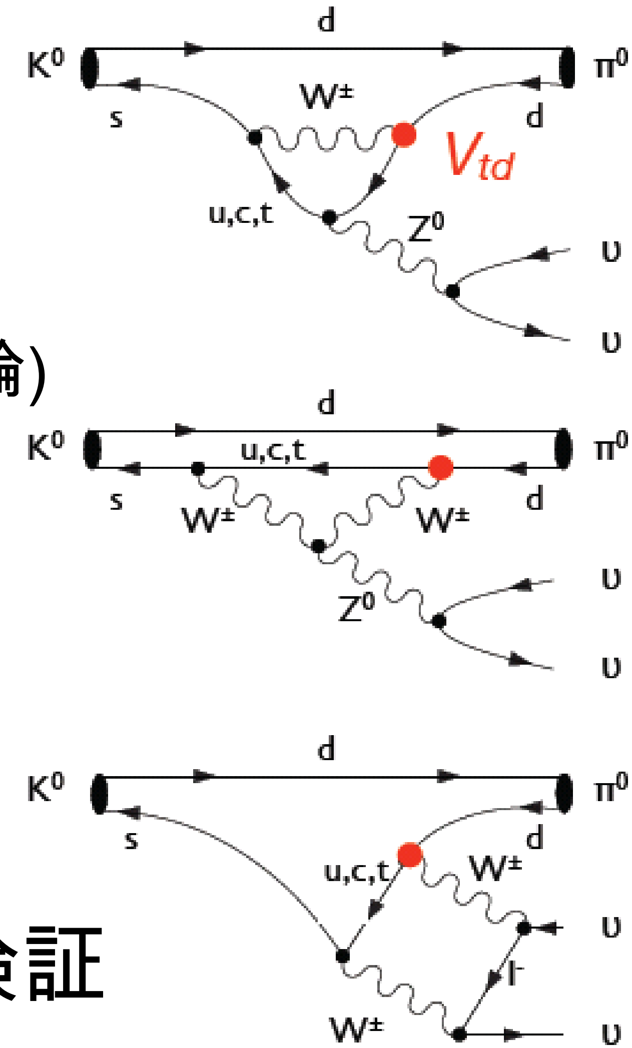
$K^{O}TO$実験の現状

京都大学
南條　創

- Contents
  - KOTO introduction
  - J-PARC
  - KL beam line
  - Beam line survey
  - Other activities

$K^{O}TO$=K0 at Tokai

- $K_L \rightarrow \pi^0 \nu\nu$崩壊
  - CP violating, FCNC process
    - Top quark, W, Z　loop (High energy)
    - Rare : Br = (2.8 +- 0.4) x 10^{-11} (標準理論)
    - New physics感度
      - New particleがループに寄与
  - Branching ratio ∝　η^2
    - $K^0 - \overline{K^0}$ → 　Im(Vtd)
  - 理論的不定性　2%程度



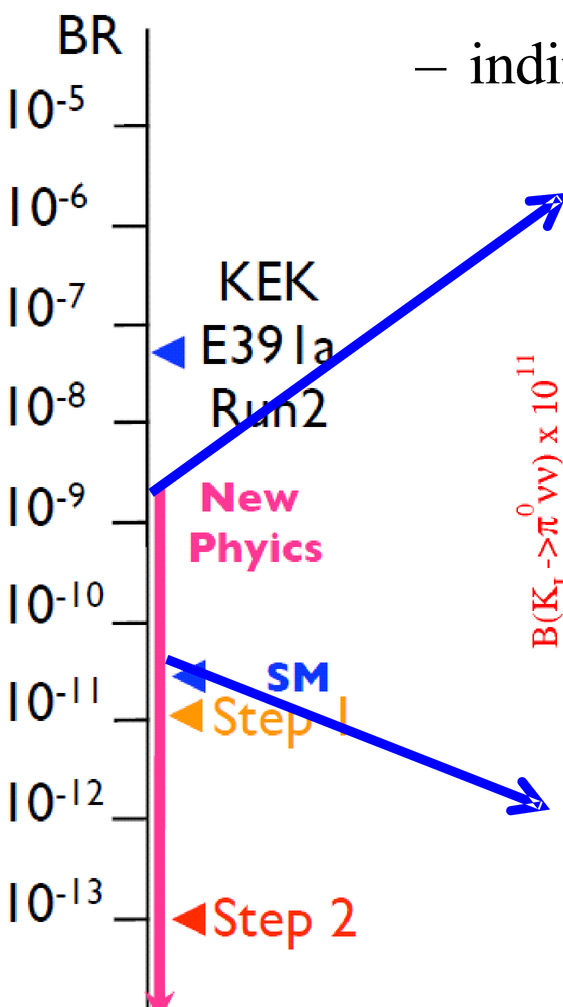
- KOTO : New physics探索 & SM検証
  - 感度 ~10^{-11} with S/N ~ 2
    - ビーム強度2x10^{14} proton/3.3sec
    - 3 snowmass yearで到達

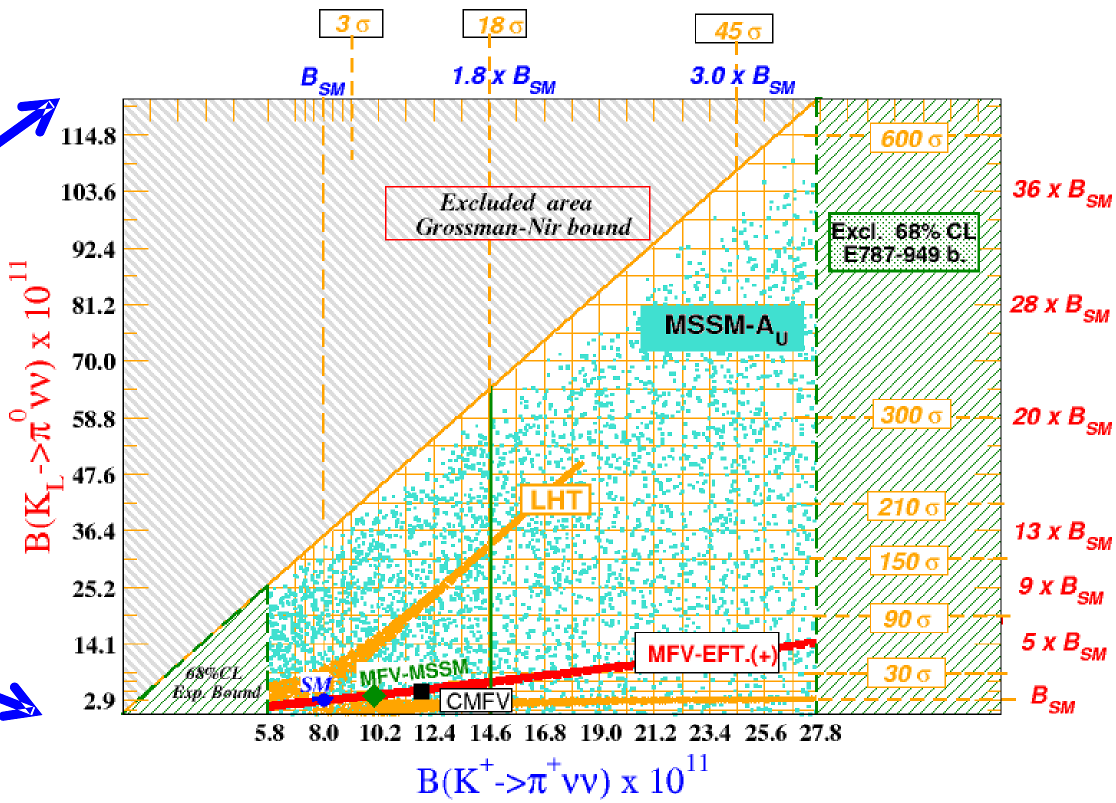
First Observationが目標

2010 ICEPP Sympo @Hakuba

New Physics

- KEK-PS E391 Run2 $Br < 6.7 \times 10^{-8} (90\%CL)$
  - Run3 : Br<2.6x10
- Grossman-Nir bound $Br < 1.46 \times 10^{-9} (90\%CL)$
  - model independent (can be violated if LFV)
  - indirect limit from $K^+ \to \pi^+ \nu \bar{\nu}$ BNL E797/E949 $Br = 1.73^{+1.15}_{-1.05} \times 10^{-10}$



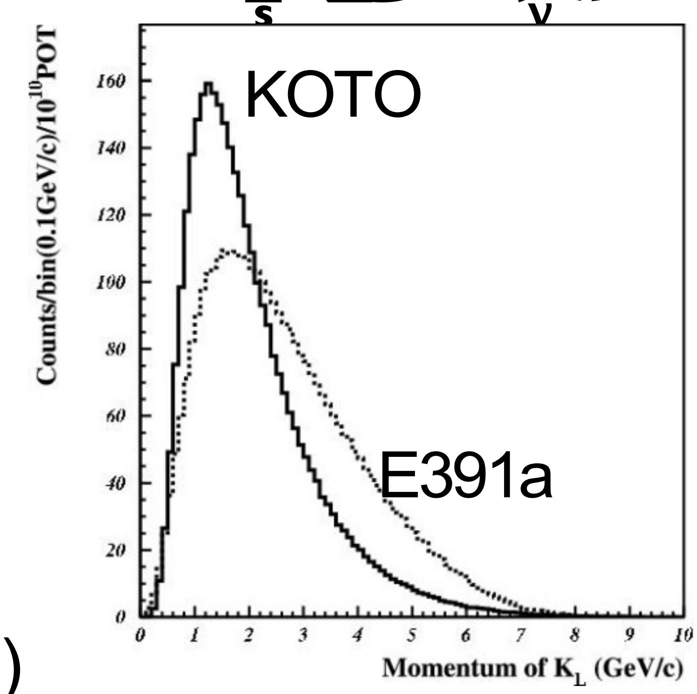


MSSM

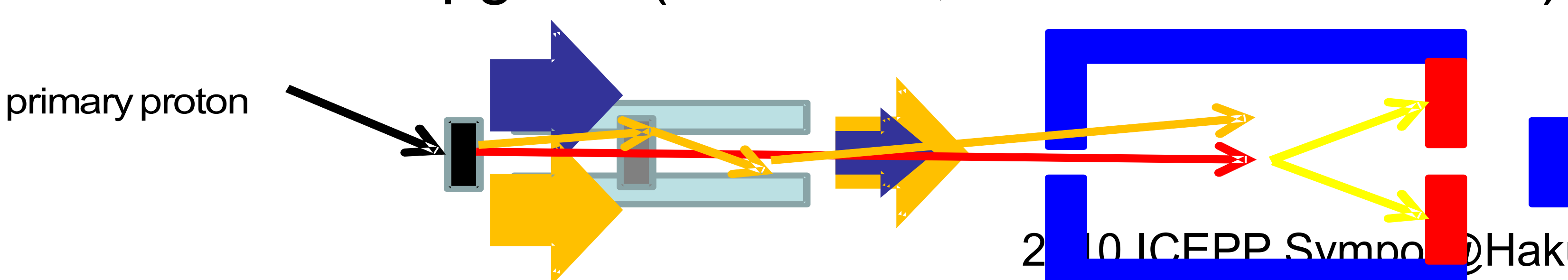
Little Higgs with T-parity

実験の原理

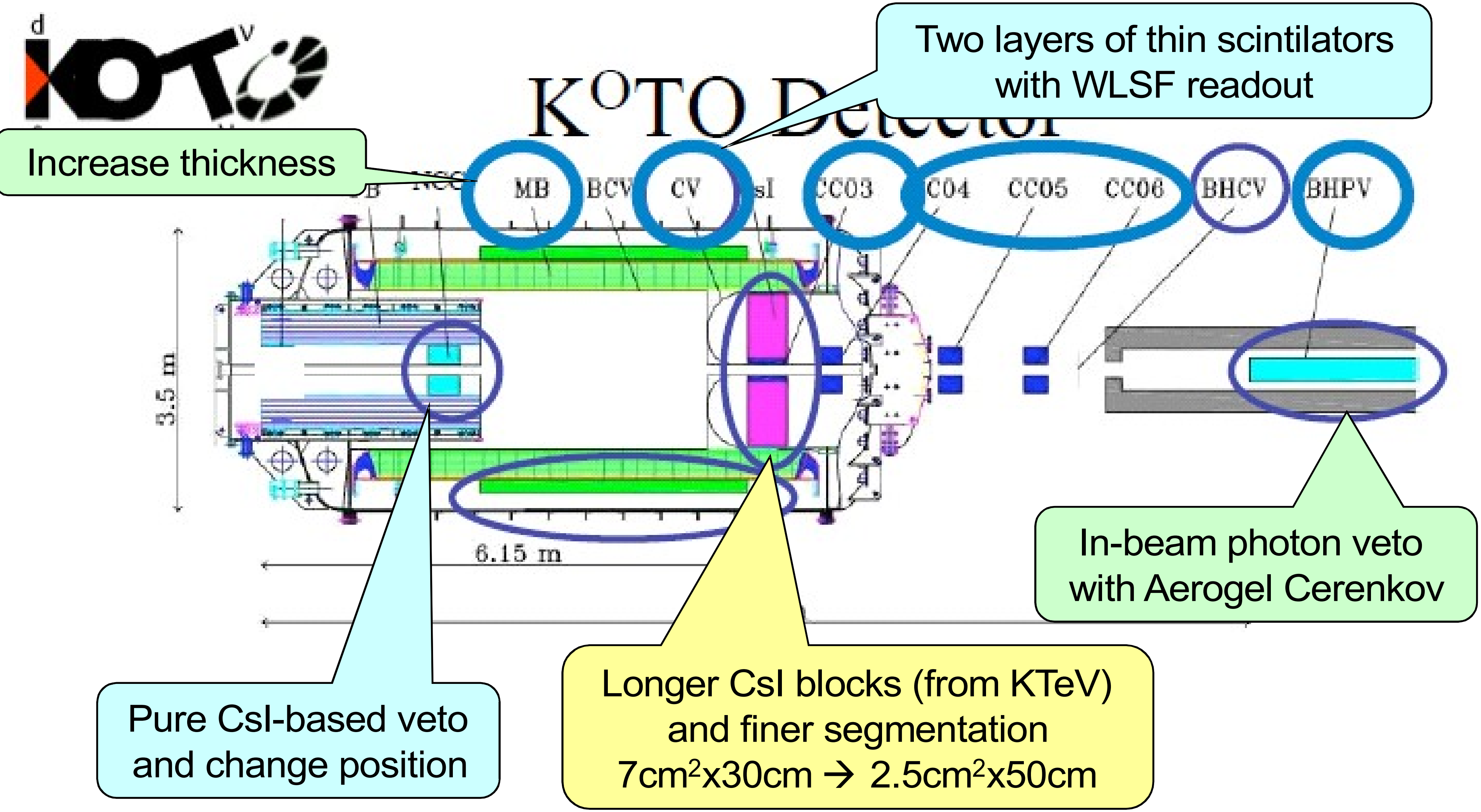
- E391aと同じ手法
  - Π0 and nothing
    - CsI calorimeter + hermetic veto
  - Pencil beam
    - beam軸上を仮定したKL 再構成
    - Beam hole vetoの負担を減らす



- J-PARC 大強度beam (KEK PSの100倍)
  - KL yield x DecayProbxRunTimexAcceptance
    = 30 x 2 x 10 x 5=3000
- New beam line (halo中性子削減)
- E391検出器をupgrade(Veto強化, halo 中性子BG削減)



KOTO検出器



KOTO Detector
MB
BCV
CV
CsI
CC03
CC04
CC05
CC06
BHCV
BHPV
3.5 m
6.15 m
Increase thickness
Two layers of thin scintilators with WLSF readout
In-beam photon veto with Aerogel Cerenkov
Pure CsI-based veto and change position
Longer CsI blocks (from KTeV) and finer segmentation
7cm²x30cm → 2.5cm²x50cm

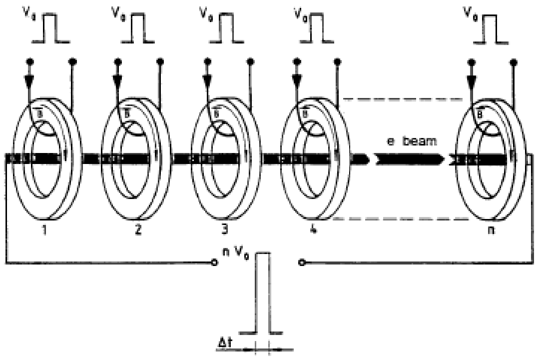
K^OTO実験予定

- 2008
  - Beam line design
  - 2009.2 J-PARC Hadron Hall 1st beam
- 2009
  - 2009.4-2009.9 Beam line construction
  - 2009.10-2010.2 Beam line survey　　現在進行中
  - Detector preparation
    - CsI preparation : ~3000 crystals
    - DAQ with 125MHz FADC
    - Other detectors
- 2010 CsI Engineering Run
- 2011 Full detector and Physics Run

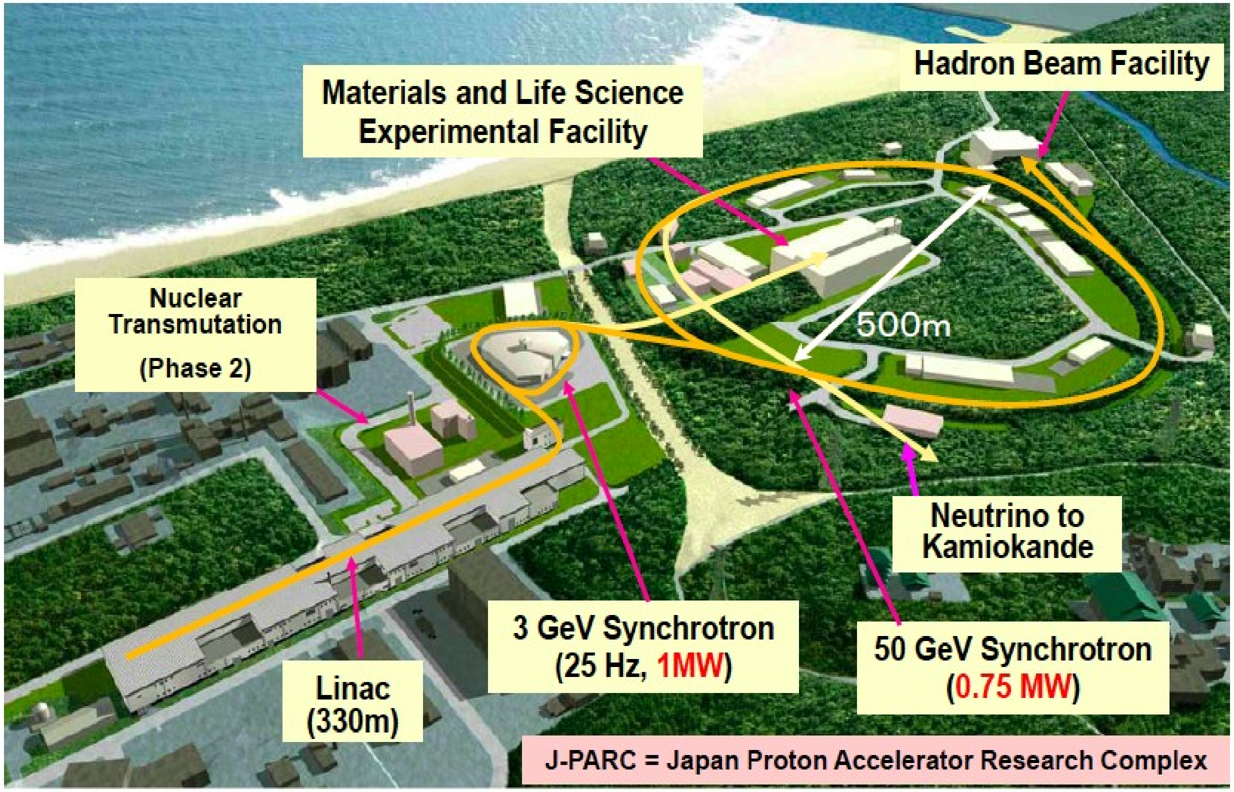
加速器の状況

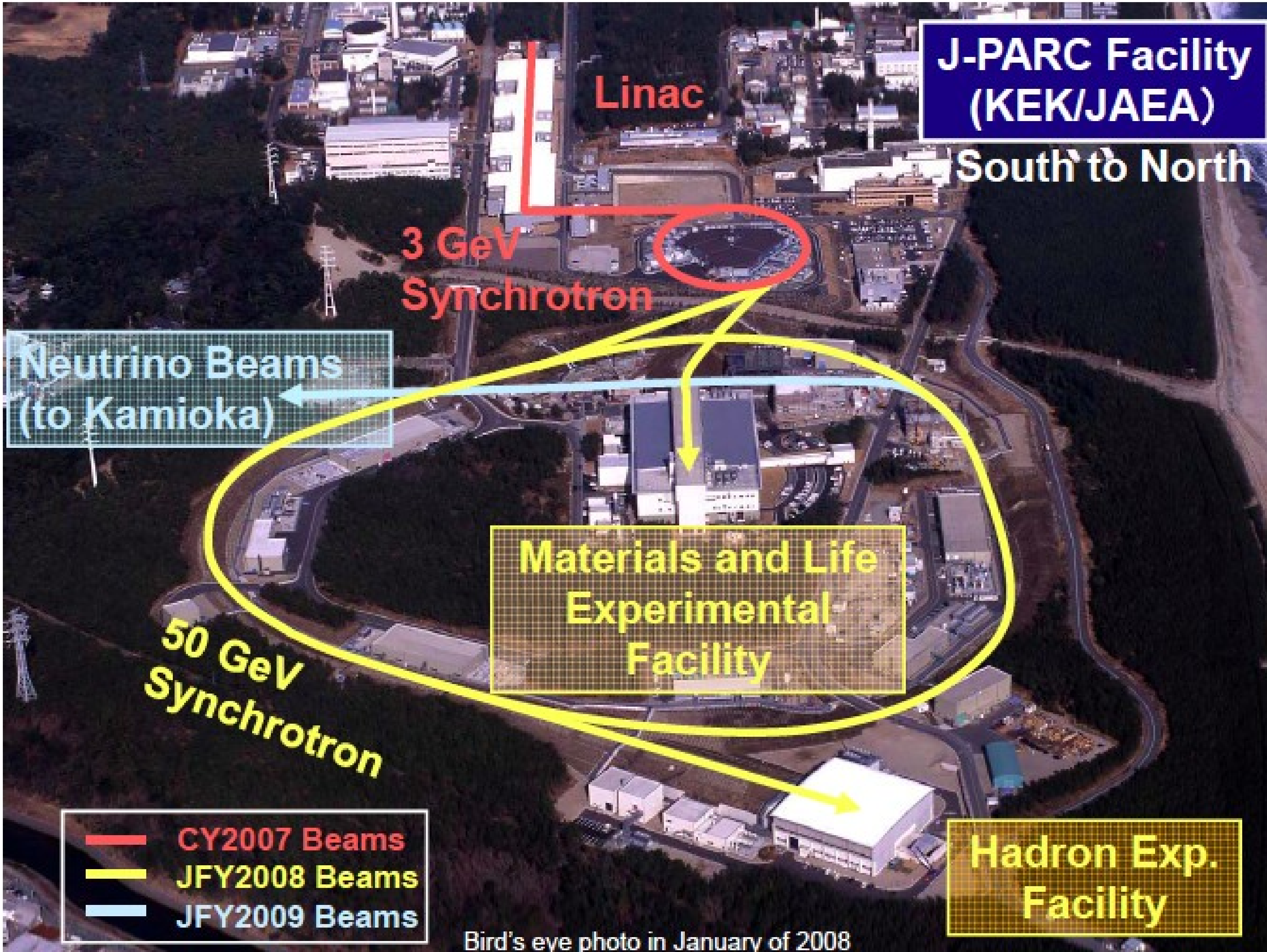
J-PARC

- H⁻イオン源→ RFQ→DT Linac　180MeV
- RCS 3GeV
  - H⁻ →proton→誘導加速
    (ファインメットRFコア)



- MR 30GeV
  - Fast extraction
  - Slow extraction
    デザイン 300kW
    2×10^{14} ppp
    0.7sec/3.3sec





J-PARC Facility
(KEK/JAEA)
South to North
Linac
3 GeV
Synchrotron
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

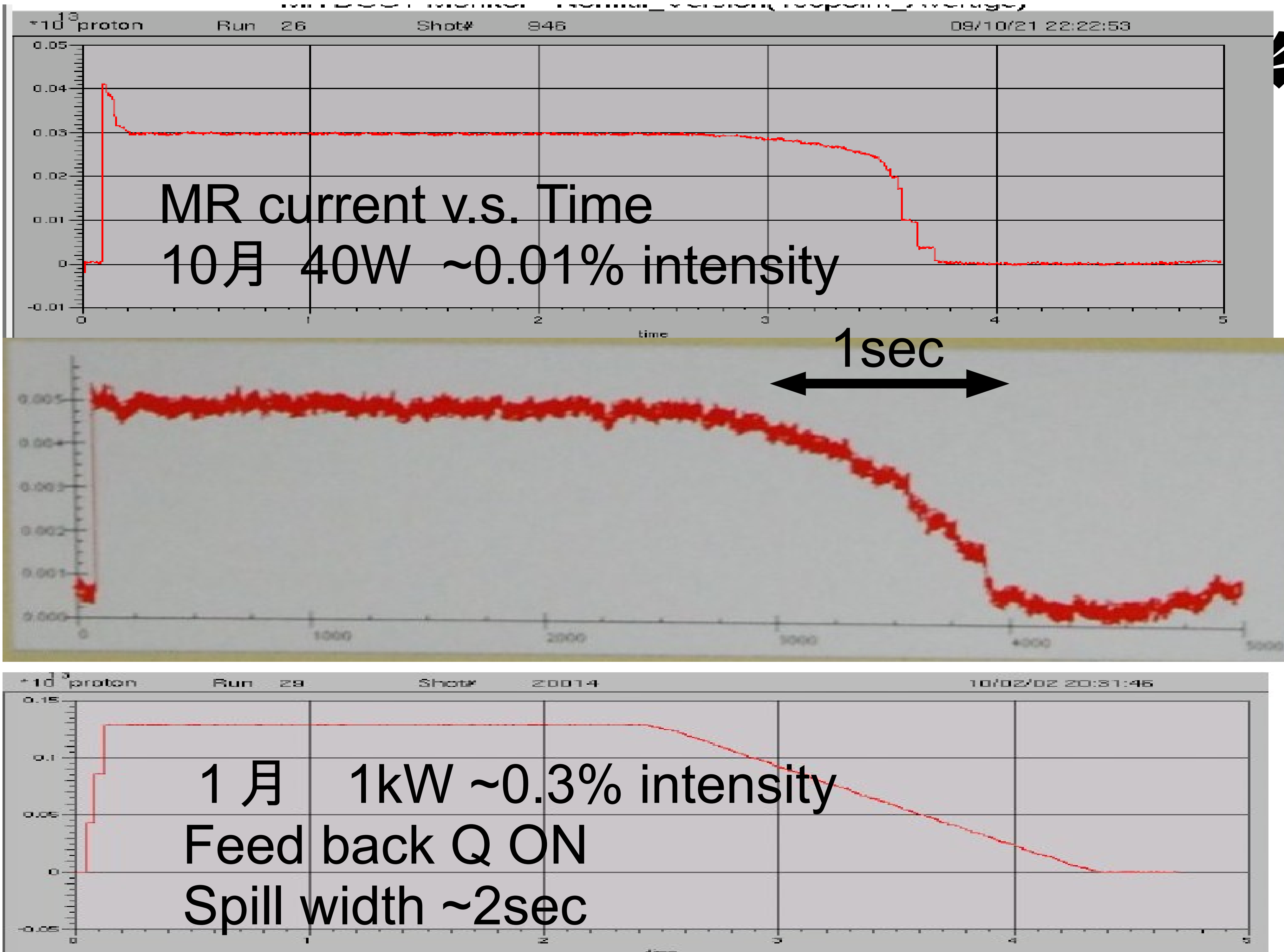
J-PARCの状況

- ビームパワー
    - 徐々に上昇(RCS 300kW,Fast Ext.は100kW try, Slowは3kW try)
- RFQ
  - 電極で放電、３日に１日休み(コンディショニング)

    →　真空改善により放電問題解消へ向かっている
- Slow Extraction
    - Beamをかんなで削るようにしてゆっくり取り出す→ 難しい
  - リップル
    - Magnet電源のリップルでビーム軌道不安定
    - スパイク状にビームが取り出される

      →RQ/EQというフィードバックQマグネットで少し改善
  - ビームロス　ビーム中にセプタム→ ロス

    →　1.5%程度のロス 数kWでは問題ない→ 今後の課題


*10 proton Run 26 Shot# 946 09/10/21 22:22:53
MR current v.s. Time
10月 40W ~0.01% intensity
1sec
*10 proton Run 29 Shot# 20014 10/02/02 20:31:46
1 月 1kW ~0.3% intensity
Feed back Q ON
Spill width ~2sec

Spill 構造

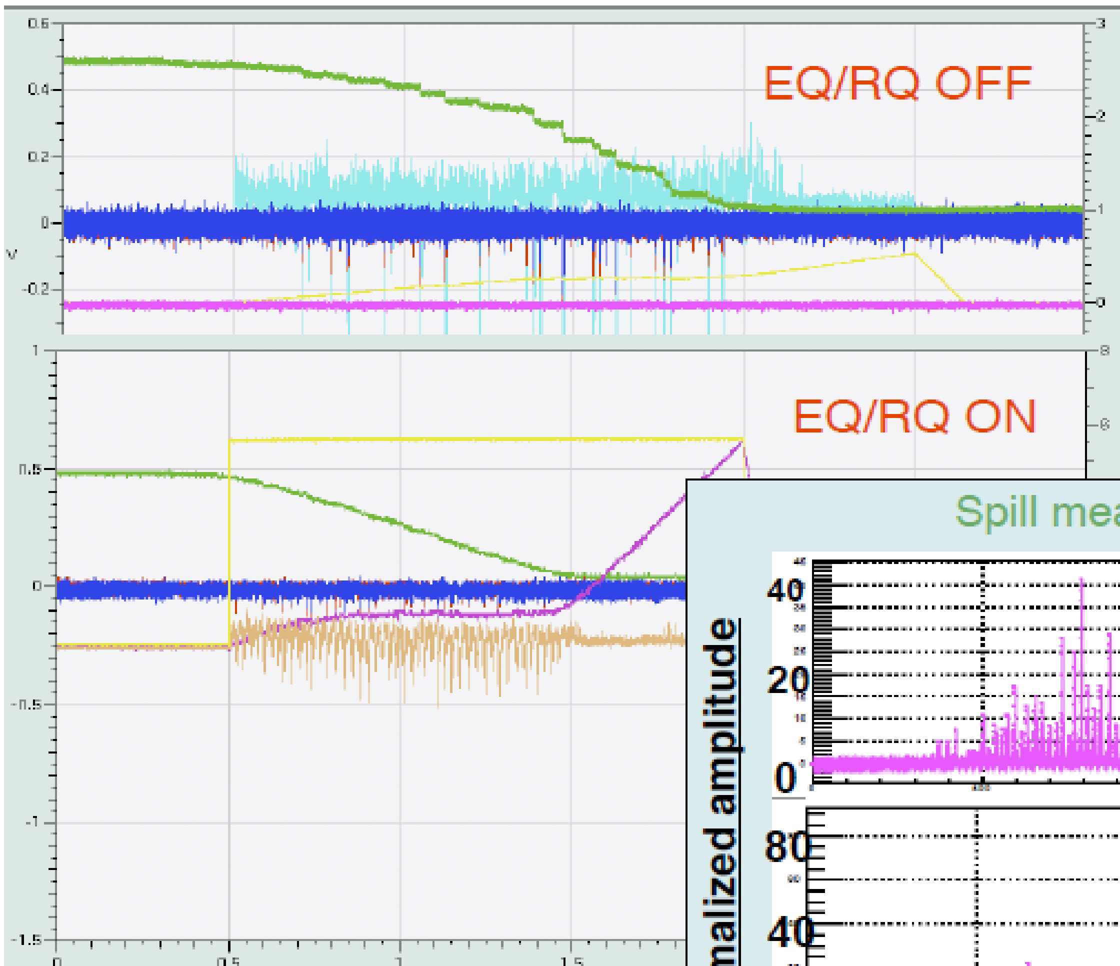
- なるべく瞬間レートを低くしたい→ Slow Ext.
  - パイルアップ、検出器の動作

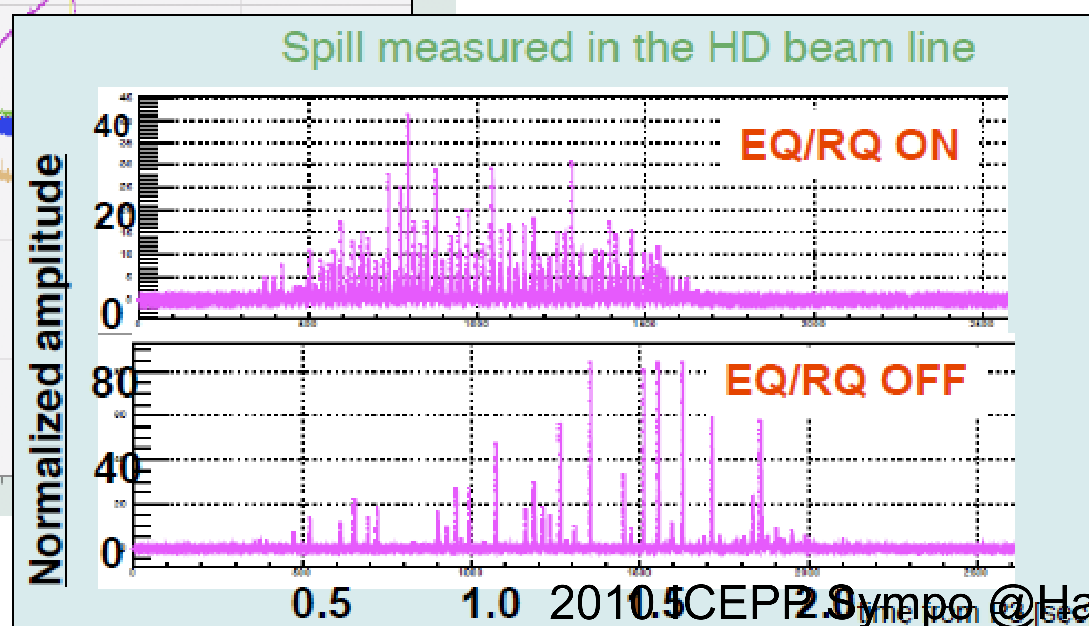
ハリハリビームは不都合

Feedback Qで、

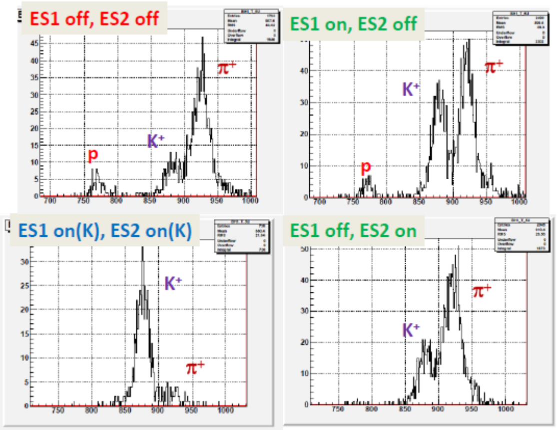
factor程度改善

→ 今後の課題

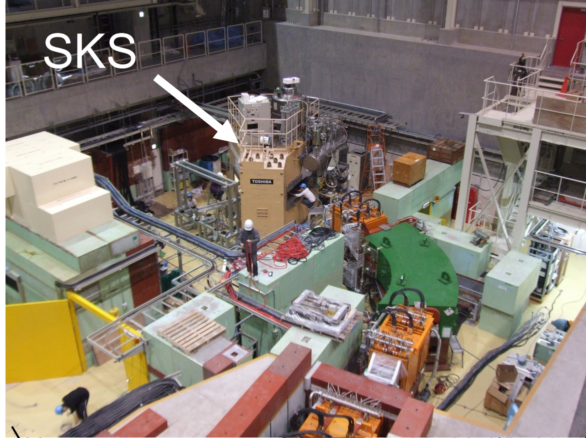




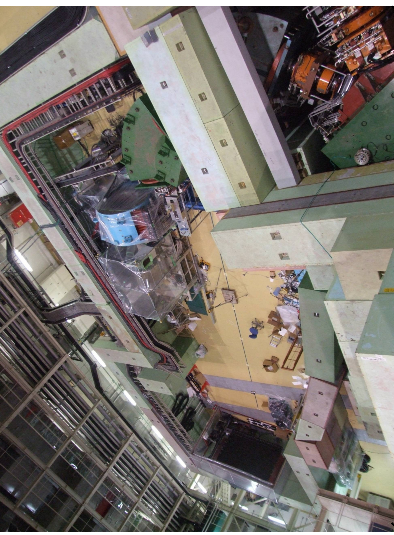
ハドロンホールの状況

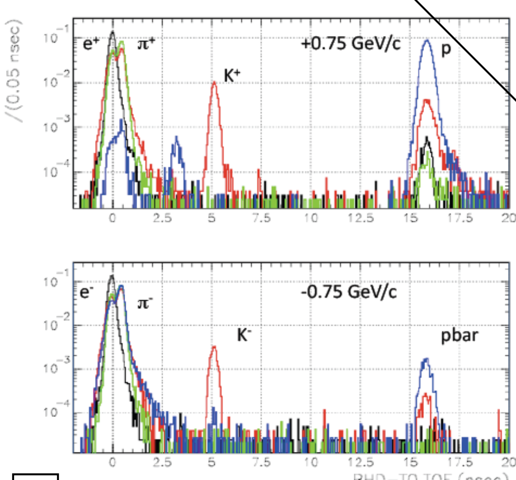


ES1 off, ES2 off
ES1 on, ES2 off
ES1 on(K), ES2 on(K)
ES1 off, ES2 on
p
K+
π+

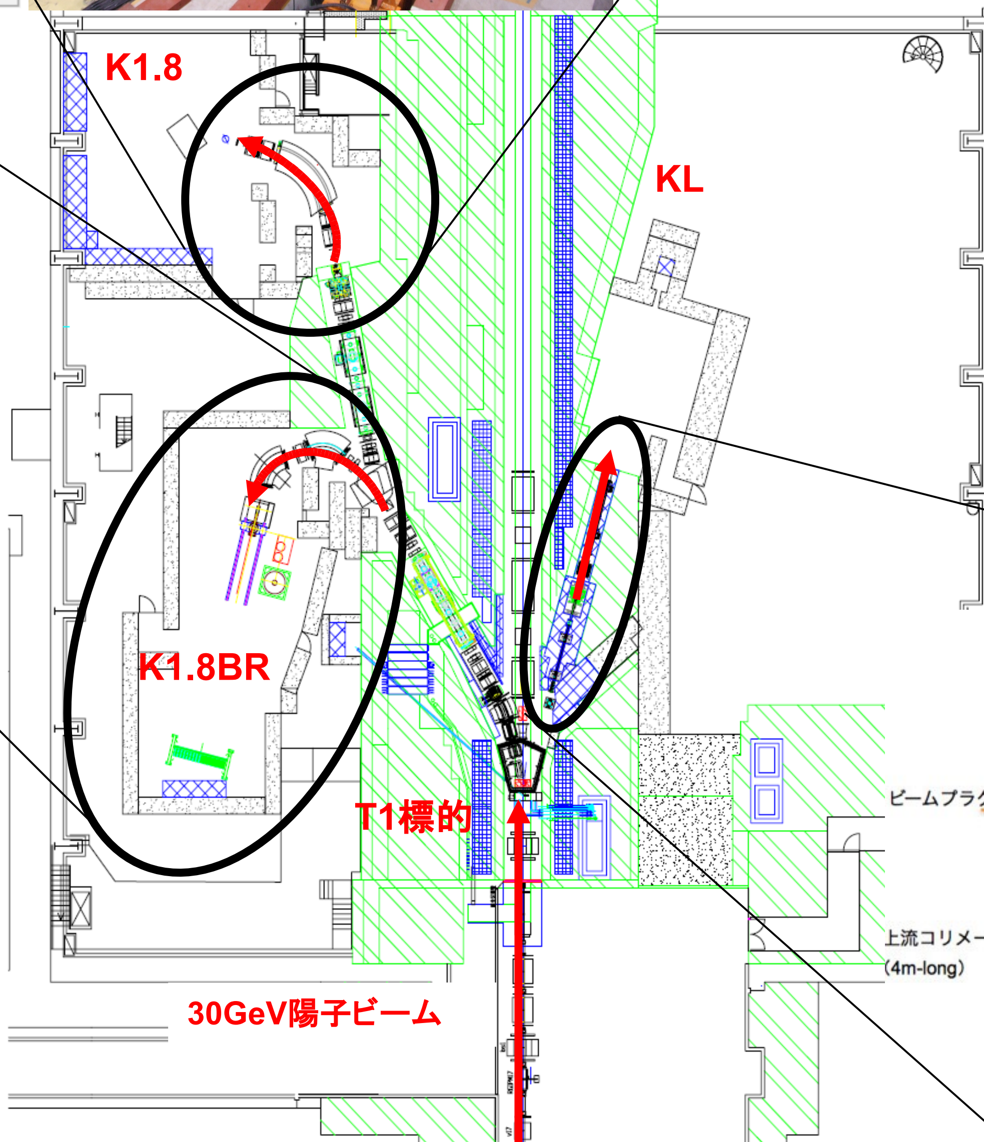


SKS

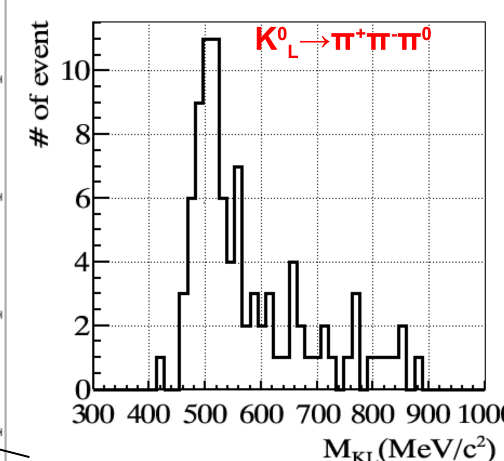




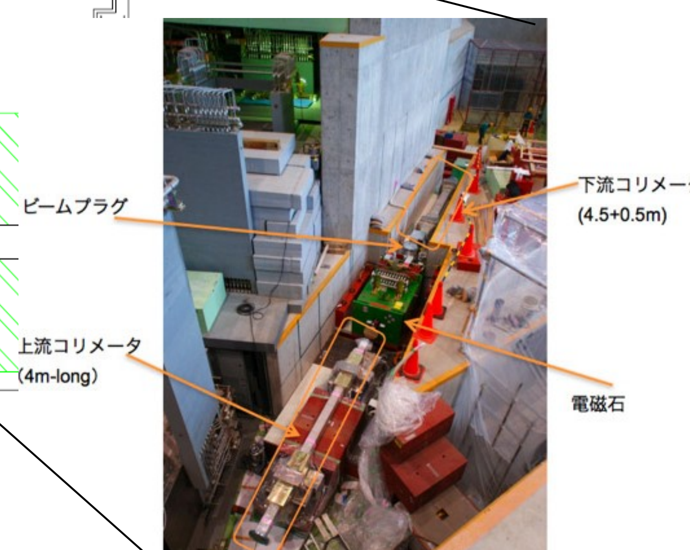
/(0.05 nsec)
+0.75 GeV/c
-0.75 GeV/c
e+
π+
K+
p
e-
π-
K-
pbar
BHD−T0 TOF (nsec)



K1.8
KL
K1.8BR
T1標的
30GeV陽子ビーム

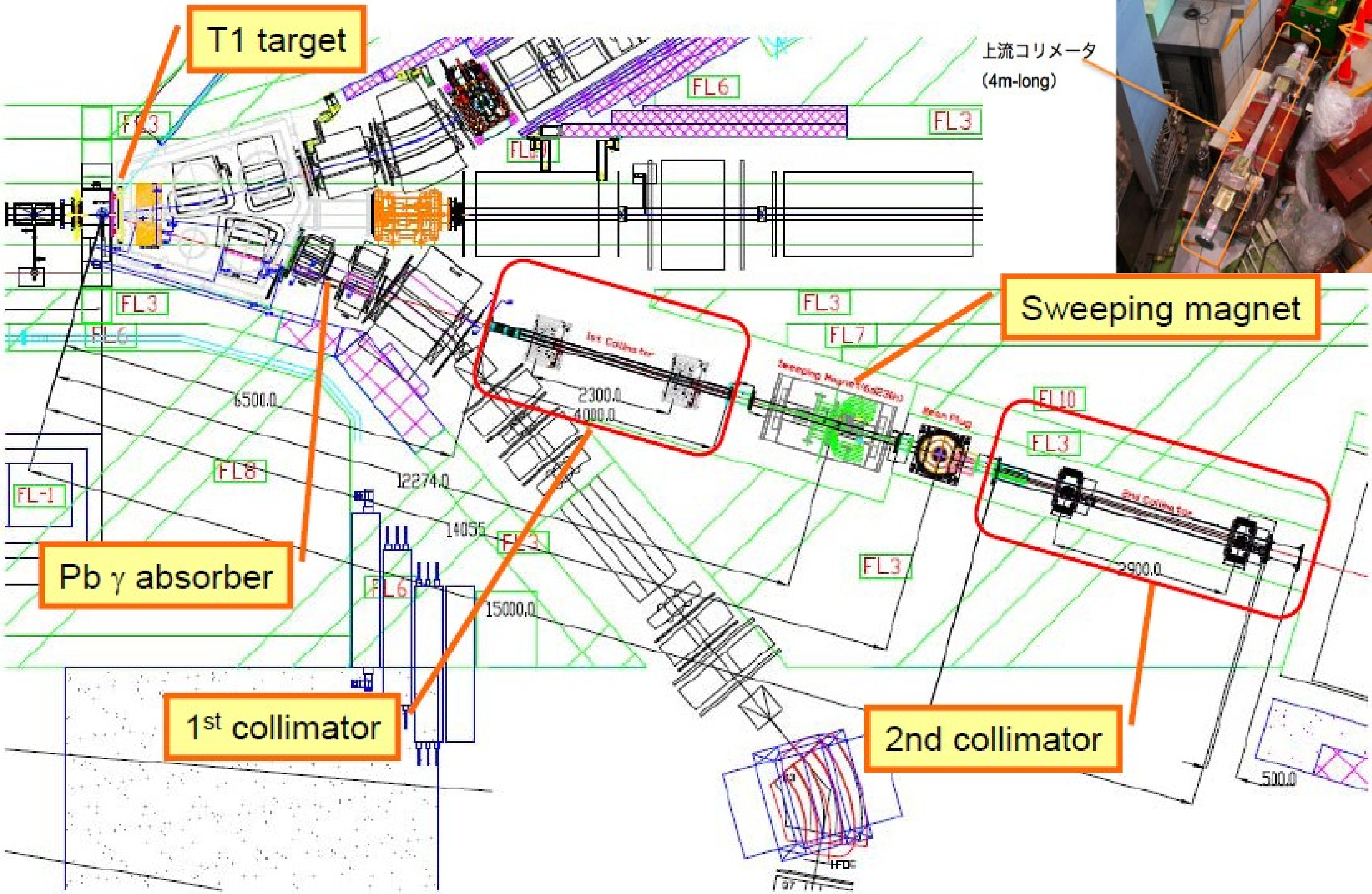


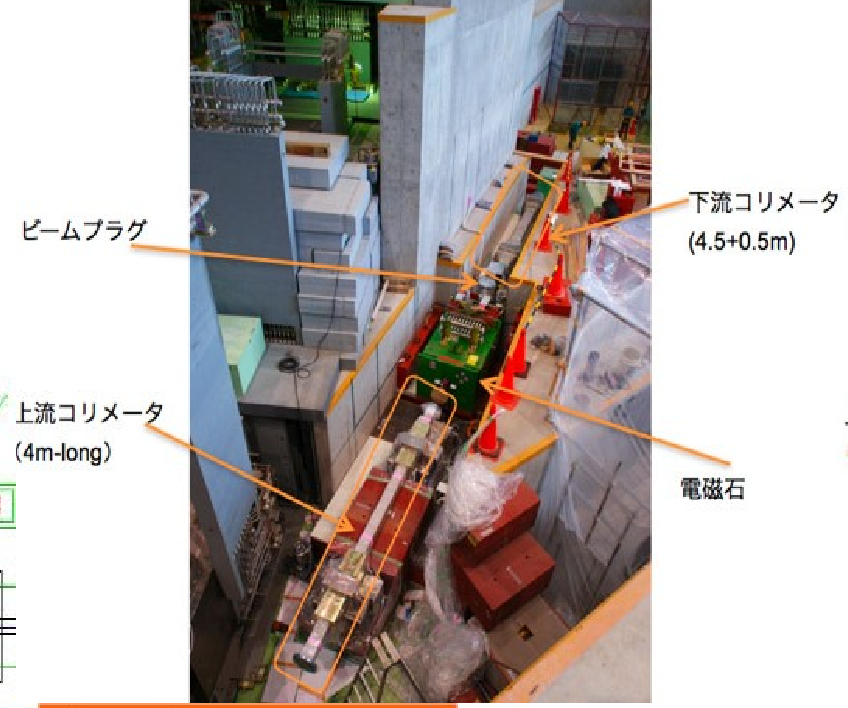
$K^0_L \to \pi^+\pi^-\pi^0$
# of event
M_{KL}(MeV/c^2)



ビームプラグ
上流コリメータ
(4m-long)
下流コリメータ
(4.5+0.5m)
電磁石

KL beam line

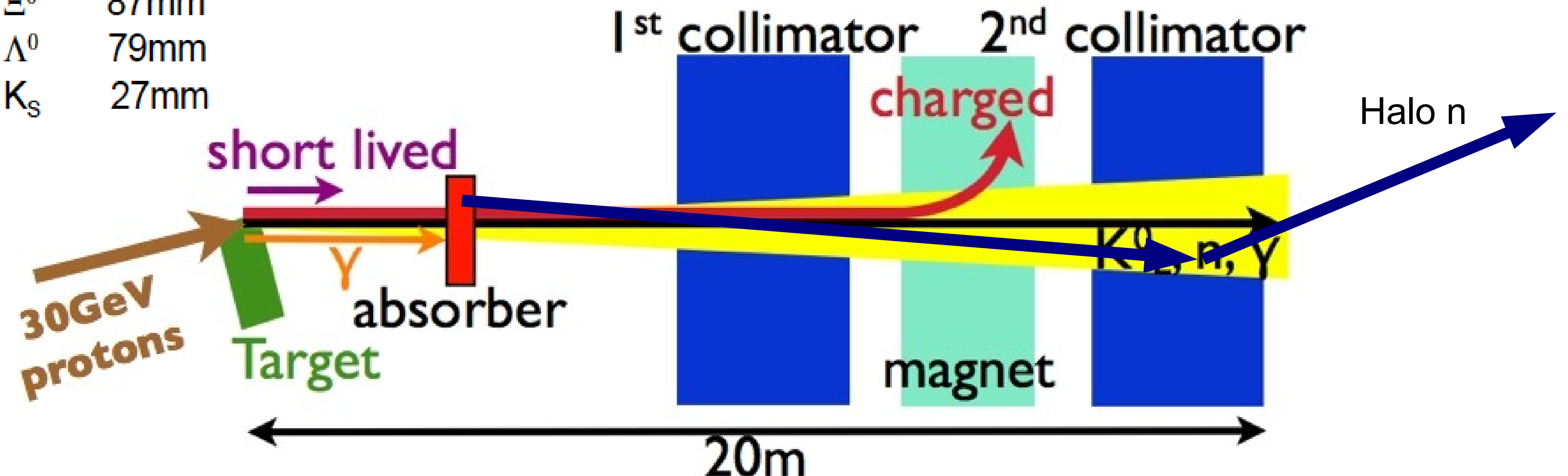




lakuba

Neutral beam line

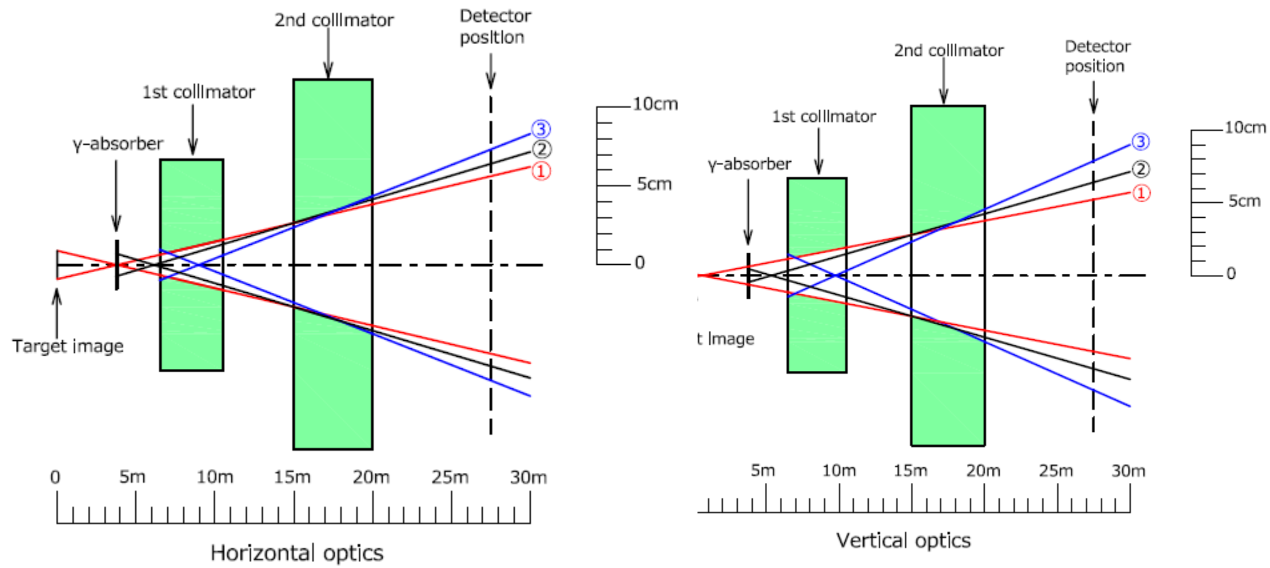
	cτ
K_L	15000mm
Ξ^0	87mm
Λ^0	79mm
K_S	27mm



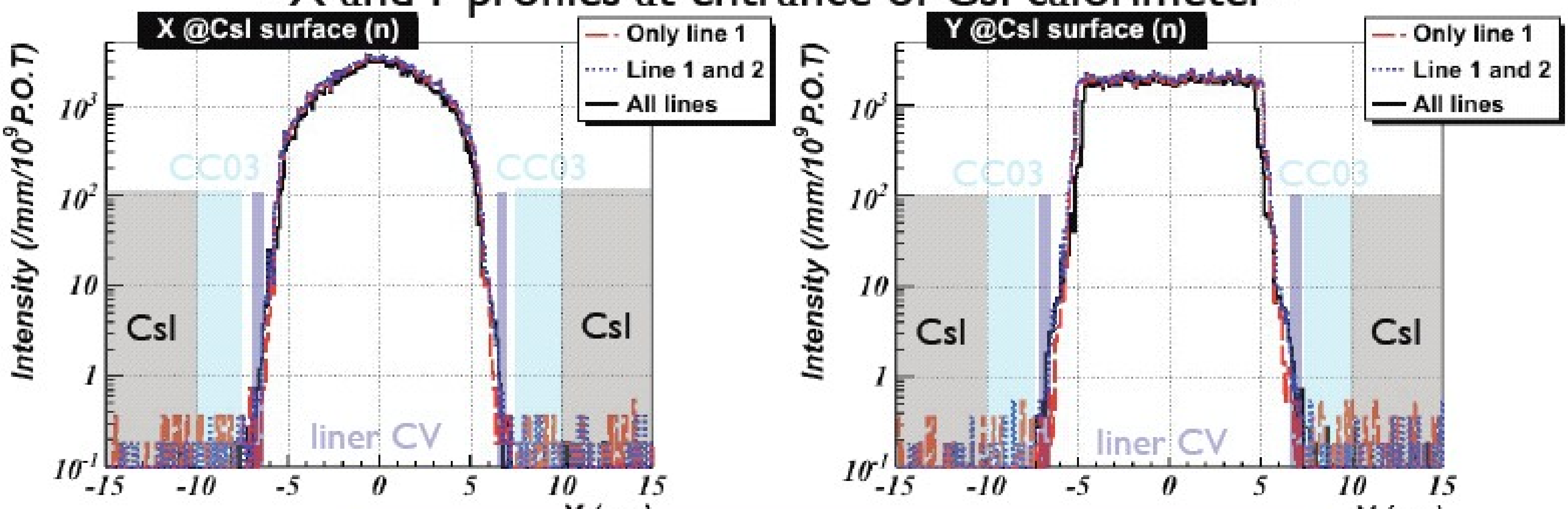
- proton→target (16 deg ext.)   KL→Collimator
  - Charged particles : Sweeping Magnet(2T)
  - Short lived : 20m long beam line
  - Gamma : 7cm thick Pb absorber:
  - Neutron →core/halo neutron
    - Halo n : multiple scattering on the surface of the collimator or Pb absorber.

Collimator Design

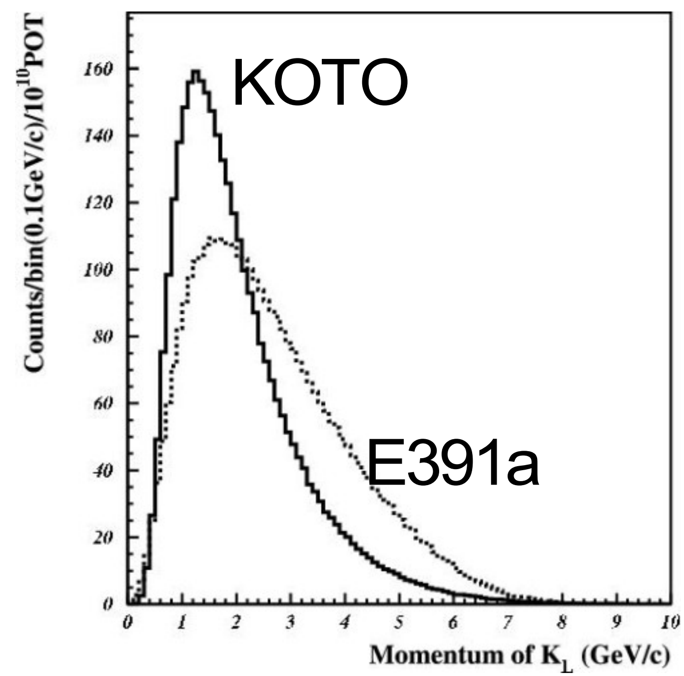
- Rectangular
  - Target image
  - X,Y独立
- Halo neutron
  - 10^{-5} of core n

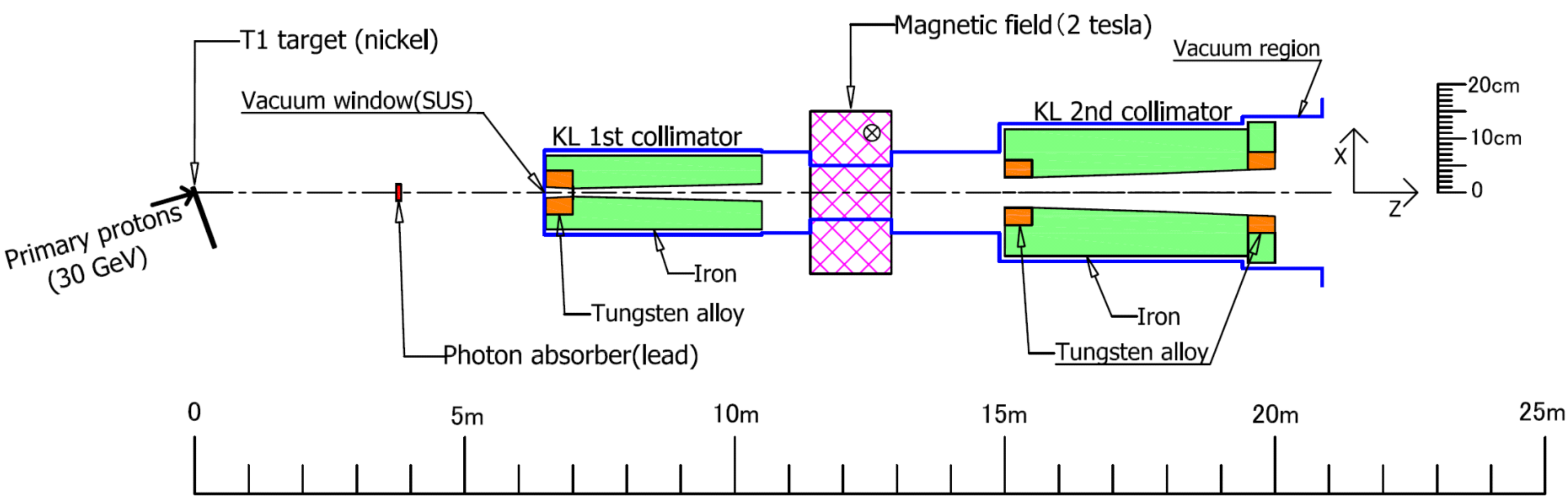


<X and Y profiles at entrance of CsI calorimeter>



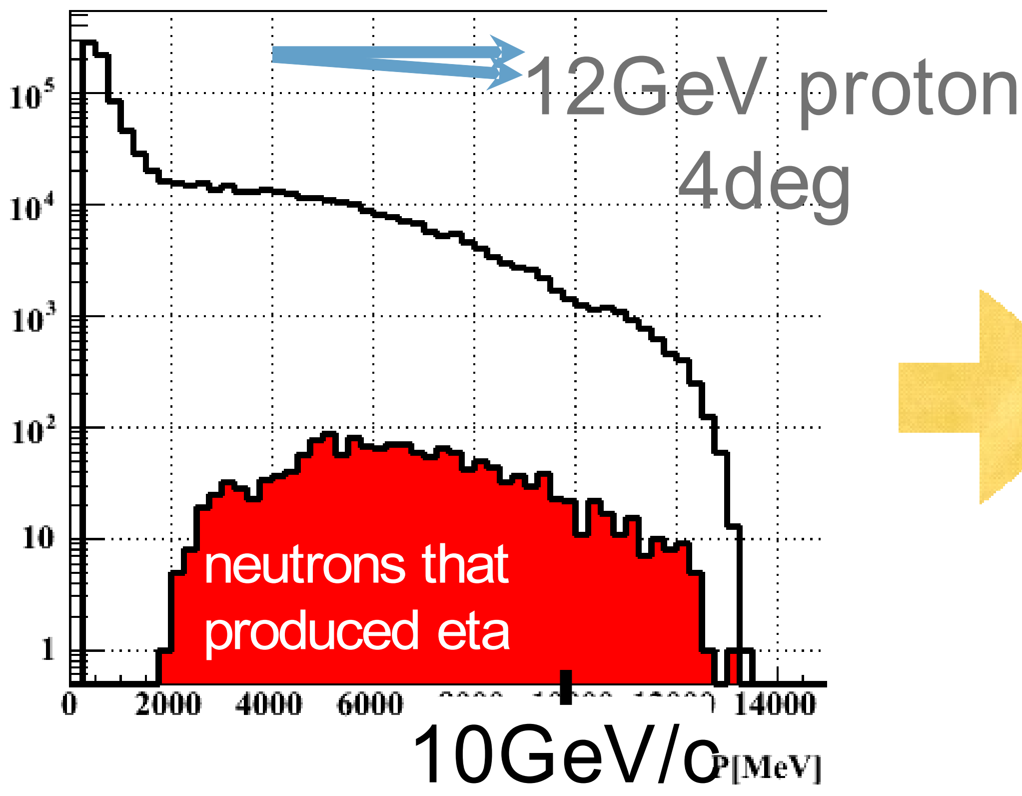
- KL:
- Core gamma: ~0.5GHz
  - →beam hole detector
- Core neutron:~0.5GHz
- Halo neutron:BG source



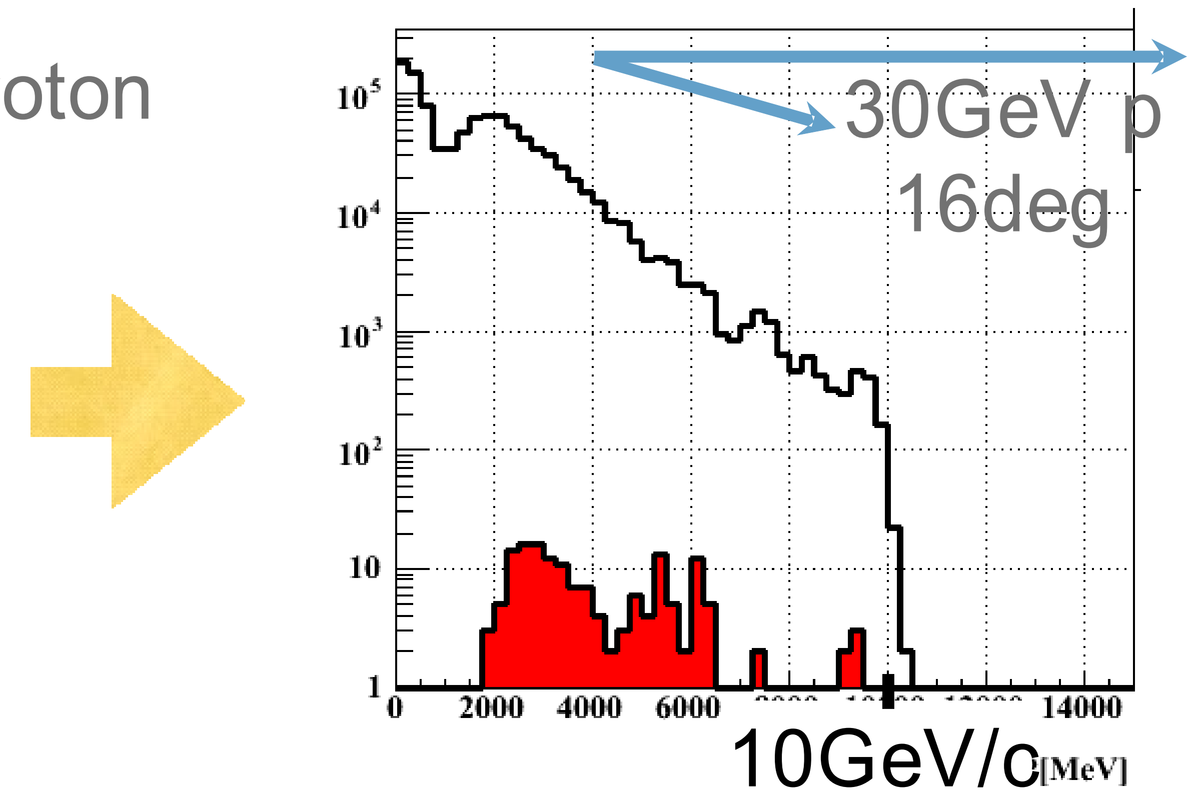


Halo neutron

KEK E391a

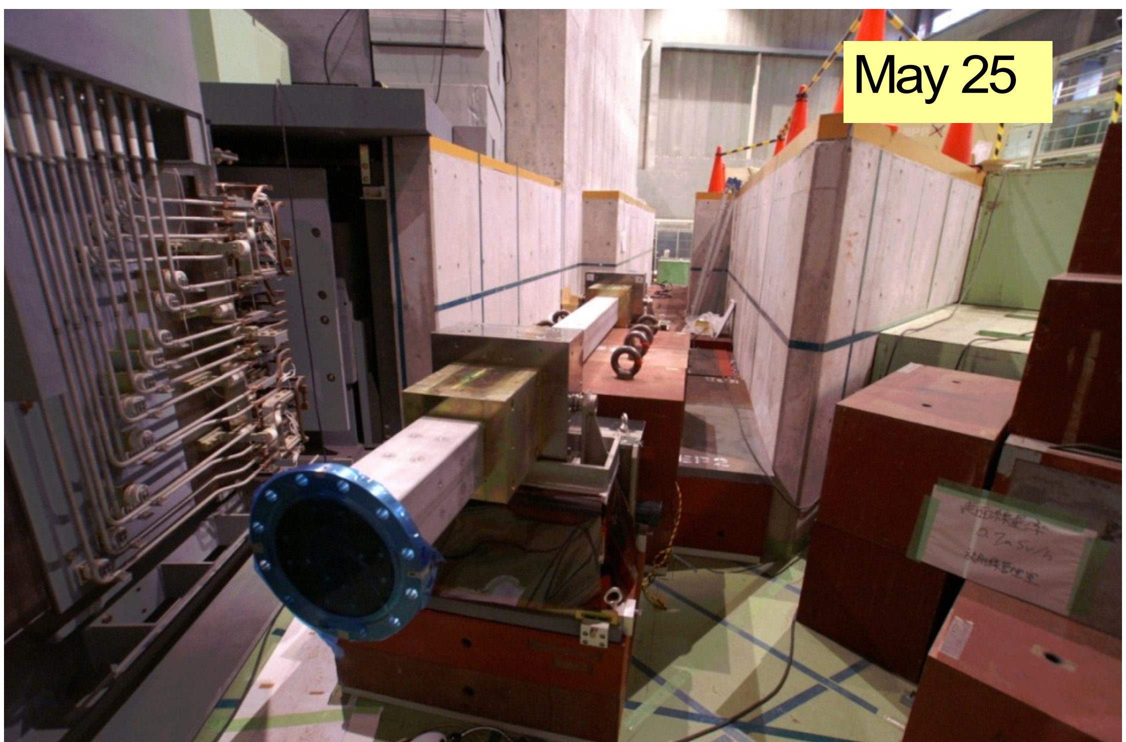


KOTO



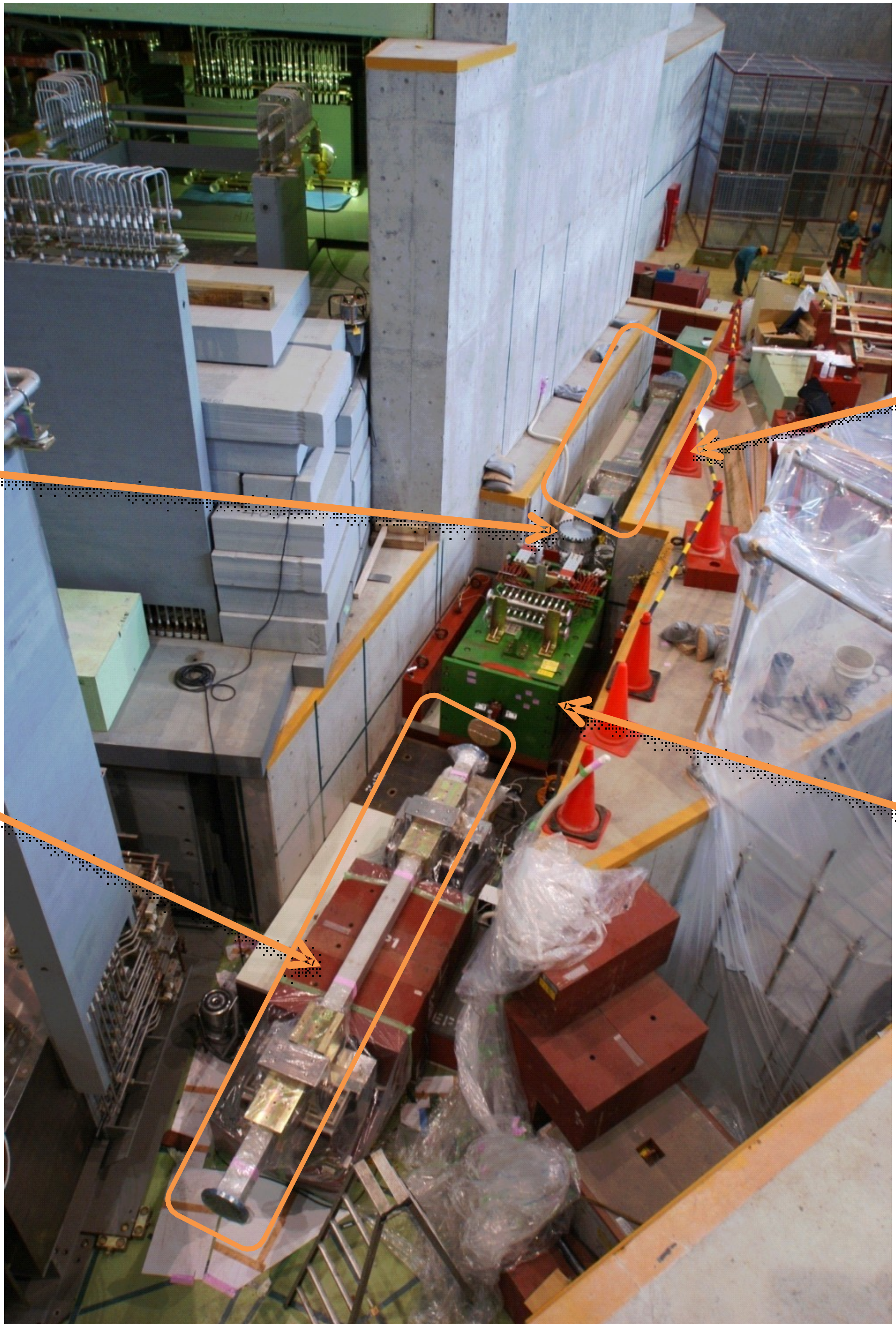

April 11

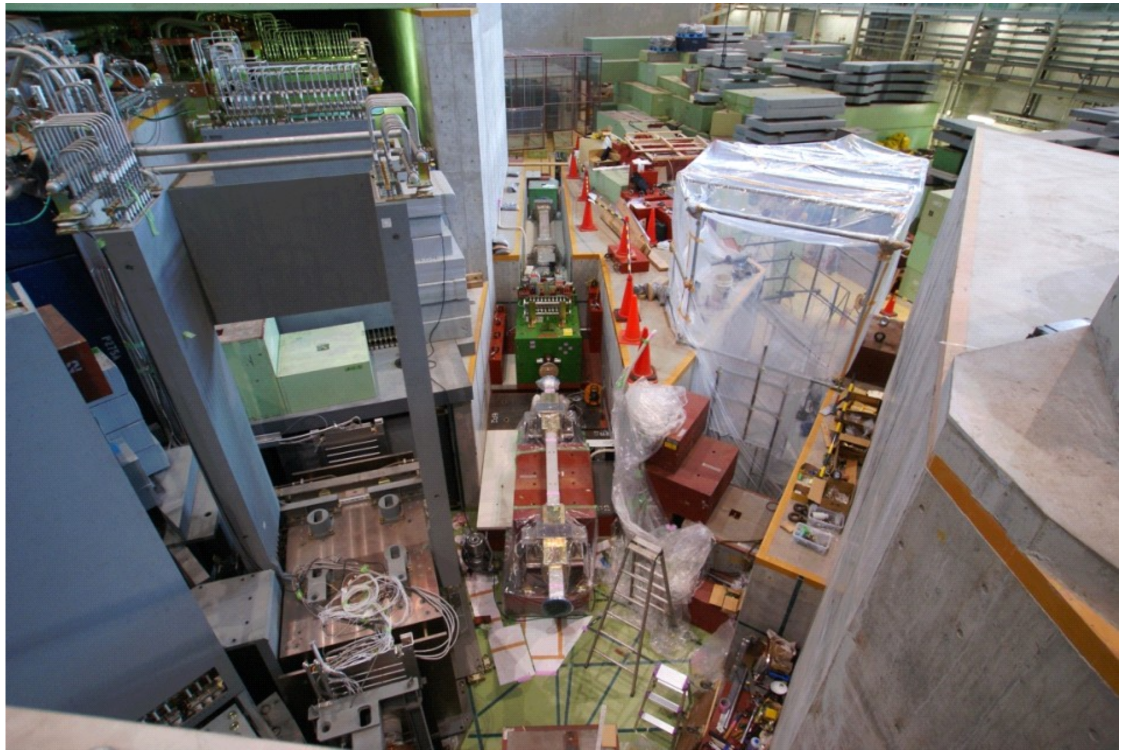

April 14

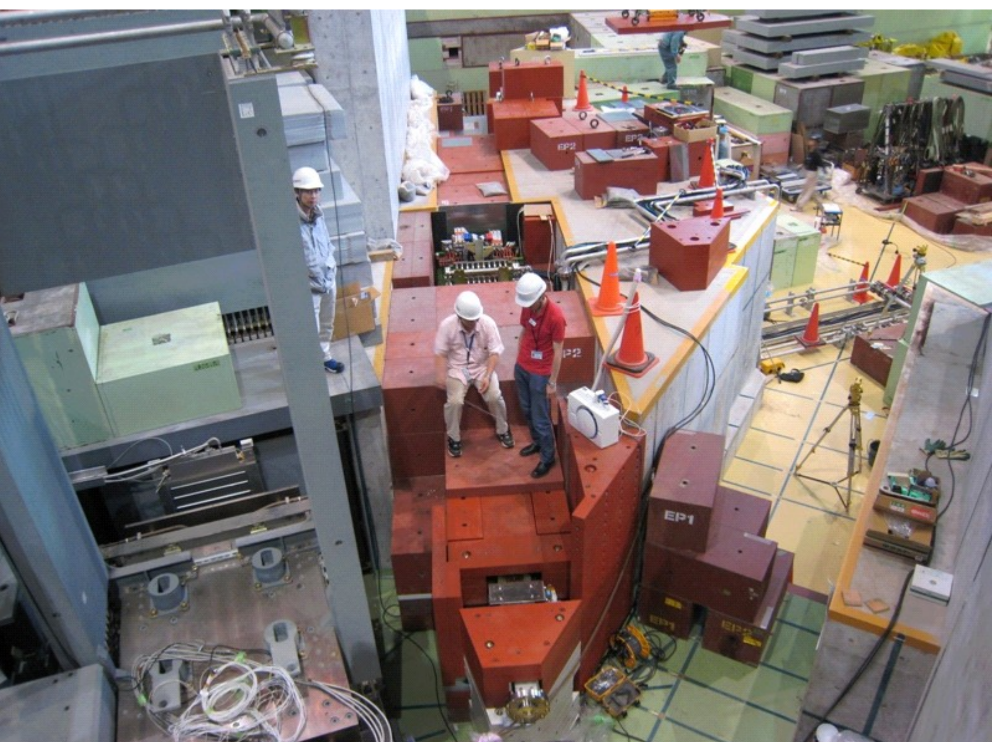

May 25

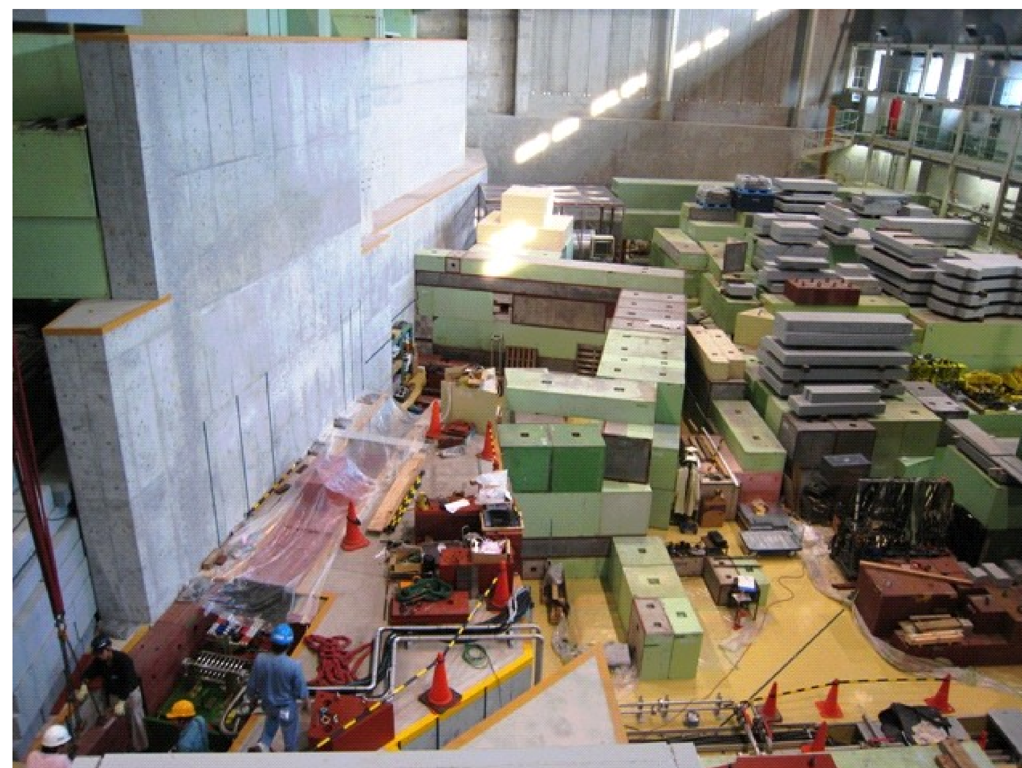

June 22

Photo on July 11.



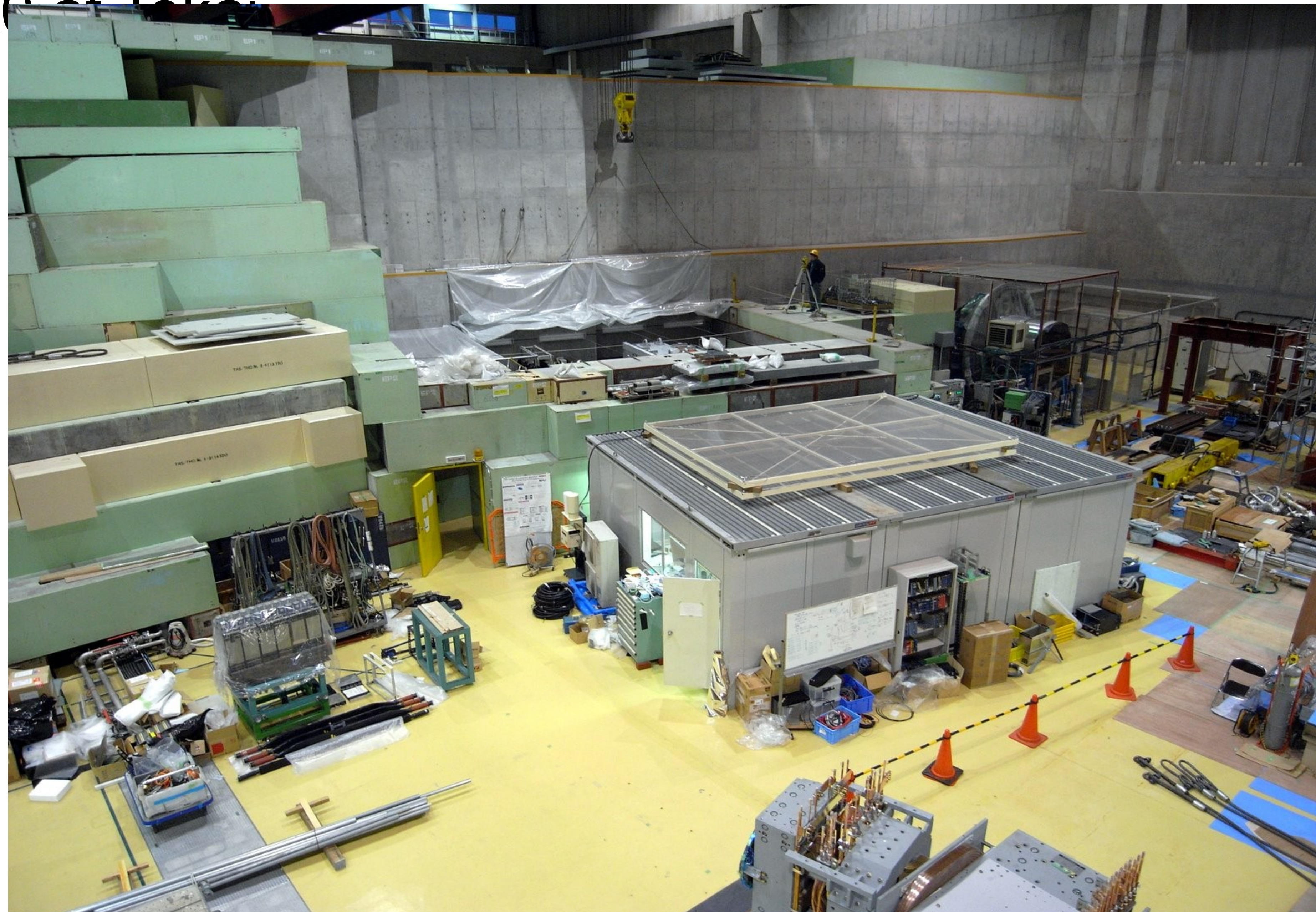



EP2
EP1



Beam line survey

- K0 at Tokai
-



Beam line survey

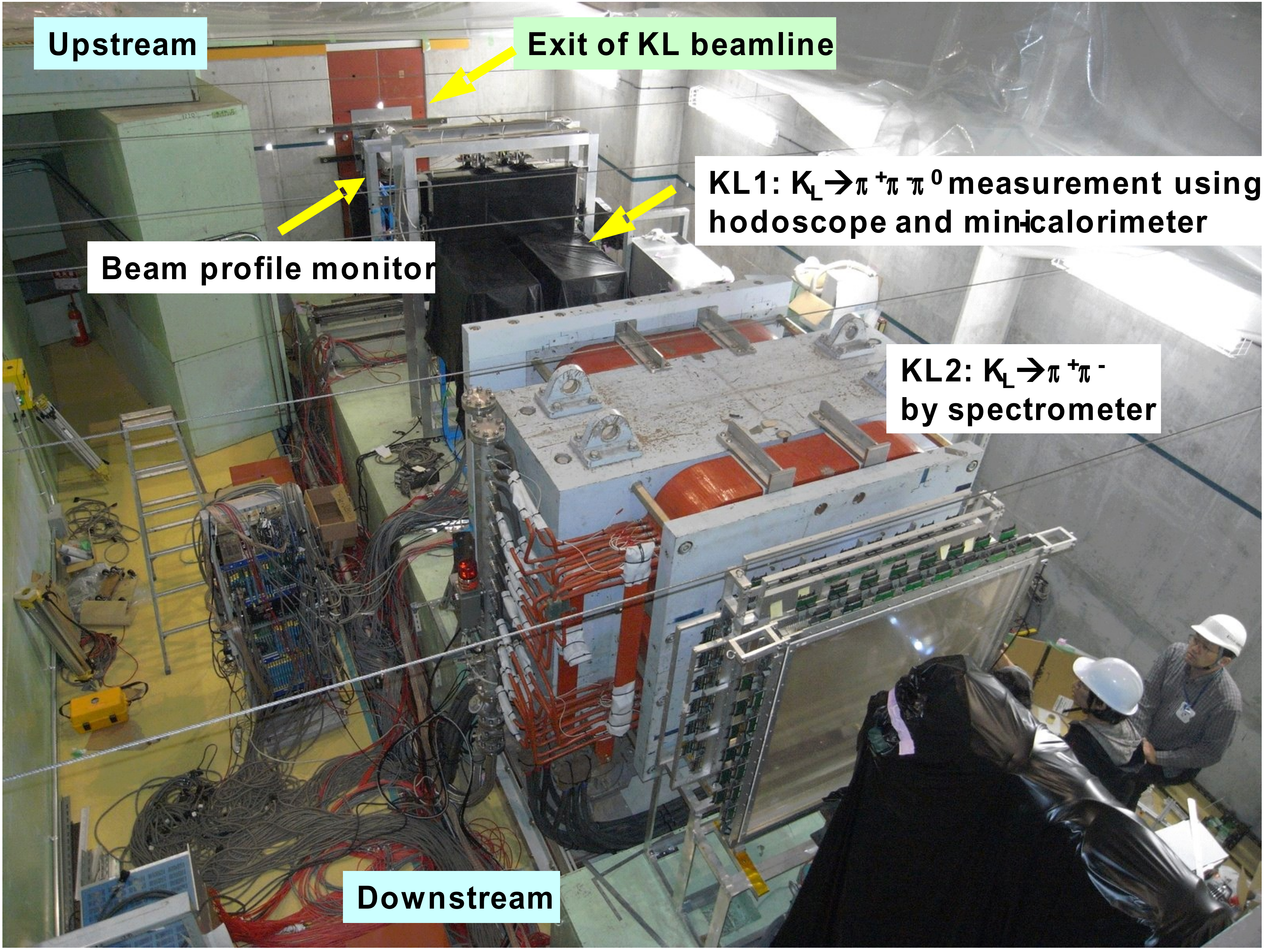
- Beam lineの性能評価
- Collimatorアラインメント
- KL　yield →1st priority
  - Factor 3程度のMCの違い
  - 30GeV proton, 16deg取り出しのデータなし
  - 10%誤差で測定を行う
- Core 測定
- Halo測定

	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	$(8.3 \pm 0.2)\times10^{-8}$

Beam line survey

- 10月-12月合計12日深夜にbeam time
  - 総計 3 日程度の時間
  - 加速器studyがメイン
  - この内30%をKL測定
-

	Run information				For KL measurement		Note
	intensity	user time	accumulated	Target	run time	accumulated	
	(ppp)	(hours)	(protons)		(hours)	(protons)	
2009/10/22	4.0E+09	11	2.6E+13	Ni	0	0.0E+00	
2009/11/14	7.0E+10	6.5	2.7E+14	Ni	2.7	1.1E+14	
2009/11/15	7.0E+10	10	4.2E+14	Ni	2.2	9.2E+13	
2009/11/18	7.0E+10	8.5	3.6E+14	Ni	2.3	9.7E+13	
2009/11/26	1.2E+11	5	3.6E+14	Ni	2	1.4E+14	
2009/12/12	2.0E+11	8.5	1.0E+15	Ni	3	3.6E+14	
2009/12/13	7.0E+11	2	8.4E+14	Pt	1.5	6.3E+14	Self inspection
2009/12/16	3.0E+11	8.5	1.5E+15	Ni	3	5.4E+14	
2009/12/16	7.0E+11	1	4.2E+14	Pt	0	0.0E+00	Government inspection
2009/12/17	3.0E+11	6.5	1.2E+15	Pt	1	1.8E+14	
2009/12/23	3.0E+11	7	1.3E+15	Ni	2.5	4.5E+14	
2009/12/23	3.0E+11	2	3.6E+14	Pt	2	3.6E+14	
	Total	76.5	8.0E+15		Total	3.0E+15	
	Ni	65	5.2E+15		Ni	1.8E+15	
	Pt	11.5	2.8E+15		Pt	1.2E+15	

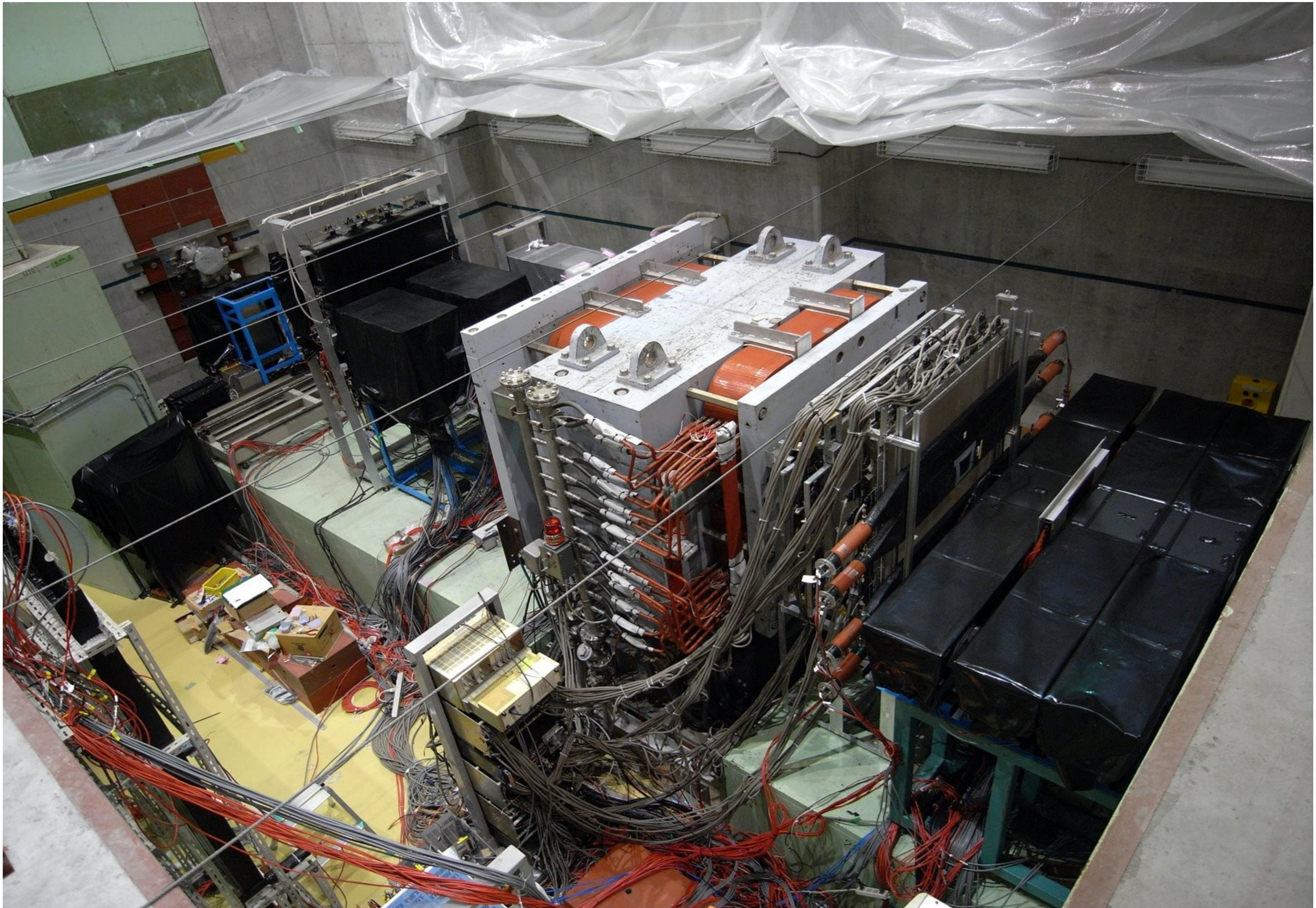


Upstream
Exit of KL beamline
KL1: $K_L \rightarrow \pi^+\pi^-\pi^0$ measurement using
hodoscope and mini-calorimeter
Beam profile monitor
KL2: $K_L \rightarrow \pi^+\pi^-$
by spectrometer
Downstream

Beam line survey

- 

Beam line survey



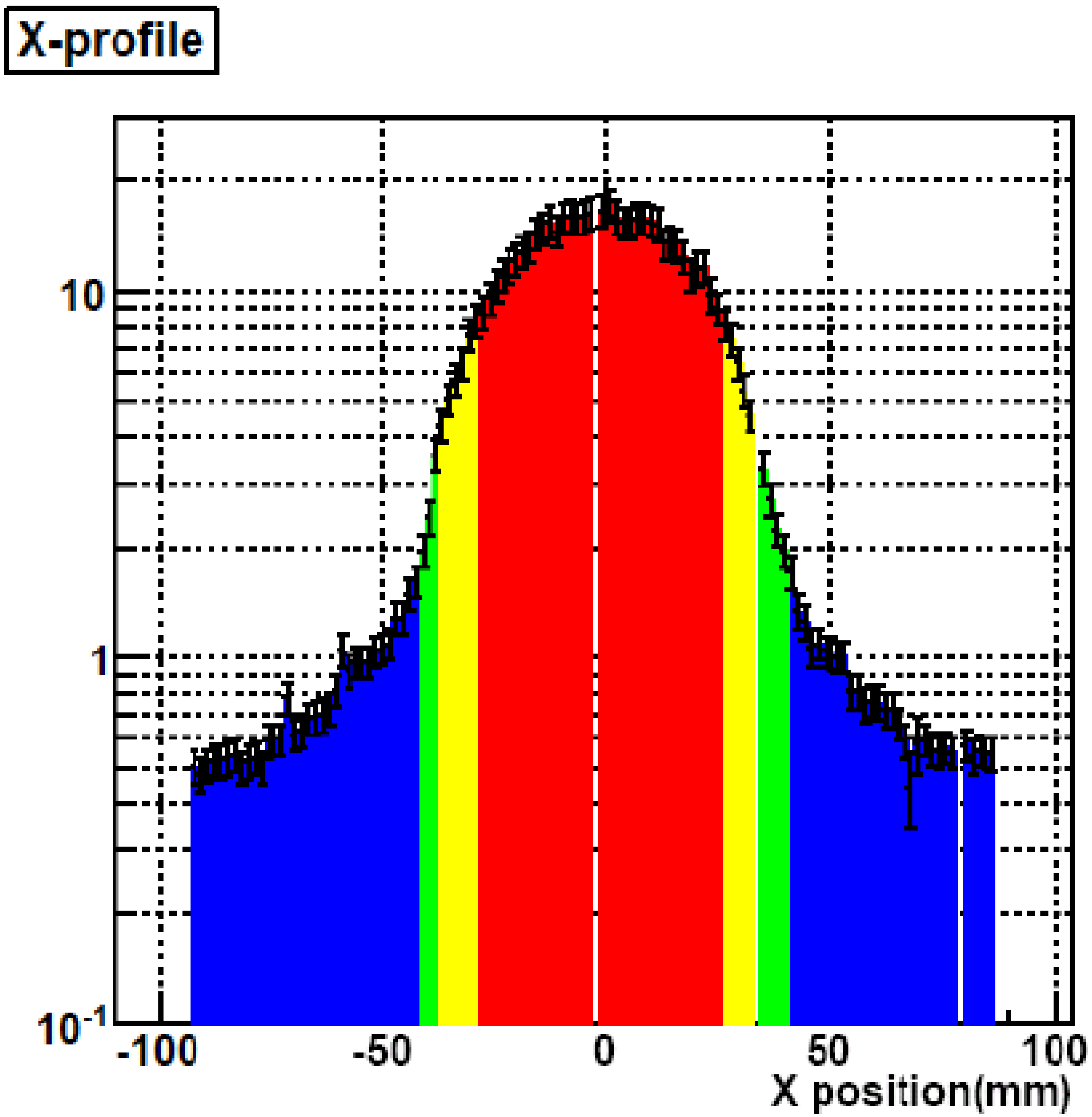
Proflile測定

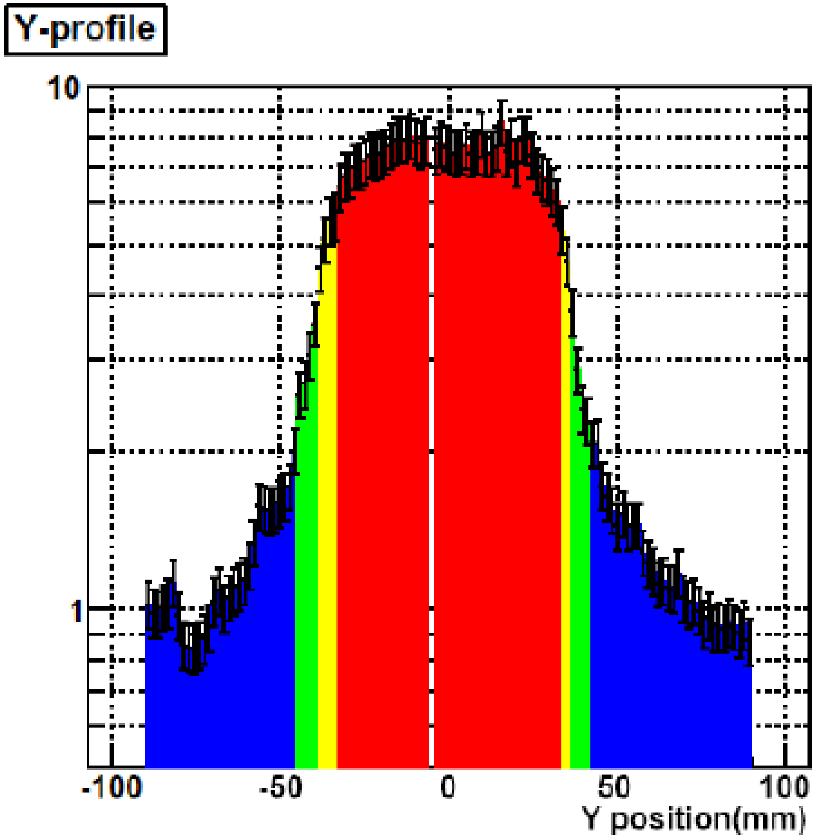
- GOHMON(Graphical Online High flux Monitor)
  - 1.5mm角シンチファイバー
    - X:128ch
    - Y:128ch
  - MAPMT(リサイクル)
  - 100msec slow shaping
  - Slow FADC(安い)

- 移動ステージによる
  スキャン
- 蛍光版

Collimatorアラインメント

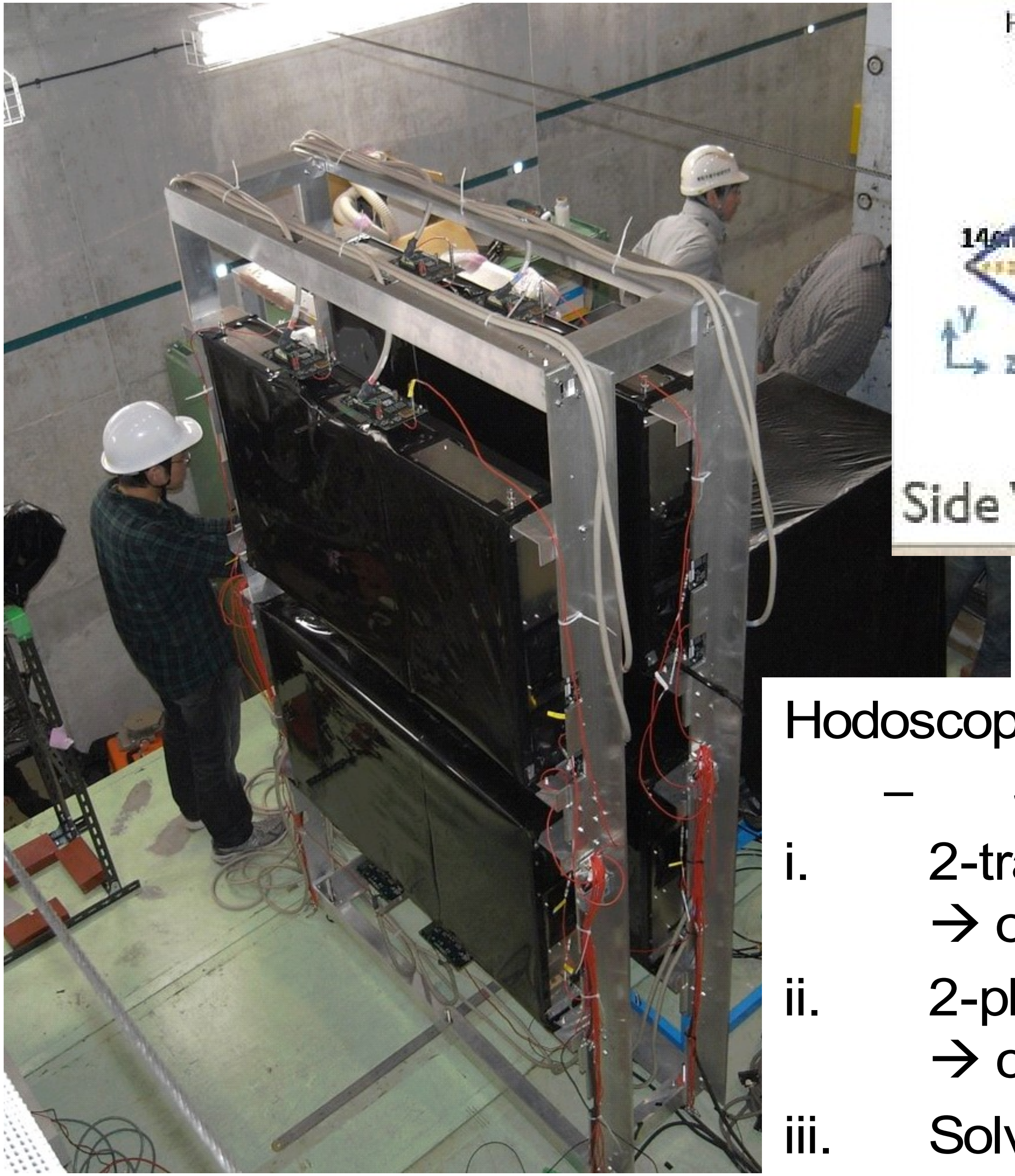
- Collimatorを動かして、プロファイル測定

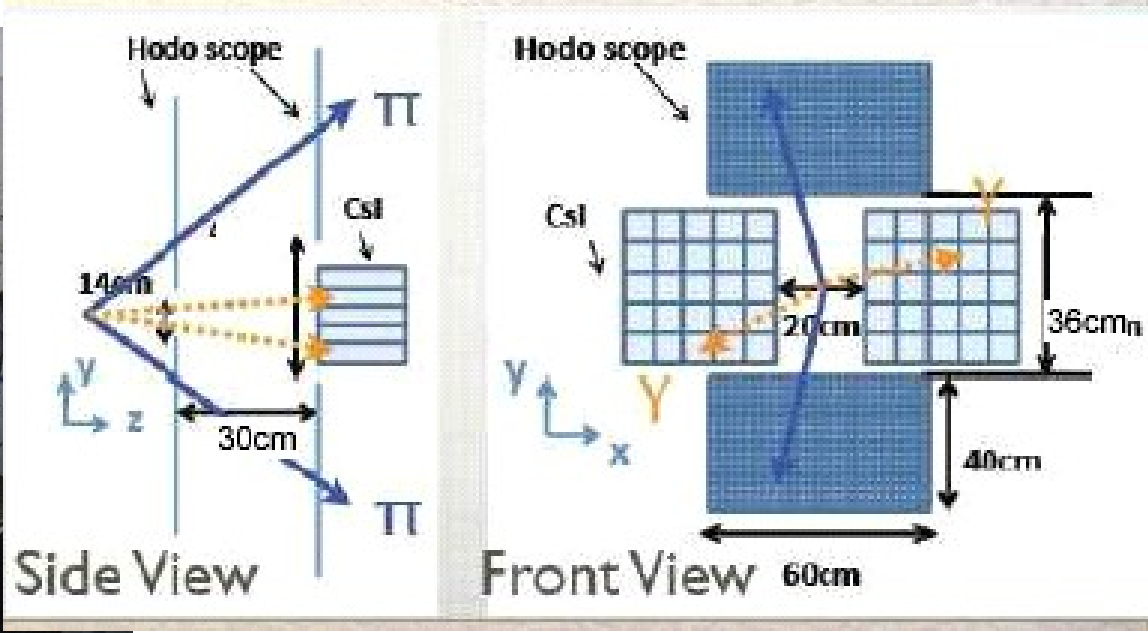




Align both in horizontal and vertical

KL測定





Hodoscope + mini -calorimeter (CsI)

– Simple and sure method

i. 2-track directions by hodoscope
→ obtain vertex

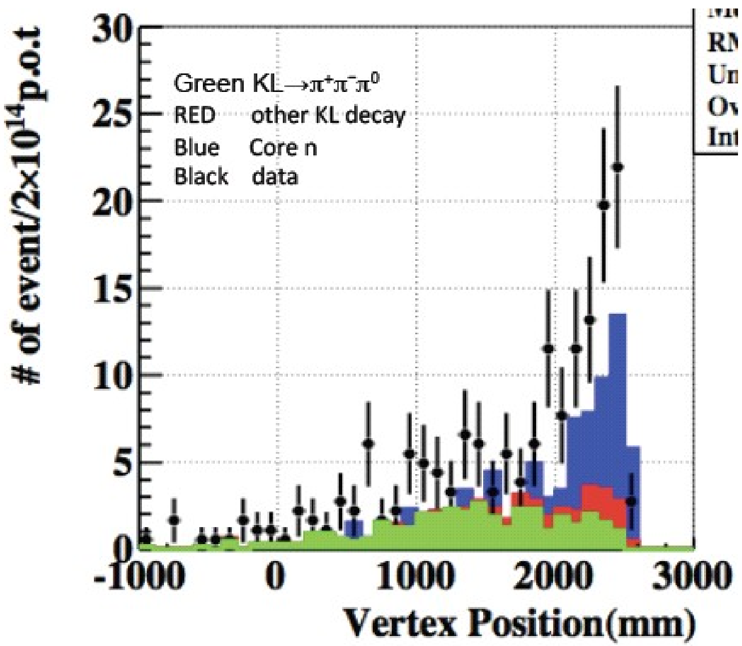
ii. 2-photon energies / positions by CsI
→ calculate M($\gamma\gamma$)

iii. Solve p_+ and p_- by requiring P_T balance

iv. Calculate M($\pi^+\pi^-\pi^0$)

- 1cm幅、5mm厚シンチレータバー
  - EJ230　紫外発光
  - 60cmx40cmをカバー
  - Vertical/Horizontal
- 1.5mmφ波長変換ファイバー
  - B2(クラレ)　紫外吸収、青発光
- 64ch MAPMT(リサイクル)
- 15p.e./5mm
-
- Pure CsI
  - 7x7x30cm 5x5を２バンク

KL測定　π^0再構成

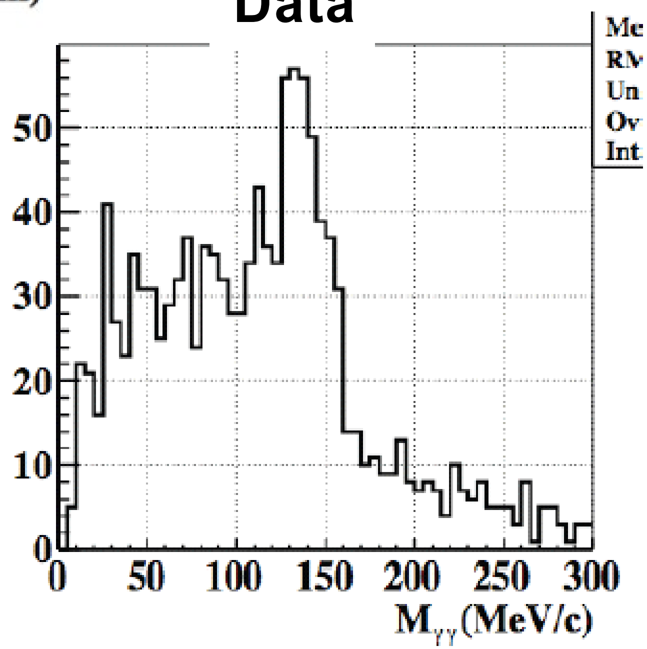


1.6e15 protons delivered

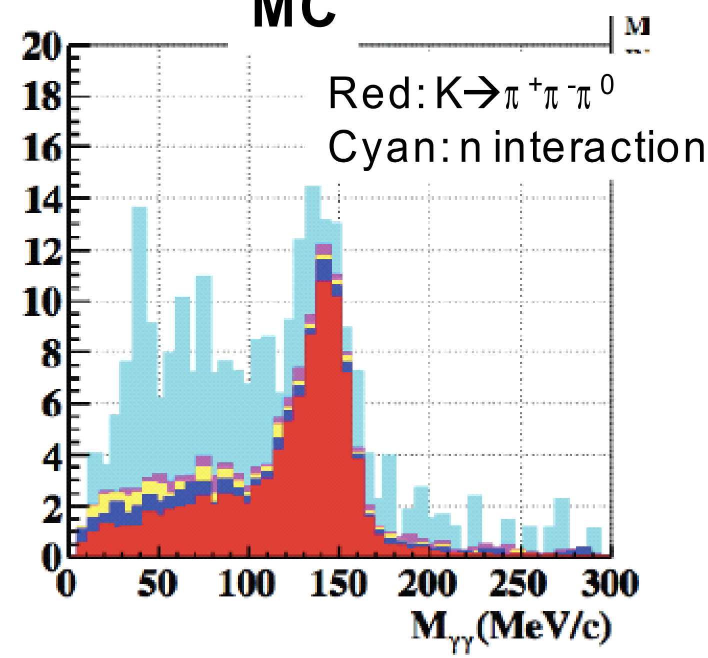
Vertex
(before π^0 mass cut)

M(γ γ)

Data



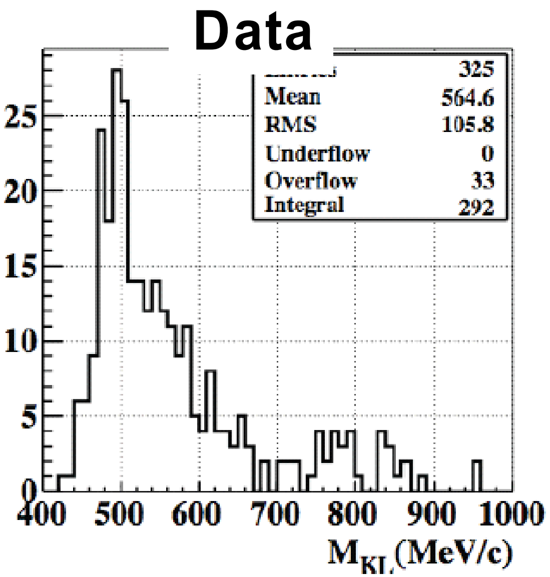
MC

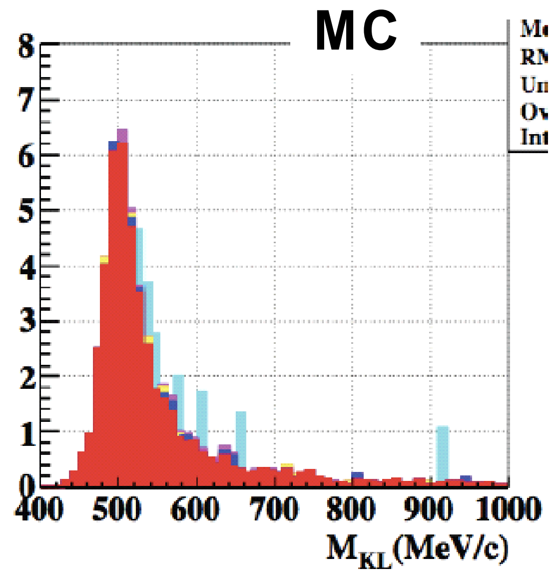


KL測定　KL再構成

$M(2T\,2\gamma) = M(\pi^{+}\pi^{-}\pi^{0})$

-

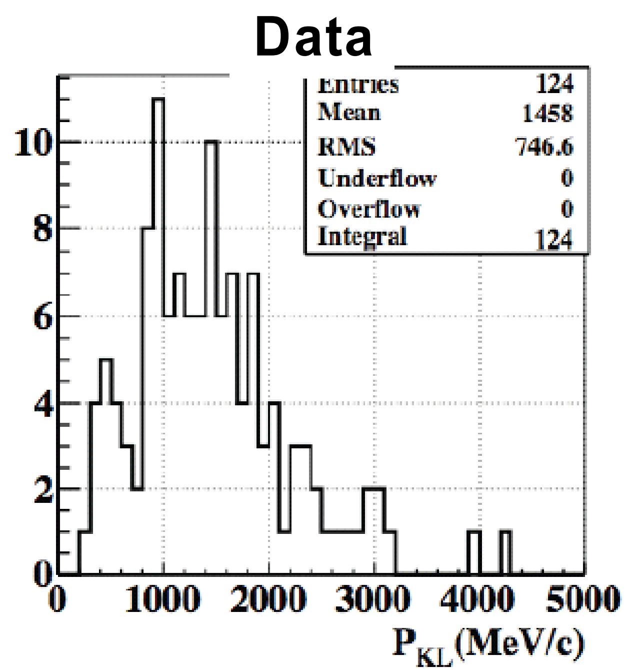


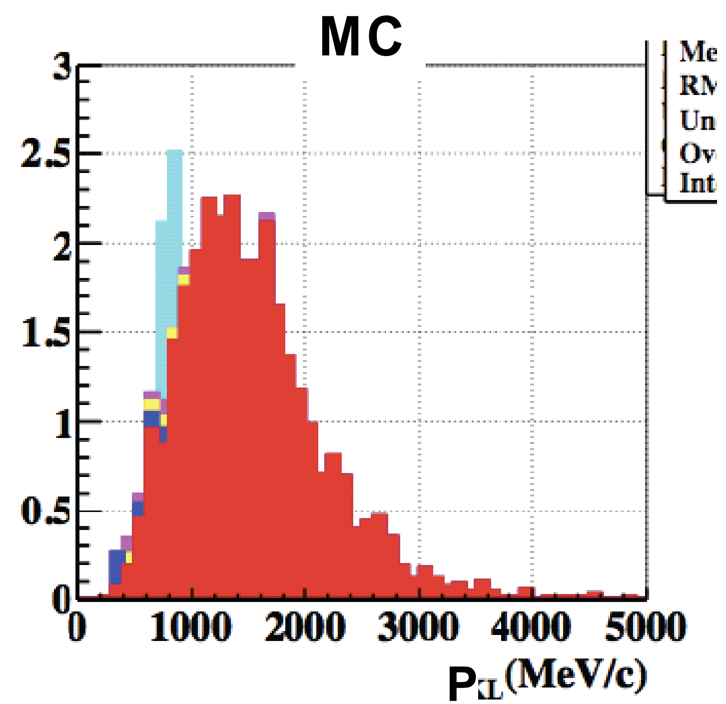


Red: $K \rightarrow \pi^{+}\pi^{-}\pi^{0}$
Cyan: n interaction

KL spectrum (after M_{KL} cut)

$460 < M_{KL} < 540$MeV



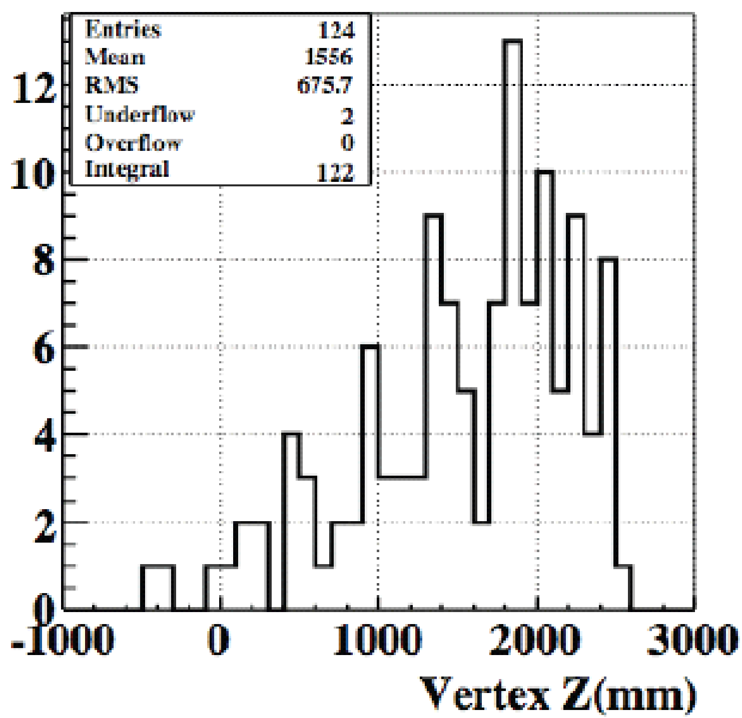


KL測定　MKL　cut

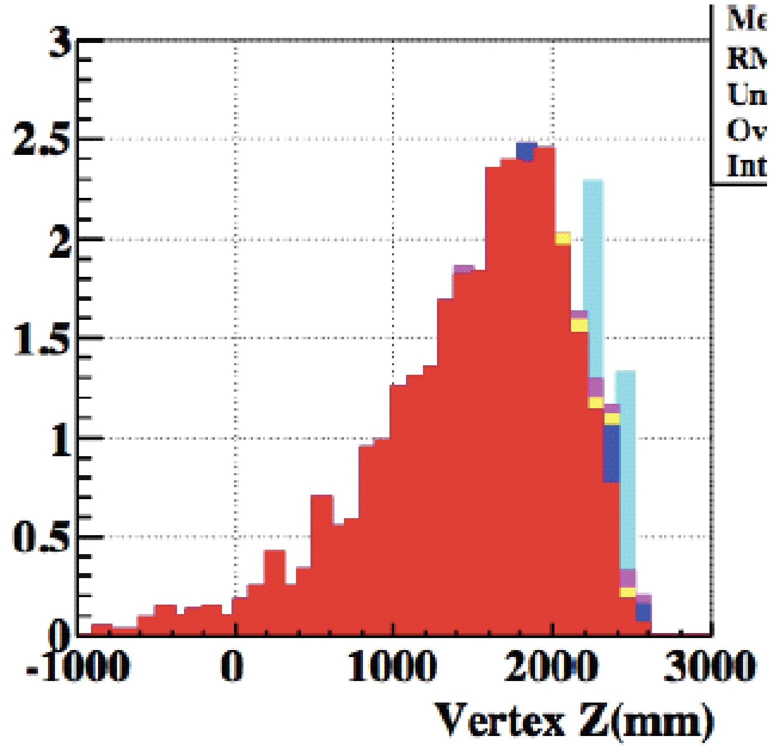
KL Vertex
(after M_{KL} cut)

Red: $K \rightarrow \pi^+ \pi^- \pi^0$
Cyan: n interaction

Data

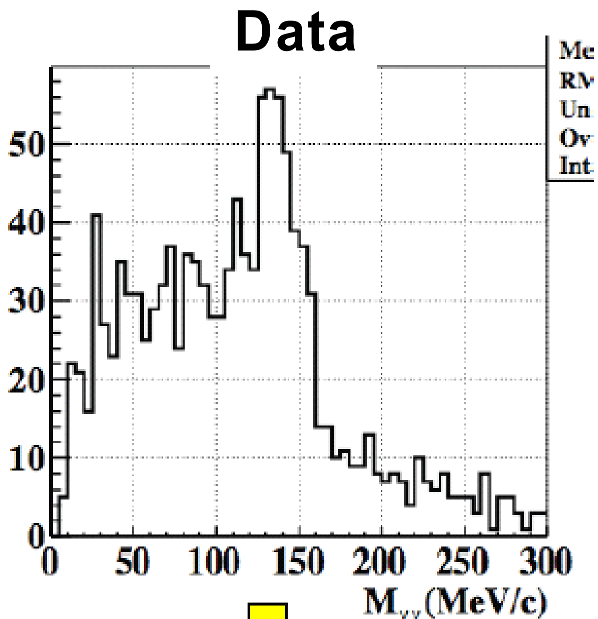


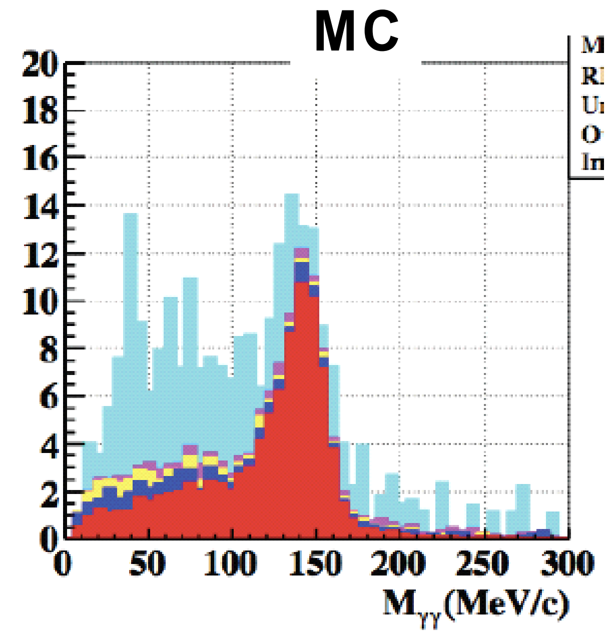
MC



KL測定　タイトカット

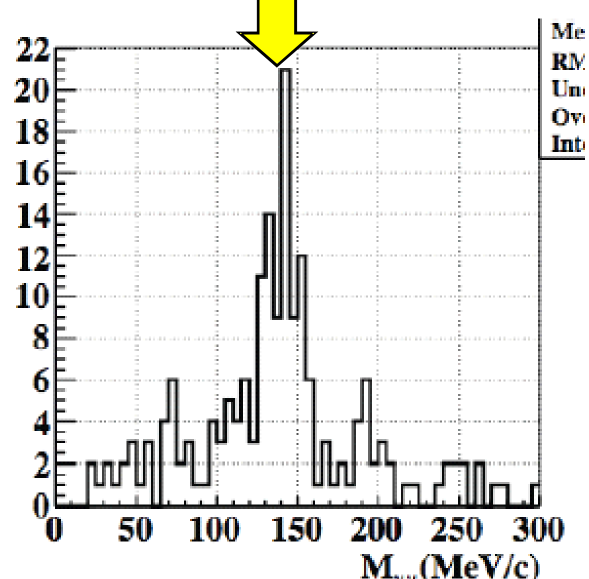
Loose cut:
Without fiducial cut in CsI

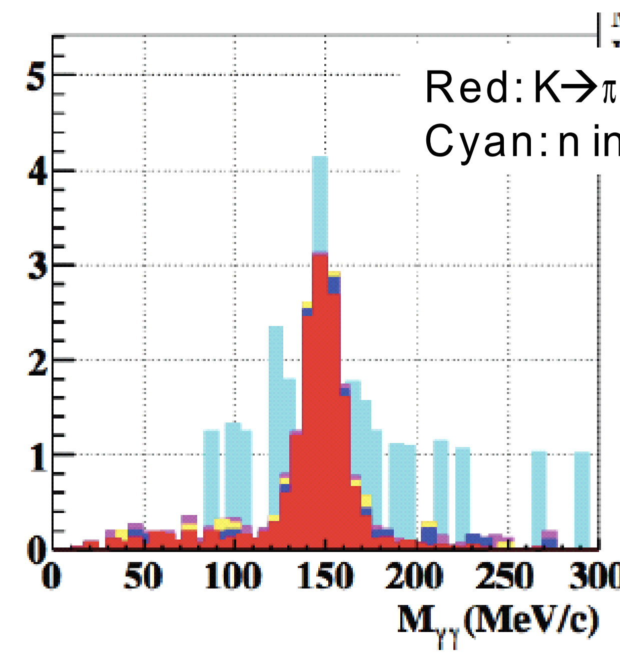




M(γ γ)

Tight cut:
Photon within 3x3 central crystals

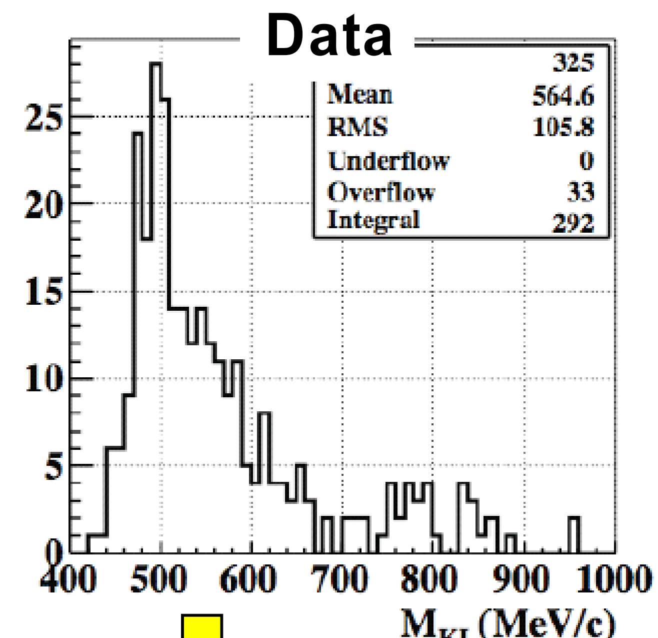


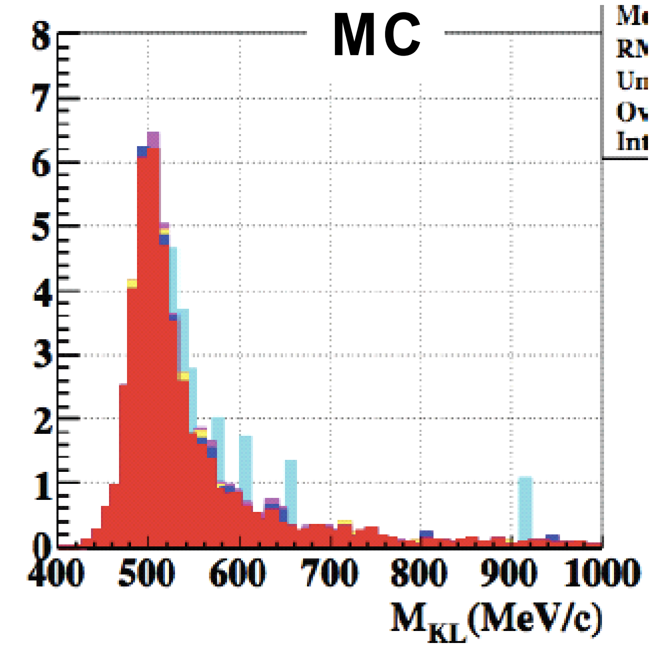


Red: $K \rightarrow \pi^+\pi^-\pi^0$
Cyan: n interaction

KL測定　タイトカット

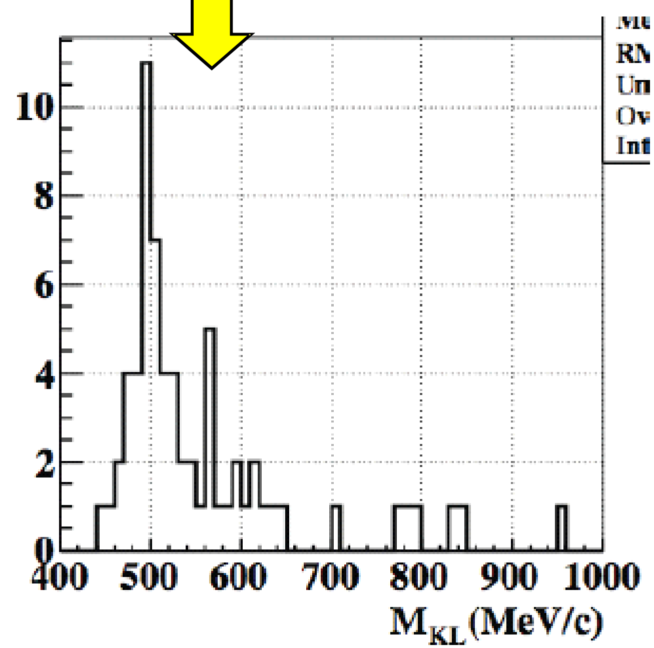
Loose cut:
Without fiducial cut in CsI

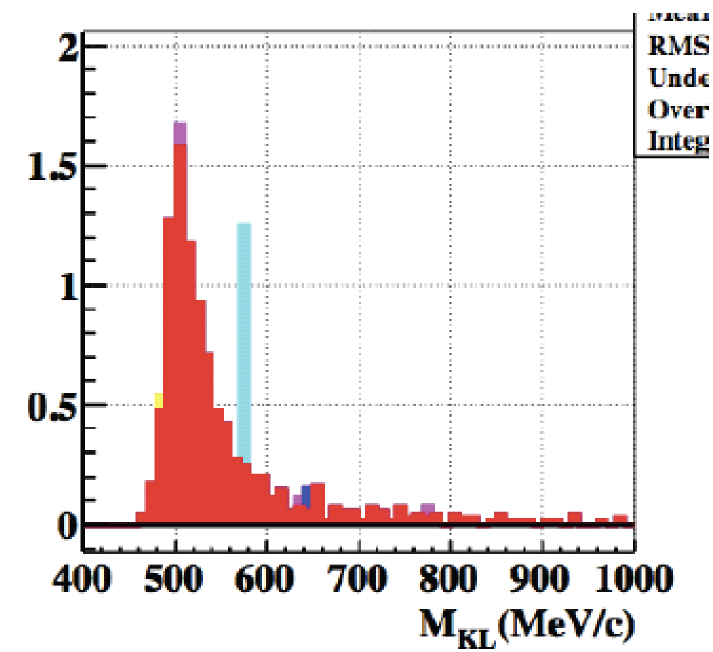




$M(\pi^+\pi^-\pi^0)$

Tight cut:
Photon within 3x3 central crystals





KL測定結果

Loose cut:
Without fiducial cut in CsI

	# of event	# of event/1e14 p.o.t
Data	145	9.10±0.75
Signal(MC)	30.41	5.13±0.11
BG(MC)	2.826	0.522±0.317

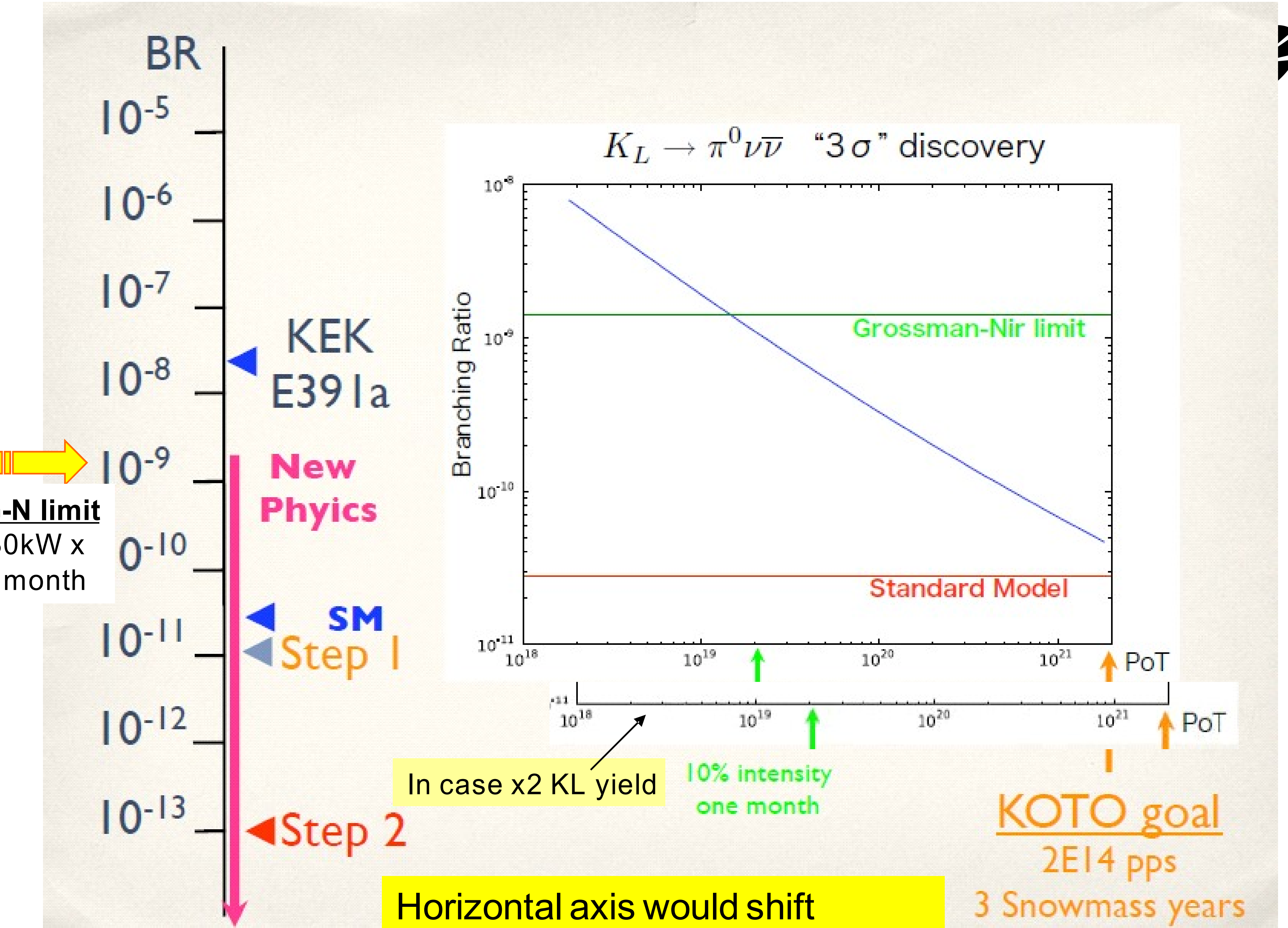
Data/MC～1.8

Tight cut:
Photon within 3x3 central crystals

	# of event	# of event/1e14 p.o.t
Data	38	2.38±0.37
Signal(MC)	6.358	1.07±0.051
BG(MC)	0.152	0.0257±0.0213

Data/MC～2.2

見積もりの２倍のKL yield!

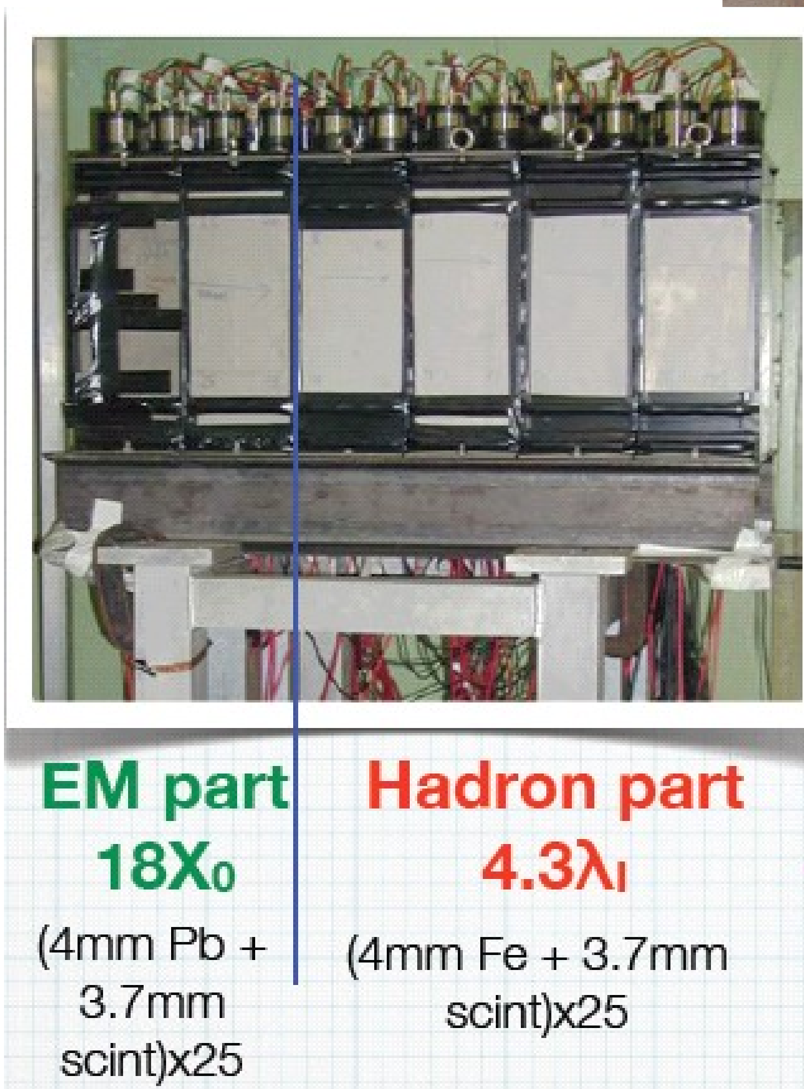


Horizontal axis would shift
if N_{KL}(Data)/N_{KL}(MC) is really 2

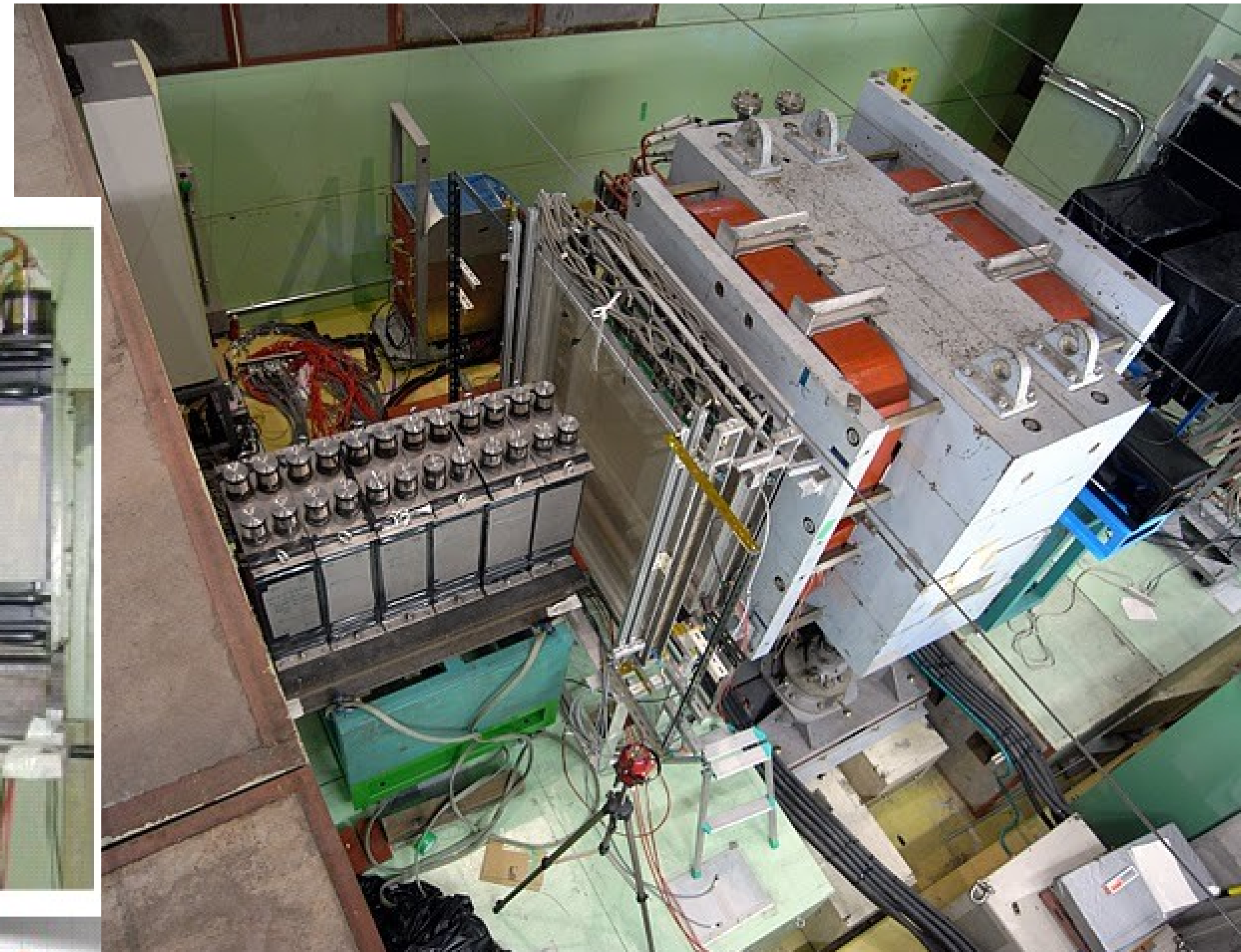
まとめ

- Beam line建設を行った
- Beam line survey進行中
  - Collimatorアラインメント成功
  - KL測定に成功
    - KL yieldは見込みの～２倍
    - 運動量分布再現
    - 1,2月のRunで統計を上げて、最終結果に
- 来年CsIスタックし、ビームデータ

Core測定

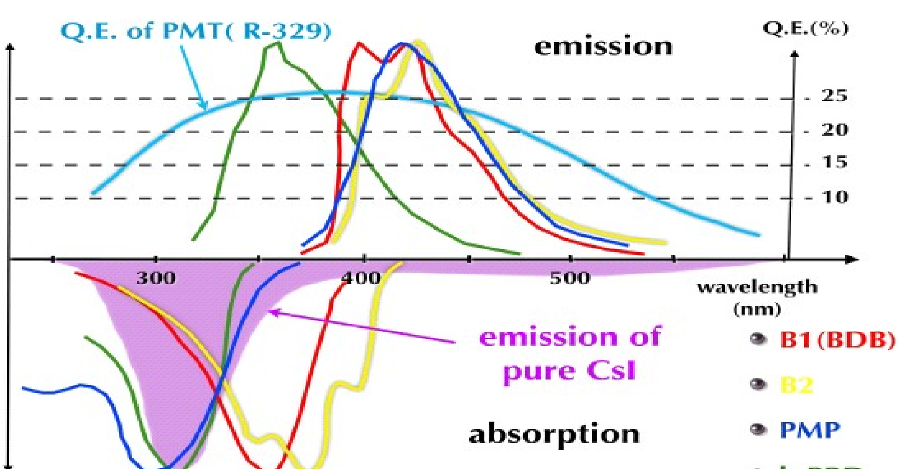


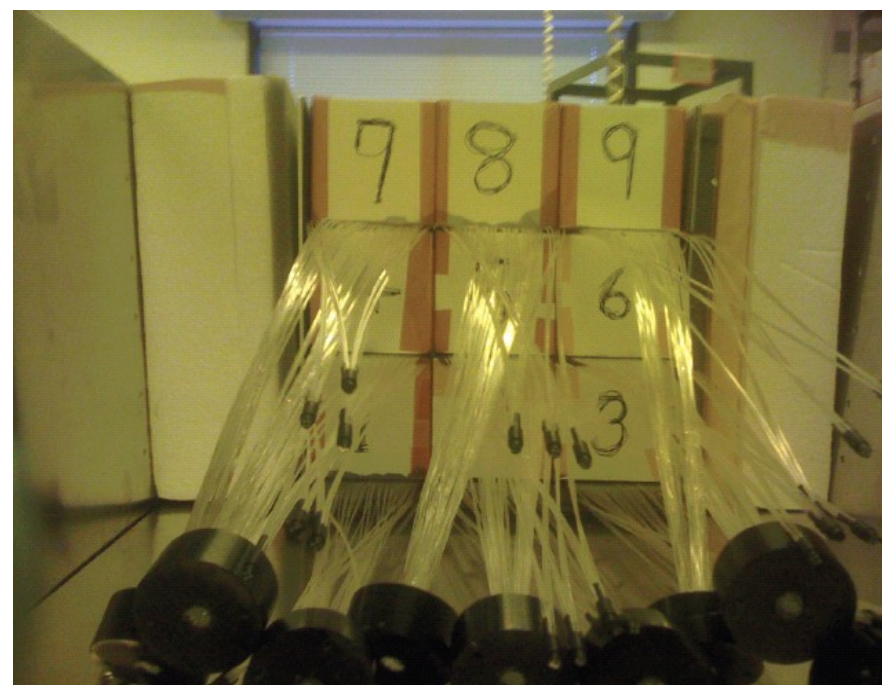
EM part
18X0
(4mm Pb +
3.7mm
scint)x25
Hadron part
4.3λI
(4mm Fe + 3.7mm
scint)x25



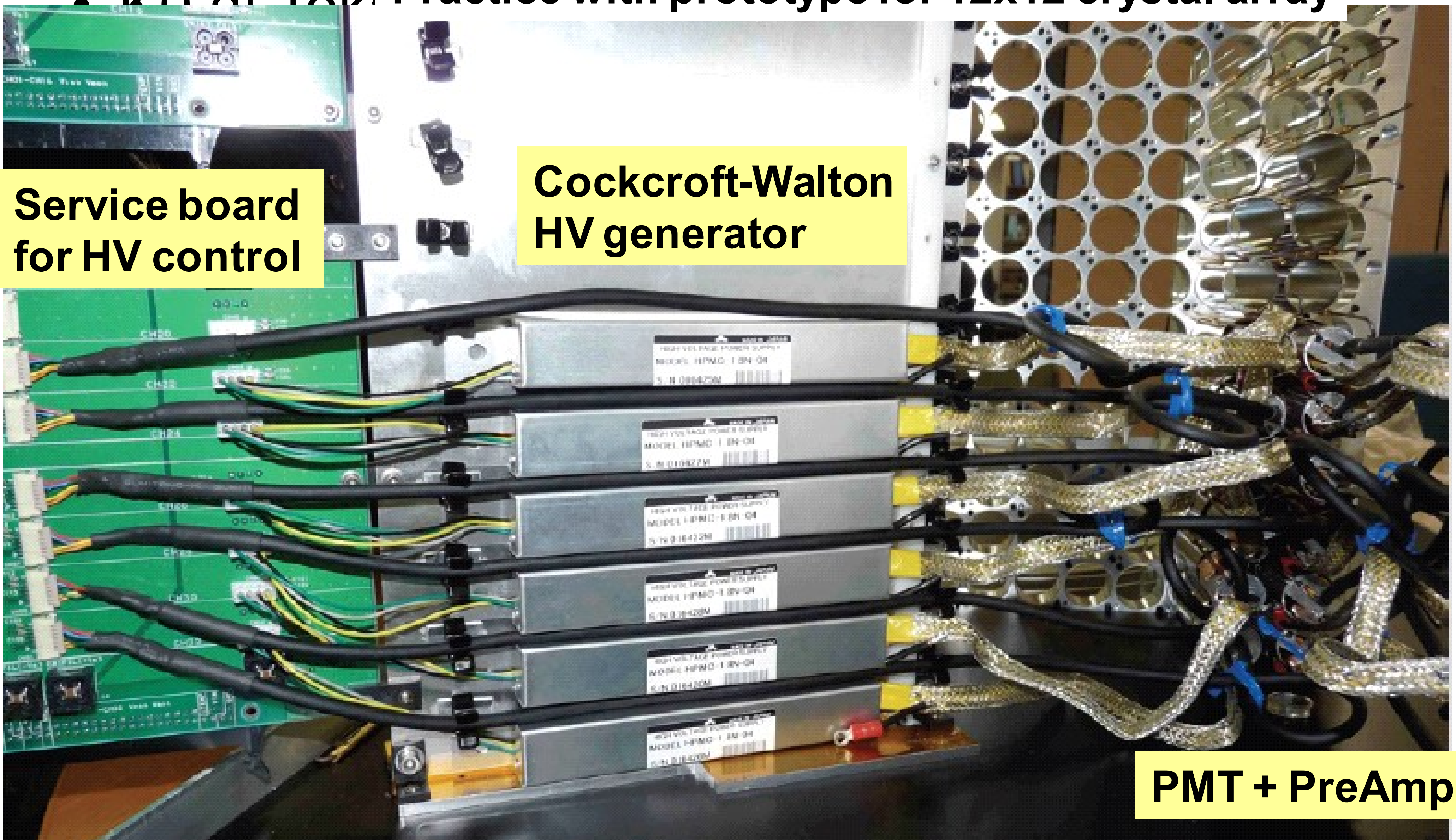
Halo測定　NCC

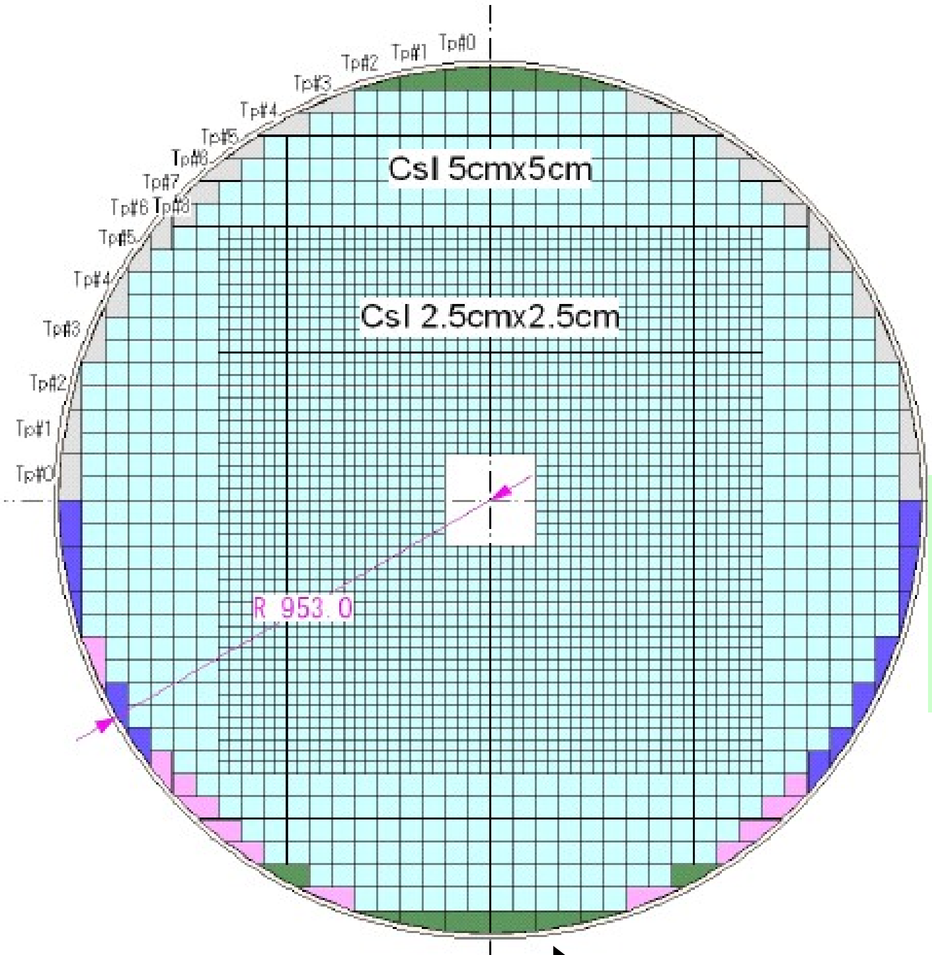
- Pure CsI
  - 7cmx7cm
  - 奥行き方向3分割
    - 15cm,20cm,10cm
- 波長変換ファイバー
  - PMP(クラレ)
  - 紫外吸収青発光





Practice with prototype for 12x12 crystal array





Photon veto for outer edge region

Specially-shaped sandwich detector w/ WLSF readout