110607
GLA11
Jyvaskyla
Finland

Near and far future at J-PARC neutrino beam

(30min incl. discussion)

Takashi Kobayashi

KEK

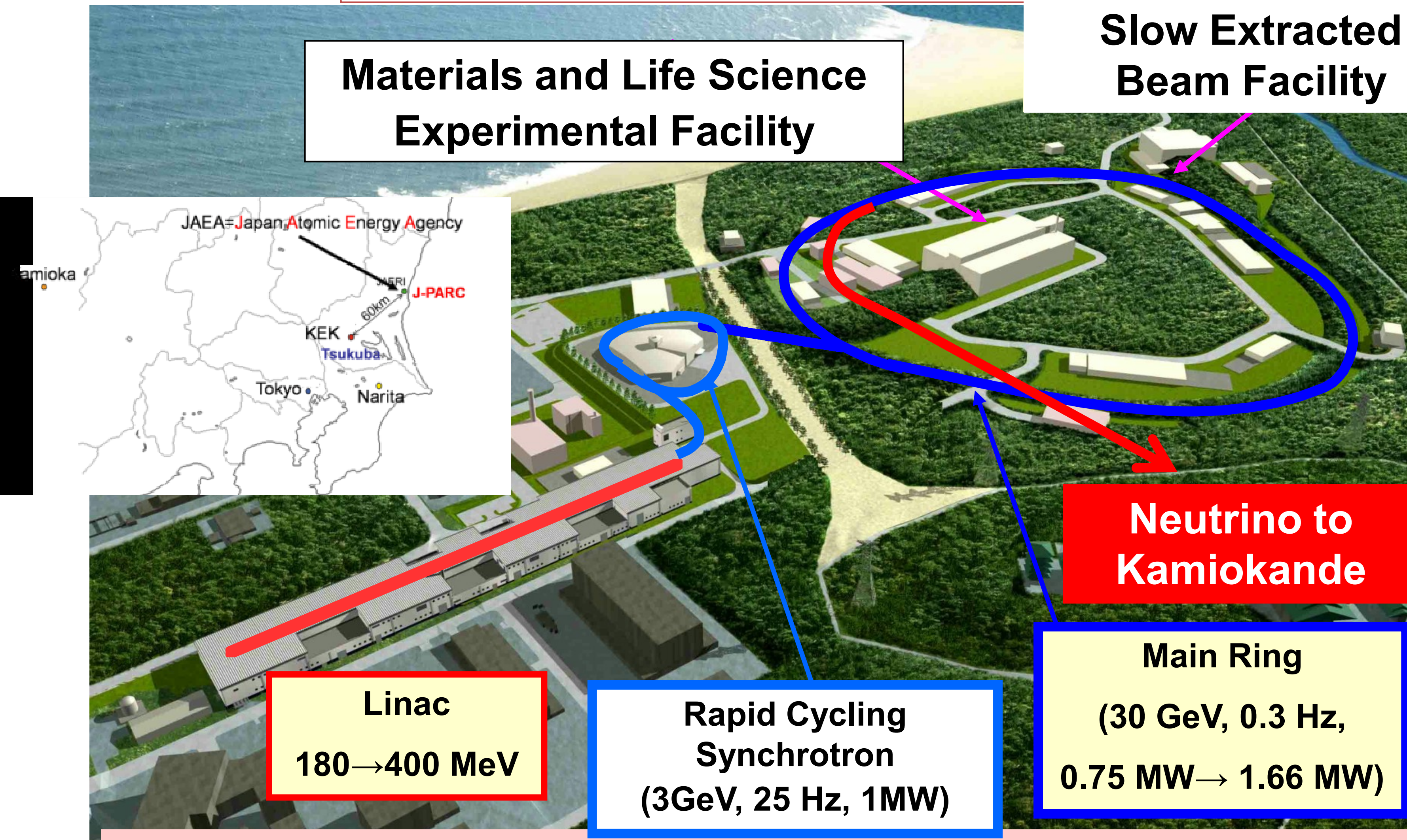
Contents

- Introduction
  - J-PARC & T2K
- Achievements
- Earthquake damages and recovery plan
- Future upgrade plan
  - Physics program
  - J-PARC upgrade
  - Detector options
  - R&D status
- Summary

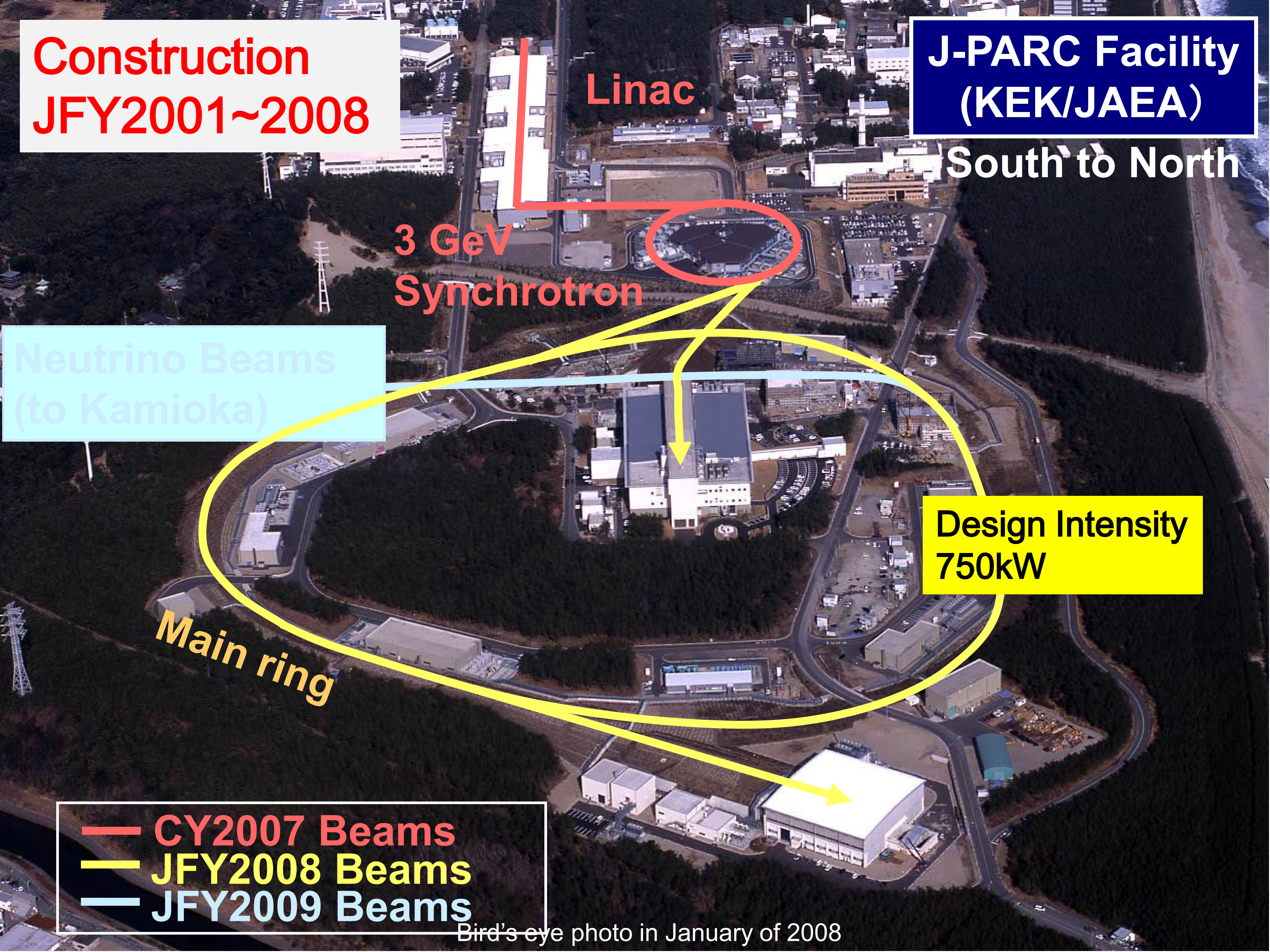
J-PARC

Japan Proton Accelerator Research Complex

Joint Project between KEK and JAEA

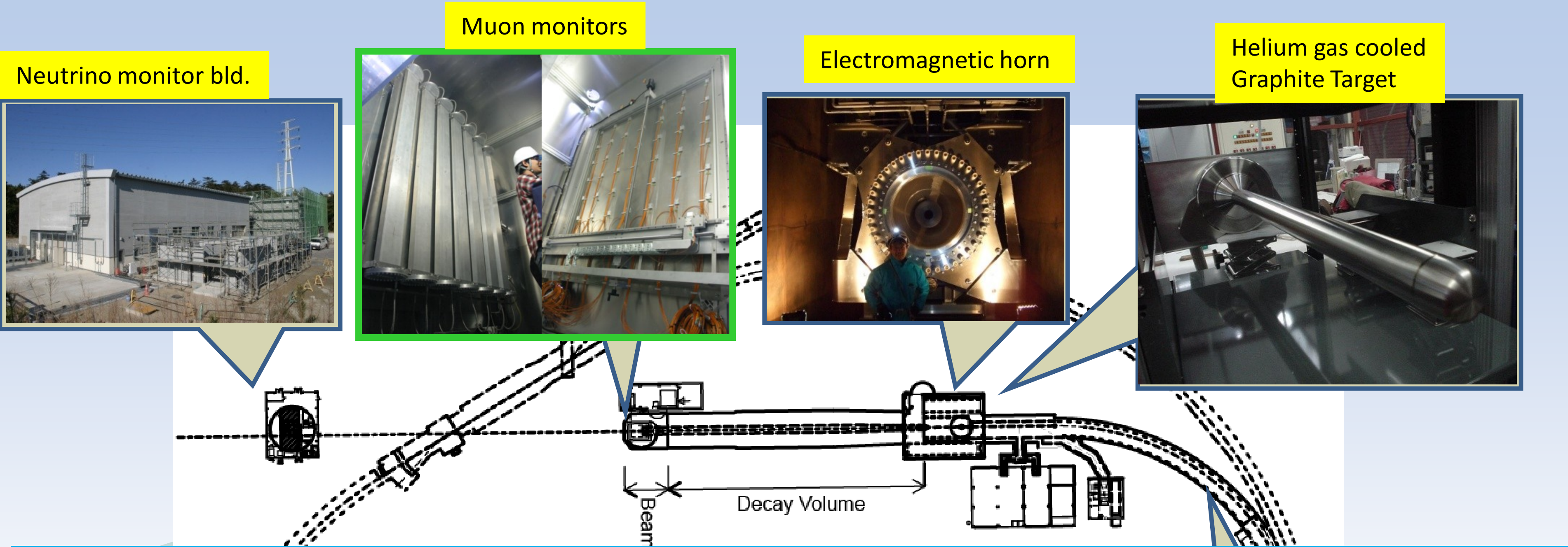


Construction: JFY01~08 (Neutrino: JFY04~08)



Construction
JFY2001~2008
J-PARC Facility
(KEK/JAEA)
South to North
Linac
3 GeV
Synchrotron
Neutrino Beams
(to Kamioka)
Design Intensity
750kW
Main ring
CY2007 Beams
JFY2008 Beams
JFY2009 Beams
Bird's eye photo in January of 2008

Neutrino facility at J-PARC



First >1MW tolerable superbeam facility in the world
First application of off-axis beam

- Major components
  - Superconducting combined function magnets
  - Graphite target (26mmϕx90cm, Helium gas cooling)
  - 3 horns @ 250kA
  - 110m of decay volume
  - Graphite beam dump

Tokai-to-Kamioka (T2K) experiment
The 1st experiment w/ J-PARC ν facility

- High intensity ν_μ beam from J-PARC MR to Super-Kamiokande @ 295km
- **Discovery of νe appearance → Determine θ_{13}**
  - Last unknown mixing angle
  - **Open possibility to explore CPV in lepton sector**
- Precise meas. of ν_μ disappearance → θ_{23}, Δm_{23}^2
  - Really maximum mixing? Any symmetry? Anything unexpected?

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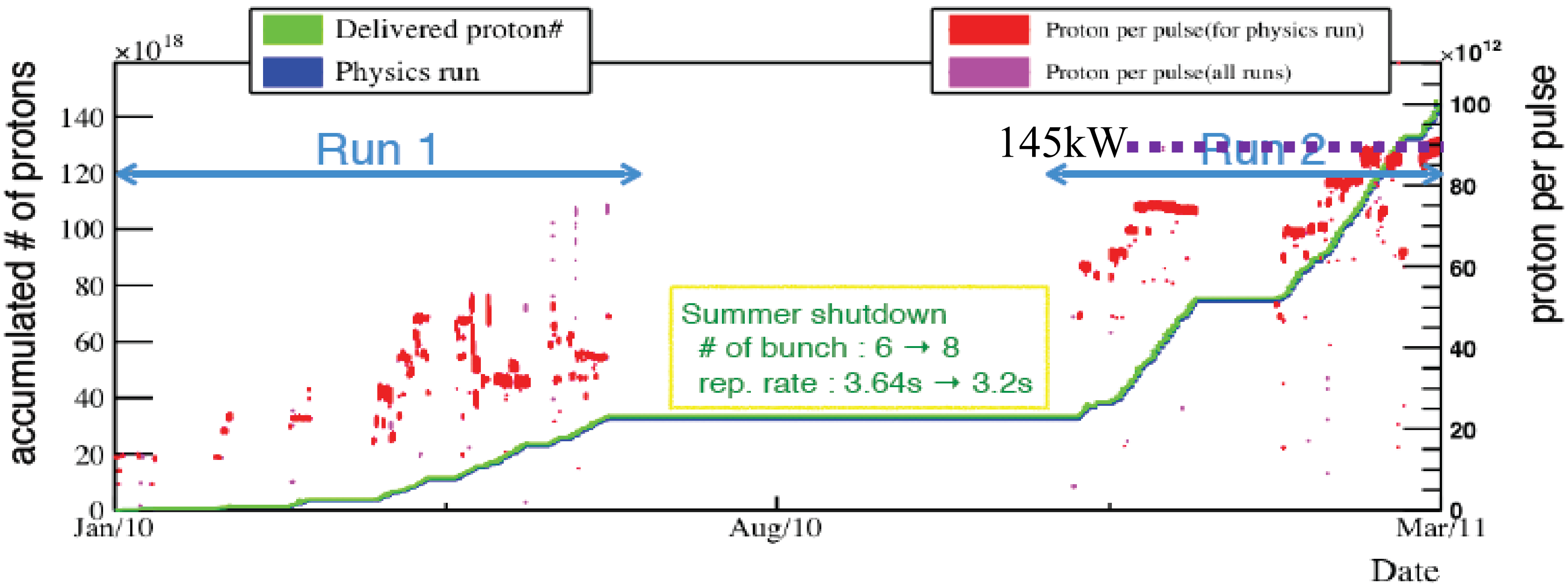
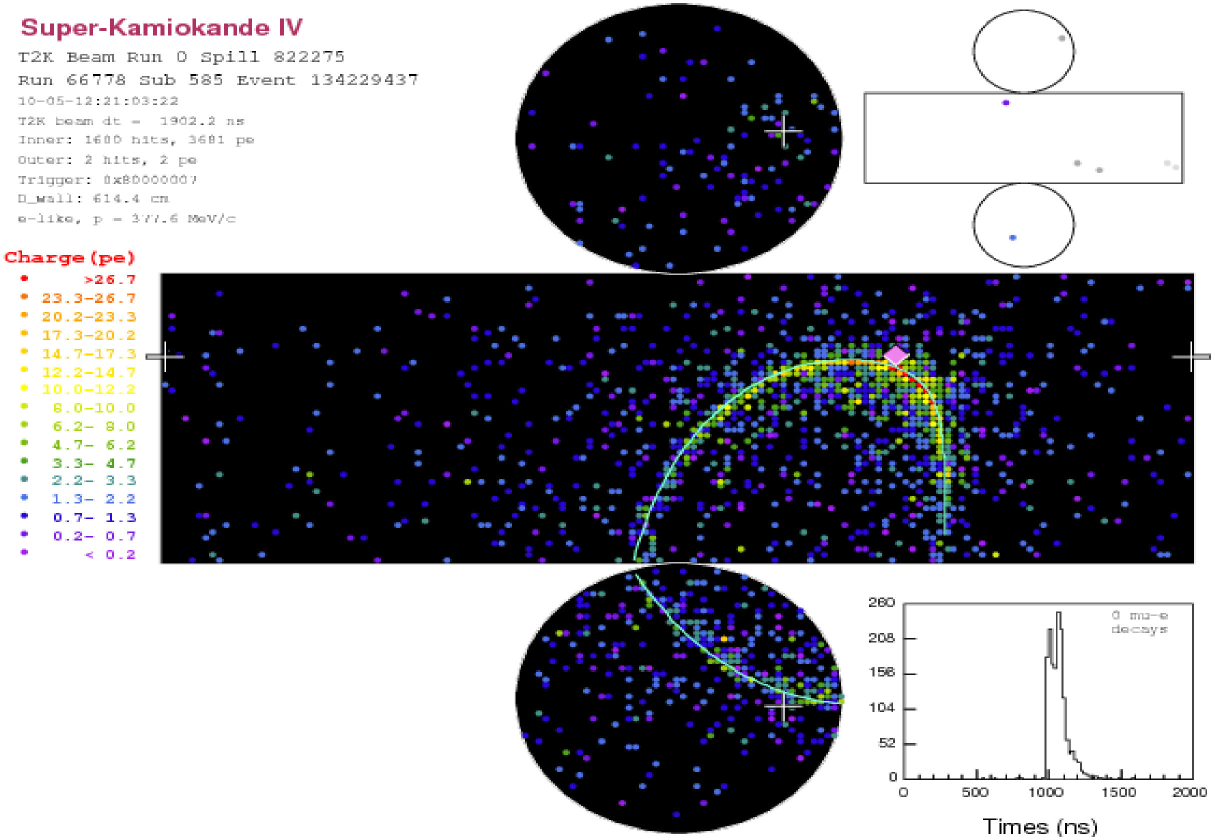
Status of T2K



- Started physics data taking in Jan. 2010
- Beam power has been increasing, reached 145 kW stable operation (~0.9x10^{14} p/pulse)
  - # of bunches: 8→ 6 w/ new FX kickers
  - Rep. rate : 3.64s → 3.02s
- 1.43x10^{20} p accumulated until Mar.11, 2011

T2K First physics results

- Based on data before Summer 2010 (0.32×10^{20}pot)
- Nue appearance search results
  - # of sig. cand. : 1
  - # of exp'ed BG: 0.30 ± 0.07
  - Upper bound on mixing angle θ_{13} is given
- We have 4.5 times more data → Results in this summer



Present Power limitation in accelerator

- Beam loss
  - Need to control beam loss to keep radio-activation level of components
  - Injection part/timing is biggest source
    - Requiremets <~200W loss (450W capacity of collimator + some safety factor)
- Present bottle neck
  - Injection kicker magets in MR
    - Dirty pulse shape produces beam loss
    - Will be replaced during this shutdown

For higher beam power :

1. Increase beam loss capacity in ring collimator and reduction of activation
   - Additional shielding in ring collimators
   - Establish the radiation maintenance of quads. between collimators
   - Local shielding and Ti chambers for hot spots

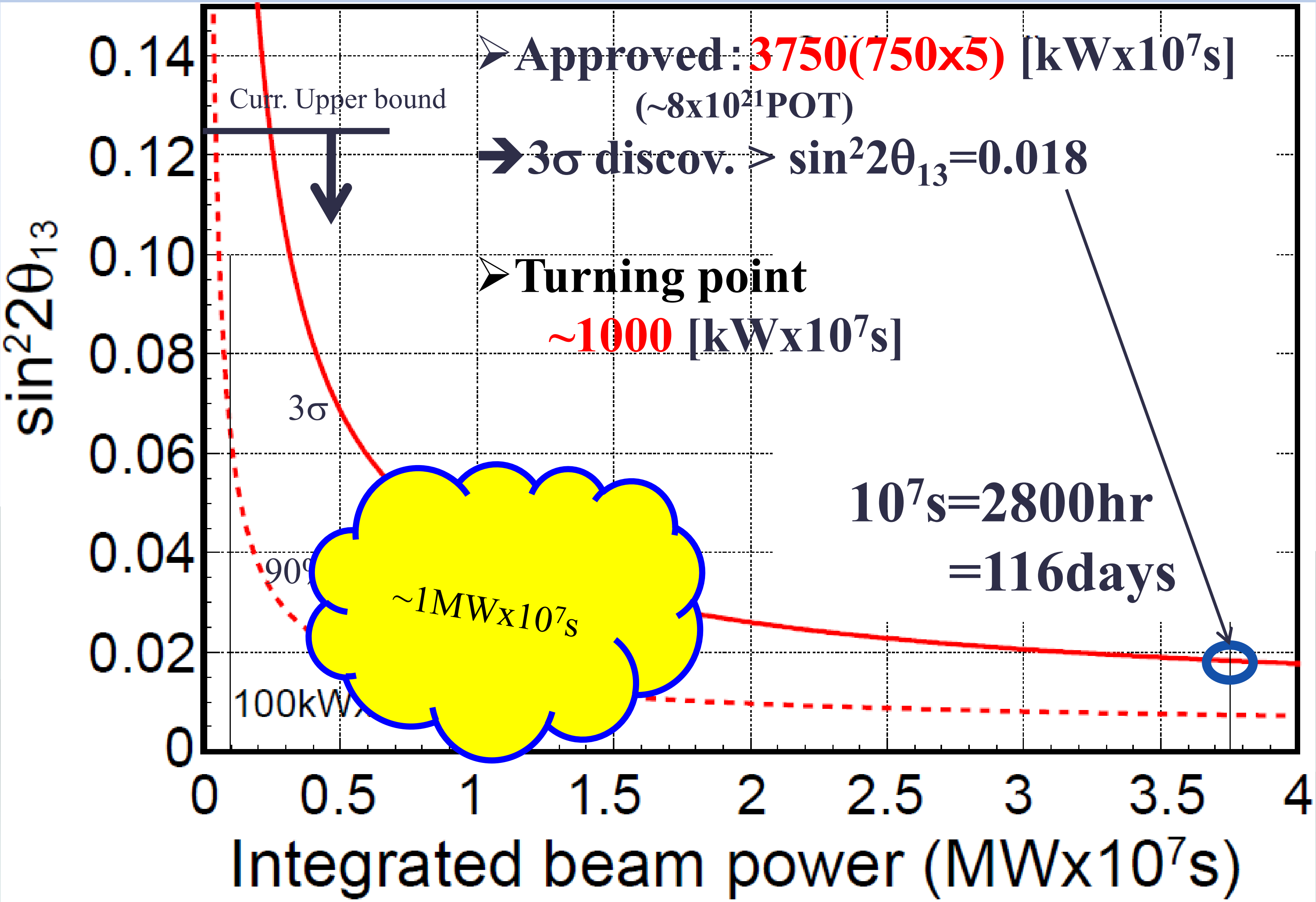
2. Increase injected number of particles per pulse
   - Second harmonic cavity for manipulation of longitudinal bunch form to reduce the effect of space charge force
   - Lower emittance beam of the RCS by adopting 400 MeV injection

3. Increase repetition rate
   - Improvement/replacement of main magnet power supplies and rf system

Higher power for neutrino facility

- Beamline is designed for
  - 750kW@50GeV with >3 safety margin (can run 1.7MW w/o major upgrade)
  - >~3MW for parts which can never be replaced
- We have ran 145kW max, and ~70kWx10^7s integ.
- We have not suffered from O(100kW) operation on heat load or thermal shock stress
- Rather, we have been facing issues on radio-activation
  - Target and horns are activated at 1Sv/h level
    - Remote maintenance in hot cell is needed AS PLANNED
    - Remote maintenance rehearsal done last summer, first real replacement will be made this summer
  - Radio-activated air
    - Regulation: ^{41}Ar<0.5mBq/cc in every exhaust stacks
    - Limiting beam power upto ~200kW now
    - Hermeticity and Air cond configuration will be improved
  - Tritium in He vessel
    - <5mBq/cc for exhaust and <20mBq/cc for working environment
    - Right after operation, O(1000mBq/cc) → ~300mBq/cc by several ventilations
  - Radio-activated water
    - Used for cooling of Horn, He vessel, DV, beam dump
    - Regulation:^{3}H<60Bq/cc and ^{7}Be<30Bq/cc if disposed to ocean
    - → O(50) dilution and 20 times disposal works required
  - All can be handled, but when we go >1MW, additional facility to handle radiation issues might be necessary

T2K goal: **Discovery of ν_e appearance**



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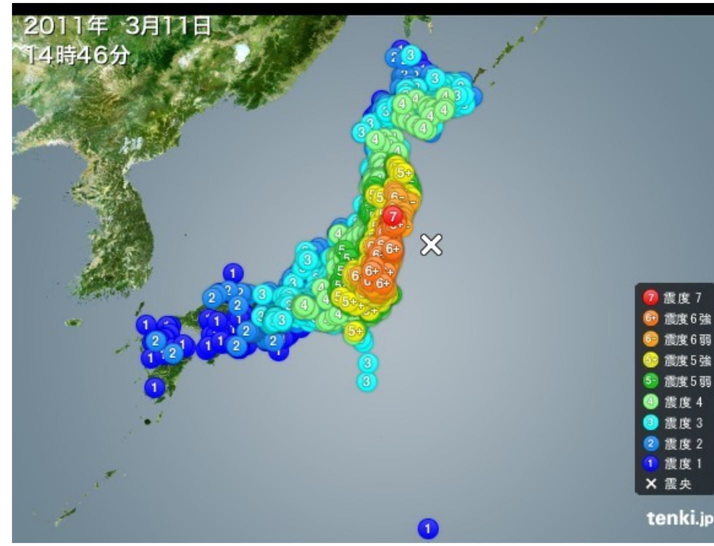
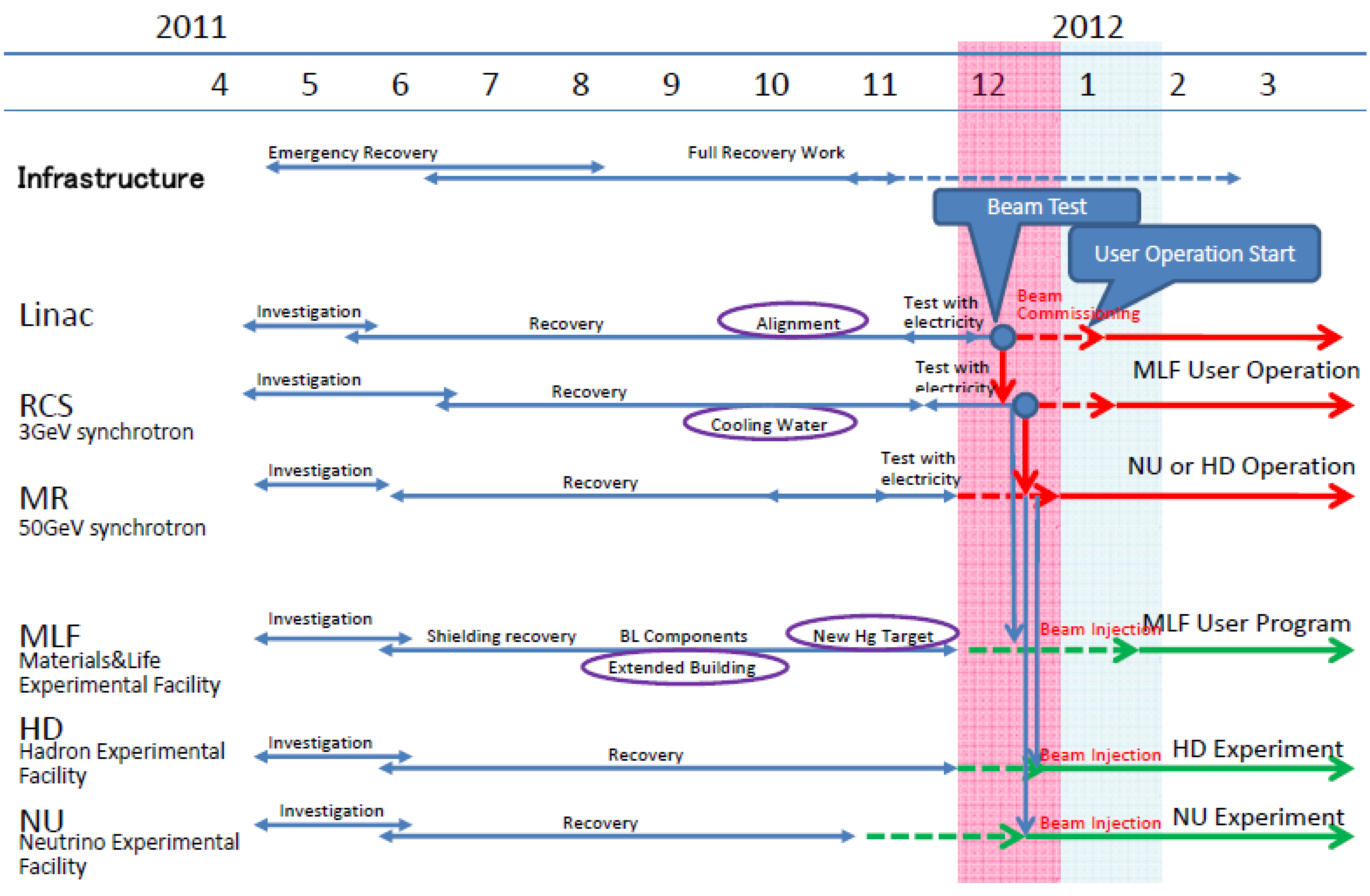
Earthquake on Mar. 11th

- Happened at 14:46 on Mar. 11th
  - Magnitude 9.0 in Richter scale
  - Seismic intensity 6+ at Tokai
  - No Tsunami reached to J-PARC
  - All of electric power was stopped
  - Maintenance day=Acc. not operated



- Damages
  - Lots of subsidence happened here&there
    - LINAC tunnel sunk ~4cm at maximum, tunnel is bent
    - RCS elec-power facility ground sink damaged the facility
    - Big water leak into MR tunnel by big cracks ➔ mostly fixed
    - 1~2m drop of surrounding ground of neutrino facility
  - No fatal damages found on accelerator & beamline components
- Recovery work is accelerating
  - Mar-Apr: Inspection
  - Apr- : Ope test/recovery

J-PARC Recovery Schedule (@2011.5.20)



- We will resume the beam within 2011
- Will make every efforts to make it earlier
- Will run beam >2 “cycle” ~ 2month in JFY2011 (until Mar. 2011)

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Quest for the Origin of Matter Dominated Universe

One of the Main Subject of the KEK Roadmap

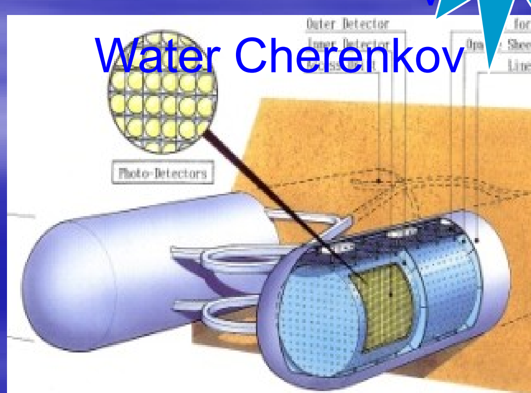
T2K (2009~) → Discovery of the ν_e Appearance

Neutrino Intensity Improvement

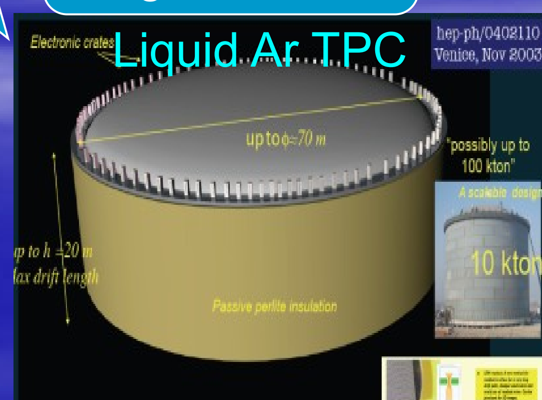
Huge Detector R&D → Establish Huge Detector Technology → Construction of Huge Detector

Discovery of Lepton CP Violation Proton Decay

Water Cherenkov

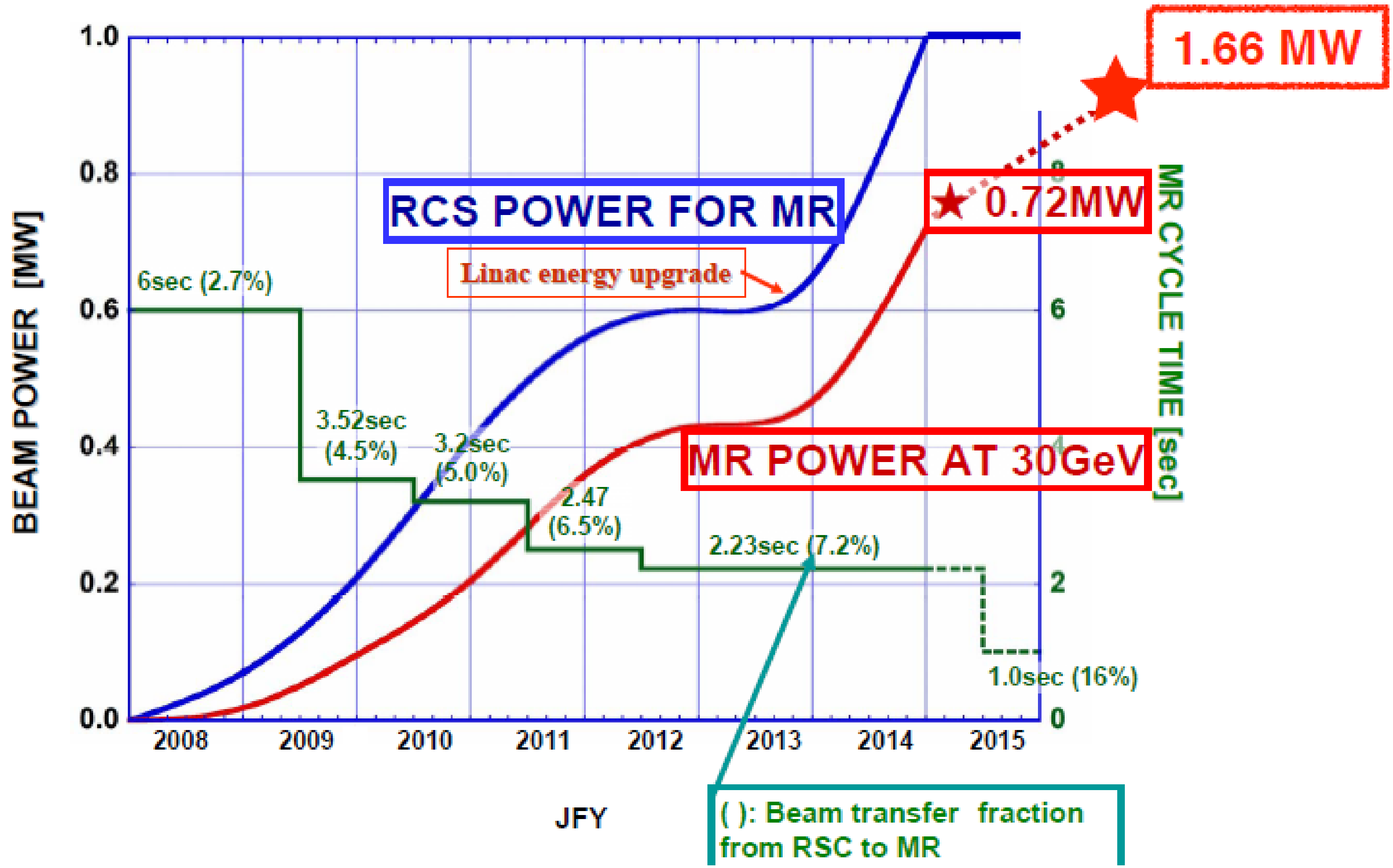


Liquid Ar TPC



MR Power Improvement Scenario

Increase rep. rate and/or increase # of protons toward high power (~1.66MW)



Studies and R&D on Power supply, RF configuration, etc are being made

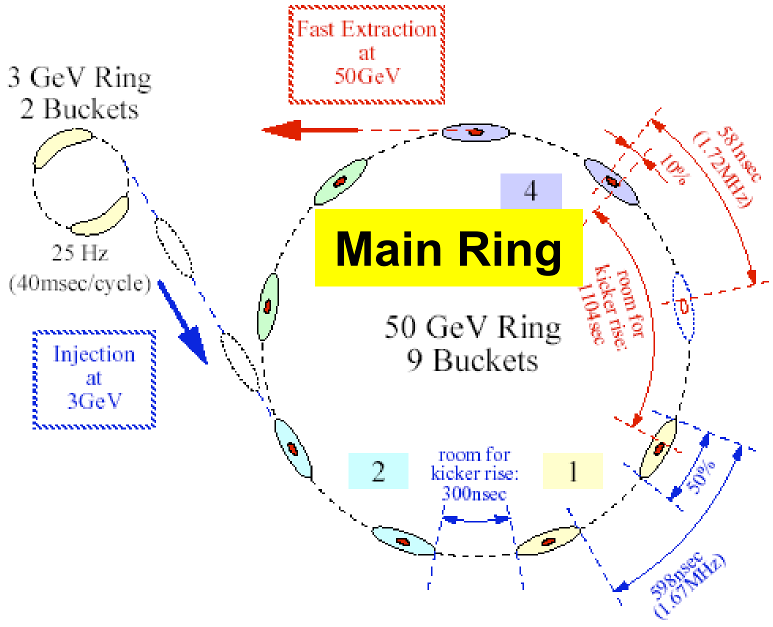
MR Power Improvement Scenario toward MW-class power frontier machine
— KEK Roadmap —

	Day1 Achieved ! (up to Mar.2011)	Next Step	KEK Roadmap
Power(MW)	0.145	0.45	>1.66
Energy(GeV)	30	30	30
Rep Cycle(sec)	3.04	2.2	1.92～0.5
No. of Bunch	8	8	8
Particle/Bunch	1.2×10^{13}	2.5×10^{13}	$4.1\sim8.3\times10^{13}$
Particle/Ring	9.2×10^{13}	2.0×10^{14}	$3.3\sim6.7\times10^{14}$
LINAC(MeV)	181	181	400
RCS	h=2	h=2	h=2 or 1

Combination of **High rep. cycle** and **High beam density**

For higher power

1. Maximize # of protons/bucket
   – Controlling beam loss is critical
2. Maximize rep rate
   – Increase accelerating RF power to shorten the acceleration time
   – Magnet power supply system for fast and good control while ramping
3. Maximize running time to increase integrated power



- Present and near future FX cycle (trial in March)
  - 160msec 4 RCS cycle injection
  - 1.9 sec →1.43 Acceleration
  - 0.13sec →0 Flat top
  - 1.04 sec →1.0 Ramp down
  - 3.2 sec → 2.6 sec : 135kW → 166kW
    - 3.02s achived

Reducing cycle time

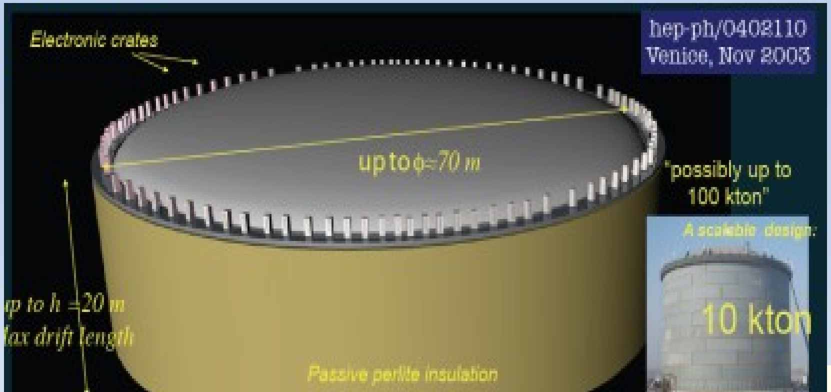
Short term project (this summer)

- Install 2 more RF cavities to shorten cycle time (6 →8)
- Continue reducing ramp/fall time with present P.S. (cycle time ~2.2 sec)
- 2^{nd} RF cavity for more protons/bunch

Long term project

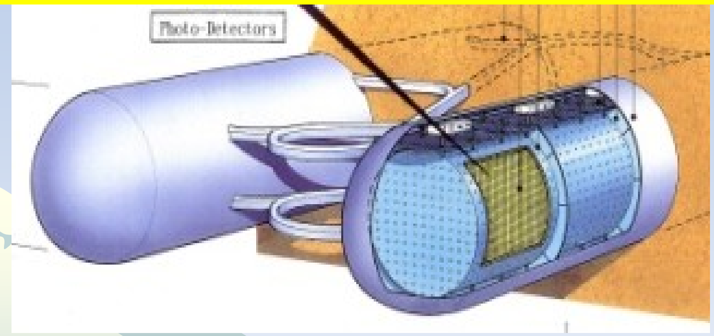
- High gradient cavity – crystalized FineMet in magnetic field
  - FT3L-based cavities are a potential solution for getting the RF voltage
  - Other cooling (Fluorinert, air) should be investigated as a back-up solution.
  - More RF cavities (effect on accelerator lattice to be investigated)
- New MR power supply
  - Reducing the number of magnets per power supply to reduce the inductive load
  - Design with IGBT technology, and use a capacitor-based energy storage scheme to eliminate line flicker and filter the ripple
- Need further developments and funding to realize

“Available” technologies for huge detector



Good at Wideband beam

Good at low E (<1GeV)
narrow band beam



Liq Ar TPC

- Aim O(100kton)
- Electronic “bubble chamber”
  - Can track every charged particle
  - Down to very low energy
- Neutrino energy reconstruction by eg. total energy
  - No need to assume process type
  - Capable upto high energy
- Good PID w/ dE/dx, pi0 rejection

Water Cherenkov

- Aim O(1000kton)
- Energy reconstruction assuming Ccqe
  - Effective < 1GeV
- Good PID (μ/e) at low energy
- Cherenkov threshold

θ_{13} & lepton CP violation

$$P(\nu_\mu \to \nu_e) = 4C_{13}^2 S_{13}^2 S_{23}^2 \sin^2 \frac{\Delta m_{31}^2 L}{4E} \times \left(1 + \frac{2a}{\Delta m_{31}^2} (1 - 2S_{13}^2)\right)$$ **Leading**

$$+8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos\delta - S_{12} S_{13} S_{23}) \cos \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \sin \frac{\Delta m_{21}^2 L}{4E}$$

$$-8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin\delta \sin \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \sin \frac{\Delta m_{21}^2 L}{4E}$$ **CP-odd**

+ other terms.. $\delta \to -\delta$, $a \to -a$ for $\overline{\nu}_\mu \to \overline{\nu}_e$

Matter eff.:

$$a = 7.56 \times 10^{-5} [\mathrm{eV}^2] \cdot \left(\frac{\rho}{[\mathrm{g/cm^3}]}\right) \cdot \left(\frac{E}{[\mathrm{GeV}]}\right)$$

CP dependent term $\propto (\sin\delta \text{ or } \cos\delta) \cdot s_{12} \cdot s_{23} \cdot s_{13}$

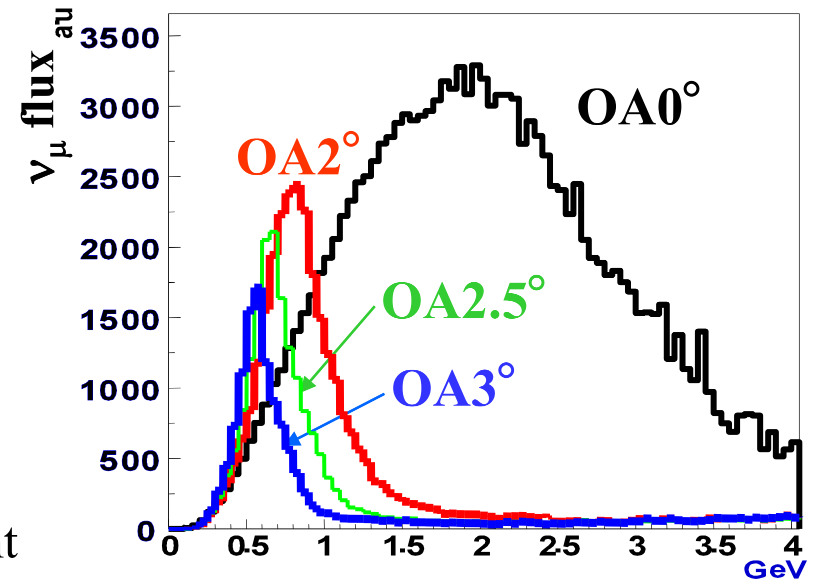
(where $\sin\theta_{12}$~0.5, $\sin\theta_{23}$~0.7, $\sin\theta_{13}<0.2$)

Effect of CP Phase δ appear as

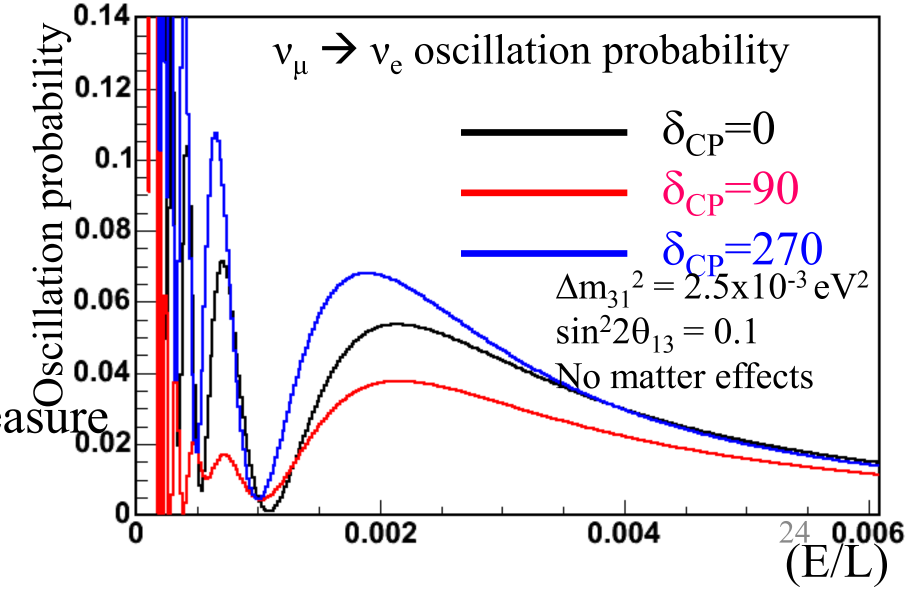
- **ν_e Appearance Energy Spectrum Shape**
  - *Peak position and height for 1st, 2nd maximum and minimum
  - *Sensitive to all the non-vanishing δ including 180°
  - *Could investigate CP phase with ν run only
- **Difference between ν_e and $\overline{\nu}_e$ Behavior**
  - Sensitive to any mechanism to make asymmetry
  - Separation from possible sources of non-CPV asymmetry needed

Optimization of Angle and Baseline

- Off-axis angle
  - On-Axis: Wide Energy Coverage,
    ◯Energy Spectrum Measurement
    ×Control of π^0 Background
  - Off-Axis: Narrow Energy Coverage,
    ◯Control of π^0 Background
    ×Energy Spectrum Measurement
    → Counting Experiment

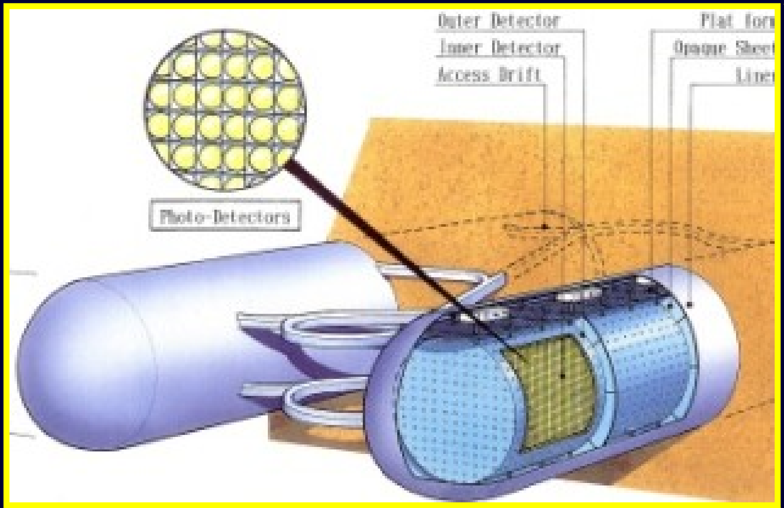


- Baseline
  - Long:
    ◯ 2^{nd} Osc. Max. at Measurable Energy
    × Less Statistics
    ? Large Matter Effect
  - Short:
    ◯ High Statistics
    × 2^{nd} Osc.Max.Too Low Energy to Measure
    ? Less Matter Effect

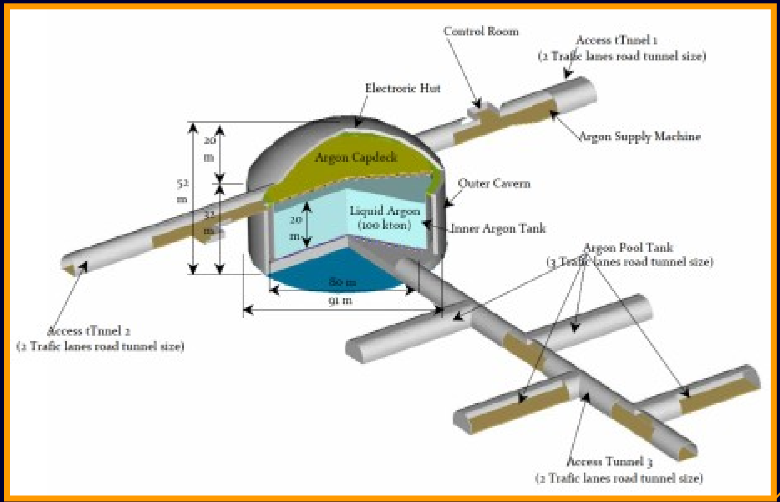


Scenarios from J-PARC

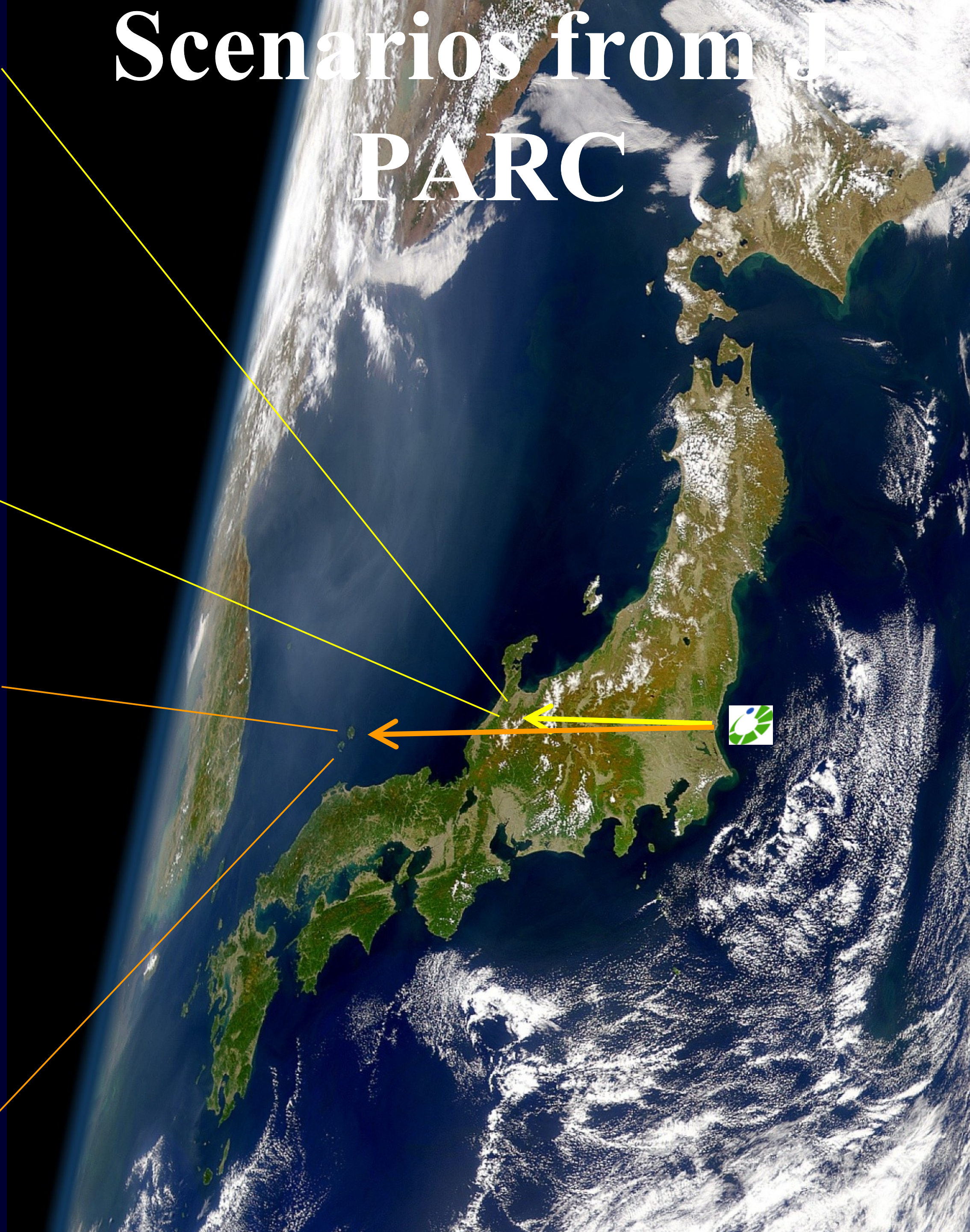
Kamioka L=295km OA=2.5deg



Okinoshima L=658km OA=0.78deg
Almost On-Axis



P32 proposal (Lar TPC R&D)
Recommended by J-PARC PAC
(Jan 2010), arXiv:0804.2111



Scenario 1

J-PARC to Okinoshima

P32 proposal (Lar TPC R&D)
Recommended by J-PARC PAC
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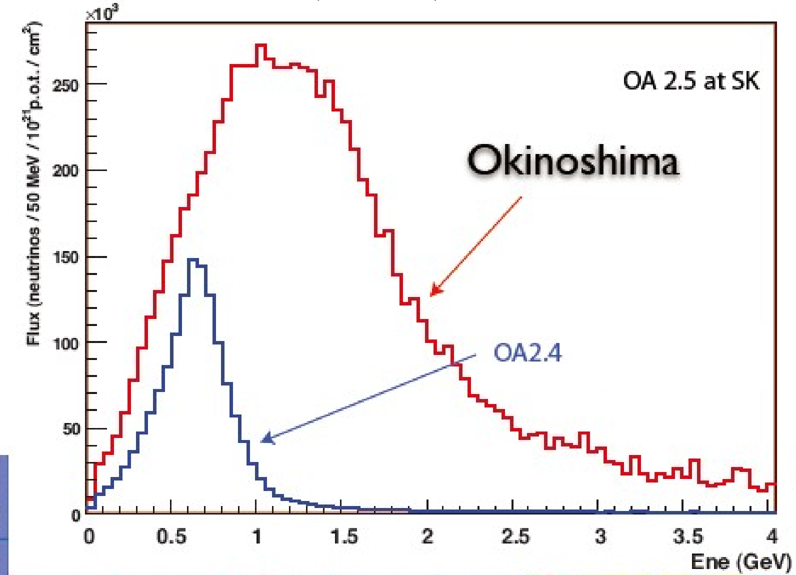
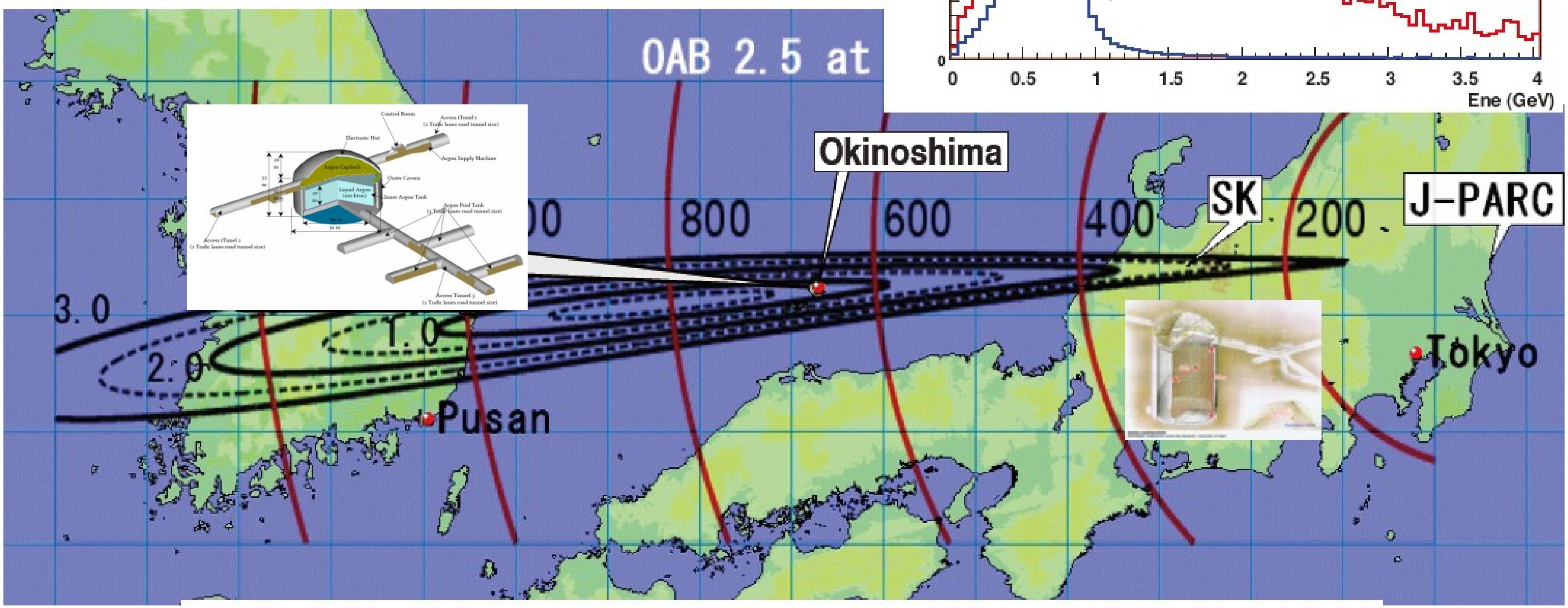
Distance = 658 km

Off-axis angle = 0.76°

(2.5° @ SK)

100 kton liquid Argon





→ Extract δ_{CP} from fit of 1st & 2nd maximum

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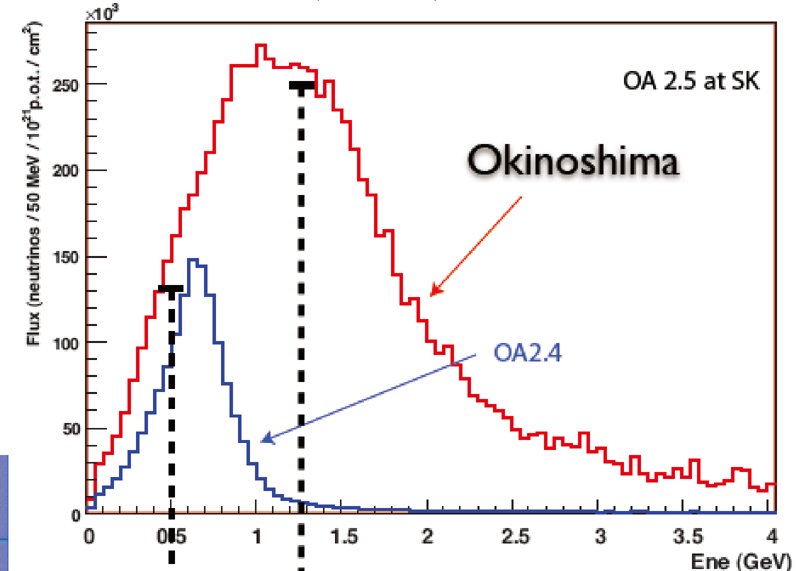
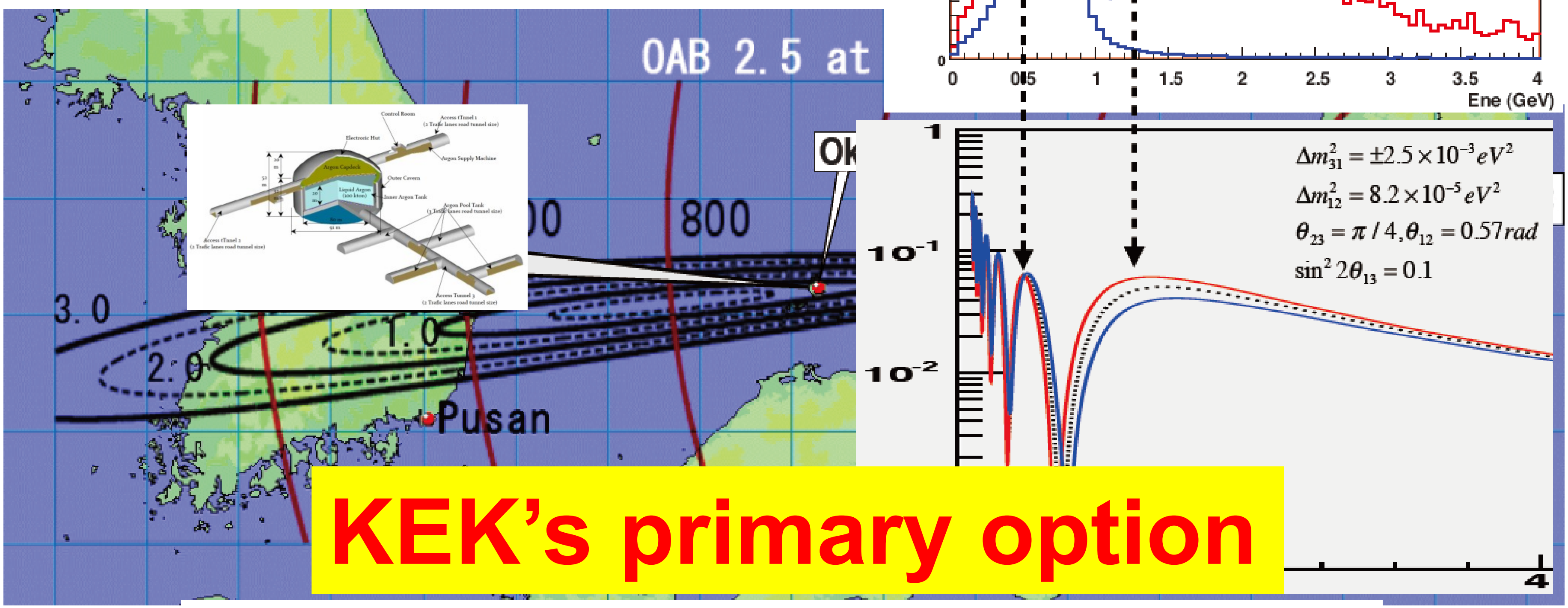




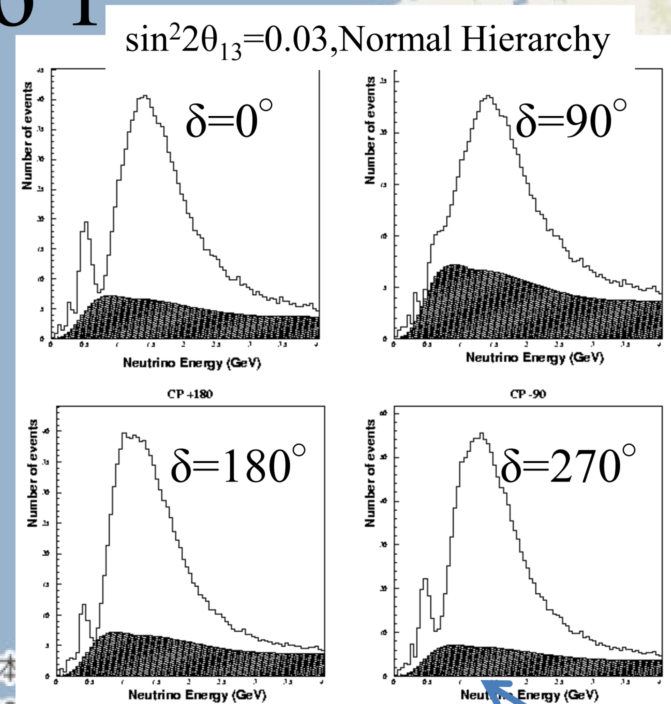
KEK's primary option

→ Extract δ_{CP} from fit of 1st & 2nd maximum

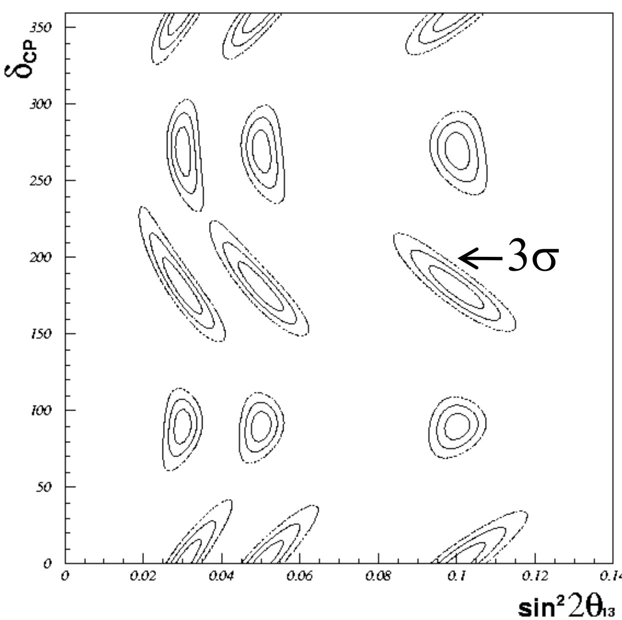
Scenario 1

- Cover 1st and 2nd Maximum
- Neutrino Run Only 5Years×1.66MW
- 100kt Liq. Ar TPC
  - -Good Energy Resolution
  - -Good e/π^0 discrimination
- Keeping Reasonable Statistics

ν_e Spectrum



CP Measurement Potential

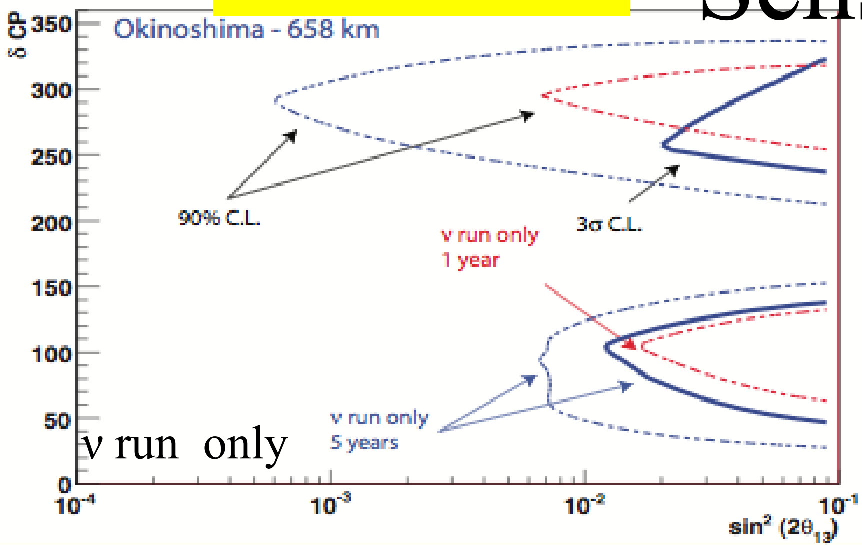


NP08, arXiv:0804.2111

Scenario 1

J-PARC to Okinoshima: Sensitivities

CP Violation



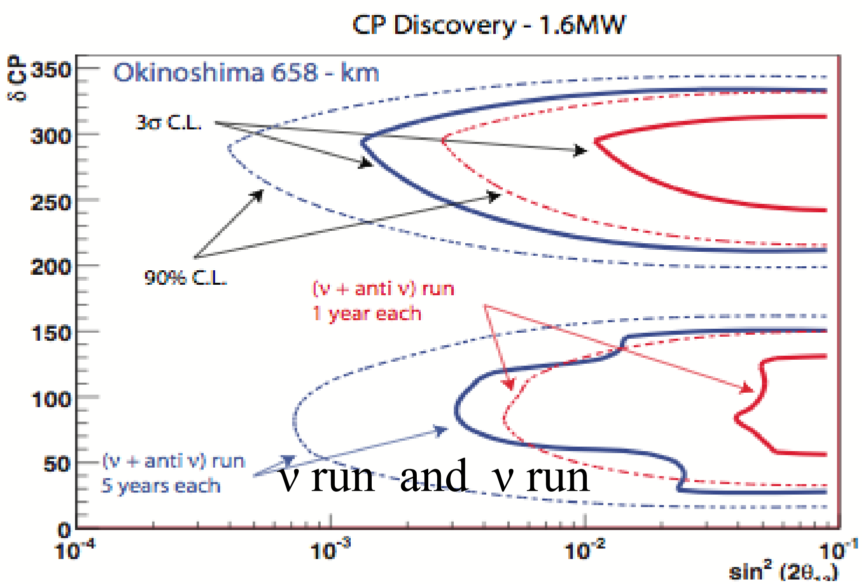


Fig. 9: Discovery potential for CP-violation at 90%C.L. and 3σ for (top) 1 resp. 5 years 1+1 resp. 5+5 years neutrino-antineutrino runs.

Hierarchy

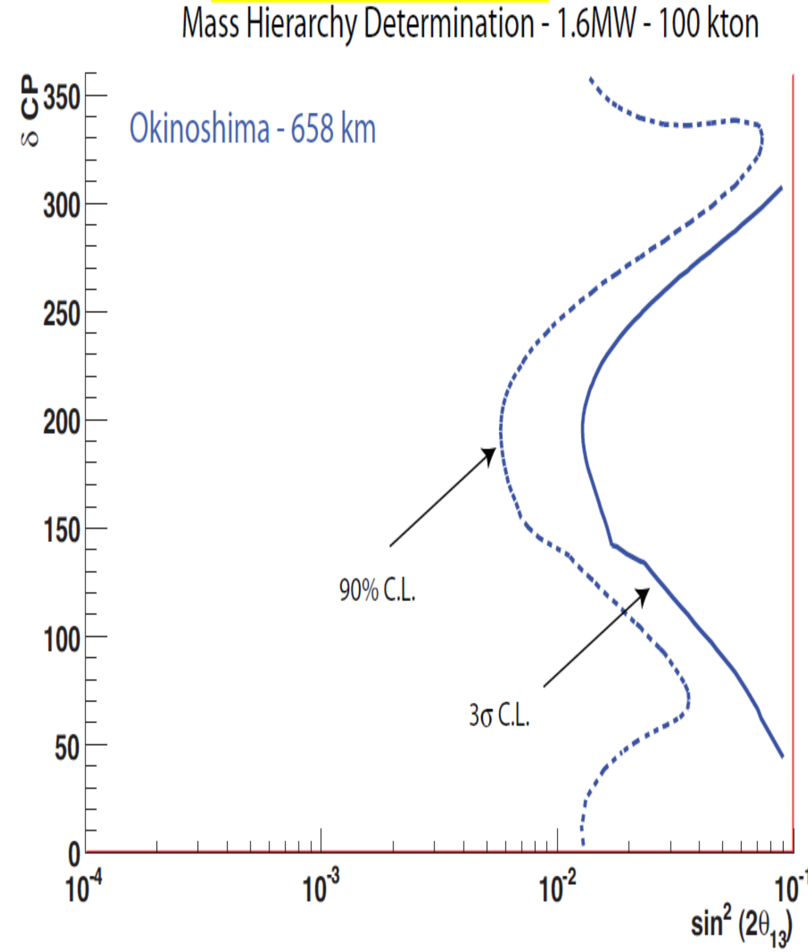
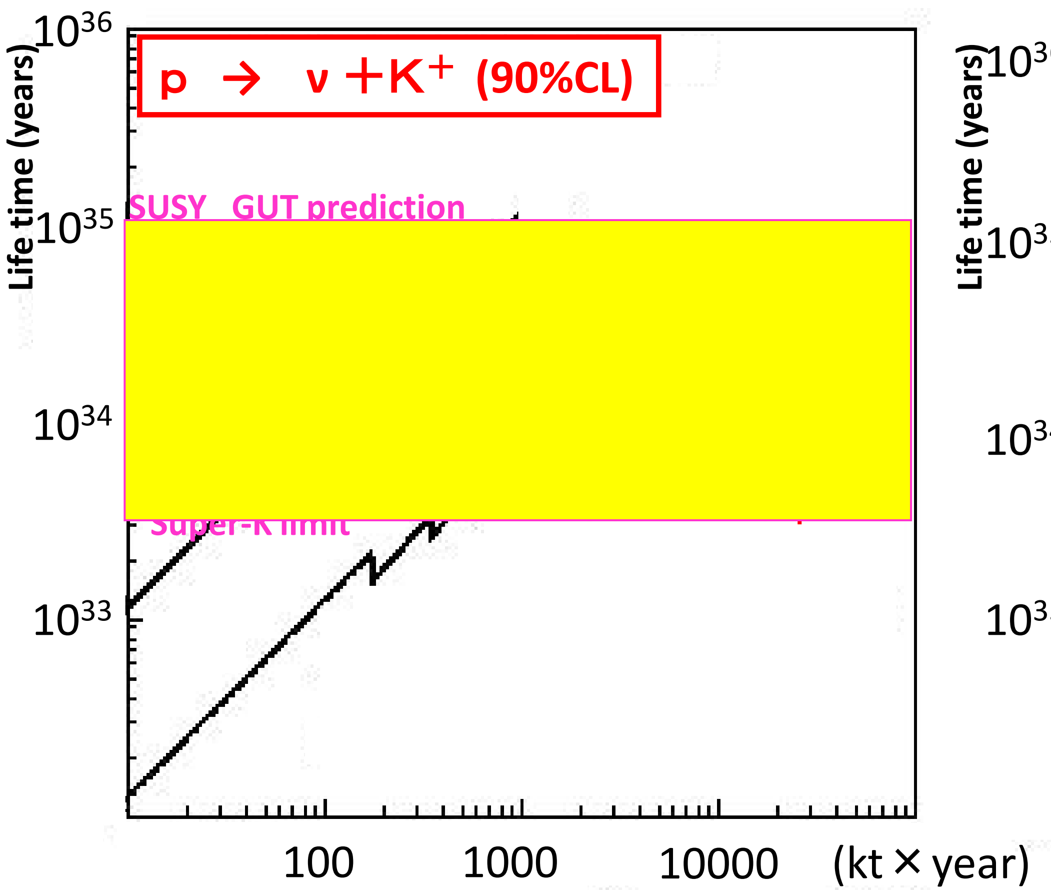
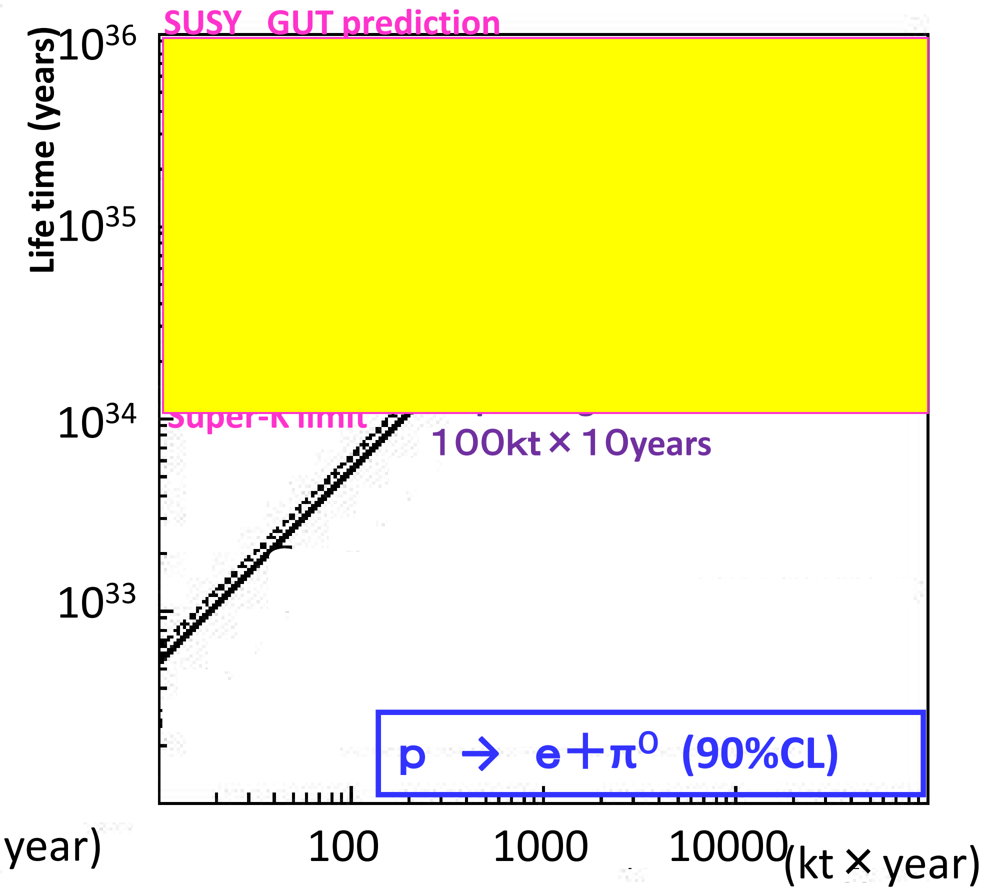


Fig. 10: Mass hierarchy discrimination at 90%C.L. and 3σ for 5+5 years neutrino-antineutrino runs.

100kt LiqAr also for Proton decay search!

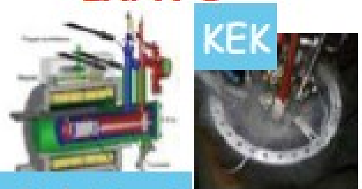
- $\nu + K^+$ mode: LAr（100kt×10years）＝～7×WC（500kt×10yeas）
- e ＋ π^0 mode: LAr（100kt×10years）＝～1/2×WC（500kt×10years）





R&D steps toward 100kt Lar detector

Single phase LArTPC



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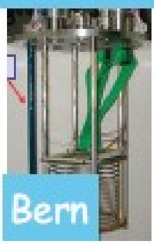
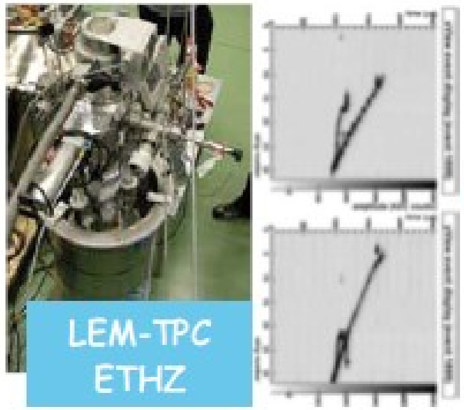
B-field test



Bern

Double phase LAr-LEM TPC



LEM-TPC ETHZ

ArDM-1t(RE18), presently operating@CERN

Move to LSC in 2011

Test beams

P32@JPARC

Beam exposed in 2010 (and 2011?)

direct proof of long drift path up to 5 m

ArgonTube @Bern

run in 2011

Test beams

6m3 @ CERN

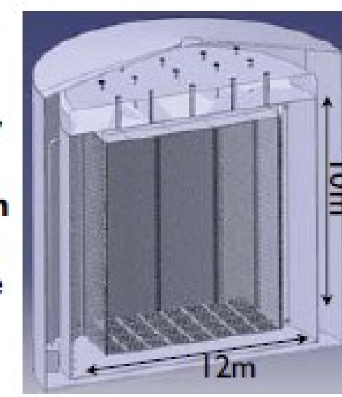
purity demonstrator

LAr: 2012, NA 2013 ?

Charged particles test beam, calorimetry, non-evacuated vessels, LAr purity

Full engineering demonstrator for larger detectors, with a stand-alone short baseline physics programme

1 kton ?



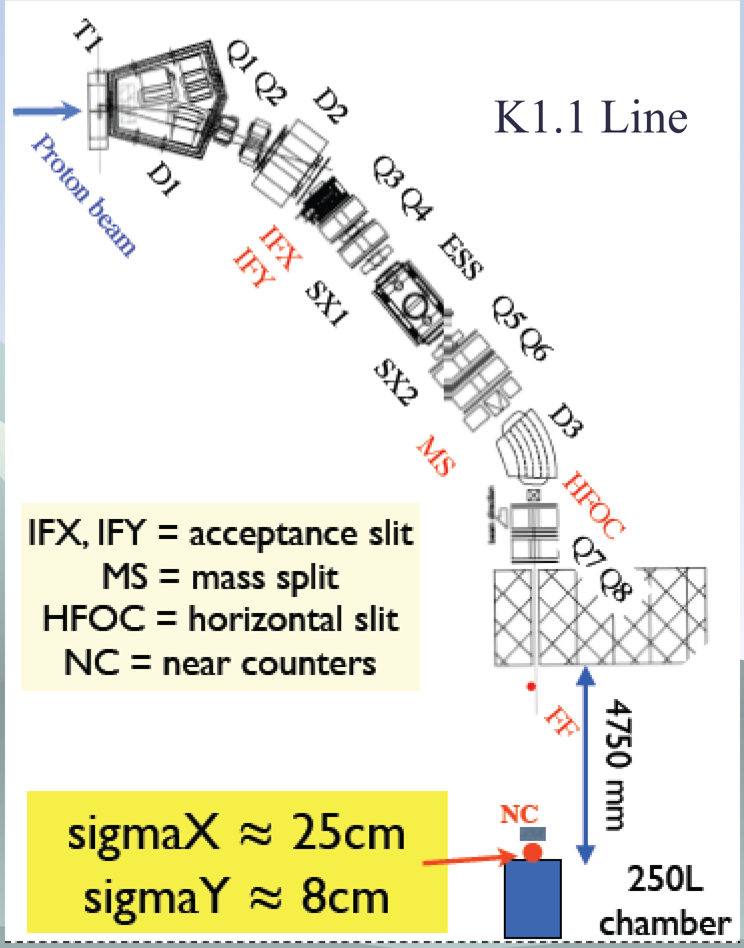
R&D effort toward large LAr TPC: T32 experiment

Towards a Long Baseline Neutrino and Nucleon Decay Experiment with a next-generation 100 kton Liquid Argon TPC detector

ETHZ, KEK, Iwate, Waseda (36members)

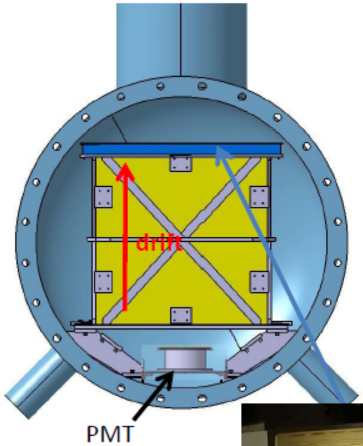
Goals of P32

- To develop a suitable scalable Liquid Argon TPC detector as an R&D for a next-generation long baseline neutrino experiment and proton decay.
- Specifically, to set up and test a 250 Liter LAr prototype TPC, operated in double phase with gas amplification in Argon vapor (LAr LEM-TPC)
- Expose the chamber to K1.1BR charged particle beam to address the physics performance of such detectors and develop reconstruction software, in particular for kaons as they occur in p→νK decays

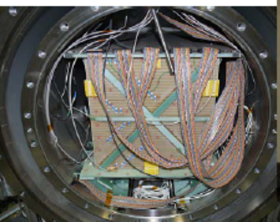


T32 test beam at J-PARC

Setup of Oct-2010 test-beam

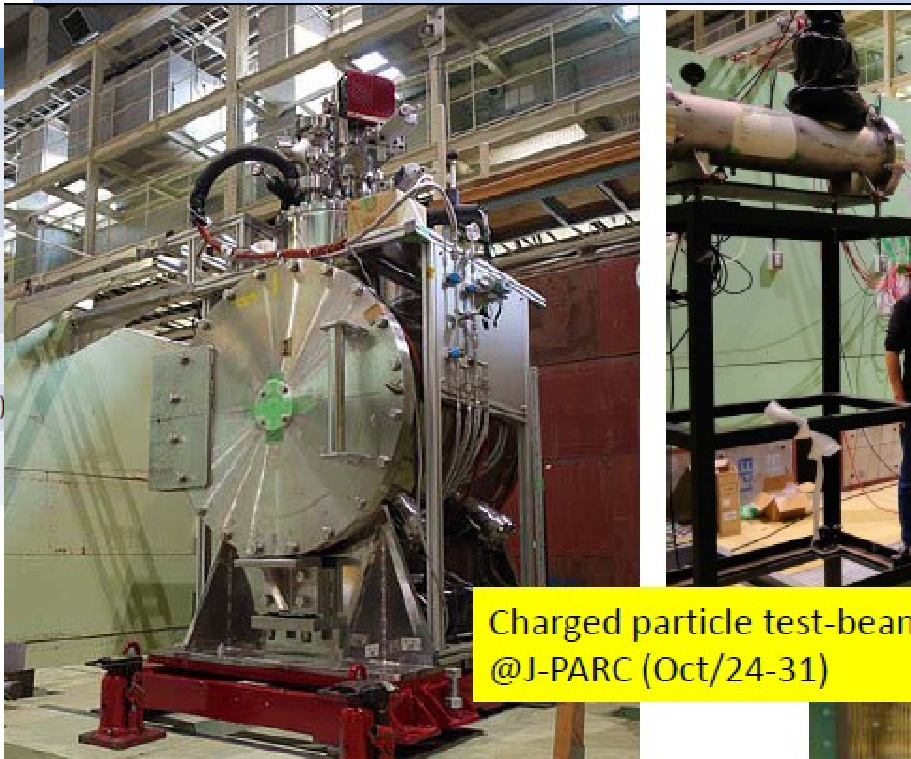


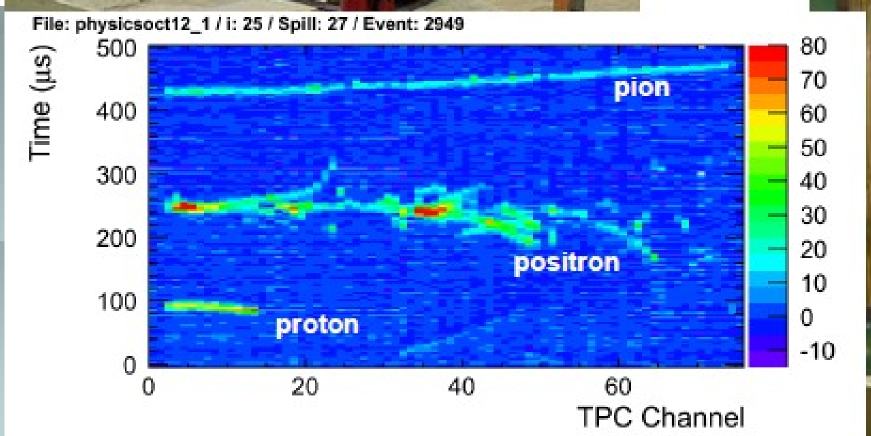
Fiducial mass	170kg
Total LAr mass	~400kg
Field cage dimension	42cm x 42cm x 78cm
Fiducial volume	40cm x 40cm x 76cm
Typical Drift Field	~225V / cm
Maximum drift voltage	12kV
Readout method	single phase (temporary)
Number of readout channels	76 strips (1cm)



76 strips (1cm) anode

- Double phase component is under testing at CERN. (Unfortunately, not in time for the test-beam.)





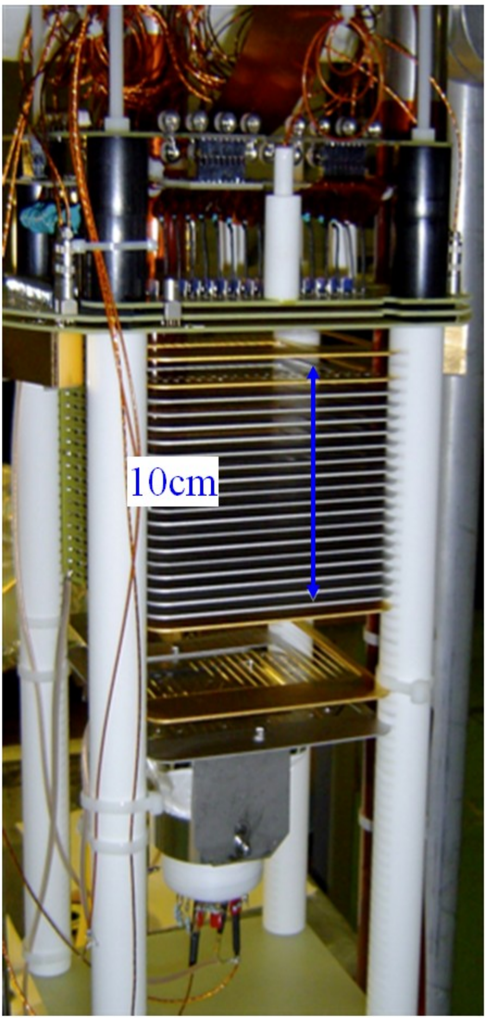
- First beam data taken in Oct/Nov, 2010
- Results will be presented in PAC (Jul.2011)
- Possible beam 2011(?)
- See Maruyama's talk

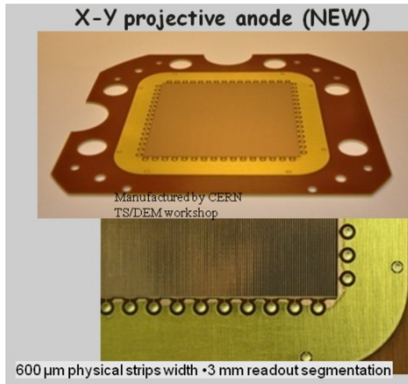
LAr LEM-TPC 3L R&D by ETHZ

Development of 2d double phase readout

See F. Resnati's talk

100 x 100 mm² test setup



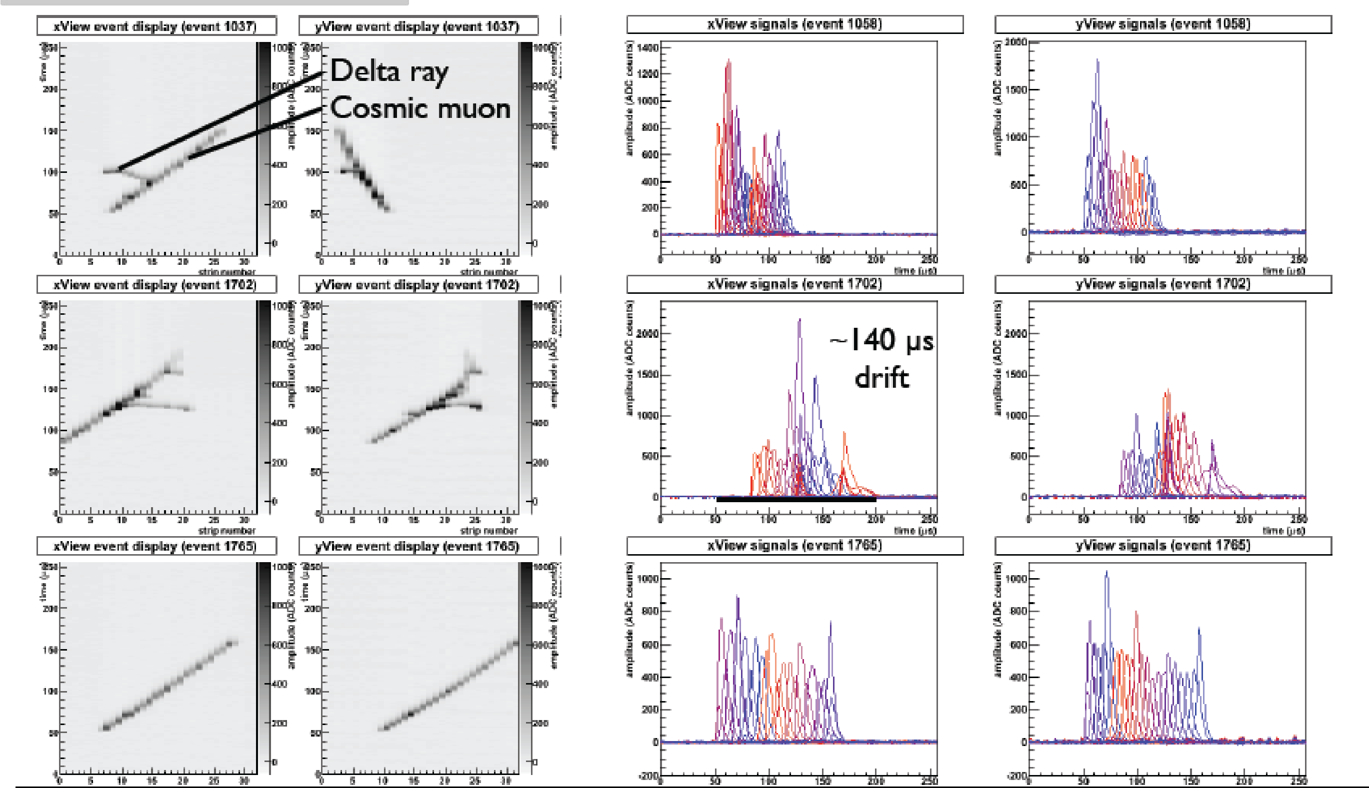


A. Badertscher, NIM A 641 (2011) 48

Event display

] eq

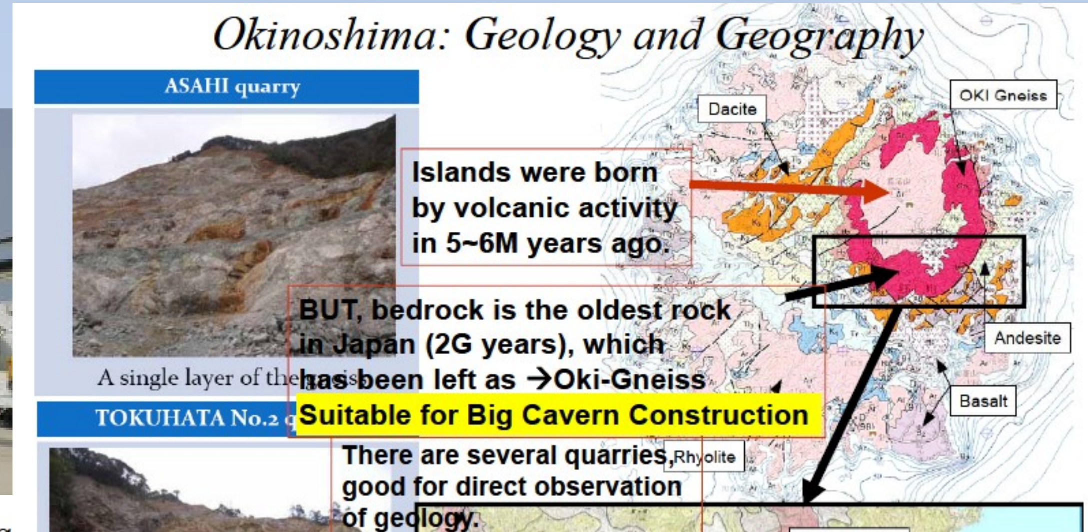
Double phase operation
Effective gain ~ 26



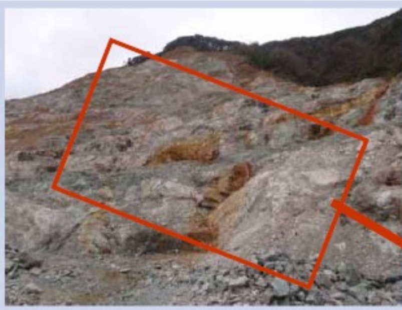
J-PARC-Okinoshima feasibility studies

(Some examples)

Site visit



ASAHI quarry

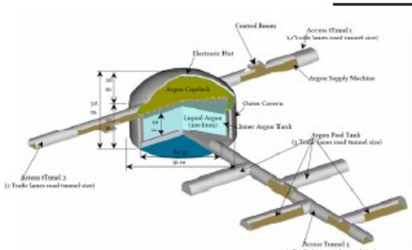


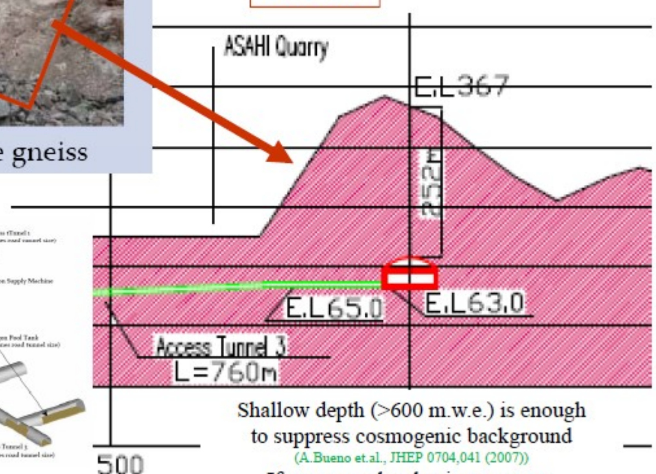
A single layer of the gneiss

Okinoshima. Geology and Geography

A conceptual design

Site No.1





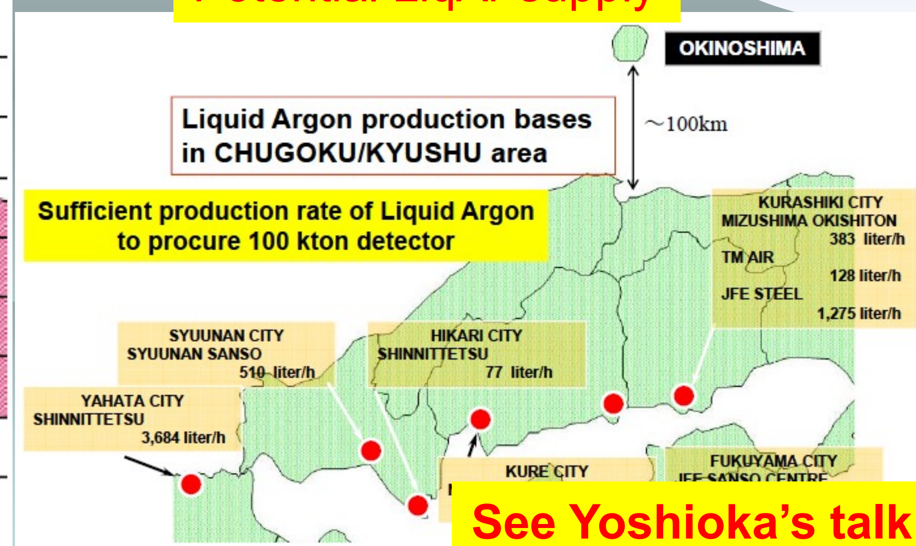
PENTA-OCEAN construction co., Ltd.,

Shallow depth (>600 m.w.e.) is enough to suppress cosmogenic background

(A.Bueno et.al., JHEP 0704,041 (2007))

If more overburden is necessary, inclined access tunnel is possible

Potential LiqAr supply



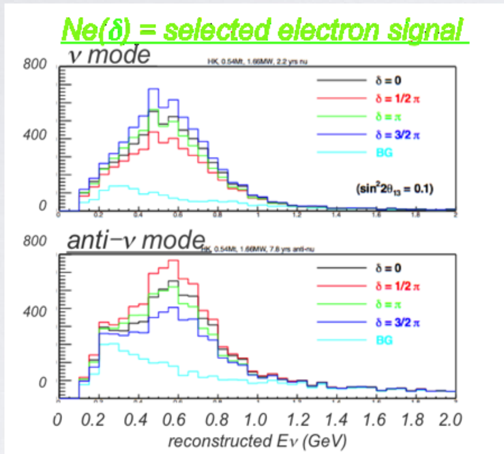
See Yoshioka's talk

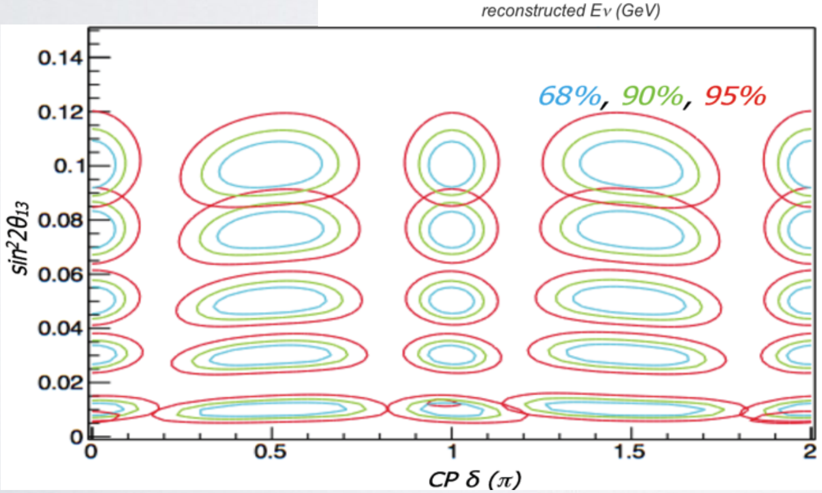
J-PARC-HyperK @ Kamioka

discovery of (θ_{23}, Δm^2_{23}) → (θ_{12}, Δm^2_{12}) → θ_{13} in a few year

→ remaining param. will be **δ_{CP}, mass-hierarchy, θ_{23}-octant**

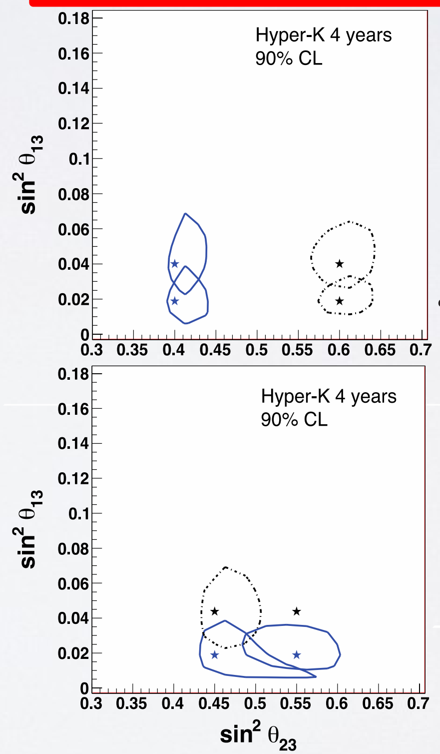
leptonic CPV w/ JPARC ν



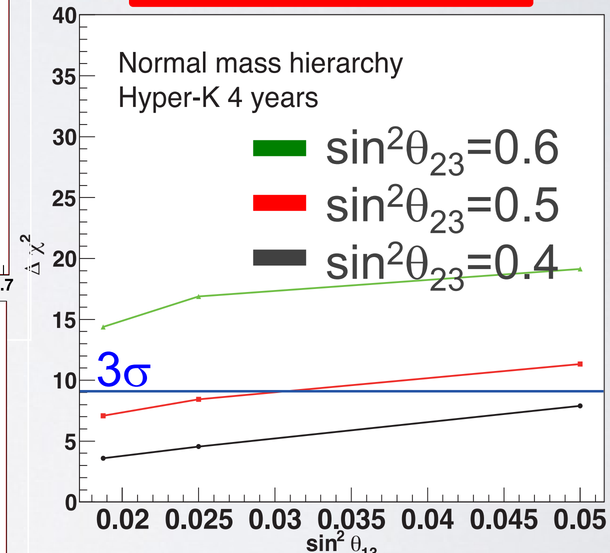


5 yrs of 1.66 MW JPARC ν data.
5% syst. errors are assumed.

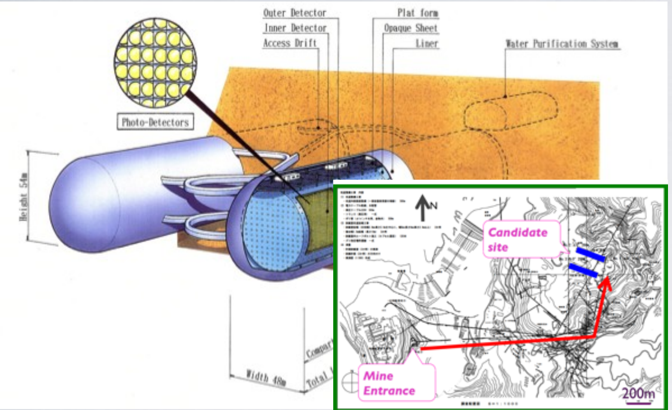
resolve θ_{23} octant w/ atmospheric ν



mass hierarchy determination w/ atmospheric ν



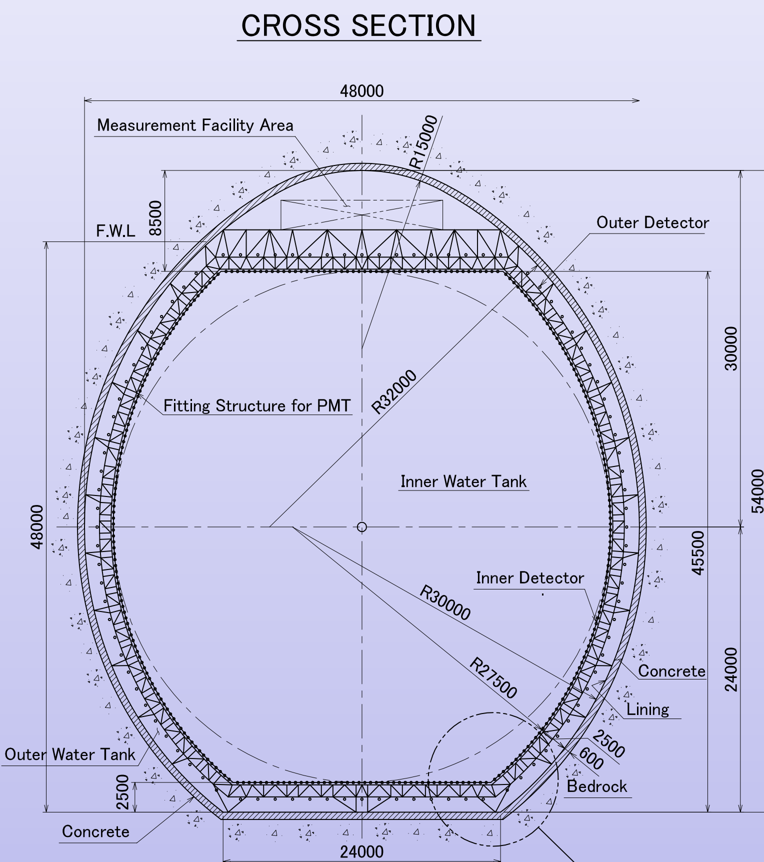
4 yrs exposure of atm. ν data.
Super-K syst. errors are assumed.

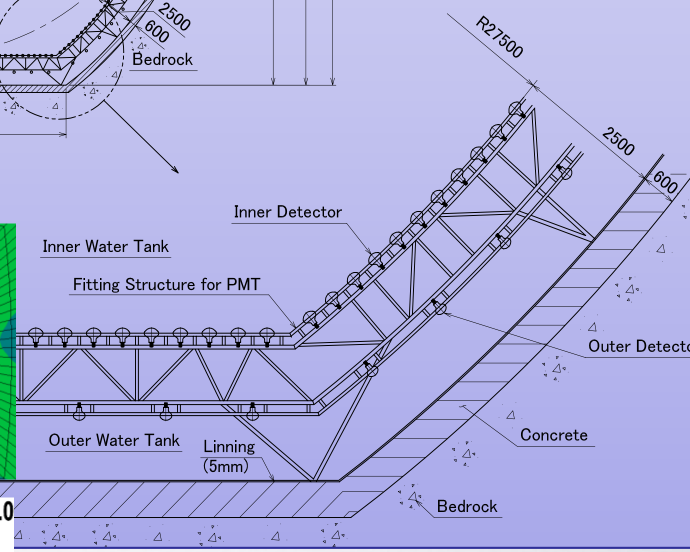


Hyper-K Base-Design

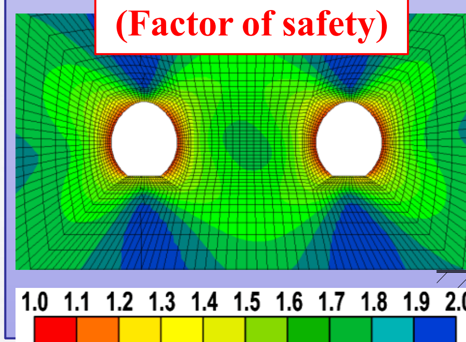
- 1Mton total volume, twin cavity
- 0.54Mton fiducial volume
- Inner (D43m x L250m) x 2
- Outer Detector >2m
- Photo coverage 20% (1/2 x SK)

- Base-design to be optimized
- Geological survey of the site is going on
- Qualitative studies on physics potential





20” PMT w/ cover



FEM analysis
(Factor of safety)

Summary

- **Aim to realize an experiment to discover CPV in neutrino and Proton decay with**
  - Upgraded J-PARC 0.75MW ➔ 1.66MW (➔??MW)
  - Huge, high sensitivity detector
- Possible options
  - 100kton LiqAr @ Okinoshima: CPV (,hierarchy)
    - **KEK pursue this option**
  - ~Mton Hyper-K @ Kamioka: CPV
- Intensive studies and R&D on going
  - Physics potential
  - Detector
    - LiqAr (ETHZ/KEK/Waseda/Iwate)
    - Water Cherenkov: Photo detector, site study, etc
- Within few years when T2K acquire ~1MW.10^7s, hope (need) to decide next direction

Spare

Critical path toward high power operation

Space charge

- Beam power is limited by beam loss
  - RCS, RCS-MR injection, and MR
- At what intensity, does the space charge effect become non-linear
  - MR Beam break-up (?) instabilities observed in MR at 1.5e13 ppb (design is 4 e13 ppb). Behavior similar to other high intensity accelerators driven by broadband impedance and/or electron cloud.
  - 2nd harmonic RF will be installed summer >1.7e13 ppb test in fall

Long term project

- Need work on more systematic studies on the nature of collective instabilities and impedance sources including possible electron cloud effects.
- Possibility of RCS h=1 operation and injection to MR
- LINAC 400MeV Operation (avoid severe space charge effect at RCS injection) → Construction of necessary component has been funded and construction started

Item to be Modified from DAY1 toward High Intensity

- No. of Bunch in MR(6→8)
  - Fast Rise Time Extraction Kicker Magnet
- Increase Repetition Rate (3.5Sec→1.92Sec)
  - RF and Magnet Power Supply Improvement
- RCS h=1 Operation (longer beam bunch to decrease space charge effect)
  - RF Improvement
- LINAC 400MeV Operation (avoid severe space charge effect at RCS injection)

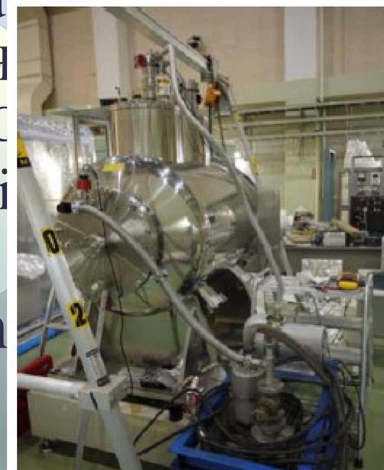
h=2: 2 bunches × 4cycle injection to MR
h=1:Single bunch with doubled no. of proton × 8cycle injection

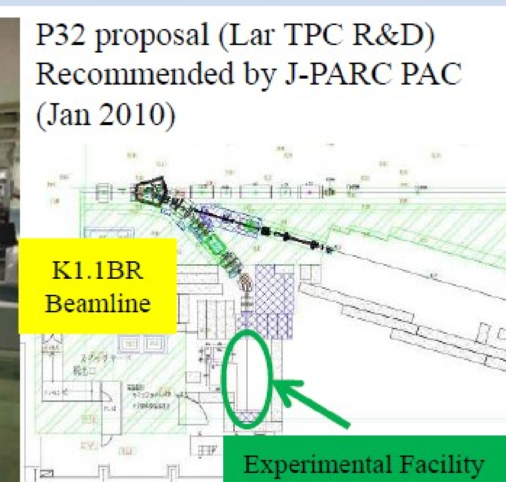
Steps towards proposal of 100 kton Giant Liquid Argon TPC

arXiv:hep-ph/0402110

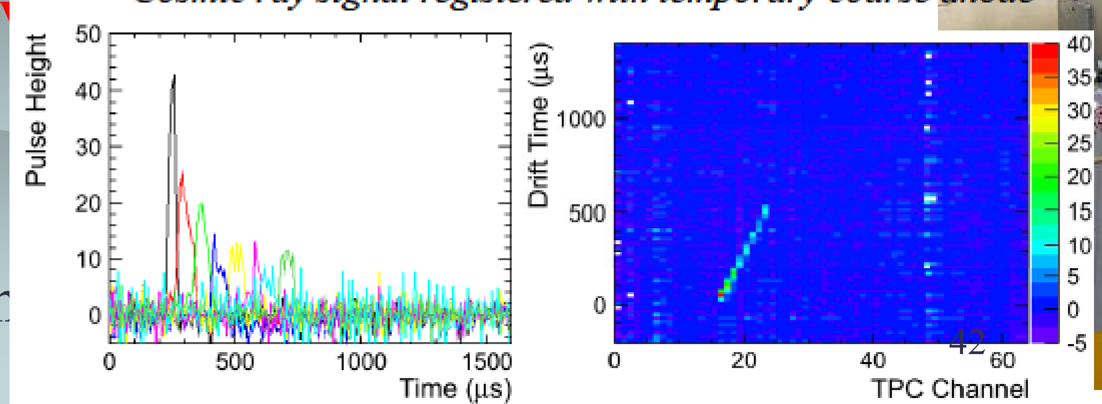
ETHZ, Iwate, KEK, Waseda,

- Additional improvement of detector technology beyond ICARUS T600
  - long drift distance to reduce readout channel
    - Signal amplification, Better purity, H
    - 3L@CERN, 10L@KEK, ArDM@C
  - Acceptable purity with No-evacuati
    - 6m3@CERN
- Performance evaluation (detection suppression, etc.)
  - 250L@KEK for J-PARC test beam
    - **First cosmic track observ**
  - etc
- Final prototyping
  - Level of 1 kt prototype
- Full engineering design ar





Cosmic ray signal registered with temporary coarse anode



Accelerator Based Neutrino Project in Japan

	K2K	T2K	3rd Generation Exp. (KEK Roadmap)
High Power Proton Synchrotron	KEK PS 12GeV 0.005MW Existing	J-PARC MR 30GeV up to 0.75MW Brand New	J-PARC MR 30GeV 1.66MW Technically Feasible Upgrade
Neutrino Beamline	K2K Neutrino Beamline Brand New	J-PARC Neutrino Beamline Brand New	J-PARC Neutrino Beamline Existing
Far Detector	Super Kamiokande Existing at KAMIOKA	Super Kamiokande Existing at KAMIOKA	***Brand New*** ***-Detector Technology ?*** ***-Place ?*** ***(Angle and BaseLine)***
1st Priority Physics Case	Neutrino Oscillation ν_μ Disappearance	Neutrino Oscillation $\nu_\mu \rightarrow \nu_e$	Lepton Sector CP Violation + Proton Decay Search

Able to concentrate on Far Detector issue toward the 3rd Generation Experiment after T2K startup

Additional requirement for far detector optimization

- Proton Decay Discovery Performance

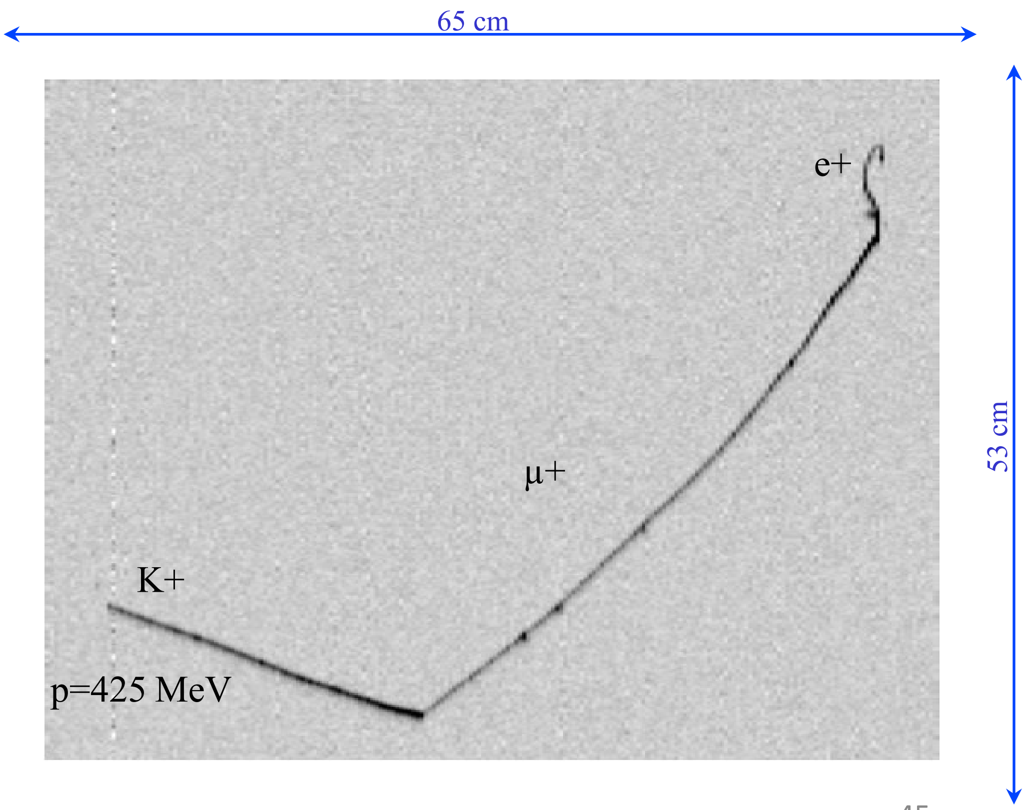
- Realization of the huge detector
  - Test of the key components
  - Experimentally prove the detector performance
    - if necessary, good prototyping (able to predict Huge Detector Performance well) is important
    - Test with the beam is important

KEK started R&D for Huge Liq. Ar TPC with ETH Zurich

Discovery of nucleon decay

- High quality tracking information, high energy resolution, low particle energy detection energy threshold
  - → Background free measurement for several decay modes
- Possible to explore 10^{34}-10^{35} years life time within 10 years for several decay mode

- Shallow depth(>600 m.w.e.) is enough to suppress cosmogenic background
- Main background is atmospheric neutrino
- Never miss $p \to \nu K^+$, $p \to e^+ K^0$, $n \to e^+ K^-$, ...etc.
- Surely detect high multiplicity final states mode (e.g. $p \to \mu \pi K$, ...)



Scenario 1

Neutrino event rate and experimental sensitivity

Events in 100 kton, 658 km, 5 years @ 1.66 MW

No Osc.	ν_μ CC	ν_e CC	$\overline{\nu_\mu}$ CC	$\overline{\nu_e}$ CC
5 years	82000	750	1460	35

δ_{cp} (deg)	0	90	180	270
$\sin^2 2\theta_{13}=0.1$	2867	2062	2659	3464
$\sin^2 2\theta_{13}=0.05$	1489	1119	1342	1908
$\sin^2 2\theta_{13}=0.03$	942	506	829	1266

* $\times$10 larger total events than T2K

* High detection efficiency, excellent background suppression, high precision electron neutrino energy spectrum measurement

- CP discovery exceeds 3σ for $\sin^2 2\theta_{13}>0.02$
- measure θ_{13} with $\delta\sin^2 2\theta_{13}\approx\pm0.01$ and test CP at better than 90%CL if $\sin^2 2\theta_{13}>0.01$
- $\sin^2 2\theta_{13}<0.001$ @ 90%CL (if no signal is found)   one order better than T2K

J-PARC to Okinoshima

Mass hierarchy investigation

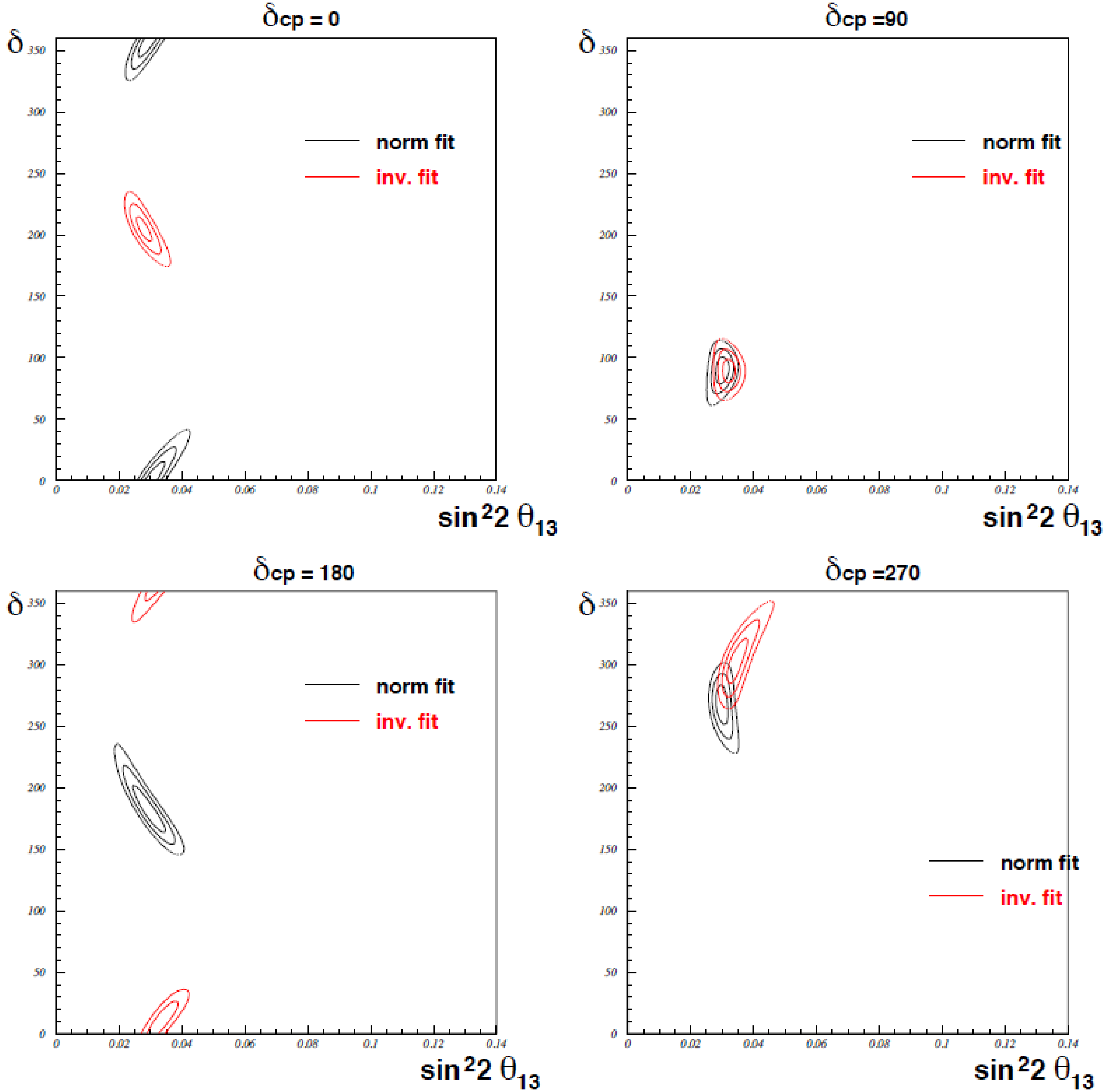


Fig. 7: Mass hierarchy investigation with neutrino run only. If fits with both hierarchy hypotheses provide neither 0 nor 180°, one can declare discovery of CP violation in the leptonic sector. If any of the fits results in a δ_{CP} of 0 or 180°, then an anti-neutrino run could be envisaged.

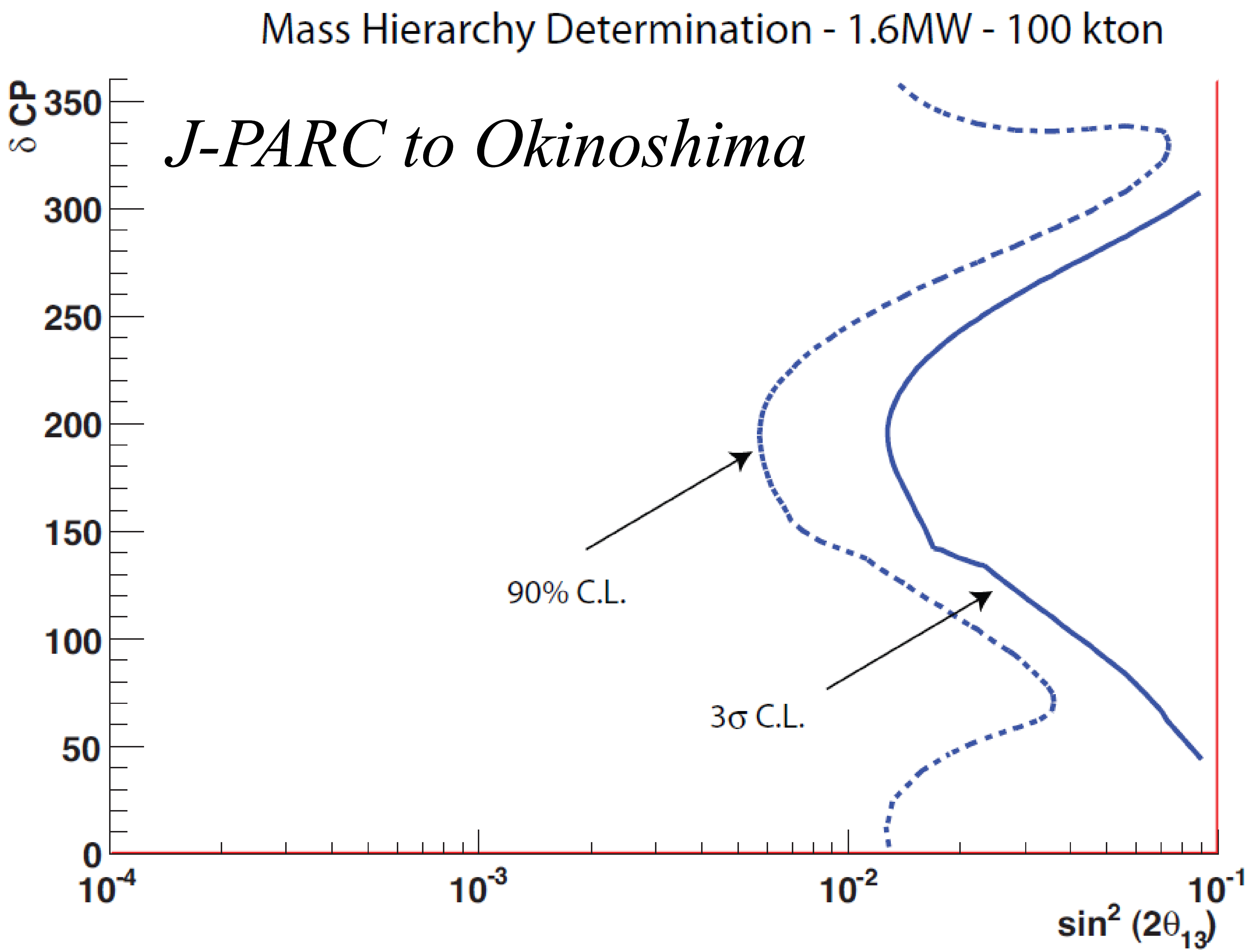
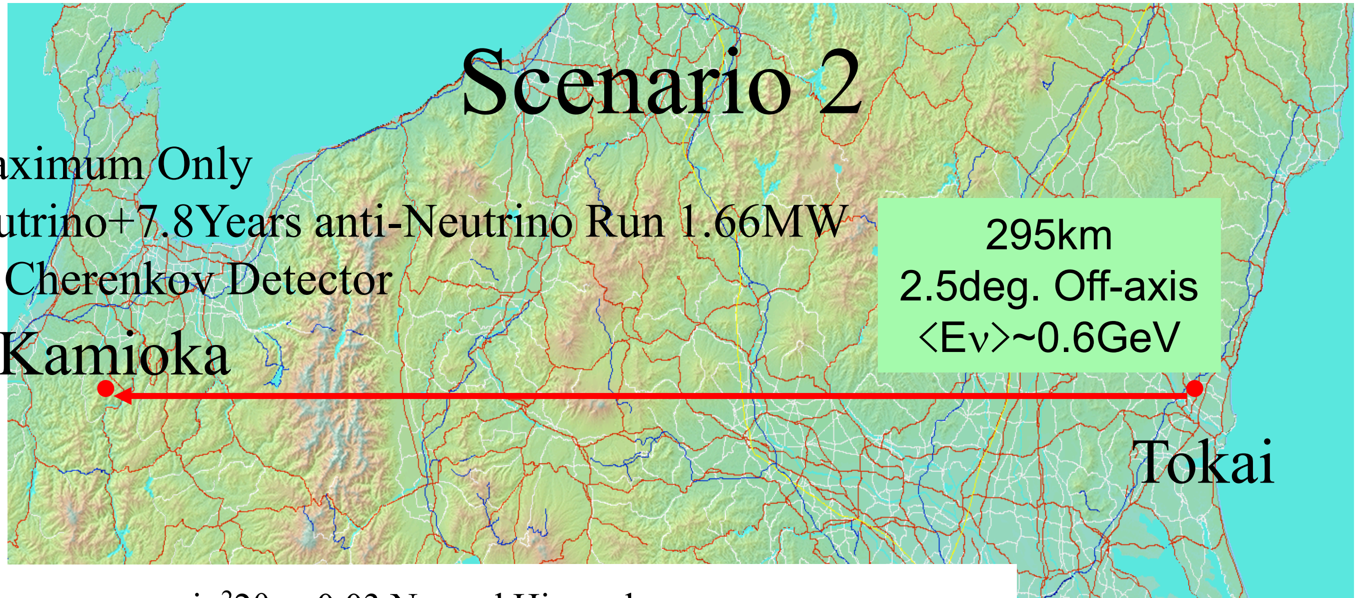


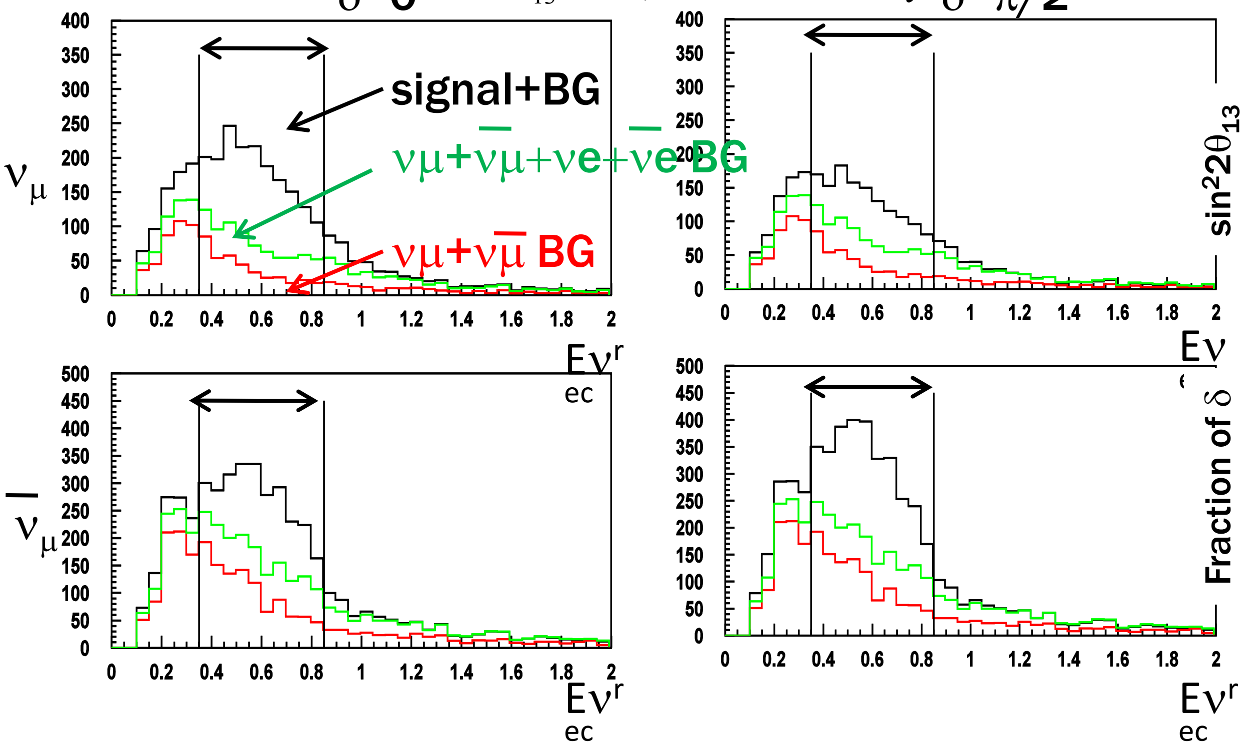
Fig. 10: Mass hierarchy discrimination at 90%C.L. and 3σ for 5+5 years neutrino-antineutrino runs.

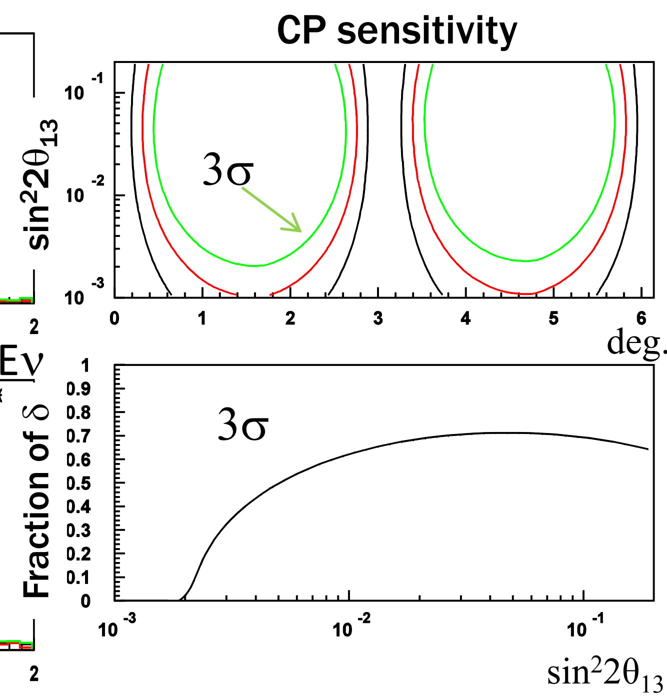
Scenario 2

- Cover 1st Maximum Only
- 2.2Years Neutrino+7.8Years anti-Neutrino Run 1.66MW
- 540kt Water Cherenkov Detector



δ=0 $\sin^2 2\theta_{13}$=0.03,Normal Hierarchy $\delta=\pi/2$

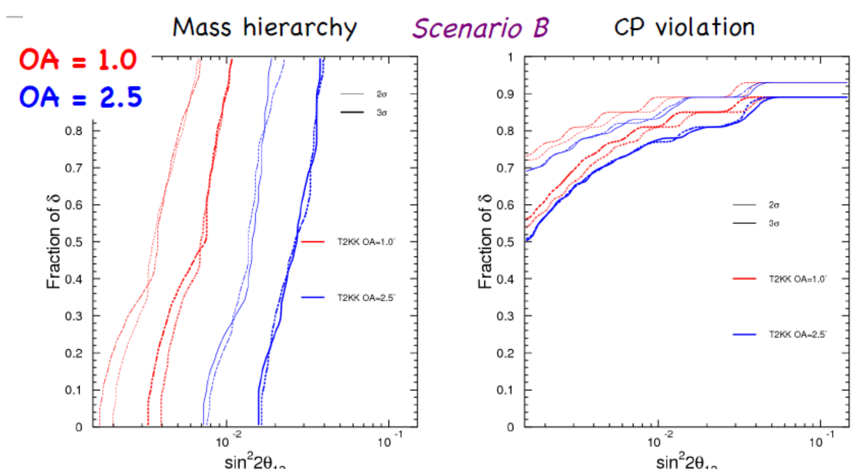


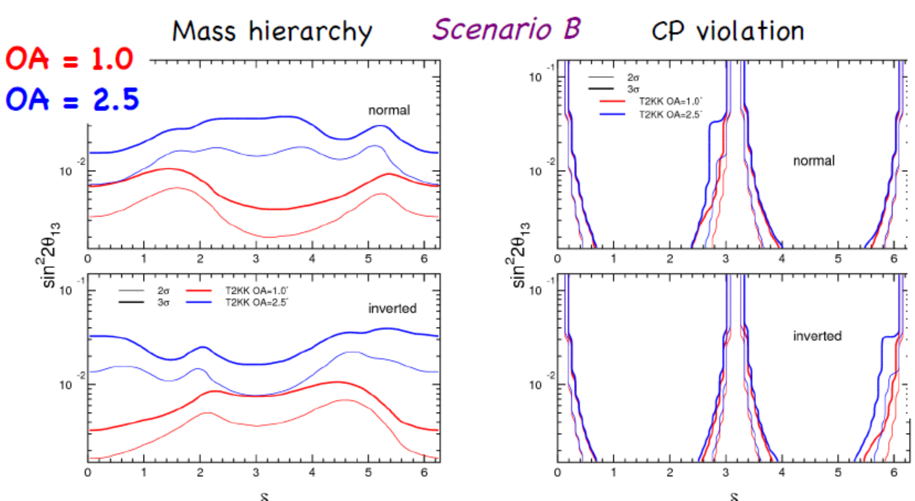


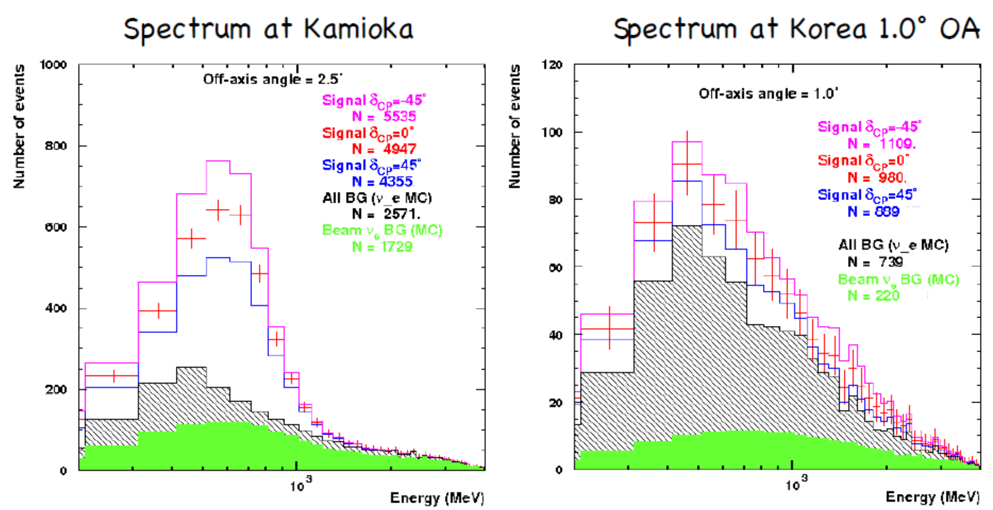
K.Kaneyuki @NP08

Scenario 3

- Cover 2nd Maximum @ Korea
- Cover 1st Maximum @ Kamioka
- 5Years ν+5Years $\bar{\nu}$ Run 1.66MW
- 270kt Water Cherenkov Detector each @ Korea, Kamioka







$\sin^2(2\theta_{13})$=0.04, neutrino, normal hierarchy, Scenario B

F.Dufour@NP08

(study is initiated by M.Ishitsuka et. al. hep-ph/0504026)

Comparison of Each Scenario

	Scenario 1 Okinoshima	**Scenario 2 Kamioka**	**Scenario 3 Kamioka Korea**
Baseline(km)	660	295	295 & 1000
Off-Axis Angle(°)	0.8(almost on-axis)	2.5	2.5 1
Method	ν_eSpectrum Shape	Ratio between $\nu_e \overline{\nu}_e$	Ratio between 1st 2ndMax Ratio between $\nu_e \overline{\nu}_e$
Beam	5Years $\nu_{\mu,}$ then Decide Next	2.2 Years $\nu_{\mu,}$ 7.8 Years $\overline{\nu}_{\mu,}$	5 Years $\nu_{\mu,}$ 5 Years $\overline{\nu}_{\mu,}$
Detector Tech.	Liq. Ar TPC	Water Cherenkov	Water Cherenkov
Detector Mass (kt)	100	2×270	270+270

Study is continuing to seek for optimum choice

Okinoshima: Geology and Geography

ASAHI quarry

A single layer of the gneiss

TOKUHATA No.2 q

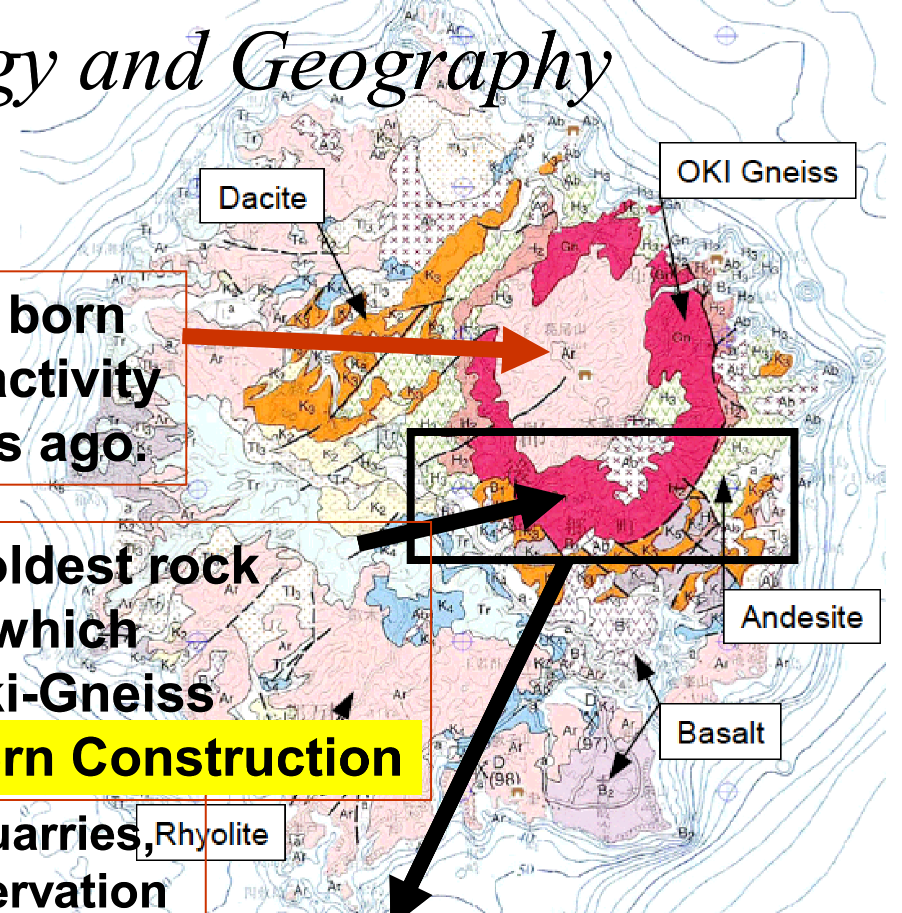
The crackle of the Igneous rock to the gneiss

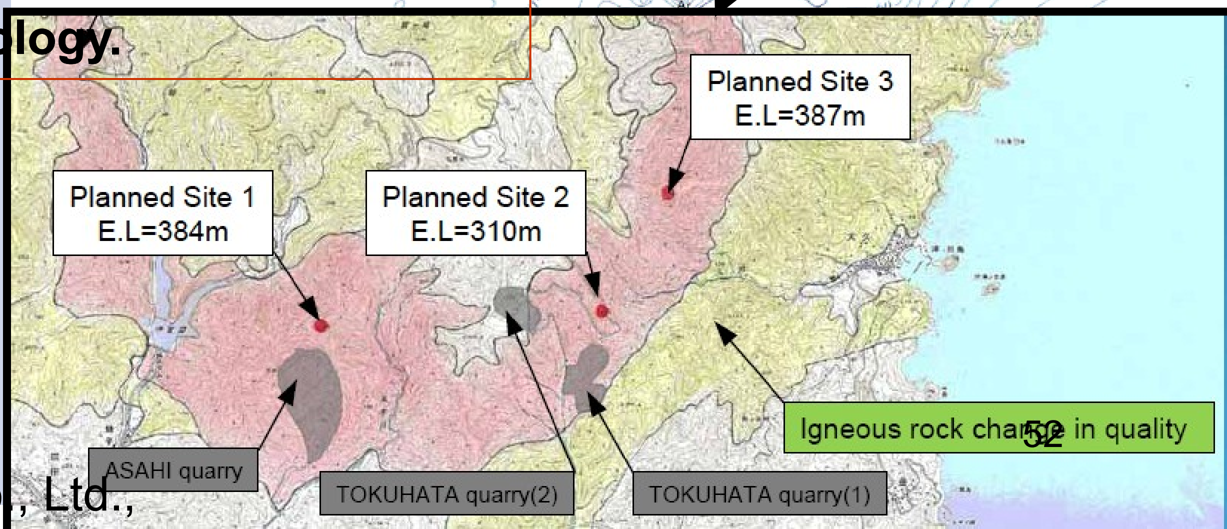
Islands were born by volcanic activity in 5~6M years ago.

BUT, bedrock is the oldest rock in Japan (2G years), which has been left as →Oki-Gneiss

Suitable for Big Cavern Construction

There are several quarries, good for direct observation of geology.





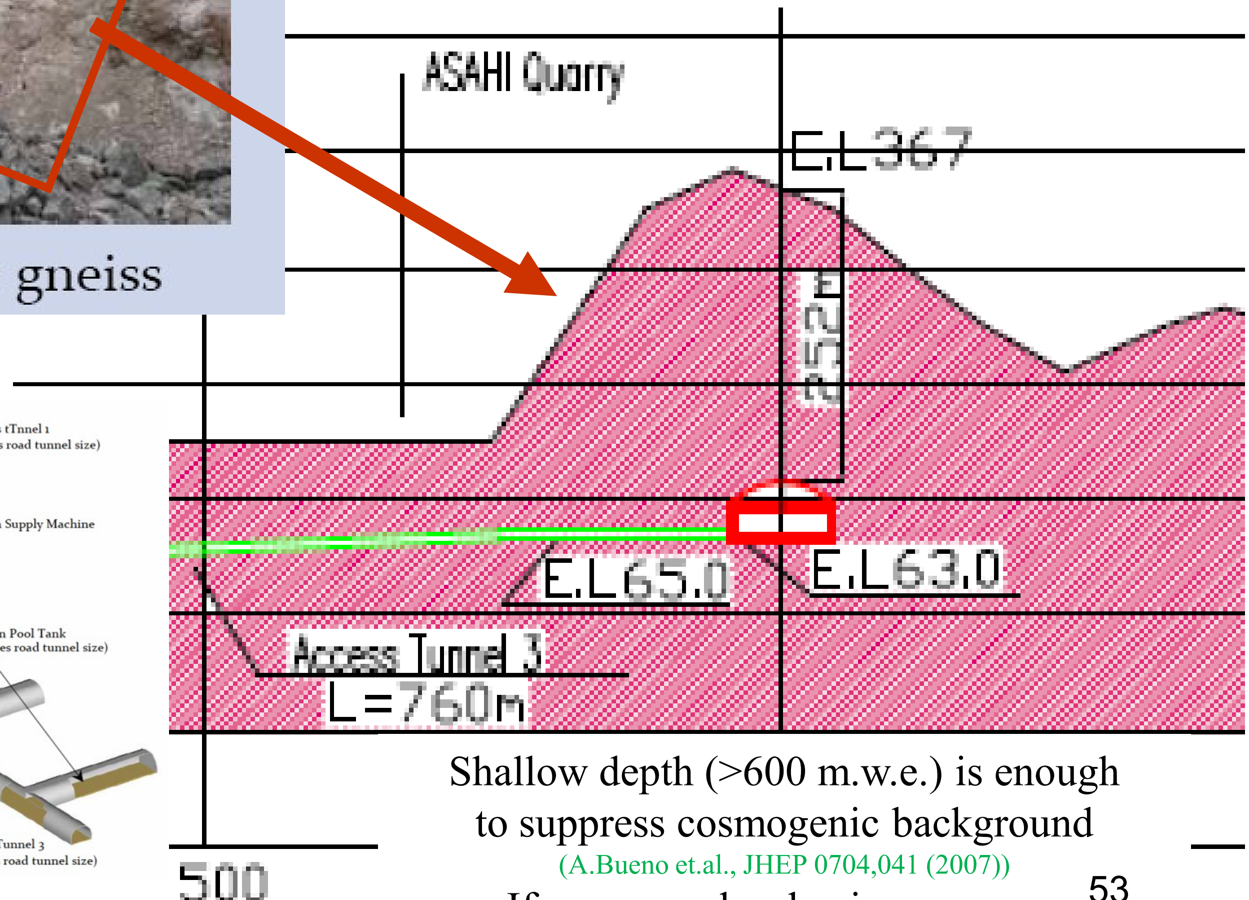
ASAHI quarry

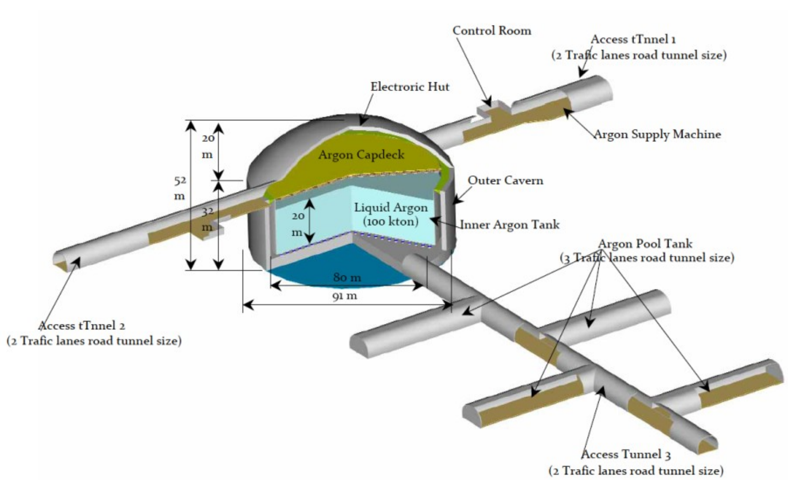
A single layer of the gneiss

Okinoshima: Geology and Geography

A conceptual design

Site No.1





PENTA-OCEAN construction co., Ltd.,

Shallow depth (>600 m.w.e.) is enough to suppress cosmogenic background
(A.Bueno et.al., JHEP 0704,041 (2007))

If more overburden is necessary, inclined access tunnel is also possible

100 kton Giant Liquid Argon TPC Preliminary design (used for cost estimate)

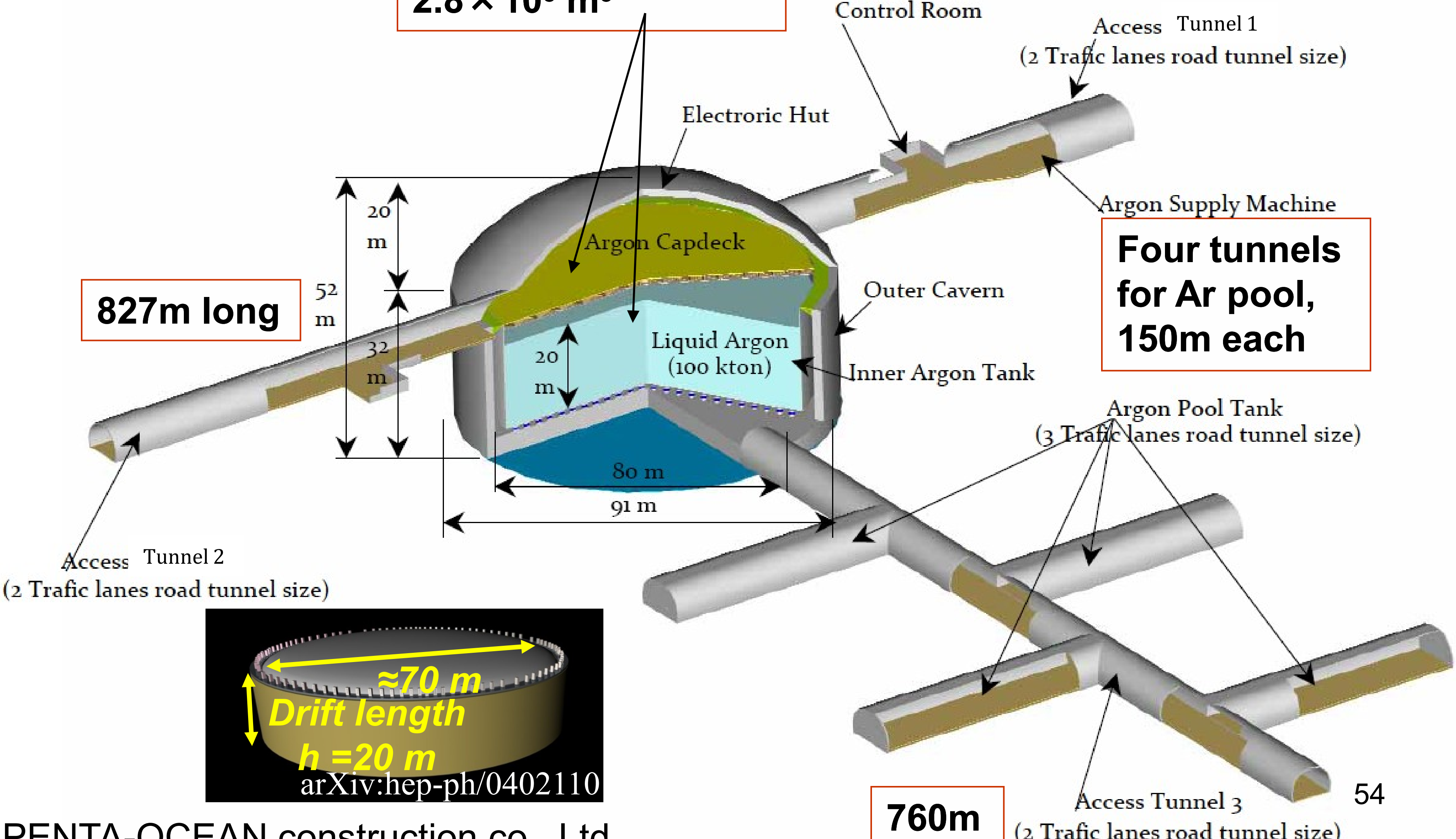
Excavation volume: 2.8×10^5 m^3

462m long

827m long

Four tunnels for Ar pool, 150m each

760m



PENTA-OCEAN construction co., Ltd.,

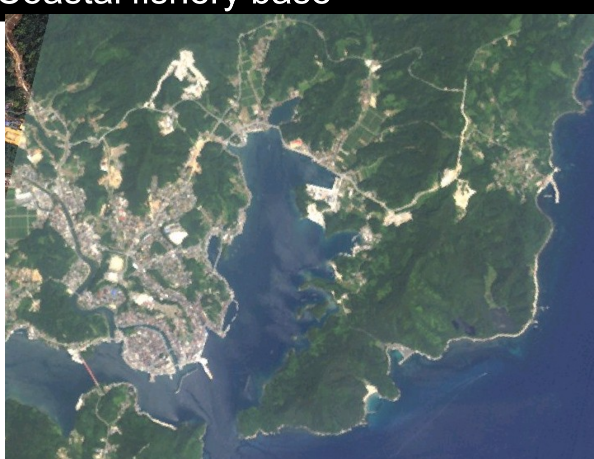
Okinoshima: Infrastructure

SAIGOU
Large electric power station enough for our facility

OMOSU port (local)
- Coastal fishery base
- Landing place of daily commodities

Candidate site

SAIGOU port (Main)
- Base of the remote island route that links Oki Islands to the mainland
- Coastal fishery base



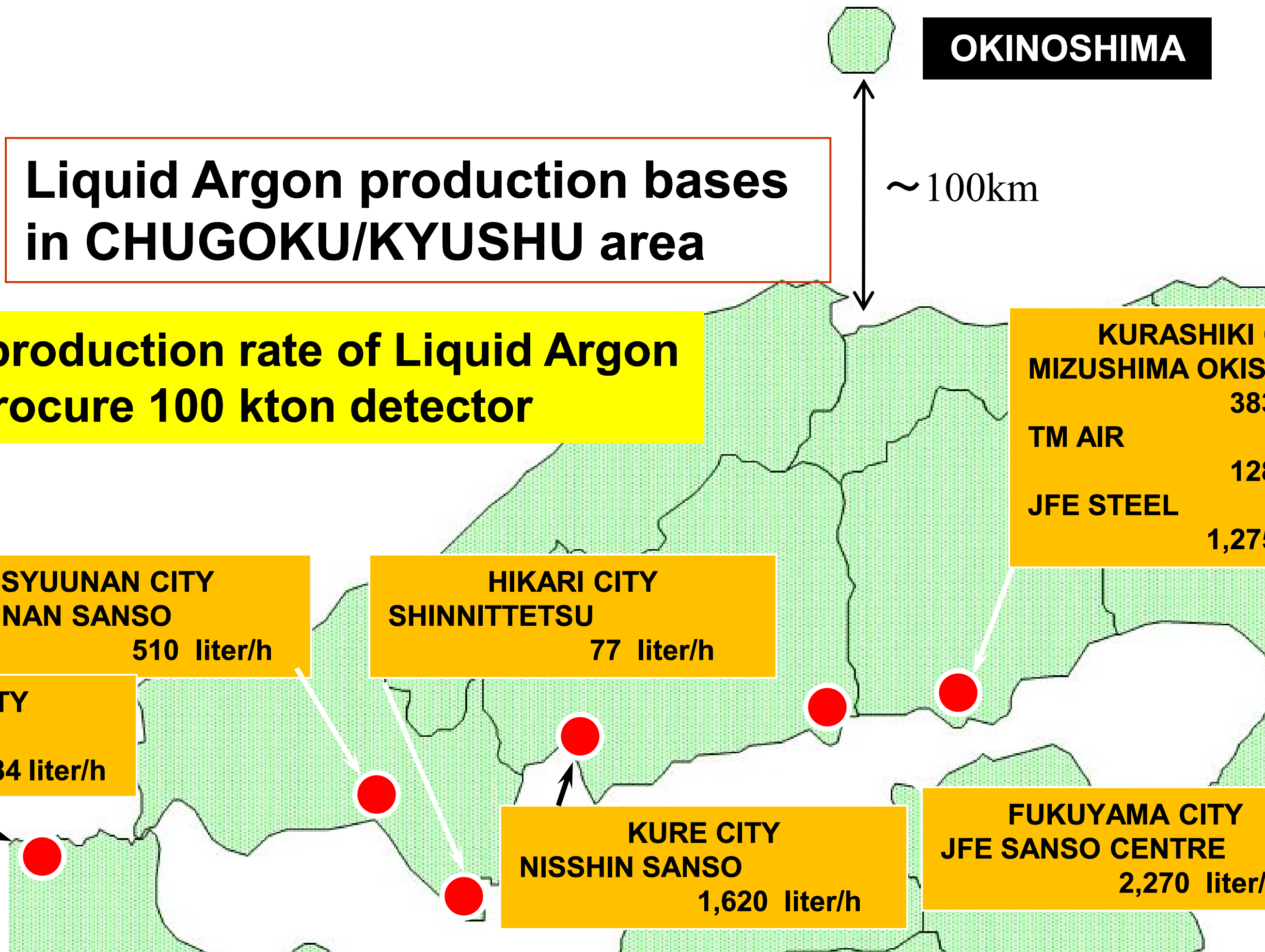
Oki airport, two regular flights
Oki – Osaka, Oki - Izumo

Okinoshima: Liquid Argon supply

Most efficient way is to use presently available ferry liner

Liquid Argon production bases in CHUGOKU/KYUSHU area

Sufficient production rate of Liquid Argon to procure 100 kton detector

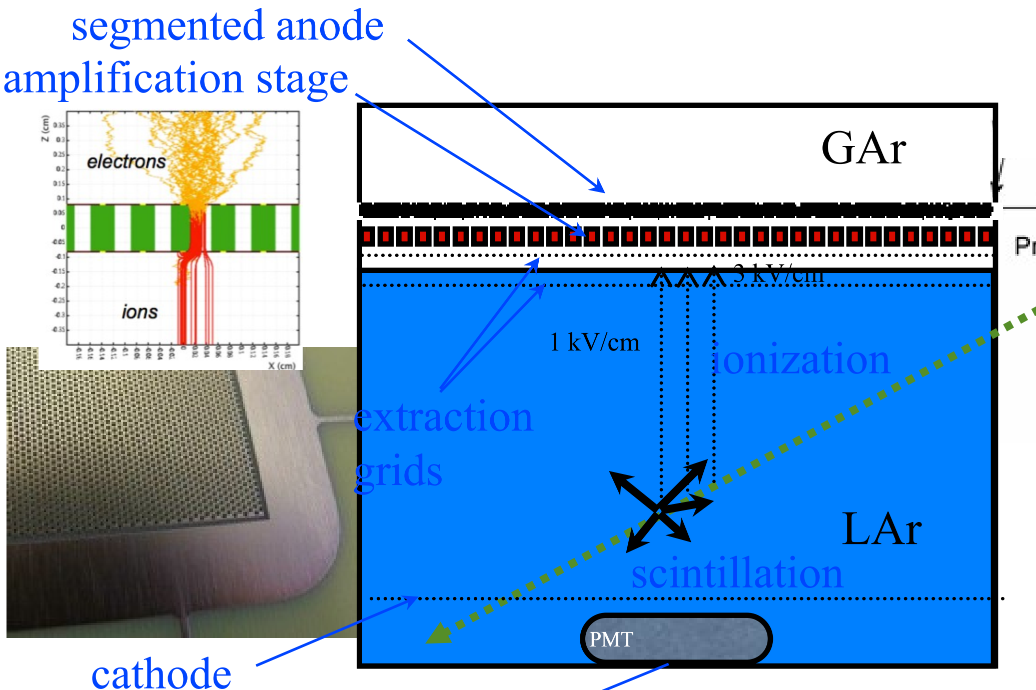


The new LAr LEM-TPC

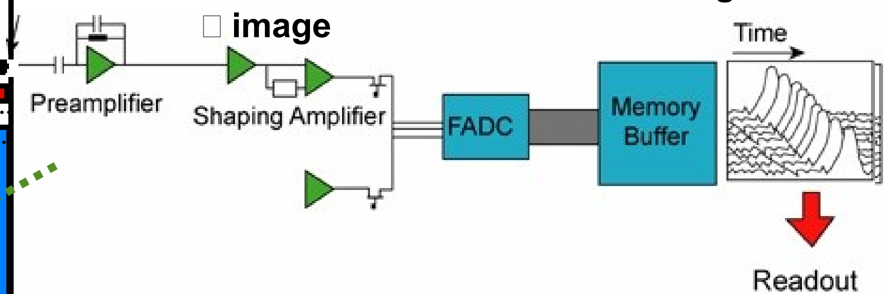
- LAr LEM TPC = Double phase TPC with gain in GAr vapor

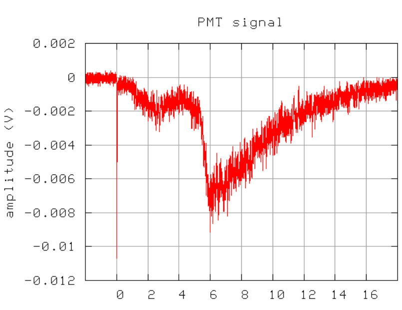
Motivated by the very long drift path needed in giant detectors and DM applications (keV detection)

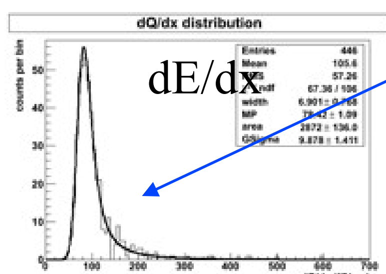
hep-ph/0402110, arXiv:0811.3384, NIM A617(2010)188, J.Phys.Conf.Ser.171:012020,2009, arXiv:1001.0076



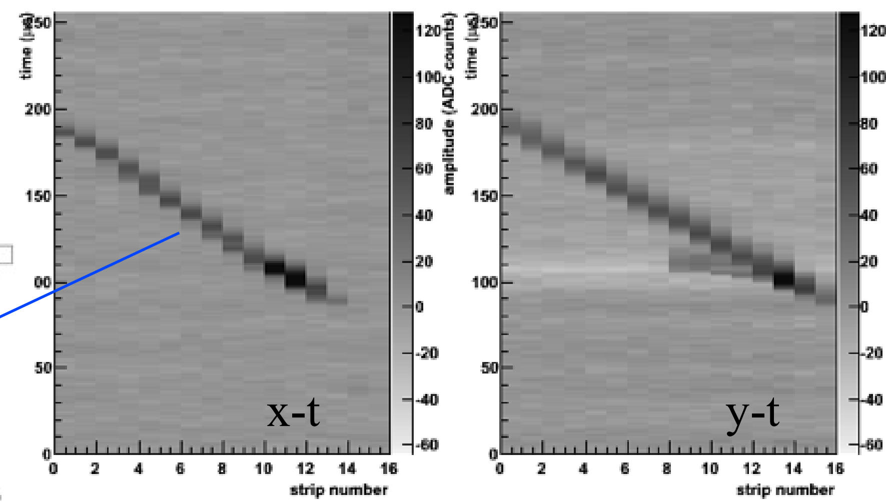
Continuous waveform recording
□ image





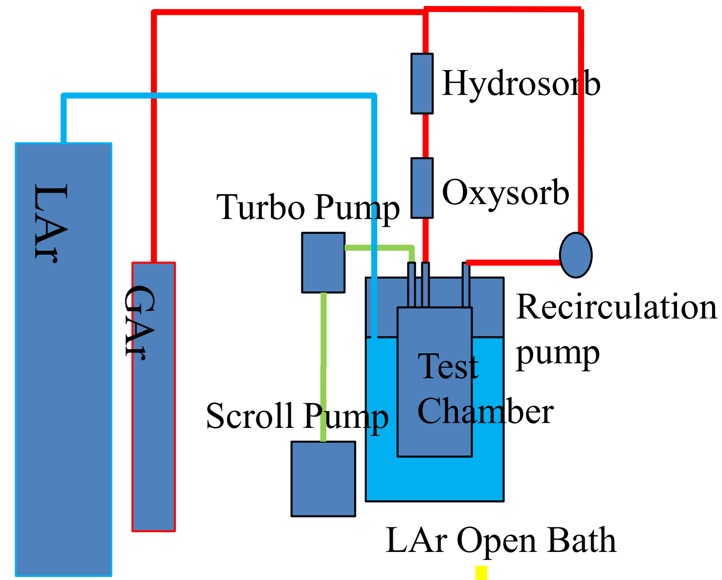


Cosmic tracks in 3 lt prototype (G≈6):

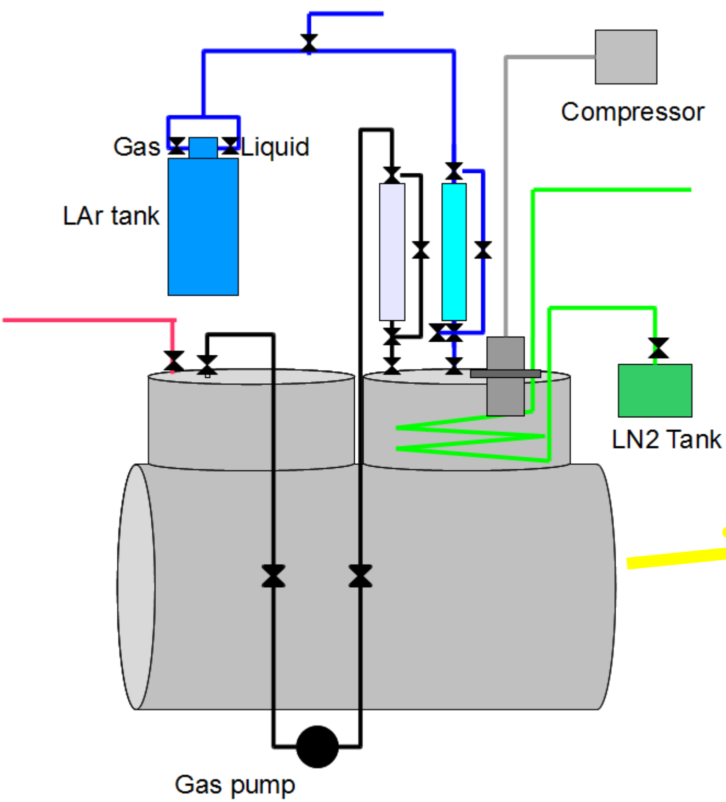


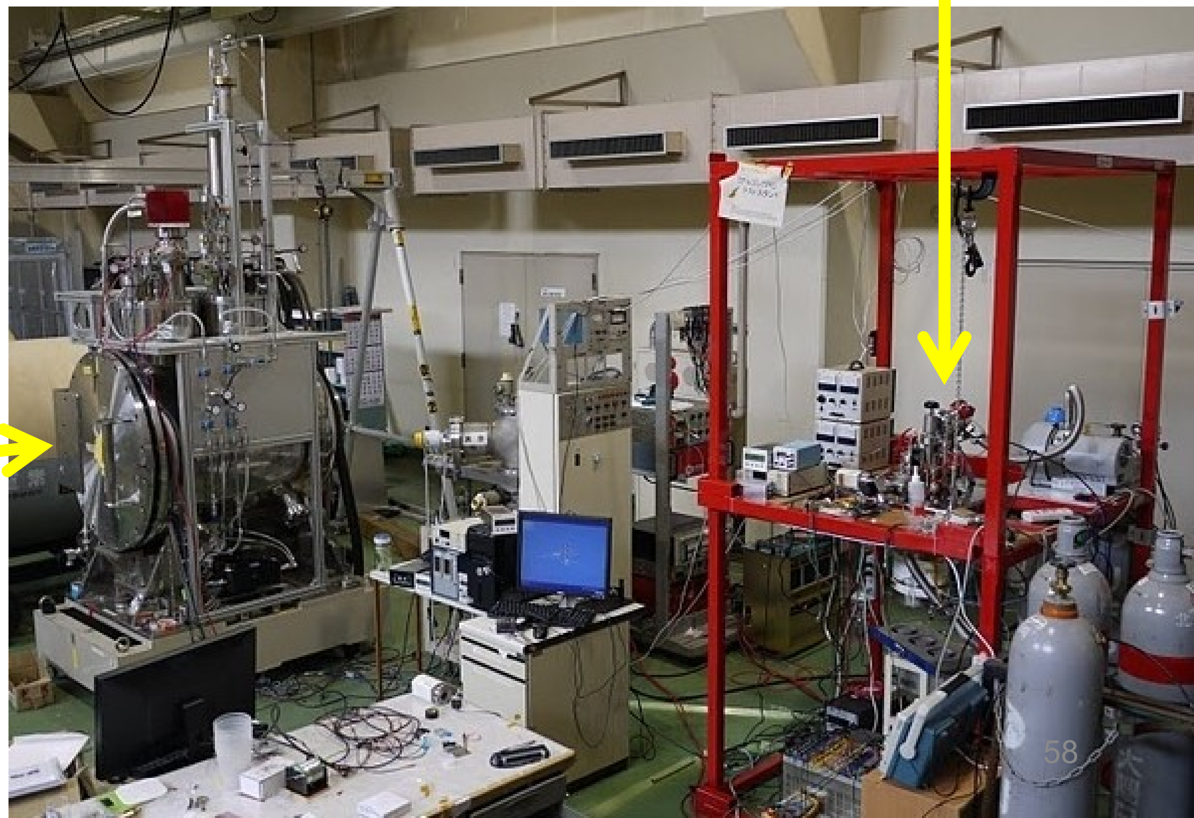
Liquid Argon TPC Lab.@KEK

10L@KEK

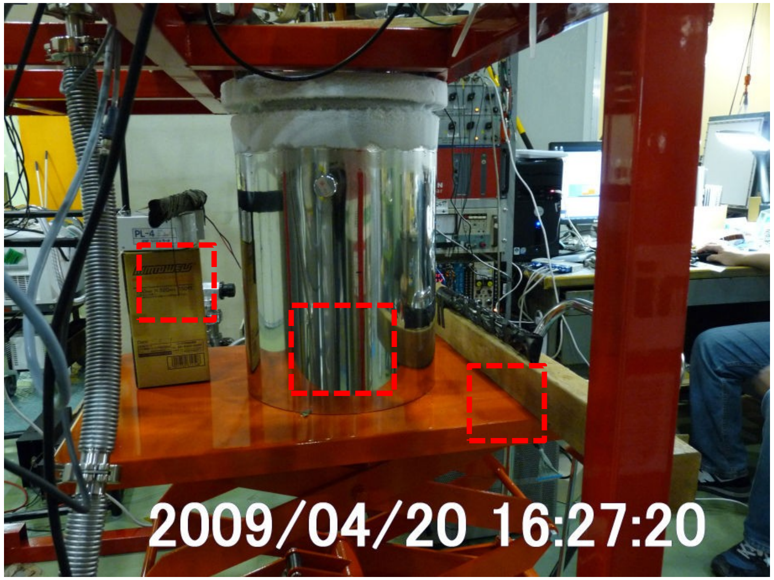


250L@KEK

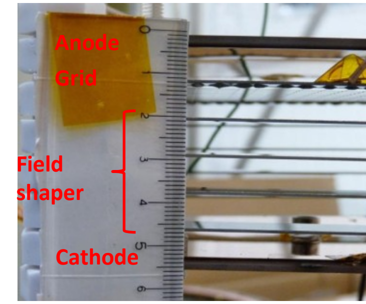


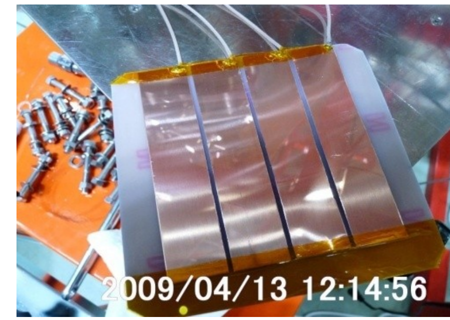


1st Liq. Ar TPC Signal with Cosmic Ray in Japan



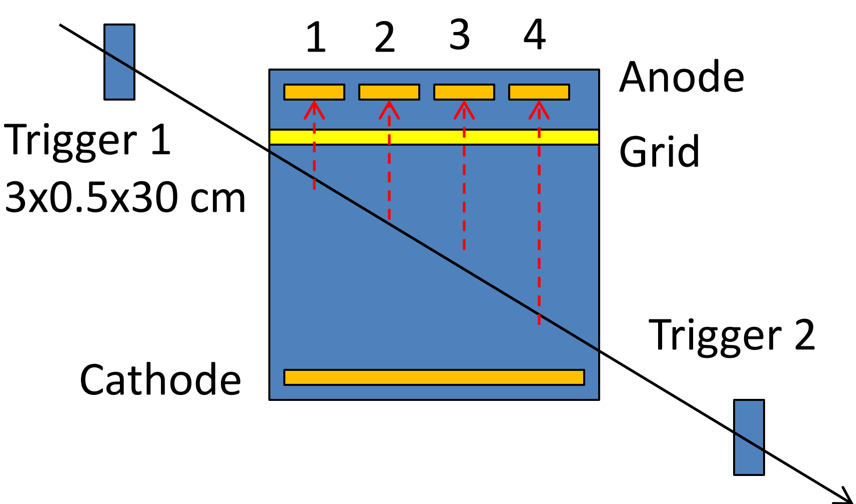
- HV setting
  - Cathode -2500 V
  - Grid -1000 V
  - Cathode-anode; 5cm
- Oscilloscope waveform
  - Ch1 is the fastest signal
  - Drift time ~20 μs

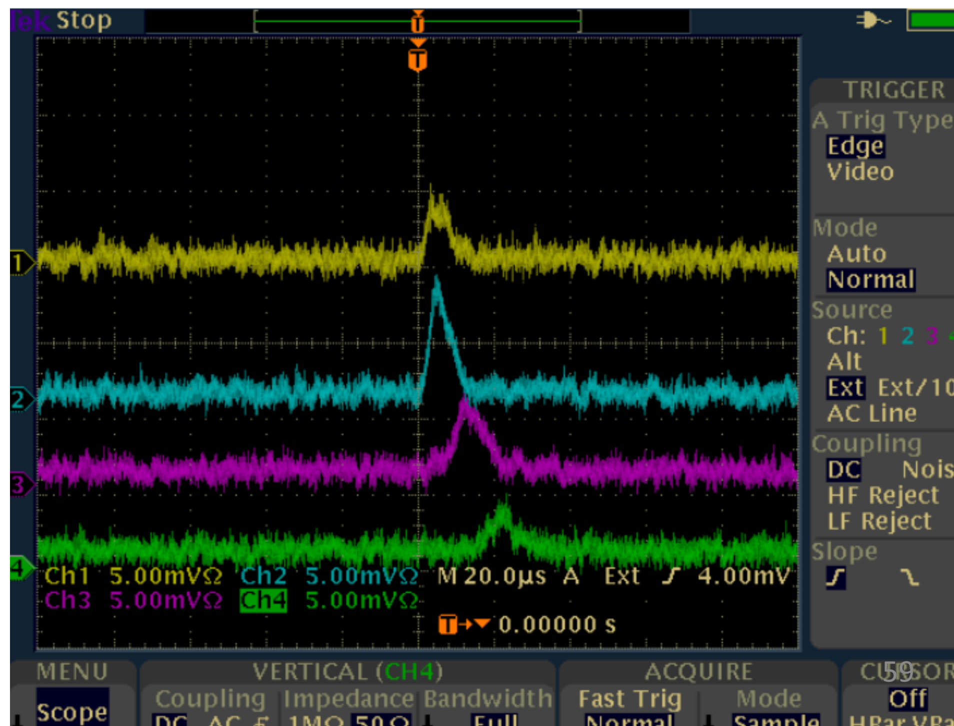




Anode: 4ch × 2.2cm × 9cm

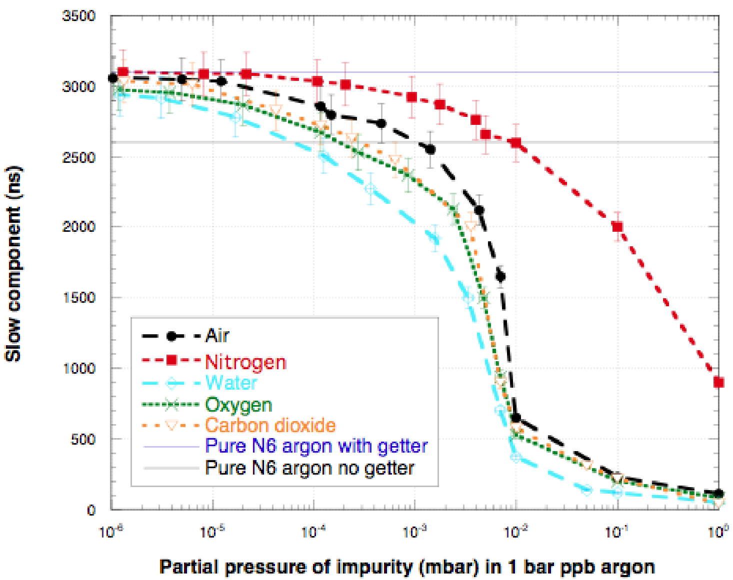
Trigger Counter set up



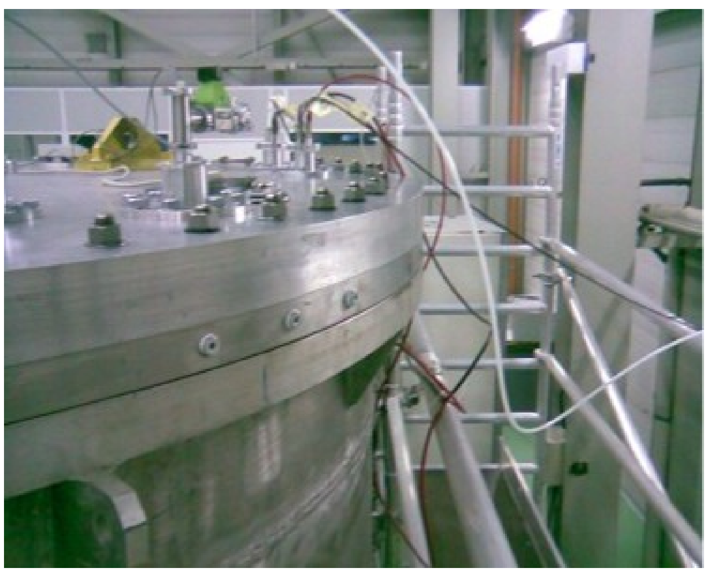


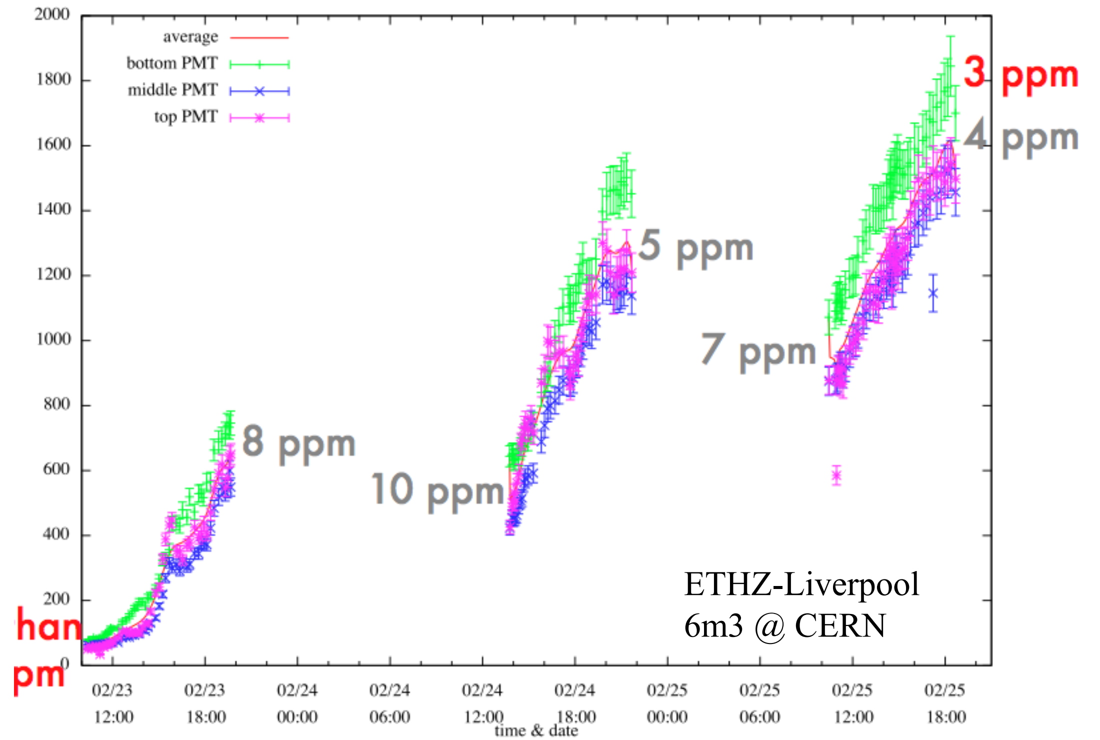
6m3 @ CERN

A. Curioni et al., GLA2010 workshop



- R&D towards non evacuated vessels on large vessel
- Purity measured with direct scintillation light measurement !
- First test purging - satisfactory!
- Piston effect seen
- Reached **3ppm** O_2 contamination via flushing
- Gas recirculation under construction



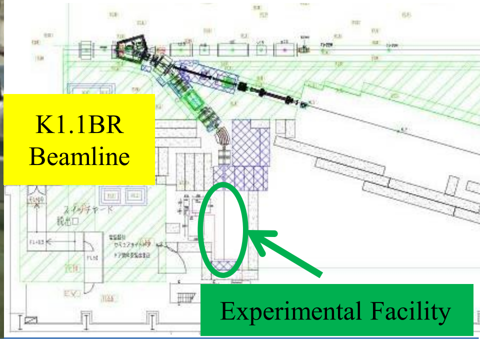


An example of performance evaluation with clear objective: 250L@KEK

Measurements with
well defined charged particle test beam

- ➢ To benchmark performance of detector
- ➢ To develop realistic simulation/reconstruction software

P32 proposal (Lar TPC R&D)
Recommended by J-PARC PAC
(Jan 2010)



- Cryogenic vessel with beam window (originally for MEG liquid Xe calorimeter test module)
- Ultra-Vacuum established
- Cryocooler and liquid Argon filling under investigation
- Liquid Argon purification system under procurement
- Exposure to low-momentum separated K beam @J-PARC

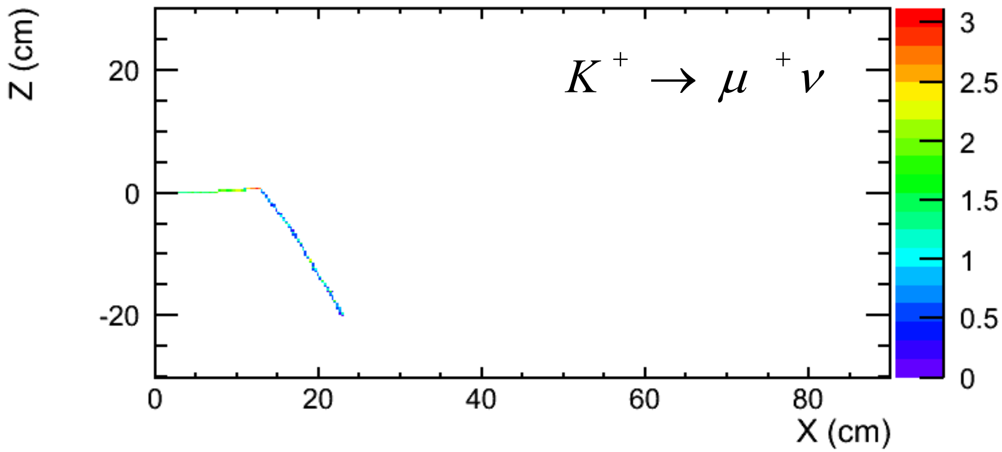
$p \rightarrow \nu K$ (340MeV/c K^{+})

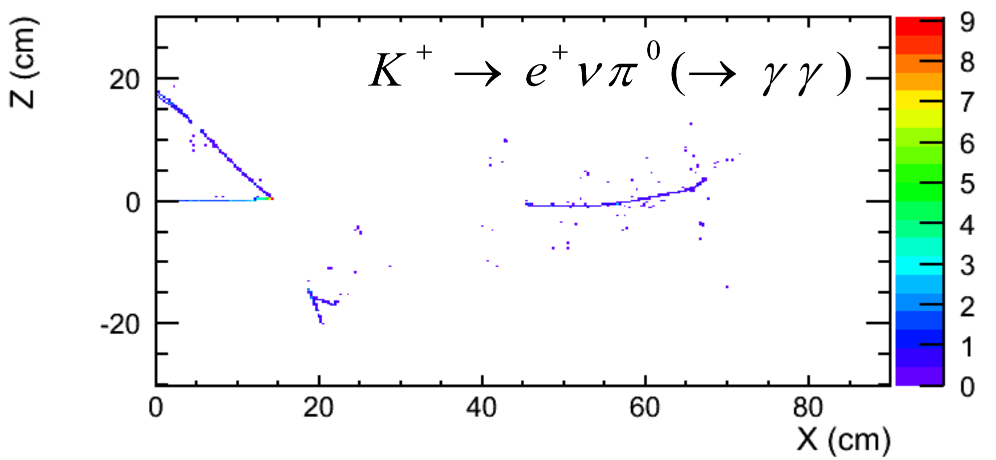
Parameters for 250L@KEK	
Fiducial mass	170 kg
Total Liquid Argon mass	～400 kg
Field cage dimensions	42×42×78 cm^3
Fiducial volume	40×40×76 cm^3
Drift field	1 kV/cm
Max. drift voltage	40 kV
Readout method	Double phase, Two view anode LEM-TPC
Readout segmentation	Two 40 ×38 cm^2 LEM-TPC
Readout pitch	3mm in x & y
Number of readout channels	288 per LEM-TPC 576 in total
LEM-TPC effective gain	～25

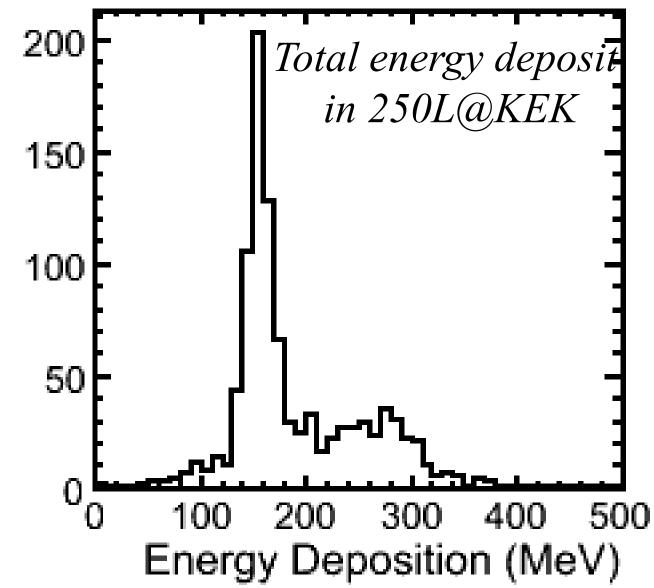
340 MeV/c K⁺ (p→Kν) in 250L@KEK

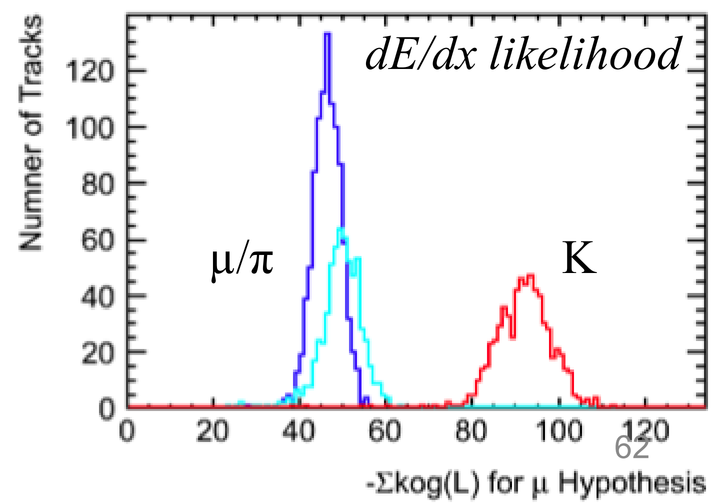
First beam exposure in October 2010

- >90% of slow kaons stop in detector with range ≈10cm (others decay in-flight)
- Many soft decay products are contained
- dE/dx analysis can be performed for particle ID

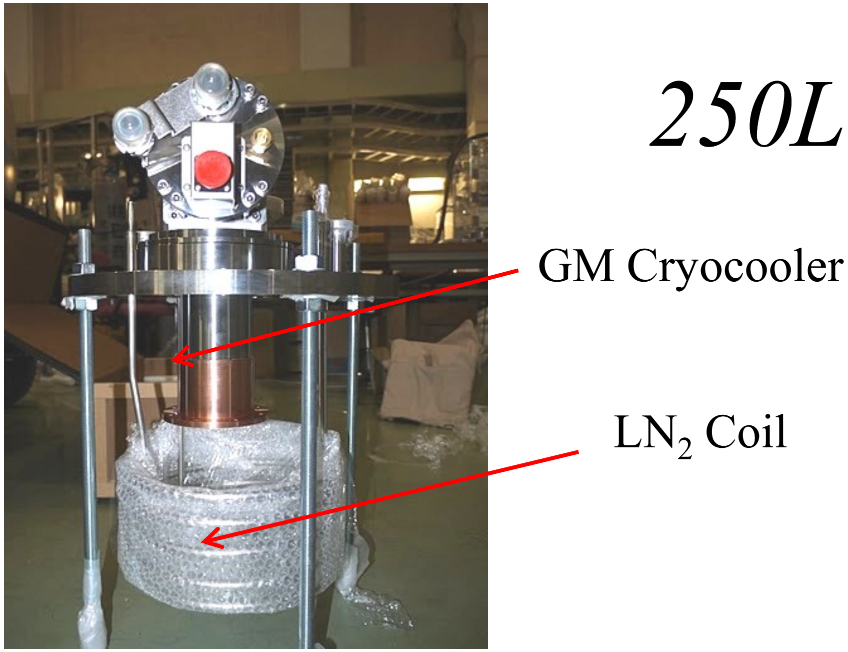




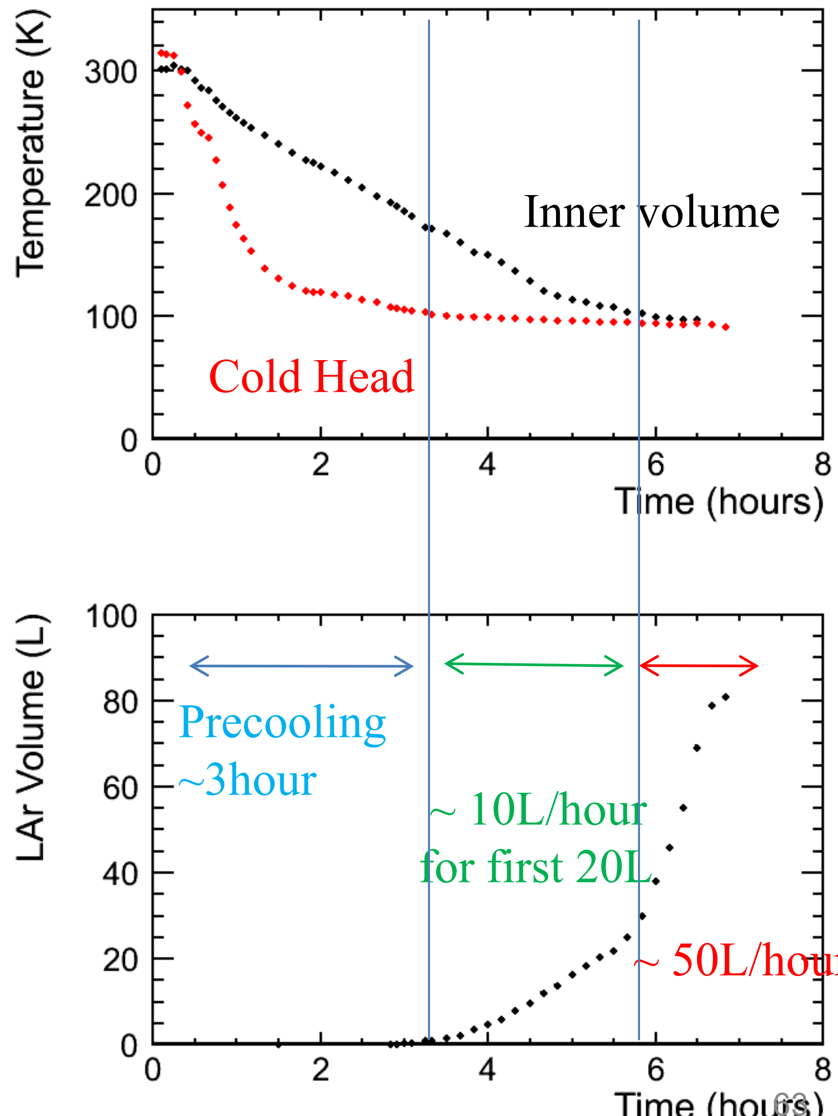




250L@KEK: Cryogenics

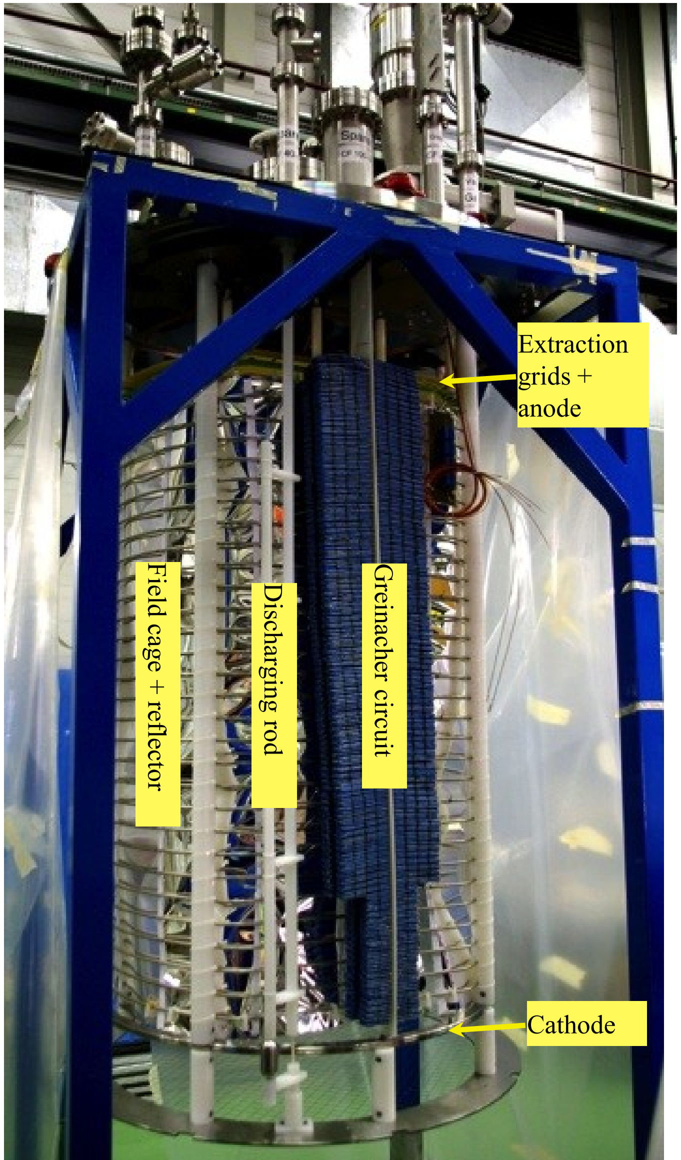


- Heat input of 250L cryostat: ~ 30W
- GM Cryocooler (~150W)
  - For normal operation
- LN_2 heat exchange coil (~500W)
  - Additional cooling equipment for pre-cooling, filling, and recirculation for purification
- Successful filling of the vessel
  - ~ 3 hours for pre-cooling
  - 7 hours for 100L filling
  - ~ 50L/hour (in case the vessel is cold enough)
- Stably kept ~1 week with cryocooler

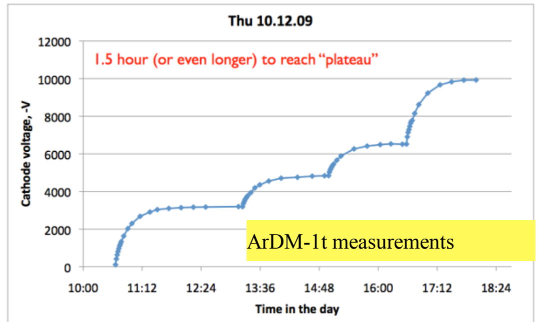


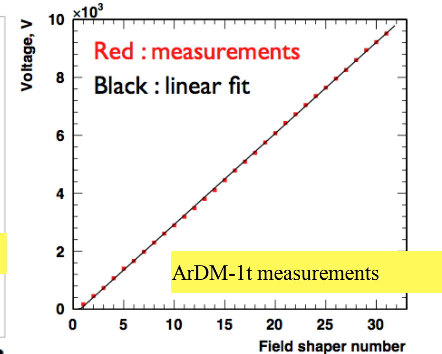
Very high drift "high" voltage...

S. Horikawa et al., GLA2010 workshop



ArDM-1t detector





Extrapolation to long drift

Extrapolation of the ArDM design

Changing Cs for fixed Cp = 2.35 pF and Vpp-in = 2E = 2.5 kV

		ArDM				
Drift length	m	1.24	5	10		20
Total output voltage for 1 kV/cm	V	124k	500k	1M		2M
Input voltage Vpp-in = 2E	V	820	2.5k	2.5k	$\times\sqrt{2}$	3.5k
Shunt capacitance, Cp	F	2.35p	2.35p	2.35p	$\times 1/2$	1.18p
Capacitor	F	328/164n	475n	1.90μ		1.90μ
Number of stages, N	–	210	319	638		903
N per 10 cm	–	16.9	6.38	6.38		4.51
Total capacitance	F	125μ	303μ	2.43m		3.43m
Capacitance per 10 cm	F	10.4μ	5.99μ	24.3μ		17.2μ
Total stored energy	J	21.7	948	7.58k		21.5k

Actual ArDM parameters are given just for comparison.

For extrapolation, 2γN = 1.42 is always assumed.

LAr vaporization heat 160 kJ/kg

$$V_{\max} = \frac{E}{\gamma}, \ \gamma \approx \sqrt{\frac{C_p}{C_s}}$$