De futurs projets MEGA-Tonic!

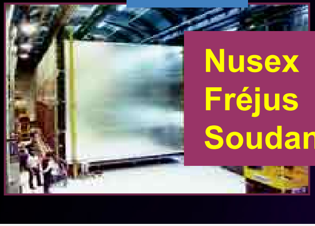
JE Campagne LAL-Orsay
SFP 4 Mars 2006

Absolument pas exhaustif…

Passé, Présent, Futur…

Track. Seg.

1kT

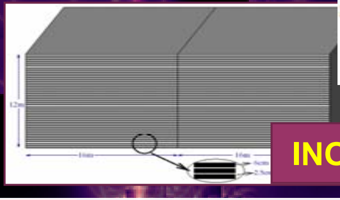


Nusex
Fréjus
Soudan

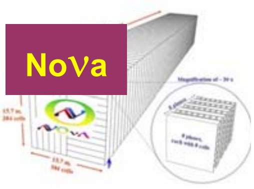
2÷3kT

Opera
Minos

50÷100kT



INO

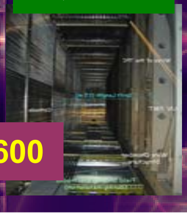


NoVa

Liq. Argon

50 litres R&D

0,6kT



T600

0,1kT

T2K-2km

50÷100kT

Flare
Glacier

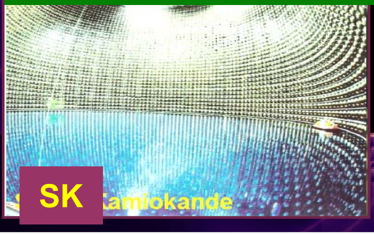
Cerenkov Eau

1kT

IMB
Kamioka

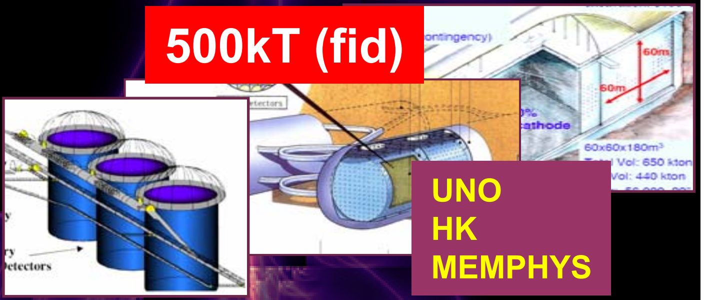
SNO

22/50kT (fid/tot)



SK

500kT (fid)



UNO
HK
MEMPHYS

Scint. Liq.

5T

CHOOZ

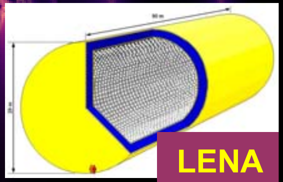
0,3÷1kT

KamLAND
Borexino
LVD

10÷30T

Double CHOOZ
Breadwood
Daya Bay…

50-100kT



LENA

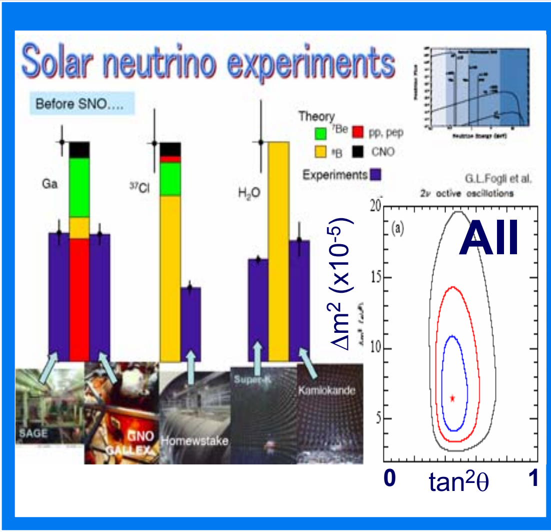
HSD

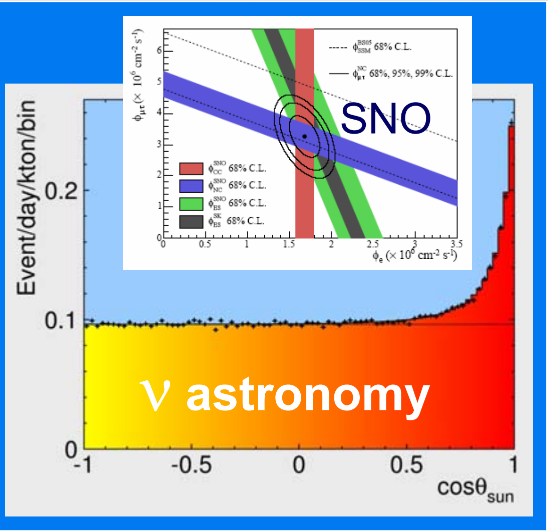
La recherche de la désintégration du proton…

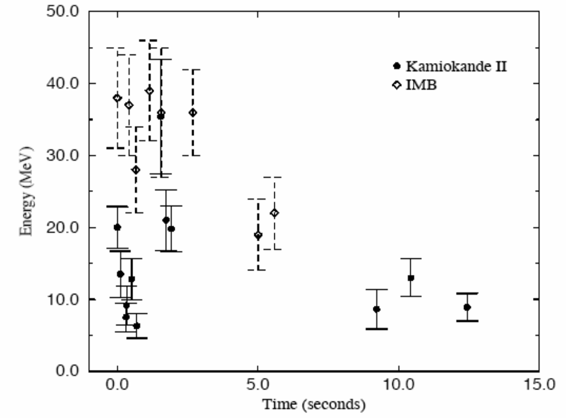
Various large detectors have been built to search for proton decays. No signal has been found…

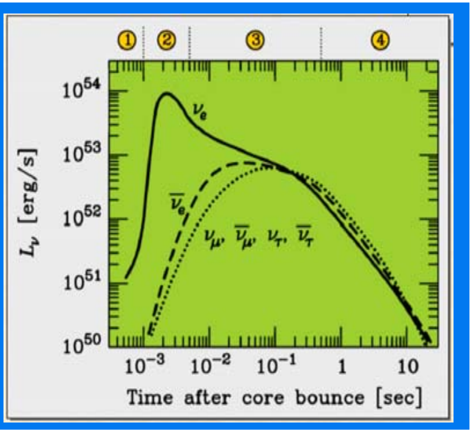
50kT of Water ≈ 10^{34} protons

But past success of the field…

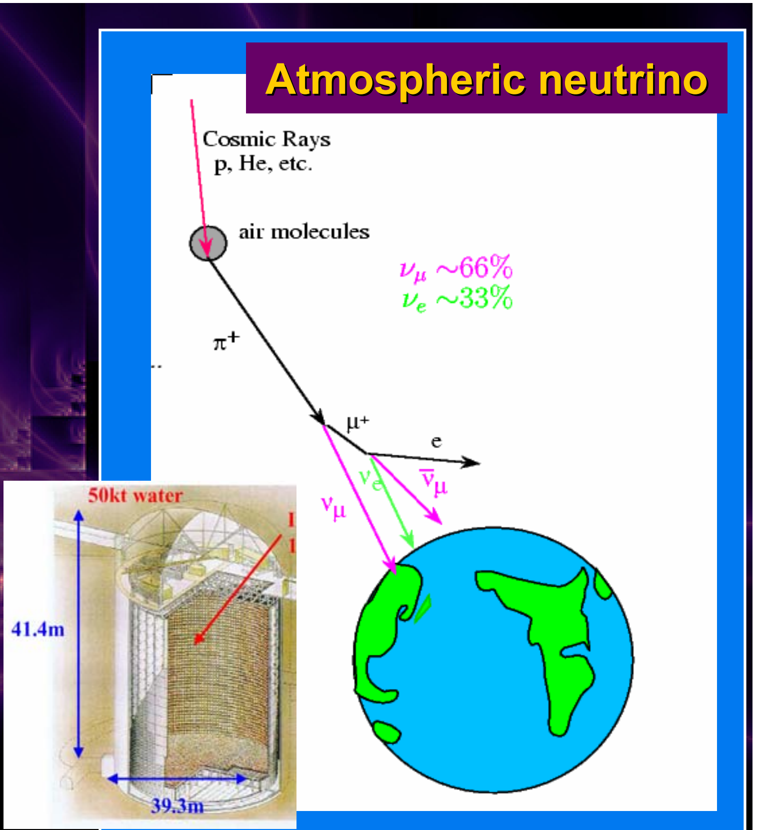


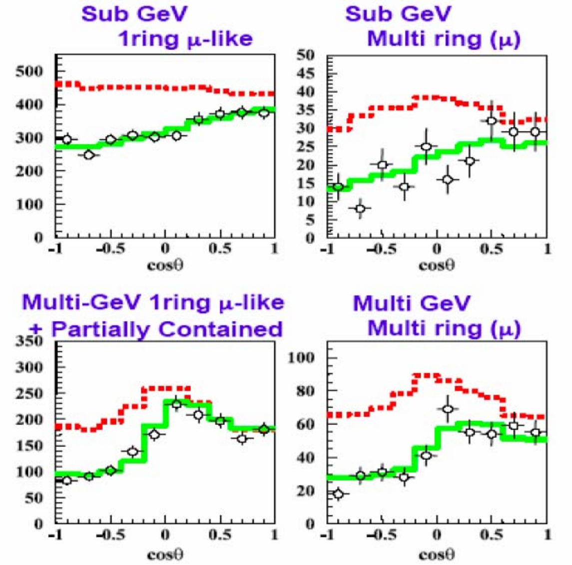






Atmospheric neutrino





- •Solar neutrino anomaly solved
- •Detection of SN-1987A (Nobel Koshiba)
- •Discovery of atm neutrino oscillations

The need for new generation experiments…

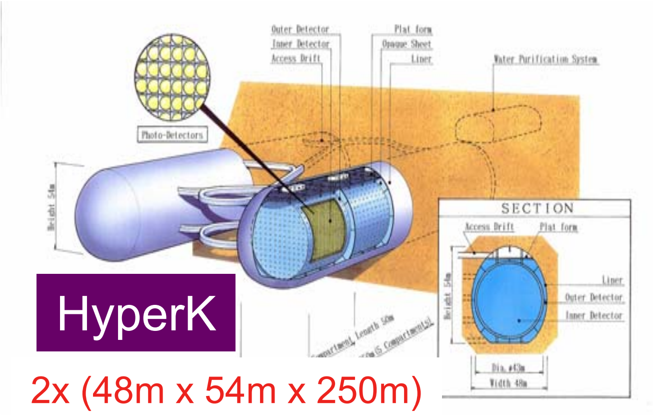
Still many important issues…

Baryon number violation	Proton decay
Astroparticle physics	
Understand gravitational collapse	Galactic SN ν
Star formation in the early universe	Relic SN ν
Explore violent phenomena in the universe	Trigger SN ν,
Dark matter and astrophysical sources	Incoming muons
Neutrino properties	LBL - ν, Atm. - ν, SN - ν,
Solar thermonuclear fusion processes	Solar - ν
Geophysical models, Earth density profile	Geo - ν , U, Th - ν

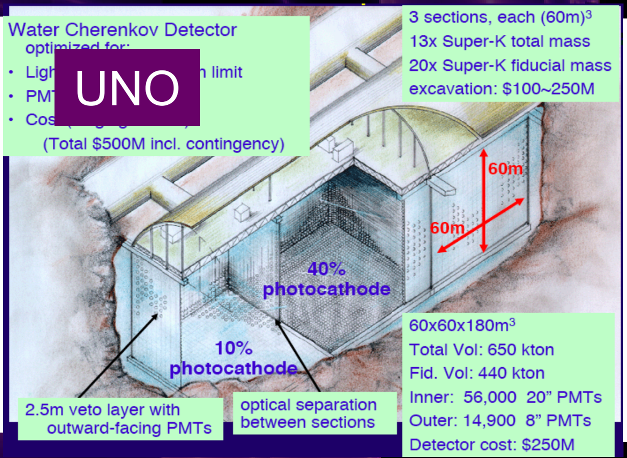
Les détecteurs envisagés… **NNN série de Workshops**

Aussois 05, Seatle 06, Hamamatsu 07

Cerenkov à Eau 500kT→1Mt



2x (48m x 54m x 250m)



Water Cherenkov Detector
optimized for:
- Ligh limit
- PMT
- Cos

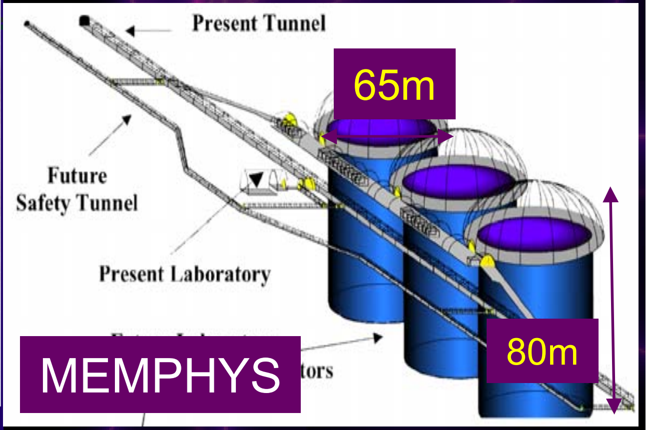
(Total $500M incl. contingency)

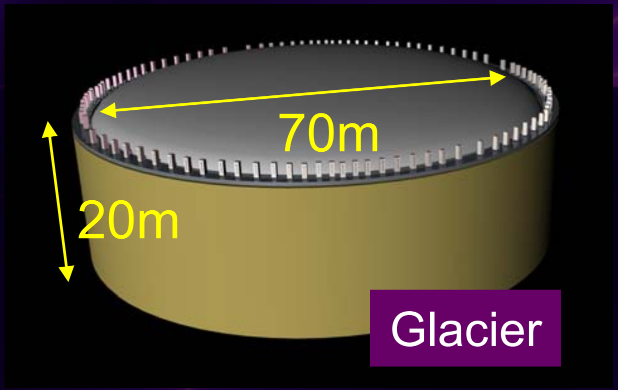
3 sections, each $(60m)^3$
13x Super-K total mass
20x Super-K fiducial mass
excavation: $100~250M

2.5m veto layer with outward-facing PMTs

optical separation between sections

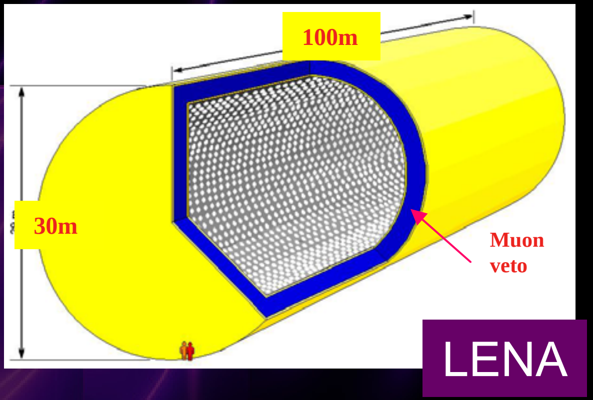
$60x60x180m^3$
Total Vol: 650 kton
Fid. Vol: 440 kton
Inner: 56,000 20" PMTs
Outer: 14,900 8" PMTs
Detector cost: $250M





Argon Liq. →100kT

Scintillateur Liq. →50kT



Mton Water Čerenkov

- Concept of a Mton water Cherenkov detector dates back to 1992
  - M. Koshiba: “DOUGHNUTS” Phys. Rep. 220 (1992) 229

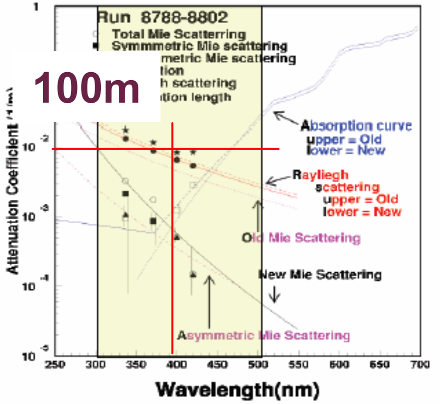
HyperK

- Concept of Hyper-Kamiokande was first presented at NNN99
  - K. Nakamura, Int. J. Mod. Phys. A18 (2003) 4053
- American concept UNO in NNN99:
  - **C.K. Jung, “Feasibility of a next generation underground water Cherenkov detector UNO”, arXiv:hep-ex/0005046**
- Similar European project in 2005:
  - A. de Bellefon et al: “MEMPHYS a large scale water Cerenkov detector at Frejus”, Contribution to the CERN Strategic Group

Well-proven technology (IMB, K, SK) for large scale however currently no wide expertise in Europe

Ex: 1 puits de MEMPHYS

About 170 γ/cm in $350 < \lambda < 500$ nm
With 81,000 PMT (12'') 30% coverage, Q.E.≈24%, CE~70%
(20'' Q.E.≈20%, CE~60%)
Relativistic particle produces
⇒≈14 photoelectrons / cm
⇒≈7 p.e. per MeV



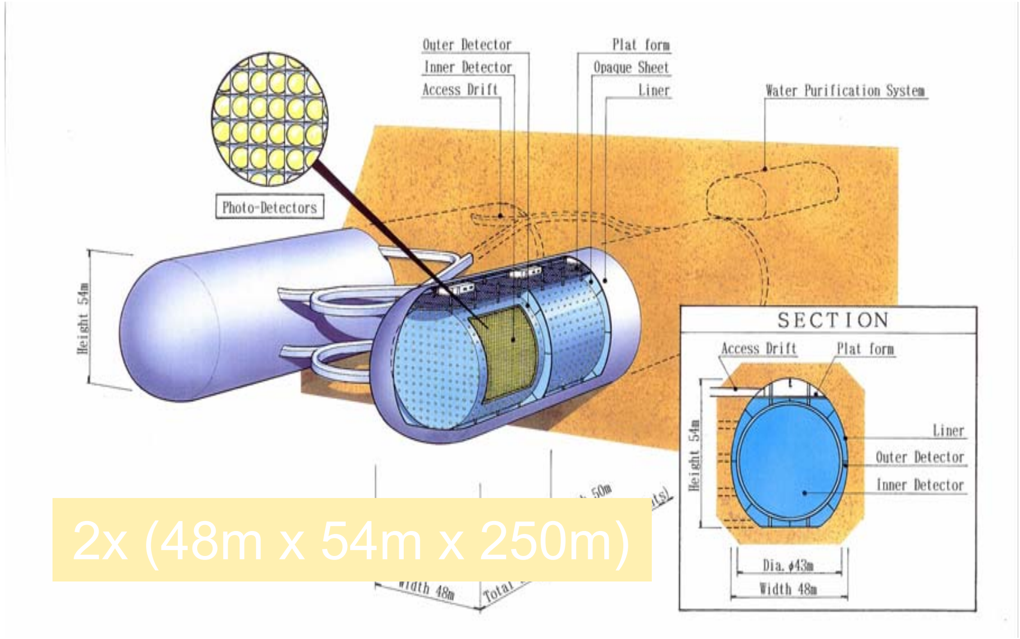
Volume total x4 SK
Fiduciel: 145kT
17535m^2 surface PMT

- Gd Cl_3 highly water soluble but acid
- Neutron capture on Gd emits a 8.0 MeV γ
- 100 tons of $GdCl_3$ in SK-III (0.2% by mass) would yield >90% neutron captures on Gd
- **Test currently on the K2K 1kT prototype**
- **A lot of Physics Potential depend from that!!!**

Beacom & Vagins Phys. Rev. Lett., **93**:171101, 2004

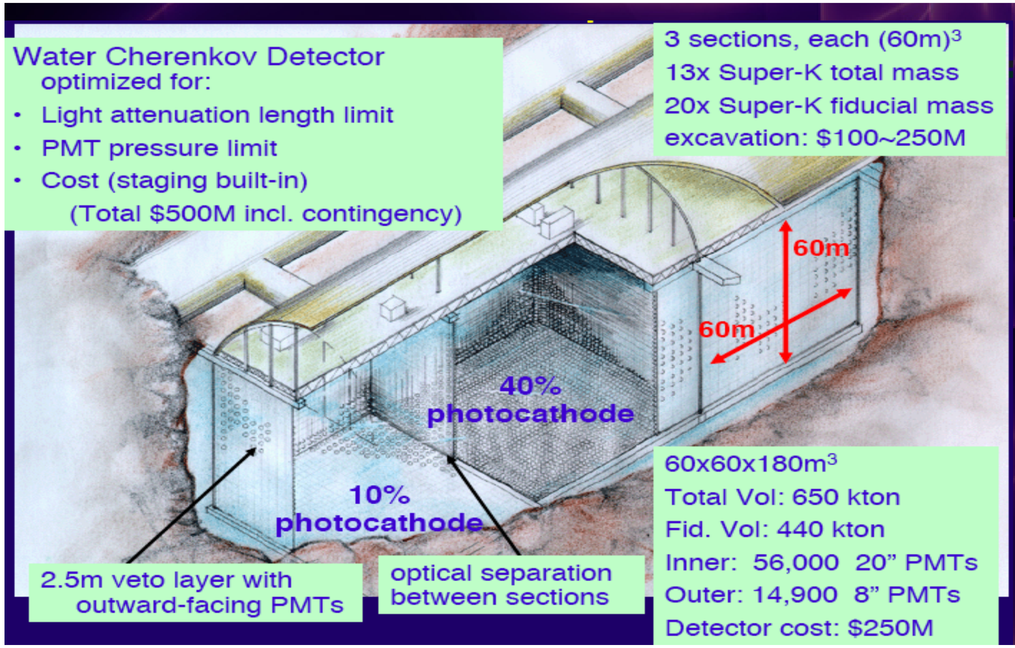
The Japanese and US projects: HK and UNO

(strong collaboration between the 3 WC projects, in NNN and beyond)



2x (48m x 54m x 250m)

- Toshibora Mine (900 mwe)
- FV 540 ktons
- Cavern study performed
- Photodetector R&D on-going
- Long baseline T2K superbeam (CP-violation)
- Decision following results from T2K-Phase 1 (2013-2022 ?)



Water Cherenkov Detector optimized for:

- Light attenuation length limit
- PMT pressure limit
- Cost (staging built-in)
  (Total $500M incl. contingency)

3 sections, each $(60m)^3$
13x Super-K total mass
20x Super-K fiducial mass
excavation: $100~250M

2.5m veto layer with outward-facing PMTs

optical separation between sections

$60x60x180m^3$
Total Vol: 650 kton
Fid. Vol: 440 kton
Inner: 56,000 20” PMTs
Outer: 14,900 8” PMTs
Detector cost: $250M

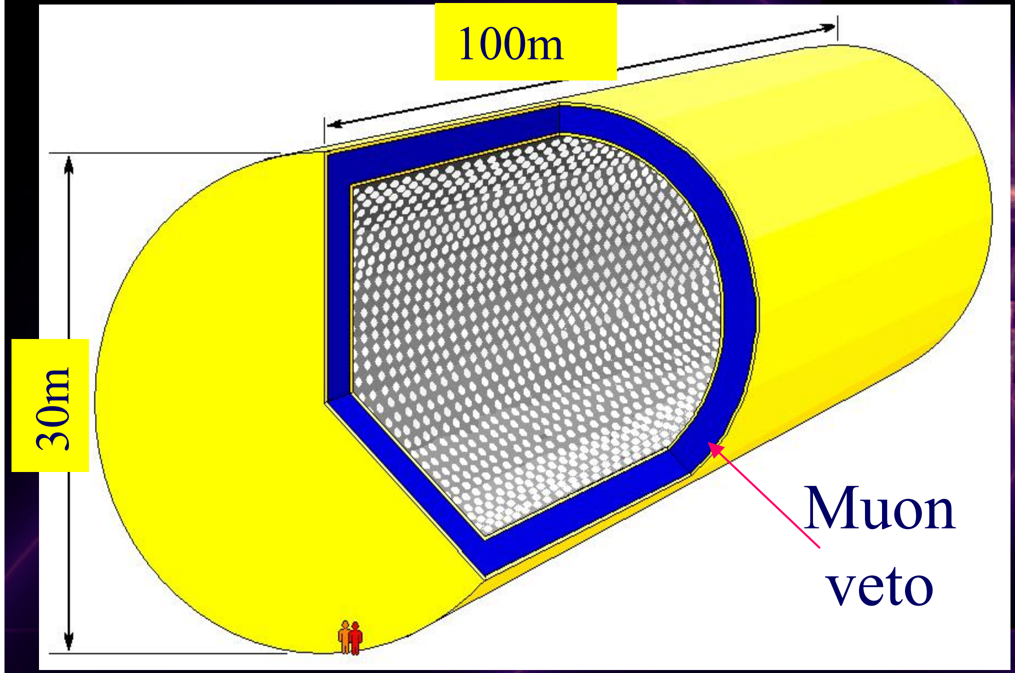
- Henderson Mine (4000 mwe, one of the 2 DUSEL sites)
- FV 440 ktons
- Cavern study to be done
- Photodetector R&D on-going
- Long baseline from BNL
- In the NSF process

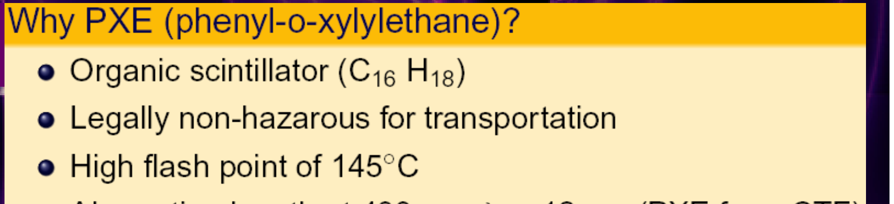
Les détecteurs Čerenkov à Eau dans le monde

	UNO (USA)	**HK (Japon)**	**MEMPHYS (EU)**
Laboratoire			
lieu	Henderson/Homestake	Tochibora	Fréjus
prof. Mwe	4500/4800	1500	4800
LBL(km)	1480÷2760/1280÷2530	290	130
Dimsensions du détecteurs			
type	3 cubes	2 tunnels de 5 compartiments	3 à 5 puits
dimension	60x60x60m^3	ϕ:43m x L:50m	ϕ:65m x L:65m
M fid. Kt	440	550	440 à 730
Photodetecteurs			
type	20" PMT	20" H(A)PD	12" PMT
#	38000 (milieu) 2 x 9500 (coté)	20,000 par compartiment	81,000 par puit
Couverture	40%/10% (milieu/coté)	40%	30%
Coût estimé… 50% excavation + 50% Photodetection			
	500M$	500 Oku ¥	161M€ x #puits +100M€ infra.

Low Energy Neutrino Astrophysics (LENA) en Europe ou HSD au USA

Conceptual design for a large (45 kT)





Why PXE (phenyl-o-xylylethane)?

- Organic scintillator (C_{16} H_{18})
- Legally non-hazarous for transportation
- High flash point of 145°C
- Absorption length at 430 nm: $\lambda = 12$ m (PXE from CTF)

Estimated light yield
~ 110 pe / MeV

12,000 8“ PMTs baseline
+ light concentrators
(a la SNO/Borexino)

Expertise from BOREXINO

Challange: get the same Radioprurity as Borexino but in 45kT detector

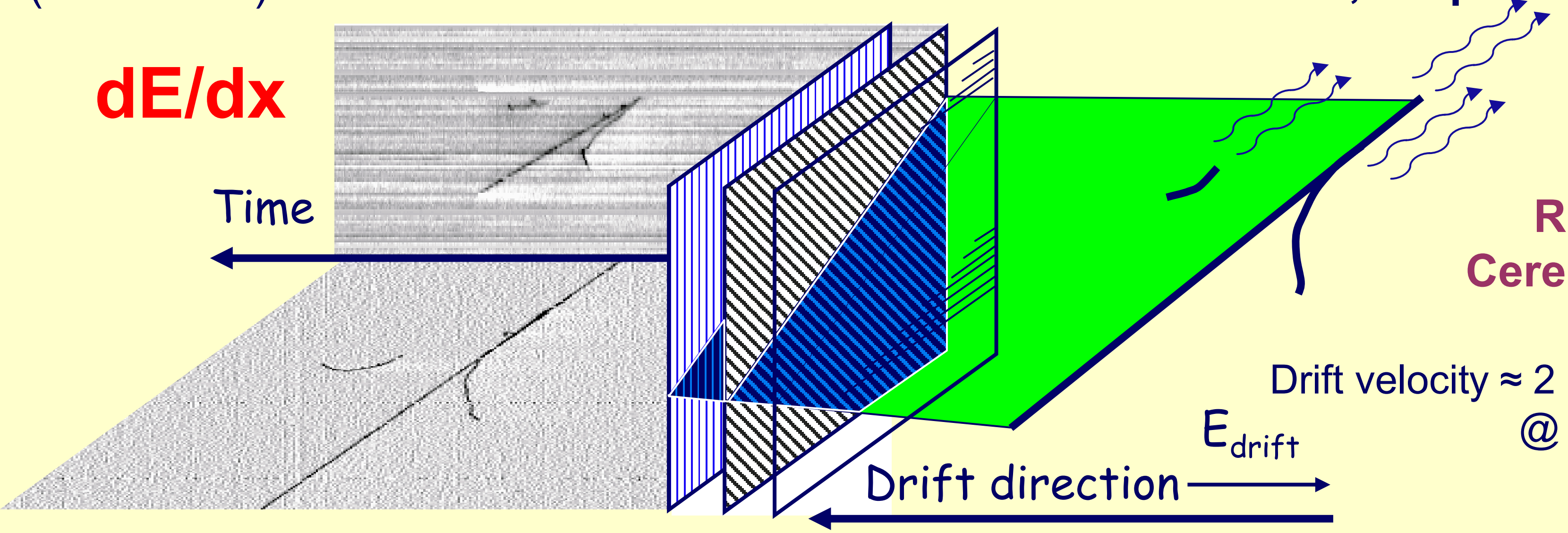
Rough cost estimate 200M€ (wo cavity excavation and purification systems)

L. Oberauer

Argon Liquide TPC

Charge yield ~ 6000 electrons/mm
(~ 1 fC/mm)

UV Scintillation Light 128nm
40,000 photons/MeV



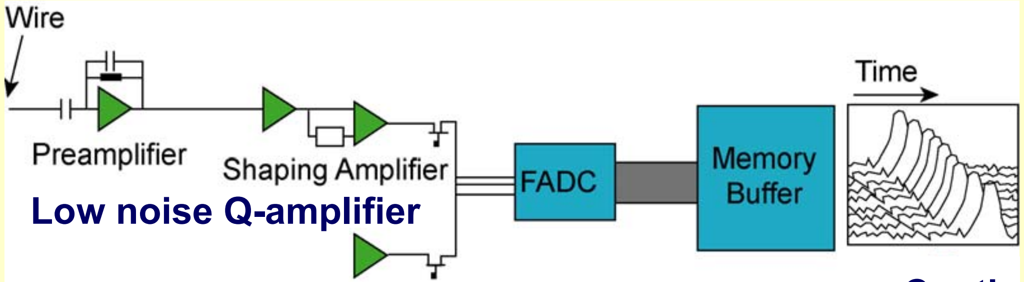
R&D
Cerenkov L

Drift velocity ≈ 2 mm/μs
@ 1 kV/cm

Drift electron lifetime:

$$\tau \approx 300ms ¥ \frac{1\,ppb}{N(O_2)}$$

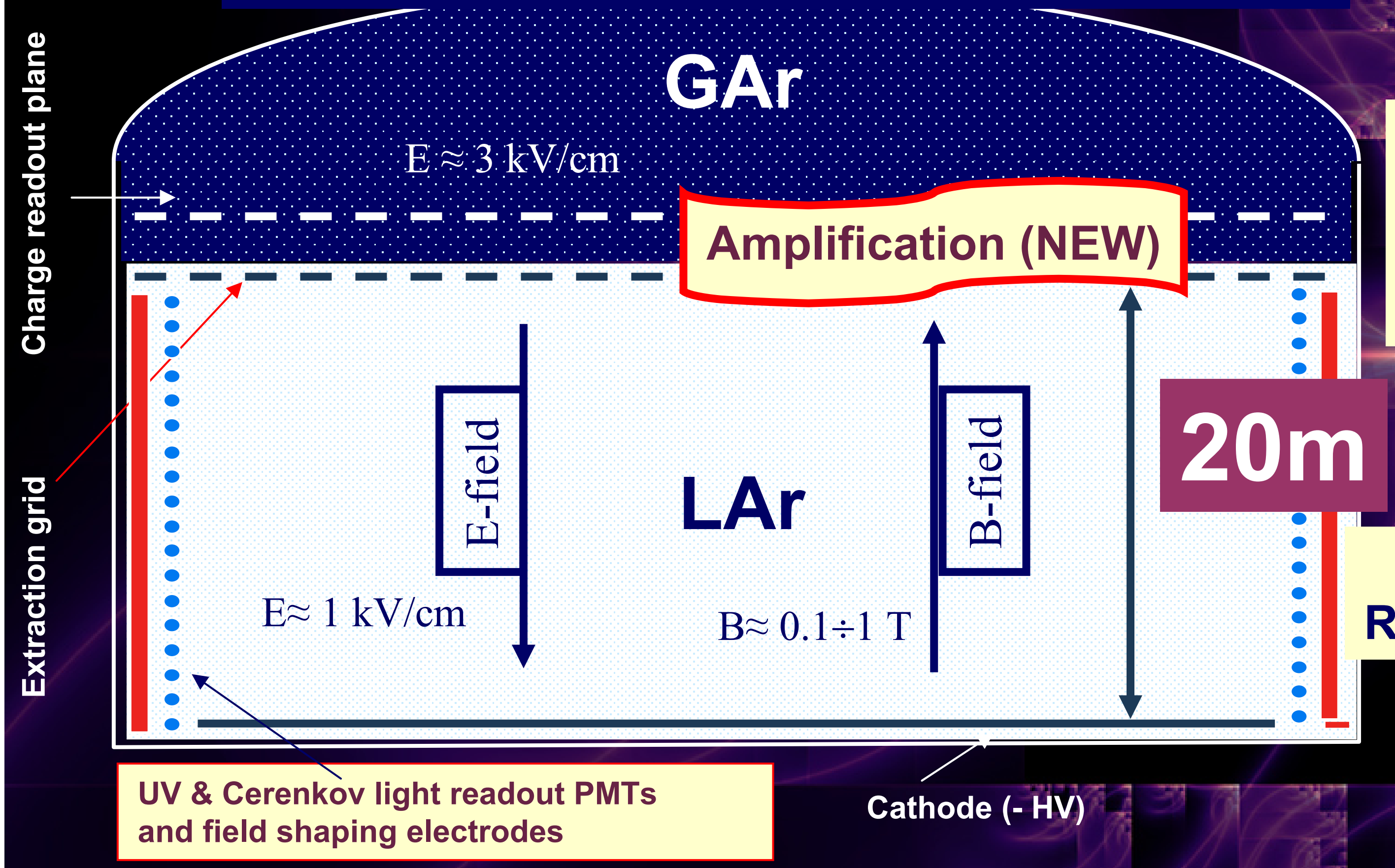
Purity < 0.1ppb O_2-equiv.



Continuous waveform recording
→ **image**

Tentative layout of a large magnetized GLACIER

LHe Cooling: Thermosiphon principle + thermal shield=LAr



GAr

E ≈ 3 kV/cm

Charge readout plane

Amplification (NEW)

Extraction grid

E-field

LAr

B-field

E≈ 1 kV/cm

B≈ 0.1÷1 T

20m

UV & Cerenkov light readout PMTs
and field shaping electrodes

Cathode (- HV)

2ans de remplissage
Production Locale
150t/j
25-30MW – 45M€

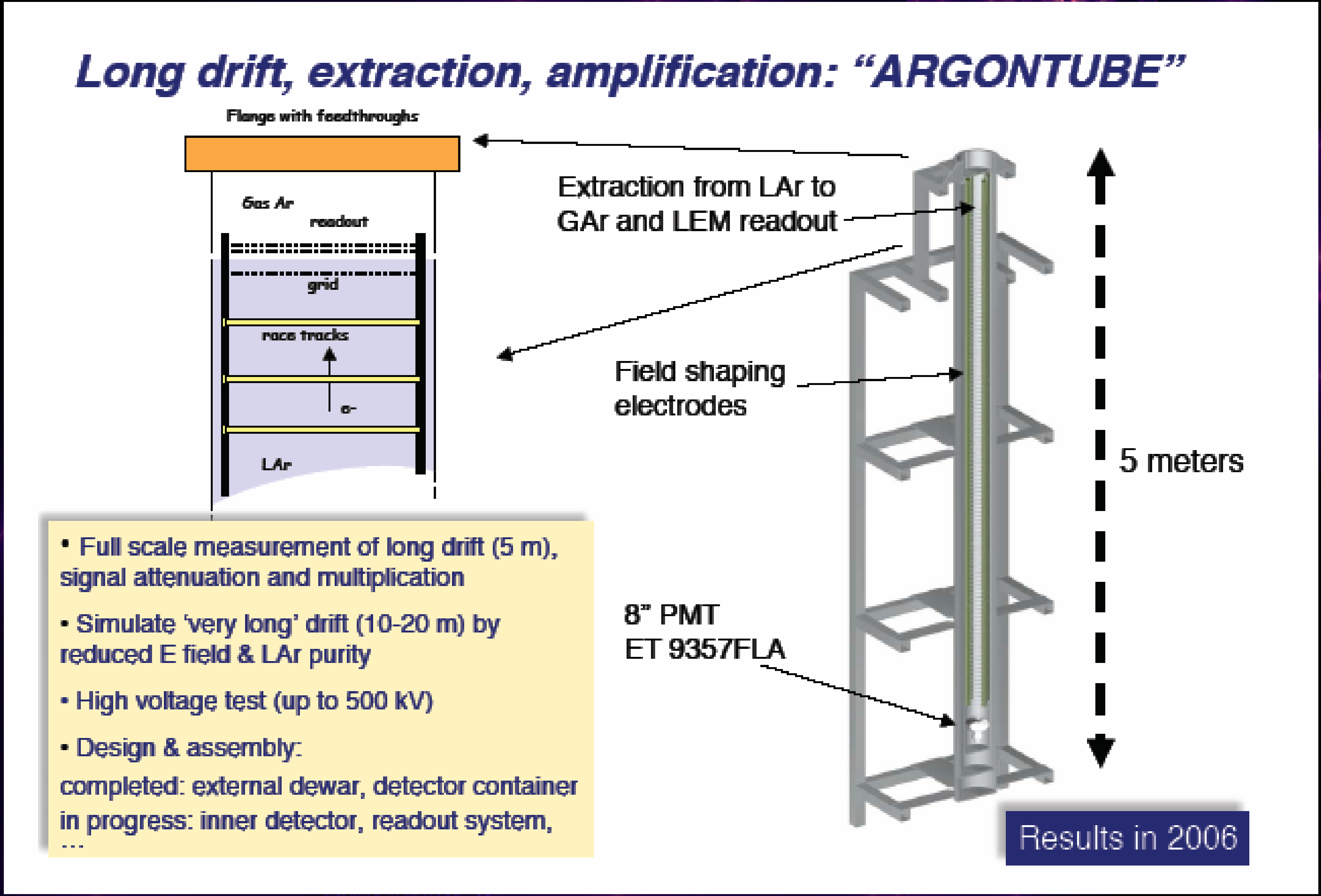
Par jour 29,000Là
Recondenser + purifier

(Magnetized is also been considered)

Rough cost estimate 400M€ with Tank 100% contingency
(10kT => 100M€) **A.Rubbia**

LNG = Liquefied Natural Gas

LAr R&D pour GLACIER: beaucoup de choses…



Long drift, extraction, amplification: "ARGONTUBE"

- Full scale measurement of long drift (5 m), signal attenuation and multiplication
- Simulate 'very long' drift (10-20 m) by reduced E field & LAr purity
- High voltage test (up to 500 kV)
- Design & assembly:

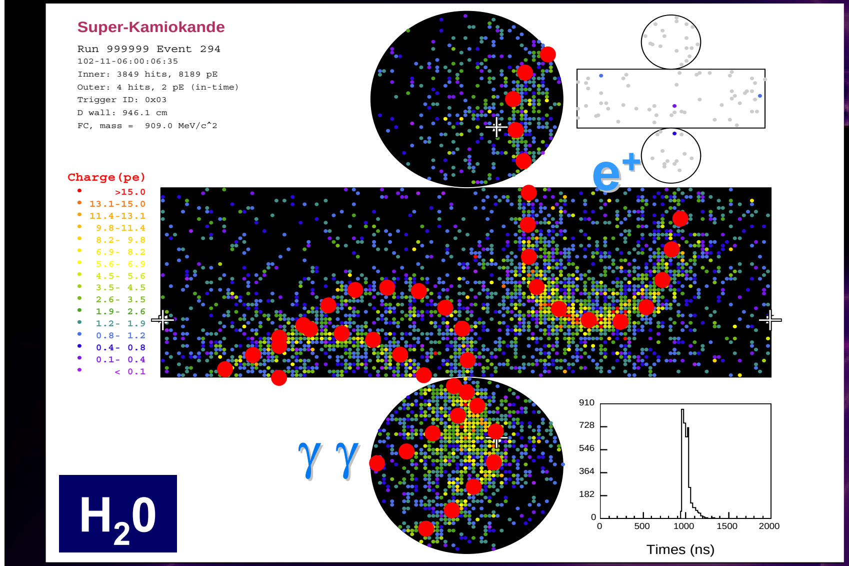
completed: external dewar, detector container

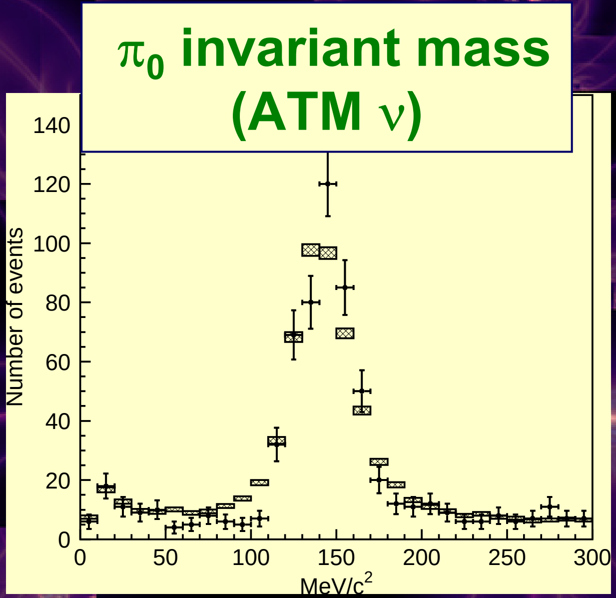
in progress: inner detector, readout system, …

Results in 2006

A. Badertscher @ BENE-ISS-KEK Jan06

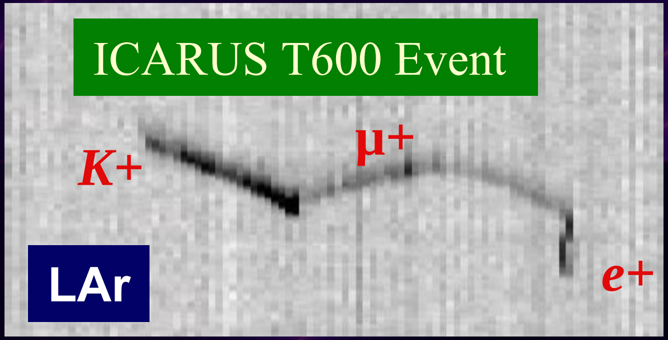
Imaging…





π_0 invariant mass (ATM ν)

1-ring vertex ~30cm



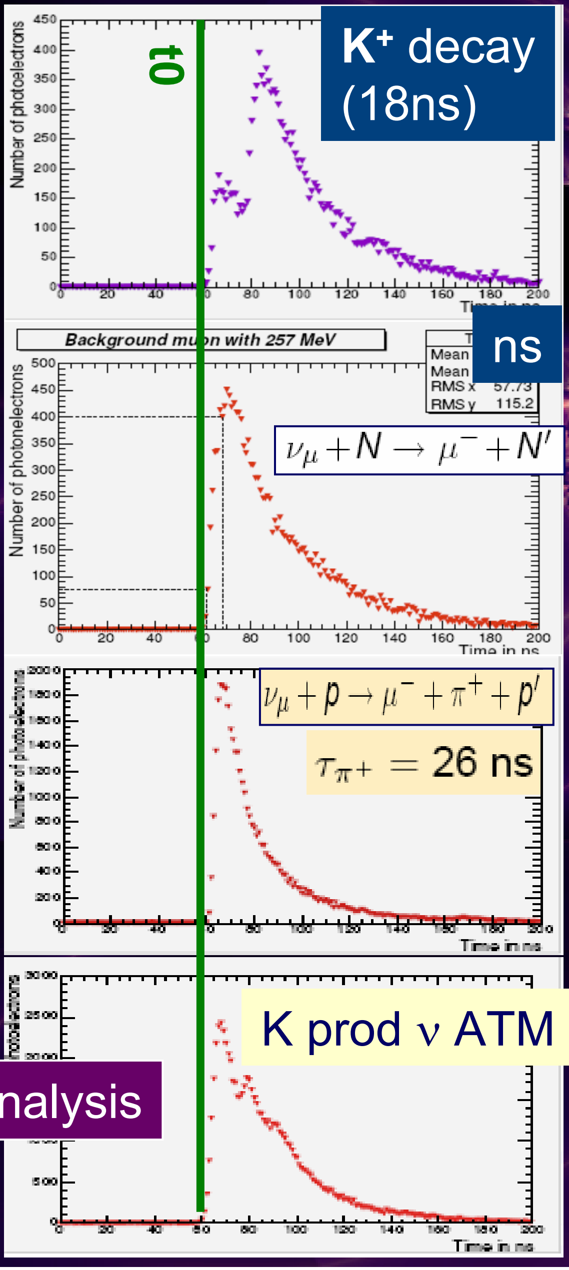
High granularity: Sampling = 0.02 X_0
"bubble" size ≈3×3×0.4 mm³

Seuil en énergie:
H_20 seuil Č: ~1.14GeV:p, ~570MeV: K±, ~120MeV:$\mu^{\pm}$ mais pour l'analyse 5MeV (trig. rate x10/MeV radioactivité ambiante)
LENA ~(200÷300)keV (100pe/Mev)
LAr few 100 keV
Résolution: LENA/GLACIER mieux

Timing…

Scint.Liq.

Nbre de PMTs



K⁺ decay (18ns)

ns

$\nu_\mu + N \rightarrow \mu^- + N'$

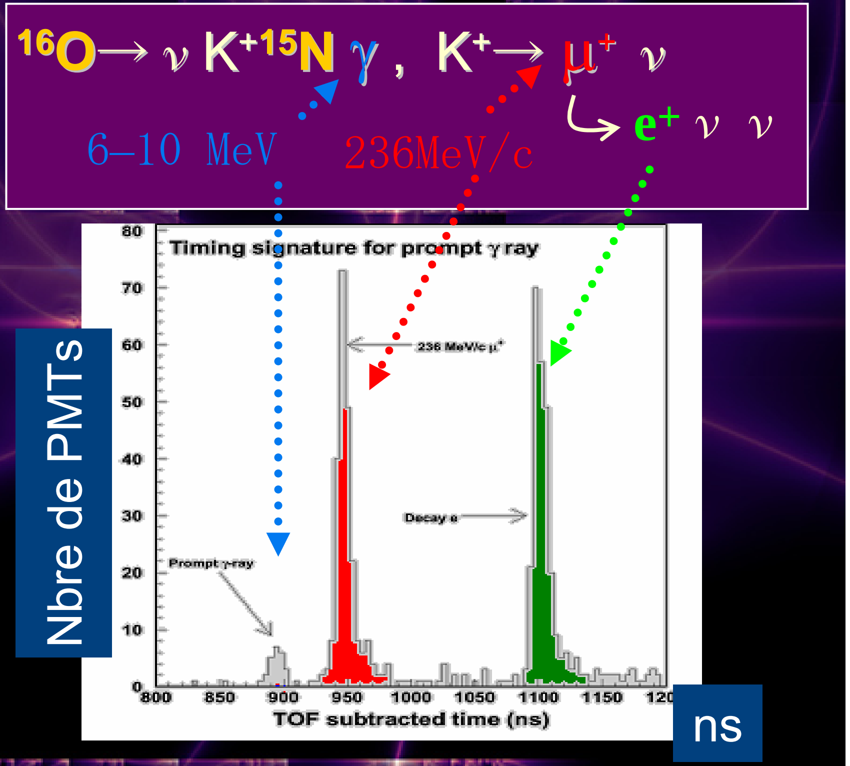
$\nu_\mu + p \rightarrow \mu^- + \pi^+ + p'$

$\tau_{\pi^+} = 26$ ns

K prod ν ATM

Pulse shape analysis

$H_2 0$



$^{16}O \rightarrow \nu K^{+ 15}N \gamma$, $K^+ \rightarrow \mu^+ \nu$

$\hookrightarrow e^+ \nu \nu$

6–10 MeV 236MeV/c

Nbre de PMTs

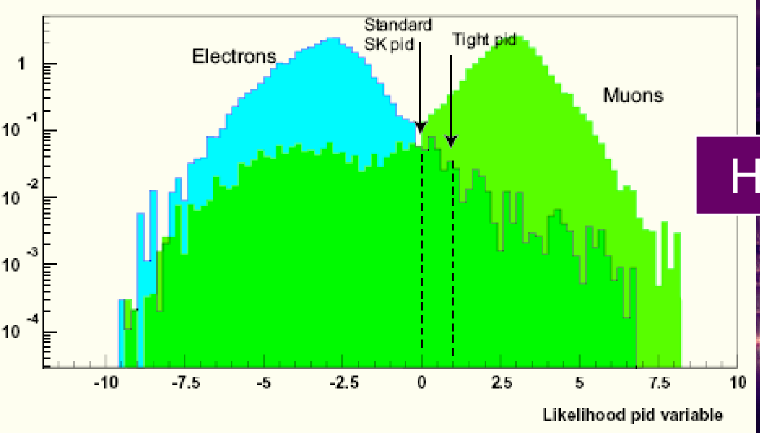
ns

All: Autotrigger capability

LAr n’a pas de possibilité (1μs)

Identification de particules

Particle ID : 99% 1-ring μ, e



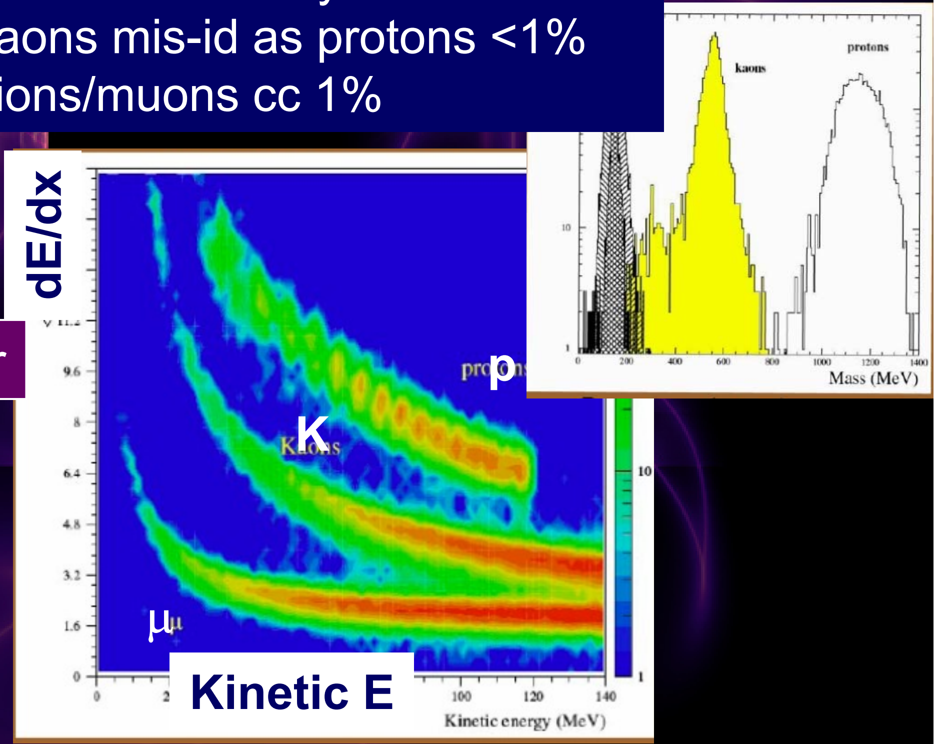
H_20

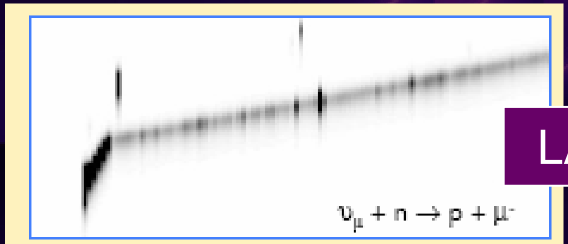
Seuil Cerenkov

Scin. Liq.

Timing μ decay (e/μ sep.)
e/α/p recul à basse énergie
n Id via capture γ
TOF pour « point like event »

Neural Net: dEdx + Length
Protons efficiency >99%
Kaons mis-id as protons <1%
Pions/muons cc 1%





MC QE event.
Proton momentum = 490 MeV/c

LAr

Voir des traces de faible énergie
(sous le seuil Cerenkov)
Ex. recul de proton QEν (T2K–2km)

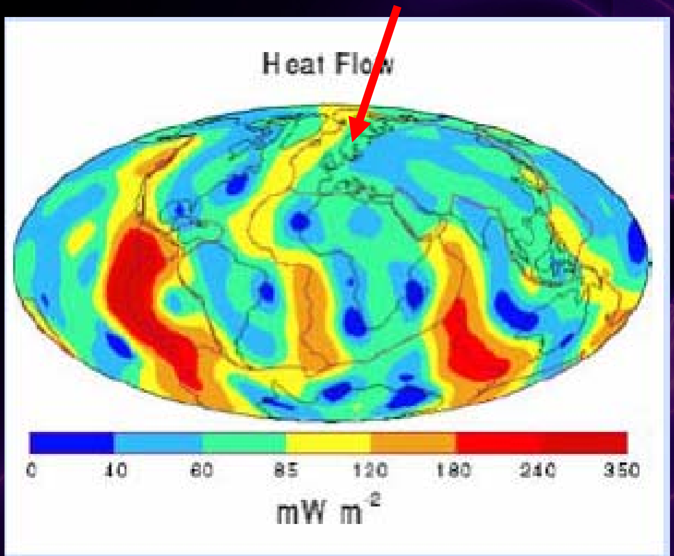
The need for new generation experiments…

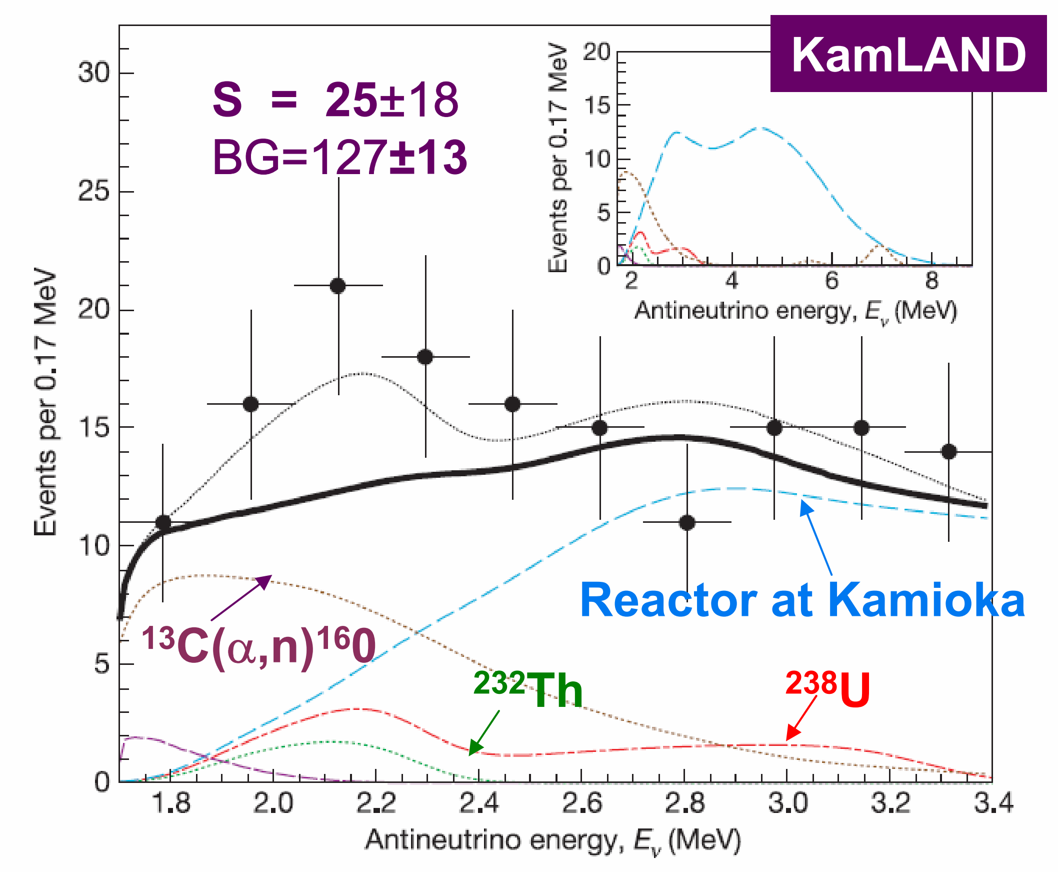
Still many important issues…

• Baryon number violation	Proton decay	★
• Astroparticle physics		
• Understand gravitational collapse	Galactic SN ν	★
• Star formation in the early universe	Relic SN ν	★
• Explore violent phenomena in the universe	Trigger SN ν,	
• Dark matter and astrophysical sources	Incoming muons	
• Neutrino properties	LBL - ν, Atm. - ν, SN - ν,	★
• Solar thermonuclear fusion processes	Solar - ν	
• Geophysical models, Earth density profile	Geo - ν , U, Th - ν	★

Geo-neutrinos (LENA)

LENA (50kT) @ Pyhäsalmi: **~ 1500 events Signal / year**





Background reduction ?

Reactor: ~1/20 Ok

α produced by ^{210}Po from ^{210}Pb (^{222}Rn): 10^{-17}g/g in KamLAND…

Proton decay

Une **borne supérieure** existe venant du secteur de GAUGE (d=6) **indépendante de modèle** I. Dorsner, P. F. Perez PLB 625 (05) 88

$$\tau_p^M \leq 6.0 \times 10^{39} \frac{(M_X/10^{16}\,\text{GeV})^4}{\alpha_{GUT}^2} (0.003\,\text{GeV}^3/\alpha)^2\,\text{years}$$

$$\tau_p^D \leq 1.4 \times 10^{37} \frac{(M_X/10^{16}\,\text{GeV})^4}{\alpha_{GUT}^2} (0.003\,\text{GeV}^3/\alpha)^2\,\text{years}$$

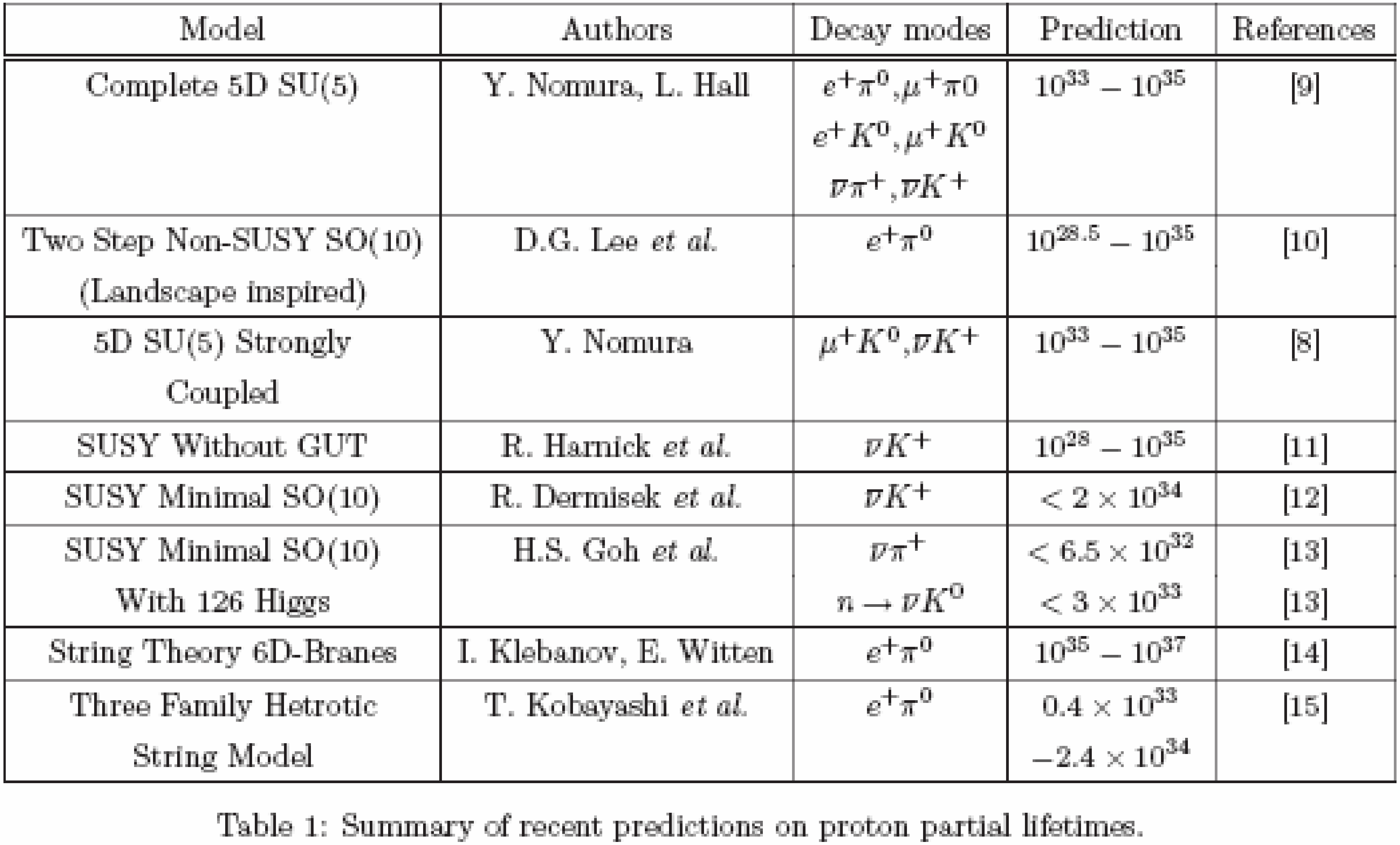
La spécialisation des modèles donne des prédictions bien en dessous des ces valeurs…

On ne peut réduire à 0 tous les canaux simultanément

$\bar{\nu}$ + méson ↔ lepton chargé + méson

$$p \to K^+ \bar{\nu}$$

$$p \to e^+ \pi^0$$

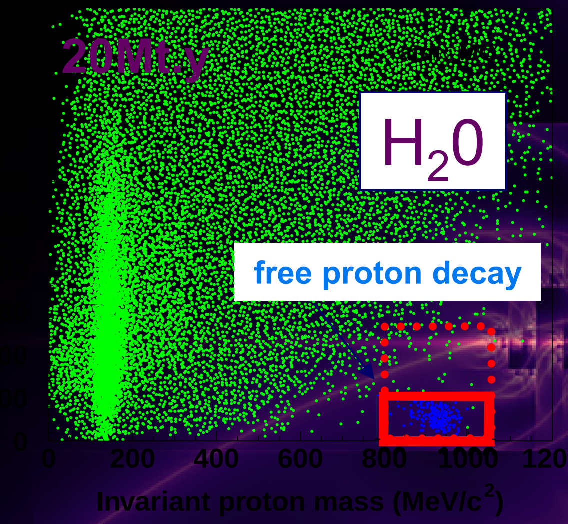


Model	Authors	Decay modes	Prediction	References
Complete 5D SU(5)	Y. Nomura, L. Hall	$e^+\pi^0$,$\mu^+\pi 0$ e^+K^0,μ^+K^0 $\overline{\nu}\pi^+$,$\overline{\nu}K^+$	$10^{33} - 10^{35}$	[9]
Two Step Non-SUSY SO(10) (Landscape inspired)	D.G. Lee *et al.*	$e^+\pi^0$	$10^{28.5} - 10^{35}$	[10]
5D SU(5) Strongly Coupled	Y. Nomura	μ^+K^0,$\overline{\nu}K^+$	$10^{33} - 10^{35}$	[8]
SUSY Without GUT	R. Harnick *et al.*	$\overline{\nu}K^+$	$10^{28} - 10^{35}$	[11]
SUSY Minimal SO(10)	R. Dermisek *et al.*	$\overline{\nu}K^+$	$< 2 \times 10^{34}$	[12]
SUSY Minimal SO(10) With 126 Higgs	H.S. Goh *et al.*	$\overline{\nu}\pi^+$ $n \to \overline{\nu}K^0$	$< 6.5 \times 10^{32}$ $< 3 \times 10^{33}$	[13] [13]
String Theory 6D-Branes	I. Klebanov, E. Witten	$e^+\pi^0$	$10^{35} - 10^{37}$	[14]
Three Family Hetrotic String Model	T. Kobayashi *et al.*	$e^+\pi^0$	0.4×10^{33} -2.4×10^{34}	[15]

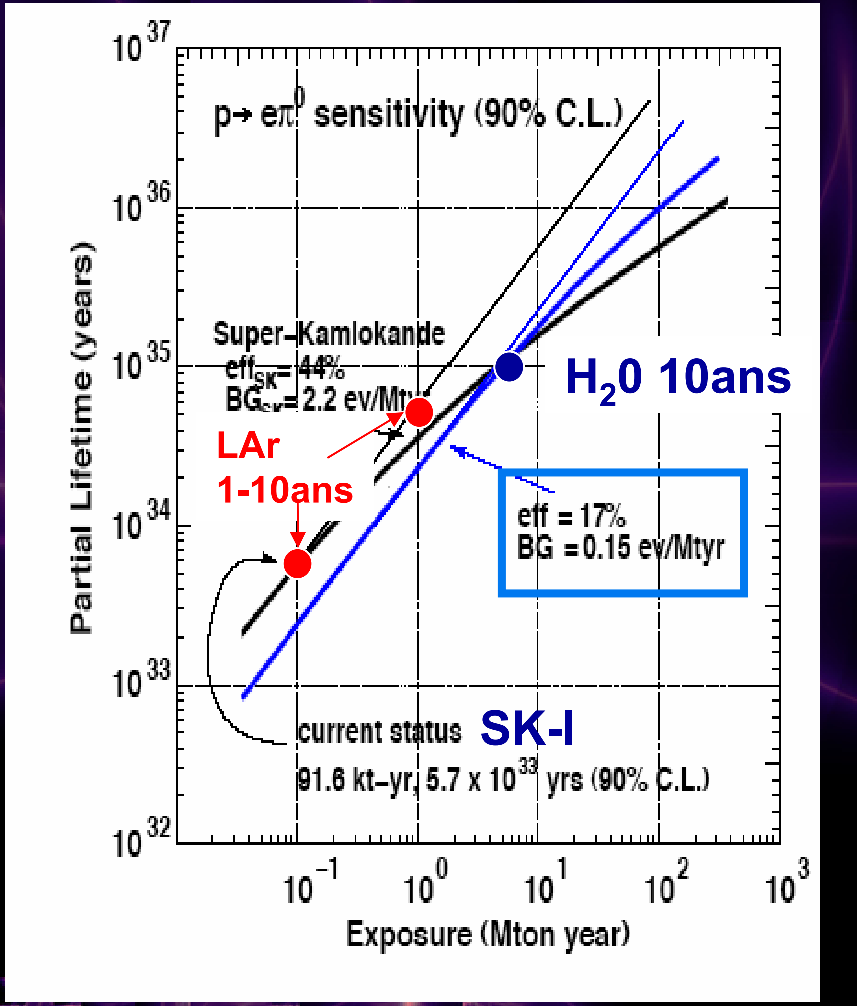
Table 1: Summary of recent predictions on proton partial lifetimes.

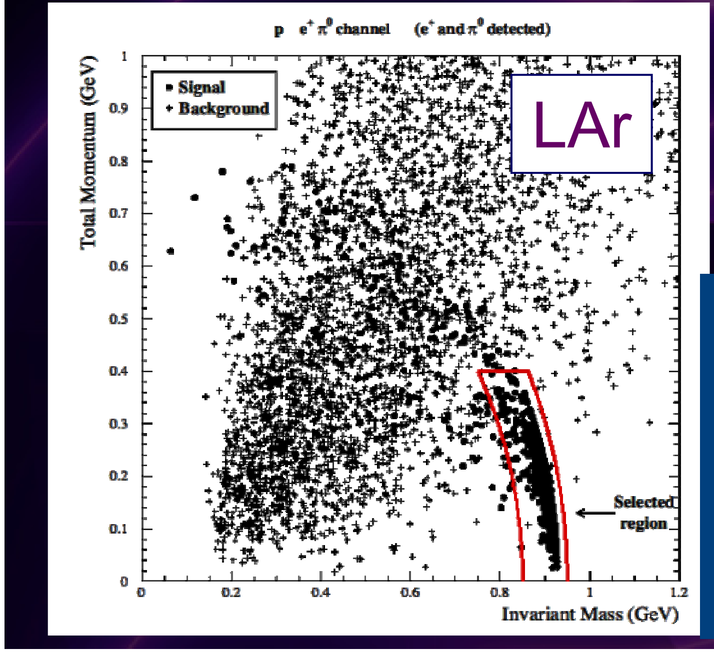
From UNO EOI

$p \rightarrow e^+ \pi^0$



SK Analysis with or wo tight cuts ~5Mt.y x-over





- Assuming perfect particle and track identification, and ±5% knowledge of the total energy
- **bkgd is 1/Mty with 45% efficiency**

  Nuclear effects dominate the efficiency (as in water)

$p \to K^+ \bar{\nu}$

H_20: K⁺ sous le seuil Č

Imaging/Timing

$K^+ \to \pi^+\pi^0; \mu^+\nu$ avec ou sans ^{15}O

$\to {}^{15}N\ \gamma$ prompt (6MeV) tag

Scint. Liq: K⁺ seul suffit

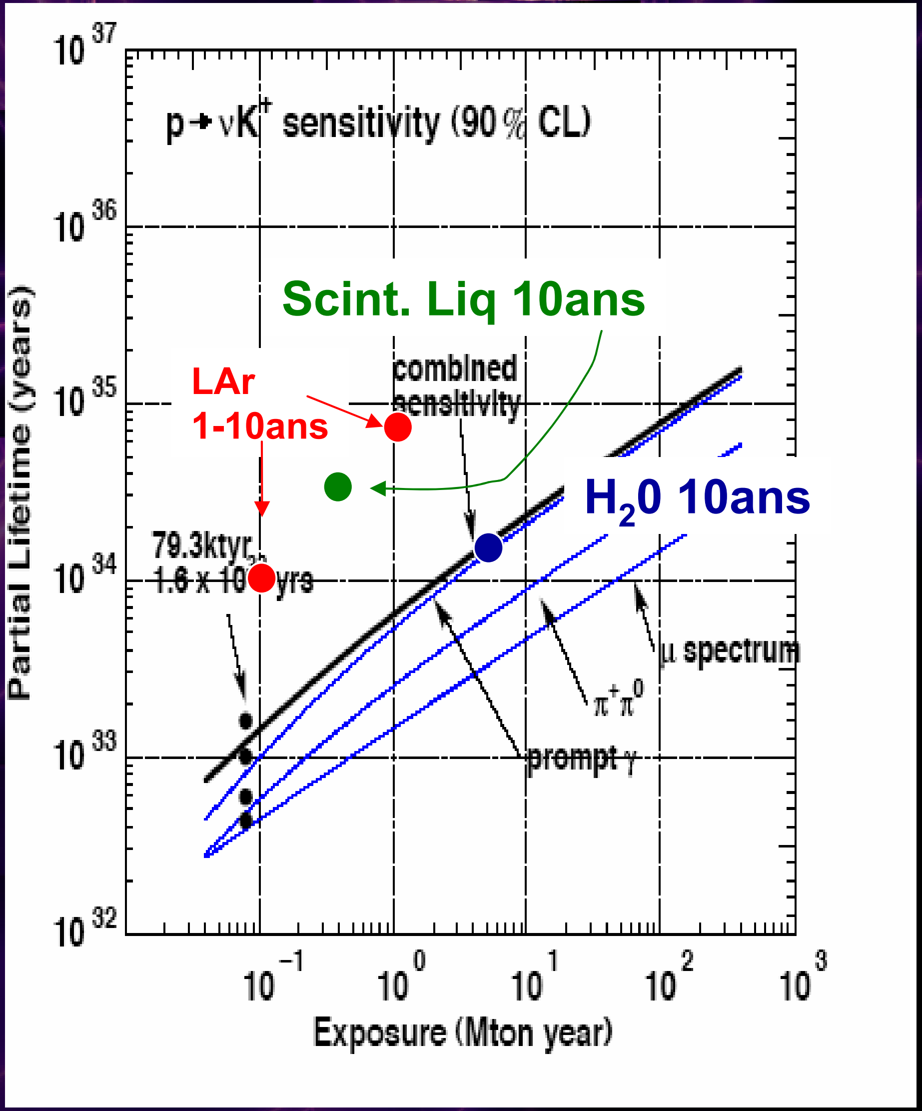
Timing du decay 12ns

LAr: K⁺ seul suffit

dEdx vs Length

	ε	Bkgd
H_2O (*)	8.6%	3/Mt.y
Scint. Liq.	65%	<1/Mt.y
LAr	97%	<1/Mt.y

*: SK analysis



$p \rightarrow K^+ \ \bar{\nu}$ (H_20 case)

(1) $P \rightarrow \nu K^+$, $K^+ \rightarrow \underline{\mu^+} \ \nu$

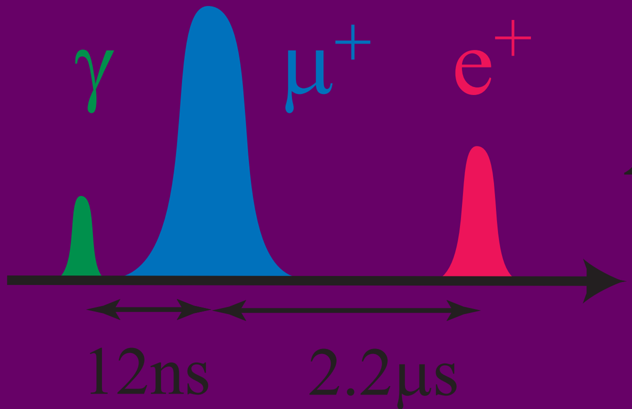
236 MeV/c

(2) $^{16}O \rightarrow \nu K^{+15}N \underline{\gamma}$, $K^+ \rightarrow \underline{\mu^+} \ \nu$

$\hookrightarrow e^+ \ \nu \ \nu$

6 – 10 MeV

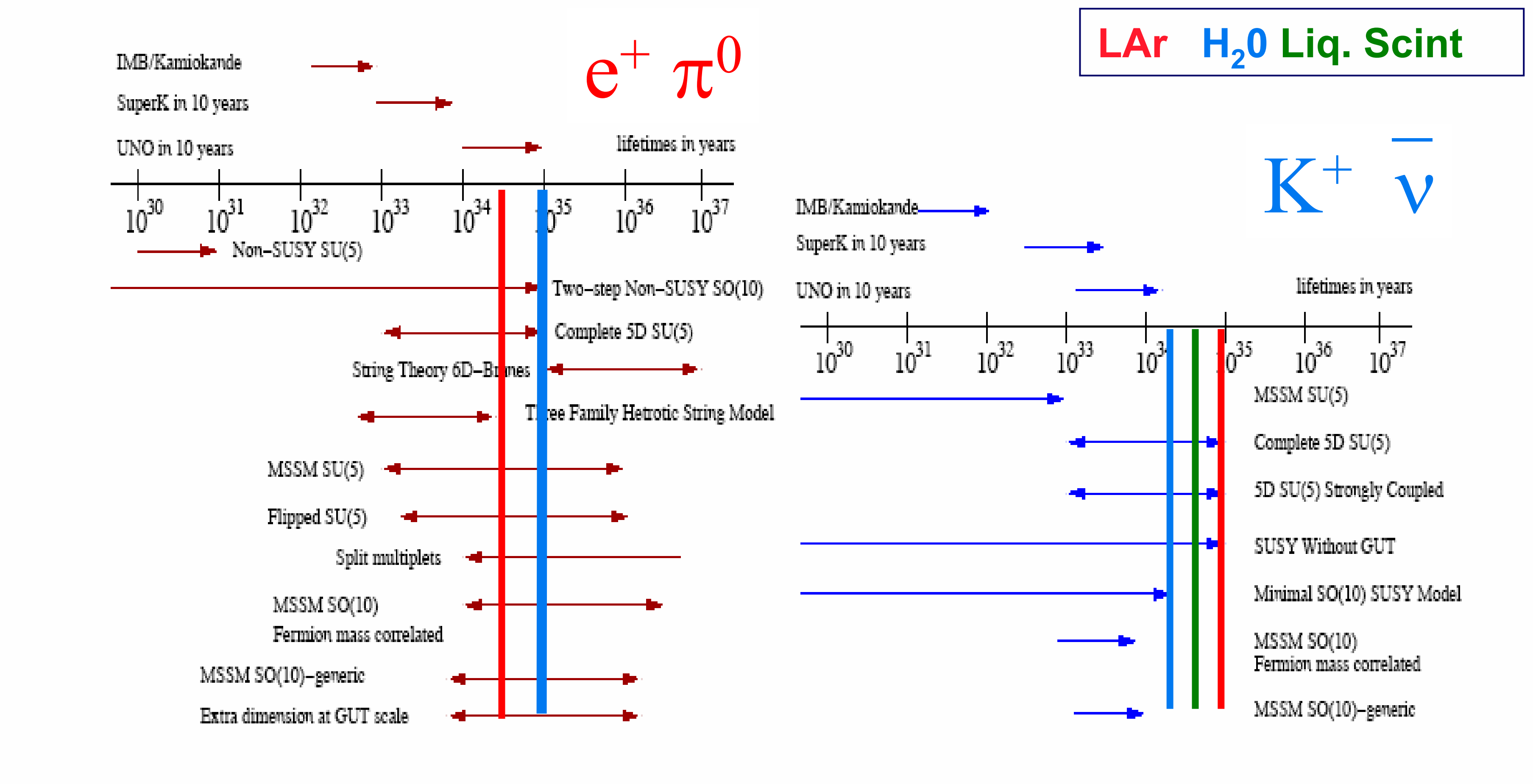
236MeV/c



(3) $P \rightarrow \nu K^+$, $K^+ \rightarrow \underline{\pi^+ \ \pi^0}$

Back to back
205MeV/c each

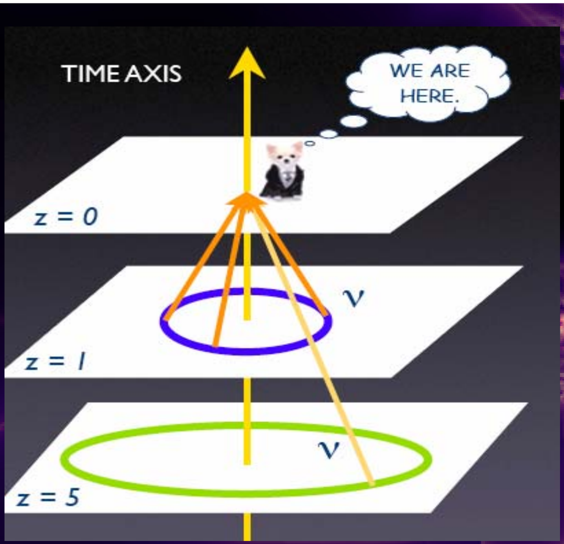
Résumé proton decay

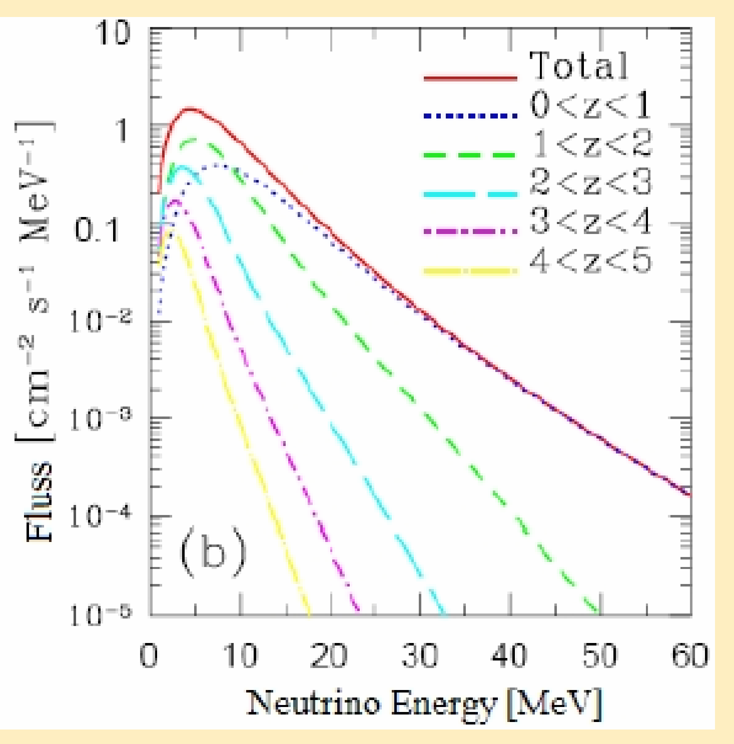


Higher dimension models (eg. 6D SO(10)) not included

Definitively not exhaustive neither p channels nor n decay…

Les traces* de SN



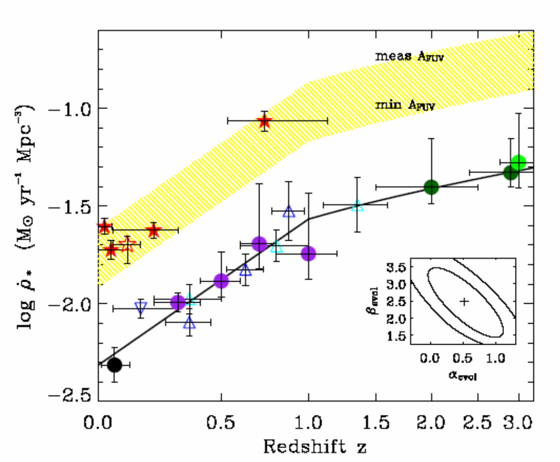


Détection de ν avec z ≲ 1

Flux ∝ **tte SN(z) dont celles donnant un Trou Noir**

***:Diffuse/Relic Supernova Neutrinos**

Limite actuelle ~ détection?



Formation Etoile

GALEX

$(1+z)^{2.5}$ z<1

$(1+Z)^{0.5}$ z>1

Astrophys.J. 619 (2005) L47

Supernova

$$\frac{dN_\nu}{dE_\nu} \propto \frac{E_\nu^2}{\exp(E_\nu/T_\nu - \eta)+1},$$

$$T_{\nu_e} = 3\ \text{MeV},$$

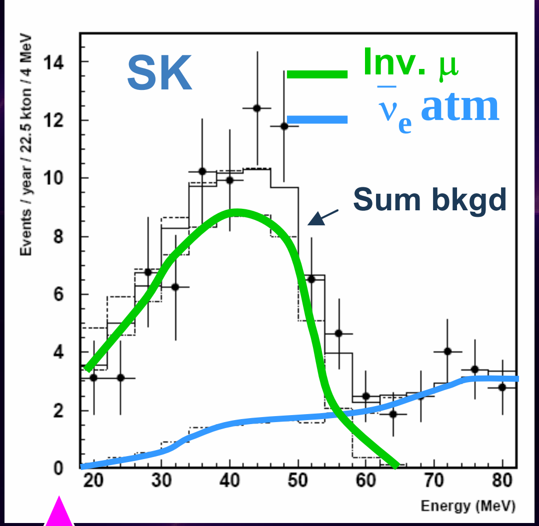
$$T_{\bar{\nu}_e} = 5\ \text{MeV},$$

$$T_{\nu_x} = 8\ \text{MeV}$$

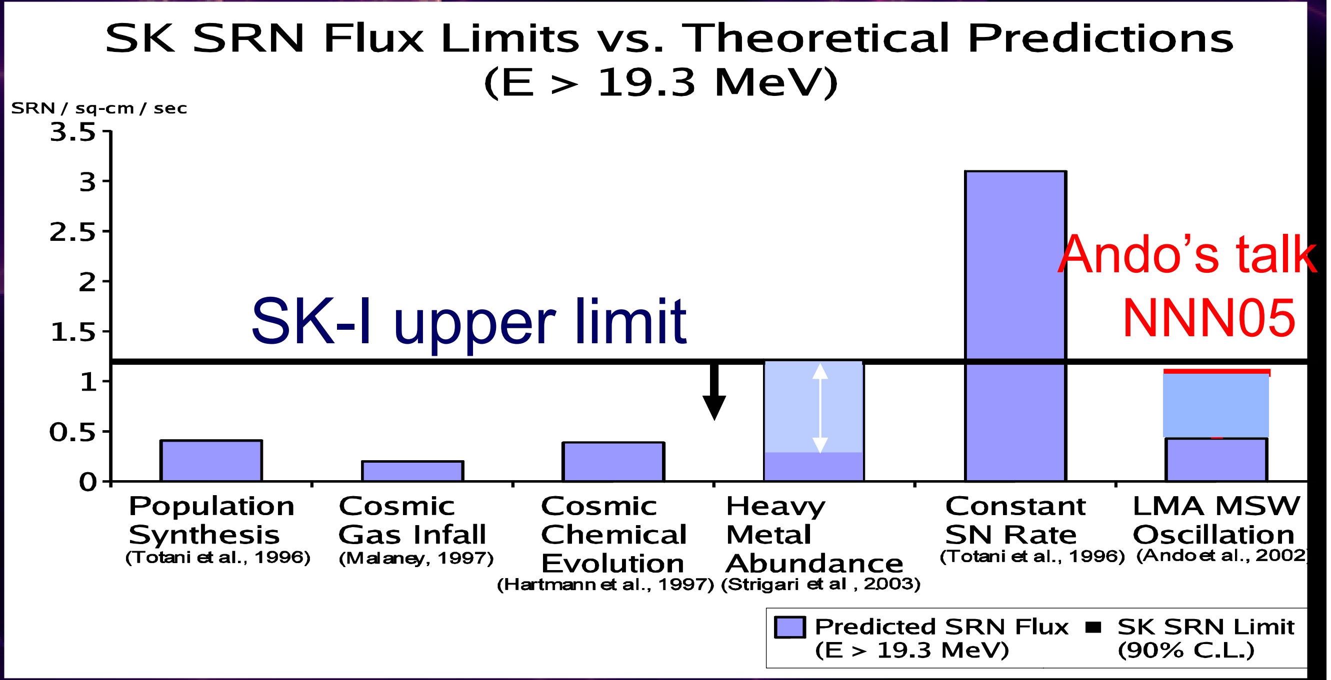
E_ν > 11.3 MeV	E_ν > 19.3MeV
5.1 $cm^{-2}s^{-1}$	1.2 $cm^{-2}s^{-1}$

Les oscillations (LMA) augmente quelque peu le flux E>30MeV

Phys. Rev. Lett 90, 061101 (2003)



Réacteur + Sun



SK SRN Flux Limits vs. Theoretical Predictions

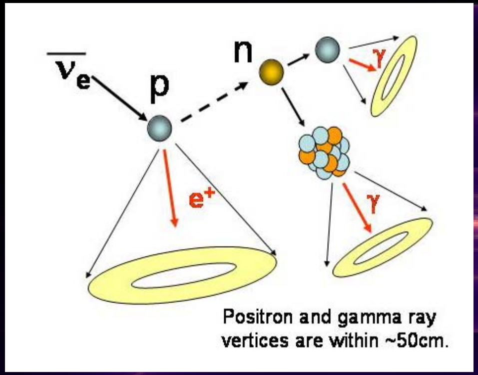
(E > 19.3 MeV)

Futur: $\bar{\nu}_e$ et ν_e complémentarité

$\bar{\nu}_e$

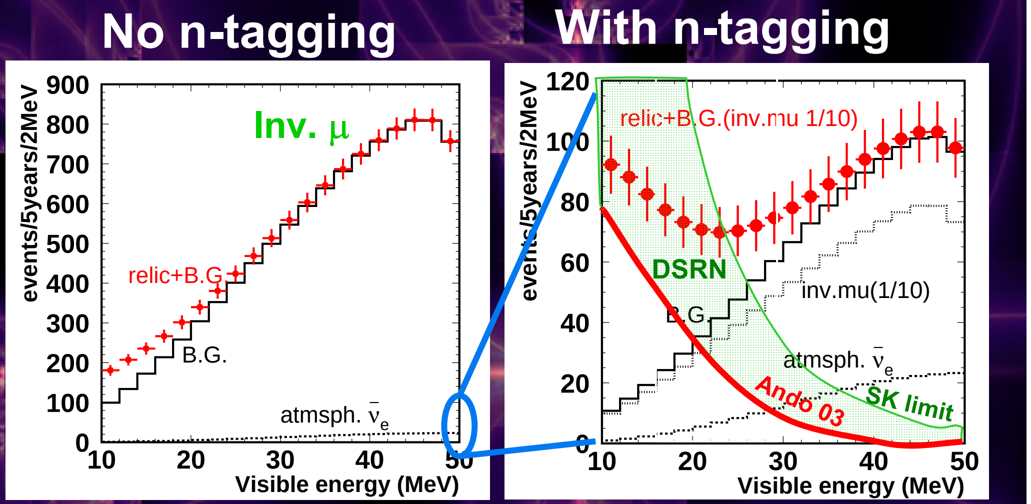
H_20 + neutron capture

30% PMT coverage



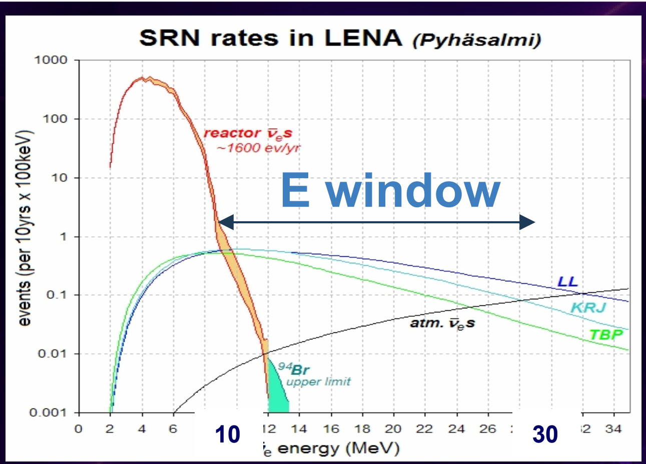
ΔT(p: 2MeV γ) = ~ 200 μs

ΔT(**Gd**: 8MeV γ) = few 10th μs



Nakahata+Vagins @ NNN05

60-150* Sig/65 BG [15-30]MeV 2yrs (1Mt.y)



L. Oberaeur @ Venice06

Scint. Liquide + neutron capture

LENA 10yrs (440kT.y) [9.5 – 30] MeV

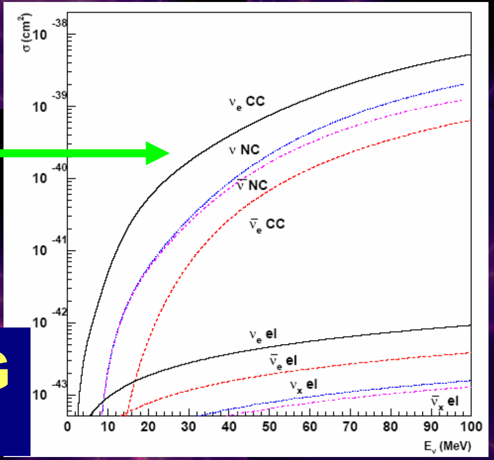
~ (40 – 260*)Sig / 20 BG

***: at SK limit**

Futur: $\bar{\nu}_e$ et ν_e complémentarité

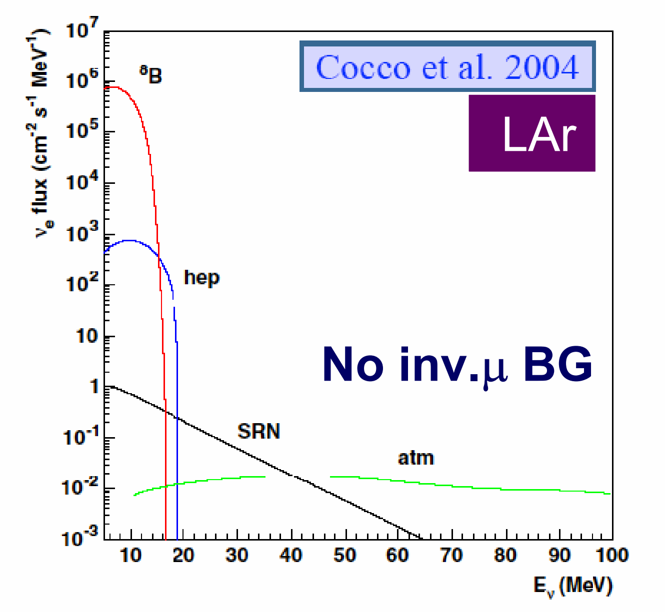
ν_e

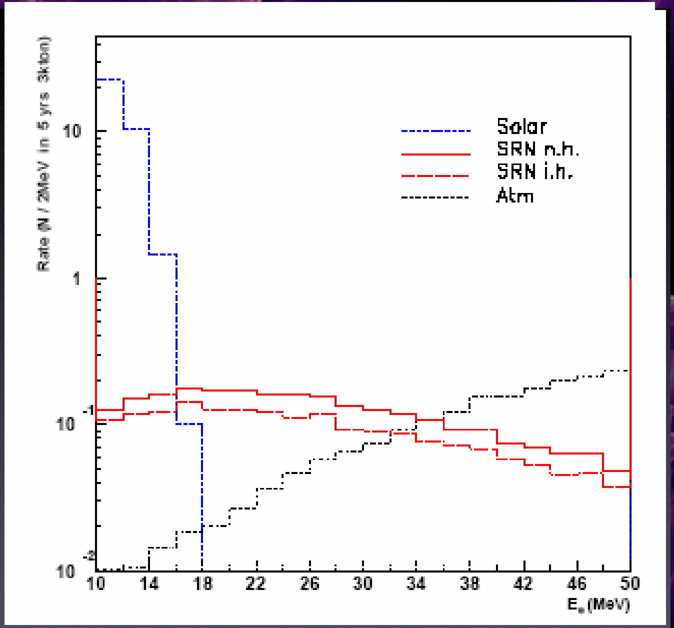
$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow {}^{40}\mathrm{K}^* + e^-$$



GLACIER 5yrs (500kT.y) [16-40] MeV: 57* Sig / 26BG

(Cocco et al. JCAP 0412 (2004) 002)

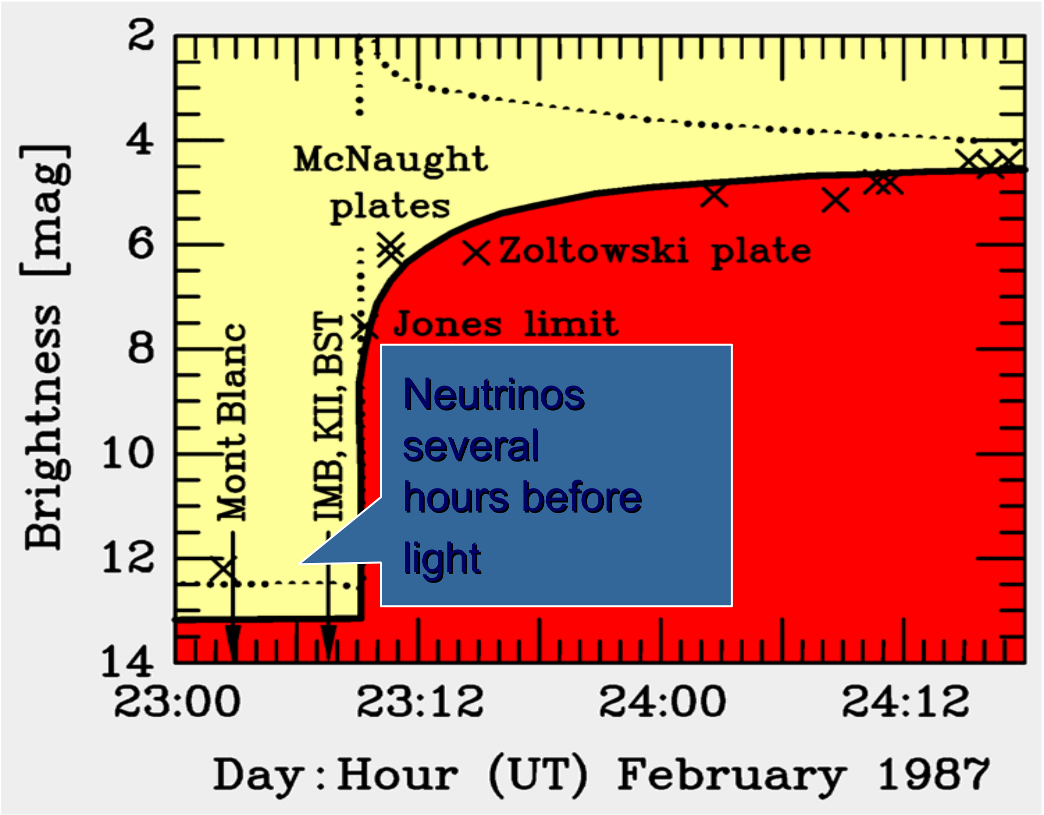




*: at SK limit

Explosion de SN II

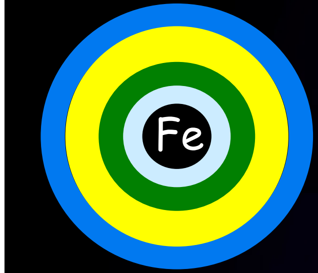
Early lightcurve of SN1987A



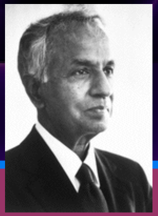
Neutrinos several hours before light

Le champ du cygne pour les étoiles M > 8 $M_\odot$ (I)

Très simplifié



$R_{Fer} \sim 10^3$km donc il y a un découplage entre l'évolution du cœur de Fer et celle du reste de l'étoile.



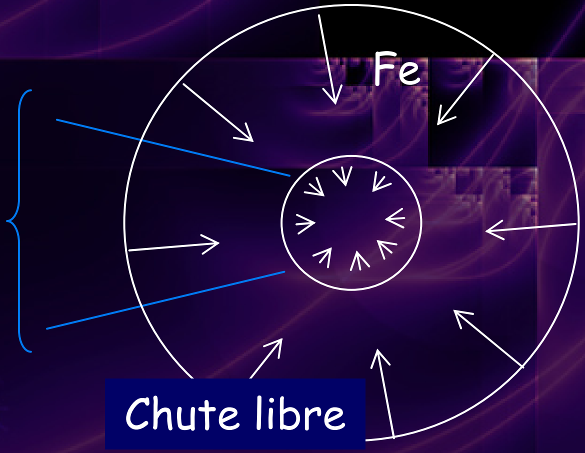
S. Chandraskhar
Nobel 83

1. Arrêt de la fusion dans le cœur de Fer (stable)
2. Collapse car $M_{fer} > M_{Ch}=1,4M_\odot$, $P_{gravit.} > P_{th} + P_{pauli}$
3. Photodissociation qui absorbe de l'énergie (accélère le collapse) et produit des **neutrons**: $^{56}Fe + \gamma \rightarrow 13\ ^4He + 4n$, $^4He + \gamma \rightarrow 2p + 2n$
4. Capture des électrons: $p(noyau) + e^- \rightarrow n + \nu_e$ (T~10^{11}K)

Première bouffée avant que le cœur devienne opaque.

ρ↗ 4 10^{11} kg/cm³
densité nucléaire

Étoile à Neutrons
R ~ 100km → 30km

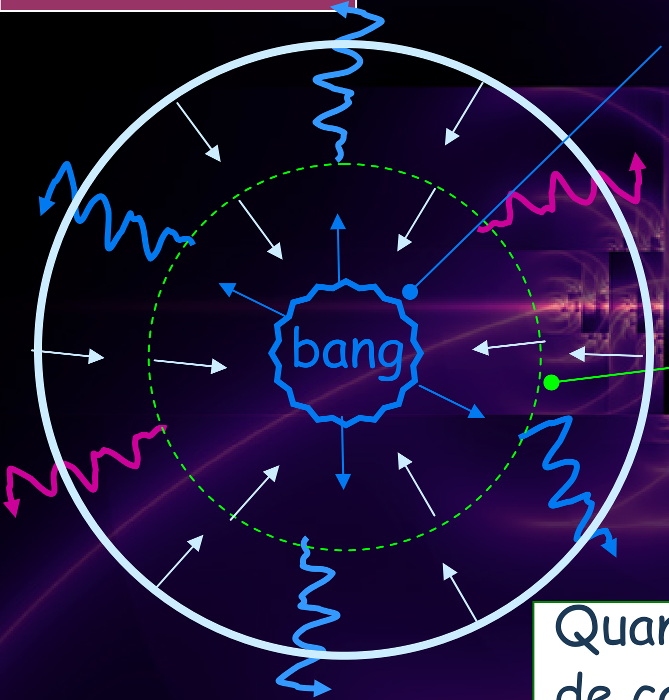


Si M_c>5 $M_\odot$ ⇒trou noir

Δt ~ 1/10 sec.

Le champ du cygne pour les étoiles M > 8 $M_\odot$ (II)

Fer ~ 1,4 $M_\odot$



Onde de choc 10^5 km/s

Collision entre les couches externes en chute libre et l'explosion du cœur comprimé au delà de la matière nucléaire.

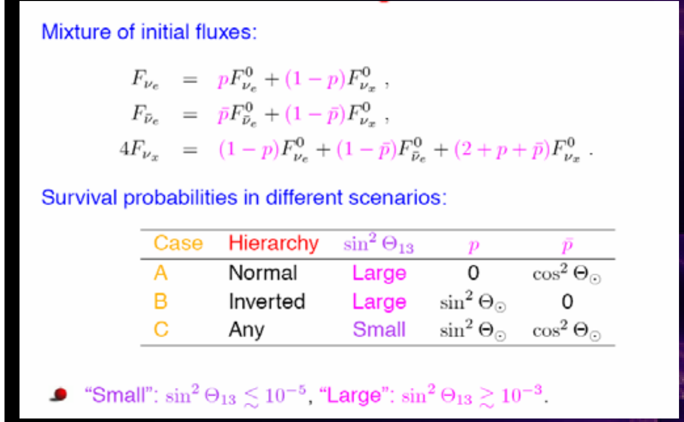
La pression des ν qui se trouvent piégés (νsphére) $\rho_{\text{piège}} > 5\ 10^8$ kg/cm³ soutiennent l'onde de choc pour dépasser le cœur de Fer et provoquer l'explosion de l'étoile!

Quand l'onde de choc rencontre la νsphére les ν_e de capture sont éjectés ($\rho < \rho_{\text{piège}}$), c'est la deuxième bouffée en $\Delta t \sim 10$ms.

Durant la phase de refroidissem^t de l'étoile à neutrons $\Delta t \sim 1$s dans couches externes où $\rho < \rho_{\text{piège}}$

$\gamma + \text{milieu} \rightarrow e^+e^- \xrightarrow{Z^0} \nu_e\bar{\nu}_e\ \nu_\mu\bar{\nu}_\mu\ \nu_\tau\bar{\nu}_\tau$ (3^e bouffée)

Les taux de comptage



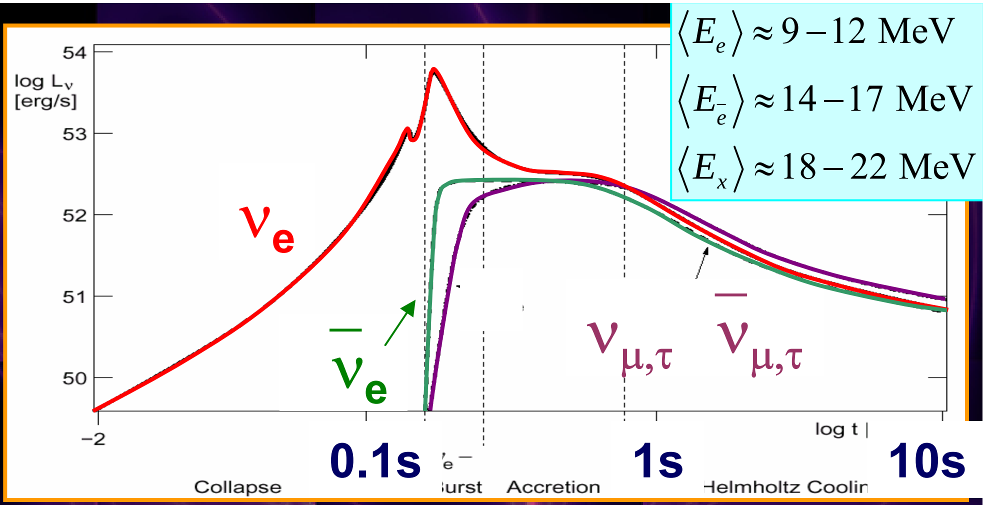
Mixture of initial fluxes:

$$\begin{aligned} F_{\nu_e} &= pF^0_{\nu_e} + (1-p)F^0_{\nu_x} \,, \\ F_{\bar\nu_e} &= \bar p F^0_{\bar\nu_e} + (1-\bar p)F^0_{\nu_x} \,, \\ 4F_{\nu_x} &= (1-p)F^0_{\nu_e} + (1-\bar p)F^0_{\bar\nu_e} + (2+p+\bar p)F^0_{\nu_x} \,. \end{aligned}$$

Survival probabilities in different scenarios:

Case	Hierarchy	$\sin^2\Theta_{13}$	p	$\bar p$
A	Normal	Large	0	$\cos^2\Theta_\odot$
B	Inverted	Large	$\sin^2\Theta_\odot$	0
C	Any	Small	$\sin^2\Theta_\odot$	$\cos^2\Theta_\odot$

- "Small": $\sin^2\Theta_{13} \lesssim 10^{-5}$, "Large": $\sin^2\Theta_{13} \gtrsim 10^{-3}$.



$\langle E_e \rangle \approx 9-12$ MeV

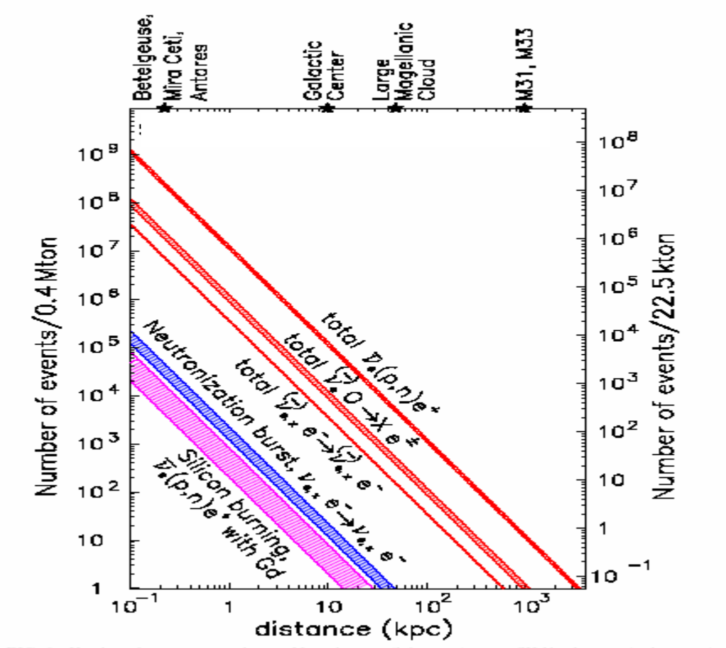
$\langle E_{\bar e} \rangle \approx 14-17$ MeV

$\langle E_x \rangle \approx 18-22$ MeV

8M$_\odot$ 10kpc	Si burn	ν_e burst	ν_e cc	$\bar\nu_e$ cc	$\overset{(-)}{\nu}_x$ e ES	$\overset{(-)}{\nu}_x$ ~~e ES~~
H_2O 0.4Mt	2-10 With Gd	15	100 p >>^{16}O		3	-
Sci Liq 50kt		85		9 p >>^{12}C	0,6	10 p >>^{12}C
LAr 100kt		380	24-31	1-2	1,3	30

x10^3

H_2O



LENA

- $\overline{\nu}_e + p \to n + e^+$ (Q=1.8 MeV)
  $n + p \to d + \gamma$; $E_\gamma = 2.2$ MeV ~8700 events
- $\overline{\nu}_e + {}^{12}\mathrm{C} \to {}^{12}\mathrm{B} + e^- +$ (Q=17.3 MeV)
  ${}^{12}\mathrm{B} \to {}^{12}\mathrm{C} + e^+ + \overline{\nu}_e$; $\tau_{1/2} = 20.20$ ms ~494 events
- $\nu_e + {}^{12}\mathrm{C} \to e^- + {}^{12}\mathrm{N}$ (Q=13.4 MeV)
  ${}^{12}\mathrm{N} \to {}^{12}\mathrm{C} + e^+ + \nu_e$; $\tau_{1/2} = 11.00$ ms ~85 events
- $\nu_x + {}^{12}\mathrm{C} \to {}^{12}\mathrm{C}^* + \nu_x$
  with ${}^{12}\mathrm{C}^* \to {}^{12}\mathrm{C} + \gamma$; $E_\gamma = 15.11$ MeV ~2925 events
- $\nu_x + e^- \to \nu_x + e^-$ (elastic scattering) ~610 events
- $\nu_x + p \to \nu_x + p$ (elastic scattering)
  Detector energy threshold: $E_{th} = 0.2$ MeV ~7370 events

10kpc

GLACIER

ν_e NC $\to {}^{40}Ar^*$ (Q=1.46MeV)	Burst	380
ν_x , $\bar{\nu}_x$ NC (${}^{40}Ar$)		30k
$\nu_e + {}^{40}Ar \to {}^{40}K^* + e^-$ (Q= 1.5MeV)		24k-31k
ν_x , $\bar{\nu}_x$ NC (e^- ES)		1,3k
$\bar{\nu}_e + {}^{40}Ar \to {}^{40}Cl^* + e^+$ (Q= 7.48MeV)		540

Quoi faire avec autant de SNν ?

- SN trigger
  - GALEX + SN formation ⇒ 1 SN/an D<10 Mpc
    - H20 450kT [18-30MeV]: 4.5/(Mpc)^2 et 0.4BG/jour
    - H20+Gd 240kT [12-38MeV]: 4.5/(Mpc)^2 et 0.3BG/jour
  - Or 9 ont été découvertes D<10 Mpc en 3 ans (x3 la prédiction)…
    - 2 events Δt < 10s (pas de BG) ⇒ ALERTE SN
    - SN via Optique ⇒ si Δt < 10s 1 event ⇒ ALERTE confirmée
  - *En coïncidence avec GW, si possible⇒ sensibilité m_ν~1eV*

Astropart.Phys.21:201-221,2004

- Phase Si → Fer si D<2kpc : demande n-capture
- Neutronisation burst : prédiction robuste, détection mieux avec GLACIER
- SN direction:
  - ES e- 2°→0.6° (H_20 + Gd), 1° (LAr)
  - **Beta Inverse:** le neutron garde une mémoire 9° (Scint. Liq.)

Spectre Energie en fonction du temps: Burst + Shock Wave +Terre

Étude de θ_{13} paramètre des oscillations + Hiérarchie de masse via les effets de matière (SN + Terre)

Hierarchy	$\sin^2\theta_{13}$	ν_e neutronization peak	Shock wave	Earth effect
Normal	$\gtrsim 10^{-3}$	Absent	ν_e	$\bar{\nu}_e$ ν_e (delayed)
Inverted	$\gtrsim 10^{-3}$	Present	$\bar{\nu}_e$	ν_e $\bar{\nu}_e$ (delayed)
Any	$\lesssim 10^{-5}$	Present	———	ν_e $\bar{\nu}_e$

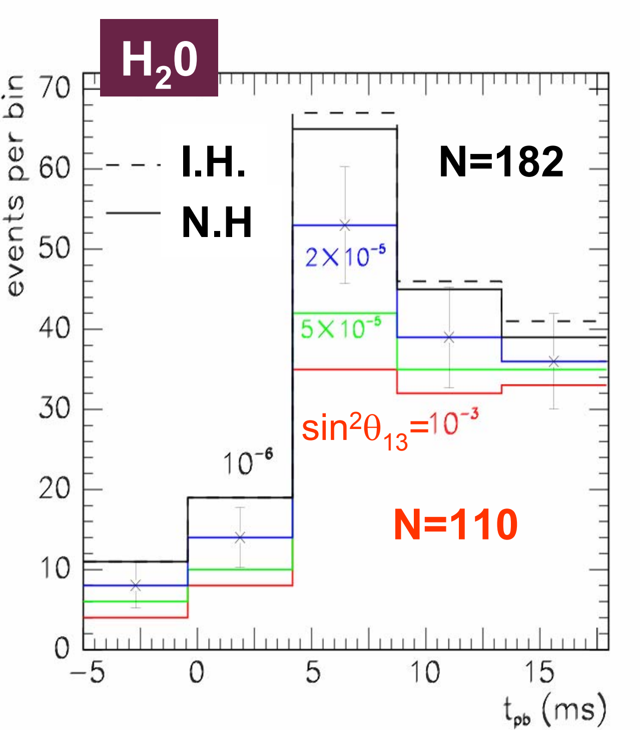
A. Mirizzi @ LPNHE 17/2/06

Exploiting these complementary signatures one could extract useful information on the neutrino mass hierarchy and on θ_{13}

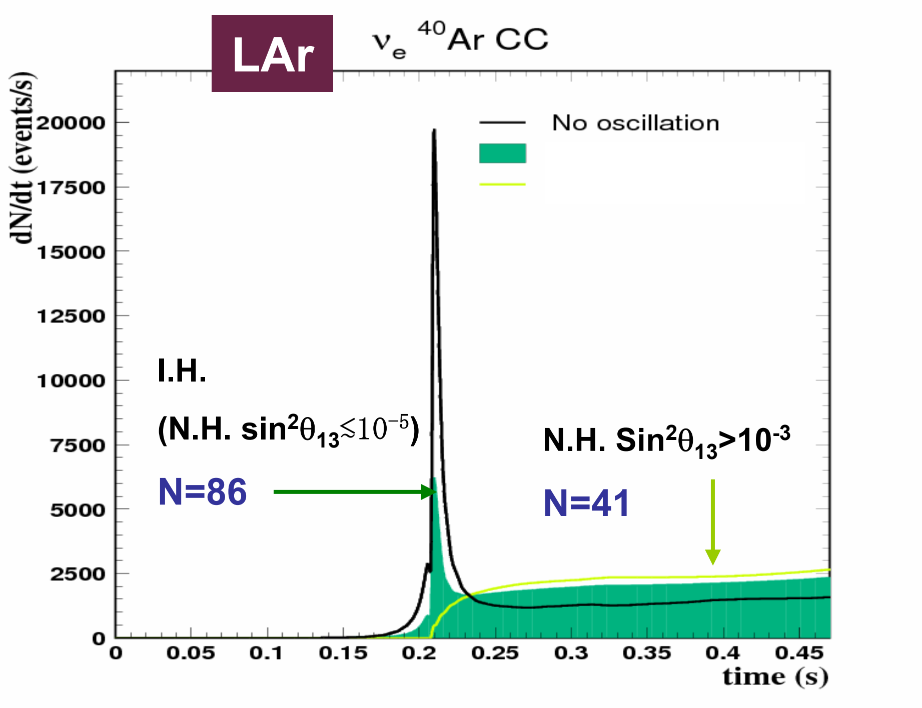
($\nu_{\mu\tau}$ + p NC measurement of independant fraction of the binding energy)

Neutronization burst (~ 25 ms, after the bounce)

Robust feature of the SN simulation



$\nu_{e,x}\, e^- \rightarrow \nu_{e,x}\, e^-$ (ES)



ν_e Ar $\rightarrow e^- K^*$ (CC)

Possibility to probe non standard physics

Resonant Spin Flavor transitions [E.Akhmedov et al., hep-ph/0310119]

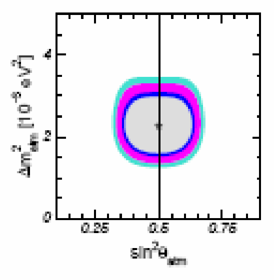
Neutrino Decay [S.Ando, hep-ph/0405200]

Possibility to look for non standard $\bar{\nu}_e$ fraction (H$_2$0)

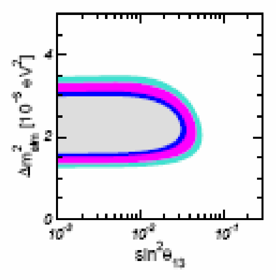
Oscillations terrestres…

Non couvert ici par ex.: échelle de masse, Majorana vs Dirac, ν stérile…

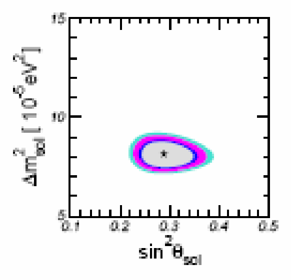
$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & e^{-i\delta} s_{13} \\ 0 & 1 & 0 \\ -e^{i\delta} s_{13} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$



atmospheric + K2K



CHOOZ

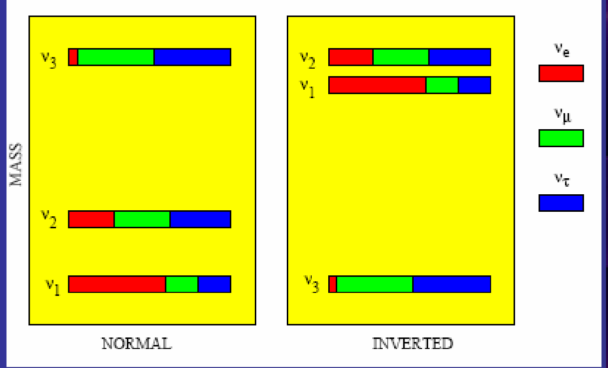


solar + KamLAND

$\sin^2\theta_{12}$	$0.31^{+0.02}_{-0.03}$	9%
$\sin^2\theta_{23}$	$0.50^{+0.06}_{-0.05}$	11%

Δm^2_{21} [10^{-5}eV^2]	7.9 ± 0.3	4%
$\lvert\Delta m^2_{31}\rvert$ [10^{-3}eV^2]	$2.2^{+0.37}_{-0.27}$	14%

Échelle de masse



$\Delta m^2_{31} > 0$ $\quad$ $\Delta m^2_{31} < 0$

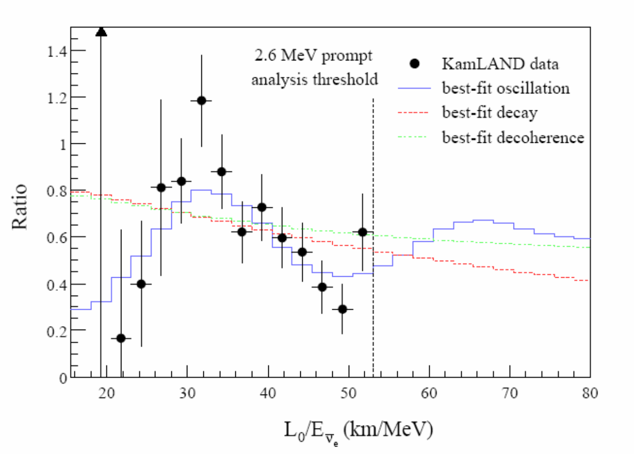
Octant de θ_{23}

θ_{13}

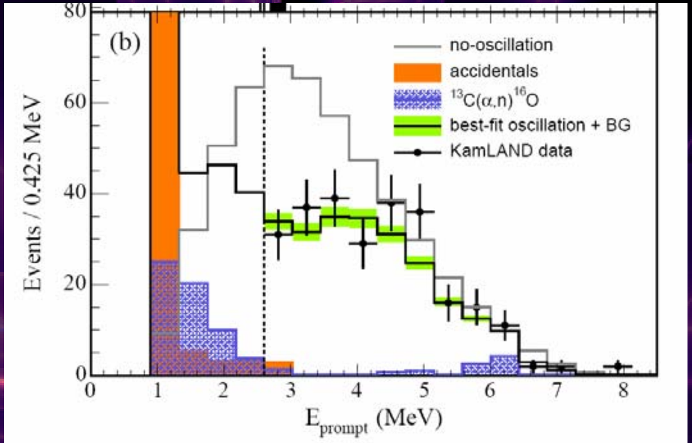
δ_{CP}

?

Δm^2_{21} et $\sin^2\theta_{12}$ « *paramètres solaires* »

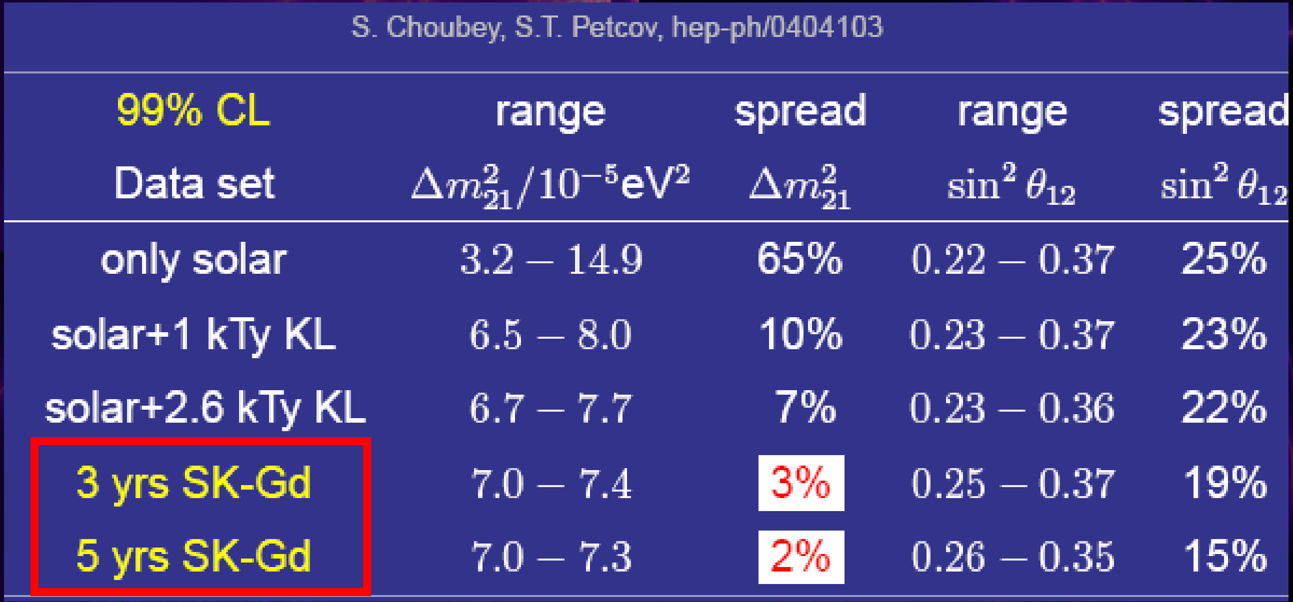


KamLAND



0.77kT.y

Réacteurs ν

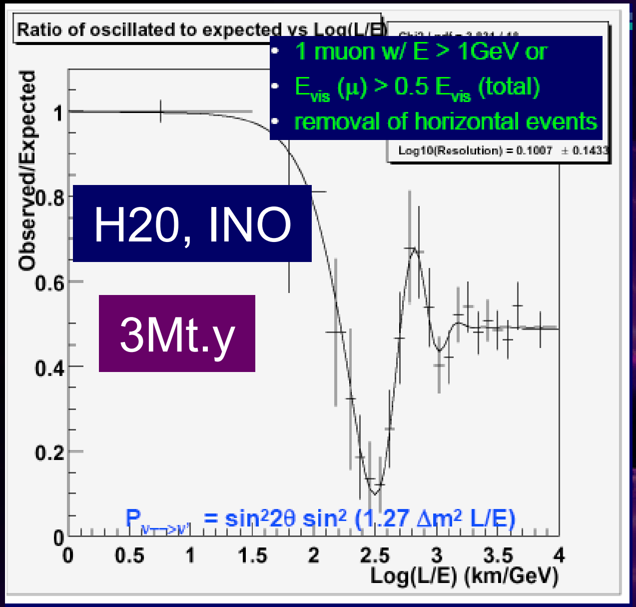


S. Choubey, S.T. Petcov, hep-ph/0404103

99% CL Data set	range $\Delta m^2_{21}/10^{-5}$eV²	spread Δm^2_{21}	range $\sin^2\theta_{12}$	spread $\sin^2\theta_{12}$
only solar	3.2 – 14.9	65%	0.22 – 0.37	25%
solar+1 kTy KL	6.5 – 8.0	10%	0.23 – 0.37	23%
solar+2.6 kTy KL	6.7 – 7.7	7%	0.23 – 0.36	22%
3 yrs SK-Gd	7.0 – 7.4	3%	0.25 – 0.37	19%
5 yrs SK-Gd	7.0 – 7.3	2%	0.26 – 0.35	15%

Bruit de fond pour les Supernova ν

Propriété ν avec des ATM-ν seuls !!!

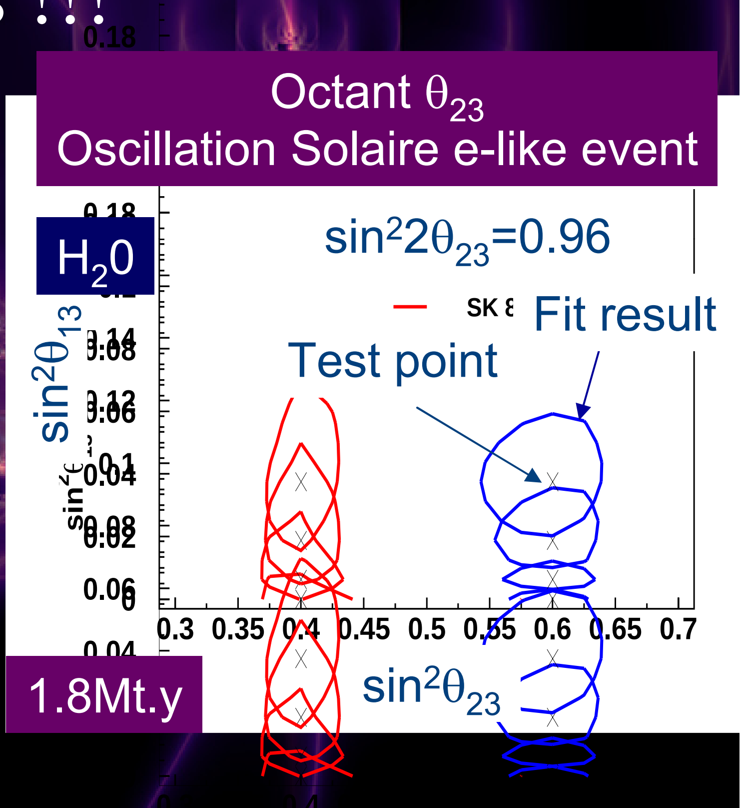


- 1 muon w/ E > 1GeV or
- E_{vis} (μ) > 0.5 E_{vis} (total)
- removal of horizontal events

$P_{\nu\to\nu'} = \sin^2 2\theta \sin^2 (1.27\,\Delta m^2\, L/E)$

H20, INO

3Mt.y



Octant θ_{23}
Oscillation Solaire e-like event

H_20

$\sin^2 2\theta_{23}=0.96$

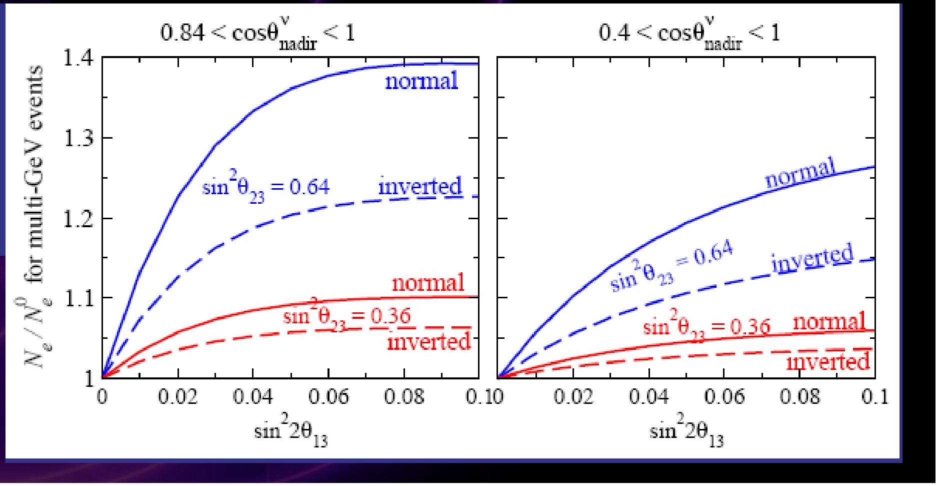
Fit result

Test point

1.8Mt.y

$$\frac{N_e}{N_e^0} - 1 \simeq (r\, s_{23}^2 - 1)\, P_{2\nu}(\Delta m_{31}^2, \theta_{13})$$

resonant matter effect in $P_{2\nu}(\Delta m_{31}^2, \theta_{13})$
for multi-GeV events ($r \approx 2.6 - 4.5$)



Sensibilité à la hiérarchie de masse

Une « Roadmap » (inspired by A. Cervera @ CSG-Orsay06)

1^{st} step: **present era**

Ongoing: 2005-2010

- Improve the precision on the atmospheric parameters looking at ν_μ disappearance
- Confirm (atm. osc)=($\nu_\mu \rightarrow \nu_\tau$) and first look at $\nu_\mu \rightarrow \nu_e$

2^{nd} step: **prospective era**

Approved/Proposed: 2009-2015

- Demonstrate visibility of sub-leading transitions:

  $\nu_\mu \rightarrow \nu_e$, $\nu_e \rightarrow \nu_e$
- Explore θ_{13} down to 2^0 (today $<10^0$)

3^{rd} step: **deep search era**

Discussed: 2015-2025

$\theta_{13} > 3^0$ —— Known by 2011 —— $\theta_{13} < 3^0$

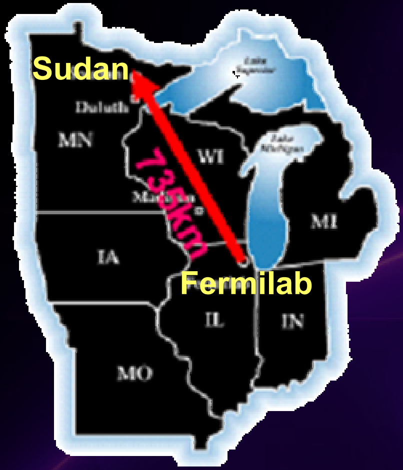
- Existing facilities could reach it
- ... but with very small sensitivity to δ_{CP} and mass hierarchy

- No access for ongoing experiments at that time

Cleaner and more intense beams + bigger detectors

Present era

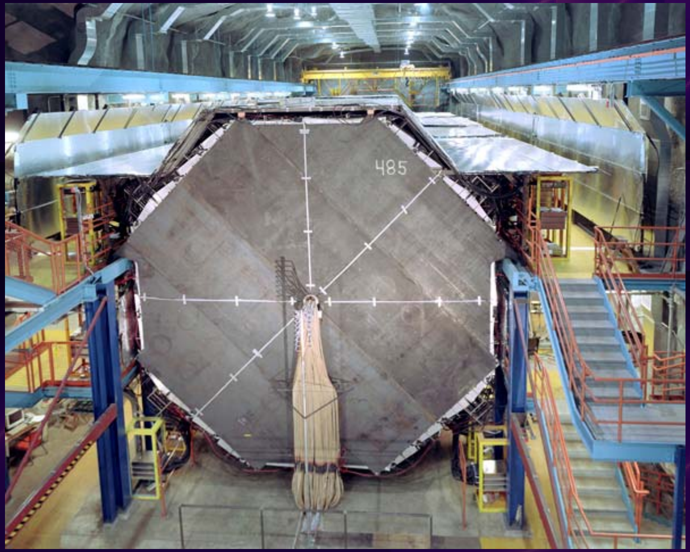
NUMI beam: MINOS (2005)



Magnetised iron calorimeter

CNGS beam: OPERA (2006)

Hybrid emulsion detector



CNGS 31 janvier 06

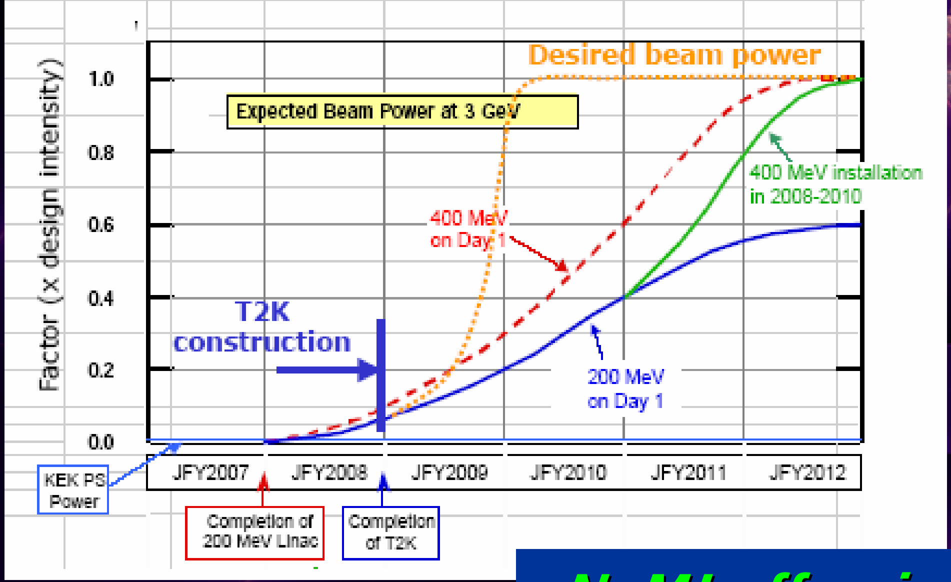
Introduction du Réflecteur sur la ligne

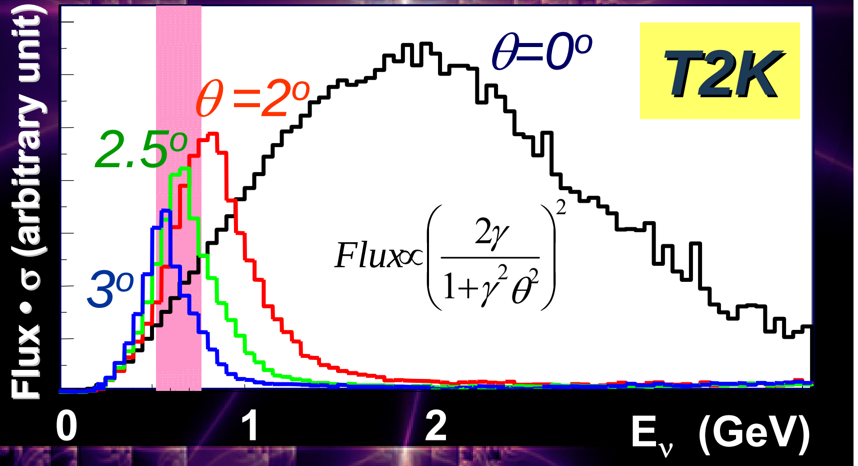
CNGS beam: OPERA (2006)

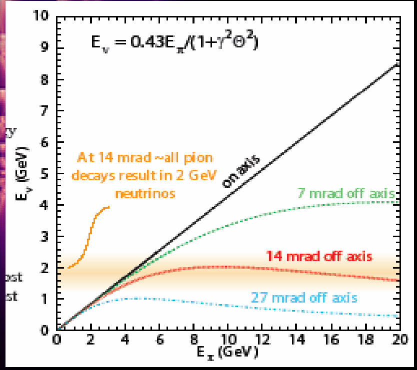
Prospective era (see D. Duchesneau pour Exp. sur Réacteur et Acc.)

Conventional ν_μ beams from pion decay
Increased proton beam power: 0.4 →0.8 MW
Off-axis technique: narrow band beam with purer composition
Tune L/E to the oscillation maximum (L/E~ 500 Km/GeV)

JPARC beam: T2K (2009)
(0.4% ν_e), L=295 Km







NuMI off-axis: NOνA (2011 ?)
Not Yet approved
(0.5-1% ν_e) L=810 Km

Deep search era (see D. Autiero for Neutrino Factory)

Super Beam

- Increase by one order of magnitude
  - power: up to 2MW (US) and 4MW (EU,Japan) (targetry R&D for NF)
  - detector mass
- Three proposals:

T2HK (“phase II”)	Japan	0.6 GeV	295 Km
SPL-MEMPHYS	Europe	0.3 GeV	130 Km
NuMI-SuperNOvA	US	8 GeV	810 Km

Beta Beam

feasibility

SPS	**γ~100**	**0.35 GeV**	**130 Km**	**MEMPHYS**
SPS (max energy)	γ~150	0.6 GeV	300 Km	?
Tevatron or S-SPS	γ~350	1.5 GeV	730 Km	GS/Canfranc
LHC	γ~1500	7 GeV	3000 Km	Canarias

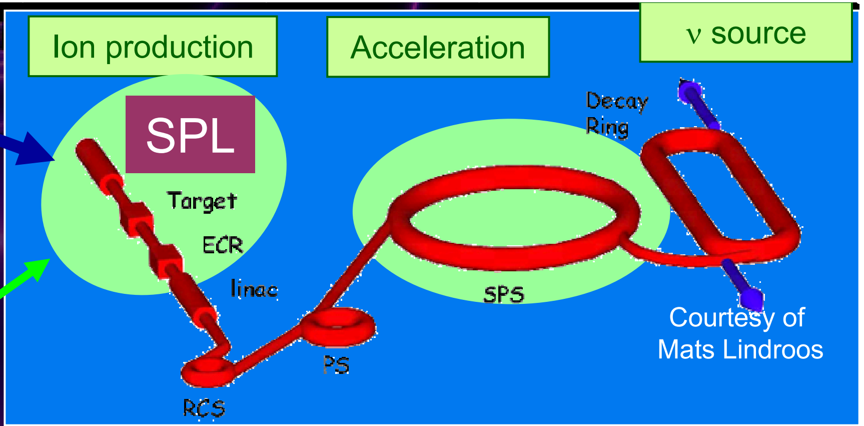
EURISOL design study

much more **feasibility** studies needed

for high γ option

New ideas in this active area

- *Monocromatic beam: Burget et Al.*
- *Efficient ion production: C. Rubbia*

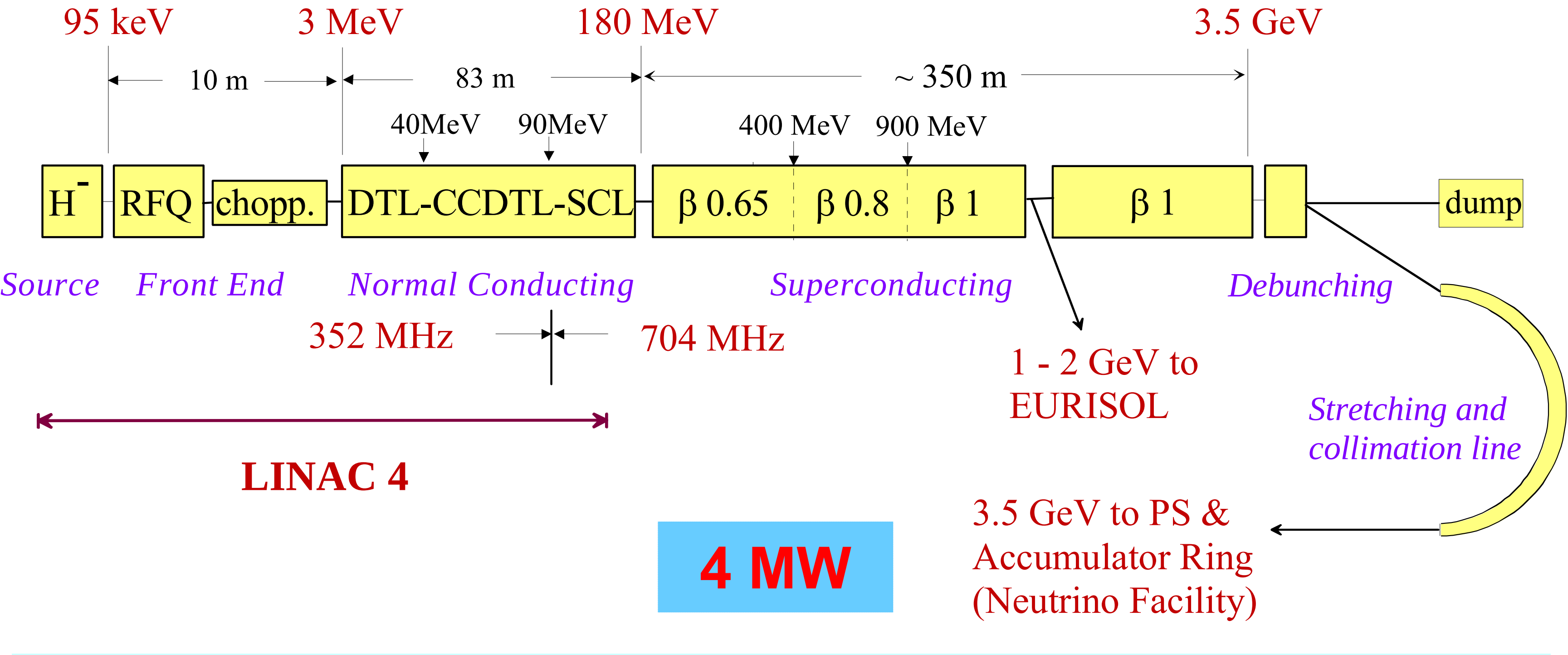


Courtesy of Mats Lindroos

SPL current design

SPL main goals:

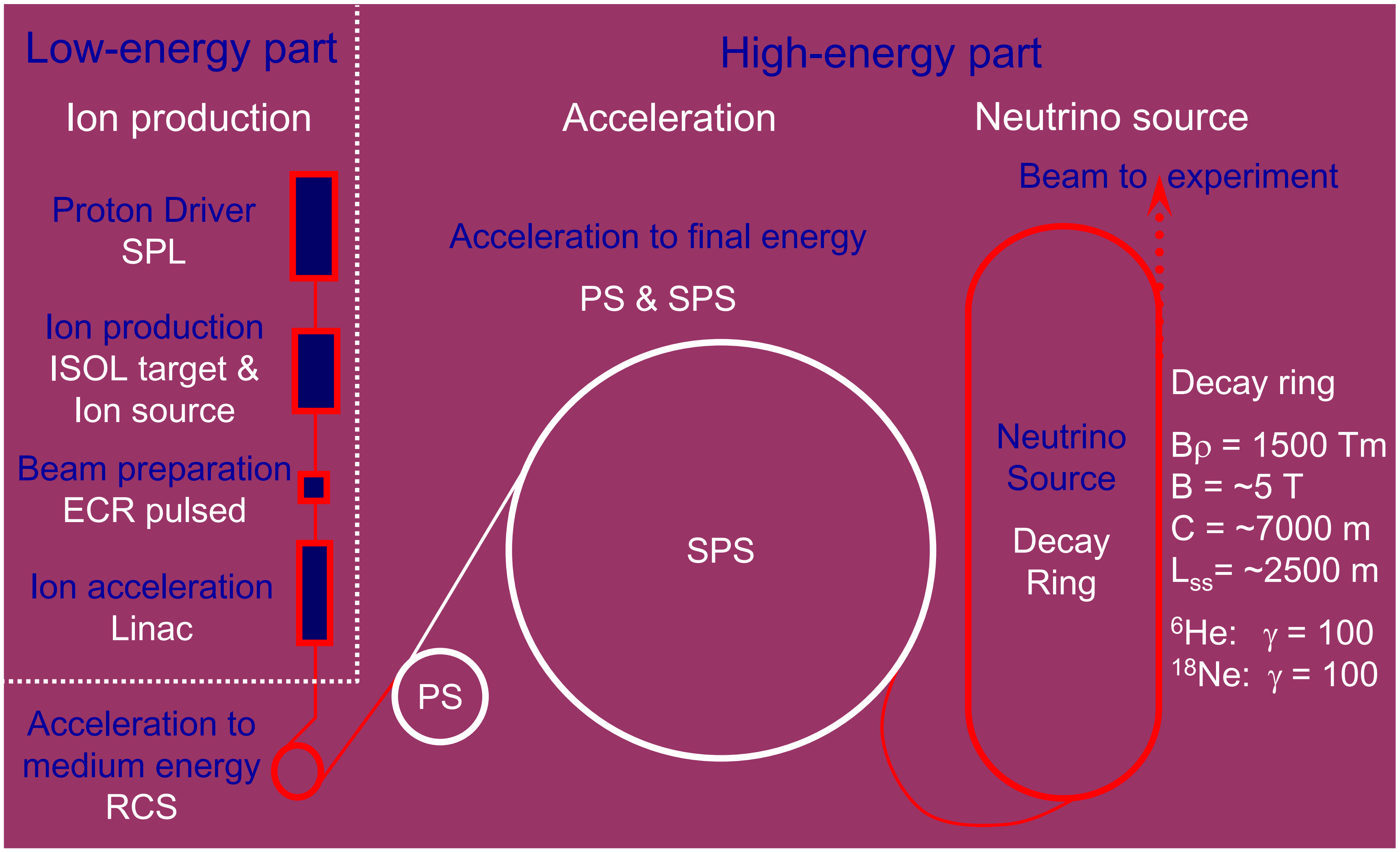
- **increase the performance of the CERN high energy accelerators (PS, SPS & LHC)**
- **address the needs of future experiments with neutrinos and radio-active ion beams**



The present R&D programme concentrates on low-energy (Linac4) items, wherever possible in collaboration with other laboratories.

From R.Garoby

Beta-beam baseline design



Low-energy part

Ion production

Proton Driver
SPL

Ion production
ISOL target &
Ion source

Beam preparation
ECR pulsed

Ion acceleration
Linac

Acceleration to
medium energy
RCS

High-energy part

Acceleration

Acceleration to final energy

PS & SPS

Neutrino source

Beam to experiment

Neutrino
Source

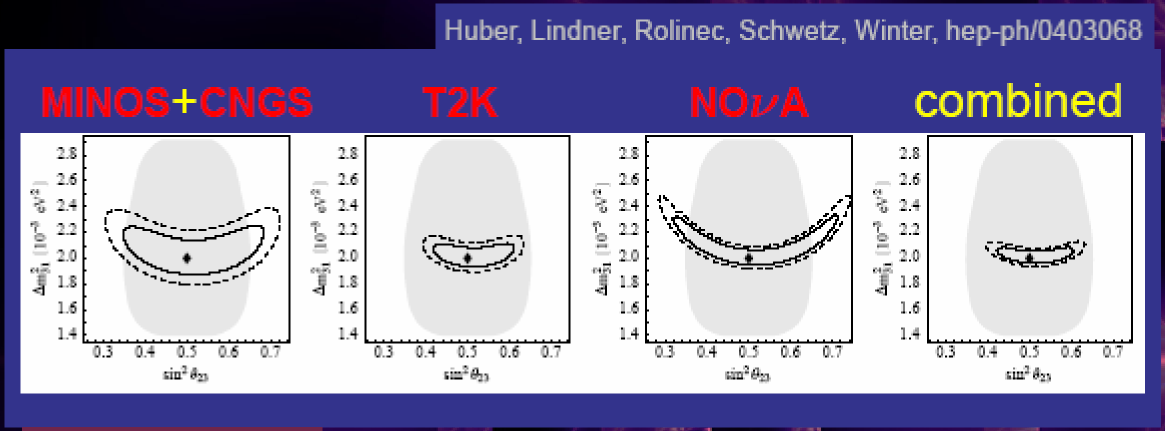
Decay
Ring

Decay ring

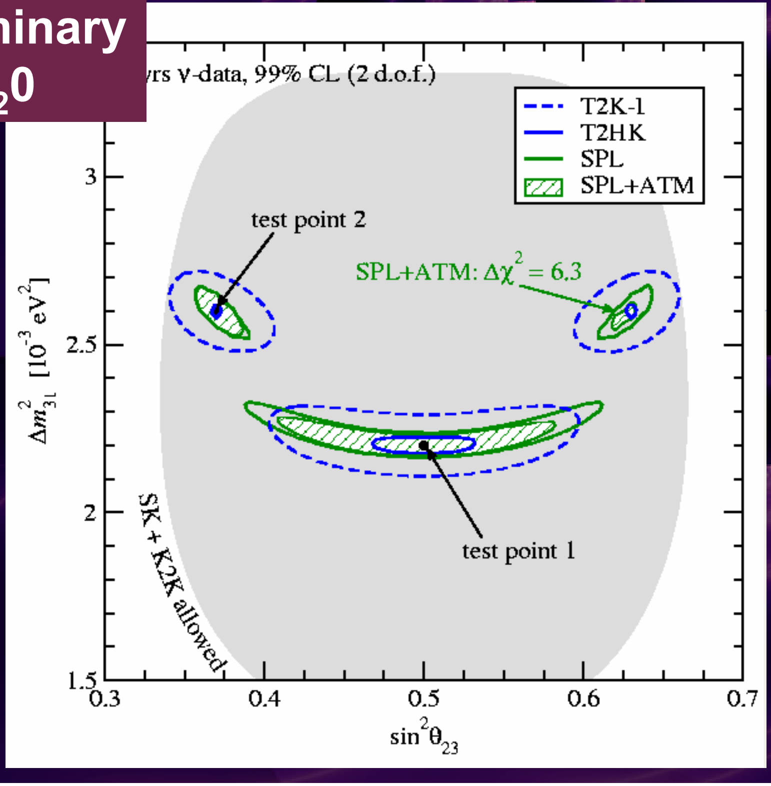
$B\rho$ = 1500 Tm
B = ~5 T
C = ~7000 m
L_{ss} = ~2500 m

^{6}He: $\gamma = 100$
^{18}Ne: $\gamma = 100$

$|\Delta m^2_{31}|$ et $\sin^2\theta_{23}$ « *paramètres atmosphériques* »



Preliminary
H_20



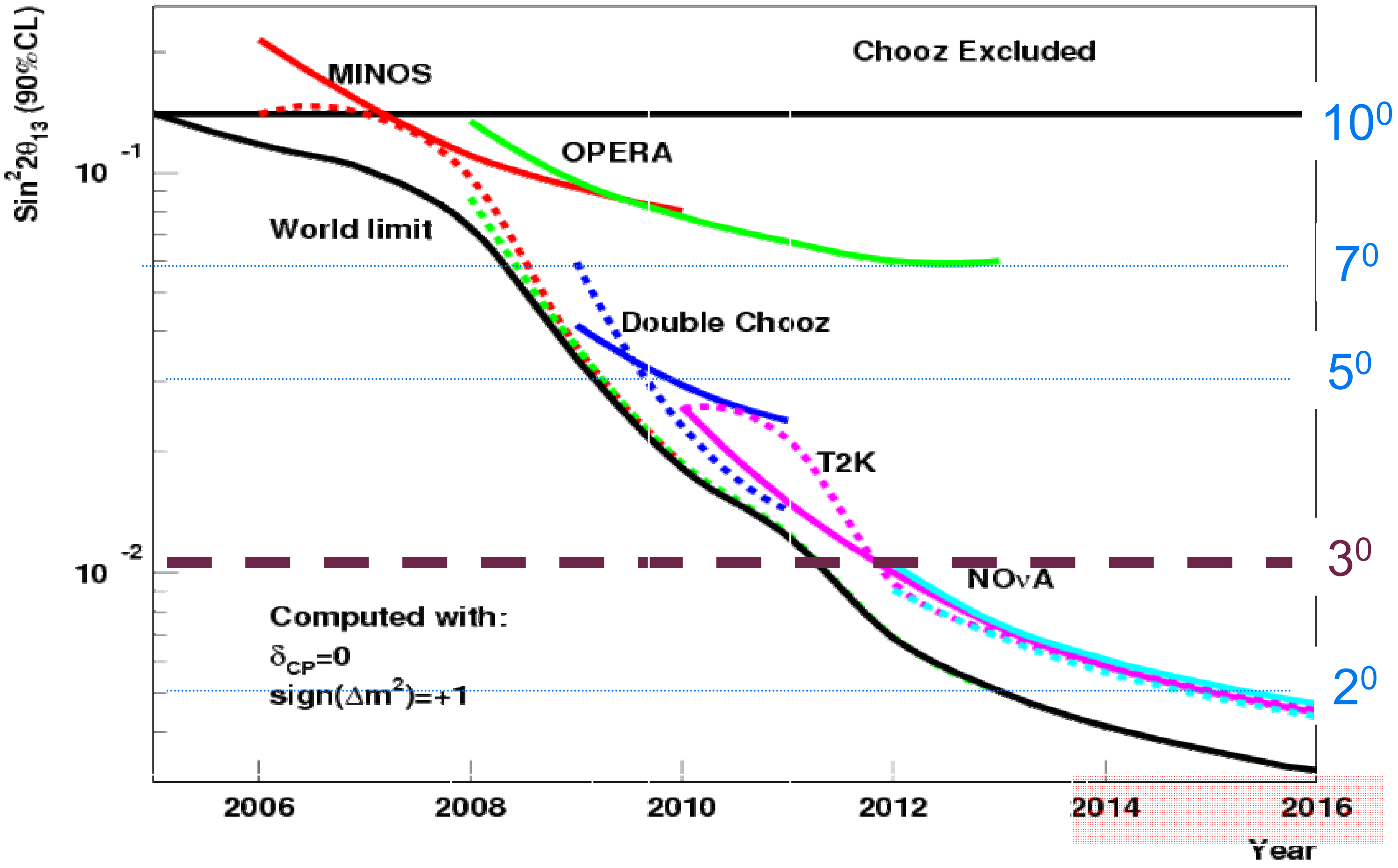
Ère de la précision !

T2HK E_ν ~ 750MeV
SPL E_ν ~ 300MeV
(Fermi motion limitation)

JECampagne, M. Maltoni, M.Mezzetto, Th. Schwetz

θ_{13} : évolution de la sensibilité

Si on trouve θ_{13} en cours de route, le paysage changera !



M.Mezzetto

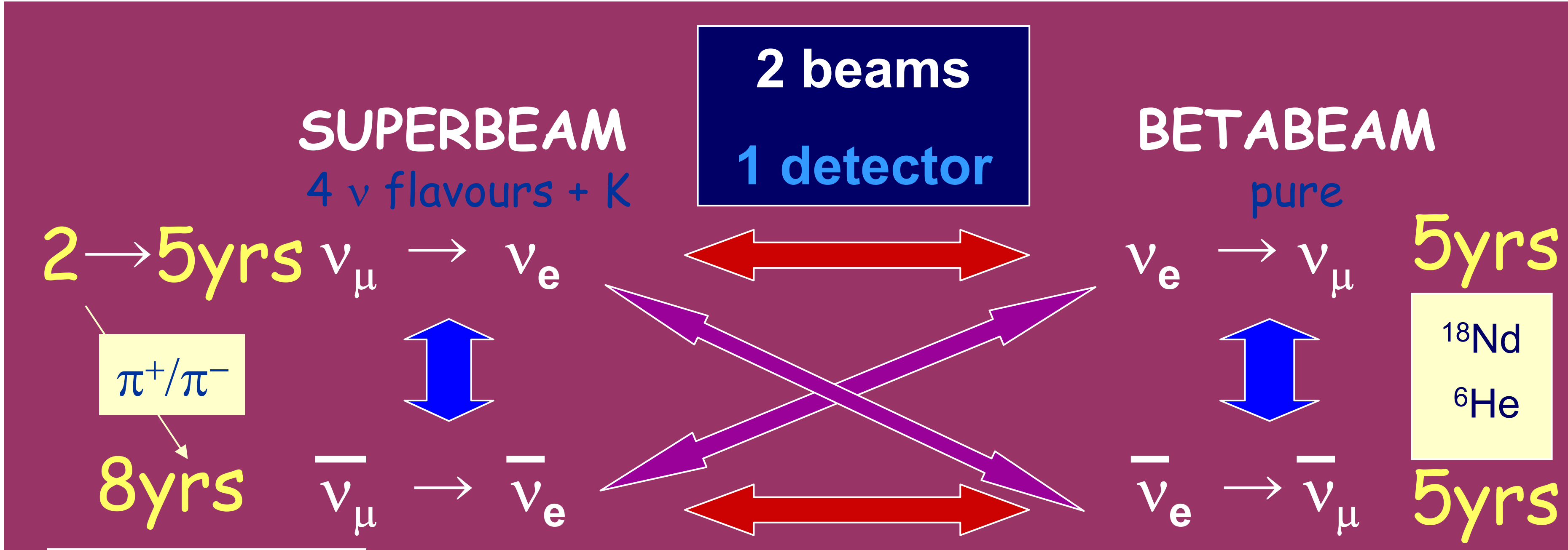
Peu de sensibilté à $\cancel{CP}$

—— Limit of the exp.

······· Word Limit wo the exp.

Le CERN est à 130km de Modane…

Super Beam + β Beam + MEMPHYS



2 beams

1 detector

SUPERBEAM

4 ν flavours + K

$2 \rightarrow 5$yrs $\nu_\mu \rightarrow \nu_e$

π^+/π^-

8yrs $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

BETABEAM

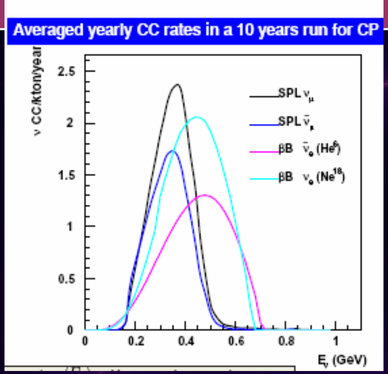
pure

$\nu_e \rightarrow \nu_\mu$ 5yrs

^{18}Nd

^{6}He

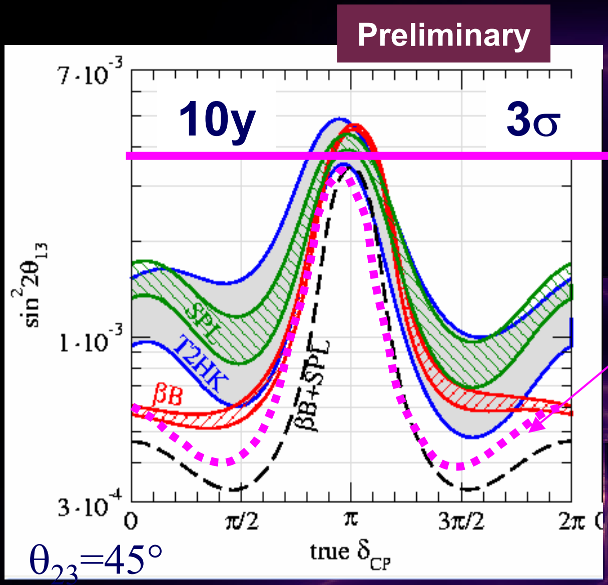
$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ 5yrs



Averaged yearly CC rates in a 10 years run for CP

2 ways of testing CP, T and CPT : redundancy and check of systematics

$\bar{\nu}_\mu$	107k	$\bar{\nu}_e$ (γ =100)	101k	
ν_μ	81k	ν_e(γ =100)	144k	4Mt.y

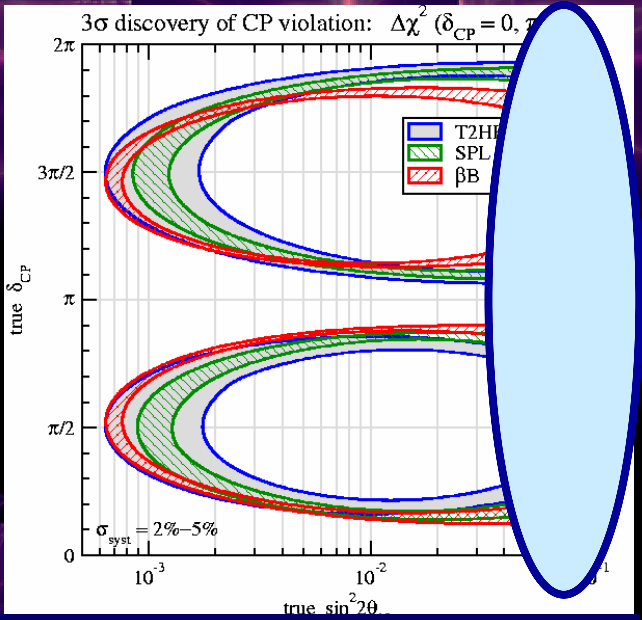


$\sin^2 2\theta_{13} < 4\ 10^{-3}$ en 10 ans

ou 5ans en combinant SPL (ν_μ) + BB(ν_e)

$\theta_{13} \neq 0$

Test de CP



En étude au sein de l'ISS/BENE

Les systématiques dominent
SB: connaissance du faisceau
SB et BB: x-section, eff./Bgd
(NF: effet de matière, eff./Bgd)

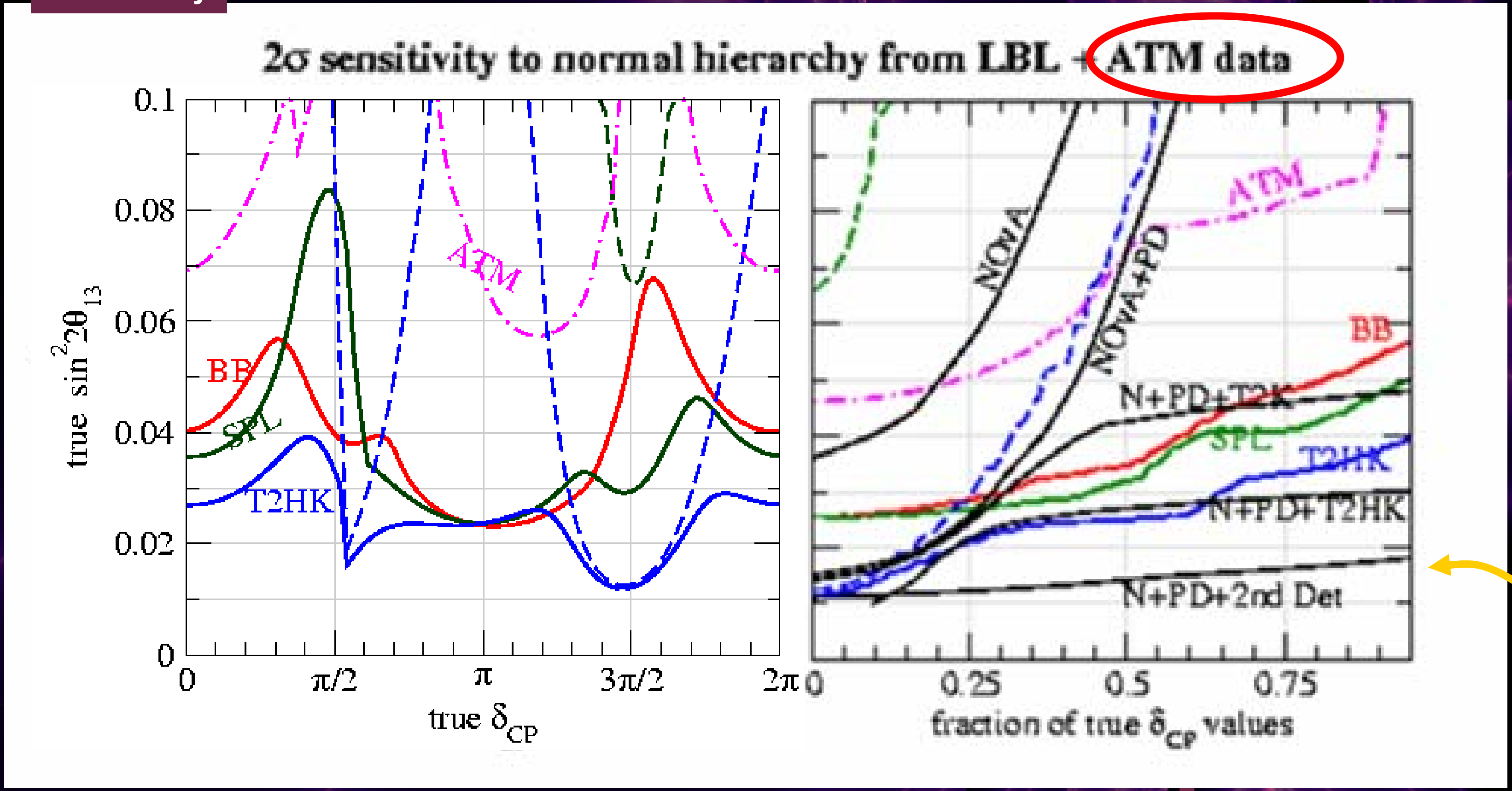
Band: 2%→5% syst
BB: 5+5y
SPL: 2+8y
T2HK: 2+8y
all: 440kT fid. mass

JECampagne, M. Maltoni, M.Mezzetto, Th. Schwetz

Hiérarchie de masse: usage des ATMν

Preliminary

JECampagne, M. Maltoni, M.Mezzetto, Th. Schwetz



ATM: ν atmosph. 4.4Mt.y

– – – : LBL alone (L_{T2HK} ~ 3 L_{Frejus})

____ : LBL + ATM

Nova alone

N(ova) + PD: Proton Driver 3y

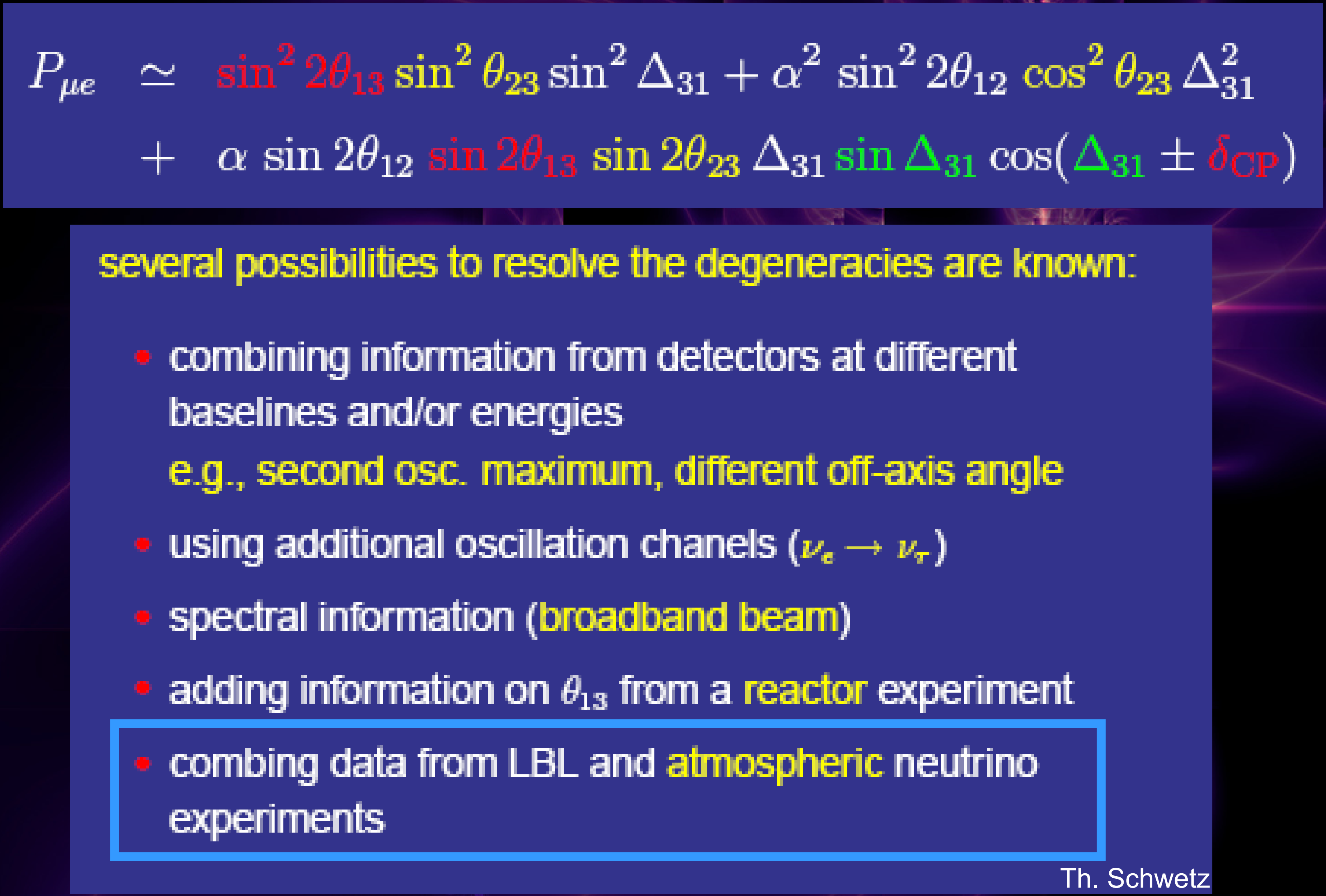
N+PD+ 2nd Det: 12y Nova with 6y 2nd Det

2nd det= 50kT: WČ ou LAr ou Scint. Liq

710km, 2nd Pic Off Axis

2nd maxi. E ↘⇒ effet CP↗ et effet de Mattière

Dégénérescences…



$$P_{\mu e} \simeq \sin^2 2\theta_{13} \sin^2 \theta_{23} \sin^2 \Delta_{31} + \alpha^2 \sin^2 2\theta_{12} \cos^2 \theta_{23} \Delta_{31}^2$$
$$+ \alpha \sin 2\theta_{12} \sin 2\theta_{13} \sin 2\theta_{23} \Delta_{31} \sin \Delta_{31} \cos(\Delta_{31} \pm \delta_{CP})$$

several possibilities to resolve the degeneracies are known:

- combining information from detectors at different baselines and/or energies
  e.g., second osc. maximum, different off-axis angle
- using additional oscillation chanels ($\nu_e \to \nu_\tau$)
- spectral information (broadband beam)
- adding information on θ_{13} from a reactor experiment
- combing data from LBL and atmospheric neutrino experiments

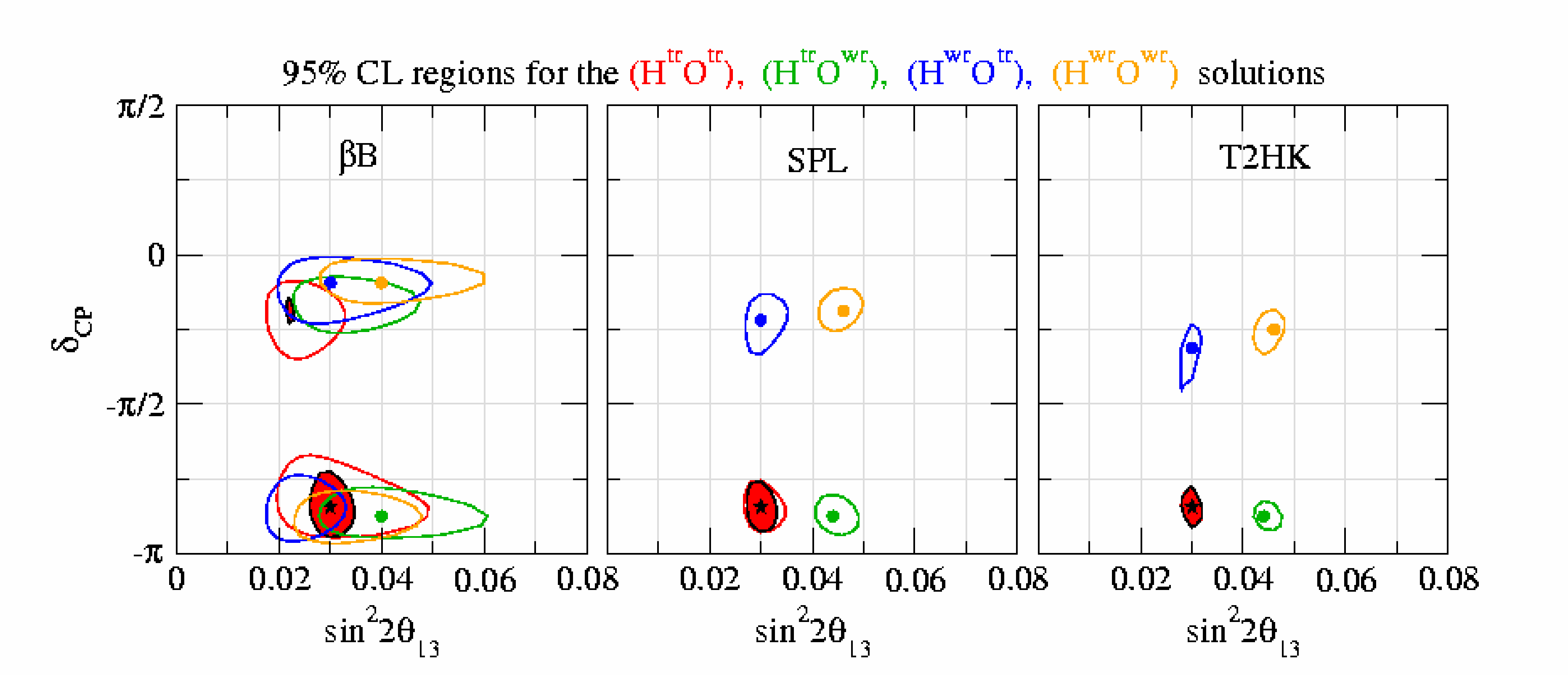
Th. Schwetz

H_20 + ATM

Preliminary

O: θ_{23}Octant H: sign $|\Delta m^2_{31}|$

$\sin^2\theta_{23}=0.6$



BB: 5+5y
SPL: 2+8y
T2HK: 2+8y
all: 440kT fid. mass

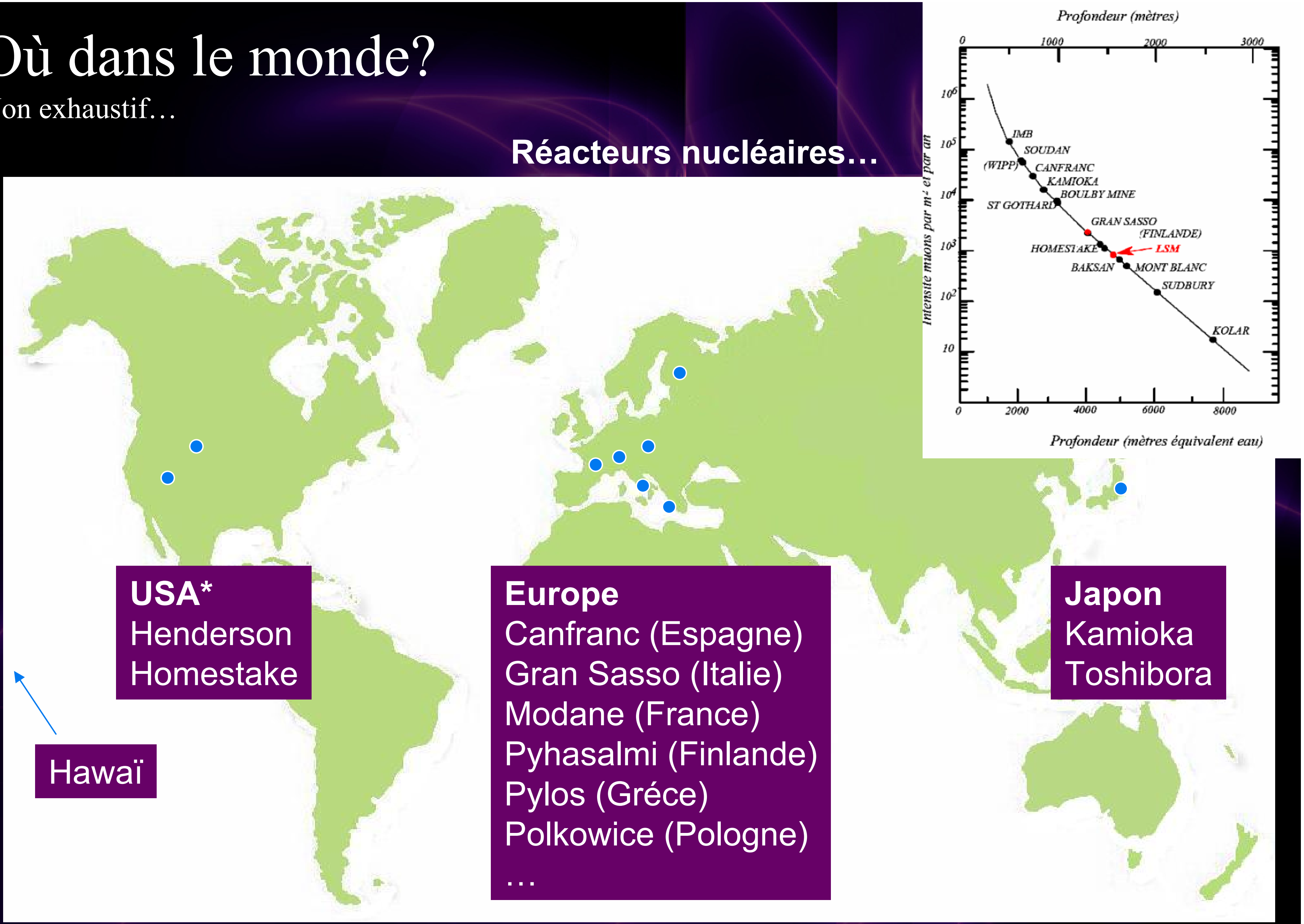
ATM can solve degeneracies!!!

JECampagne, M. Maltoni, M.Mezzetto, Th. Schwetz

Où dans le monde?

Non exhaustif…

Réacteurs nucléaires…



USA*
Henderson
Homestake

Europe
Canfranc (Espagne)
Gran Sasso (Italie)
Modane (France)
Pyhasalmi (Finlande)
Pylos (Gréce)
Polkowice (Pologne)
…

Japon
Kamioka
Toshibora

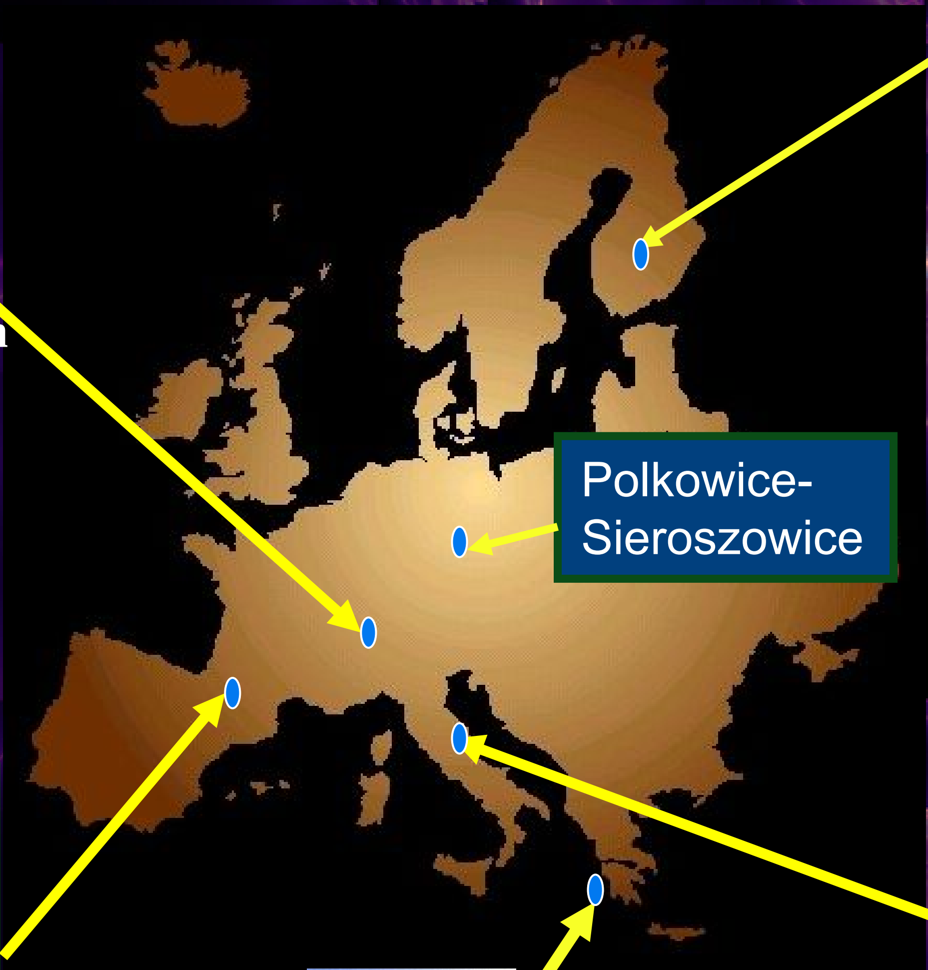
Hawaï

*: après la première sélection du comité DUSEL

(N2) Deep Underground science laboratories

(JRA1) Low background techniques underground

(TA1) Access to the EU Deep Laboratories



CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE

Laboratoire Souterrain de Modane, France

Polkowice-Sieroszowice

LSC

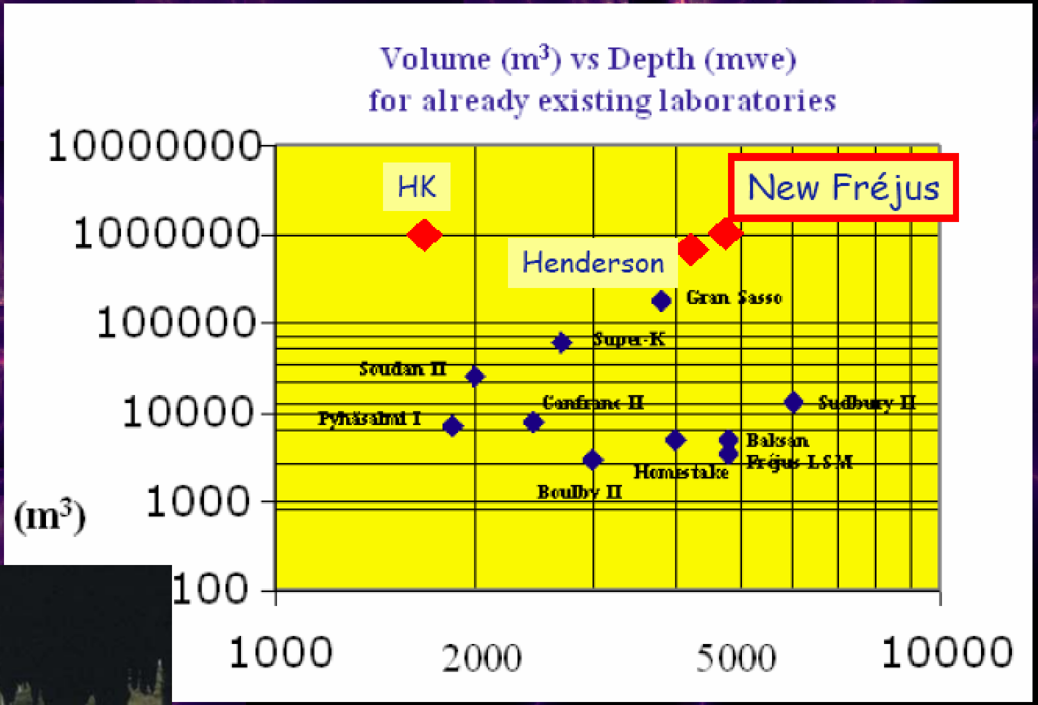
Laboratorio Subterraneo de Canfranc, Spain

LNGS

Laboratori Nazionali del Gran Sasso, Italy

PYLOS

Grandes cavités ?



Pas de réalisation artificielle de la taille requise à la profondeur

CHORANCHE cave naturelel,

Vercors (Isère) **about 60 m wide**

A new very large laboratory in Europe ?

Résultat d’une étude détaillée par la Société SETEC (construction du tunnel)

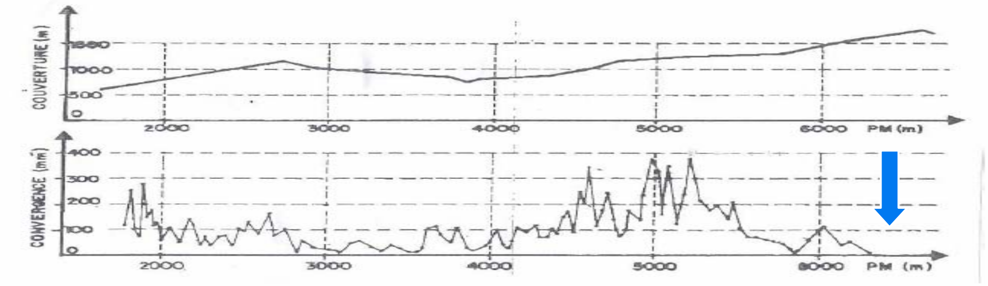
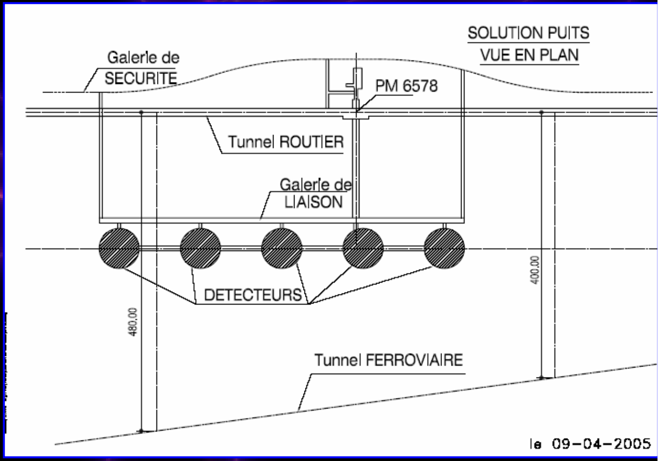
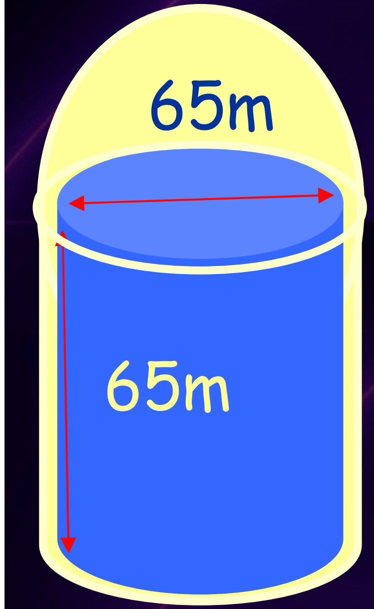


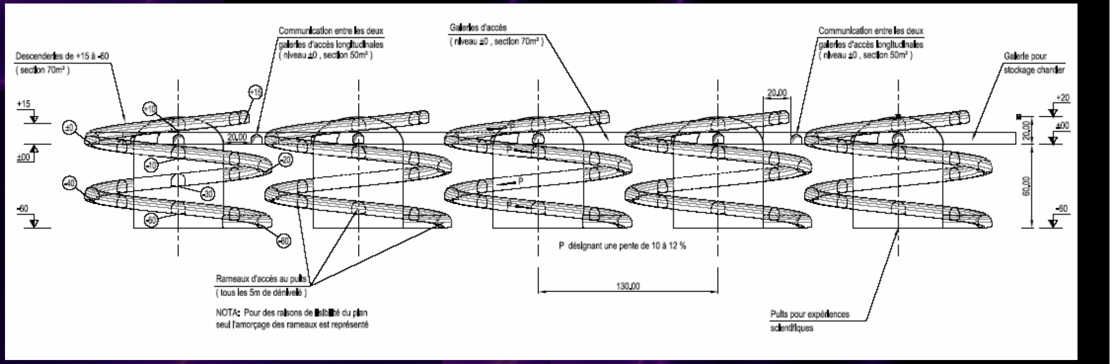
Figure 1.2 – Frejus Motorway tunnel, summary of the convergences between chainage 0+000 km and 7+000 km.





The estimated overall cost is ≈ 80 M€ X Nb of shafts

Current choice=
3 shafts
(1 shaft ≈ 150kT
fiducial mass)



A simpler scheme under study of
access tunnels

A new very large laboratory in Europe ?

(Results of a pre-study by SETEC/STONE, Fréjus tunnel construction company)

1) **The best rock quality is found in the middle of the mountain, at a depth of 4800 mwe**
2) **of all the 20 considered shapes : the “shaft (= well) shape” is strongly preferred**
3) **cylindrical shafts are feasible up to a diameter Φ = 65 m and a full height h = 80 m (≈ 250 000 m^3)**

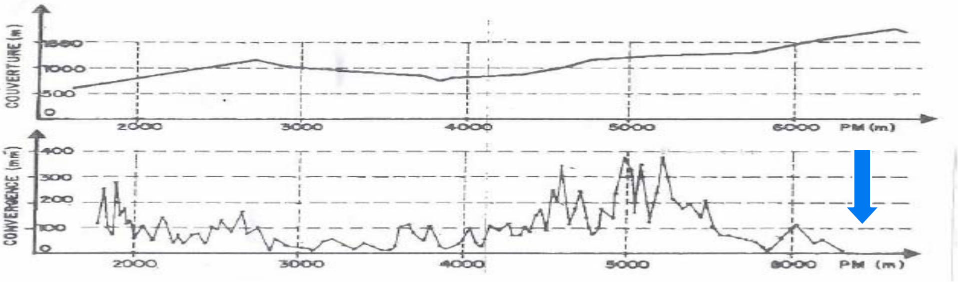
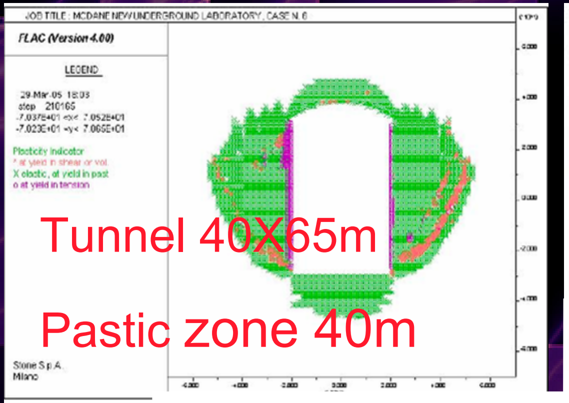
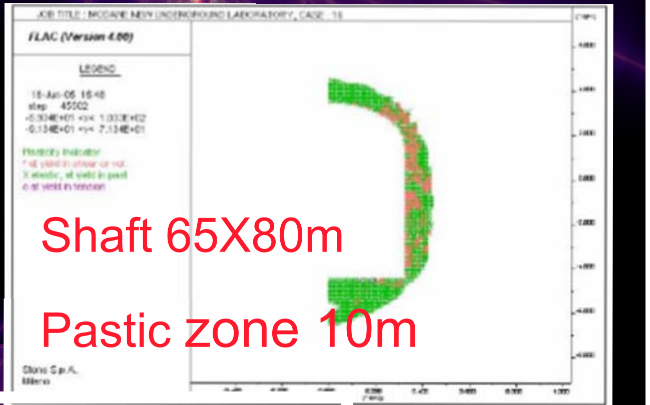


Figure 1.2 – Frejus Motorway tunnel, summary of the convergences between chainage 0+000 km and 7+000 km.



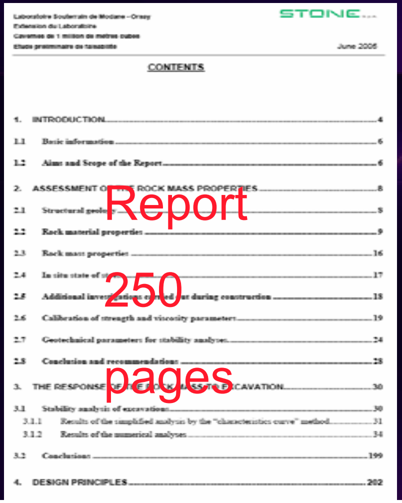
Tunnel 40X65m

Pastic zone 40m



Shaft 65X80m

Pastic zone 10m



Laboratoire Souterrain de Modane – Orsay
Extension du Laboratoire
Cavernes de 1 million de mètres cubes
Etude préliminaire de faisabilité

STONE

June 2005

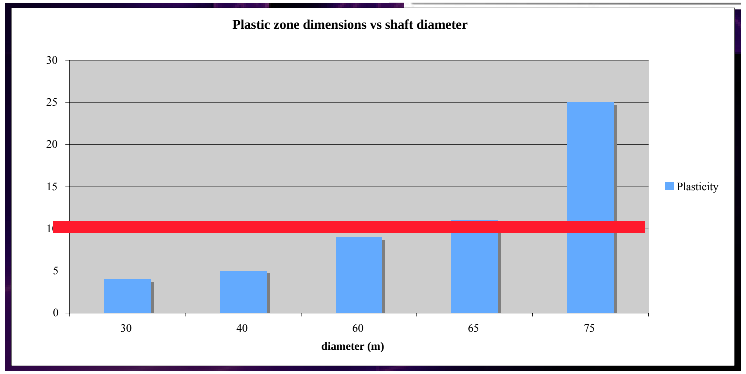
CONTENTS

Report

250

pages

Plastic zone determines the length of iron bolts



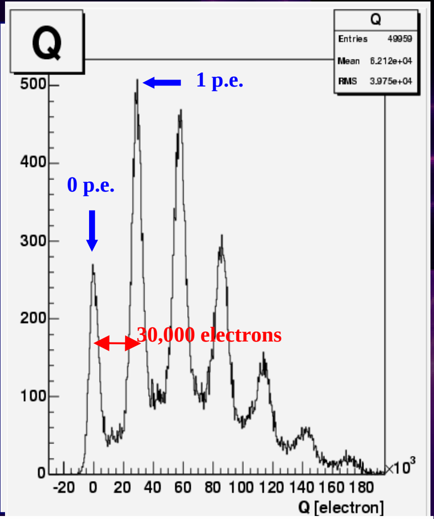
R&D Photodetecteurs

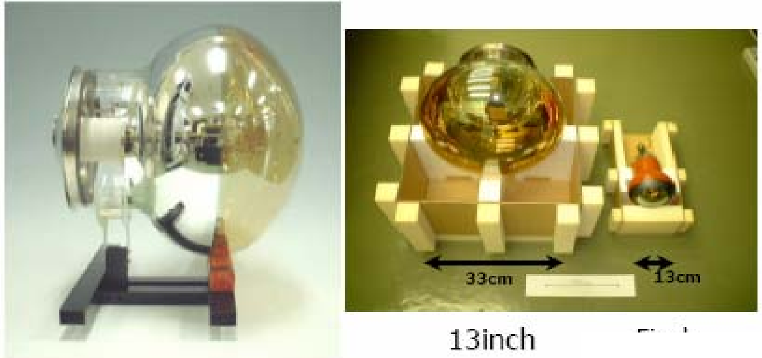
●Diameter	20“	<=>	12“	
●projected area	1660		615	cm²
●QE(typ)	20		24	%
●CE	60		70	%
●Cost	2500		800	€
●Cost/p.e/cm	13		8	€

PMT Photonis@NNN05

Hamamatsu R&D

HPD





13inch

13inch HPD → 20’’

20kV !

Summary

- R&D for a large format hybrid photo detector has started.
- Initial study shows excellent performance:
  - ✓ Single photon sensitivity
  - ✓ Wide dynamic range (up to the readout limit)
  - ✓ Good time resolution (better than 1ns)
  - ✓ Good uniformity (over a large photocathode)
- Promising

H. Aihara @ NNN05

Needs low noise electronics

R&D Electronique

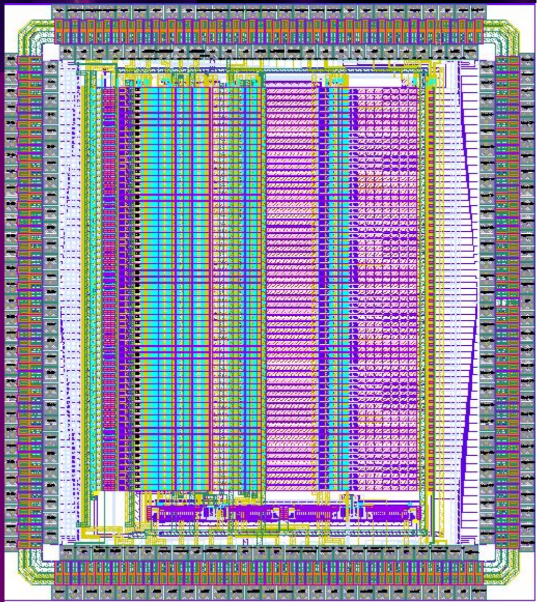
- Integrated readout : “digital PM (bits out)”
  - Charge measurement (12bits)
  - Time measurement (1ns)
  - Single photoelectron sensitivity

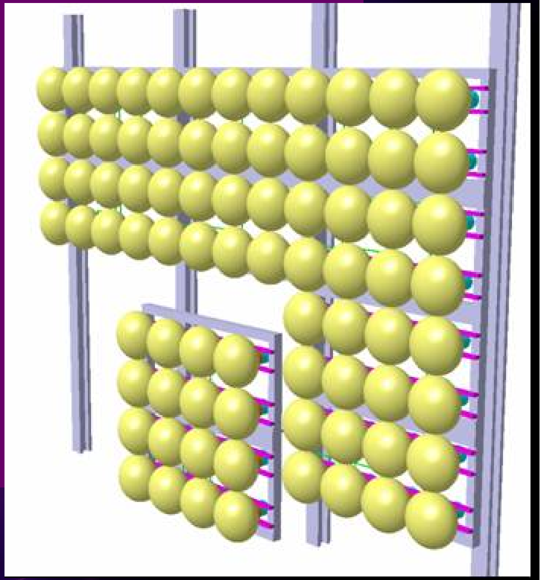
- High counting rate capability (target 100 MHz)

- Large area pixellised PM :
  - 16 low cost PMs
  - Centralized ASIC for DAQ
  - Variable gain to have only one HV

- Multichannel readout
  - Gain adjustment
  - Subsequent versions of OPERA_ROC ASICs

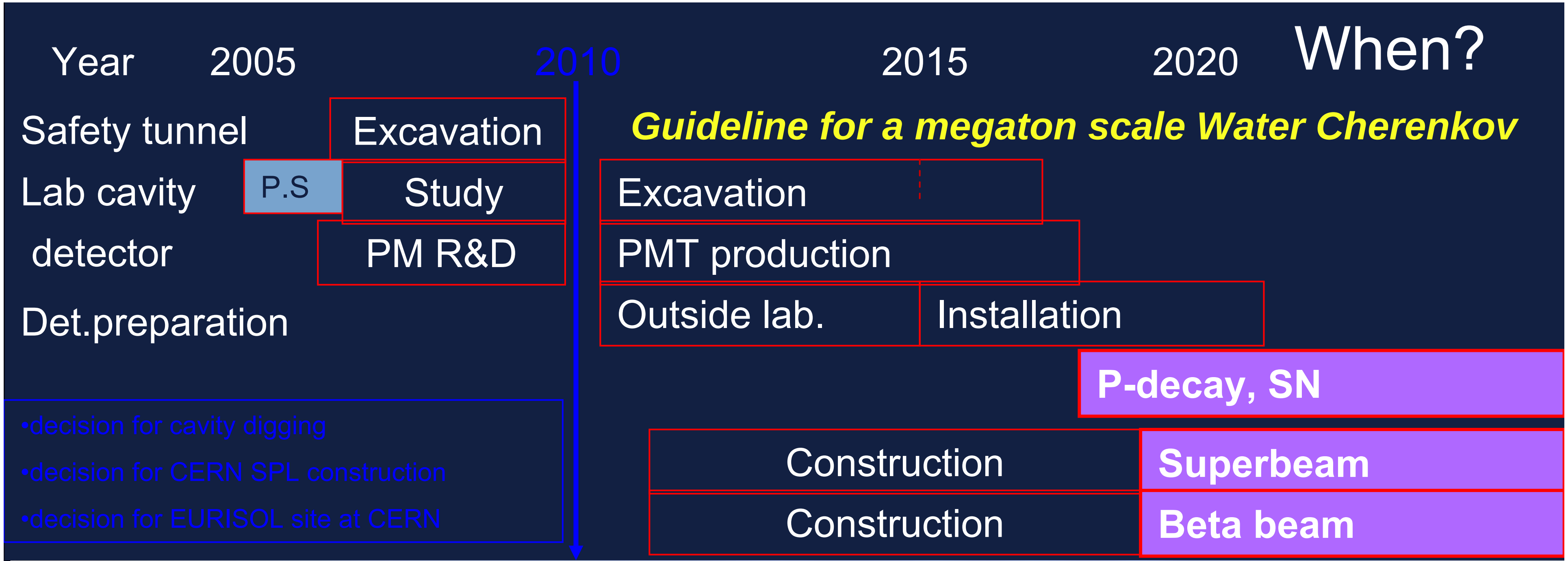
- Network
  - Wireless?





IPNO-LAL-LAPP

When?



Year 2005 2010 2015 2020

Guideline for a megaton scale Water Cherenkov

Safety tunnel: Excavation

Lab cavity: P.S, Study, Excavation

detector: PM R&D, PMT production

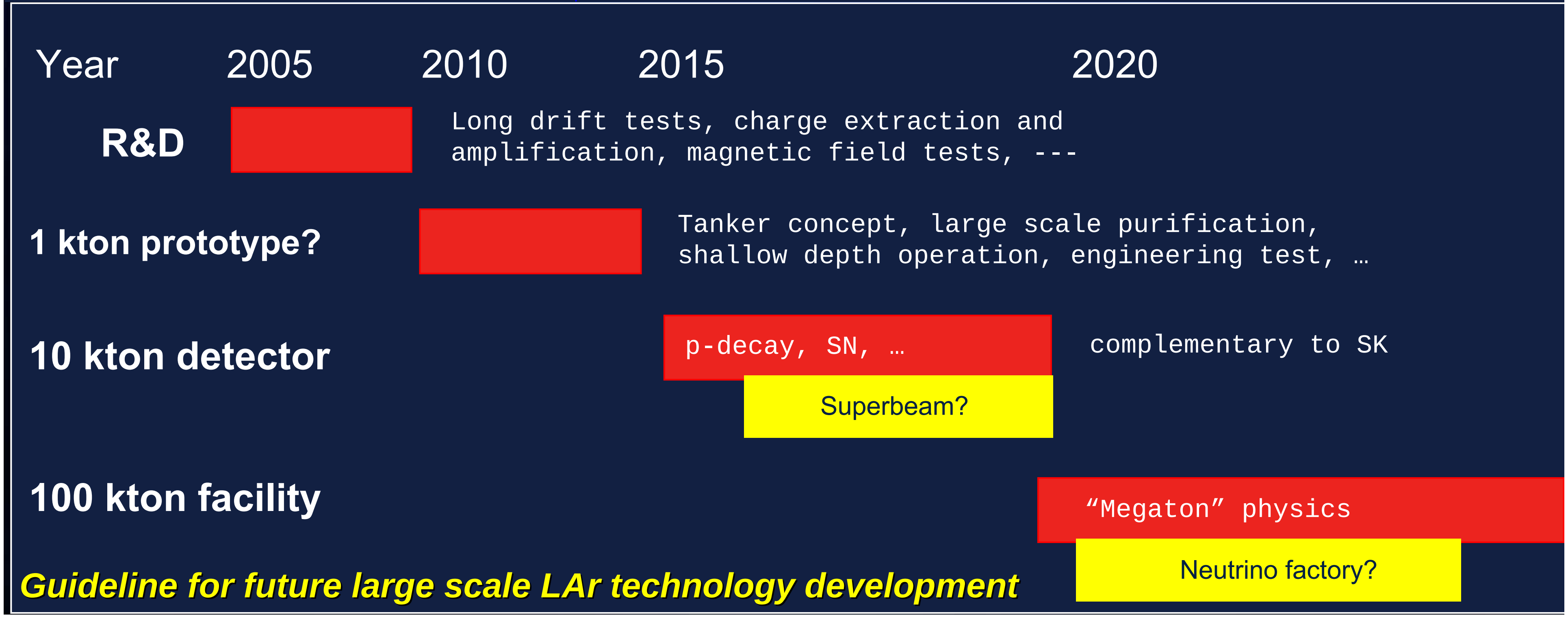
Det.preparation: Outside lab., Installation

P-decay, SN

Construction — **Superbeam**

Construction — **Beta beam**

- decision for cavity digging
- decision for CERN SPL construction
- decision for EURISOL site at CERN



Year 2005 2010 2015 2020

R&D — `Long drift tests, charge extraction and amplification, magnetic field tests, ---`

1 kton prototype? — `Tanker concept, large scale purification, shallow depth operation, engineering test, …`

10 kton detector — `p-decay, SN, …` — Superbeam? — `complementary to SK`

100 kton facility — `“Megaton” physics` — Neutrino factory?

Guideline for future large scale LAr technology development

The 3 technologies have complementarity Physics and common R&D

- **Networking activities**
- A1) Physics potential of Large Deep Underground experiments in both non- accelerator and accelerator sectors, interdisciplinary aspects (geoneutrinos)
- A2) Underground Laboratories for very large detectors : best strategies for excavation, access and equipments (ventilation, air-conditioning, power supply, low background environment, etc.),
- A3) Safety optimisation in Very Large Underground Facilities
- A4) Interdisciplinary aspects of the facility
- **Joint Research Activities**
- B1) Development of low-cost photo-sensors for Cerenkov and scintillation processes in optical and DUV regions, of different types (vacuum or gaseous, in connection with industry)
- B2) Development of solutions for low-cost readout electronic for a large number of channels
- B3) Development of large scale liquid production and purification systems
- B4) Technical feasibility and safety of large underground liquid containers (tanker)
- B5) Site definition and local studies for large scale caverns with large underground apparatuses (rock/salt quality, access requirements, ventilation systems, power supply, ...)

Start structure for FP7, connection with ILIAS…