SEEKING Θ_{13} WITH REACTOR NEUTRINOS

Simon JM Peeters

University of Sussex

CONTENTS

- What do we know about θ_{13}?
- Experimental scene
- $\bar{\nu}$ measurement at a reactor
  - Detailed experimental set-up:
- Status of Double Chooz
- Reno, Daya Bay
- Overview
- What else can you do with these?

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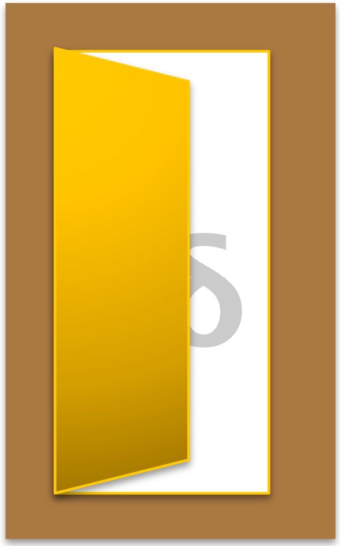
MOTIVATION

- *Fundamental physics parameter*
- *Determine the tactics to best address the search for CP violation in the electroweak sector*



Θ_{13}: portal to CP violation

E. Fiorini: doing "useless" things

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

θ_{atm} θ_{13}, δ θ_{sol}

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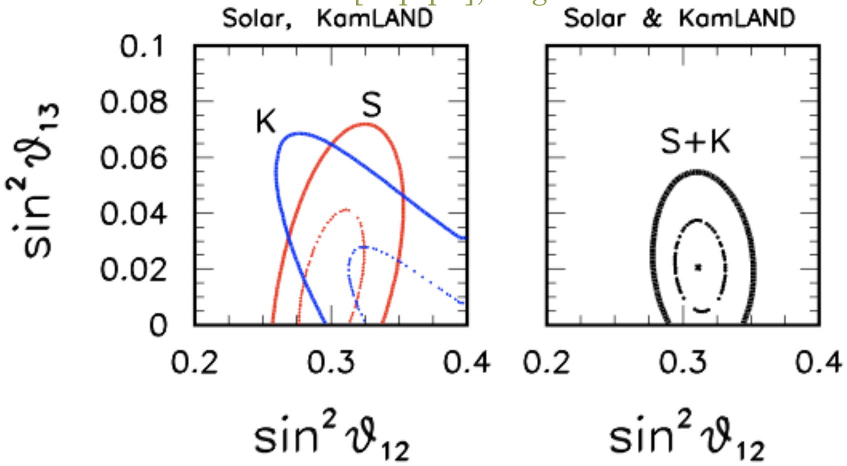
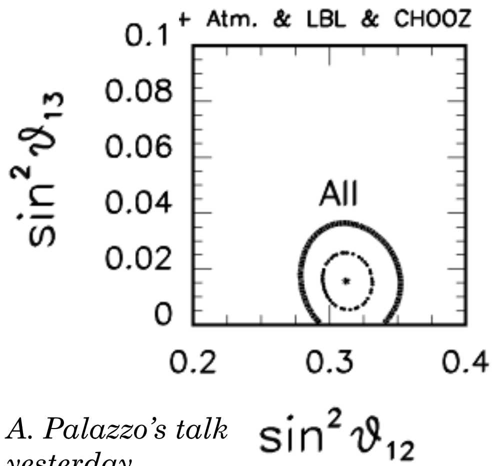
WHAT DO WE KNOW (EXP.) ABOUT θ_{13}

Global fit

ArXiv 0806.2649v1 [hep-ph], Fogli *et. al.*



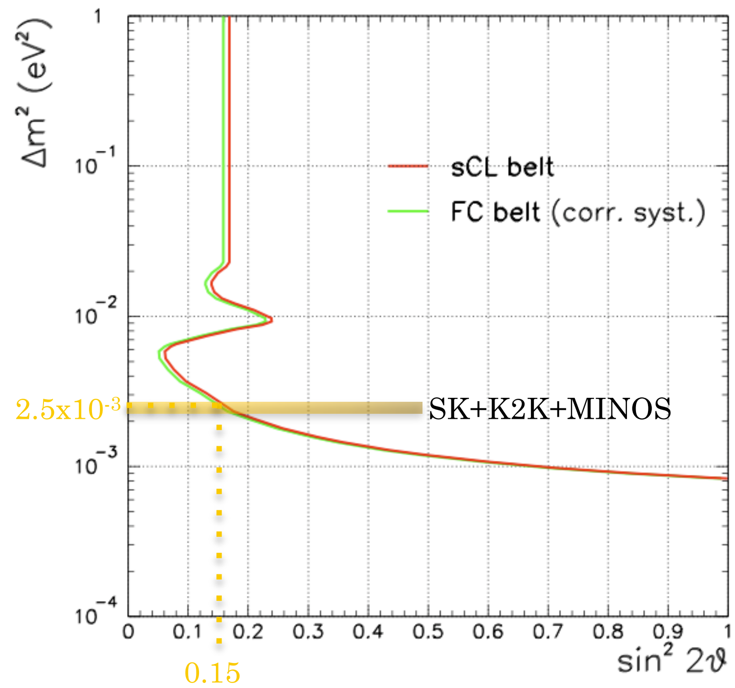


*A. Palazzo's talk yesterday_*

To be expected before first reactor data: improved analysis of solar data.

Direct measurement Chooz

ArXiv 0301017 [hep-ex]



To be expected before first reactor data: MINOS measurement see talk by Justin Evans

Experimental bias: $\sin^2 2\,\theta_{13} = 0.063 \pm 0.038$

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What do we know (th.) about Θ_{13}

Most models: $\theta_{13} > 0$

Many, many predictions…

Most models predict value close to the CHOOZ value.

Unnatural

Even if θ_{13} is zero, quantum corrections would make it non-zero at low energy

Theoretical bias: $\sin^2 2\theta_{13} > 0.01$

reactor neutrino white paper: arXiv:hep-ex/0402041v1

θ_{13} SCENE

Limits on θ_{13}:

$\sin^2 2\theta_{13} > 0.01$ (th),

$\sin^2 2\theta_{13} = 0.063 \pm 0.038$ (exo)

- T2K
- NOVA

- Double Chooz
- Daya Bay
- Reno
- Angra

See talks by
Hidekazu Kakuno &
Maury Goodman tomorrow

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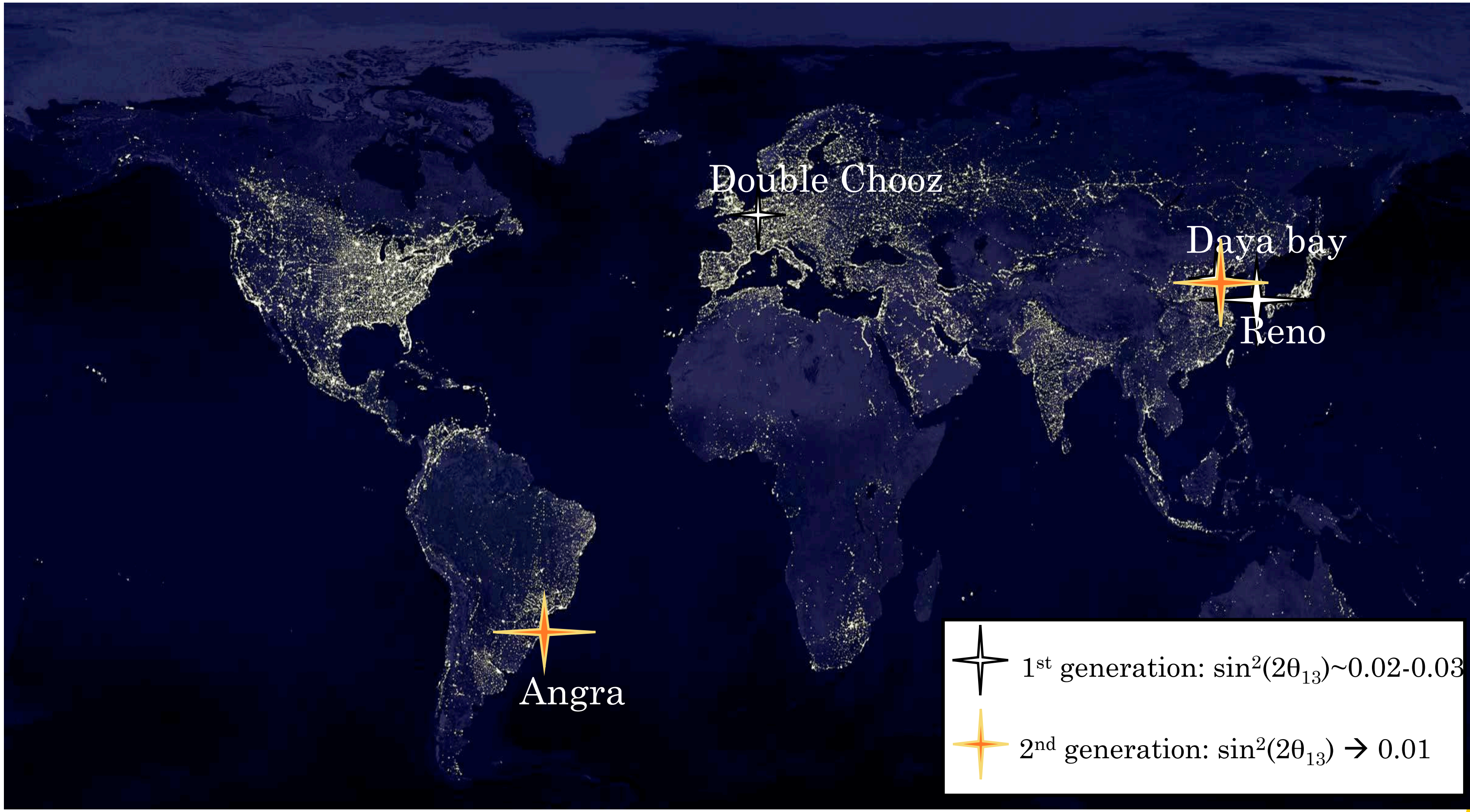
Global view of reactor experiments



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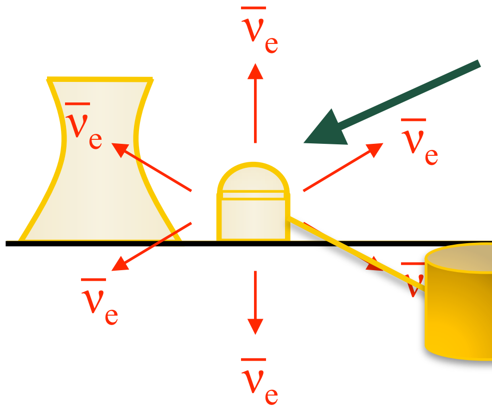
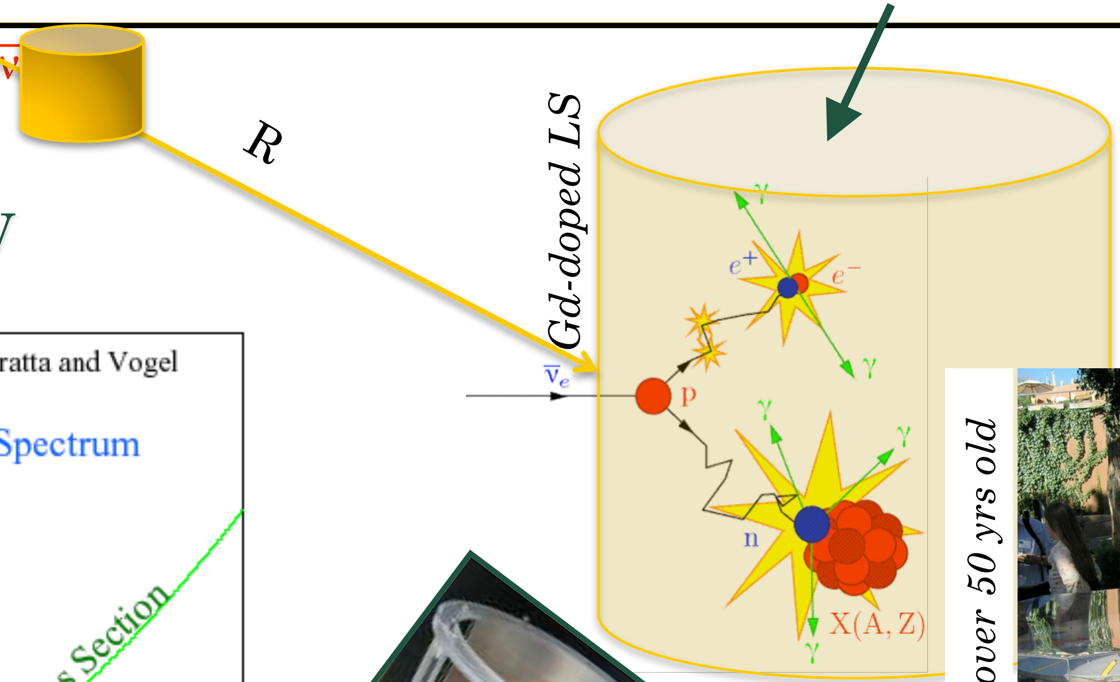
$\bar{\nu}$ MEASUREMENT AT A REACTOR

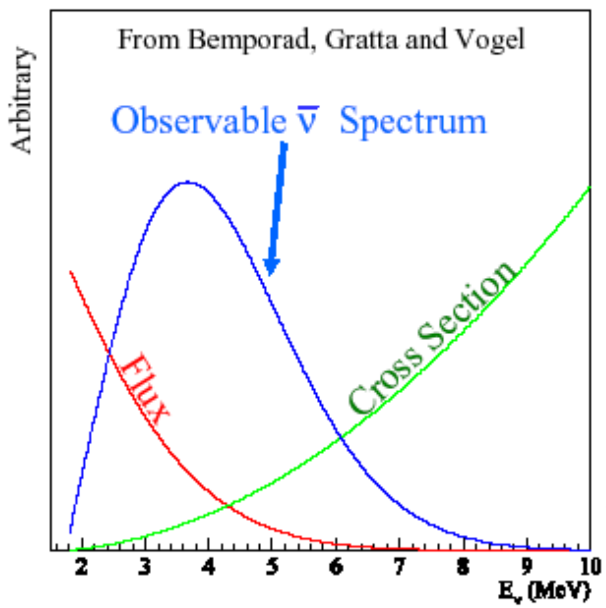


Well understood*, isotropic source of electron anti-neutrinos

Oscillations observed as **disappearance** of $\bar{\nu}_e$



$E_\nu \leq 8$ MeV



Design concept over 50 yrs old

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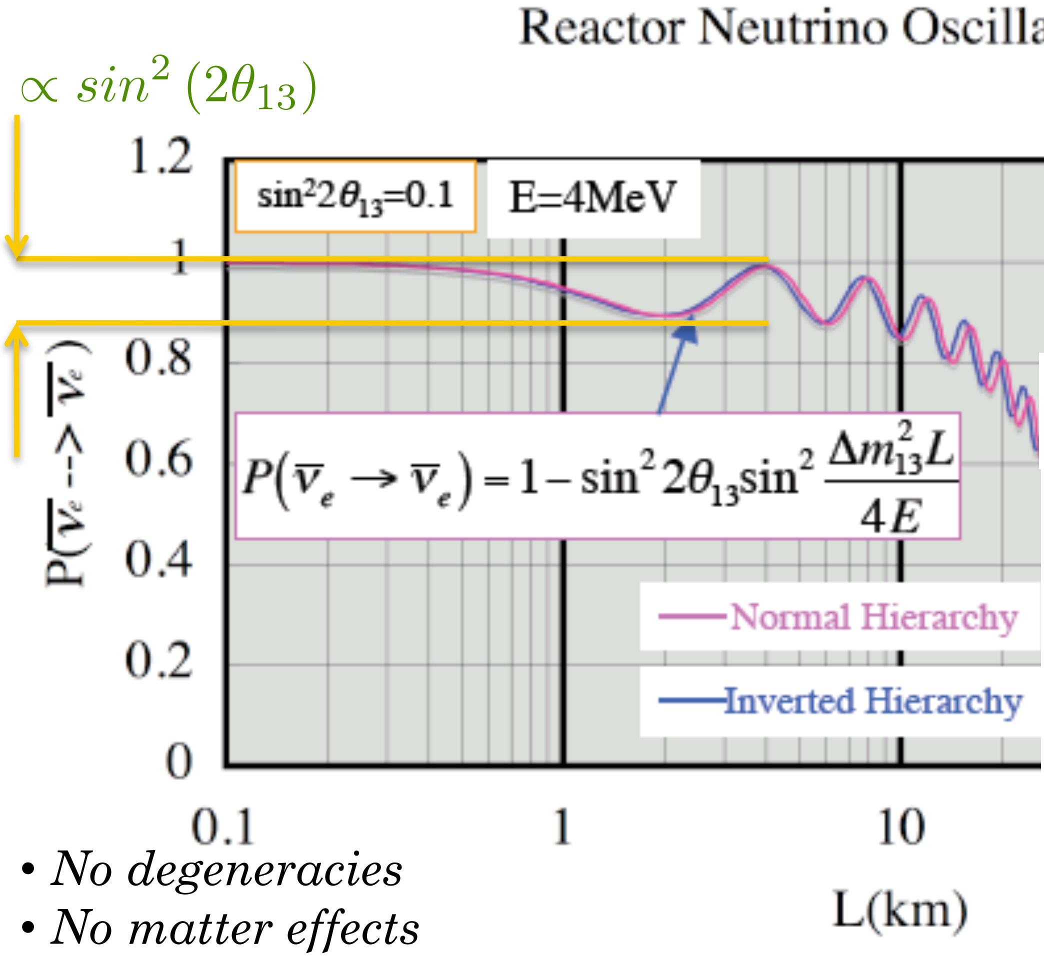
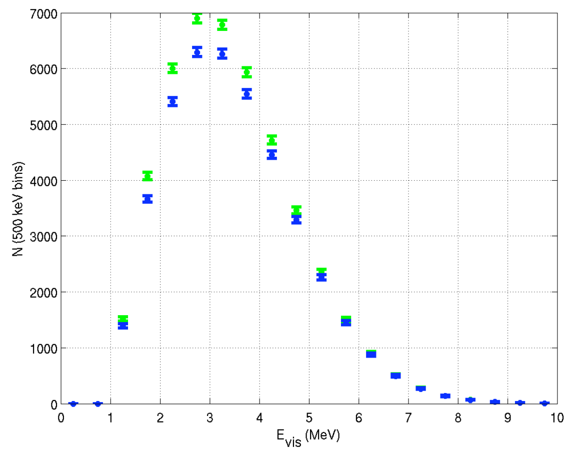
$\bar{\nu}$ MEASUREMENT AT A REACTOR



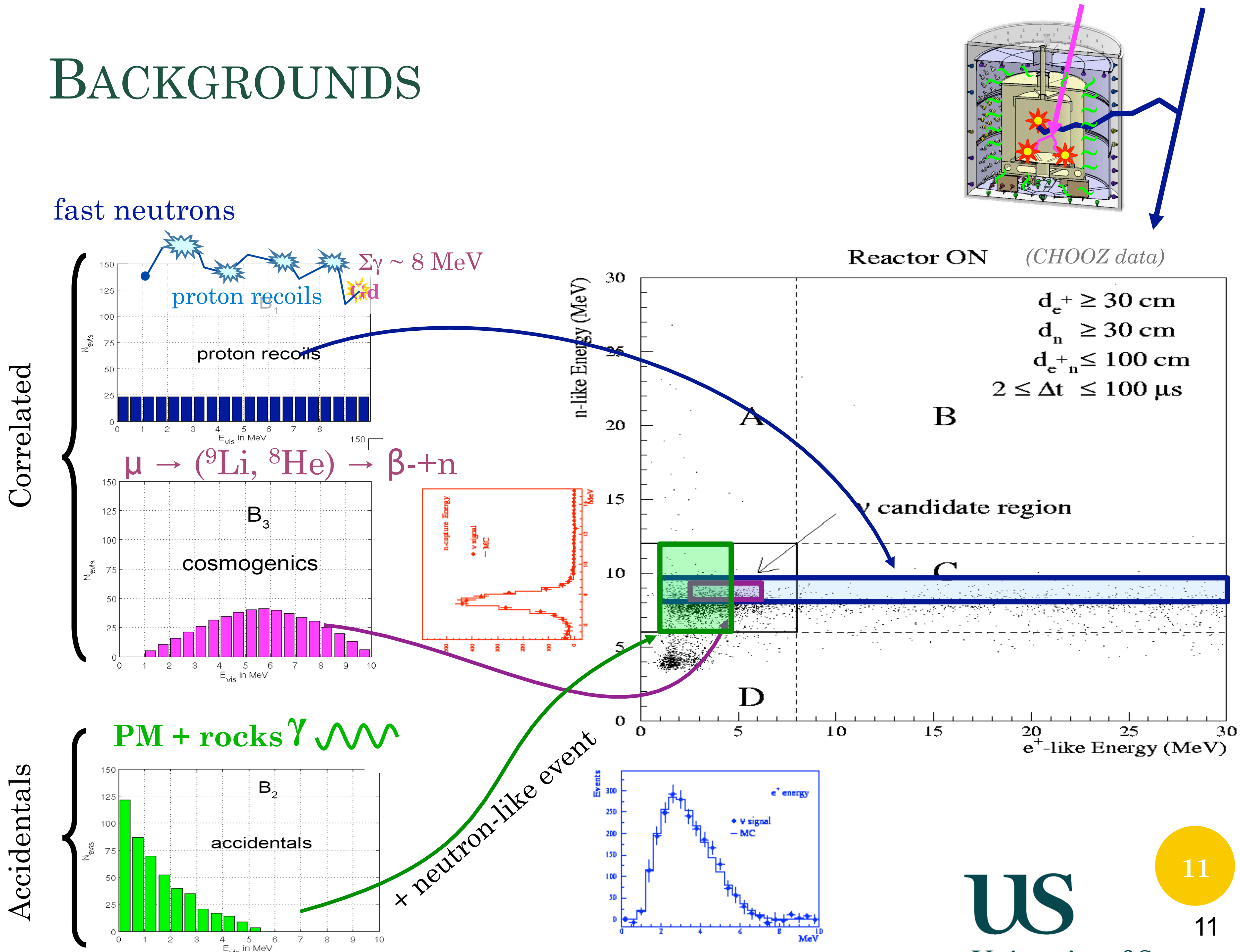
Spectral change: only small difference



- *No degeneracies*
- *No matter effects*
- *No correlations*
- *Great physics value for a relatively small amount of money*

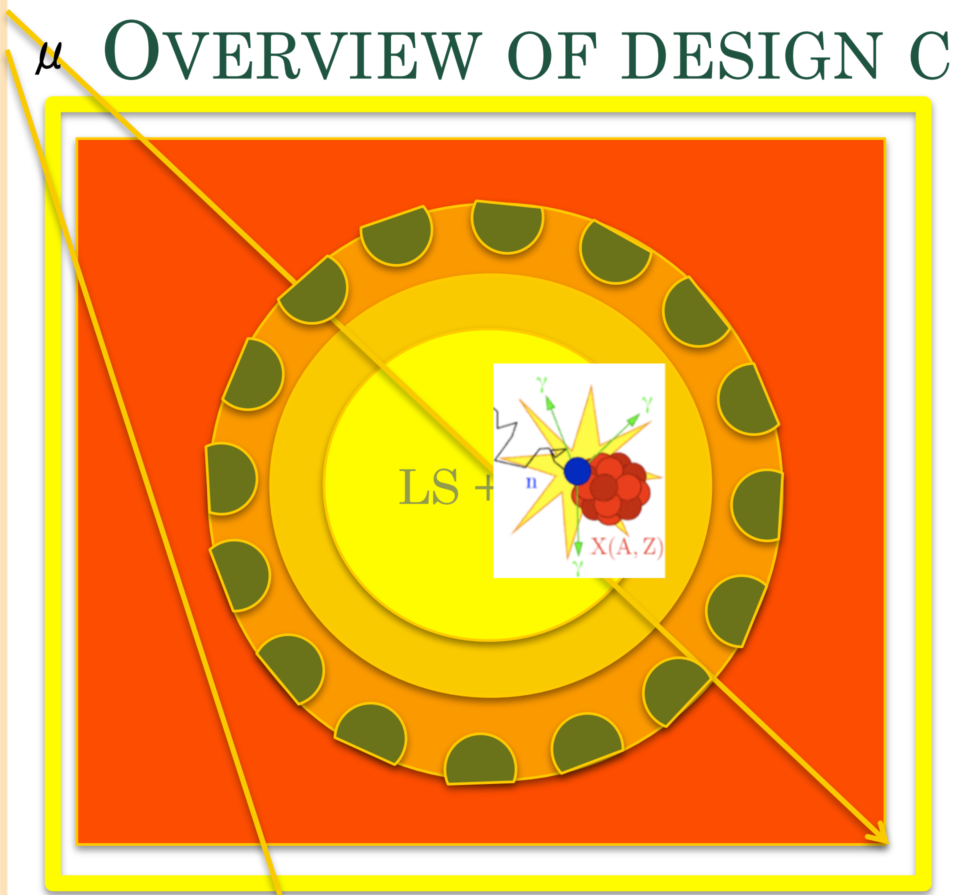
Double Chooz
3 yrs, $\sin^2 2\theta_{13} = 0.1$,
$\Delta m^2 = 2.5\times10^{-3}$
arXiv:hep-ex/0606025

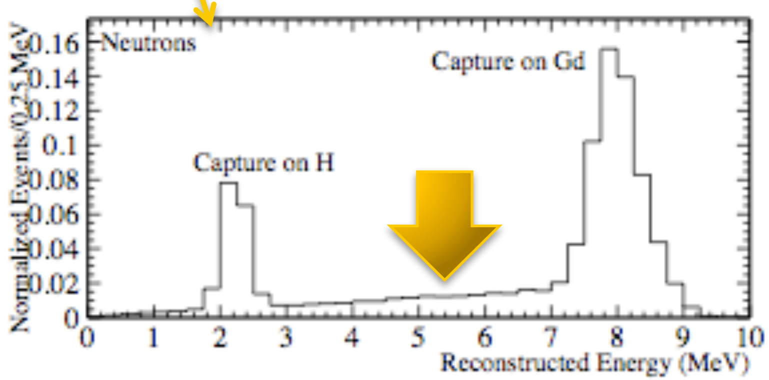
BACKGROUNDS



Slide: G. Mention

OVERVIEW OF DESIGN CONSIDERATIONS





- Keep geometry simple *(as simple as possible)*
- Light collection (energy resolution)
- Size matters: counting vs shape measurement
- Active muon shielding
- Depth: reduce muon rate
- Detect passing muons
- Gamma catcher
  - Catch escaping gammas from neutron captures on Gd: reduce tail
- Backgrounds
  - materials (Gd complex)
  - (PMT, rock) shielding
- Calibrate, calibrate…

DOUBLE CHOOZ COLLABORATION

France: APC Paris, CEA/Dapnia Saclay, Subatech Nantes, Strasbourg

Germany: Aachen, MPIK Heidelberg, TU München, EKU Tübingen

Spain: CIEMAT Madrid

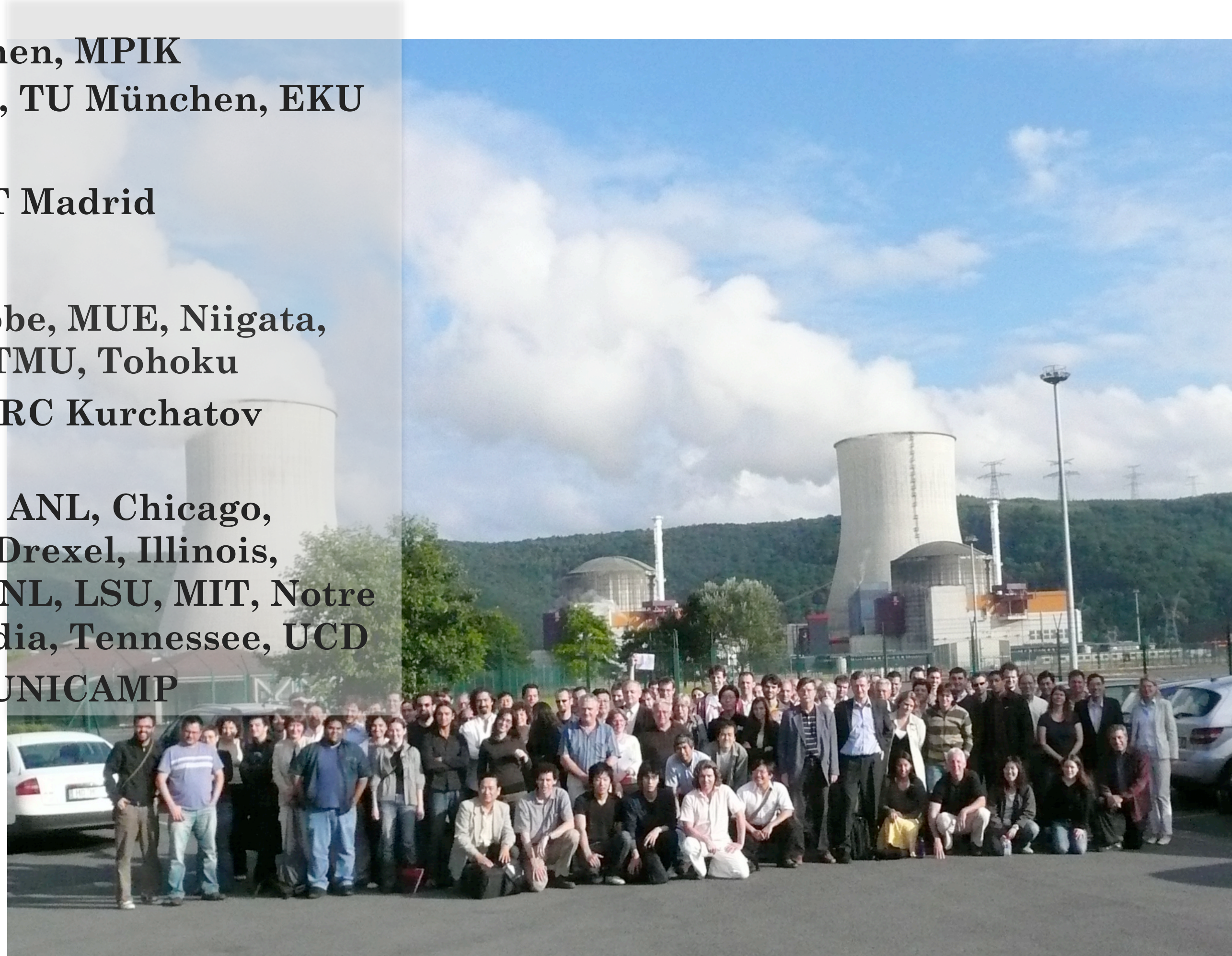
UK: Sussex

Japan: HIT, Kobe, MUE, Niigata, TGU, TIT, TMU, Tohoku

Russia: RAS, RRC Kurchatov Institute

USA: Alabama, ANL, Chicago, Columbia, Drexel, Illinois, Kansas, LLNL, LSU, MIT, Notre Dame, Sandia, Tennessee, UCD

Brazil: CBPF, UNICAMP



Collaboration meeting June 2008

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IMPROVING THE CHOOZ MEASUREMENT

Chooz result: $R_{\text{near/far}} = 1.01 \pm 2.8\%(stat.) \pm 2.7\%\ (syst.)$

Statistical error

Statistical error: 0.5%

Error Description	CHOOZ	Double Chooz	
	Absolute	Absolute	Relative
Reactor			
Production cross section	1.90 %	1.90 %	
Core powers	0.70 %	2.00 %	
Energy per fission	0.60 %	0.50 %	
Solid angle/Bary. displct.			0.07 %
Detector			
Detection cross section	0.30 %	0.10 %	
Target mass	0.30 %	0.20 %	0.20 %
Fiducial volume	0.20 %		
Target free H fraction	0.80 %	0.50 %	
Dead time (electronics)	0.25 %		
Analysis (paticle id.)			
e^+ escape (D)	0.10 %		
e^+ capture (C)			
e^+ identification cut (E)	0.80 %	0.10 %	0.10 %
n escape (D)	0.10 %		
n capture (% Gd) (C)	0.85 %	0.30 %	0.30 %
n identification cut (E)	0.40 %	0.20 %	0.20 %
$\bar{\nu}_e$ time cut (T)	0.40 %	0.10 %	0.10 %
$\bar{\nu}_e$ distance cut (D)	0.30 %		
unicity (n multiplicity)	0.50 %		
Total	**2.72 %**	**2.88 %**	**0.44 %**

ArXiv 0704.0498v2 [hep-ex]

Systematical error

- Two detector concept: near/far
- Fiducial volume defined by mechanics
- Stability of Gd-doped LS
- Calibration

… and more in careful design…

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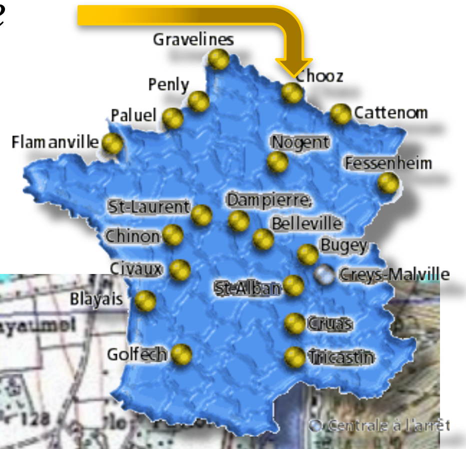
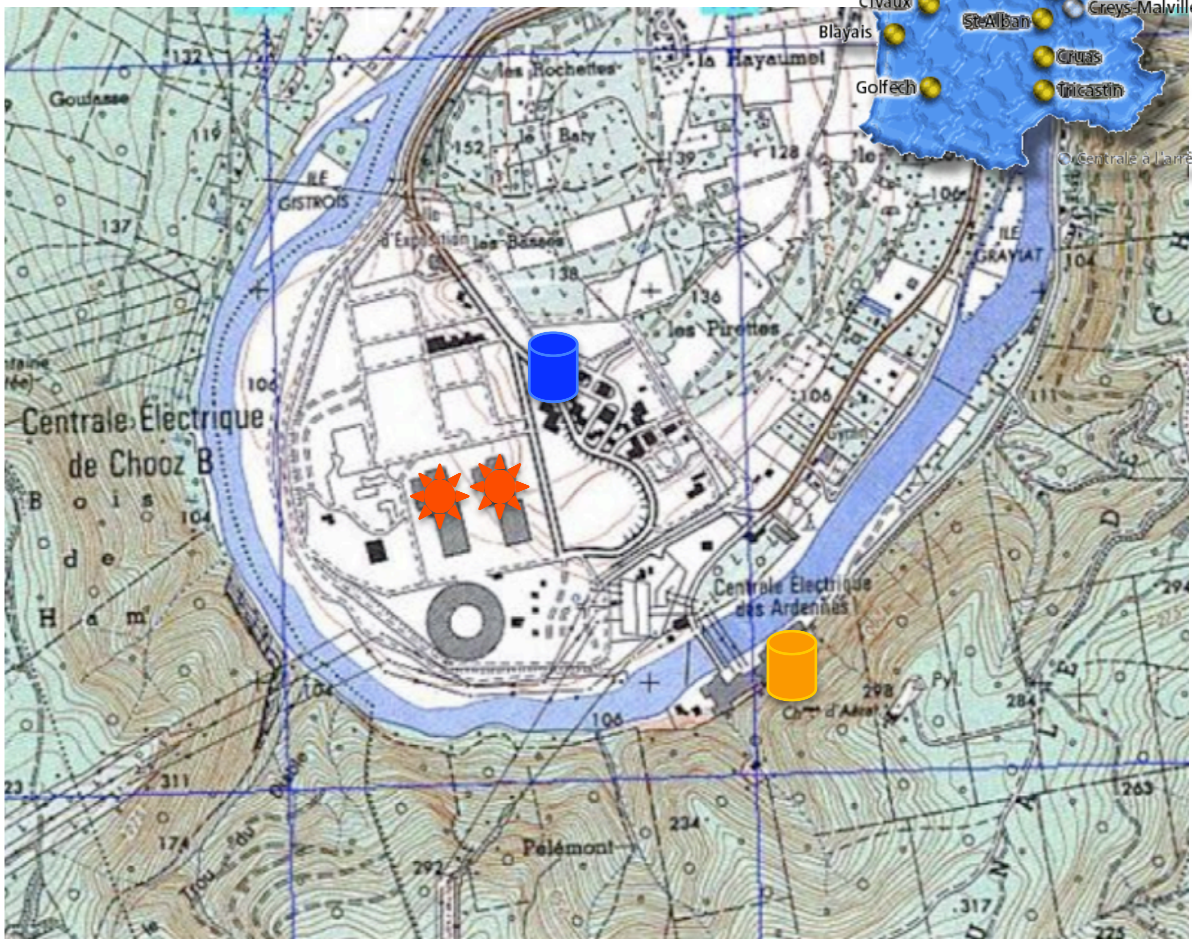
DOUBLE CHOOZ OVERVIEW

Les Ardennes, France





Existing (Chooz) pit at far detector

2 cores:

8.5 GW_{th}

Near detector:

|D| ~ 400 m

Overburden ~115 m.w.e.

(flat topology)

Far detector:

D ~ 1.05 km

Overburden ~300 m.w.e.

(hill topology)

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Chooz:
A very attractive place to visit

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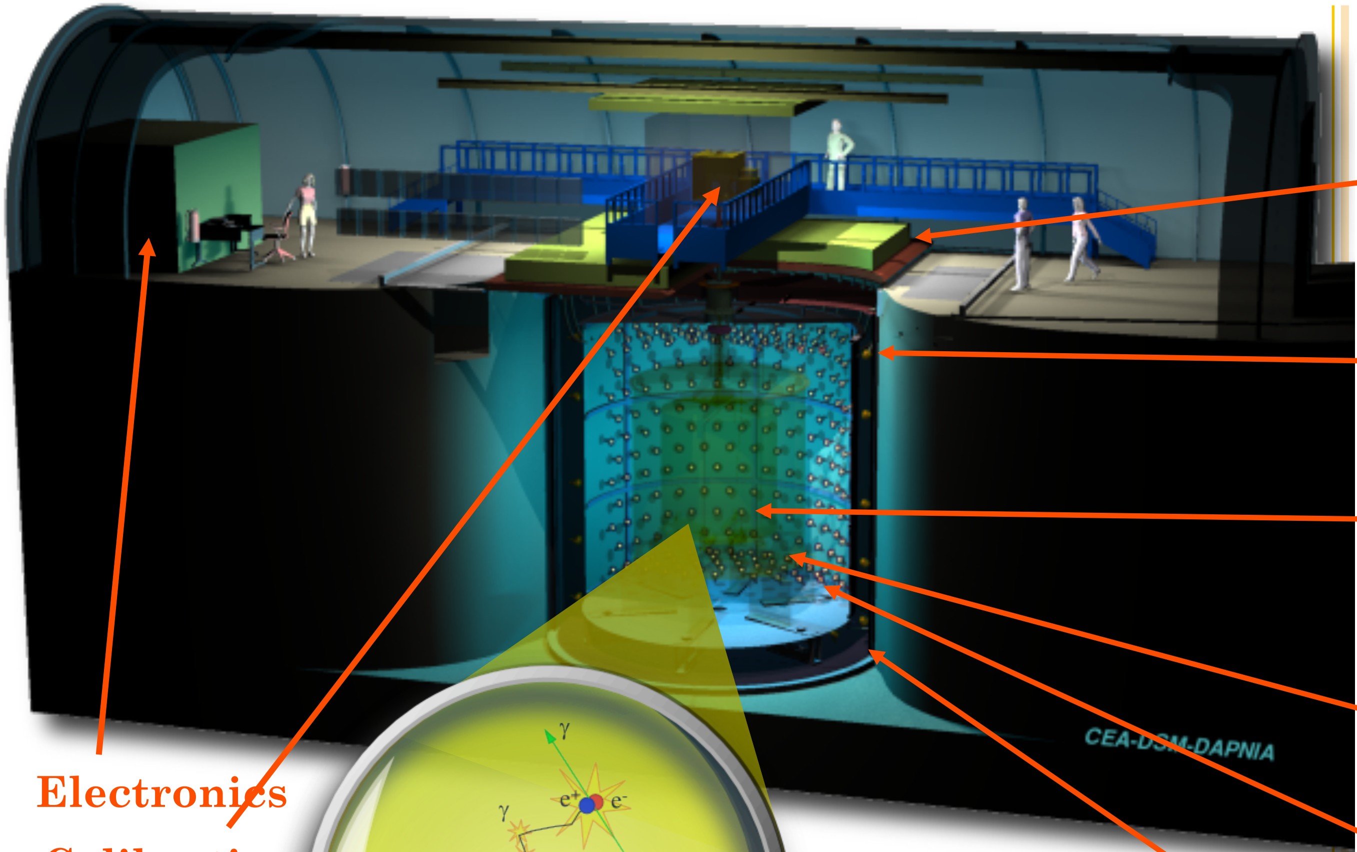

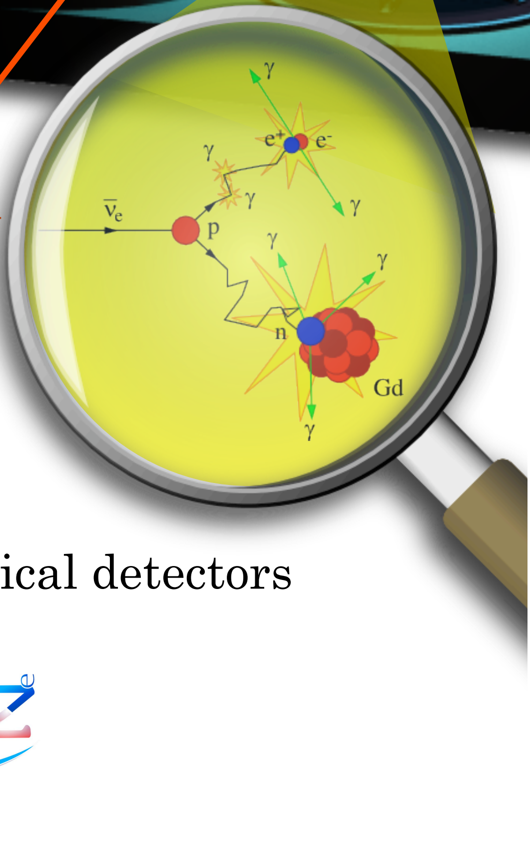

Far detector

Two identical detectors

Outer Veto:
plastic scintillator panels
(only partly shown)

Shielding:
15 cm steel

4 liquid volumes:

ν-Target:
10.3 m³ liquid scintillator doped with 0.1% Gd

γ-Catcher:
22.6 m³ liquid scintillator

Buffer:
114 m³ mineral oil with ~400 PMTs

Inner Veto:
90 m³ liquid scintillator with 80 PMTs

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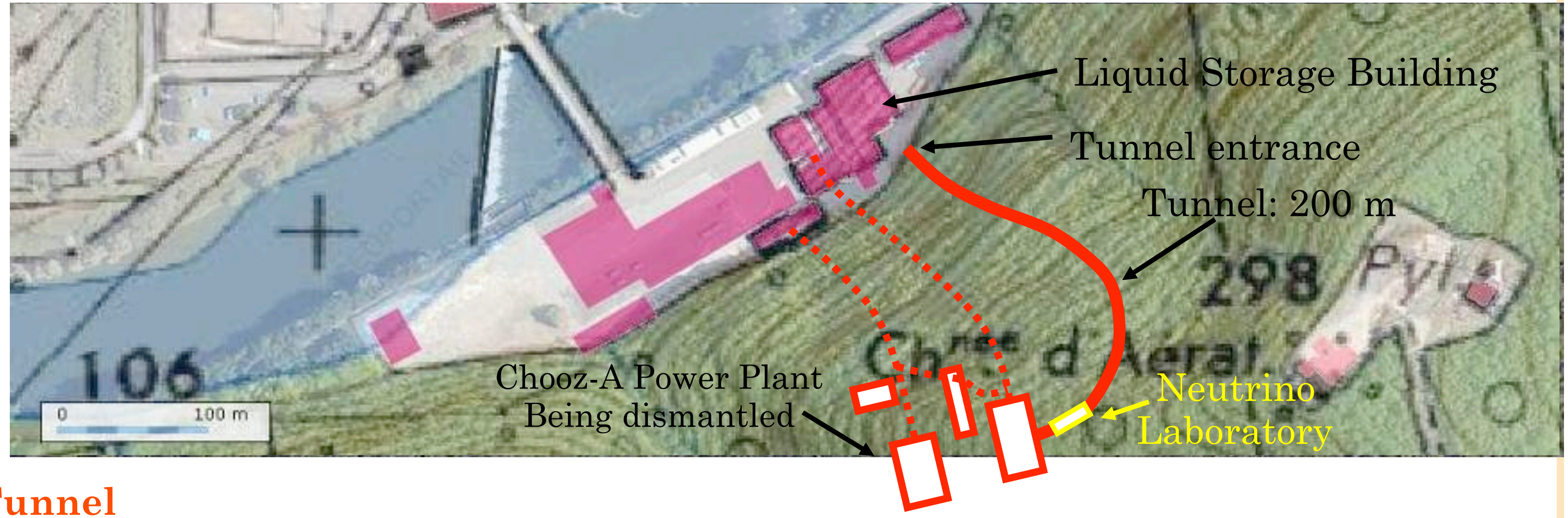
Status far site



Tunnel

200 meters @10%

New ventilation, doors, safety, …

Liquid storage building

Being upgraded

First liquids *next week*

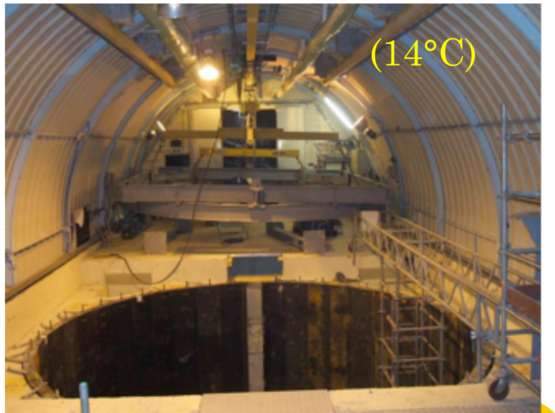
Neutrino laboratory

1.05 km baseline (50 day^{-1})

300 m.w.e., μ-Rate: ~20 Hz

Fire security, pit refubrished

Demagnetization and integration of γ shielding:



Installed

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STATUS NEAR SITE

Laboratory site

~400 m from nuclear cores (500 day^{-1})

115 m.w.e (almost flat topology)

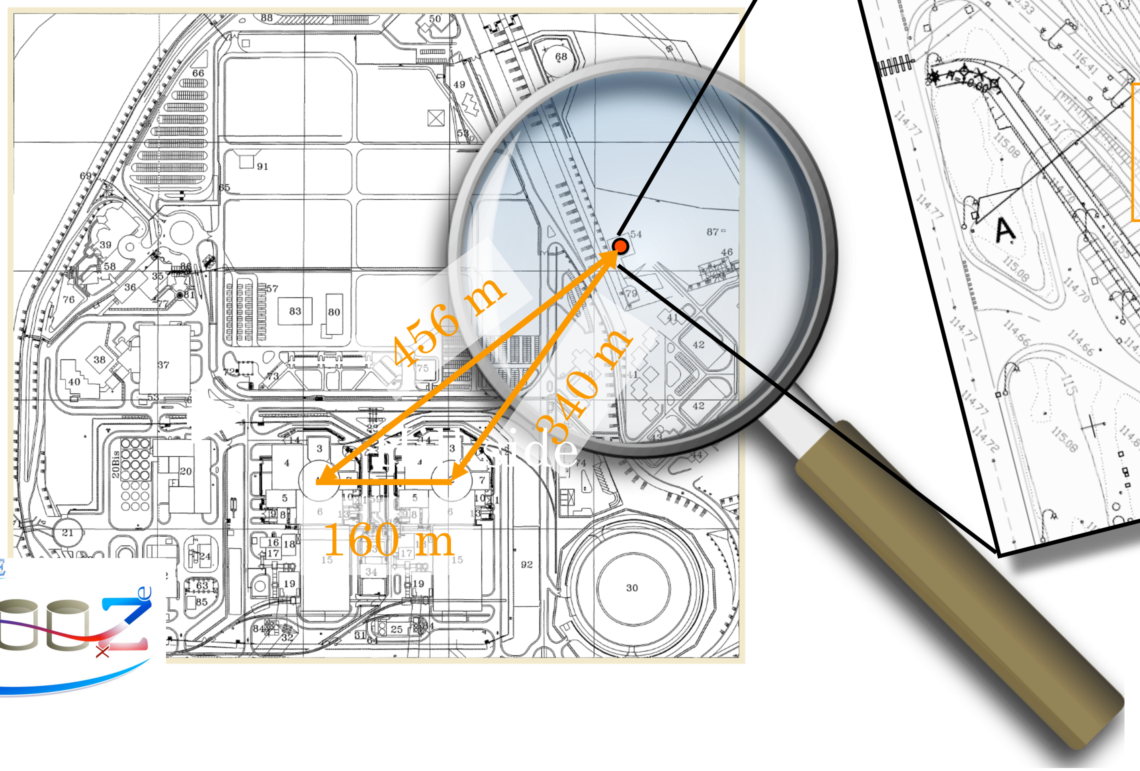
μ-Rate: ~250 Hz @IV

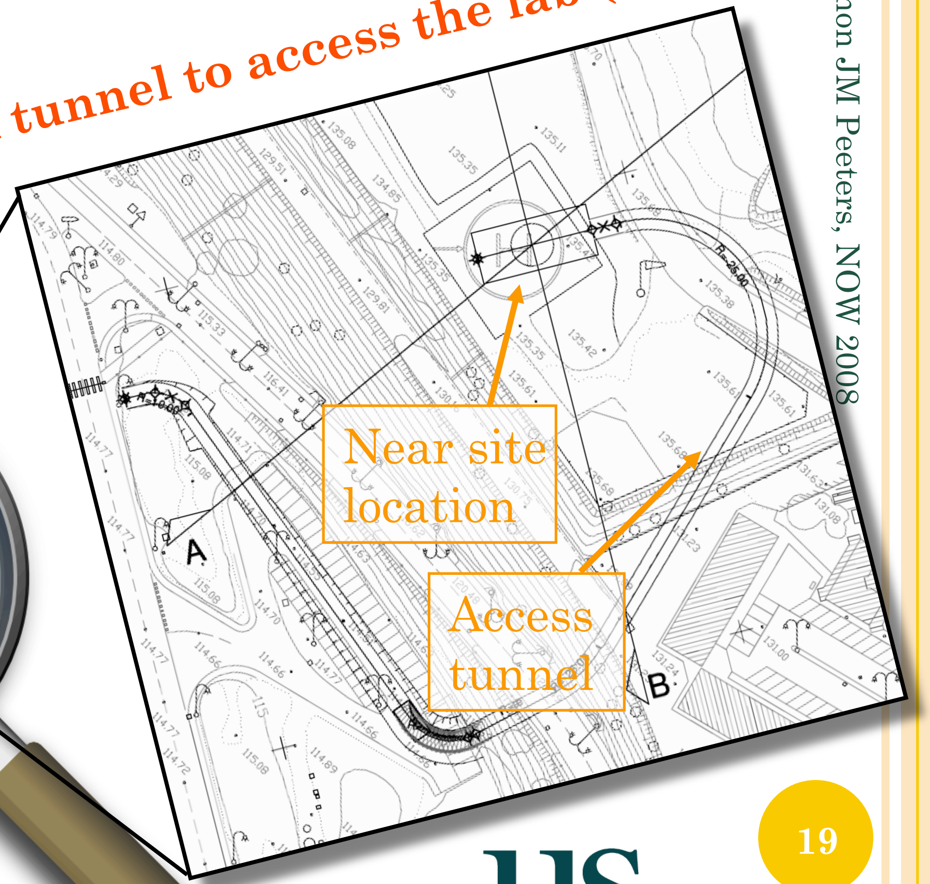
Site Engineering Study Completed

Tender process for construction soon

Laboratory is expected to be finished at the end of 2009

A tunnel to access the lab (no shaft)



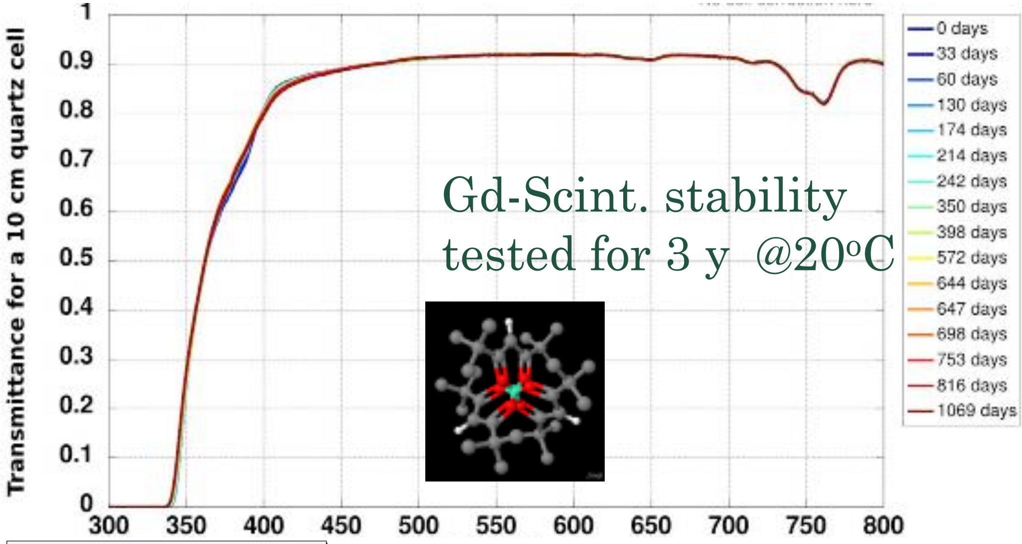


TARGET SCINTILLATOR

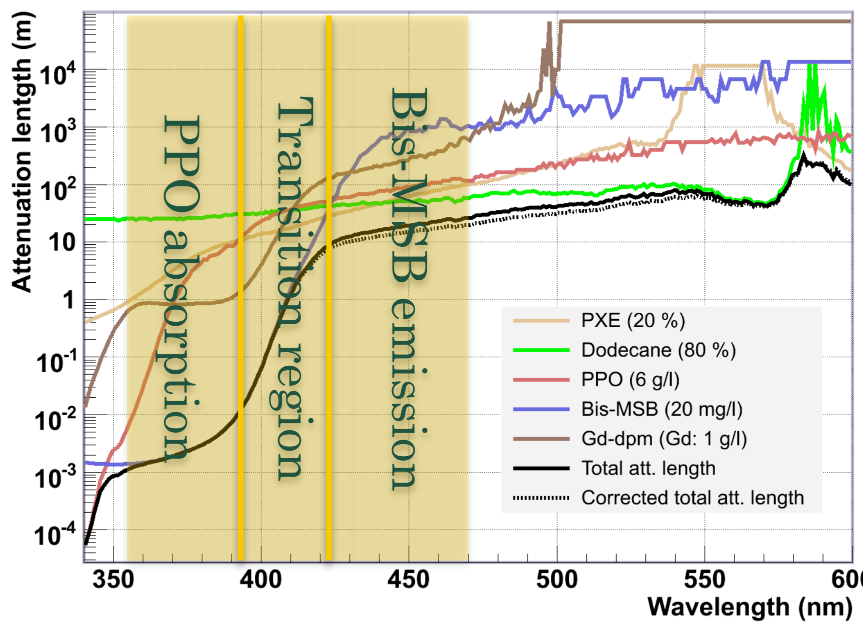
DC development

Long-term stability crucial
CHOOZ saw fast degradation of scintillator

- *Solvent*
  20% PXE + 80% dodecane
- *Fluors*
  PPO + bisMSB
- Gd loading (1 g/l)
  (via beta-diketonate)
  - Light yield:
    ~7000 photons/MeV
  - Attenuation length:
    10 m at 420 nm
  - No degradation observed after three years



Attenuation lengths

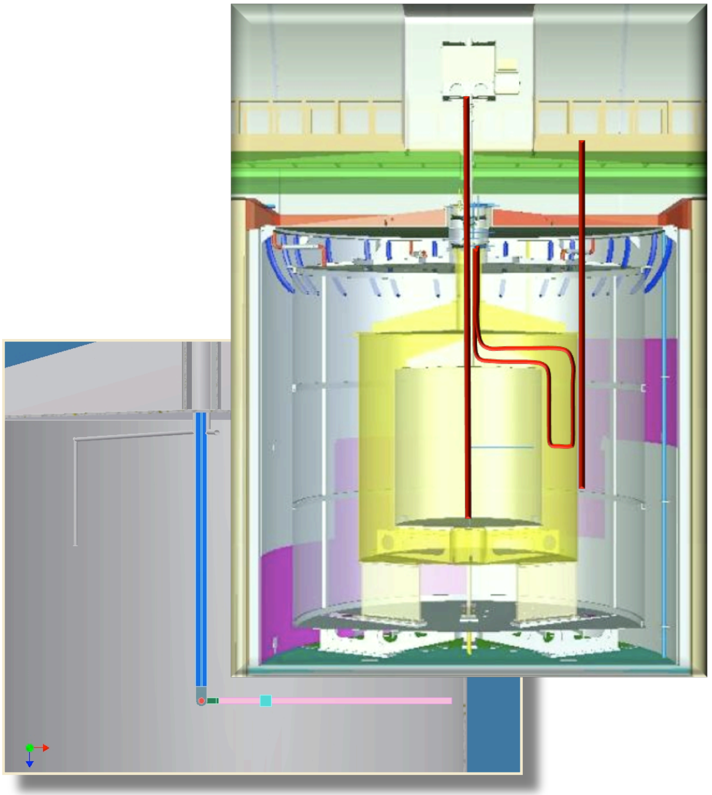


same scintillator batch for both detectors

CALIBRATION PROGRAM

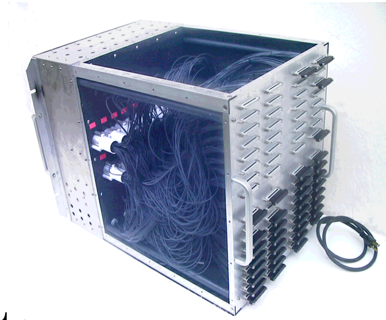
Deployable sources

- Access to LS via glovebox
- Fish-line & articulated arm
- γ-catcher and buffer guide tubes

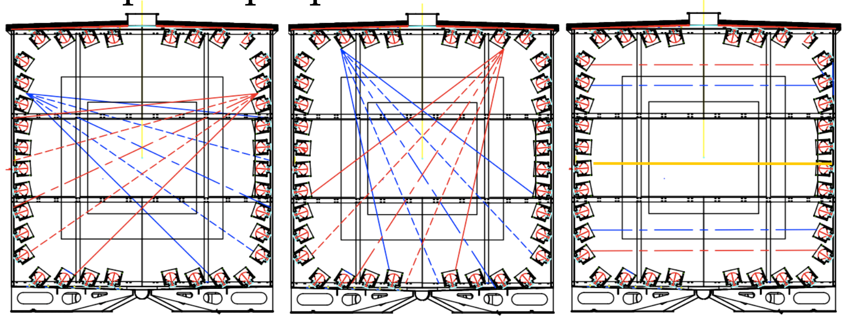


Continuous monitoring: embedded LED system

- LED pulser box (MINOS-based) with fibres leading into detector



- 46 light-injection points
- 3 wavelengths: 385 nm, 425 nm, 485 nm
- Monitor: PMT gains, linearity, timing
- Monitor: optical properties of fluids



(Inner veto will have similar system)

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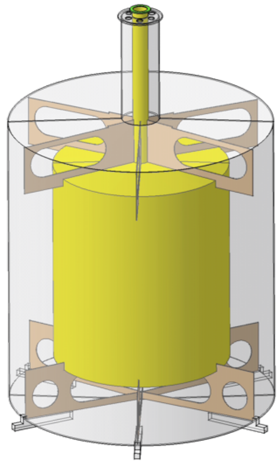
Liquid containment & handling

New scintillator hall built at MPIK

1/5 mock-up @ Saclay

3 iso-containers

installation tools



Acrylic vessels

- *Target : 8 mm, γ catcher : 12 mm*
- *R&D & Design completed*
- *Customised acrylic batch*
- *Tender ongoing*

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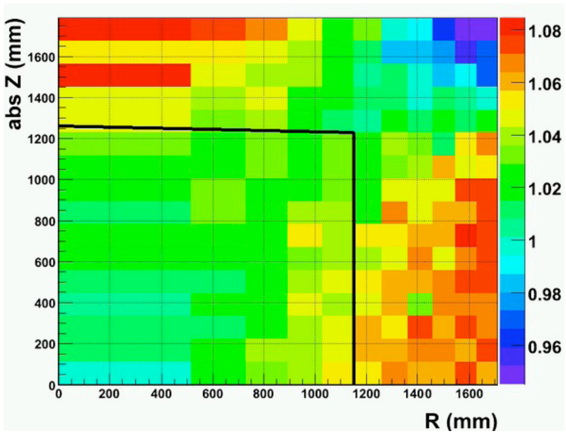
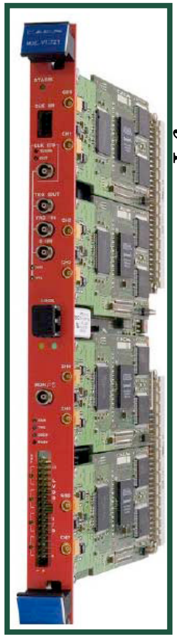
(Some of the) measures to reduce systematic errors

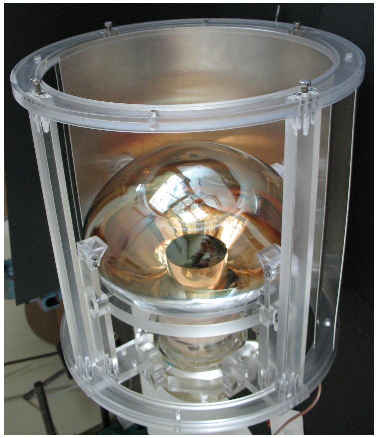
- DAQ
  - Zero deadtime
  - R/O with flash-ADC: control time-walk
- Low-background PMTs
- Magnetic shield to ensure PMT uniformity in response
- Optimised PMT coverage:
  - Spatial uniformity in light response
  - 15% coverage for 7% resolution at 1 MeV



Simulation of (rel.) amount of observed light vs. position

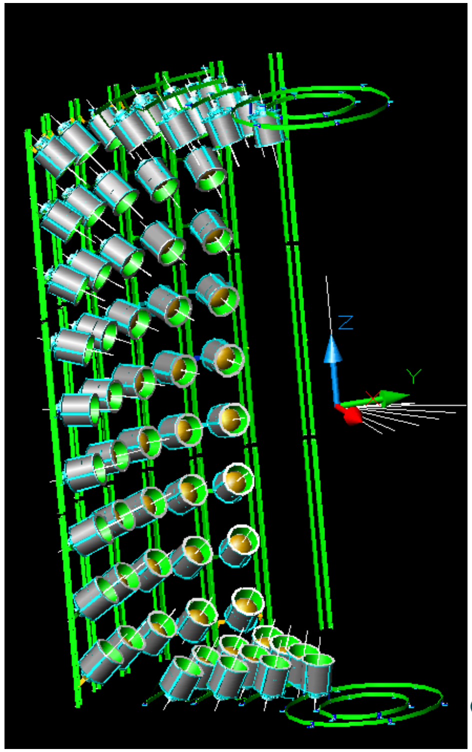


Prototype FADC



PMT with partially removed magnetic shied for illustration

L1 trigger-board ready

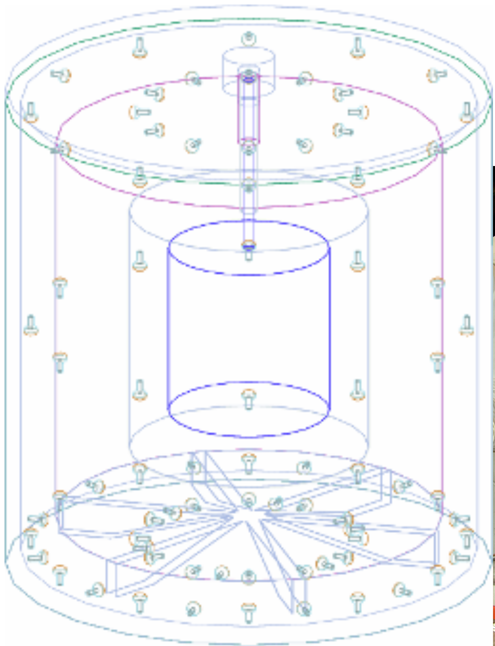


1/6th of the Double Chooz PMT configuration

VETO-SYSTEM

Inner veto

- Tag μ and secondaries
- Very high efficiency (> 99.5%)

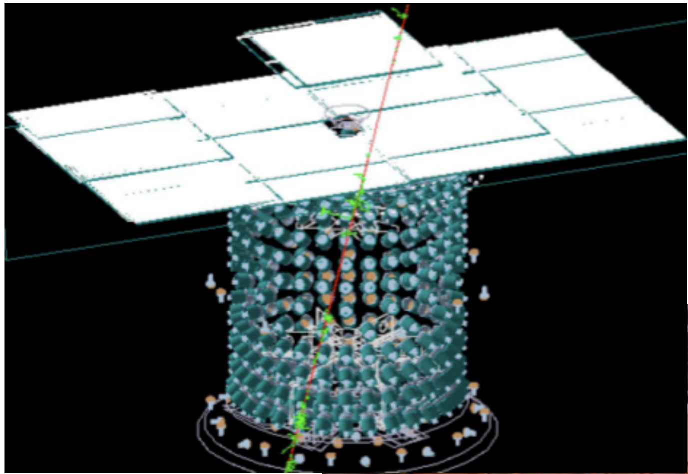



- 500 cm, LAB scintillator
- 70 8” PMTs
  (refurbished IMB tubes R1408)

To be installed in December

Outer veto

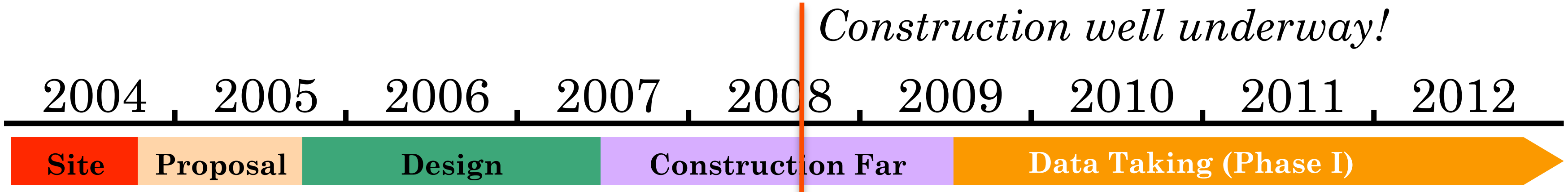
- Tag “near-miss” μ, calibrate IV
- Redundancy for high rejection power




- Panels of strips
- Coextruded scintillator + TiO_2 reflector
- 1.2 mm Ø wavelength-shifting fibre

Prototype made, material procurement has started.

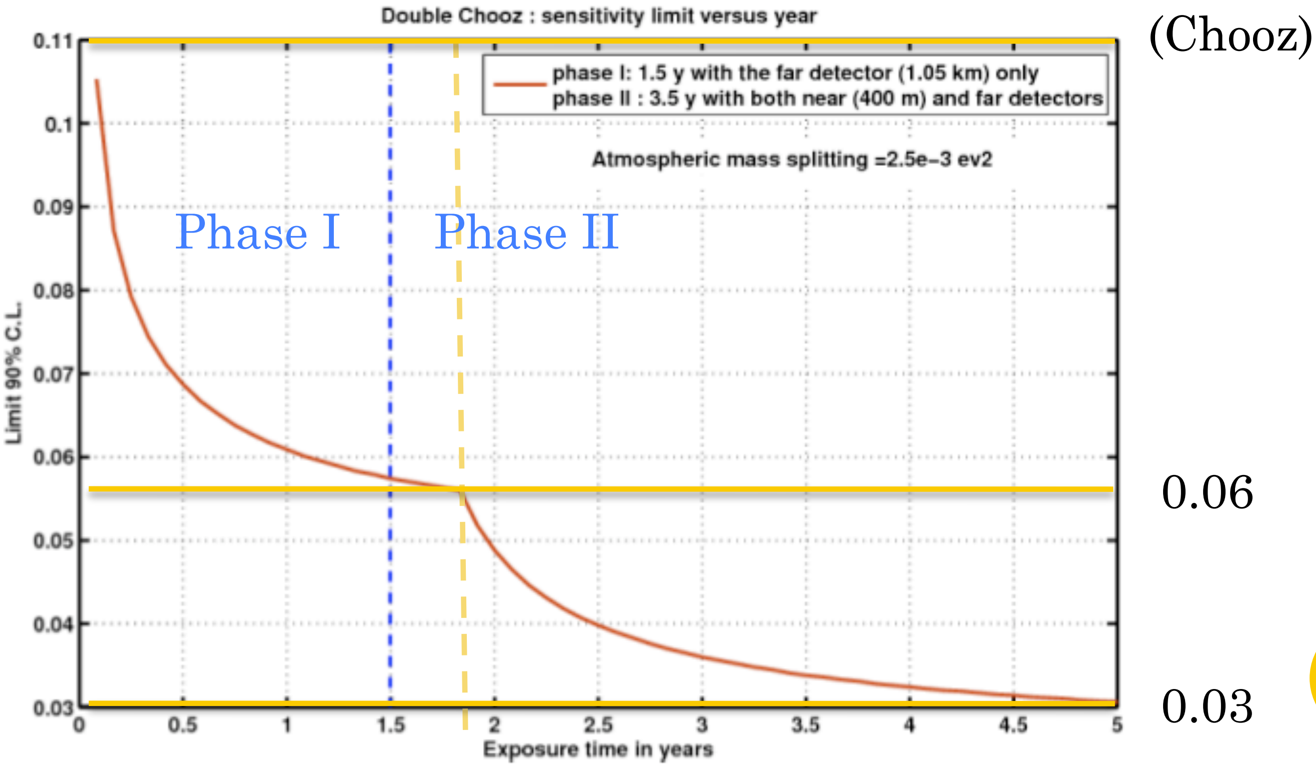
DOUBLE CHOOZ TIMELINE



- Phase 1: Only far detector

- Phase 2: Both detectors

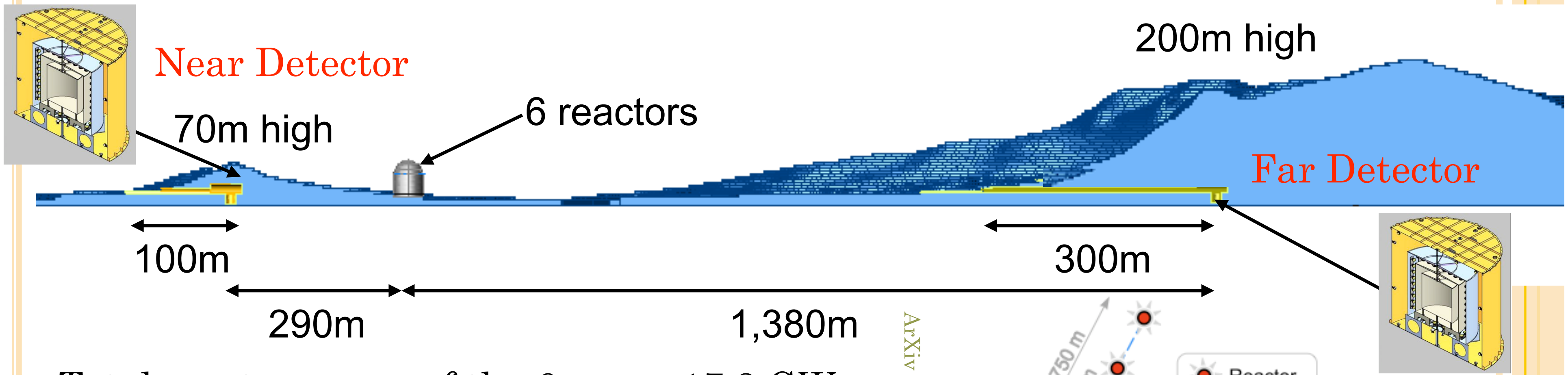
10 x times Chooz statistics in phase I: Double Chooz (phase I) will improve on Chooz within 3 months.



RENO @ YONGGWANG

REACTOR EXPERIMENT FOR NEUTRINO OSCILLATION

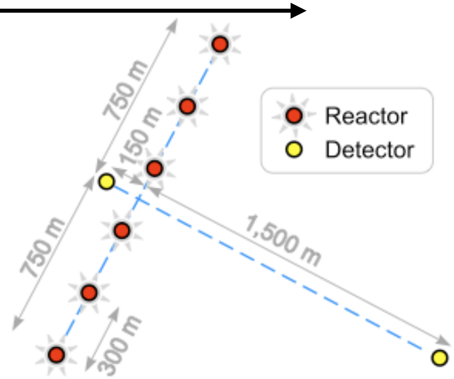
Collaboration:
South Korea + Russia



Total reactor power of the 6 cores: 17.3 GW_{th}
(although 2 contribute >80% of observed ϕ_ν)

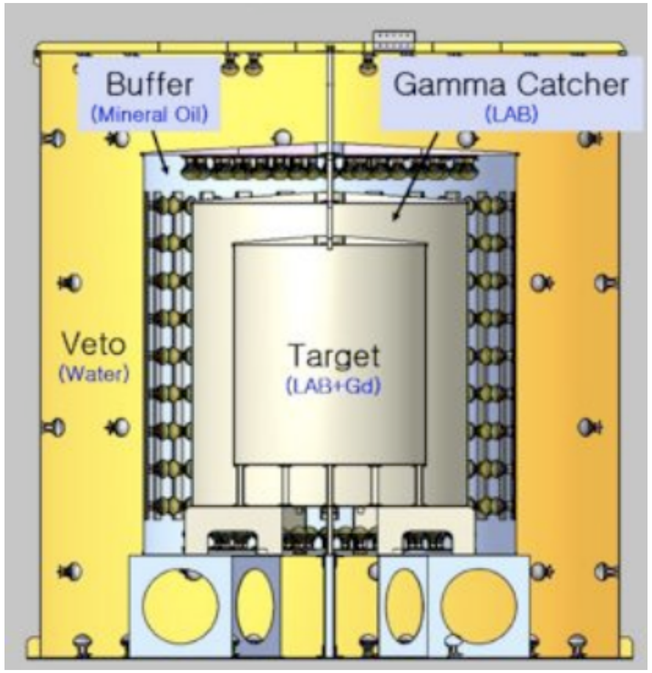
Courtesy of K. Soo-Bong

ArXiv 0704.0498v2 [hep-ex]



RENO DESIGN

- Layout very similar to DoubleChooz
- LAB scintillator

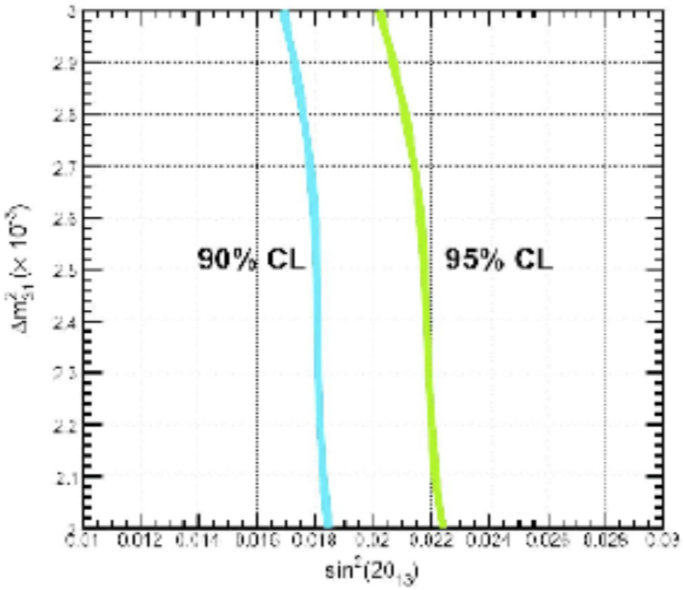


RENO STATUS

See talk of Youngdo Oh @ 15h40

Sensitivity

$\sin^2(2\theta_{13}) > 0.02$ @ 90% CL (3 yrs)



Start-up

Data taking expected to start early 2010

DAYA BAY EXPERIMENT

Collaboration:
18 institutes in Asia
15 institutes in the US
3 institutes in Europe

- 55 km from Hong Kong
- Reactor power:
  currently 11.6 GW_{th}, to be upgraded to 17.4 GW_{th} (2011)
- Close to mountain:
  underground labs with sufficient overburden.

Ling Ao: 2 × 2.9 GW_{th}

Ling Ao II: 2 × 2.9 GW_{th}

Courtesy of Kam-Biu Luk

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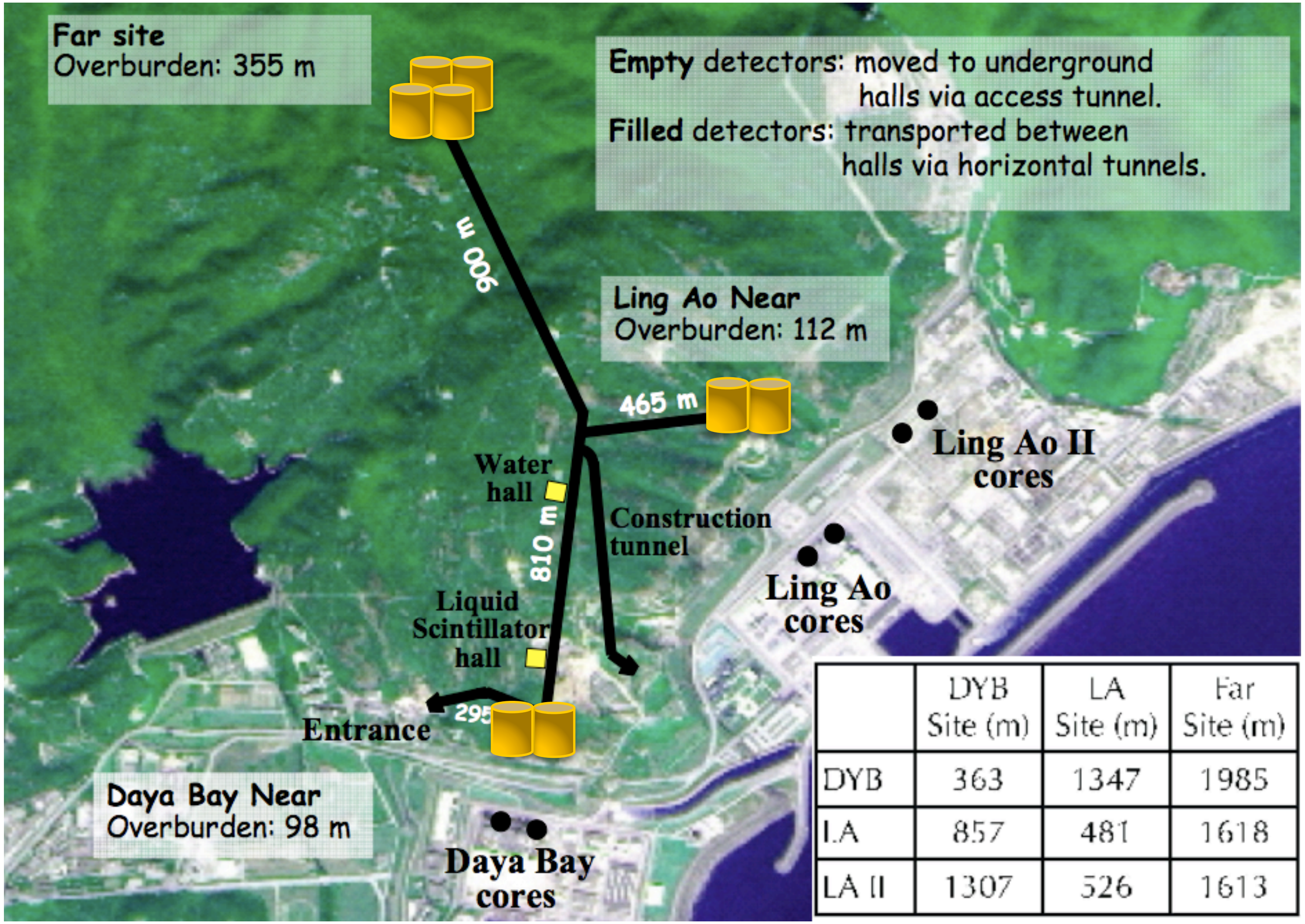
SITE OVERVIEW



	DYB Site (m)	LA Site (m)	Far Site (m)
DYB	363	1347	1985
LA	857	481	1618
LA II	1307	526	1613

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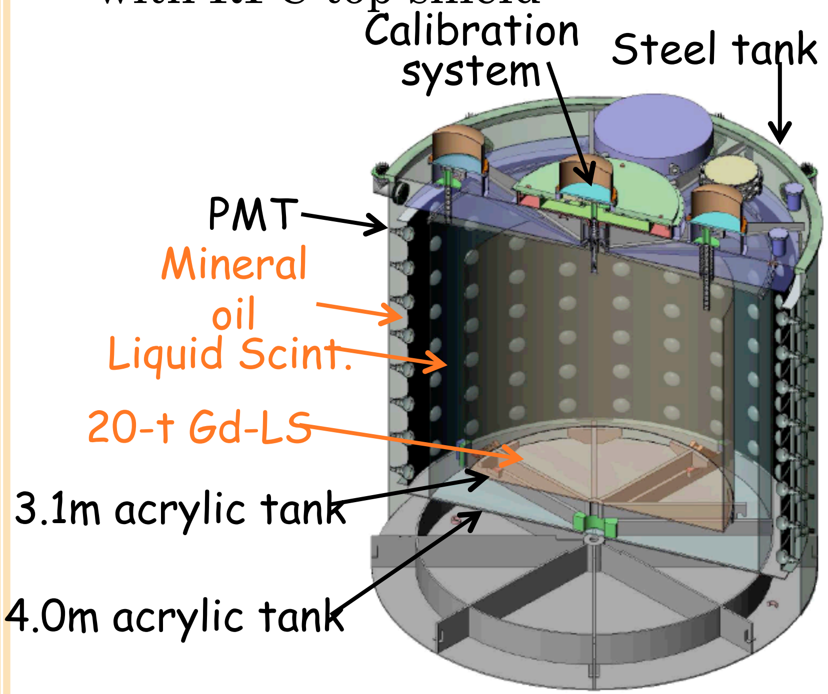
DETECTOR

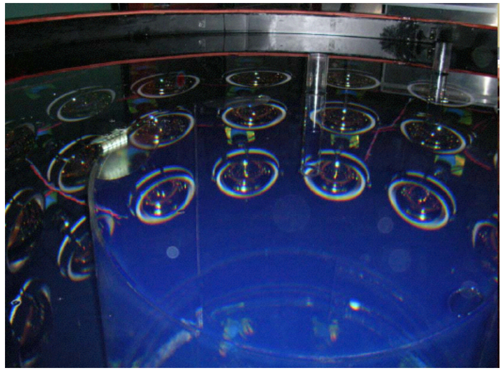
Design

Again, simular to Double Chooz,
However:
• no PMTs but reflectors
top and bottom.
• Multiple detectors in large water based outer veto system with RPC top shield

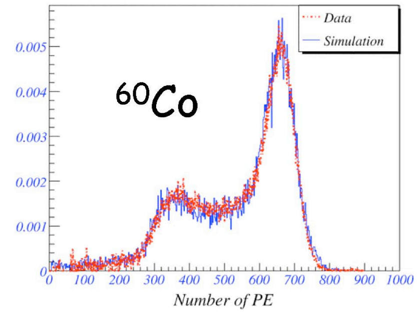


Prototype

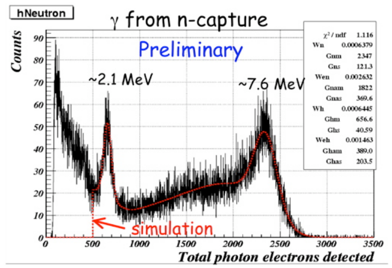
45 PMTs
0.5 tonne
reflectors top & bottom

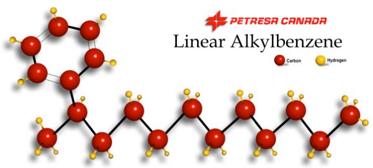


Phase I:
LAB LS
mineroil



Phase II:
Gd-loaded
LAB LS





Simon JM Peeters, NOW 2008

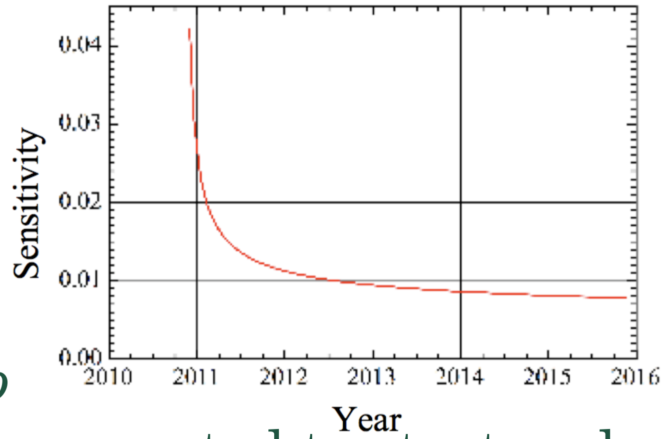
STATUS AND OVERVIEW

Sensitivity goal

$\sin^2(2\theta_{13}) < 0.01$

In construction phase

- Civil construction has started
- Subsystem prototypes exist
- Long-lead orders initiated
- Daya Bay is moving forward!

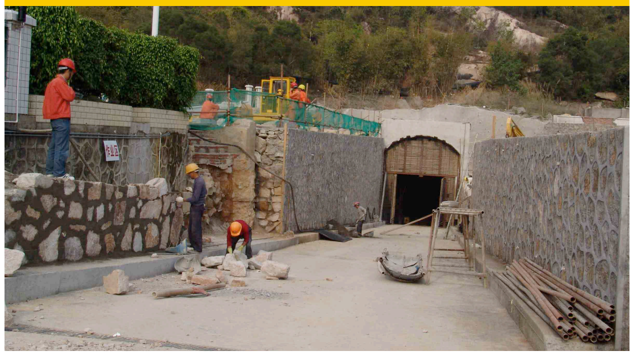


- *Start-up*

Data taking expected to start end of 2010

Groundbreaking: Oct 13, 07

Access Tunnel: Mar 08



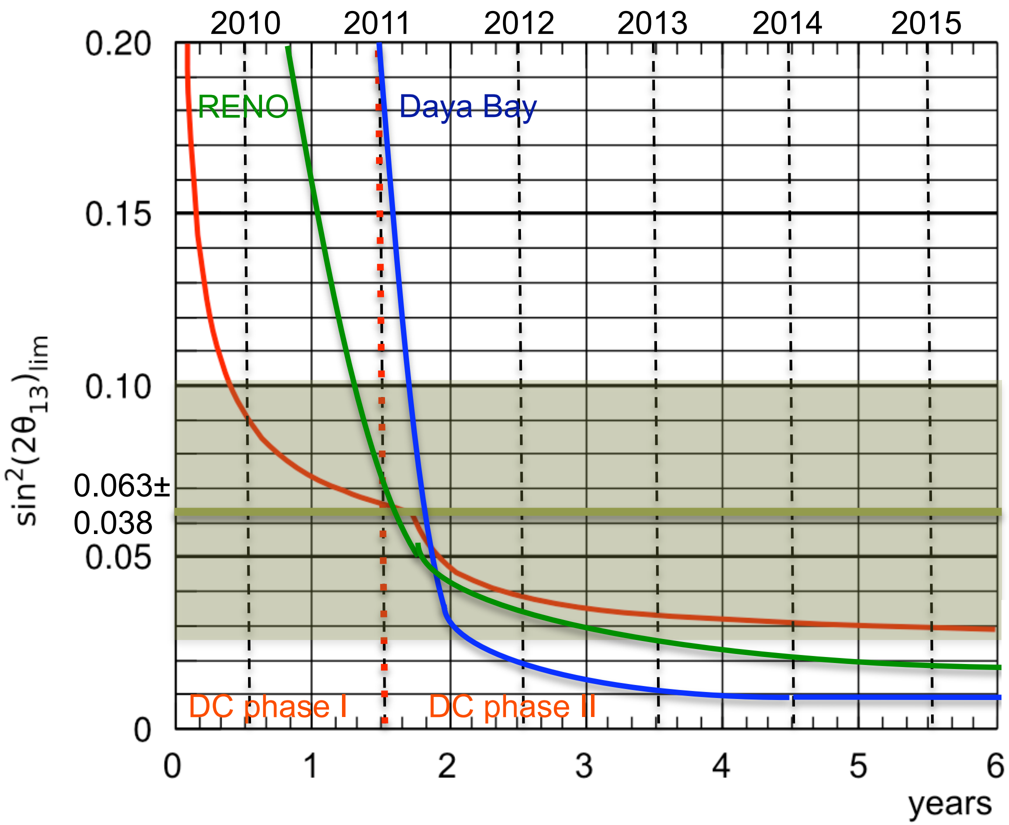
NEUTRINO EXPERIMENT AT ANGRA DOS REIS

- Collaboration in stand-by
  Joined Double Chooz effort in 2006
- 2 x 4 GWth (Angra II & III)
- 1.5 km tunnel to be excavated for far detector, cavity for near detector
- Large detector:
  (several 100 tons!)

  (Detailed)
  shape measurement

University of Sussex

COMPARISON



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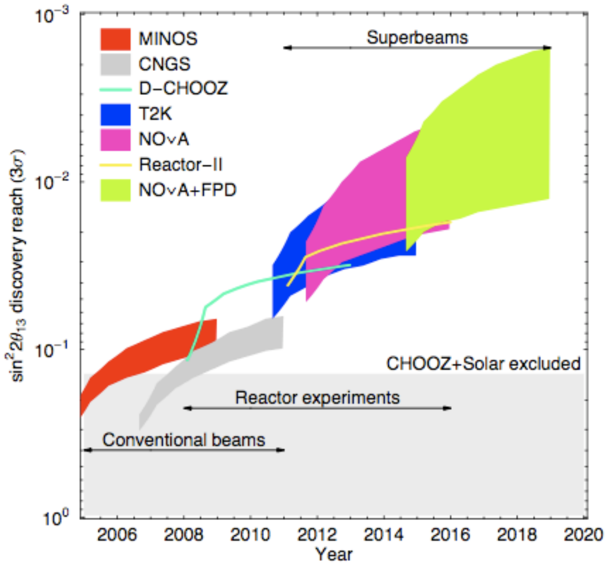
Note:
Sketch only.
Publications are not discrete points, main time factor is in construction and the understanding of the systematic error.

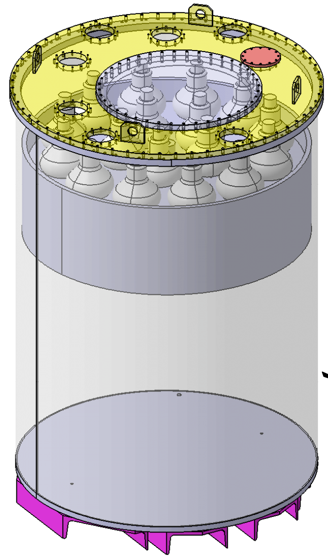
arXiv:0509019v1 [hep-ex]



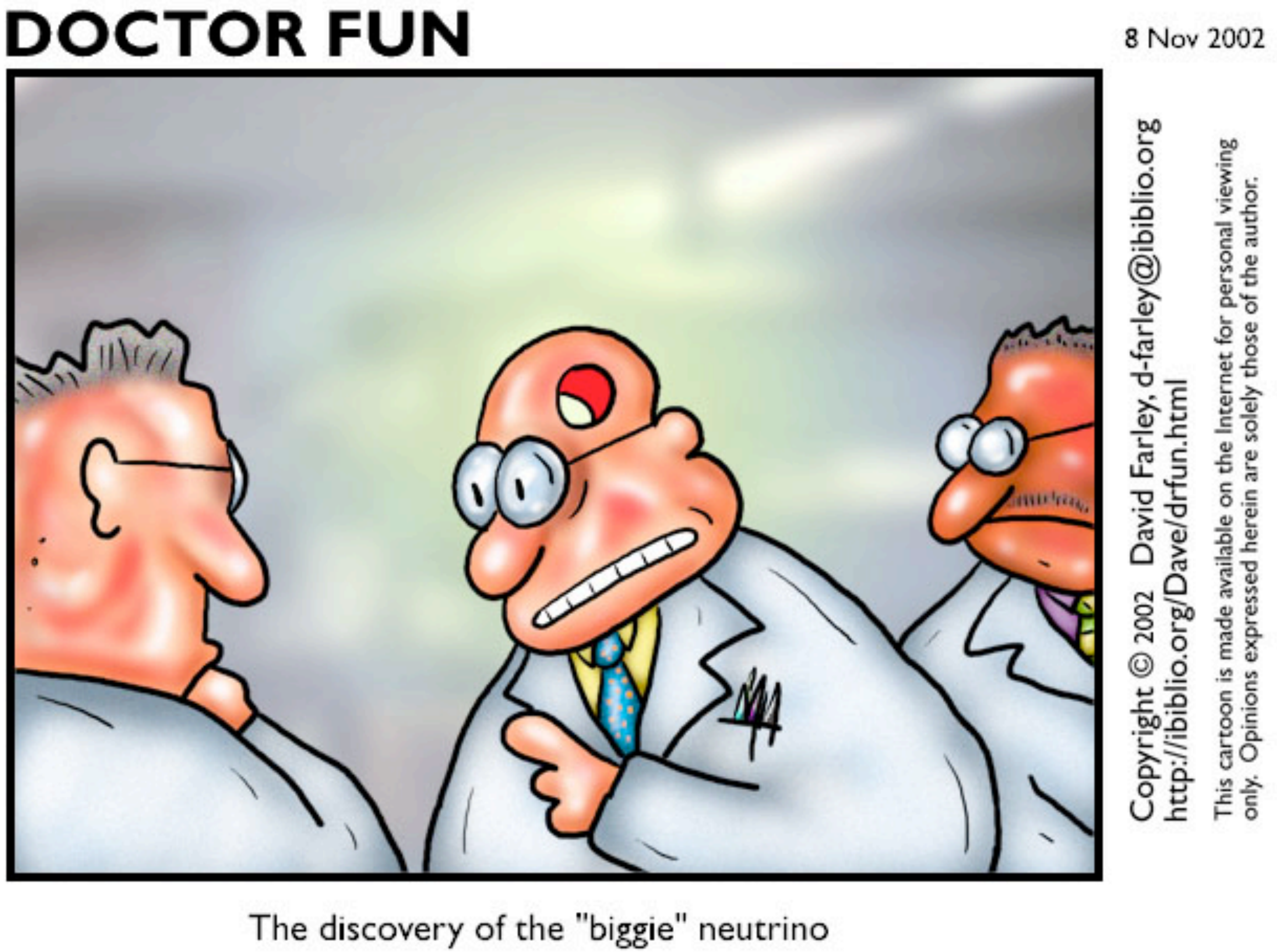
Experiment	*Reactor Power (GWth)*	*Detector mass (near/far) (tonnes)*	*Start date*	*Sensitivity 90% CL, 3yr*
Double Chooz	**8.6**	**8.3/8.3**	**06/2009,12/2010**	**0.06, 0.03**
RENO	**<17.3**	**16/16**	**01/2010**	**0.02**
Daya Bay	**17.4**	**2x40/80**	**12/201**	**0.008**

JUST Θ_{13}?

- Non-proliferation: similar technology
  (see talk of David Lhuillier @ 16h00)
- General: Scintillator development, movable detectors
- Robustness
  - Experimental:
    Neutrino measurements are challenging: cross-checks are needed
  - Theoretical:
    Is the oscillation model correct?
    (Multiple theoretical models for Non-Standard Interactions: see talk of Toshihiko Ota on Friday)
    arXiv:0708.0152v2 [hep-ph]



THANK YOU


DOCTOR FUN
8 Nov 2002
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The discovery of the "biggie" neutrino