Double Chooz

(latest results)

IHEP-APC meeting
June 2014

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CNRS / IN2P3 @ APC (Paris)

ingredients for neutrino oscillations…

Non-degenerate mass spectrum (Δm^2)

+

Mixing in the leptonic sector (θ)

=

Oscillation Probability

$\mathbf{P=f(\theta,\Delta m^2)}$

macroscopic quantum interference

$\mathbf{U^{PMNS}}$ matrix (à la CKM)

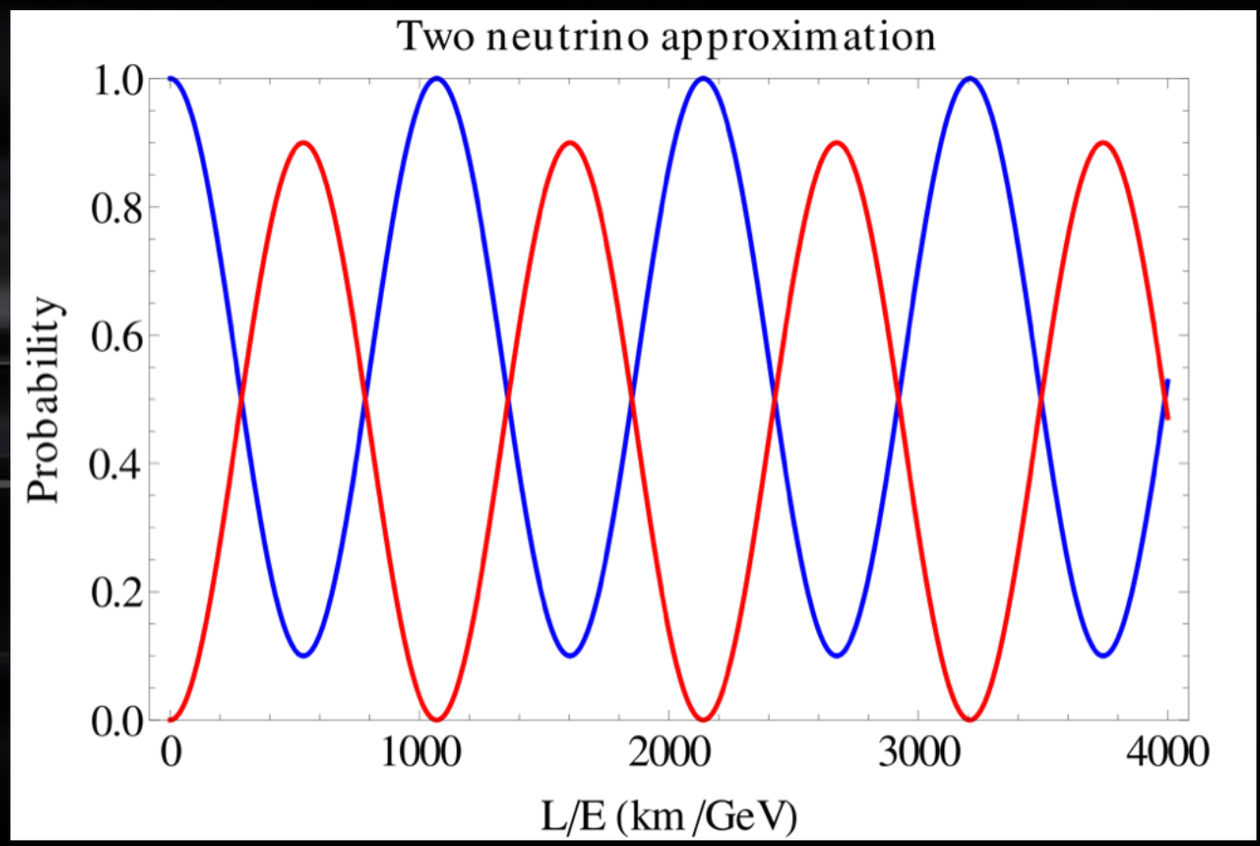
experimental setup

$\mathbf{P(L_o,\Delta E) \rightarrow f(\theta,\Delta m^2)??}$

(measure a range of phase-space)

ν_α (start with) & ν_β (mixing: 90%)

$$P = \sin^2 2\theta \sin^2 \frac{\Delta m^2 L}{4E_\nu}$$



"atmospheric" $\Longrightarrow$ θ_{23}~45°

θ_{13} & "dirac" δ_{CP}

"solar" $\Longrightarrow$ θ_{12}~33°

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}_{\Delta m^2_{31}} \text{sub-leading} \begin{pmatrix} c_{13} & 0 & e^{-i\delta} s_{13} \\ 0 & 1 & 0 \\ -e^{i\delta} s_{13} & 0 & c_{13} \end{pmatrix}_{\Delta m^2_{31}} \text{sub-leading} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}_{\Delta m^2_{21}}$$

atmos+LBL(dis)

$P(\nu_\mu \rightarrow \nu_\mu)$

Chooz+LBL(app)

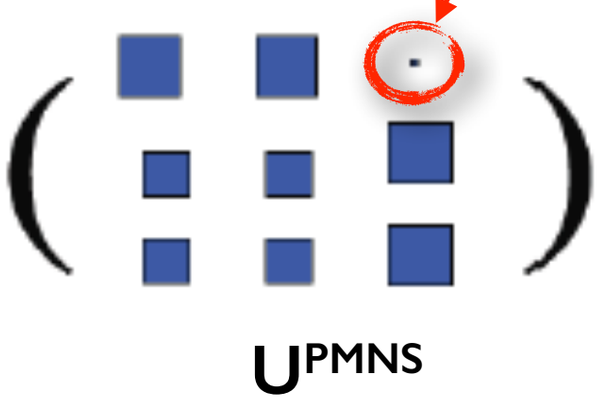
$P(\nu_e \rightarrow \nu_e)$ & $P(\nu_\mu \rightarrow \nu_e)$

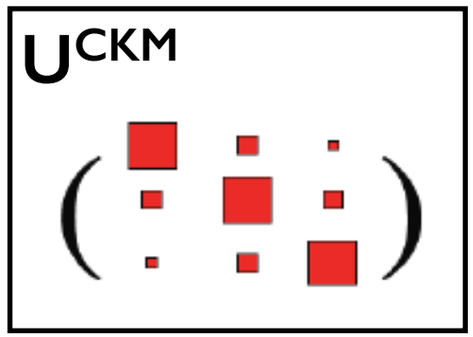
solar+KamLAND

$P(\nu_e \rightarrow \nu_x)$

knowledge on
θ_{13} & δ_{CP}
[**later**]

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





Lisi et al opinion (Jan. 2014)

Nσ ranges for single parameters (all data included):

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. See also Fig. 3 for a graphical representation of the results. 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. The CP violating phase is taken in the (cyclic) interval $\delta/\pi \in [0, 2]$. The overall χ^2 difference between IH and NH is insignificant ($\Delta\chi^2_{\mathrm{I-N}} = +0.3$).

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)	3.08	2.91 – 3.25	2.75 – 3.42	2.59 – 3.59
$\Delta m^2/10^{-3}$ eV^2 (NH)	2.44	2.38 – 2.52	2.30 – 2.59	2.22 – 2.66
$\Delta m^2/10^{-3}$ eV^2 (IH)	2.40	2.33 – 2.47	2.25 – 2.54	2.17 – 2.61
$\sin^2\theta_{13}/10^{-2}$ (NH)	2.34	2.16 – 2.56	1.97 – 2.76	1.77 – 2.97
$\sin^2\theta_{13}/10^{-2}$ (IH)	2.39	2.18 – 2.60	1.98 – 2.80	1.78 – 3.00
$\sin^2\theta_{23}/10^{-1}$ (NH)	4.25	3.98 – 4.54	3.76 – 5.06	3.57 – 6.41
$\sin^2\theta_{23}/10^{-1}$ (IH)	4.37	4.08 – 4.96 $\oplus$ 5.31 – 6.10	3.84 – 6.37	3.63 – 6.59
δ/π (NH)	1.39	1.12 – 1.72	0.00 – 0.11 $\oplus$ 0.88 – 2.00	—
δ/π (IH)	1.35	0.96 – 1.59	0.00 – 0.04 $\oplus$ 0.65 – 2.00	—

Fractional uncertainties (defined as 1/6 of 3σ ranges):

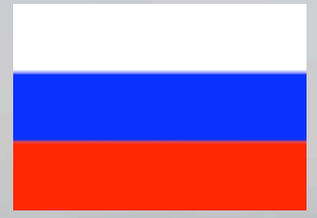
δm^2	2.6 %	→ KamLAND
Δm^2	3.0 %	→ MINOS + T2K (beam ν's)
$\sin^2\theta_{12}$	5.4 %	→ Solar experiments
$\sin^2\theta_{13}$	8.5 %	→ Reactor experiments
$\sin^2\theta_{23}$	~ 11 %	→ SuperKamiokande

non-accelerator experiments drive current knowledge…

the 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)

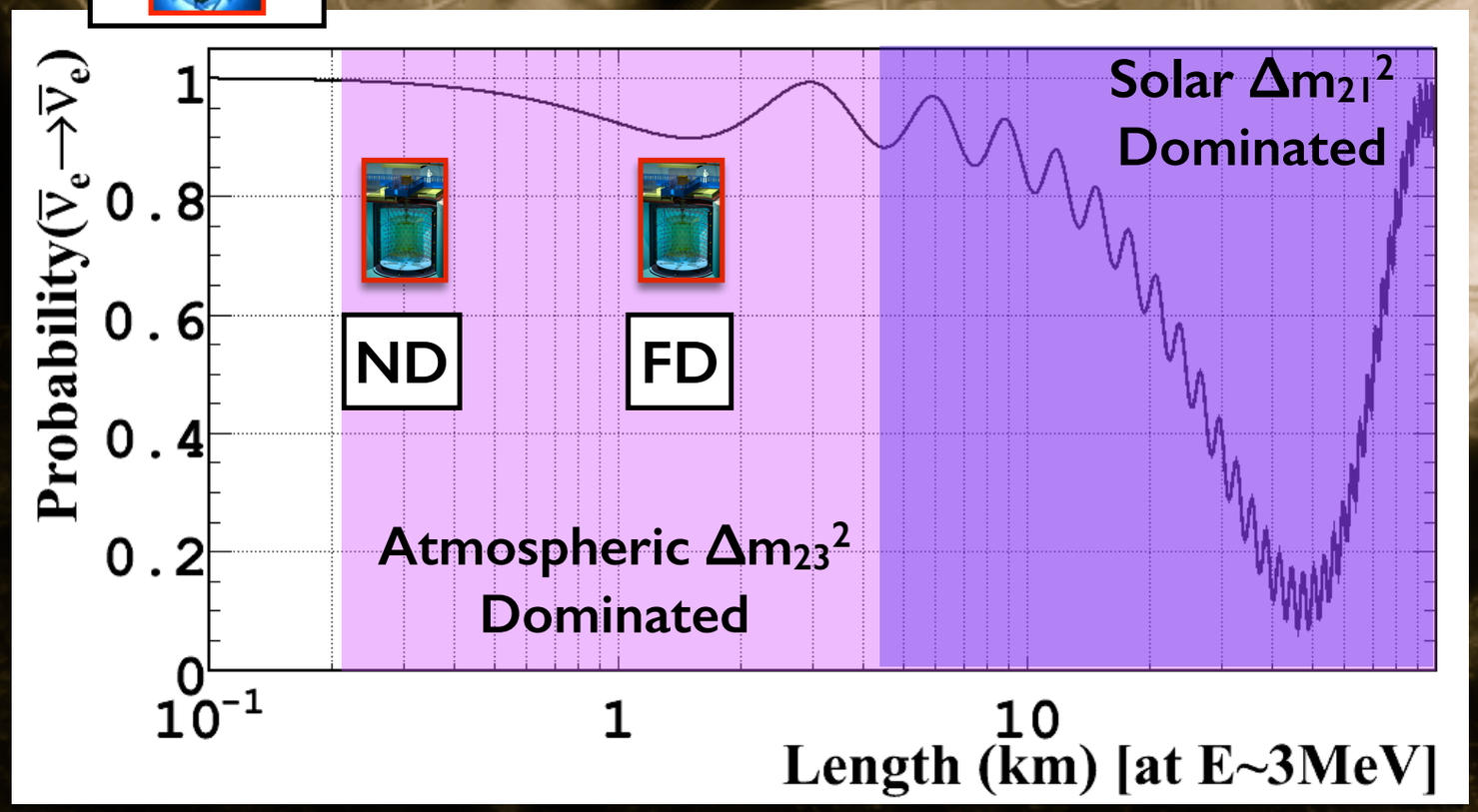
Web Site:
www.doublechooz.org/

experimental setup…

Chooz Reactors
Power: 8.5GWth
$\Longrightarrow$ ~$10^{21}\nu$/s
(N4s: very powerful)

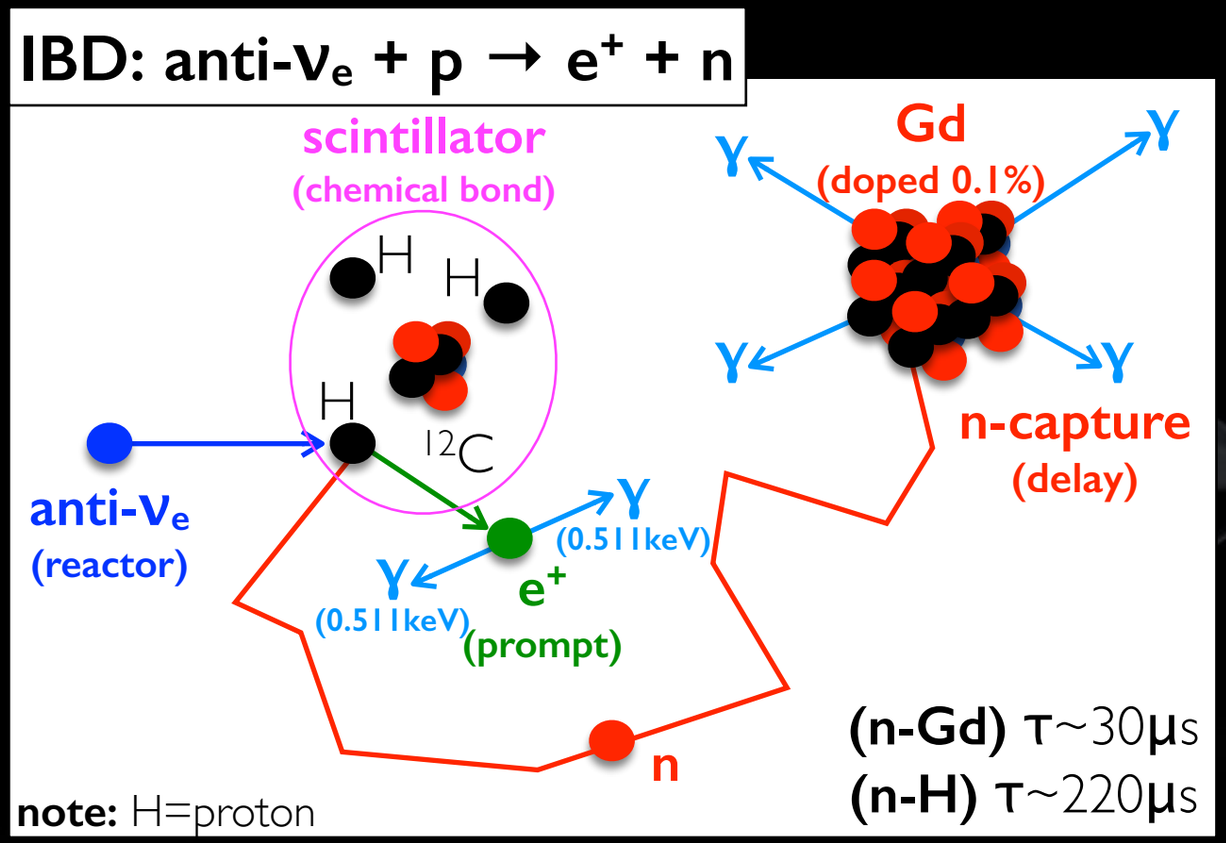
Near
<L>=408m
~270IBD/day
~120mwe
Target: 8.2t
Oct.2014

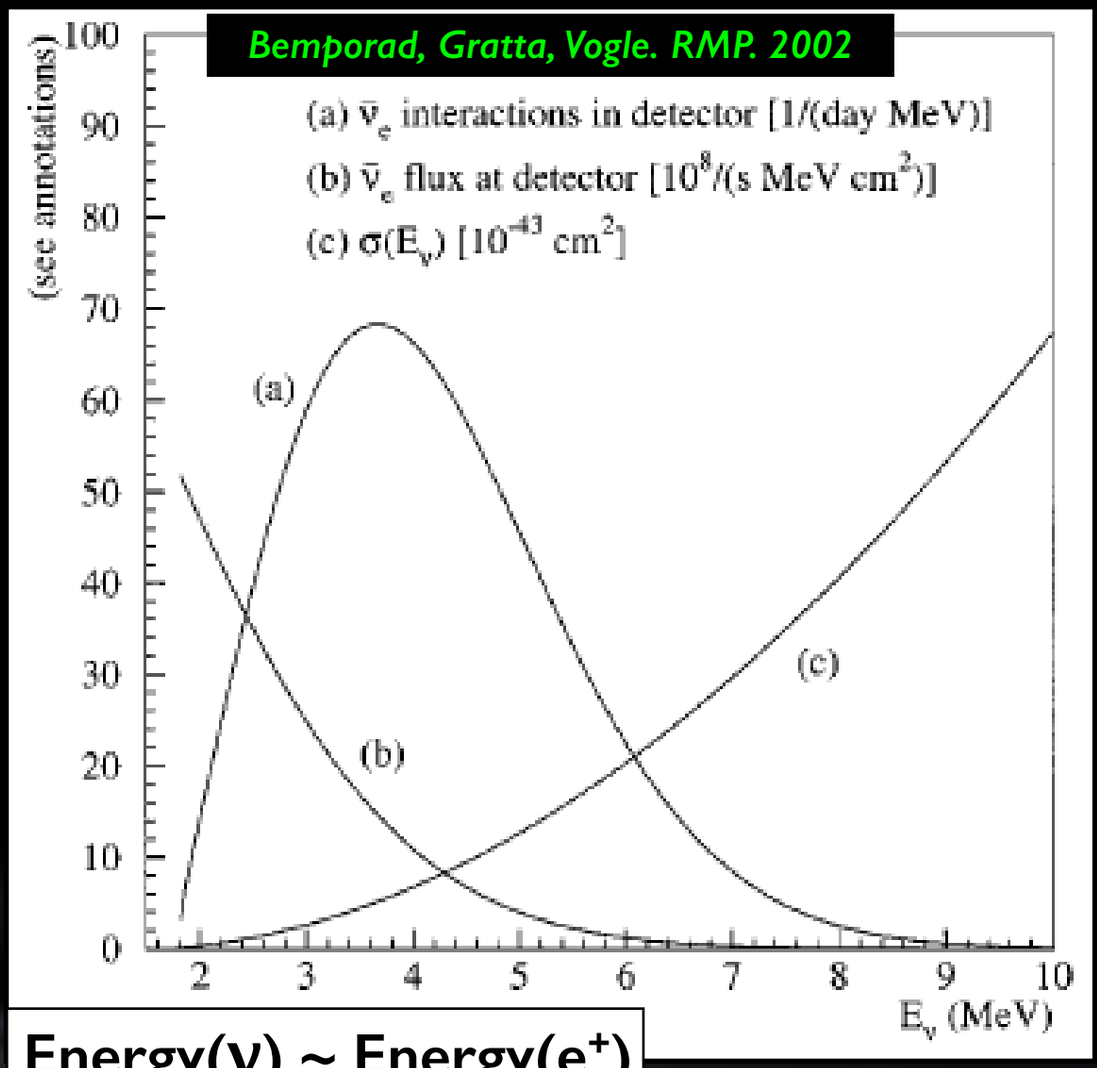
reactor



Far
<L>=1056m
~40IBD/day
~300mwe
Target: 8.2t
April 2011

IBD interaction (inverse-β decay)…





Energy(ν) ~ Energy(e+)

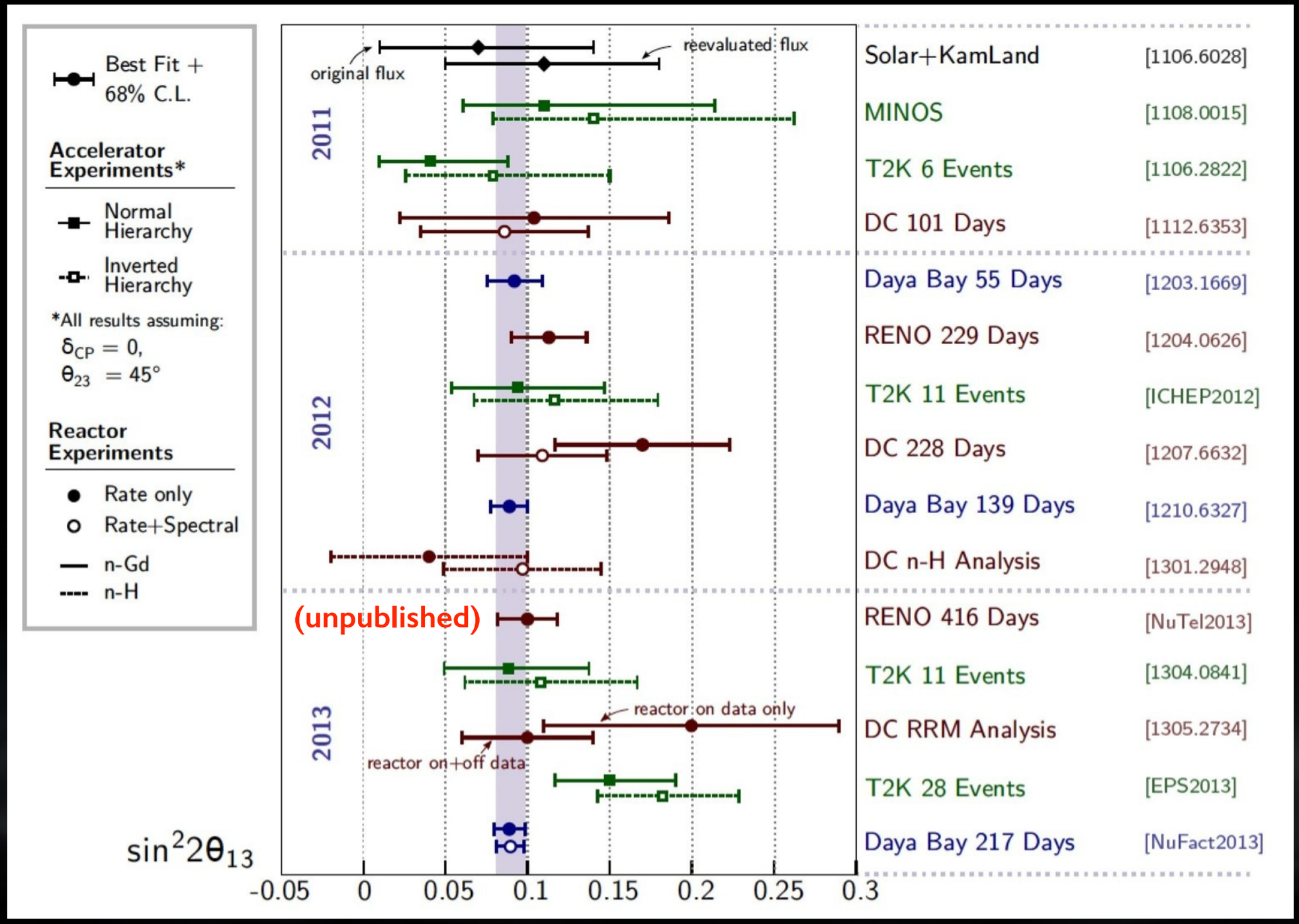
- **high & well known σ^{IBD}** [$\tau_{neutron}$=(881.5±1.5)s]
- IBD manifests via **trigger-coincidence**
  - 1st trigger→ **e+(prompt)** [ionisation ⊕ annihilation]
  - 2nd trigger→**n-Gd capture (delay @ ~8MeV)**
- **Energy(ν) ~ Energy(e+) + 0.8MeV**
- major rejection of radioactivity background…
  - time/space coincidence
  - delay @ 8MeV (radioactivity dominates ≤3MeV)

why IBD ⊕ Gd?

- small & shallow (high S/BG)
- no need for ultra-purity

⟹ **inexpensive ‰ precision!!**

θ_{13}-reactor measurements…

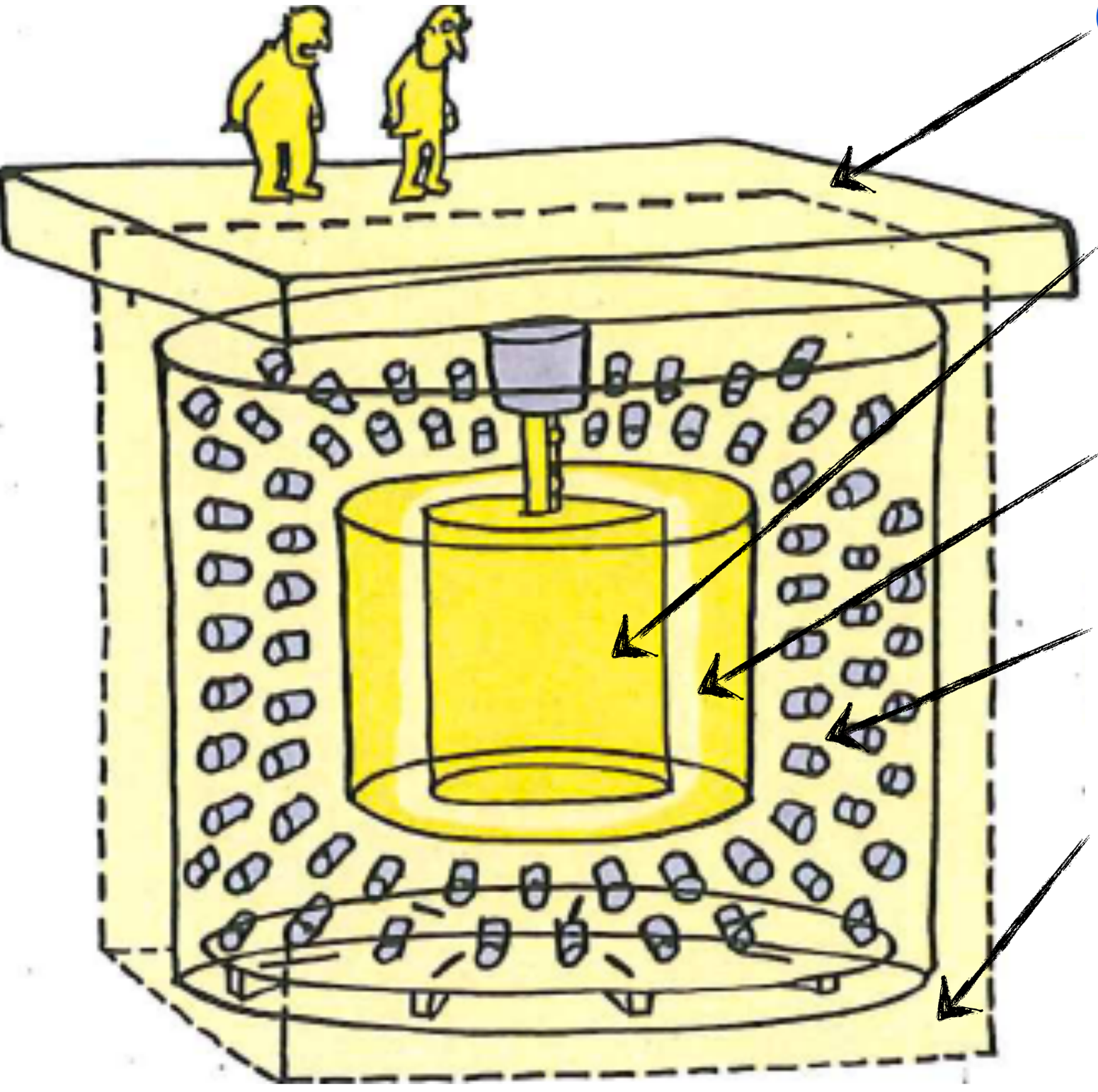


reactor precision is unsurpassable→ setting θ_{13} for several decades to go!

(also measurement by T2K, MINOS, etc)

our detectors...

a generic θ13-LAND…



Outer μ-Veto (OV)

Plastic-Scintillator: strips (→tracking)

ν-Target (NT)

Liquid-Scintillator + Gd (0.1%)

γ-Catcher (GC)

Liquid-Scintillator

Light Buffer

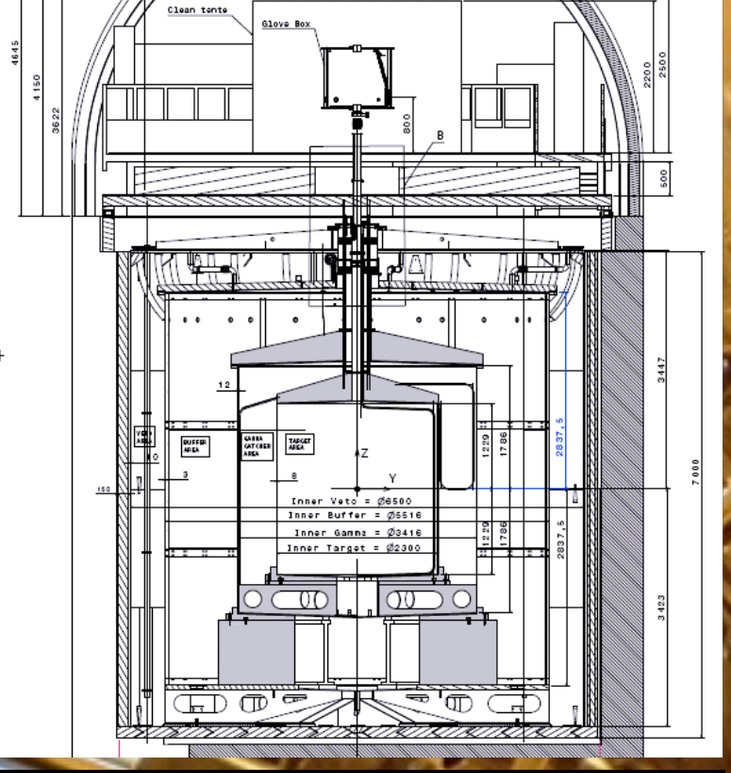
Oil (negligible scintillation)

Inner μ-Veto (IV)

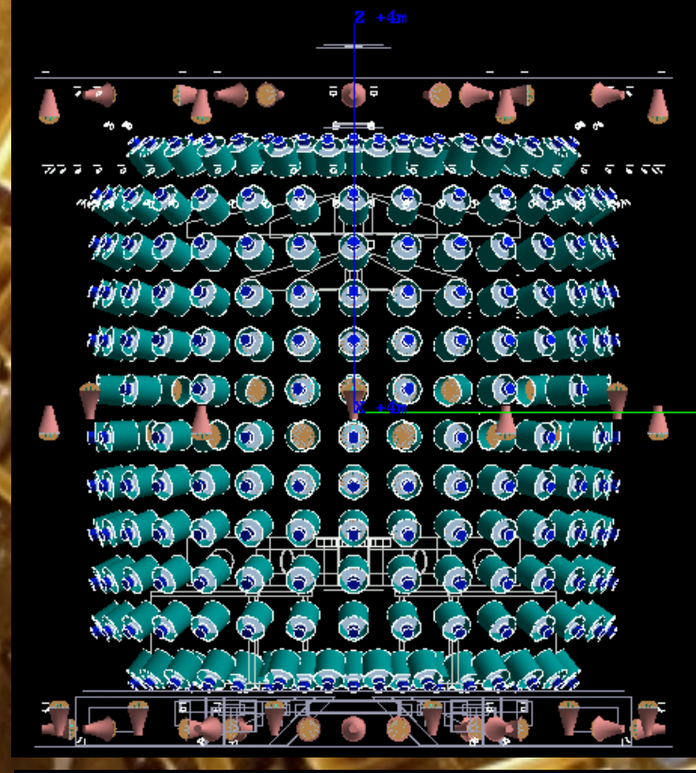
Liquid-Scintillator

Inert γ-Shield

15cm of steel (around all detector)



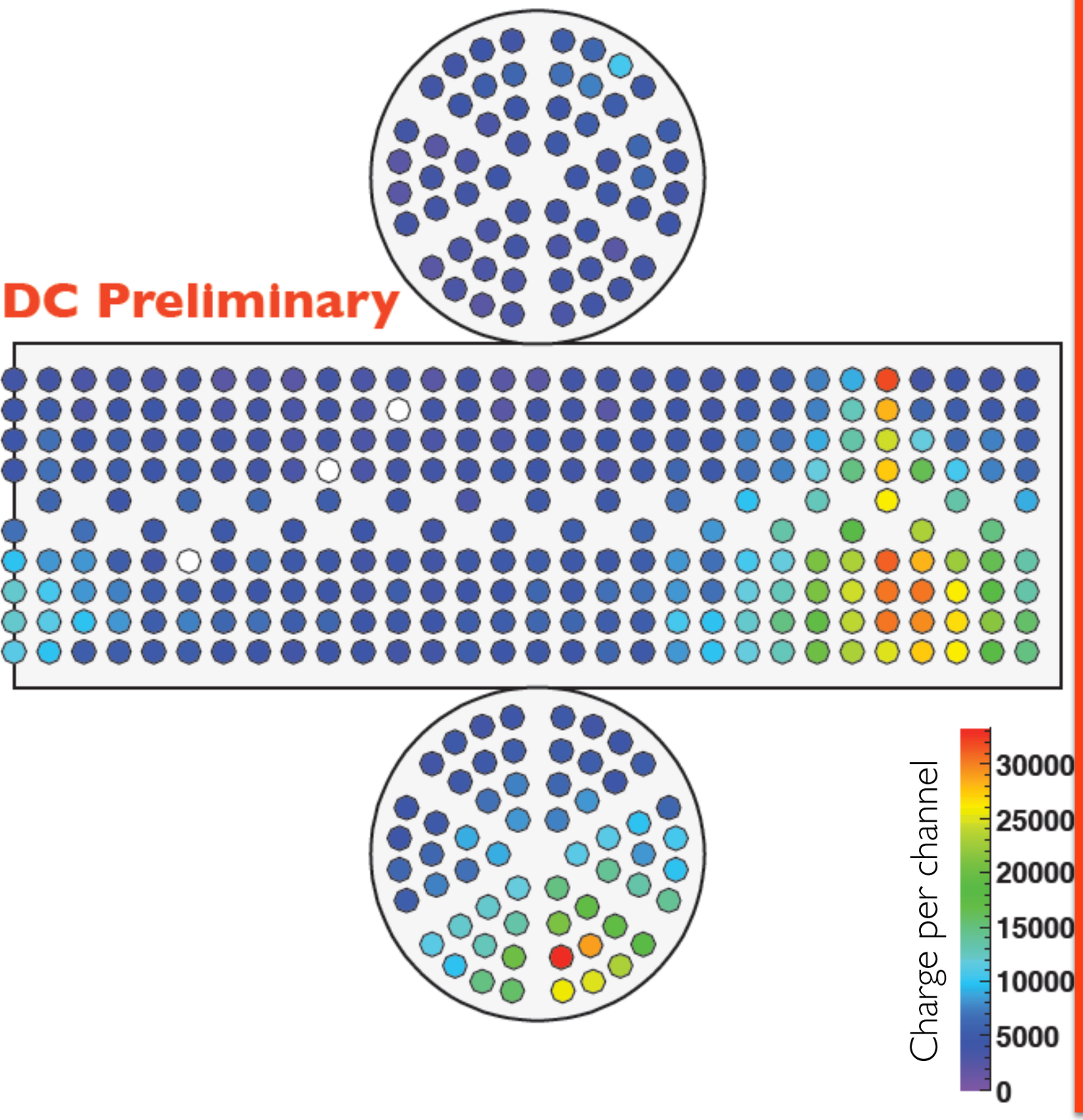
engineer's view

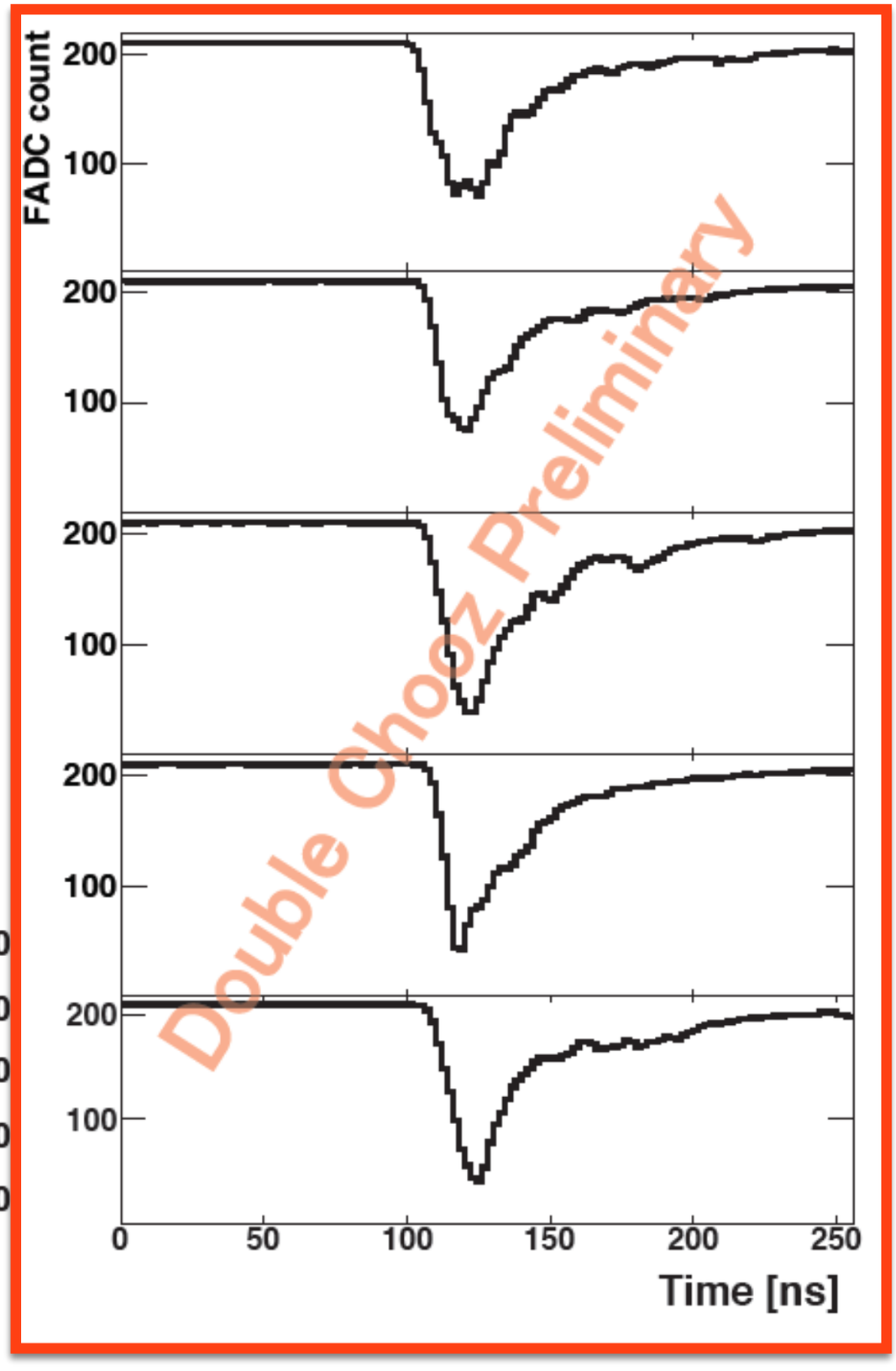


MC's view

our favourite view…

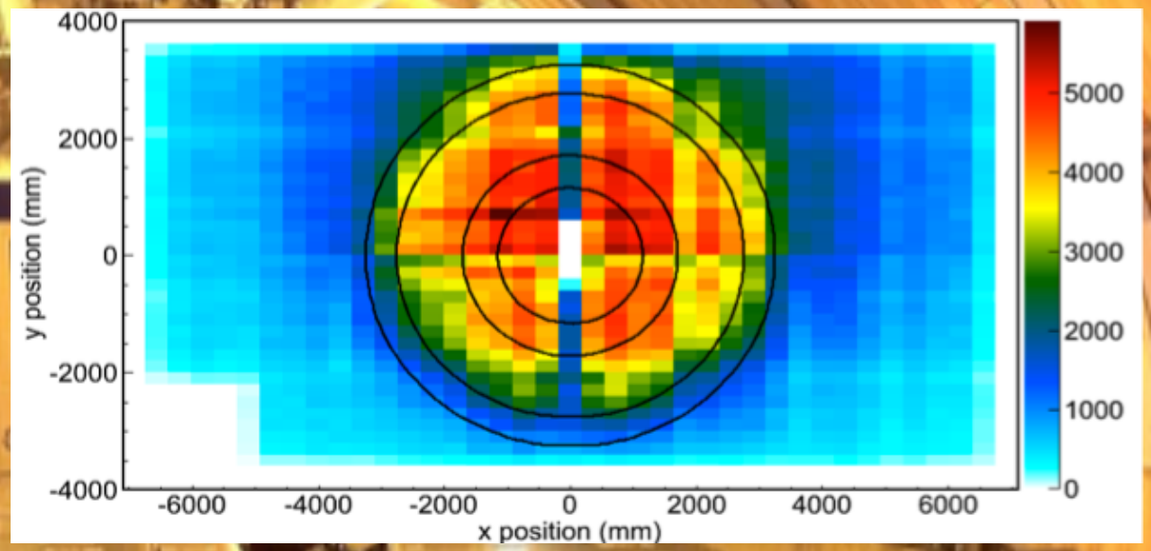
muon event (inner-detector)…





NOTE: all PMTs working (white means: no charge)

our top μ-tracker/veto (Outer-Veto)…



a "horizontal OPERA"

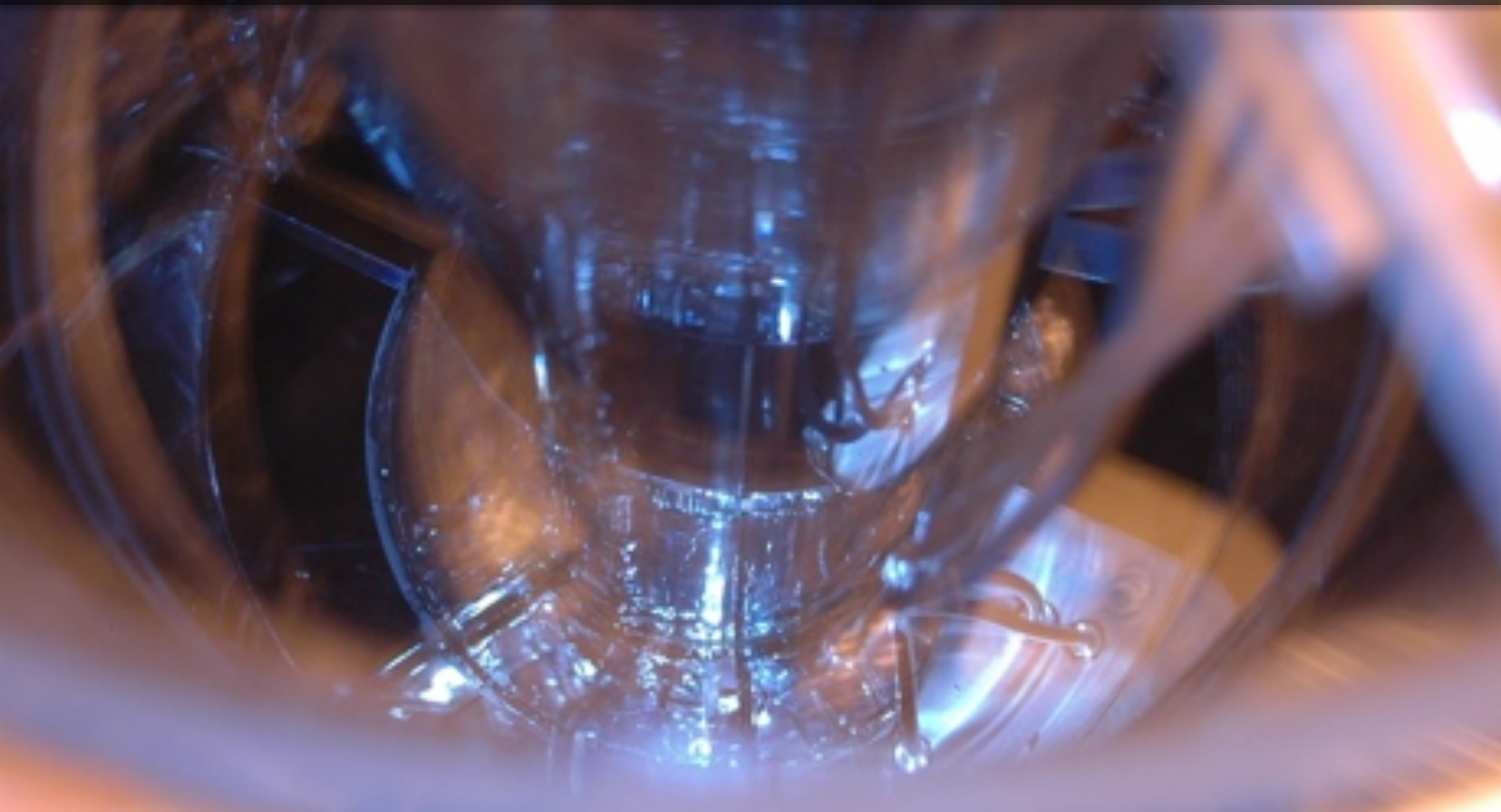
the near detector...

status

•IV instrumentation→	**done**
•detector is closed→	**just done**
•chimney mechanics→	june
•filling→	summer
•shielding (water+steel)→	summer
•data-taking commissioning→	Sept.~Oct.

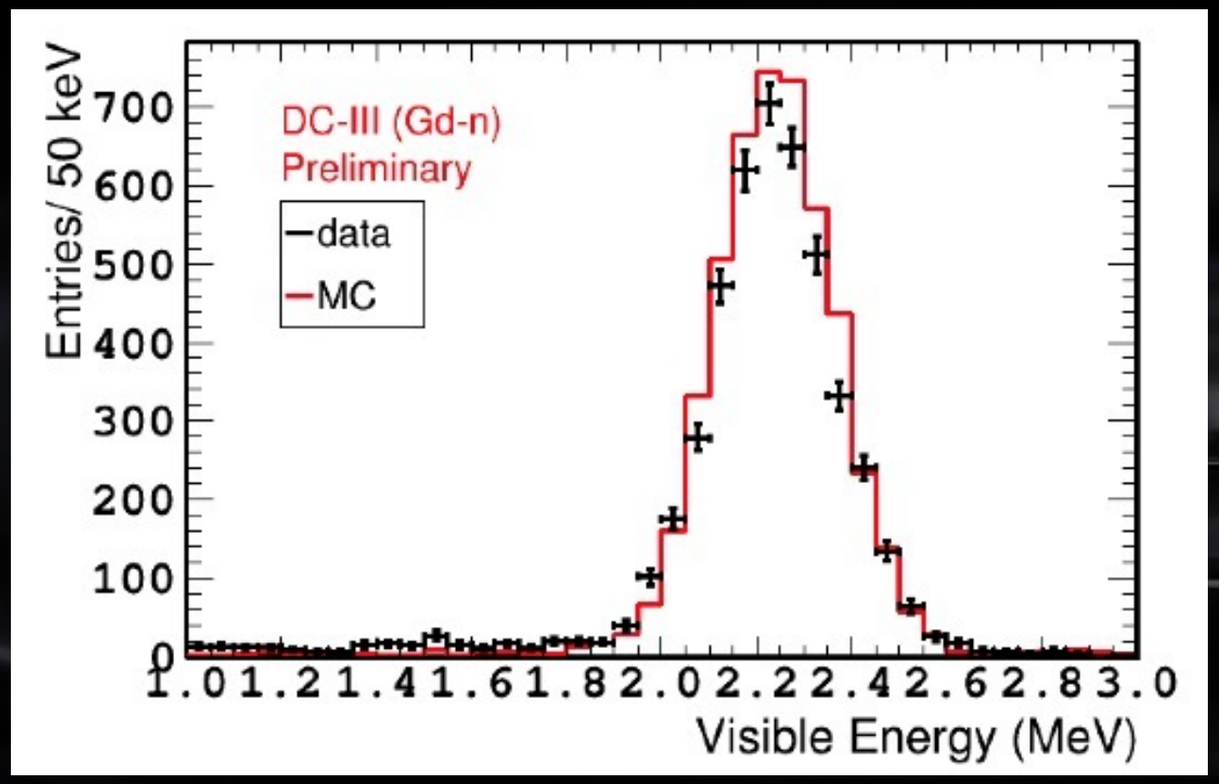
a hot summer for DC…

calibration…

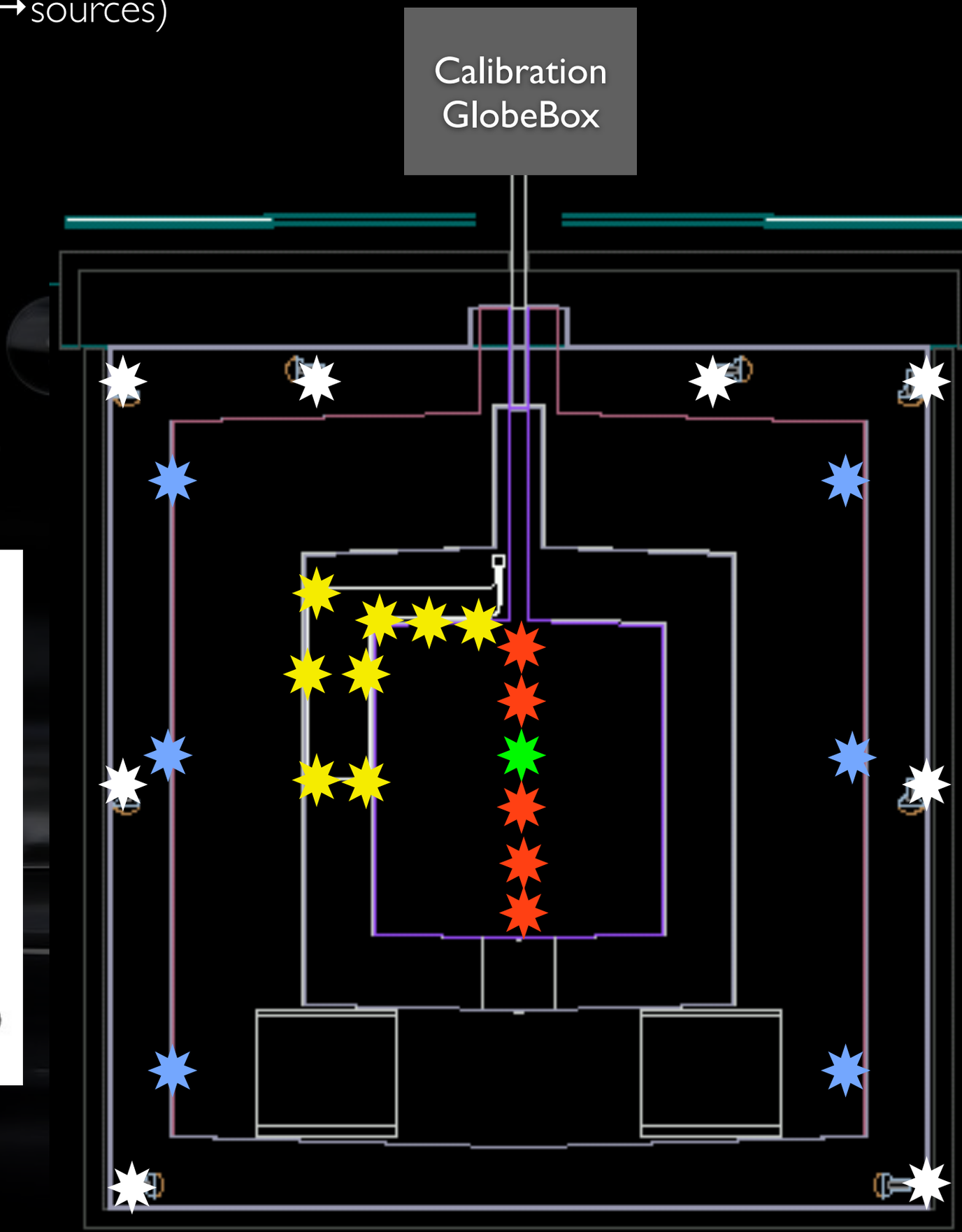


calibration system…

- **principle:** <u>redundancy</u> critical for systematics (→sources)
- **in-built:** light LED (**ID** + **IV**)
- **deployable** (^{137}Cs, ^{68}Ge, ^{60}Co, **^{252}Cf**, lasers)
  - **z-axis** (→ ν-target sampling)
  - **GC guide-tube** (→ GC sampling)
  - (not yet used) **Articulated Arm**
- **natural:** H-n, C-n, Gd-n peaks (μ's fast-n), BiPo, IBD (delay spectrum→validation)

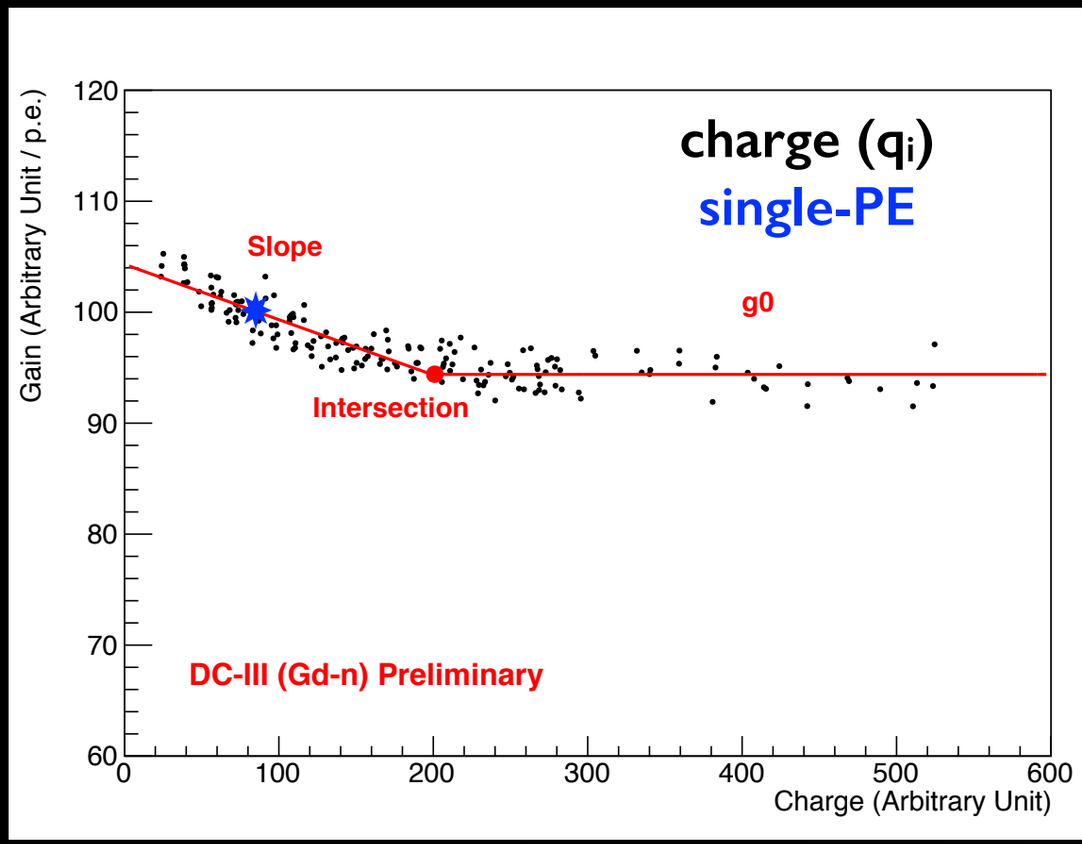


MeV definition (H-n peak @ center)
(our *<u>standard candle</u>*)

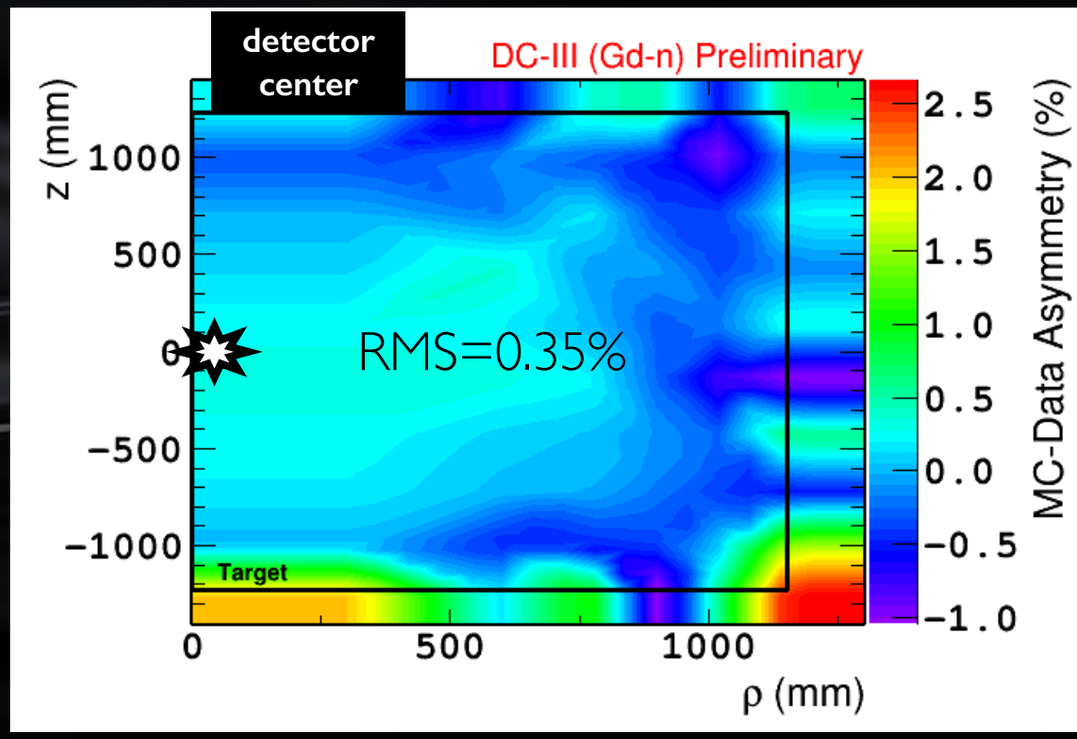


energy reconstruction (I)…

- **integrated data and MC calibration scheme**…
  - MC treated independently (as two detectors)
  - MC (no free knobs→ lab measurement + calibration)
- **Linearised-PE & Alpha Calibration**…
  - def: **PE = α(PE,#PMT hit) x [Σqi x g(qi)]**
  - conversion **Q[Δ~5%]→PE[Δ≤0.5%]** @ H-n peak center
  - impact: **stability (+++)**, **linearity (++)**, uniformity (+)
  - source: gain non-linear [@electronics] + other (zeroes, etc)

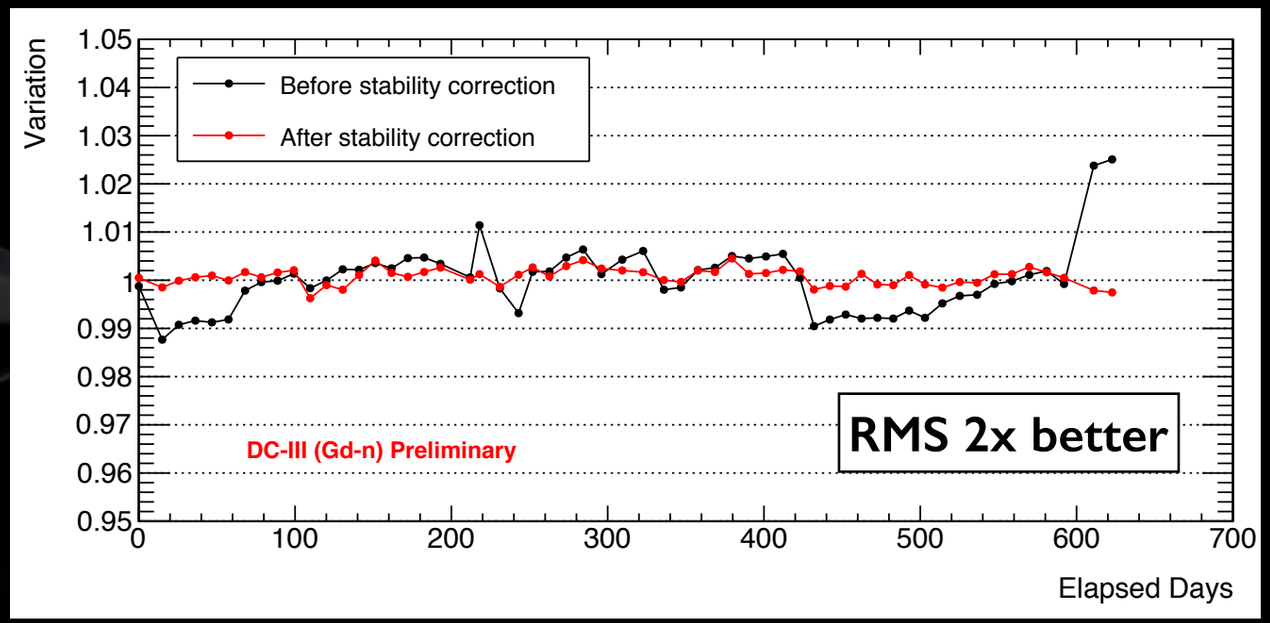


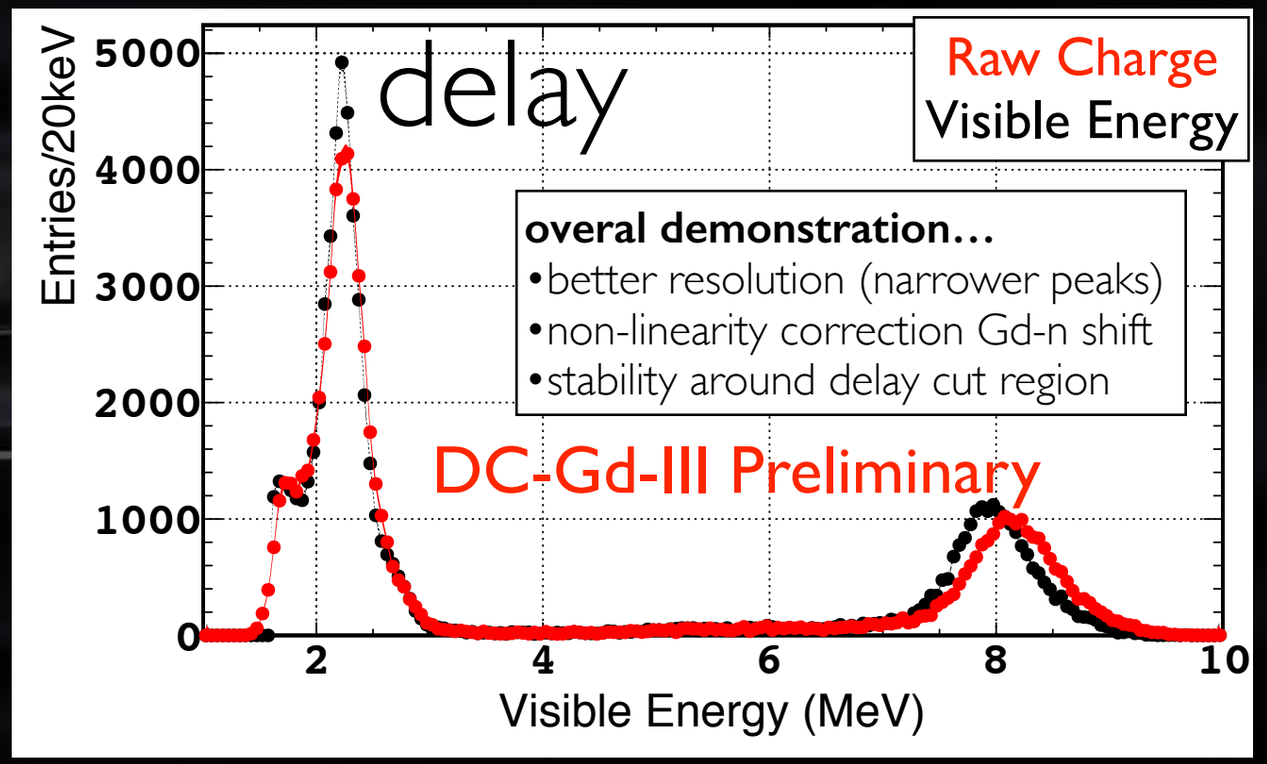
- **Uniformity Calibration**…
  - def: create H-n response full volume MAP
  - conversion **PE(ρ,z)[Δ≤8%]→PE(center)** [Δ≤0.5%]
  - impact: **uniformity (+++)**
- **MeV (or absolute) Energy Calibration**…
  - conversion: PE(0,τ)→MeV(0, τ)
  - use ^{252}Cf @ (ρ=0, z=0, t=τ)→ H-n peak: 2.223MeV
  - DATA to MC equalisation (prior <0.5% agreement)



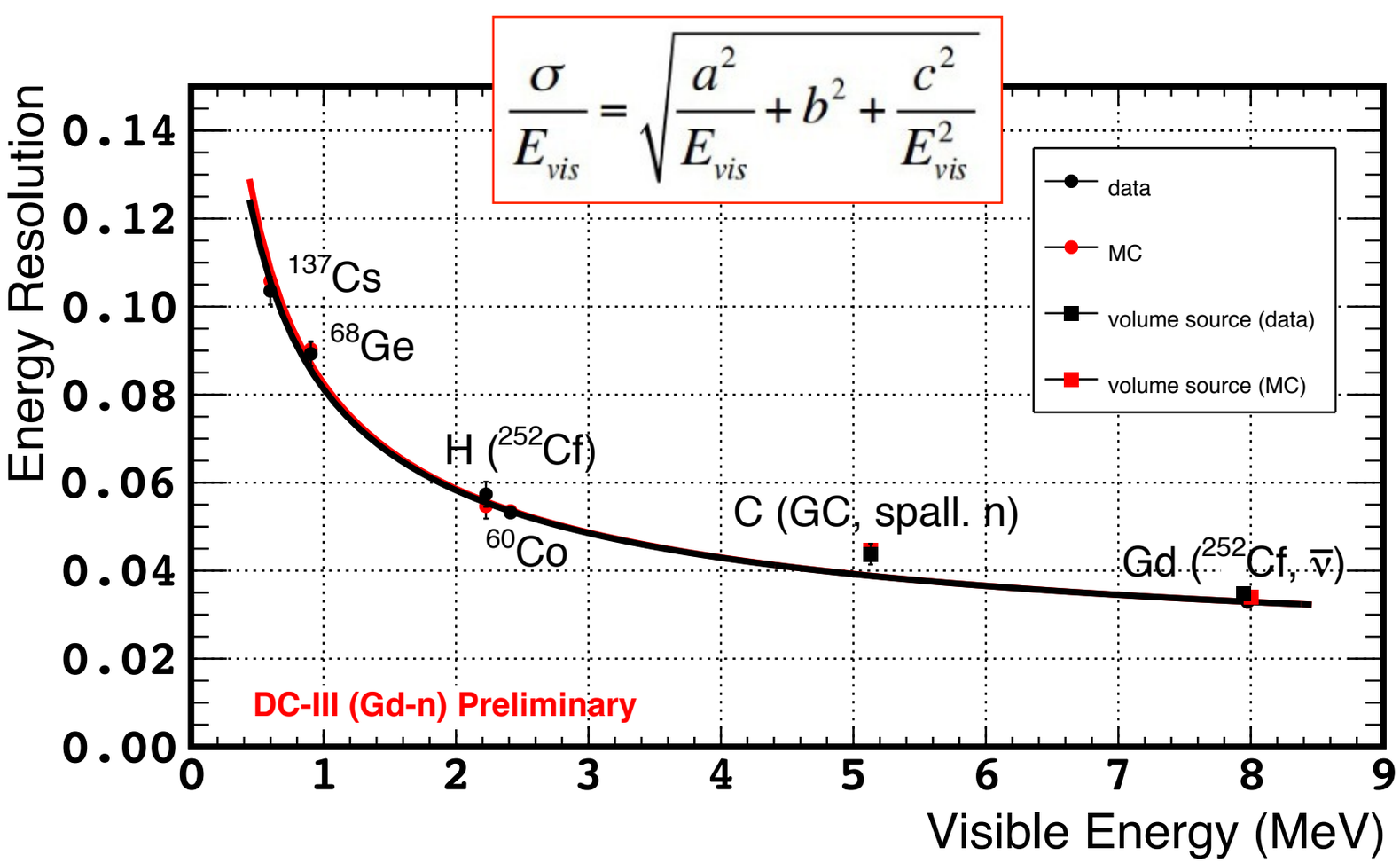
energy reconstruction (2)…

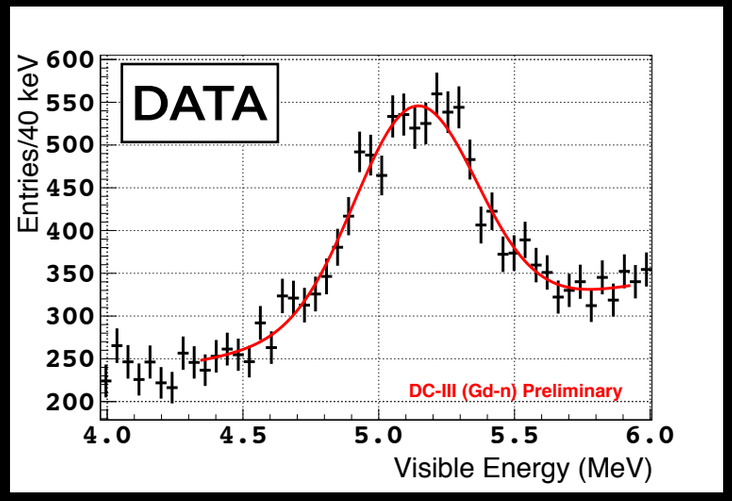
- **Drift Stability Calibration**…
  - def: **PE(t)→PE(τ)**, where **τ**: time MeV definition
  - response drift by +0.5%/years (unknown)
  - impact: **stability (+)**
- **Charge Non-Linearity Calibration**…
  - readout driven-non-linearity→ **Δ**(H-n,Gd-n)=~1%
  - validation with C-n peak @ 5MeV & ^{12}B spectrum
  - impact: **linearity (+)**
- **Light Non-Linearity Calibration**…
  - single-**γ** scintillation quenching measurement
    - many calibration sources @ center
  - conversion: **MeV(e+)→MeV(single-γ)** [only MC]
  - impact: **linearity (++)**
- **Overall performance**…
  - from Q(q,**ρ**,z,t) [RMS~10%] to MeV [RMS≤1.0%]
  - better detection systematics→ **θ**$_{13}$, BGs, **Δ**m^2.

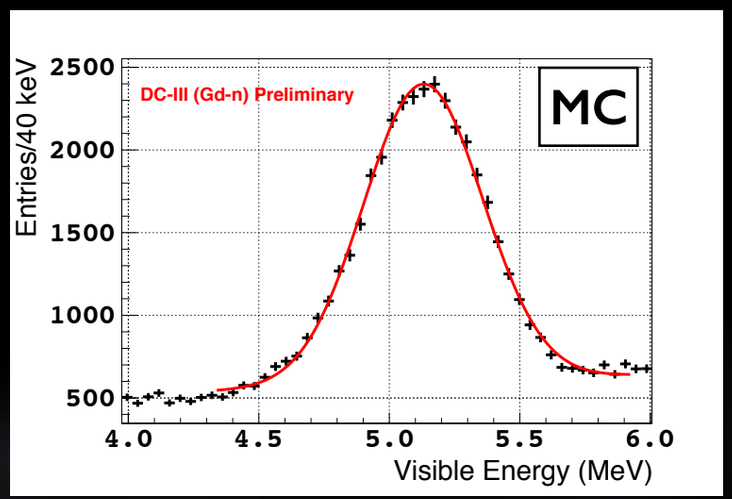




response coherence all throughout…







a: statistical term
b: constant term
c: e.g. electric noise

Data
a=0.0773±0.0025
b=0.0182±0.0014
c=0.0174±0.0107

MC
a=0.0770±0.0018
b=0.0183±0.0011
c=0.0235±0.0061

- **remarkable agreement data to MC** throughout full energy range
  - identical curves (→ no free knobs in MC)
  - most relevant region for θ_{13} is ≤4MeV
- **excellent precision:** peak position and widths (highly non-trivial)
  - true for peaks in center or anywhere in NT and GT
  - C-n peak (mainly from GC) → slight different response in GC (worse)
- **constant term of resolution ~1.8%** (powerful calorimetry)
  - dominated by stochastic term

our analyses (I,II and today III)…

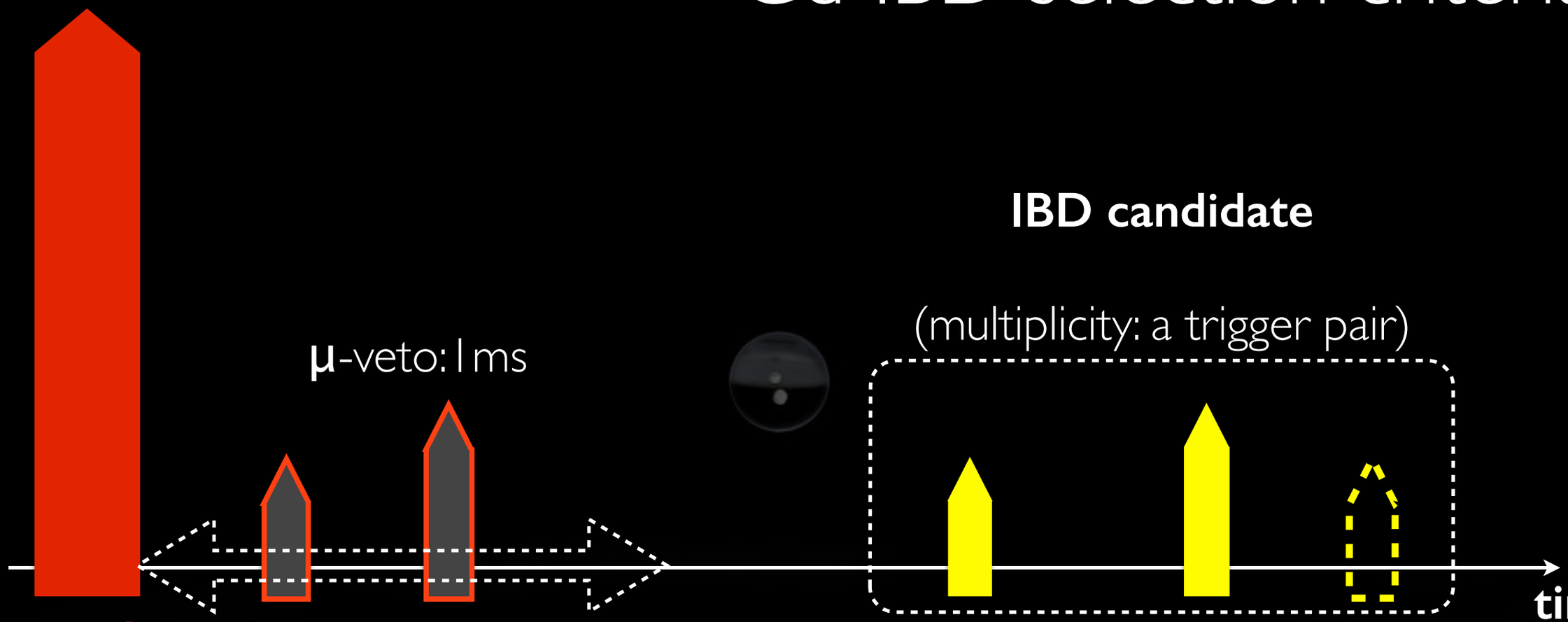
status Gd-III improvement…

- **more statistics** (2x)
- **new selection Gd-III**
(wide-open + more efficient)
- **new energy**
(more accurate + non-linear correction)
- **new BG vetoes**
(remarkable active BG rejection)
- **all BGs measured by data (no MC)**
(reduce systematics when measuring θ_{13})

translates into

- **improvement of δ(stat)**
(better S/BG + more stats)
- **improvement of δ(BG)**
(~3x wrt Gd-II)
- **improvement of δ(detection)**
(~2x wrt Gd-II)
- **major improvement with ND**
(flux systematics now eclipses)

Gd-IBD selection criteria…

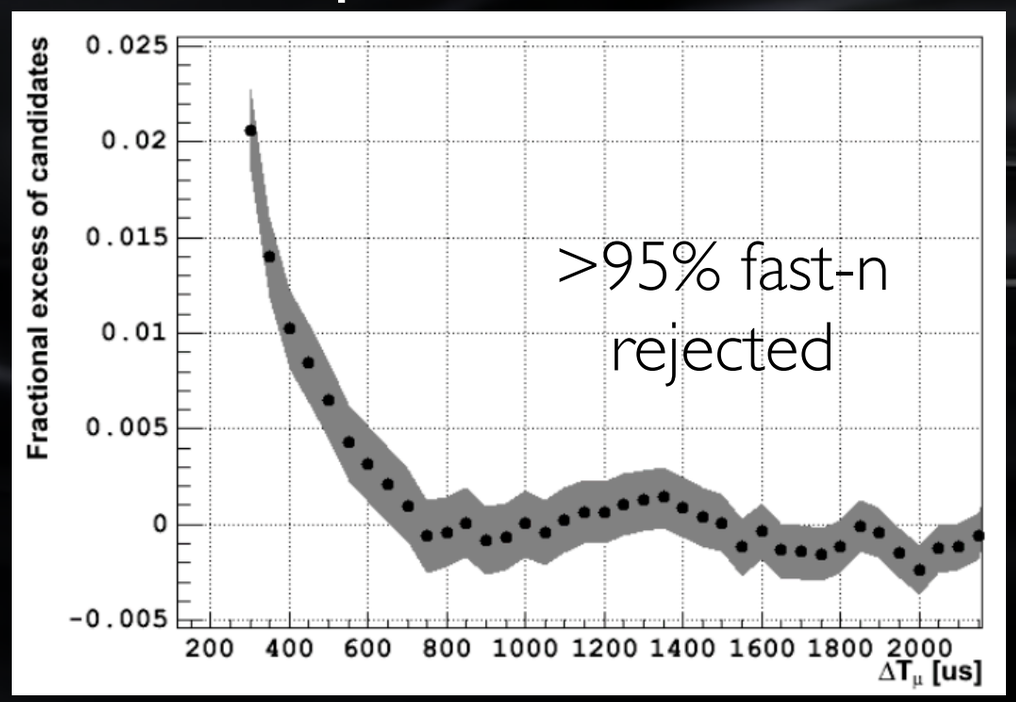


tagged μ
(μ or Michel e±)

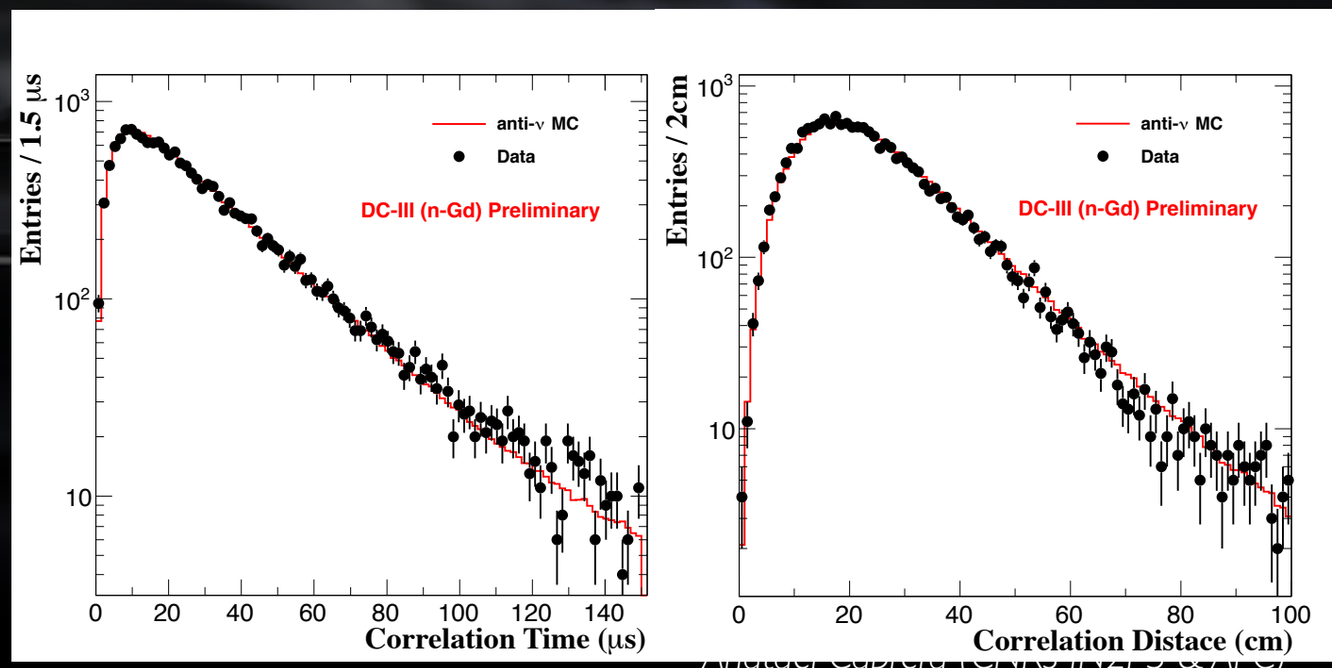
prompt [0.5,20.0]MeV

delay [4,10]MeV

after-μ correlated IBDs



IBD time/space (e^+~n) correlation



selection details…

	Gd-III IBD candidate criteria
μ-tagging	Energy(ID)≥20MeV & Charge(IV)≥30k(a.u.) NEW!!
Δt(μ)	1ms
QmQt	≤0.12 NEW!!
RMS(time,charge)	2D cut NEW!!
ΔQ	30k(a.u.) NEW!!
	[0.5,150]μs NEW!!
	≤1m NEW!!
E(delay)	[4,10]MeV NEW!!
E(prompt)	[0.5,20.0]MeV NEW!!
Multiplicity	[-0.2,0.6]ms (relative to prompt) NEW!!
OV veto	yes
IV veto	yes NEW!!
FV veto	yes NEW!!
Li+He veto	yes NEW!!

μ-Veto Selection

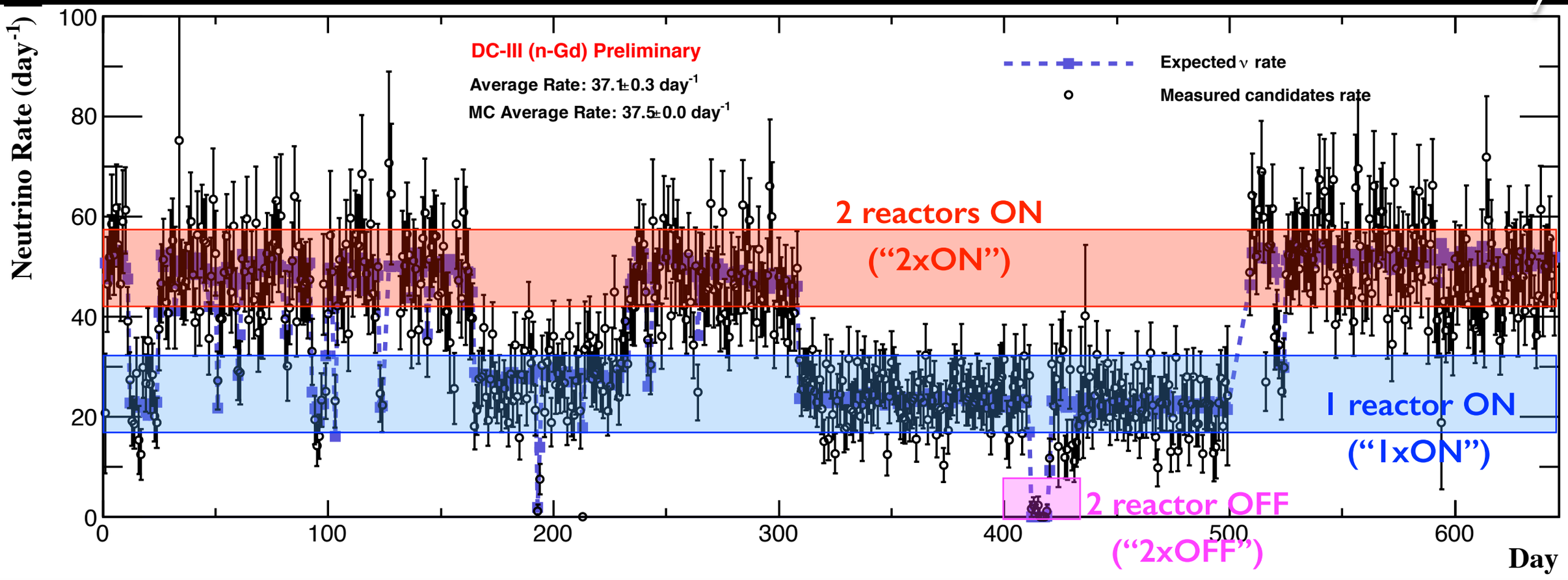
Light Noise Selection

IBD Selection

BG Rejection

17359 IBD candidates (including BG)
no oscillation expectation: 17359 (only IBD)
467.9days

IBD candidates track reactor activity…

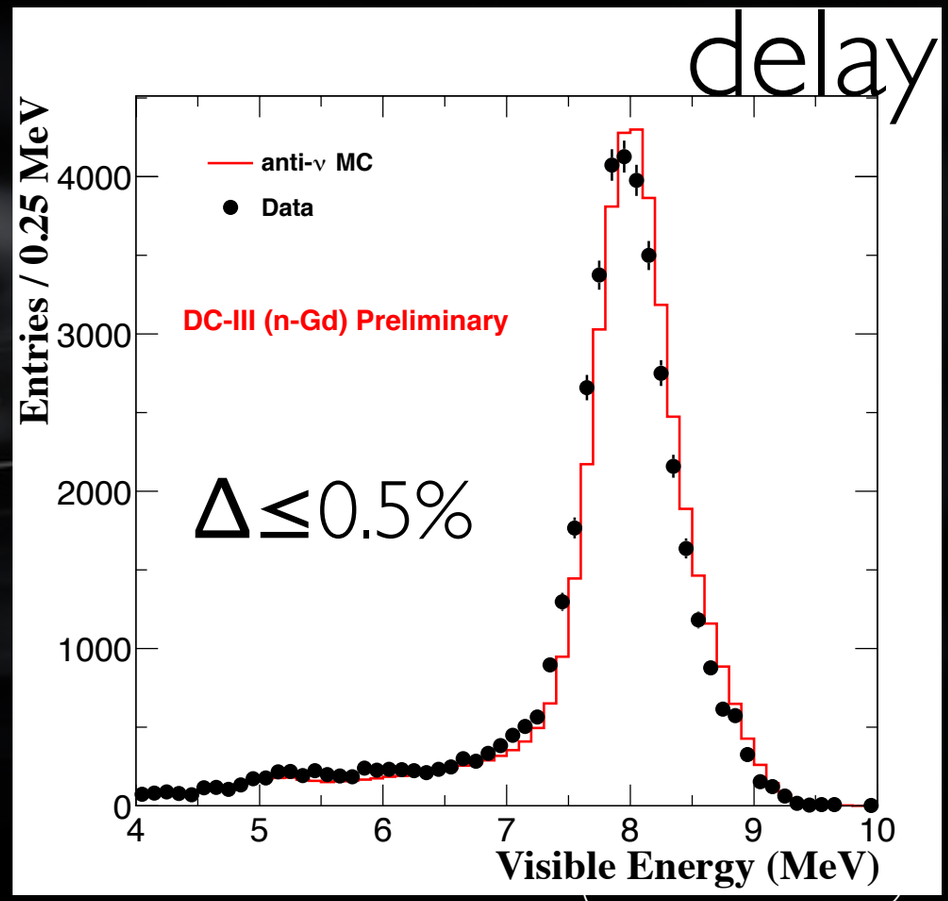


daily IBD candidate variation (no BG subtraction)

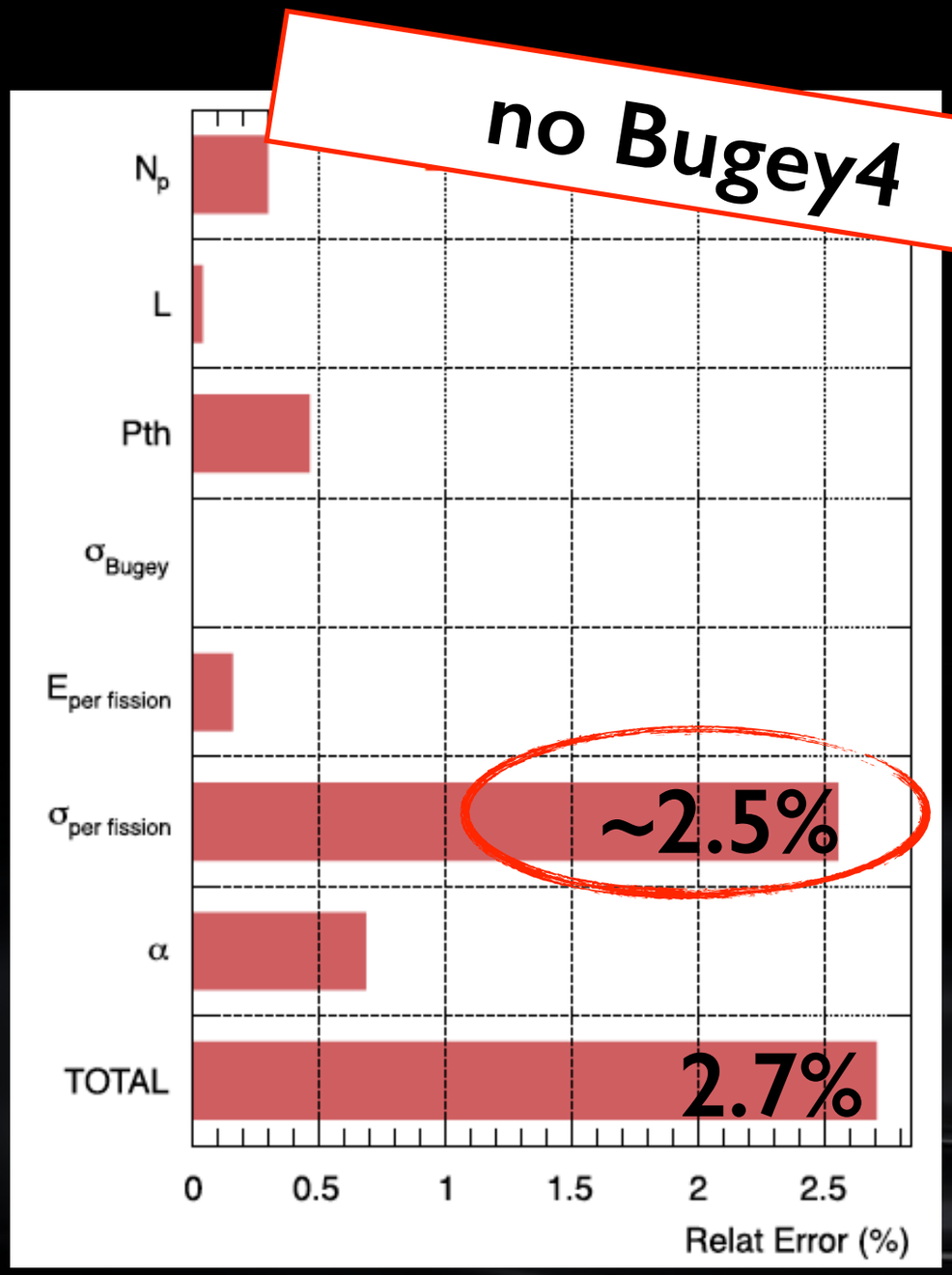
- MC uses reactor power info (100x→ negligible stats)
- accurate reactor power tracking (data~MC)

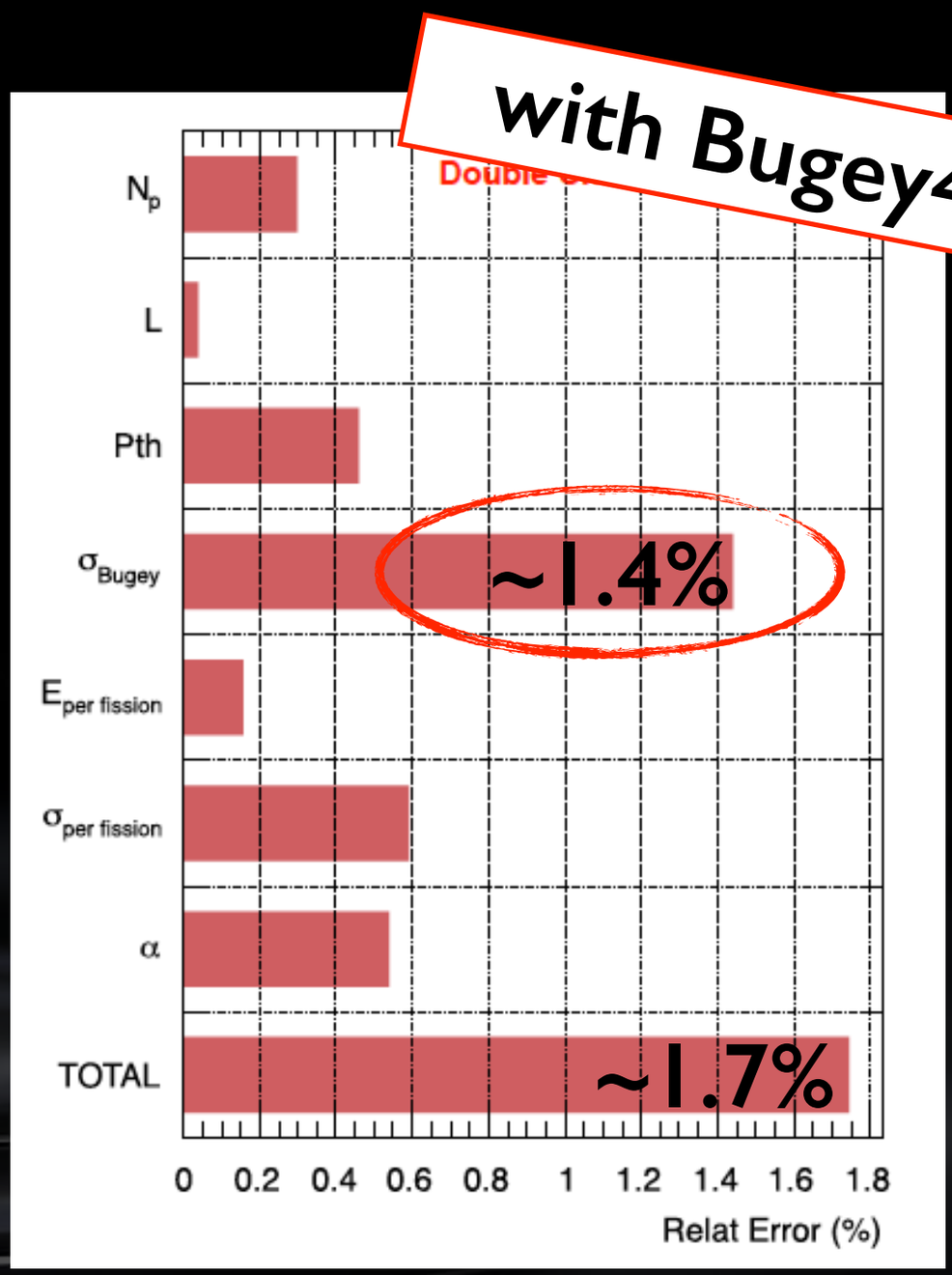
excellent data/MC agreement on Gd-n peak

- energy reconstruction (dominating still?)
- Gd multi-γ de-excitation physics model
  - scintillator quenching (non-linearity)
- n-capture physics model (thermalisation)



Bugey4 our "near" detector now…



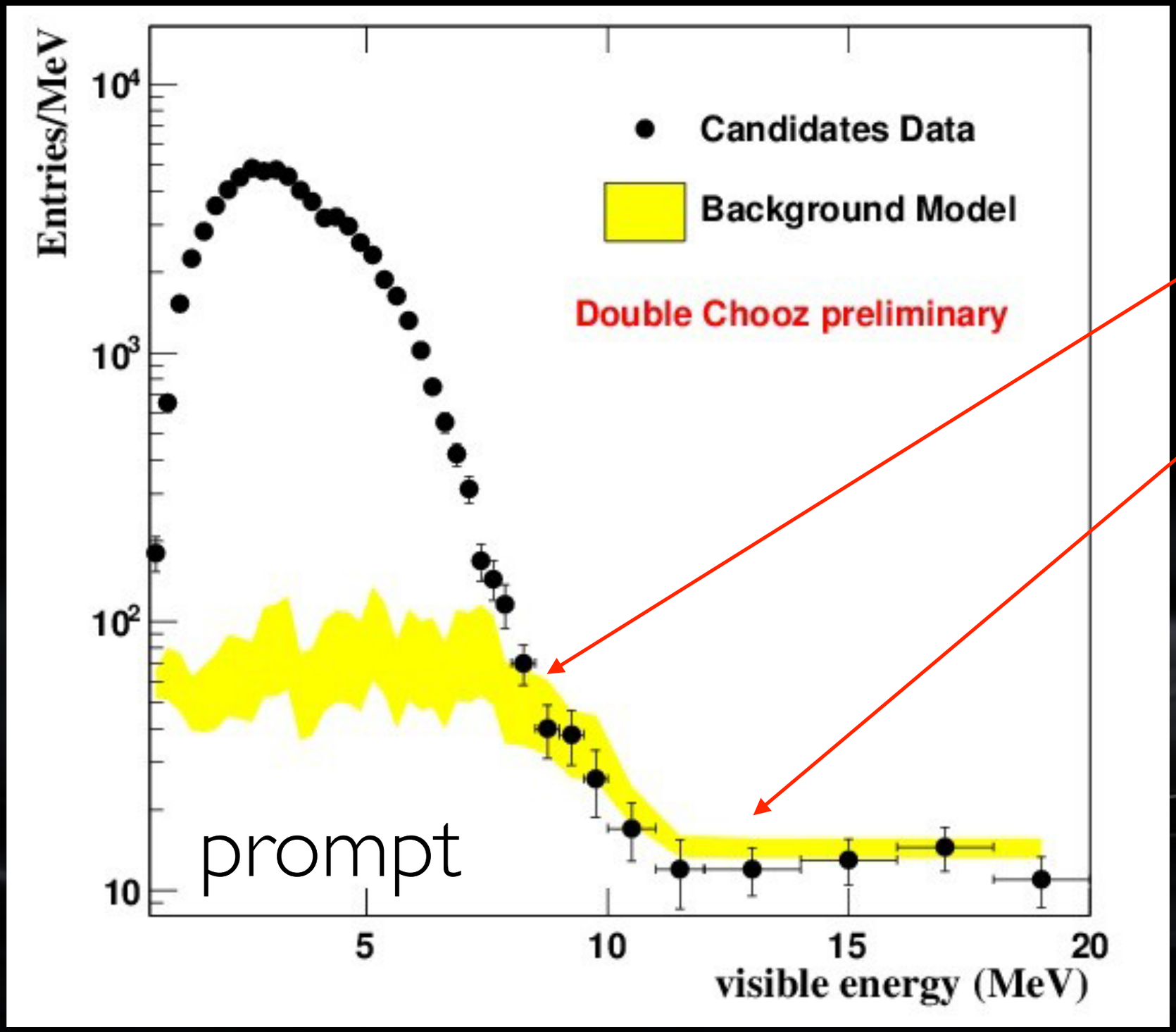


DC used Bugey as effective ND (via MC)

(technique reduces ~30% the dominant flux uncertainty→ used by KamLAND, etc)

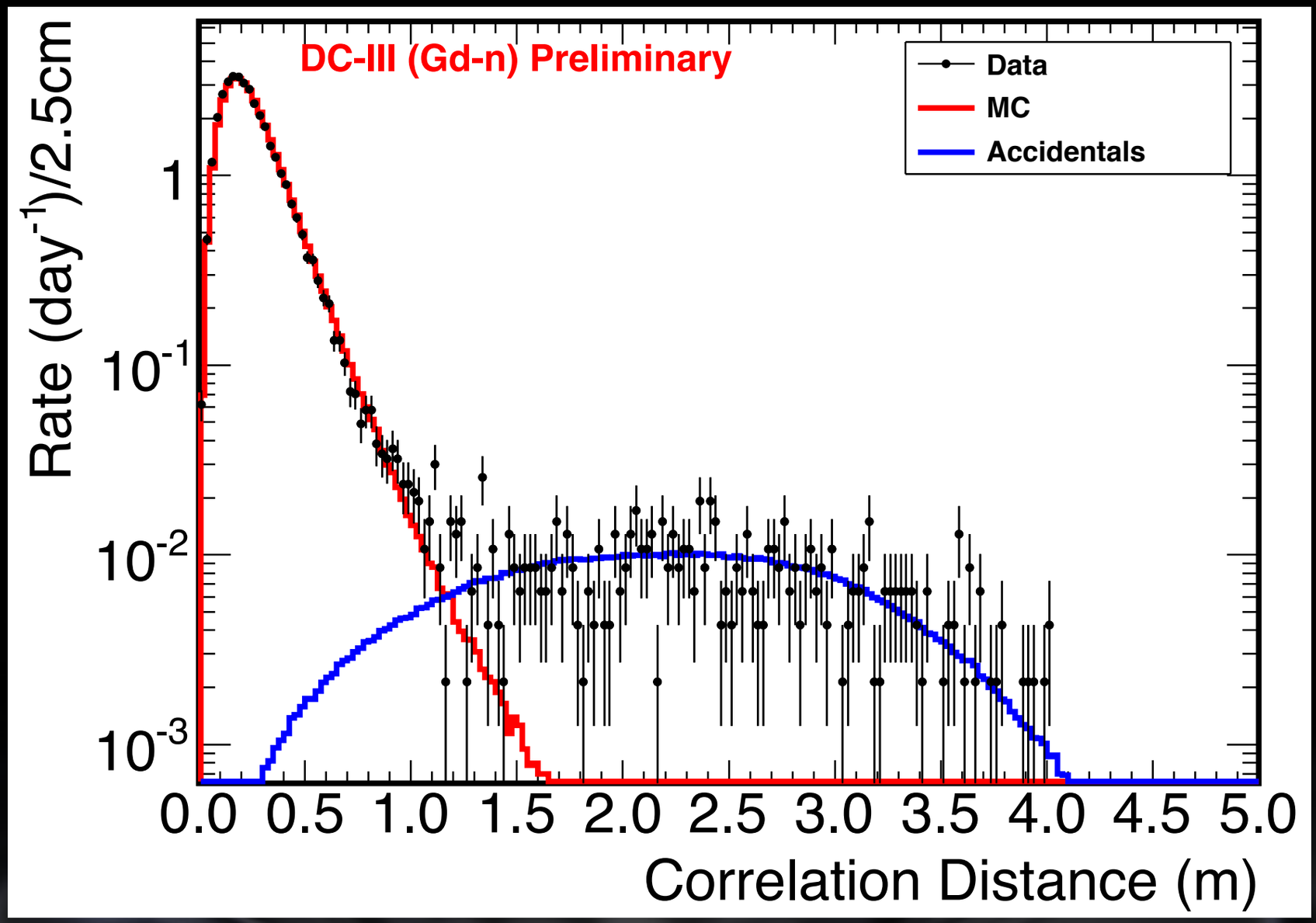
BACKGROUNDs

our background (BG) model…



- **^{9}Li (+ a little ^{8}He)**
  (dominant & knowledge @ 20%)
- **fast-n (+ little stopped-μs)**
  (still visible & knowledge @ <10%)
- **stopping-μ:** ~fully rejected
- **all the rest negligible**
  - accidentals
  - $^{13}C(\alpha,n)^{16}O$
  - ^{12}B related

DC goes accidentals-less…



e^+~n correlation distance→ >10x rejection on accidental BG

S/BG(accidental)<0.2% (negligible)

wide-open selection (→3x less IBD inefficiency wrt DC-Gd-II)

heavily studied for long (→ spatial reconstruction + detector model dependence): negligible

(excellent spatial-reco tuning) sharpest distribution + spectacular data/MC agreement

(**IBD inefficiency @ 1m <0.4%**)

BGs @ DC…

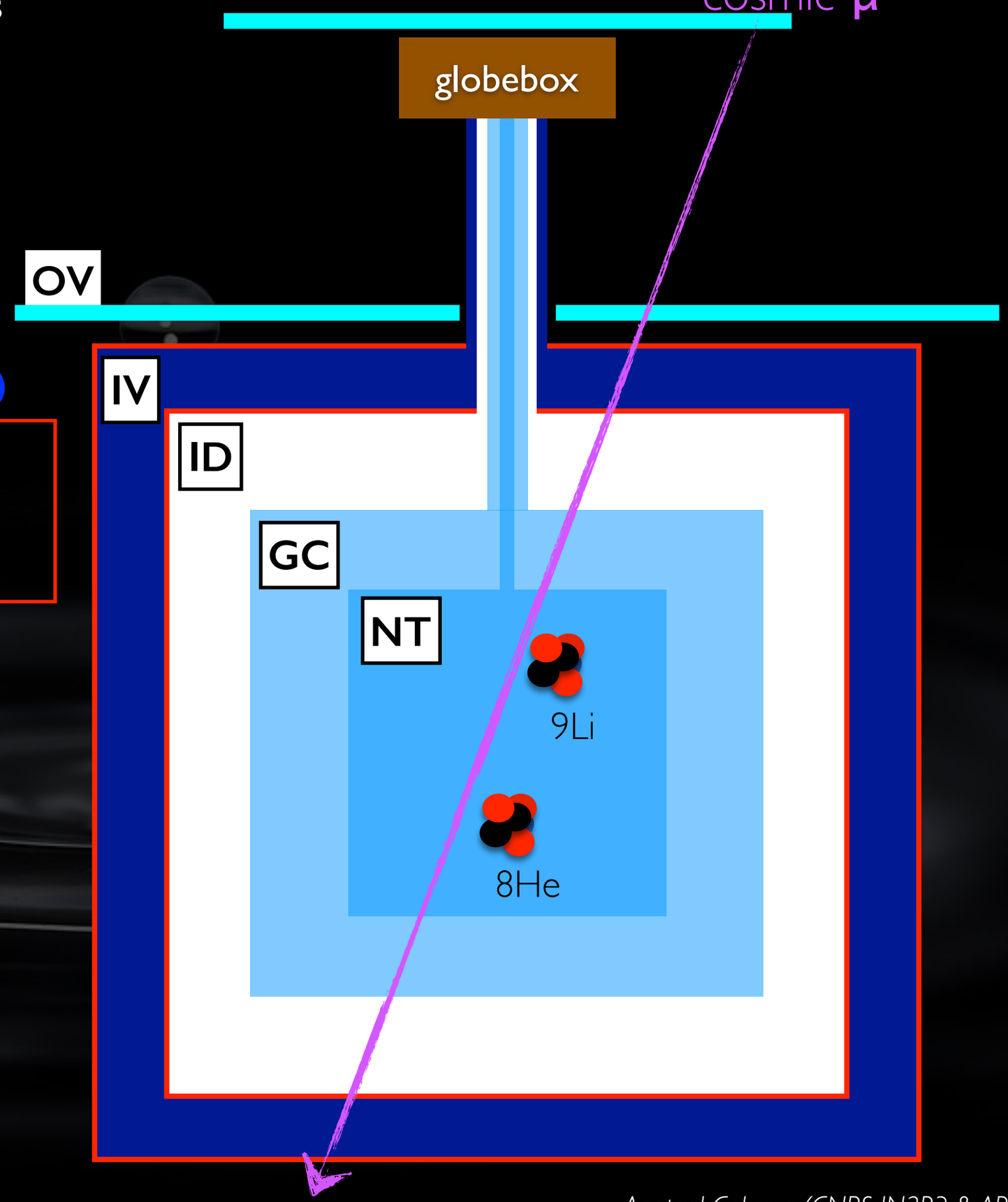
- (one way another) **all BG related to μ's**

⟹ μ-veto is starting point

- existence BG→ missed the μ-correlation
  - **μ beyond acceptance**
  - **μ correlation untraceable**

DC BGs (must have ≥1 n in final state)

- **Li+He** (by μ-spallation)
  - unstable isotope decay: β-n
  - **tagging:** trace the progenitor μ
- **fast-n** (by μ-spallation nearby)
  - many n's together upon μ
  - **tagging:** sub-sample (characterise)
- **stopped-μ** (by μ and decay $e^{\pm}$)
  - acceptance hole in chimney
  - **tagging:** sub-sample (characterise)
- **accidental** (by radioactivity + fast-n)
  - no space/time correlation (easy)
    - space/time correlation→reject
  - **measure:** time/space uncorrelated



all about ^{9}Li (the rest is ~negligible)…

BG	rate (day	shape	energy range	S/BG (%)	δ(BG) (%)	suppresion (wrt Gd-II)
^{9}	**0.97**	data (Li+He tag)	[0,12]MeV	2.6	**0.78**	1.3
fast-n stopped-μ	**0.60±0.05**	data (IV tag)	[0,20]MeV	1.6	0.13	1.9
accidental	0.070±0.005	data (off-time)	<3MeV	0.2	0.01	3.7
^{12}	<0.003@68CL	neglected	[0,13]MeV	-	-	>7.0
^{13}	<0.1	neglected	<2MeV	-	-	same

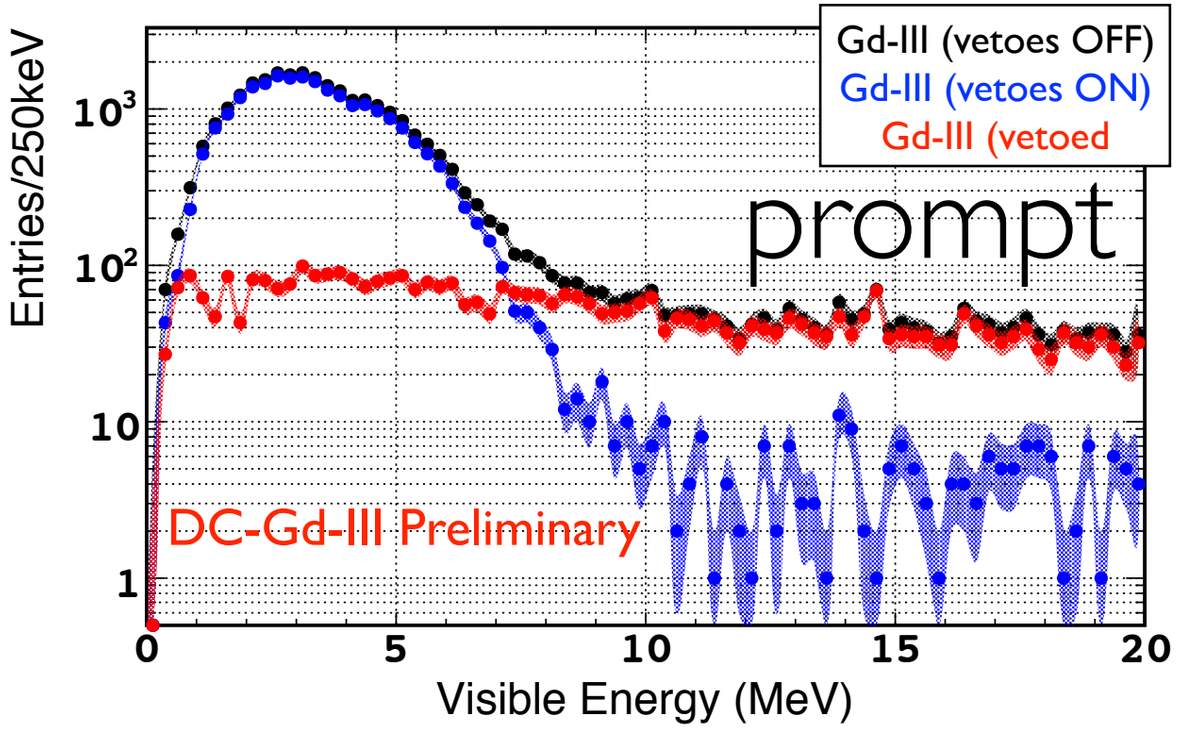
Li+He (He ≤10%) dominates BG systematics budget by >90%

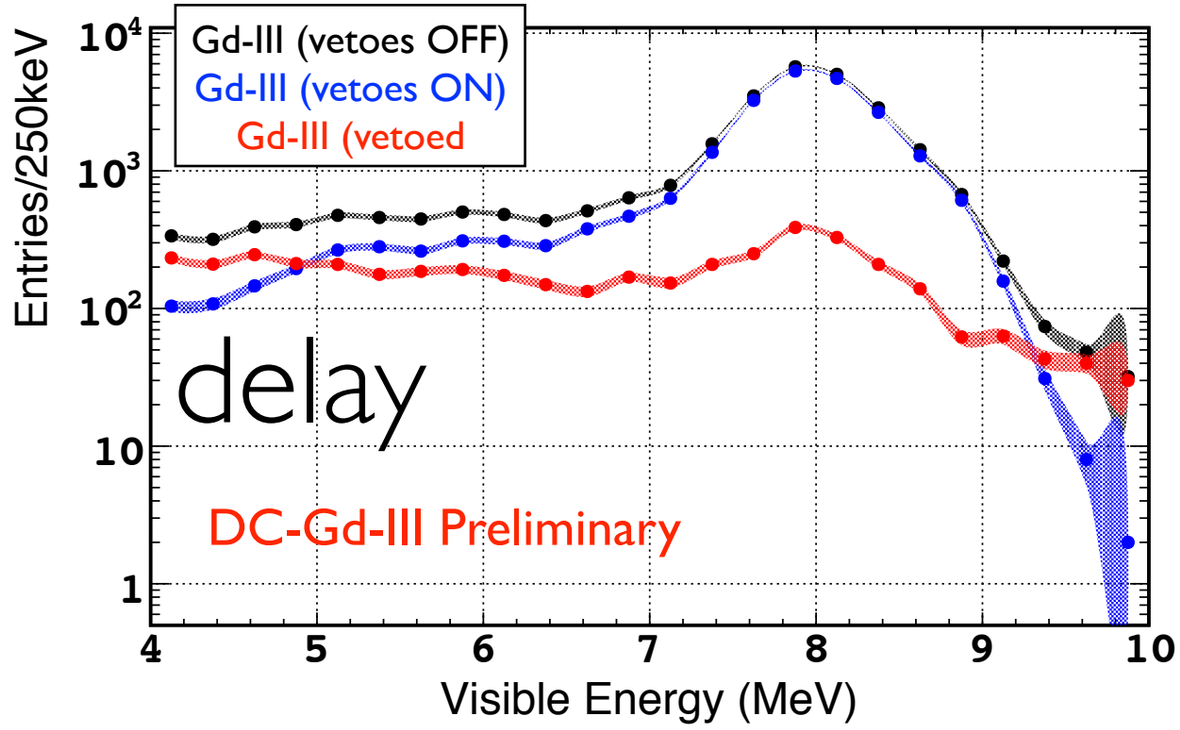
(energy spectrum data-driven→ poor statistics)

all other BG becoming negligible→ DC-III = IBDs + ^{9}Li (effectively)

(fast-n is high but well know spectrum makes it innocuous)

our BG active BG rejection vetoes…



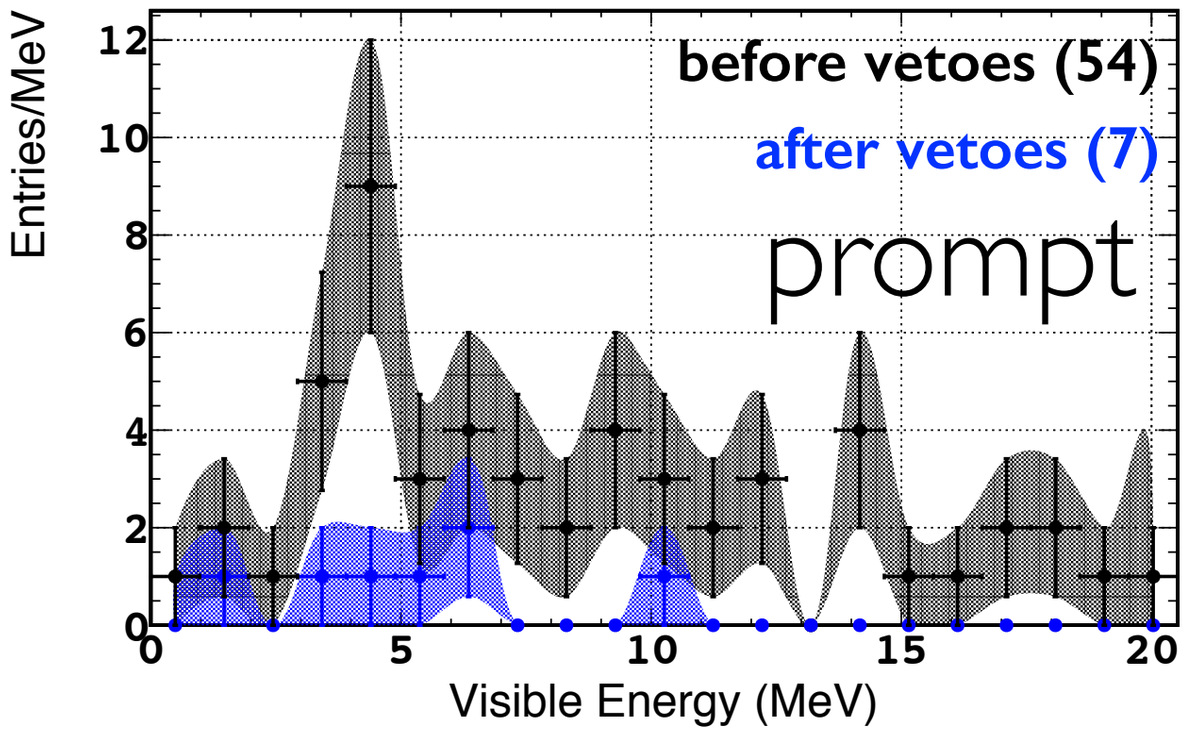


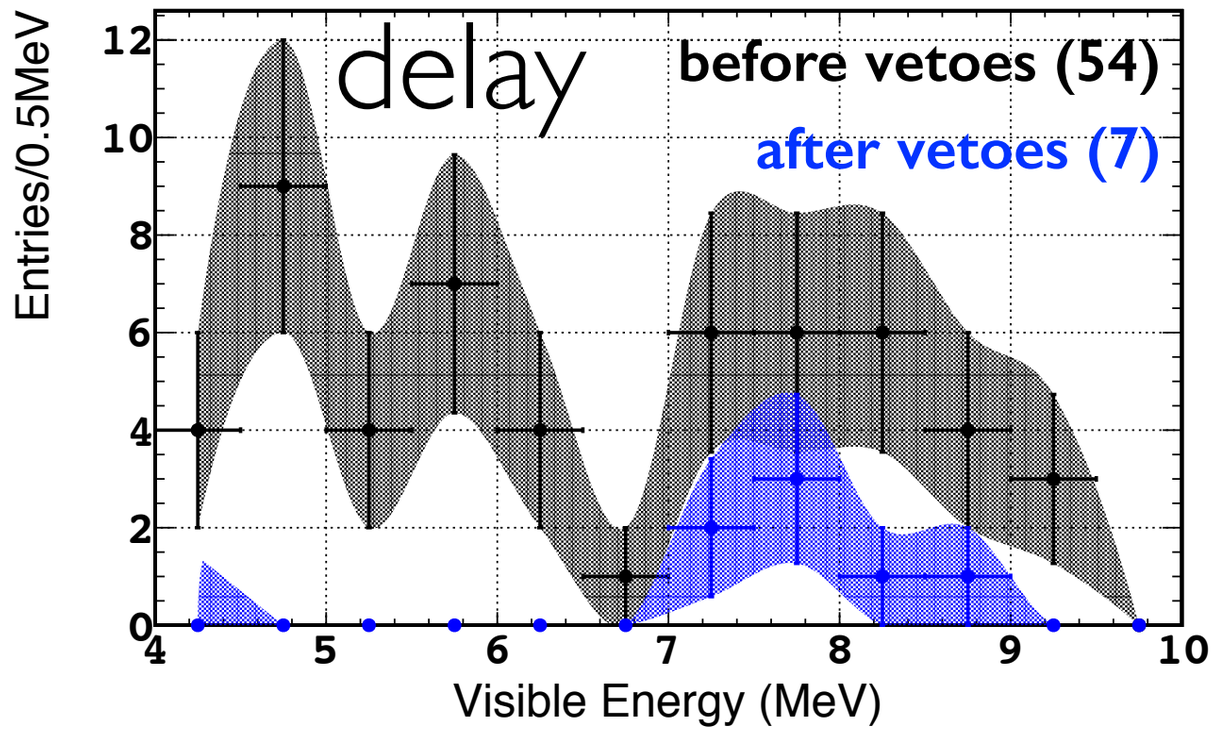
veto efficiency (%)	absolute (per veto)	uncorrelated fraction	relative (with all other vetoes)
IV veto	24	7	40
OV veto	62	7	41
FV veto	71	**19**	66
all vetoes	**90**	**33**	

Power(rejection) ~90%, estimated [12,20]MeV (high redundancy)

(VERY unusual for LS detector→ a volume of liquid flashing)

reactor 2xOFF data…





2xOFF data: powerful information before/after veto evolution

(scrutinising a few event-wise BG-only)

1 week→**poor stats** (spectral info fluctuations dominated)→ inconclusive

P(rejection)=(7.7±3.1) @ Gd-III

(in agreement with (9.9±1.0) estimated between [12,20]MeV)

Gd-III measurement of θ13…

systematics recapitulation…

systematics	DC-Gd-II (%)		DC-Gd-III (%)	
δ(flux)	1.7		1.7	
δ(detection)	~1.0		~0.6	
exposure (days)	227.9 (8249 IBDs)		467.9 (17358 IBDs)	
δ(BG) (input | output)	1.6	0.9 (R+S) 1.1 (RRM)	0.8	**0.3** (R+S) **0.5** (RRM)

RRM input

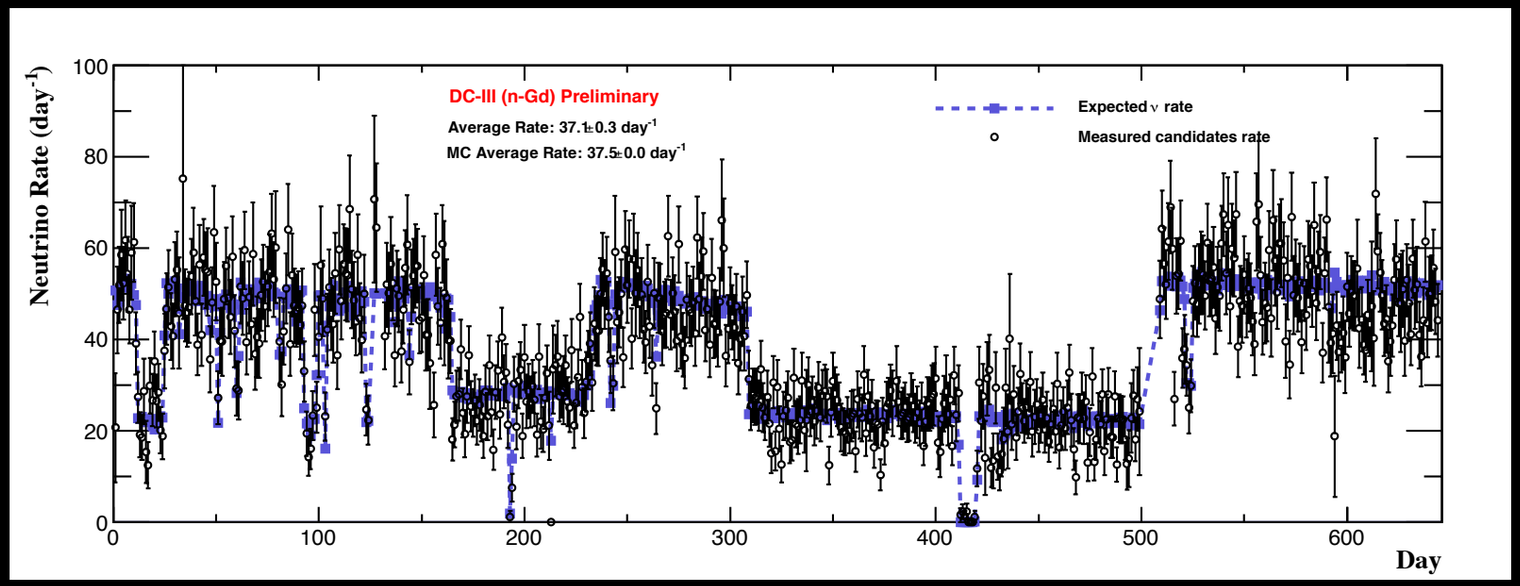
R+S input

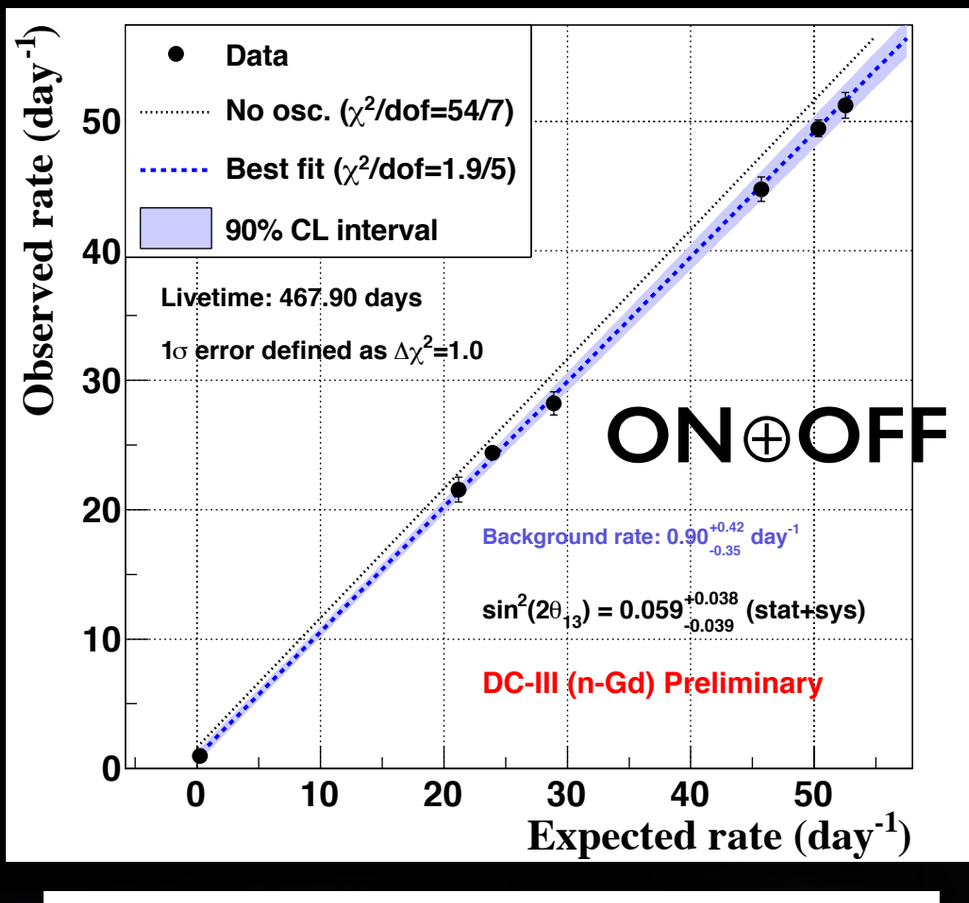
δ(BG) independent estimation: no spectral info used

$\Longrightarrow$ input to R+S (mandatory) and RRM (optional)

δ(BG) re-estimated by both R+S (spectra) and RRM

RRM analysis…

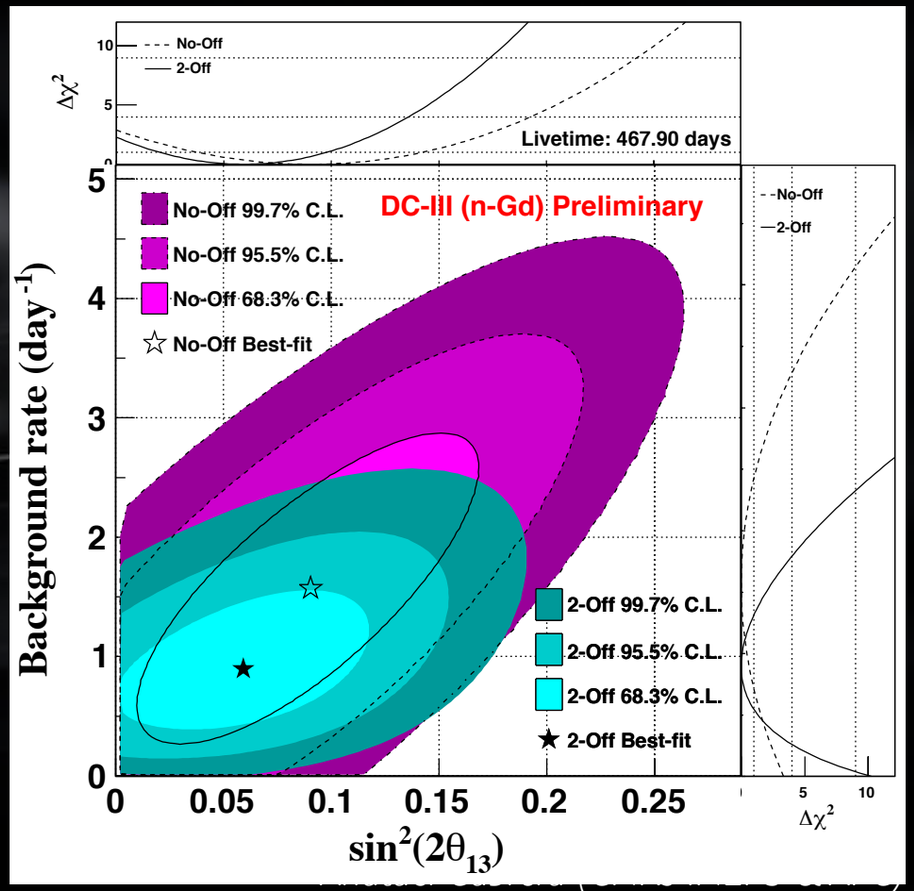




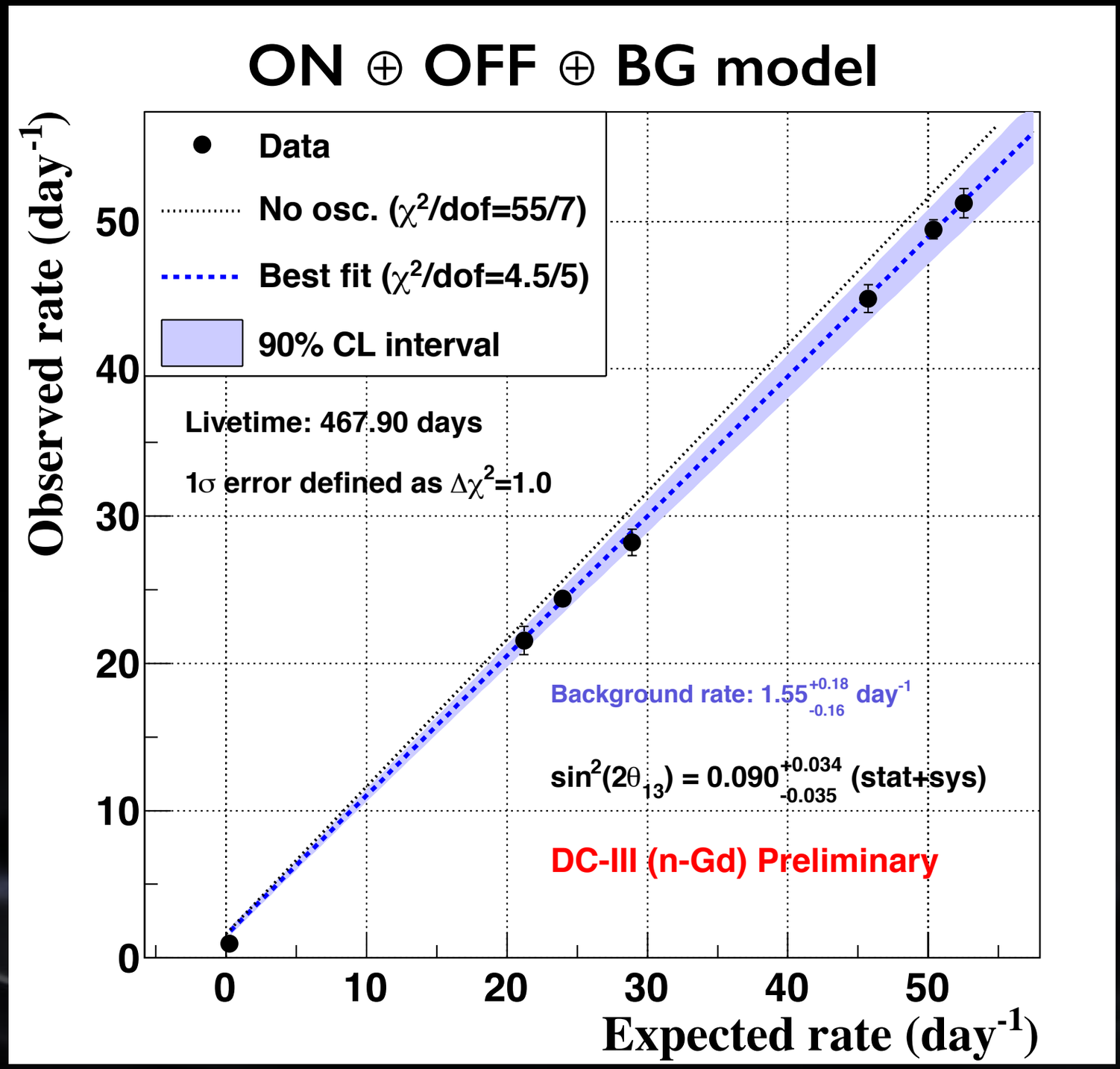
- exploit our 100% variations in reactor power…
  - **measure BG and $\sin^2(2\theta_{13})$ simultaneously**
  - **BG is inclusive** → account for unknown contributions

$\Longrightarrow$ BG measurement without BG model

- (trivial) fit is straight line…
  - **$BG^{inclusive}$** → intercept
  - **$\sin^2(2\theta_{13})$** → slope
- additionally, aid fit with extra BG constraints (pulls)…
  - **+2xOFF data** (independent $BG^{inclusive}$ measure)
    - provide a precious precise BG model cross-check
      - successful validation $<1.5\sigma$ agreement
  - **+BG estimation** (introduce BG model dependence)
    - even more precision (once validated coherent)



the ultimate RRM results…

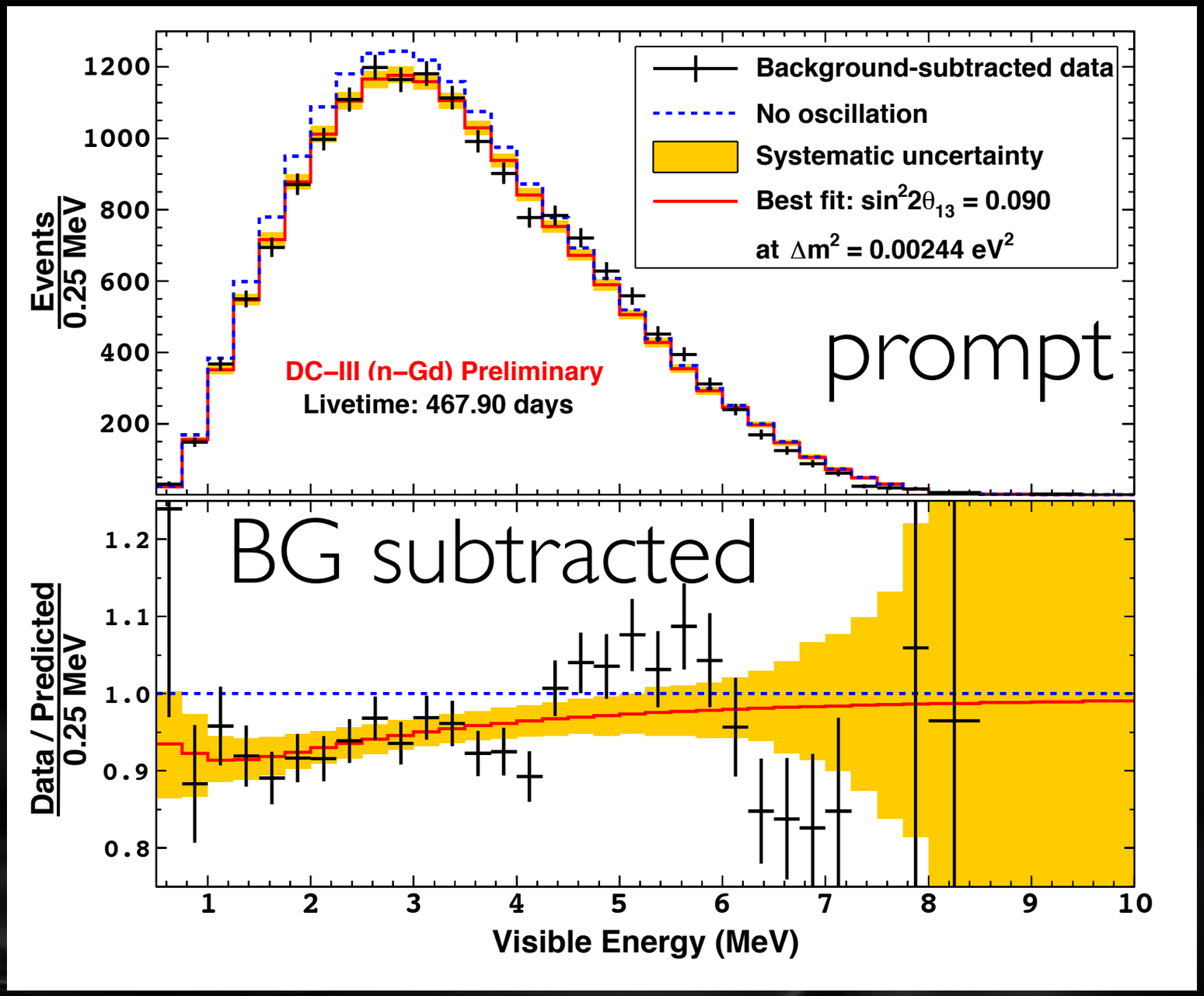


most precise rate-only (→i.e. not spectral info used)

(complementary to R+S although correlations exists)

R+S results…

- **many improvements**…
  - NEW!! • 250keV binning and [0.5,20]MeV
  - NEW!! • **BG fully data driven** (first time)
- **signal treatment…**
  - NEW!! • new spectrum with ^{238}U (low energy)
  - • Δm^2 from MINOS (+T2K)
- **BG treatment…**
  - NEW!! • 2xOFF data constraint (extra bin)
  - • **accidental pull term**
    - NEW!! • **rate:** syst. dominated
    - • **shape:** data measured
  - • **fast-n pull term** (~no stopping μs)
    - • **rate:** stats dominated
    - • **shape:** data measured
  - • **Li+He pull term**
    - NEW!! • **rate:** stats driven
    - NEW!! • **shape:** data measured (no MC!!!)
  - • negligible ^{12}B and BiPo
- **energy treatment…** NEW!!
  - • e+ energy model (via tuned MC)
  - • scintillator non-linearity (3 parameters)



$$\sin^2(2\theta_{13}) = (0.09 \pm 0.03)$$

(χ^2/n.d.f. = 51.4/40)

$\delta(BG)^{III}$ ~3x time better than DC-II

beyond Gd-III...

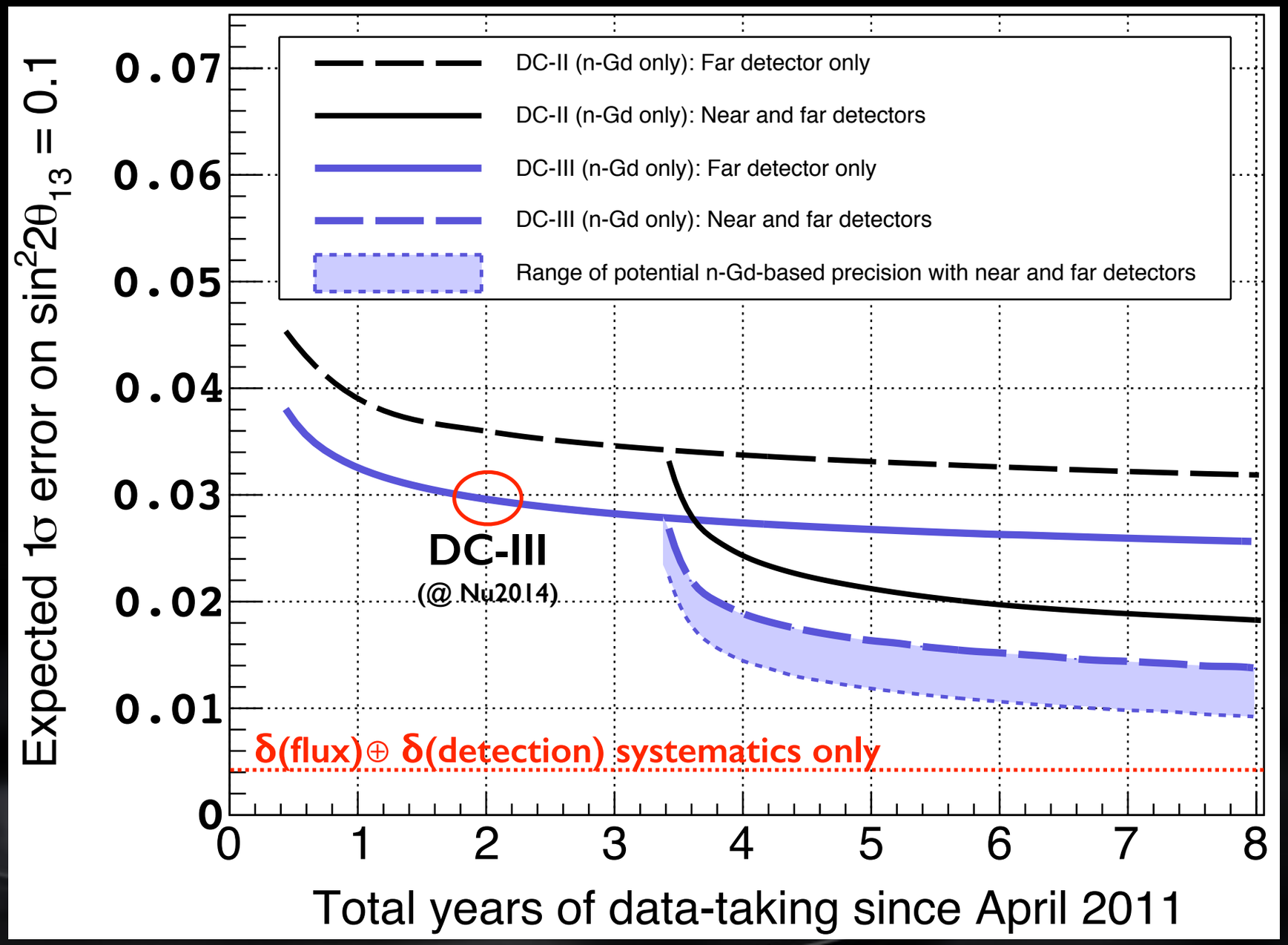
1σ error projection (via R+S analysis)…

Gd-n analysis FD+ND prospect inputs

- **δ(flux)~0.1%** (**preliminary**)
  - iso-flux suppression dominated
- **δ(detection)~0.2%**
  - à la Daya Bay / RENO
- **δ(BG)~ DC-III + R+S constraint**
  - @DC-III~0.3% (2 years data)

note:

- **δ(stat) not just $1/\sqrt{N^{FD}}$ (dominant)**
  - several effects N^{BG}, N^{ND}, etc

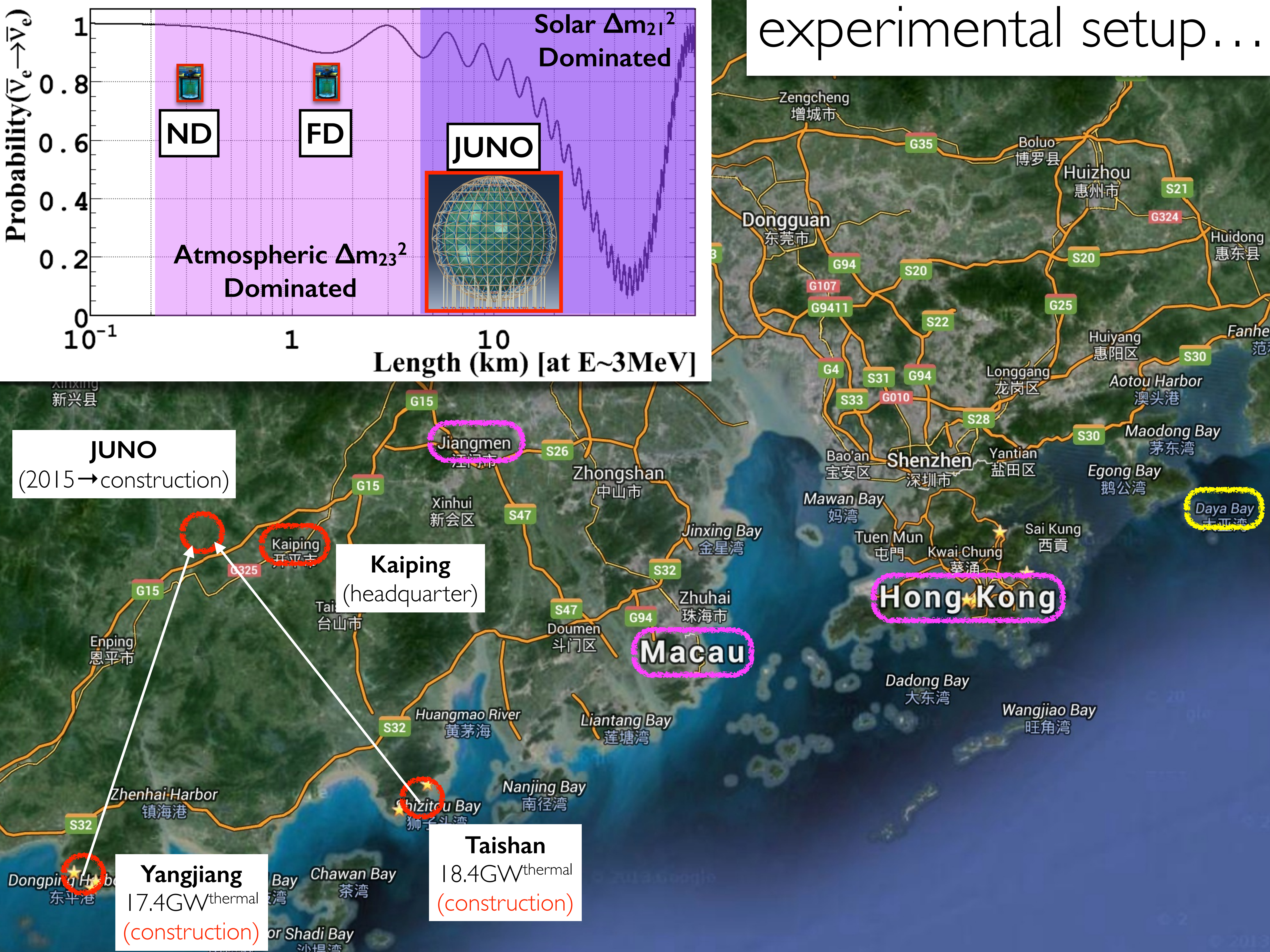


remarkable improvement of DC-III new analysis (wrt DC-II)

1σ within [0.010,0.014] with 3years FD+ND: BG systematics dependent→ **statistics dominated**

(rate+spectrum projection uses latest BG model fromDC-III)

reactors νs: future?



experimental setup…
Probability($\bar{\nu}_e \to \bar{\nu}_e$)
1
0.8
0.6
0.4
0.2
0
10^{-1}
1
10
Length (km) [at E~3MeV]
Solar Δm_{21}^2 Dominated
Atmospheric Δm_{23}^2 Dominated
ND
FD
JUNO
JUNO
(2015→construction)
Kaiping
(headquarter)
Yangjiang
17.4GW^thermal
(construction)
Taishan
18.4GW^thermal
(construction)
Jiangmen
Kaiping
Macau
Hong Kong
Daya Bay
Shenzhen
Dongguan
Huizhou
Zhongshan
Zhuhai
Xinhui
Enping
Zhenhai Harbor
Huangmao River
Liantang Bay
Nanjing Bay
Dadong Bay
Wangjiao Bay
Mawan Bay
Tuen Mun
Kwai Chung
Sai Kung
Jinxing Bay
Doumen
Bao'an
Yantian
Longgang
Huiyang
Aotou Harbor
Maodong Bay
Egong Bay
Boluo
Zengcheng
Huidong
Fanhe
Chawan Bay

JUNO participation… possible JUNO-FR (beyond OPERA)…

- **laboratories:** 3(+1) labs so far (others labs considering) [JUNO-FR strong OPERA contribution]
  - **APC** (Paris): *A. Cabrera* [→ Double Chooz]
  - **CPPM** (Marseille): *J. Busto & D. Dornic* [→ ANTARES + SuperNEMO]
  - **Subatech** (Nantes): *F. Yermia* [→ Double Chooz + SOLiD + Nucifer]
  - (technical support) **Omega** (Paris): *C. de la Taille* [→electronics + ASIC development]
- **relevant technical expertise towards JUNO (exclude physics/analysis expertise)…**
  - **reactor neutrino (Double Chooz, etc) expertise [APC + Subatech]**
    - expertise on detector, vetoes systems (low backgrounds), simulation, etc.
  - **electronics + online systems expertise [Omega+APC+CPPM]**
    - (Omega) ASIC development: electronics for many experiments (CERN, etc)
    - (APC) Double Chooz FADC electronics (co-developed with CAEN), DAQ and detector
    - (CPPM) ANTARES handle electronics immersed in water (interface, etc)
  - **reactor flux expertise [Subatech+APC]**
    - world leading knowledge/techniques on reactor flux systematics (→Double Chooz input)
  - **low radioactivity technique large expertise [CPPM]:** Ra contamination purification
- **possible technical involvement in JUNO…**
  - DAQ's "event builder farm(s)" (à la SK-IV) + data-monitoring [collaboration with Italy & Germany]
  - electronics design [collaboration with Germany]
- **(beyond OPERA) tight partnership by 3(+1) laboratories in France→ members are welcome!**

Anatael Cabrera (CNRS-IN2P3 & APC)

what to remember?

conclusions…

- DC-Gd-III have been presented (@ LAL and Nu2014)…
  - Gd-III improves everything by factors relative to Gd-II
    - higher efficiency, less BG (active BG rejection), data-driven BG estimations, etc
      - $\delta(\text{detection})^{III}$ ~2x more precise $\delta(\text{detection})^{II}$
      - $\delta(\text{BG})^{III}$ ~3x more precise $\delta(\text{BG})^{II}$
      - better energy reconstruction (fully accounting for non-linearities)
  - (powerful) analysis is now ready for ND→ more already under preparation
- DC-Gd-III results…
  - (relative Gd-II) ~2x more stats, but factor improvement in systematics…
  - (**R+S**) **$\sin^2(2\theta_{13}) = (0.09\pm0.03)$** [corresponding BG **$(1.43\pm0.15)\text{day}^{-1}$**]
  - (**RRM-All**) **$\sin^2(2\theta_{13}) = (0.09^{+0.03}_{-0.04})$** [corresponding BG: **$(1.55\pm0.17)\text{day}^{-1}$**]
    - (**RRM-2xOFF**) **$\sin^2(2\theta_{13}) = (0.06\pm0.04)$** [corresponding BG **$(0.90\pm0.39)\text{day}^{-1}$**]
- DC projections…
  - ND will run from end of summer 2014
  - **major systematics cancellation boosting 1σ error on $\sin^2(2\theta_{13})$ up to 0.01** [**only Gd-n**]
    - improvement in analysis are already in preparation