Status of DoubleChooz

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I borrowed the presentation slides from Ishitsuka's ICHEP talk.

The Double Chooz reactor neutrino experiment

Masaki Ishitsuka, Tokyo Institute of Technology
on behalf of the Double Chooz collaboration

35th International Conference of High Energy Physics
July 22-28, 2010, Paris

Physics motivations

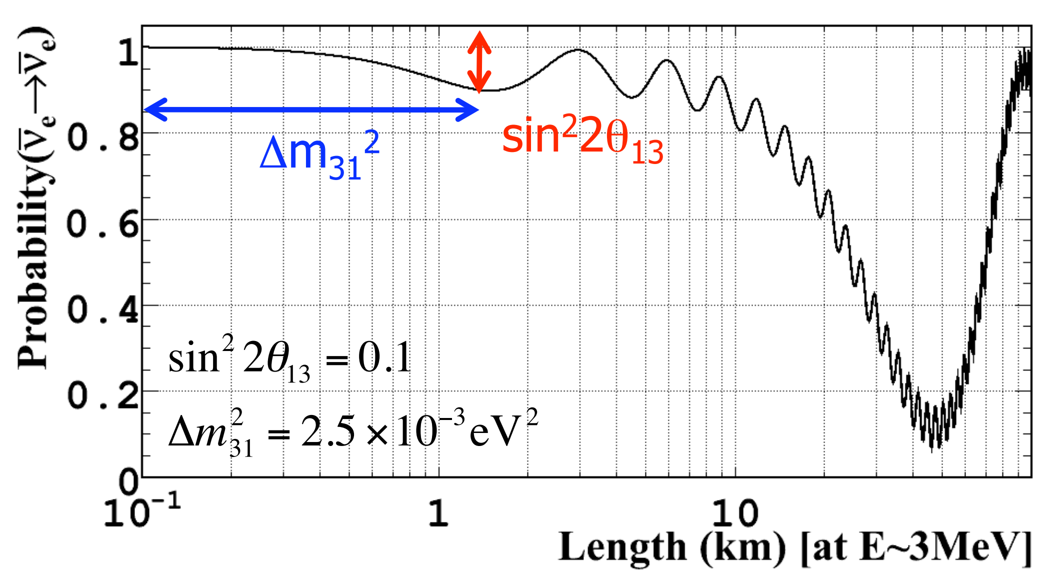
- θ_{13} is the last unknown mixing angle
  - Neutrino oscillations are fairly confirmed.
  - Two oscillation modes with different Δm^2 scales:
    $\Delta m_{21}^2 \sim 7.6\text{x}10^{-5}\text{eV}^2$, $|\Delta m_{32}^2| \sim |\Delta m_{31}^2| \sim 2.5\text{x}10^{-3}\text{eV}^2$
  - Two large mixing angles: $\theta_{12} \sim 34^o$, $\theta_{23} \sim 45^o$
  - Only the limit is set to θ_{13}: $\theta_{13} < 12^o$

- Exciting topics are waiting for the value of θ_{13}
  - δ_{CP} in neutrino sector (super beam, ν-Fact, β beam…)
  - Mass hierarchy of neutrinos

Measurement of θ_{13} is essential.

Search for θ_{13} using reactor neutrinos

$$P\left[\overline{\nu_e} \to \overline{\nu_e}\right] \cong 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{31}^2 L}{4E}\right) + O(10^{-3})$$

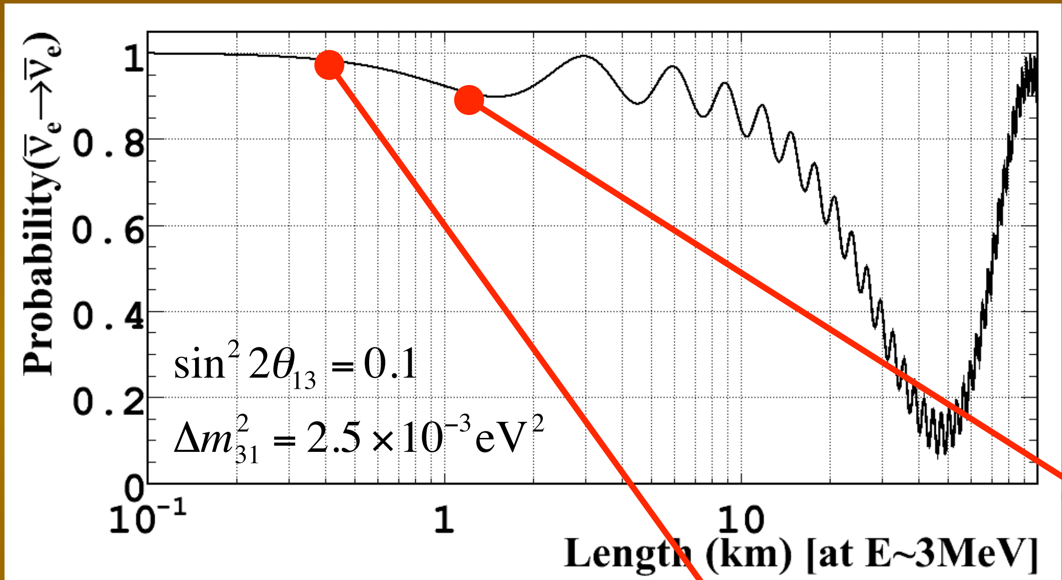


- Simple 2 flavor oscillation formula is valid at 1km baseline
  - $P(\nu_e \to \nu_e)$ as a function of Δm_{31}^2(well known) and θ_{13} (unknown)
  - Matter effects are negligible
  - Independent to CP-violation phase

⇒ Clean measurement of θ_{13}

Strategy

$$P\left[\overline{\nu_e} \rightarrow \overline{\nu_e}\right] \cong 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) + O(10^{-3})$$



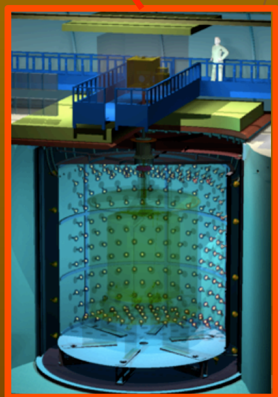
Systematic errors on

- neutrino flux
- interaction x-sec
- # of target protons
- detection efficiency

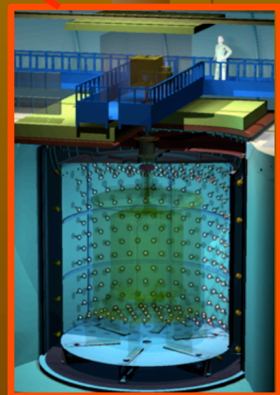
are canceled by two detectors technique.

$\bar{\nu}_e$

Chooz Reactors
4.27GW$_{th}$ x 2 cores



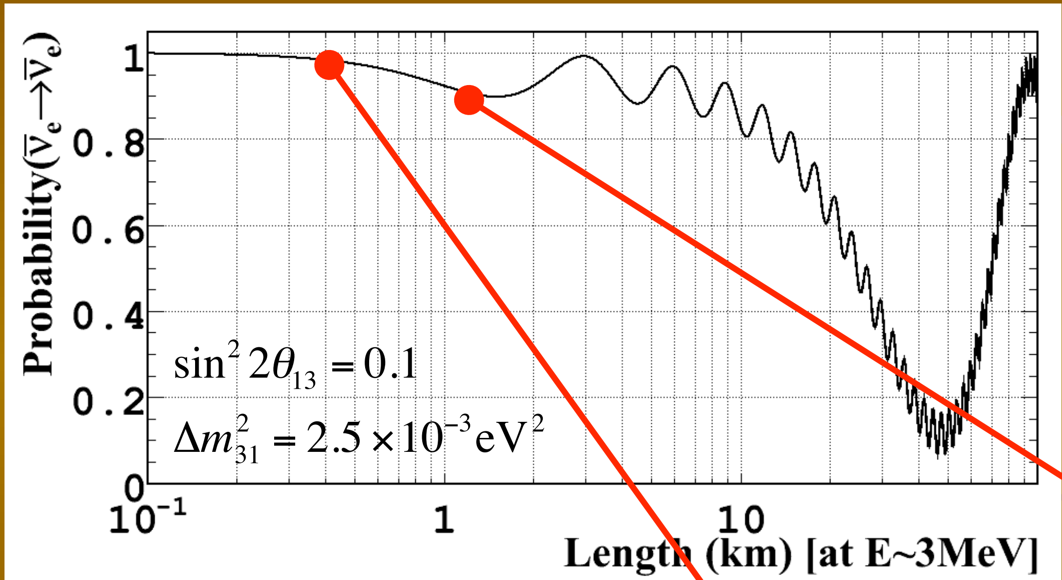
Near Detector
<L> 400m
400ν/day
120m.w.e.
Early 2012



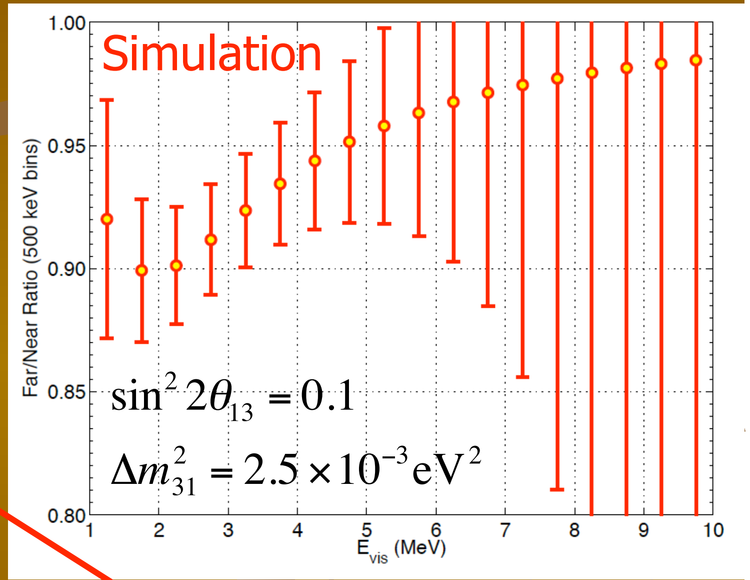
Far Detector
<L> 1050m
70ν/day
300m.w.e.
Sept. 2010

Strategy

$$P\left[\overline{\nu_e} \to \overline{\nu_e}\right] \cong 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) + O(10^{-3})$$

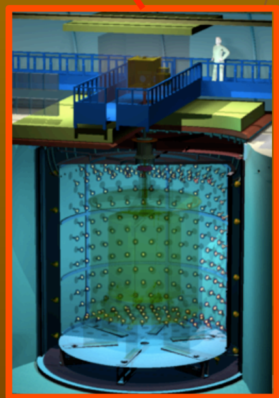


DC far/near ratio (3years)



Chooz Reactors
$4.27 GW_{th}$ x 2 cores

$\overline{\nu}_e$



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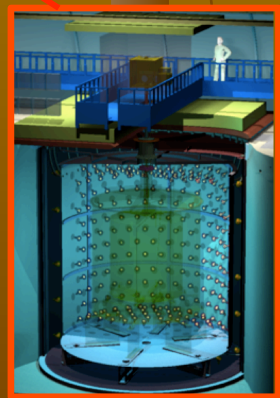
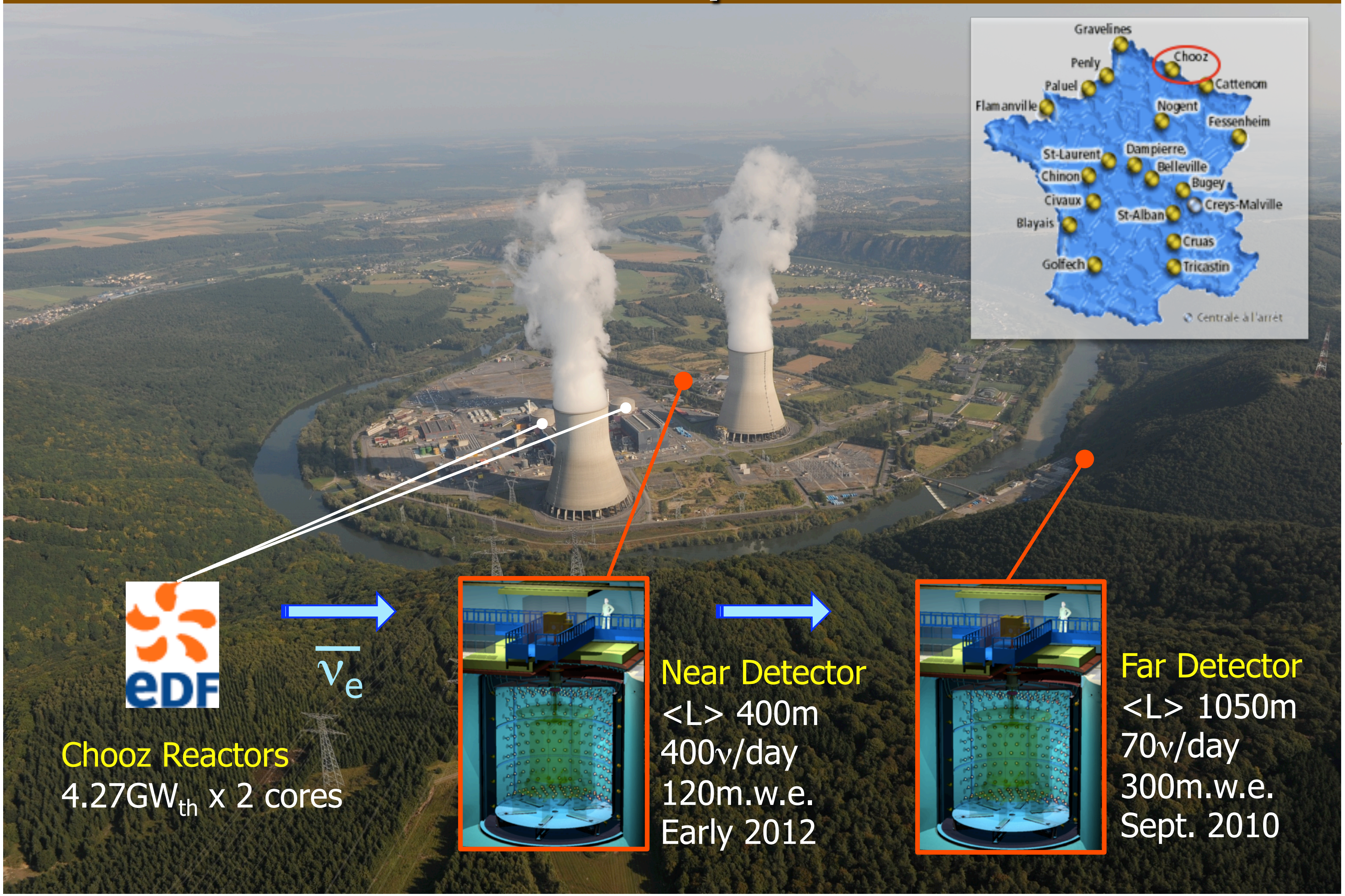


Far Detector
<L> 1050m
70ν/day
300m.w.e.
Sept. 2010

Double Chooz experiment



Double Chooz collaboration

Brazil
CBPF
UNICAMP
UFABC

France
CEA/DSM/IRFU:
- SPP
- SPhN
- SEDU
- SIS
- SENAC

CNRS/IN2P3:
- APC
- Subatech
- IPHC

ULB

Germany
EKU Tübingen
MPIK Heidelber
TU München
U. Aachen
U. Hamburg

Japan
Tohoku U.
Tokyo Inst. Tech.
Tokyo Metro. U.
Niigata U.
Kobe U.
Tohoku Gakuin U.
Hiroshima Inst Tech.

Russia
INR RAS
IPC RAS
RRC Kurchatov

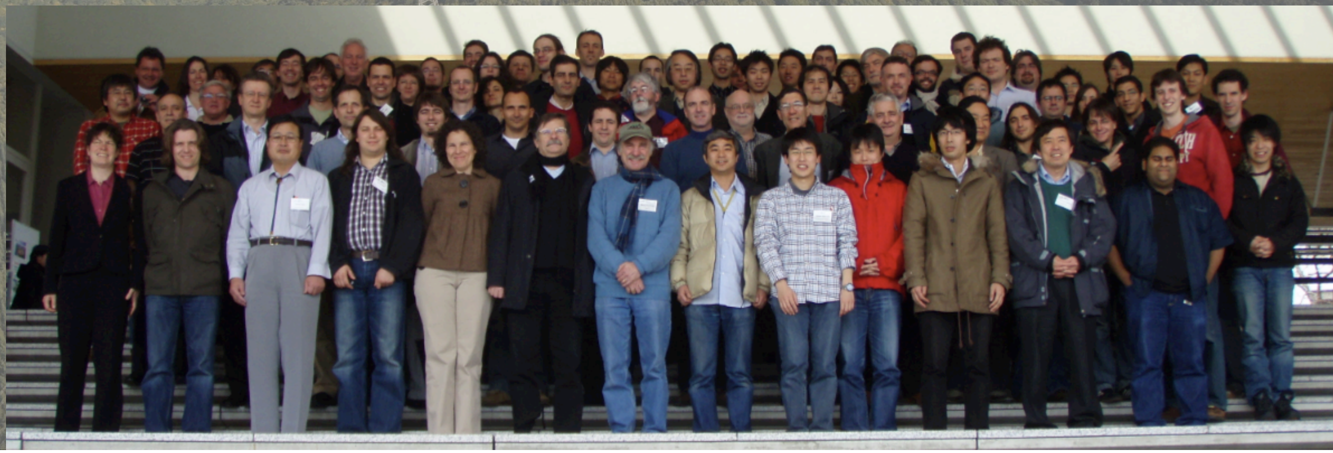
Spain
CIEMAT-Madrid

UK
Sussex

USA
U. Alabama
ANL
U. Chicago
Columbia U.
UCDavis
Drexel U.
IIT
KSU
LLNL
MIT
U. Notre Dame
Sandia National Laboratories
U. Tennessee

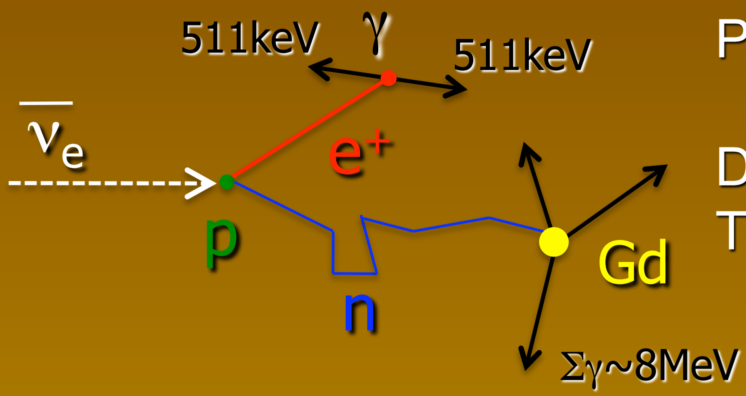
Spokesperson: H. de Kerret (IN2P3)
Project Manager: Ch. Veyssière (CEA-Saclay)

Web Site: www.doublechooz.org/



Neutrino signal and backgrounds

Neutrino signal



Prompt signal: e^+ (1~8MeV)

→ $E_\nu = E_{vis} + 0.8$MeV

Delayed signal: n-capture by Gd (~8MeV)

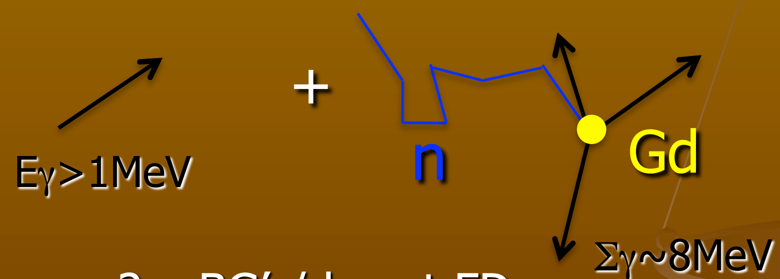
Time correlation: τ~30μs

69 ν signal's/day at FD

Background

Accidental Background

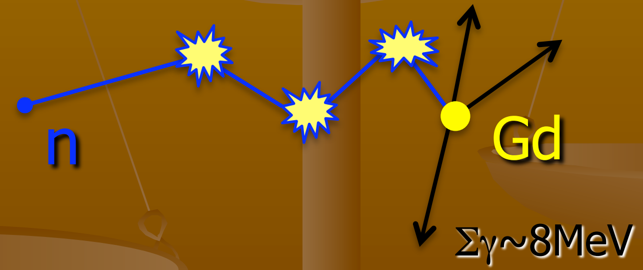
Environmental γ n-capture within time window



~2 ν BG's/day at FD

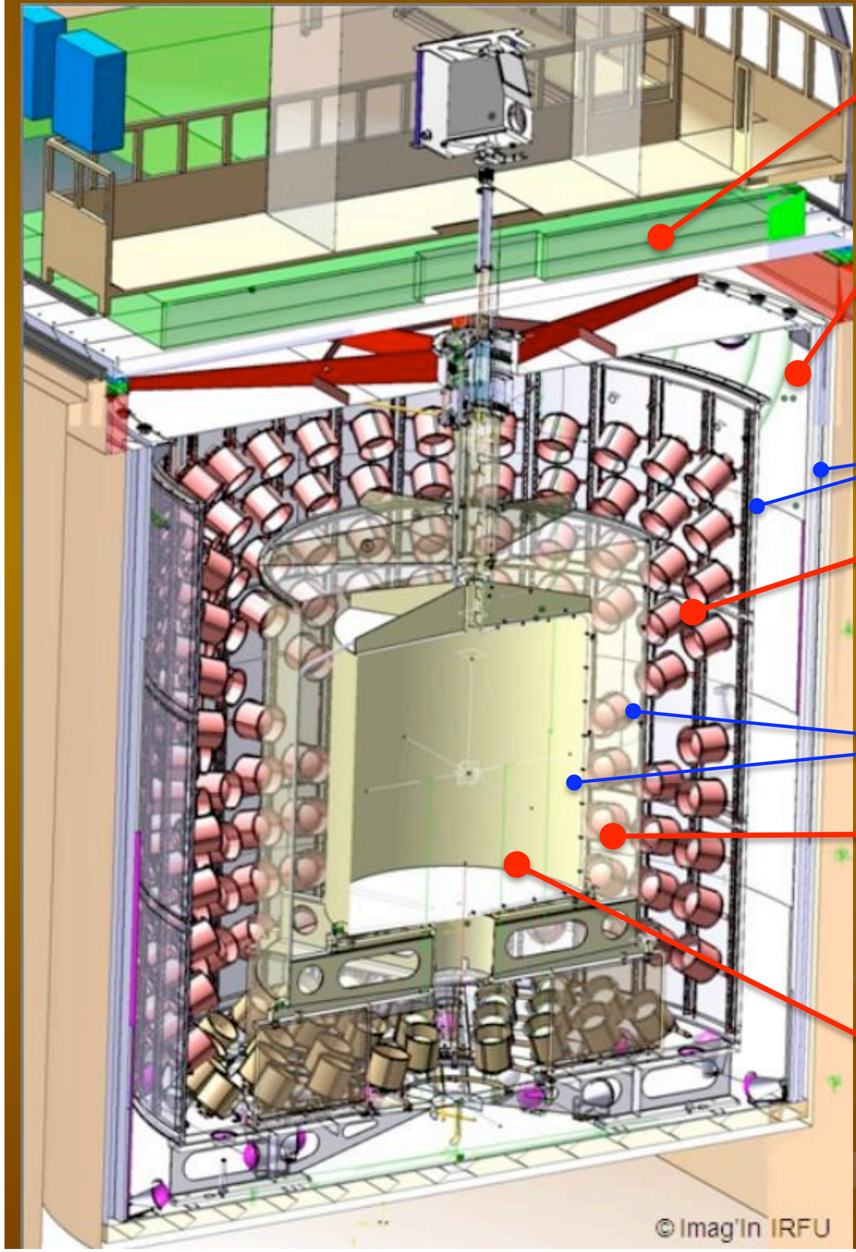
Correlated Background

Eg. Fast neutron with recoil proton signals → n-capture by Gd



~1.6 ν BG's/day at FD (total)

Double Chooz detector



Outer Veto (Plastic scint.)
- Identification of cosmic-ray μ

Inner Veto (90m³ Liquid scint.&78 PMTs)
- Detection of cosmic-ray μ and fast neutrons

Steel vessel & PMT support structure

Buffer (110m³ Mineral oil & 390 PMT's)
- Reduction of fast neutron and environmental γ from outside

Acrylic vessel

γ-catcher (22.3m³ Liquid scintillator)
- Measurement of γ's from n-capture by Gd in target volume

ν-target
(10.3m³ Gd loaded (1g/l) liquid scint.)
- Target for neutrino signals

Statistic and systematic errors

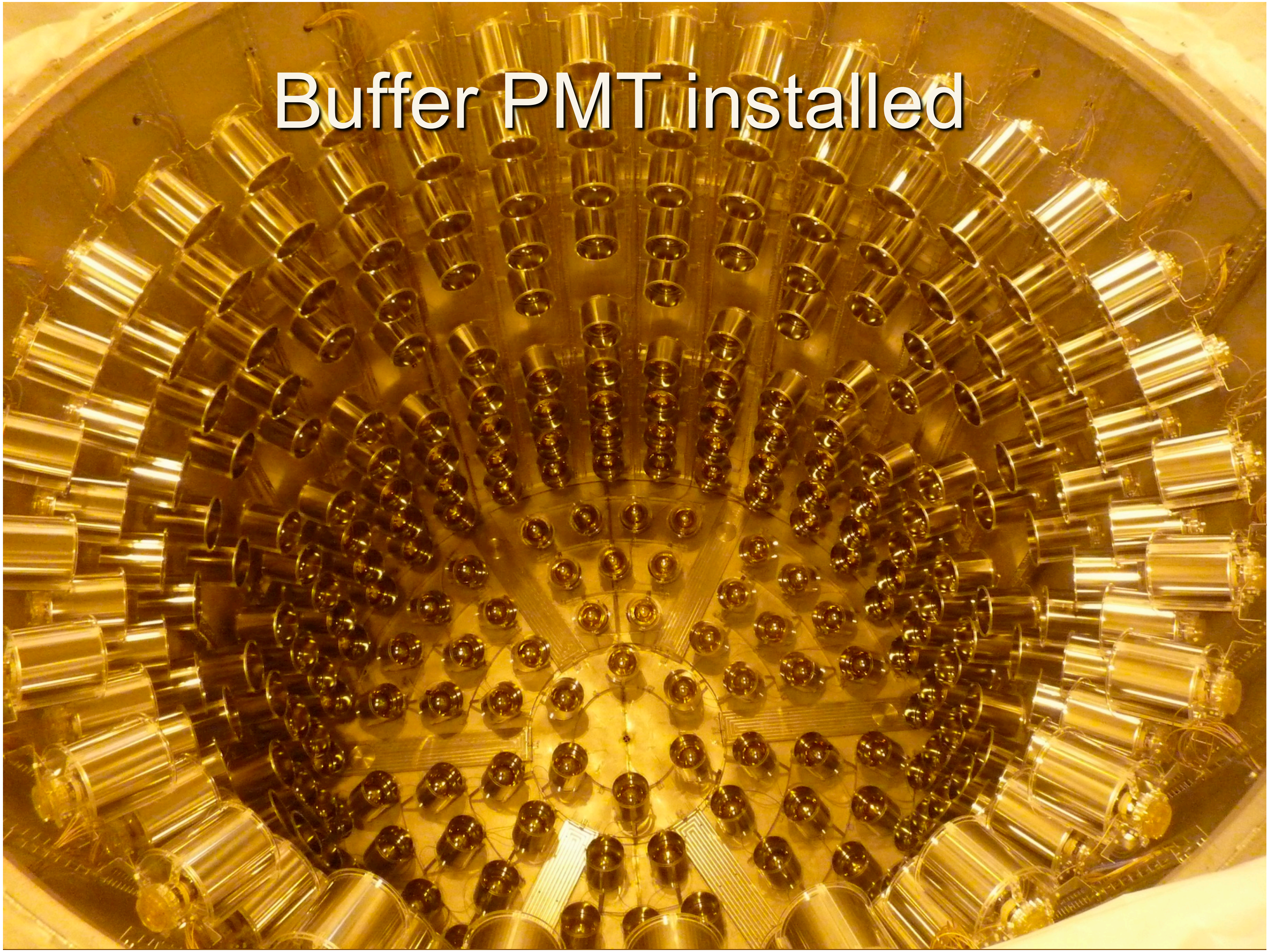
		CHOOZ	Double Chooz
Reactor (neutrino flux)	Production x-sec	1.9%	-
	Reactor power	0.7%	-
	Energy per fission	0.6%	-
	Solid angle	-	0.1%
Detector	Detection x-sec	0.3%	-
	Target mass	0.3%	0.2%
	Fiducial volume	0.2%	-
	H/C ratio	0.8%	-
	Dead time	0.25%	-
Analysis	Selection efficiency	1.4%	0.4%
Total systematic error		**2.7%** →	**<0.5%**
Statistical error		**2.8%** →	**<0.5%**

G. Mention et al., arXiv:0704.0498 [hep-ex]

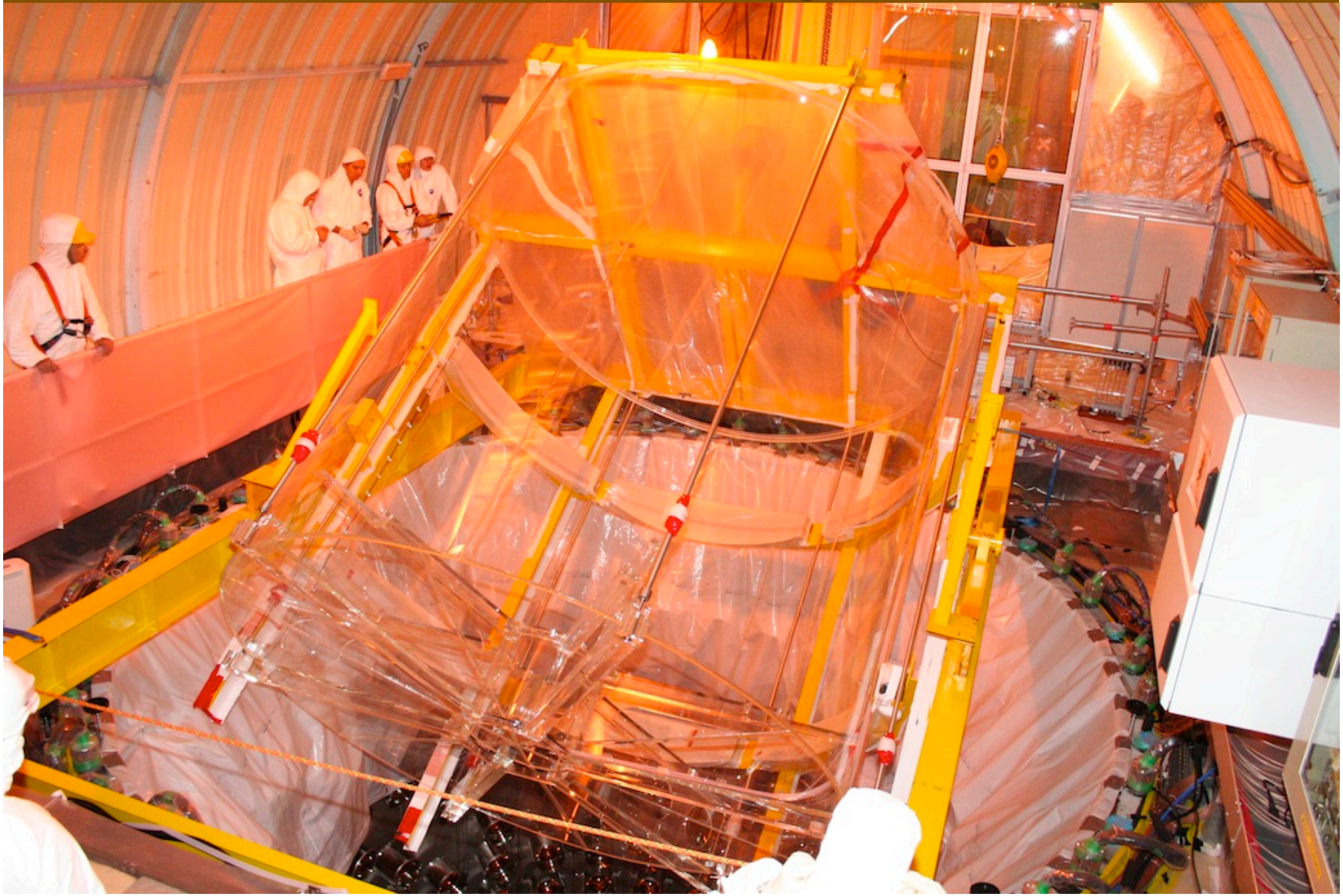

Construction @ DC far lab.

Inner veto PMT installed

Buffer PMT installed

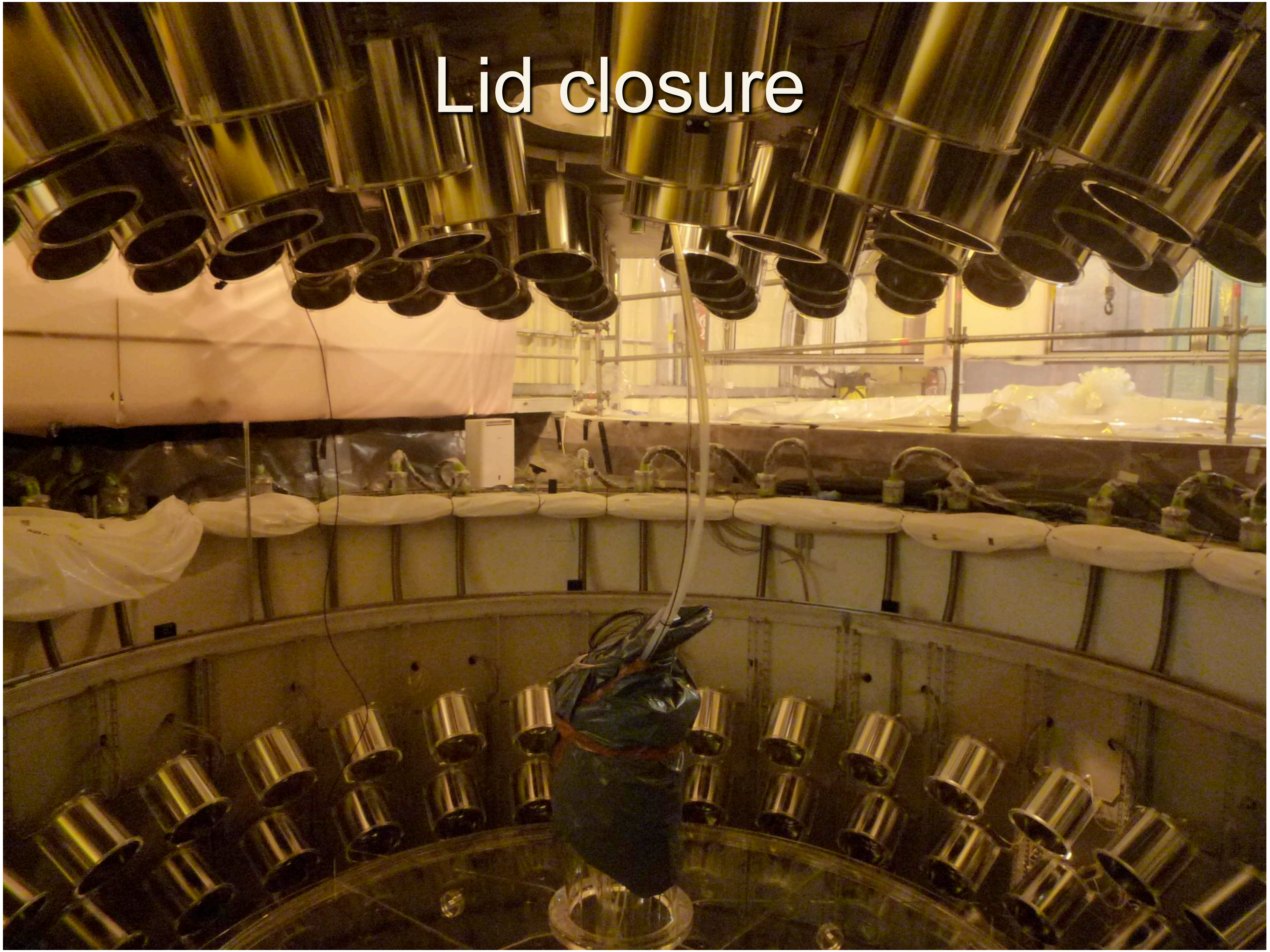


Installation of acrylic vessel



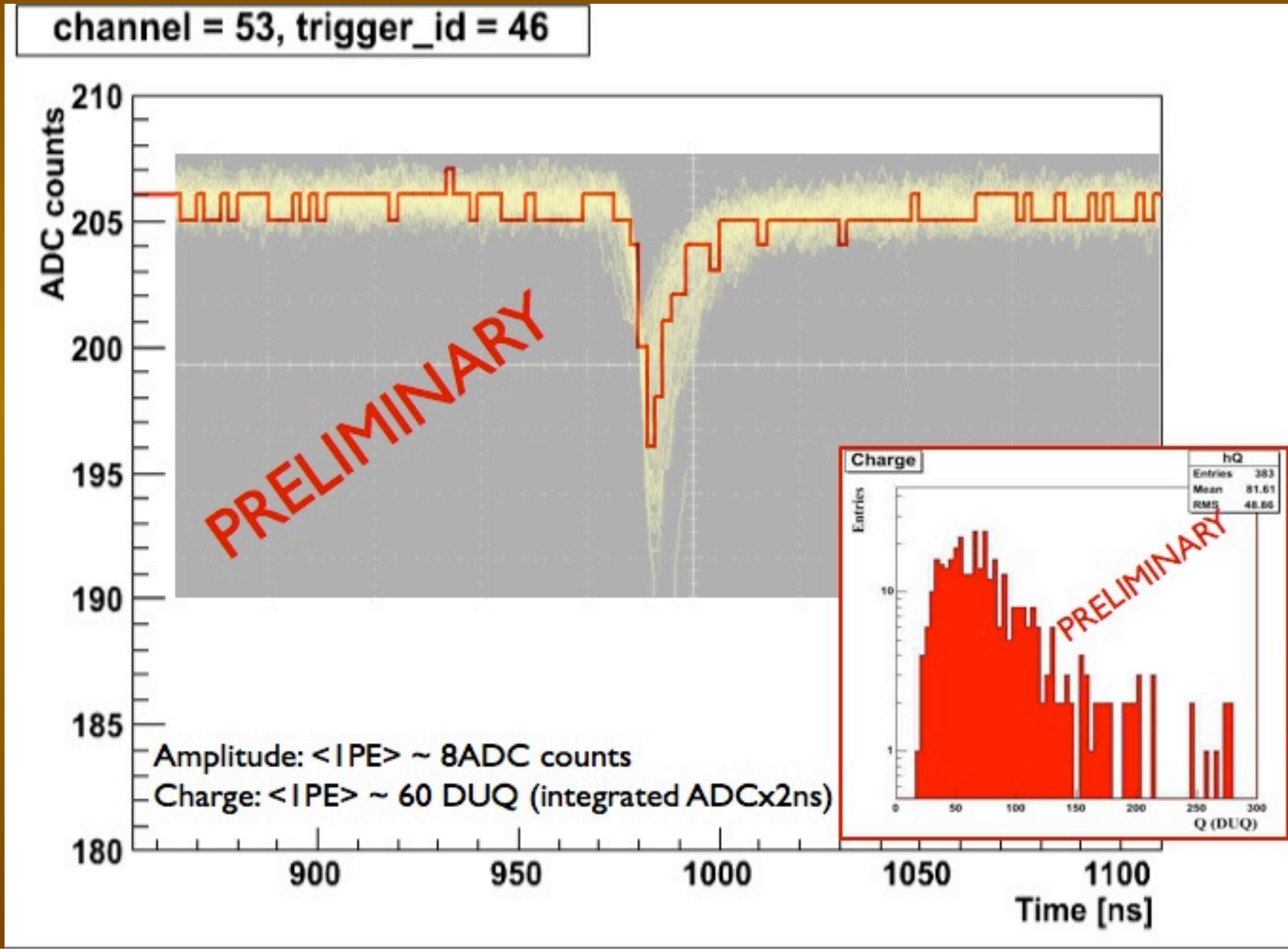
Target and γ-catcher acrylic vessels installed

Lid closure



All PMT equipped

… and the first PMT signal readout by FADC



Schedule

- Far detector construction completed.
- Liquid scintillator filling starts soon.
- Far detector commissioning in September 2010.
- Near detector:
  - Digging from November 2010
  - ND lab available in fall 2011
  - Data taking in 2012

Sensitivity to θ_{13}

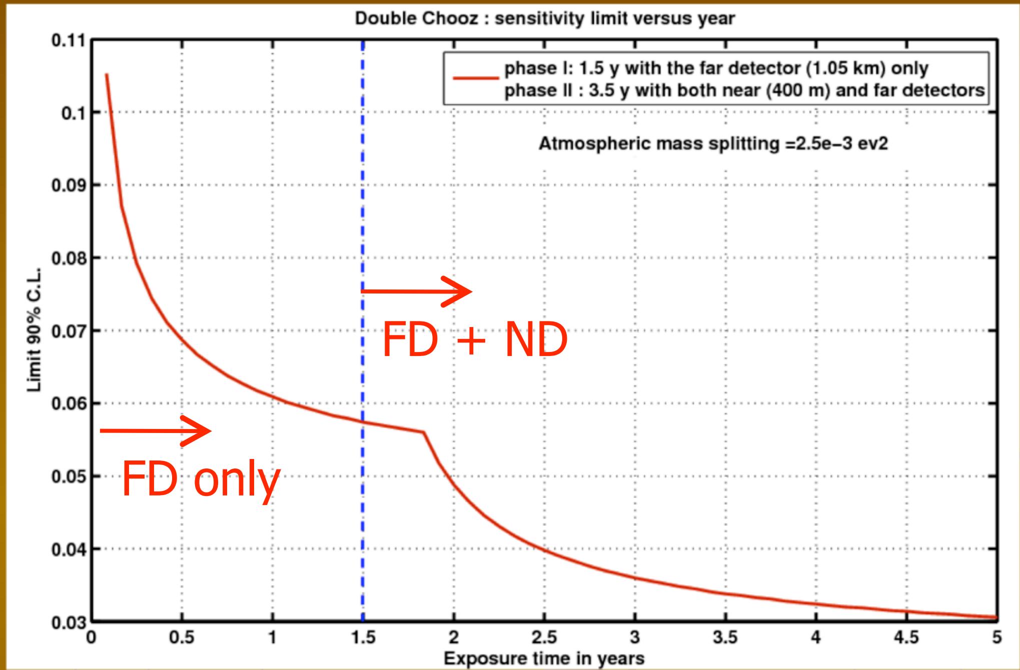
Current limit set by CHOOZ:

$$\sin^2 2\theta_{13} < 0.15$$
$$(\Delta m^2 = 2.5 \times 10^{-3} \mathrm{eV}^2)$$

"1-σ hint" of non-zero θ_{13} from Solar+KamLAND global analysis:

$$\sin^2 2\theta_{13} = 0.08^{+0.08}_{-0.07}$$

B. Aharmim et al (SNO collaboration) Phys.Rev.C81:055504,2010



- Far detector commisioning in September 2010.
  - ⇒ Sensitivity reaches $\sin^2 2\theta_{13} \sim 0.06$ (90% C.L.) in 1.5 years
- Near detector operation in 2012.
  - ⇒ Sensitivity reaches $\sin^2 2\theta_{13} \sim 0.03$ (90% C.L.) in +3 years

Reasonable chance to make the measurement of non-zero θ_{13} in a few years

Conclusion

- Double Chooz far detector is about to start data taking.
  - Detector construction completed.
  - First PMT signals observed by DAQ with all PMTs on.
  - Liquid scintillator filling starts soon.
  - Detector commissioning in September 2010.
- Near detector data taking expected from 2012.

- Prospects of θ_{13} measurement.
  - September 2010: Far detector only

    $\Rightarrow \sin^2 2\theta_{13} \sim 0.06$ (90% C.L.) in 1.5 years
  - 2012: Near and far detectors

    $\Rightarrow \sin^2 2\theta_{13} \sim 0.03$ (90% C.L.) in +3 years
  - (Current limit: $\sin^2 2\theta_{13} < 0.15$ by CHOOZ)

Backup

Two approaches to search for θ_{13}

Reactor neutrino: **Double Chooz**, Daya-Bay, RENO…

$$P\left[\overline{\nu_e} \rightarrow \overline{\nu_e}\right] \cong 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{31}^2 L}{4E}\right) + O(10^{-3})$$

- Sensitive to θ_{13}. (=> clean measurement)

Long-baseline with ν_μ beam: T2K, NOvA …

$$a(x) = \sqrt{2} G_F N_e(x)$$

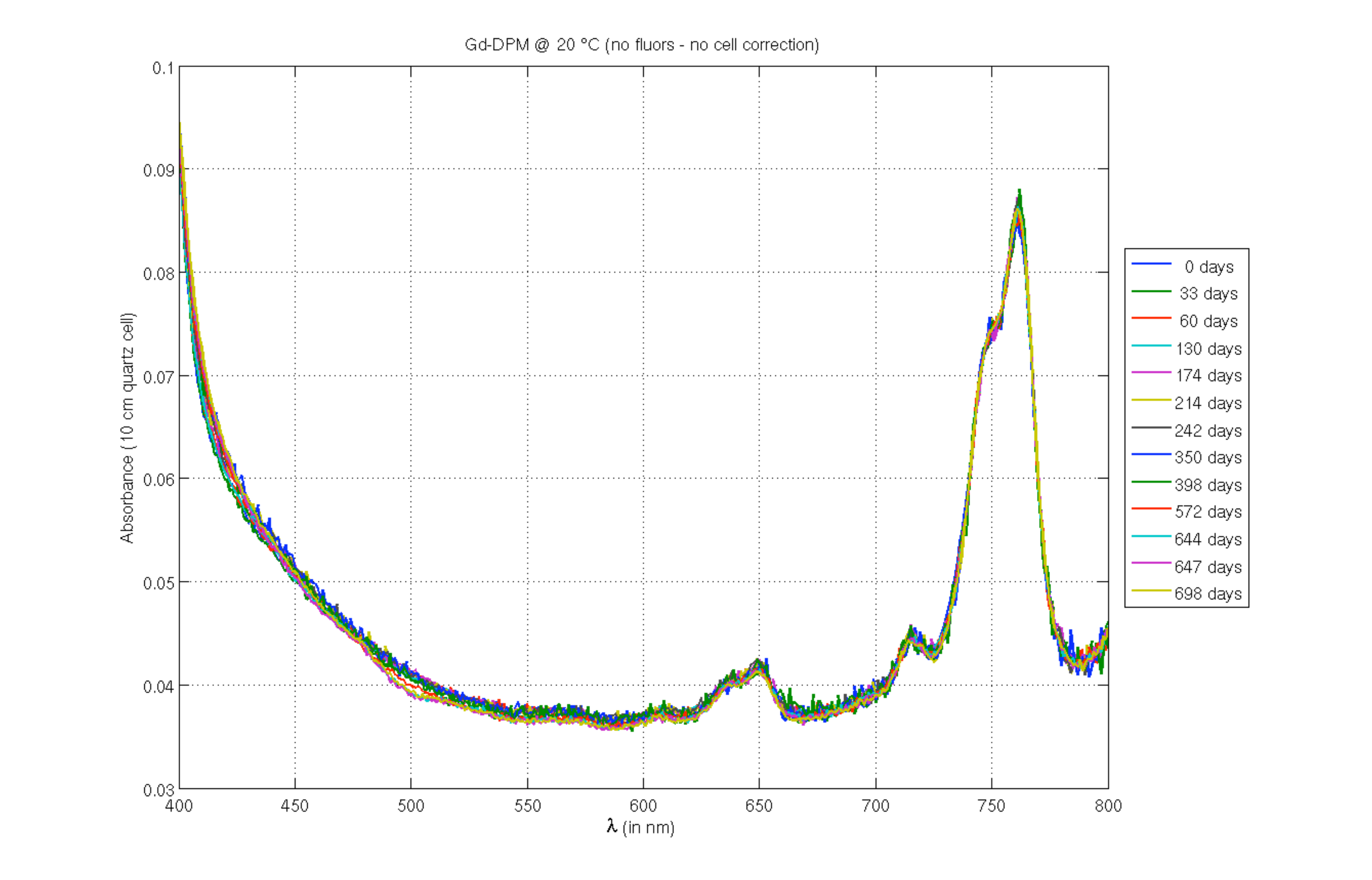
$$J_r \equiv c_{12} s_{12} c_{13}^2 s_{13} c_{23} s_{23}$$

$$\begin{aligned} P\left[\nu_\mu(\overline{\nu_\mu}) \rightarrow \nu_e(\overline{\nu_e})\right] = {} & \sin^2 2\theta_{13} s_{23}^2 \sin^2\left(\frac{\Delta m_{31}^2 L}{4E}\right) - \frac{1}{2} s_{12}^2 \sin^2 2\theta_{13} s_{23}^2 \left(\frac{\Delta m_{21}^2 L}{2E}\right) \sin\left(\frac{\Delta m_{31}^2 L}{2E}\right) \\ & + 2 J_r \cos\delta \left(\frac{\Delta m_{21}^2 L}{2E}\right) \sin\left(\frac{\Delta m_{31}^2 L}{2E}\right) \mp 4 J_r \sin\delta \left(\frac{\Delta m_{21}^2 L}{2E}\right) \sin^2\left(\frac{\Delta m_{31}^2 L}{4E}\right) \\ & \pm \cos 2\theta_{13} \sin^2 2\theta_{13} s_{23}^2 \left(\frac{4Ea(x)}{\Delta m_{31}^2}\right) \sin^2\left(\frac{\Delta m_{31}^2 L}{4E}\right) \\ & \mp \frac{a(x)L}{2} \sin^2 2\theta_{13} \cos 2\theta_{13} s_{23}^2 \sin\left(\frac{\Delta m_{31}^2 L}{2E}\right) + c_{23}^2 \sin^2 2\theta_{12} \left(\frac{\Delta m_{21}^2 L}{4E}\right)^2 \end{aligned}$$

- θ_{13}, δ_{CP}, mass hierarchy and θ_{23} (=> parameters degeneracy).
- Matter effects.
- Neutrino and anti-neutrino running.

Gd-loaded liquid scintillator

Attenuation length vs. wavelength vs. time

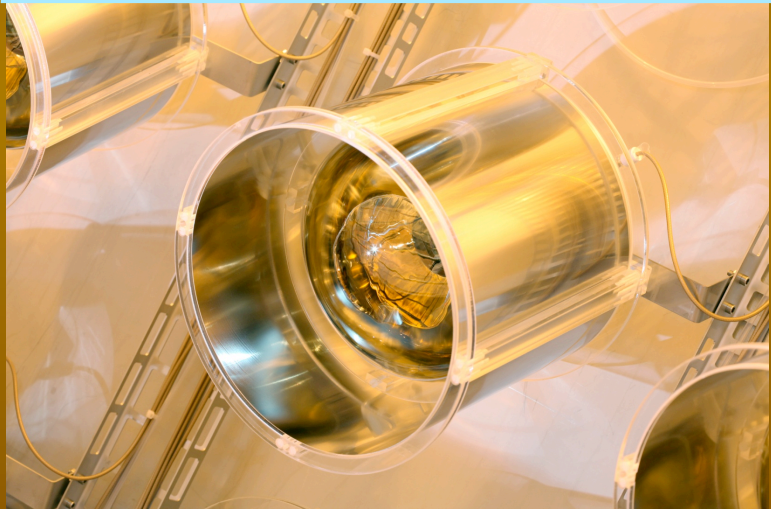


Long term test ⇒ stable over >2 years

Readout

ID & IV readout

PMT
ID: 10″ x 390PMTs
(Hamamatsu R7081 MOD (low-BG for DC))
IV: 8″ x 78PMTs
(Hamamatsu R1408)



HV-Splitter
(custom)

HV-Supply
(CAEN SY1537LC
+A1535)

Frontend
Electronics
(custom)

Trigger
& Clock
(custom)

ν-FADC
500MHz
(CAEN V1721)

μ-FADC
125MHz
(custom)

Trigger pattern & clock (T=16ns)

+ OV readout (Hamamatsu M64 + Maroc2-chip)

Calibration

- PMT/Electrtonics gain, timing
- Liquid scintillator optics
- Stability
  - LED light injection (embedded)
  - Isotropic laser and LED (deployed)
- Energy scale
  - Radioactive sources (^{137}Cs, ^{22}Na, ^{60}Co, ^{40}K, etc.)
  - H-capture peak at 2.2MeV
- Efficiency (n capture on Gd)
  - ^{252}Cf, Am-Be neutron sources
- Position dependence by deployment systems
  - Along Z-axis
  - 3D spatial calibration by articulated arm
  - Tube+wire in γ-catchaer and buffer regions