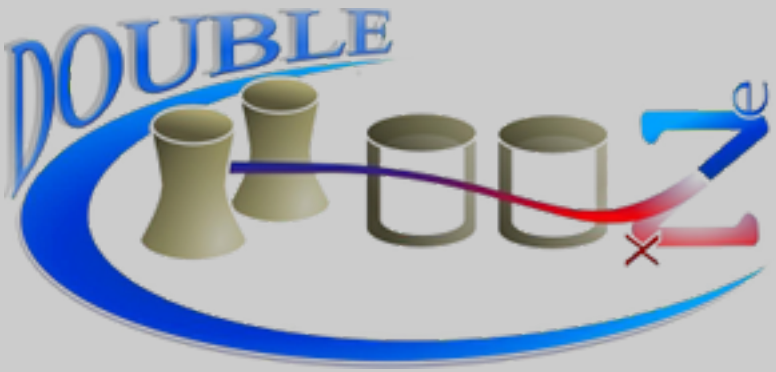


The Double Chooz experiment @CCIN2P3

February 9th –CCIN2P3 –Lyon

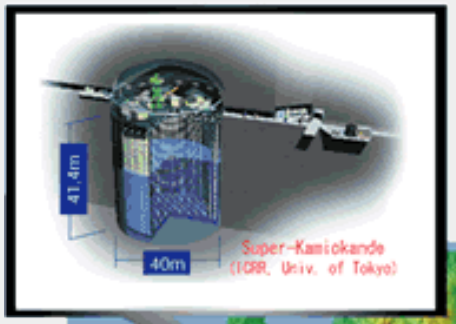
Timothée Brugière
IPHC

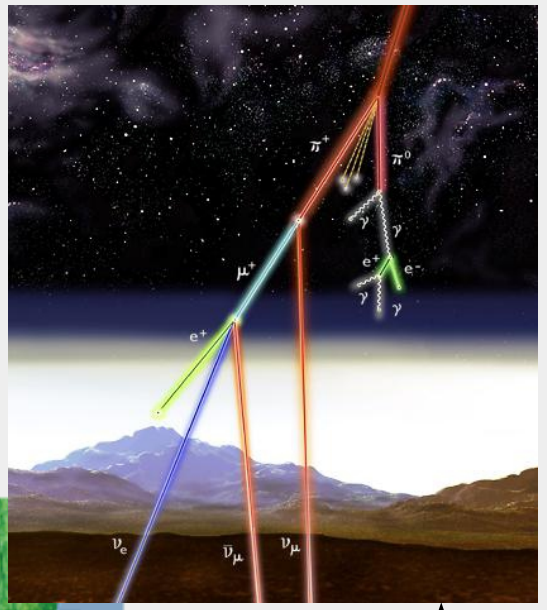
cnrs dépasser les frontières IN2P3 Les deux infinis

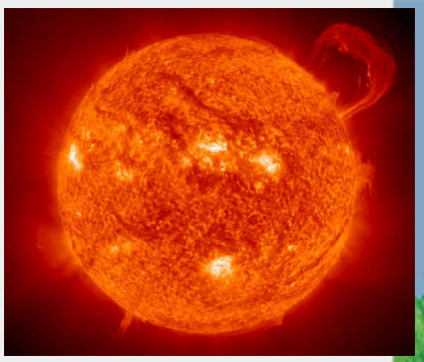
IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

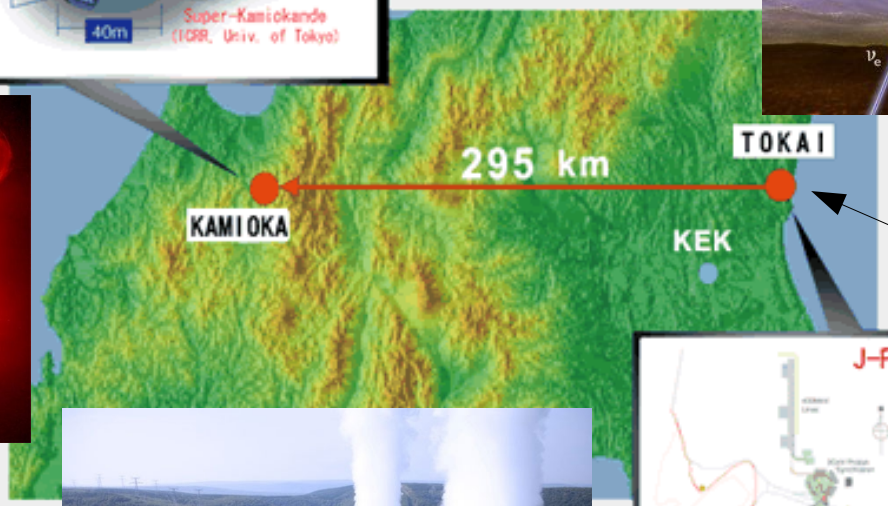
Measuring the oscillation

$\nu_\alpha \xrightarrow[L]{E_\nu} \nu_\beta$









Δm^2_{atm} , θ_{atm}

Δm^2_{sol} , θ_{sol}

$\Delta m^2_{ij} = m^2_i - m^2_j$

Exploring the neutrino mixing

$$\nu_{\alpha L} = \sum_i U_{\alpha i} \nu_{iL}$$

Oscillation parameters :

→ θ_{12}, θ_{13}, θ_{23}

→ Δm^2_{21}, Δm^2_{31}

→ δ_{CP}

Oscillation physics

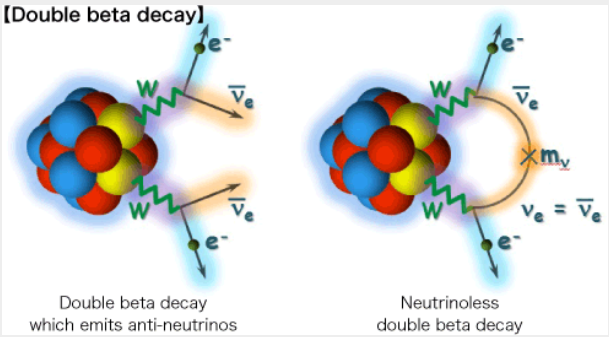
$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{21} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix}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

Atmospheric sector | **Interference sector** | **Solar sector**

$c_{ij} = \cos \theta_{ij}$

$s_{ij} = \sin \theta_{ij}$

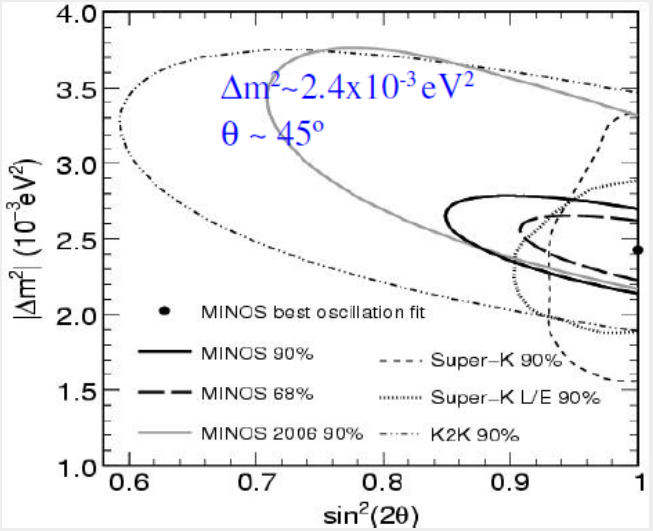
0νββ



Neutrino oscillations

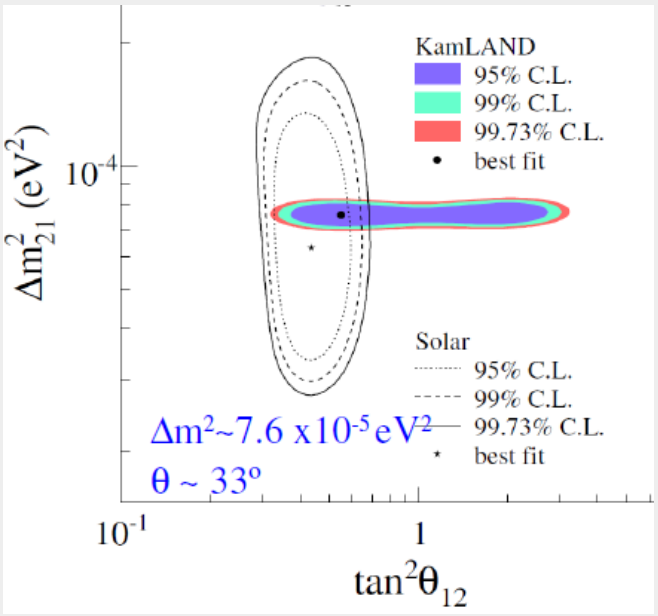
Experimental results :

- $|\Delta m^2_{atm}|$, θ_{atm} → Minos and Super-K
- Δm^2_{sol}, θ_{sol} → Kameland and solar data



$\theta_{13} \sim 8.5°$

Double Chooz, Daya-Bay, Reno
+ accelerators



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

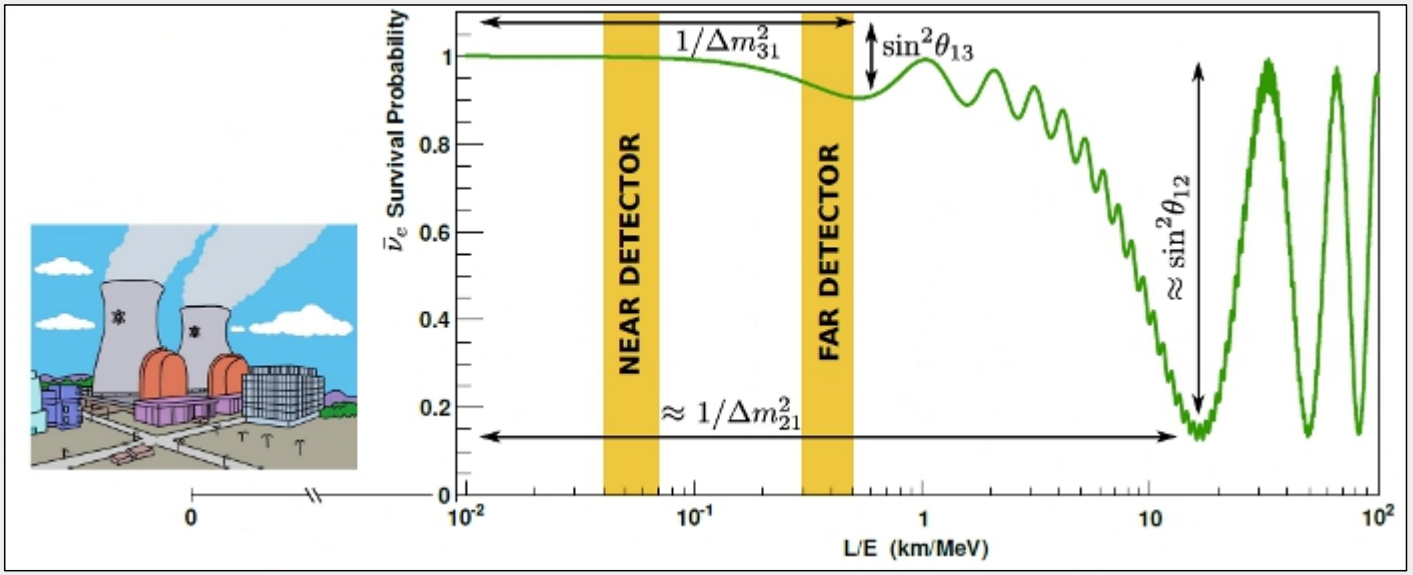
The Double Chooz experiment

Aim of the Double Chooz experiment:

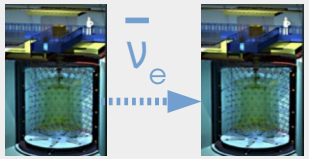
→ Measurement of θ_{13} through the observation of $\bar{\nu}_e \rightarrow \bar{\nu}_e$ transition according to the oscillation probability :

$$P_{\bar{\nu}_e \rightarrow \bar{\nu}_e} = 1 - \sin^2(2\theta_{13}) \sin^2\left(\frac{\Delta m^2_{31} L}{4\,E}\right) + O(10^{-3}) \quad \text{for } L/E \lesssim 1$$

- **Reactors:** Pure $\bar{\nu}_e$, low energy, high intensity (10^{21} $\bar{\nu}_e$/s), "Cheap"
- **Short baseline** (~ 1km) **:** no matter effect

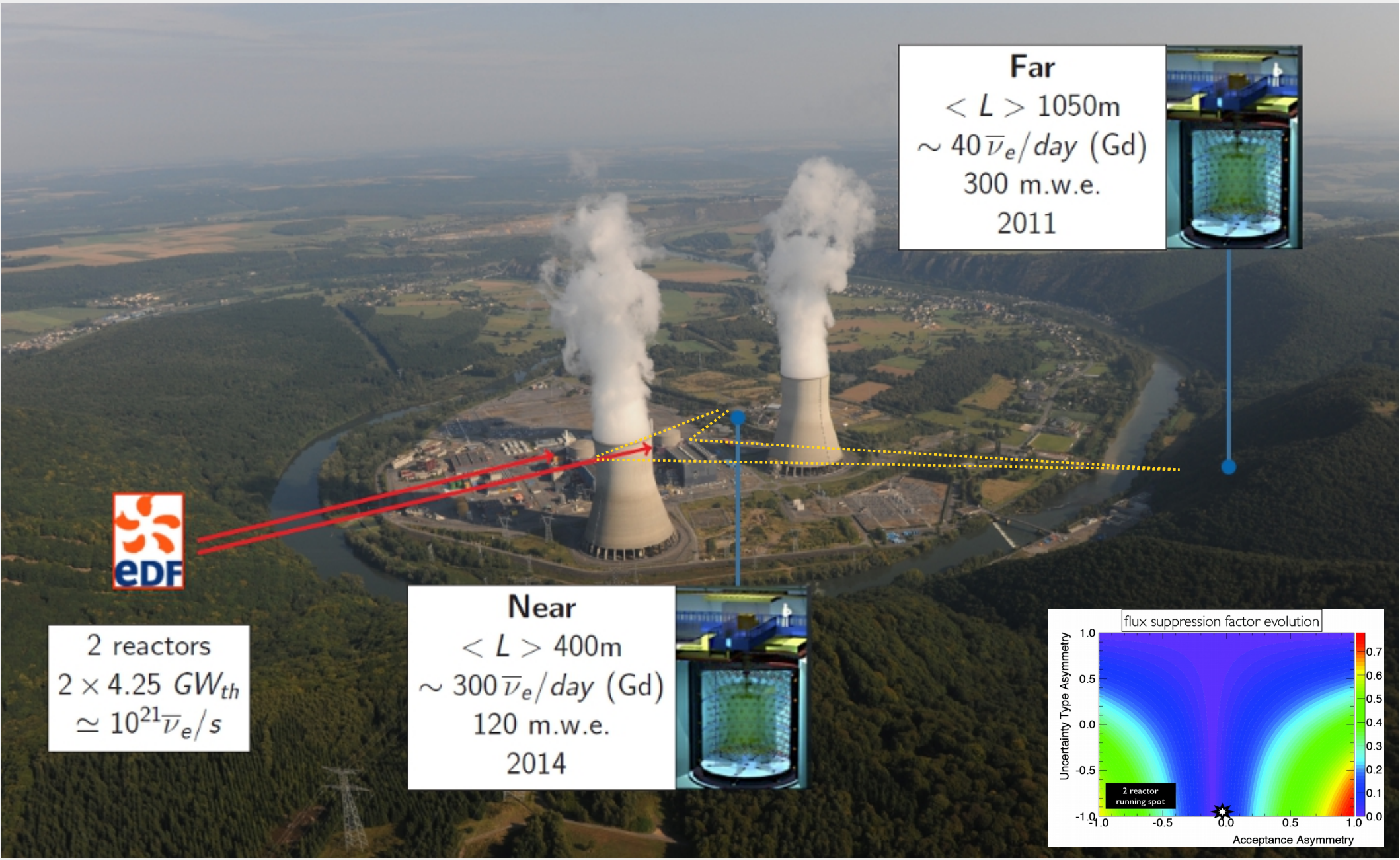


Unoscillated flux & spectrum
→ Cancel flux and efficiency uncertainties



Oscillated flux & spectrum
→ θ_{13} measurement

Power plant @ Chooz (France)



Double Chooz collaboration

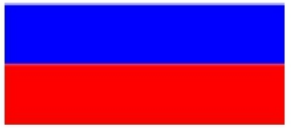
Brazil
CBPF
UNICAMP
UFABC

France
APC
CEA/DSM/IRFU
- SPP
- SphN
- SEDI
- SIS
- SENAC

CNRS/IN2P3
- SUBATECH
- IPHC

Germany
EKU Tübingen
MPIK
Heidelberg
RWTH Aachen
TU München
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

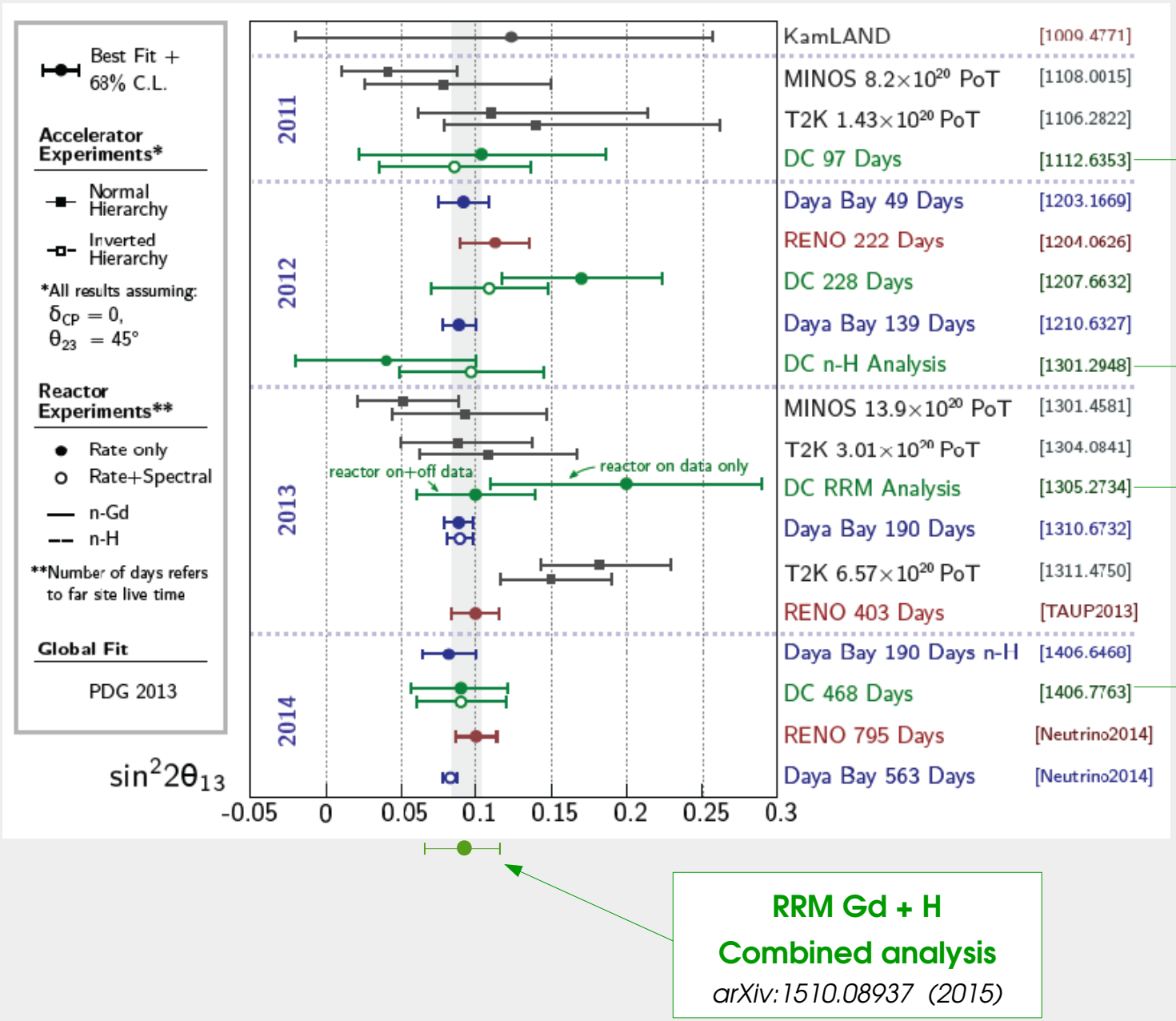
USA
U. Alabama
ANL
U. Chicago
Columbia U.
UCDavis
Drexel U.
IIT
KSU
LLNL
MIT
U. Notre Dame
U. Tennessee

Spokesperson:
H. de Kerret (IN2P3)

Project Manager:
Ch. Veyssière (CEA-Saclay)

Web Site:
www.doublechooz.org/

Double Chooz Milestones



First indication of non-zero θ_{13} and Rate+Shape analysis
Phys. Rev. Lett. 108 (2012) 131801

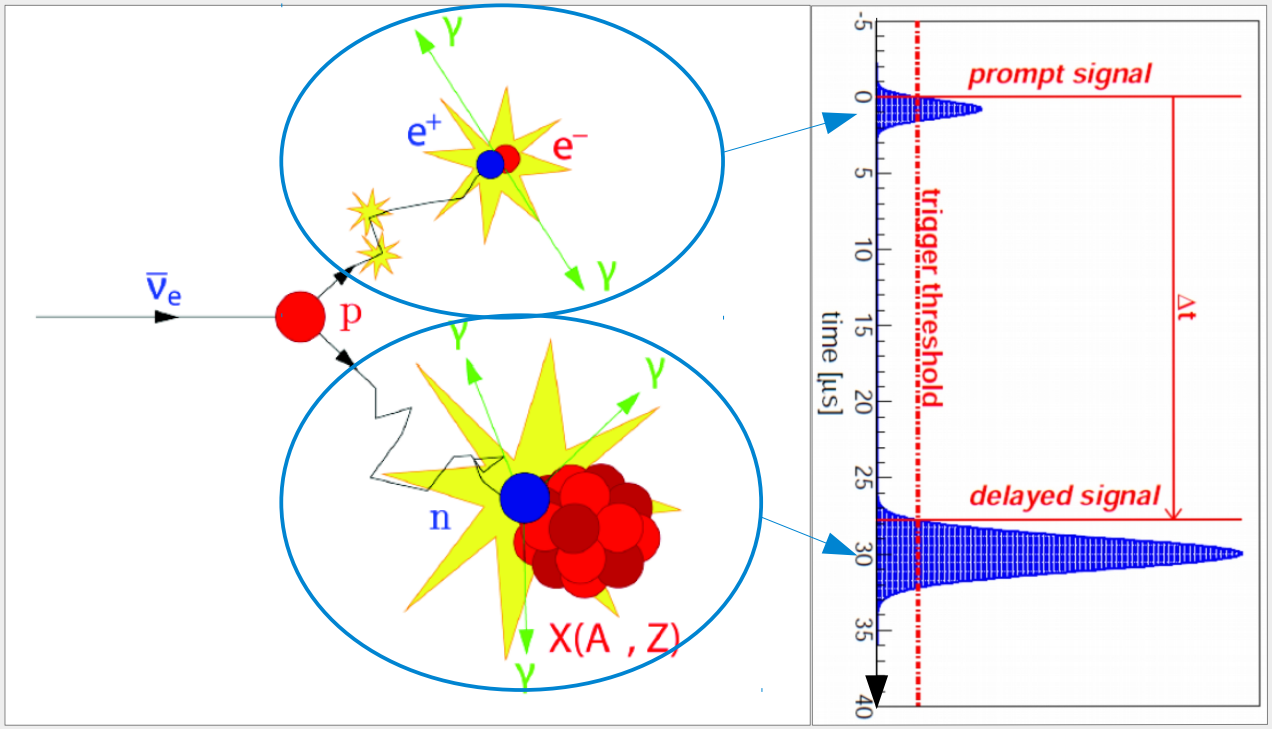
First n-H capture analysis
Phys. Lett. B723 (2013) 66-70

First (and only) Reactor Rate Modulation (RRM) analysis
Phys. Lett. B735 (2014) 51-56

First publication on the 5 MeV excess"
JHEP 1410 (2014) 86

RRM Gd + H Combined analysis
arXiv:1510.08937 (2015)

Inverse β decay (IBD)



Prompt signal:

- e^+ ionization and annihilation
- Energy proportional to E_ν

  → $\mathbf{E_{prompt} = E_\nu}$ - E_n - 0.8 MeV

  10-40 keV

Delayed signal:

- γ rays from neutron capture

  → on **Gd : 8 MeV / τ ~ 30μs**

  → on **H : 2.2 MeV / τ ~ 200μs**

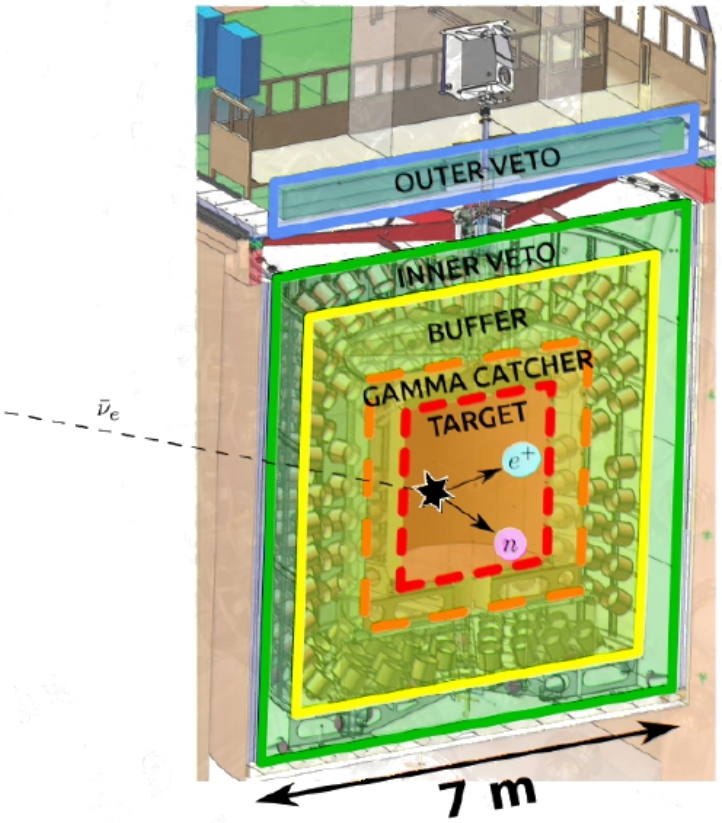
➡ **Clear twofold coincidence signature**

Neutrino detection in Double Chooz

$$\bar{\nu}_e + p^+ \longrightarrow e^+ + n$$

prompt signal: scintillation + e^+ annihilation
Eprompt ≈ E(νe) - 0.8 MeV

delayed signal: γ ray(s) from neutron capture
n-Gd Edelayed ≈ 8.0 MeV ΔT ≈ 30 μs
or n-H Edelayed ≈ 2.2 MeV ΔT ≈ 200 μs



Neutrino target:
liquid scintillator PXE + Gd

Gamma catcher:
liquid scintillator PXE (no Gd)

Buffer volume:
transparent mineral oil
with 390 x 10" PMTs assembly

→ **398 PMTs**

Inner Veto:
liquid scintillator (LAB)
with 78 x PMTs 8"

→ **78 PMTs**

Outer Veto:
plastic scintillator strips

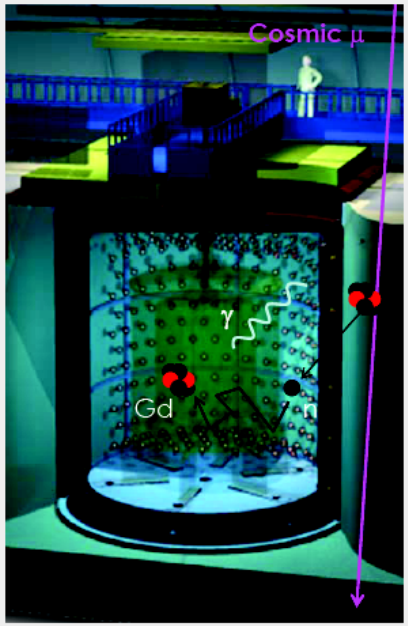
- **IBD threshold** : 1.8 MeV
- **Shielding** : Far → 150 mm of steel
  Near → 1 m of water

Data:

- 1 Waveform:
→ 128 * sizeof(double)
- 1 event:
→ ~ 0.5 Mo

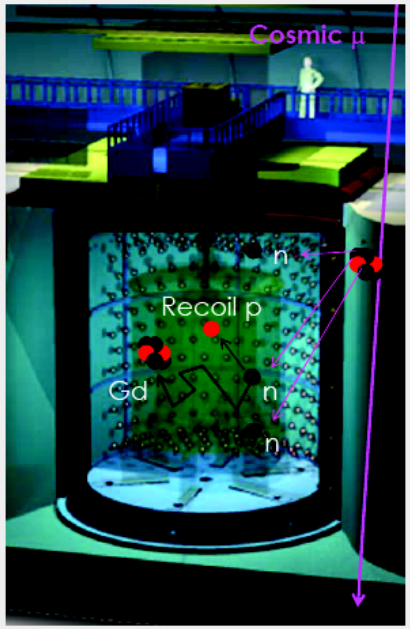
Background

Accidental BG

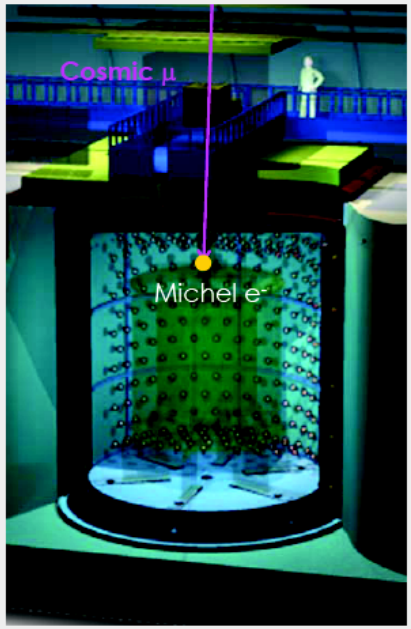


Correlated BG

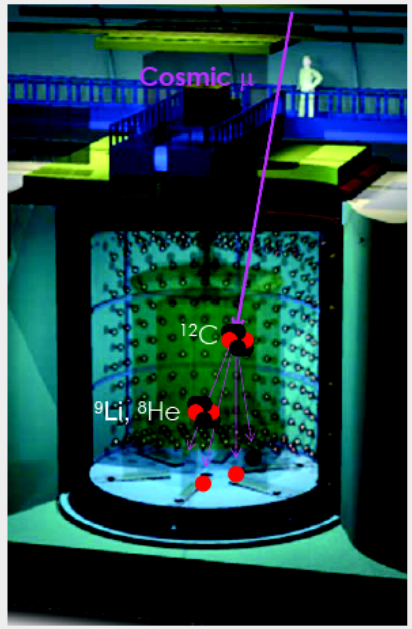
Fast neutrons



Stopping μ



Cosmogenics



	Accidental BG	Correlated BG: Fast neutrons	Correlated BG: Stopping μ	Correlated BG: Cosmogenics
Prompt	Radioactivity from materials, PMTs, surrounding rock (^{208}Tl).	Neutrons from cosmic μ spallation gives recoil protons (low energy).	Cosmic μ entering from the chimney.	Electrons from ^{9}Li/^{8}He β + n decays.
Delay	Neutrons from cosmic μ spallation captured on Gd/H, or γ like prompt fake signal in case of H analysis.	Neutrons from cosmic μ spallation captured on Gd/H, or γ like prompt fake signal in case of H analysis.	Michel electrons.	Neutrons from ^{9}Li/^{8}He β + n decays captured on Gd/H.

Candidates Selection

- **Single event selection:**

	n-Gd analysis	*n-H analysis*
After-μveto	1 ms	1.25 ms
Others	Light noise rejection	

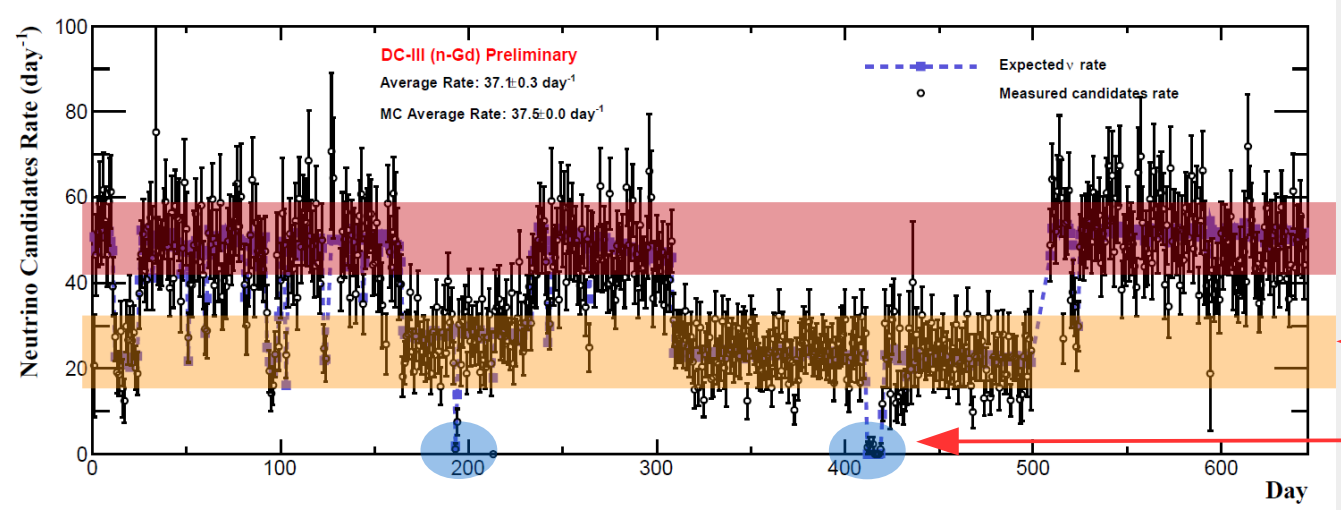
- **IBD selection:**

E_{prompt} window	0.5 –20 MeV	1 –20 MeV
$E_{delayed}$ window	4 –10 MeV	1.3 –3 MeV
Multiplicity cut (prompt)	200 μs before → 600 μs after	800 μs before → 900 μs after
Other vetos	OV, IV, FV, ^{9}Li likelihood	
Isolation (prompt-delayed)	$0.5 < \Delta T_{p \to d} < 150$ μs	$0.5 < \Delta T_{p \to d} < 800$ μs
	$\Delta R_{p \to d} < 1$ m	$\Delta R_{p \to d} < 1.2$ m
ANN		ANN output > -0.23

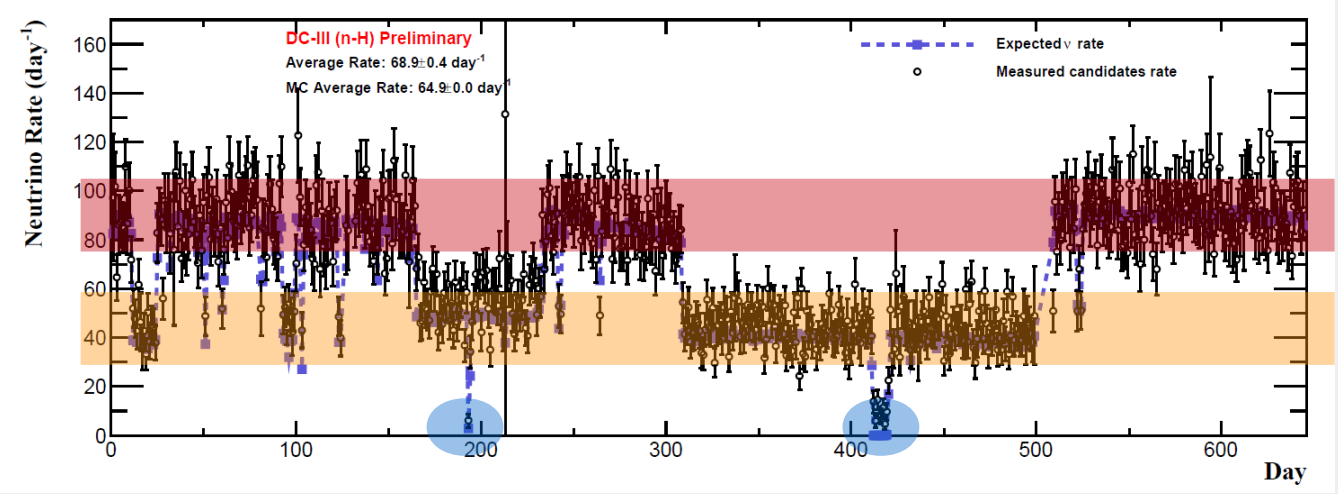
→ **All analysis done @CCIN2P3 !**

Neutrino Data

- **Gd analysis:** 460.67 days with reactors / 7.24 days 2-reactors off

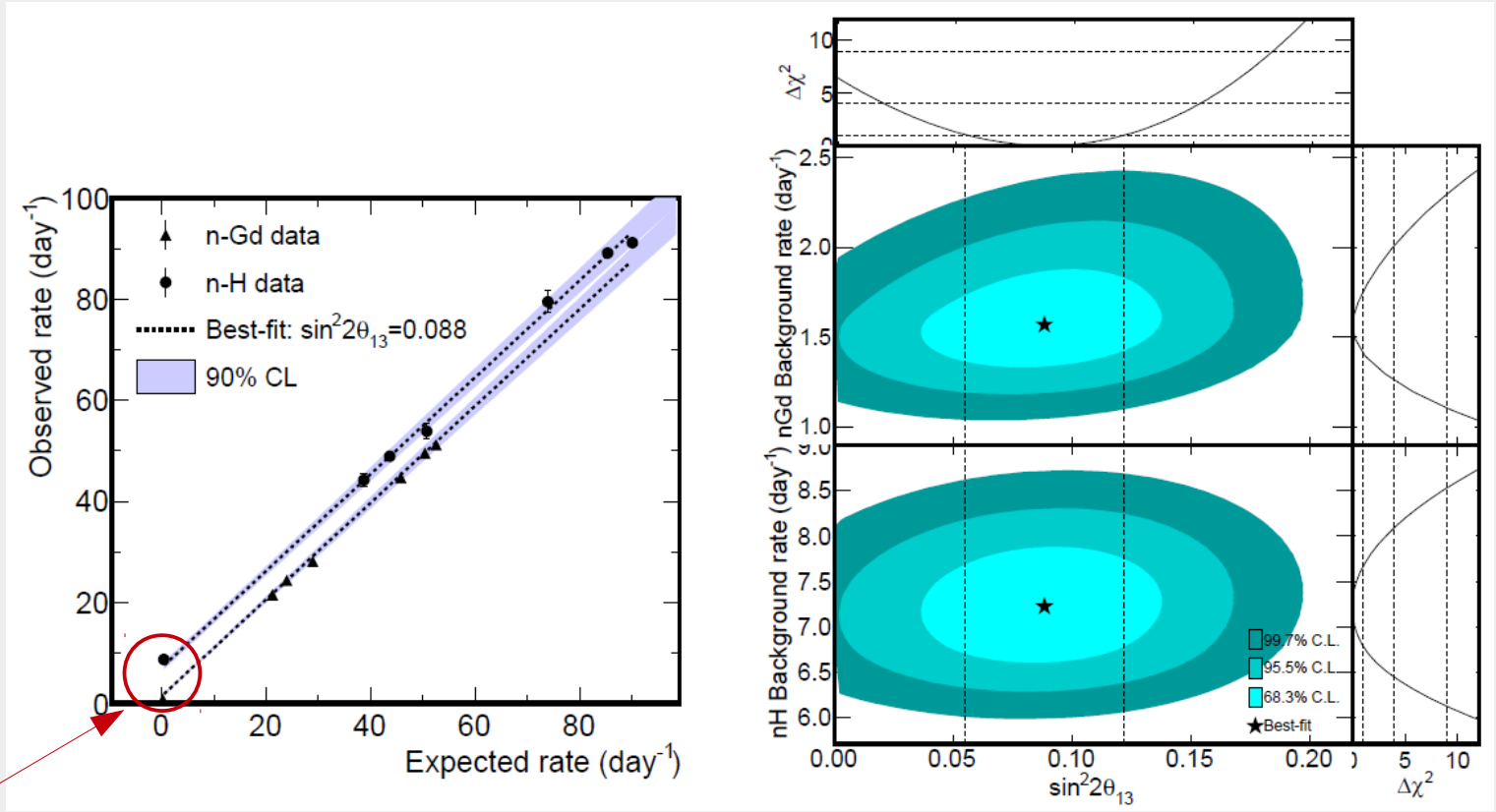


- **H analysis:** 455.57 days with reactors / 7.15 days 2-reactors off



Reactor Rate Modulation (RRM)

- **Gd+H combined analysis :**
  → Compare observed and expected IBD rate at different reactor powers
  → Fit θ_{13} and **total background** rate



Unique 2-reactor off data

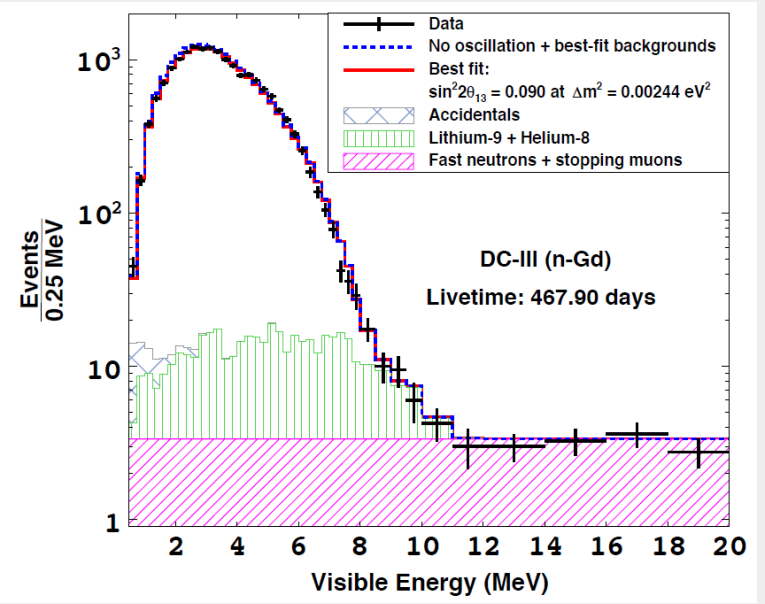
$$\sin^2 2\theta_{13} = 0.088 \pm 0.033$$

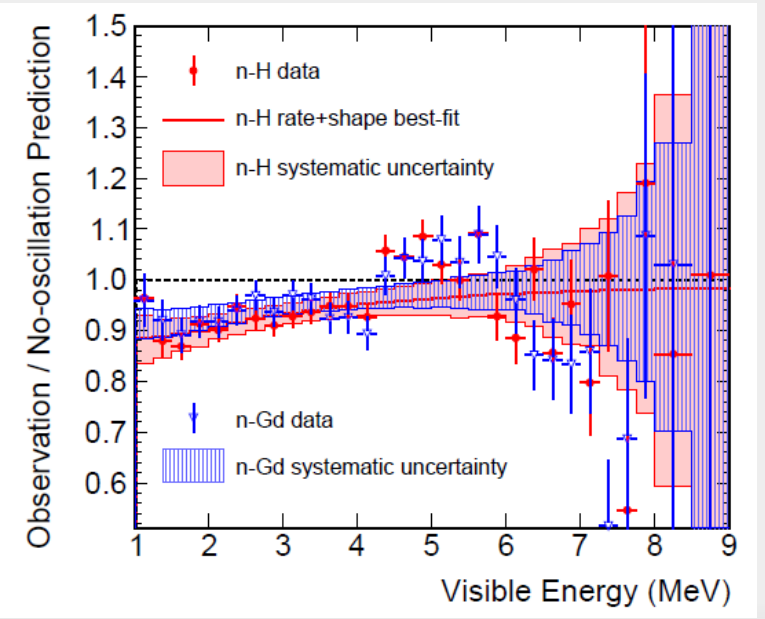
No correlation assumed (minimal impact)

Rate + Shape fit

- The rate and the shape information were used in the fit for θ_{13} measurement

- The major improvements with respect to previous analyses are:
  - Finer binning (more statistics)
  - Larger energy range (0.5 –20 MeV)
    → more precision on the background
  - Data driven background shape
  - Reactor off-off data included as a separate term in the χ^2 (low stat → rate only)





Results:

On Gd

$$\sin^2 2\theta_{13} = 0.090^{+0.032}_{-0.029}$$

arXiv:1406.7763 (hep-ex)

On H

$$\sin^2 2\theta_{13} = 0.124^{+0.030}_{-0.039}$$

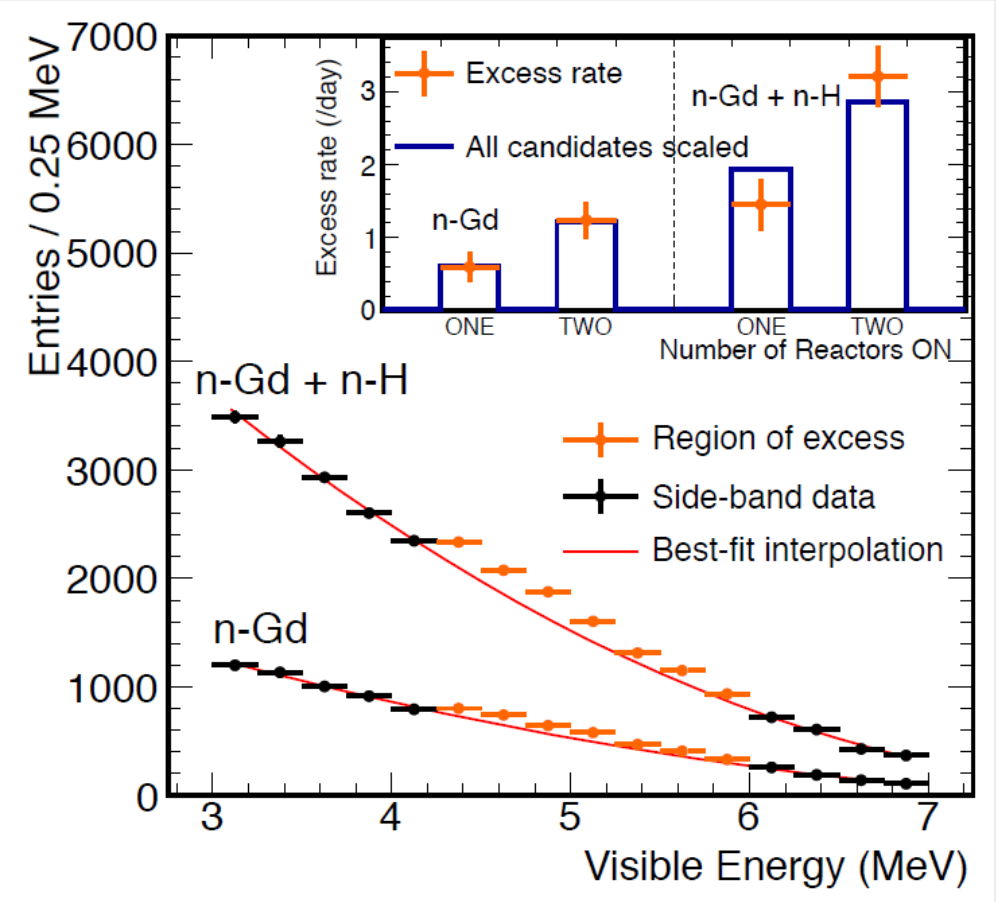
arXiv:1510.08937 (hep-ex)

Excess @ 5 MeV

- On Gd : excess ~ 3σ
  (computation on-going for H)

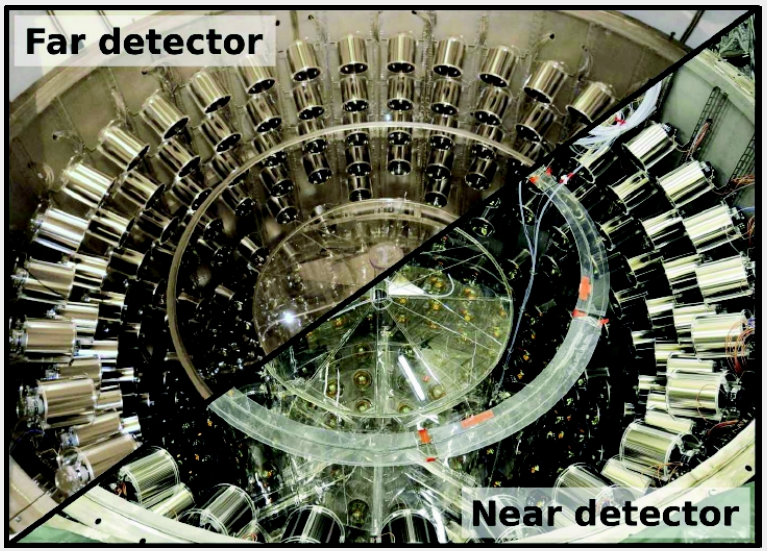
- Given the results of RRM + the tests with addition artificial excess around 5 MeV:
  → **no impact** seen **on θ_{13}** measurement

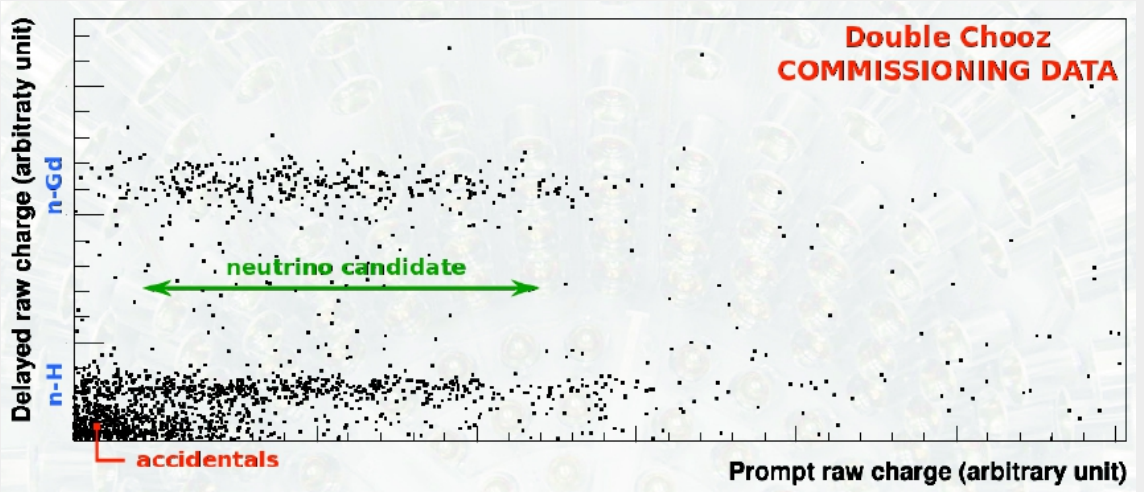
- The strong correlation of the excess with the reactor power (in both Gd and H):
  → **points** indeed towards an **unaccounted component of the reactor flux**
  → **disfavors** the possibility of an **unaccounted background component**

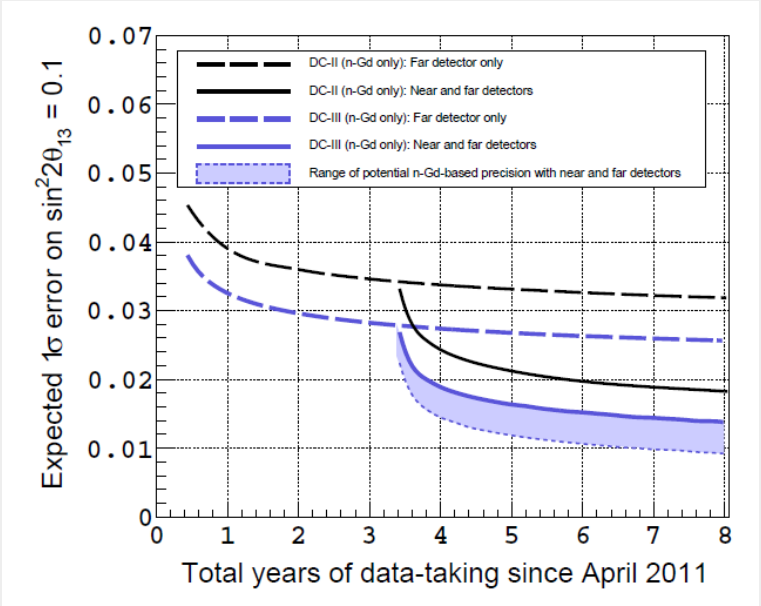


(From Gd 2014 analysis, uses a simplified n-H selection)

Future with Near+Far data







- The near detector commissioning ended in December 2014 and the **data taking has started**
- The projected sensitivity shows an error on $\sin^2 2\theta_{13}$ of 0.015 in 3 years
- Further analysis improvements will make possible a reduction to the level of $\sigma \sim 0.01$

➡ **New results coming soon !**

But also more data !

Dynamic Data Reduction (DDR)

Near Detector = More Data !

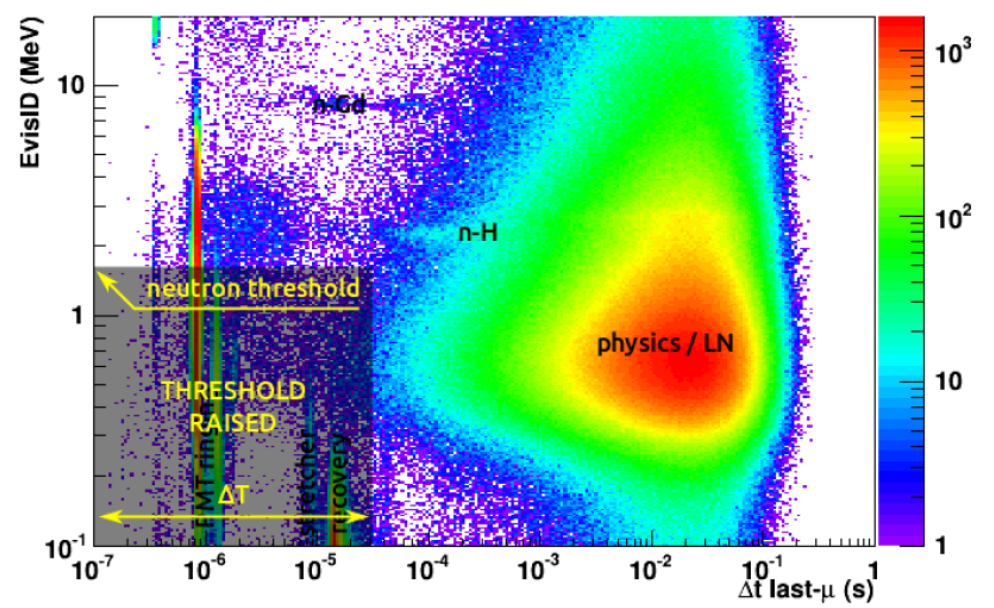
→ Muon flux higher @ Near
(less overburden)

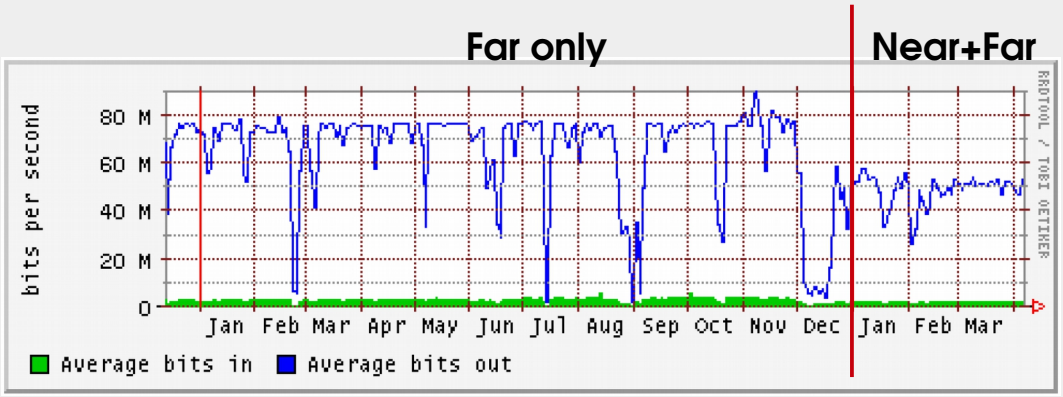
→ "Light Noise"@ Far
(PMT radioactivity)

Dynamic Data Reduction:

→ Online cuts:
- 75% of the LN events removed
- reduced data for μ and after-μ event

→ Threshod raised after a muon
- avoid ghost trigger, PMT ringing

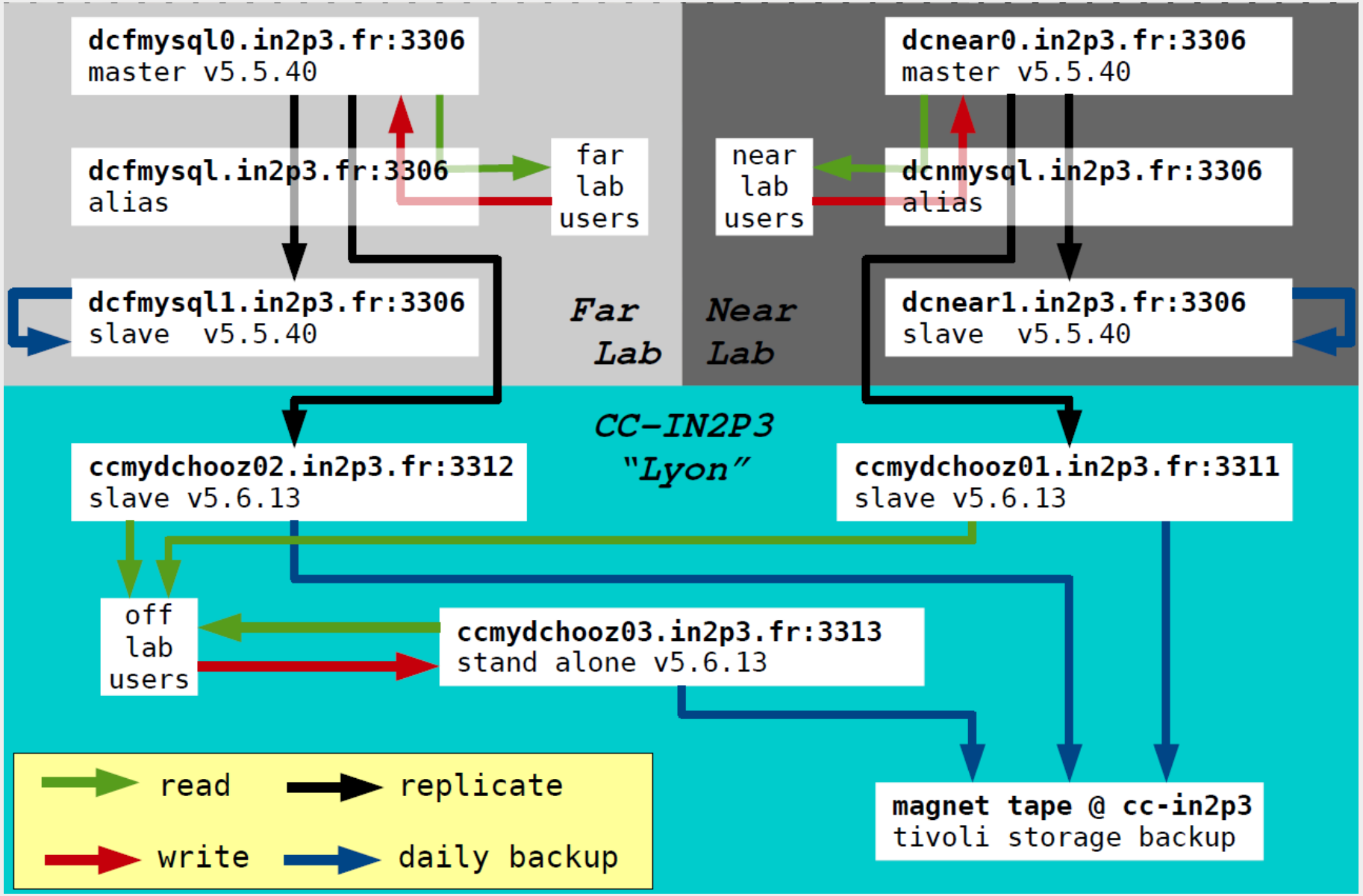




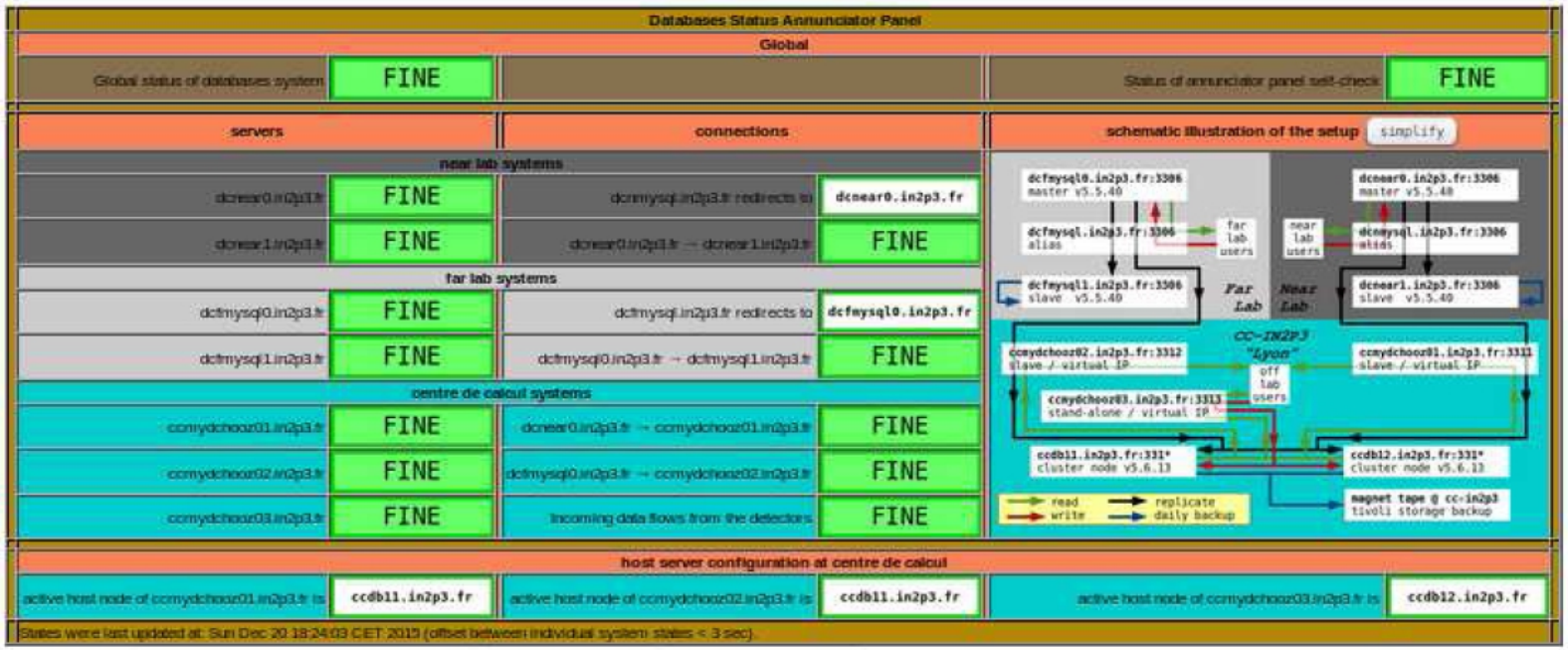
Data transfert Chooz → CCIN2P3

→ Bandwitch occupancy Near+Far lower than Far only !

DB scheme


dcfmysql0.in2p3.fr:3306
master v5.5.40
dcfmysql.in2p3.fr:3306
alias
far
lab
users
dcfmysql1.in2p3.fr:3306
slave v5.5.40
Far
Lab
dcnear0.in2p3.fr:3306
master v5.5.40
near
lab
users
dcnmysql.in2p3.fr:3306
alias
dcnear1.in2p3.fr:3306
slave v5.5.40
Near
Lab
CC-IN2P3
"Lyon"
ccmydchooz02.in2p3.fr:3312
slave v5.6.13
ccmydchooz01.in2p3.fr:3311
slave v5.6.13
off
lab
users
ccmydchooz03.in2p3.fr:3313
stand alone v5.6.13
read
replicate
write
daily backup
magnet tape @ cc-in2p3
tivoli storage backup

DB monitor



Useful for users: read section 4.6 of the shifter manual | read the DB manual | see stalled data flows

Diagnostics (for experts): see current diagnostics | see long term diagnostics | see the server logs at Chooz | see ELOG | see the service status of CC

Below you learn what the states mean:

Status	FINE	server.in2p3.fr	WARNING	NO UPDATE	CRITICAL	UNKNOWN	ERROR	Database expert contact details
Meaning	Within expectation	Active host server	Just within expectation	Data flow from detectors is stalled	Out of expectation	No connection to server / server error	Monitor error	
Explanation	All monitored parameters are within their required ranges.	The servers visible to the users are only virtual servers hosted by physical servers.	The system is still alright, it is just slow, very occupied or a redundant component has failed.	At least one detector component has unexpectedly stopped to write data into the databases.	A system failure has happened or is imminent.	A connection to the server cannot be established. The server or network might be down.	The system is probably alright, it is just this monitor page which has a malfunction.	Contact expert via email Email account: ddhooz-hardware-3b@physik.rwth-aachen.de Call expert via Skype Skype account (calls only): dc.aachen
Required actions	Smile and be happy.	If you see a server name with a green frame around it, smile and be happy.	No need to panic. Please just observe the system more frequently to see if it recovers or if it becomes critical.	This is not urgent. Please ask the shift leader to drop an email to the databases expert (look right). No need to call or wake up anybody. You can get more info by hitting the "see stalled data flows" button.	Please ask the shift leader to hit the panic button and to call the databases expert (look right) immediately even if he/she has to be woken up.	Check if systems apart from the databases are affected. If this is the case, please ask the shift leader to hit the panic button and to call the databases expert (look right) immediately even if he/she has to be woken up. Else, please ask the shift leader to just drop an email to the databases expert (look right).		

File tracking

Double Chooz Run Info Tracker Homepage

This page was last updated at Sat Feb 6 23:50:51 CET 2016
PHP version 5.3.8

Far Detector:

Run 212758

Run Summary

Shifter: losecco
Profile: DCPHYS_RUN_D2
Length: 3600 [s]

Run Config

RUN_DESCRIPTION=PHYSICS RUN>>Neutrino Physics with DDR [NuDAQ ON with 256ns Window and OVDAQ ON)
DCNUDAQ_DDR_SCHEME=DDR_SCHEME_DYNREDUCTION0 DCNUDAQ_TRIGGER_EXTERNAL=ON DCNUDAQ_TRIGGER_INTERNAL_ID=ON
DCNUDAQ_TRIGGER_INTERNAL_IV=ON DCNUDAQ_TRIGGER_FIXEDRATE=ON DCNUDAQ_TRIGGER_FIXEDRATE_FREQ=1
DCOVDAQ_CONFIG_TABLE=online_CHOOZ_45 DCOVDAQ_OFFLINE_THR=73 DCOVDAQ_OFFLINE_TRIGGER_TYPE=2 DCIDLI_ENABLE=OFF
DCIVLI_ENABLE=OFF DCNUDAQ_IVLIPMT_ENABLE=OFF DCEXTLI_ENABLE=OFF DCLASER470NM_ENABLE=OFF DCLASER375NM_ENABLE=OFF
DCRADIO_ENABLE=OFF DCRADIO_TAGGED_ENABLE=OFF

Comment

Phys D2

Enabled DAQ

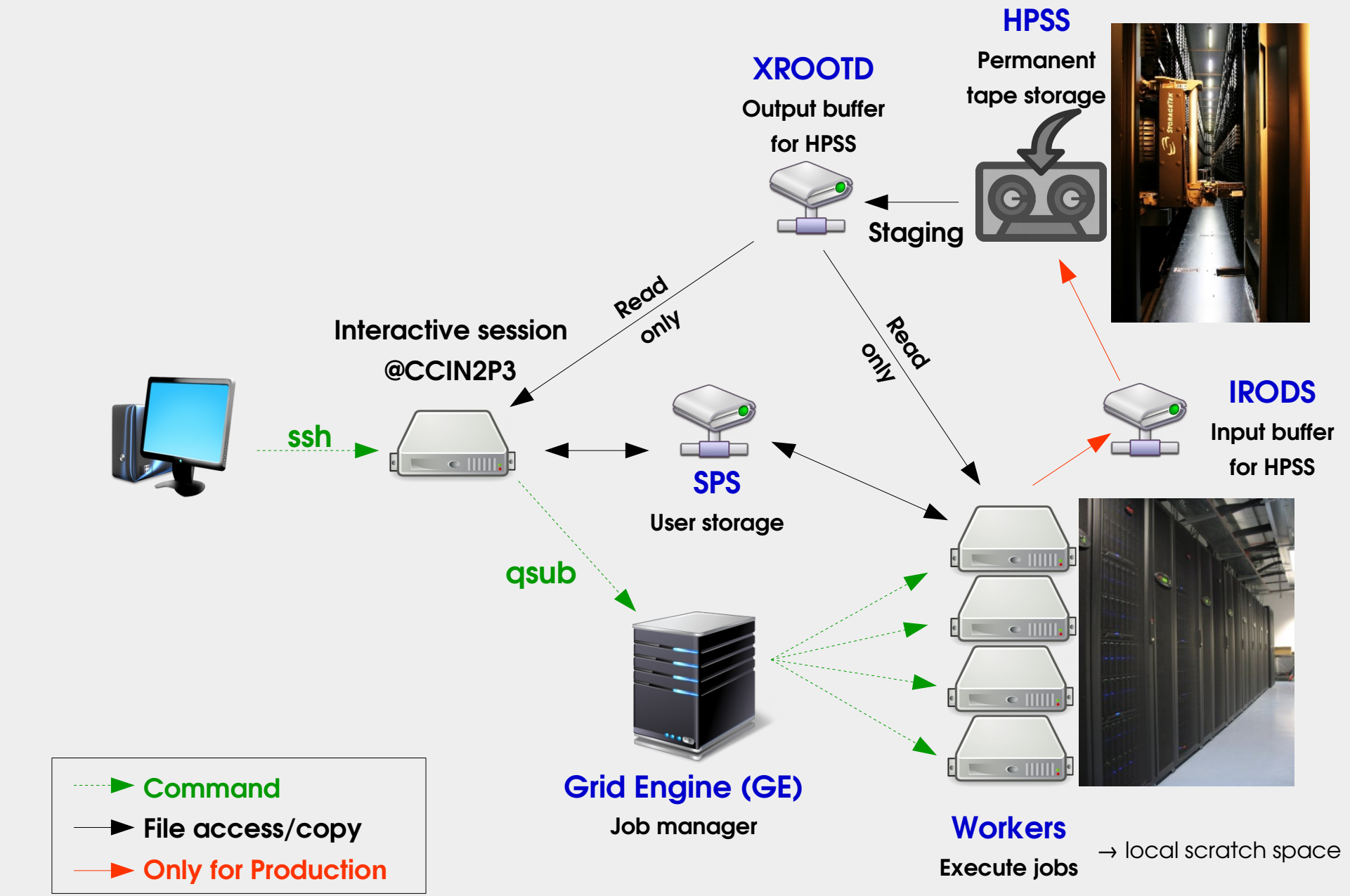
Nu DAQ	Mu DAQ	OV DAQ
1	1	1

Start/End/Log Time

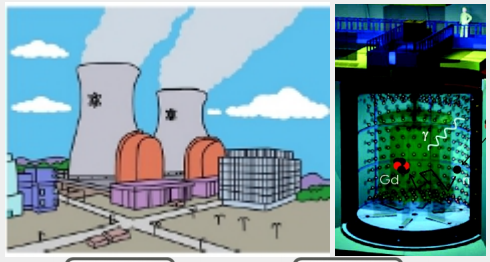
Start Time	End Time	Logged Time
2016-02-06 22:39:06	2016-02-06 23:39:06	2016-02-06 23:39:20

Hosted by IN2P3
Maintained by RWTH Aachen Double Chooz Group
This website is broken, ugly, wrong or hard to understand? ... Please contact the website maintainers.

File production and access @CCIN2P3



DATA Production @CCIN2P3



ν-daq OV-daq

@Chooz

@CCIN2P3

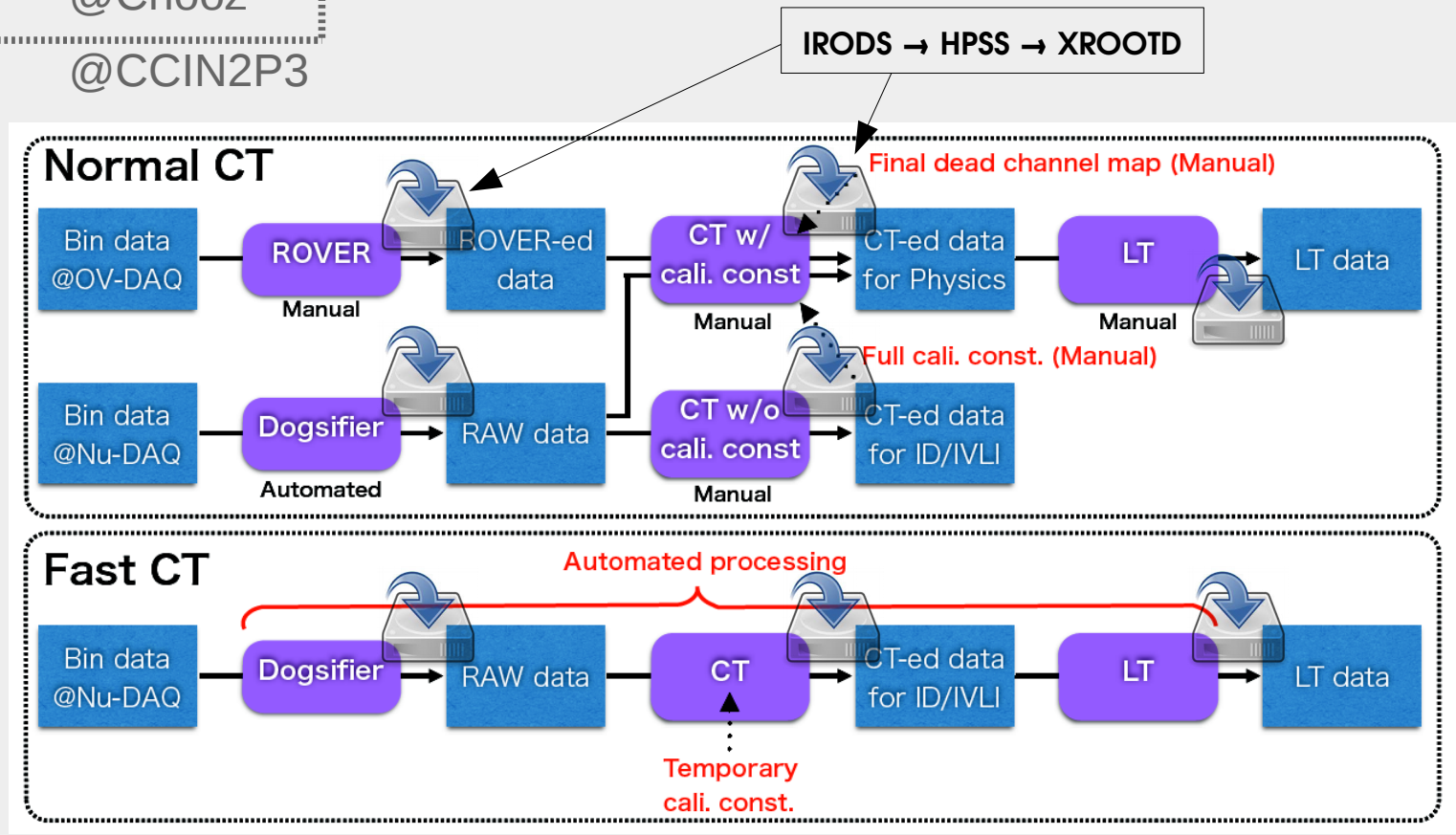
BIN files

IRODS

HPSS

XROOTD

- BIN to ROOT data → Dogsifier
- DATA Production → CT
- DATA Selection and Reduction → LT
- → Analysis by analyzers



→ **DATA + MC to be produced !**

Jobs management

Lyon Batch Resource

The table below shows the total Lyon batch (GridEngine) resource availability and the current usage.
The available number is shown in the denominator while currently occupied is shown on the numerator.

	XROOTD Tokens	IRODS Tokens	HPSS Tokens	SPS Tokens	# Workers	CT Tokens	ROVER Tokens
Currently Used (Count)	40/1100	7/1025	/200	10/1100	10/1100	3/400	/200
Currently Used (Fraction)	3.64 %	6.83 %	0 %	9.73 %	9.73 %	9.75 %	0 %
Currently Queued (Count)	0/1100	1/1025	1/200	2/1100	2/1100	0/400	0/200
Currently Queued (Fraction)	0 %	0.0976 %	0.5 %	0.182 %	0.182 %	0 %	0 %

User:
Name:
Status: status
Limit Entries:: 3000
Submit Reset

LOG_TIME	Job ID	Name	Owner	Project	Class & Worker	Resource	CPU Time	Status
2016-02-06 23:42:59	23742326	DOGSIFIER_Run5221515	dcprod	P_dchooz_prod	huge@ccwsge0764.in2p3.fr	irods sps	0:00:00:25	r
2016-02-06 23:42:59	23742035	CT_CRON_SHORTLY_1602062345	dcprod	P_dchooz_prod		sps irods hpss		qw
2016-02-06 23:42:59	23741839	DOGSIFIER_Run0211780	dcprod	P_dchooz_prod	huge@ccwsge0760.in2p3.fr	irods sps	0:00:31:42	r
2016-02-06 23:42:59	23741832	DOGSIFIER_Run0211779	dcprod	P_dchooz_prod	huge@ccwsge0690.in2p3.fr	irods sps	0:00:17:21	r
2016-02-06 23:42:59	23740598	DOGSIFIER_Run0211778	dcprod	P_dchooz_prod	huge@ccwsge0755.in2p3.fr	irods sps	0:01:37:57	r
2016-02-06 23:42:59	23740595	DOGSIFIER_Run0211777	dcprod	P_dchooz_prod	huge@ccwsge1136.in2p3.fr	irods sps	0:01:50:25	r
2016-02-06 23:42:59	23739959	CT_CRON_DAILY_1602062306	dcprod	P_dchooz_prod	medium@ccwsge0195.in2p3.fr	irods sps	0:00:18:10	r
2016-02-06 23:42:59	23733130	DCND_MC_runAfterPy_9months_Run0000001_Seq001	dnavas	P_dchooz	long@ccwsge1160.in2p3.fr	xrootd sps	0:15:57:13	r
2016-02-06 23:42:59	23732831	DOGSIFIER_Run0211776	dcprod	P_dchooz_prod	huge@ccwsge0357.in2p3.fr	irods sps	0:21:14:47	r
2016-02-06 23:42:59	23732255	DOGSIFIER_Run0211775	dcprod	P_dchooz_prod	huge@ccwsge0364.in2p3.fr	irods sps	0:22:20:30	r
2016-02-06 23:42:59	23732250	DOGSIFIER_Run0211774	dcprod	P_dchooz_prod	huge@ccwsge0189.in2p3.fr	irods sps	0:21:13:59	r
2016-02-06 23:42:59	23732245	DOGSIFIER_Run5221514	dcprod	P_dchooz_prod	huge@ccwsge0759.in2p3.fr	irods sps	1:02:07:55	r
2016-02-06 23:42:59	23732243	DOGSIFIER_Run5221513	dcprod	P_dchooz_prod	huge@ccwsge0152.in2p3.fr	irods sps	0:23:03:24	r
2016-02-06 23:42:59	23732219	JOB_NeutronShootVince_7.18	fischerv	P_dchooz	long@ccwsge0639.in2p3.fr	sps	1:04:52:36	r
2016-02-06 23:42:59	23732218	JOB_NeutronShootVince_7.17	fischerv	P_dchooz	long@ccwsge0167.in2p3.fr	sps	0:00:00:00	r
2016-02-06 23:42:59	23732217	JOB_NeutronShootVince_7.16	fischerv	P_dchooz	long@ccwsge0281.in2p3.fr	sps	1:00:37:09	r

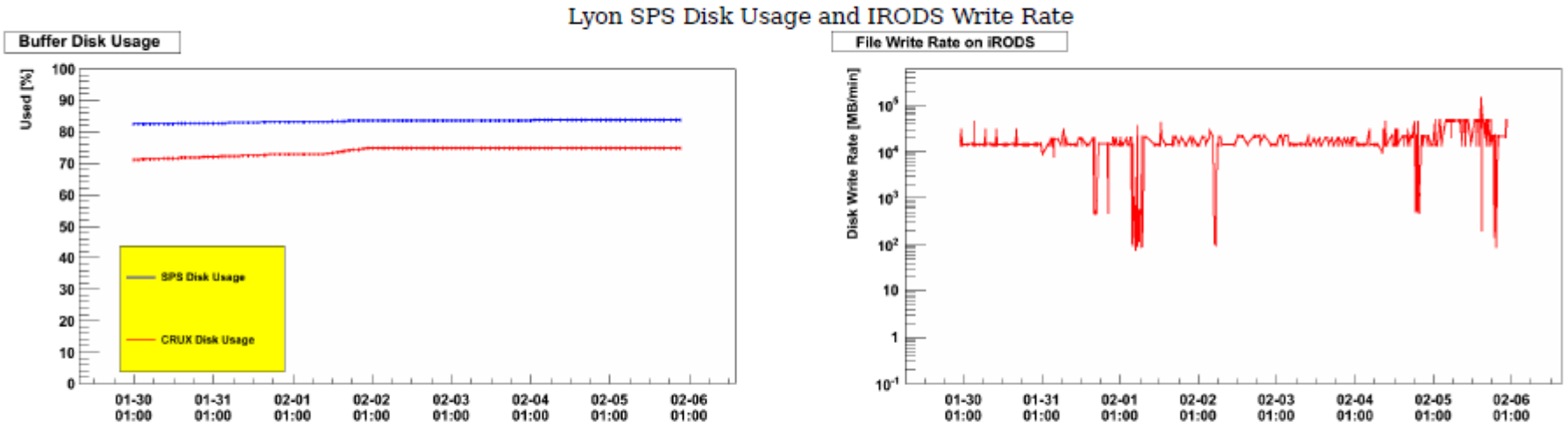
Effort done on job efficiency:

Jul. → Sept. 2015
93%

58%
Jan. → Mar. 2015

Disk and CPU usage

Lyon Buffer Disk



LOG TIME	Crux Disk Usage	Sps Disk Usage
2016-02-06 23:42:58	74.7 %	83.84 %

Production Statistics Summary

From left: Total DAQ runs, CT-ed runs, and subset of CT-ed runs recommended for analysis.

	ALL Runs	CT-ed Runs	GOOD CT-ed Runs
# Runs	181341	61231	
Run Length [day]	2593.4143518519	1013.2789351852	

Total disk space usage history on iRODS disk server.
Note that the disk is purged once the available quota is filled.
The numbers shown is total file size written in the past.

	Total Nu-DOGSifier Filesize	Total CT Filesize	Total ROVER Filesize
Space Used [TB]	773.332	116.105	8.98954

CPU consumption:

→ ~2 000 000 HS06.h / month

→ increasing

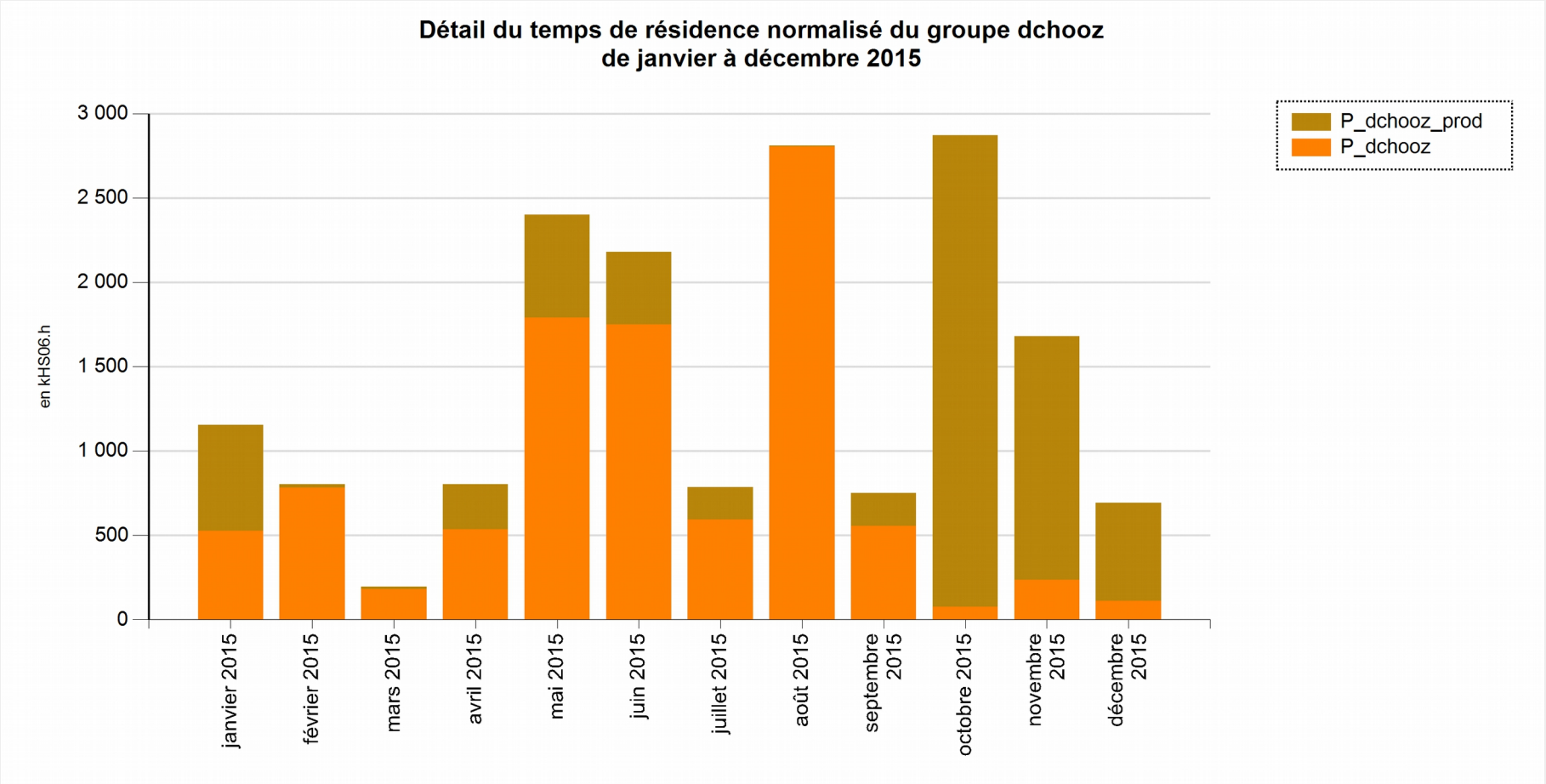
TODAY for CT:

→ 2 months of data / day

→ ~ 20 TB / day on IRODS

→ up to 200 000 HS06.h / day

Disk and CPU usage



DC@CCIN2P3 - Requests for 2016

	CURRENT	1st trimester	2nd trimester	3rd trimester	4th trimester
CPU (HS06.h)	9 000 000	7 000 000	7 000 000	9 000 000	9 000 000
AFS THRONG_DIR	60 GB	Saturated – extensive use by all dchooz developpers			
SPS	88 TB	+60 TB on /sps/dchooz, +20 TB on /sps/dchooz/crux			
IRODS	150 TB	+100 TB → ~ 5 days of DATA production			
HPSS	1657 TB*	+220 TB	+220 TB	+220 TB	+220 TB
XROOTD	562 TB*	+170 TB	+170 TB	+170 TB	+170 TB

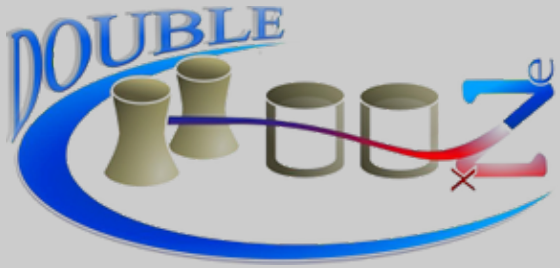
* not a limit, used space

- **2017** → Requests ~
- **End of 2017 / early 2018** → End of the data taking, no additional request expected

Some other comments

- **EDF reactor data** → confidential, access granted to only few DC users (power vs. time, fuel composition)
- **Turn over** → regular checks of logins / corresponding storage space
- **Data cleaning** → old / non used data files (not BIN)
- **Backup for BIN files** → @TUM (Munich, Germany), dedicated Irods account
- **Data file transfer to Japan** → dedicated Irods account

DC progress

- May 2008 to October **2010** → Far detector construction
- December **2010** → Far detector filling completed
- April **2011** → Far detector commissioned, start data taking !
- April **2011** → Near lab construction started
- July **2011** → Outer veto commissioned (more data)
- December **2011** → 1st results
- **2012** → First indication of non-zero θ_{13}
- **2013** → First n-H analysis
- **2014** → RRM fit
- December **2014** → Near detector commissioned
- **2015** → new n-Gd / n-H / combined RRM analysis
- 2015 → resources @CCIN2P3 x 4 ! (effort on code stability)
- End 2015 → Data are 6 times faster to produce (vs. early 2015)
- **2016** → **First Near + Far analysis !**
- **End of 2017/early 2018** → **end of data taking**

Remerciements de la part de Double Chooz !