The Double Chooz Experiment

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on behalf of the Double Chooz Collaboration.

université PARIS DIDEROT PARIS 7

XXIV Workshop on Weak Interactions and Neutrinos
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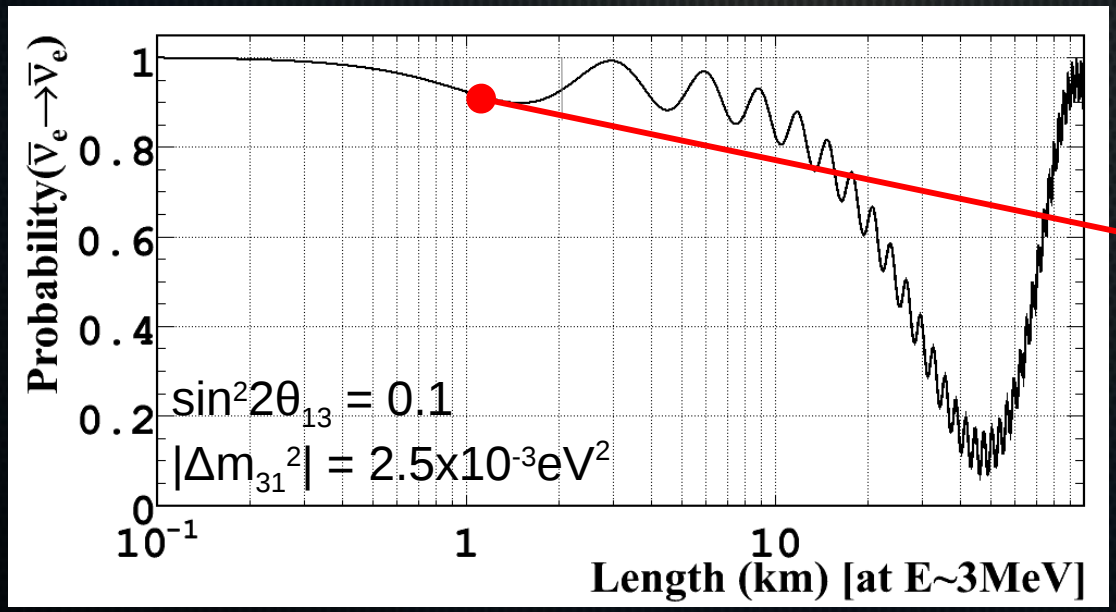
Experiment Overview

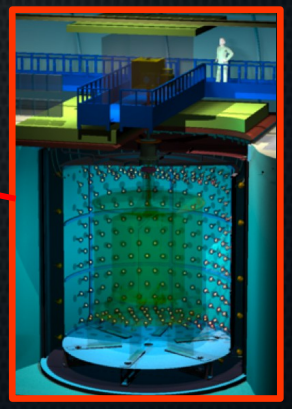
θ_{13} measurement with reactor neutrinos

- Reactor is a free and rich electron antineutrino source
- Direct measurement of θ_{13} with no parameter degeneracy

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

Simple 2 flavor oscillation formula is valid at L~1km with no matter effect

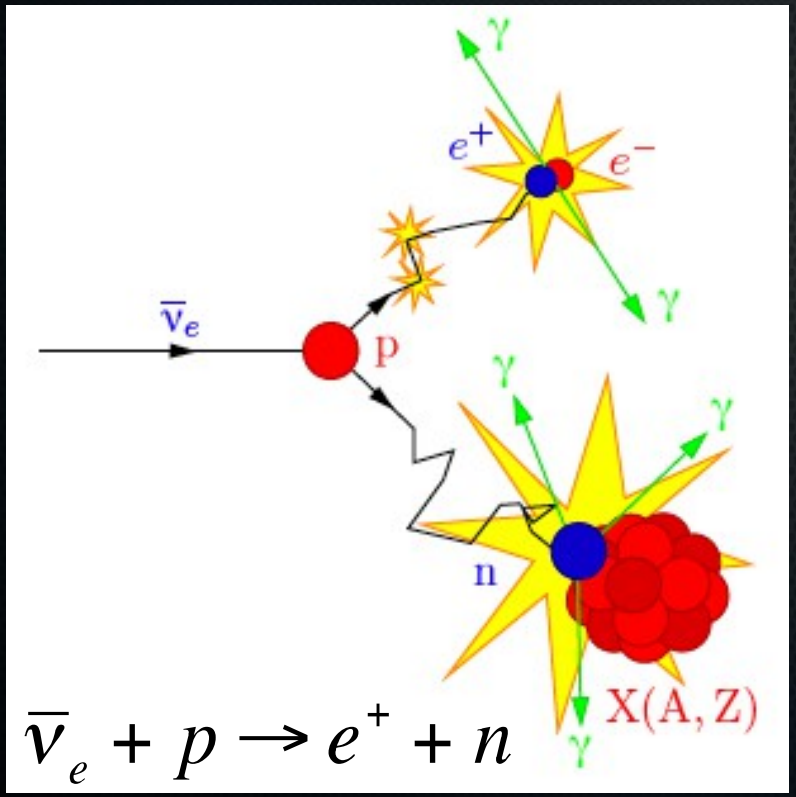




$\sin^2 2\theta_{13}$ = 0.1
$|\Delta m^2_{31}|$ = 2.5x10^{-3}eV^2

θ_{13} measurement with reactor neutrinos

- Reactor is a free and rich electron antineutrino source
- Direct measurement of θ_{13} with no parameter degeneracy
- Background is strongly suppressed by delayed coincidence



Prompt signal:

positron + annihilation γ's:
1 ~ 12MeV

Delayed signal:

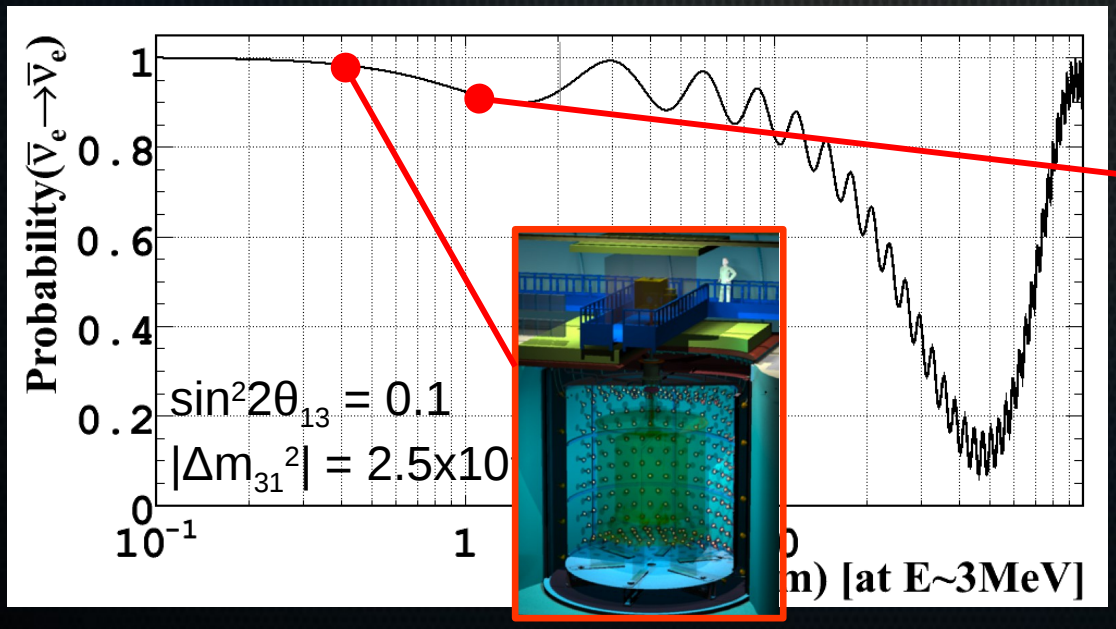
γ's from neutron capture
on Gd: 8 MeV
on H: 2.2 MeV

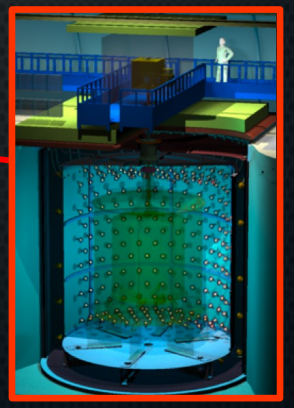
- Time interval:

Gd: Δt ~ 30μs
H: Δt ~ 200μs

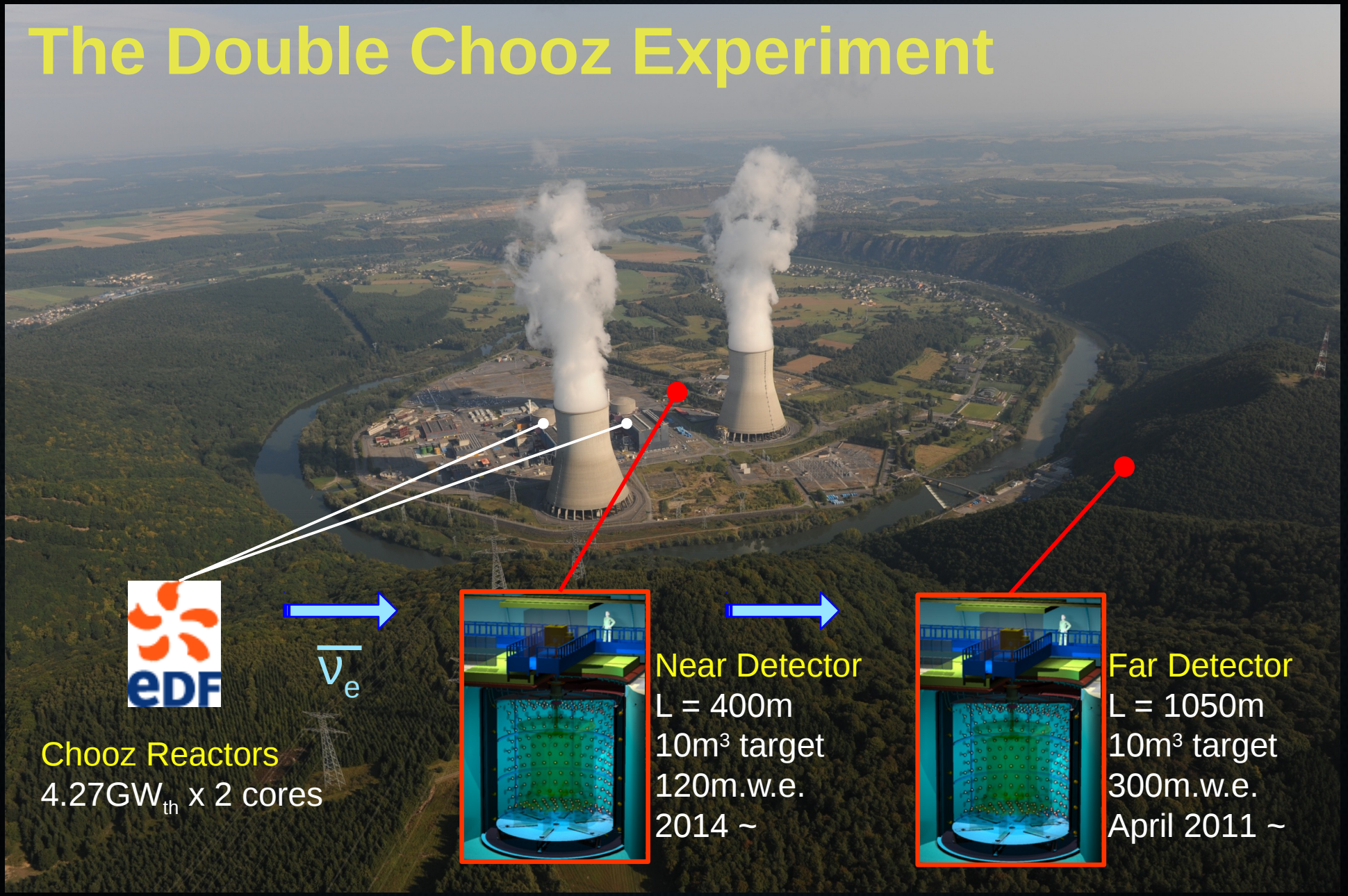
θ_{13} measurement with reactor neutrinos

- Reactor is a free and rich electron antineutrino source
- Direct measurement of θ_{13} with no parameter degeneracy
- Background is strongly suppressed by delayed coincidence
- Flux expectation within 2% uncertainties
- Systematic uncertainties are further reduced (<1%) using two detectors at different baselines





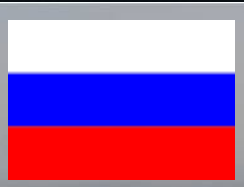
$\sin^2 2\theta_{13}$ = 0.1
$|\Delta m_{31}^2| = 2.5 \times 10^{-3}$eV2


The Double Chooz Experiment
$\overline{\nu}_e$
Chooz Reactors
4.27GW$_{th}$ x 2 cores
Near Detector
L = 400m
10m^3 target
120m.w.e.
2014 ~
Far Detector
L = 1050m
10m^3 target
300m.w.e.
April 2011 ~

Experiment overview







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The Brazilian group

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UFABC

Pietro Chimenti	(Professor)

Brazilian Supporting Agencies

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RENAFAE

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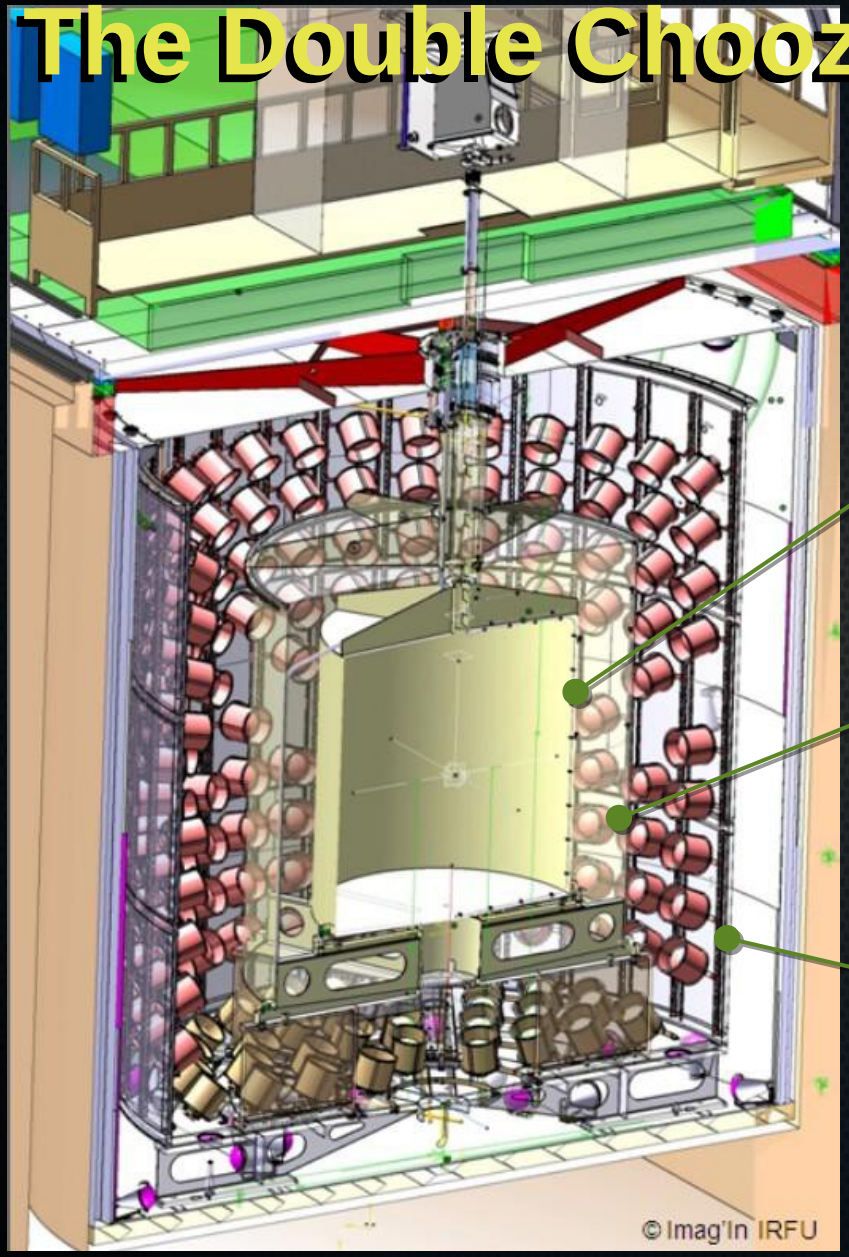
Conselho Nacional de Desenvolvimento Científico e Tecnológico

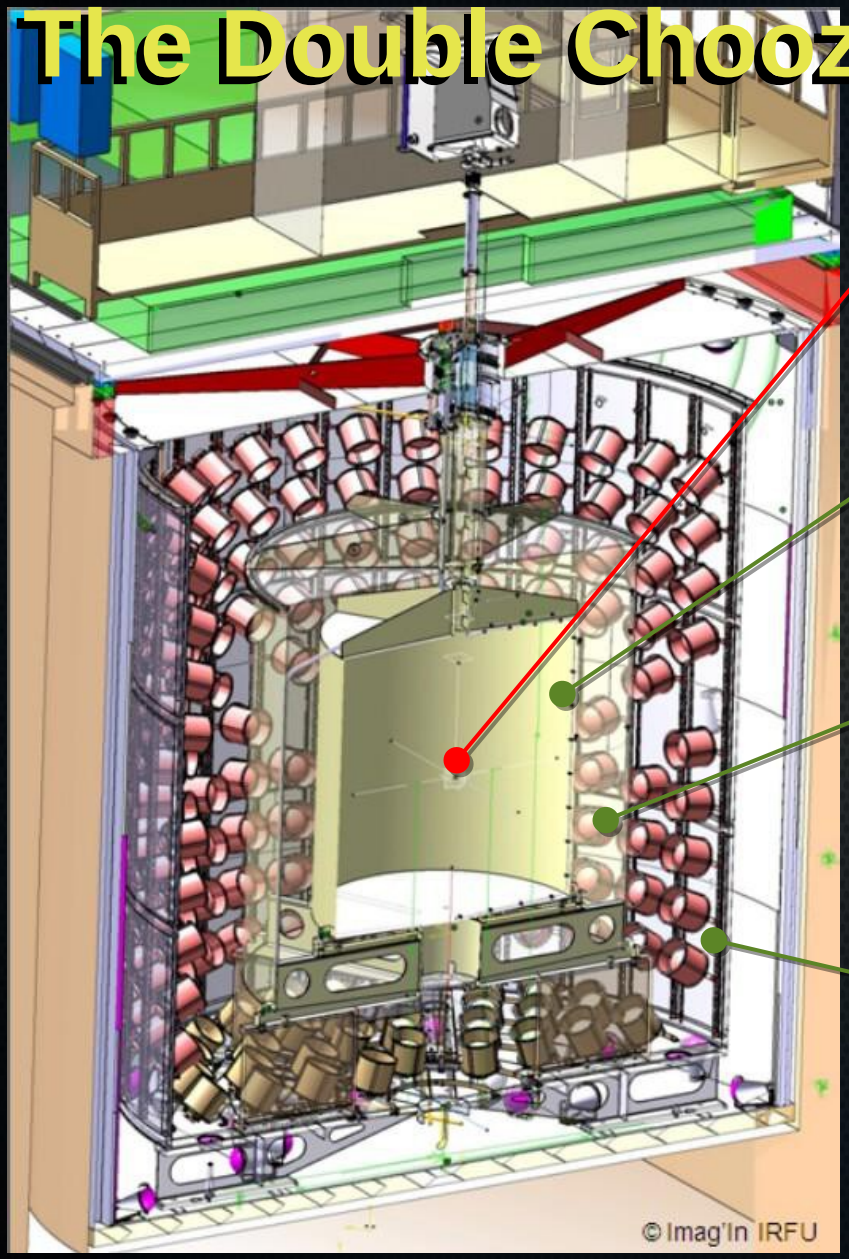
CAPES

FAPESP

The Double Chooz Detector



The Double Chooz Detector



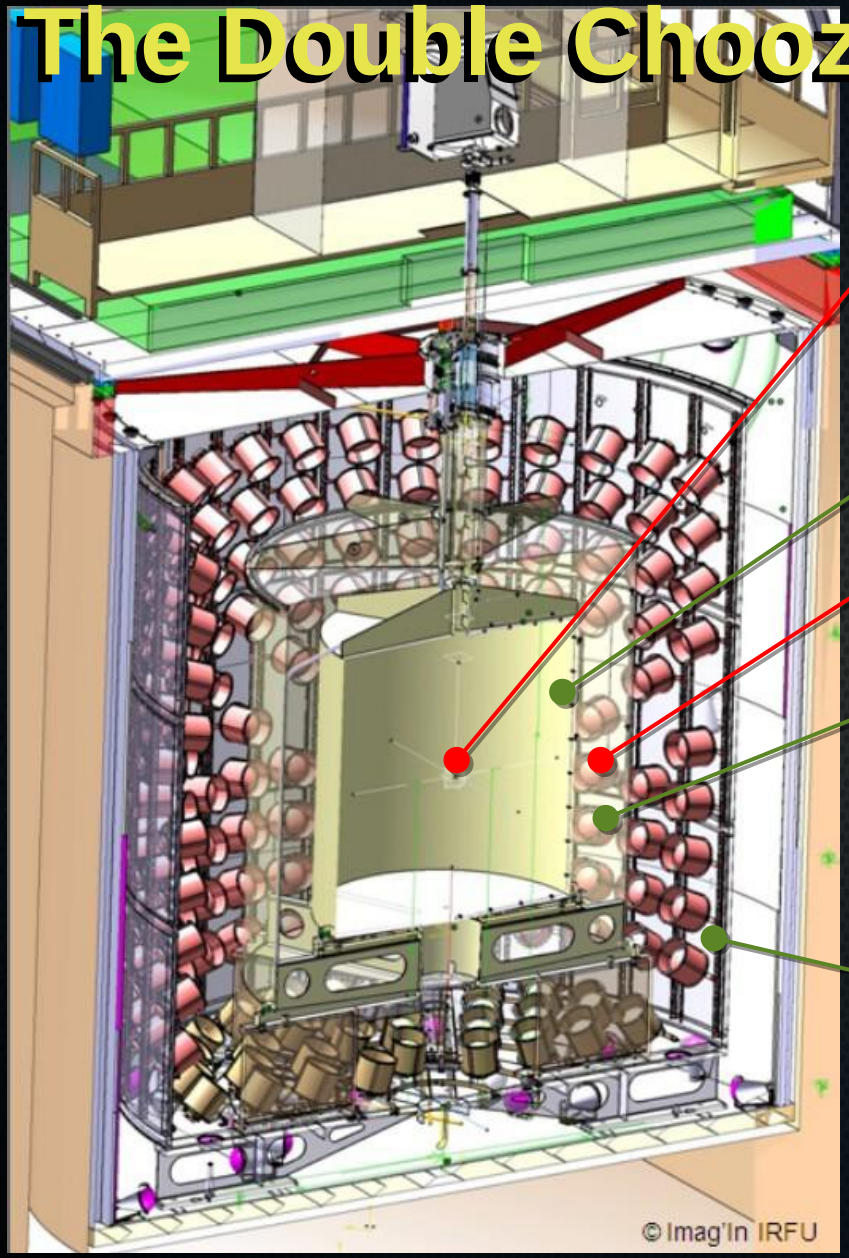
ν-target:
Gd loaded (1g/l) liquid scint. ($10m^3$)
Target of neutrino interaction
Neutrons captured on Gd + H

Acrylic vessel

Acrylic vessel

Steel vessel

The Double Chooz Detector



ν-target:
Gd loaded (1g/l) liquid scint. (10m³)
Target of neutrino interaction
Neutrons captured on Gd + H

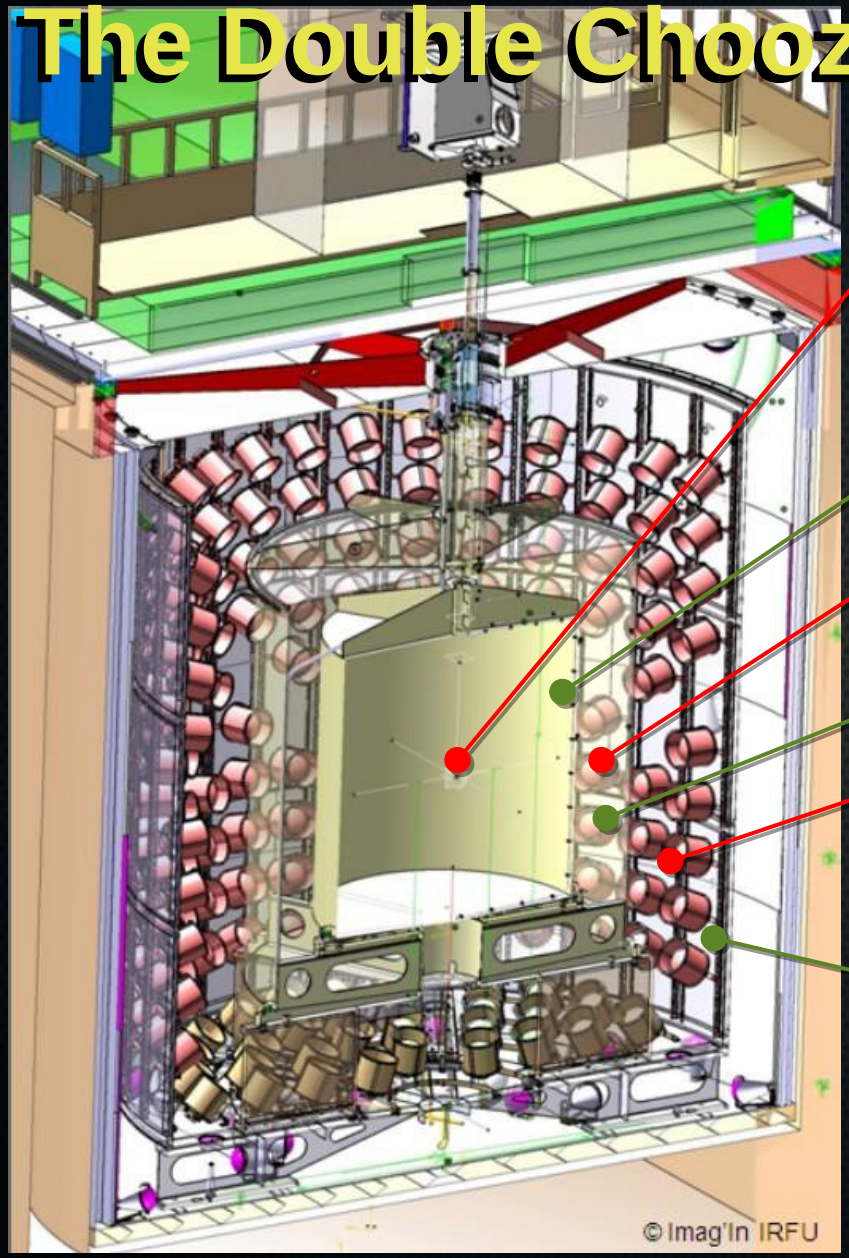
Acrylic vessel

γ-catcher: Liquid scintillator (22m³)
Measure γ's escaped from ν-target + H

Acrylic vessel

Steel vessel

The Double Chooz Detector



ν-target:
Gd loaded (1g/l) liquid scint. (10m³)
Target of neutrino interaction
Neutrons captured on Gd + H

Acrylic vessel

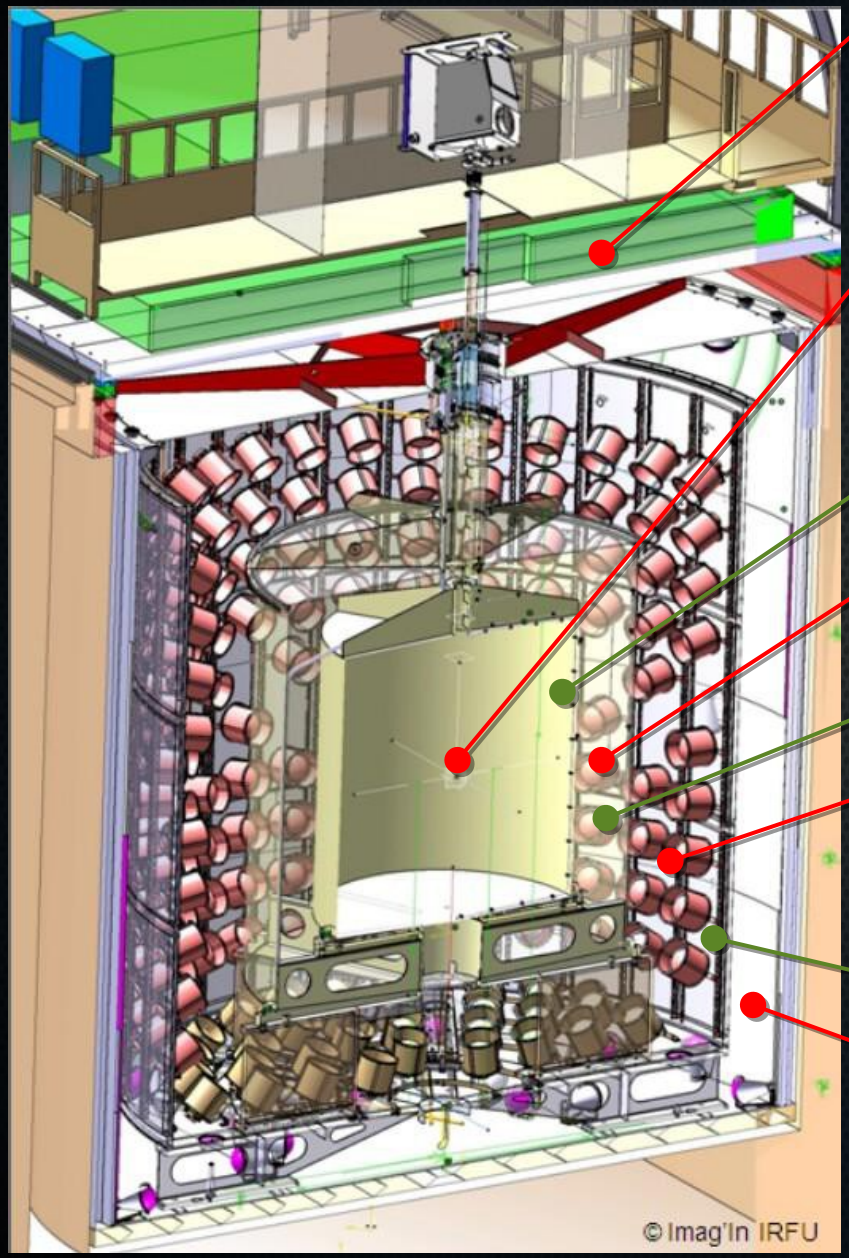
γ-catcher: Liquid scintillator (22m³)
Measure γ's escaped from ν-target + H

Acrylic vessel

Buffer:
Mineral oil (110m³) & 390 10-inch PMT
Reduction of environmental γ's

Steel vessel

Experiment overview



Outer Veto: Plastic scintillator strips
Identify cosmic μ

ν-target:
Gd loaded (1g/l) liquid scint. ($10m^3$)
Target of neutrino interaction
Neutrons captured on Gd + H

Acrylic vessel

γ-catcher: Liquid scintillator ($22m^3$)
Measure γ's escaped from ν-target + H

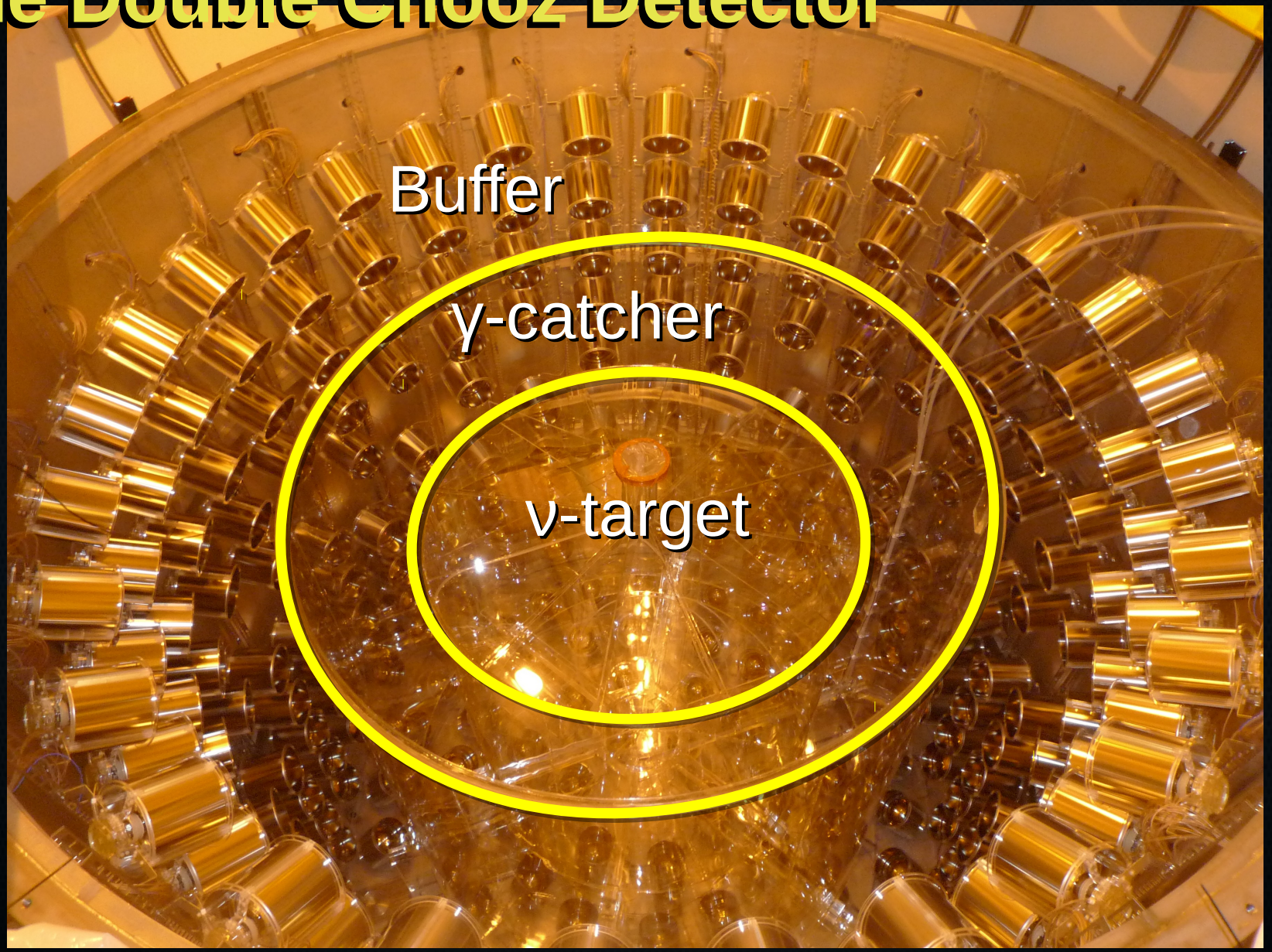
Acrylic vessel

Buffer:
Mineral oil ($110m^3$) & 390 10-inch PMT
Reduction of environmental γ's

Steel vessel

Inner Veto:
Liquid scintillator ($90m^3$) & 78 8-inch PMT
Identify cosmic μ & reduction neutrons

The Double Chooz Detector



Neutrino Selection - Gd

Muon veto

- No coincidence signal in IV
- $\Delta t_\mu > 1$ msec

Prompt event

- $0.7 < Evis < 12.2$ MeV
- PMT light noise cuts

Delayed event

- $6 < Evis < 12$ MeV
- PMT light noise cuts

Delayed coincidence

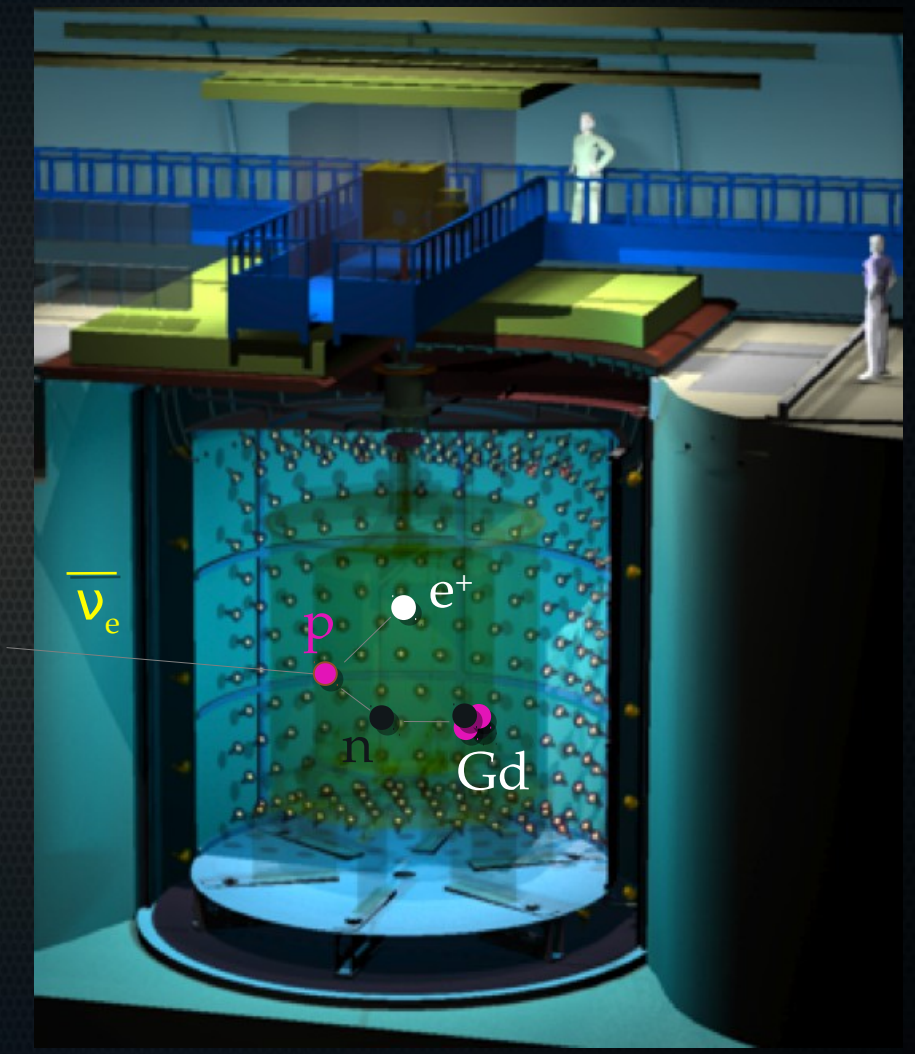
- $2 < \Delta t < 100$ µsec

Multiplicity

- No extra events around signal (500µ µsec)

Further BG reduction

- $\Delta t_\mu > 500$ msec ($E_\mu > 600$MeV)
- No coincidence signal in OV



Neutrino Selection - Gd

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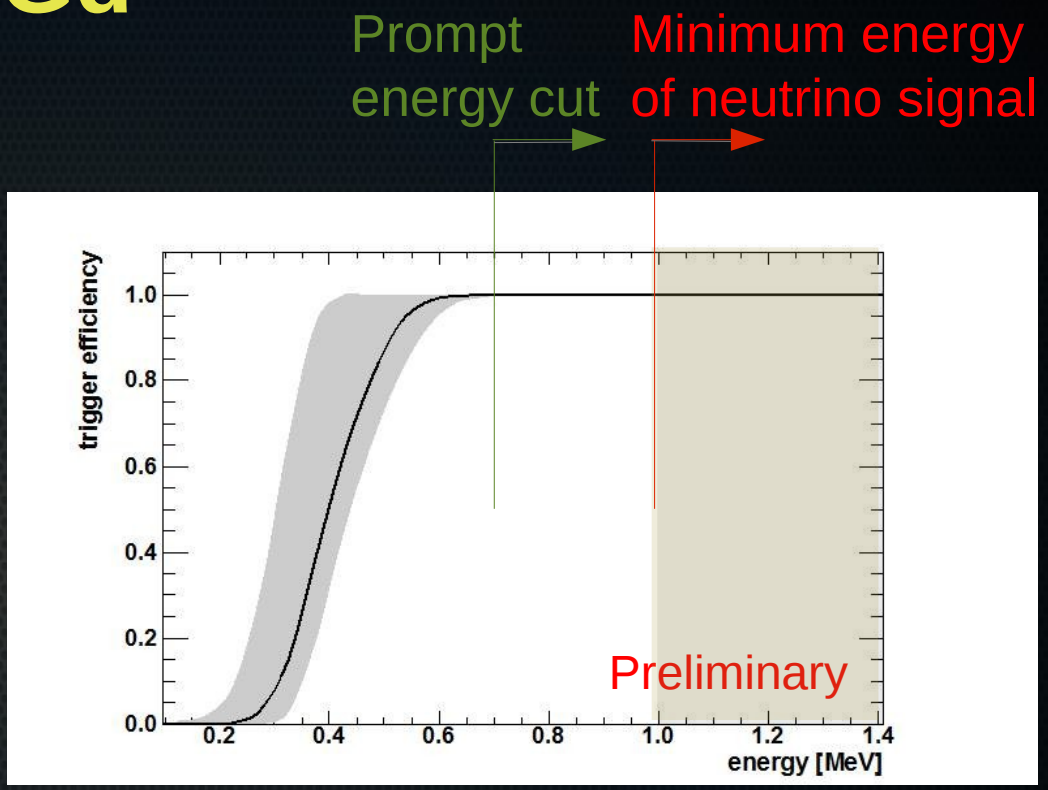

Trigger efficiency

- Threshold at 400keV (ε=50%)
- ε=100% above 700keV

Neutrino Selection - Gd

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- No coincidence signal in IV
- Δt_μ > 1 msec

Prompt event

- 0.7 < Evis < 12.2 MeV
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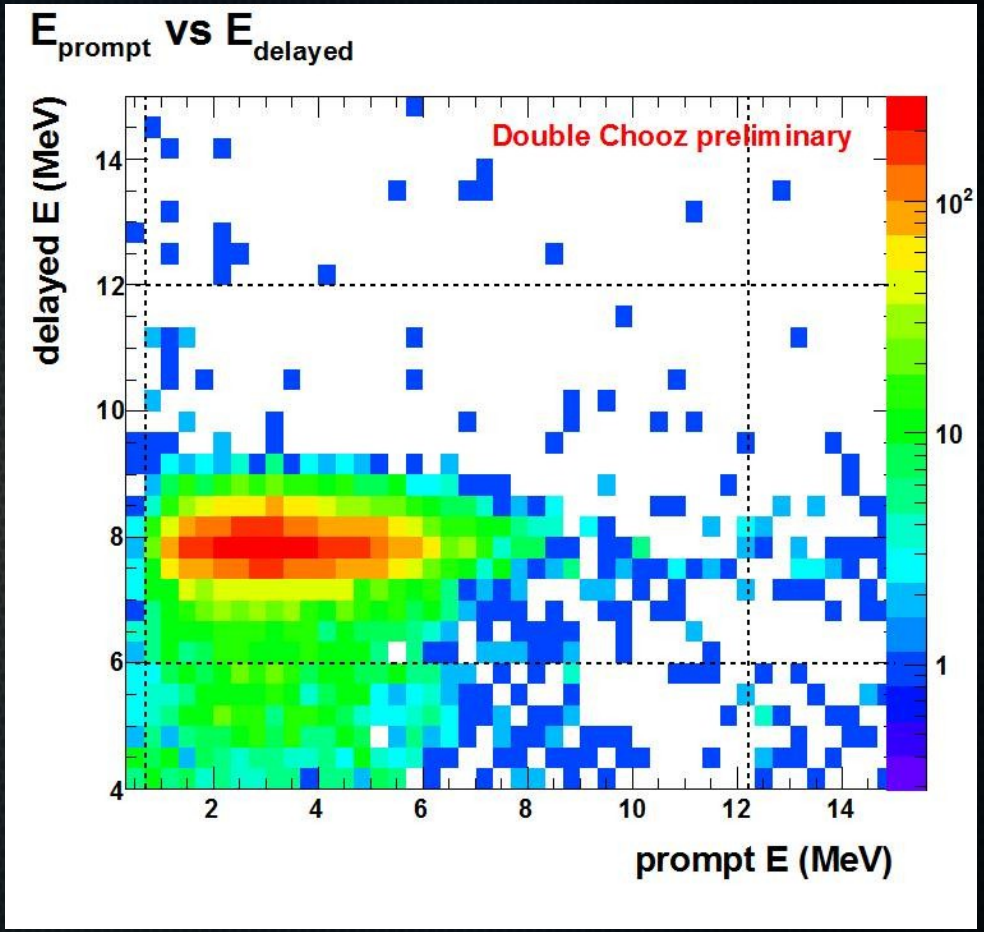

Neutrino Selection - Gd

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- No coincidence signal in IV
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Prompt event

- 0.7 < Evis < 12.2 MeV
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Delayed event

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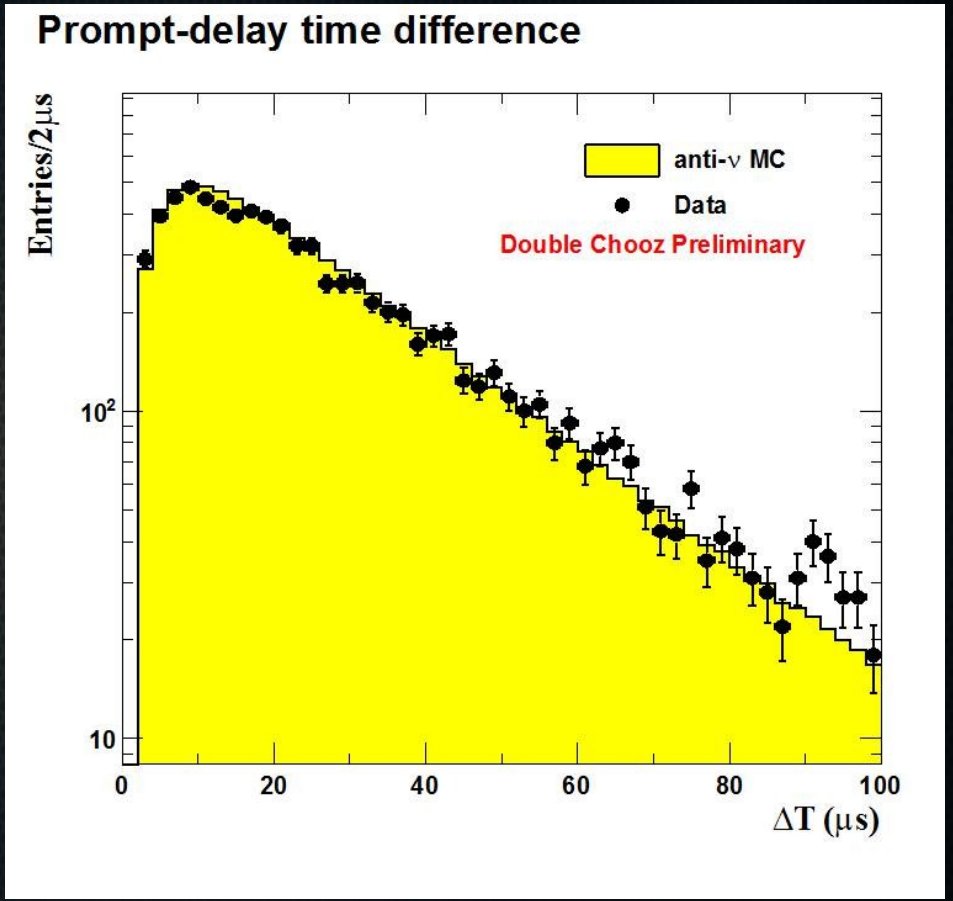


Neutrino Selection - Gd

Muon veto
- No coincidence signal in IV
- Δt_μ > 1 msec

Prompt event
- 0.7 < Evis < 12.2 MeV
- PMT light noise cuts

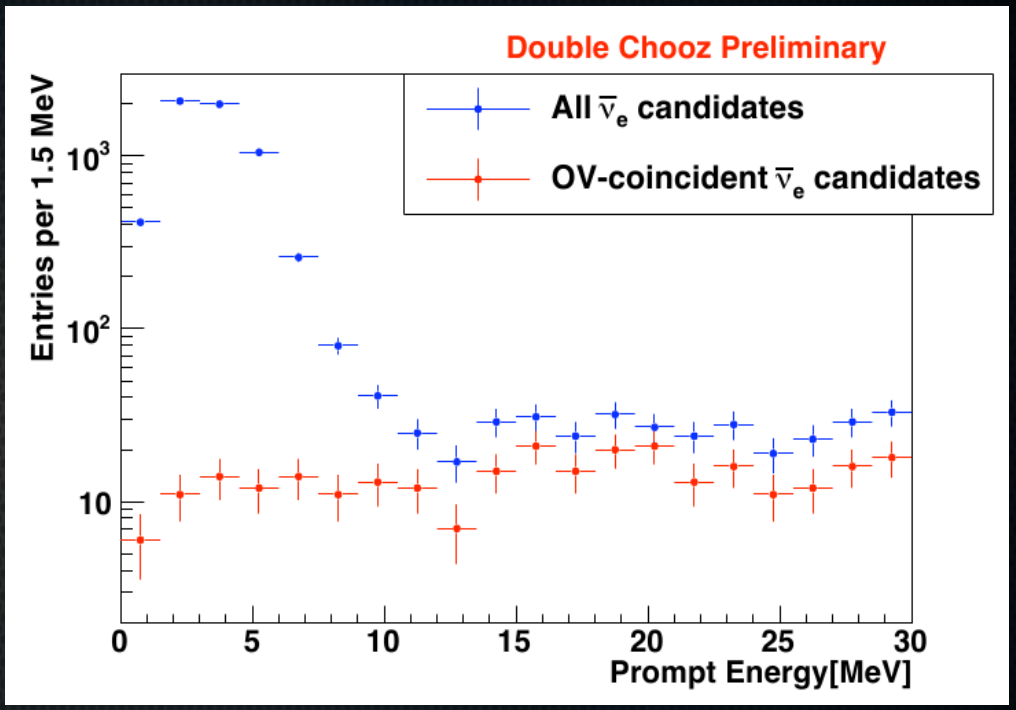
Delayed event
- 6 < Evis < 12 MeV
- PMT light noise cuts

Delayed coincidence
- 2 < Δt < 100 μsec

Multiplicity
- No extra events around signal (500μ μsec)

Further BG reduction
- Δt_μ > 500 msec (E_μ > 600MeV)
- No coincidence signal in OV

Contribution of OV-coincidence events in neutrino candidates



- **41% of ^{9}Li BG** is rejected by additional **muon veto** (~5% live-time)
- **28% of fast neutron/stop μ BG** is rejected by **OV anticoincidence**

Neutrino Selection - H

Muon veto

- No coincidence signal in IV
- $\Delta t_\mu > 1$ msec

Prompt event

- 0.7 < Evis < 12.2 MeV
- PMT light noise cuts

Delayed event

- 1.5 < Evis < 3.0 MeV
- PMT light noise cuts

Delayed coincidence

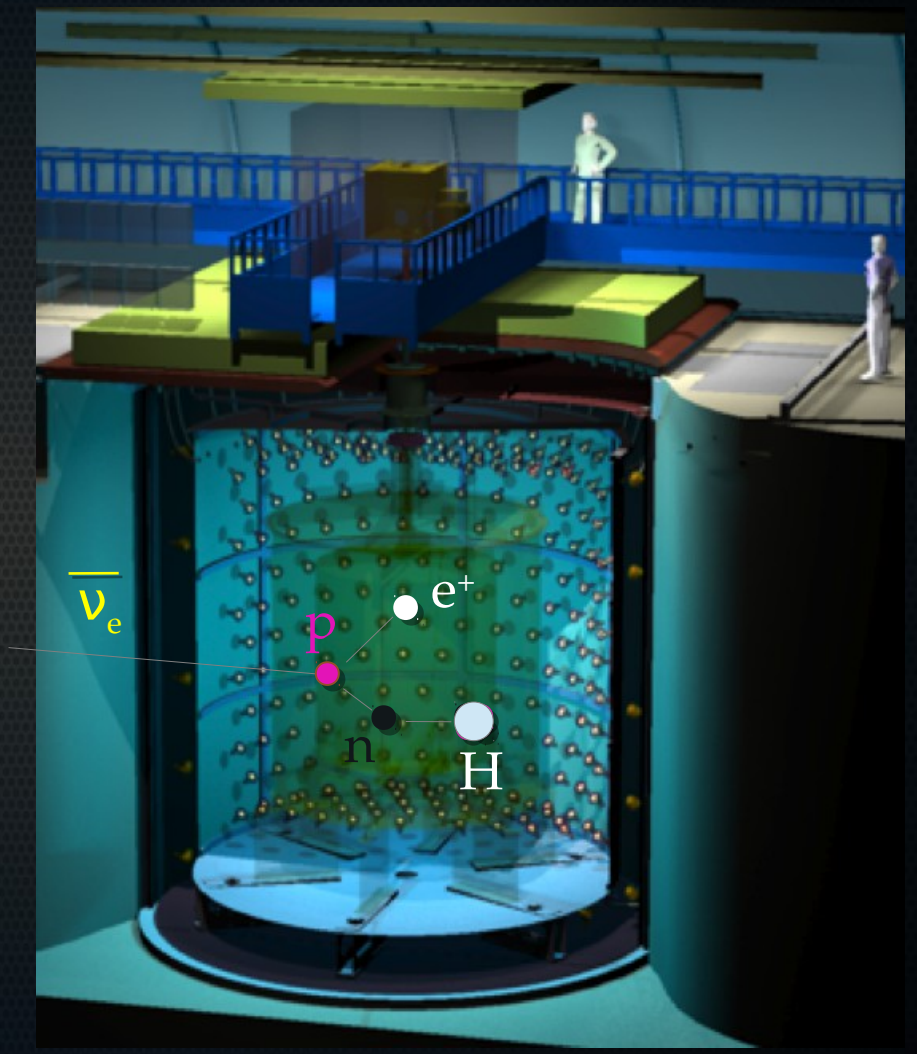
- 10 < Δt < 600 μsec

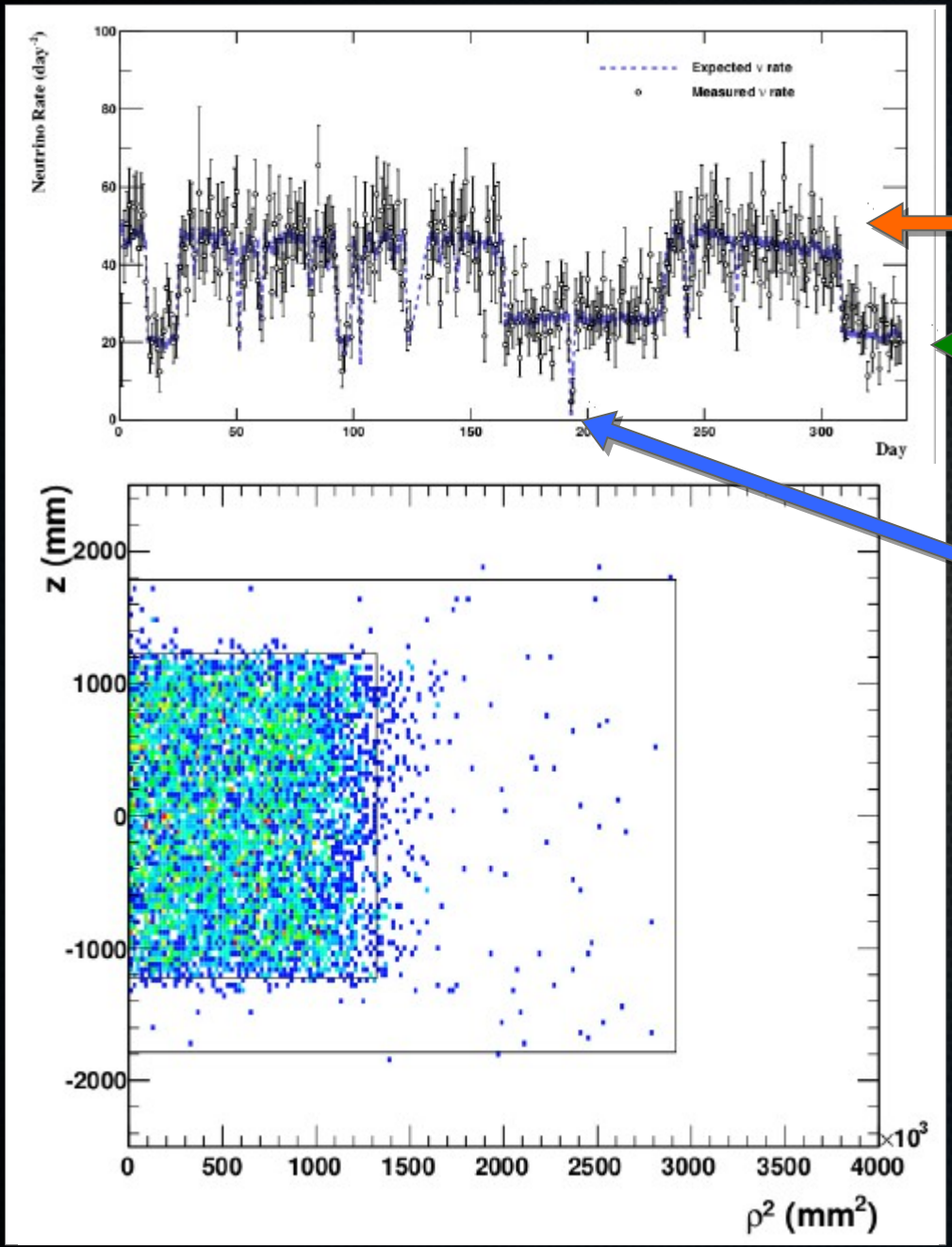
Multiplicity

- No extra events around signal (1600 μsec)

Further BG reduction

- No coincidence signal in OV
- ΔR < 90 cm





Gd selection
April 2011 – March 2012

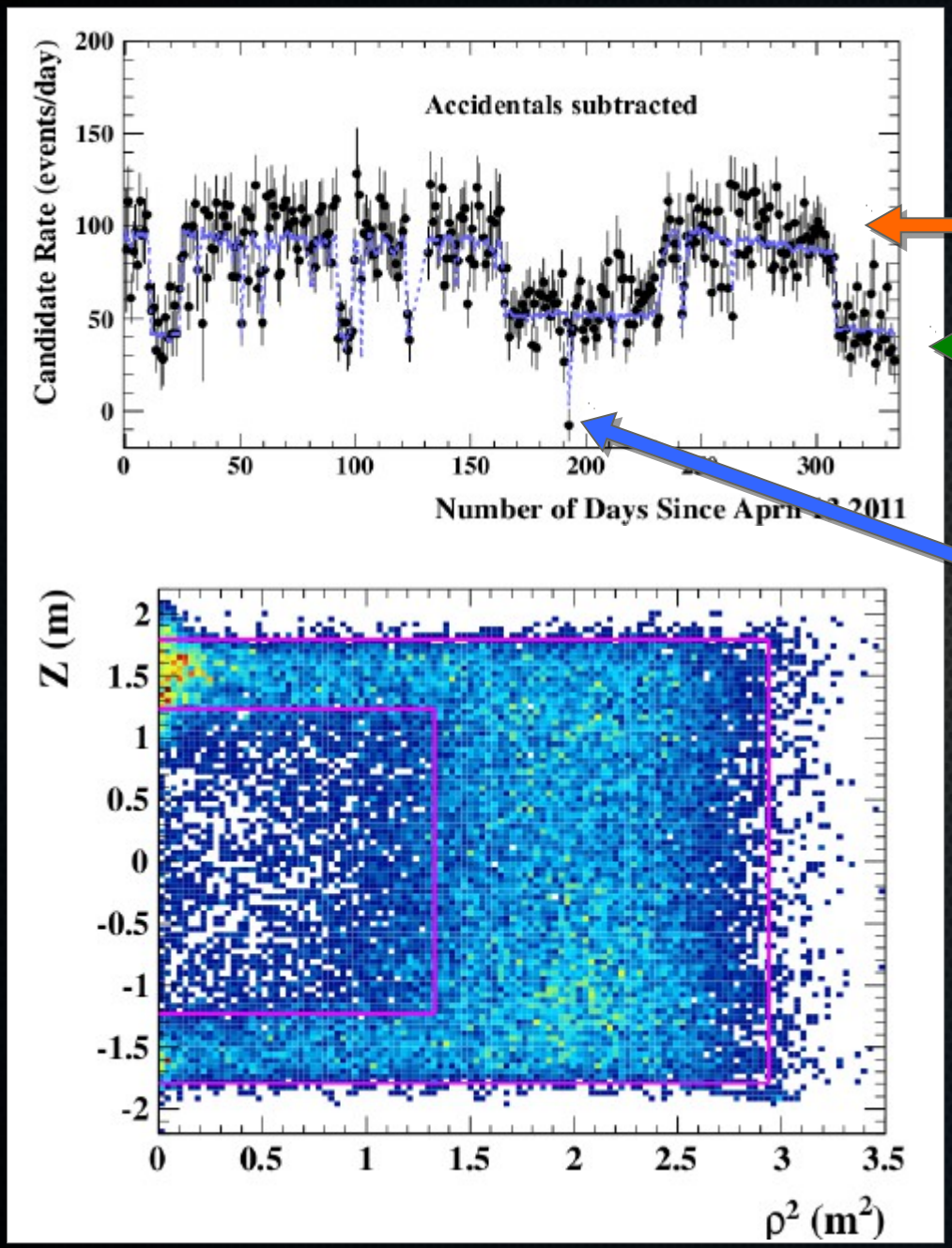
2 reactors on (~60%)

1 reactor on (~40%)

Both reactors off (~1 day)

Live time: 227.9 days
Candidates: 8,249

Expected for no-oscilation: 8,440



H selection
April 2011 – March 2012

2 reactors on (~60%)

1 reactor on (~40%)

Both reactors off (~1 day)

Live time: 240.1 days
Candidates: 36,284

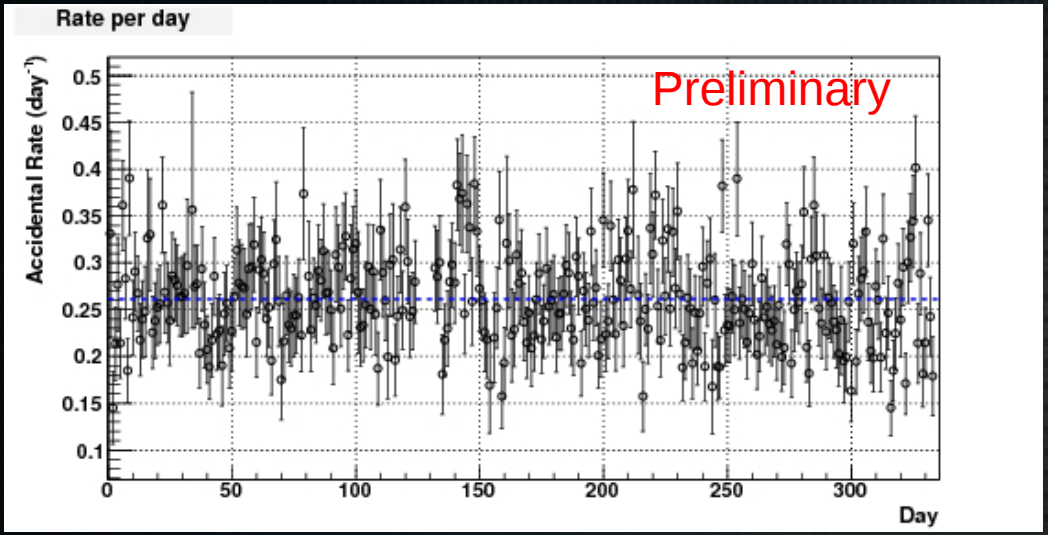
Expected for No-oscilation + Background: 36,680

Expected Background: 18,990

Background: accidental

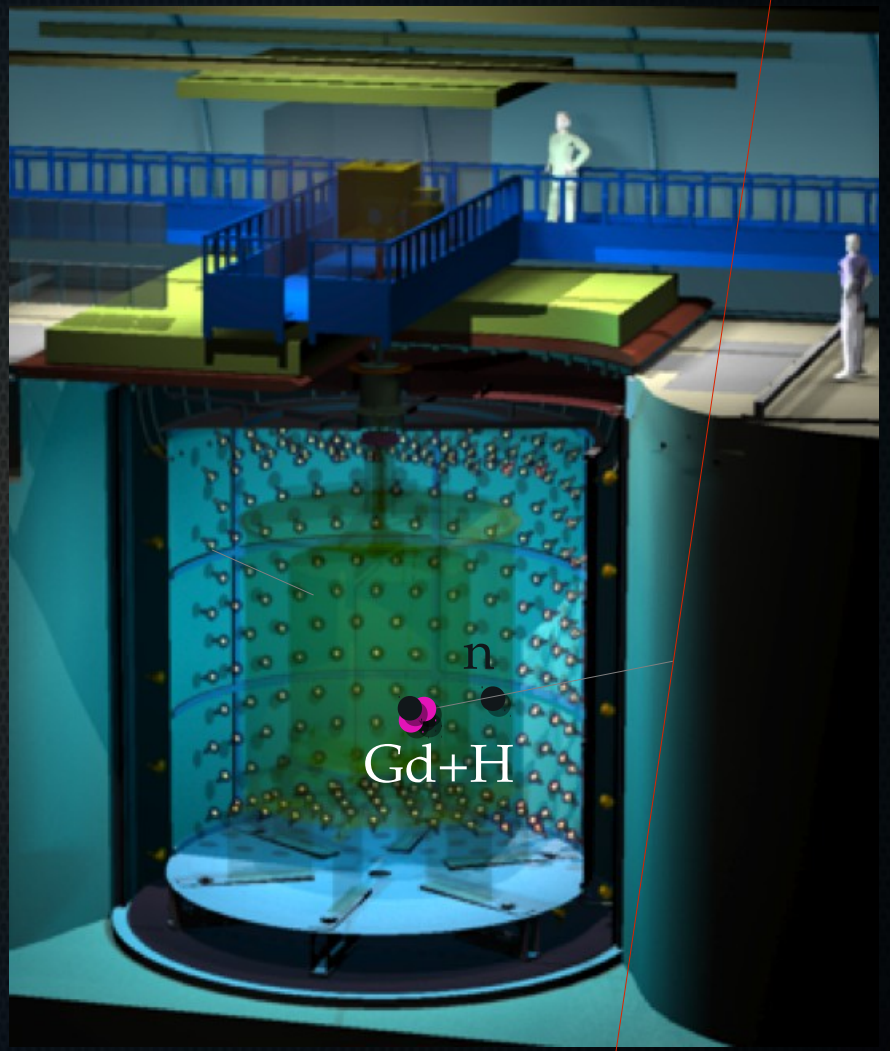
Accidental coincidence:

E.g. Environmental γ → Fast-neutron



BG estimated from coincidence in off-time window

- Gd: 0.261±0.002 event/day
- H: 73.5±0.2 event/day

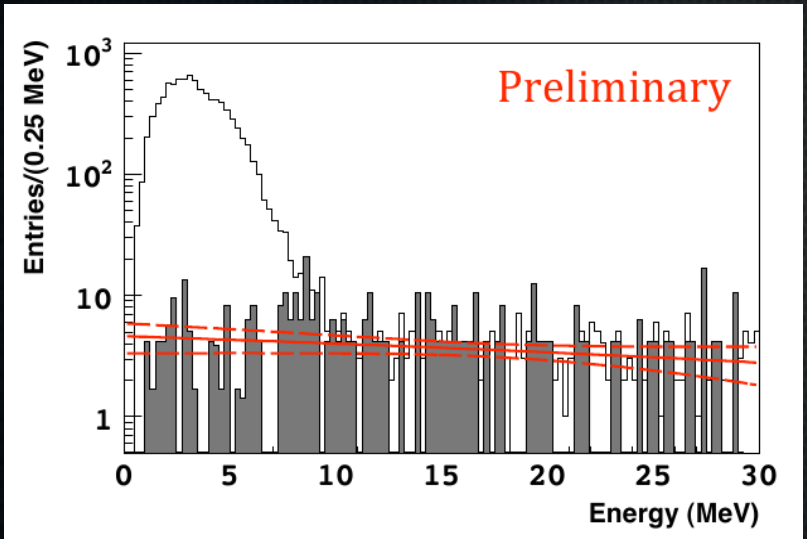


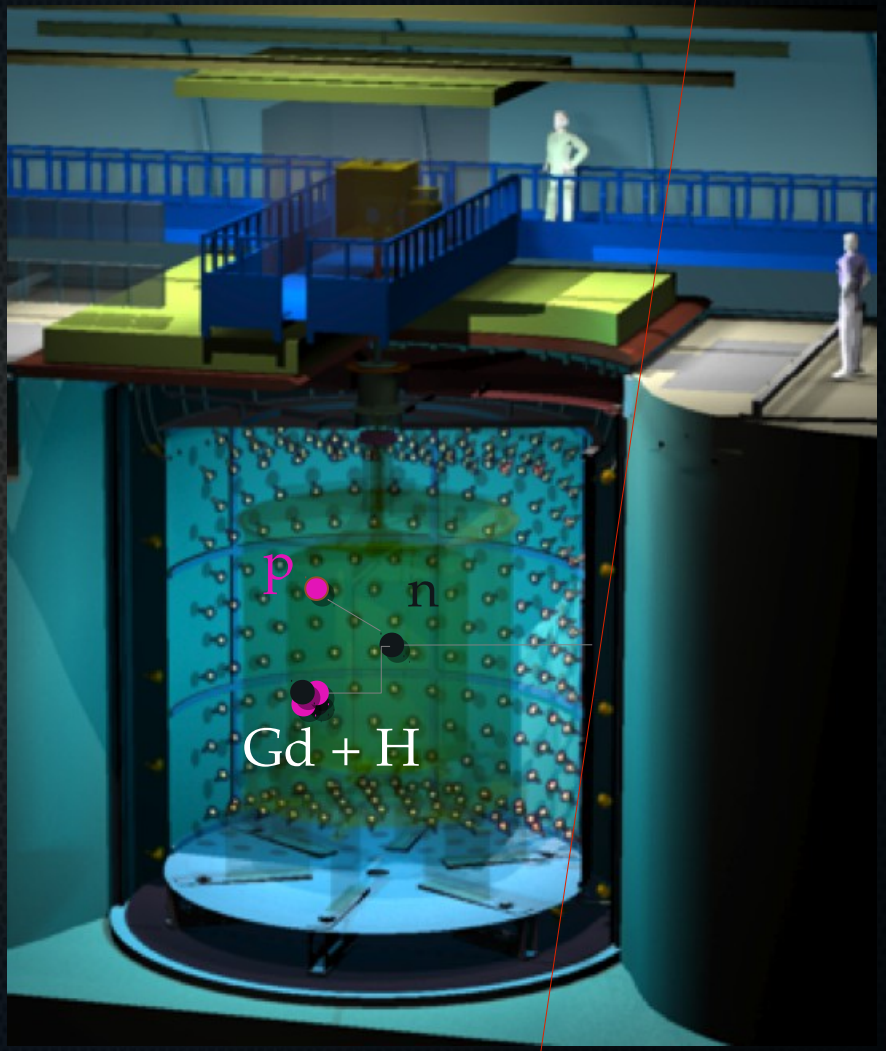
Background: fast neutron + stop μ

Correlated background:

Fast-n: recoils proton → captured on Gd+H

Stop μ: μ → delay (mostly tagged by OV)





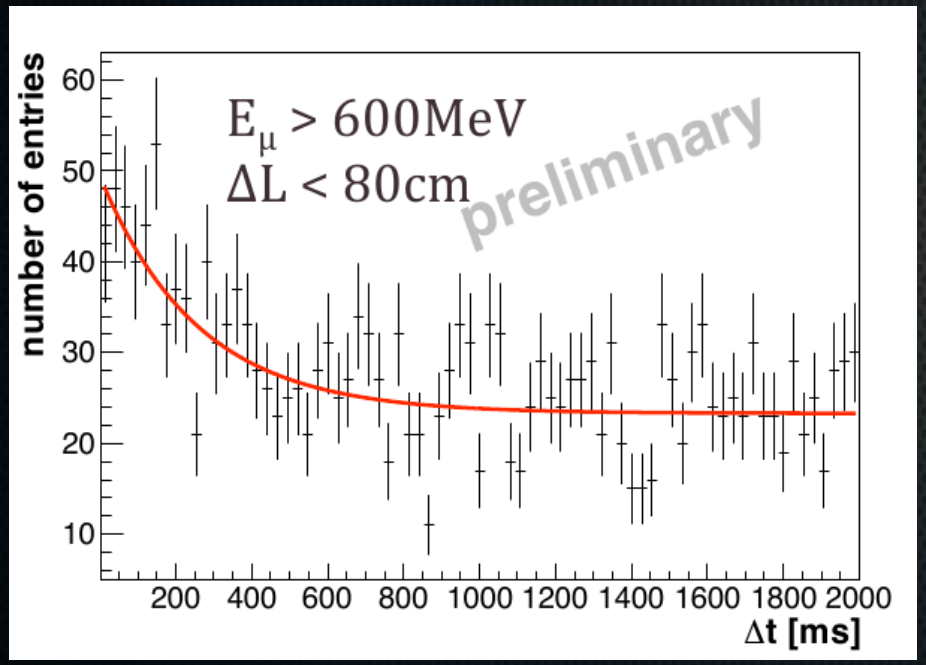
- BG estimated from IV and OV coincident events
- Gd: 0.7 ± 0.2 event/day
- H: 2.5 ± 0.5 event/day (all fast neutrons)

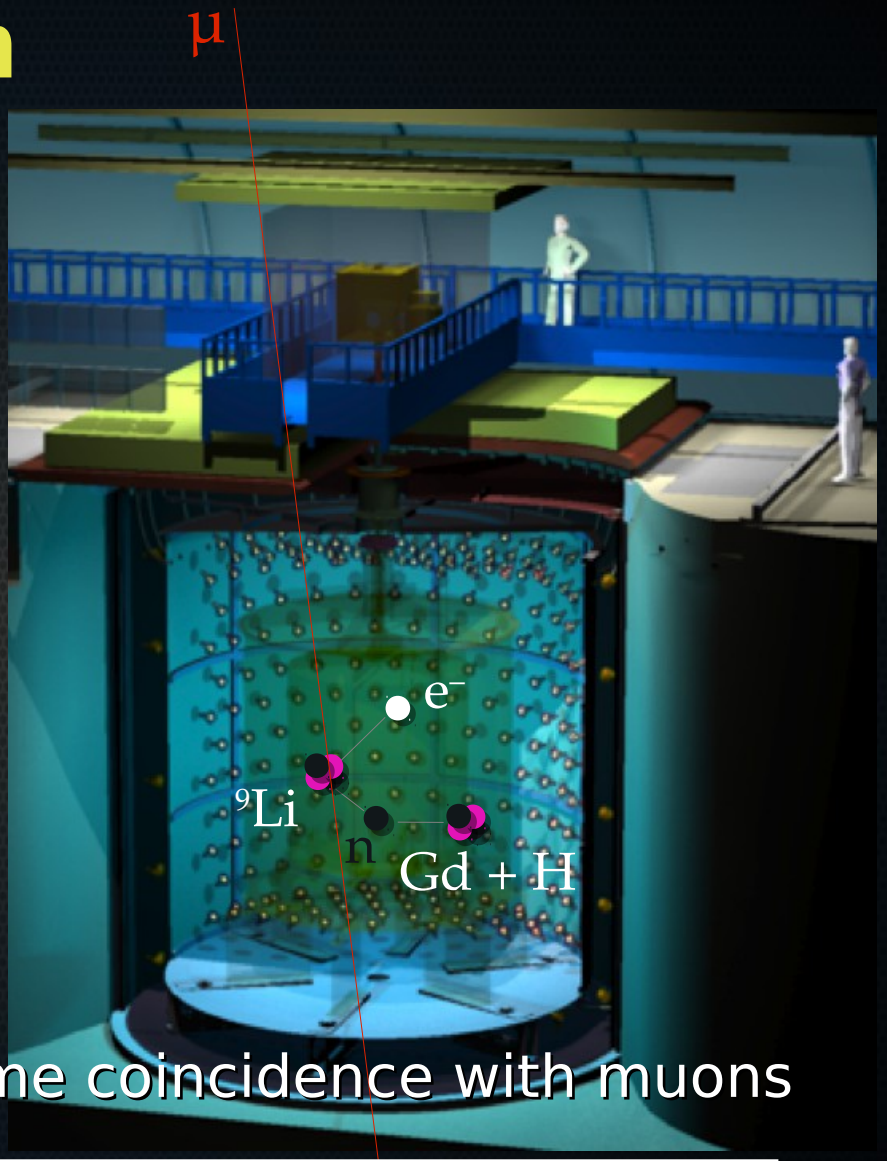
Background: 9-Lithium

Spallation products from muon:

$^{9}Li \rightarrow e^{-} + n + {}^{8}Be$

($\tau \sim 200$ msec)





- BG estimated from spatial and time coincidence with muons
- Gd: 1.3 ± 0.5 event/day
- H: 2.8 ± 1.2 event/day

Rates of 9 Li and FN + SM are further constrained in final fit.

Neutrino Reactor Simulation

Reactor neutrino flux calculation

Inverse β decay reaction (whole volume)

Detector simulation (Geant4 base)

Readout and trigger simulation

Neutrino yield per fission

$$N_\nu^{\exp}(E,t) = \frac{N_p \varepsilon}{4\pi L^2} \times \frac{P_{th}(t)}{\langle E_f \rangle} \times \langle \sigma_f \rangle$$

$$\langle \sigma_f \rangle = \langle \sigma_f \rangle^{Bugey} + \sum_k \left(\alpha_k^{DC}(t) - \alpha_k^{Bugey} \right) \langle \sigma_f \rangle_k$$

Bugey4 measurement as anchor point

Fission fraction in CHOOZ core

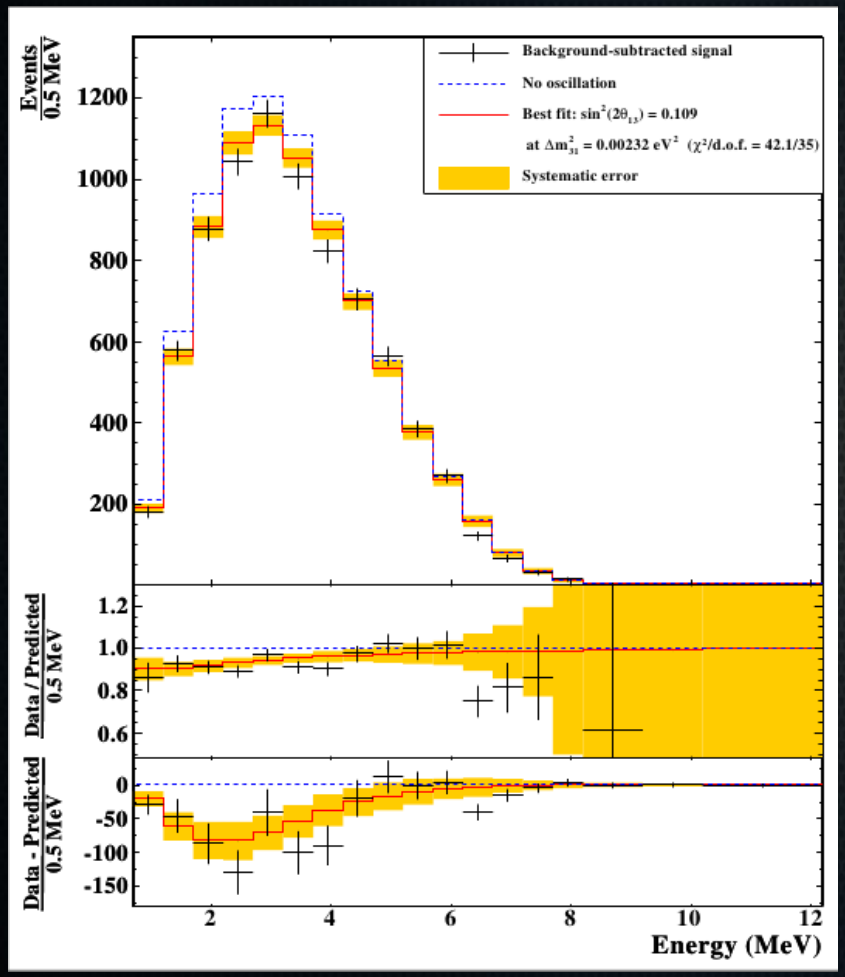
Uncertainty on neutrino flux suppressed using Bugey4 measurement

Normalized uncertainties (wrt signal):

Source	Gd selection	H selection
Reactor $\bar{\nu}_e$ flux	1.8%	1.8%
Efficiency	1.0%	1.6%
^{9}Li rate	1.5%	1.6%
Fast n + stopping μ rate	0.5%	0.6%
Accidentals rate	<0.1%	0.2%
Total statistical error	1.12%	1.08%

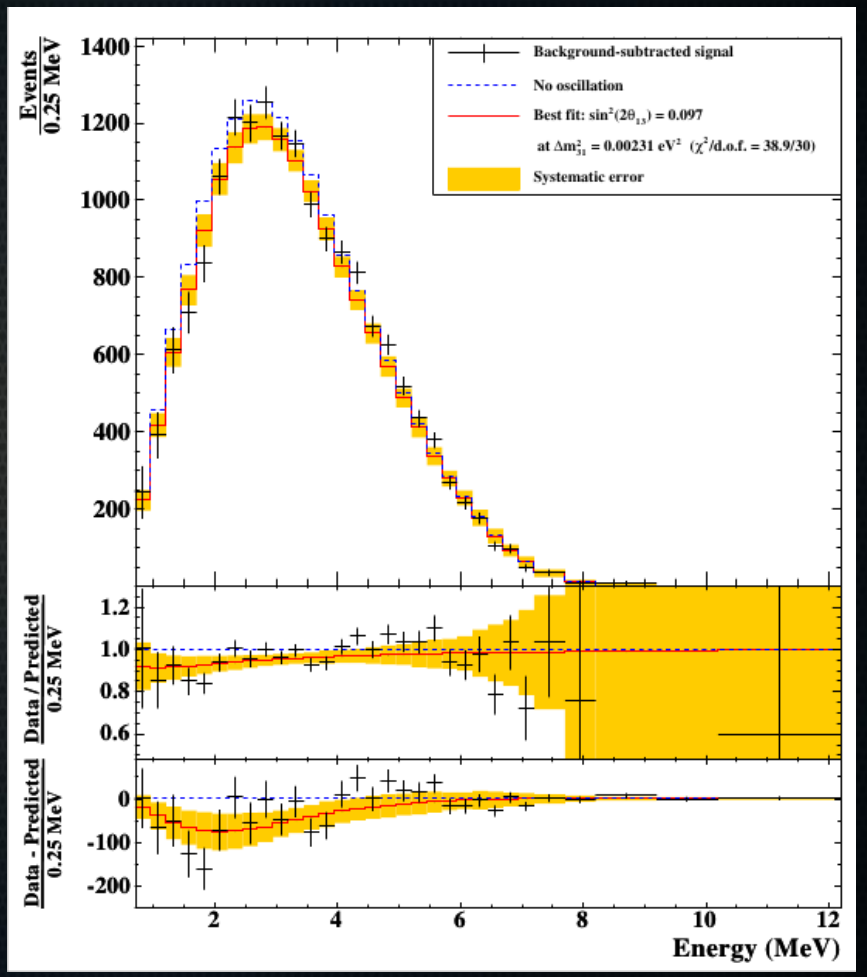
Published Results

Gd analysis, June 2012
Phys. Rev. D 86 (2012)



$\sin^2(2\theta_{13}) = 0.109 \pm 0.039$

H analysis, December 2012
Phys. Lett. B 723 (2013)



$\sin^2(2\theta_{13}) = 0.097 \pm 0.048$

Latest Results

7.5 days of data with both reactors off.
Phys. Rev. D. 87 (2013)

- **Unique Double Chooz capability**

- **Gd selection: 1.0 ± 0.4 day^{-1} with residual νe subtracted**
(expected 2.0 ± 0.6 day^{-1})

- **H selection: 11.3 ± 3.4 day^{-1} with residual νe and accidentals subtracted**
(expected 5.8 ± 1.3 day^{-1})

- **New constraint for oscillation fits**

Combined H + Gd fit

Same dataset, from April 2011 to March 2012, with background constrained by reactor-off measurements

Preliminary:

Rate only: $\sin^2(2\theta_{13}) = 0.107 \pm 0.045$ ($\chi 2/\mathrm{dof} = 6.1/3$)

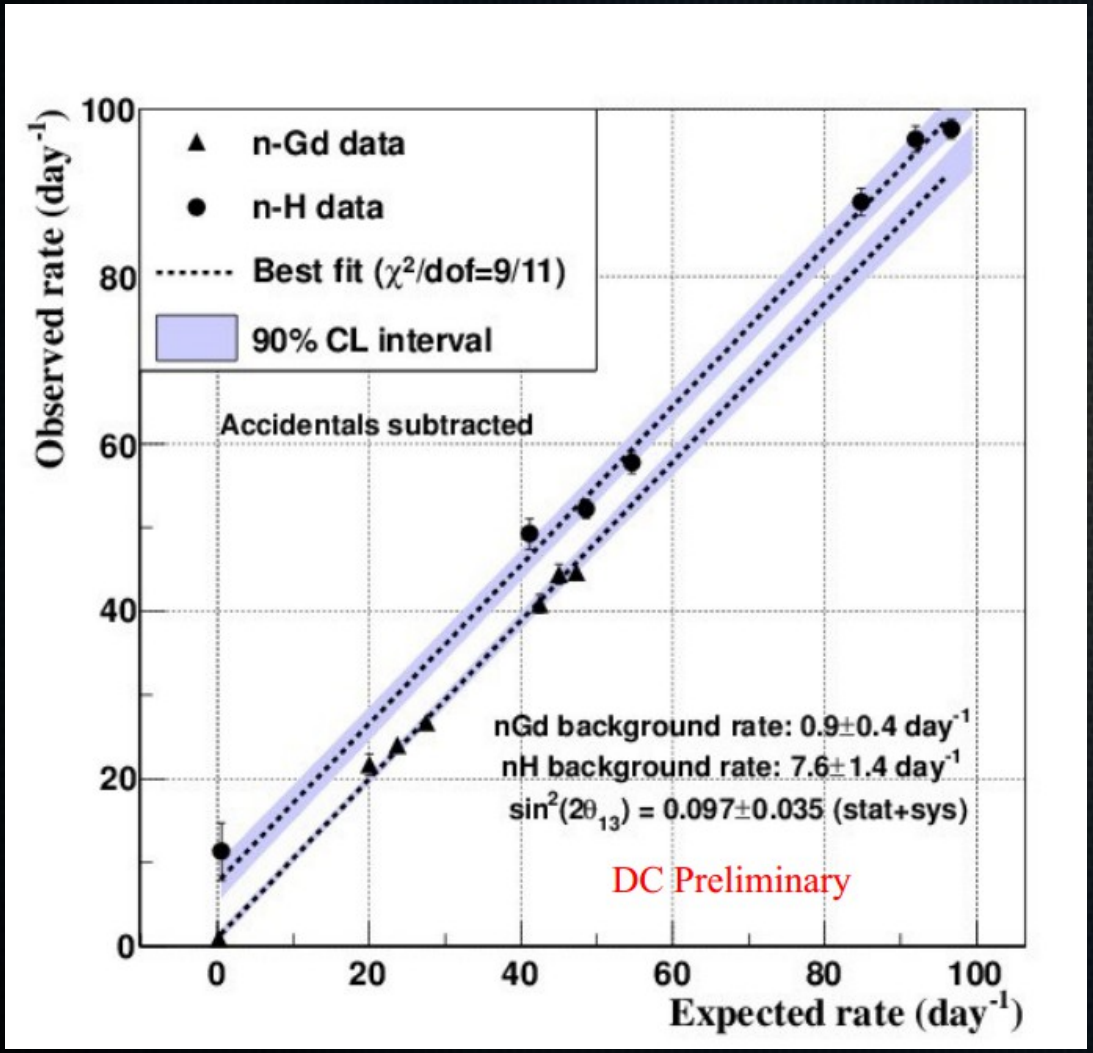
Rate + Shape: $\sin^2(2\theta_{13}) = 0.109 \pm 0.035$ ($\chi 2/\mathrm{dof} = 61.2/50$)

Last published Gd Result

$\sin^2(2\theta_{13}) = 0.109 \pm 0.039$

Gd analysis, June 2012
Phys. Rev. D 86 (2012)

Reactor Rate Modulation



RRM:
$\sin^2(2\theta_{13}) = 0.097 \pm 0.035$

Consistent with DC published results:
– Almost same precision;
– θ_{13} value and BG model confirmed;

Last published Gd Result

$\sin^2(2\theta_{13}) = 0.109 \pm 0.039$

Gd analysis, June 2012
Phys. Rev. D 86 (2012)

Future of Double Chooz

The Very Near Future

New far detector-only analysis by the end of 2013

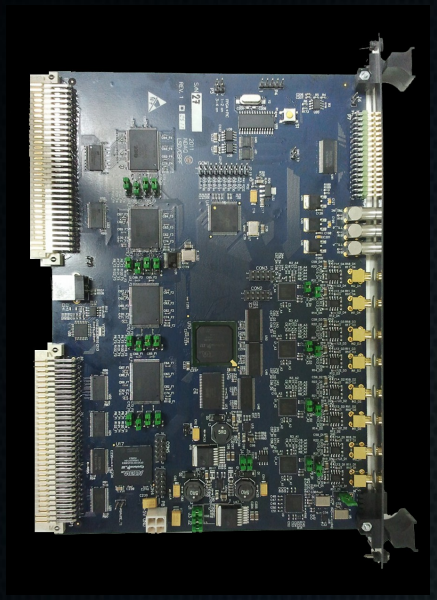
~ 2× more statistics (~490 live days) + optimized selection

Reduced systematic errors

The Near Future

- Upgraded DAQ + The Muon Electronics

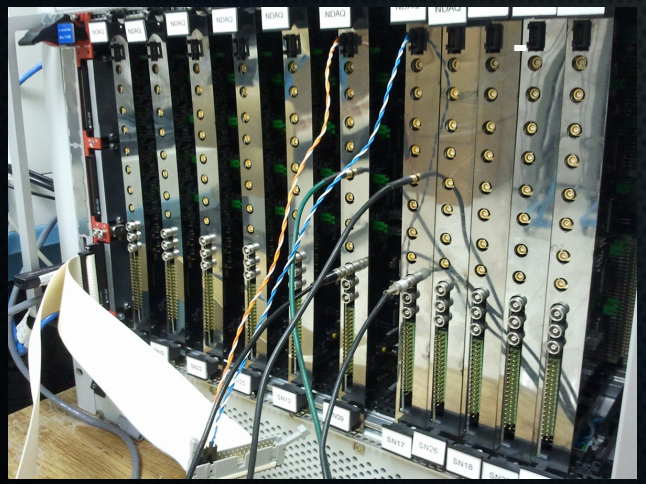
The Muon Electronics



- Designed and assembled in Brazil (Rio de Janeiro and Campinas);

- Each card consist in 8 fADCs (10bits, 125MHz) and 8 TDCs (81ps nominal, ~100ps jitter between cards);

- Working in parallel with the Neutrino Flash ADC, the MuE will digitilize high energy events (> 40MeV);



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- Better energy and track reconstruction for muons and, in special, muon spallation events;

- Better understanding on cosmogenic background.

And for 2014...

Future of Double Chooz

The Near Detector

Near detector will begin taking data in 2014.

Summary

- Improved analysis (~2x statistics) by end of 2013;
- Reactor-off analysis;
- New Gd + H Rate + Shape analysis;
- New Reactor Rate Modulation (RRM) analysis;
- Updated DAQ + Muon Electronics soon!
- Near detector taking data in 2014!

Rate only: $\sin^2(2\theta_{13}) = 0.107 \pm 0.045$ ($\chi 2/\mathrm{dof} = 6.1/3$)

Rate + Shape: $\sin^2(2\theta_{13}) = 0.109 \pm 0.035$ ($\chi 2/\mathrm{dof} = 61.2/50$)

RRM: $\sin^2(2\theta_{13}) = 0.097 \pm 0.035$

Thank you very much!