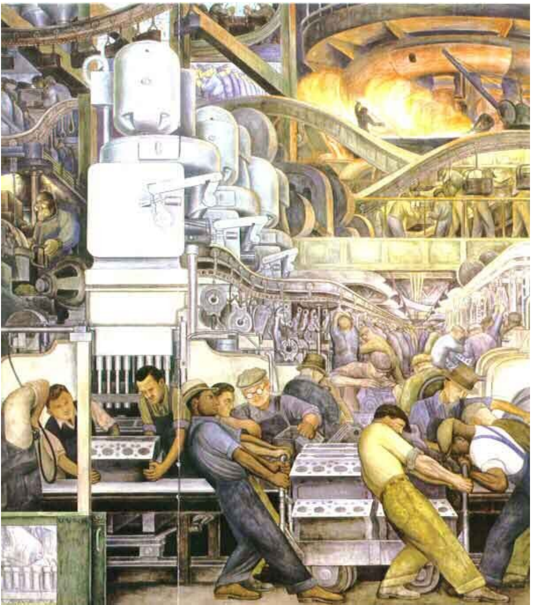
SuperBeam experiments: T2K, NOvA and beyond

Marco Zito

Irfu/SPP, CEA-Saclay

marco.zito@cea.fr



NUFACT09

Chicago, July 21 2009

Outline

- T2K-> JPARC upgrade
- NOνA-> FNAL-Dusel LB
- European studies and plans

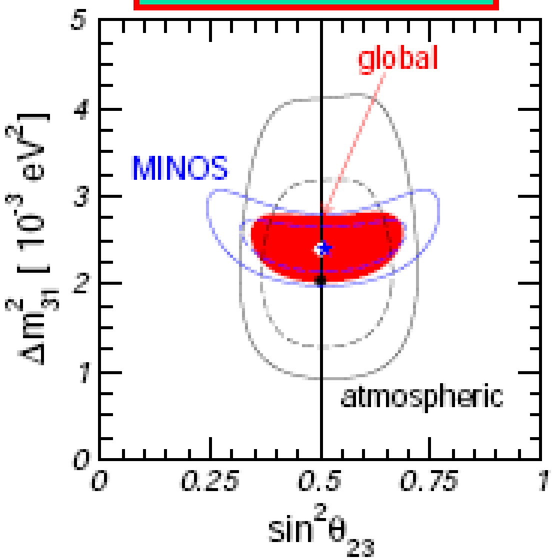
Current status of neutrino mass and mixings

"Atmospheric" "Solar"

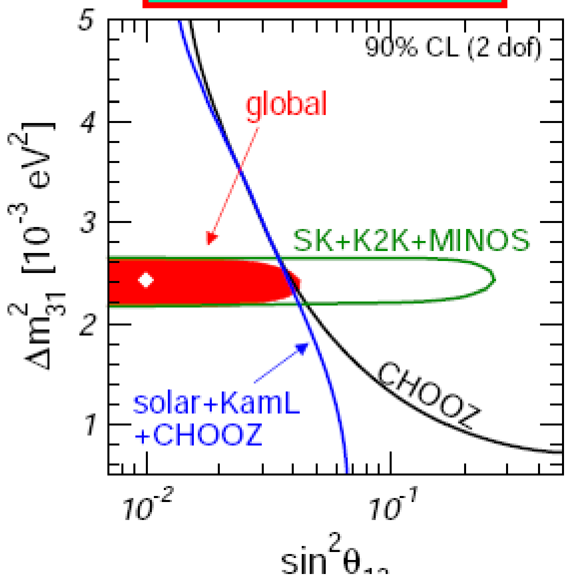
$$U=\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

3 mixing angles (θ_{12}, θ_{23}, θ_{13})
1 CPV phase (δ)
2 (indep.) mass differences ($\Delta m^2_{ij}=m_i^2-m_j^2$)
Additional phases if Majorana neutrinos

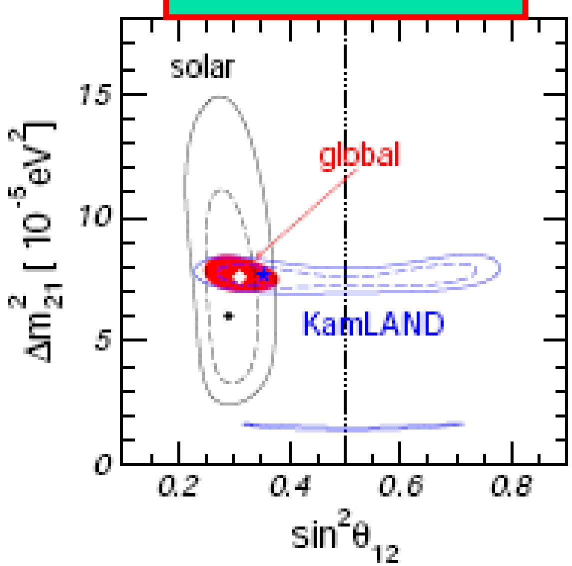
$\theta_{23}, \Delta m_{32}^2$



$\theta_{13}, \Delta m_{31}^2$



$\theta_{12}, \Delta m_{21}^2$

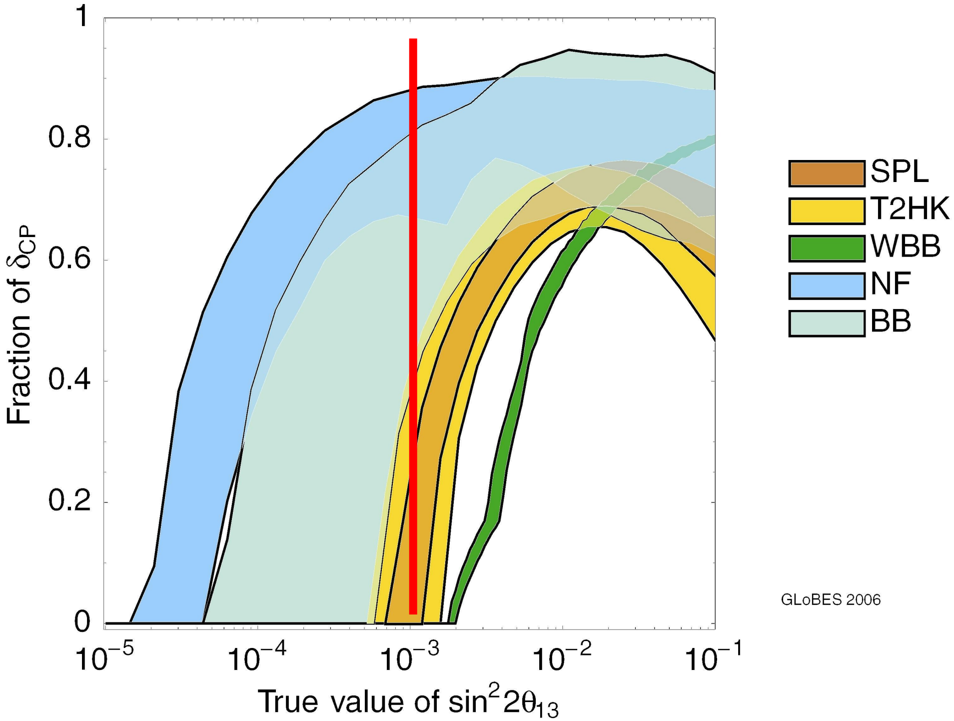


Outstanding questions in neutrino physics

- Discover the last oscillation channel θ_{13} (T2K,NOνA, Double Chooz, Daya Bay)
- Measurement of neutrino mass
- Dirac or Majorana? (Neutrinoless Double Beta Decay)
- Mass hierarchy
- CP violation in the leptonic sector (leptogenesis!)

Super Beam features

- "Conventional" technology
- Shorter schedule
- Competitive CP sensitivity down to $\sin^2(2\theta_{13})\sim10^{-3}$

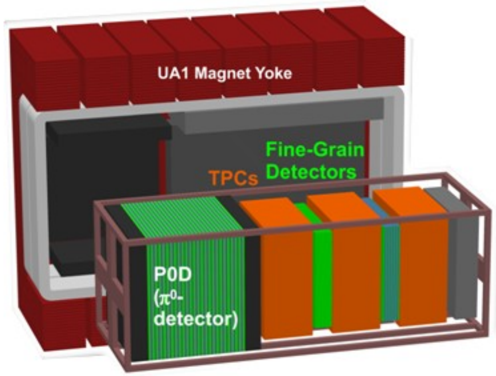


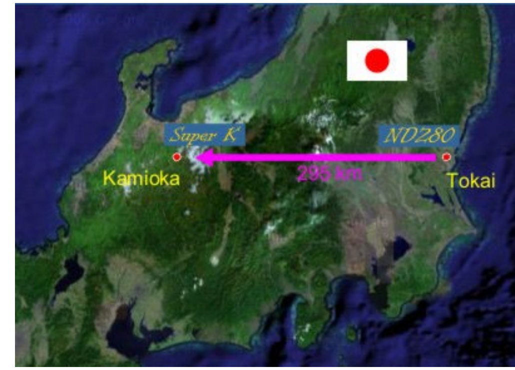
First indications about $\sin^2(2\theta_{13})$ in 2010-2011 (T2K+...) eagerly expected!

From conventional beams to SuperBeams

Exp.	Power (MW)	Baseline	Start	Goal
MINOS	0.192	735	2005	Atm osc.
Opera	0.5	730	2006	ν_τ app
T2K	0.75	295	2009	θ_{13}
NOvA	0.7	810	2011	Θ_{13} hierarchy
Fnal->Dusel	2.3	1290	>2014	CP, mass hierarchy
JPARC+	1.66	295->	>2014	CP
SPL	4	135	>2018	CP

Tokai to Kamioka (T2K) long baseline neutrino oscillation experiment

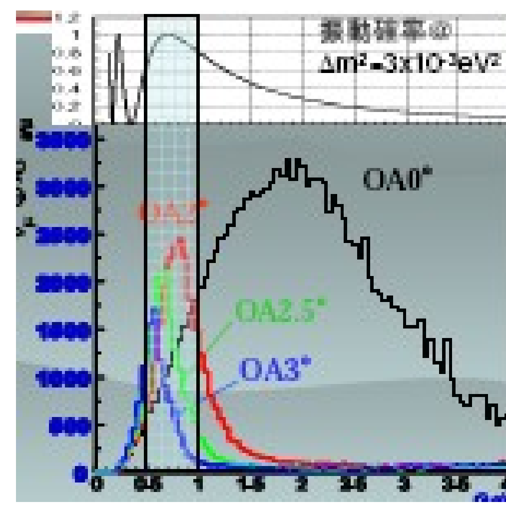


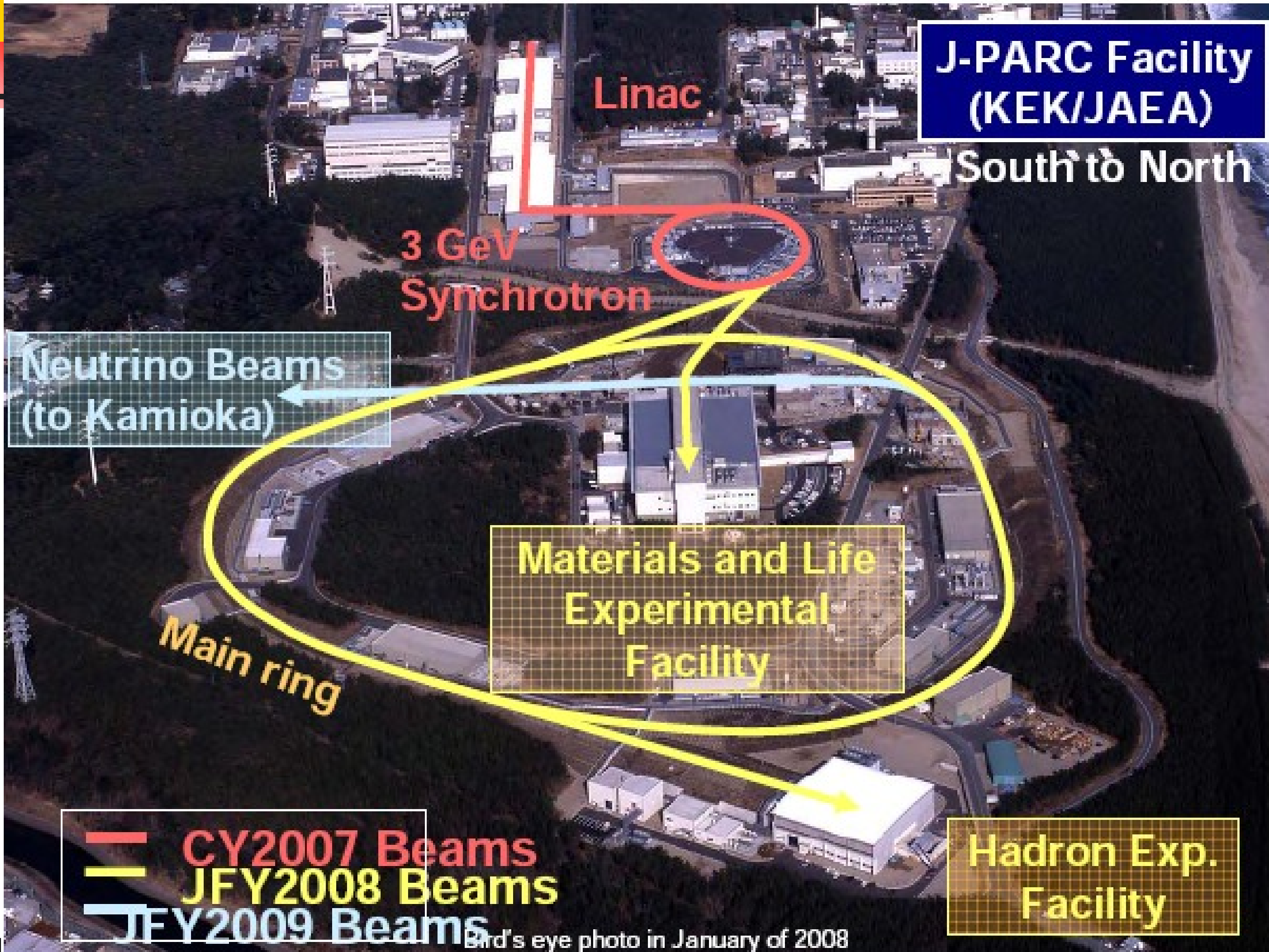


- Intense proton beam from JPARC
- Off-axis by 2.5 deg
- Tuned at osc. max
- Goals:
- discover ν_e appearance
- Precise measurement of ν_μ disapp.
- SK: 1600 CC/yr/22.5kt

First off axis beam!

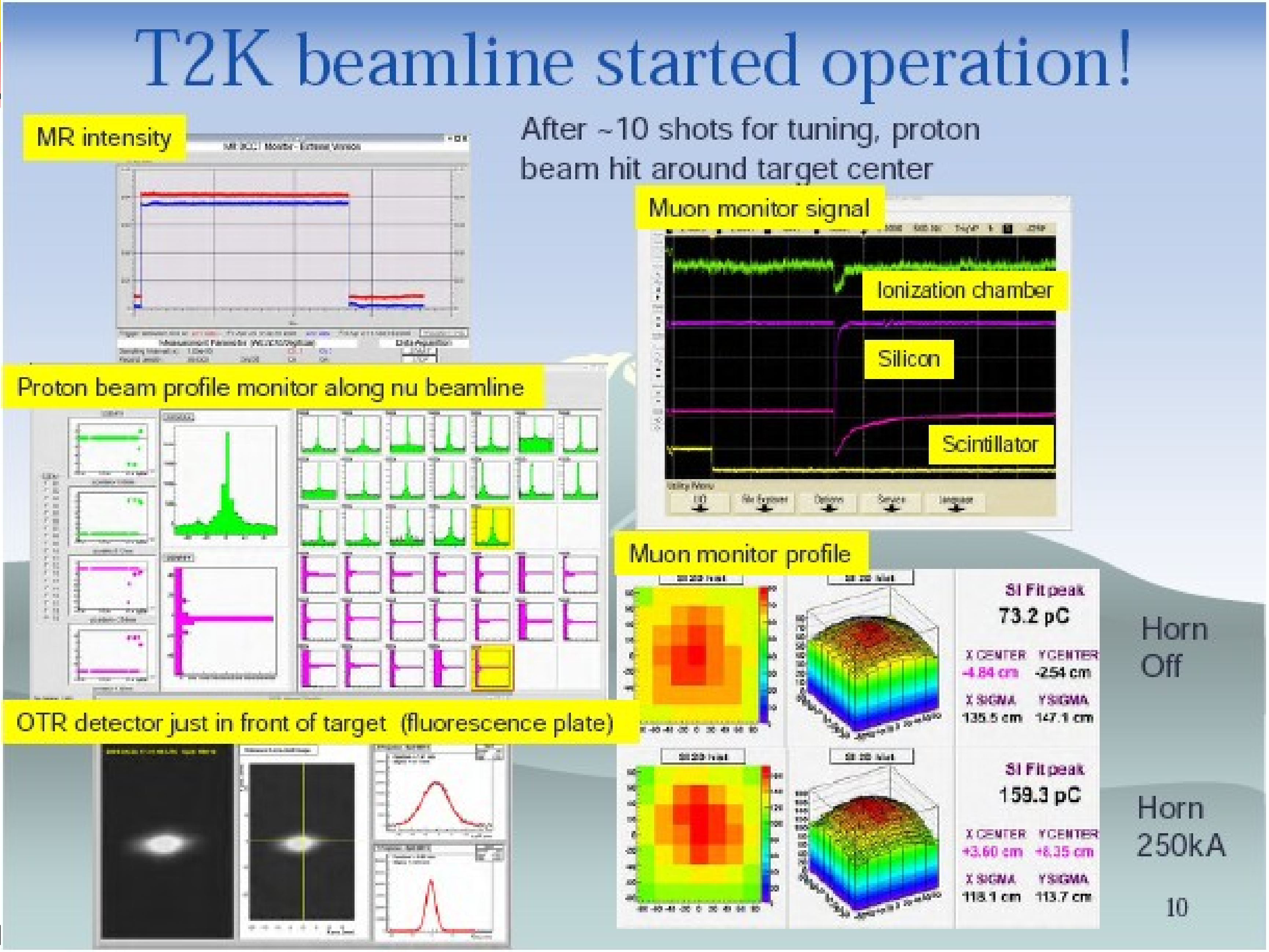
Zito




J-PARC Facility
(KEK/JAEA)
South to North
Linac
3 GeV
Synchrotron
Neutrino Beams
(to Kamioka)
Materials and Life
Experimental
Facility
Main ring
Hadron Exp.
Facility
CY2007 Beams
JFY2008 Beams
JFY2009 Beams
Bird's eye photo in January of 2008

Neutrino beamline

- 5 year construction 2004~2009
- Construction completed on schedule!
- Start beam commissioning in April 2009!


T2K beamline started operation!
After ~10 shots for tuning, proton beam hit around target center
MR intensity
Muon monitor signal
Ionization chamber
Silicon
Scintillator
Proton beam profile monitor along nu beamline
Muon monitor profile
SI Fitpeak
73.2 pC
X CENTER
-4.84 cm
Y CENTER
-2.54 cm
X SIGMA
135.5 cm
Y SIGMA
147.1 cm
Horn Off
SI Fitpeak
159.3 pC
X CENTER
+3.60 cm
Y CENTER
+8.35 cm
X SIGMA
118.1 cm
Y SIGMA
113.7 cm
Horn 250kA
OTR detector just in front of target (fluorescence plate)
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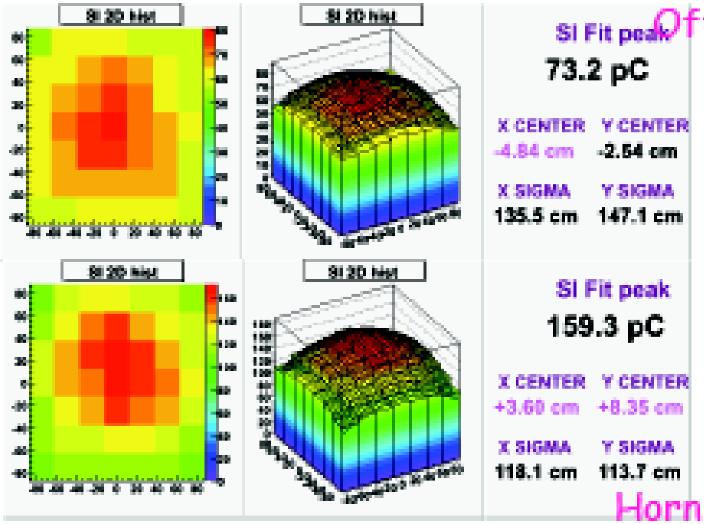
Achievements in the beam commissioning

9 days, 705 shots in total (Apr-May '09)

- ☑ transfer the proton beam without any significant beam loss
- ☑ SC combined function magnets work as expected
- ☑ Muon yield is increased by Horn On
- ☑ control beam position on the target
- ☑ beam dir. was stable ($\Delta\theta_{\mu}$ < 1mrad) during 0.5 hour operation

Muon monitor signal
with/without Horn Magnet (online monitor)

Horn Off



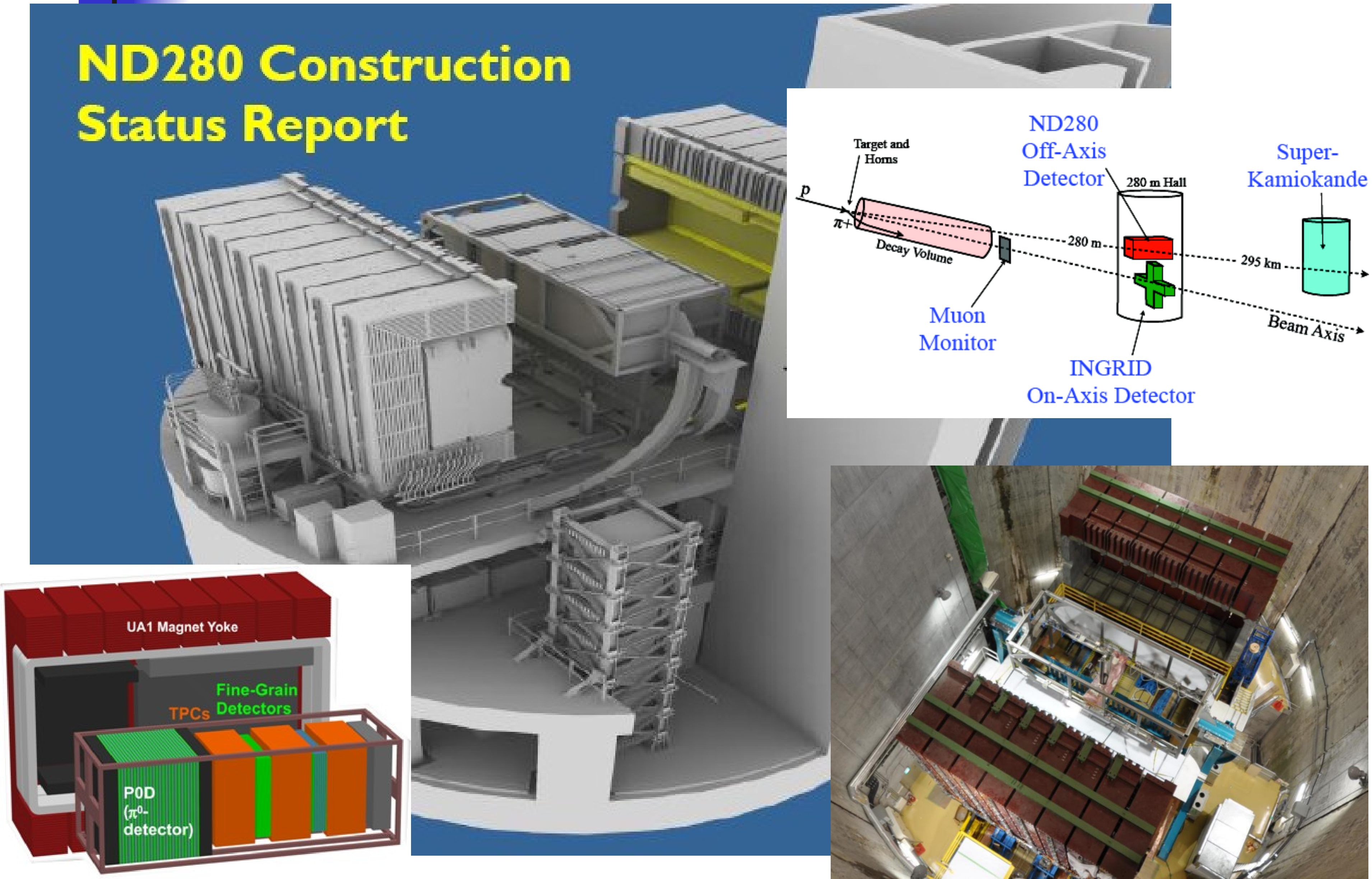
Horn ON (273kA)

- ☑ Successfully pass the government inspection of radiation
- ☑ operate with several beam condition (e.g. 2-bunches operation)

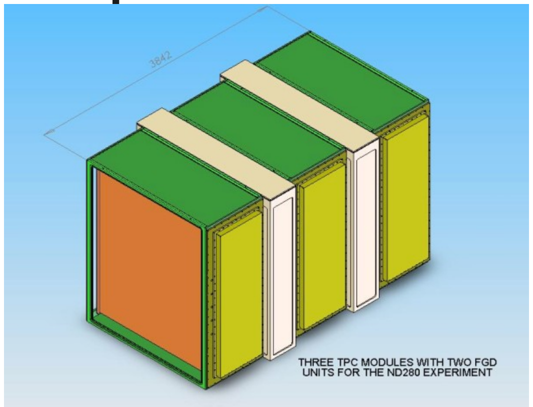
T2K ν beam-line works with expected performance

T2K beamline started operation!

T2K Near Detector: ND280

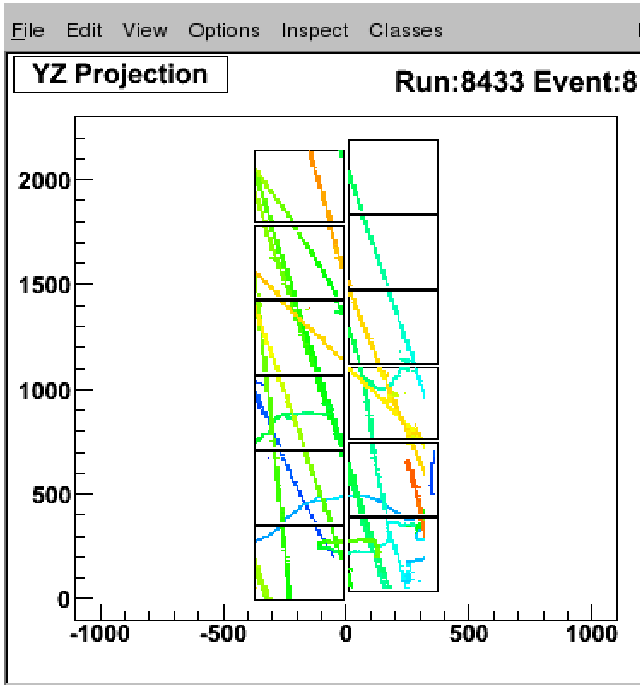


T2K ND280 Tracker



2 Active targets (FGD)
1 cm**2 scint. Bars
Read out with MPPC

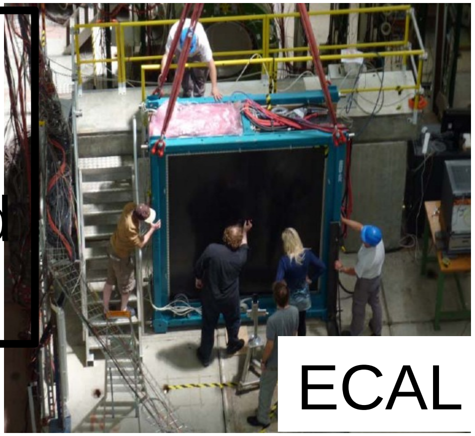
3 TPC equipped with Micromegas det.
9m**2 sensitive area 120 k channels

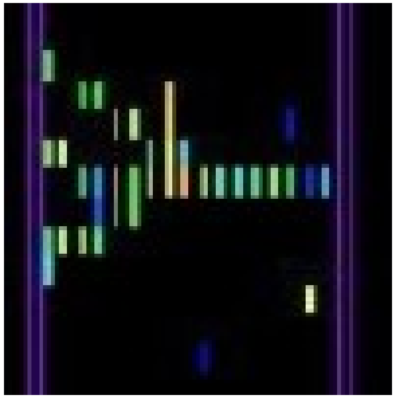


NUFACT09,
Chicago, July 2009

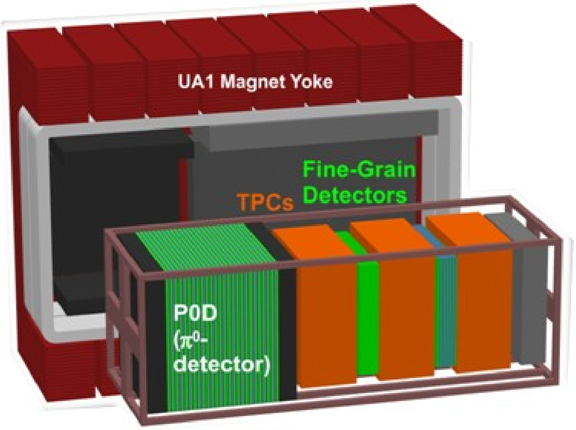
T2K ND280 scintillator detectors

ND280 detectors:
- Test beam performed
- Construction almost finished
- Being installed in JPARC


ECAL



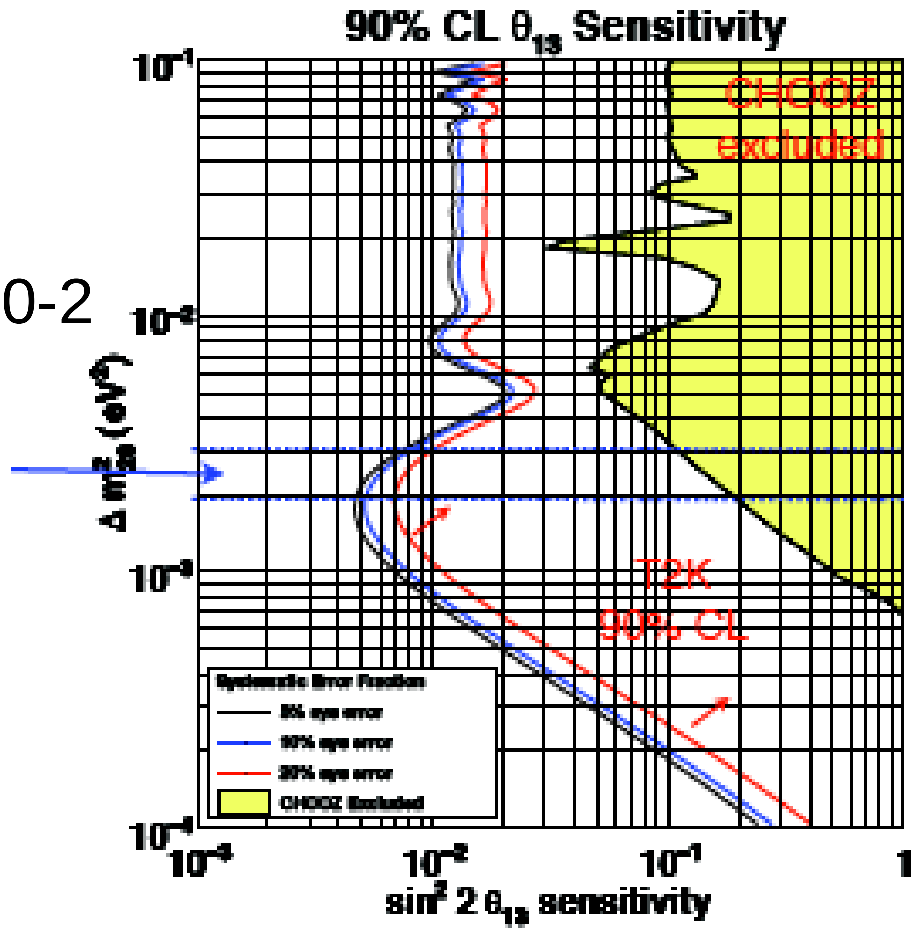
P0D



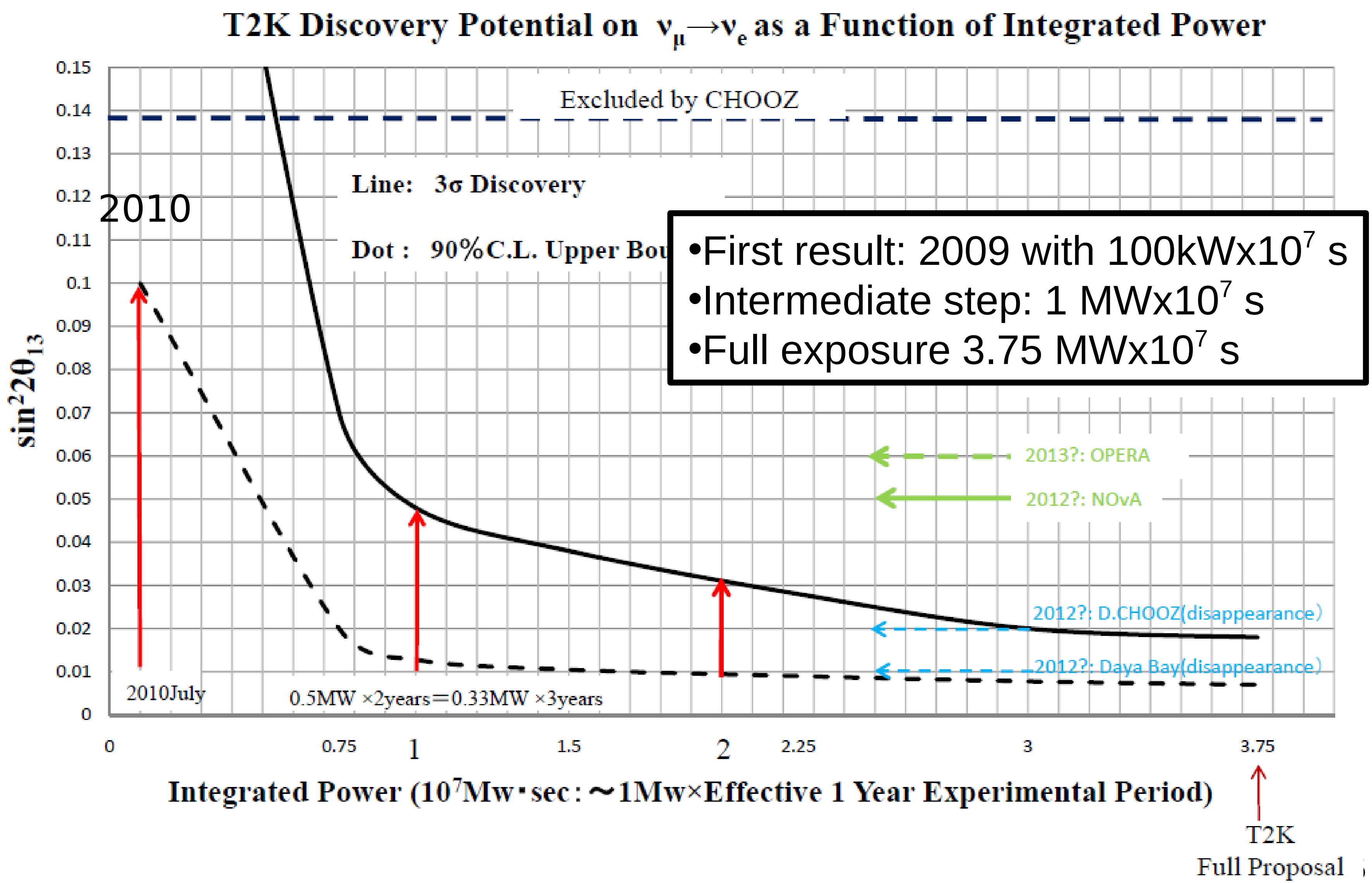

SMRD

T2K ν_e appearance sensitivity

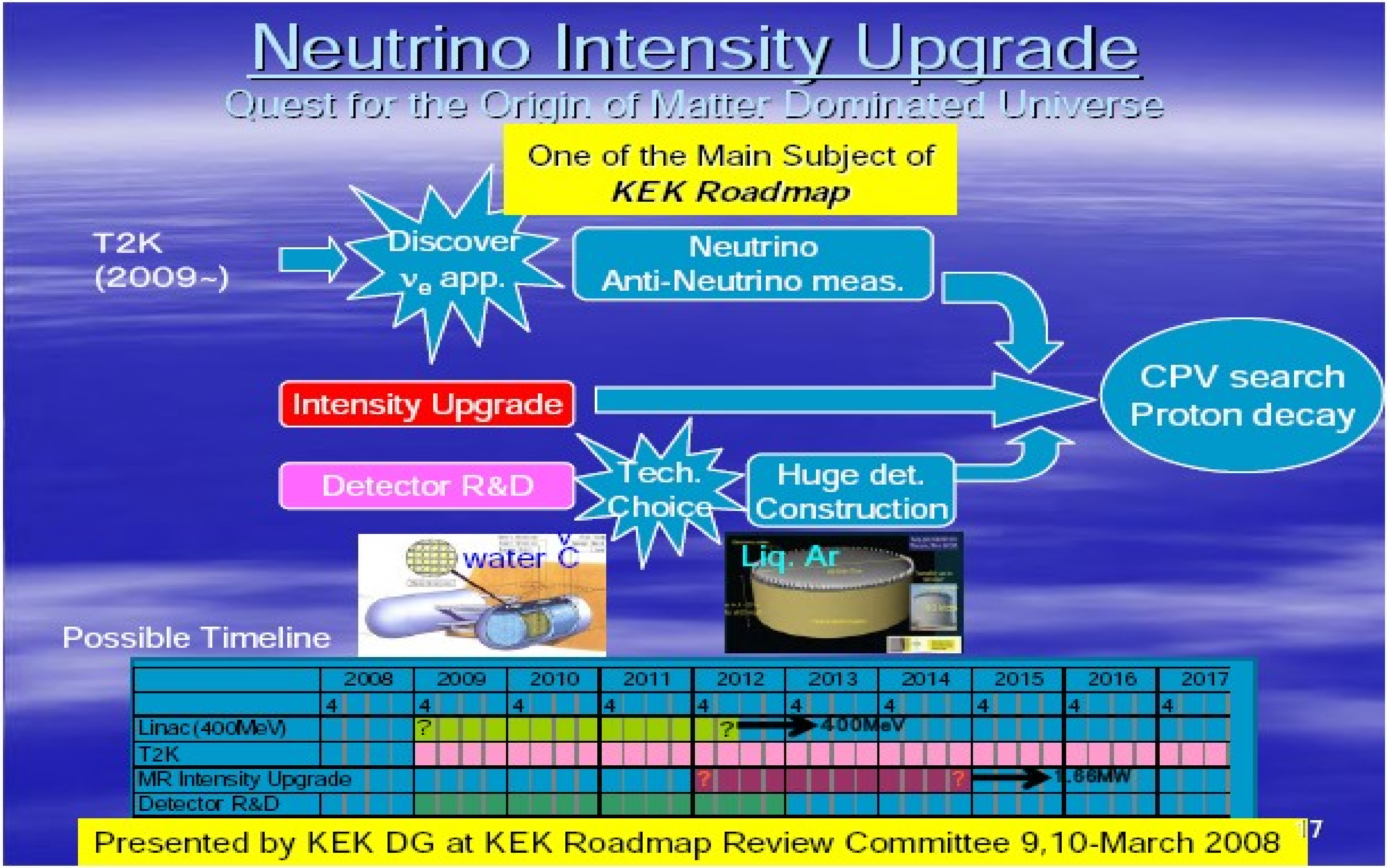
- Five years at 750 kW
- For δ=0
- Sensitivity (90%CL) below 10-2



T2K discovery potential and plan



- •First result: 2009 with 100kWx10^7 s
- •Intermediate step: 1 MWx10^7 s
- •Full exposure 3.75 MWx10^7 s


Neutrino Intensity Upgrade
Quest for the Origin of Matter Dominated Universe
One of the Main Subject of
KEK Roadmap
T2K
(2009~)
Discover
νe app.
Neutrino
Anti-Neutrino meas.
CPV search
Proton decay
Intensity Upgrade
Detector R&D
Tech.
Choice
Huge det.
Construction
water C
Liq. Ar
Possible Timeline
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Linac(400MeV)
? ? 400MeV
T2K
MR Intensity Upgrade
? ? 1.66MW
Detector R&D
Presented by KEK DG at KEK Roadmap Review Committee 9,10-March 2008
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Technically Feasible
MR Power Improvement Scenario
— KEK Roadmap —

	Day1 (up to Jul.2010)	Next Step	KEK Roadmap	Ultimate
Power(MW)	0.1	0.45	1.66	?
Energy(GeV)	30	30	30	
Rep Cycle(sec)	3.5	3-2	1.92	
No. of Bunch	6	8	8	
Particle/Bunch	1.2×10^{13}	$<4.1 \times 10^{13}$	8.3×10^{13}	
Particle/Ring	7.2×10^{13}	$<3.3 \times 10^{14}$	6.7×10^{14}	
LINAC(MeV)	181	181	400	
RCS	h=2	h=2 or 1	h=1	

After 2010, plan depends on financial situation

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Three Possible Scenario Studied at NP08 Workshop

NP08 is **The 4th International Workshop on Nuclear and Particle Physics at J-PARC**

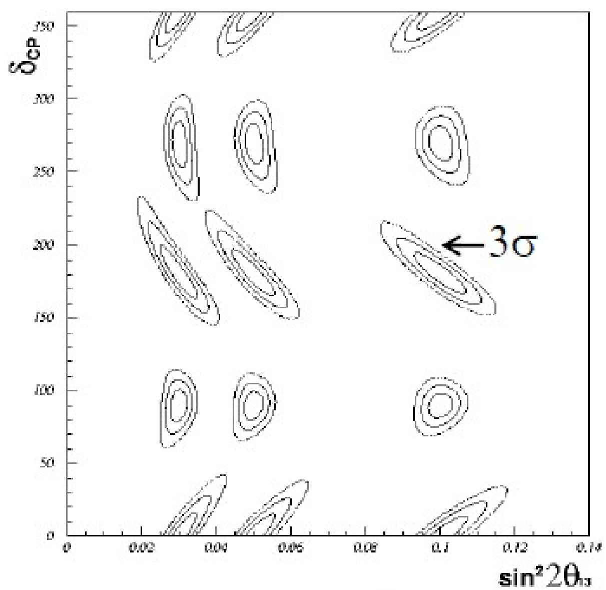
http://j-parc.jp/NP08

T. Hasegawa

Scenario 1

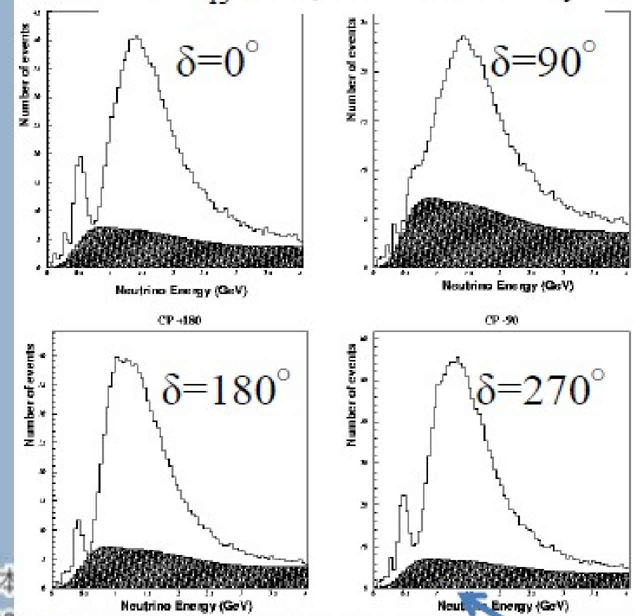
- Cover 1st and 2nd Maximum
- Neutrino Run Only 5Years × 1.66MW
- 100kt Liq. Ar TPC
  - -Good Energy Resolution
  - -Good e/π^0 discrimination
- Keeping Reasonable Statistics

CP Measurement Potential



ν_e Spectrum

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

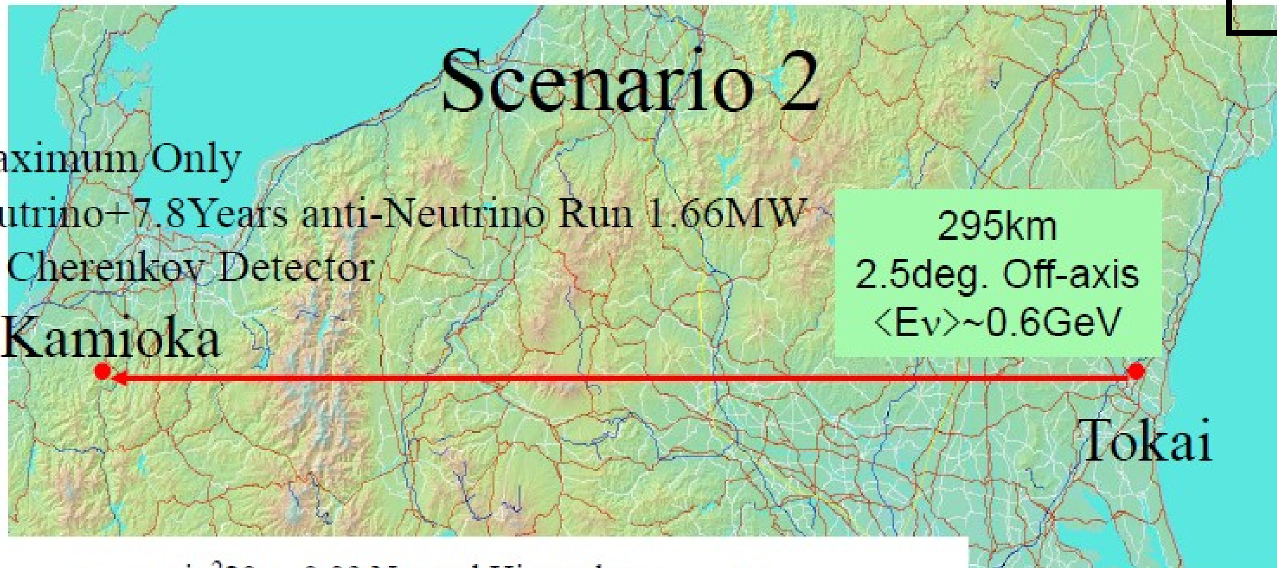


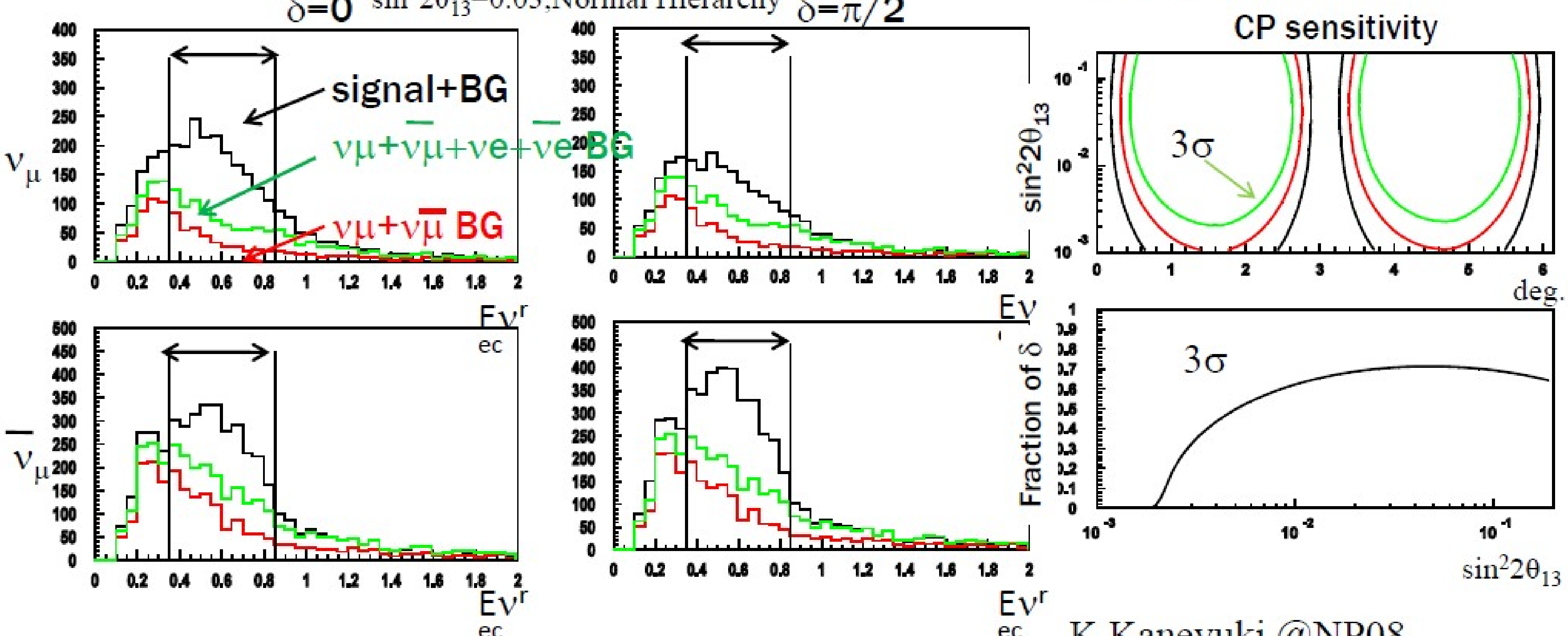
NP08, arXiv:0804.2111

T. Hasegawa

Scenario 2

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



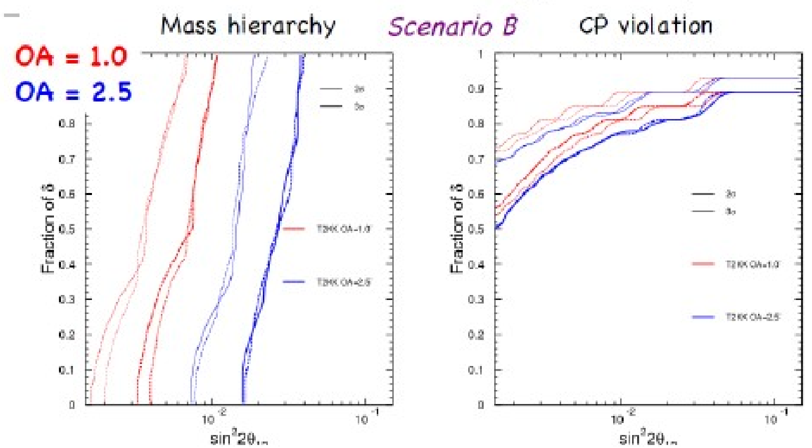


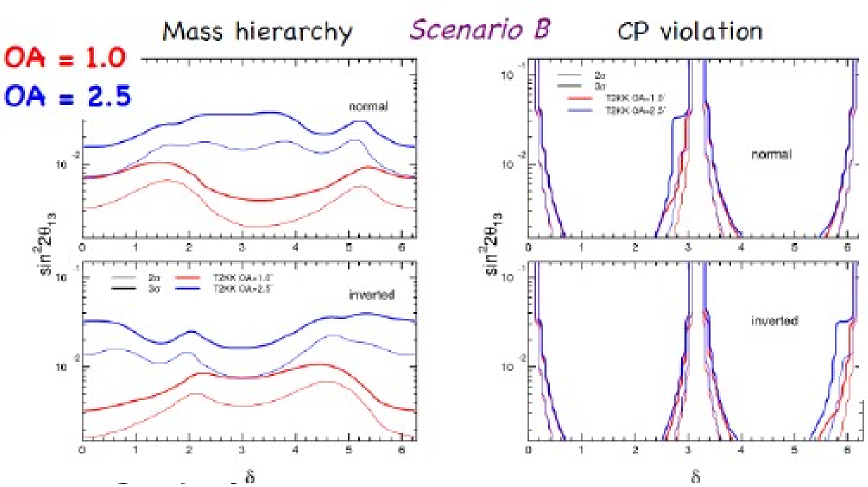
K.Kaneyuki @NP08

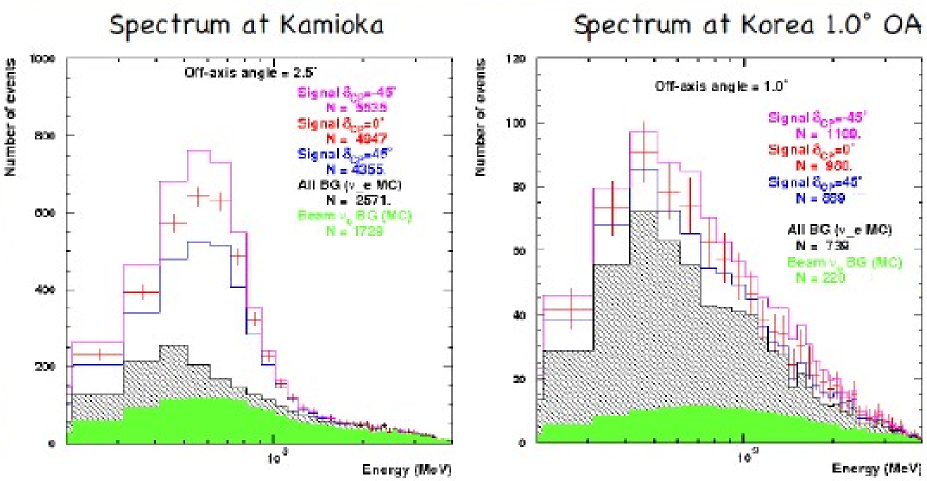
T. Hasegawa

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)

T. Hasegawa

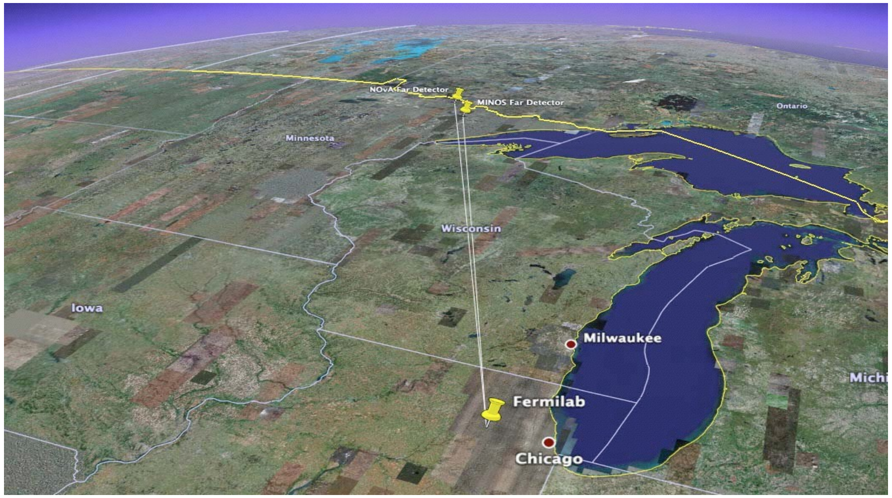
Comparison of Each Scenario

	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 $\nu_e \bar{\nu}_e$	Ratio between 1st 2ndMax
Beam	5Years $\nu_{\mu,}$ then Decide Next	2.2 Years $\nu_{\mu,}$ 7.8 Years $\bar{\nu}_{\mu,}$	5 Years $\nu_{\mu,}$ 5 Years $\bar{\nu}_{\mu,}$
Detector Tech.	Liq. Ar TPC	Water Cherenkov	Water Cherenkov
Detector Mass (kt)	100	2×270	270+270

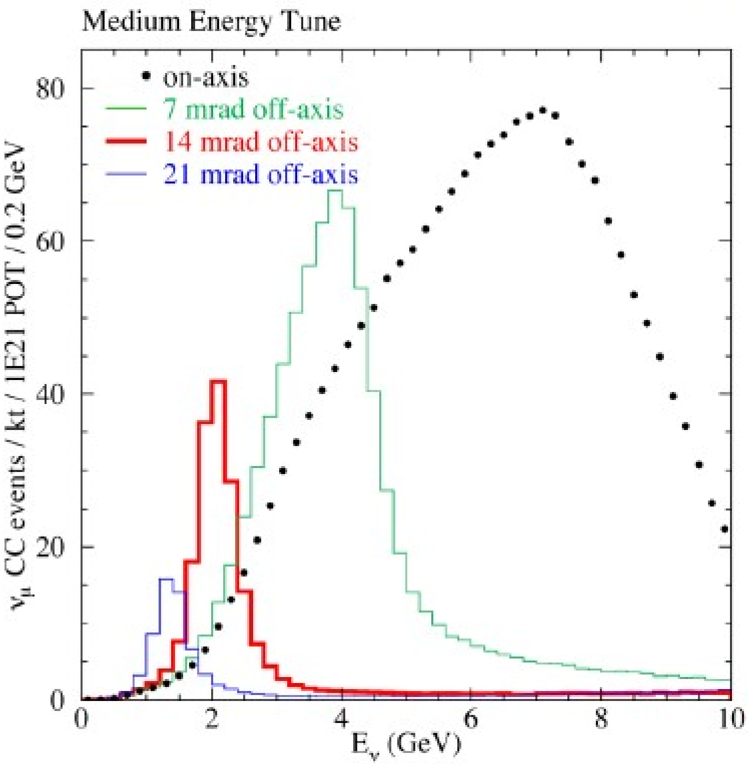
Study is continuing to seek for optimum choice

NOνA and beyond

NOνA



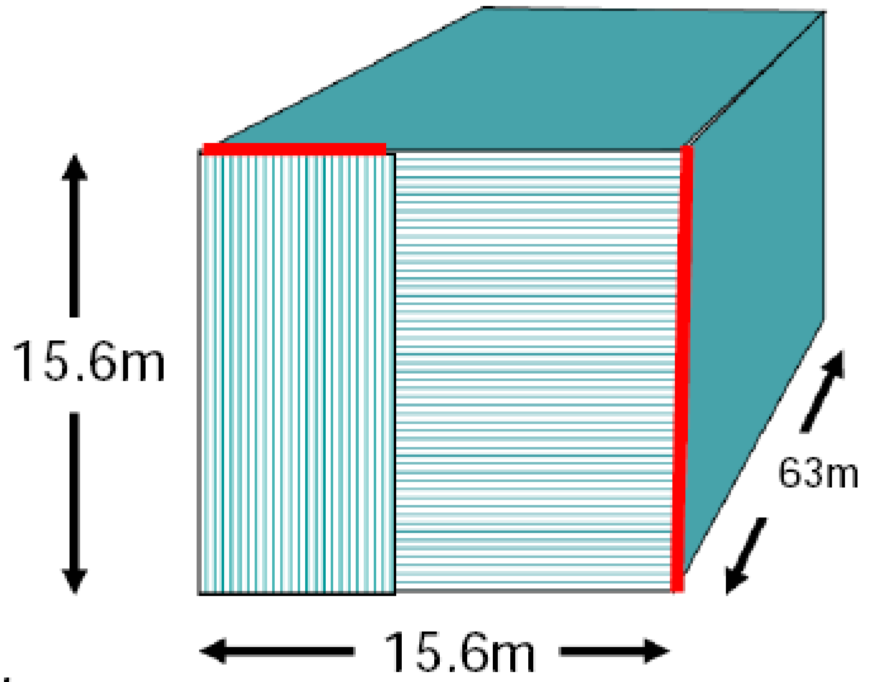
- Uses NuMi off axis beam
- Baseline 810 km
- Far detector 14 kt
- Ground breaking: May 1 2009
- Installation, data taking 2011
- Finish installation 2013



NovA Far detector (Ash River)

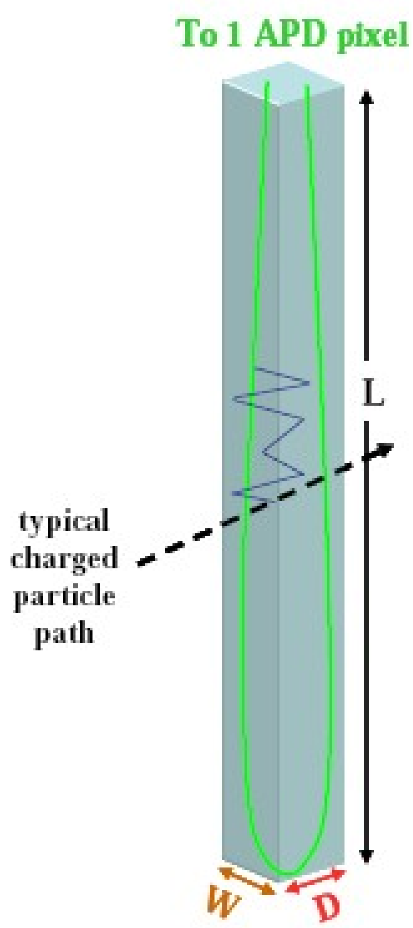
Slide by L. Mualem
at FNAL User meeting 2009

- 14 ktons
- 15.6m x 15.6m x 63m
- 930 liquid scintillator planes, (~73% active)
- Scintillator cells 3.8 x 6.0 x 1540 cms
- Read out from one side per plane with APDs
- Expected average signal at far end of 30pe

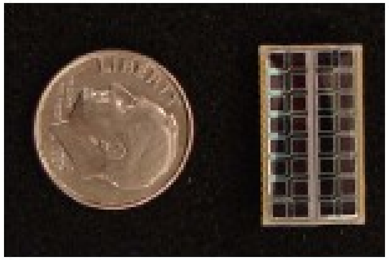


NovA Far detector

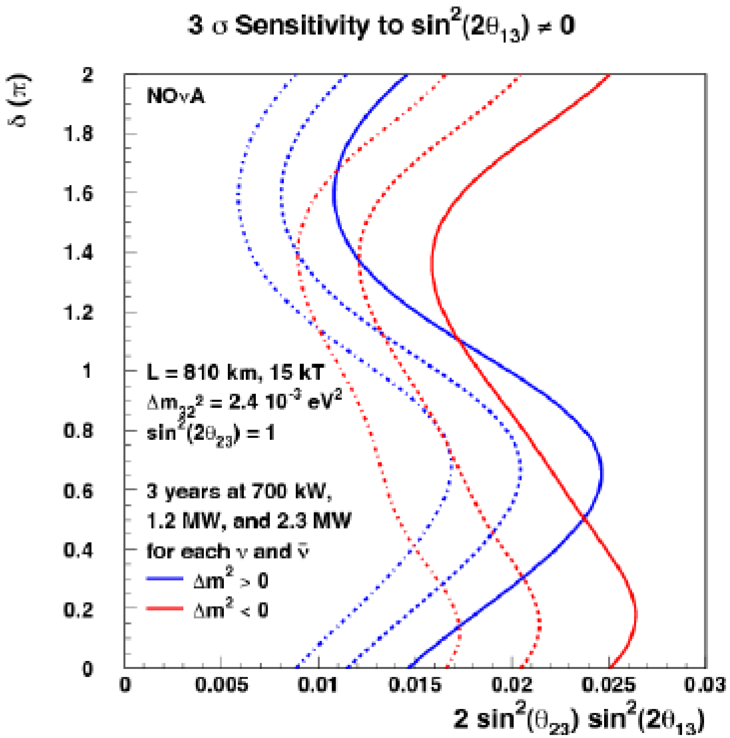
Slide by L. Mualem
at FNAL User meeting 2009



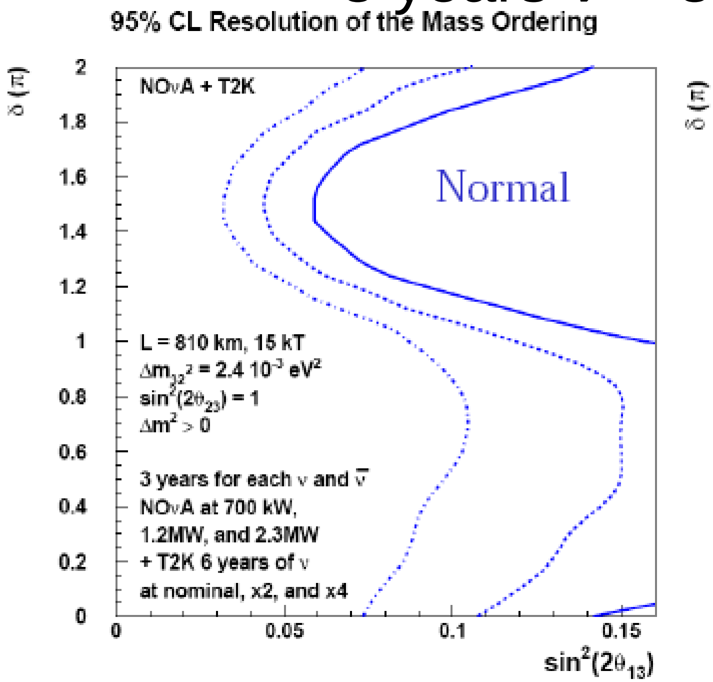
- Liquid Scintillator
  - 4.1% pseudocumene as scintillant
  - Mineral oil and waveshifters (PPO, bis-MSB)
- PVC cell for primary containment
  - Horizontals:3.87 cm x 6.0 cm x 15.4 m long
  - Verticals: 3.76 cm x 5.7 cm x 15.4 m long
  - Highly reflective, 15% titanium dioxide
- Looped wavelength shifting fiber to collect light
  - 0.7 mm diameter, double clad, K27 waveshifter
  - Almost perfect mirror, 3.6*light in 1 fiber
- Avalanche Photodiode
  - 85% quantum efficiency
  - Gain of 100, operate at -15°C
- Low noise amplifier



NovA sensitivity



3 years ν + 3 years ν



Physics program:

- Measurement of θ_{13}
- Determination of mass hierarchy

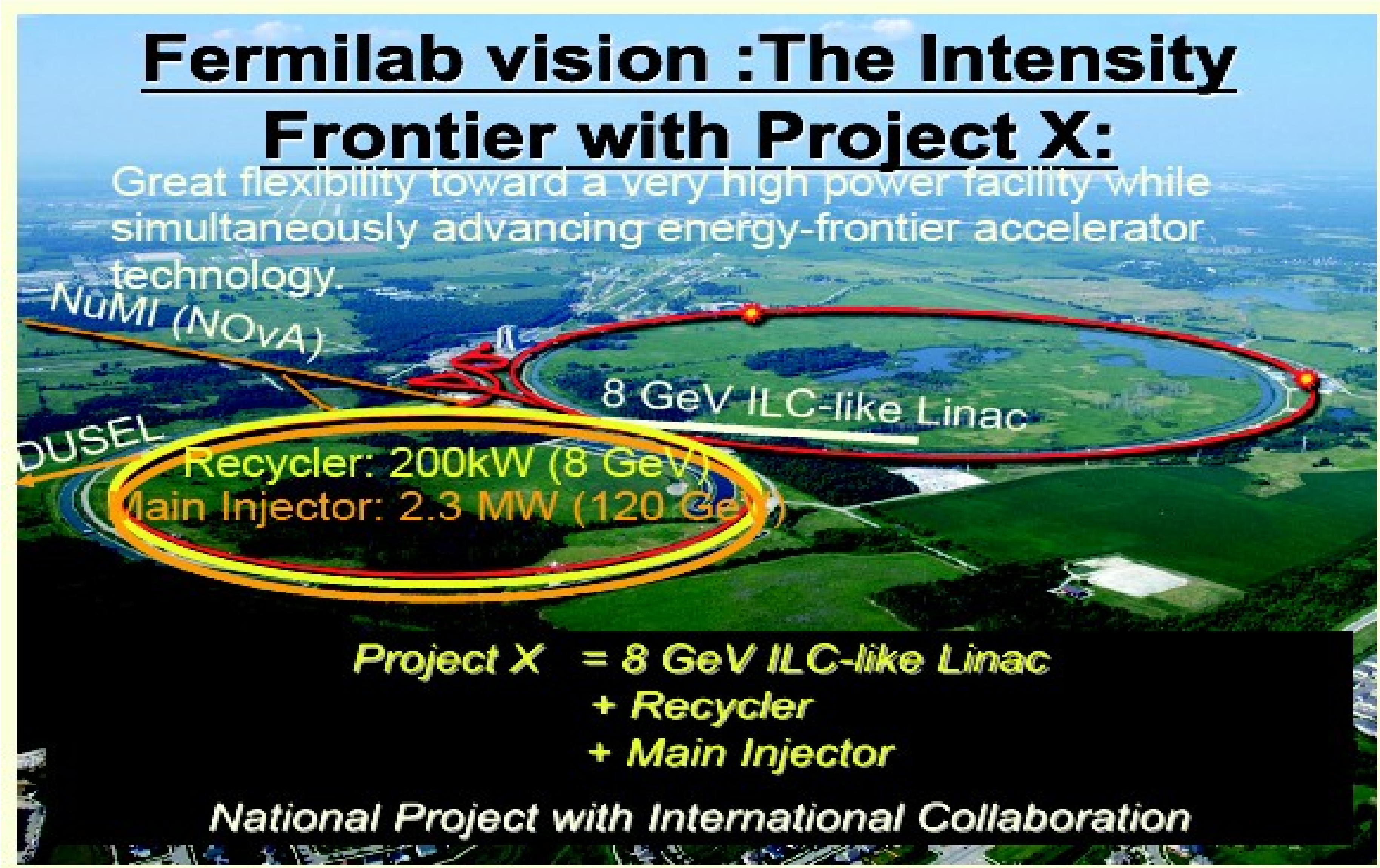
US program beyond NOνA

Based on slides by G. Rameika at last Neutrino GDR Paris april 2009

- Various studies (BNL-FNAL LB) have explored the various options (WBB, longer baseline, detector technology) concluding that
- Future experiments using conventional neutrino beams can be designed to have 3-5σ discovery potential for measuring CP violation and the neutrino mass hierarchy for values of $\sin^2(2\theta_{13})$ as low as ~ 0.01

These sensitivities are reached assuming :

- – a proton source at the Megawatt level (or decades of running time)
- – a neutrino beam optimized to the oscillation probability (covering the 1st and 2nd oscillation maximum)
- – an experiment baseline > 1000 km (sensitivity to the mass hierarchy)
- – a Detector with effective mass (mass*efficiency) > 100kT
- Large detector in DUSEL and high intensity neutrino beam at FNAL are recommended by the P5 Report

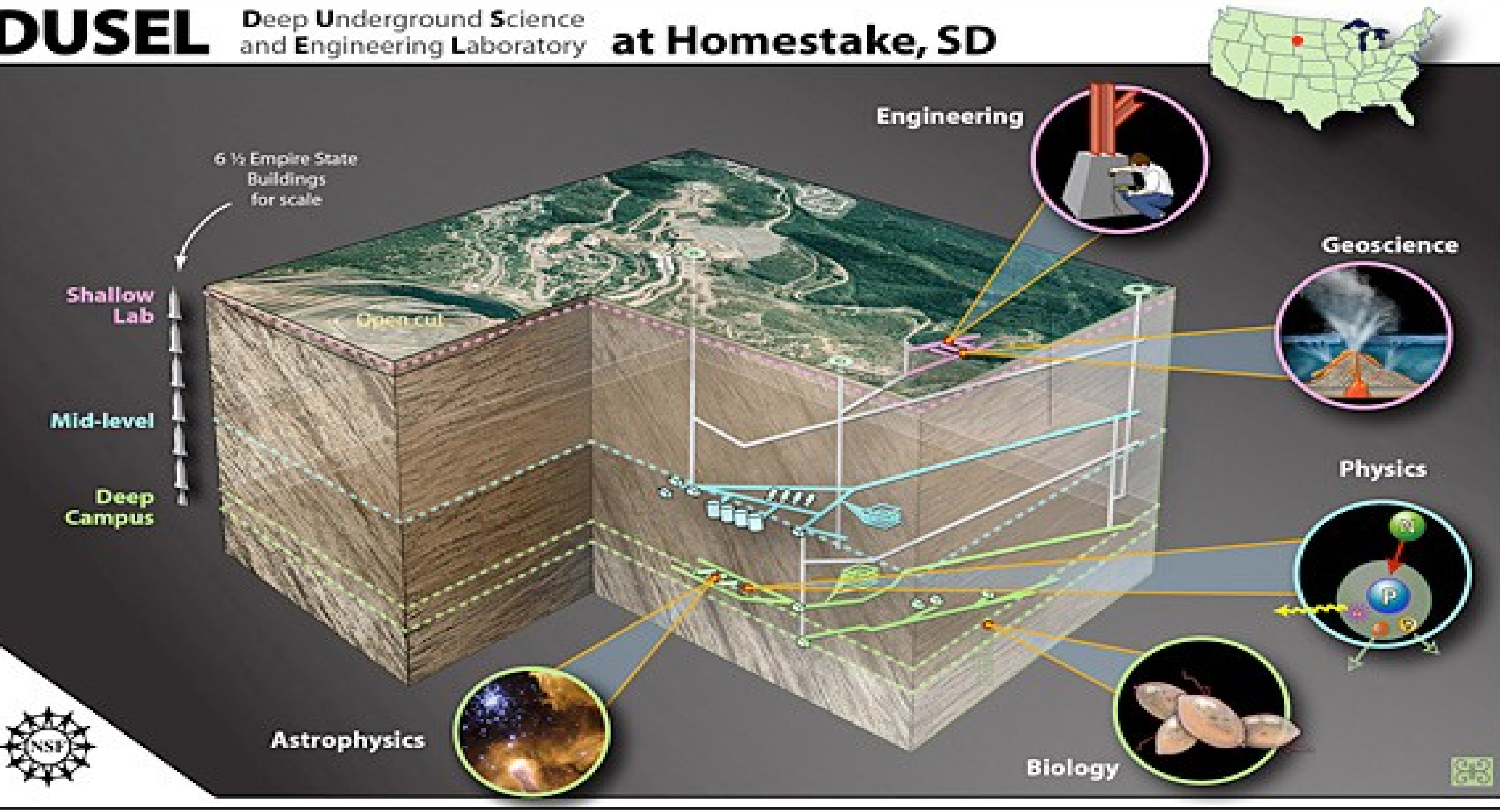


Fermilab vision :The Intensity Frontier with Project X:
Great flexibility toward a very high power facility while simultaneously advancing energy-frontier accelerator technology.
NuMI (NOvA)
DUSEL
8 GeV ILC-like Linac
Recycler: 200kW (8 GeV)
ain Injector: 2.3 MW (120 Ge
Project X = 8 GeV ILC-like Linac
+ Recycler
+ Main Injector
National Project with International Collaboration

Fermilab to Homestake DUSEL (1290km)

Dusel

FDR 2012
Construction starts in 2013



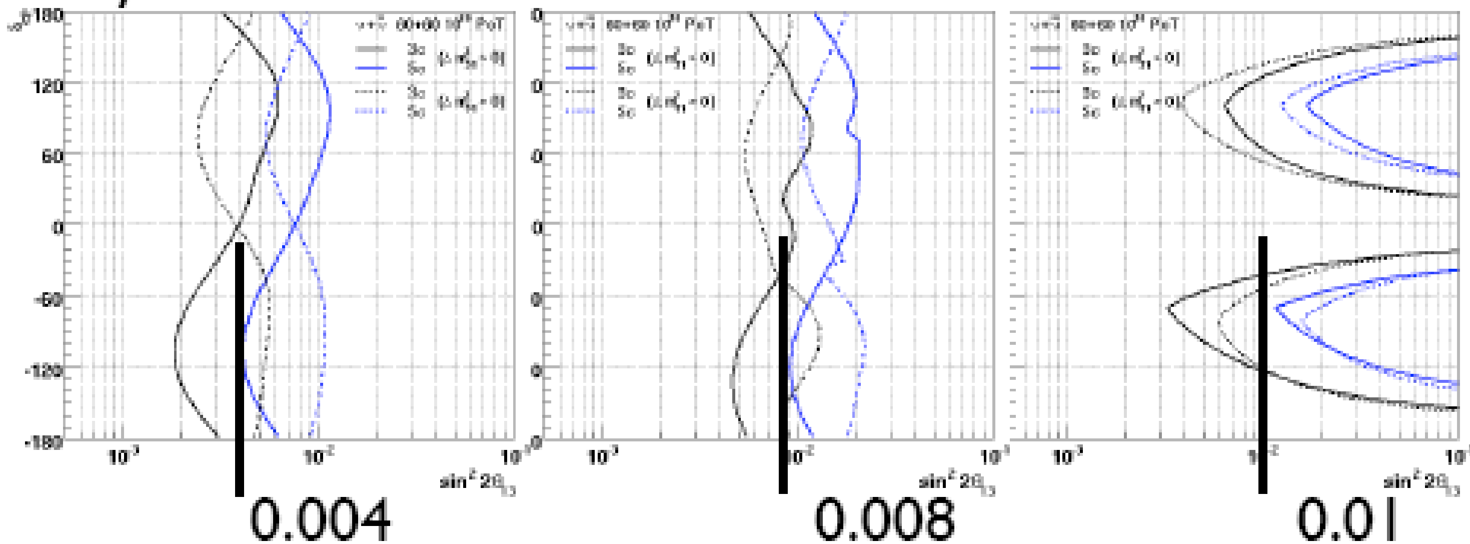
WBLE to DUSEL(1300km) 3sig, 5sig discovery regions.

300 kT WCh

Stat+syst

60 10^20 POT for each nu and anu

th13 mass ordering CP violation



CP Fraction: Fraction of the CP phase (0-2pi) covered at a particular confidence level.

Report the value of th13 at the 50% CP fraction.

Europe

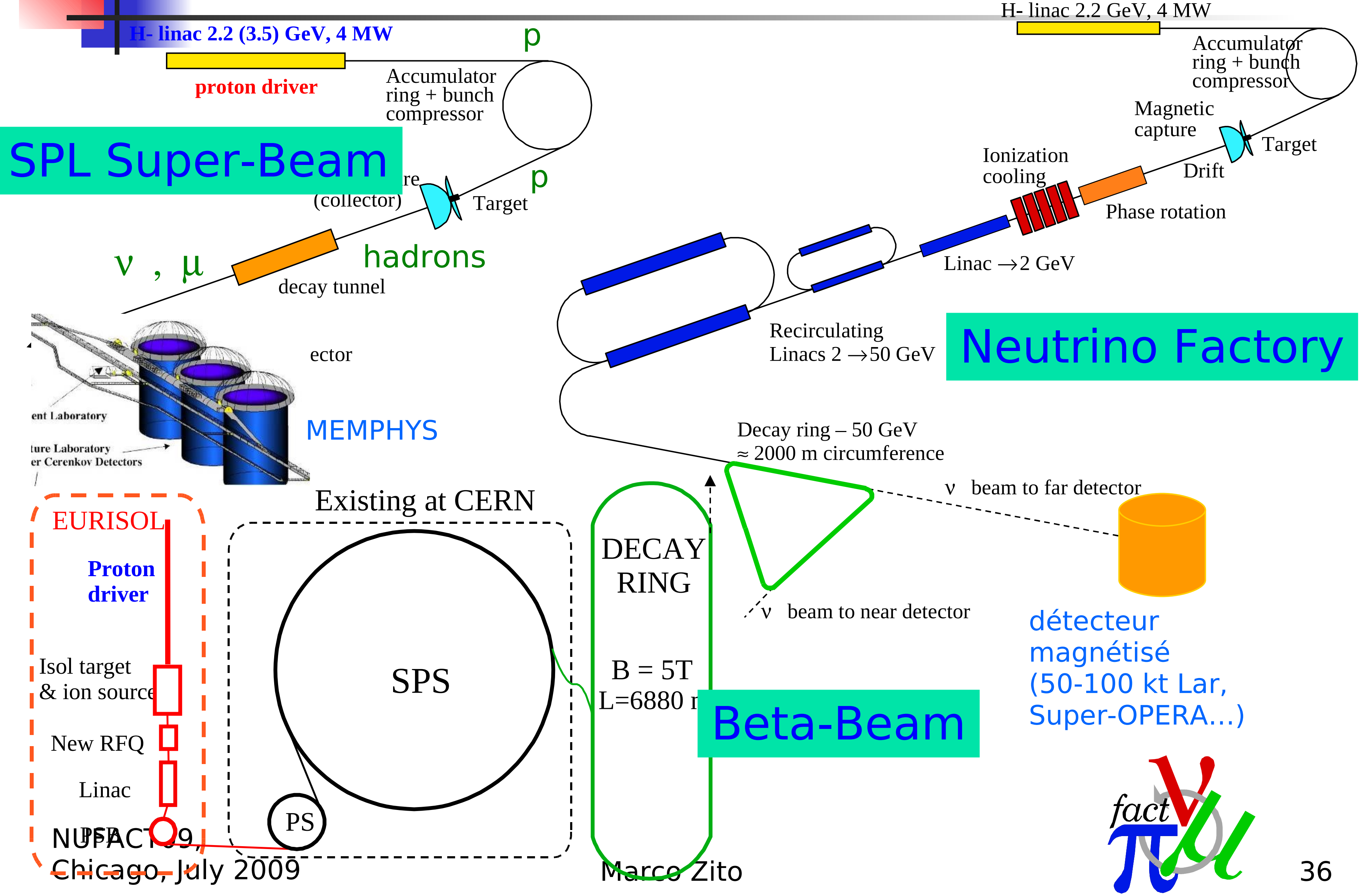
- Start of design studies FP7 EUROnu (2008-2012, beams) et LAGUNA (2008-2010, underground labs)
- CERN: Workshop “New Physics Opportunities” (may 2009) and Workshop Neutrinos (october 2009)

CERN workshop (1-3 October 2009)

The workshop is also directly related to the work of the Panel on Future Neutrino Facilities, established by the Scientific Policy Committee in December 2008 at the request of the CERN Council.

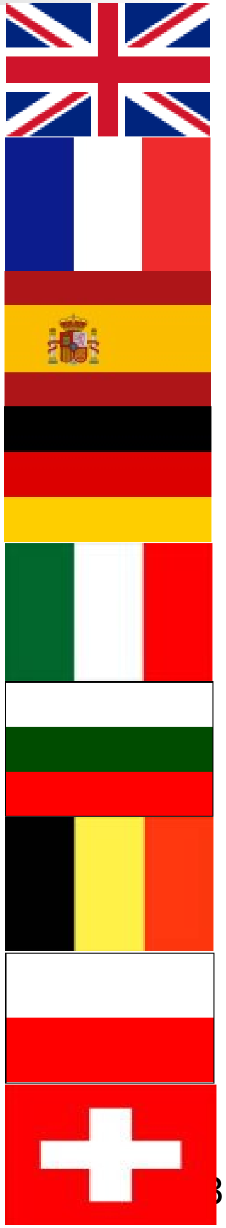
This request concerns “Relations between CERN and the ongoing development work regarding future neutrino facilities”, and specifically requests answers concerning the importance of precise measurements of the neutrino oscillation parameters, CERN’s role in the R&D work for future neutrino facilities, irrespective of where they would be sited, and to what degree neutrino experimentation should have a place on the future CERN roadmap.

EUROnu: what beam for a neutrino oscillation facility ?



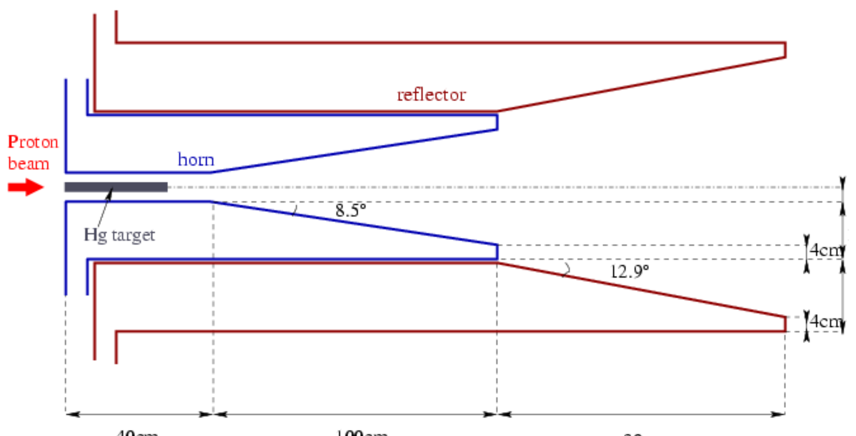
EUROnu Participants

Participant no. *	Participant organisation name	Part. short name	Country
1 (Coordinator)	Science and Technology Facilities Council	STFC	UK
2	Commissariat à l'Energie Atomique	CEA	France
3	European Organisation for Nuclear Research	CERN	Switzerland
4	University of Glasgow	Glasgow	UK
5	Imperial College of Science, Technology and Medicine	Imperial	UK
6	Consejo Superior de Investigaciones Cientificas	CSIC	Spain
7	Centre National de la Recherche Scientifique	CNRS	France
8	Cracow University of Technology	CUT	Poland
9	University of Durham	UDUR	UK
10	Istituto Nazionale di Fisica Nucleare	INFN	Italy
11	Max-Planck-Gesellschaft zur Frderung der Wissenschaften e.V. (Max-Planck-Instiut fuer Kernphysik, Heidelberg)	MPG	Germany
12	The Chancellor, Masters and Scholars of the University of Oxford	UOXF.DL	UK
13	Sofia University St. Kliment Ohridski	UniSofia	Bulgaria
14	University of Warwick	Warwick	UK
15	Université Catholique de Louvain	UCL	Belgium



EUROnu SuperBeam studies

- Aim: prepare a CDR for an european SuperBeam
- Proton driver: SPL HP option 4 MW, 5 GeV
- Baseline: CERN to Fréjus (130 km)
- Target concepts: start studies of a solid graphite target (T2K like, length 78cm, diam. 2.6cm)
- Possible progression according the needs:
  - Multiple (4) targets
  - Powder jet
- Simulation, optimization and physics reach: studies resumed
- Optimization of horn under way
- see **A. Longhin talk on friday**



SPL

CERN–2006–0
12 July 2006

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIR

CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCI .

Conceptual design of the SPL II

A high-power superconducting H^- linac at CERN

F. Gerigk (Editor), M. Baylac[1], E. Benedico Mora, F. Caspers, S. Chel[2], J.M. Deconto[1], R. Duperrie
E. Froidefond[1], R. Garoby, K. Hanke, C. Hill, M. Hori[3], J. Inigo-Golfin, K. Kahle, T. Kroyer,
D. Kuechler, J.-B. Lallement, M. Lindroos, A.M. Lombardi, A. López Hernández, M. Magistris,
T.K. Meinschad, A. Millich, E. Noah Messomo, C. Pagani[4], V. Palladino[5], M. Paoluzzi, M. Pasini
P. Pierini[4], C. Rossi, J.P. Royer, M. Sanmarti, E. Sargsyan, R. Scrivens, M. Silari, T. Steiner,
J. Tückmantel, D. Uriot[2], M. Vretenar

Figure 1: Layout of the new proton injector complex at CERN.

Table 1: Parameters of the "nominal" SPL and of the low-power LP-SPL.

	unit	*SPL*	*LP-SPL*
Energy	[GeV]	5.0	4.0
Beam power (for ν factory)	[MW]	4.0	0.192
Repetition rate	[Hz]	50	2
Average pulse current	[mA]	40	20
Peak pulse current	[mA]	64	32
Chopping ratio	[%]	62	62
Beam Pulse length	[ms]	0.6	1.2
Protons per pulse for PS2	[10^{14}]	1.5	1.5
Beam duty cycle	[%]	2.0	0.24
Number of klystrons (LEP)		14	14
Number of klystrons (704 MHz)		57	28
Peak RF power	[MW]	219	100
Average power consumption	[MW]	38.5	4.5
Cryogenics av. power consumption	[MW]	4.5	1.5
Cryogenic temperature	[K]	2.0	2.0
Length	[m]	534	459

EUROnu: Simulation of the CERN-Fréjus SuperBeam

see **A. Longhin talk on friday**

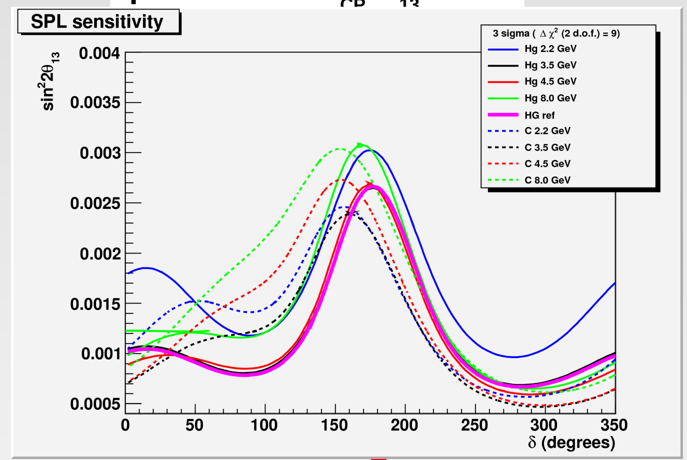
- Full simulation chain with latest software tools (FLUKA+GEANT4)
- Focus on solid target option

-more realistic and feasible than liquid mercury target as originally envisaged

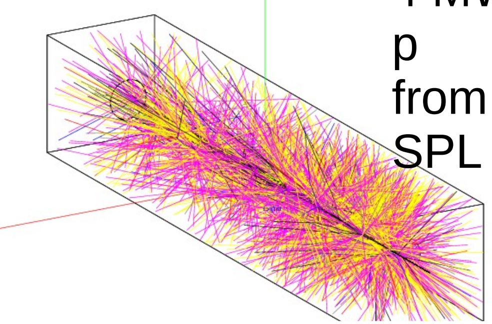
-very promising results: physics reach not compromised !

-design of an optimized focusing system is ongoing

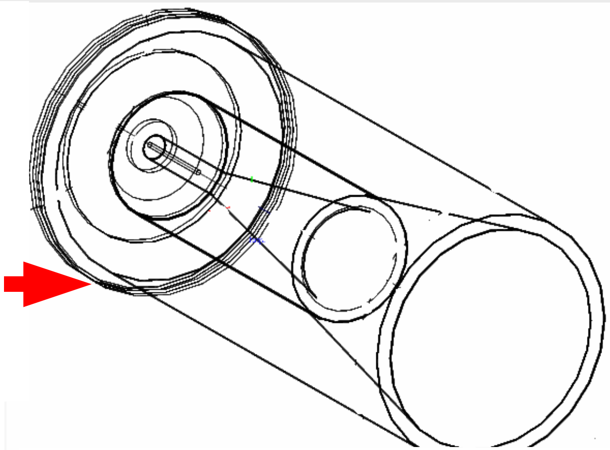
Sensitivity on fundamental parameters: δ_{CP}, θ_{13}



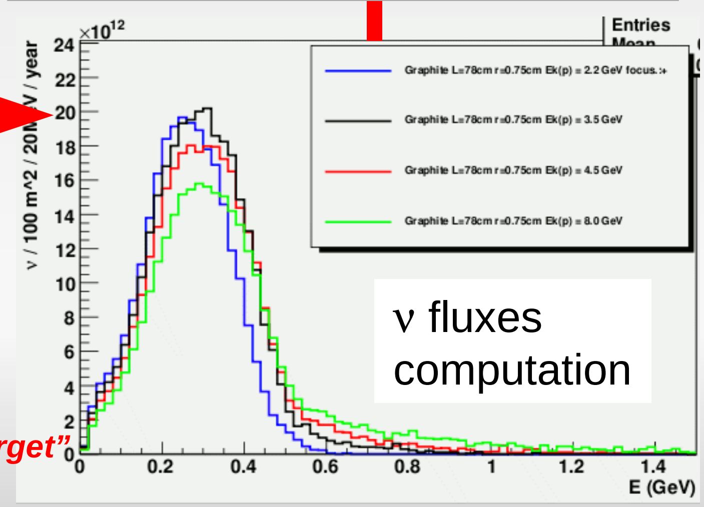
- 4 MW p from SPL



primary π/K production (FLUKA)



π/K focusing with magnetic horn (GEANT4)



ν fluxes computation

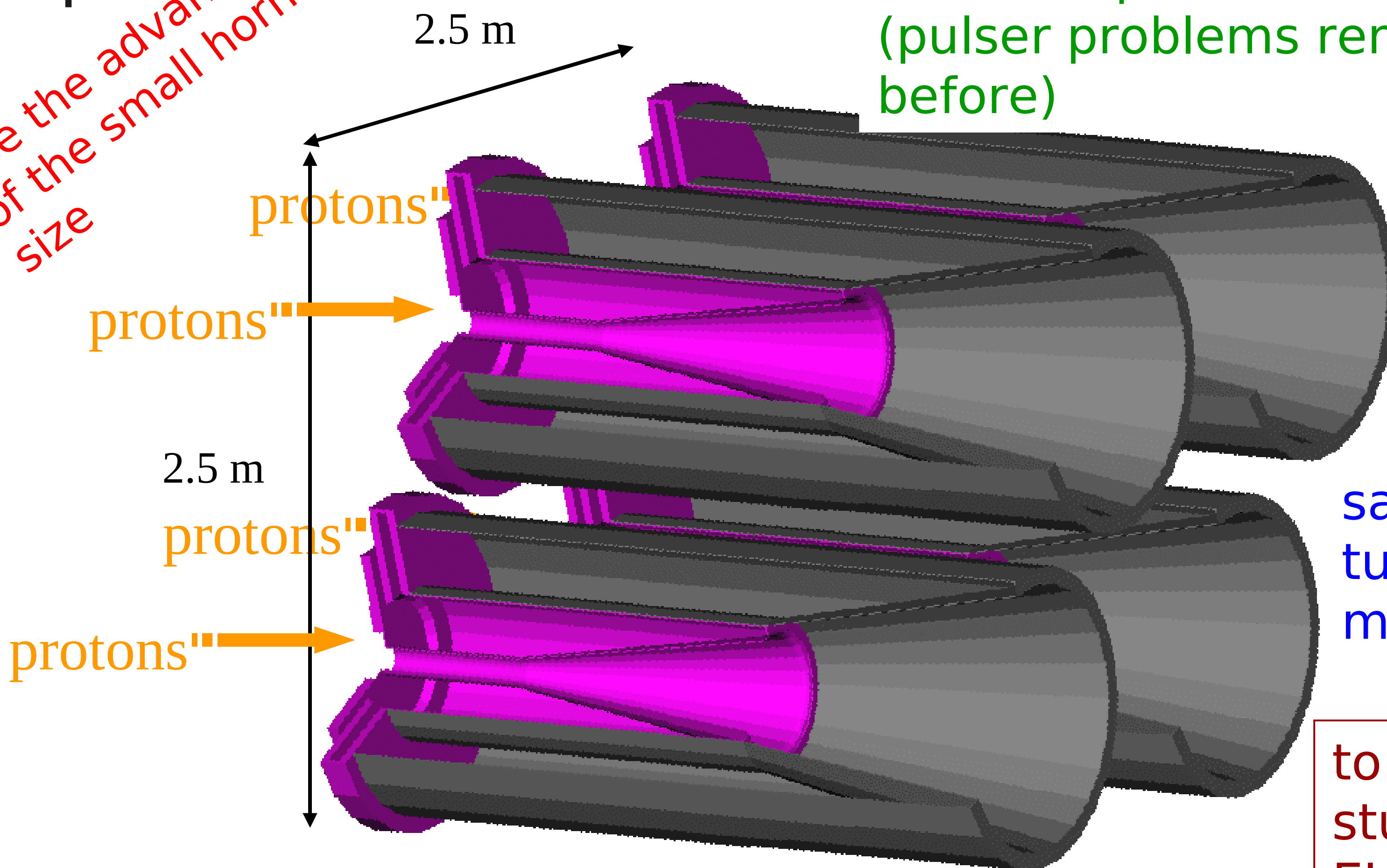
"Study of the performance of the SPL-Frèjus Super Beam using a graphite target"
A. Longhin. EUROnu note (available on www.euronu.org)

Possible scheme to mitigate the target difficulty

M. Dracos

use the advantage of the small horn size

minimize power dissipation and radiation problems
(pulser problems remain as before)

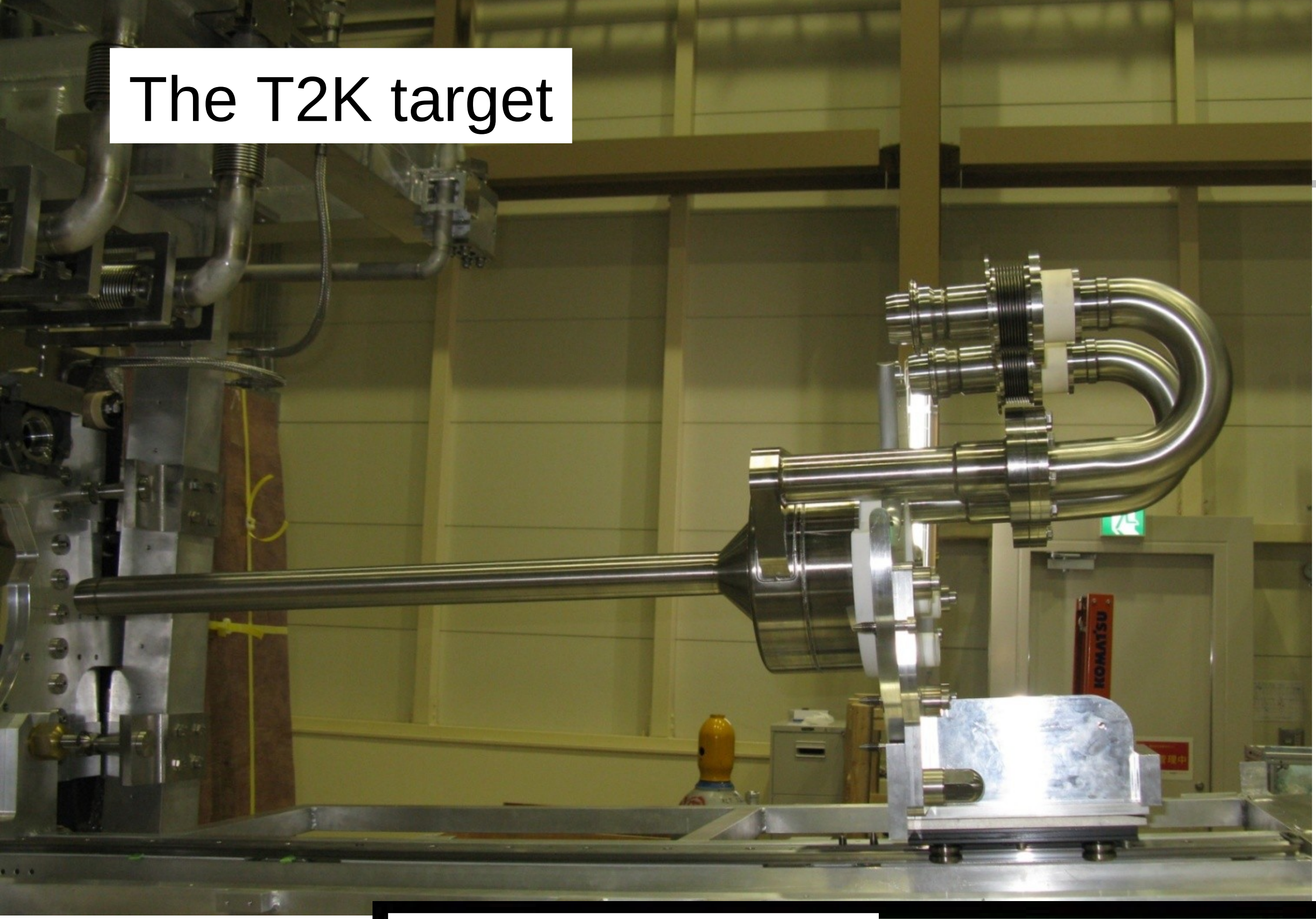


same decay tunnel Ø 3 m

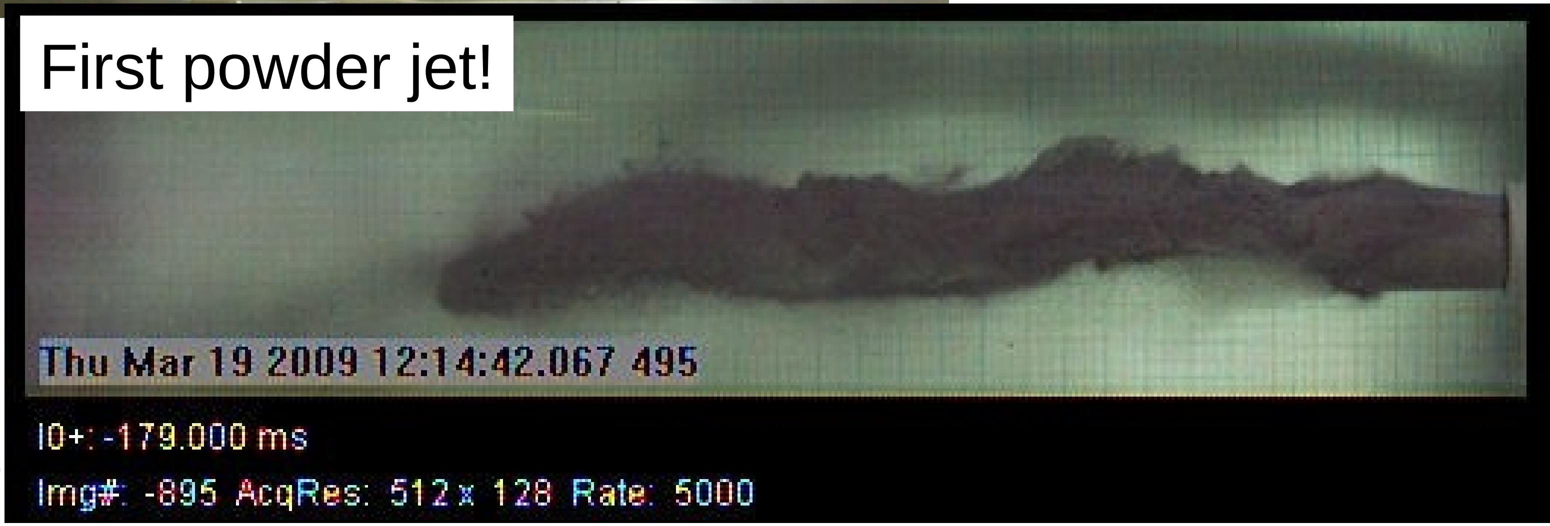
to be studied in EUROν

2 options:

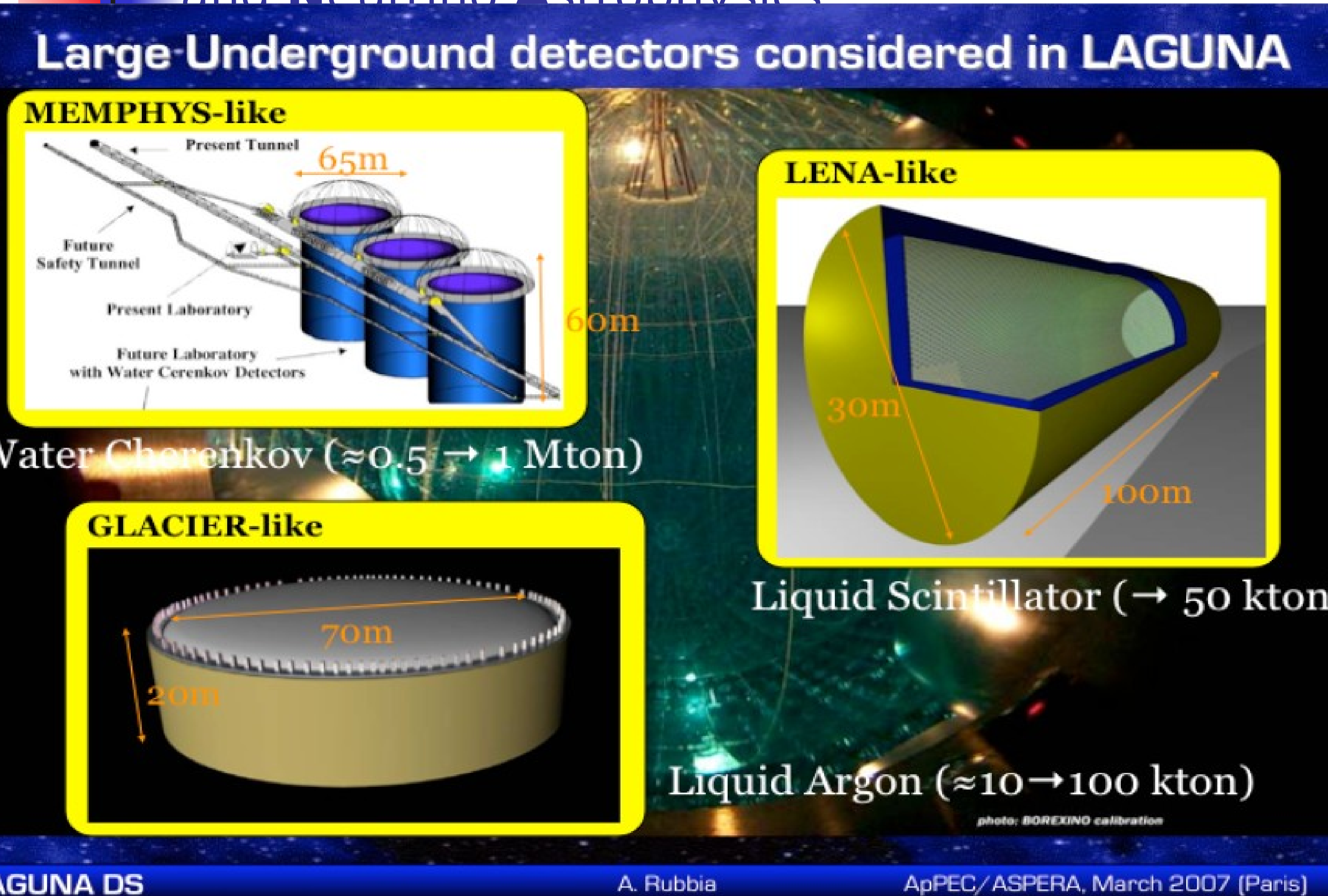
- send at the same time 1 MW per target/horn system
- send 4 MW/system every 50/4 Hz → possibility to use solid target?



C. Densham,
M. Fitton, O. Caretta



Large Apparatus for Grand Unification and Neutrino Astrophysics



Possible location of the future large underground laboratory

Candidate sites
1. Boulby, UK
2. Canfranc, Spain
3. Fréjus, France
4. Pyhäsalmi, Finland
5. Sieroszowice, Poland
6. Slanic, Romania
7. Caso, Italy

LAGUNA is studying a rich number of European options

A. Rubbia

Studies of a new CNXX beam ongoing

SuperBeam strategies

- SuperBeam strategies are widely different from long baseline-wide band beam (US) to shorter baseline-narrow beam (CERN->Fréjus)
- Also some span of timelines
- Many similar problems across the projects (targets, tools, detectors)
- Far detector (Water Cherenkov vs Lar) ?
- NuFact may play a beneficial role as the forum where SuperBeams problems, solutions and experiences can be exchanged

Conclusions

- T2K neutrino beam started in 2009!
- First results expected in 2010
- NOvA groundbeaking
- The first results on θ_{13} will give crucial hints for the future experimental program
- Active studies ongoing for future SuperBeam facilities

Three flavour osc. parameters summary

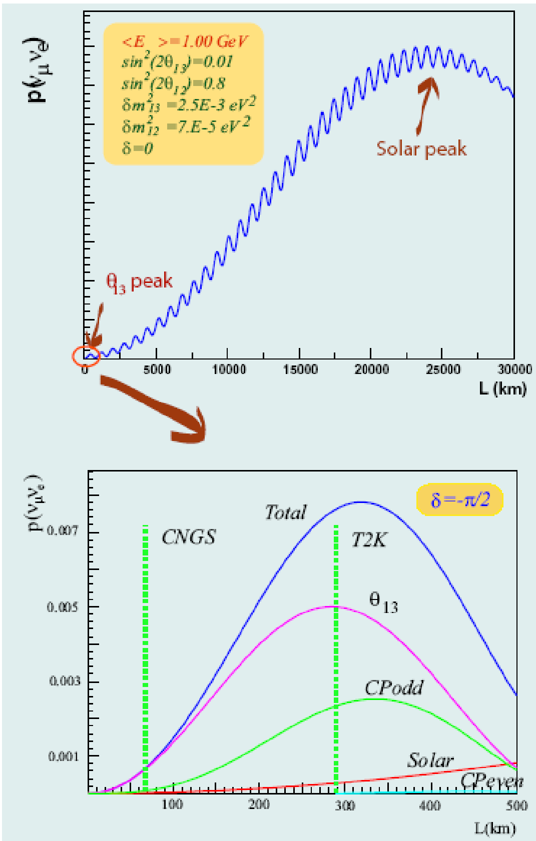
	bf $\pm 1\sigma$	acc. @ 3σ	
Δm^2_{21}	$(7.65^{+0.23}_{-0.20})\,10^{-5}\,\mathrm{eV}^2$	(8%)	KamLAND
$\sin^2\theta_{12}$	$0.304^{+0.022}_{-0.016}$	(19%)	SNO
$\|\Delta m^2_{31}\|$	$(2.40^{+0.12}_{-0.11})\,10^{-3}\,\mathrm{eV}^2$	(14%)	MINOS
$\sin^2\theta_{23}$	$0.50^{+0.07}_{-0.06}$	(30%)	SK atm

$\sin^2\theta_{13} < 0.056$ @ 3σ CHOOZ

TS, Tortola, Valle, 0808.2016

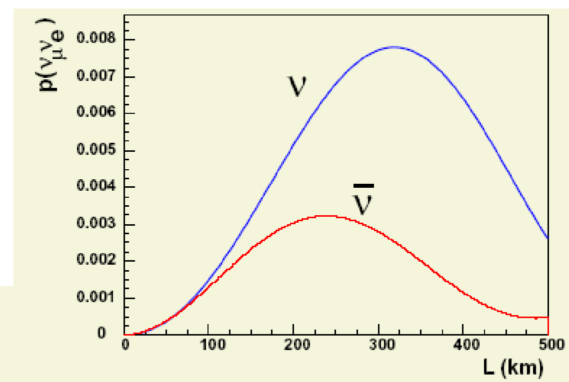
M. Mezzetto

Sub leading $\nu_\mu - \nu_e$ oscillations



$$
\begin{aligned}
p(\nu_\mu \rightarrow \nu_e) = {} & 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} && \theta_{13} \text{ driven} \\
& + 8c_{13}^2 s_{12} s_{13} s_{23} (c_{12} c_{23} \cos\delta - s_{12} s_{13} s_{23}) \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} && \text{CPeven} \\
& - 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin\delta \sin \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} && \text{CPodd} \\
& + 4s_{12}^2 c_{13}^2 \{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12} c_{23} s_{12} s_{23} s_{13} \cos\delta\} \sin \frac{\Delta m_{12}^2 L}{4E} && \text{solar driven} \\
& - 8c_{12}^2 s_{13}^2 s_{23}^2 \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E} (1 - 2s_{13}^2) && \text{matter effect (CP odd)}
\end{aligned}
$$

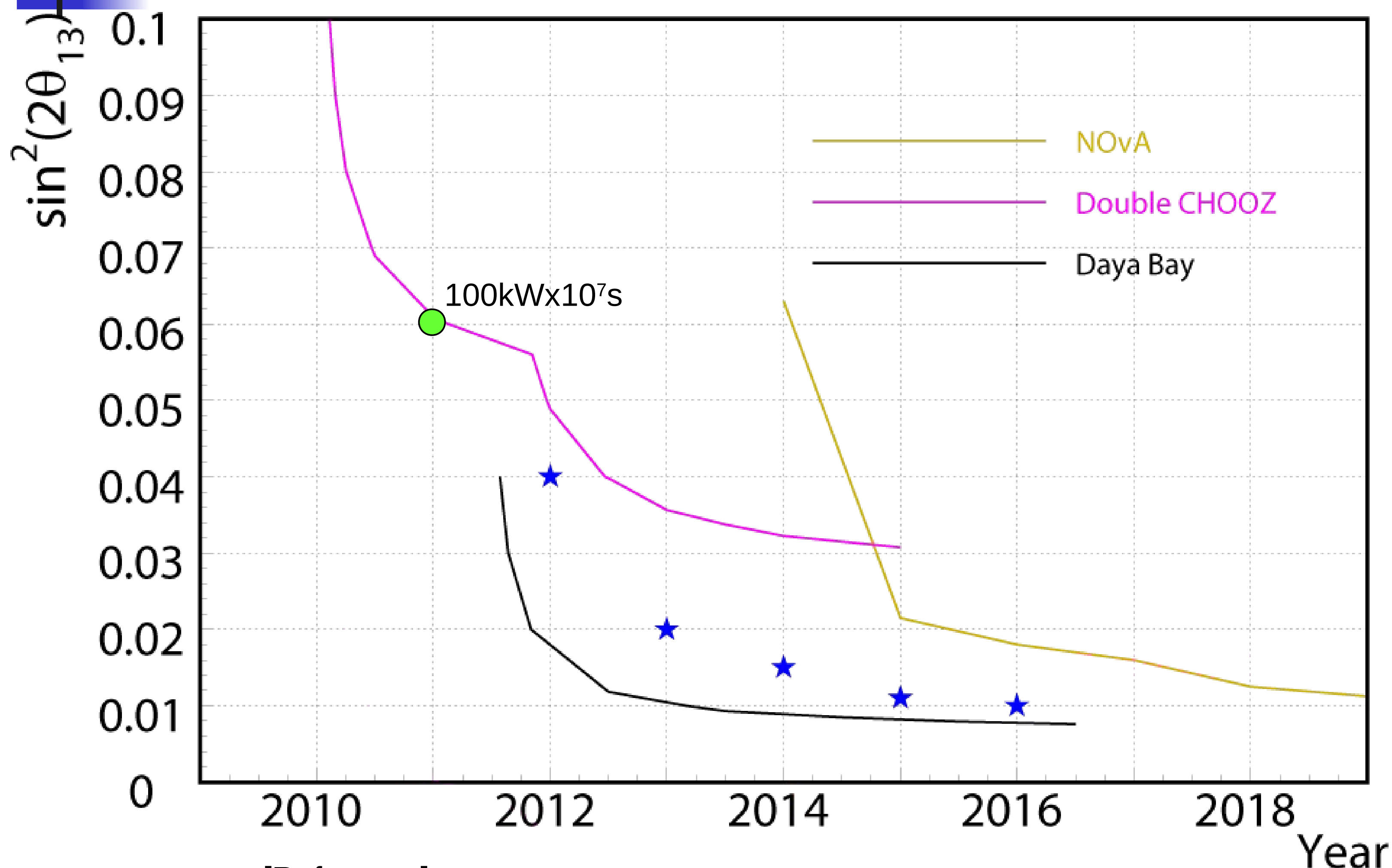
θ_{13} discovery requires total probability greater than solar driven probability



Leptonic CP discovery requires

$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\bar\nu_\mu \to \bar\nu_e)}{P(\nu_\mu \to \nu_e) + P(\bar\nu_\mu \to \bar\nu_e)} \neq 0$$

$Sin^2 2\theta_{13}$ sensitivity (90% CL)



[Reference]
NOvA: M. Messier, FNAL Director's CD-3b Review, 2009/6/16
Double CHOOZ: A. Porta, Rencontres de Moriond EW 2009, 2009/3/13
Daya Bay: P. Rubin, ibid