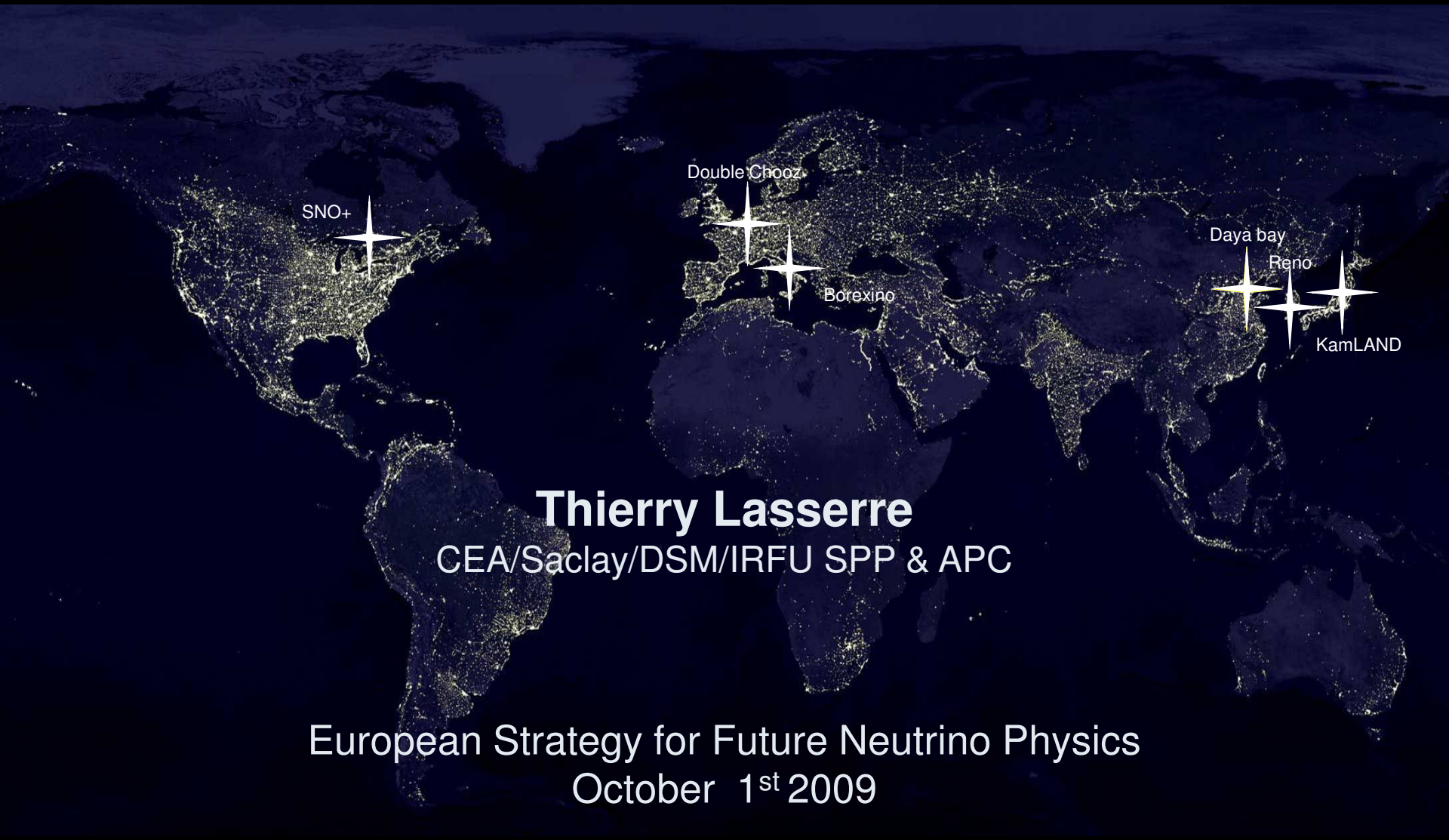
Reactor Neutrino Experiments



Thierry Lasserre
CEA/Saclay/DSM/IRFU SPP & APC

European Strategy for Future Neutrino Physics
October 1st 2009

MeV Reactor Neutrinos

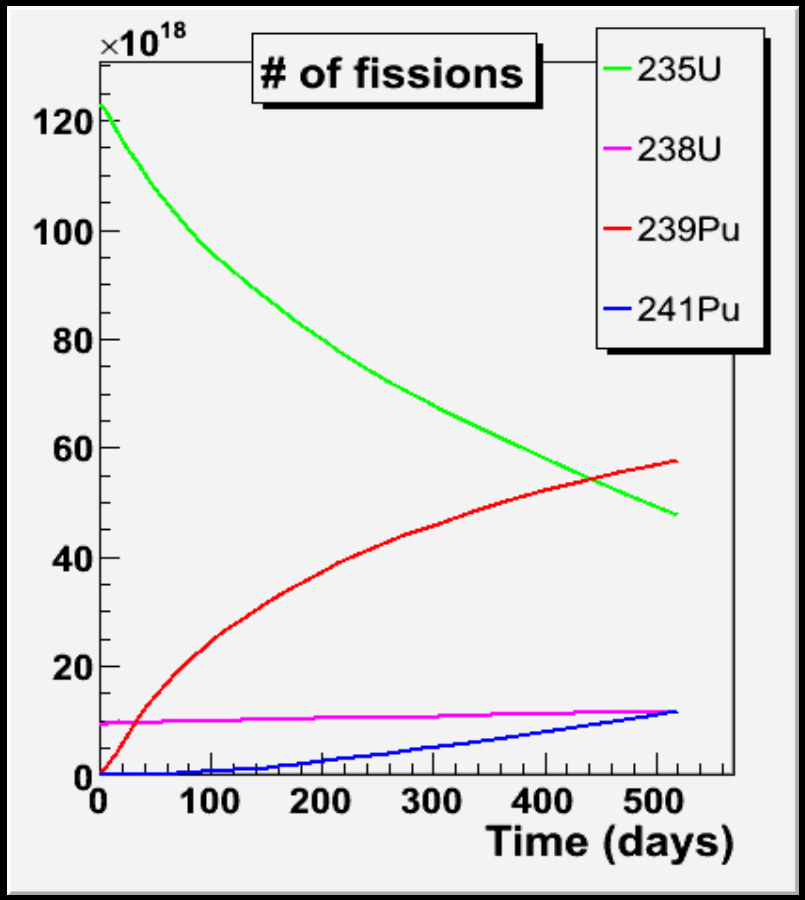
- **Electron antineutrinos Emitted through Decays of Fission Products**
  - FP of: ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu
  - $^{238}_{92}U + n \rightarrow {}^{239}_{92}U \xrightarrow{23\,min} {}^{239}_{93}Np \xrightarrow{2.3\,d} {}^{239}_{94}Pu$
- **Luminosity**

$$1\,GW_{th} \Leftrightarrow 2.10^{20}\,\nu/s$$

$$N_{\bar{\nu}} = \gamma(1+k)P_{th}$$

γ: reactor constant

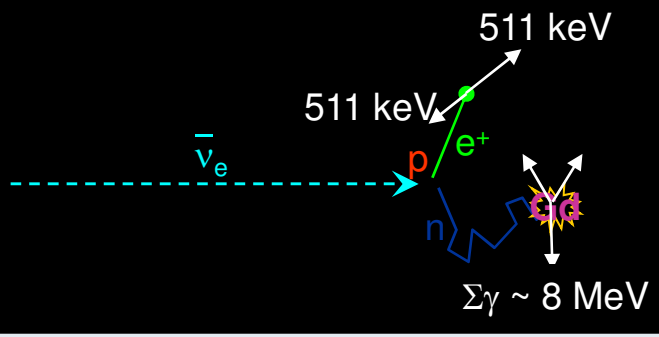
k : burn up dependent correction
up to 10%



t_0: ~3.5% ^{235}U, 96.5% ^{238}U

Backgrounds & Signal

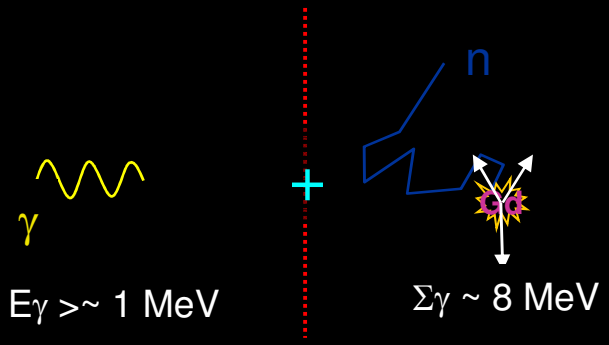
Electron antineutrino signature through inverse beta decay



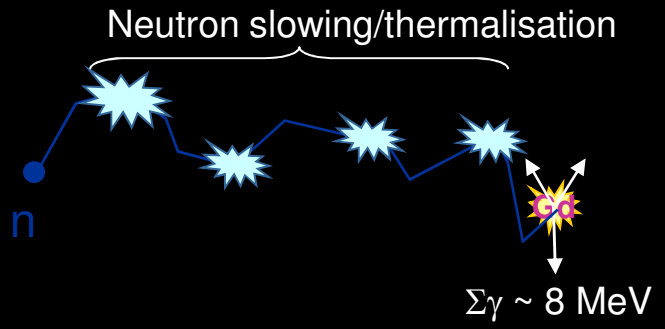
Prompt e^+ (1-8 MeV) Delayed n Gd-capture (8 MeV)

Time correlation: τ~30 μs Space correlation: <1 m

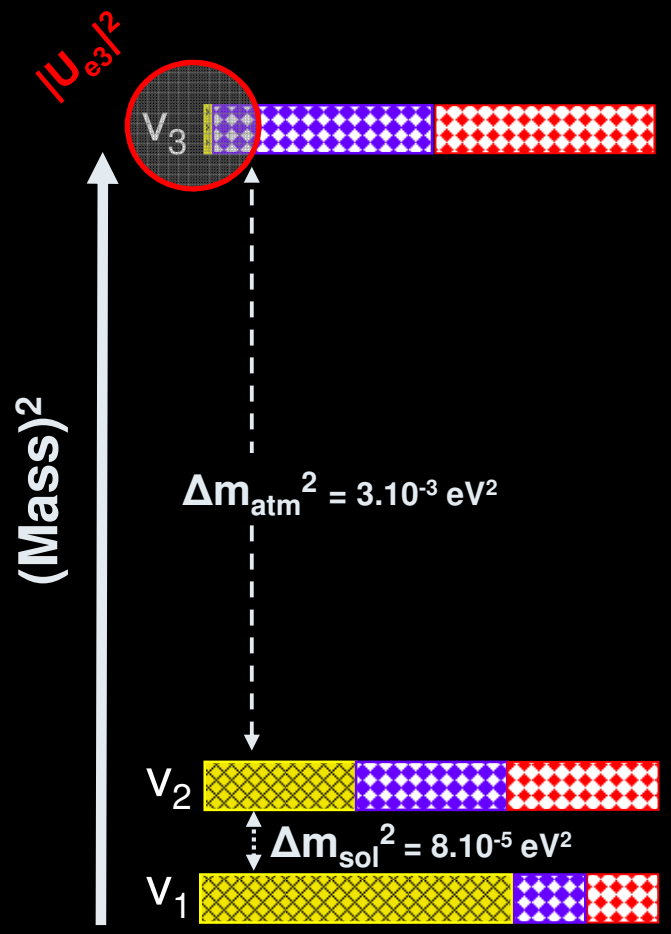
Accidental Background



Correlated Background



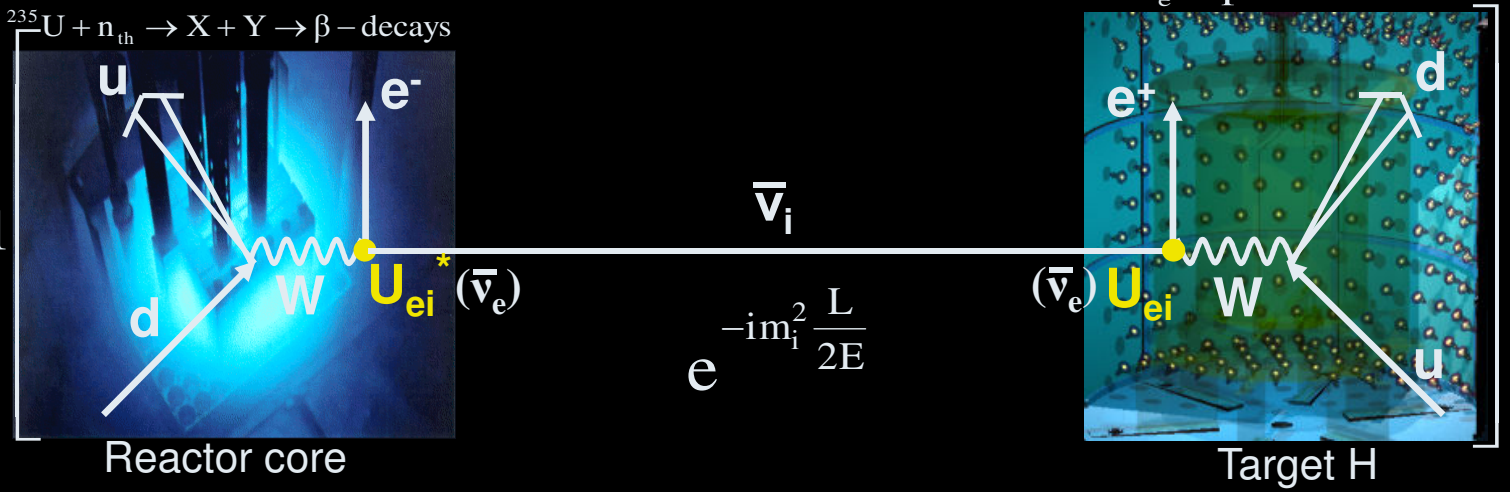
θ_{13}



ν_e $|U_{ei}|^2$ ν_μ $|U_{\mu i}|^2$ ν_T $|U_{Ti}|^2$

Underlying ν-Oscillation Physics

$$P(\bar{\nu}_e \to \bar{\nu}_e) = \left| \sum_{i=1,2,3} \text{Ampl} \right|^2$$



$$P(\bar{\nu}_e \to \bar{\nu}_e) = \left[\sum_i U_{ei}^* e^{-im_i^2 \frac{L}{2E}} U_{ei} \right]^2 = 1 - \sin^2(2\theta_{13}) \left[\sin\left(1.27 \frac{\Delta m^2_{atm\ (eV^2)} L_{(m)}}{E_{(MeV)}} \right) + O\left(\frac{\Delta m^2_{sol}}{\Delta m^2_{atm}}\right) \right]$$

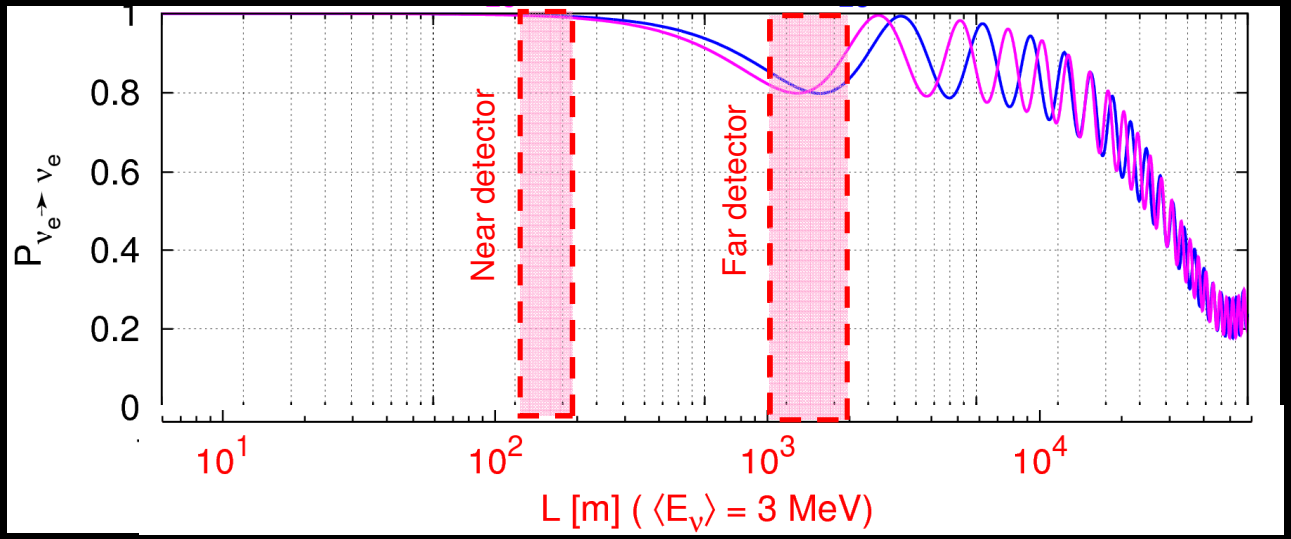
- Simple oscillation formula
  - ➔ depends $\sin^2(2\theta_{13})$ & Δm^2_{atm}, weakly on Δm^2_{sol}
- MeV electron antineutrinos ➔ only disappearance experiments
  - ➔ $\sin^2(2\theta_{13})$ measurement independent of δ-CP
- MeV neutrinos + 1 km baseline → negligible matter effects O[10^{-4}]
  - ➔ $\sin^2(2\theta_{13})$ measurement independent of sign(Δm^2_{13})

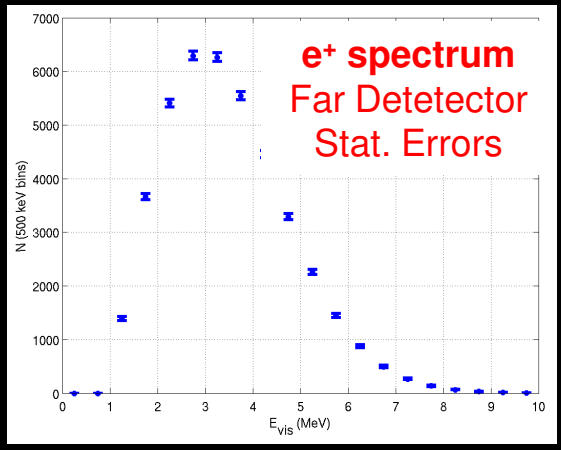
'clean' θ_{13} information

The experimental concept for θ_{13}

Lev Mikaelyan (Kurchatov, 2000)

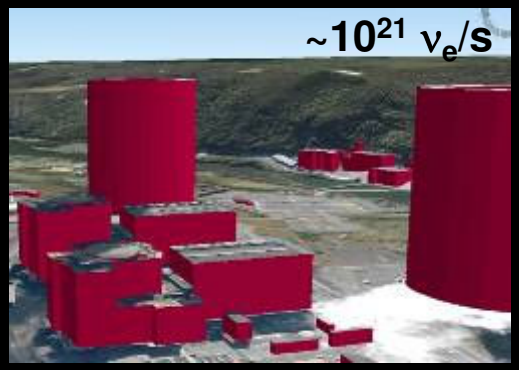
$P(\nu_e \rightarrow \nu_e) = 1-\sin^2(2\theta_{13})\sin^2(\Delta m^2_{31} L/4E)$





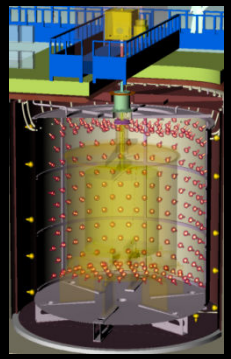
$\Delta m^2_{atm} = 3.0\ 10^{-3}\ eV^2$

$\sin^2(2\theta_{13}) = 0.12$



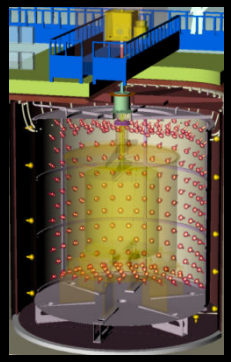
Nuclear Power Station

$\bar{\nu}_e$

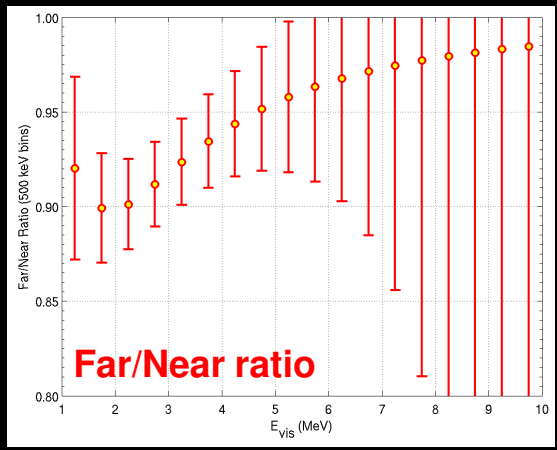


Near detecto'(s)
<500 m

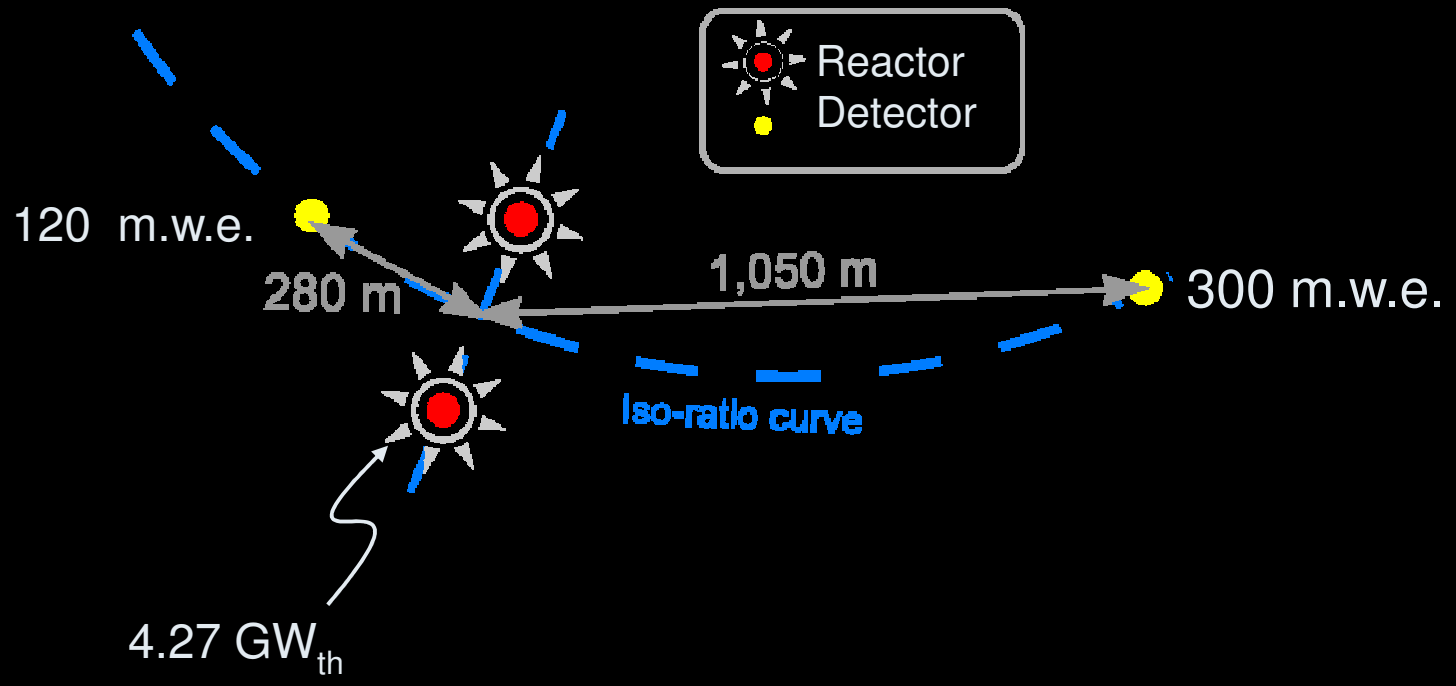
$\bar{\nu}_{e,\mu,\tau}$



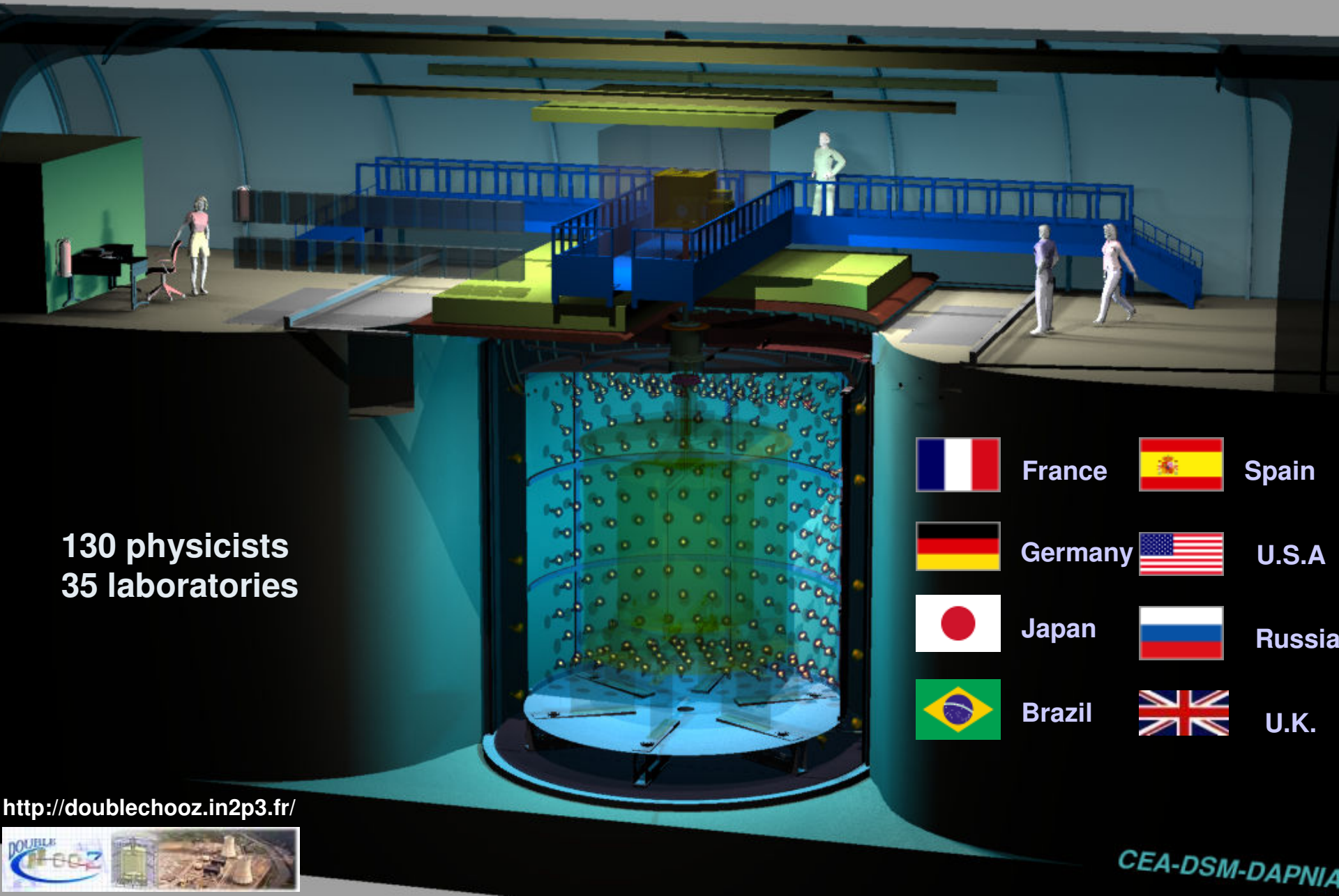
Far detector(s)
1-2 km



Double Chooz



Double Chooz



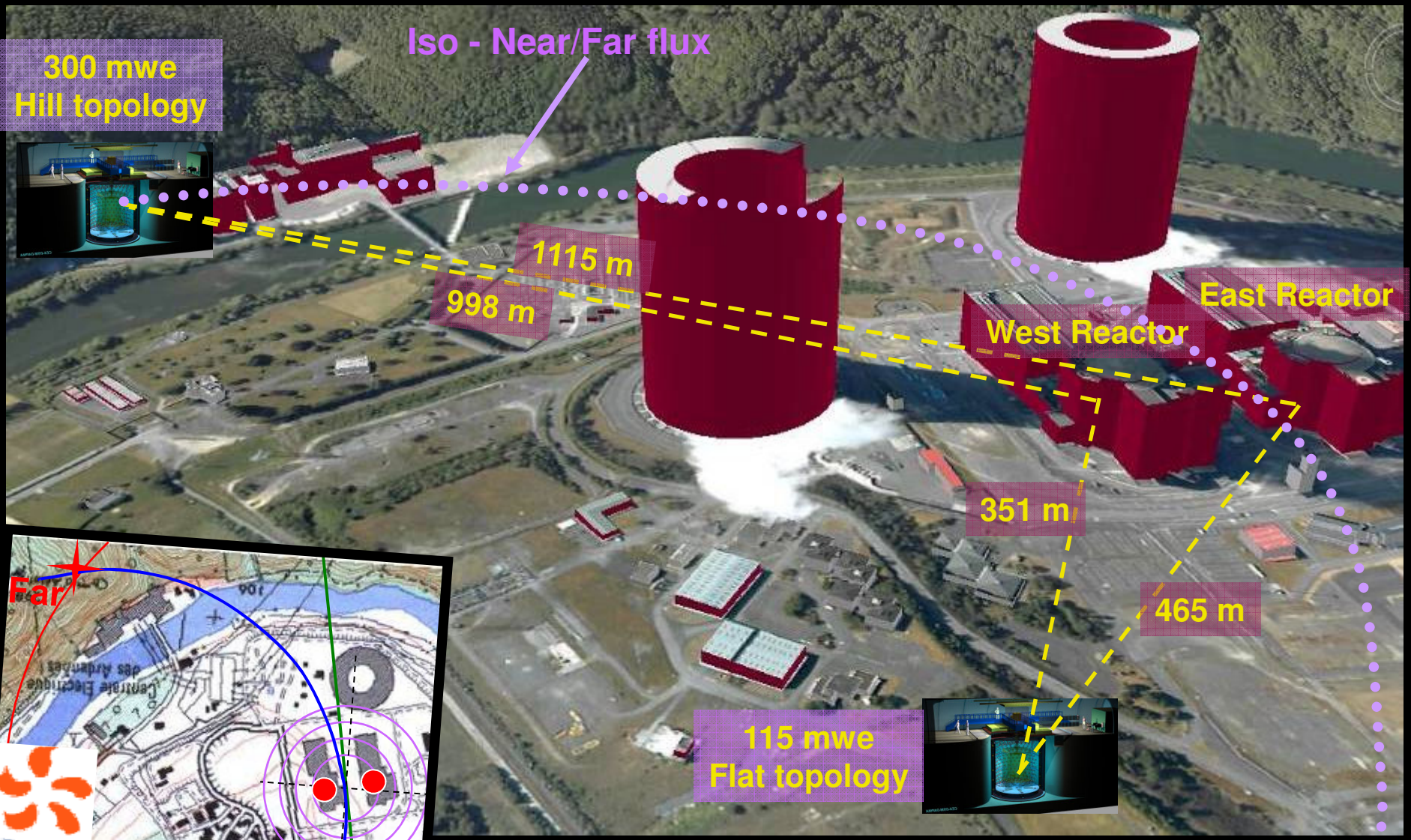
130 physicists
35 laboratories

France
Spain
Germany
U.S.A
Japan
Russia
Brazil
U.K.

http://doublechooz.in2p3.fr/

CEA-DSM-DAPNIA

Chooz site in French Ardennes



Far Site Status

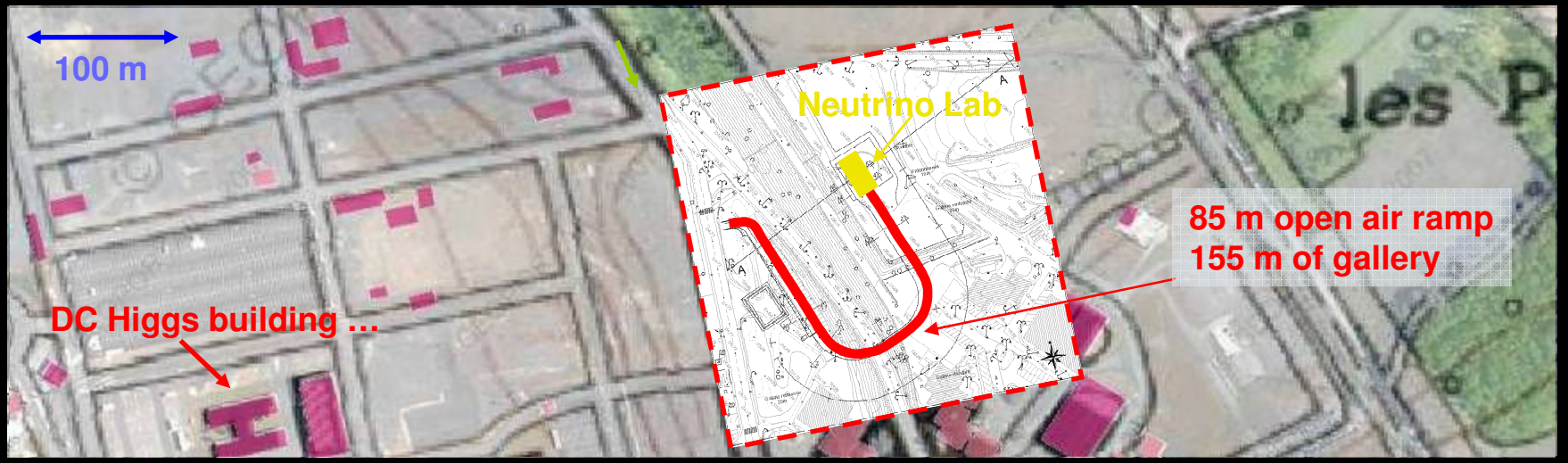
- Laboratory status:
- Site of the CHOOZ experiment
- Integration ongoing

- **Features:**
- 1 km baseline (15 000 y^{-1})
- 300 m.w.e. (hill topology)
- μ-Rate: ~20 Hz @IV
- ISO 6 Clean Room

-Liquid storage building:
- Liquids delivery in Nov/Dec

Safety files accepted by French authorities (ASN)

Near Site Status



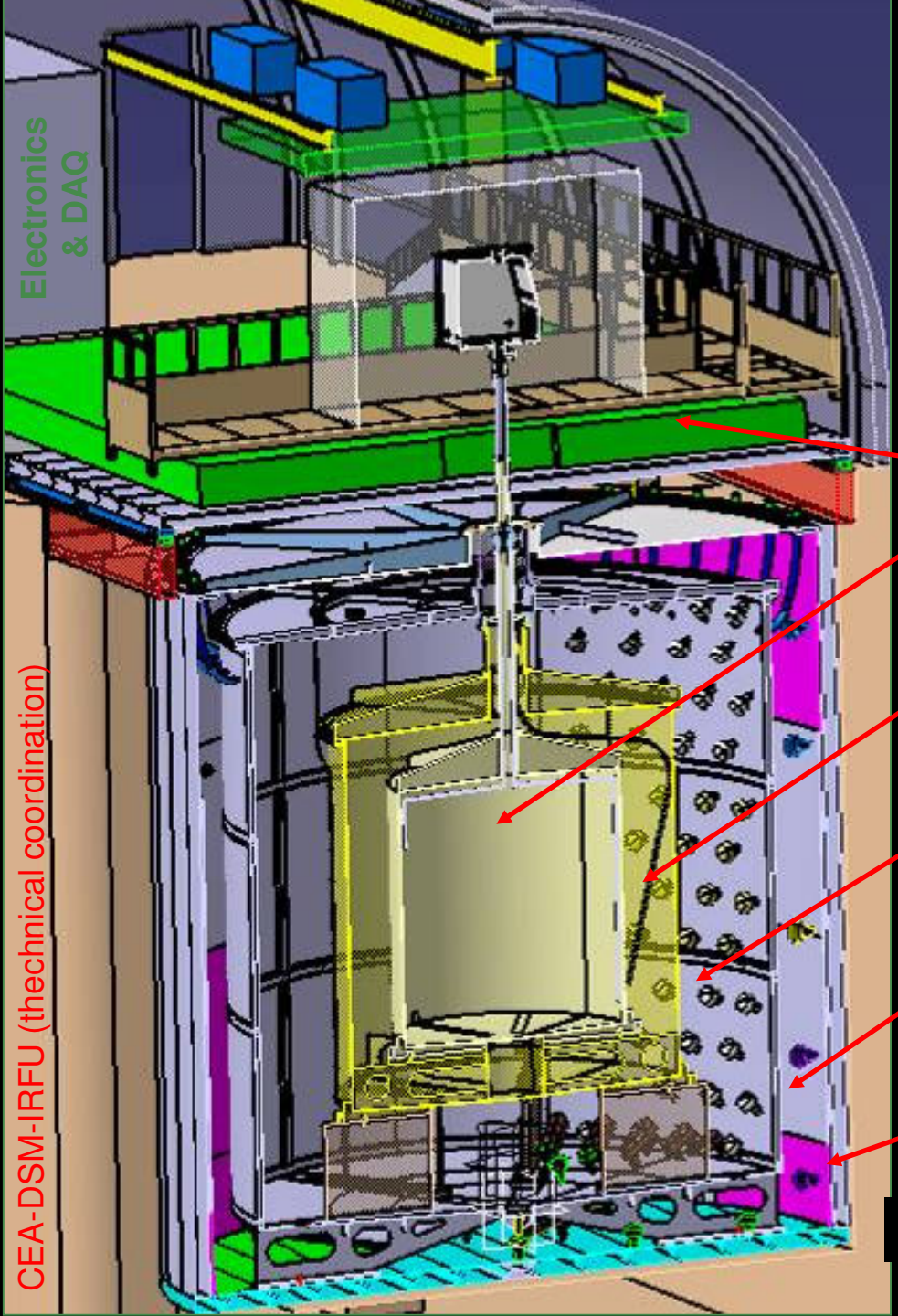
- Status:

- Fully Funded (7 partners)
- Site Engineering Study Completed
- Complementary bore hole study in Oct.
- Schedule: laboratory delivery mid-2011

- Features:

- 400 m from nuclear cores (150 000 y^{-1})
- A 155 m tunnel to access the new lab
- 115 m.w.e (almost flat topology)
- μ-Rate: ~250 Hz @IV

Schiste-Gres rock



Detector Design

New 4-region large detector concept from Double Chooz Coll. (2003)

http://bama.ua.edu/~busenitz/rnu2003_talks/lasserre1.doc

Outer Veto: plastic scintillator strips (400 mm)

ν-Target: 10,3 m^3 scintillator doped with 0,1g/l of Gd compound in an acryclic vessel (8 mm)

γ-Catcher: 22,3 m^3 scintillator in an acrylic vessel (12 mm)

Buffer: 110 m^3 of mineral oil in a stainless steel vessel (3 mm) viewed by 390 PMTs

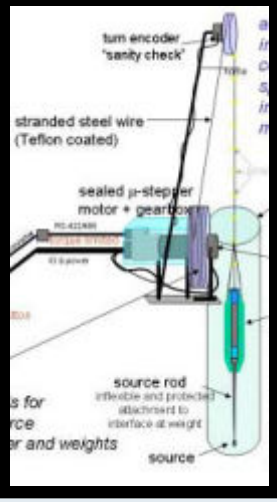
Inner Veto: 90m^3 of scintillator in a steel vessel equipped with 78 PMTs

Veto Vessel (10mm) & **Steel Shielding** (150 mm)

(4 liquid densities adjusted at 0,800 ⌖ 0,005)

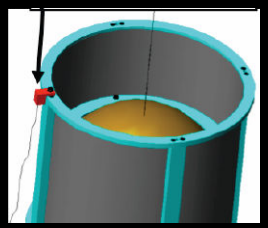
Detector Calibration Systems

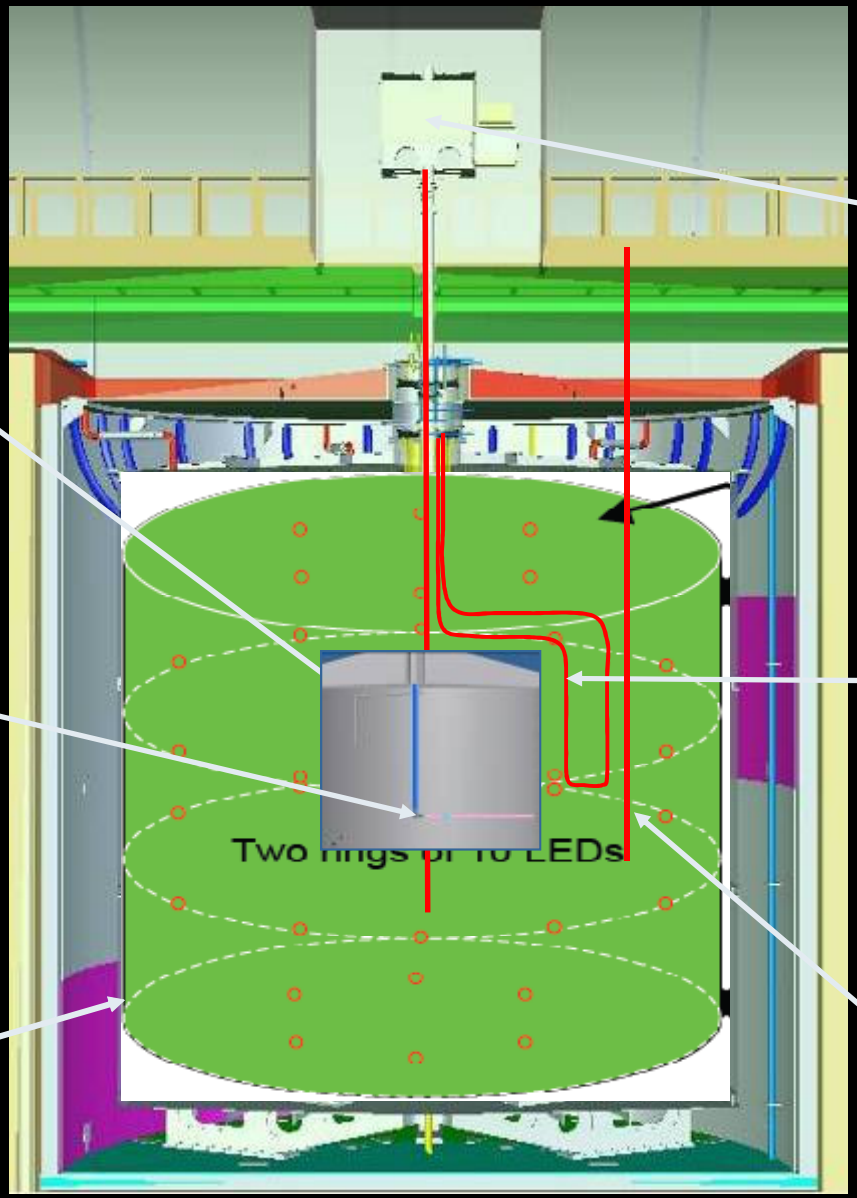
Fish-line



Articulated Arm

Embedded LED calibration system 385, 420, 470 nm





Glove Box

GC guide Tube

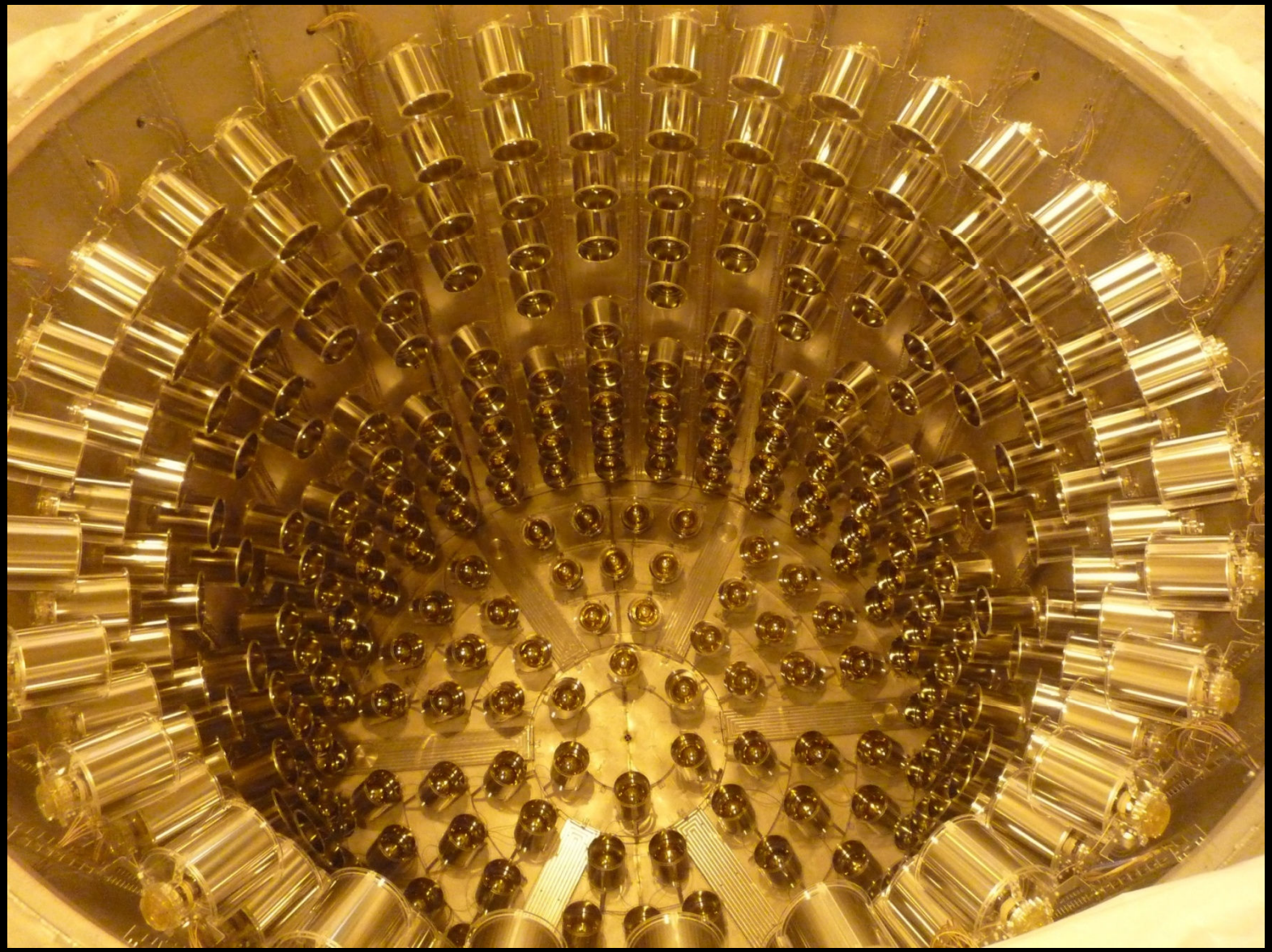
Buffer guide Tube

250 ton Steel Shielding

Inner Muon Veto

Inner Veto PMTs & Buffer Vessel

5/6 PMT Integration Completed

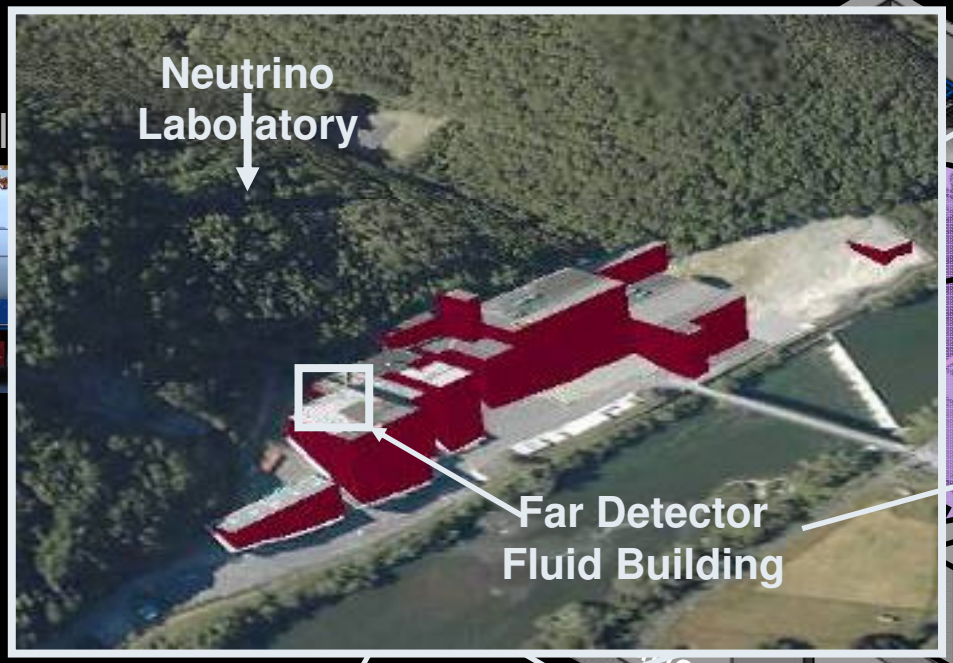


Acrylic Vessels

Integration Ongoing

Detector Filling

- 250 m^3 of liquid scintillator & mineral oil
- 22 m^3 Gd-Scintillator ready to be mixed
- Complex filling system to be installed by January 2010
- Target Weighing measurement @0,2% to control the number of free H



Target 4x6m^3

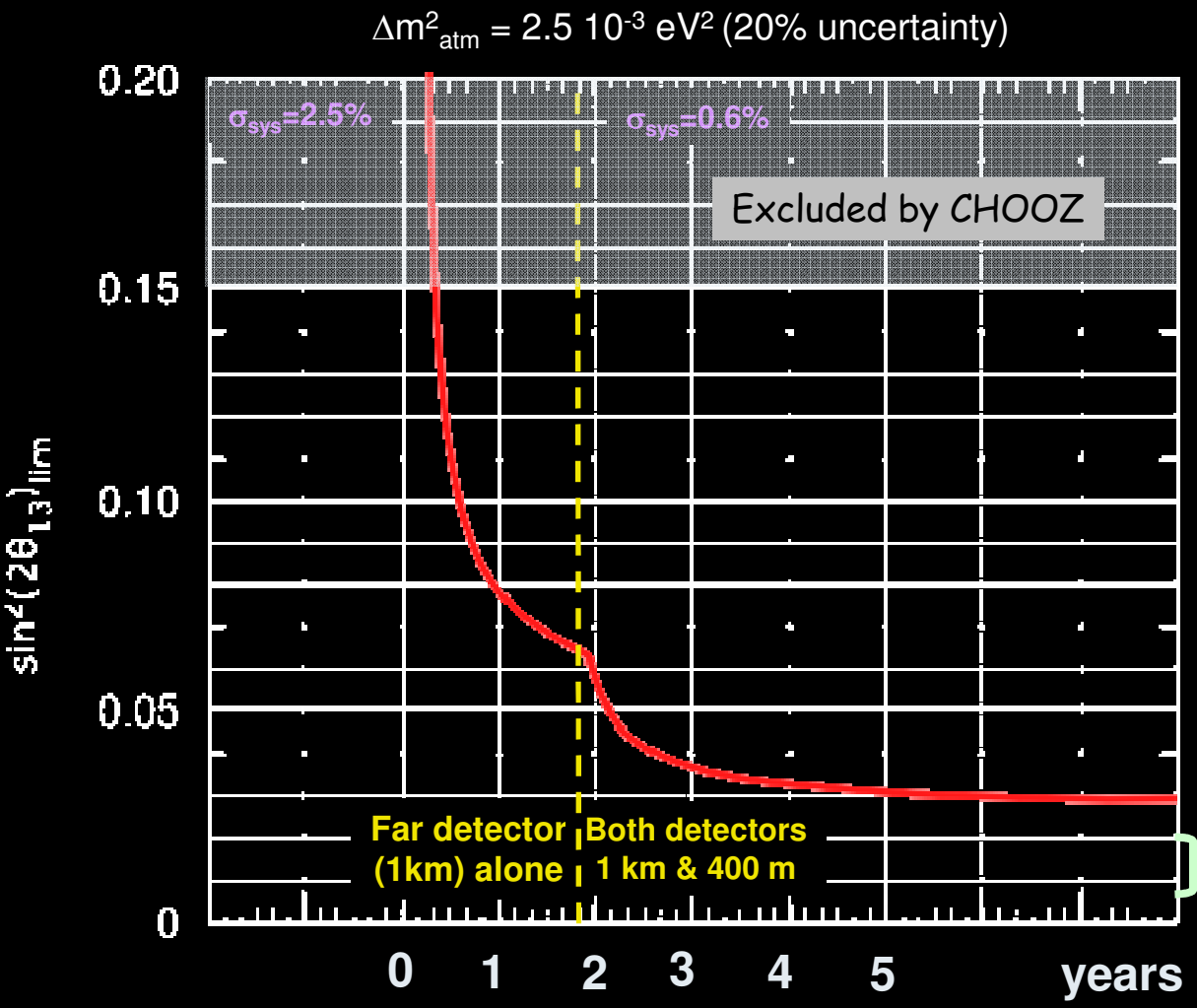
DFOS &
Auxilary,
Safety Systems

14 m

9 m

Veto Tank
3x30 m^3

Sensitivity (Limit) Timeline



- Efficiencies included
- 1% 'bin-bin' uncorrelated error on background subtraction.
- Systematics 1Det = CHOOZ
- Systematics 2Det:
  - σ_{abs} = 2.0%
  - σ_{rel} = 0.6%
  - σ_{scl} = 0.5%
  - σ_{shp} = 2.0%
  - $\sigma_{\Delta m^2}$ = 20%

Complementary With T2K

Double Chooz Status

- **2009** → Far detector construction & intégration

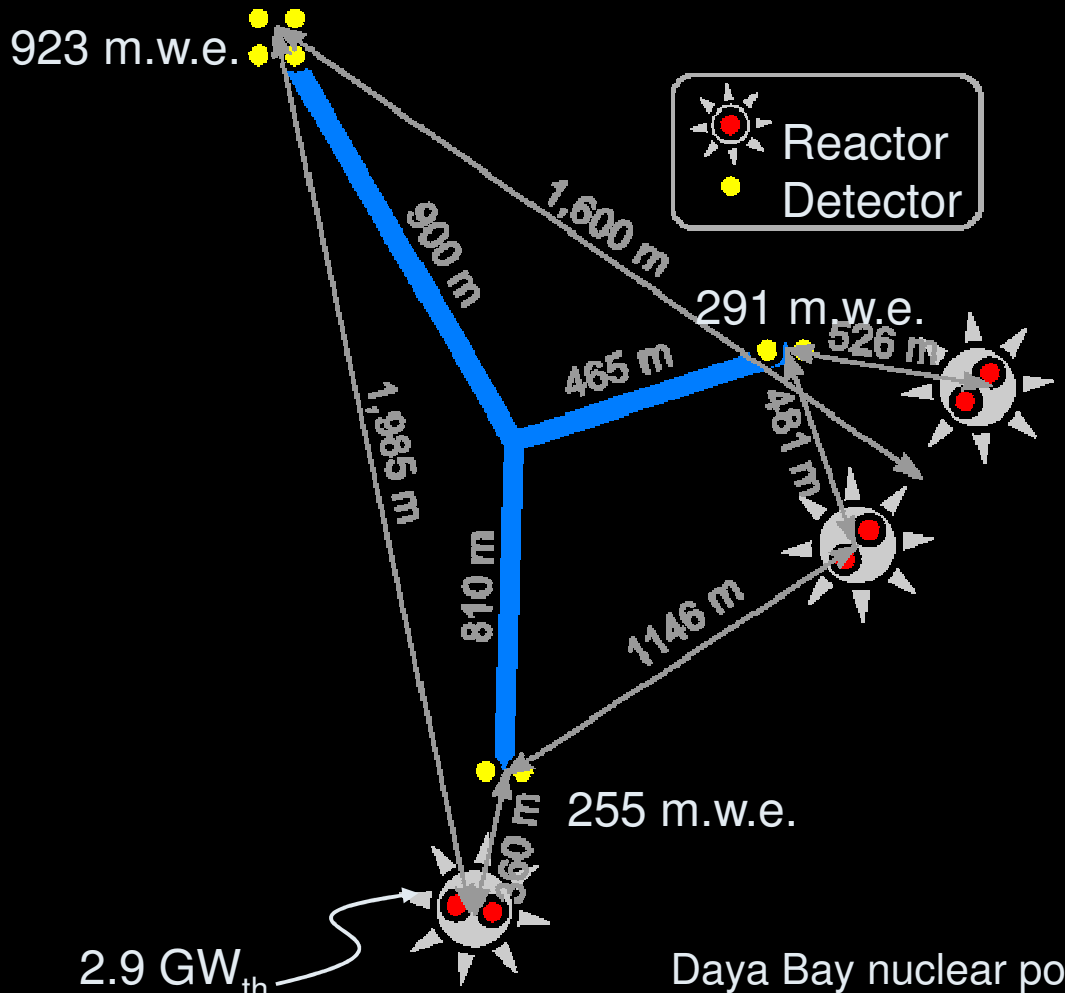
- **04/2010** → Start of phase I : Far 1 km detector alone
  $\sin^2(2\theta_{13}) < 0.06$ after 1,5 y (90% C.L.) if no-oscillation

- **2010/11** → Near Lab Excavation
  → Near Detector Integration

- **2011** → Start of phase II : both near and far detectors
  $\sin^2(2\theta_{13}) < 0.03$ after 3 y (90% C.L.) if no-oscillation

Daya Bay

Courtesy : K.. Luk



Daya Bay nuclear power station in China

Status of Daya Bay

Construction of near hall

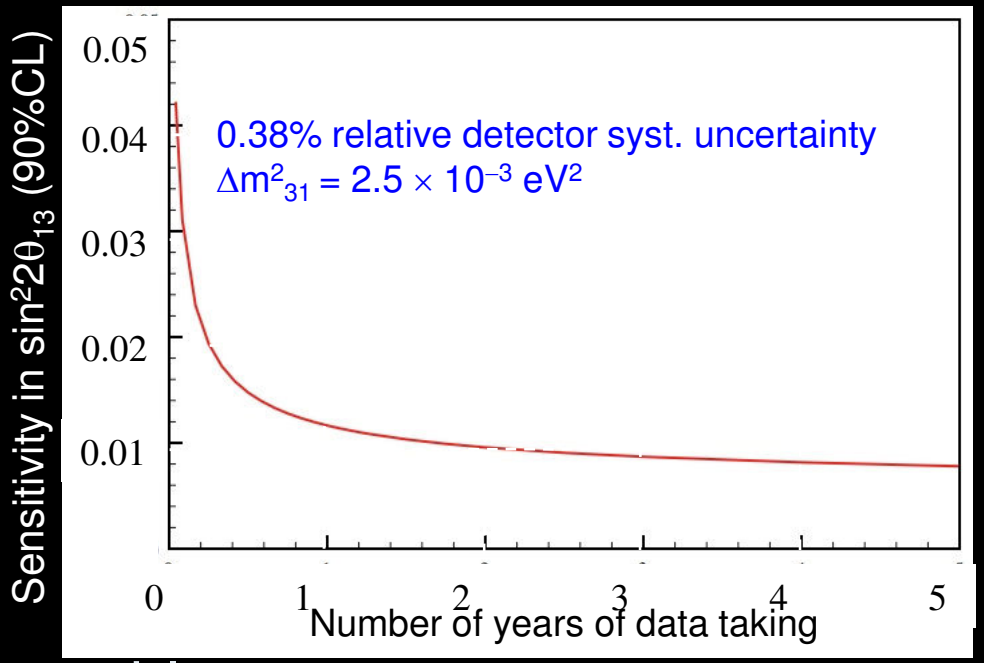
Access tunnel to the underground halls well advanced

Detector mechanics:
5-m SST vessel, 4-m and 3-m acrylic vessels in assembly hall

Sensitivity & Milestones of Daya Bay

Sensitivity in $\sin^2 2\theta_{13}$:

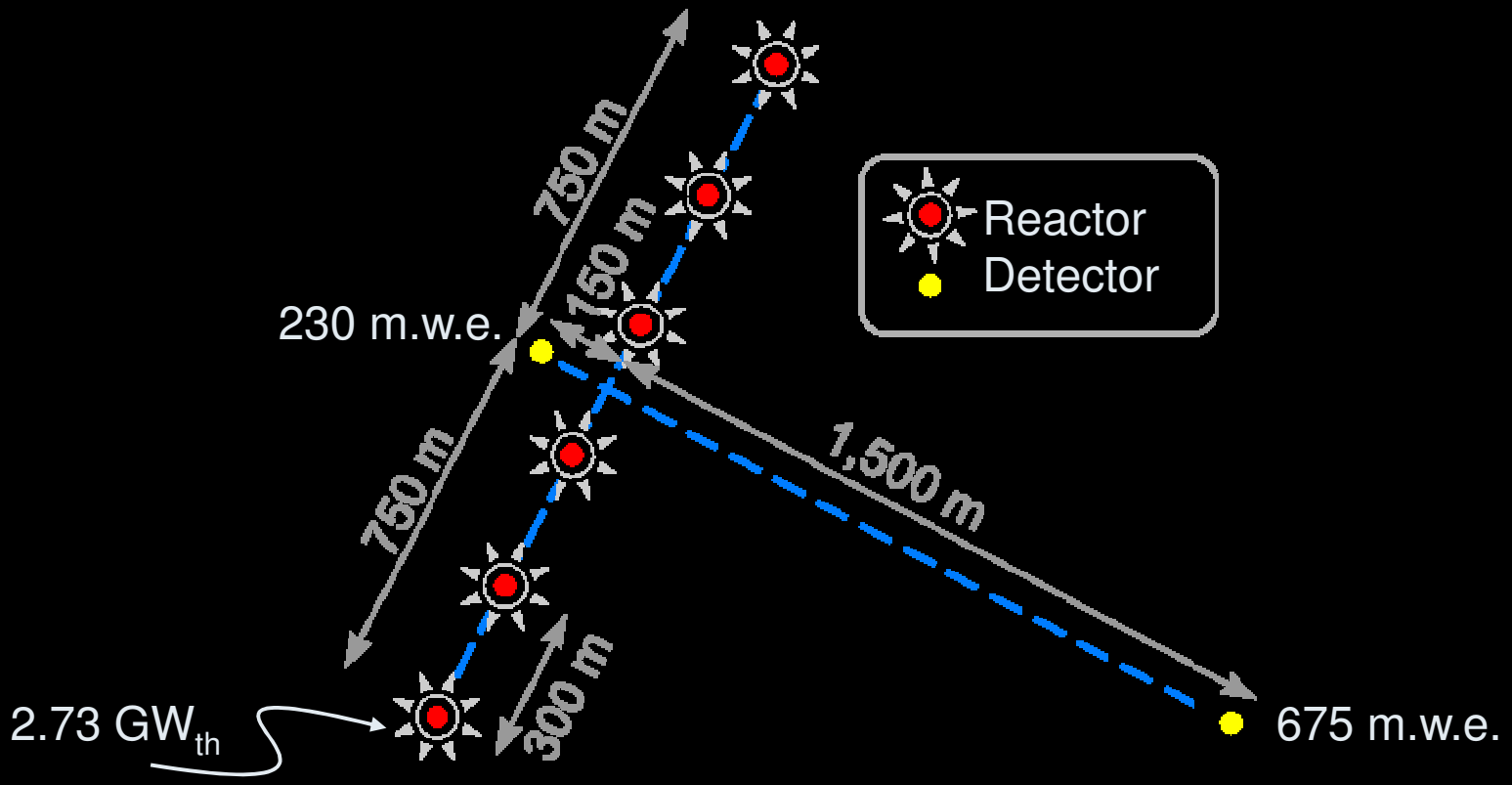
$\sin^2 2\theta_{13} < 0.01$ @ 90% CL
in 3 years of data taking



- **Aug 2009:** Begin detector assembly
- **Fall 2009:** Begin detector installation in experimental halls
- **Fall 2010:** Start data taking with first near hall
- **Summer 2011:** Start data taking with all detectors

RENO

Courtesy : S. B. Kim



Yong gwang nuclear power station in Korea

Near & far tunnels are completed

(2008.6~2009.3)

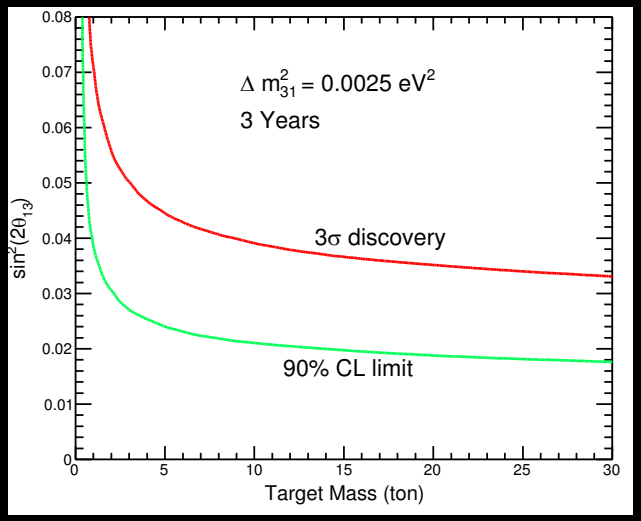
by Daewoo Eng. Co. Korea

Buffer steel tanks are installed

by NIVAK Co. Korea

Status Report of RENO

- RENO is suitable for measuring **$\sin^2(2\theta_{13}) > 0.02$**
- Civil construction completed
- Buffer steel containers are installed
- PMT installation start in Dec. 09



- Acrylic containers will be completed until Nov. 2009
- Data –taking is expected to start in mid 2010
- International collaborators are being invited

서울대 김수봉 교수가 이끄는 RENO 실험팀. 30여년간 관측에 실패한 마지막 중성미자 변환상수를 밝히기 위해 프랑스 중국과 치열한 경주를 벌이고 있다.

θ_{12}

Reactor Measurement of θ_{12}

- **Connecting the $\nu_1 - \nu_2$ (solar) neutrino pair with the electron flavor**
  - ➔ Already KamLAND, Borexino, SNO+?
  - ➔ A new disapearance experiment located at the oscillation maximum : $\text{Baseline} \approx \frac{2\pi E_\nu^{peak}}{\Delta m^2_{21}} \approx 50 - 70\text{km}$
- **Sensitivity (see Phys. Rev. D 71, 013005 2005)**
  - ➔ Exposure: 60 GW_{th} . Ton . Year
  - ➔ 4% systematics, error on $\sin^2(\theta_{12})$: **2%** (1σ)
- **No project funded but a few sites have been discussed:**
  - ➔ Sado Island (Japan), 55 km from Kashiwasaki power plant
  - ➔ San Onofre (US), with the Hano Hano detector underwater
  - ➔ Rustrel (500 mwe, France), Cruas (12 GW, 73 km), Tricastin (12 GW, 59 km)

Conclusion and Outlook

- A reactor neutrino community in Europe

- Prospect on θ_{13}
  - ➔ Double Chooz, based in Europe
  - ➔ Daya Bay & Reno, based in Asia
  - ➔ Start data taking in 2010
  - ➔ Constraint on $\sin^2(2\theta_{13}) \sim 0.01\text{-}0.03$ by 2014

- Prospect on θ_{12}
  - ➔ An efficient possibility getting $\sin^2(\theta_{12})$ @2% (1σ)
  - ➔ Needed?