DoubleChooz

(status 2019)

Colloquium Prague v19

2019

24-25 October 2019
J. Heyrovsky Institute of Physical Chemistry
Europe/Prague timezone

on behalf of the Double Chooz collaboration

Anatael Cabrera

CNRS / IN2P3 @ LAL/FLUO (Orsay) & LNCA (Chooz)

main highlights…

[most of this talk]

θ13 measurement

single-detector

multi-detector

[2011]
DC⊕T2K: θ13≠0
@ 3σ's

[most of this talk]

reactor neutrino measurement

flux (absolute)

spectrum (relative & absolute)

[2014]
spectral
distorsion
(5MeV)

anti-ν directionality via IBD

[2016]
update from
CHOOZ

many other results…

Double Chooz collaboration

Brazil	France	Germany	Japan	Russia	Spain	USA
CBPF UNICAMP	APC (IN2P3) CEA/IRFU: SPP SPhN SEDI SIS SENAC CENBG (IN2P3) LNCA (IN2P3/CEA) Subatech (IN2P3)	EKU Tübingen MPIK Heidelberg RWTH Aachen TU München	Tohoku U. Tokyo Inst. Tech. Tokyo Metro. U. Tokyo U. Science Kitasato U. Kobe U.	INR RAS RRC Kurchatov	CIEMAT-Madrid	Alabama U. ANL Chicago U. Drexel U. Hawaii U. Notre Dame U. Virginia Tech.

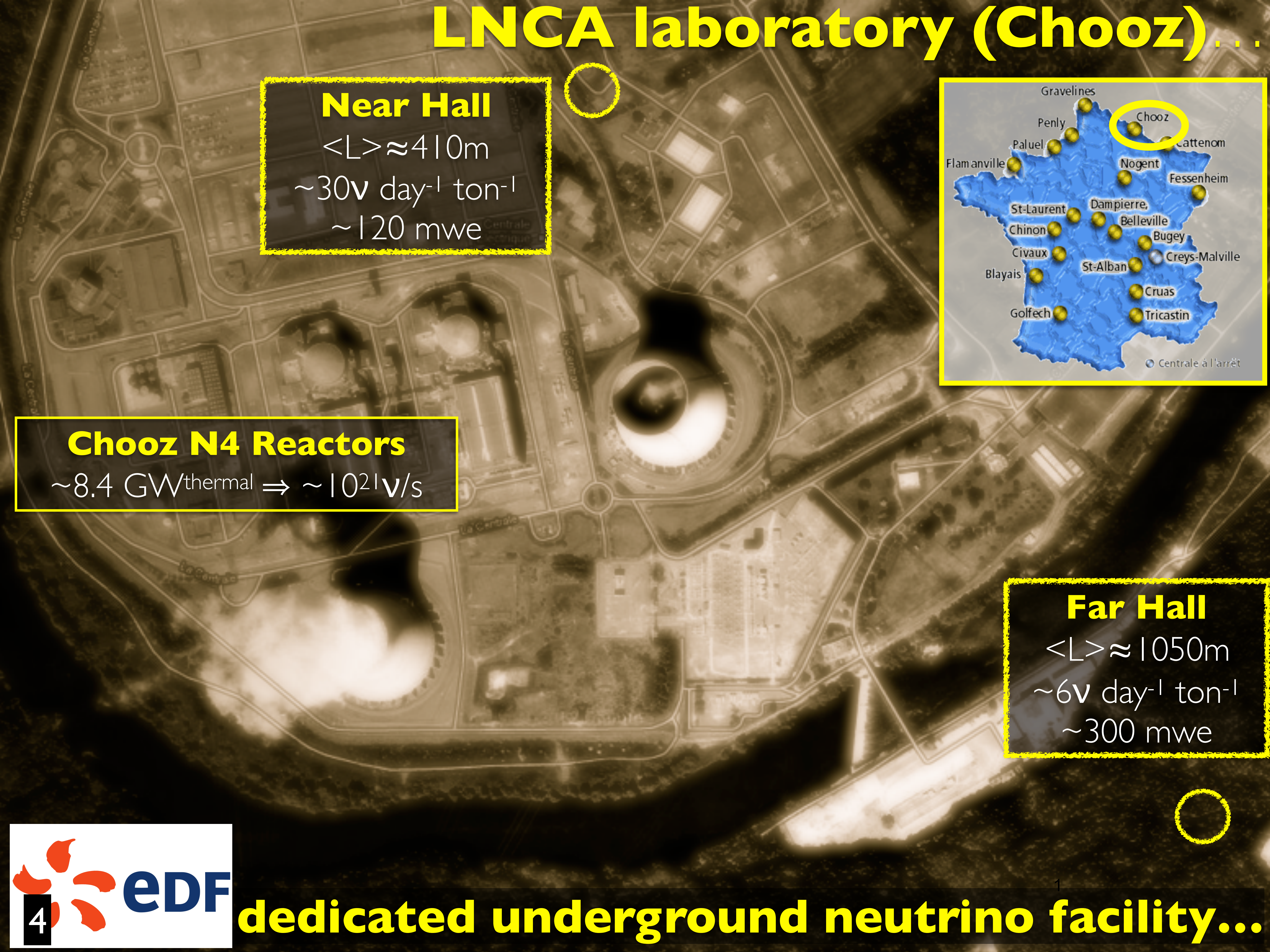
Spokesperson:
A. Cabrera (IN2P3/CNRS)

Project Manager:
Ch. Veyssière (CEA)

97 scientists 25 institutions (Americas, Asia, Europe)

web: doublechooz.in2p3.fr

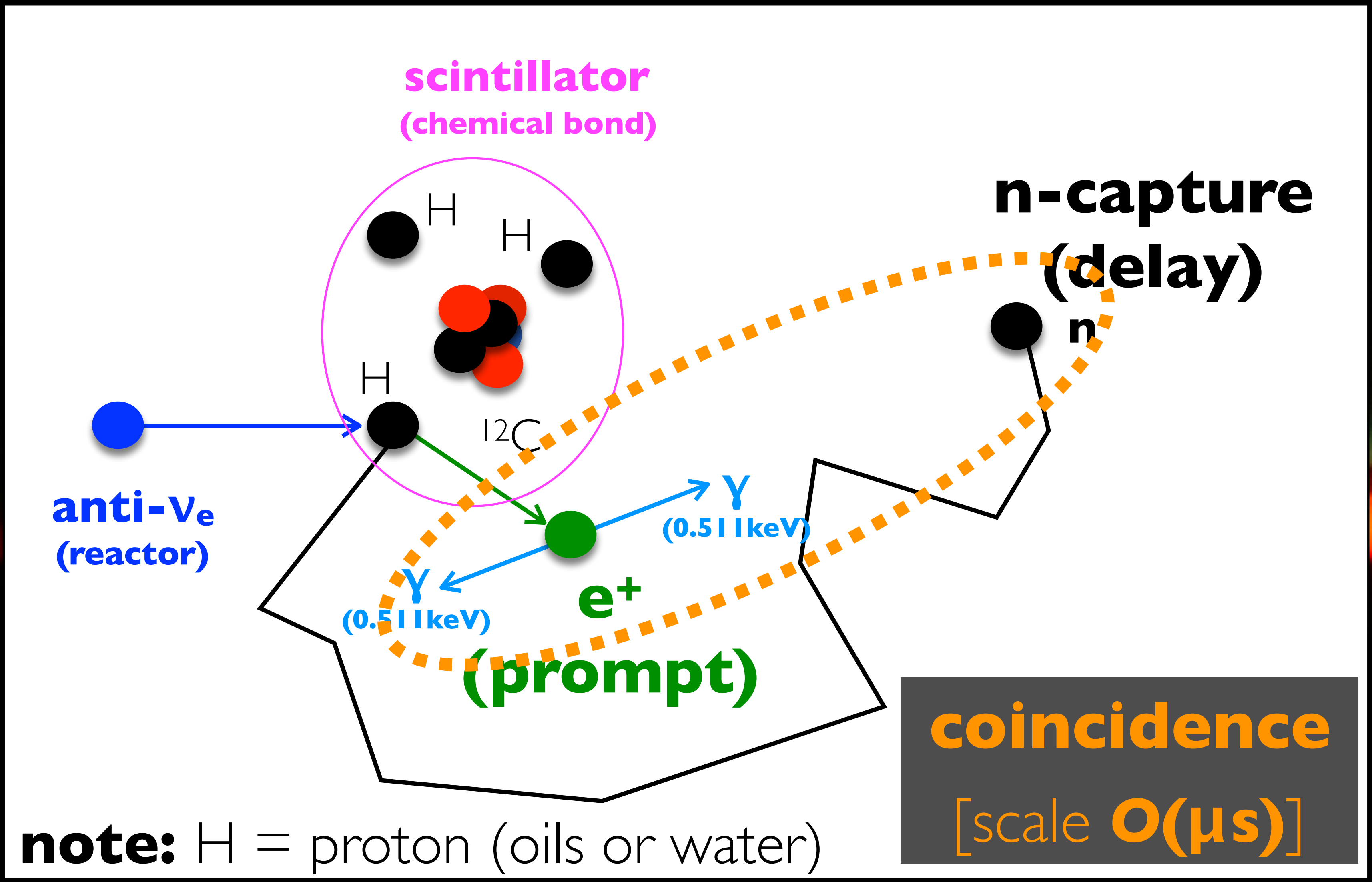
LNCA laboratory (Chooz)...



dedicated underground neutrino facility...

inverse-β decay (IBD) interaction…

IBD: anti-ν_e + p → e^+ + n



IBD detection art…

n-H (**native oil**)

n-C (**native oil**)

—

n-Cd (doped)

n-Gd (doped)

n-Li (doped)

—

^{3}He (different technology)

no e+ PID implies

$e^+ \approx$ BG ($\gamma \approx e^- \approx \alpha \approx$ p-recoil)

Anatael Cabrera (CNRS-IN2P3 & APC)

our latest analysis…

novel Total neutron Capture TnC (IBD detection)

larger detection → new statistics

new systematics

focus: *boost stats (3x) & reduce systematics*

θ13 measurement

single-detector

multi-detector

focus: *accuracy validaton*

reactor neutrino measurement

flux (absolute)

spectrum (relative & absolute)

focus: *major improvement*

Submissions

nature physics

ARTICLE

First Double Chooz θ_{13} Measurement via Total Neutron Capture Detection

Hervé de Kerret *et al* (arXiv:1901.09451)

arXiv:1901.09445v1 [hep-ex] 27 Jan 2019

First Double Chooz θ_{13} Measurement via Total Neutron Capture Detection

The Double Chooz Collaboration

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January 29, 2019

v1

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the θ13 challenge…

today's θ13 knowledge/experiments…

reactor-θ13 experiments [DC⊕DYB⊕RENO]

	<2010	today [2010-2020]			cancellation methodology
	total	total	rate-only	shape-only	
statistics	few %	~0.1%	—	—	~100/day @ 1.5km
flux	~2.2%	~0.1%	~0.1%	<0.1%	near-to-far monitor (ideal: iso-flux)
BG	few %	~0.1%	~0.1%	<0.1%	overburden→few/day
detection	2.0 %	~0.1%	~0.1%	—	identical detectors
energy	few %	~0.5%	—	~0.5%	identical detectors

- **statistics: few 10^5 (far) [≤10^6]**
- **energy control: <1% precision**
- **overburden: ≥300mwe @ FD**

systematics: ~0.1% (each) [still rate-driven]

[must: multi-detector]

Reactor-θ_{13} (combining results)

Daya Bay⊕Double Chooz⊕RENO

0th discussion/planning→@ Neutrino-2016, London (UK)

1st workshop→ October 2016 (Seoul, South Korea)
(systematics, results consistency)

2nd workshop→ June 2017 (Paris, France)
(further θ13 systematics consistency)

3rd workshop→ not yet decided (soon, I hope)

(likely) most precise input to θ_{13} for several decades…

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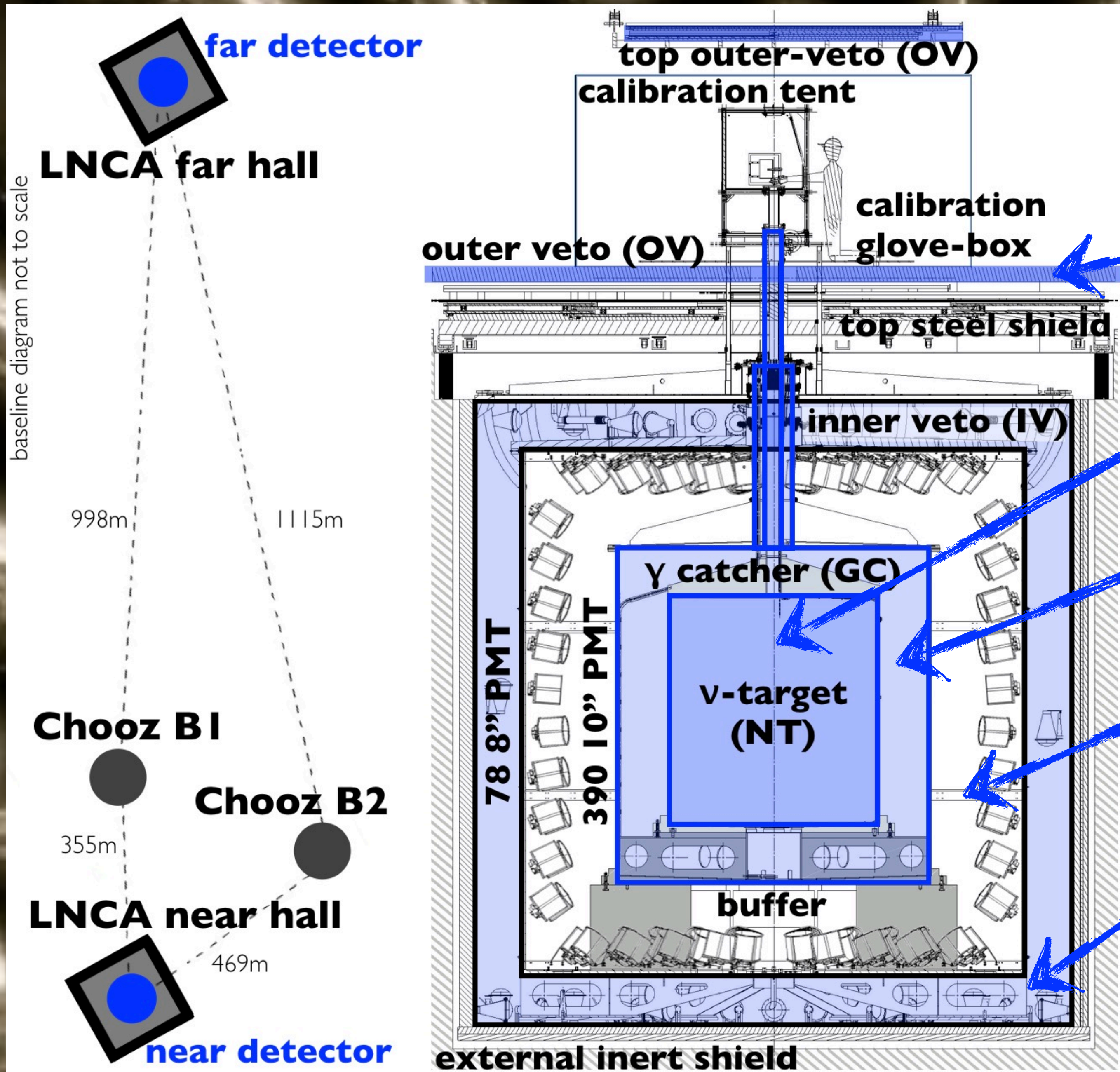
detection highlights…

DC a θ_{13}-LAND…



Outer μ-Veto (OV)
plastics-scintillator: strips (→tracking)

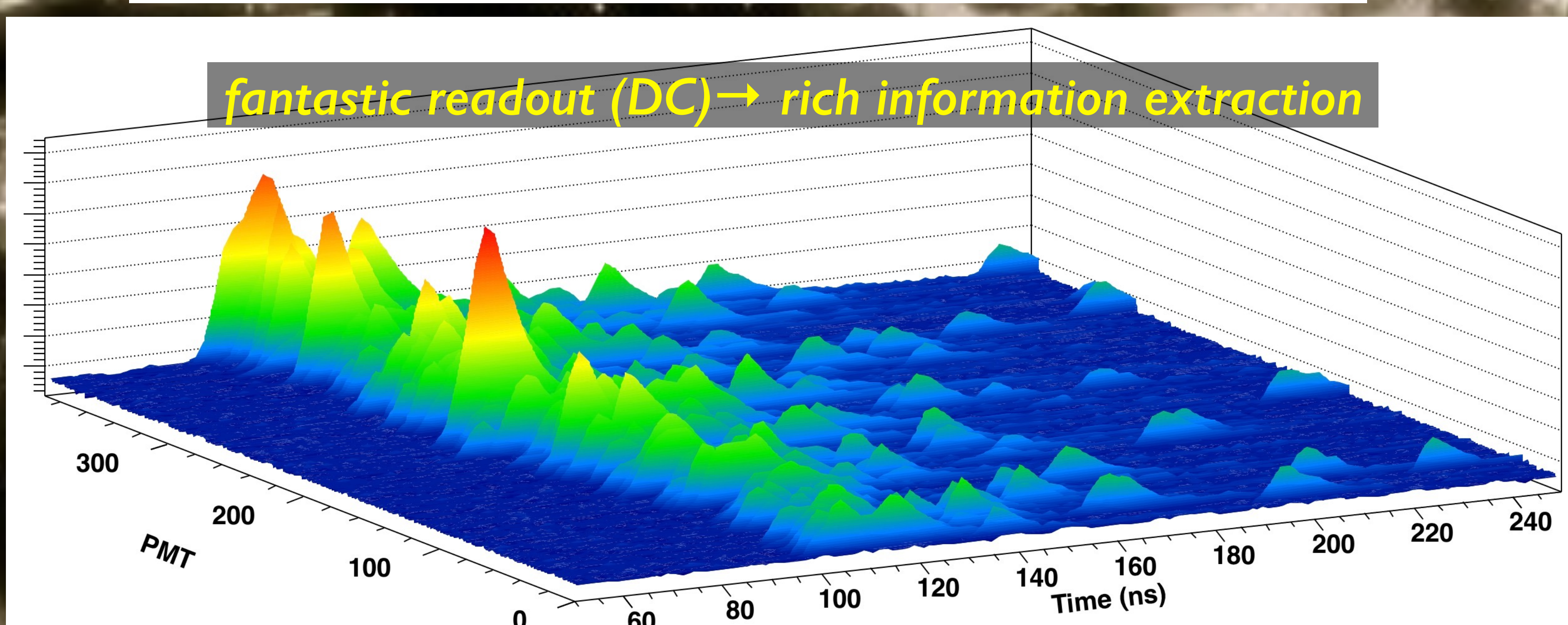
ν-Target (NT)
~10m³ Liquid-Scintillator + Gd (0.1%)

γ-Catcher (GC)
~20m³ Liquid-Scintillation

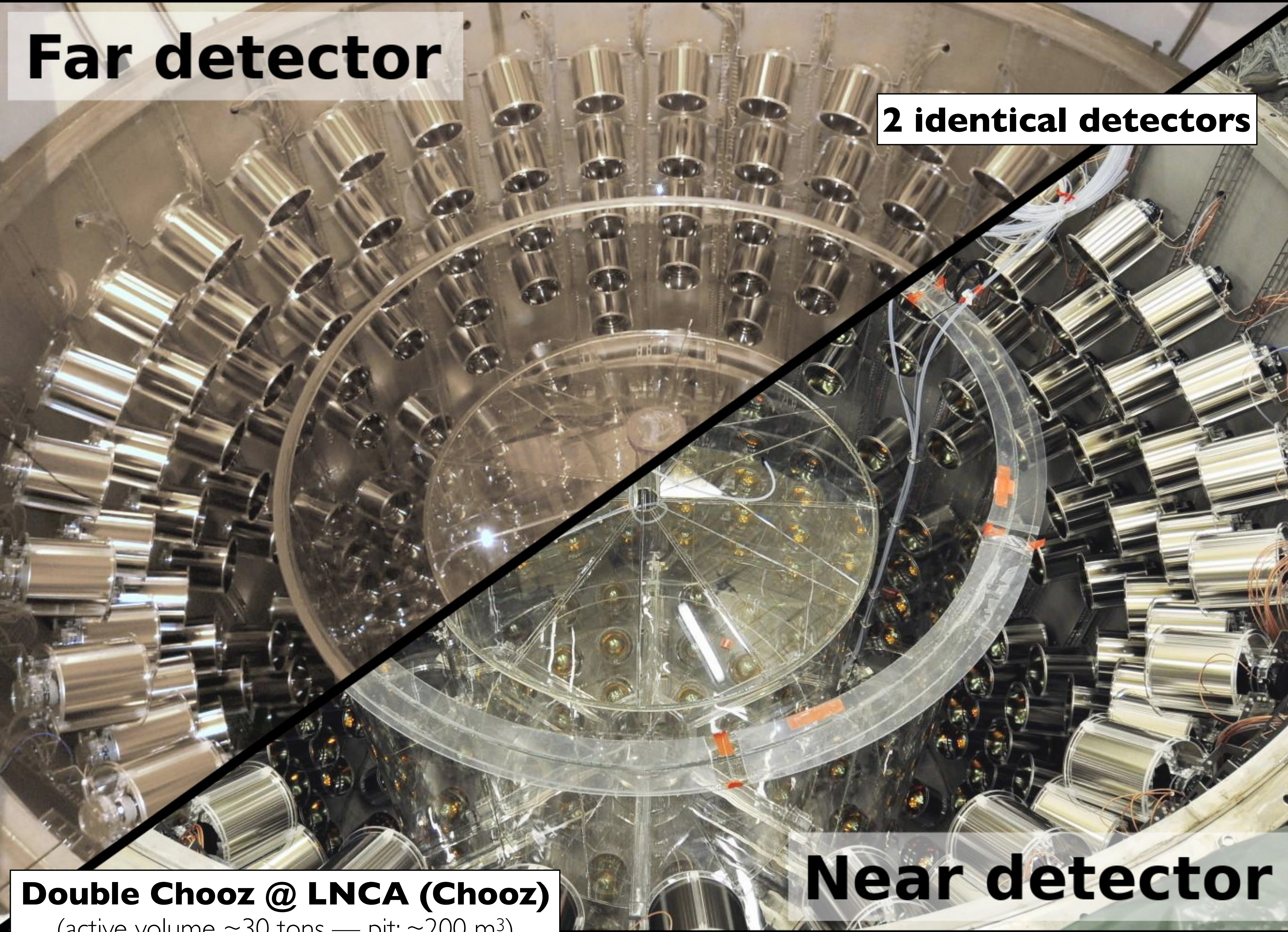
Light Buffer
~100m³ oil (no scintillation)

Inner μ-Veto (IV)
~90m³ Liquid-Scintillator

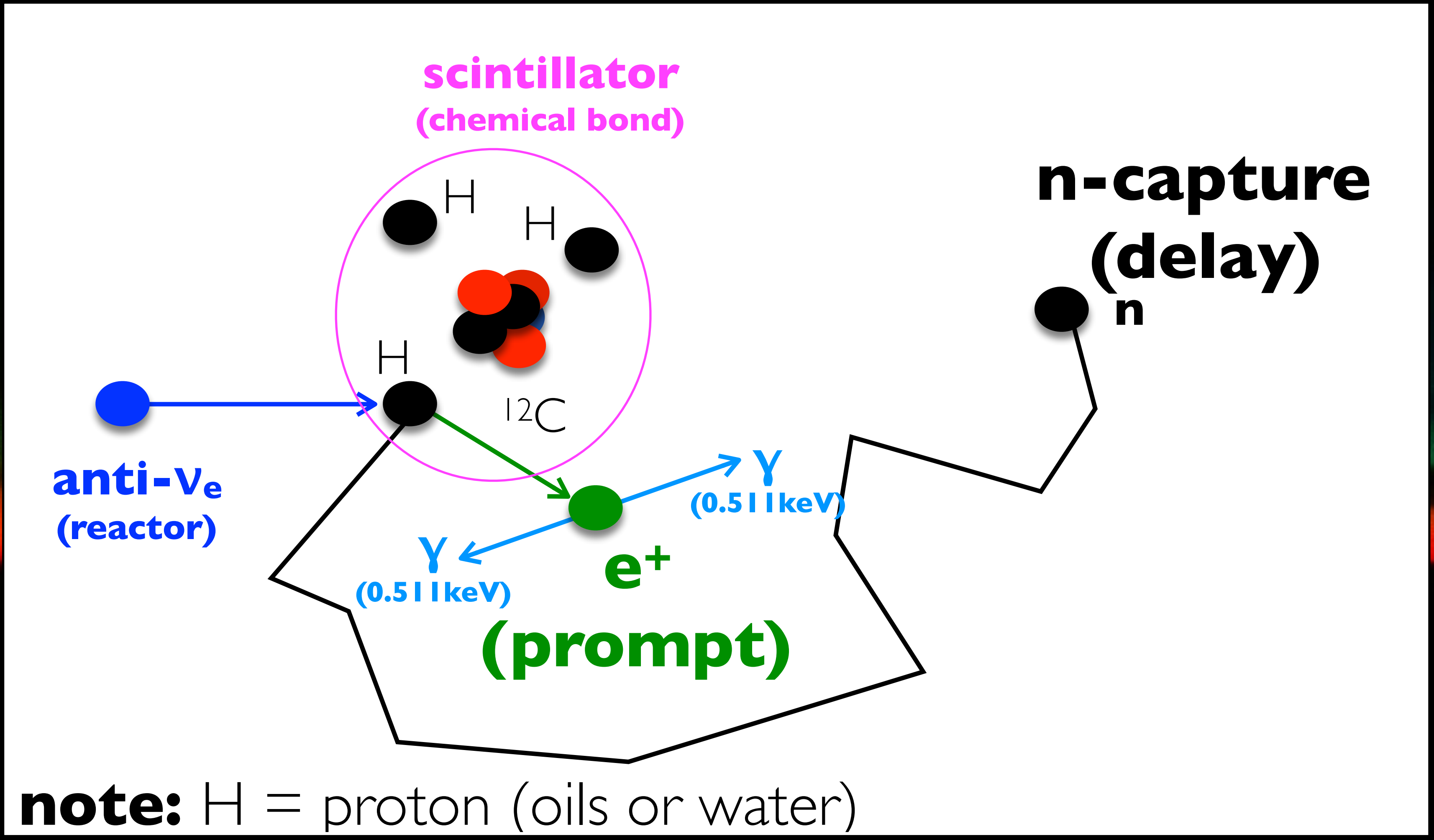
Inert γ-Shield
15cm steel [FD] / 1m water [ND]



Liquid Scintillator
⊕
10" PMTs
⊕
FADC readout
⊕
offline reconstruction
(time,charge,position,PS,multiplicity,etc)


Far detector
2 identical detectors
Near detector
Double Chooz @ LNCA (Chooz)
(active volume ~30 tons — pit: ~200 m³)

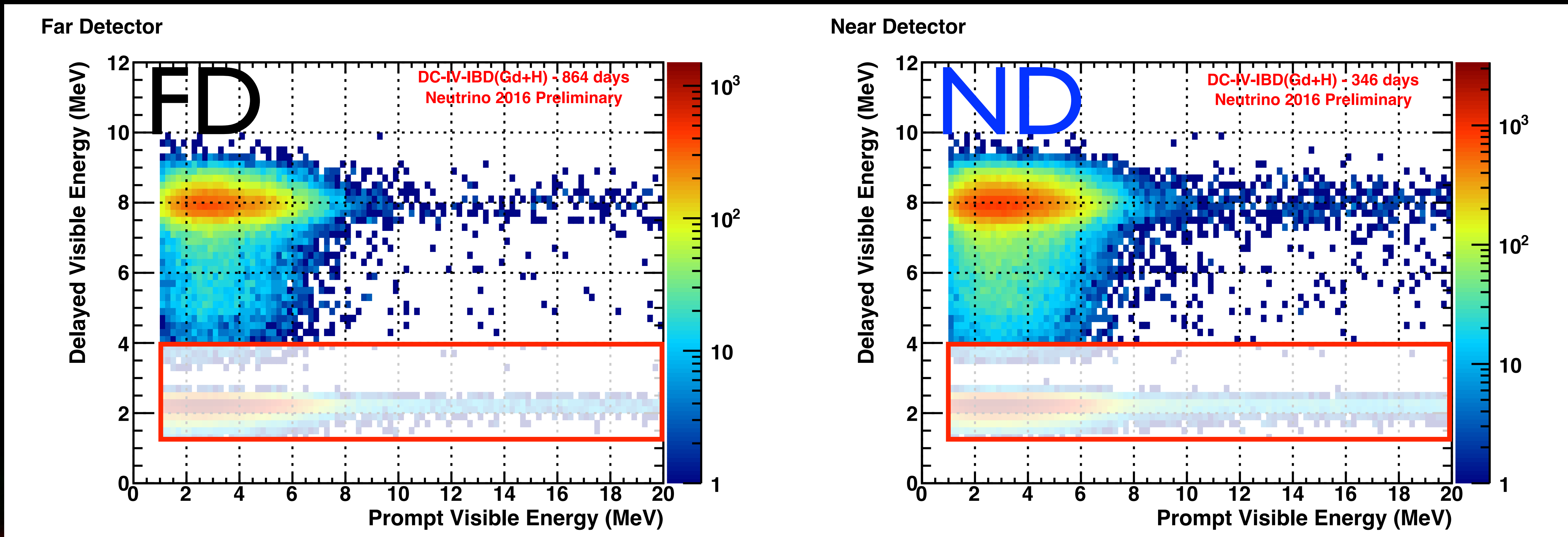
novel IBD detection strategy…



Total neutron-Capture

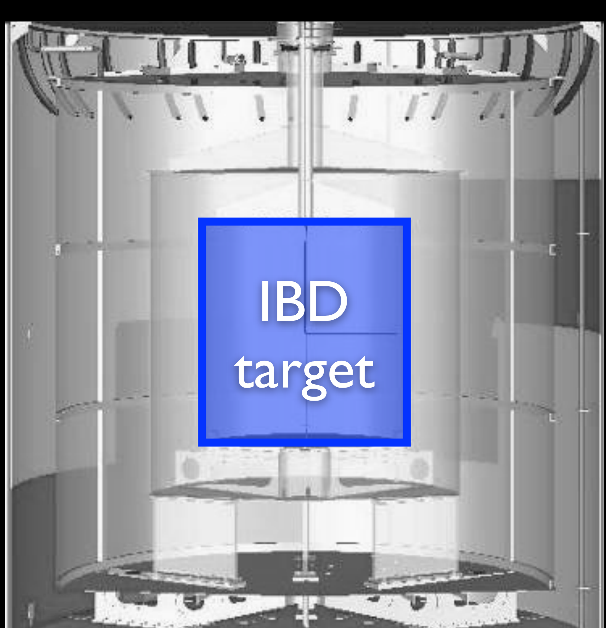
(H-n⊕C-n⊕Gd-n)

larger single-θ_{13}-target...



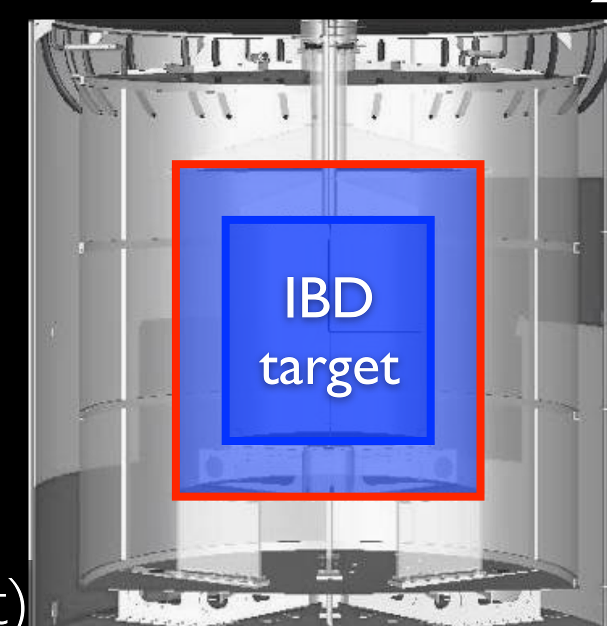
IBD(Gd)

IBD(Gd⊕H⊕C)

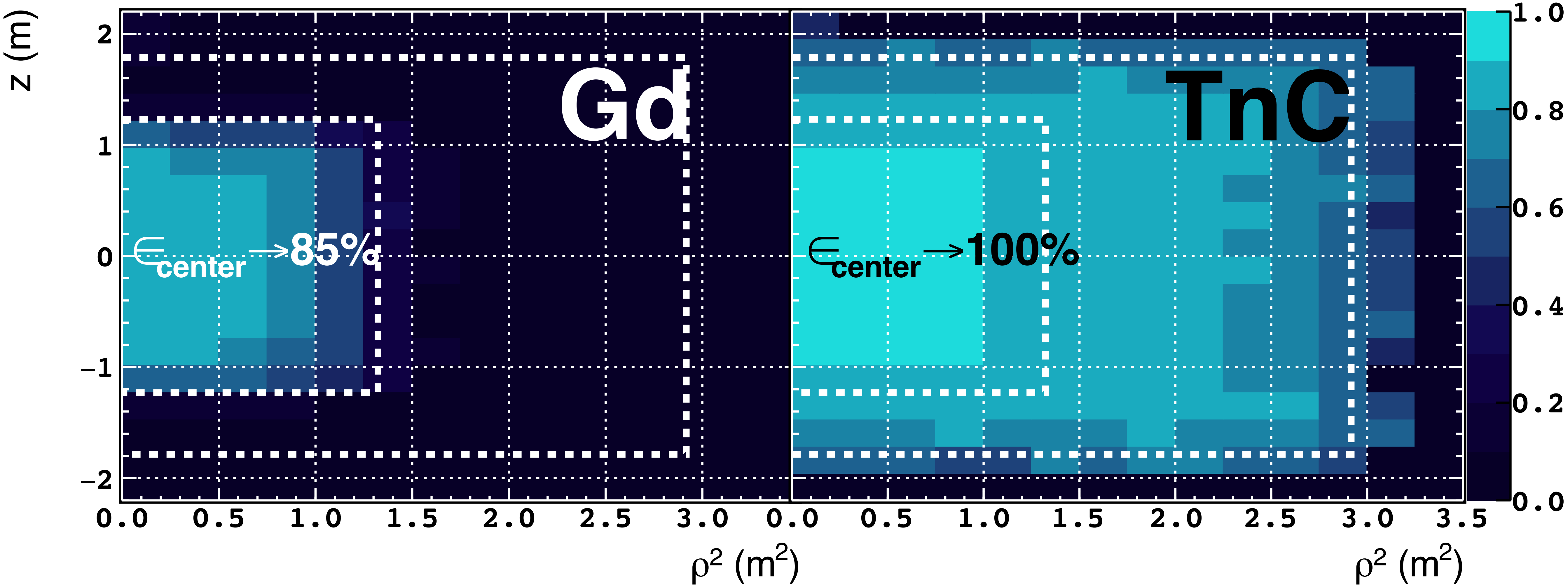


target: ~8t (smallest θ13 target)

target: ~30t (large θ13 single detector target)



TnC major detection improvement…



higher efficiency per volume: ~85% (~100% in Target)

higher efficiency total (increase fiducial volume ~x3)
[major reduction of statistical and background systematics]

lower efficiency detection systematics
[dominant systematics: **poor GC proton#→ less precise**]

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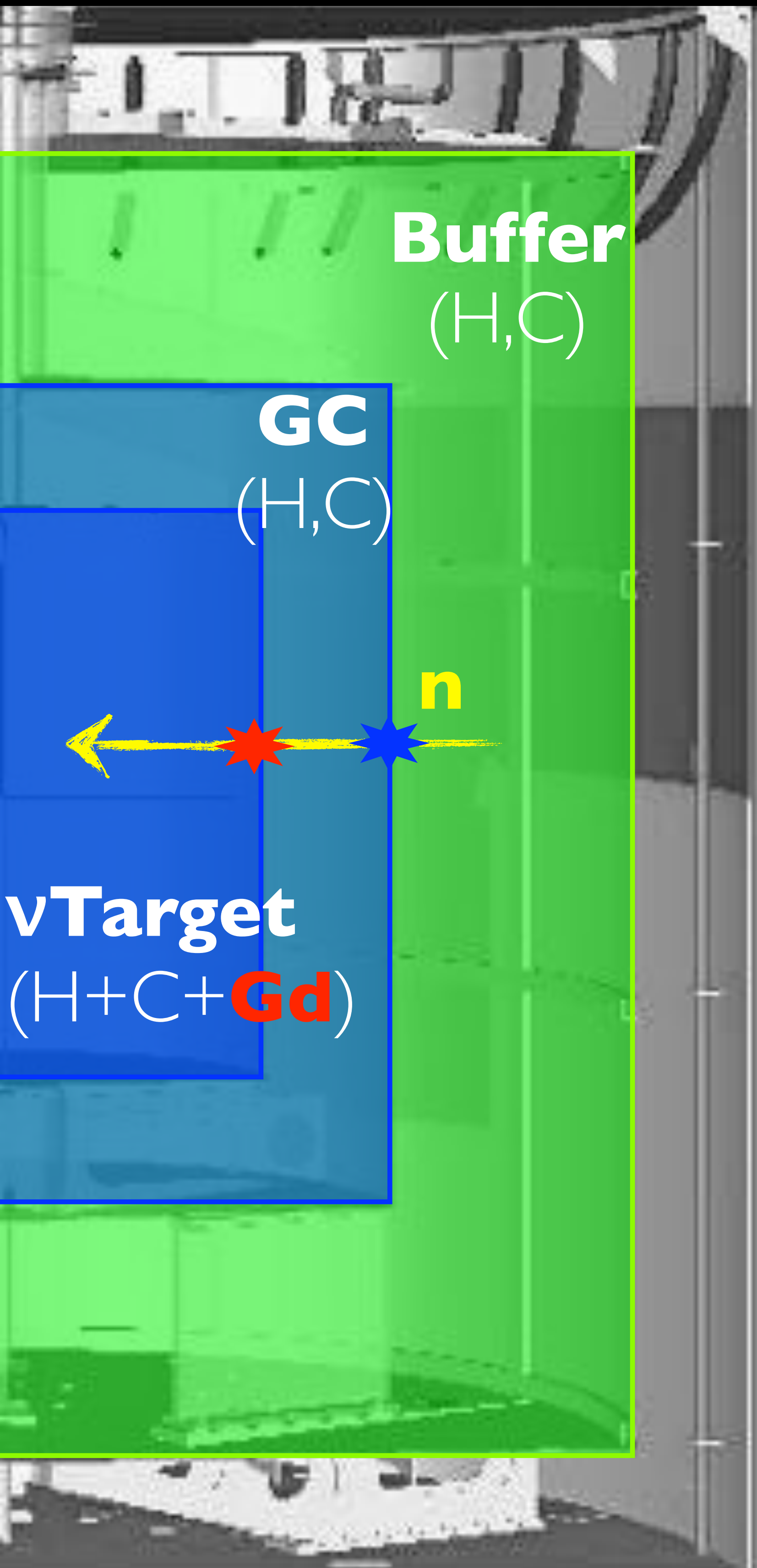
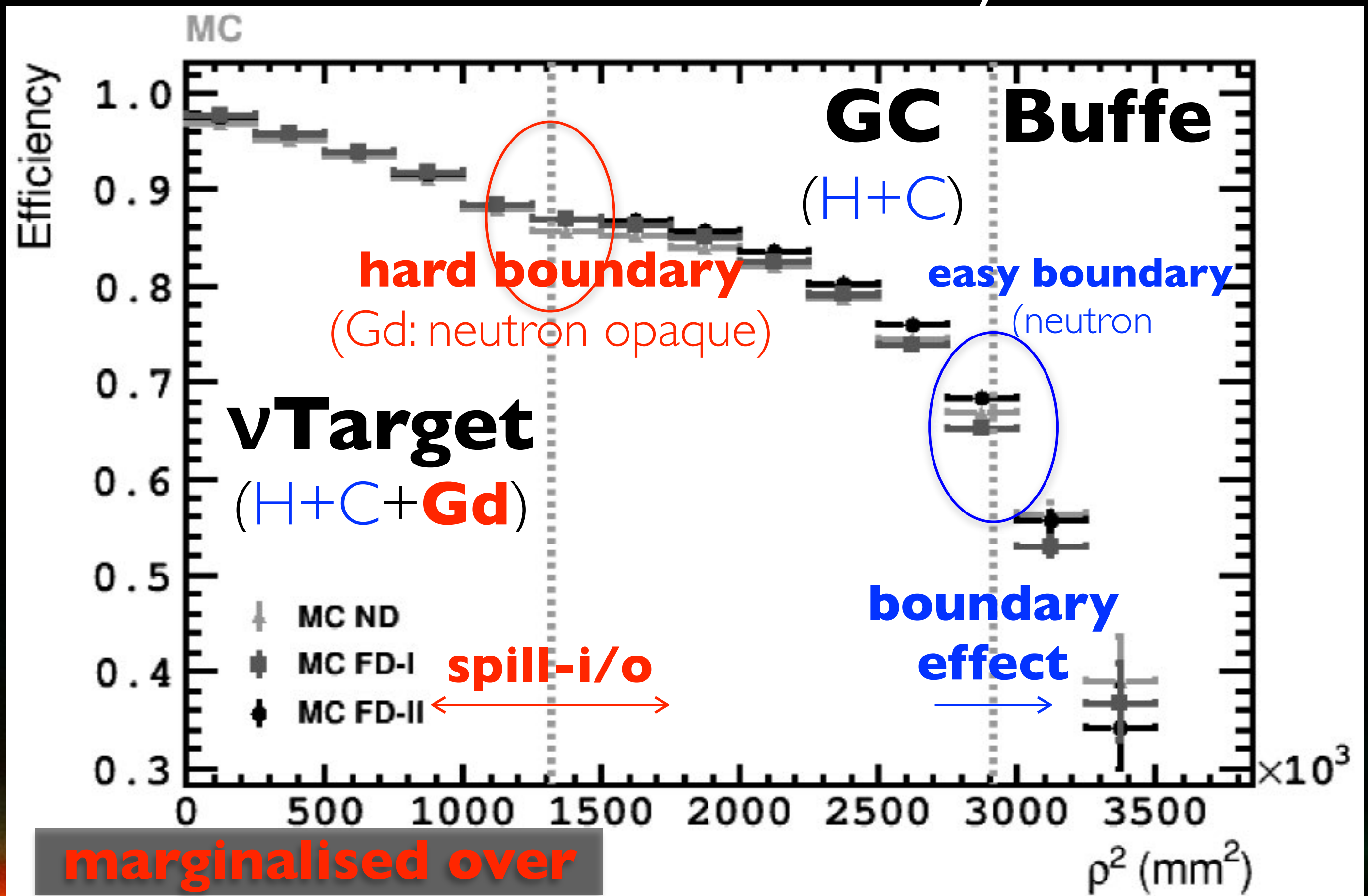
IBD(TnC) yields lower detection systematics…

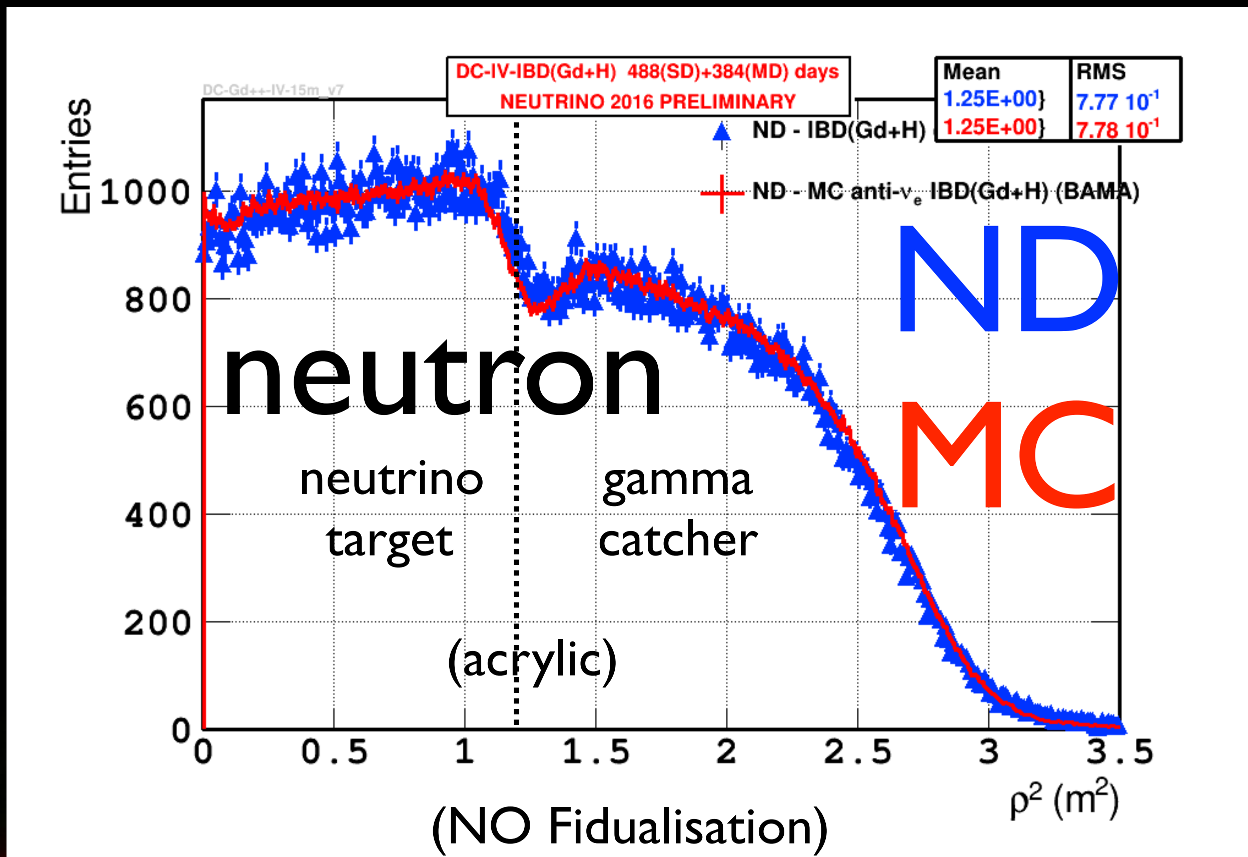


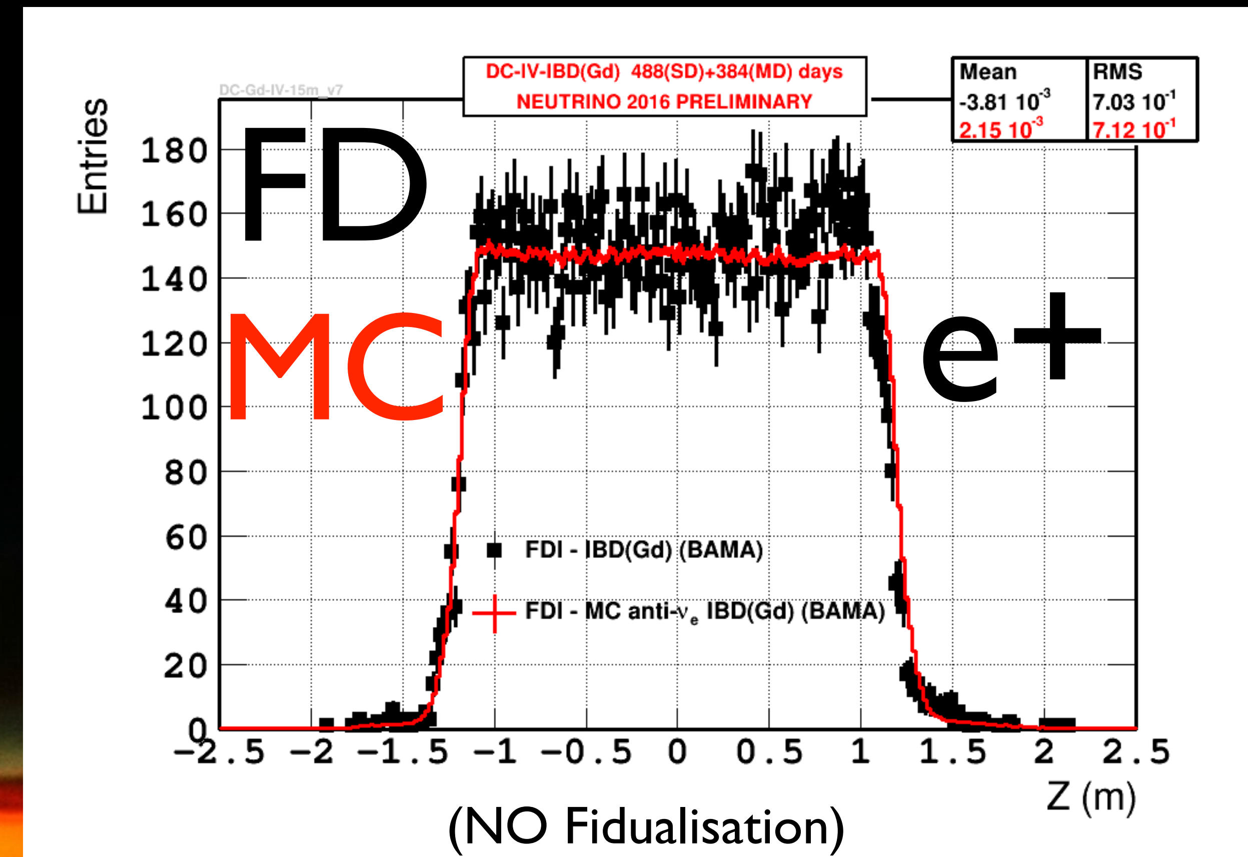


IBD(TnC) smooth neutron interface
⇒ major systematics reduction

(systematics)	IBD(Gd)	IBD(TnC)
DAQ⊕Trigger	**negligible**	**negligible**
BG rejection veto	**small (0.1%)**	**negligible**
Gd Fraction	**largest (0.4%)** →	**irrelevant**
IBD Selection (ANN)	**large (0.3%)**	**large (0.3%)**
Spill I/O	**large (0.3%)**	**irrelevant**
GC Boundary	—	**small (0.2%)**
Proton# (NT+GC)	**small (0.1%)**	**large (0.5%)**

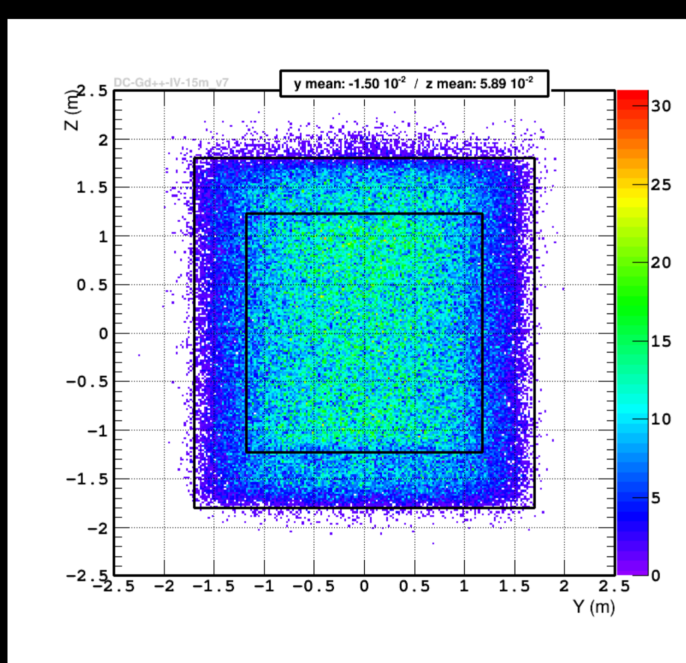
IBD(TnC)-large vs IBD(Gd)-small ν-target…





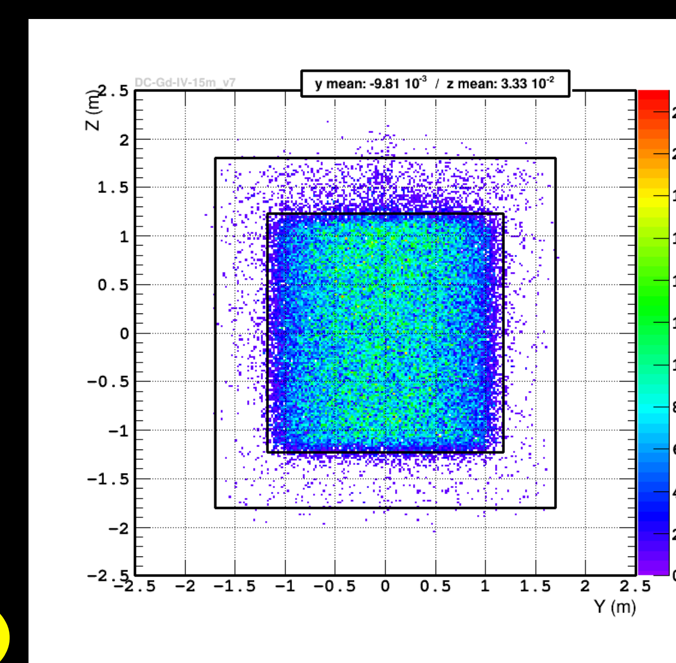
IBD(Gd⊕H⊕C)

IBD(Gd)

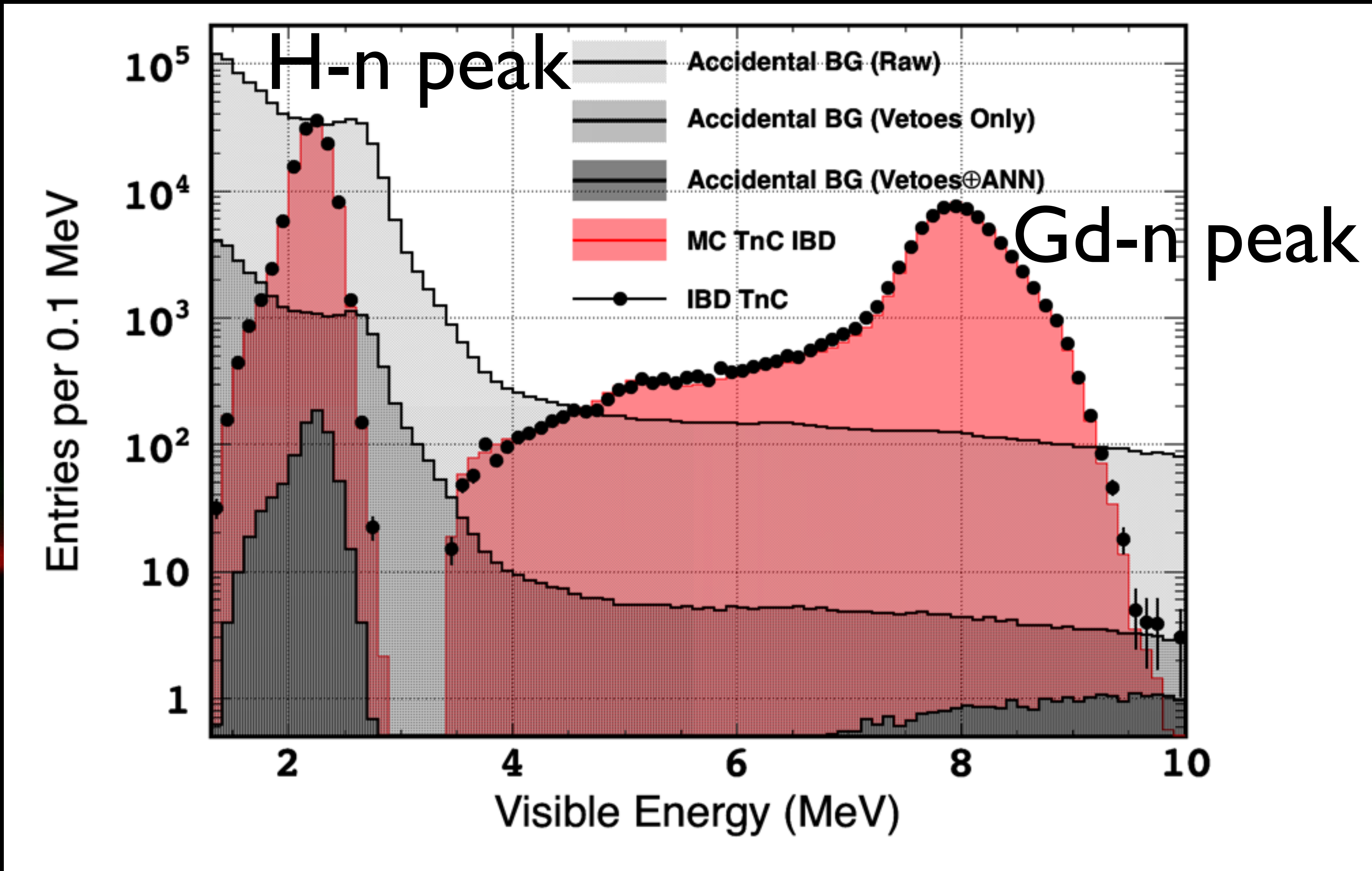


target: ~30t (large θ13 single detector target)
Signal/BG: ~10^{FD} and ~20ND

target: ~8t (smallest θ13 target)
Signal/BG: ~25^{FD} and ~30ND
IBD(Gd) reference to tune IBD(Gd+H)



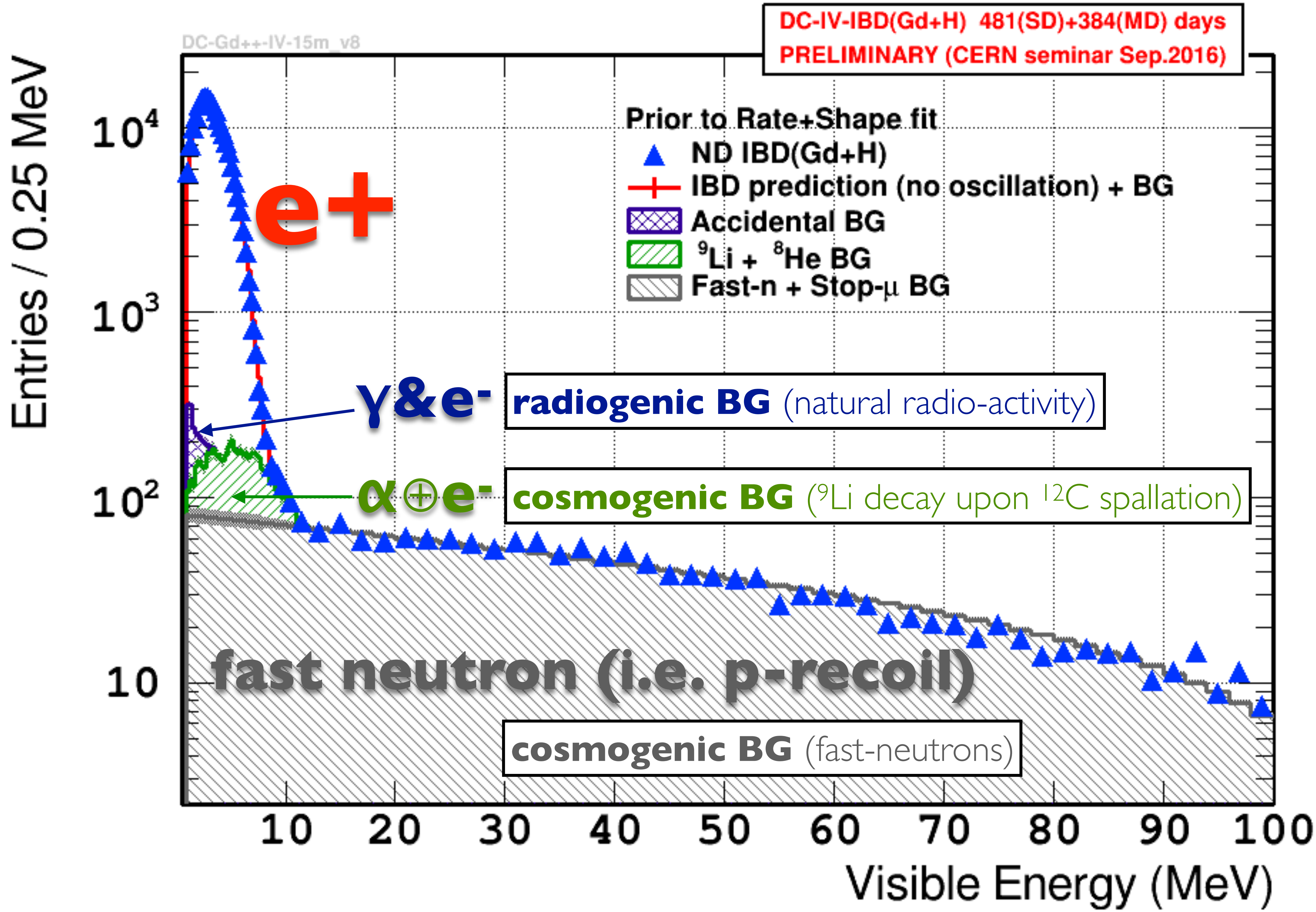
challenge: stunning BG rejection (active)...



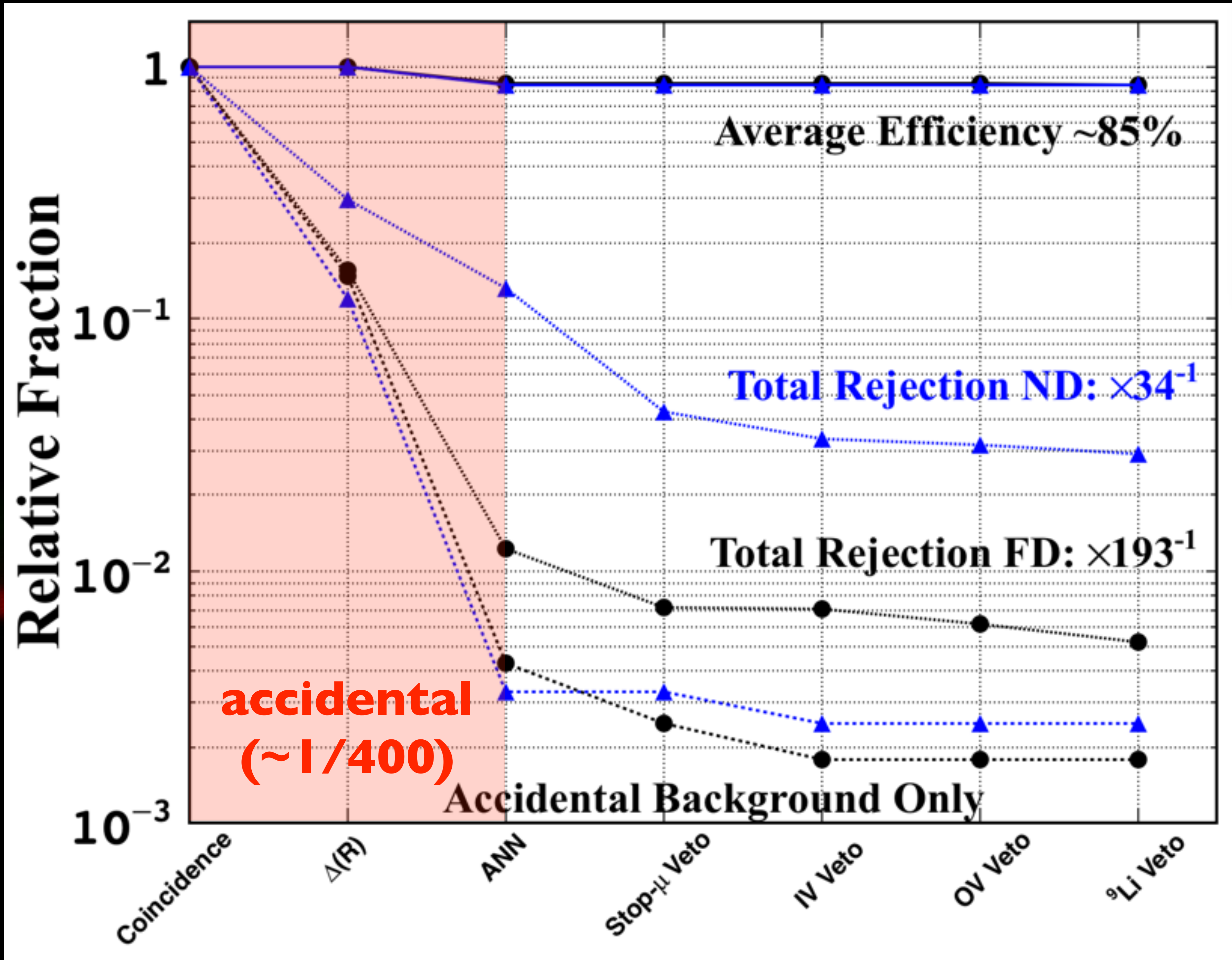
dig into BG to recover the H-n peak

(several orders of magnitude)

excellent BG rate⊕spectra knowledge…



powerful active BG rejection…



ND efficiency
total BG
accdental BG
FD efficiency
total BG
accdental BG

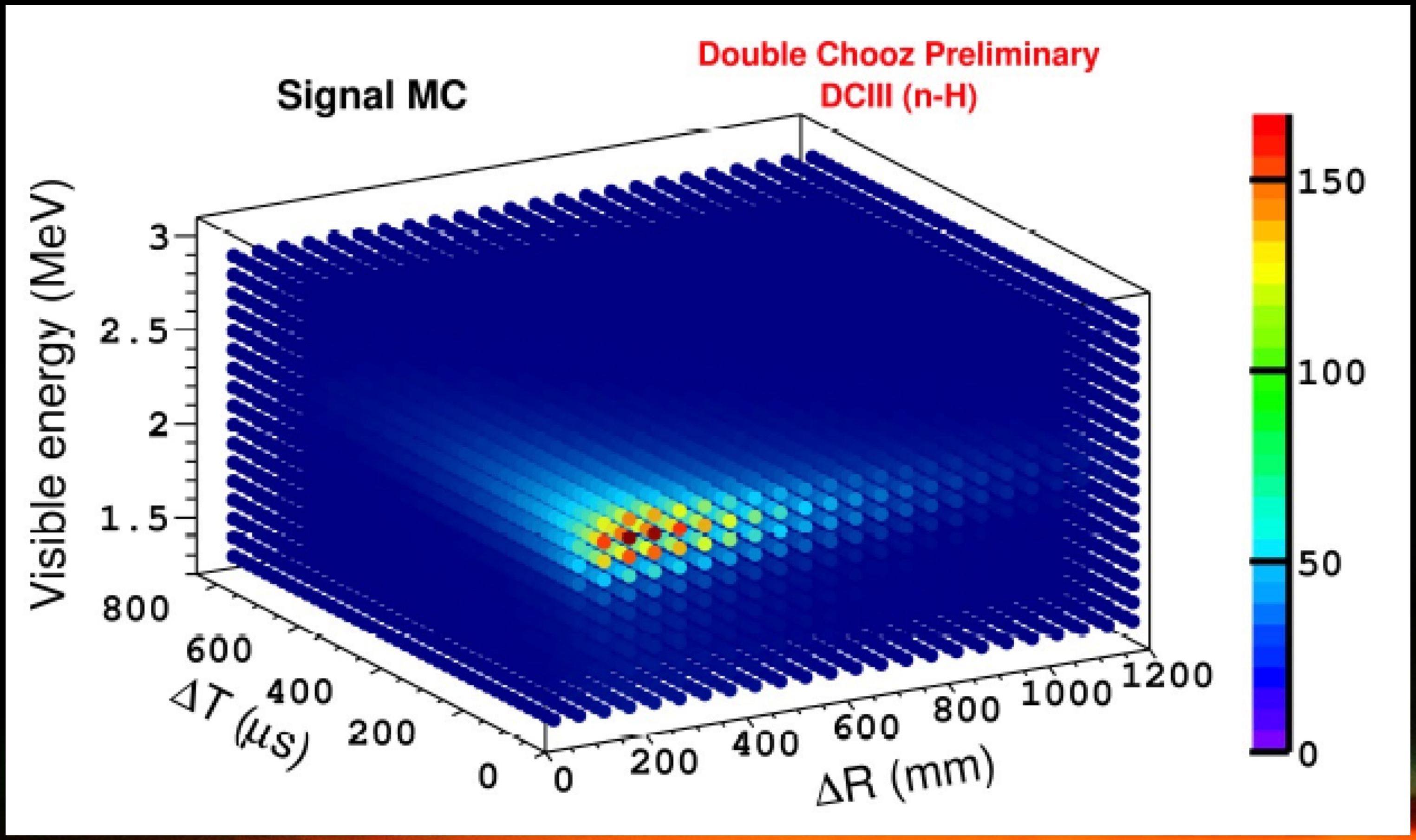
→ND cosmogenic dominated: fast-n
(overburden ~100mwe)

→FD cosmogenic dominated: ^{9}Li
(overburden ~300mwe)

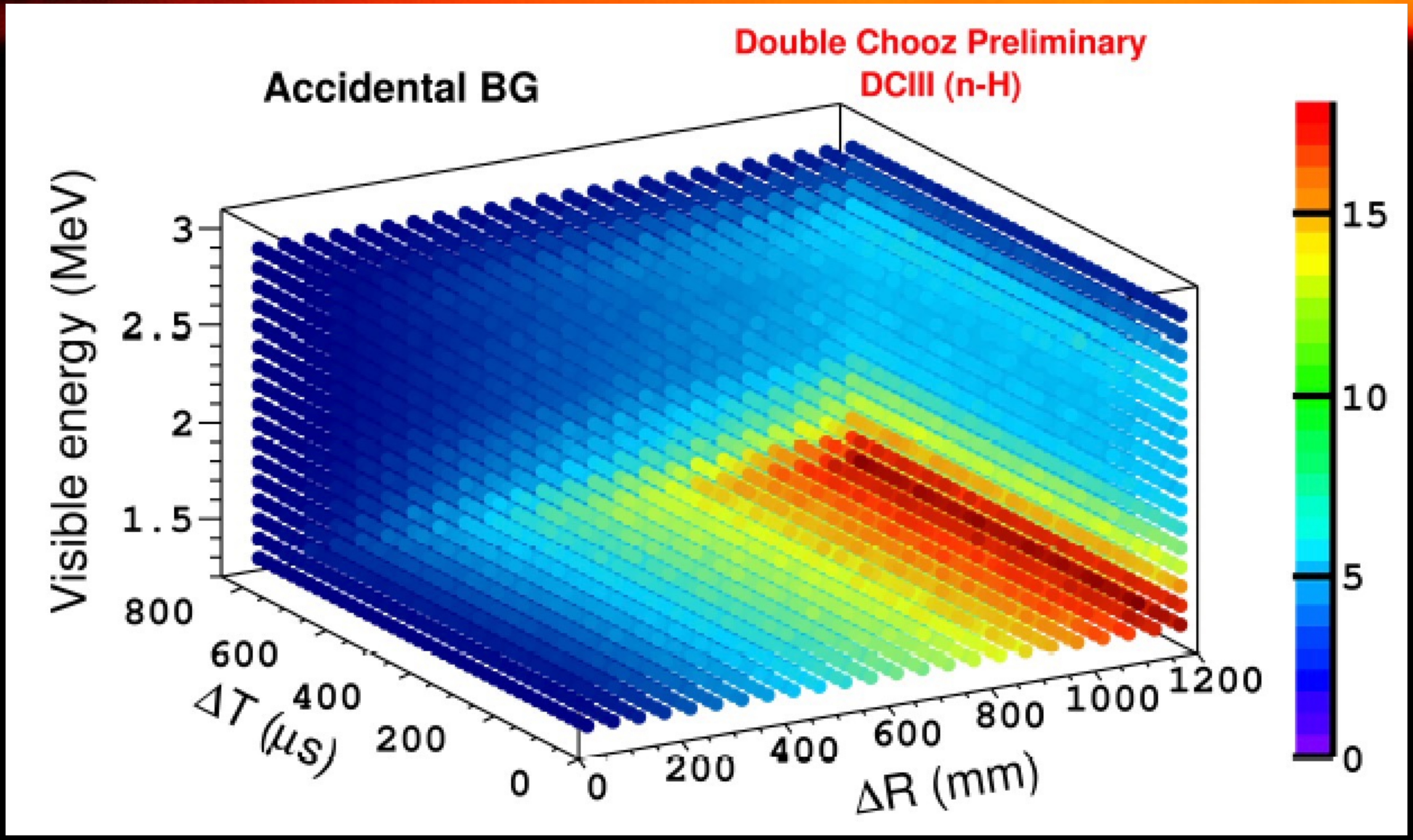
↑
loose coincidence
(~1/375 singles)

powerful veto system
(multi-layer detector articulation)

ANN accidental-BG rejection rationale…



IBD (signal)
(correlated)

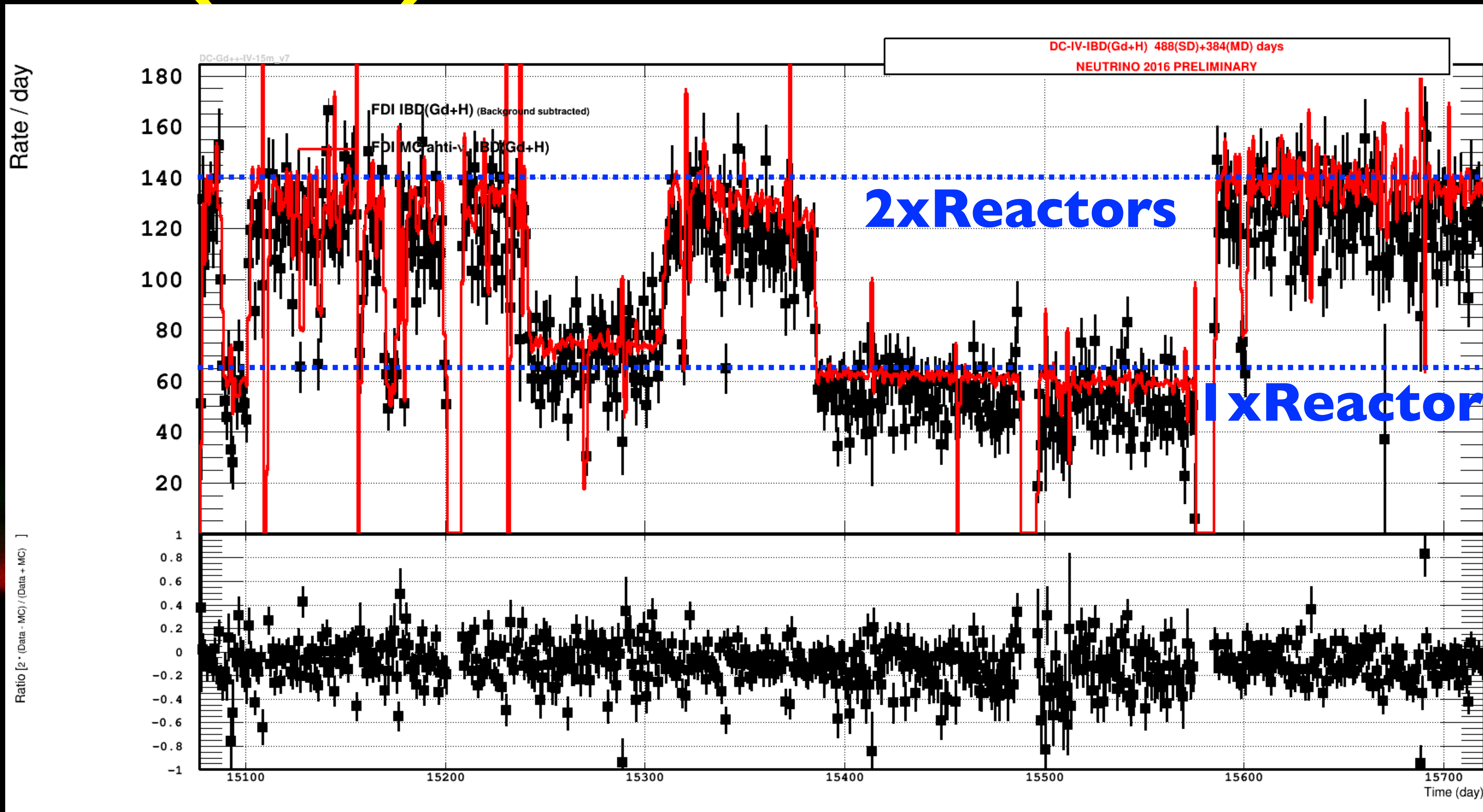


Accidental BG
(random)

(i.e. longer **Δ**t, longer **Δ**r, etc)

IBD(TnC) vs time…

IBD(TnC)



≲140day⁻¹@ FD **≲1000day⁻¹@ ND**

(≲50day⁻¹@ FD) (≲300day⁻¹@ ND)

⇒ per mille statistics in DC

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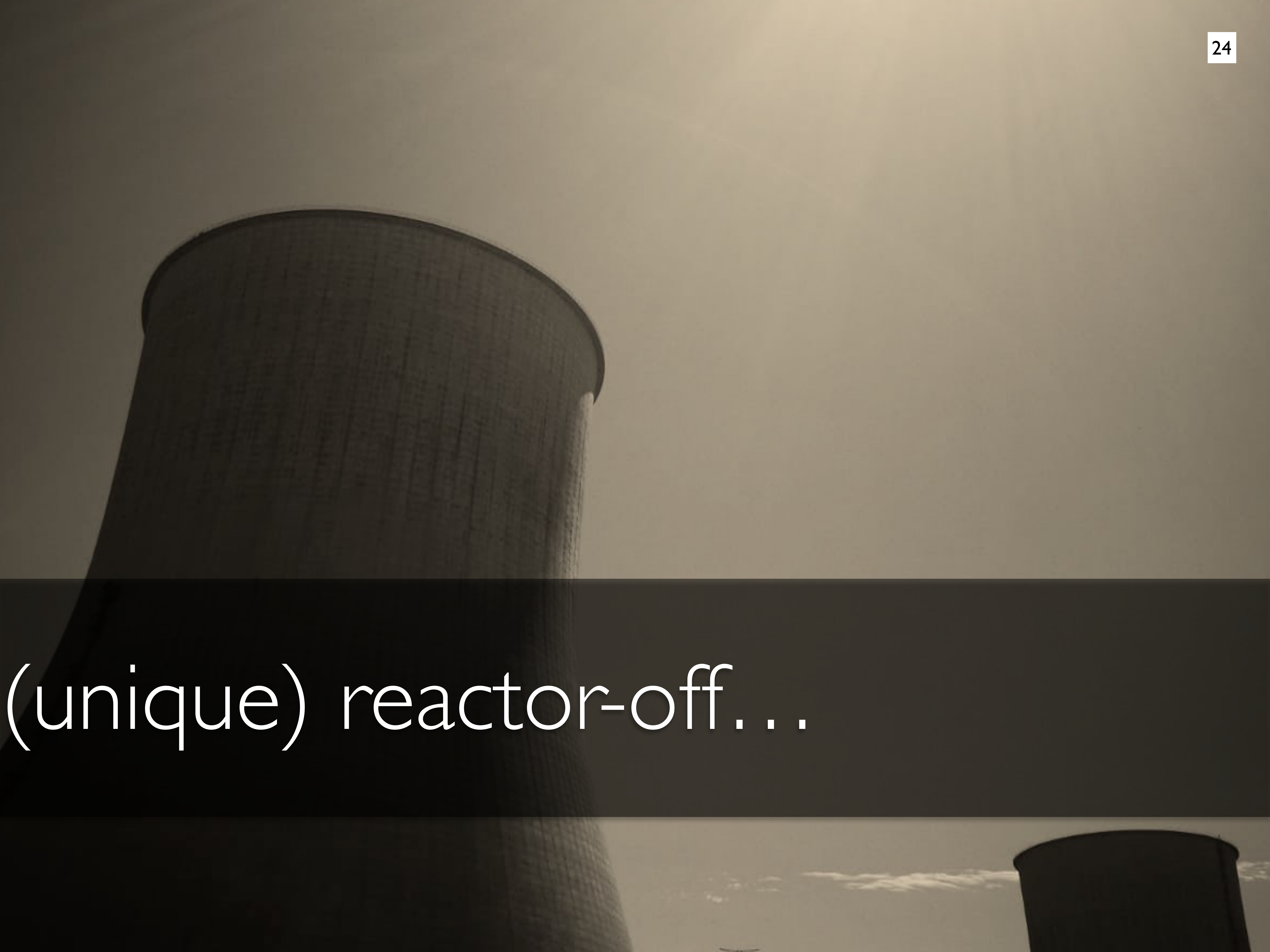
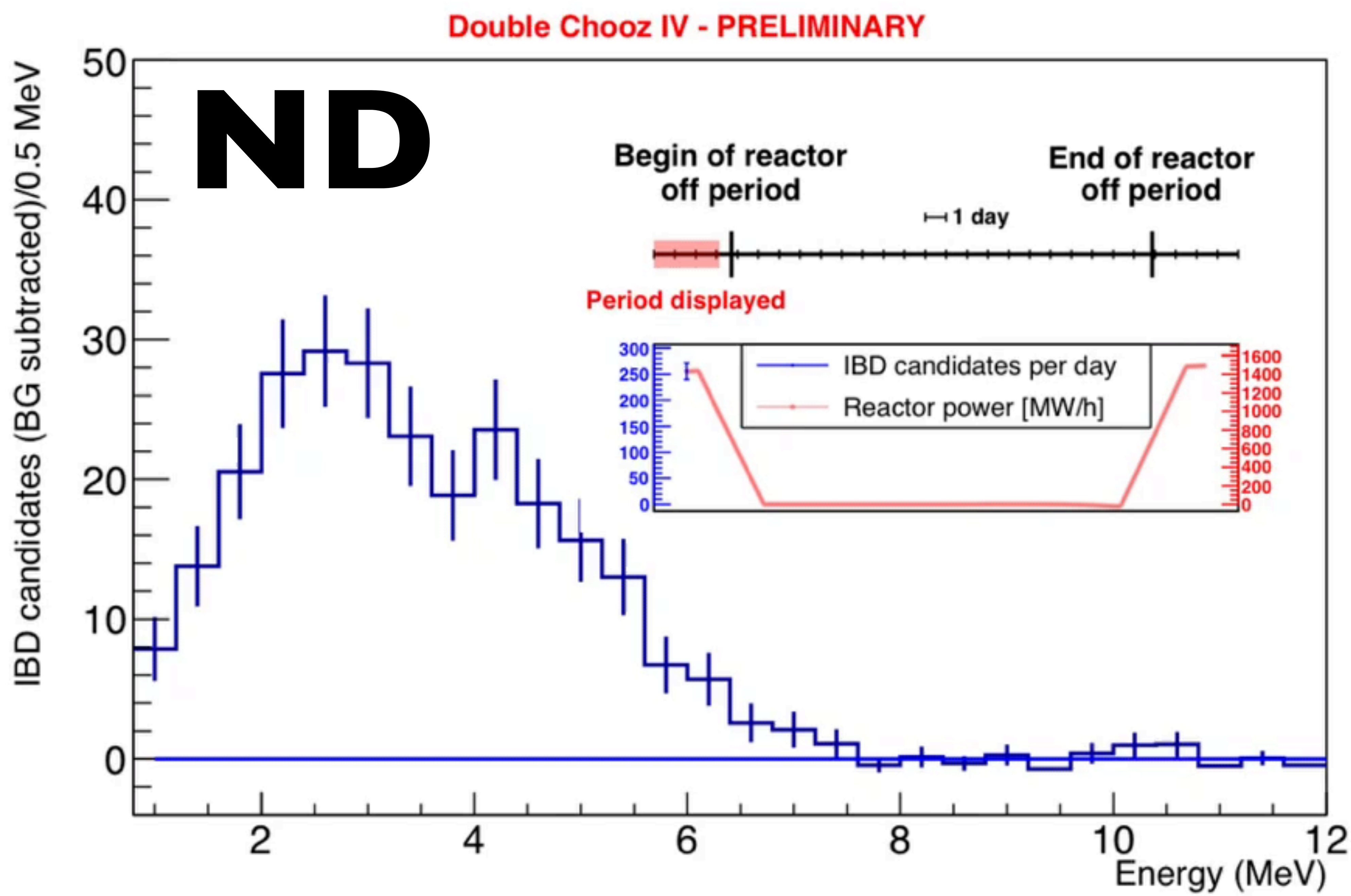

(unique) reactor-off…

reactor-OFF: beyond just BG validation…

rate(1 reactor)≈1 IBD per 3 min



BG subtracted

DC-IV signal and BG estimates…

Rate (day^{-1})	FD	ND
IBD Candidates	112	816
Breakdown		
Accidental	4.13 ± 0.02	3.110 ± 0.004
Fast-Neutron	2.50 ± 0.05	20.85 ± 0.31
^{9}Li Isotope	2.62 ± 0.27 $<1\sigma$	14.52 ± 1.48 $<1\sigma$
[μ-tag]	3.01 ± 0.60	12.32 ± 2.01
Stopped-μ	<0.19 @ 98%CL	<0.21 @ 98%CL
Others (^{12}B, BiPo)	<0.01	0.04 ± 0.01
Total		
Σ-Exclusive	9.3 ± 0.3 $<1\sigma$	38.5 ± 1.5 $<1\sigma$
Inclusive (17 days)	9.8 ± 0.9	39.6 ± 2.5
Signal to BG	11.0	20.2

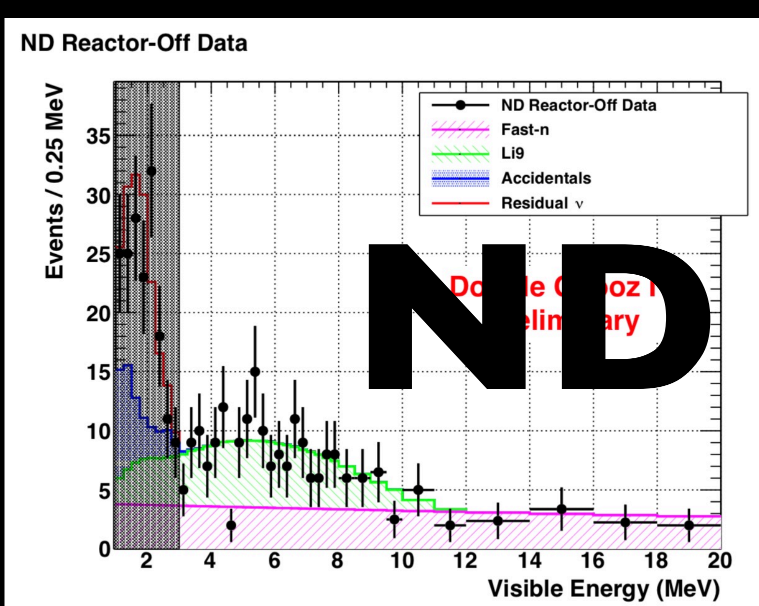
→**average rate**

→**BG breakdown**
(known BG model)

→**independent ^{9}Li**

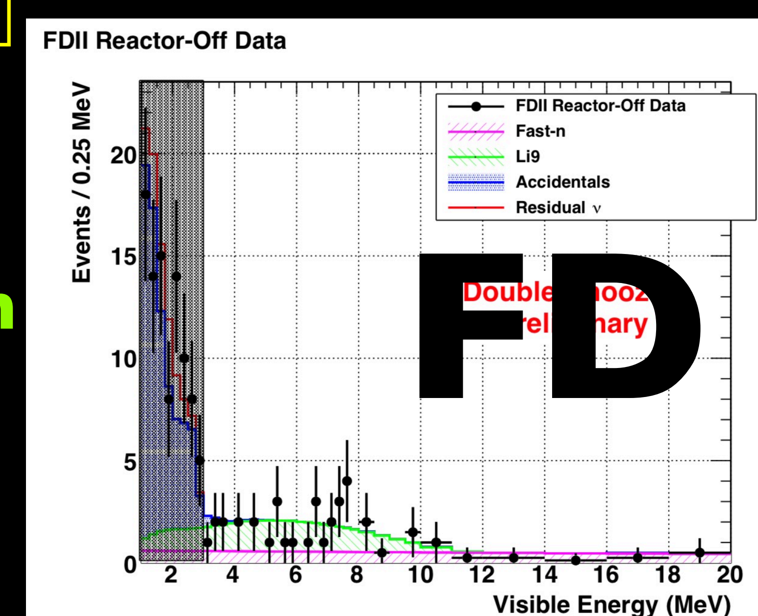
→**reactor-OFF validation**
[17 days]

DC BG is dominated ^{9}Li uncertainty (~10%)
[independent measurement articulation]



reactor-OFF spectral information
[rate+shape BG information]

FIRST TIME in DC!!!



DC stopped data taking…

April 2011 — Dec.2017
(dismantling ongoing)

physics results…

(nut-shell) experiment's rationale & history…

Chooz Reactors

~10²¹ν/s

<L>=0m

Bugey4 (~ND)

Near Detector (ND)

≲1000 ν/day

Dec.2014

<L>≈400m

Far Detector

FD-I

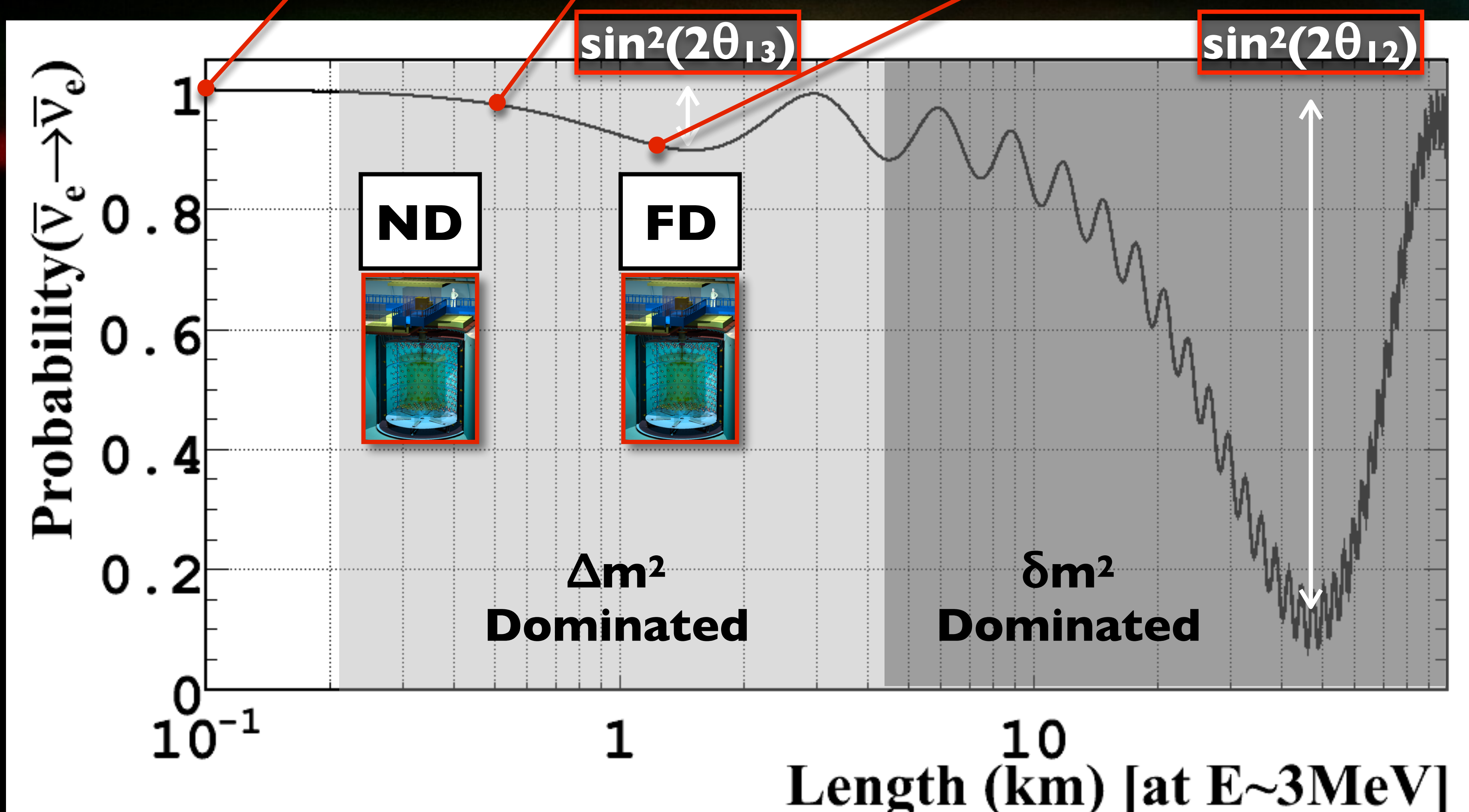
FD-II

≲140 ν/day

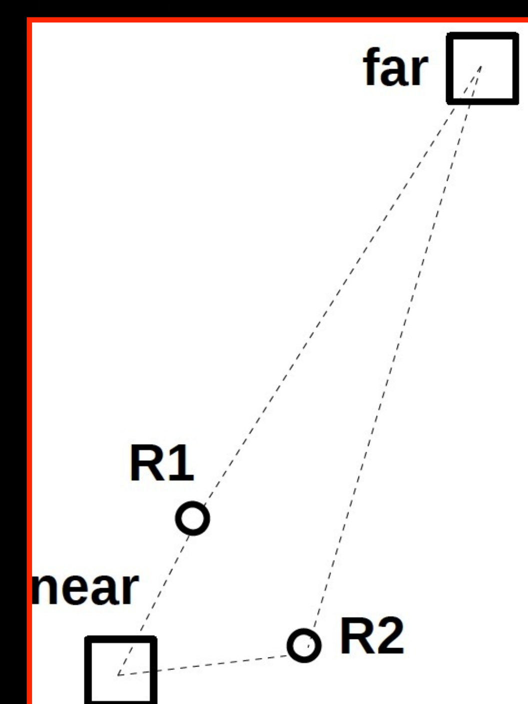
April 2011

<L>≈1050m

FD-II ⊕ ND (MD: Multi-Detector)



Site Geometry (~iso-flux)



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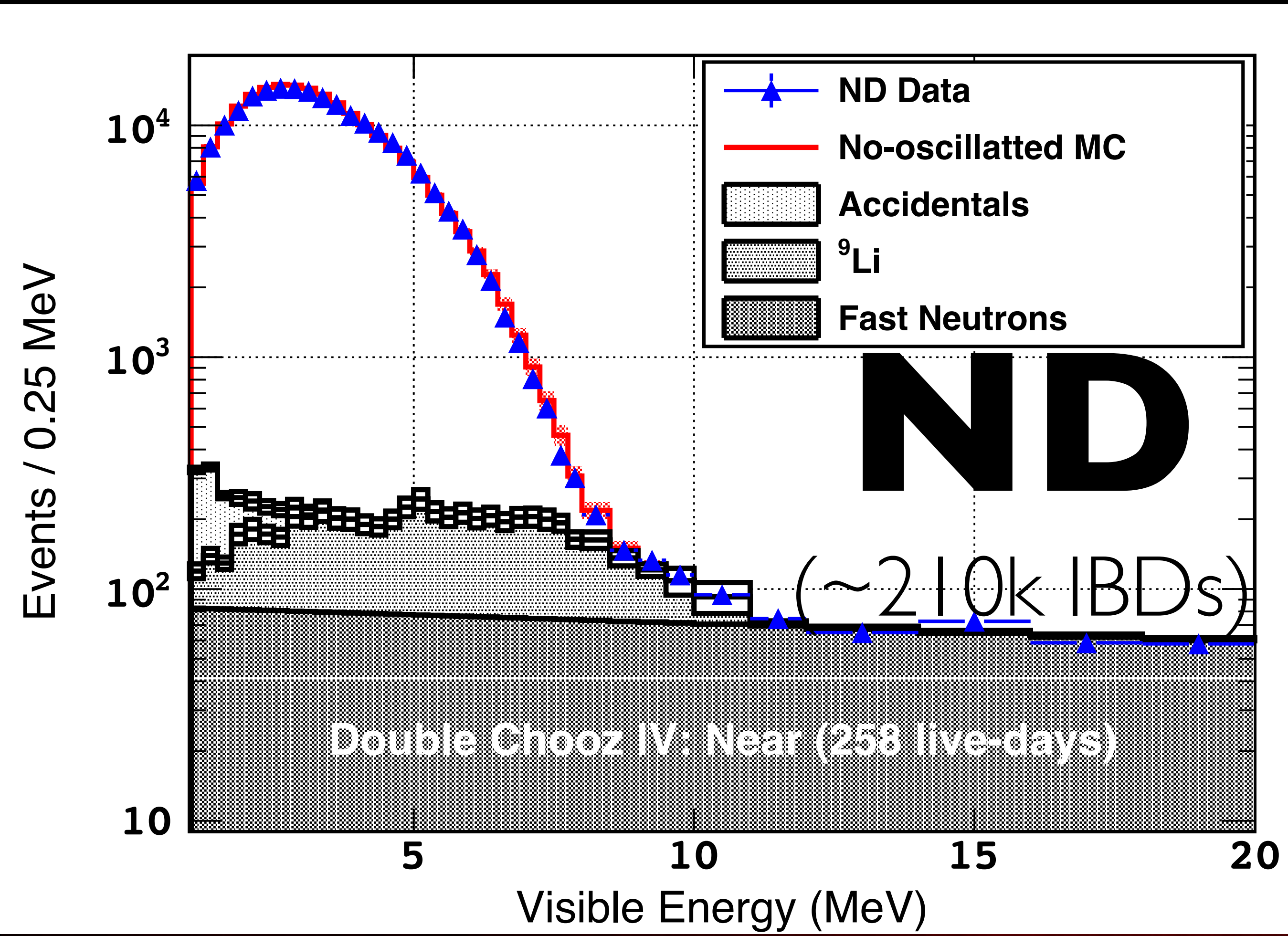
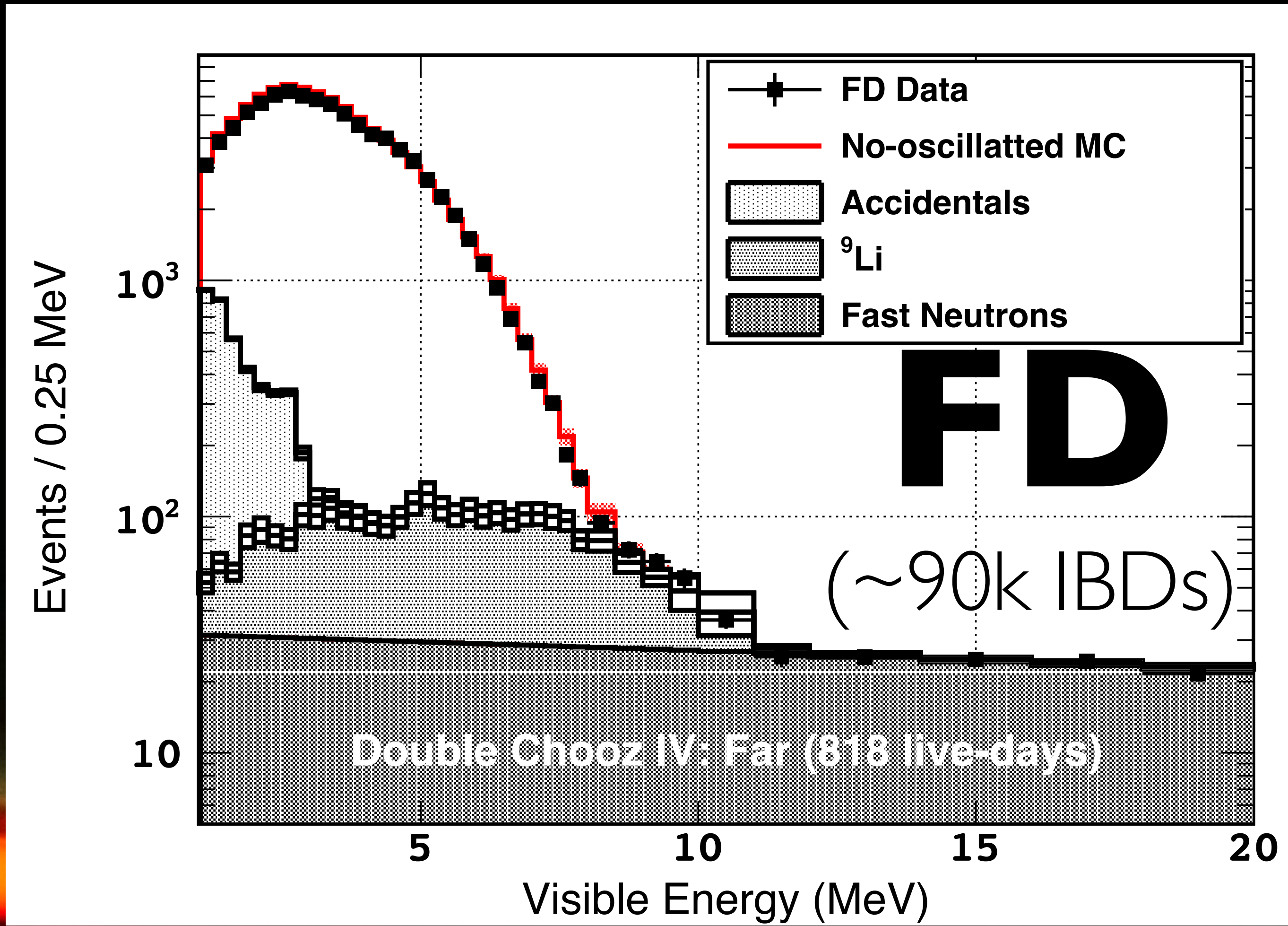
each single-detector (SD) spectra…





well understood spectra signal & BG

(**reactor "ILL data" based model**→scrutinise)

multi-detector (MD) combination

(physics extraction)

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DC's task: high accuracy…

detection systematics

"IBD inclusive" method

(against exclusive: ≲1‰)
(against calibration sources: ≲1‰)
(against fast-neutron: ≲3‰)
(Cf n-multiplicity: ≲1‰)
(pulls in θ13-fit: <1σ)

BG systematics

BG model "Σ-exclusive"

(against inclusive: ≲1σ)
(against fast-n(OV) & ^{9}Li (μ-tag): ≲1σ)
(pulls in θ13-fit: <1σ)

energy systematics

full volume control ~0.6% precision

(Cf prompt: MD deviations ≲3‰)
(energy model as pulls in θ13-fit: <1σ)

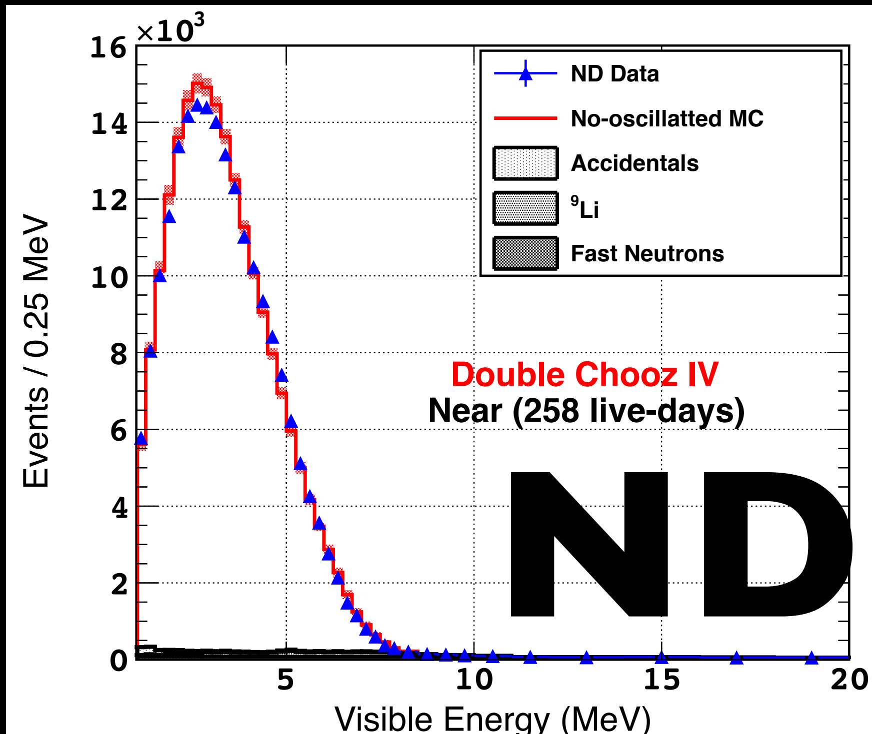
reactor flux systematics [σ_{IBD} known to ~1‰]

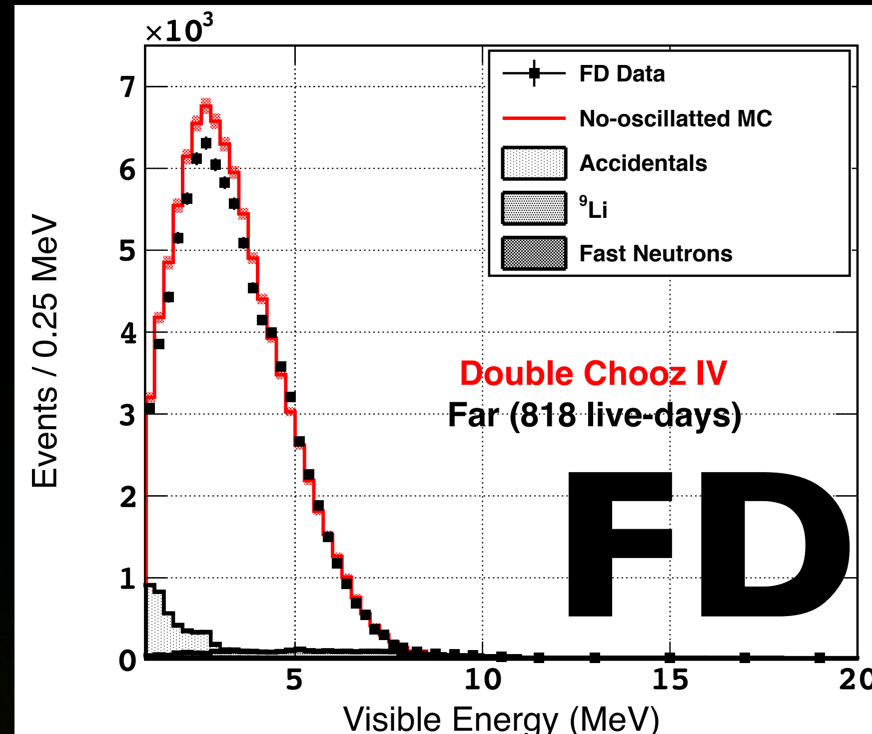
DC iso-flux geometry: cancel most

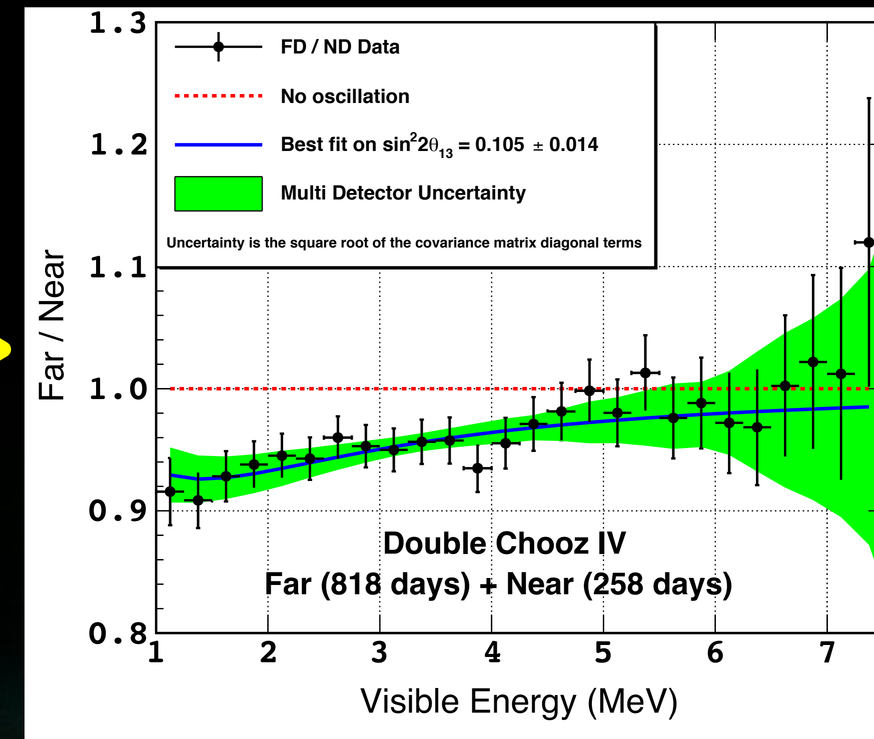
→ must scrutinise with θ13 (i.e.flux modulation)

Hervé de Kerret *et al* (arXiv:1901.09451)

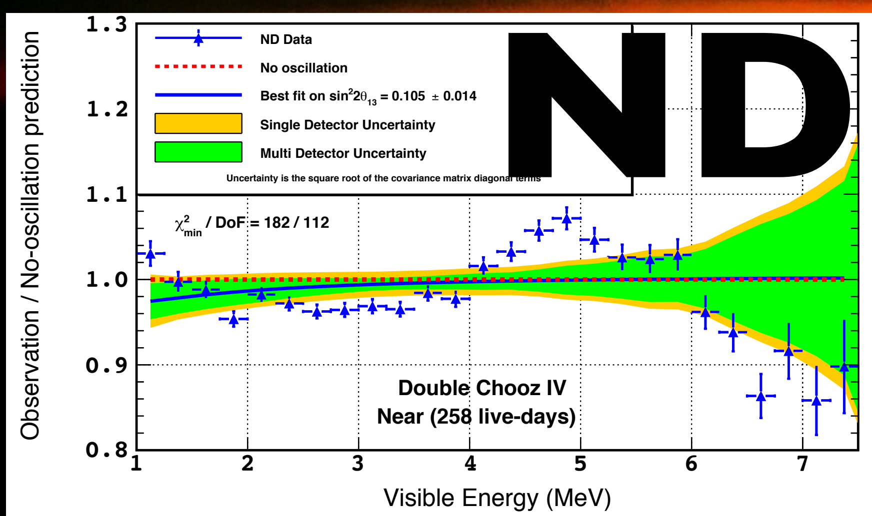
multi-detector θ13 fit extraction…

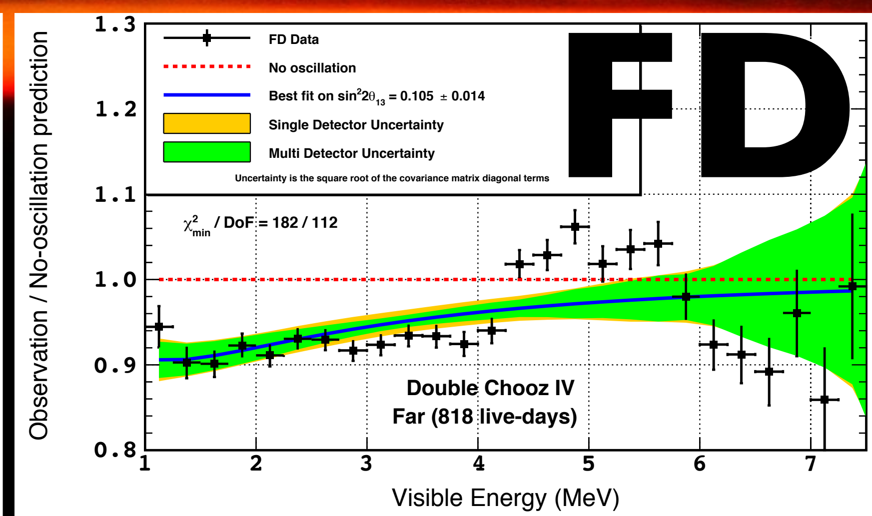






direct data to MC ratio





inter-detector ratio
(reactor model cancellation)

sin2(2θ13)=0.105±0.014
X²/DoF: 182/112

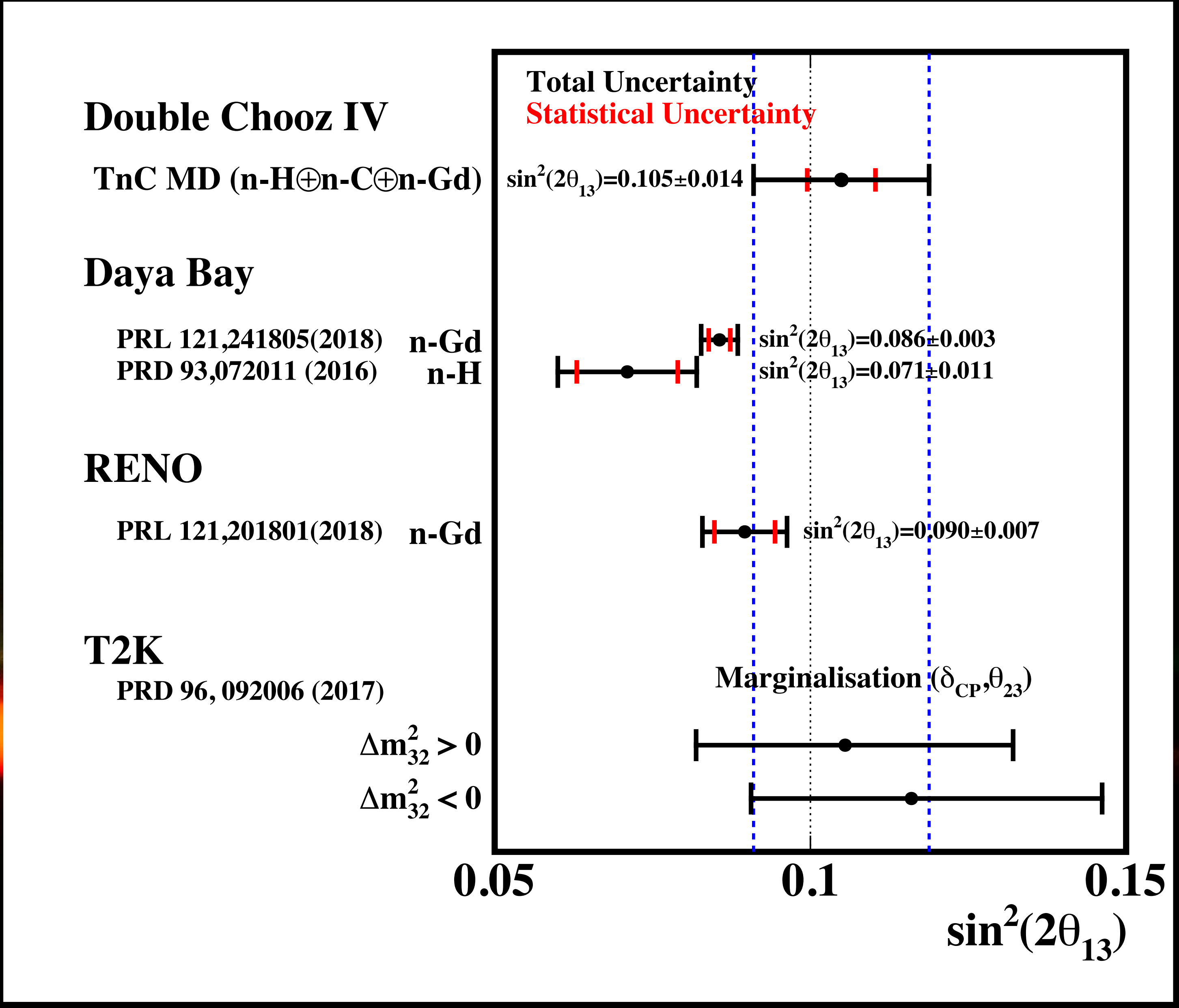
(sensitivity 0.014)

“common” (correlated) effects cancel

(MC reactor model distortion → poor X²)

DC compared to the world knowledge…

Uncertainty	Fit Output	Correlation
Statistics	0.0054 (5.0%)	–
Reactor Flux	0.0081 (7.6%)	1.1
Detection	0.0073 (6.8%)	1.2
Energy	0.0018 (1.7%)	4.0
Background	0.0018 (1.7%)	2.4
$\lvert\Delta m^2_{ee}\rvert$	0.0018 (1.7%)	1.0
Correlation	0.0065 (6.1%)	–
Total	0.0141 (13.3%)	



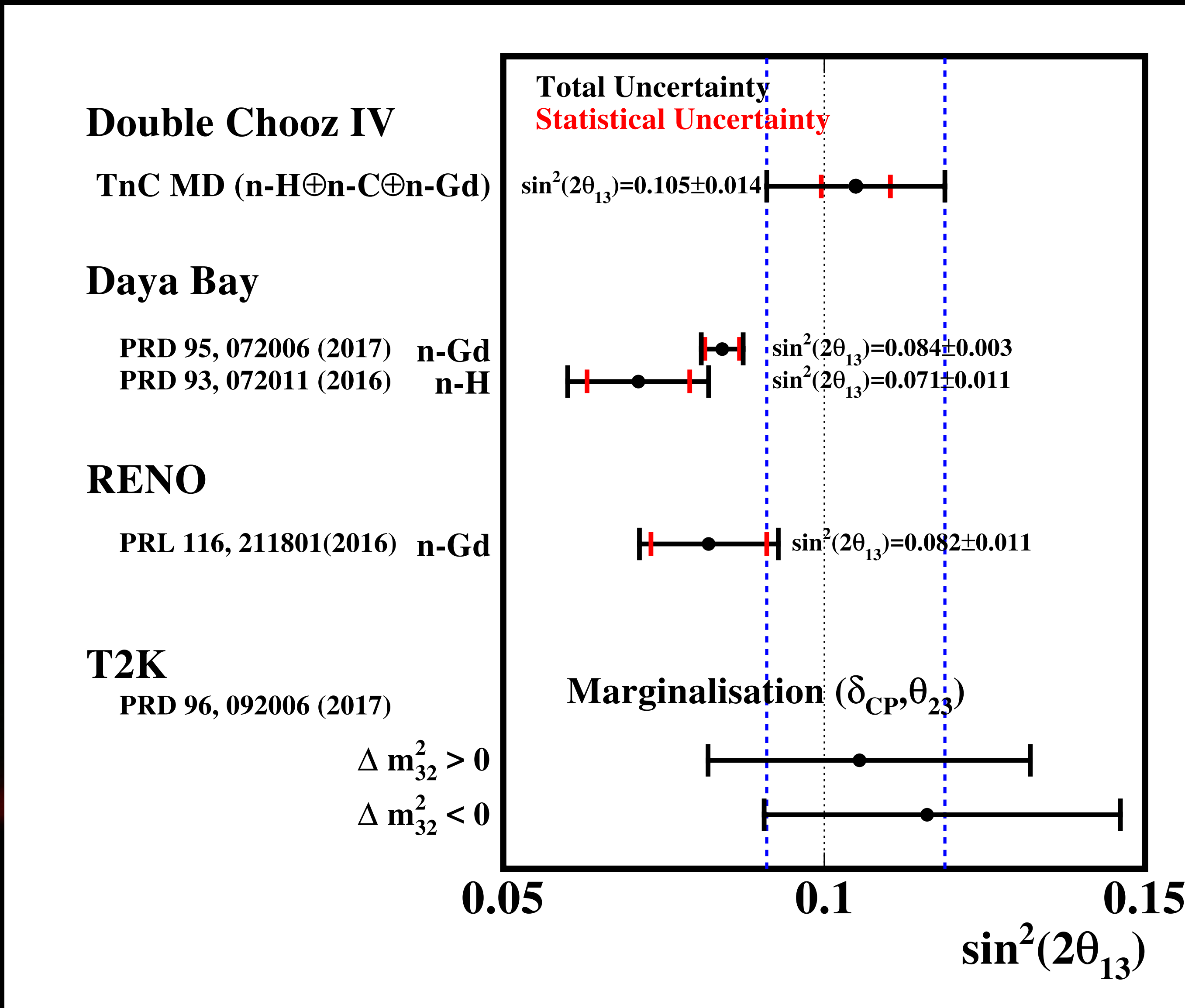
reactor systematics
(**FD-I with no ND**)

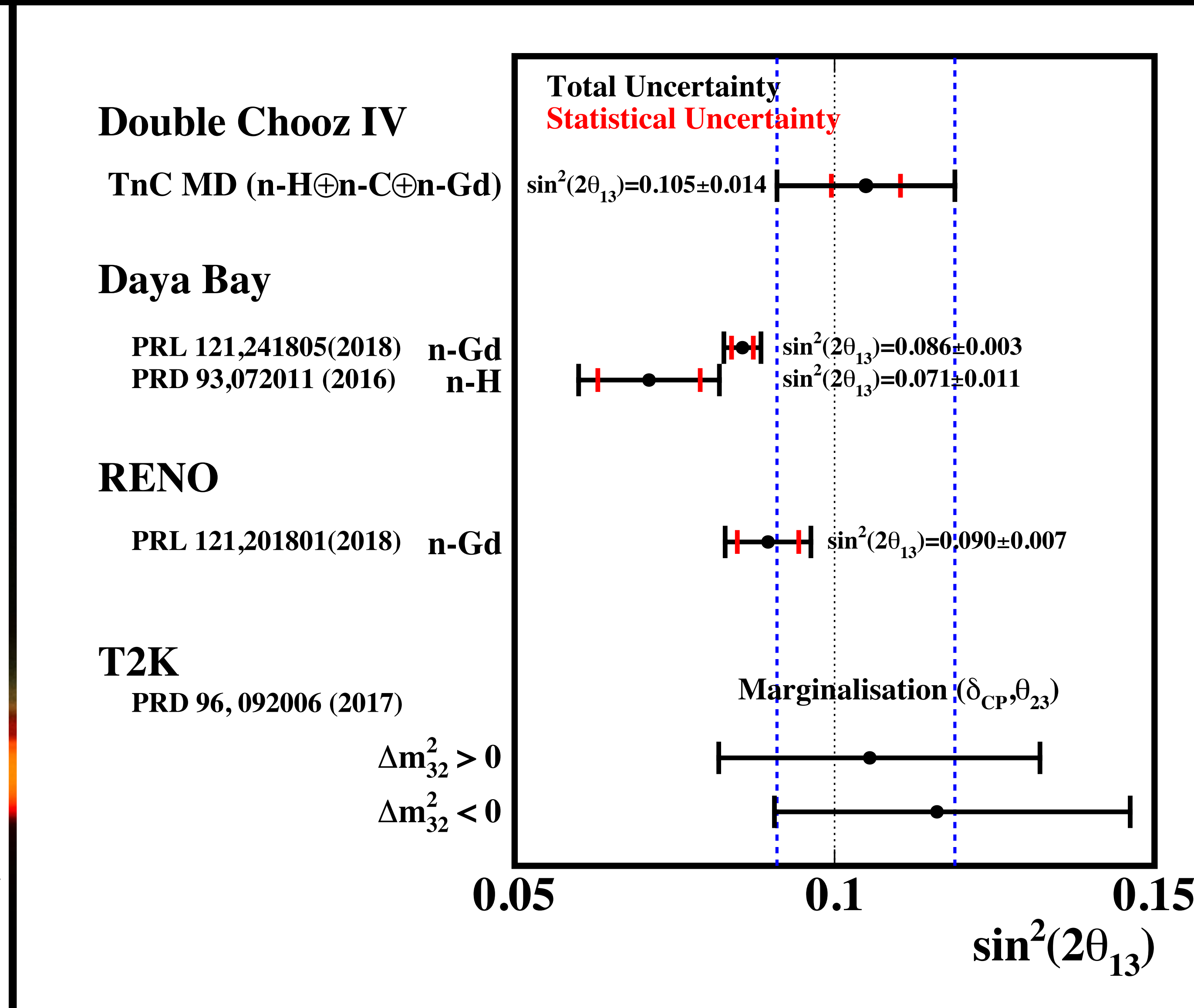
detection systematics
(**poor proton# GC**)

energy systematics
(via effective correlation to flux)

DC slightly higher [up to ≤2σ]
(DYB & RENO slightly higher @ Neutrino-2018 too)

systematics effect? ["ok"]
(statistics deviation not impossible but disfavoured)





before **after**

NEUTRINO 2018 Heidelberg 4–9 June

Anatael Cabrera (CNRS-IN2P3 & APC)

STRUCTURE

impact to θ13?

AHEAD

once upon a time (≤2010), reactor flux…

rate (norm): OK [~3%]→ Bugey4 (world reference)

2011: latest τ(neutron) ⊕ ILL re-evaluation [within DC + Huber]
today: all experiments in agreement ("deficit")→**why?**

[Antonin's talk]

new physics vs reactor bias?

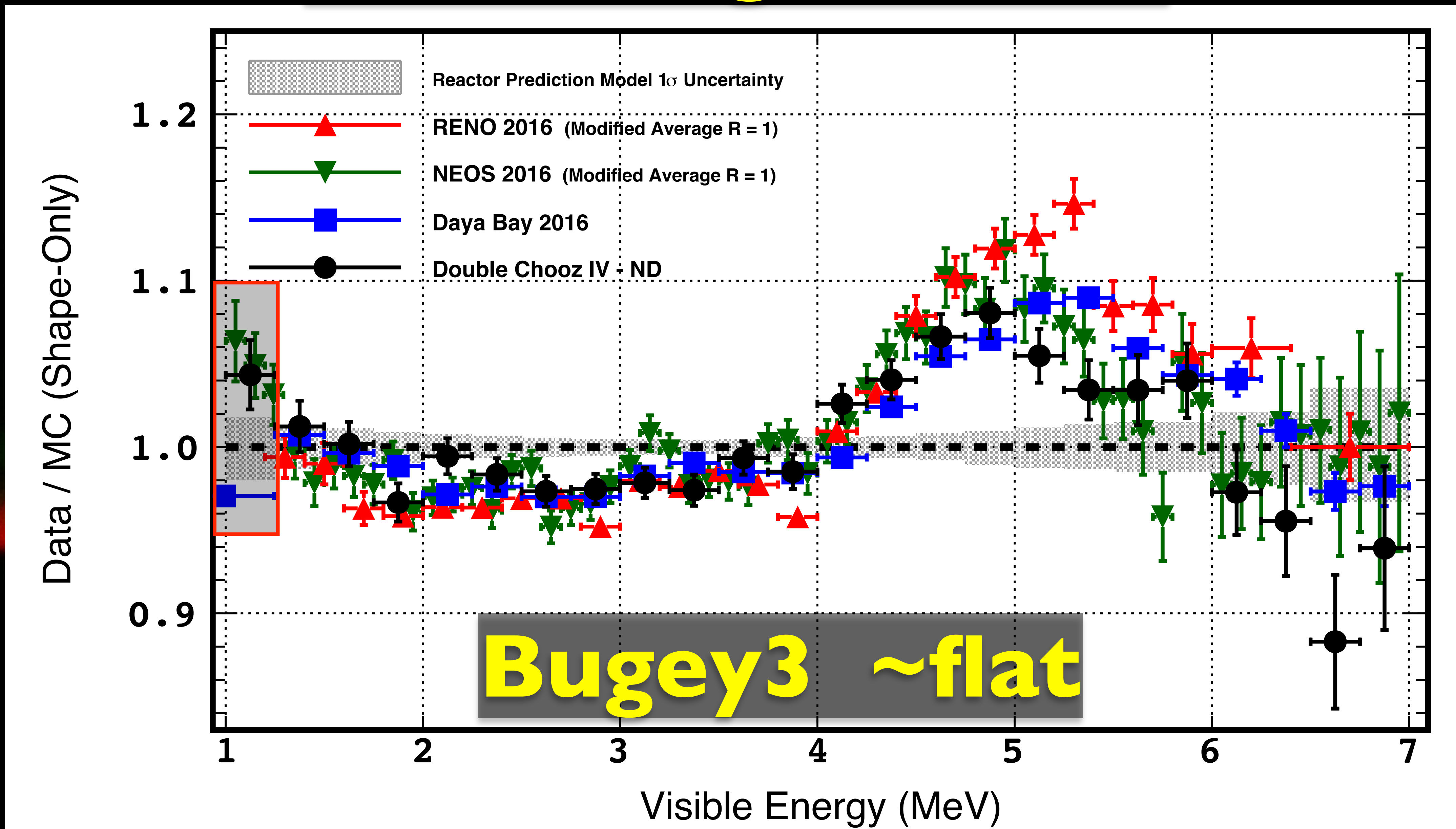
shape: OK [~3%]→ Bugey3 (world reference)

2014: DC's spectral distortion (prominent 5MeV) [most experiments]
today: only Bugey3 shows "negligible structure"→**reason? why?**

are those 2 observations independent?

reactor spectral structure (shape only)…

overall agreement

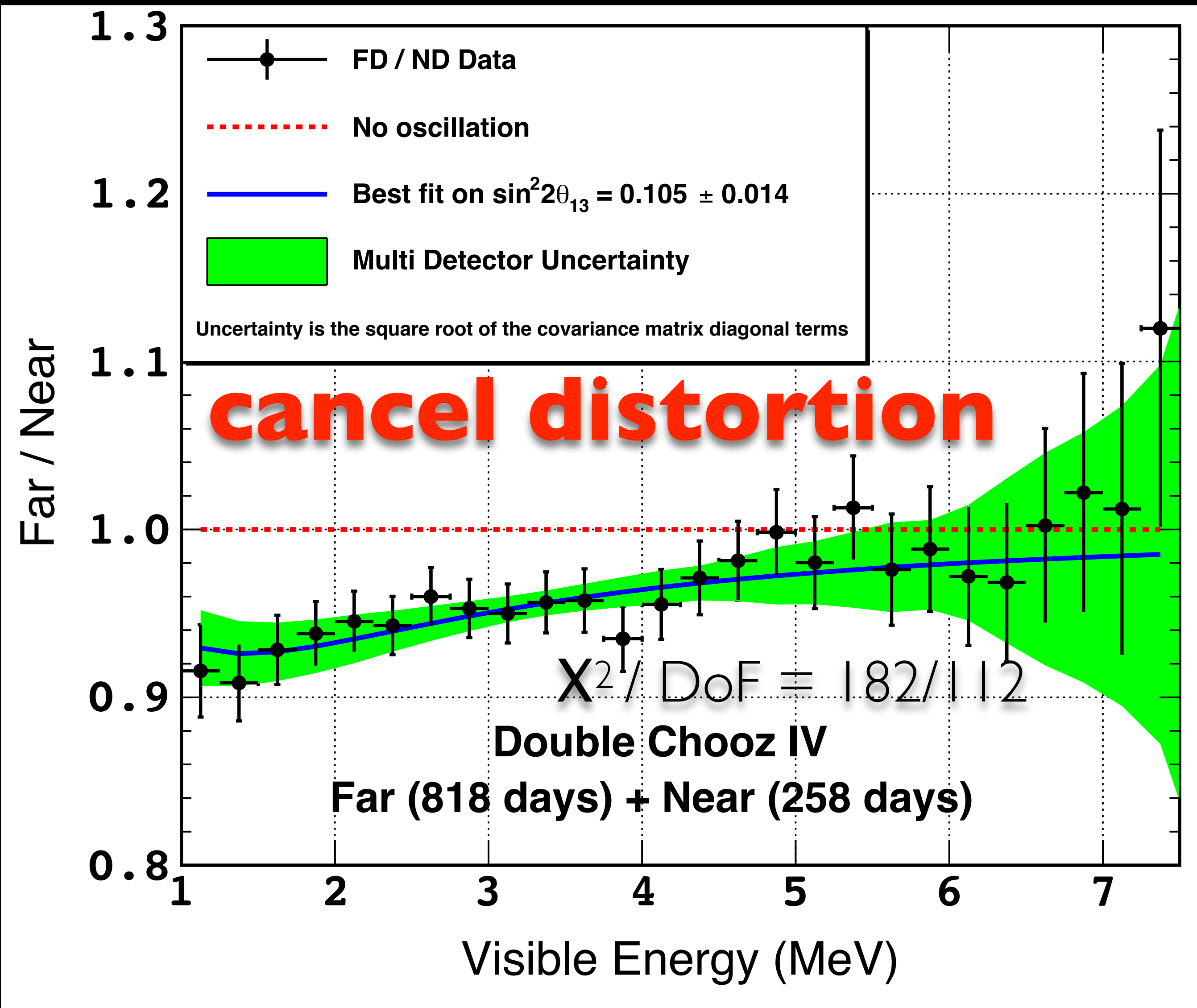


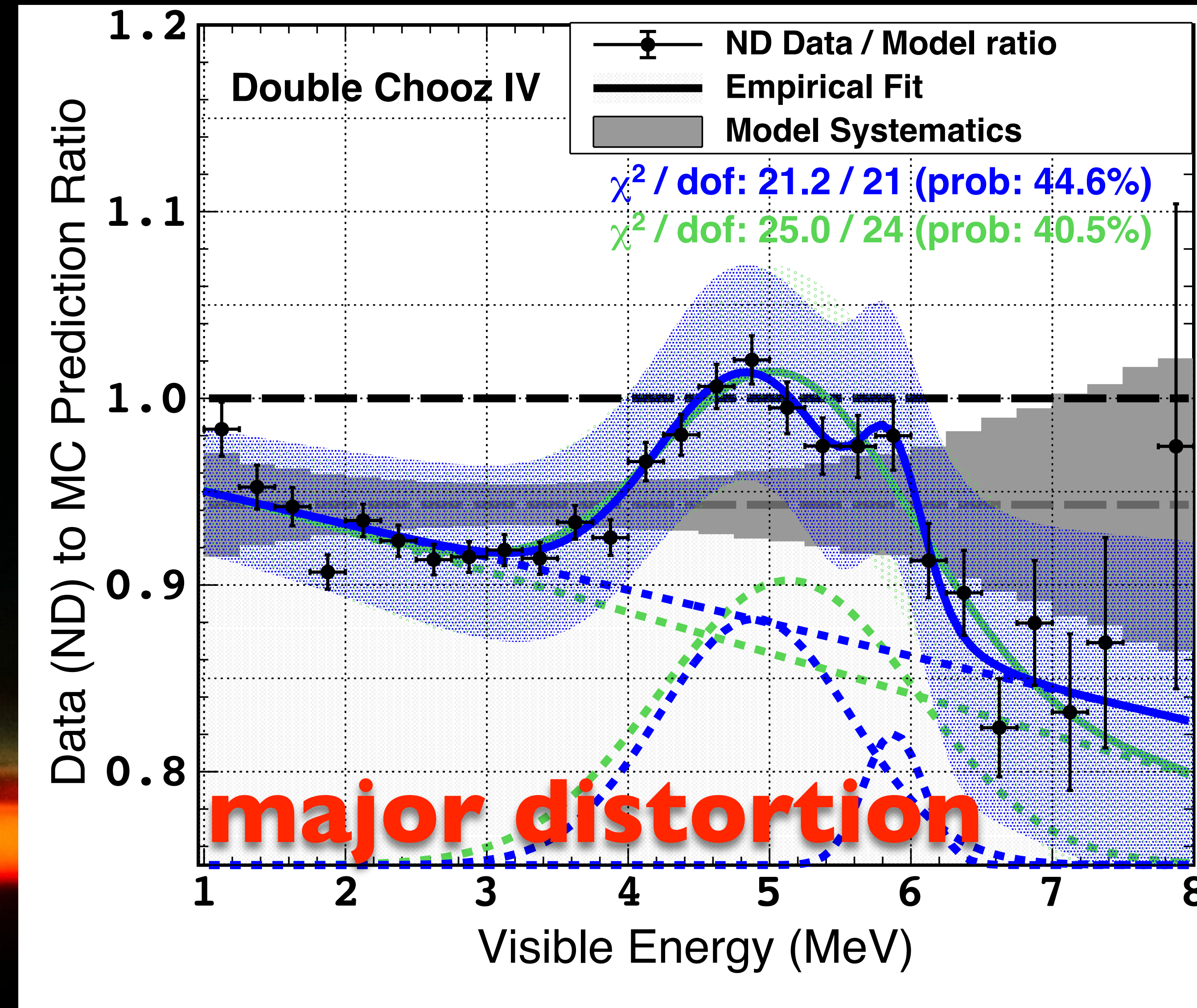
DC (re-binned) ≈ DYB

[ratio D/MC cancels matched effects by "MC tuning"]

NOTE: Goesgen, Chooz, Rovno consistent hints (a posteriori)

rate+shape DC spectral ratio's…





FD:ND ratio (θ13)
[rate+shape]

ND:MC ratio
[rate+shape]

no apparent distortion→θ13 protected?
[MC always used]

DC flux scrutiny: impact θ13?...

reactor power correlation?

yes→ <u>flux</u> and/or <u>energy</u>

common in ND and FD?

yes→ demonstrated (identical detectors)

common across experiments?

most!→ favours <u>reactor hypothesis</u> via common ILL based model [Huber+Muller]

bias via model uncertainty underestimation?

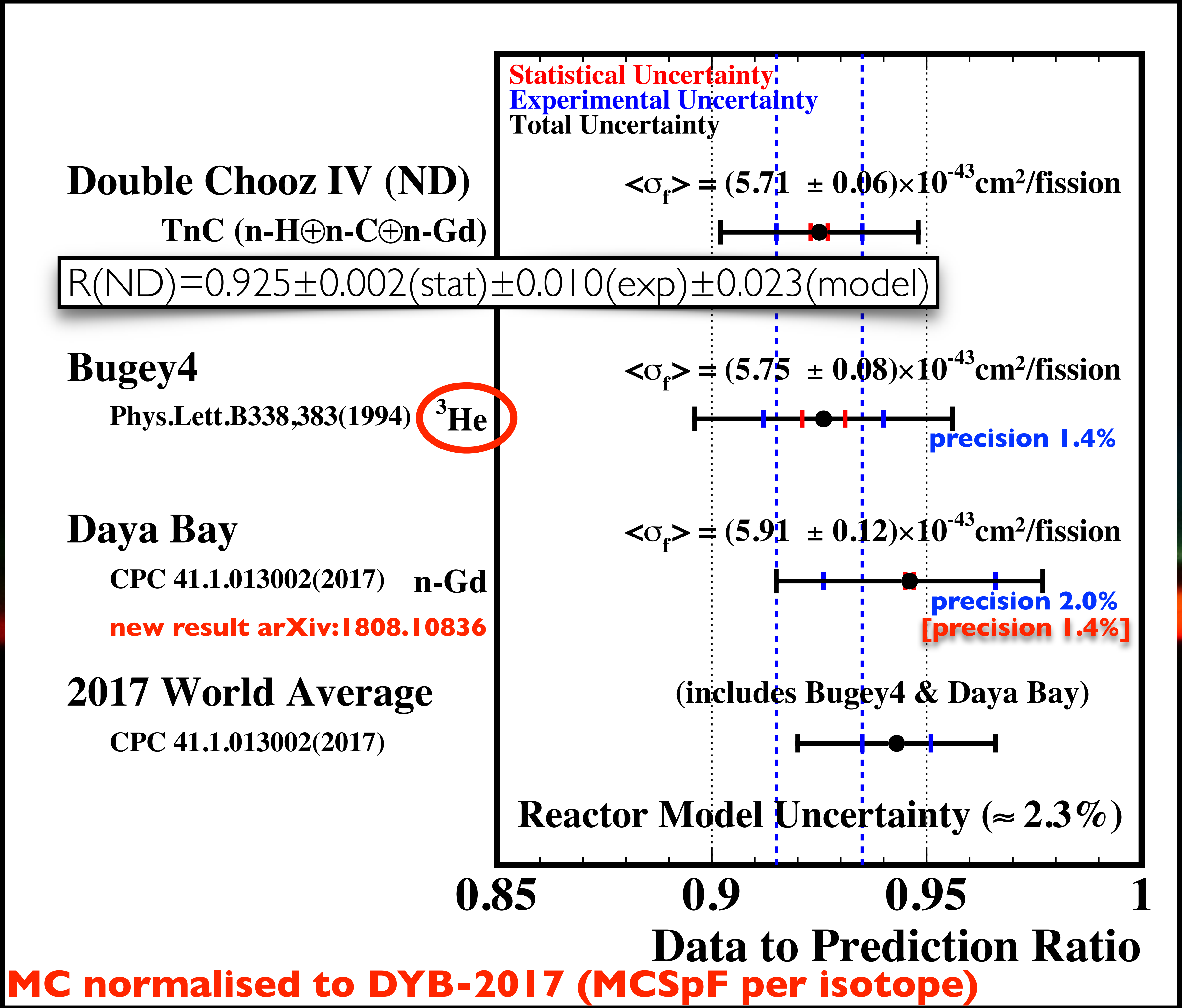
must test→ rate+shape & shape-only (use Bugey4)

ND normalisation biassed?

must test→ rate+shape & shape-only (use Bugey4)

our ND rate (normalisation) validation…

Mean Cross-Section per Fission

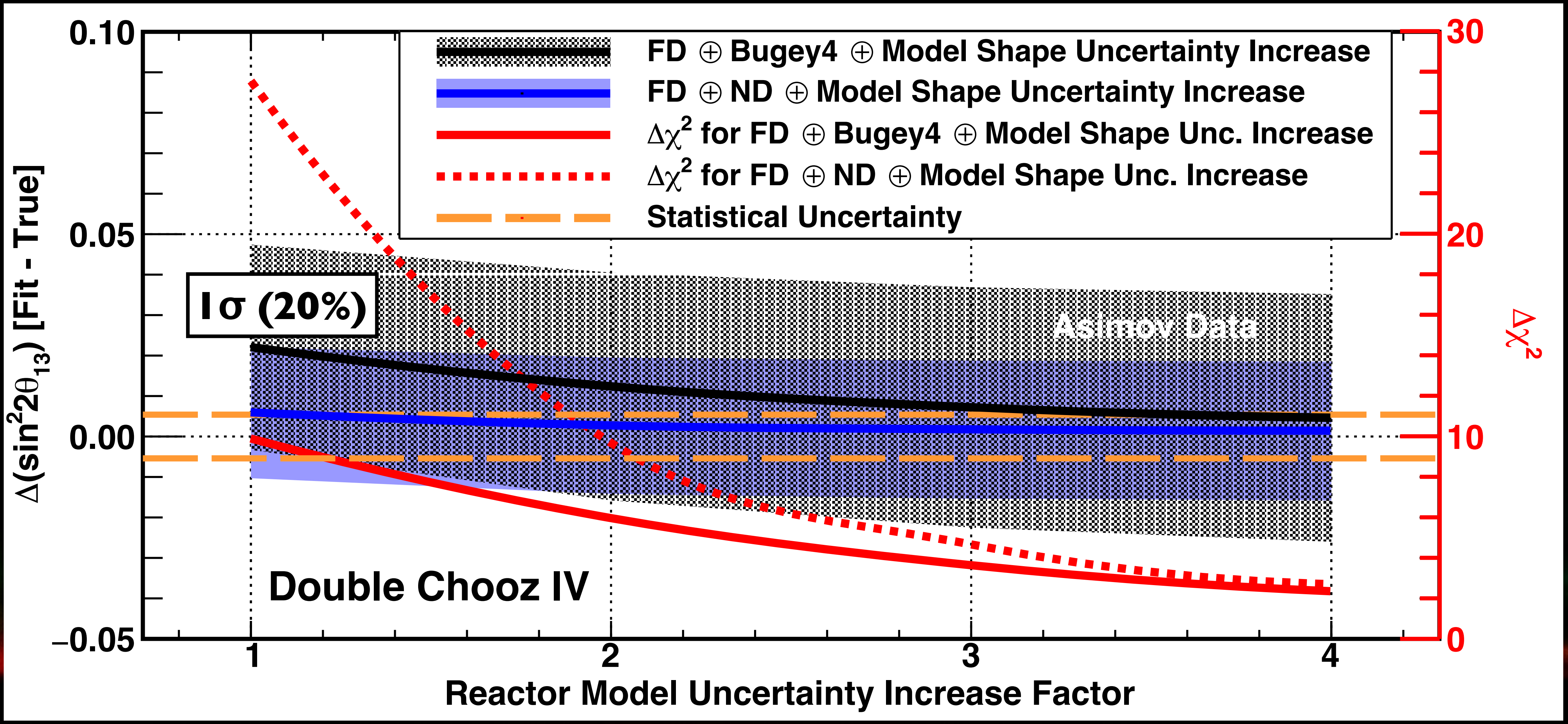


best world precision (9.7‰)

ND normalisation → no impact to θ13!

(excellent agreement with Bugey4 et al)

reactor model accuracy impact…



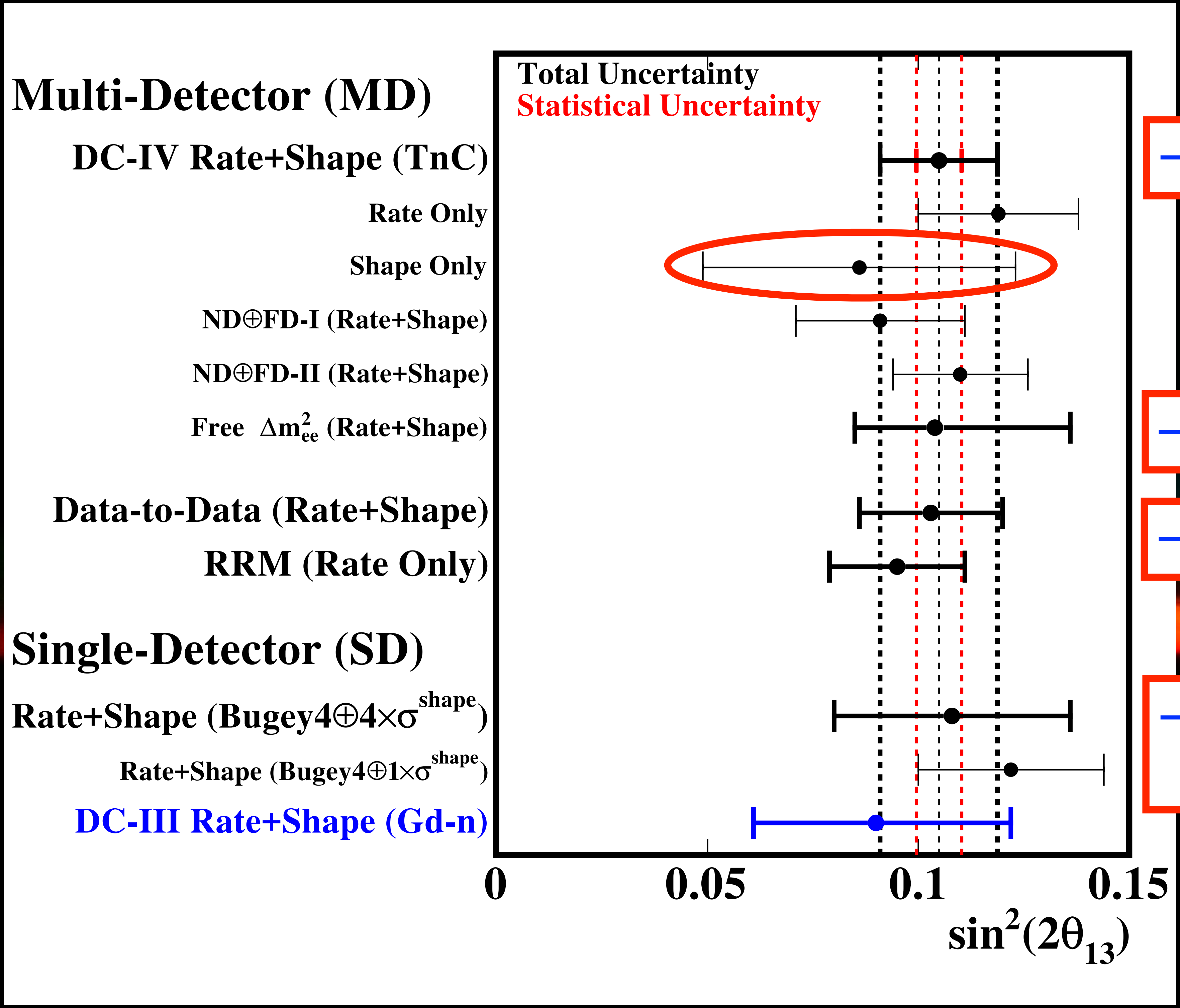
θ13 stability beyond reactor model
(SD & MD different behaviour)

SD: biassed θ13 unless model error ≥3x σ(shape) [**unprotected**]

MD: robust θ13 measurement [**ND protection**]
(increase error ≥3x σ(shape)→ reduce χ^2 from ND)

reactor model uncertainty underestimated?

DC internal multi-fit θ13 extraction…



→ nominal MD

→ free $|\Delta m^2(ee)|$

→ MC independent

→ nominal SD [new error budget]

coherent & consistent multiple θ13

(internal validation of precision⊕accuracy)

what to remember?

DC stopped data taking 31 Dec 2017
dismantling→ <u>new proton#!</u>

θ13 measurement [more!]

reactor neutrino measurement [more!]
flux (absolute) & spectrum (relative & absolute)

a few other interesting results

[2011] DC's 2σ's→ today's θ13$\neq$0 [consistent with T2K→ @ 3σ's]
[2014] DC's 3σ's→ today's spectral distorsion

still results comings…

[our DC languages]

obrigado…

merci…

danke…

ありがとう…

Спасибо…

gracias…

thank you…

谢谢…

hvala…