θ_{13} Search with Double Chooz

Nov.07 @ GDR-Susy'07
ULB & VUB (Bruxelles)

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Double Chooz @ APC (Paris)

- Physics Motivation
- Reactor ν-Oscillation Physics
- The Double Chooz Experiment
- What to remember...

Motivation...

oscillations = leptonic mixing

$(\nu_e,\nu_\mu,\nu_\tau)^T = \boldsymbol{U}\,(\nu_1,\nu_2,\nu_3)^T$ where U must be unitary & 3x3...

See Belen's Talk (this morning)

atmospheric-ν: θ_{23} | θ_{13} & dirac-δ_{CP} | solar-ν: θ_{12}

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

$P(\nu_\mu\to\nu_\mu)$ | $P(\text{anti-}\nu_e\to\nu_x)$ & $P(\nu_\mu\to\nu_e)$ | $P(\nu_e\to\nu_x)$

PMNS: 3 angles & 1 complex phase => leptonic CP violation

For Reactors...

$$1 - P_{\bar{e}\bar{e}} \simeq \sin^2 2\theta_{13}\,\sin^2\Delta + \alpha^2\,\Delta^2\,\cos^4\theta_{13}\,\sin^2 2\theta_{12}.$$

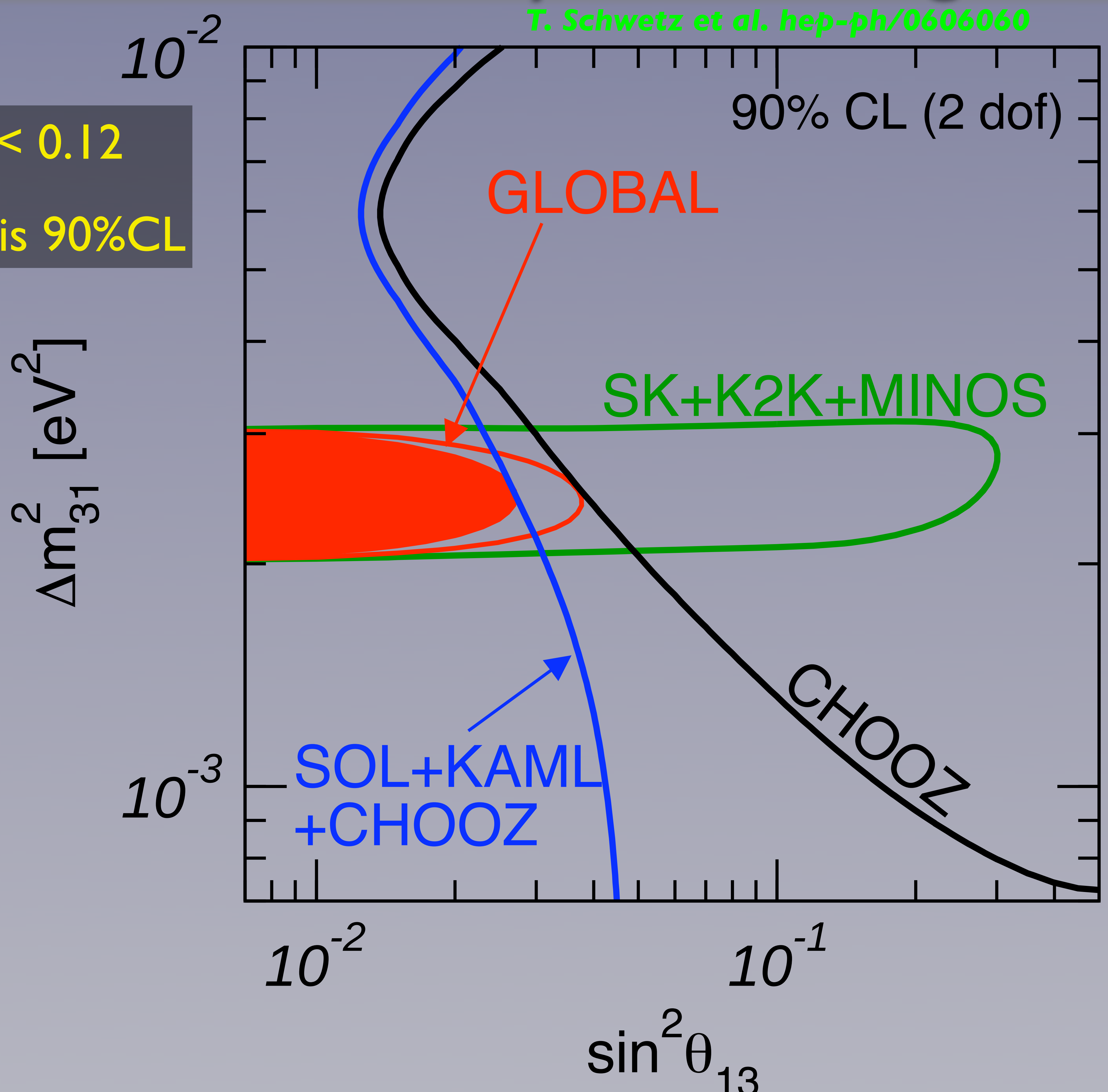
Clean measure of θ_{13}: 2x2 ν-oscillation & negligible contributions...

δ_{CP}, PMNS ambiguous solutions, other lepton contributions, NC contamination, matter-effect, ND-FD propagation, cross-section, etc...

today's knowledge on θ_{13}

$\sin^2(2\theta_{13}) < 0.12$

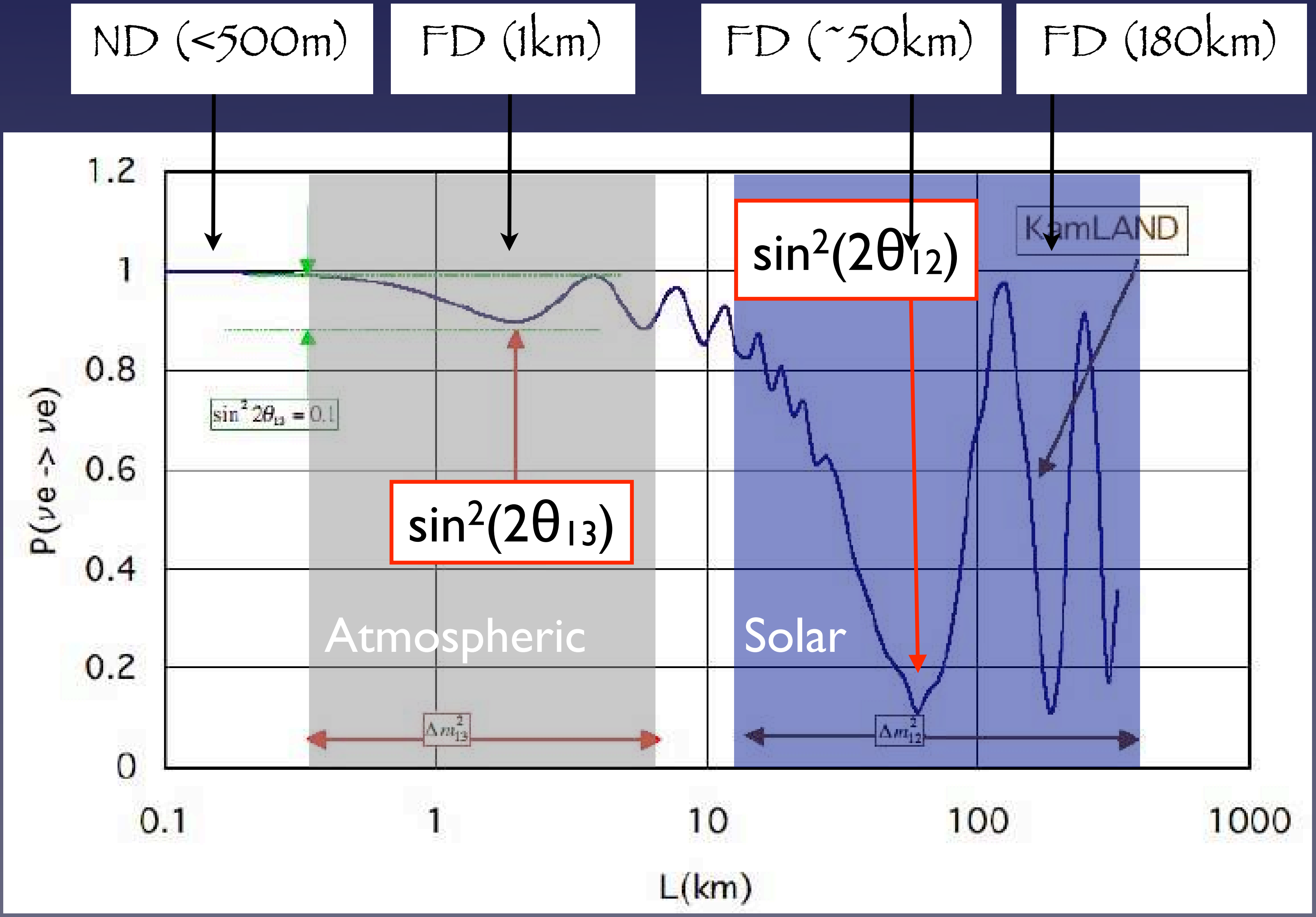
Global Analysis 90%CL



Reactor Strategy...

reactor oscillation physics...

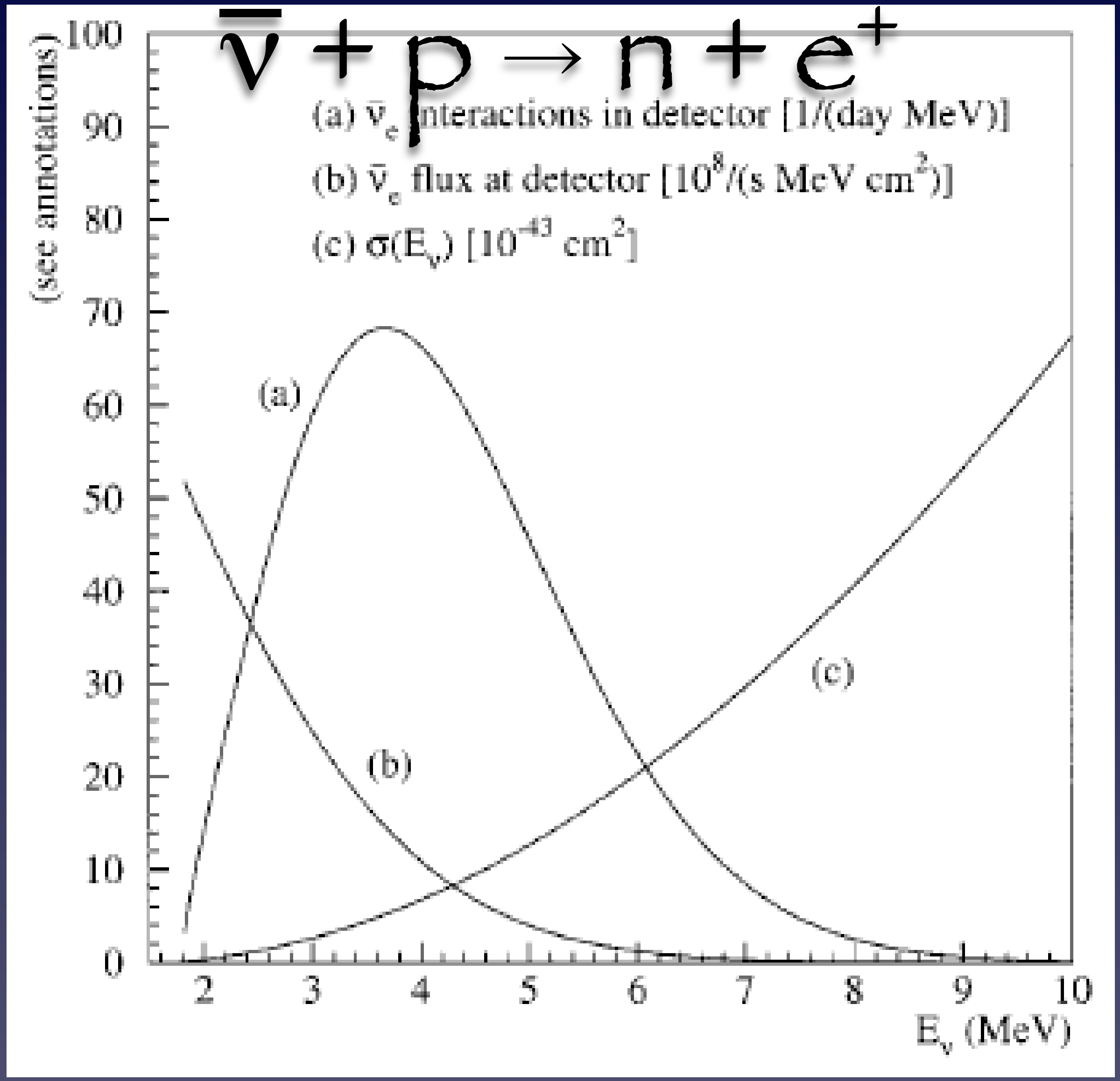
$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - 4c_{13}^2(c_{13}^2 s_{12}^2 c_{12}^2 \sin^2\Phi_{21} + s_{13}^2 c_{12}^2 \sin^2\Phi_{31} + s_{13}^2 s_{12}^2 \sin^2\Phi_{32})$$



advantages of reactor-νs

- disappearance ν-oscillation precision: high resolution E/L CC events: characterise dip
- copious, free and sometimes switchable (on/off)
- finite size and well localised [L]
- spectrum shape & normalisation (±2%)
- inverse-β:
    - cross-section (±0.2%)
    - a few MeV plenty of calibration sources [E]
- flux: multi-detector extrapolation ($1/L^2$)
- background: cosmogenic dominated => overburden

inverse-β reaction



Bemporad, Gratta, Vogle. RMP. 2002

- spectrum: convolution of...
  - Σ β-tails from fission debris
  - σ(E) => $E_{threshold}$=1.8MeV
- threshold: see only 1/4 νs
  - slow decays contribute little
- ν = e+ [prompt] + n-capture on H/Gd [delayed]:
  - E(ν)=E(e+) + Δ
  - E(n_{th}-Gd capture) ~ 8MeV => energy tag (away from BG)
- n-Gd capture τ~30μs (CHOOZ)

strategy

- make flux uncertainty negligible: multi-detector
- S/BG>100: huge statistical power => many reactors
    - large (or many) detectors: S/B ~ f(radius)
    - a few reactors may be nice too: "reactor off"
- reduce & understand backgrounds
    - overburden, radio-purity & detector design
- reduce & understand experimental systematics
    - inter-detector normalisation: <0.6%
    - inter-detector energy calibration: <1-2%

detector design

Geared to…

+ Low background

+ Inter-detector comparison

Target ν : $10{,}3\ m^3$

80% $C_{12}H_{26}$+ 20% PXE + PPO + Bis-MSB +0,1% Gd

γ Catcher : $22{,}6\ m^3$

80% $C_{12}H_{26}$ + 20% PXE + PPO + Bis-MSB

Non scintillating Buffer : $114\ m^3$

Mineral oil

uffer vessel & 390 10” PMTs :

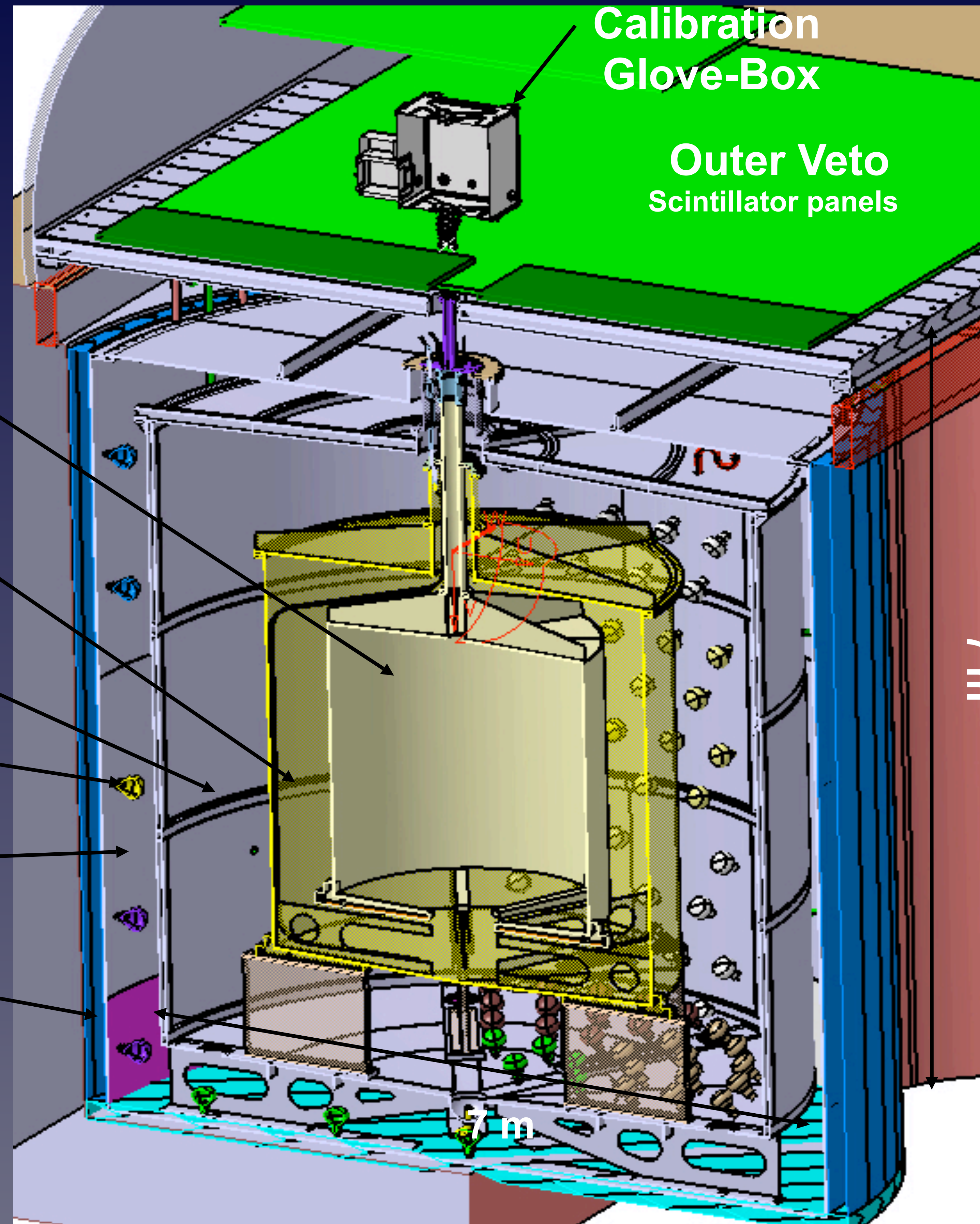
Stainless steel 3 mm

Inner Muon Veto : $90\ m^3$

Mineral oil + 70 8” PMTs

Steel Shielding :

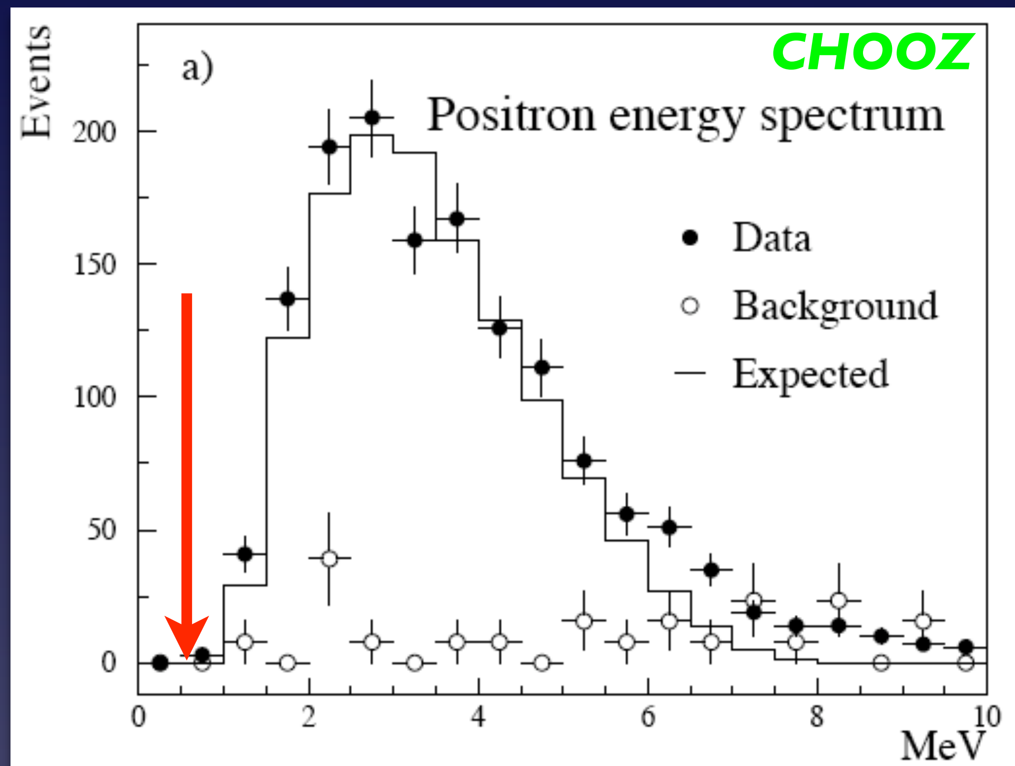
15 cm steel, All around

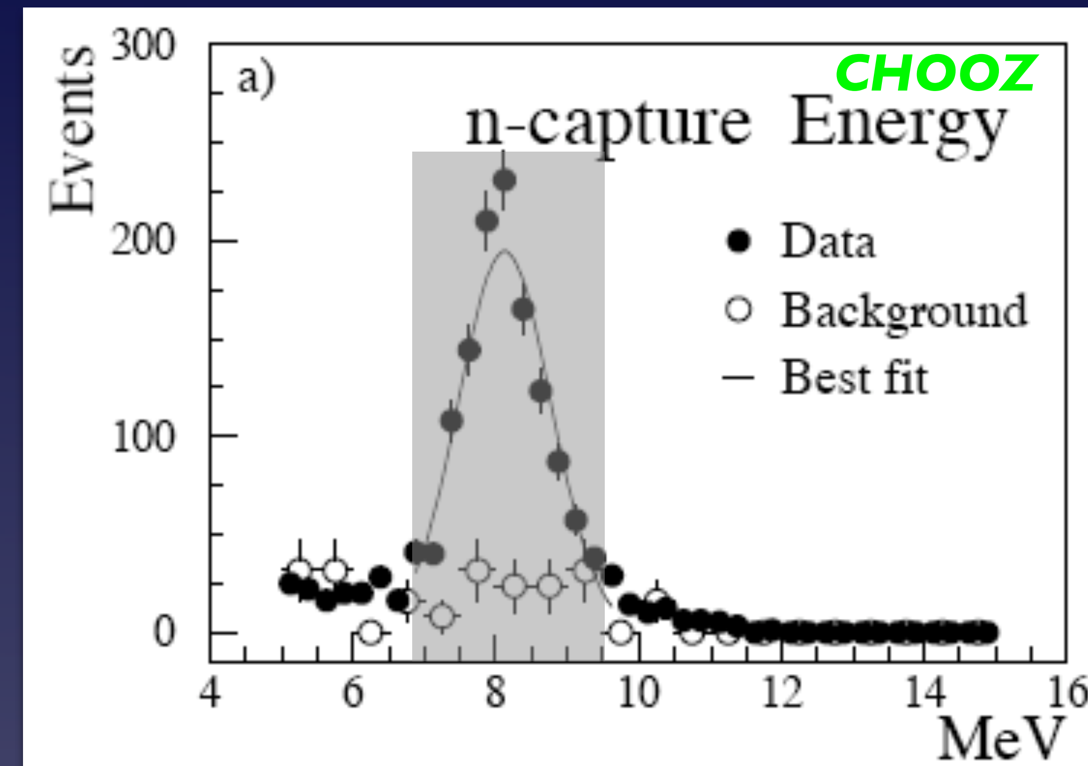


analysis: 3 cuts (7 cuts at CHOOZ)

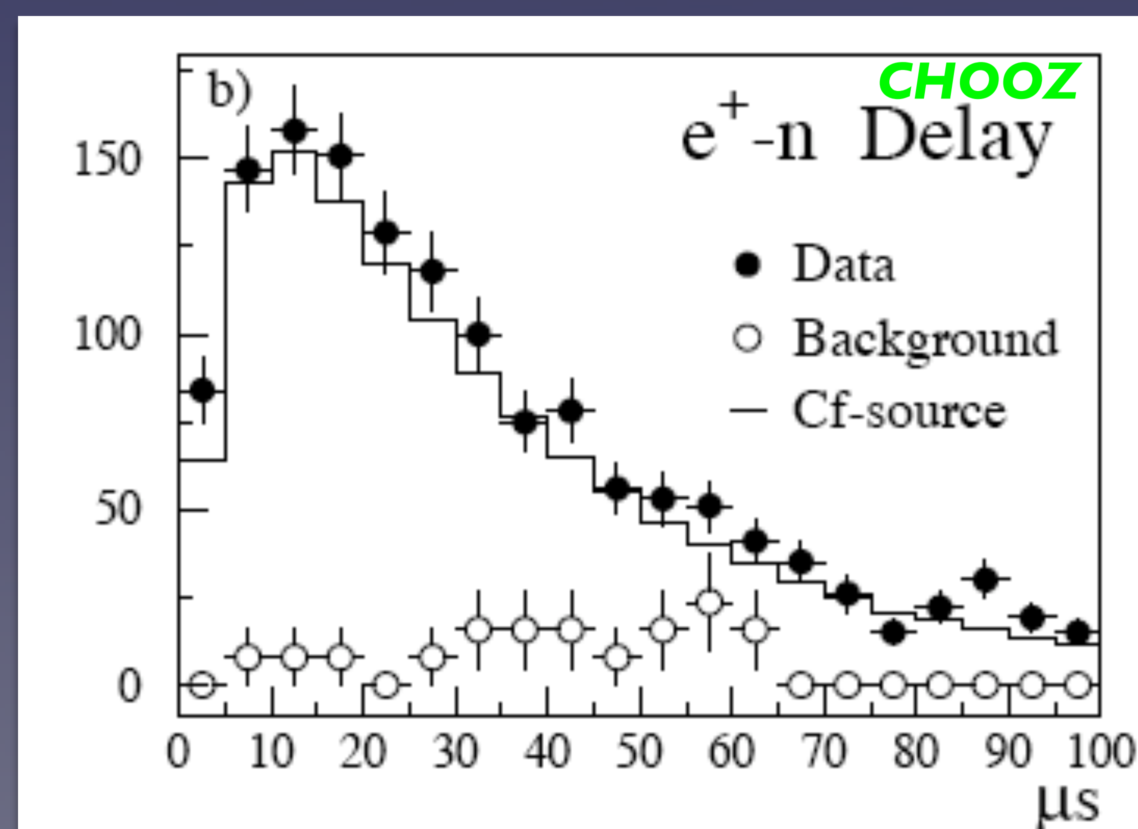
Apollonio et al (CHOOZ): hep-ex/0301017

e+-n energy deposited



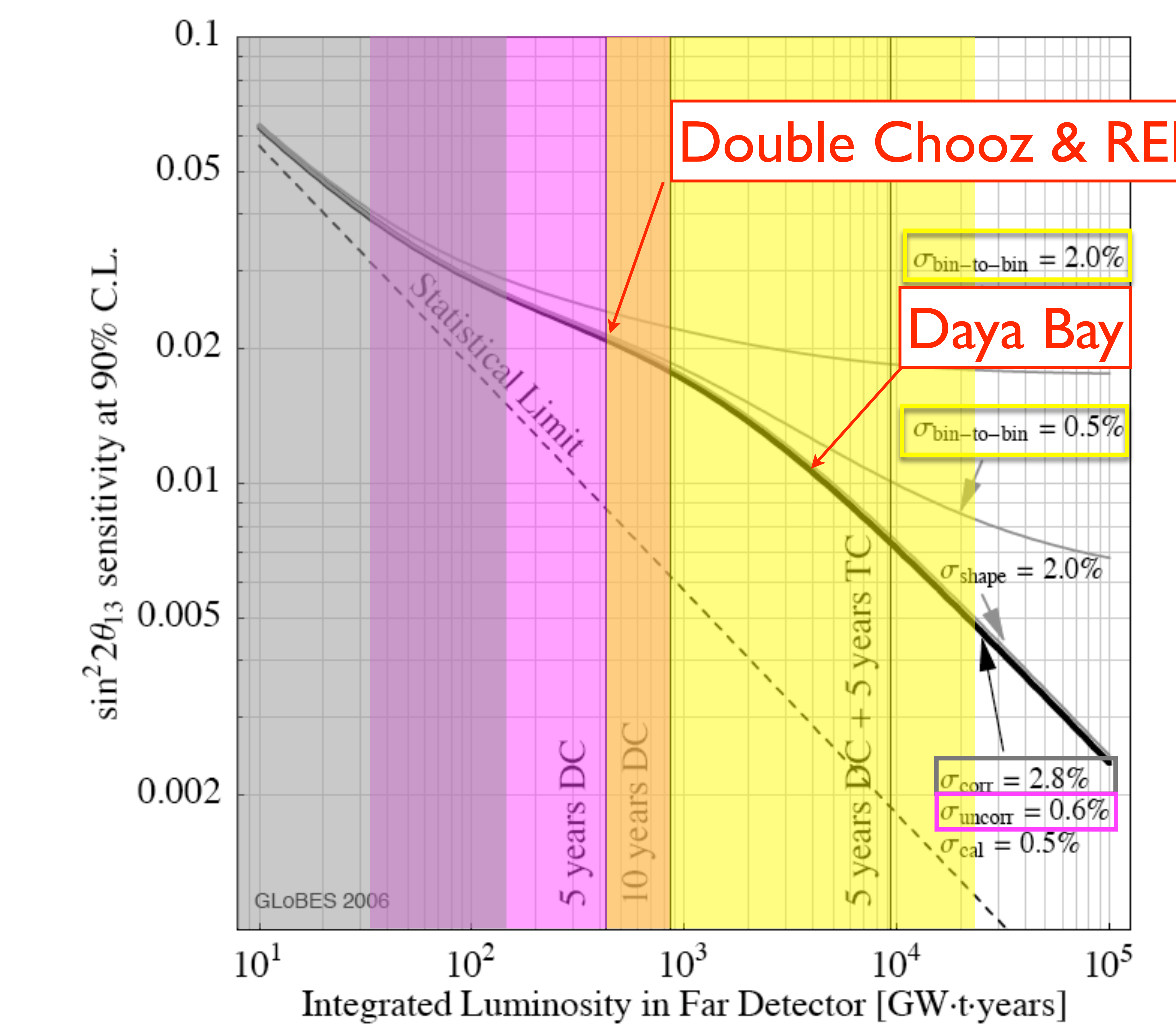


e+-n time-correlation



sensitivity regime

Huber et al. hep-ph/0601266



Domains:

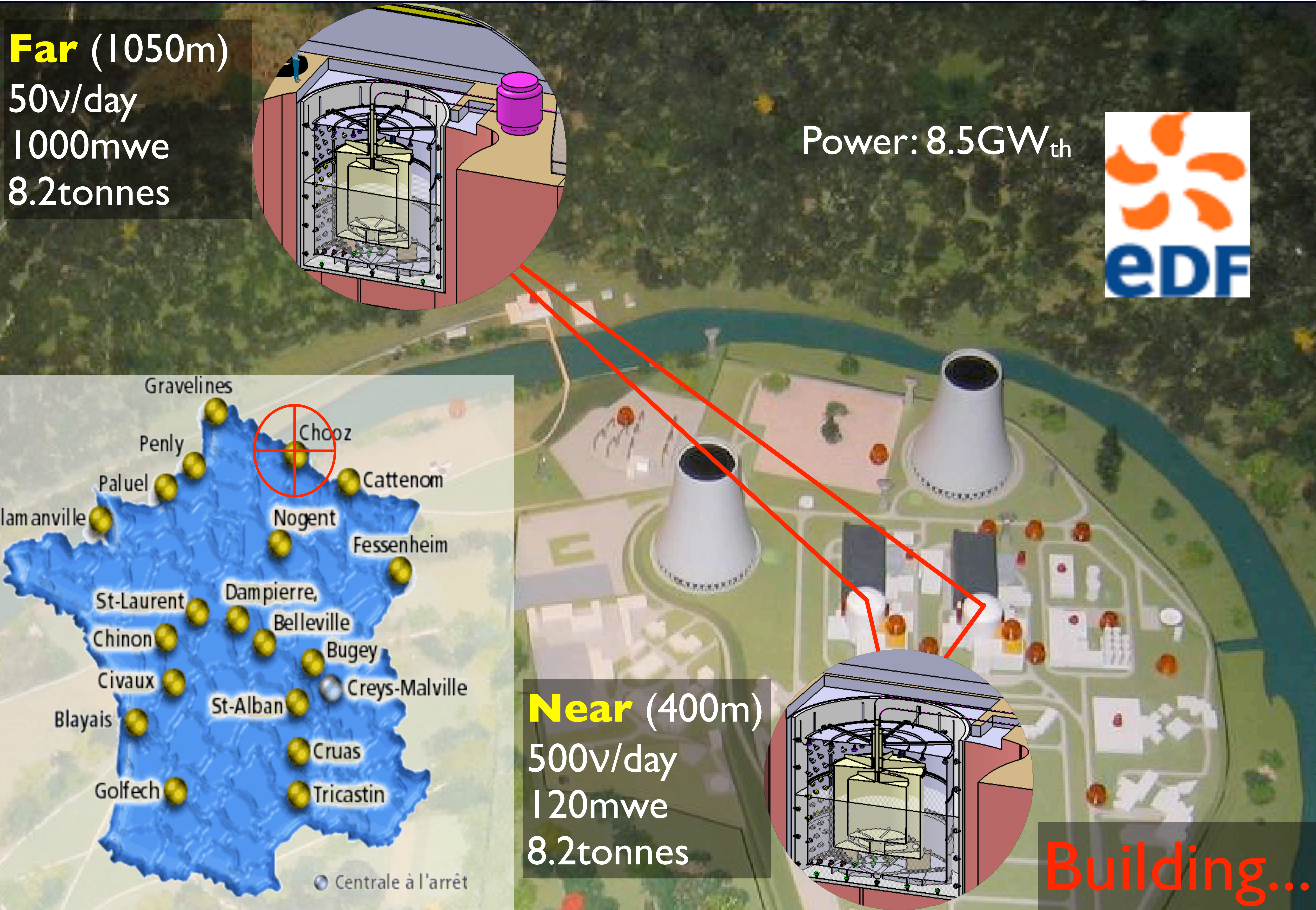
- Rate
- Rate+Shape
- Shape

Double Chooz

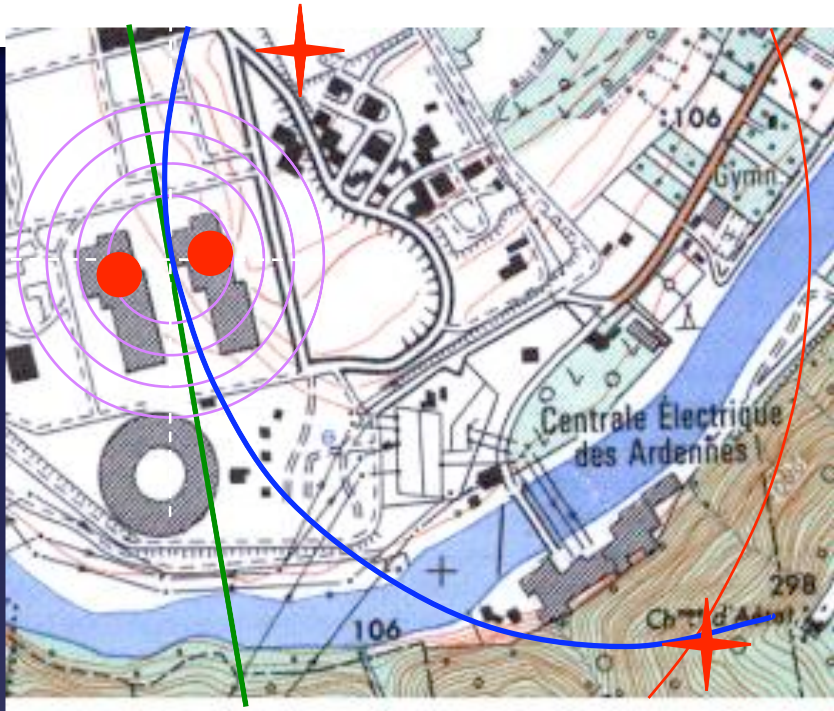
Collaboration

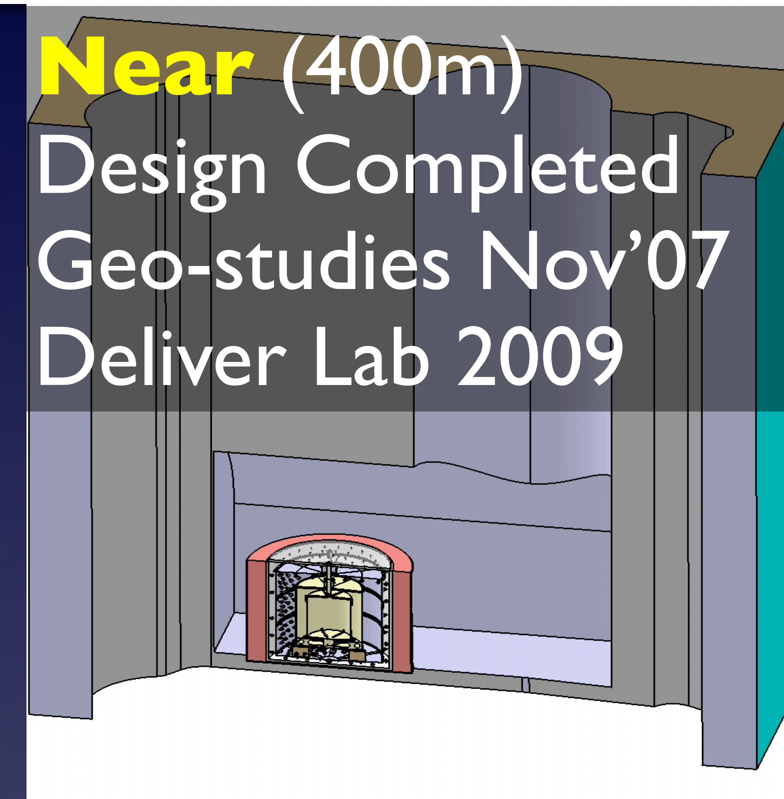
~100 physicists - 35 institutes/universities

Designed and R&D completed

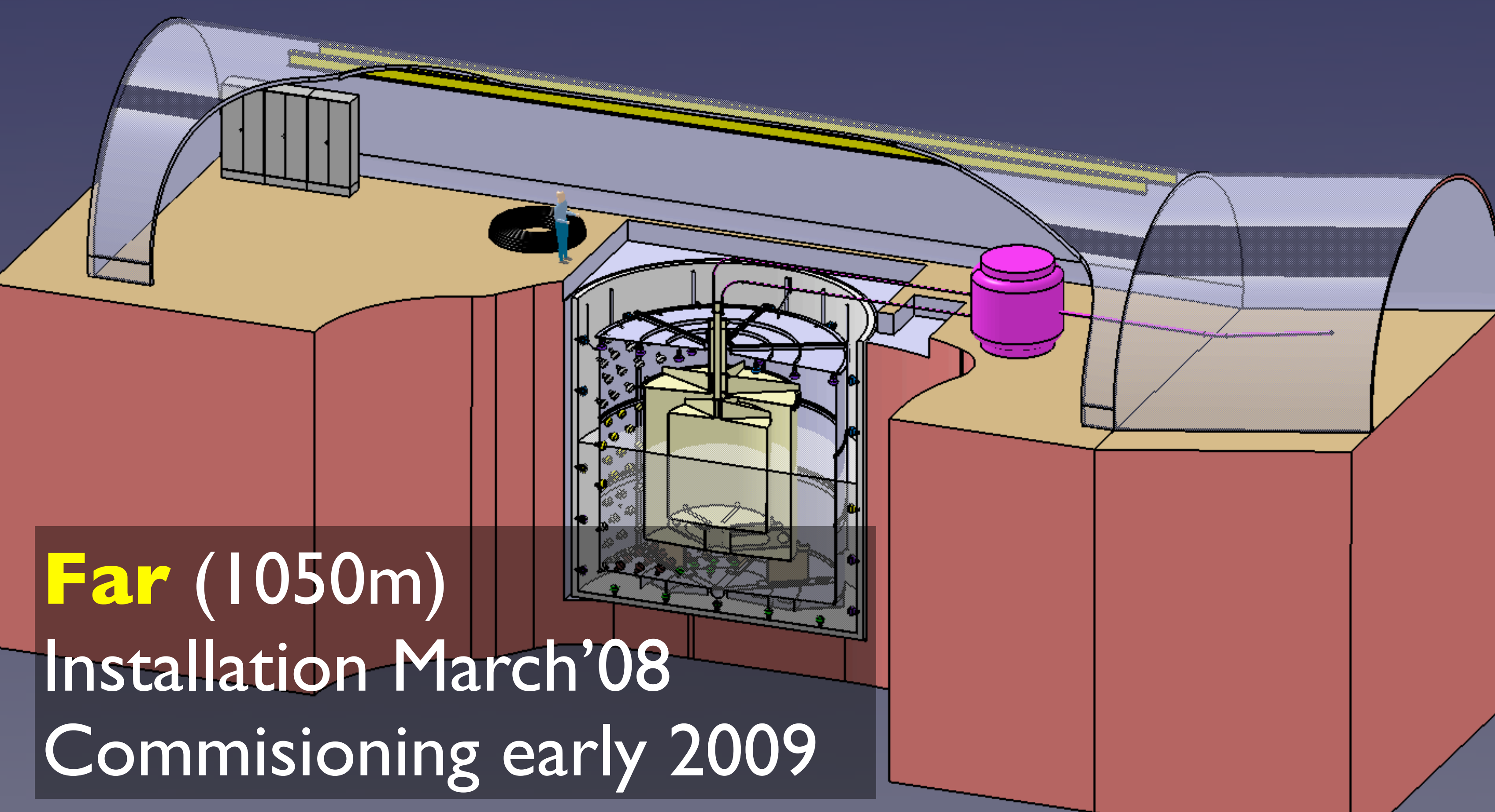


Near & Far Laboratories



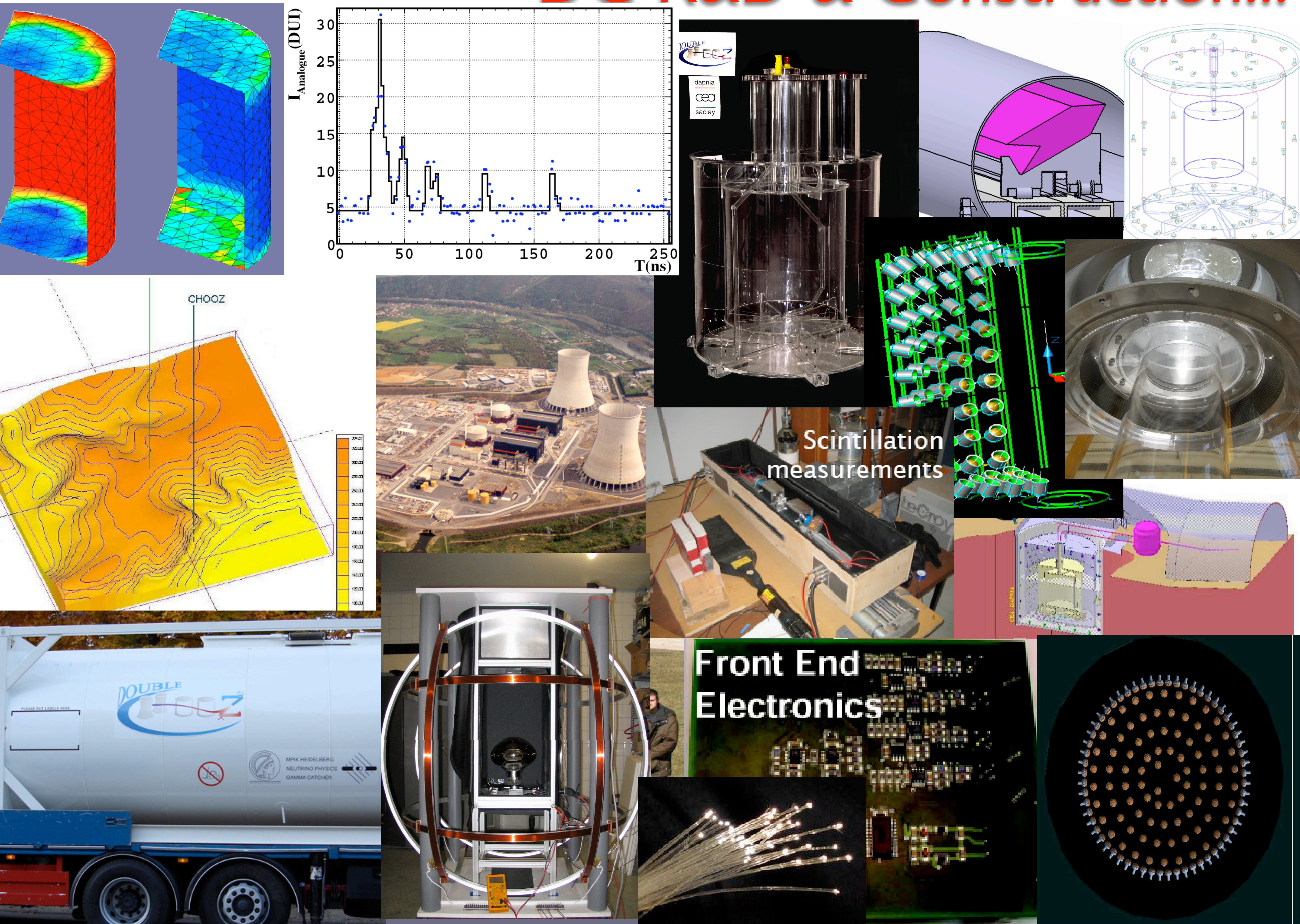


Near (400m)
Design Completed
Geo-studies Nov'07
Deliver Lab 2009



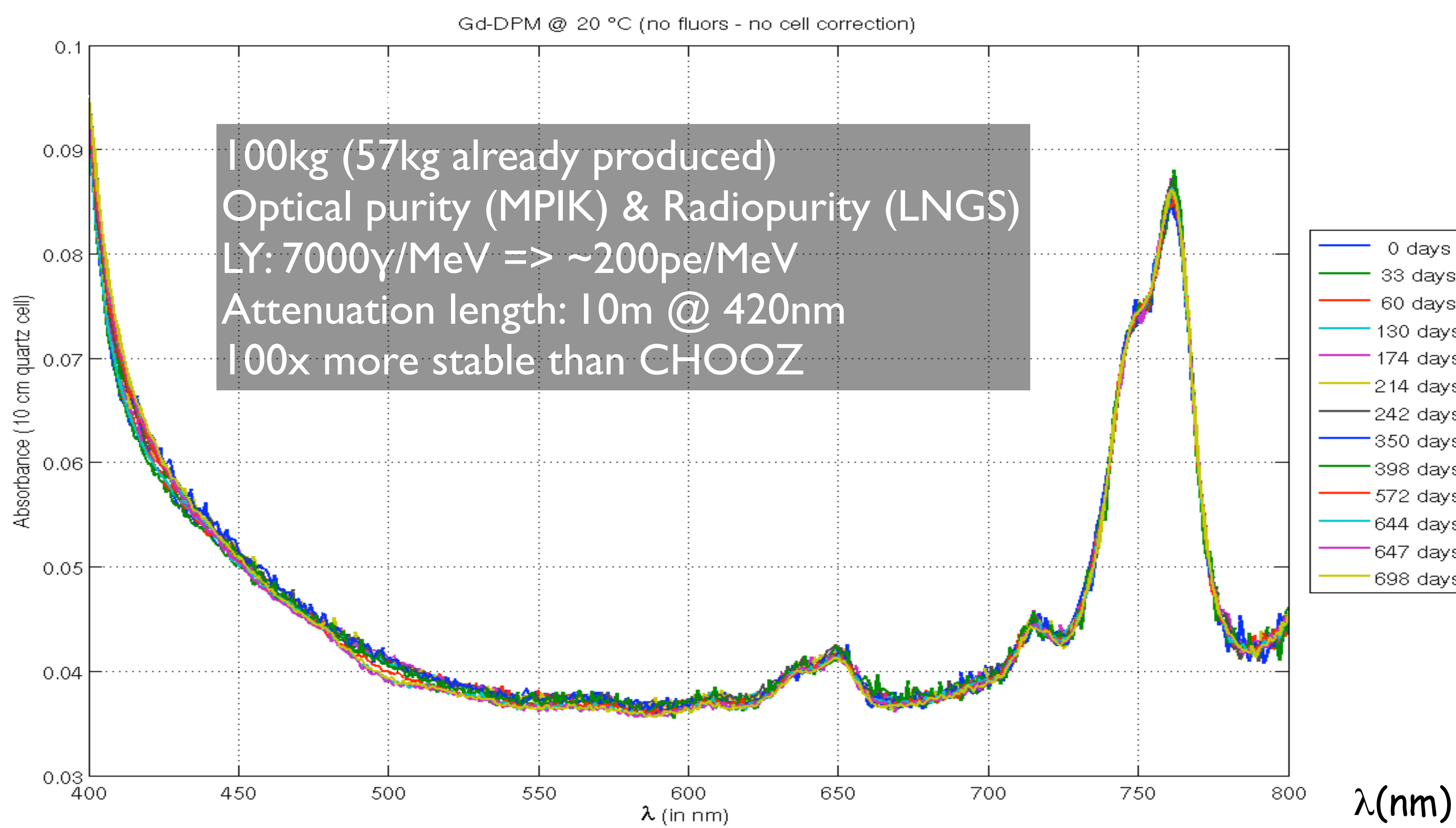
Far (1050m)
Installation March'08
Commisioning early 2009

DC R&D & Construction...

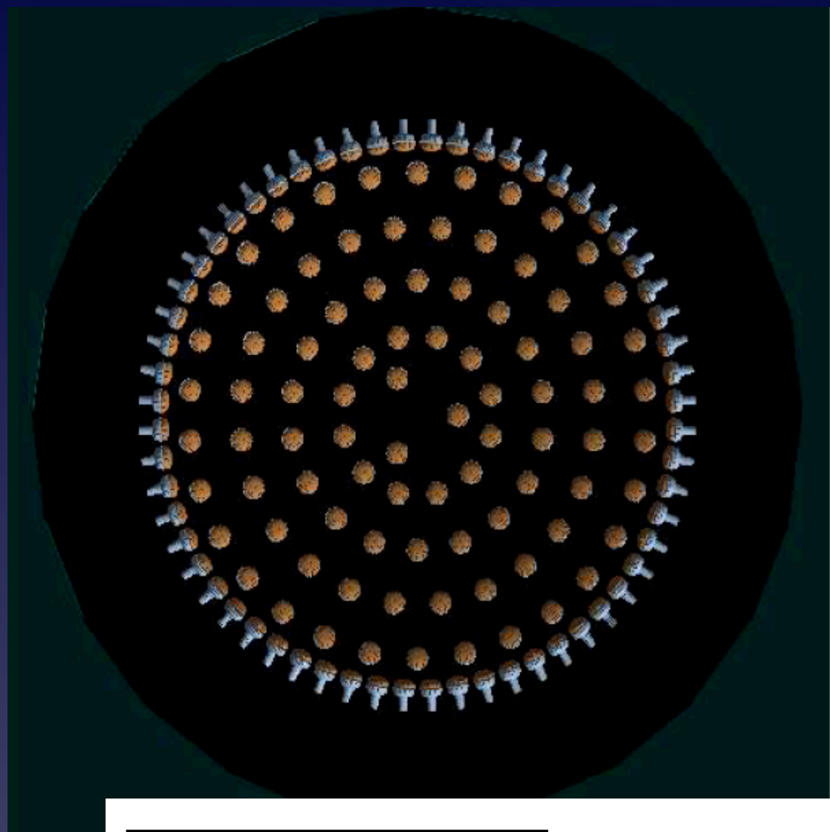


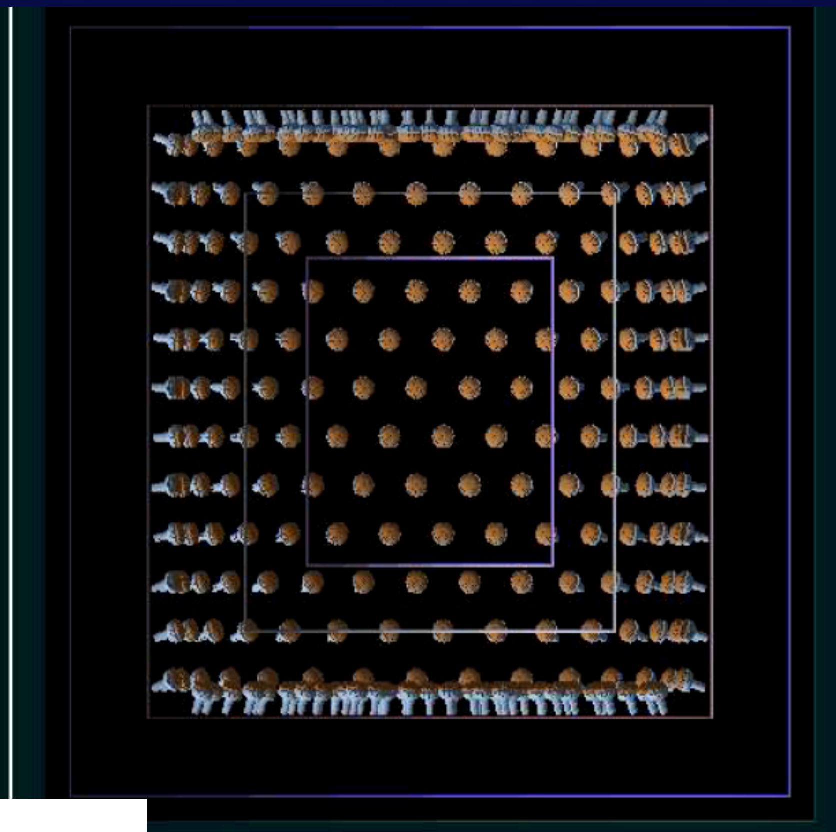
Gd doped liquid scintillator

Liquid Scintillator: 80% Dodecane + PXE 20% + 0.1%Gd



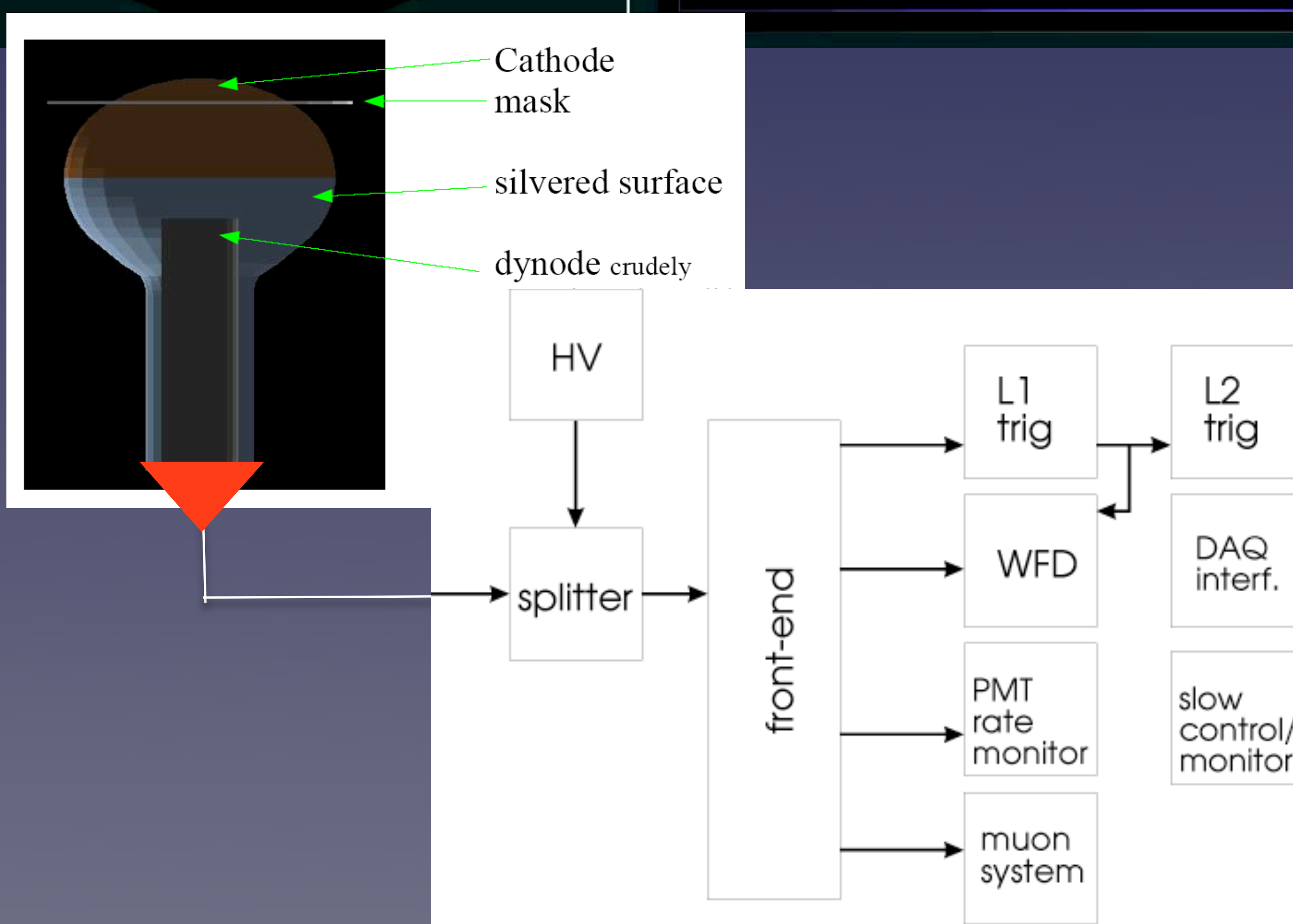
readout





390 x 10” PMs
78 x 8” PMs

deadtimeless-WFD (APC)
online baseline correction
dedicated Muon-System
online-data-reduction
deadtime known to <0.1%



Storage

knowledge versus time...

Phases:

DC-I: FD only:

10x stat CHOOZ

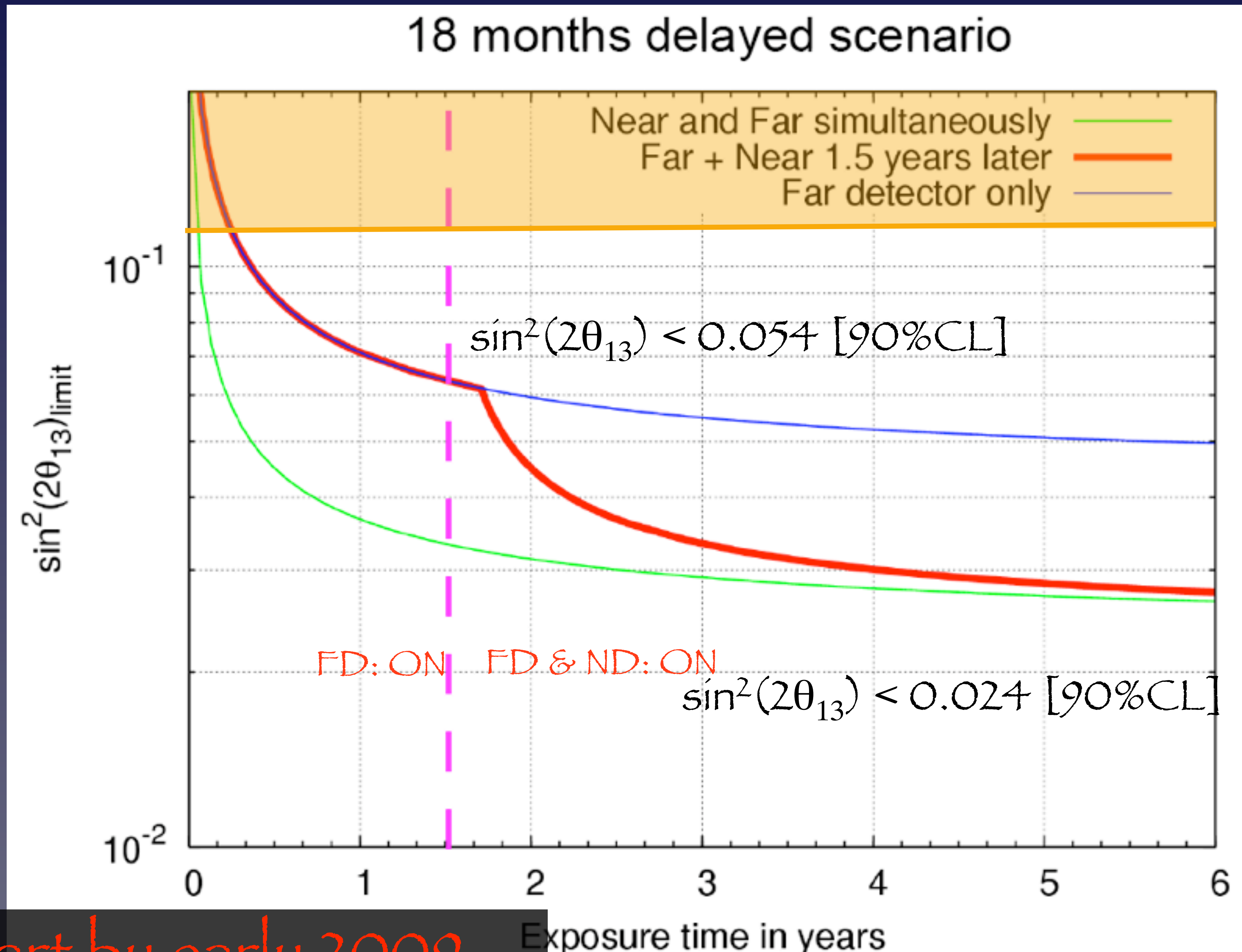
(limited by flux uncertainty)

DC-II: FD+ND:

rate + shape analysis

(limited by relative normalisation uncertainty)

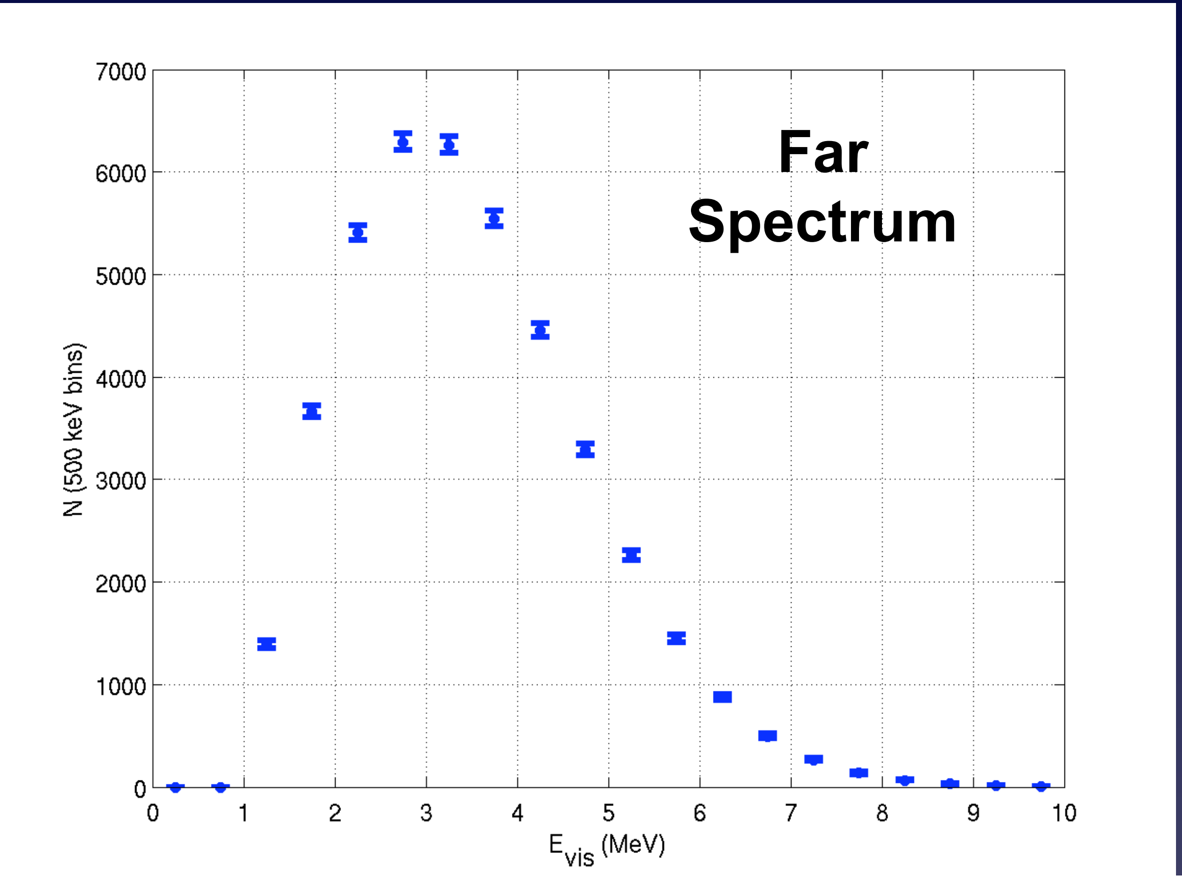
90% C.L. contour if $\sin^2(2\theta_{13})=0$ & $\Delta m^2_{atm} = 2.5 \times 10^{-3}$ eV^2

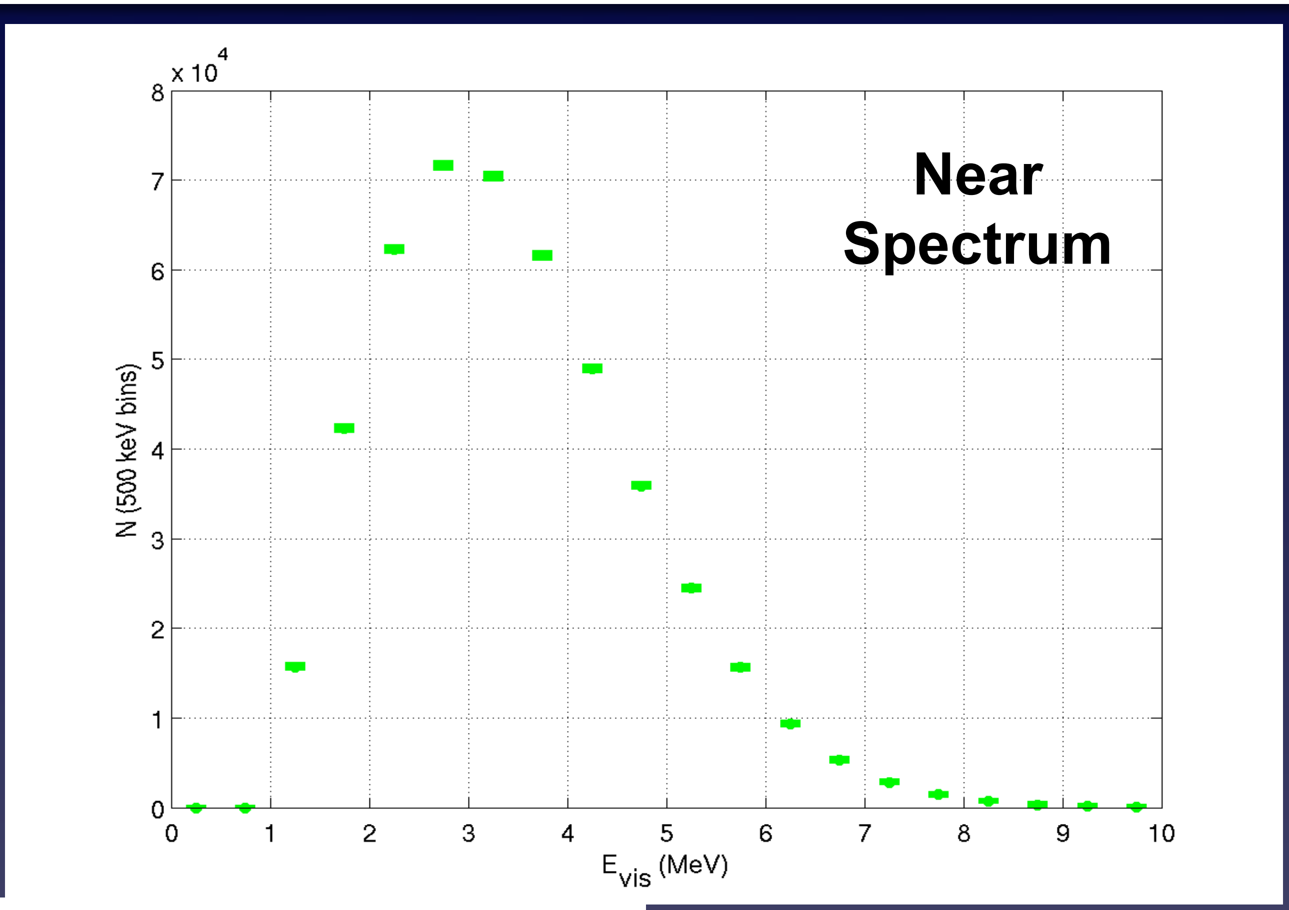


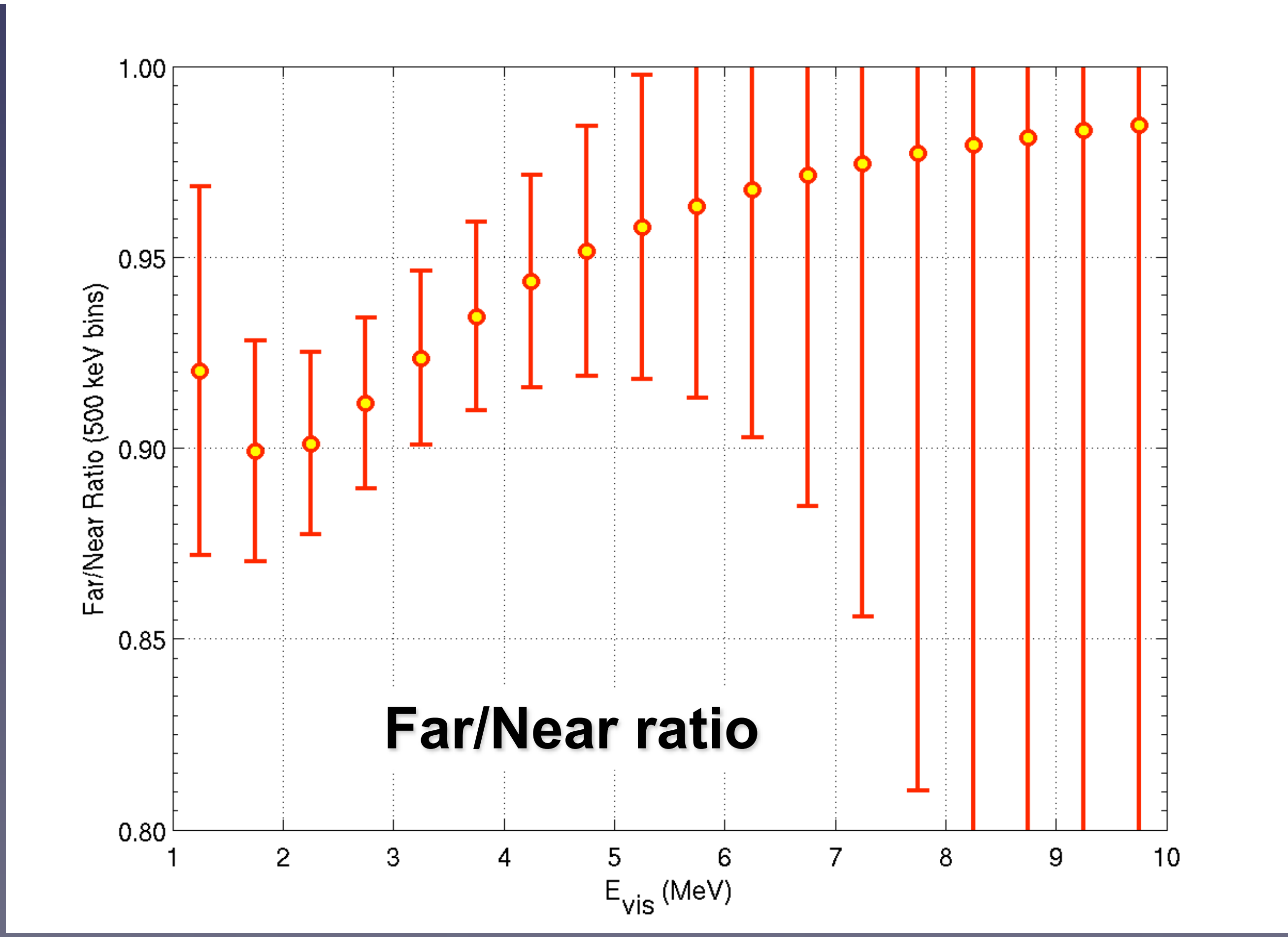
Start by early 2009....

hep-ex/0704.0498

If observed...







$\Delta m^2_{atm} = 3.0\times10^{-3}\ eV^2$

$\sin^2(2\theta_{13})=0.12$

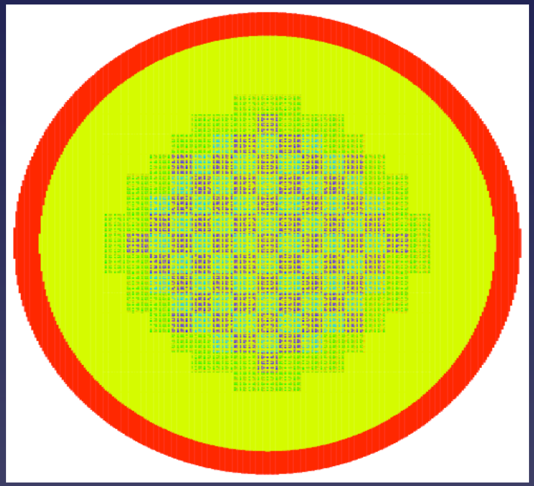
systematics break down

		CHOOZ	Double-Chooz		
Reactor-induced	ν flux and σ	1.9%	<0.1 %	Two "identical" detectors & Low background	σ^{abs}_{norm}
	Reactor power	0.7%	<0.1 %		
	Energy per fission	0.6%	<0.1 %		
Detector - induced	Solid angle	0.3%	<0.1 %	distance measured @ 10 cm & monitor core barycenter	$\sigma^{relative}_{norm}$
	Volume	0.3%	0.2%	mass measurements to 0.2%	
	Density	0.3%	<0.1 %	T control: ND & FD	
	H/C ratio & Gd concentration	1.2%	<0.1 %	mass measurements + same scintillator batch + stability R&D	
	Spatial effects	1.0%	<0.1 %	calibration	
	Deadtime	negligible	0.25%	dedicated measurements & calibration	
Analysis	From 7 to 3 cuts	1.5%	0.2 - 0.3 %	(see later)	$\sigma^{analysis}_{norm}$
	Total	**2.7%**	**< 0.6 %**		

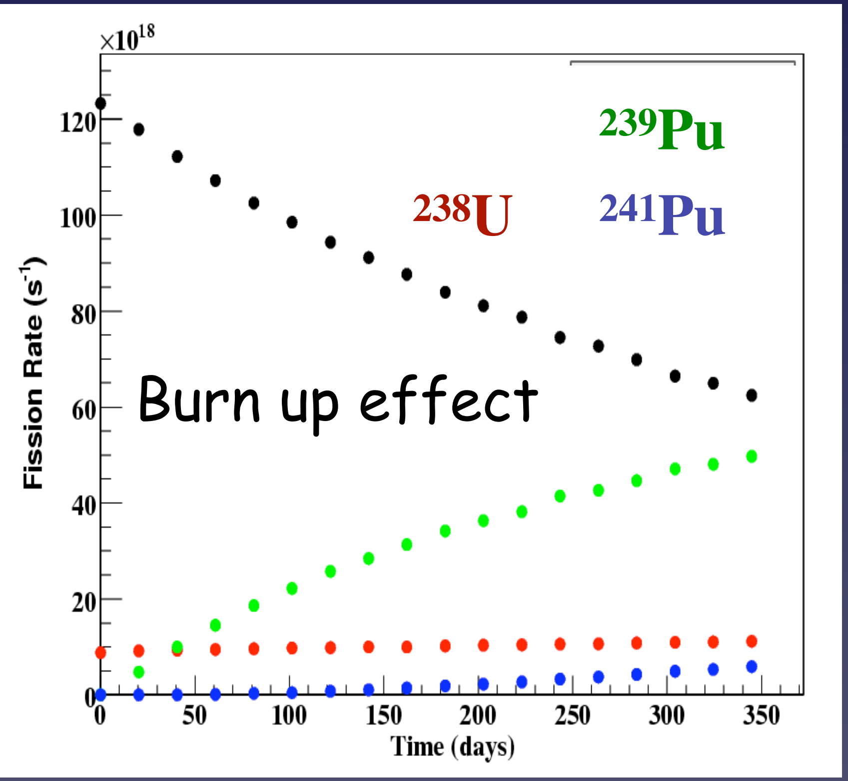
Simulation of ν Spectrum

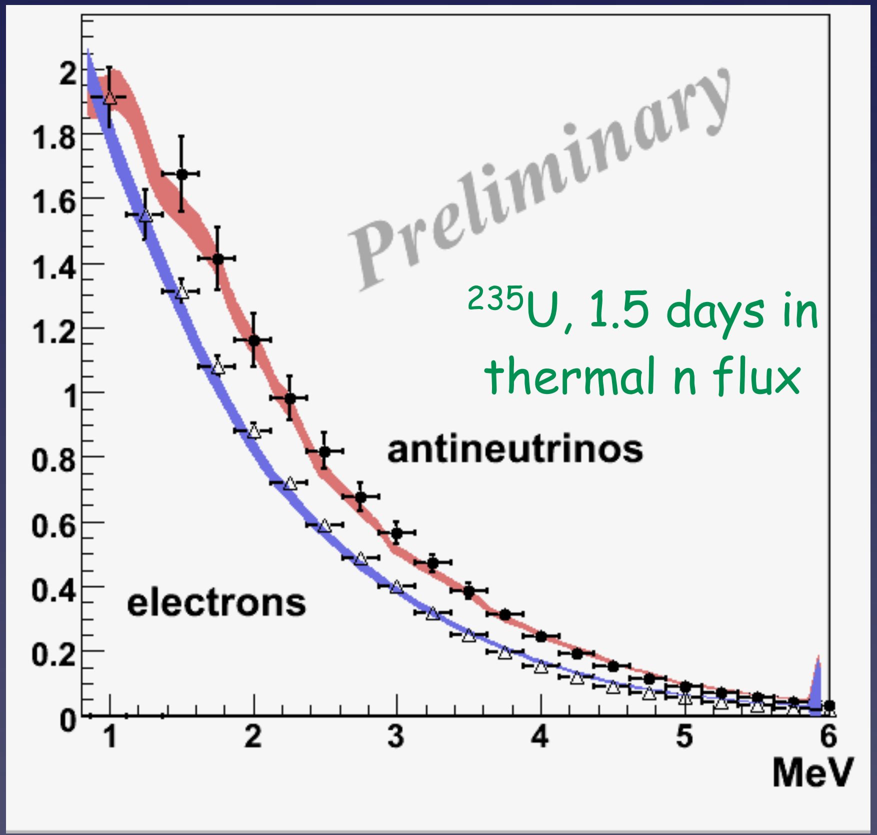
Time evolution of the isotopic composition of the cores: MURE

Construction of total ν spectrum from nuclear databases.



205 fuel assemblies





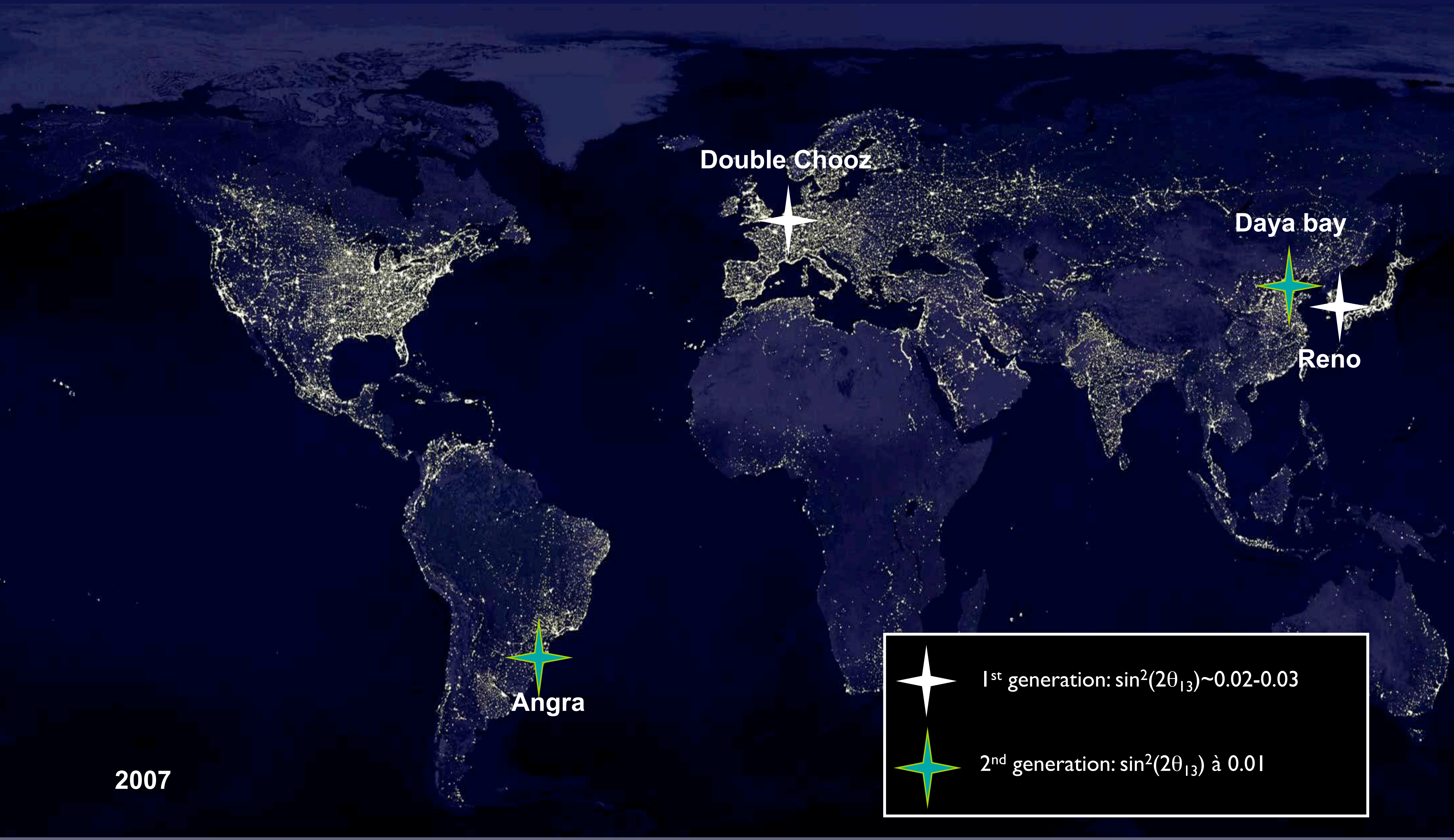
★Full propagation of errors and correlations

★Potential improved shape analysis for the extraction of oscillation parameters => critical for DC-phase I

★Tool for feasibility of applied ν physics: power measurement and non-proliferation

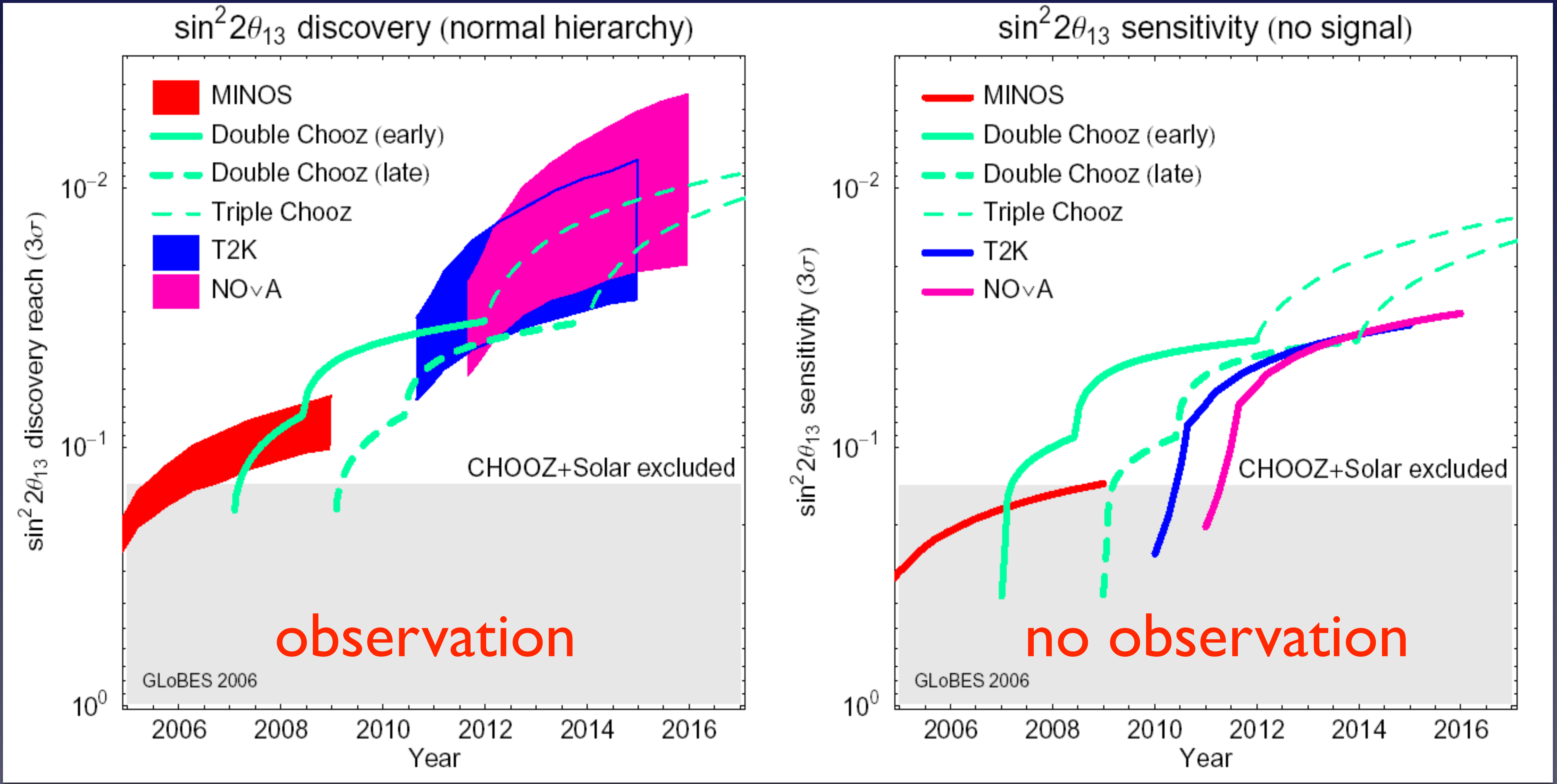
What to remember...

Projects in the World- 2007



beams + reactors = deeper insight

Competitive & overlapping coverage by both techniques!



Similar time scale

Huber et al: hep-ph/0601266

- A reactor (independent) measurement of θ_{13} is critical for global neutrino oscillation physics reach
    - Beams sensitivity is compromised by several unknown observables (θ_{13},δ_{CP},$\pm\Delta m^2_{atm}$) leading to similar signature
- Double Chooz is being built.
    - FD running by early 2009
    - ND running by mid-2010, laboratory will be available by 2009
- Double Chooz can "observe" [to 3σ if $\sin^2(2\theta_{13})>0.05$] or limit $\theta 13$:
    - Phase I: $\sin^2(2\theta_{13}) >0.06$ by 2010
    - Phase II: $\sin^2(2\theta_{13}) > 0.025$ by 2013
- Double Chooz is leader experiment in the field: defining much of the strategy to measure θ_{13} with reactors.

THE END