The Double Chooz reactor neutrino experiment

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on behalf of the Double Chooz collaboration

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

Physics motivations

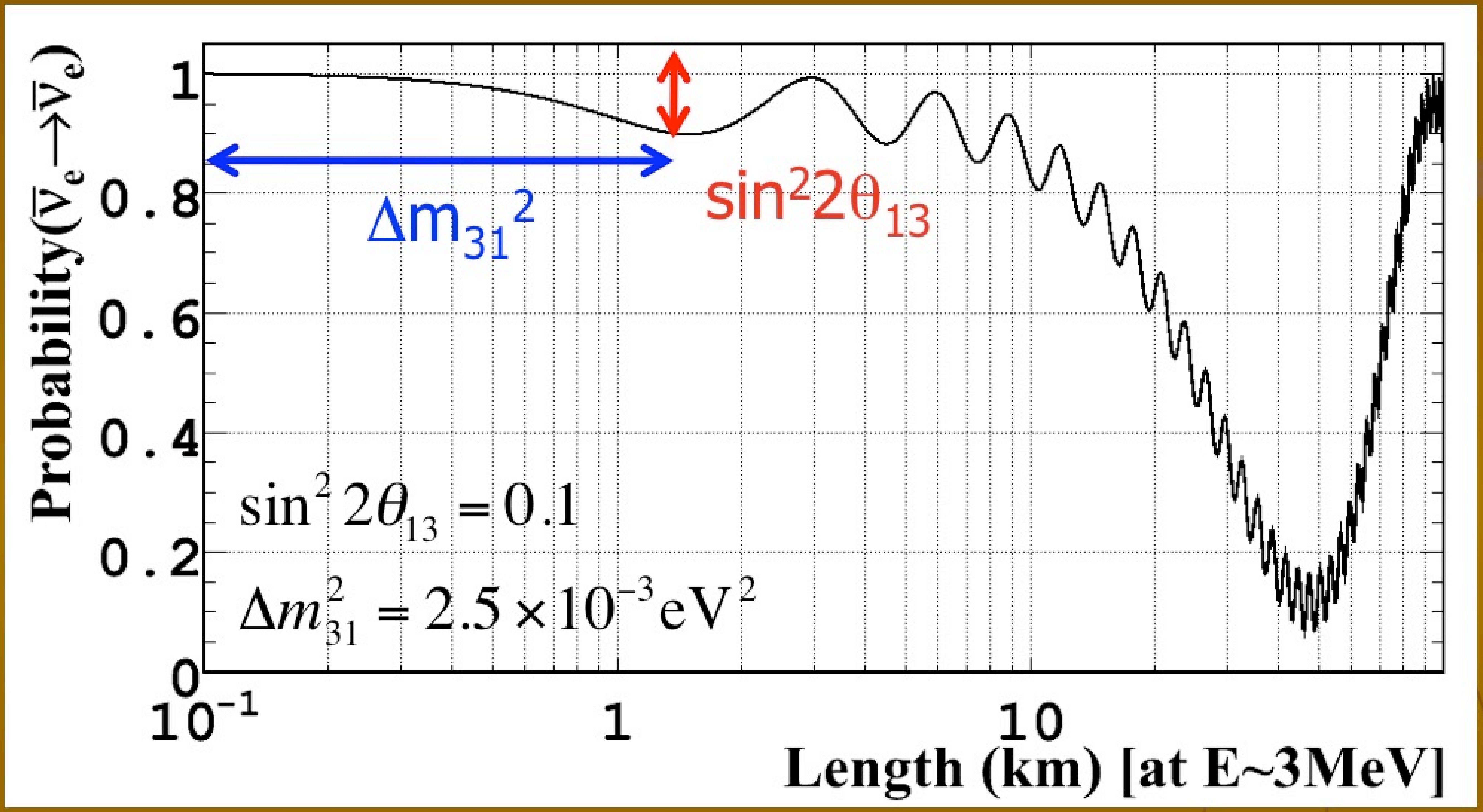
- θ_{13} is the last unknown mixing angle
  - Neutrino oscillations are fairly confirmed.
  - Two oscillation modes with different Δm^2 scales:
    $\Delta m_{21}{}^2 \sim 7.6 \times 10^{-5} eV^2$, $|\Delta m_{32}{}^2| \sim |\Delta m_{31}{}^2| \sim 2.5 \times 10^{-3} eV^2$
  - Two large mixing angles: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

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

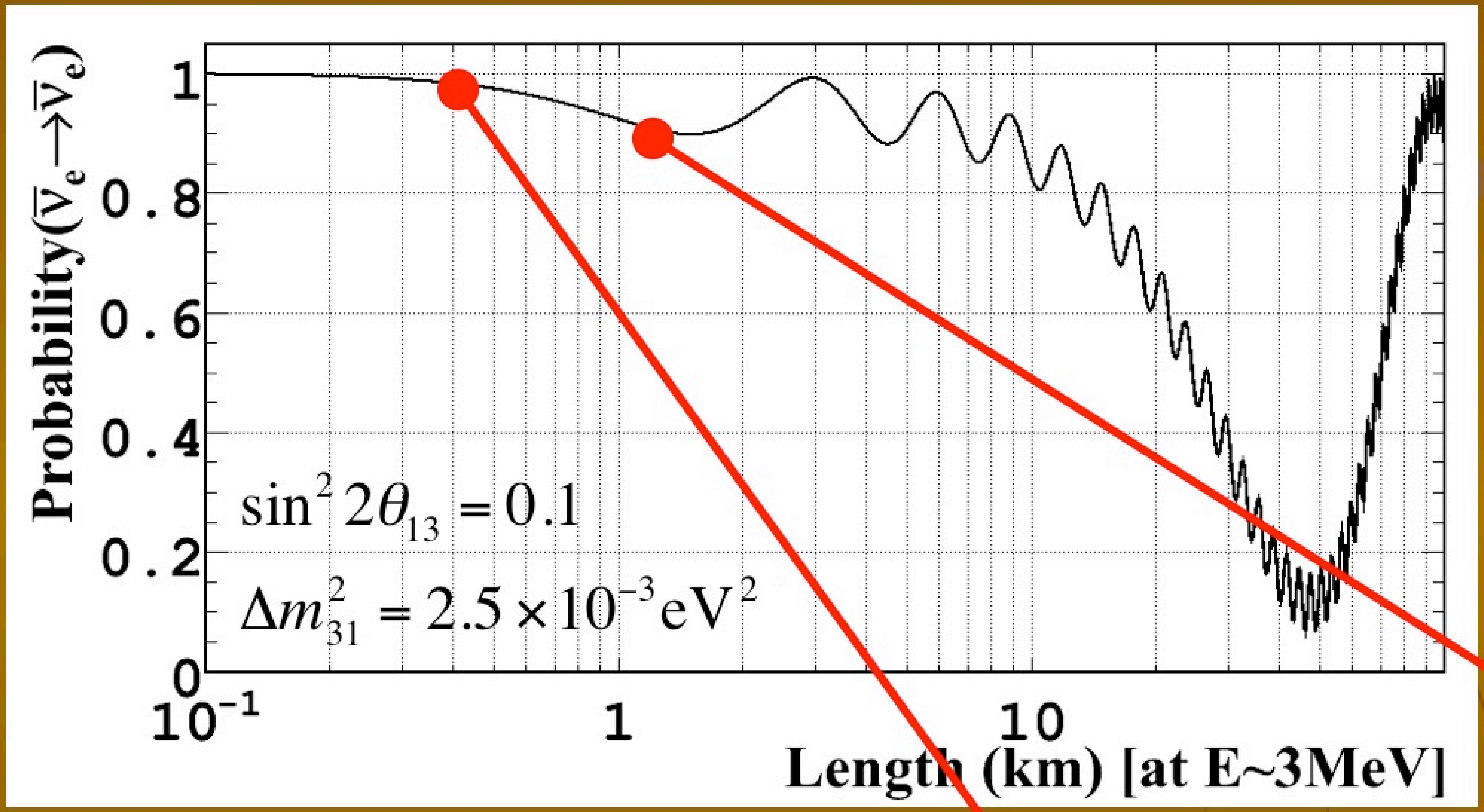


- Simple 2 flavor oscillation formula is valid at 1km baseline
  - $P(\nu_e \to \nu_e)$ as a function of Δm_{31}^2(well known) and θ_{13} (unknown)
  - Matter effects are negligible
  - Independent to CP-violation phase

⇒ 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.

$\overline{\nu}_e$

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

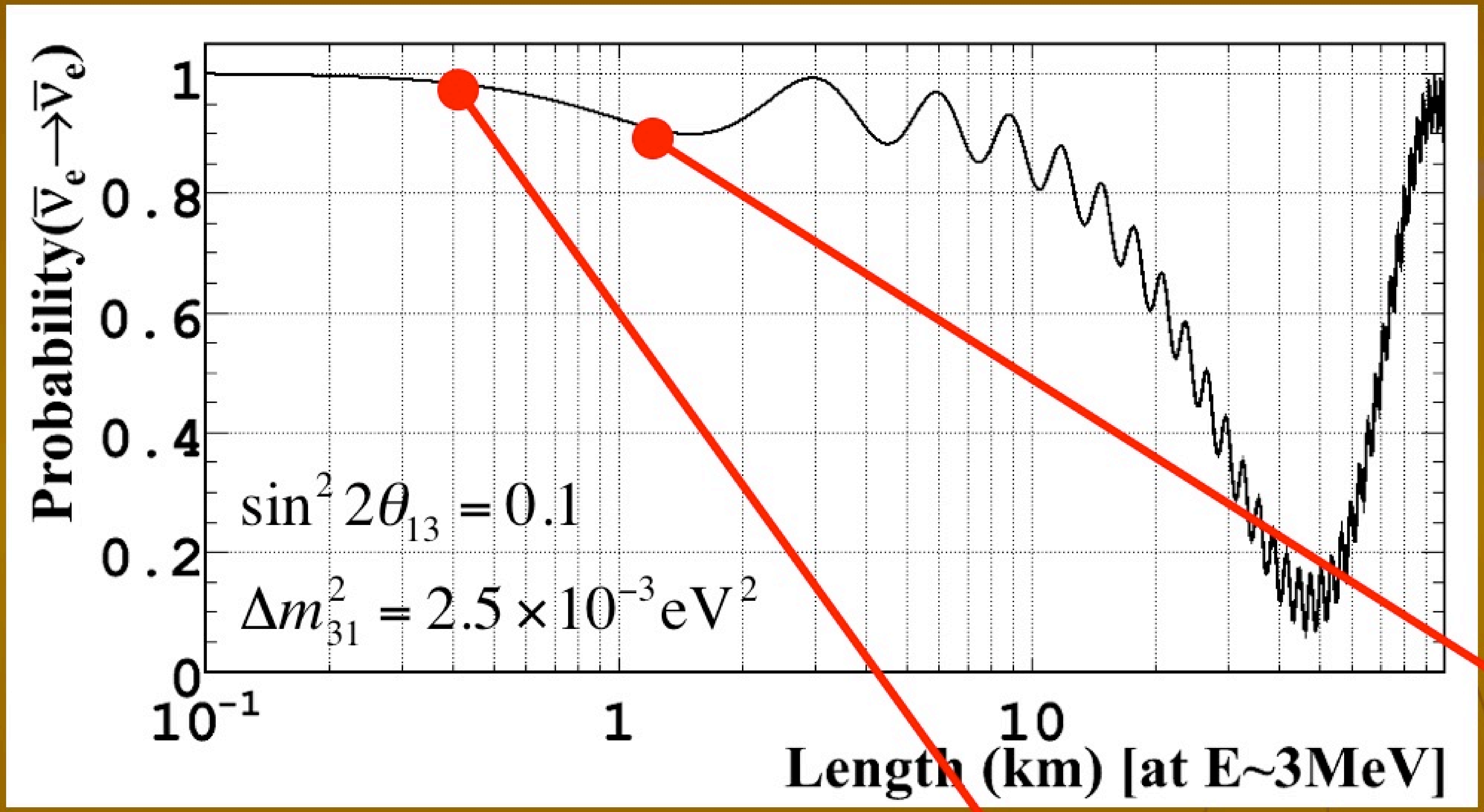
Near Detector
<L> 400m
400ν/day
120m.w.e.
Early 2012

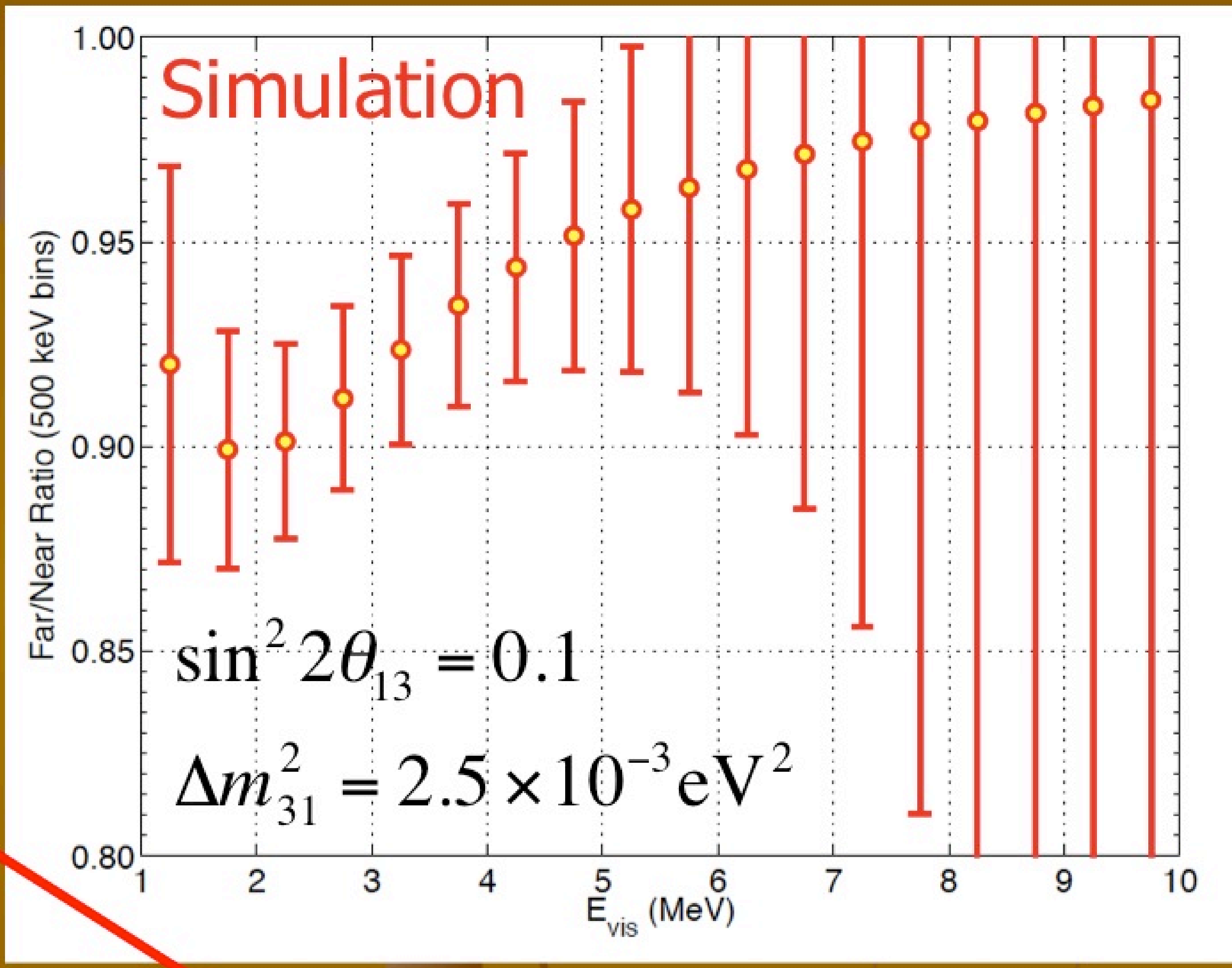
Far Detector
<L> 1050m
70ν/day
300m.w.e.
Sept. 2010

Strategy

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

DC far/near ratio (3years)





$\overline{\nu}_e$

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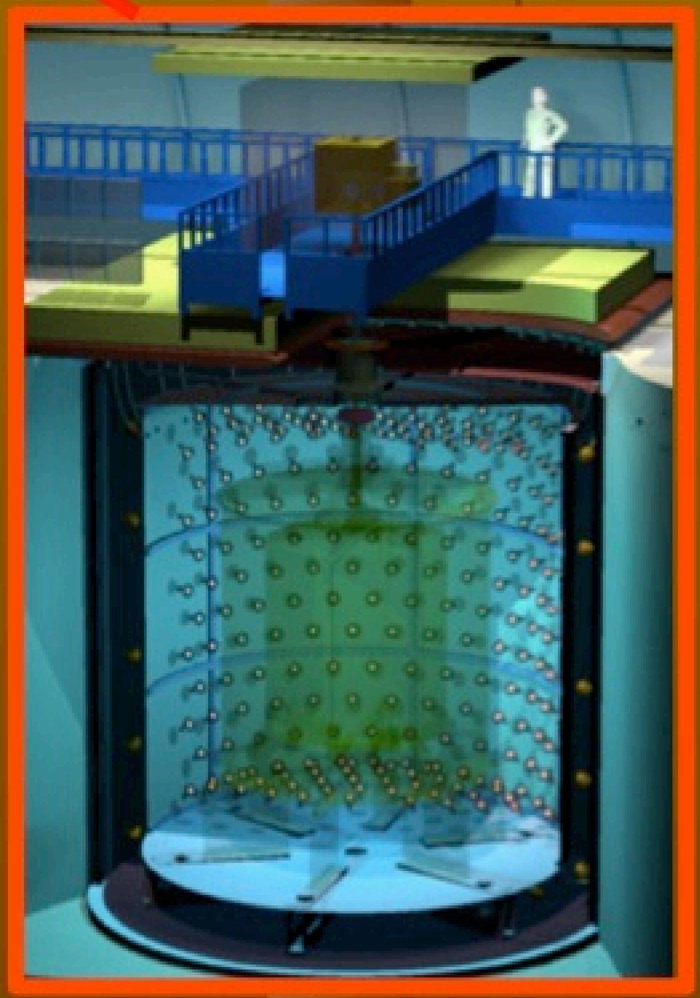

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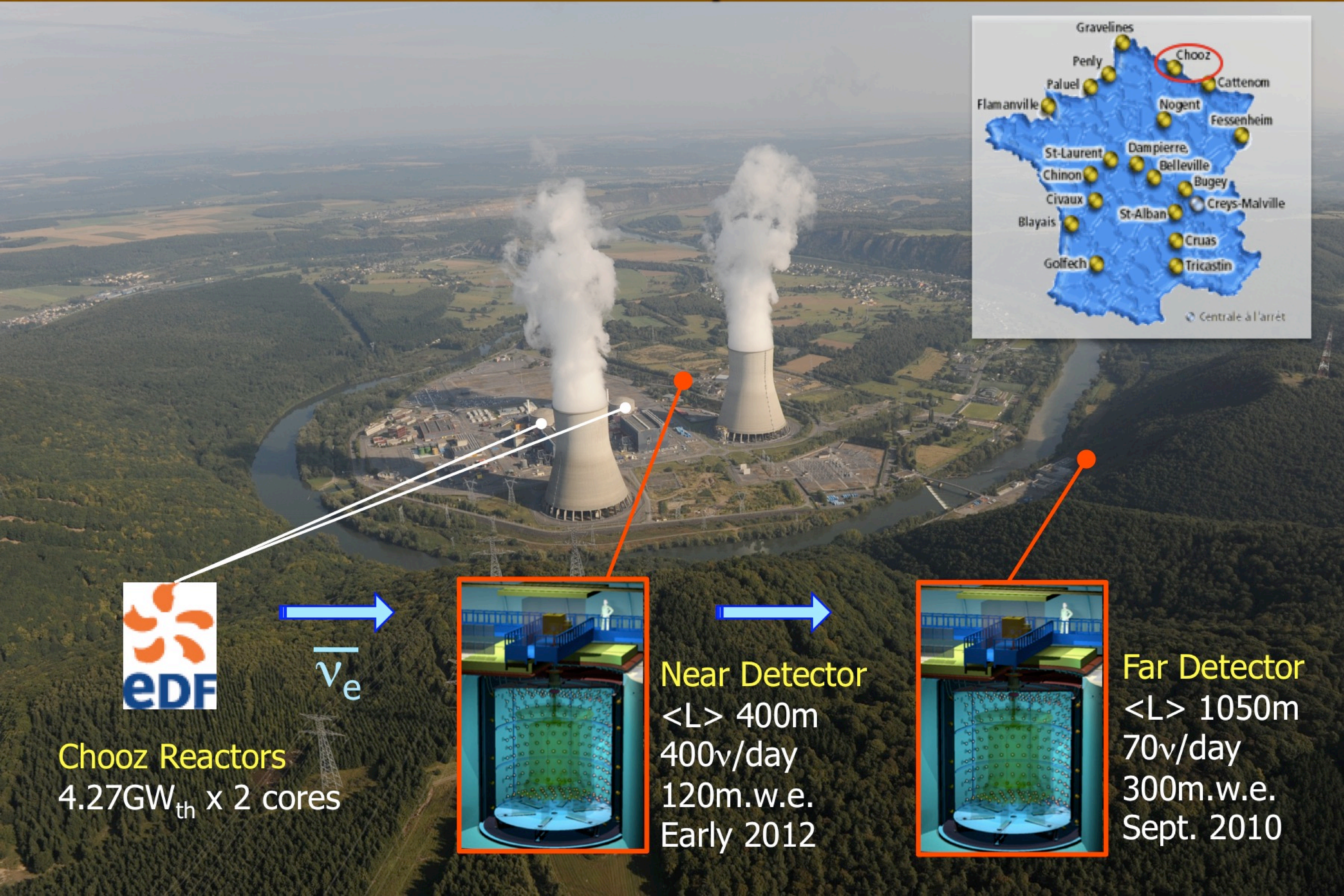
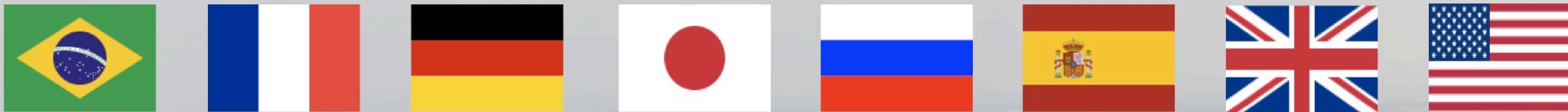
Double Chooz experiment



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

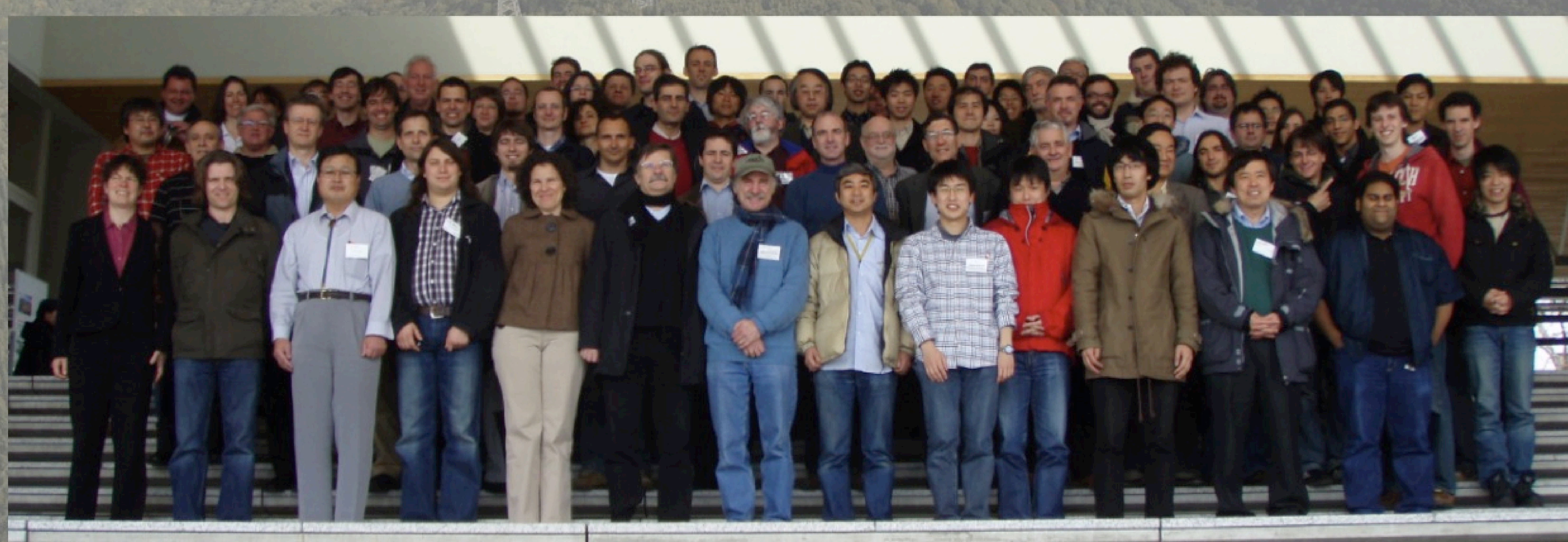
Spain
- CIEMAT-Madrid

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

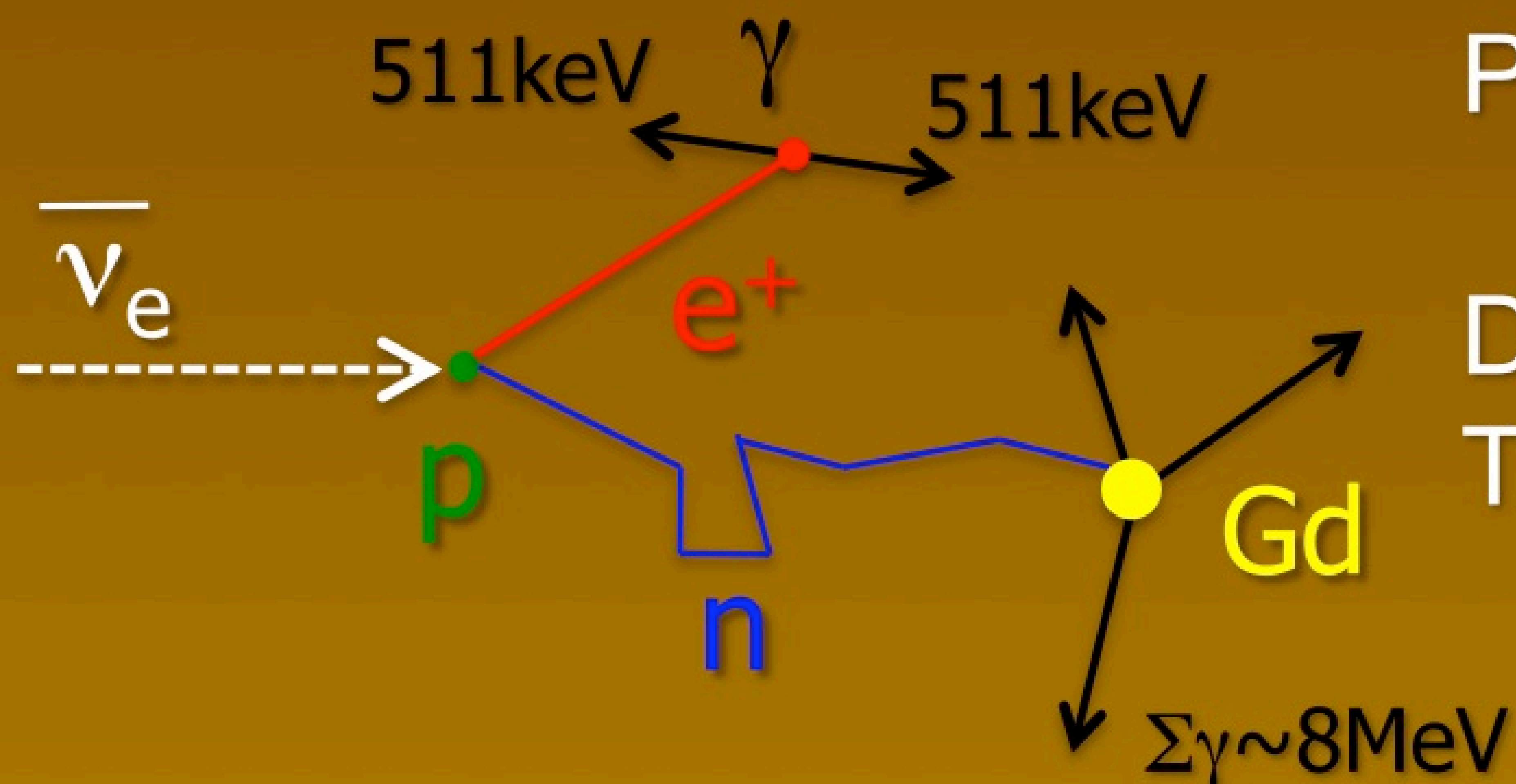
Spokesperson: H. de Kerret (IN2P3)
Project Manager: Ch. Veyssière (CEA-Saclay)

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

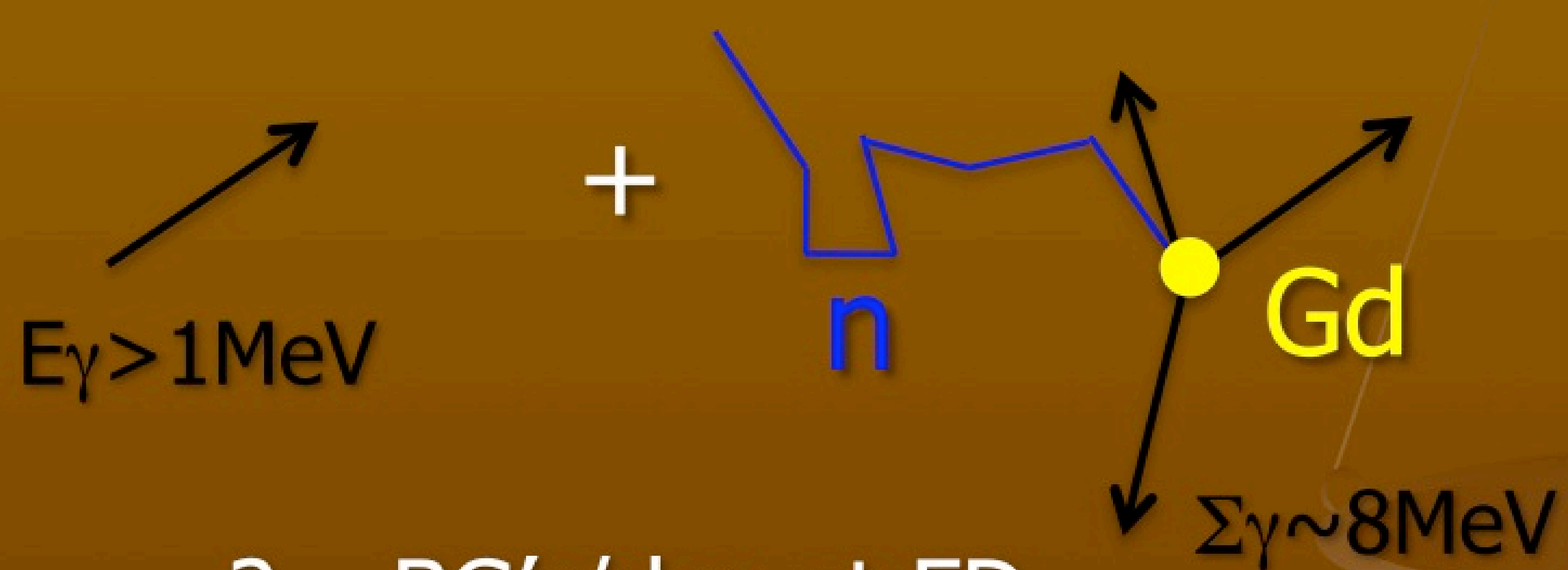
69 ν signal's/day at FD

Background

Accidental Background

Environmental γ

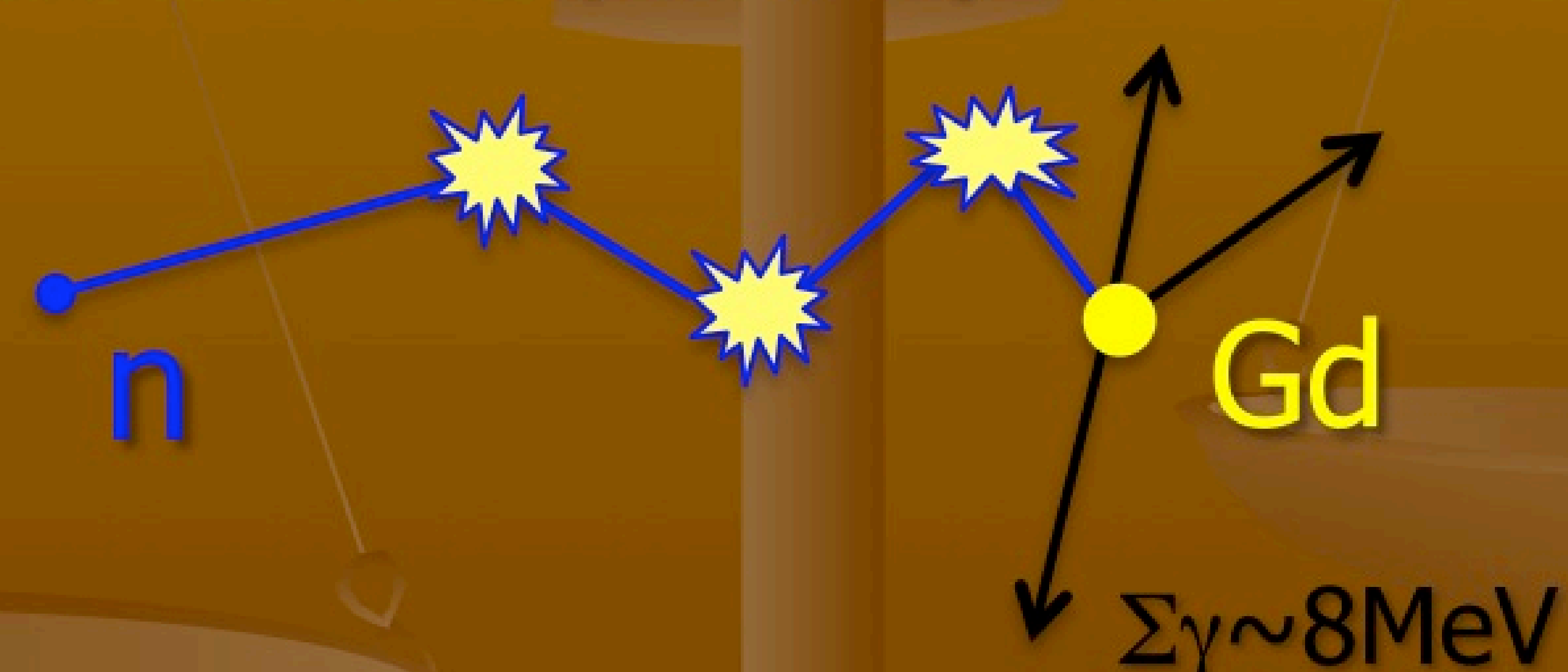
n-capture within time window



~2 ν BG's/day at FD

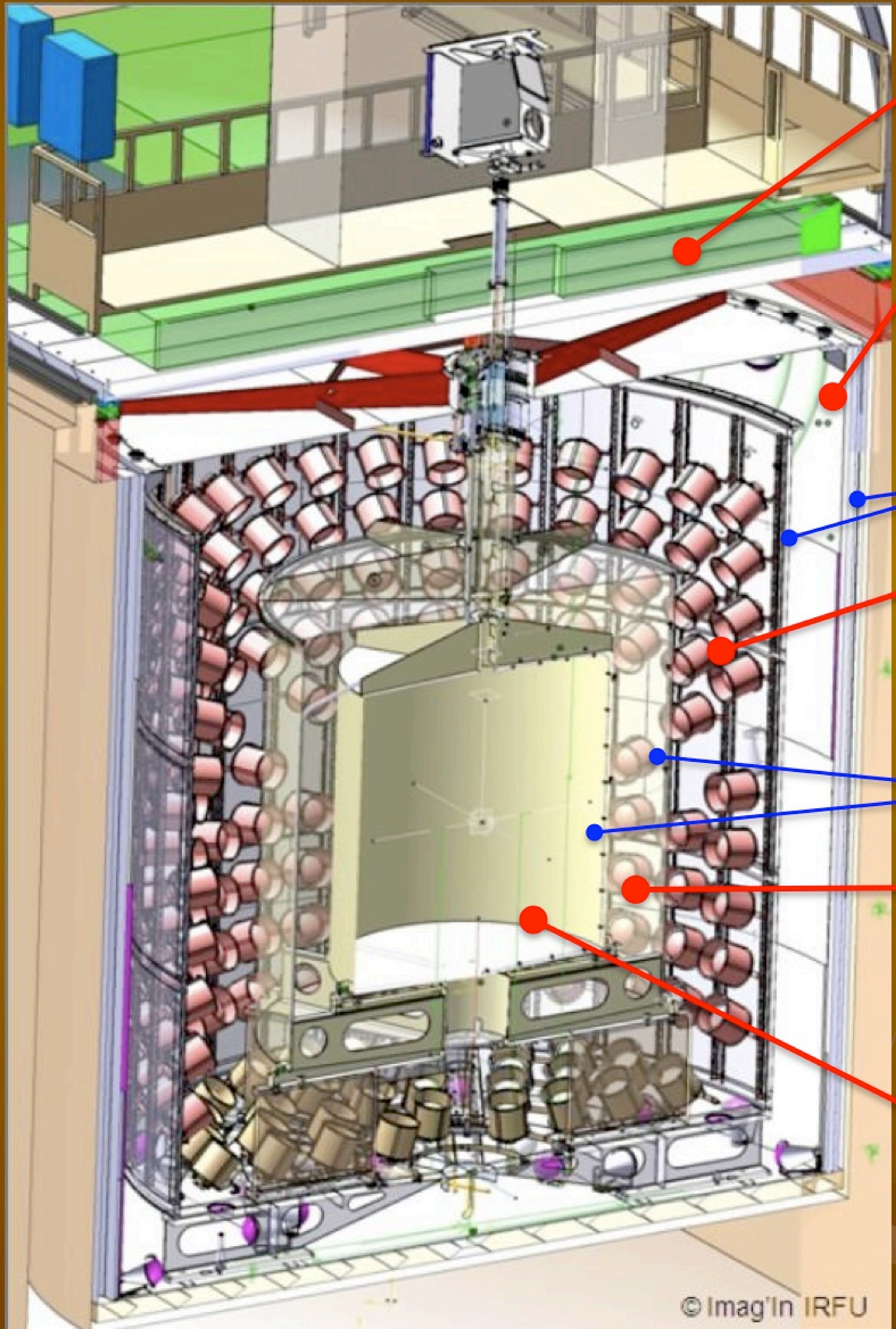
Correlated Background

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 (90m^3 Liquid scint.&78 PMTs)

- Detection of cosmic-ray μ and fast neutrons

Steel vessel & PMT support structure

Buffer (110m^3 Mineral oil & 390 PMT's)

- Reduction of fast neutron and environmental γ from outside

Acrylic vessel

γ-catcher (22.3m^3 Liquid scintillator)

- Measurement of γ's from n-capture by Gd in target volume

ν-target

(10.3m^3 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

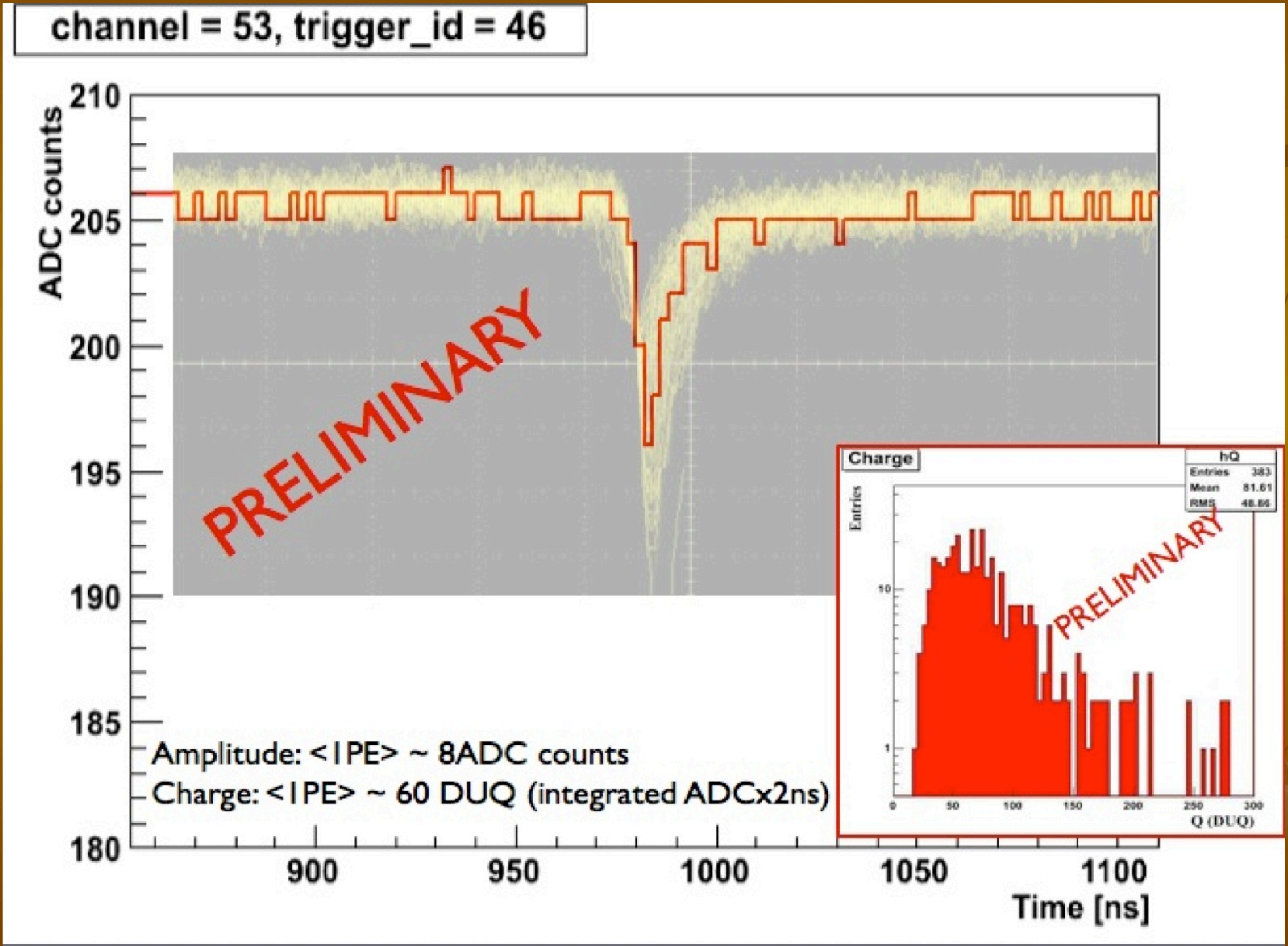

Installation of acrylic vessel

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:

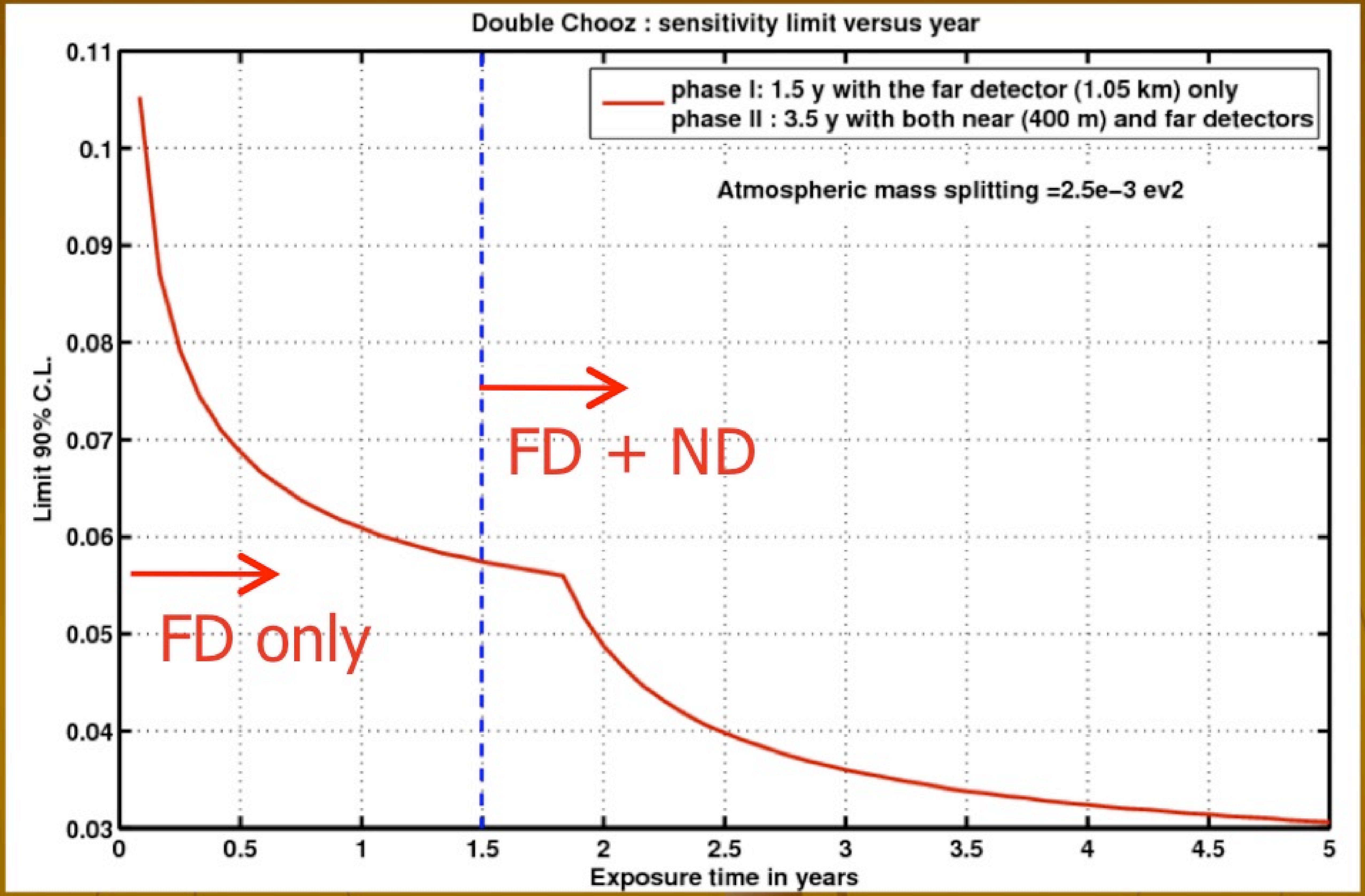
$$\sin^2 2\theta_{13} < 0.15$$

$$(\Delta m^2 = 2.5 \times 10^{-3} \mathrm{eV}^2)$$

"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…

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

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

Long-baseline with ν_μ beam: T2K, NOvA …

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

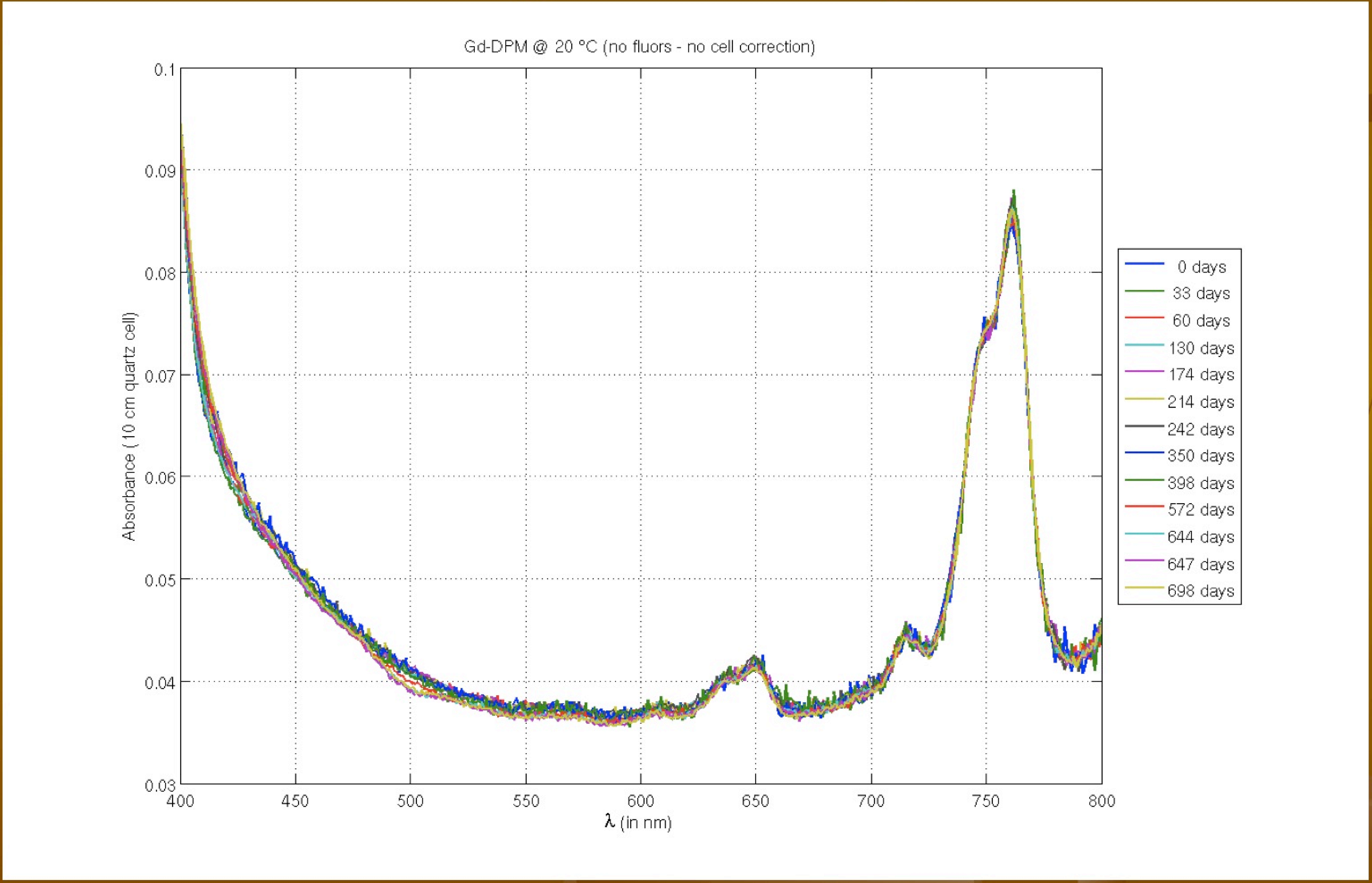
$$J_r \equiv c_{12} s_{12} c_{13}^2 s_{13} c_{23} s_{23}$$

$$\begin{aligned}
P\left[\nu_\mu(\overline{\nu}_\mu) \to \nu_e(\overline{\nu}_e)\right] = \; & \sin^2 2\theta_{13} s^2_{23} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) - \frac{1}{2} s^2_{12} \sin^2 2\theta_{13} s^2_{23} \left(\frac{\Delta m^2_{21} L}{2E}\right) \sin\left(\frac{\Delta m^2_{31} L}{2E}\right) \\
& + 2 J_r \cos\delta \left(\frac{\Delta m^2_{21} L}{2E}\right) \sin\left(\frac{\Delta m^2_{31} L}{2E}\right) \mp 4 J_r \sin\delta \left(\frac{\Delta m^2_{21} L}{2E}\right) \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) \\
& \pm \cos 2\theta_{13} \sin^2 2\theta_{13} s^2_{23} \left(\frac{4 E a(x)}{\Delta m^2_{31}}\right) \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) \\
& \mp \frac{a(x) L}{2} \sin^2 2\theta_{13} \cos 2\theta_{13} s^2_{23} \sin\left(\frac{\Delta m^2_{31} L}{2E}\right) + c^2_{23} \sin^2 2\theta_{12} \left(\frac{\Delta m^2_{21} L}{4E}\right)^2
\end{aligned}$$

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

Gd-loaded liquid scintillator

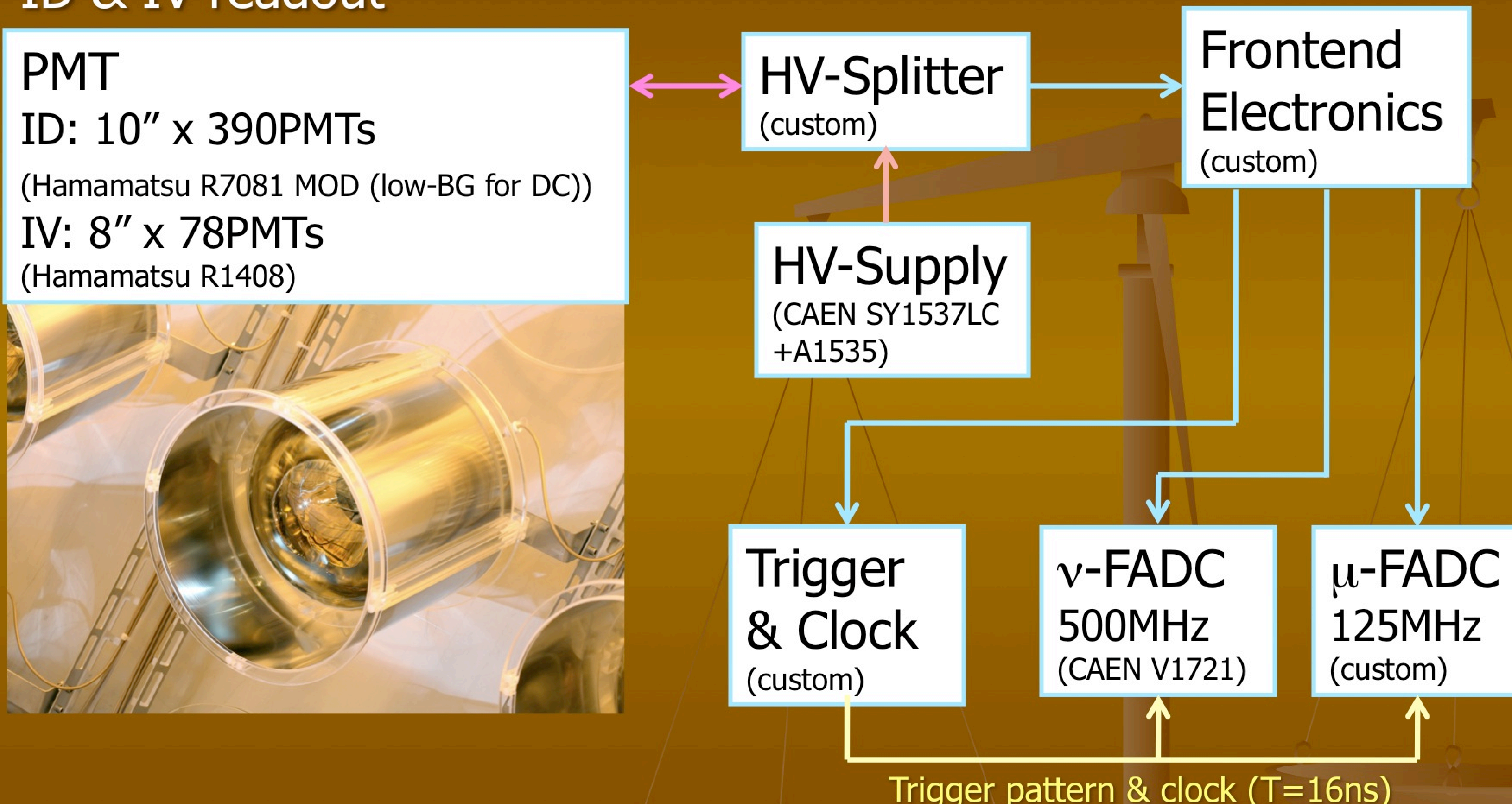
Attenuation length vs. wavelength vs. time



Long term test ⇒ stable over >2 years

Readout

ID & IV readout



+ 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