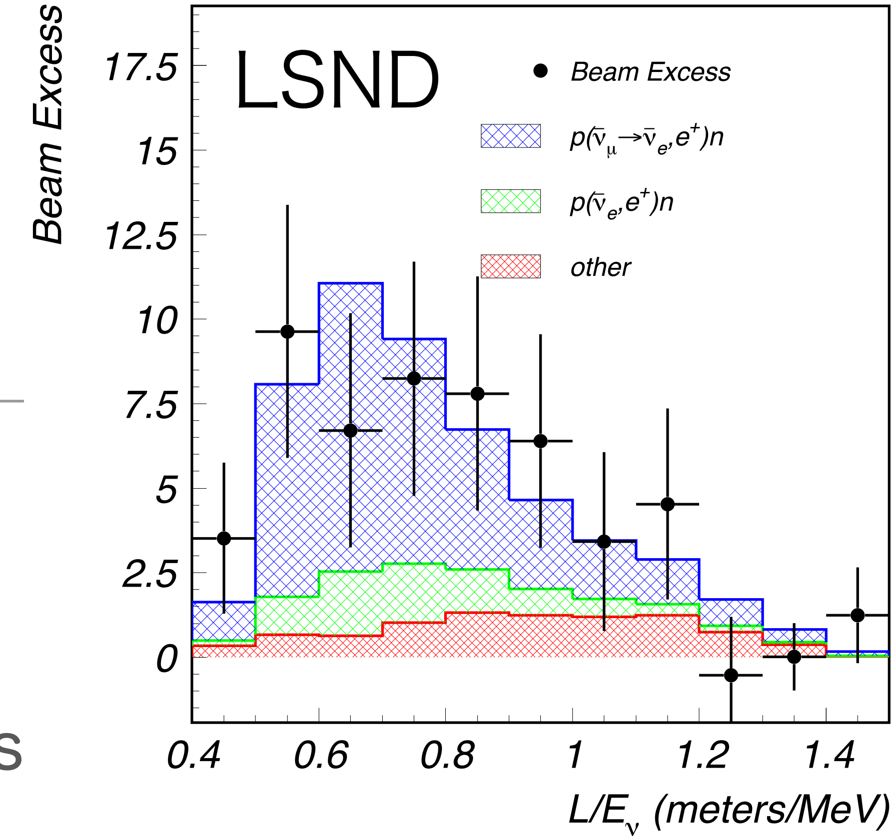
# Stopped pion experiments in the sterile neutrino field

Aug. 14, 2015 NuFact15@Rio de Janeiro

Eito Iwai, IPNS/KEK

# Sterile neutrino

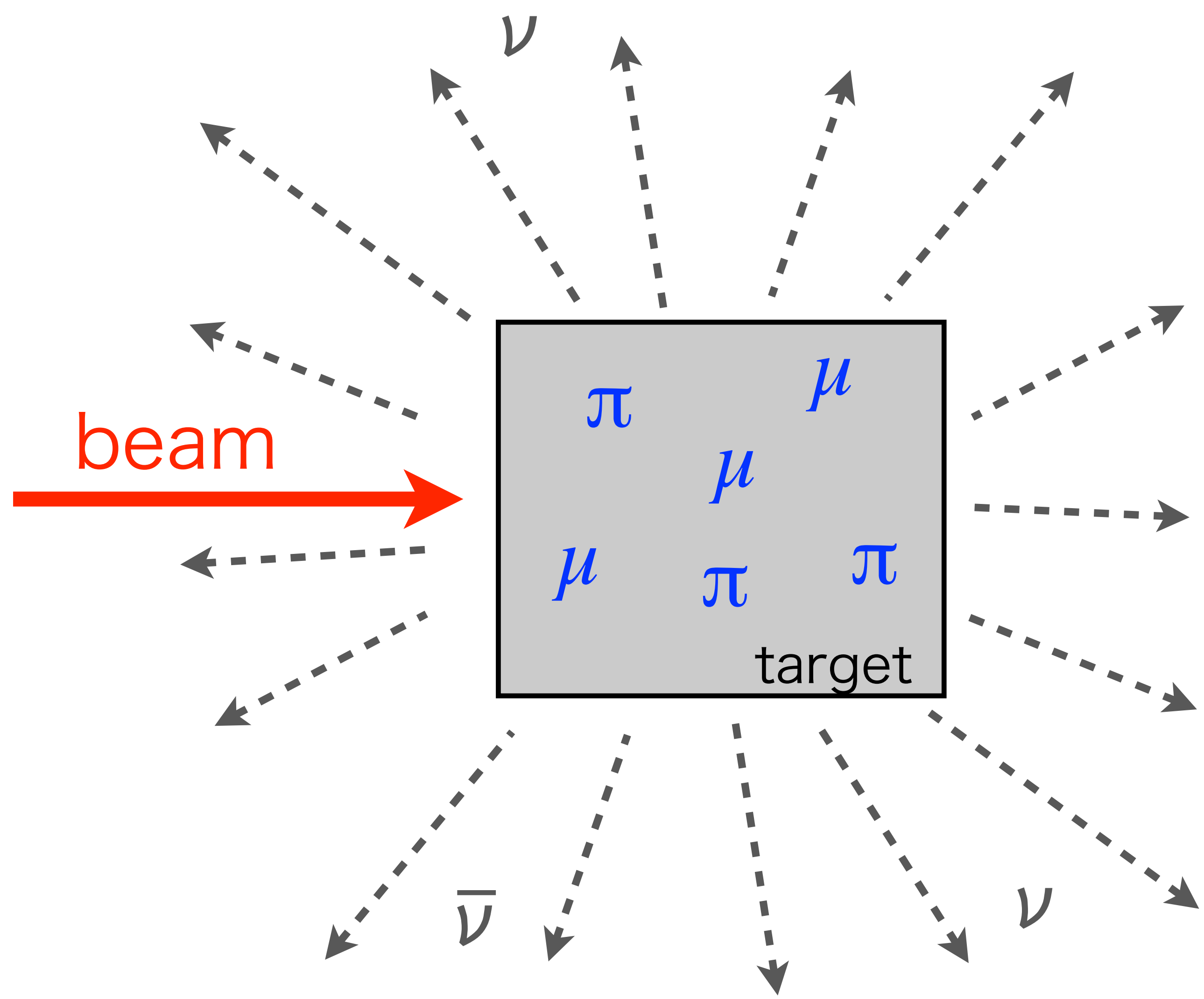



- What's sterile neutrino?
  - NO electromagnetic, strong and weak interactions
  - If exist, it is a new particle and can be a dark matter candidate
  - Can be observed only by neutrino oscillations
    → indicated by some experiments(>3$\sigma$), but not confirmed yet

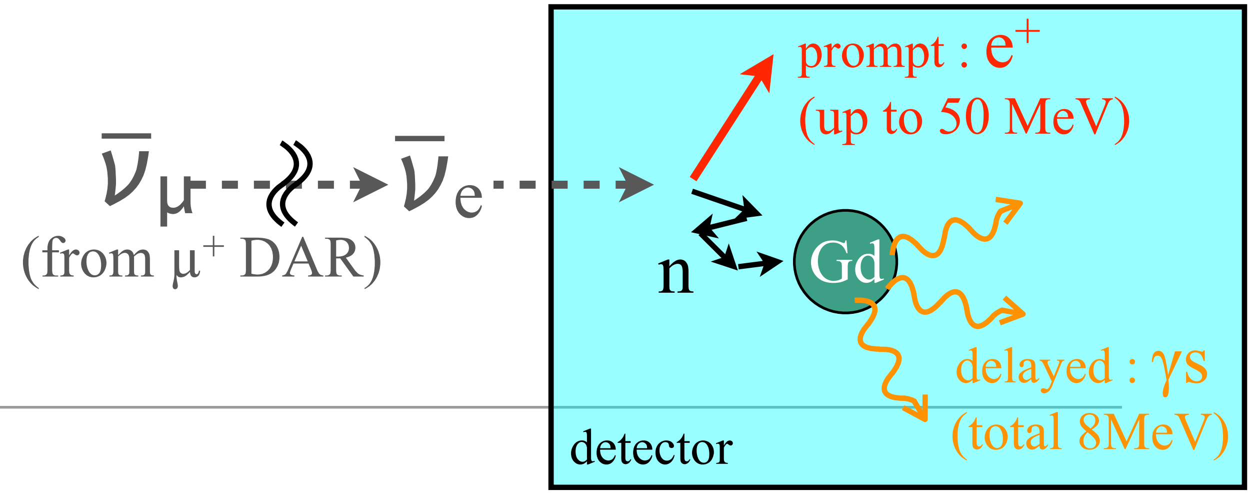
- One of the hottest topics in the neutrino field, and various new experiments are proposed and prepared in the world
- Designing a experiment with small systematic uncertainties is crucial

# Sterile neutrino experiments

- Neutrino source
  - Reactor
  - Source
  - Accelerator decay-in-flight
  - Accelerator decay-at-rest
    - JSNS$^2$ @ J-PARC MLF
    - OscSNS @ ORNL



# Principle of measurement




- signal: $\bar{\nu}_\mu$ $(\to \nu_s) \to \bar{\nu}_e$
- Neutrino source: $\bar{\nu}_\mu$ from $\pi^+ \to \mu^+ \to e^+$ decay at rest
  - intrinsic $\bar{\nu}_e$ : $\pi^- \to \mu^- \to e^-$ chain is suppressed by $\pi/\mu$ captures (by 3 orders of magnitude)
- Inverse beta decay (IBD: $\bar{\nu}_e + p \to e^+ + n$) is utilized
  - cross section and energy reconstruction method of neutrinos are well-known
- Delayed coincidence method: delayed signal is observed as $\gamma$(s) from n-capture (Gd or H)
- Direct and complete test of the LSND

# Advantages over other sterile neutrino oscillation experiments

- Low duty factor <-- beam neutrino
- Well understood $\nu$ energy spectrum <-- neutrinos from decay at rest
- Well understood $\nu$ flux <-- Normalization mode: $\nu_e + {}^{12}C \rightarrow e^- + {}^{12}N_{gs}$ etc.
- Well understood $\nu$ cross sections <-- Inverse beta decay
- Absence of nuclear effects <-- neutrinos from stopped muons ($E_\nu$ <50MeV)

# JSNS$^2$ exp. at J-PARC MLF

**Proposal:**
**A Search for Sterile Neutrino at J-PARC Materials and Life Science Experimental Facility**

September 2, 2013

M. Harada, S. Hasegawa, Y. Kasugai, S. Meigo, K. Sakai, S. Sakamoto, K. Suzuya
*JAEA, Tokai, Japan*

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M. Niiyama
*Department of Physics, Kyoto University, JAPAN*

S. Ajimura, T. Hiraiwa, T. Nakano, M. Nomachi, T. Shima
*RCNP, Osaka University, JAPAN*

T. J. C. Bezerra, E. Chauveau, T. Enomoto, H. Furuta, H. Sakai, F. Suekane
*Research Center for Neutrino Science, Tohoku University, JAPAN*

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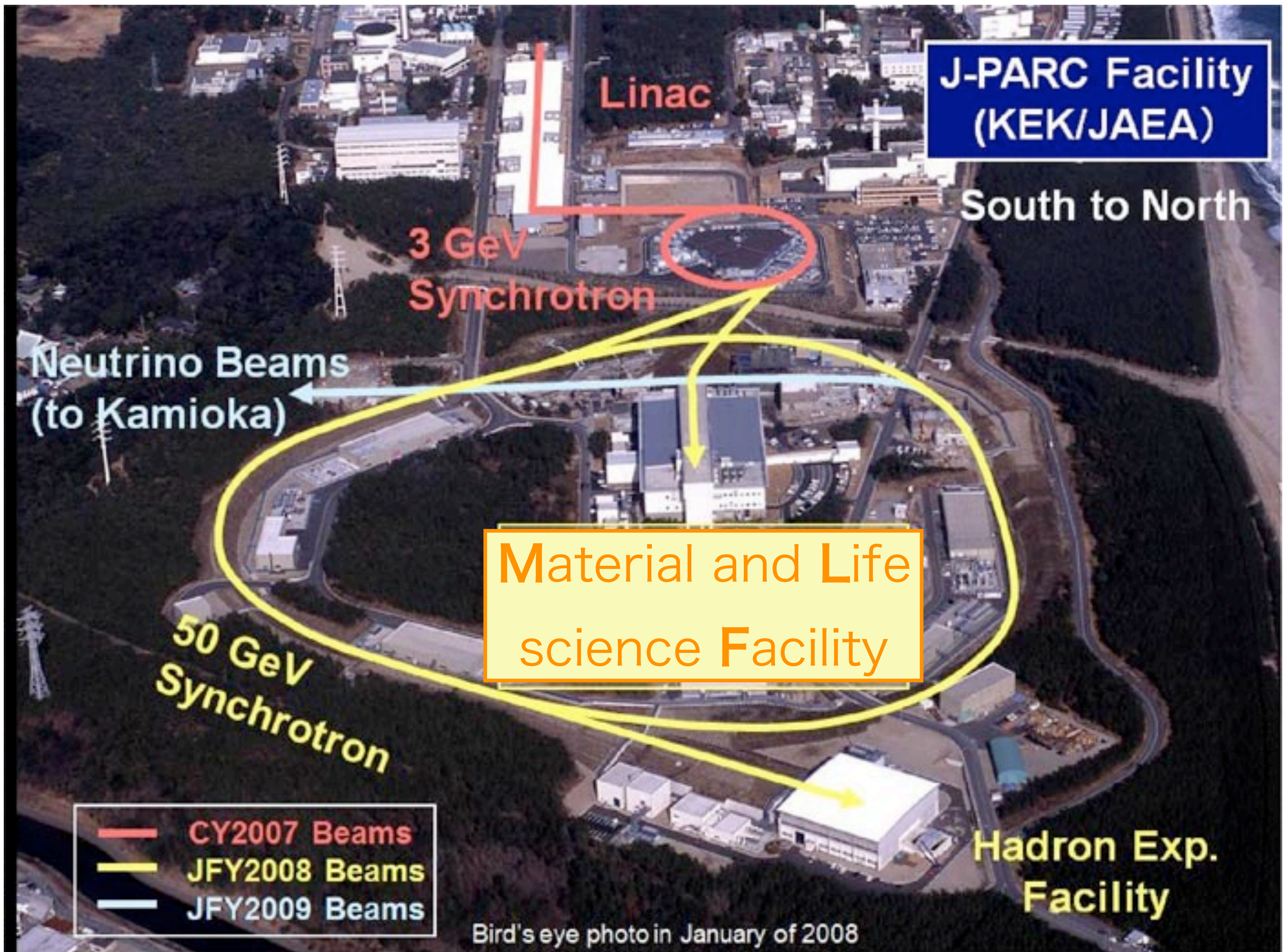
*Brookhaven National Laboratory, Upton, NY 11973-5000, USA*

W. C. Louis, G. B. Mills, R. Van de Water
*Los Alamos National Laboratory, Los Alamos, NM 87545, USA*

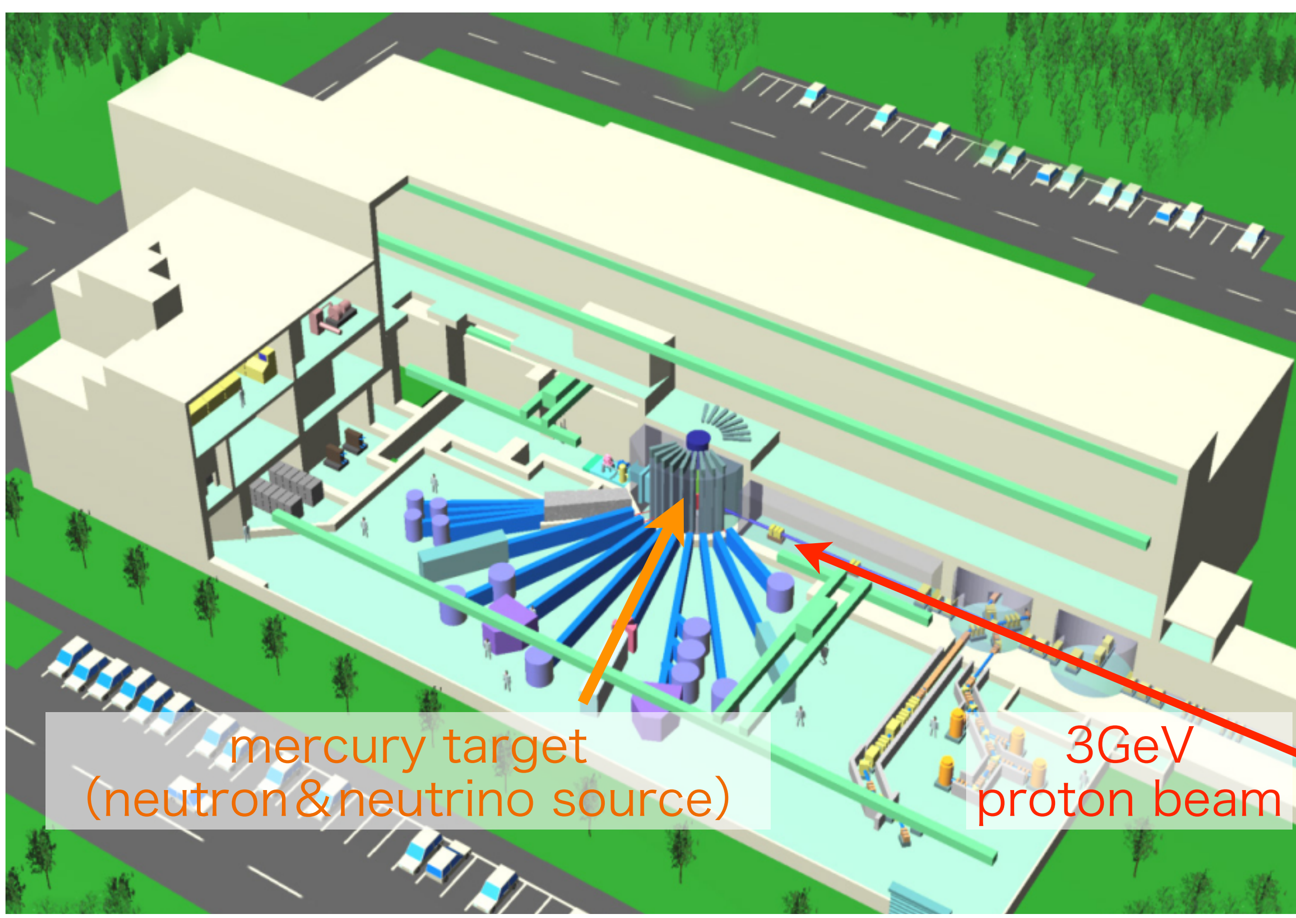
# J-PARC E56: JSNS$^2$ at MLF

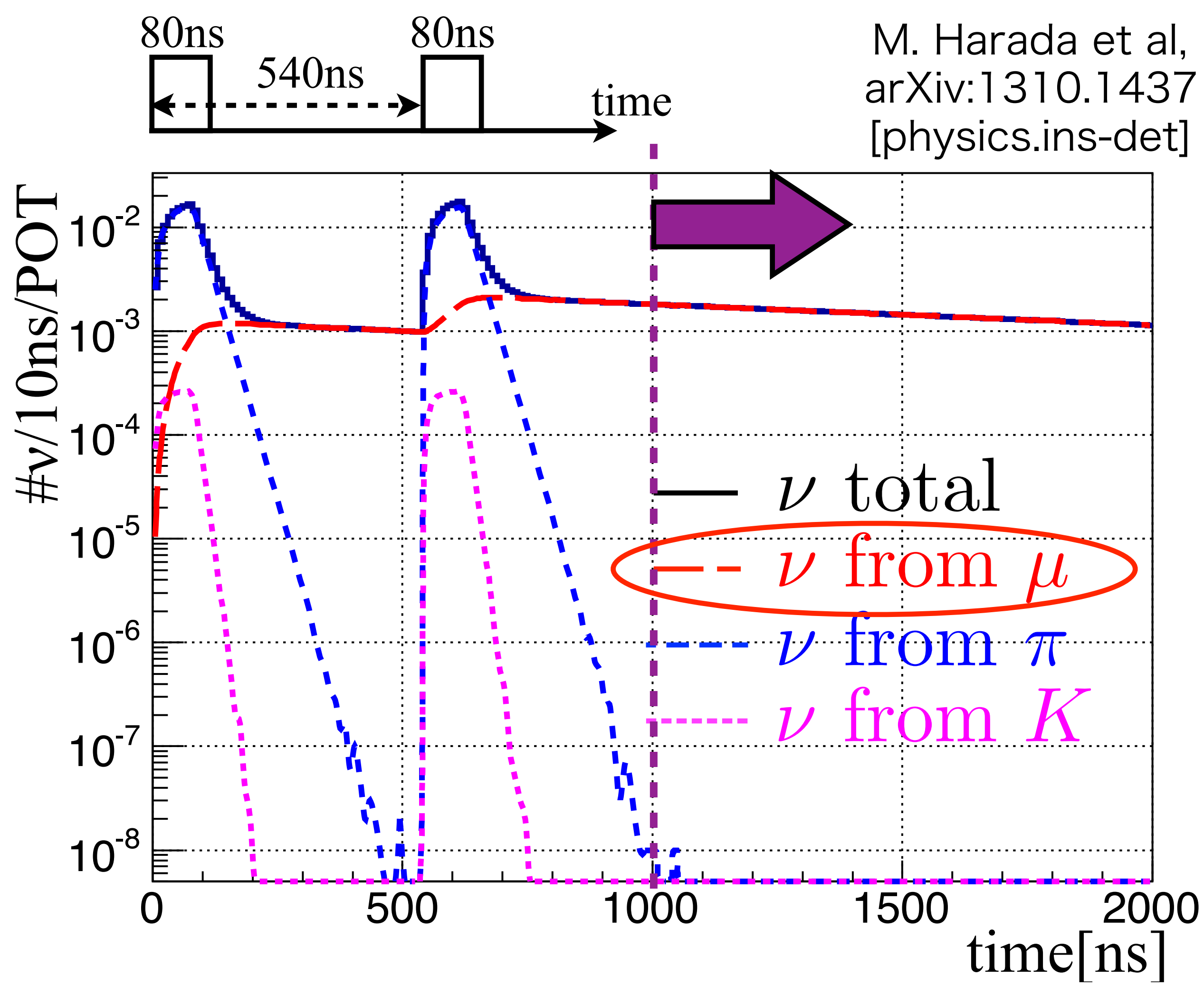
J-PARC Sterile Neutrino Search using $\nu$s from J-PARC Spallation Neutron Source



# Neutrino source: RCS + Hg target in MLF

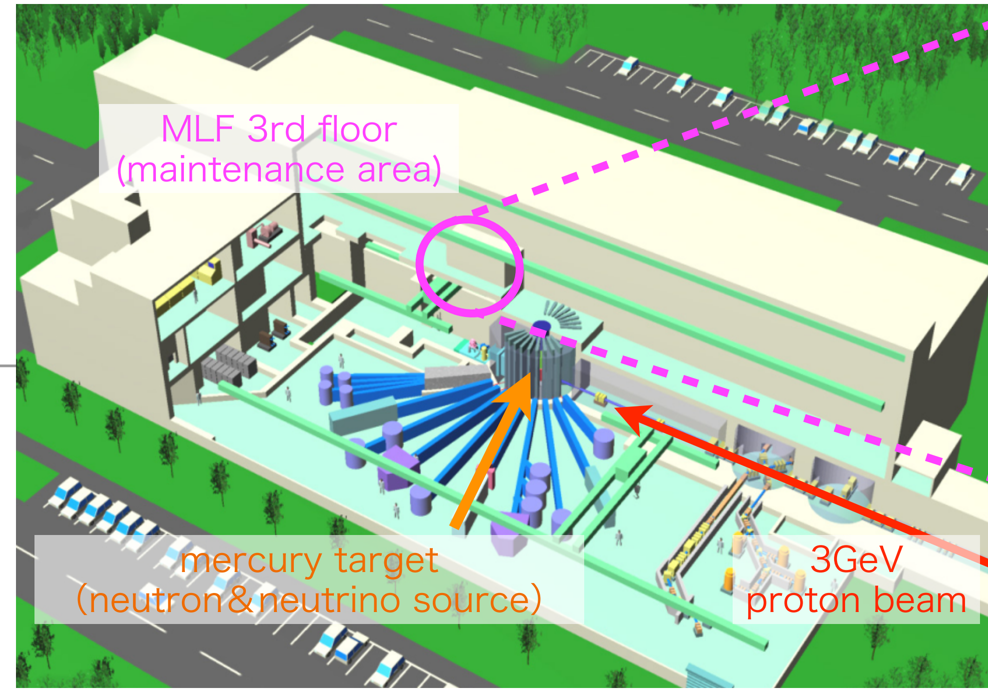
- World-class high intensity <u>neutron</u> source driven by high power proton beam from RCS
  +neutrino!!
  - beam energy: 3GeV
  - beam power: 1MW designed, 500kW continuous
- By selecting neutrinos after 1μs from the beam, pure neutrinos from stopped muons can be observed

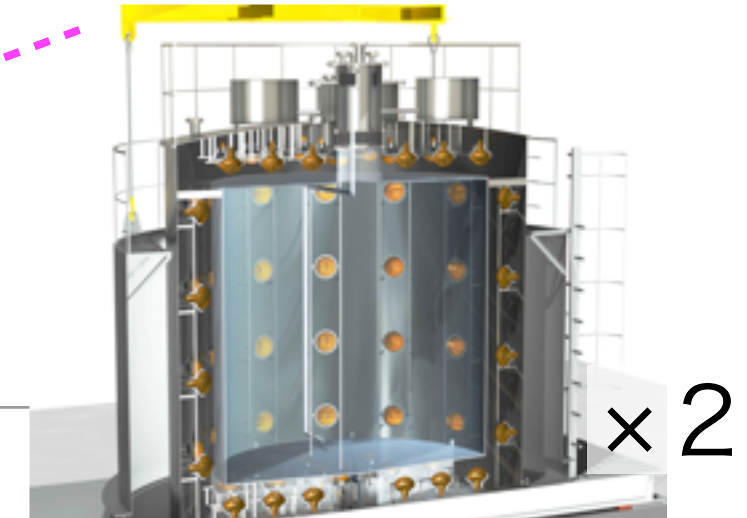



M. Harada et al, arXiv:1310.1437 [physics.ins-det]

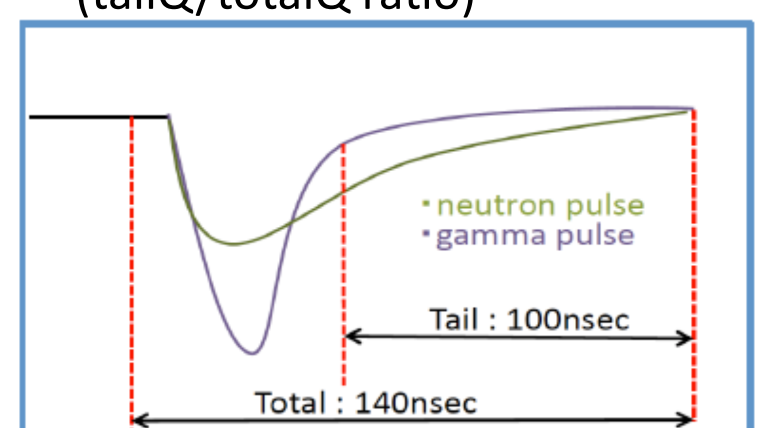
# Apparatus




- baseline: 24m
- fiducial volume: 50 tonnes
- Energy resolution $\sigma_E$ : 15%/√E [MeV]
- PID($\gamma$/n) capability by Cherenkov and/or Pulse Shape Discrimination (PSD)
- Delayed coincidence method: neutrons are observed as $\gamma$s from Gd-capture
  - Gd loaded liquid scintillator（DayaBay, Double Chooz, RENO...)
  - Detector technology is well-established
- NO new beam-line, NO new building
  - 1.5 years from grand breaking to physics runs
- Reasonable cost (~$2M/det, $4M in total)

Definition of PSD parameter
(tailQ/totalQ ratio)

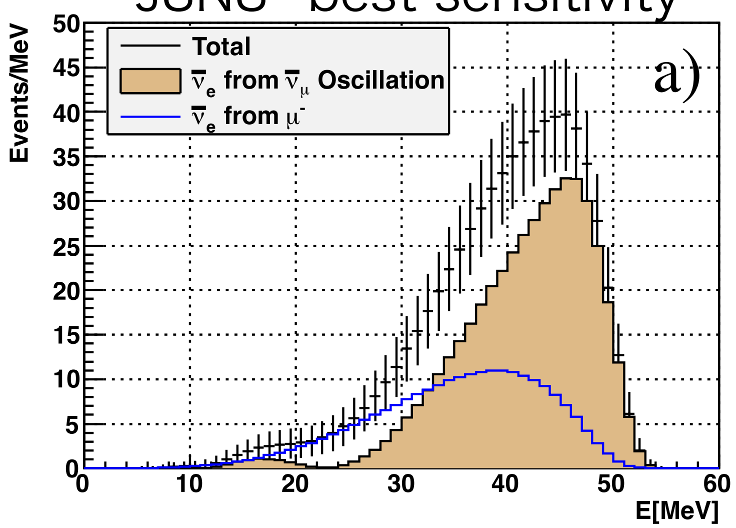


M. Harada et al,
arXiv:1502.02255
[physics.ins-det]

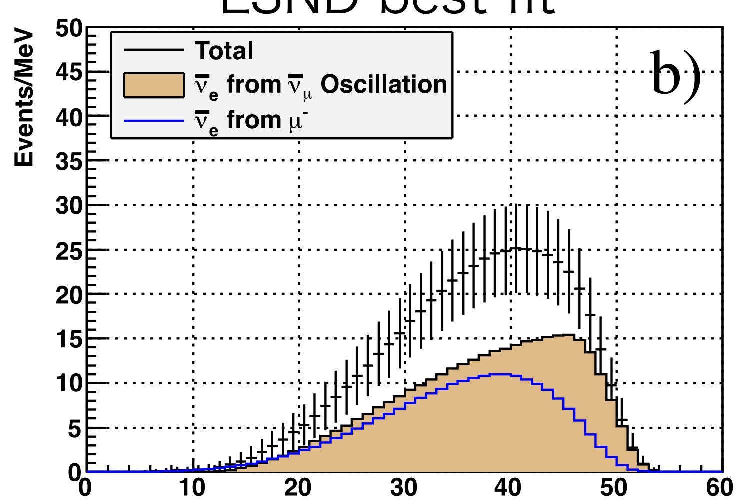
# Signal extraction and the sensitivity

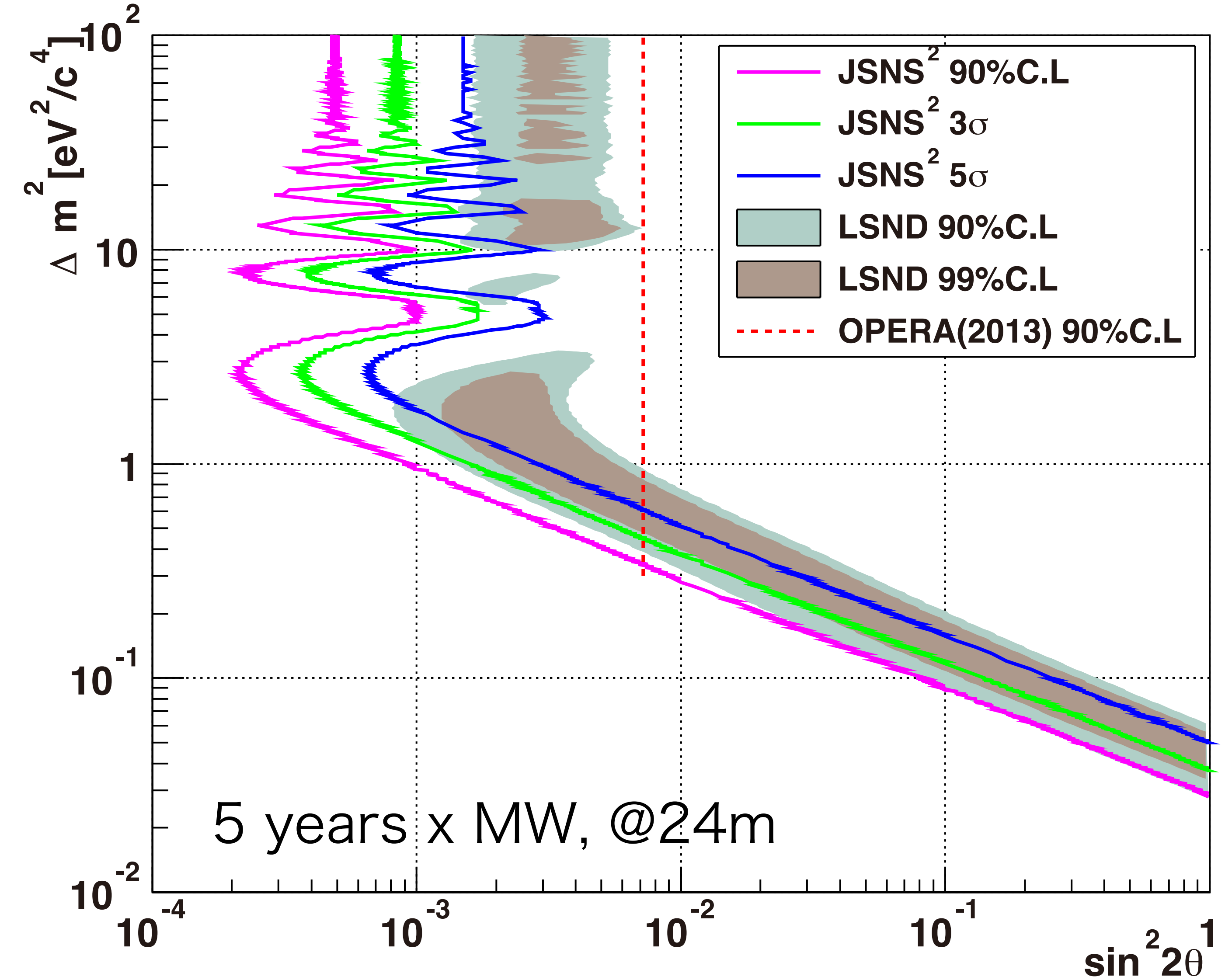
- Signal events can be distinguished from the dominant background (from another neutrino process) by using the difference of energy distributions
- Most of the parameter region indicated by LSND exp. can be explored with more than $5\sigma$ significance in 5 years with 1MW beam power

JSNS² best sensitivity




LSND best fit



# Status

2013

- Begin consideration of the experiment
- March-May: BG measurement at MLF experimental hall
- Sep. 17th J-PARC PAC: Submit proposal

2014

- April-June: BG measurement at MLF 3rd floor (candidate location)
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2015

➡ Jan.: Stage-1 approval from J-PARC PAC

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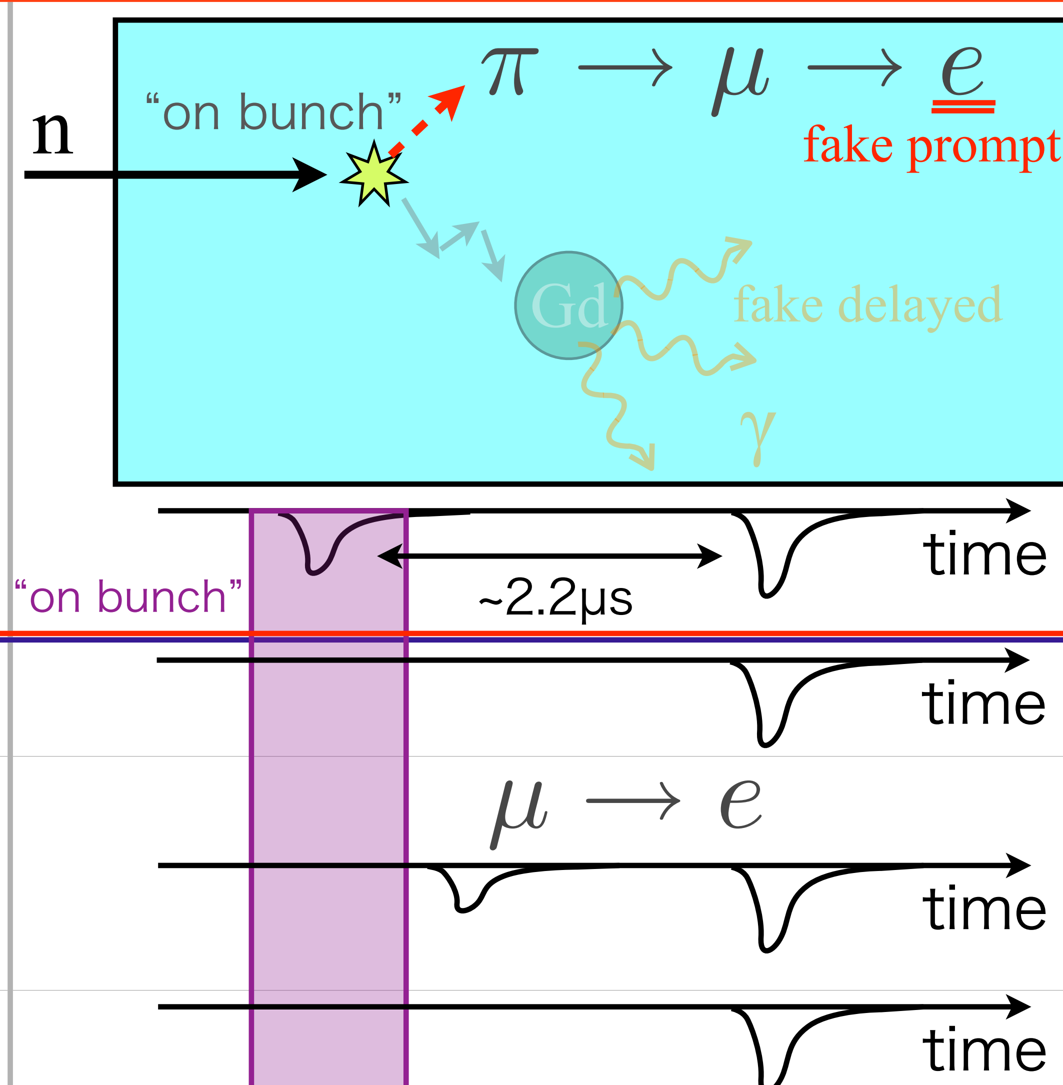
# BG measurement at candidate location

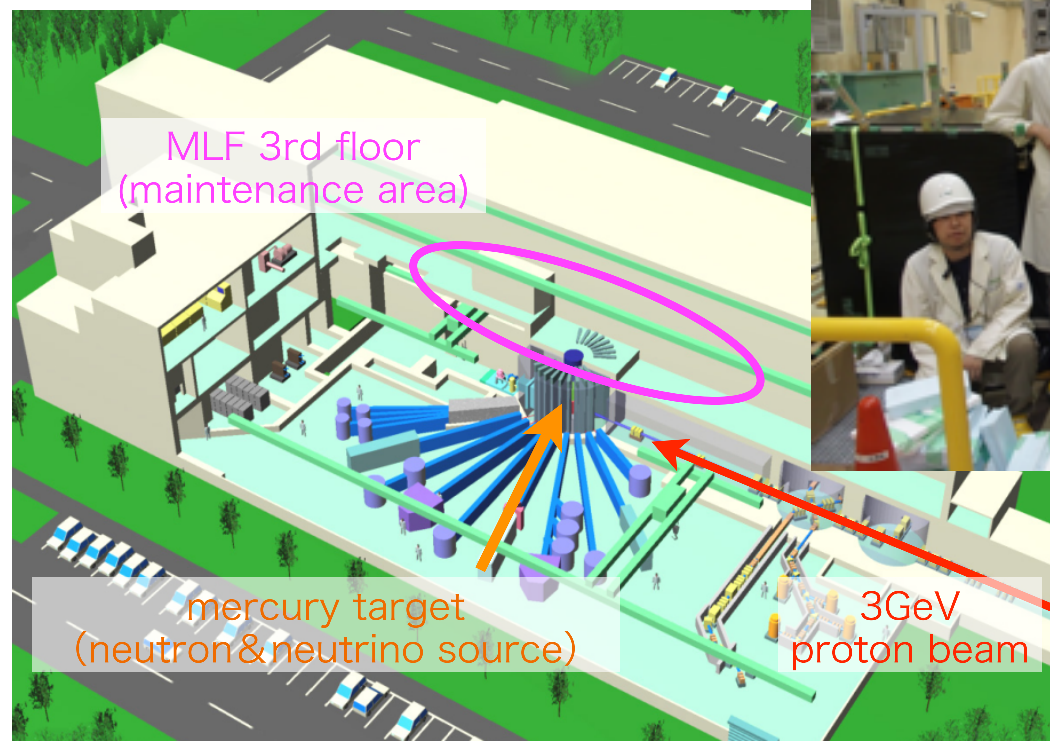
> The most critical technical issue is a detailed estimate of the actual background rate at the 3rd floor of the MLF. The PAC recommends a direct measurement of this background with a small-scale prototype detector. If the background levels are as predicted (based on an extrapolation from rates measured at BL13 using a simulation), the experiment would be technically feasible and could receive stage-I approval.
>
> 17th J-PARC PAC

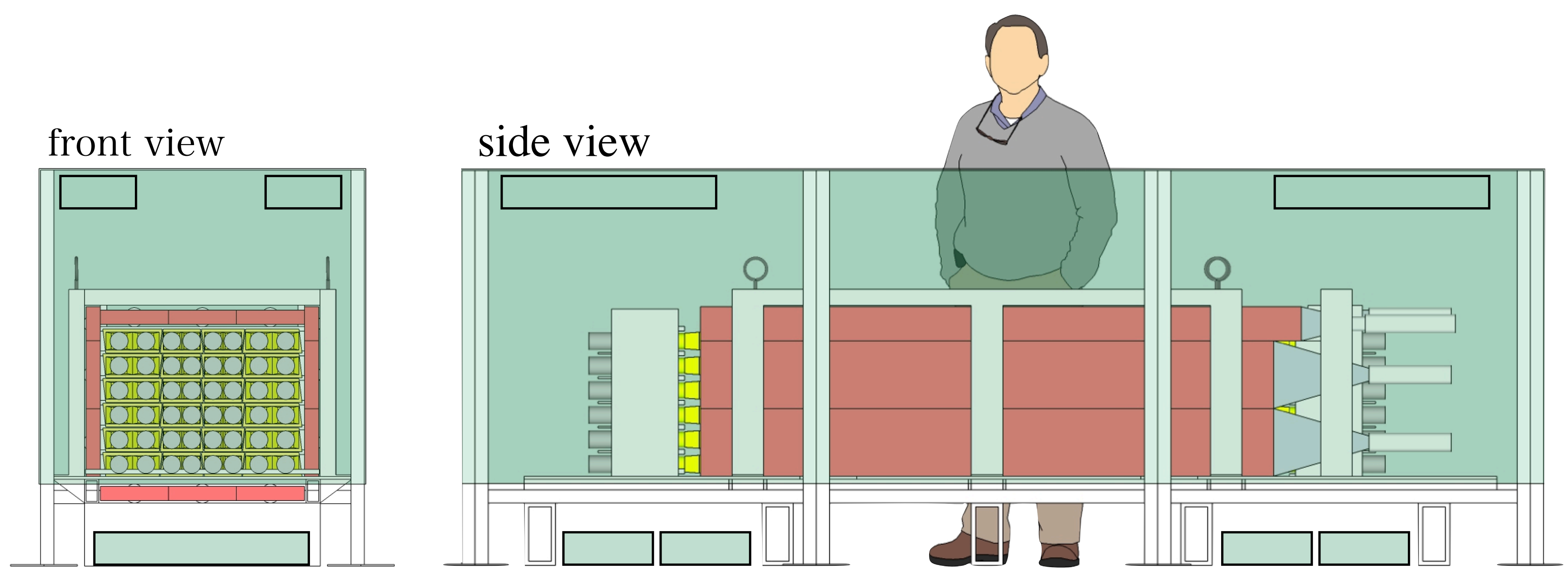
compare beam ON/OFF

| | | beam-on | beam-off | comment |
|---|---|---|---|---|
| target BG | Michel-e by beam fast neutron |  | × | delayed signals were not required |
| backgrounds | cosmic μ | | ○ | huge, rejected by veto |
| | Michel-e from cosmic μ | | ○ | rejected by detecting mother μ |
| | Other cosmic related | | ○ | accidental coincidence |

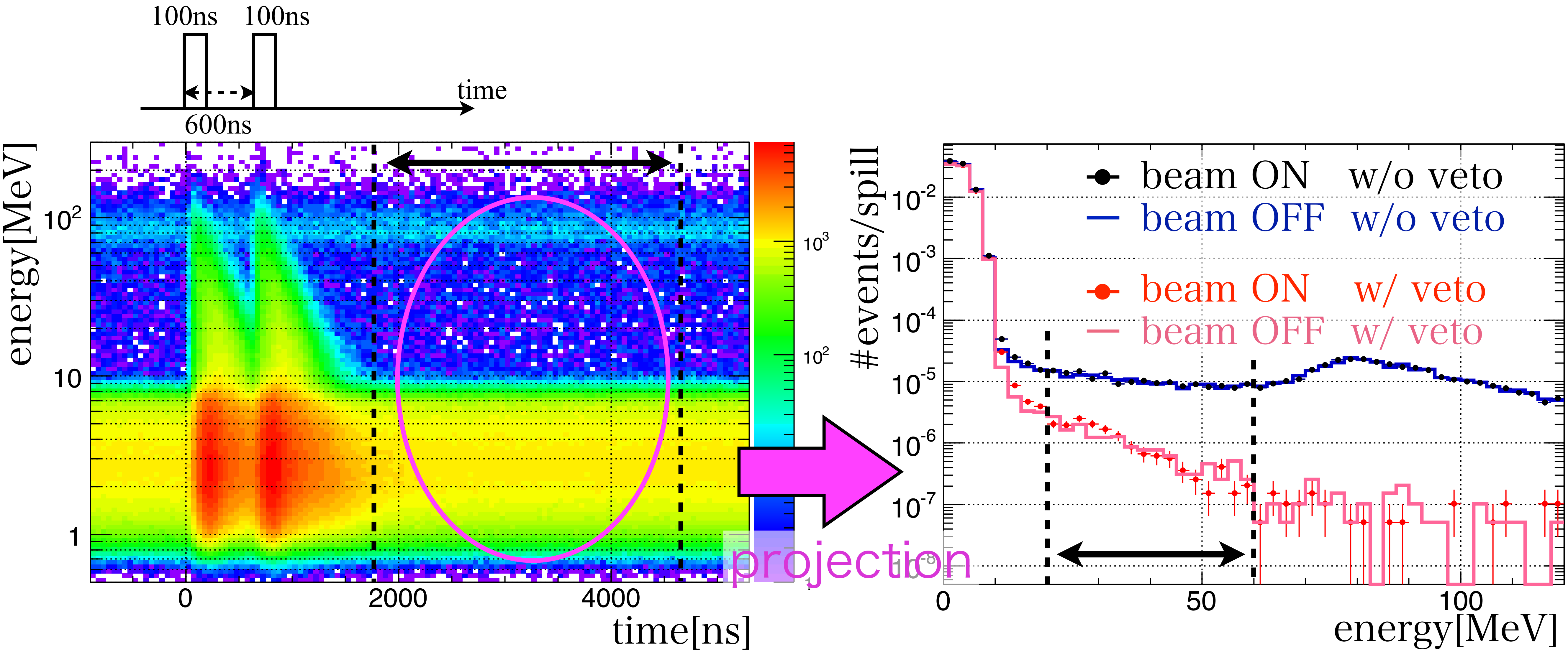
# BG measurement at candidate location

- main scintillators
  - 24 pieces, 500kg in total
- 2 layers of veto scintillators
  - inner and outer veto
  - efficiency > 99.9%



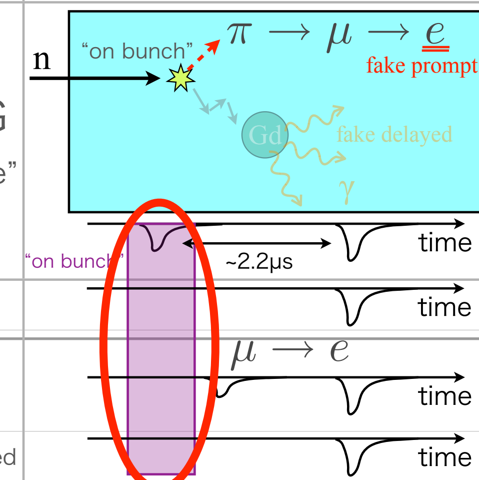
# BG measurement at candidate location




| #/spill/300kW | ON | OFF | Δ (ON-OFF) |
|---|---|---|---|
| w/o veto | $(1.68\pm0.03)\times10^{-4}$ | $(1.64\pm0.03)\times10^{-4}$ | $(4.0\pm4.2)\times10^{-6}$ |
| w/ veto | $(1.58\pm0.09)\times10^{-5}$ | $(1.52\pm0.09)\times10^{-5}$ | $(0.6\pm1.3)\times10^{-6}$ |

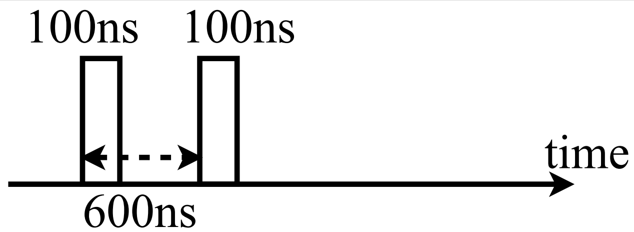
S. Ajimura et al, Prog. Theor. Exp. Phys. (2015) 063C01

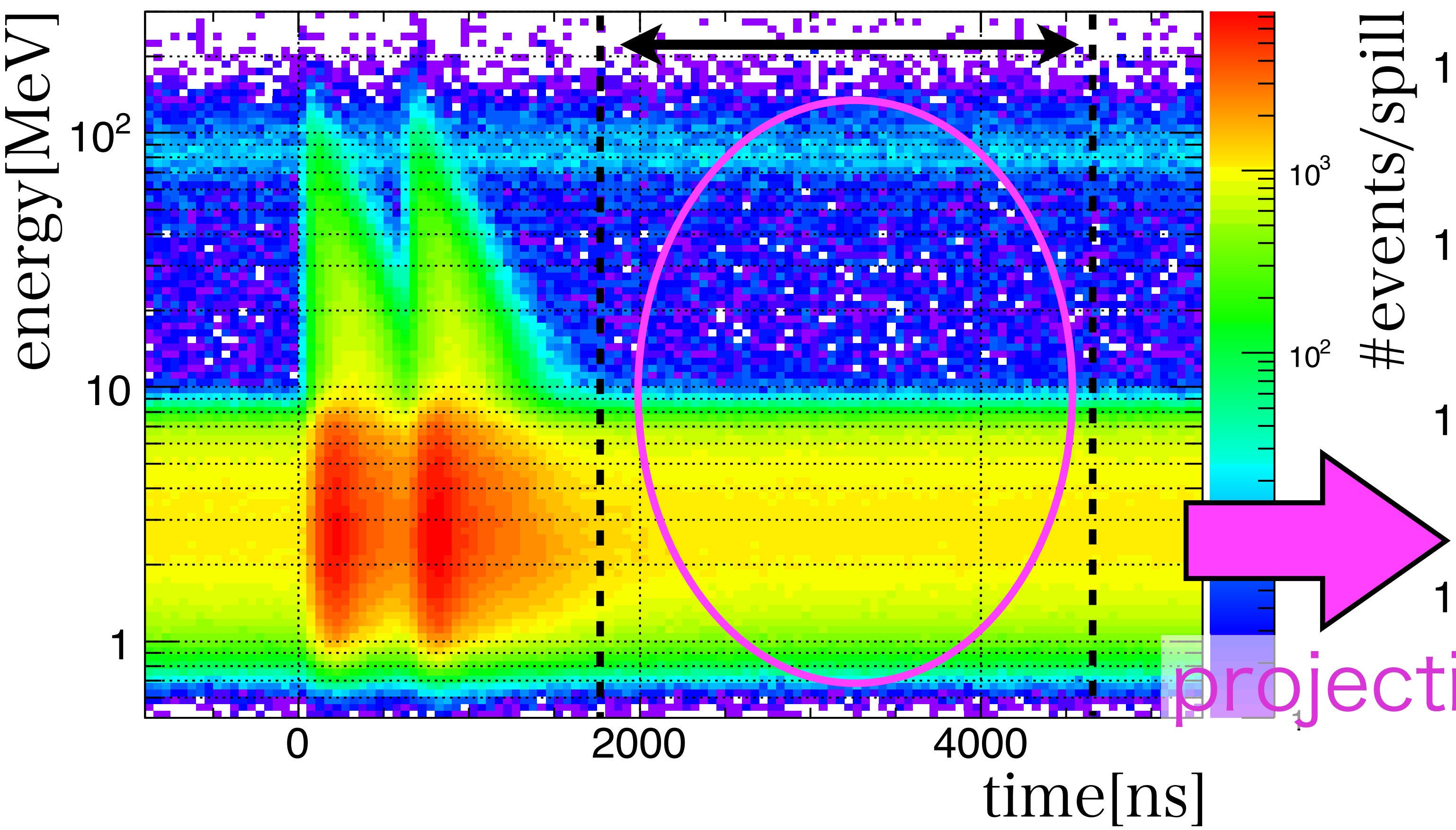
# BG measurement

| | beam-on | beam-off | comment |
|---|---|---|---|
| Target BG<br>"beam Michel-e" |  | × | delayed signals were not observed |
| cosmic μ | | ○ | huge, rejected by veto |
| Michel-e from cosmic μ | | ○ | suppressed by checking timing of mother μ |
| Other cosmic related | | ○ | accidental hit on bunch timing |

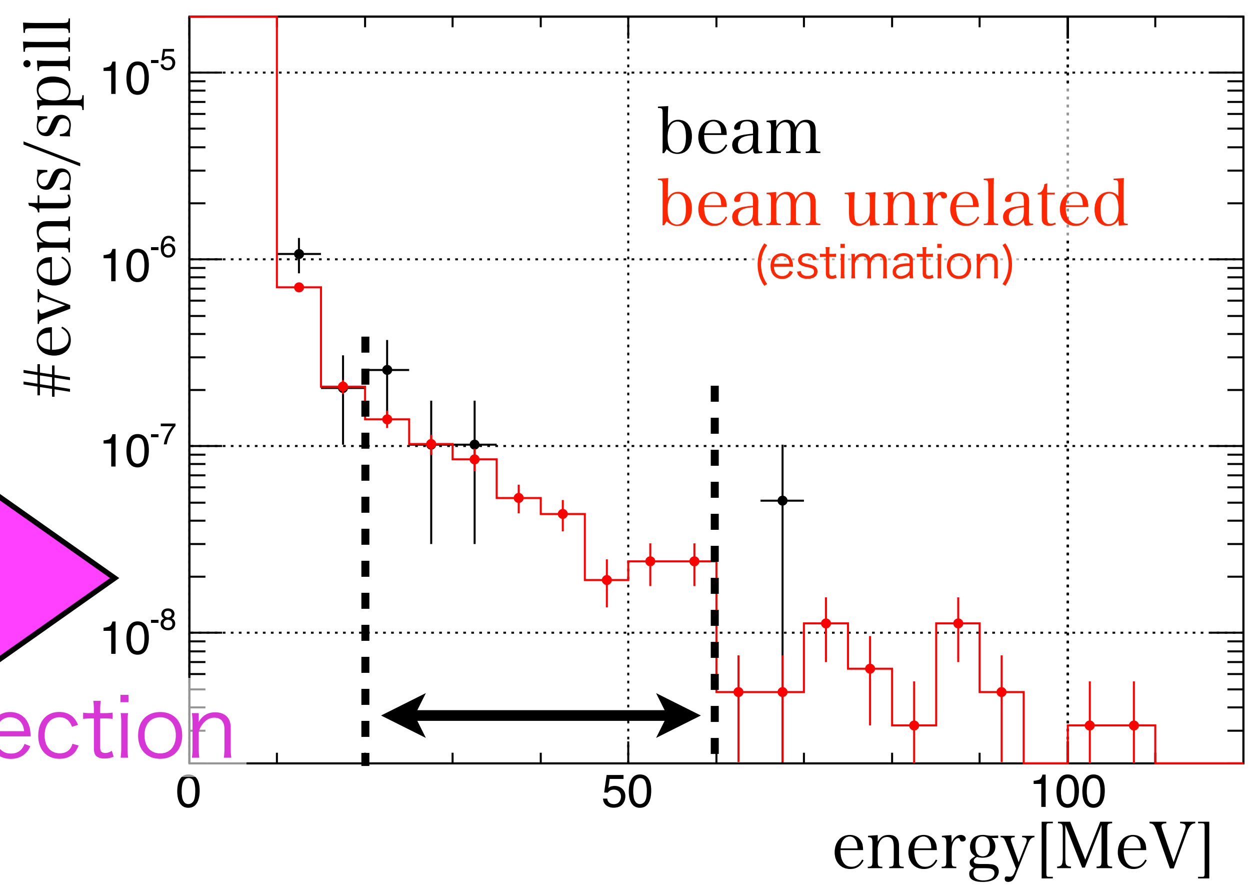


on bunch hit




projection

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| w/ veto | $(1.58\pm0.09)\times10^{-5}$ | $(1.52\pm0.09)\times10^{-5}$ | $(0.6\pm1.3)\times10^{-6}$ |
| +"on-bunch cut" | $(4.6\pm1.5)\times10^{-7}$ | $(4.9\pm0.3)\times10^{-7}$<br>※estimation | $(-0.3\pm1.6)\times10^{-7}$ |

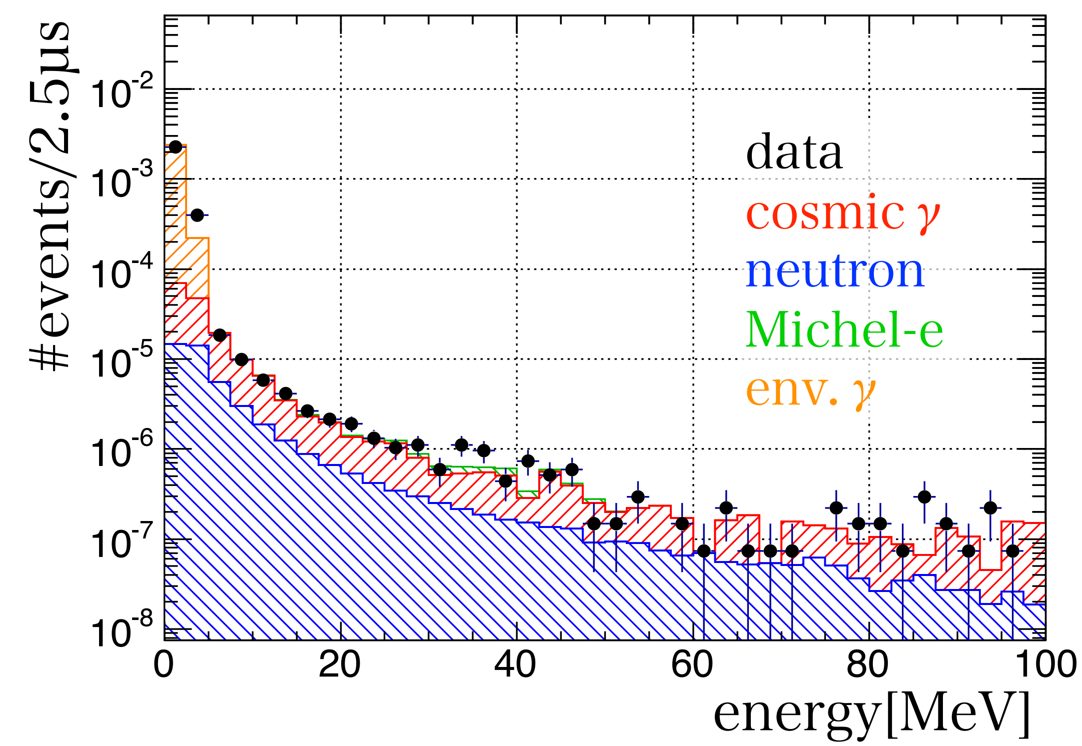
⇒ <13 /5yr/MW/50t (90% C.L)

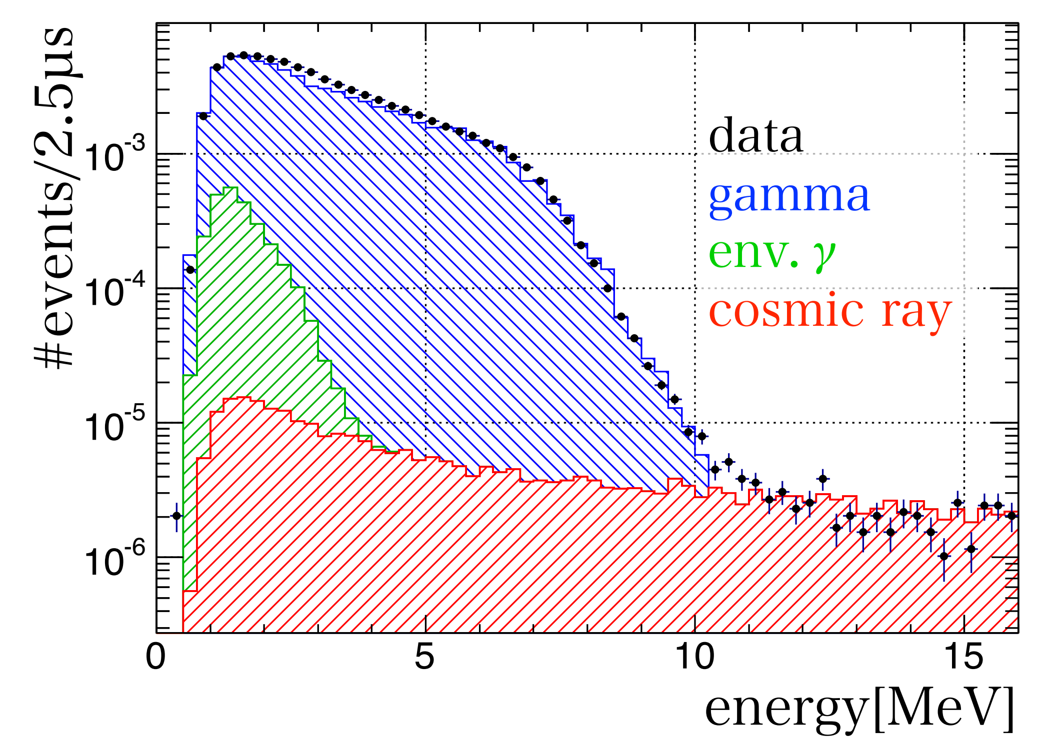
S. Ajimura et al,
Prog. Theor. Exp. Phys. (2015) 063C01

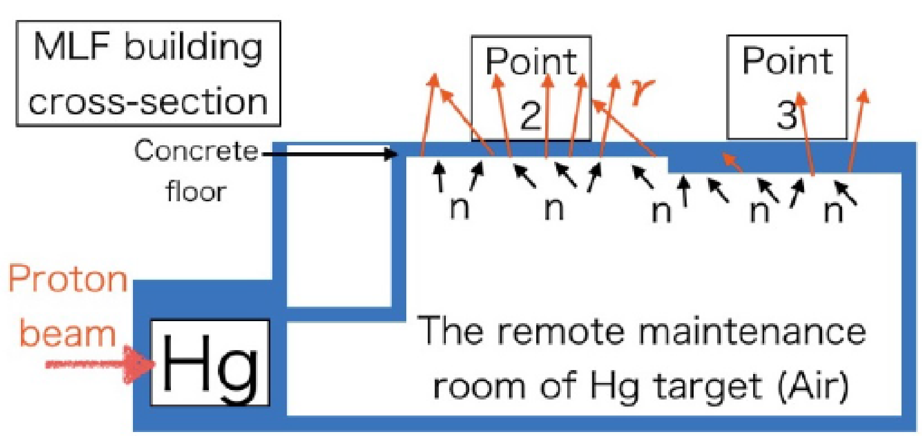
# Accidental BG

S. Ajimura et al,
Prog. Theor. Exp. Phys.
(2015) 063C01

- cosmic induced prompt BG
  - prompt energy regions on beam-off timing (+reject cosmic muon induced Michel-e by detecting mother muon)
  - Another measurement with liquid scintillator (NE213) and NaI
  - Consistent within 6% difference
- beam induced delayed gamma BG
  - gammas from floor concrete
  - suppressed by putting thick lead plates below detectors



# Status

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> Based on the background measurements presented, the PAC is convinced that the background rates described in the proposal are achievable. The PAC recommends stage-1 status for P56.
>
> 19th J-PARC PAC

2015

- Dec. 19th J-PARC PAC: Status report, request for Stage-1 approval

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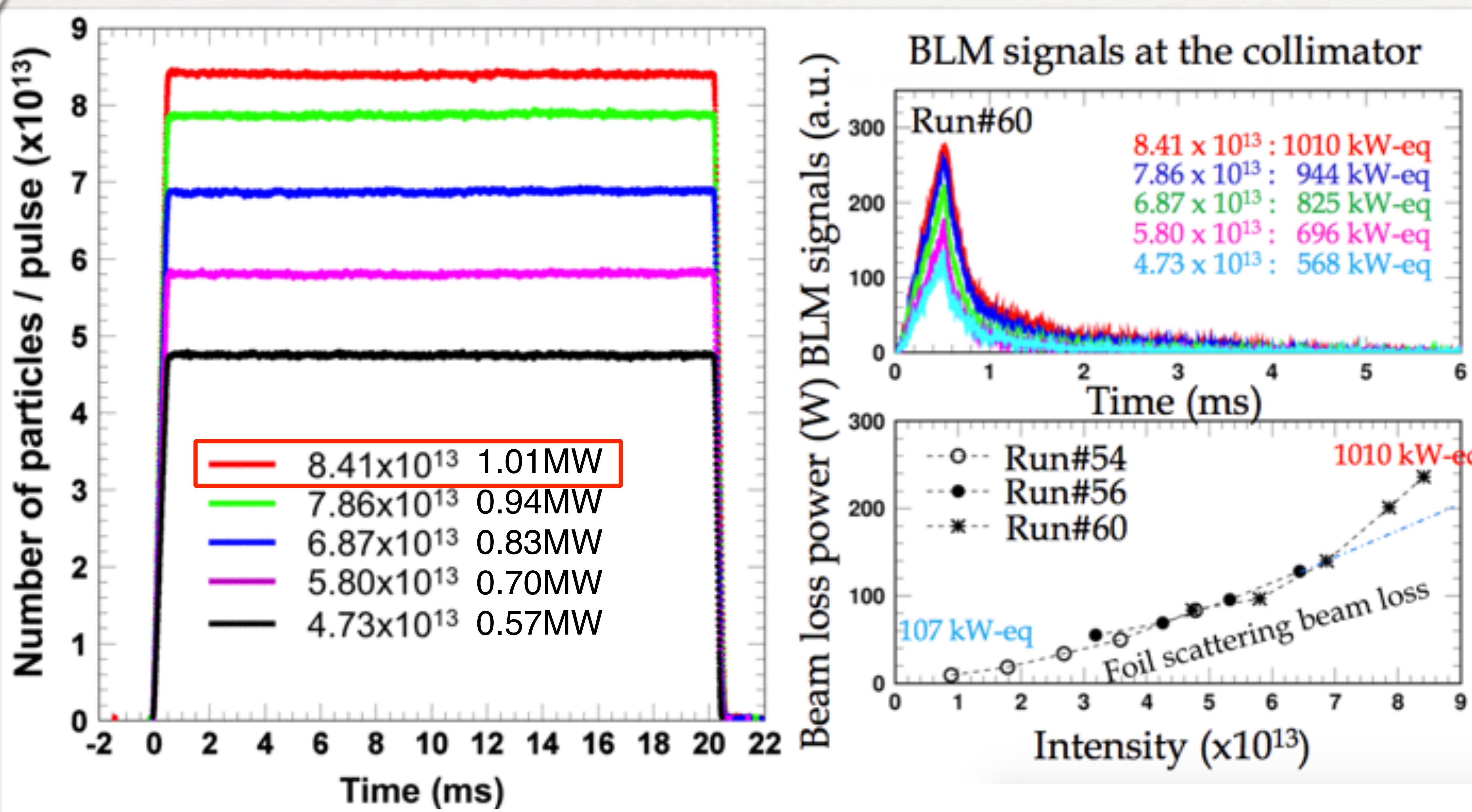
# 1MW trial (J-PARC RCS)




*** Power supplies of RF cavity were specially tuned up for the trial.**

*** The power supplies will be really upgraded in this summer.**

by Fujio NAITO(KEK/J-PARC), 20th J-PARC PAC, July 2015

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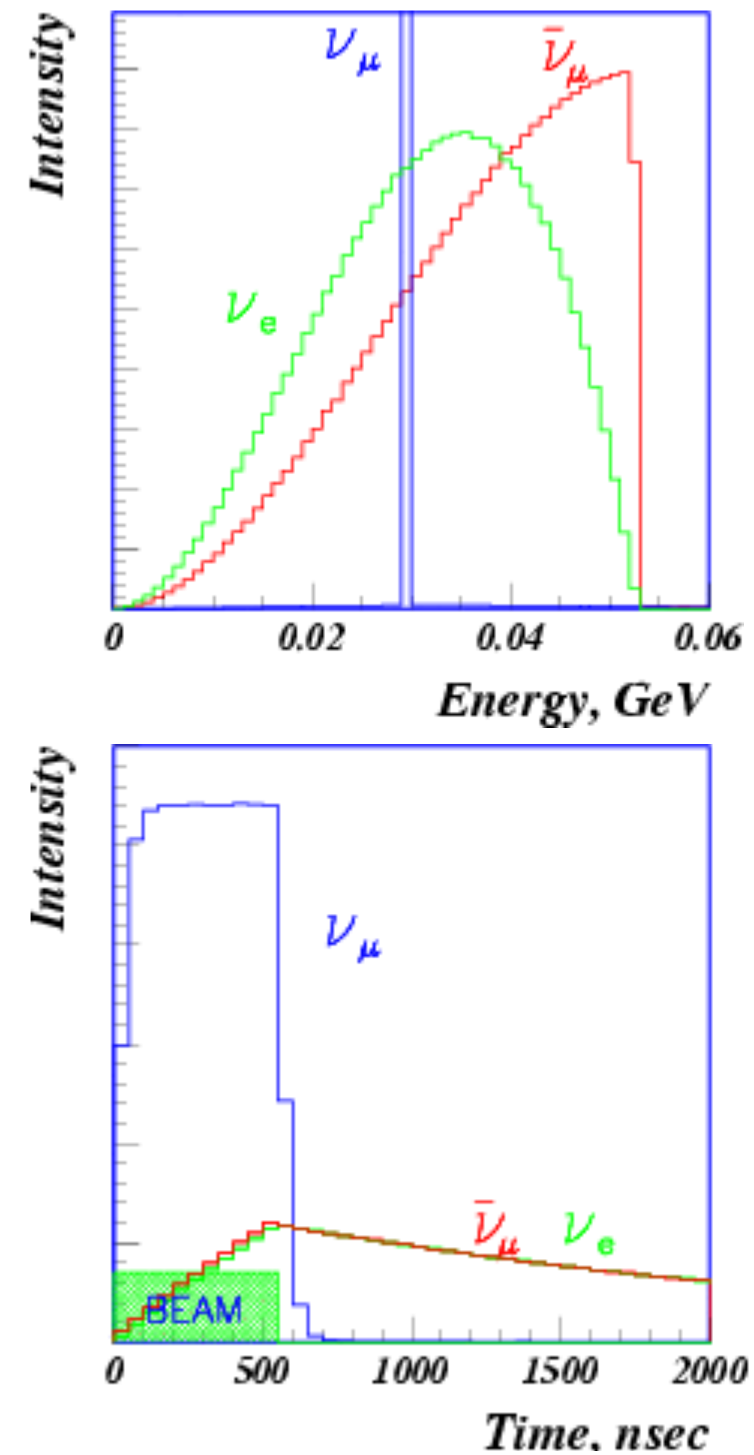
# OscSNS experiment at ORNL

# ORNL SNS

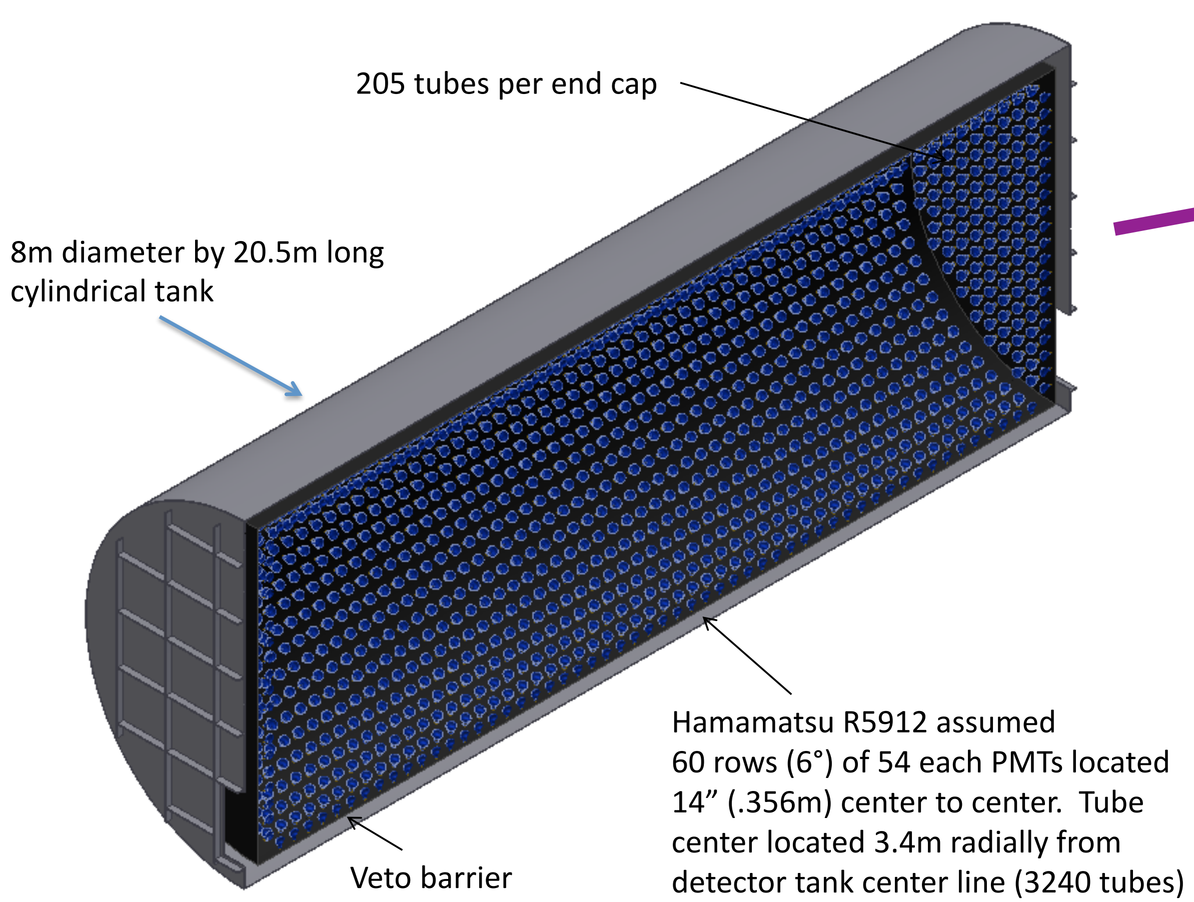
- Spallation Neutron Source at Oak Ridge National Laboratory
  - proton beam: 1GeV, 1.4MW

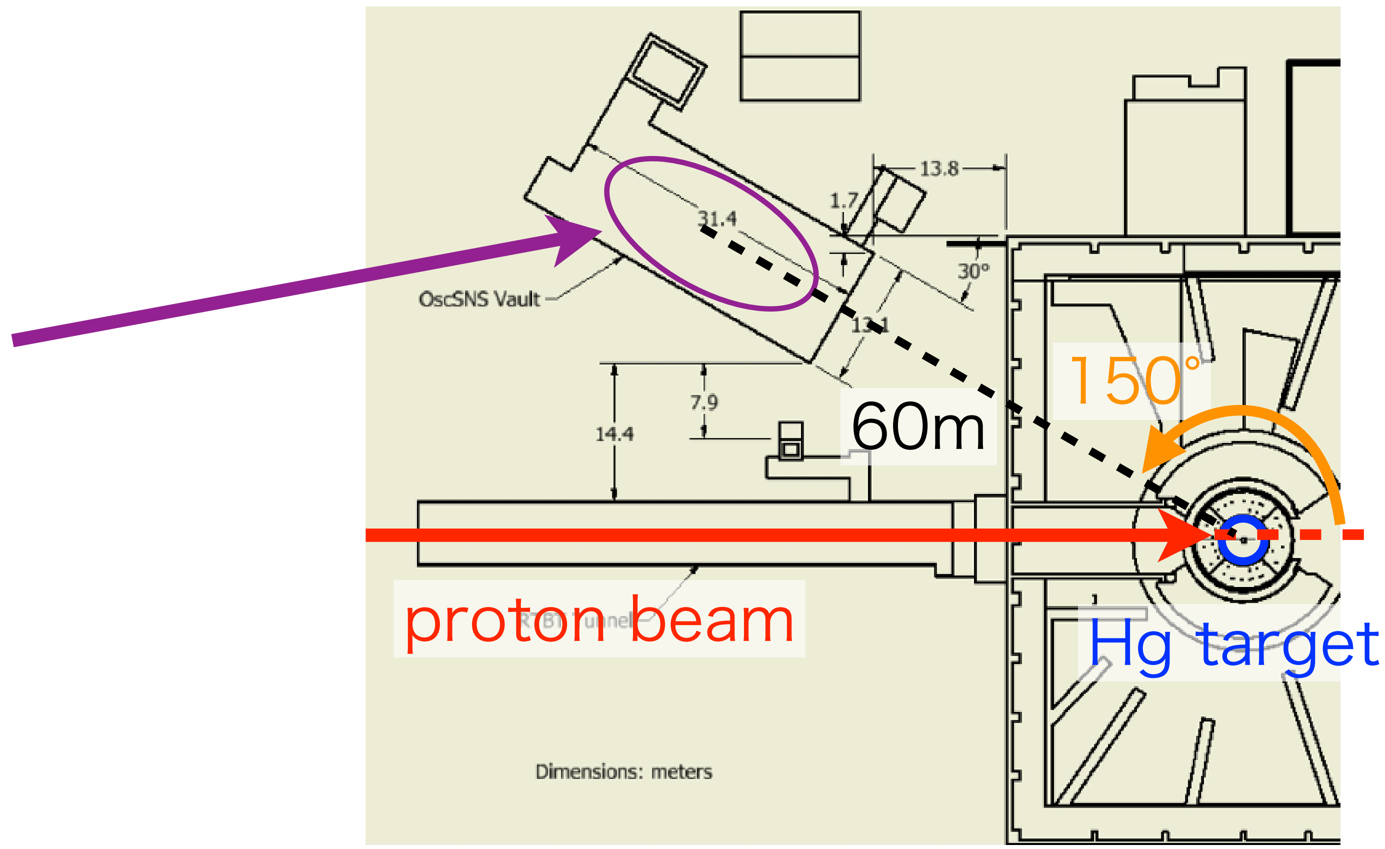
arXiv:1307.7097 [physics.ins-det]

# Baseline and detector

- similar approach ("LSND style")
- baseline: 60m
- fiducial volume: 450 tonnes
- delayed signal: H capture (Gd option?)

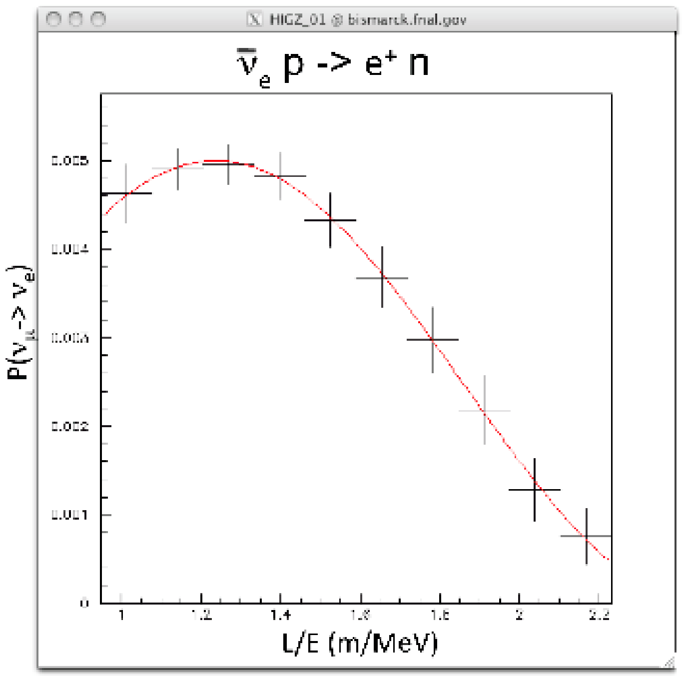


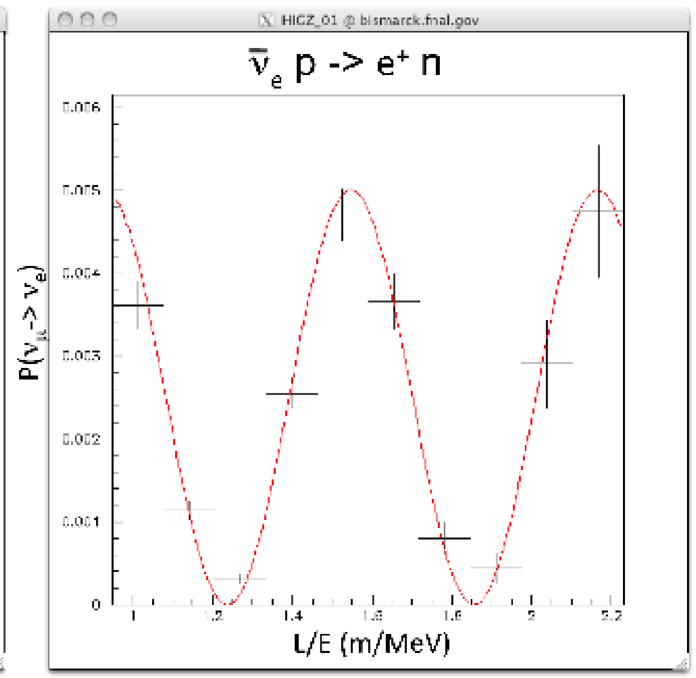



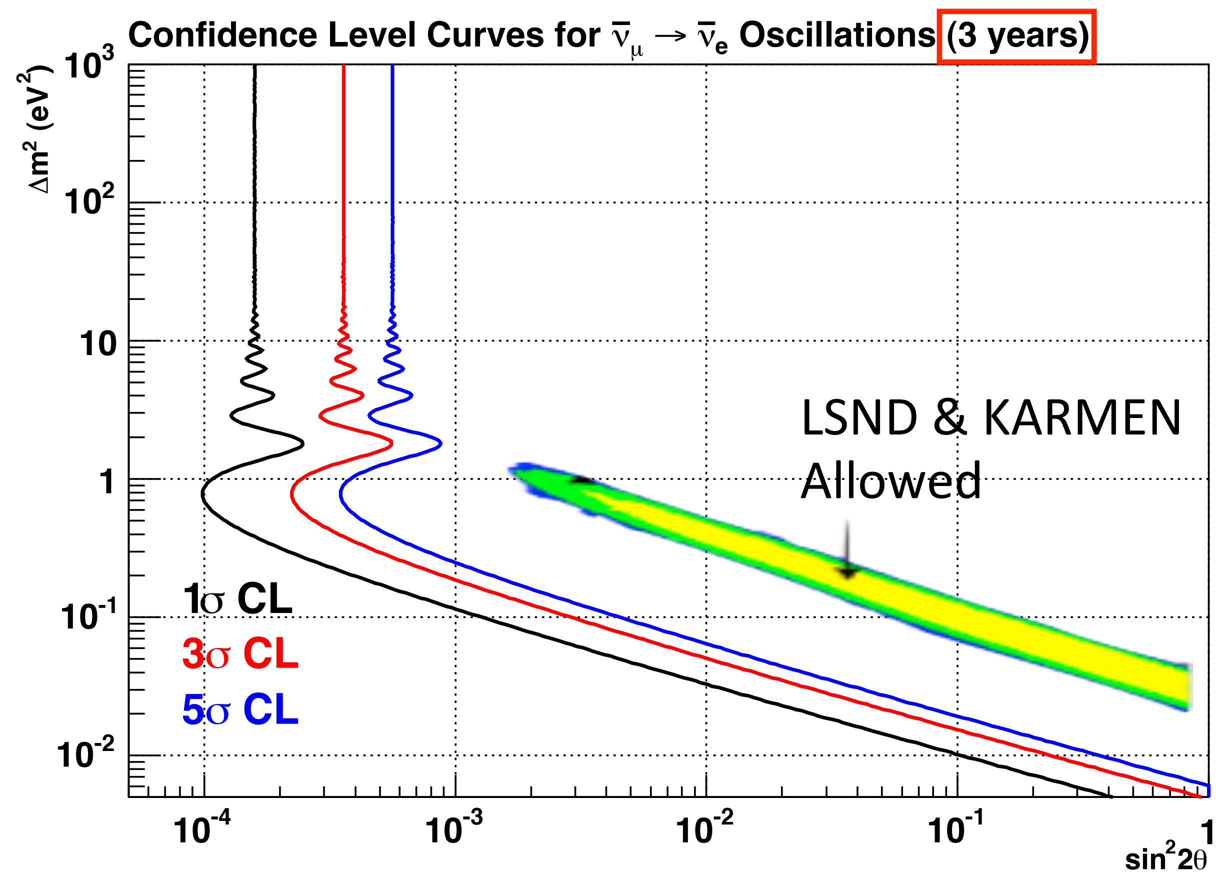
# Signal and Sensitivity

arXiv:1307.7097
[physics.ins-det]

- cylindrical --> position dependence



# Cost, status and plan

- Cost: $22M
- Status (from OscSNS White Paper, arXiv: 1307.7097)
  - Visit SNS, present physics plan. (done: April 12, 2013)
  - Attend Snowmass, garner support from the community. (done)
  - Obtain letter of support from SNS management and have it sent to DOE. (done)
  - Submit R&D proposals to DOE for the following ground work (Fall, 2013):
    - design new electronics
    - test oil and scintillators from various sources
    - develop simulations for the main detector, including reconstruction and particle ID algorithms
    - develop improved neutrino flux simulations
  - Submit white paper to DOE.
- R&D funding from DOE to start the detailed design of the experiment
- 3 years from grand breaking to start

# Comparison

| | $JSNS^2$ | OscSNS | Notes |
|---|---|---|---|
| fiducial vol. | 50t | 450t | |
| base line | 24m | 60m | LSND: 30m |
| beam energy | 3GeV | 1GeV | $JSNS^2$: larger $\pi/\mu$ prod.<br>OscSNS: less intrinsic $\bar{\nu}_e$ |
| beam power | 1MW | 1.4MW | |
| cost | $4M | $22M | $JSNS^2$: Within Grant-in-Aid coverage |
| delayed | Gd (8MeV, 30μs) | H(2.2MeV, 220μs) | OscSNS: Gd option? |
| pros/cons | - can start quickly<br>(lower cost, NO building)<br>- $\Delta m^2 > eV^2$ ($5\sigma$, Phase-1) | - take some time to start<br>- definitive<br>(mass coverage, E/L dep.) | |

# Summary

- Decay at rest neutrino experiment is a similar approach to LSND experiment, which first indicated the sterile neutrino (appearance)
  - Direct and complete test of the LSND
  - energy spectrum, cross-section of neutrinos are well-known (small systematics)
- JSNS$^2$ at J-PARC MLF
  - 24m, 3GeV/1MW, 50t fiducial
  - lower cost, can start quickly, Stage-1 approval
- OscSNS at ORNL
  - 60m, 1GeV/1.4MW, 450t fiducial
  - definitive search