Commissioning the Double Chooz detector

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Les Rencontres de Physique de la Vallee d'Aoste, 2011

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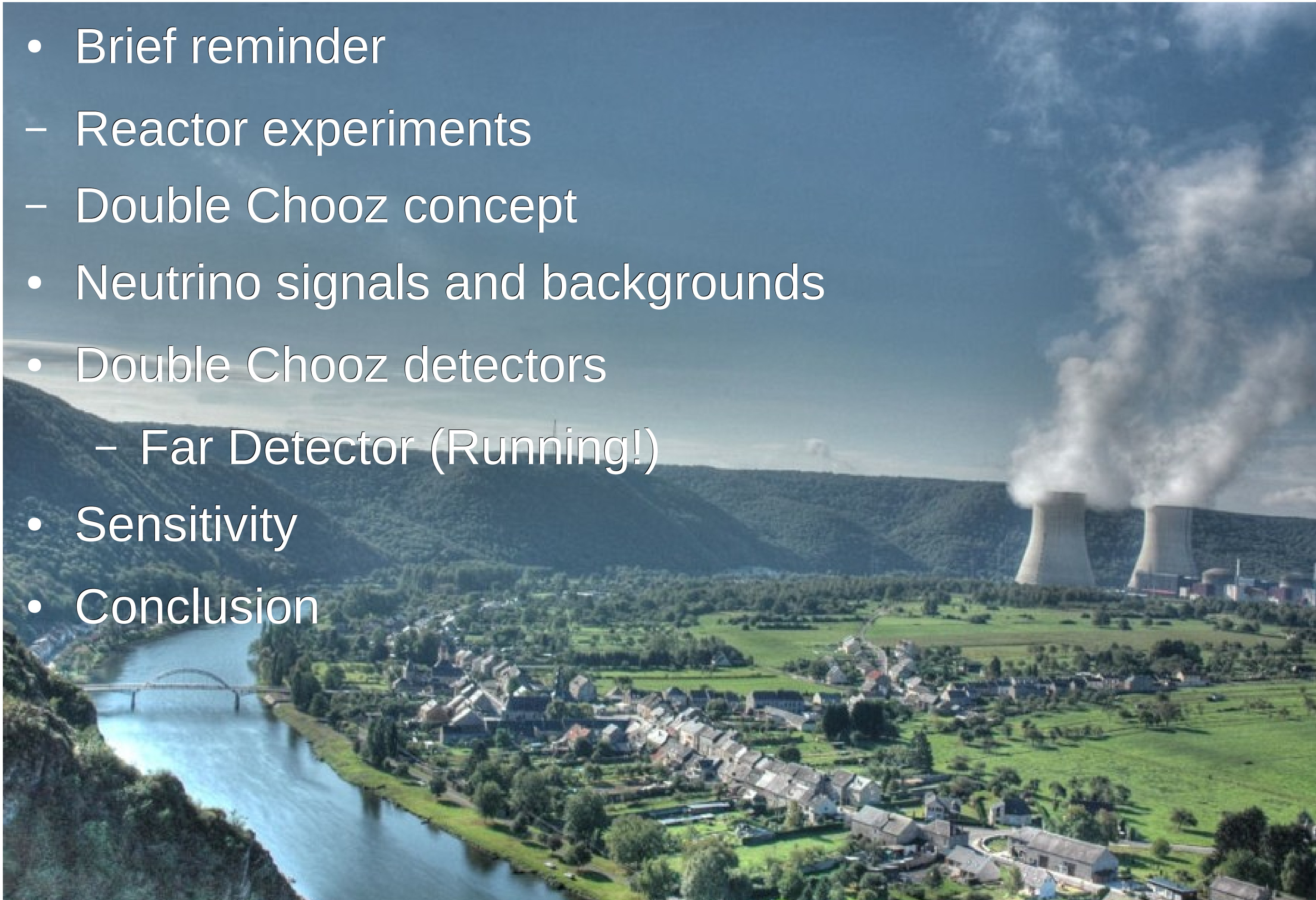


- Brief reminder
- – Reactor experiments
- – Double Chooz concept
- Neutrino signals and backgrounds
- Double Chooz detectors
  - – Far Detector (Running!)
- Sensitivity
- Conclusion

Three Neutrino Mixing

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}U_{e1} & U_{e2} & U_{e3}\\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3}\\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3}\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

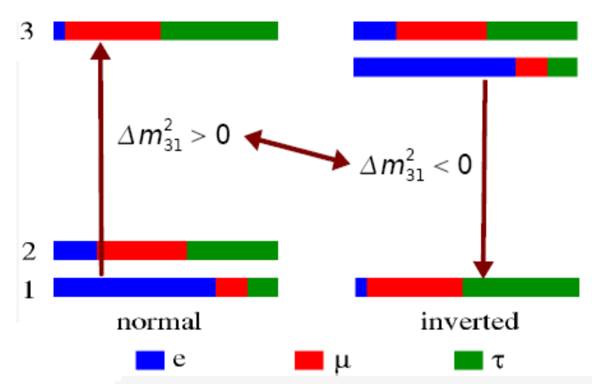
Pontecorvo – Maki – Nakagawa – Sakata (PMNS) matrix

- 3 mixing angles
- 1 CP phase

$$U = \begin{pmatrix}\cos\theta_{12} & \sin\theta_{12} & 0\\ -\sin\theta_{12} & \cos\theta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13}\end{pmatrix}\begin{pmatrix}1 & 0 & 0\\ 0 & \cos\theta_{23} & \sin\theta_{23}\\ 0 & -\sin\theta_{23} & \cos\theta_{23}\end{pmatrix}$$

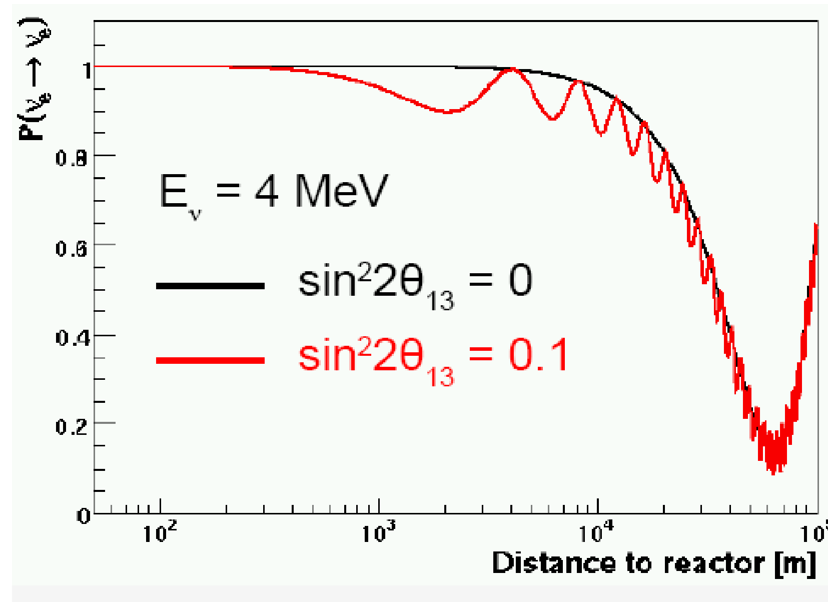
solar — atmospheric

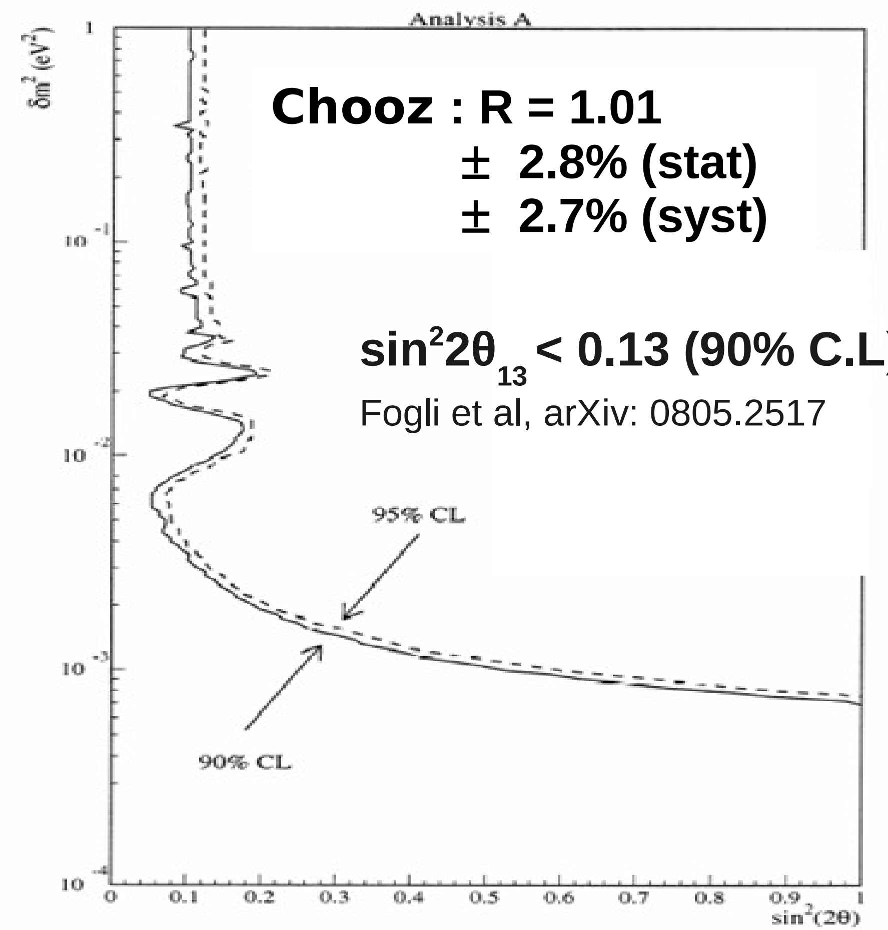
- 2 mass splittings Δm^2_{ij}
- We don't know θ_{13}, δ_{cp} and sign of Δm^2_{31}



Reactor Experiments

$$P(\overline{\nu}_e \rightarrow \overline{\nu}_e) \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{1.27\, L[km]\, \Delta m^2_{31}[10^{-3} eV^2]}{E[MeV]}\right)$$
$$- \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{1.27\, L[km]\, \Delta m^2_{21}[10^{-3} eV^2]}{E[MeV]}\right)$$



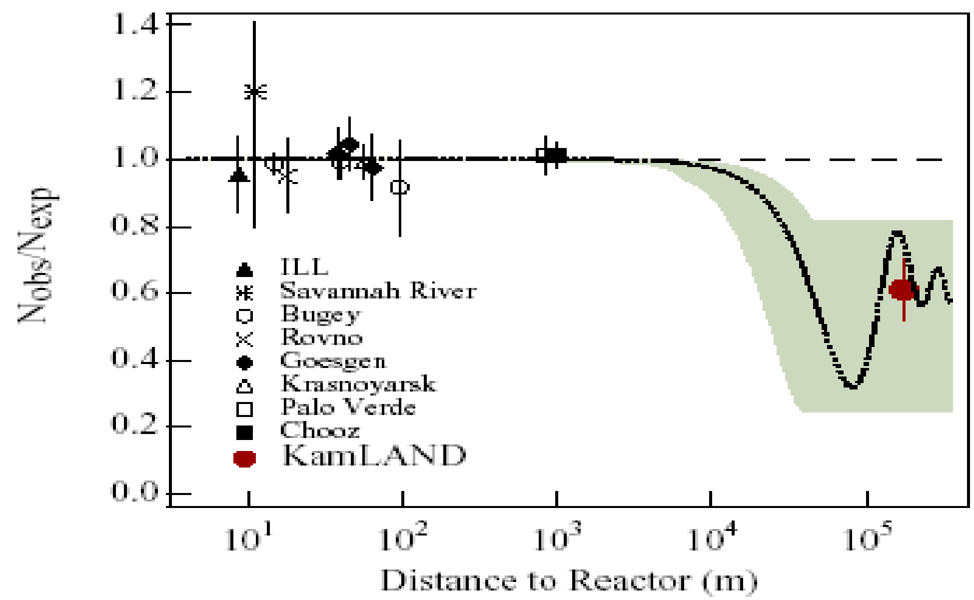


Chooz : R = 1.01
± 2.8% (stat)
± 2.7% (syst)

$\sin^2 2\theta_{13} < 0.13$ (90% C.L)

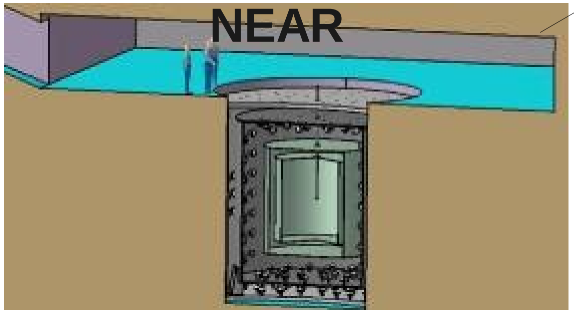
Fogli et al, arXiv: 0805.2517

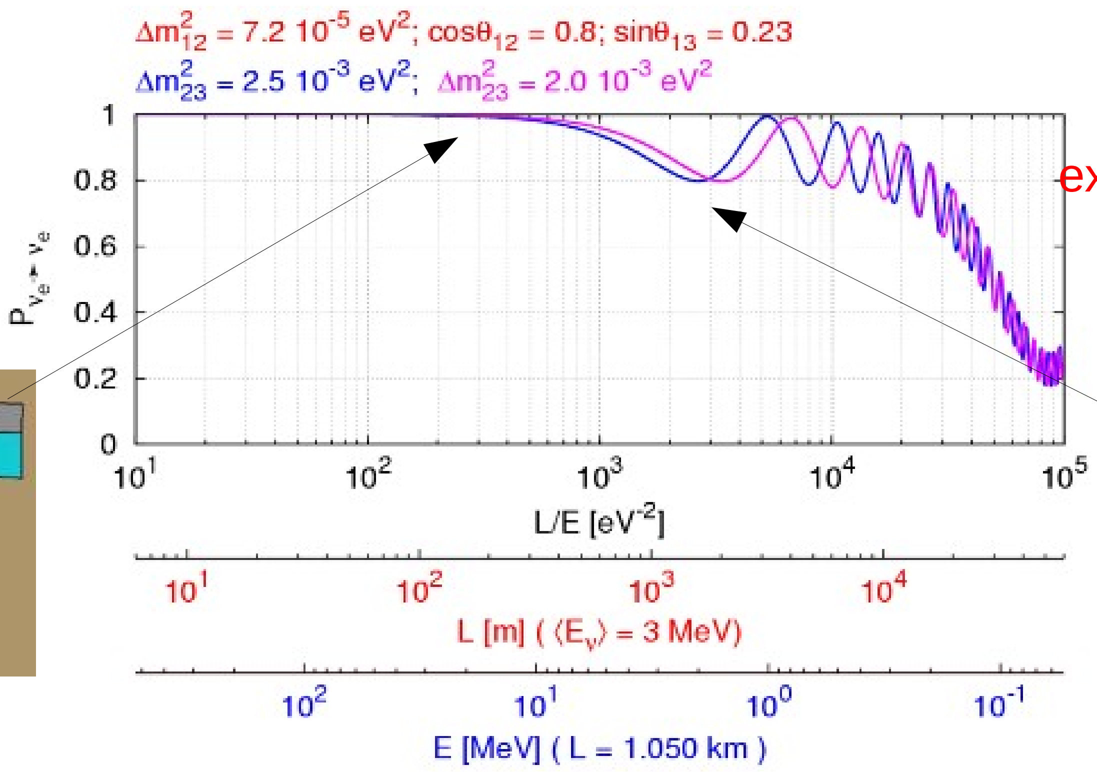
M. Apollonio et. al., Eur.Phys.J. C27 (2003) 331-374



Reactor θ_{13} Experiments

- Disappearance of anti-neutrinos (independent of δ_{cp} and sign of Δm_{31}, weak dependence of Δm_{21})
- Short distances, ~MeV signals (no matter effects)





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

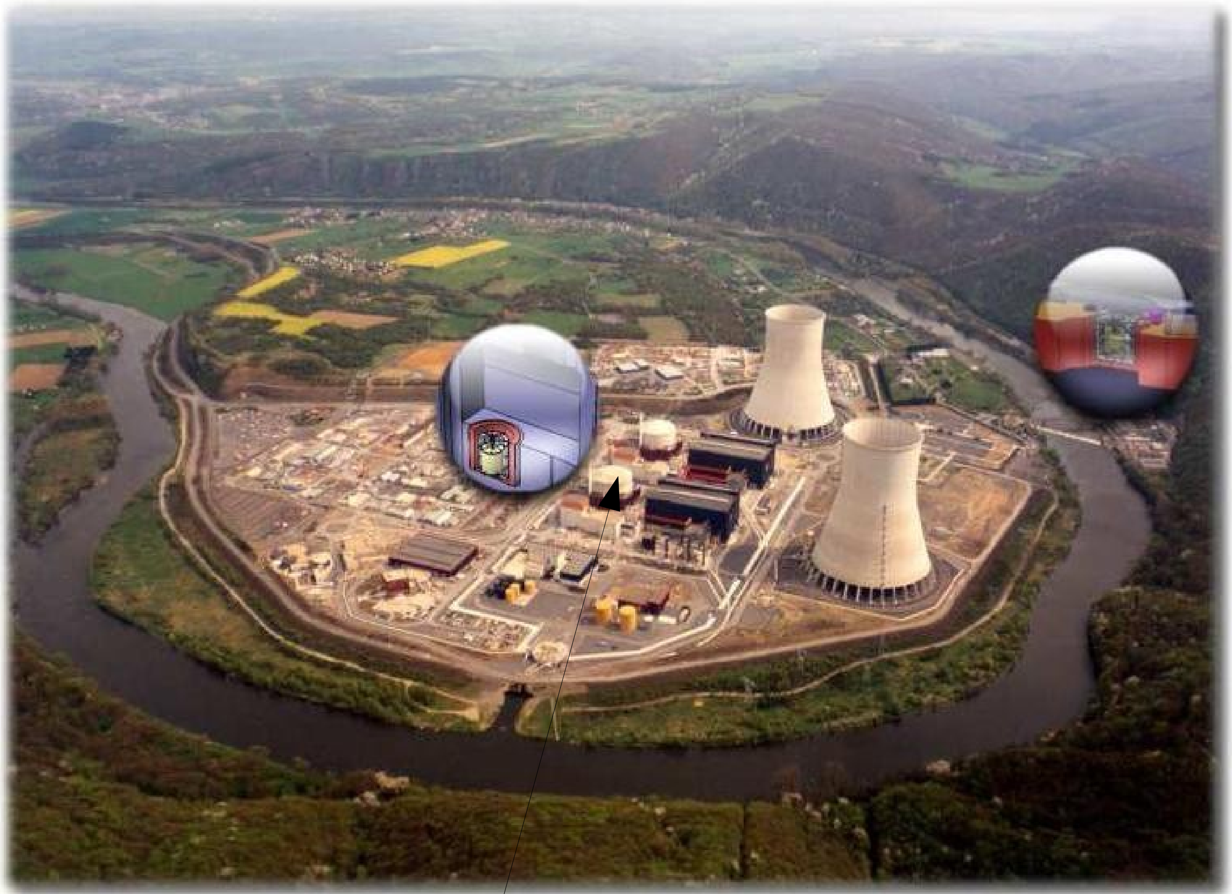
UK
Sussex

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/

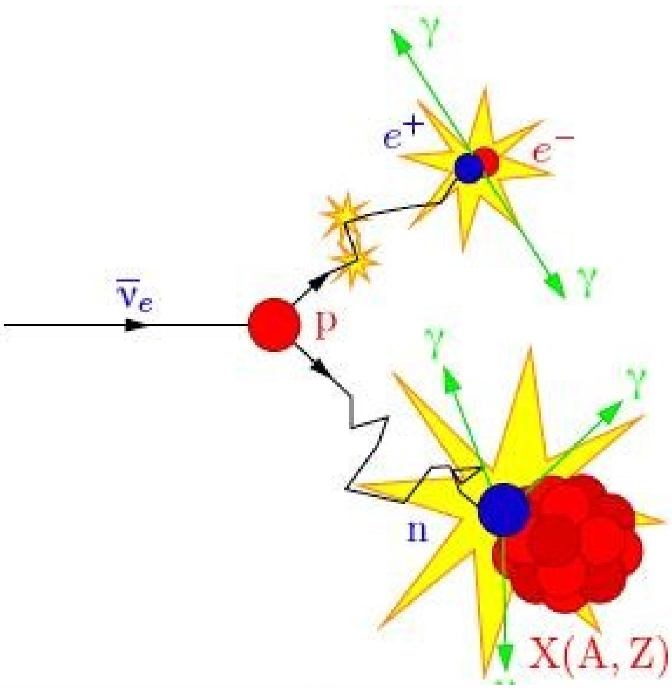
Concept

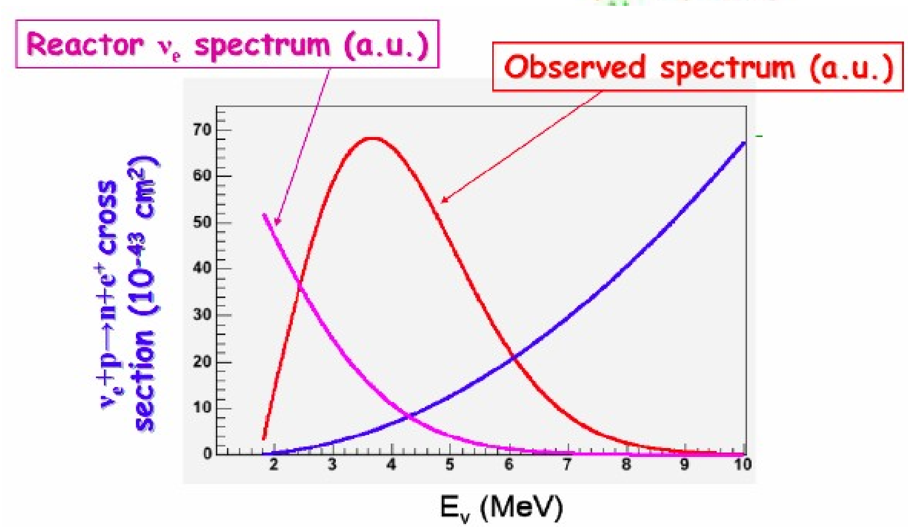


Chooz-B
2 x 4.27GW

- 2 'identical' detectors
  - **Near**
    - 410 m
    - 115 m.w.e
    - ~500 ν/day
  - **Far**
    - 1050 m
    - 300 m.w.e
    - ~70 ν/day
- Systematics on reactor power, neutrino spectrum, cross-section and detection are insignificant for a relative measurement

Neutrino Signal





- Detect anti-neutrinos via inverse beta decay
  - $p + \overline{\nu} \rightarrow n + e^+$
- In Gd- loaded scintillator
  - e^+ signal 1-8MeV
  - $e^+ e^-$ annihilation(2 x 511 keV)
    - $E_{vis} = E_\nu - (M_n - M_p) + m_e$
  - Delayed neutron capture on
    - Gd ~30 µs ~ 8 MeV (>80%)
    - H 2.2 MeV

Backgrounds

Our signal is a positron followed by a neutron capture (2 triggers)

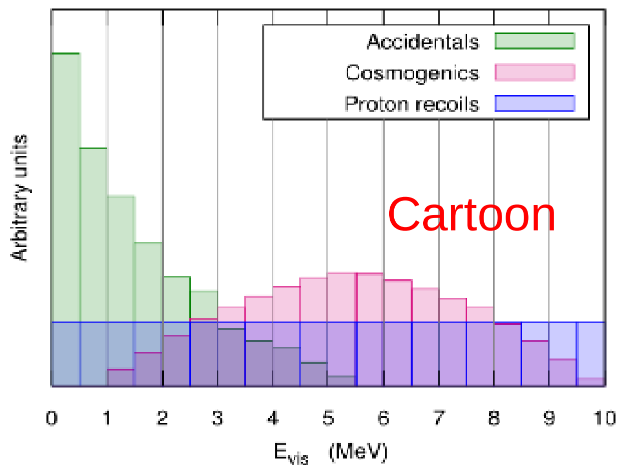
Accidental

- Dominant source of accidentals - Radioactivity (from PMT)
- Solution - we aim for a singles rate of less than 5/s above 0.7 MeV [expect far: 2 day^{-1} near: 11 day^{-1}]
  - Stringent radiopurity constraints

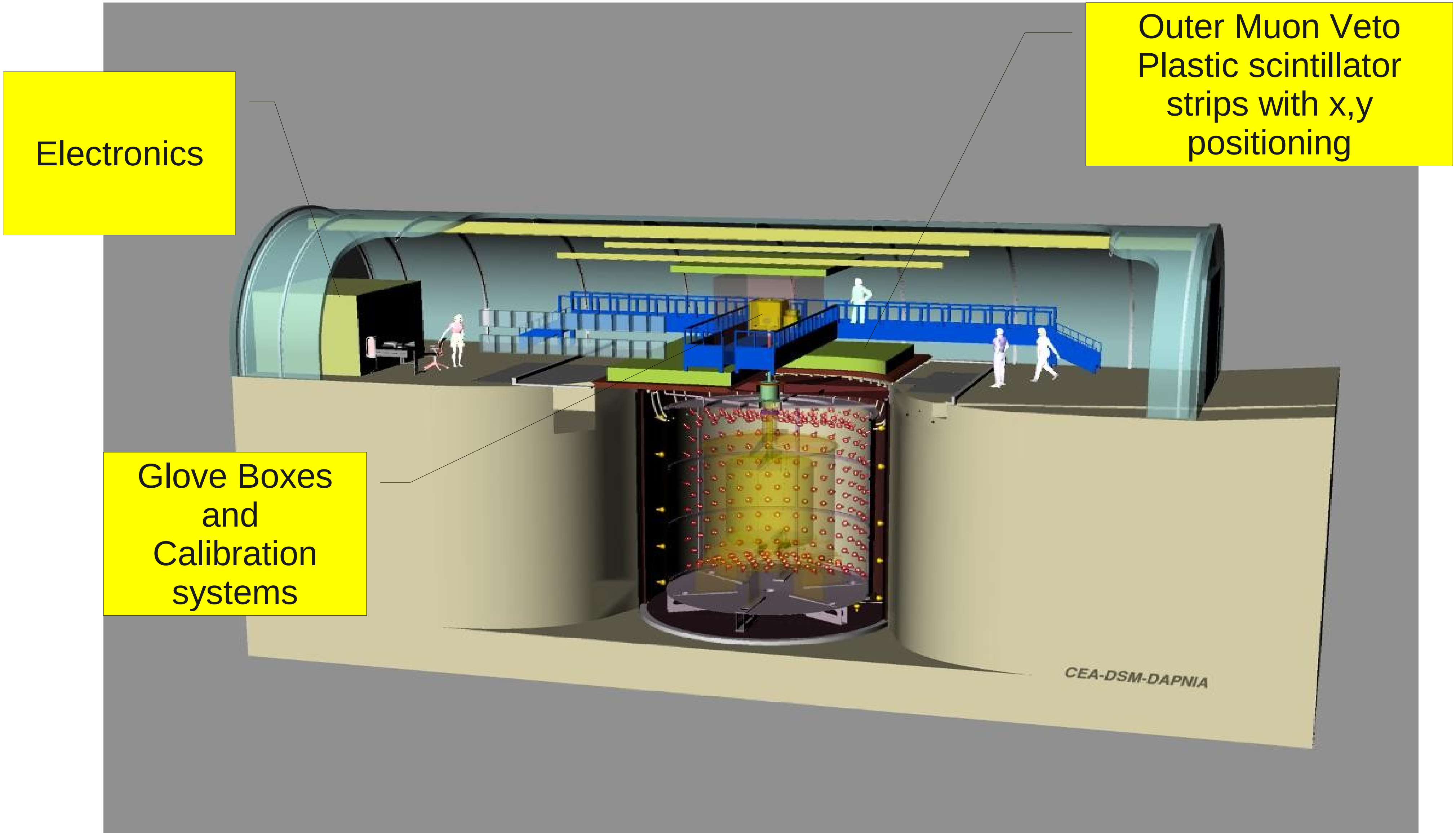
	^{40}K g/g	^{238}U g/g	^{232}Th g/g	^{60}Co mBq/Kg
Target LS	10^{-10}	10^{-13}	10^{-13}	—
Target Acrylics	10^{-8}	10^{-11}	10^{-11}	—
GC LS	10^{-10}	10^{-13}	10^{-13}	—
GC Acrylics	10^{-8}	10^{-11}	10^{-11}	—
Buffer Oil	—	10^{-12}	10^{-12}	—
Buffer Vessel	—	10^{-9}	10^{-9}	15
Veto LS	—	10^{-10}	10^{-10}	—

Correlated

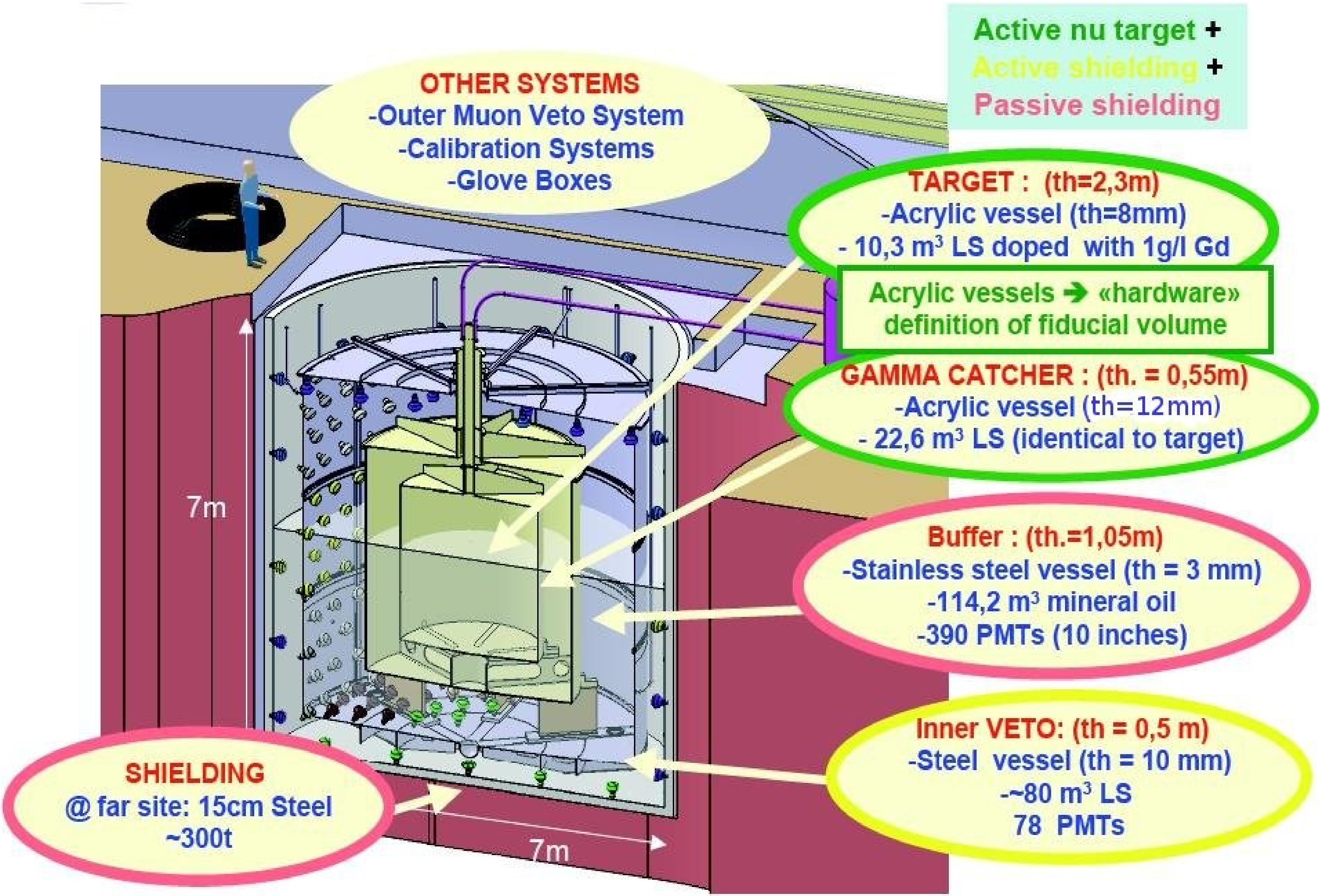
- Cosmogenics (β-neutron)
  - Li-9 and He-8 long lived [expect far: 1.5 day^{-1} near: 4 day^{-1}]
- Fast neutrons
  - Proton Recoil (positron-like signal) followed by neutron capture [expect far: 0.2 day^{-1} near: 0.5 day^{-1}]
- Caused by muons!



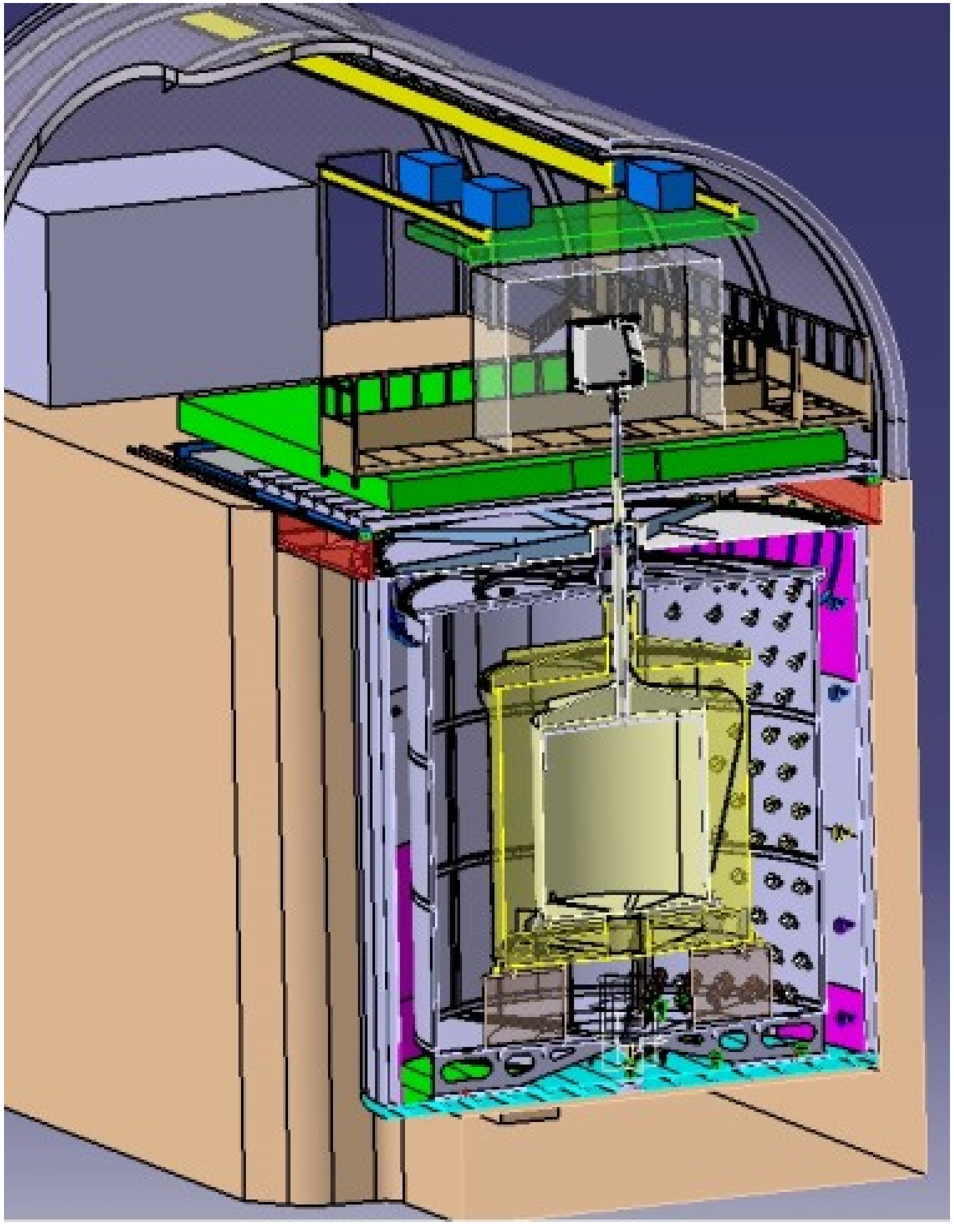
The Laboratories



The Detectors

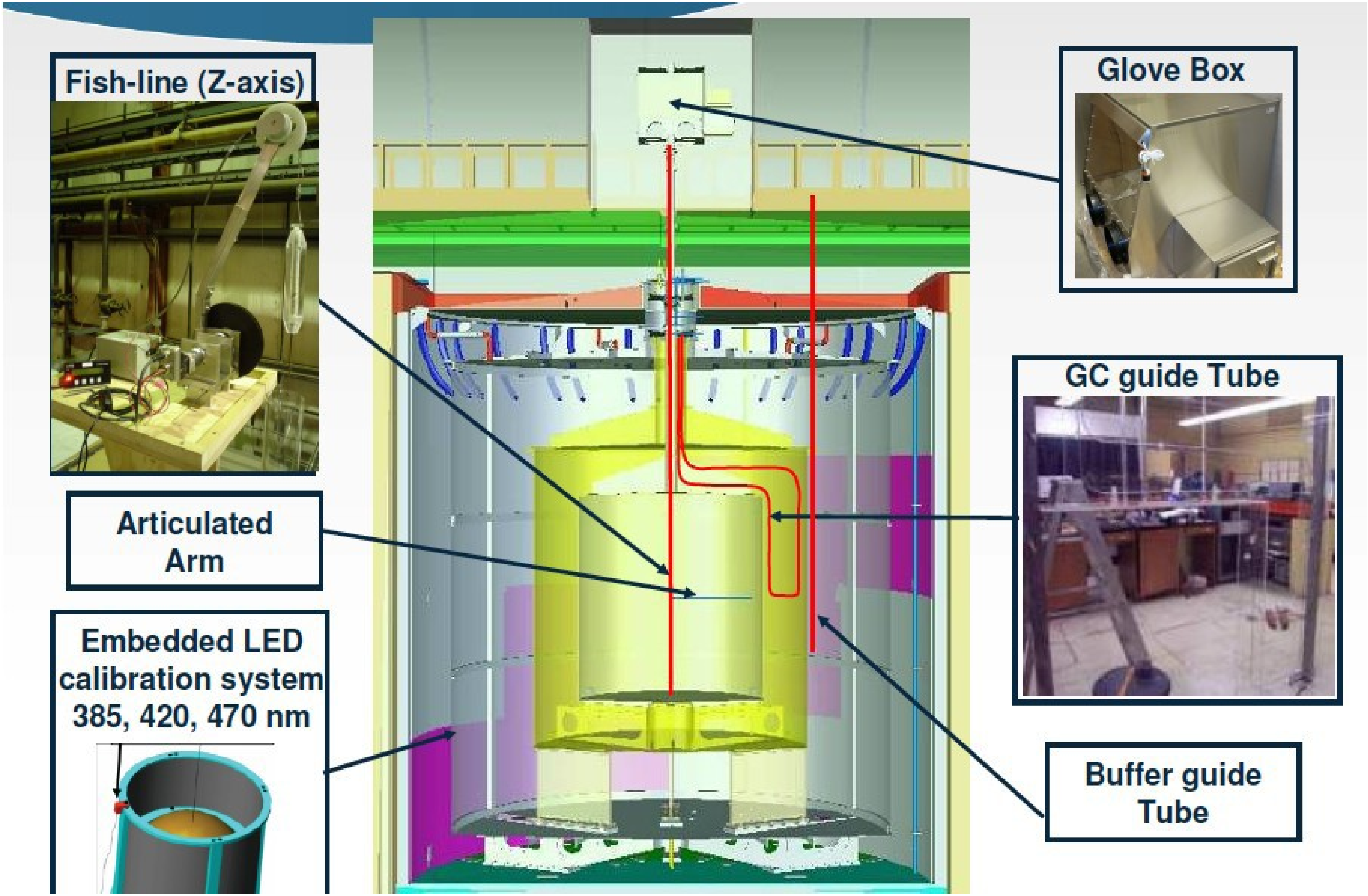


Muon Tracking



- Outer Veto
  - Tag near miss muons
  - Entry point of any muon
- Inner Veto
  - Efficient tag of muons and secondaries
  - Track muon
- Muon Electronics
  - Attenuated output of Inner Detector PMTs
  - Track muon

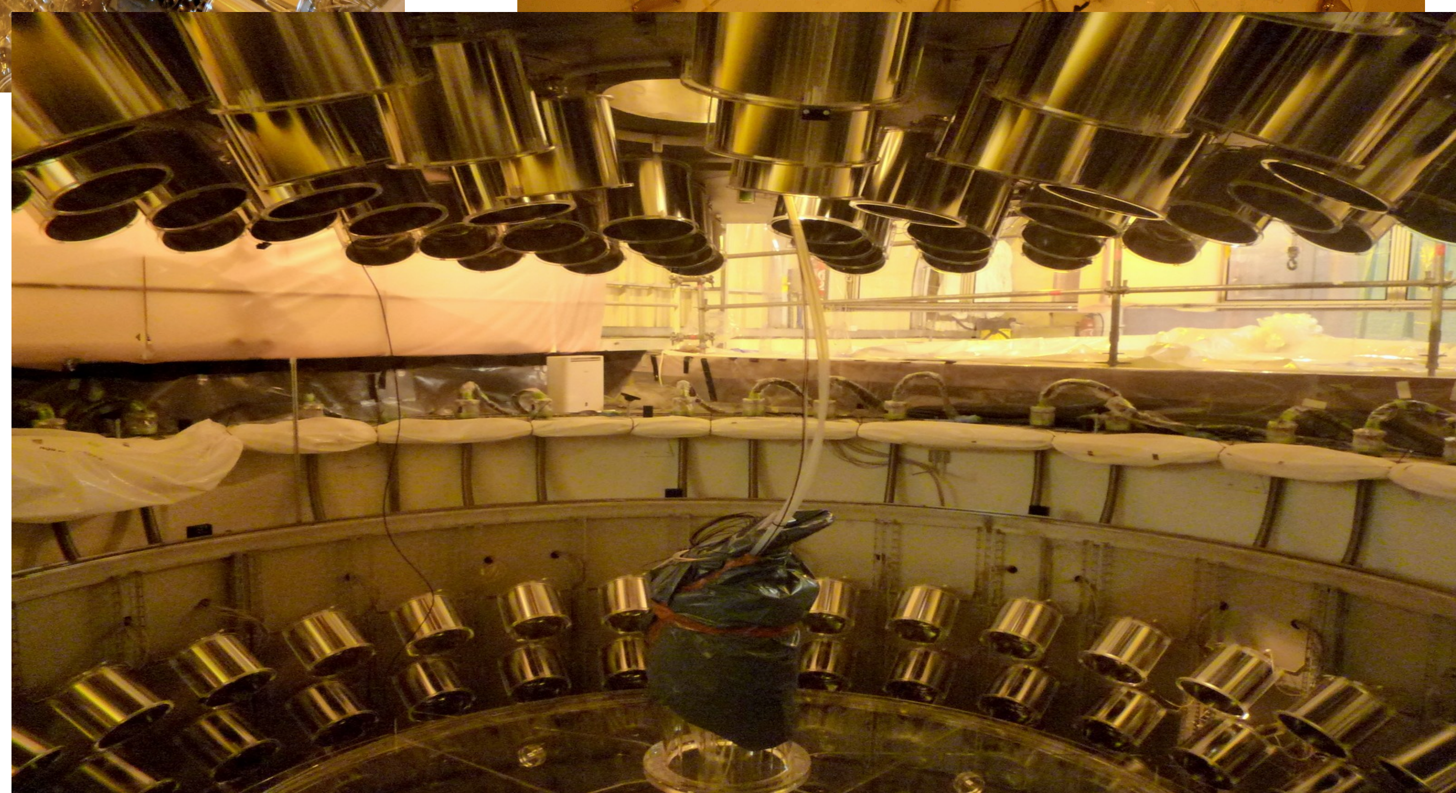
Calibration



Far Detector - history

Lab for the original Chooz experiment

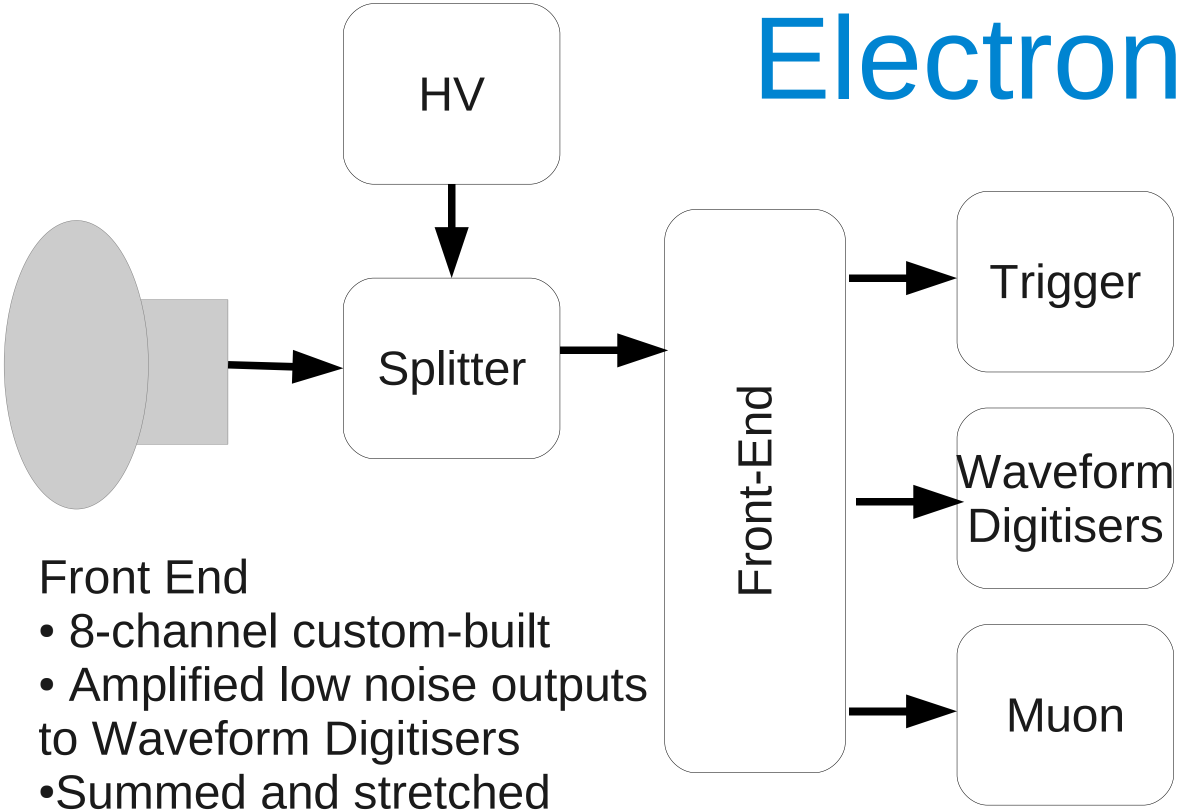
Far Detector - history



Far Detector – Filled and Shielded

Far Detector

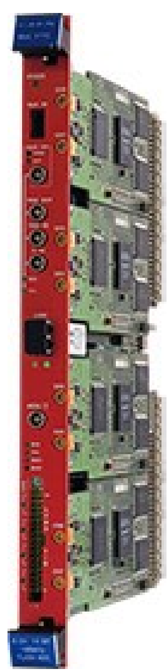
Electronics



Front End
- 8-channel custom-built
- Amplified low noise outputs to Waveform Digitisers
- Summed and stretched output to Trigger

Trigger
- custom-built trigger system (VME)
- Trigger based on analog sum on groups of PMTs.

Gives Particle ID based on Energy



Waveform Digitisers

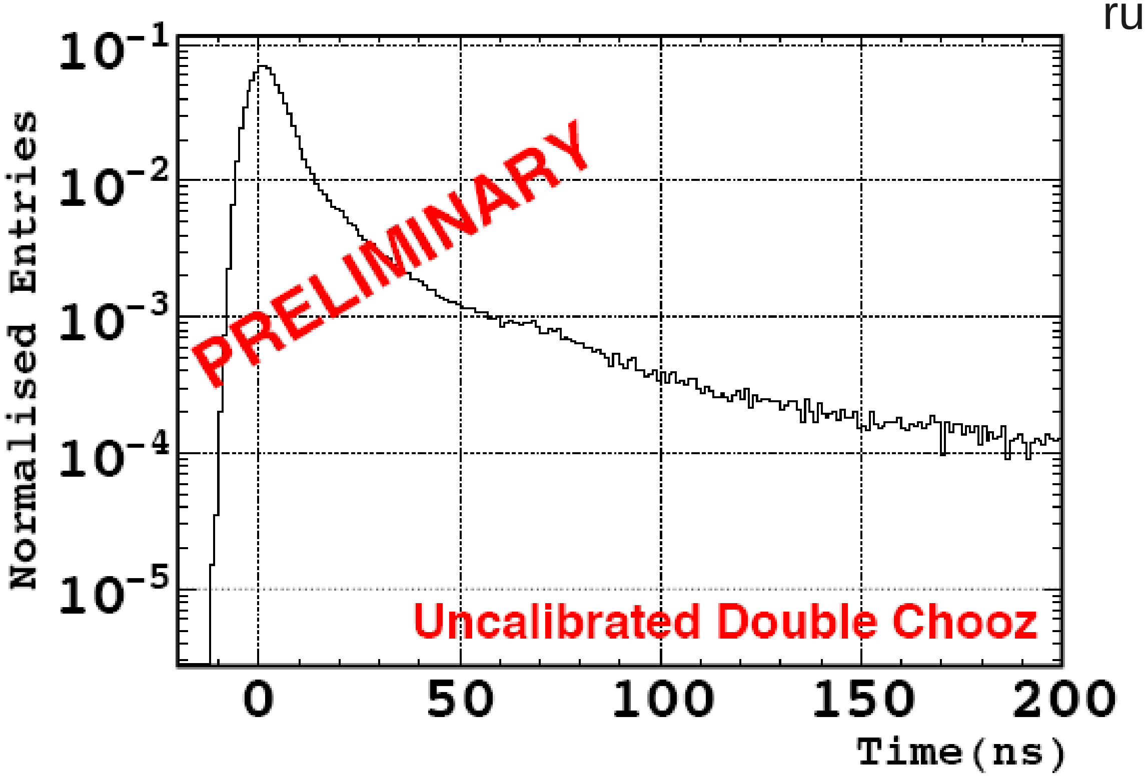
500 MHz 8-bit flash ADC (developed with Caen – V1721X)

- Dead-time-less (for our expected event rate)
- In-house firmware allows choice of event size based on
  - Info from trigger
  - Time between consecutive events

Neutrino DAQ

- Waveform Digitisers
  - Digitise all 390 Inner Detector and 78 Inner Veto PMTs
  - 60 FADC cards (split over 4 VME crates)
- Taking data now!

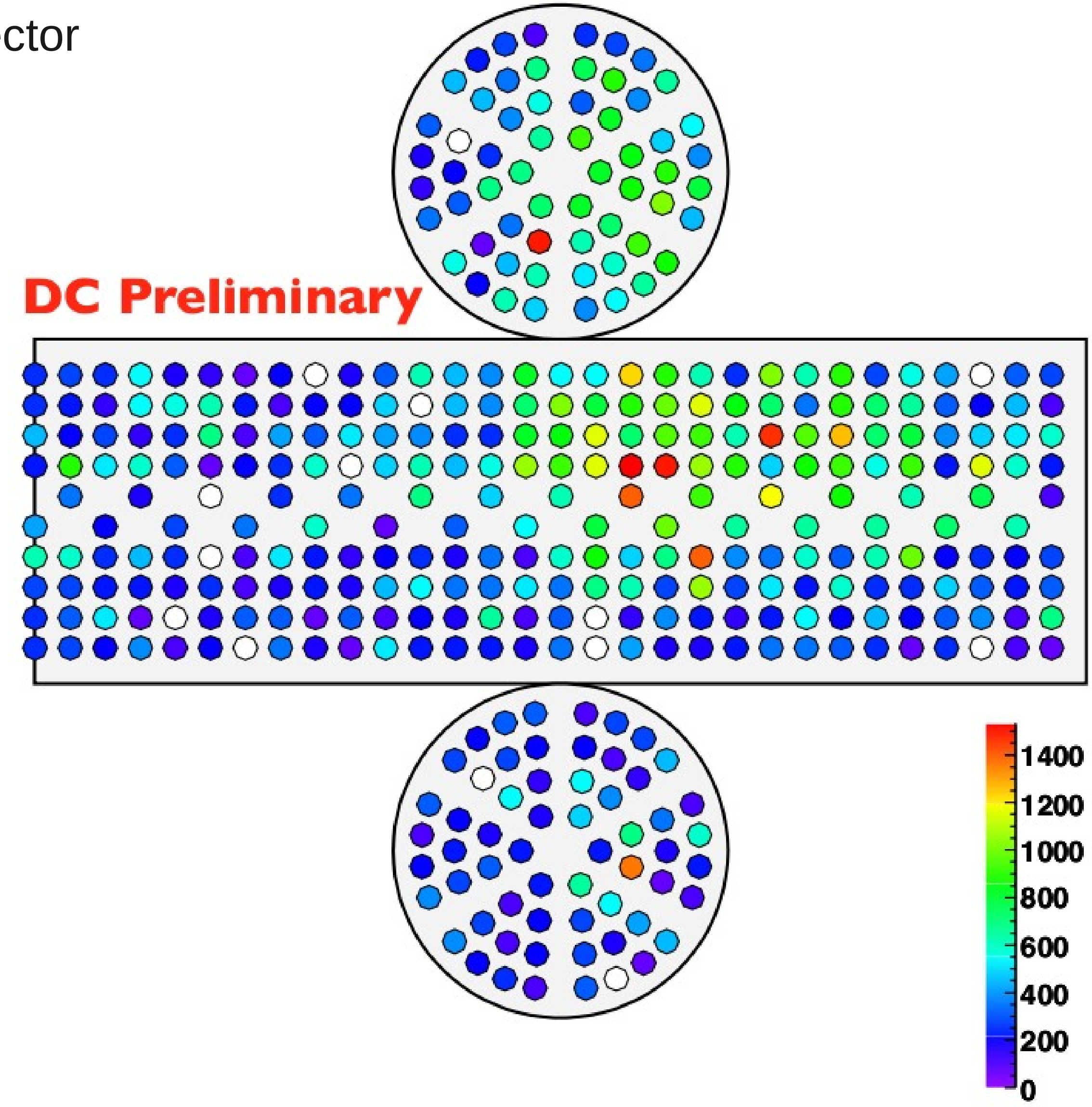
Far Detector - scintillation



Average light time response from a run during the filling of the Inner Detector

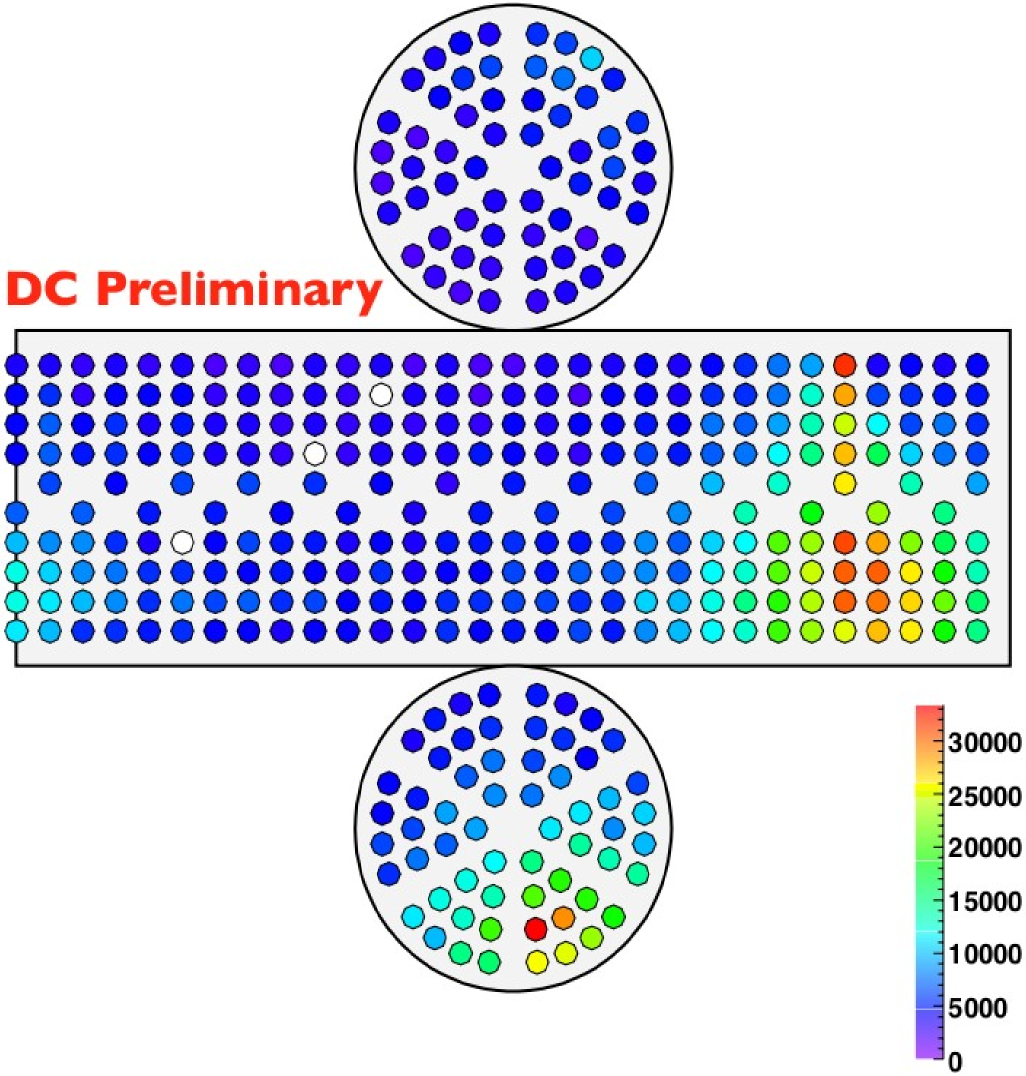
Far Detector - Events!

Event contained in Inner Detector

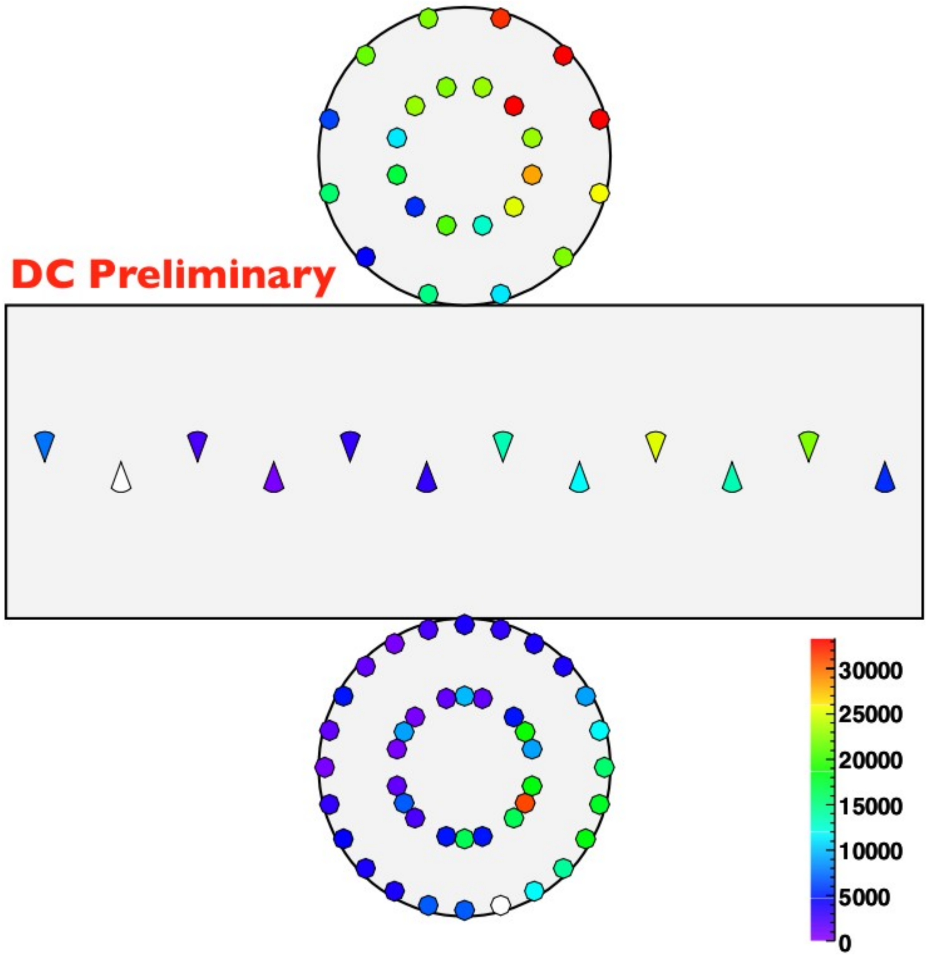


Far Detector - Events!

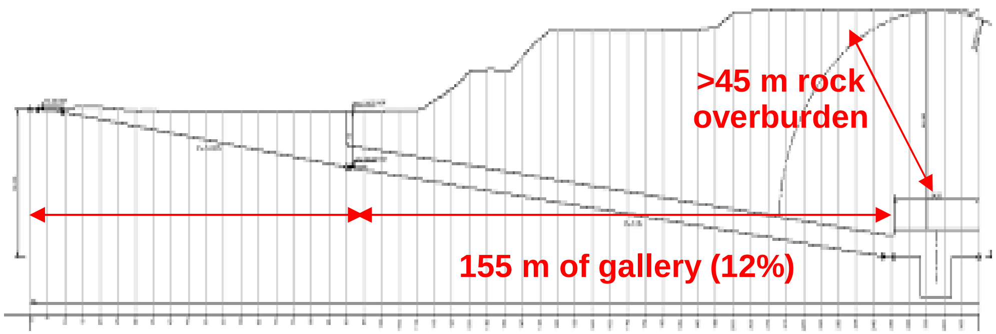
Muon in Inner Detector

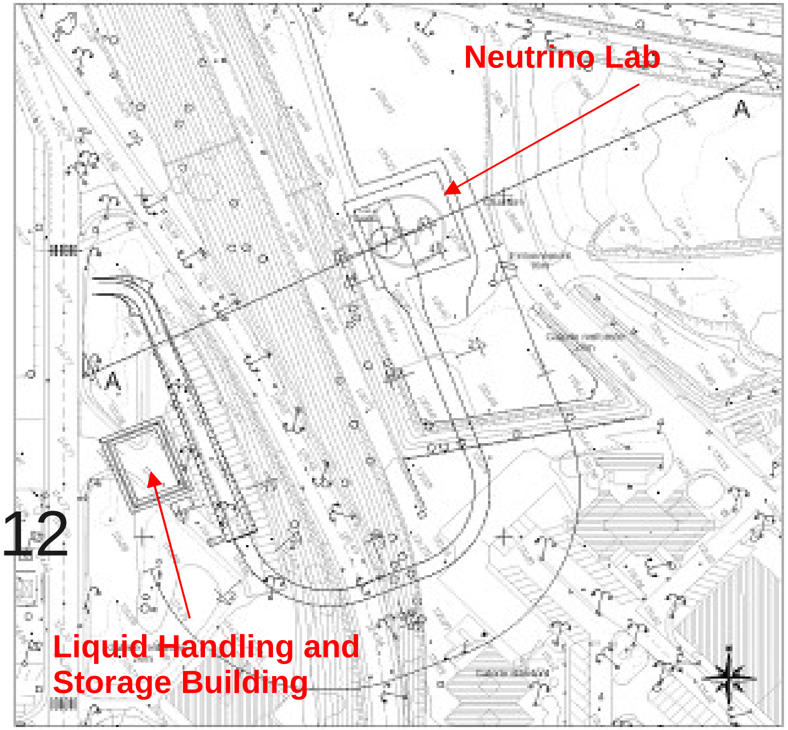


Muon in Inner Veto



Status: Near Lab





Near Lab to be completed by March 2012

Improvements on Chooz

Chooz : R = 1.01 ± 2.8% (stat) ± 2.7% (syst)

- Statistical
  - Large Volume
    - $5.55m^3$ -> $10.3m^3$
  - Run Time
    - ~months -> 3-5 yrs
  - Number of Events
  - 2700 -> 60,000 (far in 3 yrs)

➢ 0.4 %

- Systematic
  - Reactor
  - Detector
  - Analysis

➢ < 0.6%

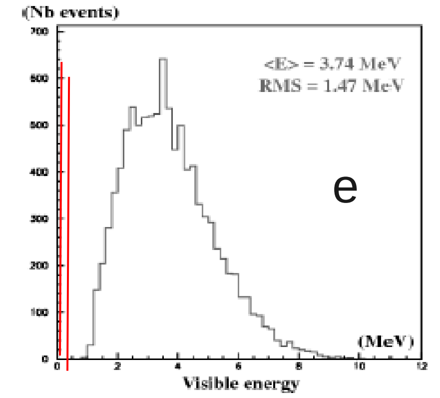
Systematics: Analysis

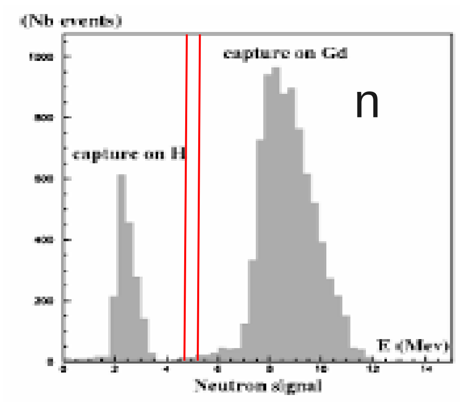
- Lower threshold (see all of positron spectrum)
- Target Acrylic vessel (no fiducial volume cut)

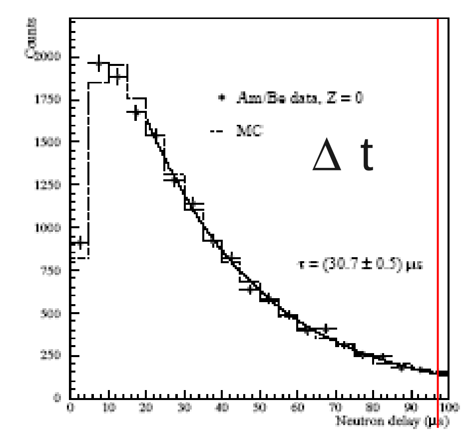
	CHOOZ	Double-CHOOZ	
selection cut	rel. error (%)	rel. error (%)	Comment
positron energy*	0.8	0	not used
* positron-geode distance	0.1	0	not used
neutron capture	1.0	0.2	Cf calibration
* capture energy containment	0.4	0.2	Energy calibration
neutron-geode distance	0.1	0	not used
neutron delay	0.4	0.1	—
* positron-neutron distance	0.3	0 – 0.2	0 if not used
neutron multiplicity*	0.5	0	not used
combined*	1.5	0.2-0.3	—

*average values

* Easier to control near vs far than absolute



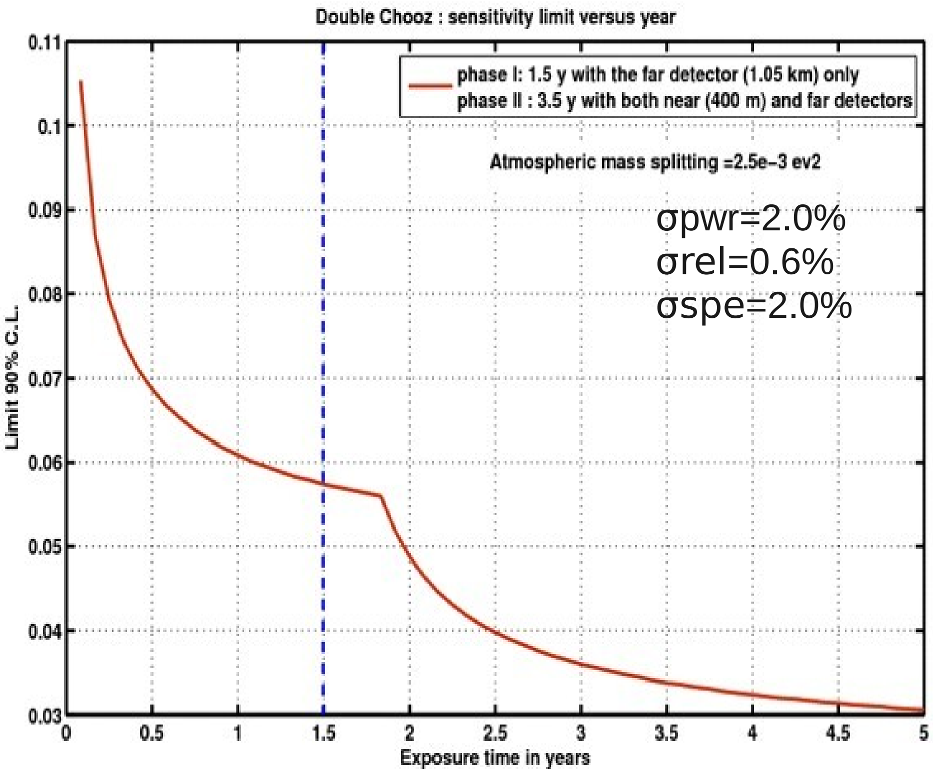




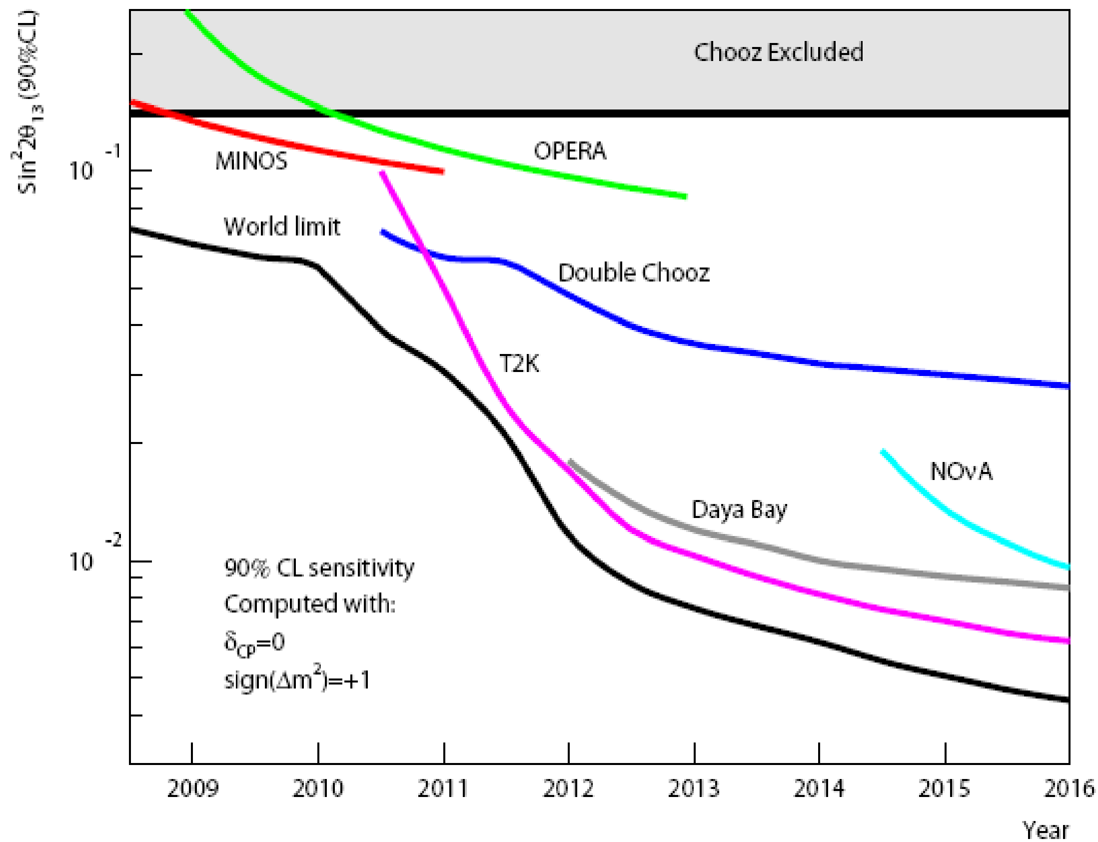
Systematics

		Chooz	Double-Chooz	
Reactor-induced	ν flux and σ	1.9 %	<0.1 %	Two "identical" detectors, Low bkg
	Reactor power	0.7 %	<0.1 %	
	Energy per fission	0.6 %	<0.1 %	
Detector - induced	Solid angle	0.3 %	<0.1 %	
	Volume	0.3 %	0.2 %	Precise target mass measurement
	Density	0.3 %	<0.1 %	Accurate T control (near/far)
	H/C ratio & Gd concentration	1.2 %	<0.1 %	Same scintillator batch + Stability
	Spatial effects	1.0 %	<0.1 %	Spill in/out compensate to ~1%
	Live time	?	0.25 %	Difference near/far is relevant !
Analysis	From 7 to 3 cuts	1.5 %	0.2 - 0.3 %	(see previous slide)
	Total	**2.7 %**	**< 0.6 %**	

Sensitivity



M. Mezzetto, 0905.2842



Double Chooz target sensitivity

$\sin^2 2\Theta_{13}$~0.03 (for $\Delta m^2_{31}=2.5\times10^{-3}$ eV^2)

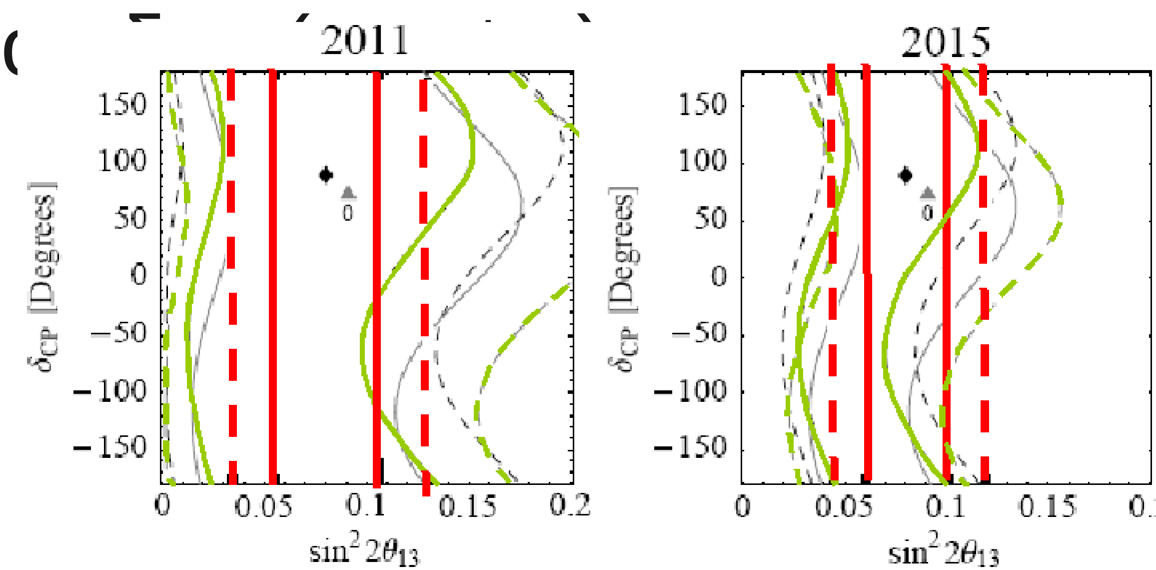
Conclusion

- Far detector is Running!
- With far
  - Achieve a sensitivity of $\sin^2 2\Theta_{13}$~0.06 with one year of data
- With near and far
  - measure $\sin^2 2\Theta_{13}$ to 3σ if $\sin^2 2\Theta_{13}$>0.05,
  - or exclude $\sin^2 2\Theta_{13}$ down to 0.03 (90% C.L) with 3 years of running
- Expect interesting results from Double Chooz soon!

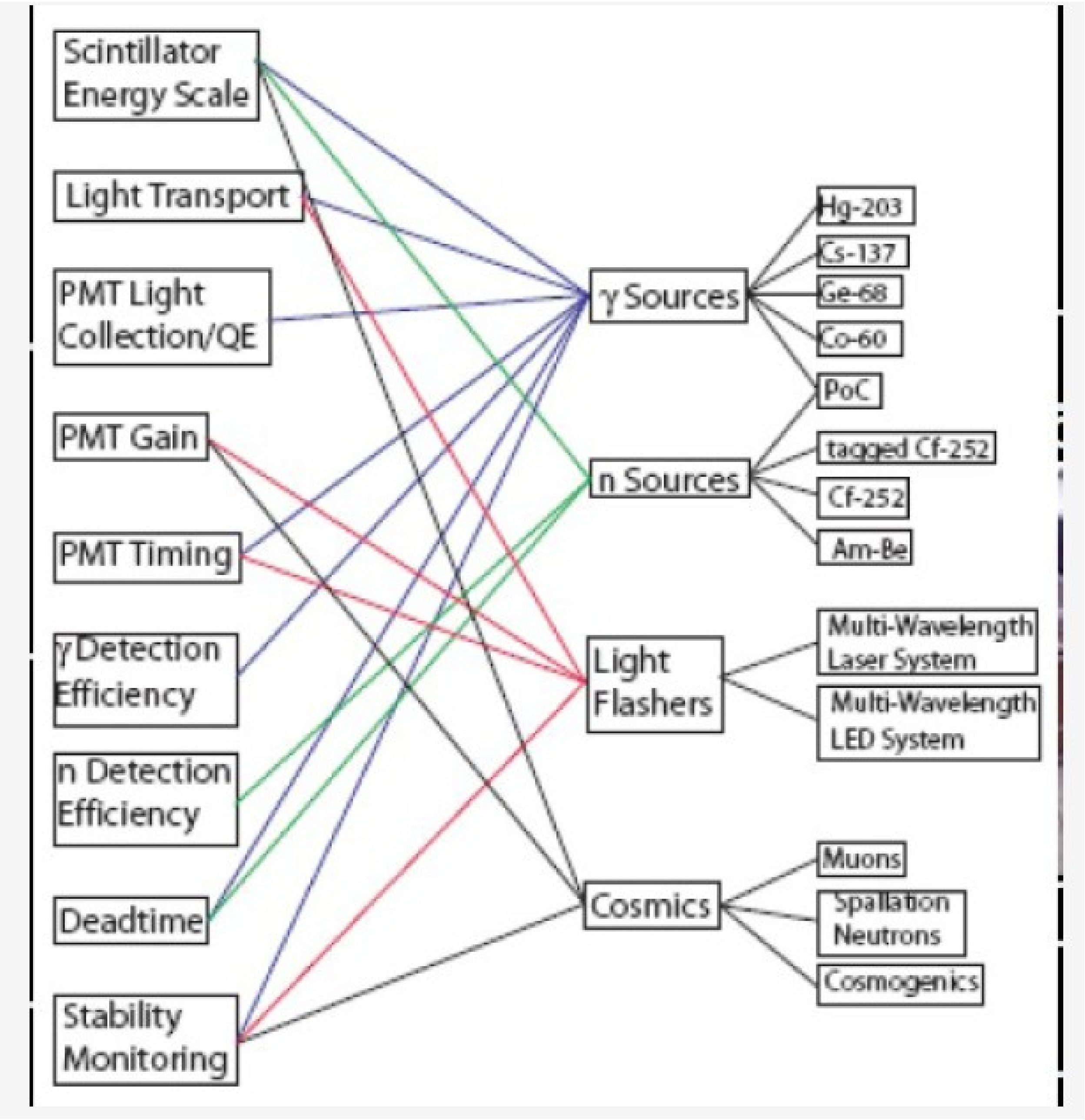
backups

Complementary to Beam experiments

- Example of Double Chooz results compared to T2K
  - Assume full power for T2K
  - 2 years of 2 detector (DC)
  - Full =90%, dashed 3σ
- No dependence o

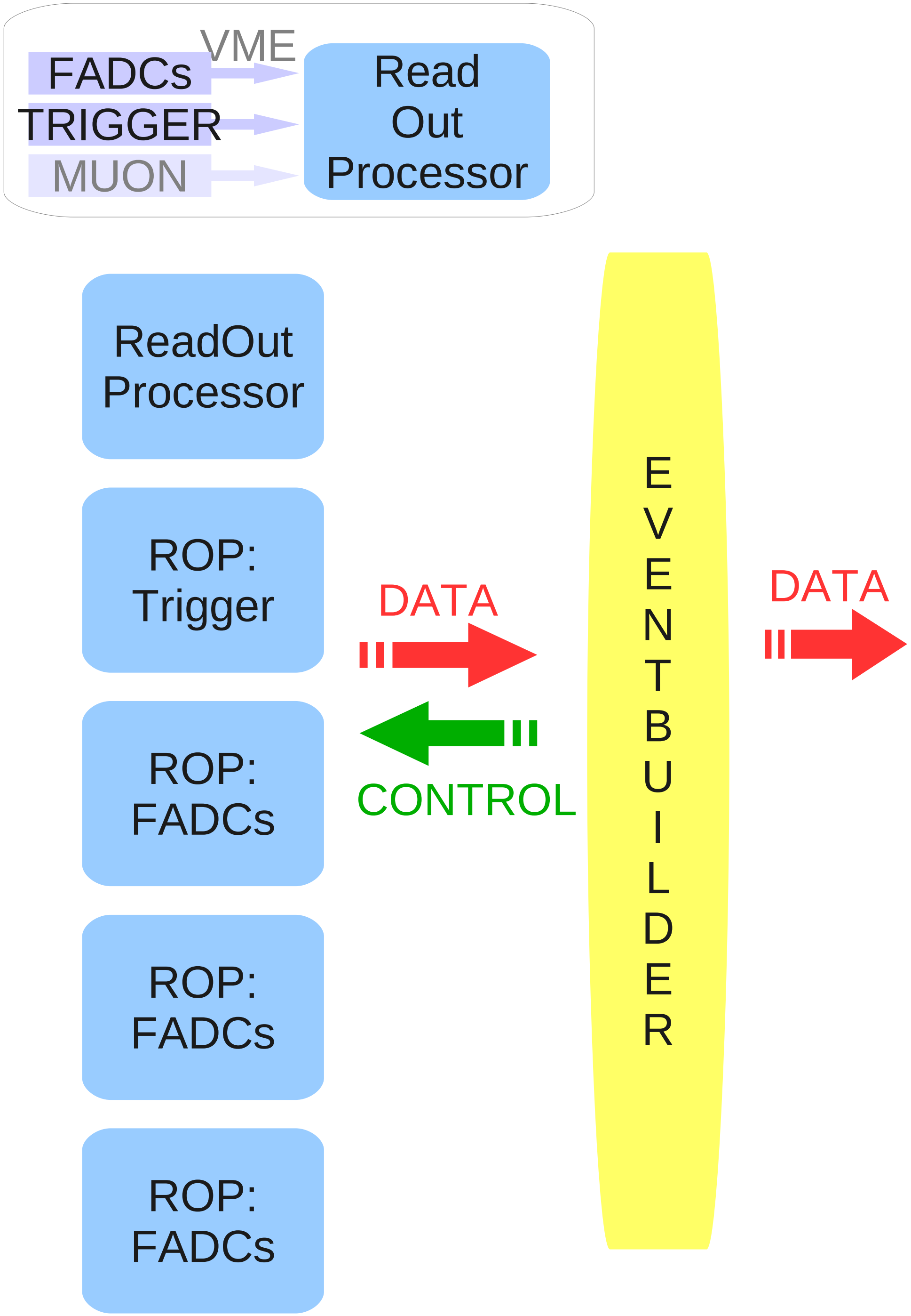


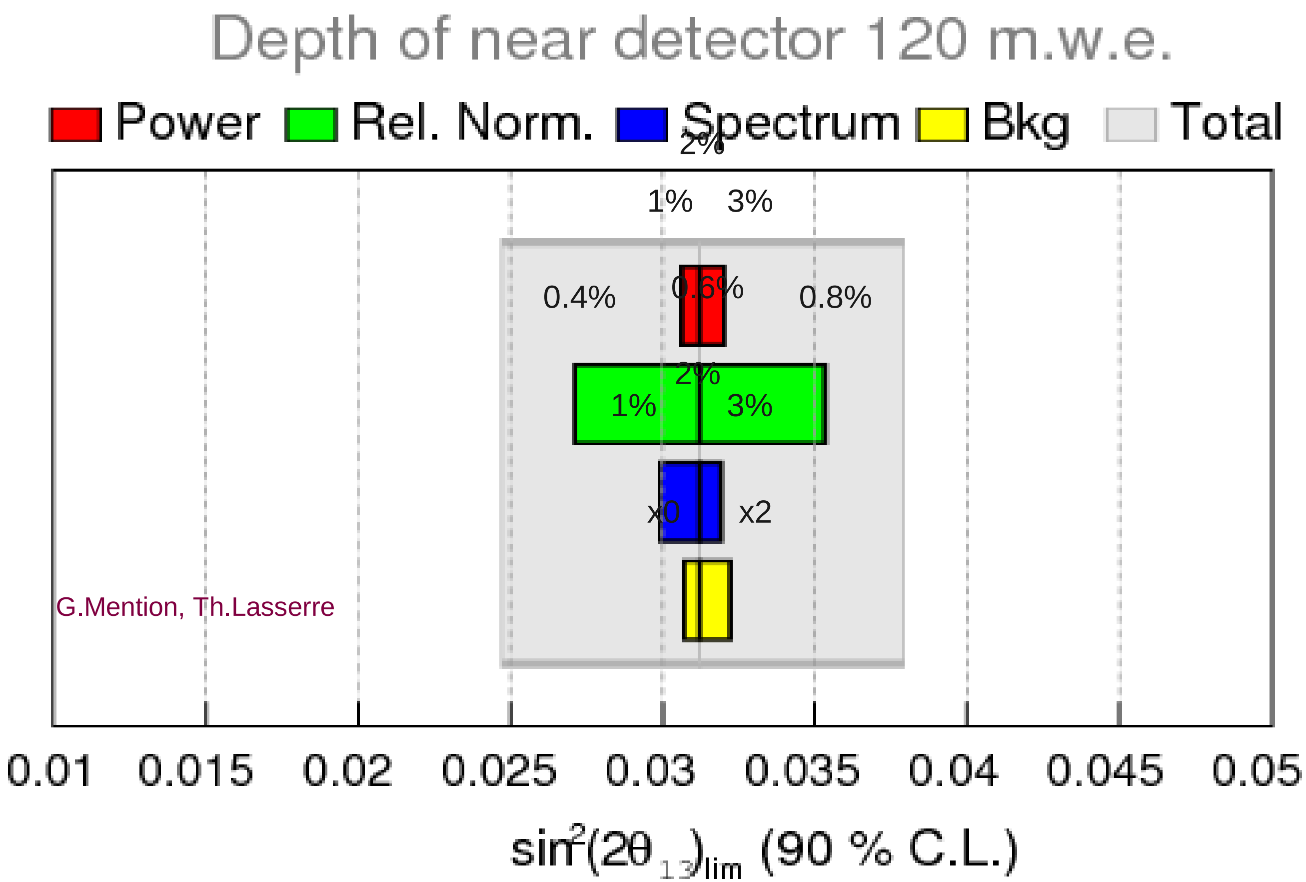
Calibration Sources



- Objectives
  - Relative neutrino detection efficiency between near and far < 0.5%
  - positron/gamma energy scale to 1%
  - Neutron energy scale to 25%

Neutrino DAQ

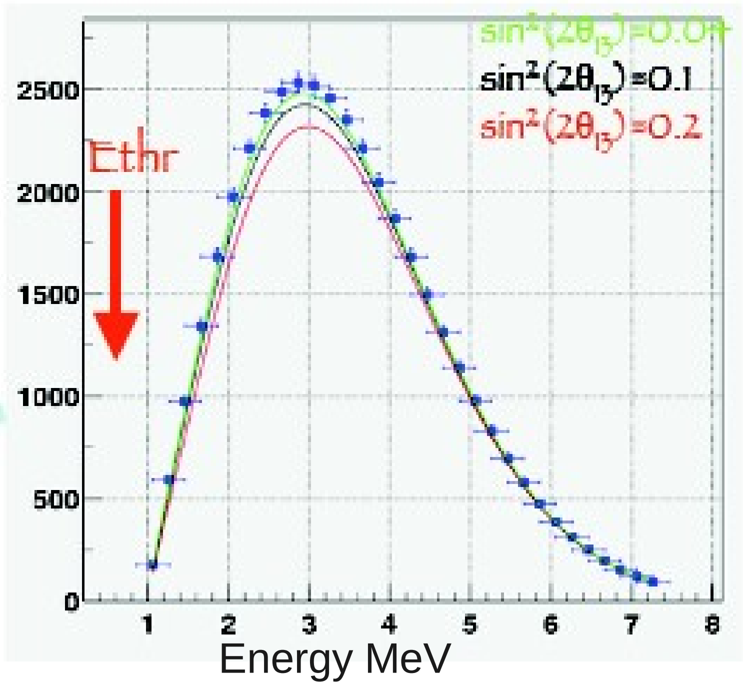


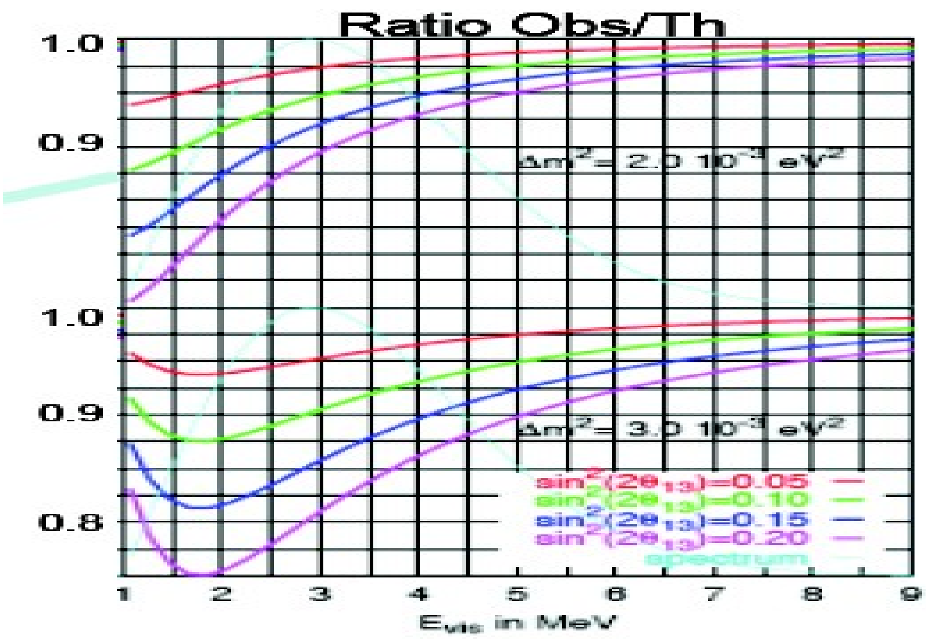


Total systematics: <~ 0.6%
Statistics: 60000 neutrino events @ Far Detector

Scintillator Liquid Storage and Handling (Oct 08)

Spectrum





- Two independent measures
  - Normalisation
  - Spectral Distortion

Background Comparison

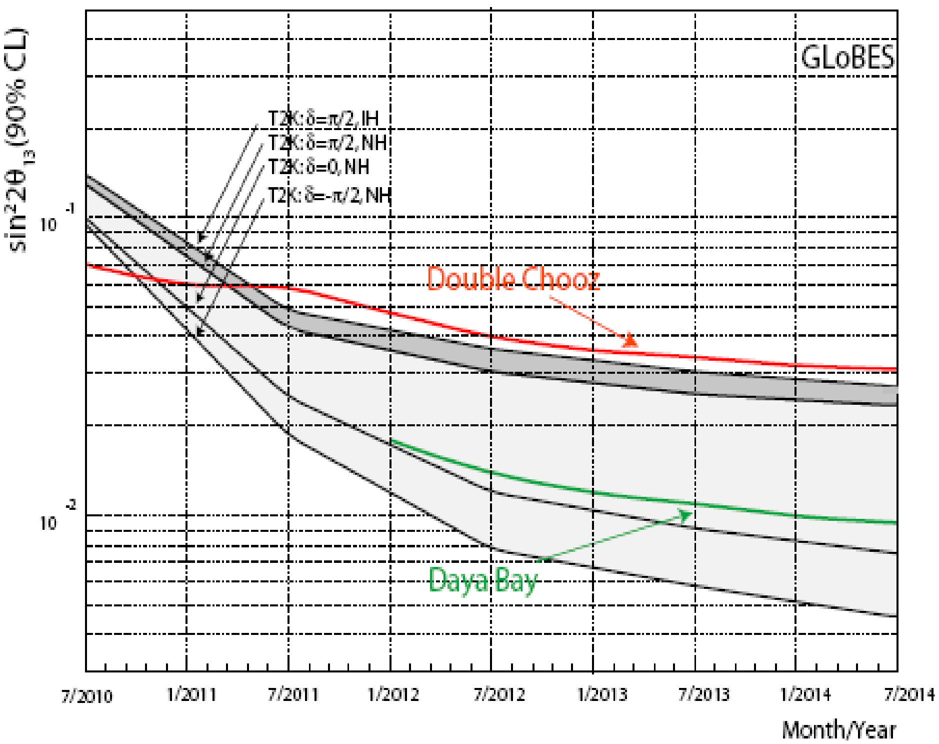
Detector	Site		Accidental: Materials	Accidental: PMTs	Correlated: Fast n	Correlated: μ-Capture	^{9}Li
CHOOZ		Rate (d^{-1})	—	—	—	—	0.6 ± 0.4
($24\ \nu$/d)		Rate (d^{-1})	0.42 ± 0.05		$1.01 \pm 0.04(stat) \pm 0.1(sys)$		
	Far	bkg/ν	1.6%		4%		
		Systematics	0.2%		0.4%		
Double Chooz		Rate (d^{-1})	0.5 ± 0.3	1.5 ± 0.8	0.2 ± 0.2	< 0.1	1.4 ± 0.5
($69\ \nu$/d)	Far	bkg/ν	0.7%	2.2%	0.2%	<0.1%	1.4%
		Systematics	<0.1%	<0.1%	0.2%	<0.1%	0.7%
Double Chooz		Rate (d^{-1})	5 ± 3	17 ± 9	1.3 ± 1.3	0.4	9 ± 5
($1012\ \nu$/d)	Near	bkg/ν	0.5%	1.7%	0.13%	<0.1%	1%
		Systematics	<0.1%	<0.1%	0.2%	<0.1%	0.2%

estimates with "old" near detector location
= conservative
(with new location: Nν/2 , N_μ/3)

hep-ex/0606025

Signal/Bkg >50

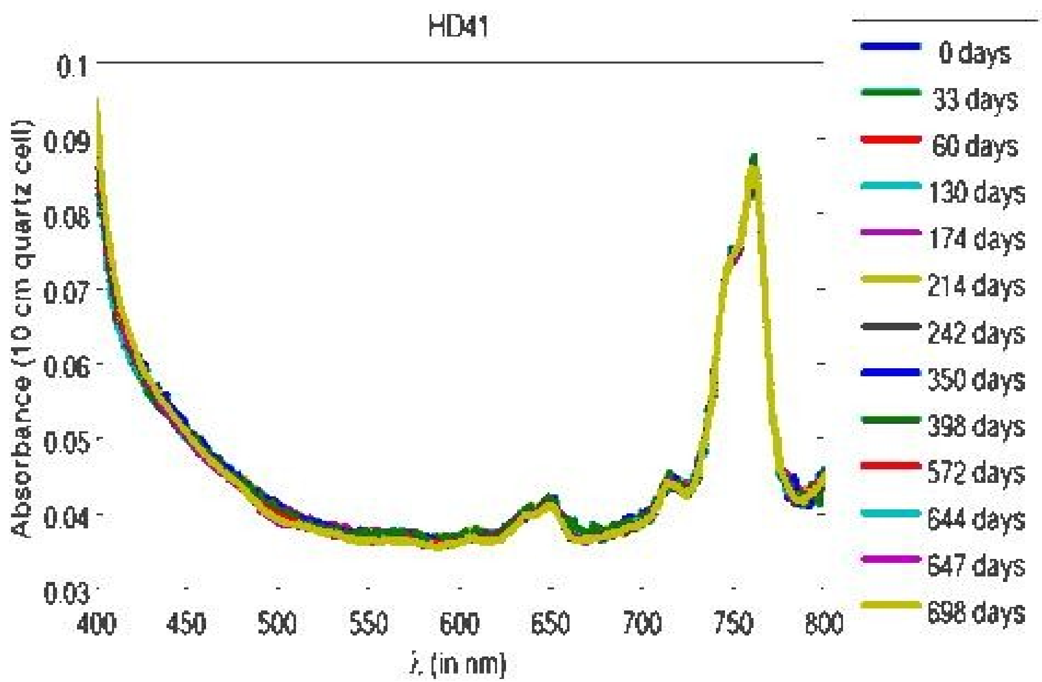
M. Mezzetto, 0905.2842



Gd-doped Liquid Scintillator

100kg Gd salt

- Stability tests reassuring
  - No change seen over ~700 days
- Scintillator ingredients for both detectors ready to be mixed (MPIK)
- Mixing in one batch
  - Exact proportions for both detectors (H, Gd)



FADC

- Waveform digitisers of νDAQ
  - APC responsibility [Courty, Kryn, Dawson, Akiri]
- Developed in partnership with CAEN - V1721X
  - 8 channels
  - digitises at 500 MHz to 8-bit
- Dead-time-less
- Enhanced with In-House firmware
  - Variable waveform size (max 4 μs)
  - 2eSST DMA transfer
- Digitise all PMT signals (60 cards)