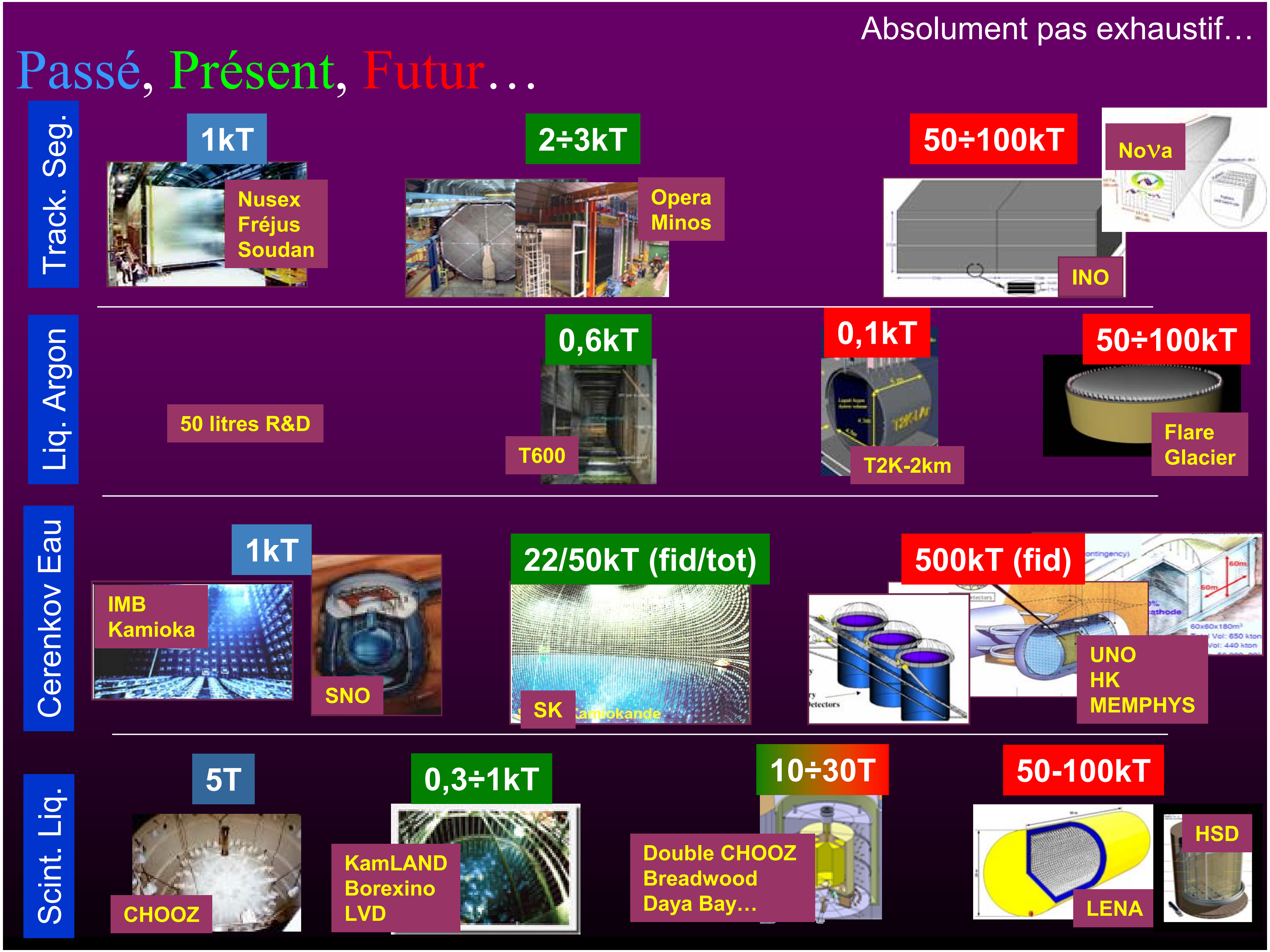
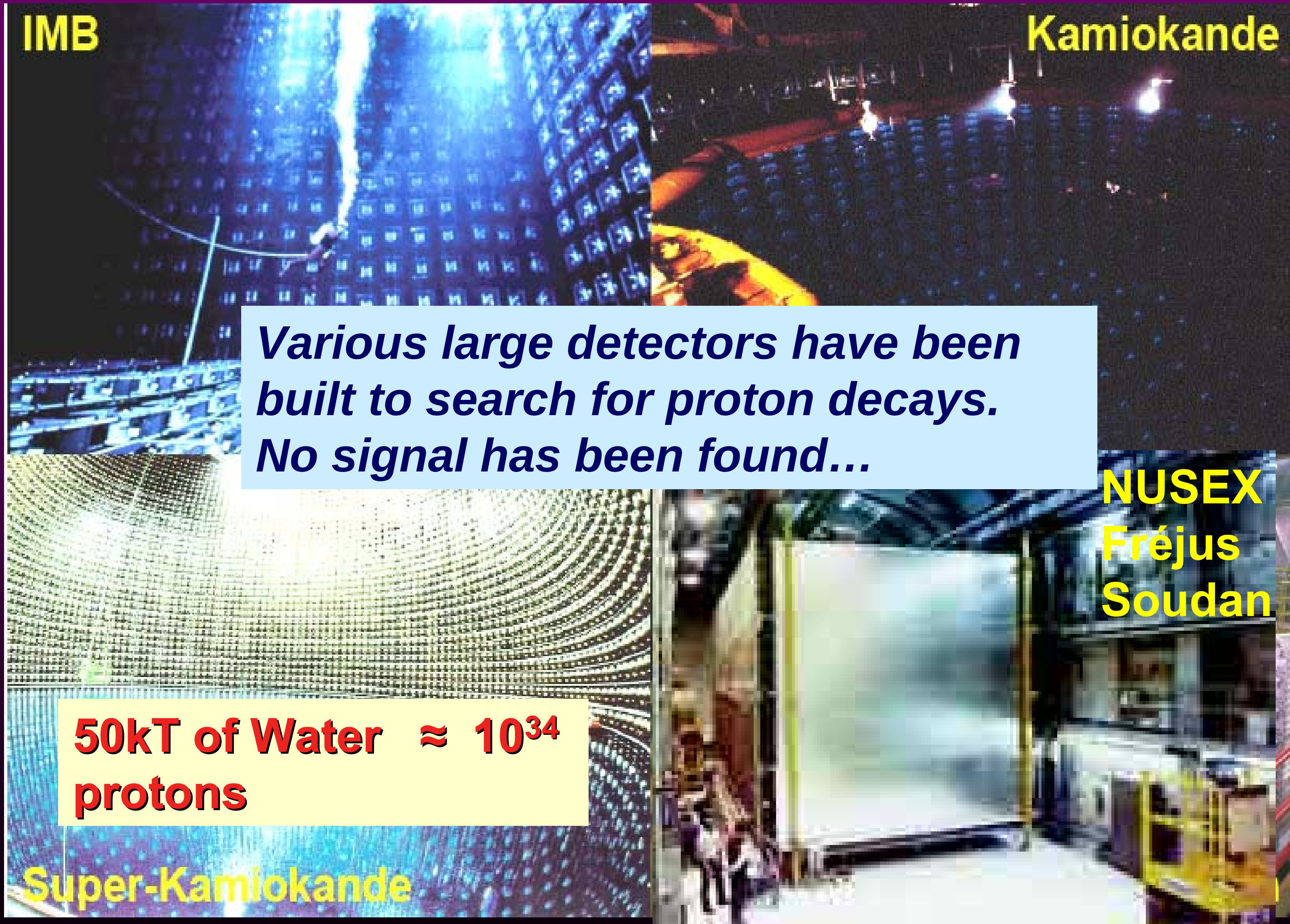
De futurs projets MEGA-Tonic!


Absolument pas exhaustif…
Passé, Présent, Futur…
Track. Seg.
1kT
Nusex
Fréjus
Soudan
2÷3kT
Opera
Minos
50÷100kT
NoVa
INO
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

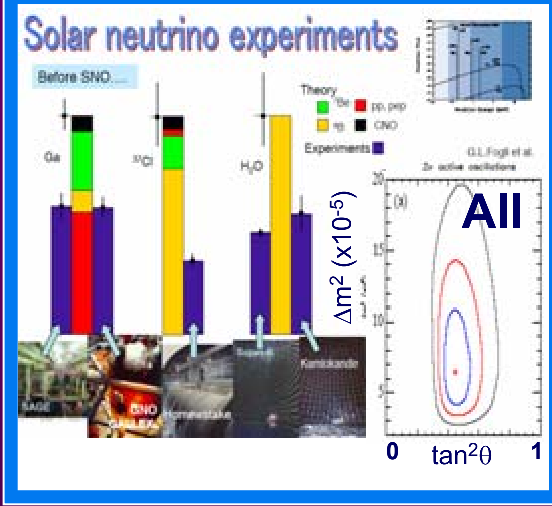
La recherche de la désintégration du proton…

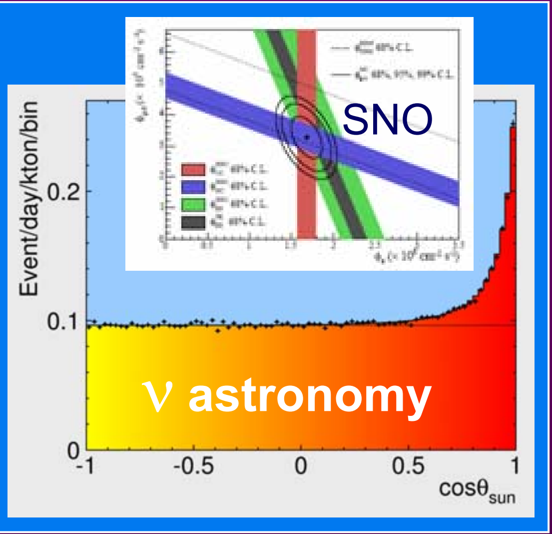


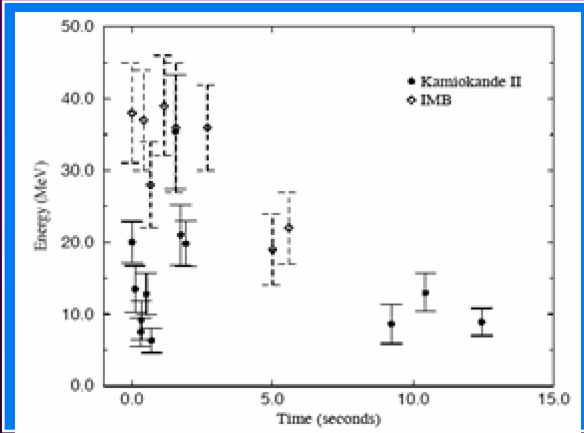
Various large detectors have been built to search for proton decays. No signal has been found…

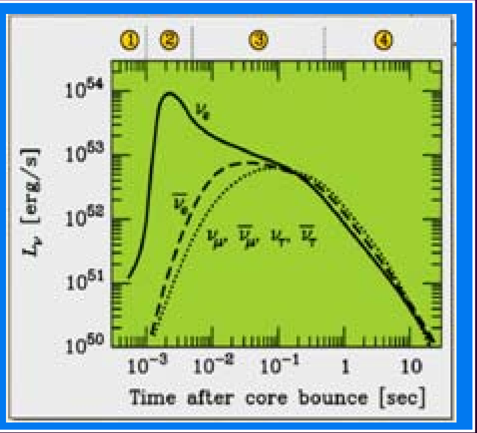
50kT of Water ≈ 10^{34} protons

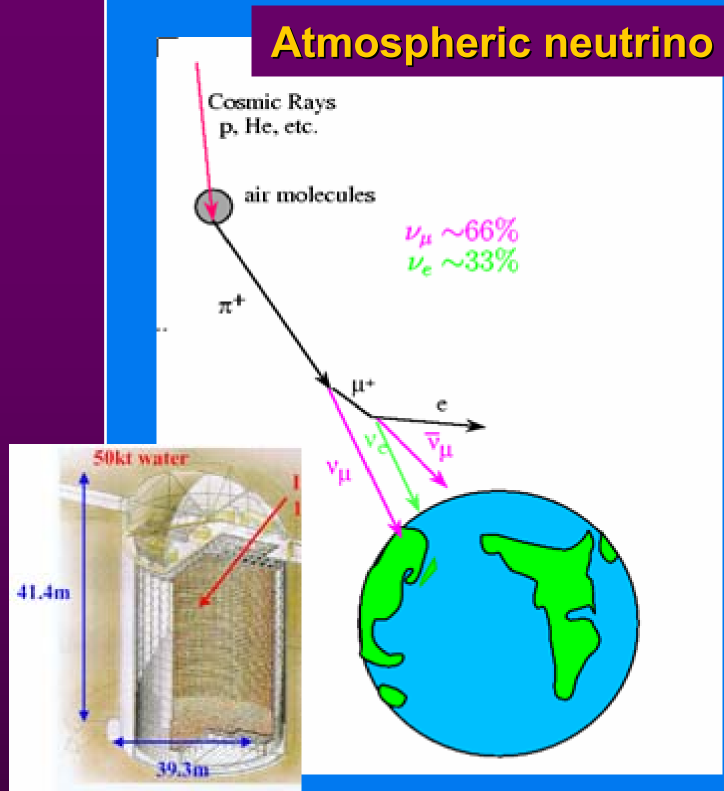
But past success of the field…

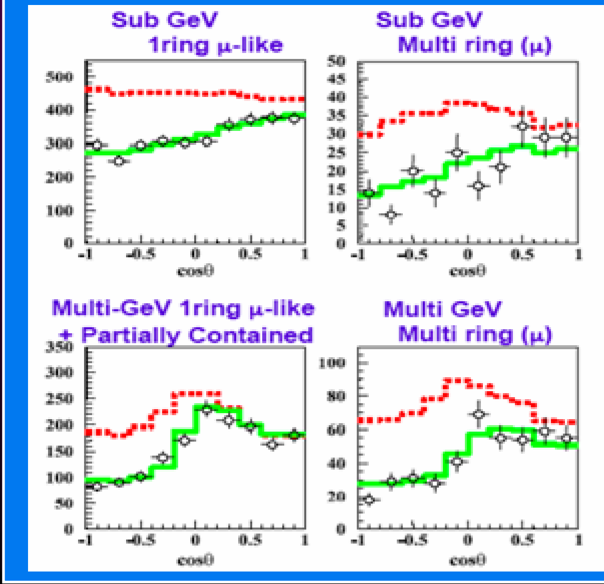












- Solar neutrino anomaly solved
- Detection of SN-1987A (Nobel Koshiba)
- Discovery of atm neutrino oscillations

The need for new generation experiments…

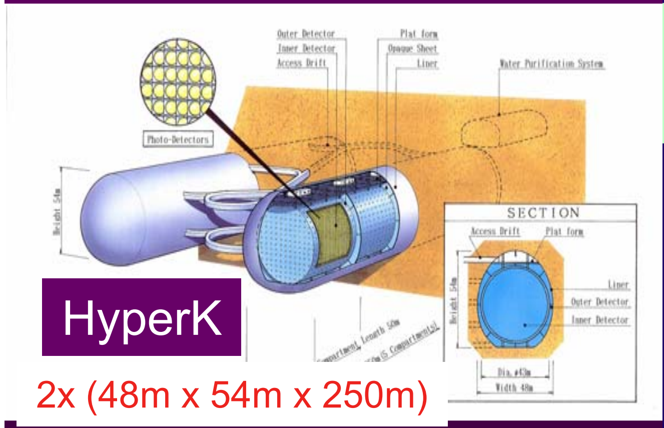
Still many important issues…

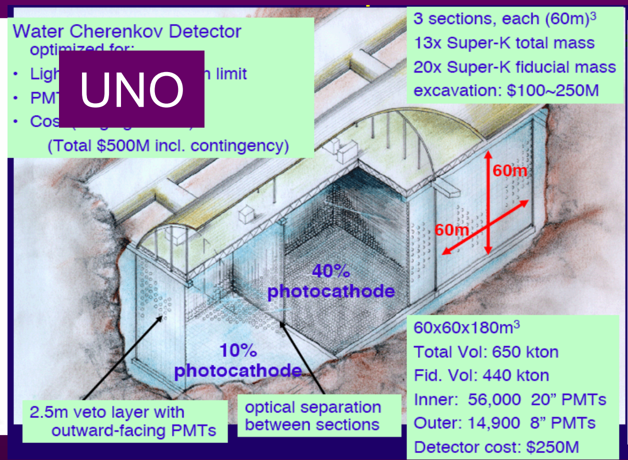
- **Baryon number violation** — **Proton decay**
- **Astroparticle physics**
  - **Understand gravitational collapse** — **Galactic SN ν**
  - **Star formation in the early universe** — **Relic SN ν**
  - **Explore violent phenomena in the universe** — **Trigger SN ν,**
  - **Dark matter and astrophysical 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**

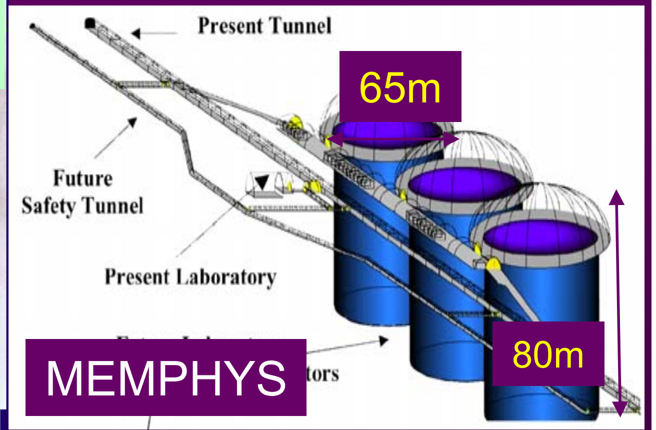
Les détecteurs envisagés… **NNN série de Workshops**

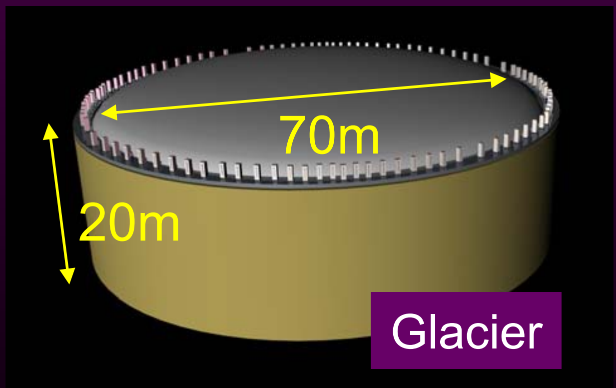
Aussois 05, Seatle 06, Hamamatsu 07

Cerenkov à Eau 500kT→1Mt



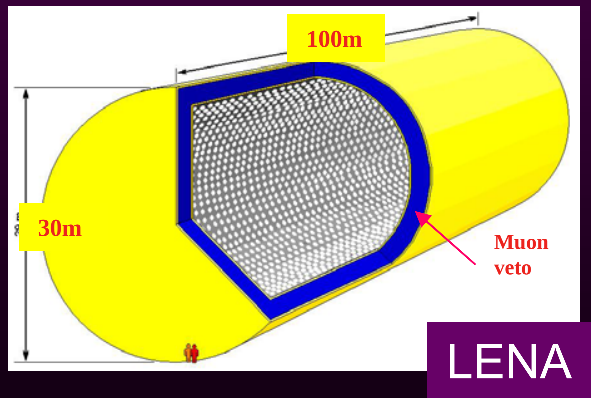






Argon Liq. →100kT

Scintillateur Liq. →50kT



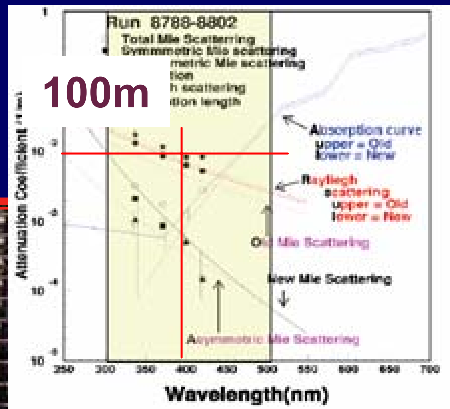
Mton Water Čerenkov

- 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 < λ < 500 nm
With 81,000 PMT (12'') 30% coverage, Q.E.≈24%, CE~70%
(20'' Q.E.≈20%, CE~60%)
Relativistic particle produces
$\Rightarrow$≈14 photoelectrons / cm
$\Rightarrow$≈7 p.e. per MeV



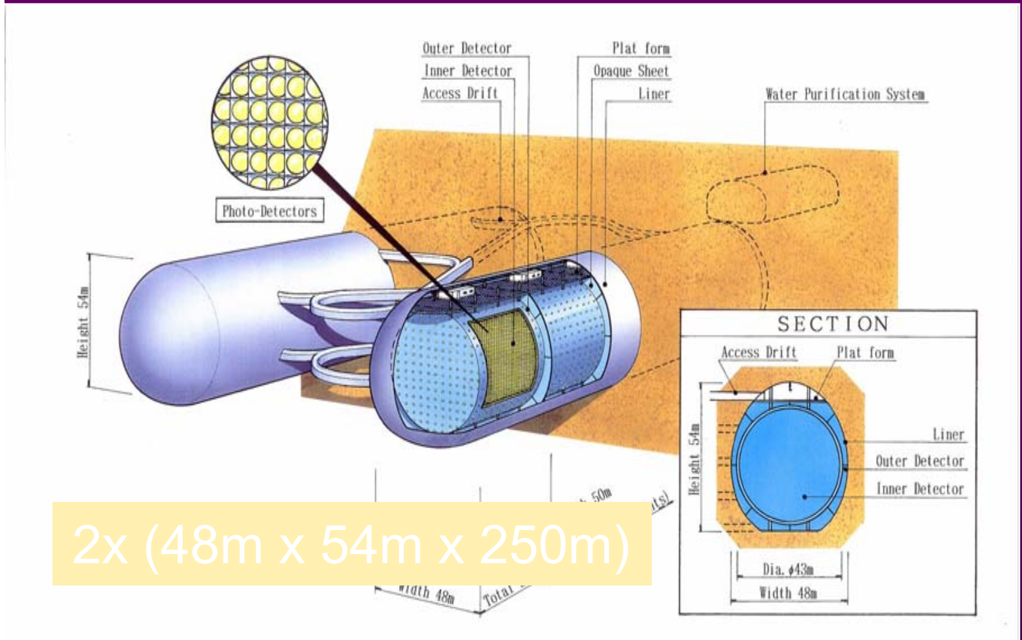
Volume total x4 SK
Fiduciel: 145kT
17535m^2 surface PMT

- 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!!!**

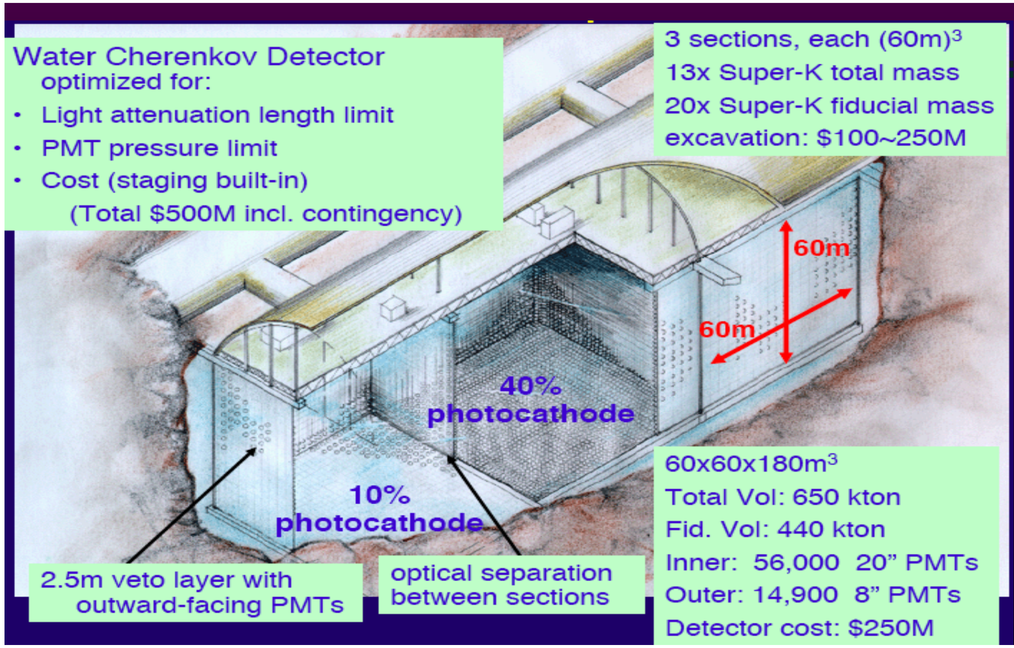
Beacom & Vagins Phys. Rev. Lett., **93**:171101, 2004

The Japanese and US projects: HK and UNO

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



- 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 ?)



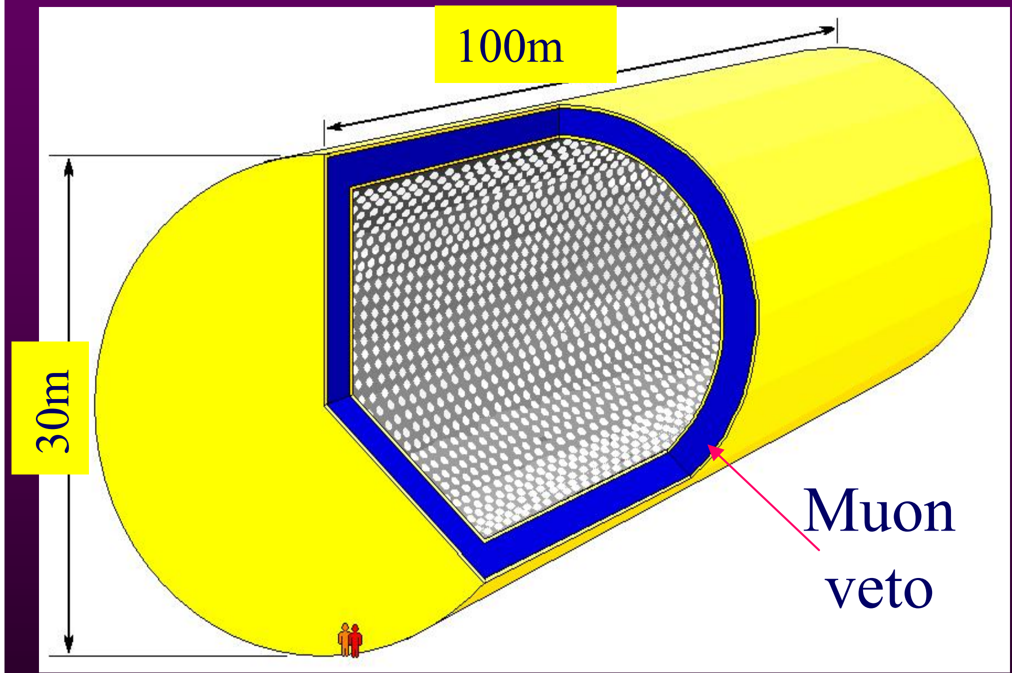
- Henderson Mine (4000 mwe, one of the 2 DUSEL sites)
- FV 440 ktons
- Cavern study to be done
- Photodetector R&D on-going
- Long baseline from BNL
- In the NSF process

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	$60 \times 60 \times 60 m^3$	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

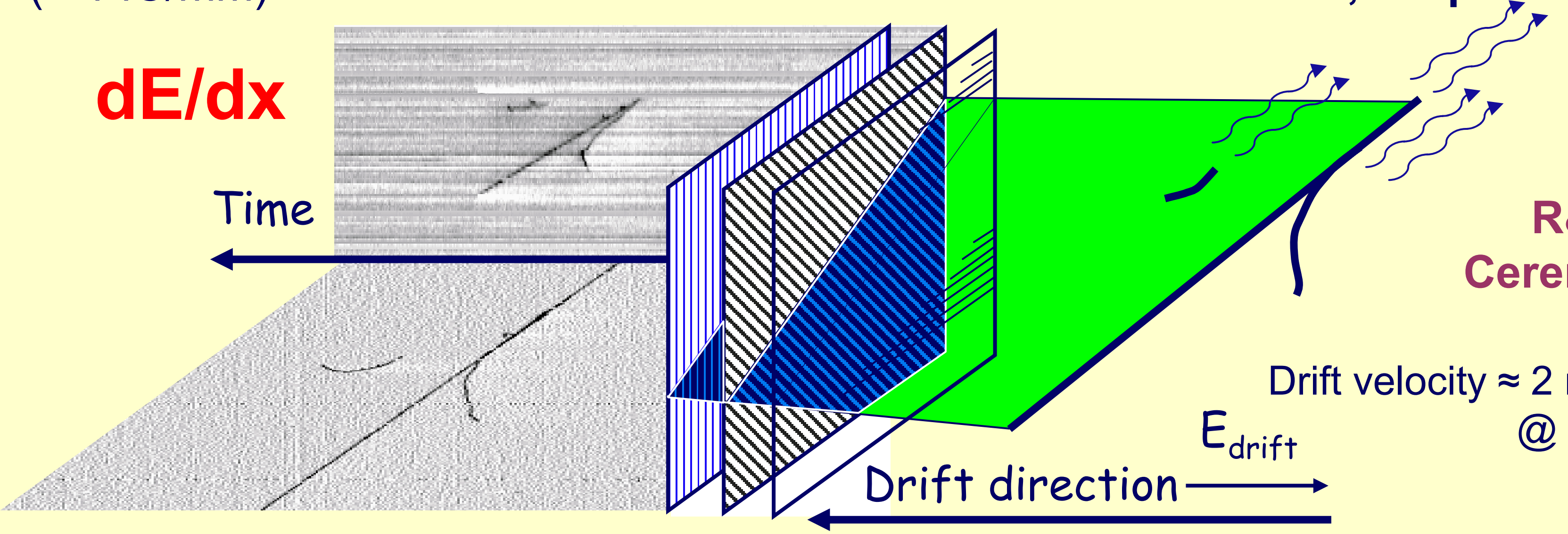
Rough cost estimate 200M€ (wo cavity excavation and purification systems)

L. Oberauer

Argon Liquide TPC

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

UV Scintillation Light 128nm
40,000 photons/MeV

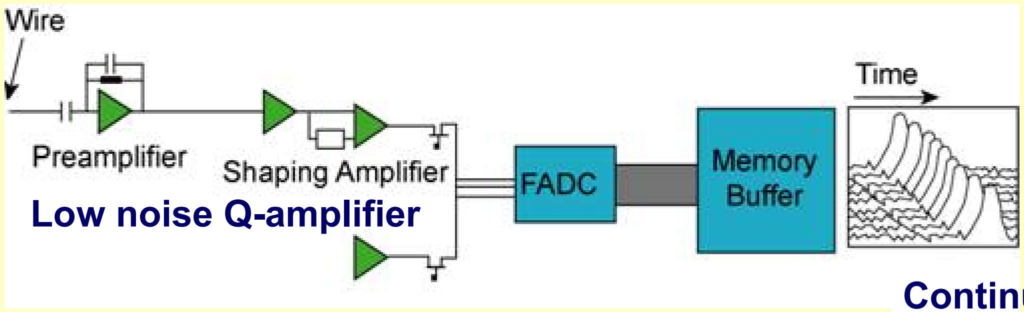


Drift velocity ≈ 2 mm/μs
@ 1 kV/cm

Drift electron lifetime:

$$\tau \approx 300\mu s \times \frac{1\,ppb}{N(O_2)}$$

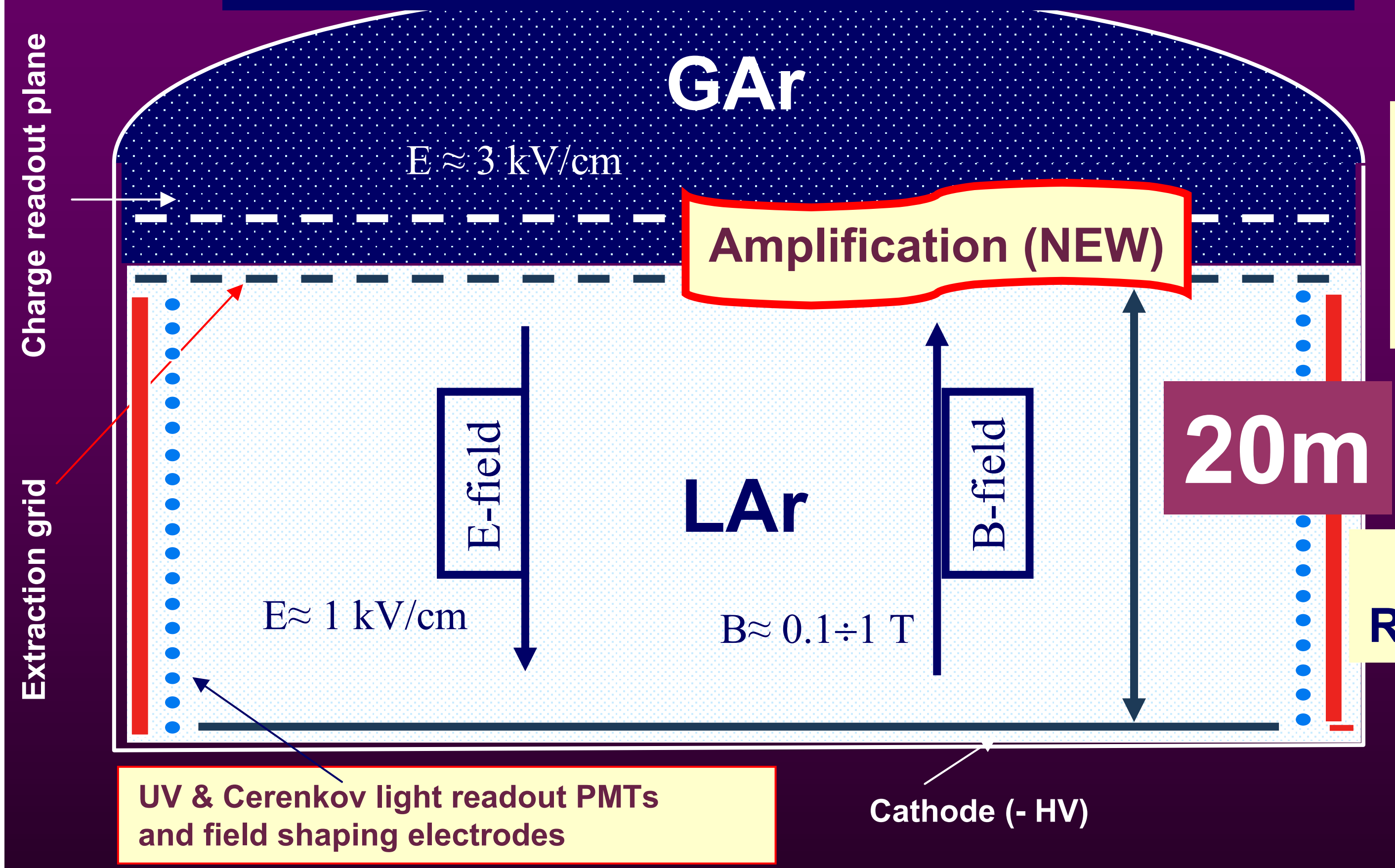
Purity < 0.1ppb O_2-equiv.



Continuous waveform recording
→ **image**

Tentative layout of a large magnetized GLACIER

LHe Cooling: Thermosiphon principle + thermal shield=LAr

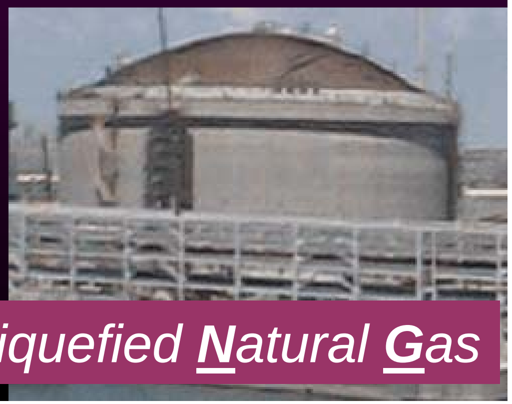


2ans de remplissage
Production Locale
150t/j
25-30MW – 45M€

Par jour 29,000Là
Recondenser + purifier

(Magnetized is also been considered)

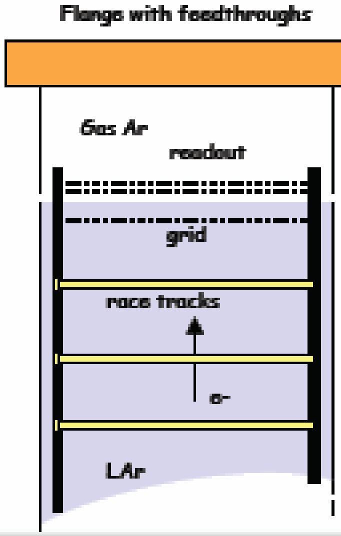
Rough cost estimate 400M€ with Tank 100% contingency
(10kT => 100M€) **A.Rubbia**

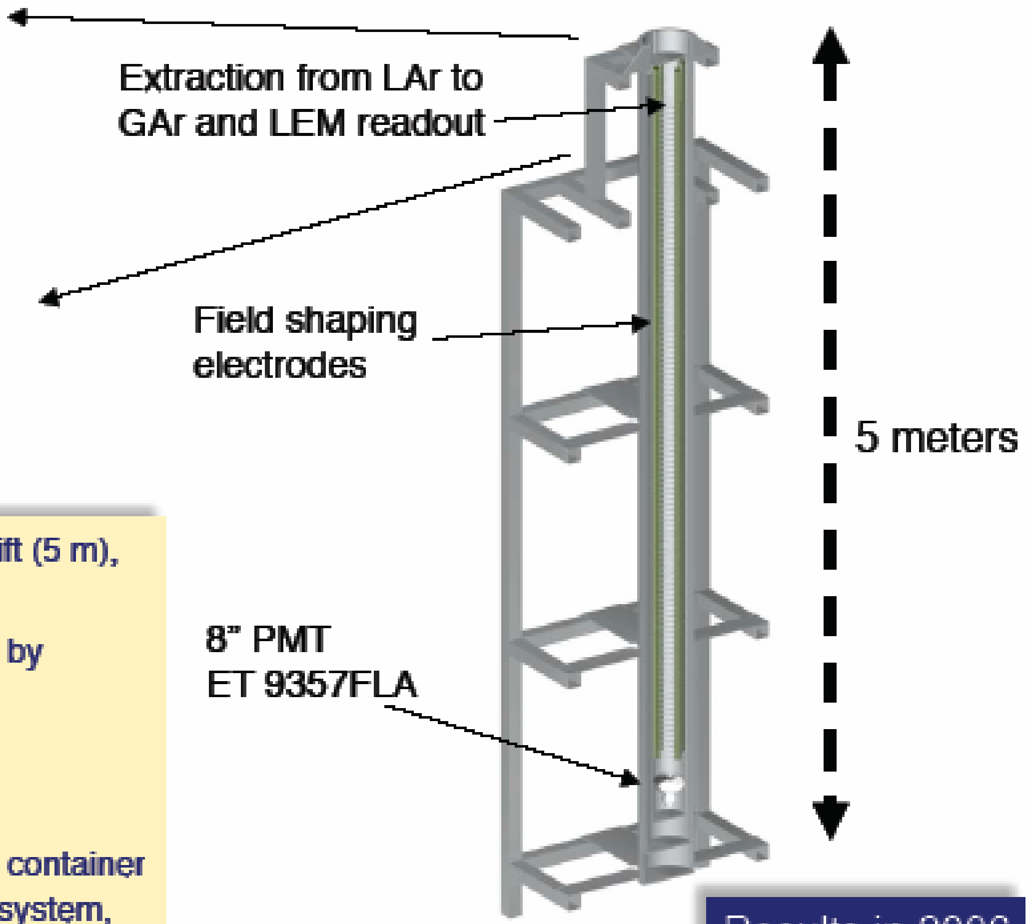


LNG = Liquefied Natural Gas

LAr R&D pour GLACIER: beaucoup de choses…

Long drift, extraction, amplification: "ARGONTUBE"





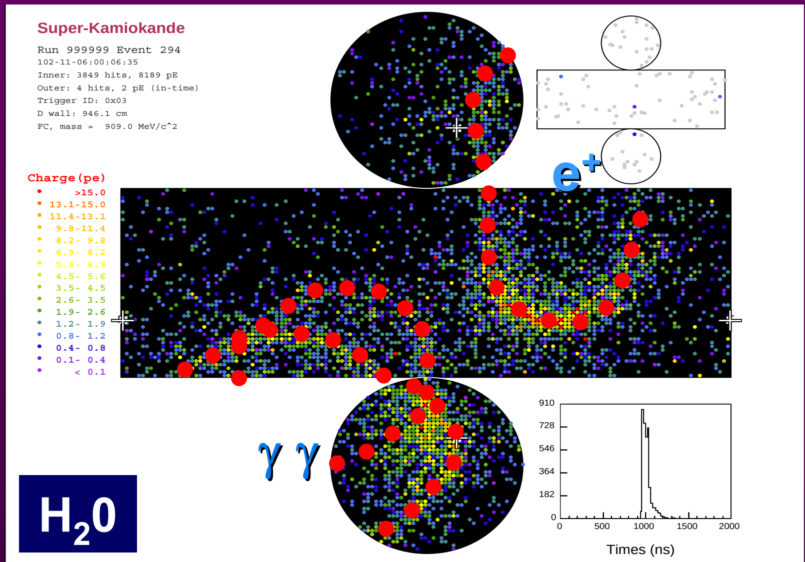
- Full scale measurement of long drift (5 m), signal attenuation and multiplication
- Simulate 'very long' drift (10-20 m) by reduced E field & LAr purity
- High voltage test (up to 500 kV)
- Design & assembly:

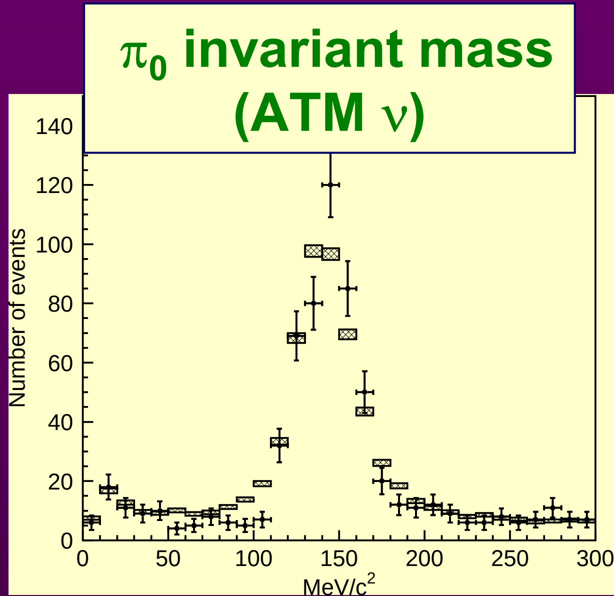
completed: external dewar, detector container
in progress: inner detector, readout system, …

Results in 2006

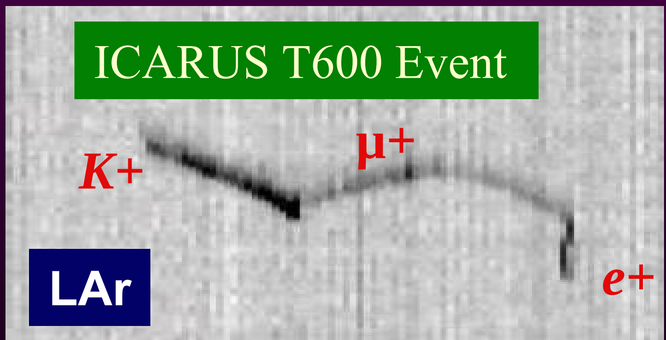
A. Badertscher @ BENE-ISS-KEK Jan06

Imaging…





1-ring vertex ~30cm



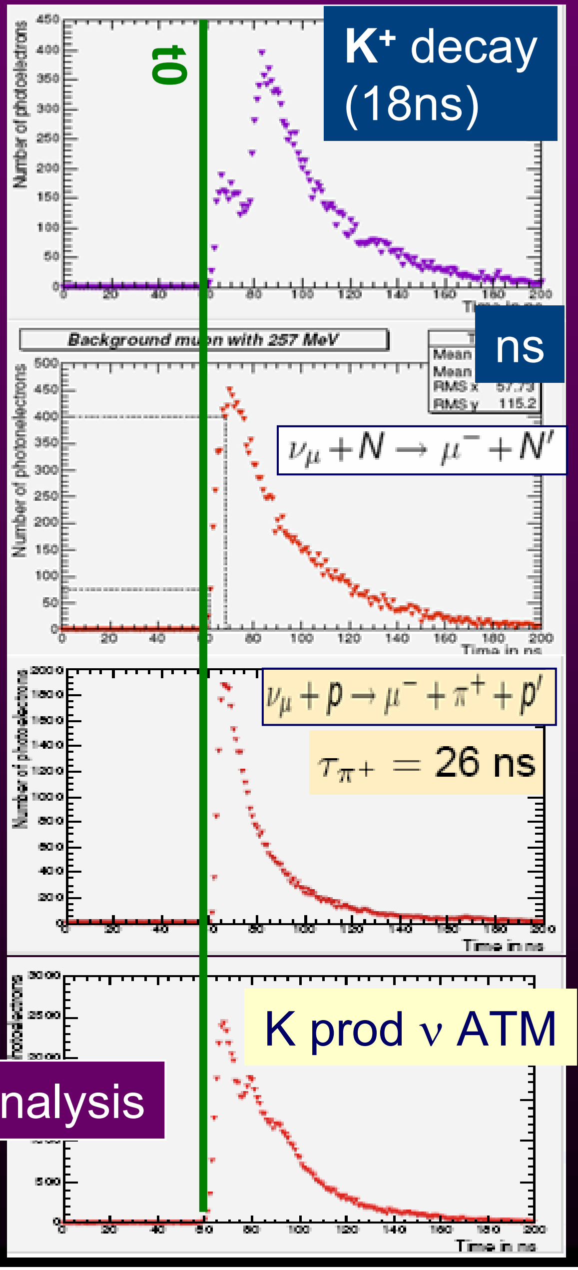
High granularity: Sampling = 0.02 X_0
"bubble" size ≈3×3×0.4 mm³

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.

H_20



Nbre de PMTs

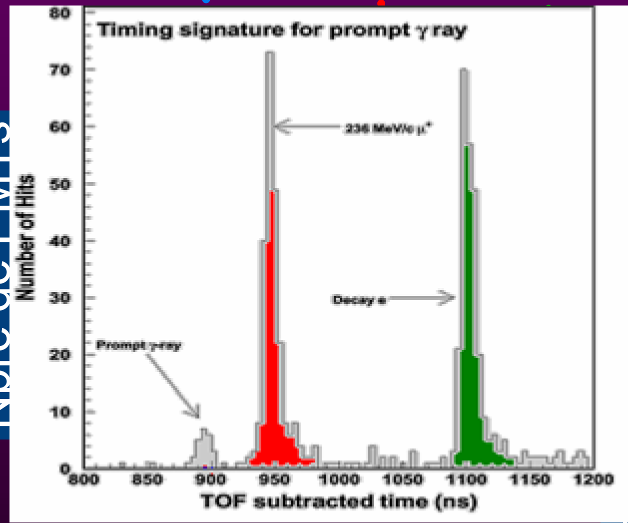
Pulse shape analysis

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

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

6–10 MeV 236MeV/c

Nbre de PMTs



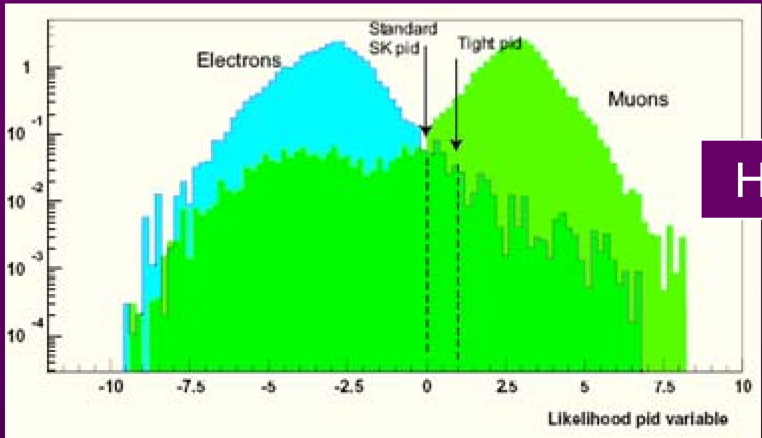
ns

All: Autotrigger capability

LAr n'a pas de possibilité (1μs)

Identification de particules

Particle ID : 99% 1-ring μ, e



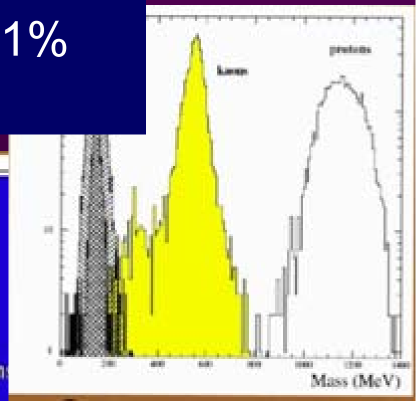
H_20

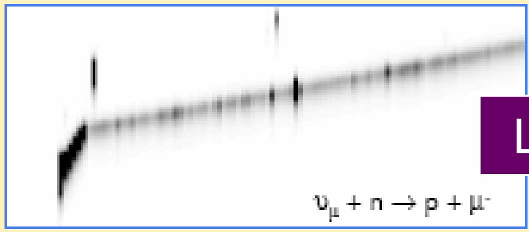
Seuil Cerenkov

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 »

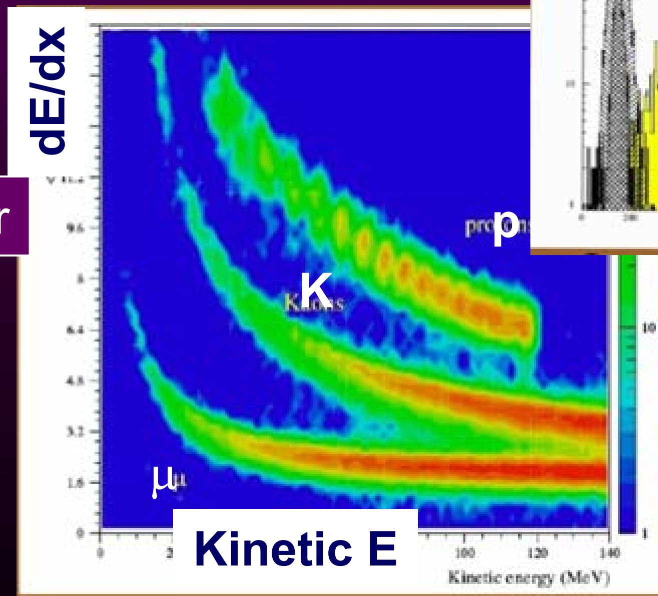
Neural Net: dEdx + Length
Protons efficiency >99%
Kaons mis-id as protons <1%
Pions/muons cc 1%





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)

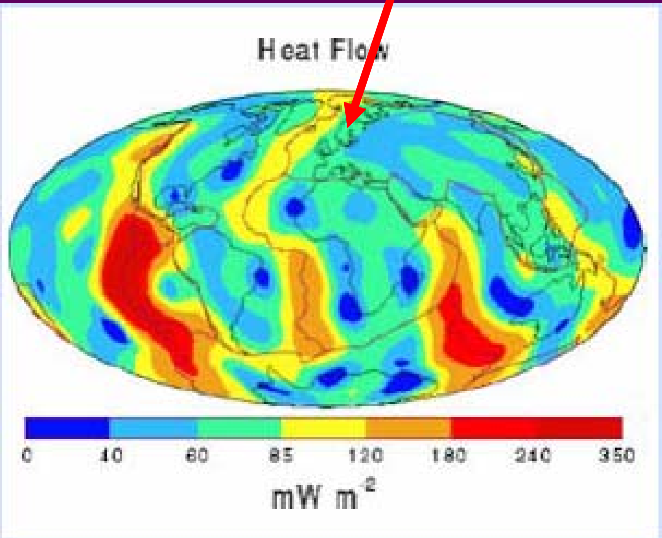
The need for new generation experiments…

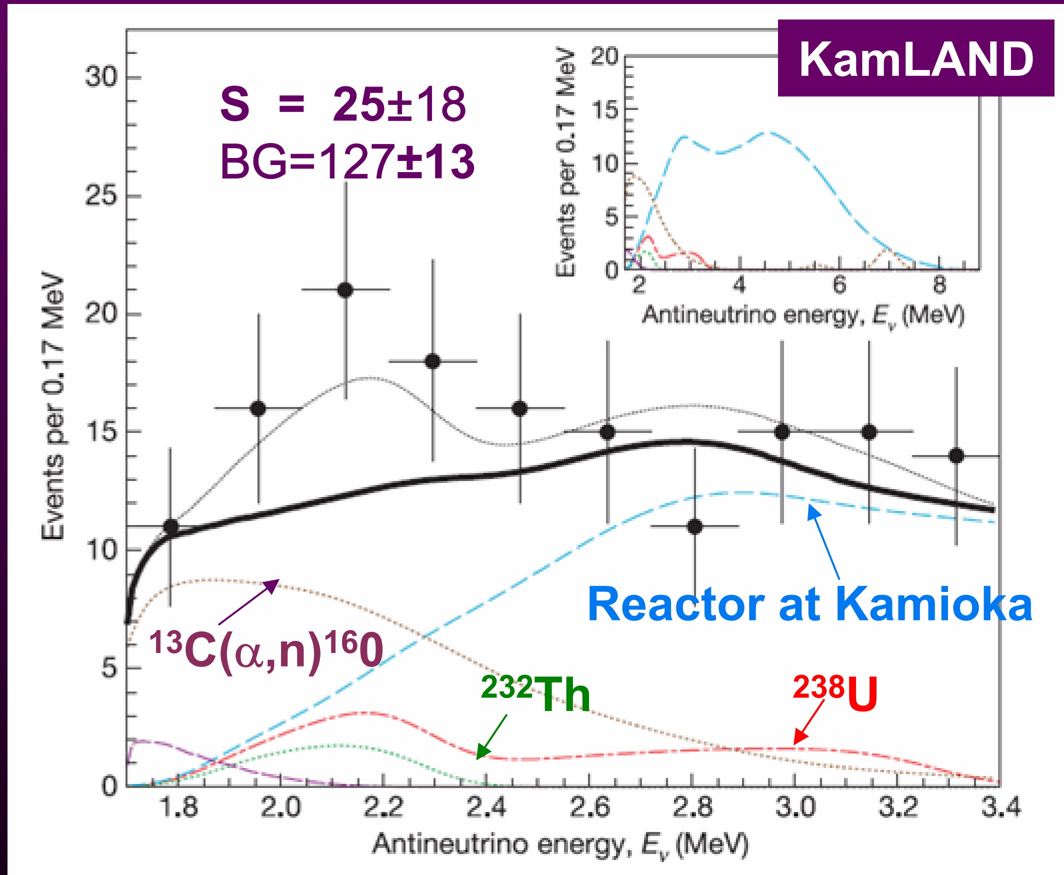
Still many important issues…

- **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

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

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

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 $\leftrightarrow$ lepton chargé + méson

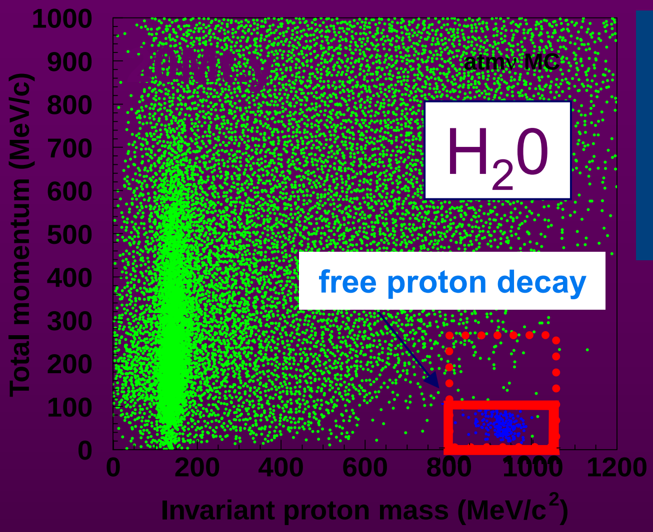
$$p \rightarrow K^+ \bar{\nu} \qquad p \rightarrow e^+ \pi^0$$

Some recent models predictions

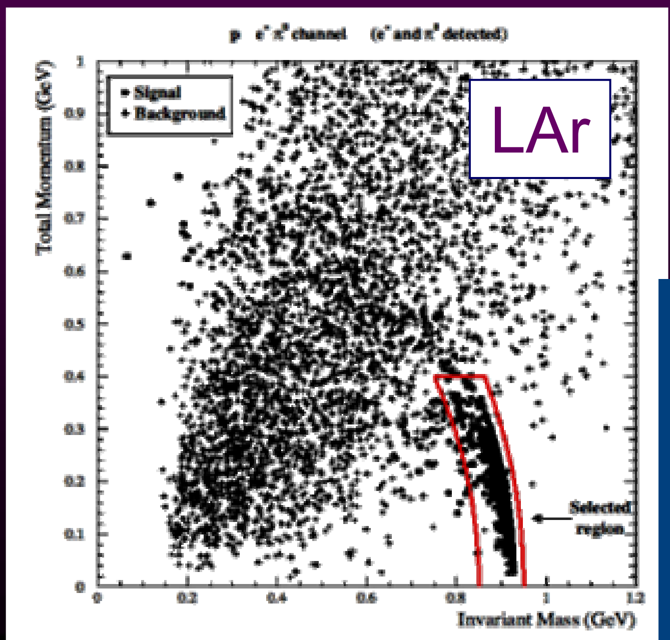
Model	Decay modes	Prediction	References
Georgi-Glashow model	-	ruled out	[8]
Minimal realistic non-SUSY $SU(5)$	all channels	$\tau_p^{upper} = 1.4 \times 10^{36}$	[9]
Two Step Non-SUSY SO(10)	$p \to e^+\pi^0$	$\approx 10^{33-38}$	[10]
Minimal SUSY $SU(5)$	$p \to \bar{\nu}K^+$	$\approx 10^{32-34}$	[11]
SUSY $SO(10)$ with 10_H, and 126_H	$p \to \bar{\nu}K^+$	$\approx 10^{33-36}$	[12]
M-Theory(G_2)	$p \to e^+\pi^0$	$\approx 10^{33-37}$	[13]

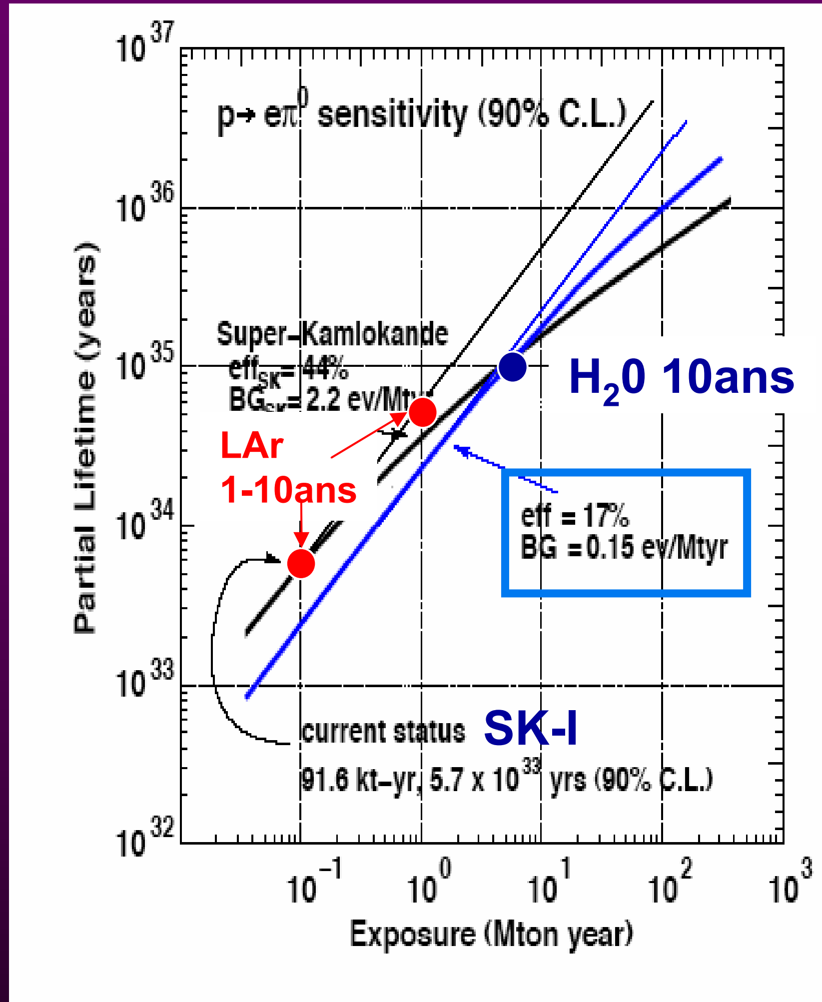
P. F. Perez

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



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)

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

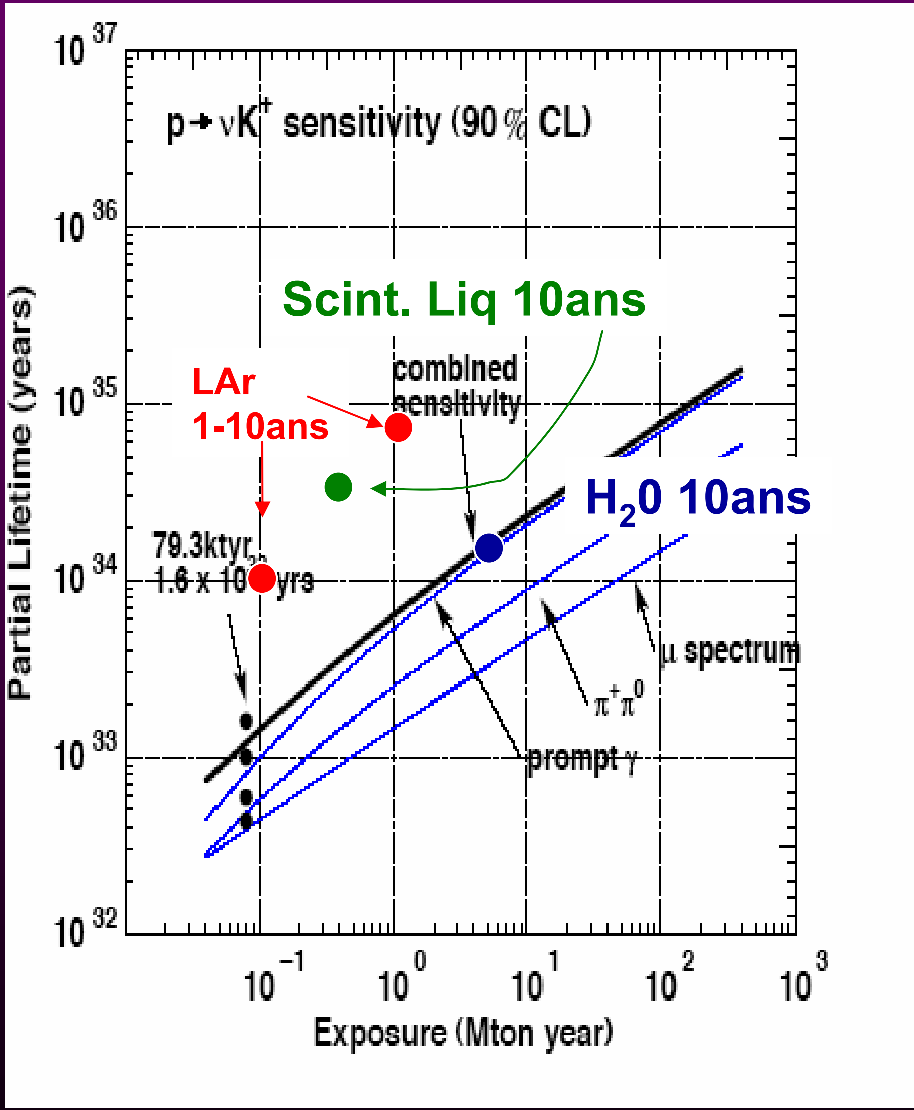
H_2O: K^+ sous le seuil Č
Imaging/Timing
$K^+ \rightarrow \pi^+\pi^0; \mu^+\nu$ avec ou sans ^{15}O $\rightarrow ^{15}N$ γ prompt (6MeV) tag

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) $P \rightarrow \nu K^+$, $K^+ \rightarrow \mu^+ \nu$

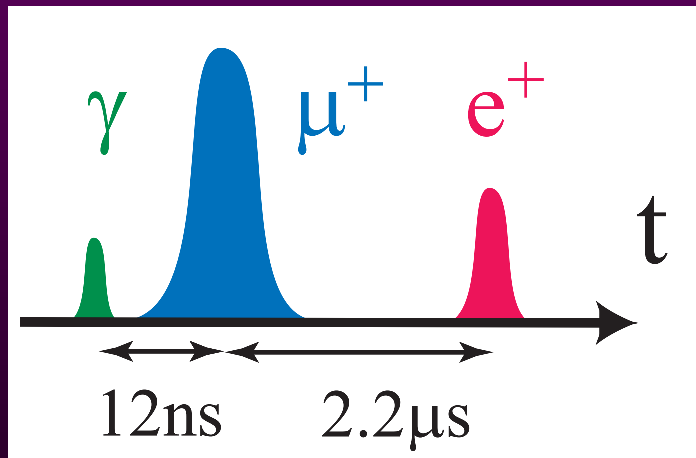
236 MeV/c

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

$\hookrightarrow e^+ \nu \nu$

6 – 10 MeV

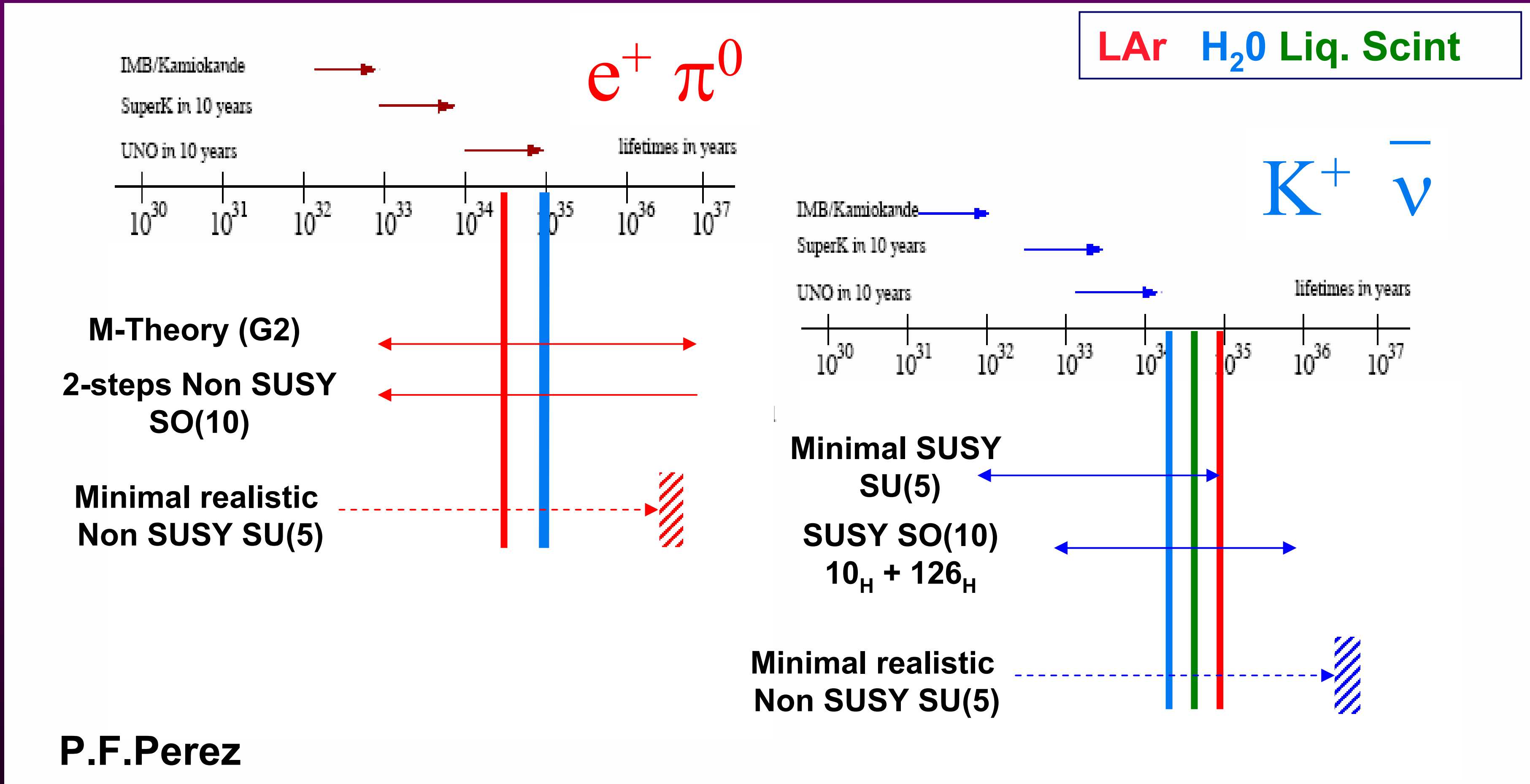
236MeV/c



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

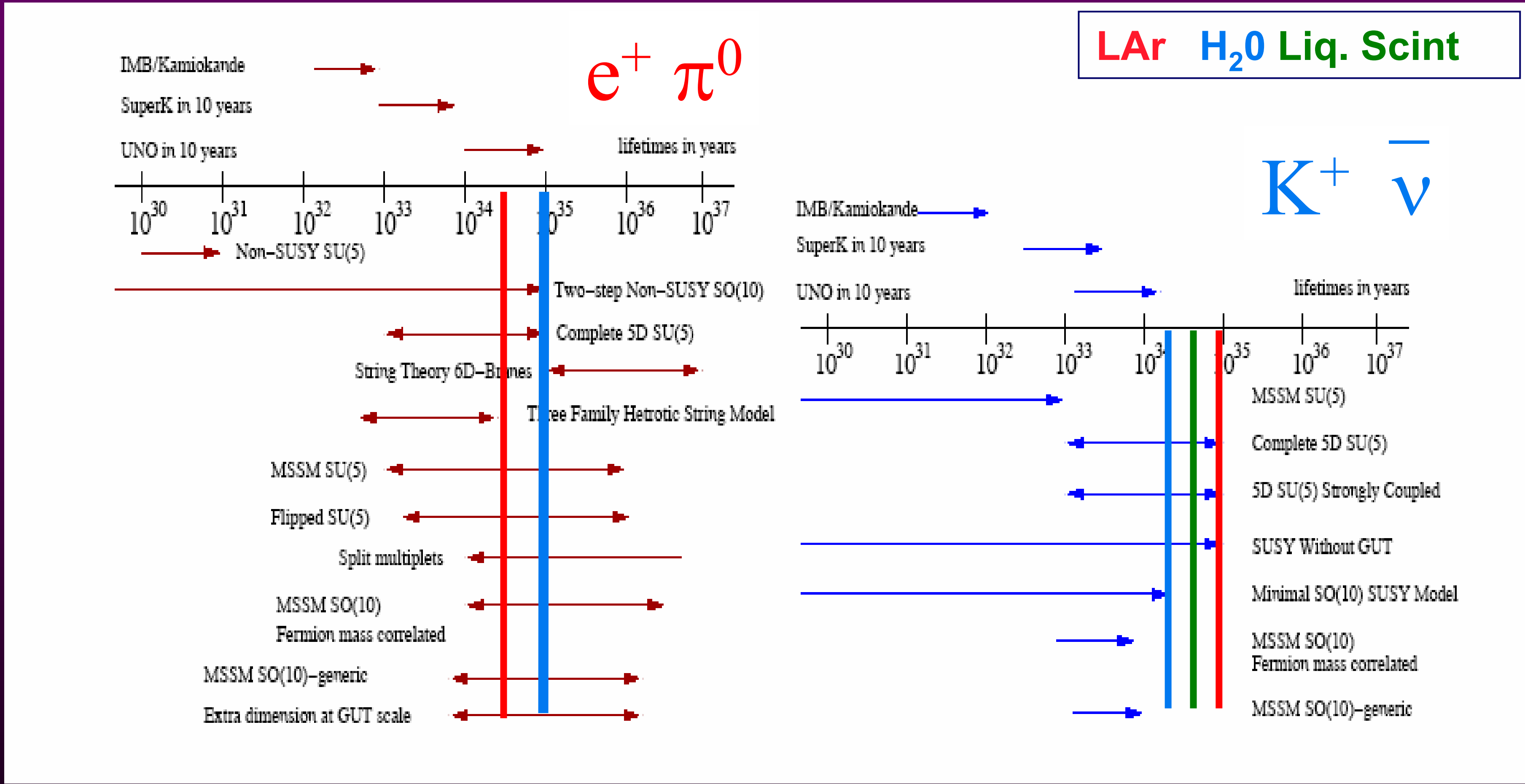
Back to back
205MeV/c each

Résumé proton decay



Definitively not exhaustive neither p channels nor n decay…

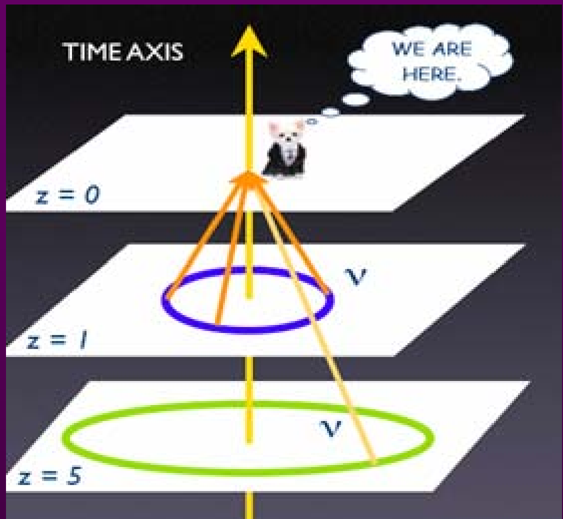
Résumé proton decay

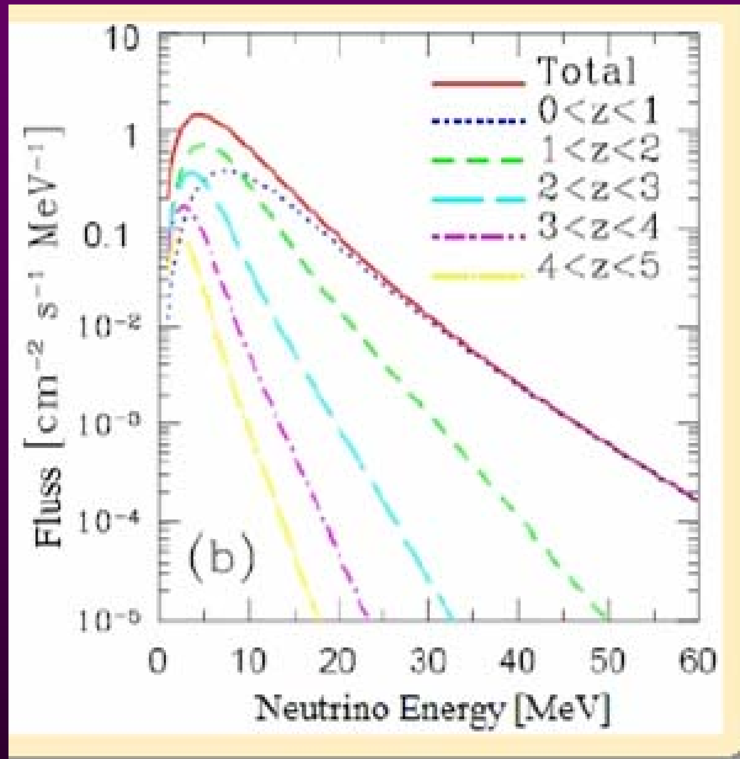


Higher dimension models (eg. 6D SO(10)) not included

Definitively not exhaustive neither p channels nor n decay…

Les traces* de SN



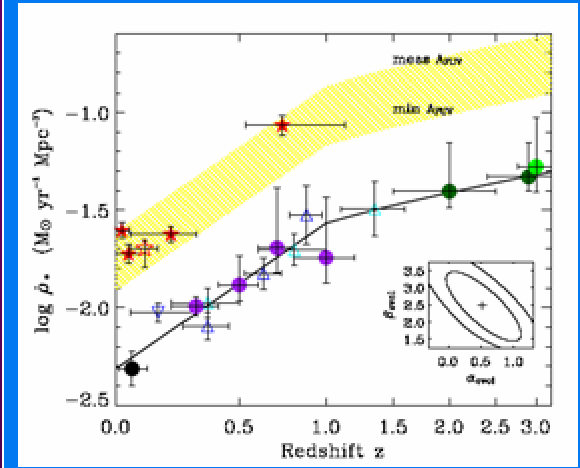


Détection de ν avec z ≲ 1

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

***:Diffuse/Relic Supernova Neutrinos (DSN)**

Limite actuelle ~ détection?



Formation Etoile

GALEX

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

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

Astrophys.J. 619 (2005) L47

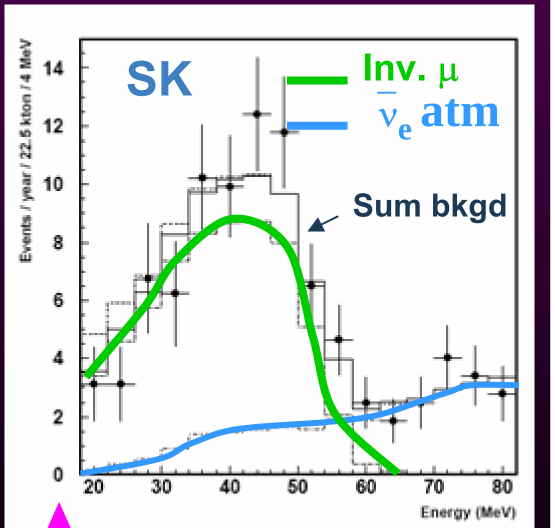
Supernova

$$\frac{dN_\nu}{dE_\nu} \propto \frac{E_\nu^2}{\exp(E_\nu/T_\nu - \eta)+1},$$
$$T_{\nu_e} = 3\text{ MeV},$$
$$T_{\bar{\nu}_e} = 5\text{ MeV},$$
$$T_{\nu_x} = 8\text{ MeV}$$

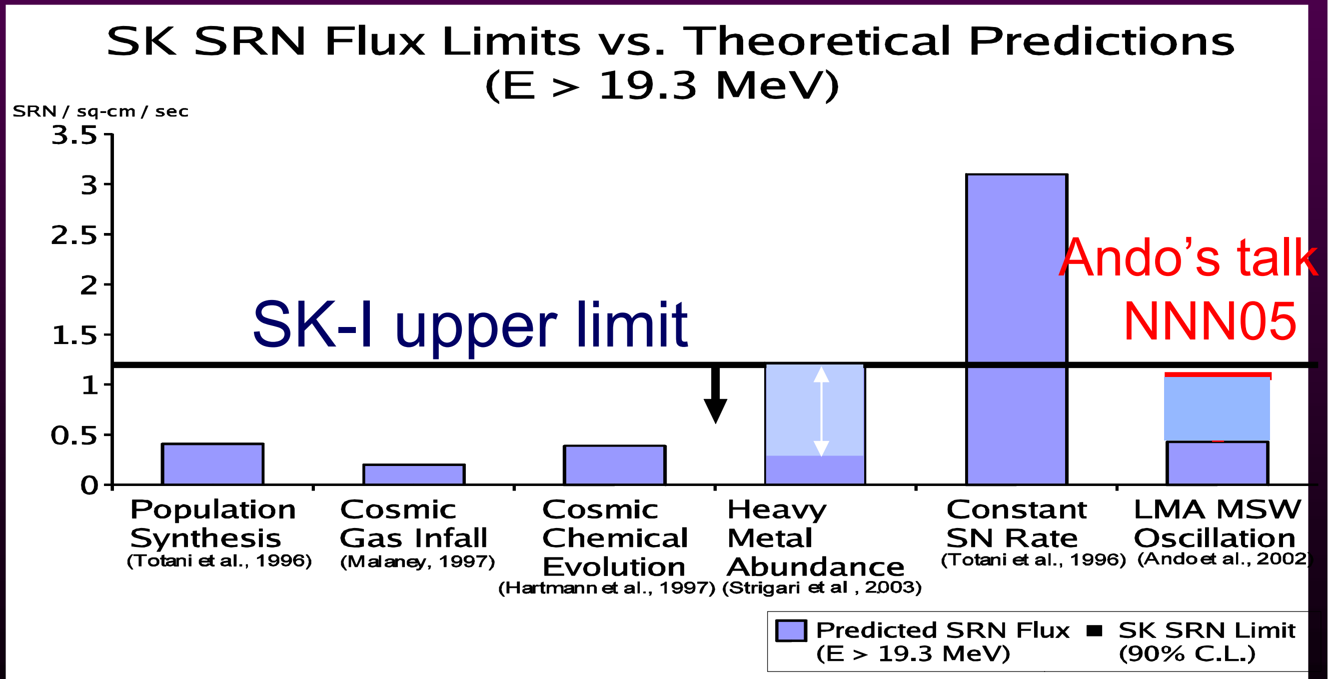
E_ν > 11.3 MeV	E_ν > 19.3MeV
5.1 $cm^{-2}s^{-1}$	1.2 $cm^{-2}s^{-1}$

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

Phys. Rev. Lett 90, 061101 (2003)



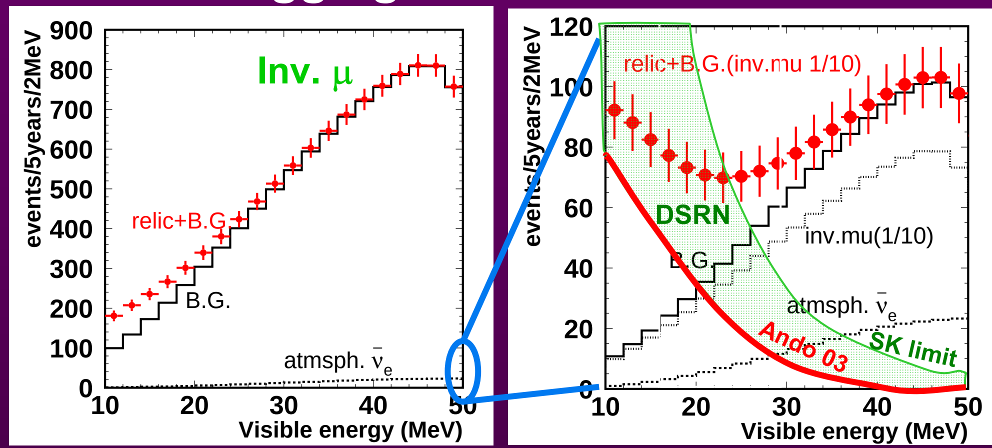
Réacteur + Sun



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

$\bar{\nu}_e$

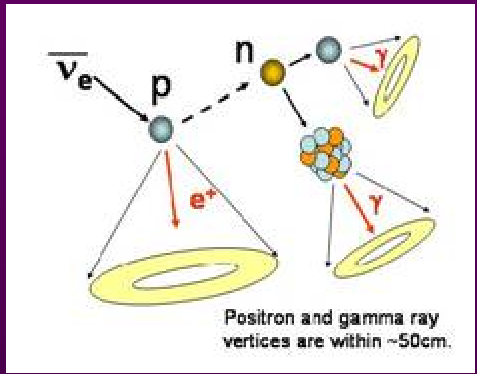
No n-tagging — **With n-tagging**



Nakahata+Vagins @ NNN05

H_2O + neutron capture

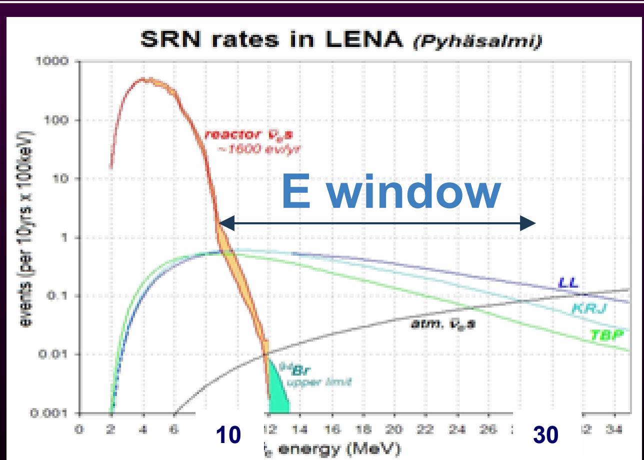
30% PMT coverage



ΔT(p: 2MeV γ) = ~ 200 μs

ΔT(**Gd**: 8MeV γ) = few 10th μs

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

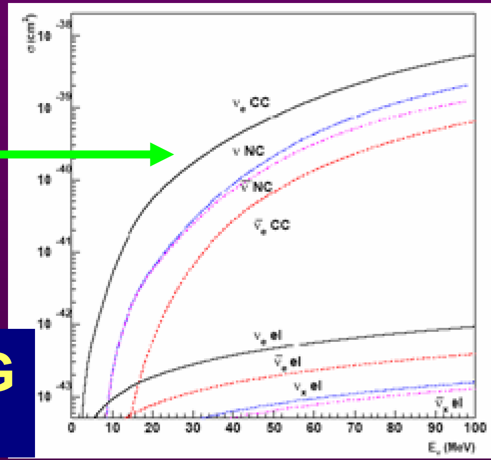
~ (40 – 260*)Sig / 20 BG

***: at SK limit**

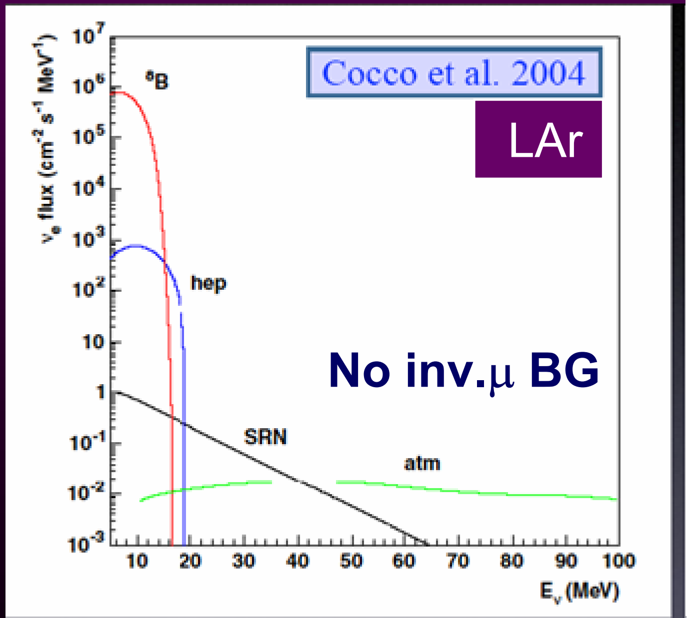
Futur: $\bar{\nu}_e$ et ν_e complémentarité

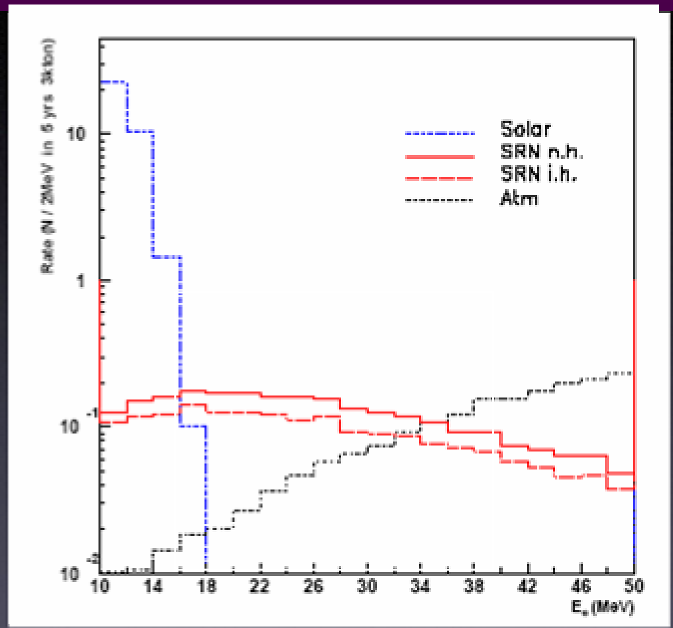
ν_e

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



GLACIER 5yrs (500kT.y) [16-40] MeV: 57* Sig / 26BG
(Cocco et al. JCAP 0412 (2004) 002)

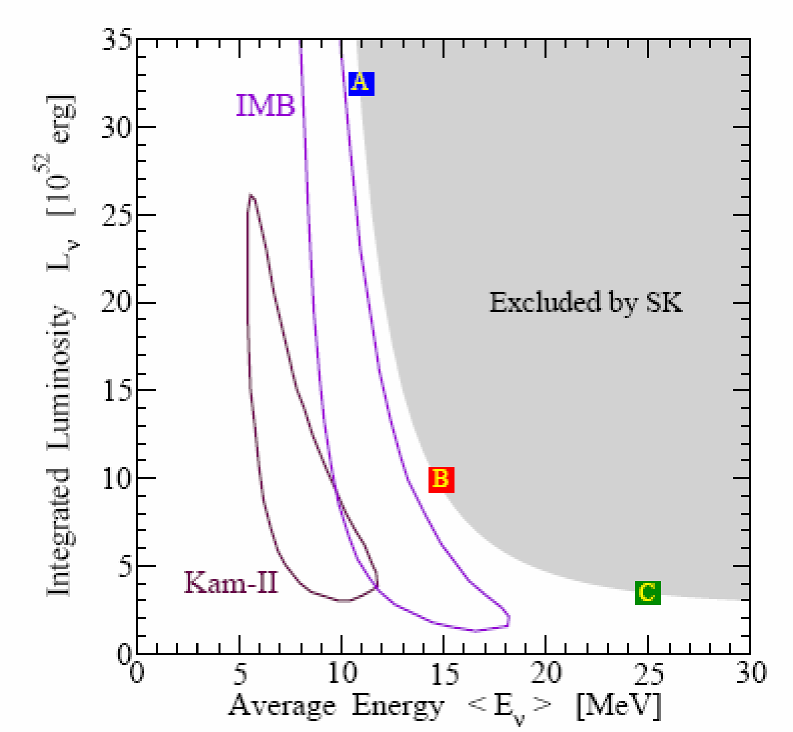




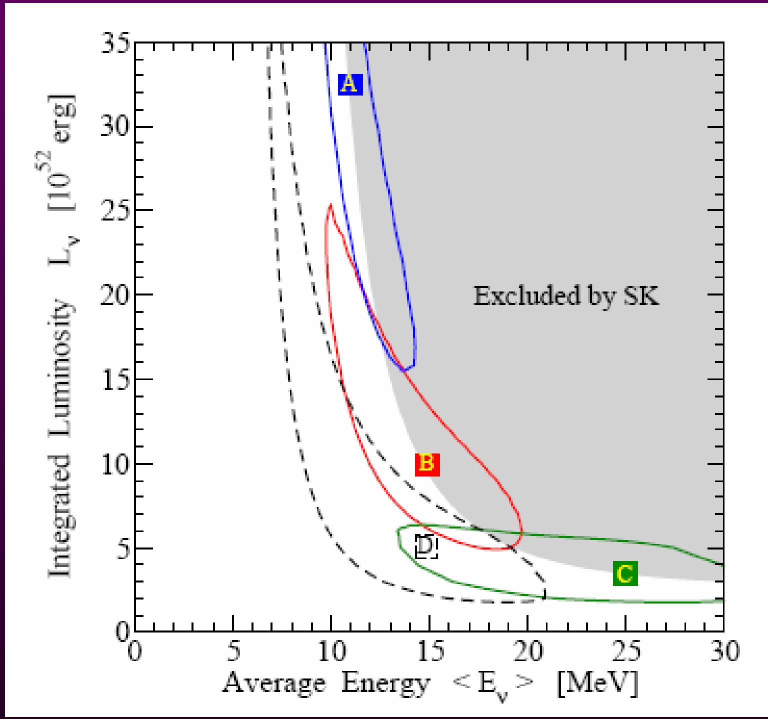
*: at SK limit

Mesure des paramètres d'émission de ν par les SN

SN 1987A (KAM-II,IMB)
DSN (SK)



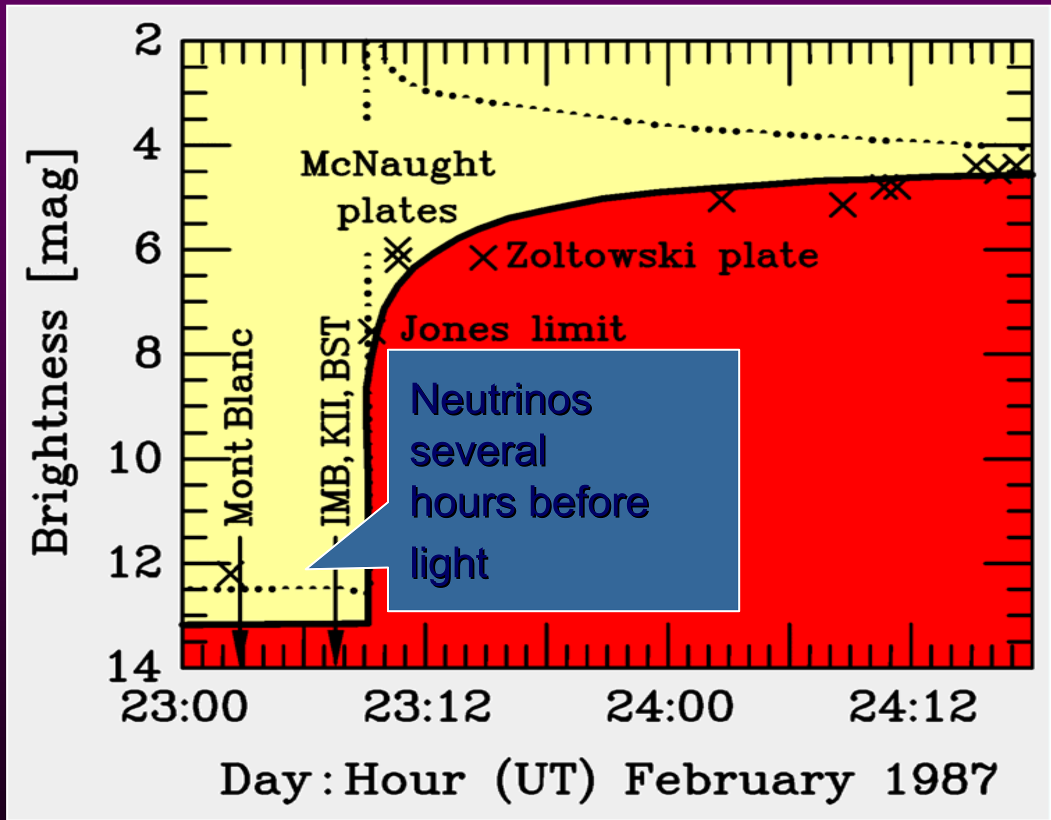
DSN
5yrs SK-Gd
⇔1yr MEMPHYS-1shaft-Gd



Yukse, Ando Beacom astro-ph/0509297

Explosion de SN II

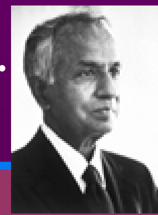
Early lightcurve of SN1987A



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.



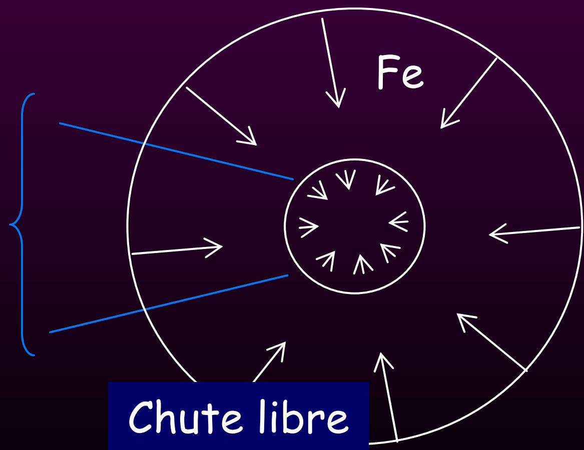
S. Chandraskhar
Nobel 83

1. Arrêt de la fusion dans le cœur de Fer (stable)
2. Collapse car $M_{fer} > M_{Ch} = 1,4 M_\odot$, $P_{gravit.} > P_{th} + P_{pauli}$
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: $p(noyau) + e^- \rightarrow n + \nu_e$ $(T \sim 10^{11} K)$

Première bouffée avant que le cœur devienne opaque.

$\rho \nearrow 4\ 10^{11}$ kg/cm^3
densité nucléaire

Étoile à Neutrons
R ~ 100km → 30km



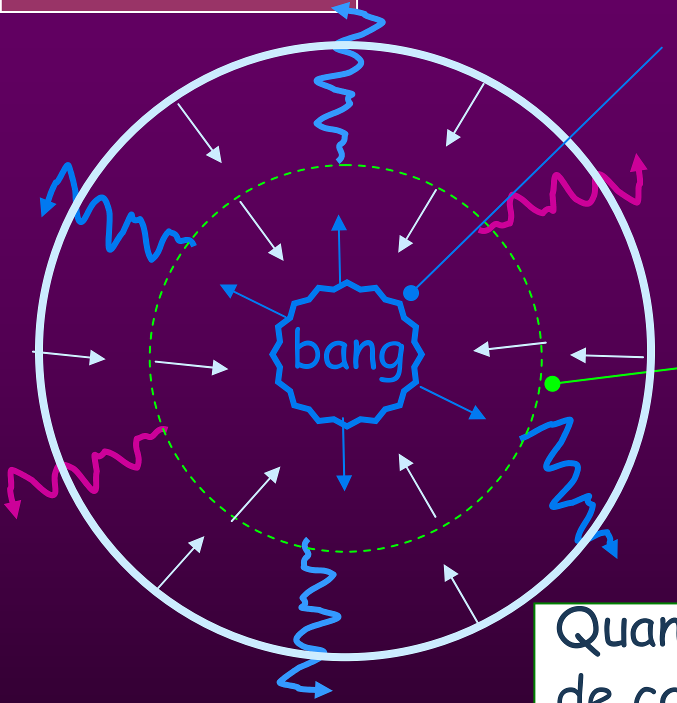
Si $M_c > 5\ M_\odot \Rightarrow$ trou noir

$\Delta t \sim 1/10$ 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) $\rho_{piège}$ > 5 10^8 kg/cm^3 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 ($\rho < \rho_{piège}$), c'est la deuxième bouffée en Δt ~ 10ms.

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

γ + 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

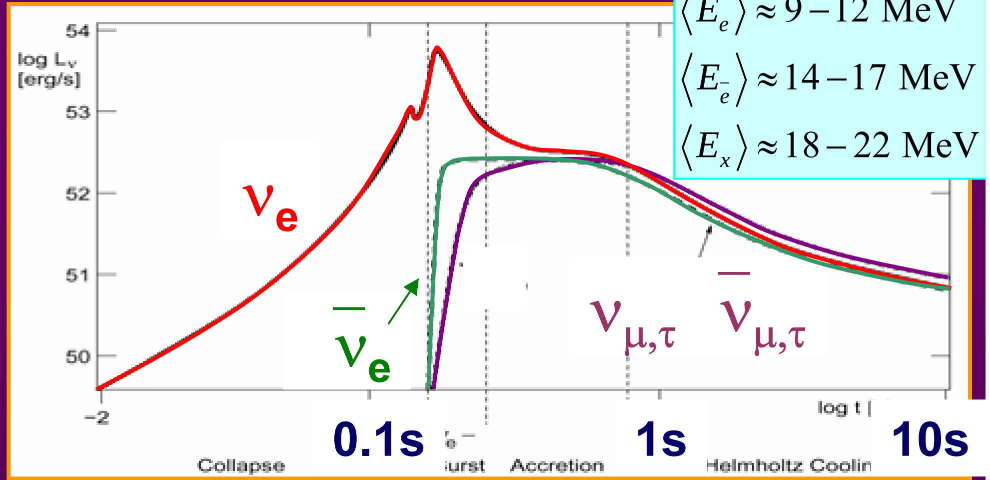
Mixture of initial fluxes:

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

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

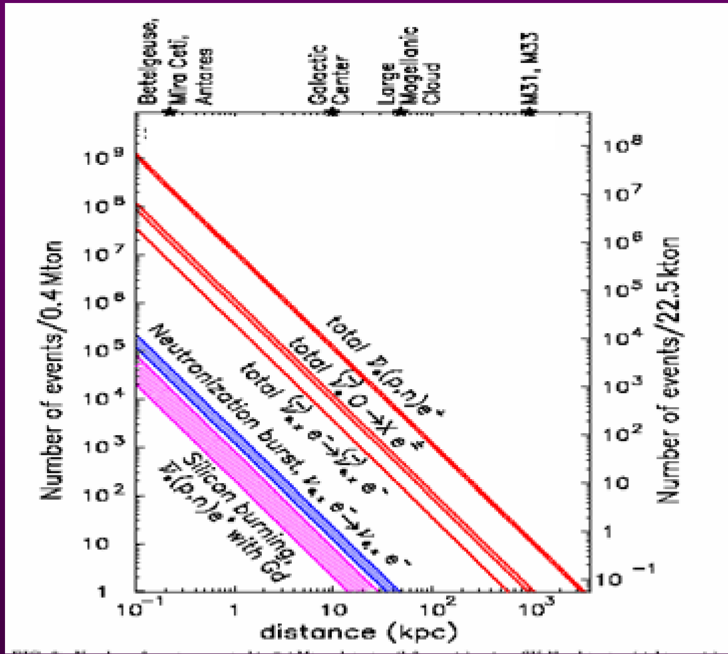
$\langle E_{\bar e}\rangle \approx 14-17$ MeV

$\langle E_{x}\rangle \approx 18-22$ 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

$\times 10^3$

H_20



LENA

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

10kpc

GLACIER

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

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 $\bar{\nu}_e$

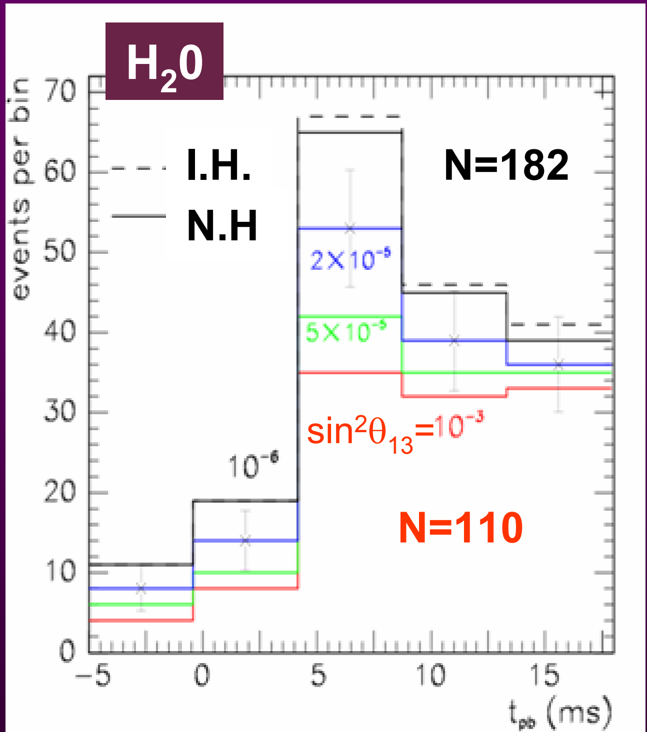
A. Mirizzi @ LPNHE 17/2/06

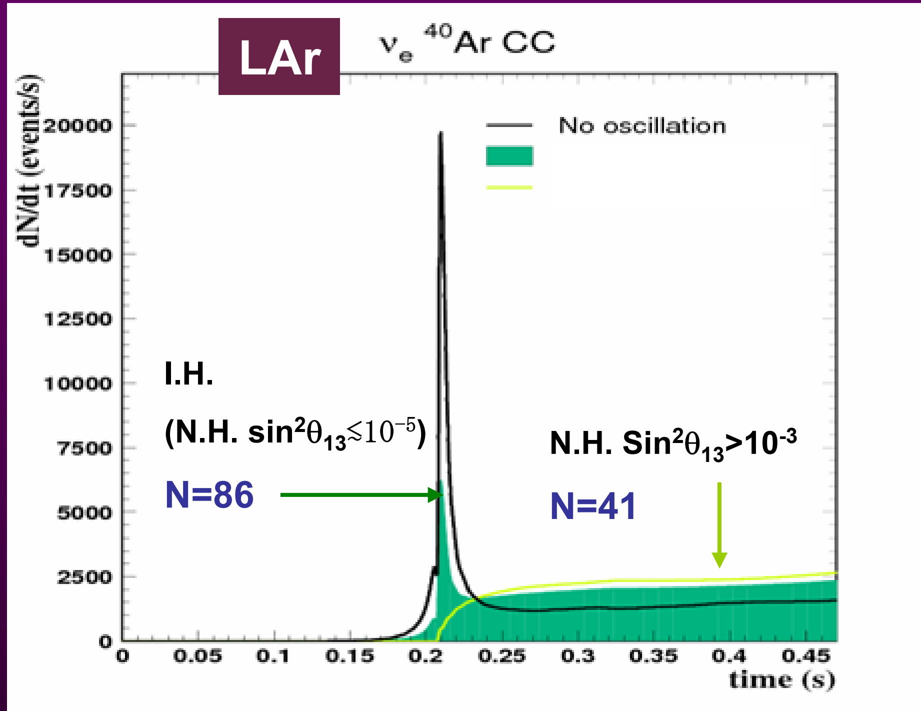
Exploiting these complementary signatures one could extract useful information on the neutrino mass hierarchy and on θ_{13}

($\nu_{\mu\tau}$ + 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)

$\nu_e\, Ar \rightarrow e^- K^*$ (CC) + NC

Possibility to probe non standard physics

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

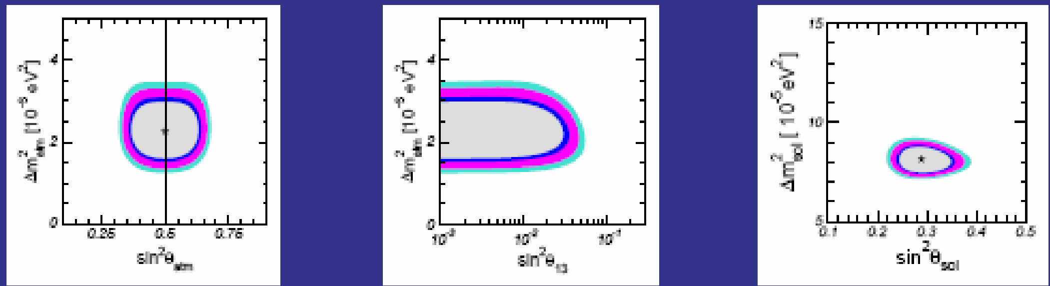
Neutrino Decay [S.Ando, hep-ph/0405200]

→ **Possibility to look for non standard $\bar{\nu}_e$ fraction (H_2O)**

Oscillations terrestres...

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

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

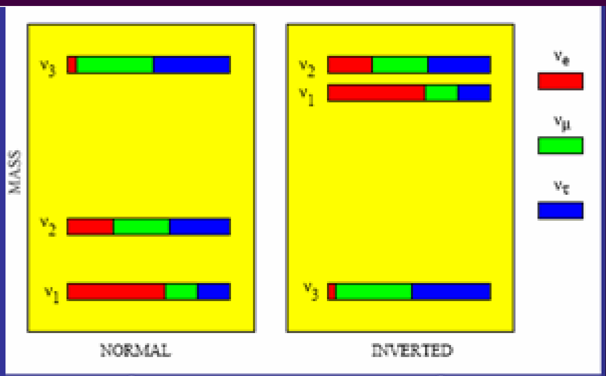


atmospheric + K2K — CHOOZ — solar + KamLAND

		1σ
$\sin^2\theta_{12}$	$0.31^{+0.02}_{-0.03}$	9%
$\sin^2\theta_{23}$	$0.50^{+0.06}_{-0.05}$	11%

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

Échelle de masse



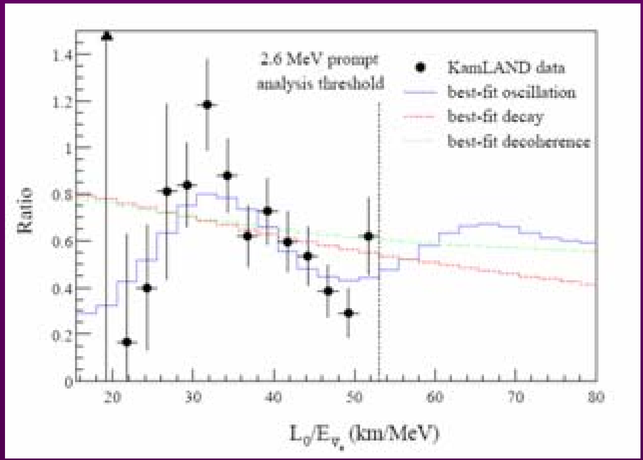
$\Delta m^2_{31} > 0$ — $\Delta m^2_{31} < 0$

Octant de θ_{23}

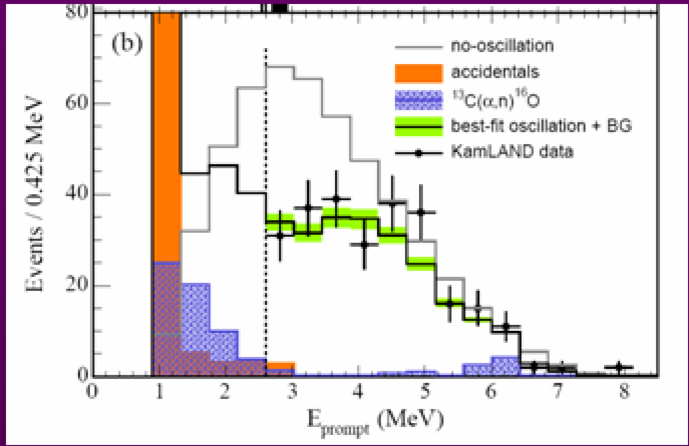
θ_{13} ?

δ_{CP}

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



KamLAND



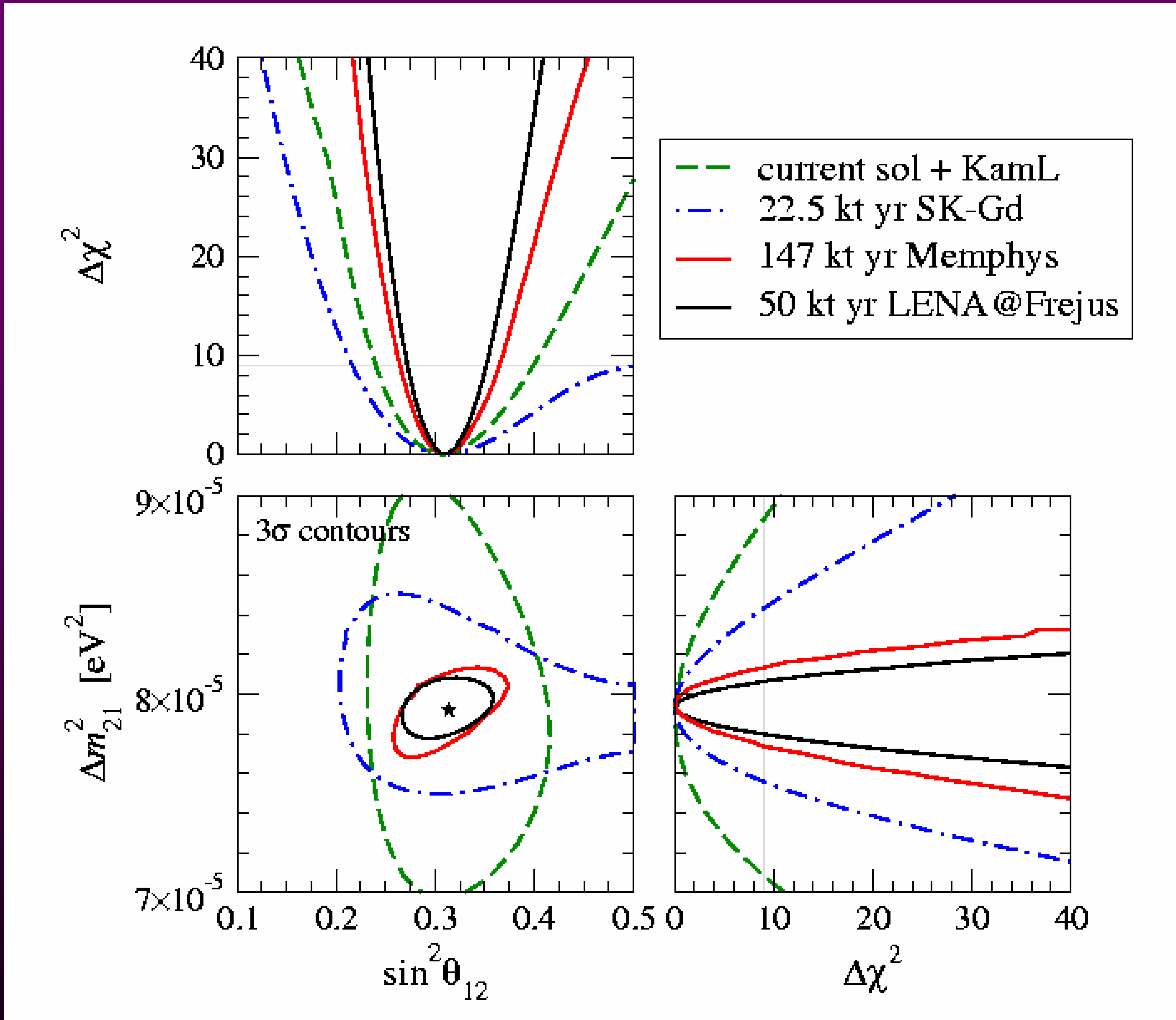
0.77kT.y

Réacteurs ν

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

99% CL Data set	range $\Delta m^2_{21}/10^{-5}$eV^2	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



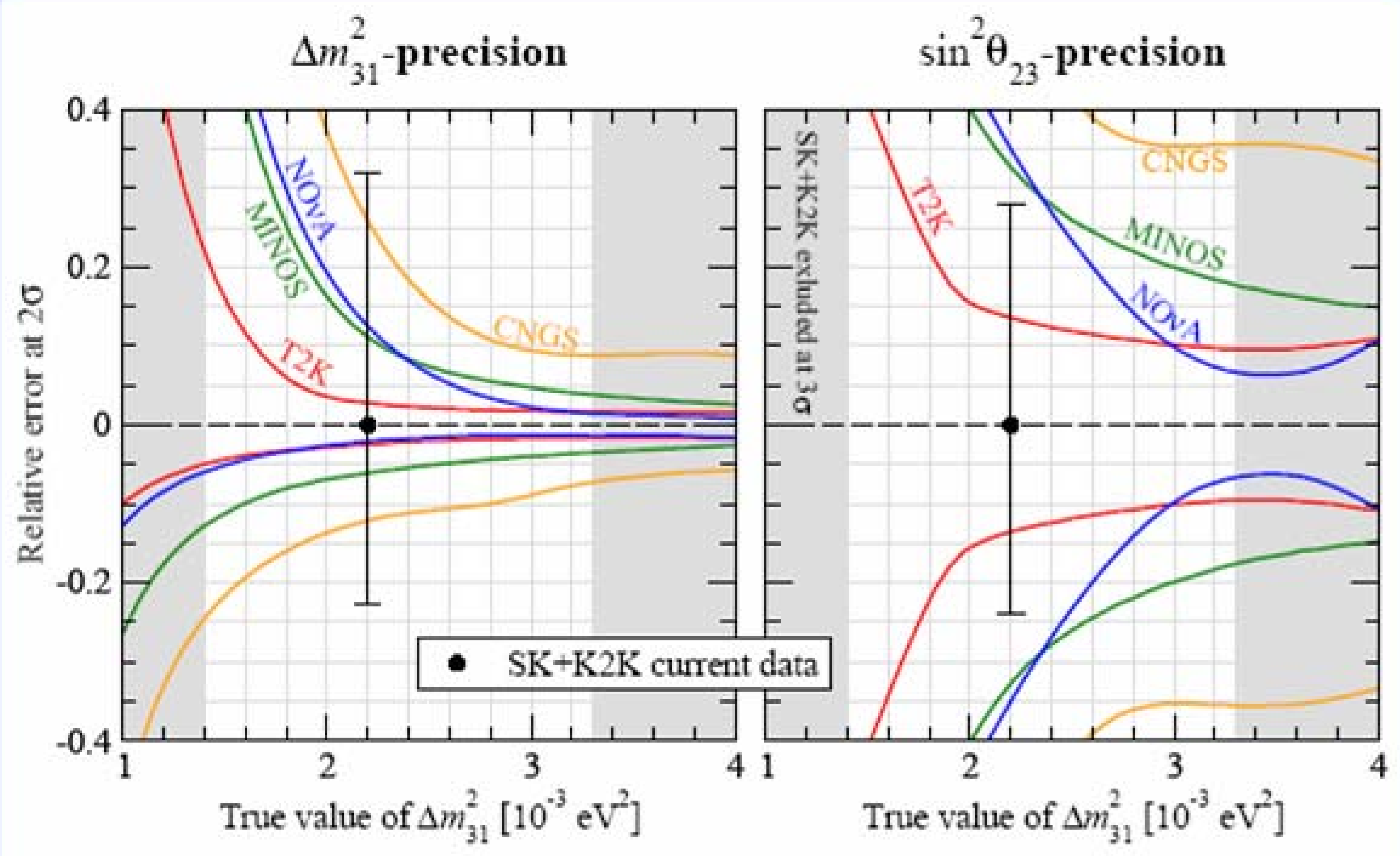
$$\langle \frac{P}{L^2} \rangle = 3.28\, MW/km^2$$

$$\langle L \frac{P}{L^2} \rangle / \langle \frac{P}{L^2} \rangle = 296\, km$$

$\Delta\theta_{12}$=3° (99%CL)

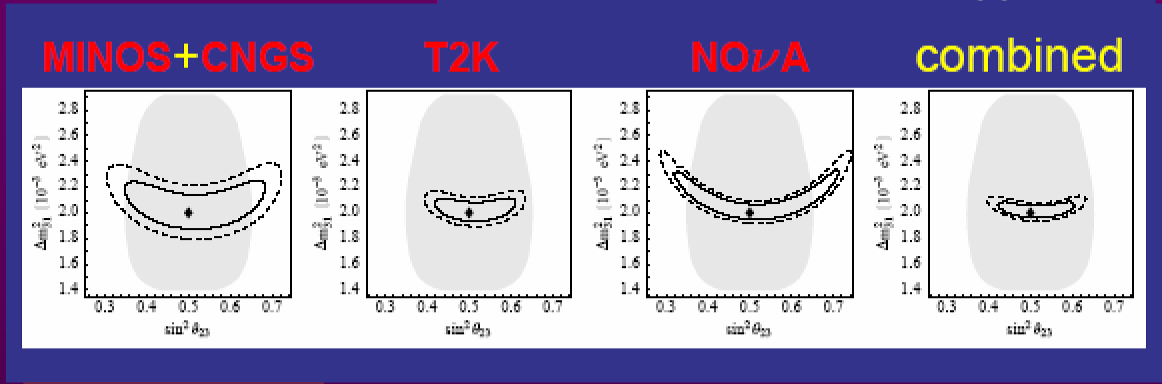
VERY PRELIMINARY

Atmospheric parameters $|\Delta m^2_{13}|$ *and* θ_{23}

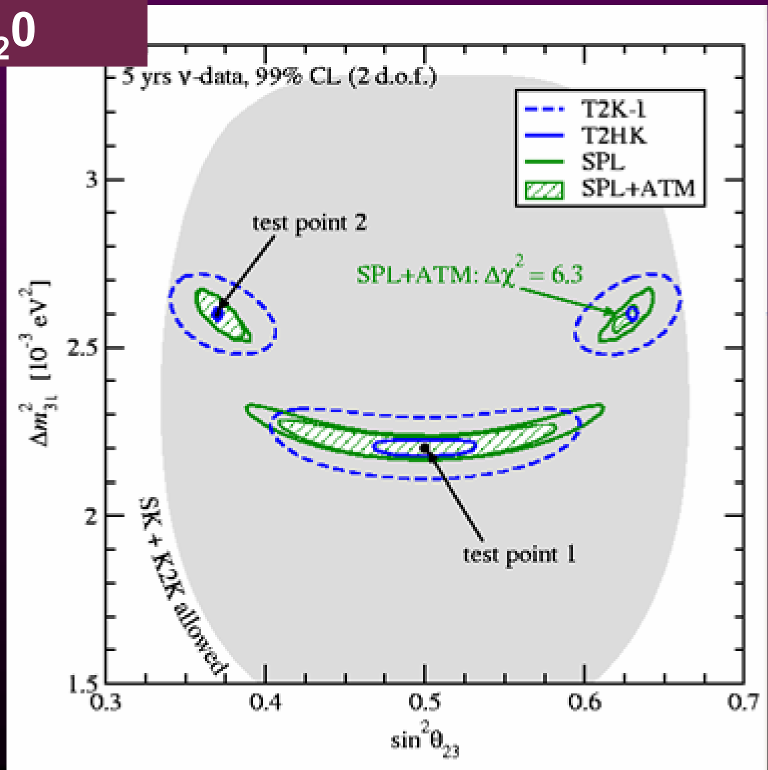


$|\Delta m^2_{31}|$ et $\sin^2\theta_{23}$ *« paramètres atmosphériques »*

Huber, Lindner, Rolinec, Schwetz, Winter, hep-ph/0403068



H_20

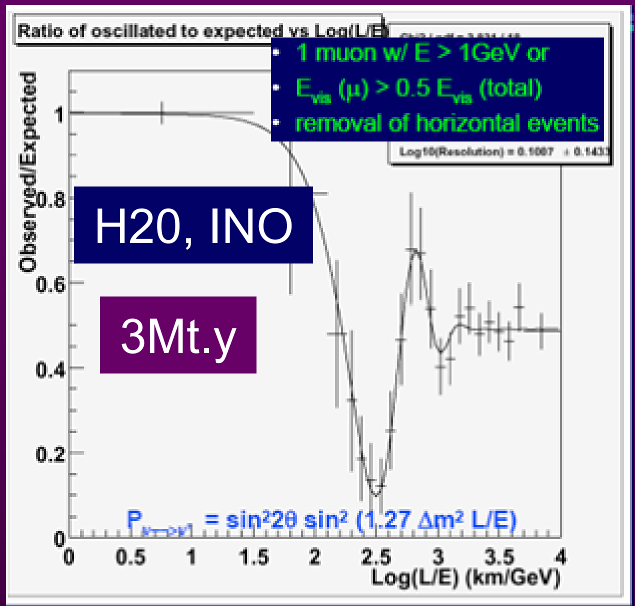


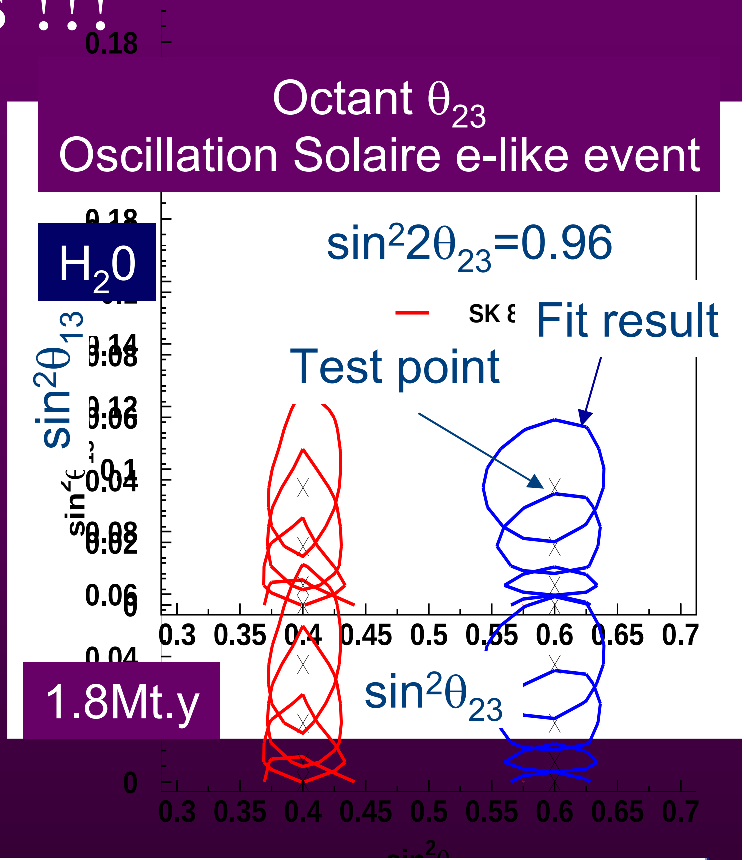
Ère de la précision !

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

JECampagne, M. Maltoni, M.Mezzetto, Th. Schwetz
hep-ph/0603172

Propriété ν avec des ATM-ν seuls !!!

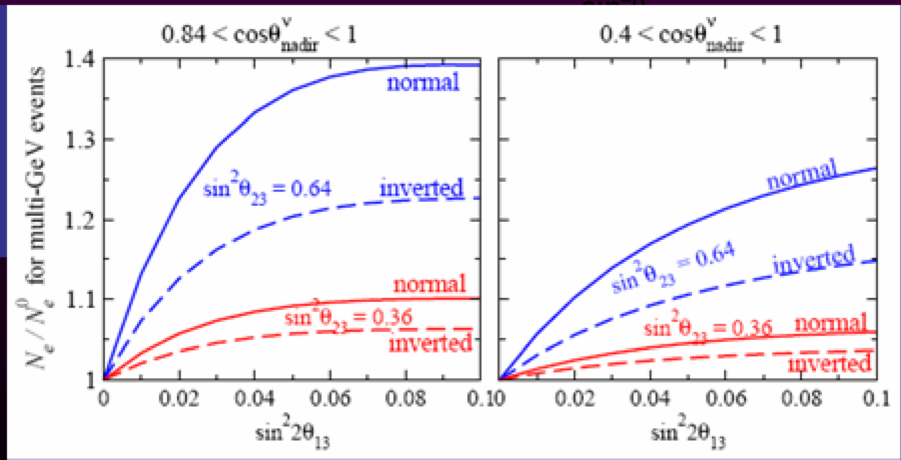




$$\frac{N_e}{N_e^0} - 1 \simeq (r\, s_{23}^2 - 1)\, P_{2\nu}(\Delta m_{31}^2, \theta_{13})$$

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)

1st 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 —— $\theta_{13} < 3^0$

$\theta_{13} > 3^0$	$\theta_{13} < 3^0$
• 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

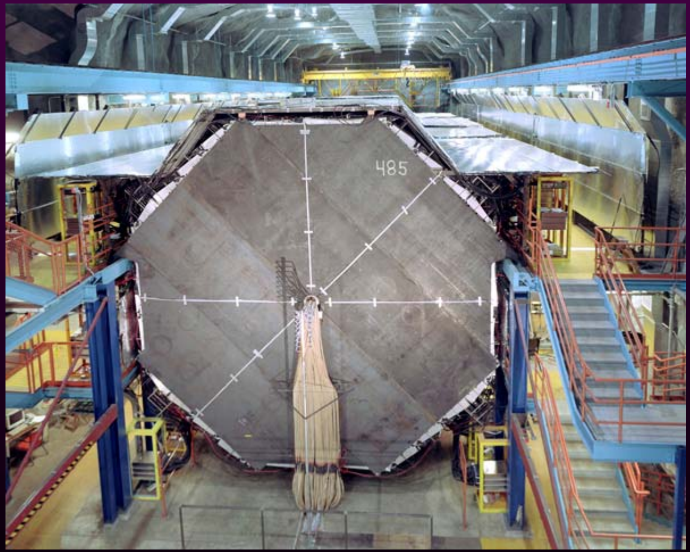
Present era

NUMI beam: MINOS (2005)

Magnetised iron calorimeter

CNGS beam: OPERA (2006)

Hybrid emulsion detector



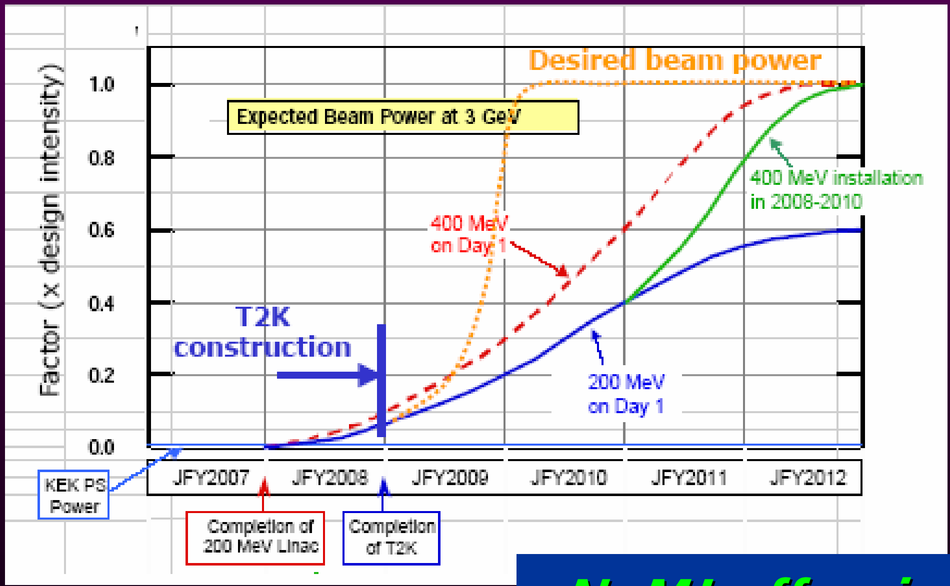
CNGS 31 janvier 06

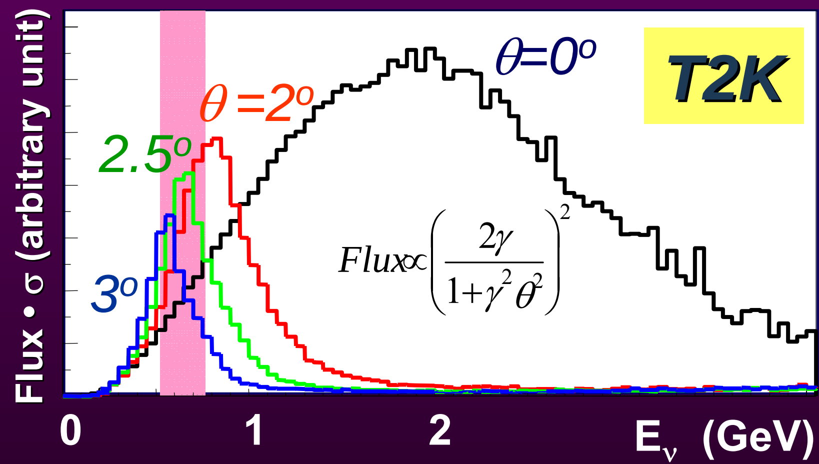
Introduction du Réflecteur sur la ligne

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

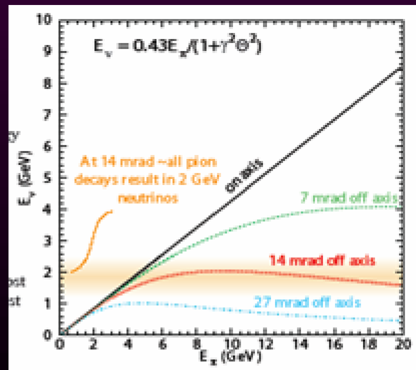
Conventional ν_μ beams from pion decay
Increased proton beam power: 0.4 →0.8 MW
Off-axis technique: narrow band beam with purer composition
Tune L/E to the oscillation maximum (L/E~ 500 Km/GeV)

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

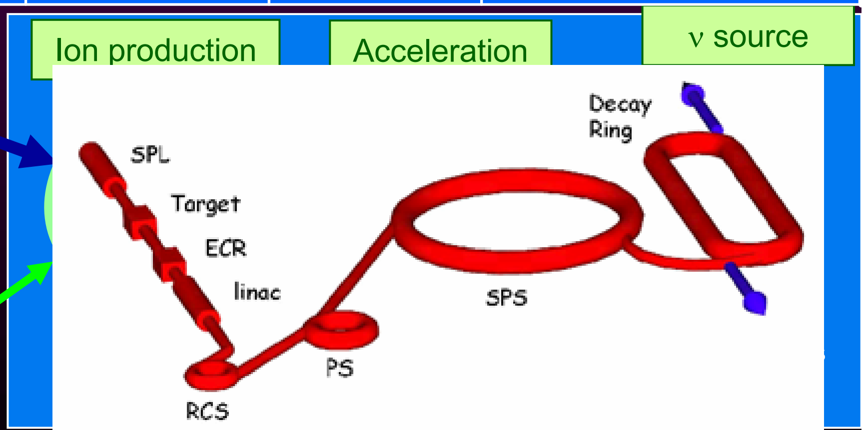
EURISOL design study

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*

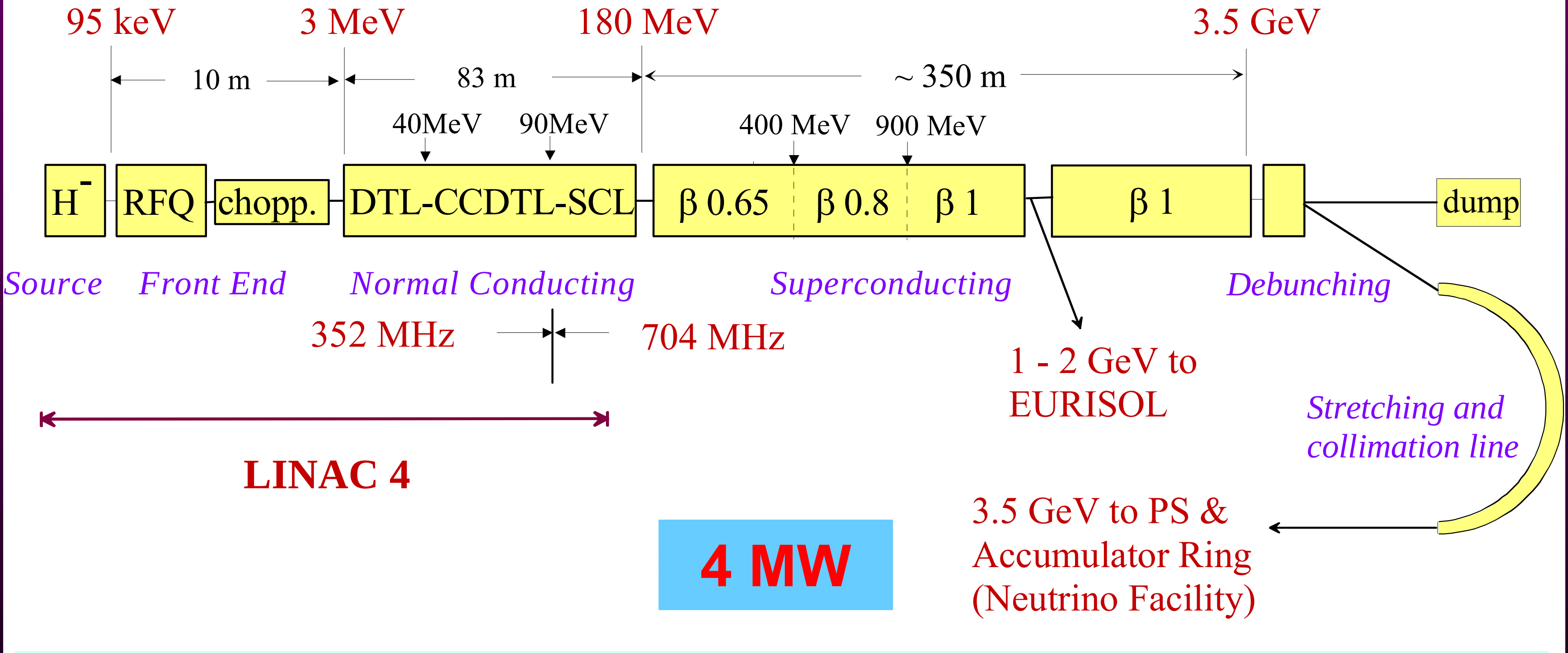


SPL current design

SPL main goals:

- increase the performance of the CERN high energy accelerators (PS, SPS & LHC)

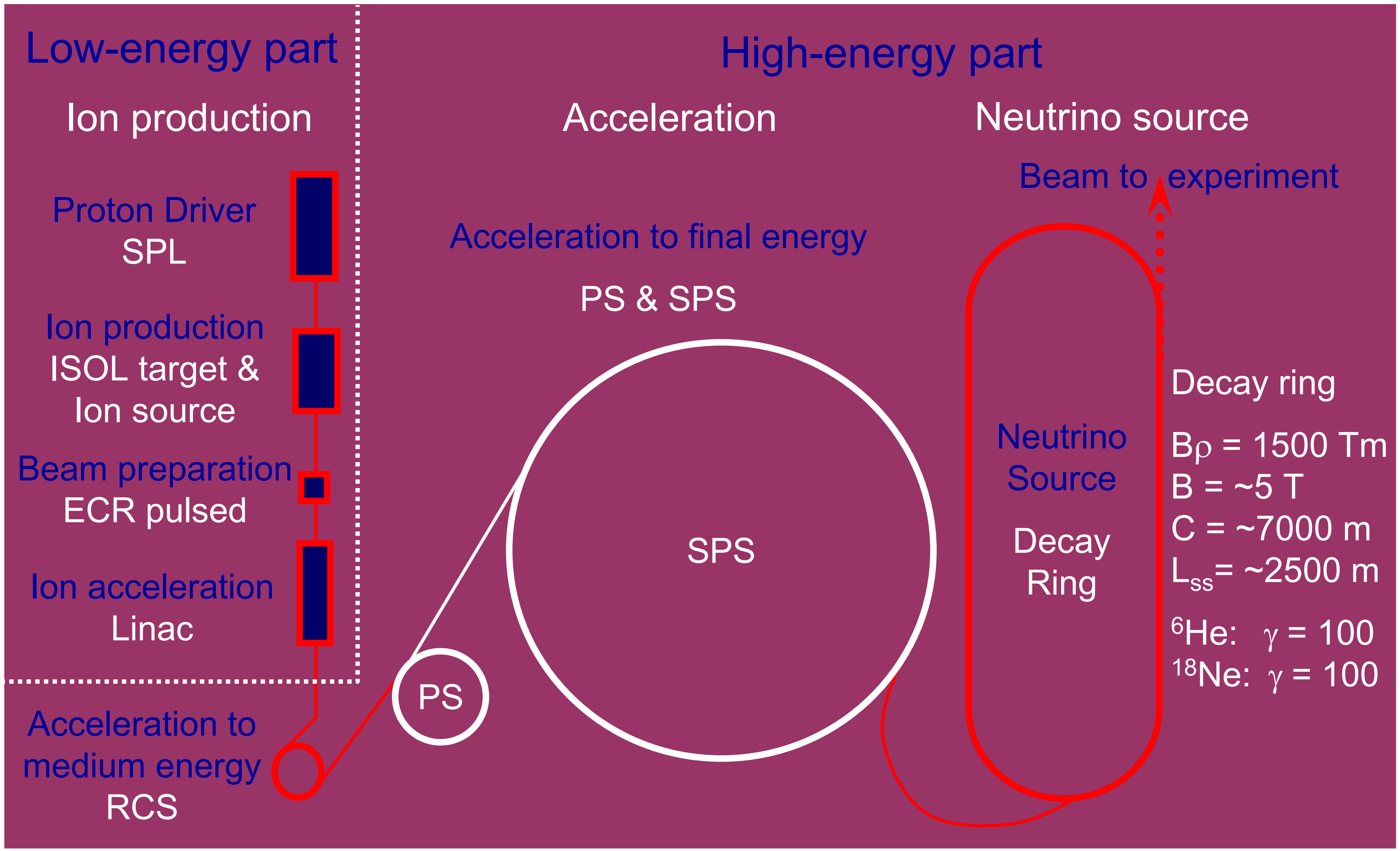
- address the needs of future experiments with neutrinos and radio-active ion beams



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

From R.Garoby

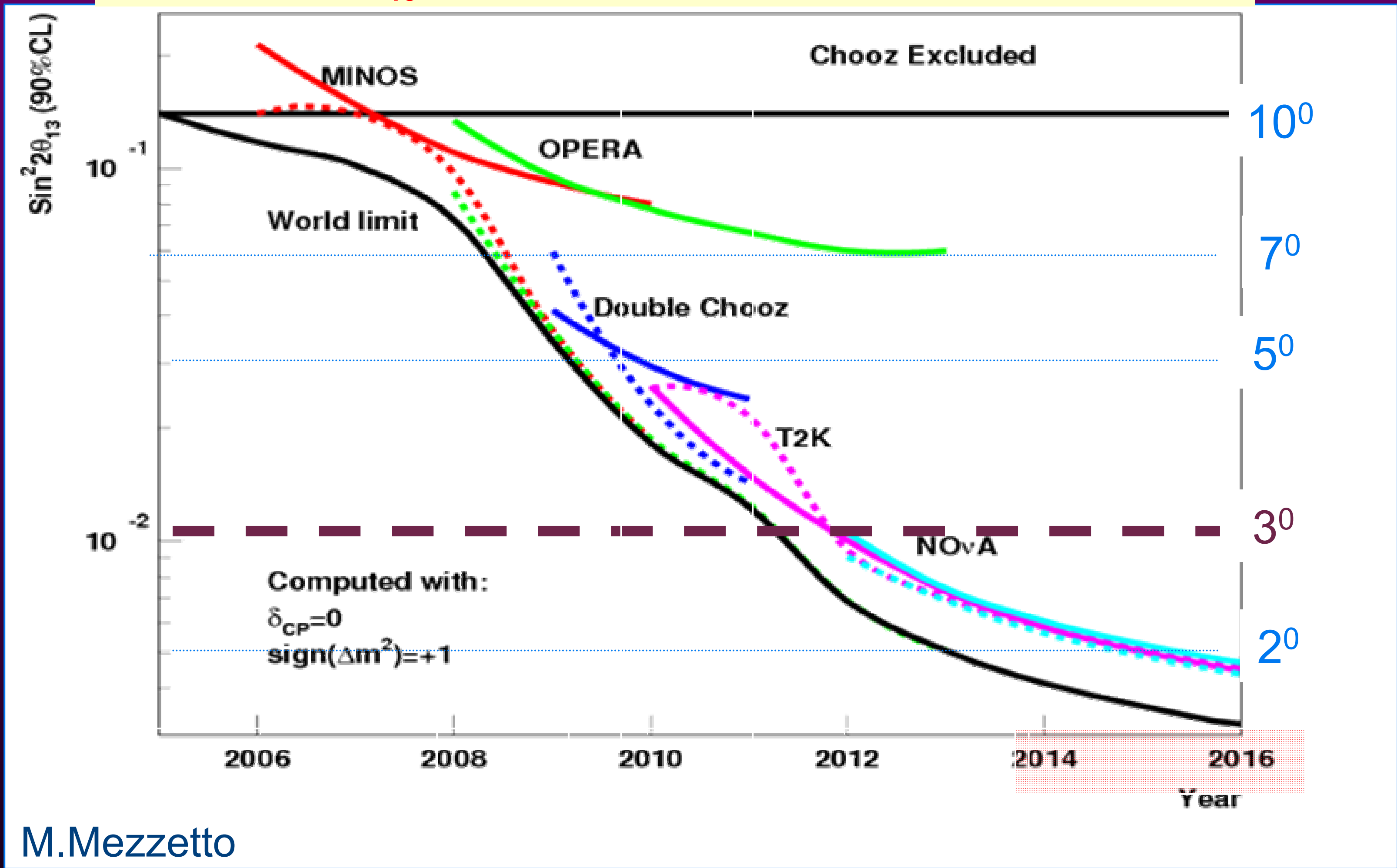
Beta-beam baseline design



M.Benedikt CERN-ISS22/9/2005

θ_{13} : évolution de la sensibilité

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



Limit of the exp.

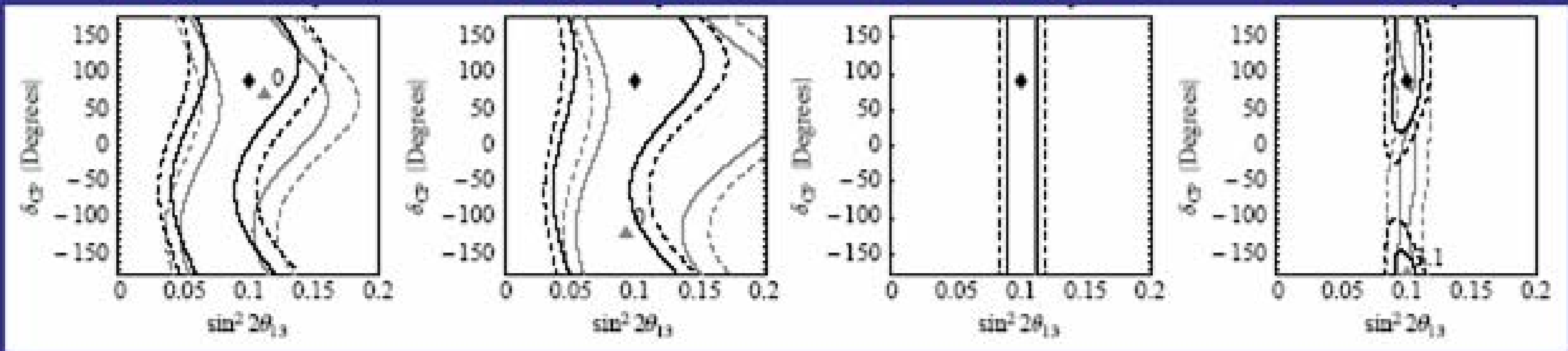
Word Limit wo the exp.

Peu de sensibilté à ~~CP~~

CP-phase and hierarchy within ten years

assume $\sin^2 2\theta_{13} = 0.1$

T2K NOνA Reactor-II combined



Huber, Lindner, Rolinec, Schwetz, Winter, hep-ph/0403068

Le CERN est à 130km de Modane…

Super Beam + β Beam + MEMPHYS

2 beams

1 detector

SUPERBEAM

4 ν flavours + K

$2\rightarrow5$yrs $\nu_\mu \rightarrow \nu_e$

π^+/π^-

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

BETABEAM

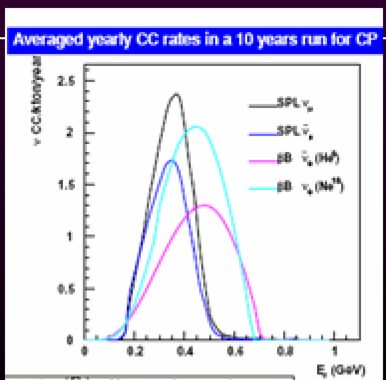
pure

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

^{18}Nd

^{6}He

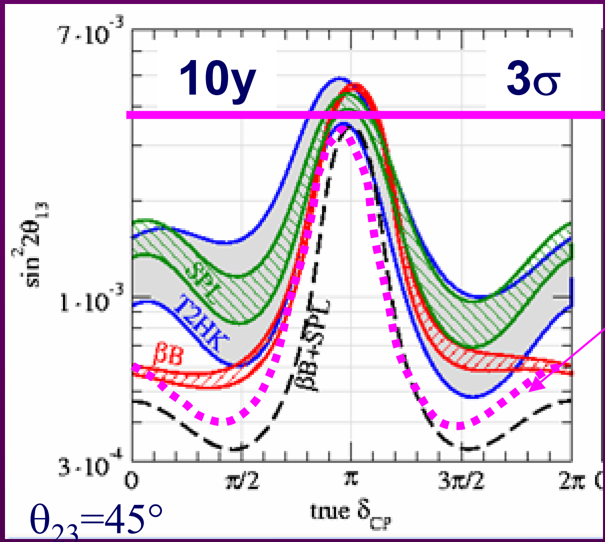
$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ 5yrs



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

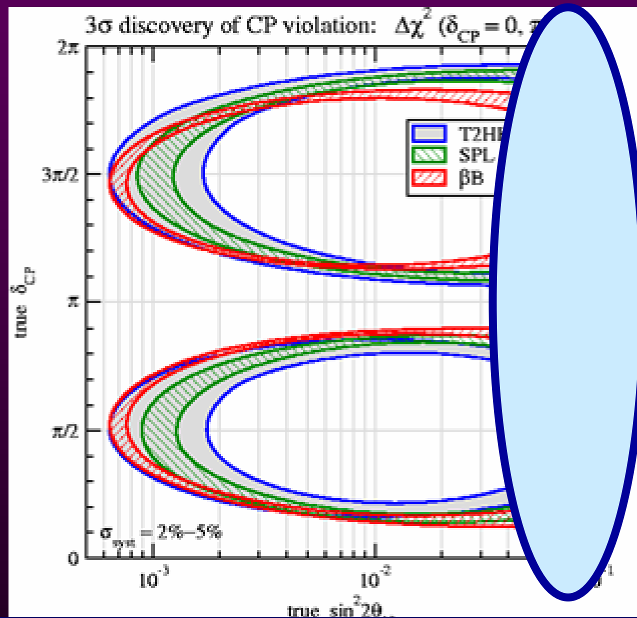


$\sin^2 2\theta_{13} < 4\ 10^{-3}$ en 10 ans

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

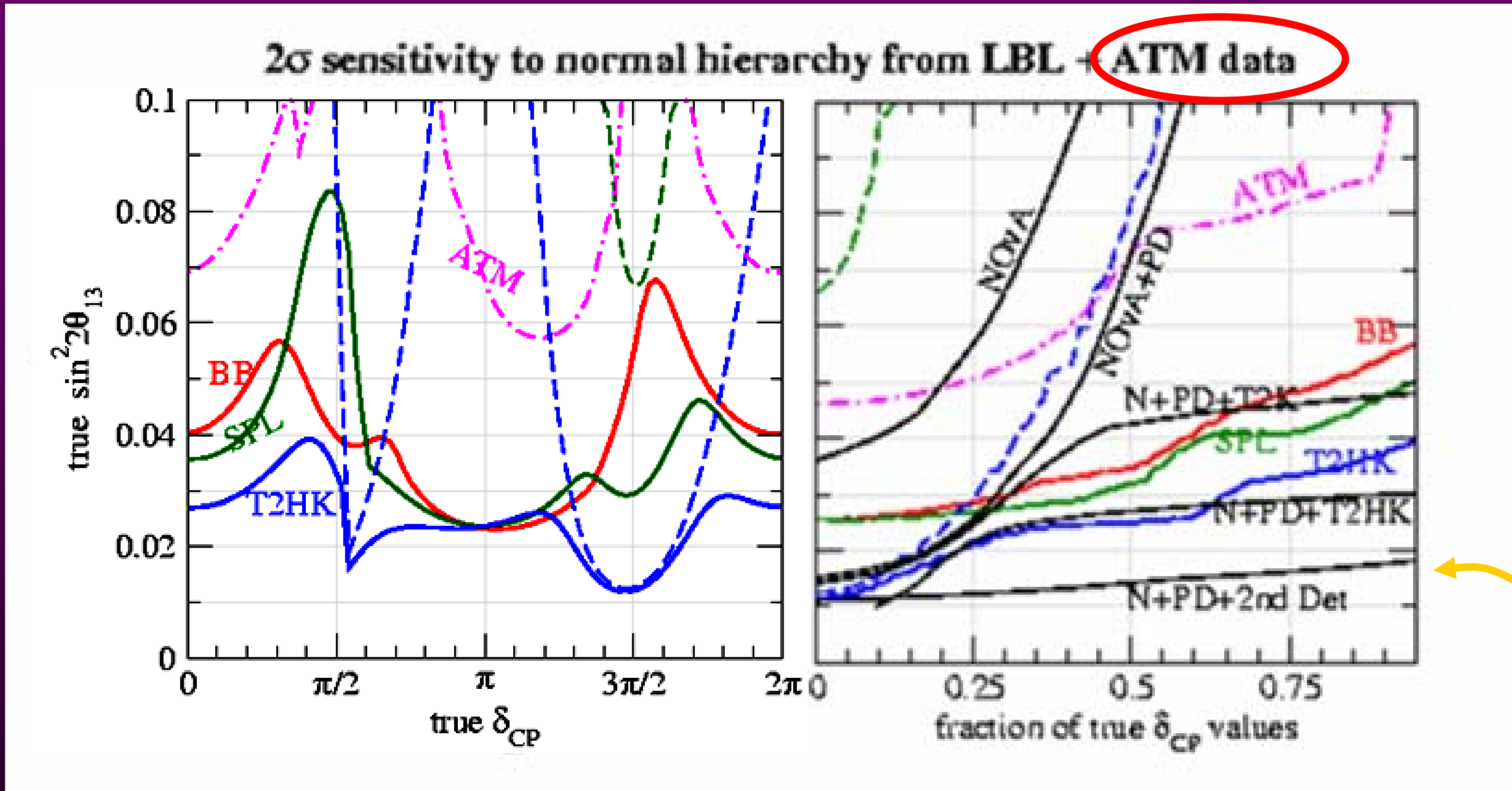
Les systématiques dominent
SB: connaissance du faisceau
SB et BB: x-section, eff./Bgd
(NF: effet de matière, eff./Bgd)

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

JECampagne, M. Maltoni, M.Mezzetto, Th. Schwetz hep-ph/0603172

Hiérarchie de masse: usage des ATMν

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

JECampagne, M. Maltoni, M.Mezzetto, Th. Schwetz hep-ph/0603172

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:

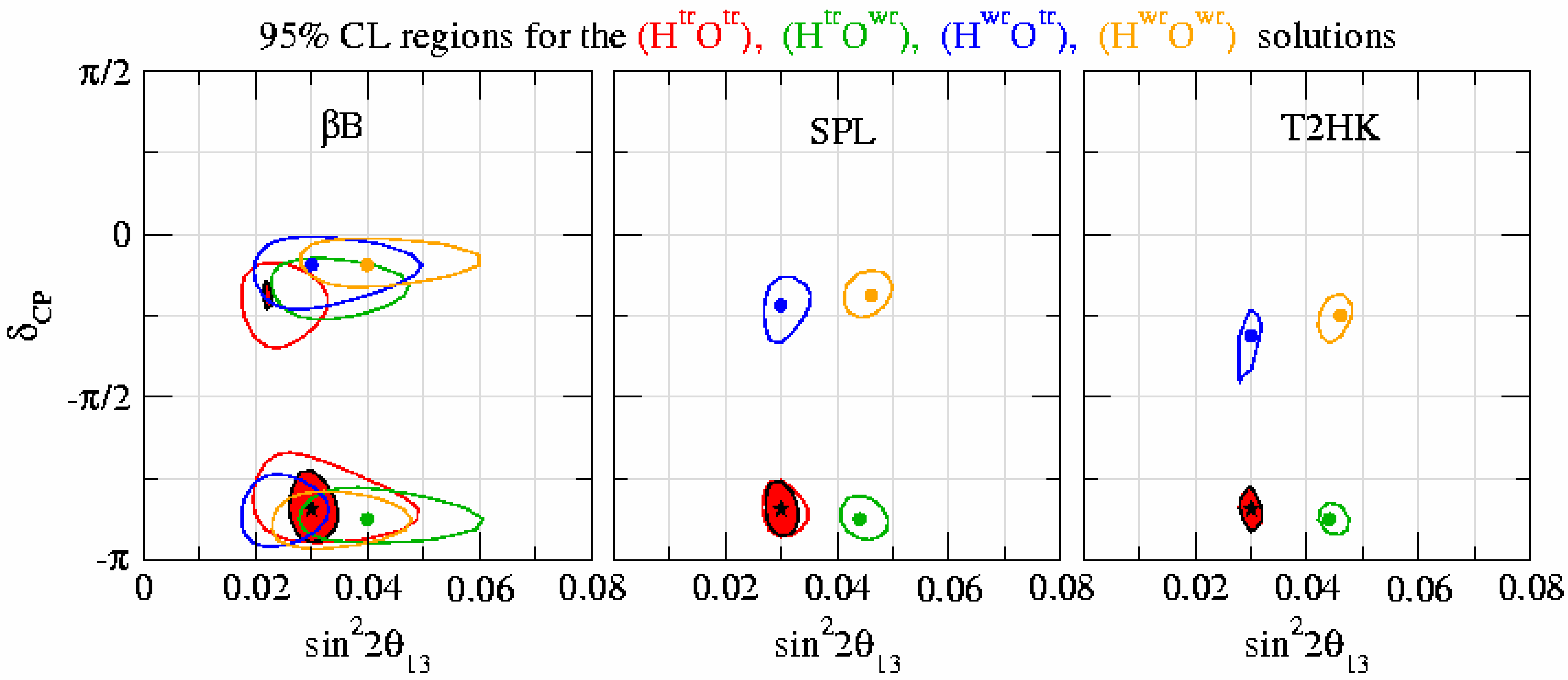
- combining information from detectors at different baselines and/or energies
  e.g., second osc. maximum, different off-axis angle
- using additional oscillation chanels ($\nu_e \rightarrow \nu_\tau$)
- spectral information (broadband beam)
- adding information on θ_{13} from a reactor experiment
-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

Th. Schwetz

H_20 + ATM

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

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



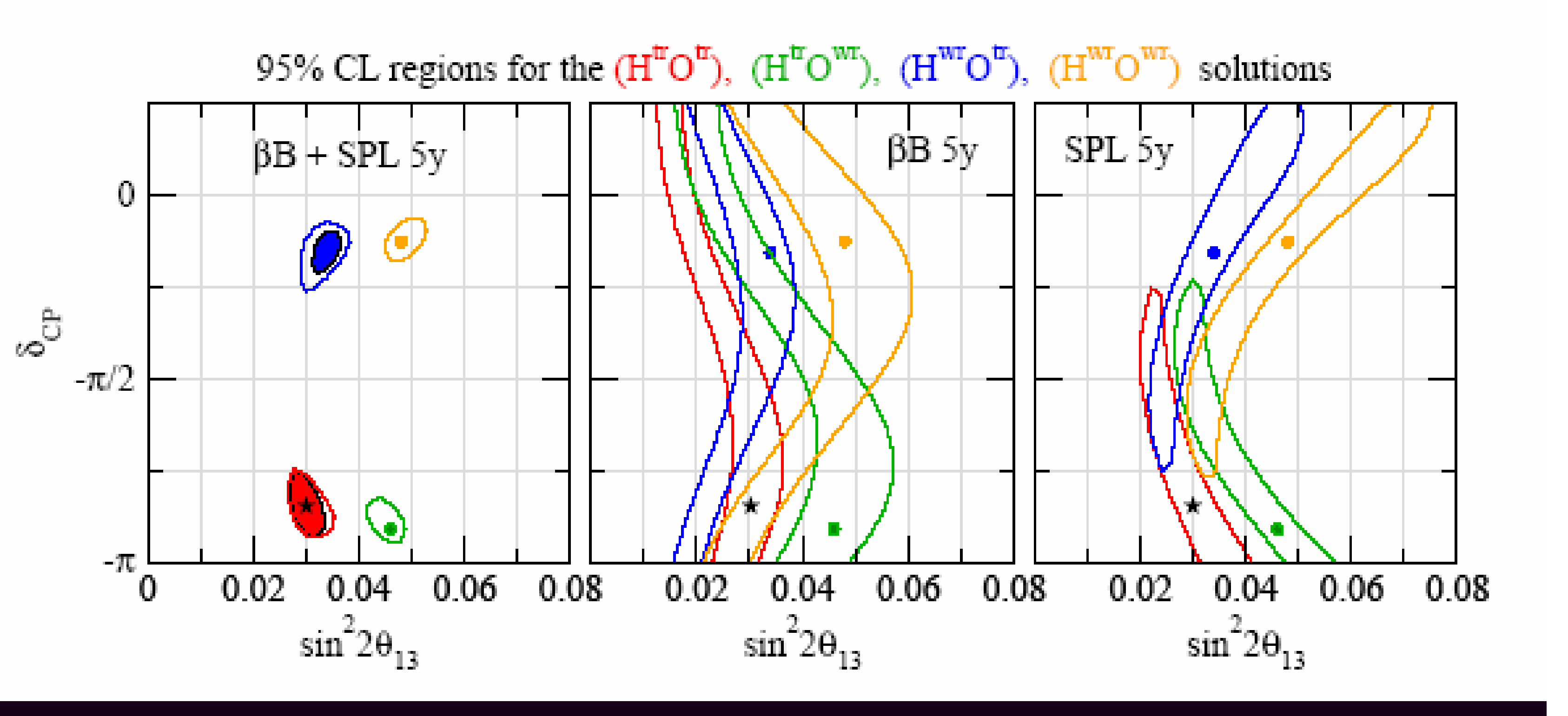
BB: 5+5y
SPL: 2+8y
T2HK: 2+8y
all: 440kT fid. mass

ATM can solve degeneracies!!!

JECampagne, M. Maltoni, M.Mezzetto, Th. Schwetz hep-ph/0603172

Autre façon de résoudre les ambiguités

BB: 5y (ν_e)
SPL: 5y (ν_μ)
ATM: 5y
MEMPHYS 440kT fid. mass

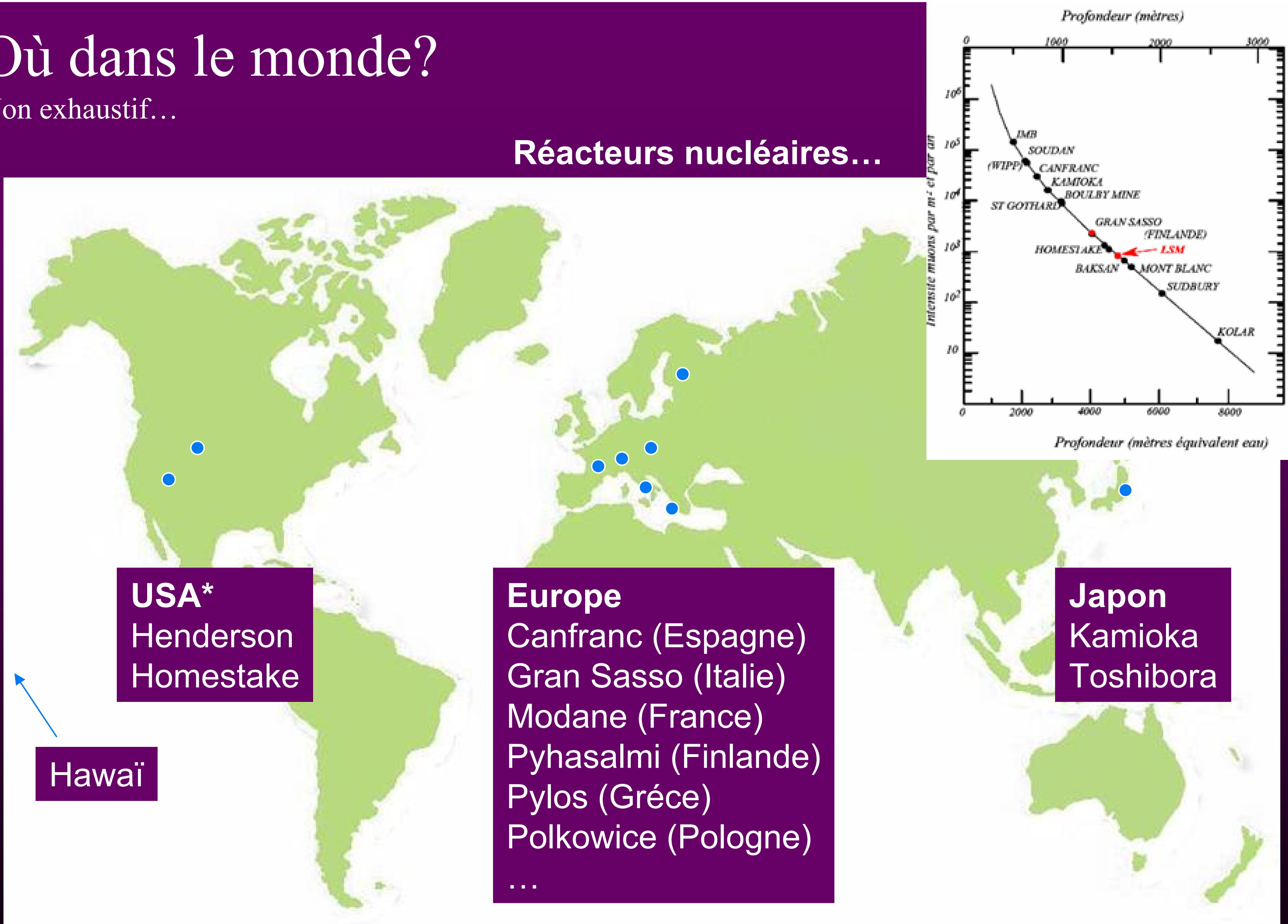


Still a wrong hierarchy clone with χ^2=3.3

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

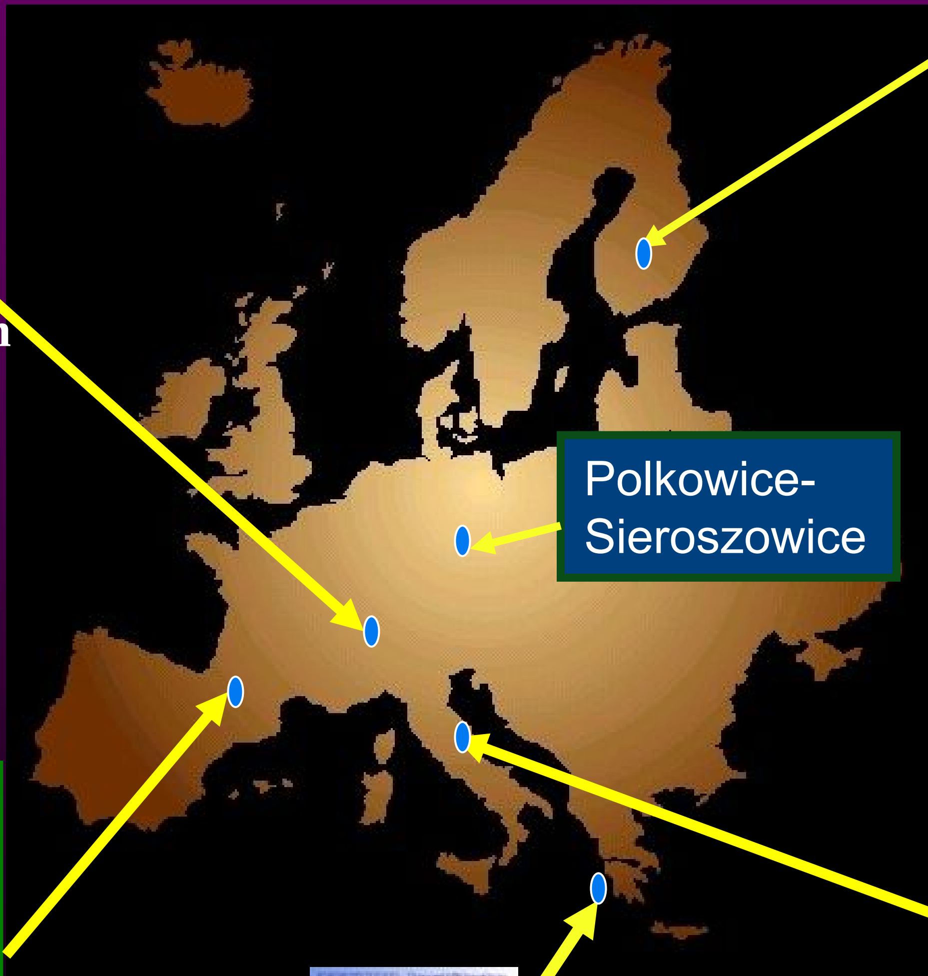
(N2) Deep Underground science laboratories

(JRA1) Low background techniques underground

(TA1) Access to the EU Deep Laboratories

CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE

Laboratoire Souterrain de Modane, France



LNGS

Laboratori Nazionali del Gran Sasso, Italy

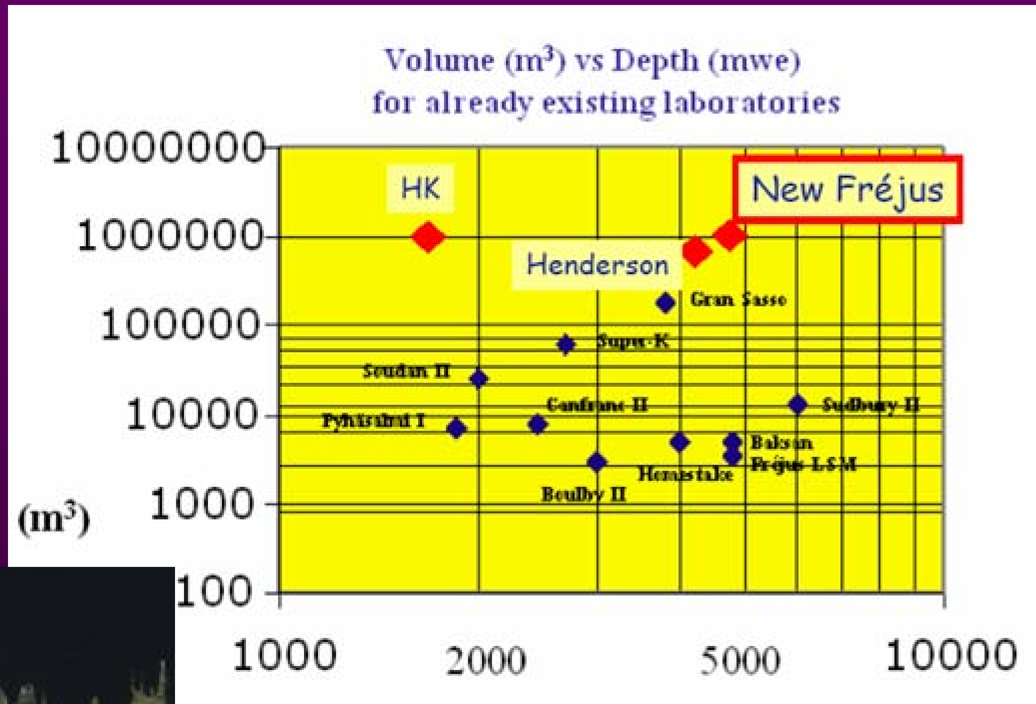
LSC

Laboratorio Subterraneo de Canfranc, Spain

PYLOS

Grandes cavités ?

Pas de réalisation artificielle de la taille requise à la profondeur

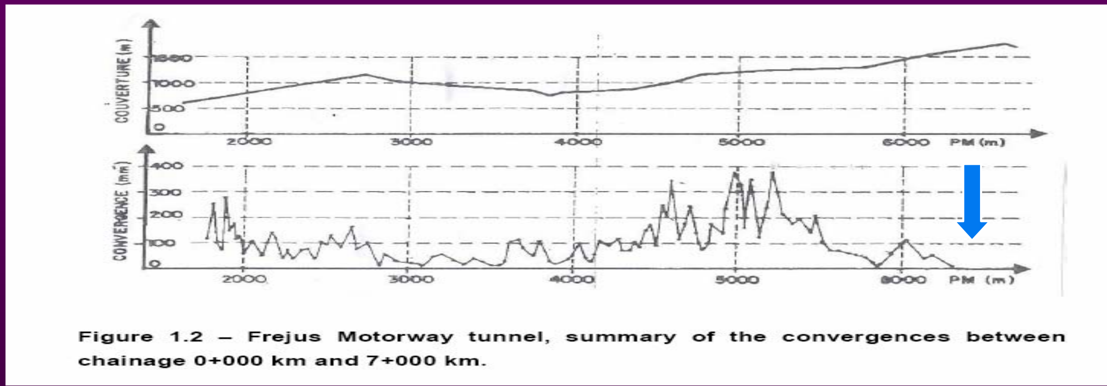


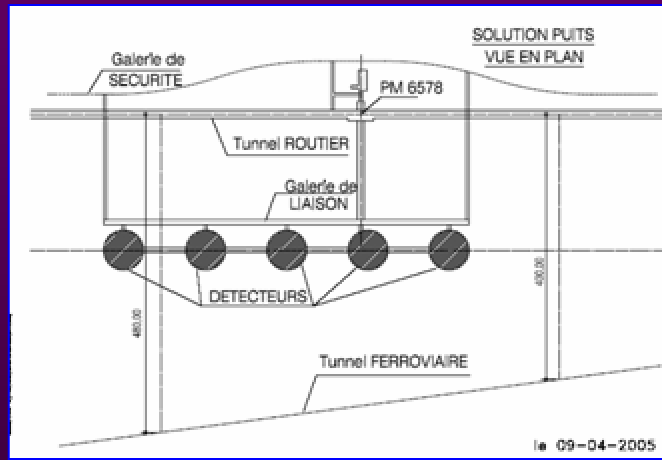
CHORANCHE cave naturelel,

Vercors (Isère) **about 60 m wide**

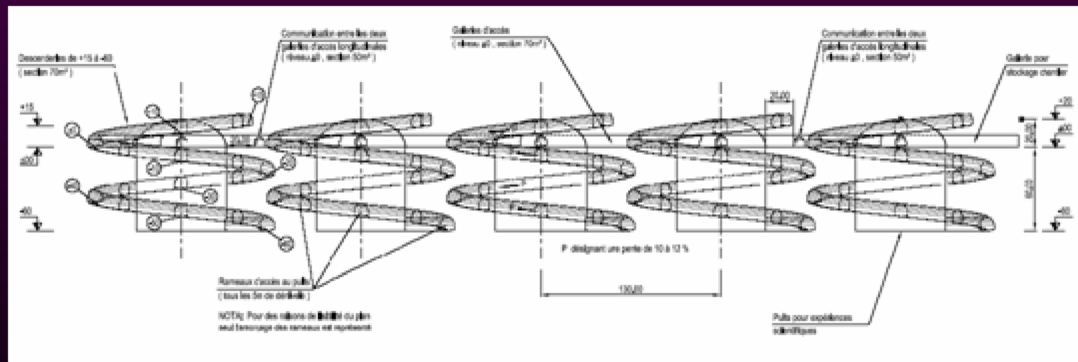
A new very large laboratory in Europe ?

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





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



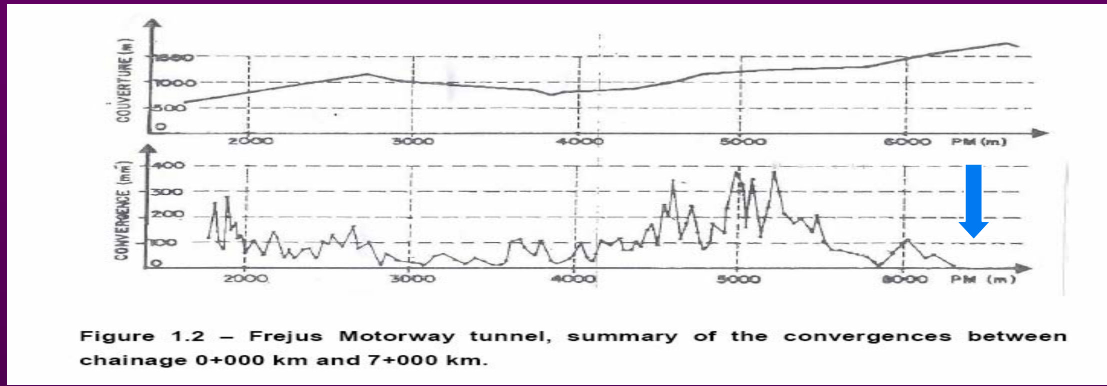
Current choice=
3 shafts
(1 shaft ≈ 150kT fiducial mass)

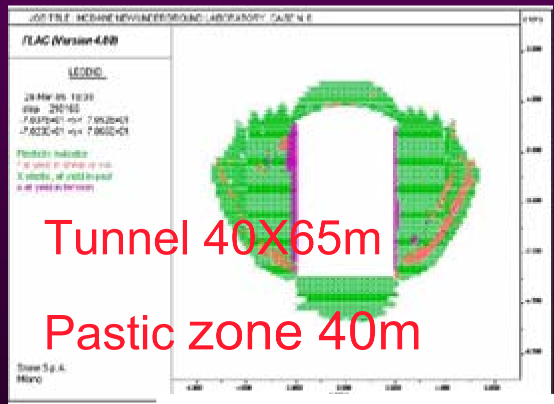
A simpler scheme under study of access tunnels

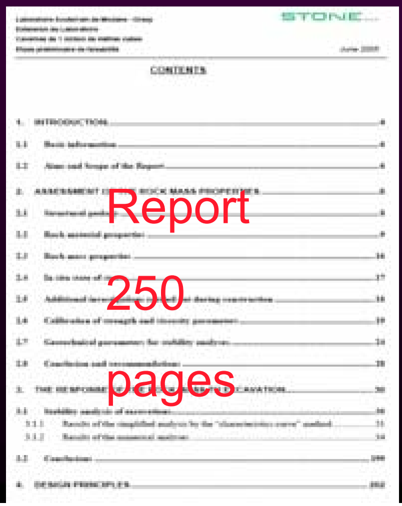
A new very large laboratory in Europe ?

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

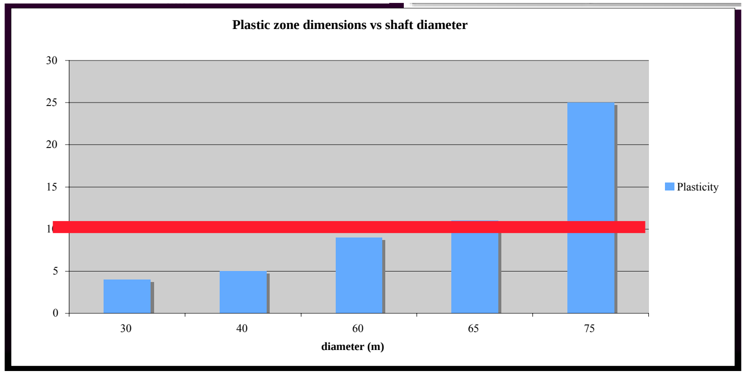
1) **The best rock quality is found in the middle of the mountain, at a depth of 4800 mwe**
2) **of all the 20 considered shapes : the “shaft (= well) shape” is strongly preferred**
3) **cylindrical shafts are feasible up to a diameter Φ = 65 m and a full height h = 80 m (≈ 250 000 m^3)**







Plastic zone determines the length of iron bolts



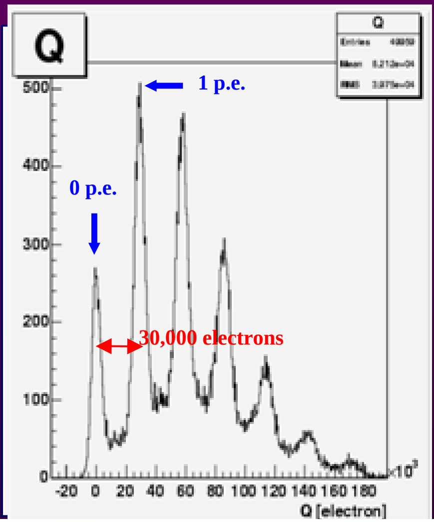
R&D Photodetecteurs

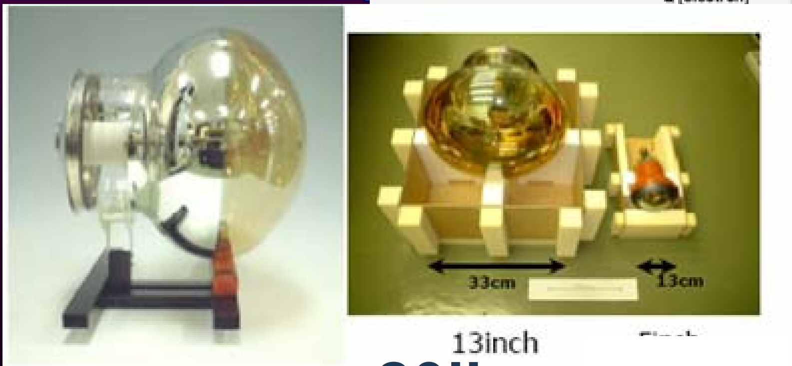
●Diameter	20“	<=>	12“	
●projected area	1660		615	cm²
●QE(typ)	20		24	%
●CE	60		70	%
●Cost	2500		800	€
●Cost/p.e/cm	13		8	€

PMT Photonis@NNN05

Hamamatsu R&D

HPD





13inch HPD → 20’’

20kV !

Summary

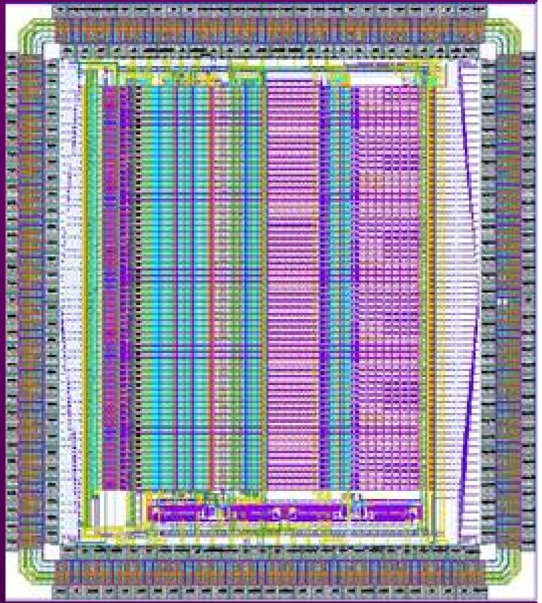
- R&D for a large format hybrid photo detector has started.
- Initial study shows excellent performance:
  - ✓ Single photon sensitivity
  - ✓ Wide dynamic range (up to the readout limit)
  - ✓ Good time resolution (better than 1ns)
  - ✓ Good uniformity (over a large photocathode)
- Promising

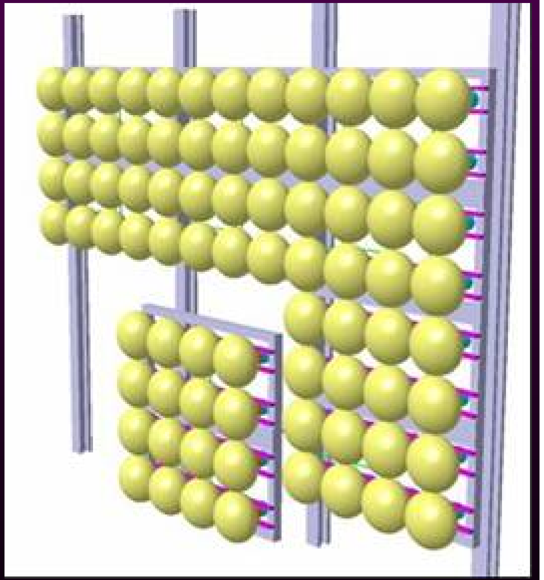
H. Aihara @ NNN05

Needs low noise electronics

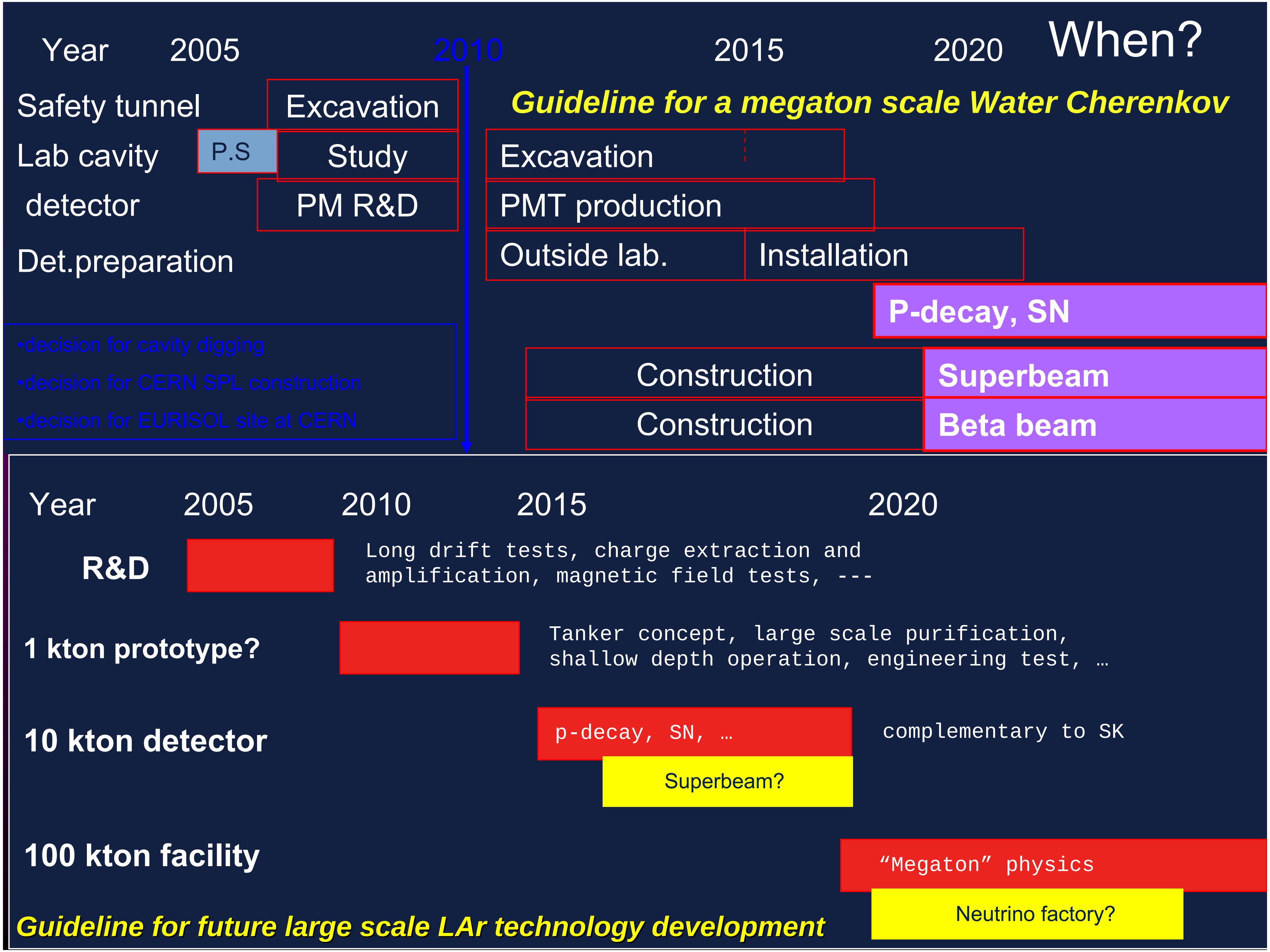
R&D Electronique

- 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
Safety tunnel
Excavation
Guideline for a megaton scale Water Cherenkov
Lab cavity
P.S
Study
Excavation
detector
PM R&D
PMT production
Det.preparation
Outside lab.
Installation
P-decay, SN
•decision for cavity digging
•decision for CERN SPL construction
•decision for EURISOL site at CERN
Construction
Superbeam
Construction
Beta beam
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, …
complementary to SK
Superbeam?
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…

BACKUP

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 $\bar{\nu}\pi^+$,$\bar{\nu}K^+$	$10^{33}-10^{35}$	[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,$\bar{\nu}K^+$	$10^{33}-10^{35}$	[8]
SUSY Without GUT	R. Harnick *et al.*	$\bar{\nu}K^+$	$10^{28}-10^{35}$	[11]
SUSY Minimal SO(10)	R. Dermisek *et al.*	$\bar{\nu}K^+$	$< 2\times 10^{34}$	[12]
SUSY Minimal SO(10) With 126 Higgs	H.S. Goh *et al.*	$\bar{\nu}\pi^+$ $n\rightarrow\bar{\nu}K^0$	$< 6.5\times 10^{32}$ $< 3\times 10^{33}$	[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