Development towards a Giant Liquid Argon Observatory in Japan

Why and How Giant Liquid Argon Observatory in Japan?

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For discovery experiment in neutrino physics

- T2K is being conducted to explore $\nu_\mu \rightarrow \nu_e$

  → talk by T.Kobayashi yesterday

- Eager to prove that $\theta_{13} \neq 0$ & measure δ_{CP}:
  - If $\nu_\mu \rightarrow \nu_e$ signal is found in T2K,

    Accelerator and **Far Detector** must be **upgraded** to measure $\boldsymbol{\delta_{CP}}$
  - If $\nu_\mu \rightarrow \nu_e$ signal is not found,

    Accelerator and Far Detector must be upgraded to continue quest with improved sensitivity by ×10

- In Japan, there is a MW-class proton synchrotron within 10 years

  → talk by K.Sakashita today

⇨ **Giant Liquid Argon Observatory** as a new **Far Detector** in **Japan**

Discovery of nucleon decay

Long baseline neutrino experiment requires highly massive main/far detector

As a consequences

Nucleon decay experiment

Research on grand unification

is also possible

⇨ **Giant Liquid Argon Observatory** for **Nucleon Decay Experiment** in **Japan**

Quest for the Origin of Matter Dominated Universe

- Lepton Sector CP Violation
  - Search for CP violation in Neutrino Oscillation Process
    - Also examine mass hierarchy of neutrinos
    - Also examine matter effect in neutrino oscillation process

- Proton Decay
  - $p \rightarrow \nu K$
  - $p \rightarrow e \pi^0$

*Non-equilibrium environment in the evolution of universe is assumed

Optimal configuration for the investigation of CP Phase δ_{CP} with Liquid Argon TPC

→ talk by K.Sakashita today

- Reason
  - Excellent ν energy resolution and reconstruction ability
    from sub GeV to a few GeV, from single prong to high multiplicity
    → Suitable for spectrum measurement with wide energy coverage
  - Excellent π^0/electron discrimination
    → Wide band On-Axis beam is tolerable
  - Neutrino intensity is finite and Energy is set（1.66MW J-PARC MR, 30GeV）
  - Results within reasonable time scale (～5years)

⇨ Spectrum measurement (1st and 2nd Oscillation Max.) with On-Axis beam with 5years ν beam run, then think next ($\bar{\nu}$?)

- Condition
  - Need long baseline(>600km) to see 2nd Osc. max, since fixed neutrino energy
  - Need On-Axis beam for wide energy coverage
  - Need gigantic detector, since finite beam flux and long baseline

⇨ 100 kton Giant Liquid Argon TPC @ Long Baseline, On-Axis

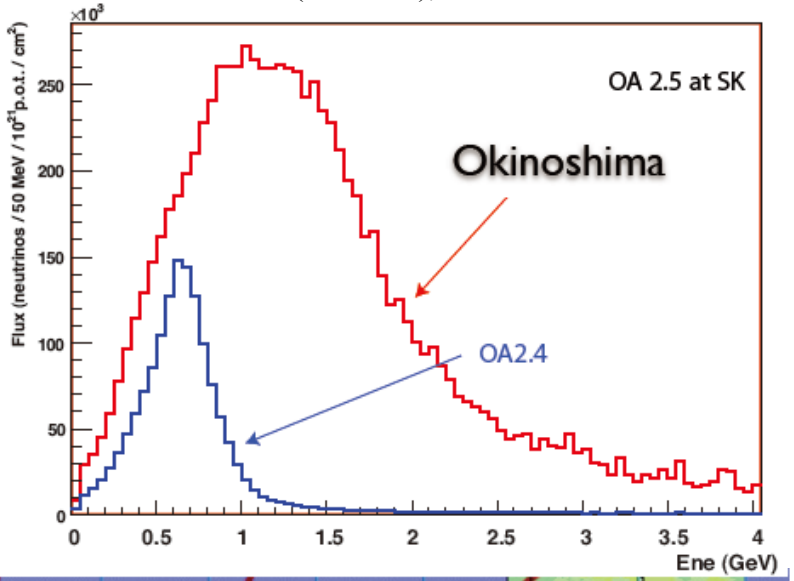
J-PARC to Okinoshima

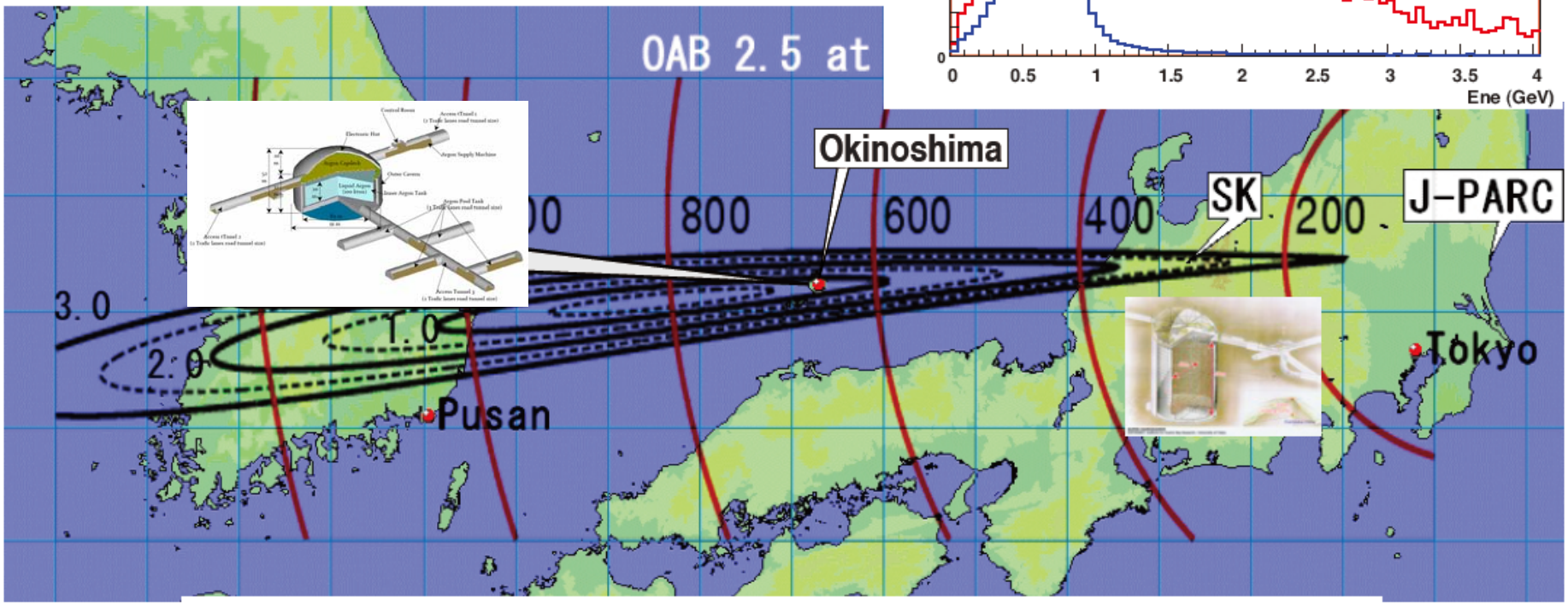
P32 proposal (Lar TPC R&D)
Recommended by J-PARC PAC
(Jan 2010), arXiv:0804.2111

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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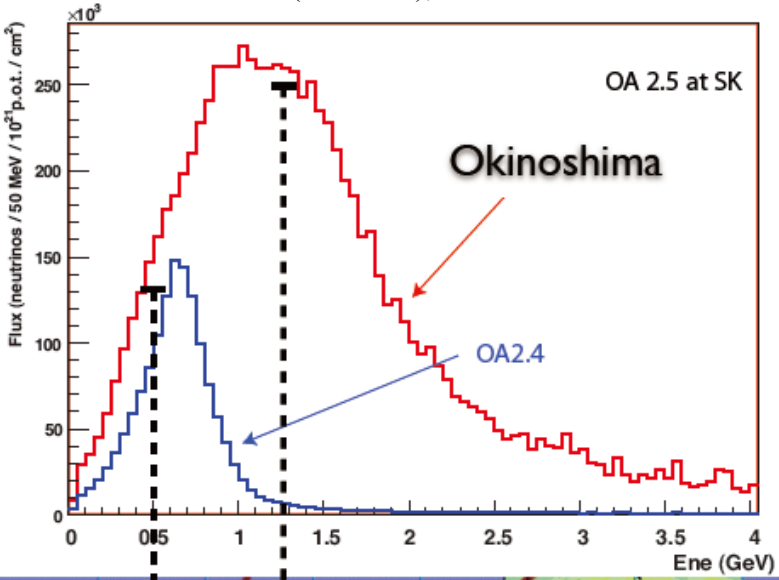
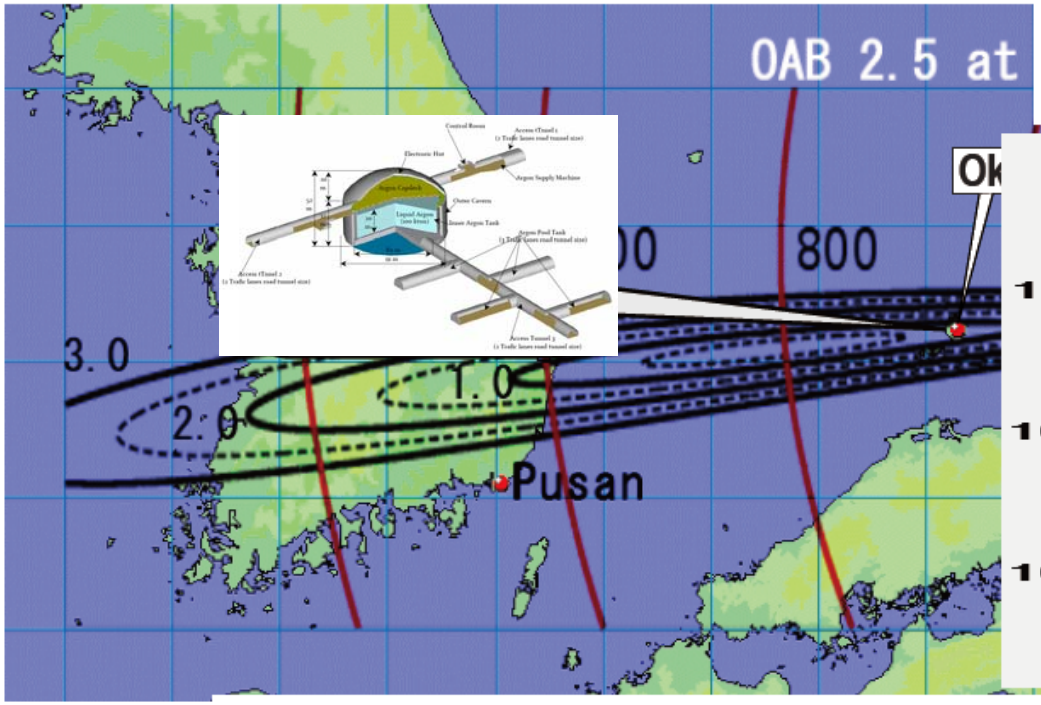
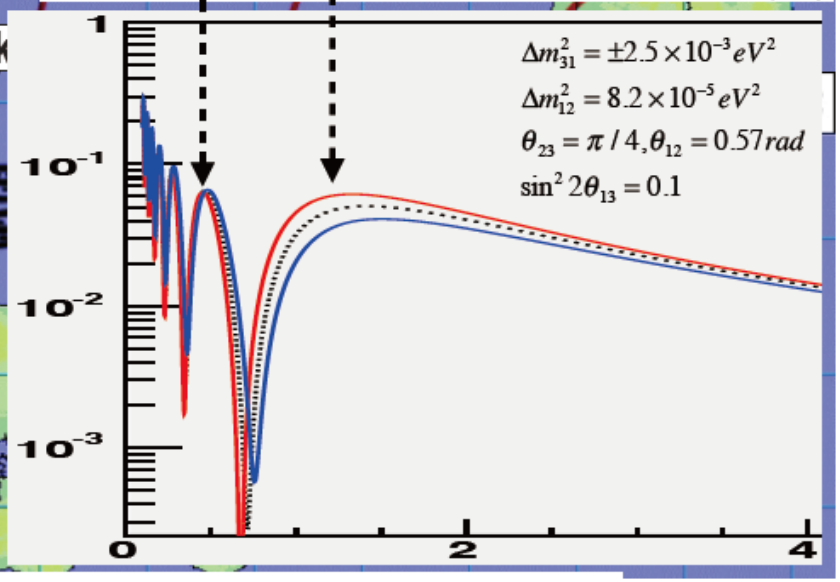




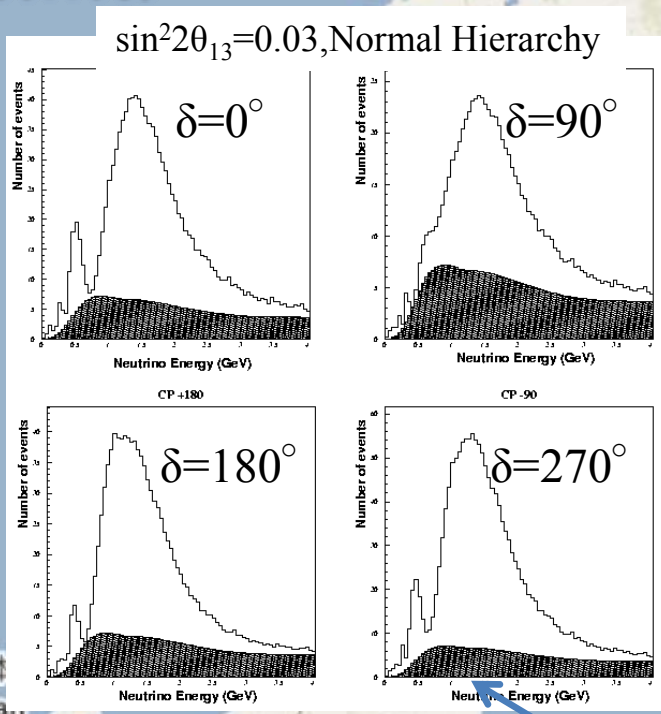


→ Extract δ_{CP} from fit of 1st & 2nd maximum

J-PARC to Okinoshima

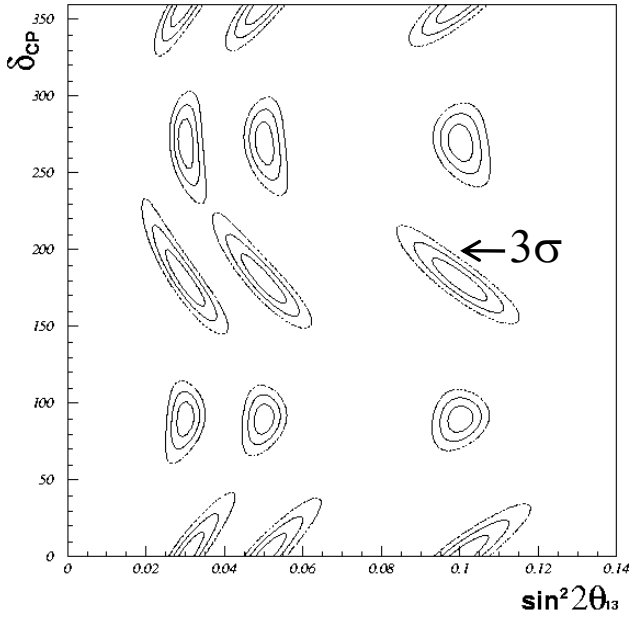
ν_eSpectrum

$\sin^2 2\theta_{13}$=0.03,Normal Hierarchy



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

CP Measurement Potential



Okinoshima

Beam ν_e Background

658km
0.8deg. almost On-axis

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

Okinoshima: Geology and Geography

ASAHI quarry

A single layer of the [illegible]

TOKUHATA No.2 q[illegible]

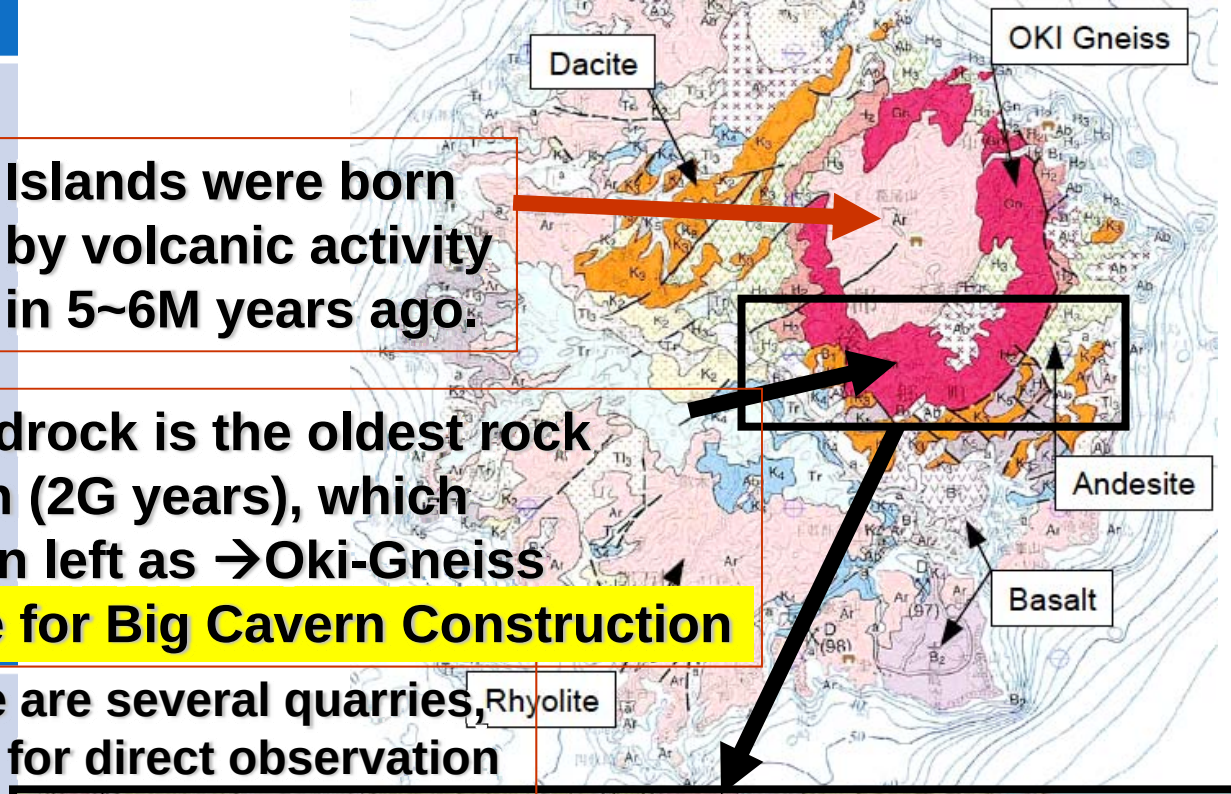
The crackle of the Igneous rock to the gneiss

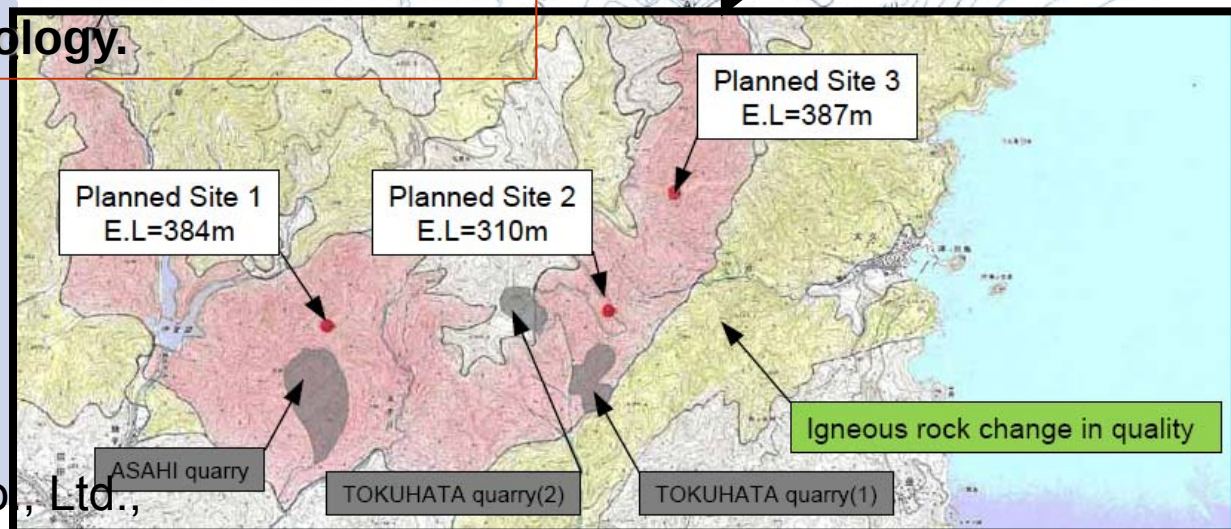
Islands were born by volcanic activity in 5~6M years ago.

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.





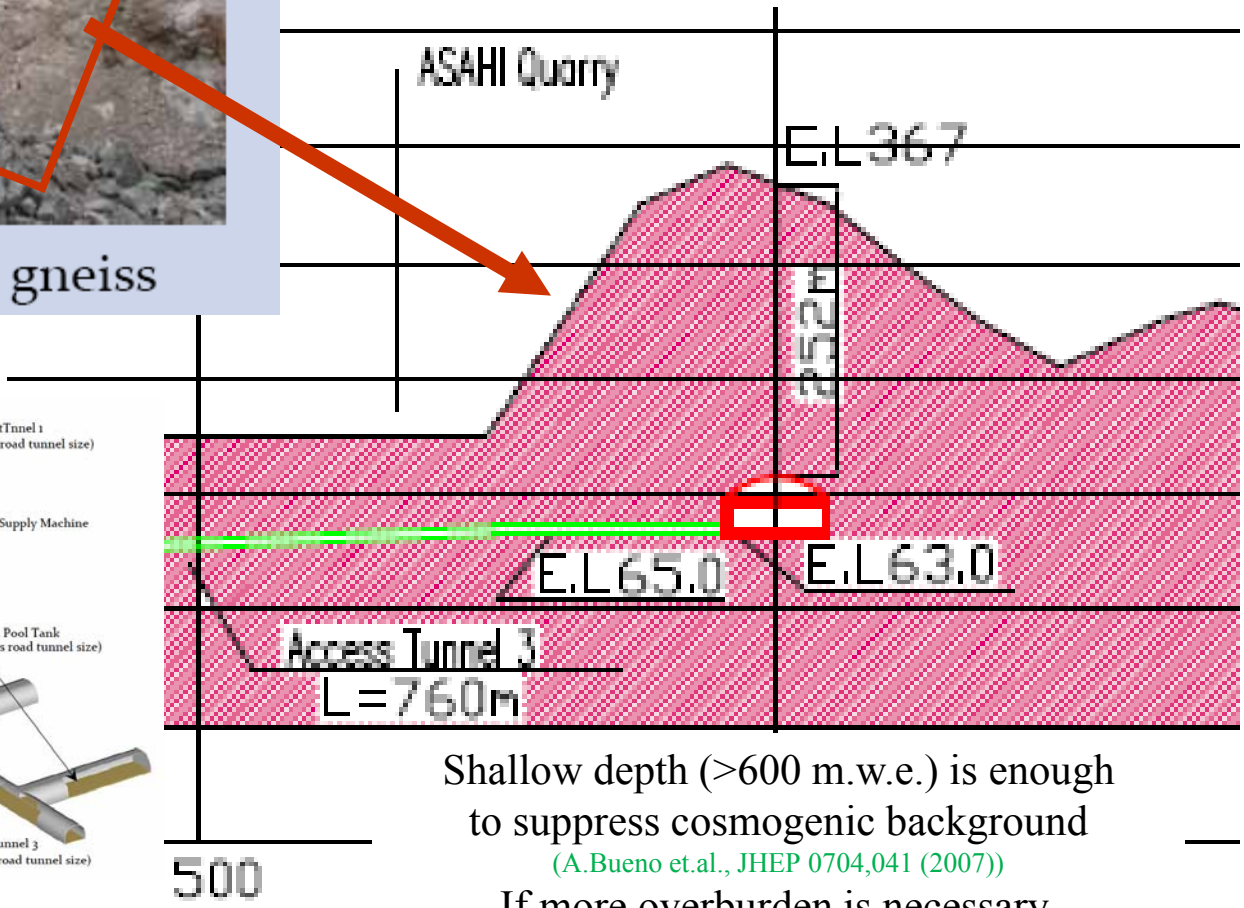
Okinoshima: Geology and Geography

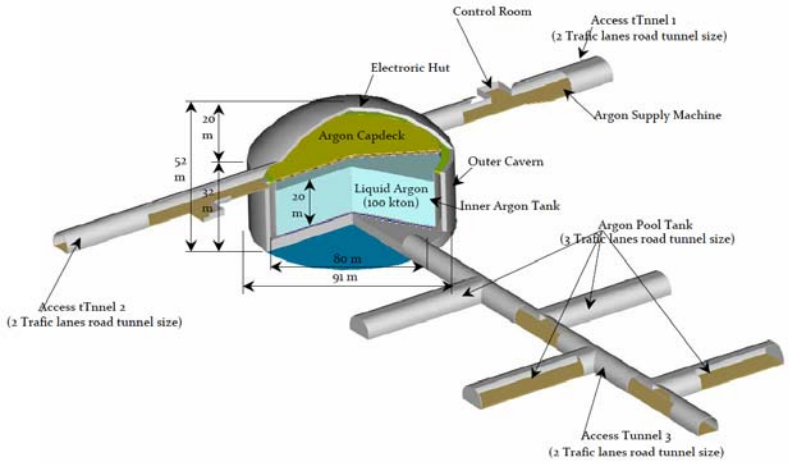
A conceptual design

Site No.1

ASAHI quarry

A single layer of the gneiss





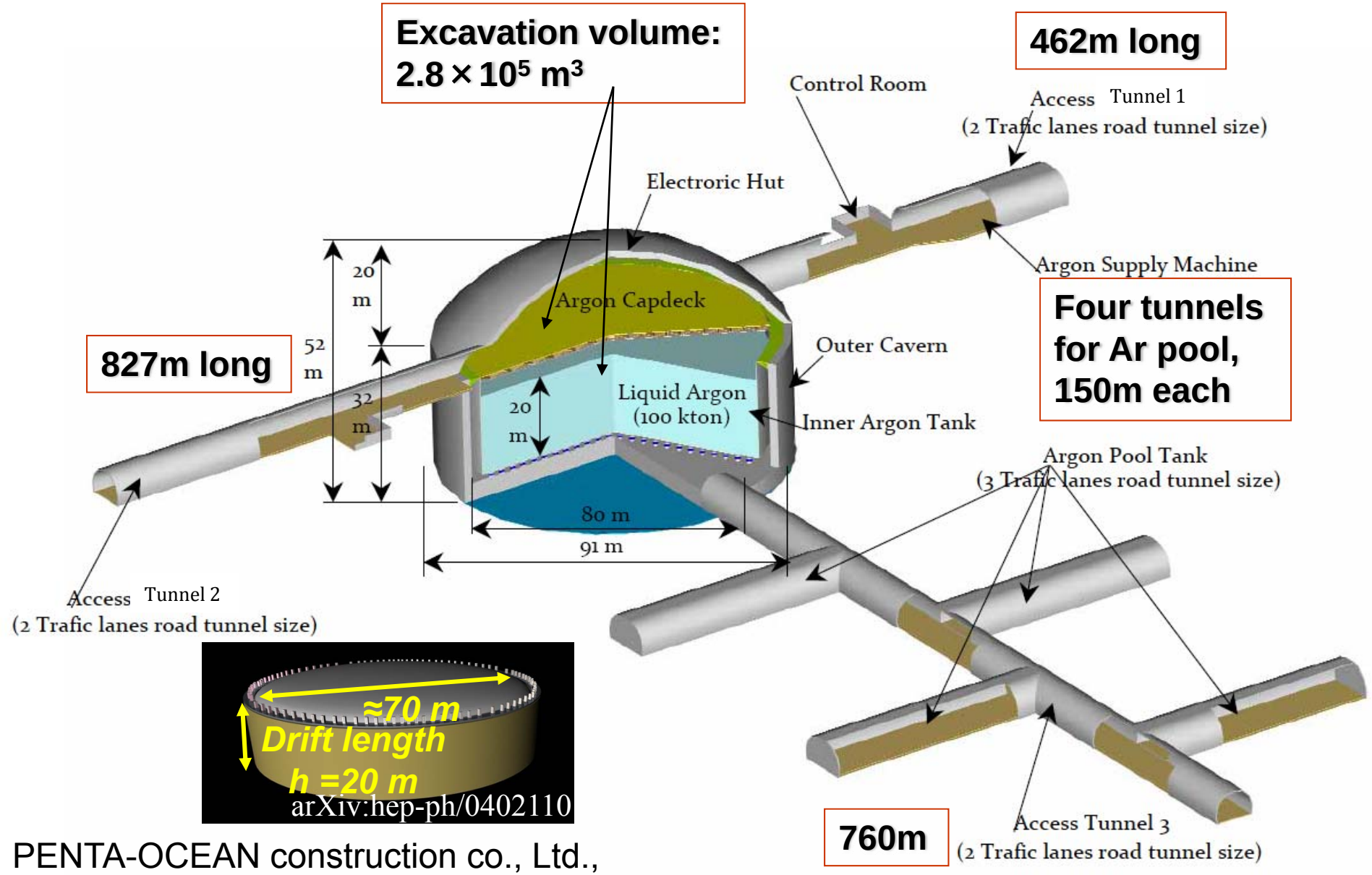
PENTA-OCEAN construction co., Ltd.,

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)

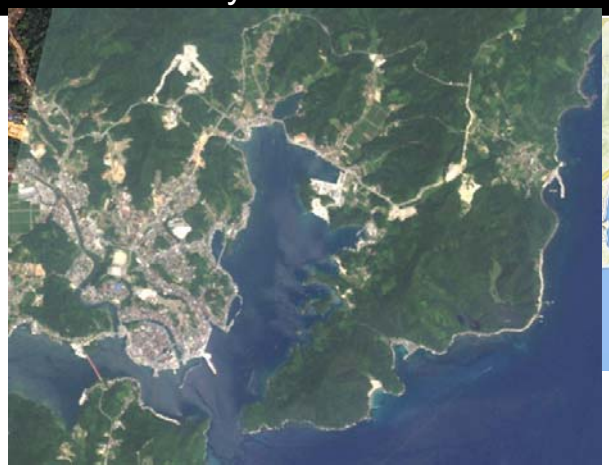


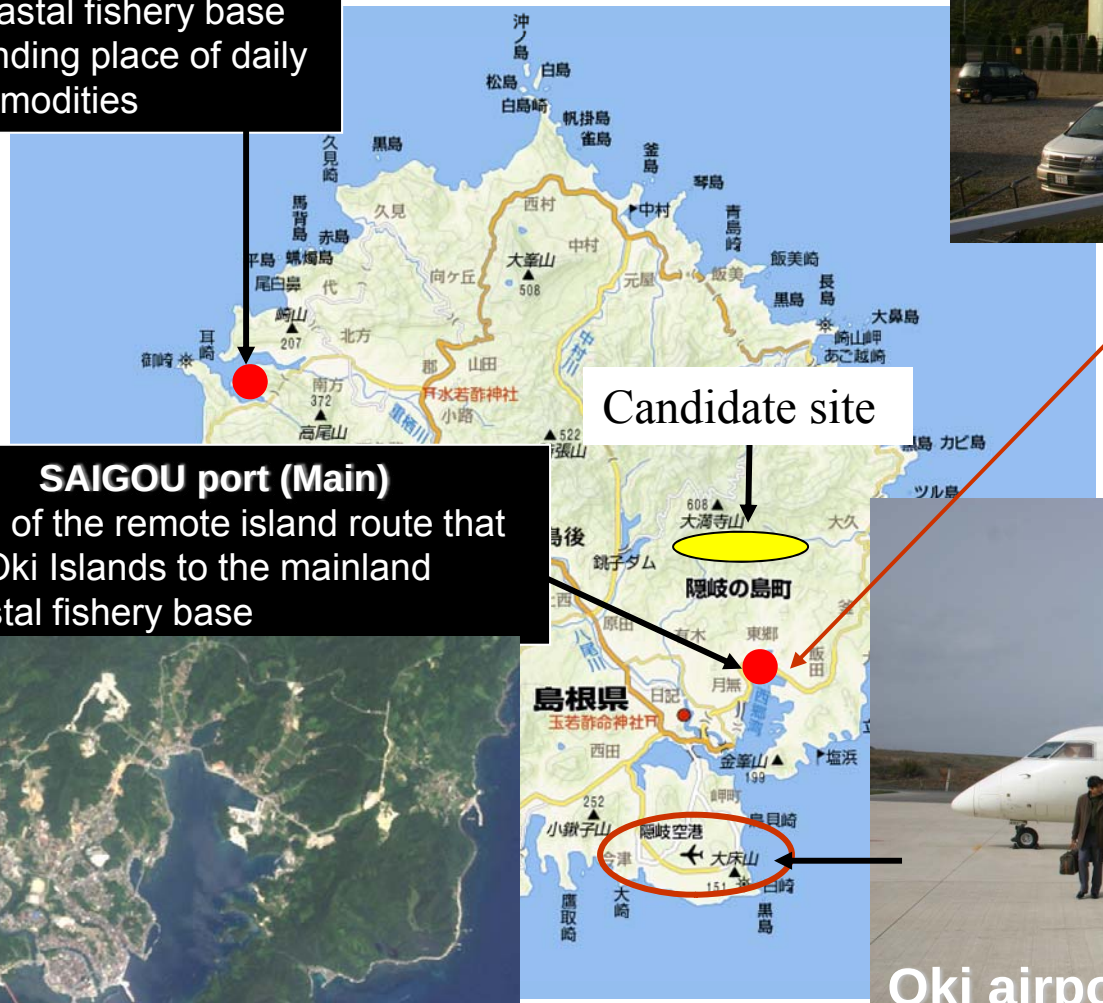
PENTA-OCEAN construction co., Ltd.,

Okinoshima: Infrastructure

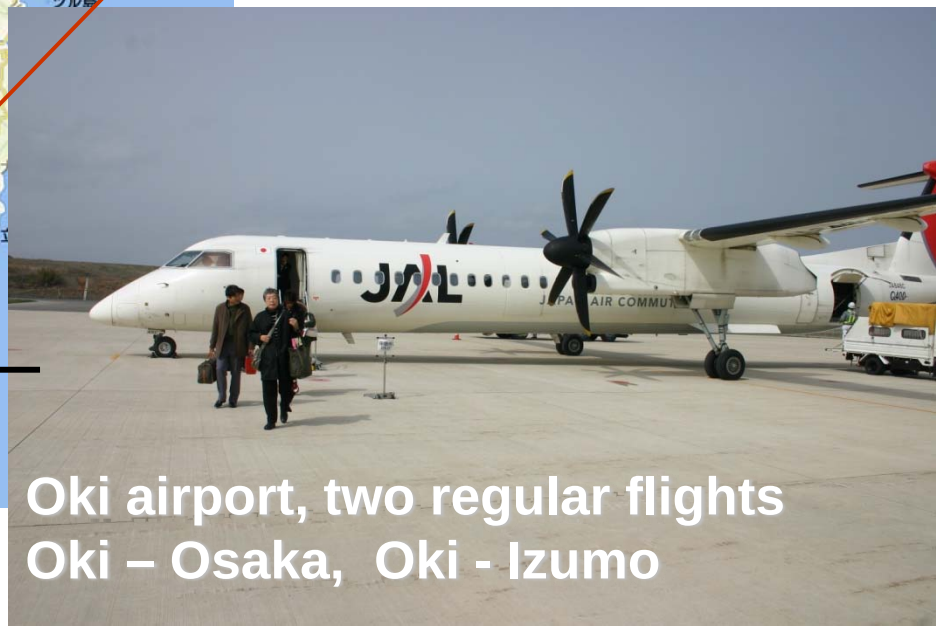
OMOSU port (local)
・Coastal fishery base
・Landing place of daily commodities

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





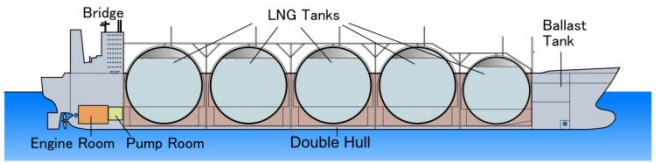
SAIGOU
Large electric power station enough for our facility



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

Okinoshima: Liquid Argon supply

LNG tanker (side view)



There isn't Cargo Ship exclusively used for Liquid Argon.

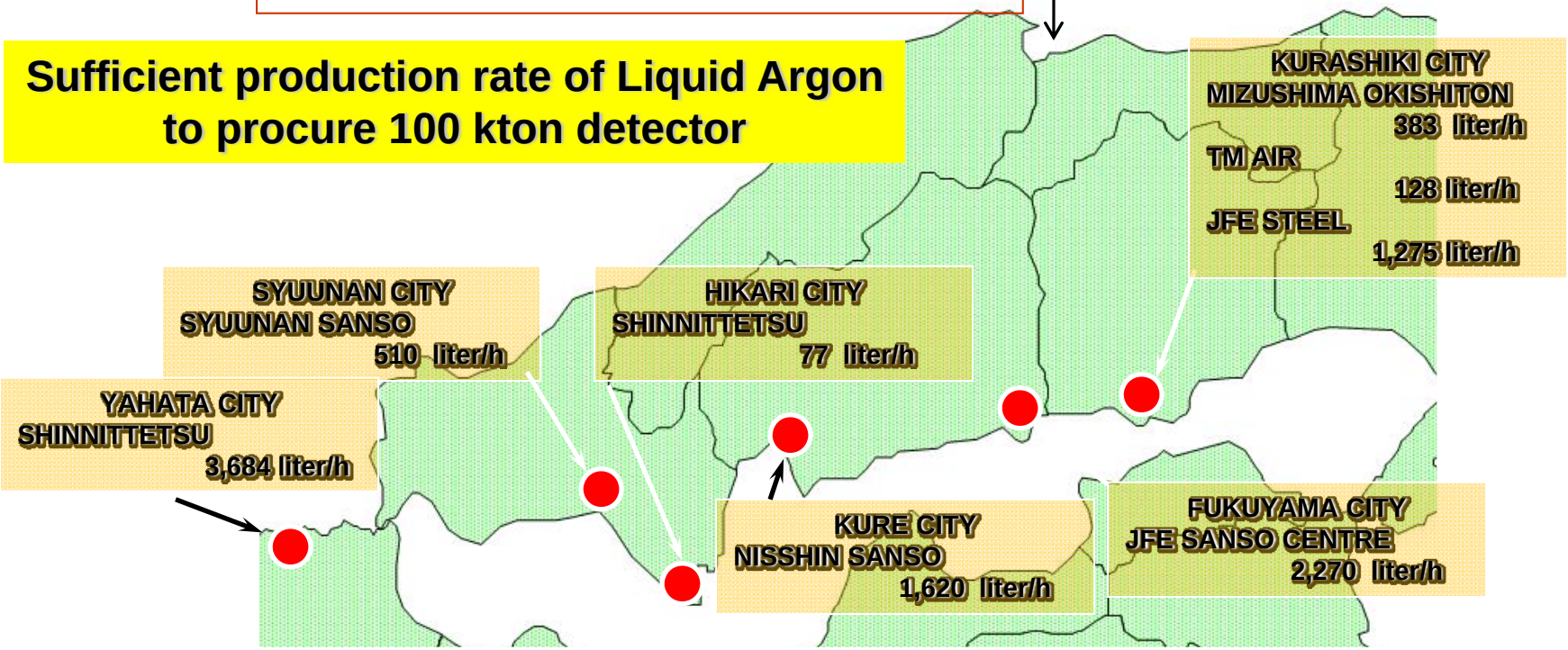
➢**Need studies how to remodel the LNG tanker.**

OKINOSHIMA

~100km

Liquid Argon production bases in CHUGOKU/KYUSHU area

Sufficient production rate of Liquid Argon to procure 100 kton detector



Towards proposal of 100 kton Giant Liquid Argon TPC

Requirements for proposal submission based on considered design

arXiv:hep-ph/0402110

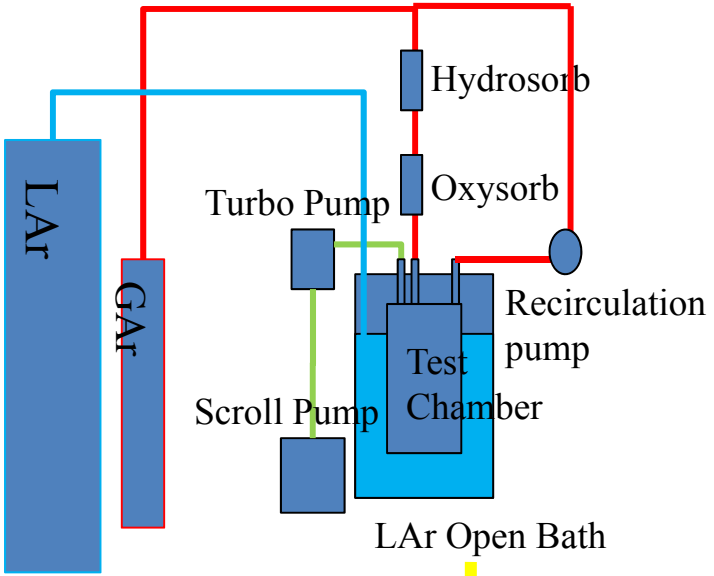
- Additional improvement of detector technology beyond ICARUS T600 ?
  - long drift distance to reduce readout channel
    → Signal amplification, Better purity, HV supply for drift system
    3L@CERN, 10L@KEK, [ArDM@CERN]*
  - Non-evacuable vessel
    → Acceptable level of purity
    [6m3@CERN]*
  - etc.

[]*: not discussed in this presentation

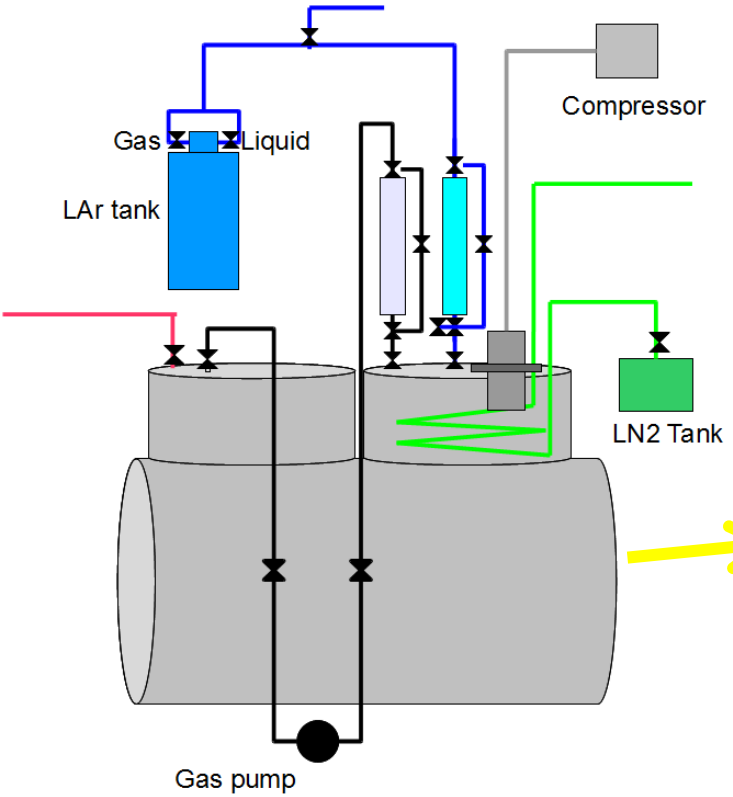
- Performance evaluation (detection efficiency, background suppression, etc.) is enough ?
  - Performance evaluation with clear objective
    e.g. 250L@KEK for J-PARC test beam
  - Final prototyping
    Level of 1 kt prototype
- Full engineering design and cost estimation ?

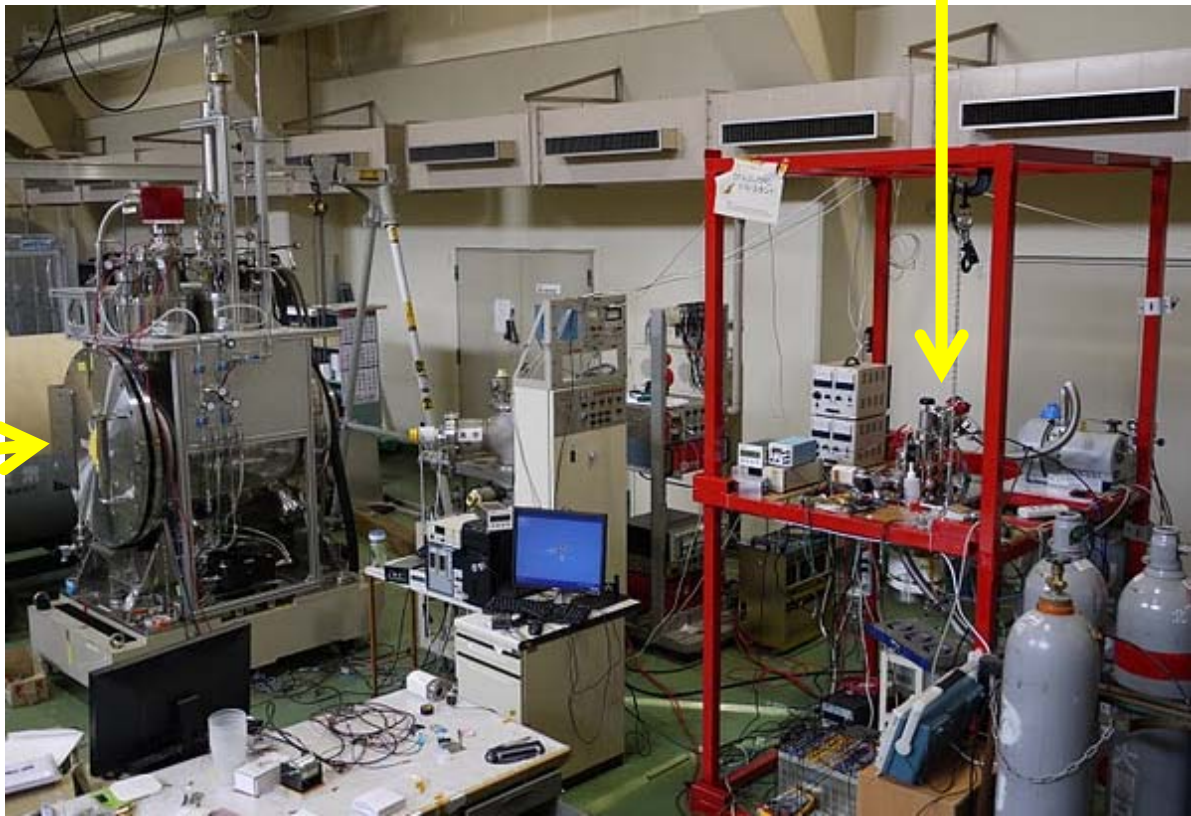
Liquid Argon TPC Lab.@KEK

10L@KEK

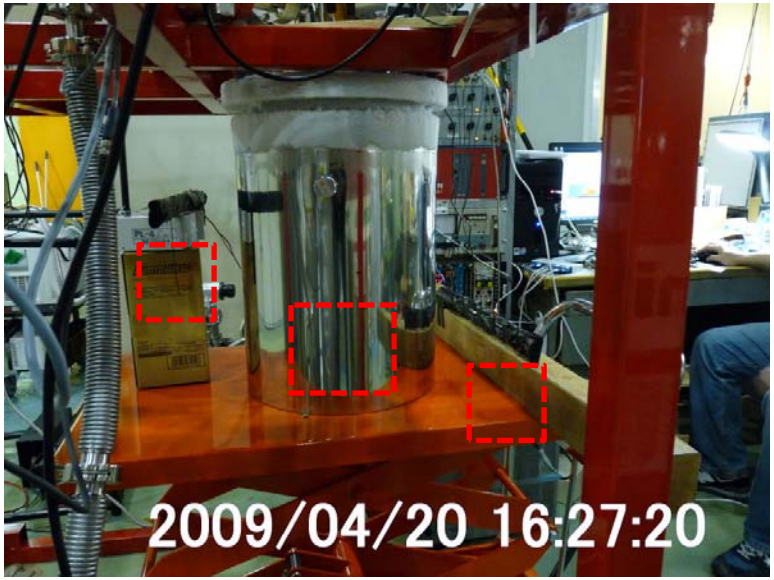


250L@KEK

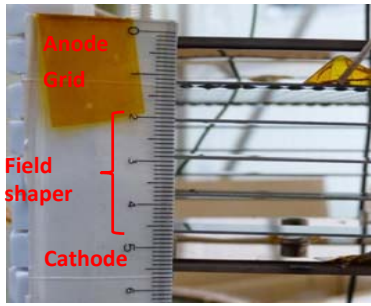


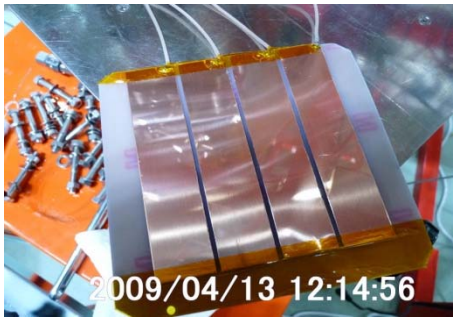


1st Liq. Ar TPC Signal with Cosmic Ray in Japan



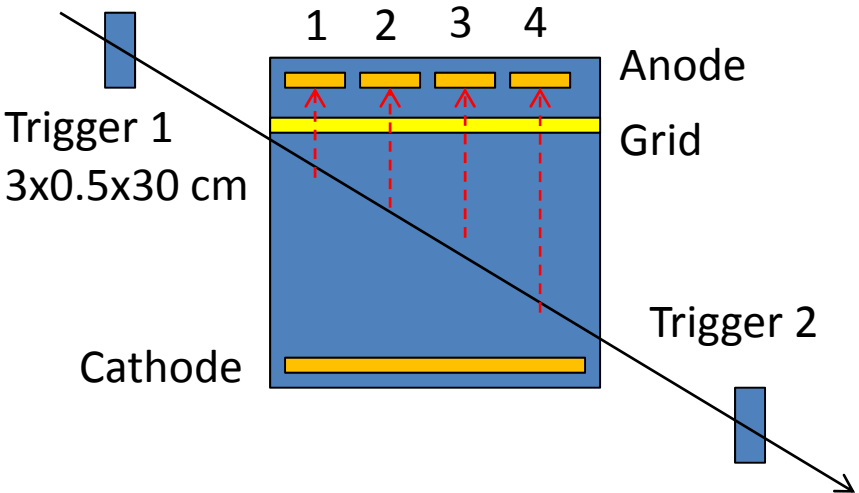
- HV setting
  - Cathode -2500 V
  - Grid -1000 V
  - Cathode-anode; 5cm
- Oscilloscope waveform
  - Ch1 is the fastest signal
  - Drift time ~20 μs

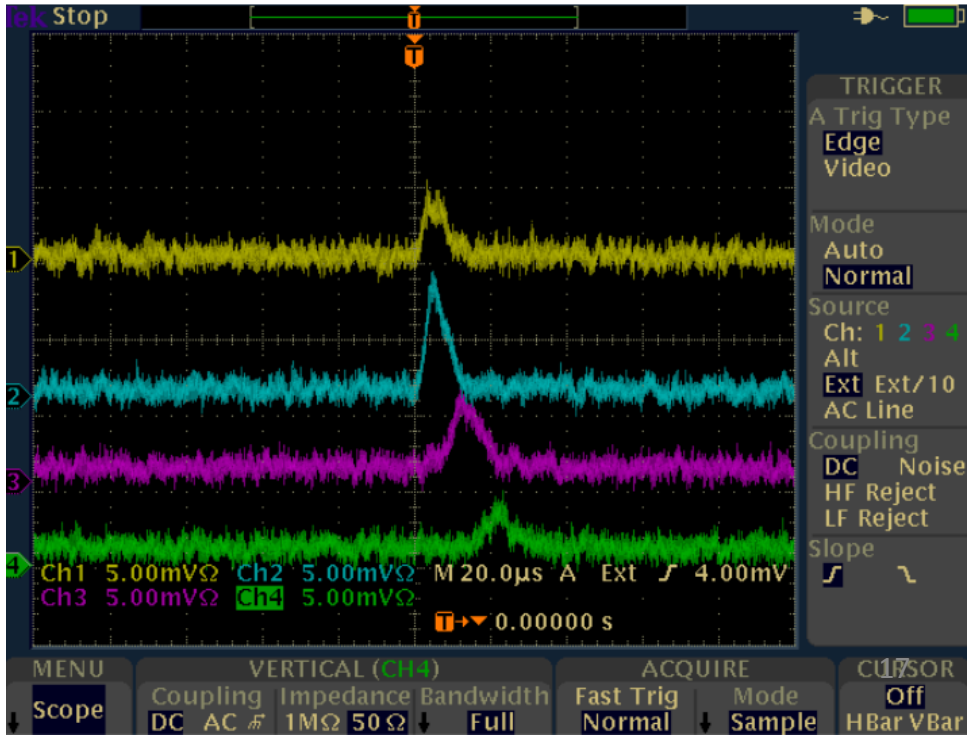




Anode: 4ch × 2.2cm × 9cm

Trigger Counter set up





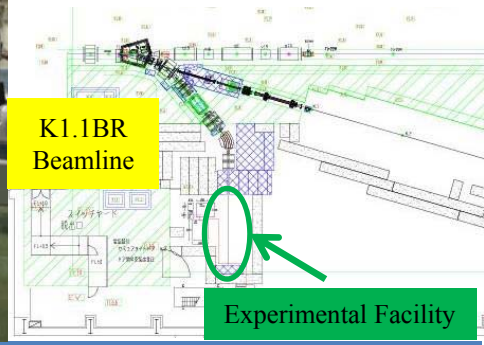
An example of performance evaluation with clear objective: 250L@KEK

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)



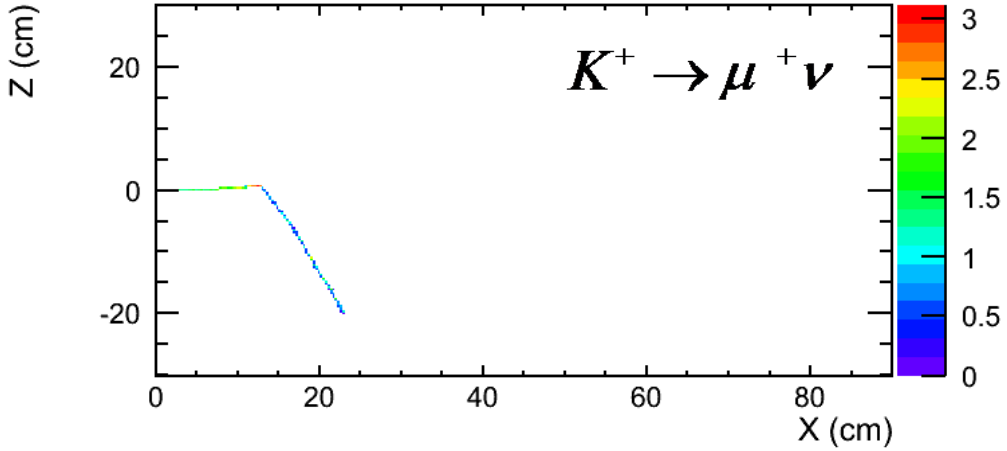
- Cryogenic vessel with beam window (originally for MEG liquid Xe calorimeter test module)
- Ultra-Vacuum established
- Cryocooler and liquid Argon filling under investigation
- Liquid Argon purification system under procurement
- Exposure to low-momentum separated K beam @J-PARC $p \rightarrow \nu K(340MeV/c\ K^+)$

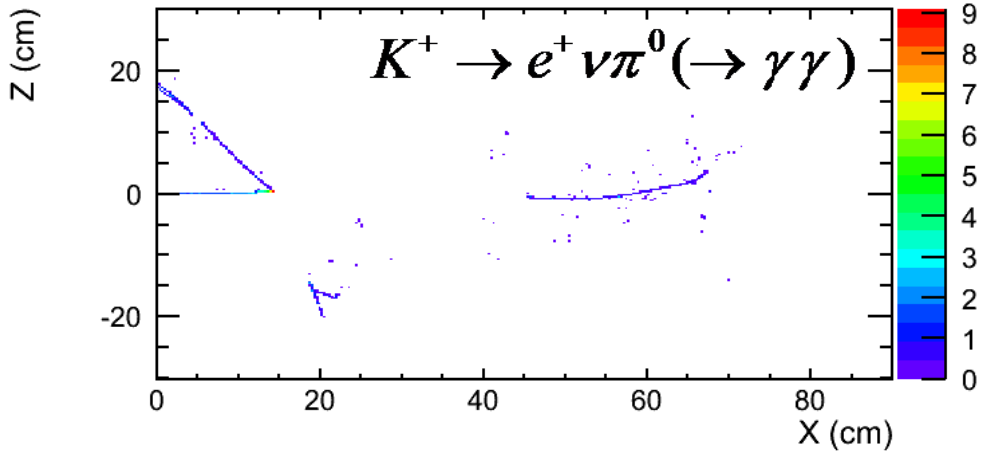
Parameters for 250L@KEK	
Fiducial mass	170 kg
Total Liquid Argon mass	～400 kg
Field cage dimensions	$42 \times 42 \times 78$ cm^3
Fiducial volume	$40 \times 40 \times 76$ cm^3
Drift field	1 kV/cm
Max. drift voltage	40 kV
Readout method	Double phase, Two view anode LEM-TPC
Readout segmentation	Two 40 $\times$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

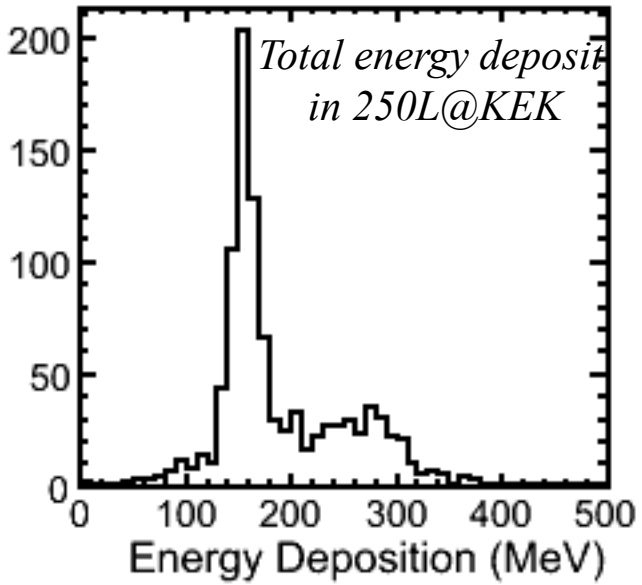
340 MeV/c K^+ ($p \rightarrow K\nu$) in 250L@KEK

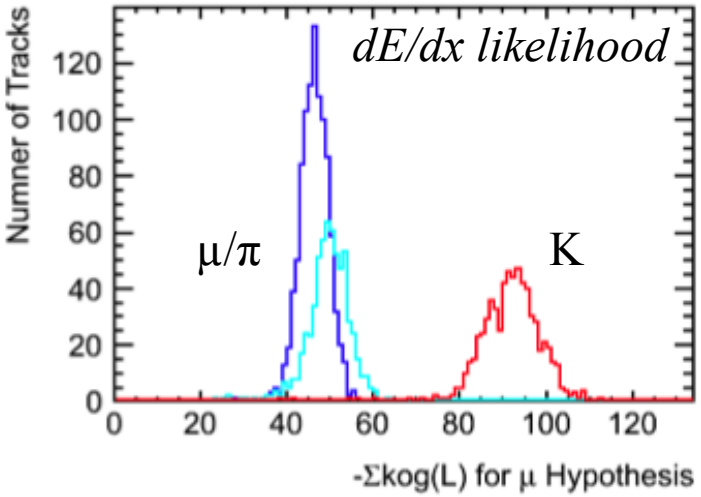
- >90% of slow kaons stop in detector with range ≈10cm (others decay in-flight)
- Many soft decay products are contained
- dE/dx analysis can be performed for particle ID

First beam exposure in October 2010

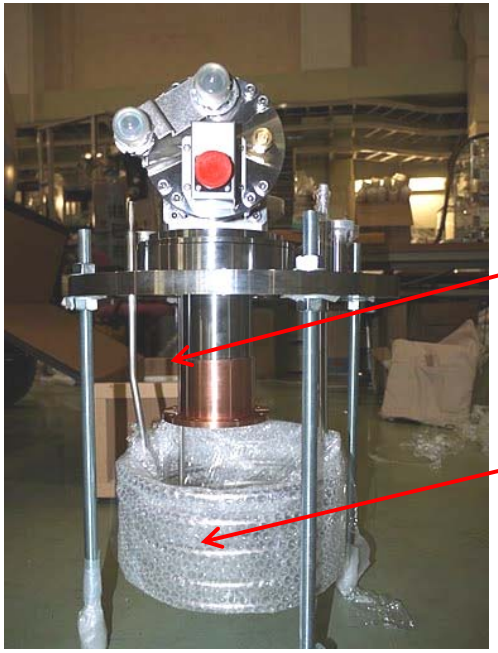


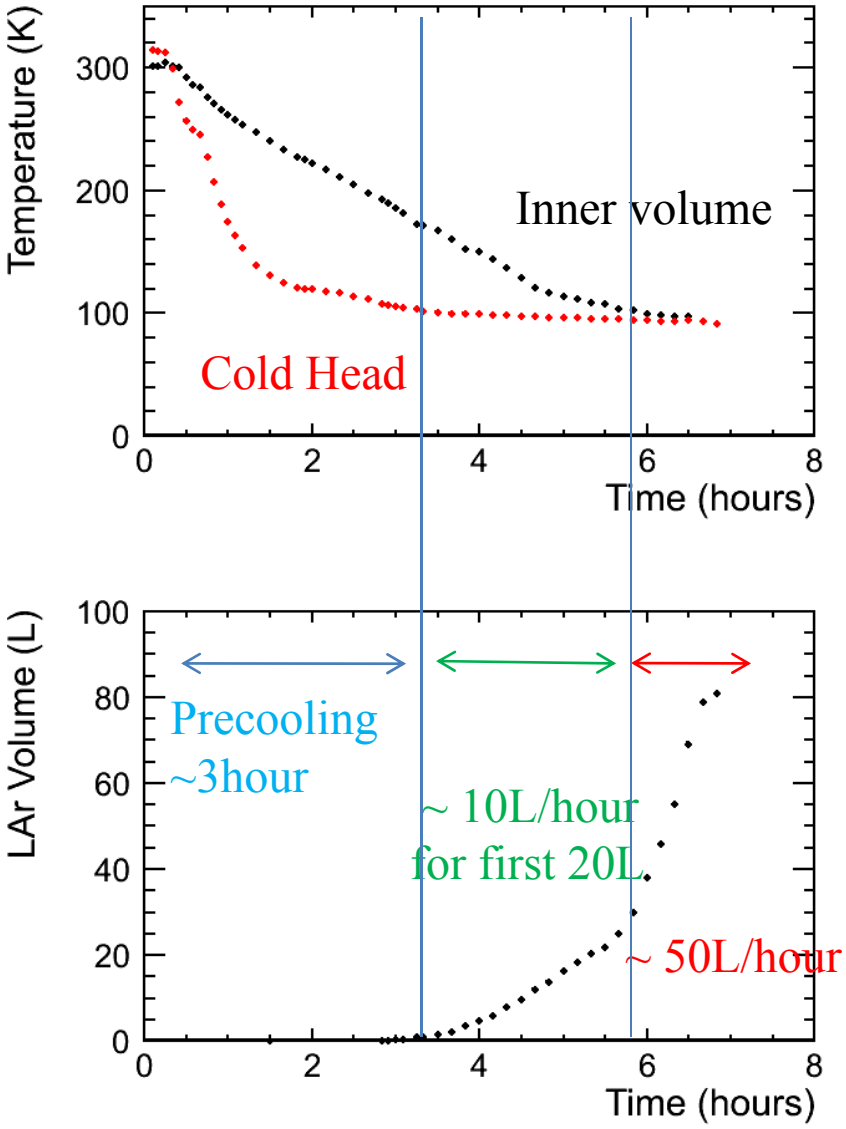






250L@KEK: Cryogenics

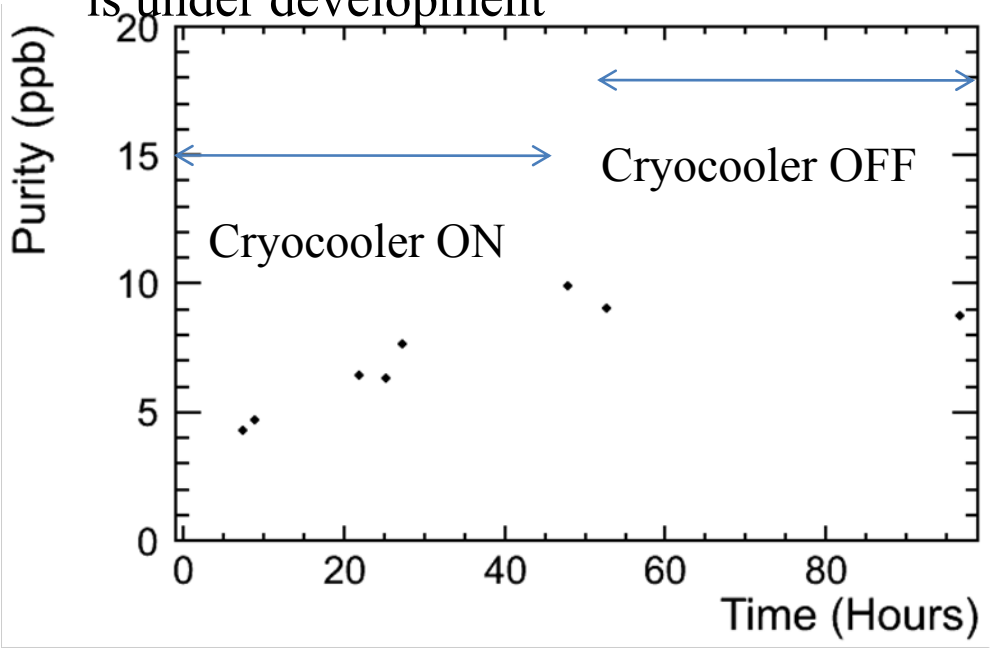


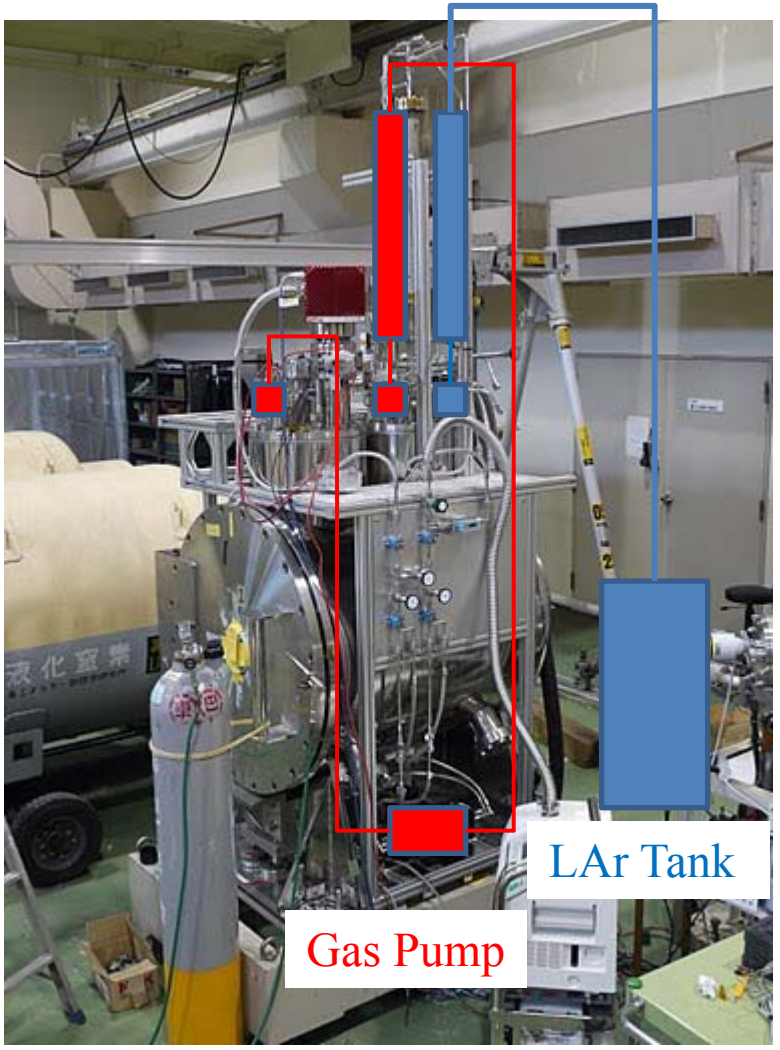


- Heat input of 250L cryostat: ~ 30W
- GM Cryocooler (~150W)
  - For normal operation
- LN_2 heat exchange coil (~500W)
  - Additional cooling equipment for pre-cooling, filling, and recirculation for purification
- Successful filling of the vessel
  - ~ 3 hours for pre-cooling
  - 7 hours for 100L filling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

250L@KEK: Purification

- Purification @ initial filling
  with purification filter
  (Activated Cu + Molecular sieve, possible to regenerate)
  - Initial purity after filling
    ~ 3ppb (~ 15 cm eq. of drift electron att. length)
  - ~3ppb/day purity degradation is observed
    (No degradation if cryocooler is OFF)
- Purity improvement with
  gas recirculation + high spec. purification filter
  is under development



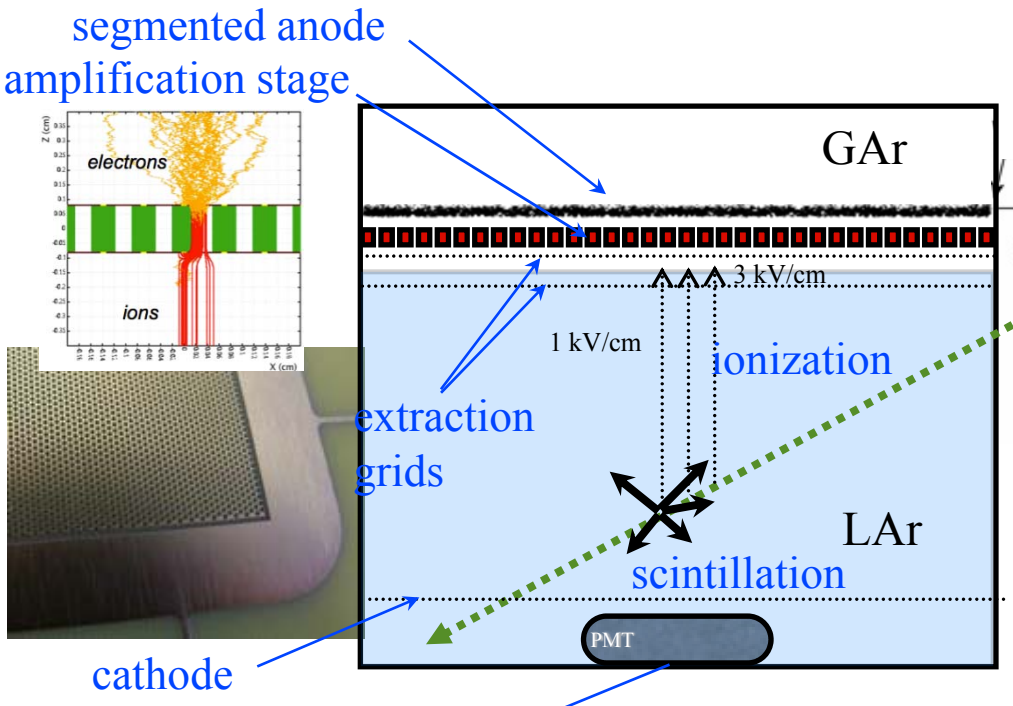


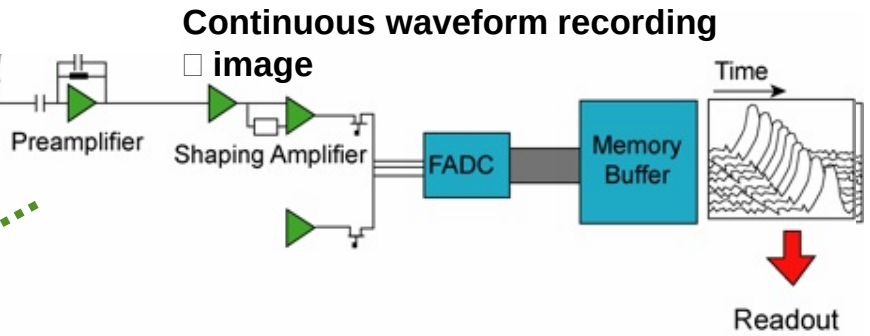
The new LAr LEM-TPC

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

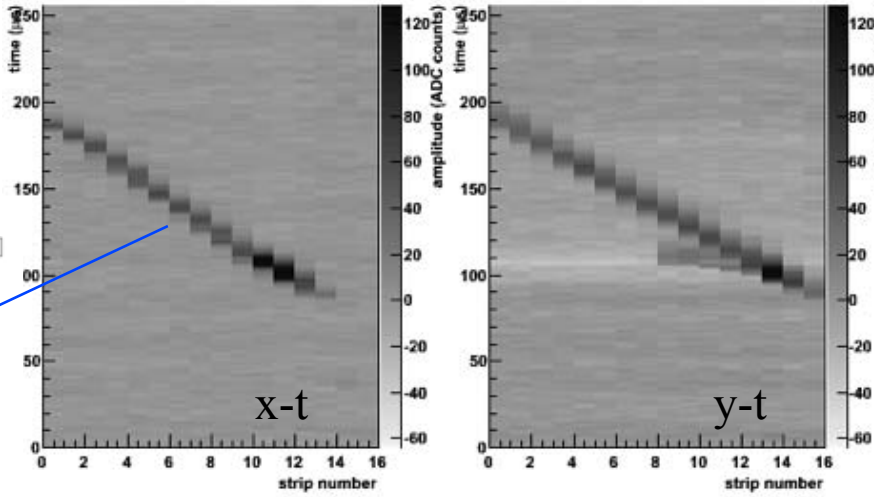
Motivated by the very long drift path needed in giant detectors and DM applications (keV detection)

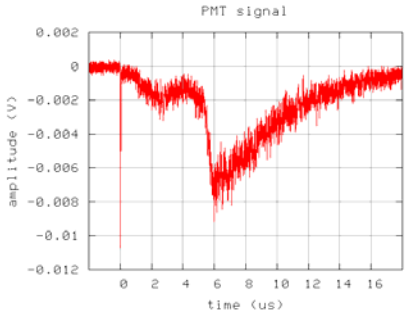
hep-ph/0402110, arXiv:0811.3384, NIM A617(2010)188, J.Phys.Conf.Ser.171:012020,2009, arXiv:1001.0076

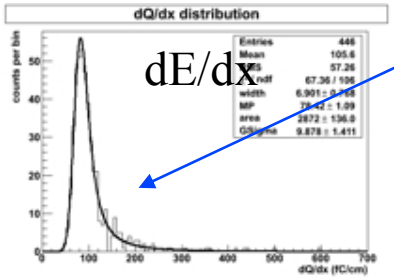




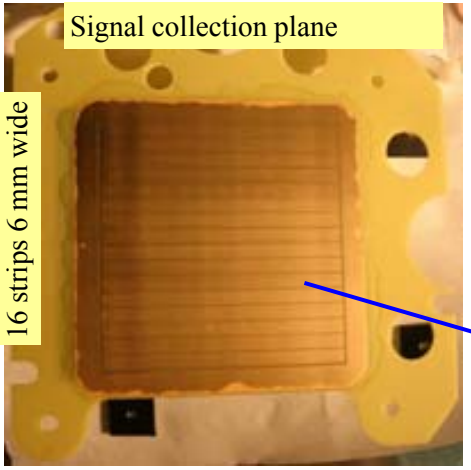
Cosmic tracks in 3 lt prototype (G≈6):

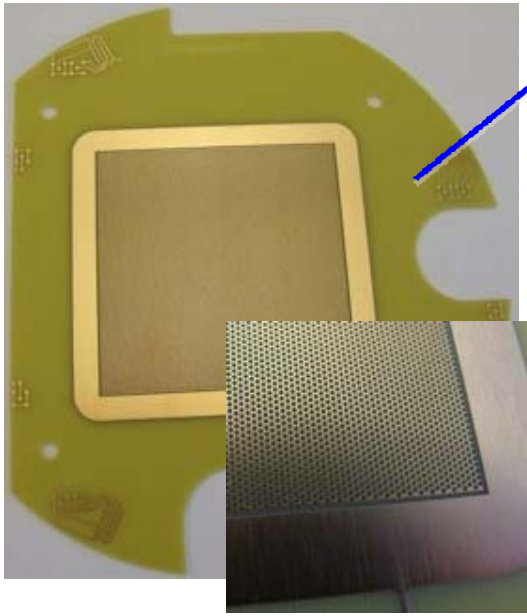




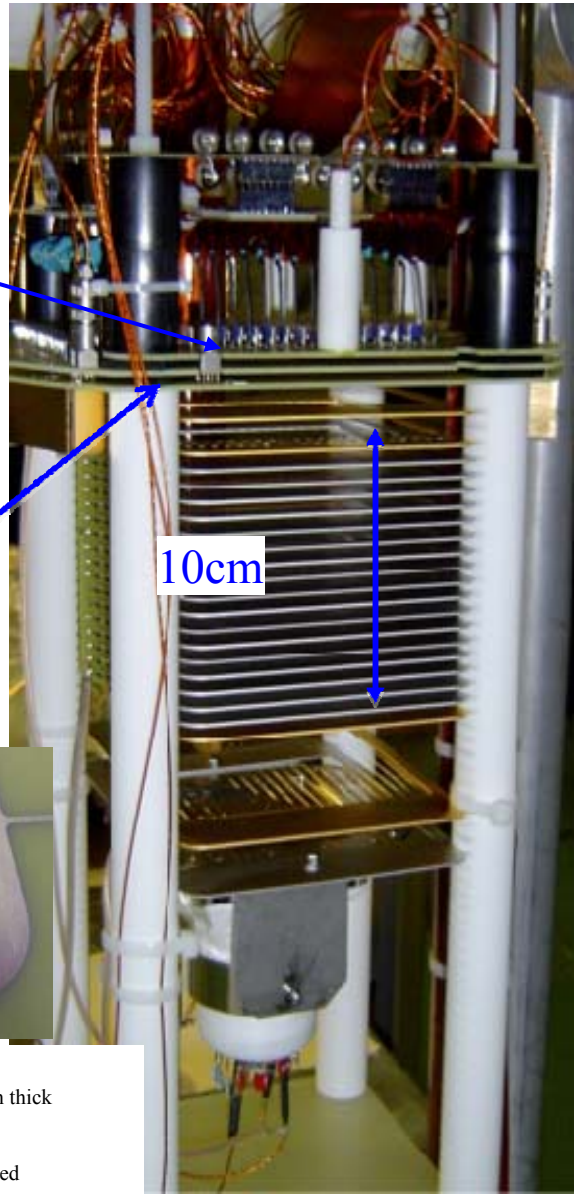


LAr LEM-TPC 3L@CERN

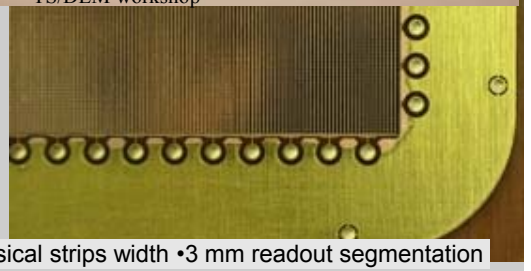




100 x 100 mm² test setup



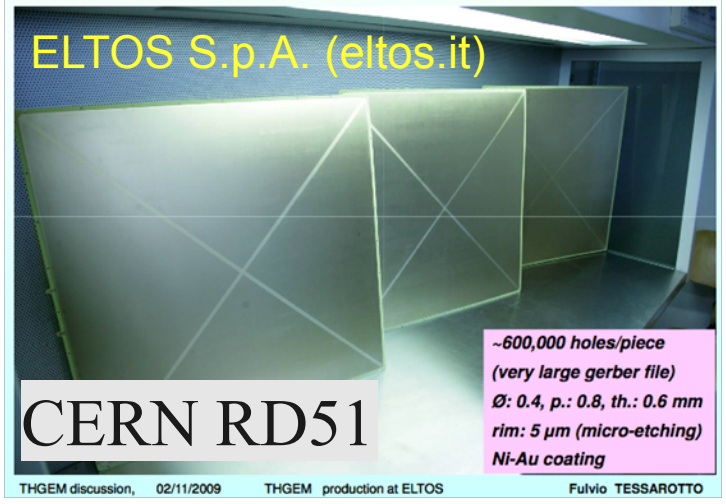
X-Y projective anode (NEW)



600 µm physical strips width •3 mm readout segmentation

- Produced by standard PCB technique
- Double-sided copper-clad (18 µm layer) FR4 plates, 1.6 mm thick
- Precision holes made by drilling
- Gold deposition on Cu (<~ 1 µm layer) to avoid oxidization
- HV decoupling (cryo-) capacitors & surge arrestors embedded

600 x 600 mm2 THGEM protoypes

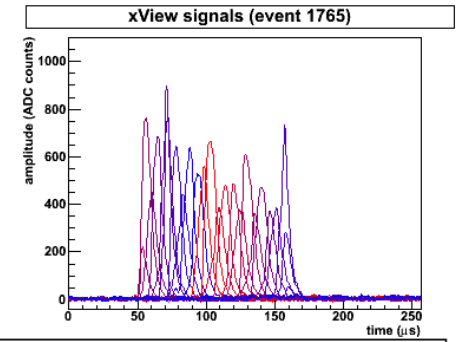


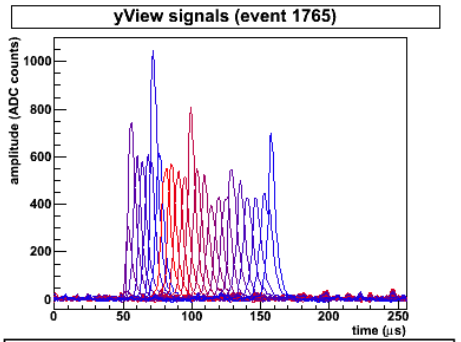
Cosmic tracks in 3L@CERN with new two view anode

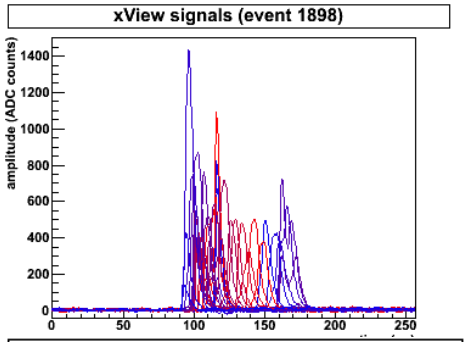
Two view anode

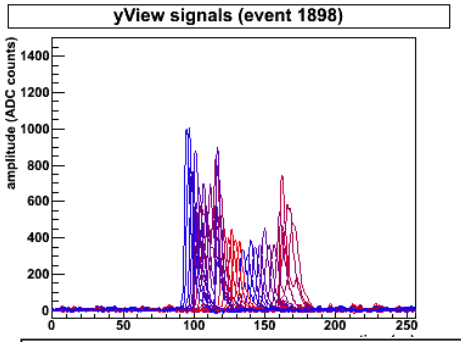
- Decouple the amplification and the readout stages
- The charge is equally shared between X and Y strips
- Same signal shape of both coordinates

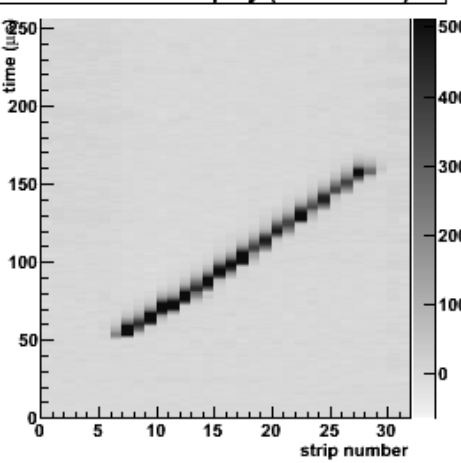
- Double phase (1.0 bar, 87K)
- Single stage LEM amplification
- Two view anode charge readout (3mm pitch)
- O_2 contamination: ~2ppb
- Gain: ~25

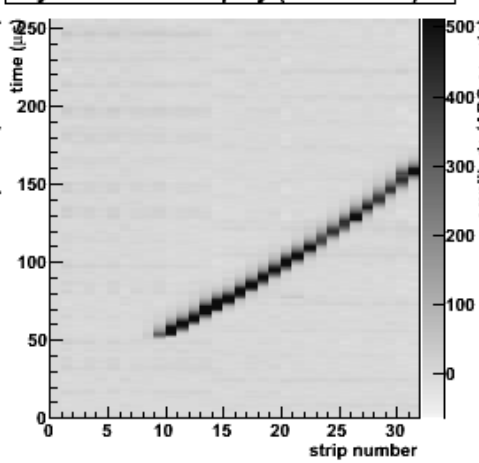


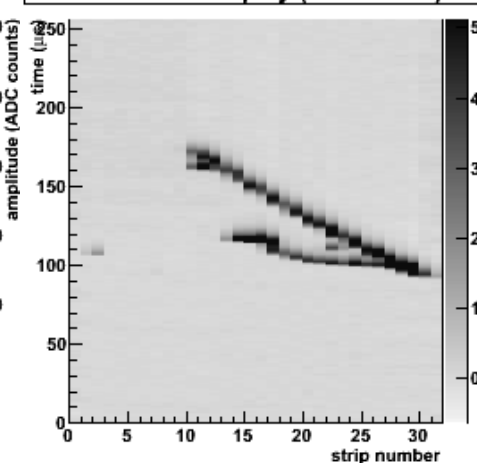


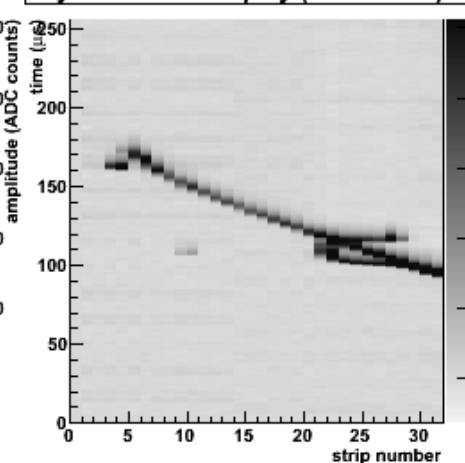












Conclusion

- Strong physics case for

  New long baseline experiment with expected J-PARC beam

  and to

  Search for nucleon decay

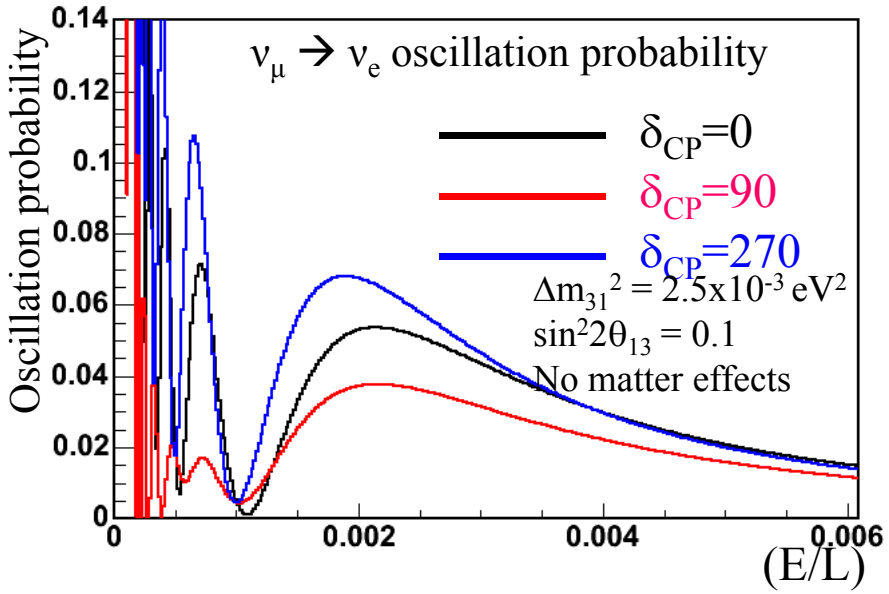
  with

  Giant Liquid Argon Observatory in Japan

- What's important to realize the project
  - J-PARC MR towards MW-Class power frontier machine
  - Successful R&D and performance evaluation with clear objective towards realization of Giant Liquid Argon TPC
  - Decision should be based on T2K results on $\nu_\mu \rightarrow \nu_e$

Lepton Sector CP Violation

Effect of CP Phase δ appears 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

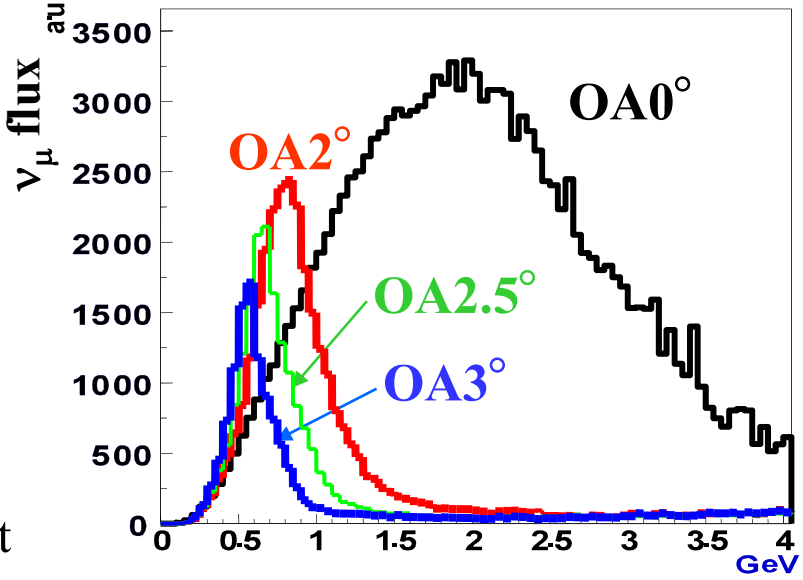
– Difference between ν_e and $\bar{\nu}_e$ Behavior

*Need both ν and $\bar{\nu}$ experiments (different systematics, low $\bar{\nu}$ event rate)

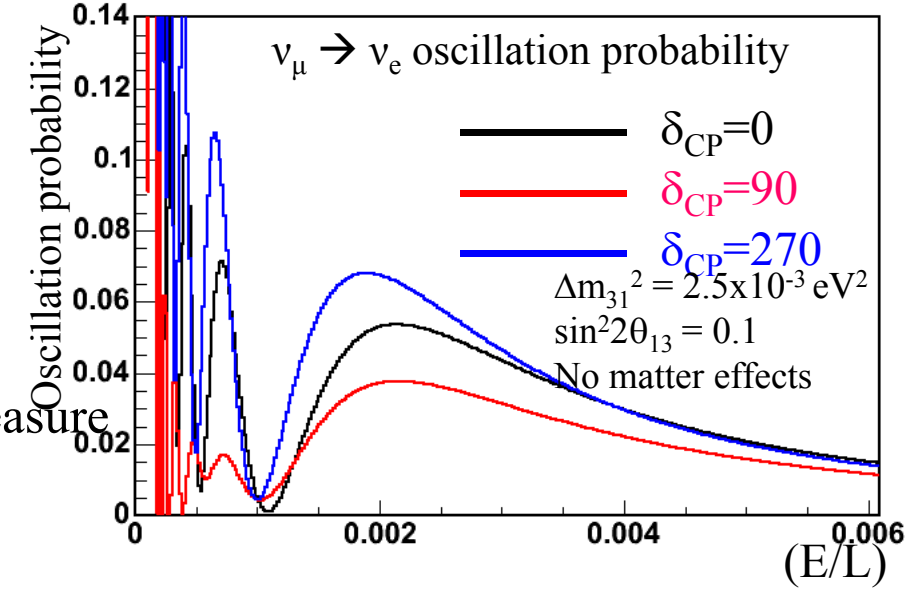
Angle and Baseline

- Angle w.r.t On-Axis
  - 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

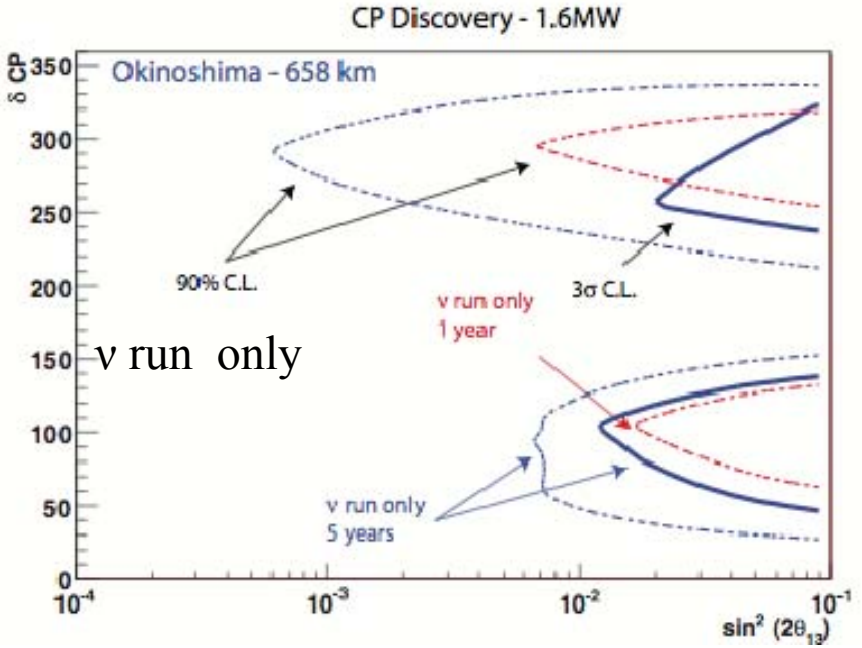


- Baseline
  - Long:
    - ○ 2nd Osc. Max. at Measurable Energy
    - × Less Statistics
    - ? Large Matter Effect
  - Short:
    - ○ High Statistics
    - × 2nd Osc.Max.Too Low Energy to Measure
    - ? Less Matter Effect

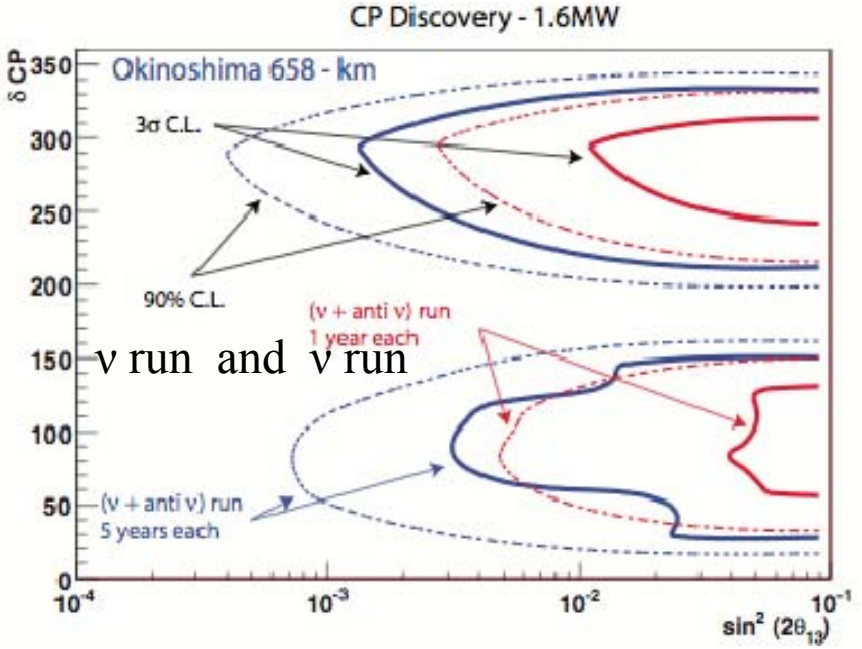


J-PARC to Okinoshima

CP Discovery potential



ν run only



ν run and ν̄ run

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	$\bar{\nu}_\mu$ CC	$\bar{\nu}_e$ 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

* ×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 $\delta\sin^2 2\theta_{13}\approx\pm 0.01$ 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

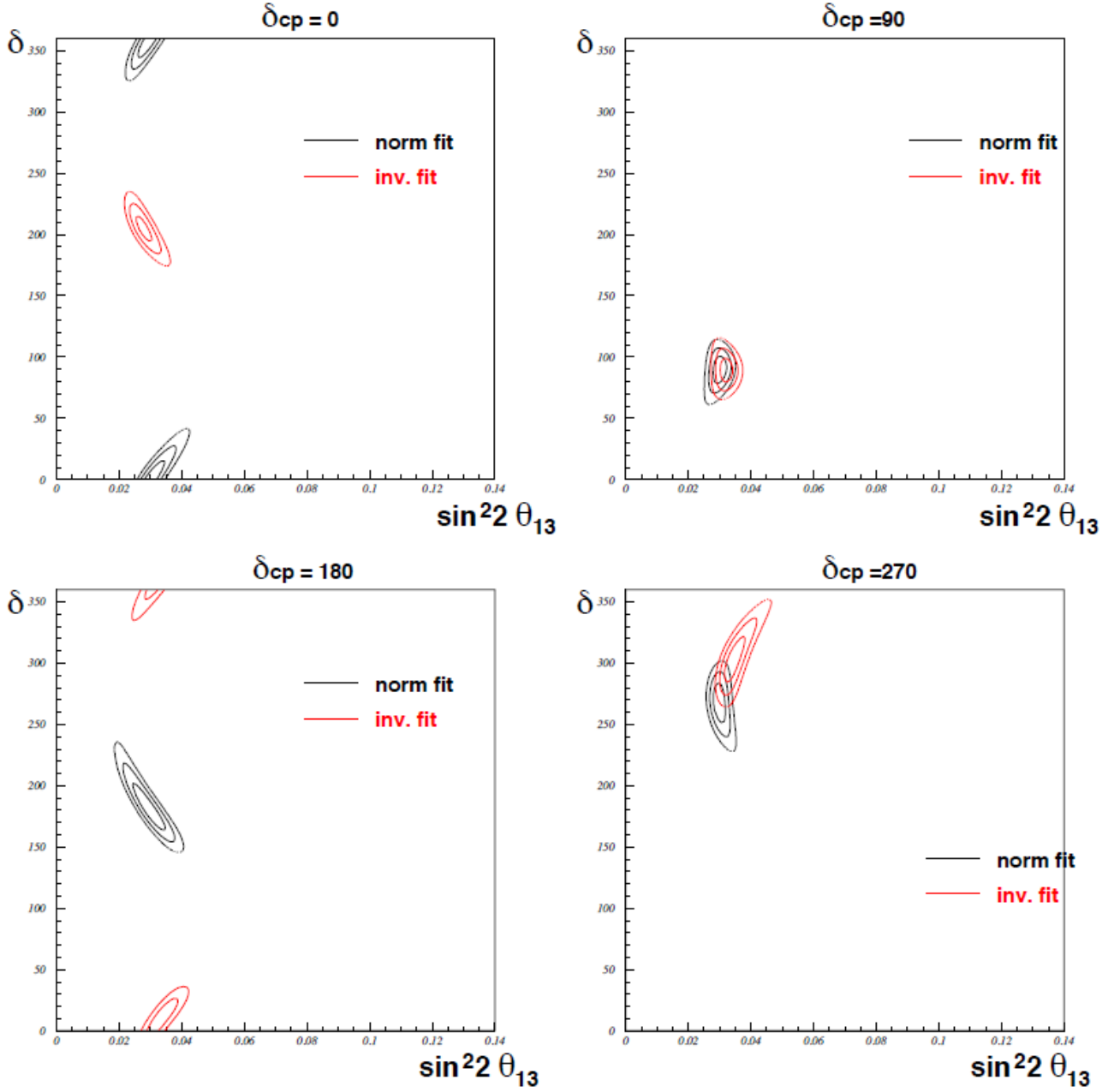


Fig. 7: Mass hierarchy investigation with neutrino run only. If fits with both hierarchy hypotheses provide neither 0 nor 180°, one can declare discovery of CP violation in the leptonic sector. If any of the fits results in a δ_{CP} of 0 or 180°, then an anti-neutrino run could be envisaged.

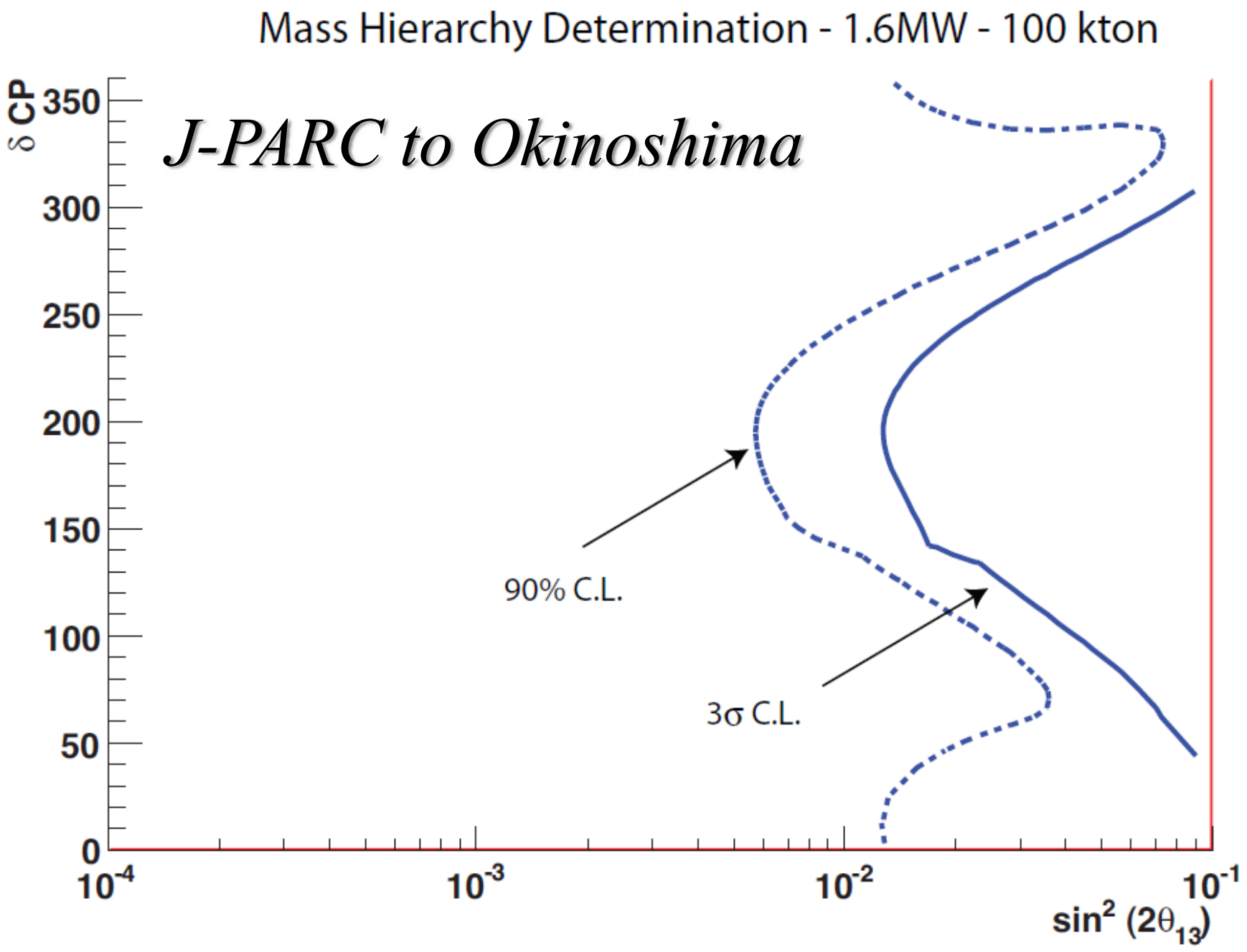


Fig. 10: Mass hierarchy discrimination at 90%C.L. and 3σ for 5+5 years neutrino-antineutrino runs.

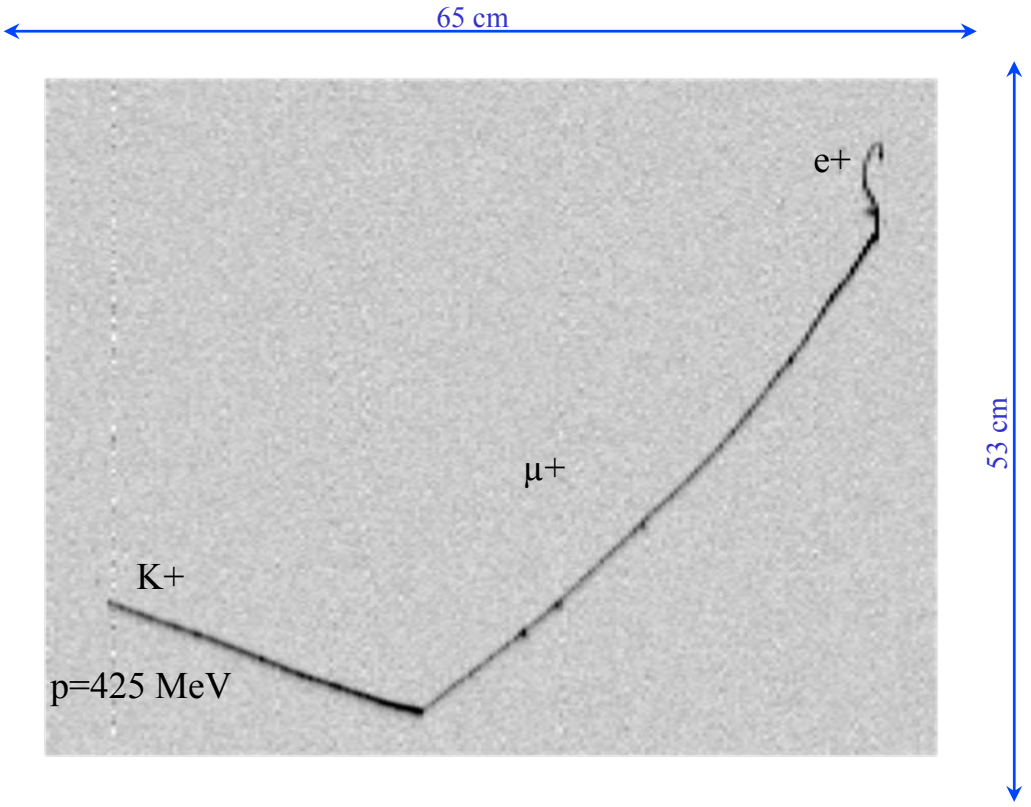
Discovery of nucleon decay

- High quality tracking information, high energy resolution, low particle energy detection energy threshold

  → Background free measurement for several decay modes

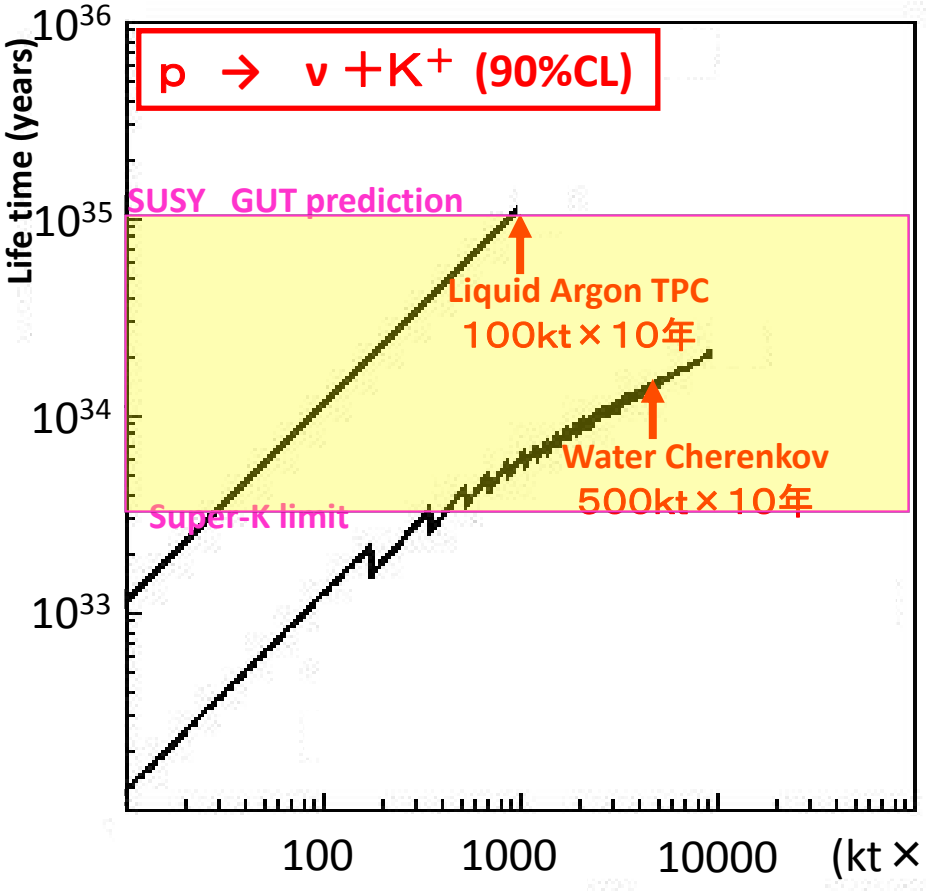
- Possible to explore 10^{34}-10^{35} years life time within 10 years for several decay mode

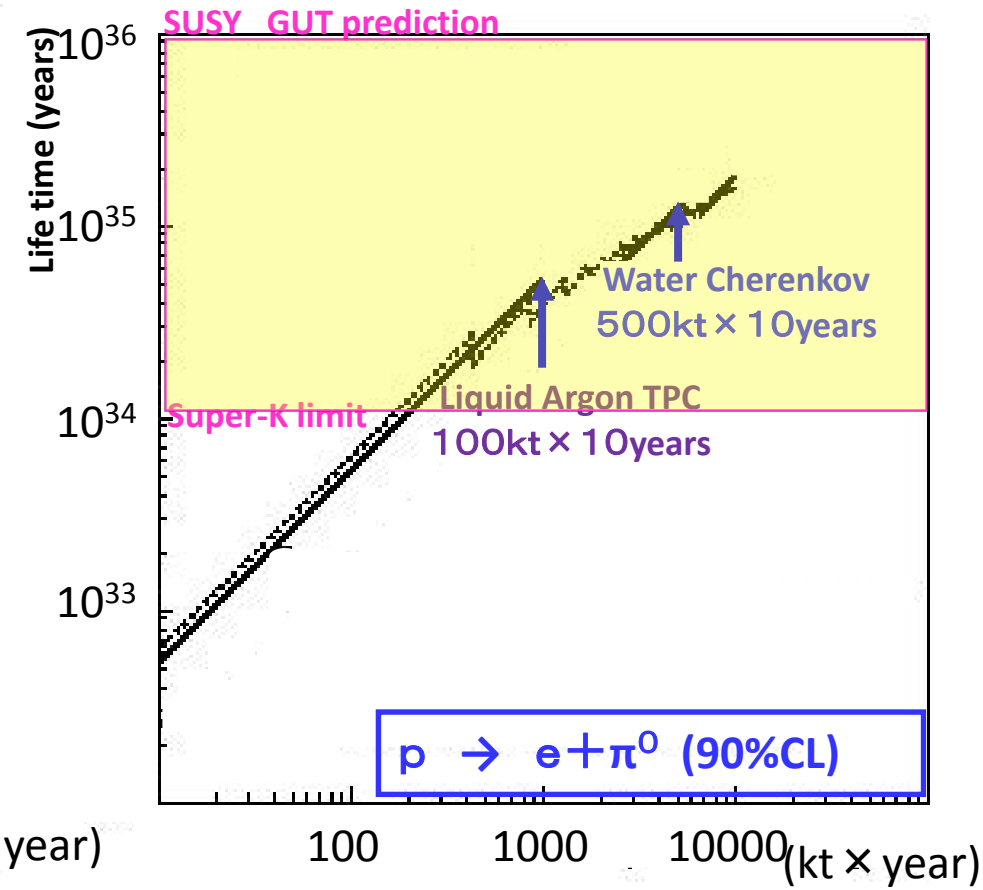
- Shallow depth(>600 m.w.e.) is enough to suppress cosmogenic background
- Main background is atmospheric neutrino
- Never miss $p \rightarrow \nu K^+$, $p \rightarrow e^+ K^0$, $n \rightarrow e^+ K^-$, ...etc.
- Surely detect high multiplicity final states mode (e.g. $p \rightarrow \mu\pi K$, ...)



Sensitivity for typical decay mode

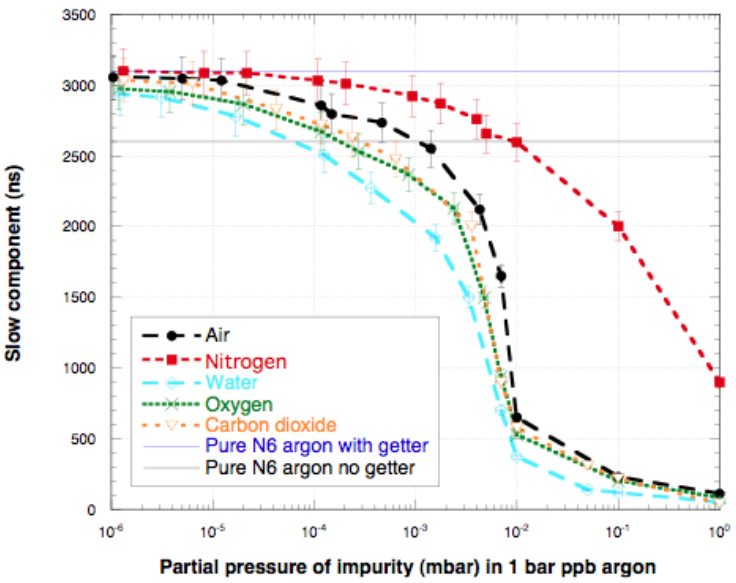
- ν + K^+ mode: LAr (100kt×10years) ＝～7×WC (500kt×10yeas)
- e + π^0 mode: LAr (100kt×10years) ＝～1/2×WC (500kt×10years)



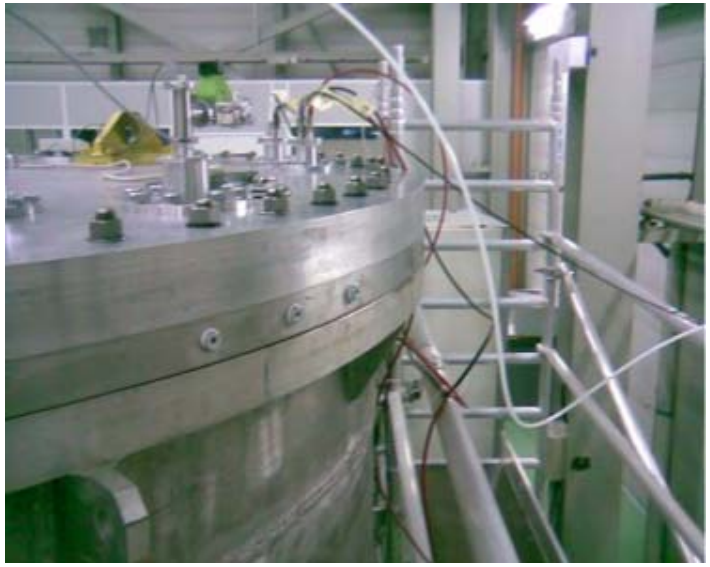


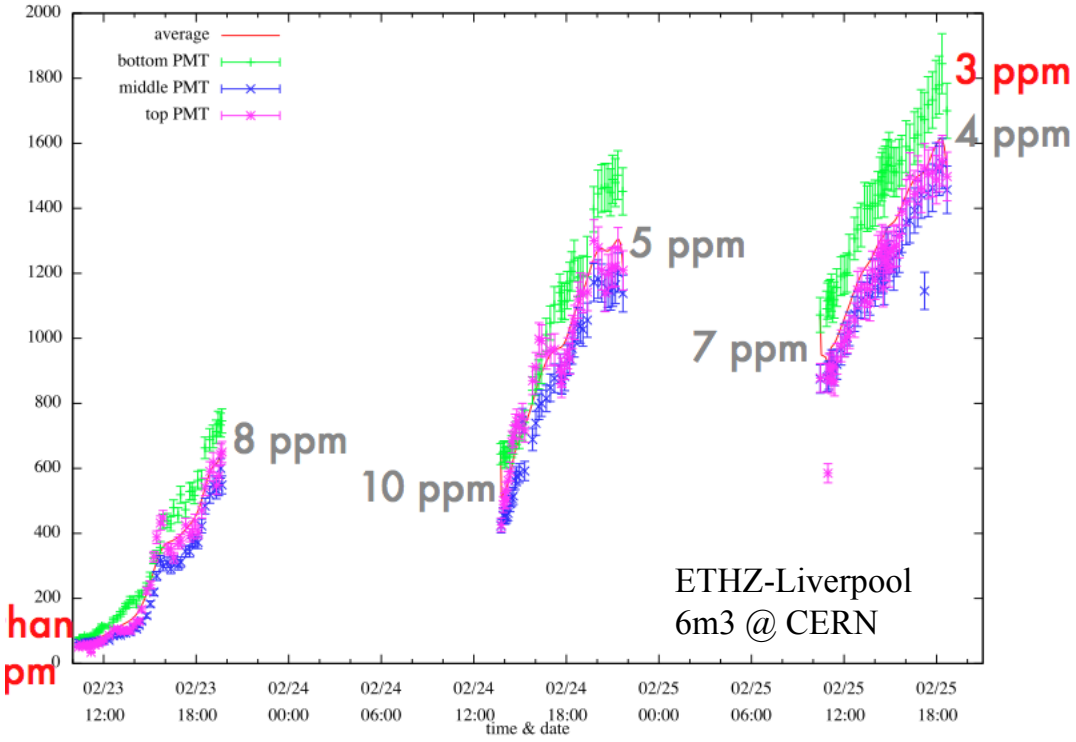
6m3 @ CERN

A. Curioni et al., GLA2010 workshop



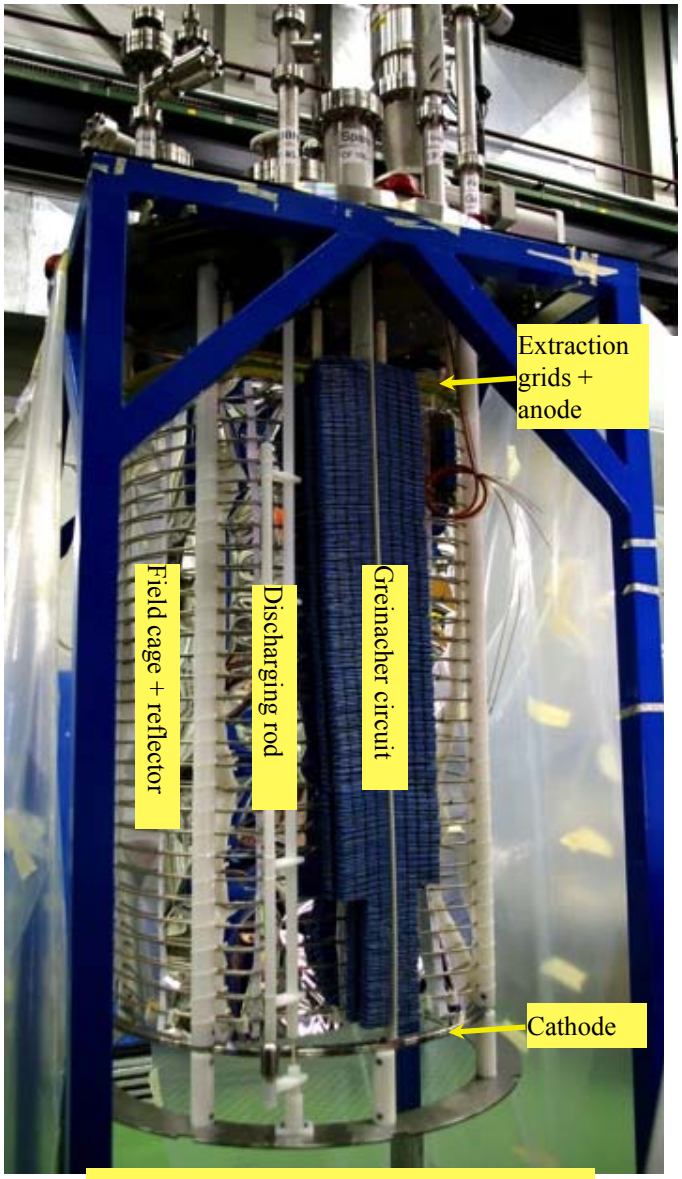
- R&D towards non evacuated vessels on large vessel
- Purity measured with direct scintillation light measurement !
- First test purging - satisfactory!
- Piston effect seen
- Reached **3ppm** O_2 contamination via flushing
- Gas recirculation under construction



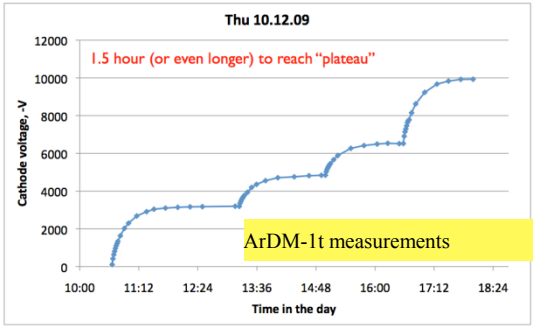


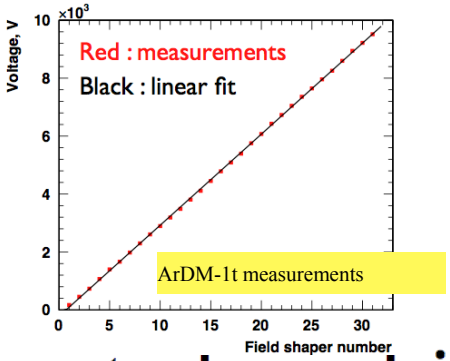
Very high drift "high" voltage...

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

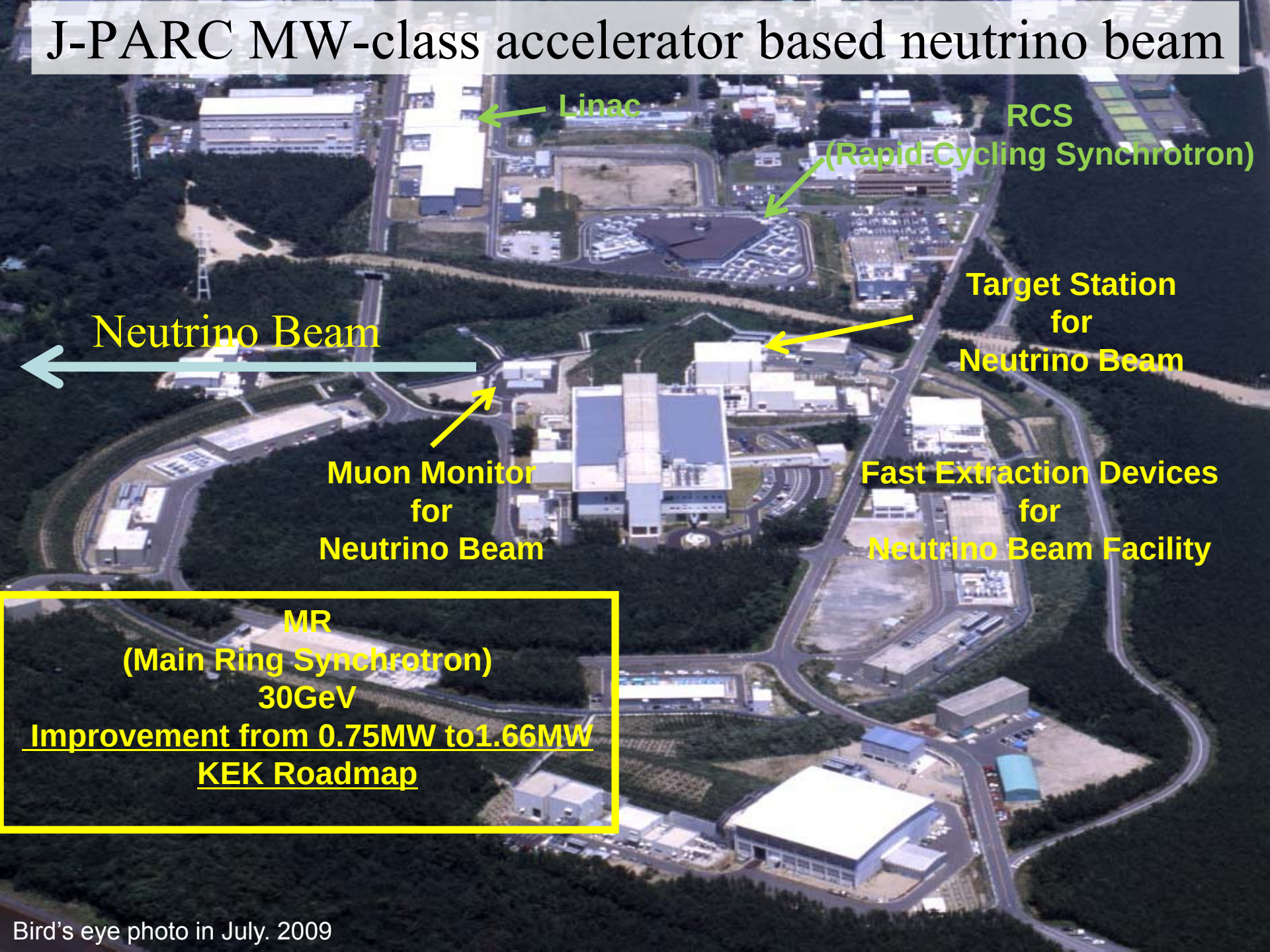
Actual ArDM parameters are given just for comparison.

For extrapolation, 2γN = 1.42 is always assumed.

LAr vaporization heat 160 kJ/kg

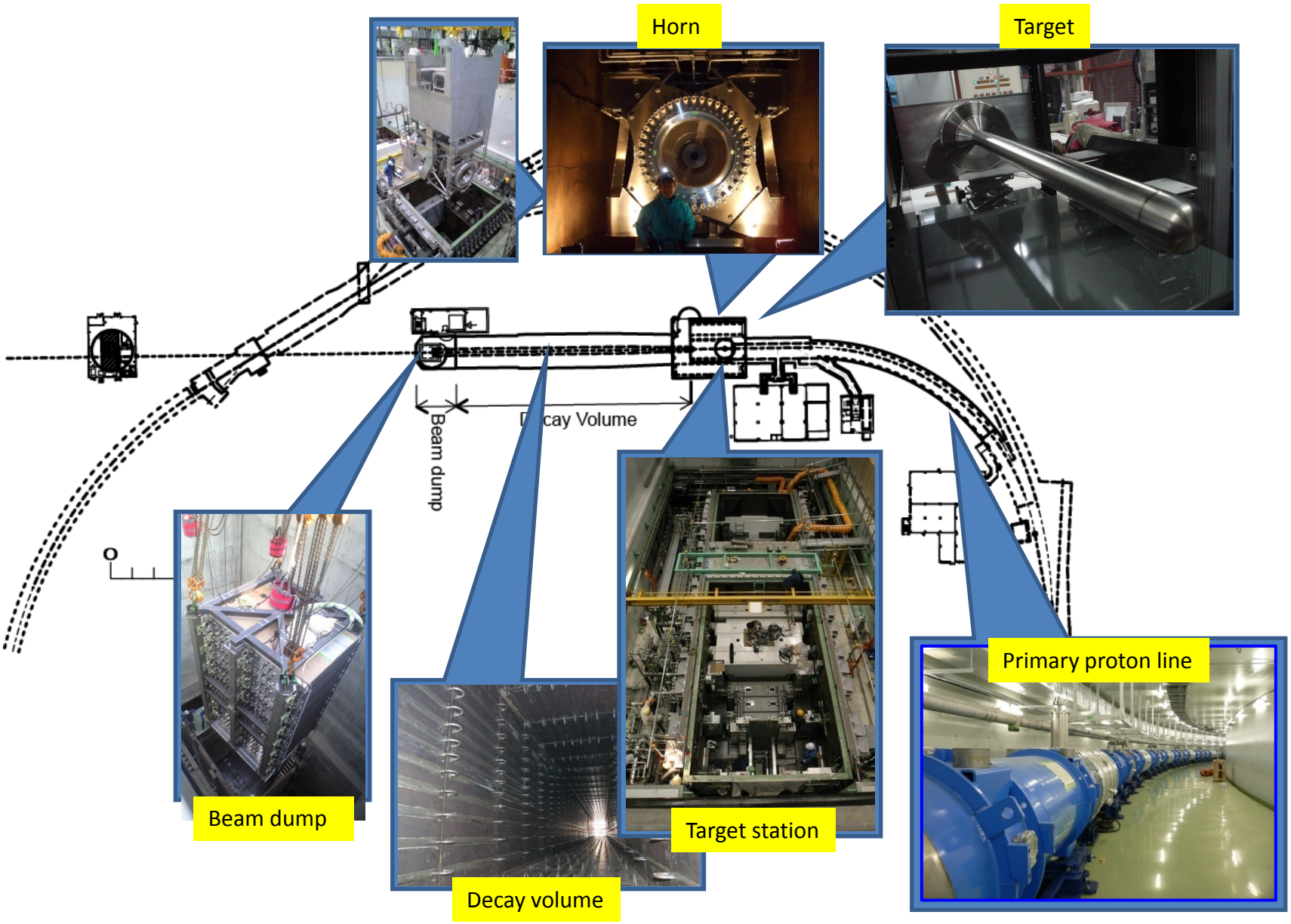
$$V_{\max} = \frac{E}{\gamma},\ \gamma \approx \sqrt{\frac{C_p}{C_s}}$$

J-PARC MW-class accelerator based neutrino beam



Bird's eye photo in July. 2009

J-PARC MW-class accelerator based neutrino beam



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

	Day1 (up to Jul.2010)	Next Step	KEK Roadmap
Power(MW)	0.1	0.45	1.66
Energy(GeV)	30	30	30
Rep Cycle(sec)	3.5	3-2	1.92～0.5
No. of Bunch	6	8	8
Particle/Bunch	1.2×10^{13}	$<4.1\times10^{13}$	$4.1\sim8.3\times10^{13}$
Particle/Ring	7.2×10^{13}	$<3.3\times10^{14}$	$3.3\sim6.7\times10^{14}$
LINAC(MeV)	181	181	400
RCS	h=2	h=2 or 1	h=2 or 1

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

Items to be modified from DAY1 toward MW-class power frontier machine

- No. of Bunch in MR(6→8)
  - Fast Rise Time Extraction Kicker Magnet

    → Installation is foreseen in 2010 summer

- Increase Repetition Rate (3.5Sec→0.5Sec)
  - RF and Magnet Power Supply Improvement

- RCS h=1 Operation (longer beam bunch to decrease space charge effect)
  - RF Improvement h=2: 2 bunches × 4cycle injection to MR
    h=1:Single bunch with doubled no. of proton × 8cycle injection

- LINAC 400MeV Operation (avoid severe space charge effect at RCS injection)

  → Construction of necessary component is approved and started