Kaon Experiments at the J-PARC

- J-PARC
- TREK
- KOTO

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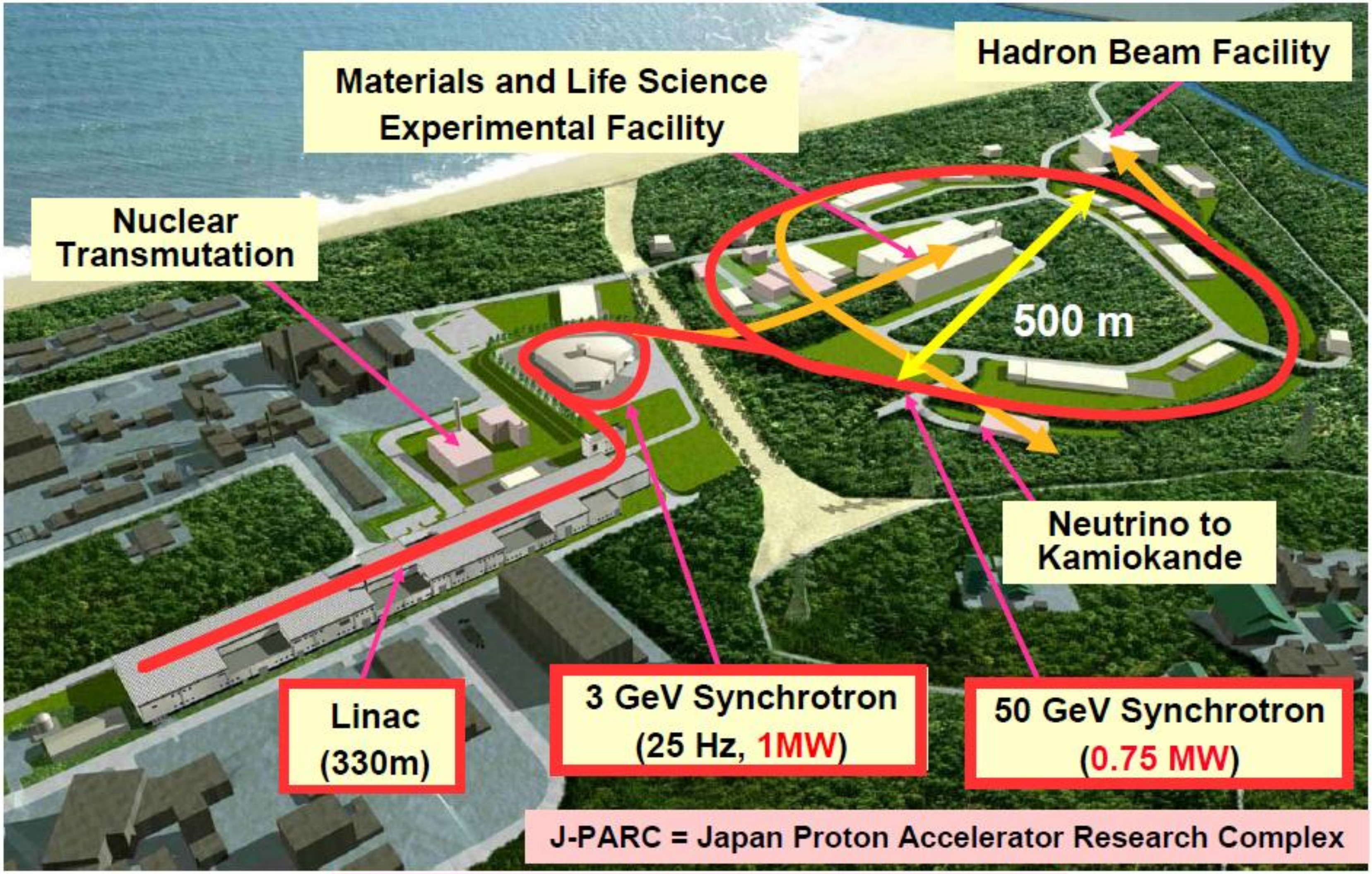
IPNS,KEK

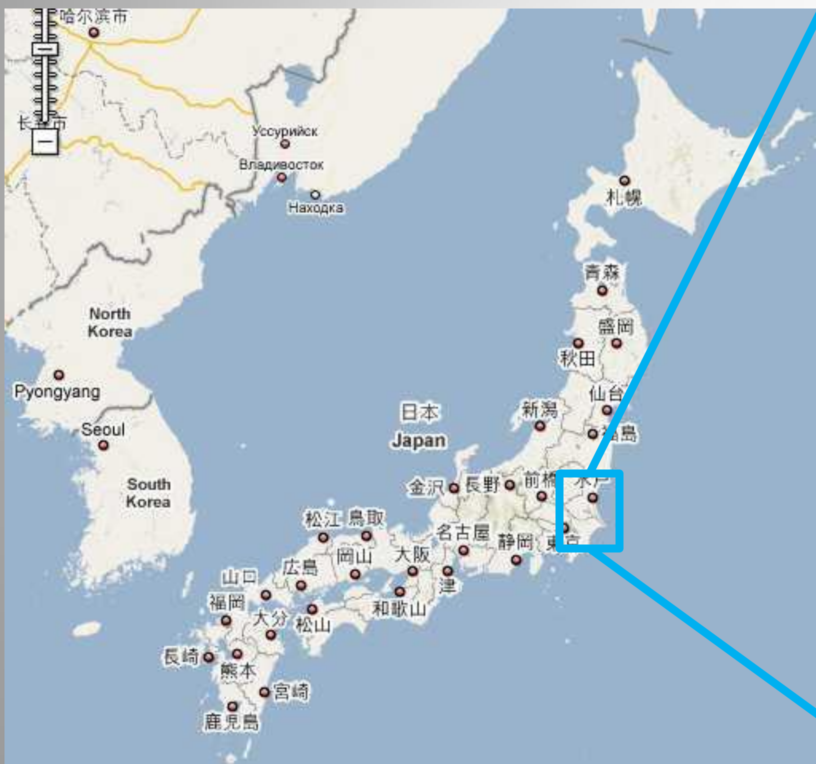
BEACH2010@ Perugia, 24th, June, 2010

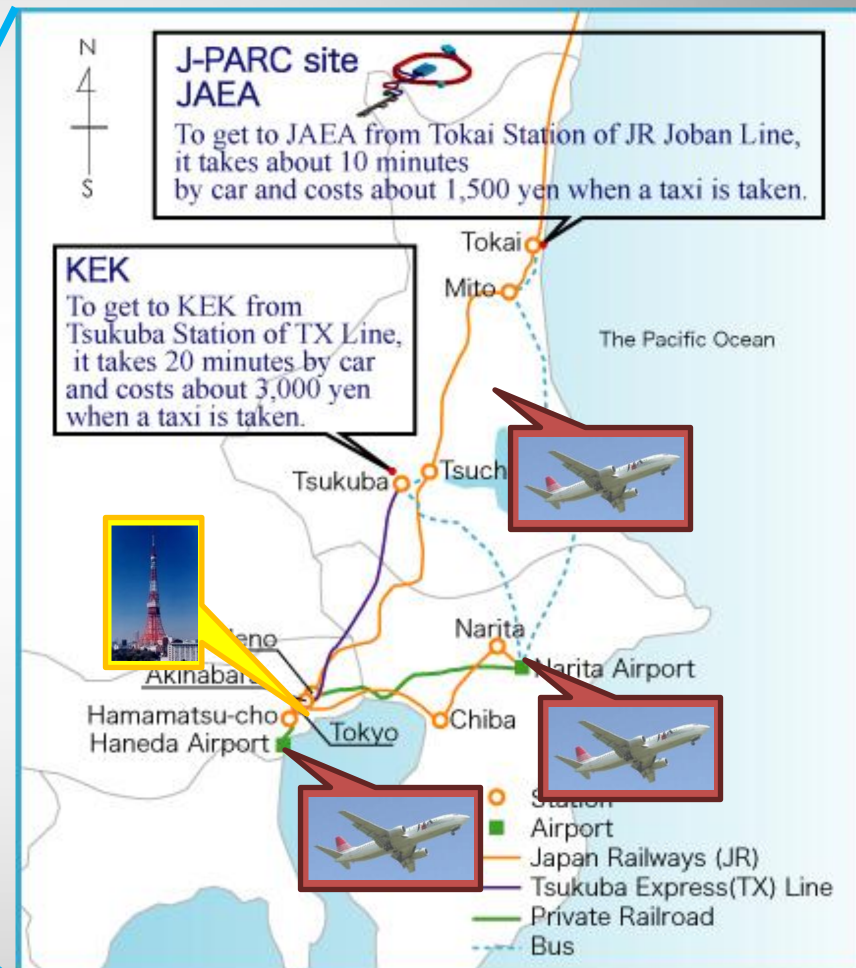
J-PARC Facility

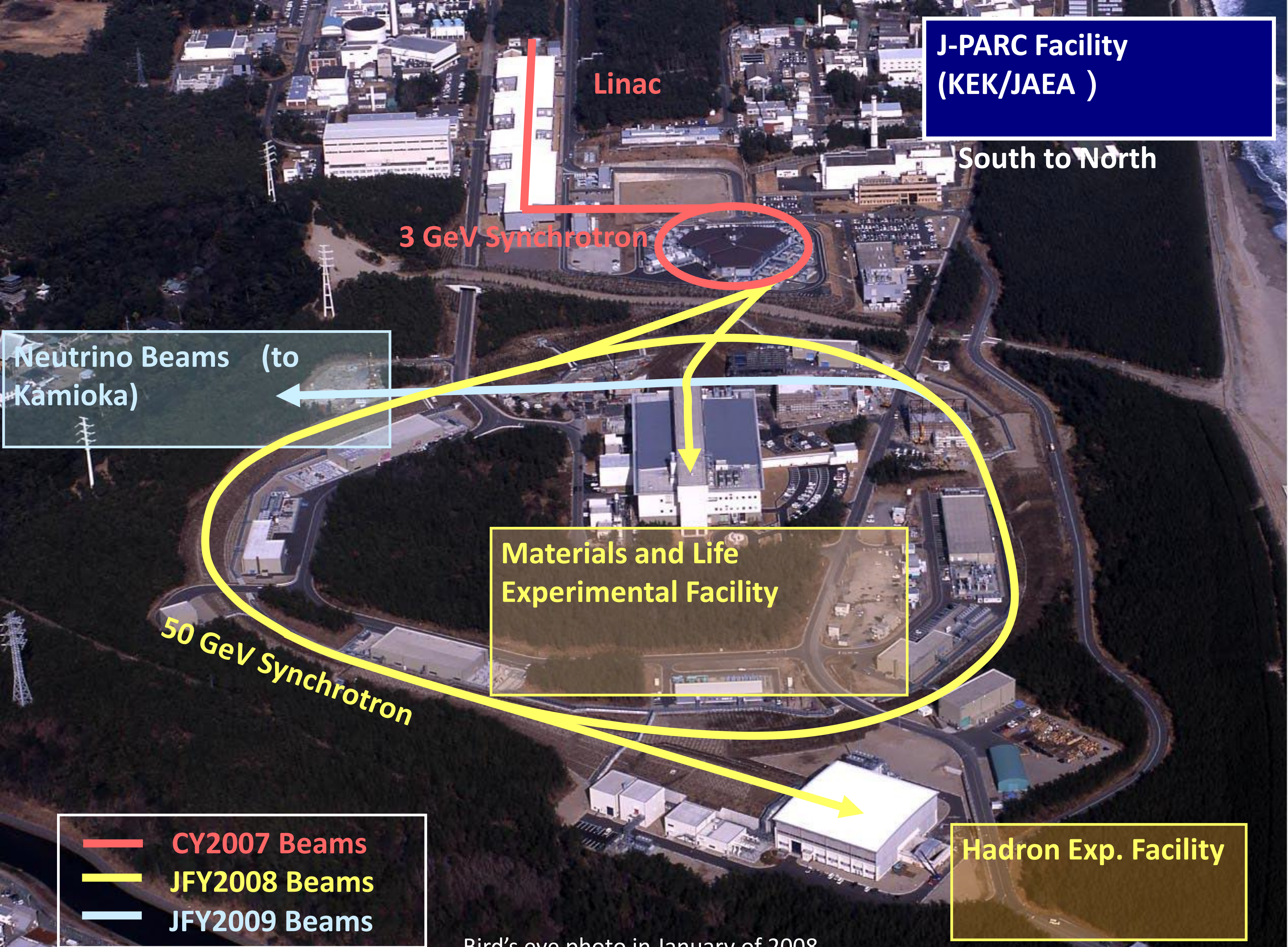


Joint Project between KEK and JAEA

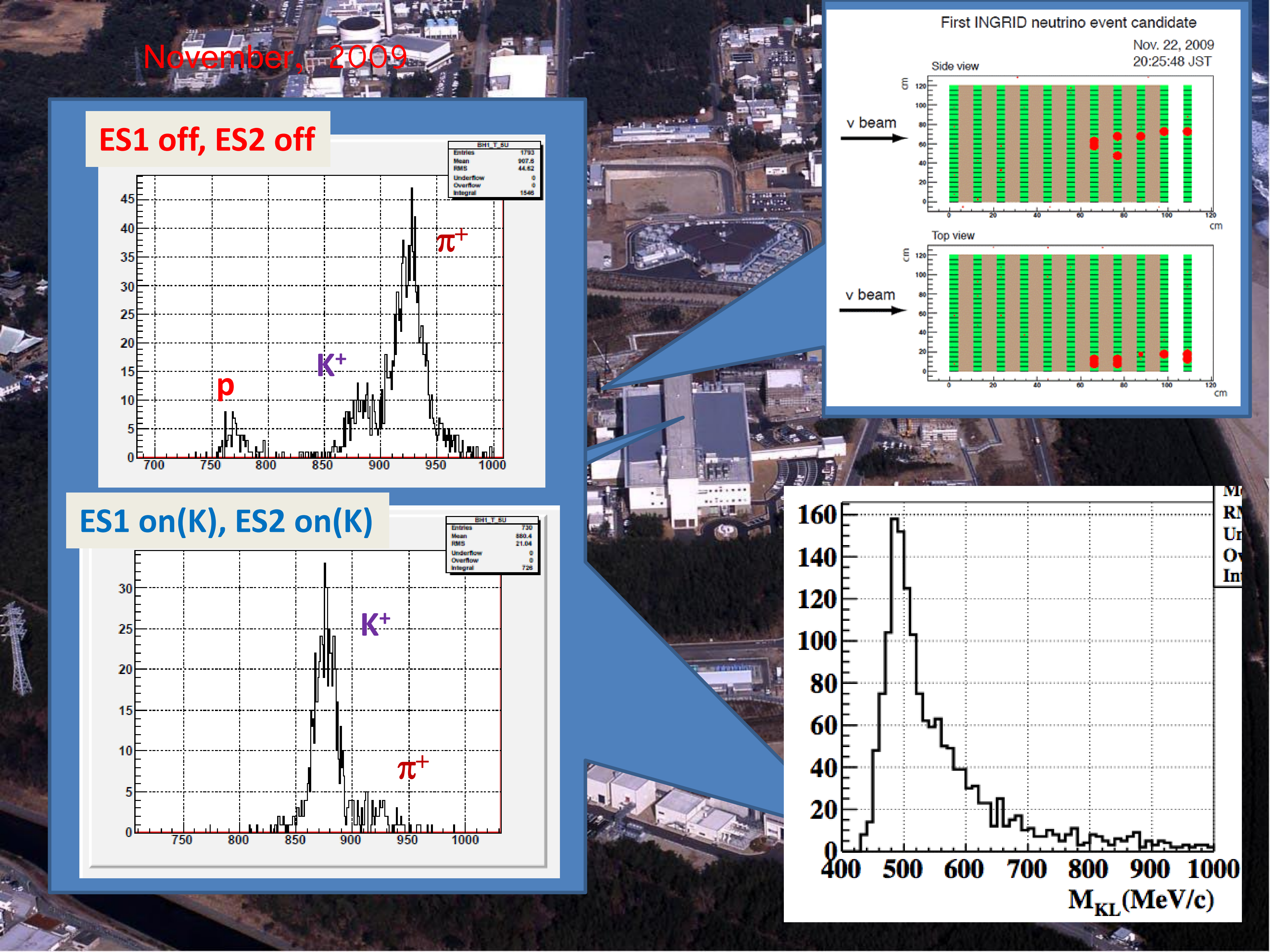
J-PARC at Tokai mura



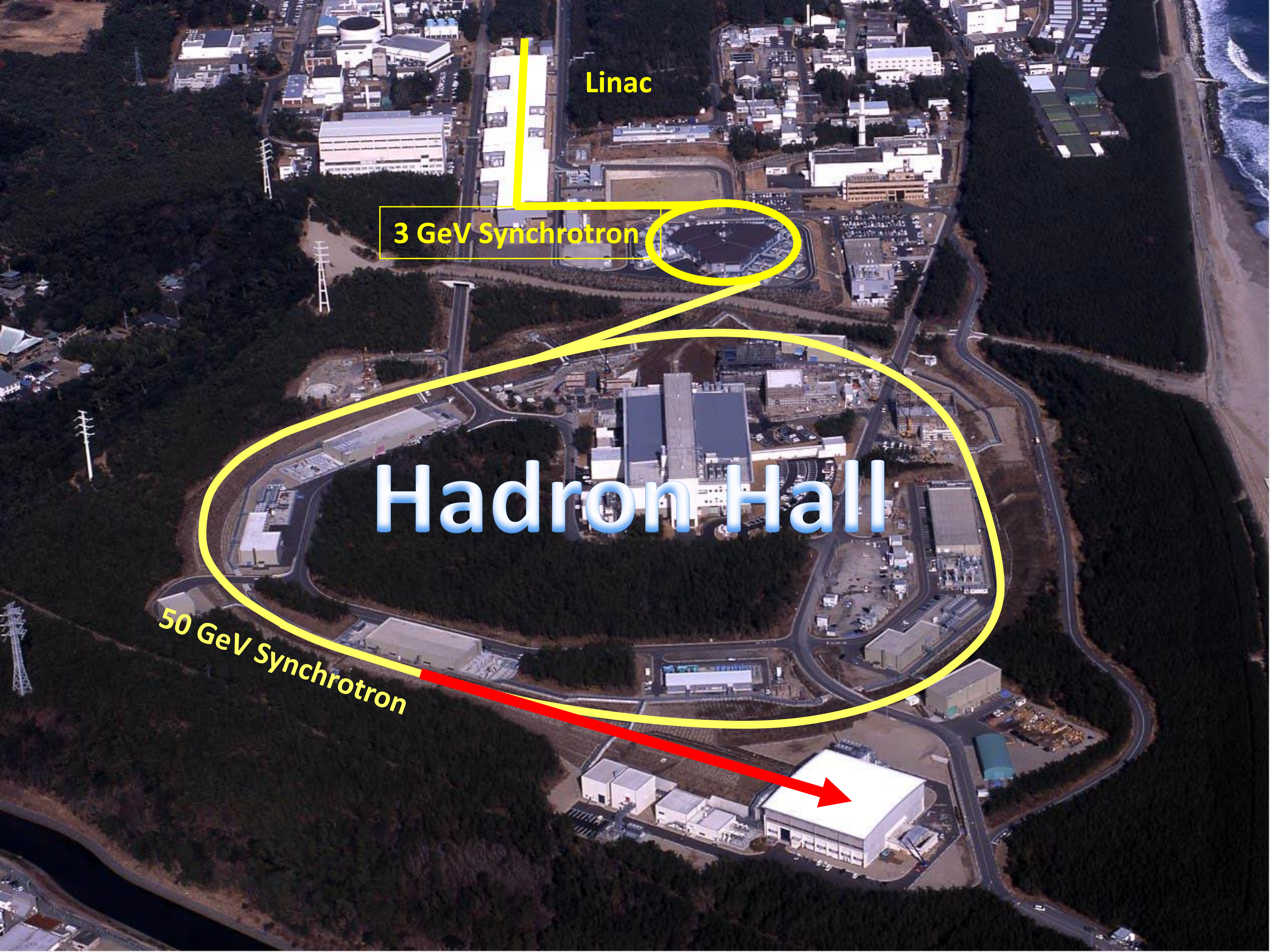


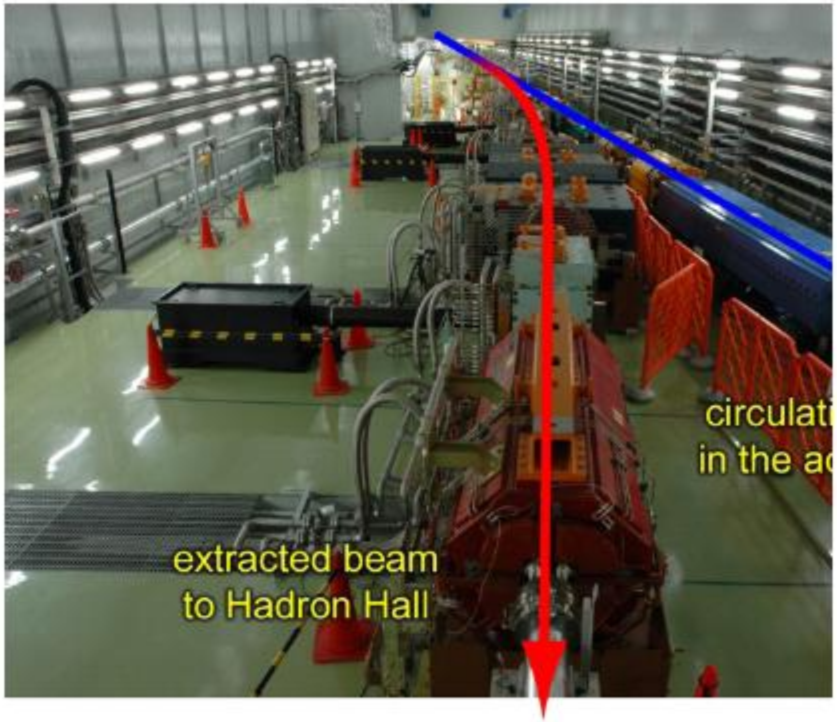


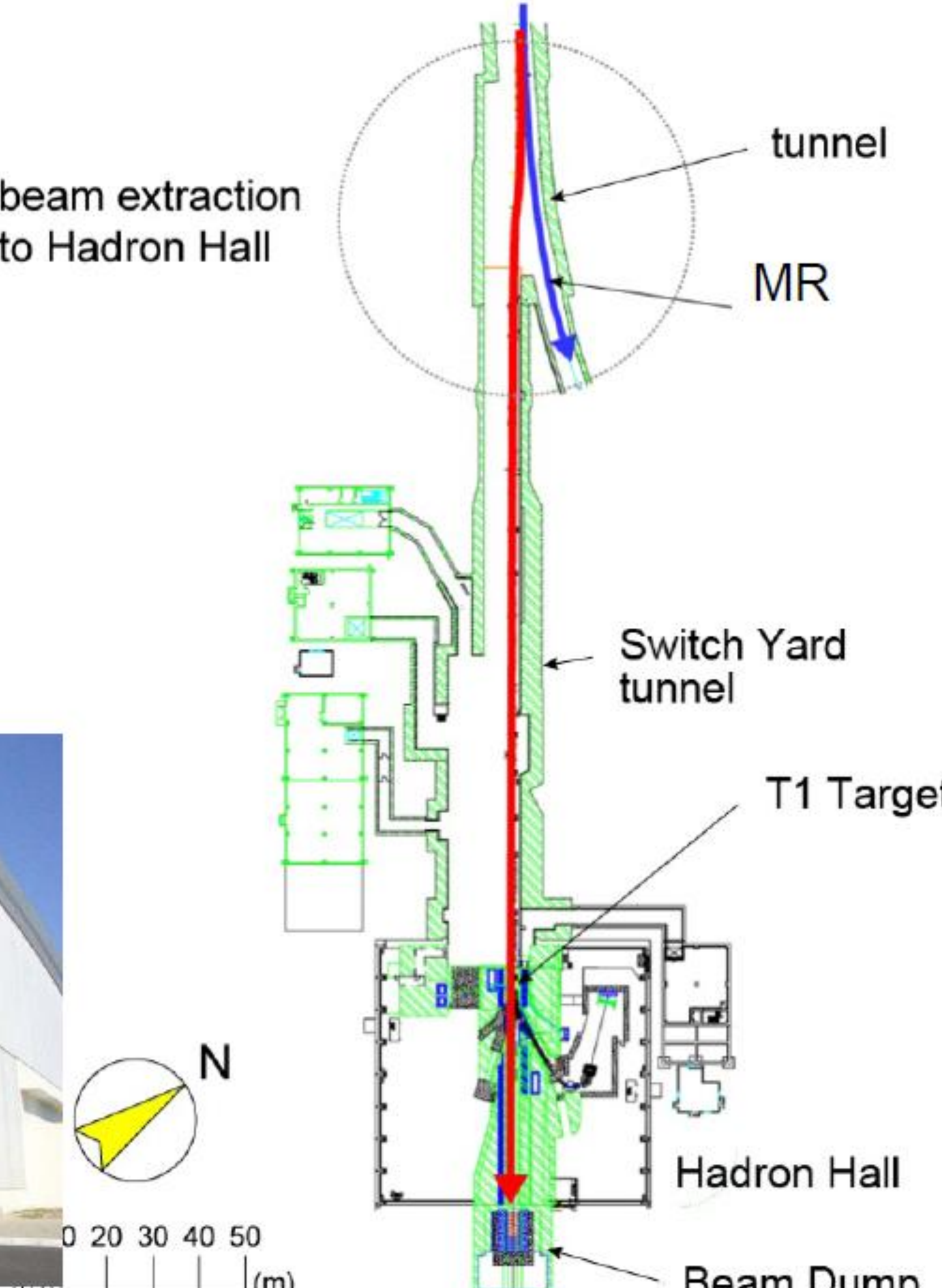
Bird's eye photo in January of 2008



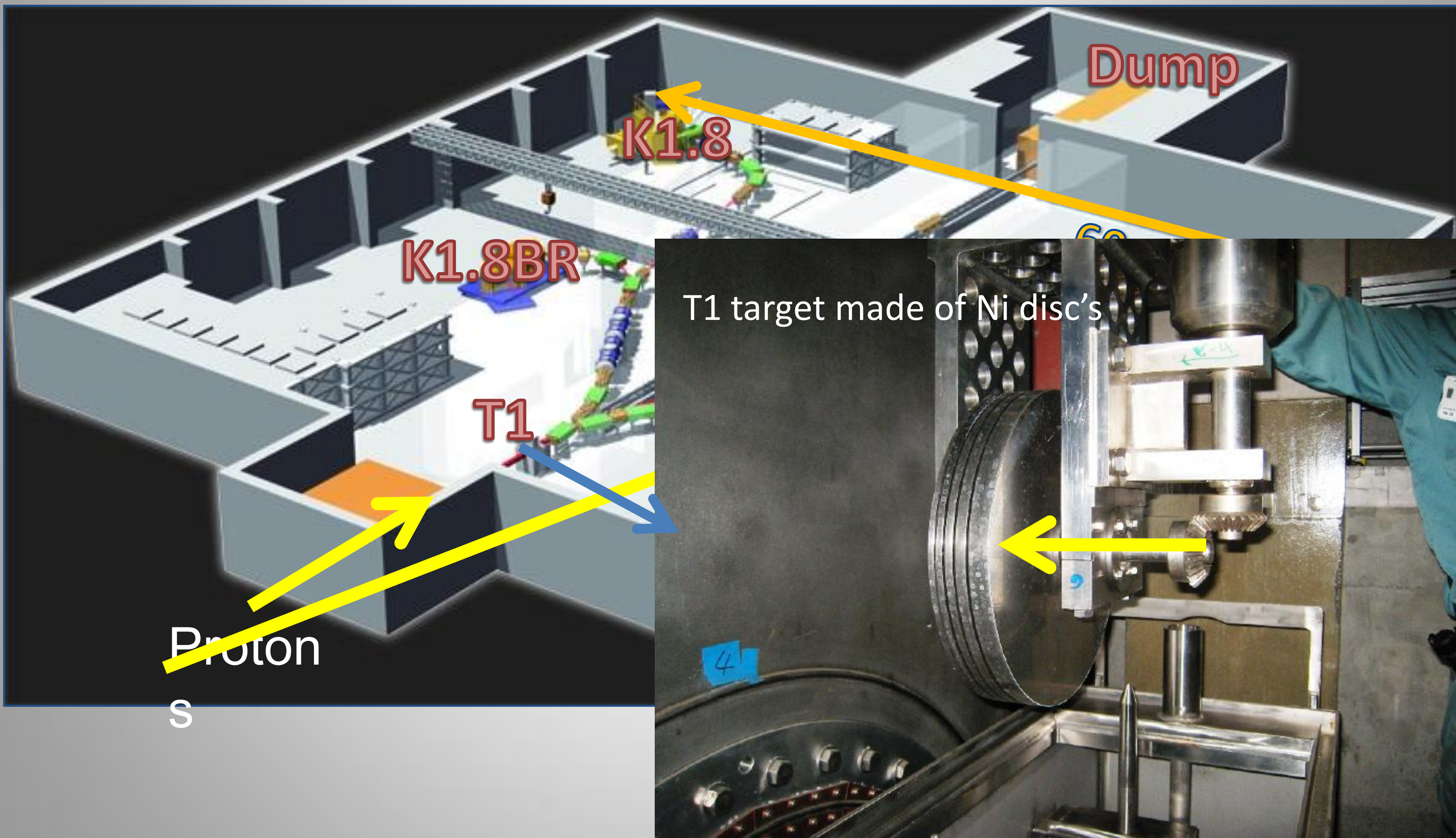
November, 2009
ES1 off, ES2 off
p
K+
π+
ES1 on(K), ES2 on(K)
K+
π+
First INGRID neutrino event candidate
Nov. 22, 2009
20:25:48 JST
Side view
ν beam
Top view
ν beam
cm
M_KL (MeV/c)


Linac
3 GeV Synchrotron
Hadron Hall
50 GeV Synchrotron


beam extraction
to Hadron Hall
extracted beam
to Hadron Hall


tunnel
MR
Switch Yard
tunnel
T1 Target
Hadron Hall
Beam Dump
N
0 20 30 40 50
(m)

Layout of Hadron Hall （Phase Ⅰ）



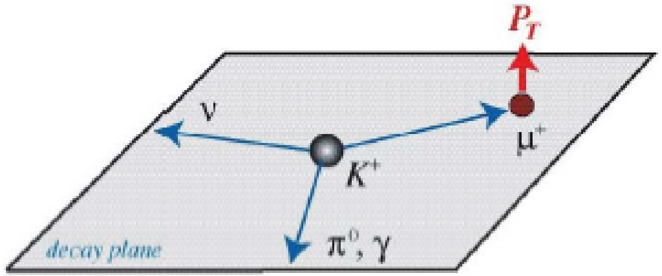
TREK

（Time Reversal Experiment with Kaons）

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

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

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



- P_T is T-odd, and spurious effects from final state interaction are small: $P_T(\text{FSI}) < 10^{-5}$
  Non-zero P_T is a signature of T violation.

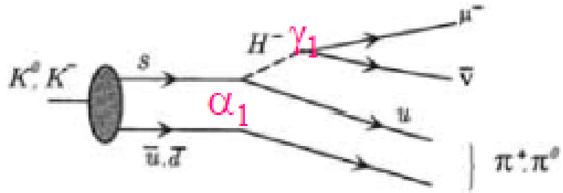
- Standard Model (SM) contribution to P_T: $P_T(\text{SM}) < 10^{-7}$

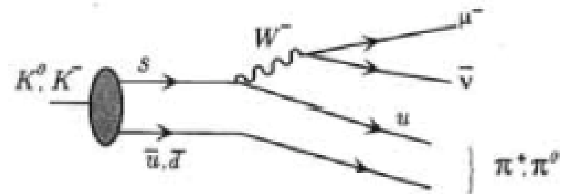
> *P_T in the range $10^{-3} \sim 10^{-4}$ is a sensitive probe of CP violation beyond the SM.*

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

Three Higgs doublet model

$$L = (2\sqrt{2}G_F)^{\frac{1}{2}} \sum_{i=1}^{2} \{\alpha_i \bar{u_L} V M_D d_R H_i^+ + \beta_i \bar{u_R} M_U V d_L H_i^+ + \gamma_i \bar{\nu_L} M_E e_R H_i^+\} + \text{h.c.},$$



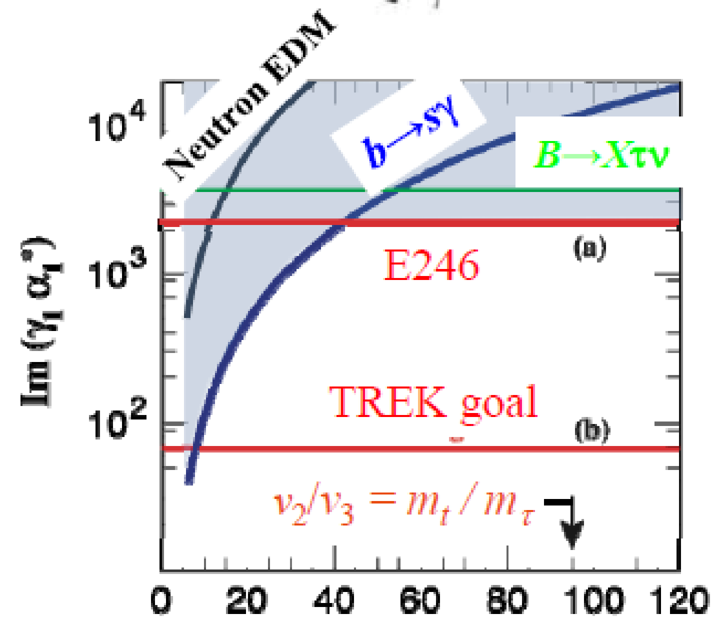


$$\mathrm{Im}\xi = \frac{m_K^2}{m_H^2} \mathrm{Im}(\gamma_1 \alpha_1^*)$$

- *c.f.* d_n, $b \to s\gamma$ $\propto \mathrm{Im}(\alpha_1\beta_1^*)$, $(\alpha_1\beta_1^*)$

  $\mathrm{Im}(\alpha_1\beta_1^*) = -v_2^2/v_3^2\, \mathrm{Im}(\gamma_1\alpha_1^*)$

  Higgs field *v. e. v.*



- $B \to X\tau\nu$ and $B \to \tau\nu$ at Super-Belle corresponds to $P_T < 3 \times 10^{-4}$

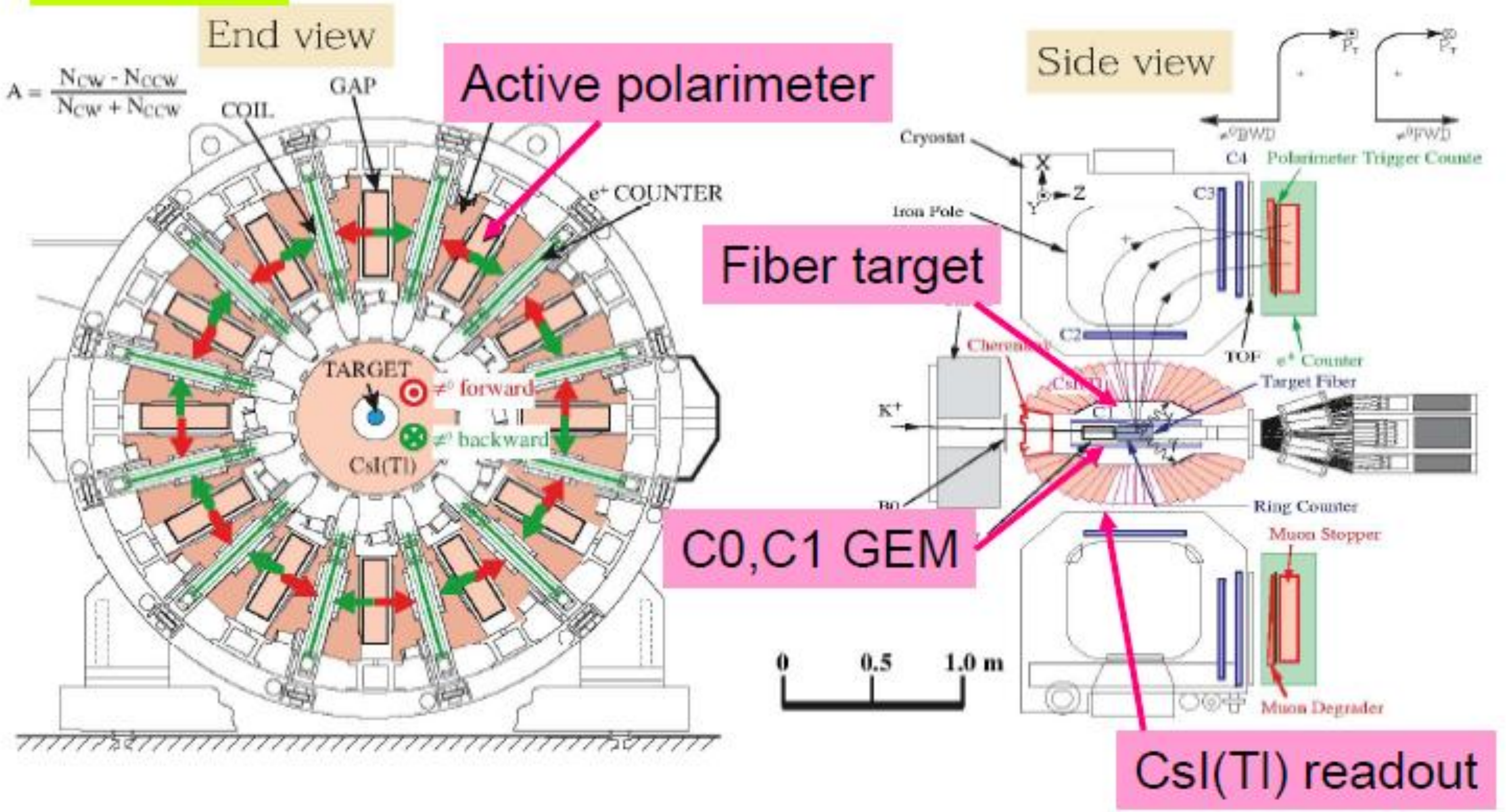
  c.f. TREK goal : $P_T \leq 1 \times 10^{-4}$

- *P_T is the most stringent constraint for* $\mathrm{Im}(\gamma_1\alpha_1^*)\, v_2/v_3$

P_T measurement

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

Use of upgraded E246 detector



- P_T *is measured as the azimuthal asymmetry* A_{e^+} *of the* μ^+ *decay positrons*

Stopped beam method

Double ratio experiment

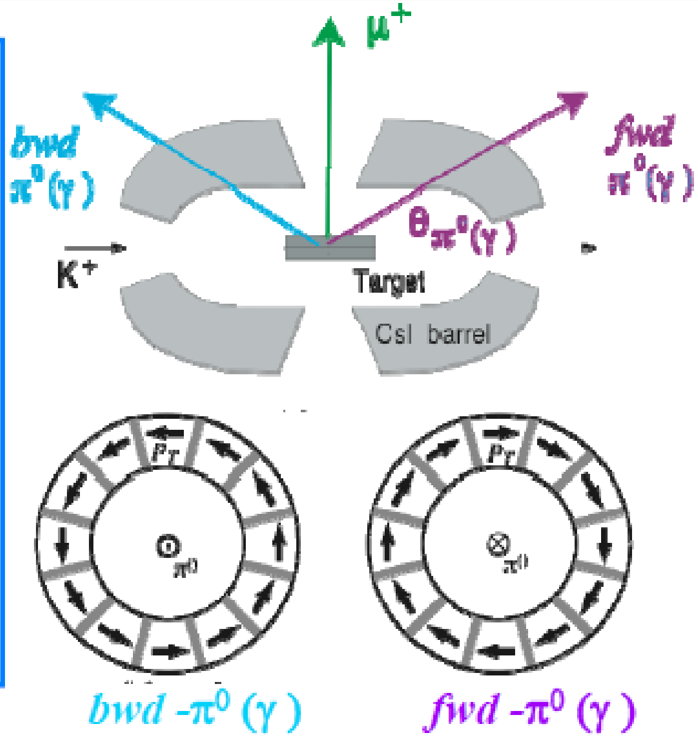
$$A_T = (A^{fwd} - A^{bwd}) / 2$$

$$A^{fwd(bwd)} = \frac{N_{cw} - N_{ccw}}{N_{cw} + N_{ccw}}$$

$$P_T = A_T / \{\alpha <\cos\theta_T>\}$$

α : analyzing power
$<\cos\theta_T>$: attenuation factor

$\mathrm{Im}\xi = P_T / KF$: physics parameter
KF : kinematic factor



Current limit from E246

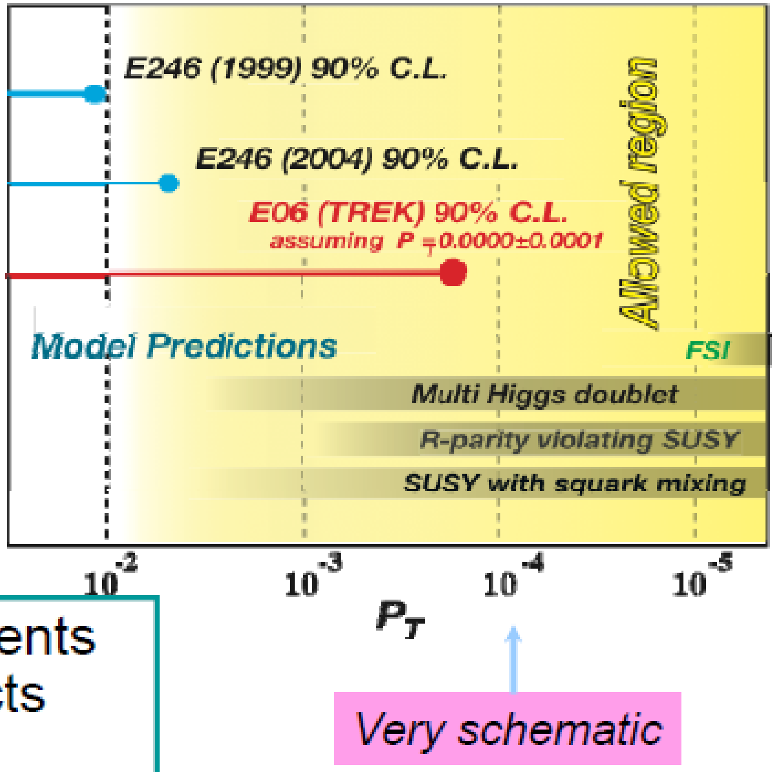
$P_T = -0.0017 \pm 0.0023(stat) \pm 0.0011(syst)$
($|P_T| < 0.0050$: 90% C.L.)
$\mathrm{Im}\xi = -0.0053 \pm 0.0071(stat) \pm 0.0036(syst)$
($|\mathrm{Im}\xi| < 0.016$: 90% C.L.) **PRD 73, 072005 (2006)**

- *E246 was Statistical error dominant*

Expected sensitivity in TREK

- $\delta P_T^{stat} \leq 0.05\ \delta P_T^{stat}$ (E246) $\leq 10^{-4}$: 1.4 x 10^7 sec of run

1) × 30 beam intensity
2) × 10 detector acceptance
3) Higher analyzing power



- $\delta P_T^{syst} \leq 0.1\ \delta P_T^{syst}$ (E246) $\leq 10^{-4}$

1) Precise calibration misalignments
2) Correction of systematic effects
3) Precise *fwd-bwd* cancellation

- *We aim at a sensitivity of $\delta P_T \sim 10^{-4}$*

KOTO

Search for $K_L \rightarrow \pi^0 \nu \nu$ Decay

= KO at Tokai

We are writing as K^0TO, too.

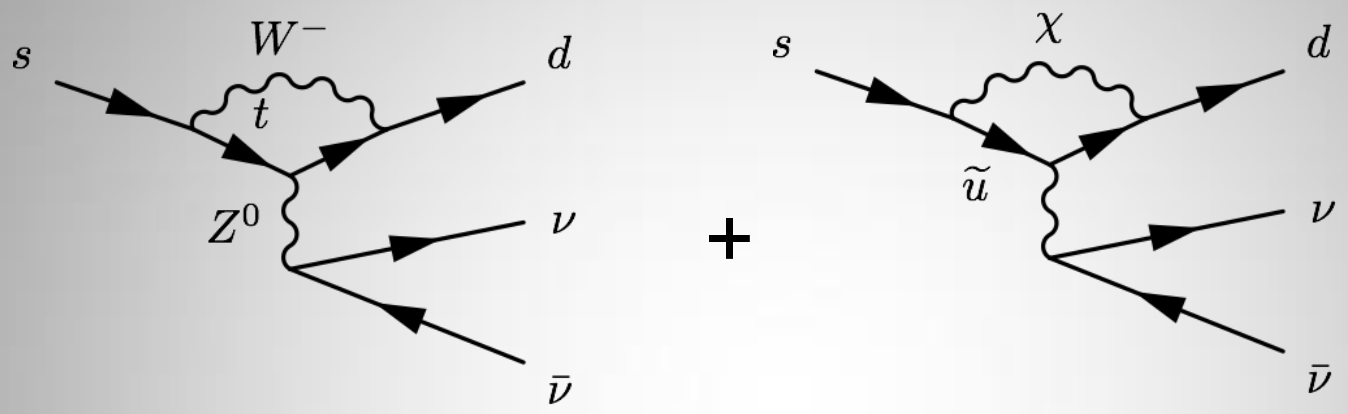
Also, we are using

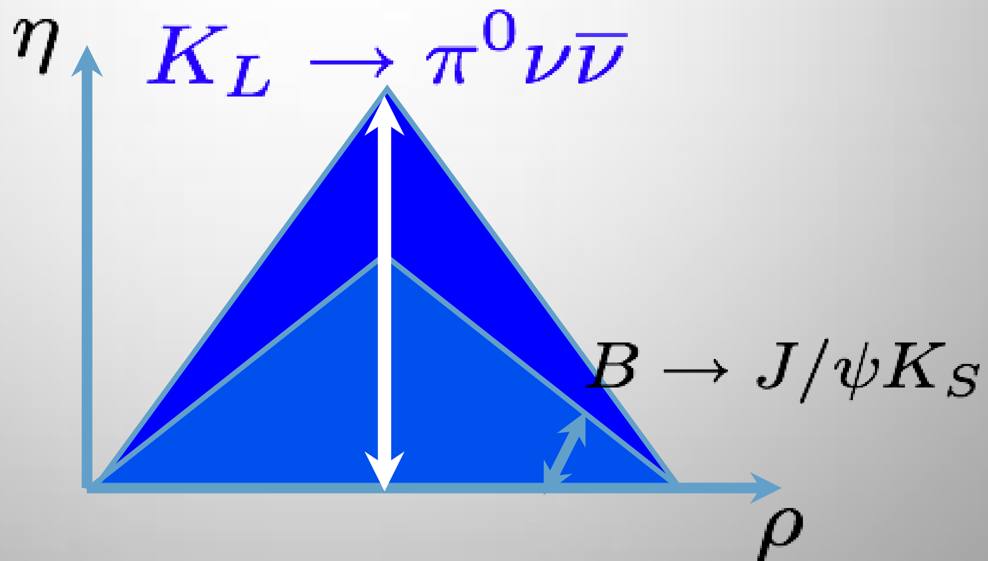
琴

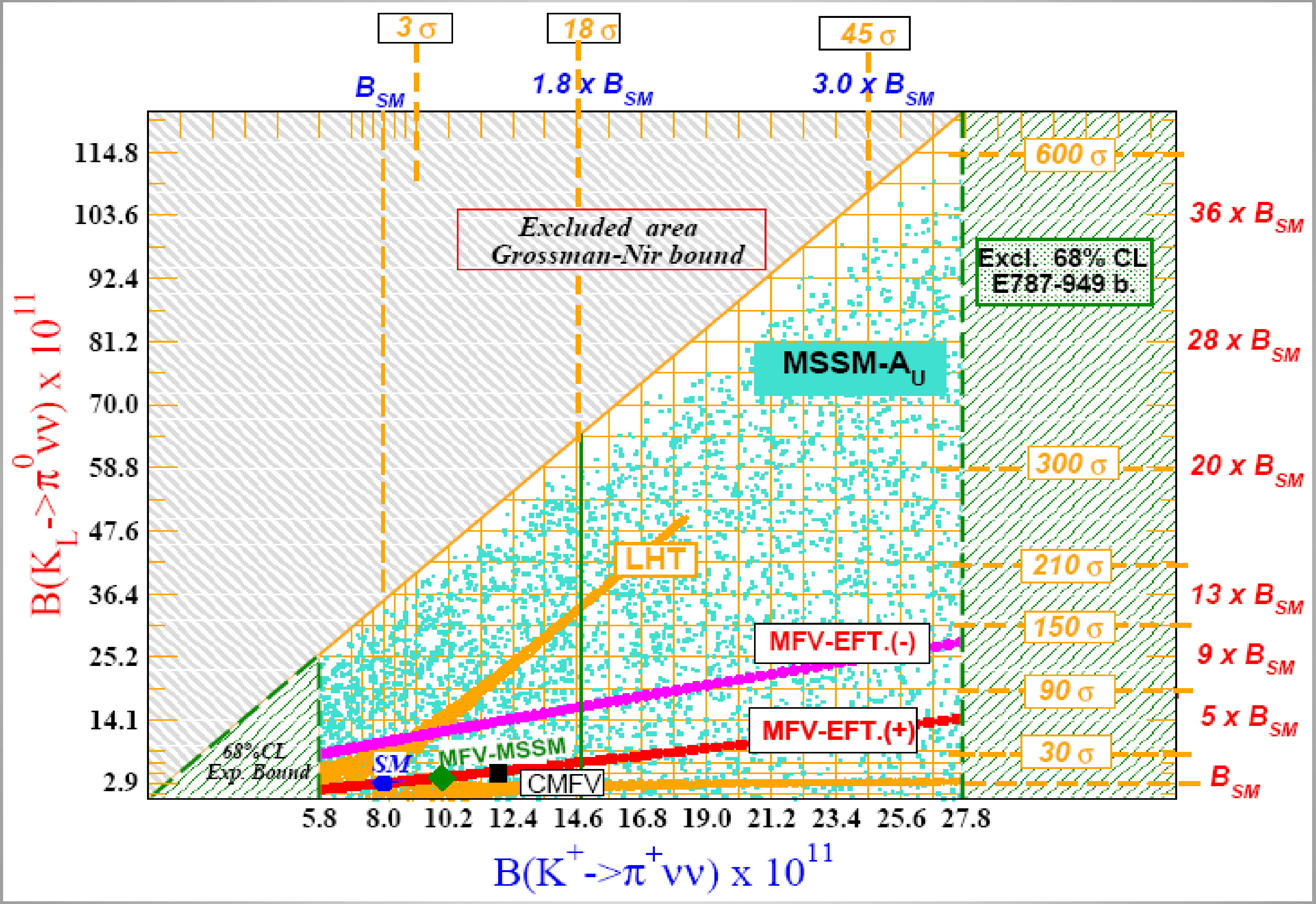
60 members from

16 institutes （6 countries）

New physics contribution

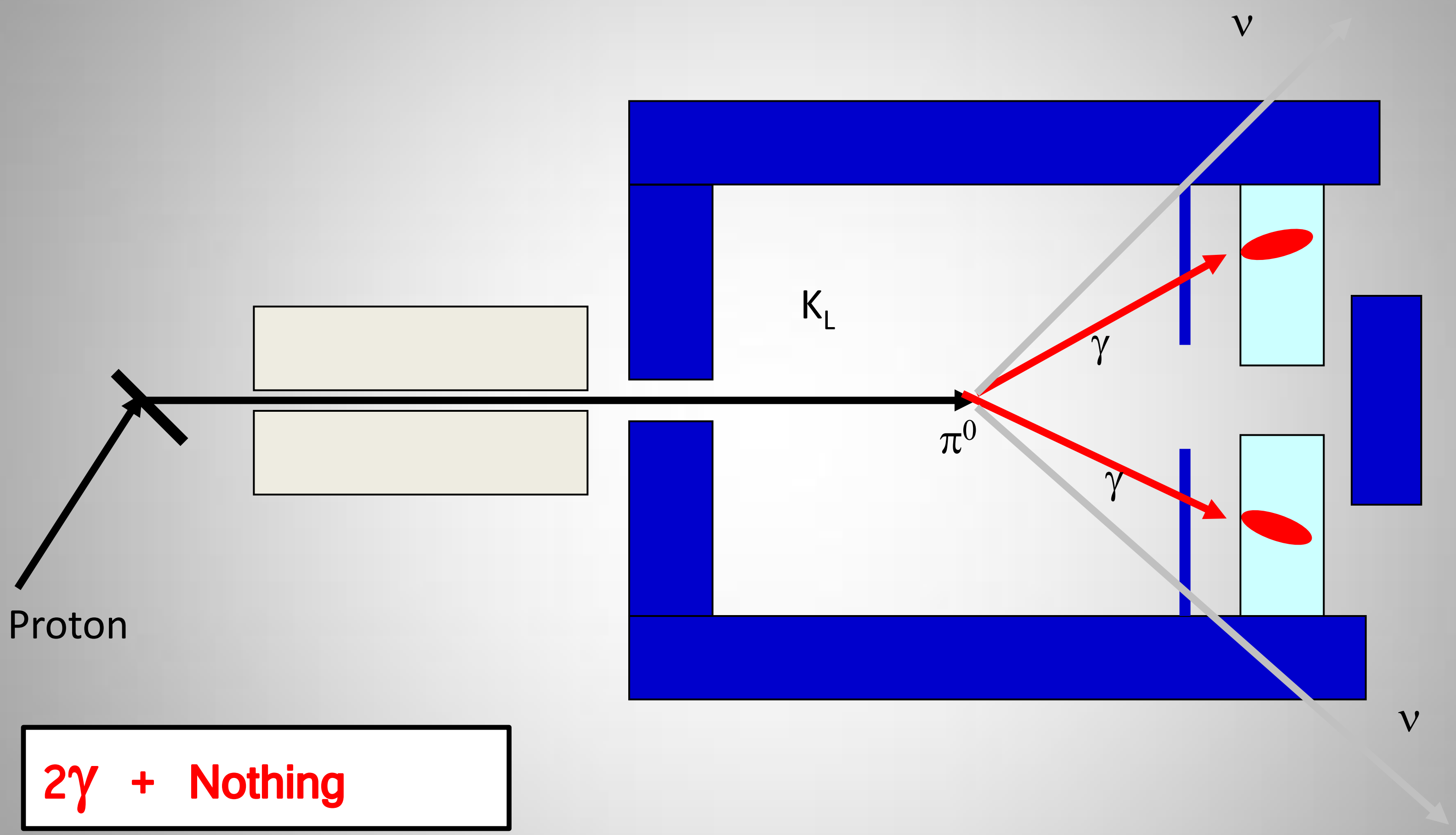






Federico Mescia, CKM2006

Experimental Method



2γ + Nothing

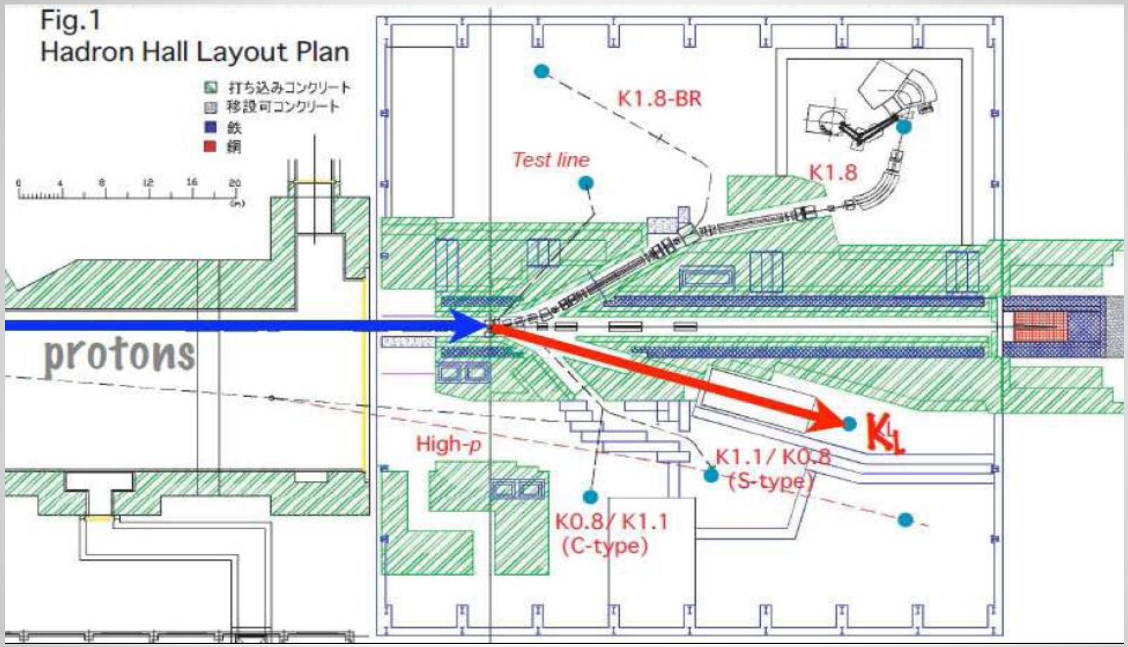
Pencil Beam + Hermetic Veto System

KOTO strategy

- Aim at the first observation of the Decay
- High Intensity proton beam @ J-PARC
  - New beam line:
    - To share protons with other beam lines
    - X30 KL with X100 Protons
  - New read-out system （pipeline with FADC）
  - New BA（Beam hole Photon Veto）
- New Electromagnetic calorimeter.
  - Longer and finer segmented CsI crystals （KTeV）
- Improving some veto counters
  - Additional Barrel counters
  - New design to suppress neutron backgrounds

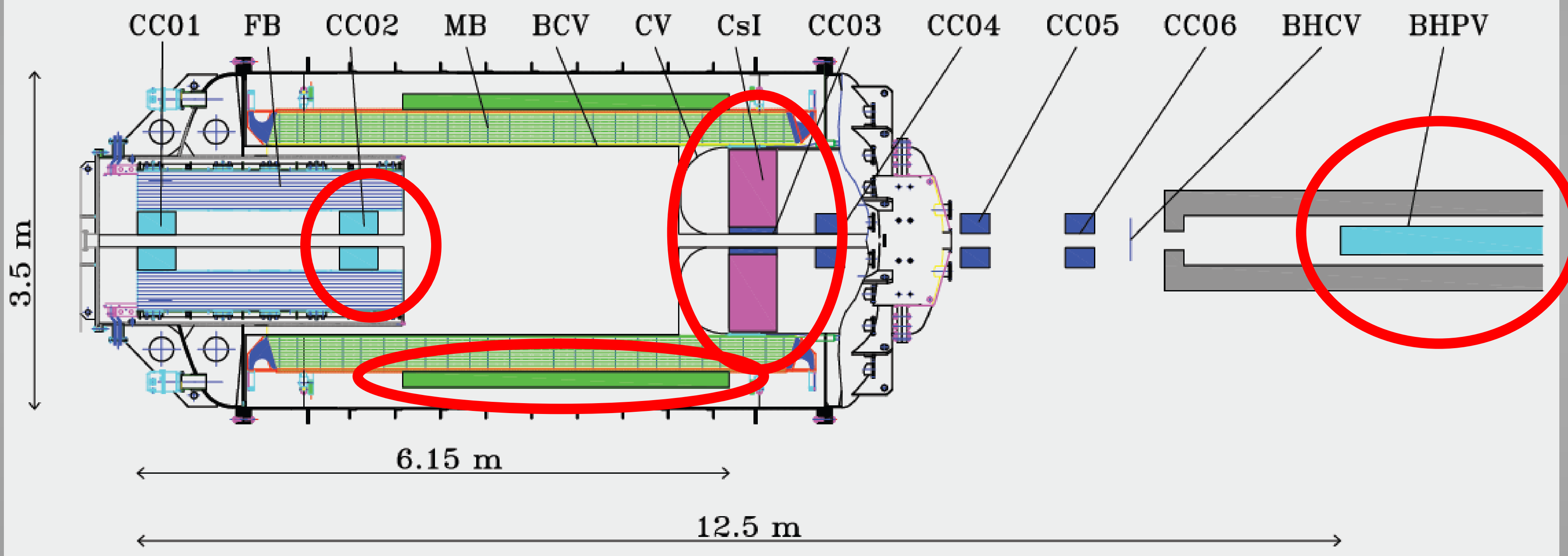
New Beam line

- Common target to share protons



- Large extraction angle (16°)
  - Softer momentum distribution
  - lower KL yield per proton
  - Better KL/n ratio

KOTO Detector



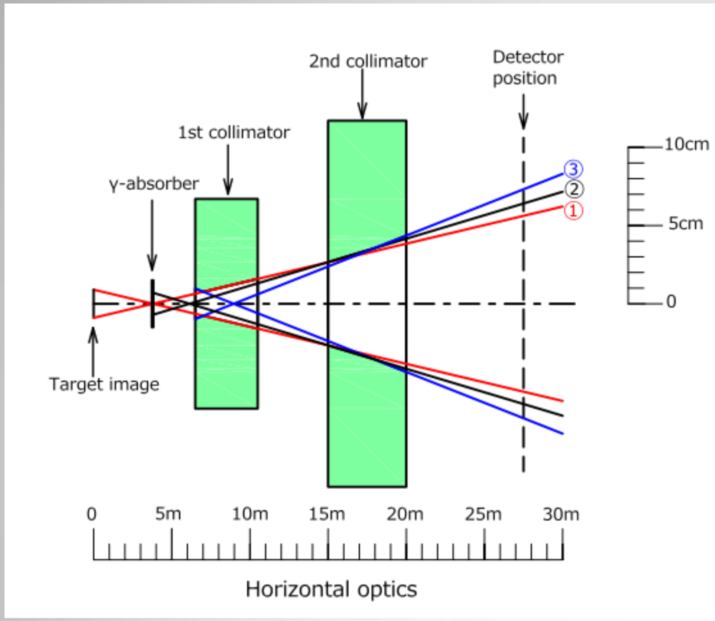
Beam line construction in 2009

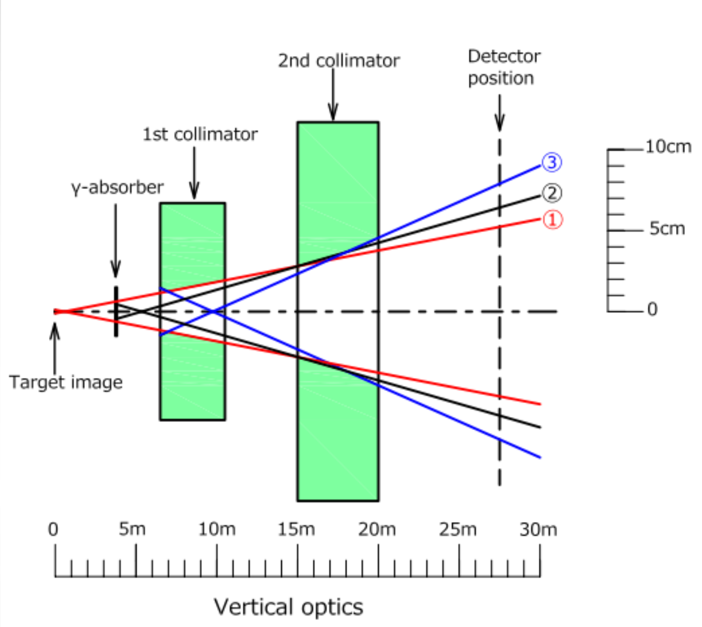
Calorimeter construction in 2010

Complete detector system in 2011

Beam Line

Collimation Scheme





Rectangular shape to fit effective shape of target

Two stages of long collimator made of iron

To avoid multiple scattering inside collimator

Bending Magnets to weep out charged particles

Lead block to control photon flux

Layout of beam line

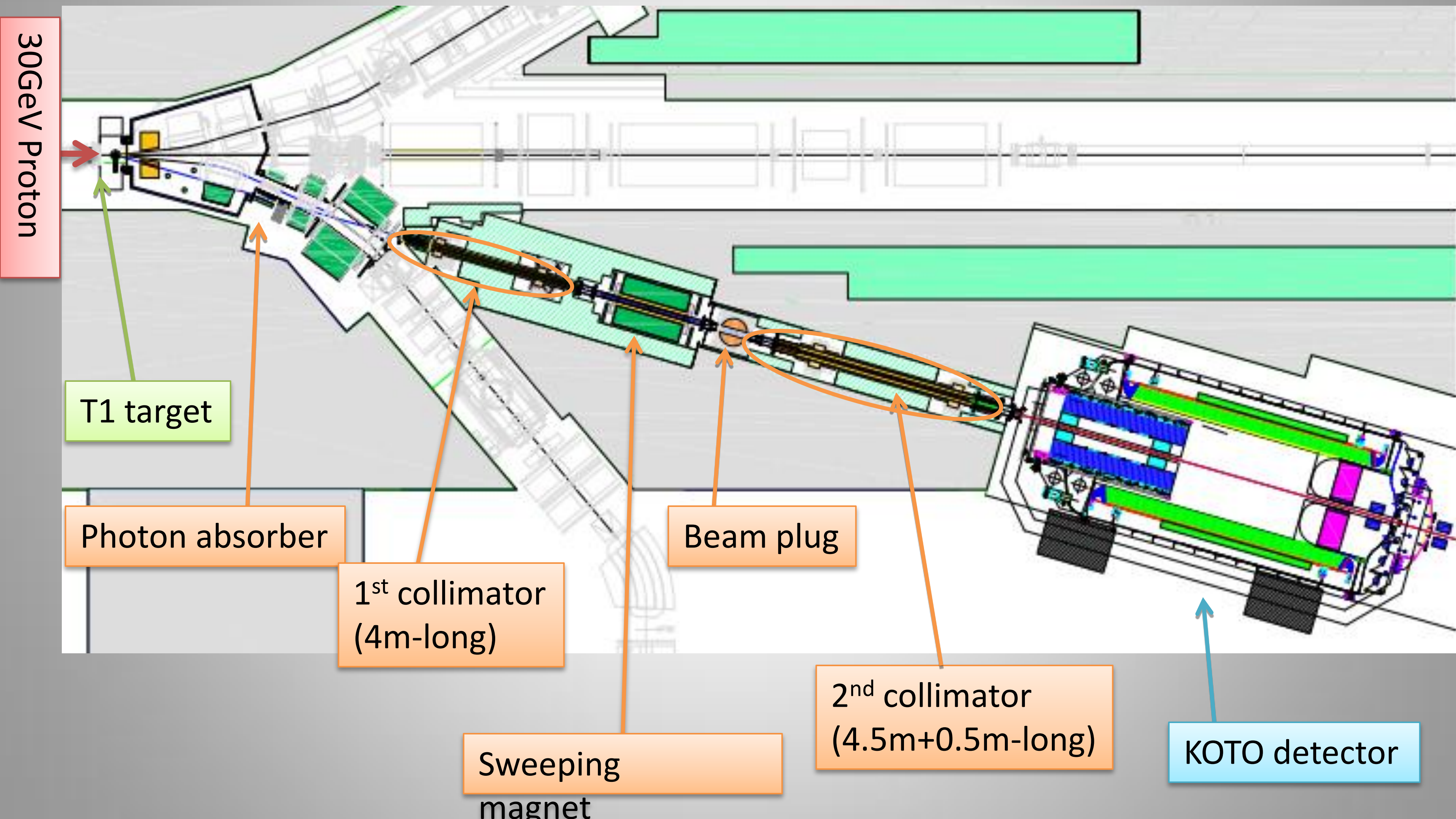
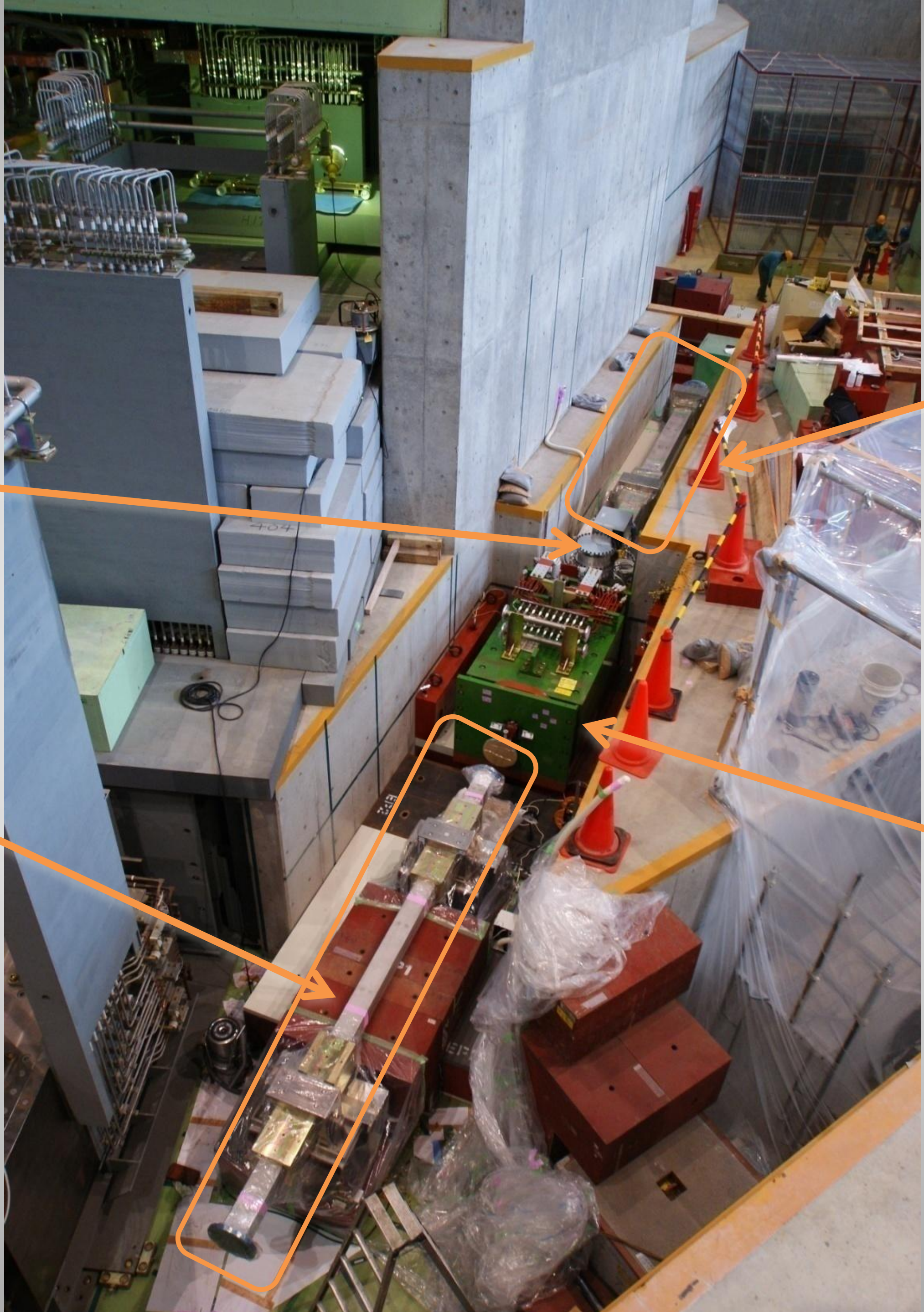


Photo on July 11.



Beam plug

2nd collimator
(4.5+0.5m)

1st collimator
(4m-long)

Dipole magnet

建設 1

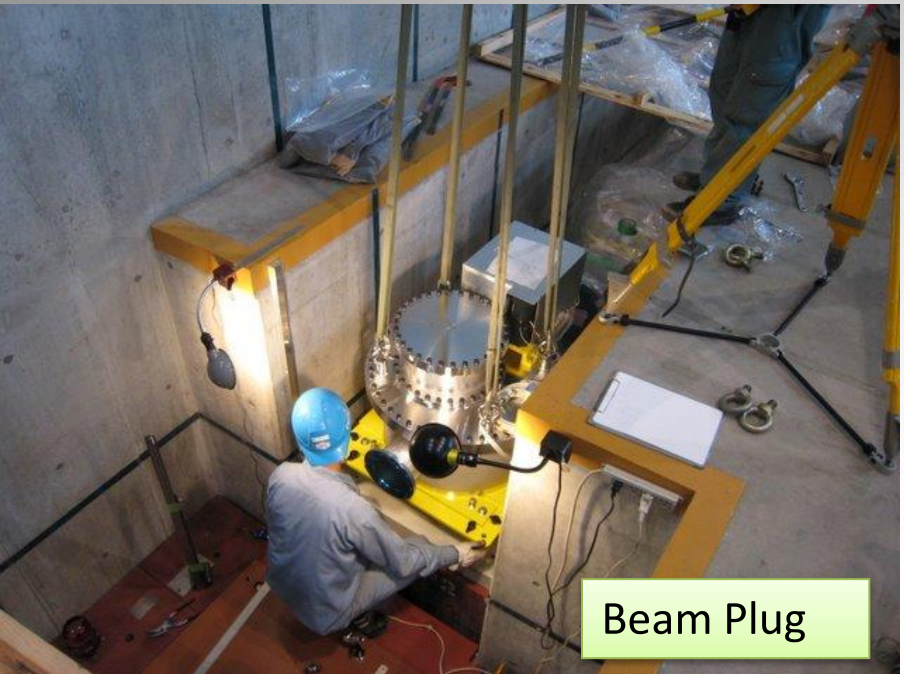

Before construction


Base iron plate

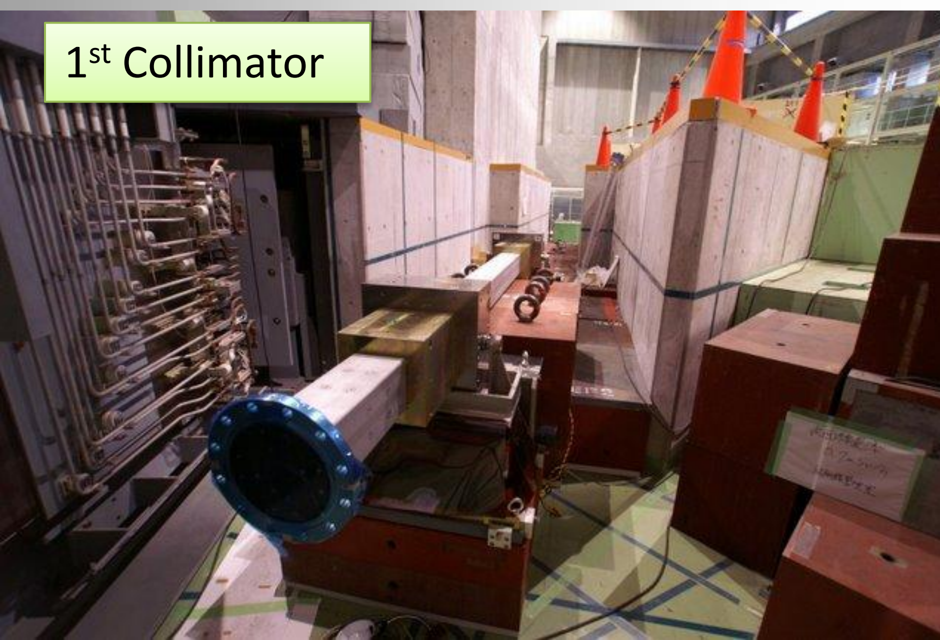

2nd Collimator

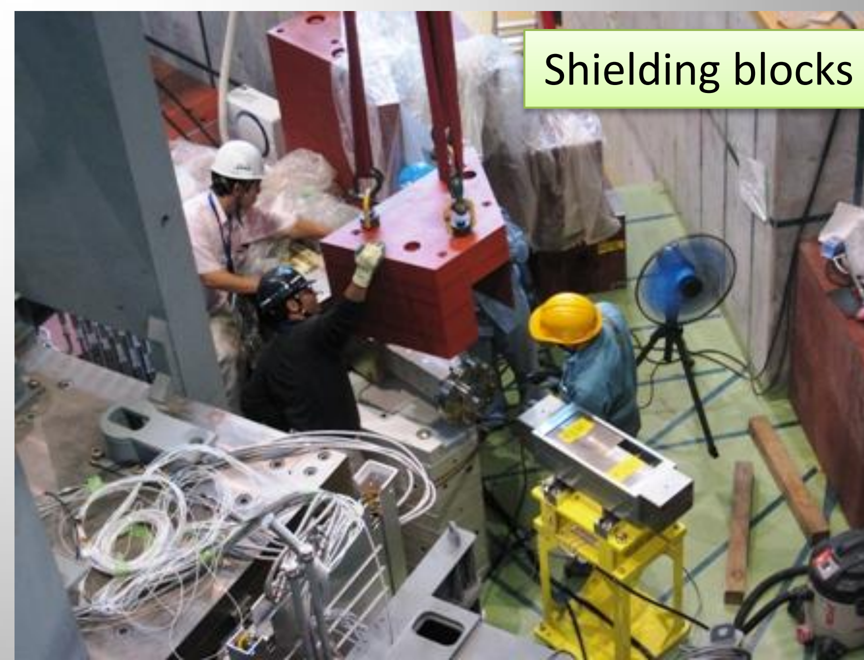

2nd Collimator

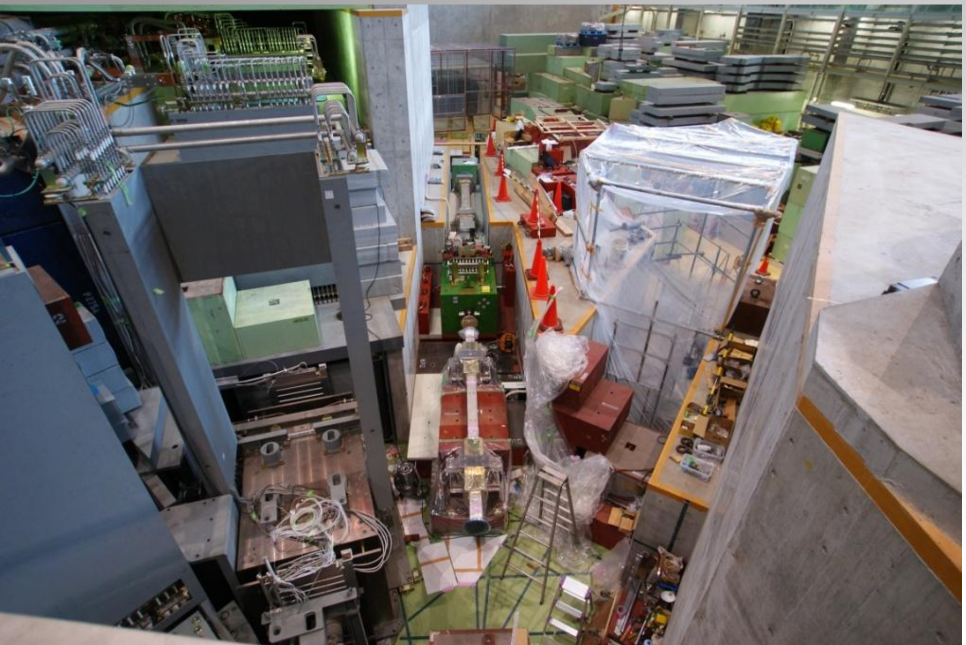
建設 2


Beam Plug


Bending Magnet


1st Collimator


Shielding blocks



Complete, Sep. 2009

Beam Survey (Nov. 2009-Feb.2010)

For high sensitivity

- High intensity KL beam

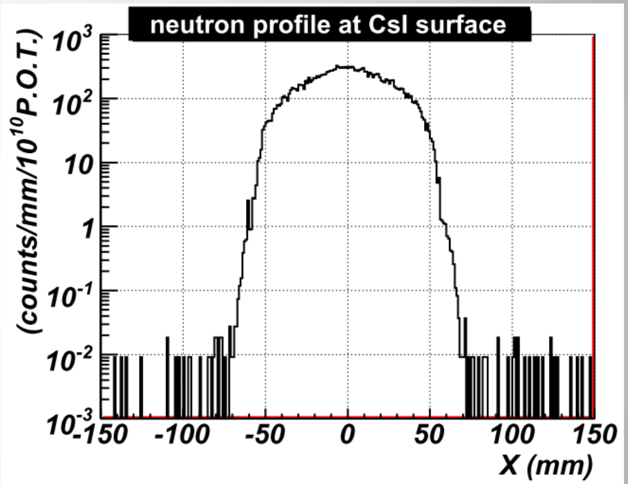
MC package	#KL
GEANT3	$(7.6\pm0.2)\times10^6$
GEANT4 (QGSP)	$(4.6\pm0.2)\times10^6$
GEANT4 (QBBC)	$(5.4\pm0.2)\times10^6$
FLUKA	$(16.6\pm0.2)\times10^6$

3.5 SM events
during 3 $X10^7$ s
with $2X10^{14}$ protons/spill

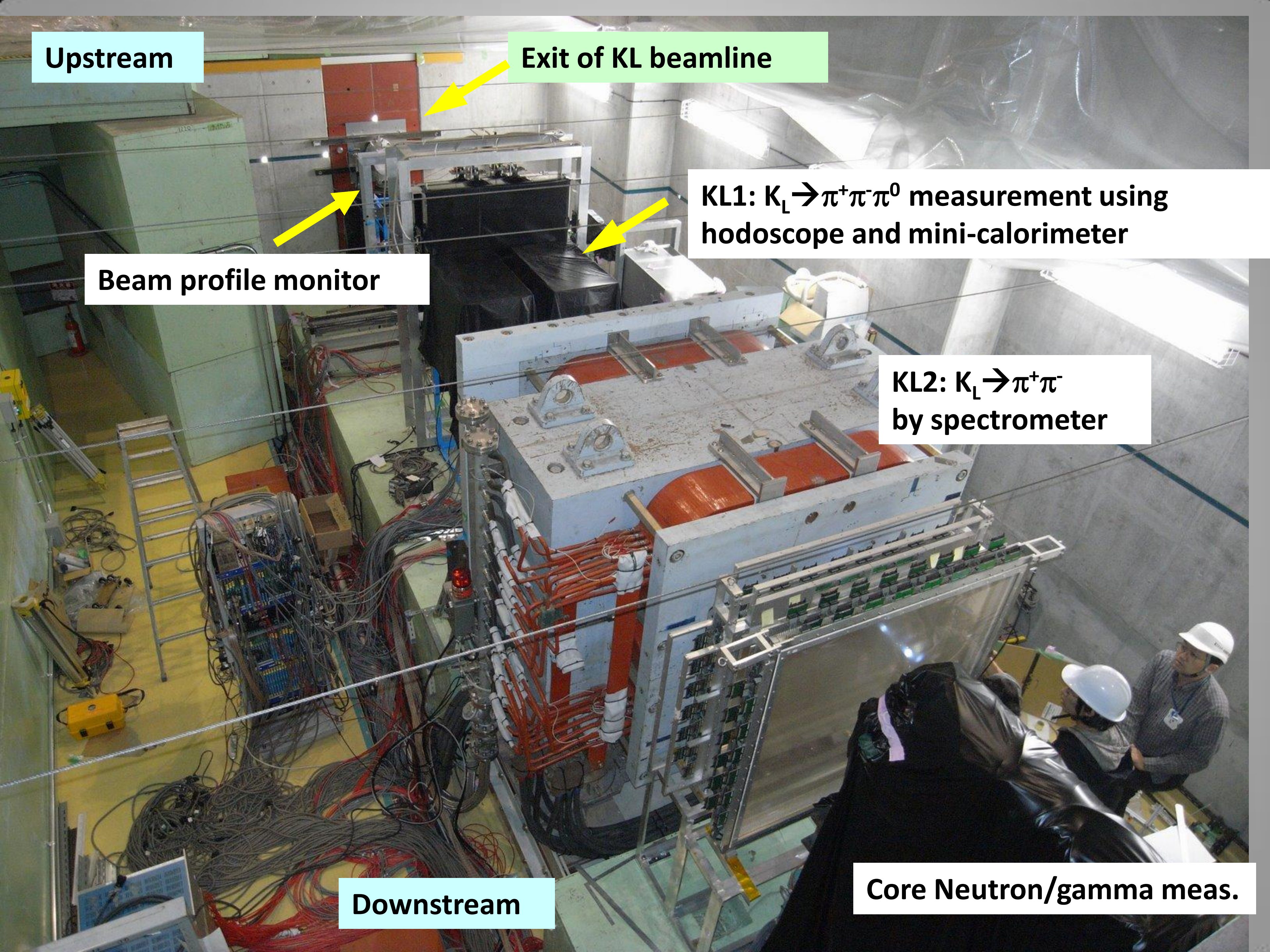
Reconstruction of KL decay
- two different methods

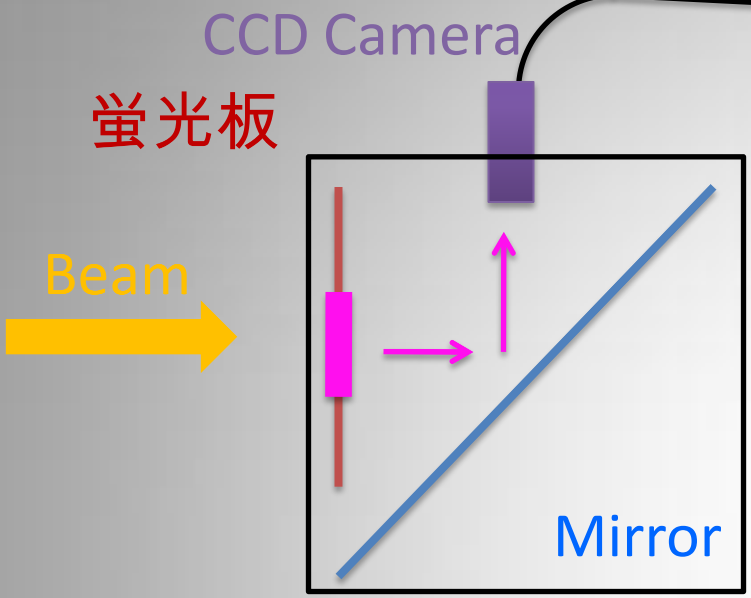
For background suppression

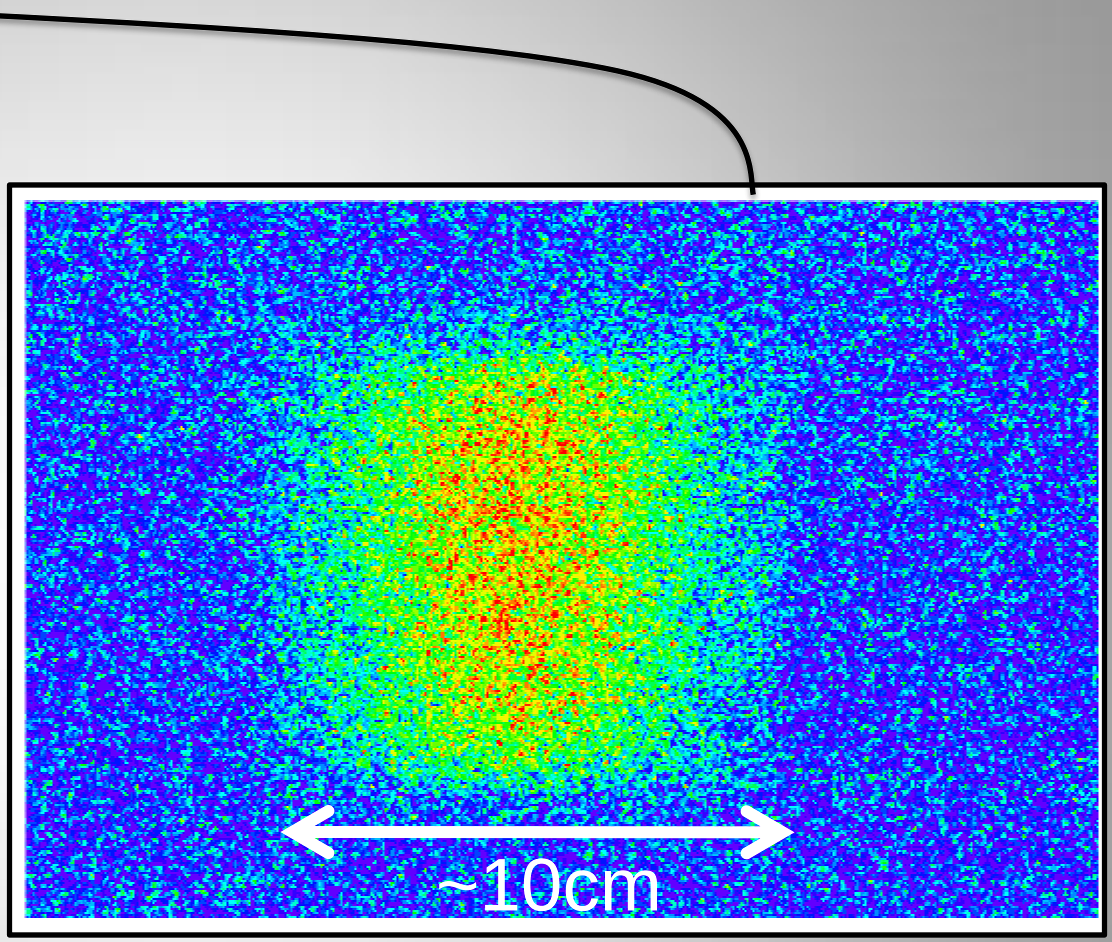
- Well collimated beam

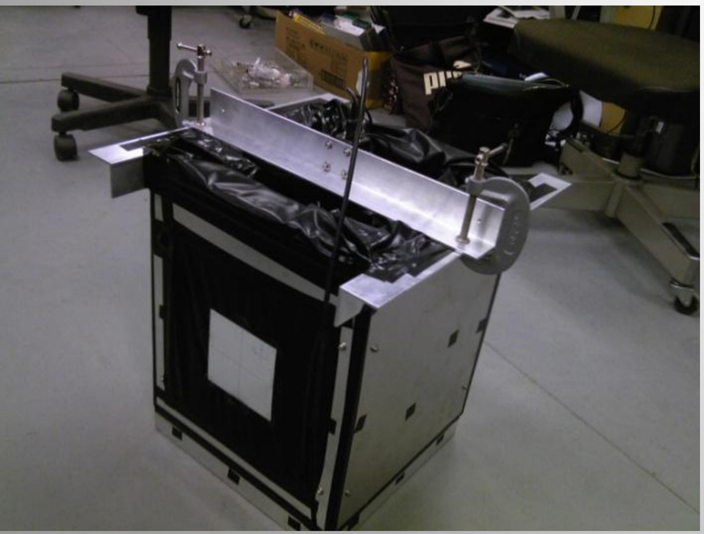


Neutron/gamma mixture
Needs several types of detectors
Response detector to n/γ
- Compare data to M.C. expectation

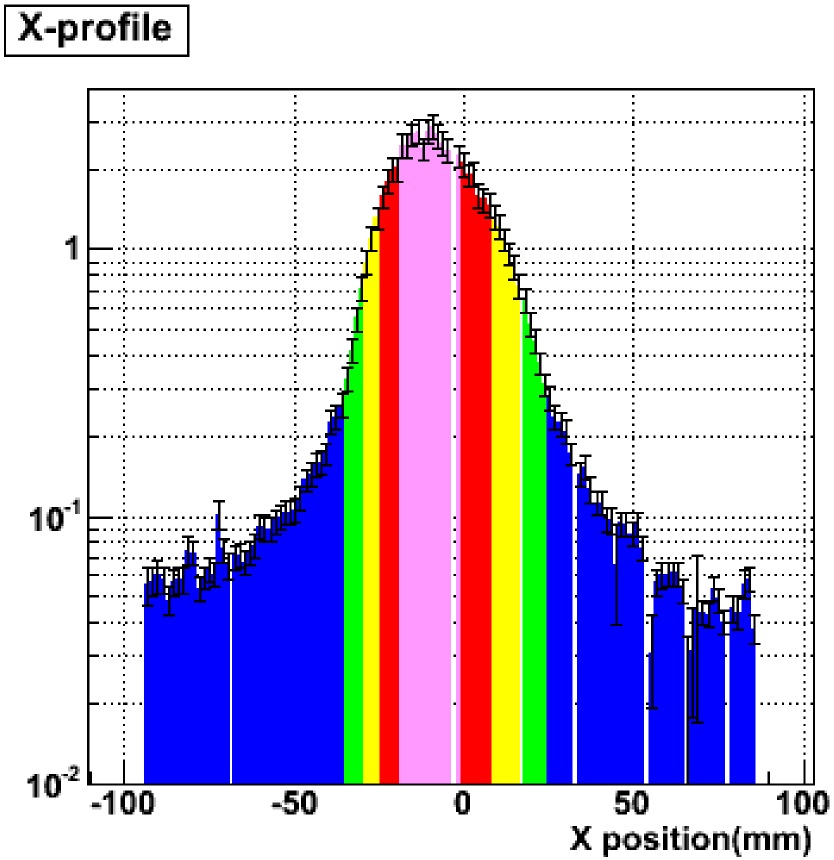

Upstream
Exit of KL beamline
KL1: $K_L \rightarrow \pi^+\pi^-\pi^0$ measurement using hodoscope and mini-calorimeter
Beam profile monitor
KL2: $K_L \rightarrow \pi^+\pi^-$ by spectrometer
Core Neutron/gamma meas.
Downstream


CCD Camera
蛍光板
Beam
Mirror


~10cm



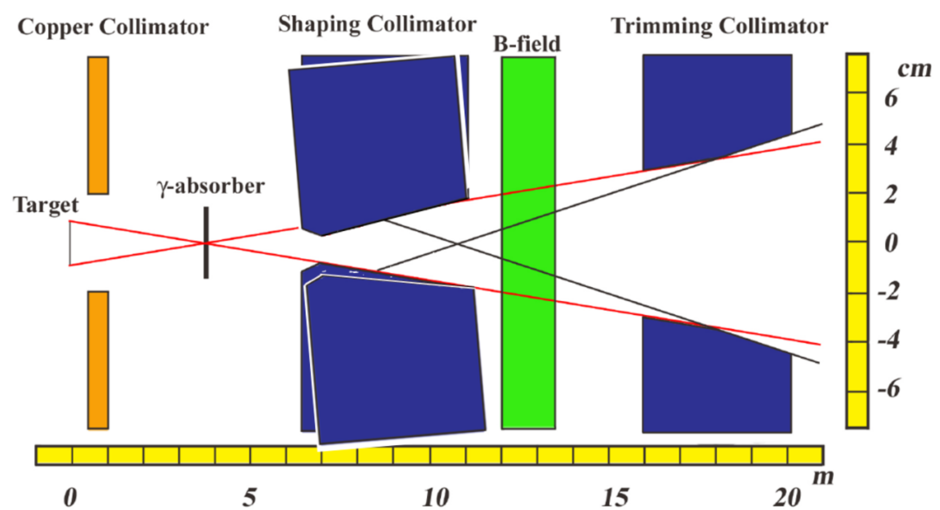
Online Profile Measurement



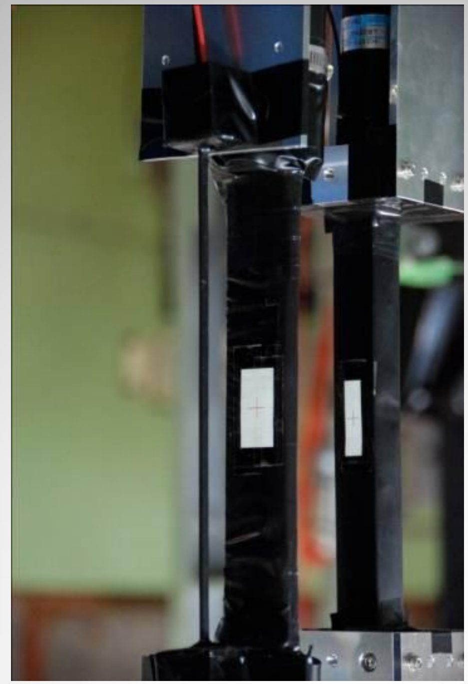
Total yield : 67.09

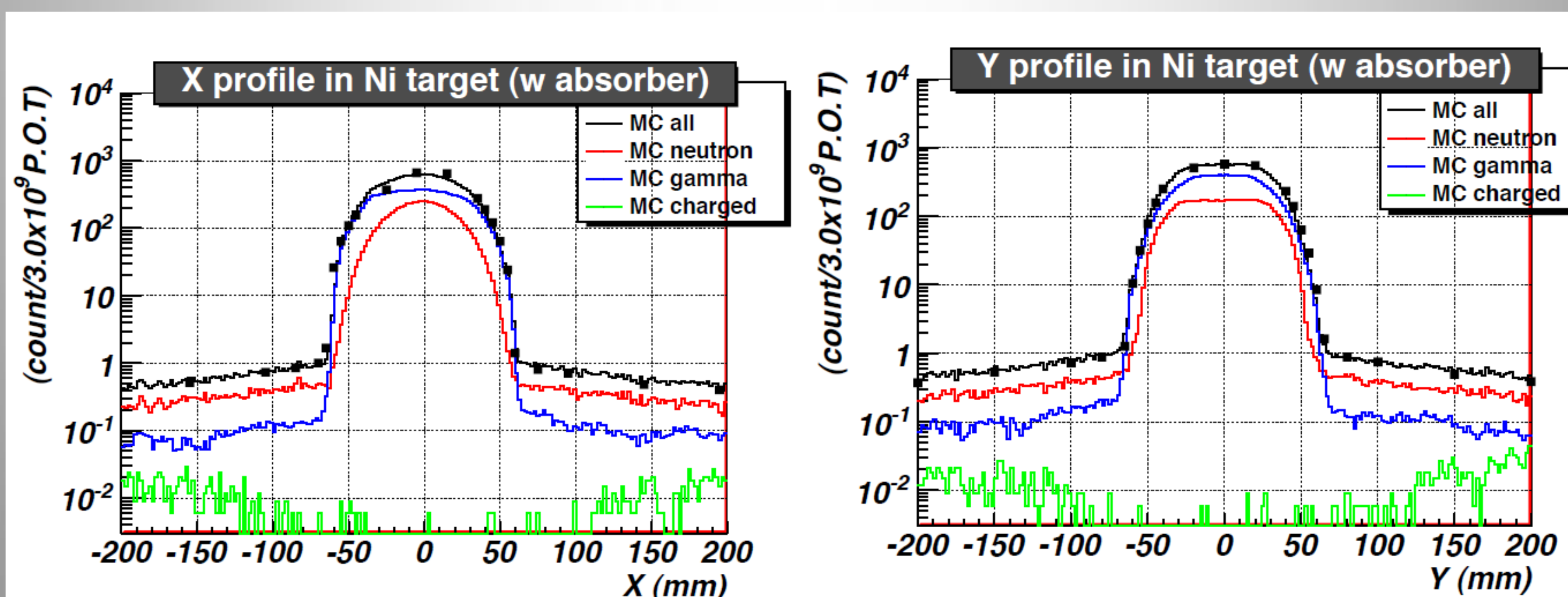
Core yield (75%) : 28.15
Edge (75%) : -18.75(mm) / -0.75(mm)
Center/Width (75%) : -9.75(mm) / 18.00(mm)

Core yield (50%) : 46.05
Edge (50%) : -24.75(mm) / 8.25(mm)
Center/Width (50%) : -8.25(mm) / 33.00(mm)



Beam Profile





Hodoscope + CsI

KL→$\pi^+\pi^-\pi^0$ Decay

Decay vertex from π^+ and π^-

(Hodoscpe)

π^0 reconstruction

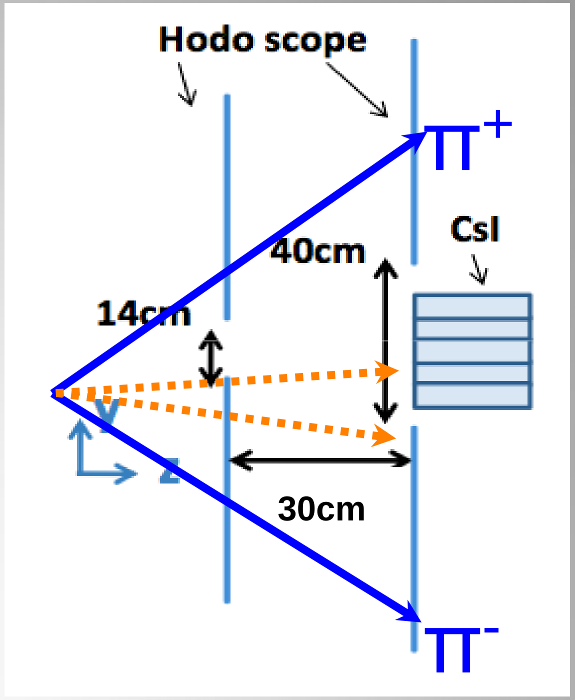
(CsI calorimeter)

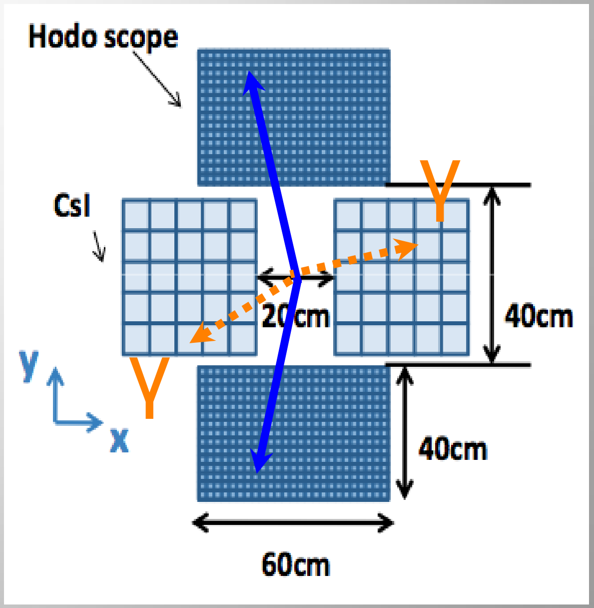
Pencil Beam (Null P_T)

$$p_x^+ + p_x^- + k_{1x} + k_{2x} = 0$$
$$p_y^+ + p_y^- + k_{1y} + k_{2y} = 0$$

KL Identification

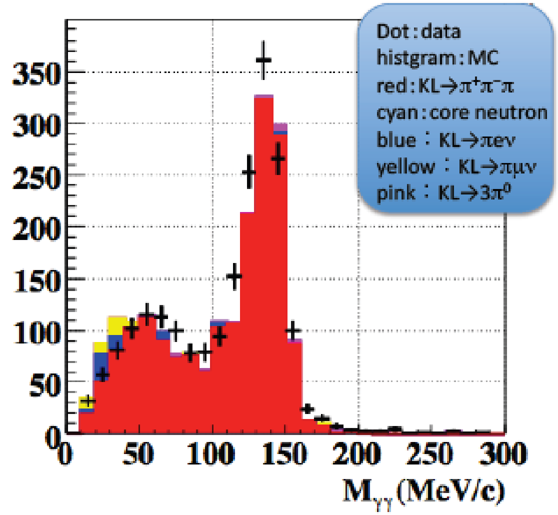
$M_{2\gamma}=M_\pi$、 $M_{\pi\pi\pi}=M_{KL}$



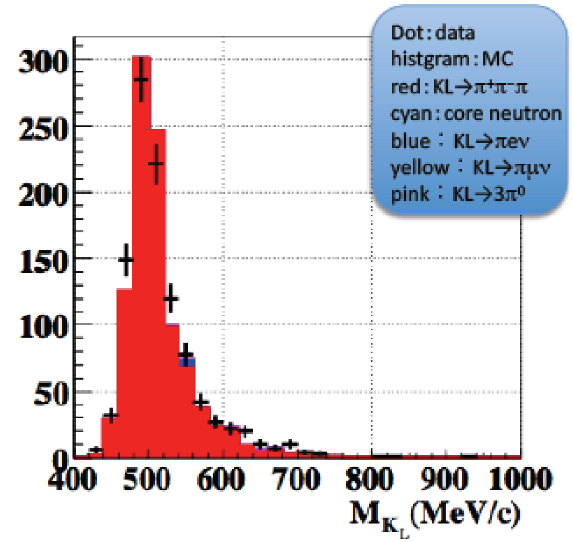


- 1258
  →$1.0\times10^{7}/2\times10^{14}$p.o.t.
- (Geant4)×1.3
- (Geant3)×0.8
- (FLUKA) ×0.4

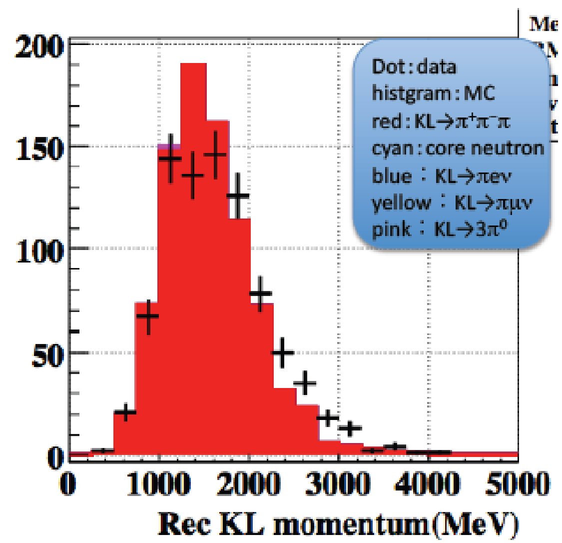
- $M\gamma\gamma$ plot



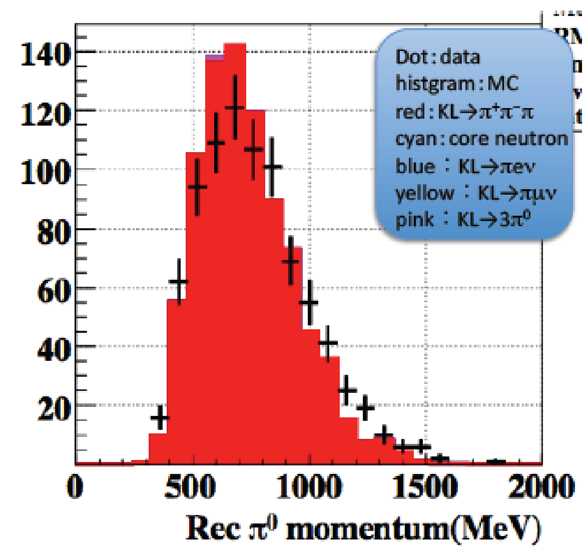
- M_{KL} plot



KL momentum distribition



- π^0 momentum distribition



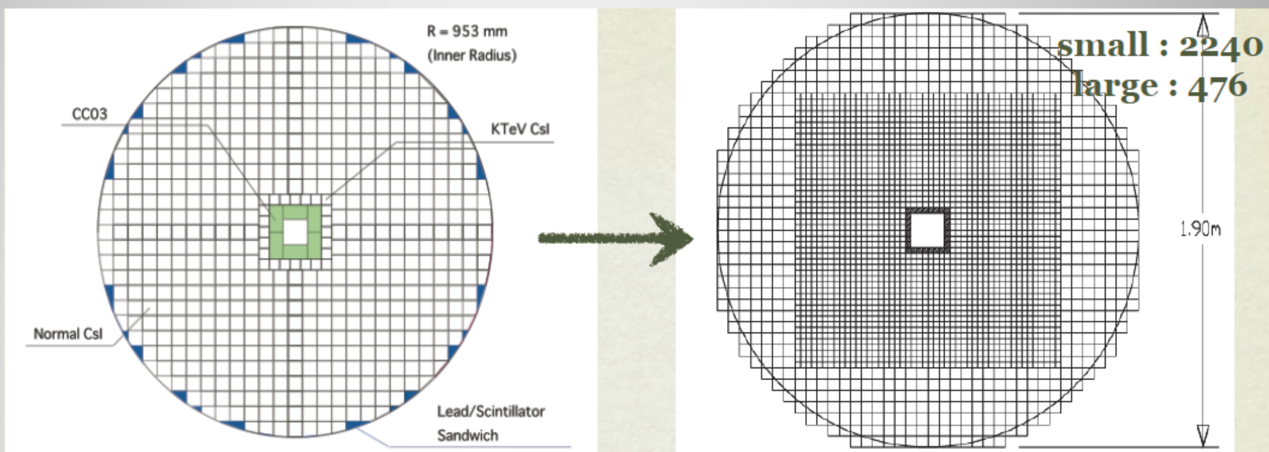
Calorimeter

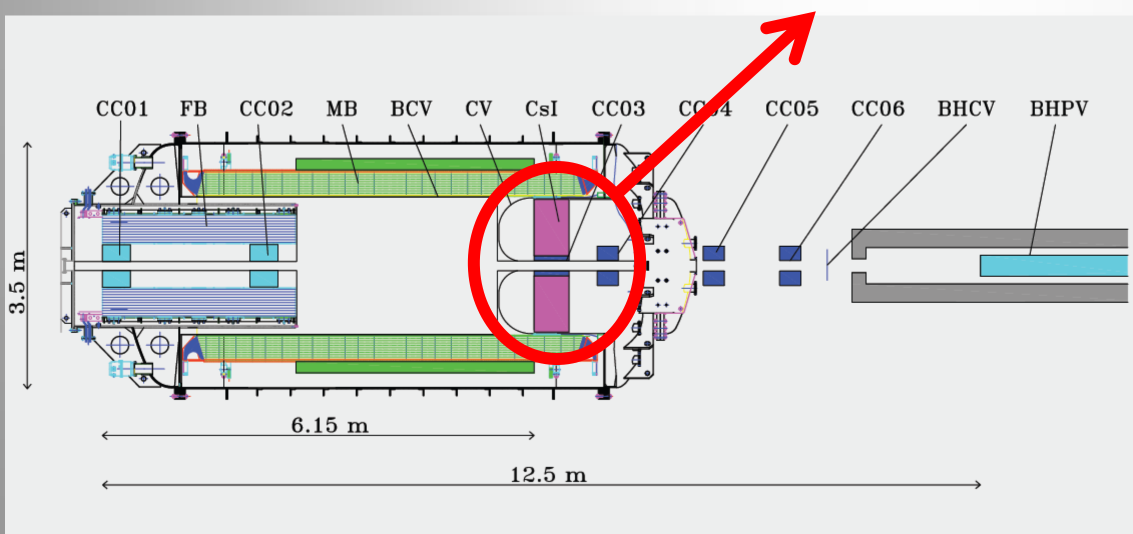
Finer segmented longer CsI crystals

7X7X30 cm^3 (16 X_0)

2.5X2.5X50 cm^3 (27 X_0)

5 X 5 X50 cm^3



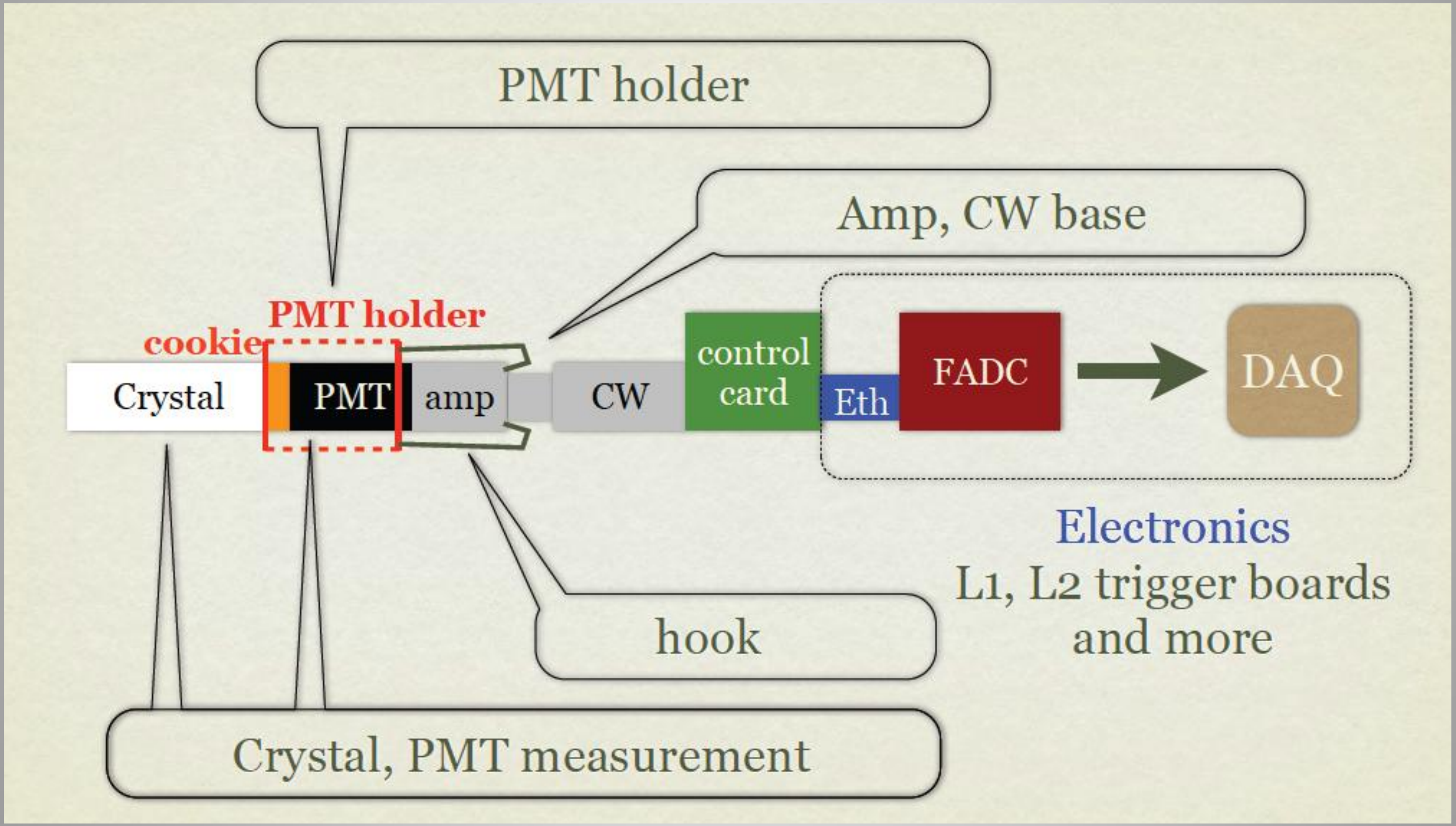


Negligible Punch-through

Better Energy resolution

Better shower shape

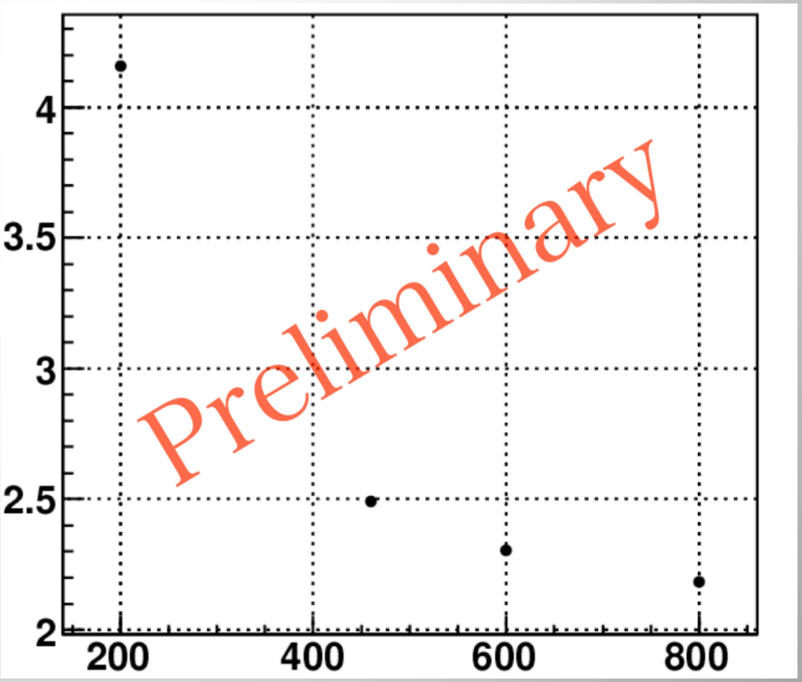
CsI Read-out



PMT holder
Amp, CW base
PMT holder
cookie
Crystal
PMT
amp
CW
control card
Eth
FADC
DAQ
Electronics
L1, L2 trigger boards and more
hook
Crystal, PMT measurement

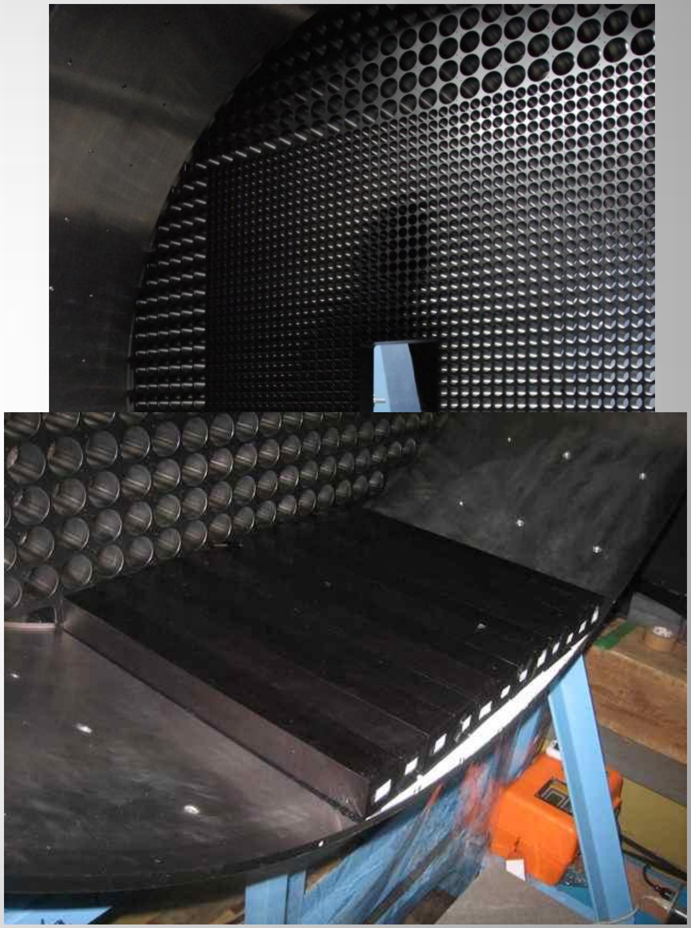
Sample test for CsI

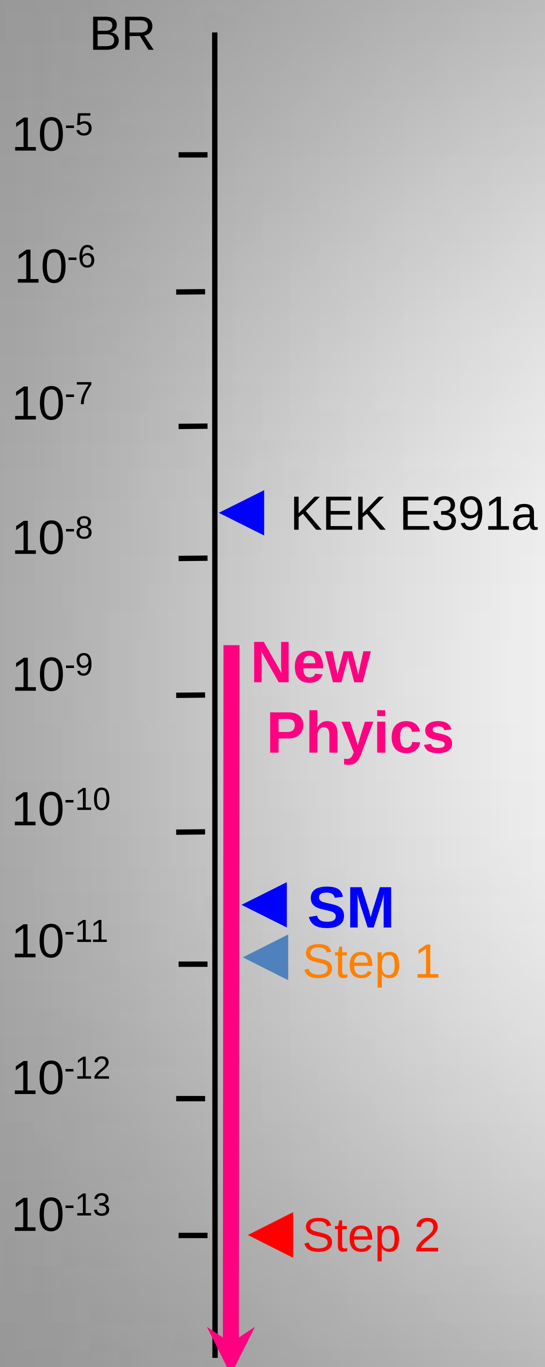
- 144 Channels are tested by positron beam
  - Performance test for complete set of read-out
  - CW-base, 125MHz FADC, Trigger board
  - Figure out problems, confirm no problem for stacking

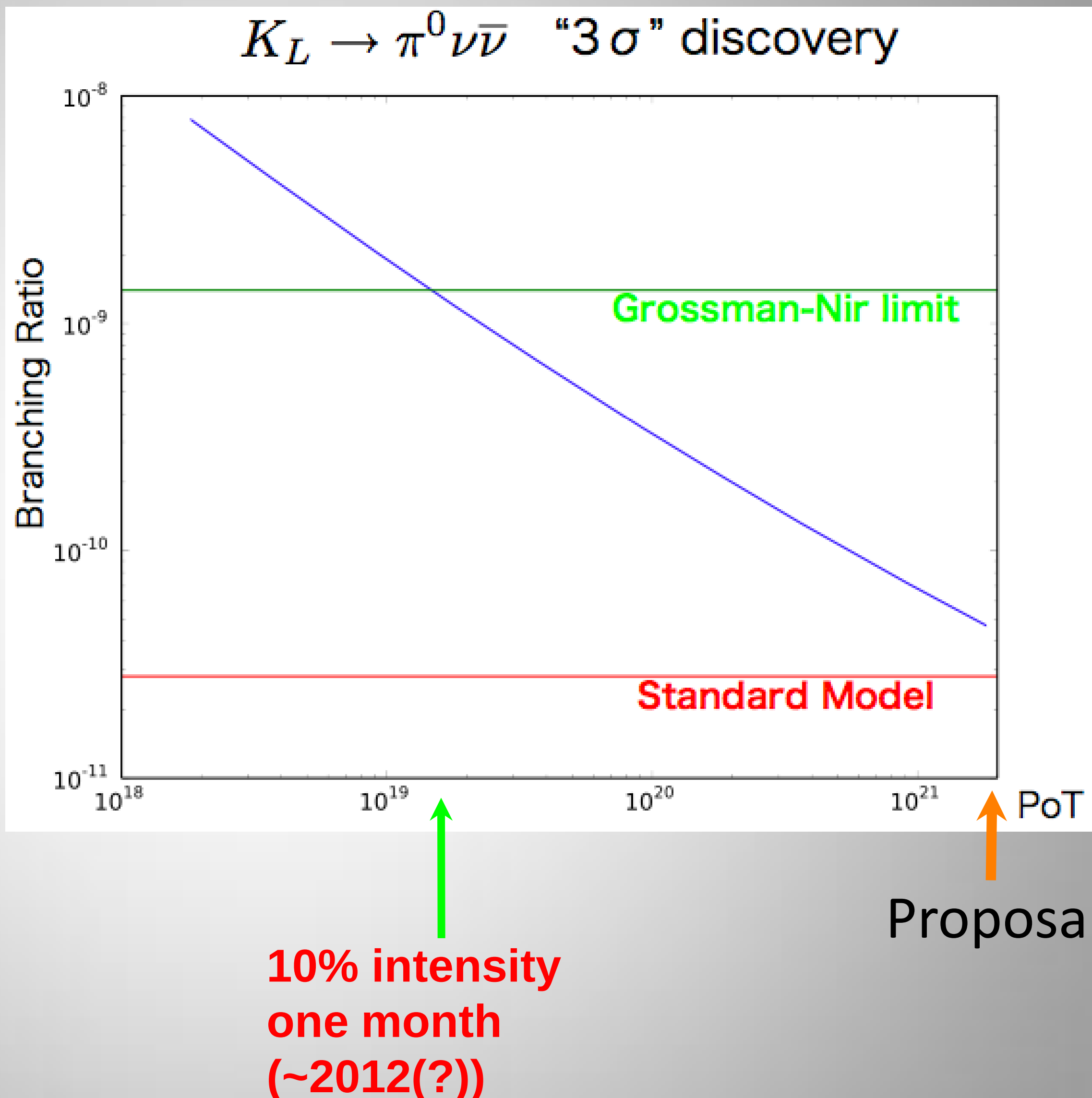


Calorimeter construction

- We built temp-humidity control room.
- Stacking will take ~ 4 months.
- We expect beam from middle of Oct., 2010.
- We will test over all test for calorimeter (Engineering run).
  - Whole read-out system
  - Calibration
  - Triggering/DAQ system




BR
10-5
10-6
10-7
KEK E391a
10-8
New
Phyics
10-9
10-10
SM
Step 1
10-11
10-12
Step 2
10-13


$K_L \to \pi^0 \nu\bar{\nu}$ "3 σ" discovery
Branching Ratio
Grossman-Nir limit
Standard Model
10-8
10-9
10-10
10-11
10^18
10^19
10^20
10^21
PoT
10% intensity
one month
(~2012(?))
Proposal

Summary

- J-PARC gradually move to operation stage.
- Two KAON experiments are preparing.
- TREK
  - Searching for T-violation using muon transverse polarization (P_T) in $K^+ \rightarrow \pi^0 \mu \nu$.
  - Beam line construction will be completed by this fall.
  - $\delta P_T \sim 10^{-4}$ with High intensity, detector system with good systematic control.
- KOTO
  - Aims at the first observation the $K_L \rightarrow \pi^0 \nu \nu$ decay.
  - Completed beam line construction in 2009.
  - Engineering run with newly constructing EM calorimeter on coming fall (2010).
  - Aims at the first physics run in 2011-2012.

Sensitivity

- 2E14 protons/3.3s x 3E7 sec

Background source	#evts
$K_L \to \pi^0\pi^0$	1.8
$K_L \to \pi^+\pi^-\pi^0$	0.46
n + residual gas	0.04
n + upstream veto	0.13
accidental coincidence	0.10
sum	2.5
$K_L \to \pi^0\nu\bar{\nu}$ signal	3.5