Status and Prospects of J-PARC KOTO Experiment

July 27, 2012 @BEACH 2012, Wichita State University

Eito IWAI, Osaka University

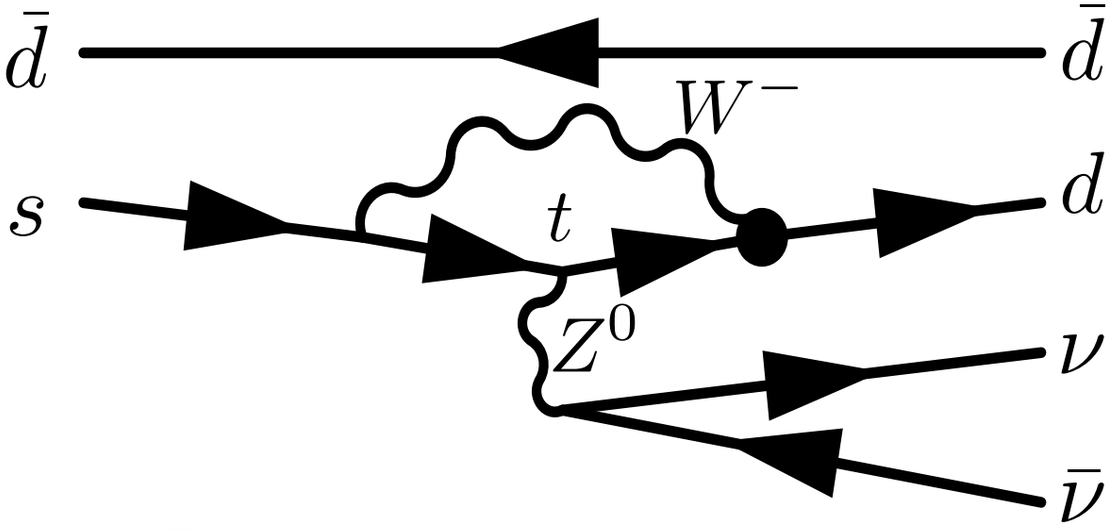
KOTO experiment

for What?	To search for CPV caused by New Physics beyond the Standard Model
How?	By observing the decay $K_L \to \pi^0 \nu\bar{\nu}$
When?	The first physics run will start in 2013 spring
Where?	J-PARC : Japan Proton Accelerator Research Complex

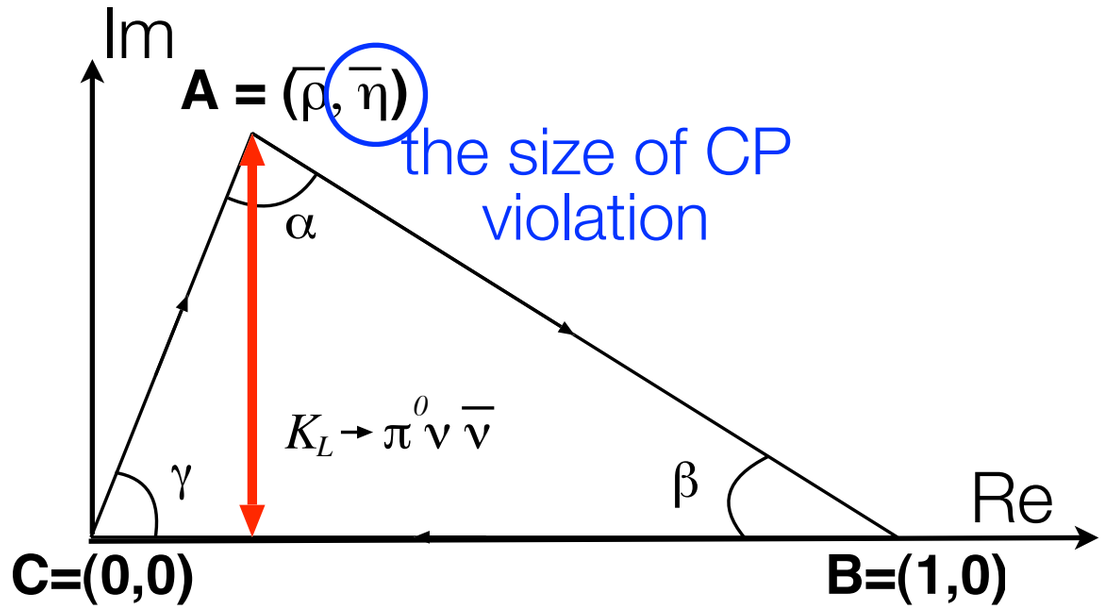
CP-

CP+

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

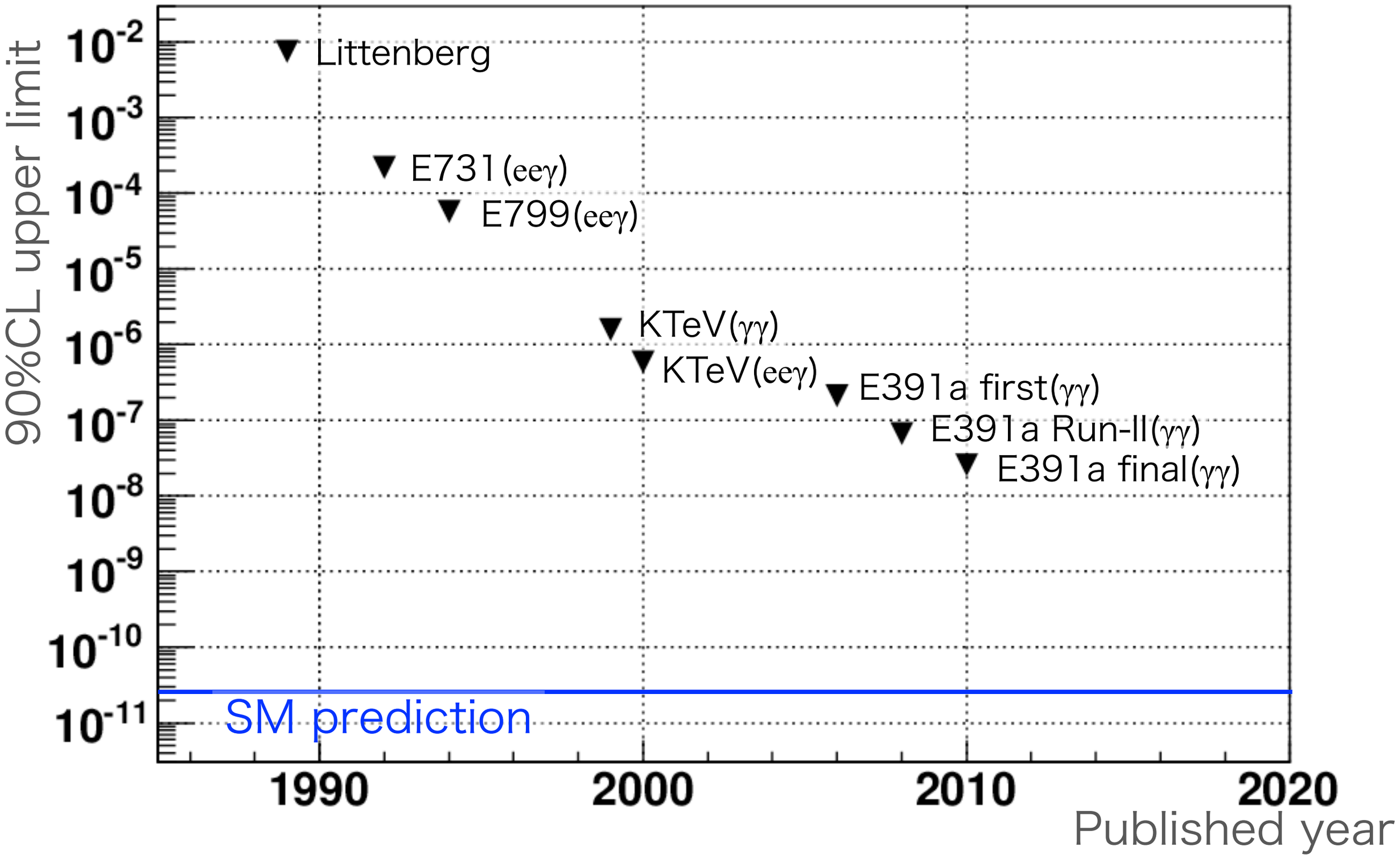


A Feynman diagram of the decay.

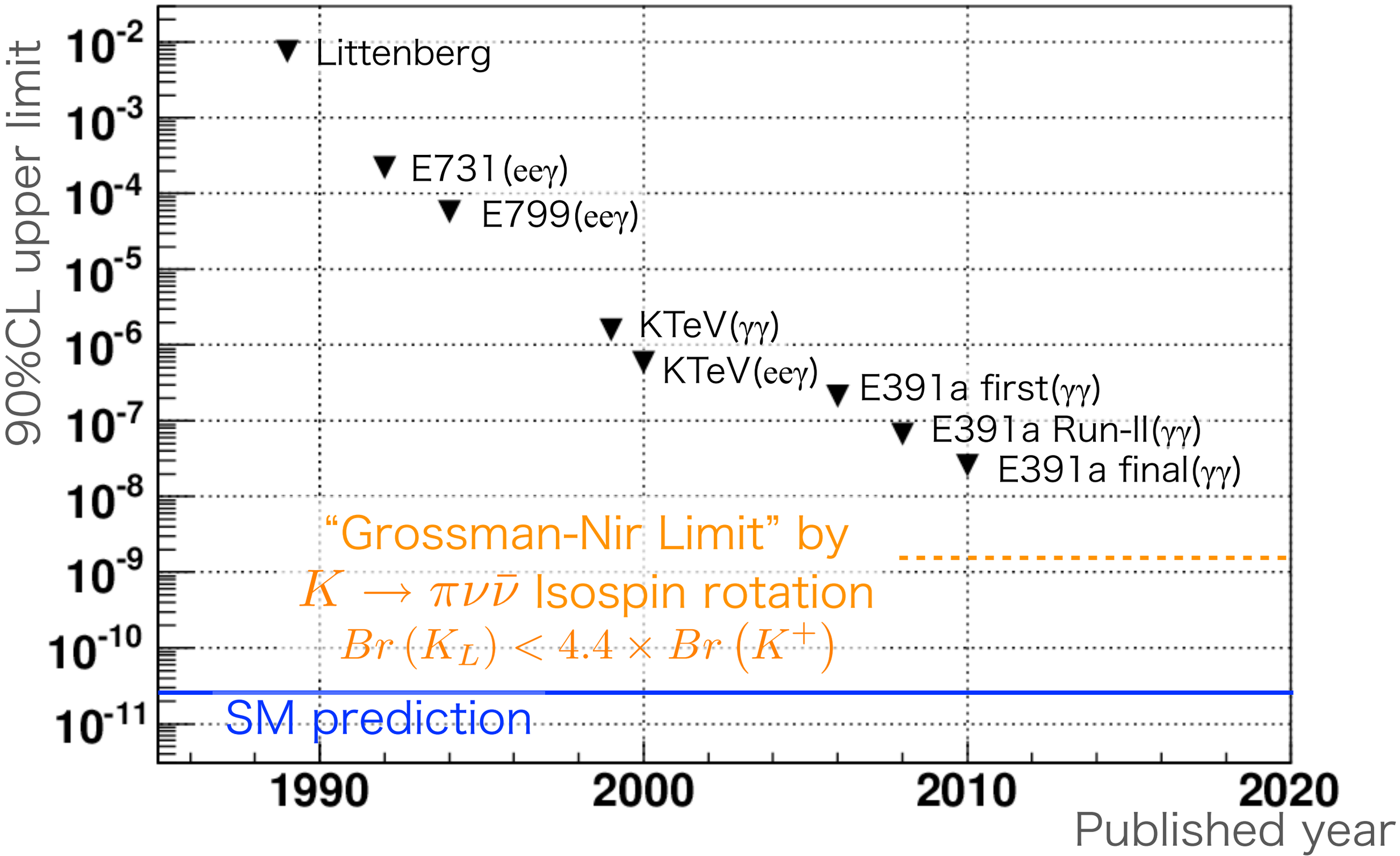


- decay via direct CPV
- loop diagram : sensitive to New Physics
- well known : theoretical error ~ 2%
- $Br^{\mathrm{SM}}\left(K_L \to \pi^0 \nu\bar{\nu}\right) = (2.43 \pm 0.39) \times 10^{-11}$

History of the experimental results



History of the experimental results



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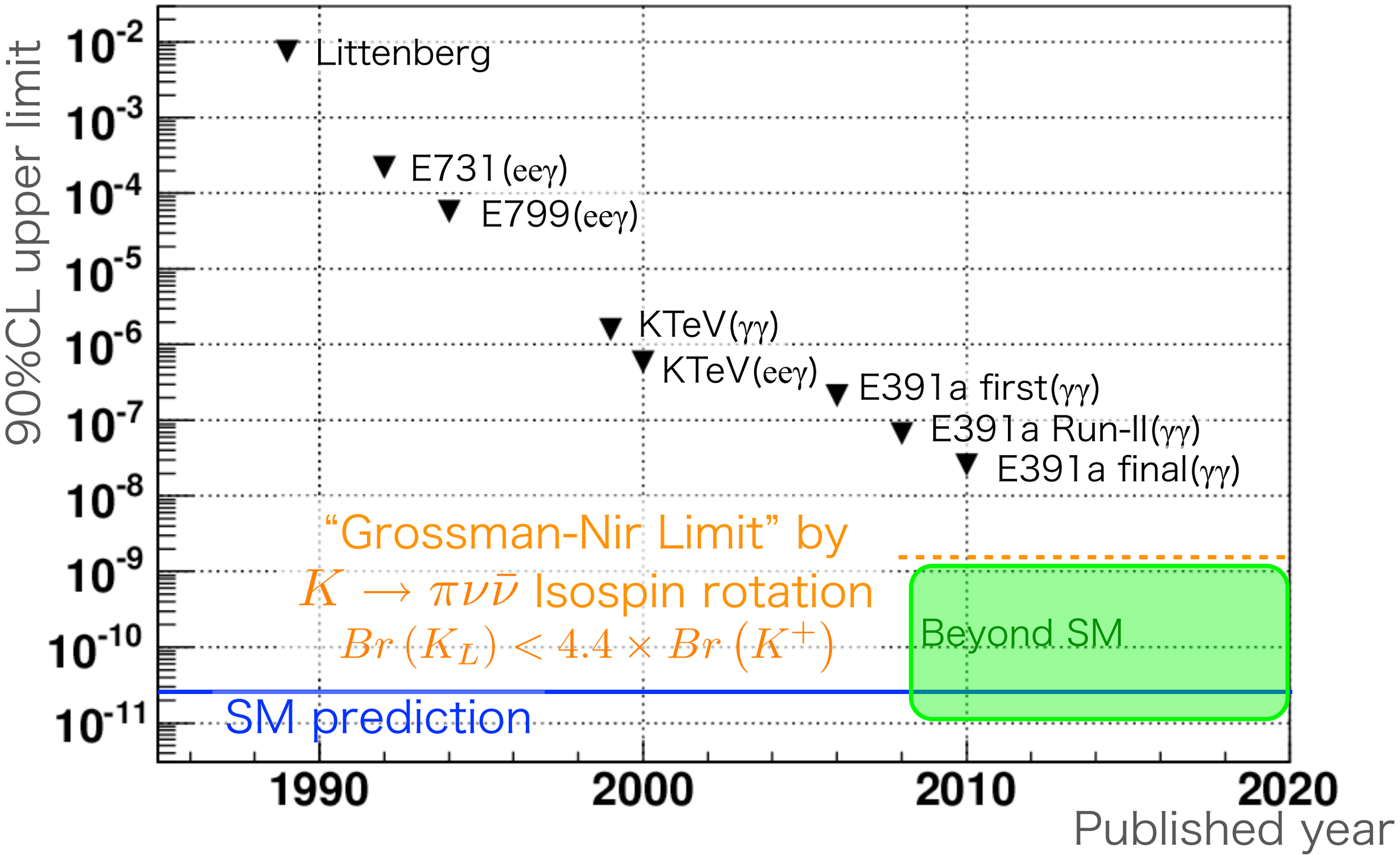

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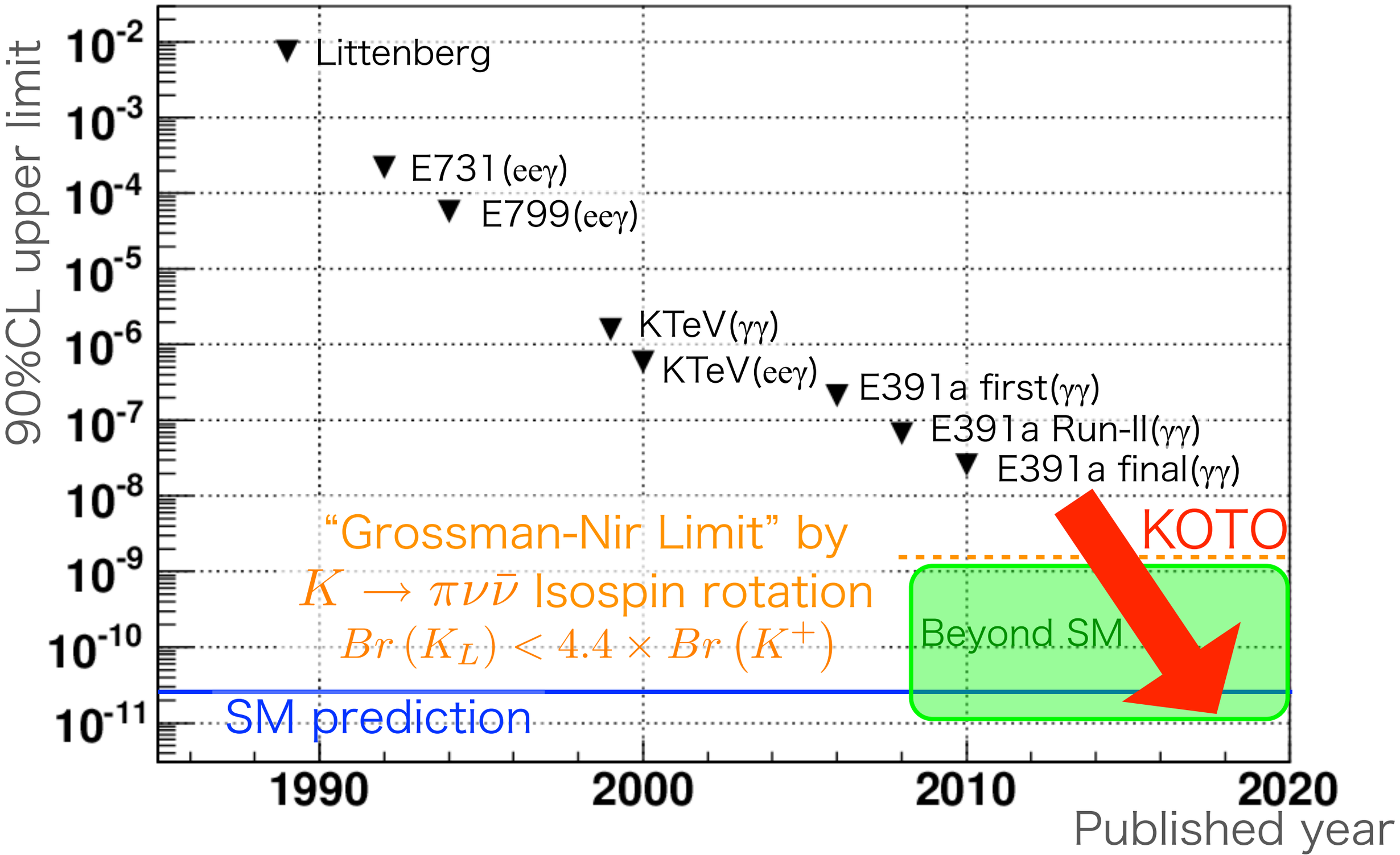
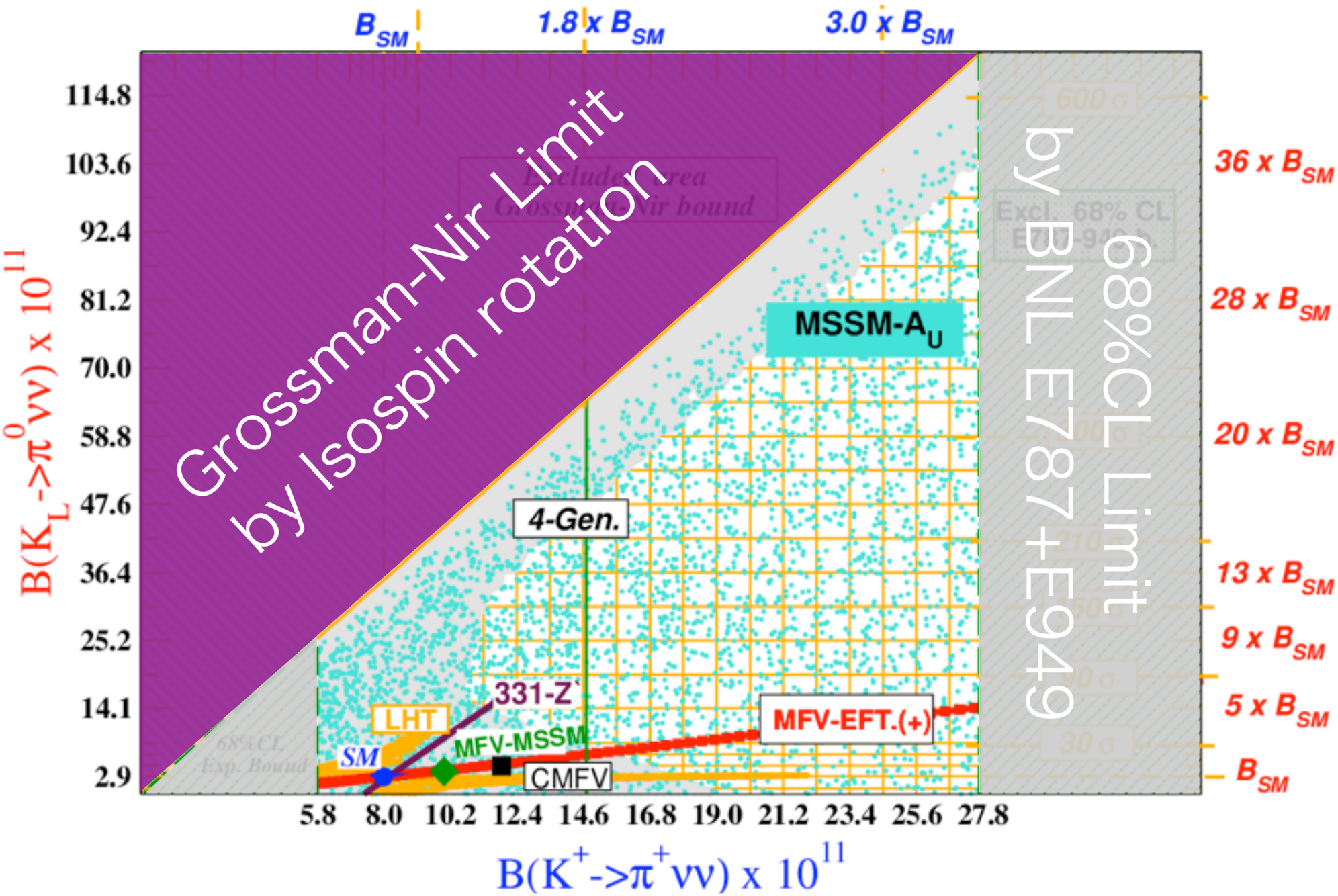


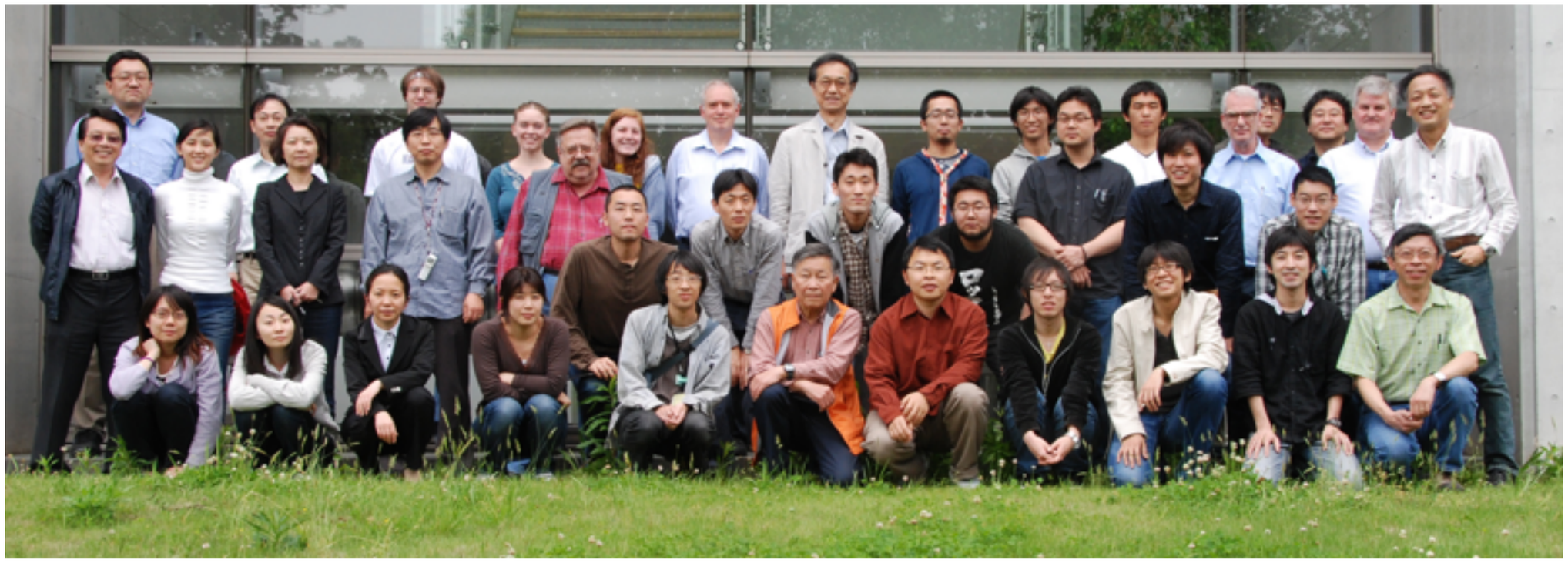
Theoretical models beyond the SM



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

J-PARC KOTO experiment

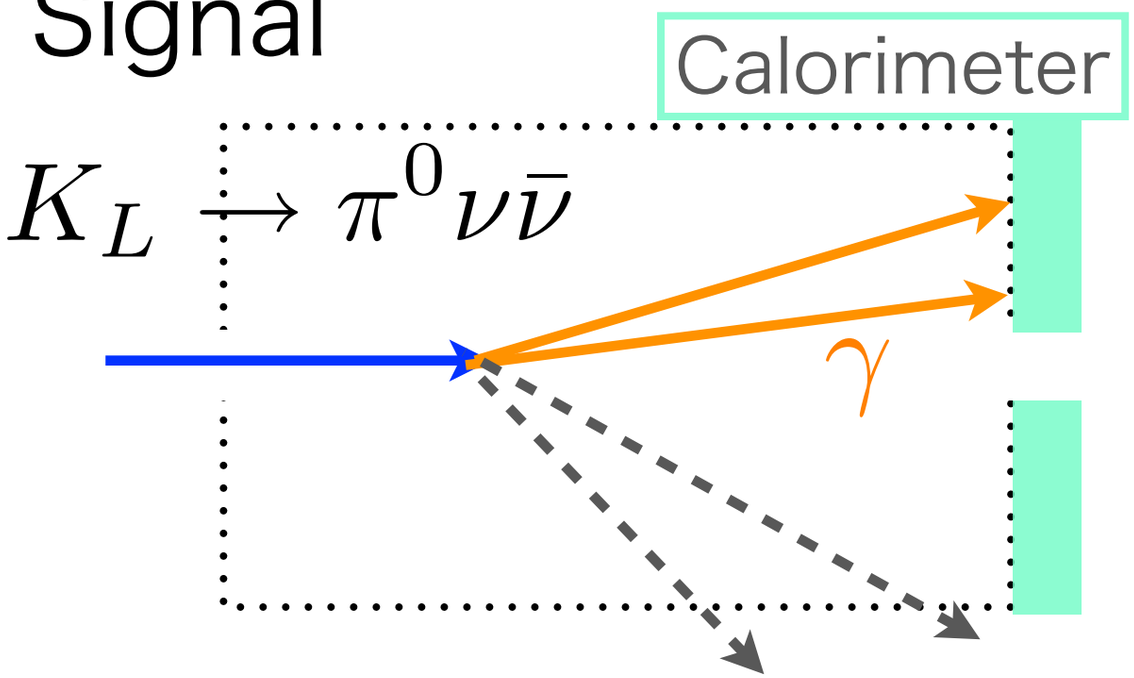
- KOTO : K0 at TOkai



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

Experimental methods

Signal



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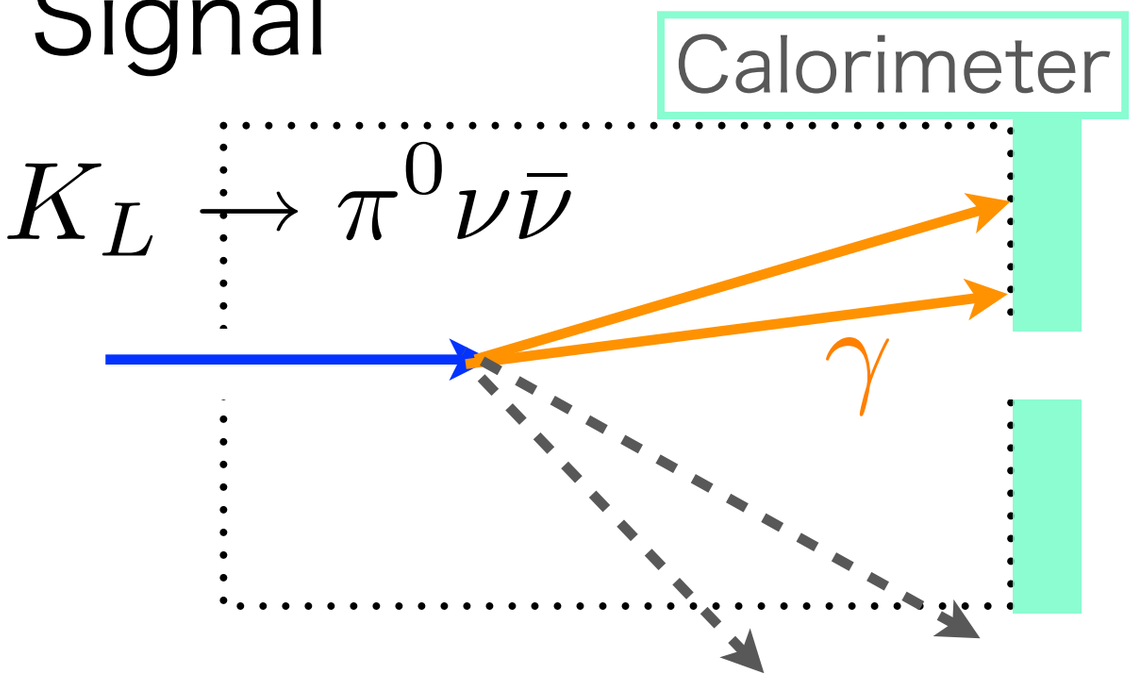
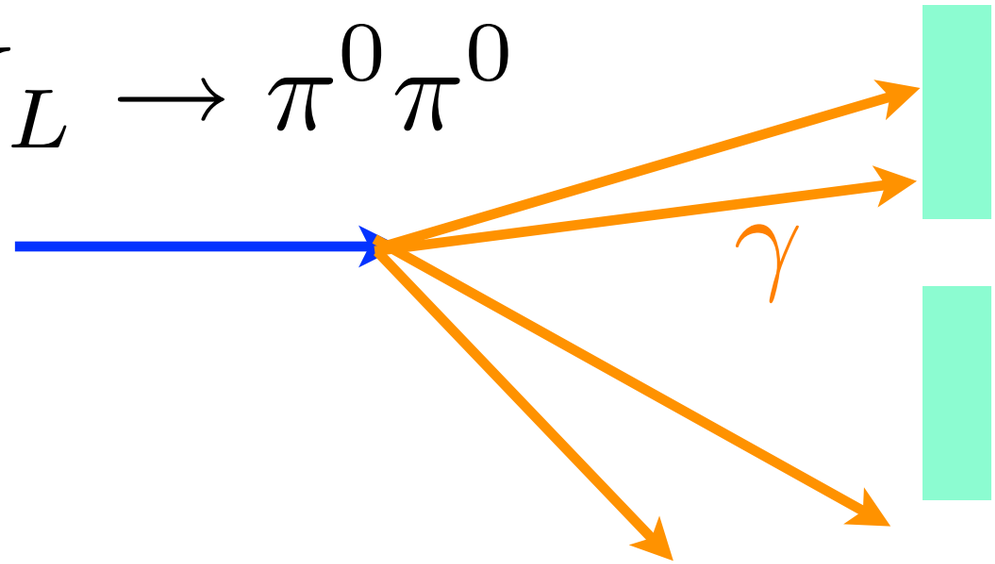


Background



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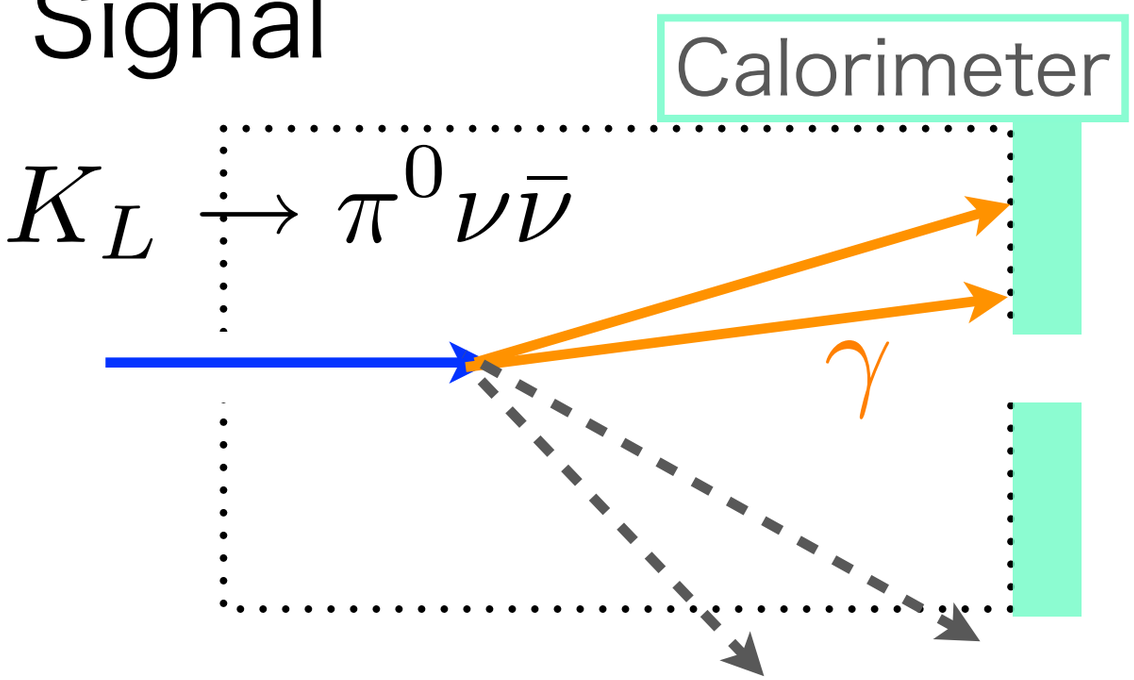

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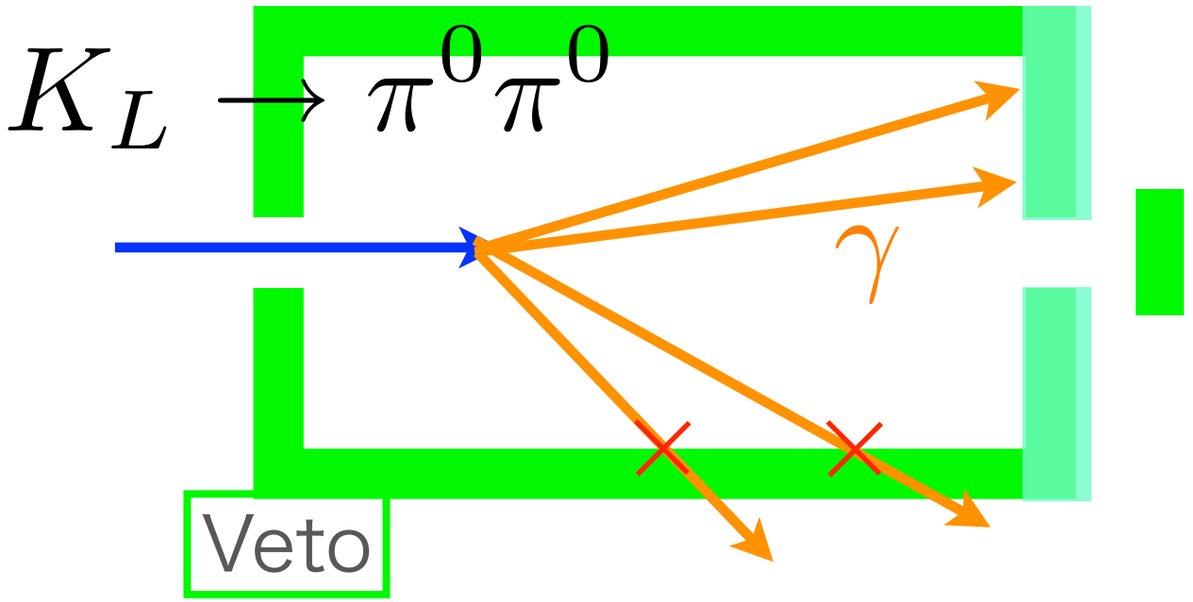
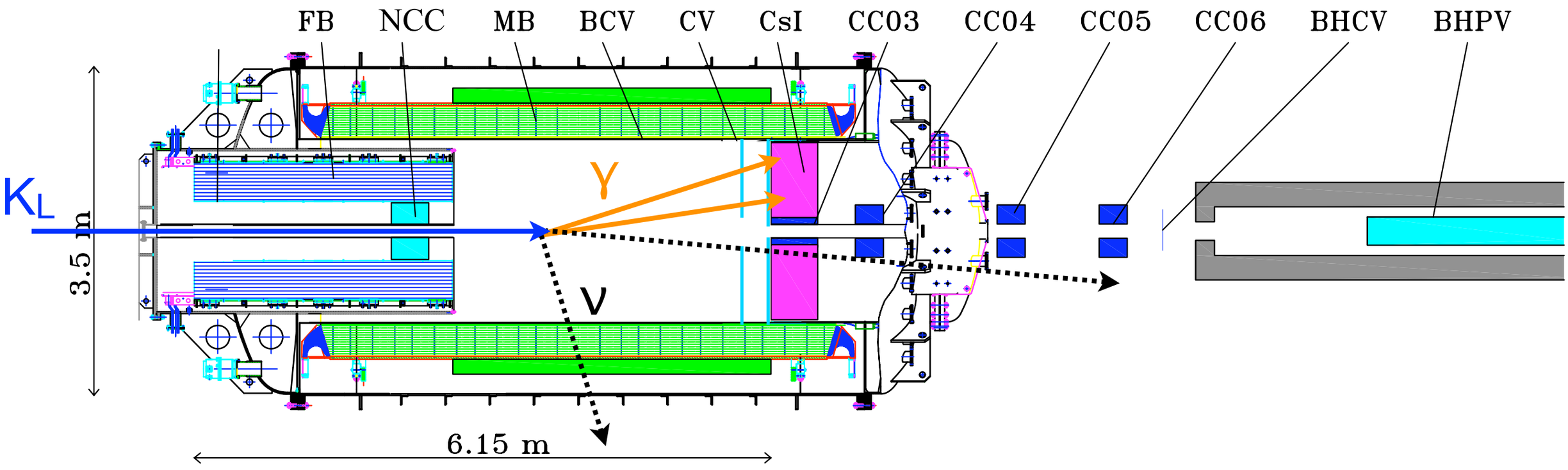


Experimental apparatus



- High intensity K_L beam
- Waveform digitization
- CsI calorimeter
- New Veto detectors

- High intensity K_L beam
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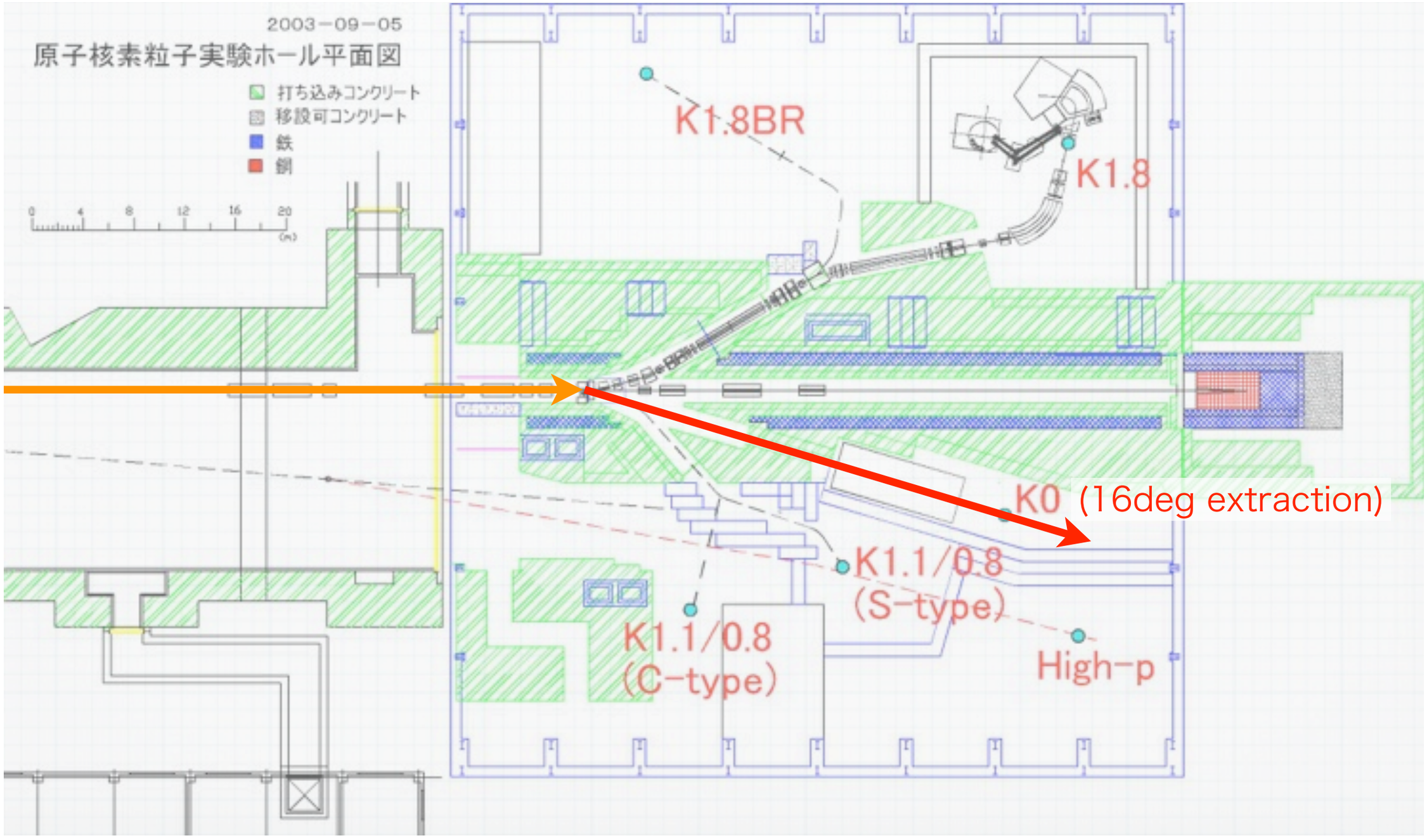
- New Veto detectors

J-PARC Laboratory

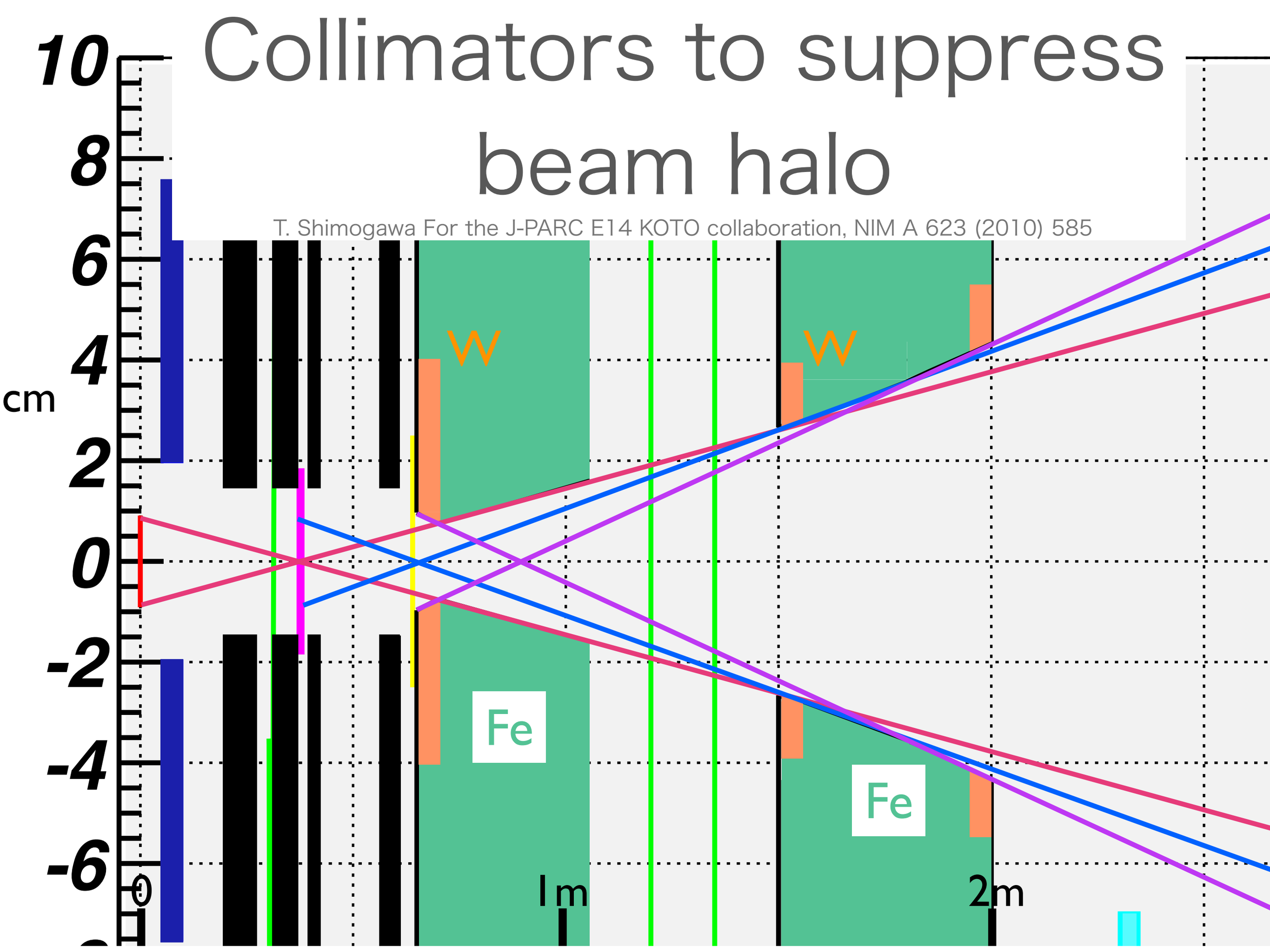
- Main ring (30 GeV protons)

Experimental Hall

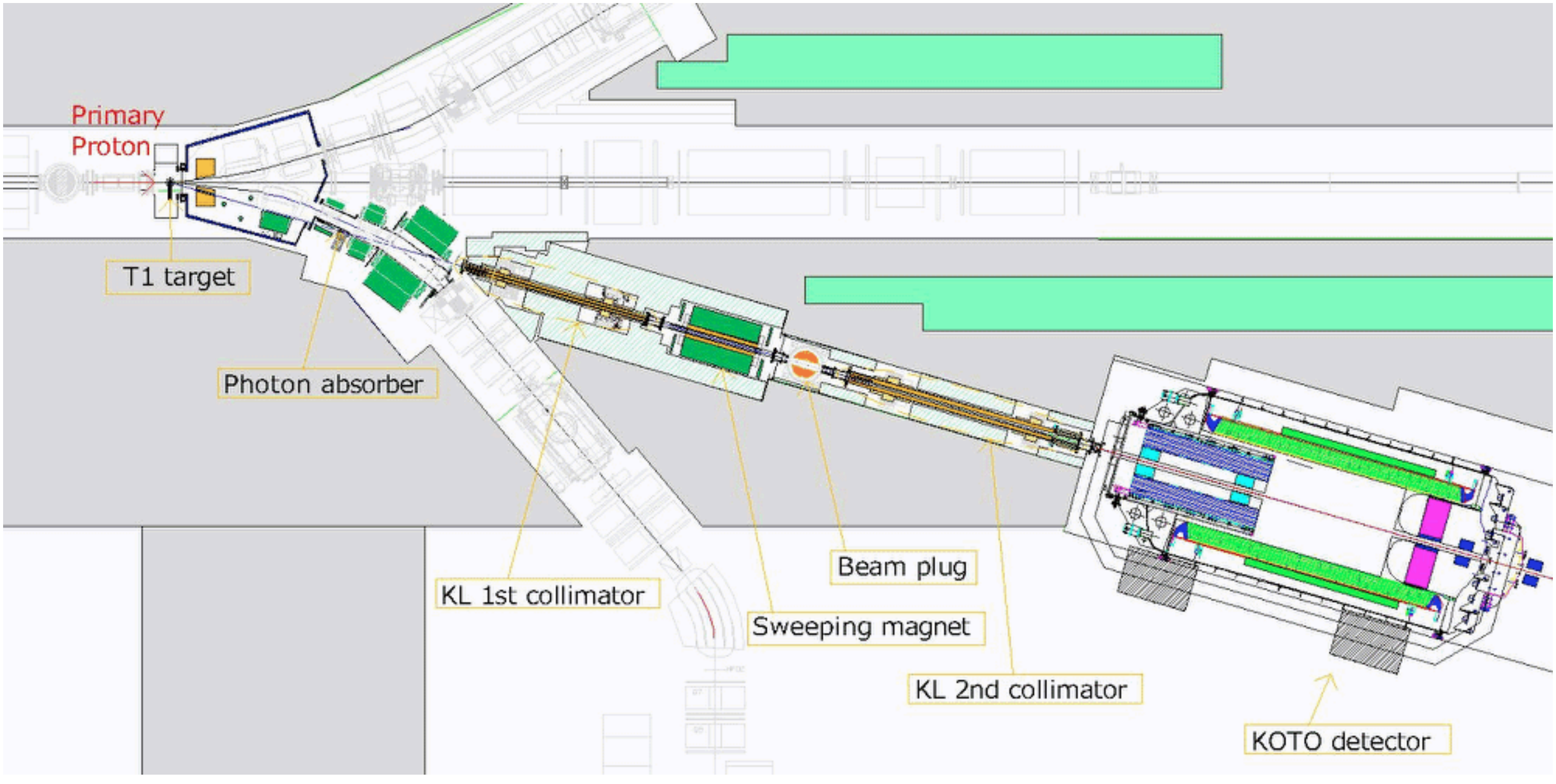


Collimators to suppress beam halo

T. Shimogawa For the J-PARC E14 KOTO collaboration, NIM A 623 (2010) 585



Neutral beam line



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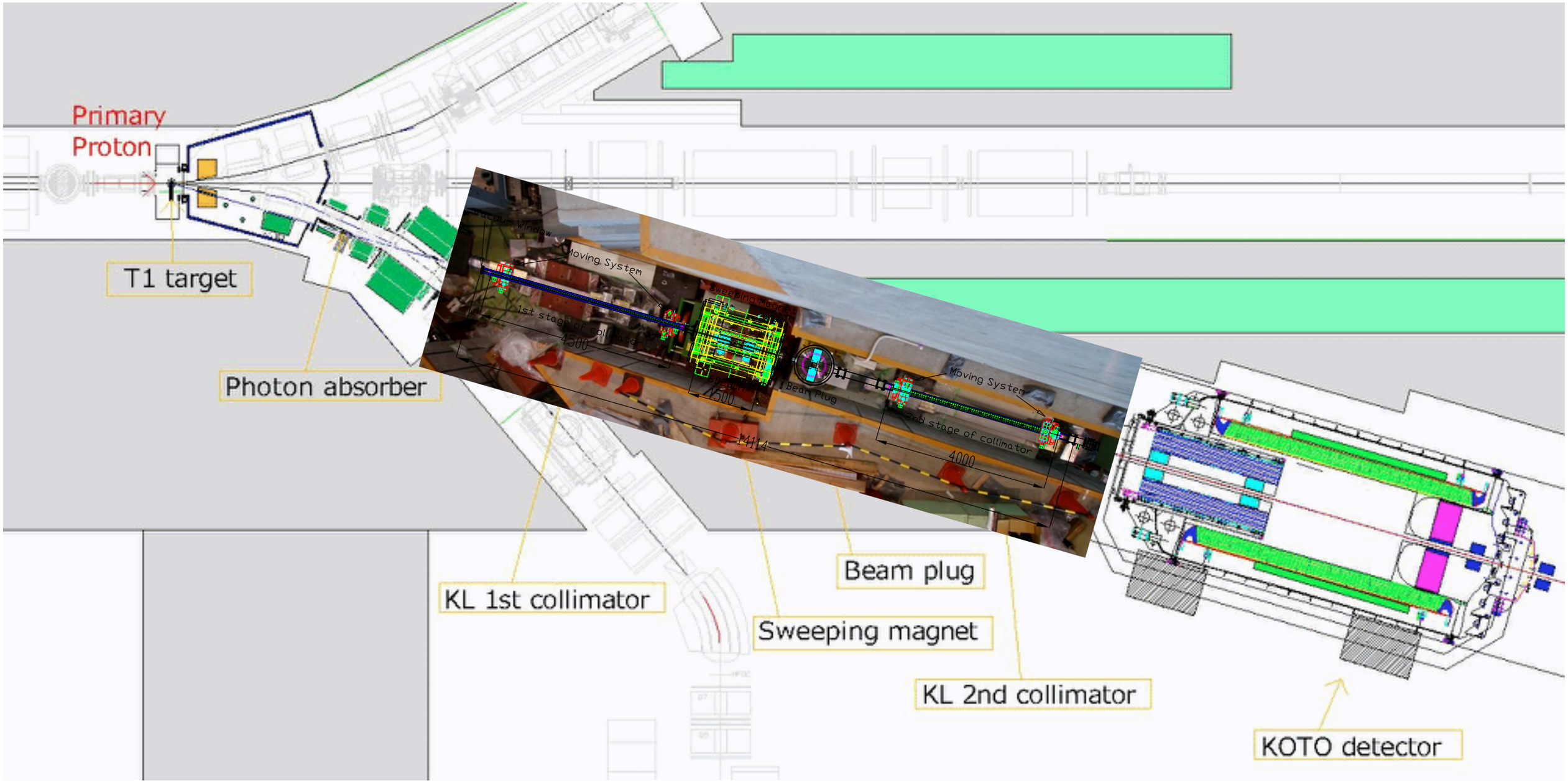
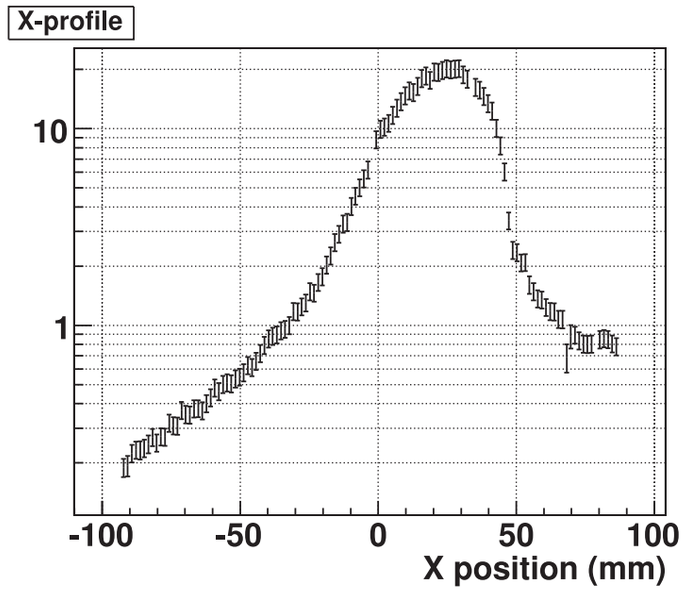
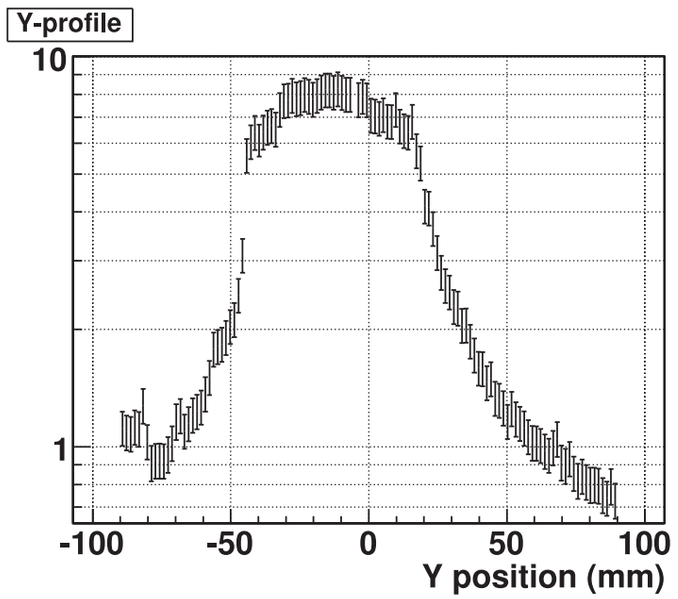


Beam survey

- We got
  - expected beam profile

G. Takahashi et al., Jpn. J. Appl. Phys. 50 (2011) 036701





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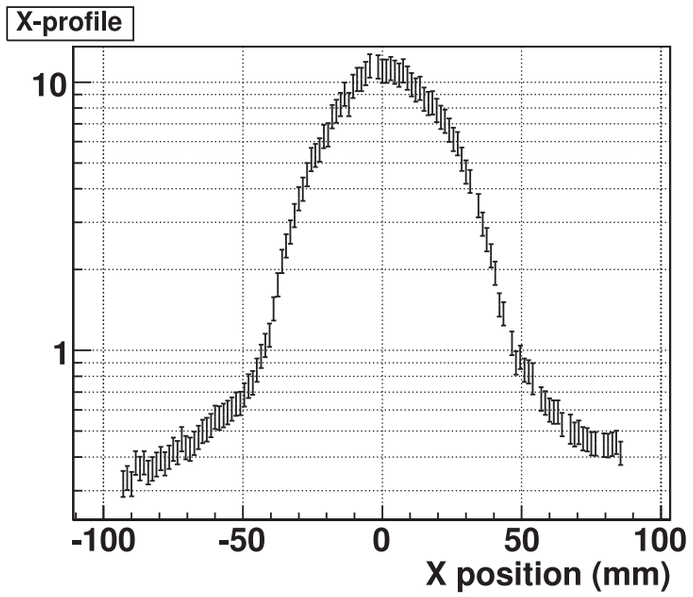

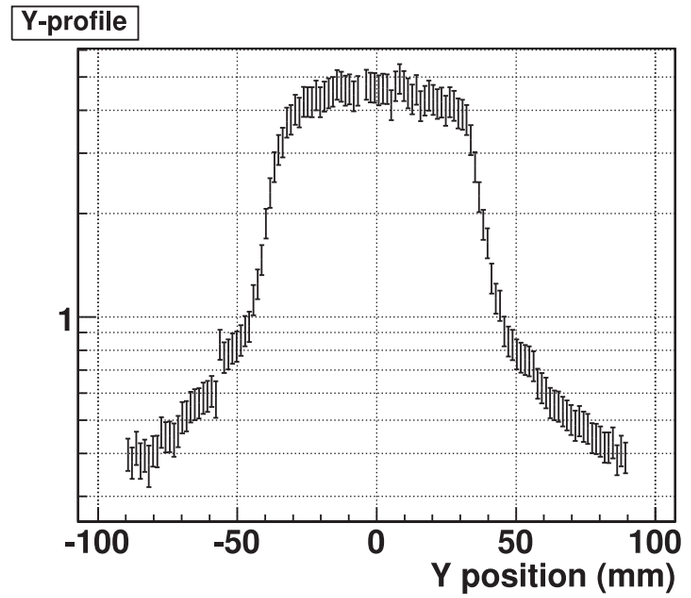

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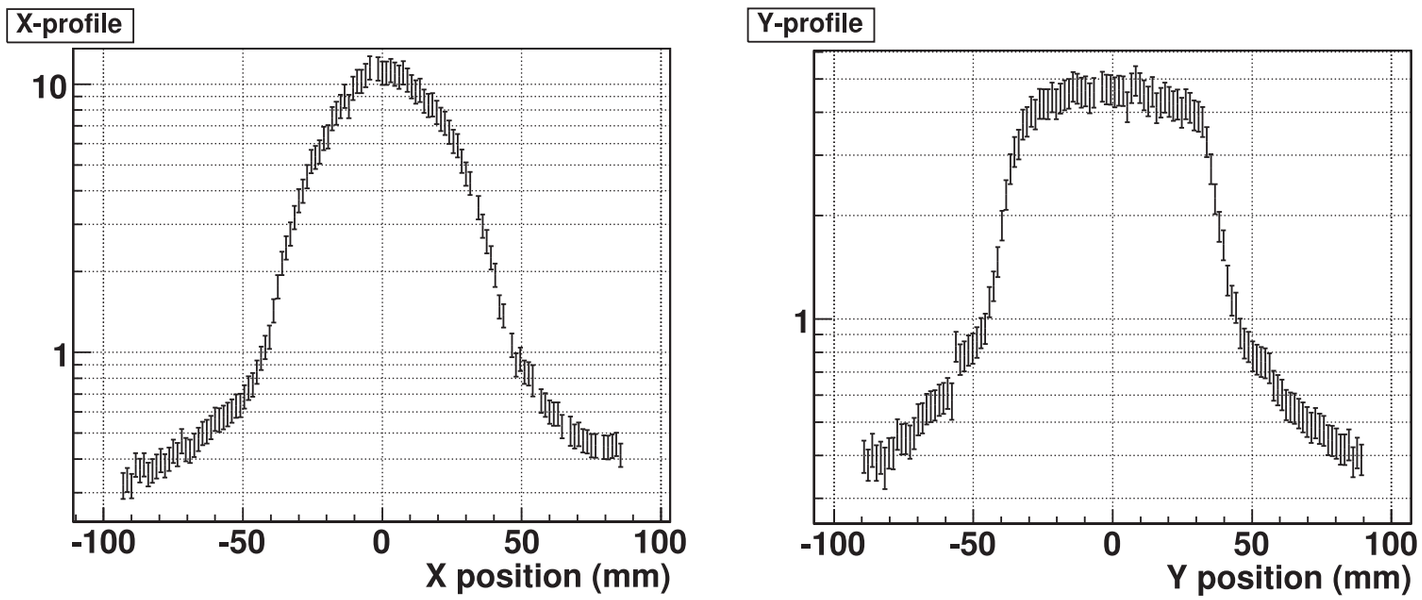
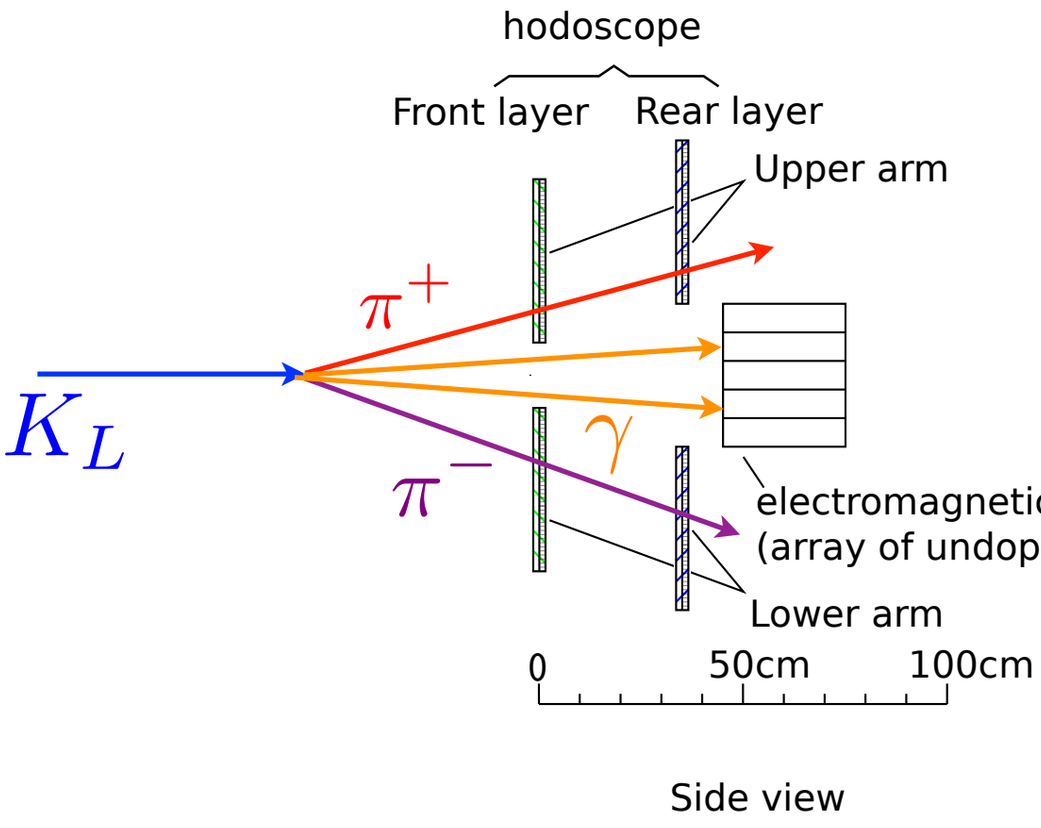
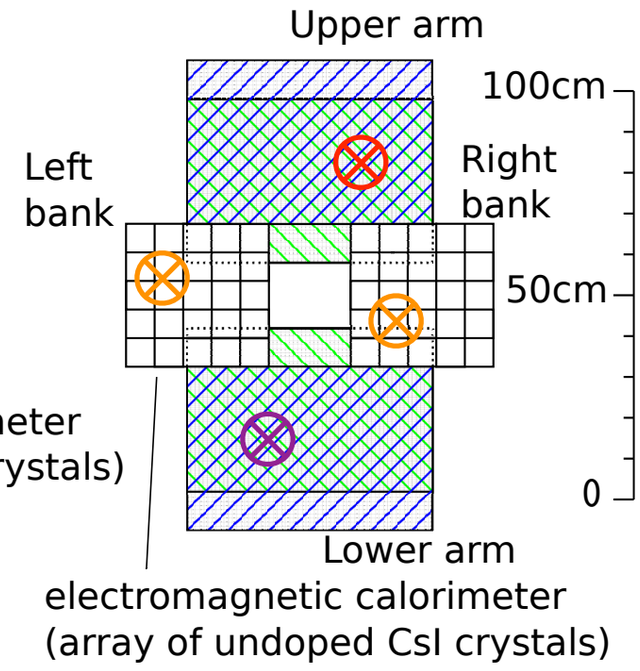


- We got
  - expected beam profile
  - 2.6 times larger number of K_L assumed at proposal (by measuring the number of $K_L \to \pi^+\pi^-\pi^0$ decays)





K. Shiomi et al., NIM A 664 (2012) 264

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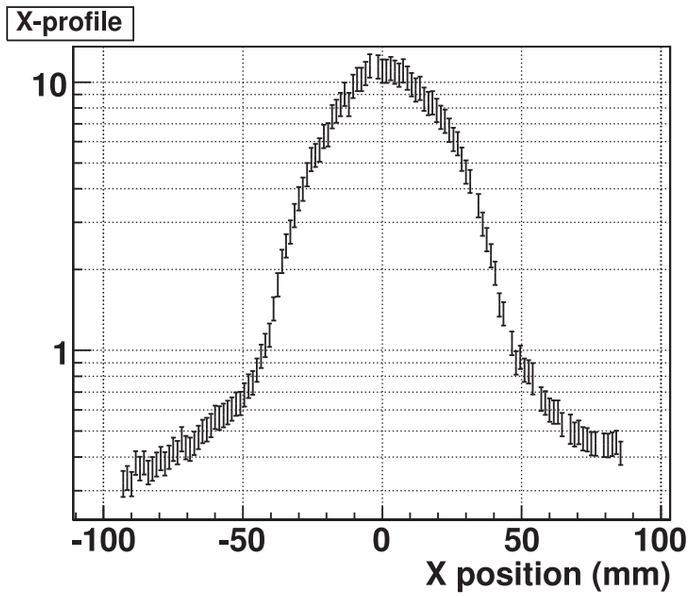

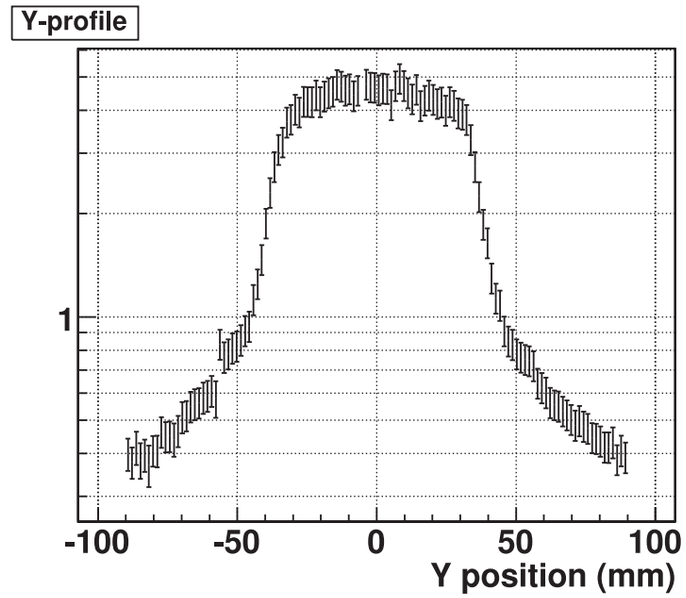

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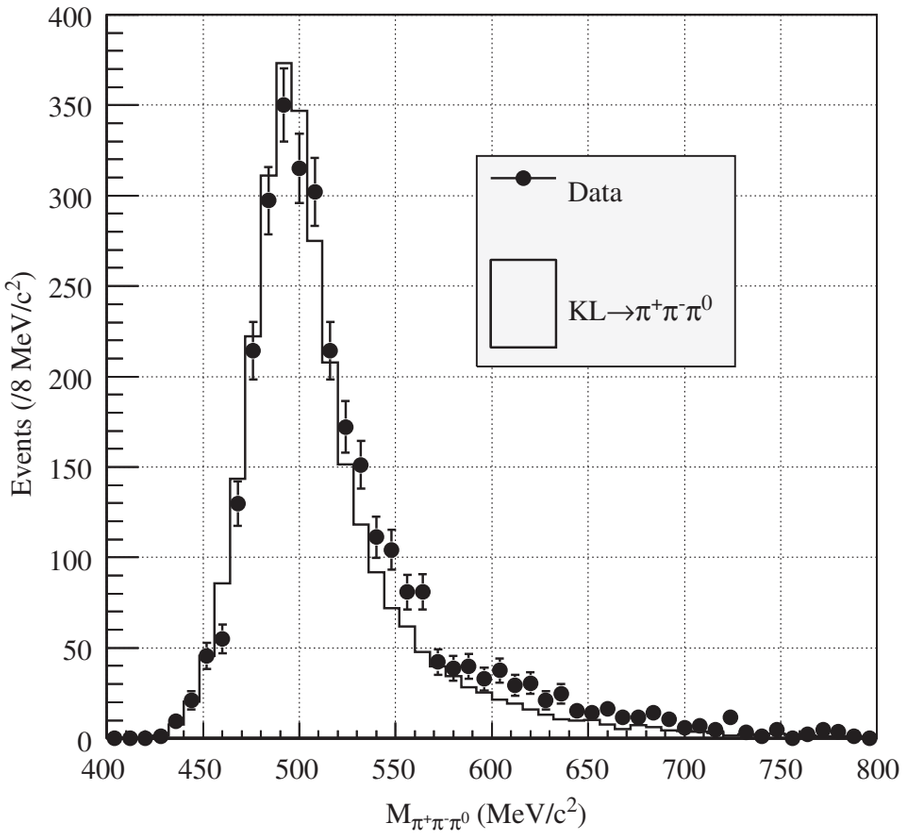
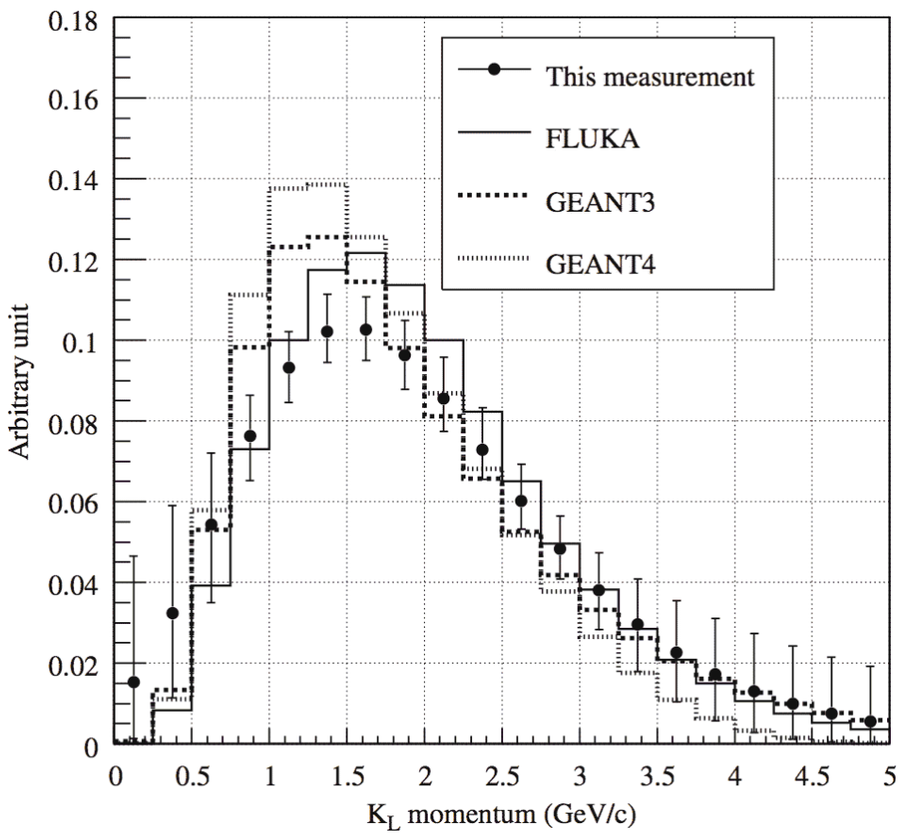


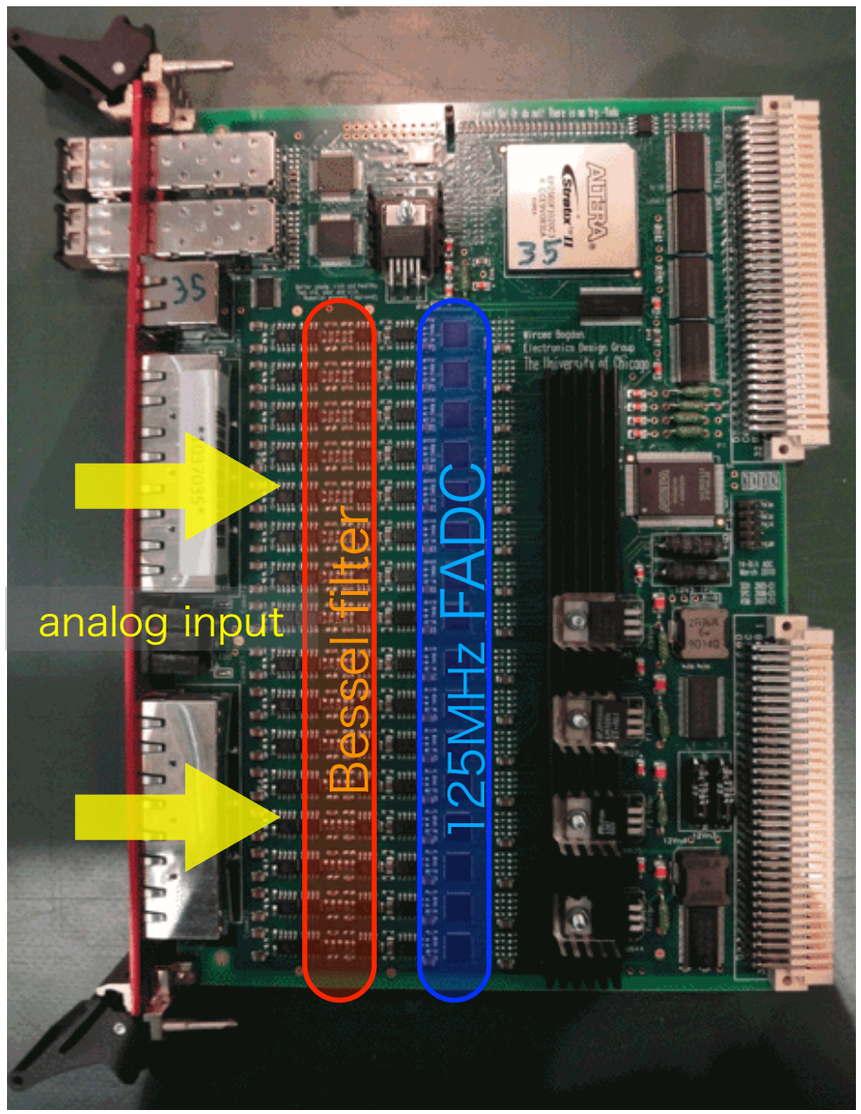


K. Shiomi et al., NIM A 664 (2012) 264

- High intensity K_L beam
- Waveform digitization
- CsI calorimeter
- New Veto detectors

Waveform readout

- 14bit FADC
  - to record waveform
  - to form triggers digitally



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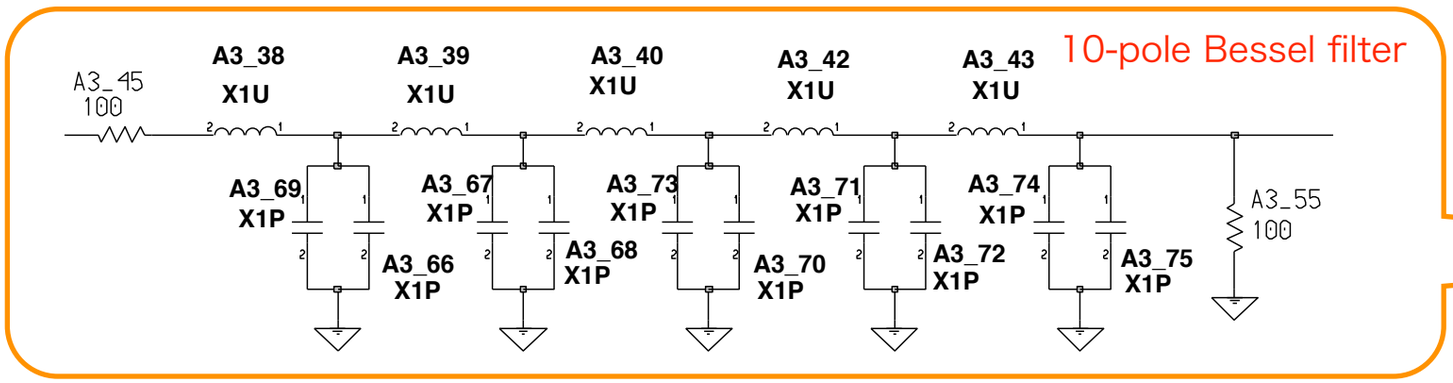

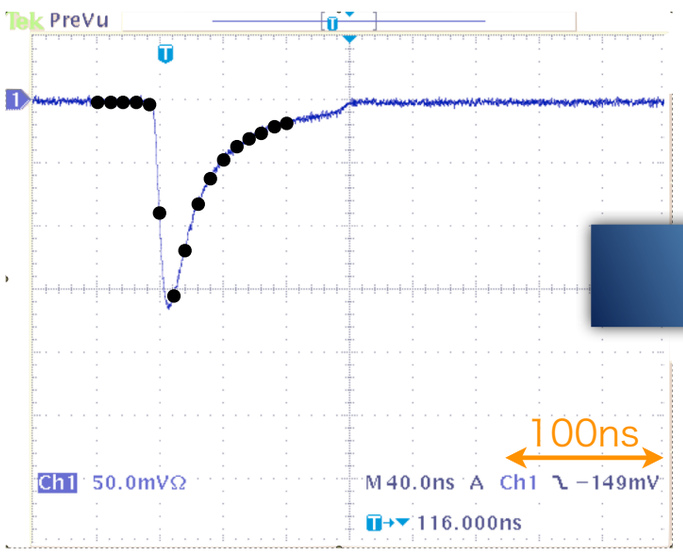

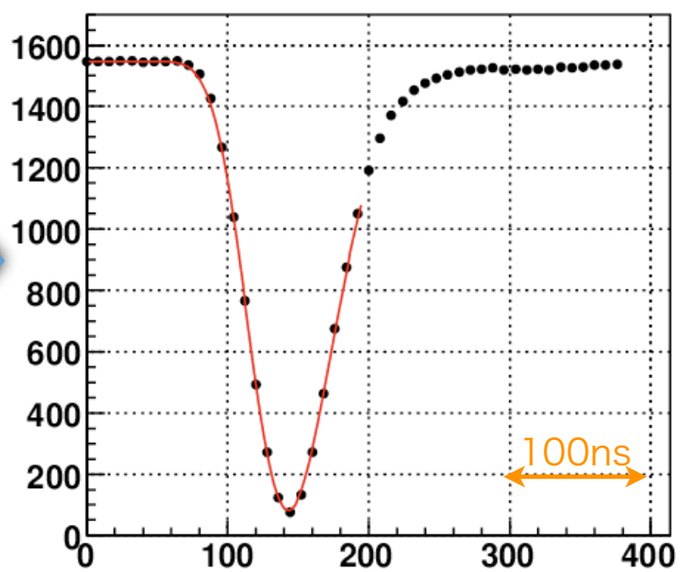

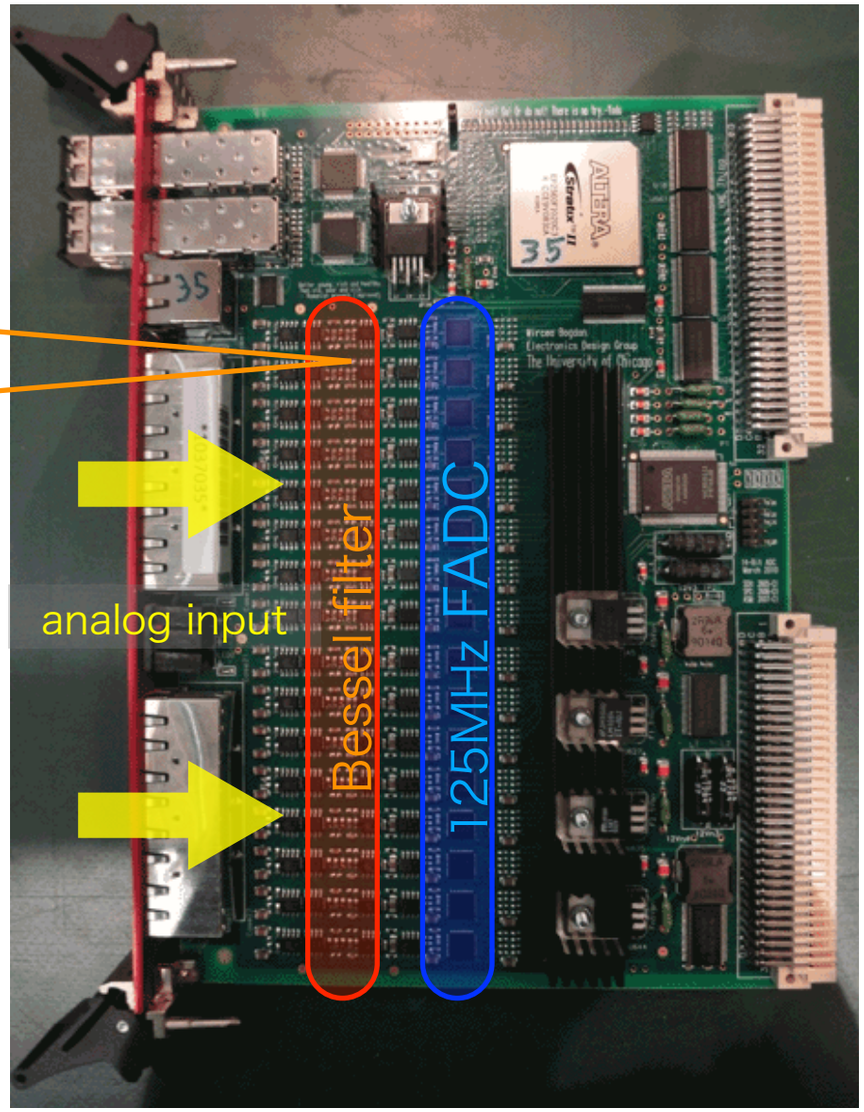

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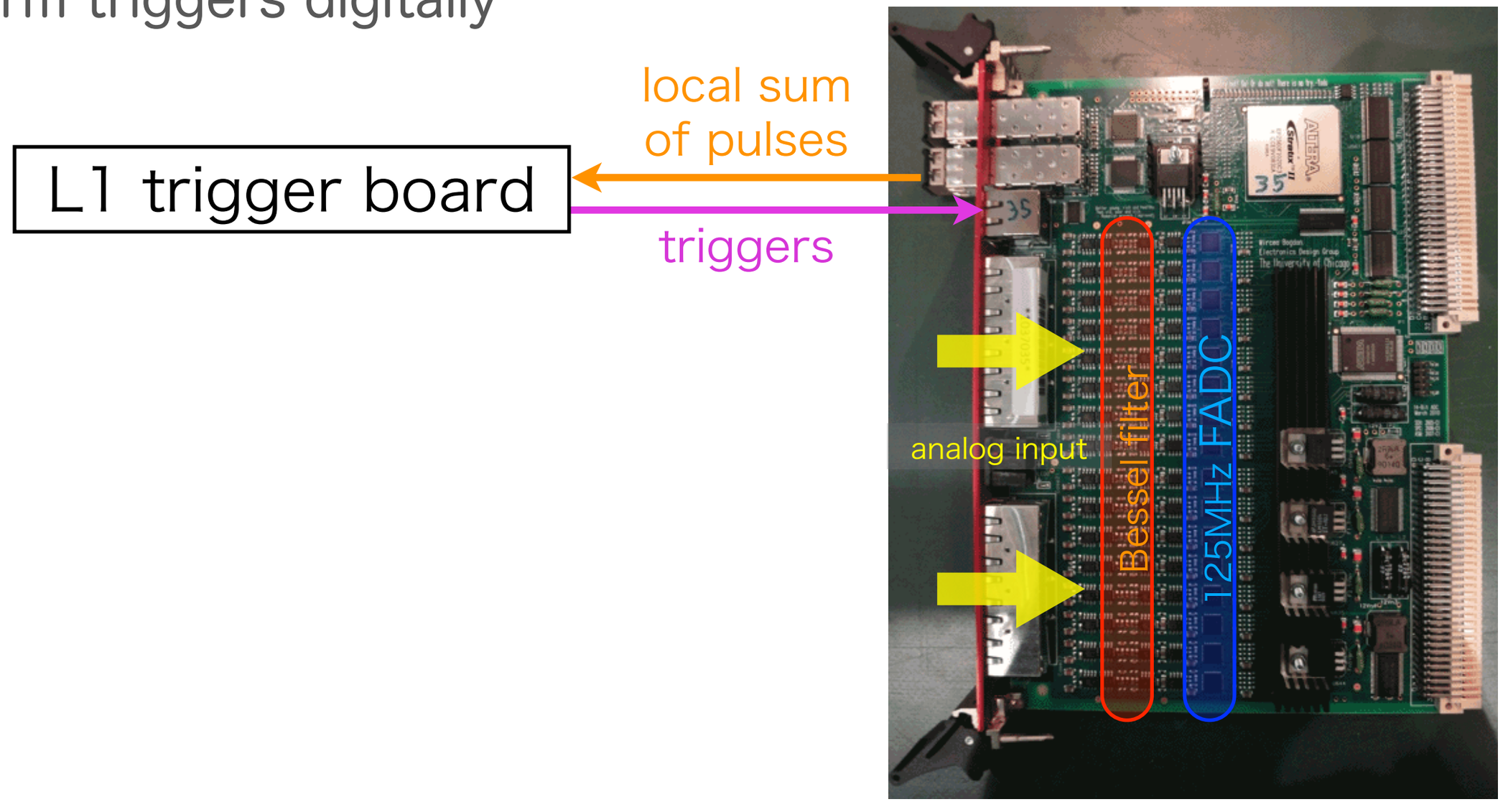

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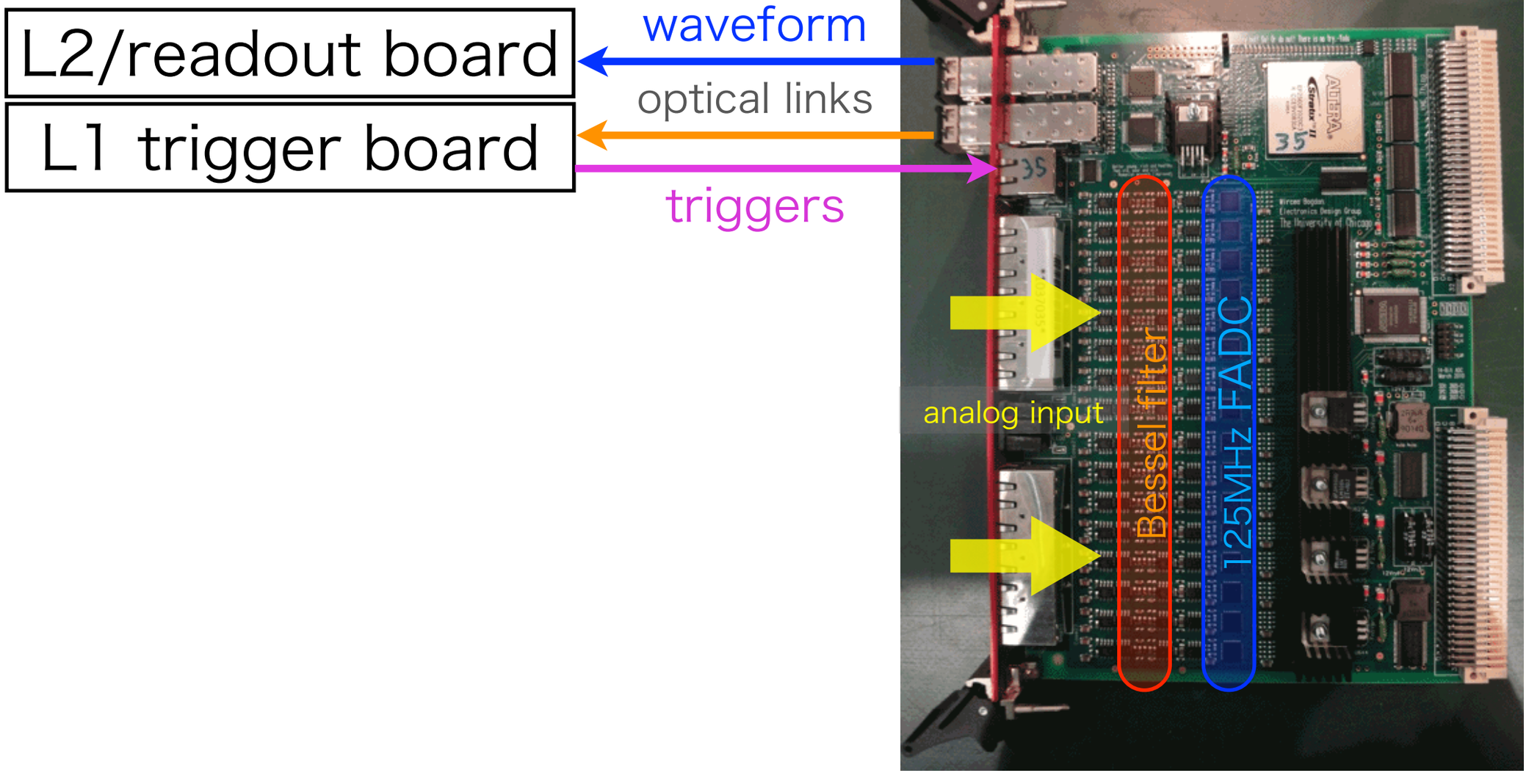

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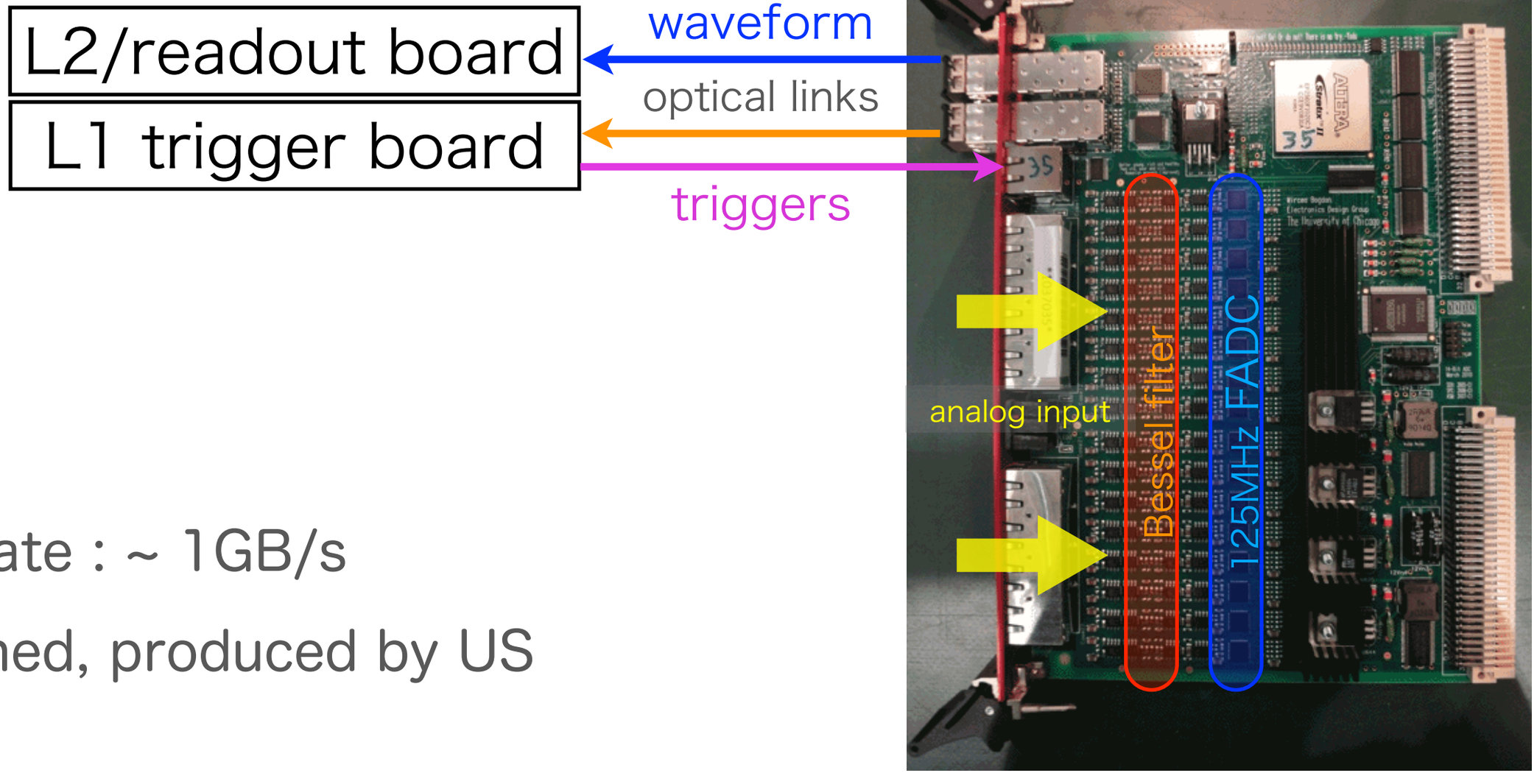
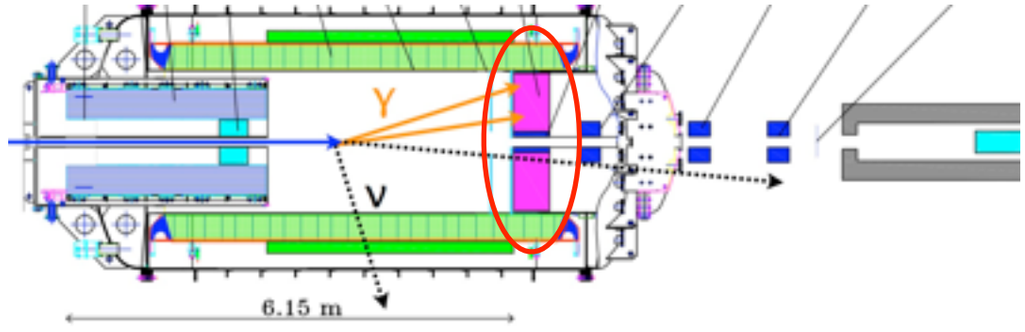


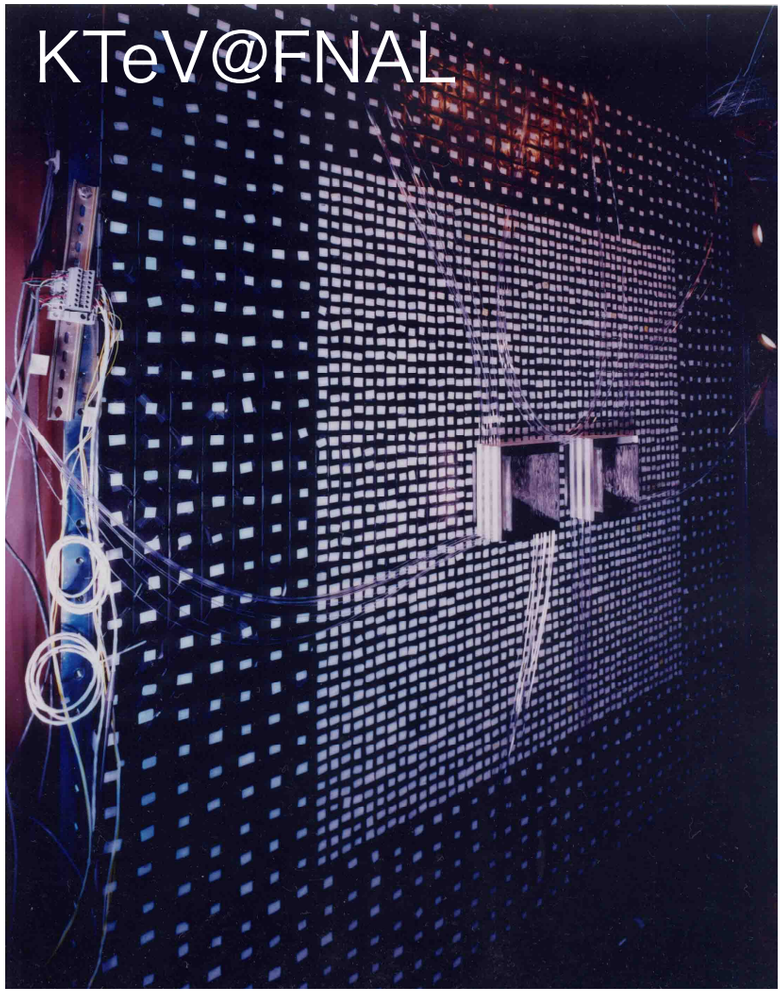
- data rate : ~ 1GB/s
- Designed, produced by US

- High intensity K_L beam
- Waveform digitization
- CsI calorimeter
- New Veto detectors

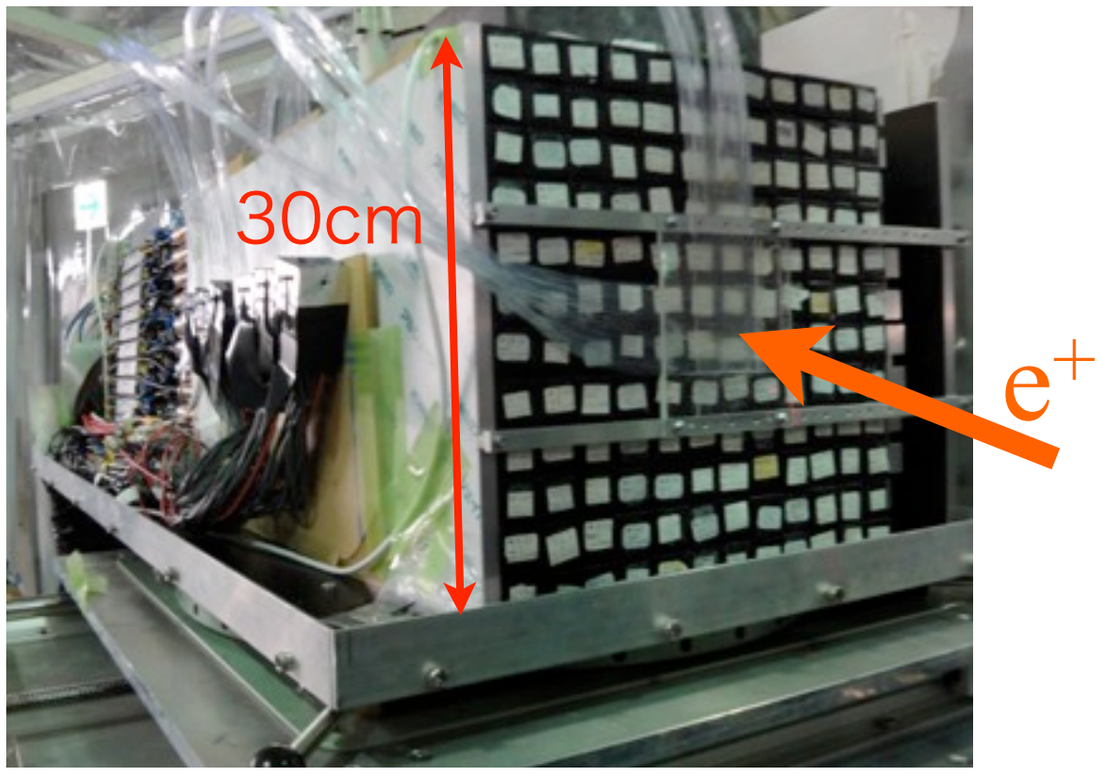
CsI calorimeter



- Longer : 30cm → 50cm ($27X_0$)
- Smaller : 7cm → 2.5/5cm square
- CsI crystals from KTeV experiment



beam test w/ prototype

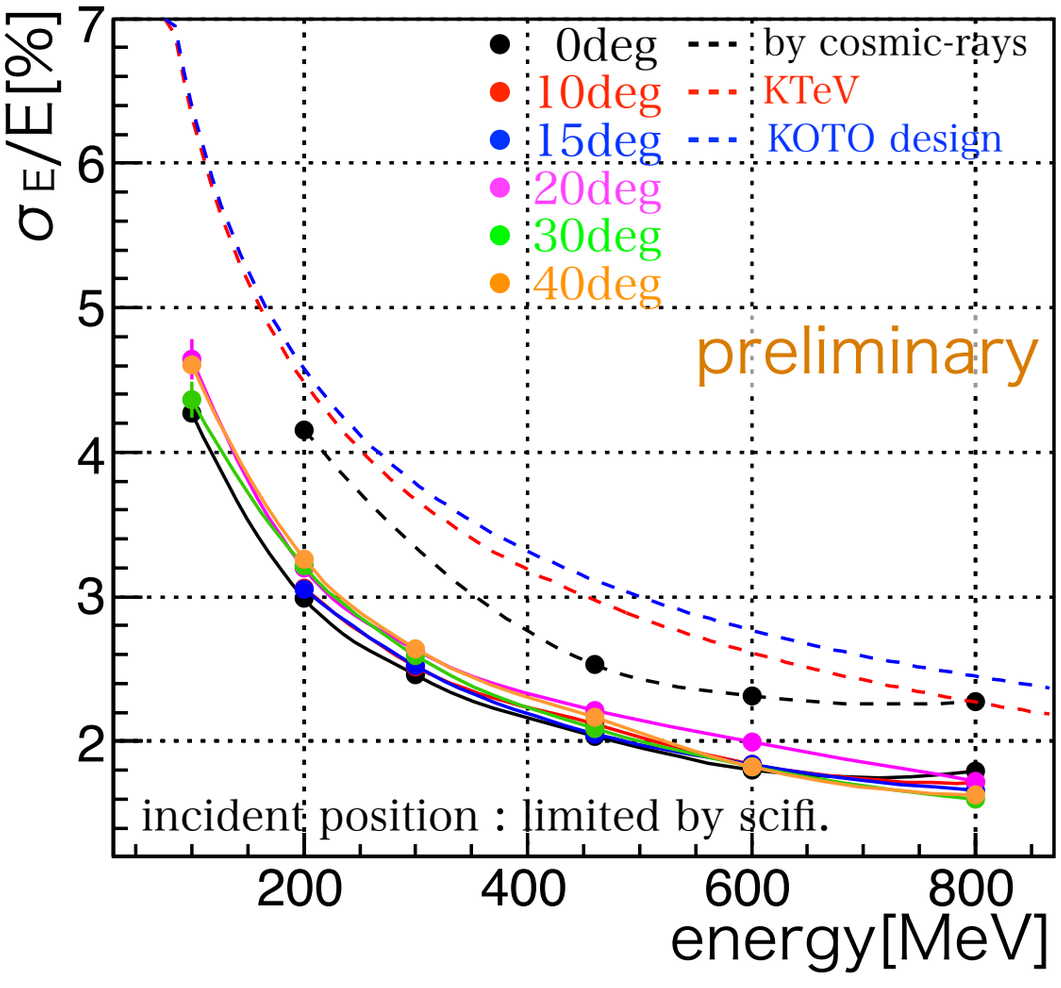


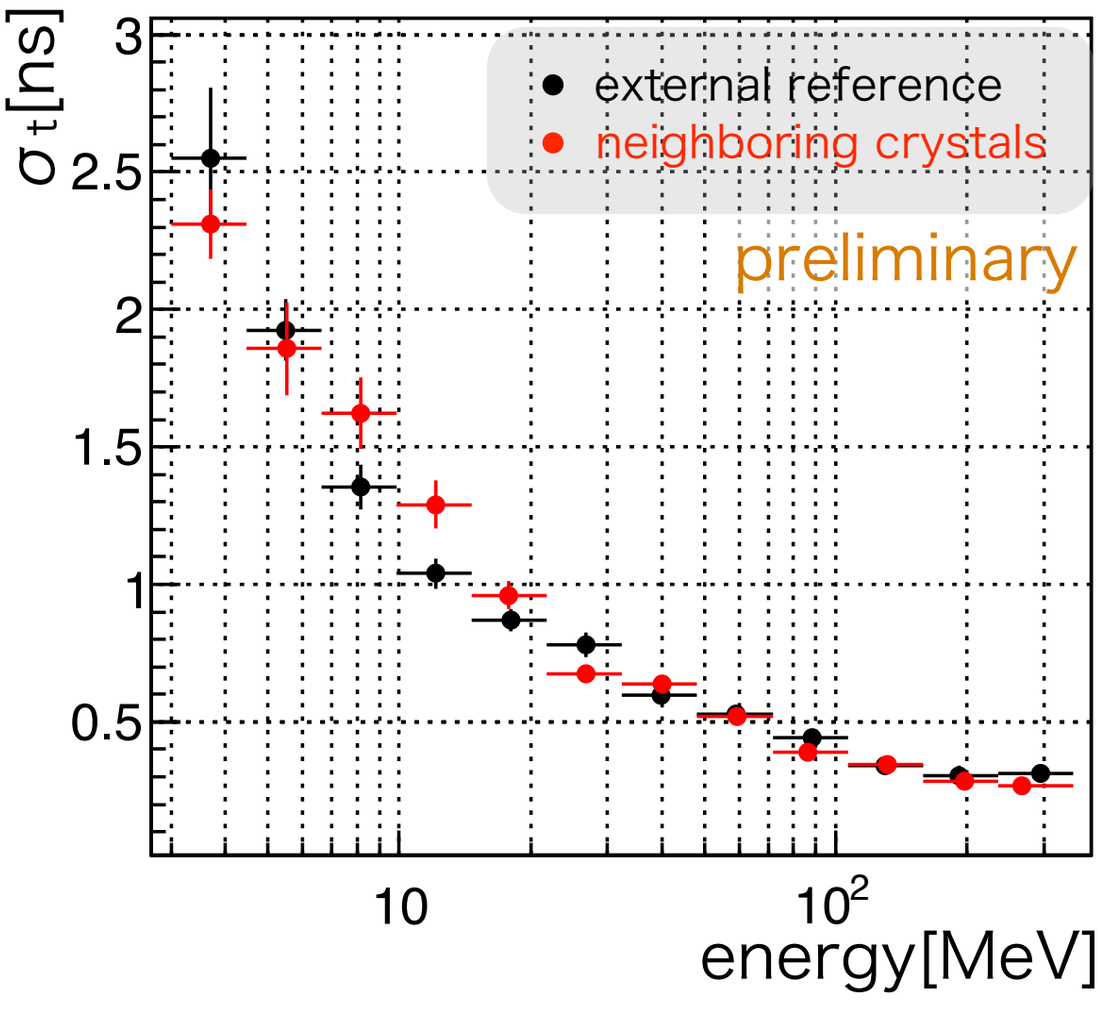
CsI calorimeter - beam test

- measure the energy and timing resolution

$$\frac{\sigma_E}{E}[\%] = \frac{1.3}{\sqrt{E}} \oplus \frac{0.1}{E} \oplus 0.8 \quad (E : \mathrm{GeV},\ 0^\circ)$$

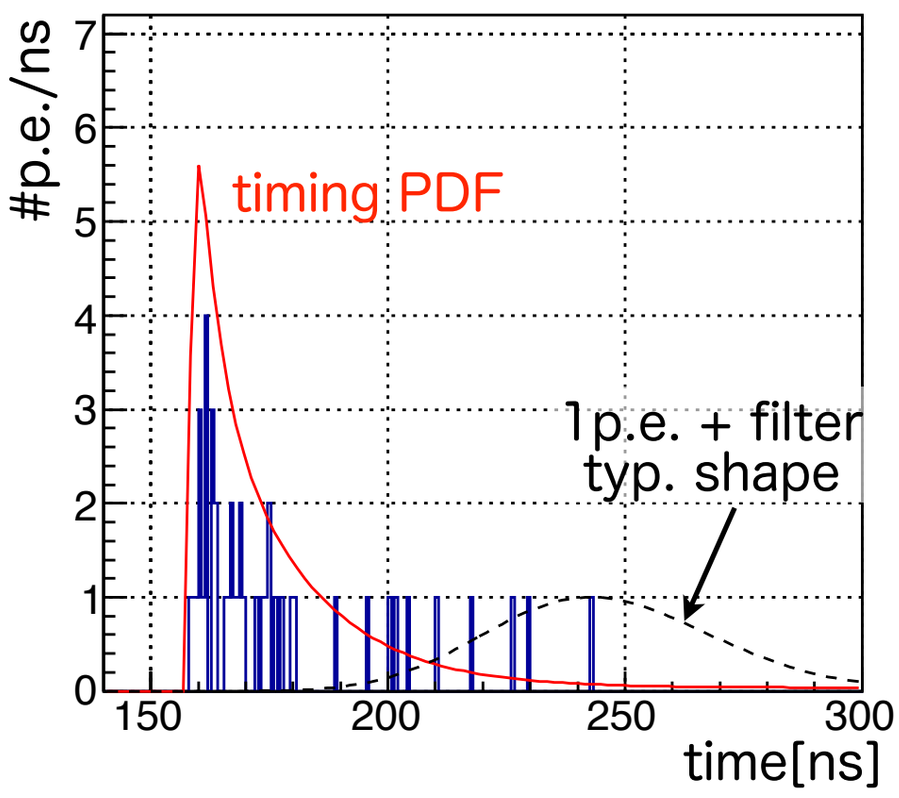
$$\sigma_t\ [\mathrm{ns}] = \frac{0.12}{\sqrt{E}} \oplus 0.10 \quad (E : \mathrm{GeV})$$

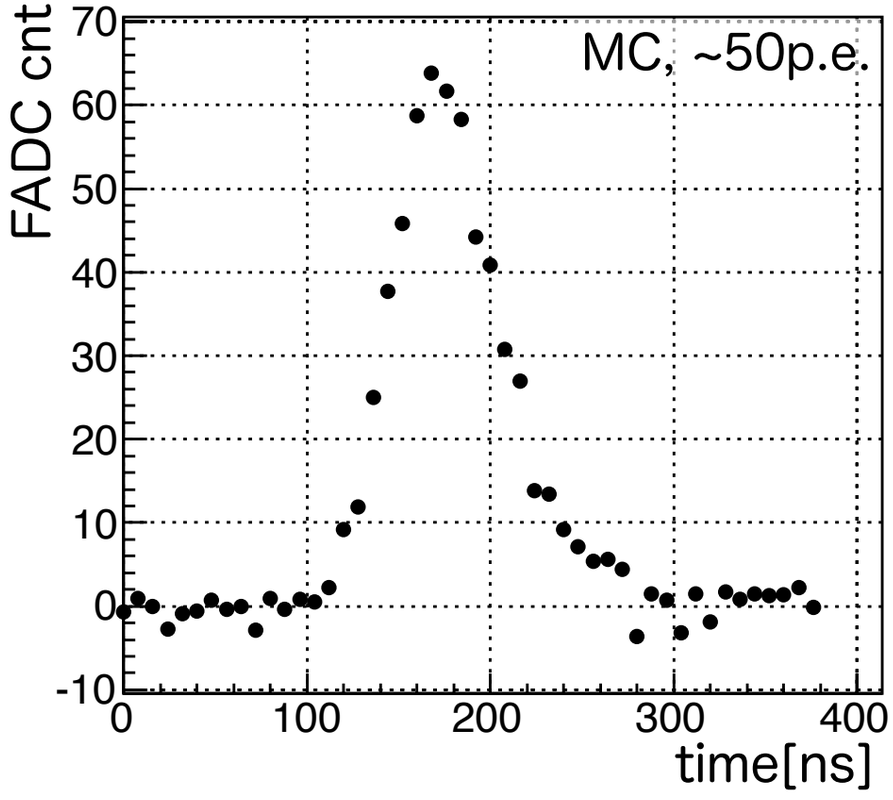




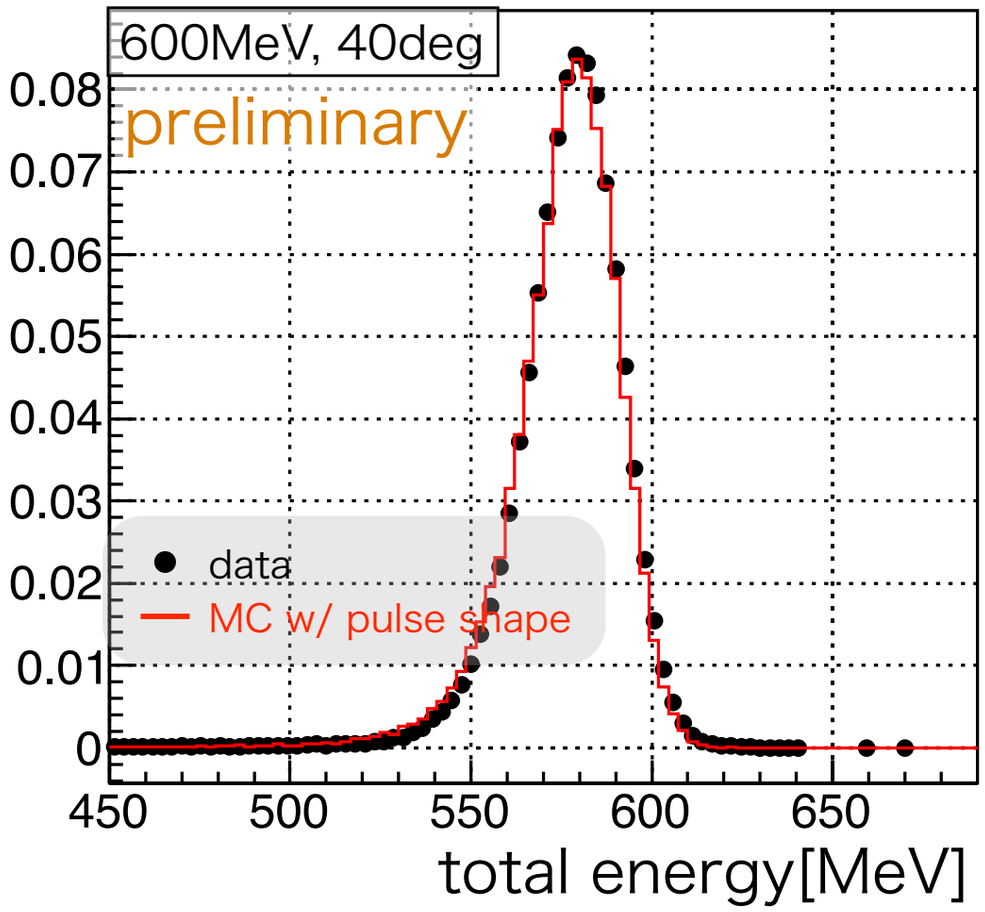
Pulse shape based estimation method

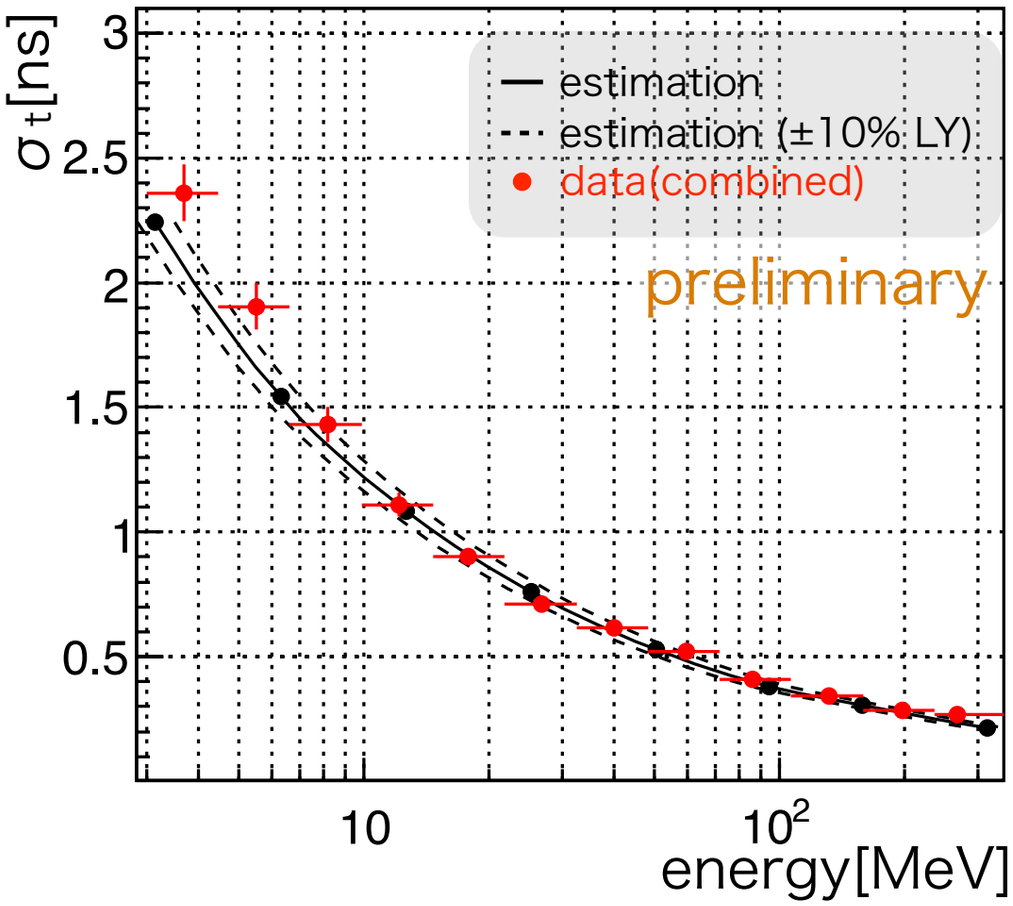
- pulse shape simulation w/ fundamental properties of single photoelectrons
  - typical waveform passing through the Bessel filter
  - probability density function in timing
- absolute light yield : 12.7 p.e./MeV (typical)





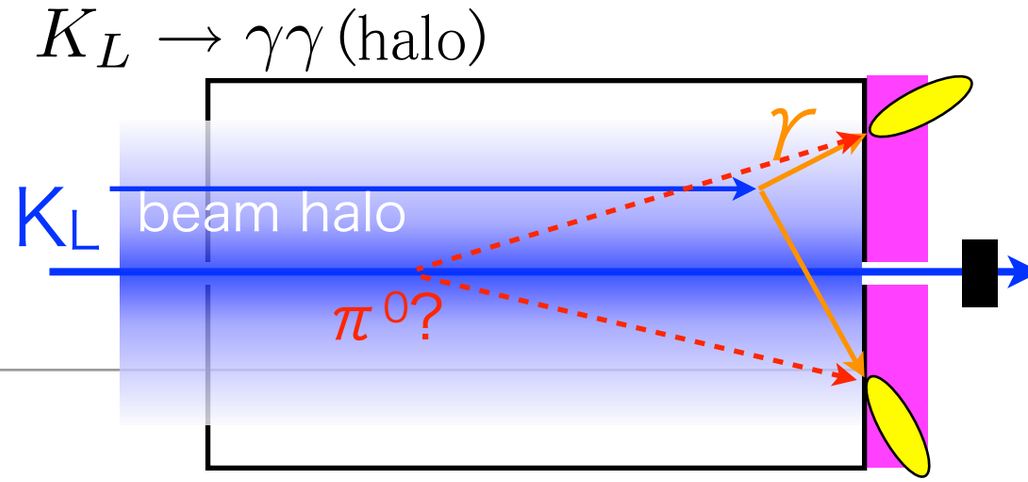
CsI calorimeter - performance evaluation



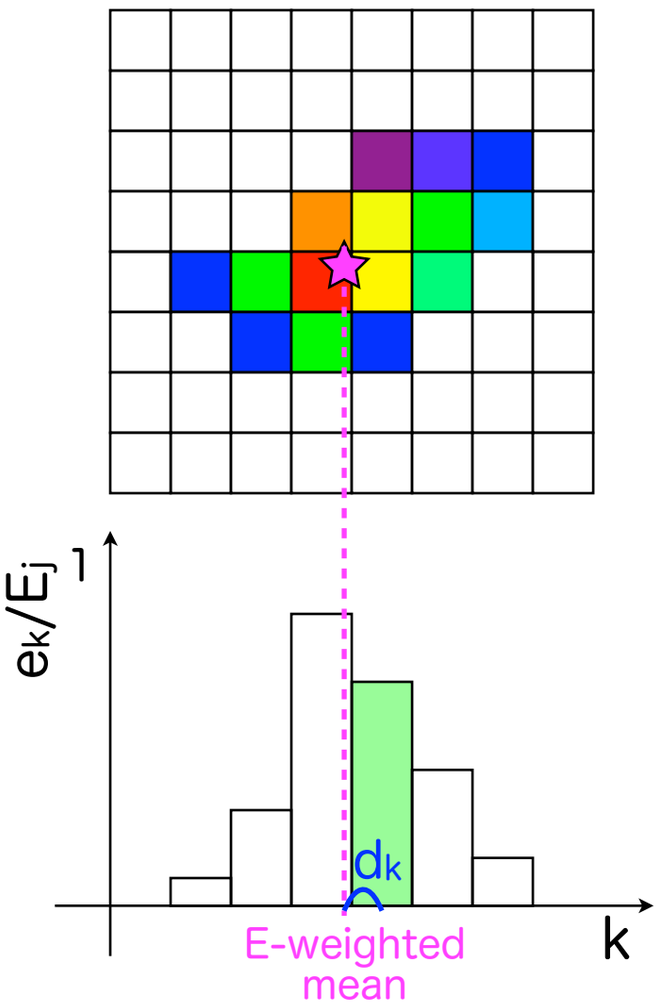


✓ understand σ_E, σ_t from 1st principles

Incident angle discrimination

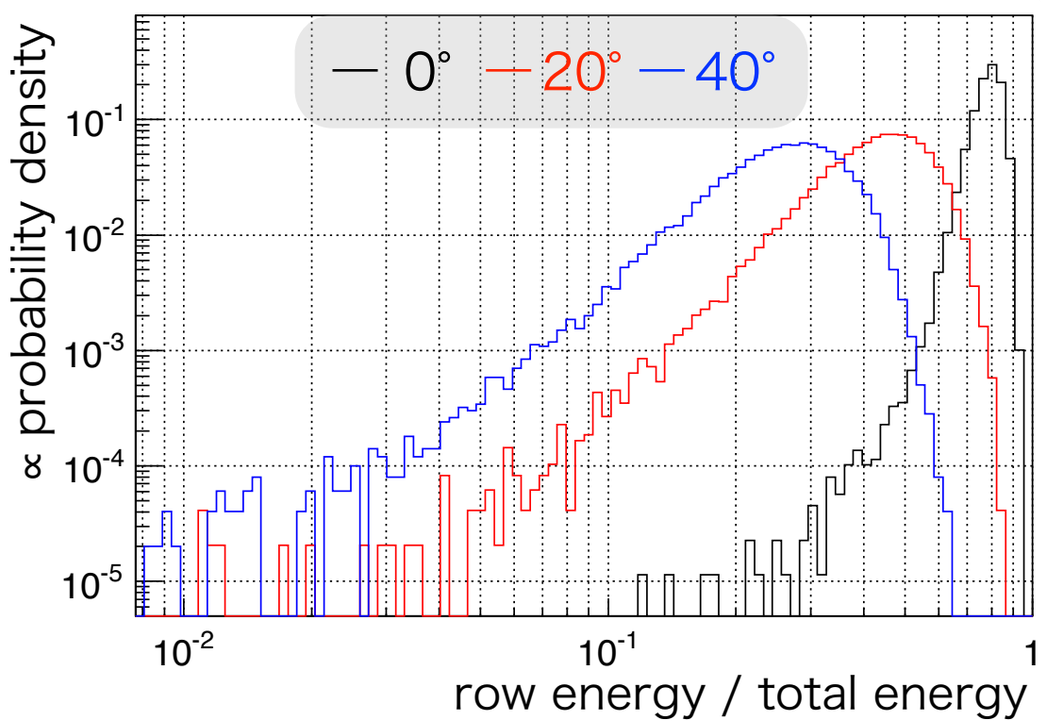


- calculate incident angles assuming signal and BG
- calculate the likelihood of the observed shower shape for each assumption



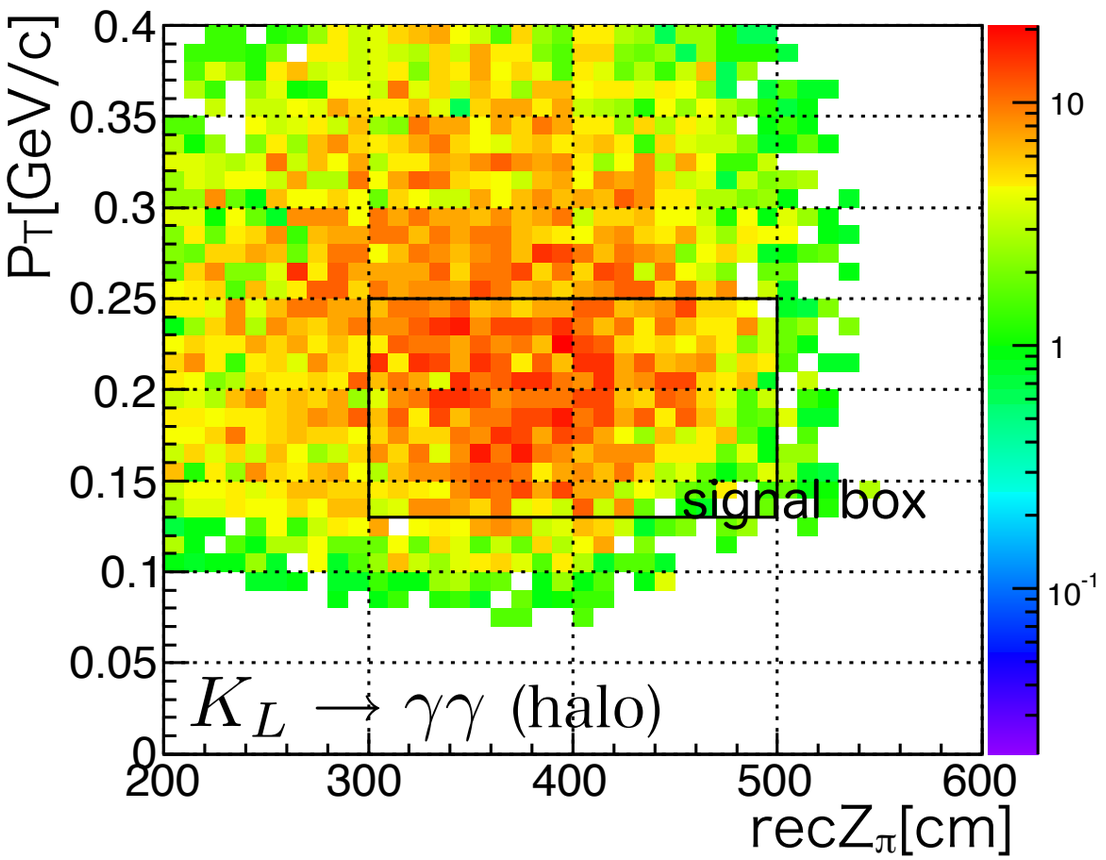
$$L_i = \prod_{j;\gamma} \prod_{x,y} \prod_{k;\mathrm{row}} P(e_k | E_j, d_k, \theta_{ij}, \phi_{ij})$$

PDF in a certain condition for each incident angle

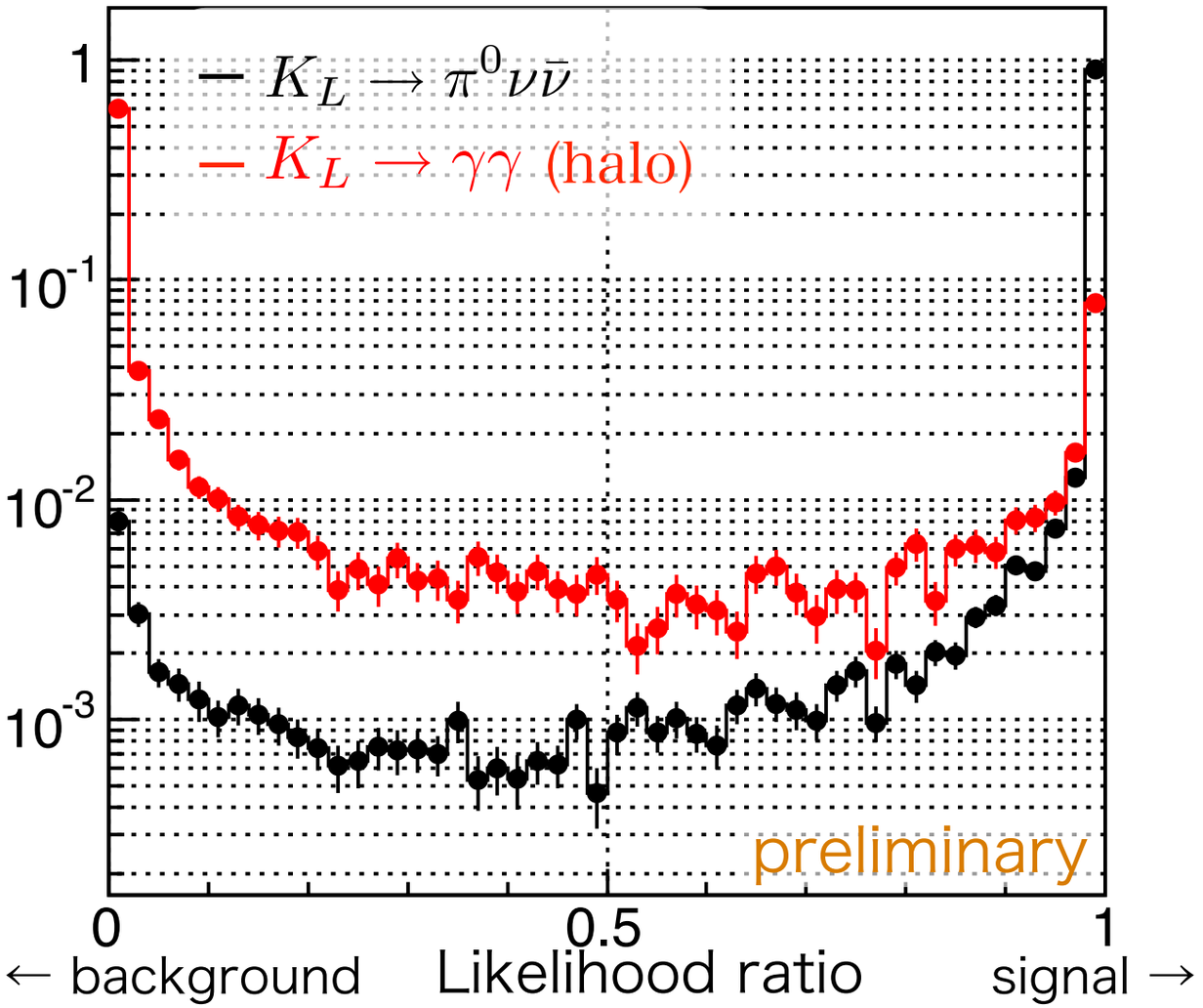


Incident angle discrimination : rejection power

- rejection power @ 83% signal efficiency
  - 53 for $K_L \to \gamma\gamma$ decay in the beam halo
  - (8.7 for $\eta \to \gamma\gamma$)



$$\text{Likelihood ratio} = \frac{L_{\text{signal}}}{L_{\text{signal}} + L_{\text{BG}}}$$



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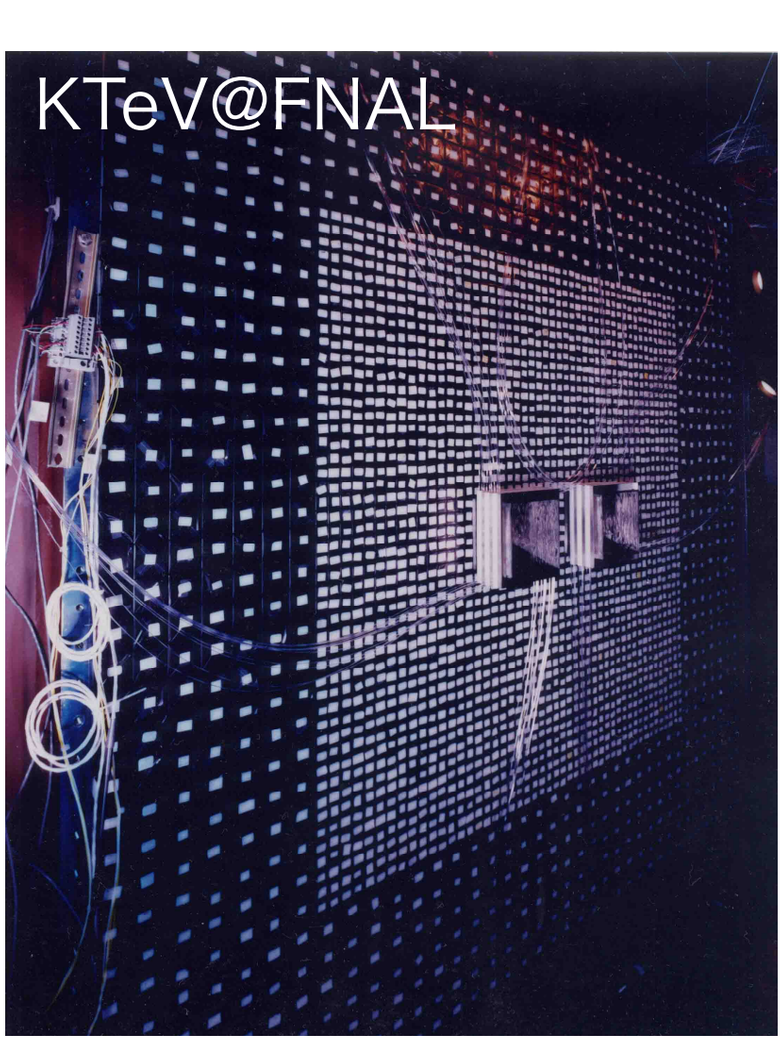
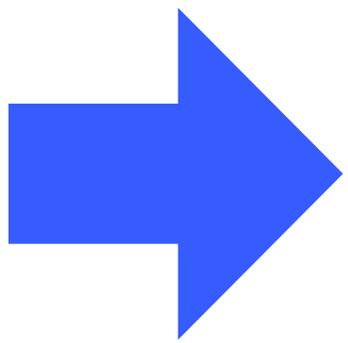
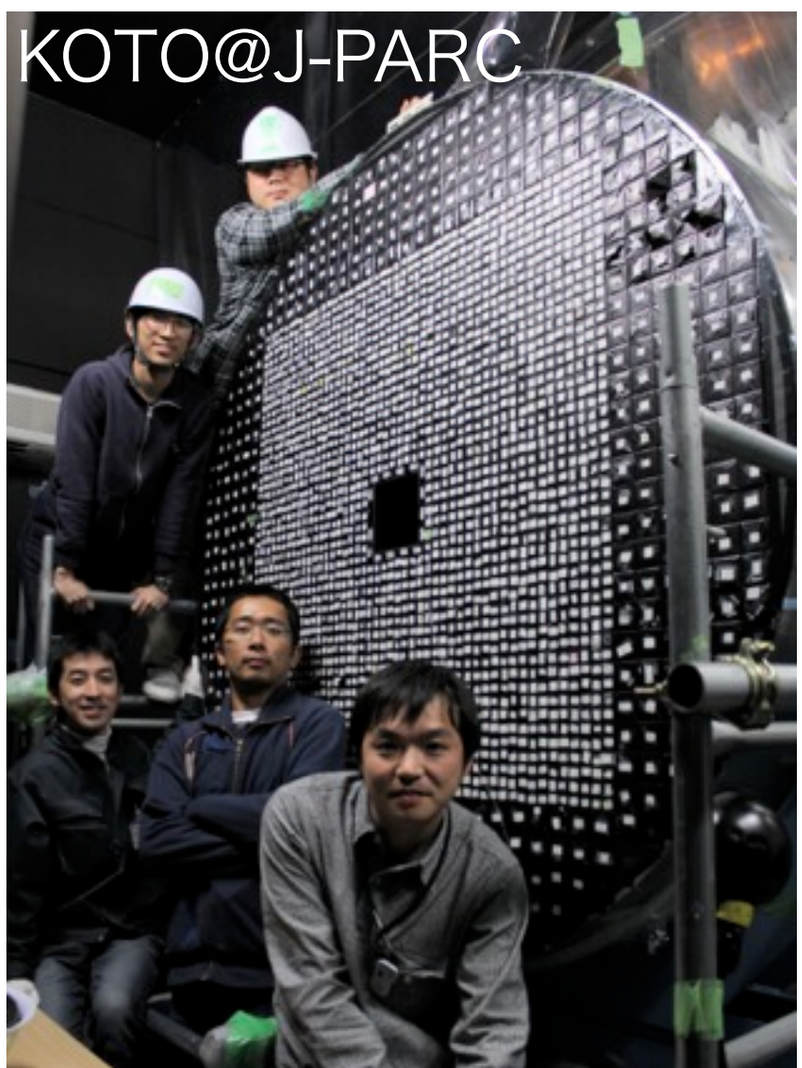
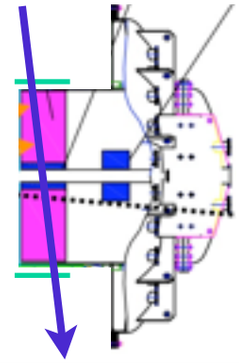
- Smaller : 7cm → 2.5/5cm square
- CsI crystals from KTeV experiment

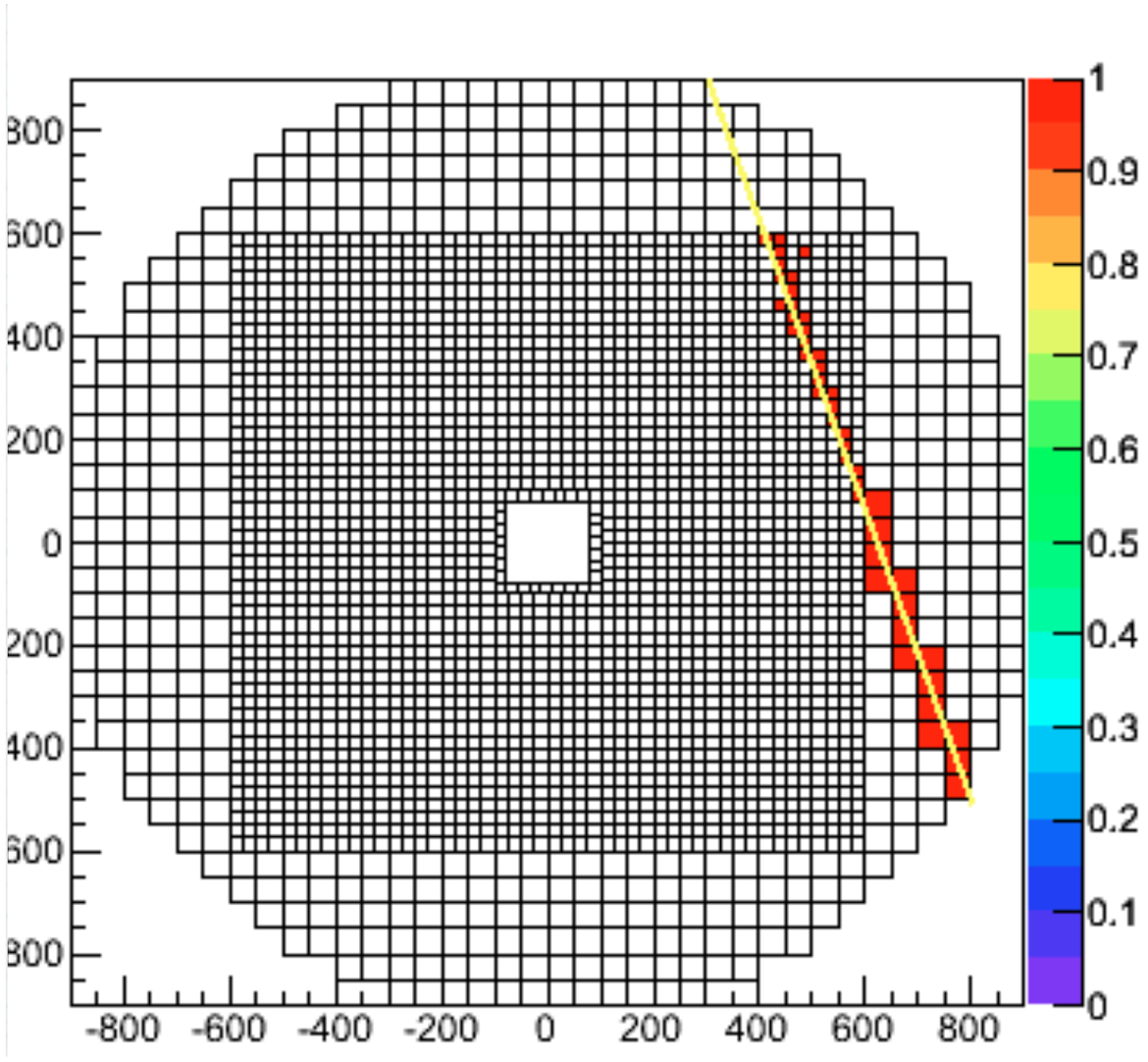


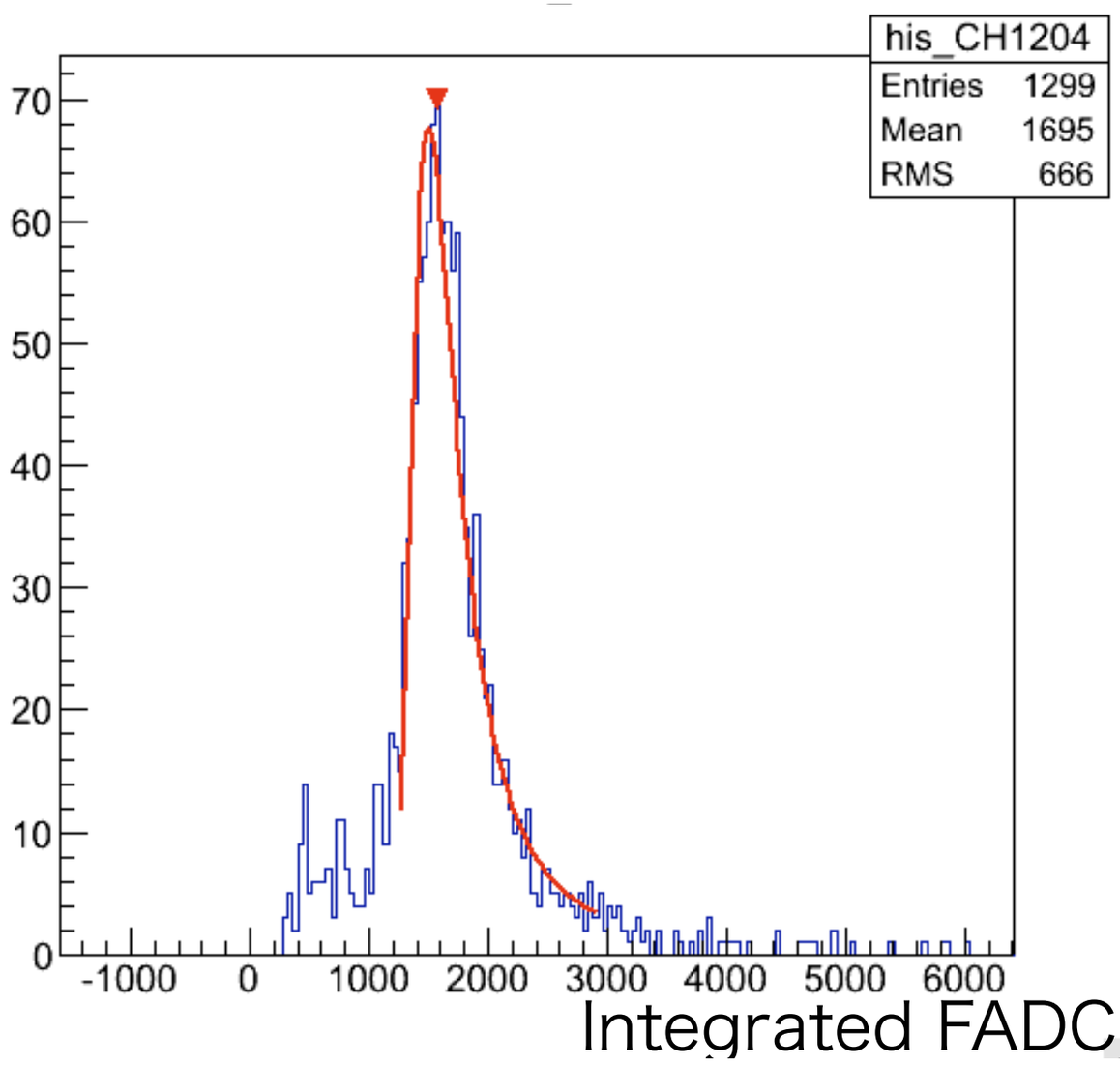




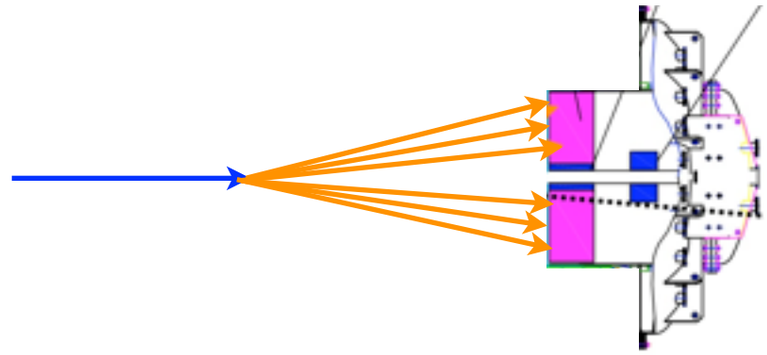
CsI calorimeter - cosmic rays

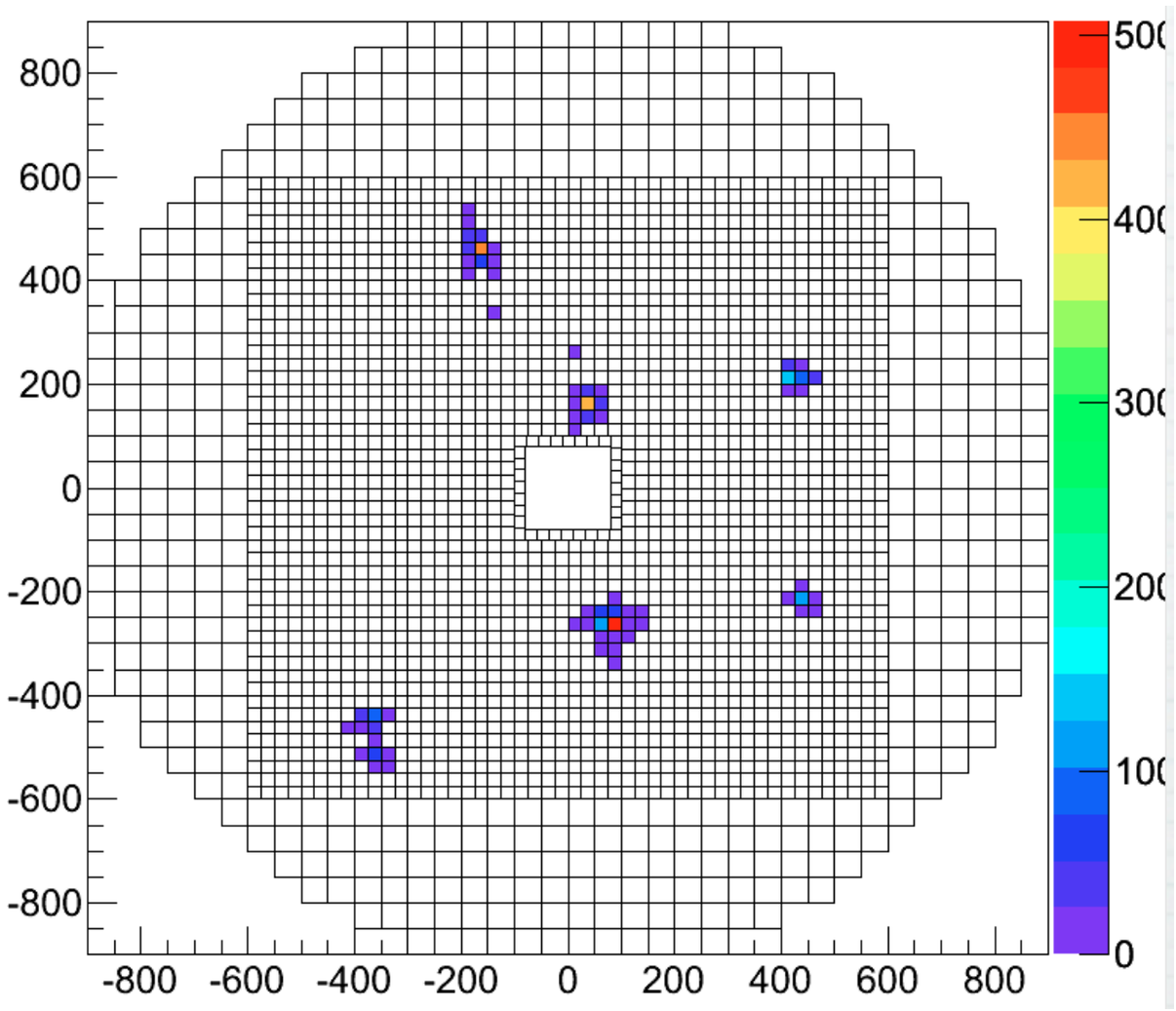


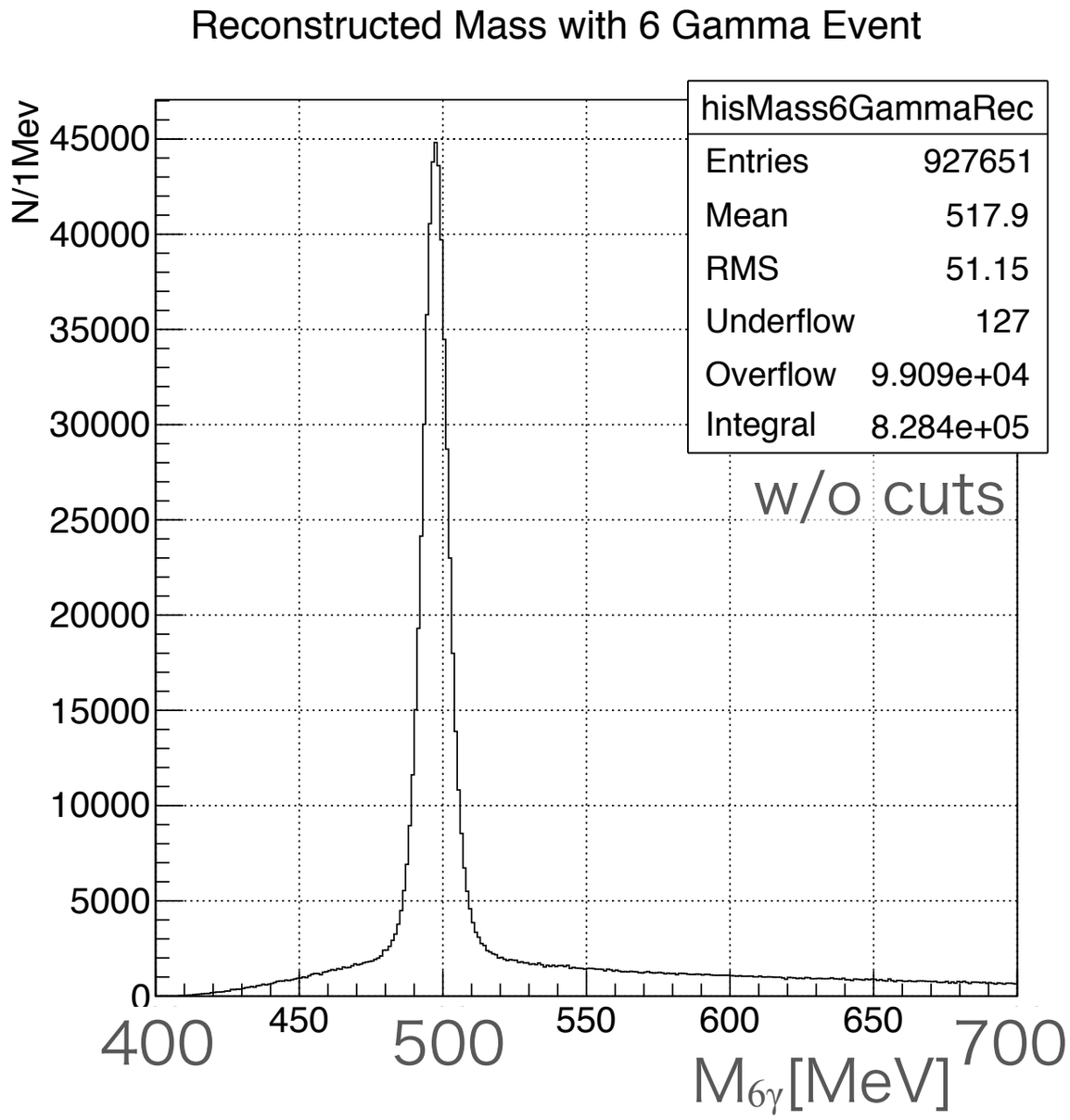




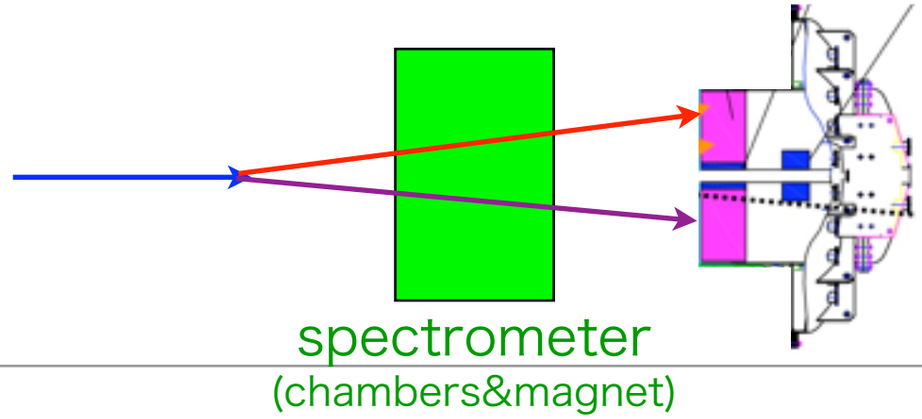
CsI calorimeter - $K_L \to \pi^0\pi^0\pi^0$

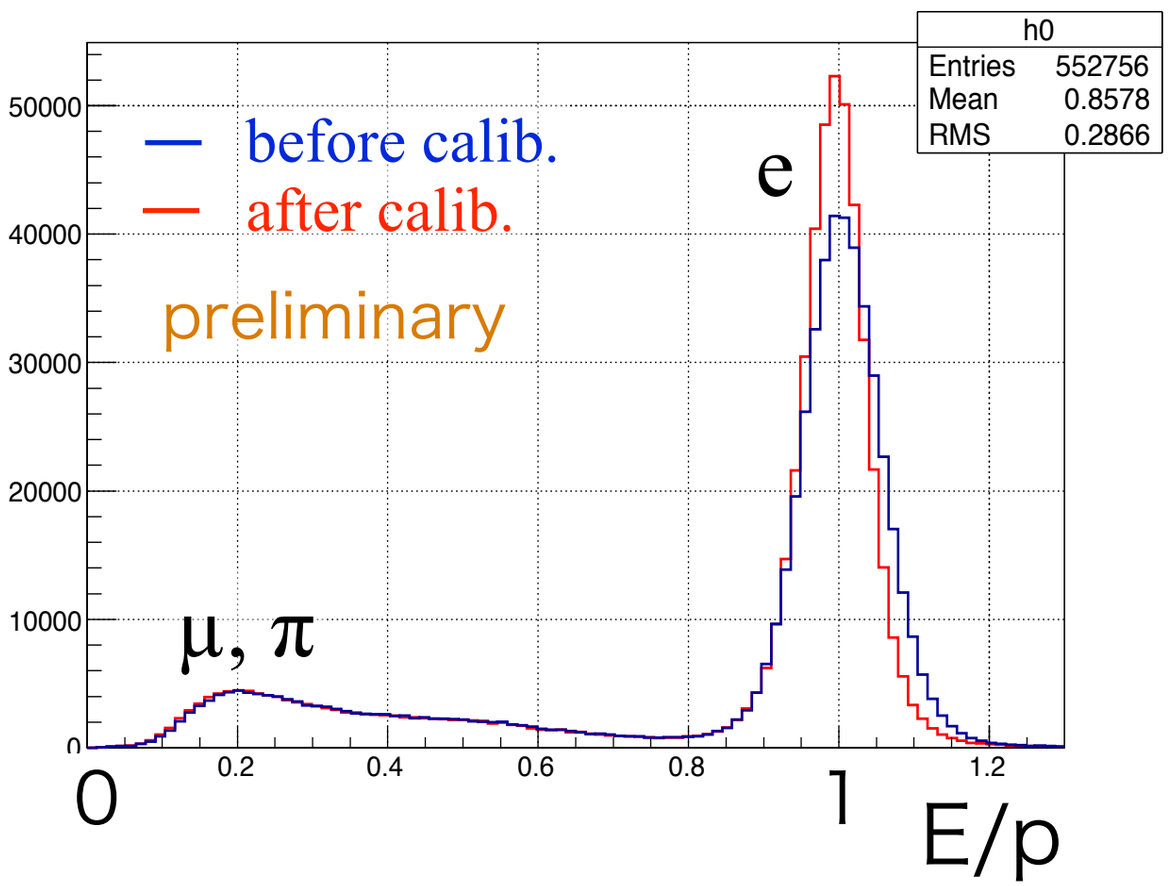


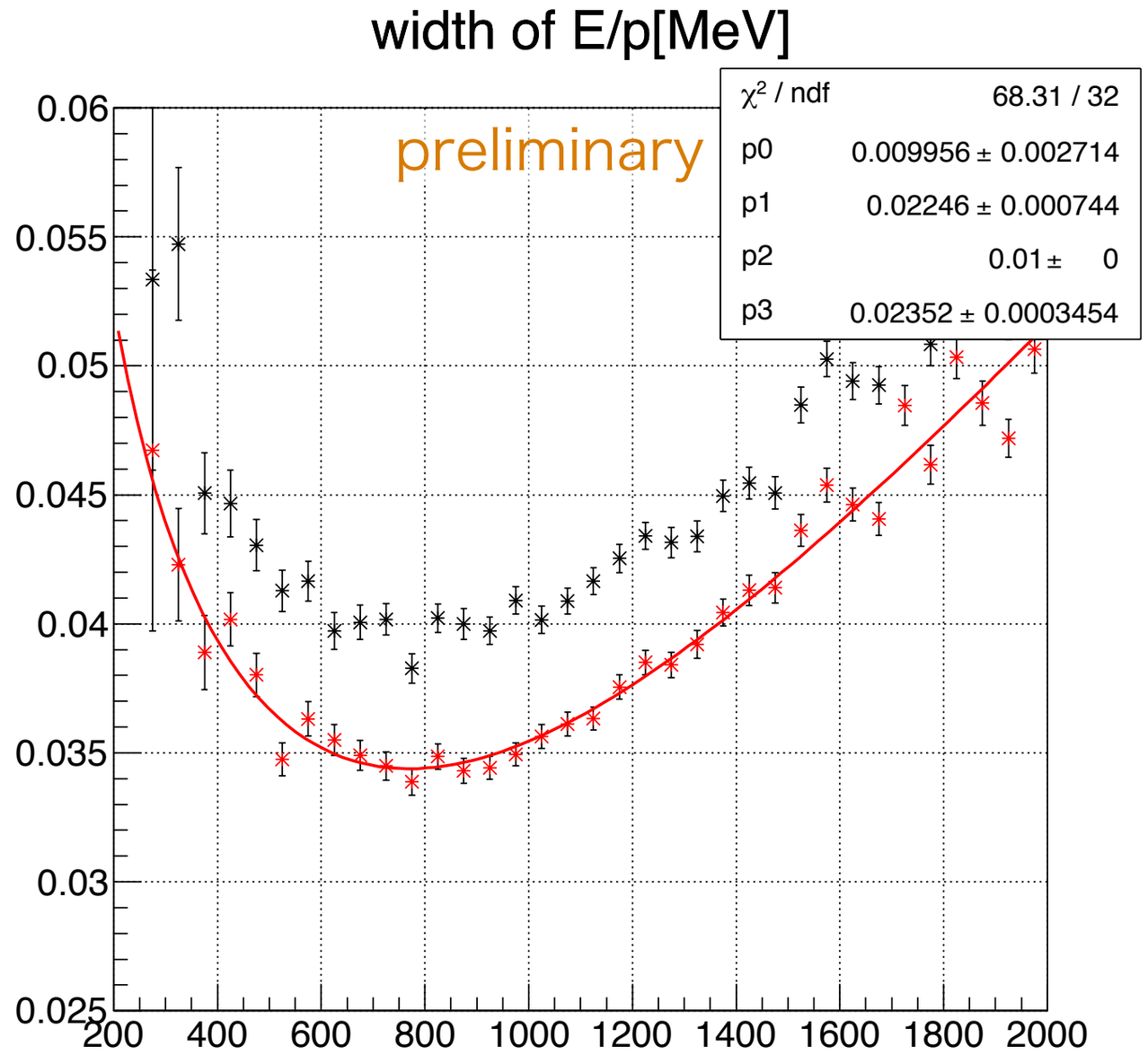




CsI calorimeter - $K_L \to \pi e \nu$

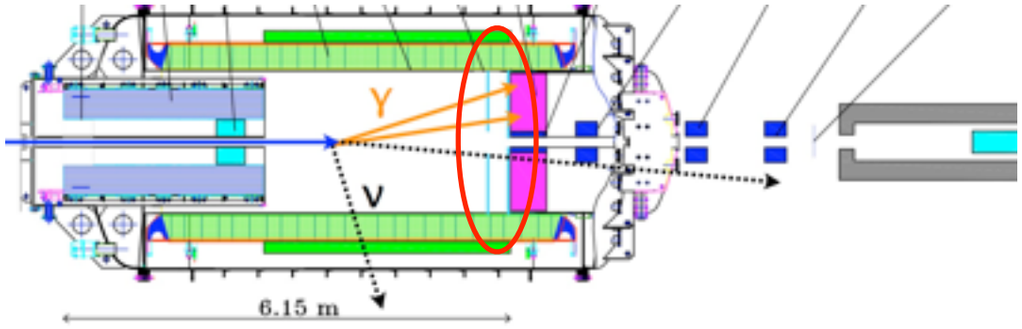




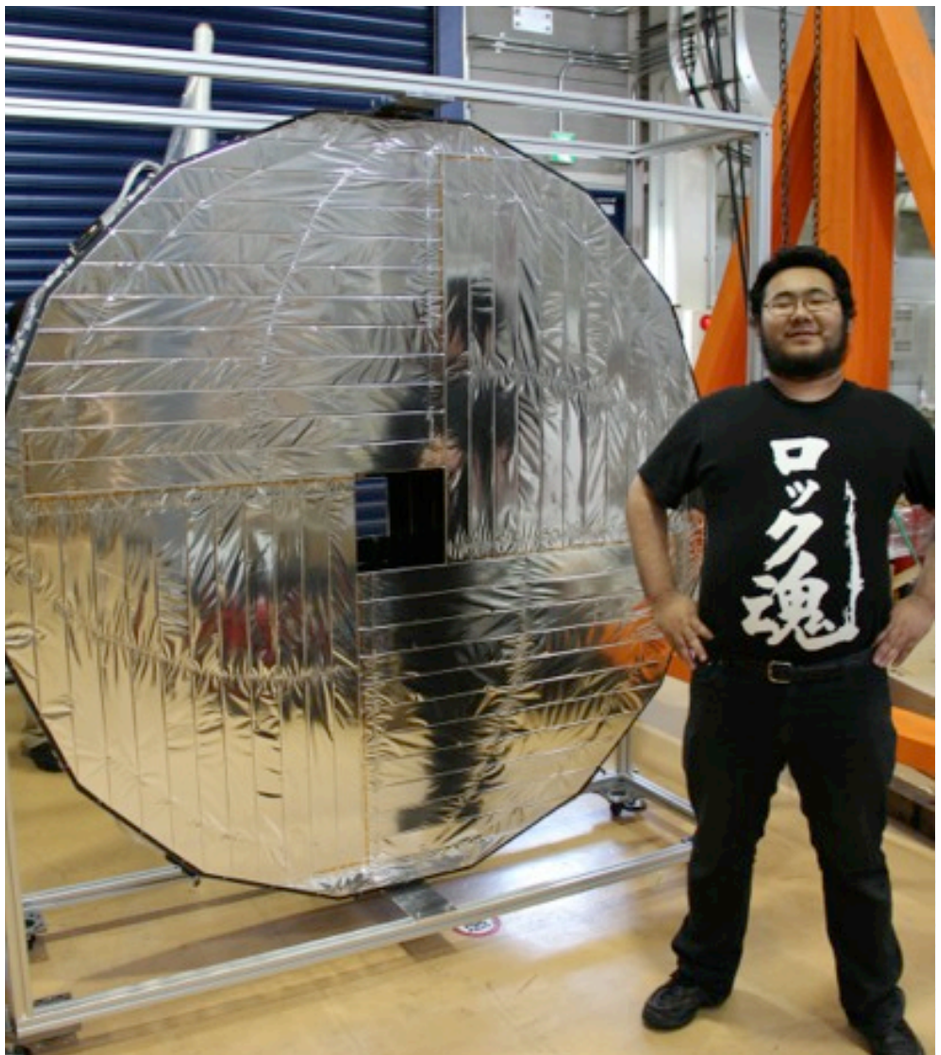


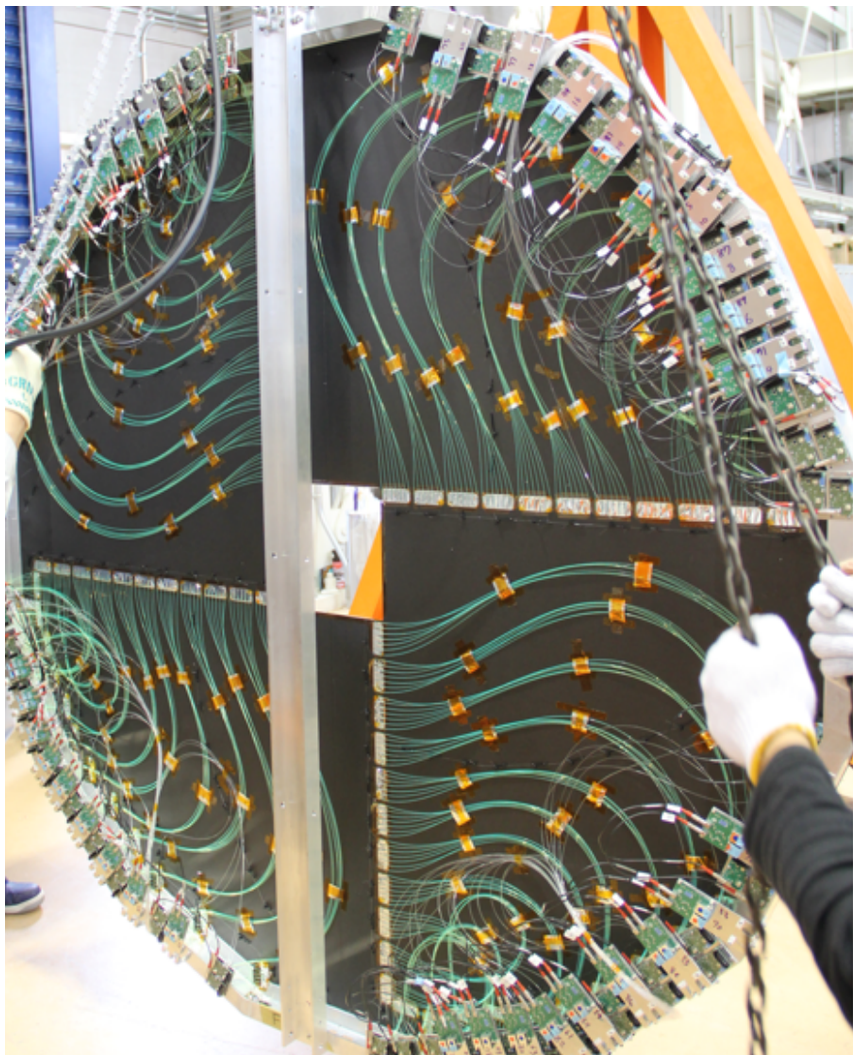
- High intensity K_L beam
- Waveform digitization
- CsI calorimeter
- New Veto detectors

Charged Veto

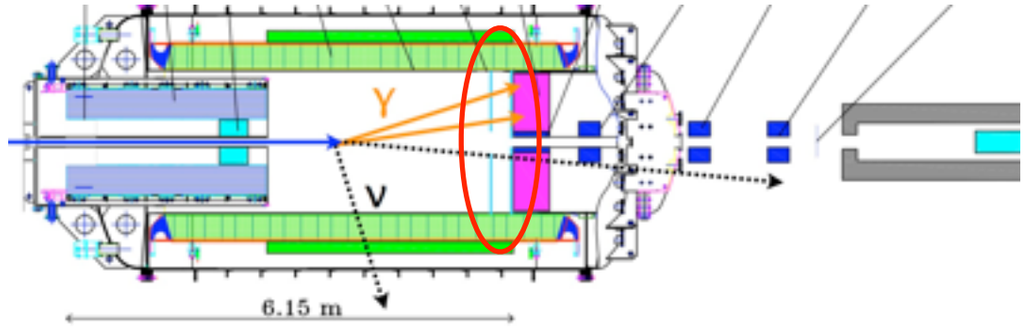


- Thin(3mm) to suppress neutron interaction
- <10^{-3} inefficiency (2 planes ~10^{-6})
  - >10p.e./100keV

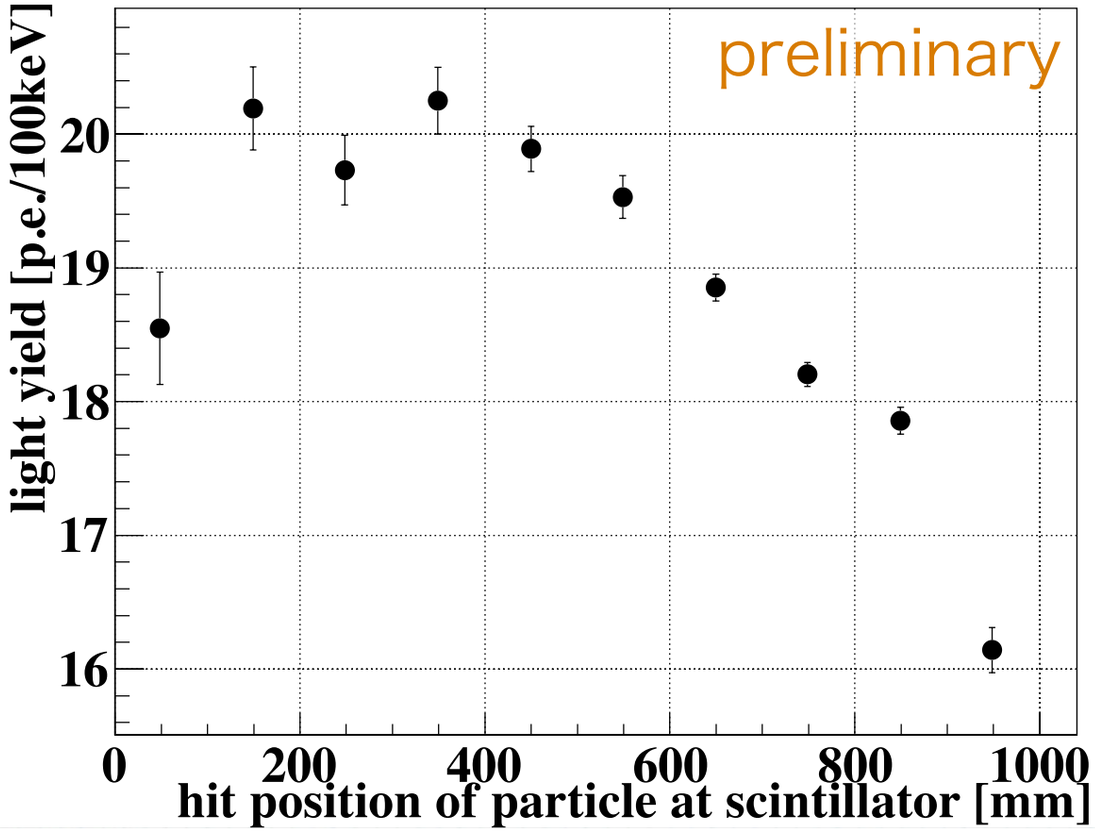


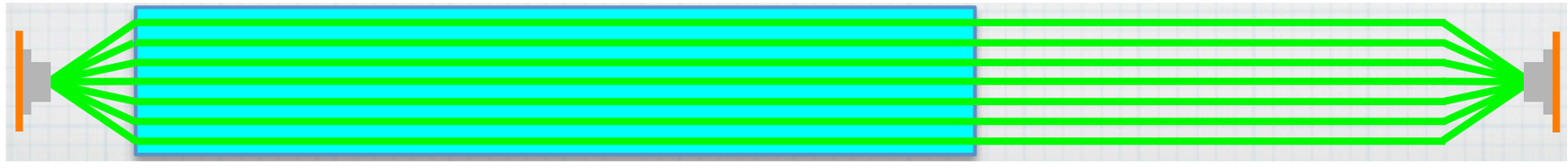


Charged Veto

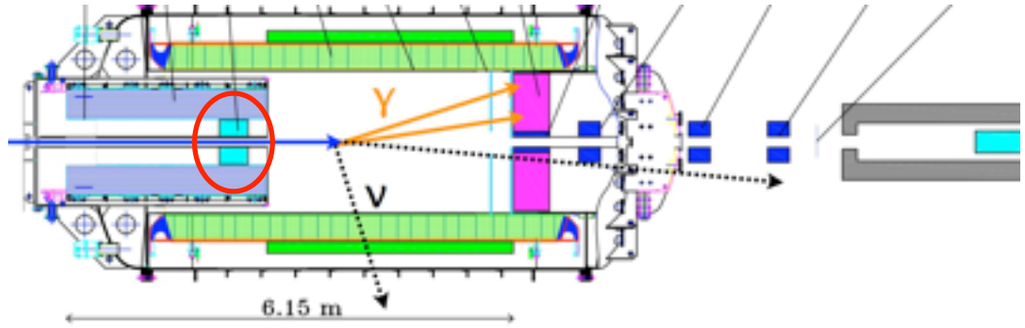


- Thin(3mm) to suppress neutron interaction
- <10^{-3} inefficiency (2 planes ~10^{-6})
  - >10p.e./100keV

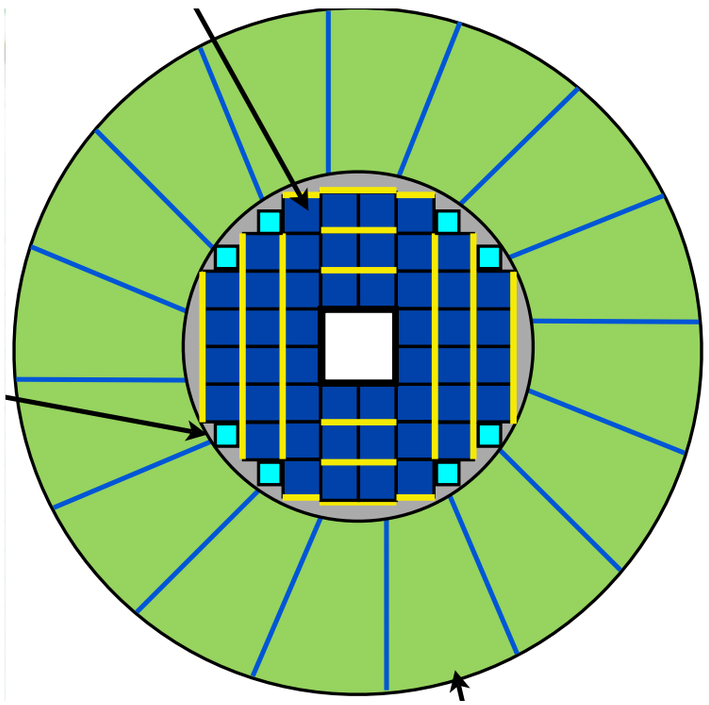


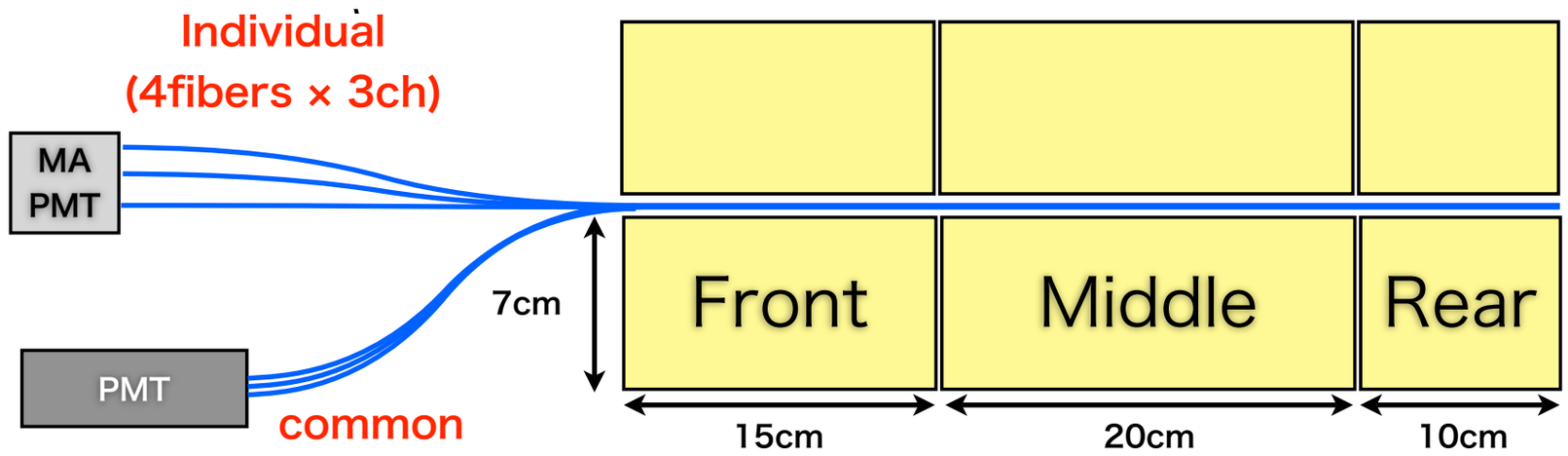


Neutron Collar Counter

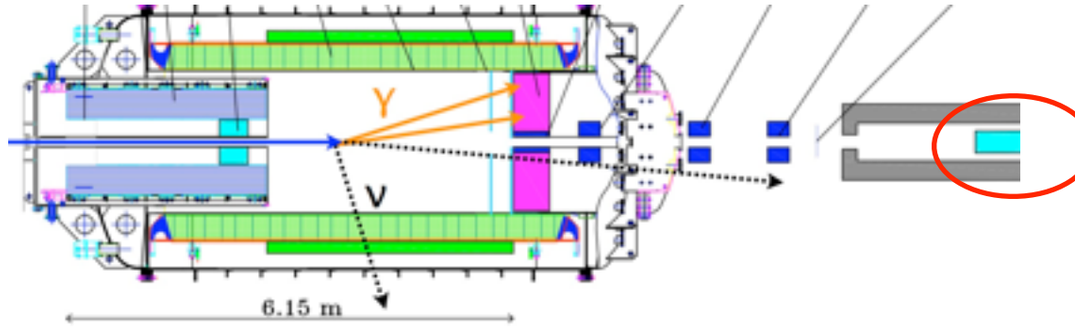


- Purpose
  - Veto photons
  - count halo neutrons
- 48 3-CsI-block modules

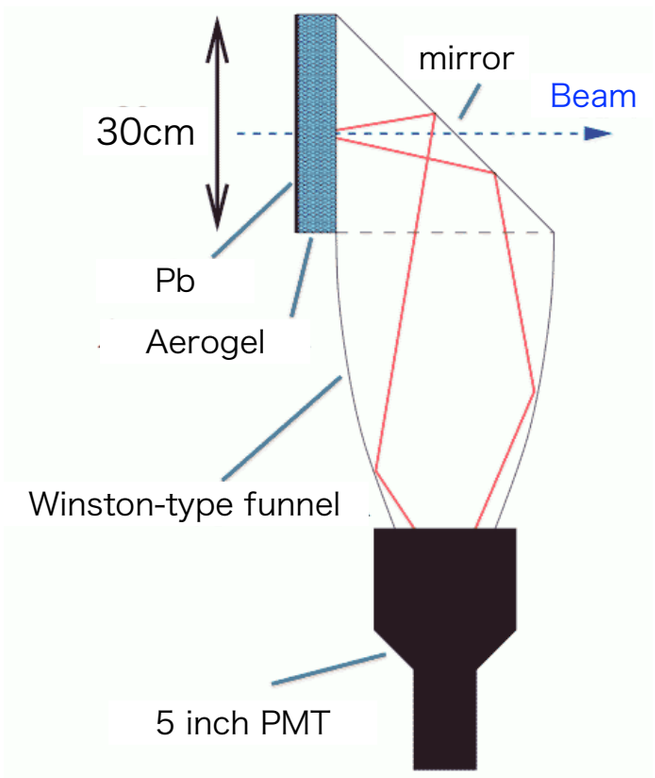


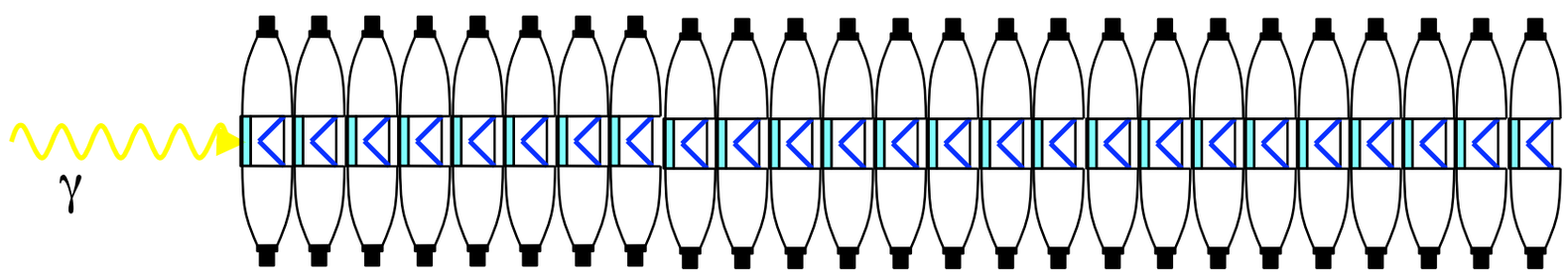


Beam Hole Photon Veto

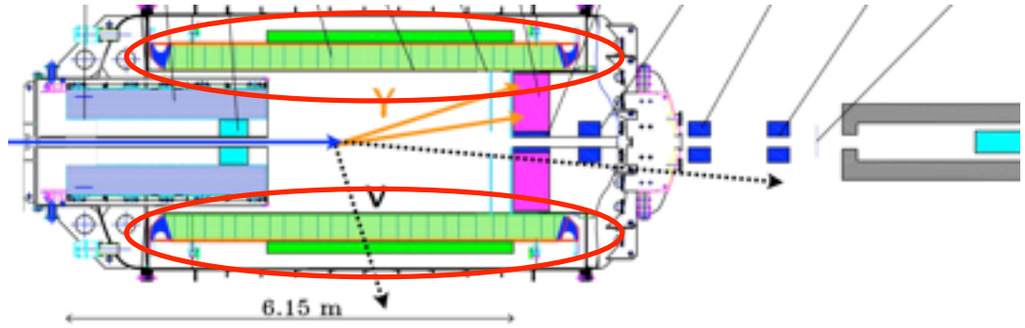


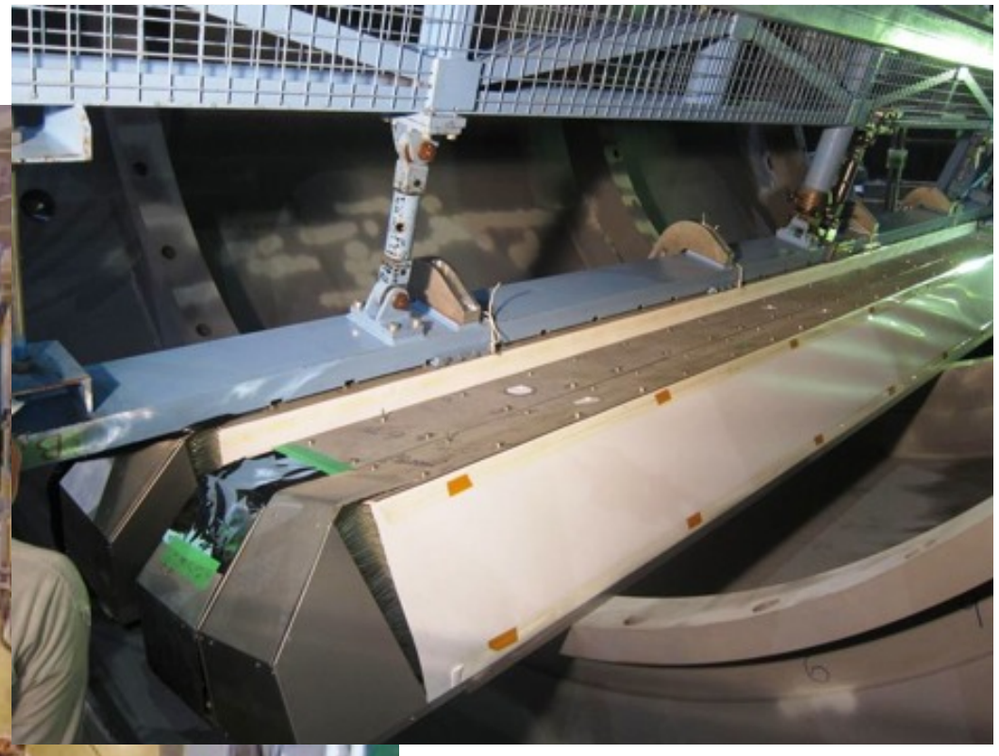
- Veto photons escaping to the beam hole
- Aero-gel cerenkov detector (25 modules)
  - good efficiency for photons
  - inefficient for neutrons in the beam core





Main Barrel





Prospect

2012 Dec — Engineering runs in air/vacuum

2013 Mar — Short Physics run

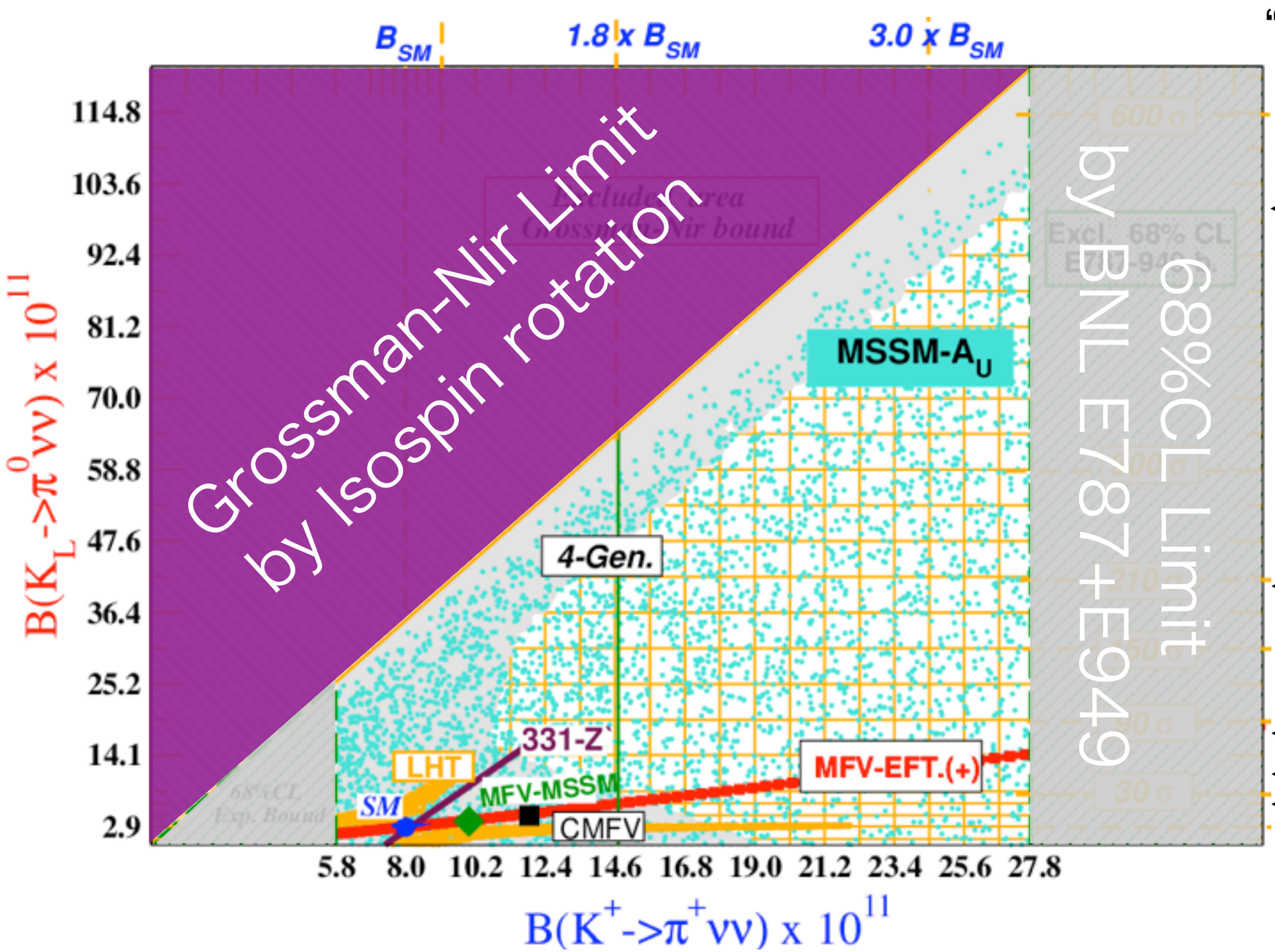
May — Long Physics run ~1month@15kW

⇒ to cross the Grossman-Nir bound

July — A long shut-down for Linac upgrade

2014 Jan

Prospect



"3sigma discovery"

← 2013

← 2014 spring

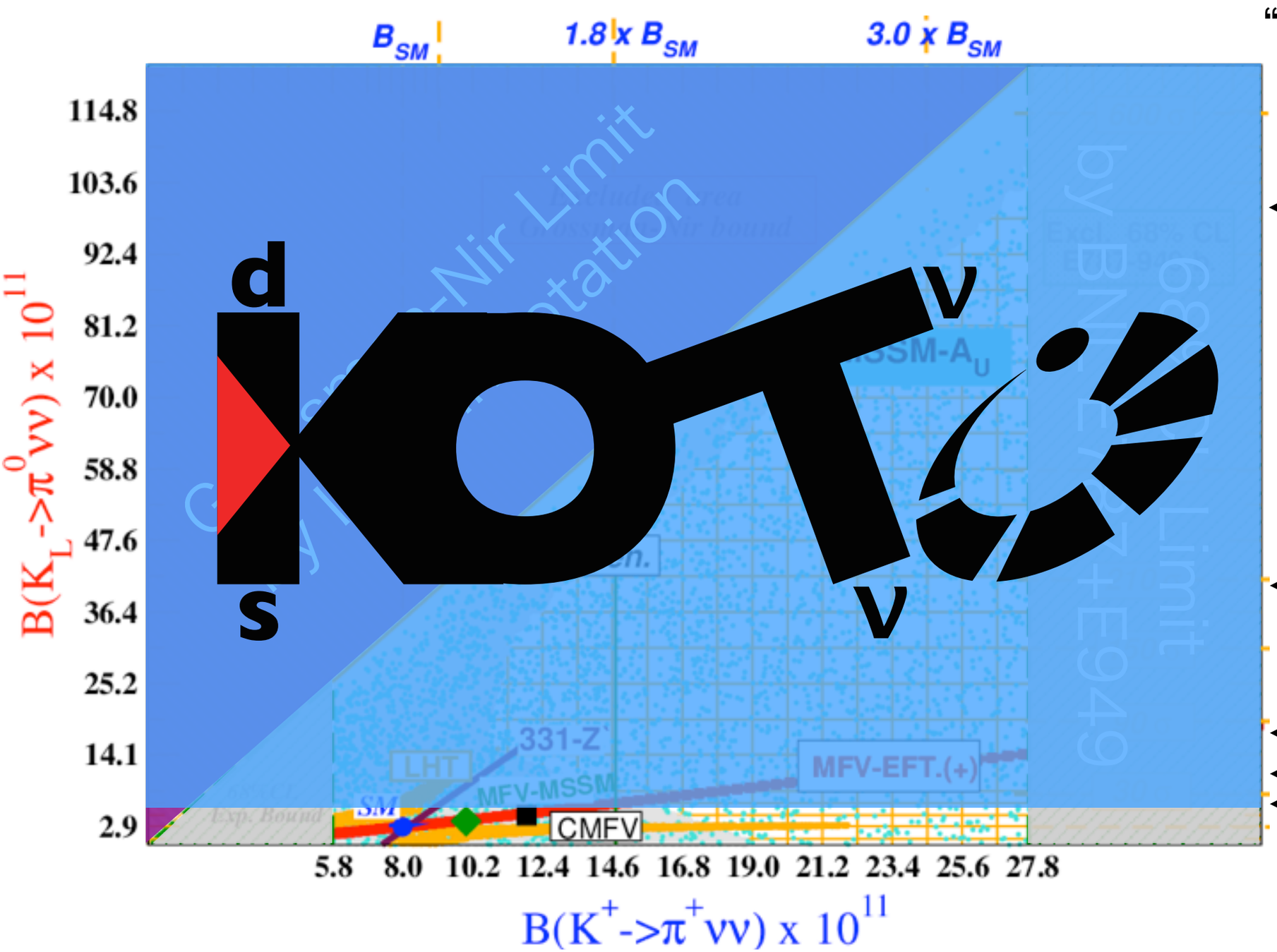
← 2014 fall

← 2015

← 2017

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

Prospect



"3sigma discovery"

← 2013

← 2014 spring

← 2014 fall

← 2015

← 2017

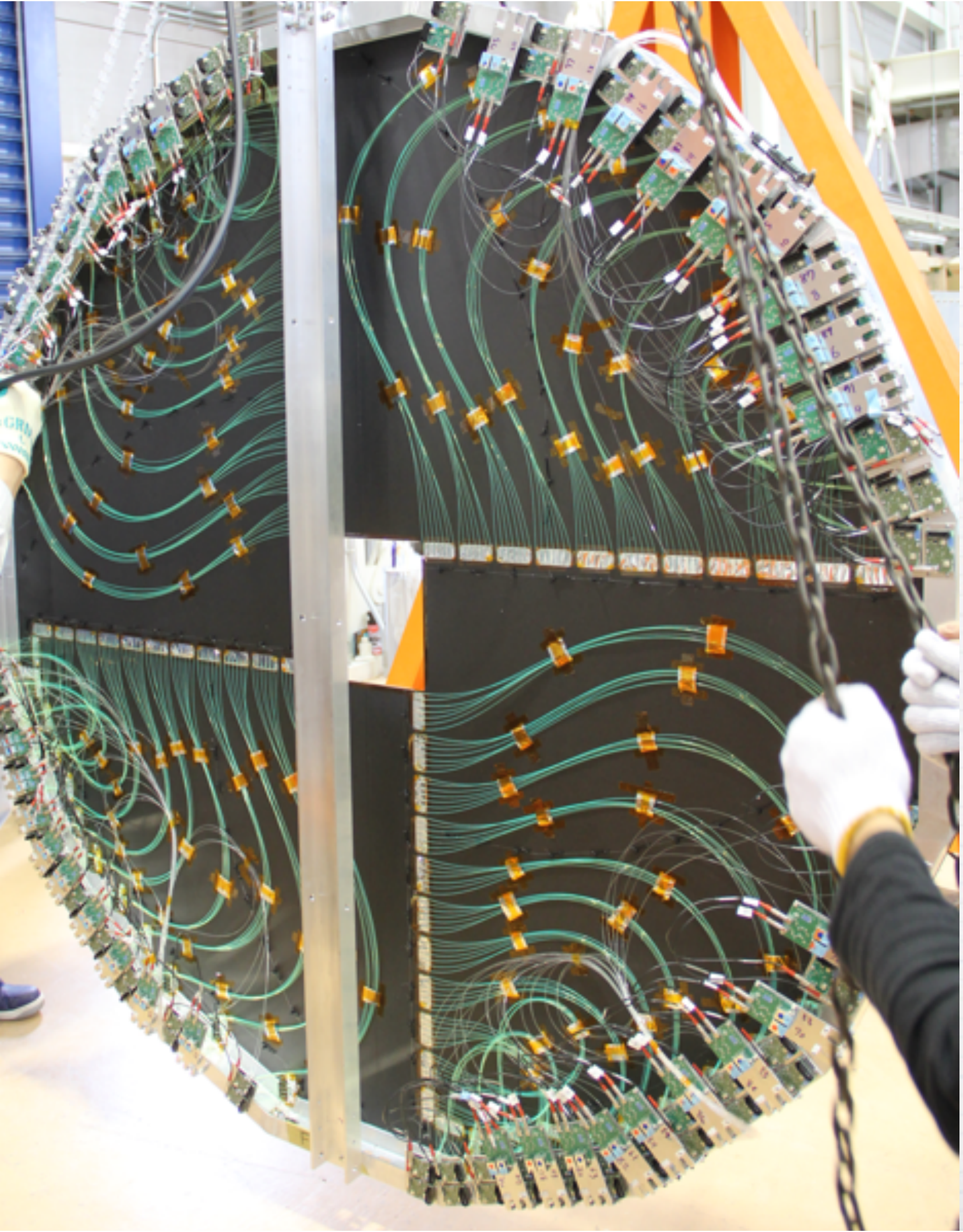
http://www.lnf.infn.it/wg/vus/content/Krare.html

Summary

- KOTO is the dedicated experiment to search for CPV caused by New Physics beyond the SM by observing $K_L \to \pi^0 \nu \bar{\nu}$ decay
- High intensity K_L beam and upgraded detectors were designed and prepared
- Experimental apparatus is almost ready to take physics data
  - The first physics run will start in 2013 spring, and the experimental sensitivity will cross the Grossman-Nir bound

➡ New physics search

- The expected final sensitivity of KOTO will reach the SM prediction



* 92 x 3mm thick scintillators
* read by WLS fibers + MPPC

Discovery Level