measured from data, and predicted by several different MC packages. QGSP and QBBC are the physics classes of hadronic interactions available in GEANT4.

	K_L Yield per POT
Run-II data	$(1.36 \pm 0.08) \times 10^{-7}$
GEANT3	$(1.32 \pm 0.03) \times 10^{-7}$
GEANT4(QGSP)	$(1.31 \pm 0.11) \times 10^{-7}$
GEANT4(QBBC)	$(1.54 \pm 0.12) \times 10^{-7}$
FLUKA	$(1.40 \pm 0.02) \times 10^{-7}$

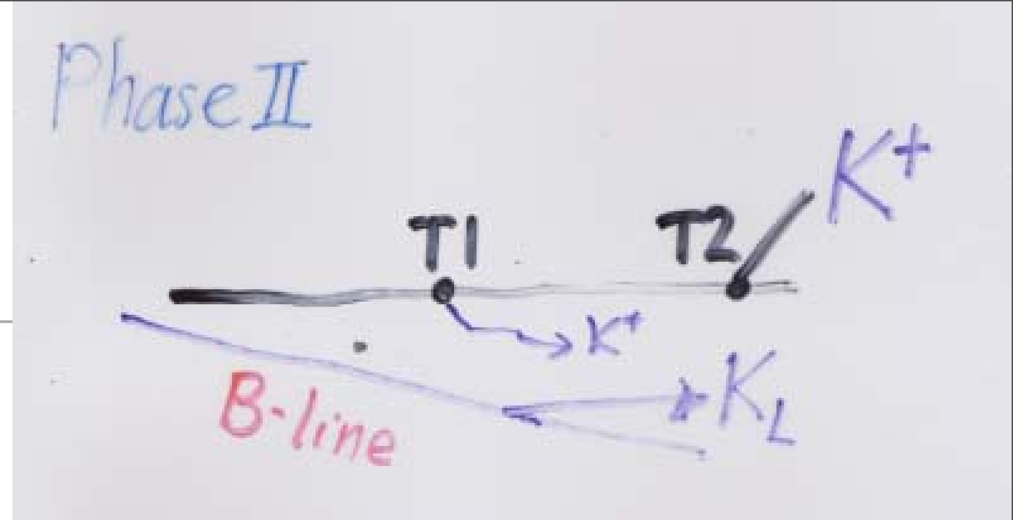
Table 10: Comparison of expected K_L yields at E14 (per POT) by various MC packages. Note this study was performed with the "original K1.1" configuration.

	K_L Yield per POT
GEANT3	$(3.8 \pm 0.1) \times 10^{-8}$
GEANT4(QGSP)	$(2.3 \pm 0.1) \times 10^{-8}$
GEANT4(QBBC)	$(2.7 \pm 0.3) \times 10^{-8}$
FLUKA	$(8.3 \pm 0.2) \times 10^{-8}$

conservative approach

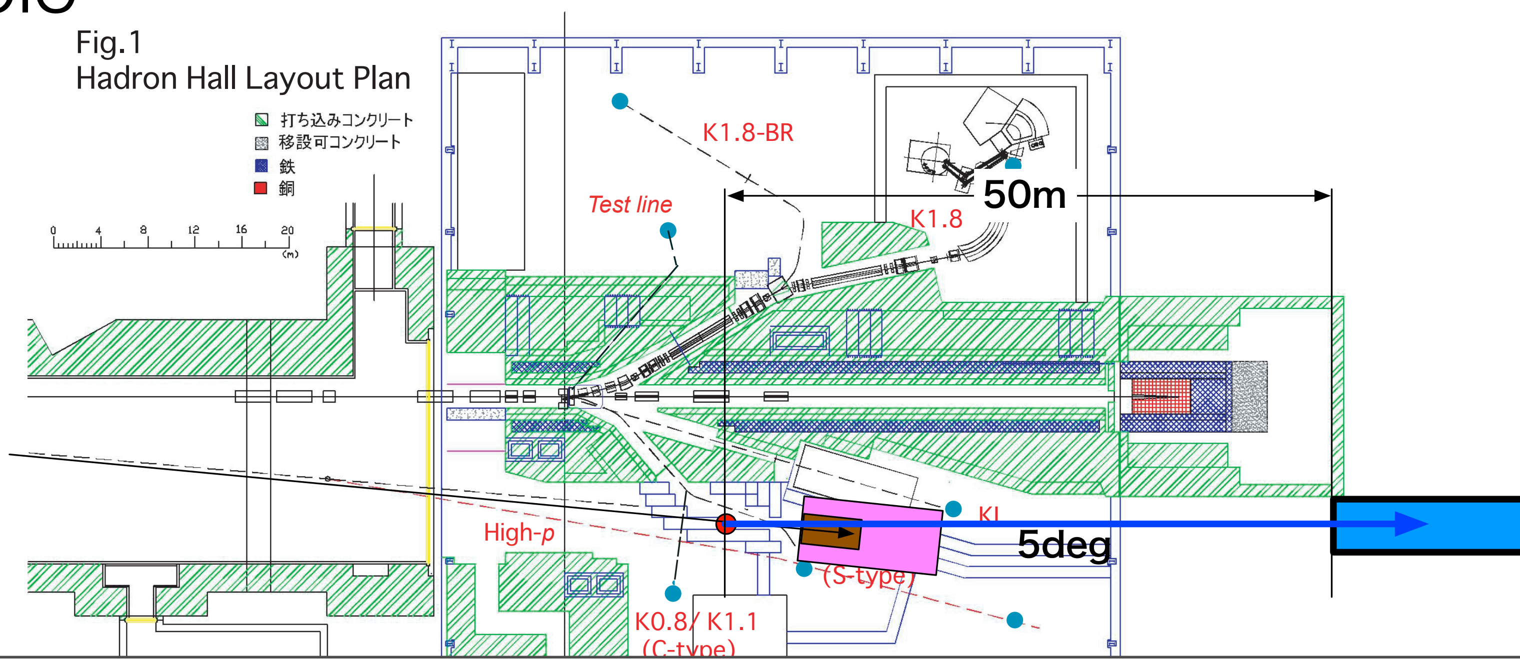
We are studying the reason for this discrepancy.

next to E14
for the B.R. measurement

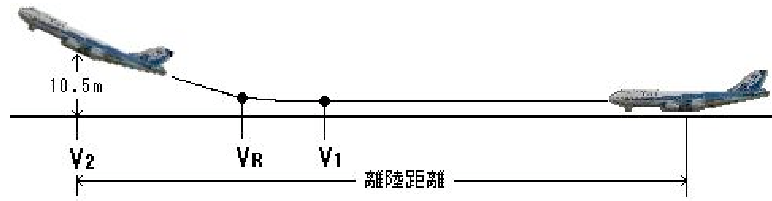


- Optimized beamline with 5deg angle for
  - higher KL momentum <PK>=5.2GeV/c
  - higher yield: 4.4E7/2μsr /3E14pot

Example

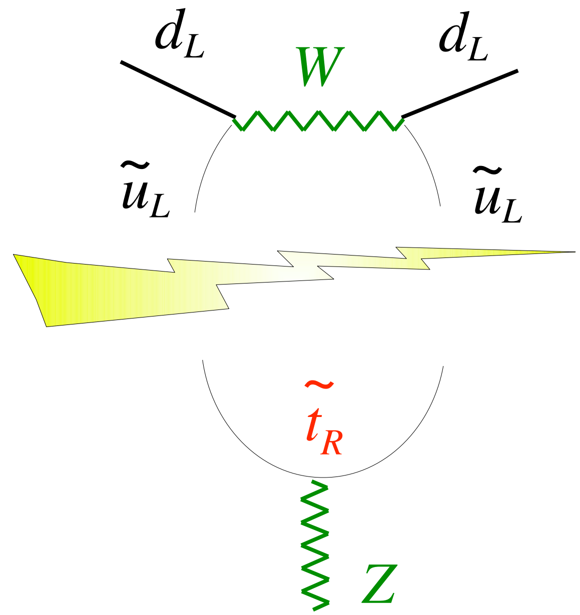


まとめ:
KLビームライン整備拡充に向けて



- E14 is taking off.

- E14 is the endeavor to investigate the flavor structure beyond the Standard Model with $K_L \to \pi^0 \nu \overline{\nu}$



- We have made great strides in the beamline and detector studies.

- The “KL beam alone” configuration shows the best performance.

- With the achievements in E14, we will proceed to the measurement of the rare decay.

Backup slides

up-to-date

Signal Sensitivity for E14 = first observation

		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

"KL line alone"
3 Snowmass years
GEANT4(QGSP) flux

Table 5: Effect of K1.1 materials.

	Signal	K BG	halo n BG	total BG	S/N
KL line alone	2.70 ± 0.05	1.8 ± 0.1	0.35	2.2	1.3
modified K1.1	2.70 ± 0.05	1.8 ± 0.1	0.7	2.5	1.1
original K1.1	1.58 ± 0.03	1.05 ± 0.06	0.8	1.9	0.9