reactor θ13

(the ultimate measurement?)

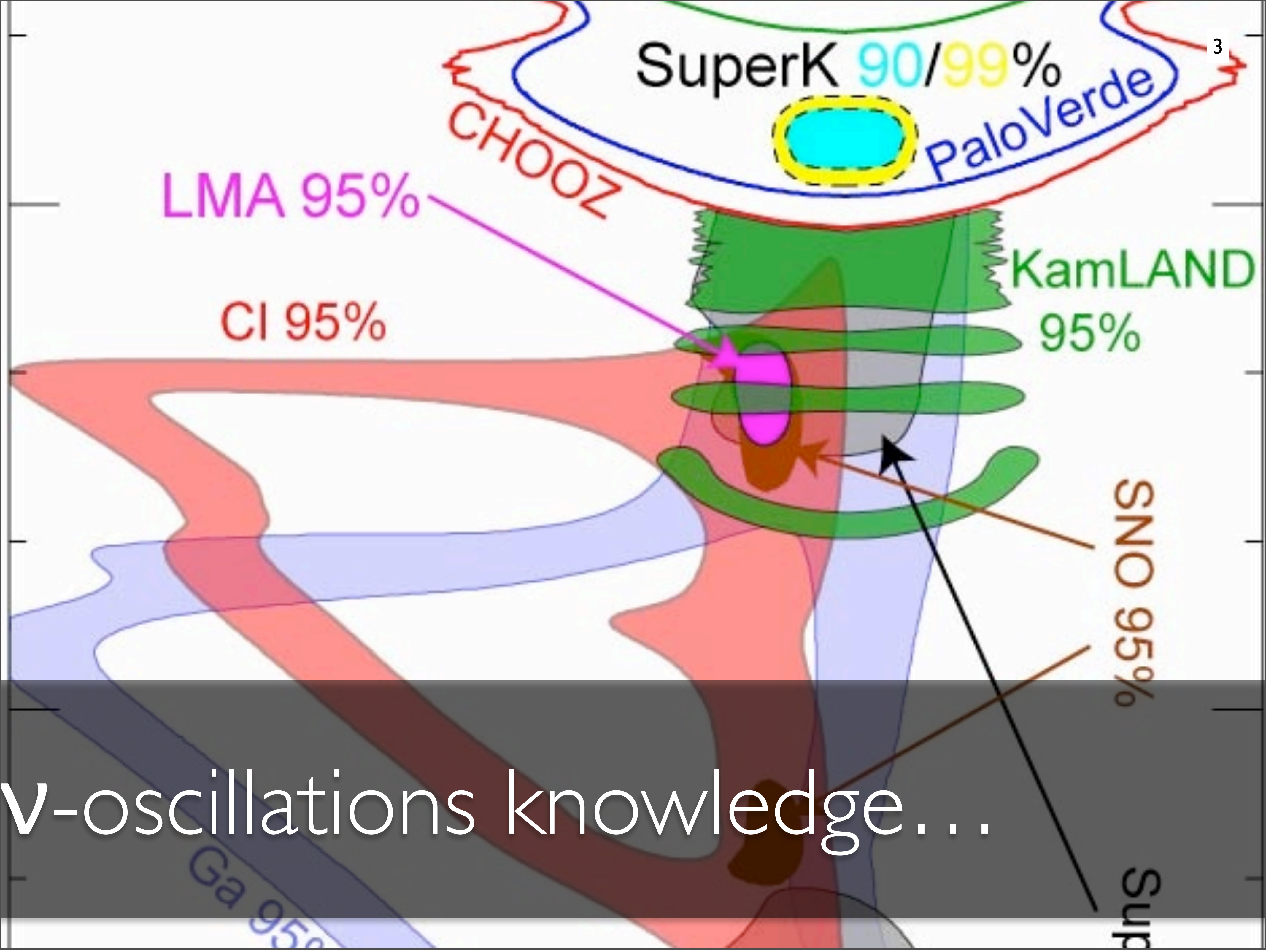
ICRR @ Tokyo (Japan)
December 2012

Anatael Cabrera
(アナタエル カブレラ)

CNRS / IN2P3
Double Chooz @ APC (Paris)

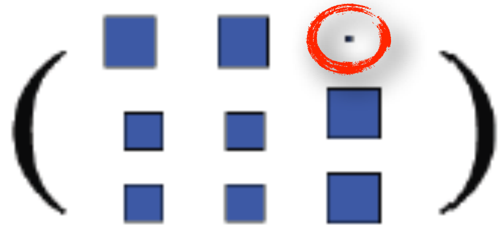
Menu

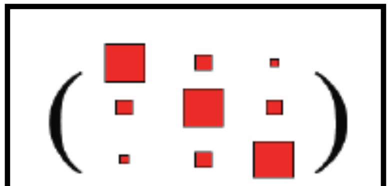
- l'apéritive...
  - neutrino oscillation (a fast reminder)
  - neutrino oscillation status
- le plat…
  - global impact of $\theta 13$ (a few examples)
  - reactor neutrinos: (a fast)why?
  - review on reactor θ_{13} experiments results
- le dessert…
  - today & tomorrow on reactor θ_{13} systematics
- conclusions…



ν-oscillations knowledge…

$(\nu_e,\nu_\mu,\nu_\tau)^T = U\,(\nu_1,\nu_2,\nu_3)^T$, where U looks like





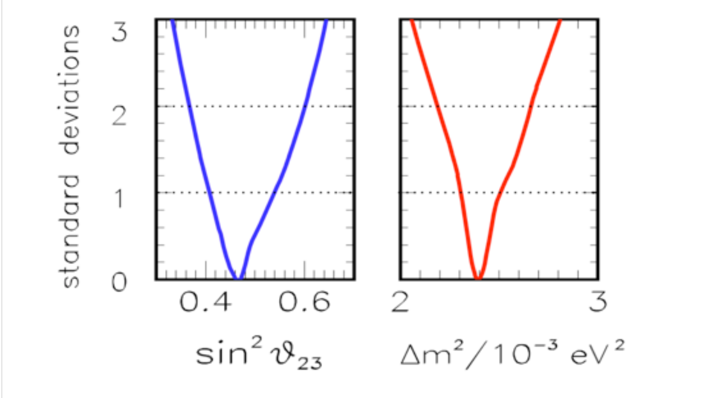
"atmospheric" θ_{23}~45°	θ_{13} <11° & "dirac" δ_{CP}	"solar" θ_{12}~33°
Δm^2_{31}	Δm^2_{31}	Δm^2_{21}

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

sub-leading → ← sub-leading

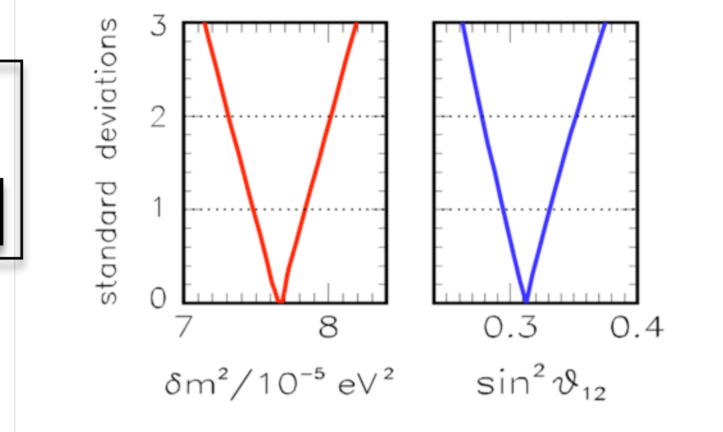
atmos+LBL(dis)	Chooz+LBL(app)	solar+KamLAND
$P(\nu_\mu \to \nu_\mu)$	$P(\nu_e \to \nu_e)$ & $P(\nu_\mu \to \nu_e)$	$P(\nu_e \to \nu_x)$

σ ~12% σ ~5%



knowledge on θ_{13} & δ_{CP} [later]

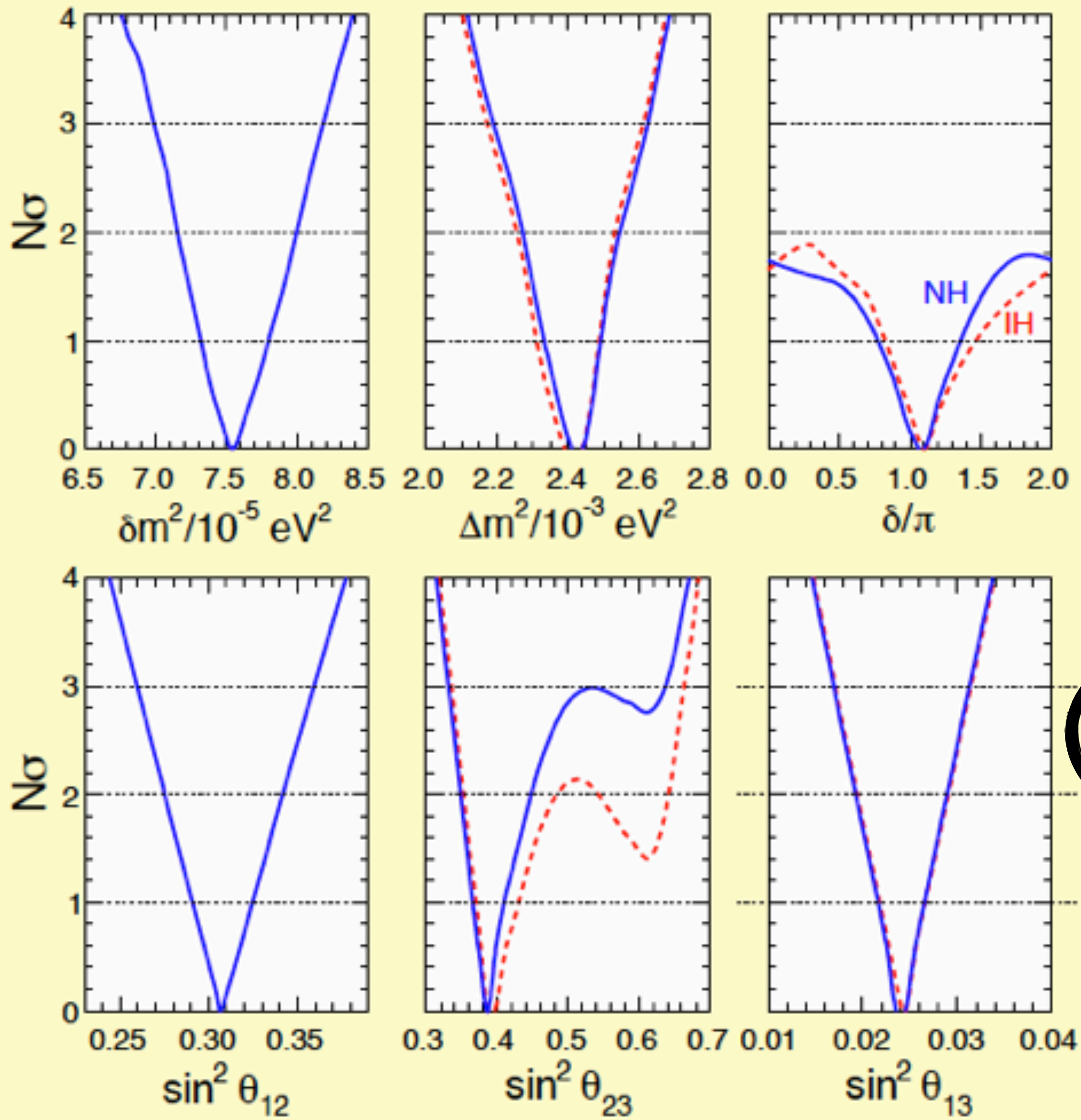
σ ~2% σ ~6%



Fogli et al arXiv:1106.6028

Lisi et al opinion (Sept. 2012)

Synopsis of global 3ν oscillation analysis



Previous hints of $\theta_{13} > 0$ are now measurements! (and basically independent of old/new reactor fluxes)

Some hints of $\theta_{23} < \pi/4$ are emerging at $\sim 2\sigma$, worth exploring by means of atm. and LBL+reac. data

A possible hint of $\delta_{CP} \sim \pi$ emerging from atm. data [Is the PMNS matrix real?]

So far, no hints for NH ⟷ IH

Lisi et al opinion (Sept. 2012)

Numerical 1σ, 2σ, 3σ ranges:

18

TABLE I: Results of the global 3ν oscillation analysis, in terms of best-fit values and allowed 1, 2 and 3σ ranges for the 3ν mass-mixing parameters. We remind that Δm^2 is defined herein as $m_3^2 - (m_1^2 + m_2^2)/2$, with $+\Delta m^2$ for NH and $-\Delta m^2$ for IH.

Parameter	Best fit	1σ range	2σ range	3σ range
$\delta m^2/10^{-5}$ eV^2 (NH or IH)	7.54	7.32 – 7.80	7.15 – 8.00	6.99 – 8.18
$\sin^2\theta_{12}/10^{-1}$ (NH or IH)	3.07	2.91 – 3.25	2.75 – 3.42	2.59 – 3.59
$\Delta m^2/10^{-3}$ eV^2 (NH)	2.43	2.33 – 2.49	2.27 – 2.55	2.19 – 2.62
$\Delta m^2/10^{-3}$ eV^2 (IH)	2.42	2.31 – 2.49	2.26 – 2.53	2.17 – 2.61
$\sin^2\theta_{13}/10^{-2}$ (NH)	2.41	2.16 – 2.66	1.93 – 2.90	1.69 – 3.13
$\sin^2\theta_{13}/10^{-2}$ (IH)	2.44	2.19 – 2.67	1.94 – 2.91	1.71 – 3.15
$\sin^2\theta_{23}/10^{-1}$ (NH)	3.86	3.65 – 4.10	3.48 – 4.48	3.31 – 6.37
$\sin^2\theta_{23}/10^{-1}$ (IH)	3.92	3.70 – 4.31	3.53 – 4.84 ⊕ 5.43 – 6.41	3.35 – 6.63
δ/π (NH)	1.08	0.77 – 1.36	—	—
δ/π (IH)	1.09	0.83 – 1.47	—	—

Fractional 1σ accuracy [defined as 1/6 of ±3σ range]

δm^2	Δm^2	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$
2.6%	3.0%	5.4%	10%	14%

Note: above ranges obtained for "old" reactor fluxes. For "new" fluxes, ranges are shifted (by ~ 1/3 σ) for two parameters only: $\Delta \sin^2\theta_{12}/10^{-1} \simeq +0.05$ and $\Delta \sin^2\theta_{13}/10^{-2} \simeq +0.08$

Hierarchy differences well below 1σ for various data combinations

Anatael Cabrera (CNRS-IN2P3 & APC)

why θ_{13}?

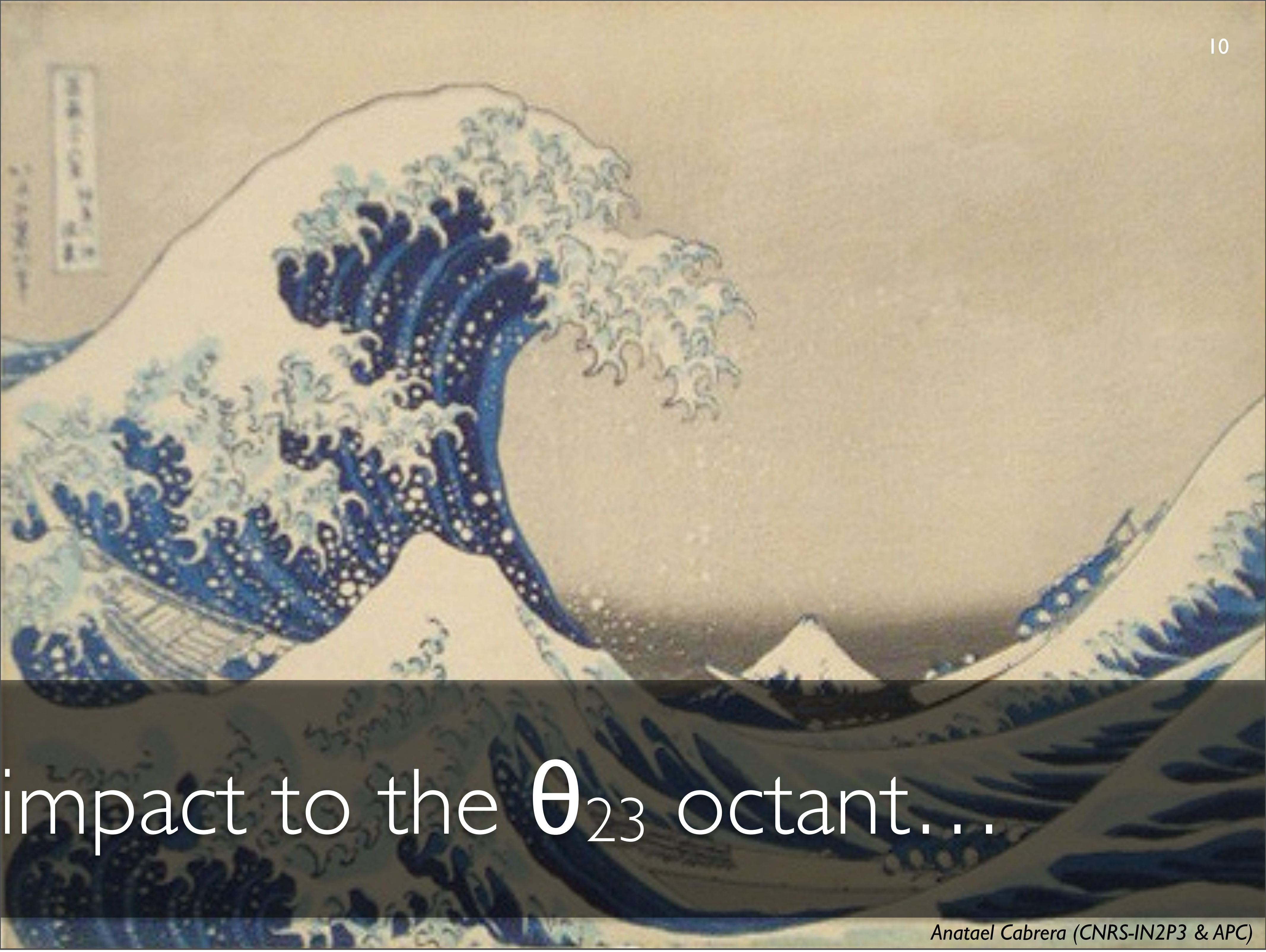
- **θ_{13} must be measured**
  - free parameter in SM (like in CKM→ parameter constraints)
  - test U_{PMNS} unitarity (hard)→ sensitive to ≥3νs (steriles?)
- a non-zero θ13 is necessary (but not sufficient) to measure δ_{CP}…
  - value important to measure the Mass Hierarchy (MH): **$\pm\Delta m^2_{31}$**
- θ13 helps to improve **our global knowledge**…
  - via global analyses (**1205.5254**, **1205.4018**, **1209.3023**, etc)
    - **θ23 octant** [example later]
    - **δ_{CP}** (Dirac phase) [example later]
- **θ_{13} oscillations observed**→ validation of 3ν oscillation model
  - confirms 3ν families (like seeing the ν_τ in 2000 by DONUT)
  - a "discovery"? [within a well established framework]
    - "solar" & "atmospheric"→ main channels for oscillations so far
- θ13→ **discriminate flavour unification models**…
  - U_{PMNS} + U_{CKM}→ quark-lepton unification flavour model
  - example: Barr et al (**hep-ph/1208.6546**), etc…

global θ_{13}

impact...

what we all want to know…

- consistent reactor-θ13 result (all reactor experiments)
  - good knowledge→**high precision**
    - constraint 3ν model & discriminate against predictions
  - good agreement→**high accuracy** (relevant when high precision)
    - constraint 3ν model & discriminate against predictions
    - **observe E/L distortion**
    - flux normalisation→flux(DB or RENO)< flux(DC) [FD only]
- consistency between reactor and beam θ13 too…
  - beam-θ13 less precise (other observables)→ (still) it must be consistent
  - δ_{CP} rather insensitive to θ13 (but need a θ13≠0)
- **mass hierarchy** is more sensitive to θ13
  - atmospheric-νs→ INO, PINGU, ORCA, etc
  - reactor-νs→ Daya Bay II (amplitude of interference term)
- if **inconsistency/tension** found→ **new physics/systematics?** (exciting!)

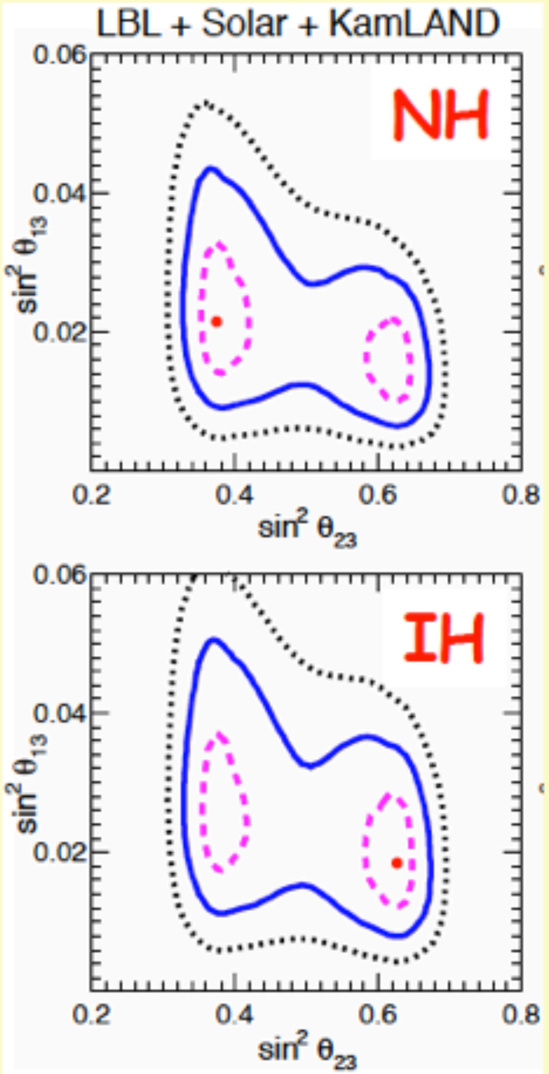


impact to the θ_{23} octant…

Lisi et al @ Shenzhen'2012

11

($\sin^2\theta_{13}$, $\sin^2\theta_{23}$) from LBL app. + disapp. data plus solar + KamLAND data:



Latest LBL disappearance data from T2K and MINOS favor nonmaximal θ_{23}

From LBL appearance+disappear. data, two quasi-degenerate θ_{23} solutions emerge, in anticorrelation with θ_{13} (one slightly above and the other slightly below $\sin^2\theta_{13} \sim 0.02$). The two solutions merge above ~1σ.

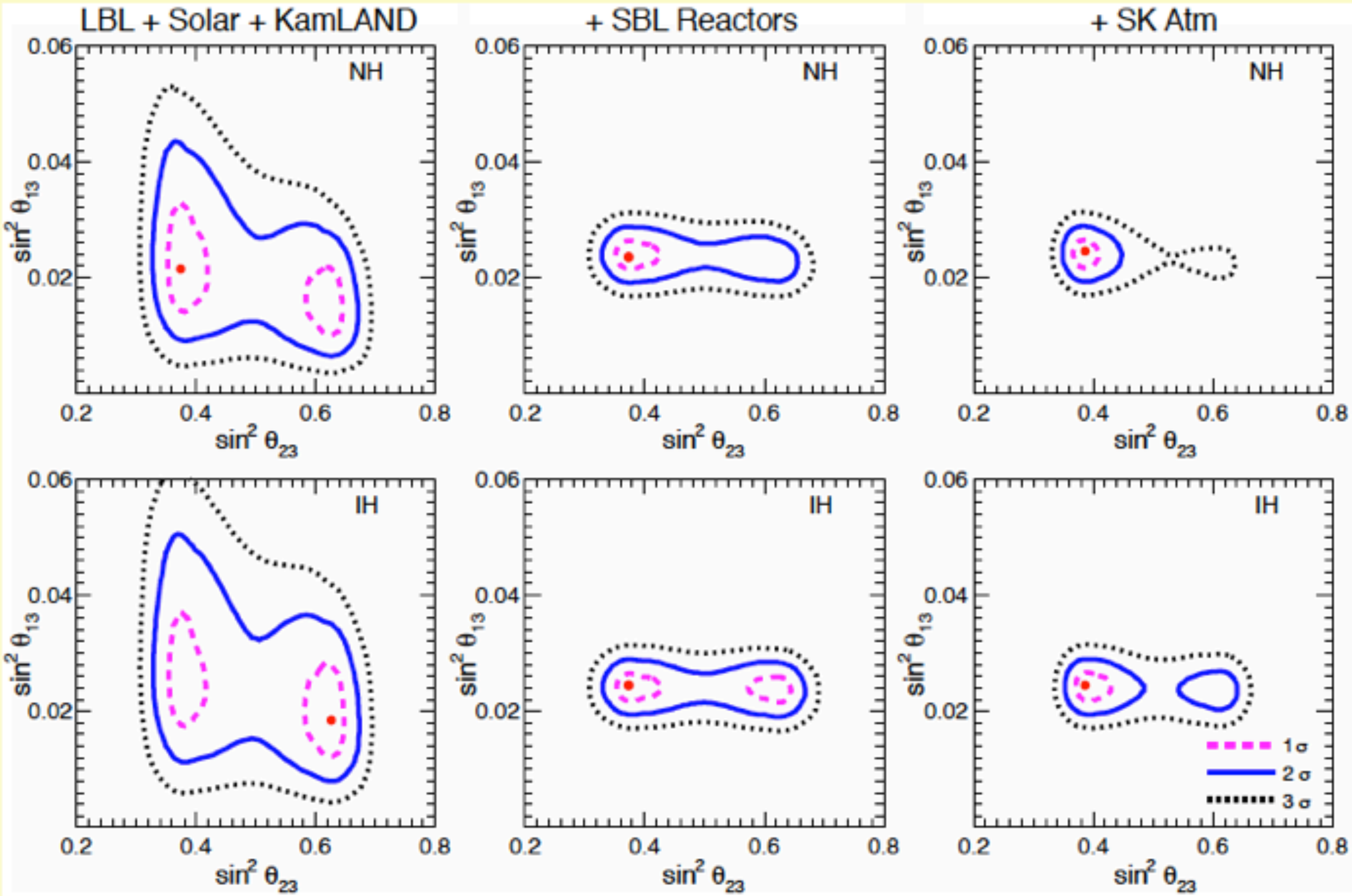
[It would be nice to see these plots in the official T2K and MINOS data analyses!]

Solar+KamLAND data happen to prefer just $\sin^2\theta_{13} \sim 0.02$, and are unable to lift the octant degeneracy: the depth of the two minima differ by only ~0.3σ.

Lisi et al @ Shenzhen'2012

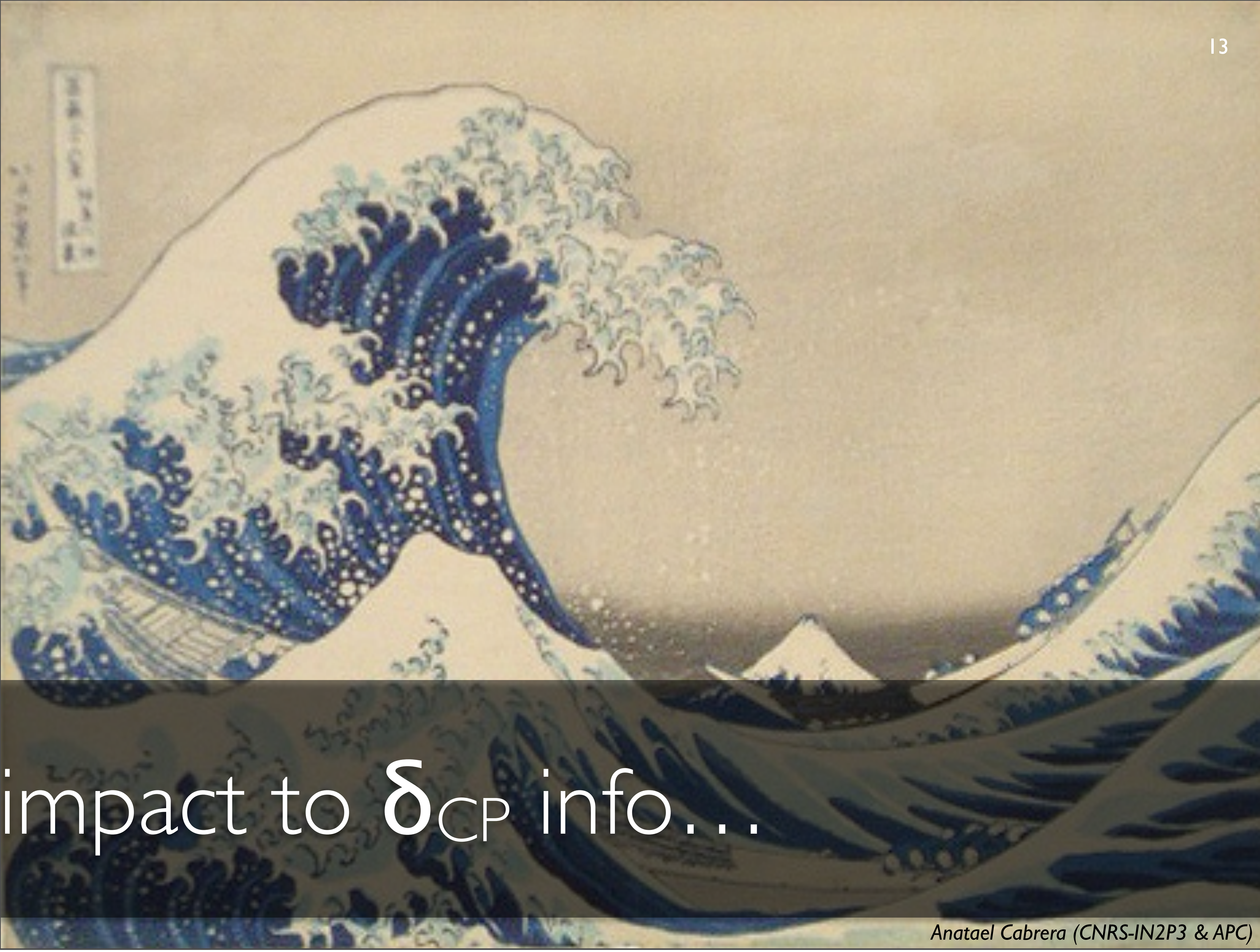
13

Adding 2012 SK atmospheric neutrino data:



Further hints for θ_{23} in 1st octant. But no significant hierarchy discrimination.

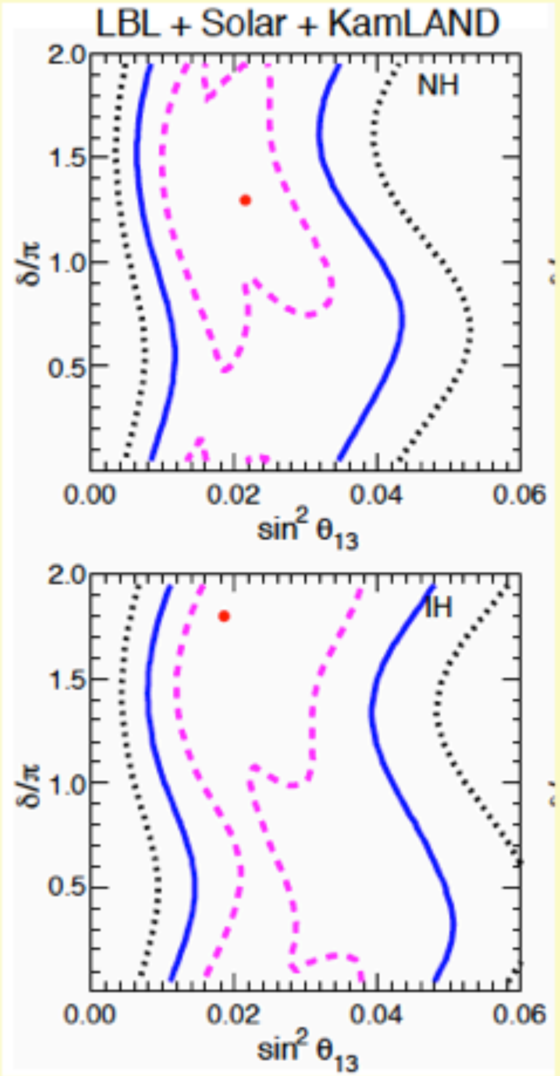
Anatael Cabrera (CNRS-IN2P3 & APC)



impact to δ_{CP} info…

Lisi et al @ Shenzhen'2012

($\sin^2\theta_{13}$, δ) from LBL app. + disapp. data plus solar + KamLAND data:



δ is basically unconstrained at ~1σ.

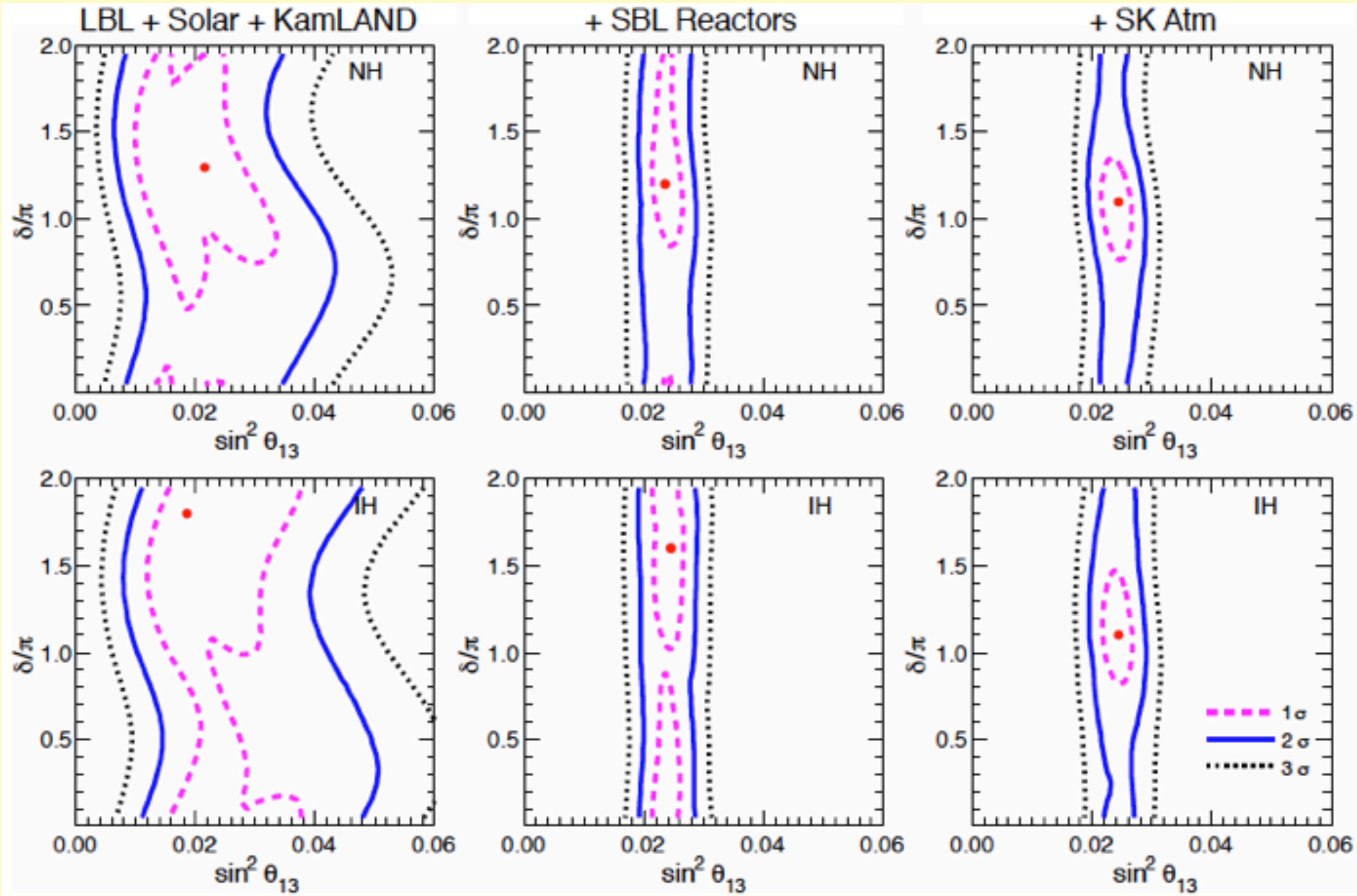
Fuzzy 1σ contours are a side effect of θ_{23} degeneracy: the two θ_{23} minima correspond to slightly different θ_{13} ranges and thus to two slightly overlapping "wavy bands" in the plot. Minima flip easily from one band to the other.

Fuzziness disappear at higher CL (degeneracy just enlarges bands).

Lisi et al @ Shenzhen'2012

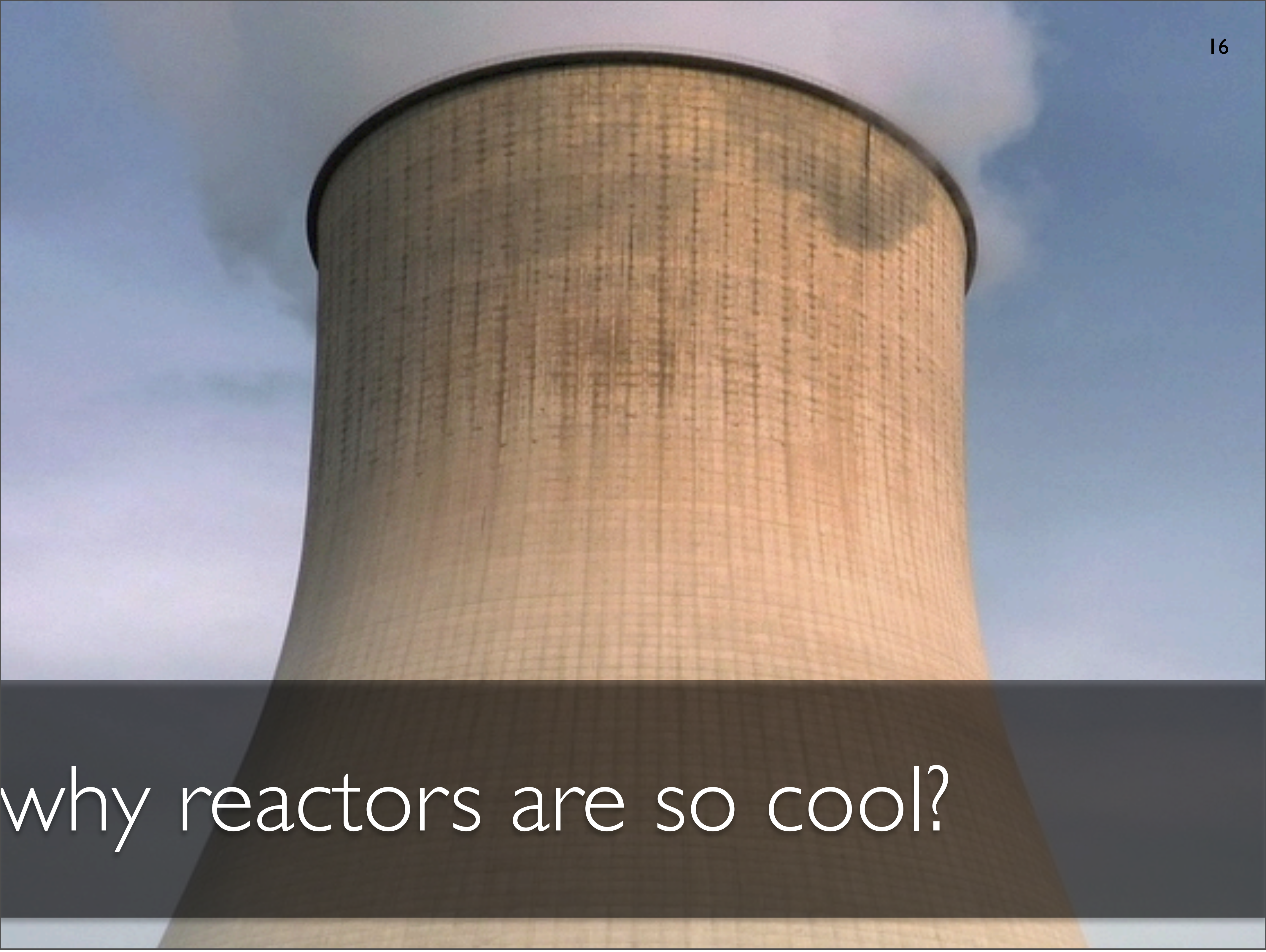
16

Adding 2012 SK atmospheric neutrino data:



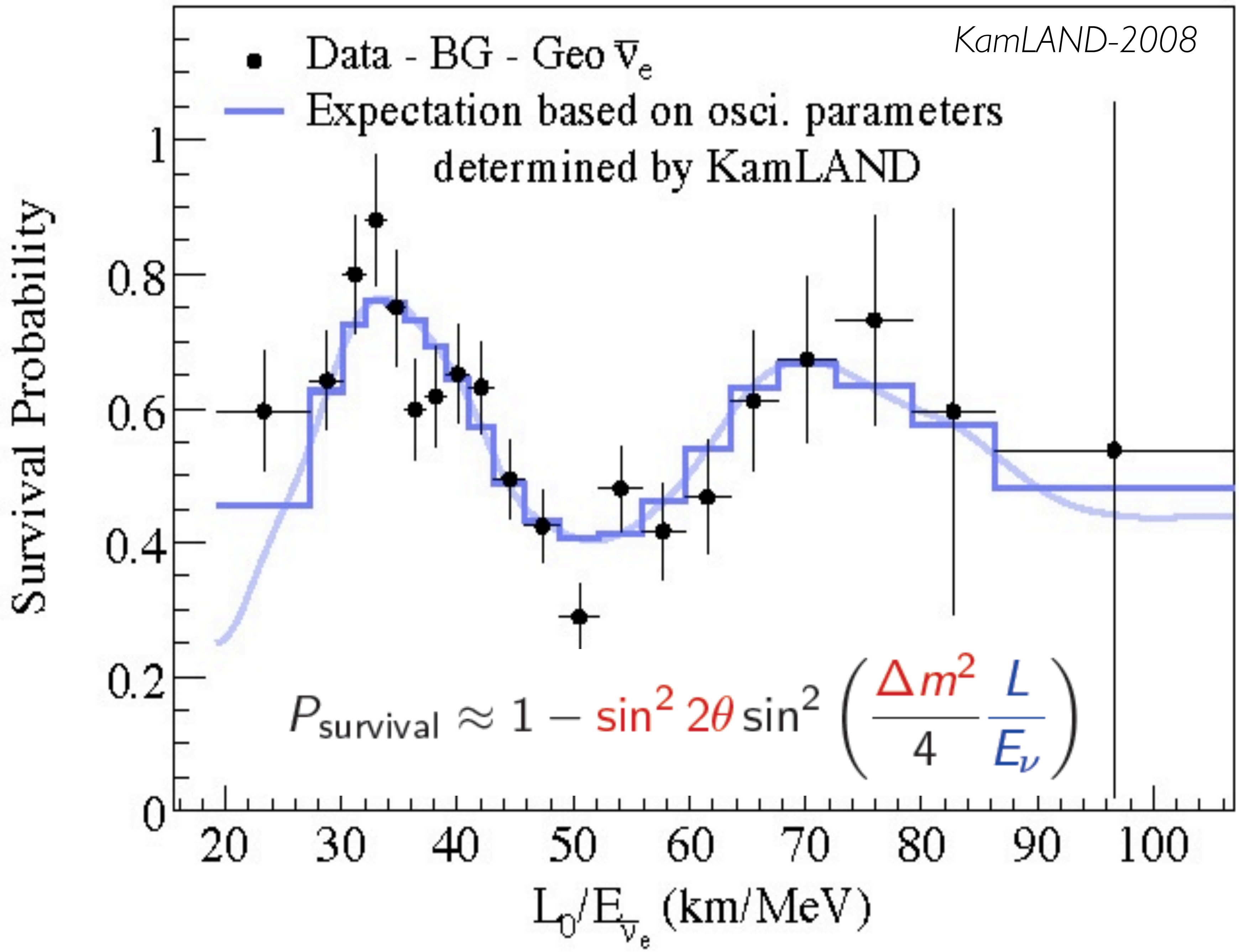
We find a preference for $\delta \sim \pi$ (helps fitting sub-GeV e-like excess in SK)

Anatael Cabrera (CNRS-IN2P3 & APC)


why reactors are so cool?

KamLAND's E/L (reactor-νs)

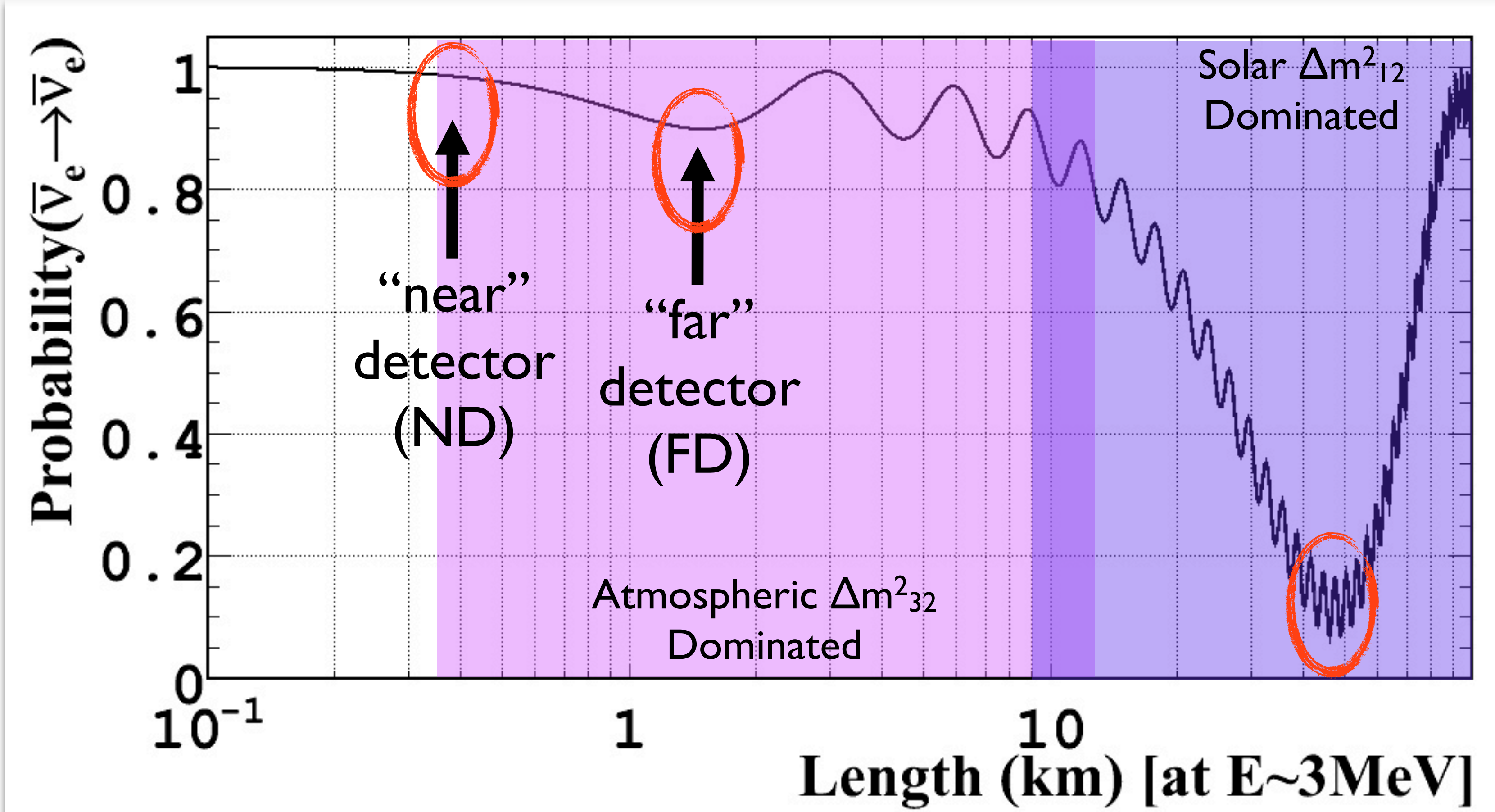
the most beautiful (to me) E/L so far...



the coolest reason for us...

$$P(\nu_e \to \nu_e) \sim 1 - \sin^2(2\theta_{13}) \sin^2(\Delta m^2_{32} L_o/E)$$

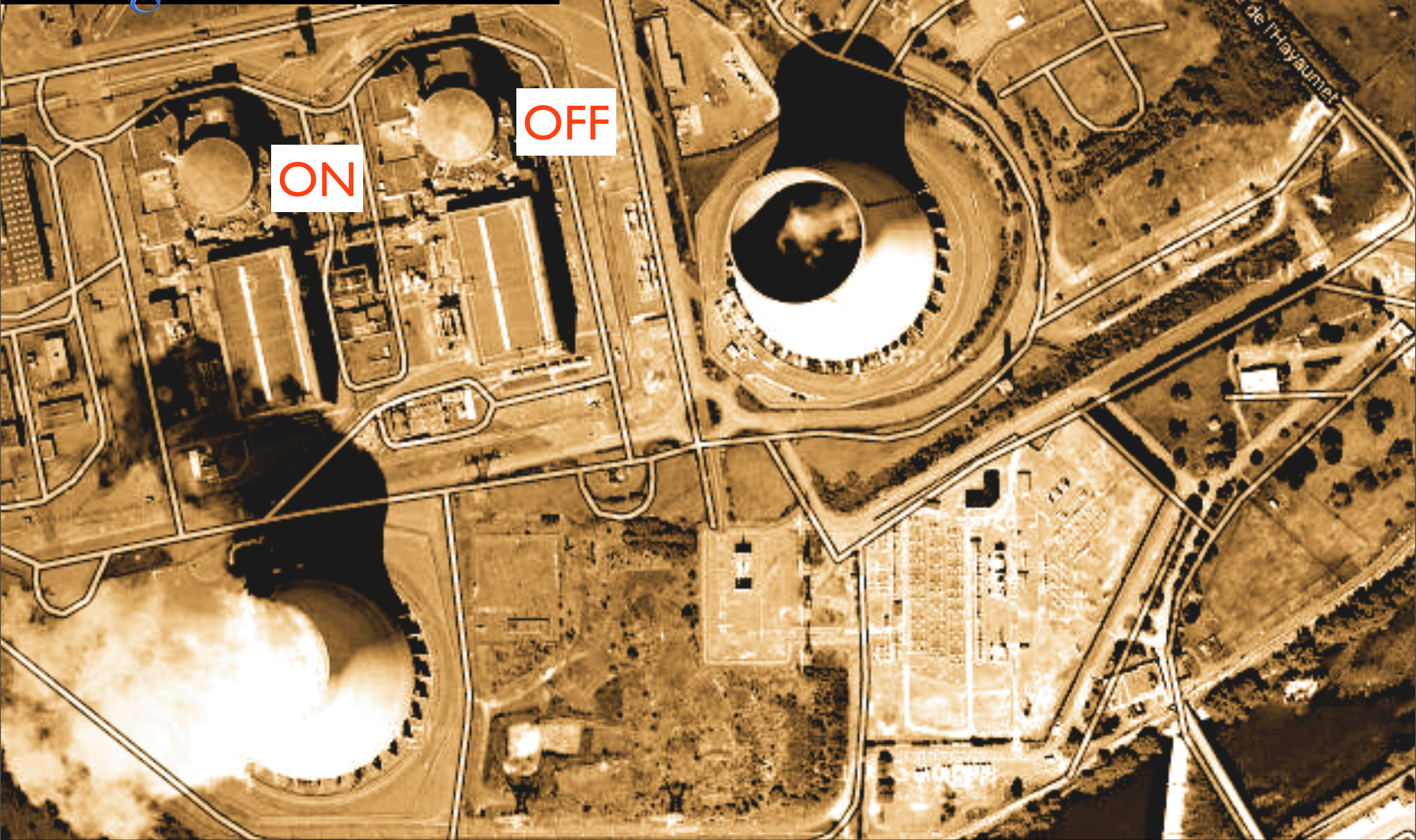
[plot: $E = 3$ MeV, $\sin^2(2\theta_{13}) = 0.1$, $\Delta m^2_{32} = 2.5\times10^{-3}$ eV^2]



ND→ reduce all correlated systematic uncertainties

ND→ isolates from other physics (reactor anomaly→ fast oscillation)

Google reactor monitor



Backgrounds always ON (radio-activity & μ-related)

→ signal can be OFF (or significantly reduce)

[ask your solar-neutrino colleagues how cool this might be…]

reactor θ_{13} measurement…

Anatael Cabrera (CNRS-IN2P3 & APC)

θ13 measurement by reactors

- **3** experiments→ **Daya Bay** (DB), **Double Chooz** (DC) & **RENO**
- **θ_{13} best measurement worldwide from reactors**
  - **hard to improve** (or re-trigger dedicated experimental activity)
  - θ13 measurement to ~5% precision (eventually)→ use by beams
    - **high precision**→ due to multi-detector technique
    - **high accuracy**→ due to several experiments (any bias?)
  - **oscillation signature**→ θ13 measure via **both rate+shape**
    - **rate-only** = "any deficit" is numerically associated to θ13 (BG, etc)
    - results are rate driven→ only DC uses shape to some extent
- **beams to use the "reactor θ13"**→ further insight in neutrino oscillations
  - **ν_e appearance:** first appearance experiment (T2K→ 5σs soon!!)
  - rich physics…
    - O(1%) precision measurement of $\Delta m^2 32$, θ23 (T2K, NOνA)
    - further (with some luck)→ δ and MH (also with atmospheric)
    - over-constraint 3ν oscillation scenario→ NSI, sterile, exotic, etc

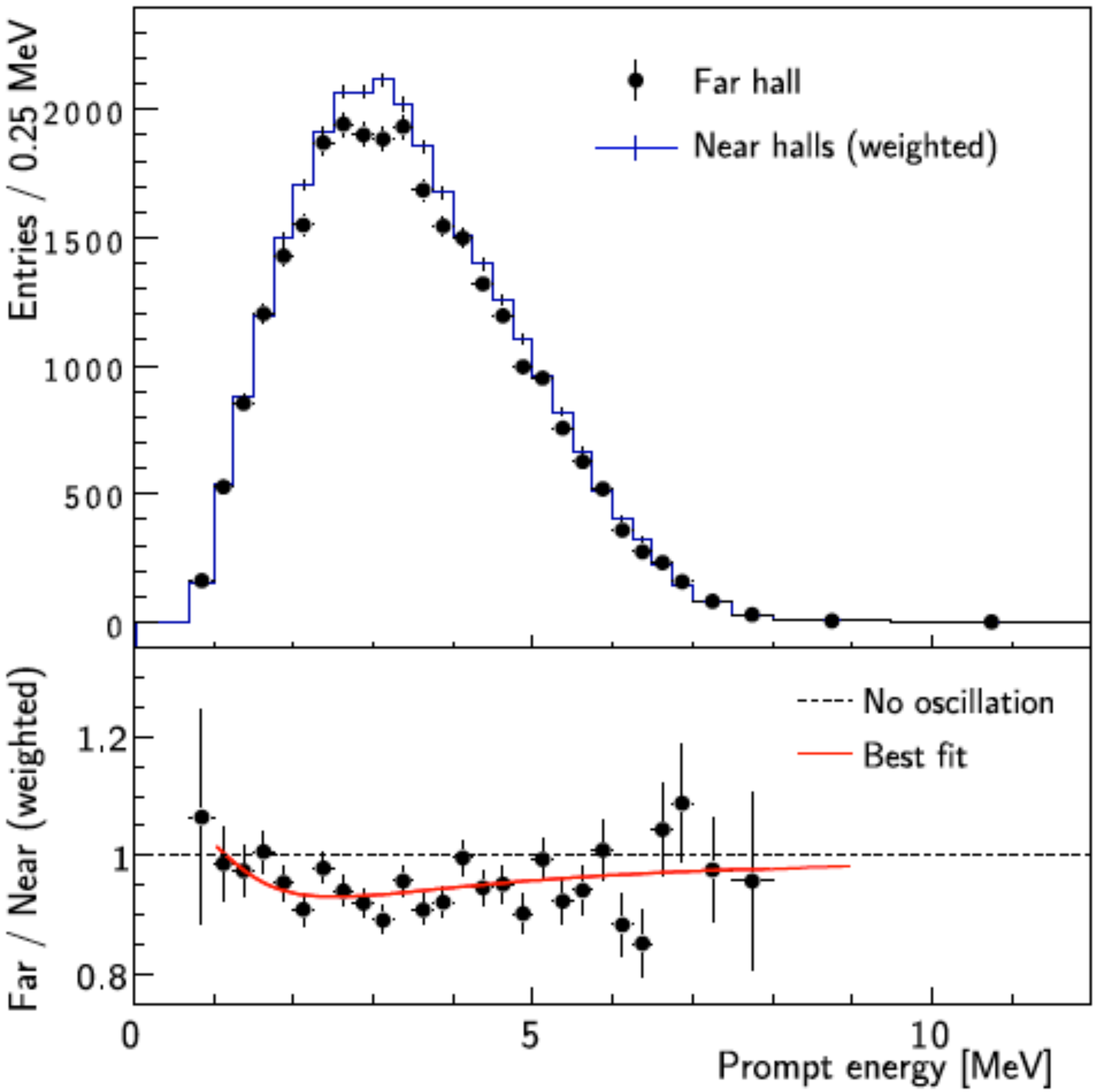
highlights on experiments…

- **RENO** (1204.0626)
  - **first multi-detector** running→ **rate only analysis** (229days)
  - remarkable effort/success by small (rather local) collaboration (Korea)
- **Double Chooz** (1112.6353,1207.6632,1210.3748, **today**)
  - **the (slow) pioneer: first detector design** (influenced the field)
  - **first result** (Nov.11) after **CHOOZ**→ θ13 large (**rate+shape**)
    - small detectors (8t target) & less overburden (still excellent BGs)
    - **FD+Bugey4** ("ND" via MC)→ high precision absolute knowledge
    - **best 1 detector results ever** (wrt CHOOZ)→ analysis quality
      - ND by spring 2014 but **5(+2) publication** so far
- **Daya Bay** (1203.1669,1210.6327)
  - **huge multi-detector complex**→ FD running since 25th Dec. 2011
    - largest θ13-detection complex→ full configuration (Sept. 2012)
    - large detectors (20t) & deepest overburden (low cosmogenic BG)
  - most precise result today→ **rate-only analysis** (139days, 6 detectors)
    - fantastic first results within 55days of data-taking

θ13 results…

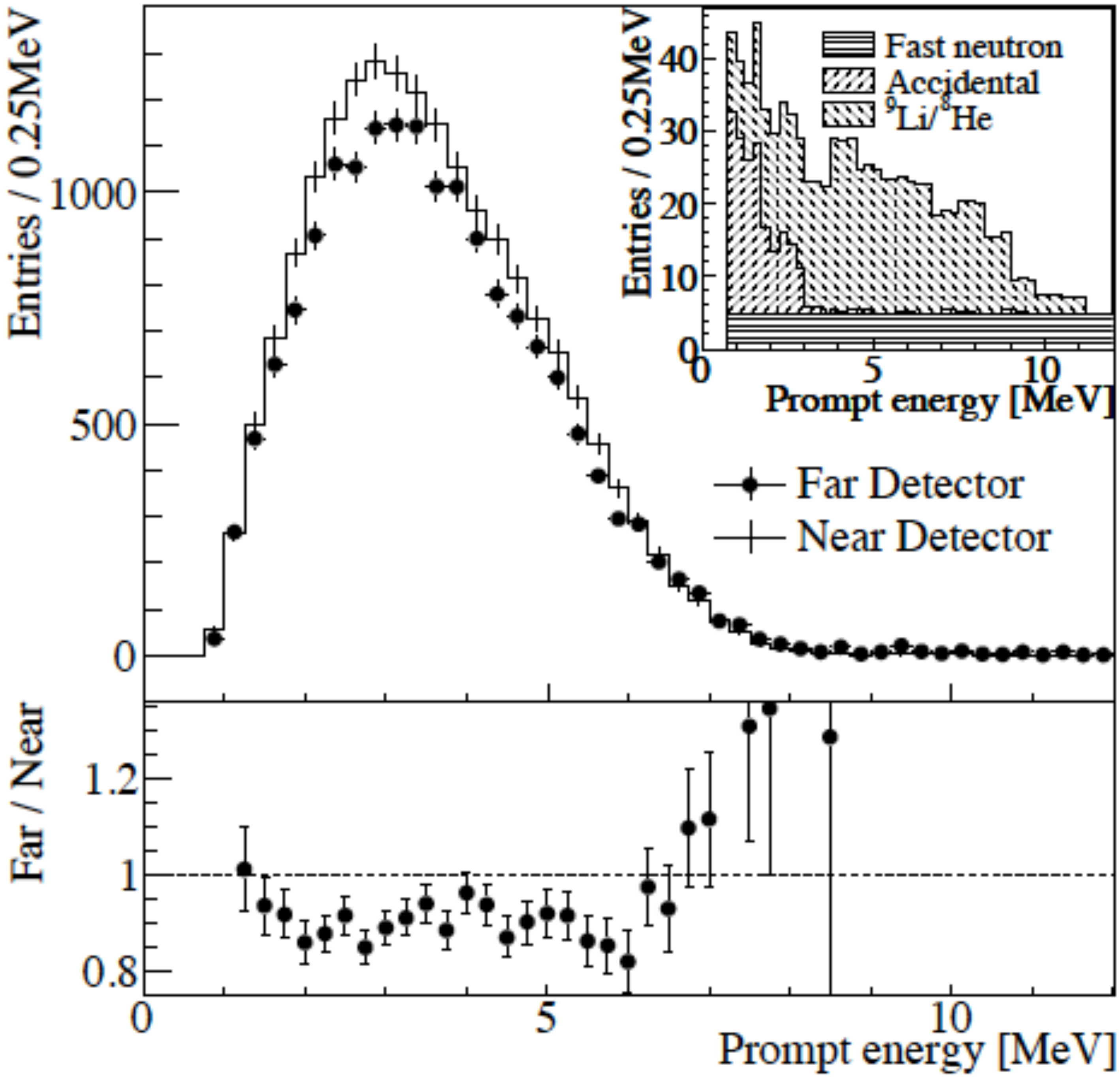
Anatael Cabrera (CNRS-IN2P3 & APC)

latest Daya Bay… [June 2012]



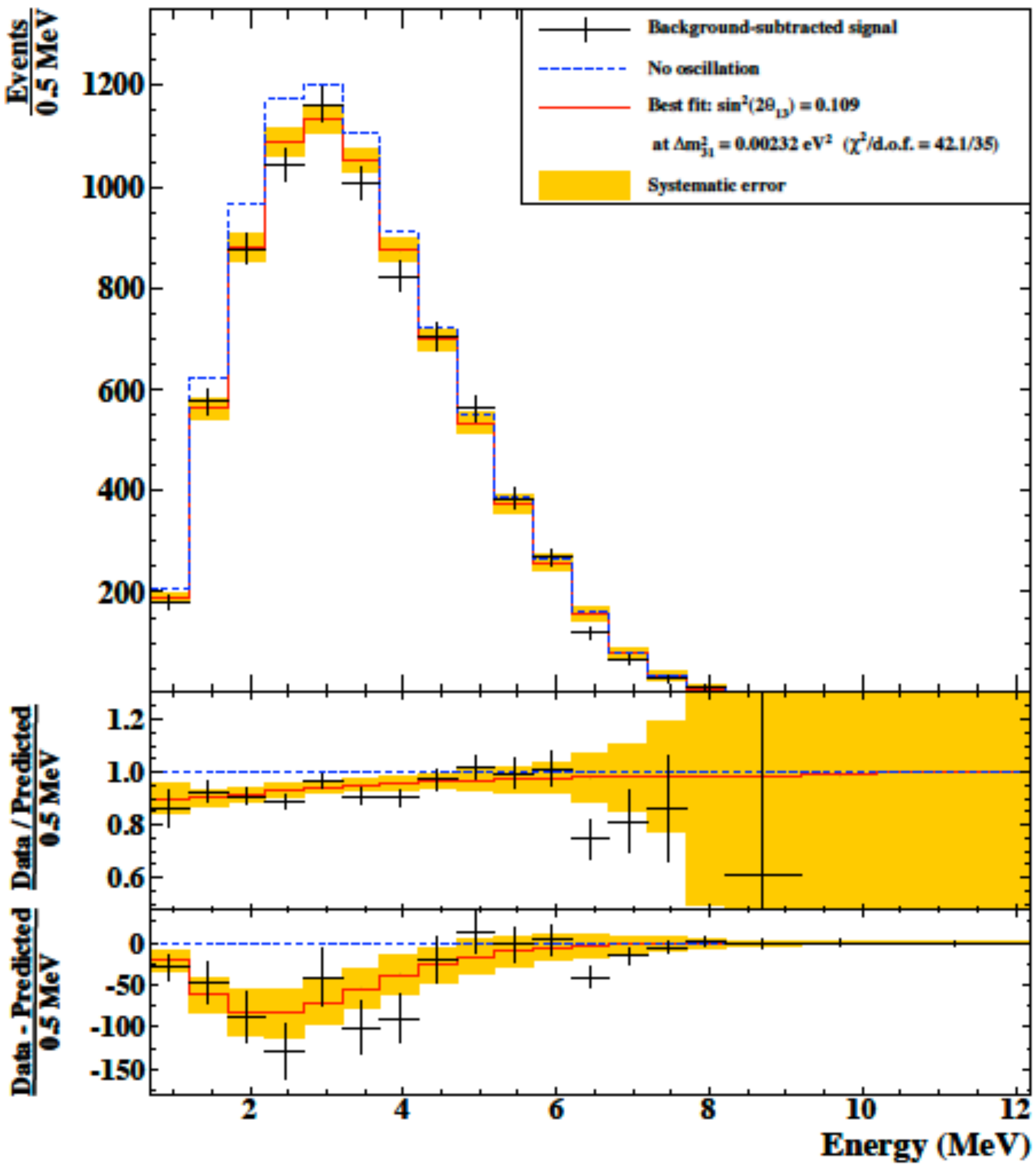
Anatael Cabrera (CNRS-IN2P3 & APC)

latest RENO… [April 2012]



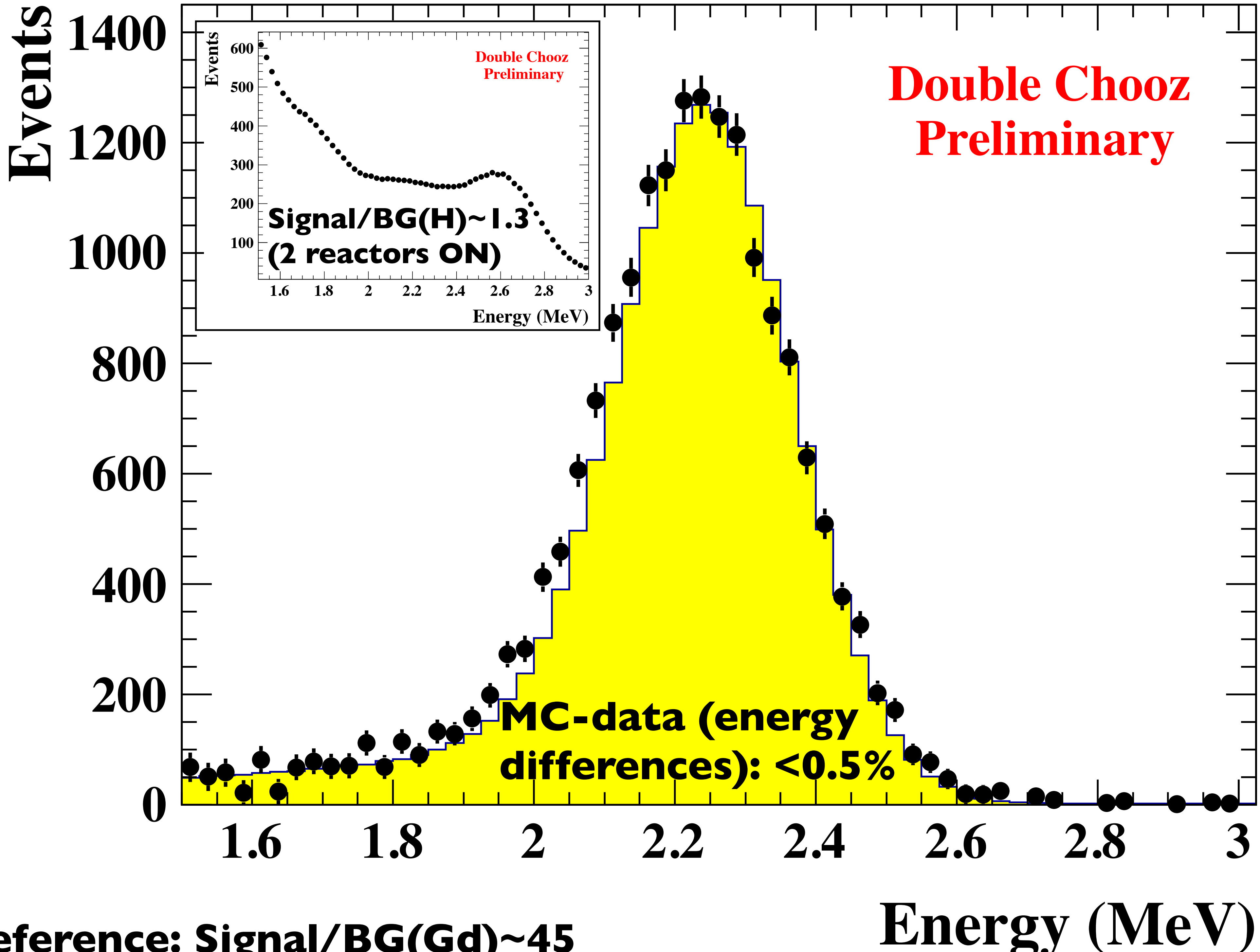
Anatael Cabrera (CNRS-IN2P3 & APC)

latest DC(Gd)…[June 2012]




12/12/3 @ APC(Paris)
official data release
new results by DC (**now**)...
Anatael Cabrera (CNRS-IN2P3 & APC)

select IBD by capturing on H…

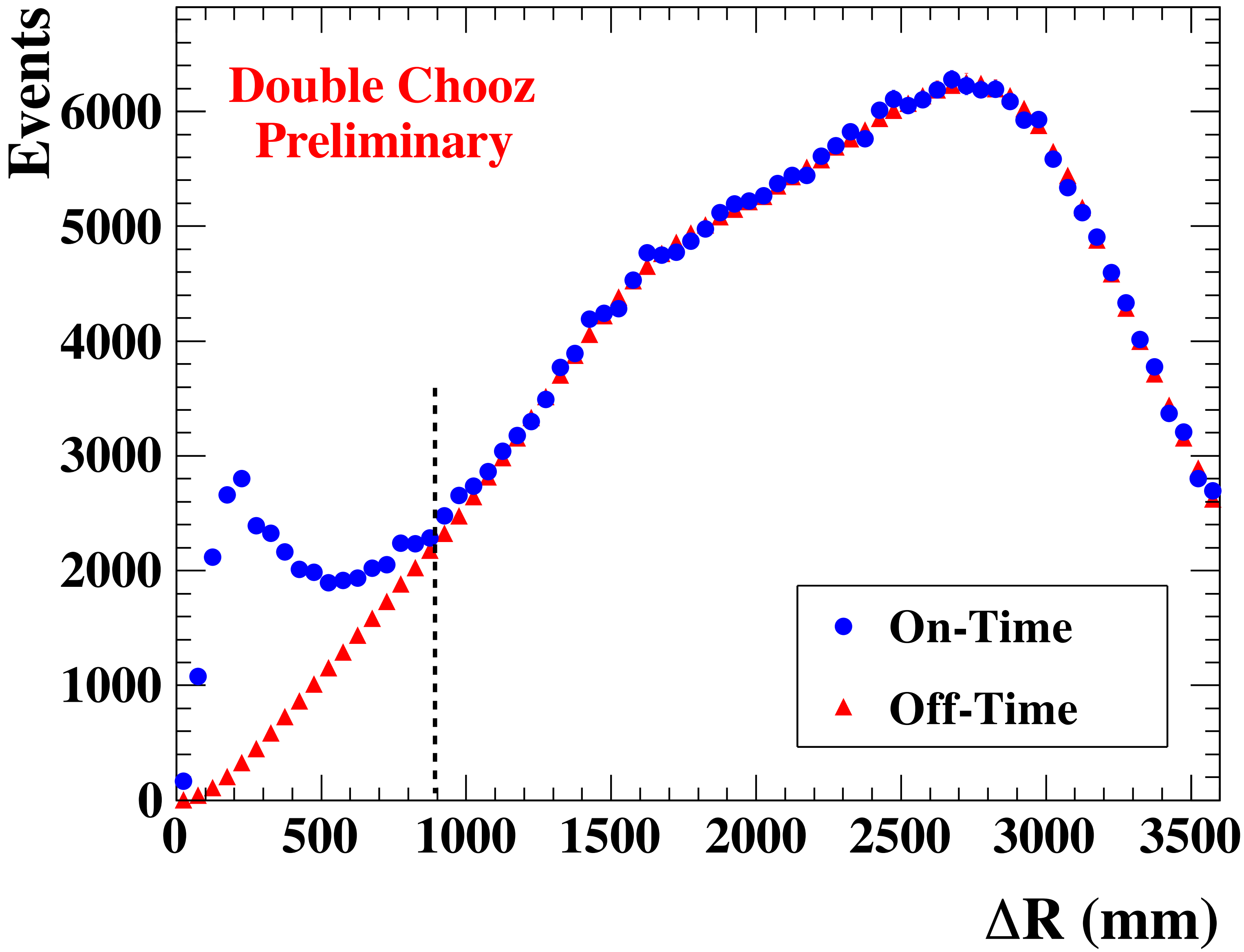


Reference: Signal/BG(Gd)~45

(PC)

killing accidentals: cut on Δd(prompt-delay)…

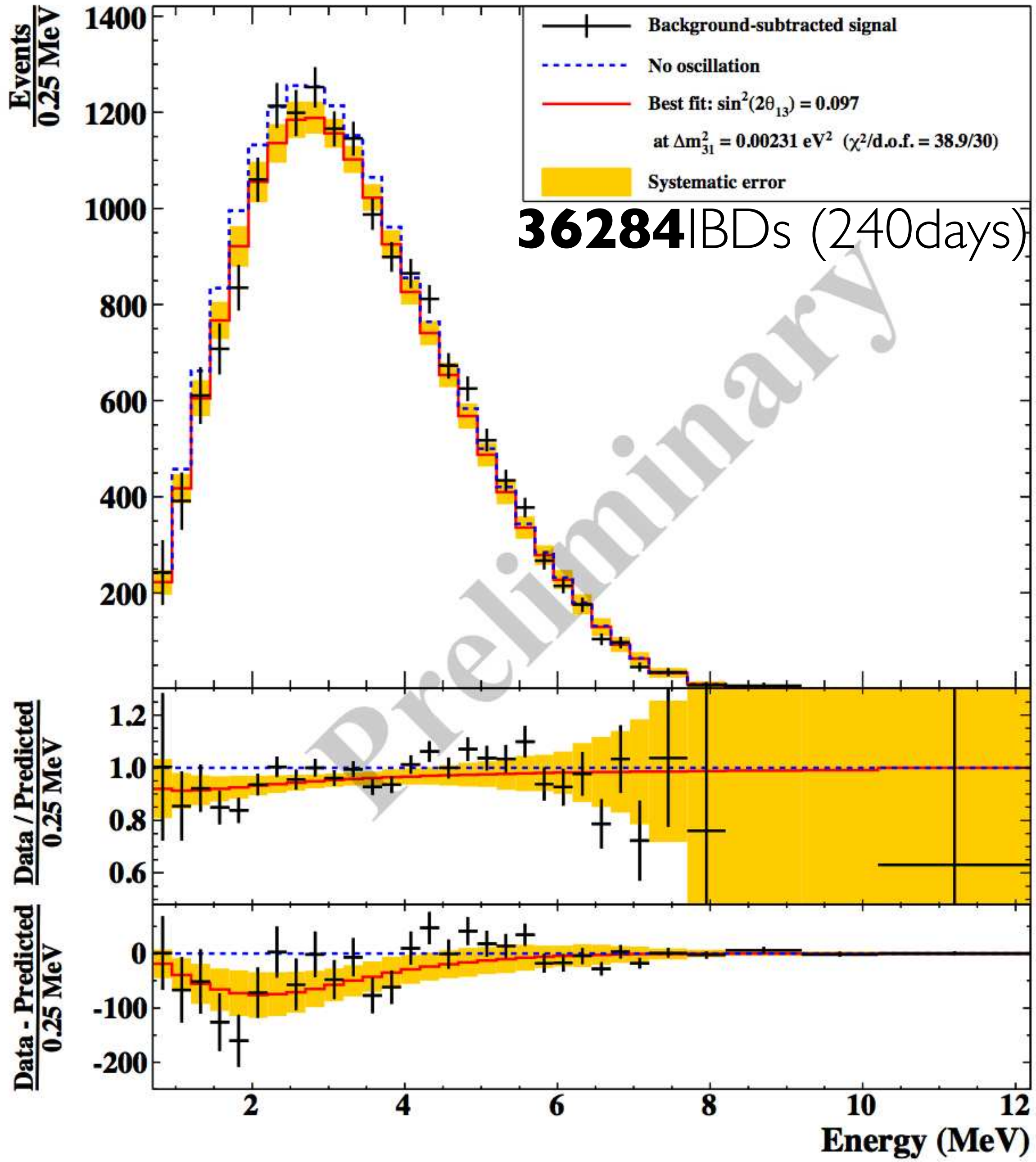
excellent precision on vertex-reco→**narrow Δd** (correlated events)



Anatael Cabrera (CNRS-IN2P3 & APC)

DC-II(H) rate+shape θ13 measurement…

BG subtracted…

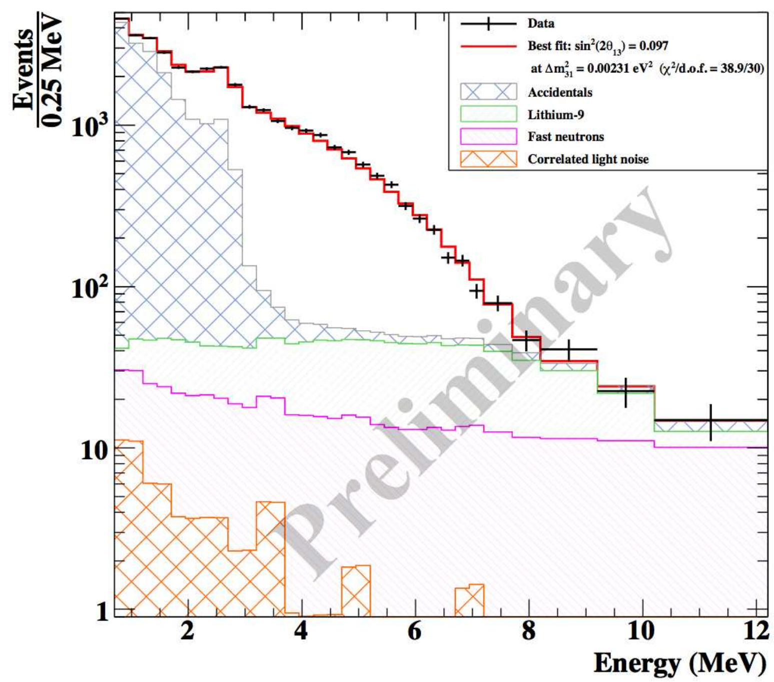


systematics budget…

Source of uncertainty	n-H variance	n-Gd variance
Total statistical error	1.05%	1.12%
Accidentals	0.21%	0.01%
Li-9	1.50%	1.46%
Fast neutrons	0.61%	0.54%
Correlated light noise	0.09%	N/A
Energy scale	0.34%	0.32%
Detection efficiency	1.57%	1.01%
Reactor	1.75%	1.76%

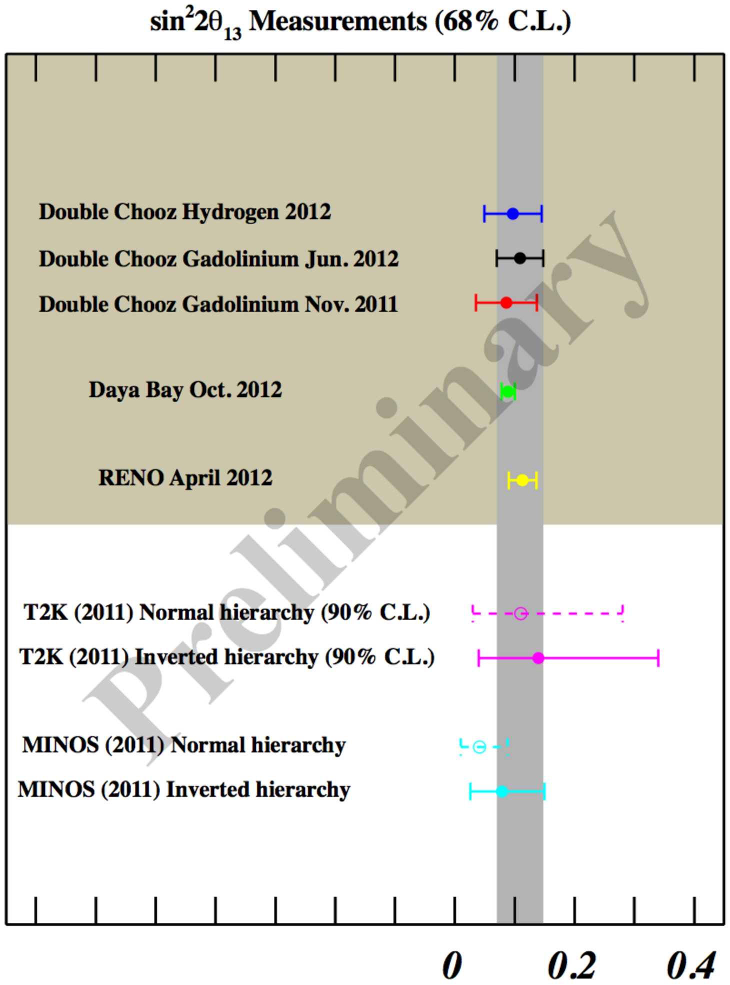
p on target: $6.75\times10^{29}\pm0.3\%(T)+1.58\times10^{30}\pm1.0\%$(GC)

with BGs…



DC-II(Gd) and DC-II(H) compatible to (68-84)% (depending on correlation)

results summary…

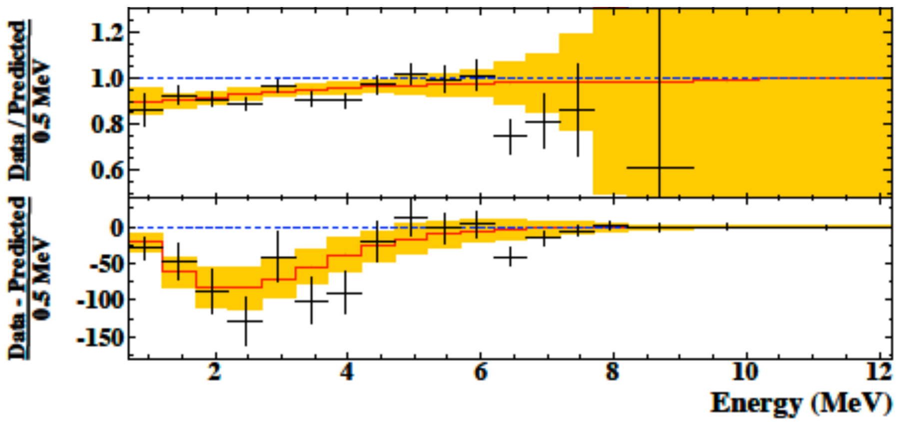


- amazing progress since end of 2011…
- all results are consistent…
    - coherent picture: θ13 is LARGE
    - easier since precision is not great yet
- accuracy→most important with higher precision
    - Daya Bay leads the way for now
    - redundancy is a must (and happening)

	$\sin^2(2\theta_{13})$	exposure (days)	arXiv
DC I(rate+shape)	$0.086\pm0.051(0.041^{stat}\pm0.030^{sys})$	96.8	1112.6353
DB I(rate only)	$0.092\pm0.017(0.016^{stat}\pm0.005^{sys})$	55	1203.1669
RENO(rate only)	$0.113\pm0.023(0.013^{stat}\pm0.019^{sys})$	229	1204.0626
DC_{Gd} II(rate only)	$0.170\pm0.053(0.035^{stat}\pm0.040^{sys})$	251	1207.6632
DC_{Gd} II(rate+shape)	$0.109\pm0.039(0.030^{stat}\pm0.025^{sys})$	251	1207.6632
DB II(rate only)	$0.089\pm0.011(0.010^{stat}\pm0.005^{sys})$	139	Nu2012
DC_{H} II(rate+shape)	$0.097\pm0.048(0.034^{stat}\pm 0.034^{sys})$	240	**this week**

E/L disappearance effects…

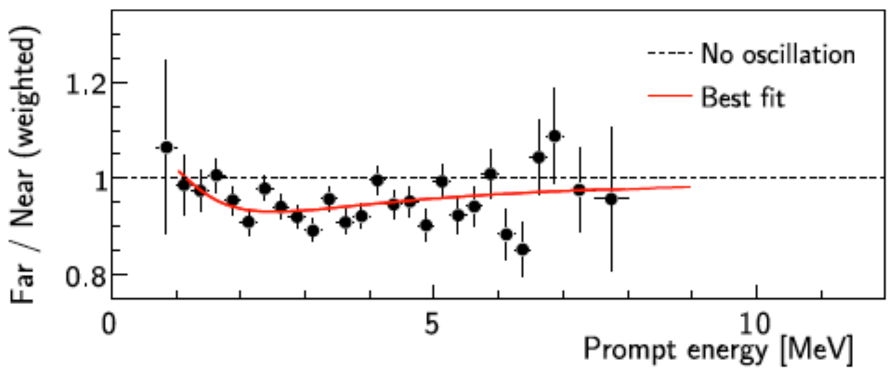
DC-II (Gd) (June'12)



<L>= 1050m

- short L→ hard to see rise (low constrain in Δm^2)
- shape analysis: $\theta 13$ only over oscillation region
- N(obs)/N(exp)→ N(exp) from MC (no BG)
- DC-II(H)→ no structure @ 6MeV

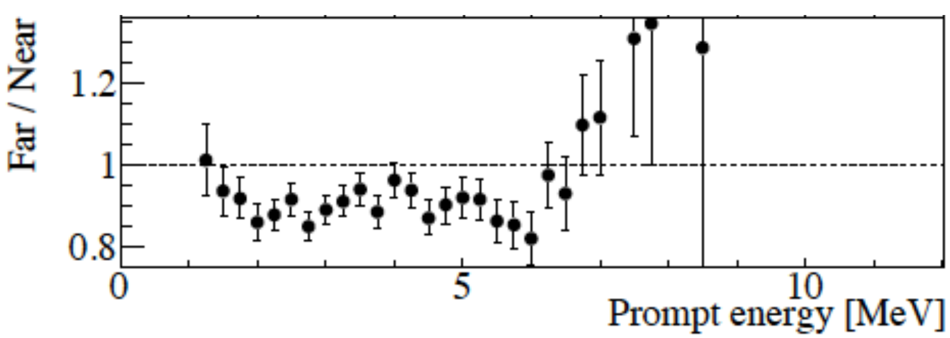
DB (June'12)



<L>= 1648m

- L/E shape→ sensitive to Δm^2
- "healthy" shape but **rate only** (no p-value)

RENO (April'12)



<L>= 1383m

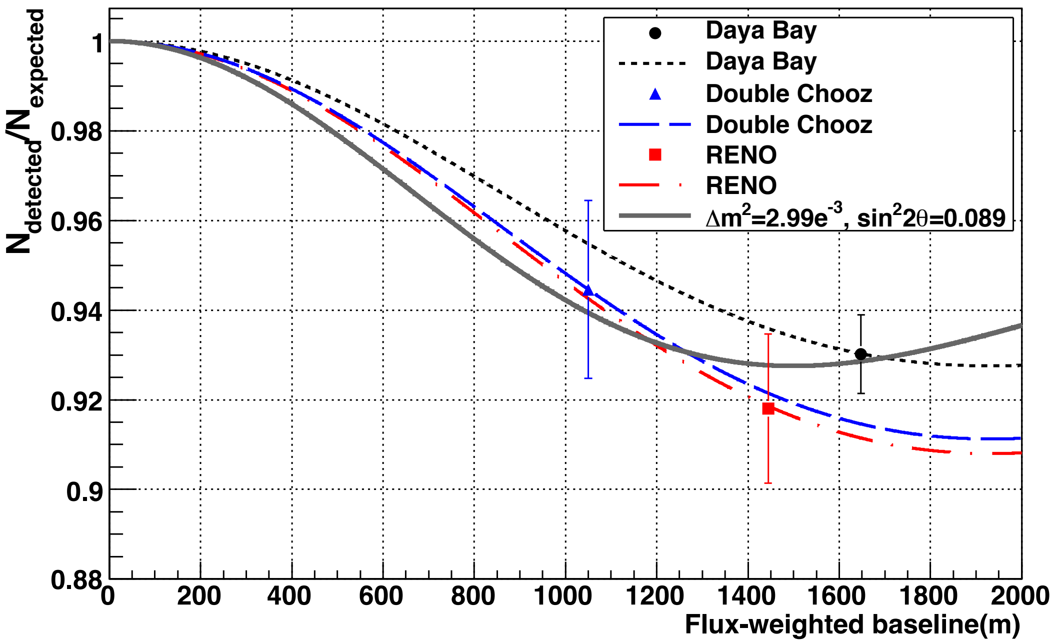
- shape: fully consistent with $\theta 13$ only effect?
- **rate-only** analysis→ all assumed to be $\theta 13$

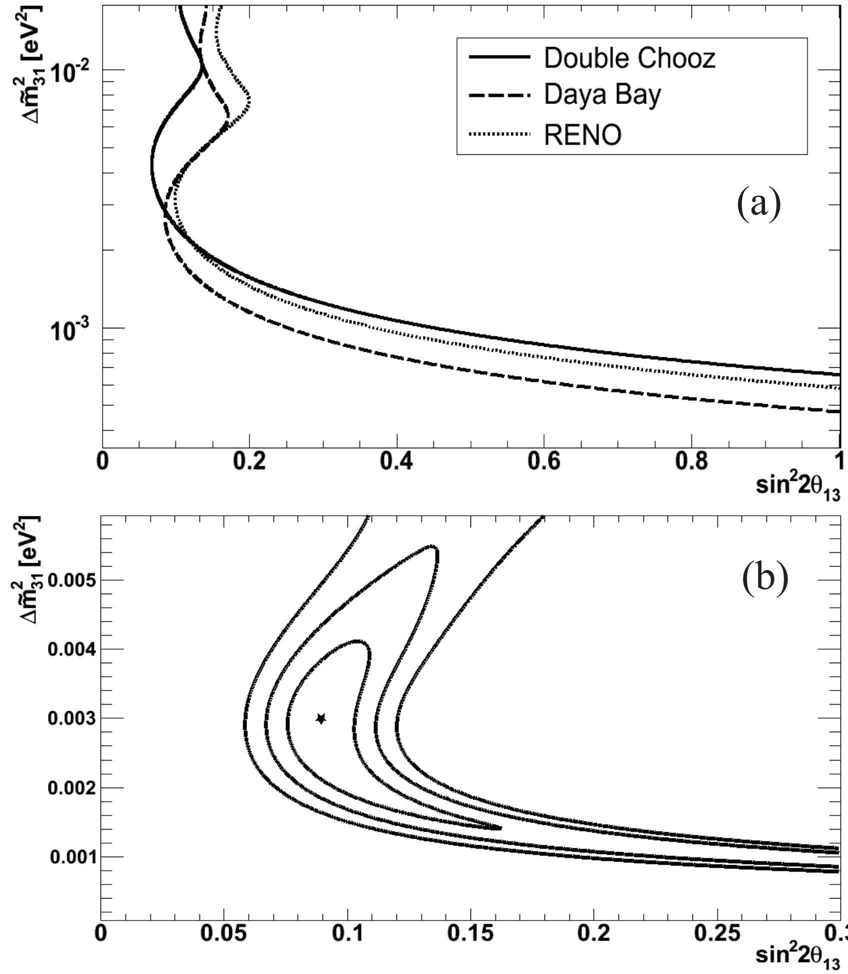
strage behaviour (@ ~6MeV)?→ **rate+shape analysis a MUST!**

combining baselines→ Δm^2_{31} measurement?

1206.6017 (Suekane-sama's team)

3 experiments→ 3x θ13 measurements





- difference baselines
- combine results→ constraint Δm^2_{31}
- important physics (even less precision than MINOS)

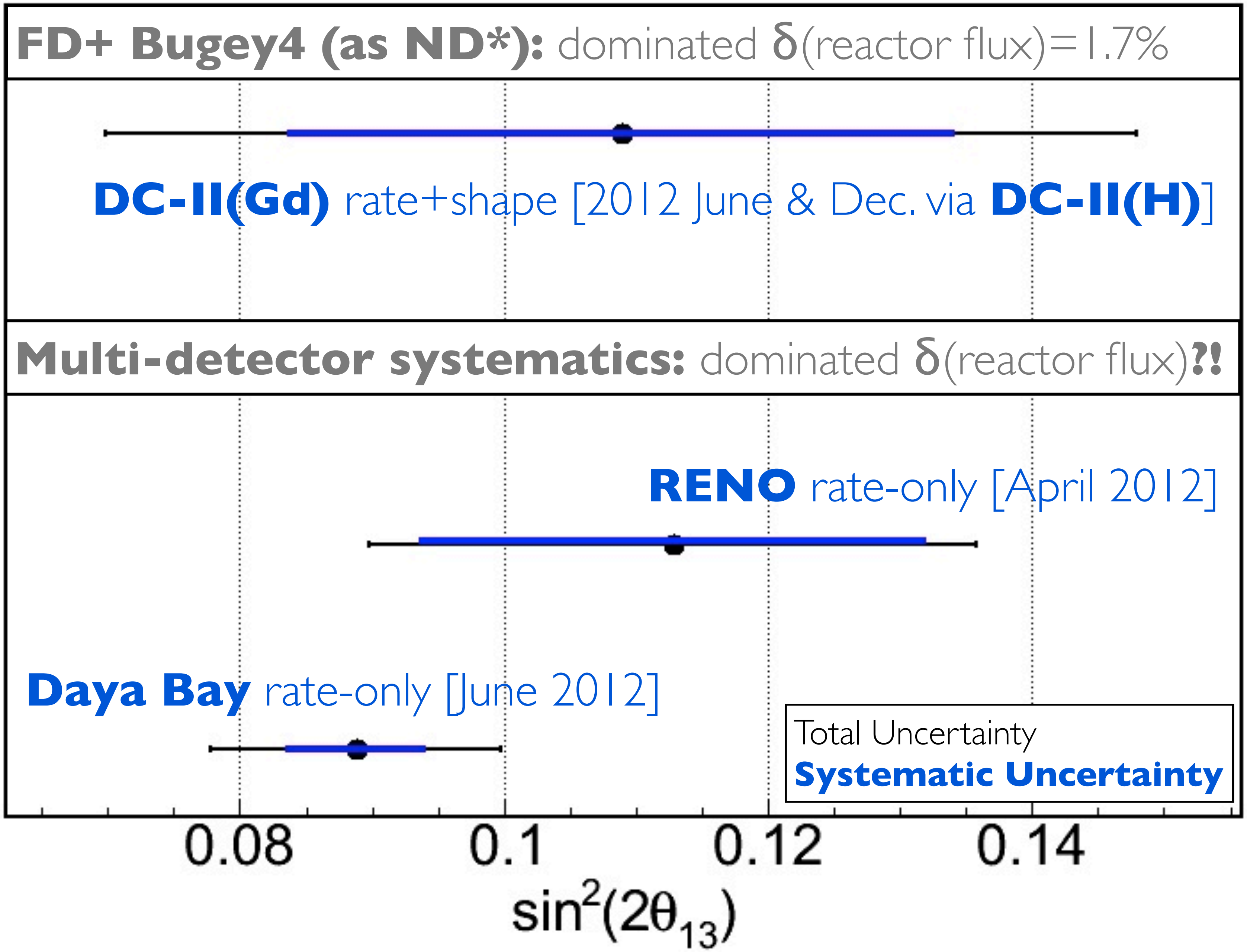
Anatael Cabrera (CNRS-IN2P3 & APC)

θ13 reactor challenges

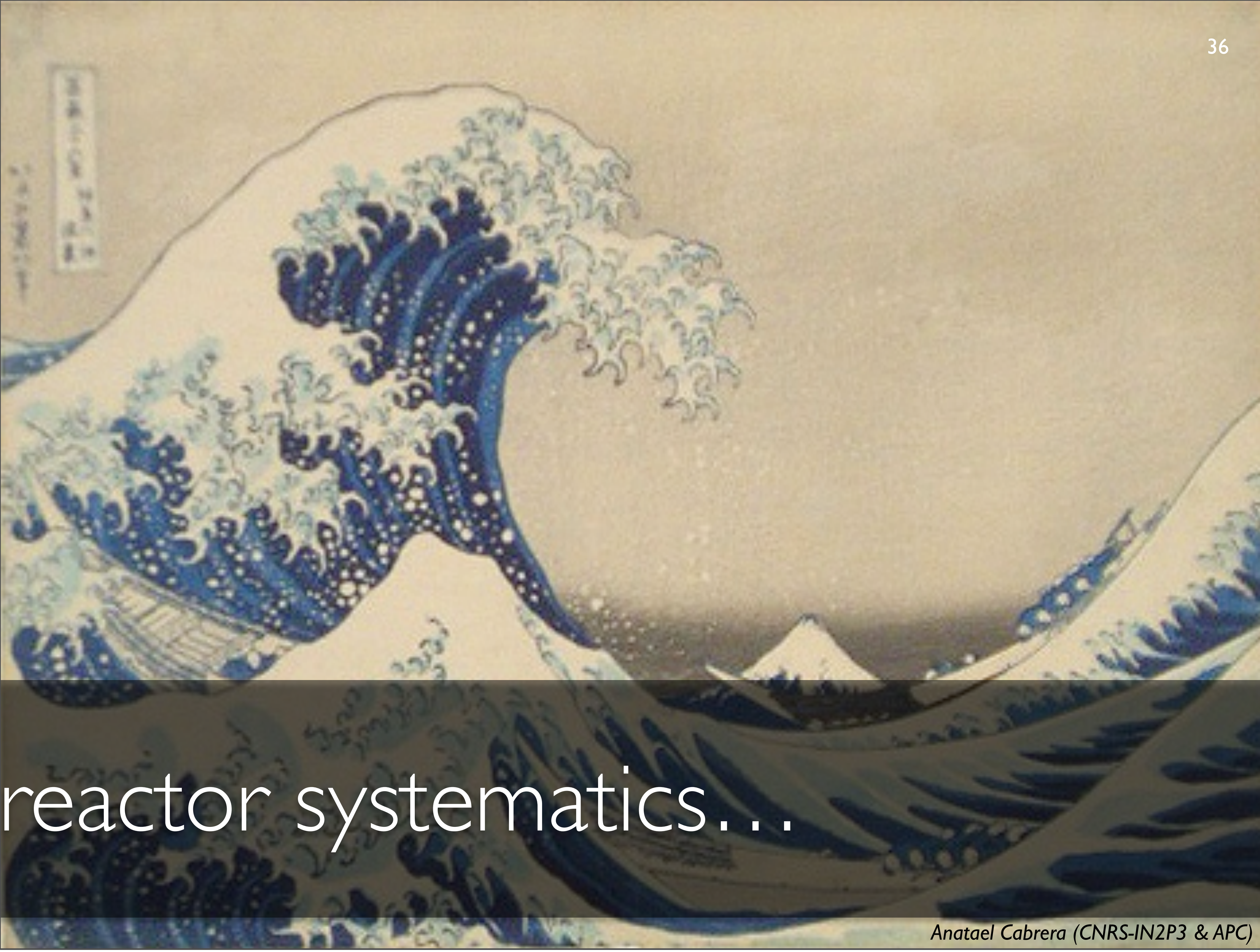
- **statistical uncertainty**
  - generally all experiments enough (DC a little too small)
- **δ(flux): flux uncertainty (→impacts mainly rate)**
  - ND critical→ eliminates primary reactor flux and spectral shape uncertainties
  - issue: **uncorrelated reactor** systematics
- **δ(detection): detection uncertainty (→impacts mainly rate)**
  - ND critical→ eliminates many inter-detector detection systematics
  - excellent detector understanding (**energy-reco** and **MC**)
  - issue: **uncorrelated inter-detector** systematics
- **δ(BG): backgrounds uncertainties (→impact both rate & shape)**
  - each site a different BG☐ rate and shape (specially correlated BG)
    - ND more signal but also more BG→ shapes can also be different
  - issue: **normalisation and shape of each BG** (with reactor ON→hard!)
- **warning: high-precision physics** (i.e. systematics @ "per-mil" level)
  - **first word** (**fast**)→ impressive θ_{13} (large) measurement "overnight"
  - **final legacy** (**slow**)→ cross-checks for best θ_{13} world knowledge

it's all about systematics...

my goal: explain to you ***how systematics are controlled***...
(please note **per-mil** systematics→ <u>very careful</u>)



√2P3 & APC)

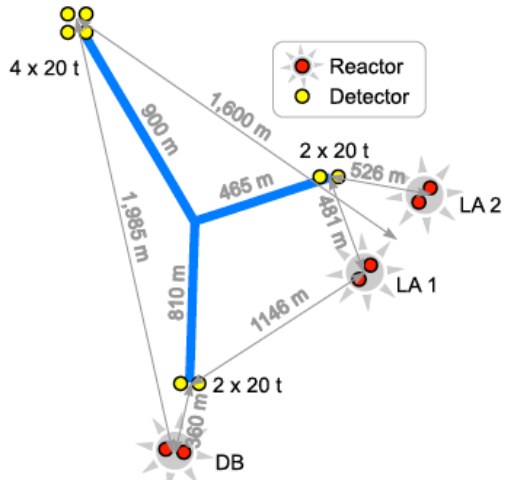


reactor systematics…

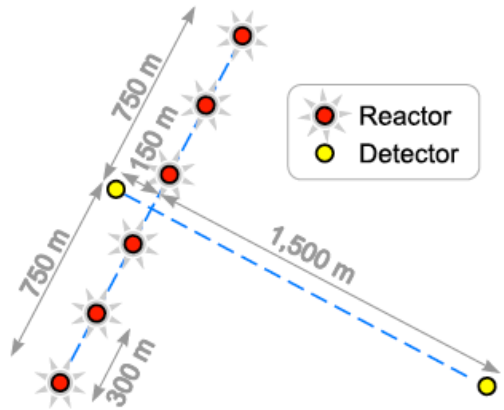
reactors vs detectors interplay…

multi-detector: "kill" δ(flux) totally? yes…? (proposals)

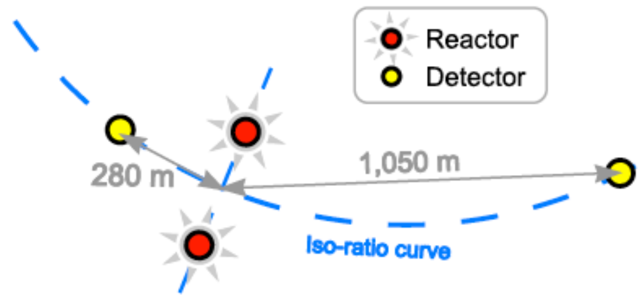
Daya Bay



RENO



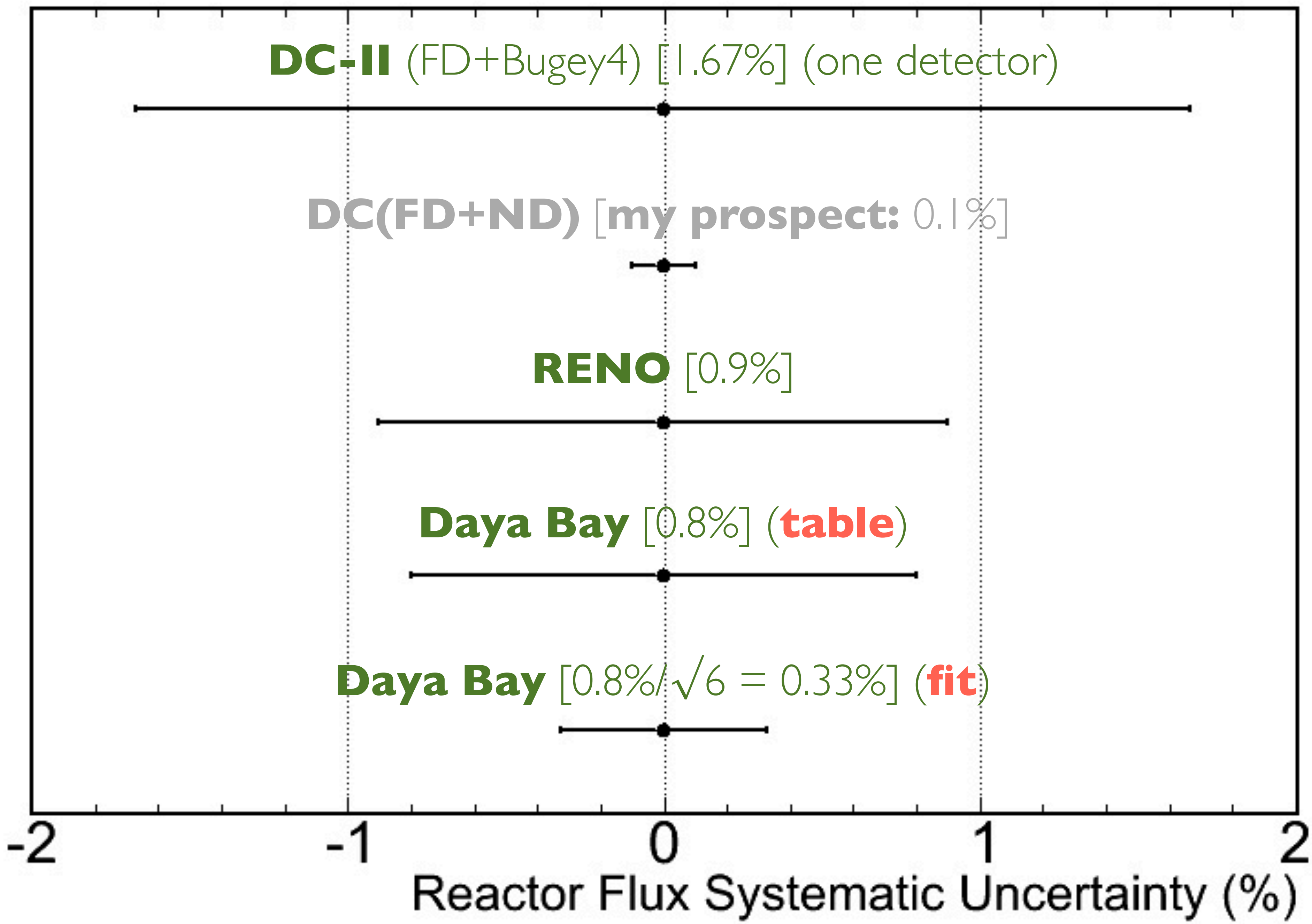
DC



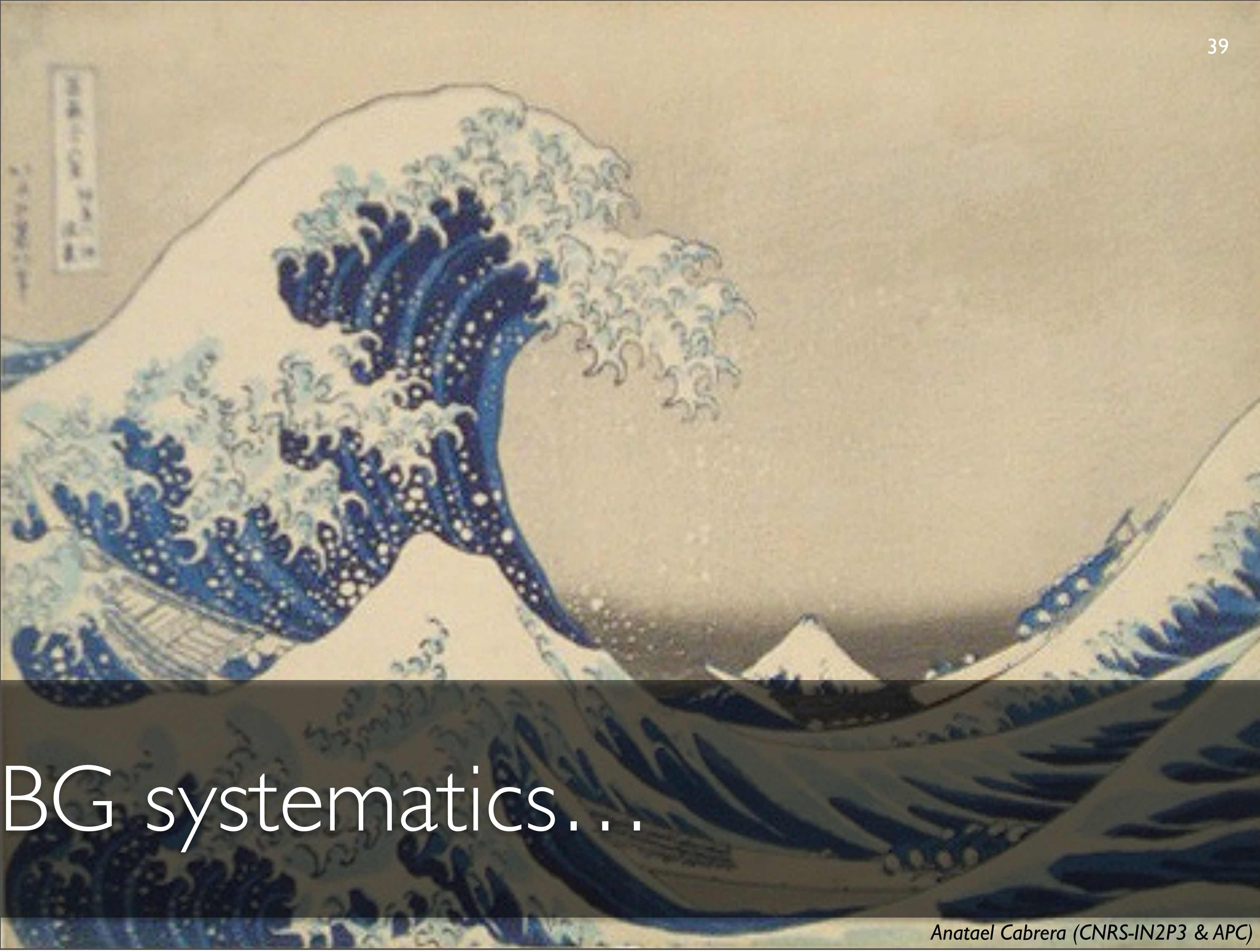
δ(flux): 0.8% (DB), 0.9% (RENO), ?(0.1~0.3)% (DC)
(*"uncorrelated reactor flux uncertainty"*)

- **RENO/DB:** ~0.5% (thermal power) & ~0.6% (fission fractions)
  - **extremely hard to improve this** (impossible?)
- geometry is **critical**…
  - *"Rate(FD)/Rate(ND) per reactor and per ND?"*
    - **DB:** to some extent(?)→ **δ(flux)=0.8%/√6** (used in publication)
    - **RENO:** not enough(?)→ **δ(flux)=0.9%** (large)
    - **DC:** almost isoflux→ **δ(flux)≤0.3%** (**under study**)
- **δ(flux) dominant uncertainty for DB & RENO [→ not DC!]**

reactor flux uncertainty…



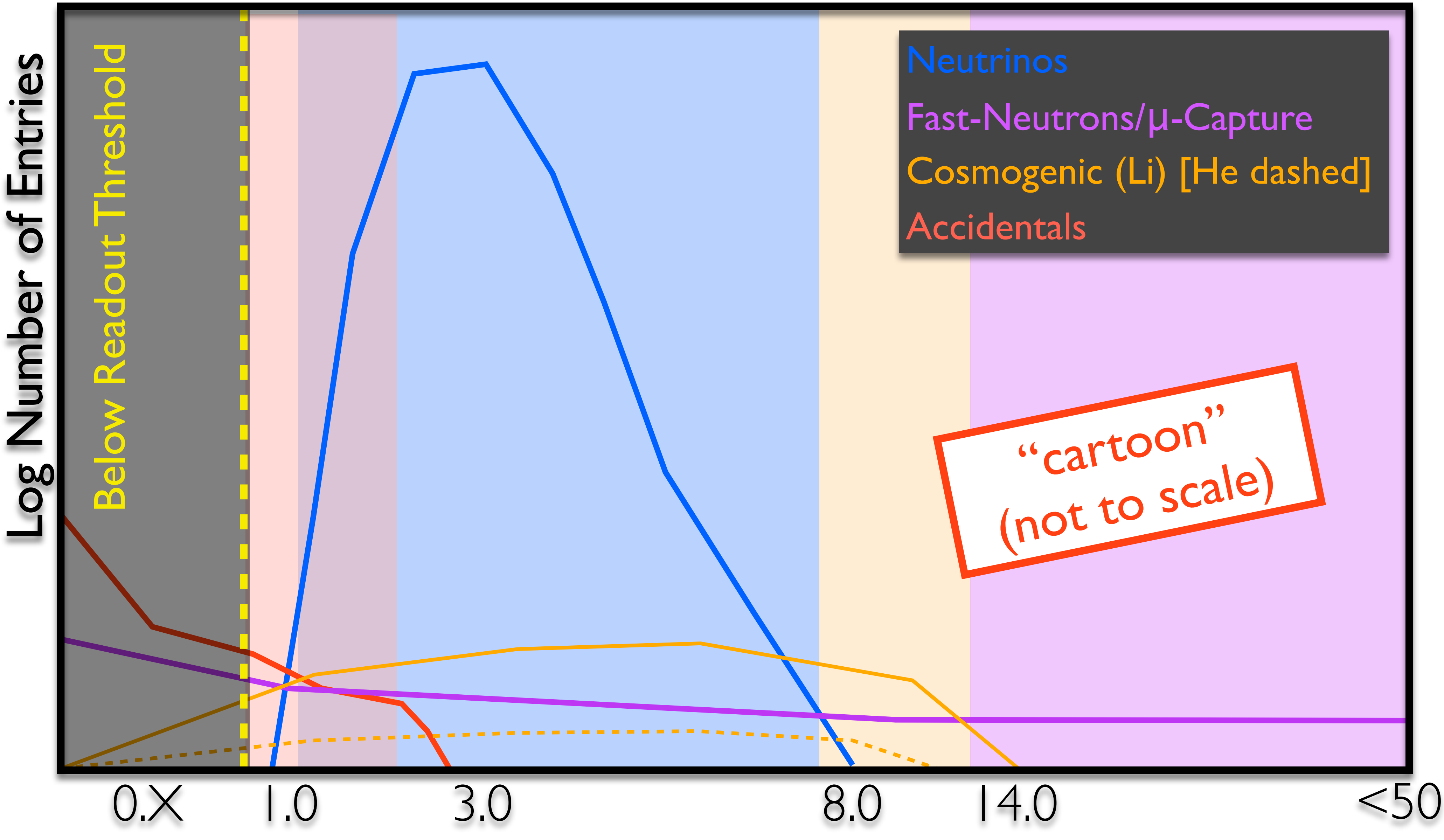
Anatael Cabrera (CNRS-IN2P3 & APC)



BG systematics…

BG model (CHOOZ+KamLAND)…

is this the full story?
(so far, entirely assumed by all experiments)



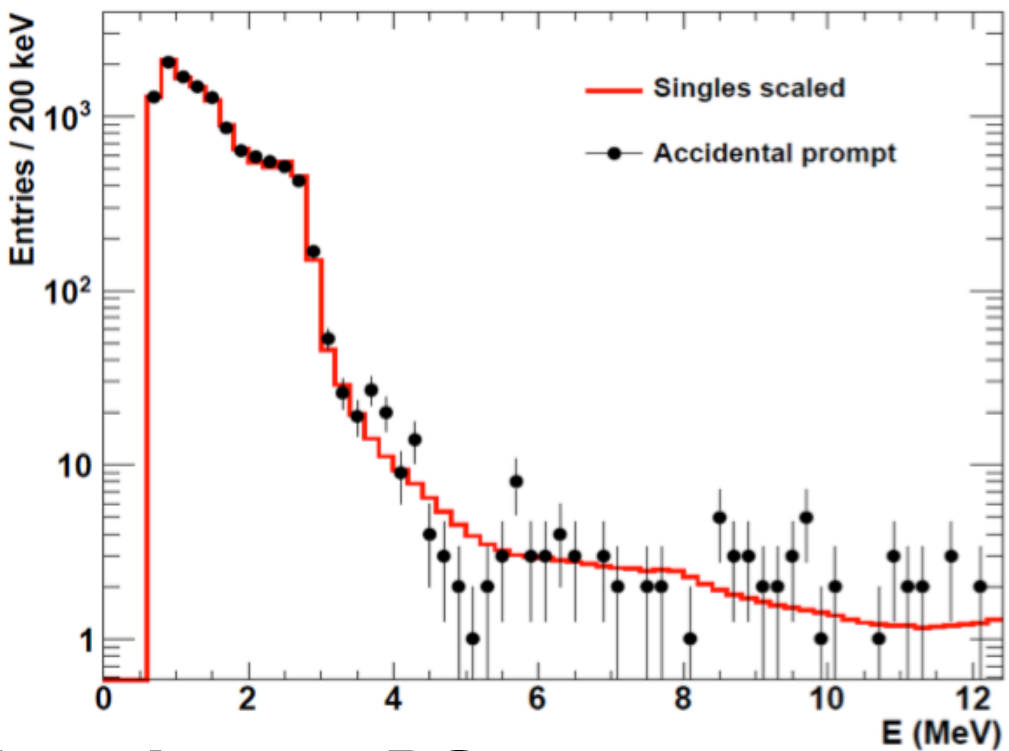
Anatael Cabrera (CNRS-IN2P3 & APC)

measuring & validating BG model…

- **BG measurement:** rate (much easier) & shape (statistics limited knowledge)
  - CHOOZ BGs→ no say on Li (reactor OFF)→ KamLAND observed it!
  - **BG knowledge better with time:** ≤1BG per day
- **1(all): measure each BG** (sample) **with reactor ON**
  - **cons:** sub-sample (different selection) & approximations/extrapolations
    - corrected/scaled (**accuracy?**) & complete (**missing shape?**)
- **2(DC): fit θ13+BGs** (shape analysis) **with reactor ON**
  - **pro:** use knowledge a priori (method-1)→propagate to θ13 (correlations)
  - **cons:** interpretation of pull-info (degeneracies) & and lack of knowledge still
- **3(DC): reactor OFF direct measurement** (total rate validation)
  - **pro:** direct measurement (no assumptions)→**complete** BG model (CHOOZ)
  - **cons:** stats very limited (1 week now)→ little BG shape information
- **4(DC): observed vs expected correlation**
  - **pro:** direct use of reactor ON and OFF→**BG rate estimation**
- **5(DC): 2 Integration Periods** when doing method-2 ("2-1 reactor" analysis)
  - **validation:** θ13 outcome is the same for 2IP~1IP (DC-II)→**BG robust**

individual measurement…
(all experiments)

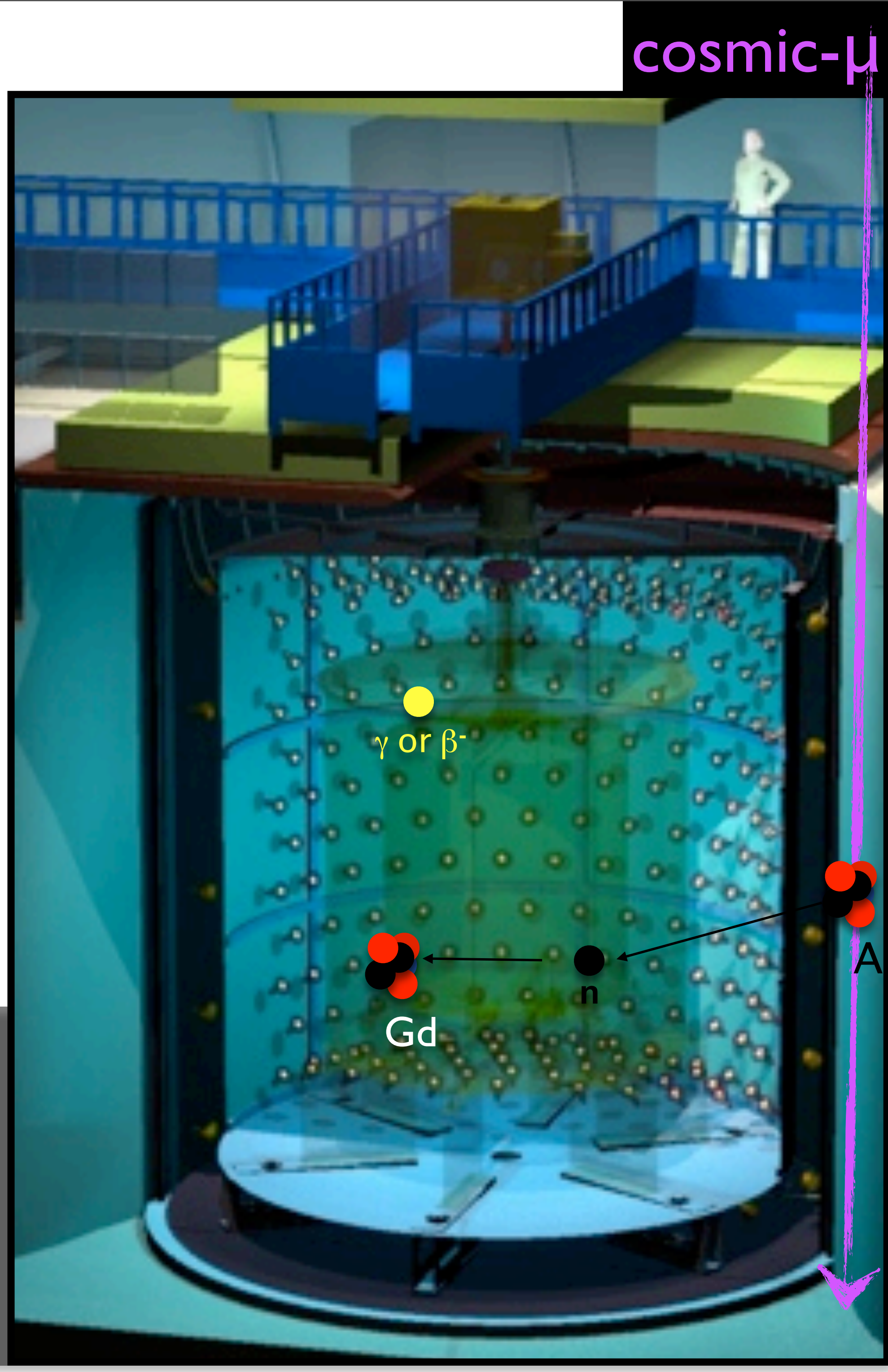
Anatael Cabrera (CNRS-IN2P3 & APC)



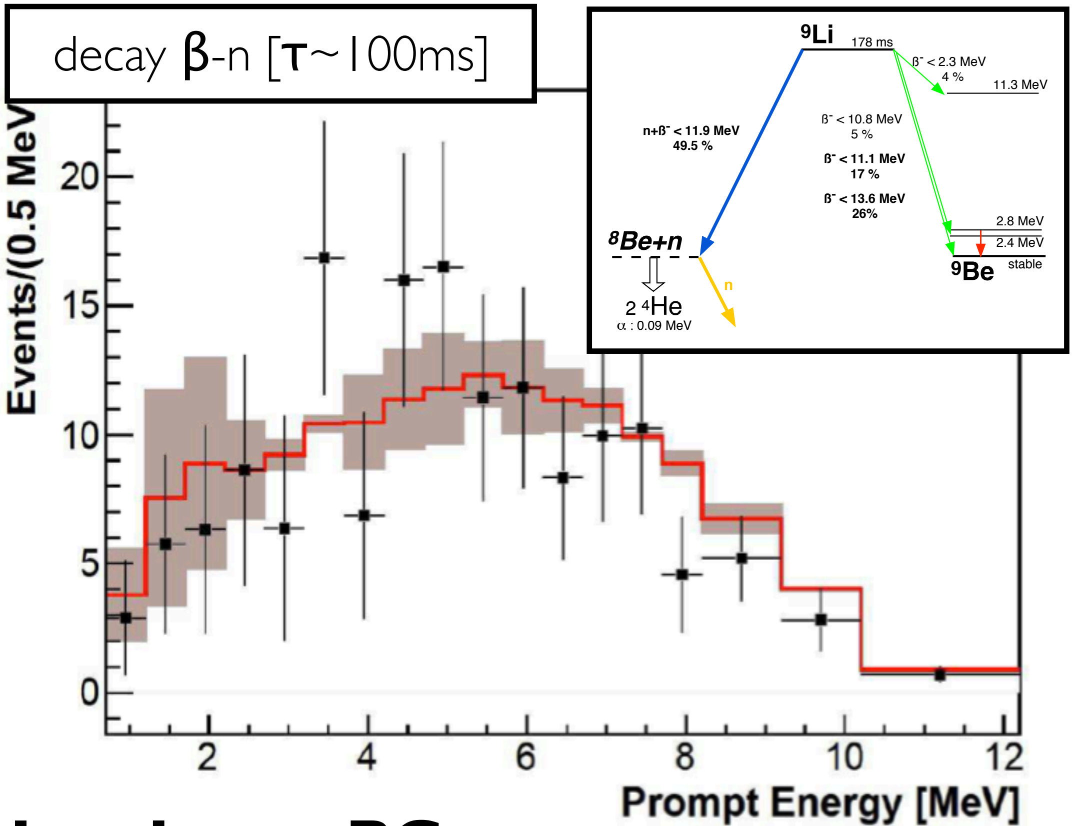
best known BG...

- δBG/Signal→0 (i.e. no rate systematics)
- (if large) distort shape @ oscillation region

accidental BG...



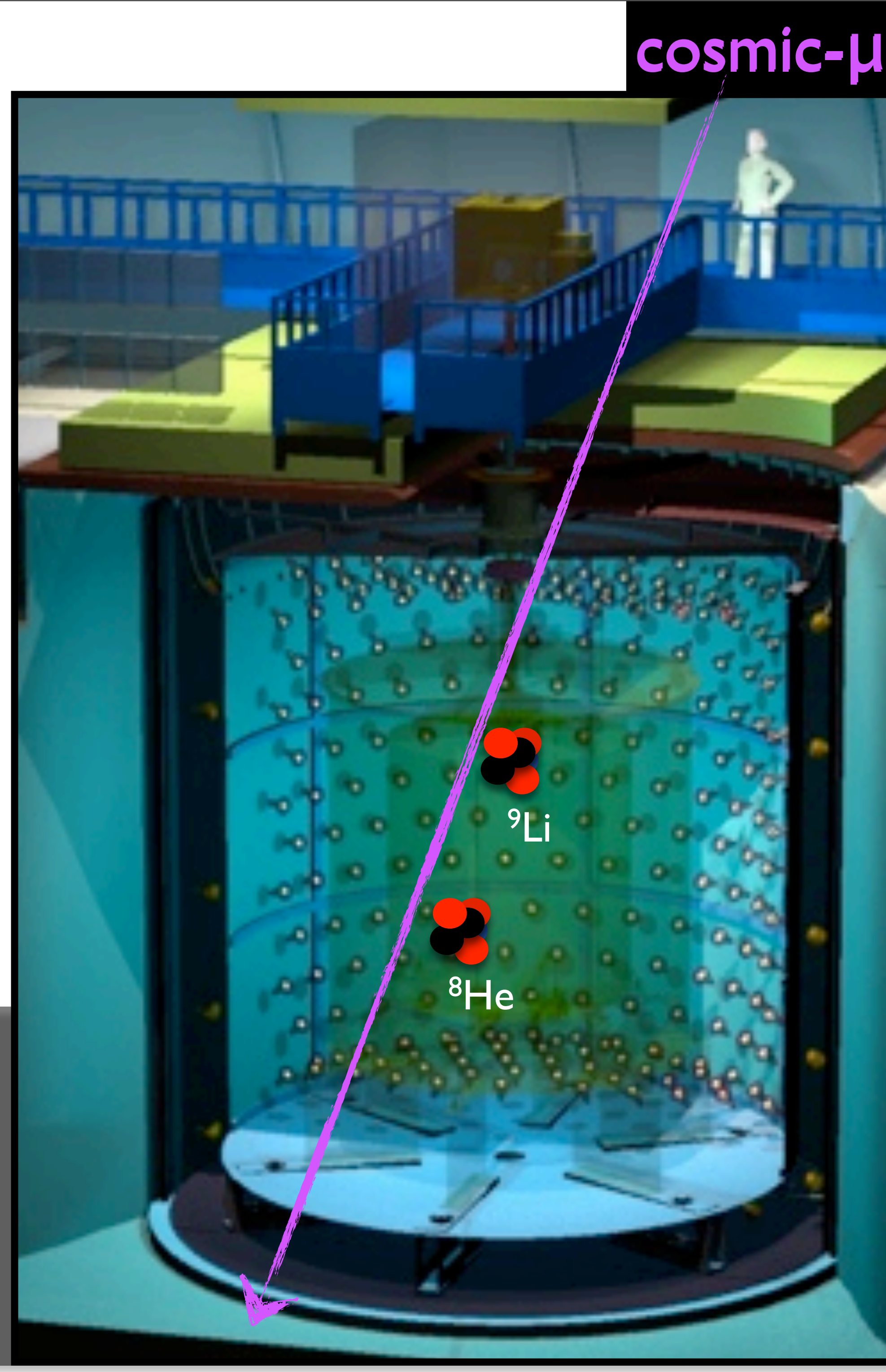
Anatael Cabrera (CNRS-IN2P3 & APC)



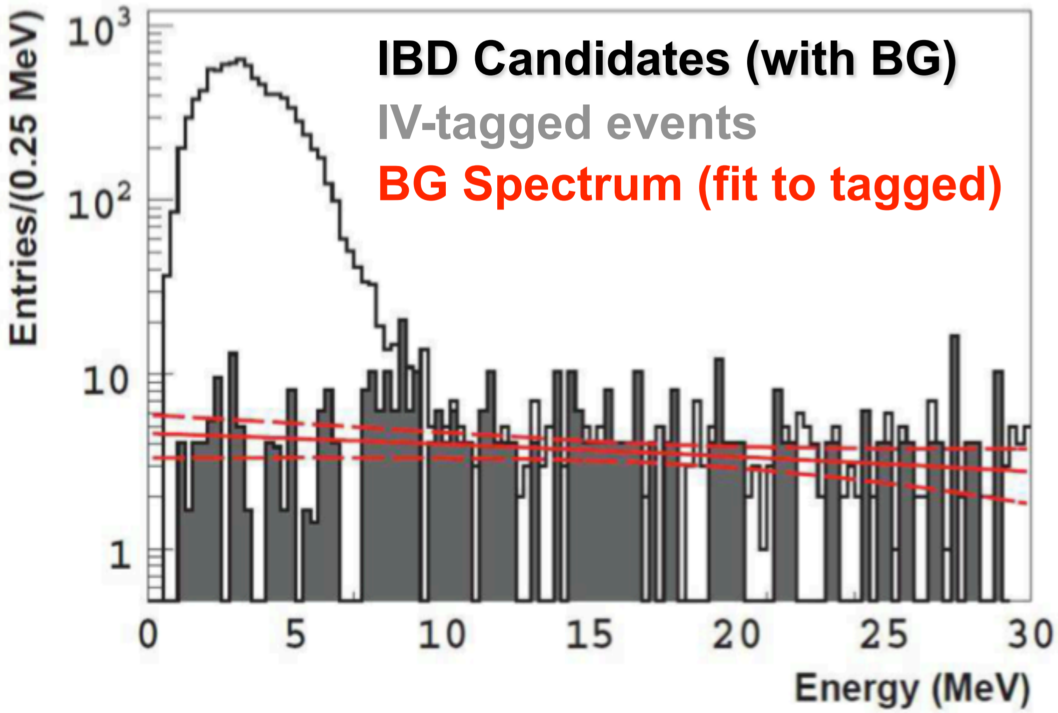
less know BG…

- δBG/Signal→largest (rate systematics)
- poorly known shape (MC→KamLAND)

cosmogenic BG… (^{9}Li and ^{8}He)



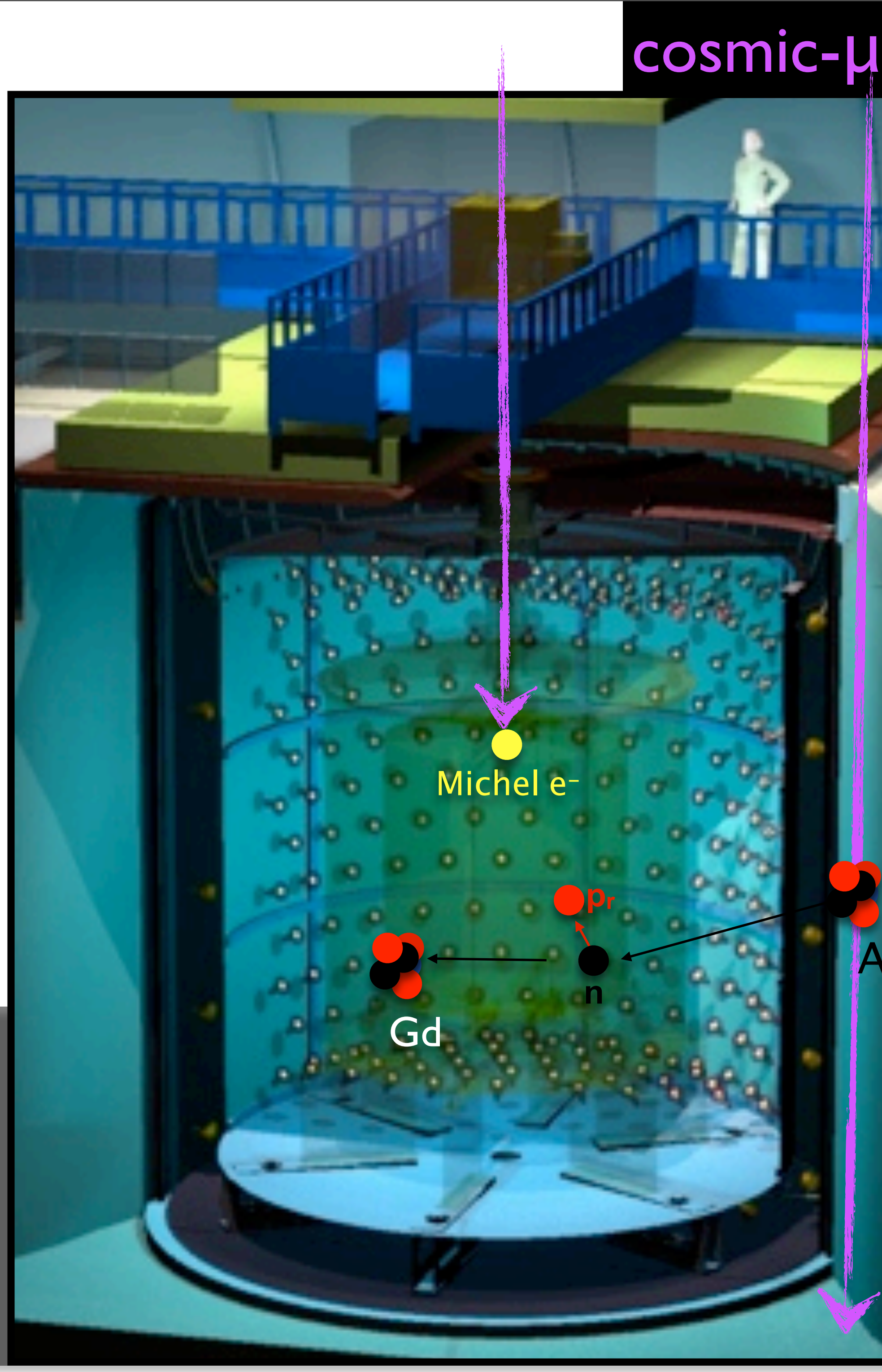
Anatael Cabrera (CNRS-IN2P3 & APC)



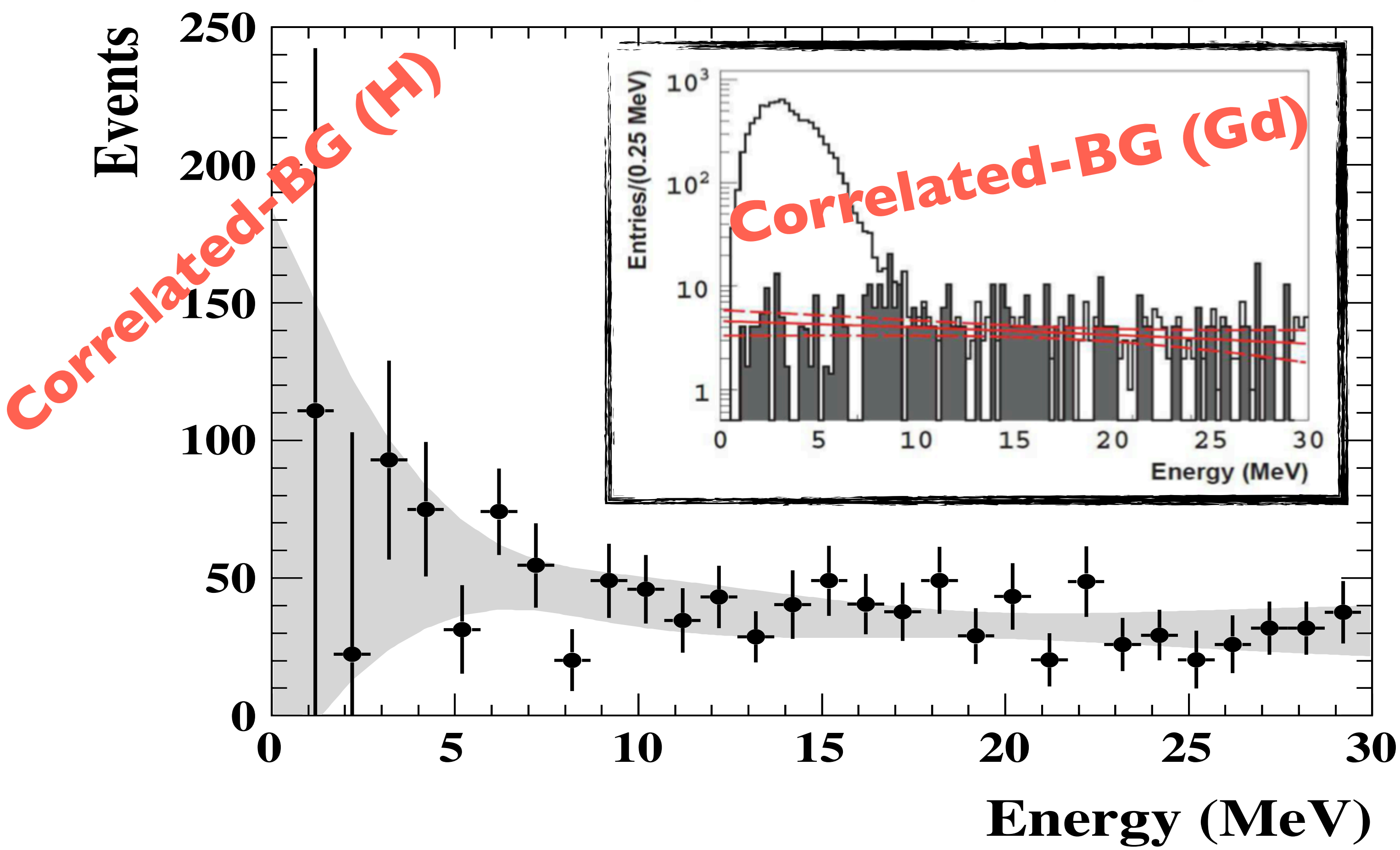
most dangerous

- shape varies per detector (acceptance & overburden) → shapes could mimics θ13
- <u>poorly known shape</u> (not easy to MC)

correlated BG... (fast-n & stopping-μ)



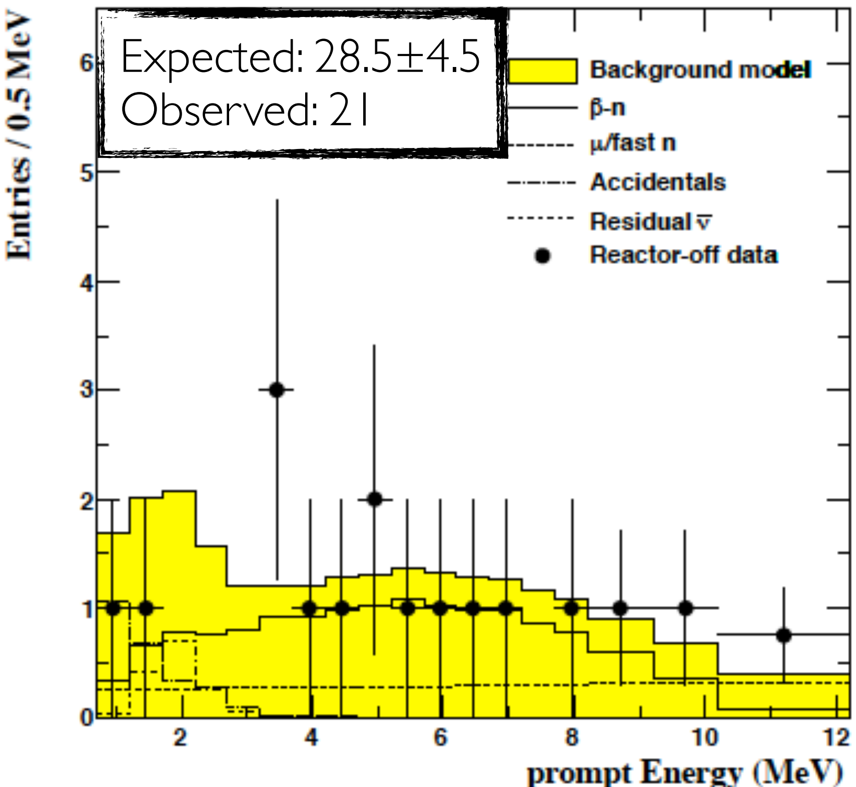
Correlated BG measurement

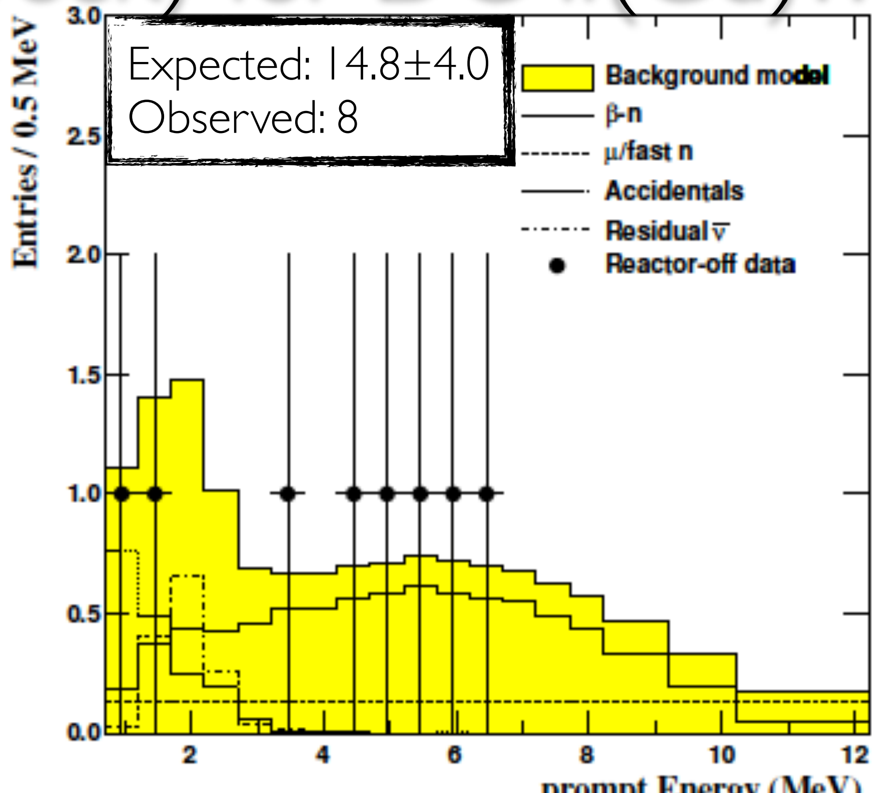


- **proton-recoil spectrum @ low energies** (**very challenging**)
    - neutron energy dependence→ size of buffer and γ-catcher
    - proton quenching effects→ difficult to MC (data-driven)
- **must measure with data**→(DC) IV & OV tagging mechanisms
- (**"naive" method**) extrapolate from high-energy (>14MeV): **good?**
    - **DC: ~25% bias** in spectral rate (rising shape @ low energies)
    - BG-spectrum **resembles θ13 signature** (slope-like)→**bias θ13?**

(only DC) BG validation/direct measurement…

reactor OFF data (~1 week) for DC-II(Gd)…





DC-I Selection

(no BG reduction)

DC-II Selection

(BG reduction)

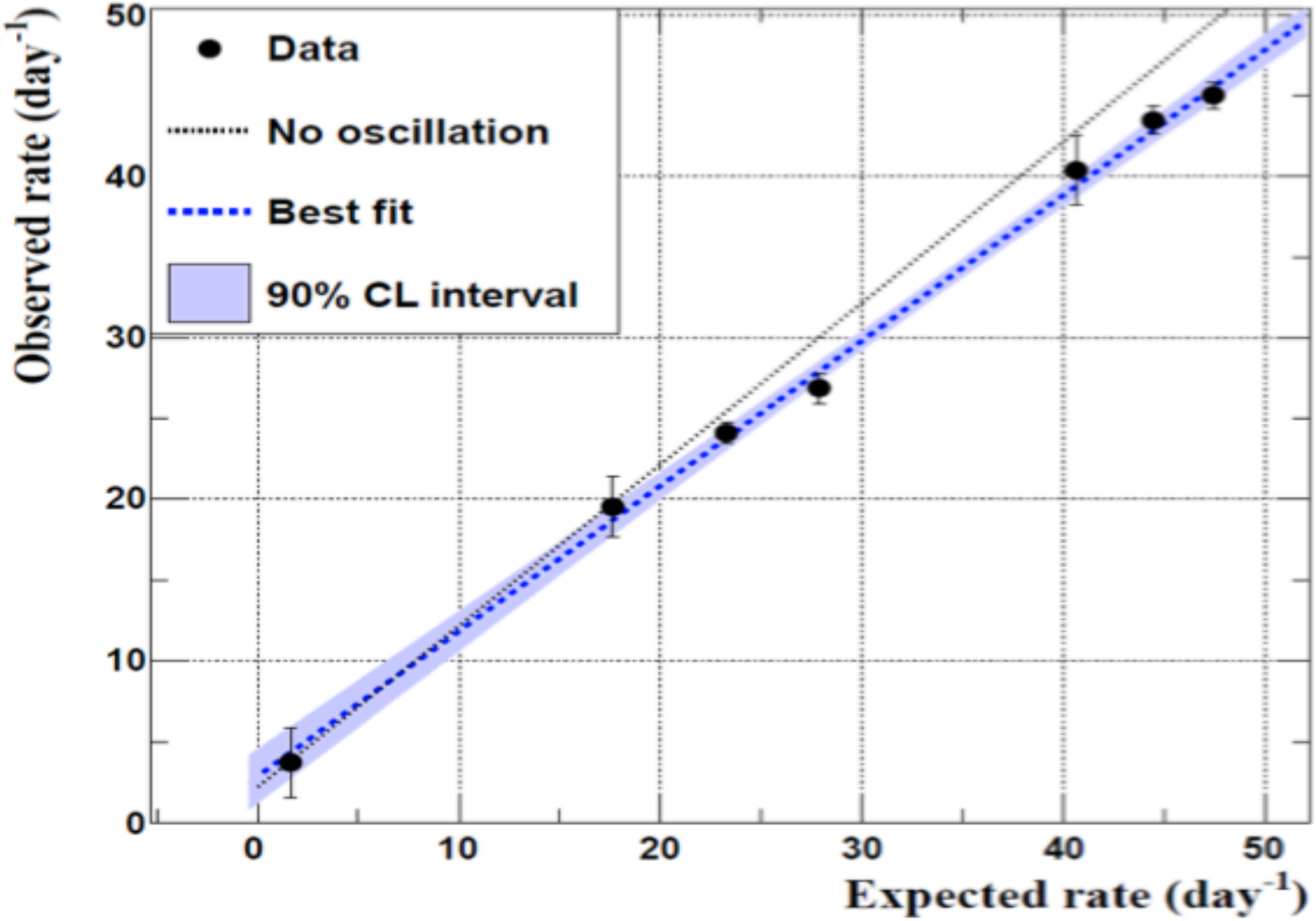
Rate (day^{-1})	β-n	Accidental	μ/fast n	Total Est.	Total Obs.
DCI	2.10±0.57	0.35±0.02	0.93±0.26	3.4±0.6	2.7±0.6
DCII	1.25±0.54	0.26±0.02	0.44±0.20	2.0±0.6	1.0±0.4

validation with two BG-selections DC-I and DC-II (BG varies by ~2x)

BG(observed) < BG(expected)

[fluctuation? σ^{stats} <1.5σ, but same trend seen shape-fit]

(**only validation**) observed vs expected rate…

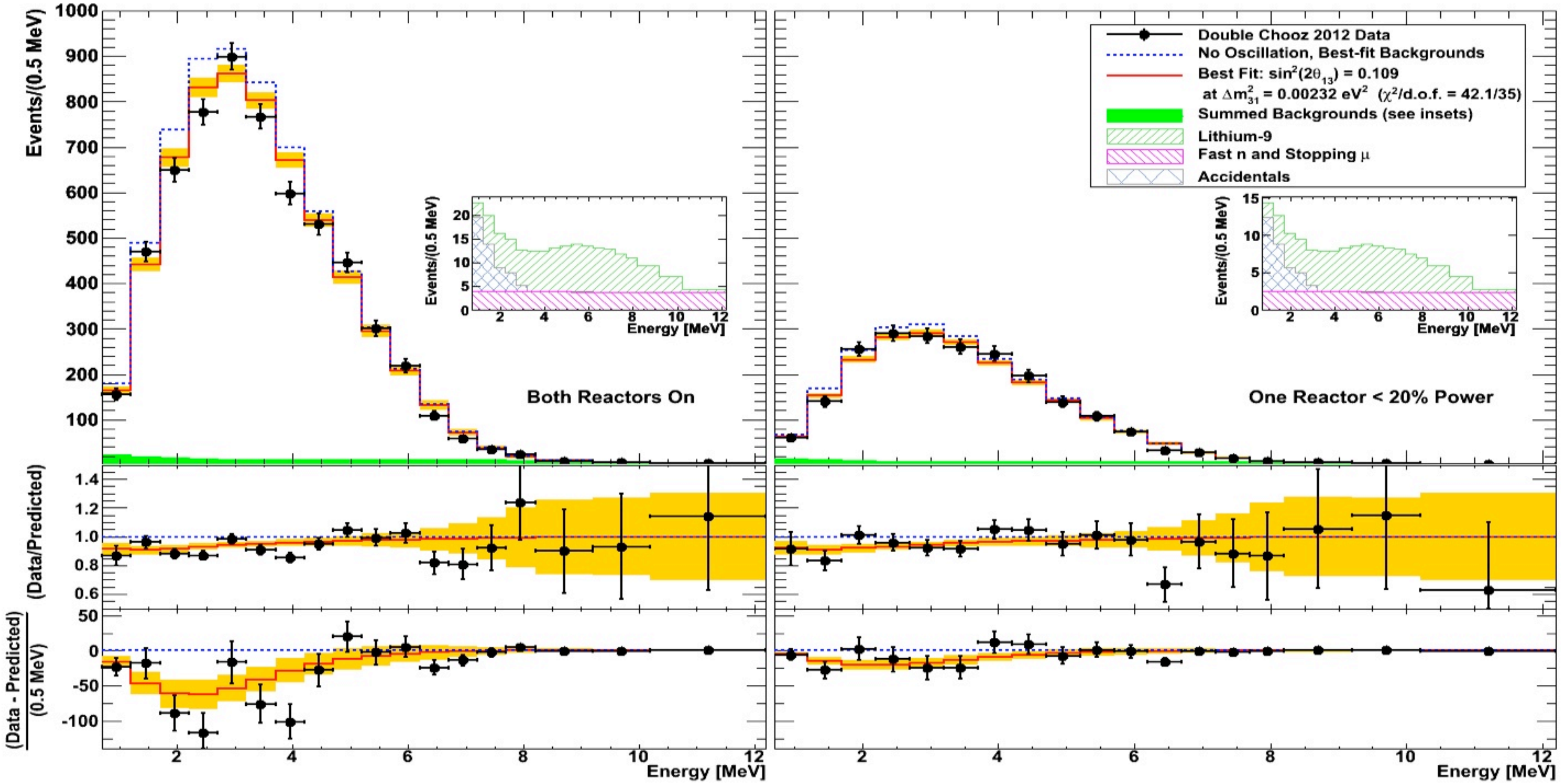


- **disappearance** (i.e. $\theta_{13} \neq 0$)→ shallower slope
- **total BG measurement** is intercept (when expected rate→0)
  - Rate(BG) with and without reactor OFF data point→consistent
  - reactor-OFF data to constraint θ13→future (stay tuned)

Anatael Cabrera (CNRS-IN2P3 & APC)

fit both θ_{13}+BGs (rate+shape) simultaneously…

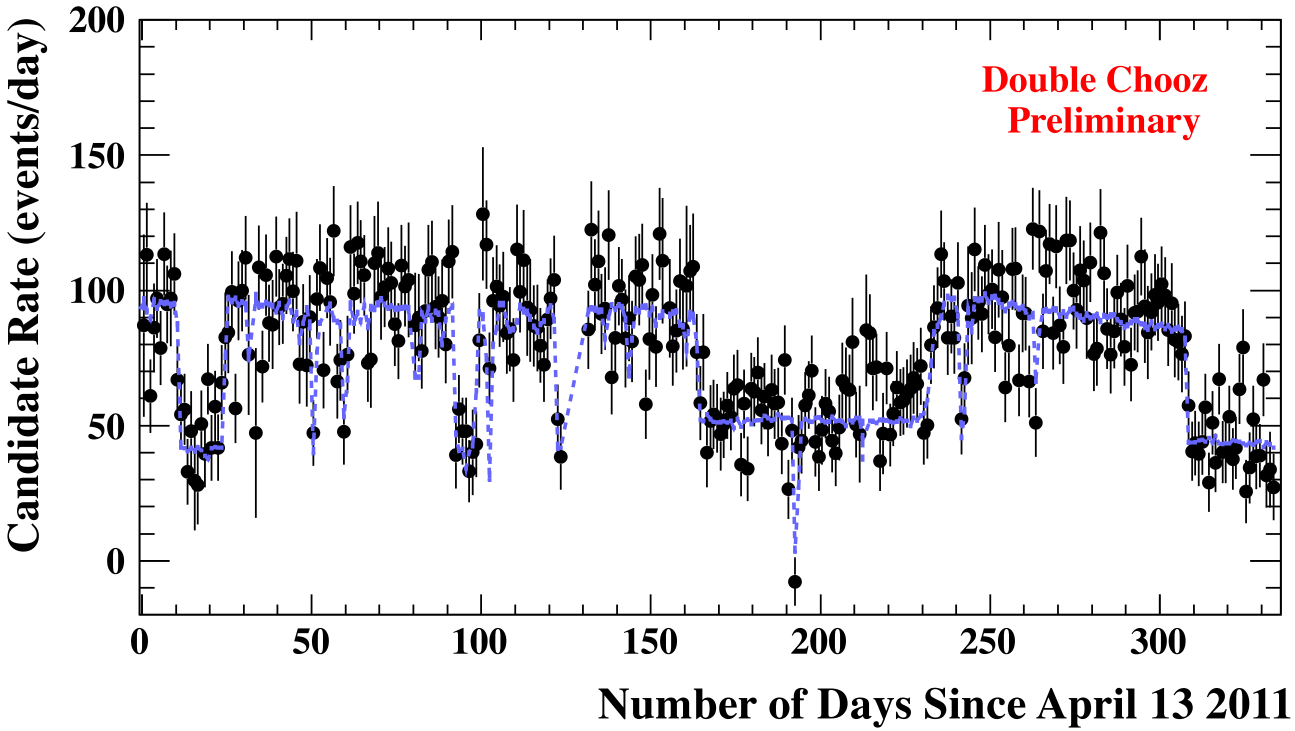
- **fit input:** full data + BGs rate&shape measurements (each)
- **fit output:** θ13 & (constraint) re-measurement of BGs (using shape)



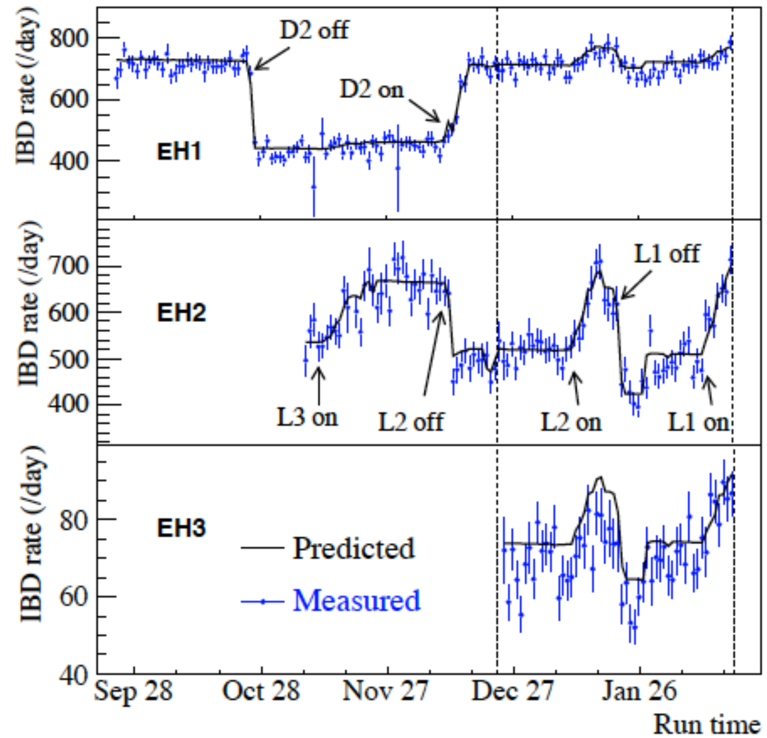
- **BG(fit) <85% BG (rate-only)→ less subtraction (smaller θ13?)**
  - BG(fit) in excellent agreement with direct reactor-OFF measurements
  - all other experiment rely on rate BG measurement→ BG bias impact?
- θ13 is approx. the same with 1 or 2 Integration Periods→ result is BG robust

Anatael Cabrera (CNRS-IN2P3 & APC)

(again) simplicity matters…



DC-II(H) (Dec. 2012)



DB (March'12)

DC has a lot of 1 and 2 reactor(s) [DC-II]

possible analysis: "2reactor - 1reactor" (rate & shape)

→BG "free" analysis? or interesting cross-check on BG model

→(mathematically) equivalent to fitting data 2 integration periods (DC-II)

summary BGs (@ FD)...

@FD	accidental [day^{-1}]	correlated [day^{-1}]	cosmo [day^{-1}]	"Am-C" [day^{-1}]	BG	δBG	δBG/BG (%)	BG/S (%)	δBG/S (%)	max. signal
DC-II	0.261±0.002	0.67±0.20	1.25±0.54	×	2.2	0.58	26.4	4.8	1.28	45
DC-II (fit)	0.261±0.002	0.64±0.13	1.00±0.29	×	**1.9**	**0.32**	16.7	**4.2**	0.71	45
DC-II (OFF)*	×	×	×	×	1.0	0.40	40.0	2.2	0.89	45
DC (H-n)*	73.45±0.16	2.50±0.47	3.00±1.00	×	79.0	1.12	**1.4**	79.0	1.12	100
RENO	0.68±0.03	0.97±**0.06**	2.59±0.75	×	4.2	0.75	17.8	5.3	0.94	80
DB (1xFD)	~3.30±0.03	~0.04±0.04	~0.16±0.11	0.2±0.2	3.7	0.23	6.3	5.3	0.33	70
DB (3xFD)	3x more	3x more	3x more	3x more	11.1	0.40	**3.6**	5.3	**0.19**	210
DB (4xFD)	4x more	4x more	4x more	4x more	14.8	0.47	3.2	5.3	0.17	280

- cosmo & correlated **BG knowledge is statistics dominated**
- **DB lowest cosmo BGs** (largest overburden and reduce Acc-BG)
- **DC** surprisingly (less overburden) **best BG/S** (excellent **δS/BG**)→ high quality analysis (precise BG estimation & 4x validation/cross-checks)

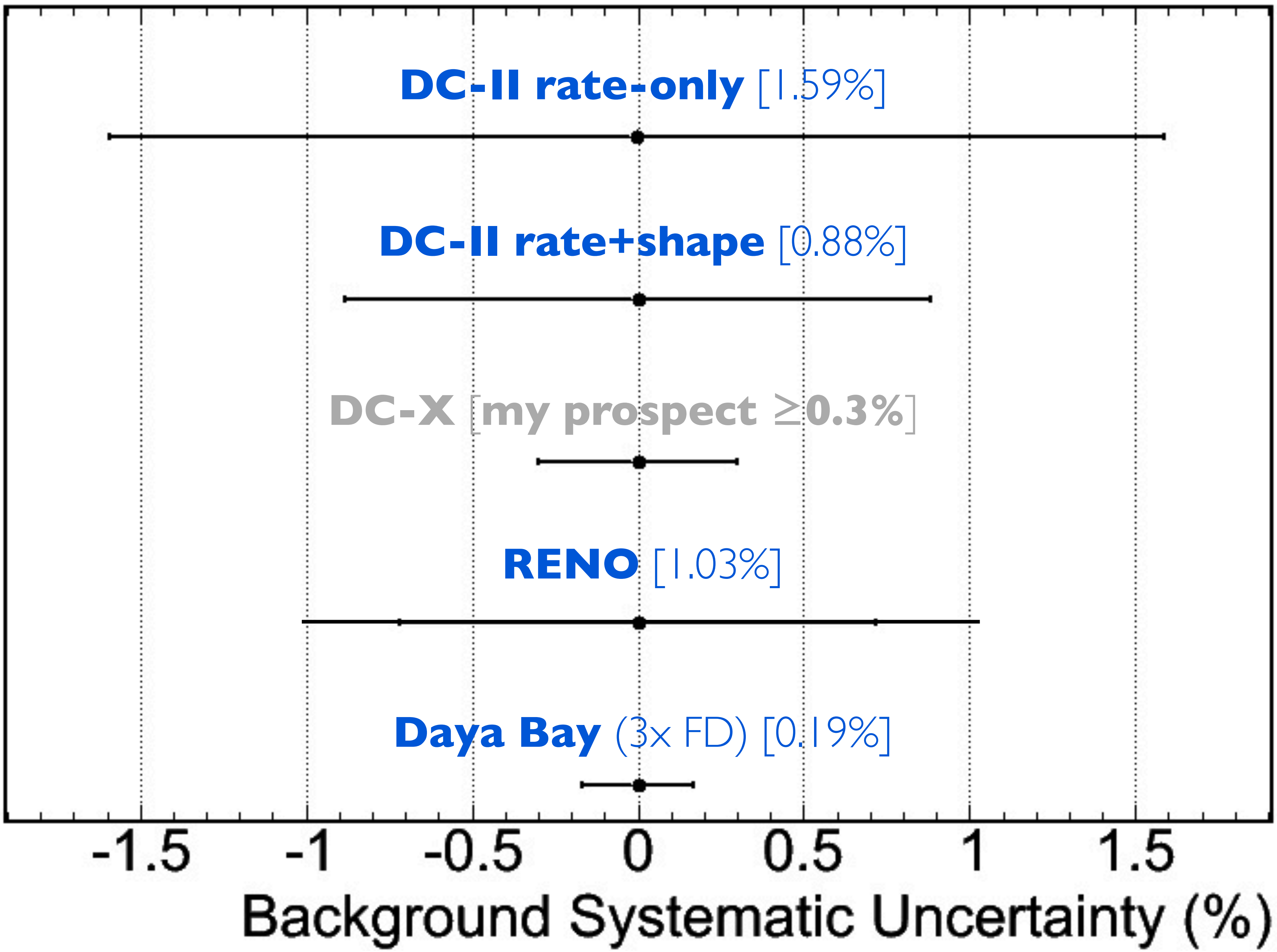
Anatael Cabrera (CNRS-IN2P3 & APC)

BG world summary…

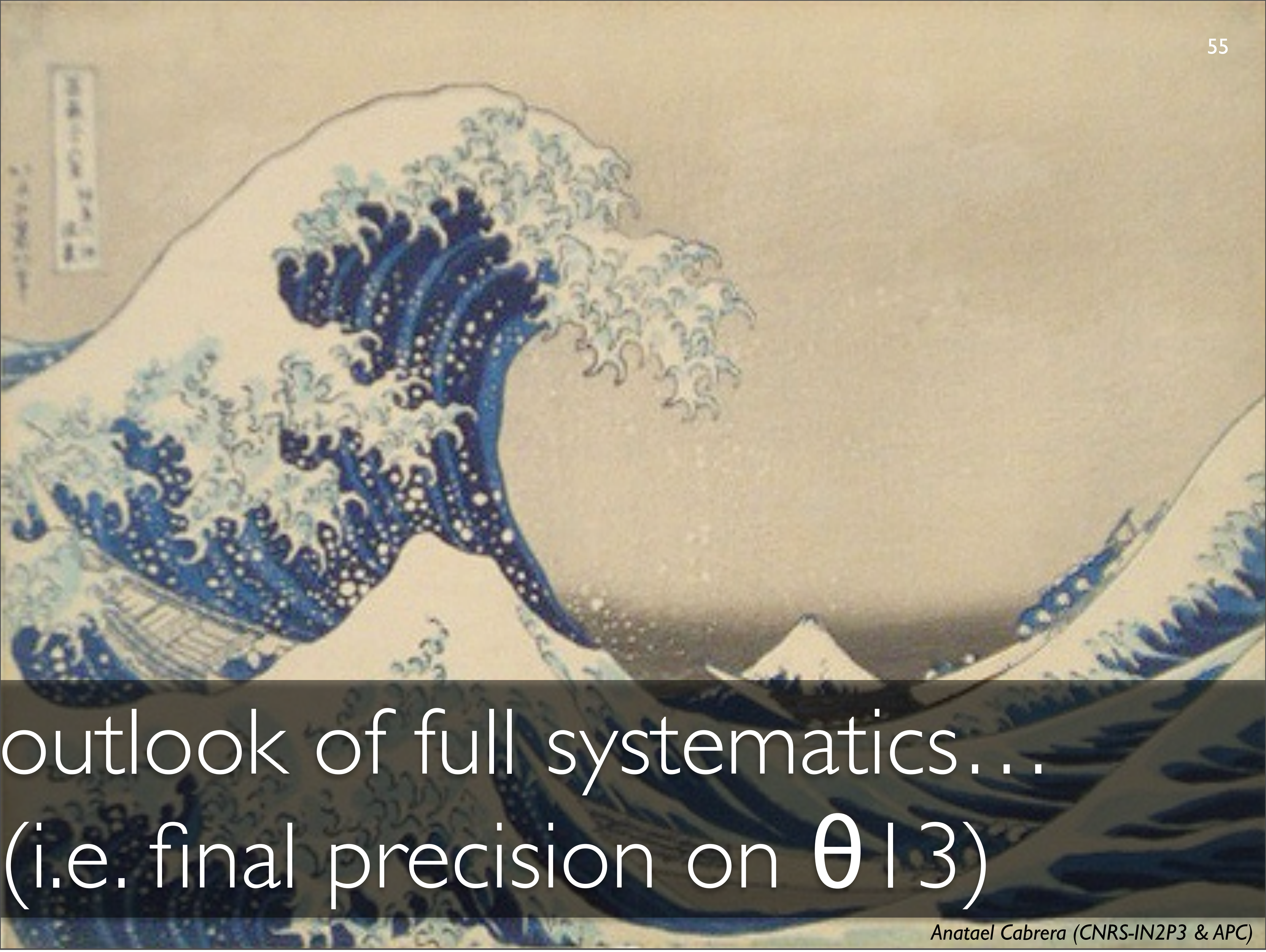
- the **worst BGs** (today and tomorrow)…
  - **Acc-BG: DB**, but will improve some (cut on Δd)
  - **Cor-BG: RENO**, but will improve little (no OV or scint-IV)
    - claimed measurement is suspicious (6% precision + extrapolation)
  - **Cosmo-BG: RENO**, but will improve with showering-μ vetoing
  - Success for **DC** analysis→less overburden ("intellect overburden"→ cheap!)
- the **best BGs**…
  - DC→ lowest Acc BG ever (~10x better with cut on Δr)
  - DB→ lowest μ-BsG (expected): deeper+vetoing+huge water pool
- the **best understood BGs** (i.e. lowest δBG and δBG/BG)…
  - DB & DC→ the best understood BG (lowest δBG and δBG/BG)
- the **best BG systematics**…
  - DB best rate BG knowledge (δBG/S)→huge signal and deep overburden)
  - DC best shape BG knowledge (BG/S)→ exploited in rate+shape analysis
  - DC powerful redundant BG→ 4x methods (stat limited) to handle BG bias

Anatael Cabrera (CNRS-IN2P3 & APC)

BG systematics (rate-only analysis)…



Anatael Cabrera (CNRS-IN2P3 & APC)



outlook of full systematics… (i.e. final precision on θ13)

Anatael Cabrera (CNRS-IN2P3 & APC)

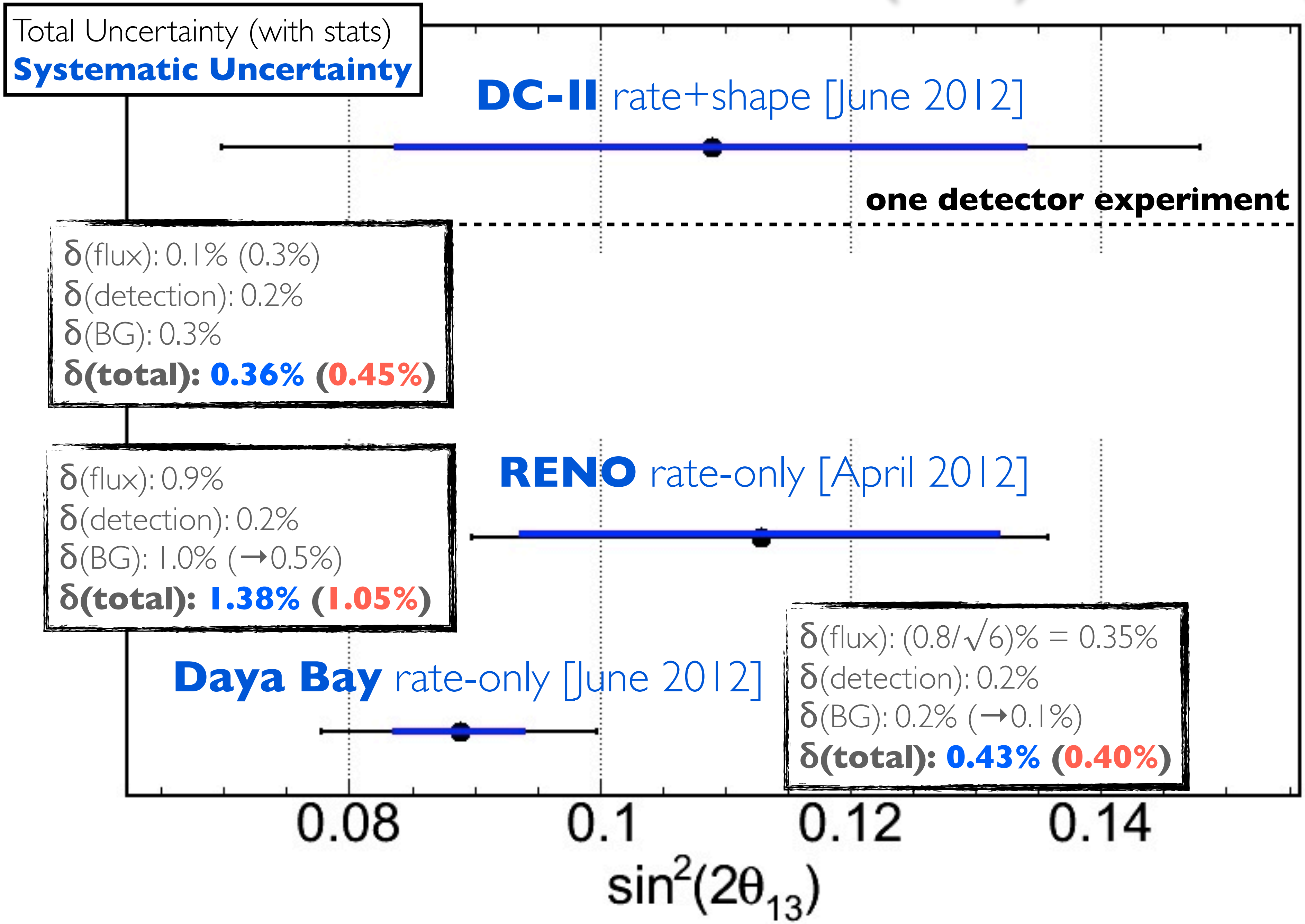
rate-driven uncertainties table...

best published results

uncertainty (%)	DC-I (rate)	DC-II (rate)	DC-II (r+s)	DC-II (OFF*)	RENO (abs)	RENO (rel)	DB (abs)	DB (rel)
flux								
reactor	1.67	1.67	**1.67**	1.67	2.00	0.90	3.00	**0.80**
detection								
efficiency	1.14	0.95	**0.95**	0.95	1.50	0.20	1.90	**0.20**
response	1.7	0.3	0.3	0.3	X	X	X	X
background for rate analysis (δBG/S)								
cosmogenic	2.82	1.49	0.80	X	1.03	1.03	0.09	0.09
correlated	0.89	0.55	0.36	X	0.08	0.08	0.03	0.03
accidental	0.07	0.01	0.01	X	0.04	0.04	0.02	0.02
"Am-C"	X	X	X	X	X	X	0.16	0.16
BG-total	2.96	1.59	**0.88**	1.10	1.03	1.03	0.19	0.19
syst total	**3.58**	**2.49**	**2.11**	**2.22**	**2.70**	**1.38**	**3.56**	**0.85**
stat total	**1.56**	**1.10**	**1.10**	**1.10**	**0.76**	**0.76**	**0.99**	**0.99**

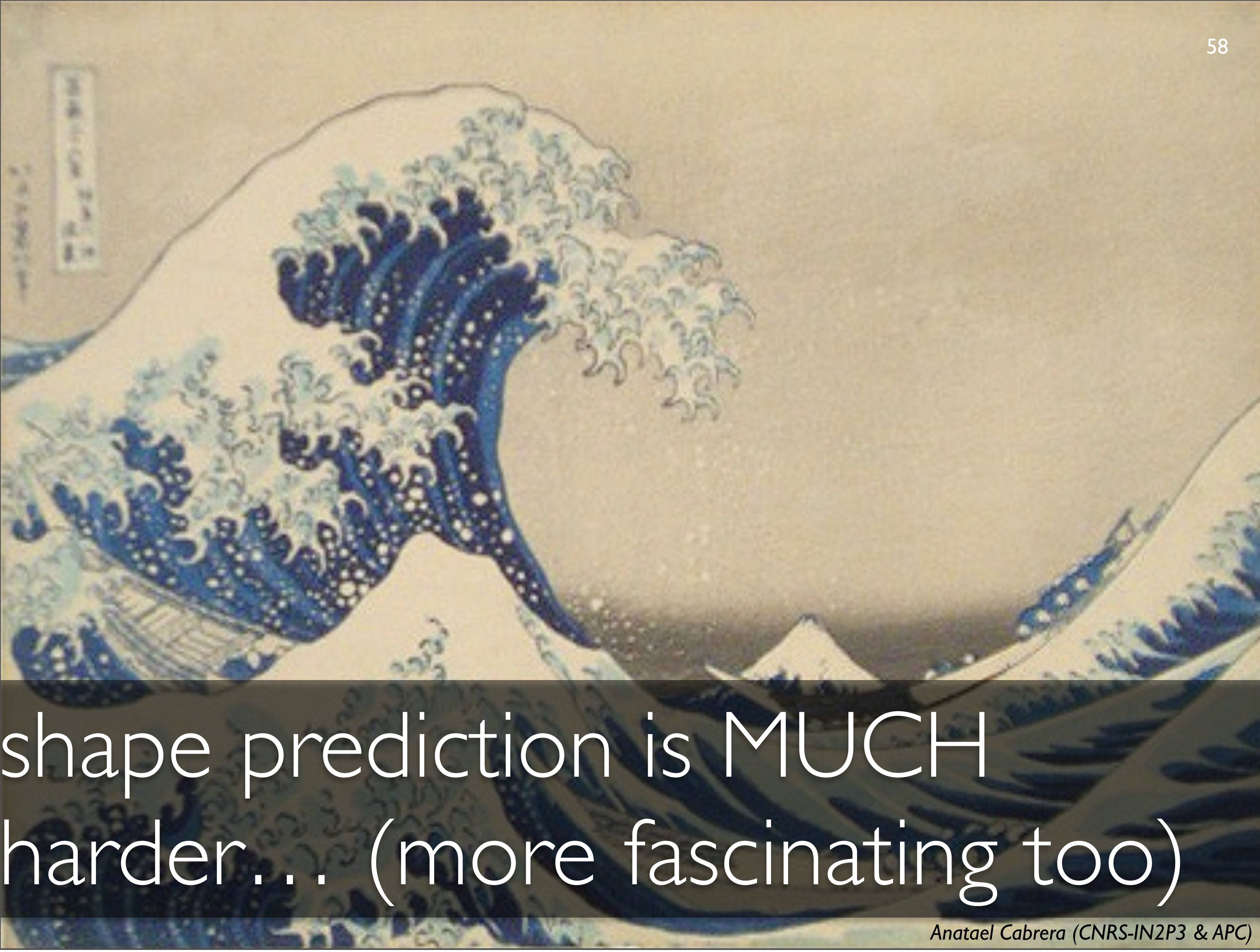
***(debatable numbers?)**

reactor θ13 ultimate (rate) knowledge…

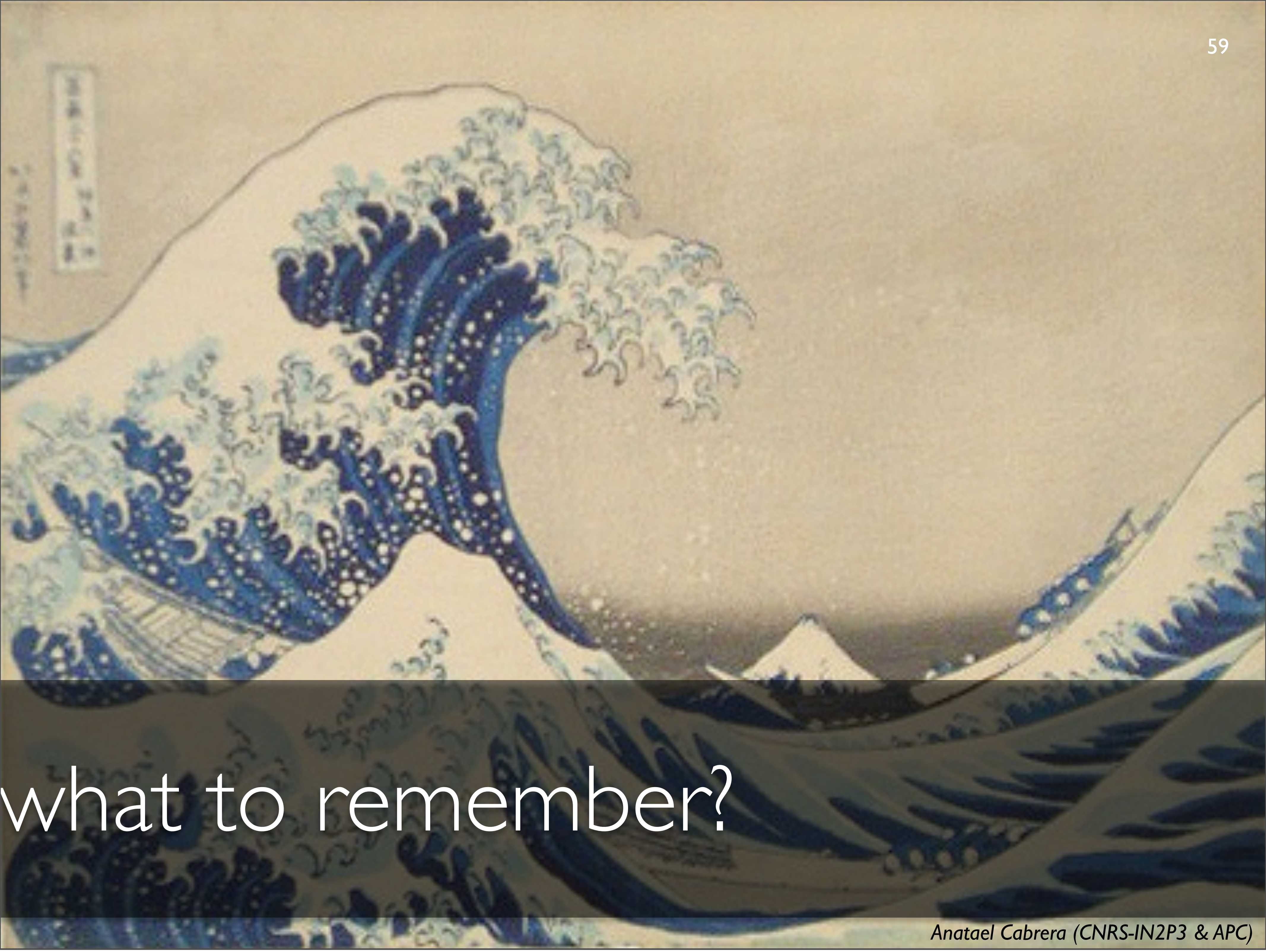


2 experiments with δ(total)<0.010→ validate accuracy

Anatael Cabrera (CNRS-IN2P3 & APC)



shape prediction is MUCH harder… (more fascinating too)



what to remember?

Anatael Cabrera (CNRS-IN2P3 & APC)

what to remember?

- **θ13 measured** by reactor experiments (→ **dominate for long!**)
  - **sure!**→ precise rate-only (DB) & clean rate+shape (DC)
  - **high precision** (*uncertainty*) & **high accuracy** (*what's the true value?*)
    - to measure/constrain 3ν oscillation model
- **high precision on θ13**→ ~5% uncertainty within 3 years
  - multi-detector→ cancellation of all correlated uncertainties
- **high accuracy on θ13**→ how to know we are unbiassed?
  - **rate+shape analysis** (E/L & BGs) to measure θ13→**a must!**
  - **cross-check** among all experiments→ on-going effort (transparency)
    - different sites/BGs/systematics/baselines, etc→ the ONLY way to learn!
- regardless **θ13 is LARGE**
  - …if you were waiting for this, **please go ahead**! **:-)**
  - Asia very efficient (congratulation!). Europe needs to improve…

Anatael Cabrera
CNRS/IN2P3
APC (Paris)
anatael@in2p3.fr

DC-APC group co-leader
DC Detector coordinator
DC Online/Electronics coordinator
DC European Analysis coordinator

thanks…