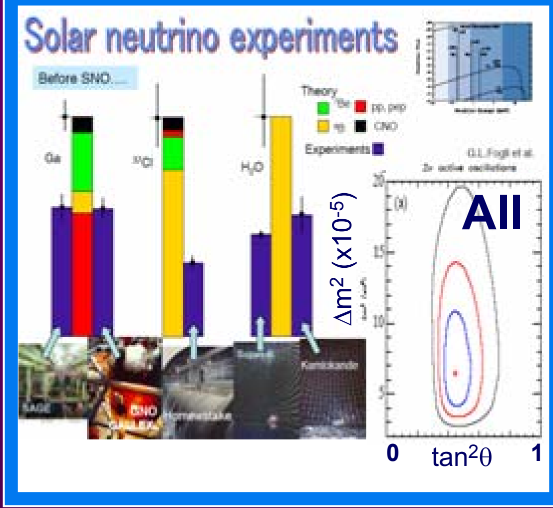
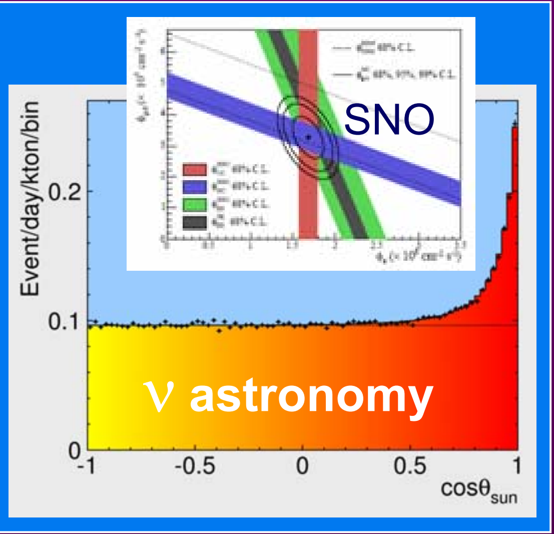
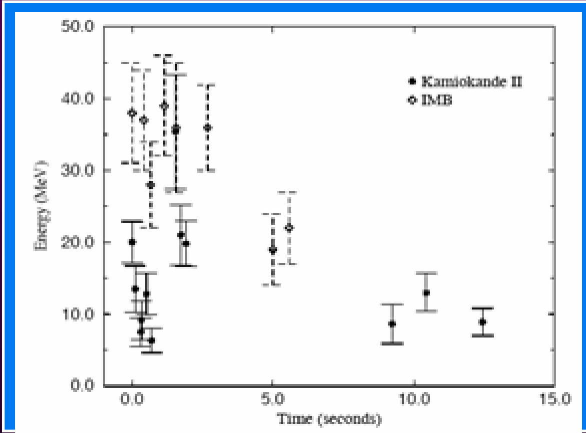
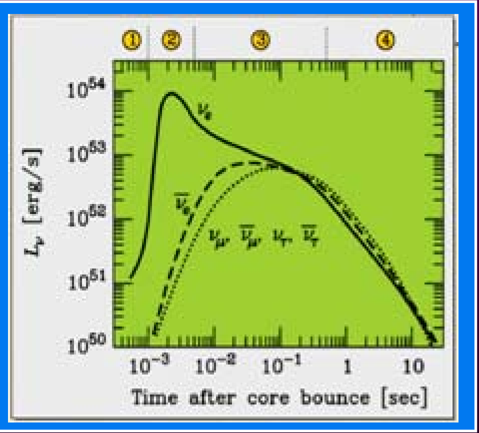
MEgaton Mass PHYSics

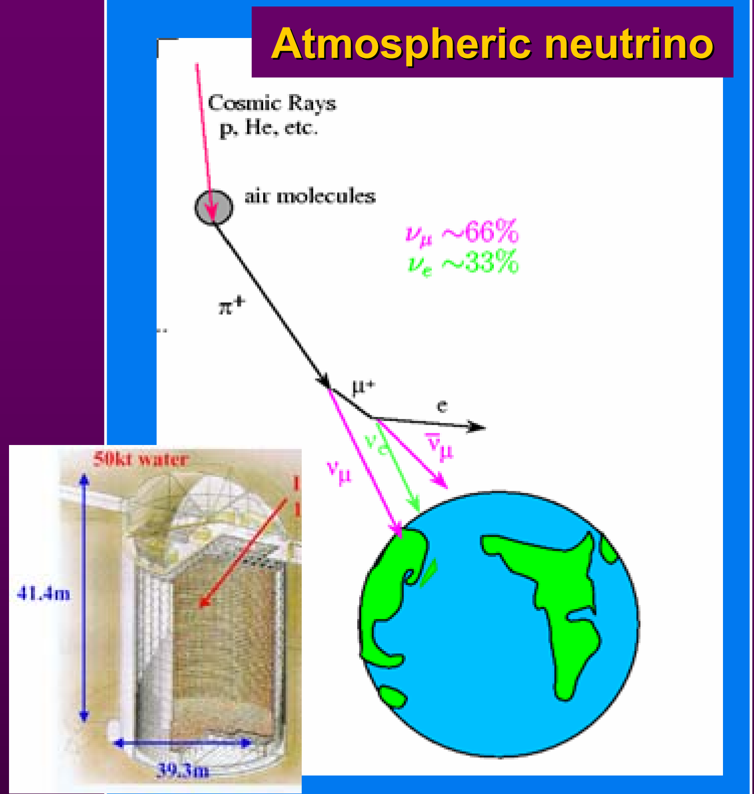
But past success of the field…

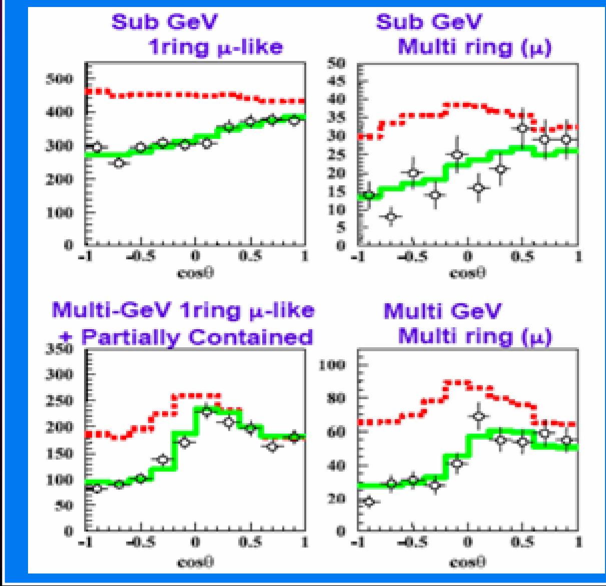












- Solar neutrino anomaly solved
- Detection of SN-1987A (Nobel Koshiba)
- Discovery of atm neutrino oscillations

The need for new generation experiments…

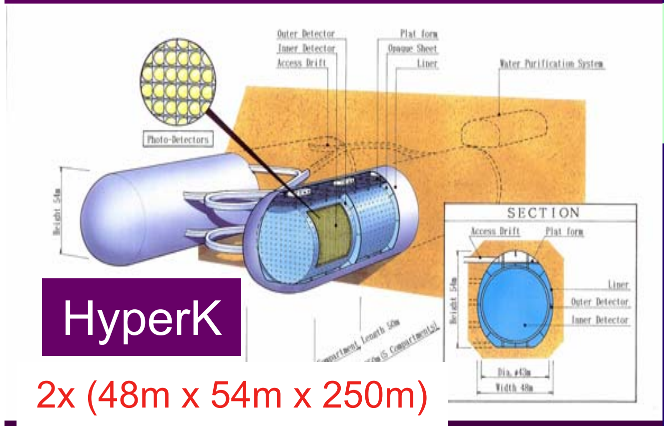
Still many important issues…

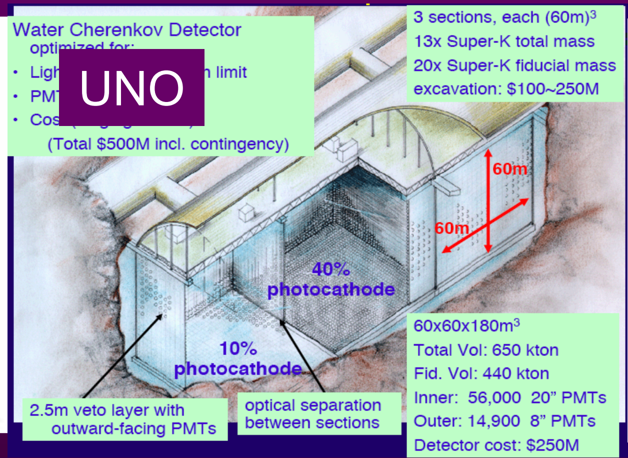
• **Baryon number violation**	**Proton decay**
• **Astroparticle physics**	
• **Understand gravitational collapse**	**Galactic SN ν**
• **Star formation in the early universe**	**Diffuse SN ν**
• **Explore violent phenomena in the universe**	**Trigger SN ν,**
• **Dark matter and astrophysical sources**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

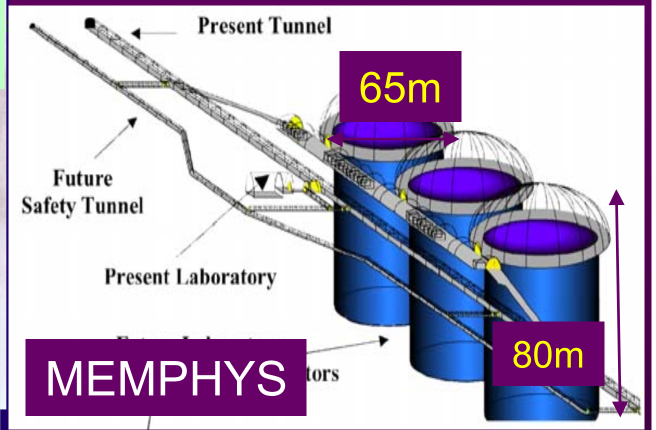
NNN Workshops

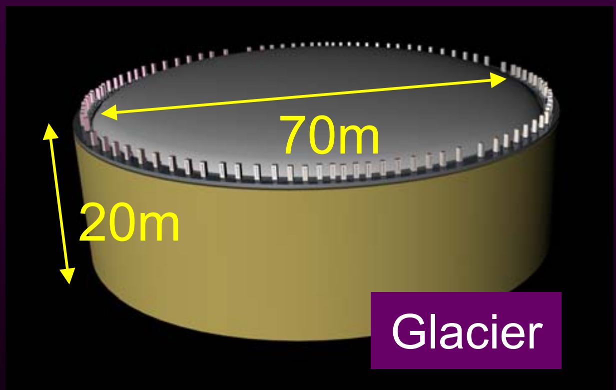
Aussois 05, Seatle 06, Hamamatsu 07

Water Cerenkov 500kT→1Mt



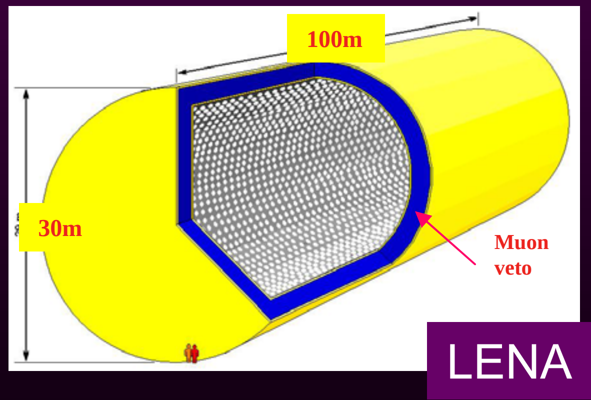






LAr →100kT

Liq. Scintillator →50kT



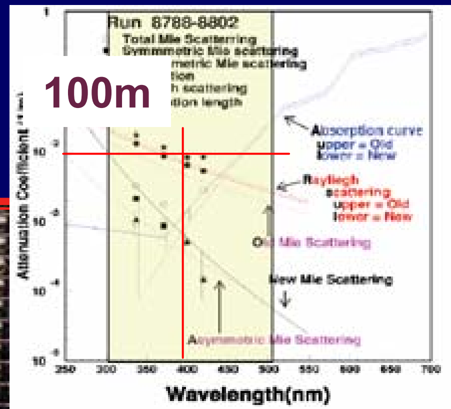
Mton Water Čerenkov

- 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: MEMPHYS 1 shaft

About 170 γ/cm in $350 < \lambda < 500$ nm
With 81,000 PMT (12'') 30% coverage, Q.E.≈24%, CE~70%
(⇔20''PMT 40% cov. ,Q.E.≈20%, CE~60%)
Relativistic particle produces
⇒≈14 p.e / cm
⇒≈6 p.e / MeV (SK-I)



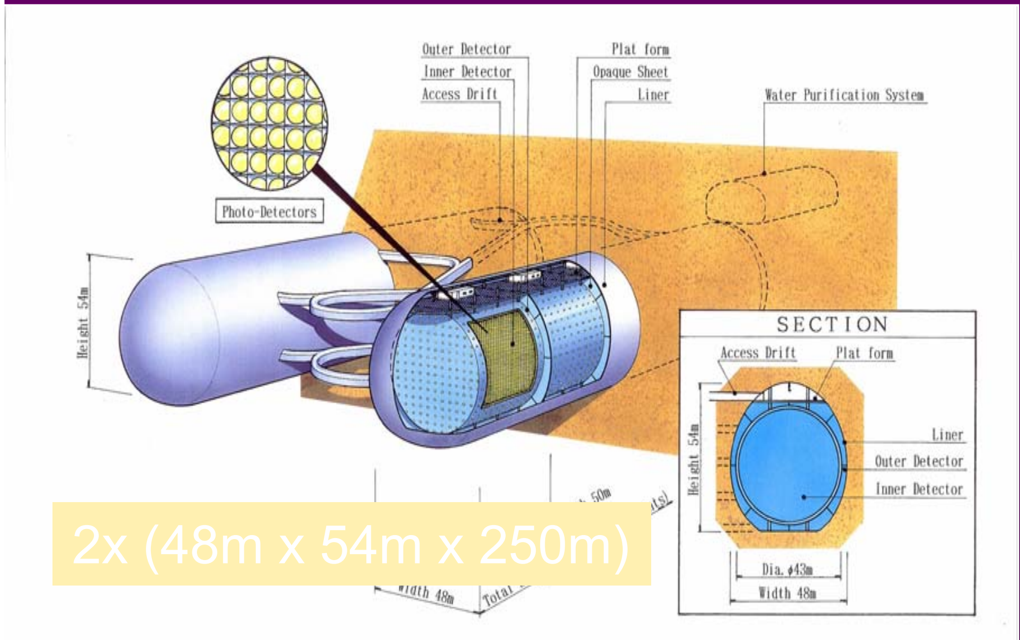
Volume total x4 SK
Fiduciel: 145kT
17535m^2 surface PMT

- 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!!!**

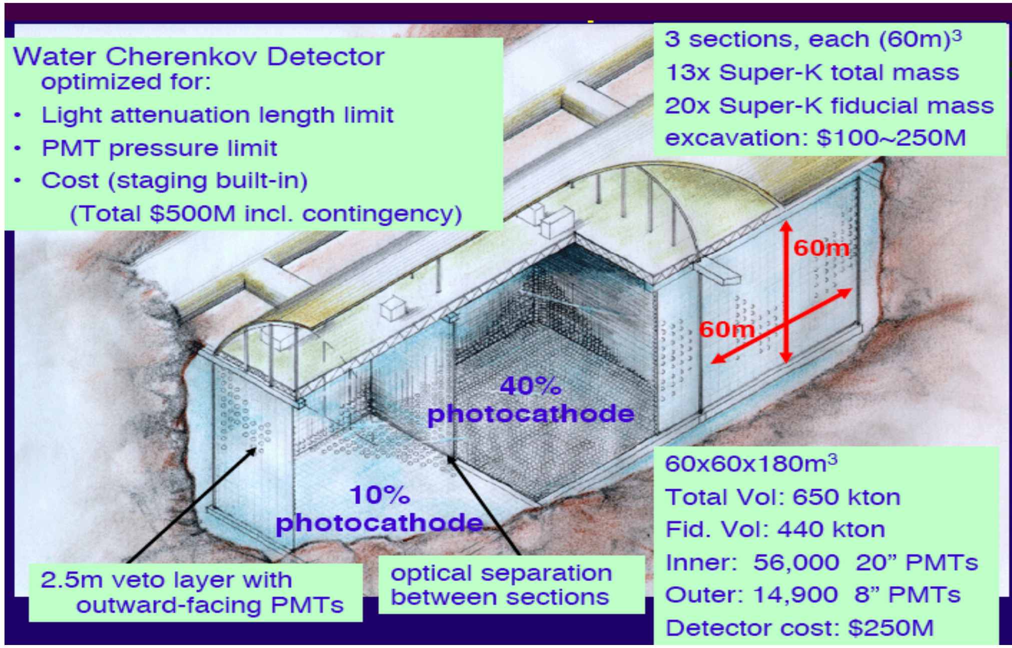
Beacom & Vagins Phys. Rev. Lett., **93**:171101, 2004

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 ?)
- 2nd location in Korea ?

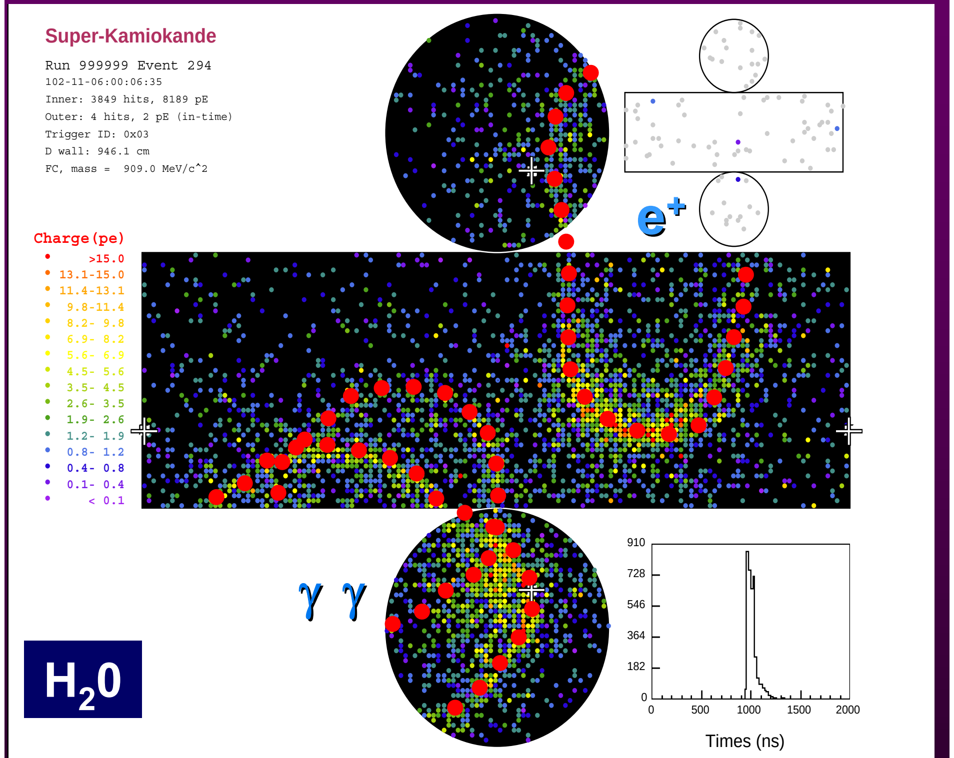


- Henderson Mine (4000 mwe, one of the 2 DUSEL sites)
- FV 440 ktons
- Cavern study to be done
- Photodetector R&D on-going
- Long baseline from BNL
- In the NSF process

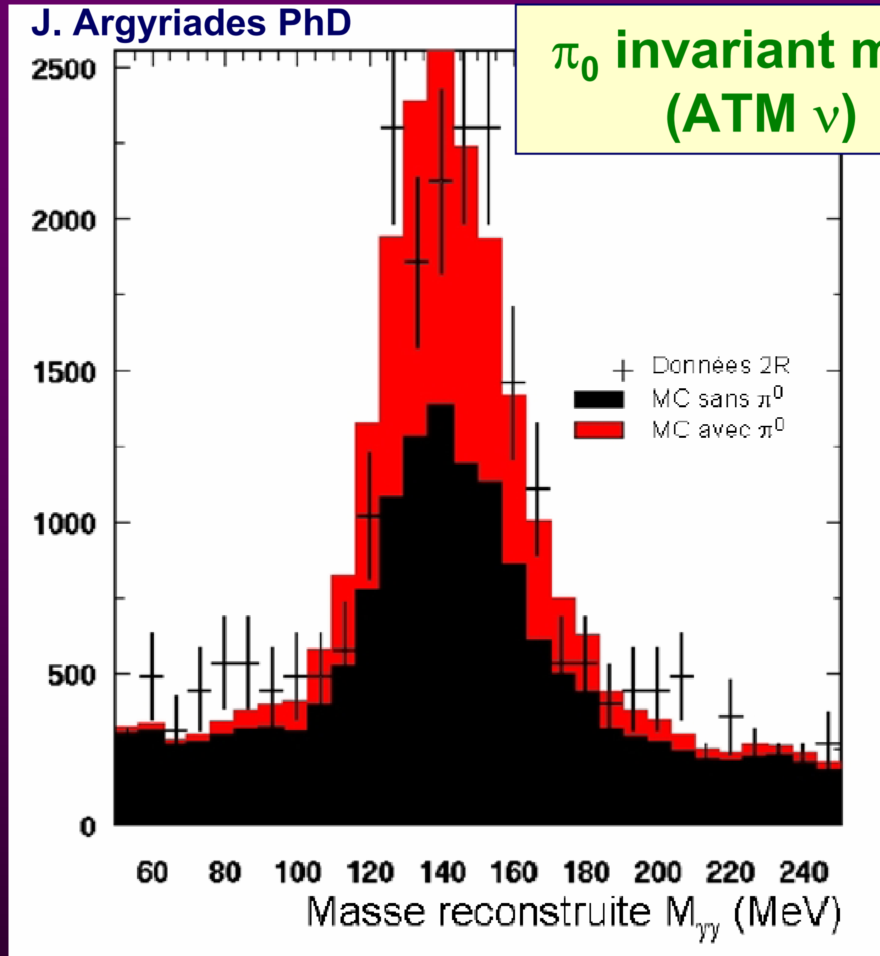
Summary of WC in the world (LAL-06-22)

	UNO (USA)	HK (Japon)	MEMPHYS (EU)
Laboratory			
location	Henderson/Homestake	Tochibora	Fréjus
prof. Mwe	4500/4800	1500	4800
LBL(km)	1480÷2760/1280÷2530	290	130
Dimsensions			
type	3 cubes	2 tunnels de 5 compartments	3 to 5 shafts
dimension	$60x60x60m^3$	ϕ:43m x L:50m	ϕ:65m x L:65m
M fid. Kt	440	550	440 à 730
Photodetectors			
type	20" PMT	20" H(A)PD	12" PMT
#	38000 (middle) 2 x 9500 (side)	20,000 per compartiment	81,000 per shaft
Couverage	40%/10% (middle/side)	40%	30%
Estimate Cost			50% excavation + 50% Photodetection
	500M$	500 Oku ¥	161M€ x #shafts +100M€ infra.

Imaging capability…



π_0 invariant mass (ATM ν)



1-ring vertex ~10cm
Ring-direction ~ 1°
σ_E ~10%/√E (45% Solar ν)
Absolute E scale @ 3%

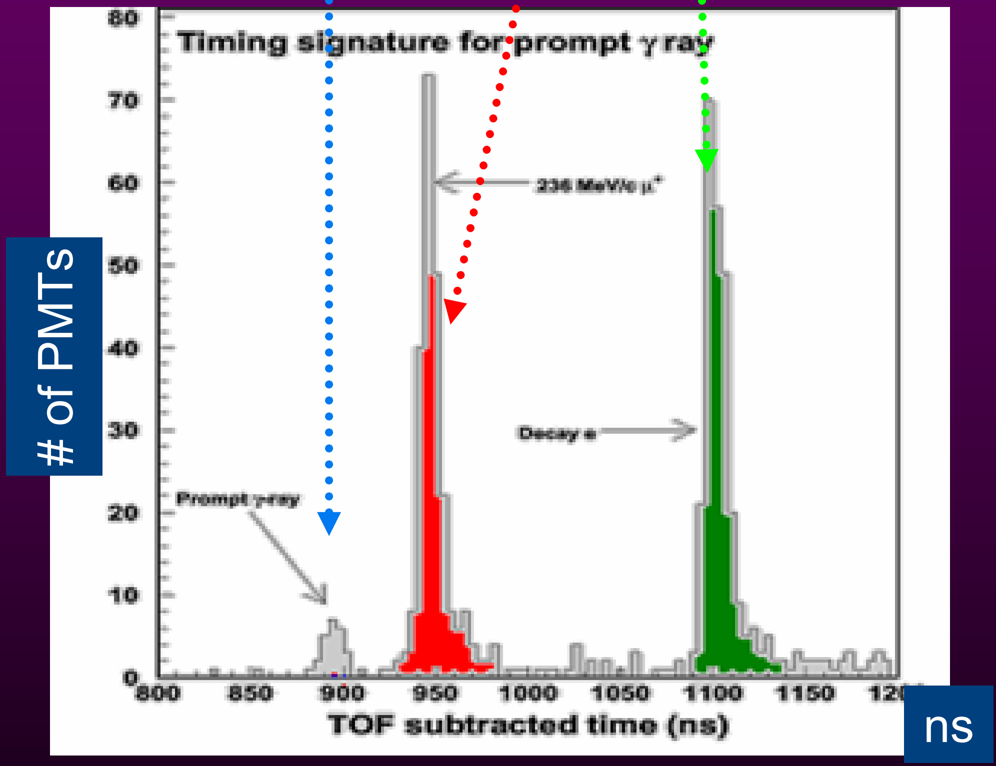
Cerenkov threshold:
~1.07GeV:p, ~570MeV: $K^\pm$,
~120MeV:$\mu^\pm$,~0.6MeV:$e^\pm$
Lowest trigger threshold: 5MeV
(trig. rate x10 every MeV due to ambiant radioactivity)

Timing capability: an example for $p \rightarrow K^{+} \bar{\nu}$

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

$\hookrightarrow e^{+} \nu \nu$

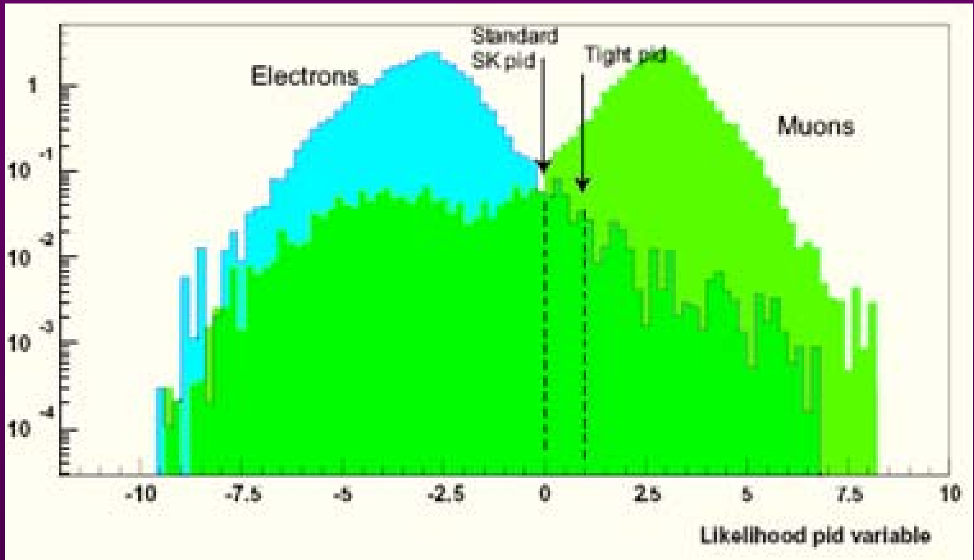
6–10 MeV 236MeV/c



Autotrigger capability

The first use of the PMT timing is the approximate vertex determination

Particle Id.



1% 1-ring $\mu \rightarrow e$
10% 1-ring $e \rightarrow \mu$

$$\mathcal{P}^{angle}(e \text{ ou } \mu) = e^{-\frac{1}{2}\left(\frac{\theta^c - \theta^{att}(e \text{ ou } \mu)}{\delta\theta}\right)^2}$$

Compare the expected and measured Cerenkov angle

$$\mathcal{P}_n^{pattern}(e \text{ ou } \mu) = e^{-\frac{1}{2}\left(\frac{\chi^2(e \text{ ou } \mu) - \chi^2_{min}}{\sigma_{\chi^2_n}}\right)^2}$$

$$\mathcal{L}_n(e \text{ ou } \mu) = \prod_{\theta_i < 1,5\,\theta^c} \text{prob}\left[q_i^{obs}, q_{i,n}^{att}(e \text{ ou } \mu)) + \sum_{n' \neq n} q_{i,n'}^{att}\right]$$

Compare the expected and measured charge of *i*th PMT from the *n*th ring

Proton decay

An Upper Bound exists coming from the GAUGE sector (d=6)
model indépendant I. Dorsner, P. F. Perez PLB 625 (05) 88

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

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

Specific model gives faster decay rates…

It is quite diffical and unatural to set to 0 all the decay channels simultaneously

$\bar{\nu}$ **+ meson** $\leftrightarrow$ **charged lepton + meson**

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

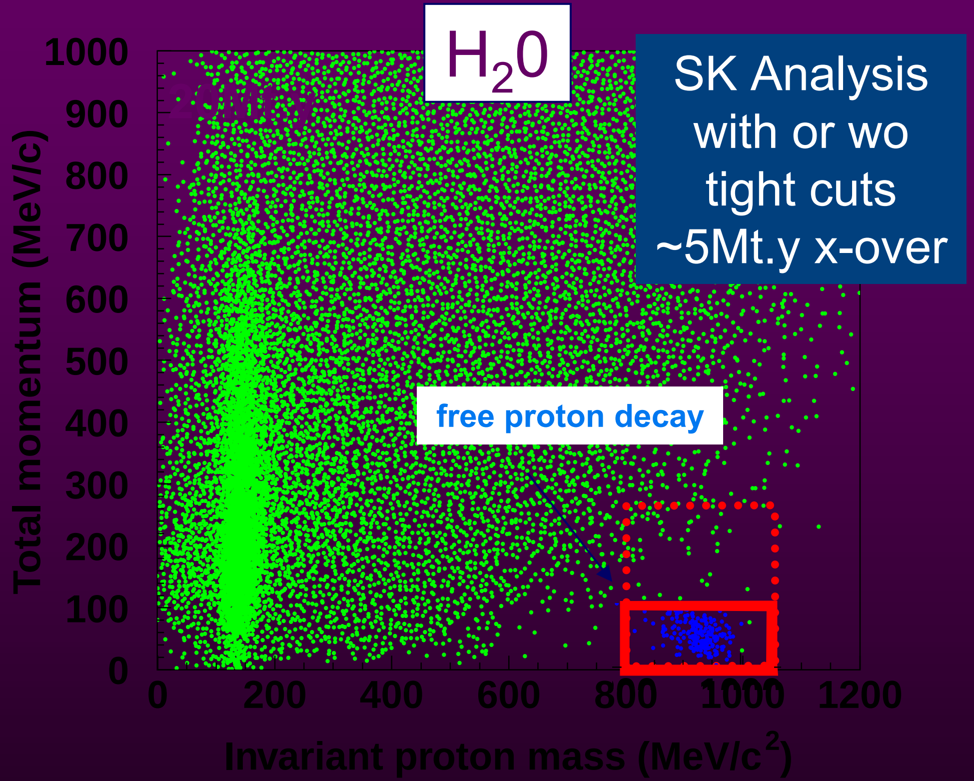
$$p \rightarrow e^+ \pi^0$$

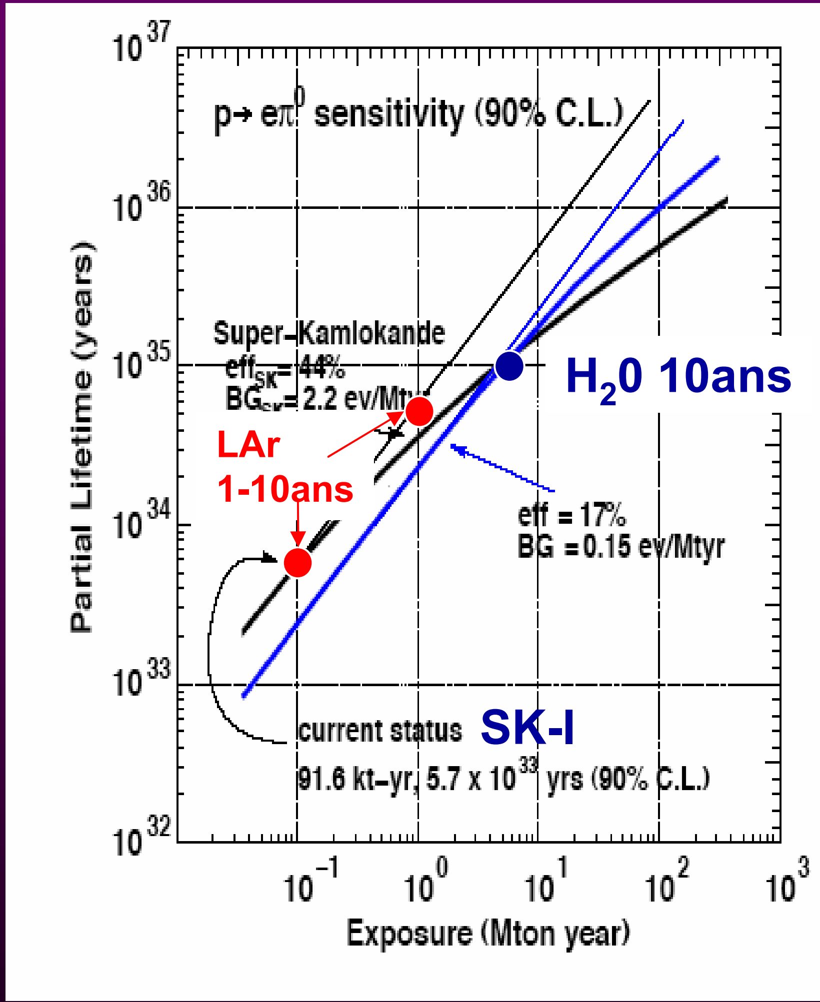
Some recent models predictions

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 @ LPNHE 17/2/06

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

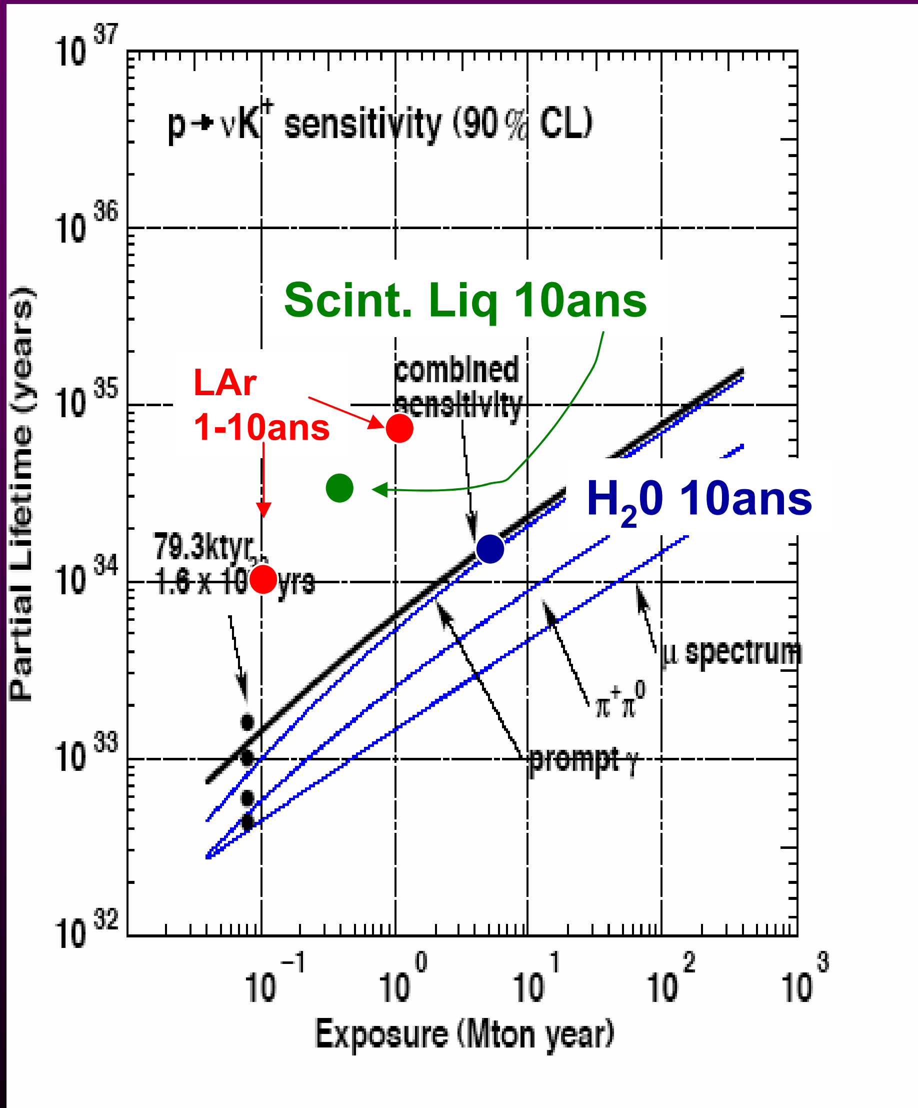




$p \rightarrow K^+ \bar{\nu}$

H_20: K⁺ below Č threshold
Imaging/Timing
$K^+ \rightarrow \pi^+\pi^0; \mu^+\nu$ avec ou sans ^{15}O
$\rightarrow ^{15}N$ γ prompt (6MeV) tag

	ε	Bkgd
H_20 (*)	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) $P \rightarrow \nu K^+$, $K^+ \rightarrow \mu^+ \nu$

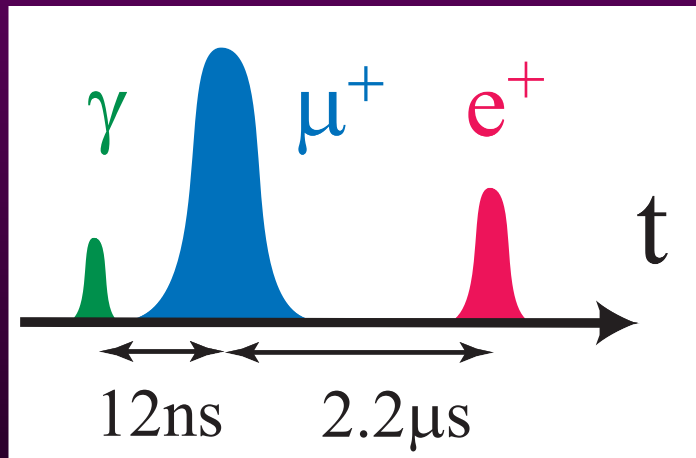
236 MeV/c

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

$\hookrightarrow e^+ \nu \nu$

6 – 10 MeV

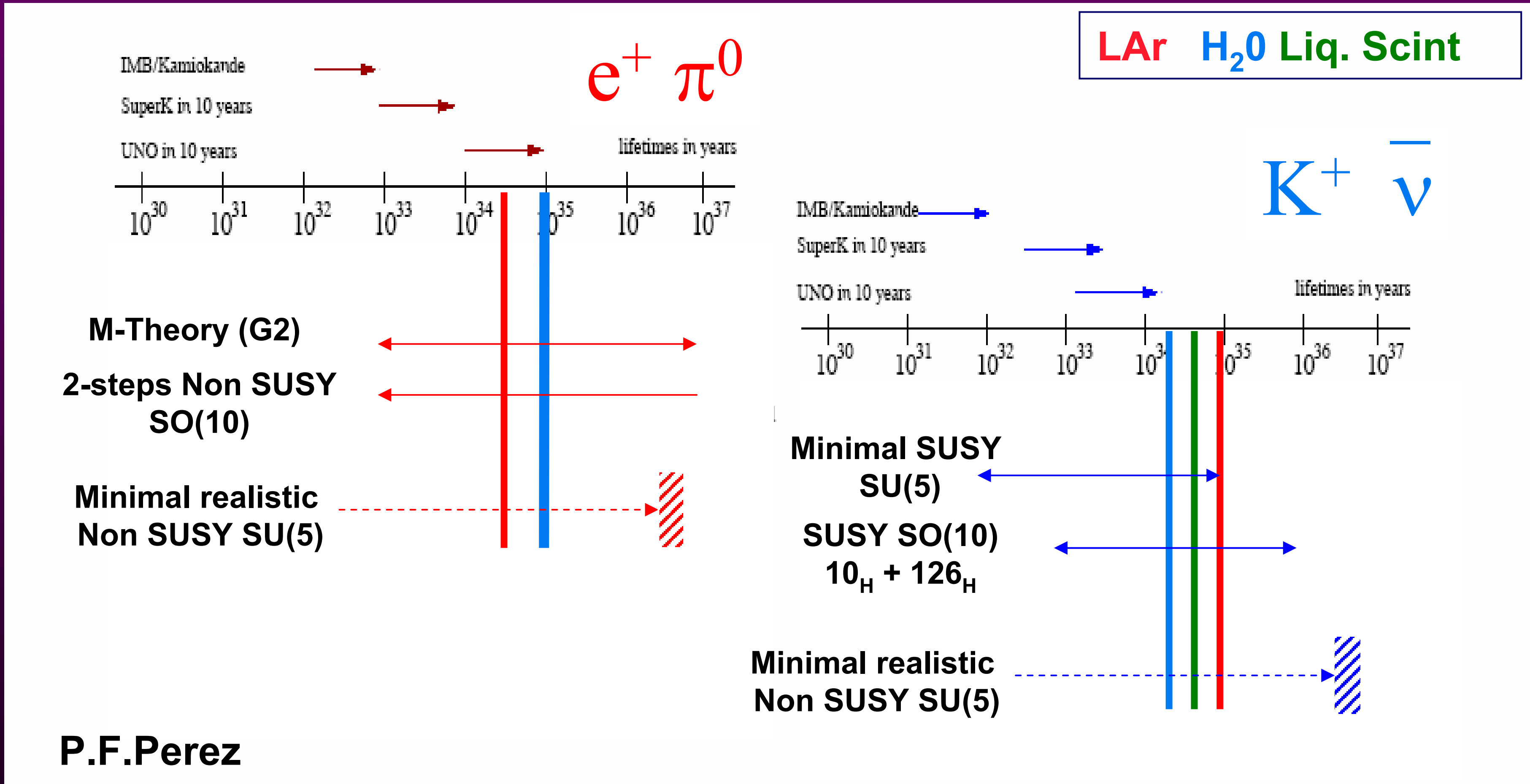
236MeV/c



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

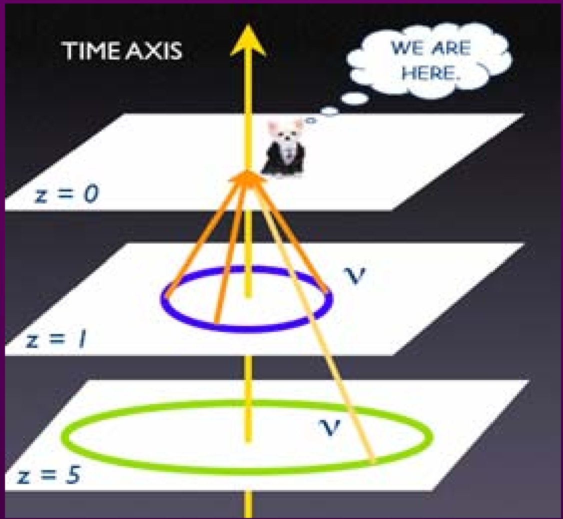
Back to back
205MeV/c each

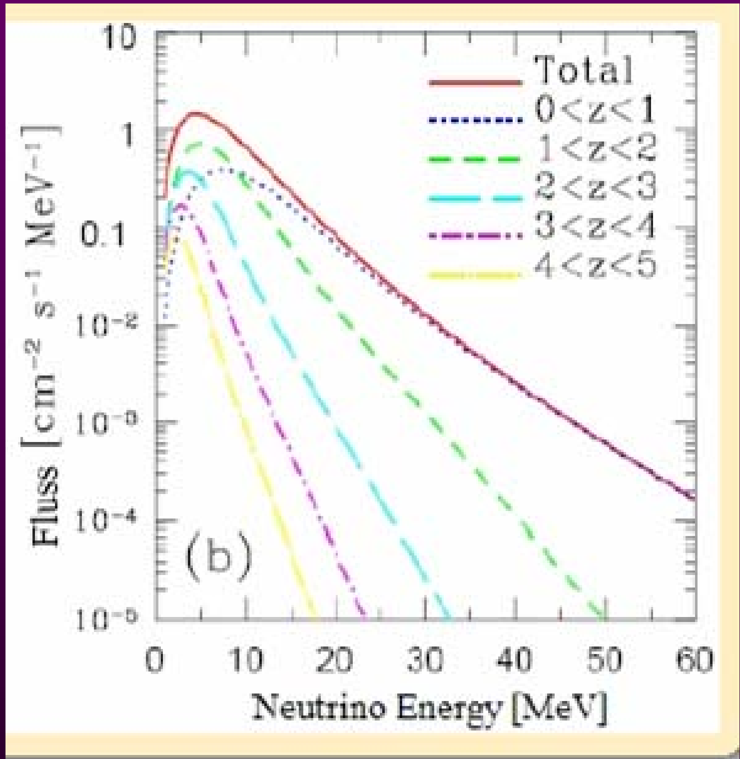
Summary of proton decay



Definitively not exhaustive neither p channels nor n decay…

Diffuse SN

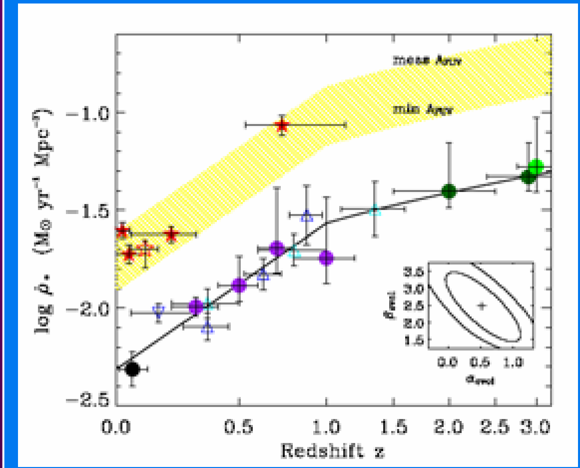




Detection of SNν with z ≲ 1

Flux ∝ **all SN(z) in particular those which produce a Black hole**

Current limit close to a detection?



Formation Etoile
GALEX
$(1+z)^{2.5}$ z<1
$(1+Z)^{0.5}$ z>1

Astrophys.J. 619 (2005) L47

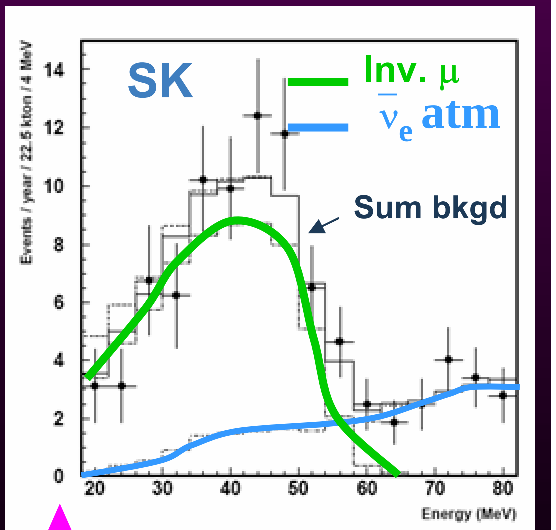
Supernova

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

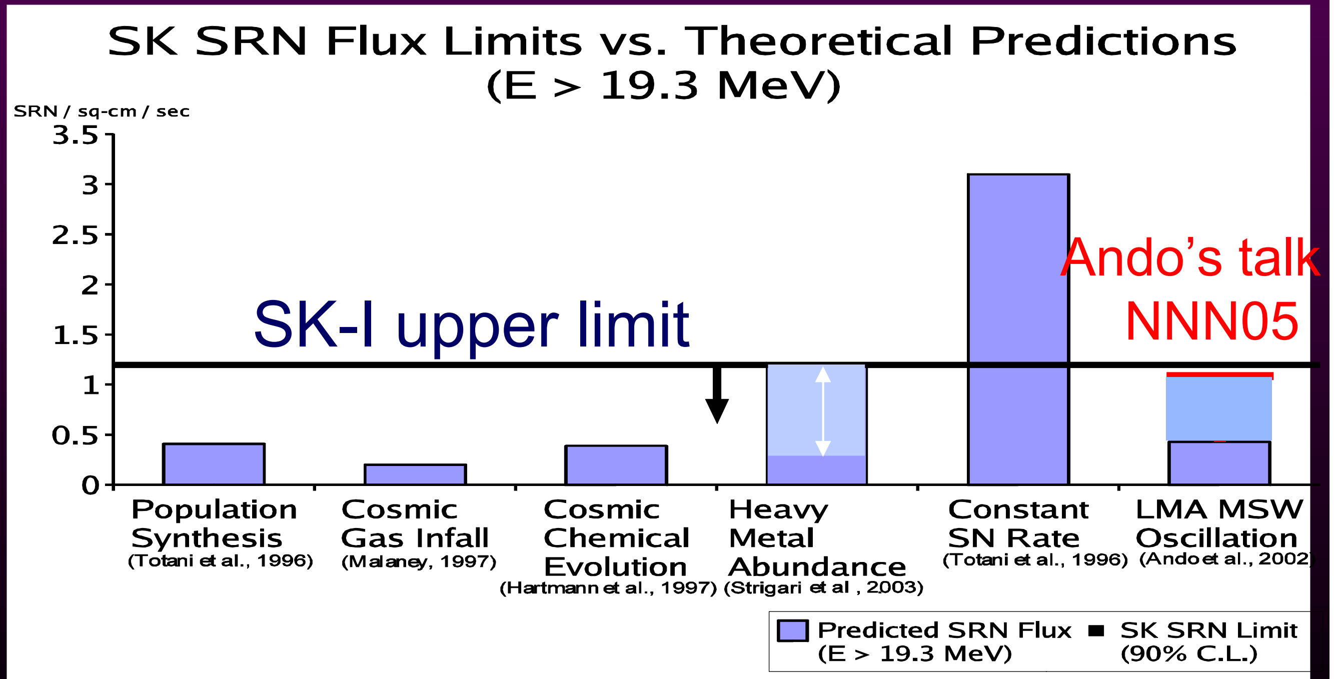
E_ν > 11.3 MeV	E_ν > 19.3MeV
5.1 $cm^{-2}s^{-1}$	1.2 $cm^{-2}s^{-1}$

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

Phys. Rev. Lett 90, 061101 (2003)



Réacteur + Sun

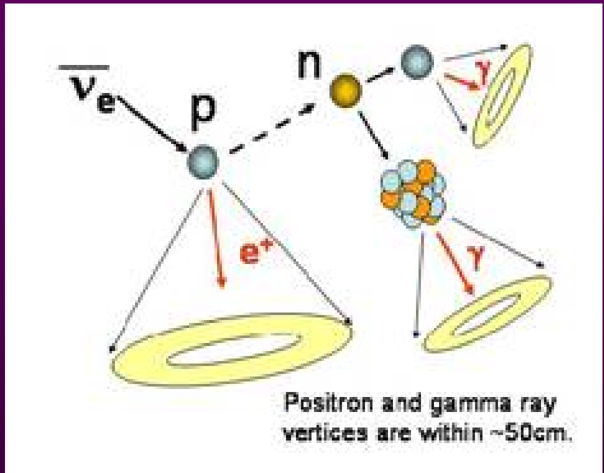


Futur: $\bar{\nu}_e$ & ν_e complementarity

$\bar{\nu}_e$

H_20 + neutron capture

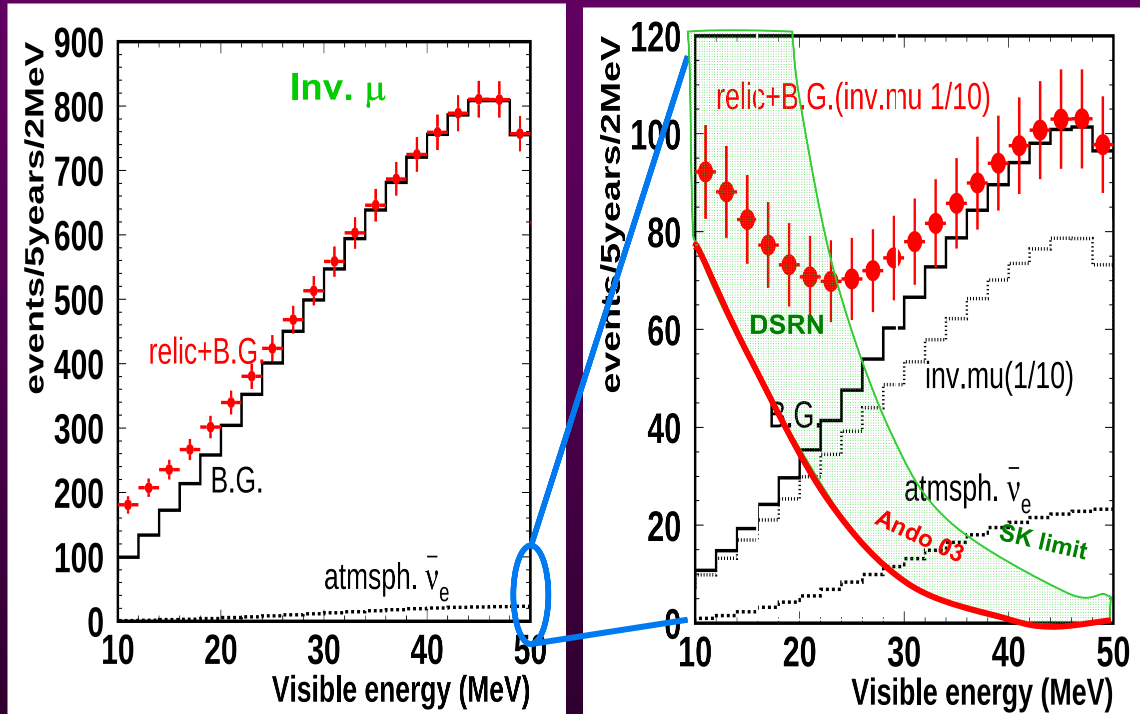
30% PMT coverage



ΔT(p: 2MeV γ) = ~ 200 μs

ΔT(**Gd**: 8MeV γ) = few 10^{th} μs

No n-tagging / **With n-tagging**



Nakahata+Vagins @ NNN05

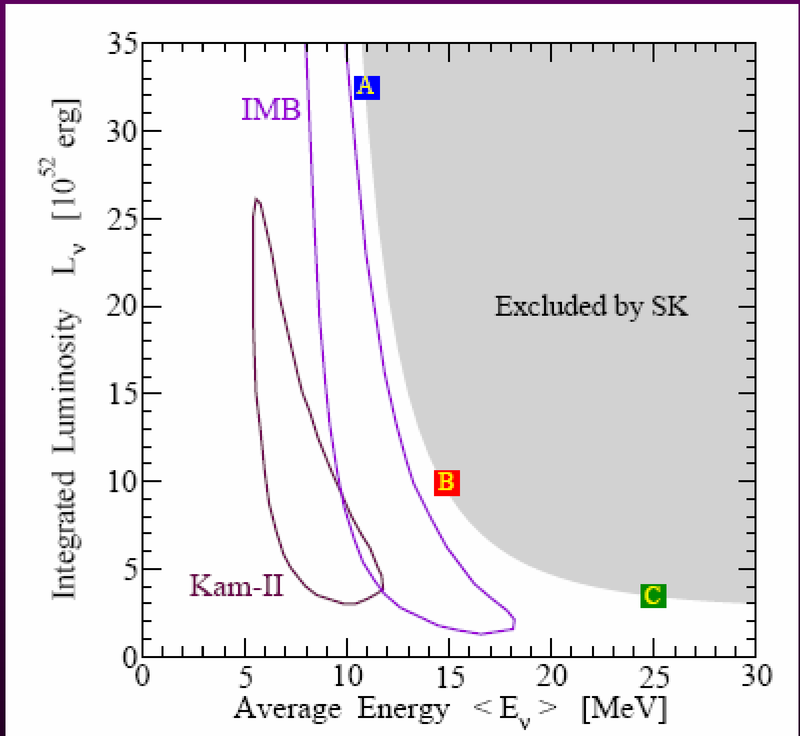
MEPHYS: 60-150* Sig/65 BG [15-30]MeV 2yrs (1Mt.y)

$$\nu_e + {}^{40}Ar \longrightarrow {}^{40}K^* + e^-$$ **(see GLACIER)**

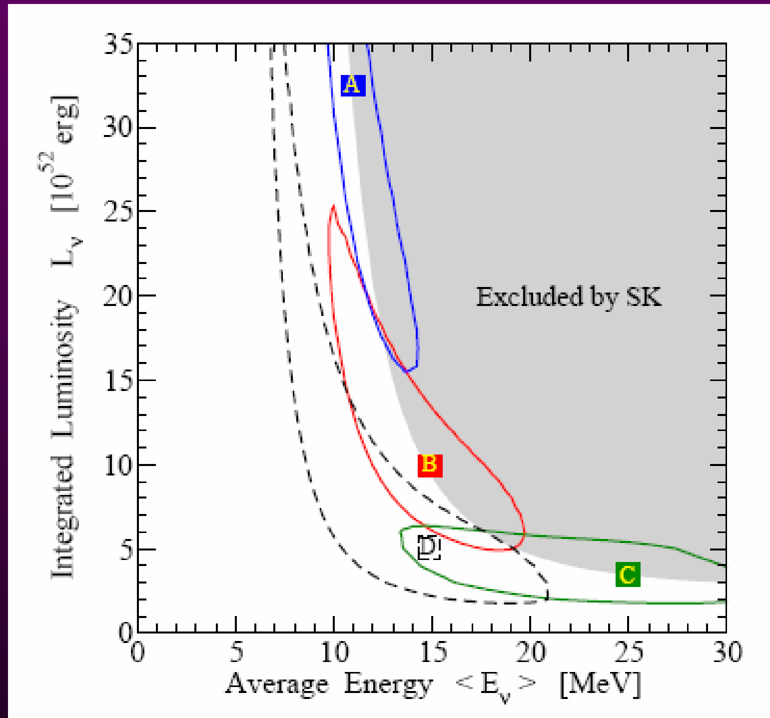
***: at SK limit**

SN parameter measurements

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



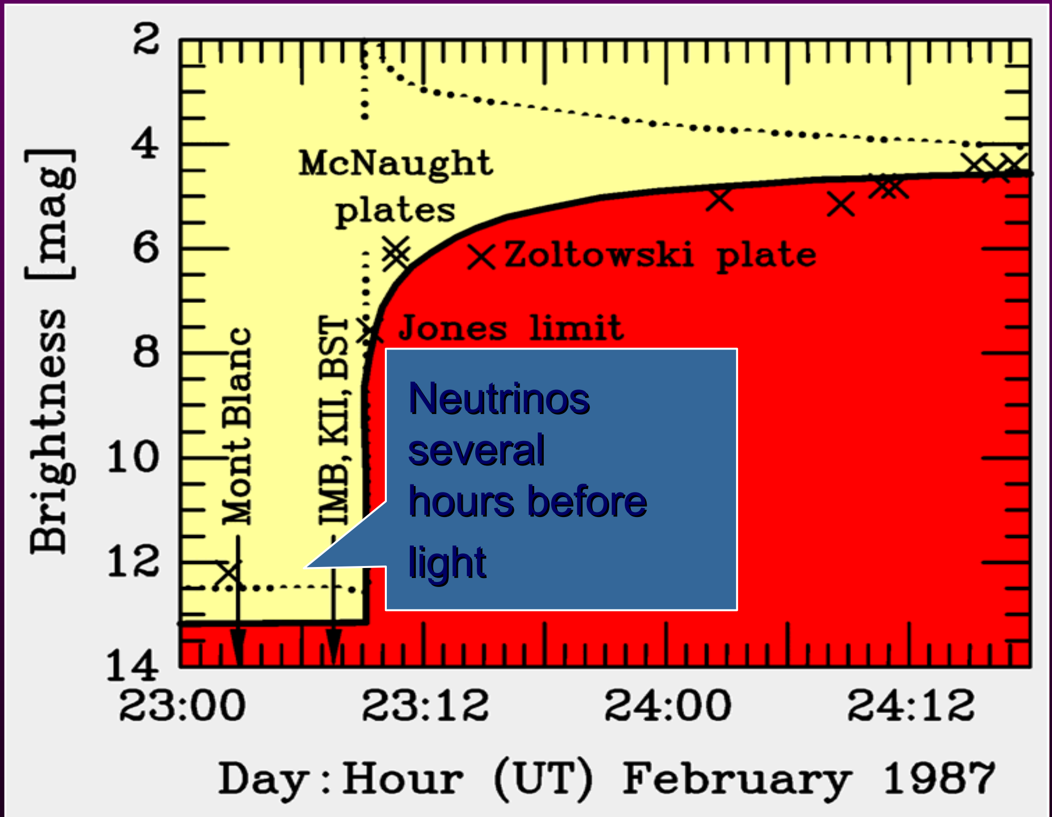
DSN
5yrs SK-Gd
⇔1yr MEMPHYS-1shaft-Gd



Yukse, Ando Beacom astro-ph/0509297

SN II Explosion

Early lightcurve of SN1987A



As for the SUN in the past…

In case of signal:

- astrophysical subject?
- neutrino physics subject?

It will depend of the respective knowledge at the time of detection

Counting rates

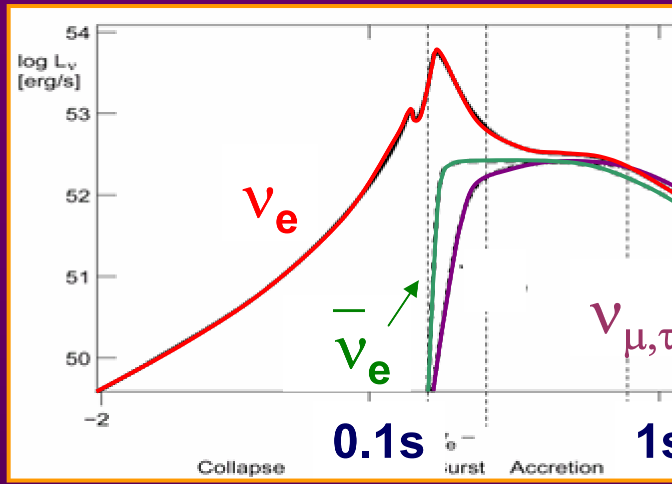
Mixture of initial fluxes:

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

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

$\times 10^3$

What to do with this SNν ?

- SN trigger
  - GALEX + SN formation ⇒ 1 SN/y D<10 Mpc
    - H20 450kT [18-30MeV]: 4.5/(Mpc)^2 and 0.4BG/day
    - H20+Gd 240kT [12-38MeV]: 4.5/(Mpc)^2 et 0.3BG/day
  - However 9 SN with D<10 Mpc in 3 years (x3 the expected rate)…
    - 2 events Δt < 10s (no BG) ⇒ SN Alarm
    - SN via Optic ⇒ if Δt < 10s 1 event ⇒ Alarm confirmed
  - *In coïncidence with GW, if possible(???)⇒ sensitivity $m_\nu \sim 1eV$*
- Si → Fer burning if D<2kpc : n-capture requested
- Neutronization burst : possible but better with GLACIER
- SN direction:
  - ES e- 2°→0.6° (H_20 + Gd)

Time evolution of the energy spectrum: Burst + Shock Wave +Earth
θ_{13} parameter + mass Hierarchy

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 $\bar{\nu}_e$

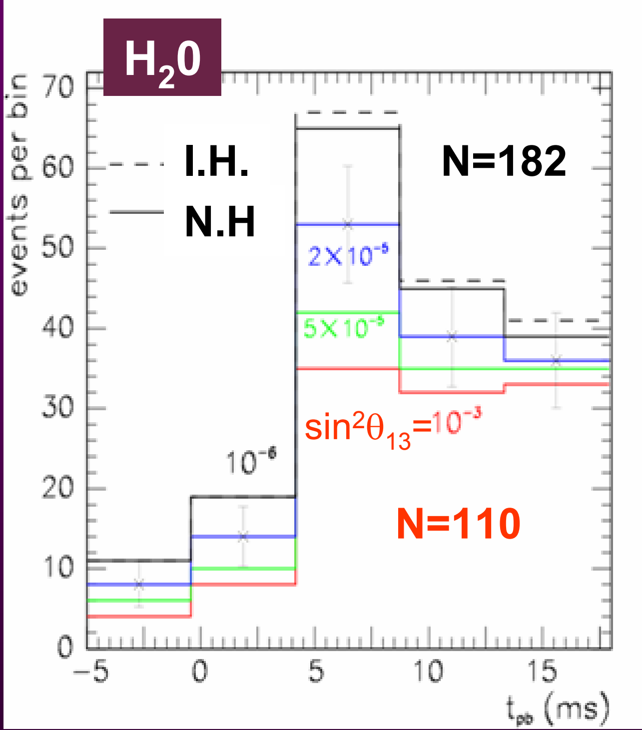
A. Mirizzi @ LPNHE 17/2/06

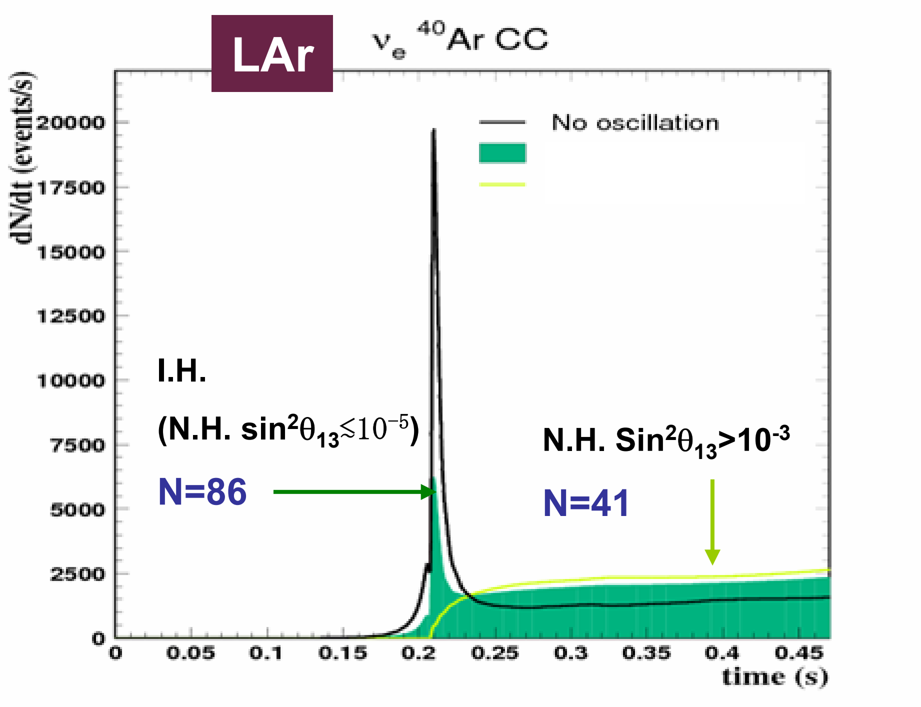
Exploiting these complementary signatures one could extract useful information on the neutrino mass hierarchy and on θ_{13}

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

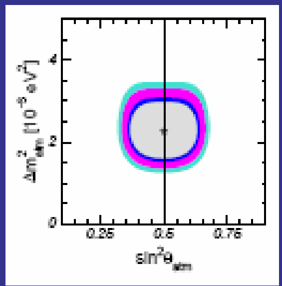
Neutrino Decay [S.Ando, hep-ph/0405200]

→ **Possibility to look for non standard $\bar{\nu}_e$ fraction (H_20)**

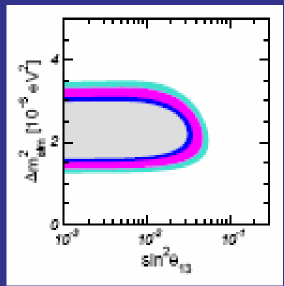
Man made Oscillations...

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

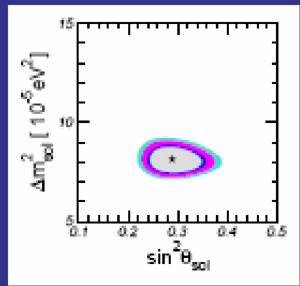
$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & e^{-i\delta} s_{13} \\ 0 & 1 & 0 \\ -e^{i\delta} s_{13} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$



atmospheric + K2K



CHOOZ

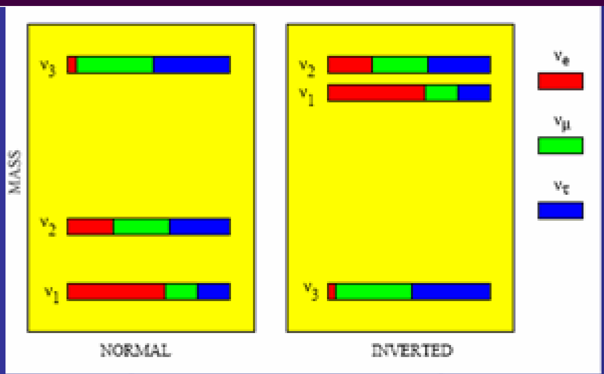


solar + KamLAND

		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



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

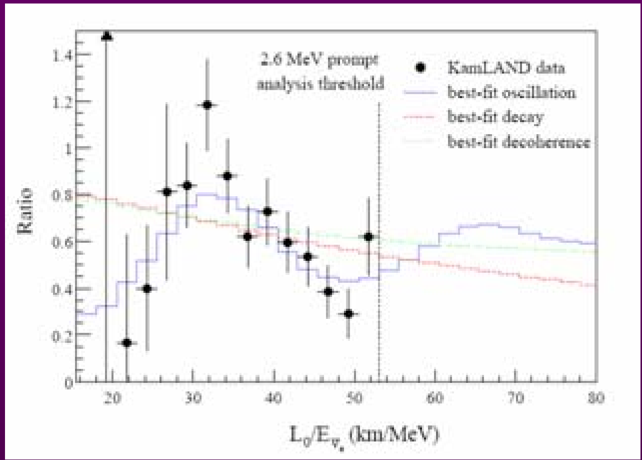
Octant de θ_{23}

θ_{13}

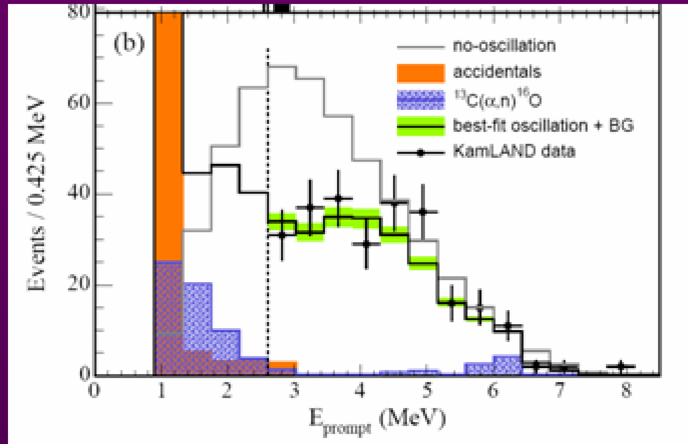
δ_{CP}

?

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



KamLAND



0.77kT.y

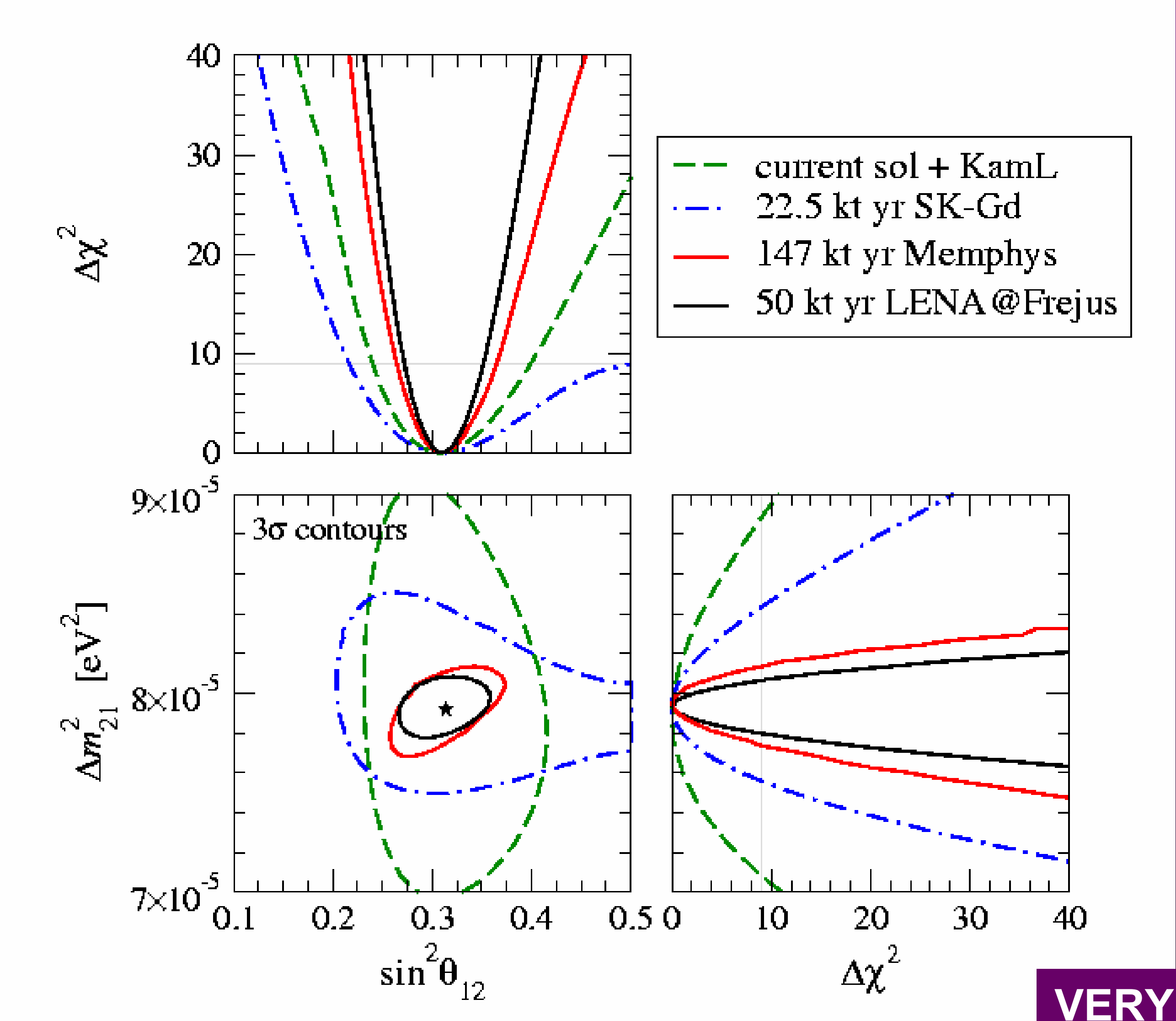
Reacteurs ν

Background for Supernova 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%

Letter by S. Petcov & Th. Schwetz to come



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

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

VERY PRELIMINARY
not to be diffused yet

$\Delta\theta_{12}$=3° (99%CL)

A possible « 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

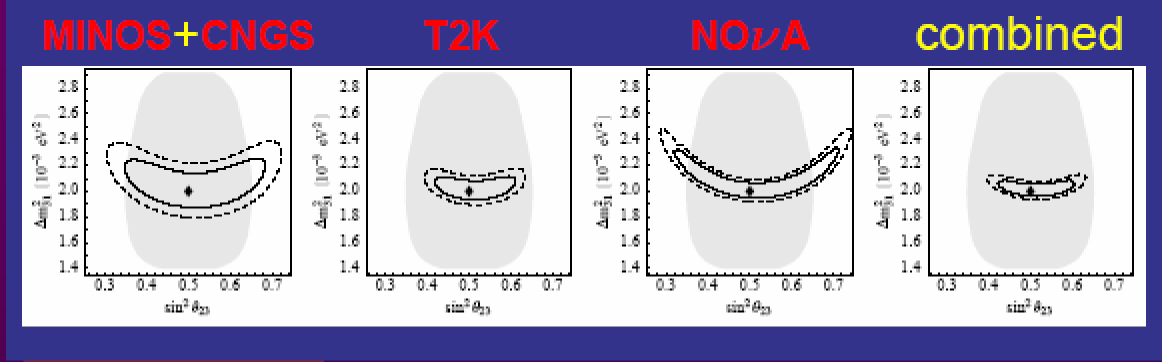
$\theta_{13} > 3^0$ —— Known by 2011 —— $\theta_{13} < 3^0$

$\theta_{13} > 3^0$	$\theta_{13} < 3^0$
• Existing facilities could reach it • ... but with very small sensitivity to δ_{CP} and mass hierarchy	• No access for ongoing experiments at that time

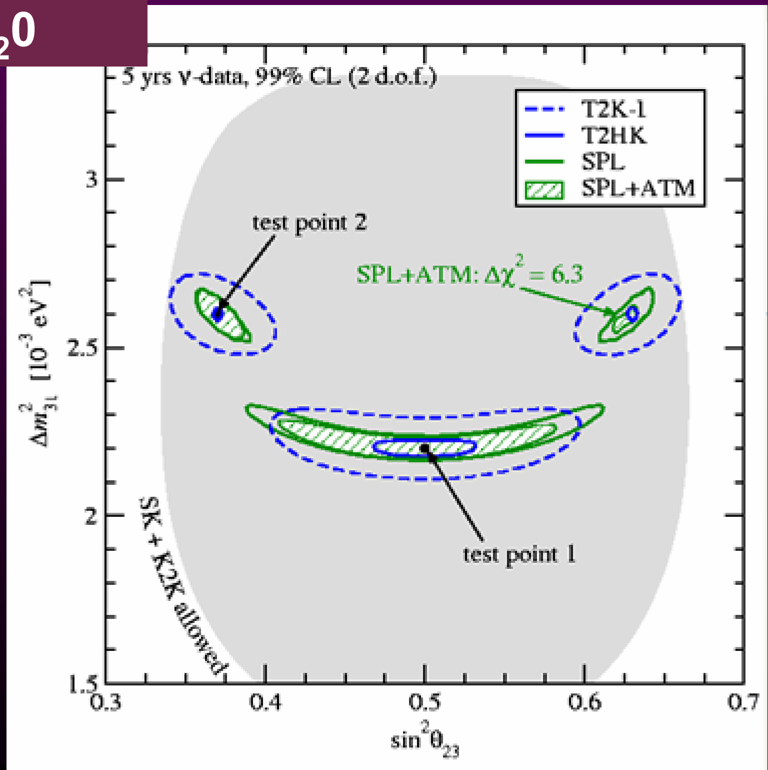
Cleaner and more intense beams + bigger detectors

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

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



H_20



precision area!

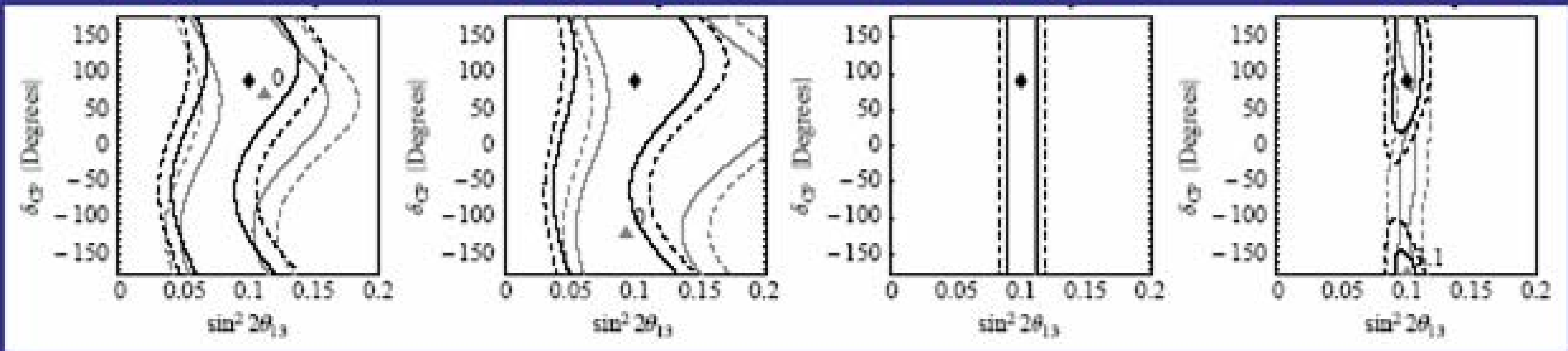
T2HK E_ν~ 750MeV
SPL E_ν ~ 300MeV
(Fermi motion limitation)

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

CP-phase and hierarchy within ten years

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

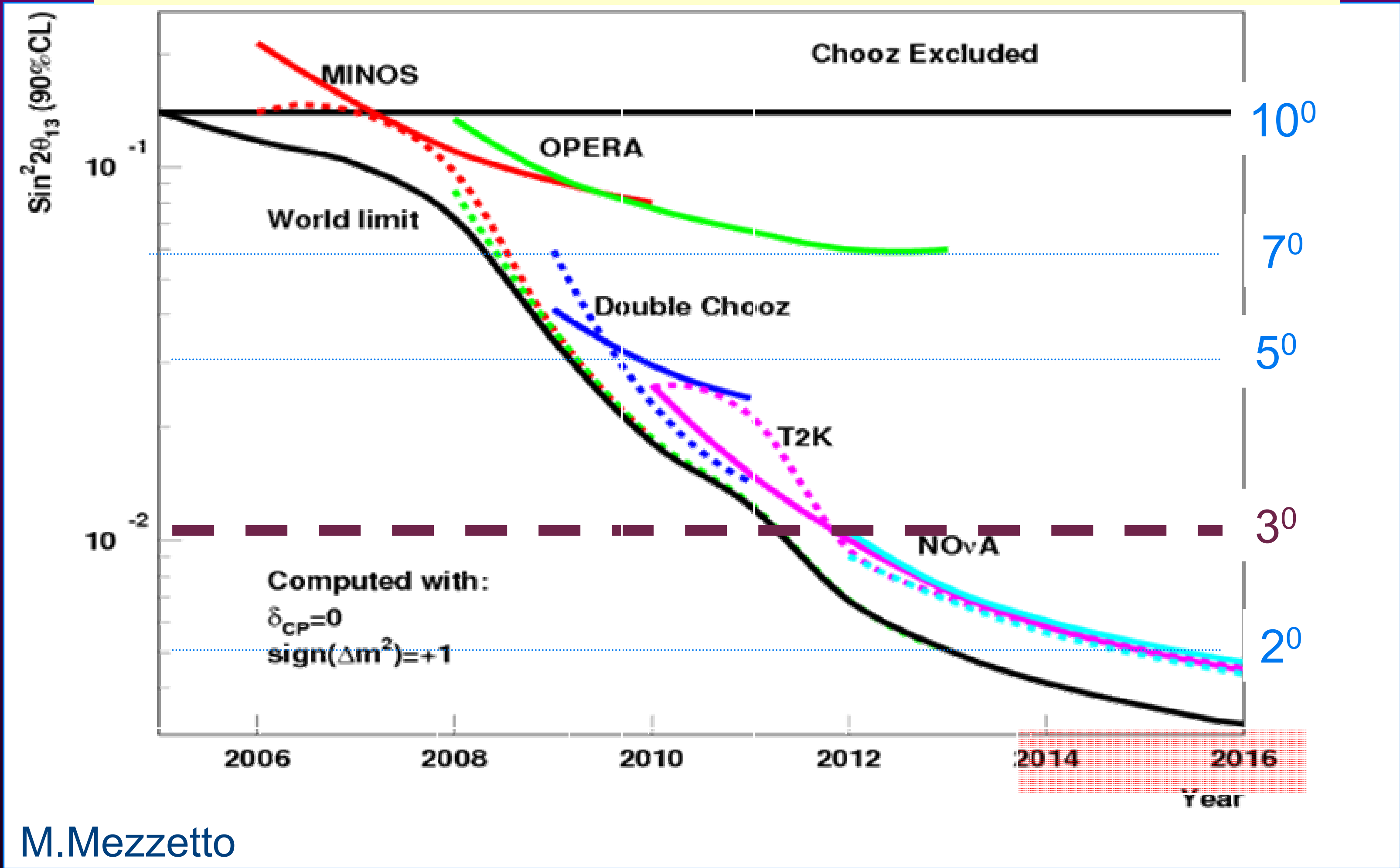
T2K NOνA Reactor-II combined



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

θ_{13} : sensitivity time evolution (take care…)

If θ_{13} is found on the road the priority will have to be adapted



Weak sensitivity to CP̸

Limit of the exp.

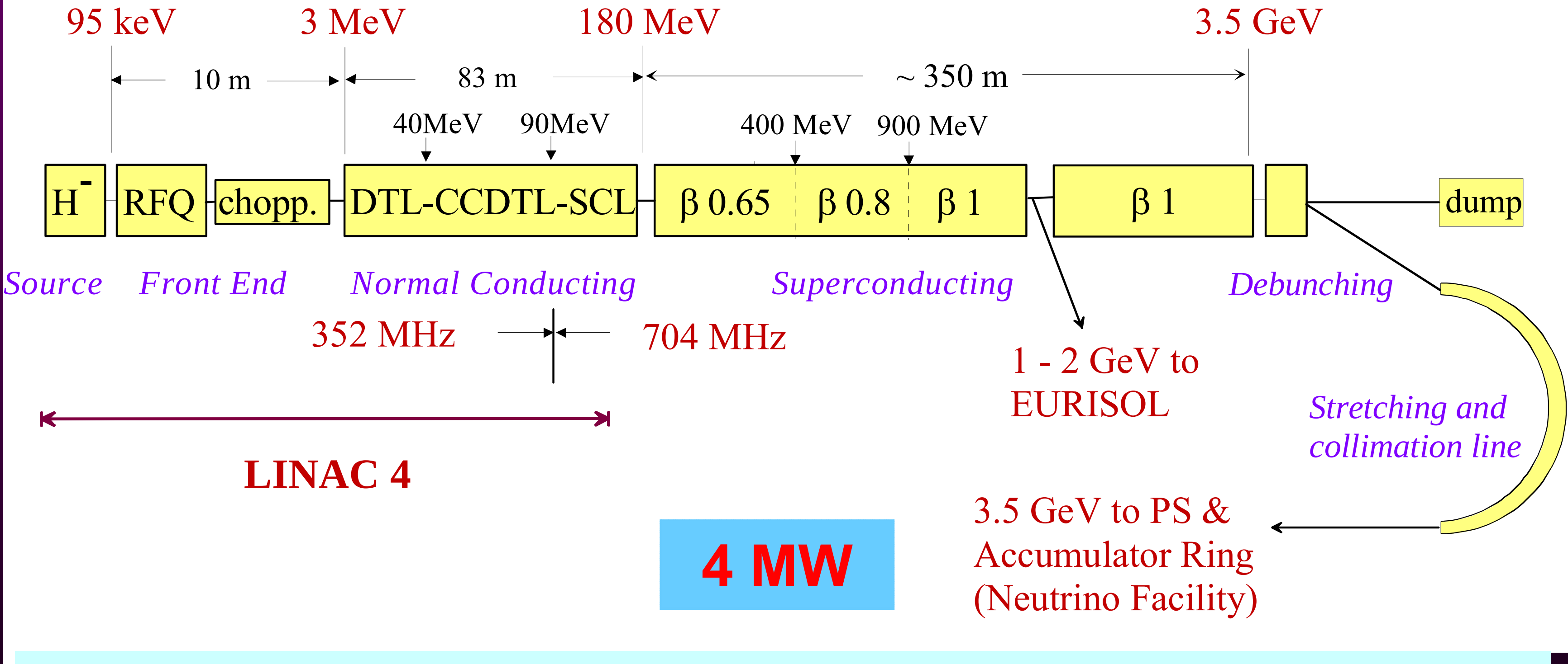
Word Limit wo the exp.

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

How to overcome Super Beam limitations ?

Main problem :

SPL protons produce less negative pions, so less antineutrinos

antineutrino cross-section ~ 5 times smaller than neutrinos

So 10 SPL years have to be shared as ~ 2 neutrino + 8 antineutrino years

A solution :

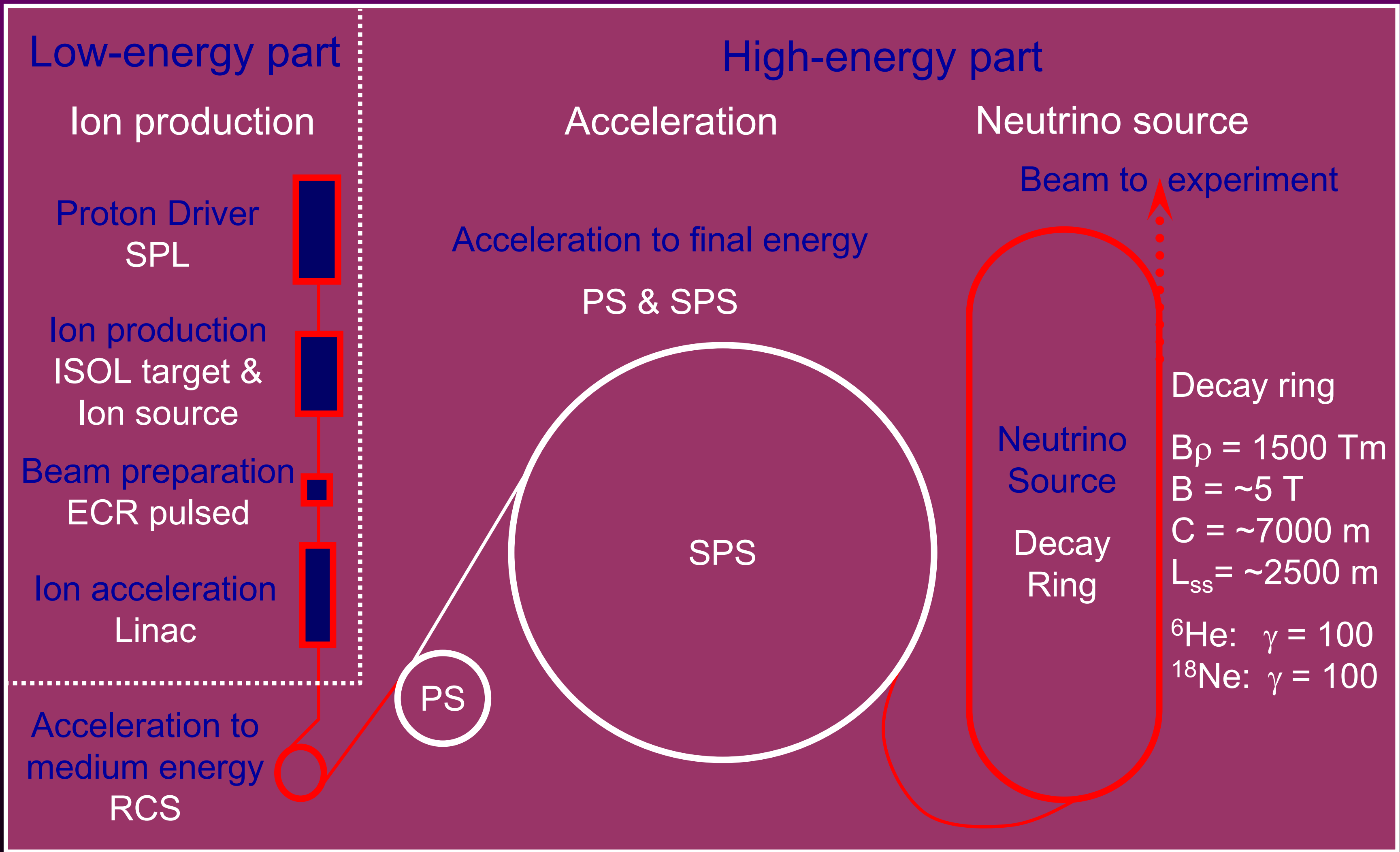
Produce a ν_e beam to study $\nu_e \rightarrow \nu_\mu$ oscillation and run it SIMULTANEOUSLY

with ν_μ beam from SPL

Compare $\nu_\mu \rightarrow \nu_e$ and $\nu_e \rightarrow \nu_\mu$ (T asymetry, equivalent to CP asymetry)

THIS WAS THE INITIAL MOTIVATION FOR A BETA BEAM

Beta-beam baseline design



Super Beam + β Beam + MEMPHYS

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

2 beams

1 detector

SUPERBEAM

4 ν flavours + K

2→5yrs $\nu_\mu \rightarrow \nu_e$

π^+/π^-

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

BETABEAM

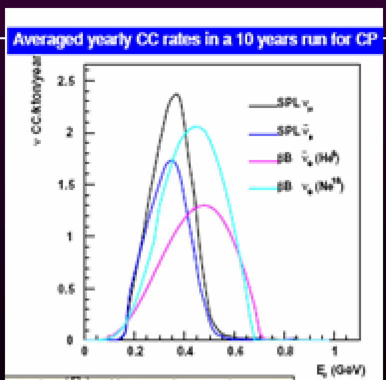
pure

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

^{18}Nd

^{6}He

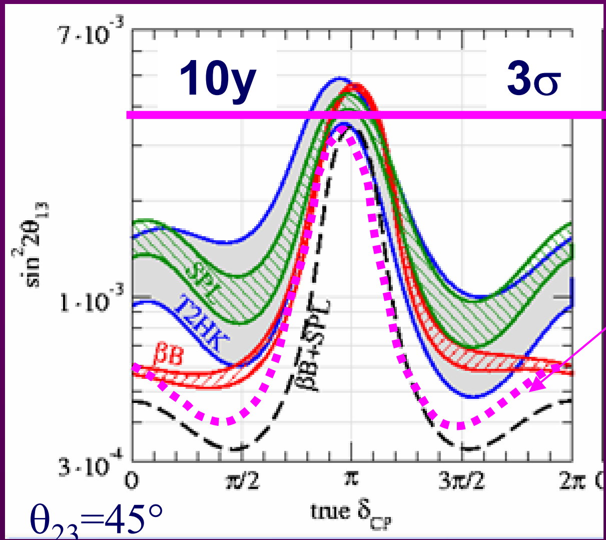
$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ 5yrs



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

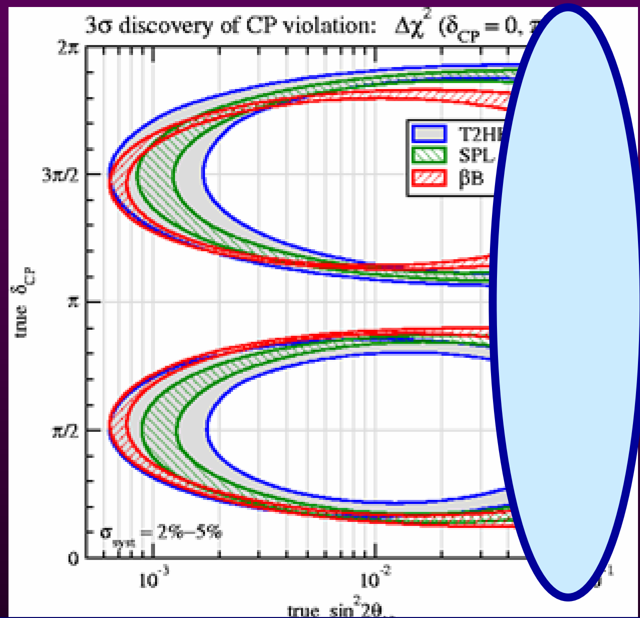


$\sin^2 2\theta_{13} < 4\ 10^{-3}$ en 10 ans

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

$\theta_{13} \neq 0$

Test CP̸



Study inside the ISS/BENE WG

Systematics dominant
SB: beam contents
SB et BB: x-section, eff./Bgd
(NF: matter profile, eff./Bgd)

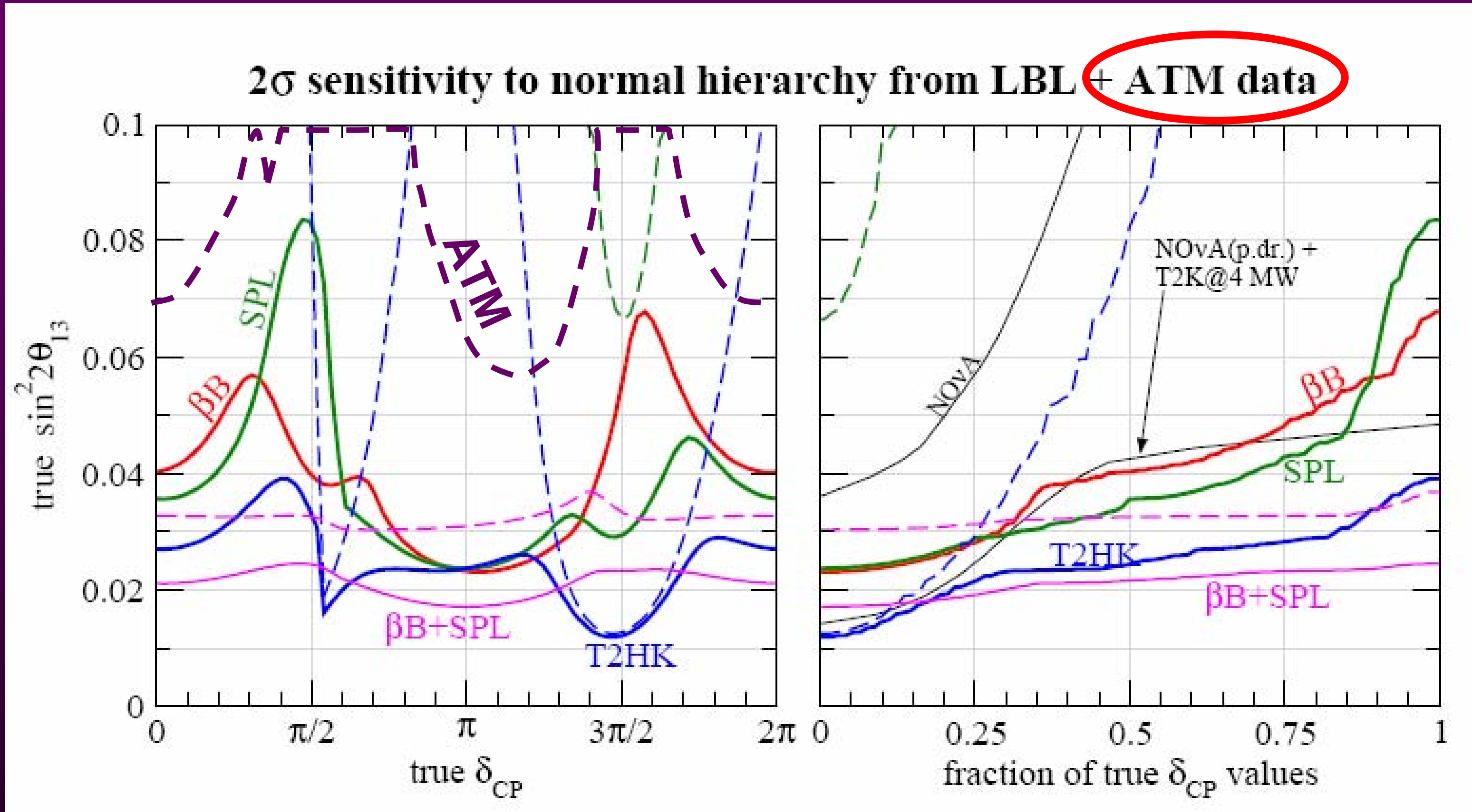
Band: 2%→5% syst
BB: 5+5y
SPL: 2+8y
T2HK: 2+8y
all: 440kT fid. mass

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

Mass hierarchy: Synergy βB & SPL, and also ATM

Contrary to Donini et al. statement

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



ATM: ν atmosph. 4.4Mt.y

– – –: LBL alone

____: LBL + ATM

Notice βB+SPL vs T2HK !!!

Not yet included in the paper

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:

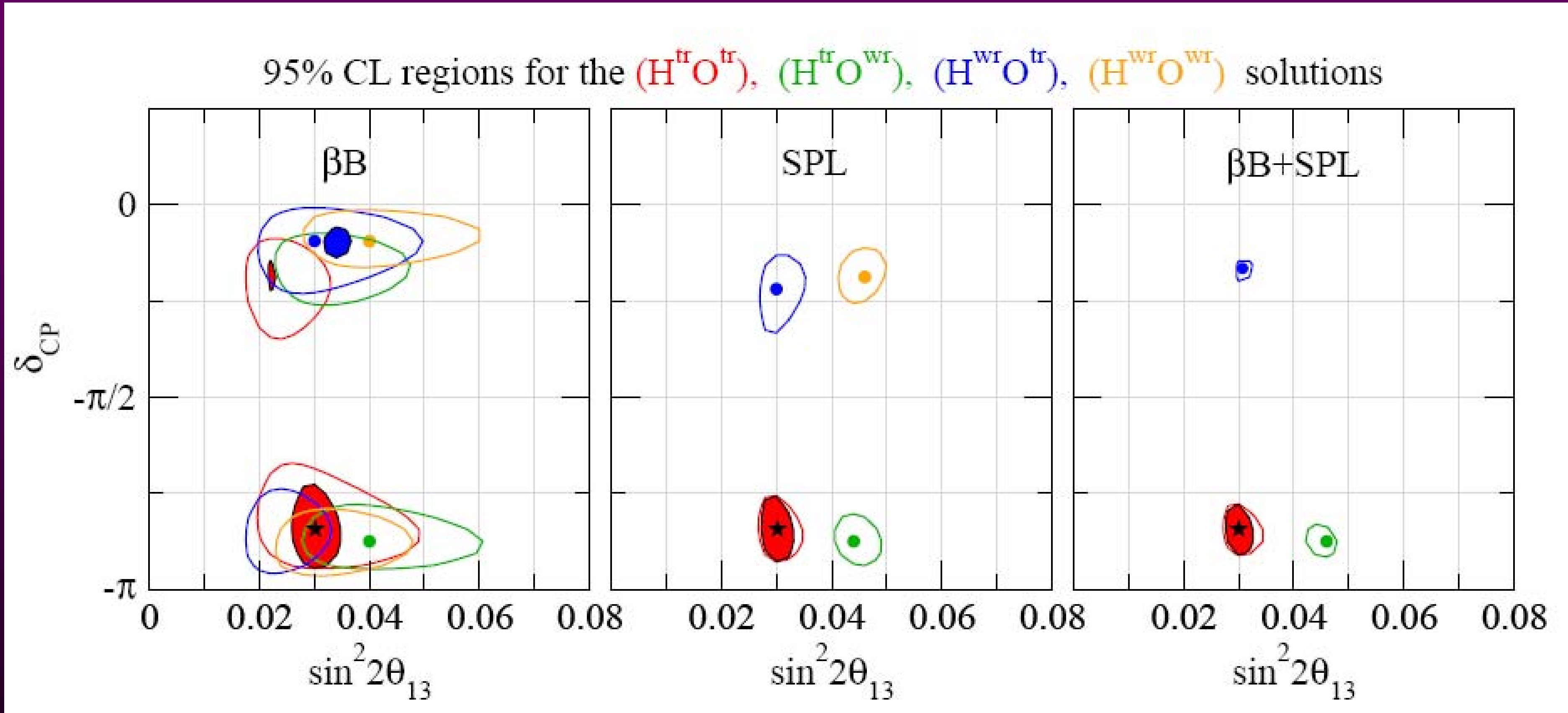
- combining information from detectors at different baselines and/or energies
  e.g., second osc. maximum, different off-axis angle
- using additional oscillation chanels ($\nu_e \to \nu_\tau$)
- spectral information (broadband beam)
- adding information on θ_{13} from a reactor experiment
- combing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

Th. Schwetz

MEMPHYS+ SPL+BB+ ATM

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

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



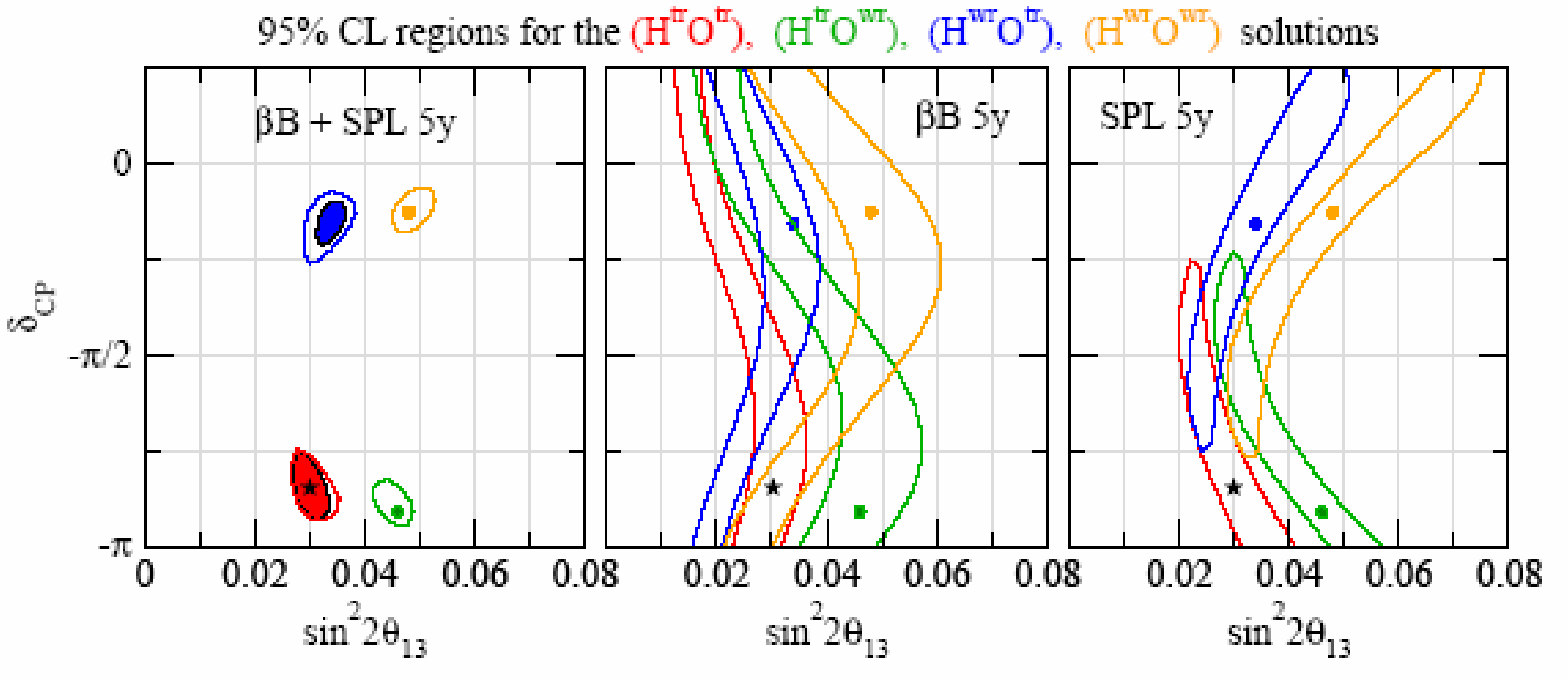
BB: 5+5y
SPL: 2+8y
440kT fid. mass

ATM can solve degeneracies!!!

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

Other way to solve the degeneracies: use ν_e and ν_μ

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



Still a wrong hierarchy clone with χ^2=3.3

A new very large laboratory in Europe ?

Results of a pre-study conducted by the SETEC Co. (present road tunnel)

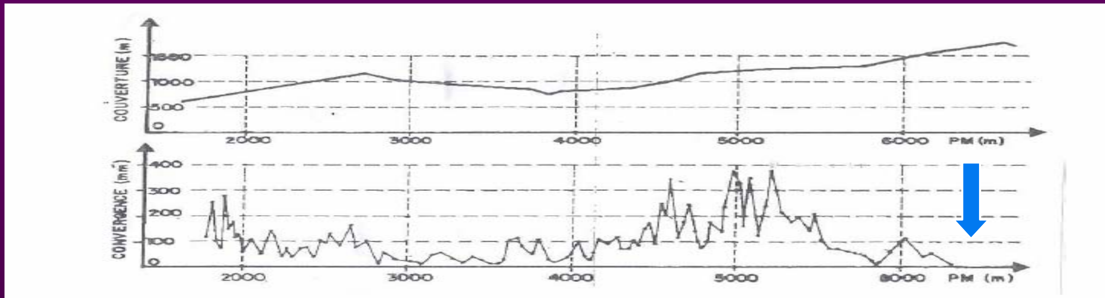
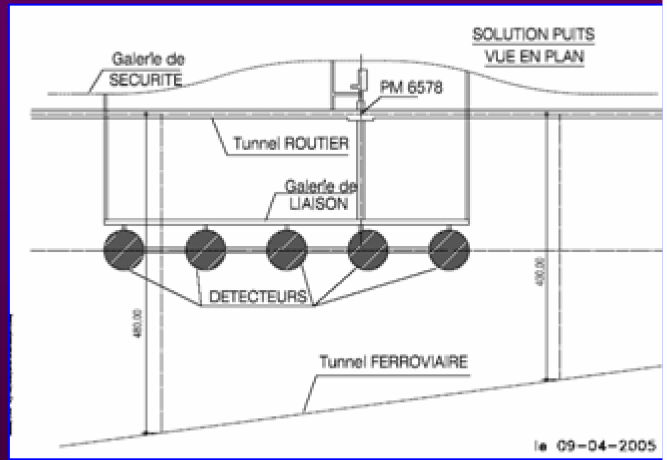
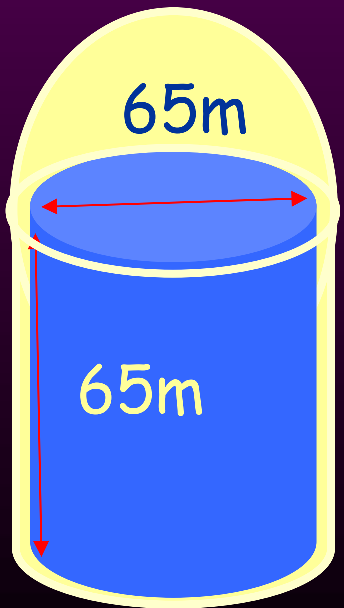


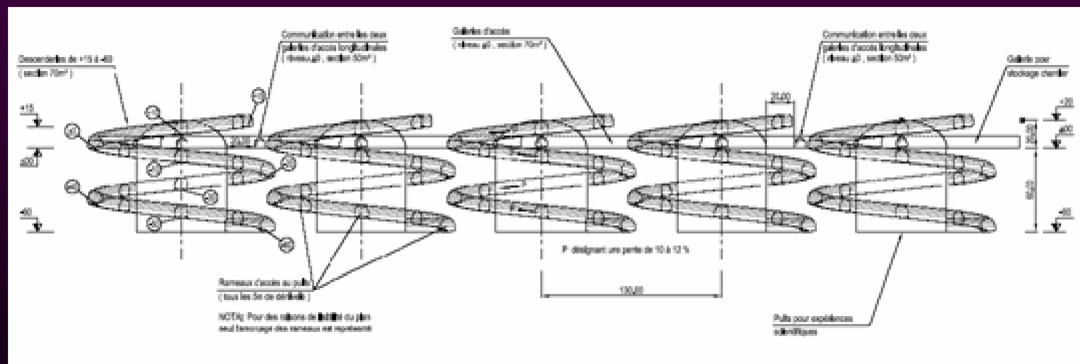
Figure 1.2 – Frejus Motorway tunnel, summary of the convergences between chainage 0+000 km and 7+000 km.



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



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

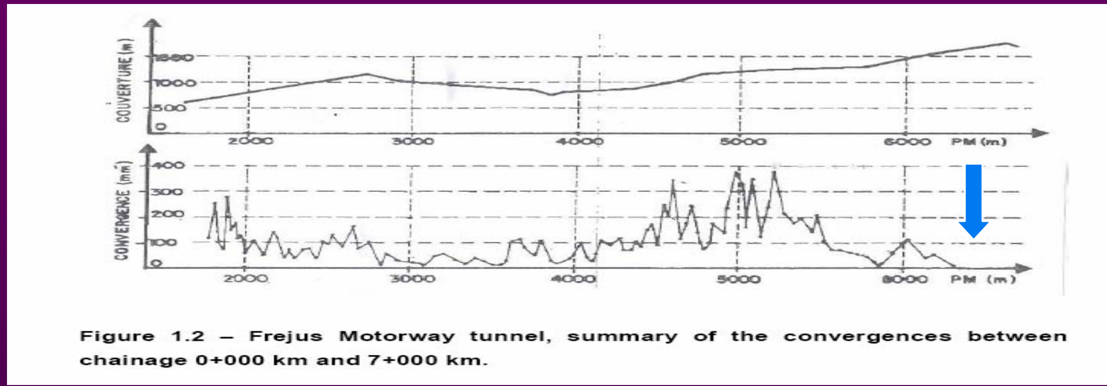


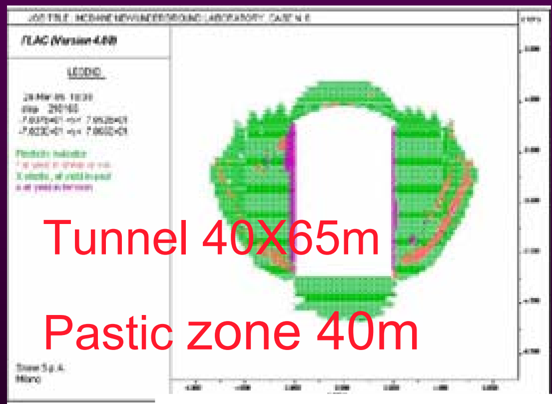
A simpler scheme under study of access tunnels

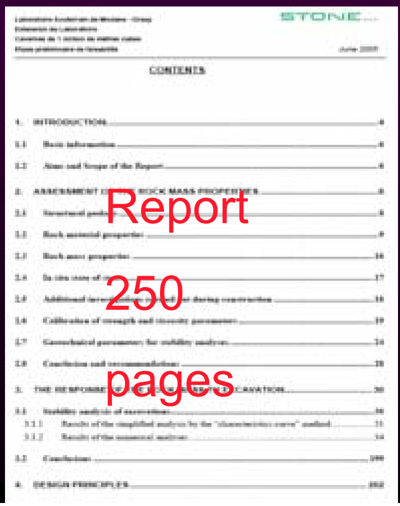
A new very large laboratory in Europe ?

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

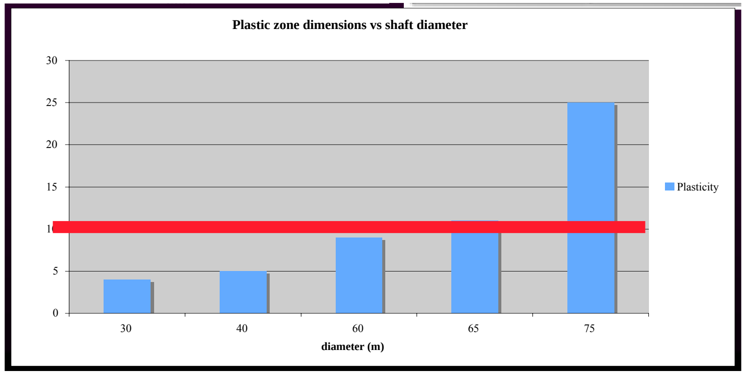
1) **The best rock quality is found in the middle of the mountain, at a depth of 4800 mwe**
2) **of all the 20 considered shapes : the "shaft (= well) shape" is strongly preferred**
3) **cylindrical shafts are feasible up to a diameter Φ = 65 m and a full height h = 80 m (≈ 250 000 m³)**







Plastic zone determines the length of iron bolts



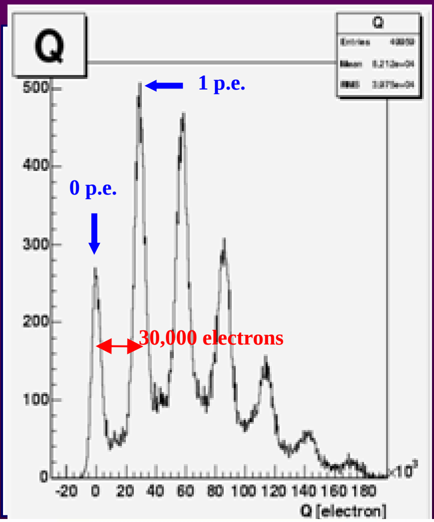
R&D Photodetecteurs

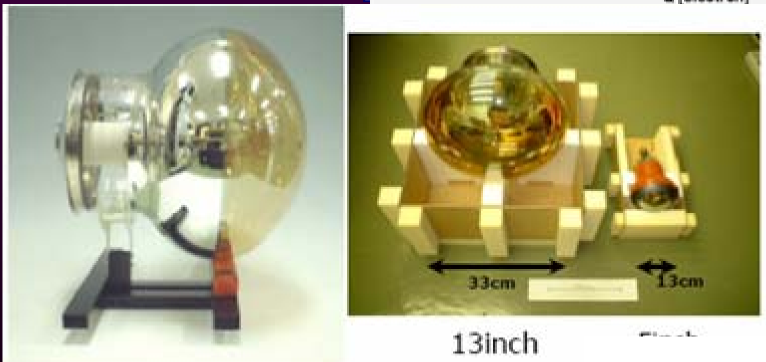
●Diameter	20“	<=>	12“
●projected area	1660		615 cm²
●QE(typ)	20		24 %
●CE	60		70 %
●Cost	2500		800 €
●Cost/p.e/cm	13		8 €

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

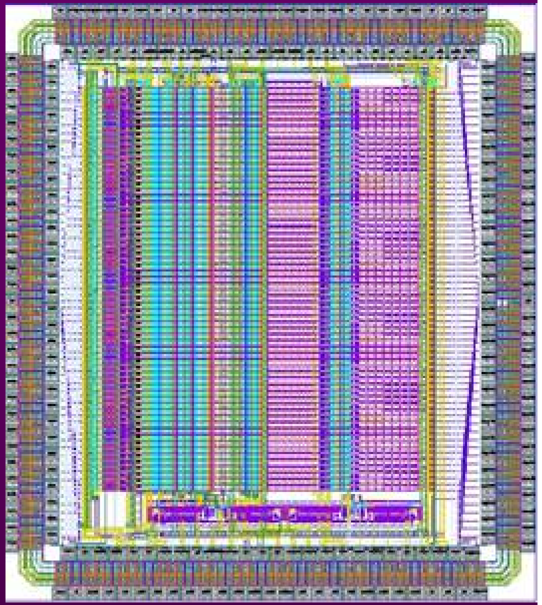
- Integrated readout : “digital PM (bits out)”
  - Charge measurement (12bits)
  - Time measurement (1ns)
  - Single photoelectron sensitivity

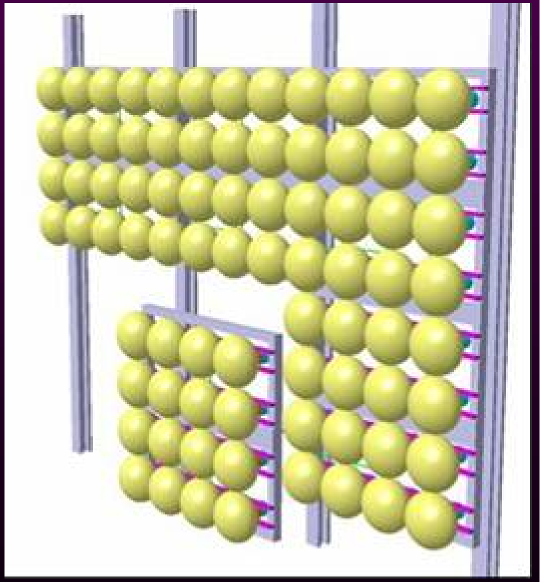
- High counting rate capability (target 100 MHz)

- 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?





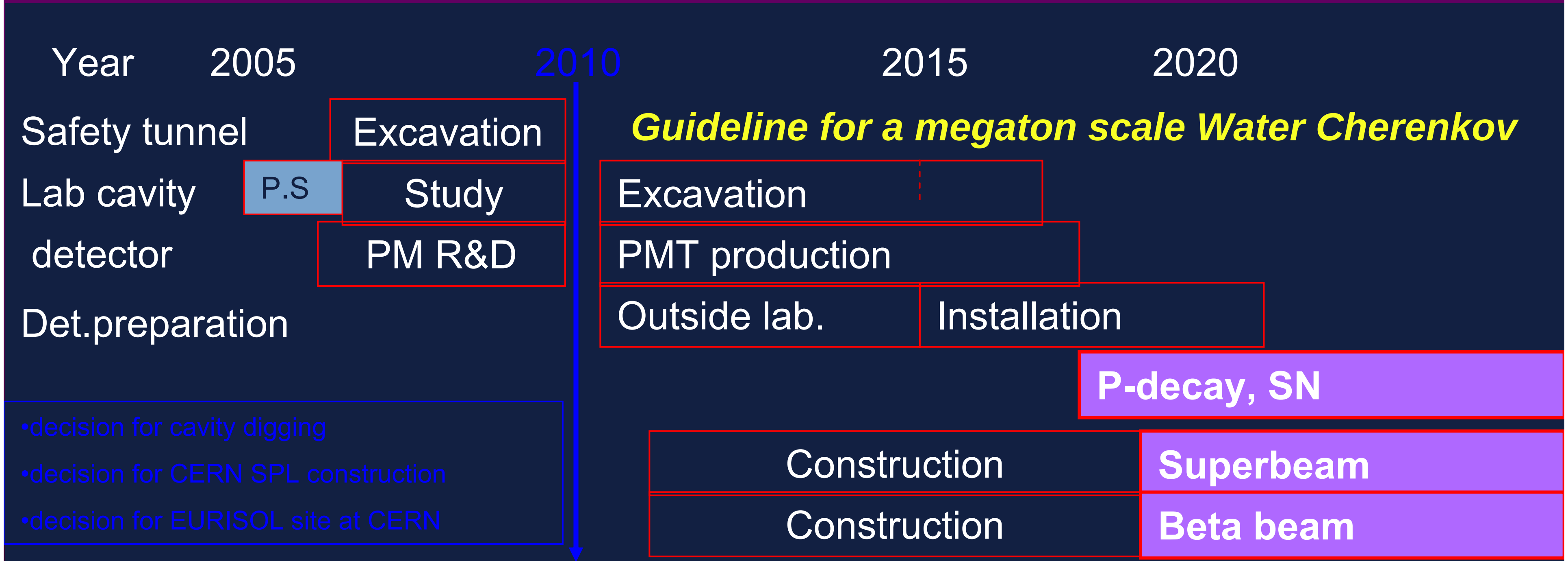
IPNO-LAL-LAPP

French funding agency
(ANR ≠ CNRS/IN2P3 and CEA)

- Demand for a Joint R&D :
  - LAL-IPNO-LAPP
  - Photonis Co.
  - 3years, 400k€, 1FTE physicist, 5FTE Engineers
- LAL: electonics: 100k€ + 1 post-doc
- IPNO: photodetector tests + mechanics: 180k€
- LAPP: Data network: 53k€
- Photonis: PMTs provider: 64k€

Expected answer in July 06

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

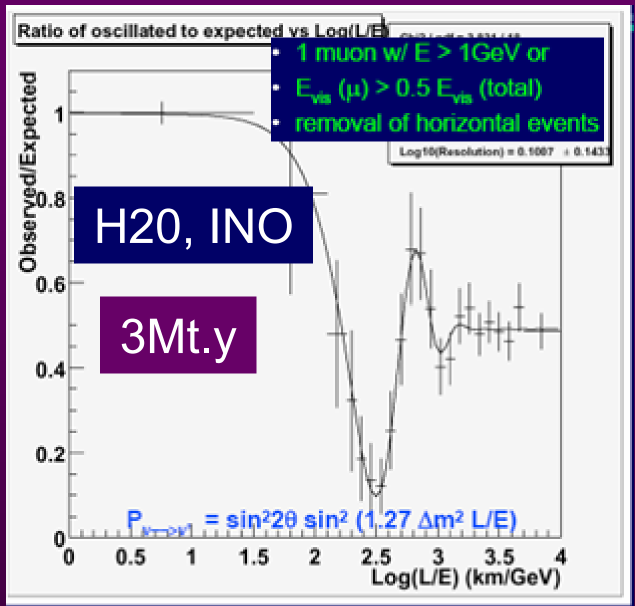
The 3 technologies have complementarity Physics and common R&D

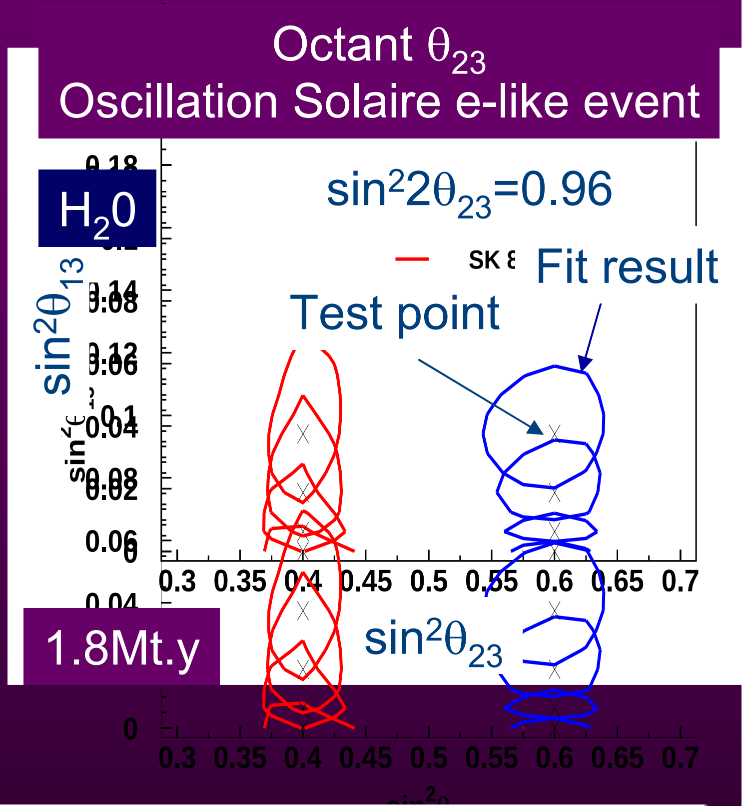
- **Networking activities**
- A1) Physics potential of Large Deep Underground experiments in both non- accelerator and accelerator sectors, interdisciplinary aspects (geoneutrinos)
- A2) Underground Laboratories for very large detectors : best strategies for excavation, access and equipments (ventilation, 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

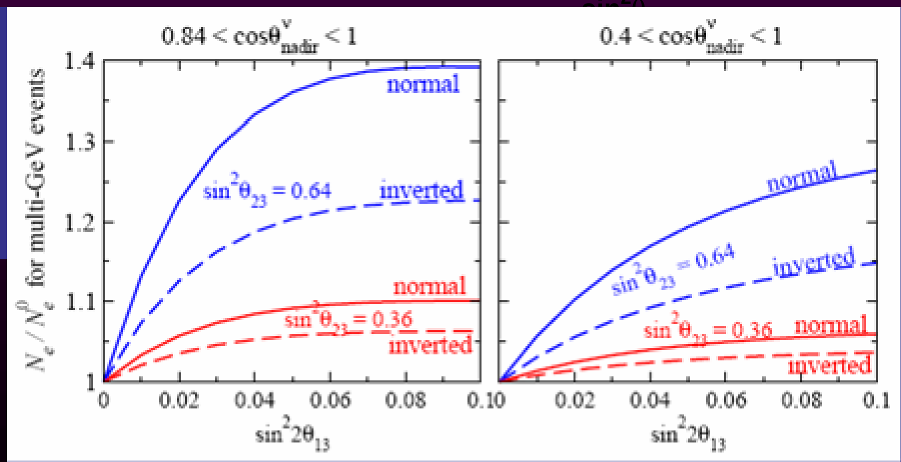
Propriété ν avec des ATM-ν seuls !!!





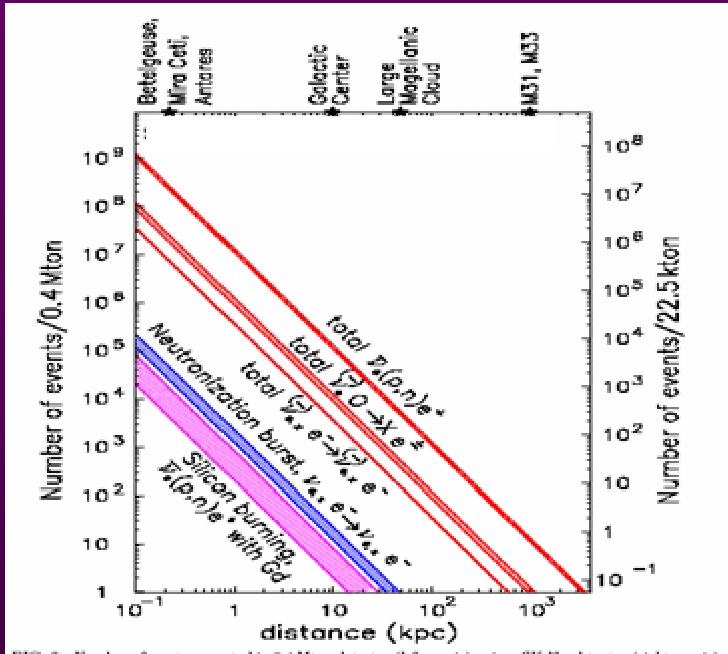
$$\frac{N_e}{N_e^0} - 1 \simeq (r\, s_{23}^2 - 1)\, P_{2\nu}(\Delta m_{31}^2, \theta_{13})$$

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

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

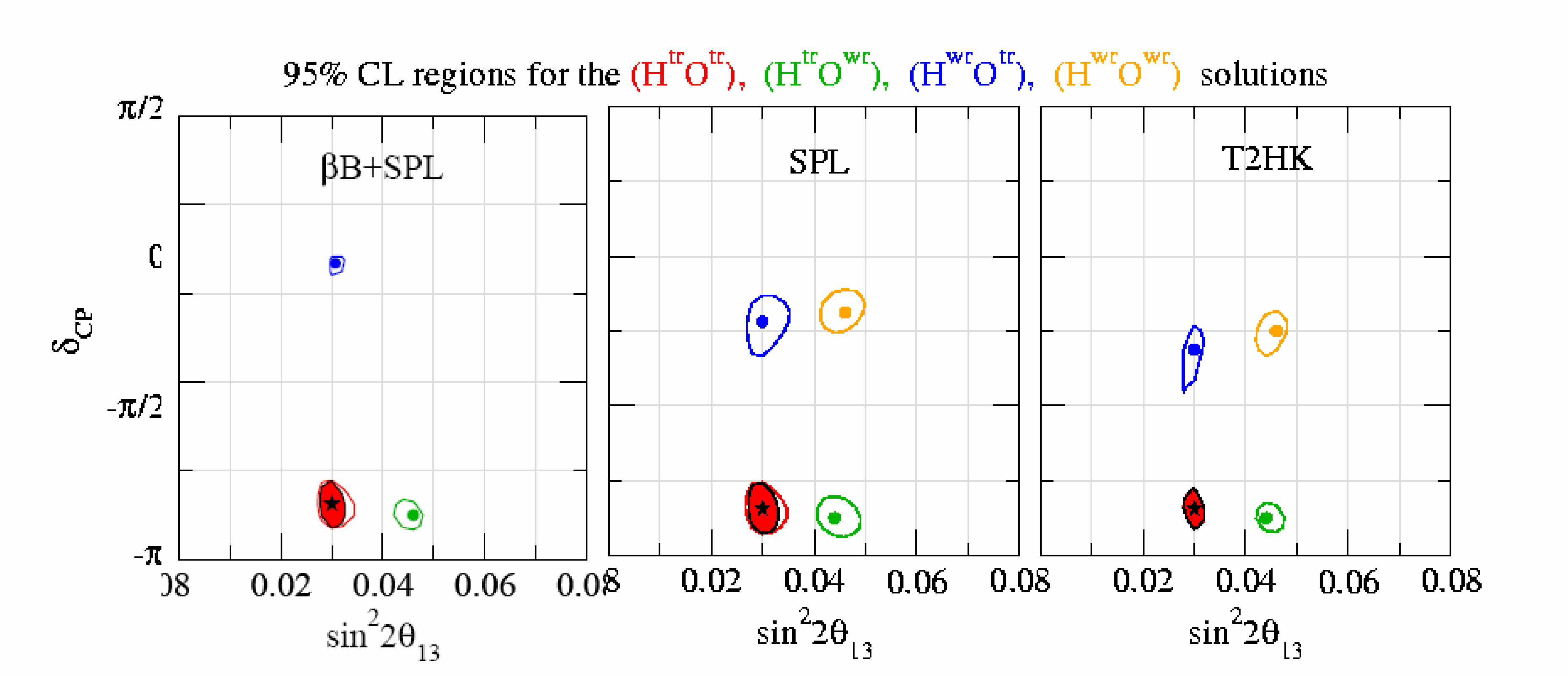
Model	Authors	Decay modes	Prediction	References
Complete 5D SU(5)	Y. Nomura, L. Hall	$e^+\pi^0$,$\mu^+\pi 0$ e^+K^0,μ^+K^0 $\overline{\nu}\pi^+$,$\overline{\nu}K^+$	$10^{33} - 10^{35}$	[9]
Two Step Non-SUSY SO(10) (Landscape inspired)	D.G. Lee *et al.*	$e^+\pi^0$	$10^{28.5} - 10^{35}$	[10]
5D SU(5) Strongly 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.*	$\overline{\nu}\pi^+$ $n \rightarrow \overline{\nu}K^0$	$< 6.5 \times 10^{32}$ $< 3 \times 10^{33}$	[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

H_20 + ATM

O: θ_{23}Octant H: sign $|\Delta m^2_{31}|$ **$\sin^2\theta_{23}$=0.6**

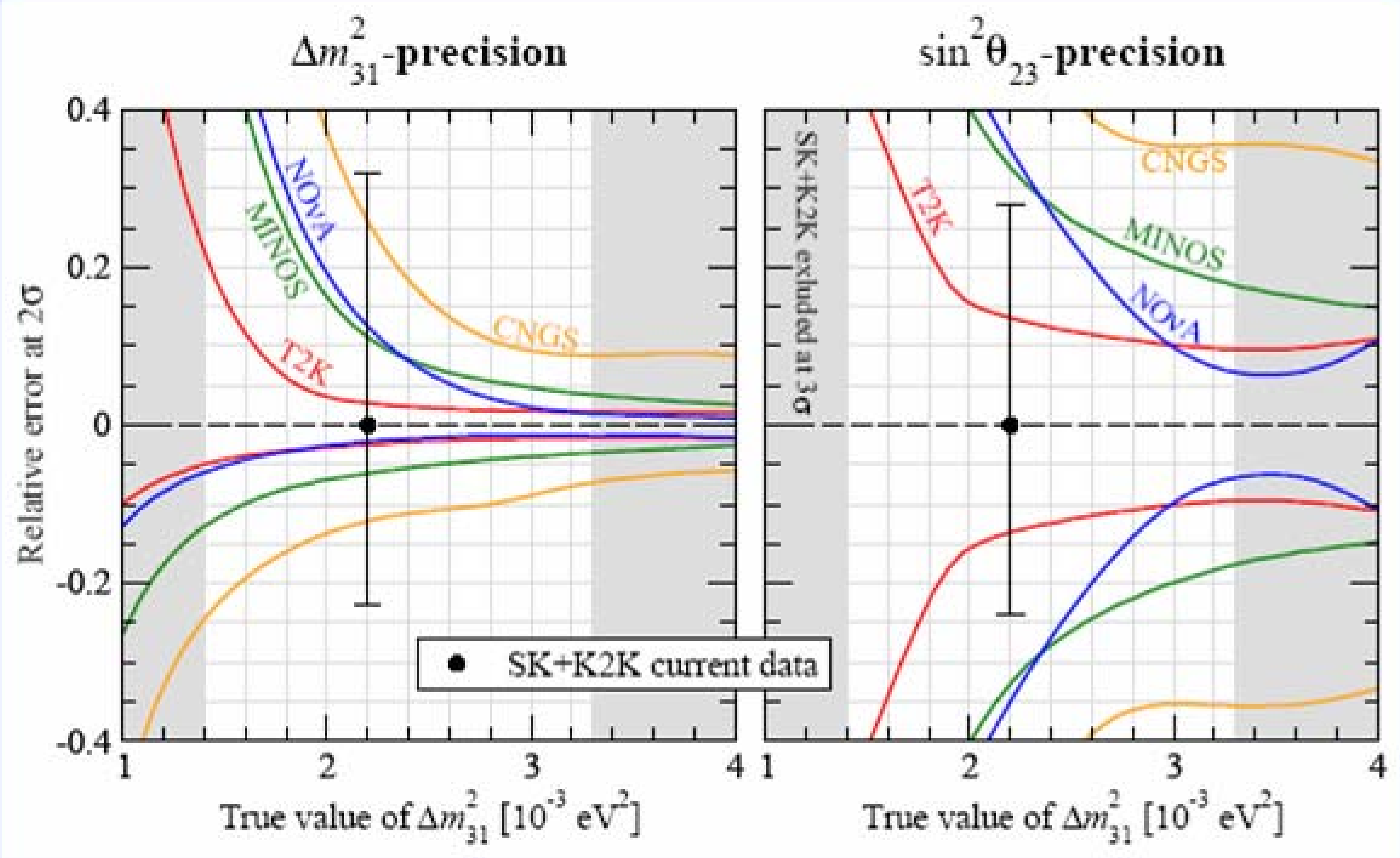


BB: 5+5y
SPL: 2+8y
T2HK: 2+8y
all: 440kT fid. mass

ATM can solve degeneracies!!!

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

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



Mass hierarchy: ATMν do the job!

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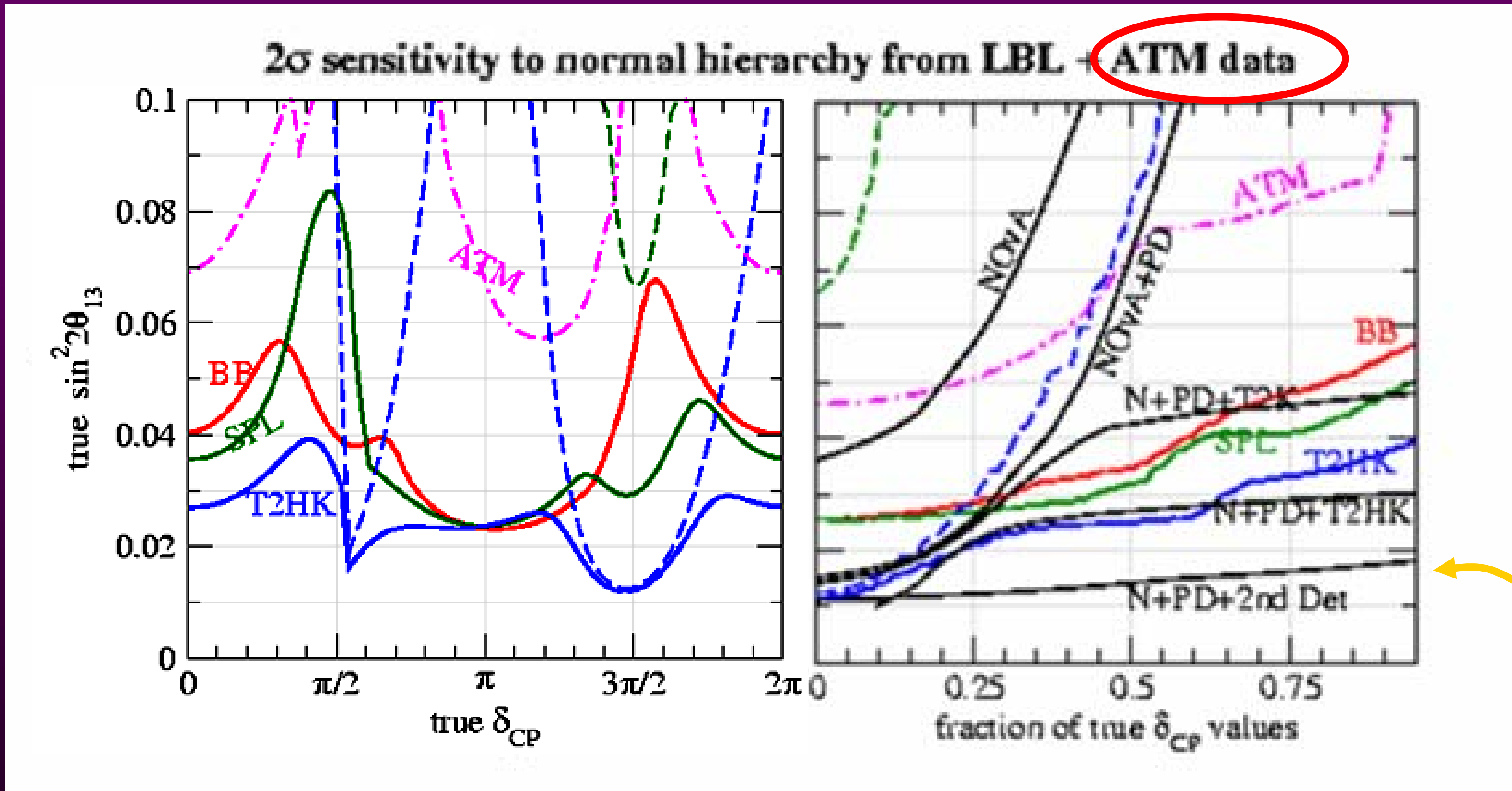

ATM: ν atmosph. 4.4Mt.y

– – – : 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 2^nd Det

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

710km, 2nd Pic Off Axis

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