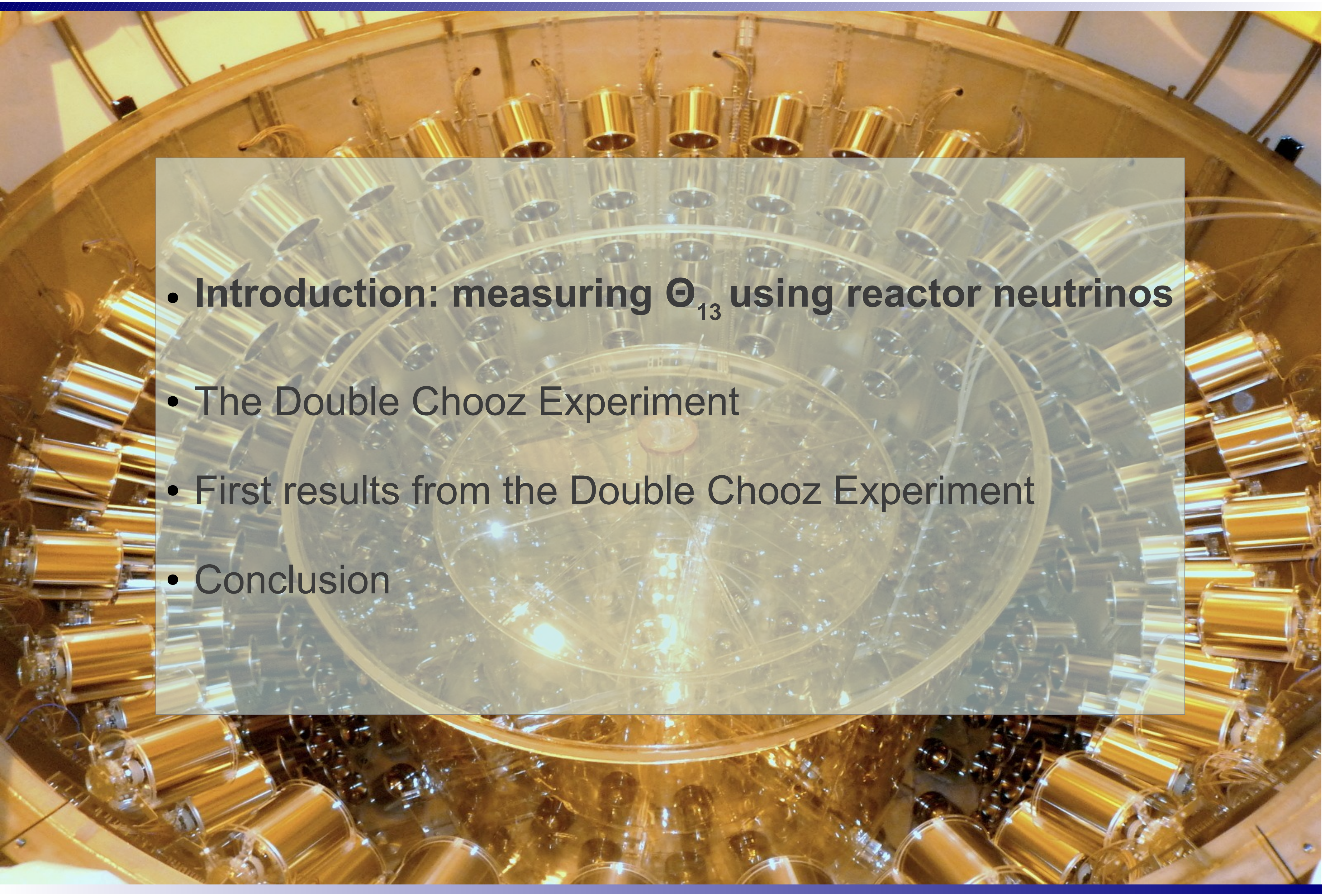
First Results from the Double Chooz Experiment

Sebastian Lucht (RWTH Aachen)
on behalf of the Double Chooz Collaboration

νTURN 2012
Laboratori Nazionali del Gran Sasso, 08-May-2012

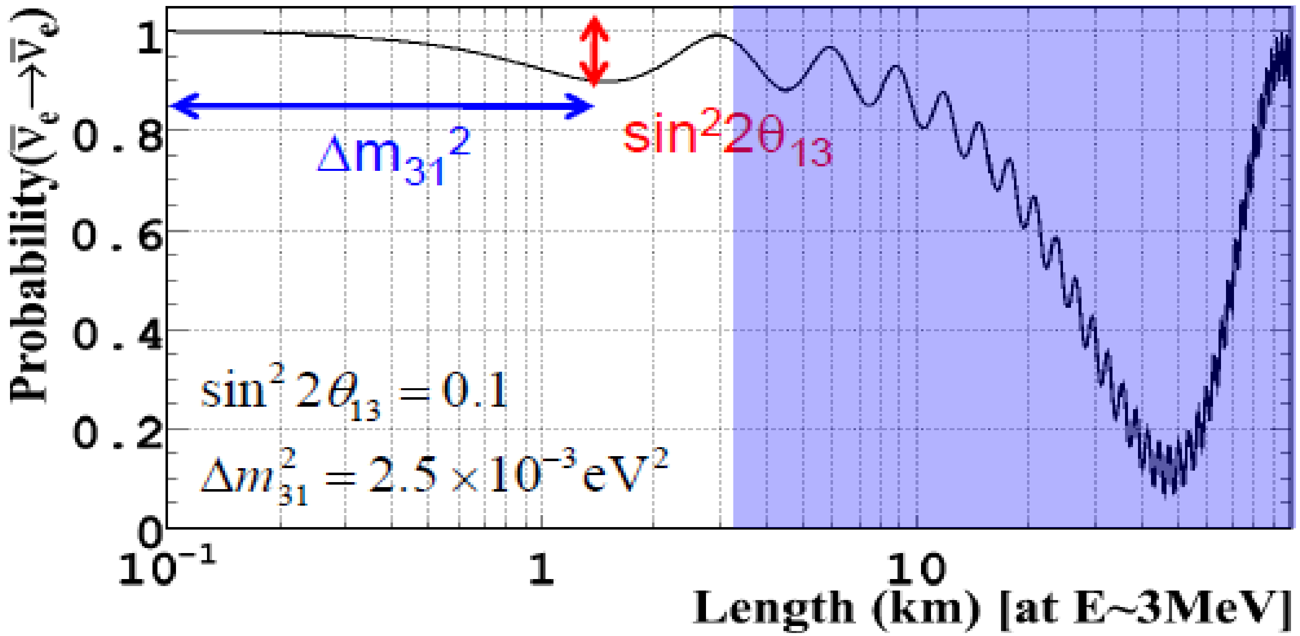
outline



- **Introduction: measuring Θ_{13} using reactor neutrinos**
- The Double Chooz Experiment
- First results from the Double Chooz Experiment
- Conclusion

measuring Θ_{13} using reactor neutrinos

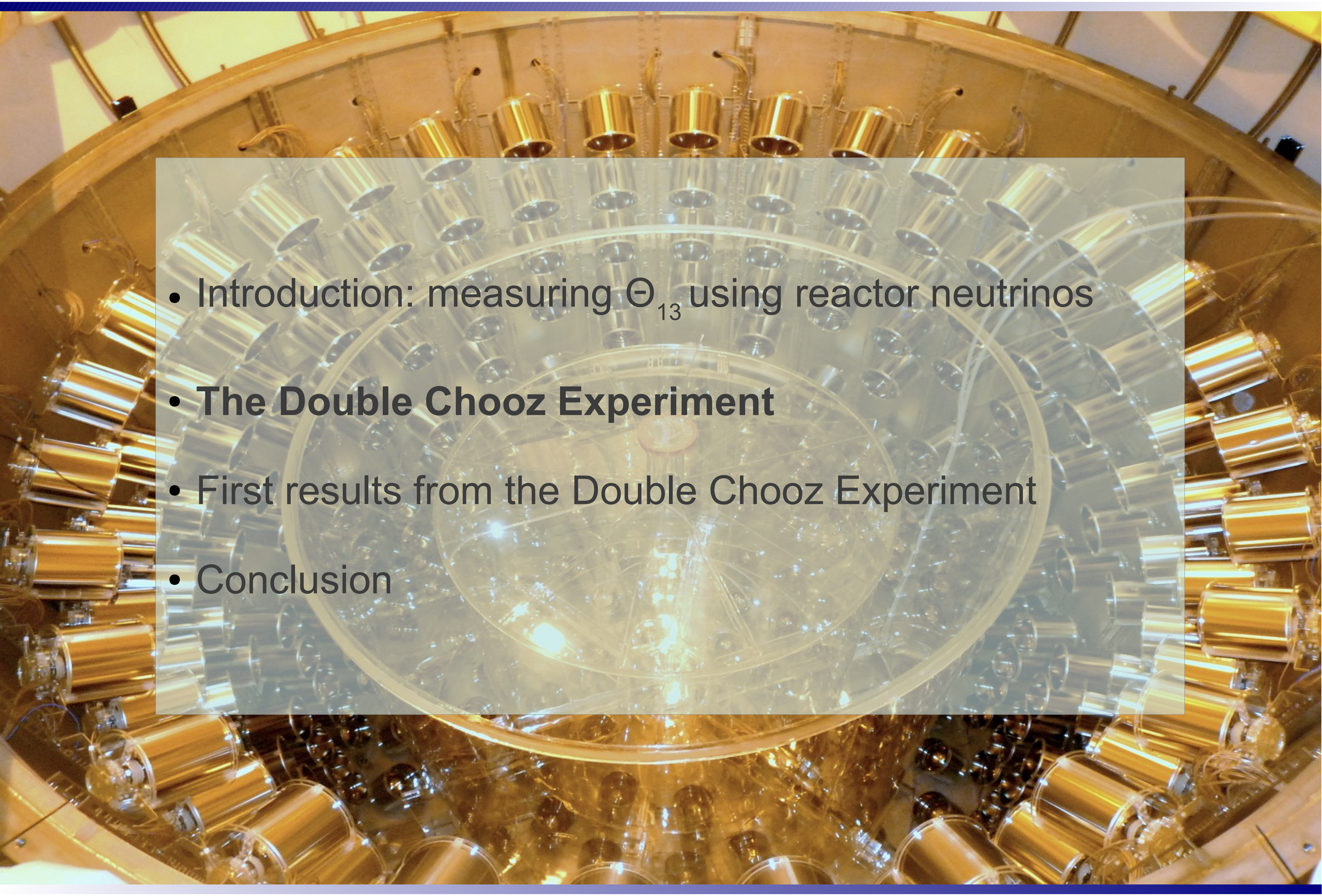
$$P\left[\overline{\nu_e} \to \overline{\nu_e}\right] \cong 1 - \boxed{\sin^2 2\theta_{13}} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) + O(10^{-3})$$



- Double Chooz is a so called disappearance experiment
  - Simple oscillation formula valid at small distances (L)
- $P(\overline{\nu}_e \to \overline{\nu}_e)$ is function of $\Delta m_{31}{}^2$ (well known) and $\sin^2 2\theta_{13}$ (goal)
  - Independent of δ_{CP}
  - Negligible matter effects

Clean and direct measurement of θ_{13}

outline



- Introduction: measuring Θ_{13} using reactor neutrinos
- **The Double Chooz Experiment**
- First results from the Double Chooz Experiment
- Conclusion

Double Chooz collaboration

Brazil
CBPF
UNICAMP
UFABC

France
APC
CEA/DSM/IRFU:
- SPP
- SPhN
- SEDI
- SIS
- SENAC

CNRS/IN2P3:
- Subatech
- IPHC

ULB/VUB

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

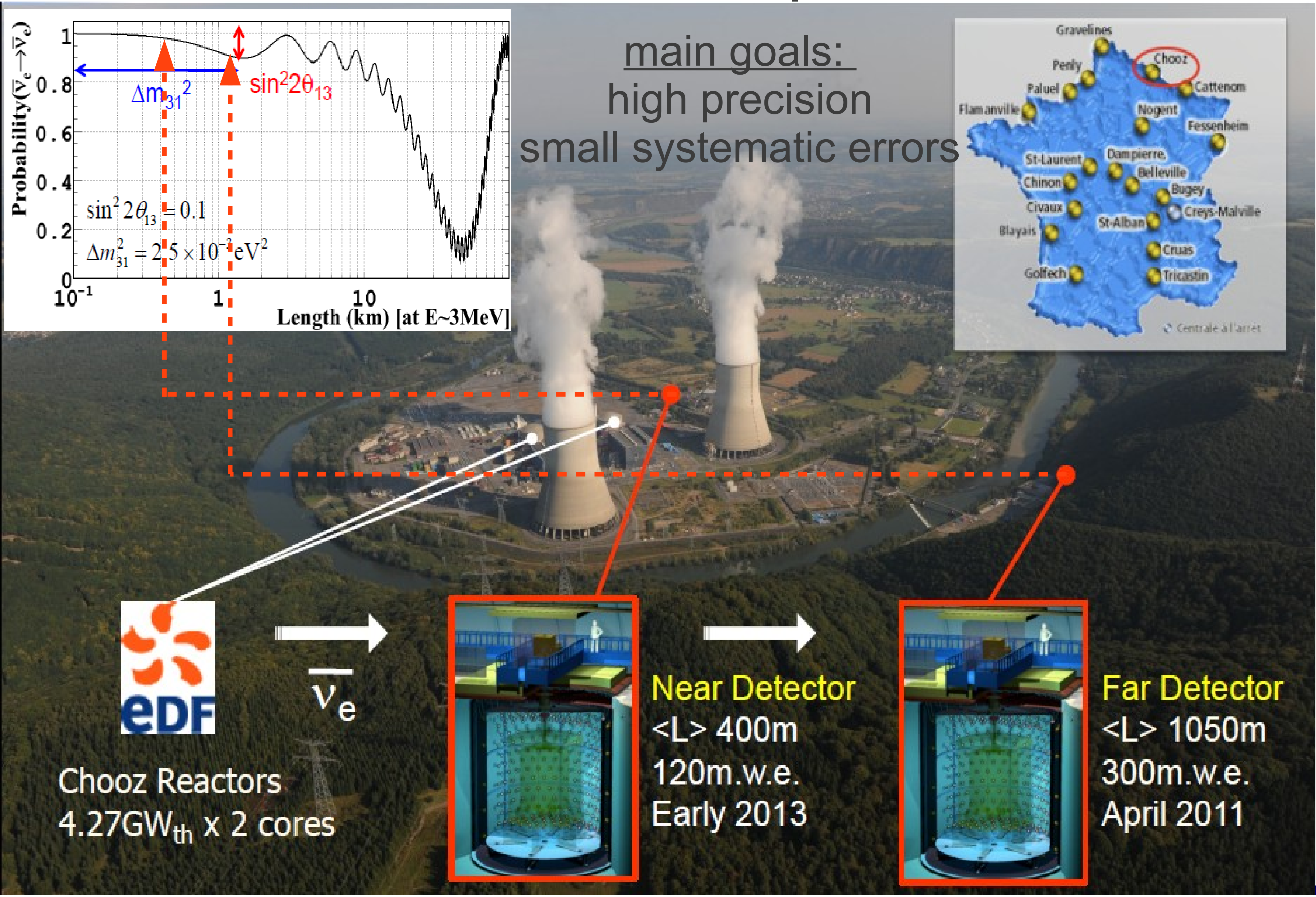
UK
Sussex

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

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

Web Site: www.doublechooz.org/

the Double Chooz experiment



$\bar{\nu}_e$ detection principle

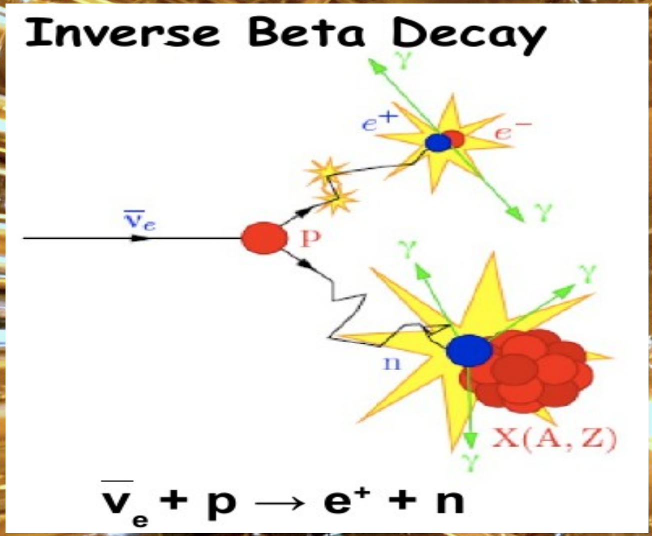
<u>delayed coincidence scheme:</u>

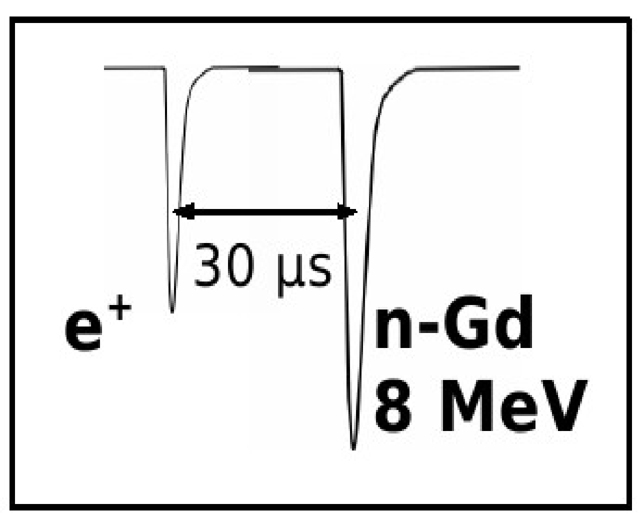
→ Prompt: e^+ annihilation

→ Delayed: n capture on Gd

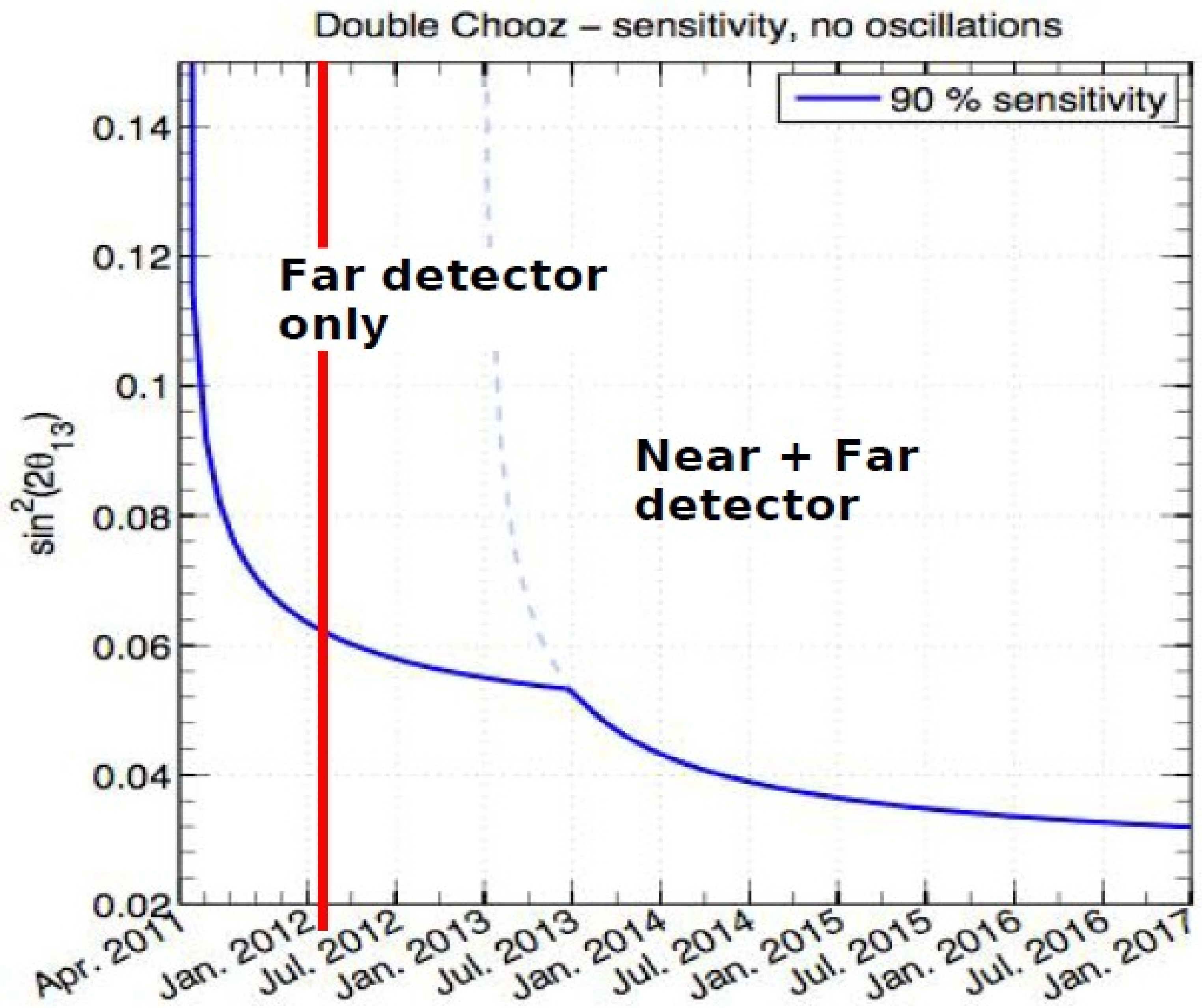
→ time correlation ~ 30 μs (thermalization of the n)

→ allows to suppress backgrounds

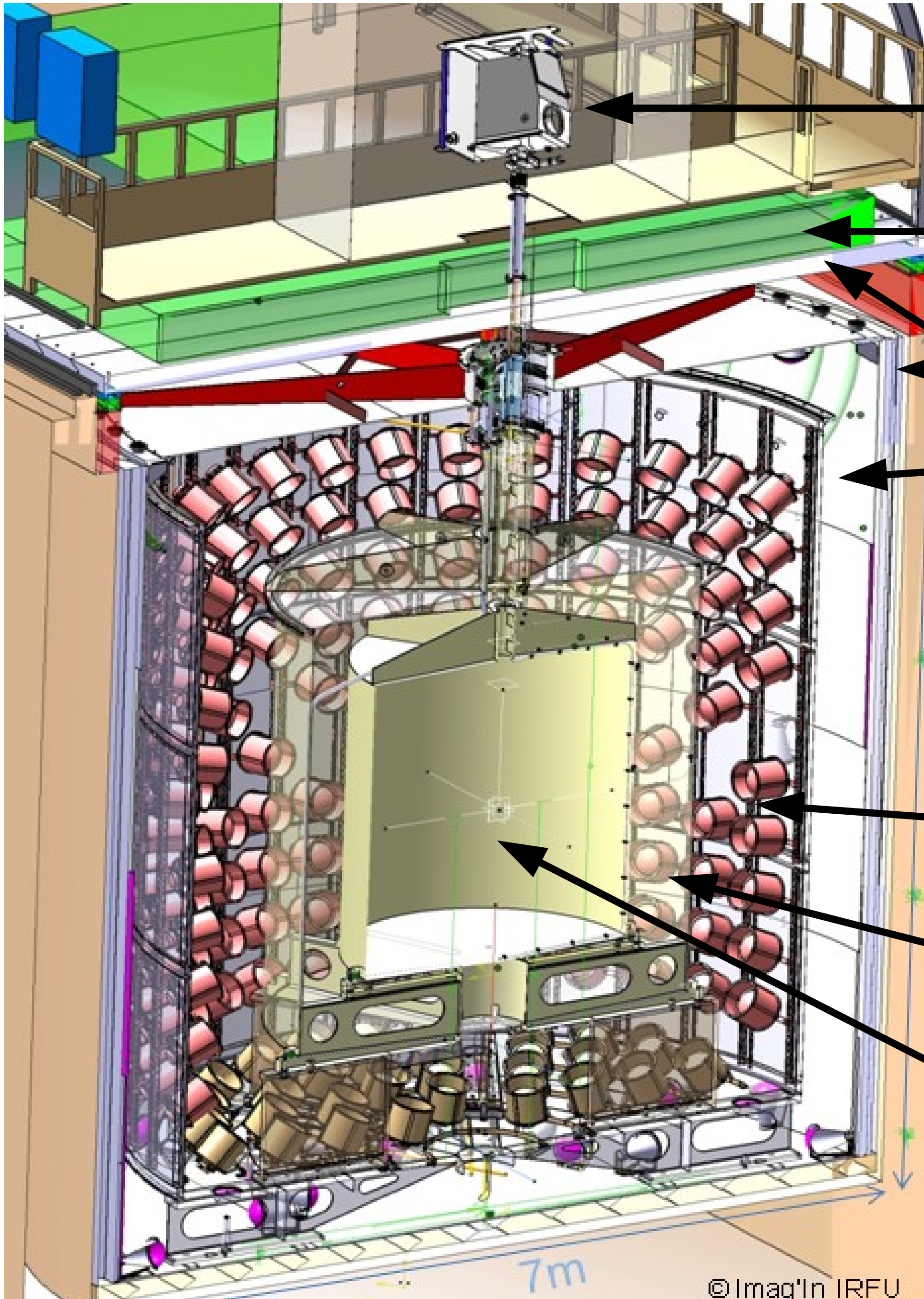




Double Chooz sensitivity



the Double Chooz detector



glove box
→ preparation of calibration sources in controlled atmosphere

outer veto (plastic scintillator strips)
→ tagging “near-by” **μ**s

shielding (250 tons of steel, 15cm thick)
→ reduce **γ** background from surrounding rock

inner veto (steel vessel, 90m³ liquid scint. + 78 PMTs)
→ detection of cosmic **μ**s, fast neutrons, **γ**s etc.

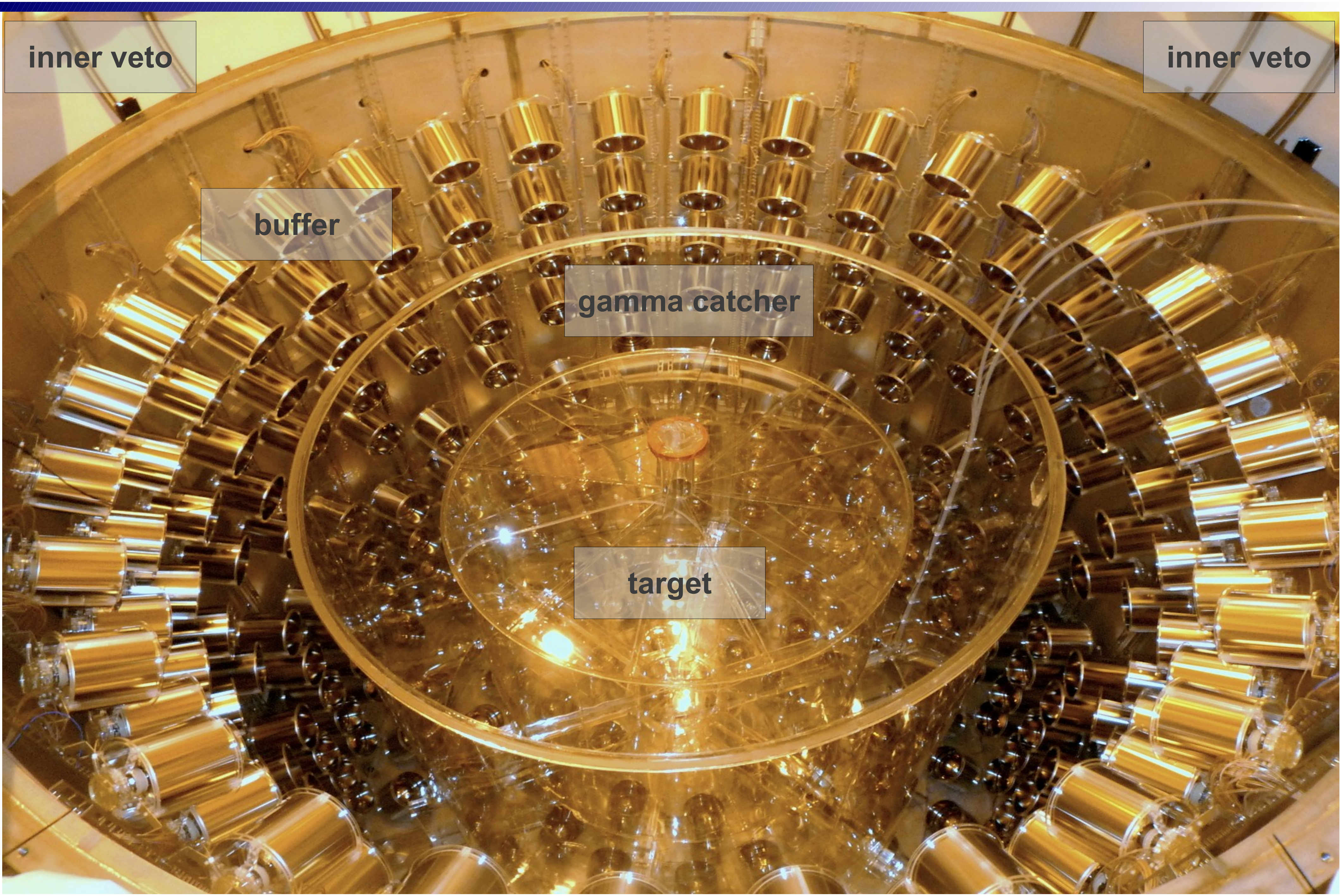
inner detector (three layers)

buffer (steel vessel, 110m³ mineral oil + 390 PMTs)
→ reduction of **γ**s from PMTs and outside and fast neutrons

gamma catcher (acrylic vessel, 22.3m³ liquid scint.)
→ conversion of **γ**s leaving the target

target (acrylic vessel, 10.3m³ liquid scint. + 1g/l Gd)
→ ν-target, fiducial volume

the Double Chooz detector

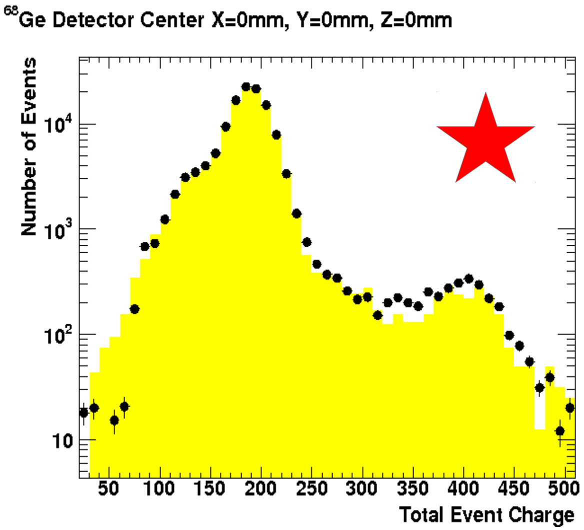


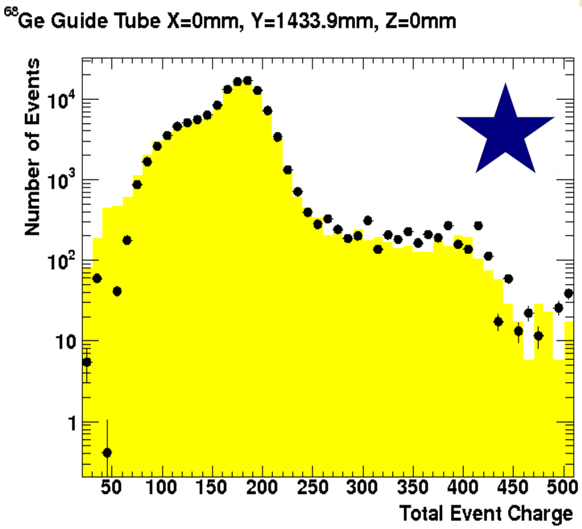
calibration systems

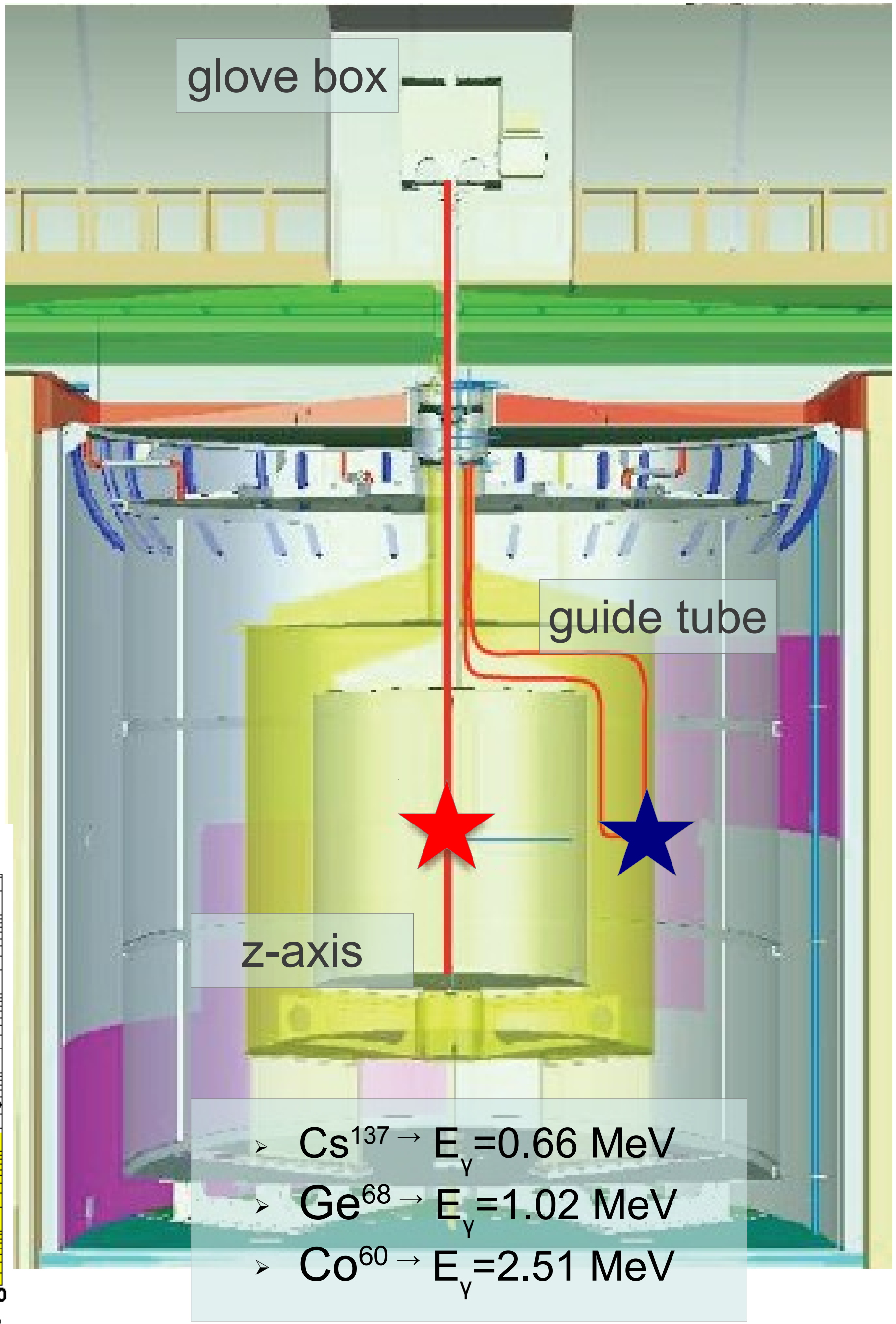
- light sources embedded
  → LED in ID & IV monitor readout (timing, gain)
- light sources deployed
  → LED, red-laser & UV-laser for PMT gain, timing, scint stability & attenuation

- radioactive source deployment
  - Cs^{137}, Ge^{68}, Co^{60} and natural (e.g. H/Gd-captures) covering most important energy range (and signal types)
  - Cf^{252} (n-source)
    → allows to study efficiencys
- deployment via z-axis, guide tube and articulated arm (future)

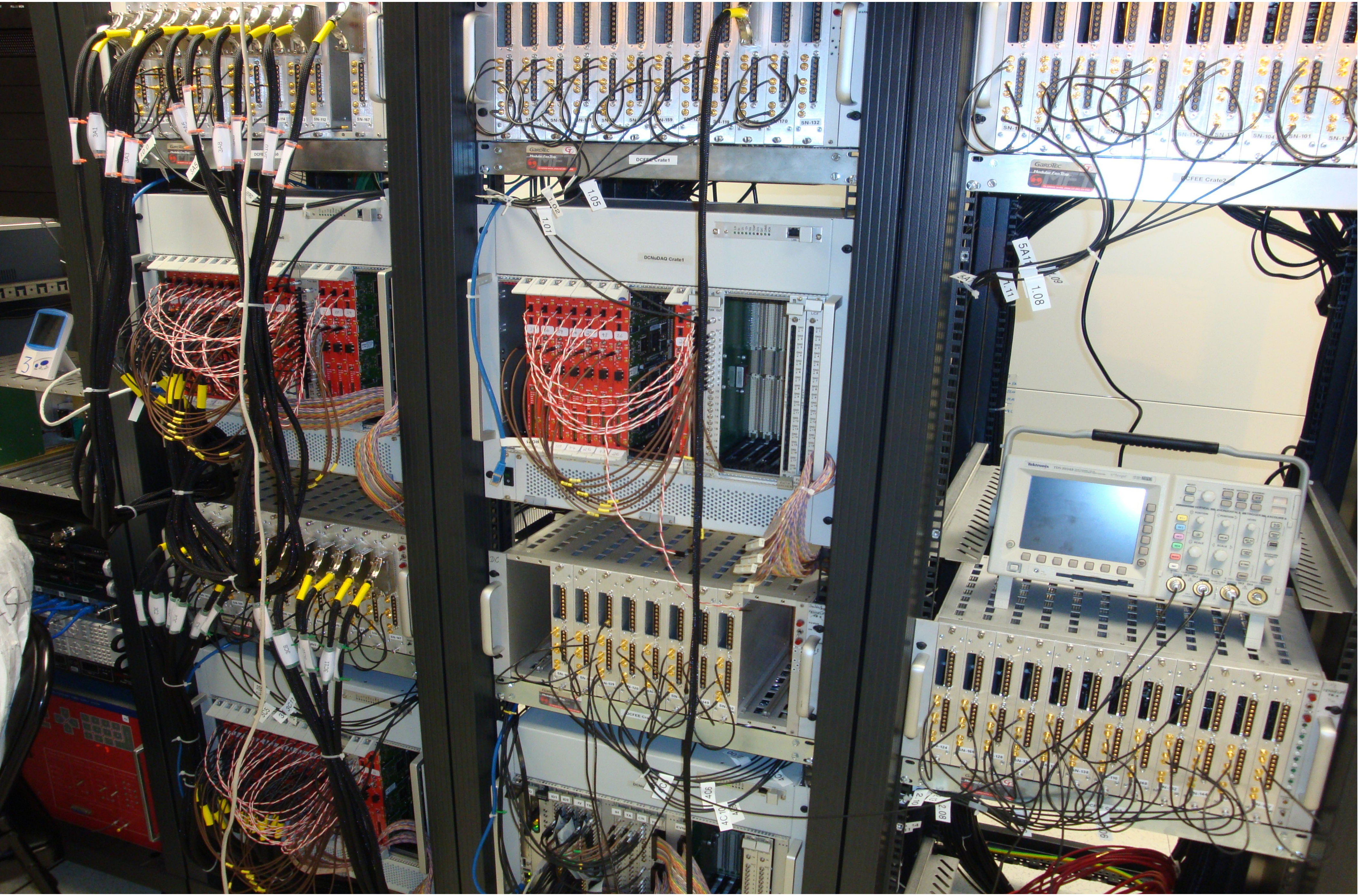
e.g. energy calibration:



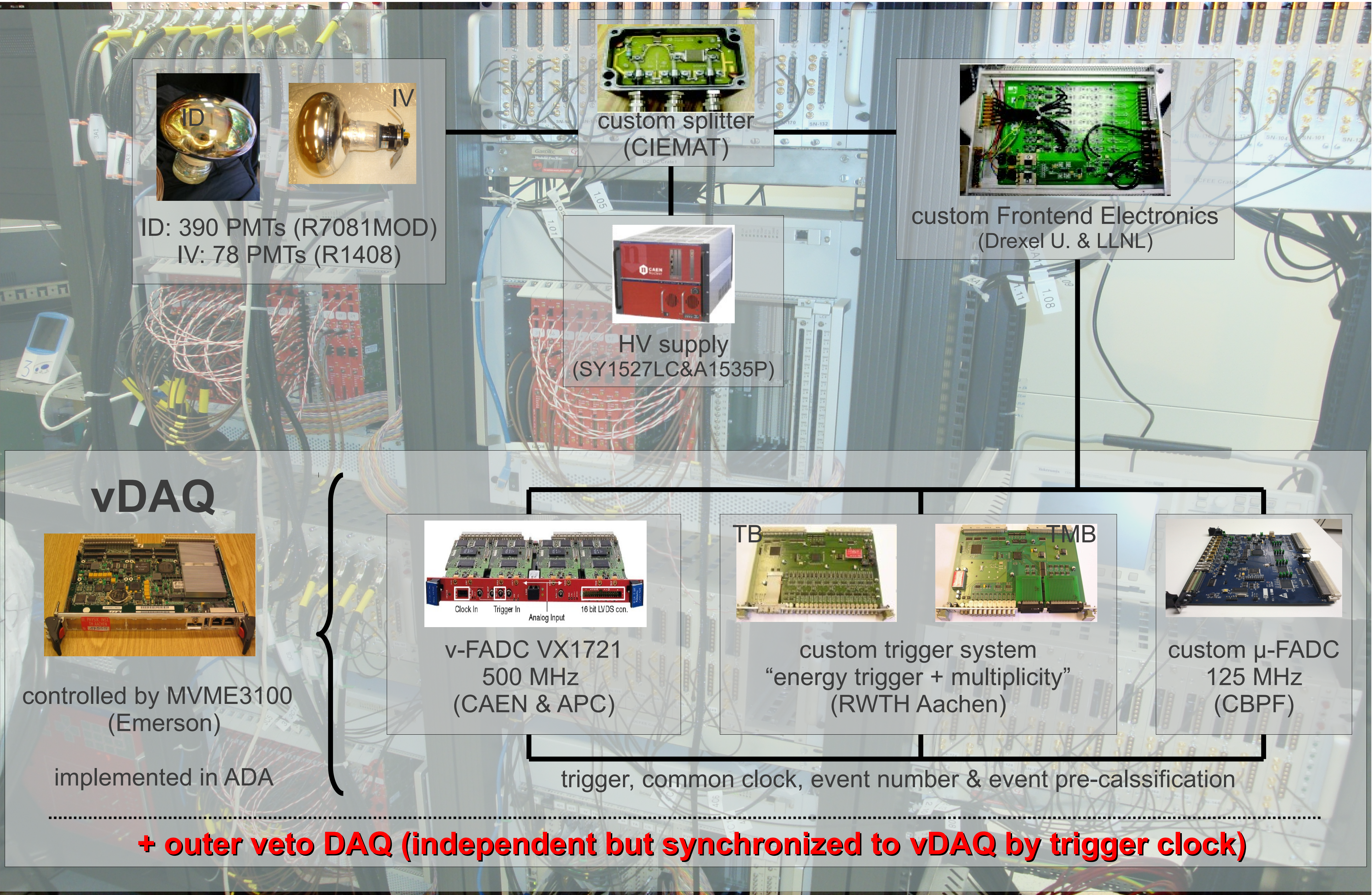




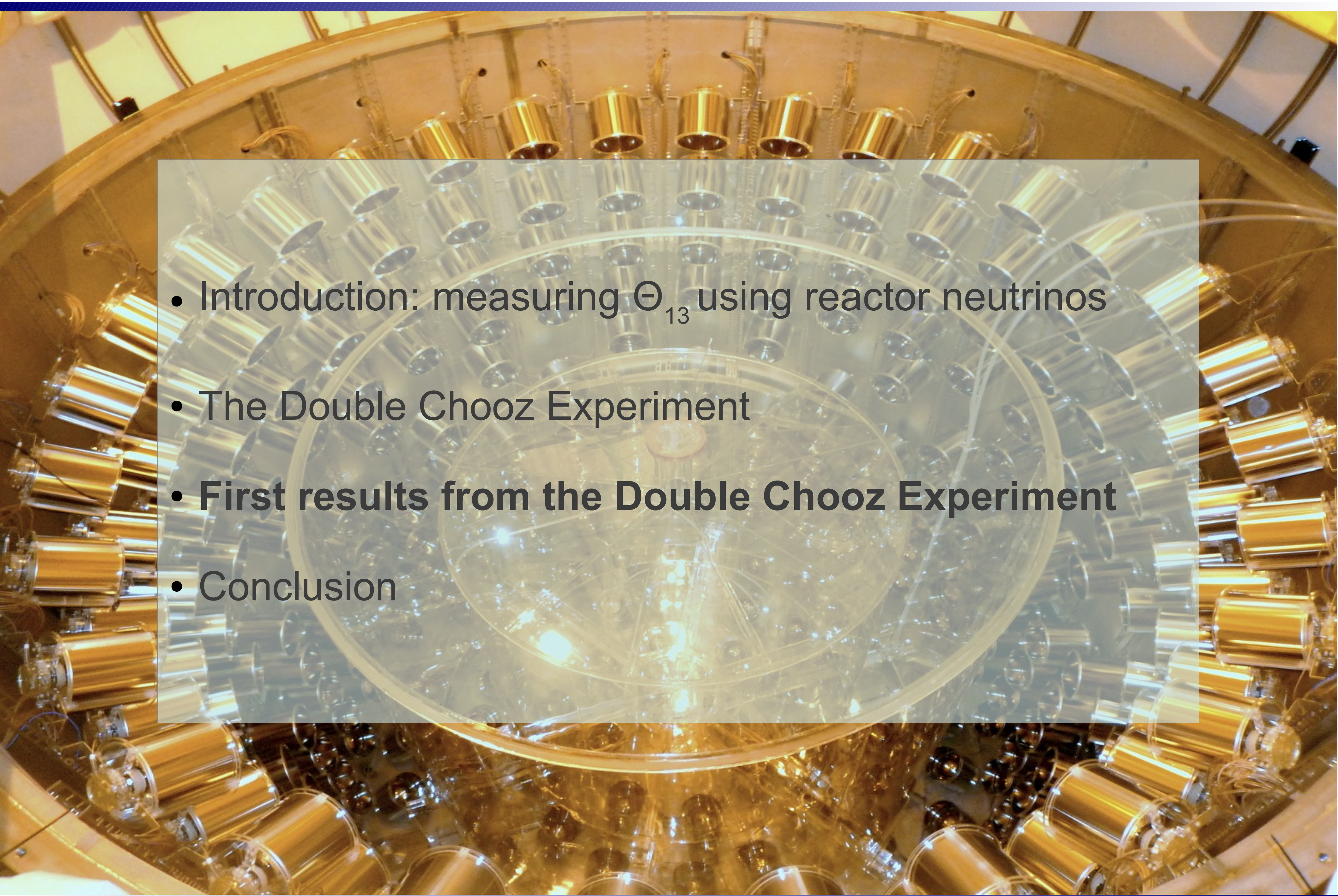
readout & electronics



readout & electronics

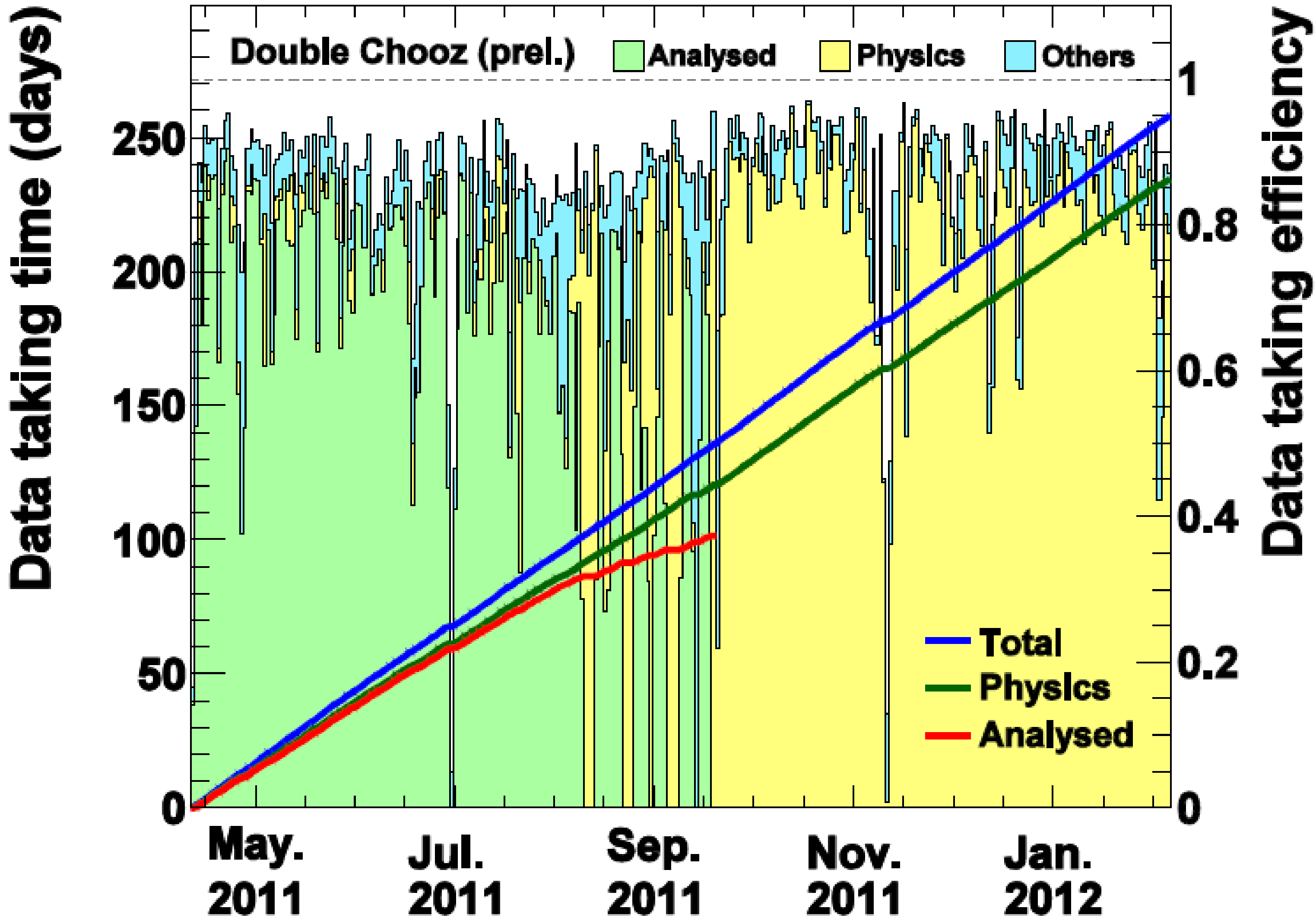


outline



- Introduction: measuring Θ_{13} using reactor neutrinos
- The Double Chooz Experiment
- **First results from the Double Chooz Experiment**
- Conclusion

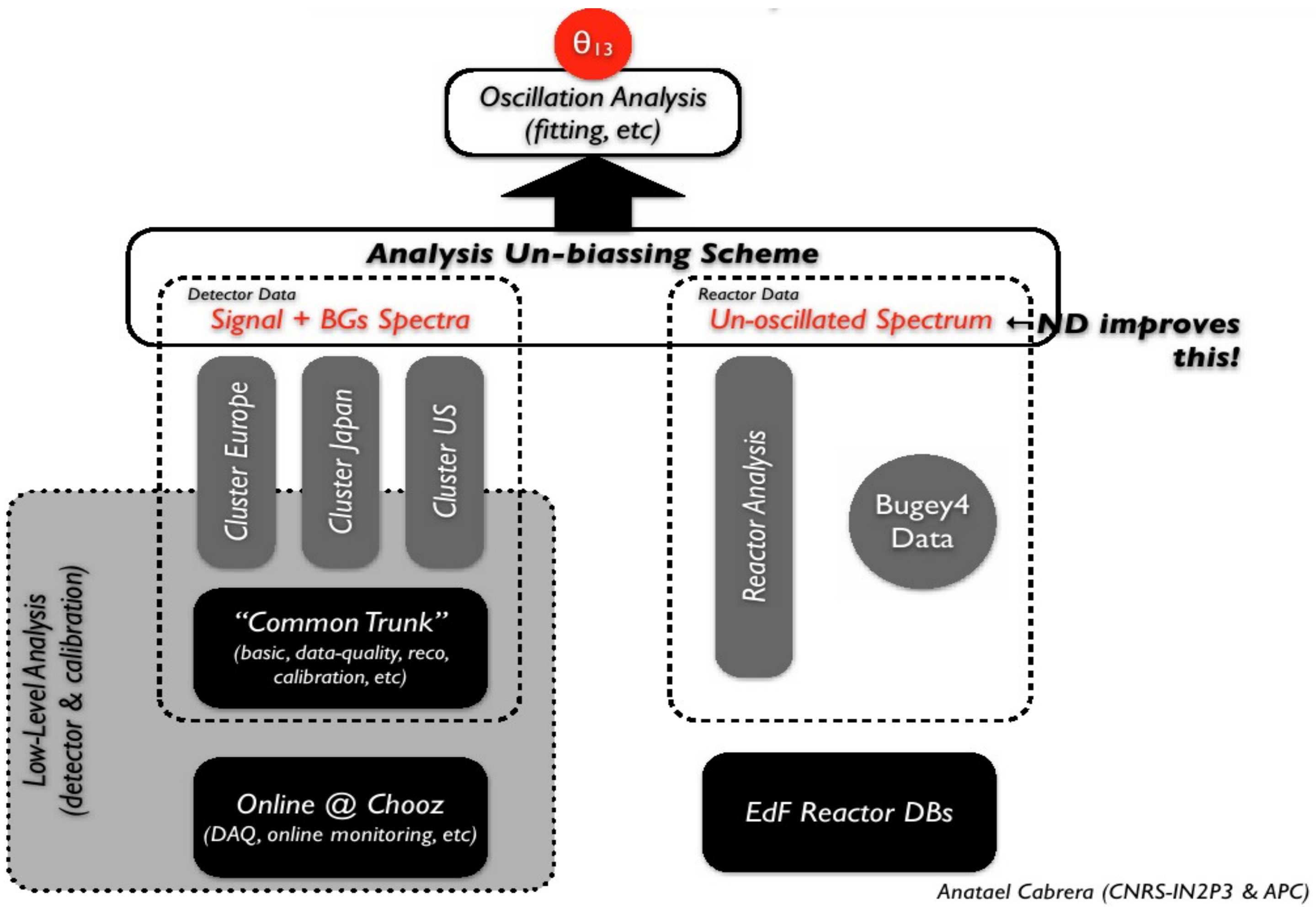
fraction of analysed data for 1. publication



Run time: 101.52 days from April 13th to September 18th

Live Time: 96.82 days due to 1ms μ veto

analysis scheme

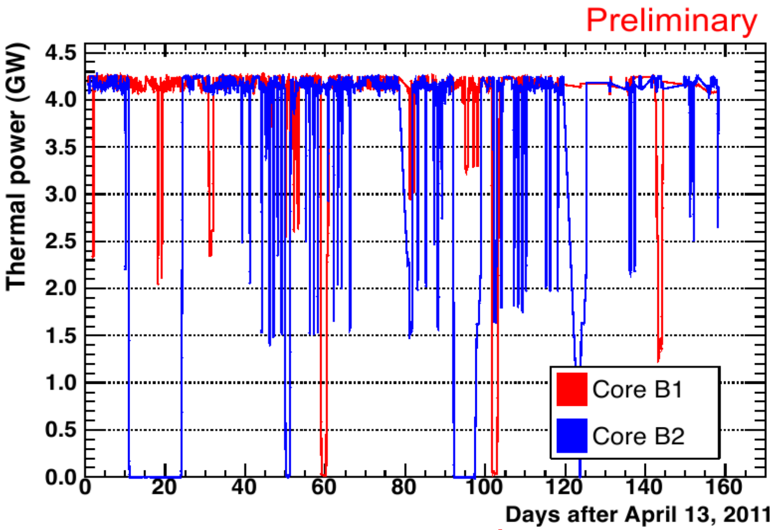


without ND we need to use predicted ν-rate for oscillation analysis

predicted neutrino rate

P_{th} continuously extracted from reactor data

$\delta P_{th}/P_{th}=0.46\%$



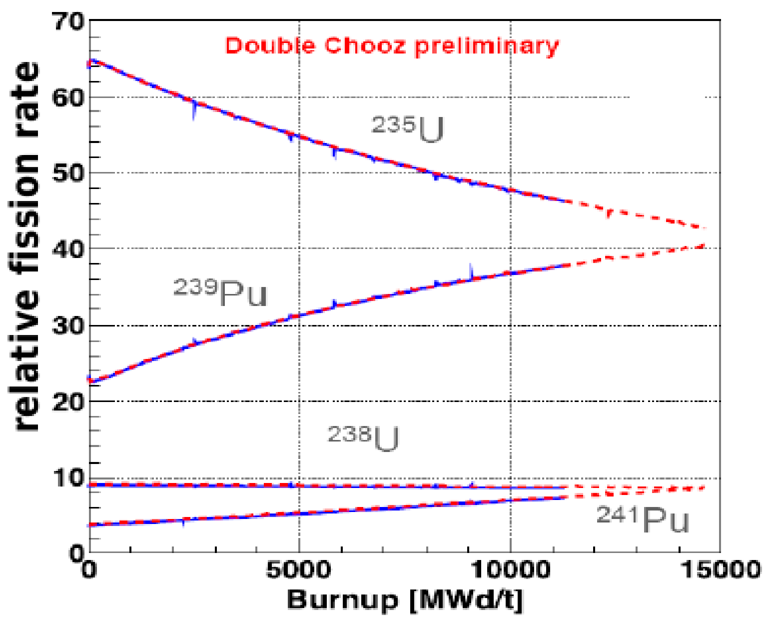
$$N_{\nu}^{exp}(E,t) = \frac{N_p\,\varepsilon}{4\pi L^2} * \frac{P_{th}(t)}{\langle E_f \rangle} * \langle \sigma_f \rangle$$

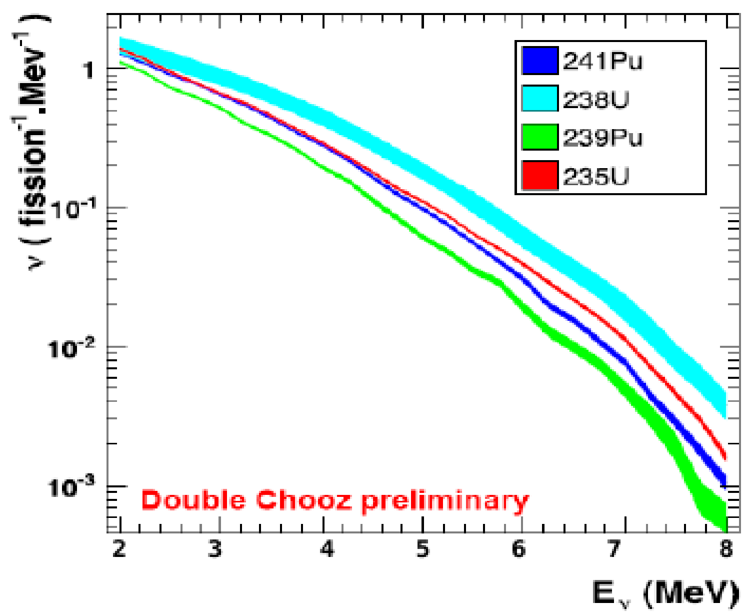
mean energy per fission

Bugey4 data as normalization

mean cross section per fission

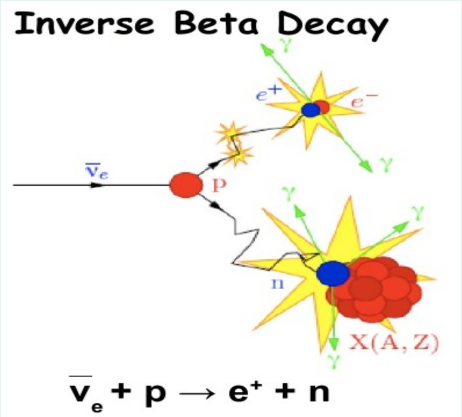
detailed simulation of core evolution (MURE & Dragon)





see: Th. A. Mueller et al, Phys.Rev. C83(2011) 054615
P.Huber, Phys.Rev. C84(2011) 024617

neutrino selection



candidate selection cuts:

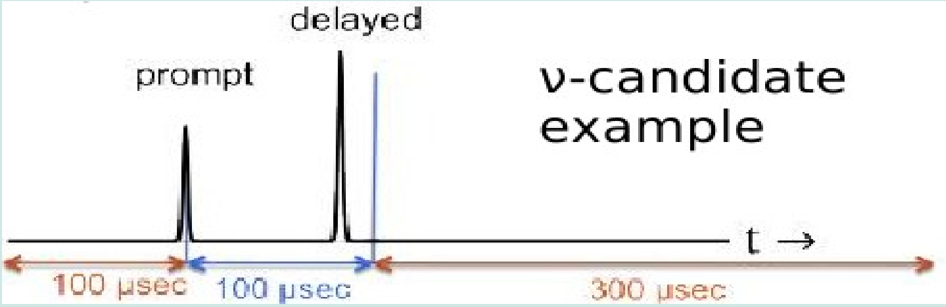
muon veto:
→ $\Delta t_\mu > 1$ ms

coincidence:
→ time coincidence: $2 < \Delta t < 100$ µs

prompt event:
→ Qmax/ Qtot < 0.09 & $RMS_{Tstart} < 40$ ns
→ $0.7 < E < 12$ MeV

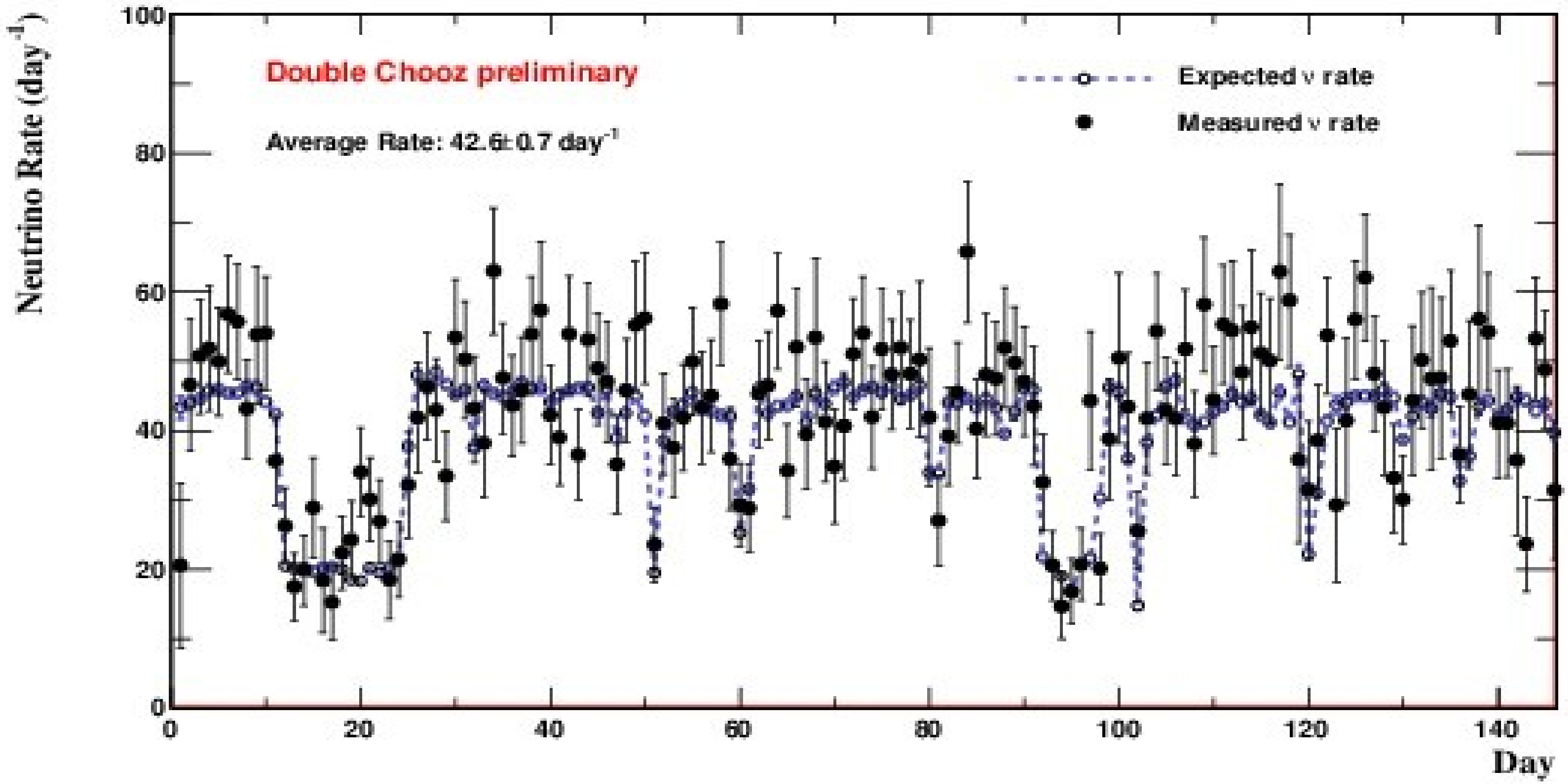
delayed event:
→ Qmax/ Qtot < 0.06 & $RMS_{Tstart} < 40$ ns
→ $6 < E < 12$ MeV

multiplicity:
→ no trigger E > 500 keV within 100 µs before prompt
→ exactly one trigger in $2 < \Delta t < 400$ µs after prompt



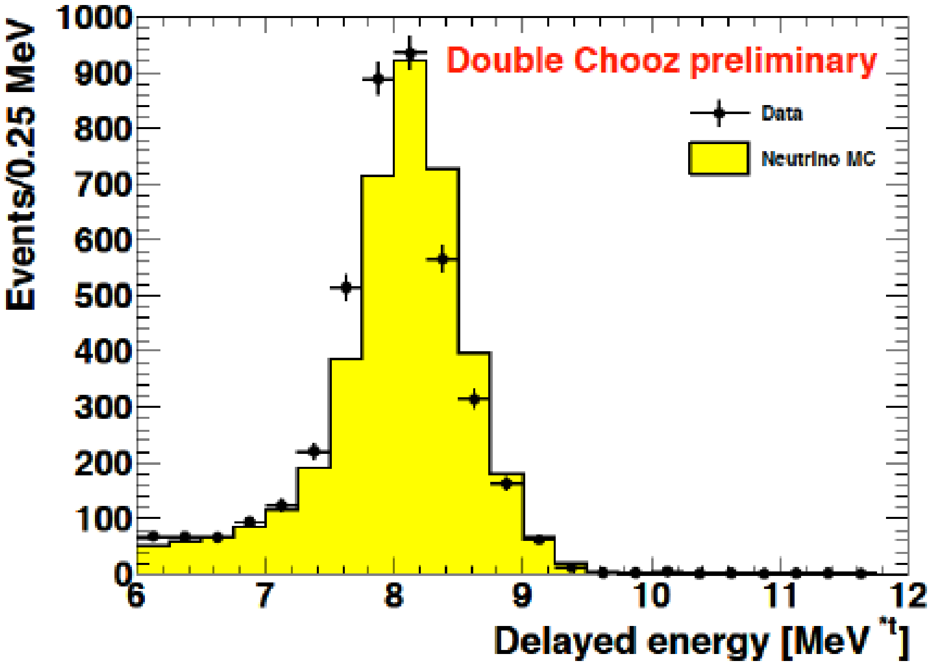
neutrino candidate rate

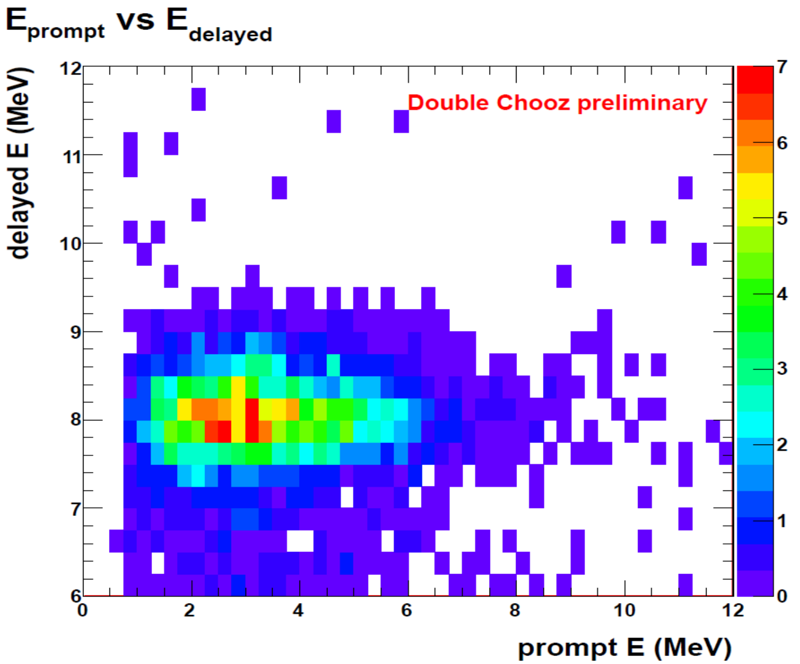
Neutrino candidates rate (background not subtracted)

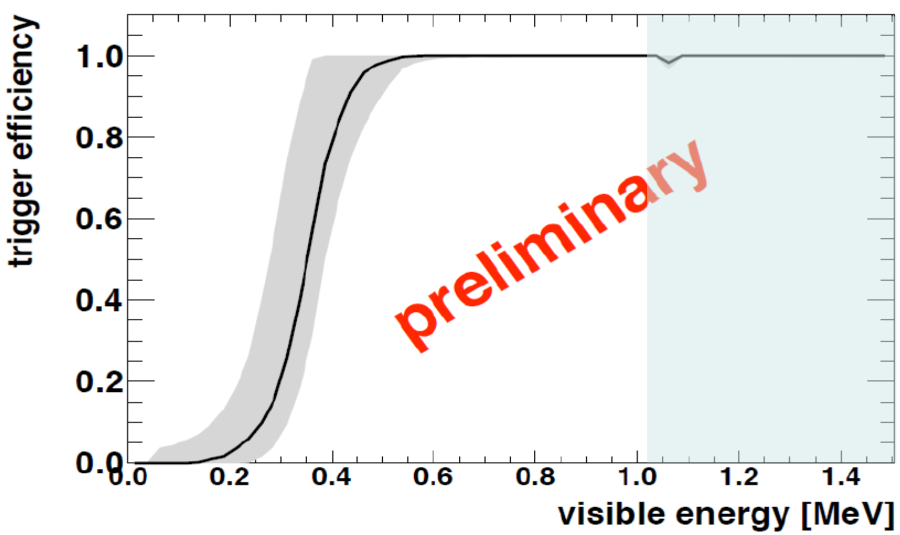


- in total 4121 candidates survive the cuts (no background substraction)
  - good correspondence to reactor power history
    - indicates low background level in detector

a few example distributions



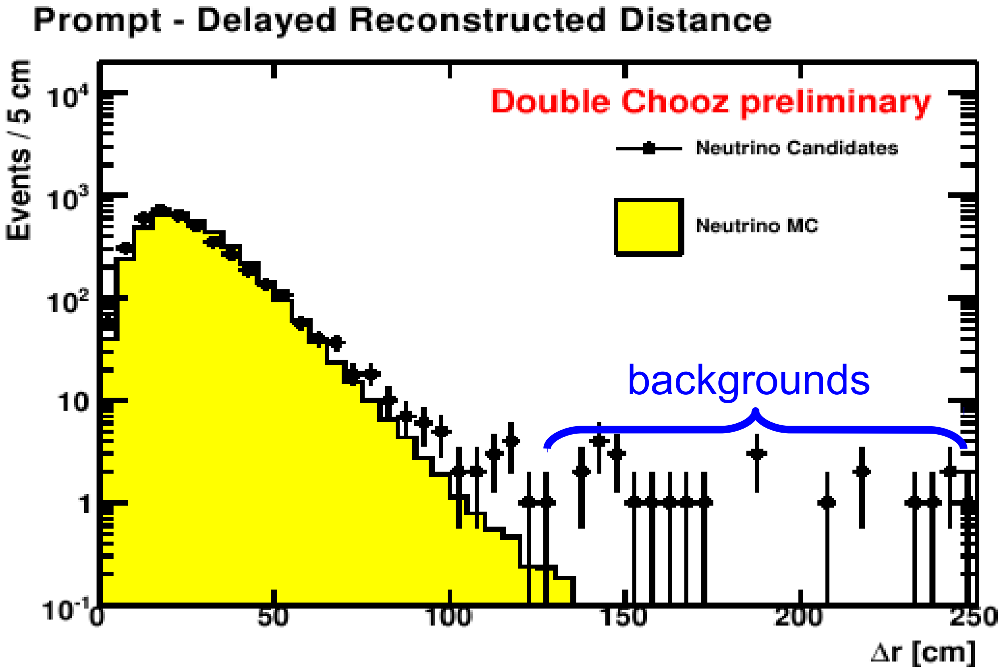




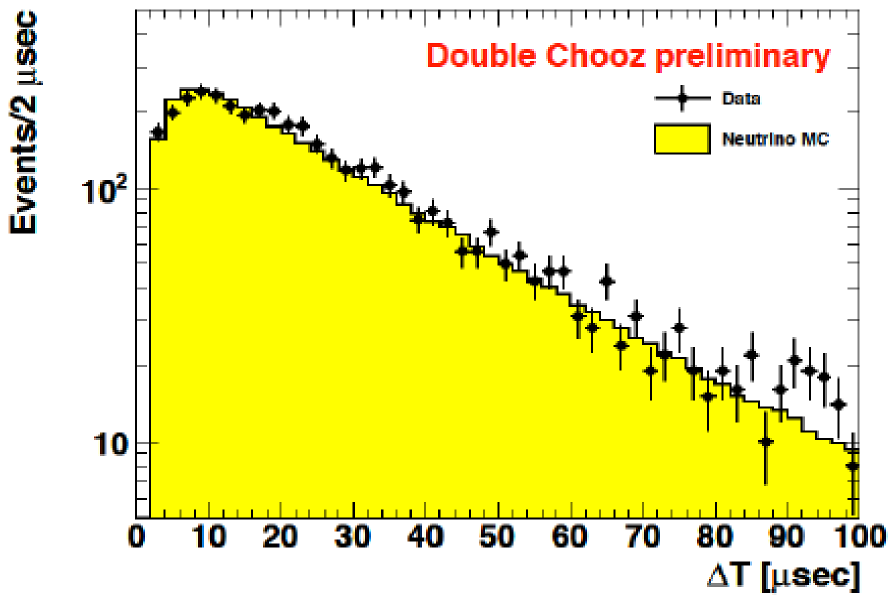
trigger efficiency above 700 keV: 1.000 +/- 0.004

a few example distributions

ΔR:

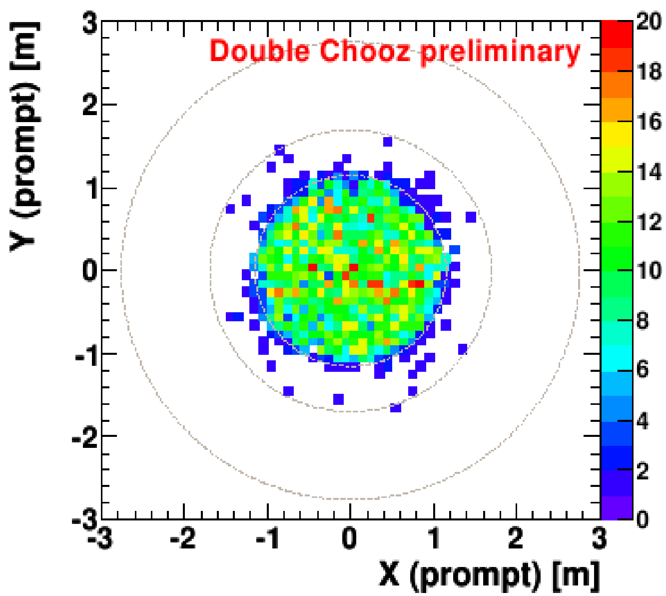


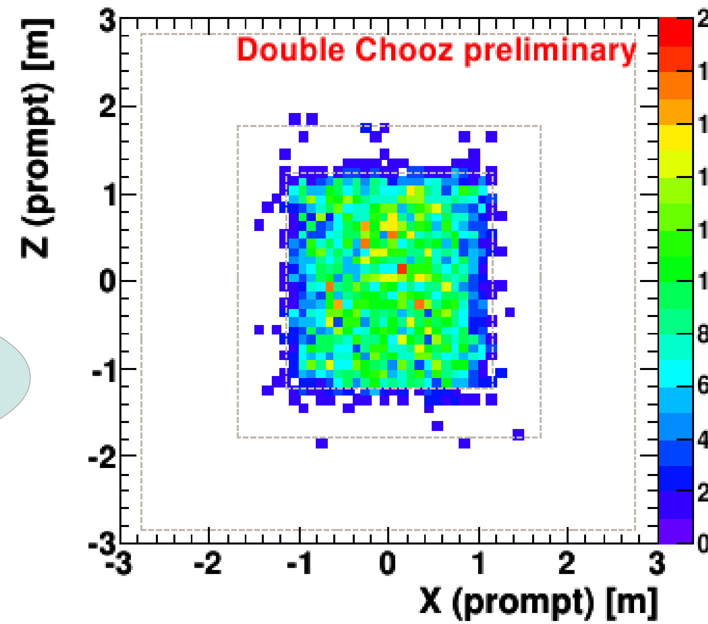
ΔT:



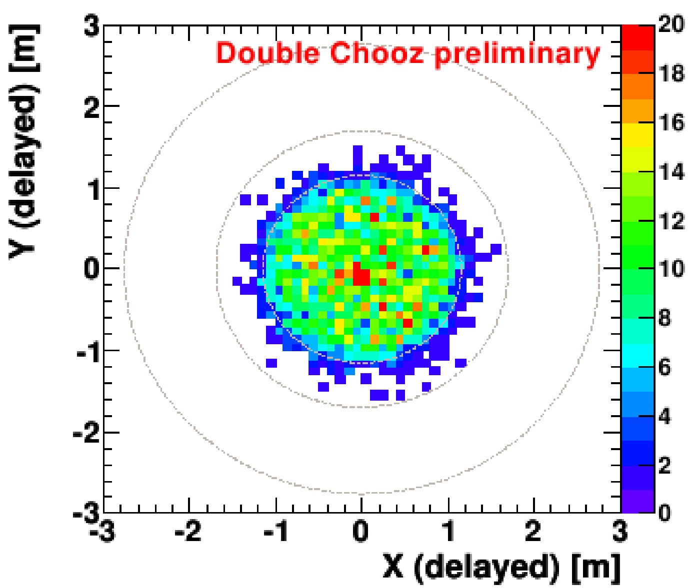
ΔT cut efficiency 96.5 ± 0.5%

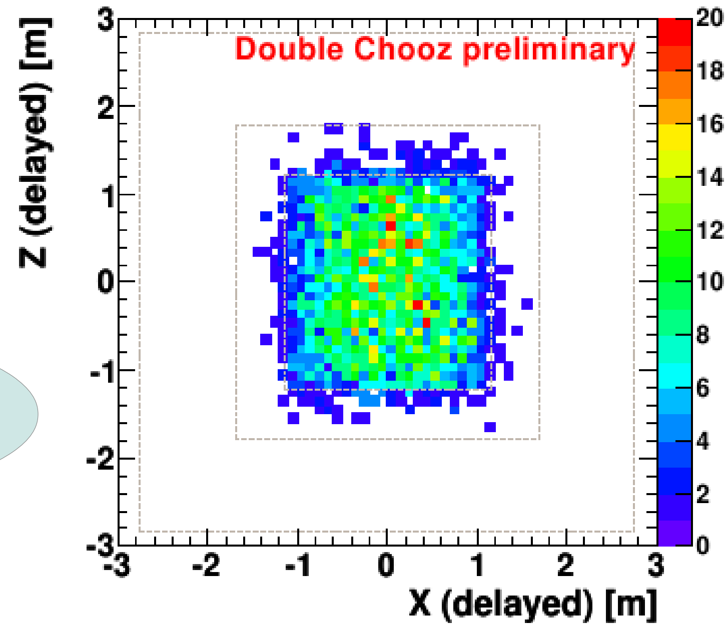
vertex distributions





prompt event





delayed event

what about backgrounds ???

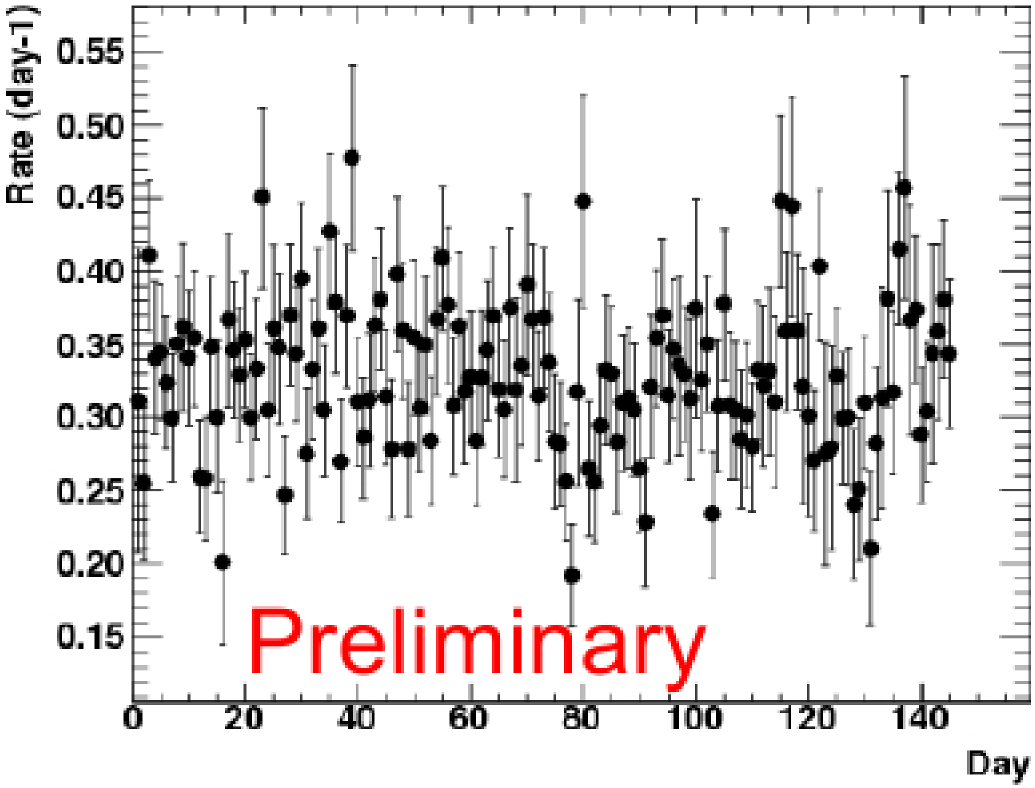
potential sources: cosmic muons (and secondaries), radioactivity

accidental background

- for example:

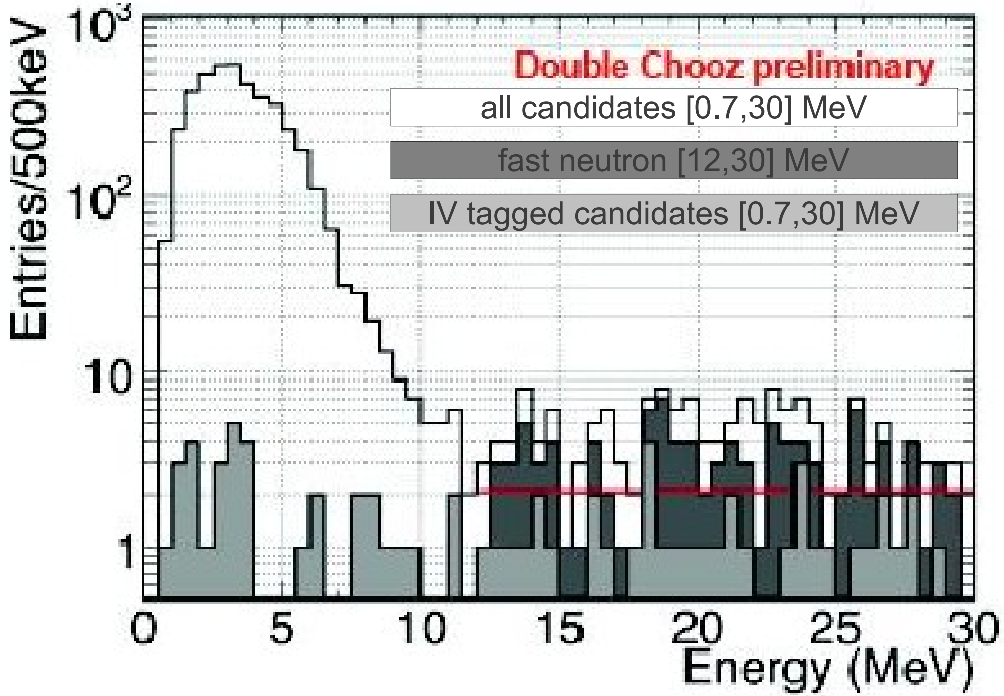
  Prompt: enviromental gamma-ray

  Delayed: muon induced neutron
- estimated by off-time method
- 0.33 ± 0.03 events/ day

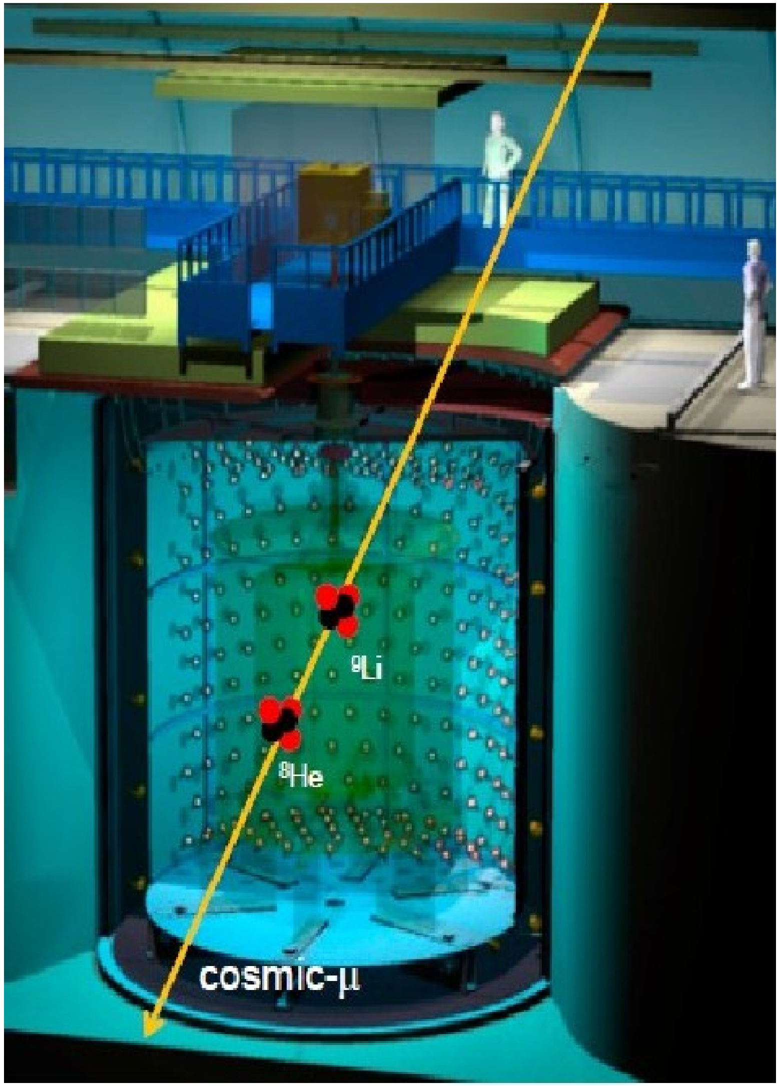


correlated background I

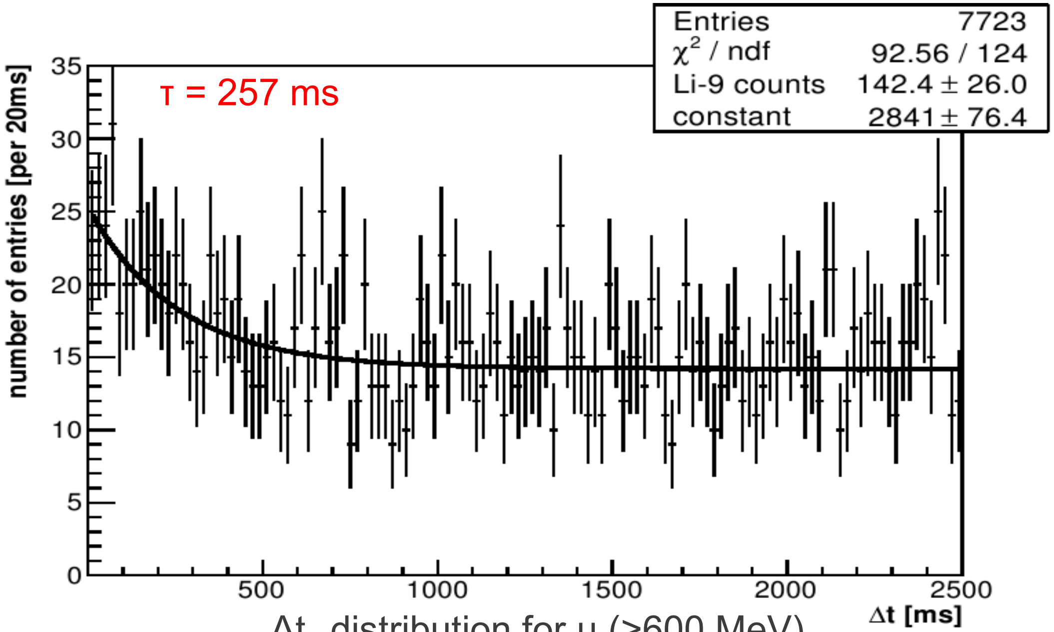
- fast neutrons:
  - Prompt: recoil proton
  - Delayed: neutron capture on Gd
- neutrino search extended to 30 MeV for prompt (>12 MeV pure background sample)
- extrapolation into low energy region assuming flat spectrum
- validated by using IV tagged events
- 0.83 ± 0.38 events/ day



correlated background II

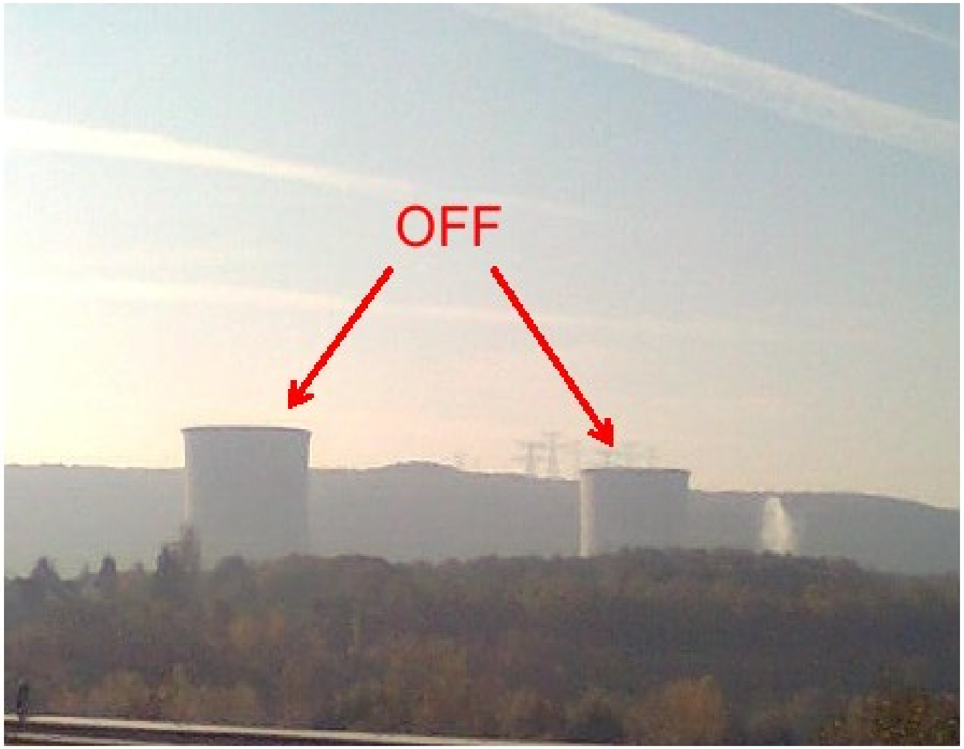


- cosmogenics (^{9}Li/ ^{8}He produced by μ-induced spallation):
- β – n emitters, perfectly mimic the ν-signal
- hard to veto due to long lifetime of isotopes
- search for triple coincidence (μ (>600 MeV) + prompt + delayed)
- fit exponential (fixed at ^{9}Li lifetime) + constant to raw Δt_μ spec.
- 2.3 ± 1.2 events/ day



Δt_μ distribution for μ (>600 MeV)

background estimates crosscheck



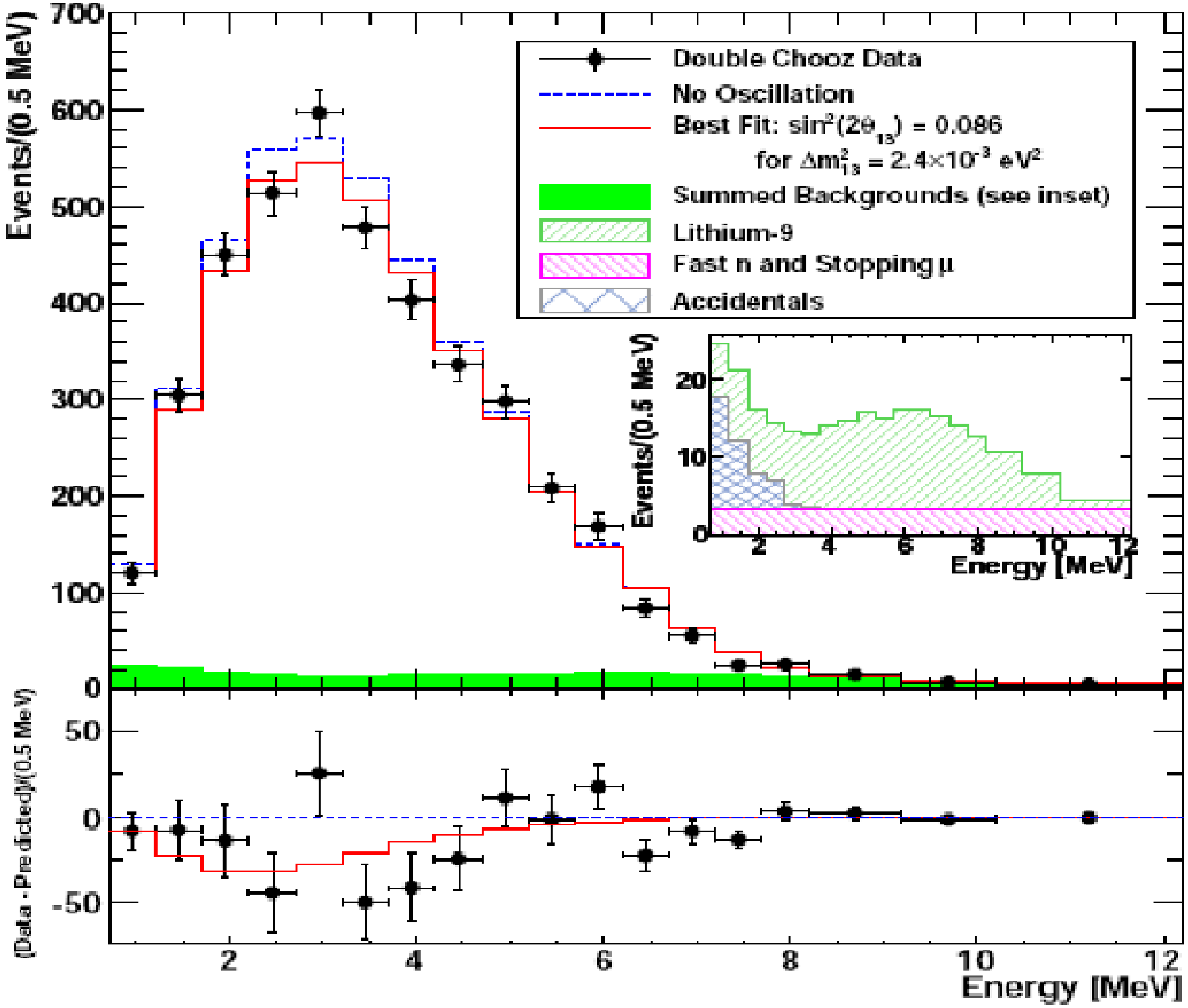
- unique opportunity to measure backgrounds in-situ
- ~ 24h of reactor OFF-OFF data
- 2 (+1) candidates found by delayed coincedence
  - 2 events in neutrino energy window ↔ likely ^{9}Li background candidates
  - 1 event with E_{prompt} = 26.5 MeV ↔ likely fast neutron background candidate
- both observations are consistent with our background observations

oscillation analysis

summary of uncertainties

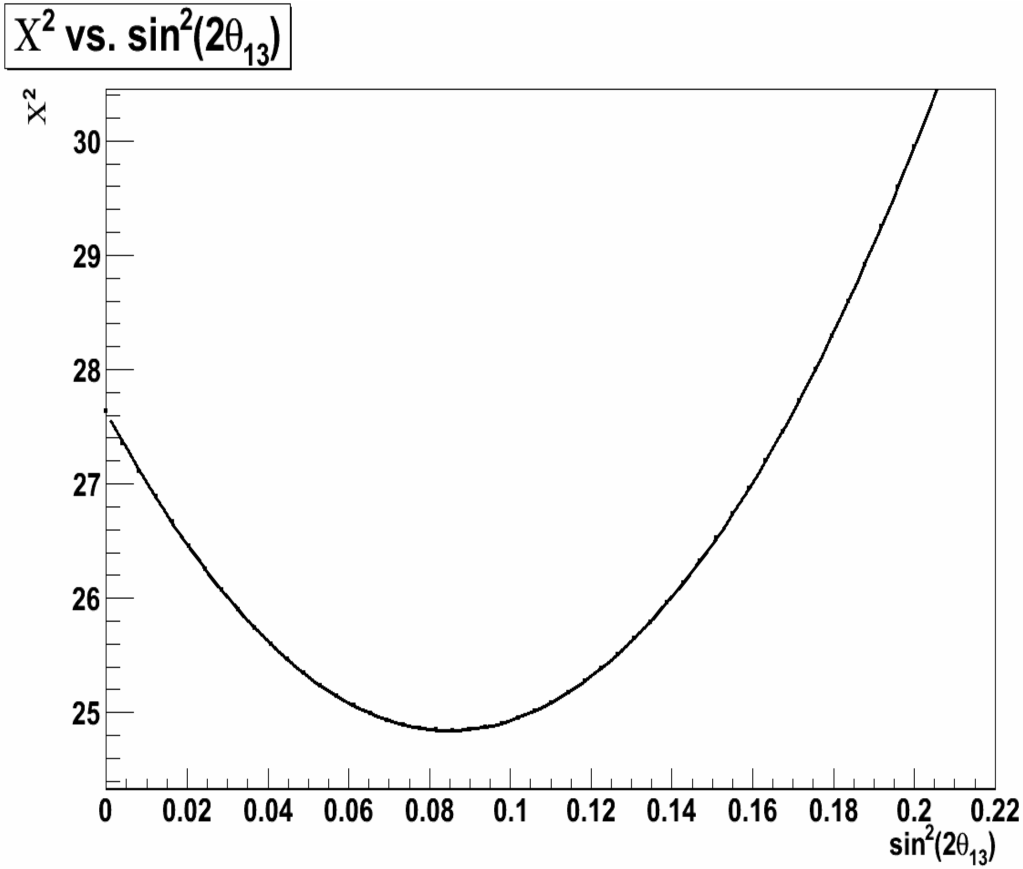
Source		Uncertainty w.r.t. signal	
Statistics		1.6%	
Reactor	Bugey4 measurement	1.4%	1.8%
	Fuel Composition	0.9%	
	Thermal Power	0.5%	
	Reference Spectra	0.5%	
	Energy per Fission	0.2%	
	IBD x-sec	0.2%	
	Baseline	0.2%	
Detector	Energy response	1.7%	2.1%
	E_{delay} Containment	0.6%	
	Gd Fraction	0.6%	
	Δt_{e+n}	0.5%	
	Spill in/out	0.4%	
	Trigger Efficiency	0.4%	
	Target H	0.3%	
Backgrounds	Accidental	< 0.1%	3.0%
	Fast neutron	0.9%	
	9Li	2.8%	

Prompt Spectrum:



rate + shape analysis

final fit results



Y. Abe et al PRL 108, 131801, (2012)

rate + shape:

$$\sin^2(2\theta_{13}) = 0.086 \pm 0.041\ (\text{stat}) \pm 0.030\ (\text{syst})$$

no-oscillation excluded @ 94.6%

outlook

- Double Chooz is running as designed

- 100 days of data have been analysed, first results on rate+shape analysis have been published

Y. Abe et al PRL 108, 131801, (2012)

$$\sin^2(2\theta_{13}) = 0.086 \pm 0.041\ (\text{stat}) \pm 0.030\ (\text{syst})$$

- promising analysis improvements underway

- two times more statistics already available for analysis

- near detector is under construction, operational 2013

… now θ_{13} is quite big …

- θ_{13} will be measured by reactor experiments (independent of δ_{CP} and mass hierarchy)

  → good precision is needed!!!

- Double Chooz can contribute!

  high value → statistics not the main point (it will be systematics)

  - Double Chooz is the only one to measure backgrounds in situ
  - only two reactors → detectors are on same iso ratio curve
    → use of power balance is the same, reducing systematics
  - good and very powerful calibration system
  - scintillator is organometallic → more stable by construction
    (strong link between Gd and LAB solvent)

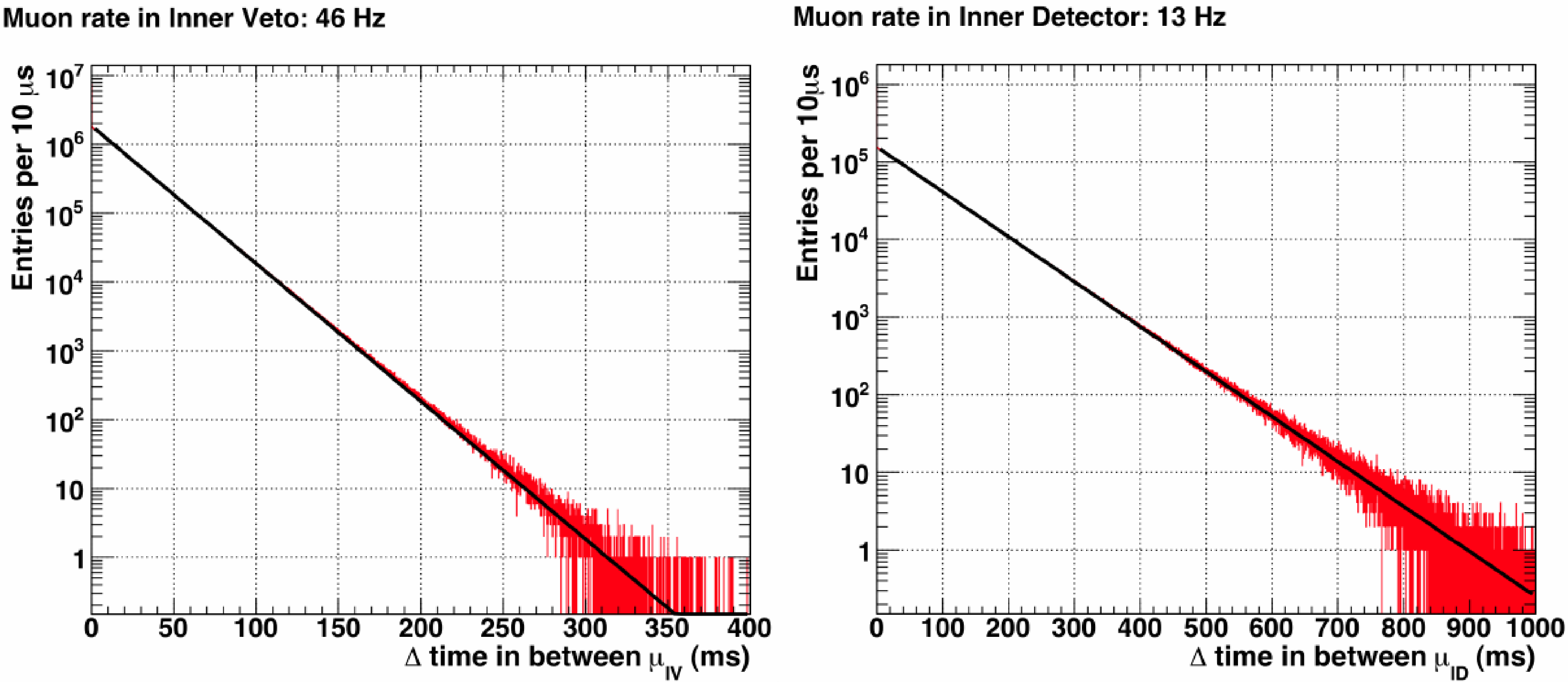
thanks for your attention!

ND expected to start running at 2013

backup

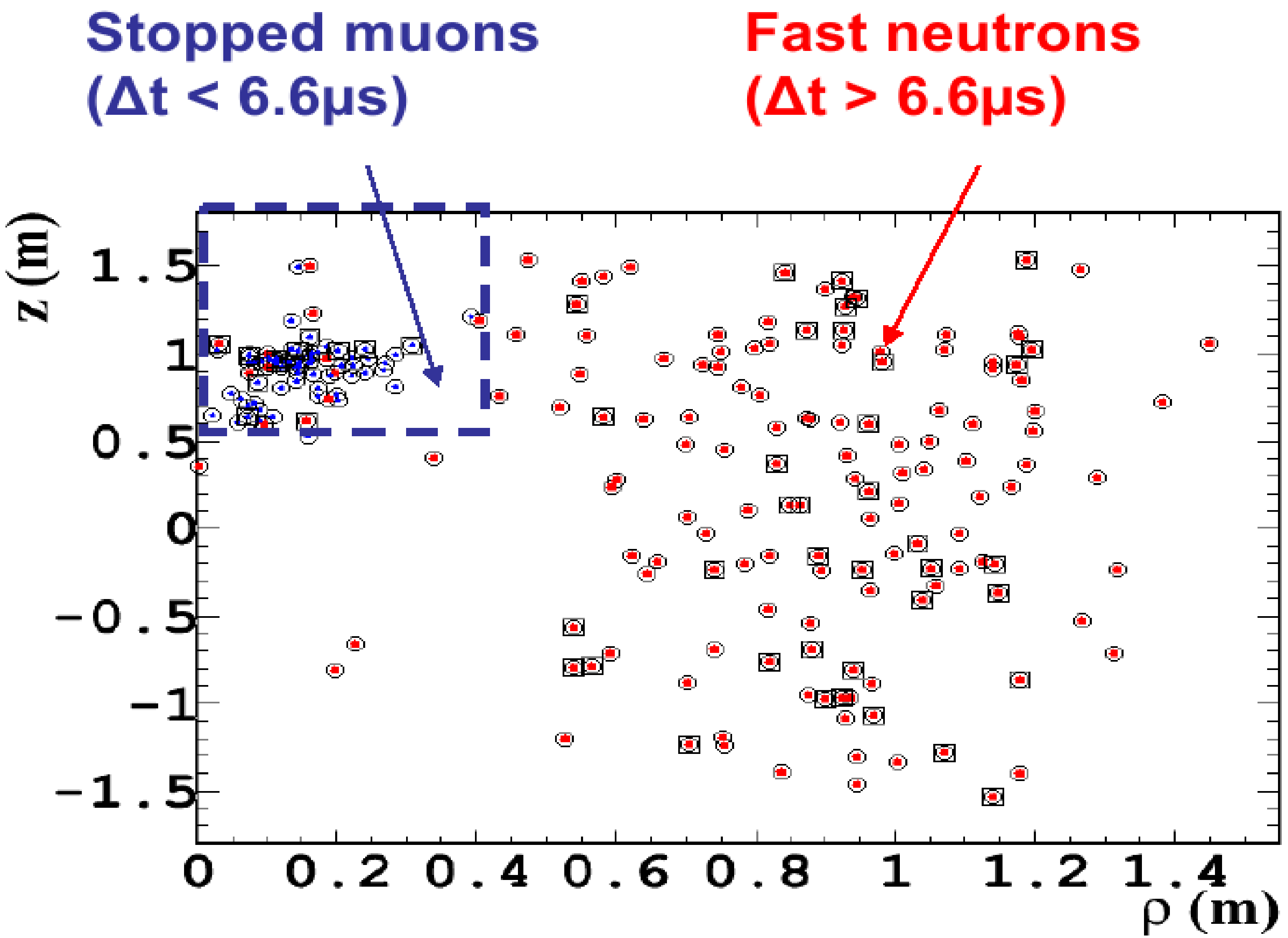
muons

- Inner Veto muon rate: 46 Hz
- Inner Detector (T+GC): 13 Hz
- ν-search: software muon cut:
  discard all events within 1 ms after a muon (IV muons)



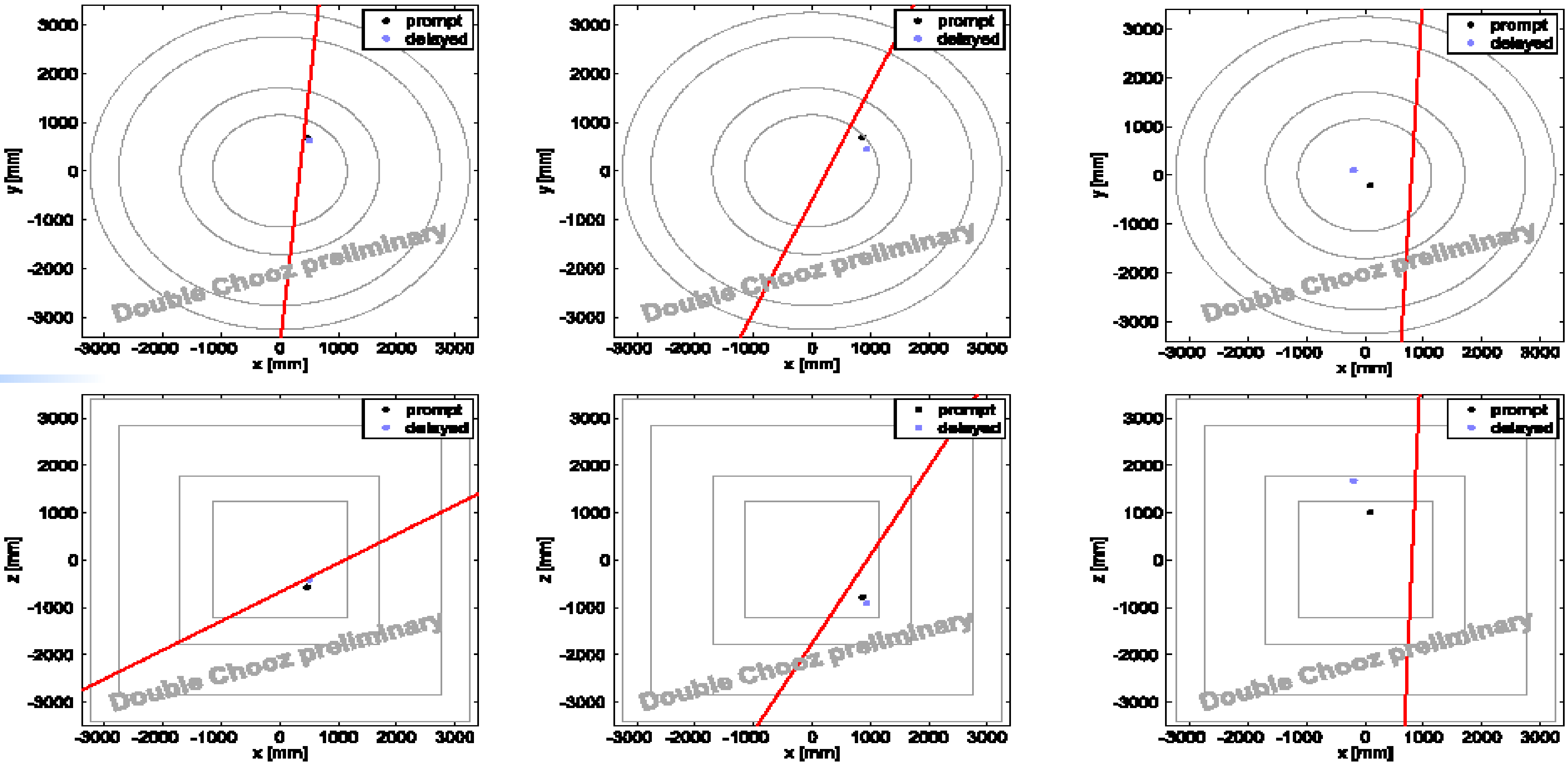
fast neutrons / stopping muons

→ our so called "fast neutron" background also includes stopping muons (clearly visible by looking at vertex and Δt distributions)



OFF-OFF analysis

^{9}Li candidate | ^{9}Li candidate | fast n candidate

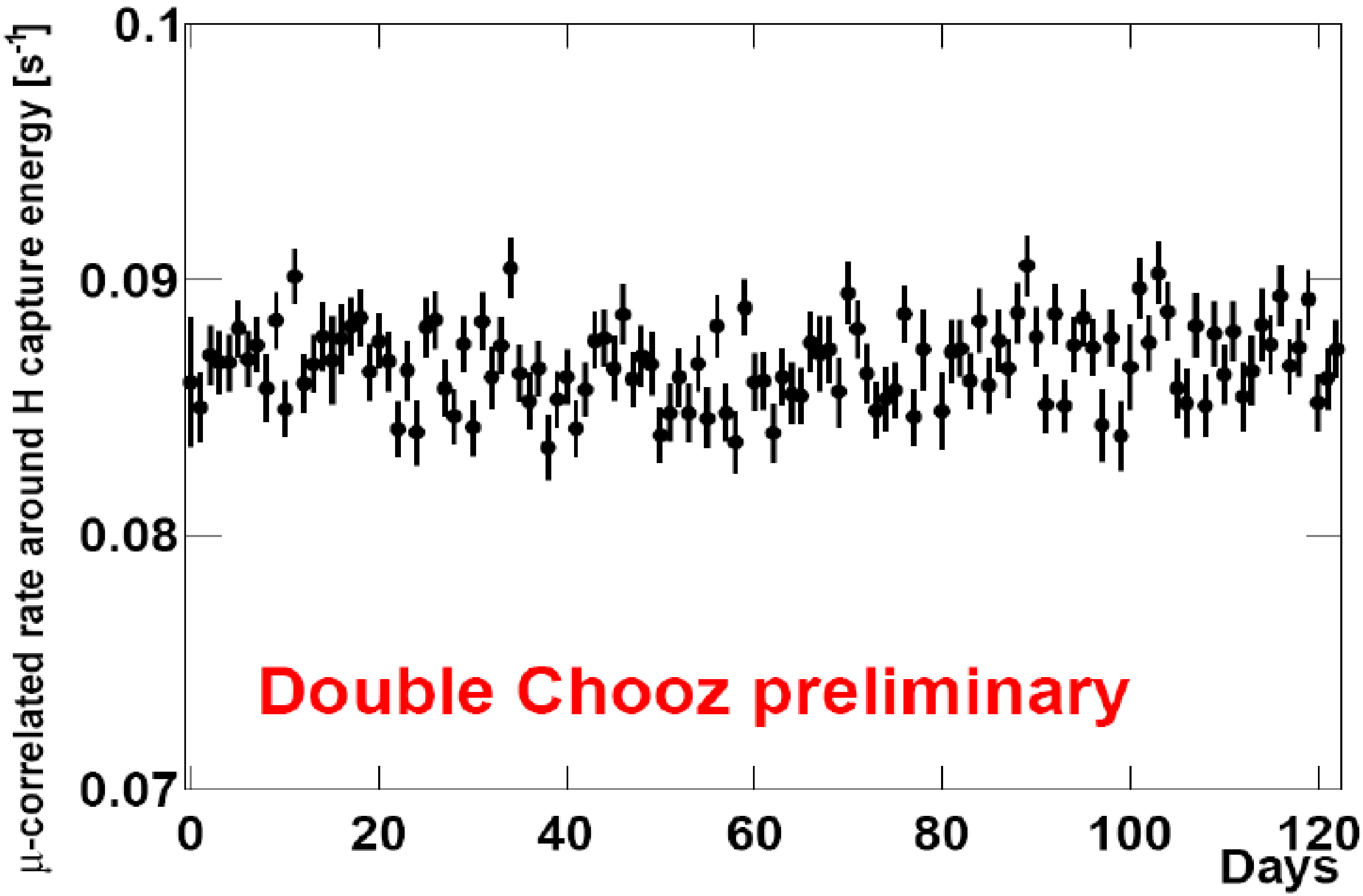


E_{prompt} = 9.8 MeV
ΔT = 4.1 μs
$\Delta T_{\mu(739\ MeV)}$ = 201 ms

E_{prompt} = 4.8 MeV
ΔT = 26 μs
$\Delta T_{\mu(627\ MeV)}$ = 241 ms

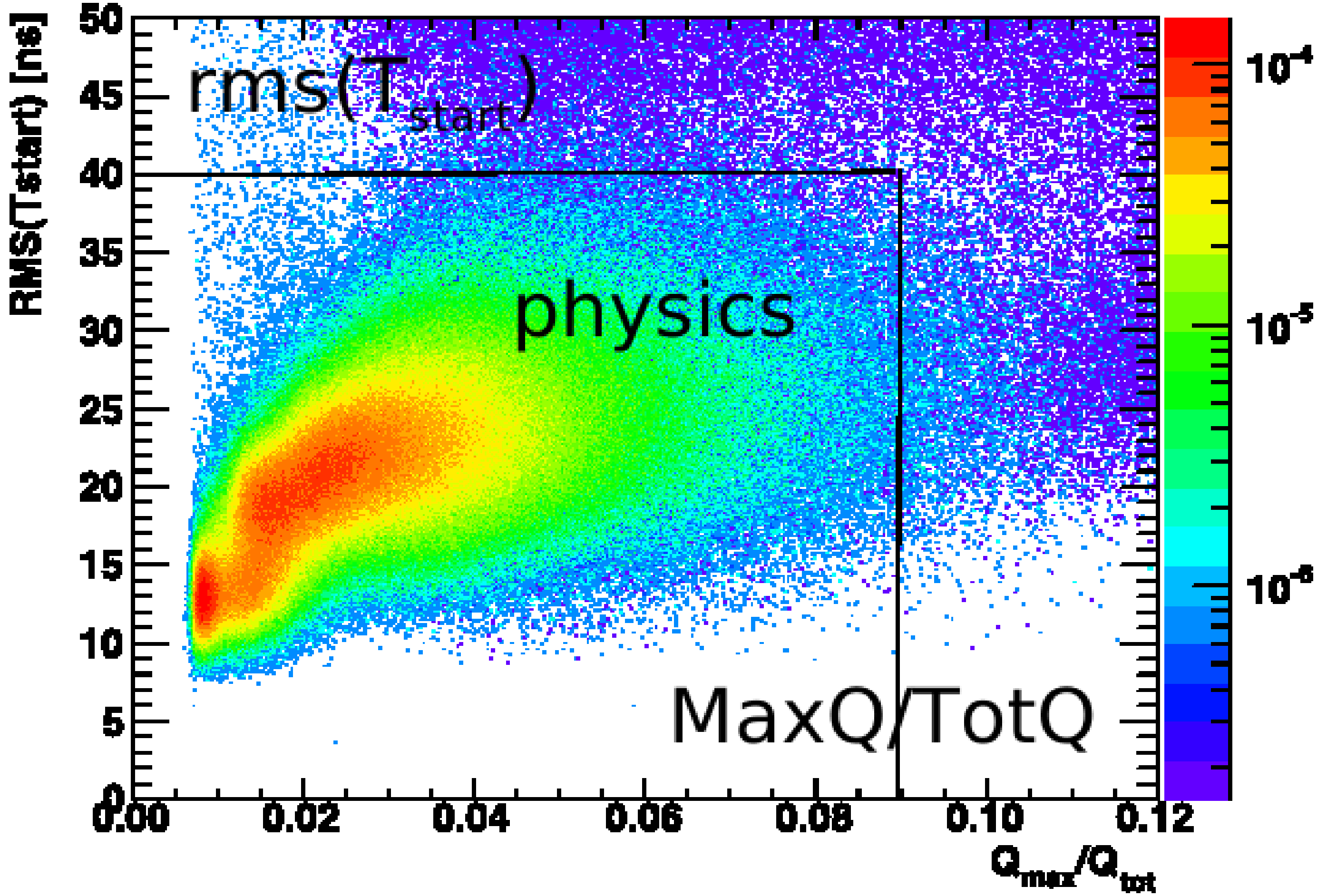
E_{prompt} = 26.5 MeV
ΔT = 2.2 ms
$\Delta T_{\mu(523\ MeV)}$ = 206 ms

detector stability



→ no sign of scintillator deterioration

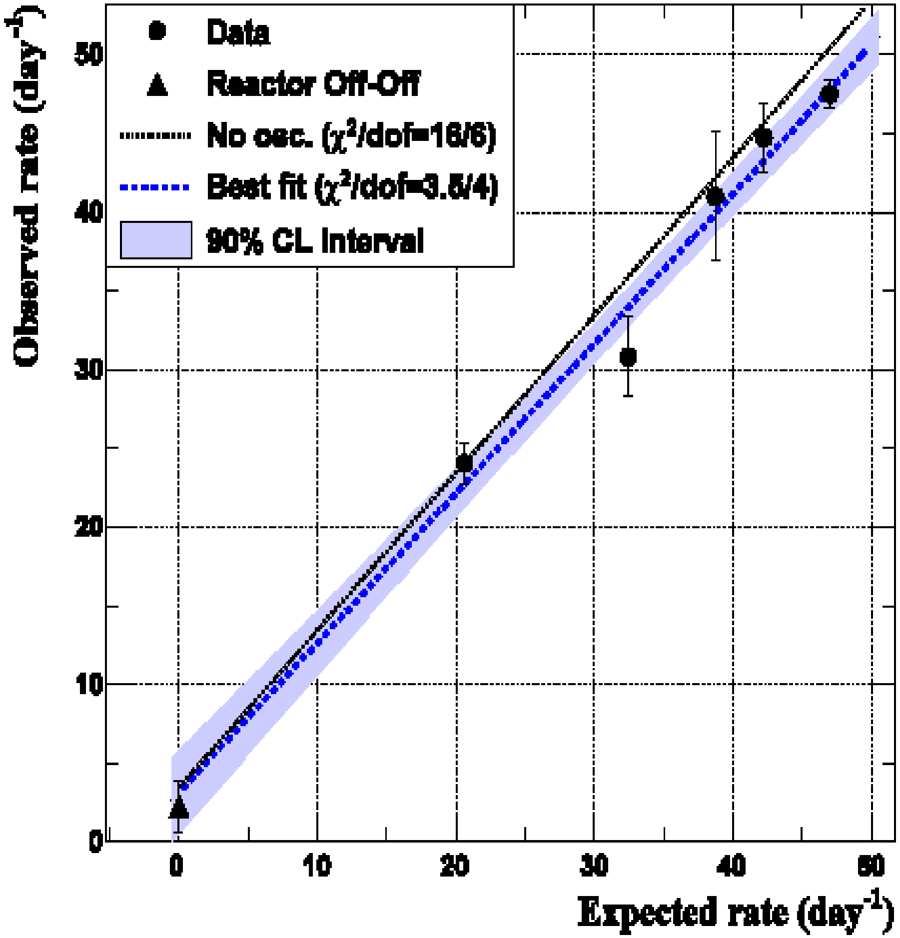
PMT spontaneous light emission cuts



- ensure light homogeneously spread across detector (Q_{max}/Q_{tot})
- ensure light arrives at approximately the same time (RMS_{Tstart} of hit time per PMT)

crosscheck: measured neutrino rate vs. expectation

- backgr. not substracted
- backgr. from fit consistent with our estimation
  3.2 ± 1.3 / day



Rate + Shape Fit:	$\sin^2 2\theta_{13} = 0.086 \pm 0.041(stat.) \pm 0.030(syst.)$
Rate Only Fit:	$\sin^2 2\theta_{13} = 0.104 \pm 0.030(stat.) \pm 0.076(syst.)$

final fit method

$$\chi^2 = \left(N_i - \left(\sum_R^{\text{Reactors}} N_i^{\nu,R} + \sum_b N_i^b(P_b)\right)\right) \times \left(M_{ij}^{\text{signal}} + M_{ij}^{\text{detector}} + M_{ij}^{\text{stat}} + \sum_b^{\text{bkgnds.}} M_{ij}^{\text{b}}\right)^{-1}$$

$$\times \left(N_j - \left(\sum_R^{\text{Reactors}} N_j^{\nu,R} + \sum_b N_j^b(P_b)\right)\right)^{\text{T}}$$

$$+ \sum_R^{\text{Reactors}} \frac{(P_R)^2}{\sigma_R^2}$$

$$+ \sum_b^{\text{bkgnds.}} \frac{(P_b)^2}{\sigma_b^2}$$

M_{ij}^{signal}: Signal covariance matrix.

M_{ij}^{detector}: Detector covariance matrix

M_{ij}^{stat}: Statistical covariance matrix.

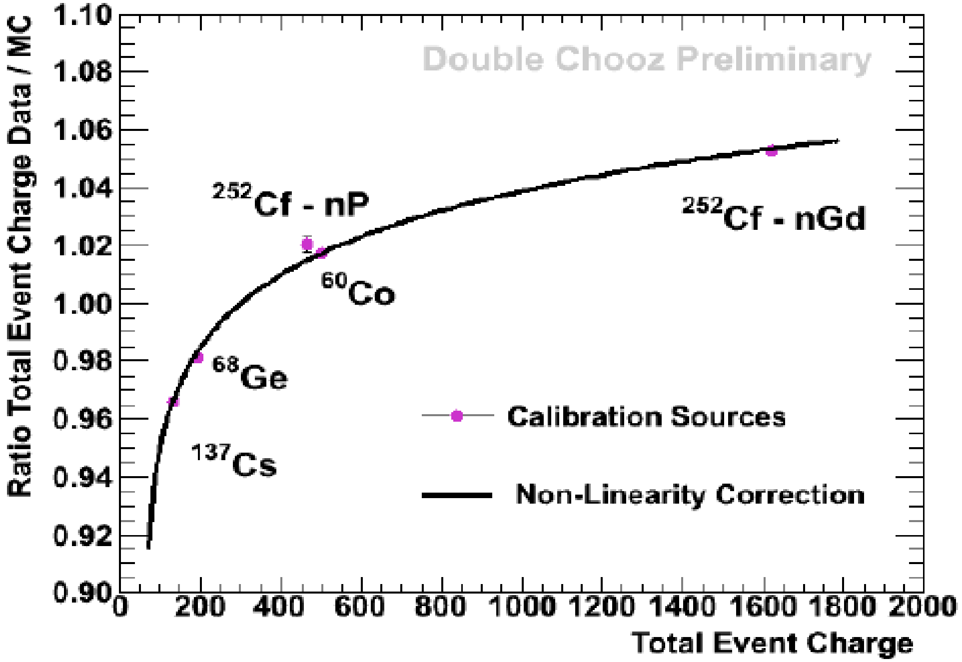
M_{ij}^{b}: Covariance matrix for background

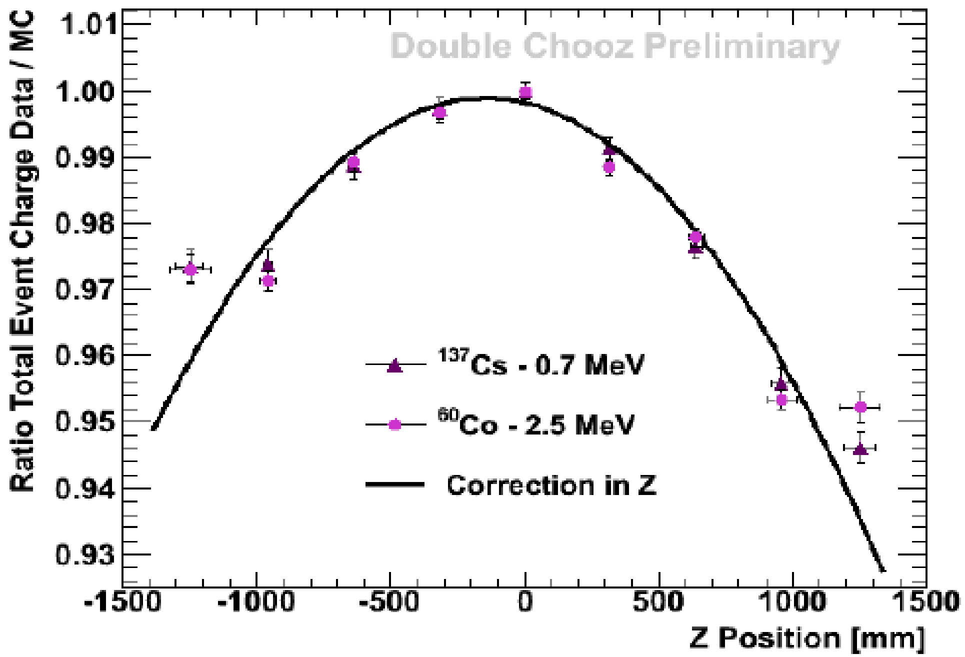
M_{signal} = accounts for conversion from neutrinos to positron spectrum (MC, reactor calculation)

$M_{detector}$ = accounts for remaining MC/ Data differences (detector effects)

$M_{backgr.}$ = spectral uncertainties of all backgrounds

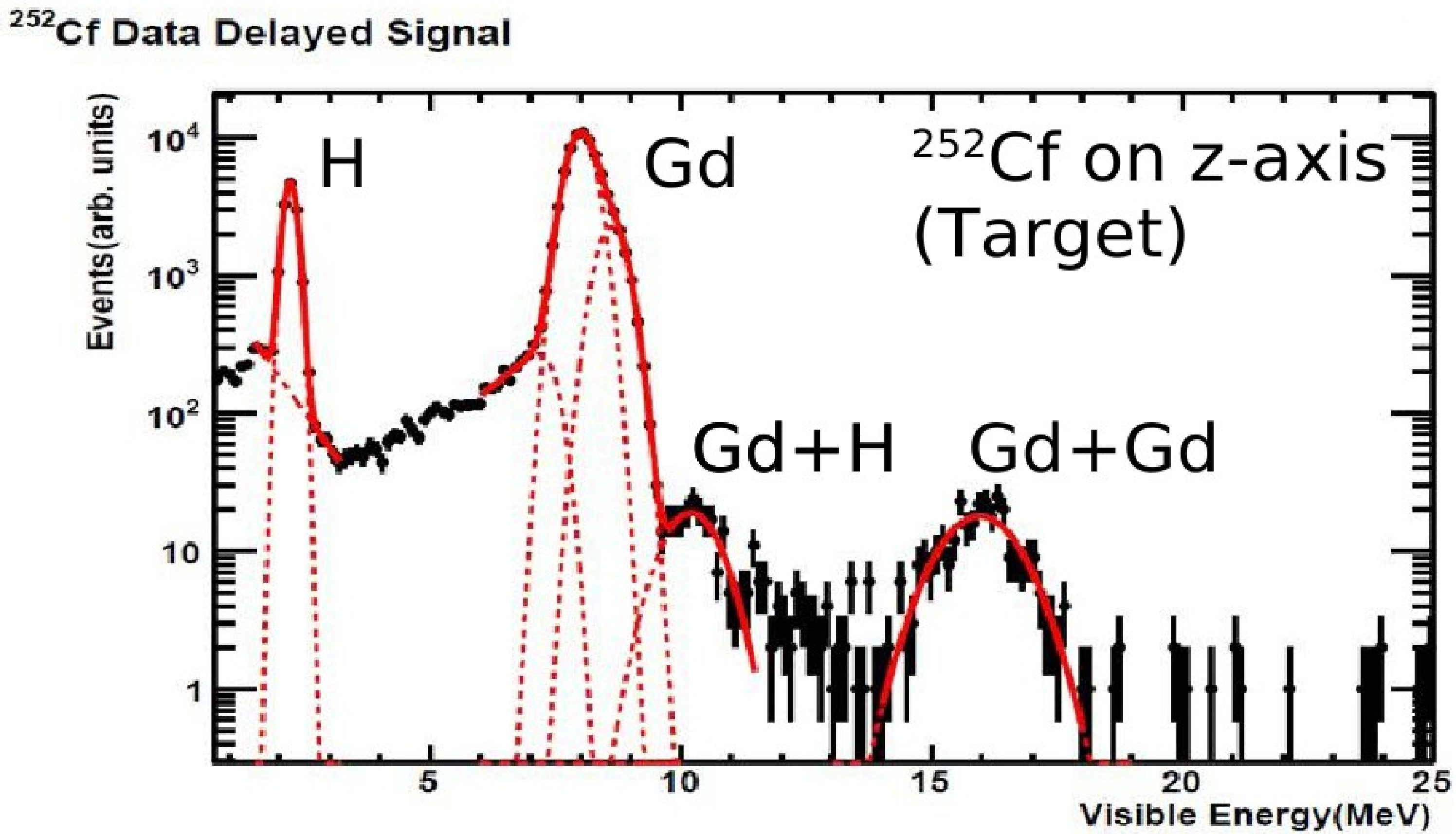
energy scale uncertainties





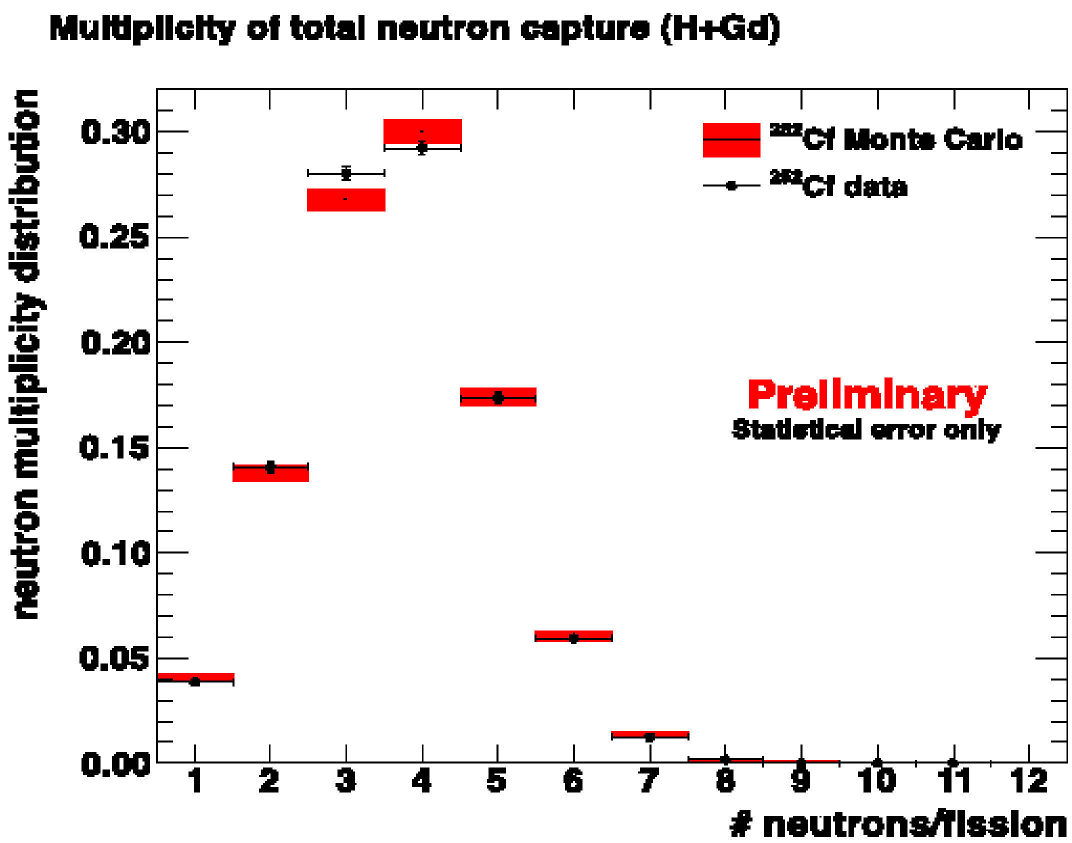
- use fit to phenomenological model to correct Data / MC differences
- correction included in covariance matrix

Gd fraction



- Gd fraction (Gd/ Gd+H) in target (data): 86 ± 0.6 %
- uncertainty estimated by Data / MC comparison

neutron multiplicity

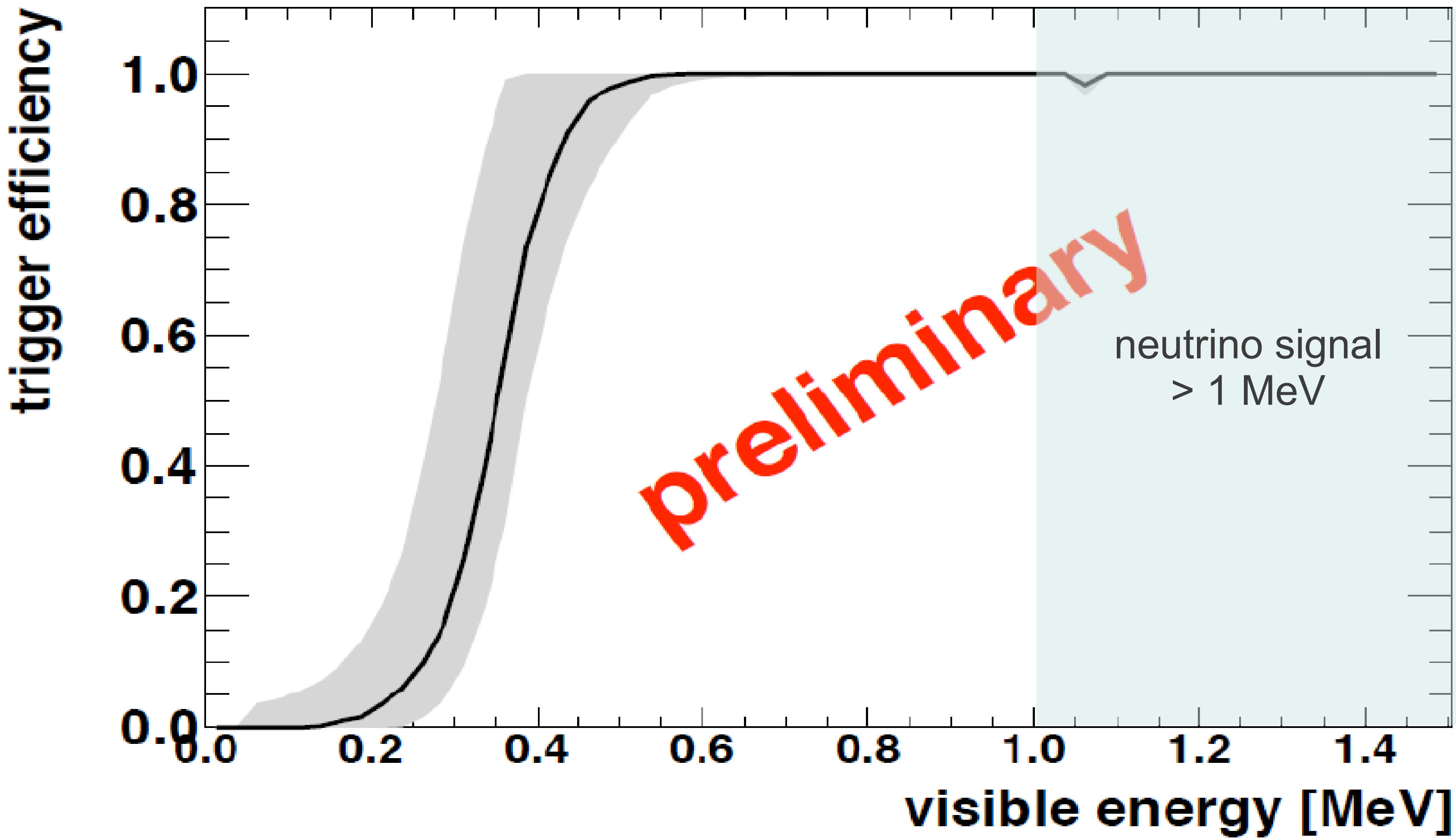


- used to verify neutron detection efficiency
- average neutron multiplicity:

DATA: 3.659 ± 0.008 (statistical)

MC: 3.677 ± 0.013 (statistical)

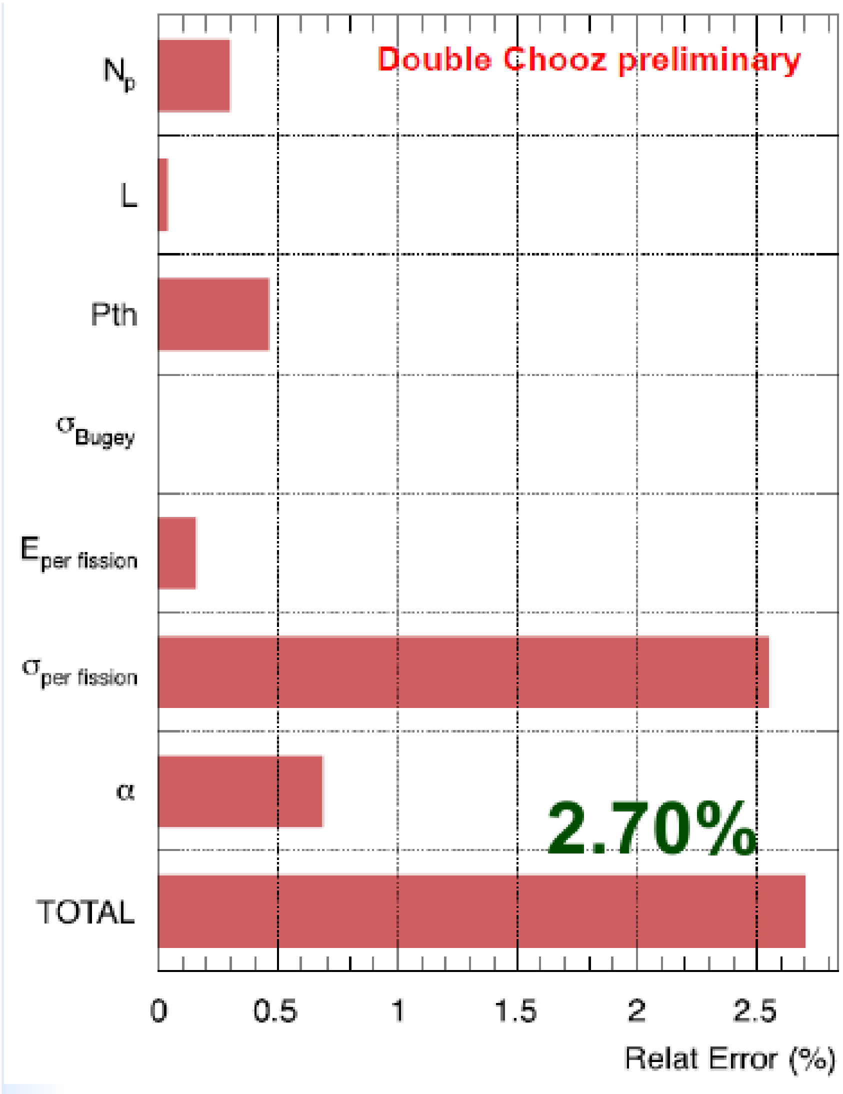
trigger efficiency



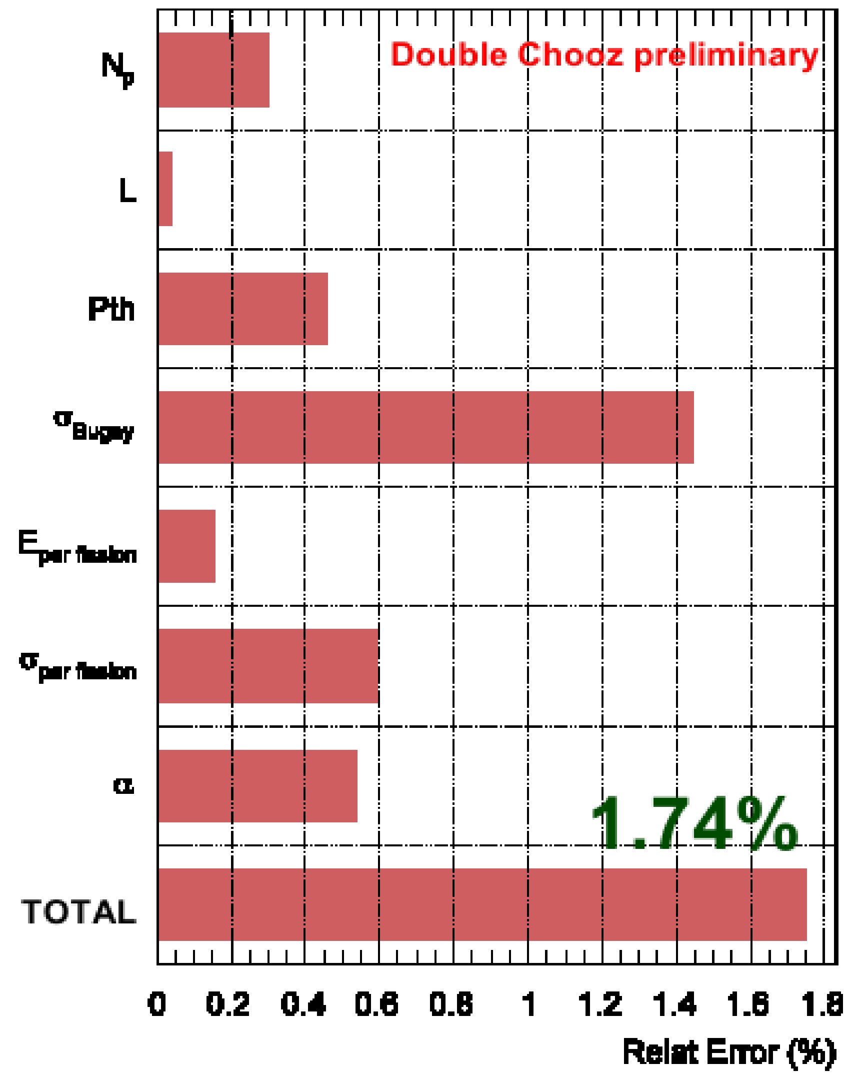
trigger efficiency above 700 keV: 1.000 +/- 0.004

errors on predicted ν-rate

Bugy4 works like a near detector as anchor point for FD only analysis
→ FD-only results less dependent on flux calculations or reactor anomaly effect

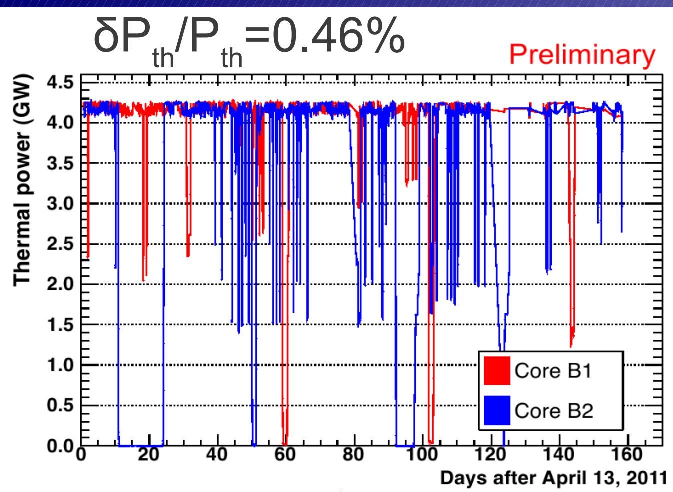


theoretical calulation



theoretical calulation
with Bugey4

predicted neutrino rate



- P_{th} continuously extracted from reactor data
- detailed simulation of core evolution (MURE & Dragon)
- normalization to Bugey4 σ_{ν} measurement (“use as ND”)

see: Th. A. Mueller et al, Phys.Rev. C83(2011) 054615
P.Huber, Phys.Rev. C84(2011) 024617

thermal power

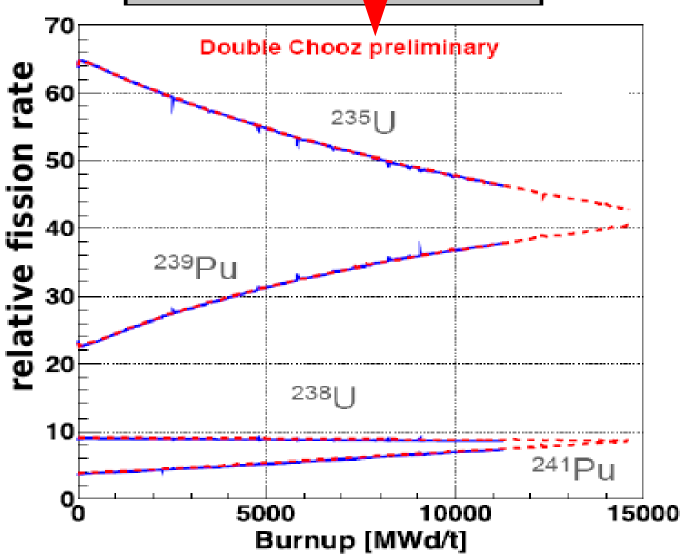
$$N_{\nu}^{exp}(E,t) = \frac{N_p\,\varepsilon}{4\,\pi\,L^2} * \frac{P_{th}(t)}{\langle E_f\rangle} * \langle\sigma_f\rangle$$

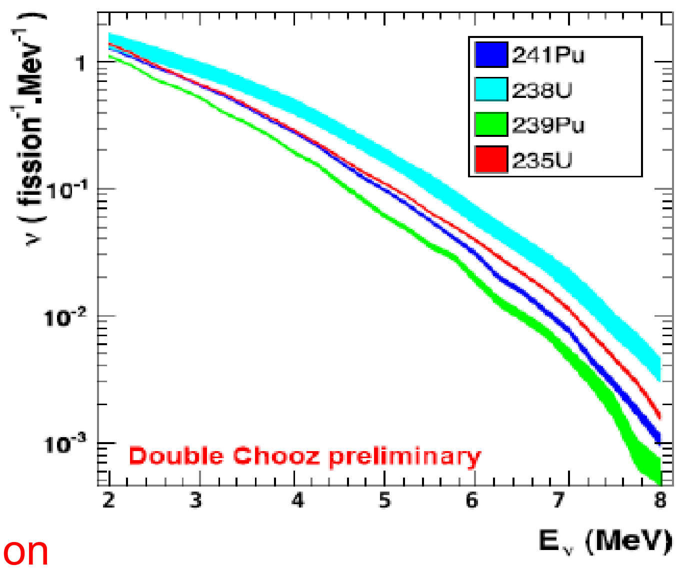
(k = ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu)

$$\langle E_f\rangle = \sum_k \alpha_k(t)\langle E_k\rangle$$

mean energy per fission

Bugey4 data as anchor point





mean cross section per fission

$$\langle\sigma_f\rangle = \langle\sigma_f\rangle^{Bugey} + \sum_k\left(\alpha_k^{DC}(t) - \alpha_k^{Bugey}(t)\right)\langle\sigma_f\rangle_k$$

$$\langle\sigma_f\rangle_k = \int_0^{\infty} dE\, S_k(E)\,\sigma_{IBD}(E)$$

milestones

- May 2008 – October 2010 → far detector construction
- December 2010 → far detector filling completed
- April 2011 → far detector commissioned
- April 2011 → start physics data taking with far detector
- April 2011 → near laboratory construction started
- July 2011 → outer veto commissioned
- November 2011 → first result @ LowNu 2011
- December 2011 → paper on arxiv:1112.6353, submitted to PRL
- March 2012 → paper published Y. Abe et al PRL 108, 131801, (2012)