ステライルニュートリノ探索の実験的レビュー

丸山　和純（KEK）

I cannot cover all experiments (e.g.; T2K-ND280 searches；　arXiv:1410.8811 [hep-ex]) since there are a lot of on-going efforts.

Also $\nu\mu \rightarrow \nu\mu$ disappearance was discussed in Yasuda-san's talk and will be discussed later for more details. (by E.Richard)

Physics (sterile neutrino search)

- Anomalies, which cannot be explained by standard neutrino oscillations for 15 years are shown;

Experiments	Neutrino source	signal	significance	E(MeV), L(m)
LSND	μ Decay-At-Rest	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	3.8σ	40, 30
MiniBooNE	π Decay-In-Flight	$\nu_\mu \rightarrow \nu_e$	3.4σ	800, 600
		$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	2.8σ	
		combined	3.8σ	
Ga (calibration)	e capture	$\nu_e \rightarrow \nu_x$	2.7σ	<3, 10
Reactors	Beta decay	$\bar{\nu}_e \rightarrow \bar{\nu}_x$	3.0σ	3, 10-100

- Excess or deficit does really exist?
- The new oscillation between active and inactive (sterile) neutrinos? ($\Delta m^2 \sim 1.0\ eV^2$)?
- One of the hottest topics in the neutrino community;
  - About quarter of the Neutrino2014 talks mentioned sterile ν_s
  - P5 (US) endorsed the short baseline neutrino experiment for sterile
  - A lot of experiments are on-going (especially, using reactors).

Neutrino oscillations with $\Delta m^2 \sim 1 eV^2$ region

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \\ \nu_s \\ \bullet \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} & \bullet \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} & \bullet \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} & \bullet \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \\ \bullet \end{pmatrix}$$

Matrix elements, which are considered in 3x3 mixing framework.

$$\sum_{j=1,3} U^*_{ej} U_{\mu j} = -U^*_{e4} U_{\mu 4}$$

Small mixiture with active ν's $\quad U_{e4}, U_{\mu 4} \sim 0.1 \quad U_{s4} \sim 1 \quad m_4 \sim 1\,eV >> m_{1,2,3}$

$$P_{e\mu} = -4 \sum_{i=1,3} (U^*_{e4} U_{\mu 4} U_{ei} U^*_{\mu i}) \sin^2 \frac{(m_4^2 - m_i^2)L}{4E_\nu} \sim 4 |U_{e4}|^2 |U_{\mu 4}|^2 \sin^2 \frac{\Delta m_4^2}{4} \frac{L}{E}$$

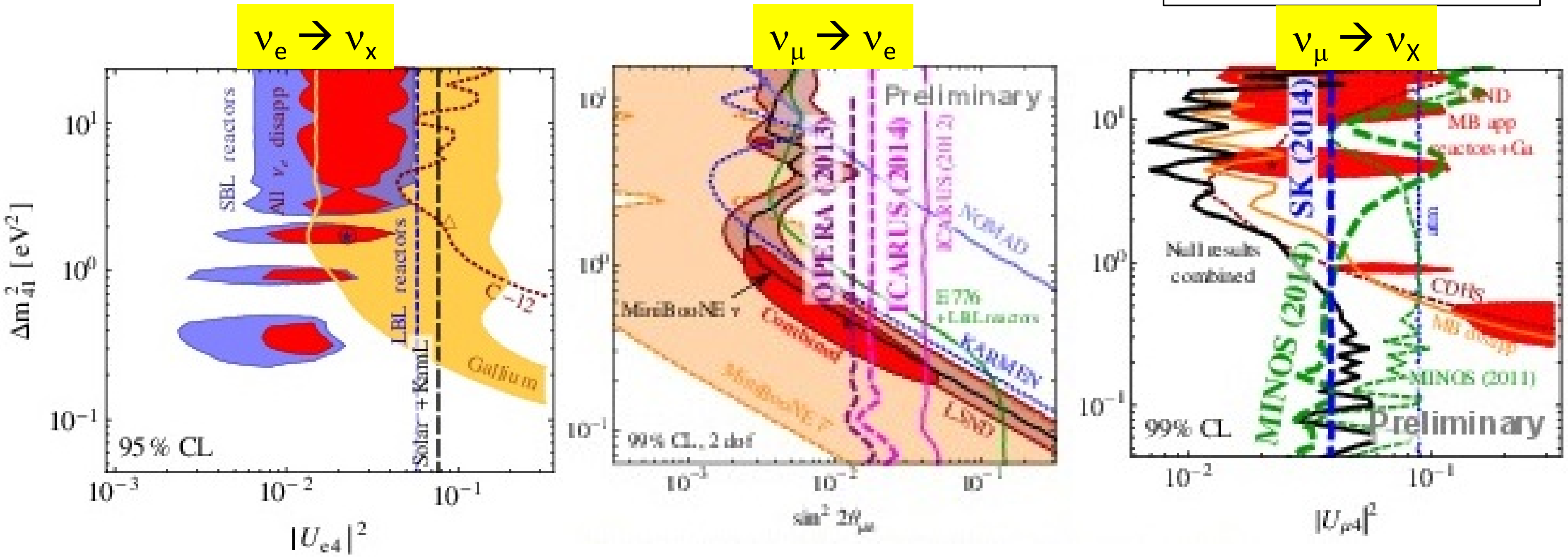
$$P_{es} = -4 \sum_{i=1,3} (U^*_{e4} U_{s4} U_{ei} U^*_{si}) \sin^2 \frac{(m_4^2 - m_i^2)L}{4E_\nu} \sim 4 |U_{e4}|^2 |U_{s4}|^2 \sin^2 \frac{\Delta m_4^2}{4} \frac{L}{E}$$

$$P(\nu_\mu \to \nu_e) = \sin^2 2\Theta \cdot \sin^2\left(\frac{1.27 \cdot \Delta m^2 \cdot L}{E_\nu}\right)$$

(3+1) model

Status as of 2014

J. Kopp's
talk at Neutrino2014



- ICARUS / OPERA experiments had new results in 2014 for appearance channel.
- SK / MINOS had new results in ν_μ disappearance channel.
- Daya-Bay had latest results on ν_e disappearance in the last summer

Discrepancy between ν_μ and others?

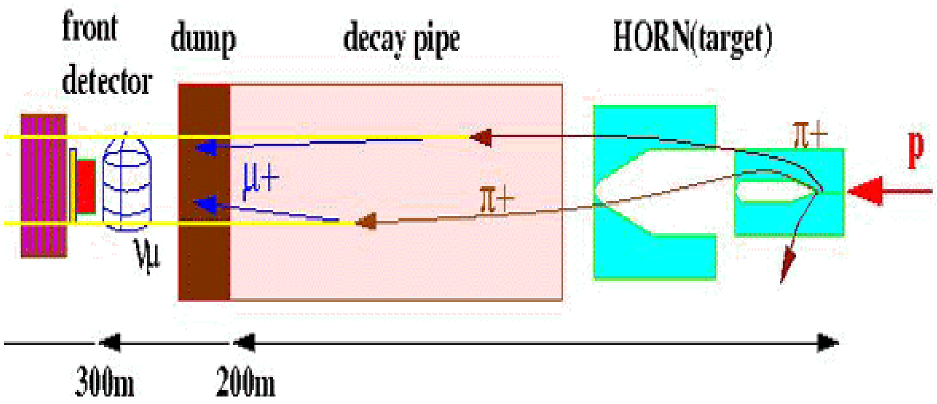
- Due to issue on theoretical model (3+1) ?
- **Confirming or refuting the anomalies with various E/L is first thing to do for experimentalists.**

典型的ニュートリノ源・検出器

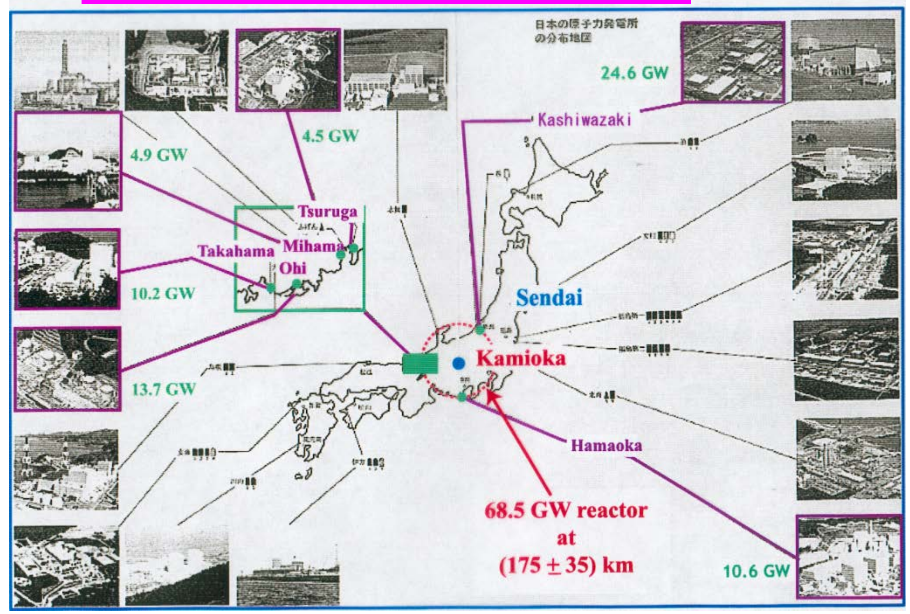
- ニュートリノ源
  - （反）電子ν 消失
    - 原子炉
    - 線源
  - νμ → νe 出現
    - 電磁ホーンを使ったν ビーム
    - 加速器ダンプν
    - μ 貯蔵リングによるビーム
  - νμ → νμ 消失
    - 電磁ホーンを使ったν ビーム
    - 大気ν
- 検出器
  - 液体シンチレータ
    - 反電子ν 検出に優れた性能
    - 原子炉・線源・ダンプν がν源の実験に良く使われる。
  - 水・氷・ミネラルオイルチェレンコフ
    - コストが安い。PID等も確立。
    - ホーンを使ったν、大気ν等。
  - 液体アルゴンTPC
    - π0/電子の区別に優れている
    - ホーンを使ったν で使用。
  - 鉄とシンチ（またはチェンバー）
    - 磁場をかけていれば粒子の電荷符号が分かる。
    - ホーンを使ったν、μ 貯蔵リングによるビーム

ニュートリノ源

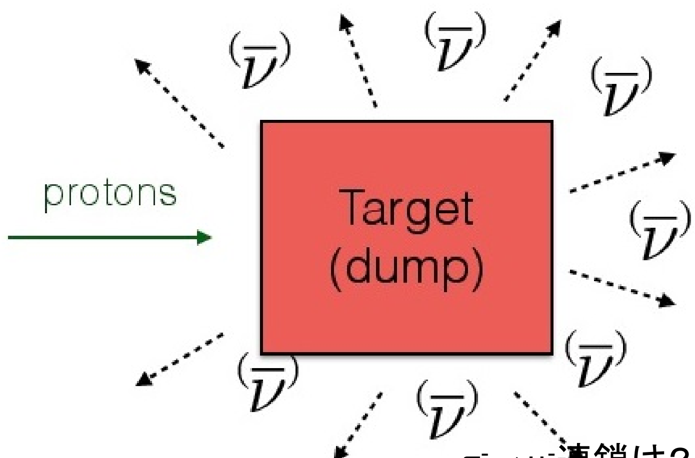
ホーンで作るν(νμ をπ DIFから作る)



原子炉　($\overline{\nu}e$　核分裂から)



ダンプで作るν(νをDARから作る)



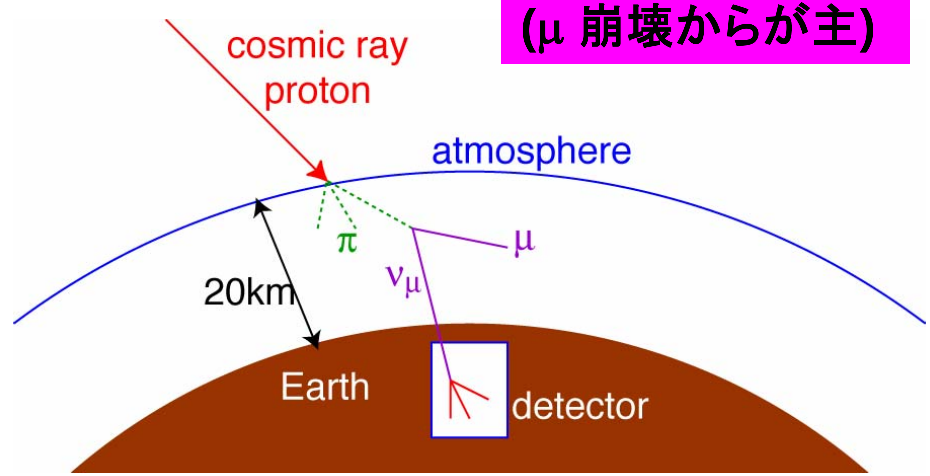
$p + X \rightarrow Y + \pi^+$

$\pi^+ \rightarrow \nu\mu + \mu^+$

$\mu^+ \rightarrow e^+ + \overline{\nu}\mu + \nu e$

$\pi^- \rightarrow \mu^-$連鎖は2段階の原子核吸収でπ^+の約1000の1。

大気ν (νe+νμ)
(μ 崩壊からが主)



nuSTORM (neutrinos from STORed Muons)

A low-energy muon storage (P_μ=3.8 GeV/c) ring based on existing technology to:

- Address the large Δm^2 neutrino oscillations
- Provide beams for precision ν_e and ν_μ cross section measurements
- Provide an accelerator technology test bed (ν-Factory & μ-Collider)
- Provide a neutrino Detector Test Facility
  - Proposal: arXiv:1308.6822
  - Project Definition Report: arXiv:1309.1389

Technologically limited Schedule: 5-7 years

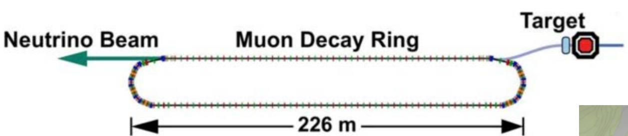
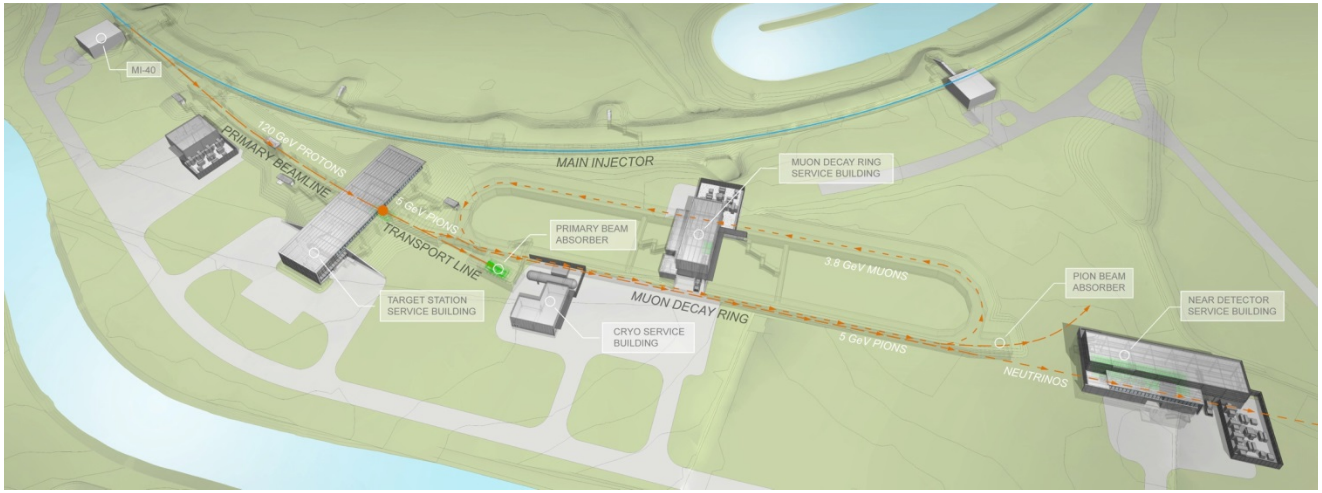


Table 1: Decay ring specifications

Parameter	Specification	Unit
Central momentum P_μ	3.8	GeV/c
Momentum acceptance	± 10%	
Circumference	480	m
Straight length	185	m
Arc length	50	m
Arc cell	DBA	
Ring Tunes (ν_x, ν_y)	9.72, 7.87	
Number of dipoles	16	
Number of quadrupoles	128	
Number of sextupoles	12	

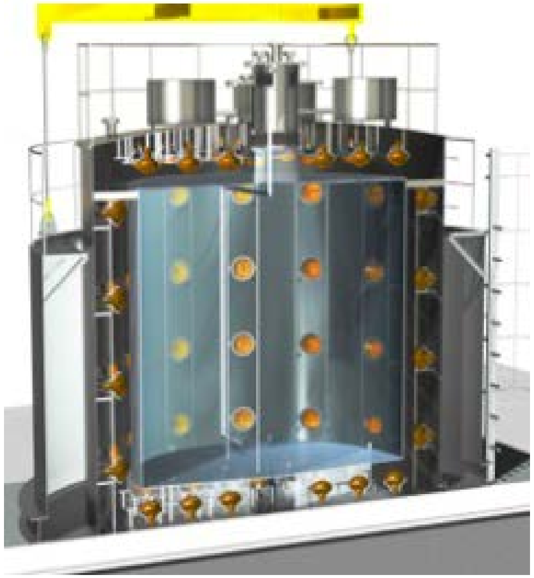
The nuSTORM facility



注； 昨年P5でエンドースを受けられなかったため、FNALで行う可能性はほぼなくなり、CERNでの可能性を残すのみとなった。

Liquid scintillator detector

Many experiments for sterile neutrino search use liquid scintillator.
→ Explaining the detection principle at first

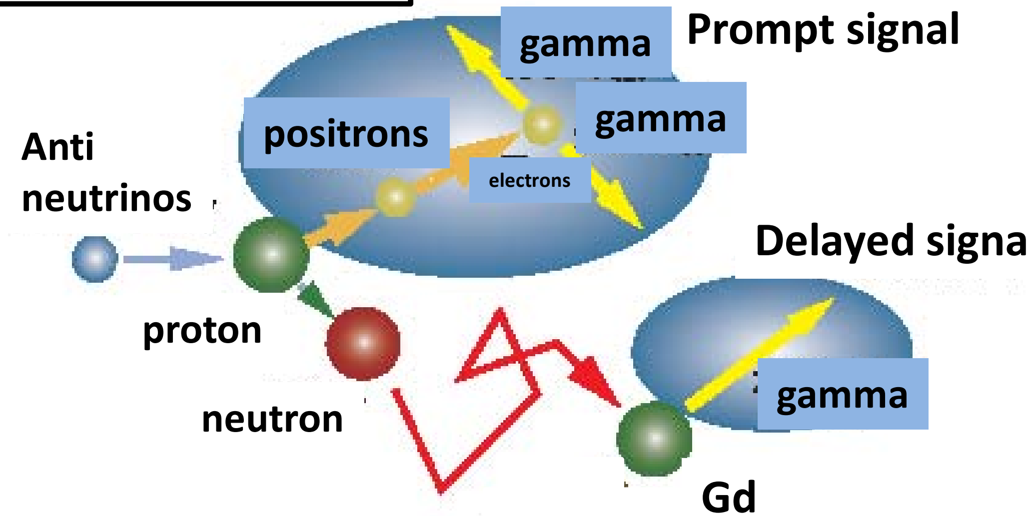


Identify neutrinos with detecting e+ and gammas from n capture on Gd (H).
=>Can reduce accidental BKG (Gd~8MeV γs, capture time ~ several tens μs; Gd case).

Inverse Beta Decay (coincidence)

$$\overline{\nu}_e + p \rightarrow e^+ + n$$

Prompt E_{vis}+0.8MeV ~ Eν ;
- < a few MeV (for beta source)
- 2~ 3MeV (for reactor)
- ~ 40MeV (for muon DAR)



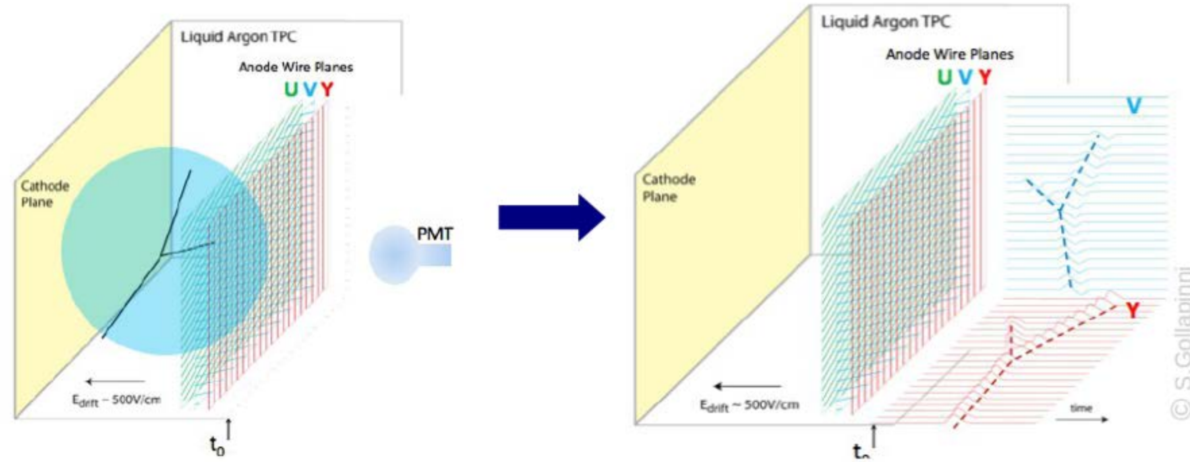
Detection Principle

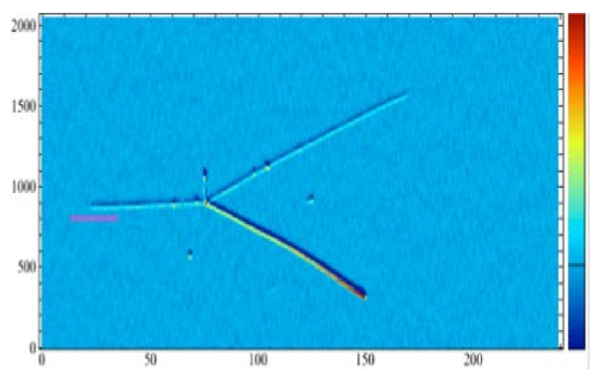
Severest BKG is fast neutrons from cosmic ray or reactor or acc. Beam.
→ Creating prompt + delayed correlated BKG.

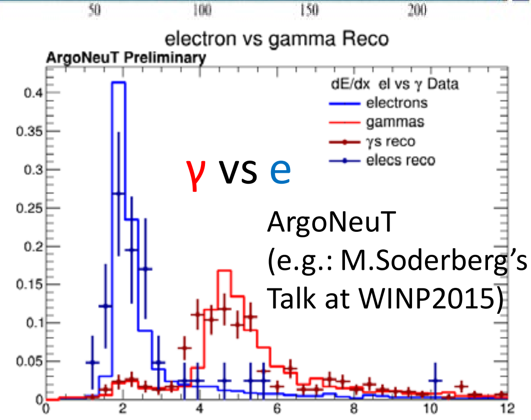
LAr TPC

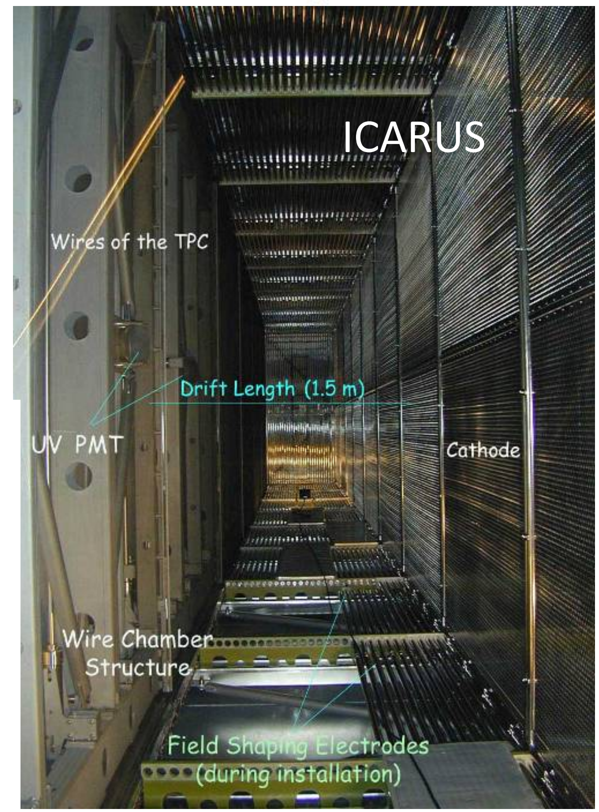
- 電離電子信号
  - ～50000　電離電子/cm（MIP）
  - ～500V/cmの電場により　～mm/μsでドリフト
  - 高純度の液体アルゴンを使い、ICARUSではほぼ1.5mのドリフト長で減衰8%程度（<0.02ppb）
  - 液体中では増幅無し
  - ドリフト電子のディフュージョンは小さい
  - TPCとして三次元飛跡再構成

- 電子とπ^0の識別が得意。
  - 全ての荷電粒子トラックが分かるので、γ→e+e-事象が分かる。(vertex付近から2電子分の電荷）
  - 電子/γ識別が得意と言った方が正確かも。









Recent status

- Sterile neutrino is **one of the most interesting topics** in the neutrino community.
  - A quarter of the presentations in Neutrino 2014 conference mentioned the sterile neutrino.
  - P5 (Particle Panel) endorsed the short baseline neutrino experiments to search for sterile neutrinos.

Presentation and Discussion of P5 Report by S.Ritz (on 22-May-2014)

- **Recommendation 15: Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm.**

Based on the P5 report, neutrino physics during intermediate span (5-10years) were discussed at BNL Feb 4-6 (WINP 2015)
https://indico.bnl.gov/conferenceDisplay.py?confId=918

Very interesting topics are discussed. Please see if you are interested.

最近の傾向・動向

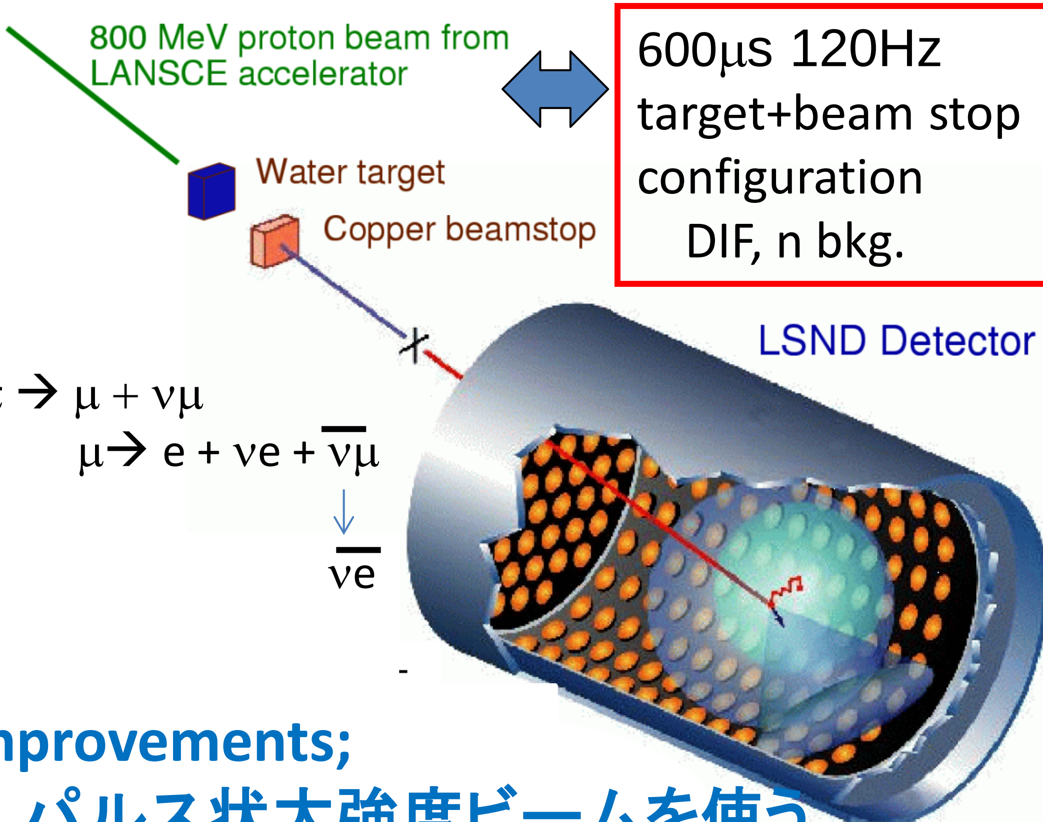
- 振動の議論をする前に、事象超過や消失が本当なのかどうか（隠れた）系統誤差を極限まで減らして結論を出す。
  - ビームの不定性
  - 検出器の不定性
  - 背景事象の不定性
- LSND, MiniBooNE, Ga, Reactor ともに、振動であれば見えるべき振動パターンを見ていない。→　見るべし
  - 距離の関数として
  - エネルギーの関数として
  - L/Eの関数として
- （３＋１）モデルが正しいのであれば、$\nu_\mu \rightarrow \nu_\mu$ 消失も $\nu_e \rightarrow \nu_e$ 消失と同じ確率で起こるはず。
  - SK、MINOS+、ICECUBE
  - 今のところ、兆候なし。

Appearance

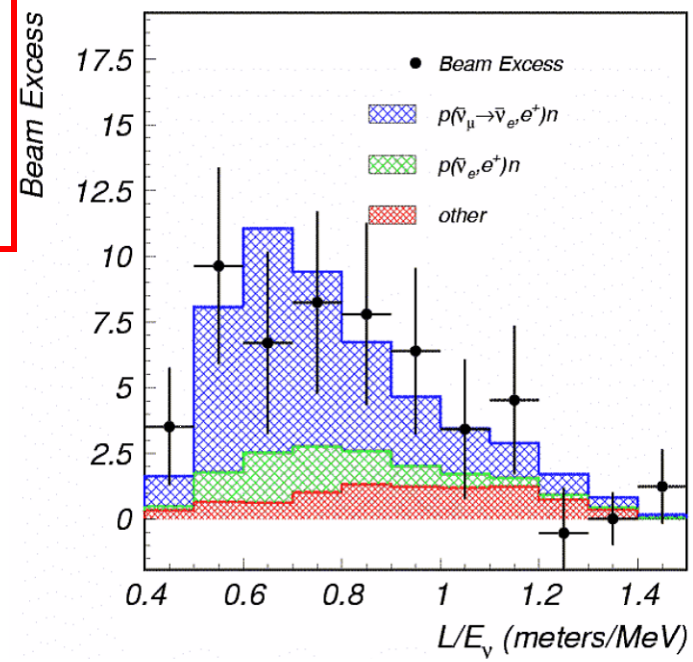
LSND $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Signal

1998

600μs 120Hz
target+beam stop configuration
DIF, n bkg.



$\pi \rightarrow \mu + \nu_\mu$
$\mu \rightarrow e + \nu_e + \bar{\nu}_\mu$
$\downarrow$
$\bar{\nu}_e$



Saw an excess of:
87.9 ± 22.4 ± 6.0 events.

With an oscillation probability of (0.264 ± 0.067 ± 0.045)%.

3.8 σ evidence for oscillation.

Improvements;

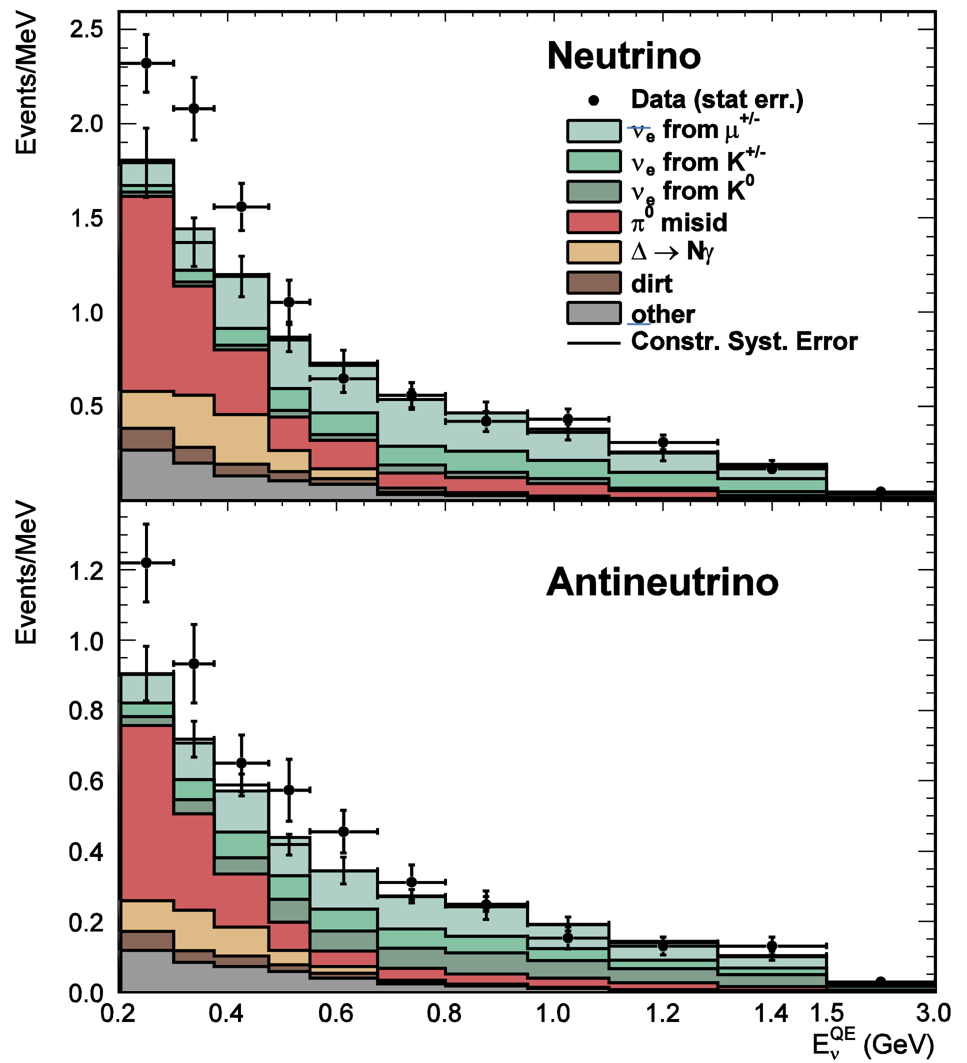
- **パルス状大強度ビームを使う。**
- **Gd入りの検出器を使う。**

π^-, μ^- absorbed before decay into ν's
there should not be $\bar{\nu}_e$ at the level of 7×10^{-4}

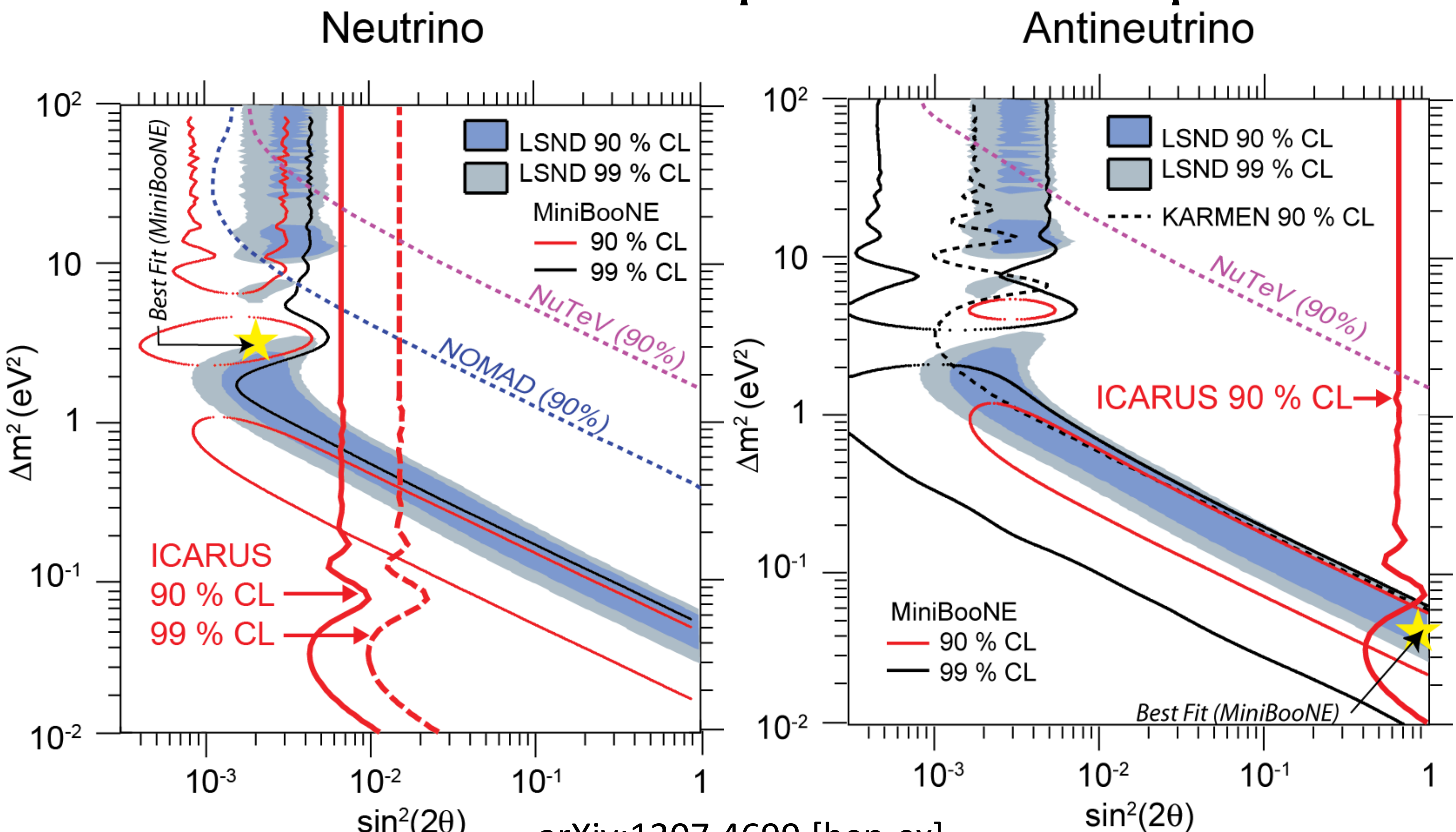
Signal : $\bar{\nu}_e\, p \rightarrow e^+ n$ $np \rightarrow d\, \gamma$(2.2MeV)

MiniBooNEからのimprovements

- 弱点とimprovements
  - 背景事象の絶対量が多い。→　MiniBooNEはミネラルオイルチェレンコフ。π0からの2γを電子と間違ってしまうことも多い。右図のうち、液体アルゴンTPCを使えば、赤部のπ^0 misIDがなくなる。
  - そもそも、こんなに多い背景事象をMCのみに頼って予言するのは難しい。→　2つ以上の検出器を設置して、nearとfarの検出器でのエネルギー分布を比較する。
  - Eν 再構成；原子核効果影響



Status of excess of $\overline{\nu\mu} \rightarrow \overline{\nu e}$ or $\nu\mu \rightarrow \nu e$



arXiv:1307.4699 [hep-ex].

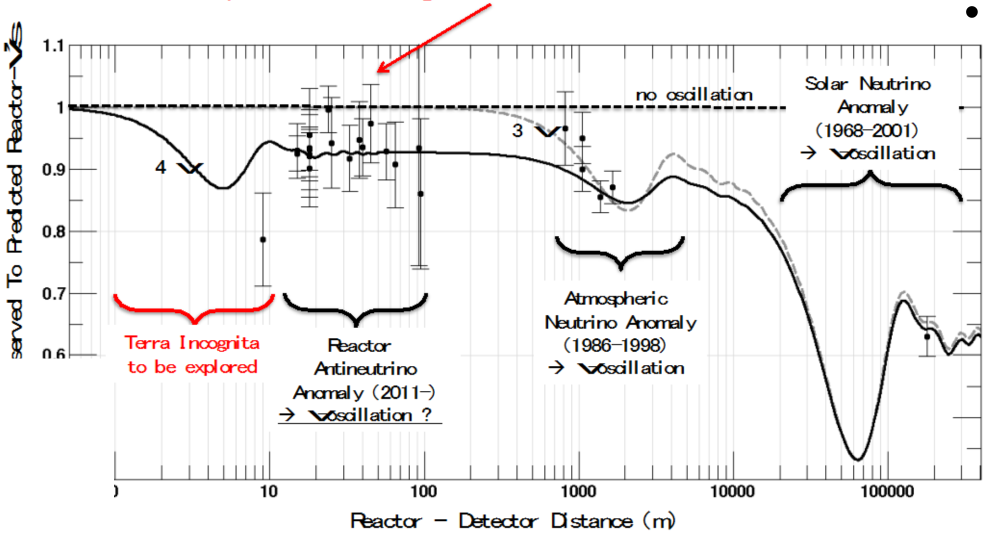
- LSND and MiniBooNE see the excess of the events.
- 3 generation model cannot explain oscillation with Δm^2>~1.0eV^2 region.
- Z measurements conclude 3 active ν → sterile
- 15年間解決しない、この混沌とした状況にどう終止符を打つか、実験屋の腕の見せどころ。

ν_e disappearance in reactor and β–source

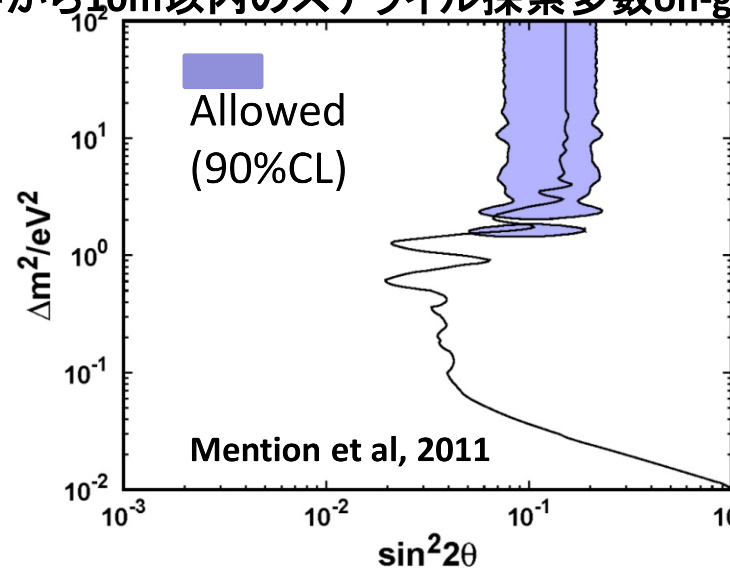
Chris Polly, Thierry Lasserre
NEUTRINO2012

The Reactor Antineutrino Anomaly

- Observed/predicted averaged event ratio: R=0.927±0.023 (3.0 σ)



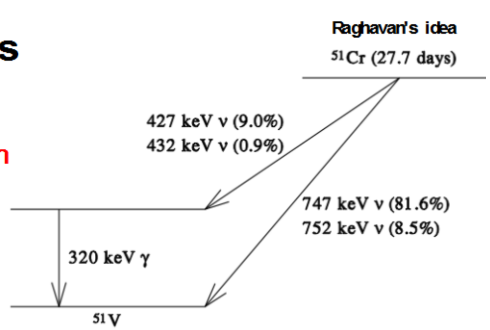
- 原子炉からの反電子νのフラックス精密調査中
- 炉から10m以内のステライル探索多数on-going

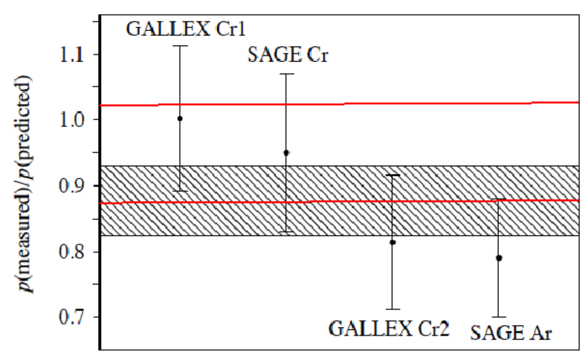


The Gallium Neutrino Anomaly

High Δm^2 ?

- Test of solar neutrino detectors GALLEX and SAGE (ν_e's)
  - E ≈ MeV, Baseline range ≈ few m
- 4 calibration runs ≈1 MCi EC ν_e emitters





~3σ

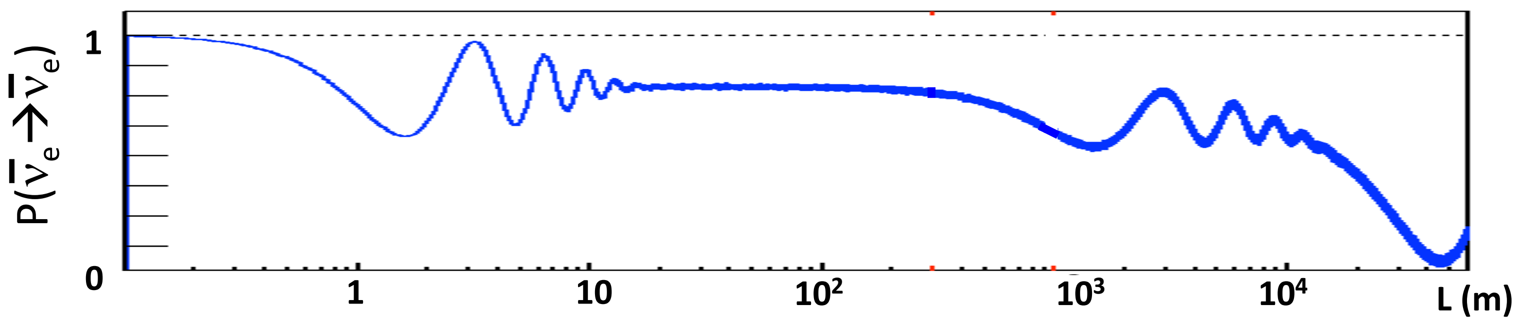
$\overline{\nu}_e \rightarrow \overline{\nu}_e$ disappearance

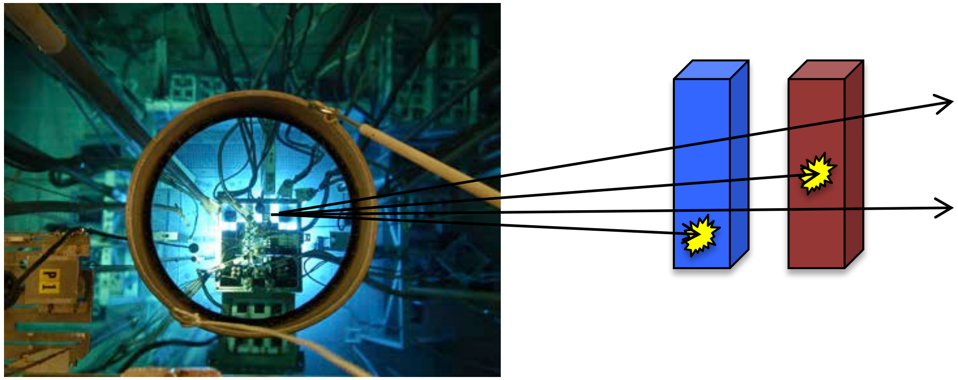
Many talks will be presented later, so I just show the prospects briefly.

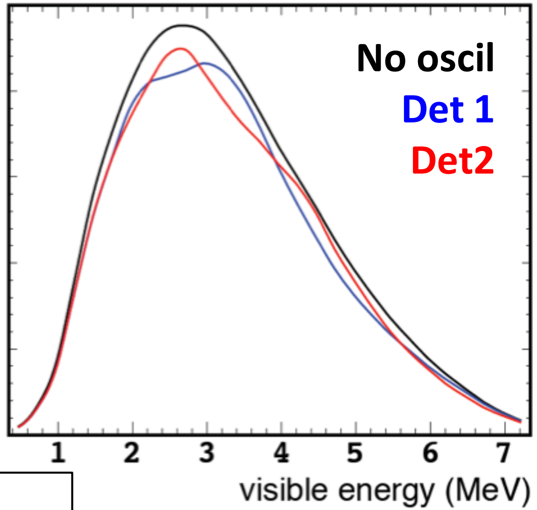
Testing the New Oscillation Hypothesis

Direct test of a new oscillation pattern in E & L

$\Delta m^2 > 0.1$, $\sin^2 2\theta > 0.05$ → L_{osc} = [1-10] m







- Relative shape distortion in identical detector modules
- Complemented by rate info.

David Lhuillier's talk at Neutrino2014

Candidate detectors

Picking up typical experiments.
Not covering all (sorry!)

Requirements

- Underground location;
- Large mass, ultra-pure detectors;
- Capability to measure E and L (oscillometry);

Existing large liquid scintillator experiments (Borexino, KamLAND, Daya-Bay)
Future large liquid scintillator experiments (SNO+, LENS, JUNO)
Future experiments based on other techniques (RICOCHET, BEST)

Experiments with radioactive sources

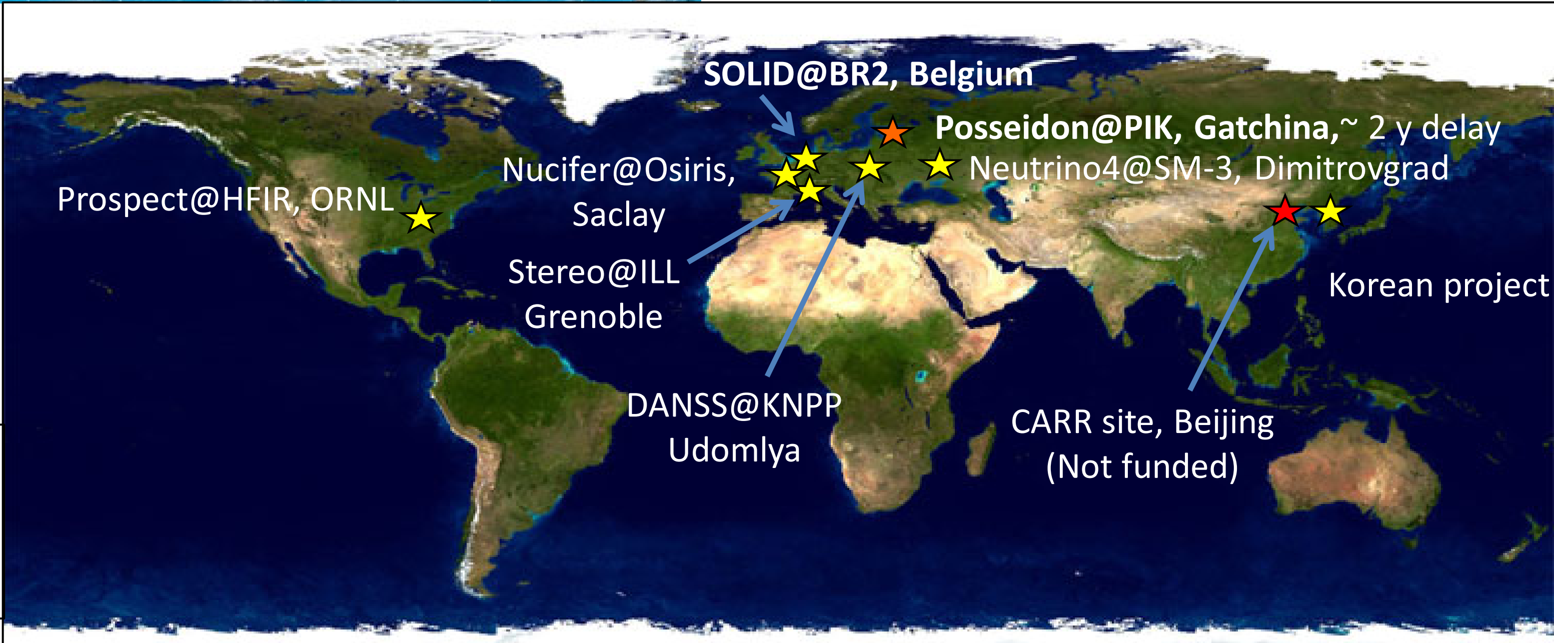
Barbara Caccianiga's talk at Neutrino 2014

Many interesting and exciting results are coming in near future. (2015~)

Many talks will be also coming

Experiments with reactors

David Lhuillier's talk at Neutrino2014



Several papers and ideas

Technique	Detector	Sources	Reaction	Activity	Reference
Large Liquid scintillator detectors (Will be started 2016)	SOX (Borexino)	^{51}Cr,	$\nu+e \rightarrow \nu+e$	10MCi	JHEP08(2013)038,
	SOX (Borexino)	^{144}Ce-^{144}Pr	$\nu+p \rightarrow e^{+}+n$	100kCi	Phys. Rev. Lett. 107, 201801 (2011)
	KamLAND	^{8}Li (ISODAR)	$\bar{\nu}+p \rightarrow e^{+}+n$	8.2 x 10^{14} ν/sec	arXiV:1205.4419, arXiV:1310.3857
	KamLAND	^{144}Ce(CeLAND)	$\bar{\nu}+p \rightarrow e^{+}+n$	100kCi	arXiv:1312.0896
	Daya-Bay	^{144}Ce-^{144}Pr	$\bar{\nu}+p \rightarrow e^{+}+n$	500kCi	arXiV:1109.6036
	LENS	^{51}Cr	$\nu+^{115}In \rightarrow ^{115}Sn^{*}+e$	10MCi	Phys.Rev.D75 093006(2007)
	JUNO	^{8}Li (ISODAR)	$\bar{\nu}+p \rightarrow e^{+}+n$	8.2 x 10^{14} ν/sec	arXiV:1310.3857
Radiochemical	BEST	^{51}Cr	$\nu+^{70}Ga \rightarrow ^{71}Ge+e$	3MCi	arXiV:1204.5379
Bolometers	Richochet	^{37}Ar	$\nu+N \rightarrow \nu+N$	5MCi	Phys. Rev. D85, 013009, (2012)

Setup

Barbara Caccianiga's talk at Neutrino 2014

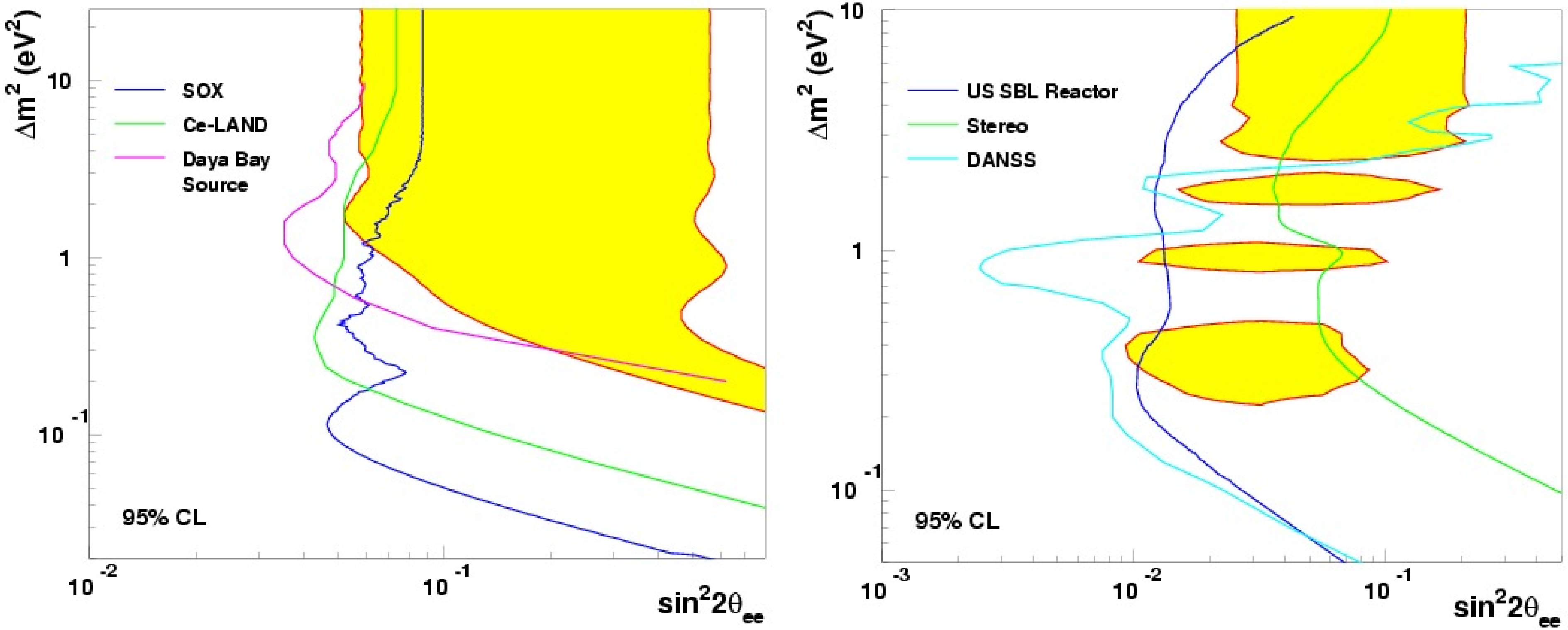
- Need **~10MCi** level radio active source ^{51}Cr, ^{144}Ce-^{144}Pr are considered. Typically $E\nu$ < a few MeV
- Need to transport the source to detector

Status	Experiment	P_{th} (MW)	M_{target} (tons)	L (m)	Depth (m.w.e.)
On-going	Nucifer (FRA)	70	0.8	7	13
	Poseidon (RU)	100	~ 3	5-8	~ 15
Start in 2015	Stéréo (FRA)	57	1.75	8.8-11.2	18
Start in 2015	Neutrino 4 (RU)	100	1.5	6-12	~ 10
Start in 2015	Hanaro (KO)	30-2800	~ 1	6	few
Final detector In 2015	DANSS (RU)	3000	0.9	9.7-12.2	50
White paper was submitted	Prospect (USA)	85	1 & 10	7-18	few
Aim to operate In 2015	NuLat (USA)	20-1500	~ 1	2.5-8	2-10
Start in 2016	SoLid (UK)	45-80	2.9	6-8	10

- Need PID to reject fast neutrons from reactors. PSD (Pulse Shape Discrimination) helps.
- Need sufficient shield.
- Need to see "Oscillation pattern"

Updated table from David Lhuillier's talk at Neutrino 2014

Sensitivities (arXiv; 1310.4340)



They can achieve the sensitivity with short time scales.
(typically < a few years for 95% C.L.)

SOX: the potential full ^{144}Ce and ^{51}Cr program

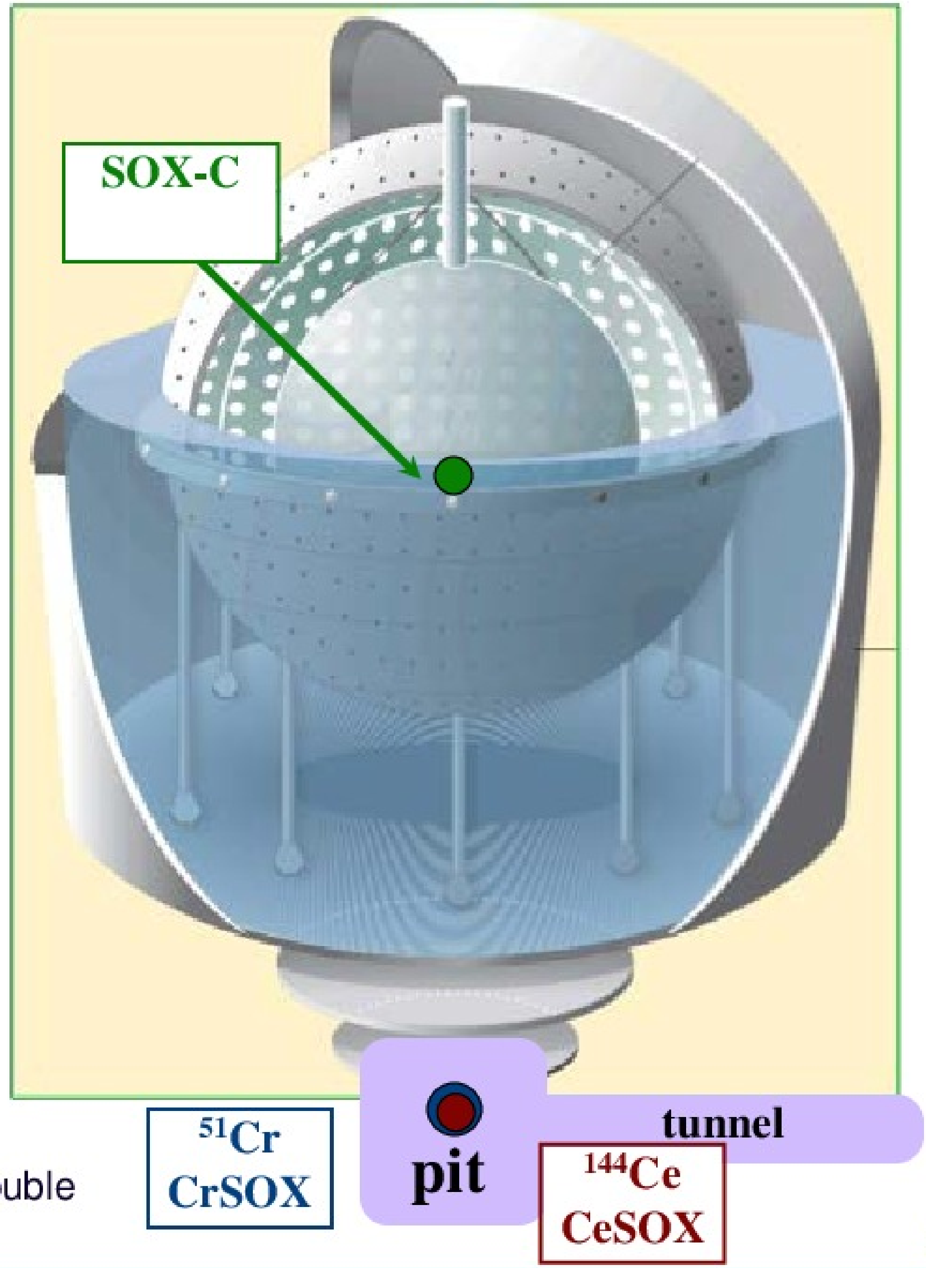
Gioacchino Ranucci's talk @ WINP 2014

- **Mission:** test the existence of low L/E ν_e and/or $\bar{\nu}_e$ anomalies by placing well known artificial sources close to or inside Borexino

- **CrSOX**
  - ^{51}Cr source in pit beneath detector
  - **8.25 m** from center
  - Activity 10 MCi (or two exposures at 5 MCi)

- **CeSOX First to be accomplished**
  - ^{144}Ce-^{144}Pr source in in pit beneath detector
  - **8.25 m** from center
  - Activity 100-150 kCi
  - Planned start-up date middle 2016

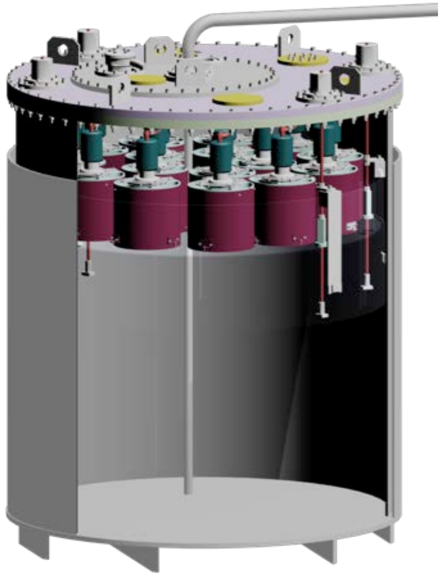
- **SOX-C**
  - ^{144}Ce-^{144}Pr or ^{51}Cr source in the center
  - Would imply a full refurbishment of the detector (suited also for a possible future Double Beta Decay exp. with Xenon)



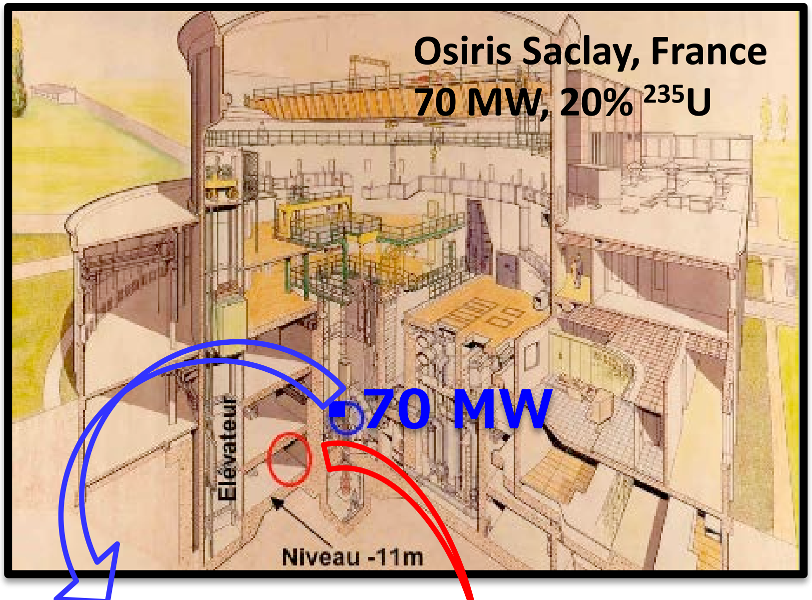
Nucifer @ OSIRIS

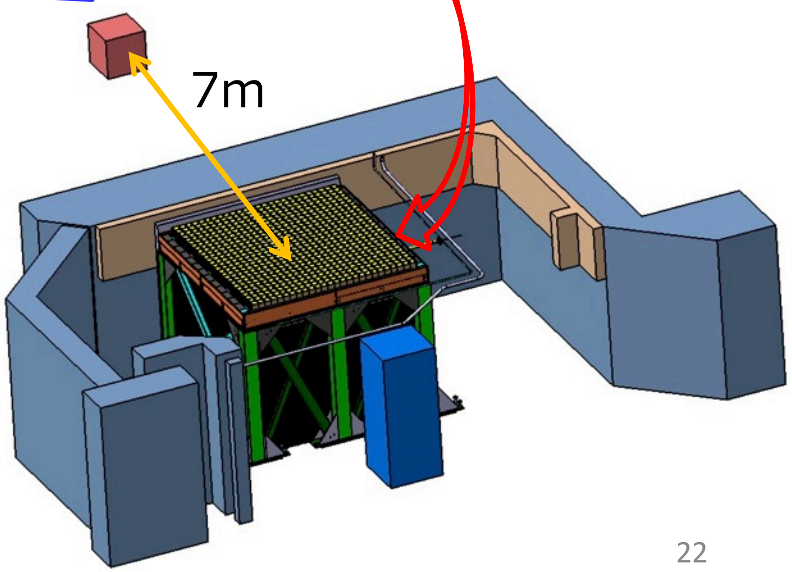
既にon-goingなNUCIFERの話をする

Simple design for reactor monitoring studies



- 850 l Gd-loaded LS
- Compact core (60x60x60 cm^3)
- Short baseline: 7m
- 10 mwe overburden
- ~300 detected ν/day expected





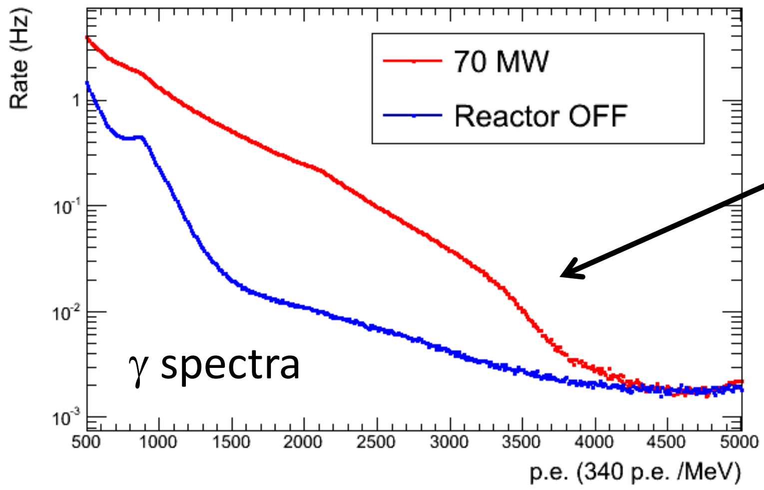
→ Some sensitivity to Sterile ν

But challenging reactor background

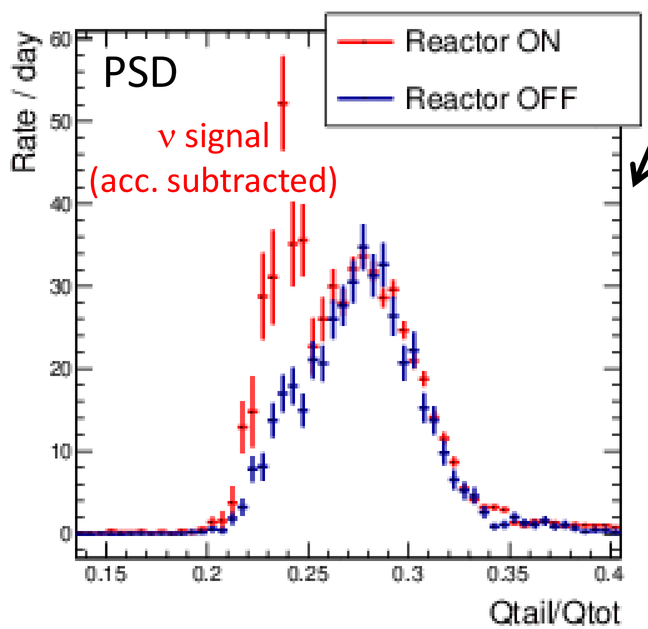
D. Lhuillier's talk in neutrino2014

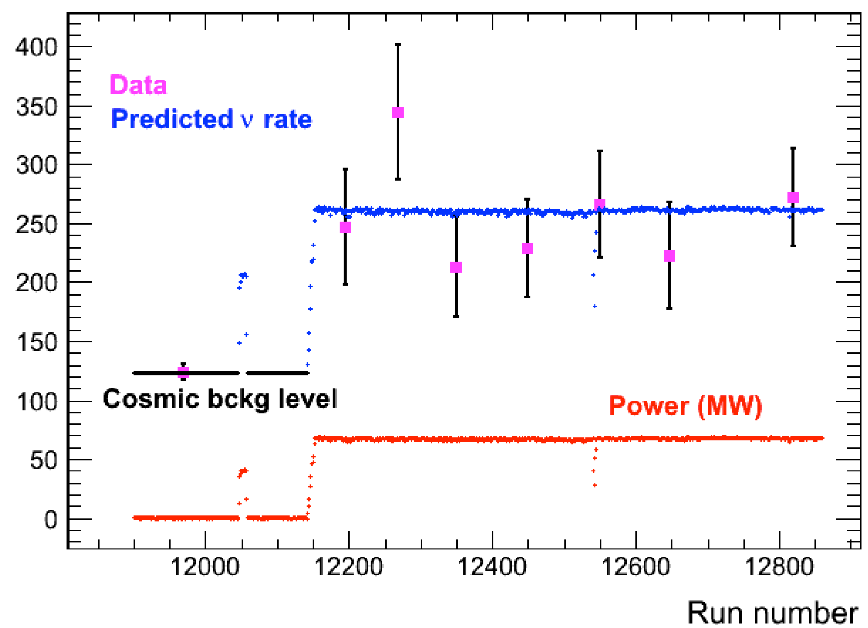
既にon-goingなNUCIFERの話をする

Nucifer @ OSIRIS



- Need further γ attenuation to reach ν/Acc ~ 1. New data taking next week with extra 4 cm of lead on reactor side.
- Rejection of cosmic background with PSD
  No reactor induced fast n @ 7m from core.





D. Lhuillier's talk in neutrino2014

$\nu_\mu \rightarrow \nu_e$ appearance

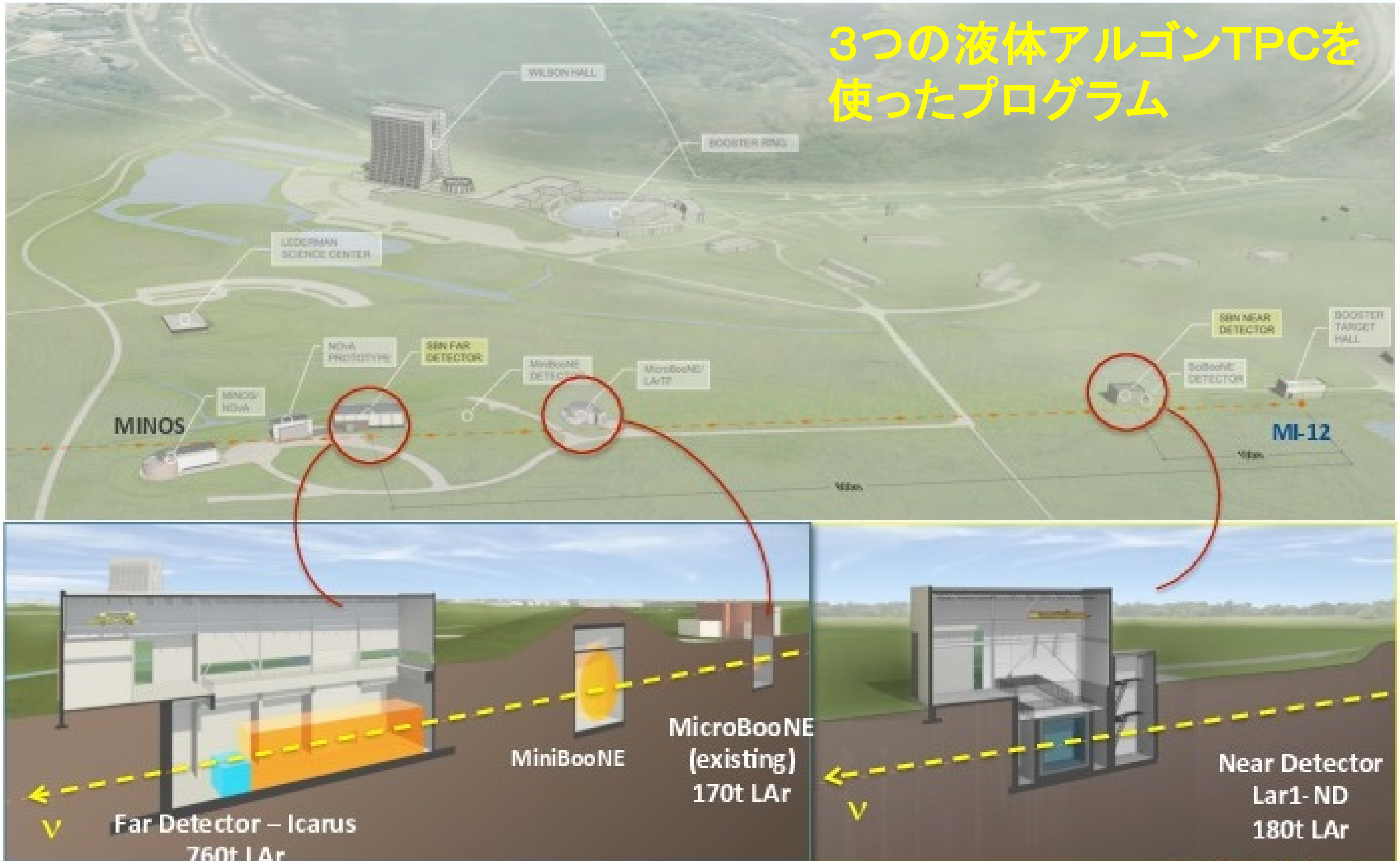
Accelerator based neutrino experiments.

$\nu_\mu \rightarrow \nu_e$ appearance

- LSND / MiniBooNE have significant excess -> to be checked
  - μ Decay-At-Rest source ; J-PARC E56 @MLF and OscSNS (white paper was submitted)
    - Better pulsed beam than LSND ($\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$; $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$)
    - Better liquid scintillator detector than KARMEN / LSND (PID / Gd loaded)
    - Direct test for LSND anomaly (same detector material + μDAR)
  - Conventional horn focused beam;
    - LAr; MicroBooNE, ICARUS,LAr1-ND -> triple LAr@FNAL ($\pi^+ \rightarrow \mu^+ + \nu_\mu$; $\nu_\mu \rightarrow \nu_e$ / reversed horn polarity)
      - Better detector (BKG rejection, e ID, ν energy reconstruction) than MiniBooNE $\rightarrow$ reduced #BKG and systematics on BKG
      - Triple detectors $\rightarrow$ flux uncertainty can be reduced.
      - same beam condition as the MiniBooNE
    - WC; νPRISM 50m tall x 10-12m diameter WC @1km (T2K beamline)
  - IsoDAR/DAEdALUS ; 10mA level very powerful cyclotron.
  - New type of beam + Fe+scintillator detector; nuSTORM
    - Using neutrinos from STORed Muons. ($\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$)

SBN Program Layout

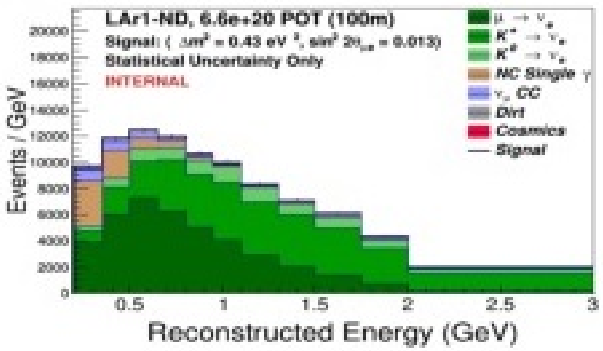
Peter Wilson's talk @ WINP workshop

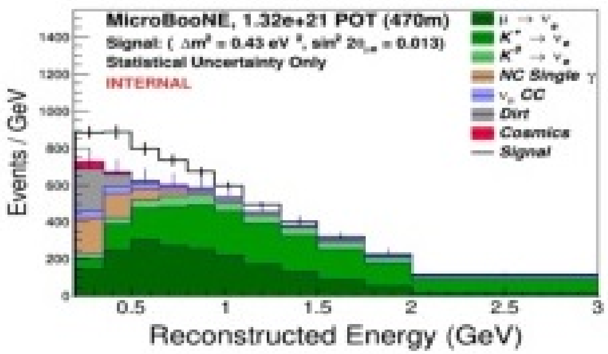


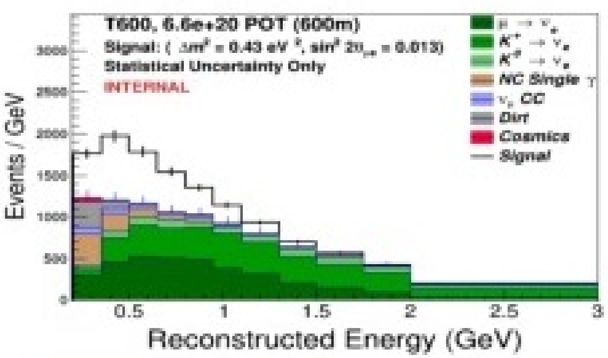
液体中の電離電子ドリフト速度は遅い(m/ms) →
地上でやるので、宇宙線が問題になるかも。

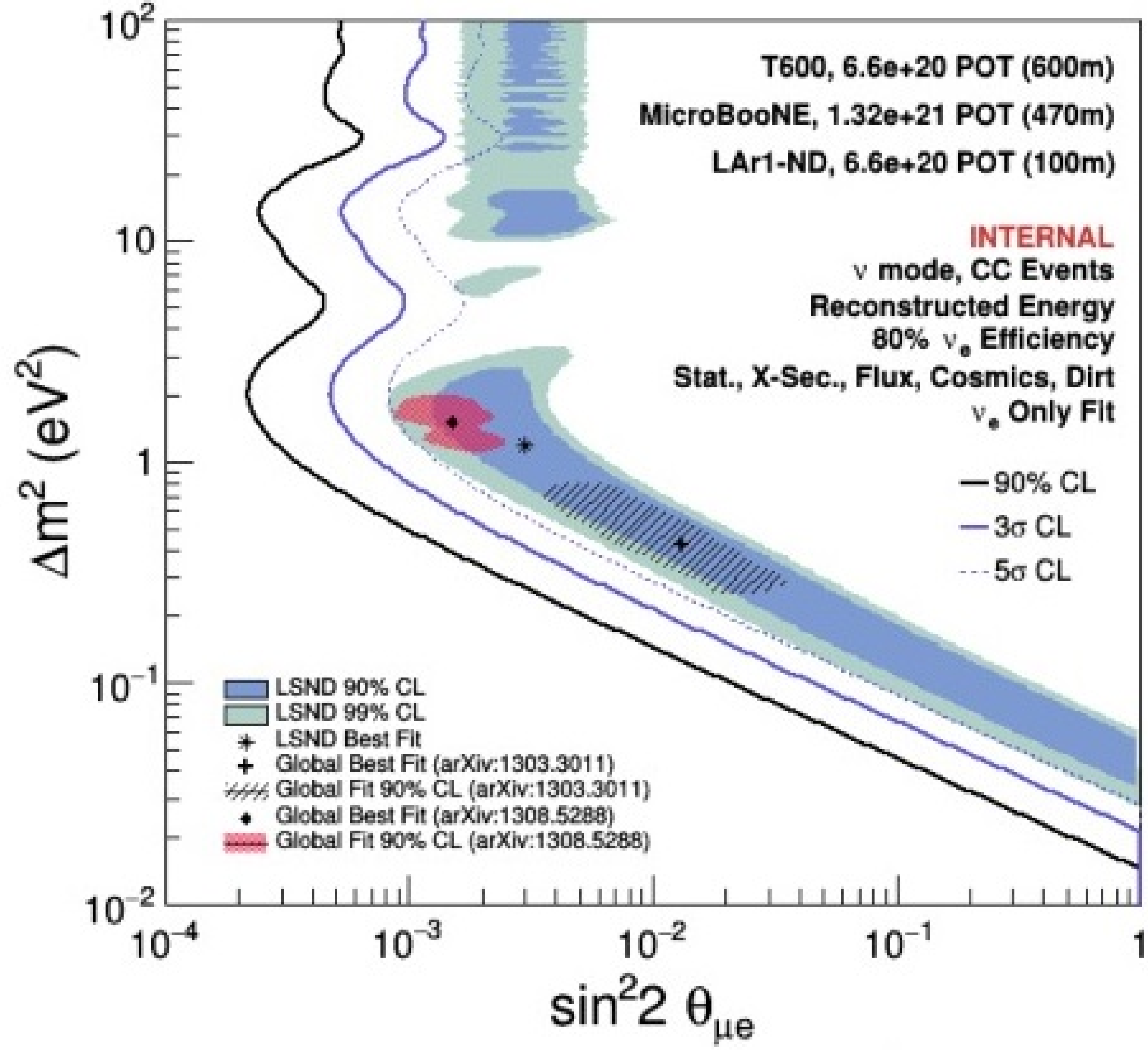
SBN ν_e Appearance Sensitivity

Peter Wilson's talk @ WINP workshop



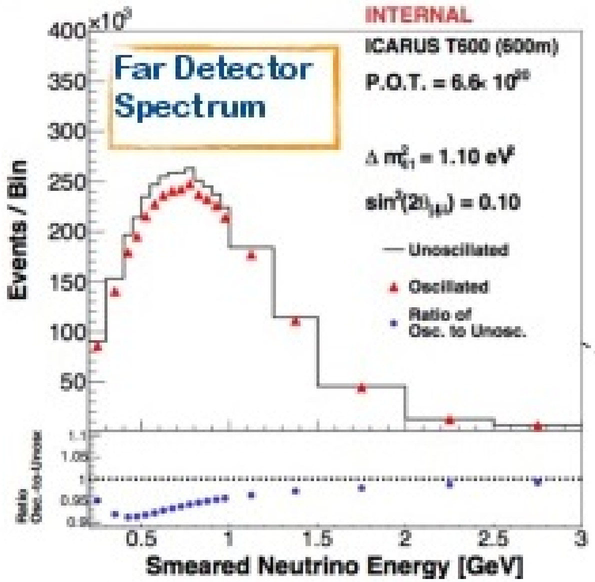


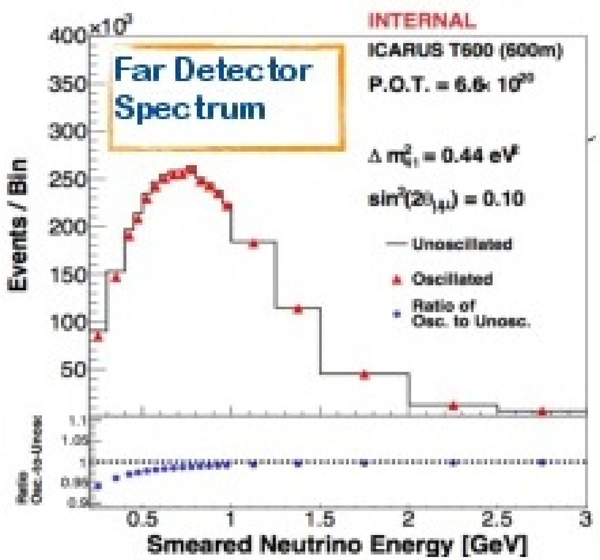


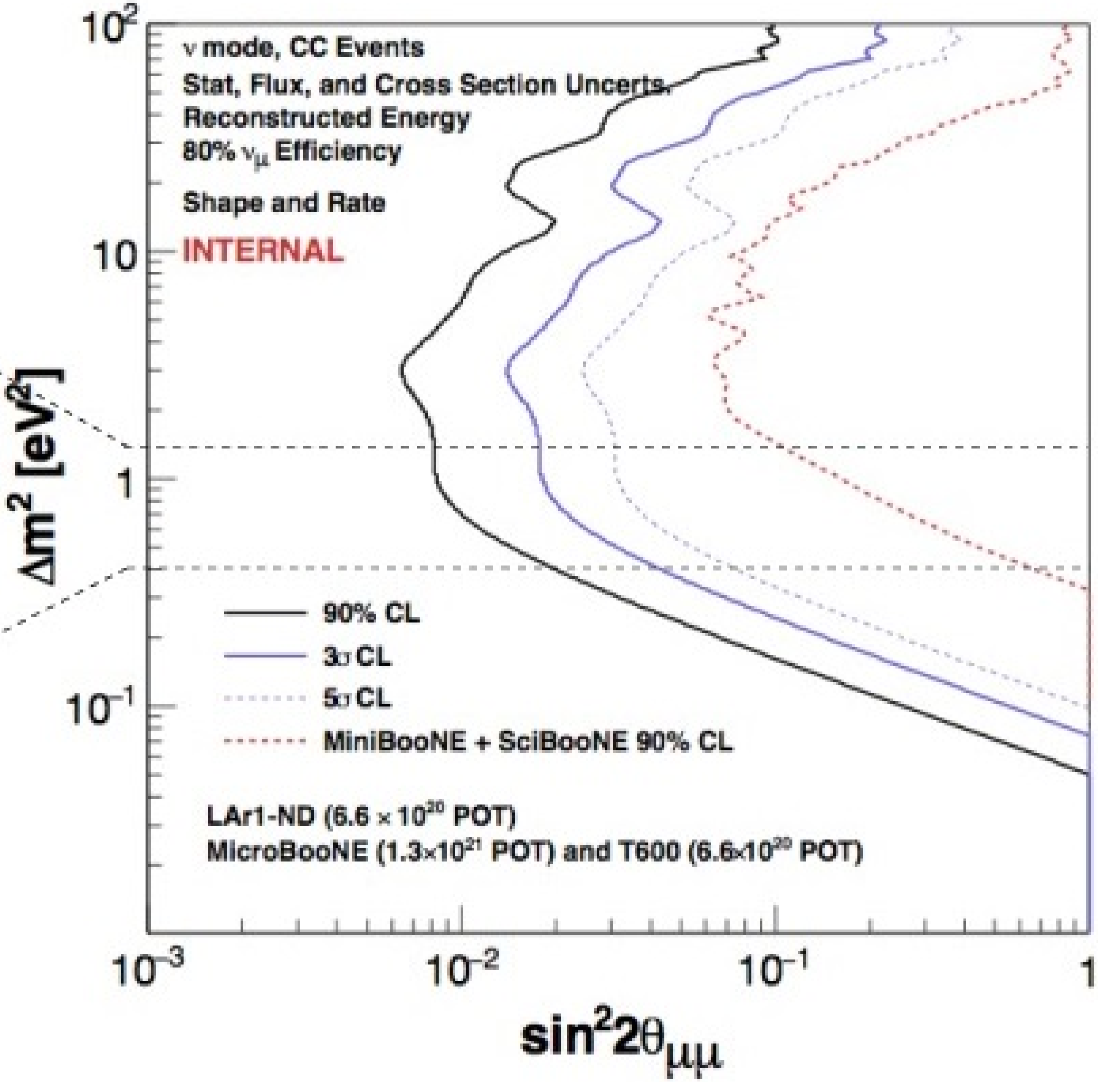


SBN ν_μ Disappearance Sensitivity

Peter Wilson's talk @ WINP workshop

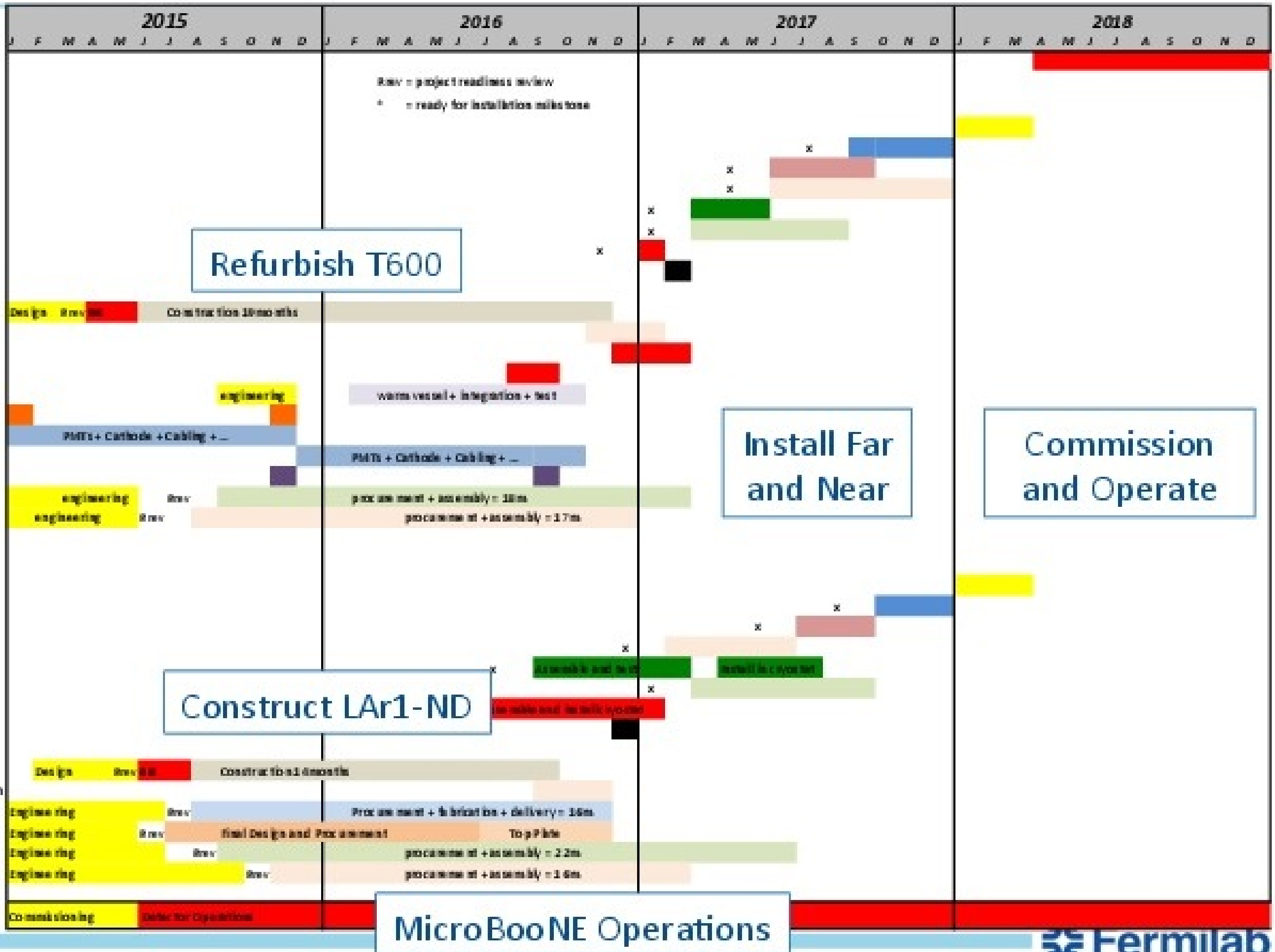






Program Schedule

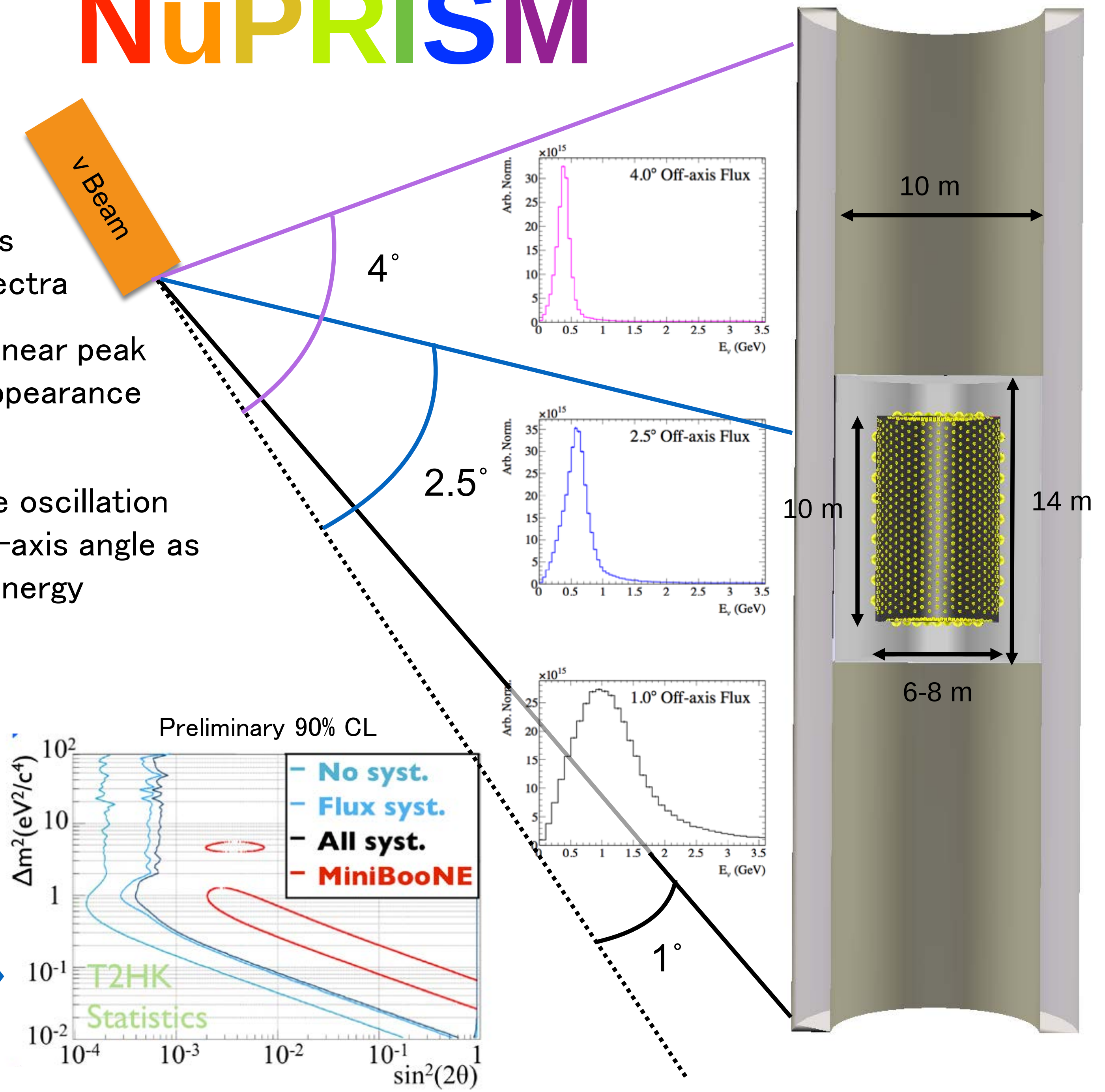
Peter Wilson's talk @ WINP workshop

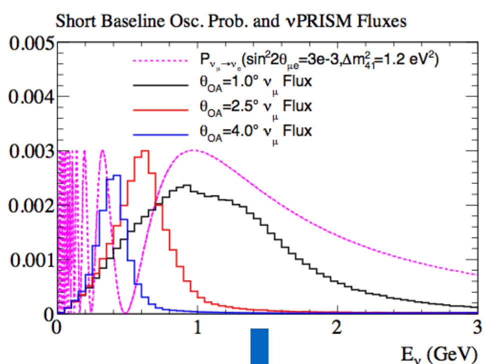


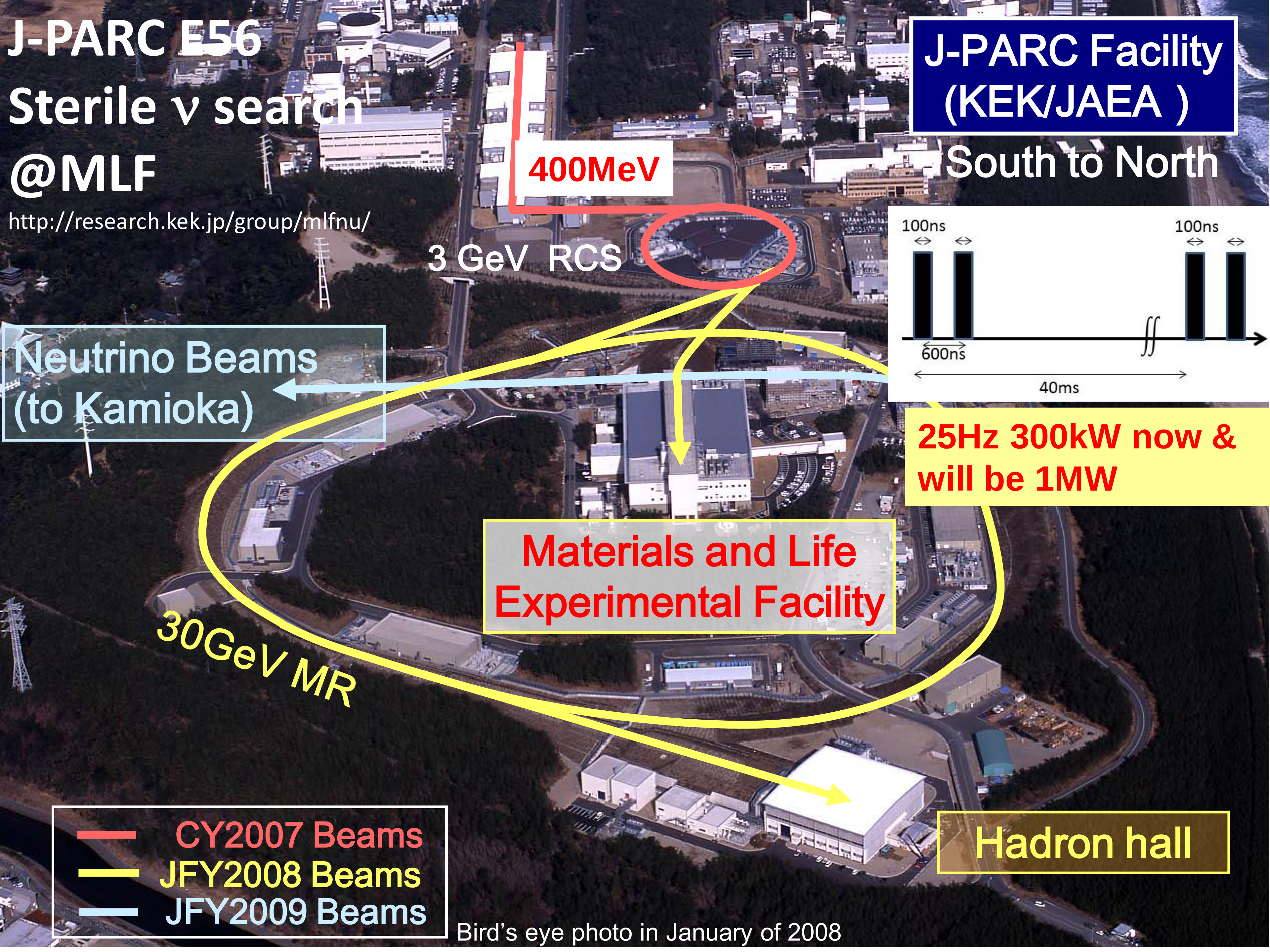
Fermilab

NuPRISM

- water–Cherenkov detector at 1 km in the J–PARC beam
- Range of off–axis angles = Range of neutrino spectra
- 0.5% ν_e contamination near peak = Short–baseline ν_e appearance measurement
- Unique capability to see oscillation pattern in observed off–axis angle as well as reconstructed energy

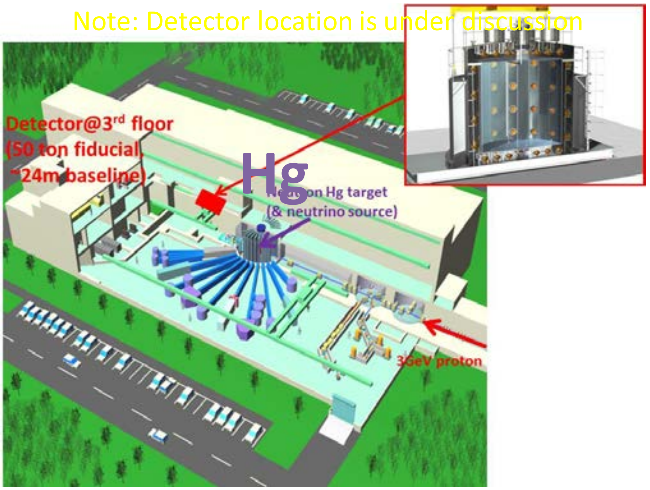





J-PARC E56
Sterile ν search
@MLF
http://research.kek.jp/group/mlfnu/
J-PARC Facility
(KEK/JAEA)
South to North
400MeV
3 GeV RCS
100ns
100ns
600ns
40ms
Neutrino Beams
(to Kamioka)
25Hz 300kW now &
will be 1MW
Materials and Life
Experimental Facility
30GeV MR
Hadron hall
CY2007 Beams
JFY2008 Beams
JFY2009 Beams
Bird's eye photo in January of 2008

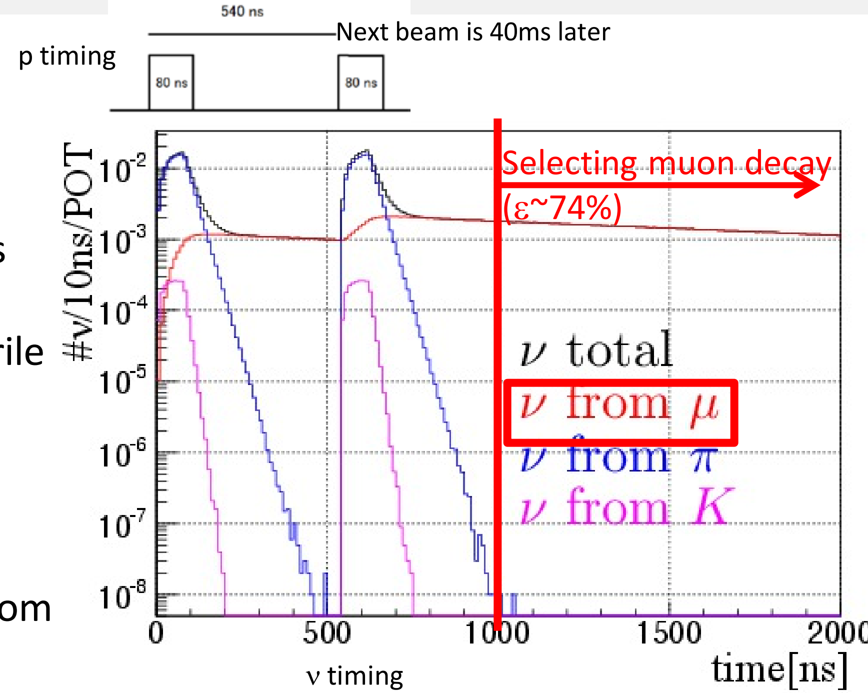
Sterile neutrino search @MLF (proposal in 2013)

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

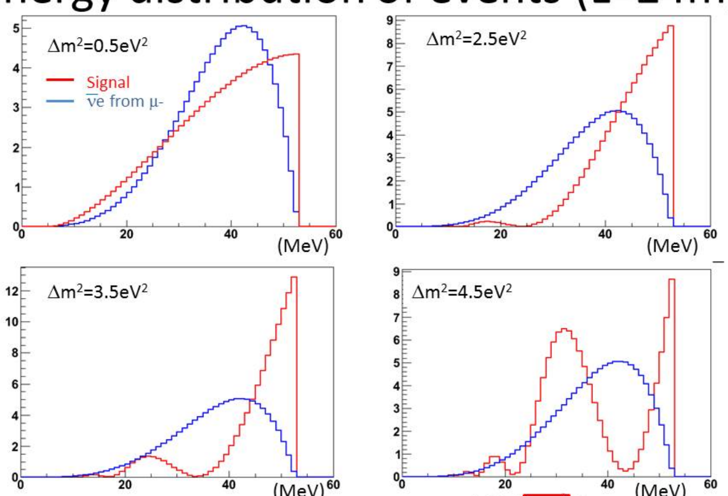


J-PARC E56

- confirms or refutes the neutrino oscillation with sterile neutrino($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$)
- uses ultra-pure neutrinos from stopping μ^+
- separates signals from BKG by measuring energy distortion

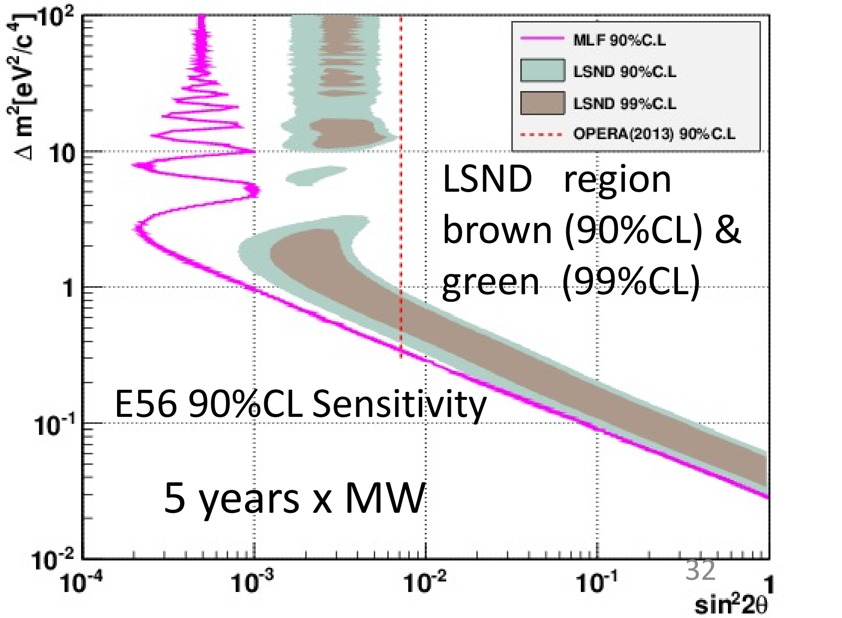


Energy distribution of events (L=24m)



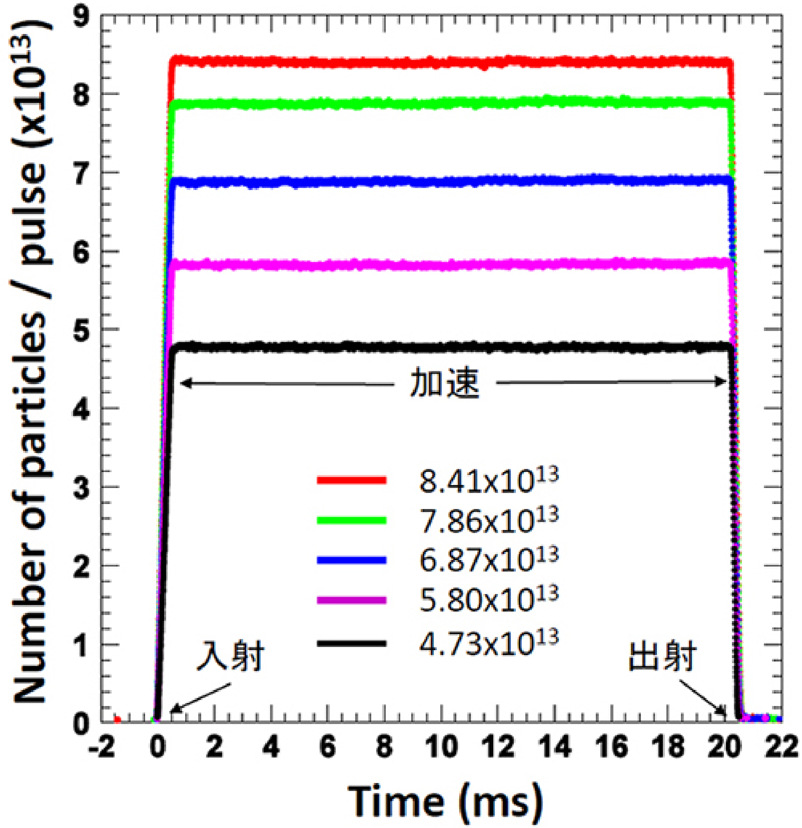
$$P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta \cdot \sin^2(\frac{1.27 \cdot \Delta m^2 \cdot L}{E_\nu})$$

- Energy is smeared by 15%/sqrt(E) (detector E resolution)



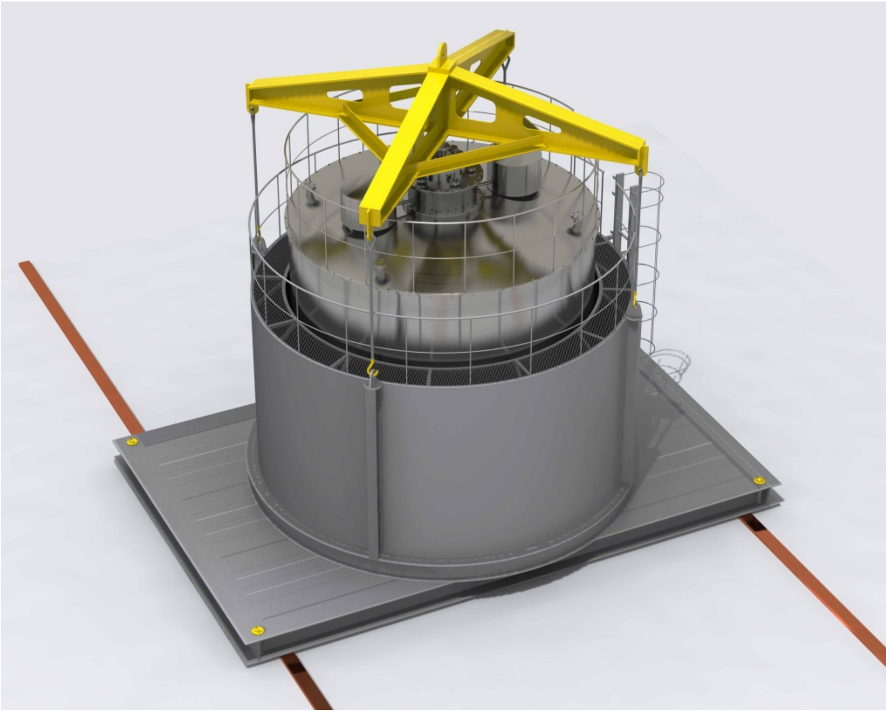
Prospects; RCS/MLF beam

- Current beam power is 300kW.
- 1MW trial during the very short period was succeeded.（下図） http://j-parc.jp/ja/topics/2015/Pulse150206.html
- The beam power will be slowly increased. Next immediate step is 300 → 400kW.

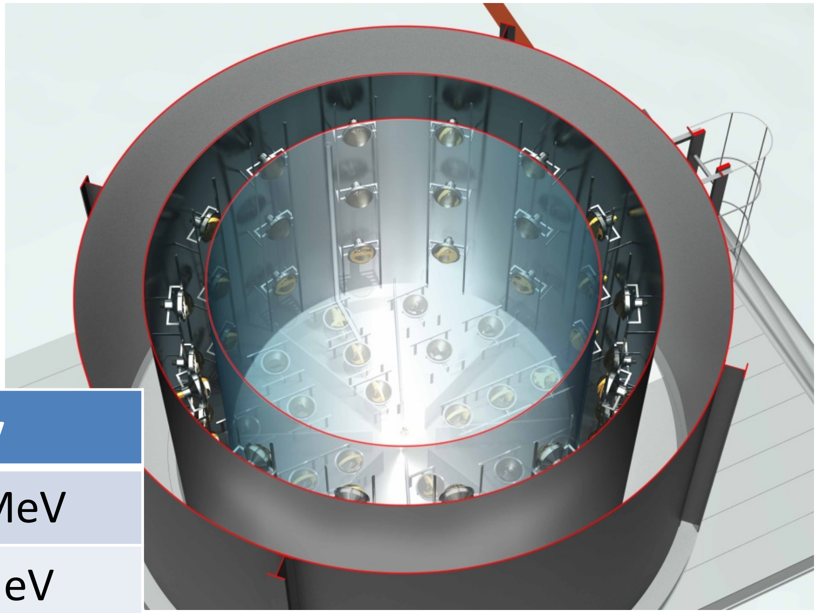


	1パルス当たりの粒子数	25Hz運転時のパワー換算値
(red)	8.41×10^{13}	1010 kW
(green)	7.86×10^{13}	944 kW
(blue)	6.87×10^{13}	825 kW
(magenta)	5.80×10^{13}	696 kW
(black)	4.73×10^{13}	568 kW

Detector



- 50 tons Gd-loaded liquid scintillator.
- Well established technique.
- Strength of tank / endurance for earthquakes were calculated.
- Some of Double Chooz / Daya-Bay collaborators joined E56.
- Will be located at MLF 3rd floor : the maintenance area → need to avoid interference

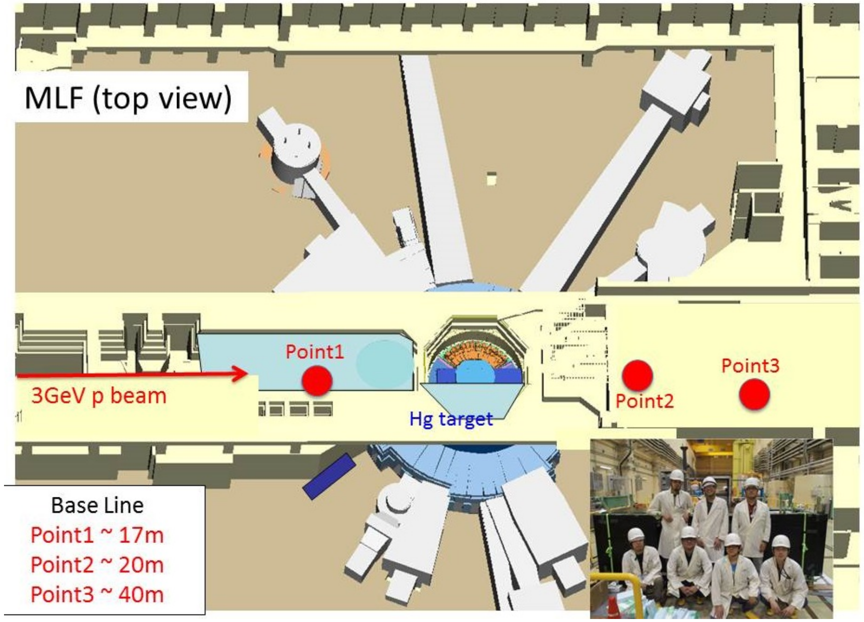


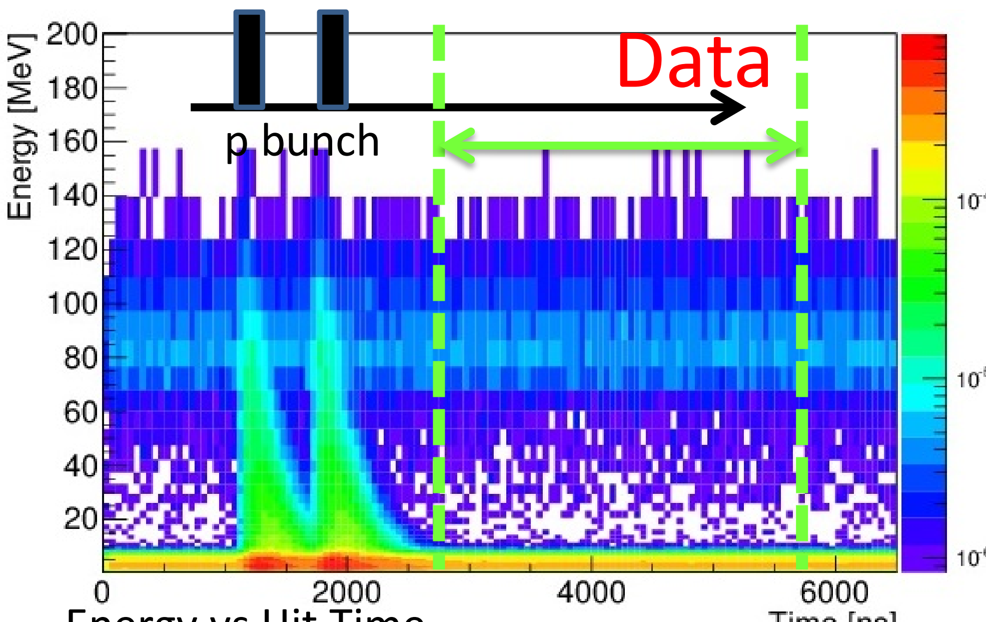
	Time from beam	Energy
Prompt signal	$1<T_p<10\mu s$	20<E<60MeV
Delayed signal	$T_p<T_d<100\mu s$	6<E<12MeV

J-PARC E56; Achievements so far

- 2013 Feb-May; A background measurement on the 1st floor
- 2013 Sep; A proposal was submitted to the J-PARC PAC
  - The PAC recommended to measure the background at the detector candidate site (3rd floor of MLF)
- 2014 Apr-Jul; We measured the BKG rate at 3rd floor. (MLF 2014BU1301 test experiment). -> Small beam/cosmic BKGs to perform E56 experiment.
  arXiv:1502.02255 [physics.ins-det]
- 2014-Dec; A status report were submitted to J-PARC PAC. We obtained the stage-1 approval from the PAC.
  http://j-parc.jp/researcher/Hadron/en/pac_1412/J-PARC-PAC-19-final_141205.pdf

2014BU1301 experiment (@MLF 3rd floor)

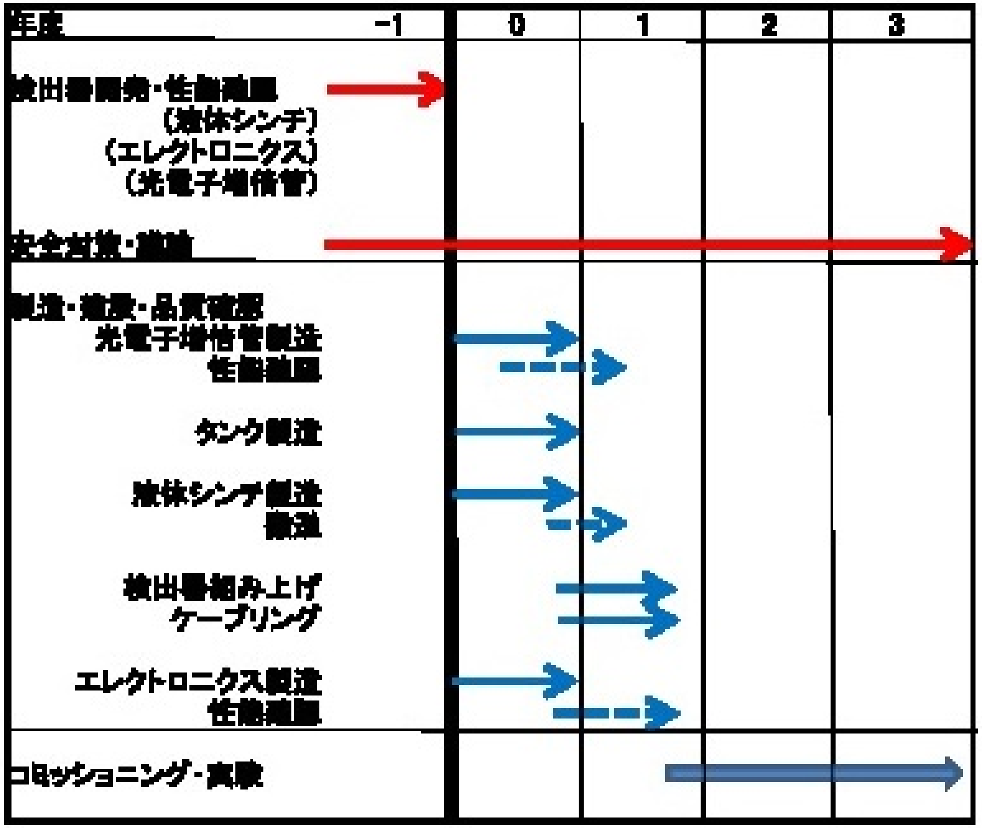




Energy vs Hit Time

J-PARC E56 Timescale

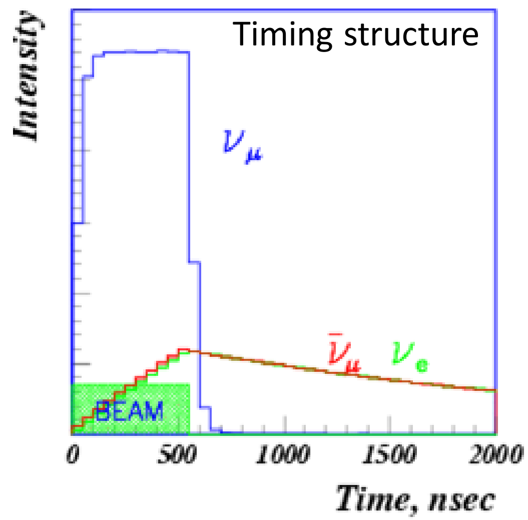
- 2015;
  - 液体シンチのR&D・性能確認(含ビームテスト)
  - エレクトロニクスR&D
  - タンク等のデザインの最終化.
  - 追加のマイナーな背景事象測定。
  - MLFと安全面・検出器のメンテナンスに関する議論
- 検出器建設から約1.5年で実験をスタート。

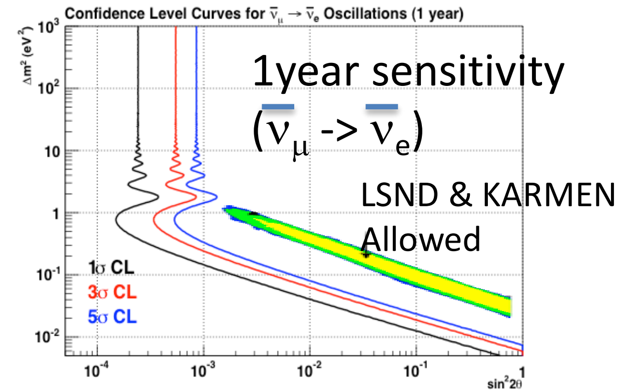


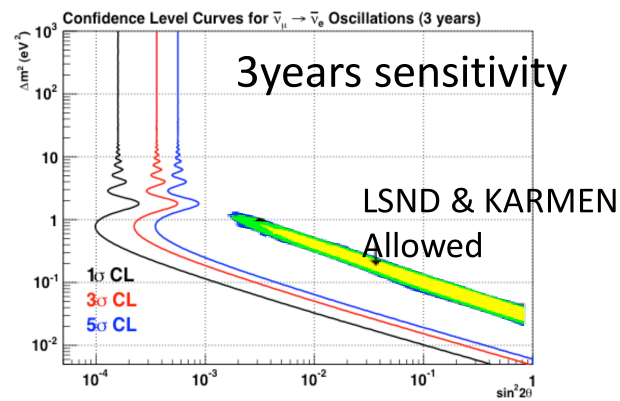
- 新しいビームライン/検出器建屋(穴)が必要ないので、非常にコスト効率が高い。検出器1基 ～2億円
- また、上記に加え、検出器も良く理解されたものを使うことで、世界に先駆けて結果を出せる可能性が高い。

OscSNS (arXiv:1307.7097)

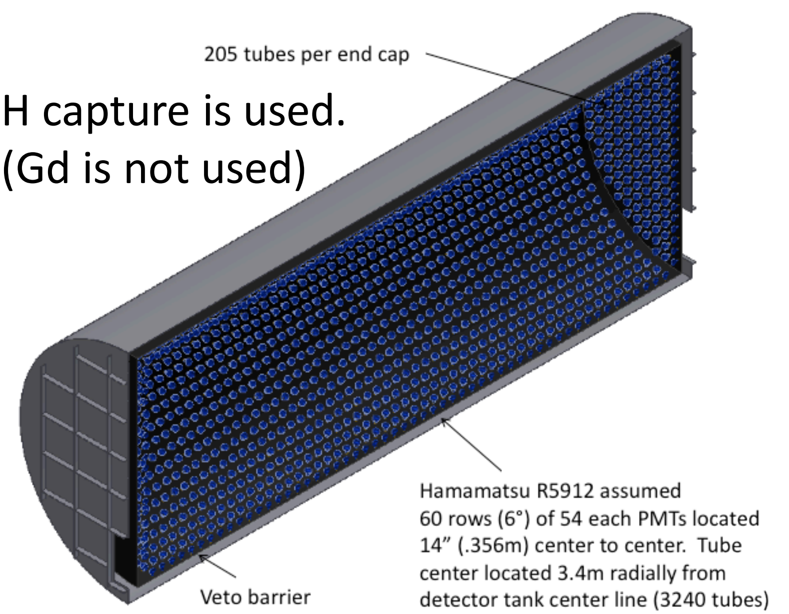
- Use Spallation Neutron Source (SNS) at ORNL
- ~1GeV protons on Hg target (1.4MW)
- Free source of neutrinos
- Well understood flux of neutrinos





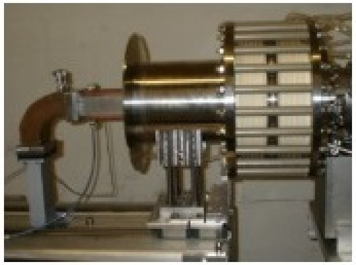


H capture is used.
(Gd is not used)



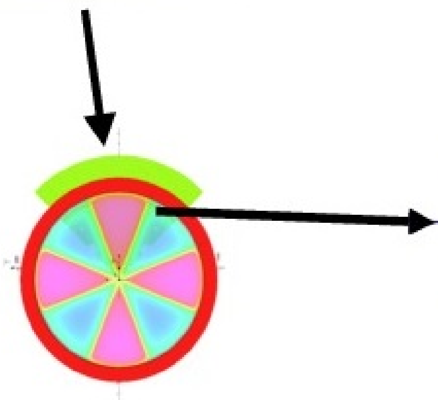
IsoDAR / DAEδALUS

Ion source

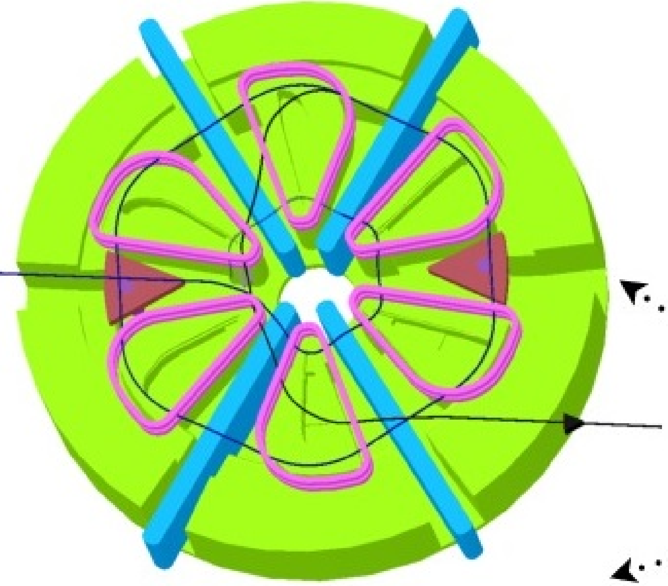


Superconducting ring cyclotron (DAEδALUS)

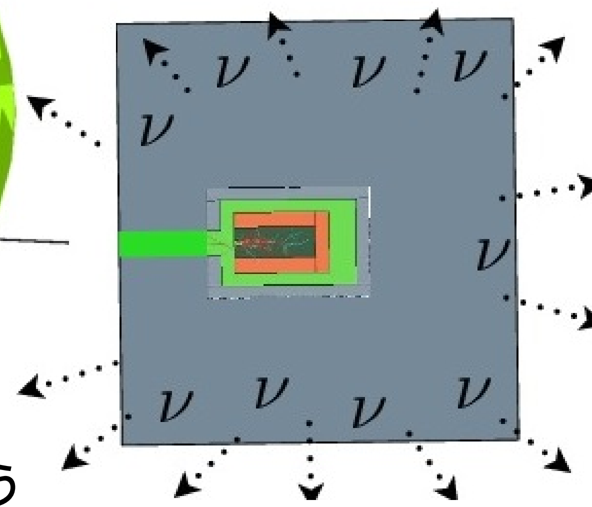
J.Spitz’s talk @ WINP2015

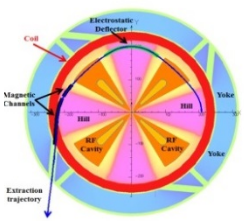


Injector cyclotron (IsoDAR)



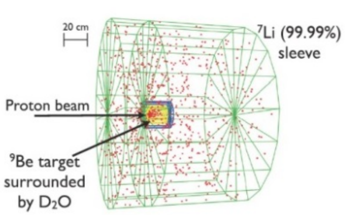
Target/dump





Accelerating H_2^+, 60MeV/n @ 5ma

Neutrons capture on ^{7}Li to make ^{8}Li.



- 強力なCyclotronビームを使う
- DAEδALUSの最終的なビームは 700MeVで5MWくらい。
- IBDが起こる巨大検出器に 向かって打ち込む。（加速器を距離を 変えて、3つくらい作る）

mode	experiments	ν source	Detector	Pros	comments
$\overset{(-)}{\nu}_e \rightarrow \overset{(-)}{\nu}_x$	Nucifer, STEREO, etc	Reactor	Gd-LS	Ton-scale detector, variation of L	BKG from reactor/CR
	PROSPECT	Reactor	Li-LS	PSD for delayed n signal (double PSD)	R&D
	SOX, etc	Radio active source (Cr,Ce-Pr)	Gd-LS	Fastest results(?) / ν and ν sources	MCi level source / transportation
$\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e$	J-PARC E56/Osc SNS	μ DAR	Gd-LS / LS	Well-establish det. / small BKG / Eν rec	MLF maintenance / new hole (SNS)
	IsoDAR/DAEδAL US	μ DAR	LS or Gd-H_2O	Very strong beam	R&D
	Triple LAr	π DIF	LAr-TPC	Beam / MicroBooNE / ICARUS are available. e/π^0 sep	CR on ground Erec(?) LAr1-ND plan
	nuPRISM	π DIF	WC	Beam is available / different Eν	Eν rec
$\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_\mu$	SK/MINOS+/T2K-ND/ICECUBE	π DIF	WC/Fe-Scinti	On-going	---

Summary

- LSND、MiniBooNE、Ga較正、原子炉で見られる事象超過と事象欠損が本当にあるかどうかは、系統誤差が小さい実験で早く決着をつけるべき問題。
- 現在、出現・消失モードに関する多数の実験がon-going または予定されている。
  - 線源・原子炉と液体シンチを用いたν_e消失
  - ダンプνと液体シンチを用いた反ν_e出現
  - 電磁ホーンν とLAr/鉄シンチ/WCを用いた反ν_e出現、ν_μ消失。
- 後、5-10年の間に全てのモードでだいたいの結果が出そろう。
  - 非常にエキサイティングな時期
  - 小回りや自分のアイディアが活かされる実験も多い。
  - ➢ 是非、みなさんの知恵を実験に！！！

backup

Conventional beam + LAr TPC

- LAr TPC can see all of charged particle tracks.
- Clear electron, π^0 and single γ PID can be performed.

FIGURES

ICARUS arXiv:1307.4699 [hep-ex].

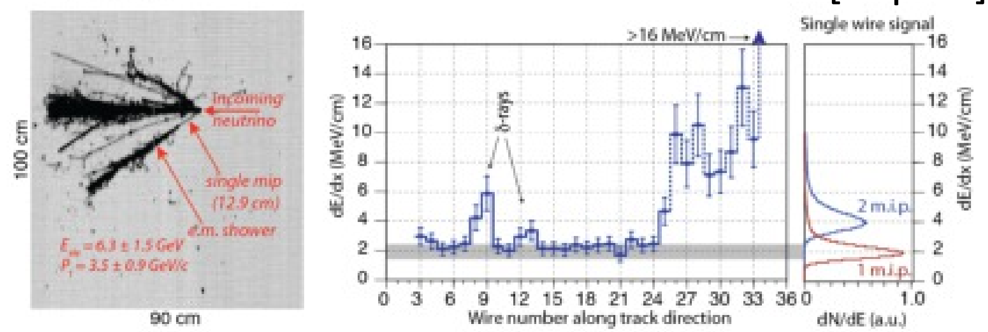
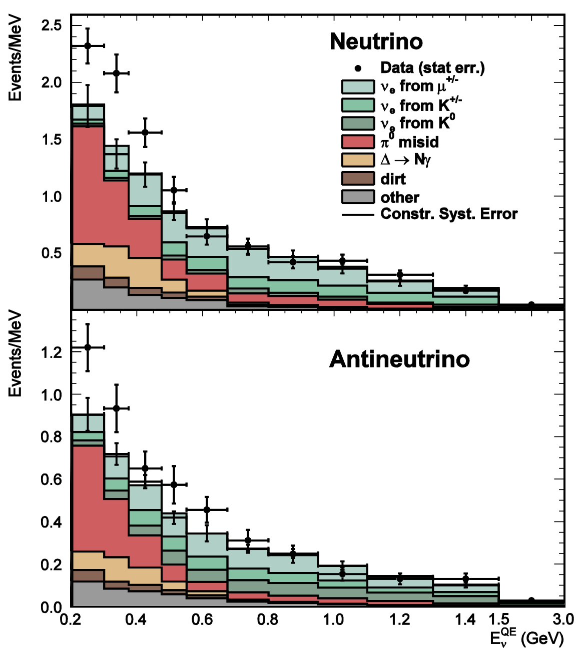


Figure 1. Experimental pictures of the first of the two events with a clear electron signature found in the additional sample of 904 neutrino interactions. The evolution of the actual dE/dx from a single track to an e.m. shower for the electron shower is shown along the individual wires. The event has a total energy of ~27 GeV and an electron of 6.3 ± 1.5 GeV with a transverse momentum of 3.5 ± 0.9 GeV/c.

MiniBooNE Excess

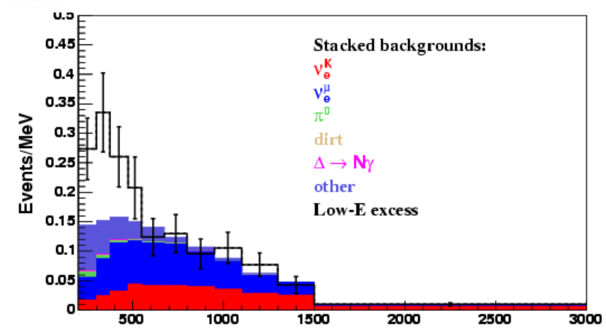
PRL 110.161801,2013.

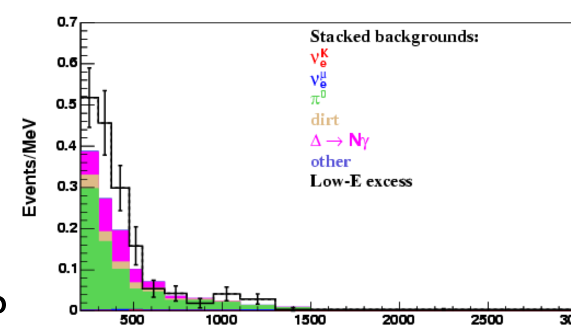


Electron excess (oscillation)?

MicroBooNE

or γ excess (uncertainty of ν cross section)?





CMB and Neff

- They first calculate the whole radiation energy density from the thermal fluctuation . (ρ_{rel})
- Subtracting the energy density of the photons from the whole energy density. ($\rho_{rel} - \rho_{photon}$)
- Then the Neff is calculated by dividing the energy density by the neutrino energy density of 1 generation

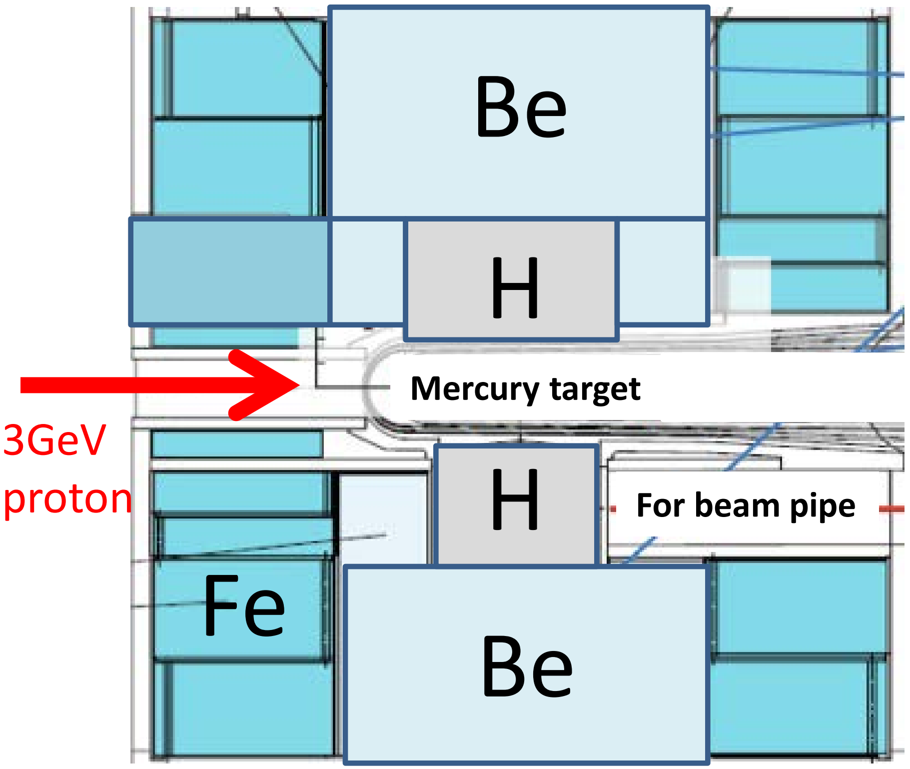
  $Neff = (\rho_{rel} - \rho_{photon})/\rho_{nu,thermal}$

- Here we assume neutrinos are in [thermal equilibrium]() to calculate the energy density of the neutrinos for one generation.
- If neutrinos are in thermal equilibrium, the energy density of neutrinos are related to that of photon with the equation;

  ($\rho_{nu} = 0.22 * Neff * \rho_{photon}$)

- Sterile neutrinos may or may not be in thermal equilibrium via neutrino oscillations (depending on the model), so Neff could not prove the number of generations of sterile neutrinos. (E.g.; see http://arxiv.org/pdf/1303.5368v2.pdf for further details)

MLF mercury target and Intrinsic $\overline{\nu_e}$ BKG estimation



	Target	π^- absorb	μ^- capture	suppression	x	π^-/π^+
LSND	H2O	96%	88%	5×10^{-3}	x	0.13
J-PARC E56	Hg(+Fe+Be)	99%	~80%	1.7×10^{-3}	x	1.

We will assume ~ 1.7×10^{-3} Intrinsic background hereafter.