
Double Chooz
commissioned?
XIV Workshop on Neutrino Telescopes
(March 2011)
on behalf of the DC collaboration...
Anatael Cabrera
アナタエル カブレラ
CNRS / IN2P3
Double Chooz @ APC (Paris)

brief status on θ_{13}...

Talks by McDonald, King, Maltoni, Schewtz

"atmospheric" $\Longrightarrow \theta_{23}$ | θ_{13} & dirac-δ_{CP} | "solar" $\Longrightarrow \theta_{12}$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

sub-leading | sub-leading

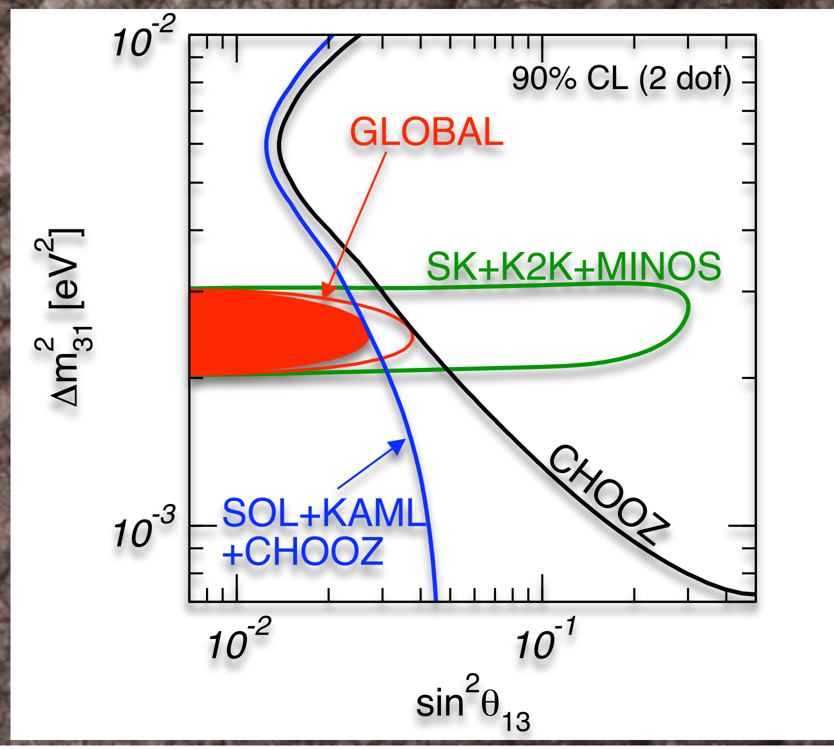
$P(\nu_\mu \to \nu_\mu)$ | $P(\nu_e \to \nu_e)$ & $P(\nu_\mu \to \nu_e)$ | $P(\nu_e \to \nu_x)$

PMNS (Unitary & 3x3) $\Longrightarrow$ 3 mixing angles & 1 complex phase $\Longrightarrow$ leptonic CP violation

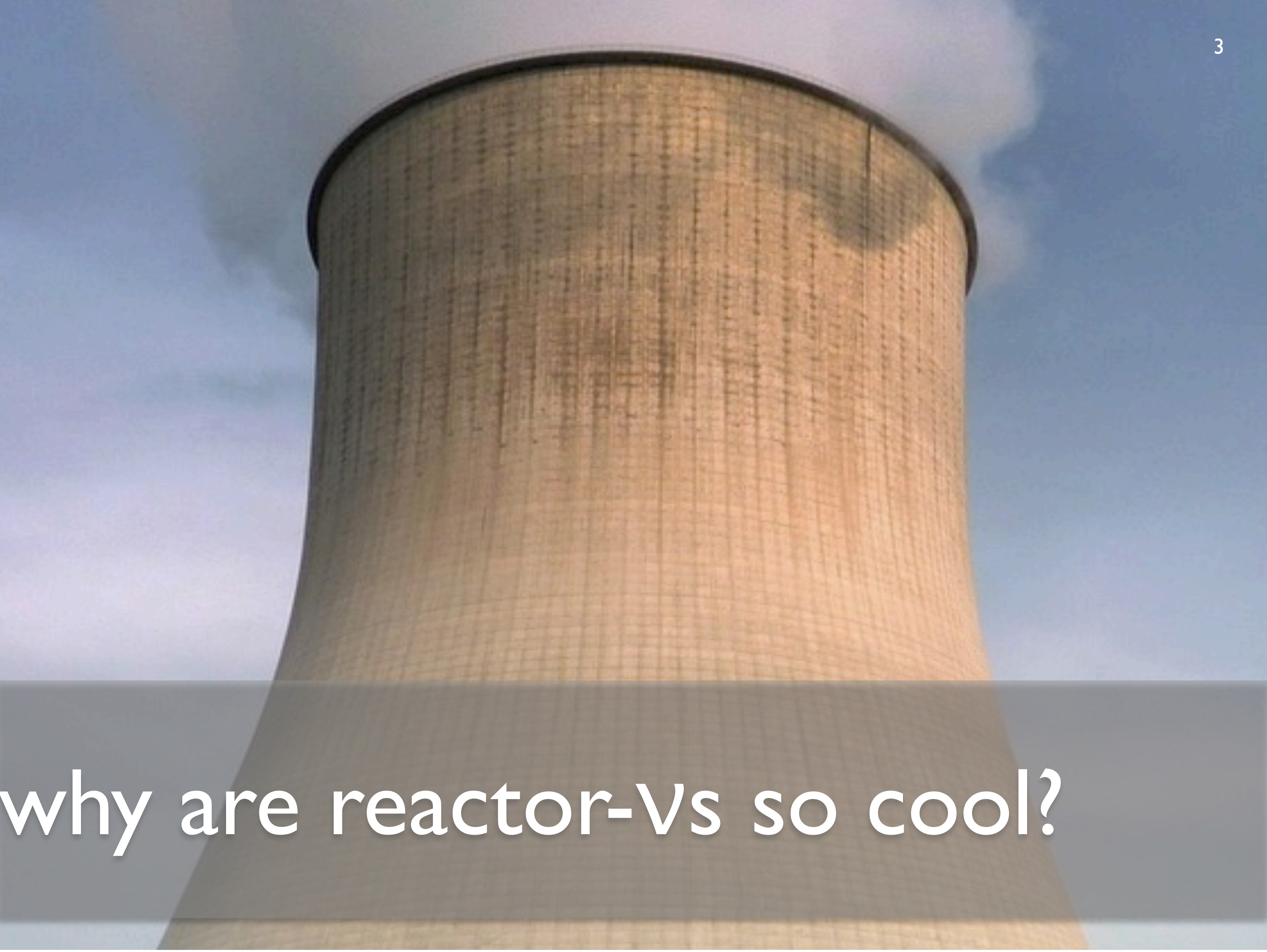
Experiments: limits (CHOOZ, MINOS, KamLAND, Solar, SK) $\Longrightarrow \sin^2(2\theta_{13}) <$ ~0.10 @ 90%CL

Global Analysis: hint on $\theta_{13} > 0$ @ ~1.5sigmas

T.Schwetz et al. arXiv:1103.0734
M.Concha-García et al. arXiv:1001.4524



P3 & APC)

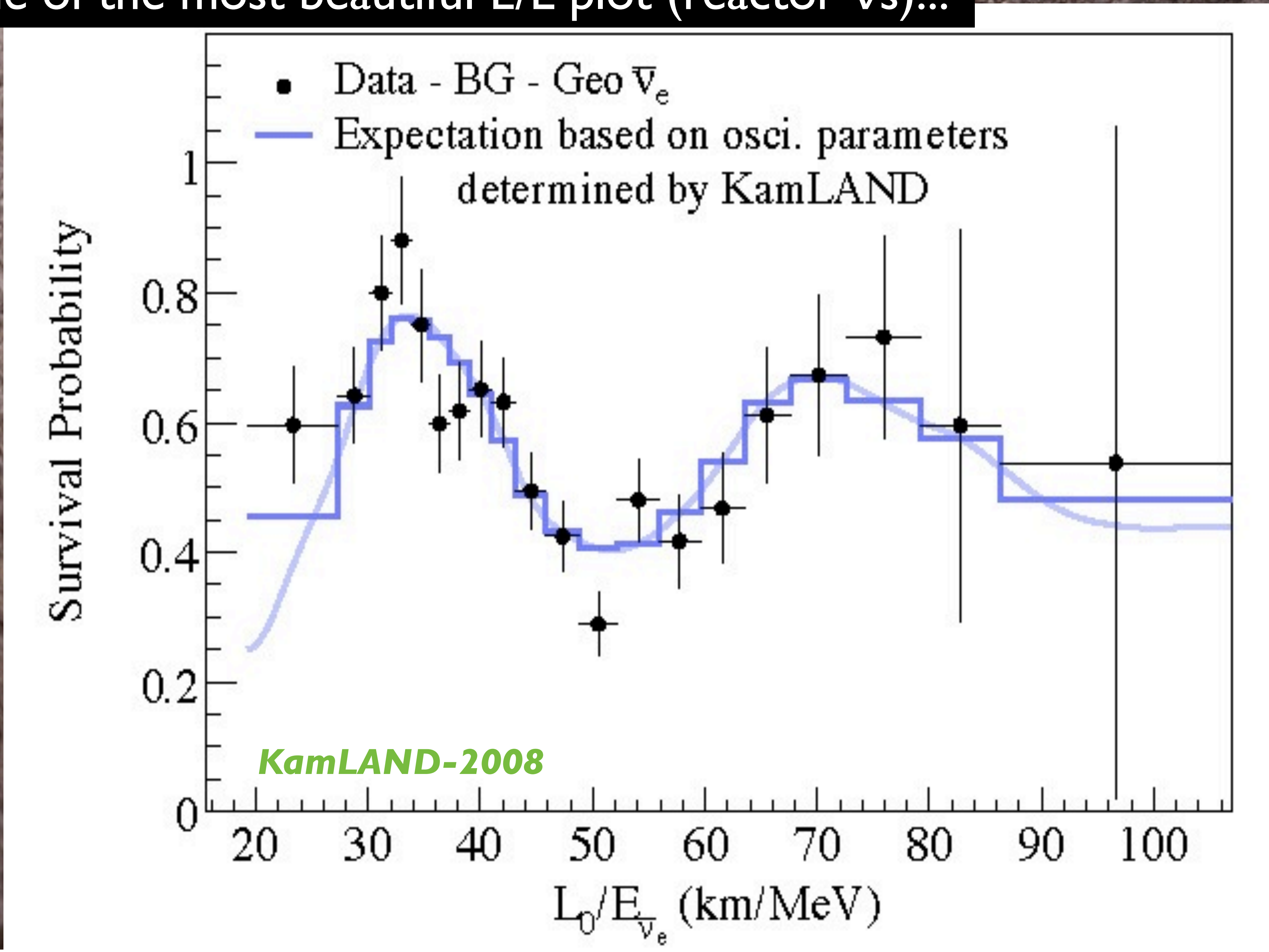


why are reactor-Vs so cool?

- discovery of neutrinos (1956$\Longrightarrow$ Nobel Prize 1995)
    - validation of neutrino hypothesis (Pauli)
- dominant contribution to limit on θ_{13} so far (CHOOZ)
    - dramatic improvement on the way…
- best measurement of Δm^2_{12} (KamLAND)
    - a better measurement @ 60km baseline?
- complementary input in the neutrino oscillation quest…
    - comparison wrt Solar $\Longrightarrow$ θ_{13} & NSI
    - comparison wrt Beams $\Longrightarrow$ θ_{13} & [δ_{CP} & $\pm\Delta m^2_{13}$]

“solar” E/L @ KamLAND (reactor-νs)

one of the most beautiful E/L plot (reactor νs)...



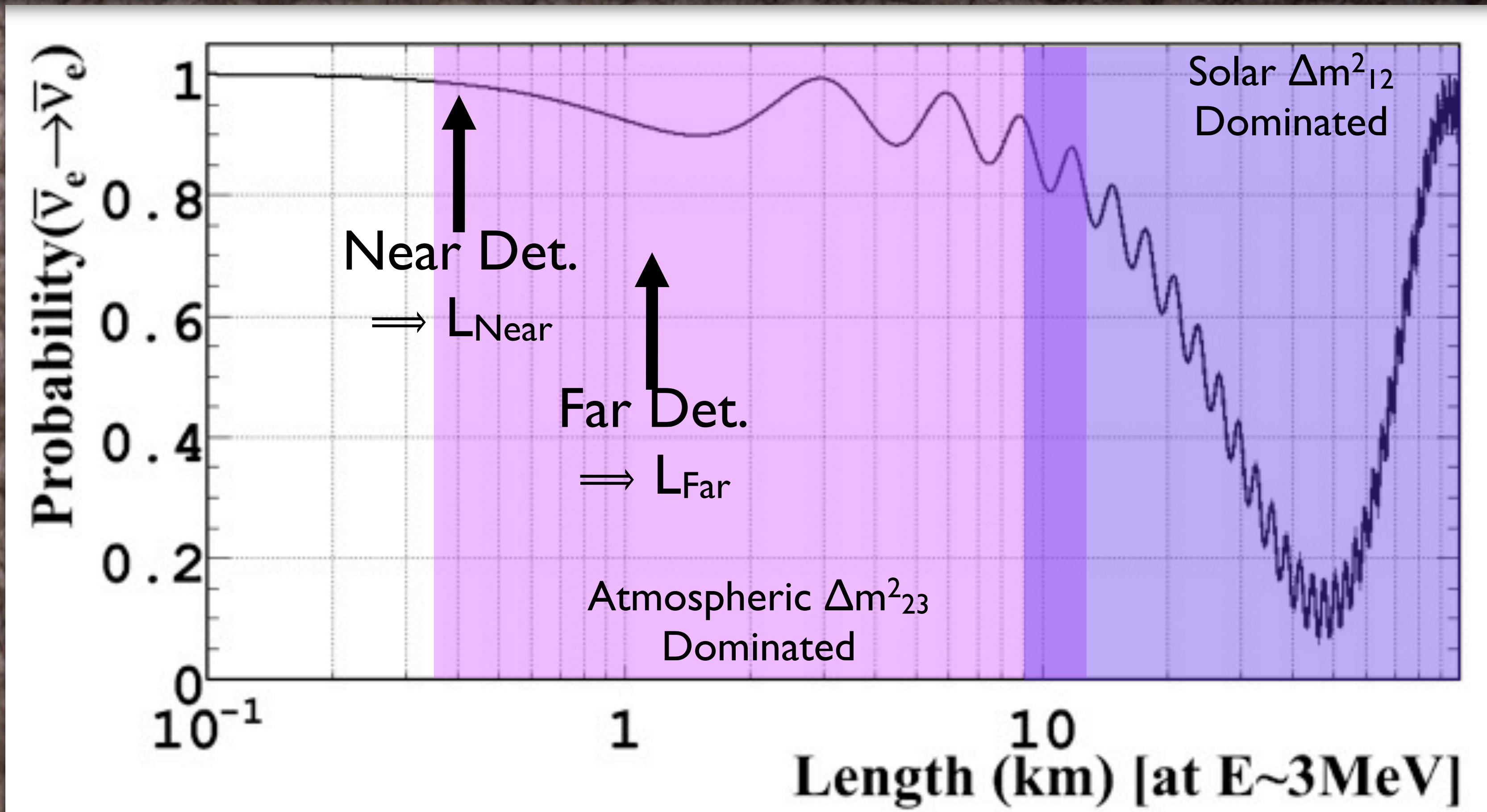
3 & APC)

Talks by Lassere, Wang, Kim

the coolest reason for us...

$$P(\nu_e \to \nu_e) \sim 1 - \sin^2(2\theta_{13}) \sin^2(\Delta m^2_{23} L_o/E)$$

[plot: $E = 3MeV$, $\sin^2(2\theta_{13}) = 0.1$, $\Delta m^2_{23} = 2.5\times10^{-3} eV^2$]

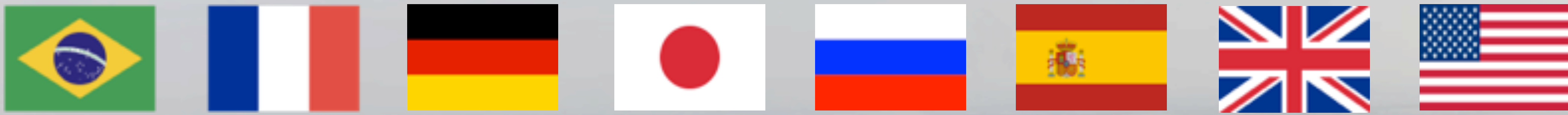


ND⟹ reduce several systematic uncertainties (mainly flux rate & shape) wrt FD

DC strongly involved in leading efforts to improve **reactor flux measurements**

→ Just published: ***Mueller et al. (arXiv:1101.2663) & Mention et al. (arXiv:1101.2755)***

Double Chooz Collaboration



Brazil
CBPF
UNICAMP
UFABC

France
APC
CEA/DSM/IRFU:
SPP
SPhN
SEDI
SIS
SENAC
CNRS/IN2P3:
Subatech
IPHC
ULB

Germany
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MPIK Heidelberg
TU München
U. Aachen
U. Hamburg

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Tokyo Inst. Tech.
Tokyo Metro. U.
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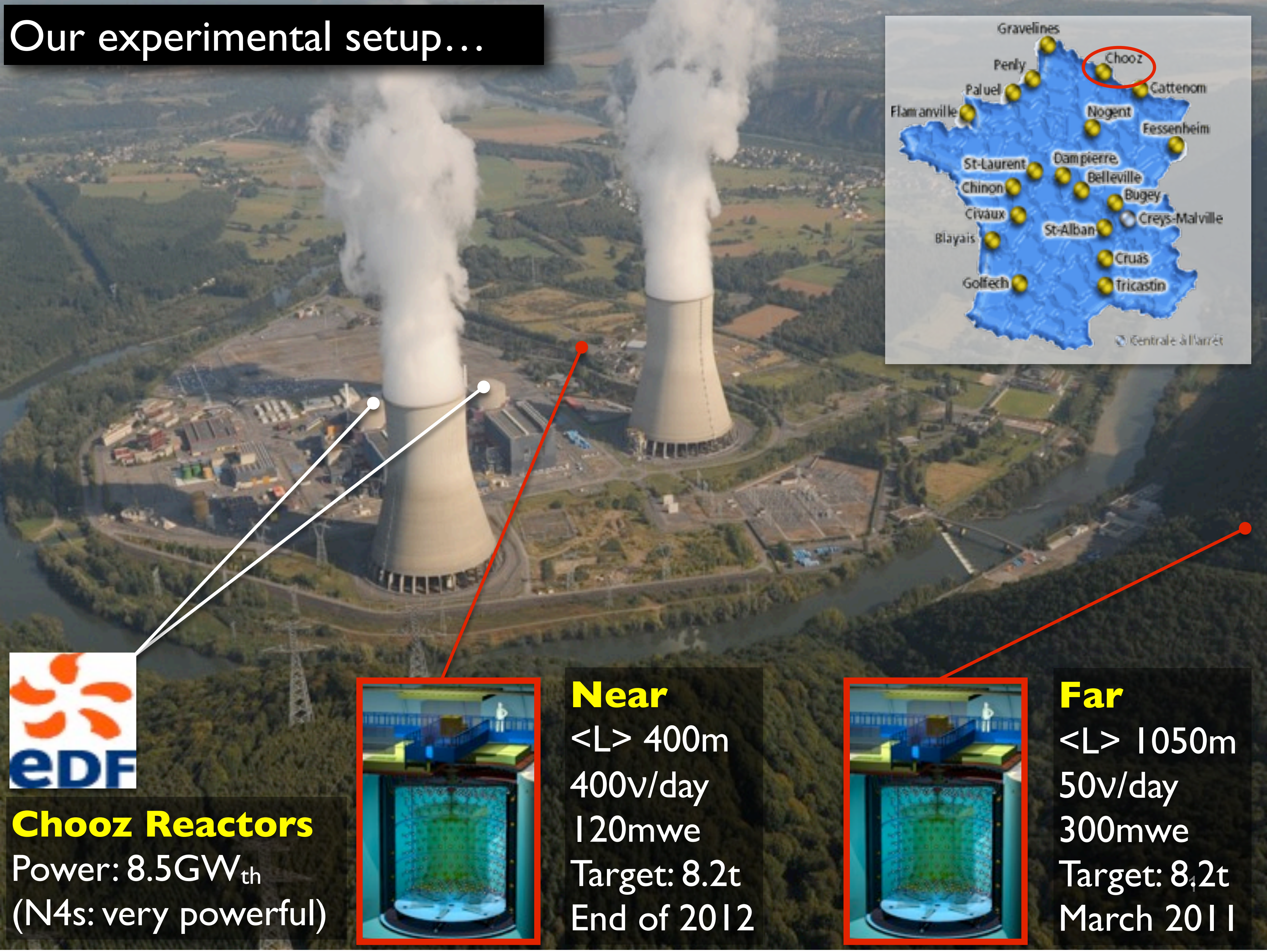
Sandia National Laboratories
U. Tennessee

!!!all DC Japanese colleagues safe!!!

Spokesperson: H. de Kerret (CNRS/IN2P3-APC)
Project Manager: Ch. Veyssière (CEA-Saclay)

Web Site: www.doublechooz.in2p3.fr/

Our experimental setup…



Chooz Reactors
Power: 8.5GW_{th}
(N4s: very powerful)

Near
<L> 400m
400ν/day
120mwe
Target: 8.2t
End of 2012

Far
<L> 1050m
50ν/day
300mwe
Target: 8.2t
March 2011

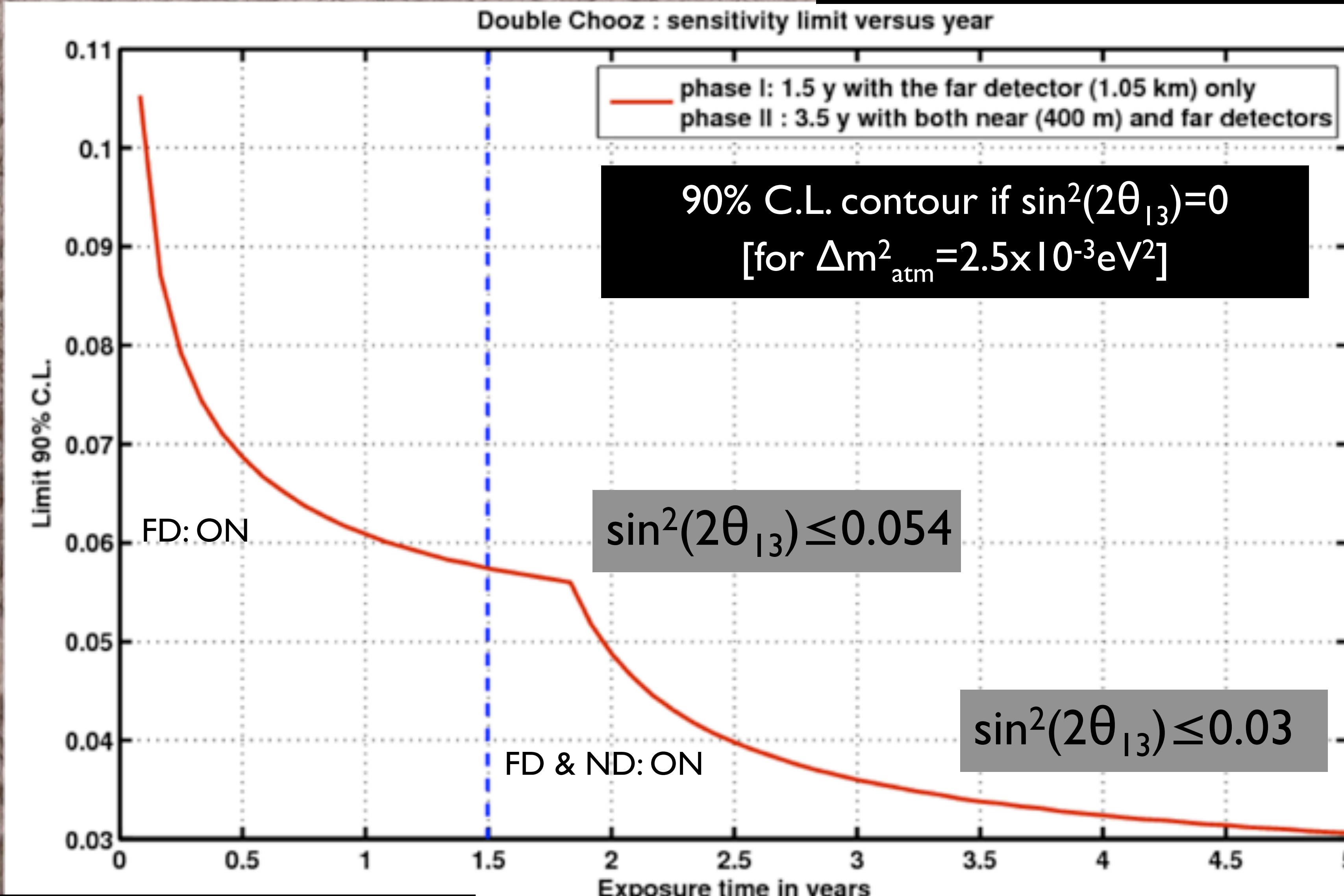
our θ_{13} knowledge versus time...

DC Proposal: hep-ex/0606025

Phases:

DC-I (FD only)
10x more statistics than CHOOZ
Limited by:
rate and shape reactor flux uncertainties (2.8%)

DC-II (FD+ND)
more robust
Limited by:
inter-detector normalisation systematic uncertainties (0.6%)



90% C.L. contour if $\sin^2(2\theta_{13})=0$
[for $\Delta m^2_{atm}=2.5\times10^{-3}eV^2$]

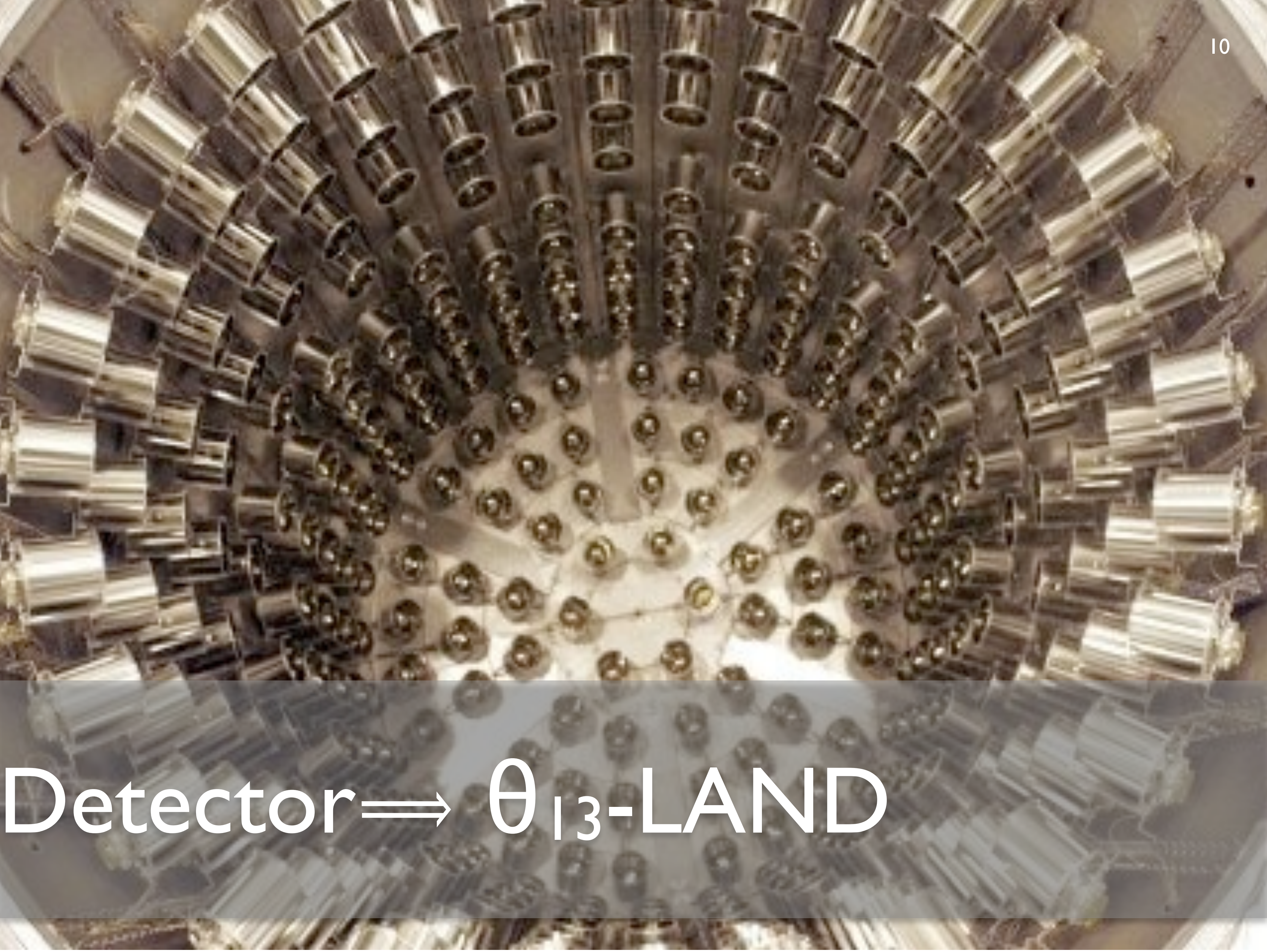
$\sin^2(2\theta_{13})\leq0.054$

$\sin^2(2\theta_{13})\leq0.03$

Normalisation strategy for FD phase→ *under discussion*

Discovery @ 3σs if $\sin^2(2\theta_{13})>0.05$

Anatael Cabrera (CNRS-IN2P3 & APC)



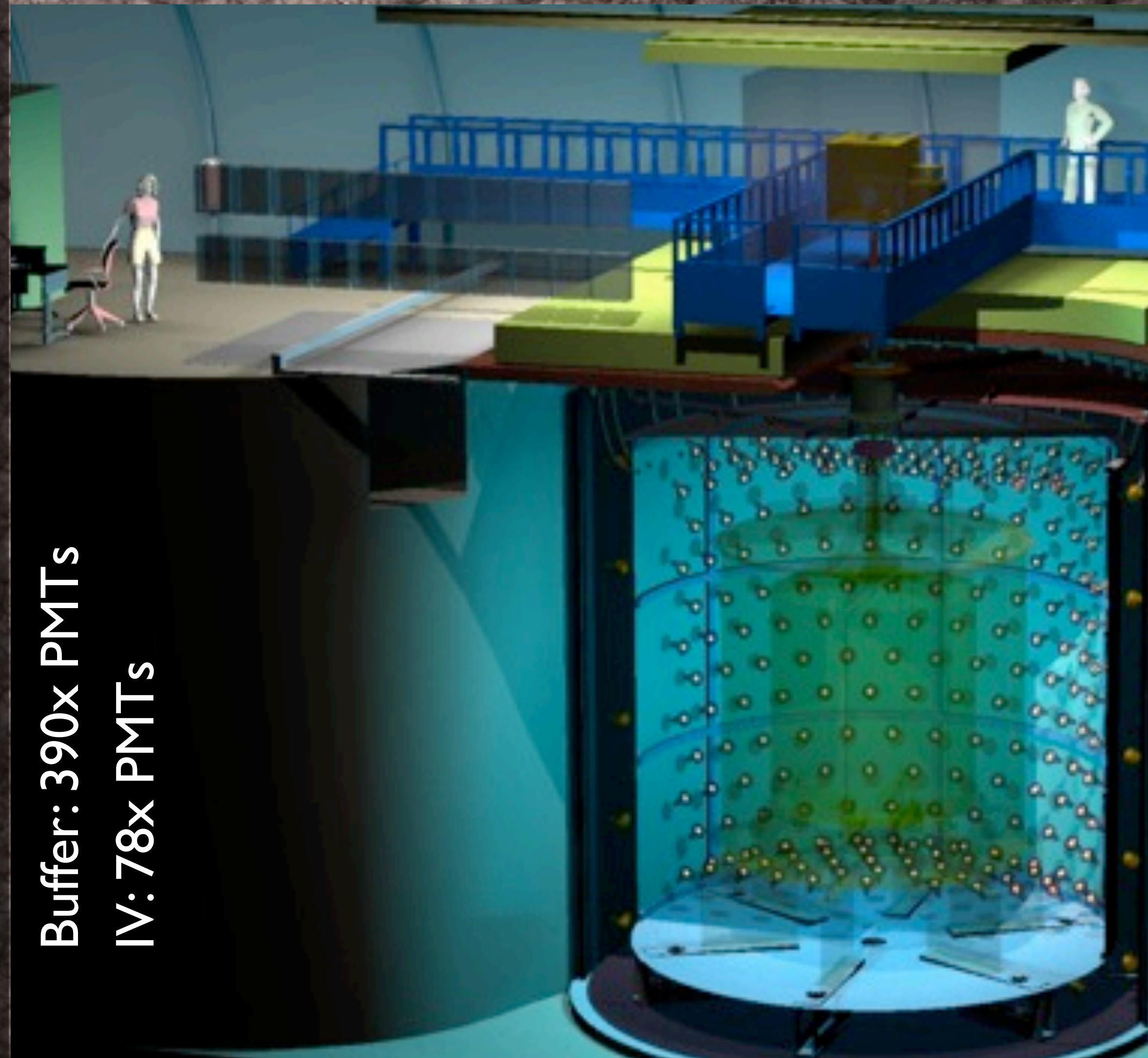
Detector$\Longrightarrow$ θ_{13}-LAND

a θ_{13}-LAND...

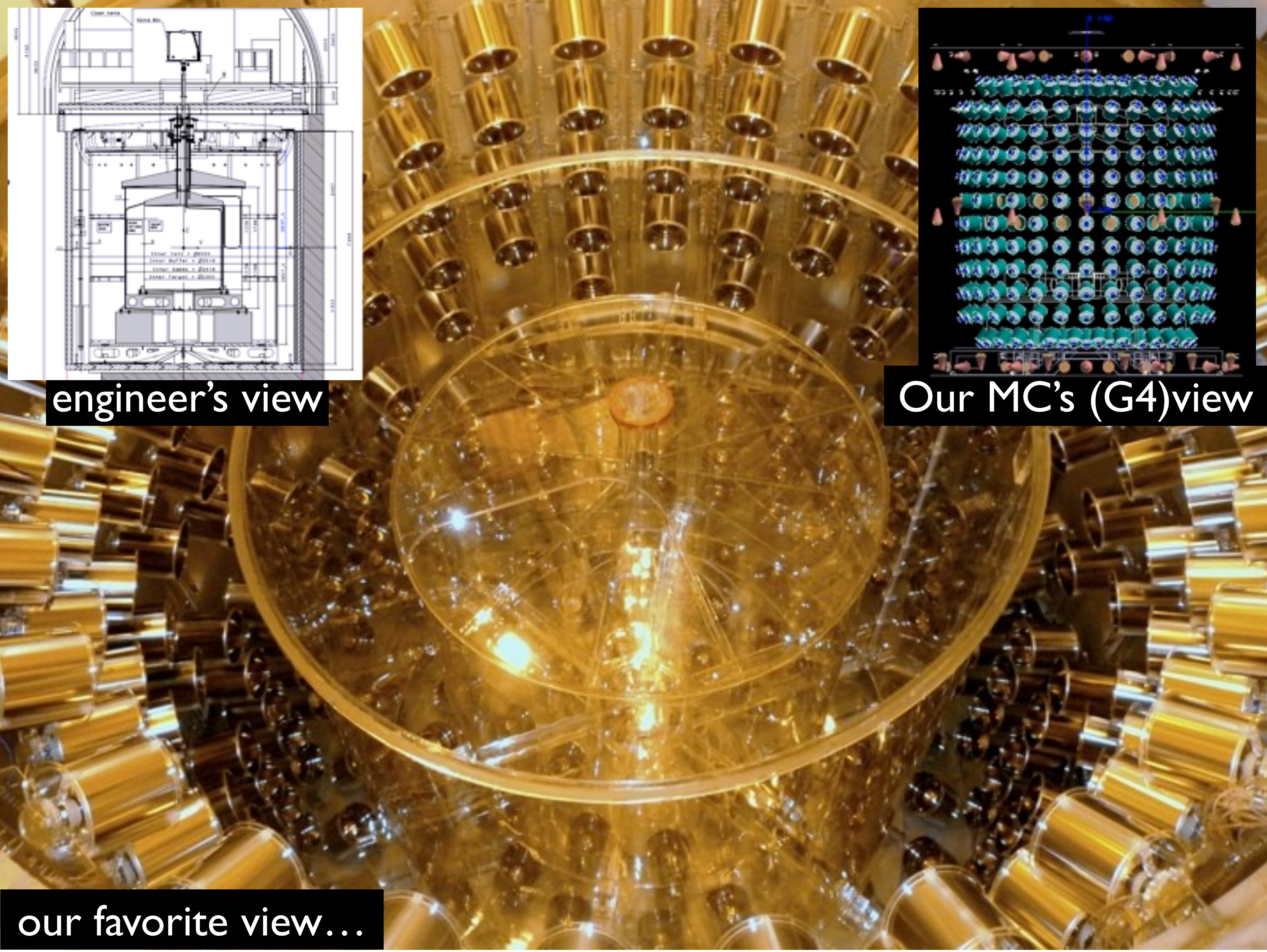
- **Pit**: 7mx7m (FD: CHOOZ lab) ⟹ max. fiducial volume cylinder
- **Inner-Detector**
  - **Target**: acrylics + scint & 0.1%Gd ⟹ n-Gd interaction region
  - **γ-Catcher**: acrylics + scint ⟹ extra calorimetry containment
  - **Buffer**: oil (no scint.)⟹ isolation
- **Inner-Veto**: scint* ⟹ tagged μs and fast-n
- **Outer-Veto**: scint-strips (a la MINOS) ⟹ tagged near-by μs
- **γ-Shield**: 15cm steel ⟹ reduce rock-γs (singles)
- **Glove-Box** ⟹ calibration apparatus contamination-less

θ_{13}-LAND must...

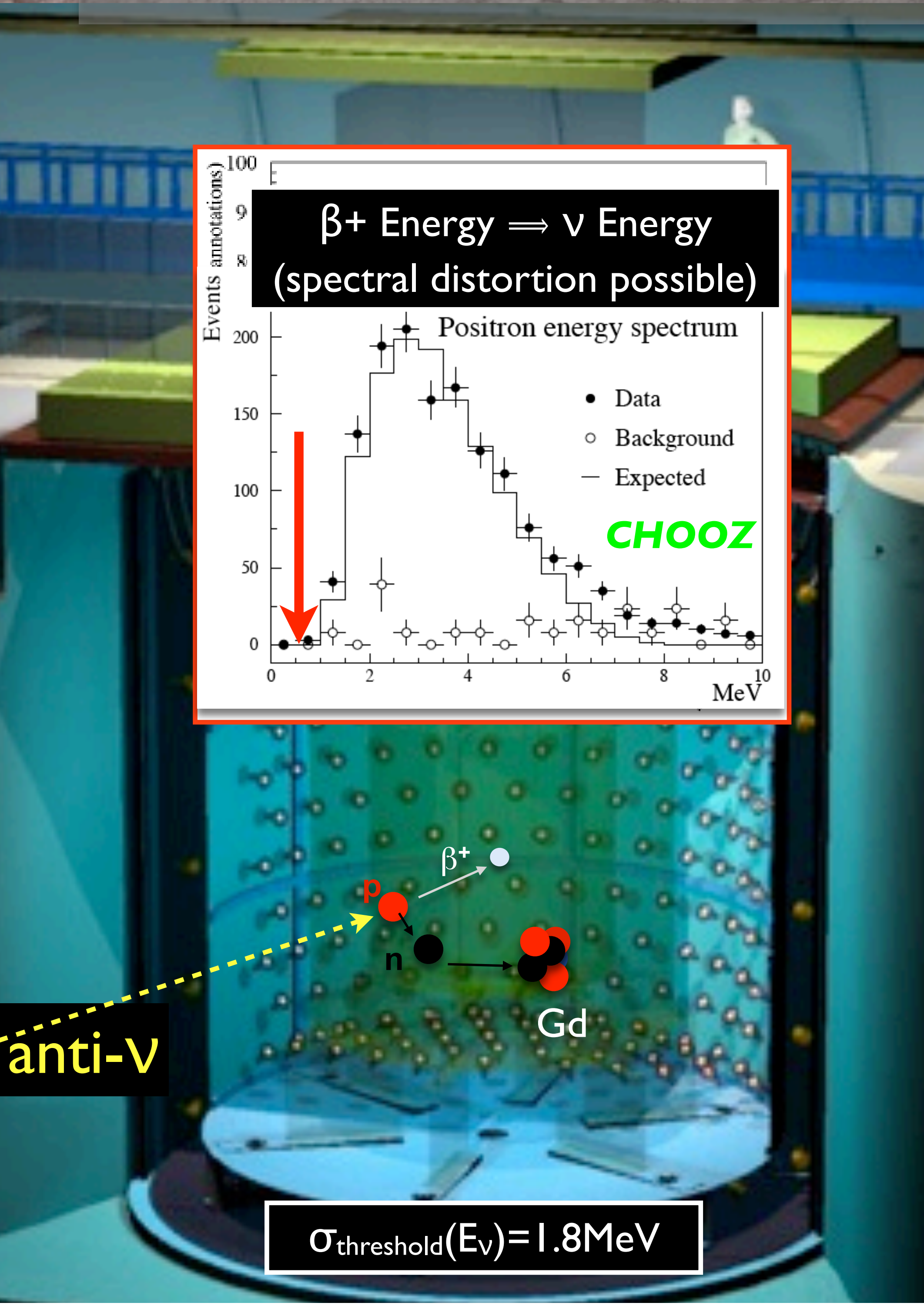
- inter-detector comparison systematic <1%
- radio-purity & material compatibility



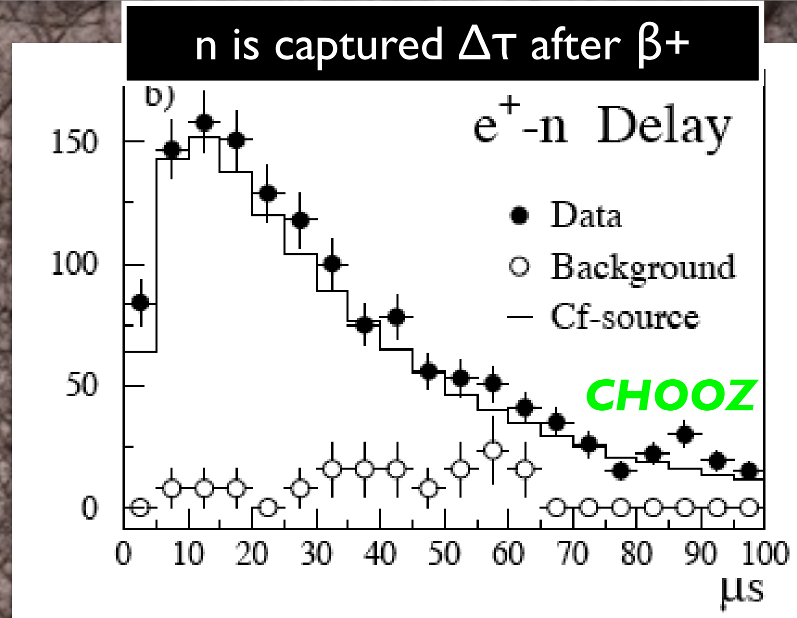
scint*⟹ LAB
scint ⟹ Dodecane(80%)+PXE(20%)+PPO+Bis-MSB


engineer's view
Our MC's (G4)view
our favorite view…

inverse-β reaction

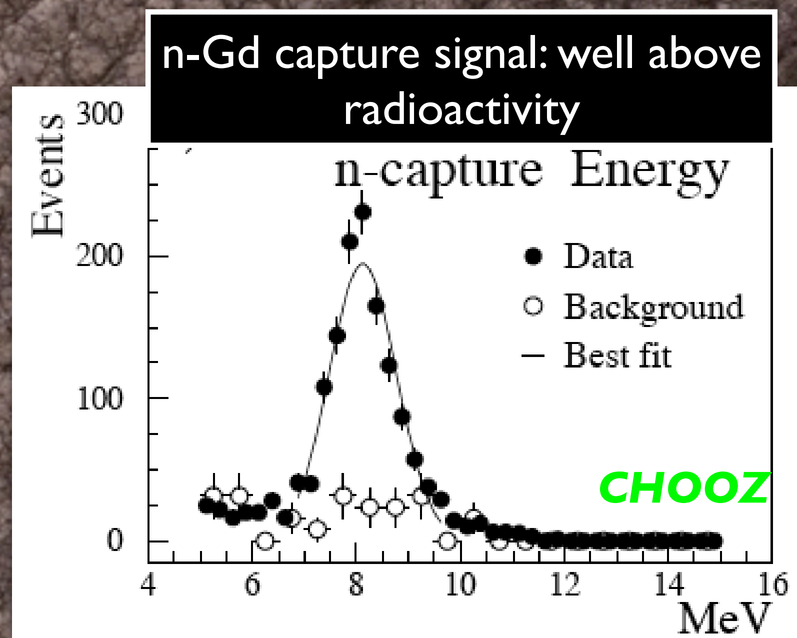


n is captured Δτ after β+



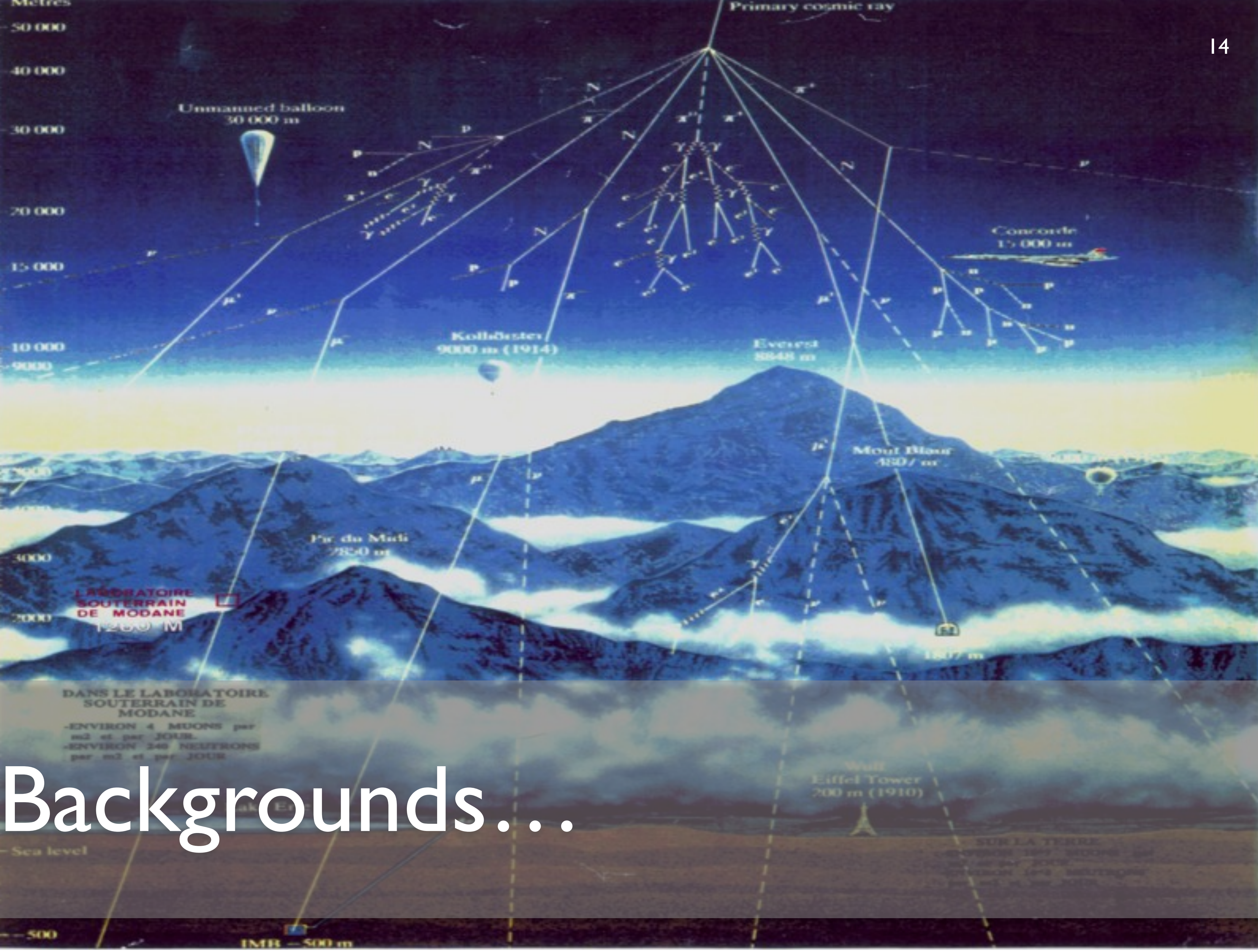
Coincidence Δτ depends on Gd concentration
⟹ excellent BG rejection mechanism

n-Gd capture signal: well above radioactivity



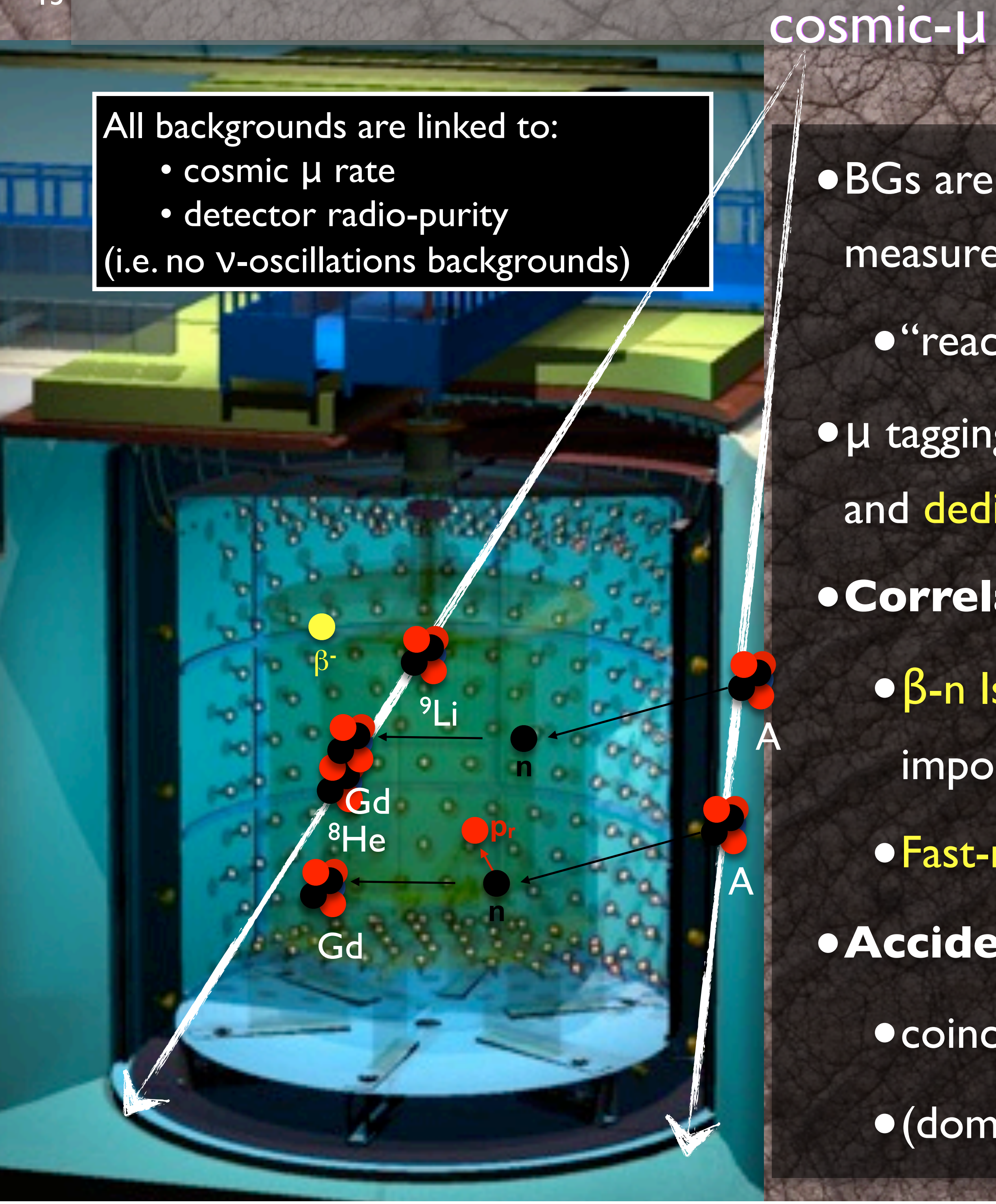
Apollonio et al (CHOOZ) hep-ex/0301017

2P3 & APC)



Backgrounds…

backgrounds…



- BGs are reduced⟹ detector design & measurements in situ
  - "reactor-off" measurements by CHOOZ
- μ tagging & detection⟹ IV, OV detectors and dedicated electronics
- **Correlated BGs** (<2/day & <10/day)
  - β-n Isotopes (half-life time ~100ms)⟹ impossible to veto (time/location)
  - Fast-neutron: recoil + Gd-capture
- **Accidental BGs** (singles @ ID <10Bq)
  - coincidence: radioactivity + fast-neutrons
  - (dominated) shielding & radio-purity

BG rates

Critical input by CHOOZ experiment (even some spectral info)

FD $\Longrightarrow$ "fast-n"-like & isotopes measured @ CHOOZ ("off")

ND $\Longrightarrow$ CHOOZ measurements extrapolated to shallower site

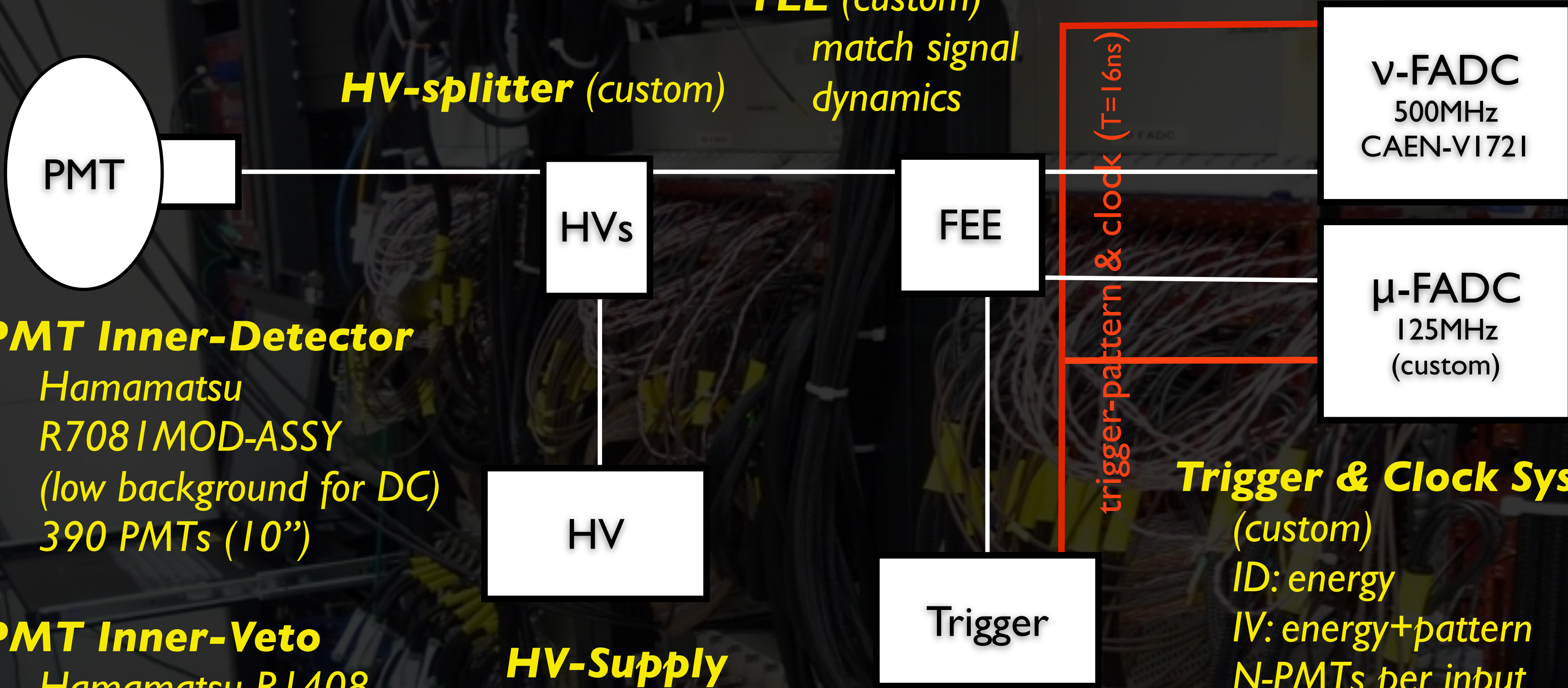
Detector	Site		Background				
			Accidental		Correlated		
			Materials	PMTs	Fast n	μ-Capture	^{9}Li
CHOOZ		Rate (d^{-1})	—	—	—	—	0.6 ± 0.4
(24 ν/d)		Rate (d^{-1})	0.42 ± 0.05		$1.01 \pm 0.04(stat) \pm 0.1(sys)$		
	Far	bkg/ν	1.6%		4%		
		Systematics	0.2%		0.4%		
Double Chooz		Rate (d^{-1})	1 ± 0.1	1 ± 0.1	0.15 ± 0.15	0.42 ± 0.2	1 ± 0.5
(69 ν/d)	Far	bkg/ν	1.4%	1.4%	0.2%	0.6%	1.4%
		Systematics	0.2%	0.2%	0.2%	0.3%	0.7%
Double Chooz		Rate (d^{-1})	7.2 ± 1.0	7.2 ± 1.0	1.4 ± 0.14	2.6 ± 1.2	5.2 ± 3.2
(990 ν/d)	Near	bkg/ν	0.7%	0.7%	0.14%	0.26%	0.6%
		Systematics	0.1%	0.1%	0.2%	0.1%	0.3%

DC Proposal: hep-ex/0606025

readout & online

one channel

Trigger Rate (cosmic-μs @ ND)⟹ <300Hz



VME-Bus
DAQ software in Ada

FEE *(custom)*
match signal dynamics

HV-splitter *(custom)*

PMT Inner-Detector
Hamamatsu
R7081MOD-ASSY
(low background for DC)
390 PMTs (10")

PMT Inner-Veto
Hamamatsu R1408
78 PMTs (8")
(from IMB)

HV-Supply
CAEN-A1535P

Trigger & Clock System
(custom)
ID: energy
IV: energy+pattern
N-PMTs per input

OV readout à la OPERA (Hamamatsu M64 + Maroc2-chip)

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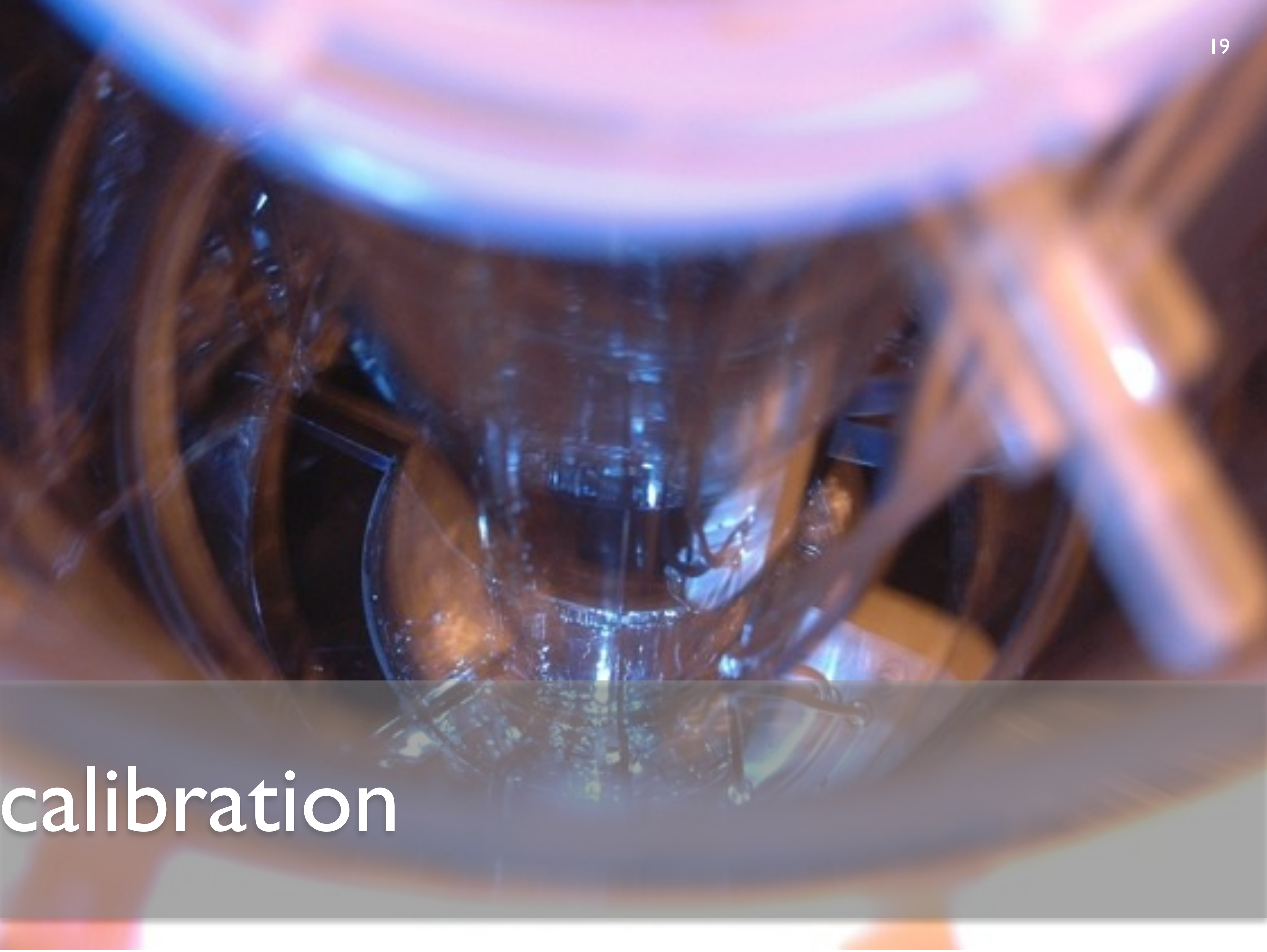

calibration

far detector status…

once upon a time, in a tiny village of France (near Belgium)…

…2 of the most powerful reactors in the world got built$\Longrightarrow$ **<u>Chooz</u>**

FD underground lab access: 300m walk @ a small angle

Lab cleaning

Installation Veto and Veto-PMTs

Installation Buffertank

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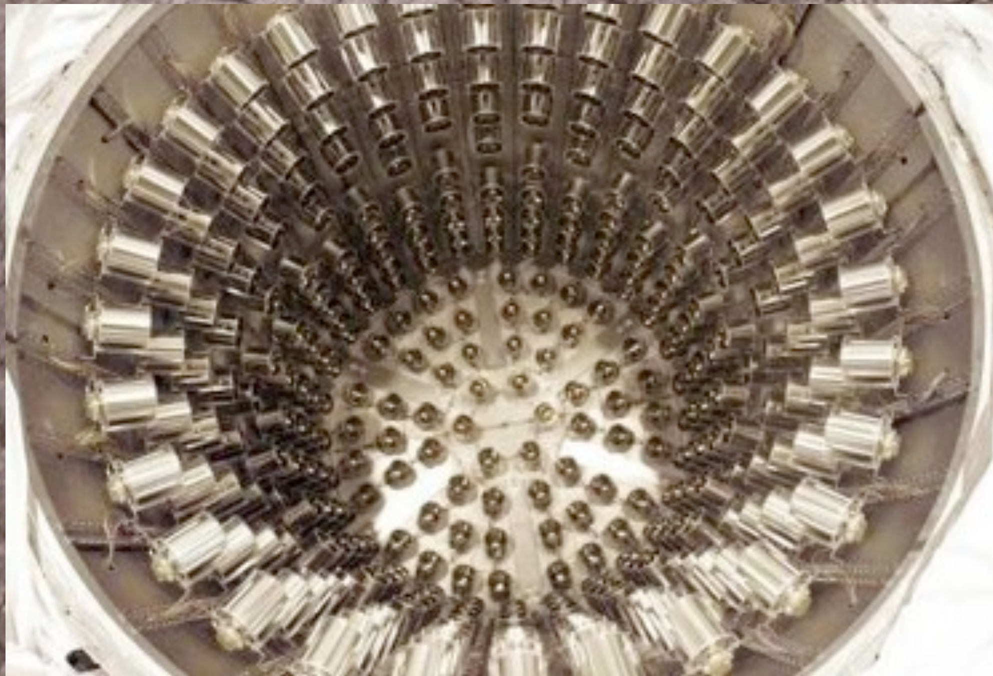


PMT installation

Gamma Catcher installation

All vessels in detector

Liquid transport to Chooz

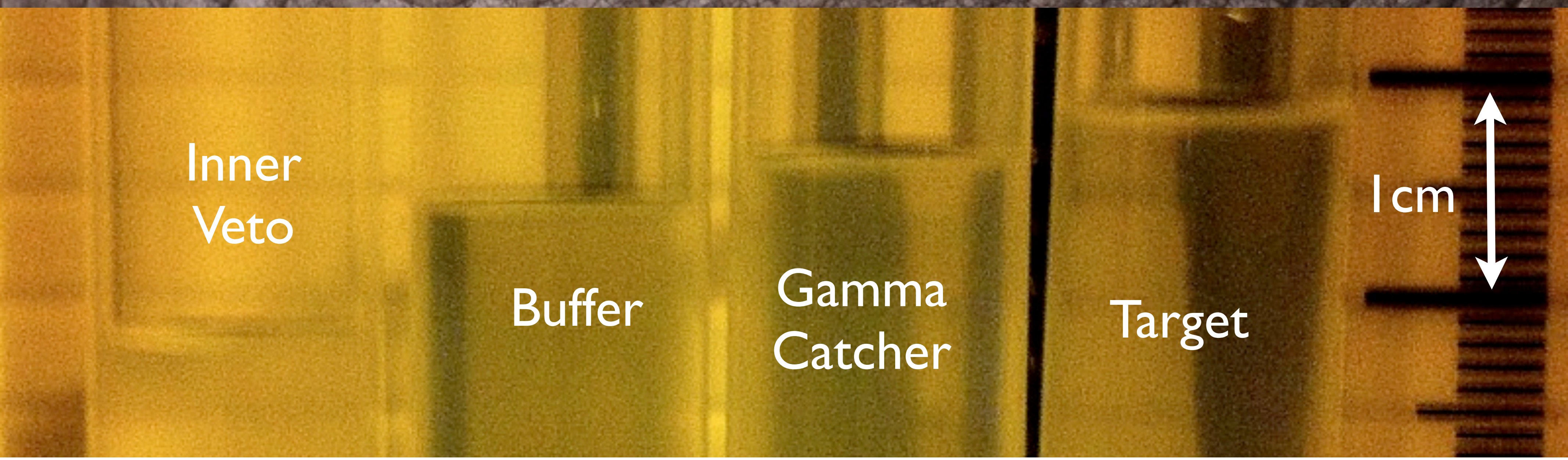
our ν detector (in fact: 2 detectors)

Inner-Detector⟹ PMT installation

Inner-Veto Detector (scintillator)⟹ tag μs & possibly fast-neutrons

filling: a very delicate/precise operation

- **gas systems**: flushing, blanket and vents
- **liquid systems**: 4 operating modules (one per volume), safety features and online monitoring
- **very precise operation**:
  - pressure control (differences within ~0.1mbar)
  - liquid level control (difference within ~1cm)
  - density control (differences within ~1g/l)
  - temperature corrections



- **commissioning “mechanical detector”**: **done**
    - **detector filled** (end of 2010)
    - **top-shield installed** (end of 2010)
- **commissioning “instrumental detector”**: **imminent**
- **next**: outer-veto & glove-box (for deployment) installation

instrumental commissioning...

- **necessary conditions**:
    - filling $\Longrightarrow$ light-level, physics, etc...
    - shielding $\Longrightarrow$ event rate and energy spectrum
- "**instrumental commissioning**" (mid-Jan-now:)
    - **superb performance & high quality data**
    - study response of the detector
    - tune readout response (all PMTs & channels working)
    - tune trigger response (thresholds, etc)
    - optimise DAQ to detector response/rates
- **start of neutrino-physics run**?$\Longrightarrow$ **O(days!)**

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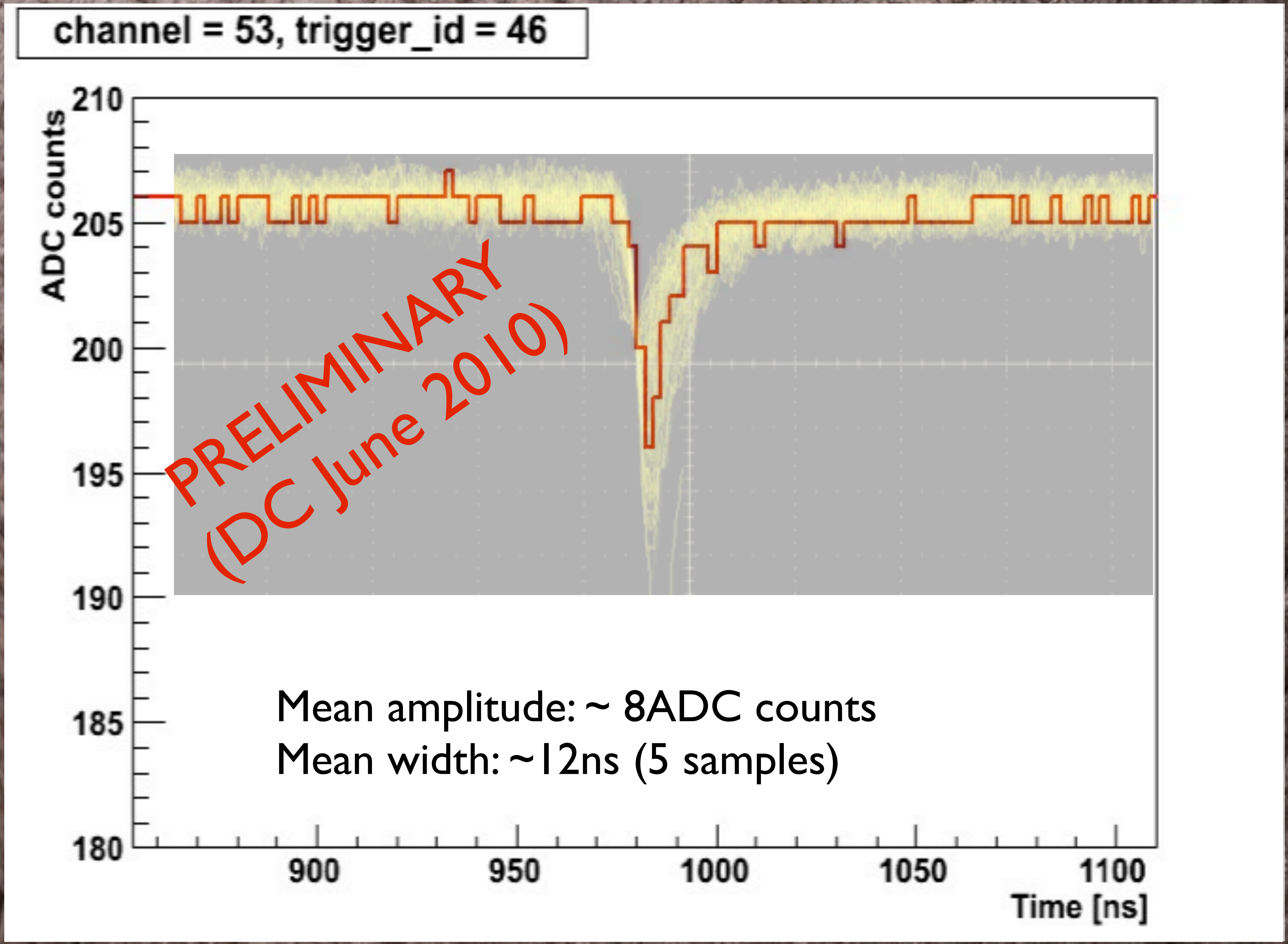
the first single-PEs detected @ FD…



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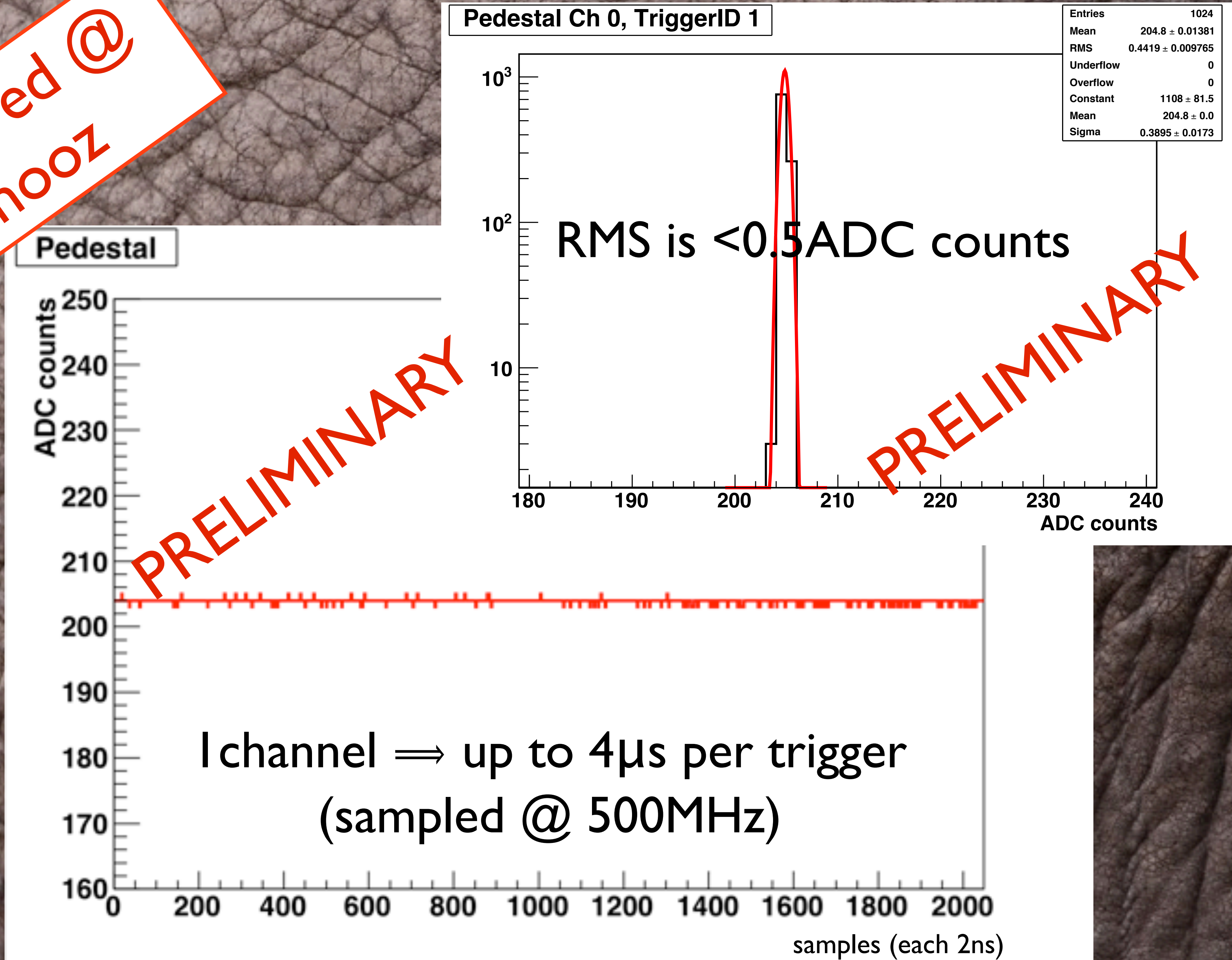
checking electronics noise with FADC…

Measured @ Chooz

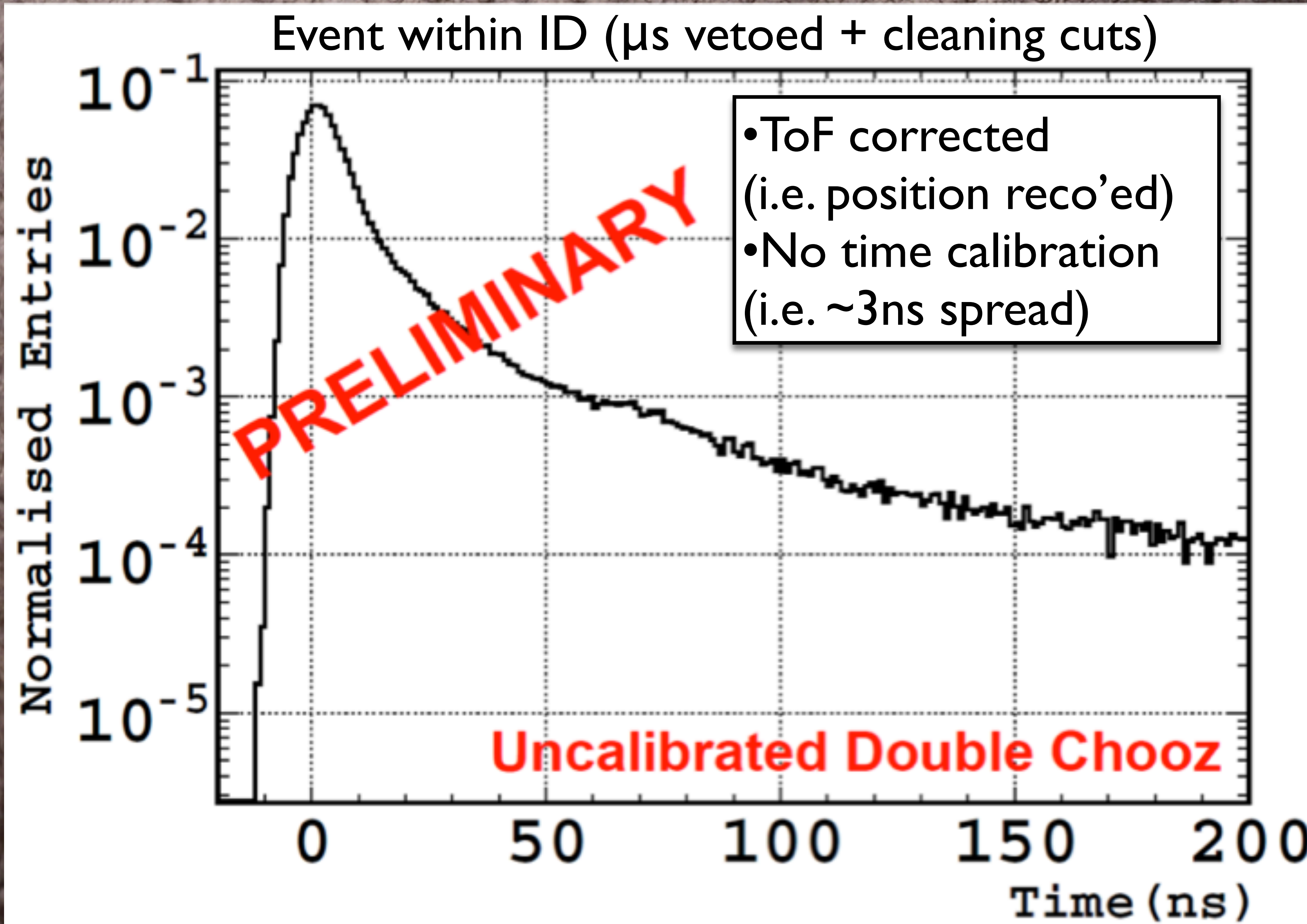


RMS is <0.5ADC counts

1channel $\Longrightarrow$ up to 4μs per trigger (sampled @ 500MHz)

samples (each 2ns)

inner-detector time response…



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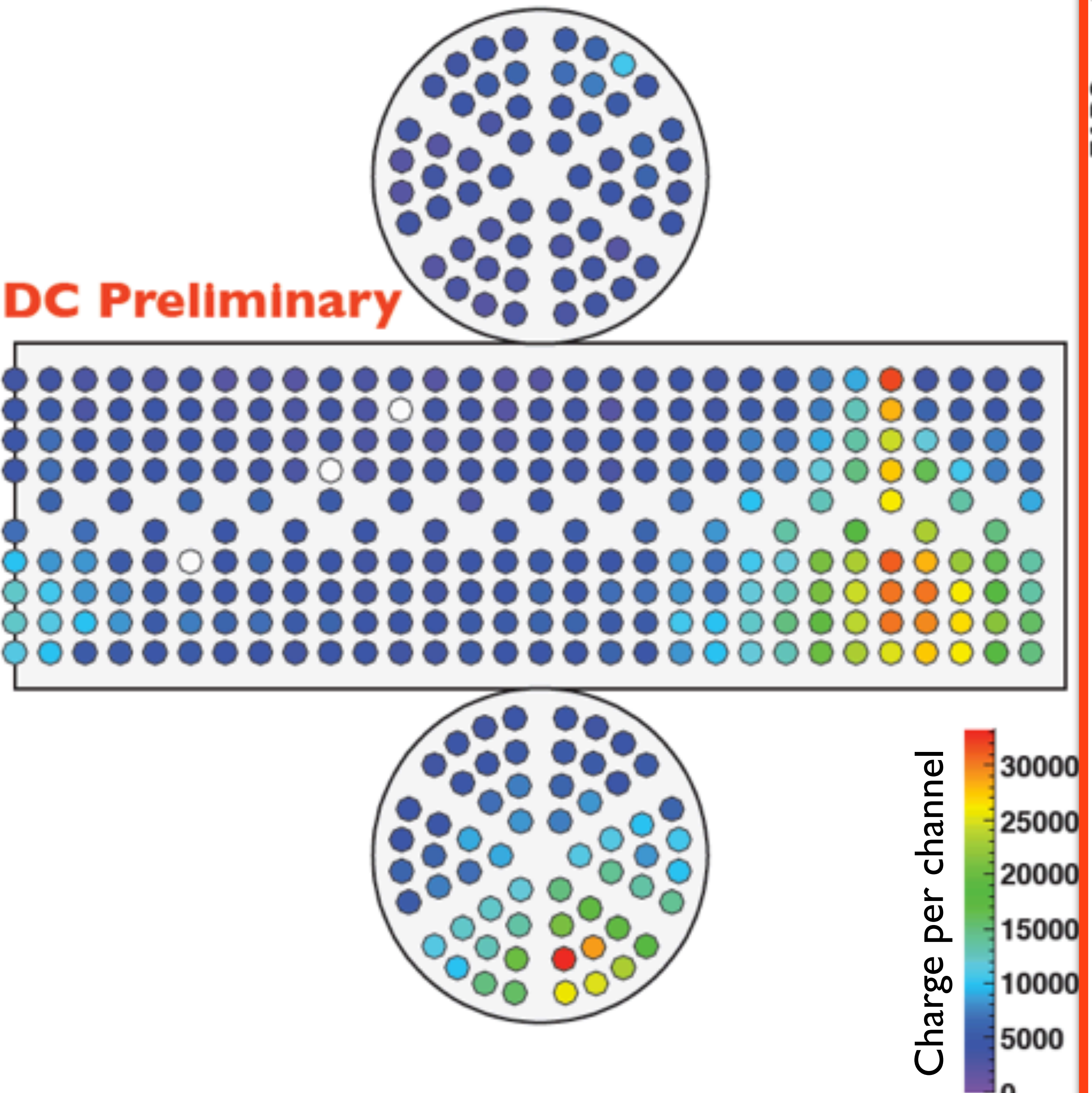
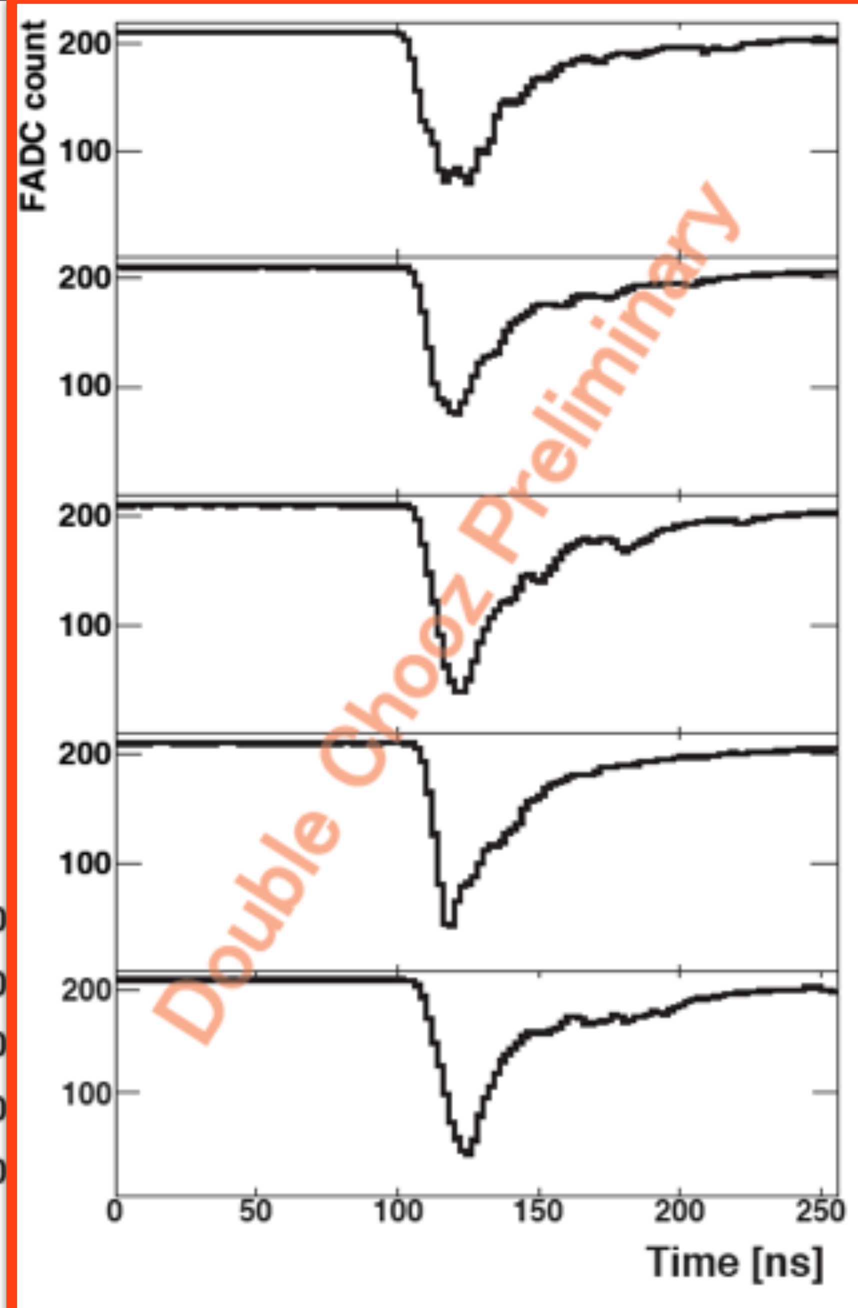
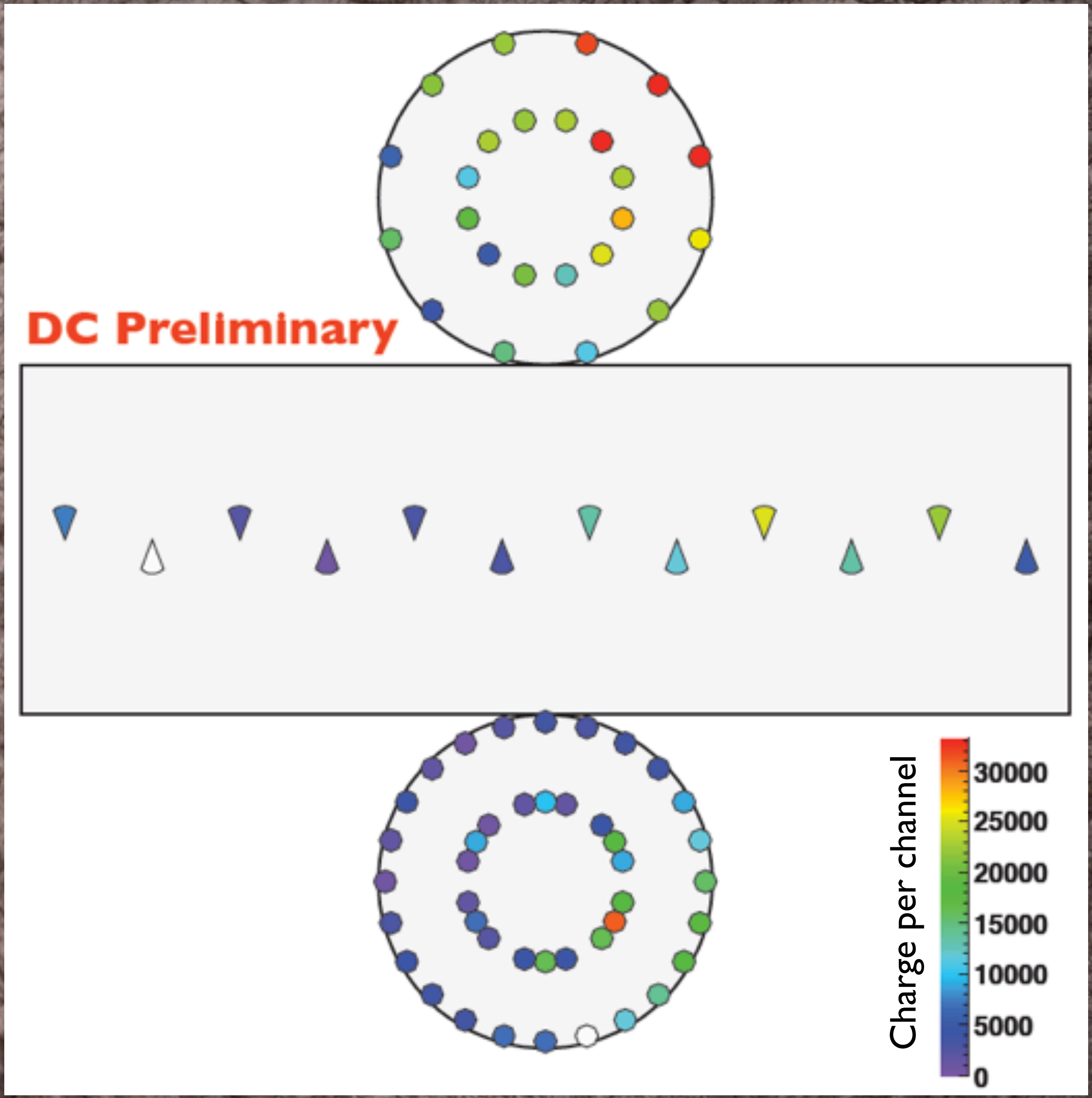
muon event (inner-detector)...



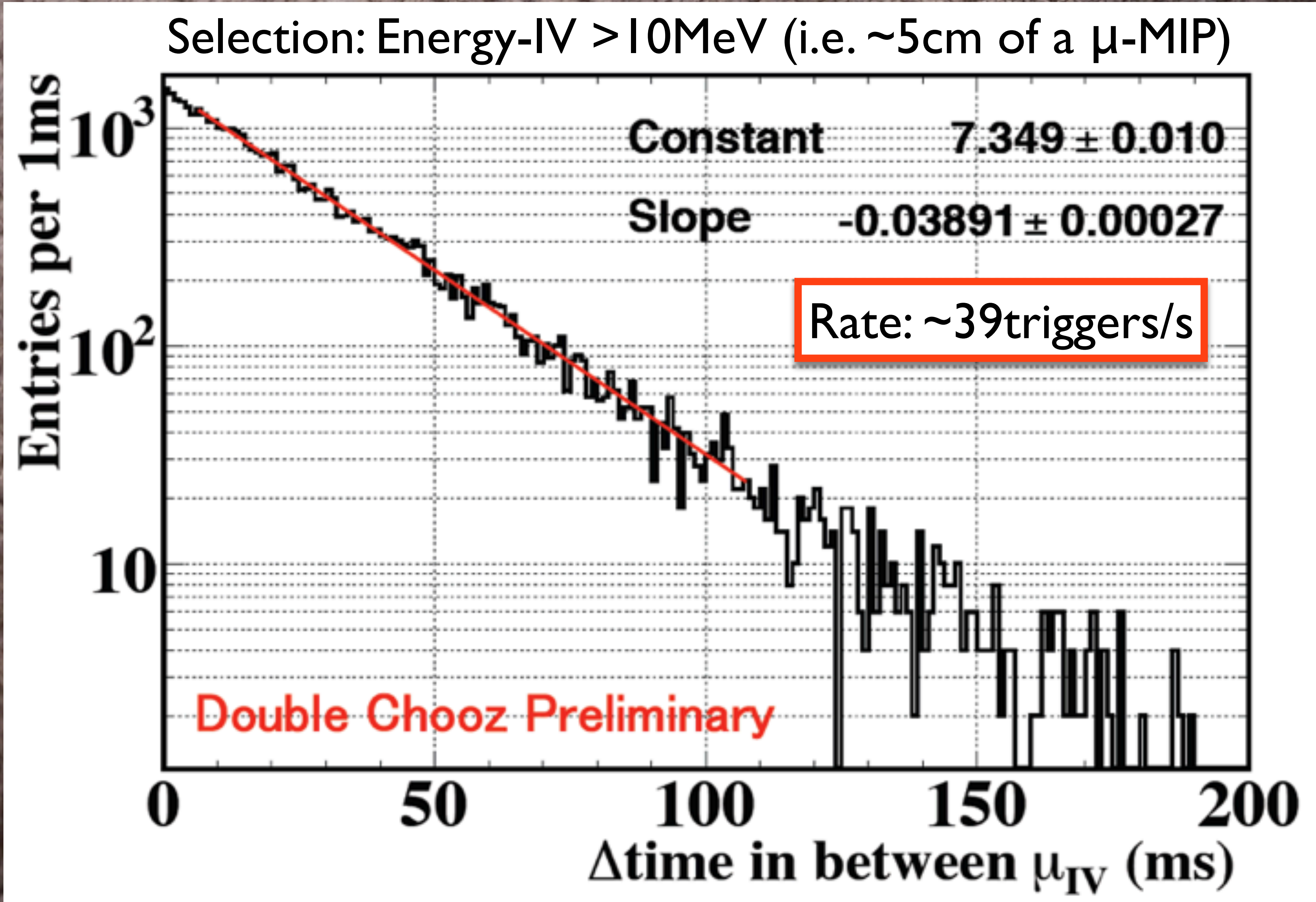


muon event (inner-veto detector)...



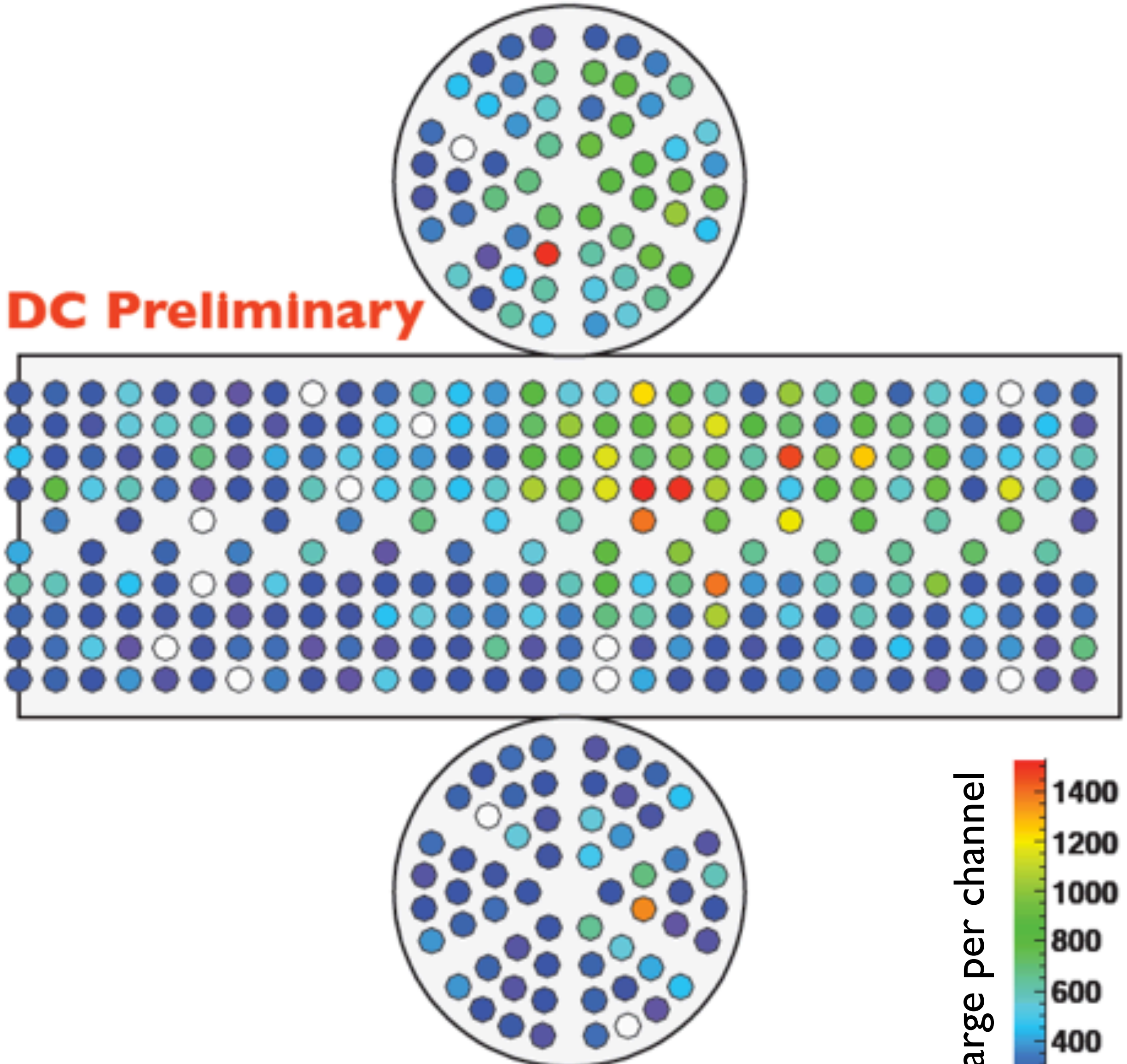
Anatael Cabrera (CNRS-IN2P3 & APC)

time between "μ-like" (inner-veto detector)

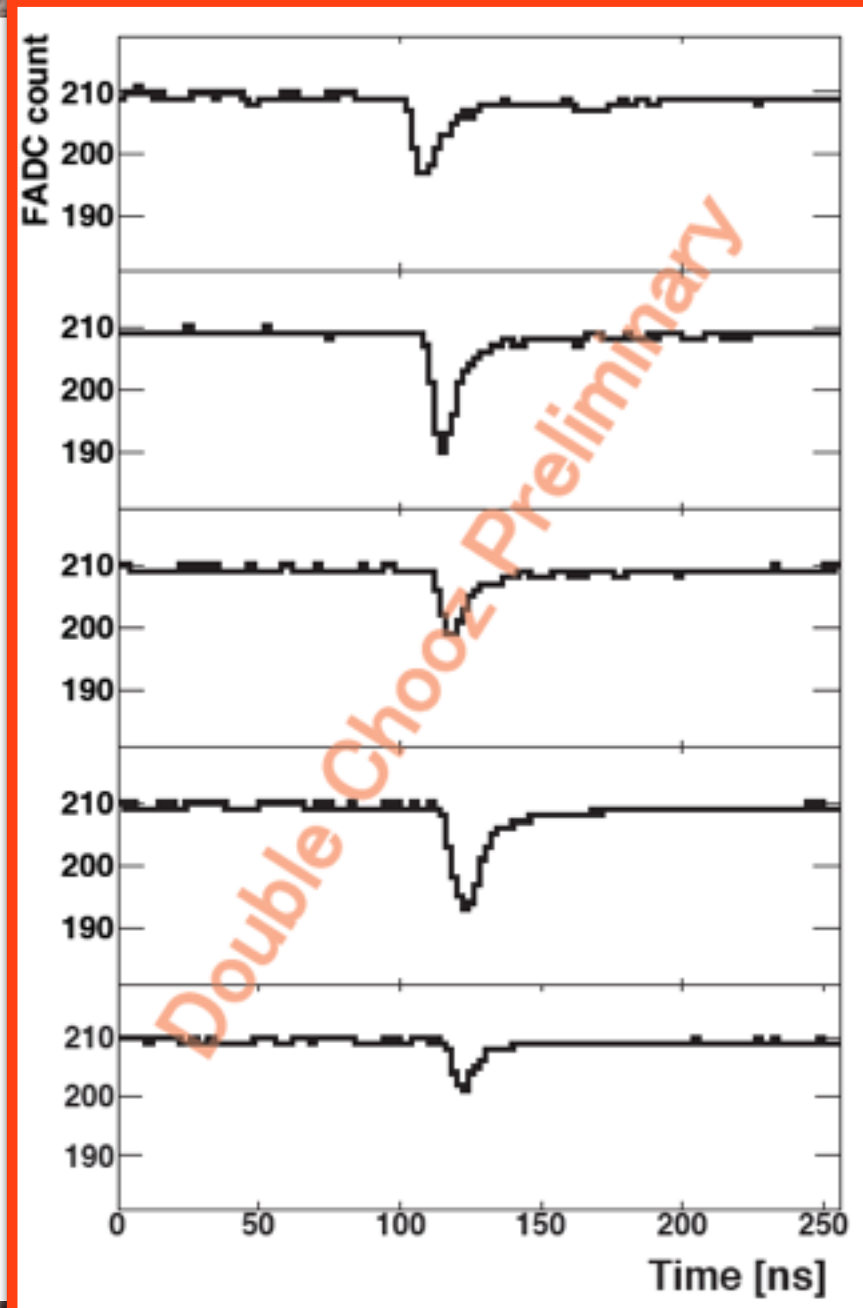


Anatael Cabrera (CNRS-IN2P3 & APC)

contained event...



Estimated Energy ~8MeV



Anatael Cabrera (CNRS-IN2P3 & APC)

what to remember…?

- **Double Chooz Status…**
  - FD construction ⟹ done
  - FD first lights ⟹ done (since June "dry" detector)
  - FD filling ⟹ since (since end of 2010)
  - FD commissioning ⟹ imminent (a matter of days)
  - FD measurement of θ_{13} ⟹ **very soon!!**
  - ND laboratory ⟹ starts digging April 2011 (till April 2012)
  - ND detector ⟹ towards the end of 2012
- DC can reach CHOOZ's worth of **signal** data in ~2 months
  - **$\sin^2(2\theta_{13}) \leq 0.054$ @ 90%CL** with FD only (about 1.5years of data)
  - **$\sin^2(2\theta_{13}) \leq 0.030$ @ 90%CL** with FD & ND (about 3years of data)

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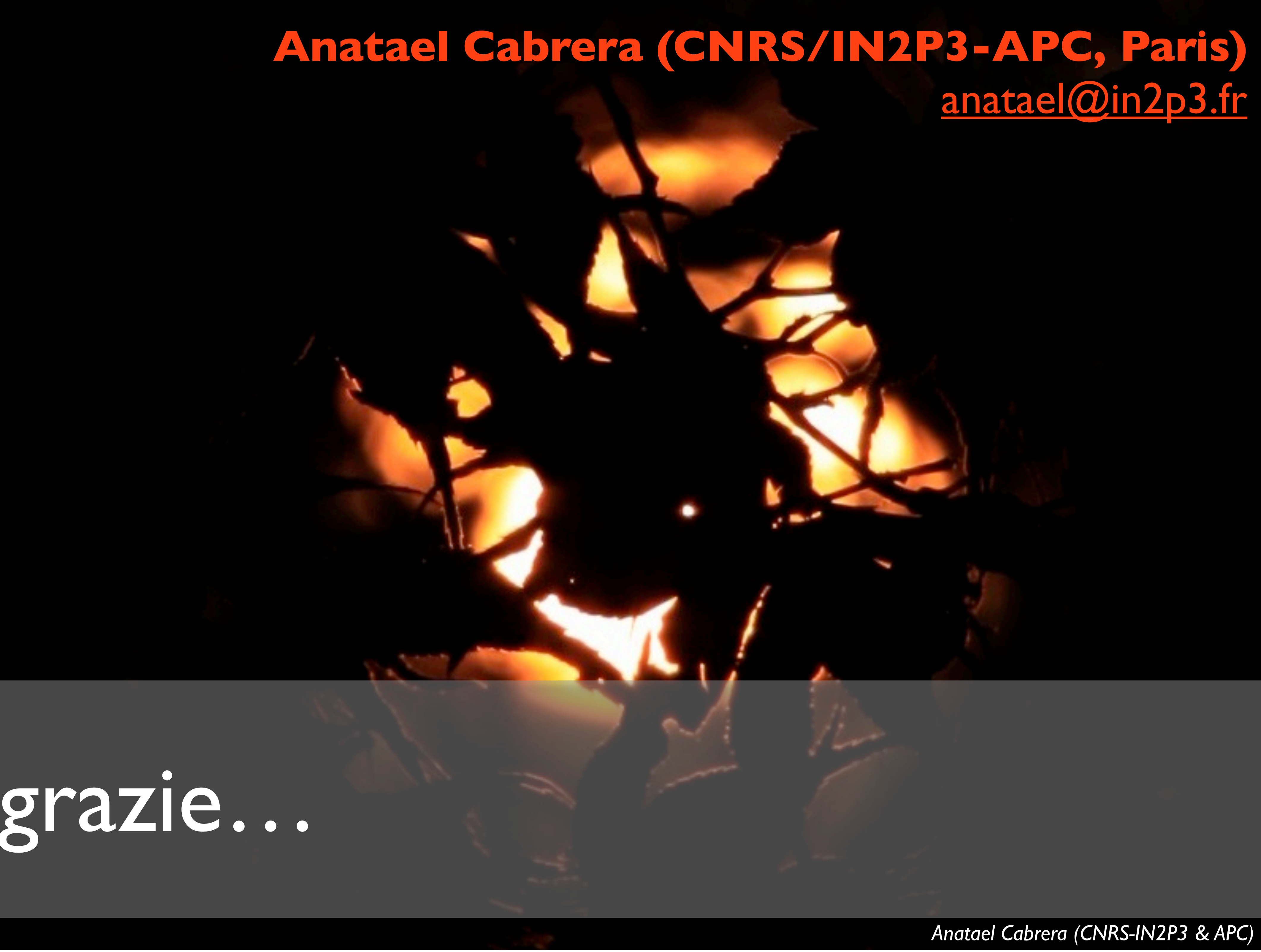
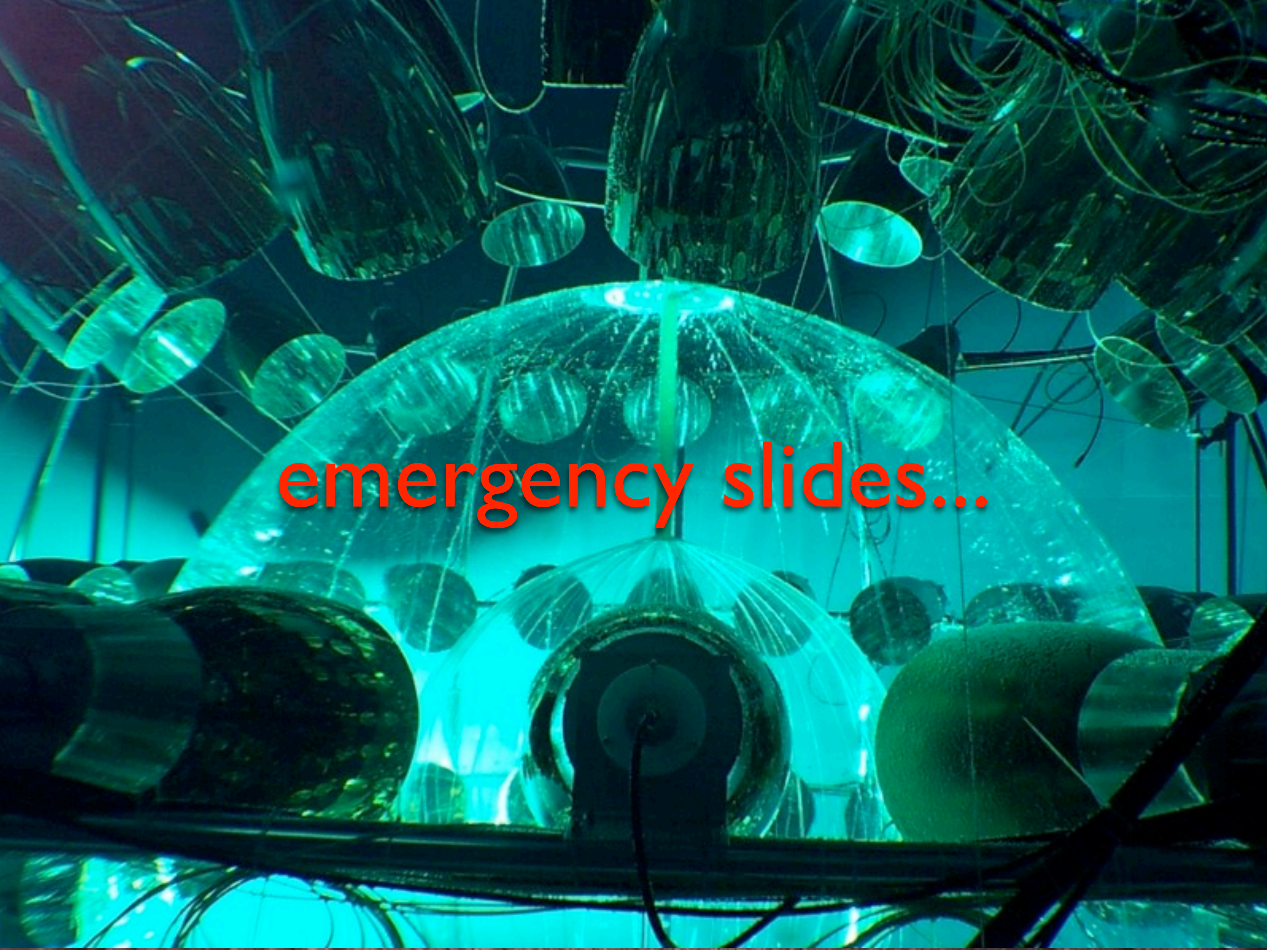
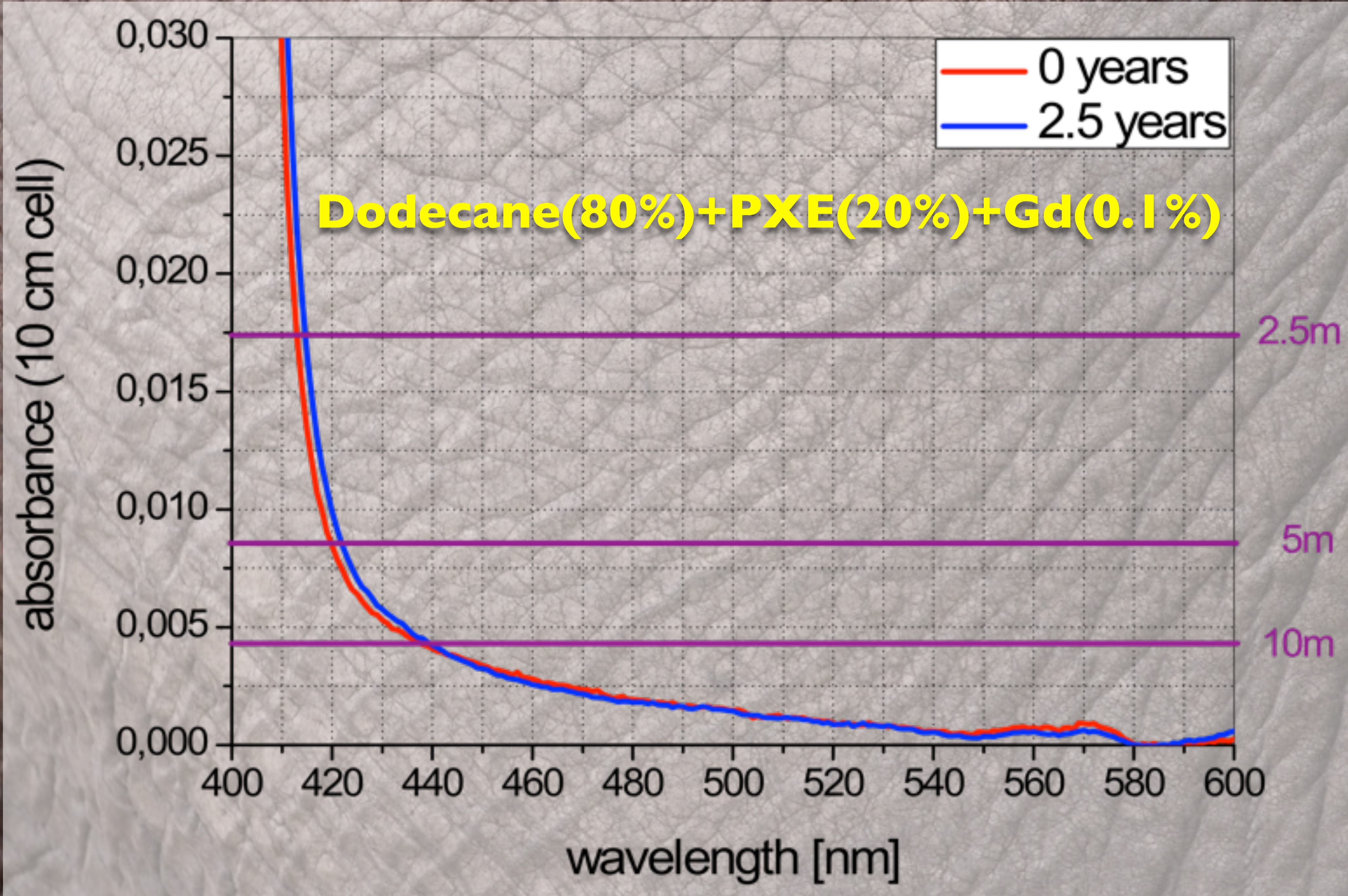


grazie…


emergency slides...

Gd loaded scintillator⟹ stable & transparent!



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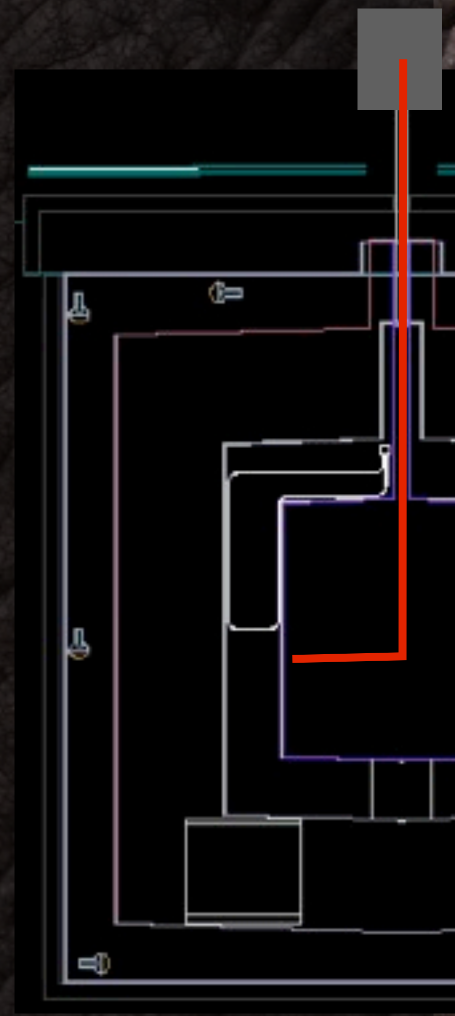
calibration…

- **Redundancy** ⟹ cross-check & understand inter-detector systematics
- light sources (embedded, i.e. non-intrusive): LEDs in ID and IV
  - monitor stability of readout (timing, gain) and scintillator
- light sources (deployed): LED, red-laser & UV-laser
  - PM gain, timing, scintillator stability & attenuation
- radioactive source: across most energy scale
  - Cs^{137}, Ge^{68}, Co^{60} and natural sources (H-capture, michel-e+)
- n-sources: n capture on Gd (study efficiencies)
  - Cf^{252}(untagged) & AmBe (light tagged)⟹ 3D deployable
- 3D calibration strategy: map out detector response & efficiencies
  - along z-axis, articulated arm (off z-axis), GC & Buffer tubes
- 2 detectors⟹ calibration source absolute knowledge less important
  - same source response comparison ND and FD (cancel some systematics)



Anatael Cabrera (CNRS-IN2P3 & APC)

systematics breakdown

Error Source	Error Type	Error Description	CHOOZ Absolute	DC Absolute	DC Relative
		Reactor			
		Production Cross Section	1.90%	1.90%	
Reactor		Core Powers	0.70%	0.70%	
		Energy per Fission	0.60%	0.60%	
		Solid Angle/Bary. Displct.			0.20%
		Detector			
		Detection Cross Section	0.30%	0.10%	
Detector	Free H in TG	Volume	0.30%	0.20%	0.20%
		Fiducial Volume	0.20%	0.20%	
		Density		0.10%	0.01%
		H/C (Chemical Composition)	0.80%	0.80%	0.10%
	Electronics	Dead Time	0.25%		0.00%
Analysis		**Analysis**			
	Particle Id				
	Positron	Escape	0.10%		
		Capture	0.00%		
		Identification Cut	0.80%	0.10%	0.10%
	Neutron	Escape	1.00%		
		Capture (% Gd)	0.85%	0.30%	0.30%
		Identification Cut	0.40%	0.10%	0.10%
	Anti-neutrino	Time Cut	0.40%	0.10%	0.10%
		Distance Cut	0.30%		
		Unicity (neutron multiplicity)	0.50%		
		Efficiency uncert due to bkg			
Total			2.90%	2.31%	0.46%

Upgraded to expected ND location

N2P3 & APC)