Double Chooz

Searching for θ_{13} with reactor neutrinos

XLVI^TH Rencontres de Moriond
Electroweak Interactions and Unified Theories
March 2011, La Thuile

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For the Double Chooz Collaboration

MINISTERIO DE EDUCACIÓN Y CIENCIA

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

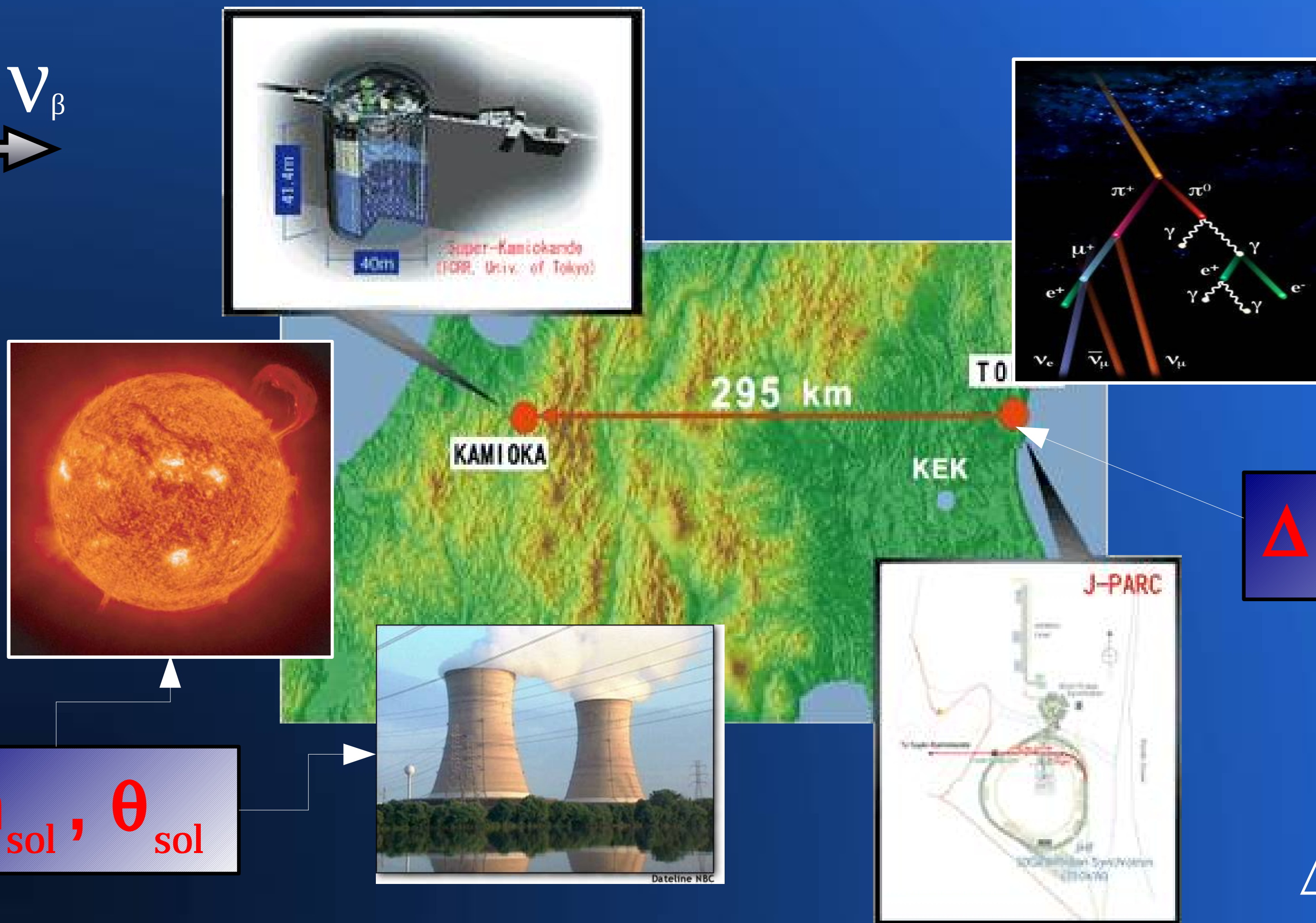
Overview

- Reactors neutrinos towards θ_{13}
- The Double Chooz experiment
- The new-born detector
- Taking the most from Double Chooz

Measuring the oscillation

ν_α E_ν ν_β

L



Δm_{atm} , θ_{atm}

Δm_{sol} , θ_{sol}

$\Delta m_{ij}^2 \equiv m_i^2 - m_j^2$

Exploring the neutrino mixing

$$\nu_{\alpha L} = \sum_{k=1}^{n} U_{\alpha k} \nu_{kL}$$

Oscillation parameters: $(\theta_{12}, \theta_{13}, \theta_{23})$, $(\Delta m^2_{21}, \Delta m^2_{31})$, δ

Oscillation physics

ββ0ν

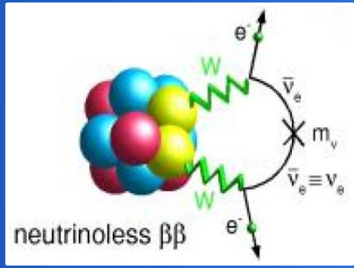
$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{21} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} e^{i\alpha_1} & 0 & 0 \\ 0 & e^{i\alpha_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Atmospheric sector

interference sector

?

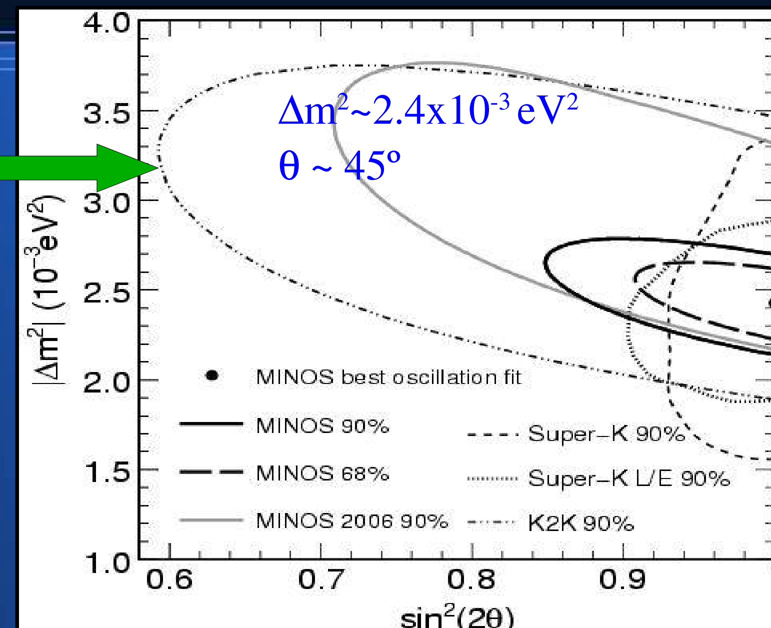
Solar sector



What's next?

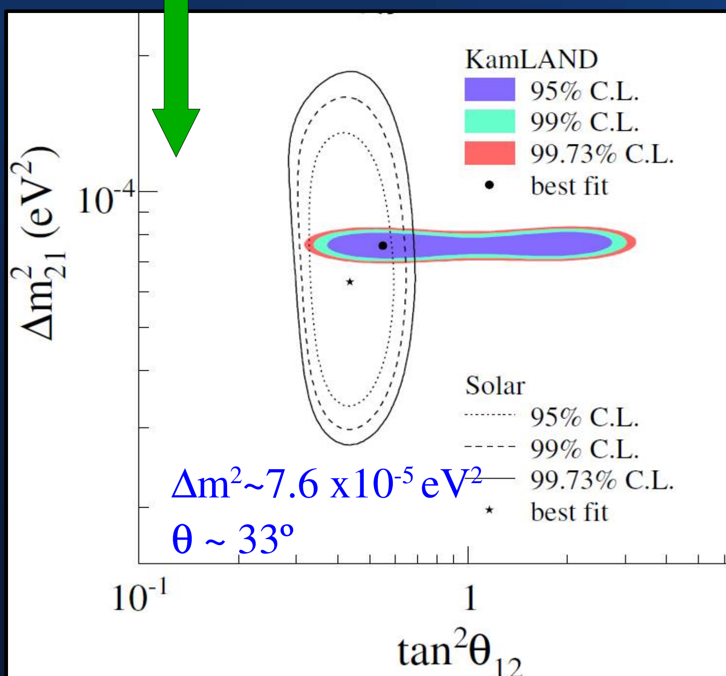
- Experimental results:

- $(|\Delta m^2_{atm}|, \theta_{atm})$ → Minos and Super-K



Phys. Rev. Lett. 101:131802,2008

- $(\Delta m^2_{sol}, \theta_{sol})$ → Kamland and solar data



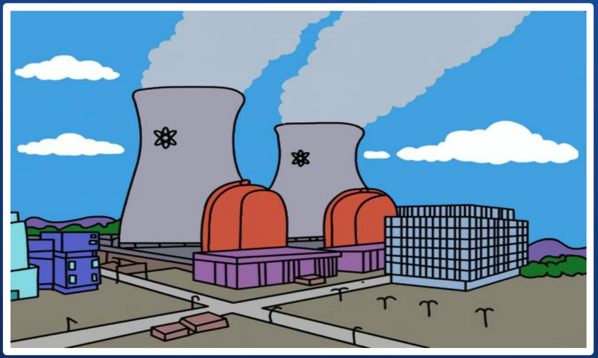
Phys. Rev. Lett. 100:221803, 2008

- $\sin^2(2\theta_{13}) < 0.15$ from **CHOOZ**: δ?

θ_{13}

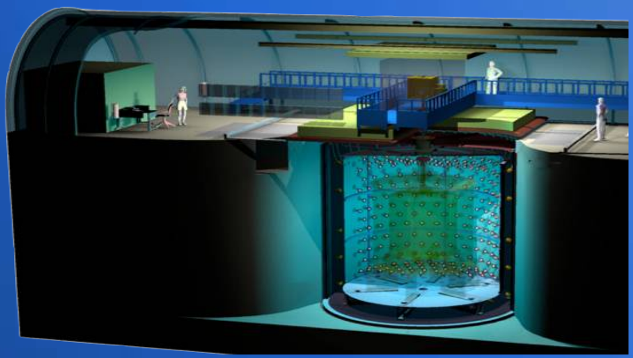
- Measurement of δ_{cp}
- Sign of Δm^2_{atm} (hierarchy)
- Design of next experiments

Why reactor neutrinos?



L ~ 1 km

$P(\bar{\nu}_e \rightarrow \bar{\nu}_x)$



- In contrast to accelerator experiments...

$$P_{ee}(E_{\overline{\nu}_e}, L, \Delta m^2_{31}, \theta_{13}) = 1 - \sin^2(2\theta_{13})\sin^2\left(1.27\frac{\Delta m^2_{31}[10^{-3}\ \mathrm{eV}^2]L[\mathrm{km}]}{E_{\overline{\nu}_e}[\mathrm{MeV}]}\right)$$

- No parameter correlations
- Nearly pure $\bar{\nu}_e$ beam
- Low energy
- No matter effects
- Cheap, as source exists
- High flux and large xsection

The Double Chooz Experiment

The Double Chooz Collaboration

Brazil
CBPF
UNICAMP
UFABC

France
APC
CEA/DSM/IRFU:
 SPP
 SPhN
 SEDI
 SIS
 SENAC
CNRS/IN2P3:
 Subatech
 IPHC
ULB

Germany
EKU Tübingen
MPIK Heidelberg
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

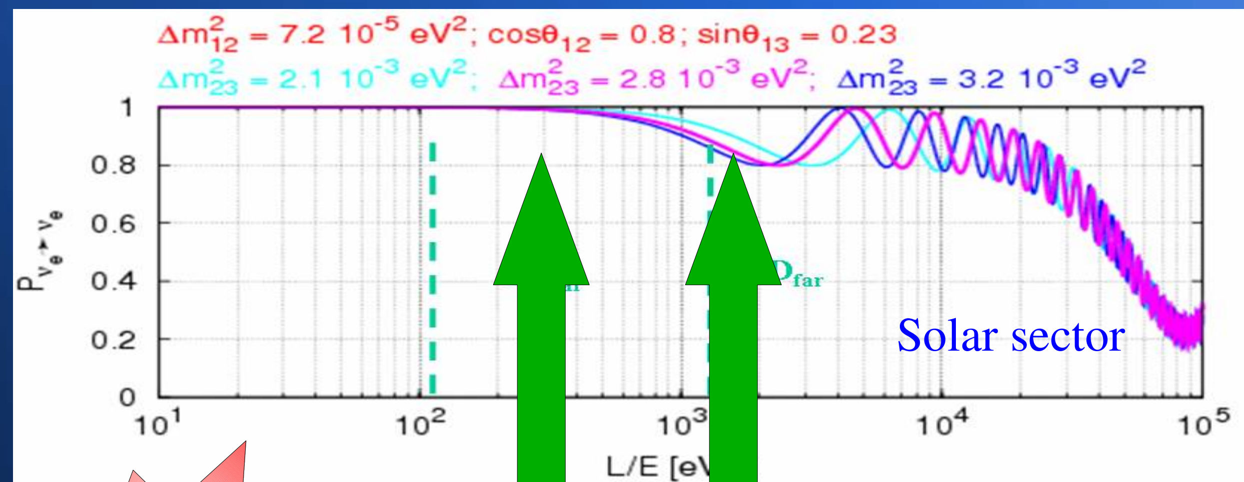
Spokesperson: H. de Kerret (IN2P3)
Project Manager: Ch. Veyssière (CEA-Saclay)

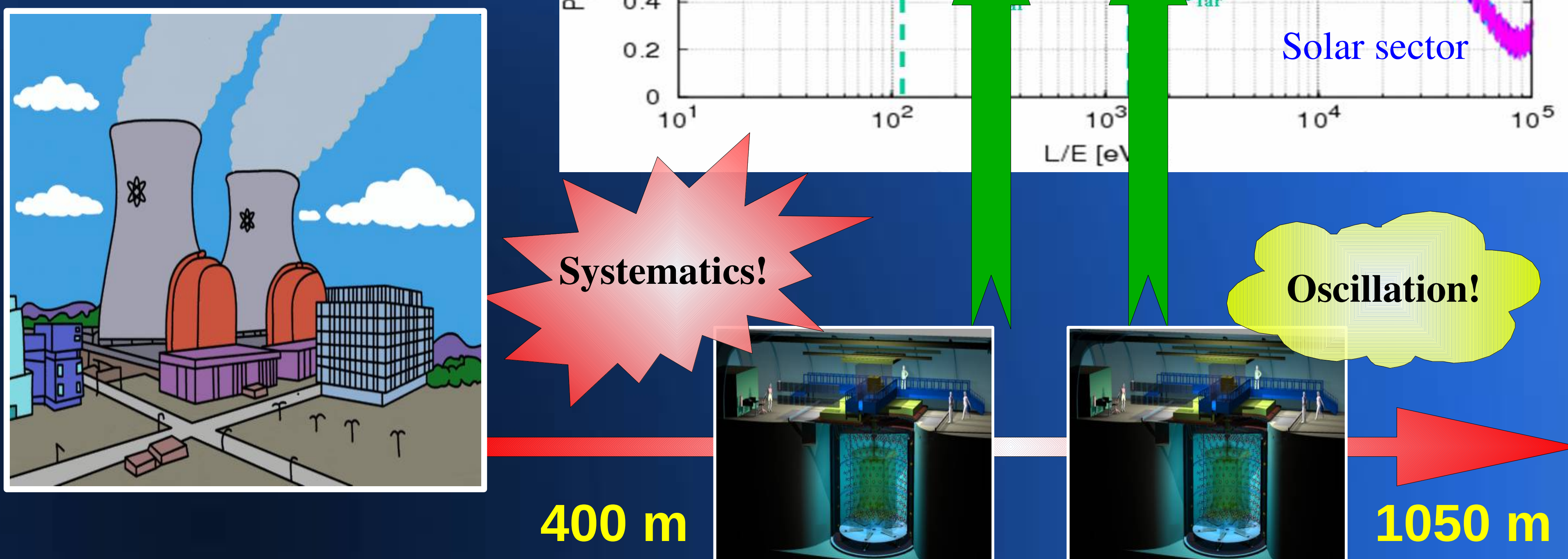
Web Site: www.doublechooz.org/

Setting up the experiment

Reactor neutrinos:

$\langle E_\nu \rangle \sim 4$ MeV



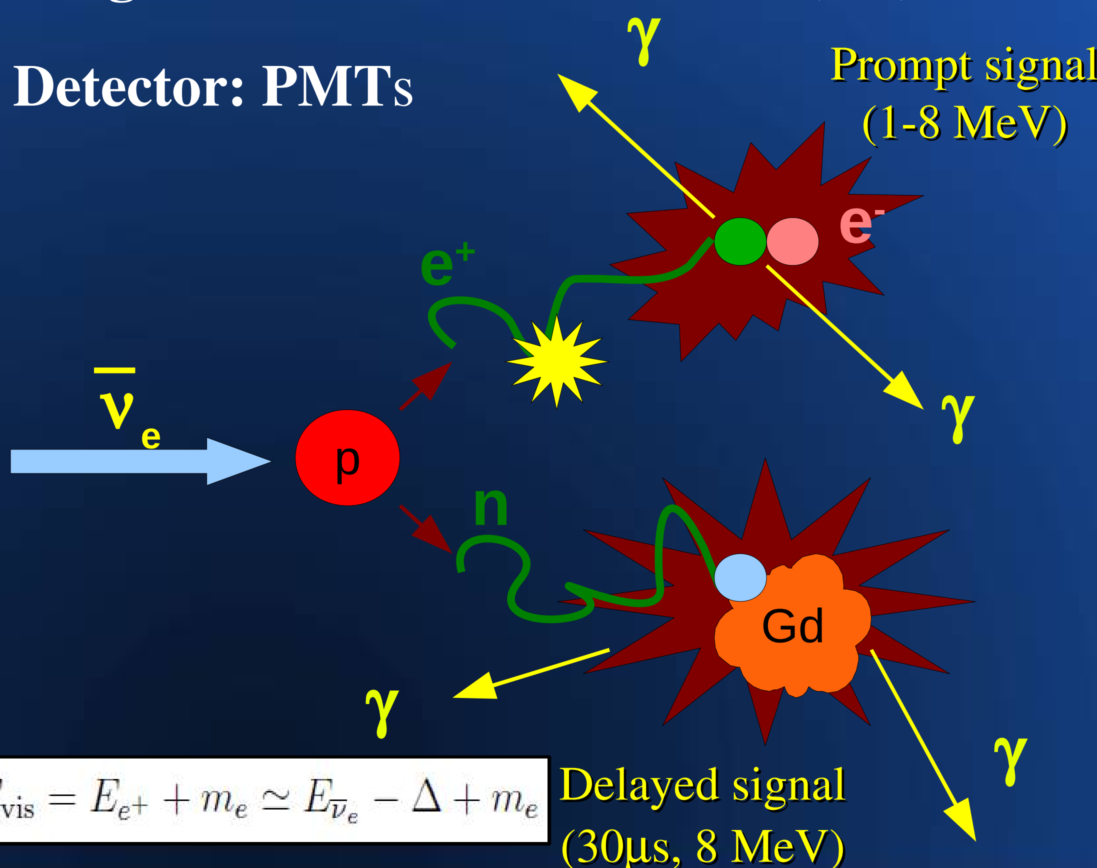


Detecting reactor neutrinos

IBD: $\bar{\nu}_e + p \rightarrow e^+ + n$

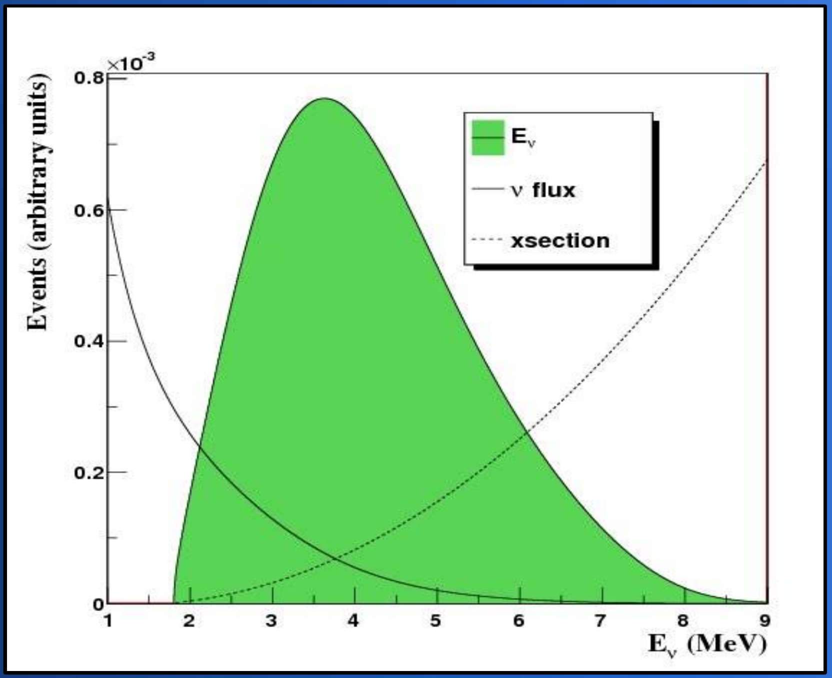
- **Target: scintillator + n-catcher (Gd)**
- **Detector: PMTs**

Th: 1.8 MeV. **Disappearance!**



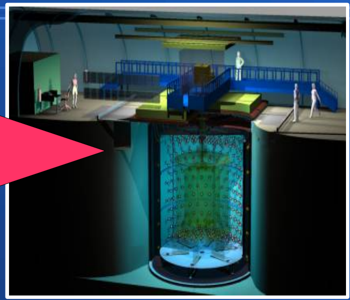
$$E_{\text{vis}} = E_{e^+} + m_e \simeq E_{\bar{\nu}_e} - \Delta + m_e$$

E_ν spectrum



Expected oscillation signal

1 km

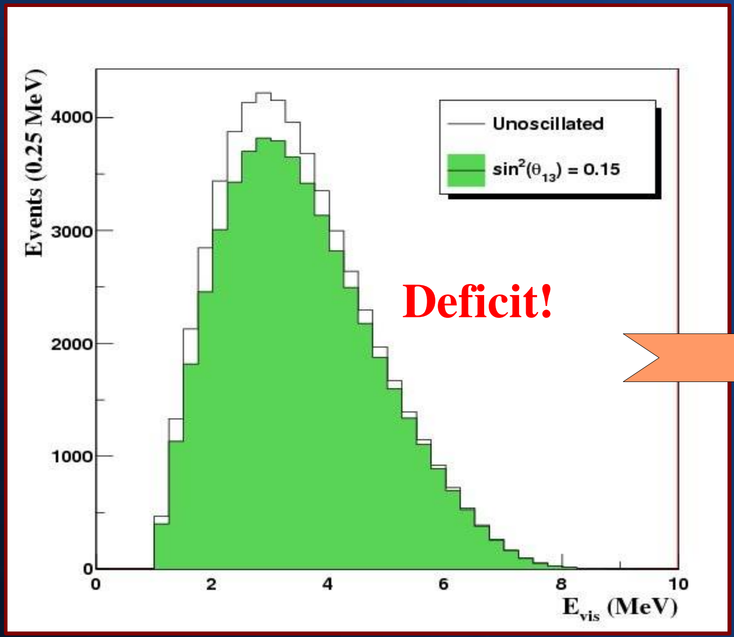


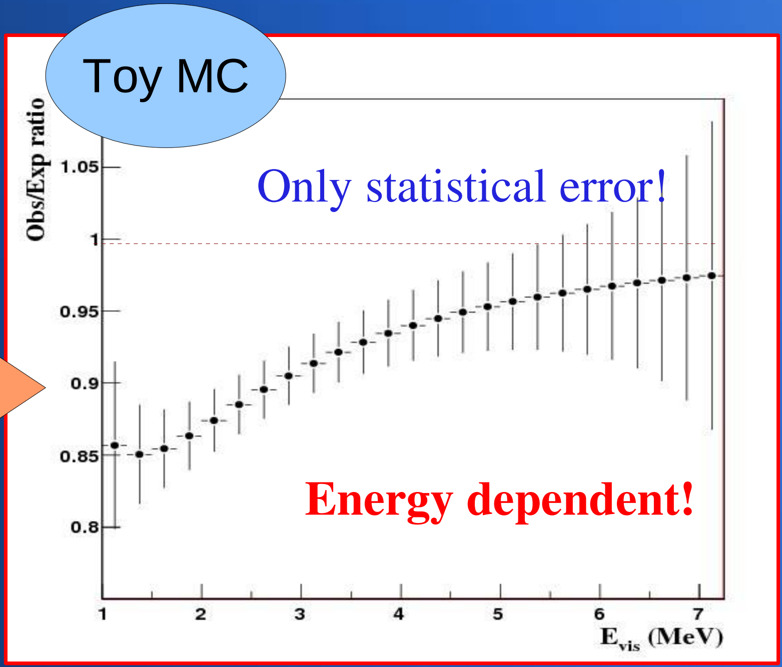
Toy Monte Carlo

- $8x10^{29}$ free protons
- Detection efficiency 80%

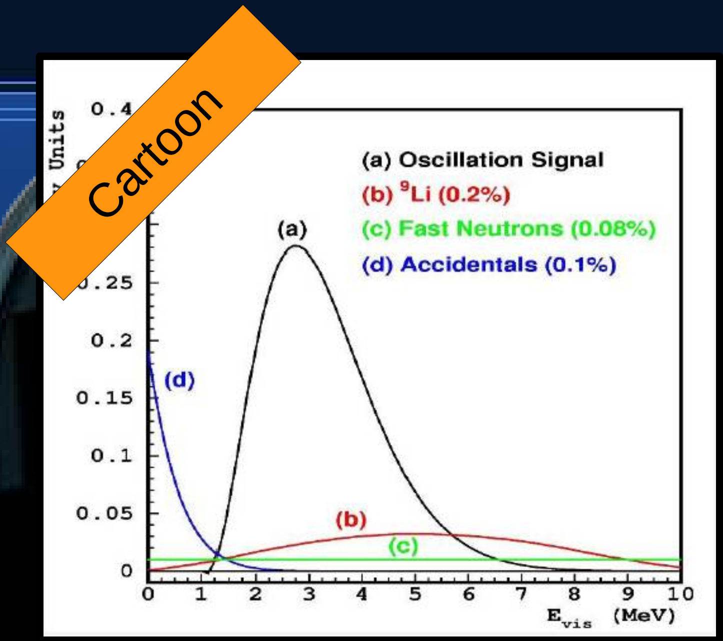
3 years:

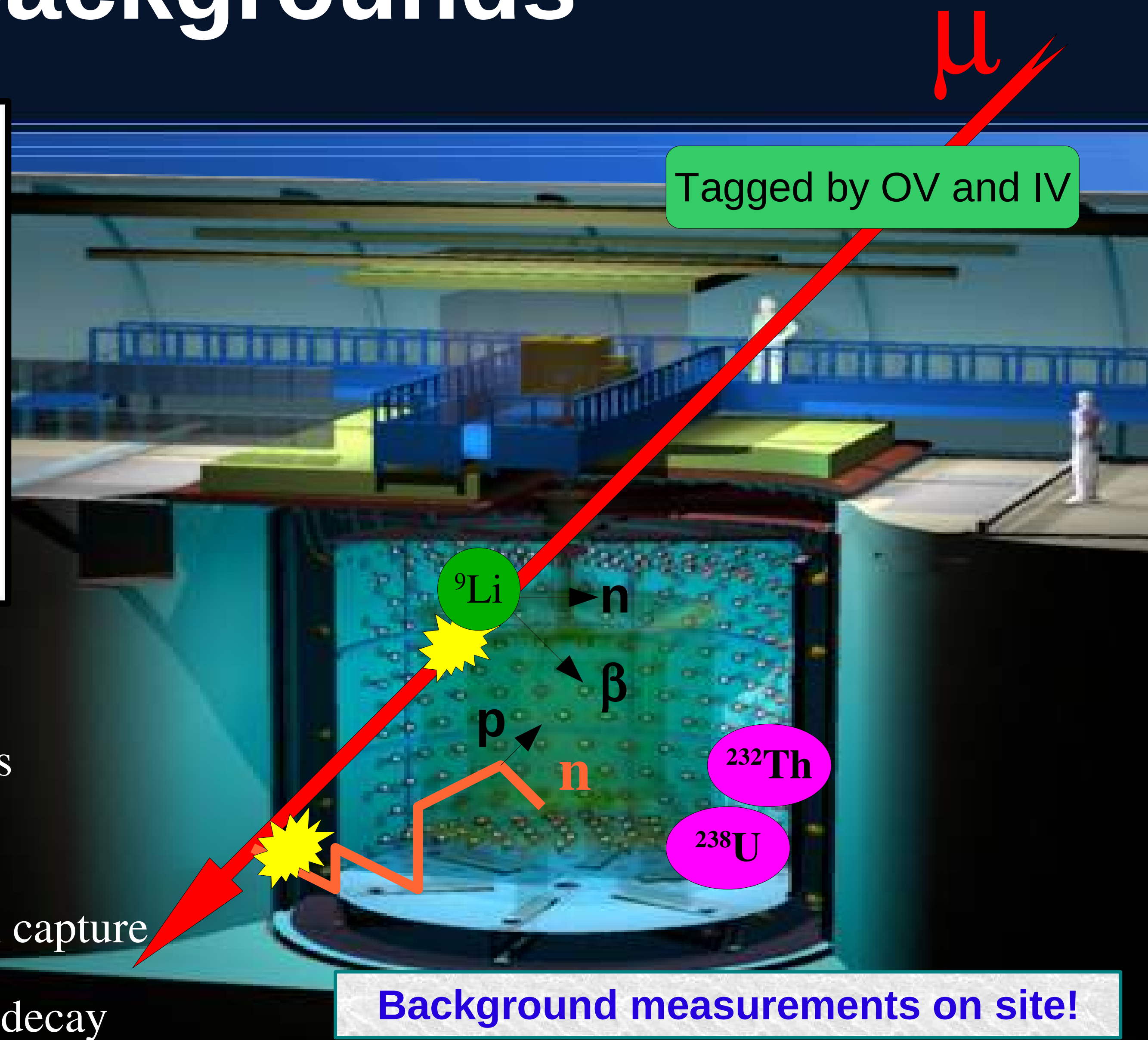
~ 50.000 events expected





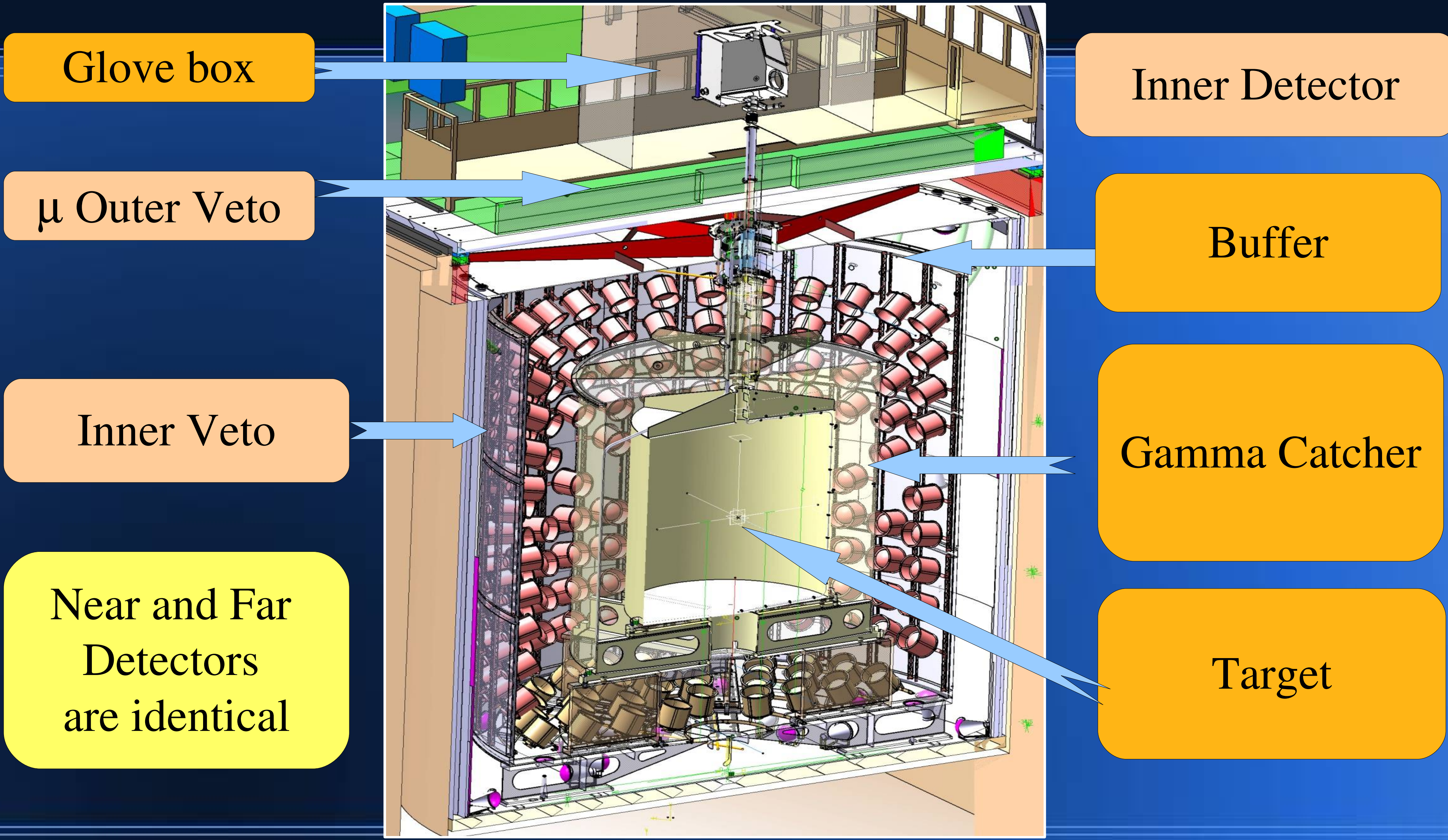
Backgrounds





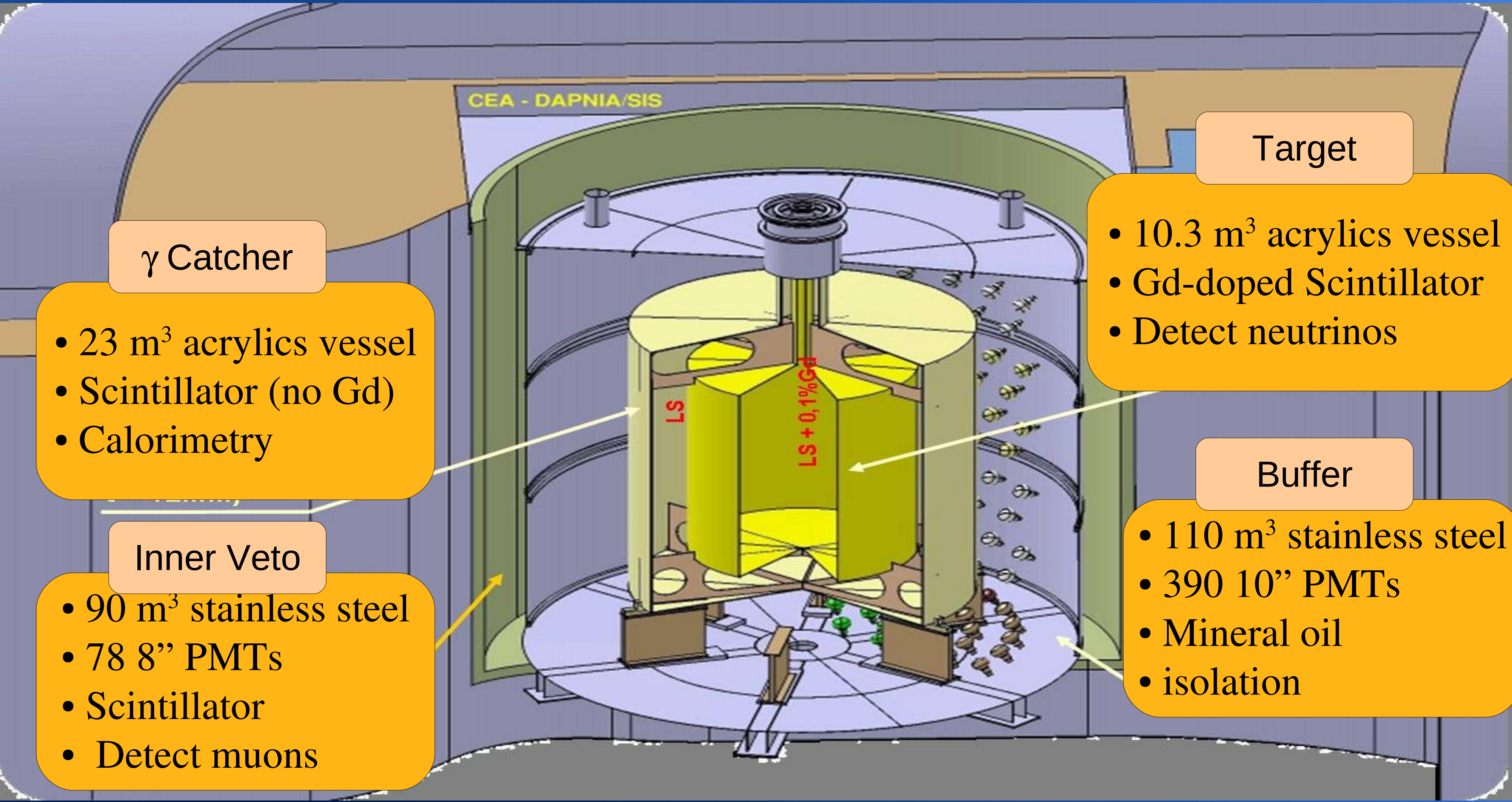
- Uncorrelated:
  - Radioactivity + fast neutrons
- Correlated:
  - Fast neutrons: p recoil + n capture
  - cosmogenic isotopes: n-β decay

Double Chooz Detectors

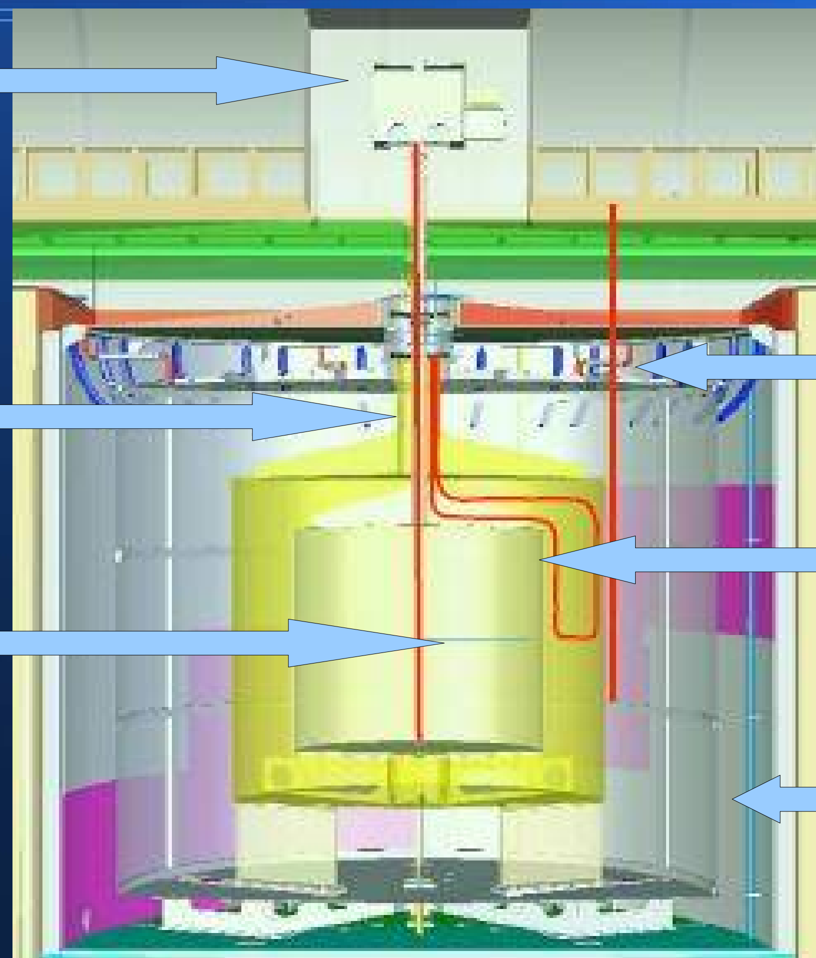


Near and Far Detectors are identical

Double Chooz Detectors

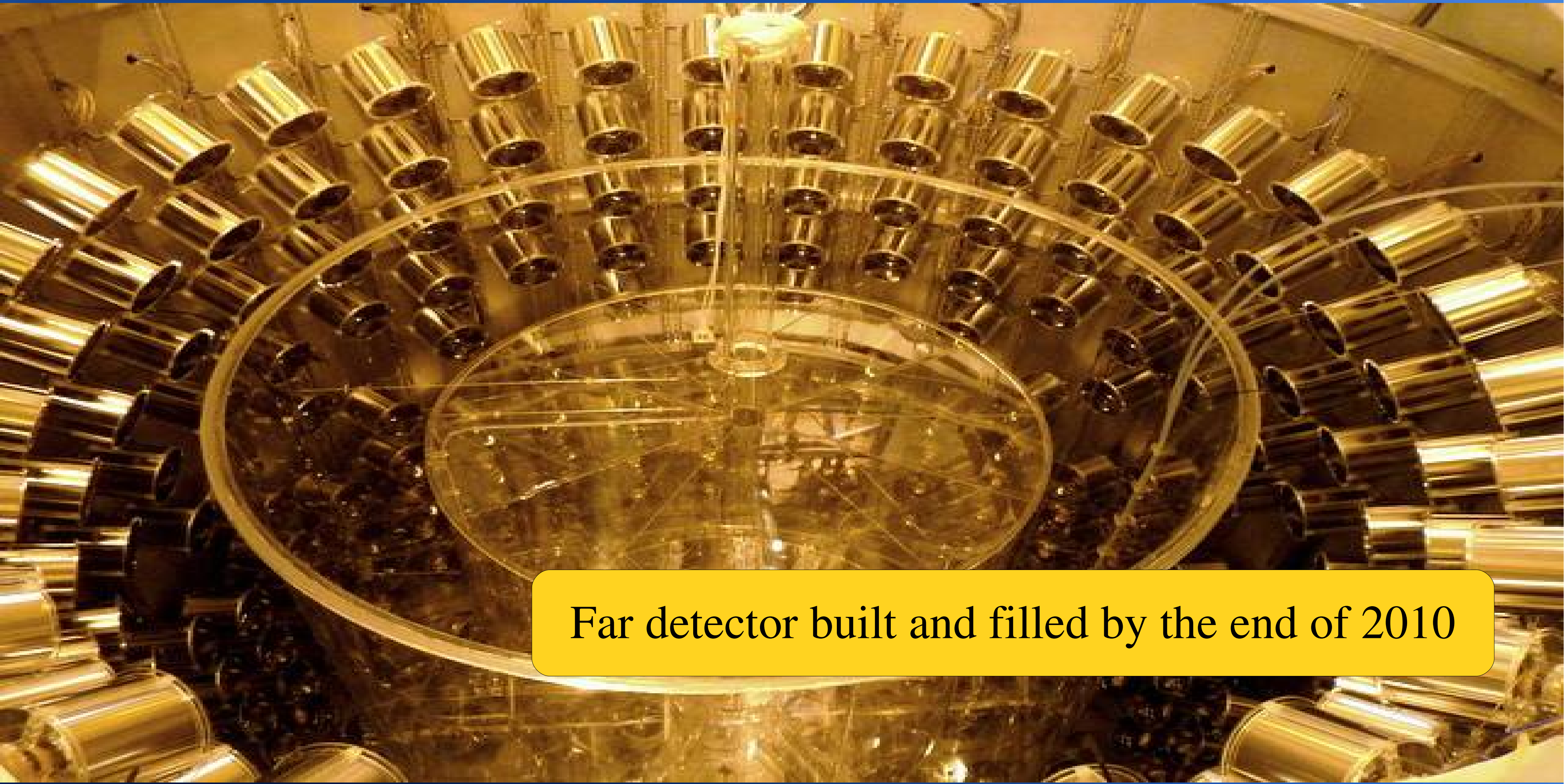


Calibration Systems



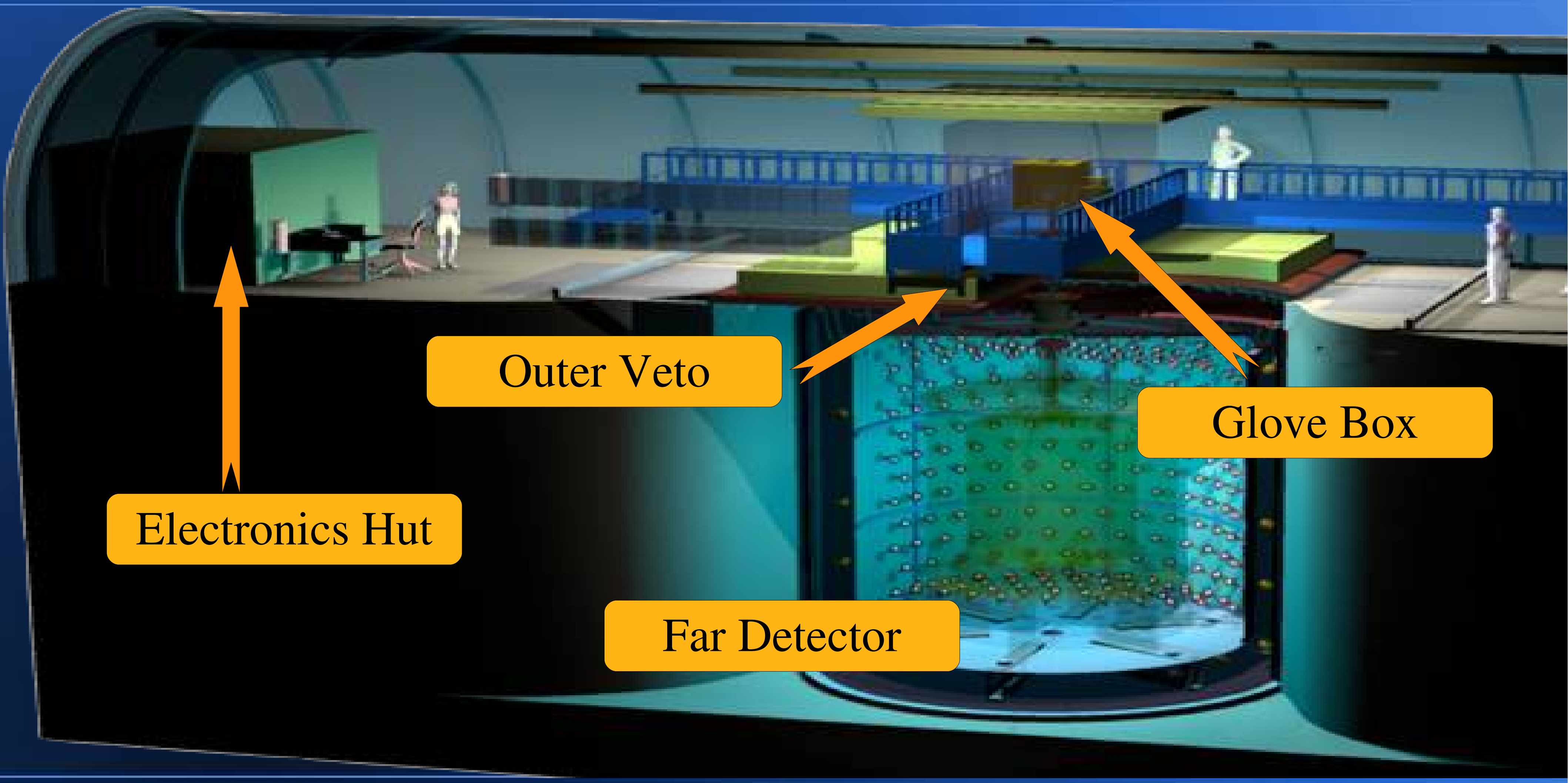
- 3 Calibration sources:
  - Natural: H n-capture peak
  - Radioactive sources
  - Laser and LED system

The New Born Detector



Far detector built and filled by the end of 2010

Far Detector Hall



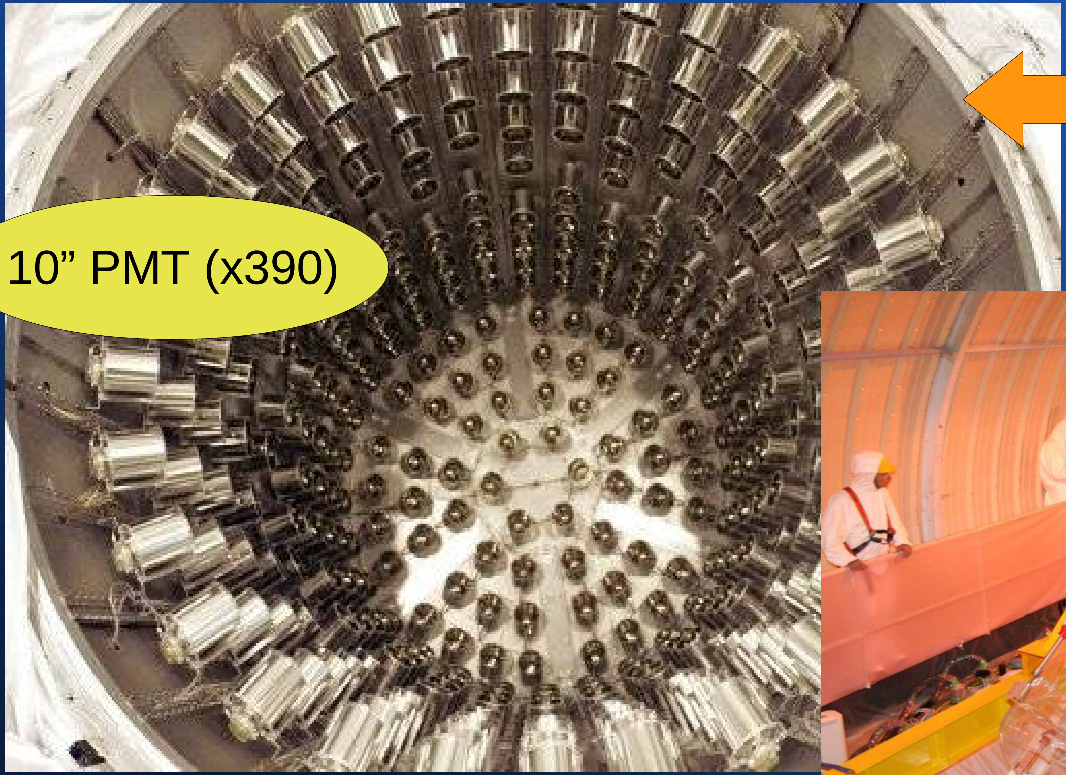
The Inner Veto

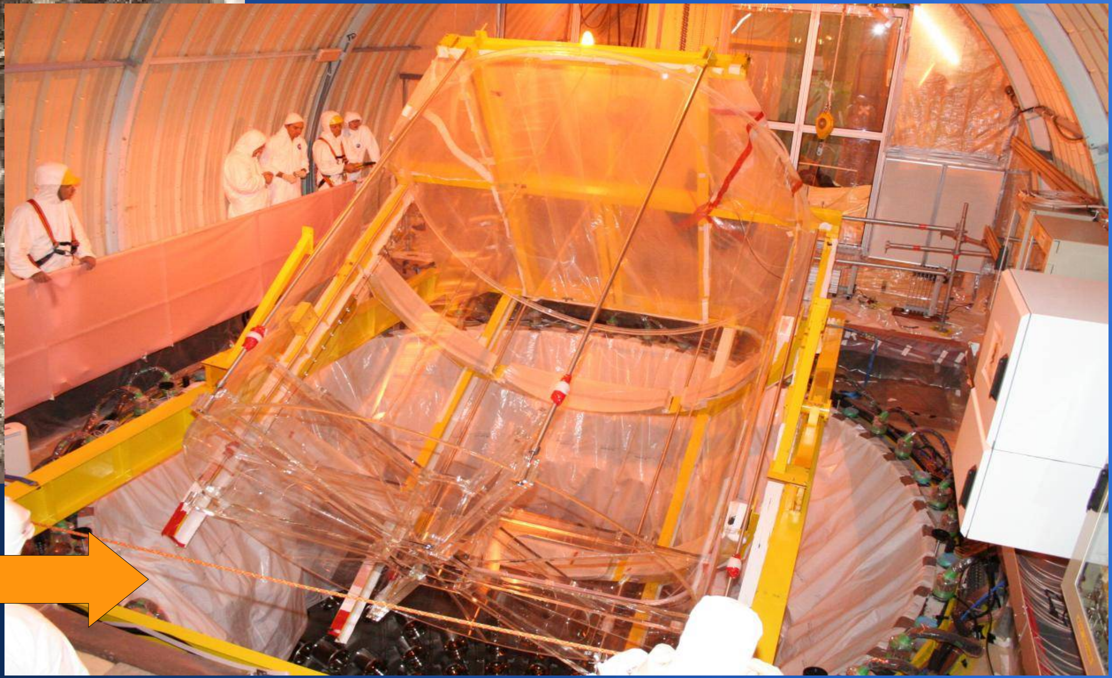
The Pit and Shield

8” PMT (x78)

The Inner Veto

The Inner Detector



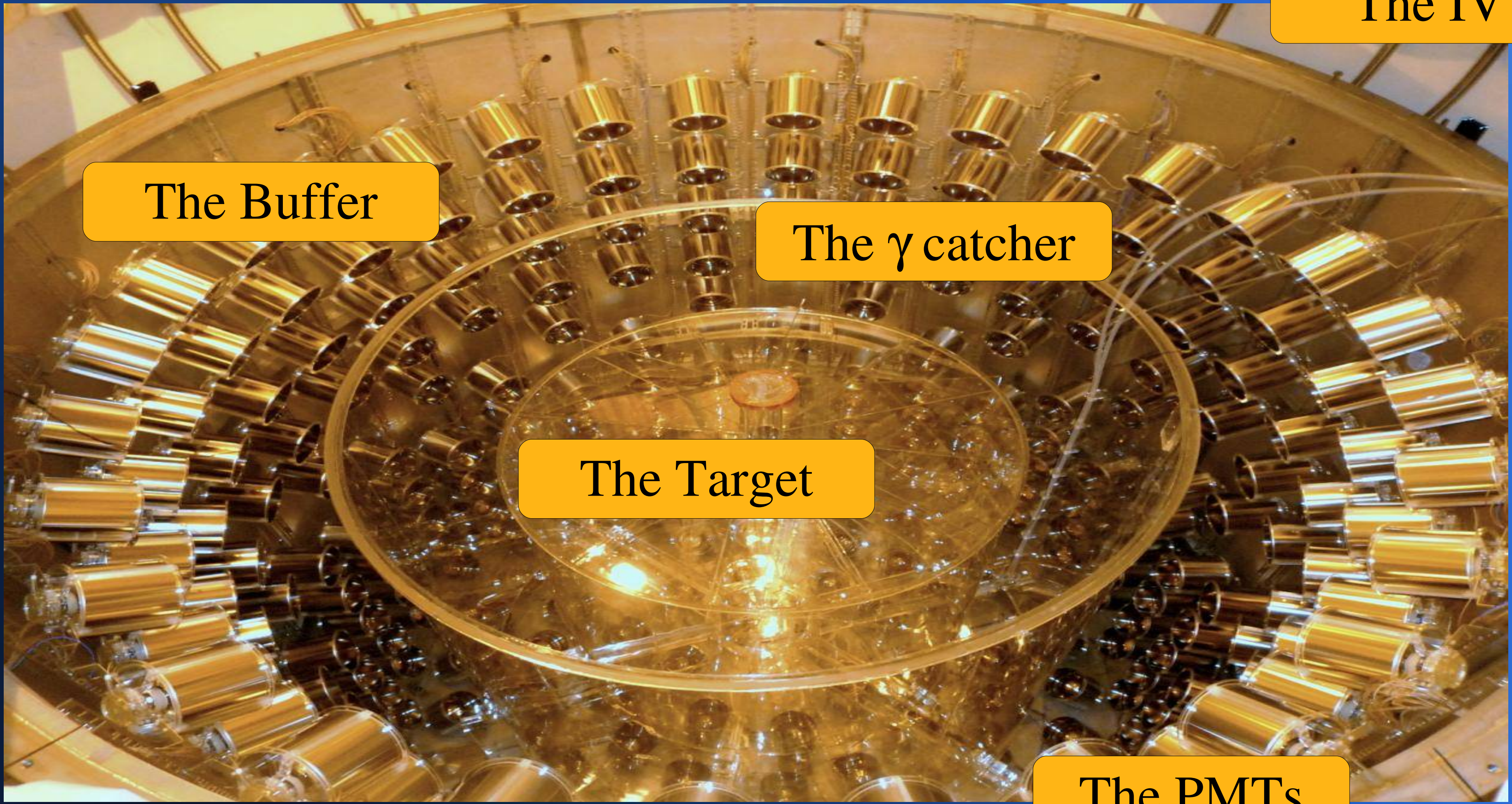


The Buffer

10” PMT (x390)

The Acrylic vessels

The Inner Detector (II)



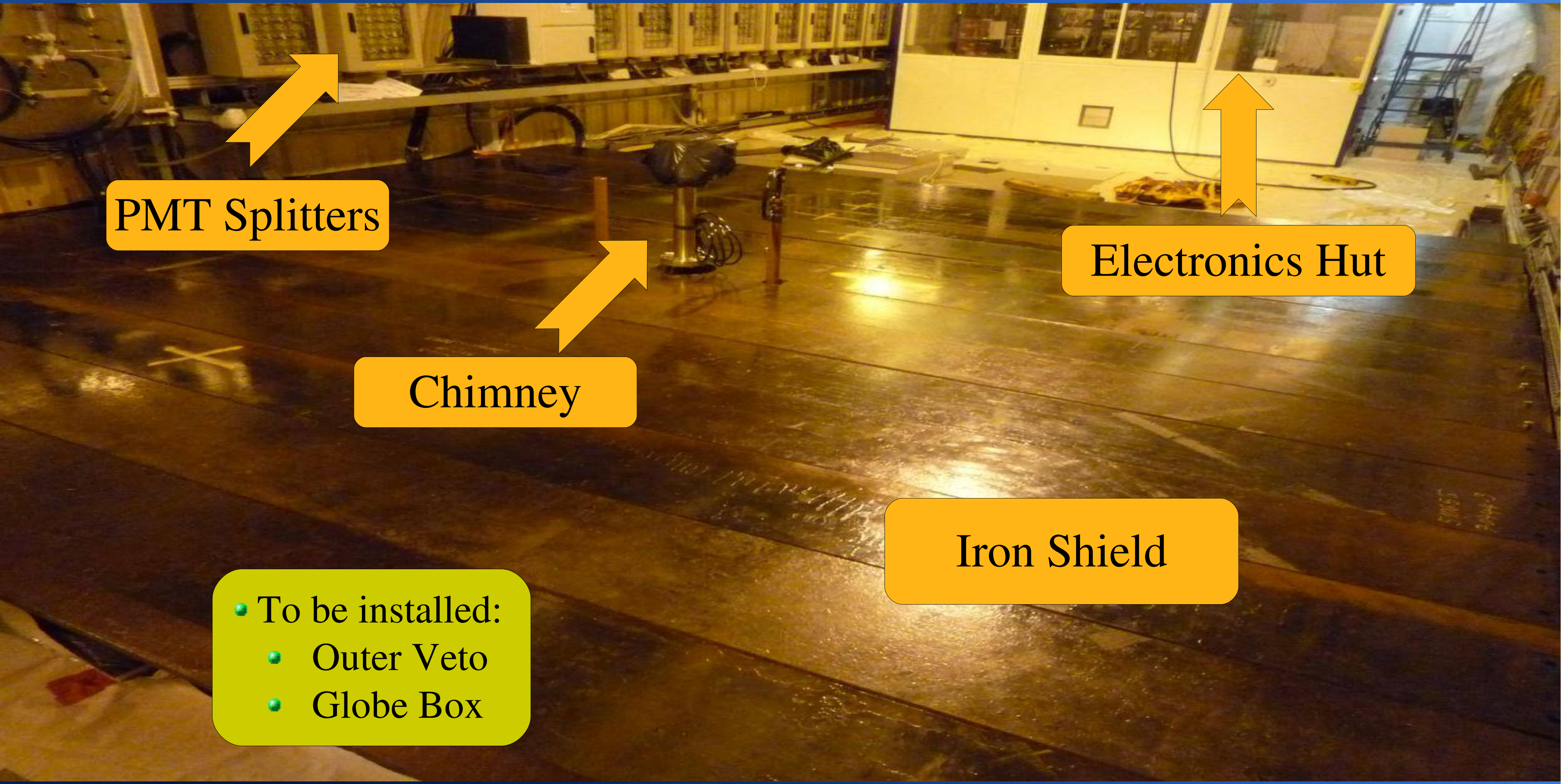
Closing The Detector


Feeding The Detector

The Filling Station

Measuring the liquid level

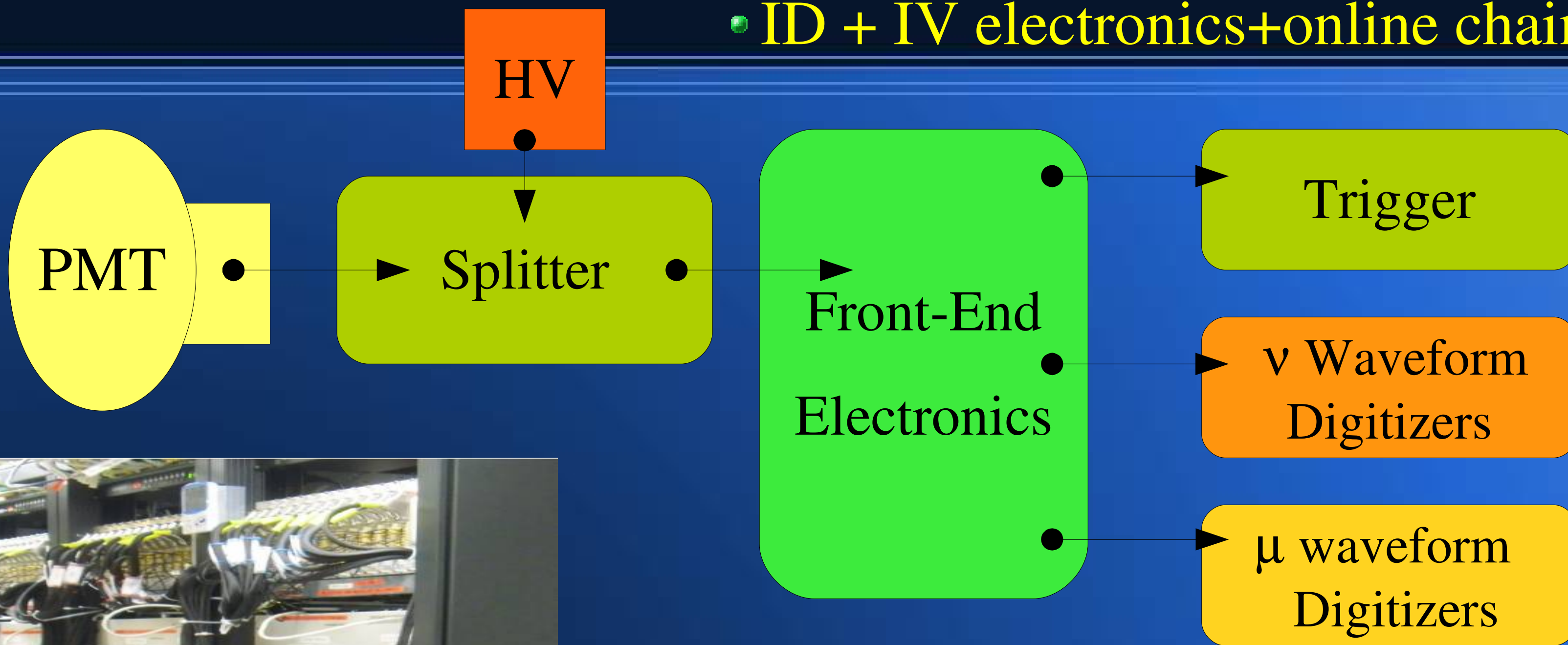
The Shield



- To be installed:
  - Outer Veto
  - Globe Box

The Detector Brain

- ID + IV electronics+online chain

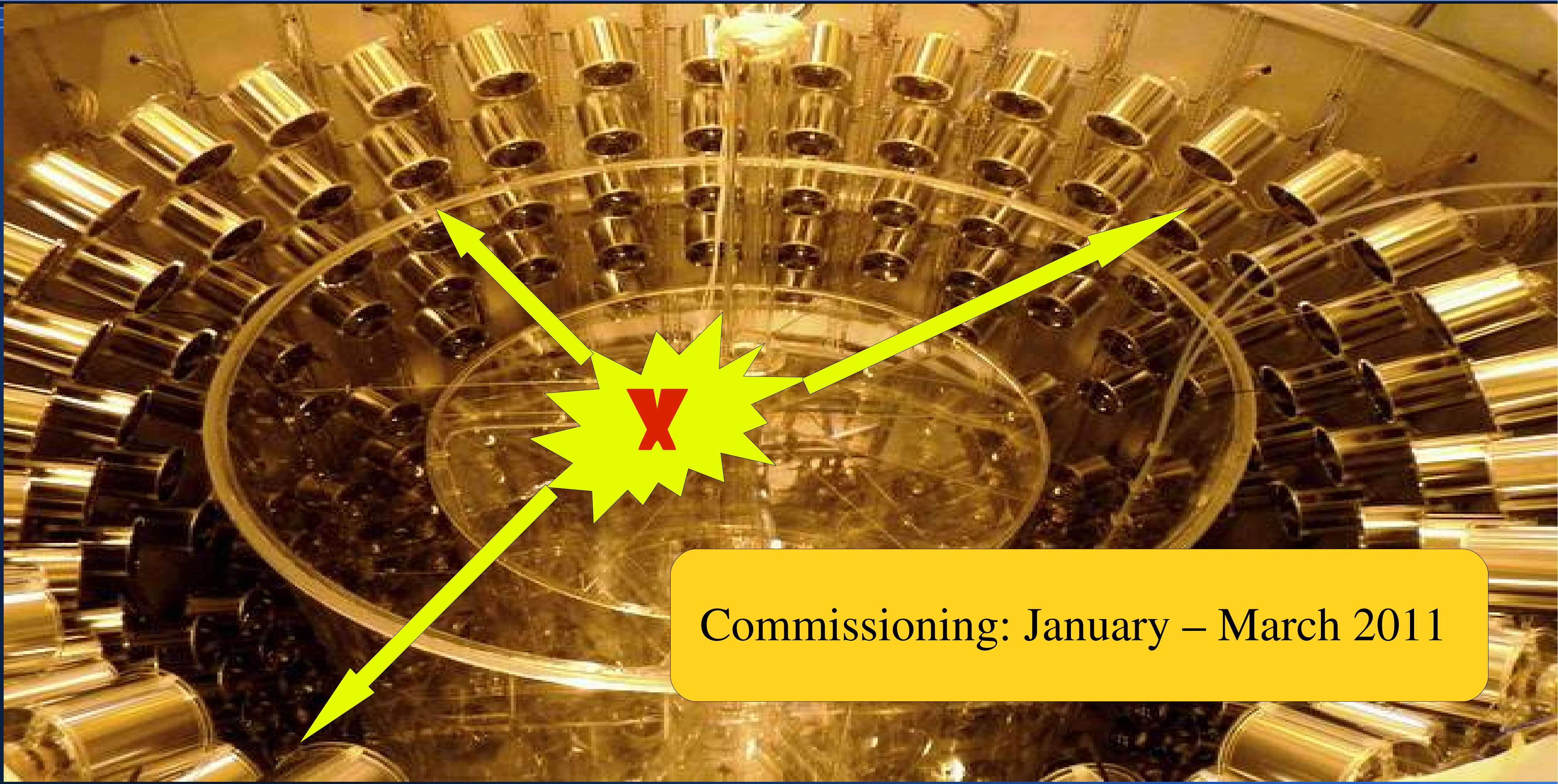


The Electronics Hut

- DAQ and trigger up and running

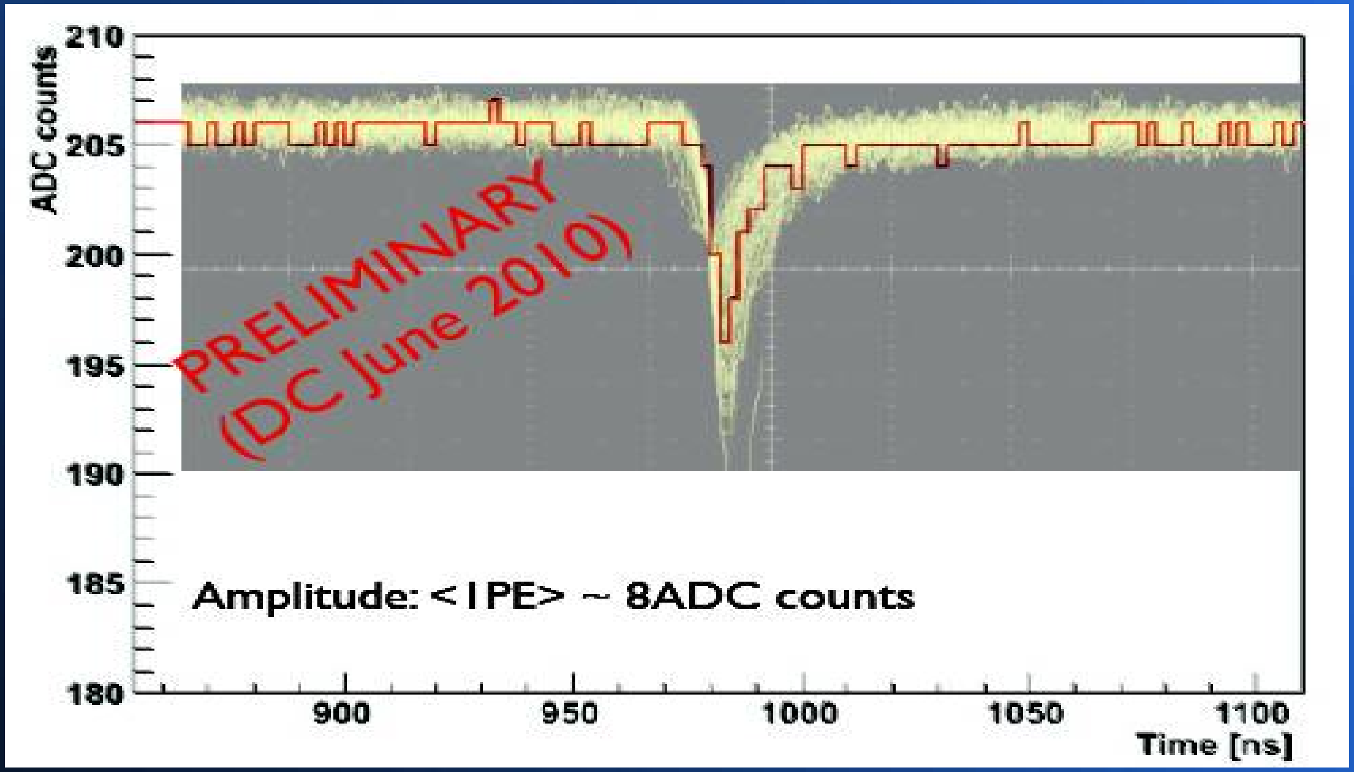
- Outer veto: PMT + maroc2 chip

Seeing the light



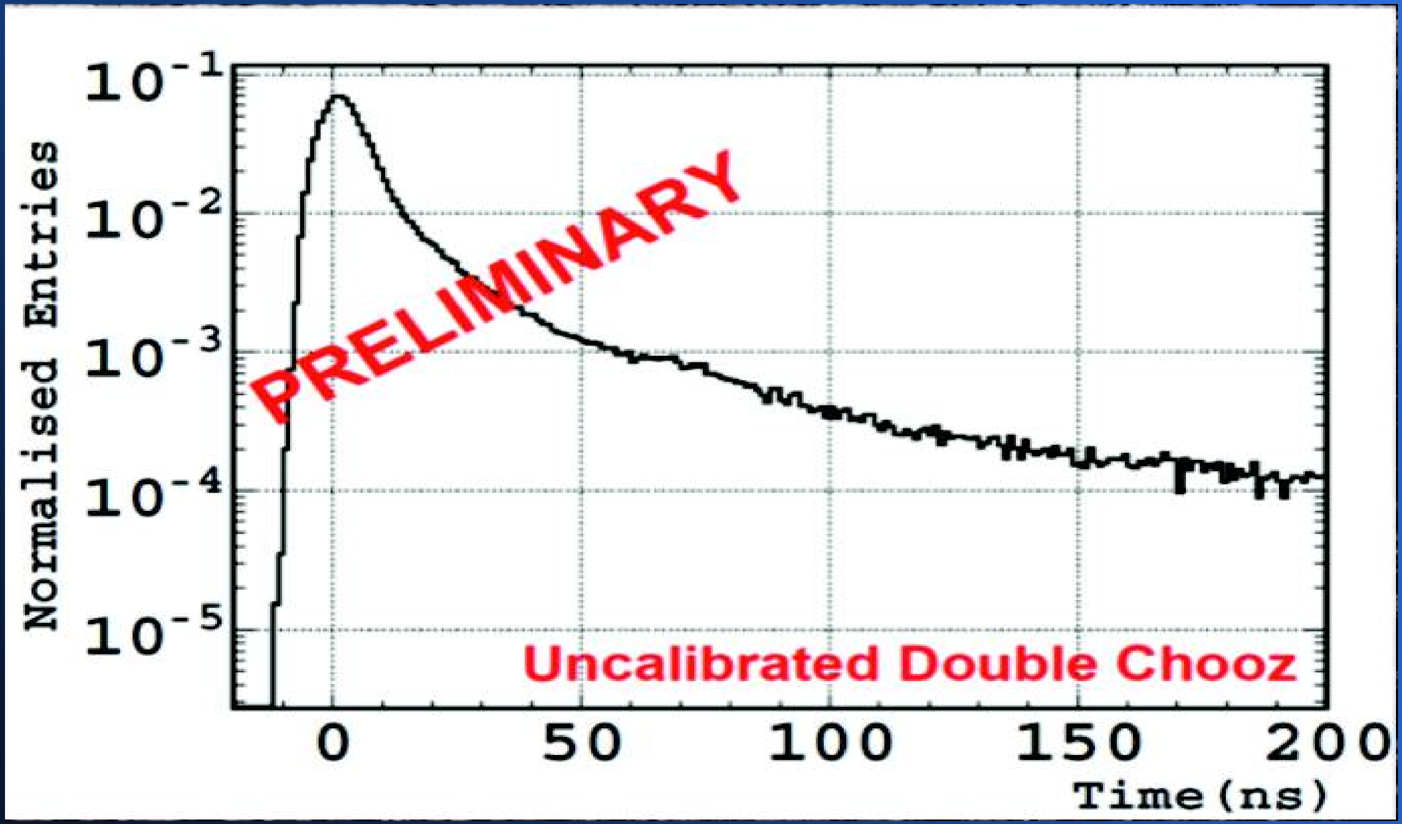
First PEs @ Chooz

- Summer 2010: first PEs detected in a empty detector



Scintillator Time Response

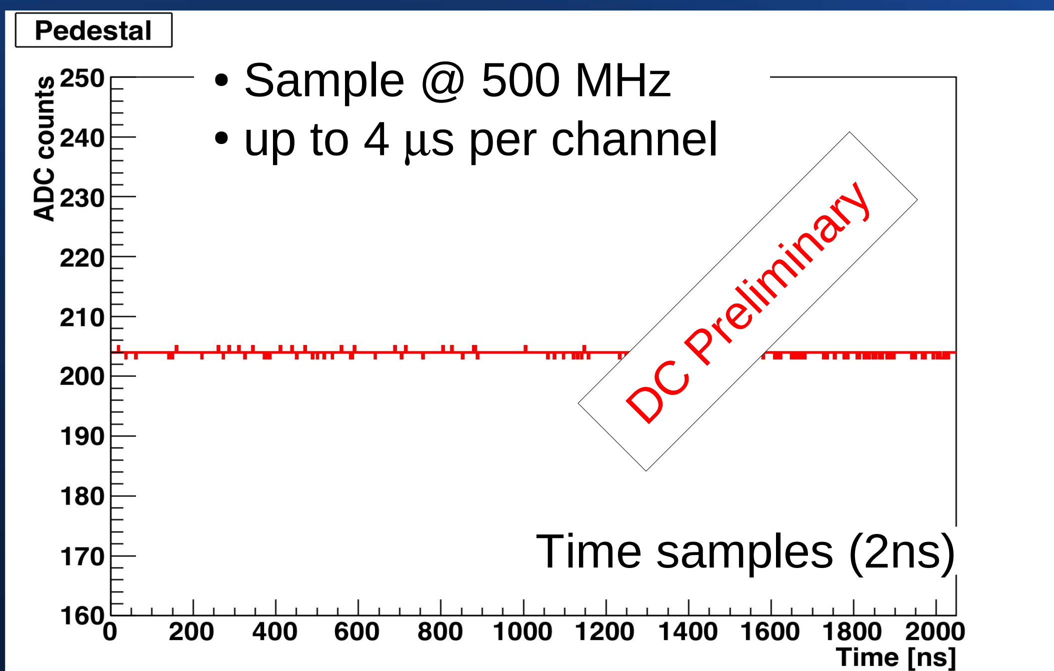
- 2010: reconstructed scintillator time response in partially filled detector



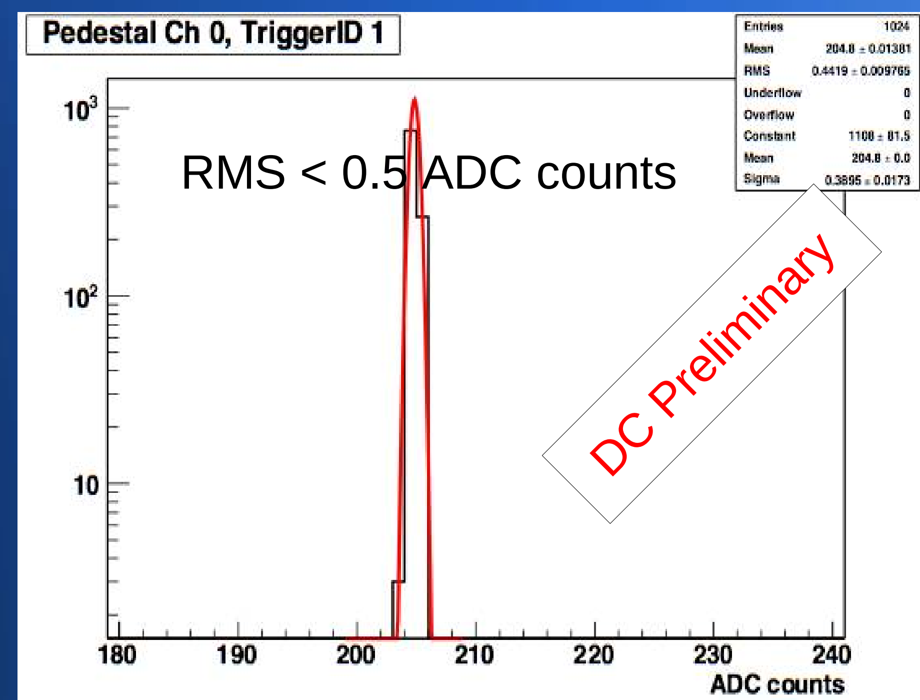
Electronics noise

- 2010: stability of the electronics

- **4 μs Baseline in Channel 0**



- **Baseline mean in Channel 0**



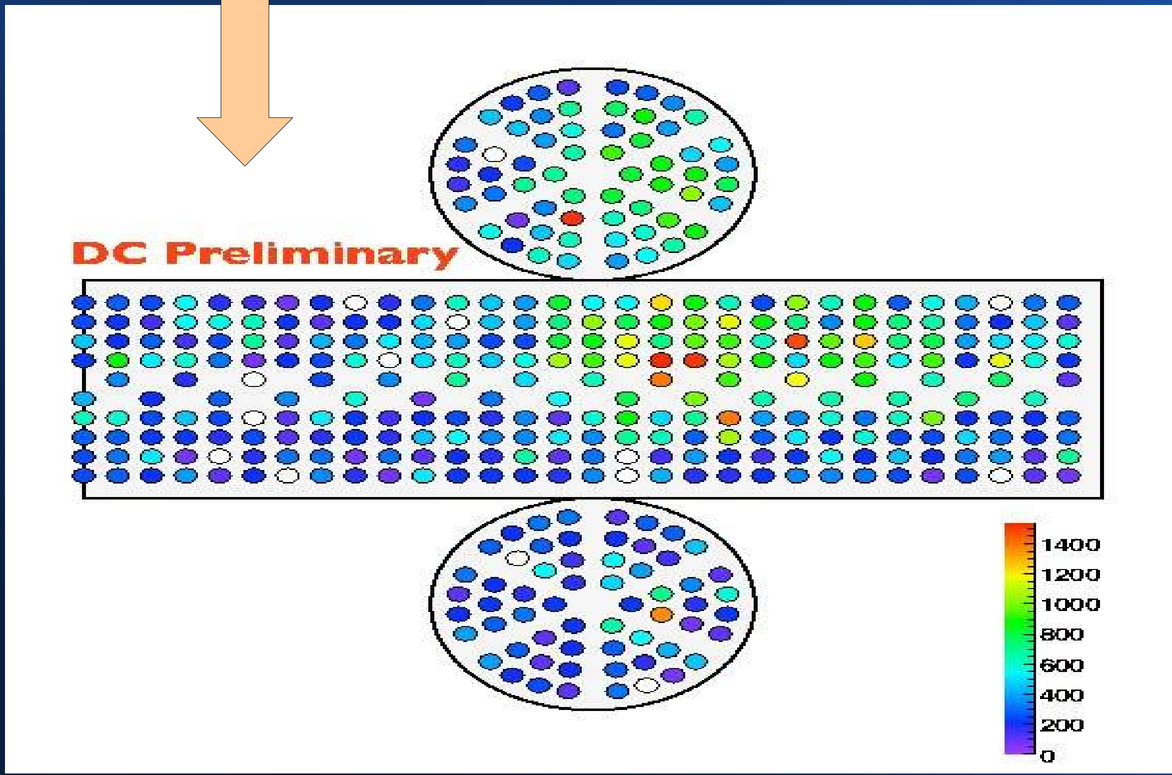
- Electronics noise very low and stable

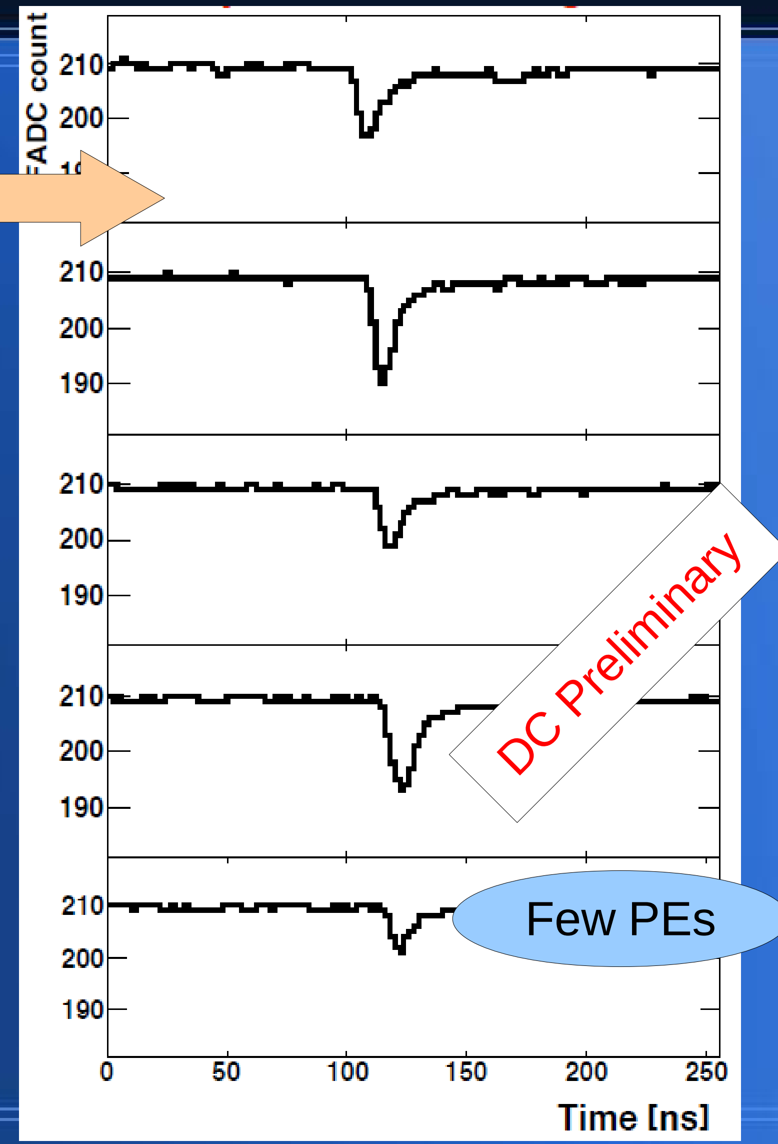
Inner Detector Events

- 2011: first events with a filled detector

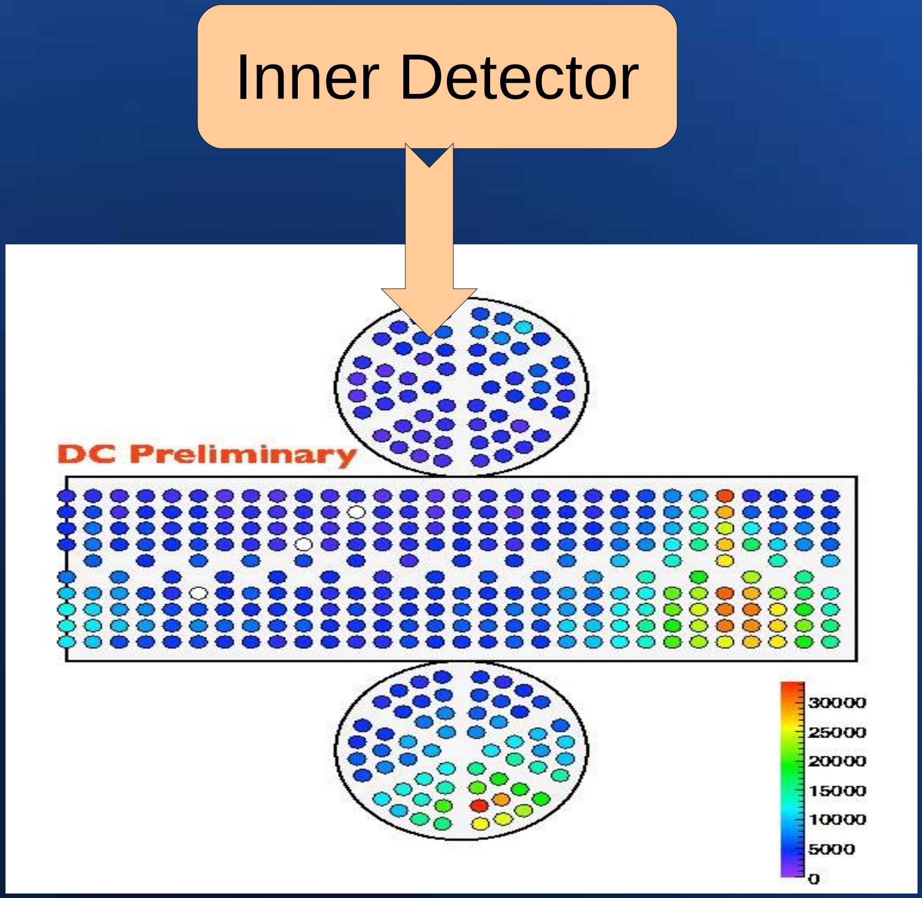
ID Contained Event

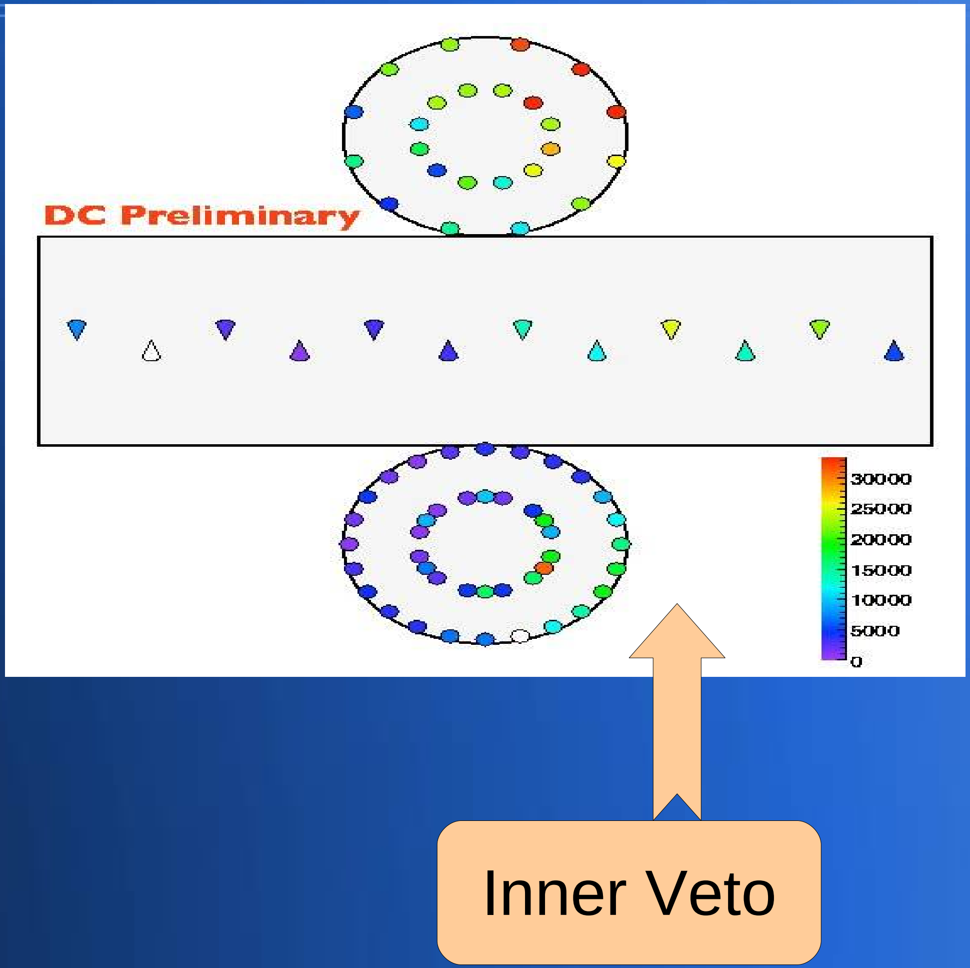
ID Waveforms





Detecting the muons

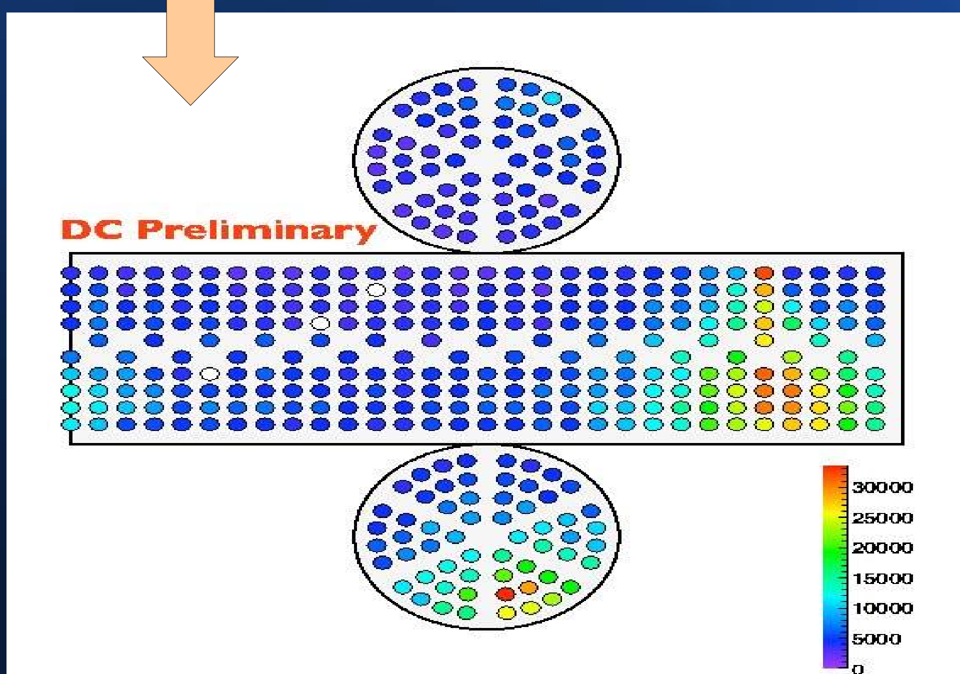


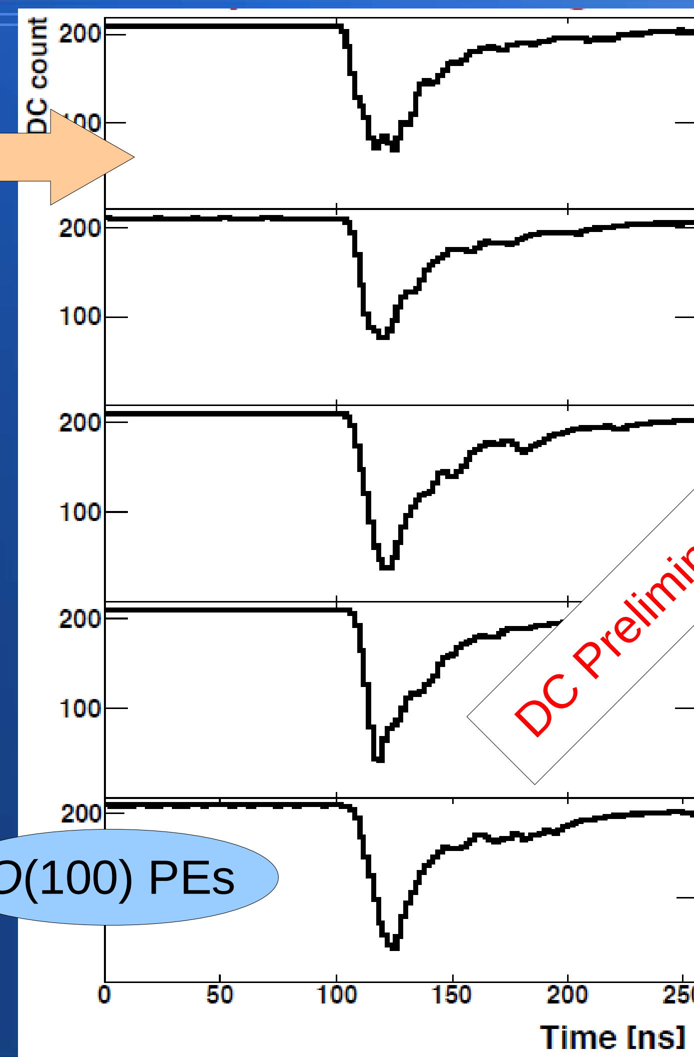


Muons in the Inner Detector

μ in ID

μ ID Waveforms

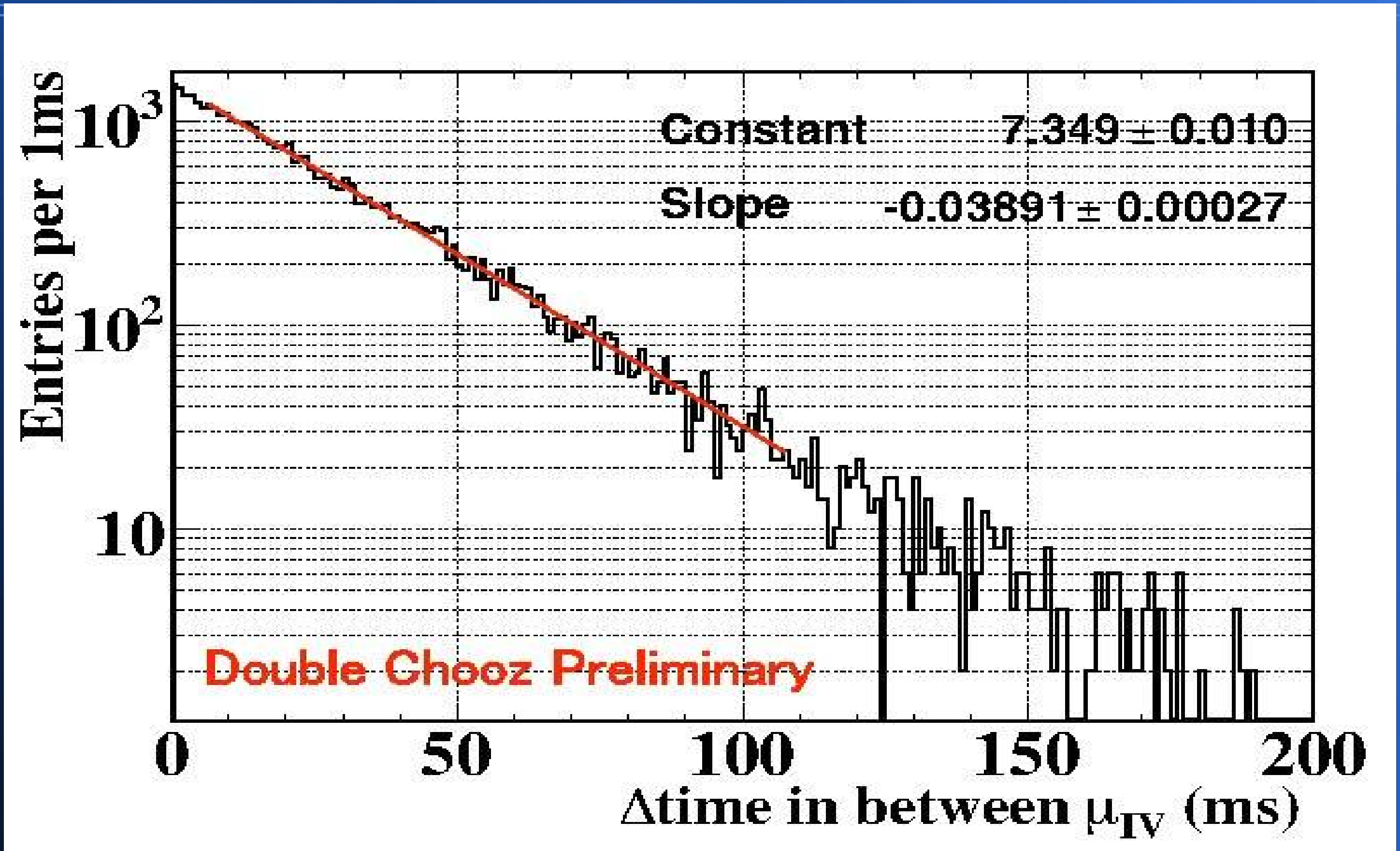




O(100) PEs

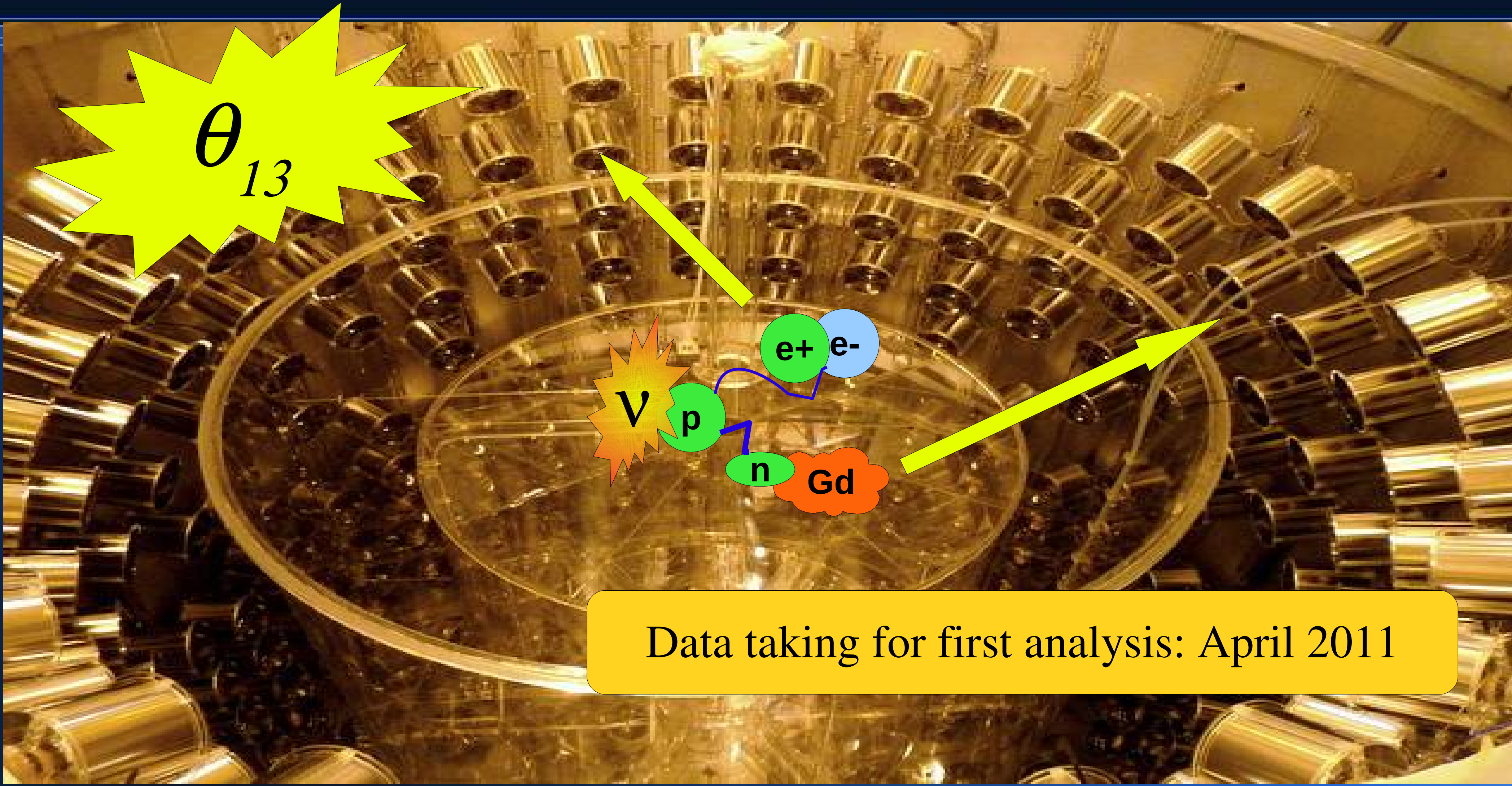
Muon Rate @ Inner Veto

Time difference between μ in the IV



- First estimation of muon rate: 38.8 trigger / second

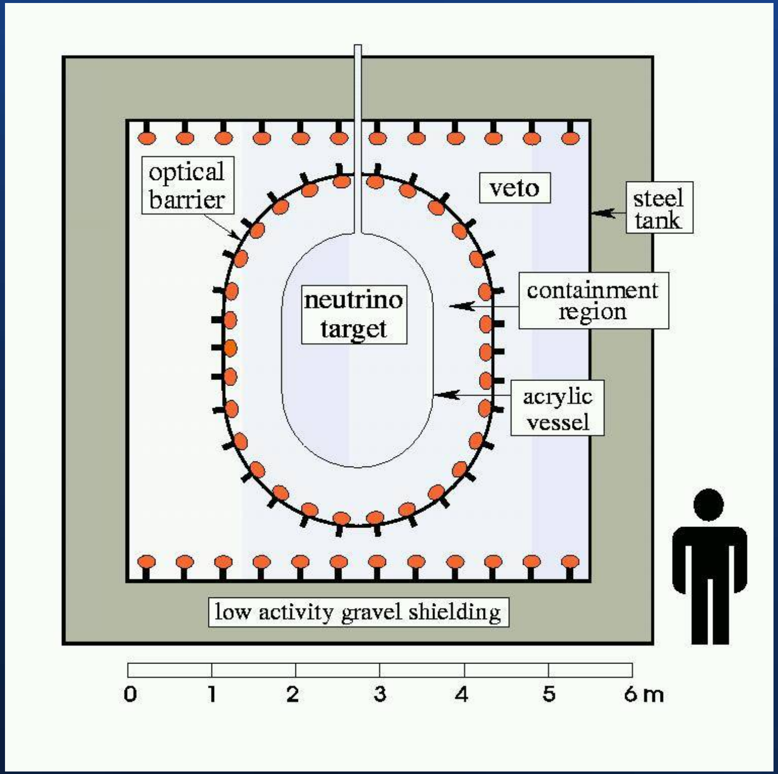
Taking the most from DC



Data taking for first analysis: April 2011

Improving CHOOZ

- CHOOZ Detector



- $\sin^2(2\theta_{13}) < 0.15$

$(\Delta m^2 = 2.5\times10^{-3}\ eV^2)$

- **Statistical error:**

	CHOOZ	Double Chooz
Target Volume	5.55 m3	10.3m3
Data Taking	Few months	3-5 years
Statistical Error	2.8%	0.5%

- **Systematics:**

	CHOOZ	Double Chooz
Reactor Flux	2%	--
Number of protons	0.8%	0.2
Systematic Error	2.7%	0.6%

Two Phases

Source	Systematic	DC Phase I	DC Phase II
Reactor	Production σ	1.9%	--
	Core powers	2.0%	--
	Energy per fission	0.6%	--
	Solid angle	--	0.1%
Detector	Number of protons	0.5%	0.2%
	Gd concentration	0.3%	--
	Detection σ	0.1%	--
Analysis	Event selection	0.4%	0.4%
	Total	**< 2.8%**	**< 0.6%**

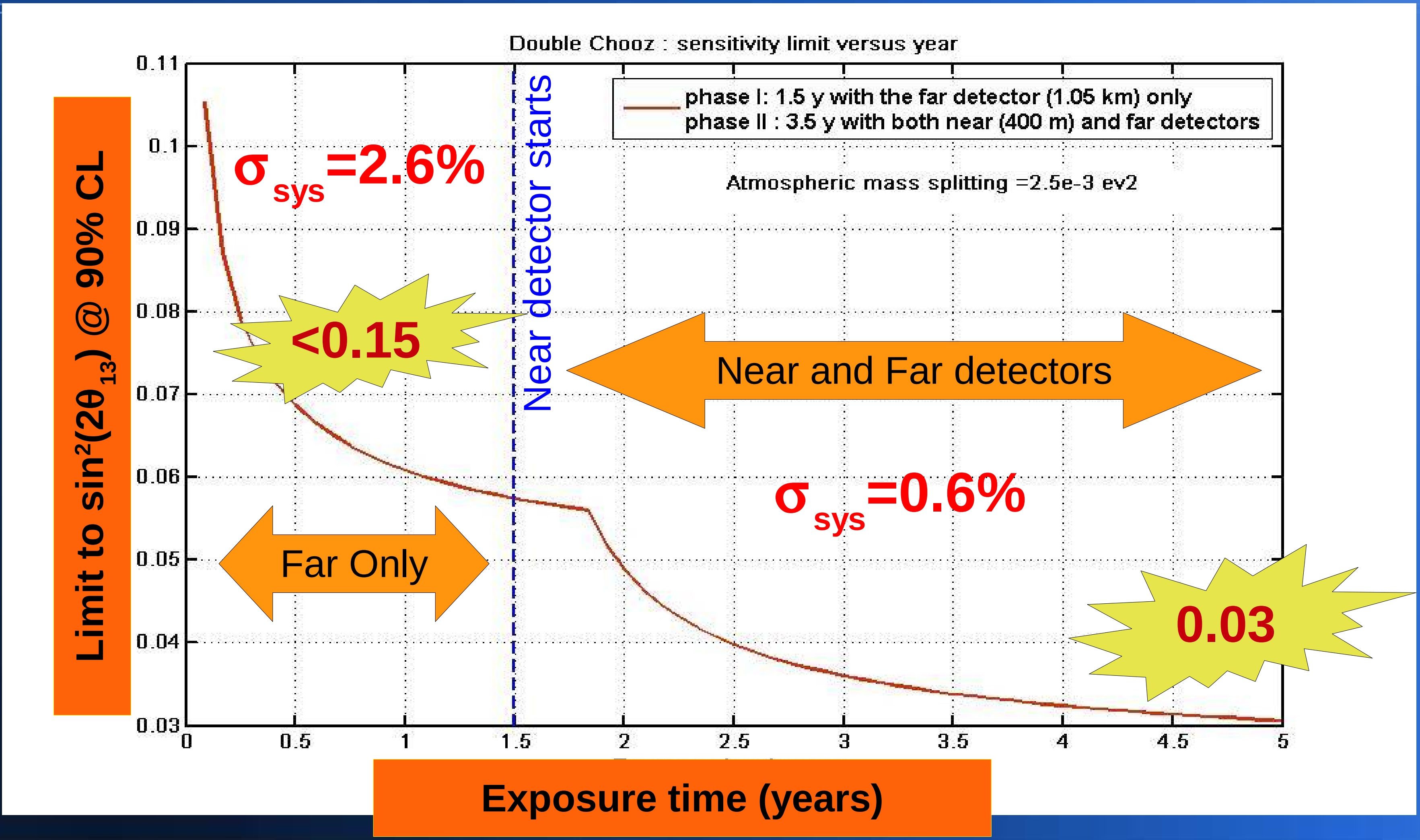
- **Phase I: Far Detector only**
  - 2011 (**Now!!!**)

Sensitivity limited by
the uncertainties
in reactor neutrino fluxes

- **Phase II: Far and Near Detectors**
  - 2012

Sensitivity limited by
Detector relative normalization
and energy scale

Double Chooz Sensitivity



Summary

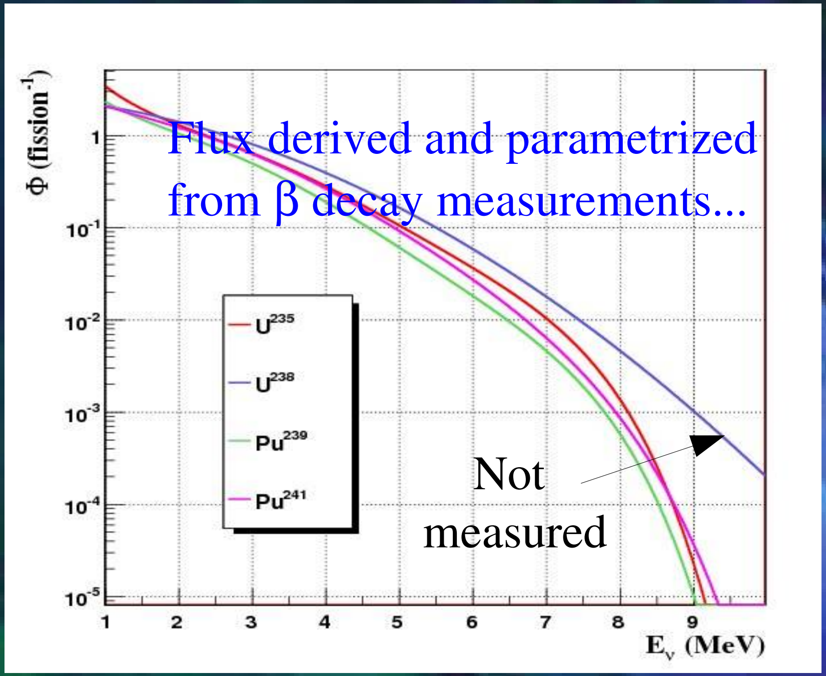
- Double Chooz will search for $\sin^2(2\theta_{13})$ down to 0.03
  - The quest has just begun!
    - The far detector was built and filled by December 2010
    - Commissioning period: January 2011 – March 2011
    - Detector yields good and stable performance
    - Far Detector is almost ready to take *physics* data
    - Results improving CHOOZ limit to θ_{13} quite soon!

θ_{13}

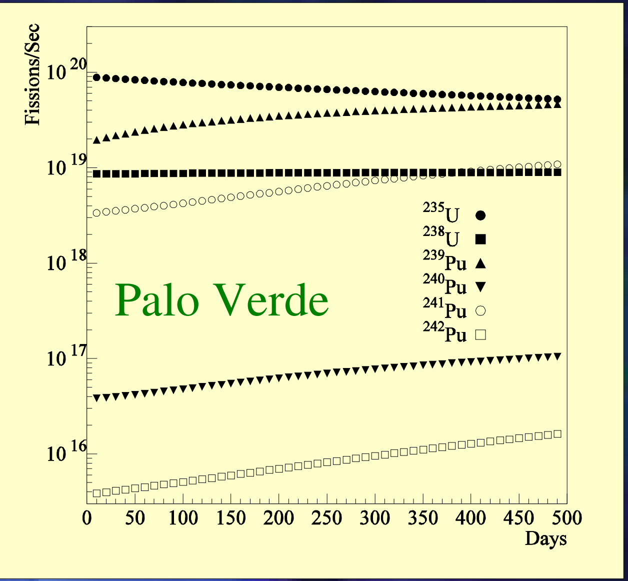

Thank you!
Photo: Lola Garrido

Reactors as ν source

ν come from fission products...



- ν Flux depends on fuel composition:



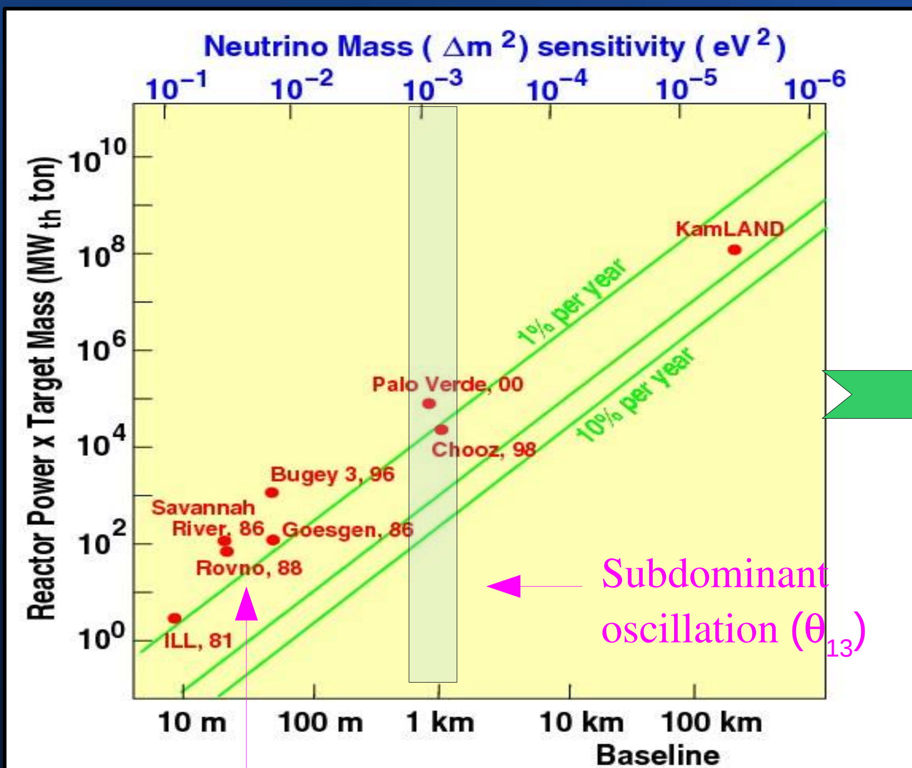
- ν Flux known to only 2%

- **High flux: 1GW$_{th}$ ~ 2×10^{20} $\bar{\nu}_e$ / s**

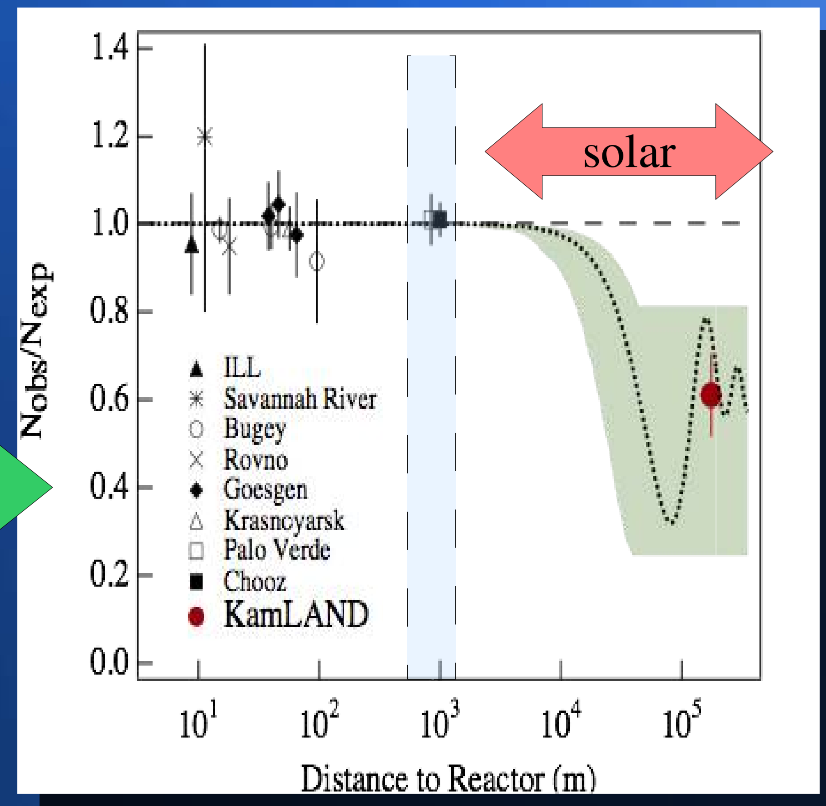
What we know about θ_{13}

- Past reactor experiments...

Gratta et Al. Rev. Mod. Phys, 74, 2002



Measurement of reactor flux



Phys. Rev. Lett. 90, 021802 (2003)

- From CHOOZ: $\sin^2(2\theta_{13}) < 0.15$

$\Delta m^2 = 2.5\times10^{-3}\ eV^2$

Comparing the experiments

Power	Target
8.6 GW	8.24 tons

Near	Far
400 m/115 wme	1.05 km/300 wme

DOUBLE CHOOZ

2010

RENO

Power	Target (x2x4)
17.4 GW	20 tons

Near (x2)	Far
360-500 m/ 260 mwe	1.6-2.0 km/910 wme

Daya Bay

Time

2011

θ_{13}?

Power	Target
17.3 GW	16 tons

Near	Far
290 m/130 wme	1.38 km/460 wme

	σ_{stats} (%)	σ_{sys} (%)	s^2_{13lim} (90% CL)
D. Chooz	0.5	0.6	**0.03**
Reno	0.3	0.5	**0.02**
Daya Bay	0.2	0.4	**0.01**

Calibration

- Calibration Strategy:
  - Redundancy of several calibration systems
  - Cross-check and accurate understanding of the systematics

- Calibration Goals:
  - PMT+Electronics Gain and Timing
    - Embedded LED system and deployed isotropic aser
  - Liquid Scintillator optics and stability
  - Detector stability
    - Embedded LED system and deployed isotropic laser
  - Energy scale
    - Radioactive sources (137Cs, 22Na,60Co,...)
    - n-capture on H
  - Gd n-capture efficiency
    - Neutron sources (252Cf Am-Be, tagged/un-tagged)
  - 3D response
    - Deployment of sources along Z-axis (fish-line)
    - Calibration arm off Z-axis
    - Deployment of sources in GC and Buffer guide lines