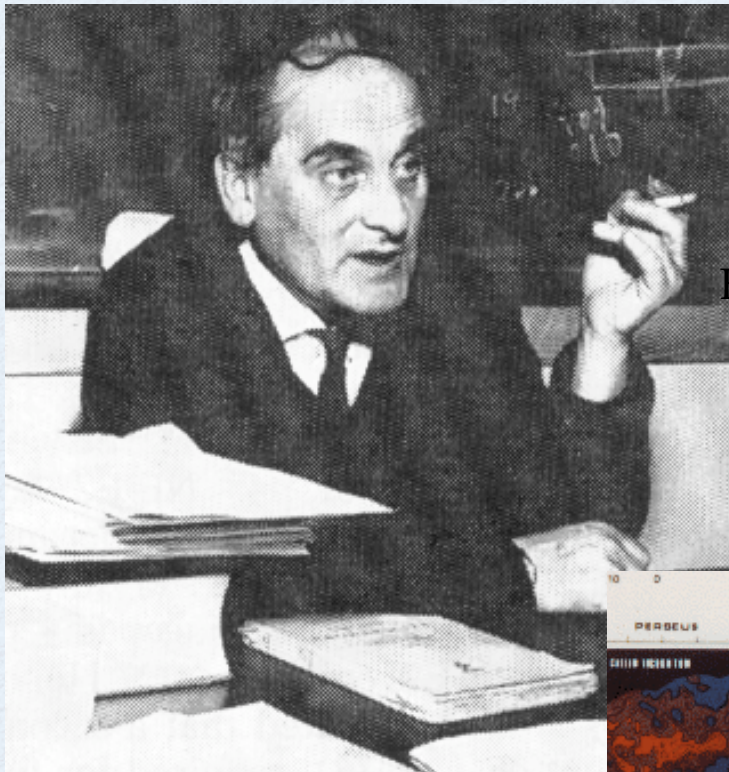


- MATERIA OSCURA MASSA NEUTRINI E CSN2

G Occhialini e astroparticelle

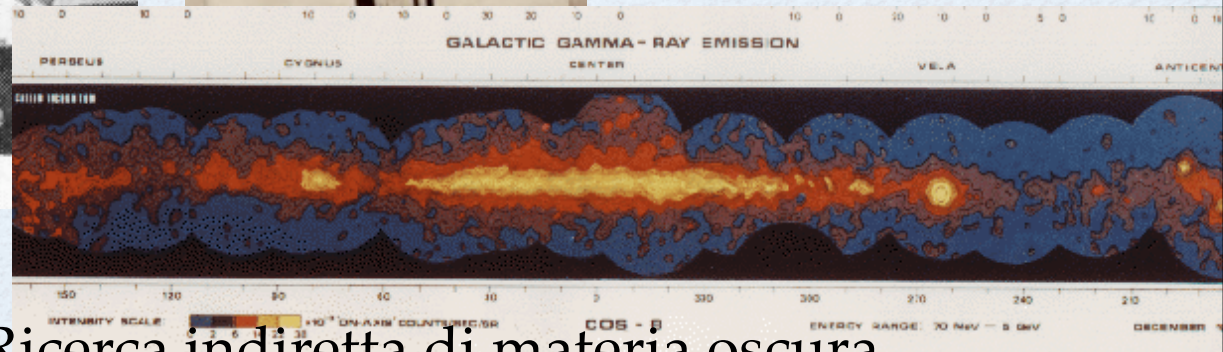


Emulsioni ancora usate in Ol
(oscillazione neutrini)



Cos B:

1975- prima missione ESA
per astronomia gamma



Ricerca indiretta di materia oscura

MATERIA OSCURA

VEDI ANCHE PROSSIMO NUMERO DI ASIMMETRIE

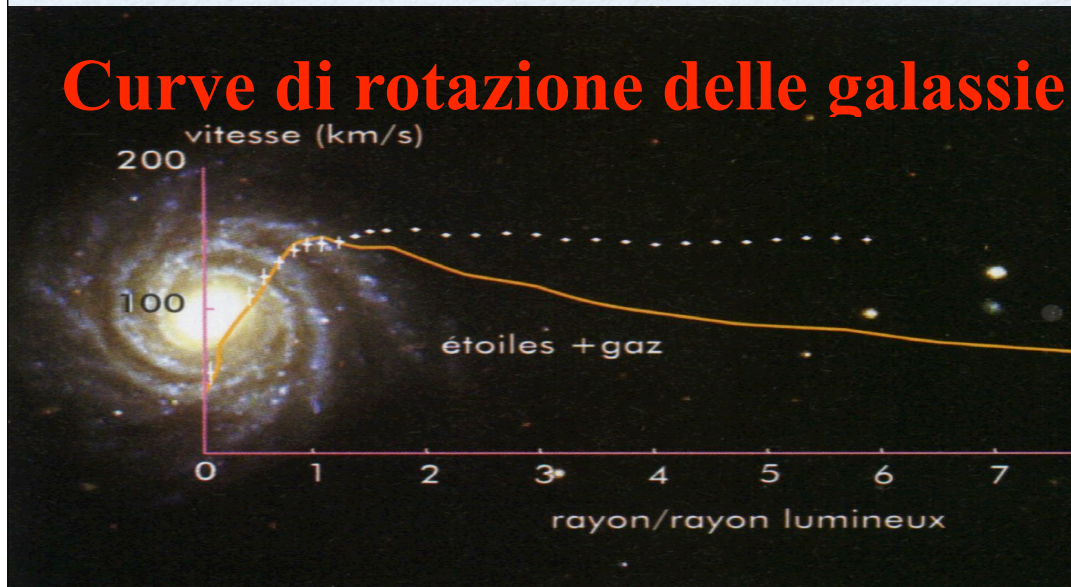
- Motivazioni astronomiche e cosmologiche:

Roncadelli: Aspetti astrofisici della materia oscura (Bibliopolis 2004)

- Fino agli anni 1930 anomalie nelle orbite hanno suggerito spesso compagni oscuri (prima applicazione 1844 con Sirio poi 1862 scoperta di Sirio B)
- 1932 -1933 studio del moto di stelle e galassie, teorema del viriale ad ammasso Chioma di Berenice (Oort, Zwicky..)
- solo dal 1970 in poi con la necessità di ipotizzare materia oscura non barionica materia oscura diventa sinonimo di nuova fisica (nuove particelle)

MATERIA OSCURA O MANCANTE

Curve di rotazione delle galassie



La materia oscura è presente a tutte le scale, aloni galattici inclusi, incluso il nostro quello della nostra Galassia. Se materia oscura costituita da particelle esse debbono avere scarse possibilità di interazione.

WIMPs = weakly interacting massive particles

Nel sistema galattico: distribuzione di velocità = Maxwelliana troncata alla velocità di fuga, $v_{esc} \approx 500-600 \text{ km/s}$

Ordine di grandezza $\langle \beta_\chi \rangle \approx 10^{-3}$, simile a stelle, simile a elettroni atomici

Densità attesa $\rho_\chi \approx 300 \text{ TeV m}^{-3}$

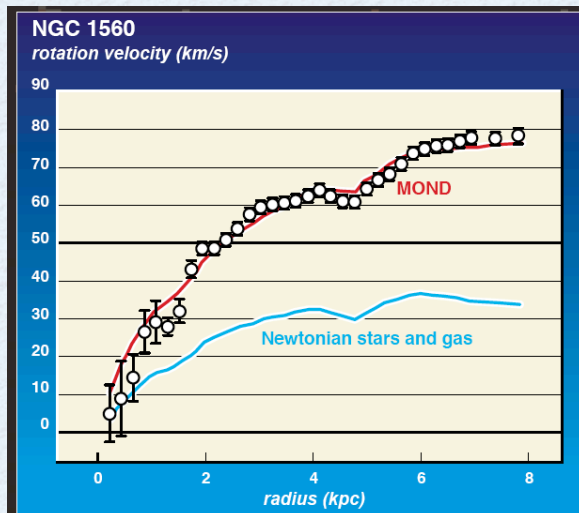
Per $m_\chi \approx 100 \text{ GeV}$ densità numerica, $n \approx 3000/\text{m}^3$ flusso $\Phi_\chi \approx 10^9 \text{ s}^{-1} \text{ m}^{-2}$

Energia cinetica tipica $E_{kin} \approx 50 \text{ keV}$

MODIFICHE DELLA GRAVITÀ?

MOND=modified newtonian dynamics

- modifiche “empirica” legge $F=ma$ per a molto piccoli ($a \sim 2 \times 10^{-10} \text{ m}^2 \text{ s}^{-1}$) $F = m a \mu(a/a_0)$ $\mu \rightarrow 1$ $a \gg a_0$ $\mu \rightarrow 0$ $a \ll a_0$
- Anomalia della sonda Pioneer $F = 8.74 \pm 1.33 \times 10^{-10} \text{ m/s}^2$ ancora troppo vicino al sole per verifica MOND
- Possibilità di verifica sulla terra con rivelatori di Onde Gravitazionali?
 $a \sim 0$ in Groenlandia ed Antartide con $dt < 1 \text{ msec}$ (ma necessari approfondimenti) Ignatiev PRL 98 9 marzo 2007
- ~ok per la rotazione delle Galassie ma non spiega collisione di Galassie



Bullet cluster : collisione di due cluster di Galassie (2006)

Blu: materia da lente gravitazionale

rosso:
emissione X (gas caldi)

Chandra 0.5 Msec image

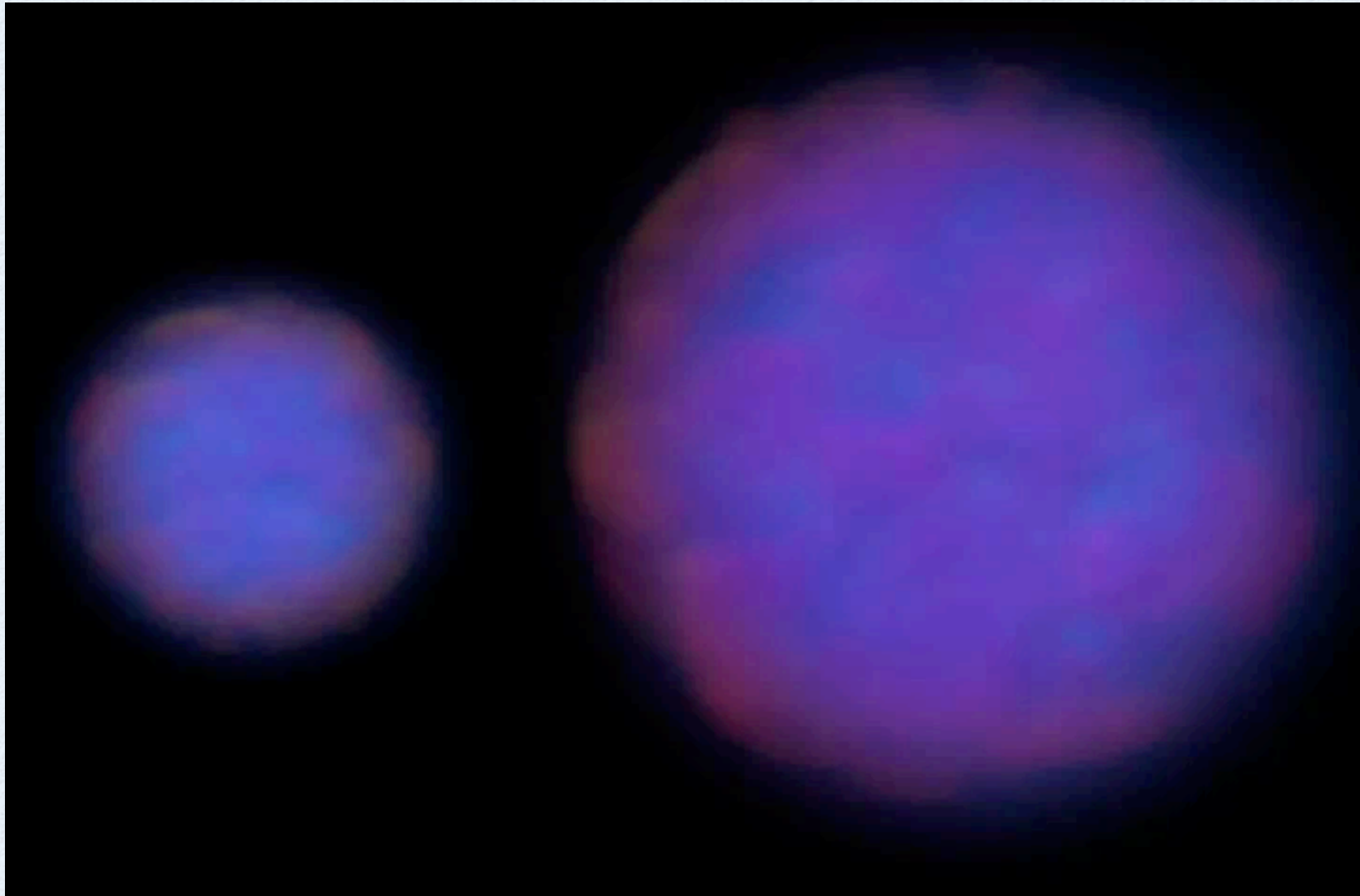
0.5 Mpc

$z=0.3$

2010

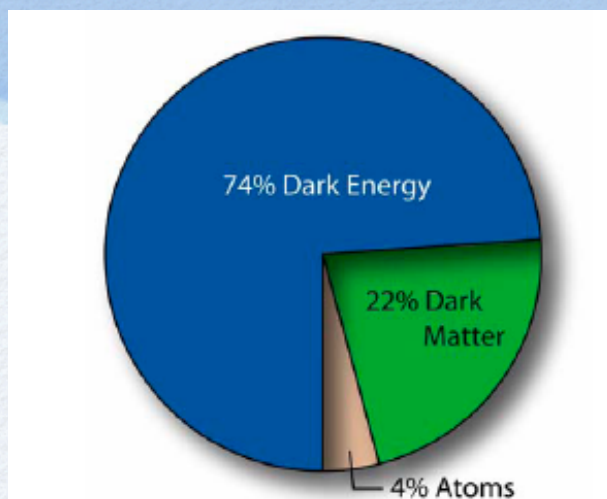
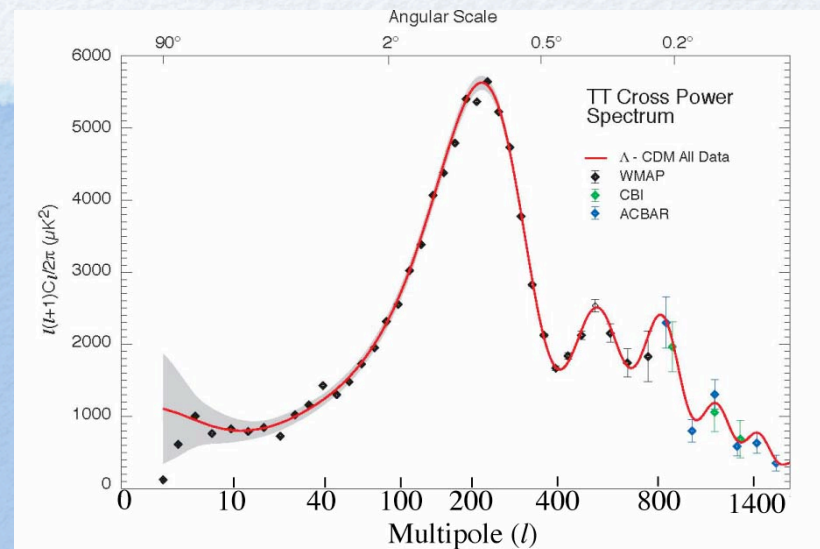
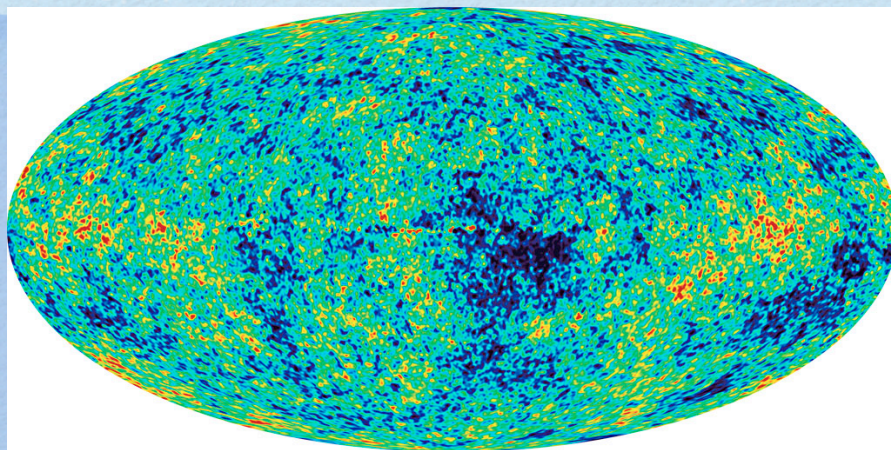
BULLET CLUSTER

ALL'INIZIO MATERIA OSCURA E MATERIA
NORMALE SOVRAPPOSTE



MASSA MANCANTE E BIG BANG

radiazione di Corpo Nero



$\Omega_m h^2$ da altezza 1° picco + posizioni picchi + LSS +
... = 0.127 ± 0.0008

$\Omega_b h^2$ (indipendentemente) = 0.0223 ± 0.0008

• **Nucleosintesi D_2 @ t = pochi secondi**

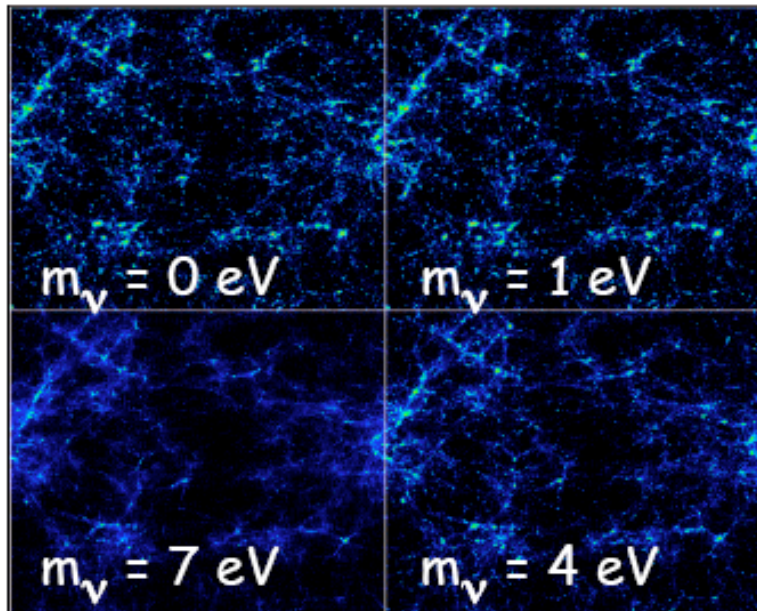
$\Rightarrow h^2 \Omega_b = 0.020 \pm 0.002$

vedi Sironi...

CONTIBUTO NEUTRINI A MASSA MANCANTE MOLTO PICCOLO

Neutrini erano considerati un buon candidato per la materia oscura

Neutrini leggeri si disaccoppiano a 1 Mev essendo veloci tendono a ridurre a concentrare le strutture iniziali



$$\Omega_\nu h^2 = \frac{\sum m_\nu}{93 \text{ eV}}$$

Cosmologia $m_\nu < 0.17 \text{ eV}$

Fogli et al Phys Rev D75 (2006)

Esperimenti trizio $m_\nu < 0.17 \text{ eV}$

(E.g., Ma 1996)

adattato da Masiero IFAE Napoli

F. Ronga Milano Piano Triennale 2008-2010

MATERIA OSCURA

POSSIBILITÀ

- **MACHO's** oggetti massicci oscuri (senza emissione di luce) $10^{-7} M_{\text{sun}} < M < 20 M_{\text{sun}}$ cercati con il “microlensing” (Paczynski, 1985) ed esclusi da esperimenti come EROS, MACHO, SUPERMACHO...
- **WIMPS**: weakly interacting massive particles, nome generico per indicare particelle stabili con piccolissima interazione, la più interessante come candidato è il **neutralino** (la più leggera e stabile delle particelle predette dalle supersimmetrie)
- **altri candidati** : **WIMPzilli** grandissima massa (raggi cosmici elevatissima energia), **Kaluza-Klein**, **nucleariti**, **assioni** ...

UN CANDIDATO GENERICO: WIMPS WEAKLY INTERACTING MASSIVE PARTICLES

Come cercarli?

- Produzione con acceleratori (LHC) *

- Metodo indiretto ricerca di segnali dovuti ad annichilazione al centro della terra, sole od oggetti astronomici

CSN2 : PAMELA,AMS,GLAST,AGILE,MAGIC (fotoni o antimateria) MACRO,ANTARES,NEMO: neutrini da terra o sole

- metodo diretto : interazione materia oscura alone galattico con rivelatore in ambiente a bassa radioattività (sotto terra LNGS..)

CSN2 : DAMA,WARP

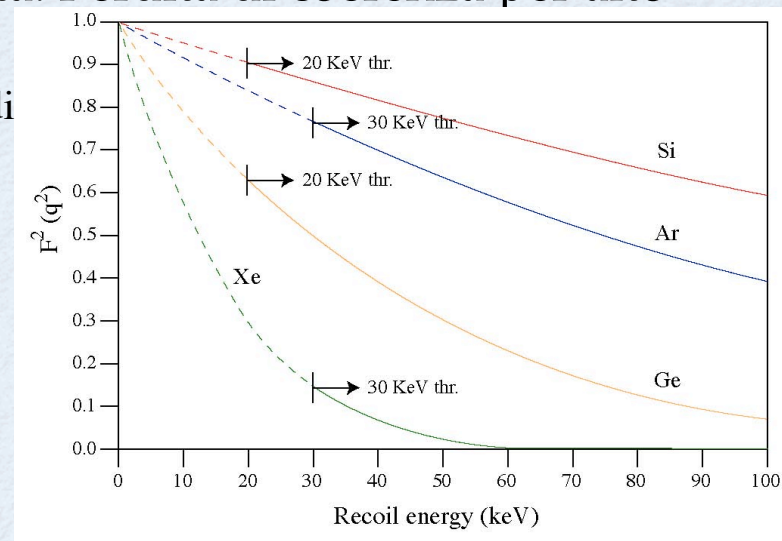
Approcci complementari ! Identificazione richiede molti esperimenti!

WIMPS: SEZIONE D'URTO

- I WIMPS possono interagire con accoppiamento sia dipendente sia indipendente da spin.
- Per un WIMP con entrambi gli accoppiamenti l'interazione spin indipendente con nuclei pesanti favorita da effetti coerenti. Molti esperimenti diretti fatti con nuclei pesanti per ottimizzare la sensibilità. Perdita di coerenza per alto momento trasferito.

Perdita di coerenza parametrizzata nel “fattore di forma” $F(Q)$, decresce circa esponenzialmente

Parametrizzazione solo grossolana; il suo uso rende insicuro il confronto dei risultati in nuclei diversi



- Ma anche modelli con accoppiamento spin indipendente fortemente soppresso, richiedono basso A ed alto spin
- **Accoppiamento non conosciuto!** Servono esperimenti con materiali diversi. Paragone tra esperimenti con materiali diversi difficile : **deve essere fatto con accuratezza**

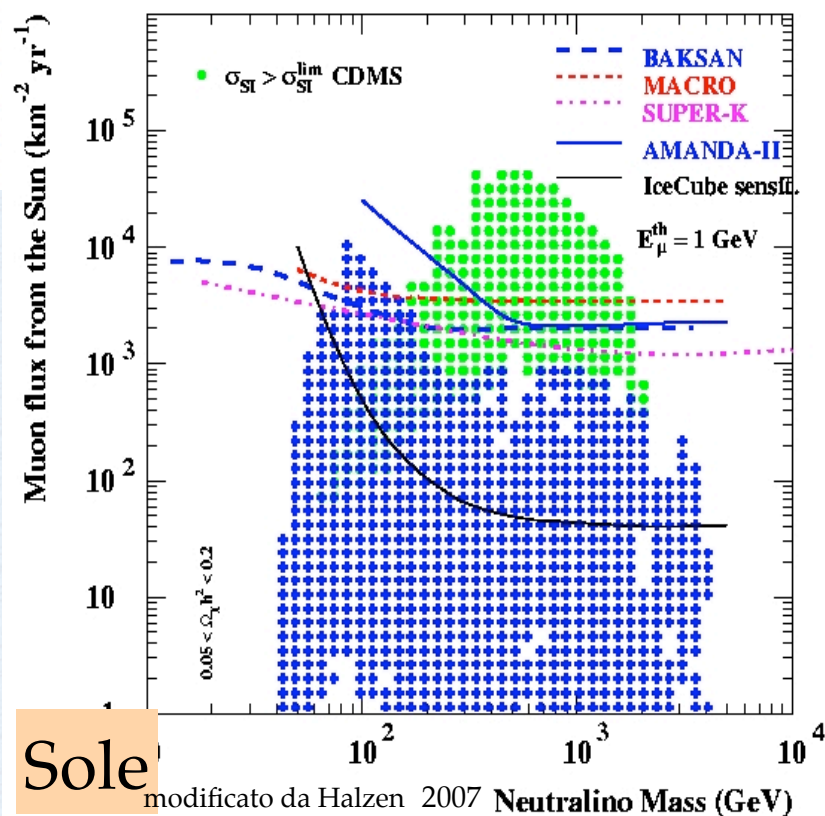
MUONI DA NEUTRINI DAL SOLE O DA CENTRO TERRA



CSN2: **MACRO** : terminato
ANTARES, NEMO, KM3
sottomarini



or yr^{-1})



Sole

RICERCA WIMPS INDIRETTA

ANTIMATERIA NEI RAGGI COSMICI

CSN2:

AMS01 shuttle

AMS stazione Spaziale

PAMELA satellite in orbita

Eccesso AMS01 potrebbe
essere correlato a neutralini,
ma possibili anche altre cause

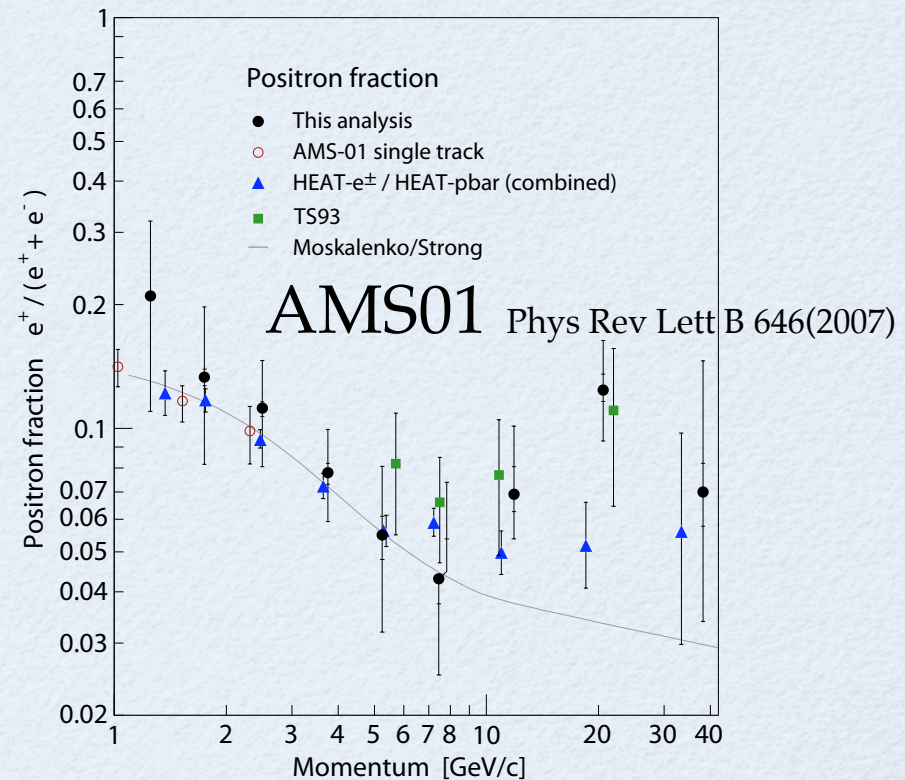


Figure 4: The positron fraction $e^+/(e^+ + e^-)$ measured in this analysis (filled circles), compared with earlier results from AMS-01 (open circles) [12], TS93 (squares) [13], the combined results from HEAT- $e^\pm$ and HEAT-pbar (triangles) [14], together with a model calculation for purely secondary positron production from [15] (solid line). The total error is given by the outer error bars, while the inner bars represent the systematic contribution to the total error.

RICERCA WIMPS INDIRETTA

ASTRONOMIA GAMMA

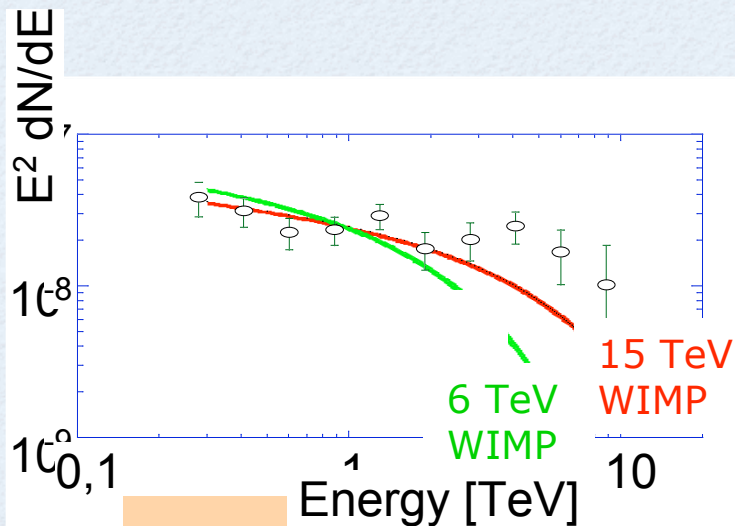
CSN2:

MAGIC : Cherenkov Canarie in funzione

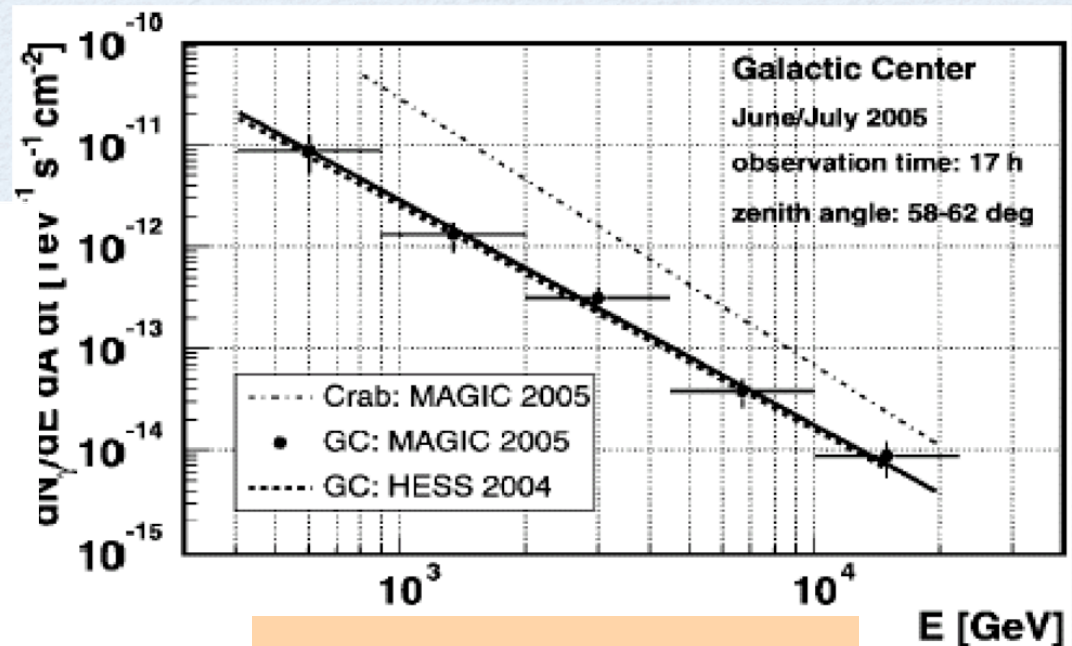
AGILE satellite in orbita

GLAST satellite inizio 2008

Un segnale da annichilazione nel centro galattico dovrebbe produrre un taglio nello spettro dei fotoni per masse elevate. A basse masse (10-100) GeV un segnale di annichilazione e' più difficile da individuare



Hess



Magic

Astrophys.J.638:L101-

Direct Detection WIMP Experiments Worldwide



Rivelazione di WIMP. Principi

Rivelatore=Bersaglio: misura l'energia depositata dal nucleo urtato E_{rec}

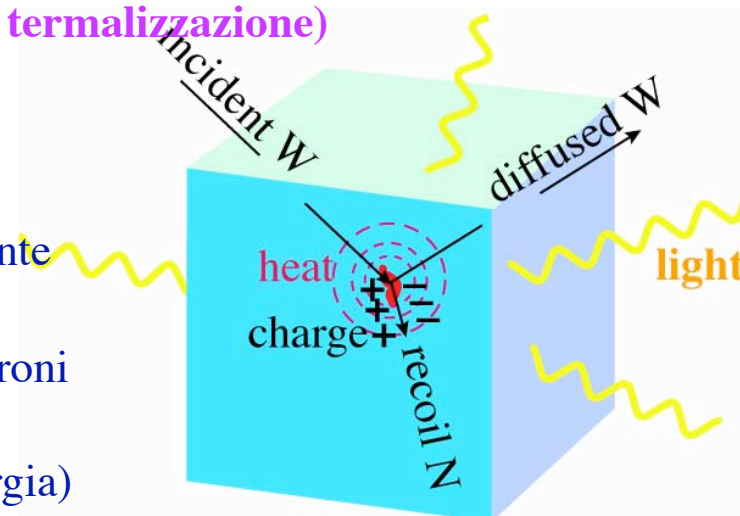
$E_{rec} \Leftrightarrow$ 3 forme: **elettroni**, **fotoni**, **fononi (= calore dopo termalizzazione)**

Problemi

- Bassa frequenza di conteggio
- Piccolo deposito di energia (pochi keV)
- Spettro segnale decresce rapidamente con E_{rec} crescente

•3 fondi di base

- elettromagnetico (β & γ); dominante $\Rightarrow$ rinculo=elettroni
- neutroni $\Rightarrow$ rinculo nucleare (=WIMP)
- contaminazioni su superficie (rilascio parziale di energia)



Armi contro fondi

- Lavoro in laboratorio (non basta un sito) sotterraneo
- Schermi passivi o attivi.** Solo contro fondi esterni. Sviluppo tecniche per materiali iper-puri.
- Discriminazione.** Contro fondi esterni e interni. Basata su diversità nella fisica dei depositi energetici di elettroni e di nuclei
- Reiezione “evento per evento”** (dopo tagli). Più potente per “zero” bkg
- Reiezione statistica.** Pericolo: il background non è modellizzabile accuratamente, non si può sottrarre. In presenza di background **sensibilità** $\propto$ (**esposizione**)^{1/2}

DAMA

1996-2002: esposizione **107731 kg d**

In soglia = 5.5-7.5 fotoelettroni/keV_{ee}

Soglia energetica software = 2 keV_{ee}

Caratteristiche attese

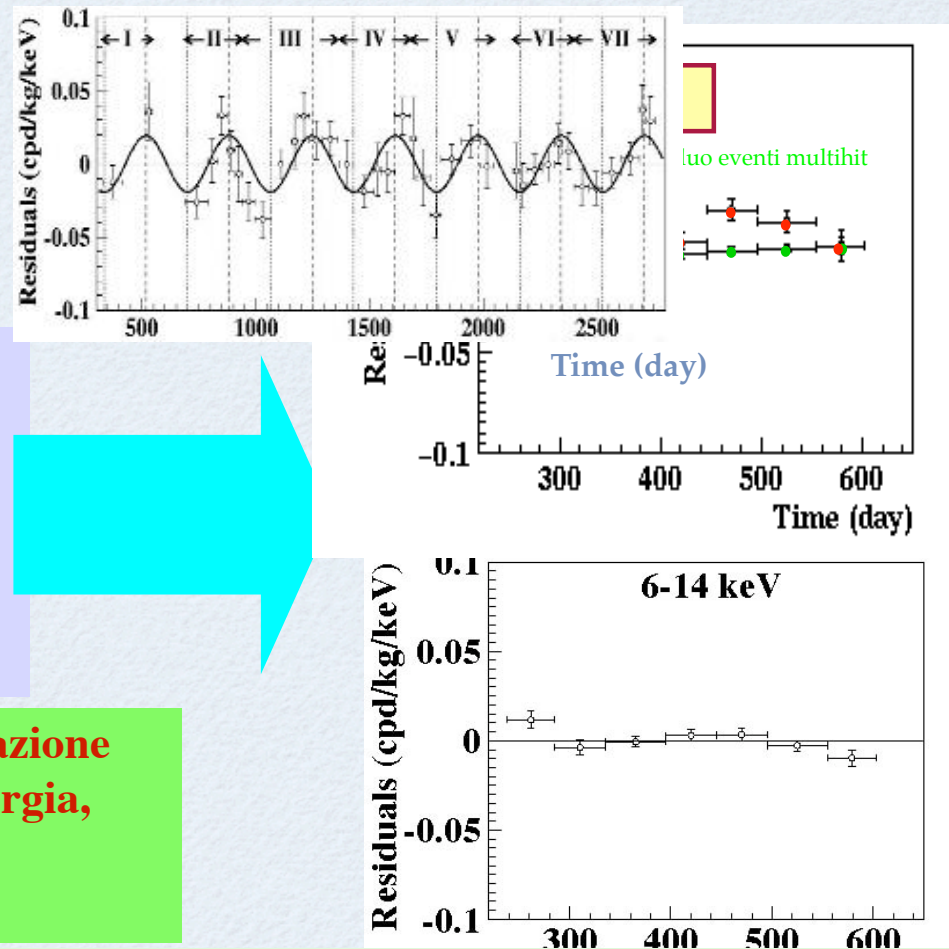
1. Dipendenza dal tempo = coseno
2. Periodo = 1 yr
3. Fase: max @ $\approx$ 2 giugno
4. Ampiezza: pochi %
5. Solo alle energie più basse
6. Hits in un solo cristallo

Controllate possibili origini spurie da variazione annuale di T , Rn, rumore, calibrazione energia, efficienza, backgrounds, flusso di μ
 $\Rightarrow$ tutti $<1\%$

LIBRA è il nuovo apparato DAMA con massa di NaI $\approx$ 250 kg + miglioramenti

In presa dati da marzo 2003

tecniche simili: KIMS in Corea 250 kg CsI, in sviluppo, ANAIS 100 kg NaI a Calfranco (Spagna)



DAMA LIBRAThe Stability Parameters

Modulation amplitudes obtained by fitting the time behaviours of main running parameters, acquired with the production data, when including a WIMP-like modulation

Running conditions stable at a level better than 1%

	DAMA/LIBRA-1	DAMA/LIBRA-2	DAMA/LIBRA-3
Temperature	$-(0.0009 \pm 0.0055) ^\circ\text{C}$	$(0.0026 \pm 0.0086) ^\circ\text{C}$	$(0.001 \pm 0.015) ^\circ\text{C}$
Flux N_2	$-(0.09 \pm 0.24) \text{ l/h}$	$(0.10 \pm 0.25) \text{ l/h}$	$-(0.07 \pm 0.18) \text{ l/h}$
Pressure	$(0.012 \pm 0.015) \text{ mbar}$	$-(0.013 \pm 0.025) \text{ mbar}$	$(0.022 \pm 0.027) \text{ mbar}$
Radon	$-(0.015 \pm 0.024) \text{ Bq/m}^3$	$-(0.03 \pm 0.03) \text{ Bq/m}^3$	$(0.015 \pm 0.029) \text{ Bq/m}^3$
Hardware rate	$-(0.09 \pm 0.15) \times 10^{-2} \text{ Hz}$	$(0.09 \pm 0.17) \times 10^{-2} \text{ Hz}$	$-(0.03 \pm 0.20) \times 10^{-2} \text{ Hz}$

All the measured amplitudes well compatible with zero

+none can account for the observed effect

(to mimic such signature, spurious effects and side reactions must not only be able to account for the whole observed modulation amplitude, but also simultaneously satisfy all the 6 requirements)

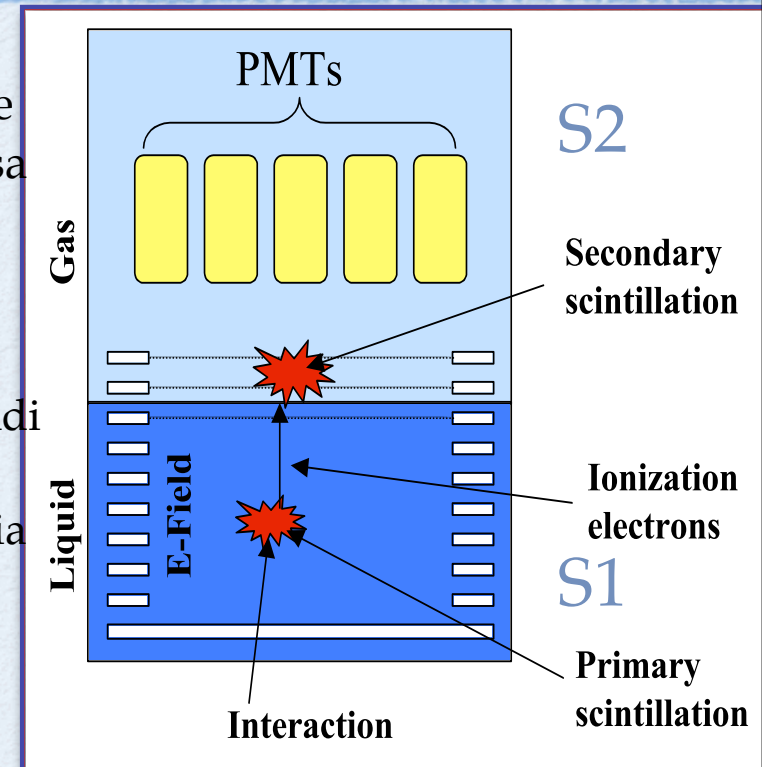
LIQUIDI NOBILI : ARGON

due fasi :gas e liquido

doppia misura : luce di scintillazione e ionizzazione

amplificazione carica ionizzazione nella fase gassosa

- rinculi nucleari: tracce corte S2 piccolo ma S1 grande elettroni, fotoni S2 grande
- rapporto S2/S1 usato per discriminare WIMPS da fondi S2/S1 elettroni $\gg$ S2/S1 rinculi nucleari
- ulteriori informazioni da forma scintillazione primaria
- fondo interno decadimento beta ^{39}Ar



WARP 140 Kg in costruzione a LNGS finestra segnale 30-100KeV Veto attivo 60 cm. **Prototipo 3.2 Kg** in funzione dal 2006

WARP Risultati prototipo 3.2 Kg ai LNGS

astro-ph/0701286

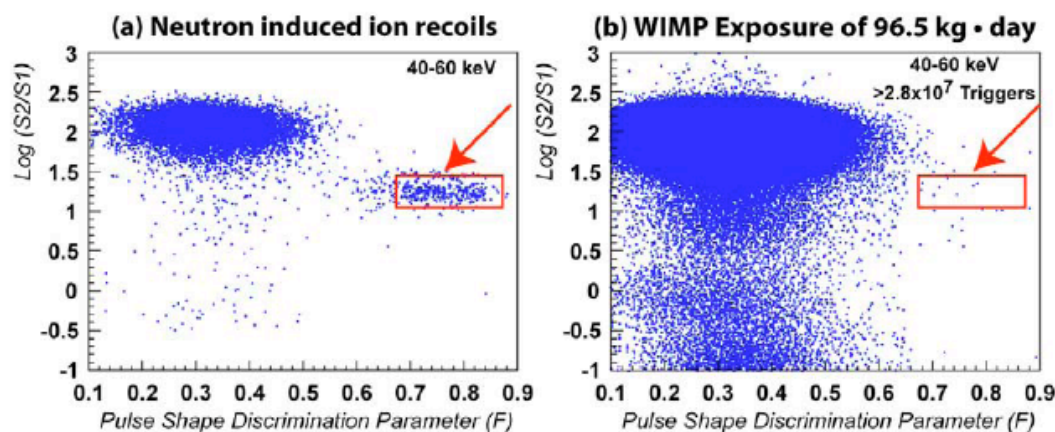
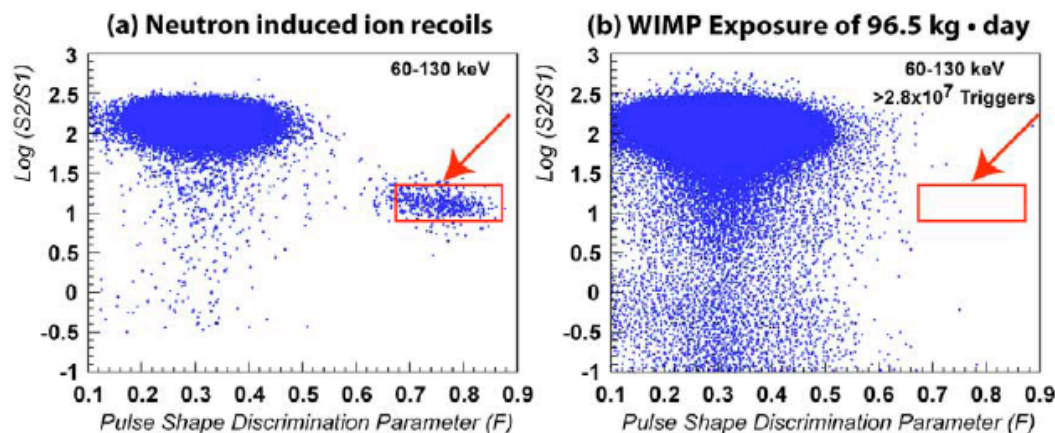


Figure 6



Misure con sorgente neutroni

Dati :nessun evento > 60 keV

WARP: RISULTATI PROTOTIPO

3.2 KG 90% C.L LIMITI

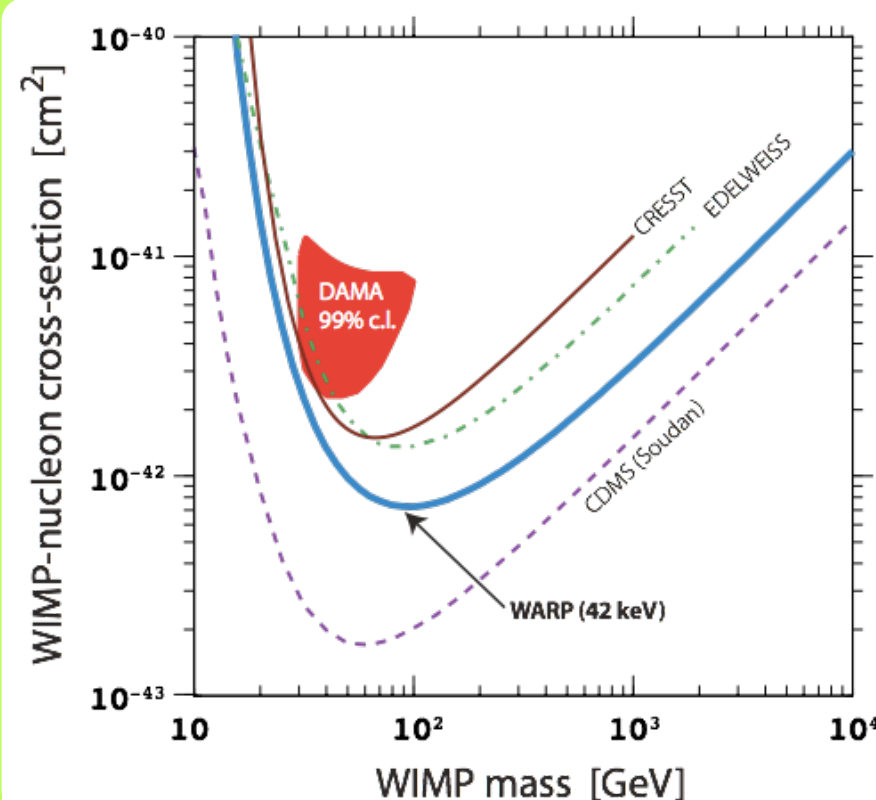
no recoil-like events are observed above **42 keV_{ion}** in a total fiducial exposure of **96.5 kg x day** (2.8×10^7 trigger).

The evaluated 90% C.L. upper limit for **spin-independent interaction**, in the standard WIMP scenario, is plotted. Energy resolution due to statistical fluctuations and to a non uniform light collection has been taken into account.

The dominant systematic effect is due uncertainties on scintillation yield. An error of 15% on Y_{Ar} corresponds to a variation of 20% @ $M_W=100 \text{ GeV}/c^2$ and of 30% @ $M_W=50 \text{ GeV}/c^2$.

Attenzione:

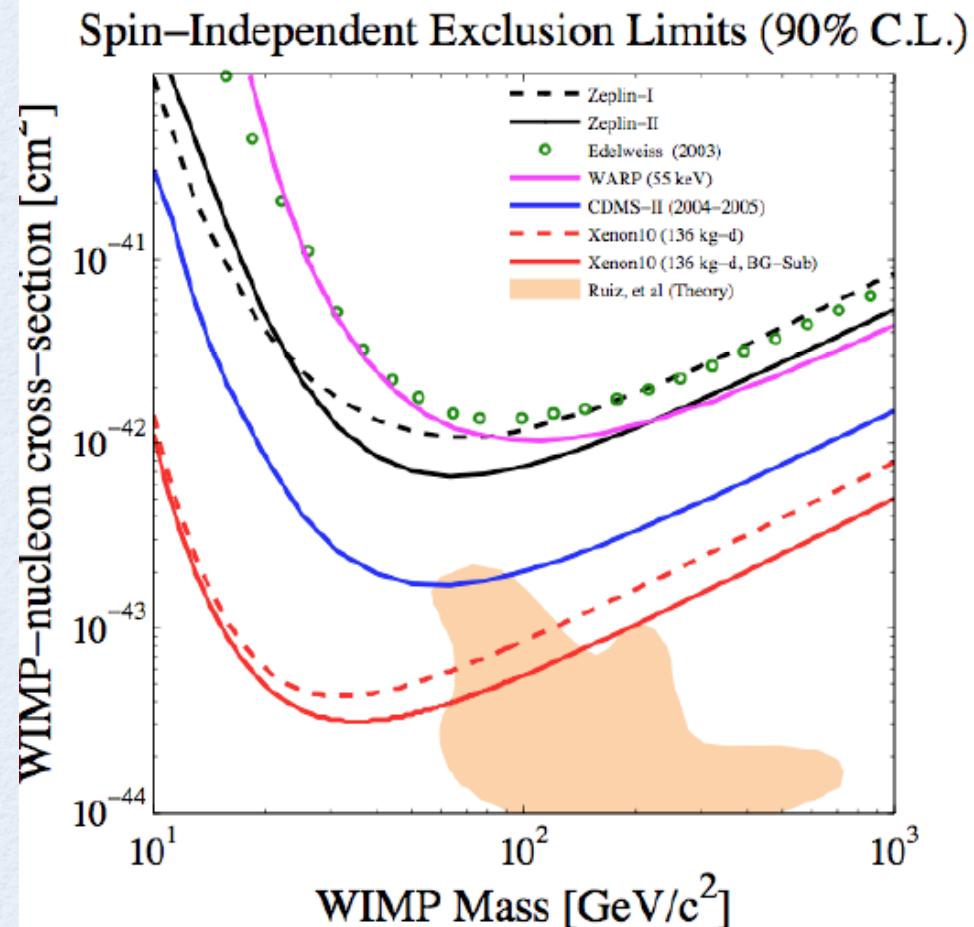
confronti sono difficili in particolare con DAMA(nuclei diversi, possibilità di assioni ..)



PROTOTIPO 15 KG XENON(USA) AL GRAN SASSO RISULTATI APRILE 2007

XENON10 Experimental Upper Limits

- $A_{\text{Xe}}^2 / A_{\text{Ar}}^2 \approx 10$



- Upper limits on the WIMP- nucleon cross section derived with Yellin Maximal Gap Method (PRD 66 (2002))
- For a WIMP of mass 100 GeV/c²
 $9.0 \times 10^{-44} \text{ cm}^2$ Max Gap (4.5-15.5keV)
 $5.5 \times 10^{-44} \text{ cm}^2$ including known Back
- Factor of 6 below best previous limit
- XENON10 is testing SUSY models. With a phased approach towards ton scale, XENON aims at maximizing discovery potential at every phase

(see Gaitskell Talk)

RIVELAZIONE MATERIA OSCURA CON METODI DIRETTI : SOMMARIO

- molti esperimenti ma necessari: strategia ottimale ancora da capire, conviene avere tecniche diversificate
- evoluzione verso rivelatori 1 Ton dovrà limitare il numero di tecniche
- rivelatori nobili molto promettenti
- confronti tra nuclei diversi difficili.
- segnale modulazione annuale di DAMA diventa sempre più incompatibile con i risultati degli esperimenti a “zero” fondo. Ma attenzione : tagli severissimi per eliminare fondo, segnale potrebbe essere non WIMPS (ad esempio assione..ecc.)
- sensibilità nella zona delle supersimmetrie
- anni futuri estremamente interessanti!!!!!!



Oscillazione e massa Neutrini

Oscillazioni di Neutrino : dopo la scoperta ora siamo alle misure di precisione

scenario standard

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

Gozales-Garcia Maltoni aiXiv 0704.1800 hep-ph (aprile 2007)

Atmosferici

ora anche acceleratori

intervalli 1 sigma

$\sin^2(\theta_{23}) \sim 0.47$ [0.405, 0.54]

$\Delta m^2 \sim 2.6 \pm 0.2 \cdot 10^{-3} \text{ eV}^2$

$\nu_\mu \rightarrow \nu_e$ esperimenti terrestri

$\sin^2(\theta_{13}) < 0.038$ (90%CL)

sole / reattori

$\sin^2(\theta_{12}) \sim 0.31$

$\Delta m^2 \sim 7.9 \cdot 10^{-5} \text{ eV}^2$

Gruppo di Bari nu-telescope 2007

$\delta m^2 = 7.92 (1 \pm 0.09) \times 10^{-5} \text{ eV}^2$

$\Delta m^2 = 2.6 (1^{+0.14}_{-0.15}) \times 10^{-3} \text{ eV}^2$

$\sin^2 \theta_{12} = 0.314 (1^{+0.18}_{-0.15})$

$\sin^2 \theta_{23} = 0.45 (1^{+0.35}_{-0.20})$

$\sin^2 \theta_{13} < 3.1 \times 10^{-2}$ (only upper bound)

La matrice PMNS (Pontecorvo Maki-Nakagawa-Sakata) U (intervalli 90%)

0.81 - 0.85	0.53 - 0.58	0.0 - 0.12
0.32 - 0.49	0.52 - 0.69	0.60 - 0.76
0.27 - 0.46	0.47 - 0.64	0.65 - 0.80

Stato delle oscillazioni di neutrino

matrice di mescolamento 3 x 3 con parametri:

(parametri simili nella matrice dei quark)

θ_{12}, θ_{23} misurati

$\theta_{13} < 11.5^\circ$ δ (fase) 0-360°

Se entrambi diversi da zero ==>> violazione CP

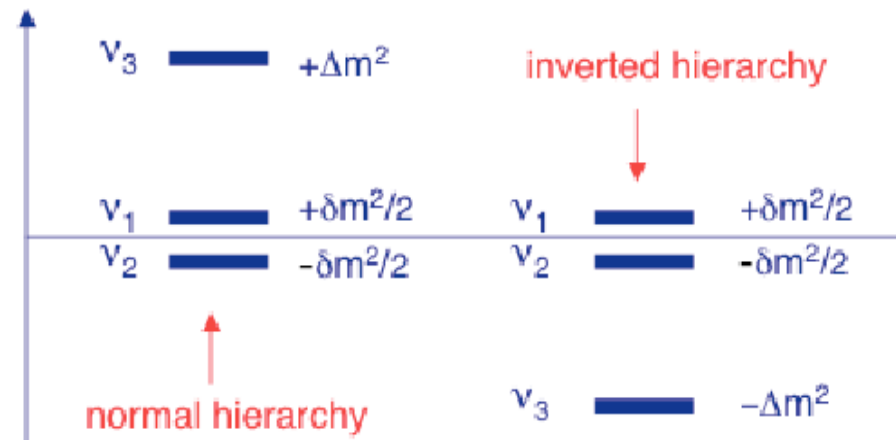
Δm^2_{12} δm^2_{23} misurati

M_0 sconosciuto

M_0 misura diretta massa da decadimento β

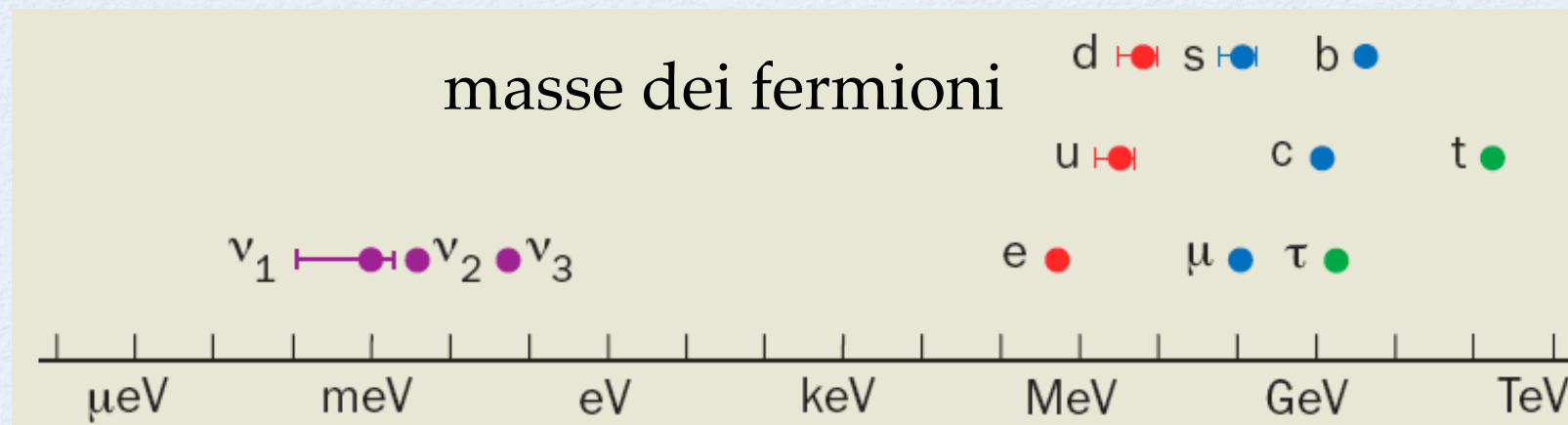
decadimento 2β decay se neutrino = antineutrino
(Majorana)

misure astrofisiche (Wmap..)



MASSA DEI NEUTRINI E NUOVA FISICA

- modello standard costruito assumendo massa dei neutrini =0, nessun motivo fondamentale per questa assunzione
- valori numerici masse suggeriscono **differenza fondamentale** tra neutrini ed altre particelle ~ 7 ordini grandezza rispetto all'elettrone e ~ **10 ordini di grandezza** tra neutrino e leptone più pesanti (τ)



(supponendo massa neutrini più pesante ~100meV)

- Inoltre matrice di mescolamento PMNS molto diversa da quella dei quark

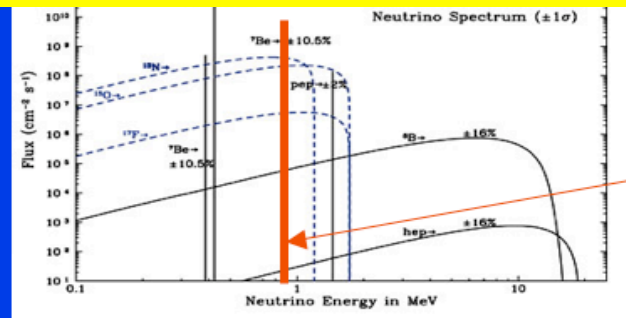
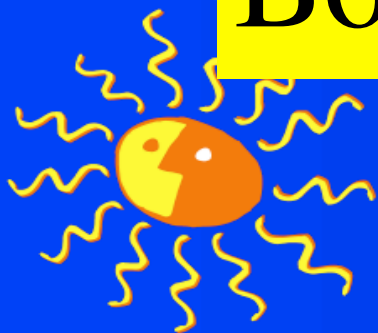
==>> nuova fisica

Oscillazioni: questioni sperimentali ancora aperte:

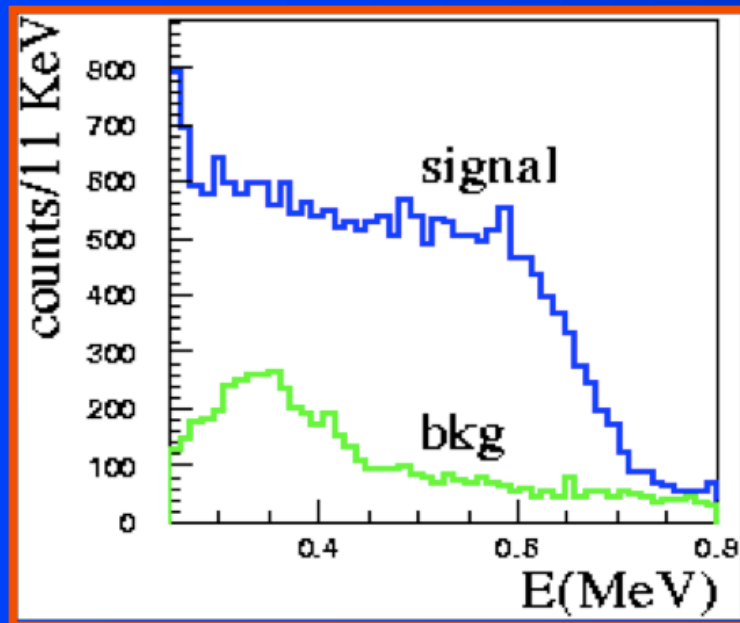
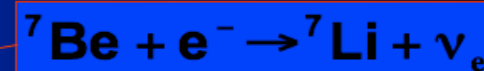
- 1) **Quanto $\sin^2(2\theta_{23})$ è diverso da 1?** $\Rightarrow$ **migliorare la precisione in θ_{23} (and Δm^2_{23})** esperimenti LBL (MINOS)..ma anche e meglio, atmosferici Monolith -INO
- 2) Valore di θ_{13} ? $\Rightarrow$ **migliorare i limiti su θ_{13}** . Esperimenti su reattori (Double-Chooz, Daya Bay..) e su fasci di neutrino da acceleratori (MINOS,CNGS,T2K,NOVA, poi..CNGS2...beta beam, neutrino factories). Solo se $\theta_{13} \neq 0$ (e $\delta \neq 0$) si può misurare δ e avere violazione di CP
- 3) Misure di precisione sul meccanismo di oscillazione: apparizione dei tau, unitarietà della matrice di mixing, effetti materia nel sole (**OPERA,ICARUST600, BOREX**) ecc
- 4) Misura del segno di Δm^2_{23} (**effetto materia, se $\theta_{13} \neq 0$**) **Nova,T2k..**

CNS2: **OPERA,ICARUST600,BOREX,LVD**

Borexino Ora In misura!!!



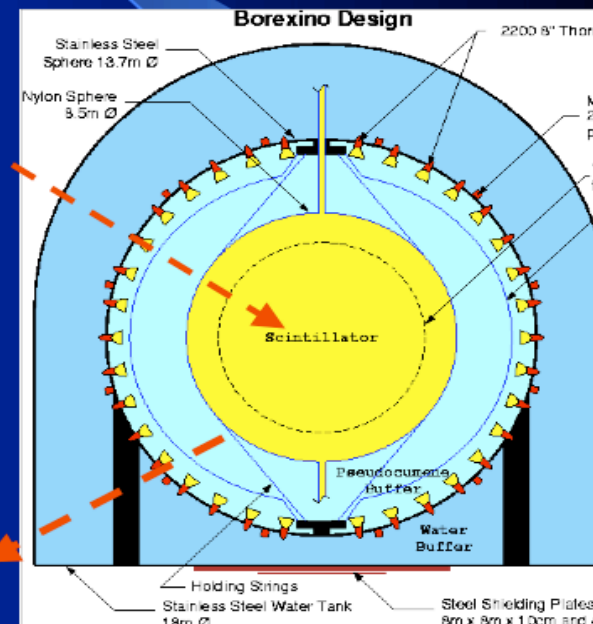
$$\Phi_{\text{SSM}} = 4.8 \times 10^9 \text{ v/sec/cm}^2$$



“ ν window” (0.25-0.8 MeV)

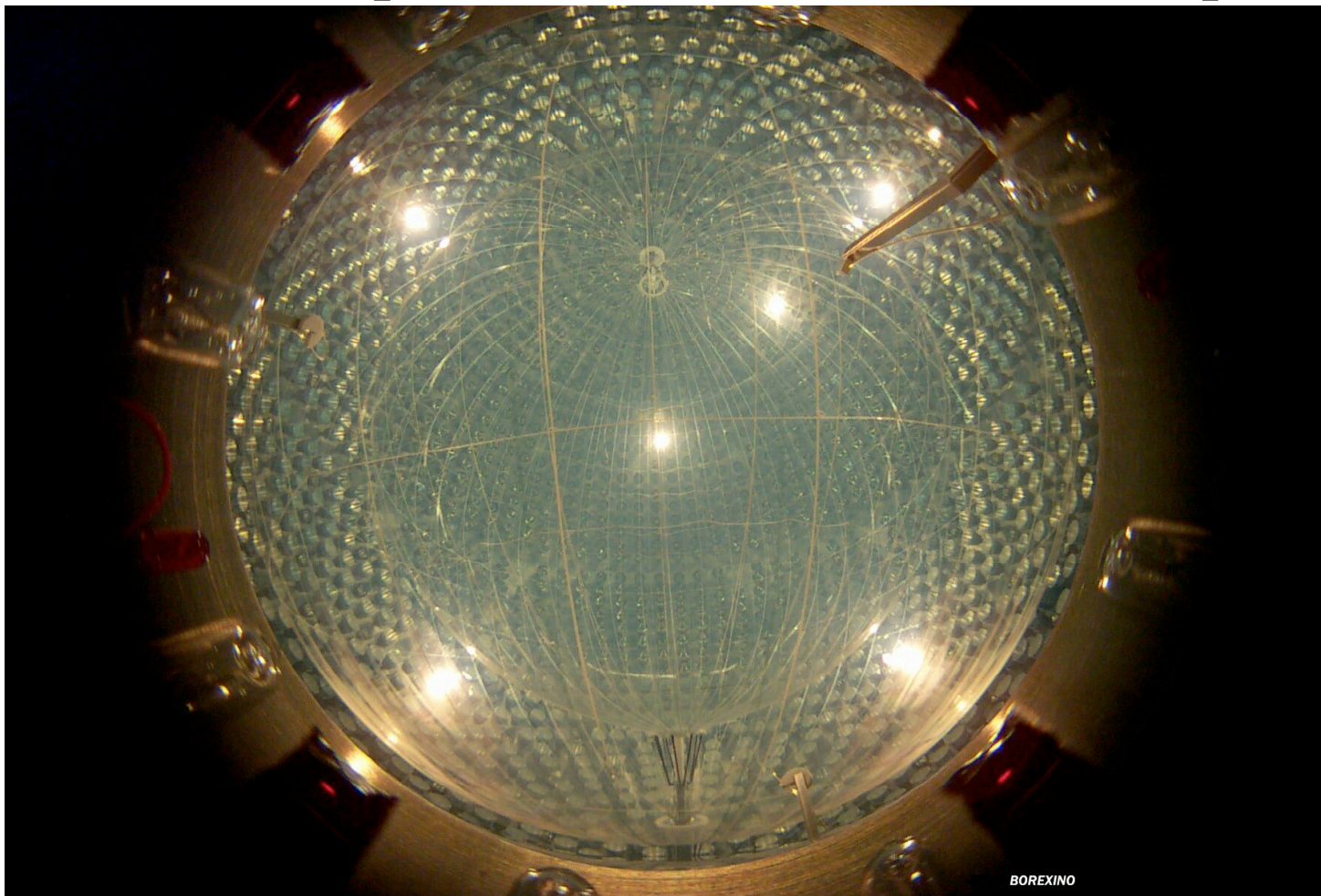
$$e^- + \nu_x \rightarrow e^- + \nu_x$$

$$\sigma = 10^{-44} \text{ cm}^2$$



expected rate (LMA hypothesis) is 35 counts/day in the neutrino window

Borexino completo di scintillatore e buffer liquido



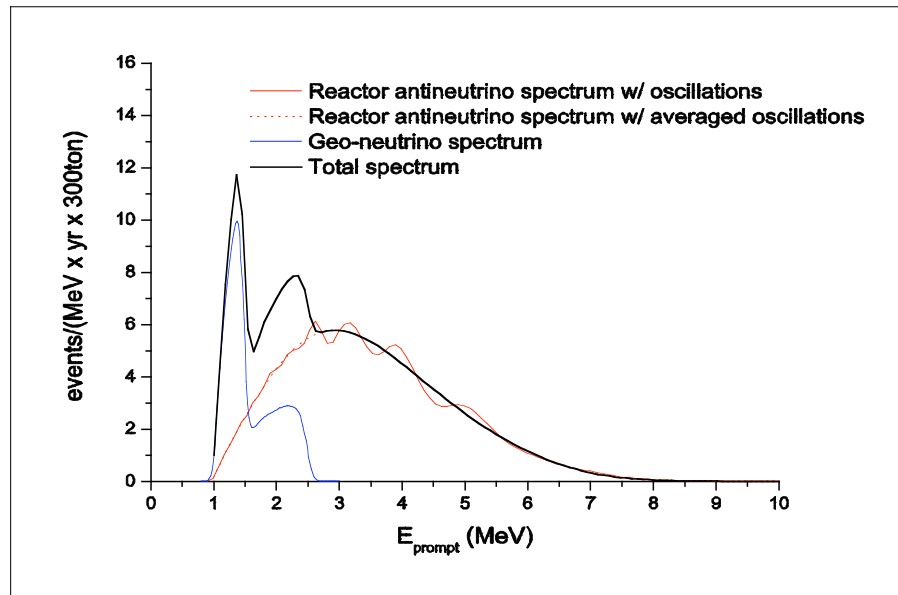
Cronologia degli ultimi 10 mesi

- **Aug. 1, 2006**
 - **Inizio Water filling della sfera**
- **Nov. 15, 2006**
 - **Fine water filling della sfera**
 - Rivelazione di alcuni eventi di neutrino dal fascio **CNGS**
- **Nov. 15 – Jan. 12, 2007**
 - Ultime “precision cleanings” e preparazione degli impianti
 - Completamento del muon veto
 - Chiusura del portellone della WT
 - Completamento e attivazione del “flip-flop” per lo scarico delle acque dell’impianto di osmosi inversa
 - Completamento della unloading station (12 gennaio ore 21!)
- **Jan 12**
 - **Il primo isotank di PC entra in sala C**
 - Inizio riempimento di BX
 - Inizio riempimento con acqua della WT (dalla SSS via filtro al carbone e dal W.Pur.Plant)
- **Jan 12 – Apr 13**
 - 56 camion di PC dalla Sardegna (987 t)
 - Nessun intoppo serio
- **Jan 27 –**
 - Inizio progressivo della presa dati
 - Monitoraggio della qualità dello scintillatore
 - Fine tuning del rivelatore
 - Test dei programmi
 - Learning curve generale della “macchina Borexino”
- **May 15-18**
 - Inizio del run di fisica!

BOREXINO: a low energy ($\leq 1\text{MeV}$) neutrino experiment

- **Explore the low energy solar neutrinos in real-time**
 - **never measured** (explored only 0.01% of the spectrum over 5 MeV)
- **Provide a strong test of LMA-MSW**
 - Up-turn of survival probability
 - Day-Night effect?
- **Test how well neutrino-matter interactions are understood**
 - Search for non-standard interactions
- **Test the SSM**
 - Improve accuracy of pp[pep] and ^7Be fluxes
 - Check photon luminosity vs neutrino luminosity
 - Test CNO

GEONEUTRINOS



Very low background from
reactors antineutrinos at G.S.

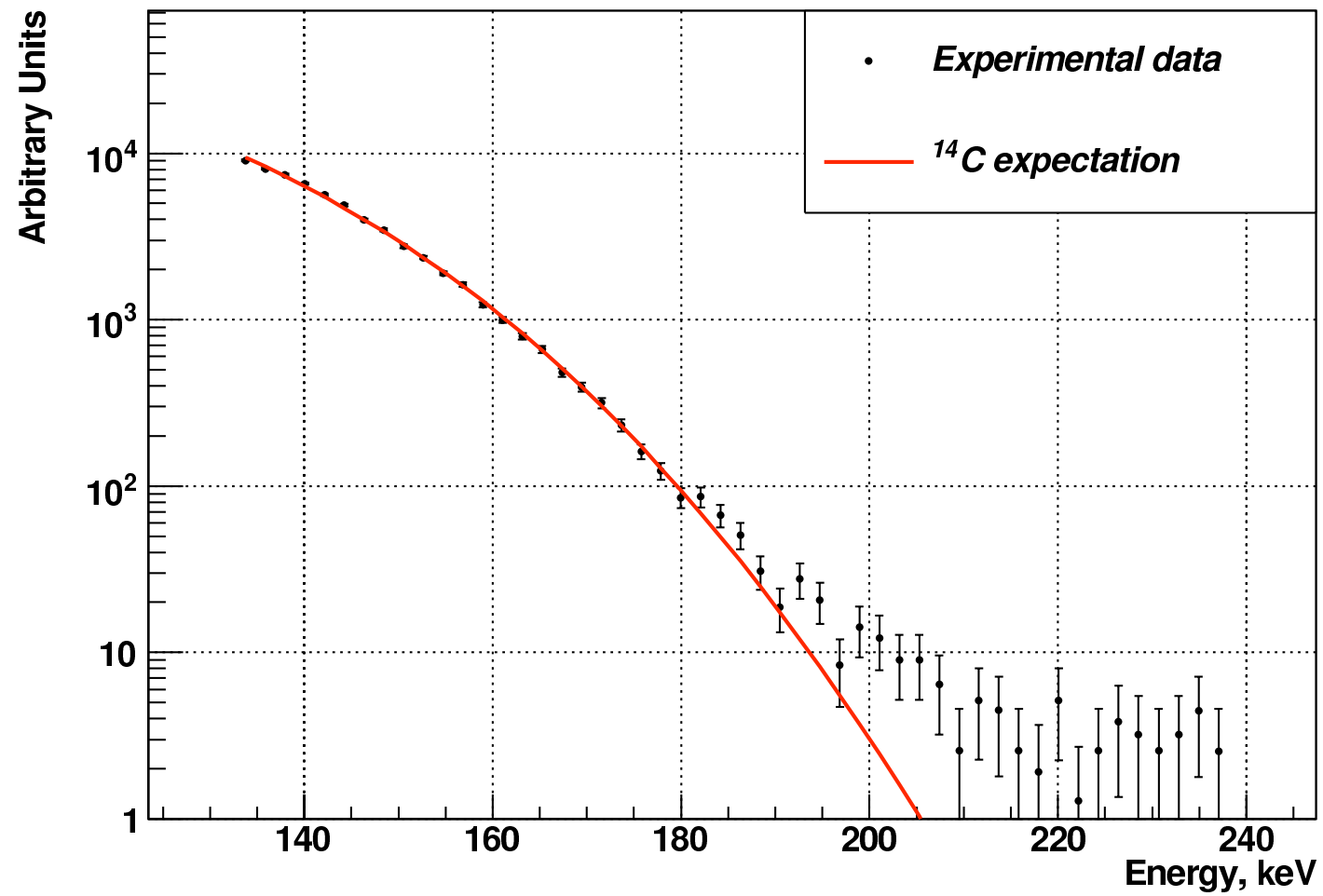
S/N 1:1 in Borexino
1:5.8 in Kamland

SUPERNOVA

The low threshold allows the detection of the neutrino-proton scattering, which, due to the p quenching, is induced by muon and tau neutrinos.

$$\bar{\nu}_\mu, \bar{\nu}_\tau - \text{proton}$$

Measurement of the time delay between $\bar{\nu}_e$ scattering
And the inverse beta decay induced by



The background of the slide is a photograph of a calm body of water, likely a lake, under a clear sky. The water is a deep blue, and the sky is a pale, hazy blue. The horizon line is visible in the middle of the frame. The text is centered over the water.

CNCS PRIMO RUN
SCIENTIFICO AGOSTO
2006

Past Despite :

- CNGS postulated in 1979
- Kamiokande result in 1988
- Project frozen until C. Rubbia directorate (1989-1993), approved only in 1999

European physicists have limited the accelerator ν program inside the fence of CERN, arguing on:

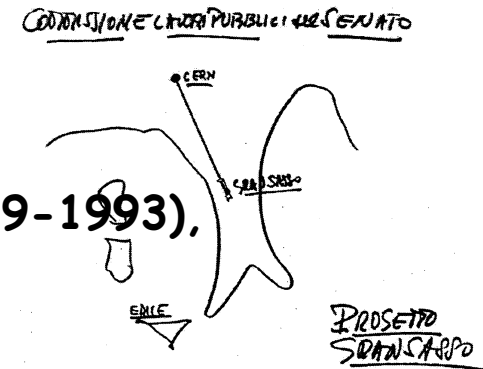
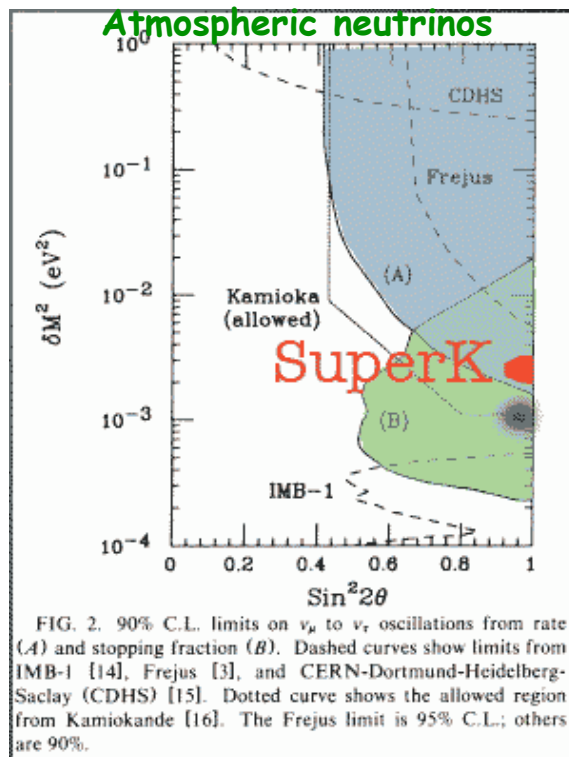


Figure 1.1.1: Sketch by A. Zichichi, 1979

Confusing experimental results



+ LSND ...

Strong Theoretical arguments:

- J. Ellis et al. (CERN-TH-6569-92)
- G. Altarelli et al. (Neutrino Telescope)

Typical Theorist's View ca. 1990

- Solar Neutrino Problem must be solved by **Small Angle MSW** solution because it is so **beautiful**
- Important scale for oscillation is $\Delta m^2 \approx 10-100 \text{ eV}^2$ because it is **cosmologically relevant**
- θ_{23} must be about $\theta_{23} \approx V_{cb} \approx 0.04$
- atmospheric neutrino anomaly must **go away** because it requires large mixing angle

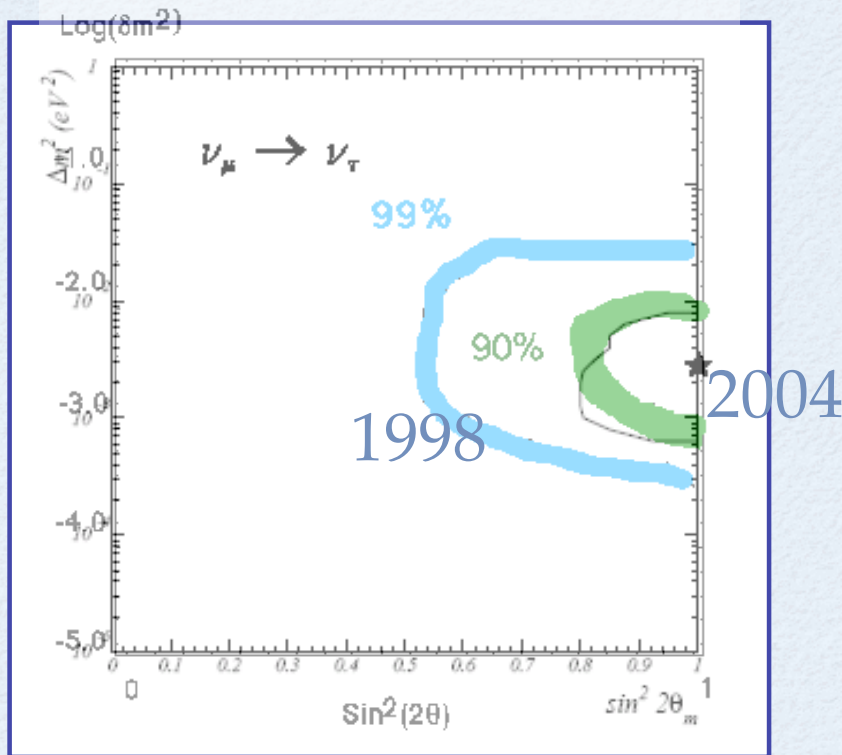
All
Wrong

Y Declais Now2006

PREGIUDIZI E RITARDI NELLE DECISIONI SUL FASCIO

ATMOSFERICI IN ITALIA : MACRO USA-ITALY TERMINATO NEL 2000

- l'unico esperimento con sufficiente statistica per confermare SK indipendentemente nel 1998



In 1984, proposal anticipates MACRO sensitivity and contribution to neutrino oscillations

Hence, in two years of operation, our experiment can set a 3σ limit for neutrino oscillations for mass differences in excess of 10^{-3} eV^2 for maximal mixing. In Fig. (2)13, this limit (shaded region) is compared with the present limits set by other neutrino oscillation experiments. For $\sin^2 2\theta > 0.6$, the experiment should yield nearly an order of magnitude improvement for the limit on Δm^2 .

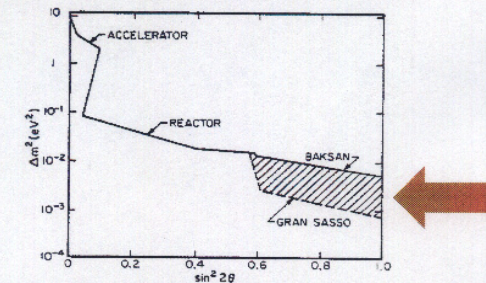
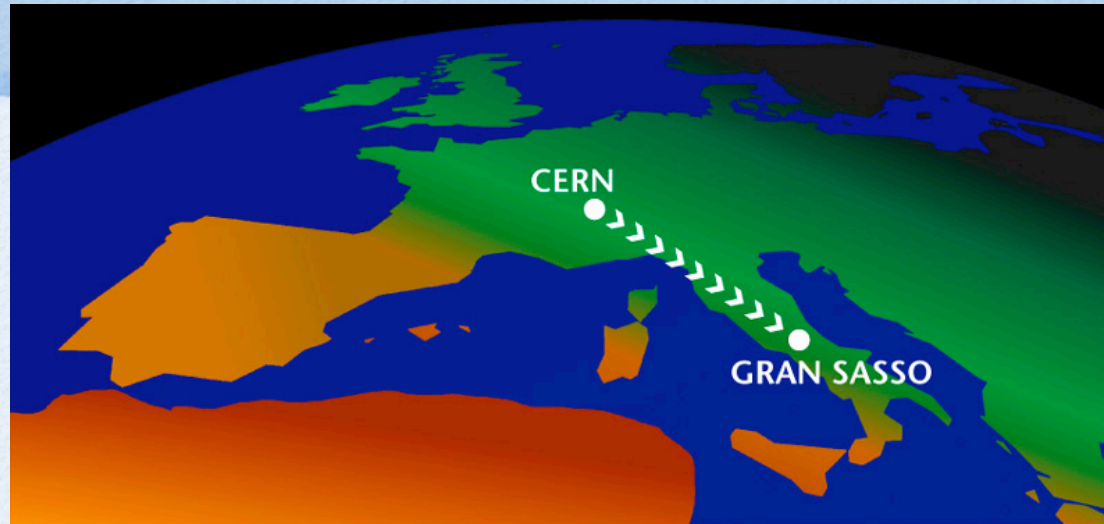
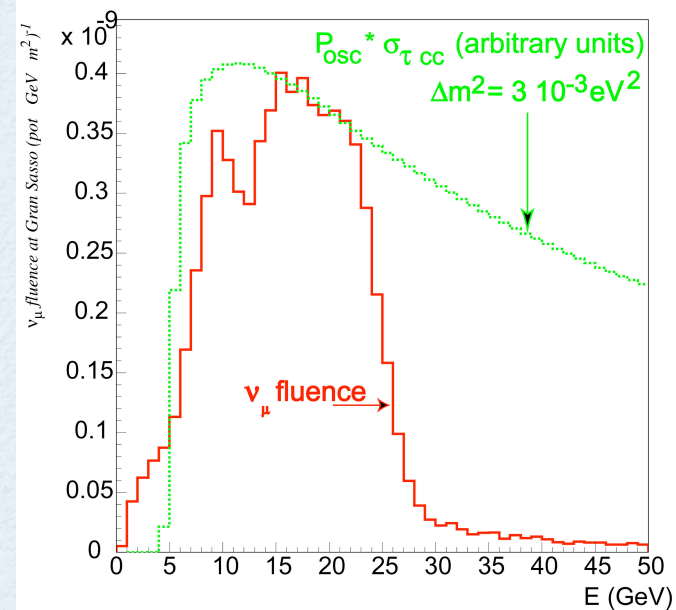


Fig. (2)13 Present best limits on Δm^2 vs. $\sin^2 2\theta$. The shaded region represents the improvement obtainable with our experiment.

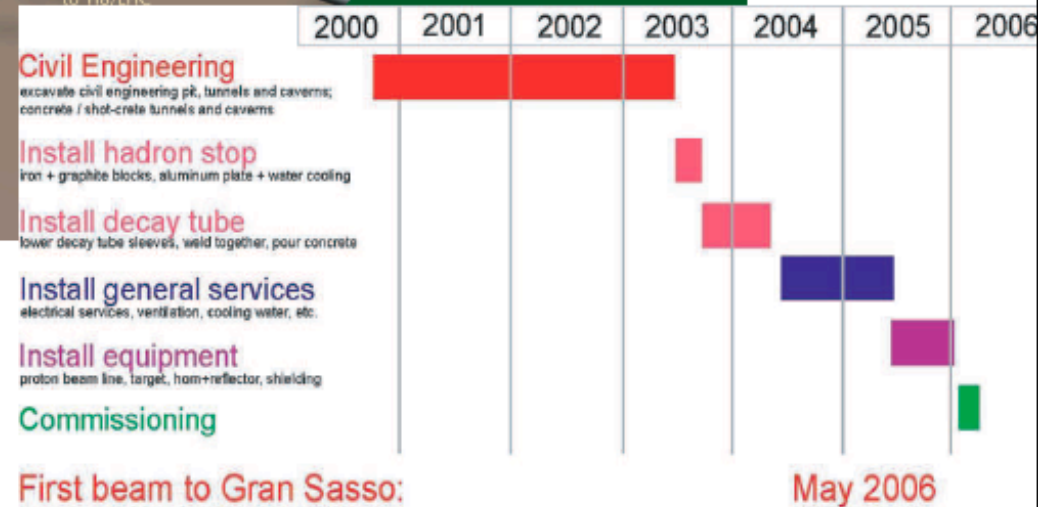
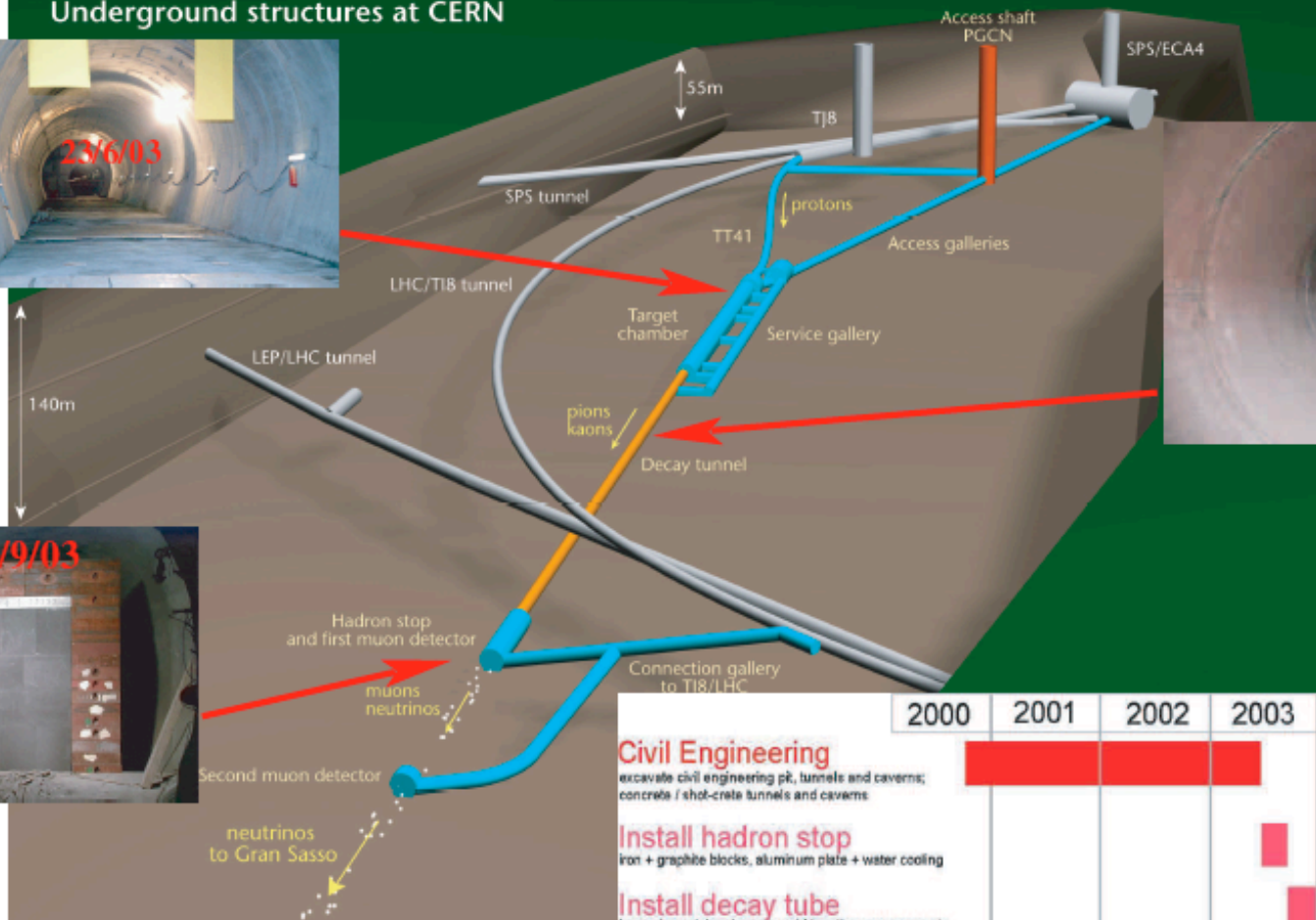
Cern Neutrinos to Gran Sasso (CNGS)



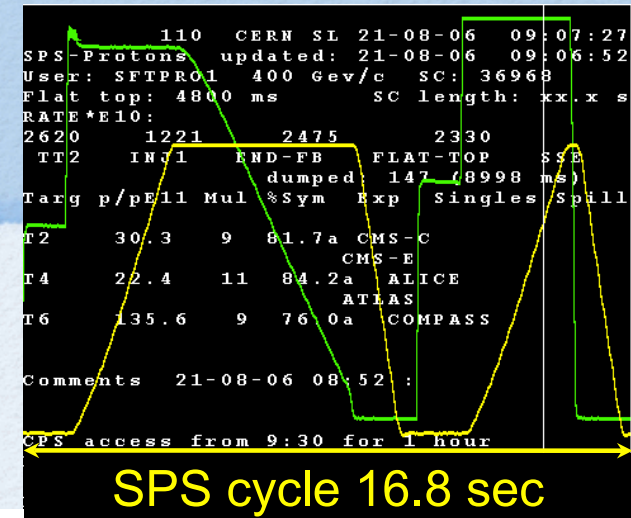
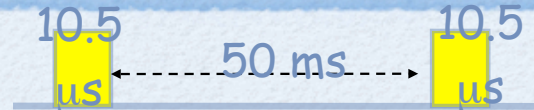
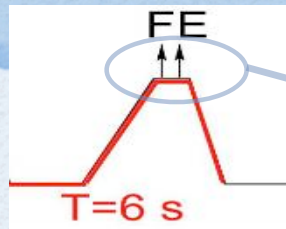
ν_μ CC / kton	2900
ν_μ NC / kton	875
$\langle \underline{E} \rangle_\nu$ (GeV)	17
$-(\nu_e + \bar{\nu}_e) / \nu_\mu$	0.85 %
ν_μ / ν_μ	2.1 %
ν_τ prompt	negligible



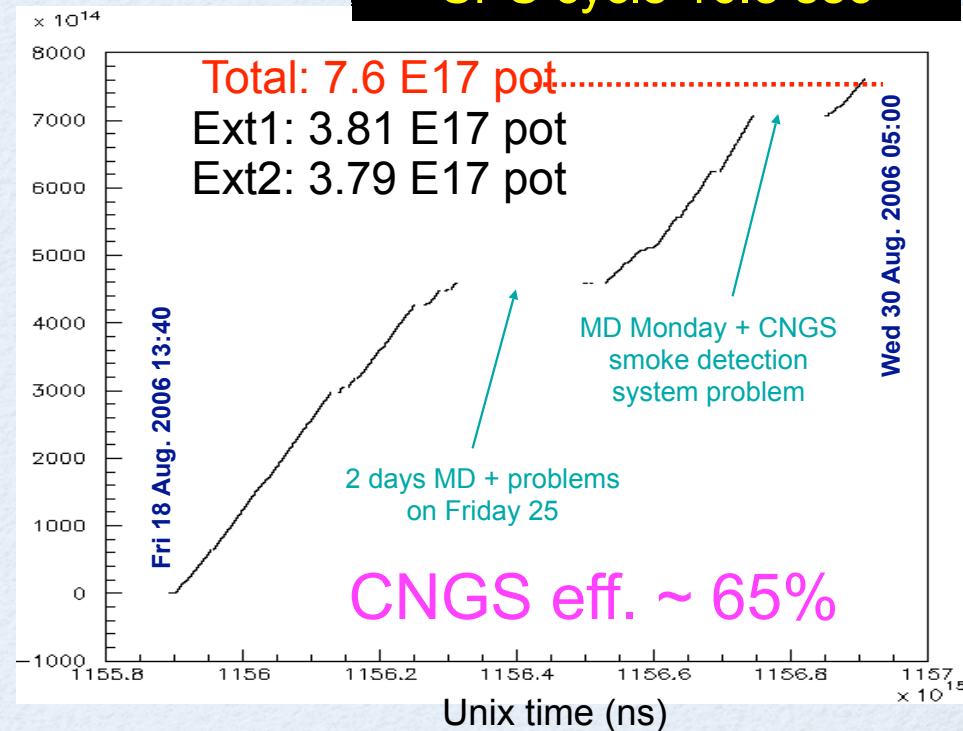
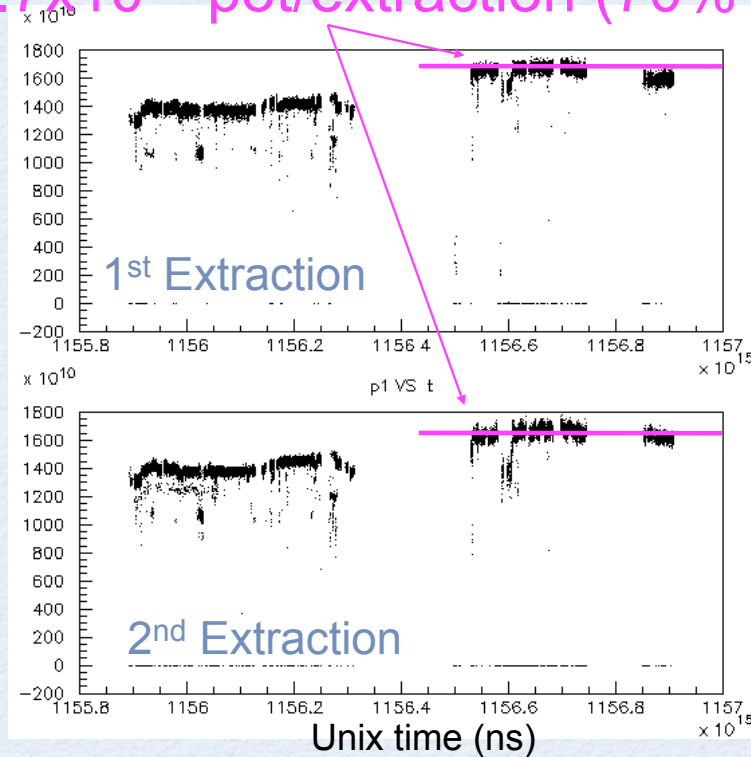
CERN NEUTRINOS TO GRAN SASSO Underground structures at CERN



1st CNGS run: august '06



1.7×10^{13} pot/extraction (70% nom.)

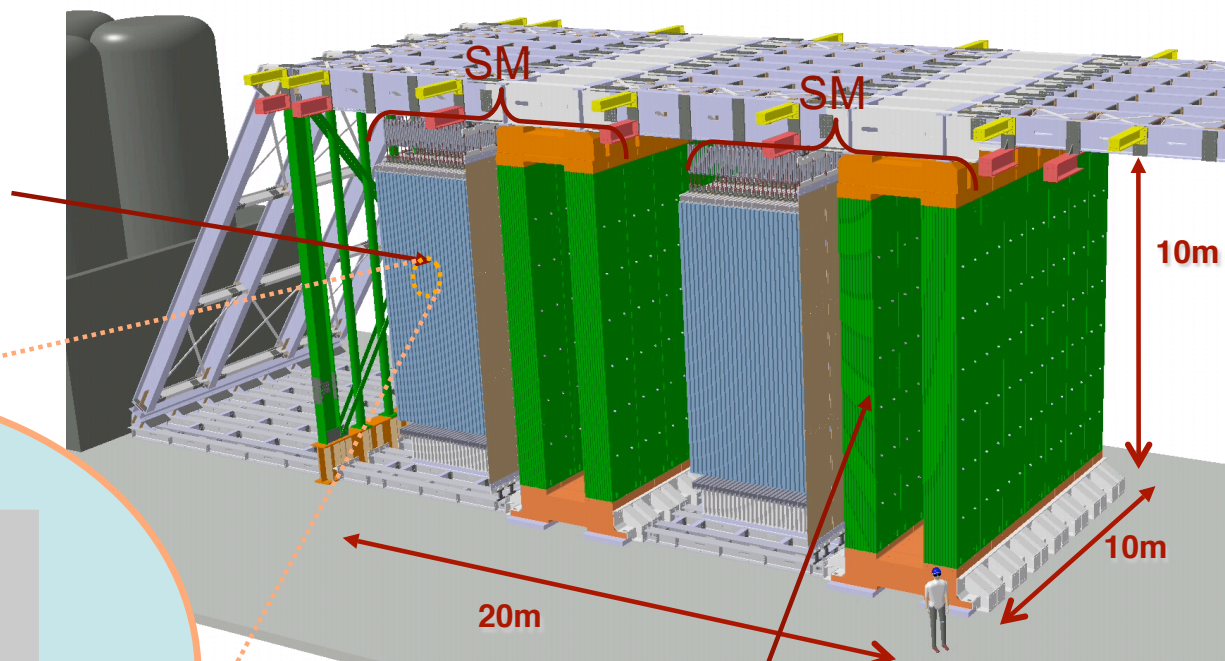
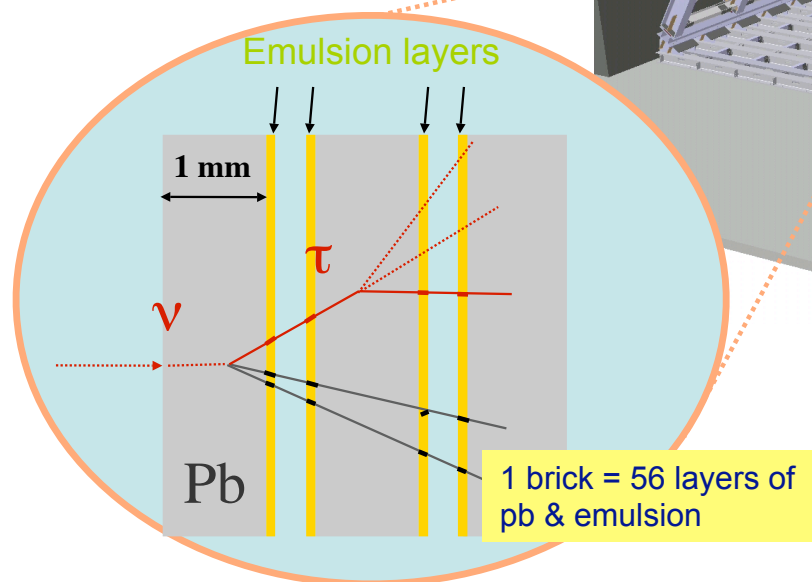


OPERA (Oscillation Project with Emulsion-tRacking)

Apparatus Conceptual design

Target:

- Lead/emulsions bricks alternated to scintillator strips
- emulsion tracking resolution:
 $\delta x < 1\mu\text{m}$, $\delta\theta < 1\text{mrad}$
- 206336 bricks = ~ 1.8 kton



Muon Spectrometer:

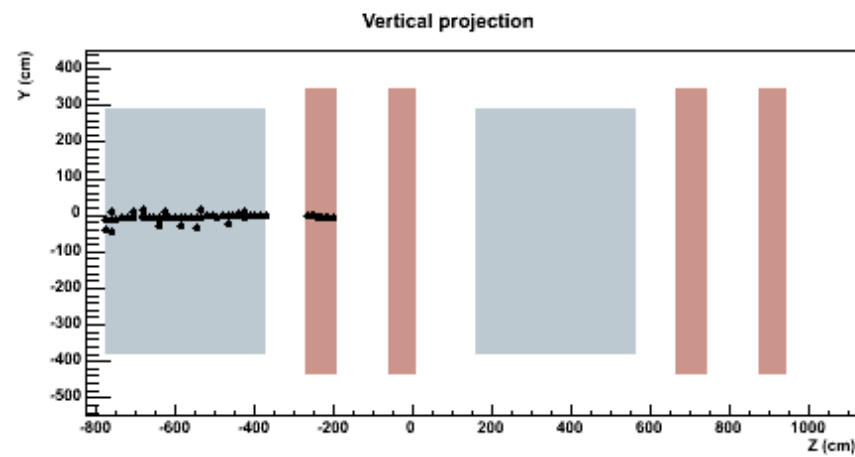
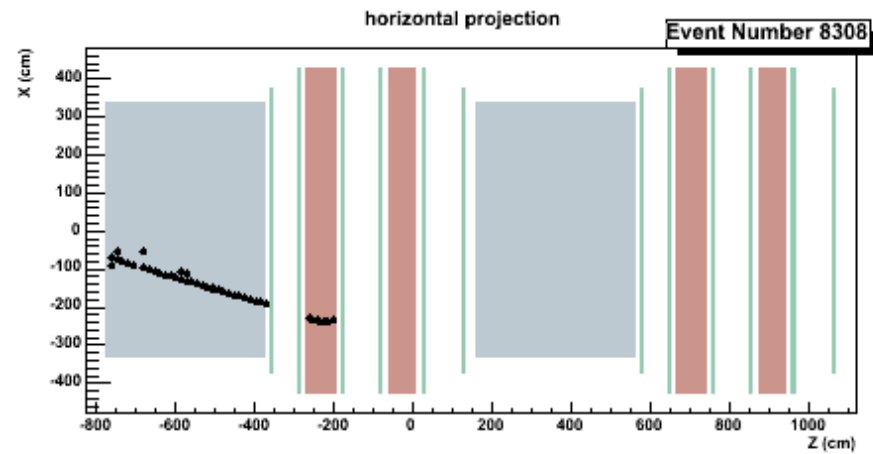
- Vertical drift tubes for μ p measurement from deflection through 24 magnetized iron slabs.
- Magnet instrumented with 22 RPC plane for
- $\Delta p/p \sim 25\%$ up to 50 GeV, charge miss-ID $< 0.3\%$

Collab.: Italy, France, Germany, Belgium, Turkey, Switzerland, Russia, Japan, Israel, Croatia

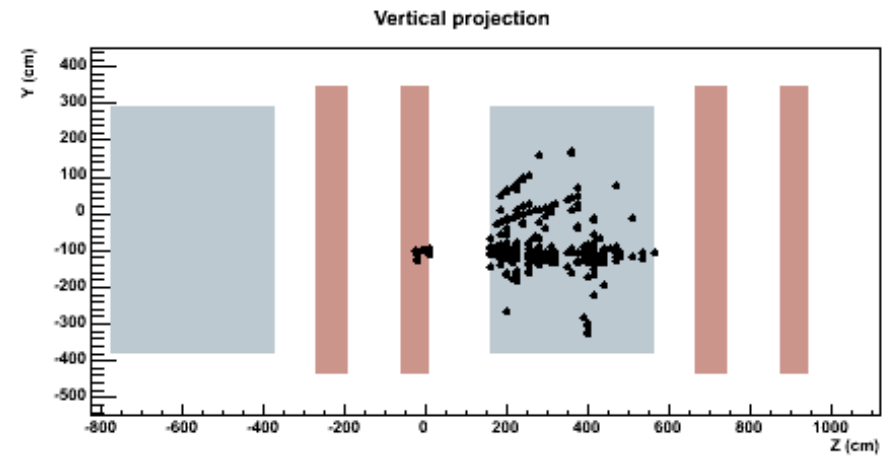
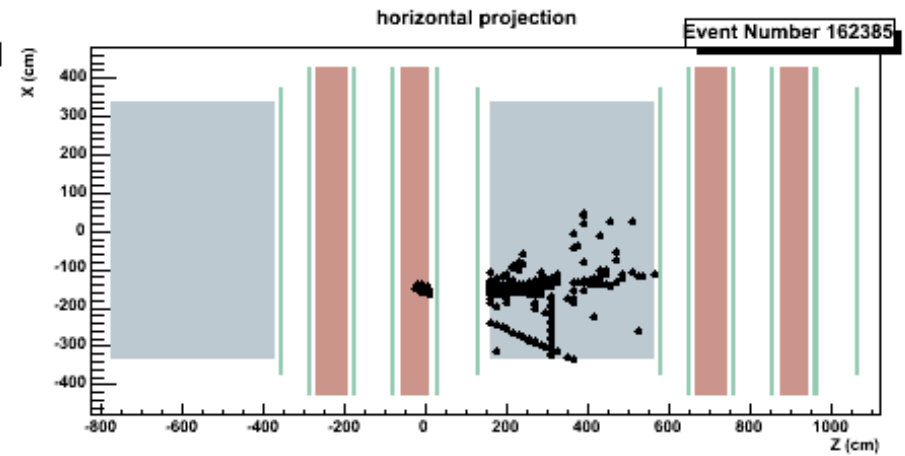
August '06 run events



stopping track (first event)



ν_μ CC in magnet



May 11th, 2007

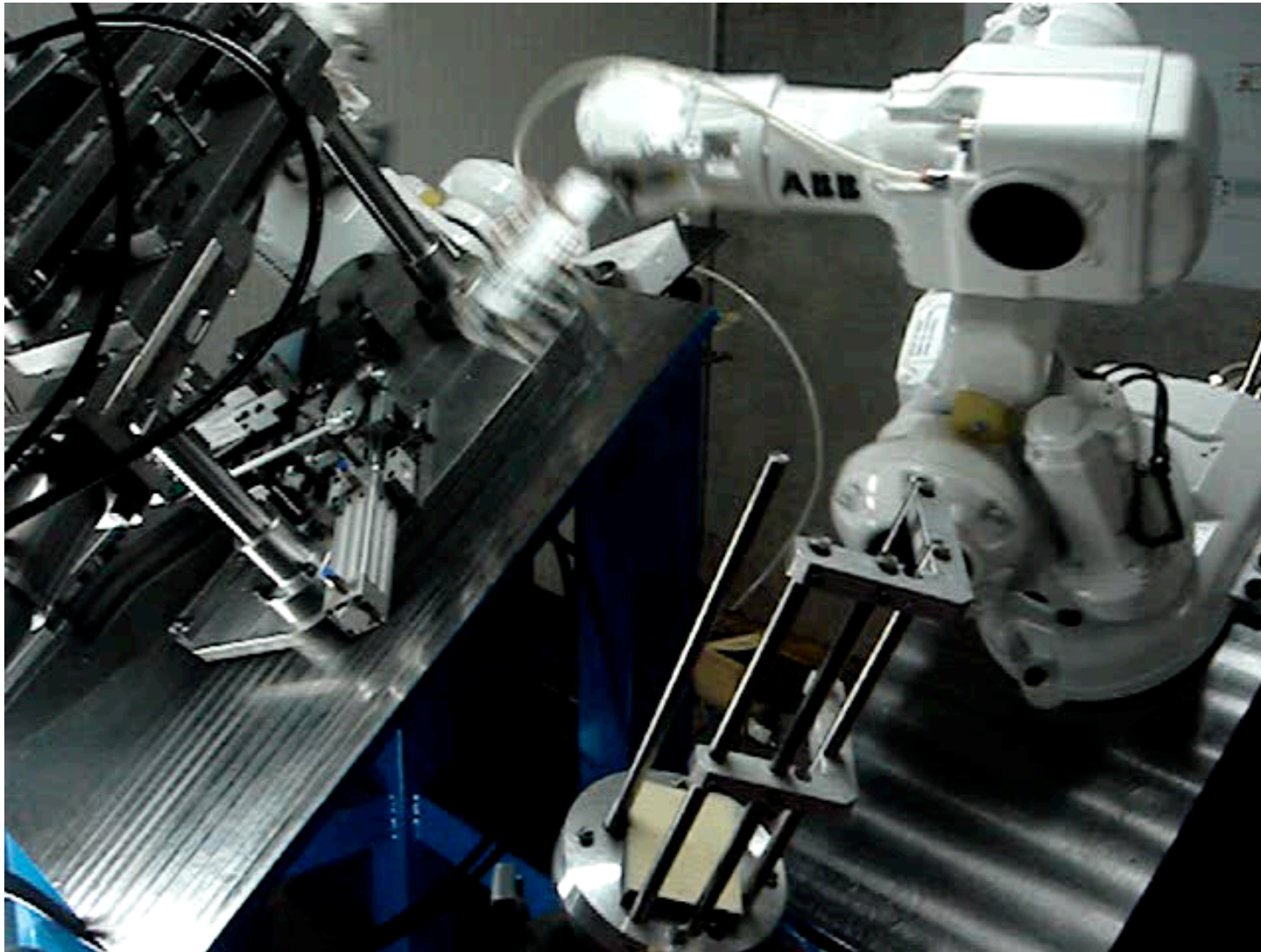
LNF Scient. Comm

M.Spinetti



Brick assembling and
installation in progress





Search for $\nu_\mu \rightarrow \nu_\tau$ oscillation: expected number of events

τ decay channels	Signal		Background
	$\Delta m^2 = 2.4 \times 10^{-3} \text{ eV}^2$	$\Delta m^2 = 3.0 \times 10^{-3} \text{ eV}^2$	
$\tau \rightarrow \mu$	3.6	5.6	0.23
$\tau \rightarrow e$	4.3	6.7	0.23
$\tau \rightarrow h$	3.8	5.9	0.32
$\tau \rightarrow 3h$	1.1	1.7	0.22
ALL	12.8	19.9	1.0

Main background sources:

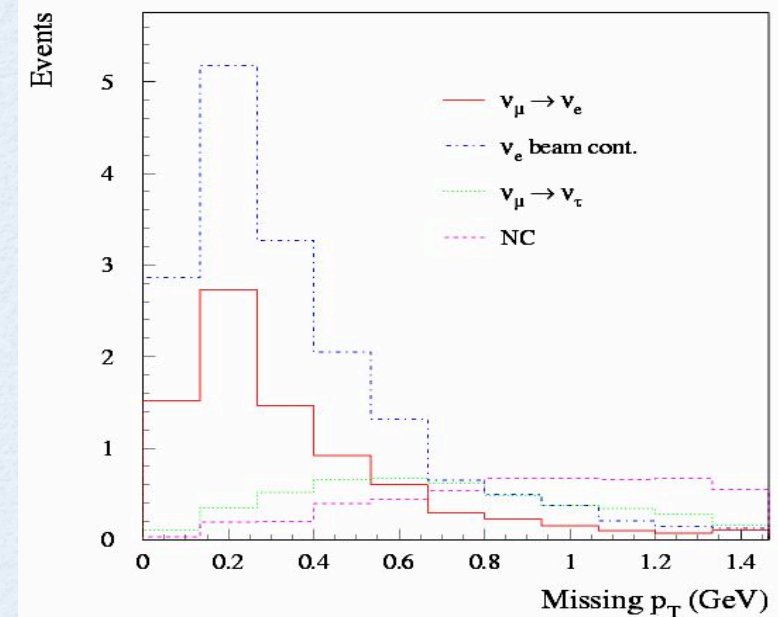
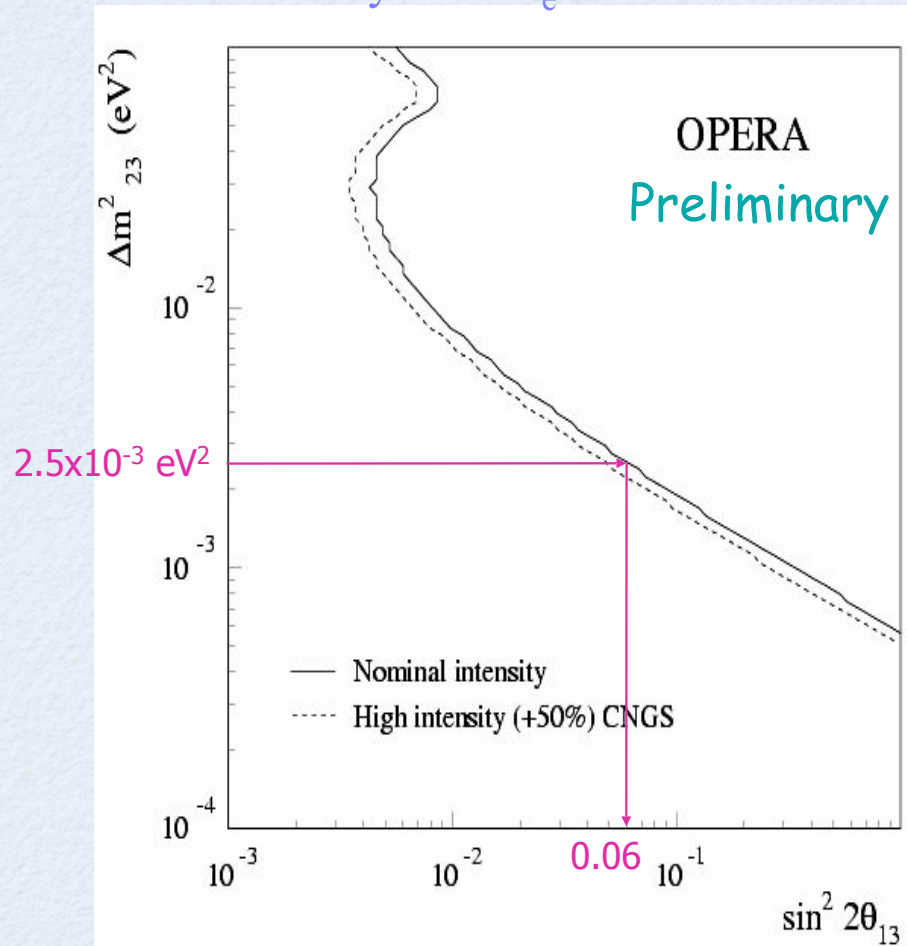
- charm production and decays
- hadron re-interactions in lead
- large-angle muon scattering in lead

full mixing, 5 years run @ 4.5×10^{19} pot / year

OPERA sensitivity to θ_{13}

Simultaneous fit of E_e , missing p_T and E_{vis} distributions

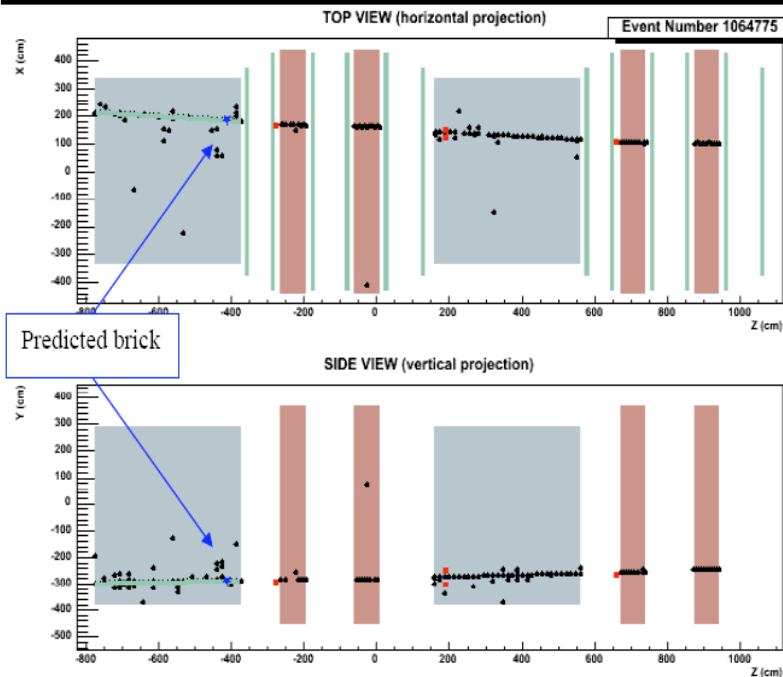
10% syst. in ν_e contamination



Limits at 90% CL for
 $\Delta m^2 = 2.5 \times 10^{-3} \text{ eV}^2$ full mixing

	$\sin^2 2\theta_{13}$	θ_{13}
CHOOZ	<0.14	11°
OPERA	<0.06	7.1°

First neutrino event in emulsion



Prediction accuracy :

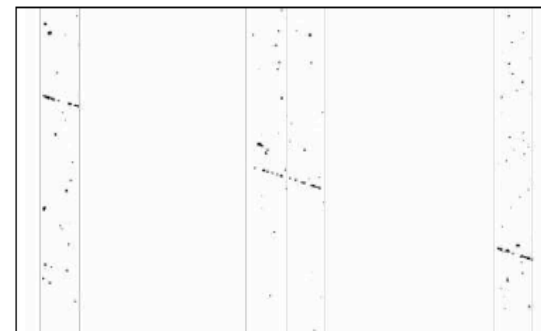
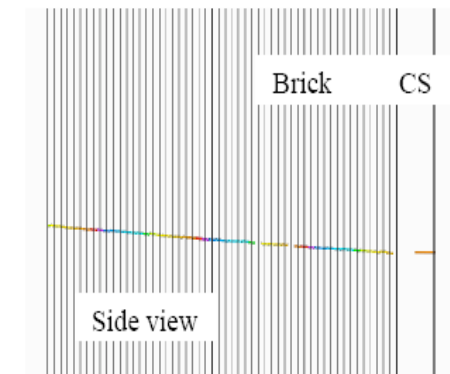
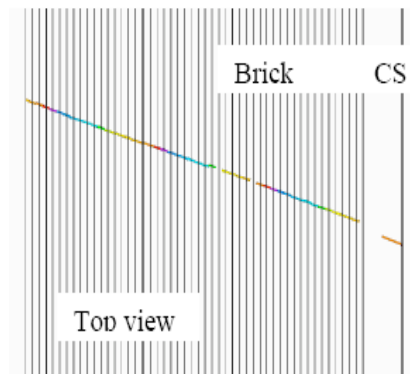
- $\Delta x = 5.5$ mm (along the tray)
- $\Delta y = 0.4$ mm (vertical direction)
- $\Delta \theta_x = 16.6$ mrad
- $\Delta \theta_y = 24.8$ mrad

Muon momentum:

- MCS (coord method) : 6.4 ± 1 GeV/c
- Spectrometer (RPC) : 7.05 ± 0.4 GeV/c

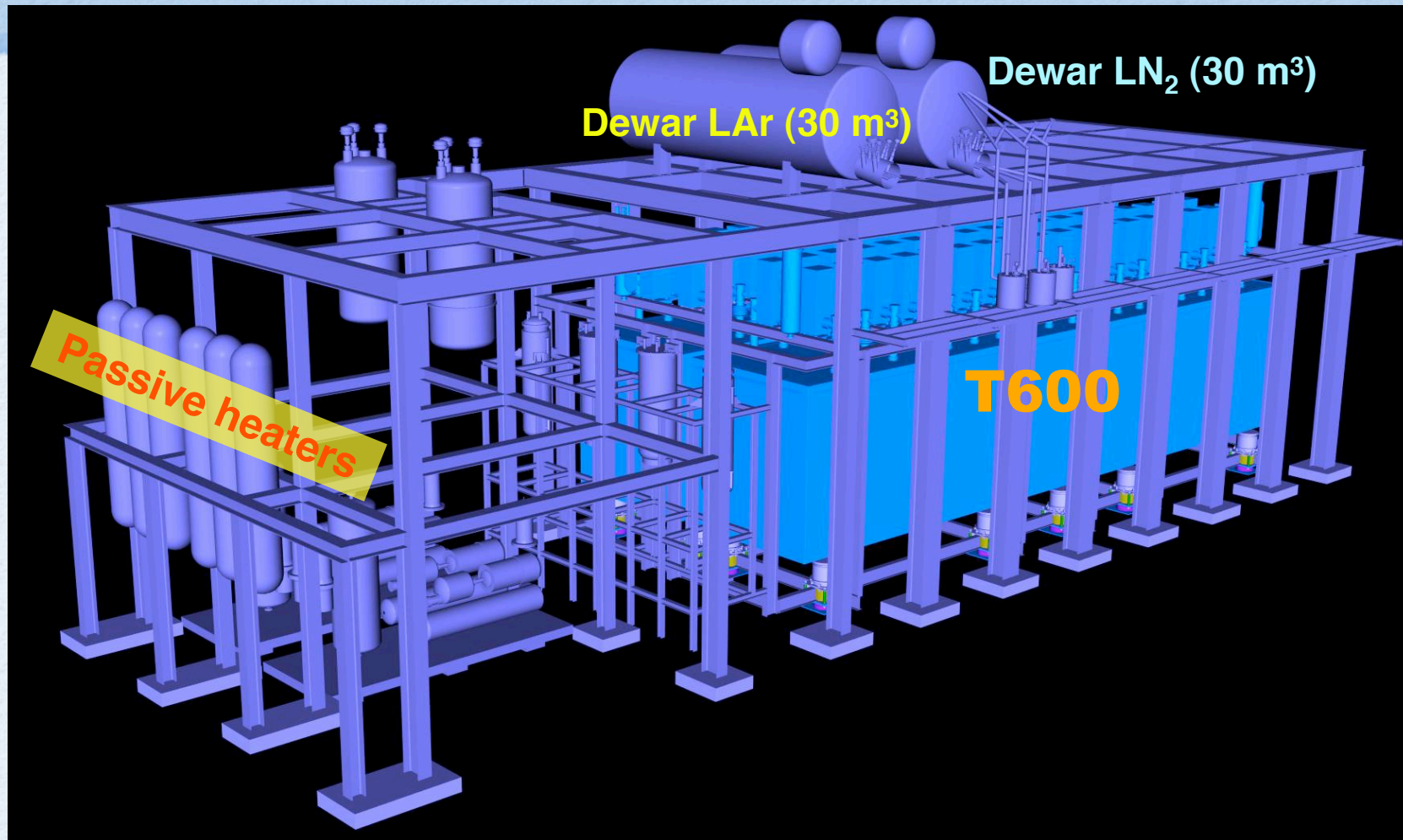
October CNGS run:

- CNGS induced rock muon selected by electronic detectors
- brick tagging using the reconstruction software
- CSD and brick analysed using the standard scanning system



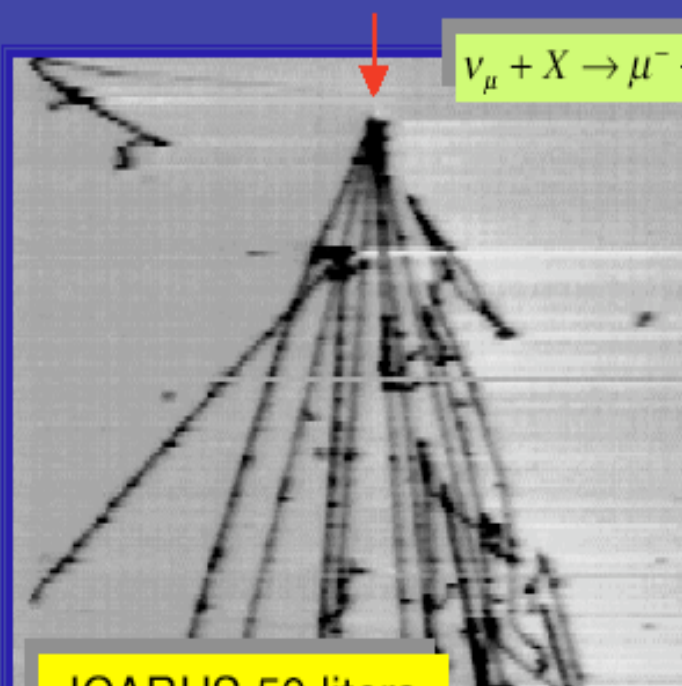
Details of the CS scanning showing the reconstructed grains.

ICARUS T600 (approvato ~1997)



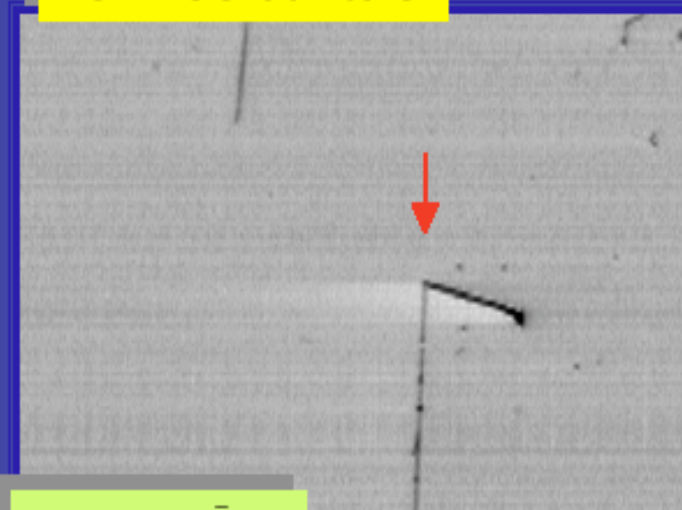
Installazione in corso nella sala B del Gran Sasso Hall B, ritardi della movimentazione, messa in funzione fine 2007, necessità liquefattore azoto

Real neutrino events observed by LAr TPC and water Cerenkov



ICARUS 50 liters

$$\nu_{\mu} + X \rightarrow \mu^{-} + \text{many prongs}$$



Super-Kamiokande

Run 7436 Event 1405412
99-06-19:18:42.4
inner: 516 hits, 1018 px
outer: 2 hits, 2 px (in-time)
Trigger ID: 0x0
D wall: 240.4cm

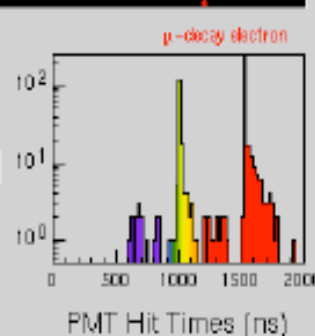
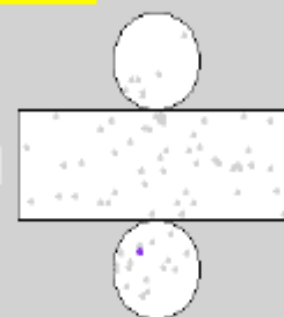
Resid(ns)

* > 182
* 160- 182
* 137- 160
* 114- 137
* 91- 114
* 68- 91
* 45- 68
* 22- 45
* 0- 22
* -22- 0
* -45- -22
* -68- -45
* -91- -68
* -114- -91
* -137- -114
* < -137

FIRST K2K EVENT
RECORDED BY SUPER-K

K2K

Neutrino Beam
Direction
from KEK



$$\nu_{\mu} + n \rightarrow \mu^{-} + p$$

CNGS2 E MODULAR

A new, very massive modular Liquid Argon Imaging Chamber to detect low energy off-axis neutrinos from the CNGS beam.

(Project MODULAR)

Abstract.

The paper is considering an opportunity for the CERN/GranSasso (CNGS) neutrino complex, concurrent time-wise with T2K and NOvA. It is a preliminary description of a ≈ 20 kt fiducial volume LAr-TPC following very closely the technology developed for the ICARUS-T600, which will be operational as CNGS2 early in 2008.

The present preliminary proposal, called MODULAR, is focused on the following three main activities, for which we seek an extended international collaboration:

(1) *the neutrino beam* from the CERN 400 GeV proton beam and an optimised horn focussing, eventually with an increased intensity in the framework of the LHC accelerator improvement programme.

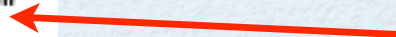
(2) *A new experimental area* LNGS-B, of at least $50'000 \text{ m}^3$ at 10 km off-axis from the main Laboratory, eventually upgradable to larger sizes. As a comparison, the present LNGS laboratory has three halls for a total of $180'000 \text{ m}^3$. A location is under consideration at about 1.2 km equivalent water depth. The bubble chamber like imaging and the very fine calorimetry of the LAr-TPC detector will ensure the best background recognition not only from the off-axis neutrinos from the CNGS but also for proton decay and cosmic neutrinos.

(3) *A new LAr Imaging detector*, at least initially with about 20 kt fiducial mass. Such an increase in the volume over the current ICARUS T600 needs to be carefully considered. It is concluded that a single, huge volume of such a magnitude is uneconomical and inoperable for many reasons. A very large mass is best realised with a modular set of many identical, but independent units, each of about 5 kt, "cloning" the basic technology of the T600. Several of such modular units will be such as to reach at least 20 kt as initial sensitive volume. Further phases may foresee extensions of MODULAR to a mass required by the future physics goals.

Compared with large water Cherenkov (T2K) and fine grained scintillators (NOvA), the LAr-TPC offers a higher detection efficiency for a given mass and lower backgrounds, since virtually all channels may be unambiguously recognized. In addition to the search for θ_{13} oscillations and CP violation, it would be possible to collect a large number of accurately identified cosmic ray neutrino events and perform search for proton decay in the exotic channels.

The experiment might reasonably be operational in about 4/5 years, provided a new hall is excavated in the vicinity of the Gran Sasso Laboratory and adequate funding and participation are made available.

arXiv:0704.1422 [hep-ph
aprile 2007



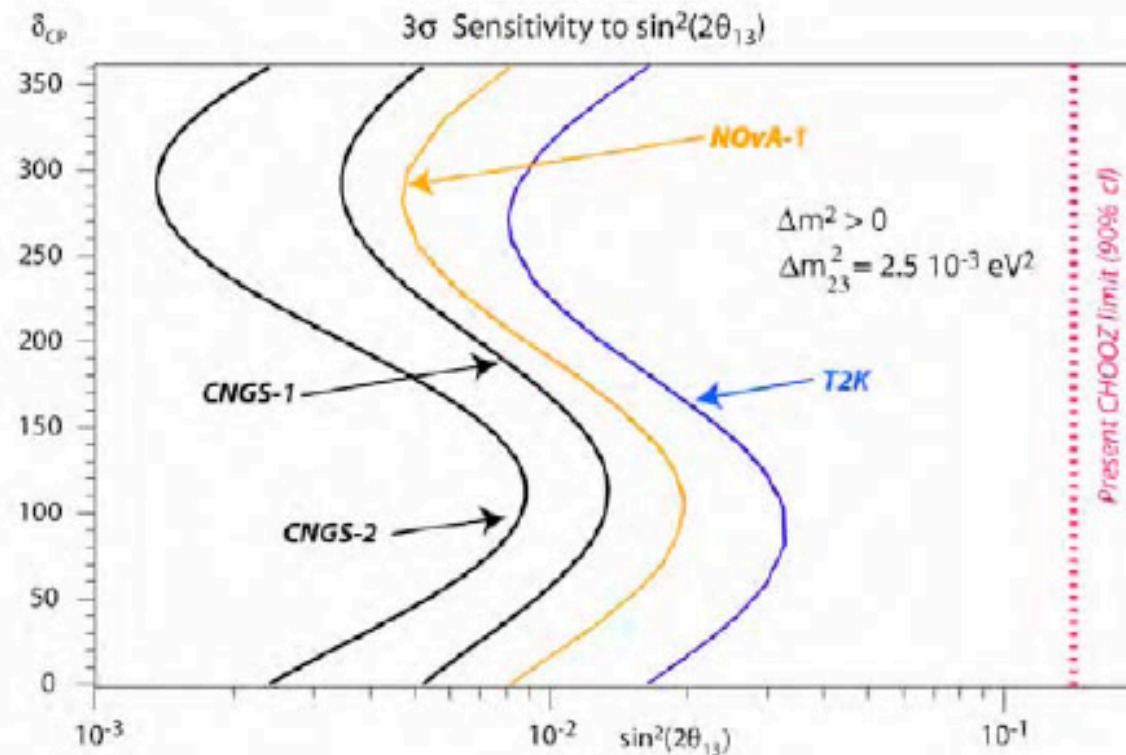


Figure 10. Comparison of the sensitivities for δ_{CP} , $\sin^2(2\theta_{13})$ plane at 3σ , all based on 5 years of neutrino operation for T2K, NOvA-1 and two proposed future scenarios at CNGS, 20 kt fiducial LAr detector. The CNGS-1 beam configuration is for (1) $1.2 \cdot 10^{20}$ POT/year at 400 GeV, (2) a cycle integrated beam power of 512 kWatt, (3) a new target/optics configuration optimized for a low energy neutrino beam, (4) 10 km off-axis detector and (5) without substantial increases of the SPS performance. The CNGS-2 configuration assumes an hypothetical improvement of the SPS and CPS to $4.33 \cdot 10^{20}$ POT/year corresponding to 1.6 MWatt beam power. The intensity of the NOvA-1 experiment is $6.5 \cdot 10^{20}$ POT/year at 120 GeV and a cycle integrated beam power of 768 kWatt. The corresponding intensity improvements for NOvA-2 are not completely identified and therefore the sensitivity is not shown. . All cases are computed for $\Delta m > 0$. Note the much higher sensitivity offered by the LAr approach which ensures higher discovery potentials, since every type of event is then clearly recognized and identified, contributing to the determination of the oscillation phenomenon. As a comparison, for instance in the case of NOvA, only 24% of the events may be used and a sizeable contaminant of mis-interpreted neutral current events add to the intrinsic ν_e emission from the beam. Similar inefficiency considerations apply to the water Cherenkov counter at T2K.

Convegno
CRYODET2
14-15 Giugno ai
LNGS

LARGE VOLUME DETECTOR

per Supernovae Galattiche

INFN and INR Russia



CNGS BEAM MONITOR WITH THE LVD DETECTOR.

Nucl. Instrum. Meth. A **516**, 96-103 (2004)

e-Print Archive: [hep-ex/0304018](https://arxiv.org/abs/hep-ex/0304018)



Misura Massa Neutrini

MASSA DA DECADIMENTO BETA

- Grande spettrometro in costruzione in Germania : KATRIN per arrivare a $\sim 0.2\text{eV}$ (90%C.L.) nel 2015. Decadimento del trizio. Tecnica al limite, difficile pensare a sensibilità maggiori
- CSN2 da molti anni si sta sviluppando (Milano Bicocca, Como, Genova..) una tecnica basata su **microcalorimetri** di **Renio** superconduttore (idea dovuta a S. Vitale). Misura tutta l'energia (non solo quella dell'elettrone)

Attuale $M\nu_e < 15\text{ eV}$ (90% cl)

Futuro vicino $M\nu_e < 1-2\text{ eV}$

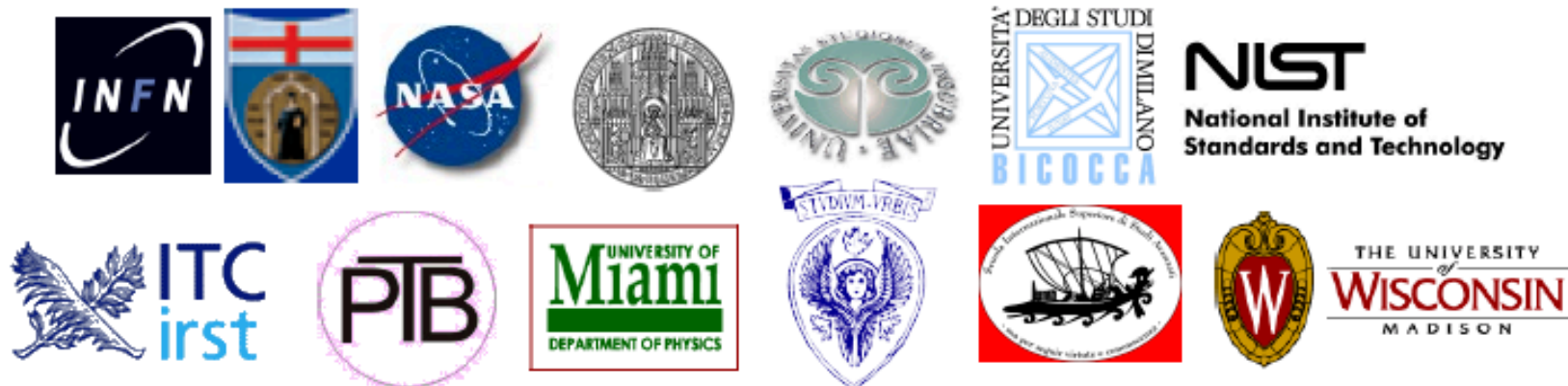
Futuro lontano $M\nu_e < 0.2\text{ eV}$

MARE misura diretta della massa del neutrino R/D goal ~ 0.2 eV

MARE: Microcalorimeter Arrays for a Rhenium Experiment

Università di Genova e INFN Sez. di Genova
Goddard Space Flight Center, NASA, Maryland, USA
Kirkkhof-Institute Physik, Universität Heidelberg, Germany
Università dell'Insubria, Università di Milano-Bicocca e INFN Sez. di Milano-Bicocca
NIST, Boulder, Colorado, USA
ITC-irst, Trento e INFN Sez. di Padova
PTB, Berlin, Germany
University of Miami, Florida, USA
Università di Roma "La Sapienza" e INFN Sez. di Roma1
SISSA, Trieste
Wisconsin University, Madison, Wisconsin, USA

...



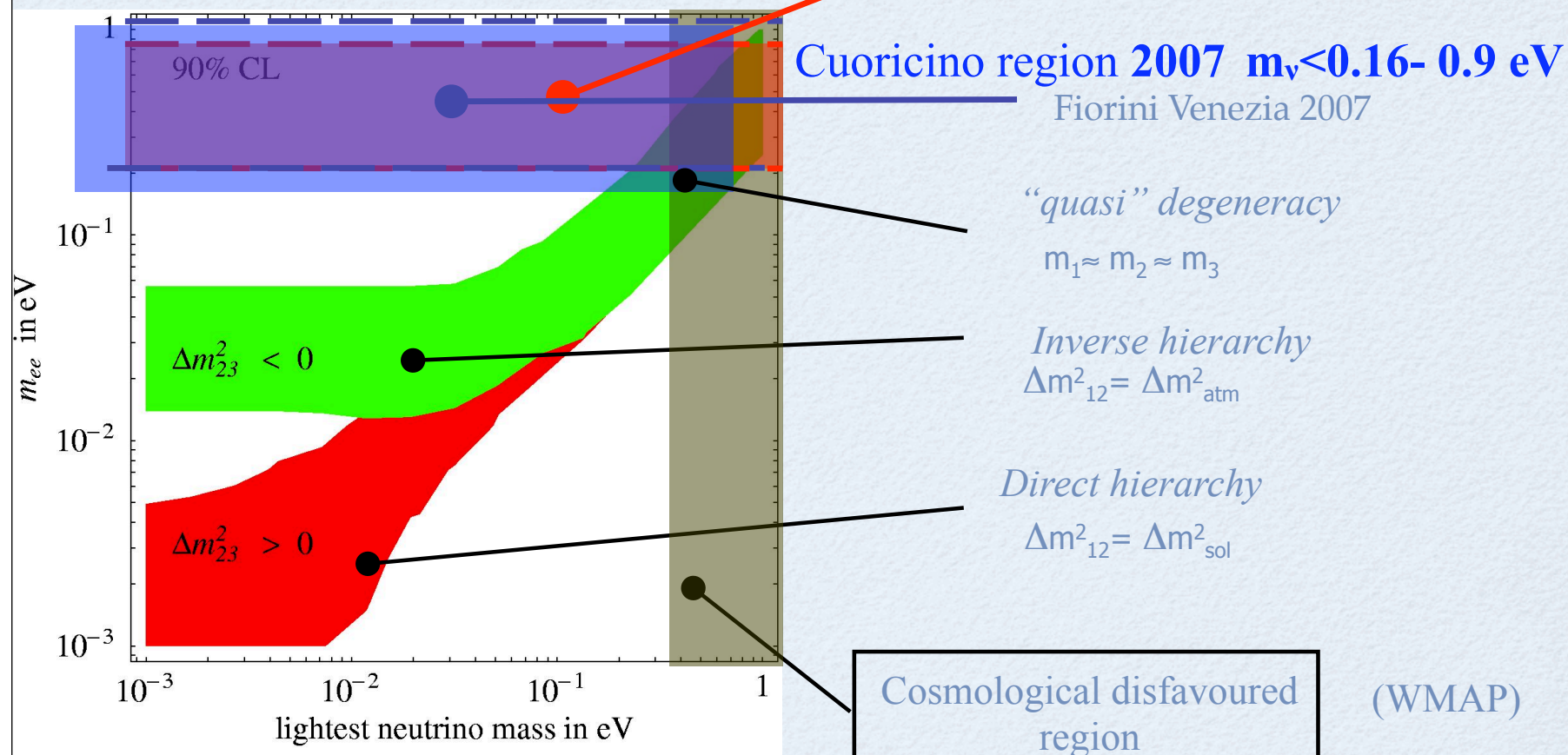
Decadimenti doppio beta senza neutrini

sensibilità masse $< 0.2 \text{ eV}$ e scoperta fondamentale!

Neutrini di Majorana

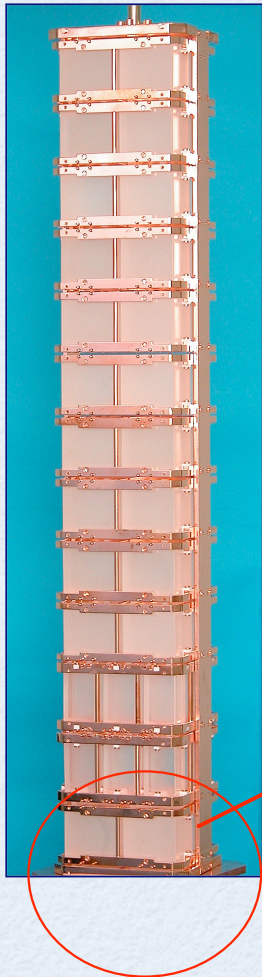
Possible evidence
(best value 0.39 eV)

H.V. Klapdor-Kleingrothaus et al., Nucl. Instrum. and Meth. ,522, 367 (2004).

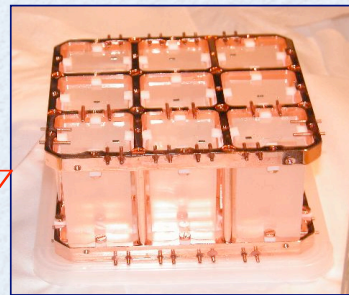


Feruglio F., Strumia A., Vissani F. hep-ph/0201291

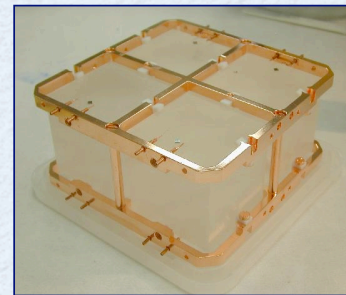
Doppio Beta : CUORICINO (LNGS)



- ✓ Search for the $2\beta|_{\text{ov}}$ in ^{130}Te ($Q=2529$ keV) and other rare events
- ✓ At Hall A in the Laboratori Nazionali del Gran Sasso (LNGS)
- ✓ 18 crystals $3\times 3\times 6$ cm³ + 44 crystals $5\times 5\times 5$ cm³ = 40.7 kg of TeO₂
- ✓ Operation started in the beginning of 2003
- ✓ **Background $.18\pm.01$ c /kev/ kg/ a**



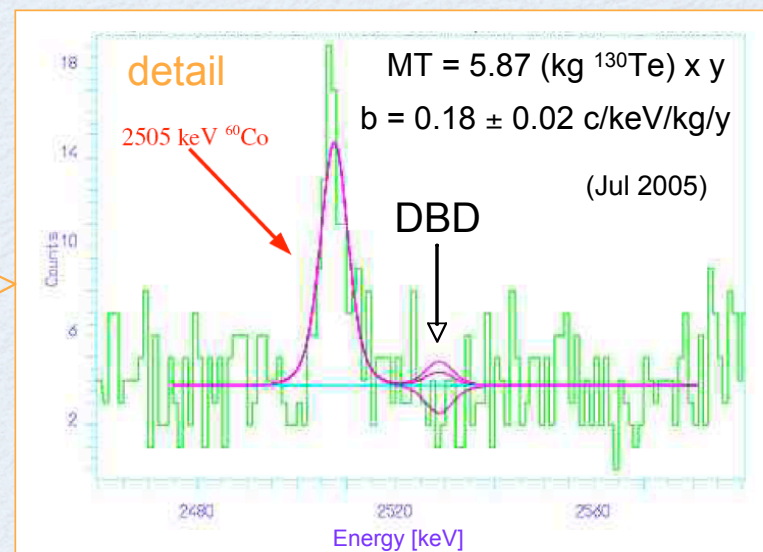
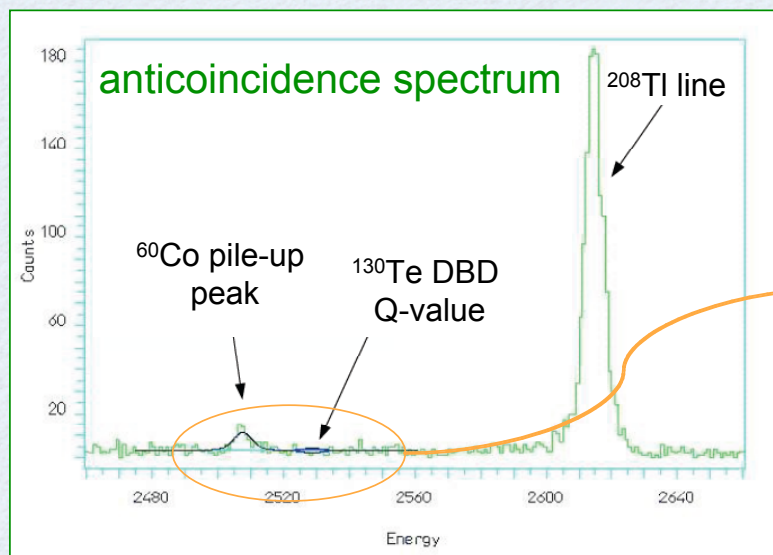
2 modules, 9 detector each,
crystal dimension $3\times 3\times 6$ cm³
crystal mass 330 g
 $9 \times 2 \times 0.33 = 5.94$ kg of TeO₂



11 modules, 4 detector each,
crystal dimension $5\times 5\times 5$ cm³
crystal mass 790 g
 $4 \times 11 \times 0.79 = 34.76$ kg of TeO₂

Doppio Beta : CUORICINO (LNGS)

Present CUORICINO result (new)



$$\tau > 3 \times 10^{24} \text{ (90 \% c.l.)}$$

$$\langle m_{0\nu} \rangle < .16 - .9 \text{ eV} \Rightarrow \text{Klapdor et al } m_{0\nu} < .1 - .9 \text{ eV}$$

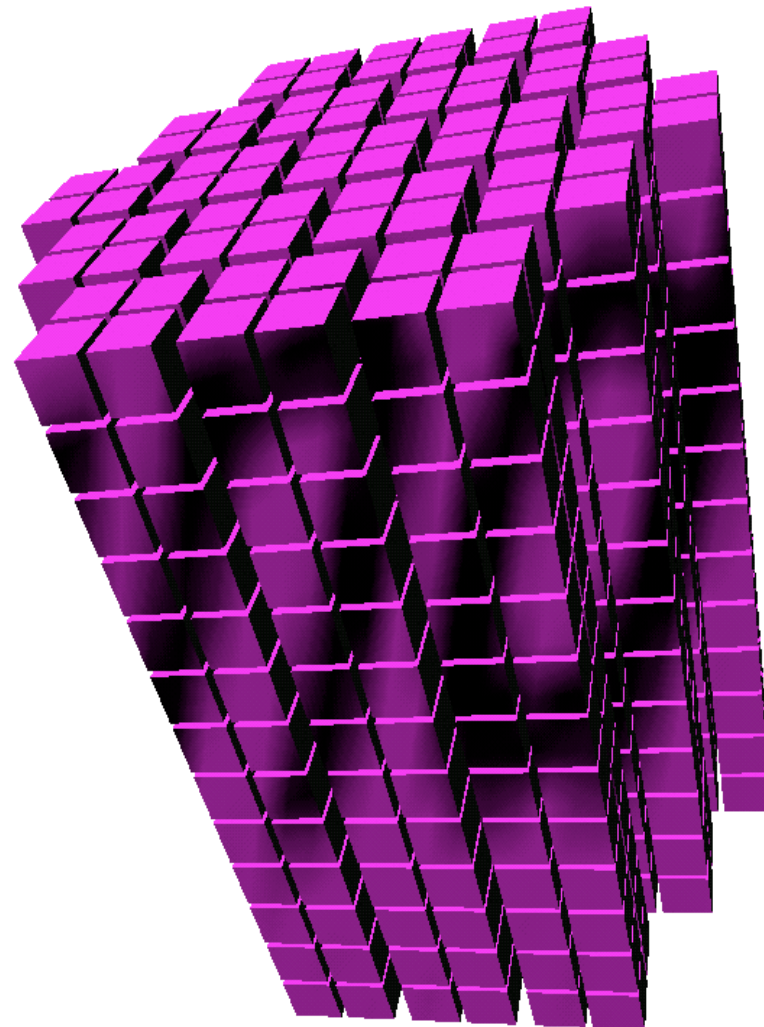
Doppio Beta: **CUORE** (Italia,USA, Spagna,Cina)

CUORE ha **988** bolometri
raggruppati grouped in **19**
colonne con 13 piani di
4 cristalli

750 kg TeO₂ => 600 kg Te
=> 203 kg ¹³⁰Te

I Cristalli sono separati di
alcuni **mm** con poco
materiale tra i piani

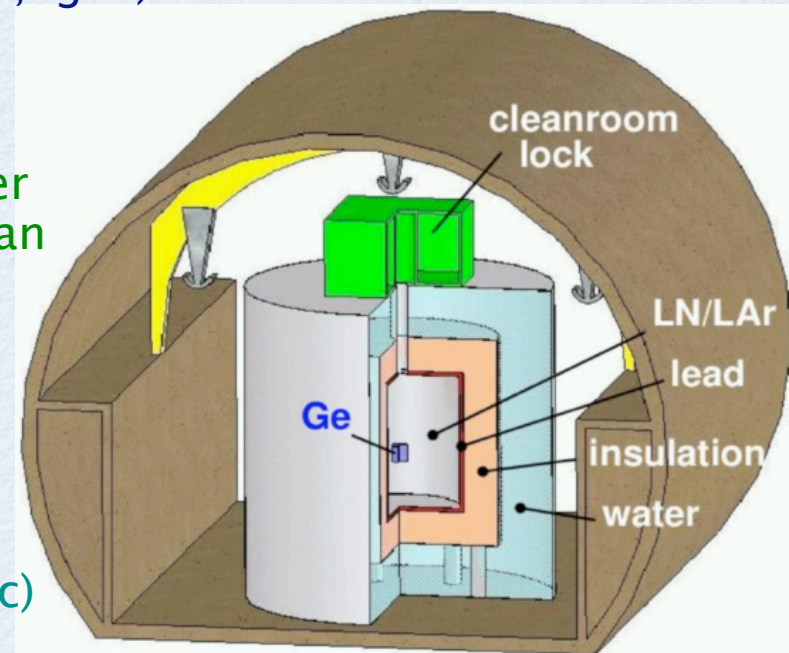
sensibilità~9-57 meV



Doppio beta

- goal: analyse HM evidence in a short time using existing ^{76}Ge enriched detectors (HM, Igex)
- approach similar to GENIUS but less LN2
 - ▶ naked Ge crystals in LN2 or LAr
- more compact than GENIUS
 - ▶ 1.5 m LN2(LAr) + 10 cm Pb + 2 m water
 - ▶ 2–3 orders of magnitude better bkg than present Status-of-the-Art
 - ▶ active shielding with LAr scintillation
- 3 phases experiment
- Phase I: ~2008
 - radioactivity tests
 - ≈ 20 kg ^{76}Ge from HM and Igex
 - expected bkg 0.01 c/keV/kg/y (intrinsic)
 - check at 5σ HM evidence
 - ▶ 15 kg $\times$ y 6 ± 1 $\beta\beta$ events on 0.5 bkg events
- Phase II:
 - add new enriched segmented detectors with special care for activation
 - expected background ≈ 0.001 c/keV/kg/y
 - 2×10^{26} y with 100 kg $\times$ y
 - $\langle m \rangle$ 0.09 $\div$ 0.29 eV
- Phase III: $\Rightarrow$ 0.01 eV with 1 ton Ge
 - ▶ worldwide collaboration

GERDA (Germany-Italy-Russia)



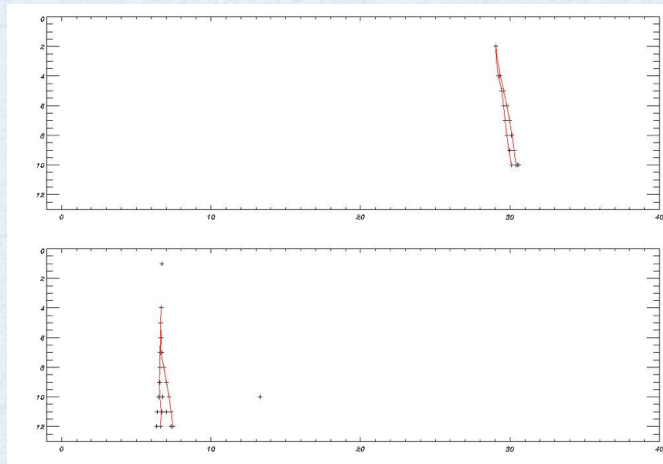
- Approved by LNGS S.C.
- site: Hall A northern wing
- funded 40 kg enriched ^{76}Ge for phase II
- aggressive time schedule

PER CSN2 2007 ANNO DI SUCCESSI!!

- Giugno 2006 inaugurazione nel Tibet di **ARGO** (raggi cosmici e gamma astronomia) per completamento RPC e presa dati
- Luglio 2006 lancio di **PAMELA** (antimateria nei raggi cosmici) primo apparato spaziale complesso assemblato in una sede INFN (Roma2)
- Agosto 2006 primo run scientifico fascio di neutrini **CNGS con OPERA, LVD, BOREX**
- Dicembre 2006 in mare al largo di Catania prototipo torre di **NEMO**

2007 È CSN2 ANNO DI SUCCESSI!!!

- Aprile 2007 lancio di **AGILE** (gamma astronomia)



primo fotone
convertito rivelato in AGILE
dal tracciatore al silicio

- Maggio 2007 completamento riempimento con scintillatore di **BOREX** (neutrini solari) e inizio presa dati scientifica
- Maggio 2007 inizia run scientifico di **VIRGO** (onde gravitazionali) insieme a LIGO come “unico” esperimento
- Risultati scientifici a conferenze estive TAUP, ICRC..

- Questi successi sono figli di R/D e sviluppi in nuovi campi, molto dibattuti e anche criticati nel passato
- Bisogna sfruttare al meglio gli investimenti fatti nel decennio passato ma bisogna evitare che le attuali difficoltà finanziarie blocchino completamente le idee più nuove e rischiose e le proposte dei ricercatori più giovani

FINE

BACKUP

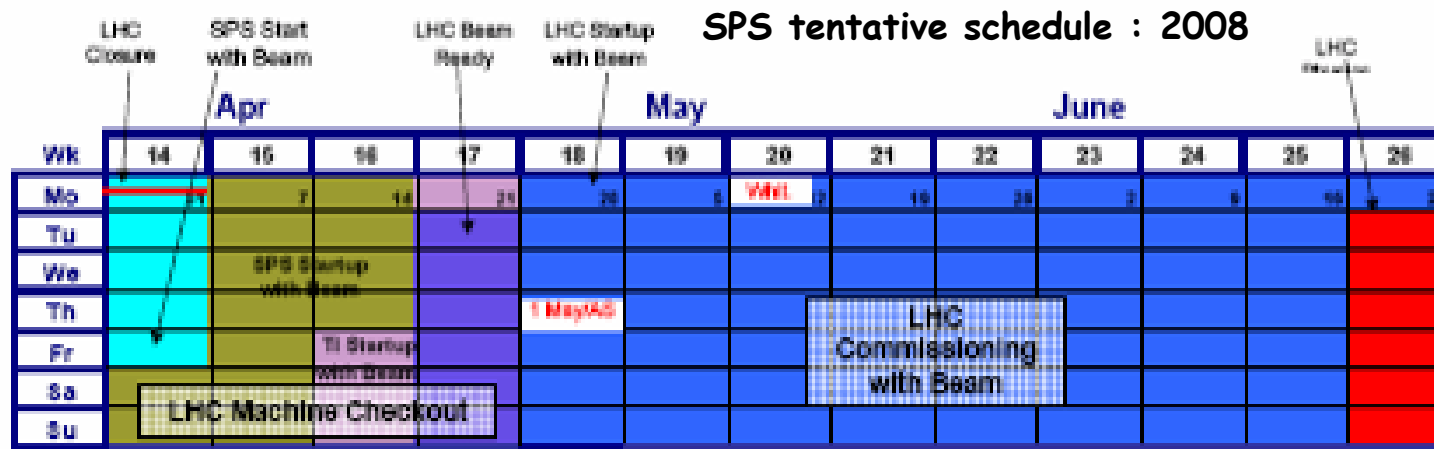
Detector filling



Assumptions :

- Number of bricks on the end of April: 10000 (ok)
- Ramp up from average actual speed 4 drums/w to 10 drums/w on April 30th (~ok)
- Reaching 15 drums/week on september 1st

→ Full target filled (150000 bricks) in May 2008
(including 15% contingencies and 3 weeks for holidays)



Physics starts end of april

Some of the possible corollary quests for the candidate - II

Light axion-like bosons class: examples of allowed volumes/regions

IJMP A21(2006)1445

Light bosons: Axion-like particles, similar phenomenology with ordinary matter as the axion, but significantly different values for mass and coupling constants are allowed.

A wide literature is available and various candidate particles have been and can be considered.

The detection is based on the total conversion of the absorbed bosonic mass into electromagnetic radiation.

In these processes the target nuclear recoil is negligible and not involved in the detection process (i.e. signals from these candidates are lost in experiments applying rejection procedures of the electromagnetic contribution)

A complete data analysis of the total 107731 kgxday exposure from DAMA/NaI has been performed for pseudoscalar (a) and scalar (h) candidates in some of the possible scenarios.

DAMA Esempio di interpretazione WIMPS

Allowed multi-dimensional volume

The pseudoscalar case (a)

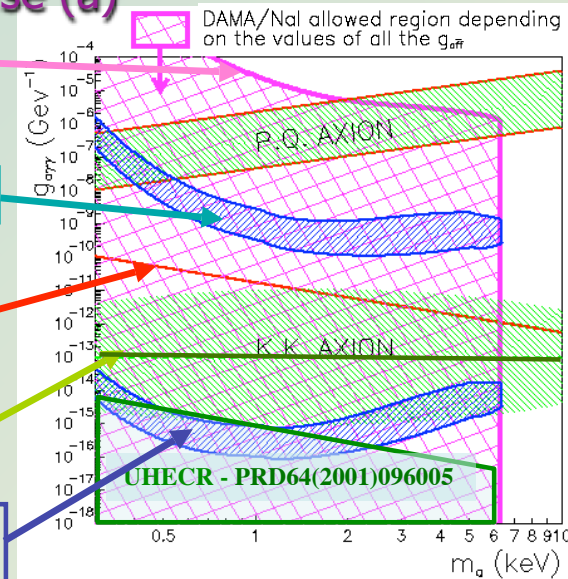
Maximum allowed photon coupling

only electron coupling

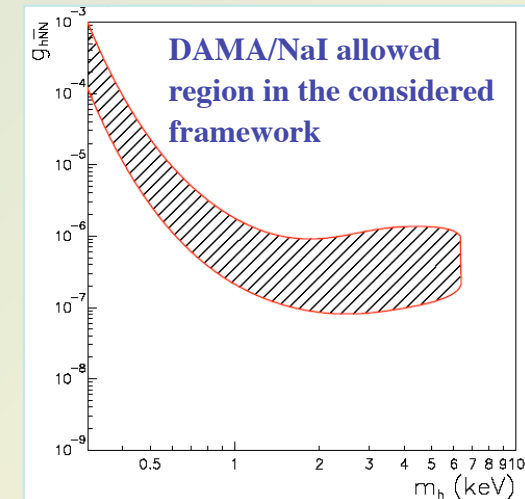
cosmological interest: at least below

Di Lella, Zioutas
AP19(2003)145

Majoron as in
PLB99(1981)411



The scalar case (h)



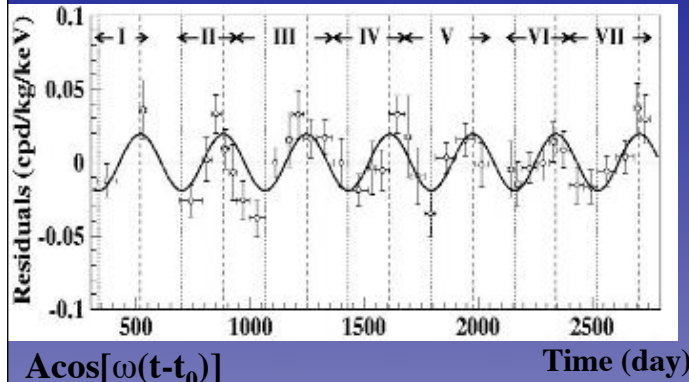
Many configurations are of cosmological interest

Final model independent result by DAMA/NaI

7 annual cycles: total exposure $\sim 1.1 \times 10^5 \text{ kg} \times \text{d}$

Riv. N. Cim. 26 n. 1 (2003) 1-73, IJMPD 13 (2004) 2127

Experimental residual rate of the single hit events in 2-6 keV over 7 annual cycles



$\text{Acos}[\omega(t-t_0)]$

$P(A=0) = 7 \cdot 10^{-4}$

Solid line: $t_0 = 152.5 \text{ days}$, $T = 1.00 \text{ years}$
from the fit:

$A = (0.0192 \pm 0.0031) \text{ cpd/kg/keV}$

from the fit with all the parameters free:

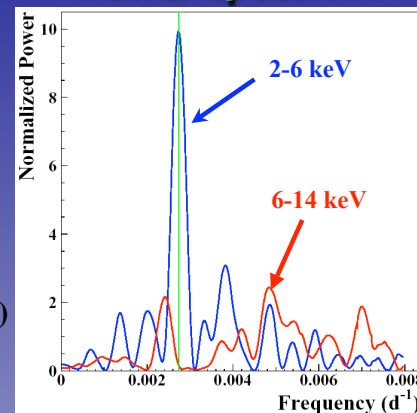
$A = (0.0200 \pm 0.0032) \text{ cpd/kg/keV}$

$t_0 = (140 \pm 22) \text{ d}$

$T = (1.00 \pm 0.01) \text{ y}$

No systematics or side reaction able to account for the measured modulation amplitude and to satisfy all the peculiarities of the signature

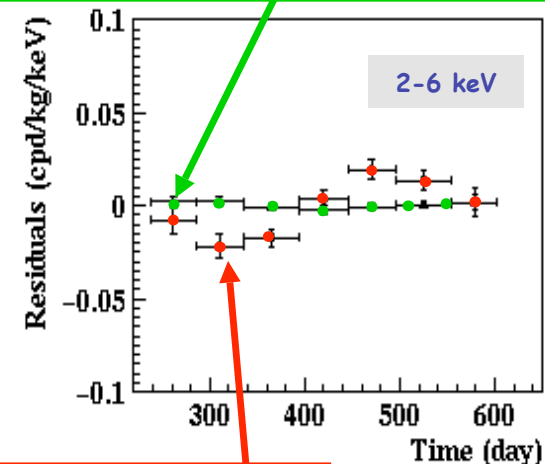
Power spectrum



Principal mode

$\rightarrow 2.737 \cdot 10^{-3} \text{ d}^{-1} \approx 1 \text{ y}^{-1}$

experimental residual rate of the multiple hit events (DAMA/NaI-6 and 7) in the 2-6 keV energy interval: $A = -(3.9 \pm 7.9) \cdot 10^{-4} \text{ cpd/kg/keV}$



experimental residual rate of the single hit events (DAMA/NaI-1 to 7) in the 2-6 keV energy interval:
 $A = (0.0195 \pm 0.0031) \text{ cpd/kg/keV}$

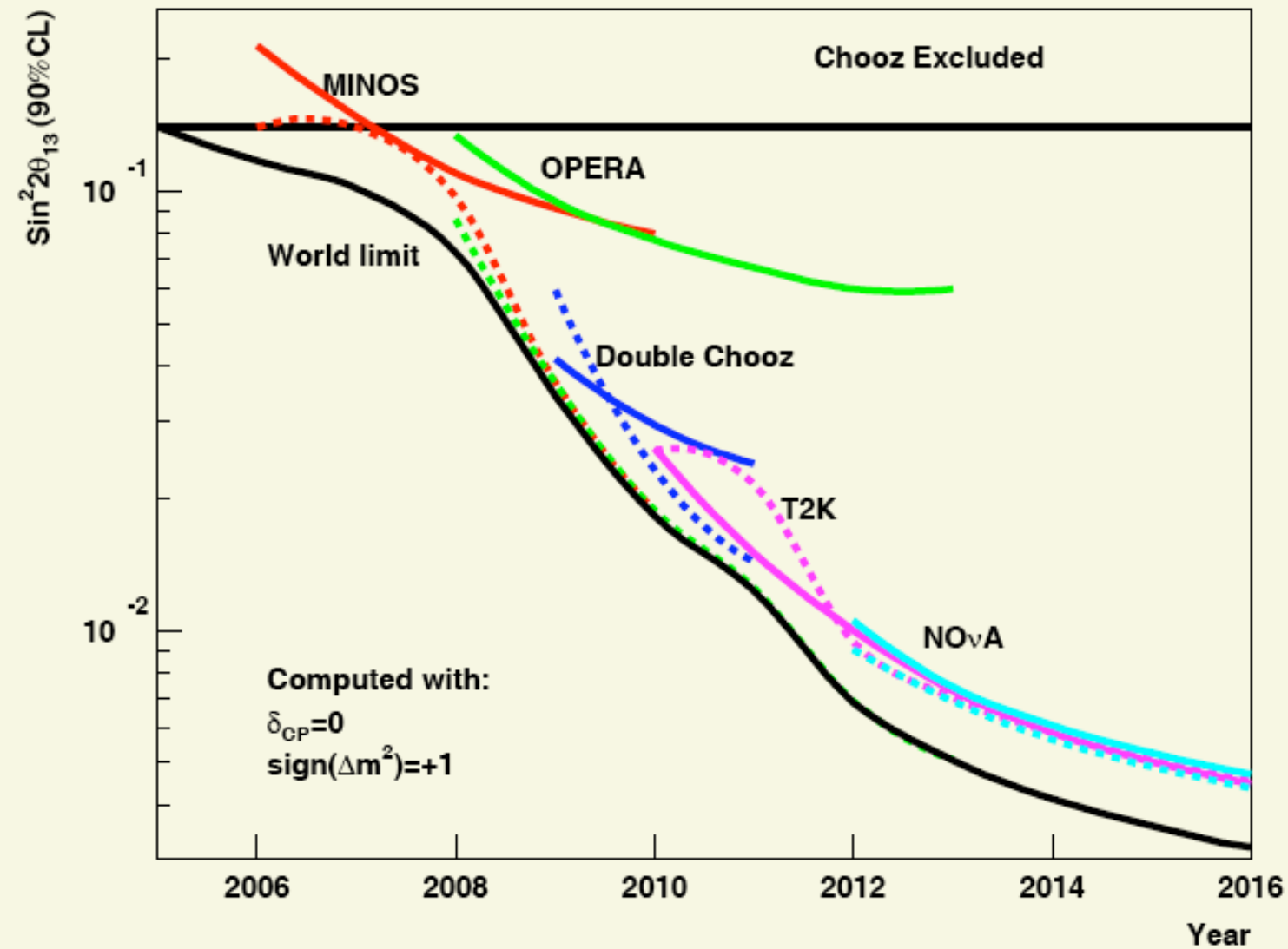
Multiple hits events = Dark Matter particle "switched off"

This result offers an additional strong support for the presence of DM particles in the galactic halo further excluding any side effect either from hardware or from software procedures or from background

All the peculiarities of the signature satisfied

model independent evidence of a particle Dark Matter component in the galactic halo at 6.3 σ C.L.

La roadmap degli esperimenti long baseline



Physics goals for Borexino

- ❑ Measure ${}^7\text{Be}$ solar neutrinos (0.25-0.8 MeV)
 - ❑ Measured vs MSW-LMA predicted event rate
 - ❑ Time variation of solar signal in the sub-MeV range
- ❑ Study CNO and pep neutrinos (0.8-1.3 MeV)
(rejection of ${}^{11}\text{C}$ cosmogenic background – proved in CTF **hep-ex/0601035**)
- ❑ Neutrinos from the Earth
- ❑ Neutrinos from supernovae
- ❑ Neutrino magnetic moment (also in conjunction with the ${}^{51}\text{Cr}$ source calibration)

Present experimental situation Non aggiornata

LNGS

Nucleus	Experiment	%	$Q_{\beta\beta}$	Enr	Technique	$T_{0\nu}$ (y)	$<m_\nu$
^{48}Ca	Elegant IV	0.19	4271		scintillator	$>1.4 \times 10^{22}$	7-45
^{76}Ge	Heidelberg-Moscow	7.8	2039	87	ionization	$>1.9 \times 10^{25}$	.12 - 1
^{76}Ge	IGEX	7.8	2039	87	Ionization	$>1.6 \times 10^{25}$	.14 – 1.2
^{76}Ge	Klapdor et al	7.8	2039	87	ionization	1.2×10^{25}	.44
^{82}Se	NEMO 3	9.2	2995	97	tracking	$>1. \times 10^{23}$	1.8-4.9
^{100}Mo	NEMO 3	9.6	3034	95-99	tracking	$>4.6 \times 10^{23}$	.7-2.8
^{116}Cd	Solotvina	7.5	3034	83	scintillator	$>1.7 \times 10^{23}$	1.7 - ?
^{128}Te	Bernatovitz	34	2529		geochem	$>7.7 \times 10^{24}$	.1-4
^{130}Te	Cuoricino	33.8	2529		bolometric	$>2 \times 10^{24}$	.16-.82.
^{136}Xe	DAMA	8.9	2476	69	scintillator	$>1.2 \times 10^{24}$	1.1 -2.9
^{150}Nd	Irvine	5.6	3367	91	tracking	$>1.2 \times 10^{21}$	3 - ?

LNGS

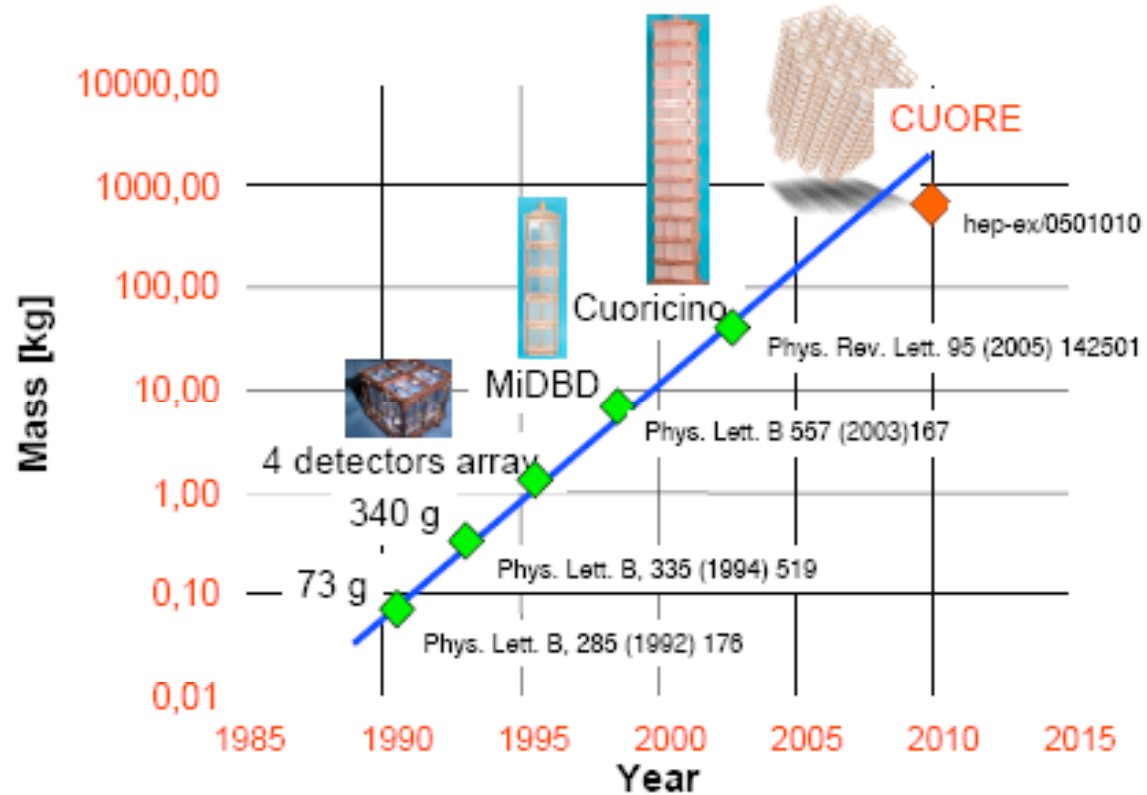
LNGS

Necessari più esperimenti con nuclei diversi per verificare segnale genuino

da Fiorini Venezia 2007

F. Ronga Milano Piano Triennale 2008-2010

Bolometric $0\nu\beta\beta$ Experiments: Past & Future



Cuoricino: Currently the largest bolometer & most sensitive $0\nu\beta\beta$ experiment running
 CUORE: Next generation with 741 kg of TeO_2 (200 kg of ^{130}Te)

RISULTATI RECENTI DI MINIBONE

ESCLUDONO QUARTO NEUTRINO (STERILE) SUGGERITO DA LSND

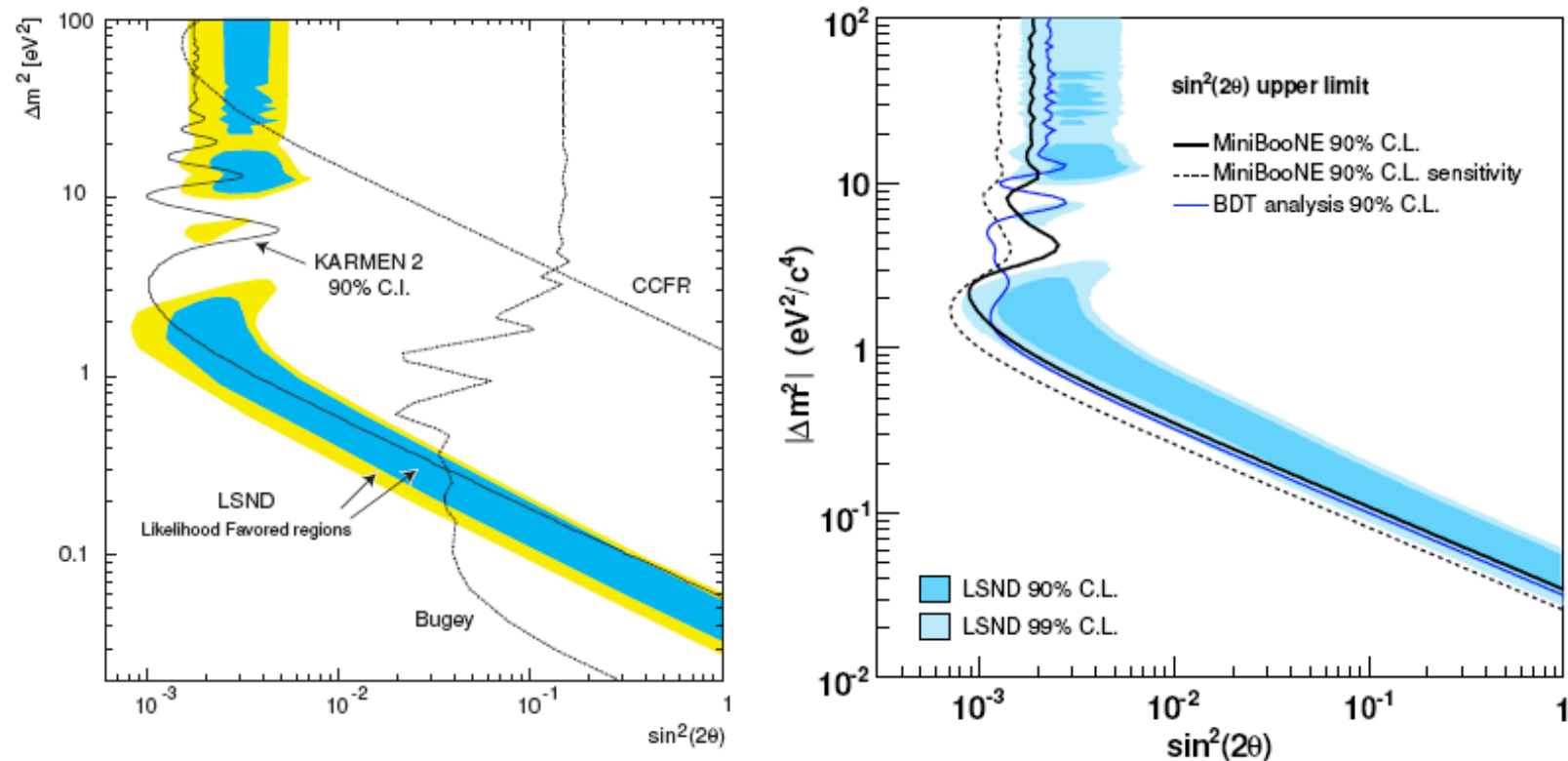


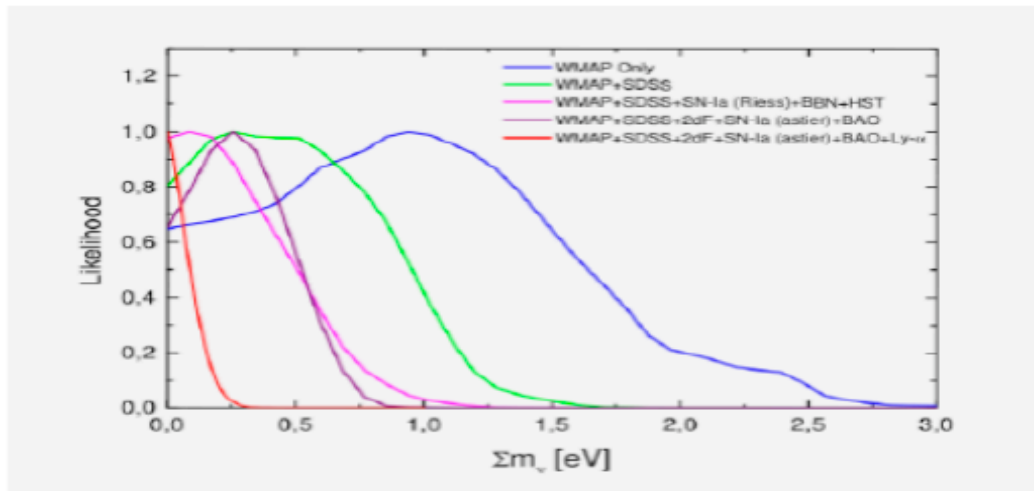
Fig. 6. (Left) Allowed regions (at 90% and 99% CL) for $\nu_e \rightarrow \nu_\mu$ oscillations from the LSND experiment compared with the exclusion regions (at 90% CL) from KARMEN2 and other experiments (from Ref. [87]). (Right) $\nu_\mu \rightarrow \nu_e$ excluded regions from MiniBooNE compared to the LSND allowed region (from Ref. [95]).

Next generation experiments

LNGS
LNGS

Name		%	$Q_{\beta\beta}$	% E	B c/y	T (year)	Tech	<m> meV
CUORE	^{130}Te	34	2533	90	3.5	1.8×10^{27}	Bolometric	9-57
GERDA	^{76}Ge	7.8	2039	90	3.85	2×10^{27}	Ionization	29-94
Majorana	^{76}Ge	7.8	2039	90	.6	4×10^{27}	Ionization	21-67
GENIUS	^{76}Ge	7.8	2039	90	.4	1×10^{28}	Ionization	13-42
Supernemo	^{82}Se	8.7	2995	90	1	210^{26}	Tracking	54-167
EXO	^{136}Xe	8.9	2476	65	.55	1.3×10^{28}	Tracking	12-31
Moon-3	^{100}Mo	9.6	3034	85	3.8	1.7×10^{27}	Tracking	13-48
DCBA-2	^{150}Nd	5.6	3367	80		1×10^{26}	Tracking	16-22
Candles	^{48}Ca	.19	4271	-	.35	3×10^{27}	Scintillation	29-54
CARVEL	^{48}Ca	.19	4271	-		3×10^{27}	Scintillation	50-94
GSO	^{160}Gd	22	1730	-	200	1×10^{26}	Scintillation	65-?
COBRA	^{115}Cd	7.5	2805				Ionization	
SNOLAB+	^{150}Nd	5.6	3367				Scintillation	

LIMITI COSMOLOGICI SULLA MASSA DEI NEUTRINI



Cosmological Bounds on the sum of the masses of the 3 neutrinos from increasingly rich samples of data sets

Case	Cosmological data set	Σ bound (2σ)
1	WMAP	< 2.3 eV
2	WMAP + SDSS	< 1.2 eV
3	WMAP + SDSS + SN_{Riess} + HST + BBN	< 0.78 eV
4	CMB + LSS + SN_{Astier}	< 0.75 eV
5	CMB + LSS + SN_{Astier} + BAO	< 0.58 eV
6	CMB + LSS + SN_{Astier} + Ly- α	< 0.21 eV
7	CMB + LSS + SN_{Astier} + BAO + Ly- α	< 0.17 eV

$m_{\nu e} < 2.2$ eV esperimenti decadimento beta