Results of the KOTO experiment at J-PARC

Flavor Physics Conference July 30th 2014

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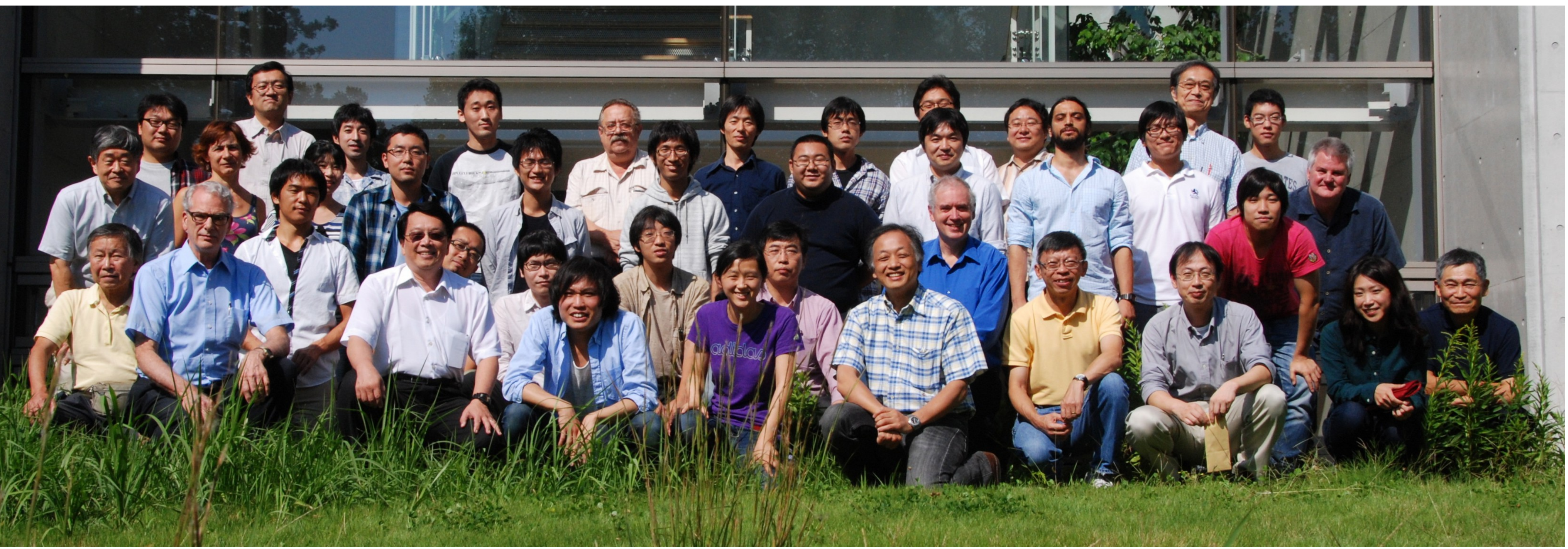
for the KOTO collaboration



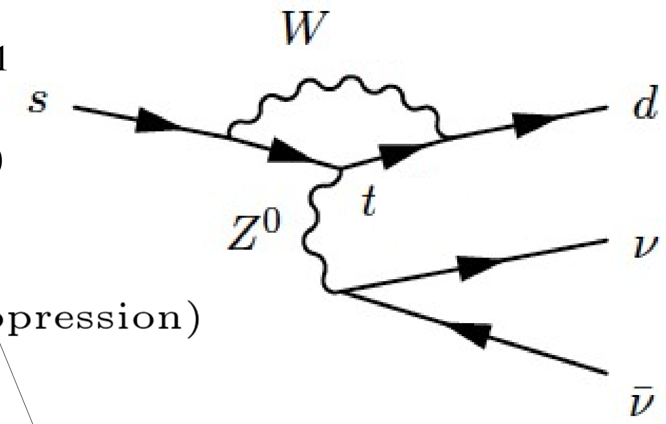
Arizona State, Chicago, Chonbuk, Jeju, JINR, KEK, Kyoto, Kyungpook, Michigan, NDA, NTU, Okayama, Osaka, Pusan, Saga, Yamagata

Contents

- KOTO took 1st physics run in May 2015.
  - Only 100 hours due to the accident in J-PARC Hadron Hall.
- Blind analysis is still on going. We will show the results soon. Not today.
- I will show
  - How we understand the detector performance
  - Detector/Accelerator plan
  - Expected sensitivity toward the future

$K_L \to \pi^0 \nu \nu$

- Rare FCNC process Br(SM)=$(2.4\pm0.4)\times10^{-11}$
  - GIM suppression for u, c (Only t contribution for this decay)
  - Hierarchical structure of CKM for t quark
- Small theoretical uncertainty (~2%)
  - Short distance (W,Z,t)
  - Ke3 hadron matrix element from data
- Direct CP violation



(λ^5 suppression)

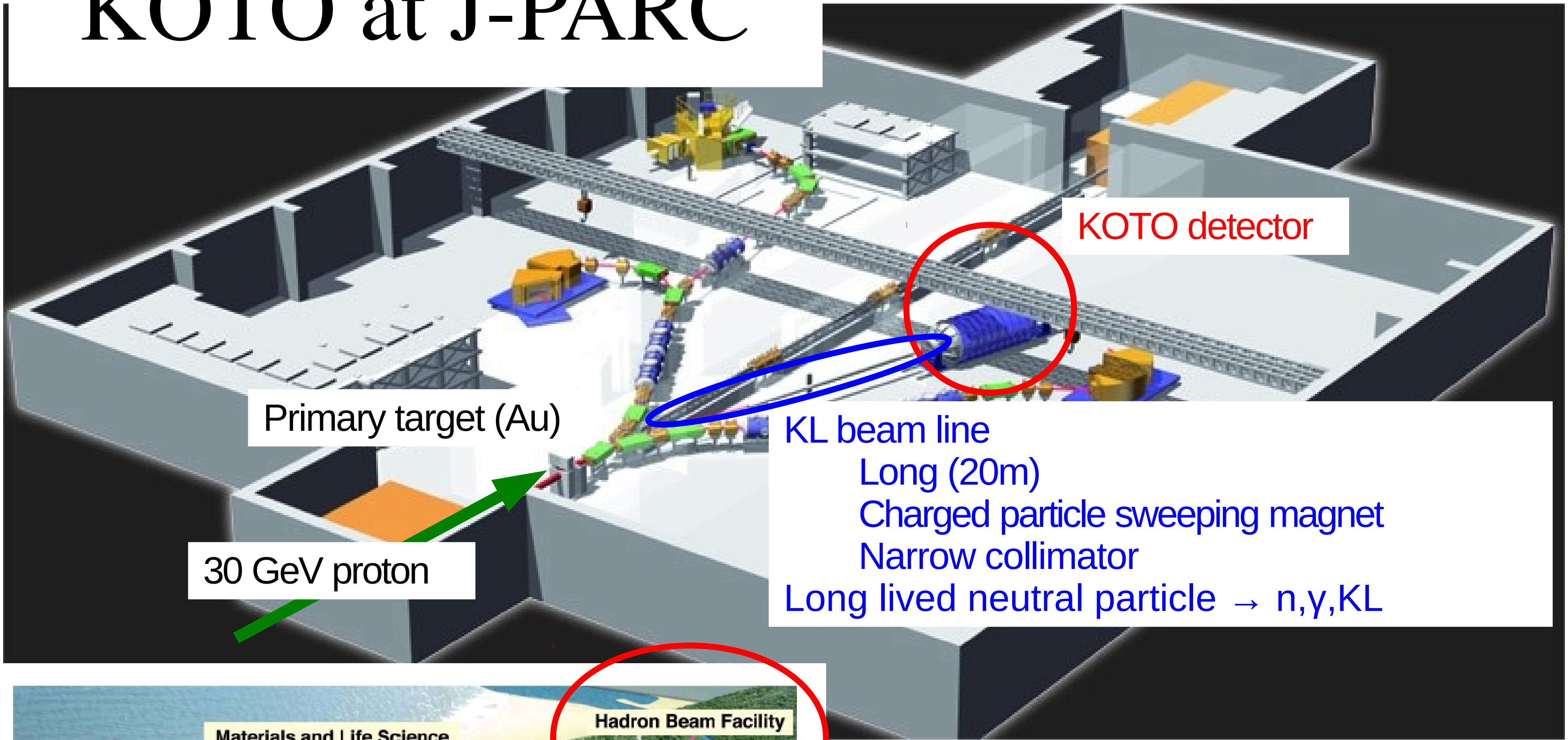
Sensitive to new physics which break flavor structure and add new CP-violation

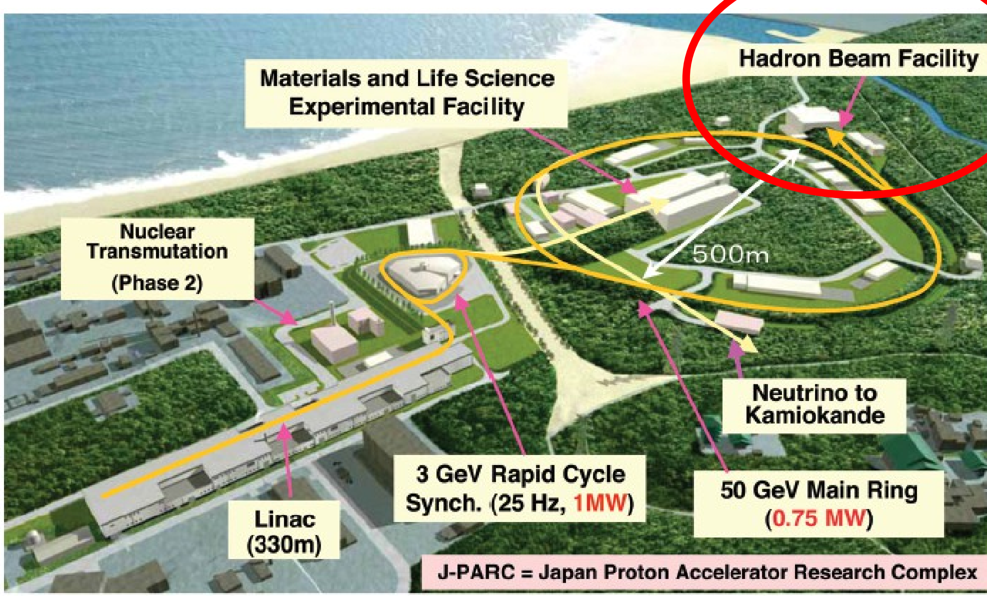
$$\mathcal{A}(K_L) \propto \mathcal{A}(K^0) - \mathcal{A}(\overline{K_0}) \propto \mathrm{Im}(\mathcal{A}_{s\to d}) \propto \eta \quad \text{(in the SM)}$$

	d	s	b
u	1	λ	$\lambda^3(\rho - i\eta)$
c	$-\lambda$	1	λ^2
t	$\lambda^3(1-\rho-i\eta)$	$-\lambda^2$	1

$\lambda \sim 0.23$

KOTO at J-PARC

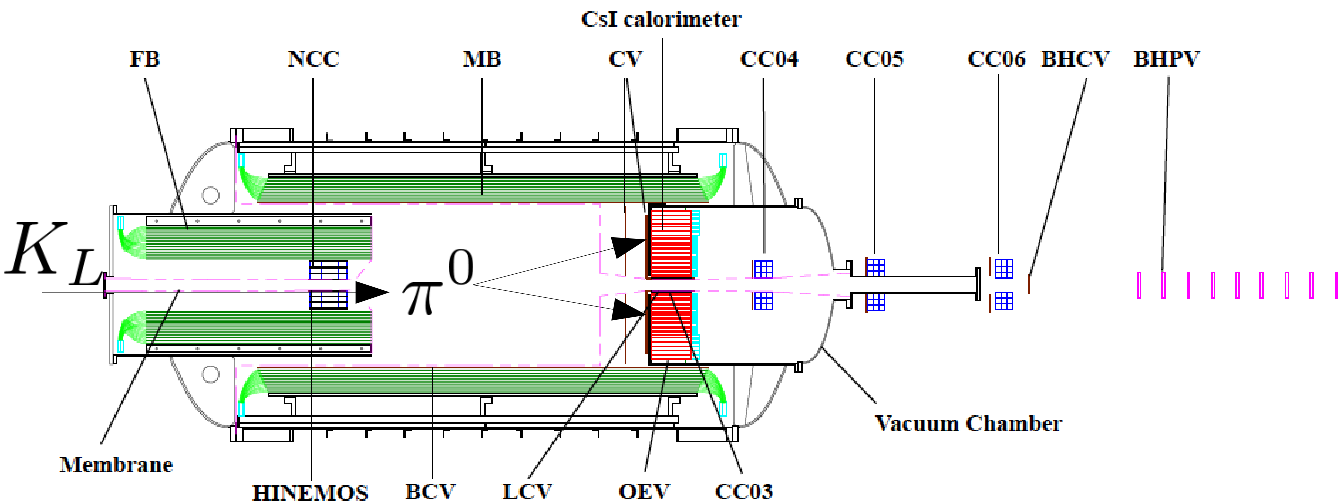


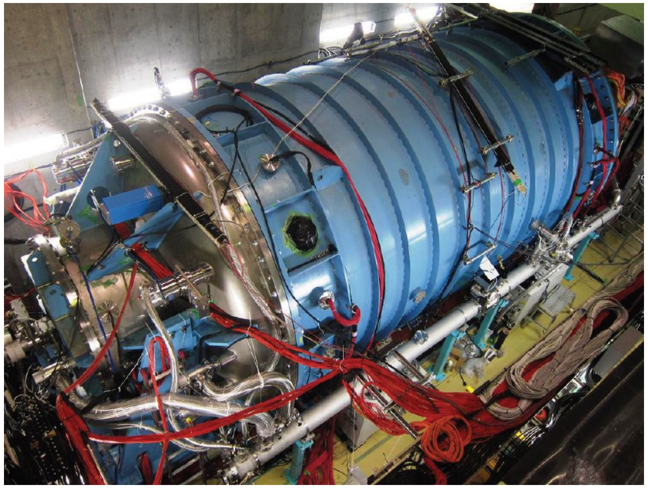


High intensity proton beam (30GeV)
Slow extraction
24kW(2013) → 100kW

KOTO detector

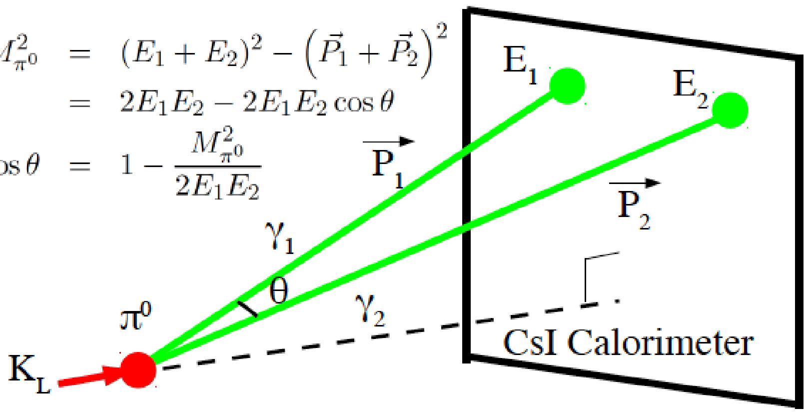
"Two γ from π^0 and nothing else" CsI calorimeter and Hermetic veto





$$M_{\pi^0}^2 = (E_1+E_2)^2 - \left(\vec{P}_1+\vec{P}_2\right)^2 = 2E_1E_2 - 2E_1E_2\cos\theta$$

$$\cos\theta = 1 - \frac{M_{\pi^0}^2}{2E_1E_2}$$



π^0 with high P_T discriminate $K_L \to 2\gamma$

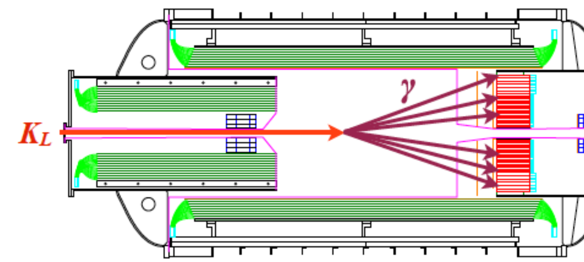
Other K decays have
charged or γ more than two

Decay Modes	Branching Fraction
$K_L \to \pi^0\nu\bar{\nu}$	$(2.4 \pm 0.4) \times 10^{-11}$
$K_L \to \pi^\pm e^\mp \nu$	(40.55 ± 0.11) %
$K_L \to \pi^\pm \mu^\mp \nu$	(27.04 ± 0.07) %
$K_L \to 3\pi^0$	(19.52 ± 0.12) %
$K_L \to \pi^+\pi^-\pi^0$	(12.54 ± 0.05) %
$K_L \to 2\pi^0$	$(8.64 \pm 0.06) \times 10^{-4}$
$K_L \to 2\gamma$	$(5.47 \pm 0.04) \times 10^{-4}$

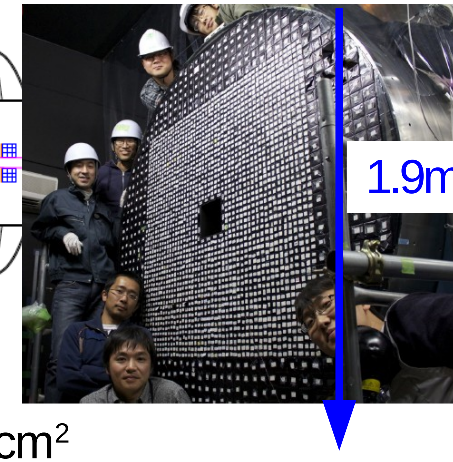
"Veto almost everything" experiment

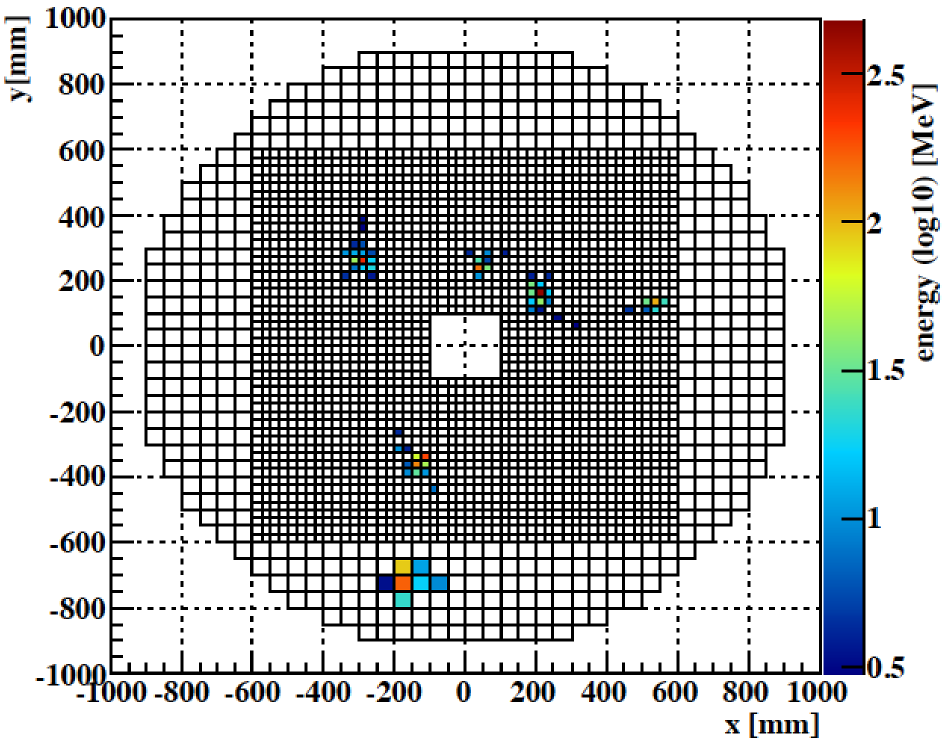
Calorimeter performance

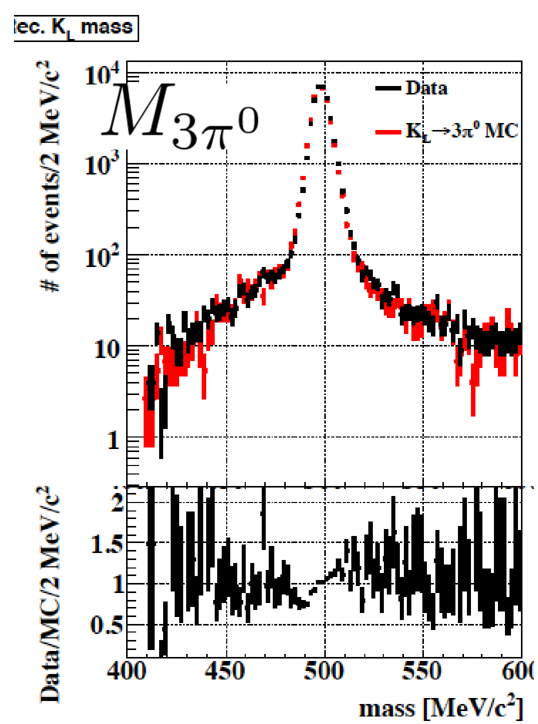
- 6 cluster sample
  - π^0 reconstruction
  - Calorimeter resolution
    - Tuned MC: $\frac{\sigma}{E} = \frac{1.9}{\sqrt{E(\mathrm{GeV})}} \oplus 0.6\%$

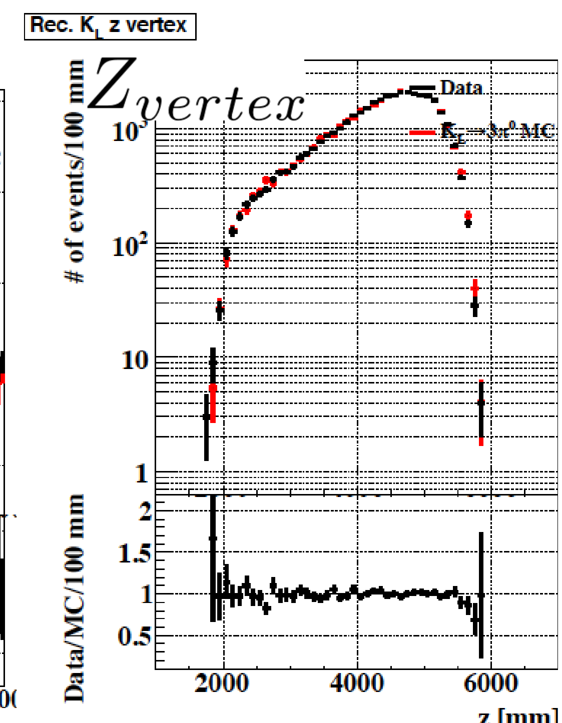


2716 Undoped CsI
50 cm in length
2.5x2.5 or 5x5 cm^2



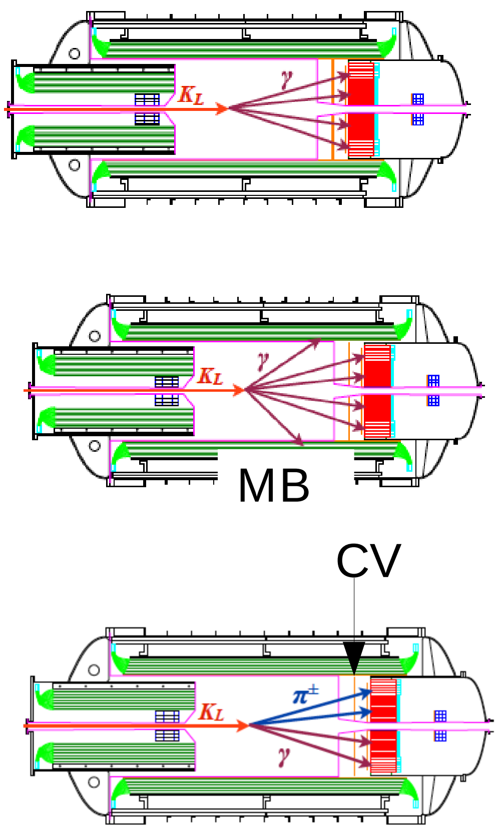


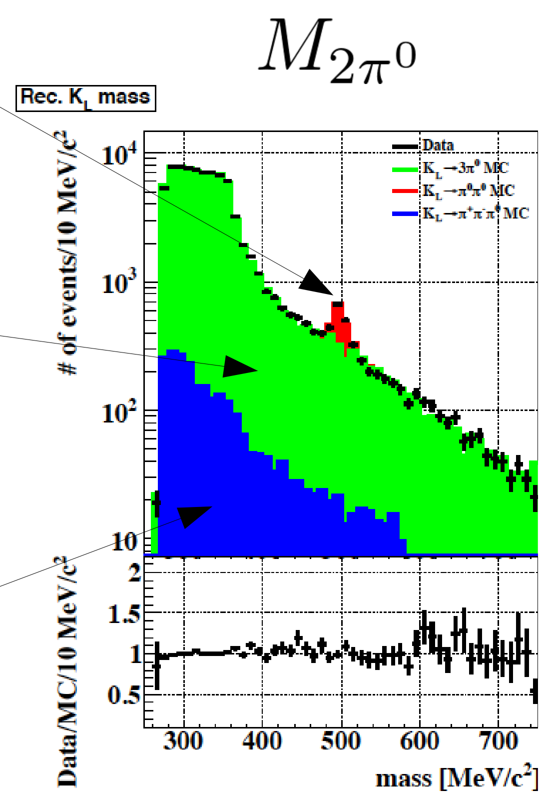




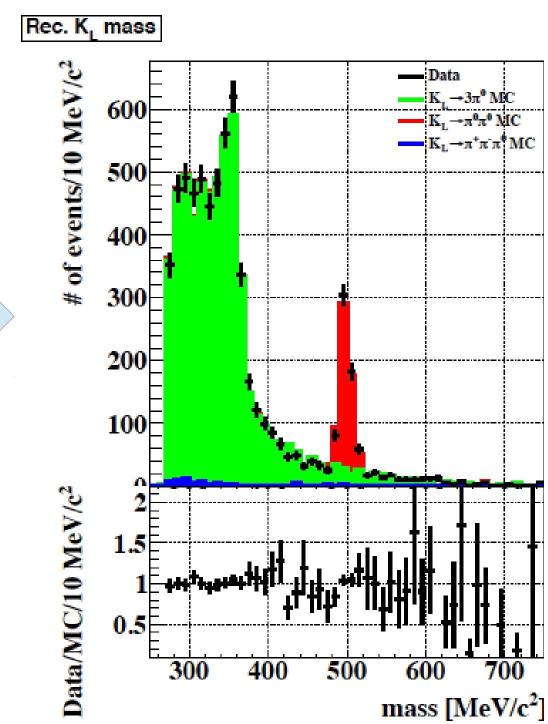
Veto performance (1)

- Four cluster sample
  - Charged veto (CV) and Barrel photon veto (MB)
  - We understood the veto performance as expected.





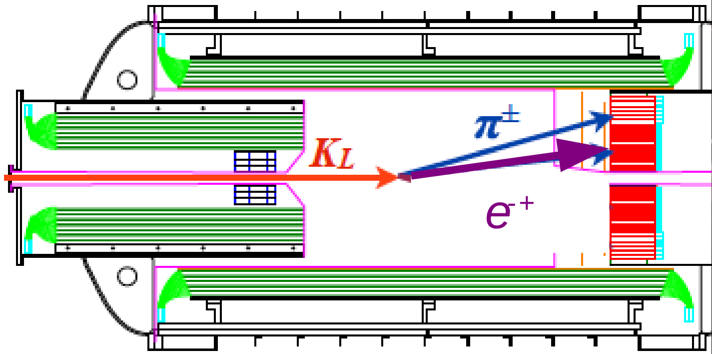
Apply
MB veto
CV veto

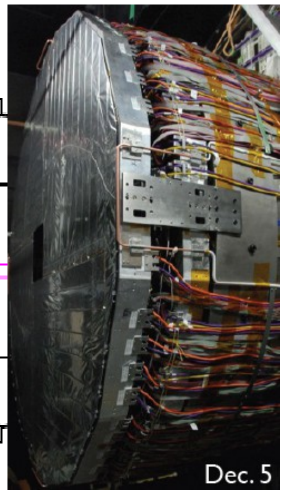


Veto performance (2)

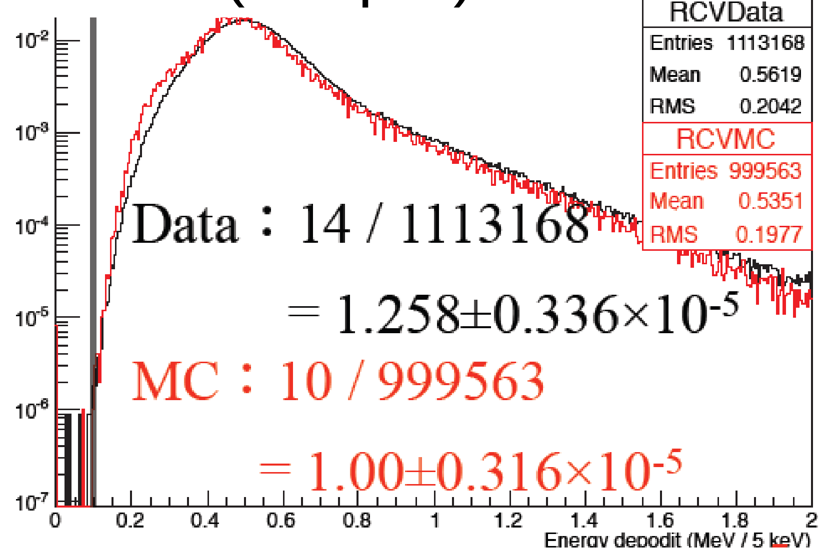
- Special study with a tracking system in 2012.
  - Single charged particle
    - Track with drift chambers upstream of CV
    - Require calorimeter hit downstream of CV
  - Inefficiency < $2x10^{-5}$ for single layer
    - Two layers of 3mm thick plastic scintillator with WLS fiber readout
    - High light yield with MPPC ($3x3mm^2$)

10^3 is required to reduce Ke3 background





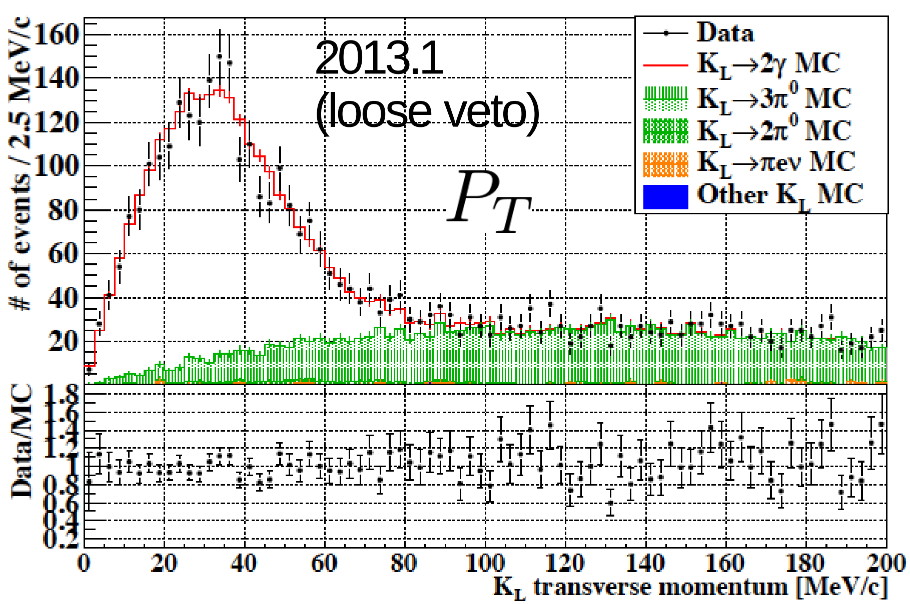
Energy deposit in CV

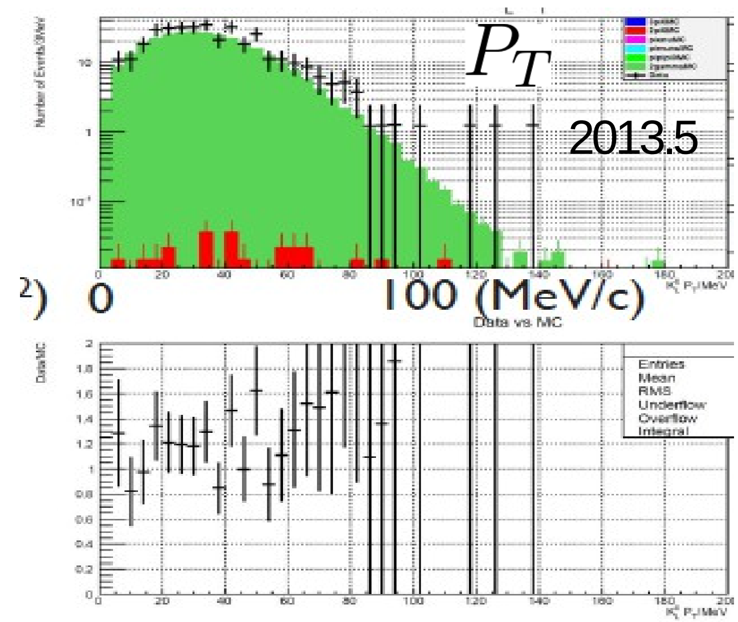


P_T reconstruction

- Two cluster sample → Reconstruct K_L assuming
  - K_L mass
  - Vertex on Z axis

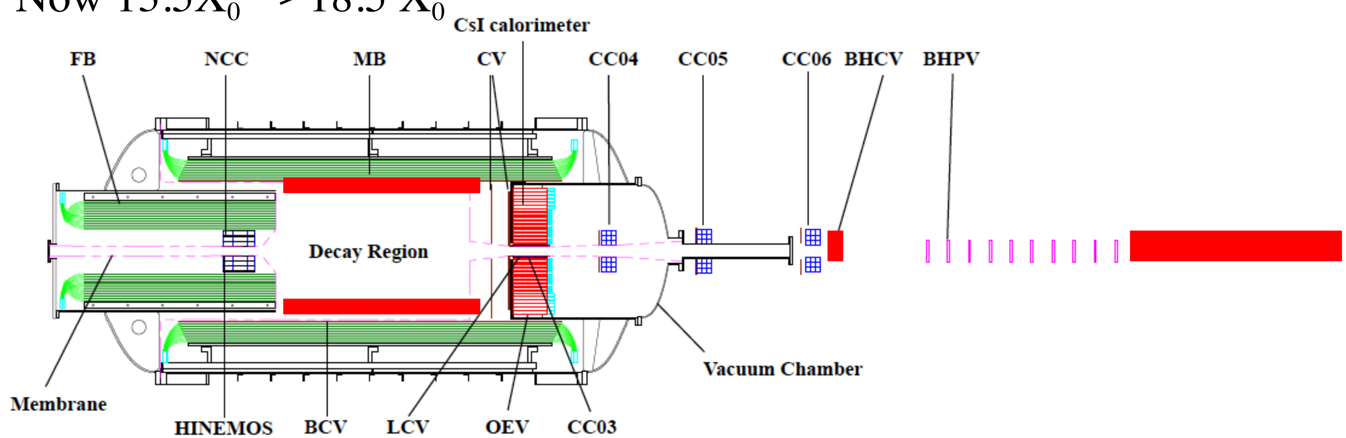
  for $K_L \rightarrow$ 2 gamma
- Understanding of the collimated beam and gamma measurement with the calorimeter.
- Veto detector performance is also as expected.





Detector staging / upgrading

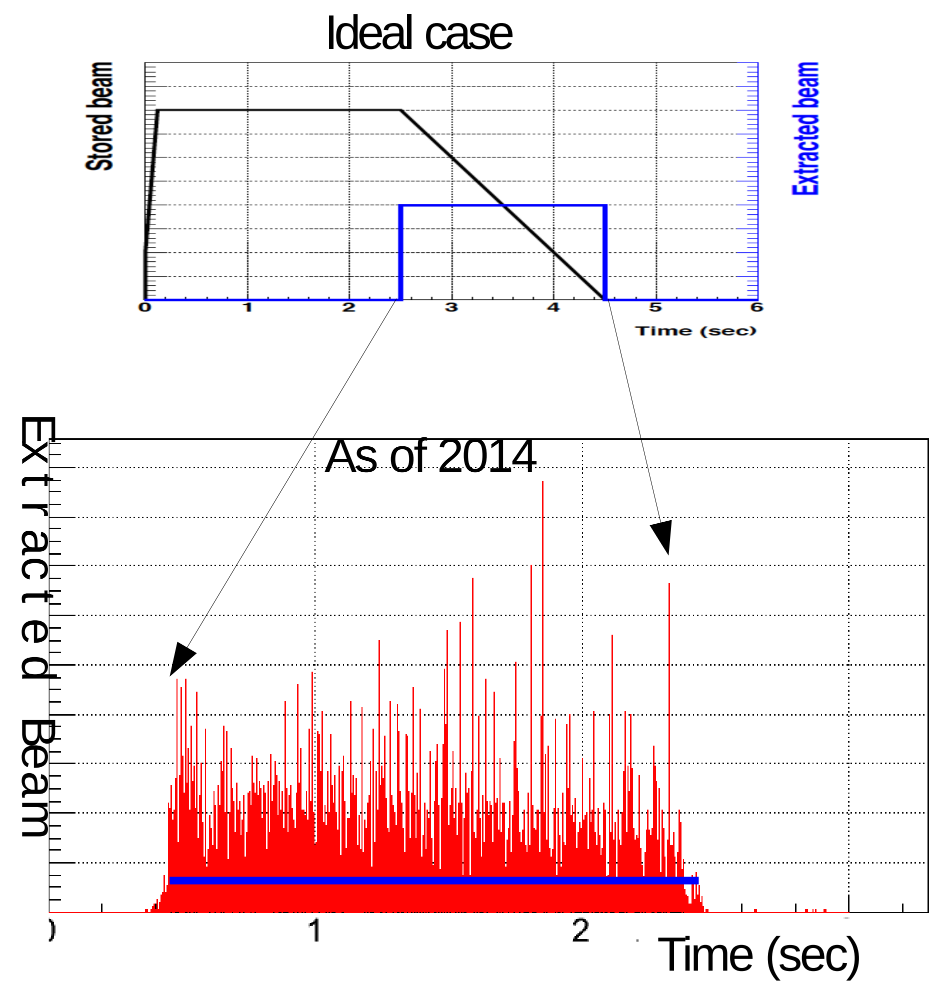
- In-beam charged veto (BHCV)
  - 3mm-thick plastic scintillator → ~3mm-thick wire chamber (2014).
  - Reduce accidental hits in-beam gamma and neutron
    - Now 6MHz hit rate (maximum in KOTO)
- In-beam photon veto (BHPV)
  - Lead-aerogel sandwich Cerenkov counter. (insensitive to neutron)
  - Increase the depth along the beam axis to reduce punch-through inefficiency
    - Now $4X_0$ (4% in efficiency) → $5.4X_0$(1.5% in efficiency) (2014) → $9X_0$ for the final design
- Barrel photon veto (MB) (Summer 2015)
  - Lead-plastic scintillator sandwich
  - Increase the depth to reduce punch-though inefficiency
    - Now $13.5X_0$ → $18.5\ X_0$

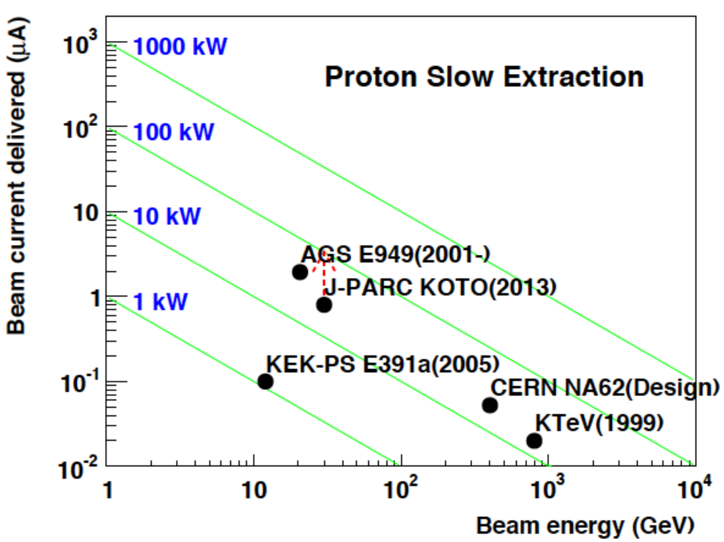


J-PARC Slow Extraction

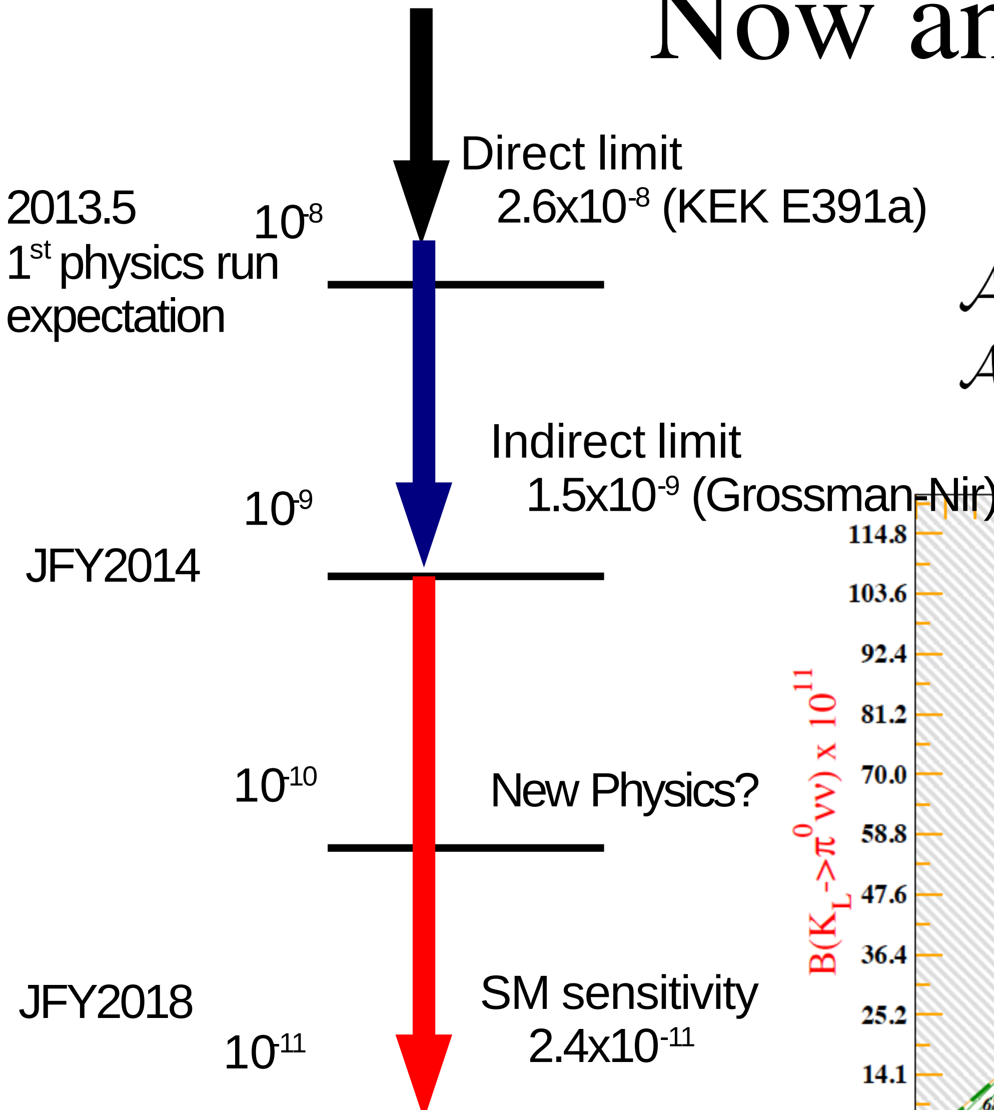
- Power in 2013 : 24kW → 100kW planed in 2017
- Duty : 2sec/6sec
- Duty in spill : ½
  - High accidental rate (x2)

  → trying to reduce

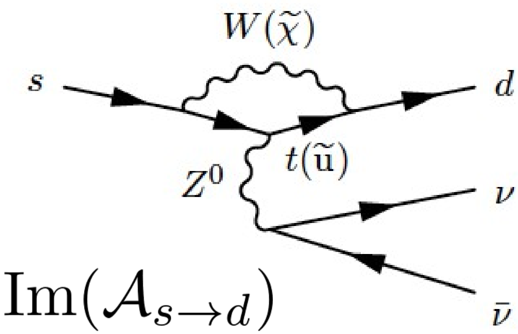




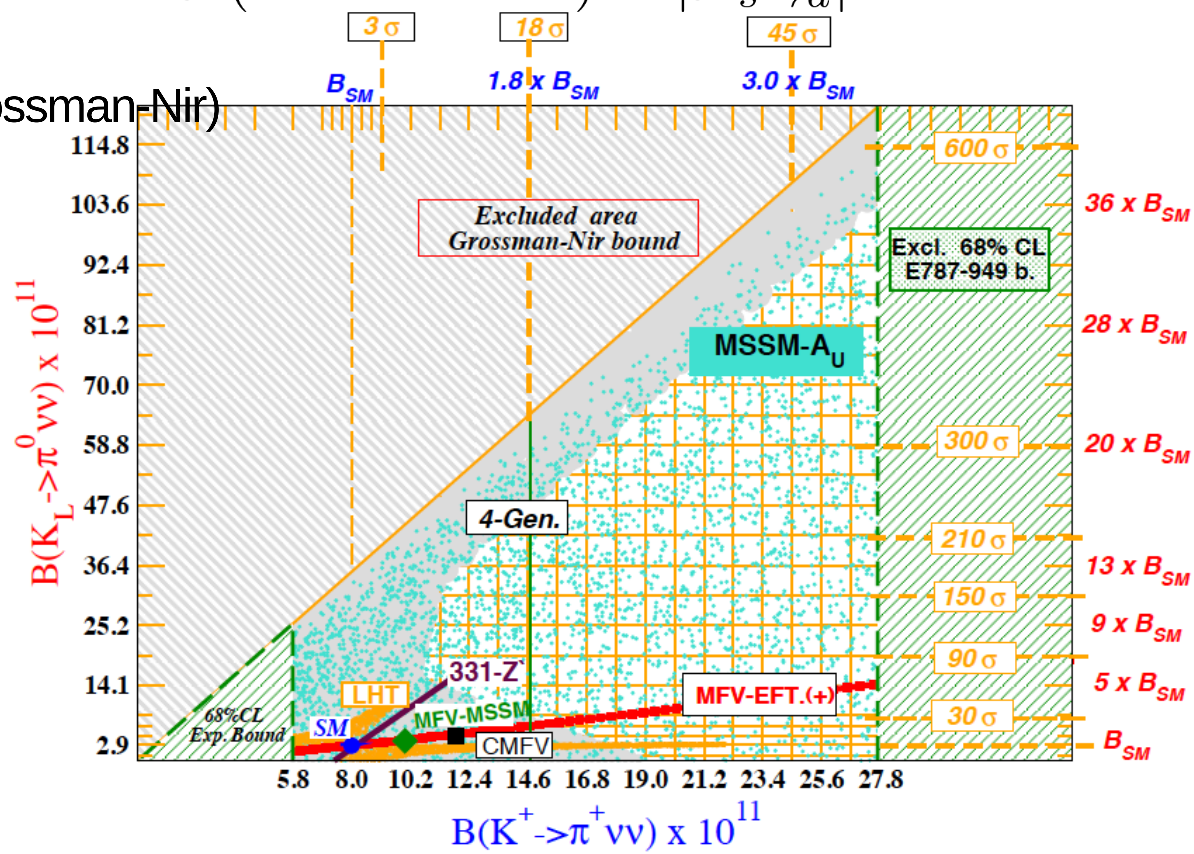
Now and Future



O(100) SM events or more
in KOTO Step-2 plan



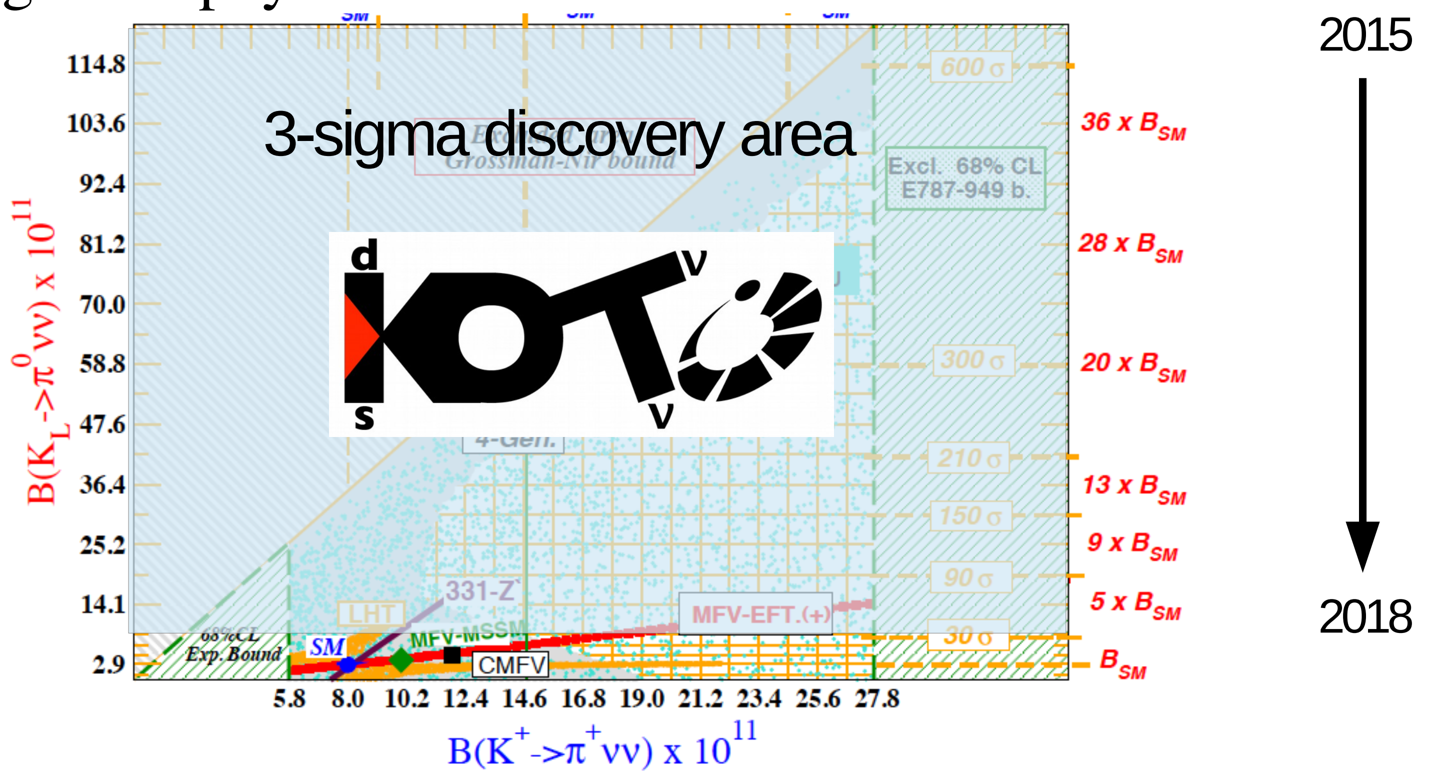
$$\mathcal{A}(K_L \to \pi^0 \nu\nu) \propto \mathrm{Im}(\mathcal{A}_{s\to d})$$
$$\mathcal{A}(K^+ \to \pi^+ \nu\nu) \propto |\mathcal{A}_{s\to d}|$$



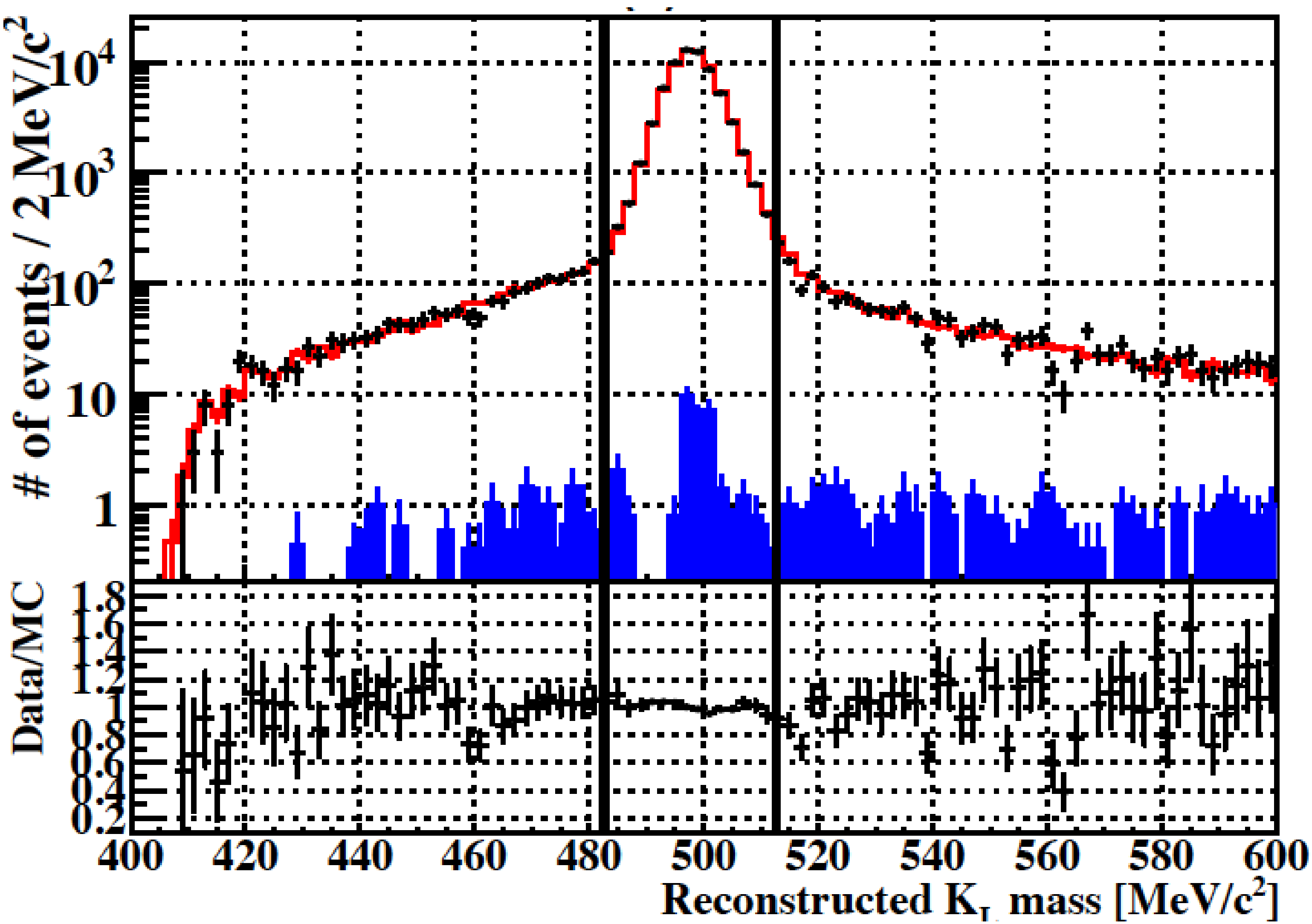
Summary

- Blind analysis for 1st Physics run → coming soon
  - Calorimeter and veto performances are well understood.
- Next run will be started in early 2015

  → beyond the Grossman-Nir bound.
- Detector staging/upgrade is on going.
- Explore large new physics area with accelerator efforts.



backup



# of events / 2 MeV/c²
10⁴
10³
10²
10
1
Data/MC
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
400
420
440
460
480
500
520
540
560
580
600
Reconstructed K_L mass [MeV/c²]

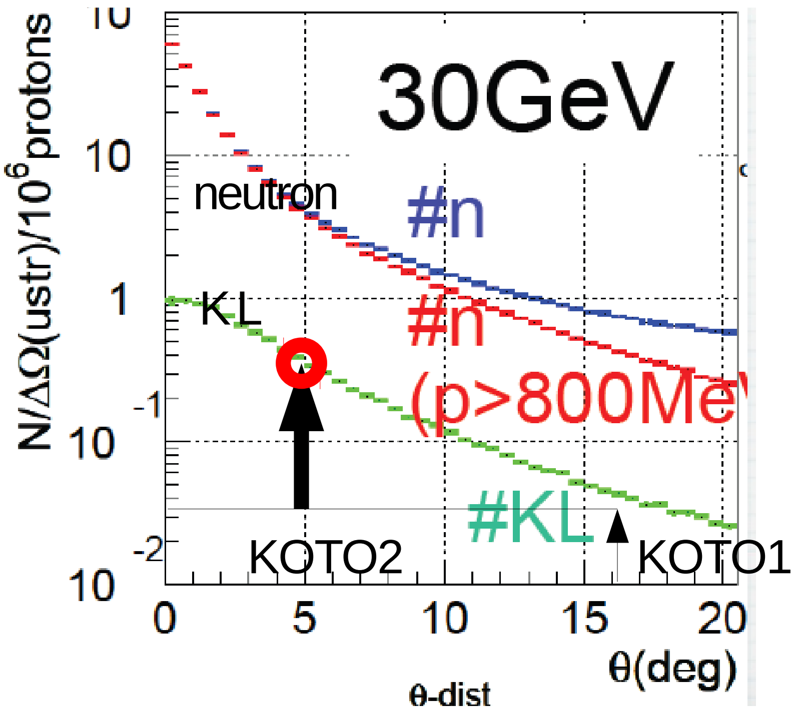
Accident at J-PARC Hadron Hall on May 23, 2013

* Malfunction of a magnet for slow extraction caused a very short beam to the hall.
  - In usual (as of May 2013): 3×10^{13} protons/2 sec.
  - On accident: ~2×10^{13} protons/5 msec.
* This made a damage on the common Au target.
* A part of radioactivities from the damaged target was leaked to the hall and the outside of the hall.

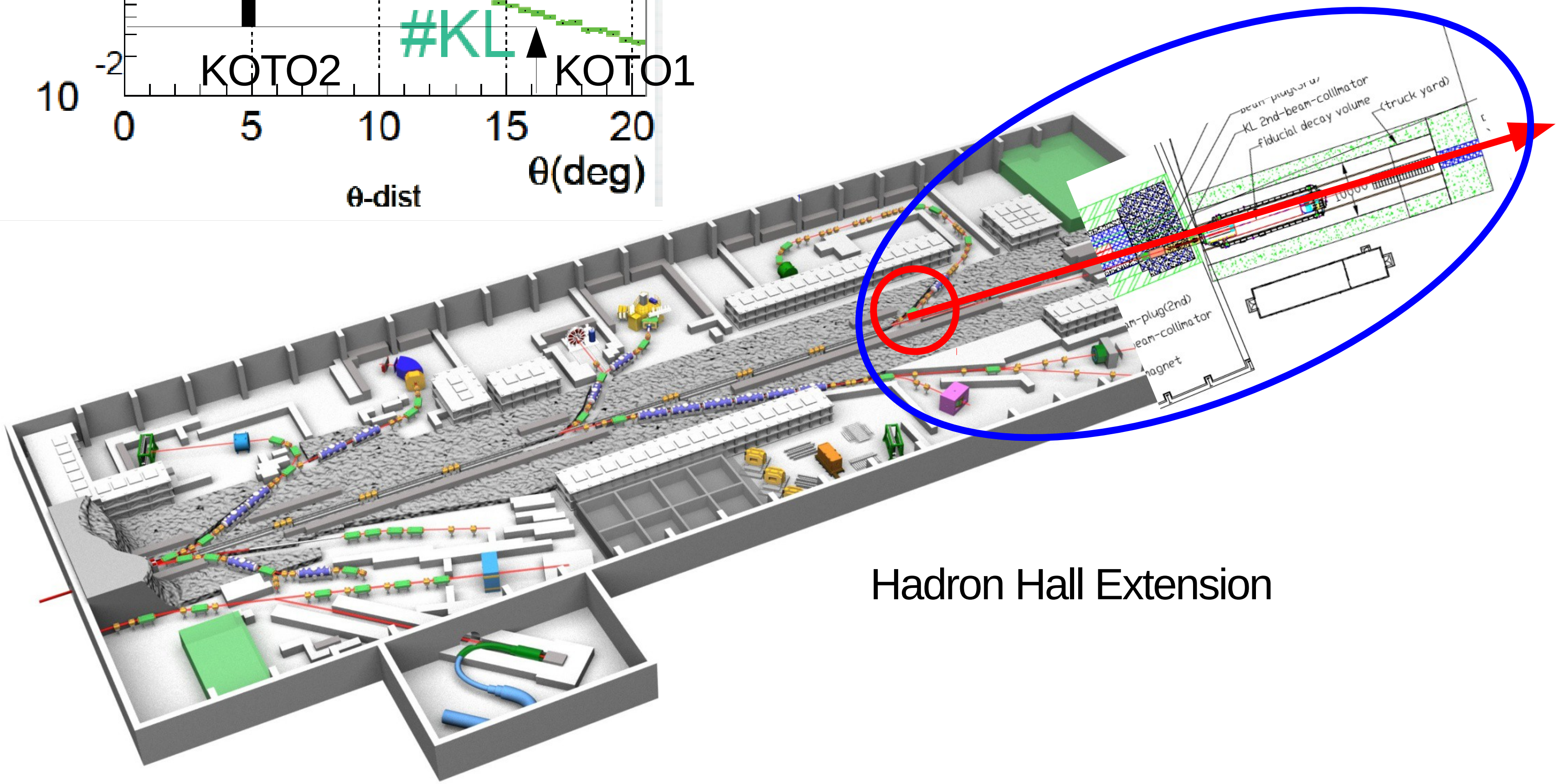
➡ Improvement for safety (target system, air tightness, monitoring) is on-going.

KOTO2

of KL,neutron v.s. Extraction angle



- Extraction angle : 5 degree
- Just behind dump
  - ~50m from target
- Long decay volume and large calorimeter
- 100 SM events → 10% measurement of BR



Hadron Hall Extension

- CP violation in quark sector and Baryogenesis
- Why Minimum Flavor Violation?
- New physics models for KOTO and LHC limitation

- E391a final result with ~100 days run time
  - Br < 2.6x10^{-8} (90% CL)