Highlights della Sessione "Neutrini e Astrofisica Particellare"

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Outlook

Microphysics (Fundamental Interactions)

↕

Astrophysics, observational & theoretical

Dreams (or nightmares):

- Cosmological constant (dark energy)?
- Baryon asymmetry?
- Dark matter?
- Neutrino properties and experiments

Fighting the cosmological constant

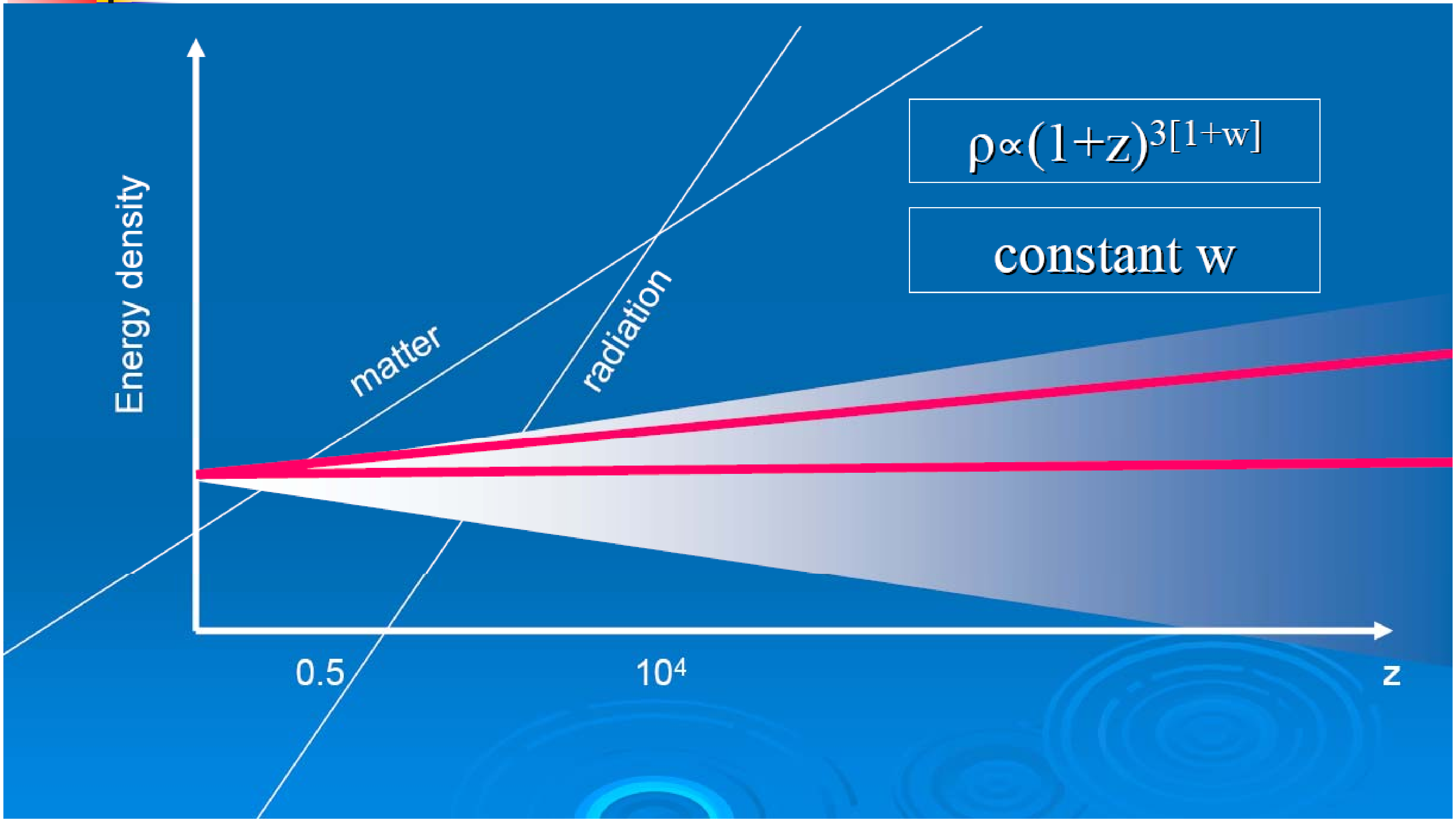
geometry

$$G_{\mu\nu}+\Lambda g_{\mu\nu}=8\pi T_{\mu\nu}+V g_{\mu\nu}$$

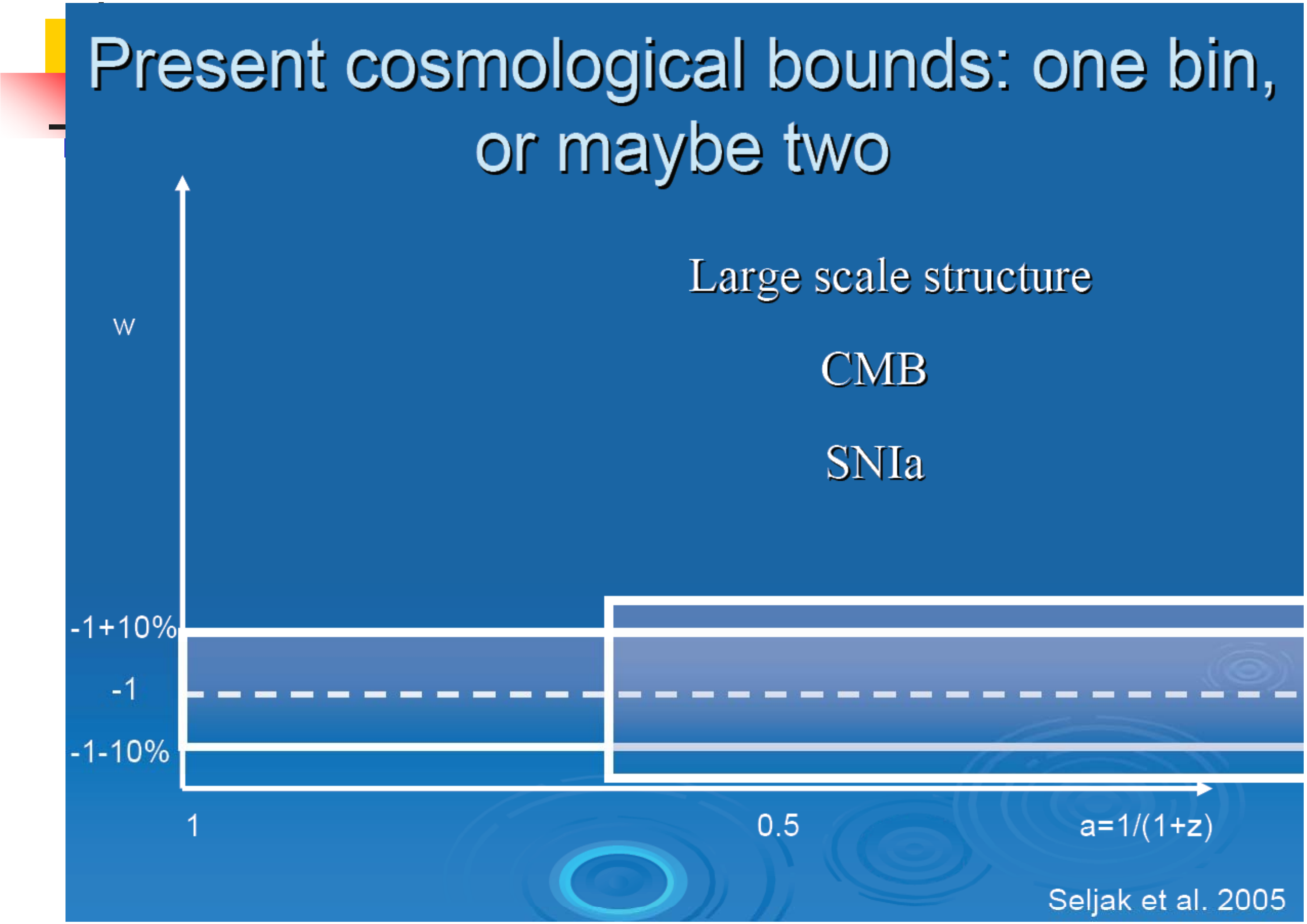
quantum vacuum

$$|\Lambda-V|/M^4_{Planck} \lesssim 10^{-123}$$

C. Baccigalupi



C. Baccigalupi

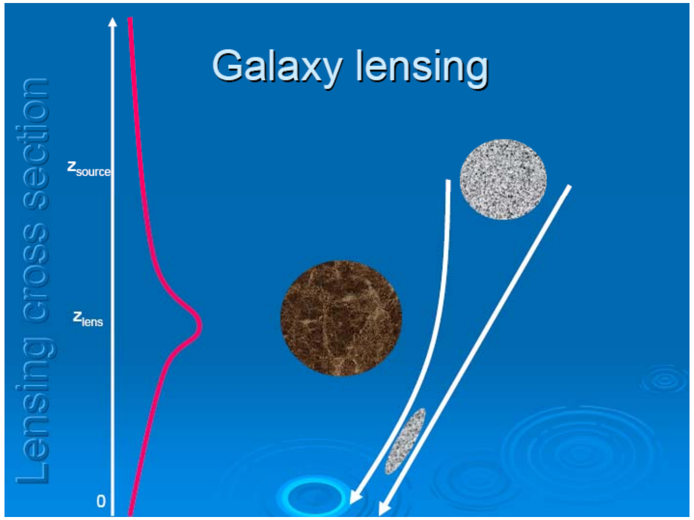


C. Baccigalupi

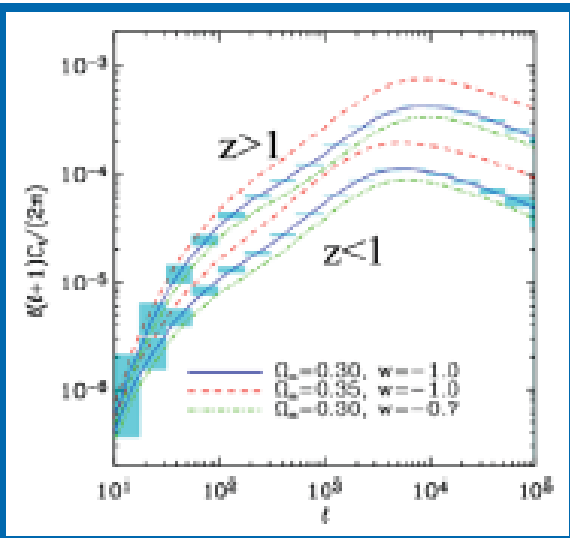
The “modern” era: “slicing” dark energy

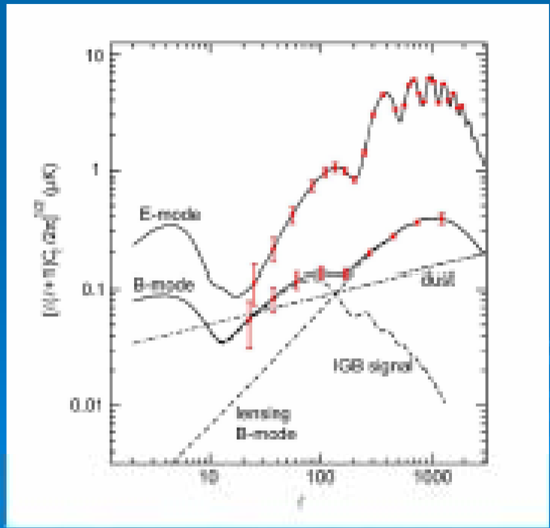
- structure formation in dark energy cosmologies, from galaxy clusters to relevant fractions of the Hubble volume
- Measure H(z) and therefore ρ(z), looking for effects which are sensitive to slices in redshifts
- Baryon acoustic oscillations
- Weak lensing in the optical band from lensing induced ellipticity on background galaxies by lenses at different redshifts
- Complementary weak lensing studies on CMB

C. Baccigalupi



- DUNE (Dark Universe Explorer) to be proposed in June within the Cosmic Vision Program, able to measure the dark energy abundance in a few bins between z=0 and 1, with percent accuracy
- CMB lensing within reach of the forthcoming detectors





C. Baccigalupi

Matter-antimatter asymmetry

- Symmetric Universe with matter- anti matter domains ? Excluded by CMB + cosmic rays

$$\eta_B^{CMB} = (6.3 \pm 0.3) \times 10^{-10} \gg \eta_B^{-}$$

- Pre-existing ? It conflicts with inflation ! (Dolgov '97)

dynamical generation (baryogenesis)

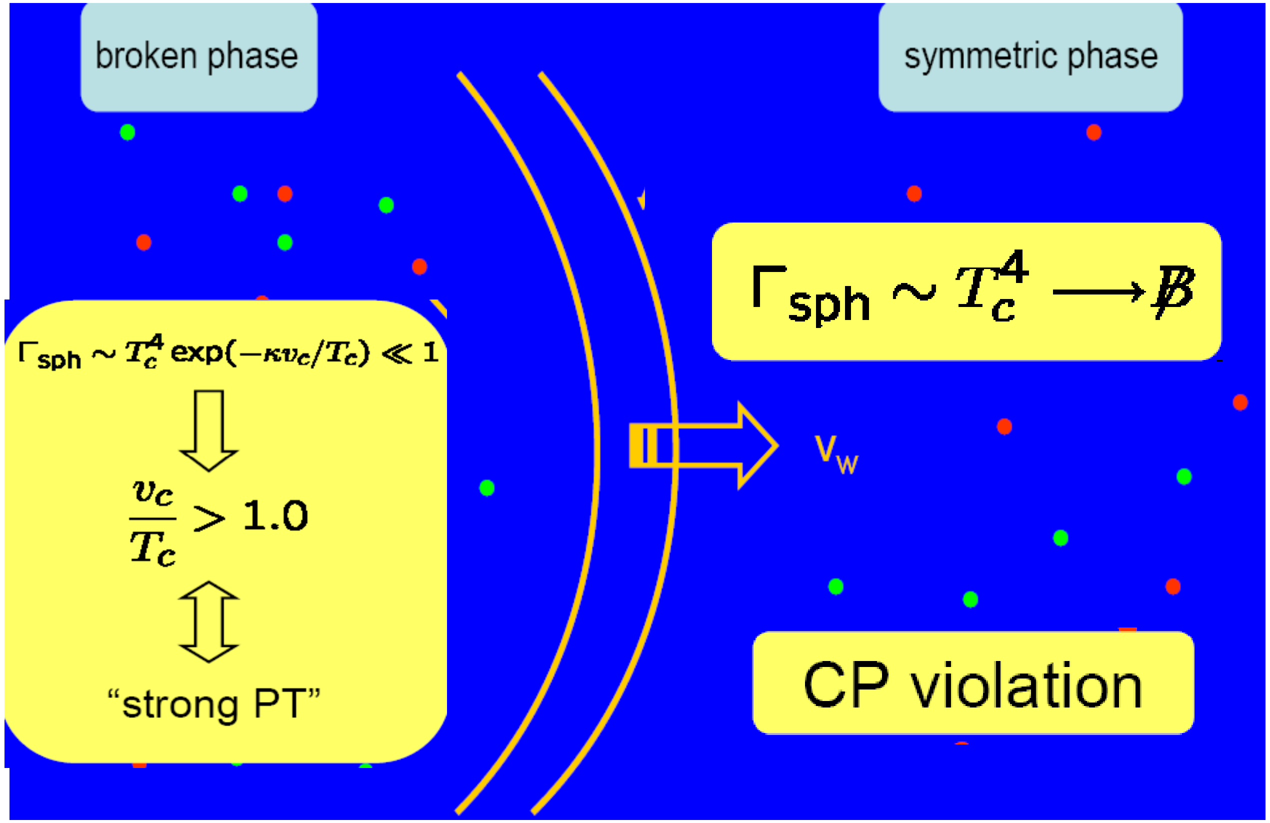
(Sakharov '67)

Models of Baryogenesis

- From phase transitions:
  - EWBG:
    - * in the SM
    - *** in the MSSM**
    - * in the NMSSM
    - * in the 2 Higgs model
    - * …………………
- Affleck-Dine:
  - at preheating
    - Q-balls
  - ……….
- From Black Hole evaporation
- Spontaneous Baryogenesis
- ………………………………….
- From heavy particle decays:
  - GUT Baryogenesis
  - **LEPTOGENESIS**

EWBG in the SM

If the EW phase transition (PT) is 1st order ❾ **broken phase bubbles nucleate**



P.Di Bari

In the SM the ratio v_c/T_c is directly related to the Higgs mass and only for $M_h < 40$ GeV one can have a strong PT EW baryogenesis in the SM is ruled out by the LEP lower bound M_h ♦ 114 GeV ! (also not enough CP)

New Physics is needed!

Is EWBG still alive ?

3 possible attitudes:

- Optimistic: Not only it is alive but the allowed region in the MSSM parameter space has interesting features also to solve another of the cosmological puzzles: Dark Matter

  (Carena et al. '05)
- Realistic: EWBG in the MSSM has strong constraints but these can be relaxed within other frameworks:
  - in the NMSSM

    (Pietroni '92,Davies et al. '96, Huber and Schmidt '01)
  - in the nMSSM

    (Wagner et al. '04)
  - in left-right symmetric models at B-L symmetry breaking

    (Mohapatra and Zhang '92)
  - …….
- Pessimistic: We need some other mechanism; SUSY has not yet been discovered but on the other hand ….

Basics

(Fukugita, Yanagida '86)

M, m_D, m_ν are complex matrices natural source of CP violation

$$N_i \xrightarrow{\Gamma} l\, H^\dagger \qquad\qquad N_i \xrightarrow{\bar{\Gamma}} \bar{l}\, H$$

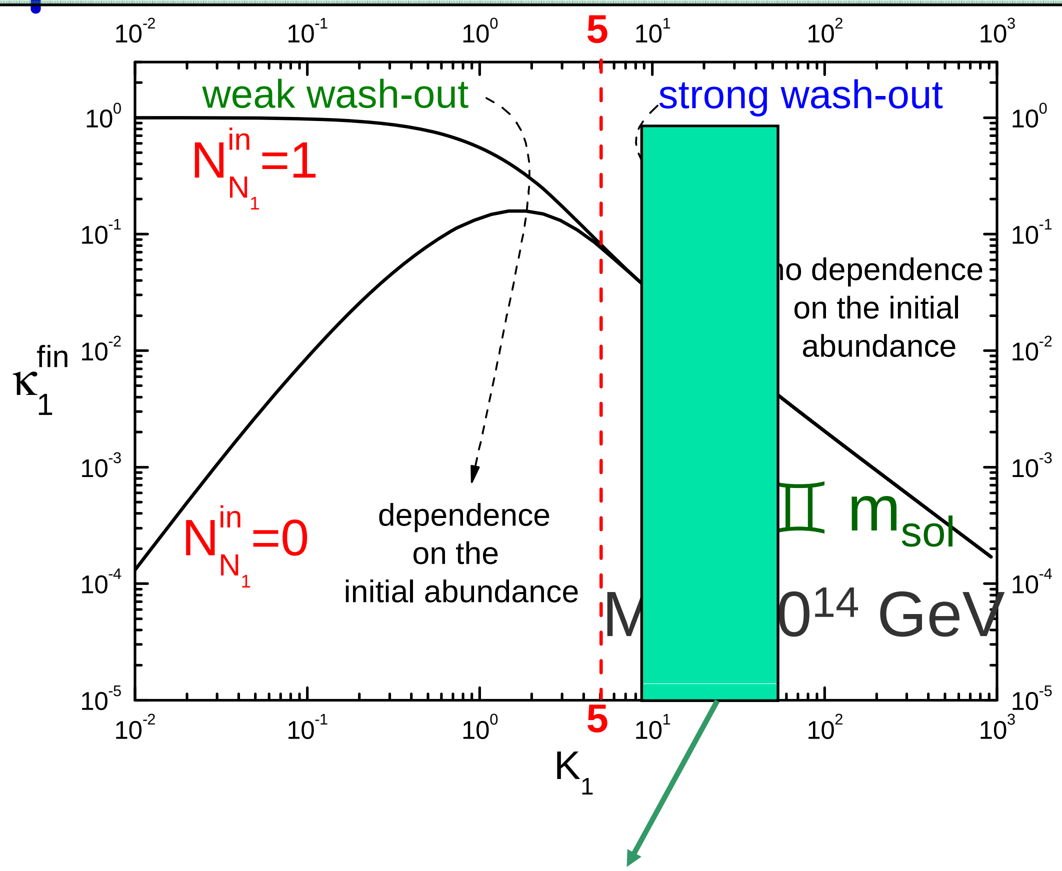
CP asymmetry $\varepsilon_i \equiv -\frac{\Gamma_i - \bar{\Gamma}_i}{\Gamma_i + \bar{\Gamma}_i}$

If $\varepsilon_i \neq 0$ a **lepton asymmetry** is generated from N_i decays and partly converted into a **baryon asymmetry** by sphaleron processes **if T_{reh} > 100 GeV !** (Kuzmin, Rubakov, Shaposhnikov, '85)

$$N_{B-L}^{\rm fin} = \sum_i \varepsilon_i\, \kappa_i^{\rm fin} \Rightarrow \eta_B = a_{\rm sph}\, \frac{N_{B-L}^{\rm fin}}{N_\gamma^{\rm rec}}$$

efficiency factors **# of N_i decaying out-of-equilibrium**

Dependence on the initial conditions



$$K_{\rm sol} \simeq 9 \lesssim K_1 \lesssim 50 \simeq K_{\rm atm}$$

Neutrino mixing data favor the strong wash-out regime !

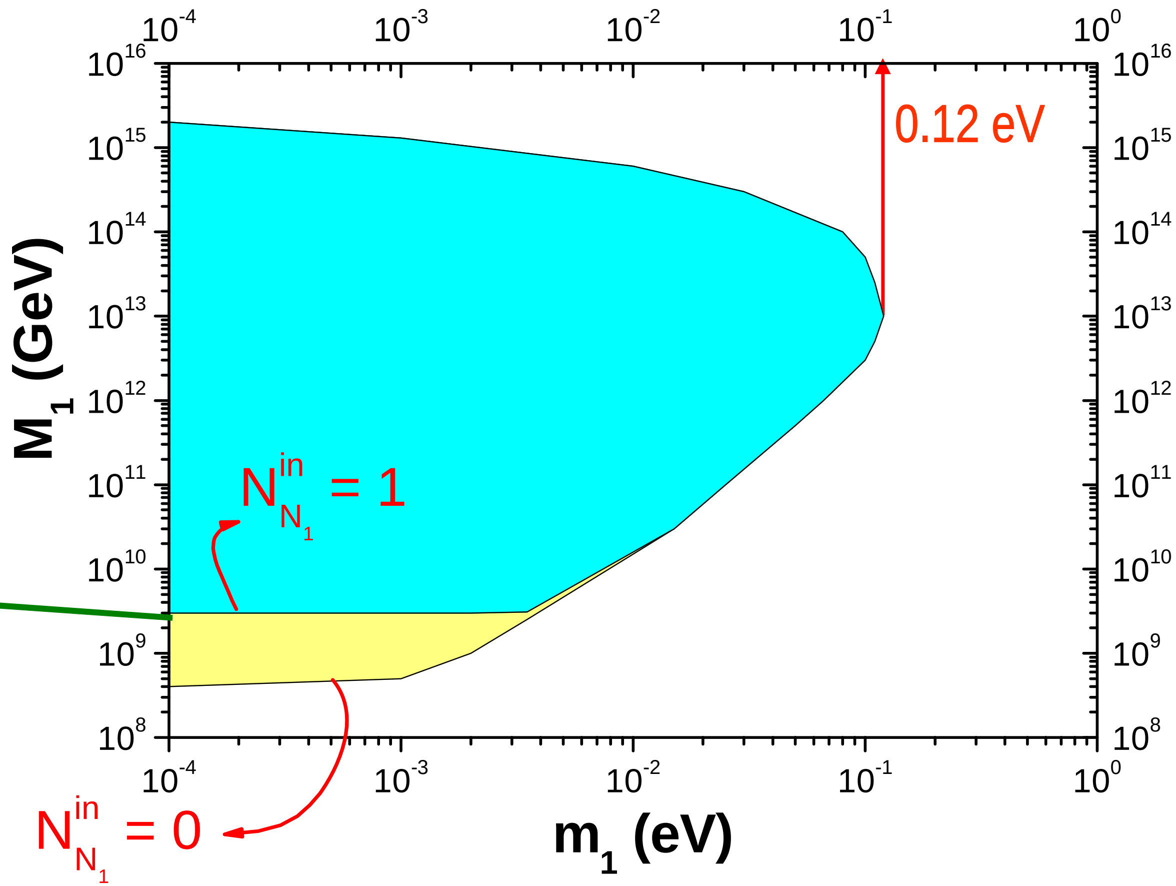
P.Di Bari

Upper bound on the absolute neutrino mass scale

(Buchmüller, PDB, Plümacher ‘02)

Lower bound on M_1

(Davidson, Ibarra ’02; Buchmüller, PDB, Plümacher ‘02)



3×10^9 GeV

Lower bound on T_{reh} : $T_{reh} \simeq 1.5 \times 10^9$ GeV

(Buchmüller, PDB, Plümacher ‘04)

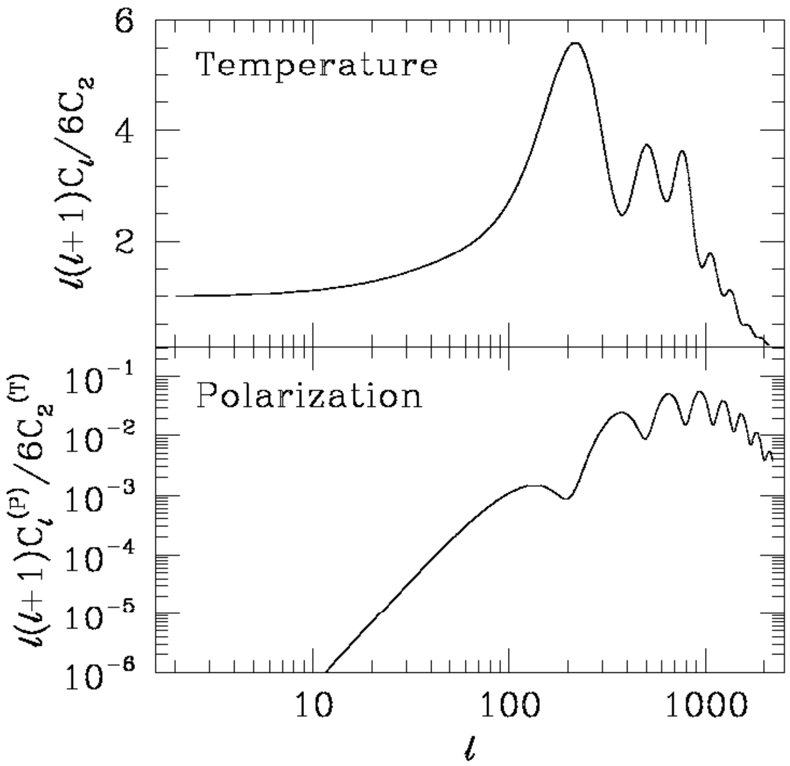
P.Di Bari

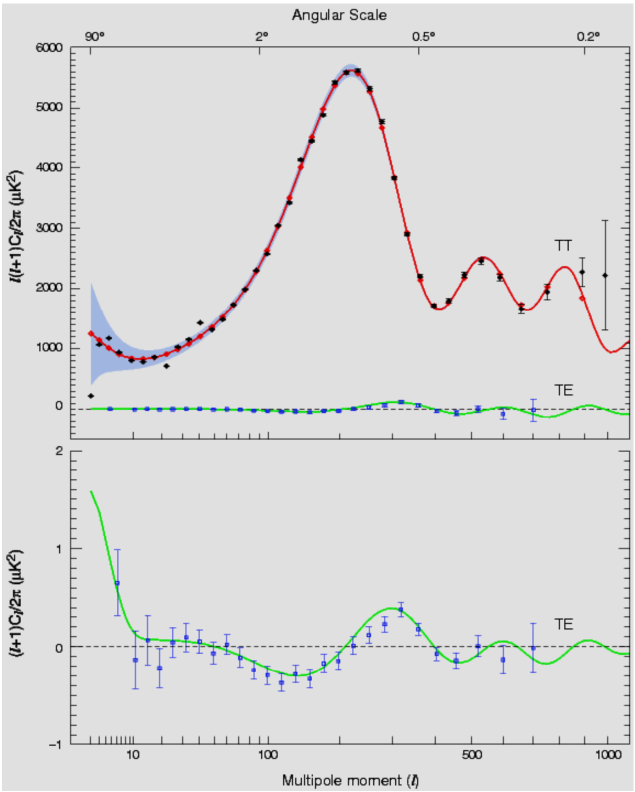
How standard is the standard cosmological model?

Looking for new physics

CMB: Theory and Data

$$\left\langle \frac{\Delta T}{T}(\vec{\gamma}_1)\frac{\Delta T}{T}(\vec{\gamma}_2)\right\rangle = \frac{1}{2\pi}\sum_{\ell}(2\ell+1)C_\ell P_\ell(\vec{\gamma}_1\cdot\vec{\gamma}_2)$$





1/(Angular Scale)

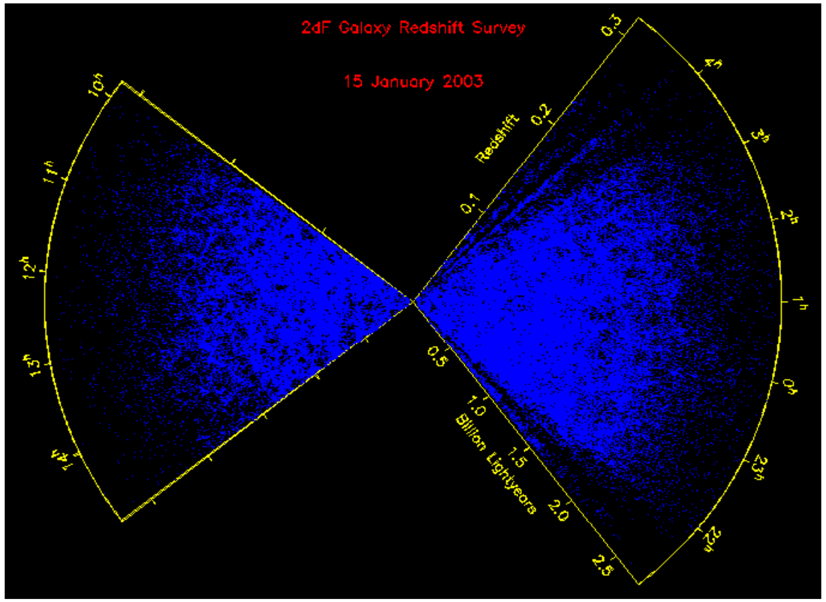
A. Melchiorri

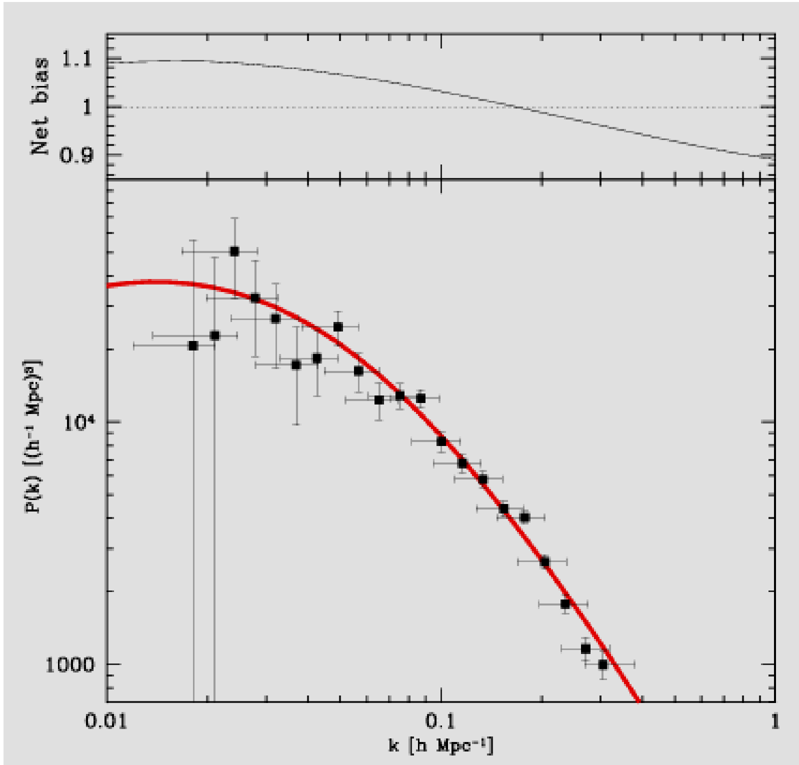
Galaxy Clustering: Theory

$$\xi(r,t) = \langle \delta(\vec{x},t)\delta(\vec{x}+\vec{r},t) \rangle$$

$$\xi_{galaxies}(r,t) = b^2 \xi(r,t)$$

$$P(k,t) = \int d^3 r \xi(r,t) e^{i\vec{k}\cdot\vec{r}}$$





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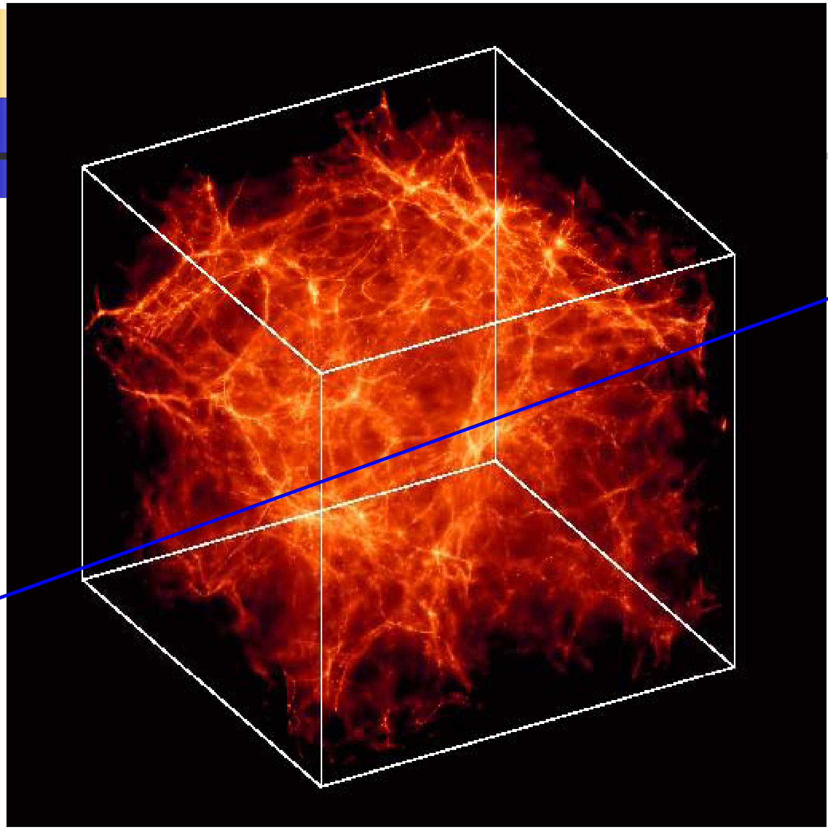
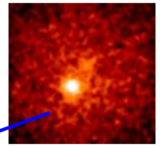
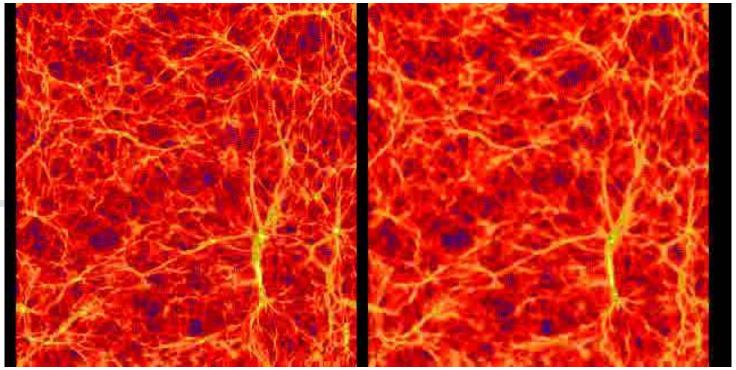




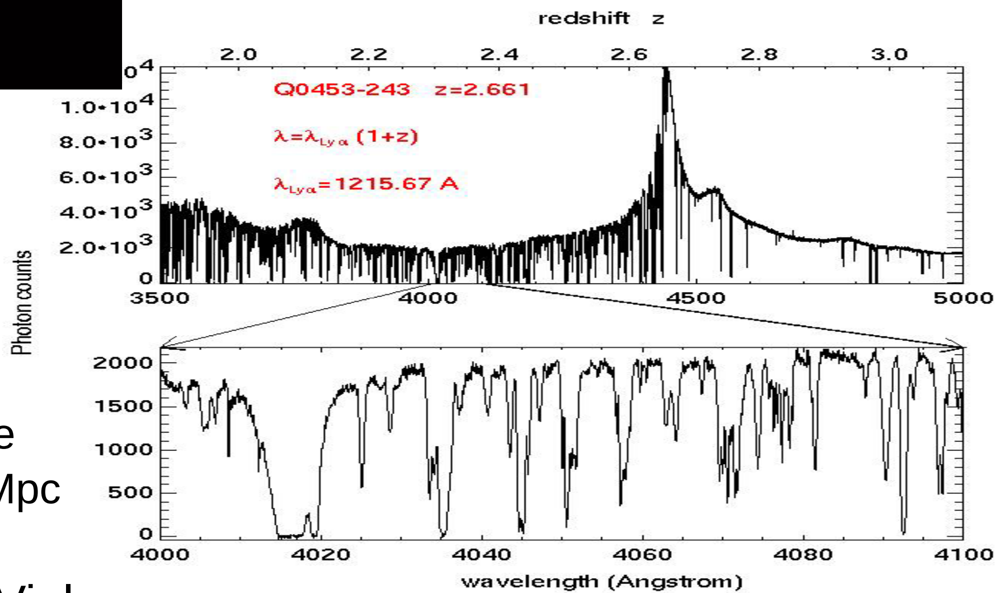


Physics of the simulations is simple: dark matter,
Gas cooling, photoionization heating, star formation

80 % of the baryons at z=3
are in the Lyman-α forest

Bi & Davidsen (1997), Rauch (1998)

baryons as tracer of the dark matter density field



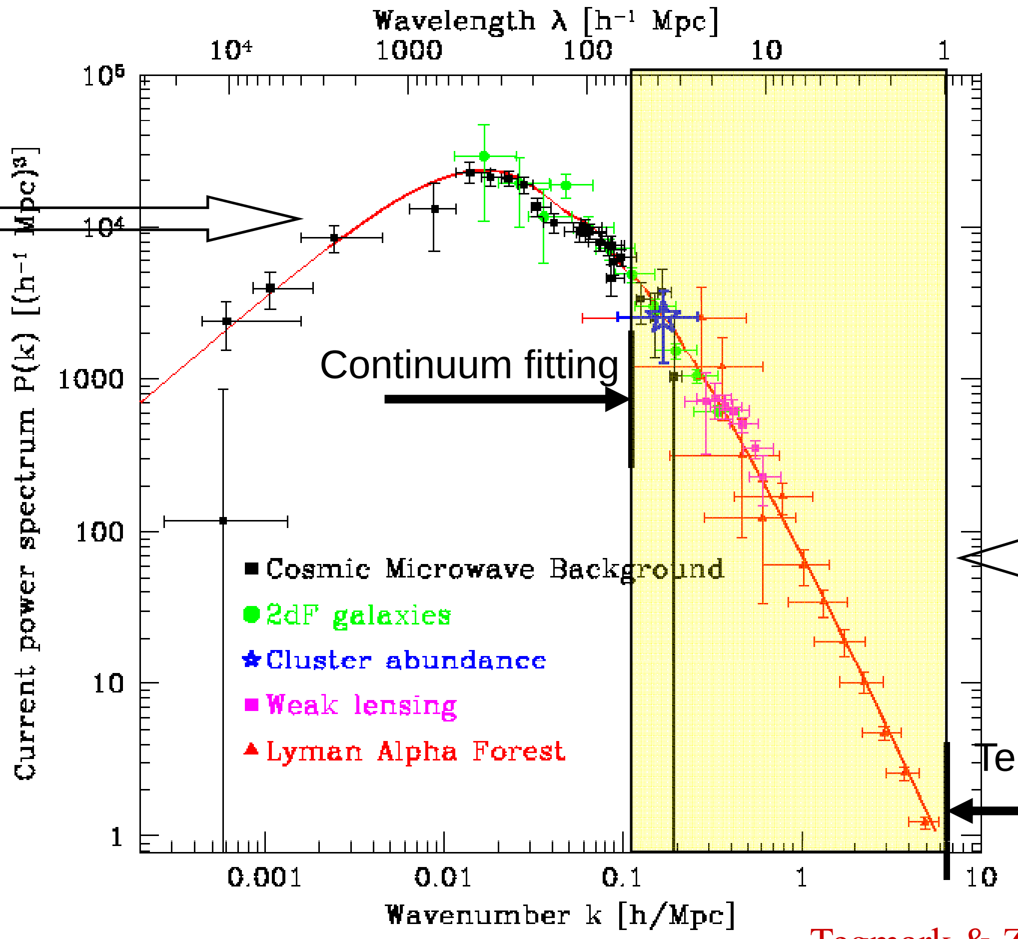
$\delta_{IGM} \sim \delta_{DM}$ at scales larger than the Jeans length ~ 1 com Mpc

$\tau \sim (\delta_{IGM})^{1.6}\, T^{-0.7}$

M. Viel

GOAL: the primordial dark matter power spectrum from the observed flux spectrum

CMB physics
z = 1100
dynamics



Lyα physics
z < 6
dynamics
+
termodynamics

Tegmark & Zaldarriaga 2002

CMB + Lyman α ⇒ Long lever arm

Constrain spectral index and shape

Relation: $P_{FLUX}(k) - P_{MATTER}(k)$??

M. Viel

Cosmological (Active) Neutrinos

Neutrinos are in equilibrium with the primeval plasma through weak interaction reactions. They decouple from the plasma at a temperature

$$T_{dec} \approx 1MeV$$

We then have today a Cosmological Neutrino Background at a temperature:

$$T_\nu = \left(\frac{4}{11}\right)^{1/3} T_\gamma \approx 1.945K \rightarrow kT_\nu \approx 1.68 \cdot 10^{-4} eV$$

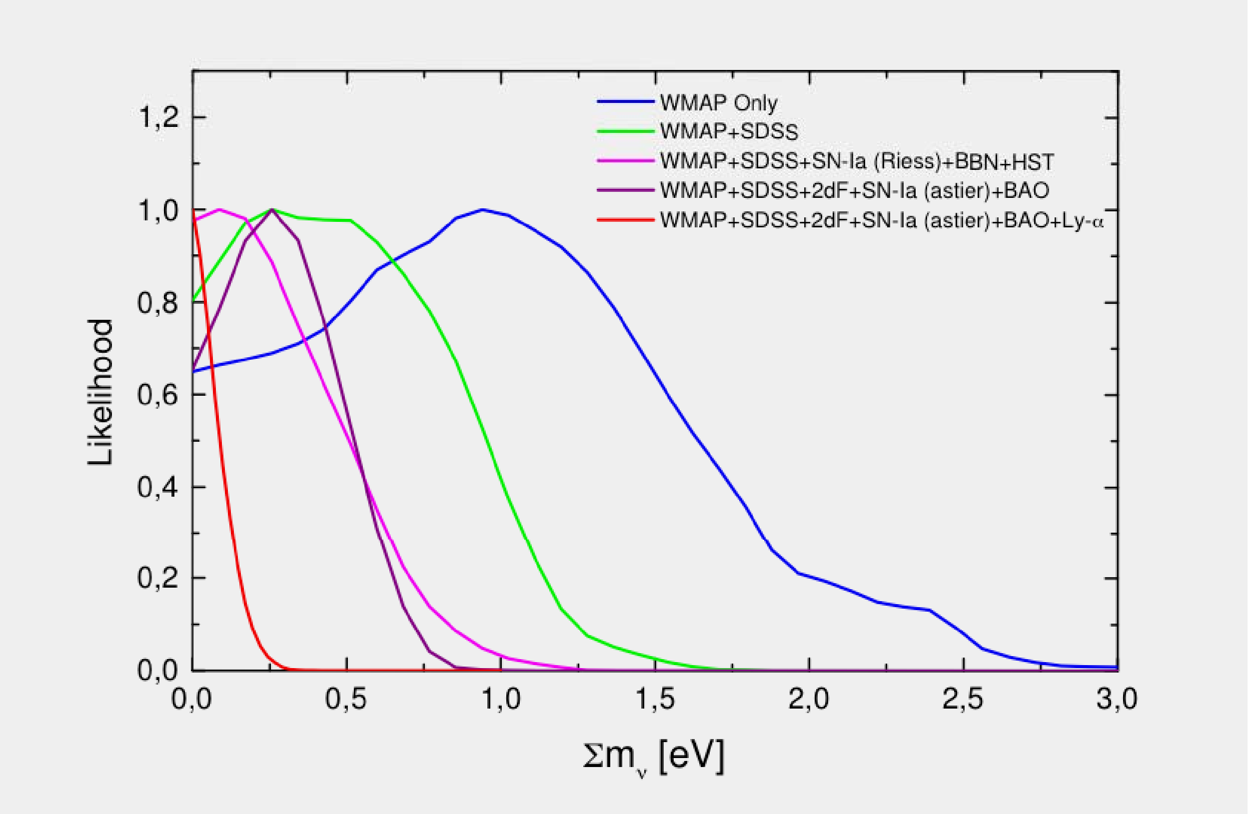
With a density of:

$$n_f = \frac{3}{4}\frac{\varsigma(3)}{\pi^2} g_f T_f^3 \rightarrow n_{\nu_k,\bar{\nu}_k} \approx 0.1827 \cdot T_\nu^3 \approx 112 cm^{-3}$$

A. Melchiorri

That, for a massive neutrino translates in:

$$\Omega_k = \frac{n_{\nu_k,\bar{\nu}_k} m_k}{\rho_c} \approx \frac{1}{h^2}\frac{m_k}{92.5eV} \Rightarrow \Omega_\nu h^2 = \frac{\sum_k m_k}{92.5eV}$$



Bounds on Σ for increasingly rich data sets (assuming 3 Active Neutrino model):

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

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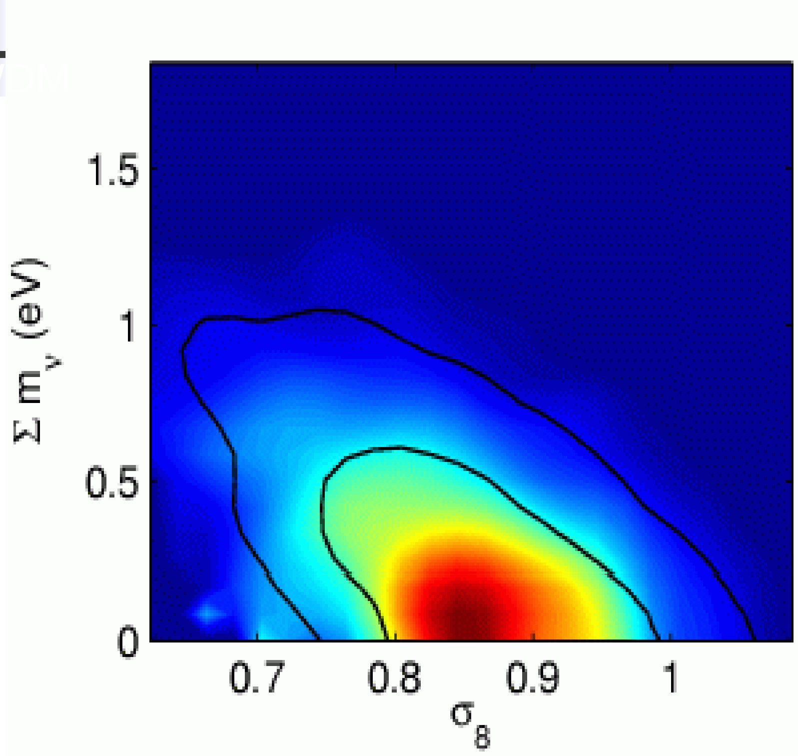
Fogli et al., Phys. Rev. D 75, 053001 (2007)

Active neutrinos and Lyman-α

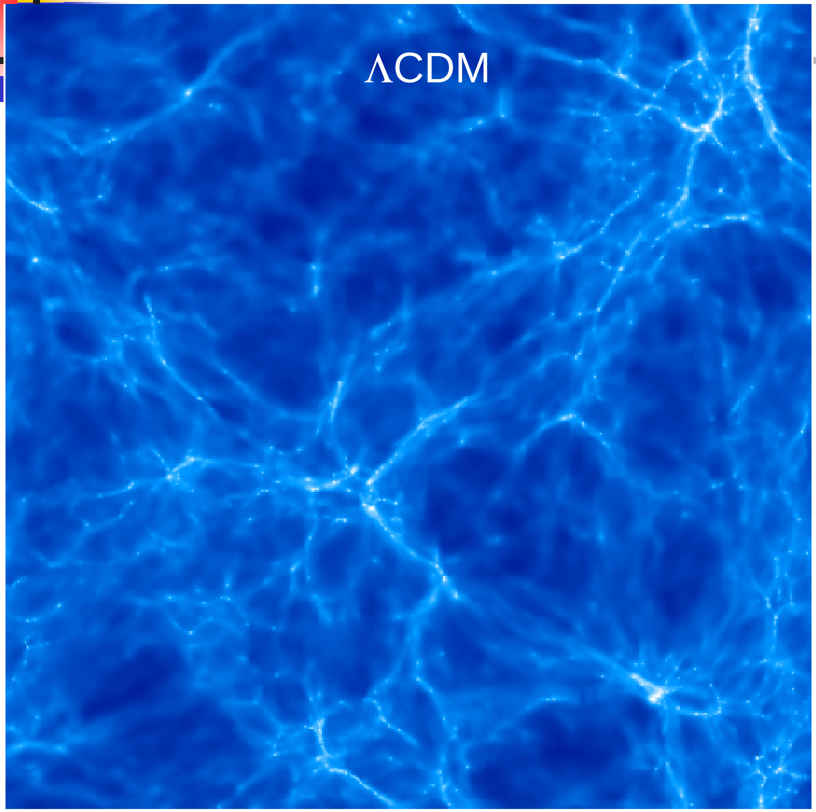


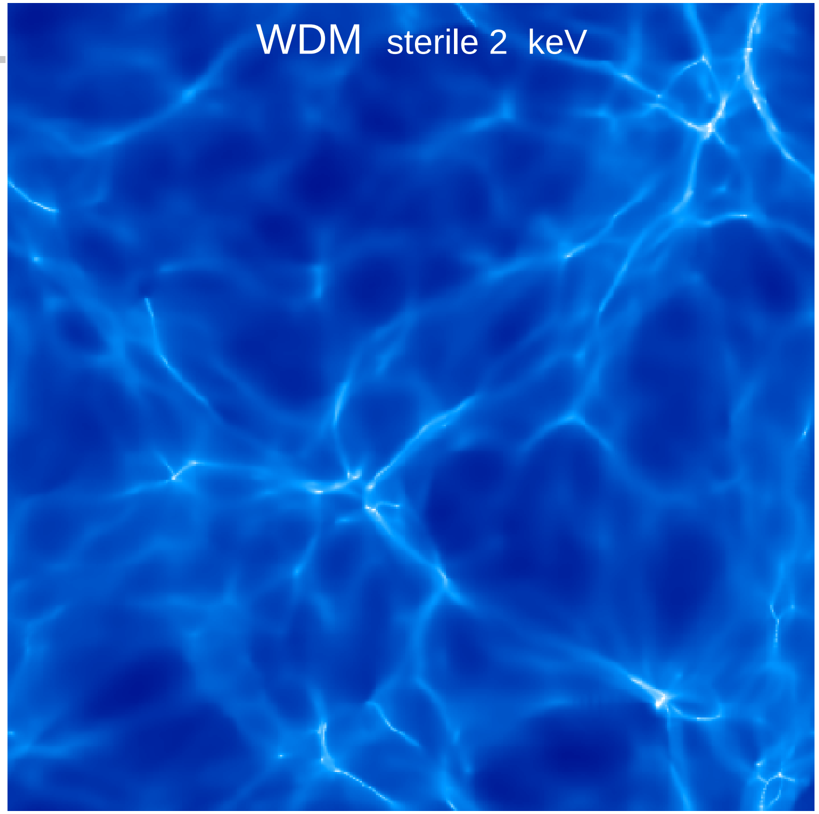
$\Sigma m\nu$ (eV) < 1 eV (95 % C.L.)
WMAP1 + 2dF + LYα

Good agreement with the latest Tegmark et al. results…..

M. Viel

Lyman-α and Warm Dark Matter





30 comoving Mpc/h z=3

In general

$k_{FS} \sim 5\, T_\nu/T_x\, (m_x/1\mathrm{keV})\ \mathrm{Mpc}^{-1}$

Set by relativistic degrees of freedom at decoupling

See Bode, Ostriker, Turok 2001
Abazajian, Fuller, Patel 2001

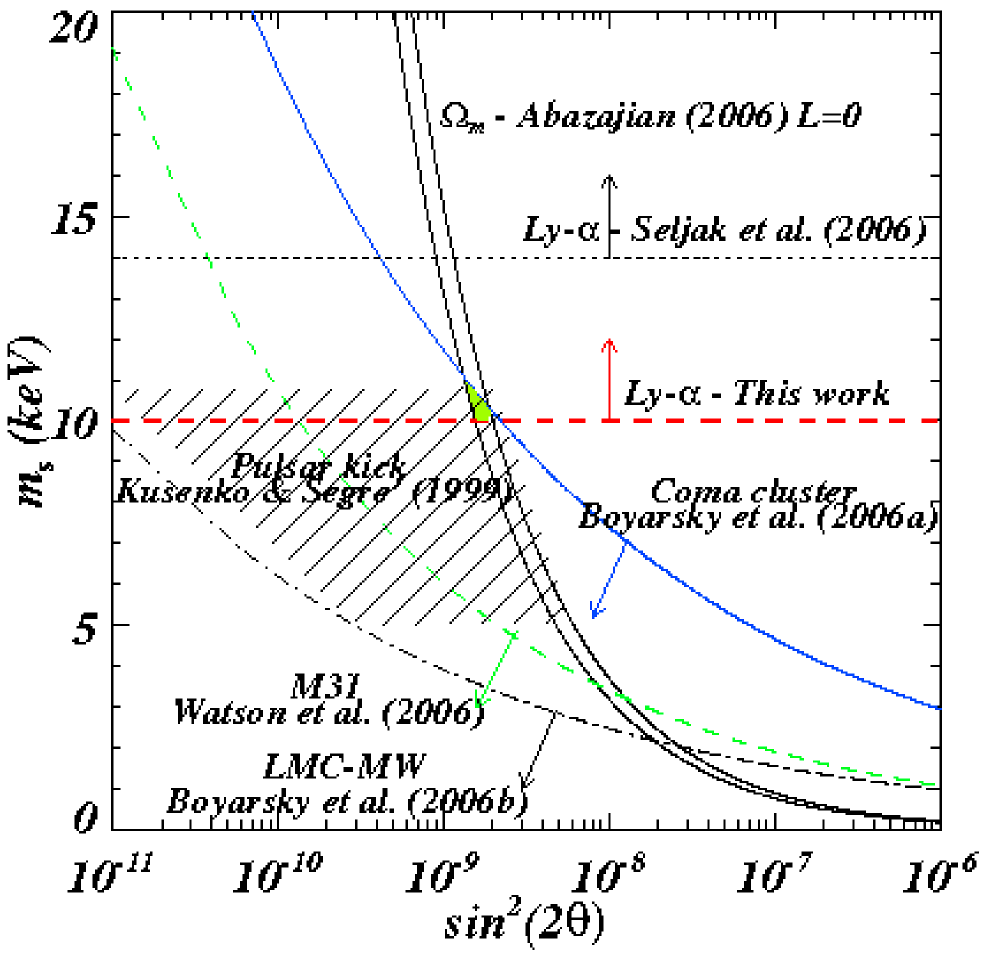
M. Viel

Viel, Lesgourgues, Haehnelt, Matarrese, Riotto, PRD, 2005, 71, 063534

RESULTS

STERILES

Warm dark matter



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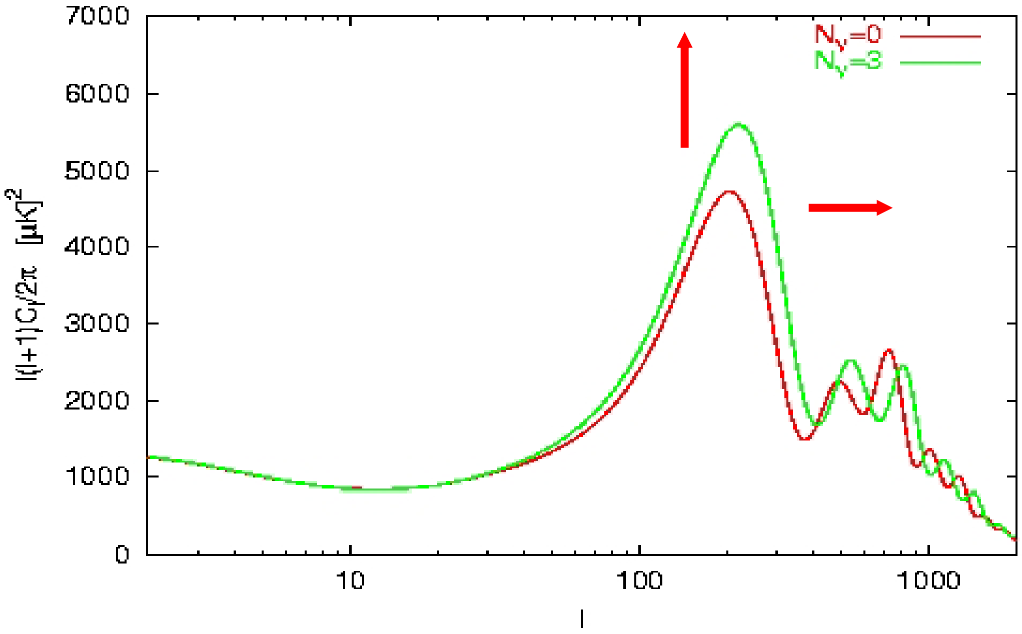
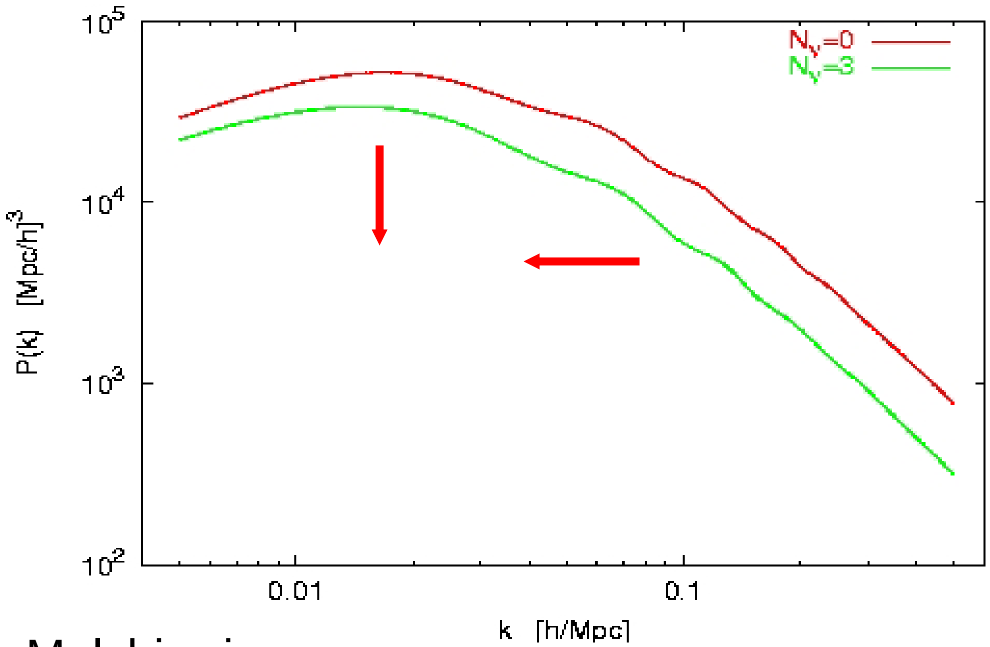
Viel, Lesgourgues, Haehnelt, Matarrese, Riotto, Phys.Rev.Lett., 2006, 97, 071301

Increasing the Neutrino Massless number postpone the equivalence (while keeping constant the time of decoupling).
This produces a shift in the CMB power spectra since changes the sound horizon at decoupling. The height of the first peak is also increased thanks to the Early Integrated Sachs-Wolfe. The LSS matter power spectrum is also shifted since the size of the horizon at equivalence is now larger. There is less growth of perturbations in the MD regime.





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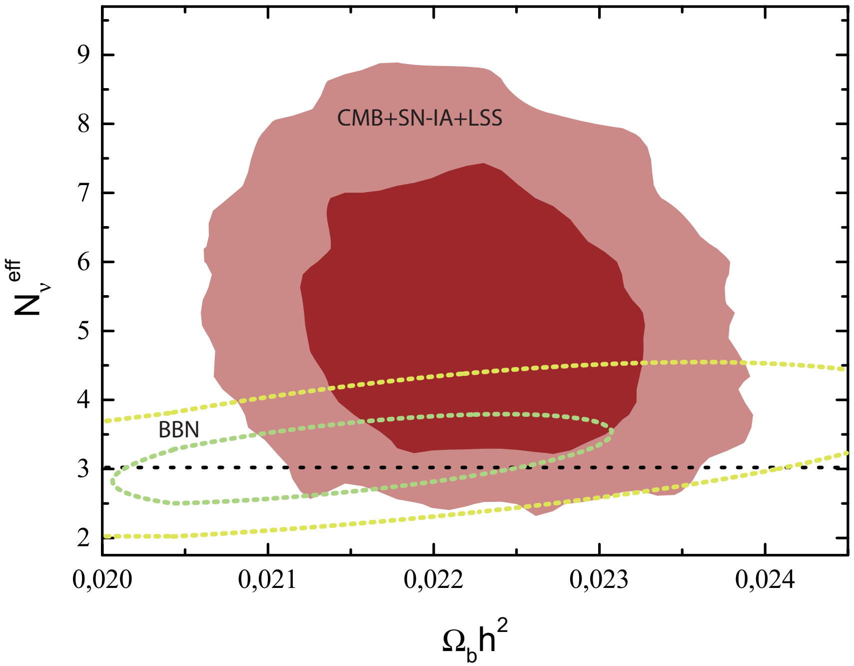
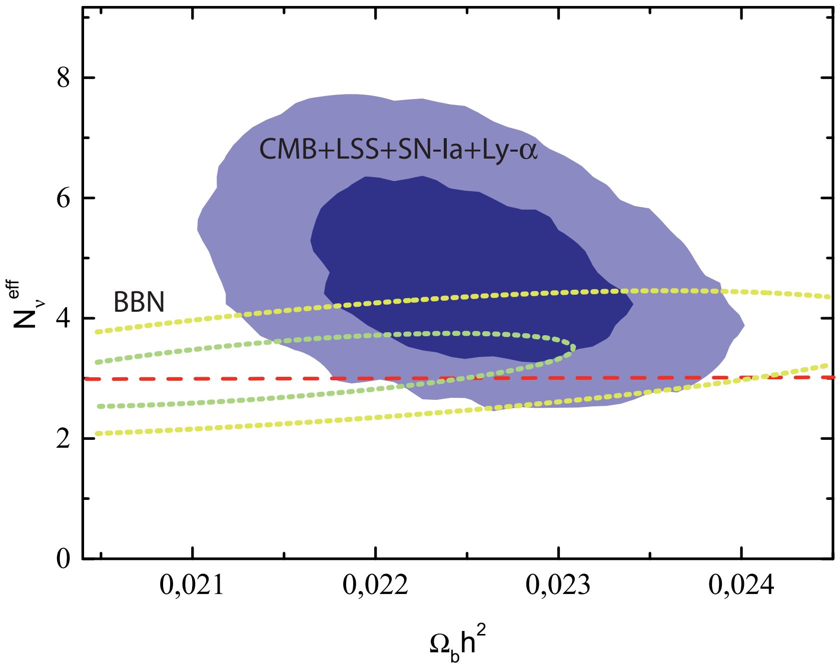
Latest Analysis: Indication for N>3 from Cosmology ?



$$\omega_b = 0.0224 \pm 0.0012$$

$$N_\nu^{eff} = 5.2^{+2.7}_{-2.2}$$



$$\omega_b = 0.0224 \pm 0.0011$$

$$N_\nu^{eff} = 4.6^{+1.6}_{-1.5}$$

A. Melchiorri

Mangano, Melchiorri, Mena, Miele, Slosar JCAP03(2007)006

Theoretical uncertainties

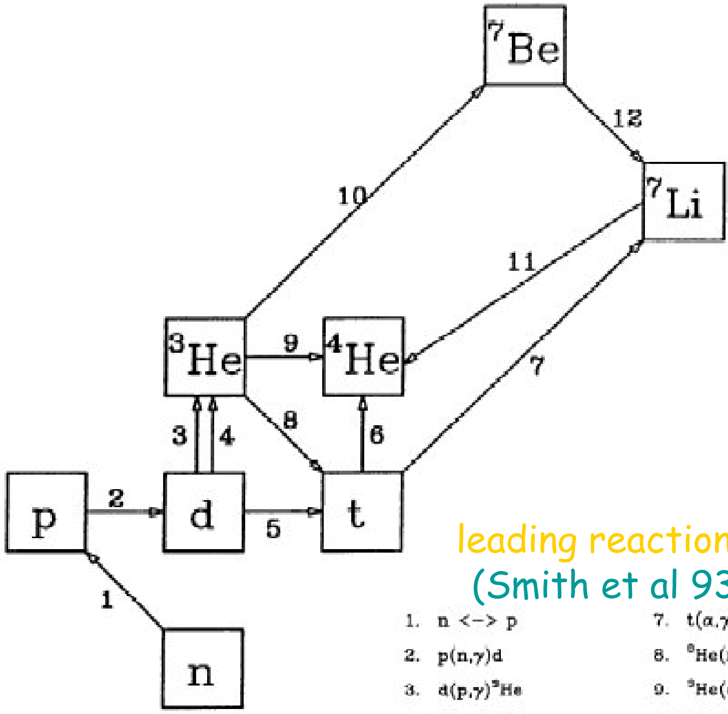
Reaction rate uncertainties translate into uncertainties in theoretical predictions:

Monte-Carlo evaluation of uncertainties
Krauss & Romanelli 90,
Smith et al 93,
Kernan & Krauss 94

Semi-analytical evaluation of the error matrix
Fiorentini et al 98
Lisi et al. 00

Re-analysis of nuclear data
Nollet & Burles 00, Cyburt et al 01,
Descouvement et al. 04, Cyburt et al. 04,
Serpico et al. 04

Recent new data and compilations
NACRE Coll. Database
LUNA: $D(p,\gamma)^3He$, $^3He(\alpha,\gamma)^7Be$



leading reactions
(Smith et al 93)

1. $n \leftrightarrow p$
2. $p(n,\gamma)d$
3. $d(p,\gamma)^3He$
4. $d(d,n)^3He$
5. $d(d,p)t$
6. $t(d,n)^4He$
7. $t(\alpha,\gamma)^7Li$
8. $^3He(n,p)t$
9. $^3He(d,p)^4He$
10. $^3He(\alpha,\gamma)^7Be$
11. $^7Li(p,\alpha)^4He$
12. $^7Be(n,p)^7Li$

Sub-leading reactions
(see Serpico et al. 04)

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Nuclear cross sections and BBN abundances

Based on Fiorentini et al, 1998

Relative errors on σ and their relative contribution to the theoretical uncertainty on BBN abundances

Inputs can be taken from different analysis of nuclear data

k	Reaction	Des04 dR/R	Contributo all'errore totale ($\Delta Y_k / \Delta Y$) He4	D	Li	He3
1	n lifetime	0,0009	0,92	0,01	0,00	0,00
2	p(n,g)d	0,040	0,27	0,29	0,51	0,10
3	d(p,g)3He	0,050	0,00	0,64	0,28	0,54
4	d(d,n)3He	0,030	0,25	0,61	0,19	0,15
5	d(d,p)t	0,020	0,14	0,35	0,01	0,14
6	t(d,n)4He	0,020	0,00	0,00	0,00	0,00
7	t(a,g)7Li	0,040	0,00	0,00	0,01	0,00
8	3He(n,p)t	0,015	0,00	0,01	0,04	0,07
9	3He(d,p)4He	0,040	0,00	0,02	0,28	0,81
10	3He(a,g)7Be	0,080	0,00	0,00	0,73	0,00
11	7Li(p,a)4He	0,060	0,00	0,00	0,02	0,00
12	7Be(n,p)7Li	0,007	0,00	0,00	0,05	0,00

Errore Teorico Percentuale ΔY (%)

He4	D	Li	He3
0,07	2,6	10,7	3,7

k	Reaction	SKM93	Cyburt01	Des04	Cyburt04
1	n lifetime				
2	p(n,g)d	0,07	0,0445	0,0400	0,0250
3	d(p,g)3He	0,10	0,1320	0,0500	0,0698
4	d(d,n)3He	0,10	0,0310	0,0300	0,0545
5	d(d,p)t	0,10	0,0159	0,0200	0,0693
6	t(d,n)4He	0,08	0,0401	0,0200	0,0516
7	t(a,g)7Li	0,26	0,0421	0,0400	0,2313
8	3He(n,p)t	0,10	0,0352	0,0150	0,0440
9	3He(d,p)4He	0,08	0,0915	0,0400	0,0730
10	3He(a,g)7Be	0,16	0,1060	0,0800	0,1692
11	7Li(p,a)4He	0,08	0,1140	0,0600	0,0802
12	7Be(n,p)7Li	0,09	0,0387	0,0070	0,0625

Summarizing …
Theoretical uncertainties at the level of:

^{4}He 0.1% - 0.2%
D 5% - 10%
^{3}He 5% - 10%
^{7}Li 15% - 30%

depending on the analysis of nuclear data.

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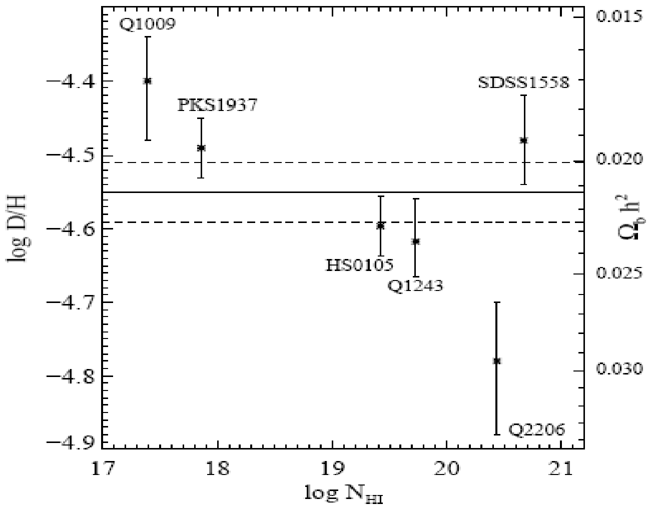
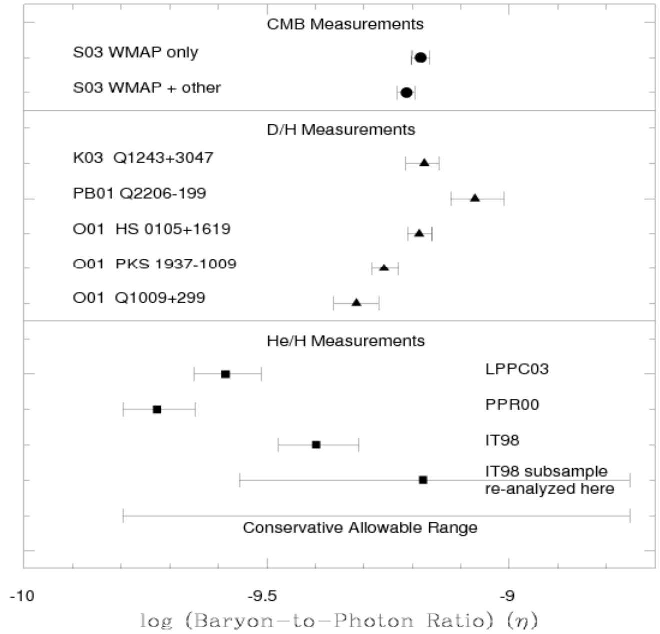
See also: Serpico et al. 04 - Sub-leading reactions contributions to uncertainties





Lithium-7

Observations in metal poor stars in the Halo of our galaxy ($Z \sim 10^{-4} - 10^{-5} Z_o$)

Spite plateau: Li abundance does not vary significantly for $Z < 1/30\ Z_o$:

$^7Li/H$ =	$(1.23 \pm 0.06)\ 10^{-10}$	Ryan et al. 00
	$(2.19 \pm 0.28)\ 10^{-10}$	Bonifacio et al. 02
	$(2.34 \pm 0.06)\ 10^{-10}$	Melendez et al. 04

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$^7Li/H$ = $(1.7 \pm 0.02\ ^{+1.1}_{-0})\ 10^{-10}$ Field e Sarkar – PDG06

SBBN ($N_\nu^{eff}=3$) and CMB data would require: $^7Li/H \sim 4.5\ 10^{-10}$ (depletion?)

Conclusions

Standard BBN: Very accurate, very precise
Costant progress in the last decade

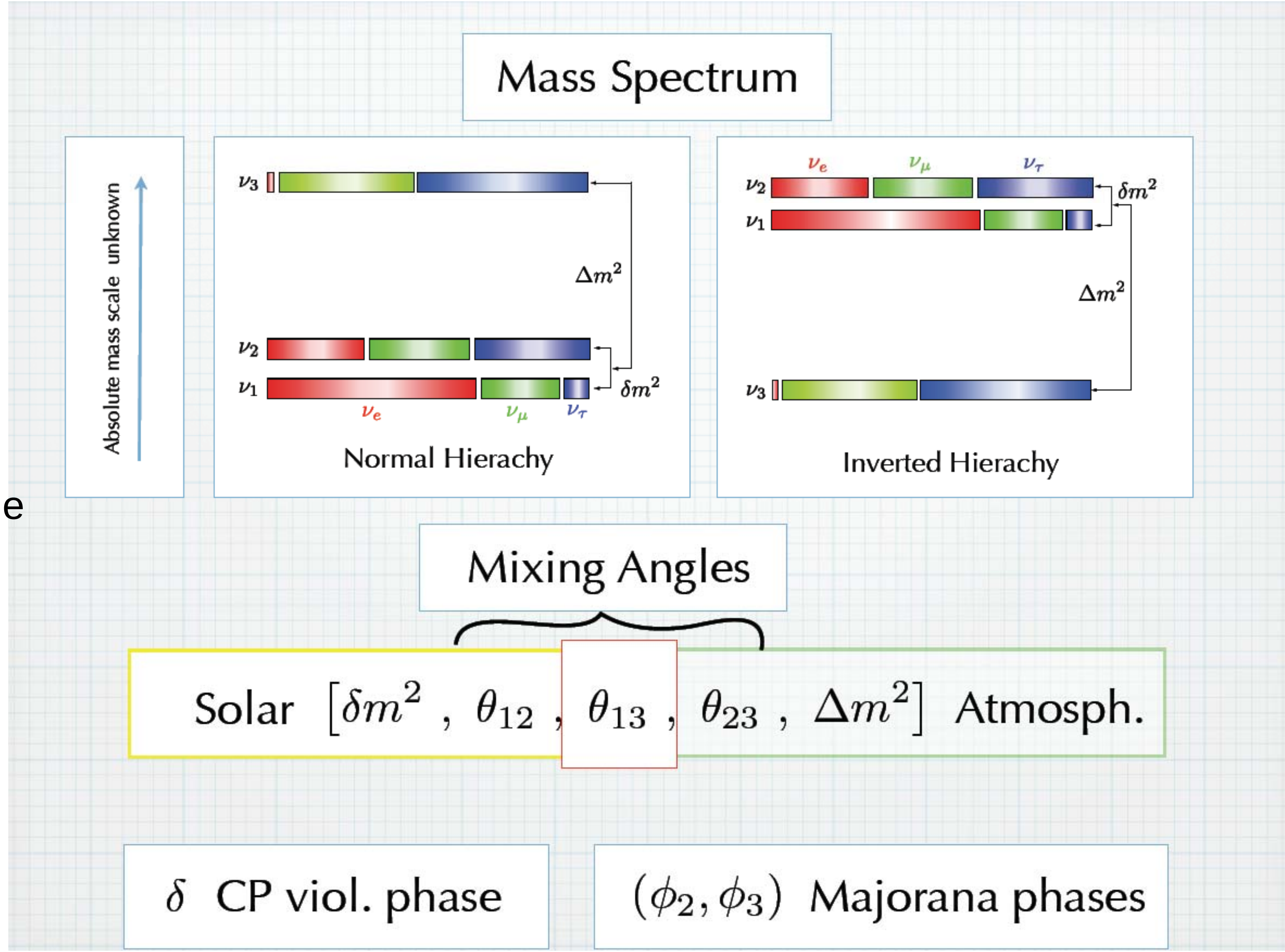
BBN and AstroParticle: BBN is a unique window to early universe.
Sensitive to a variety of non-standard effects

- Variations of "fundamental" constants;
- new light particles;
- ν_e and $\nu_{\mu\tau}$ degeneracy;
- Active-Sterile neutrino oscillations;
- ……

Observations: Progress in (D/H) determination;
Necessary to improve Y_p $(\delta Y_p/Y_p \sim 0.02 \rightarrow \Delta N\nu \sim 1$ at $2\sigma)$
Necessary to understand ^{3}He and ^{7}Li

Moving to closer scales:

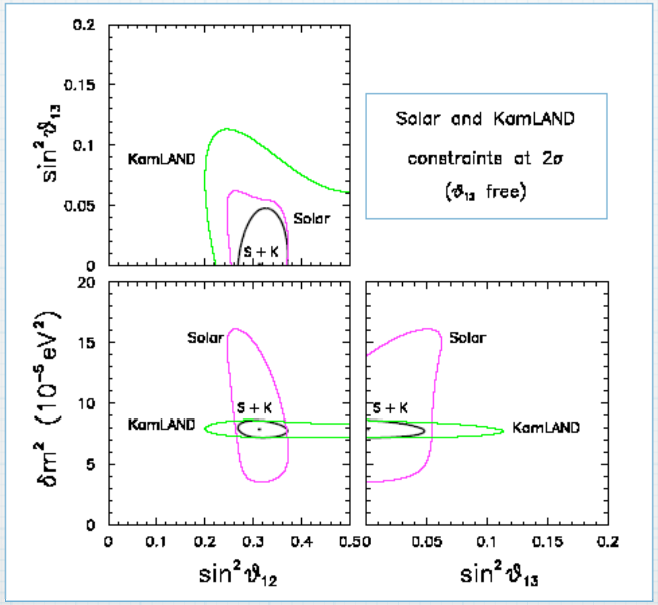
Neutrino oscillations and mass from stars and lab experiments



A.Marrone

3ν Analysis: Solar + KamLAND

- Solar neutrino data identify LMA solution
- SNO CC/NC disfavors maximal mixing by more then five sigmas
- Mass hierarchy in the solar sector fixed by MSW effect
- KamLAND -> δm^2
- Seasonal variation in agreement with $1/R^2$
- No evidence of day/night variation (--> earth MSW)



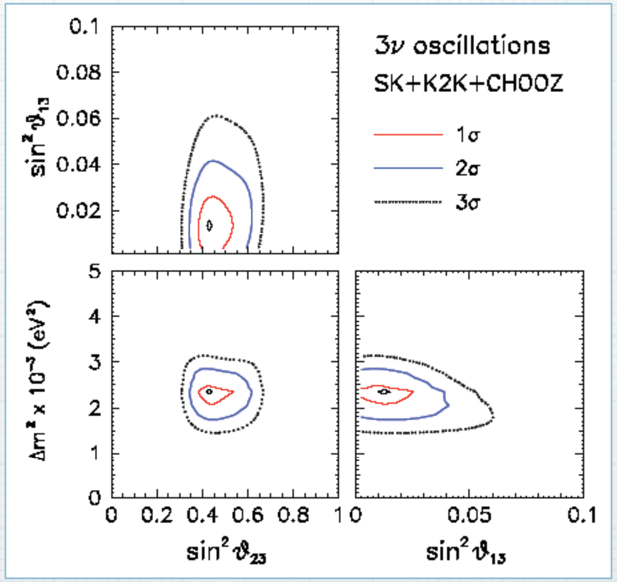
3ν Analysis of SK + K2K + CHOOZ

The more stringent limit on θ_{13} comes from the negative results of the CHOOZ experiment

The analysis includes subleading LMA effects and marginalization with respect to the four cases

$[\cos\delta = \pm 1] \otimes [\mathrm{sign}(\pm\Delta m^2)]$

A slightly non zero value of θ_{13} is preferred, although without statistical significance



A.Marrone

Oscillation Parameters

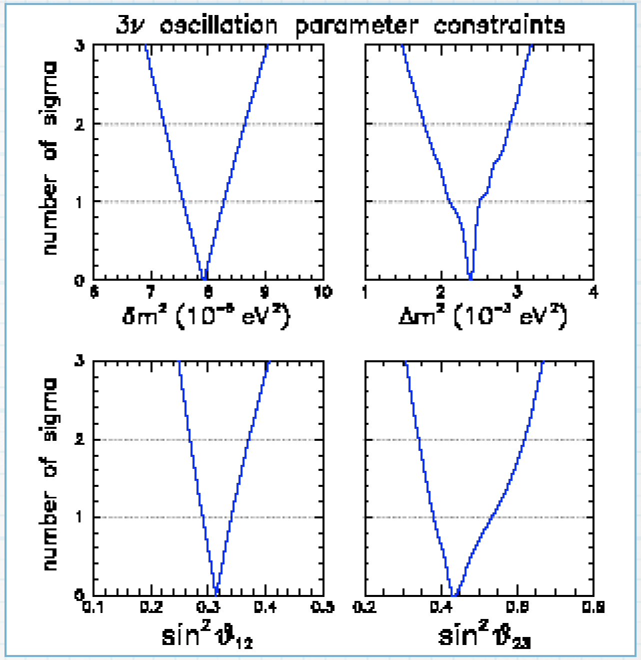
$$\delta m^2 = 7.92(1 \pm 0.09) \times 10^{-5}\ \mathrm{eV}^2$$

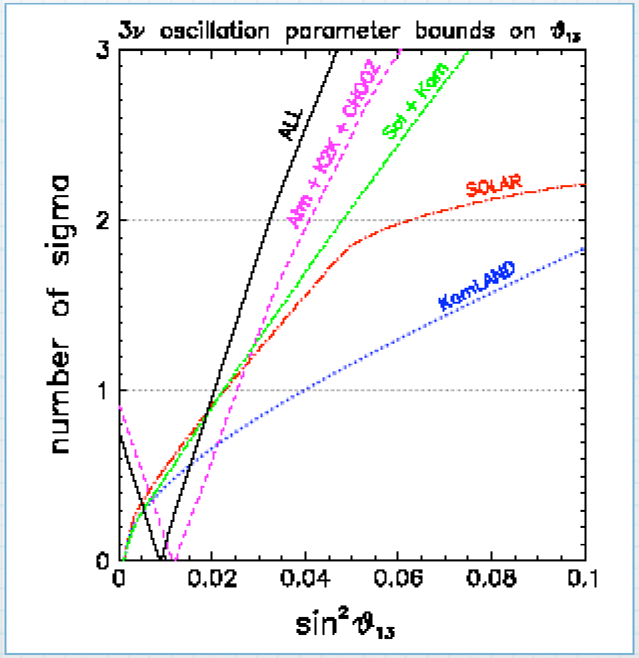
$$\sin^2\theta_{12} = 0.314(1^{+0.18}_{-0.15})$$

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

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

$$\sin^2\theta_{13} = 0.8(1^{+2.3}_{-0.8}) \times 10^{-2}$$





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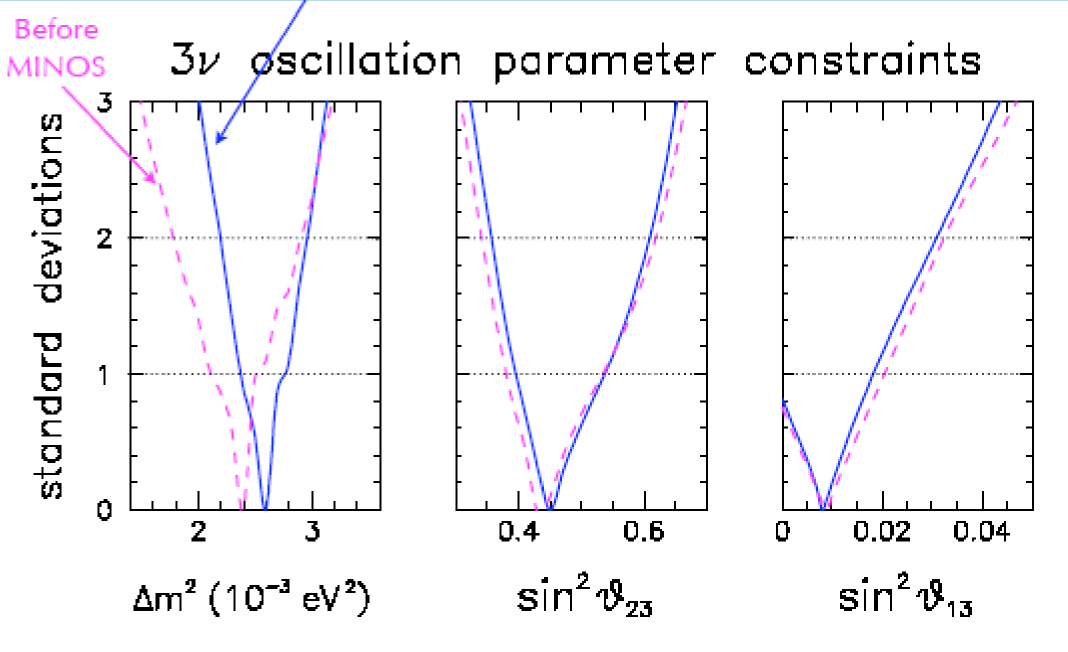
Impact of MINOS



2σ error on Δm^2 reduced from 24% to 15%

MINOS currently insensitive to $(\delta m^2, \theta_{12})$

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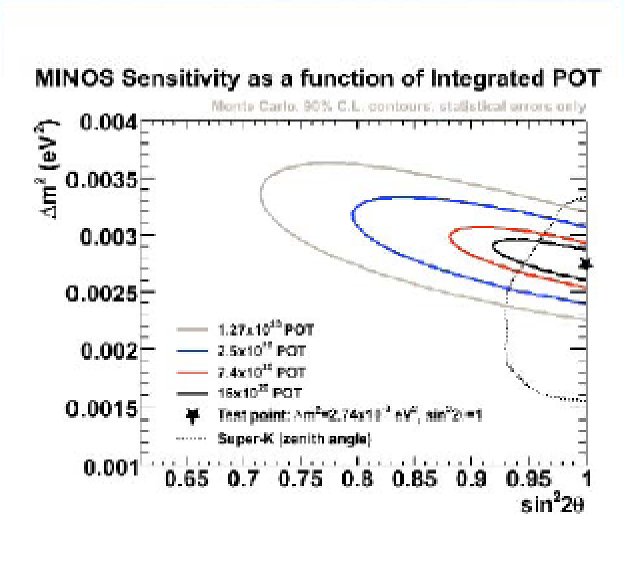
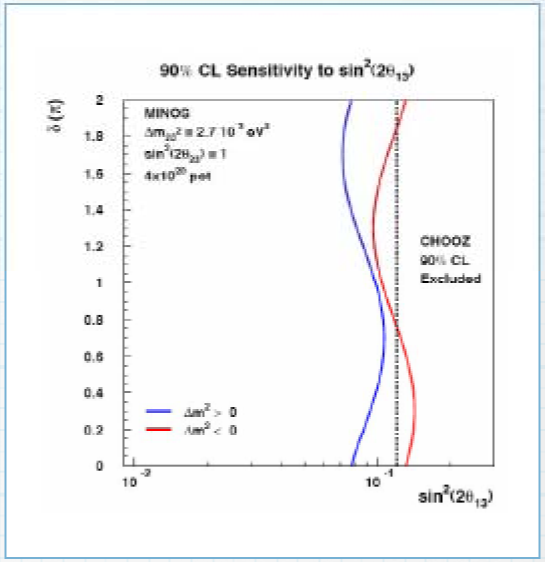
MINOS & OPERA



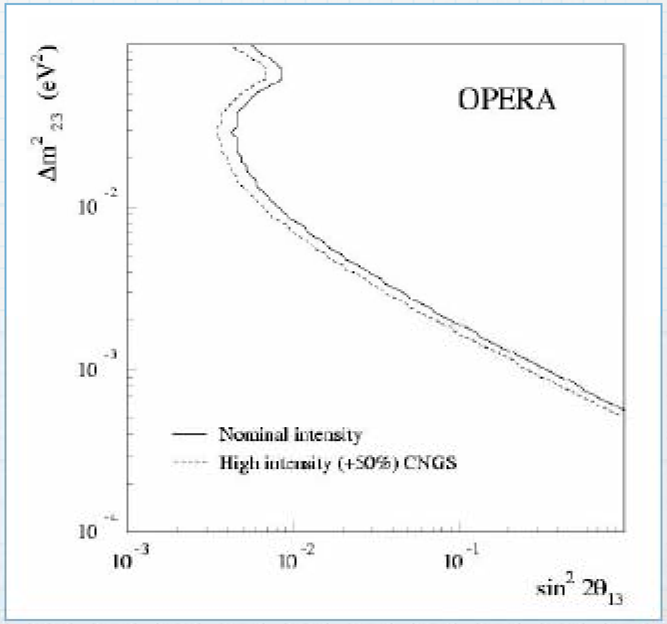
MINOS ν_μ CC $(4 \times 10^{20}$ POT$)$
Can improve limit of CHOOZ

5-10 % error on Δm^2



Harris@win07

5 years of nominal CNGS beam



A.Marrone

Sirignano@neutrino2006

The SN1987A

February 23,1987

LSD
Scintillator
0.09Kt
UT = 2:52:37
5 events

BAKSAN
Scintillator
0.2Kt
UT = 7:36:06
5 events

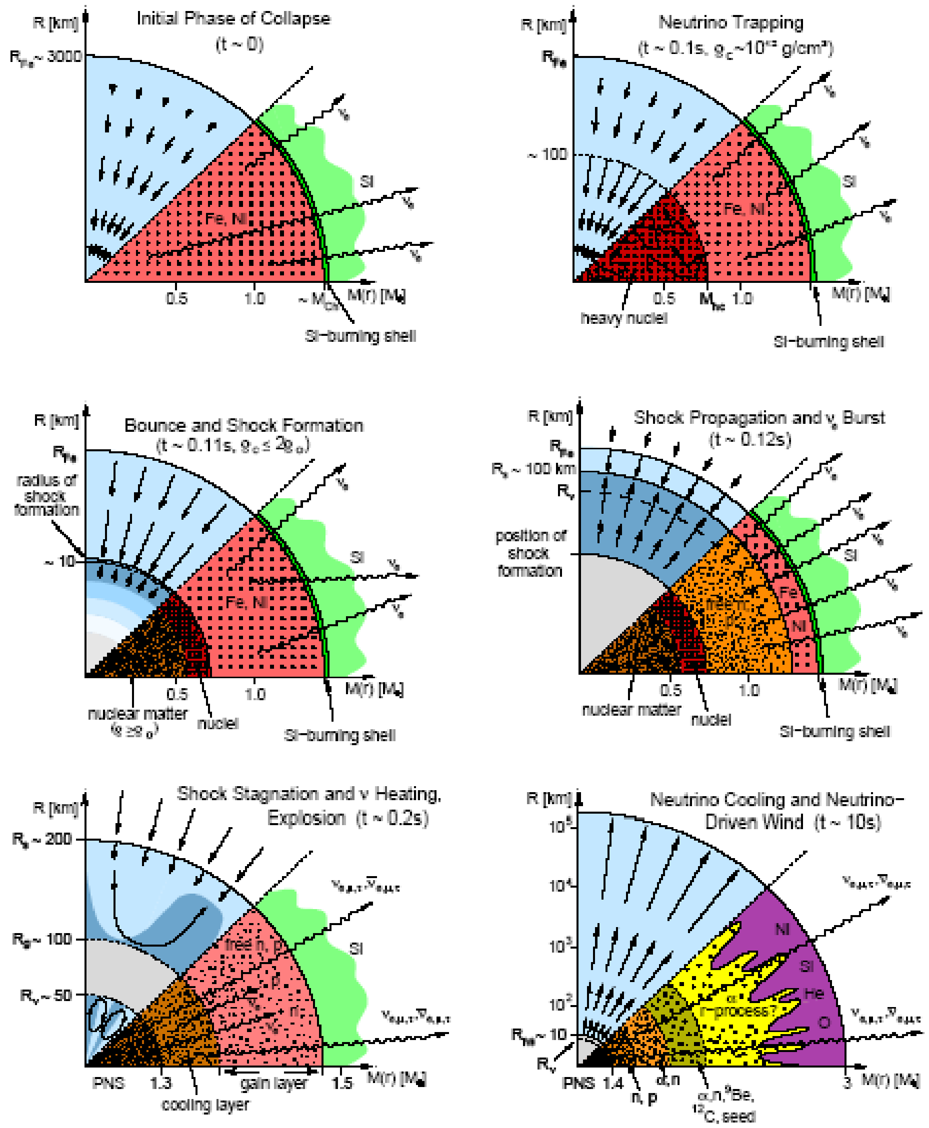
IMB
Water
Cerenkov
6.8Kt
UT = 7:35:41
8 events

KII
Water
Cerenkov
2.14Kt
UT = 7:35:35
12+4 events

G.Pagliaroli

Standard Core Collapse SN

1. Collapse
2. Bounce
3. Shock Propagation
4. Shock Stagnation
5. Accretion ➡ 10%
6. Cooling PNS ➡ 90%



$N_\nu \approx 10^{58}$

$< E_\nu > = 10 - 20 MeV$

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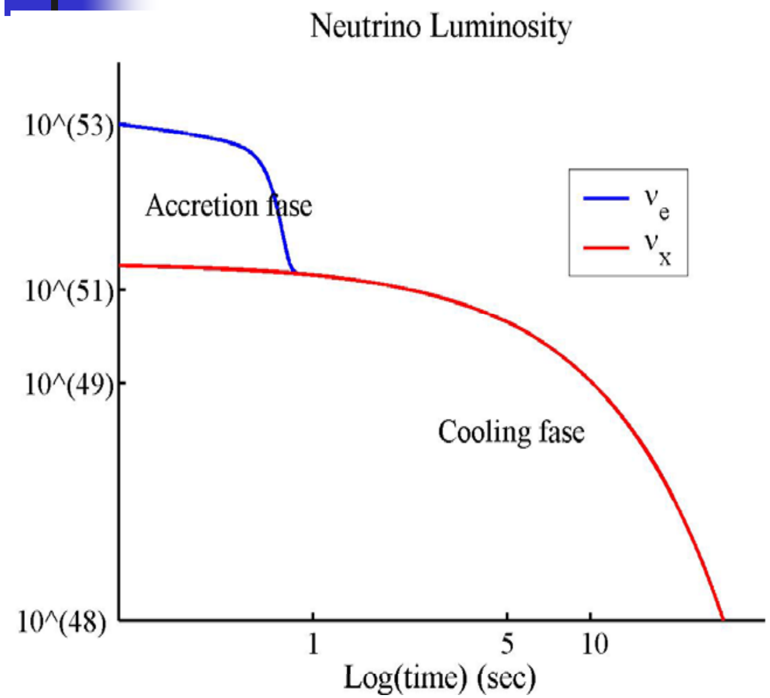
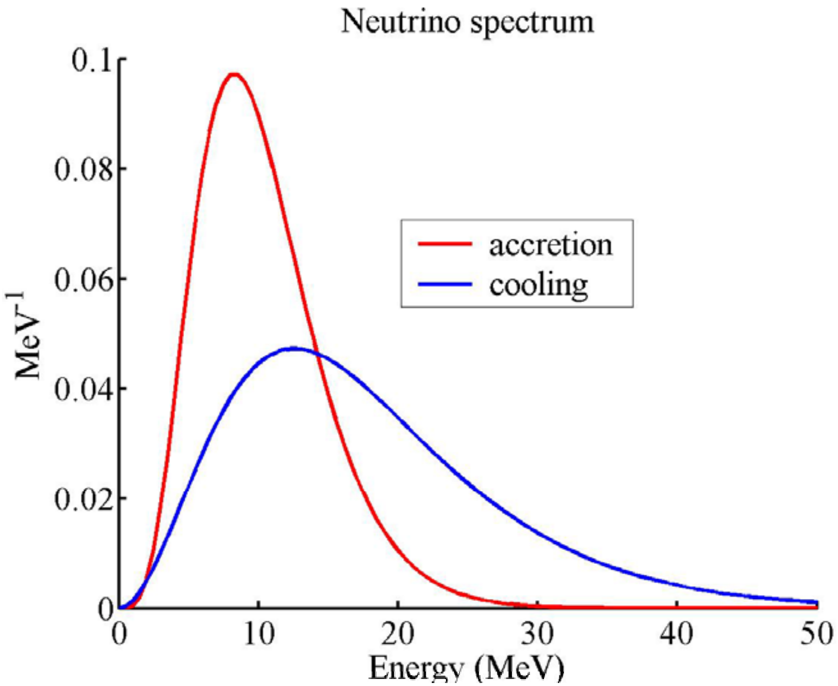
Results





LIKELIHOOD RATIO TEST

$$LR = \frac{L^{cool}}{L^{accr+cool}} = 0.0011 \Rightarrow \alpha = 0.9989 > 3\sigma$$

G.Pagliaroli

Future of neutrino physics (from accelerators)

- 1st stage: Conventional ν beams from a secondary meson beam (K2K, MINOS, CERN/G.Sasso, T2K 1st phase) and Double Chooz (reactor).
partial improvement of θ_{13} ; Not enough to study the leptonic CP violation

- 2nd stage: Superbeams (T2K 2nd phase, NovνA, CERN)
- beam luminosity increase: θ_{13} precise measurement and/or (eventual) CP violation
- search
- \- T2K (Japan, 2009) 2nd phase: ν_μ beam from JParc to SuperK (L=295 Km)
- \- NovνA (USA): use the beam of NuMI at FNAL, detector at about 800 Km
- -CERN: possible superbeam exploiting the CERN SPL

- 3rd stage (end of next decade): ν from primary beam decays
- **Neutrino factories:** ν from decay of muons (tens of GeV) in accumulation rings
- ($n \to p + e^- + \bar{\nu}_e$) $p \to n + e^+ + \nu_e$
- **Beta beams**: ν beams from β decays (few GeV)
-

Weinberg angle determination

- **6 cross sections: neutrino (antineutrino) current on proton (neutron) and neutrino (antineutrino) charged currents**

- **Fixing the value of the electric form factors there are 6 parameters left : Weinberg angle and 5 form factors (G^p_M, G^n_M , G^S_M , G_A , G^S_A)**

- - Using for fluxes and energy:

  $\Phi_\nu \cong 10^{16}$ (m^2/yr) ; $\Phi_{anti-\nu} \cong 5\ 10^{14}$ (m^2/yr) ; $E_\nu = 1$ GeV

  - Detector : 10 ktons Liquid Ar
  - Assuming in data generation $\sin^2\theta_w = 0.2312$
  - From simultaneous fit of $\sin^2\theta_w$ and $G_M{}^S$, varying $G_A{}^S$, we get:

- $\sin^2\theta_w = 0.2309 \pm 0.0019$ (stat) ± 0.0024 (syst)

Detector alternatives

1) Water Cherenkov:

Pro: there is the possibility of assembling a very large mass (some MTon)

Con: the Cherenkov threshold prevents the detection of recoiling protons with p<1 GeV.

2) Liquid Argon TPC

Pro: in principle p down to 50 MeV can be identified.

Con: Difficult to assemble a large mass; nuclear reinteractions in Ar are more important than in water

For p > 300 MeV ⇒ $Q^2 > 0.1\ GeV^2$, about 75% of the events surviving. Measurements at near detector already competive with detector below kton (around 500 ton)

Interesting possibility mainly for superbeams

V.Antonelli

Experimental speakers

- Neutrino Physics
  - MiniBoone first results (M. Sorel)
  - Neutrinos from accelerators (F. Terranova)
  - Neutrinos from reactors (A. Tonazzo)
  - Absolute neutrino masses (M. Sisti)
- Astroparticle Physics
  - Satellite experiments (F. Cafagna)
  - Gamma astronomy (T. Di Girolamo)
  - Cosmic ray experiments (I. De Mitri)
  - Neutrini telescopes (P. Sapienza)
  - Gravitation waves (G. Cella)

What still we have to observe or measure with higher precision?

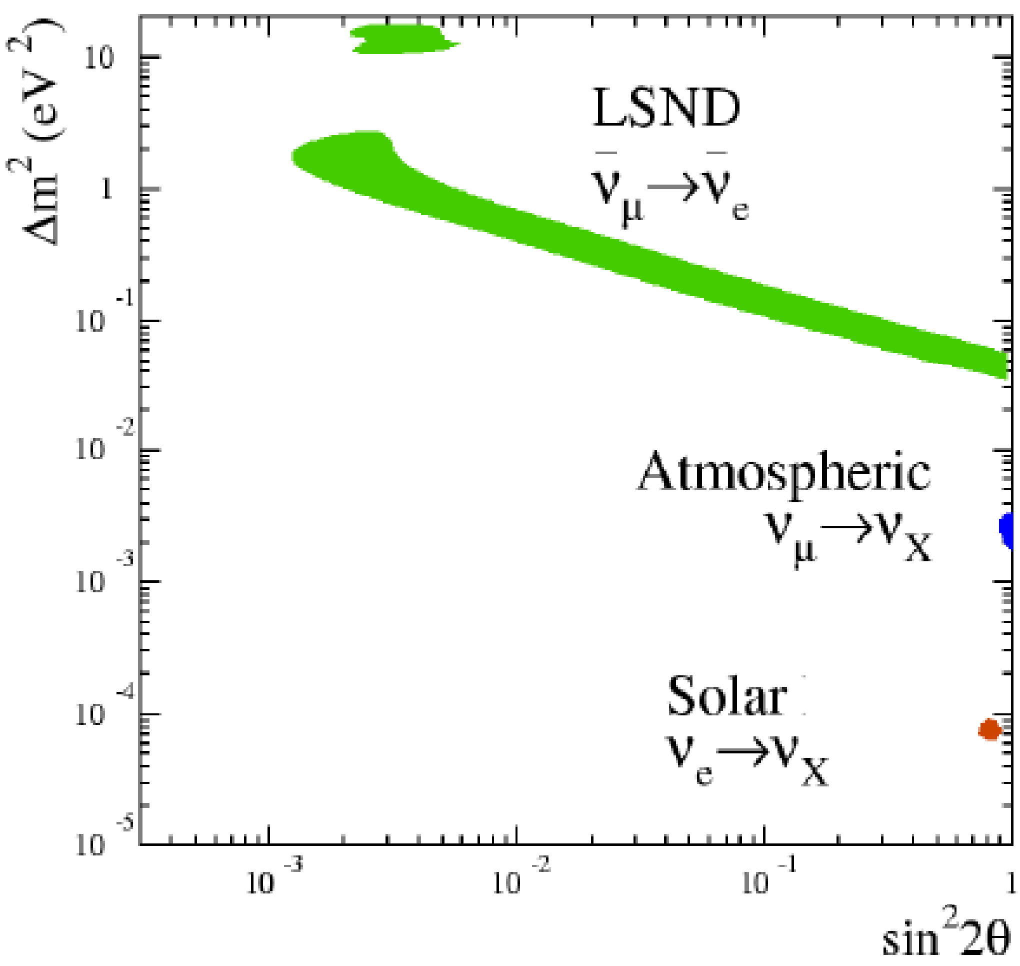
- Are there more - sterile - neutrinos? Confirm or disprove LSND
- The source of atmospheric oscillations (detect τ appearance)
- Three angles (θ_{12}, θ_{13}, θ_{23})
- Two mass squared differences (Δm^2_{12}, Δm^2_{23})
- The sign of the mass squared difference Δm^2 ($\pm\Delta m^2_{23}$)
- One CP phase (δ)
- The absolute masse scale
- Are neutrino Dirac or Majorana particles (or both)?

Discovery

Precision meas.


MiniBooNE
Primi risultati per la ricerca di oscillazioni nella regione permessa da LSND
M. Sorel, IFIC (CSIC e U. de Valencia)
IFAE 2007, Napoli, 11-13 Aprile 2007

LSND result



$\overline{\nu_e}$ candidate excess:
$(87.9 \pm 22.4 \pm 6.0) \rightarrow 3.8\sigma$

If interpreted as oscillations:
$\langle P(\overline{\nu_\mu} \rightarrow \overline{\nu_e}) \rangle = (0.264 \pm 0.067 \pm 0.045)\%$

Mass and mixing parameters:
$\Delta m^2 \sim 0.1 - 10 \ eV^2$, small mixing
Large $(\sin^2 2\theta, \Delta m^2)$ degeneracy

$\Delta m^2_{LSND} \gg \Delta m^2_{atm} + \Delta m^2_{sol}$ and
$\Delta m^2_{LSND} \sim 1 \ eV^2$:
Cannot be explained within the standard neutrino physics and cosmology paradigms

MiniBooNE Goal and Design Strategy

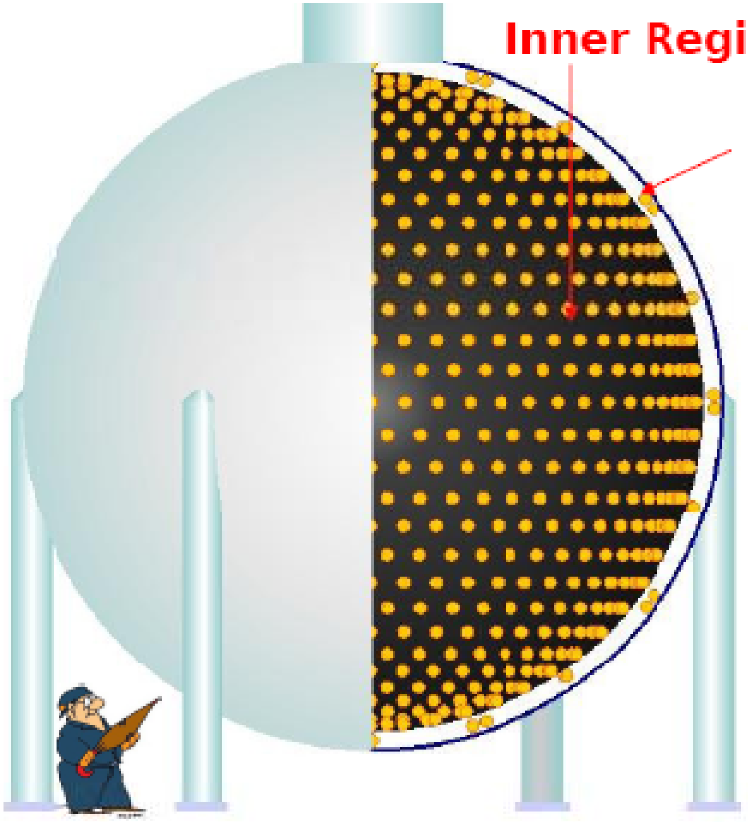
- **Primary goal:**

confirm or refute the oscillation interpretation of the LSND anomaly in an unambiguous and independent way

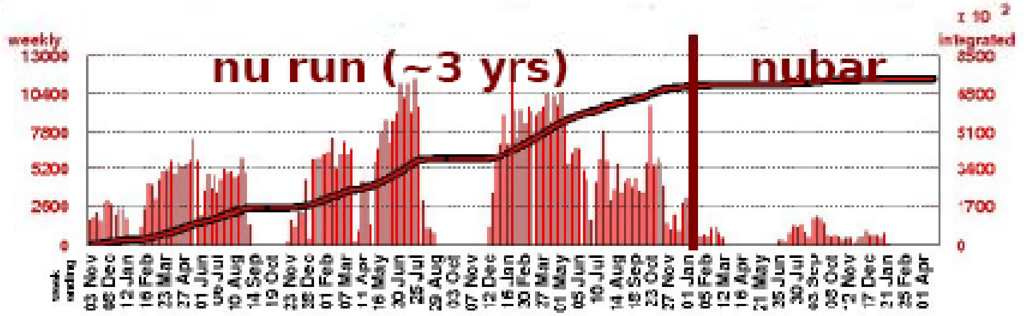
- **Design strategy to accomplish this goal:**
  - High statistics sample of electron neutrino candidate events
  - Keep L/E as LSND, with order-of-magnitude longer baseline (~500 m) and higher neutrino energy (~800 MeV)

    -> different oscillation signature, backgrounds, systematics

Neutrino Detector



- 12 m in diameter sphere filled with 800 t of undoped mineral oil
- Light tight inner region with 1280, 20 cm diam., PMTs (10% coverage)
- 240 PMTs in veto region (>99.9% veto efficiency)
- Neutrino interactions in oil produce:
  - Prompt, ring-distributed, Cerenkov light
  - Delayed, isotropic, scintillation light
- Light transmission affected by: fluorescence, scattering, absorption (>20m for >400 nm light)



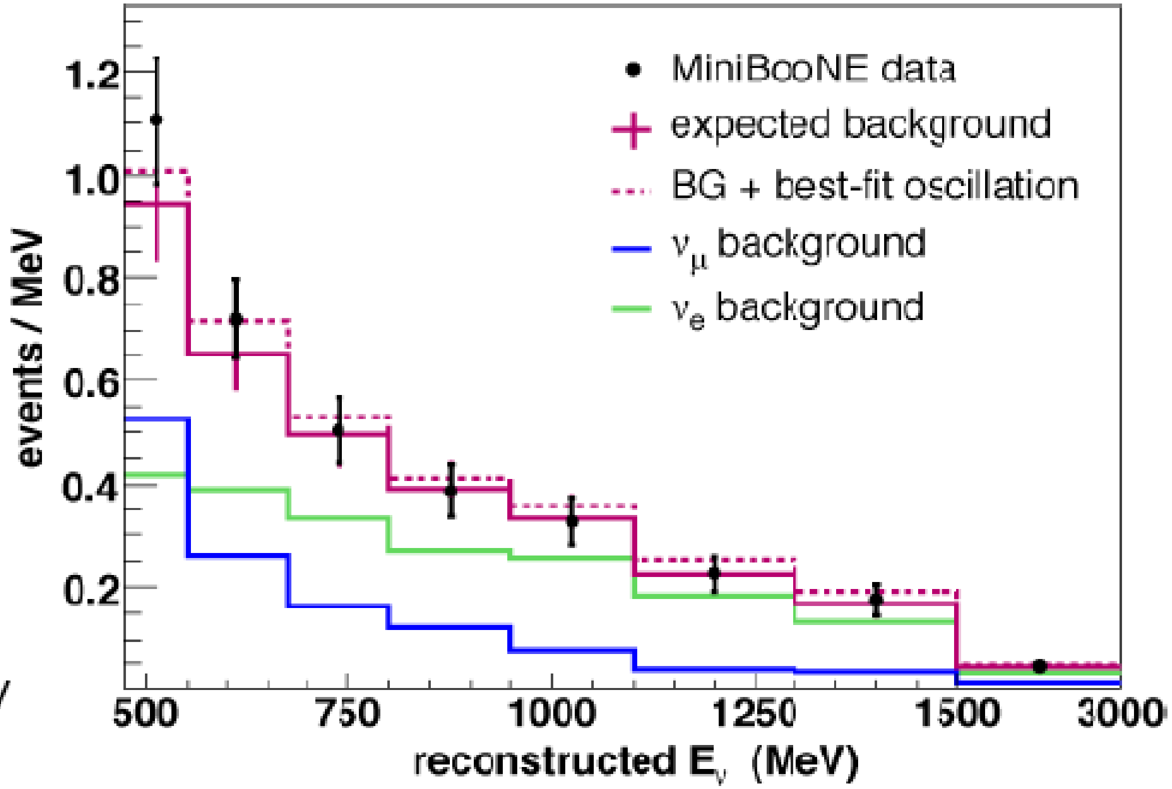
Number of accumulated neutrino interactions: $7.4 \cdot 10^5$

Full Box Opening and Oscillation Best-Fit Results

Energy-dependent Oscillation Best-Fit (475-3000 MeV):

- $\sin^2 2\theta = 1.1\times10^{-3}$
- $\Delta m^2 = 4.1\ eV^2/c^4$
- $\chi^2_{null} - \chi^2_{best} = 0.94$

- Data error bars are statistical
- Predictions error bars from diagonal elements of syst.-only covariance matrix



Counting experiment (475-1250 MeV):

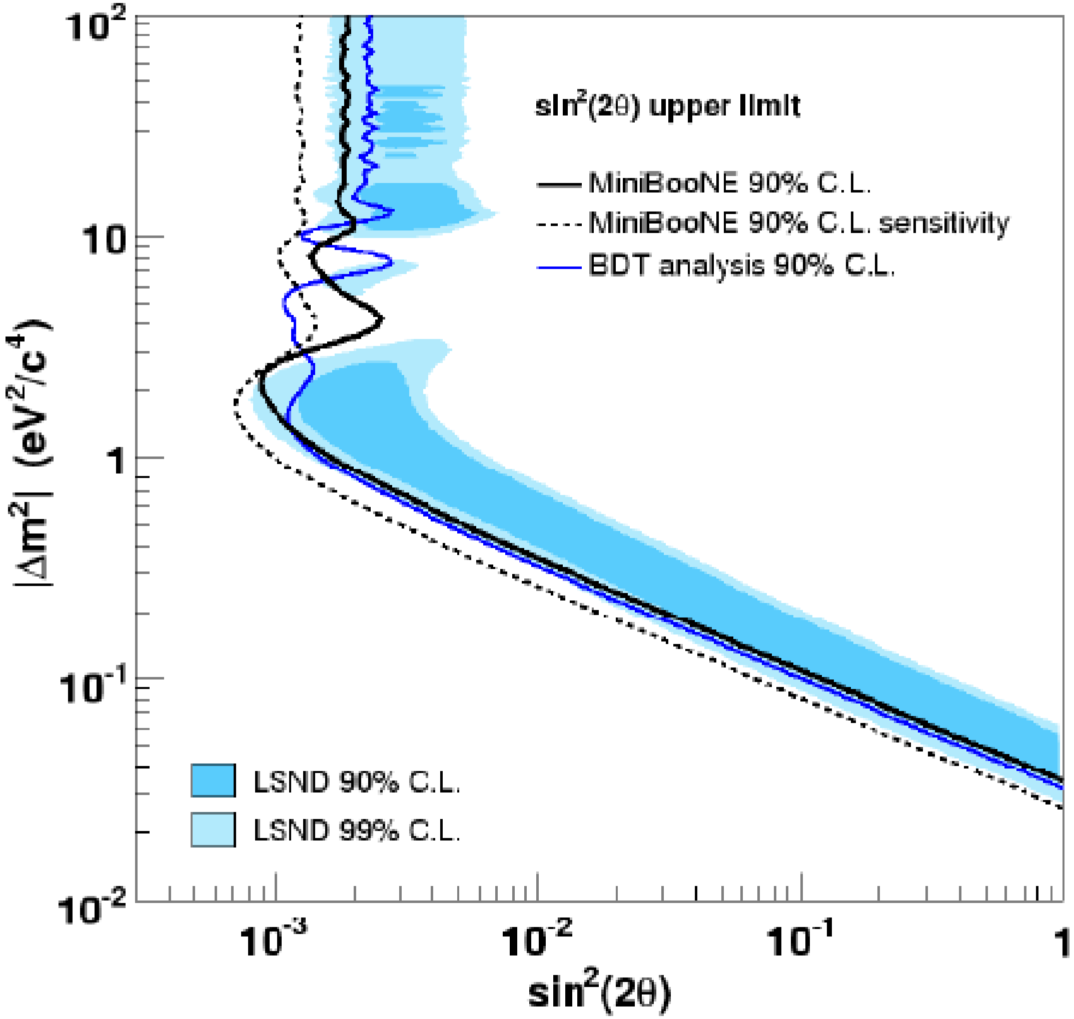
- Observe **380 events,** predict **358±19±35 events**
- **0.55 σ** excess over background

Oscillation Parameters Exclusion

- MiniBooNE **excludes** two neutrino appearance-only oscillations as the explanation of the LSND anomaly at **~98% CL**

- Very similar oscillation fit result obtained with independent boosted decision tree (BDT) analysis

- Any interpetation of the LSND anomaly that would produce a significant excess for E_ν>475 MeV at MiniBooNE is also ruled out



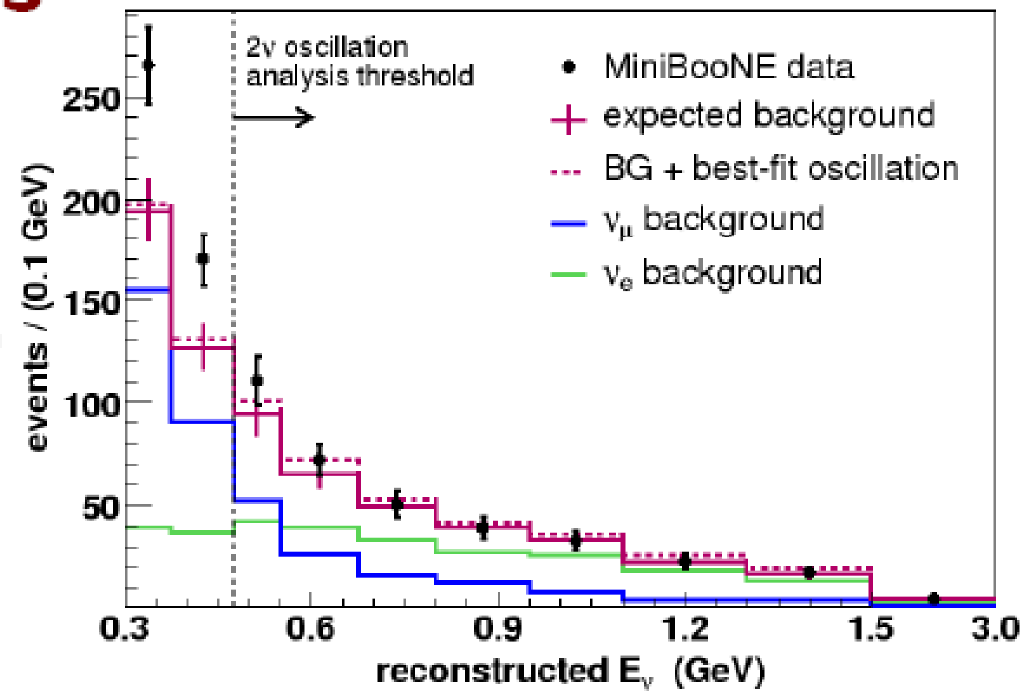
Low-Energy Excess

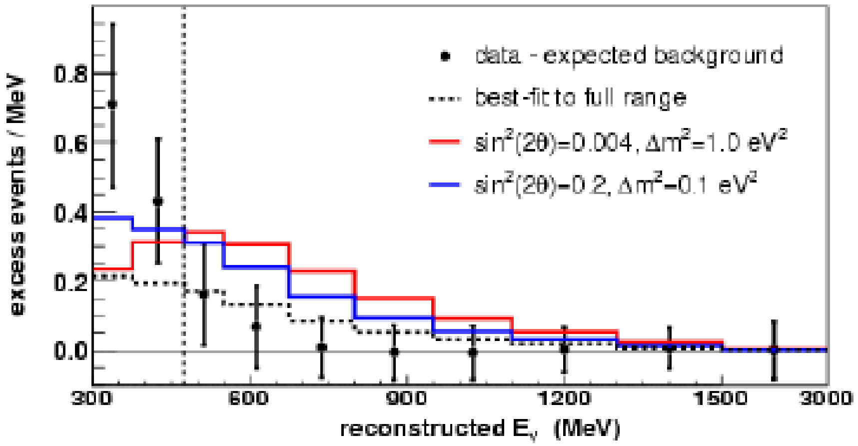
- Electron candidate events over the full ($300 < E_\nu < 3000$ MeV) energy range

- The low-energy data does not match expectations:

3.7σ excess in ($300 < E_\nu < 475$ MeV)

- This discrepancy is *not* understood





- Low-energy excess is *not* consistent with two neutrino appearance oscillations

- Fit to the ($300 < E_\nu < 3000$ MeV) energy range gives a 18% χ^2 probability

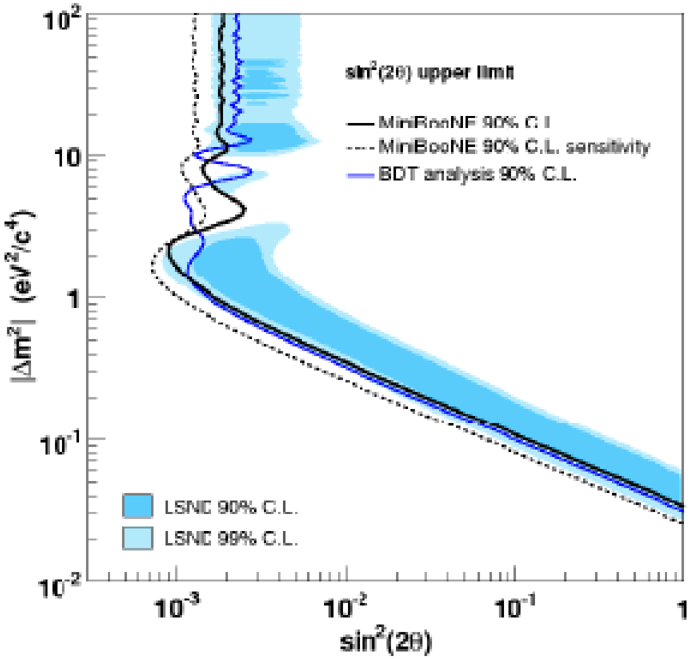
- Need to do more analysis and gather more facts before making any conclusions

Conclusions

The LSND anomaly remains ... an anomaly:

- MiniBooNE finds excellent agreement between data and the no-oscillation prediction in the oscillation analysis region

- MiniBooNE excludes at ~98% confidence level the interpretation of the LSND anomaly put forward by the LSND collaboration to interpret its own result:



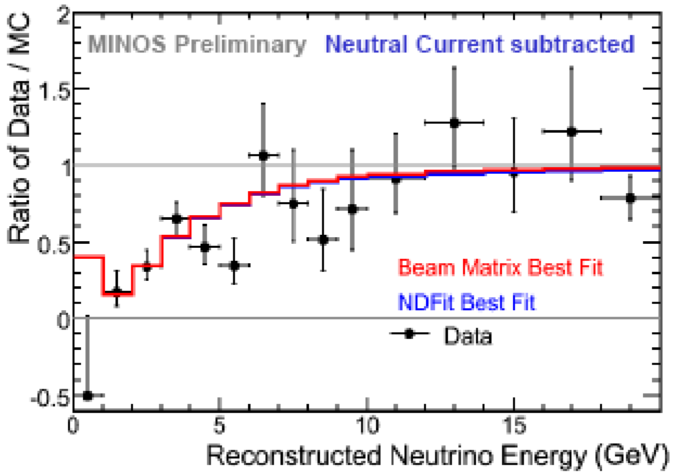
two neutrino, muon-to-electron neutrino appearance-only oscillations

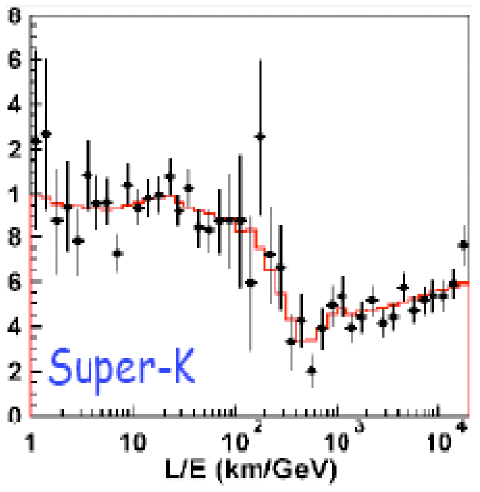
MiniBooNE finds a discrepancy at energies below the oscillation analysis range:

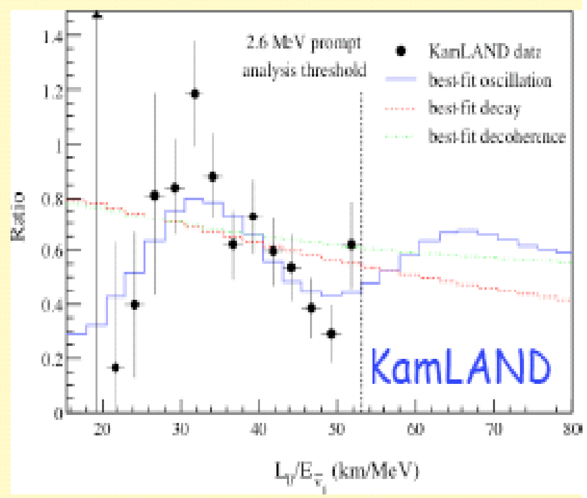
- currently not understood and under investigation

Importanza degli esperimenti agli acceleratori

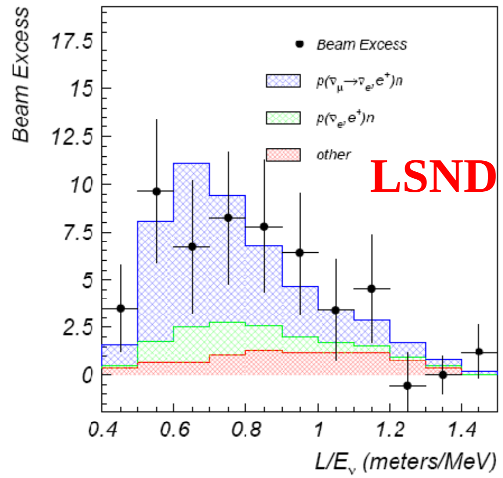
Sulla carta, l'appearance di nuovi flavor è il modo più ovvio per studiare le oscillazioni. Al momento il ruolo che ha avuto questa metodologia è assolutamente marginale







L'unica evidenza positiva in appearance <u>non</u> fitta con l'interpretazione standard delle oscillazioni di neutrino

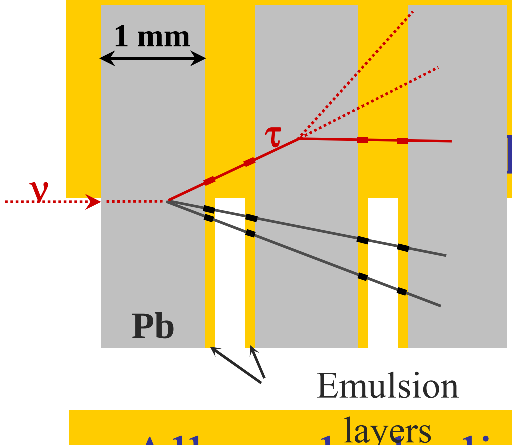


Perchè?

Alla scala dei solari tutte le sorgenti disponibili sono al di sotto della soglia cinematica per la produzione di muoni

Alla scala degli atmosferici le oscillazioni dominanti sono:

$$P(\nu_\mu \rightarrow \nu_\tau) \approx \cos^4 \vartheta_{13} \sin^2 2\vartheta_{23} \sin^2 [1.27 \, \Delta m^2_{23} \, L(km)/E(GeV)]$$



Bisogna identificare il τ

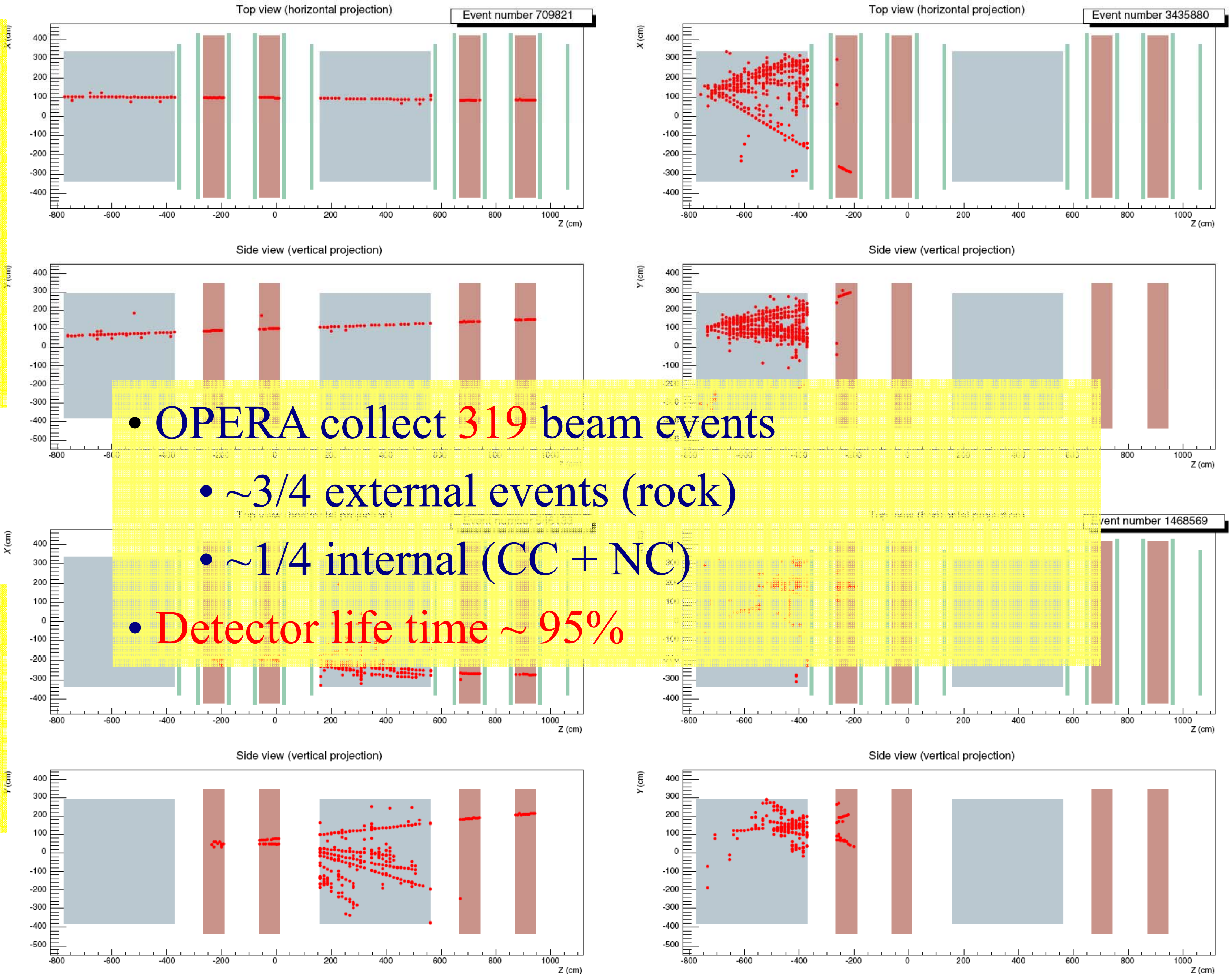
E' il caso di fisica del CNGS/OPERA

Alla scala degli atmosferici le oscillazioni subdominanti $\nu_\mu \rightarrow \nu_e$ sono ricchissime di informazioni ma sono soppresse dall'angolo di mixing tra la prima e la terza famiglia. Ci vogliono sorgenti straordinariamente intense per vedere l'effetto e estrarre i parametri

E' il futuro (prevedibile) della fisica delle oscillazioni

νCC in rock (rock muon)

νCC in Target Tracker



- OPERA collect 319 beam events
  - ~3/4 external events (rock)
  - ~1/4 internal (CC + NC)
- Detector life time ~ 95%

νCC in Magnet

νNC in Target Tarcker

R Acquafredda et al., New J. Phys. 8 (2006) 303

Il dilemma di θ_{13}

In teoria possiamo determinare con exp terrestri TUTTA la matrice di mixing leptonica e distinguere tra gerarchia diretta e inversa.

Tutto dipende dal valore di ϑ_{13}

Se $\vartheta_{13} \approx 10^o$ (vicino ai limiti attuali) non e' necessaria la costruzione di nuovi rivelatori [progetti con costi ≈ 150 M$]

Se $\vartheta_{13} > \approx 3^o$ e' necessaria la costruzione di nuovi rivelatori (e.g. 1 Mton water cherenkov) e fasci tradizionali ma piu' intensi (Superbeams) [progetti dell'ordine di 0.5-1 G$]

Se $\vartheta_{13} > \approx 1^o$ e' necessaria la costruzione di nuovi rivelatori (e.g. 1 Mton water cherenkov) e di fasci di nuova concezione (beta beams e neutrino factories) [progetti dell'ordine di 1-2 G$]

La questione della determinazione di ϑ_{13} ha dominato il dibattito sulla roadmap dei neutrini negli ultimi tre anni

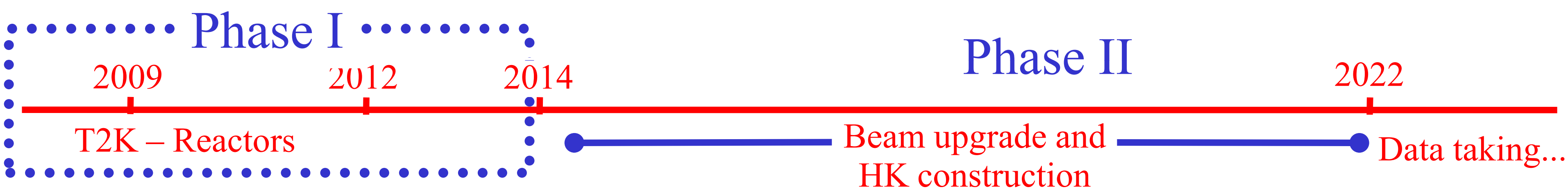
Near future plans

Non per i giapponesi perché hanno grossi investimenti pregressi che possono sfruttare: SuperKamiokande e il complesso J-PARC (1 G$!!! per fisica della materia, biologia, fisica nucleare…). E' comunque un grosso i

T2K è l'unico long-baseline approvato e finanziato finalizzato alla scoperta delle subdominanti $\nu_\mu \rightarrow \nu_e$

No se si evita di utilizzare i long-baseline: c'è ancora margine di miglioramento ($\sin^2 2\vartheta_{13} \approx 0.01$) con gli **esperimenti ai reattori** che richiedono investimenti O(20 M$) V. talk A. Tonazzo

Esperimenti di terza generazione ai reattori (post-CHOOZ) raccolgono un enorme consenso come esperimenti "preparatori" ai long-baseline di nuova concezione

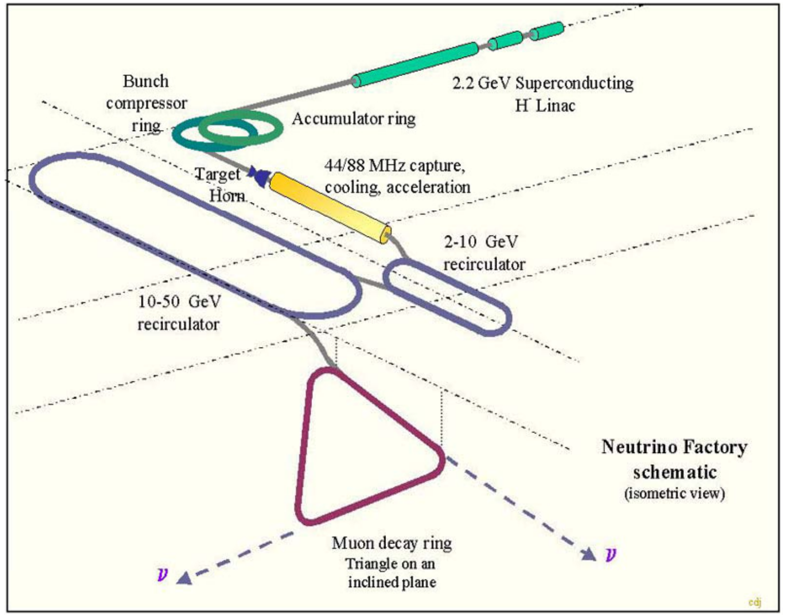


Alternative più controverse:

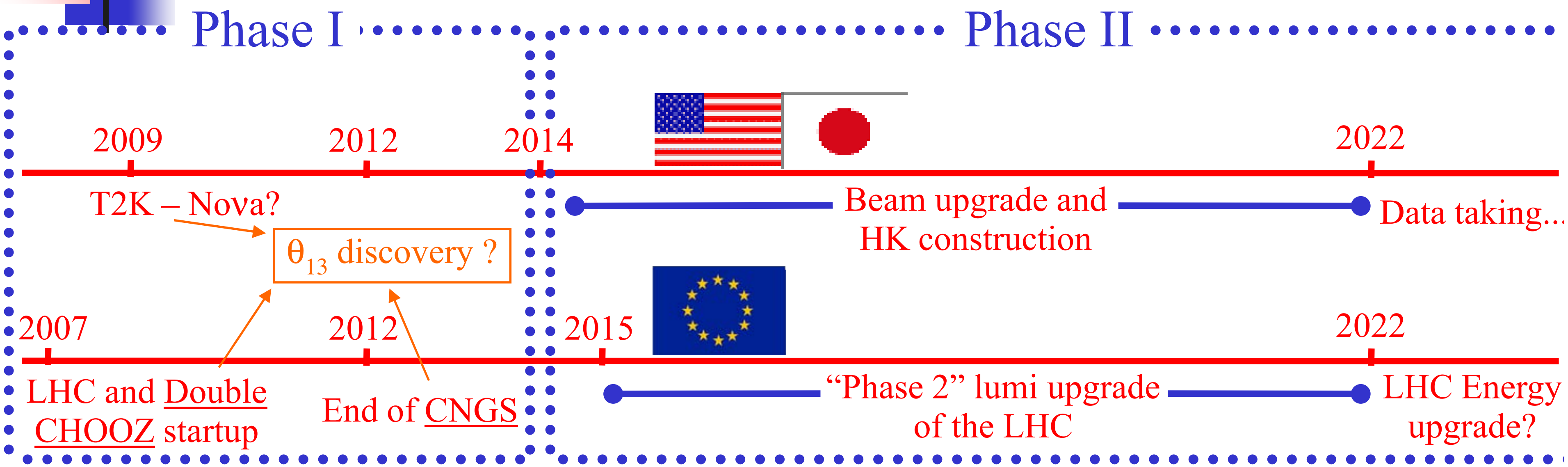
Nova (US): utilizzo massimale di NUMI con un nuovo rivelatore (investimento di circa 200 M$). Physics case molto simile a T2K – sensibilità alla gerarchia di massa marginale con NuMI: interessante con un nuovo driver da 2 MW (anche per CPV). Se si include il nuovo driver, diventa un esperimento di "Fase II"… qualcuno comincia a dire "Perche' non aspettiamo per vedere quanto è grande ϑ_{13}"?

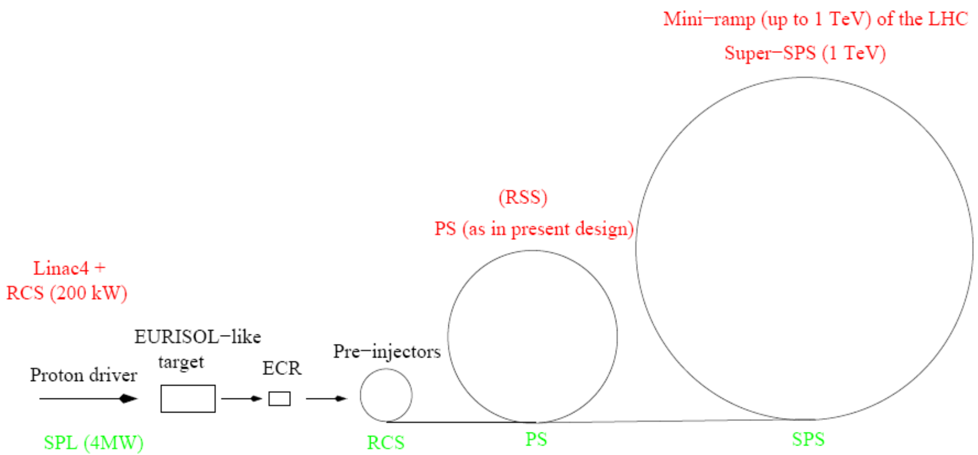
Approccio "conservativo": Lasciare la Fase I ai giapponesi e ai reattori (EU: Double-Chooz) e puntare su una facility di fase II in caso di risultato positivo (UK) o addirittura prima (Frejus).

Lascia spazio a tecnologie profondamente innovative come le Neutrino Factories o i Beta Beams



Una variante basata sugli upgrade di macchina per l'LHC + BetaBeam + far detector al Gran Sasso





+ the decay ring

A.Donini et al., EPJ C48 (2006) 787

A.Donini, et al. hep-ph/0703209

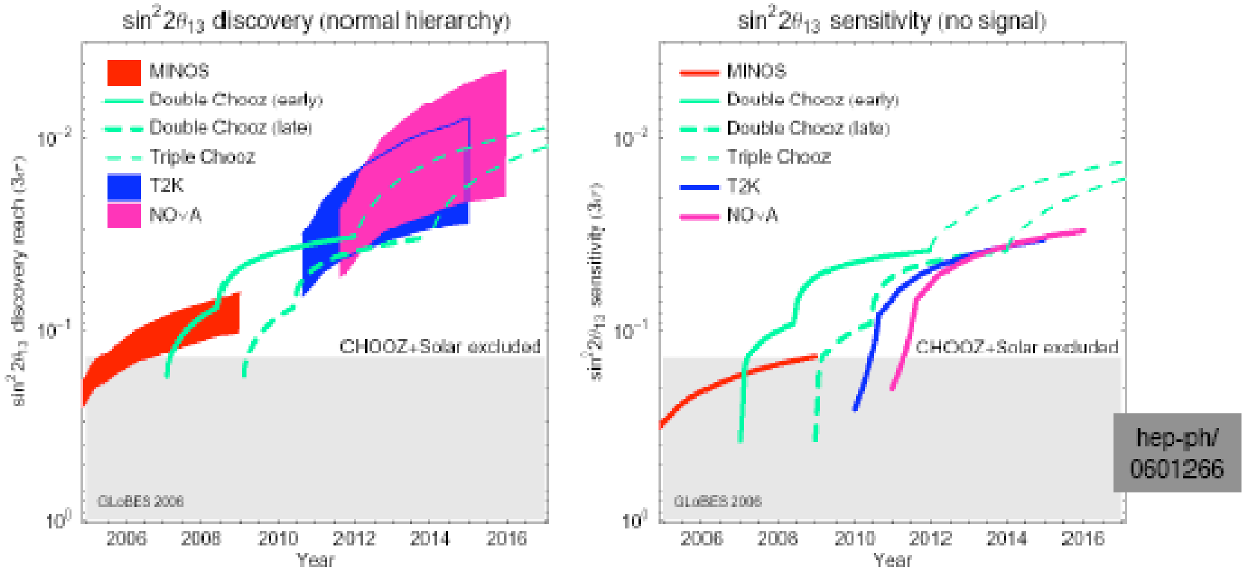
Una facility di fase due con rivelatore di ferro magnetizzato (!) ai LNGS che lavora in appearance di ν_μ (NON ν_e!)

θ_{13} at reactors

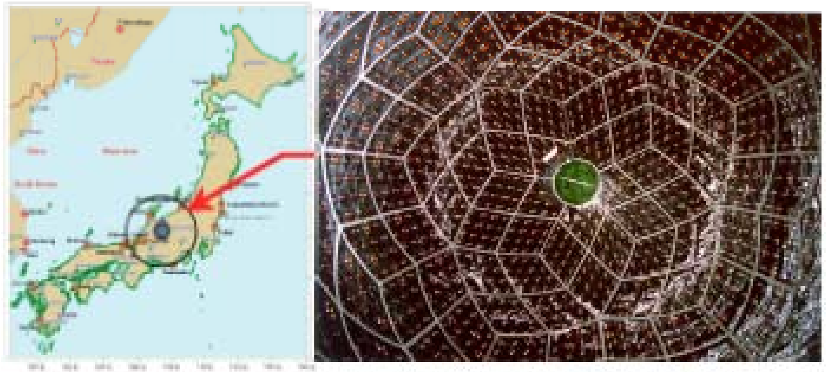
- $P(\nu_e \rightarrow \nu_e)$ independent of δ-*CP*, weak dependence on Δm^2_{21}
- O(MeV) + small distances $\Rightarrow$ Matter effects negligible $\Rightarrow$ measurement independent of *sign*(Δm^2_{13})

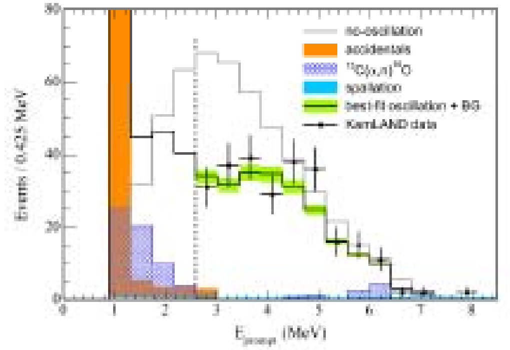
➡ "Clean" θ_{13} measurement, complementary to beams

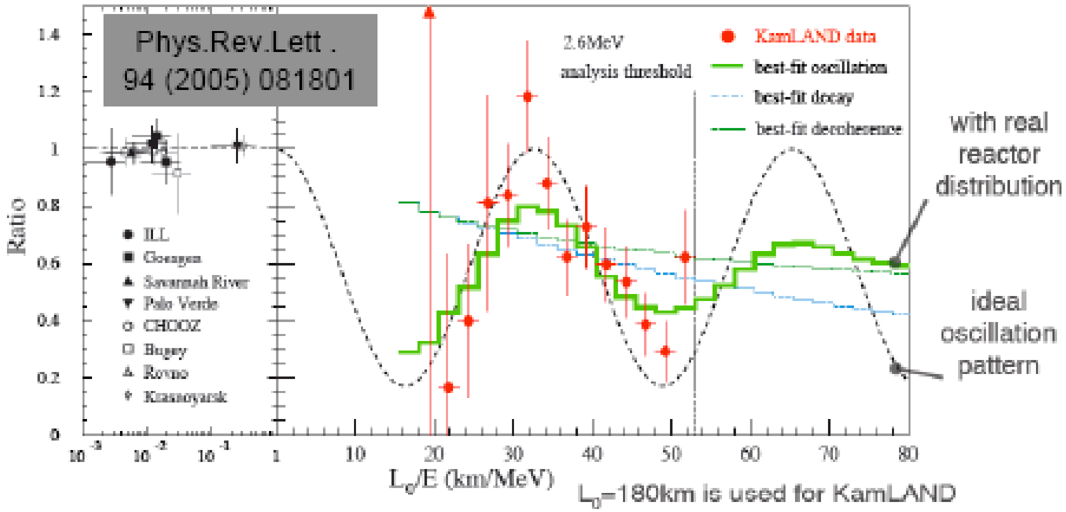
➡ Experiments can be carried out on a short time scale and for relatively low cost $\Rightarrow$ input on decision for future beams

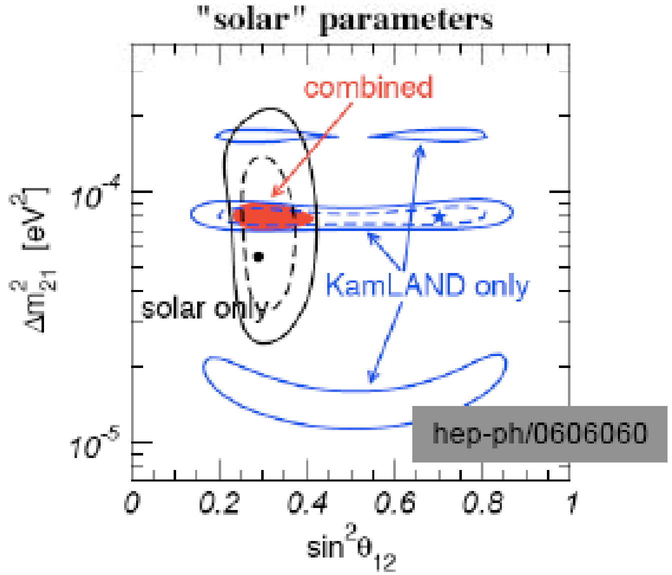


Δm_{12} @ KamLAND









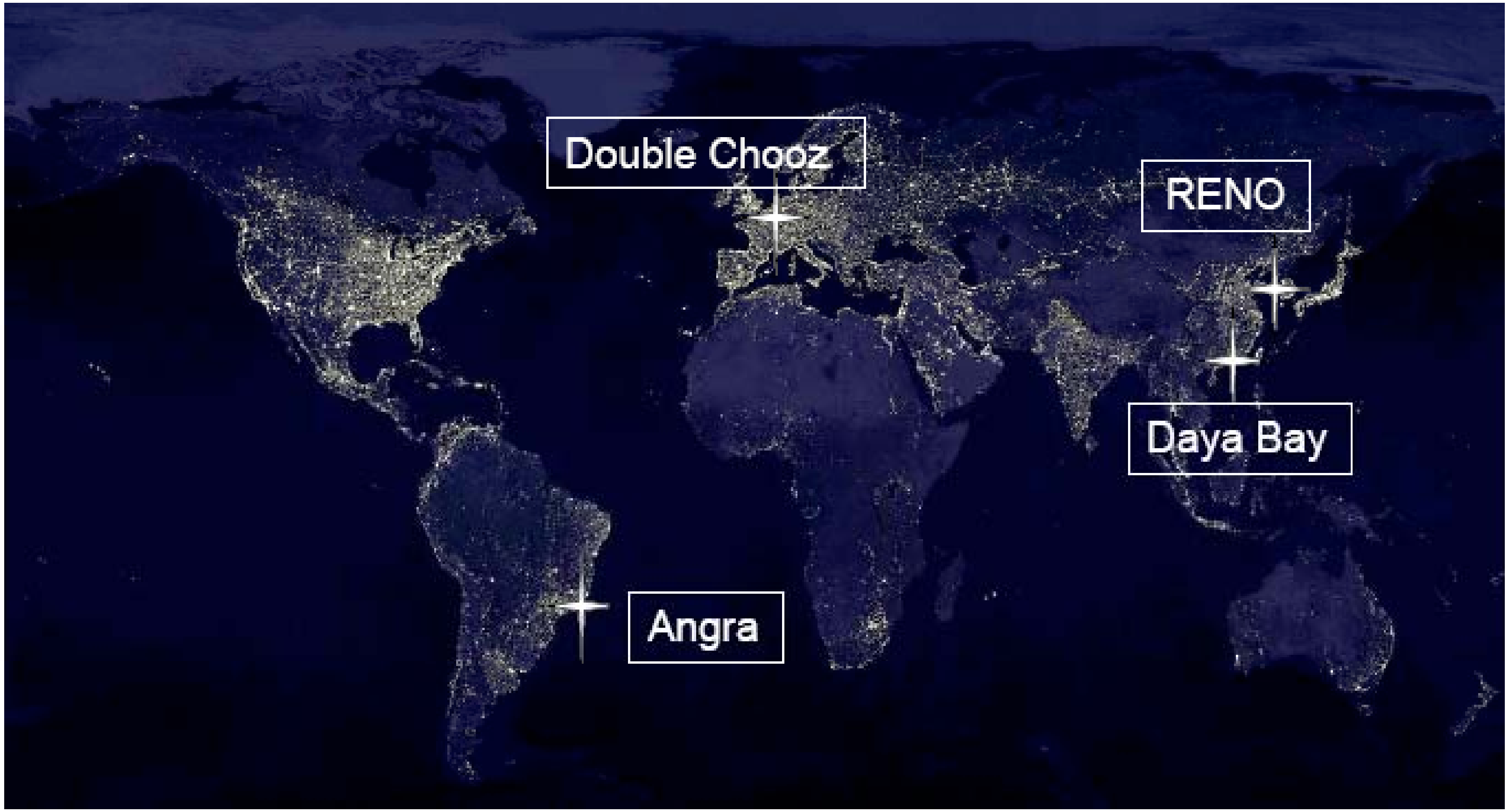
$$\Delta m^2 = 7.9^{+0.6}_{-0.5} \cdot 10^{-5} eV^2 \quad (2\sigma)$$

How can we improve?

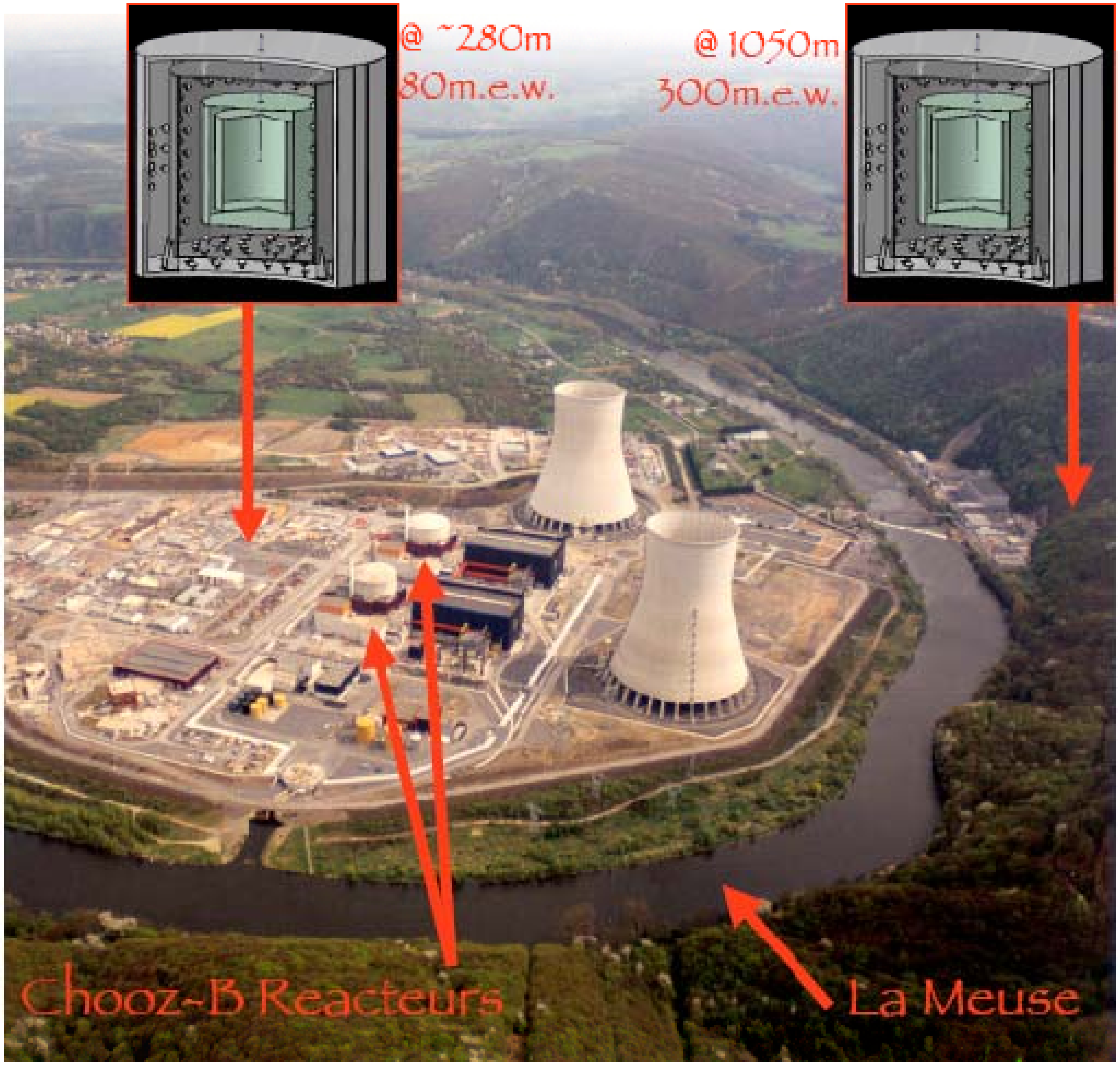
CHOOZ : R_{osc} = 1.01 ± 2.8% (stat) ± 2.7% (syst)

- **Statistics**
  - More powerful reactor (multi-core)
  - Larger detection volume
  - Longer exposure
- **Experimental error**: ν flux+spectrum and cross-section uncertainty
  - Multi-detector → relative measurement
  - Identical detectors to reduce experimental systematics (normalisation, calibration …)
- **Background**
  - Improve detector design ⟶ larger S/B
  - Increase overburden ↗
  - Improve bkg knowledge by direct measurements

Reactor θ_{13} projects «today»



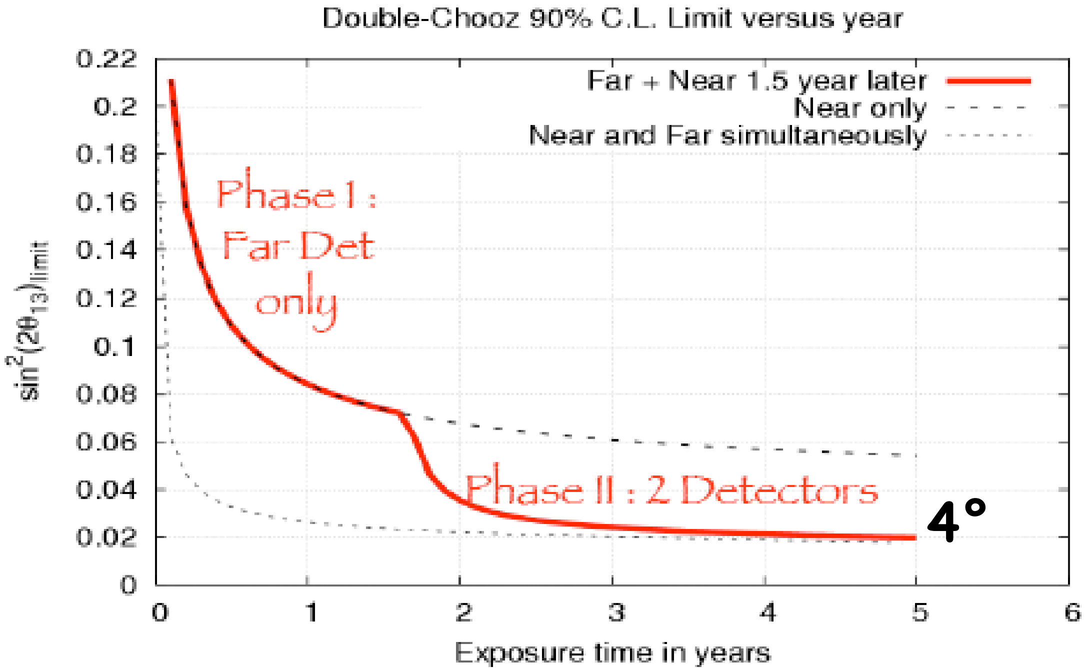
(Double-)Chooz site in the Ardennes



Double Chooz schedule

Proposal
hep-ex/0606025

Approved & financed in France, Germany, Russia, Spain, UK (Japan? US?)



2003	2004	2005	2006	2007	2008	2009…
Site	**Prop.**	**design+test simulation**		**Construction**		
					Data taking and analysis	

Summary and outlook

Potential for oscillation measurement at reactors is vast:

- Δm^2_{12} @KamLAND will be improved by reducing systematics
- A new idea for mass hierarchy determination has appeared
- The hottest topic: θ_{13} "quick & clean" measurement

  Four multi-detector experiments currently proposed:

  1st generation: **Double Chooz**, **RENO**

  $\rightarrow \sin^2 2\theta_{13} < 0.02\text{-}0.02$ in 2011-2012

  2nd generation: **Daya Bay**, **Angra**

  $\rightarrow \sin^2 2\theta_{13} < 0.01$ after 2013

Double Chooz is a pacemaker in development of detector items that will allow control of systematics to desired level.

Its construction is starting soon… we're looking forward to its results !

La misura della scala di massa

β-decay: m_β
model independent
status: $m_\beta < 2.3$ eV
potential: $m_\beta < 200$ meV

Exp.: KATRIN, MARE(?)

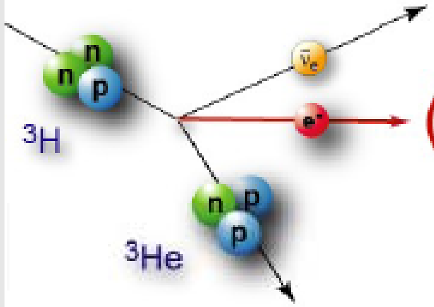
0νββ-decay: m_{ee}
model dependent, ν-nature (CP)
status: $m_{ee} < 0.5$ eV
potential: $m_{ee} < 20\text{-}50$ meV

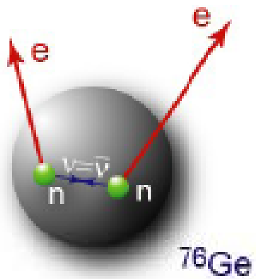
Exp.: Majorana, GERDA, CUORE, SUPERNEMO, ...

laboratory

m_β m_{ee}

neutrino mass measurements
status & potential

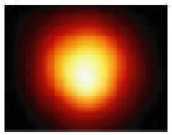


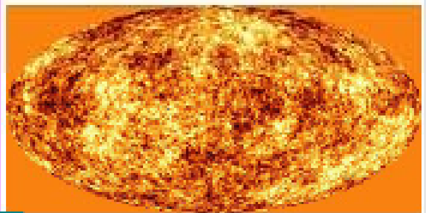


Σm_i

cosmology: Σm_i
model dependent
status: $\Sigma m_i < 0.7$ eV
potential: $\Sigma m_i < 70$ meV

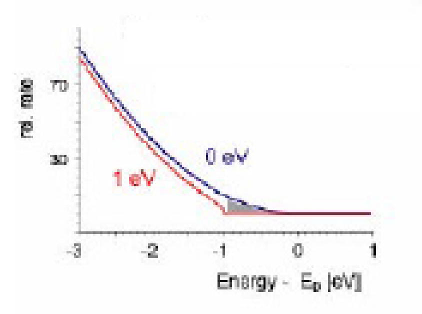
Exp.: WMAP, Planck, SDSS


SN20xx


CMBR

Decadimenti beta singolo e doppio beta a confronto

β decay



$$m_\beta^2 = \sum |U_{ei}|^2 m_i^2$$

Il decadimento ha luogo per neutrini sia di Dirac che di Majorana

Con buona approssimazione, la parte finale dello spettro è sensibile ad una combinazione di masse al quadrato (pesate dal contenuto di "sapore elettronico") detta "**massa effettiva del neutrino elettronico**" m_β:

$$m_\beta = \left[c_{13}^2 c_{12}^2 m_1^2 + c_{13}^2 s_{12}^2 m_2^2 + s_{13}^2 m_3^2\right]^{\frac{1}{2}}$$

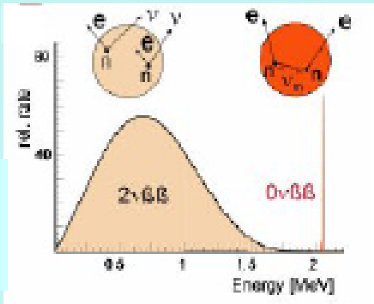
→ **no interferenza distruttiva**

Limite attuale: m_β < ~ 2 eV

Sensibilità futura: m_β < ~ 0.2 eV

0νββ decay

$$m_{ee} = \left| \sum U_{ei}^2 \; m_i \right|$$



Il decadimento ha luogo solo se il neutrino è di Majorana

Il decadimento è sensibile alla cosiddetta "**massa effettiva di Majorana**" m_{ee} (e fasi relative) che, assumendo tre neutrini, è una combinazione lineare di tre canali neutrinici con ampiezze complesse:

$$m_{ee} = \left|c_{13}^2 c_{12}^2 m_1 + c_{13}^2 s_{12}^2 m_2 e^{i\phi_2} + s_{13}^2 m_3 e^{i\phi_3}\right|$$

→ **possibile interferenza distruttiva**

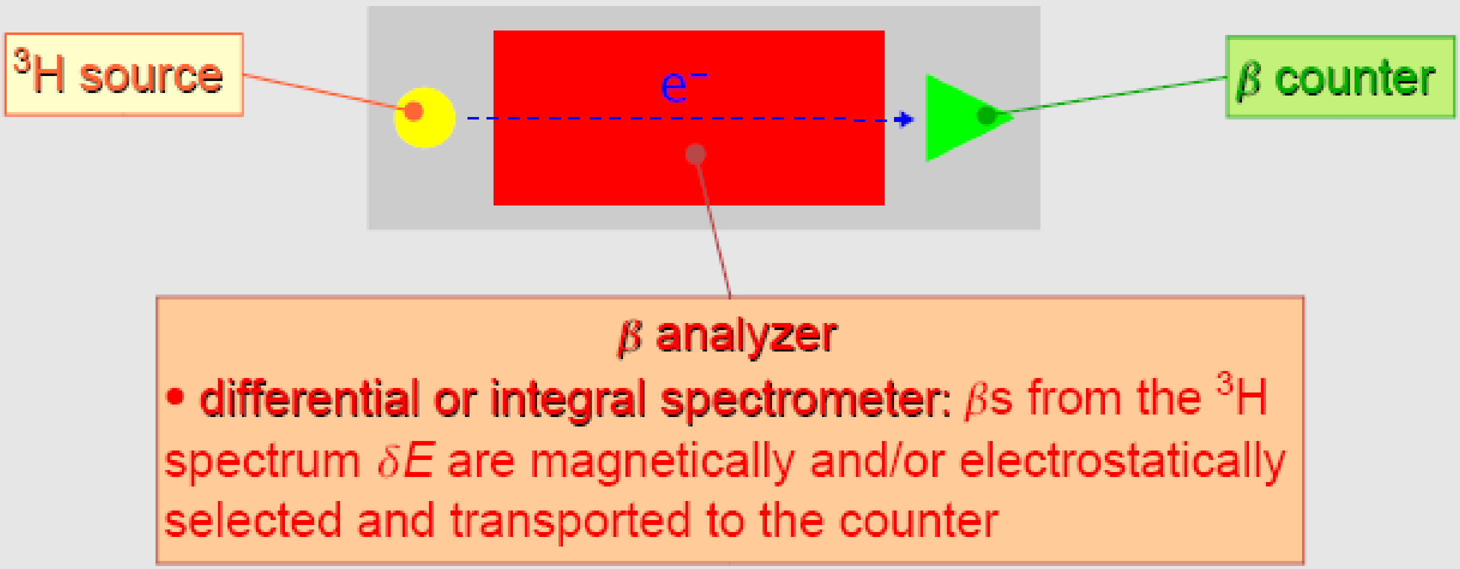
Limite attuale: m_{ee} < ~ 0.5 eV

Sensibilità futura: m_{ee} < ~ 0.05 eV

COMPLEMENTARY MEASUREMENTS

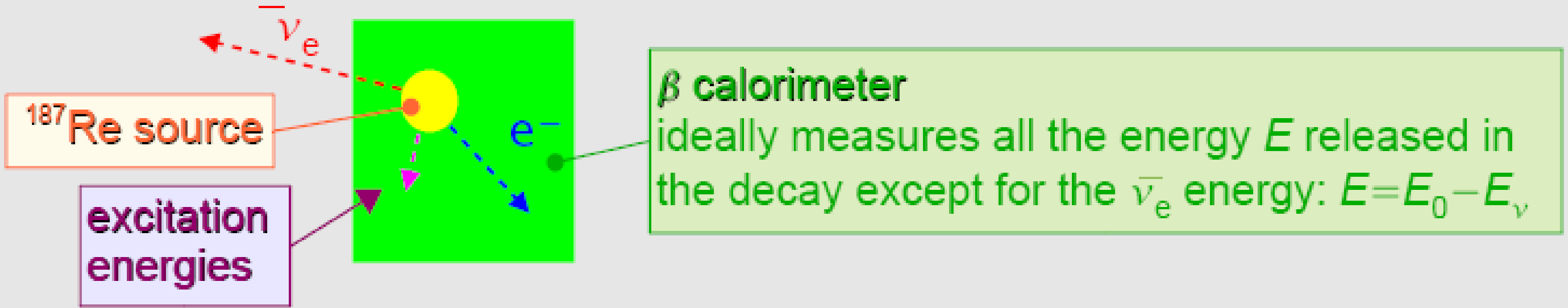
Approcci sperimentali alla misura diretta

- **Spectrometers: source ≠ detector**



Present best limit on m_ν: Mainz-Troitzk ⇒ 2.2 eV (95% C.L.)

- **Calorimeters: source ⊆ detector**



Present best limit on m_ν: Mibeta ⇒ 15 eV (90% C.L.)

Spettrometri e calorimetri a confronto

Spectrometers

- **Choice of β-emitter: ^{3}H**
  - E_0 = 18.6 keV
  - $\tau_{1/2}$ = 12.3 y
- **Advantages**
  - high statistics
  - high energy resolution
- **Drawbacks**
  - systematics due to source effects
  - systematics due to decays to excited states
  - background

Present sensitivity <2.2 eV

Future planned sensitivity:

KATRIN → 0.2 eV

Calorimeters

- **Choice of β-emitter: ^{187}Re**
  - E_0 = 2.5 keV
  - $\tau_{1/2}$ = 43.2 Gy
- **Advantages**
  - measure neutrino energy
  - no backscattering/self-absorption
  - no excited final state effects
  - no solid state excitation
- **Drawbacks**
  - limited statistics
  - systematics due to pile-up
  - energy dependent background

MARE
Università and INFN Genova (IT)
Goddard Space Flight Center (USA)
Universität Heidelberg (GER)
Università dell'Insubria (IT)
Università and INFN Milano-Bicocca (IT)
NIST (USA)
ITC-irst, Trento, and INFN-Padova (IT)
Phys.-Tech. Bundesanstalt (GER)
University of Miami (USA)
Università "La Sapienza" and INFN-Roma1 (IT)
SISSA, Trieste (IT)
University of Wisconsin (USA)

Present sensitivity <15 eV

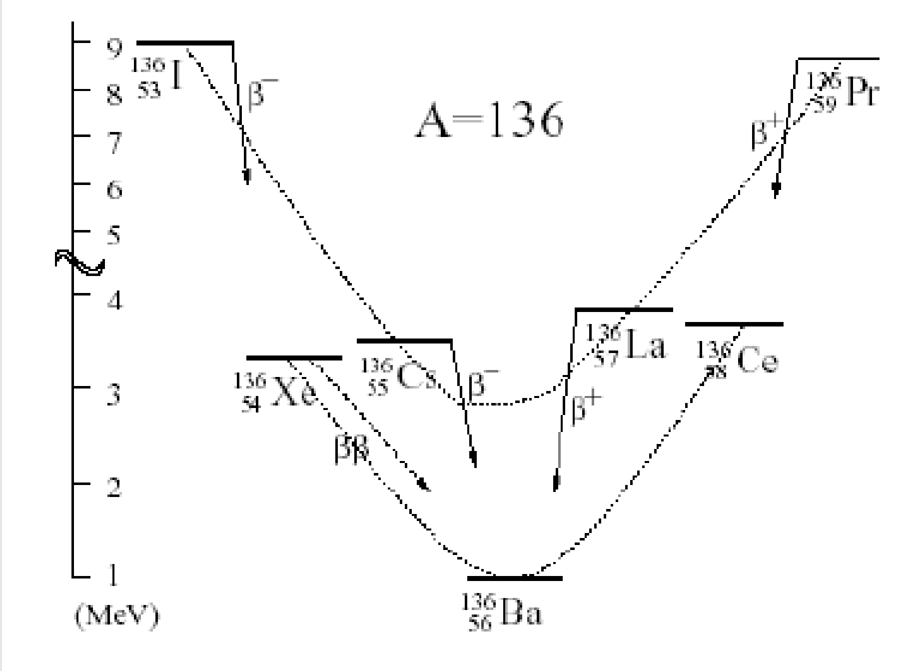
Future planned sensitivity:

MARE → 0.2 eV

Complementary techniques – Different systematics

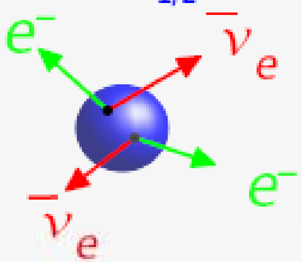
Il decadimento doppio beta

processo debole del secondo ordine
per nuclei pari-pari
con numero di massa A pari



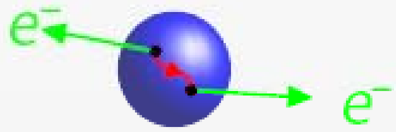
ββ-2ν: $(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\nu_e$

- **permesso** nel Modello Standard
- osservato con $\tau_{1/2} > 10^{19}$ anni

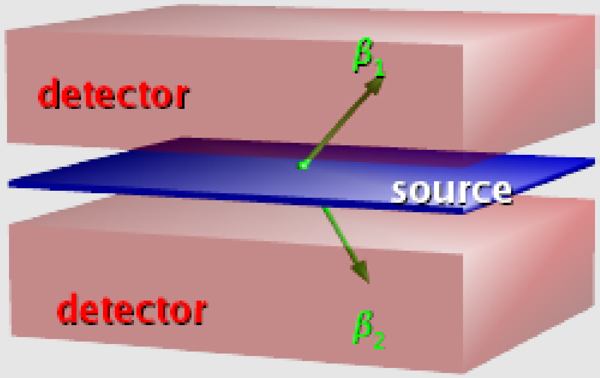


ββ-0ν: $(A, Z) \rightarrow (A, Z+2) + 2e^-$

- **non permesso** nel Modello Standard (ΔL=2)
- atteso con $\tau_{1/2} > 10^{25}$ anni
- attualmente: una evidenza sperimentale molto criticata

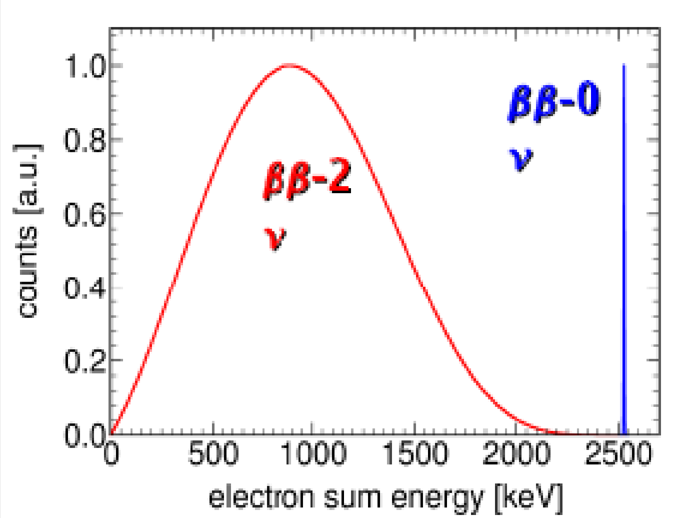


Approcci sperimentali al $\beta\beta 0\nu$



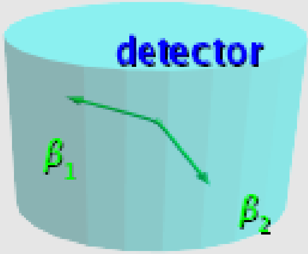
Source ≠ detector

- source in foils
- electrons analyzed by TPCs, scintillators, drift chambers,...
  - ▲ background rejection by event topology
  - ▲ angular correlation gives signature of mass mechanism
  - ▲ any isotopes with solid form possible
  - ▼ small amount of material
  - ▼ poor efficiency
  - ▼ poor energy resolution



Source ⊆ detector (calorimetry)

- detector measures sum energy $E = E_{\beta_1} + E_{\beta_2}$
  - ► $\beta\beta$-0ν signature: a peak at $Q_{\beta\beta}$
- scintillators, bolometers, semiconductor diodes, gas chambers
  - ▲ large masses
  - ▲ high efficiency
  - ▲ many isotopes possible
- depending on technique
  - high energy resolution (bolometers, semiconductors)
  - moderate topology recognition (Xe TPC, semiconductors)



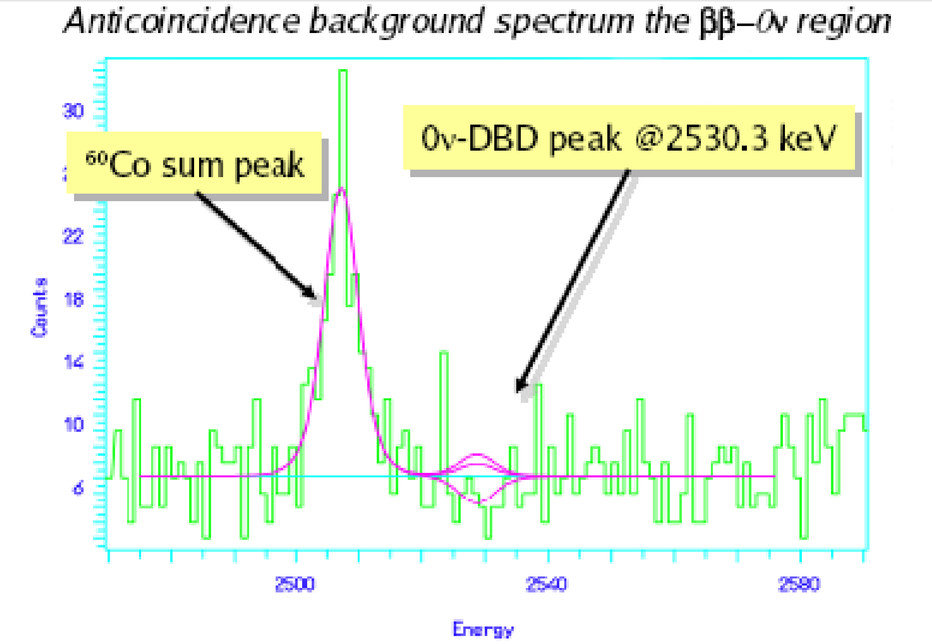
Other approaches (geochemical, milking)

- do not separate $\beta\beta$-0ν and $\beta\beta$-2ν

Situazione sperimentale attuale

Nucleus	Experiment	i.a.	$Q_{\beta\beta}$	Enr	Technique	$T_{0\nu}$ (y)	$<m_\nu>$ eV
^{48}Ca	Elegant IV	0.19	4271		scintillator	$>1.8x10^{22}$	7-45
^{76}Ge	Heidelberg-Moscow	7.8	2039	87	ionization	$>1.9x10^{25}$	0.1 - 0.9
^{76}Ge	IGEX	7.8	2039	87	Ionization	$>1.6x10^{25}$	0.14–1.2
^{76}Ge	Klapdor et al	7.8	2039	87	ionization	$1.2x10^{25}$	0.44
^{82}Se	NEMO 3	9.2	2995	97	tracking	$>1.2x10^{23}$	1.8-4.9
^{100}Mo	NEMO 3	9.6	3034	95-99	tracking	$>5.8x10^{23}$	.7-2.8
^{116}Cd	Solotvina	7.5	3034	83	scintillator	$>1.7x10^{23}$	1.7 - ?
^{128}Te	Bernatovitz	34	2529		geochem	$>7.7 \times 10^{24}$	1.0 - 4.4
^{130}Te	Cuoricino	33.8	2529		bolometric	$>3x10^{24}$	0.2 - 0.8
^{136}Xe	DAMA	8.9	2476	69	scintillator	$>1.2x10^{24}$	1.1 -2.9
^{150}Nd	Irvine	5.6	3367	91	tracking	$>1.2x10^{21}$	3 - ?

Risultati di Cuoricino su ββ0ν del ^{130}Te



Started in February 2003
long interruption for maintenance

ΔE_{FWHM} ~ 8 keV @ 2615 keV

Total statistic ~ 11.8 kg (^{130}Te) × y

b = 0.18 ± 0.01 c/keV/kg/y

Maximum Likelihood
flat background + fit of 2505 peak

$$\tau_{1/2}^{0\nu} \geq 3.0 \cdot 10^{24}\, y \left(90\%\ CL\right) \Rightarrow \left\langle m_\nu \right\rangle \leq 0.16 - 0.84\, eV^{*} \quad \left(90\%\ \ CL\right)$$

* Depending on the nuclear matrix element values

Cuoricino potentiality (on the way to CUORE):

in 3 years running time (60% bkg live time):

$\tau_{1/2} 0\nu\beta\beta \sim 5 \cdot 10^{24}$ y @ 90C.L.

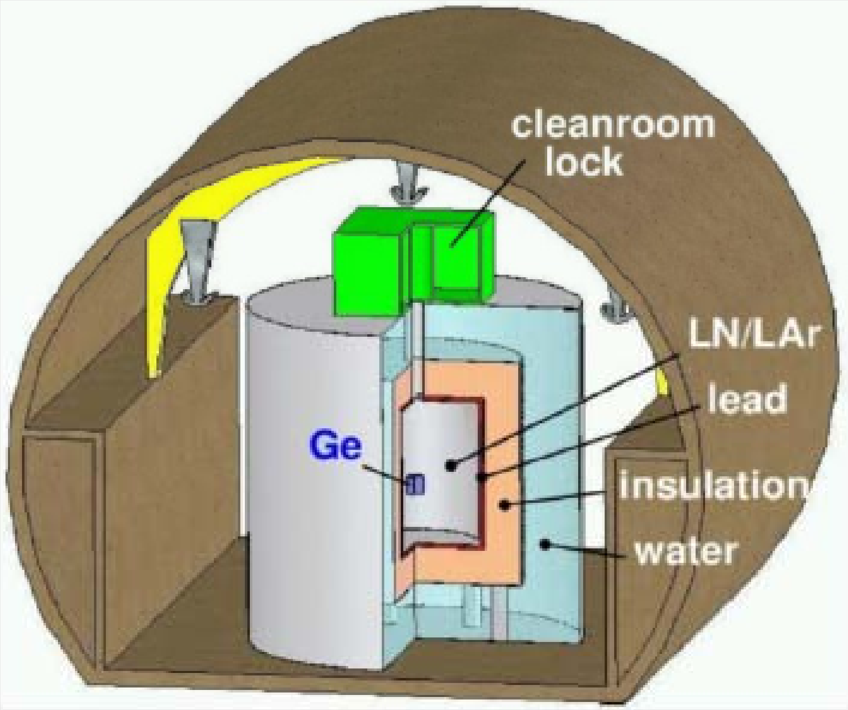
$<m_{ee}> < 0.1 - 0.6$ eV

Il futuro del decadimento doppio beta

EXP.		i.a.	$Q_{\beta\beta}$	Enr	Bkg c/y	$T_{0\nu}$ (y)	Tech	<m> **meV**
CUORE	^{130}Te	34	2533	-	3.5	$7x10^{26}$	Bolometric	11-57
GERDA	^{76}Ge	7.8	2039	90	3.85	$2x10^{27}$	Ionization	29-94
Majorana	^{76}Ge	7.8	2039	90	.6	$4x10^{27}$	Ionization	21-67
GENIUS	^{76}Ge	7.8	2039	90	.4	$1x10^{28}$	Ionization	13-42
Supernemo	^{82}Se	8.7	2995	90	1	$2x10^{26}$	Tracking	54-167
EXO	^{136}Xe	8.9	2476	65	.55	$1.3x10^{28}$	Tracking	12-31
Moon-3	^{100}Mo	9.6	3034	85	3.8	$1.7x10^{27}$	Tracking	13-48
DCBA-2	^{150}Nd	5.6	3367	80		$1x10^{26}$	Tracking	16-22
Candles	^{48}Ca	.19	4271	-	.35	$3x10^{27}$	Scintillation	29-54
CARVEL	^{48}Ca	.19	4271	-		$3x10^{27}$	Scintillation	50-94
GSO	^{160}Gd	22	1730	-	200	$1x10^{26}$	Scintillation	65-?
COBRA	^{116}Cd	7.5	2805				Ionization	
SNOLAB+	^{150}Nd	5.6	3367				Scintillation	

^{76}Ge: GERDA

- goal: analise 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**
  - 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 phase experiment
- **Phase I:**
  - radioactivity tests
  - ≈15 kg ^{76}Ge from HM and Igex
  - expected bkg ≤0.01 c/keV/kg/y (intrinsic)
  - **check at 5σ HM evidence**
  - 15 kg·y ⇒ **6±1 $\beta\beta$ events on 0.5 bkg events**
- **Phase II:**
  - Add **≈20 kgnew enriched segmented detectors** with special care for activation
  - expected background ≈0.001 c/keV/kg/y
  - $\tau_{1/2} \geq 2 \times 10^{26}$ y with 100 kg·y
  - $\langle m_\nu \rangle \leq 0.09 \div 0.29$ eV
- **Phase III: $\langle m_\nu \rangle \leq 0.01$ eV with 1 ton Ge**
  - worldwide collaboration



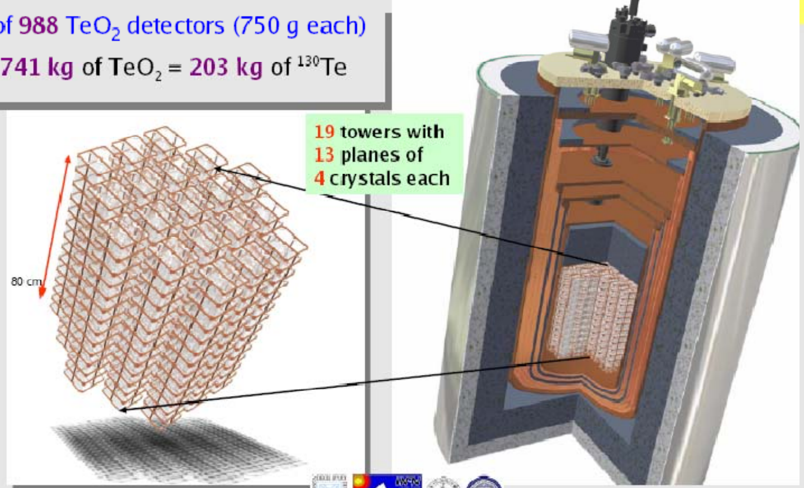
Proposal: hep-ex/0404039

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

^{130}Te: CUORE - *Cryogenic Underground Observatory for Rare Events*

Array of 988 TeO_2 detectors (750 g each)

M = 741 kg of TeO_2 = 203 kg of ^{130}Te



Present Collaboration
39 European Collaborators
28 US Collaborators

Monica Sisti – IFAE 2007 – Napoli, 11.04.2007

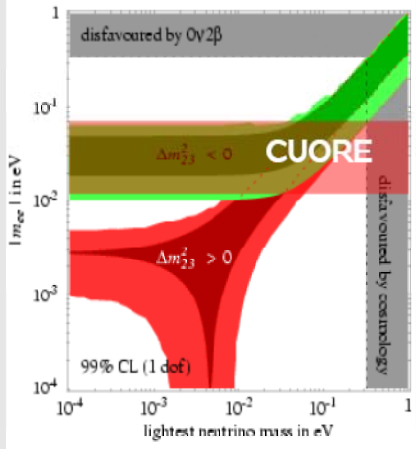
CUORE: la sensibilità attesa

CUORE $\beta\beta(0\nu)$ sensitivity will depend strongly on the background level and detector performance.

In five years:

B(counts/keV/kg/y)	Δ(keV)	$T_{1/2}$(y)	$\|\langle m_\nu \rangle\|$ (meV)
0.01	1C	1.5×10^{26}	23–118
0.01	5	2.1×10^{26}	19 100
0.001	1C	4.6×10^{26}	13–67
0.001	5	6.5×10^{26}	11-57

A.Strumia and F.Vissani.: hep-ph/0503246



Spread in $\langle m_\nu \rangle$ from nuclear matrix element uncertainty

Present status

- approved by INFN and LNGS
- dilution refrigerator design and construction
- underground building design and construction
- material selection and cleaning procedure settling

Full experiment

- CUORE experiment due to start data taking in 2011 @ LNGS

Commenti

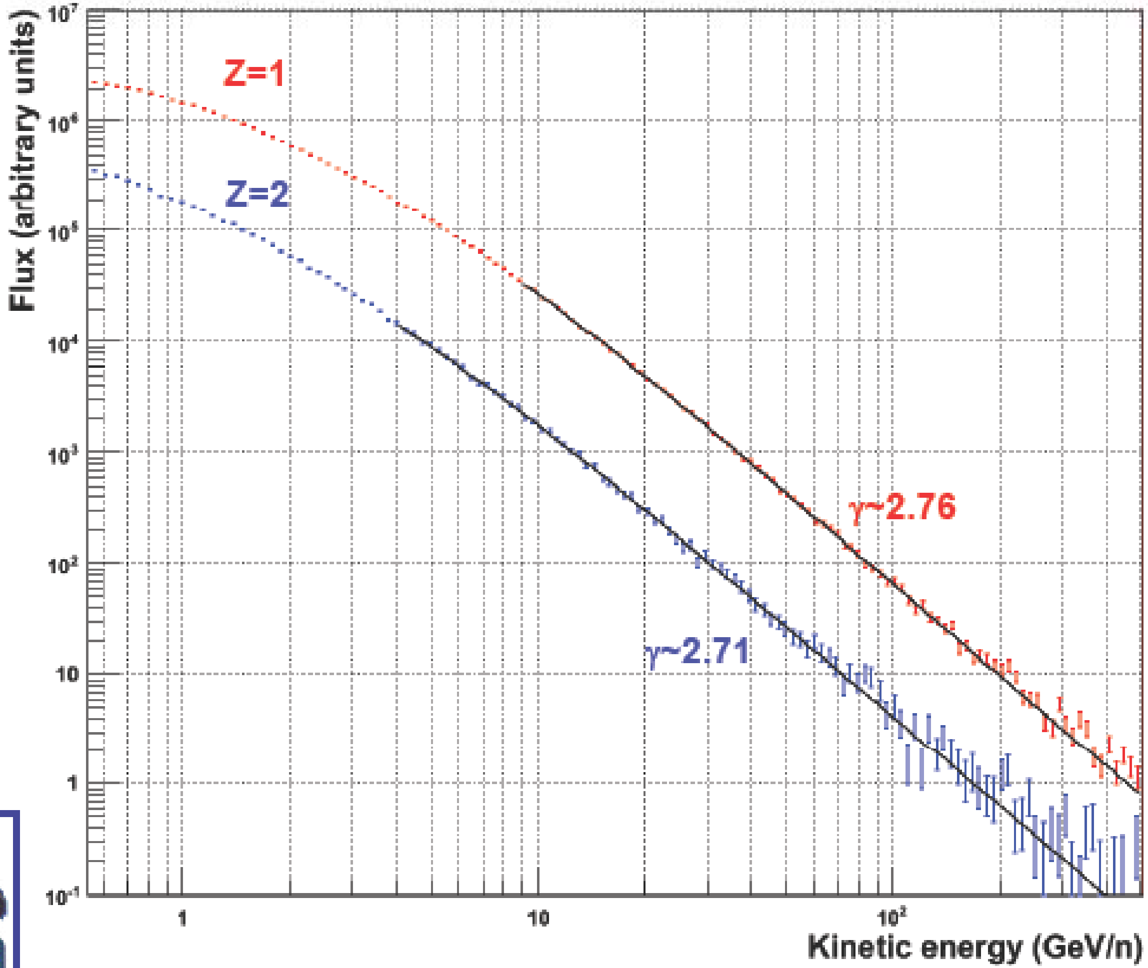
- E' di cruciale importanza una misura (anche non di precisione) di θ_{13} in tempi brevi
  - ☞ La possibilità di studiare la violazione di CP nel settore leptonico dipende da θ_{13}. Se < 1° diventa impossibile
  - ☞ Importante per definire le strategie future
- La scoperta del decadimento doppio beta senza neutrini ha un'importanza teorica enorme
  - Importante spingere sui programmi sperimentali che si propongono tale fine

Astroparticle physics

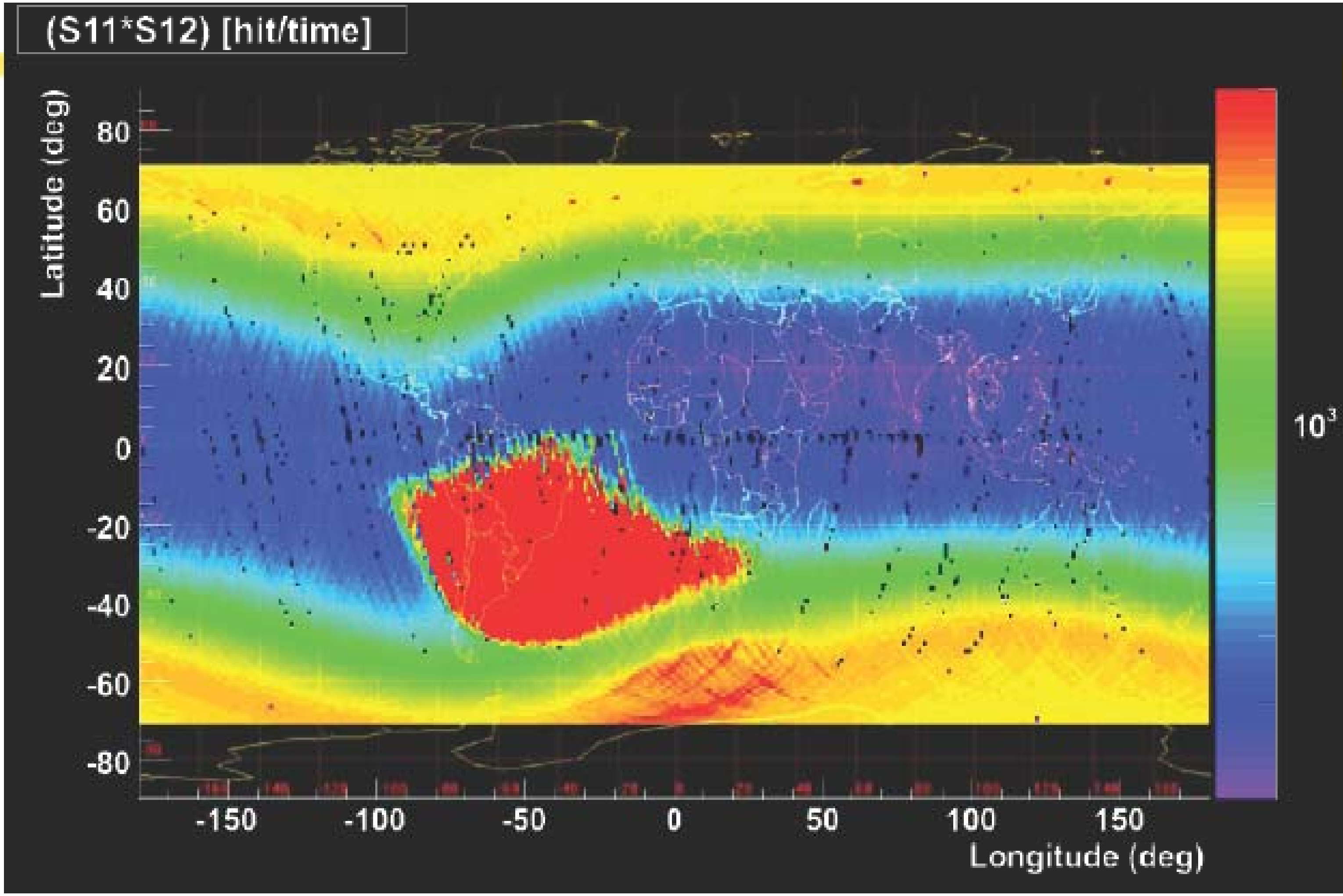
L'importanza della fisica astroparticellare e gli esperimenti su satellite ampiamente discussi da R. Battiston

PAMELA DATA

PAMELA PRELIMINARY !!!!



PAMELA DATA

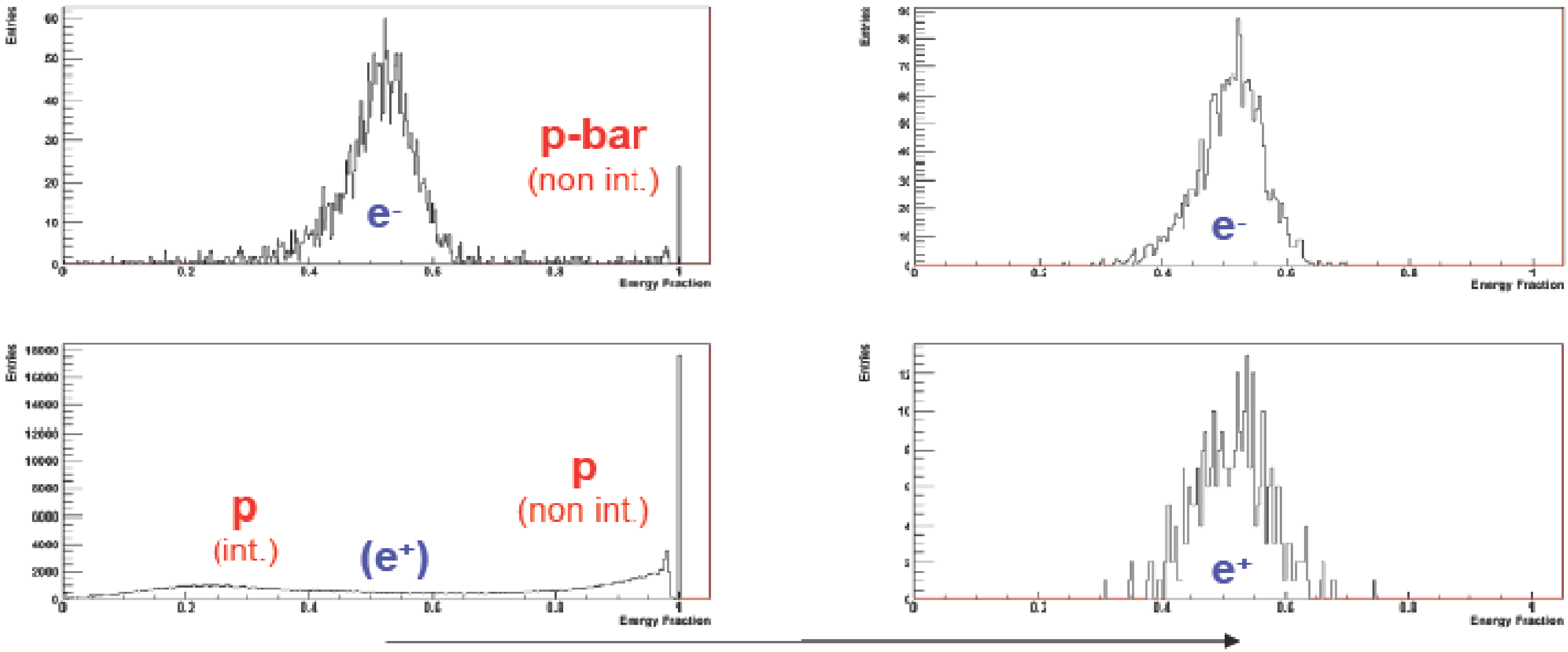


PAMELA PRELIMINARY !!!!

PAMELA

PAMELA PRELIMINARY !!!!

Fraction of charge released along the track



Many selection criteria provided by the calorimeter:
- total energy release
- longitudinal and later shower development
- shower topology
- ...

Primi risultati ufficiali attesi per ICRC

Ground based CR experiments

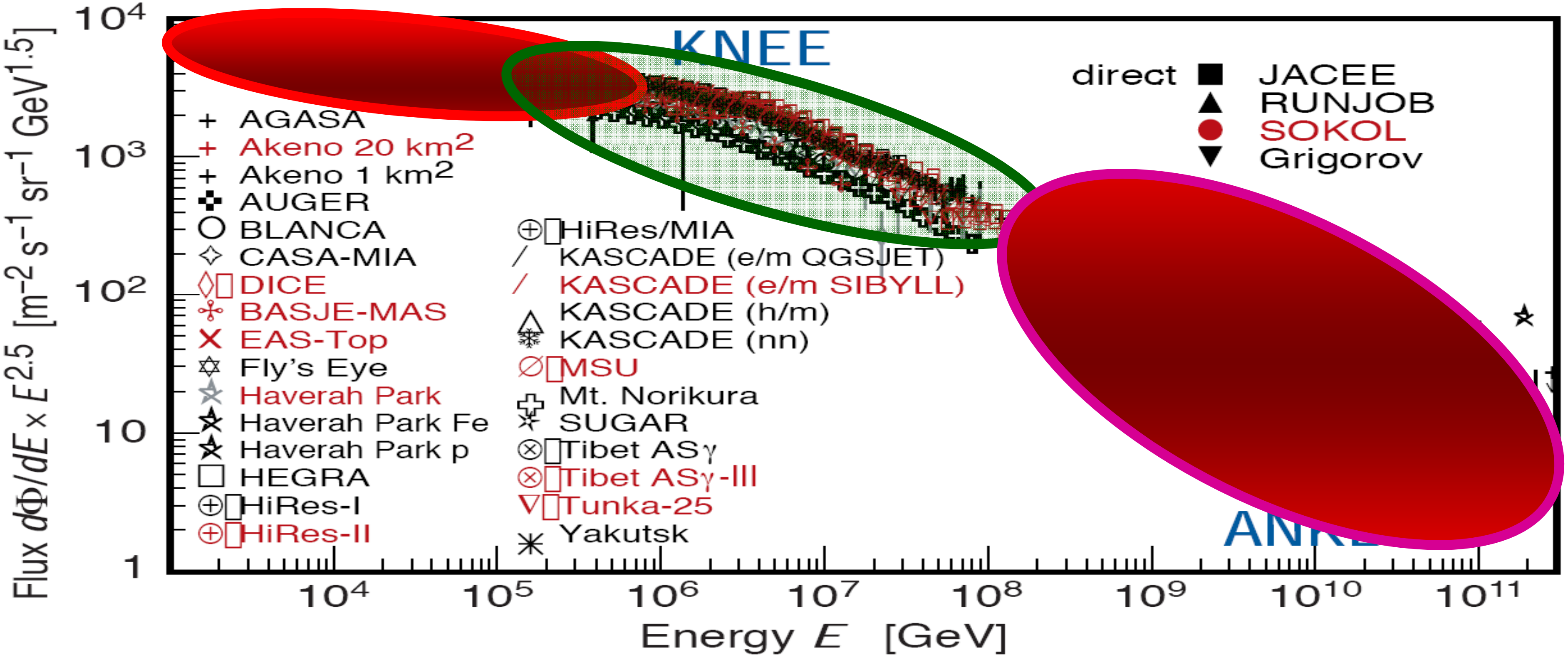
Physical Motivation(s)

To study and understand:

- CR origin (production sites, acceleration mechanisms,….)
- High Energy Astrophysics and Cosmology
- Particle physics at c.m. energies up to 1000 TeV
- …….

Through the measurement of:

- Energy spectra
- Chemical composition
- Arrival directions
- …..



- Below the knee: measure the unaccompanied hadrons flux with hadrons calorimeters; go to high altitude to lower the energy threshold
- The knee region: Measure the particle distributions at ground; Use the air Cherenkov signal produced in along the shower development
- The ankle region: measure the particle distributions at ground with huge arrays; use the atmosphere as a scintillator by detecting the fluorescence light

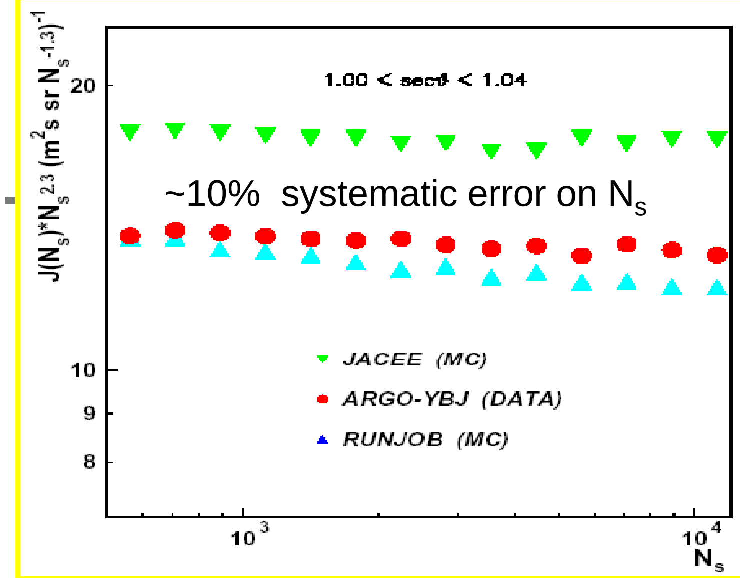
High Altitude Cosmic Ray Laboratory @ YangBaJing

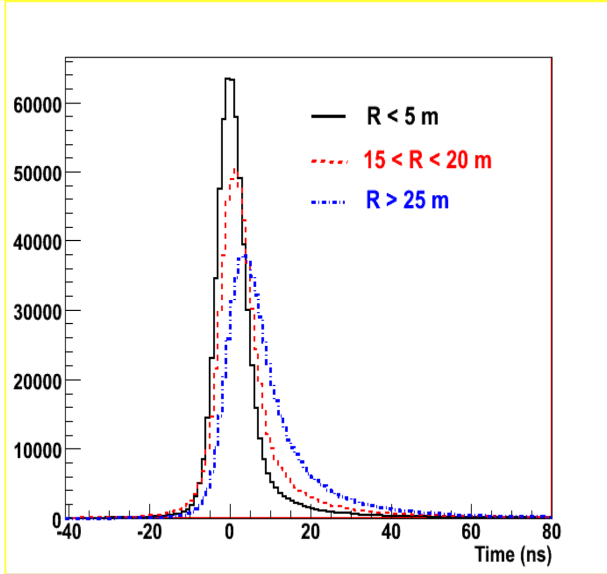
Site Altitude: 4300 m a.s.l. , ~ 600 g/cm^2

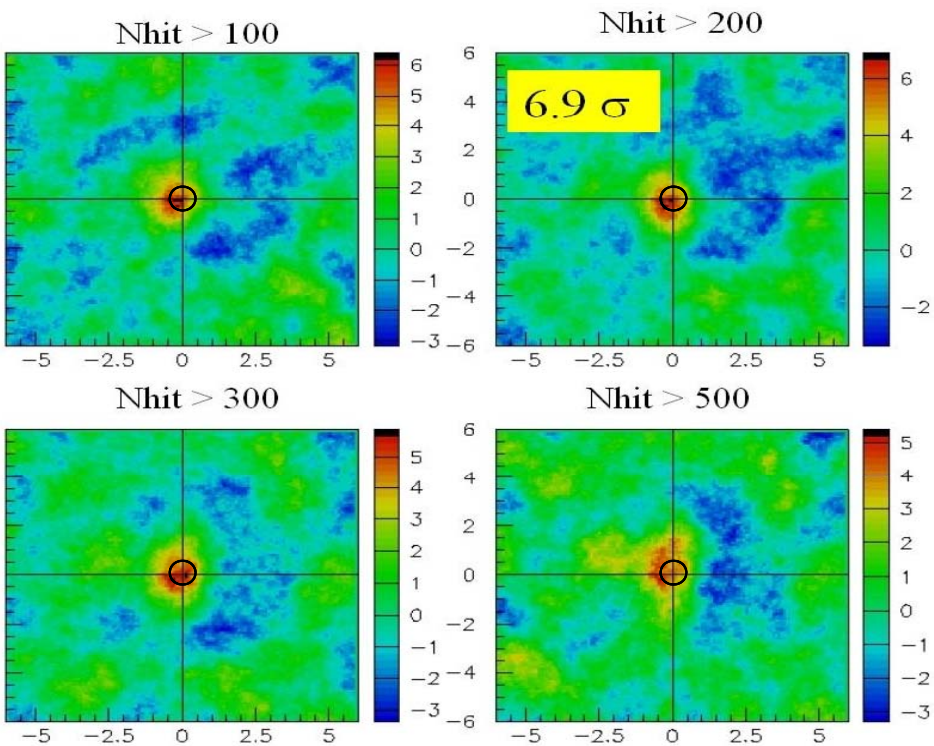
Site Coordinates: longitude 90° 31’ 50” E, latitude 30° 06’ 38” N

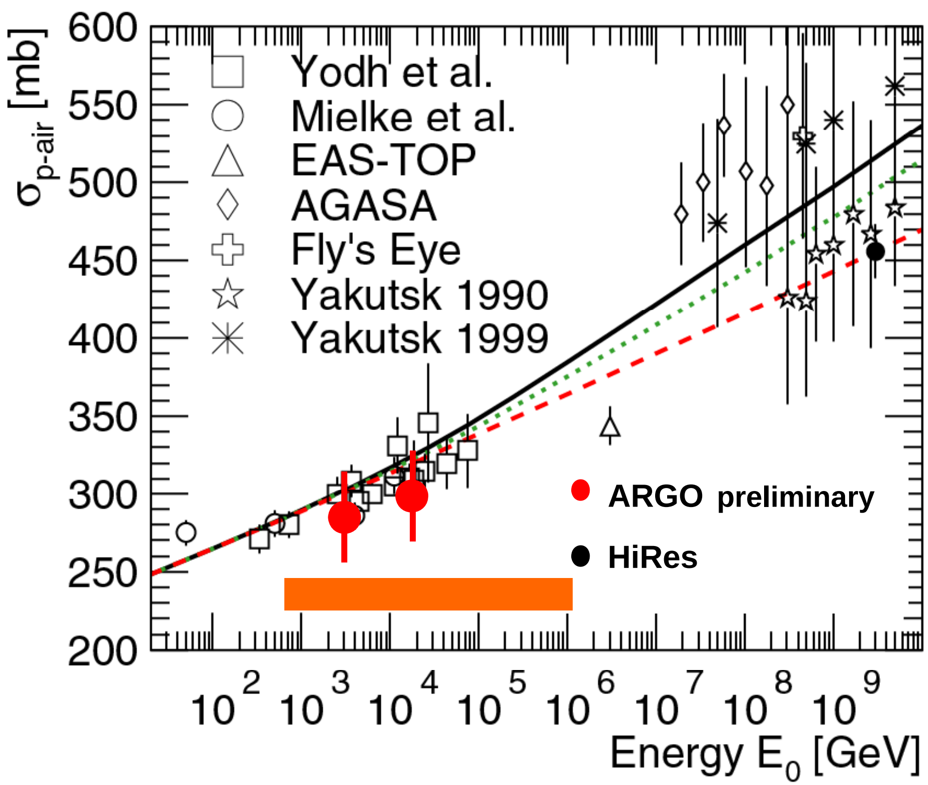
First preliminary results on:

- EAS phenomenology
- CR spectrum
- primary interaction
- Moon shadow , …..



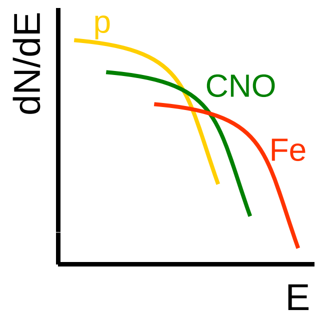


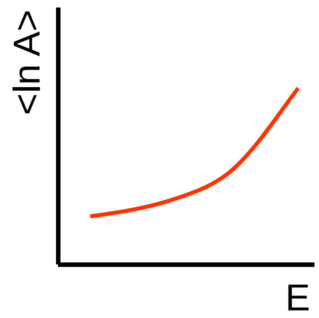




The "knee" summary (at first order)

- "All-particle" energy spectra are reasonably under control
- Individual energy spectra are sensitive to the interaction models
- New inputs needed by running and future CR experiments and by accelerator data (low p_t particles, …)





- SNR maximun acceleration energy and/or galactic diffusion provide a good possible explanation of the knee
- Transition from light to heavy elements (Z dependent cutoff) …
- …till the onset of the extragalactic component (ankle)

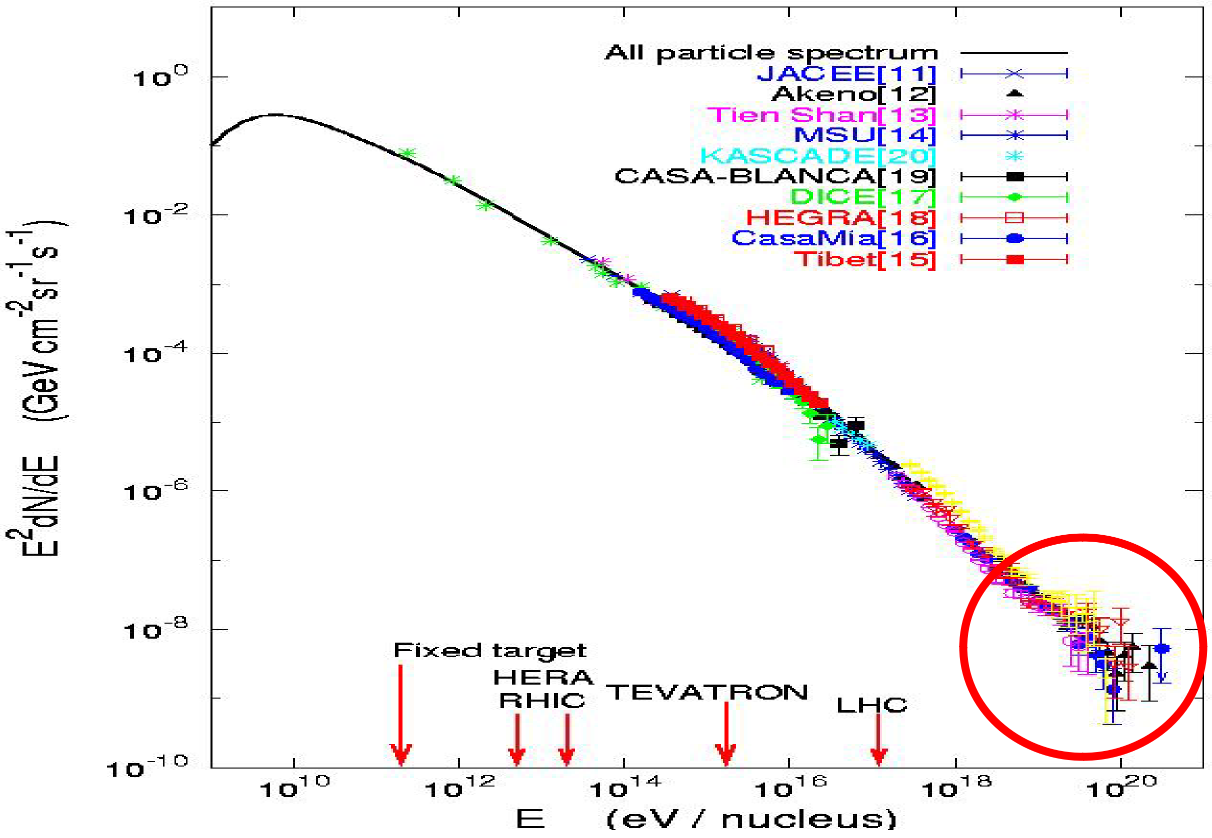
Eo >10^{20} eV:

1 part. / (km^2 century sr)

→ 10^2 - 10^3 km^2 areas

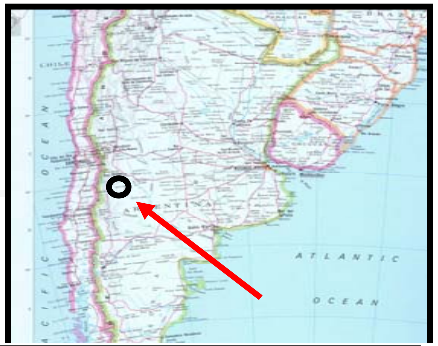
Time

- Volcano Ranch (SD)
- Haverah Park (SD)
- Yakutsk (SD)
- Fly'Eye (FD)
- AGASA (SD)
- HiRes (FD)
- AUGER (SD + FD)



- Understand the ankle and GZK features (galactic/extragalactic, matter distribution,..)
- Study particle physics at c.m. energy 1000 TeV (x-sections, Lorentz invariance, …)
- Map extragalactic sources (Active Galactic Nuclei, …)
- Study acceleration processes (electromagnetic, hadronic, …)
- Test Top-down models (topological defects, ..) and other exotic mechanisms
- ……………

AUGER



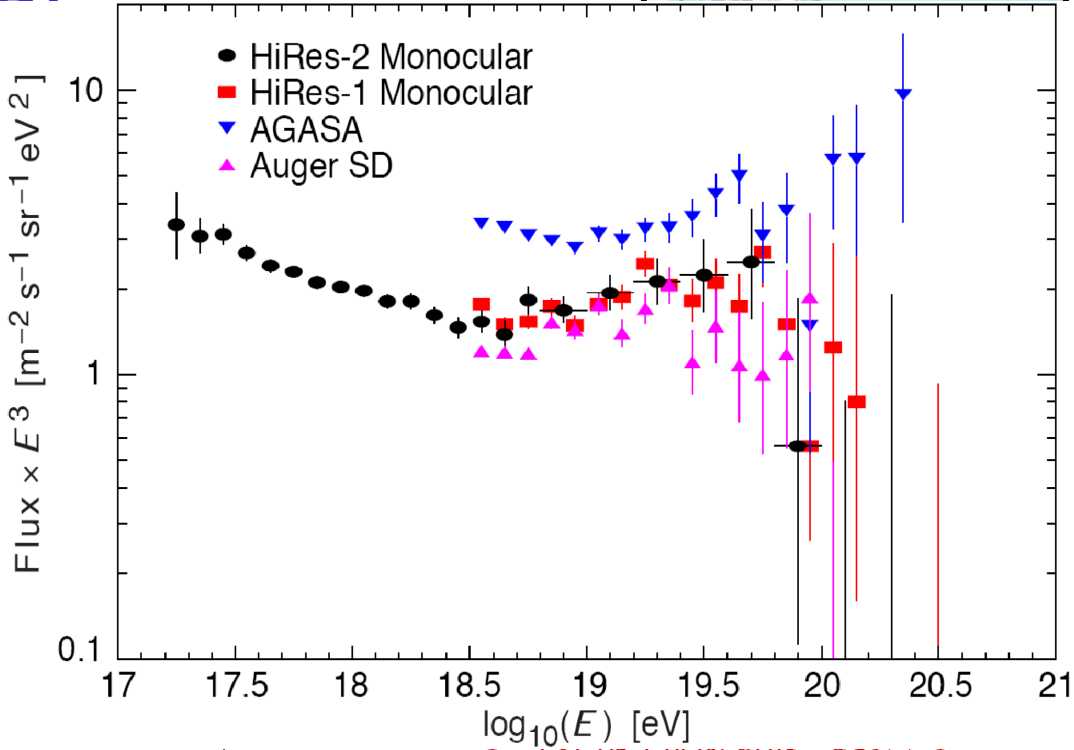
Fluorescence Detector (FD)

First AUGER science results

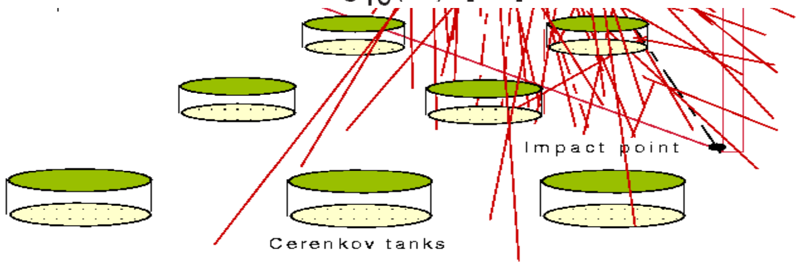
Updated energy spectrum coming soon

AGASA and Sugar excess from the galactic center was not confirmed (with much larger stats)

Strong limit on the primary γ flux



- **Front of shower at ground**
- **Direction of the shower**
- **“High” statistics**

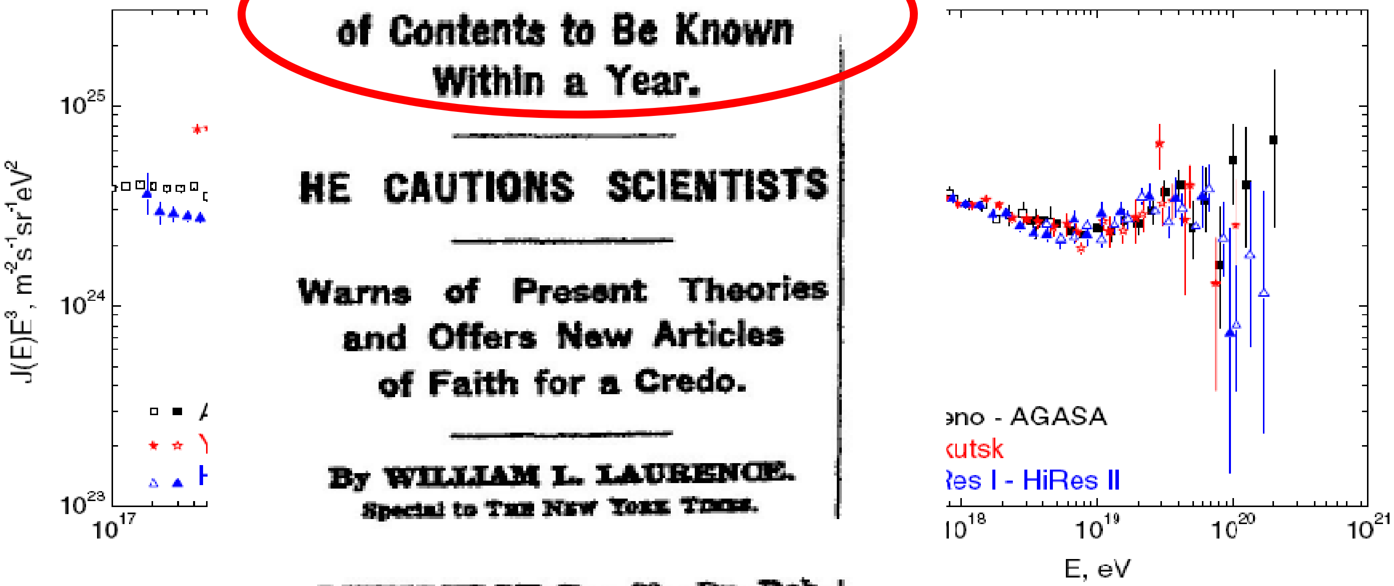


The New York Times

Dec 30, 1934

The "... st order)

- GZK feature not y...
- Systematics in en... chniques (SD vs FD)
- Use the "dip" to ca... ?



COSMIC RAY PUZZLE DUE TO BE SOLVED

Dr. Millikan Expects Nature of Contents to Be Known Within a Year.

HE CAUTIONS SCIENTISTS

Warns of Present Theories and Offers New Articles of Faith for a Credo.

By WILLIAM L. LAURENCE.
Special to THE NEW YORK TIMES.

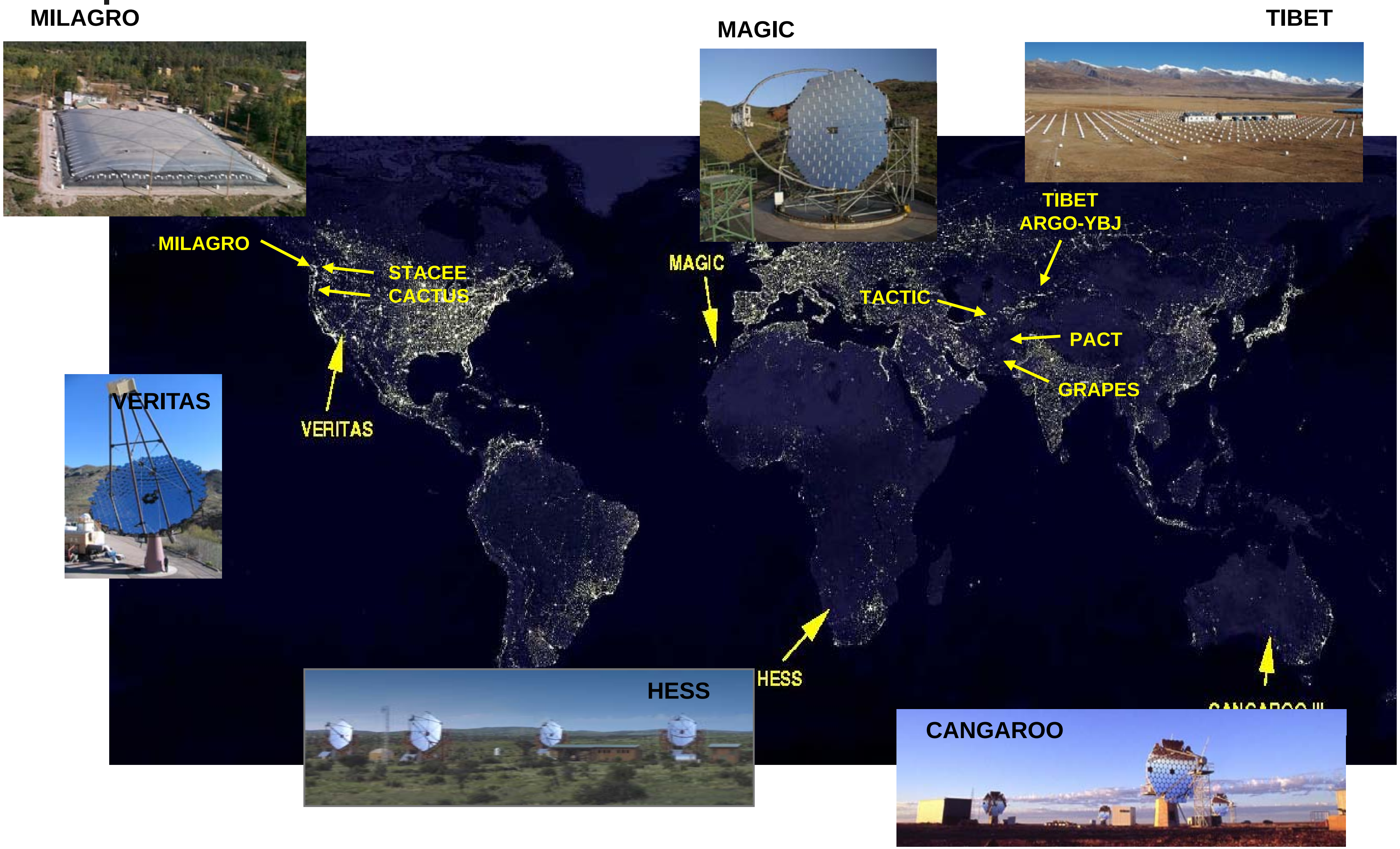
PITTSBURGH, Dec. 29.—Dr. Robert A. Millikan, Nobel Prize winner and pioneer in cosmic ray research, told a gathering of science teachers and physicists here today that he expected a definite settlement "within a twelvemonth" of one of the greatest controversies in modern science.

- The observed spe... e consistent with a transition from gala... onents
- Need more expos... cs (AUGER)

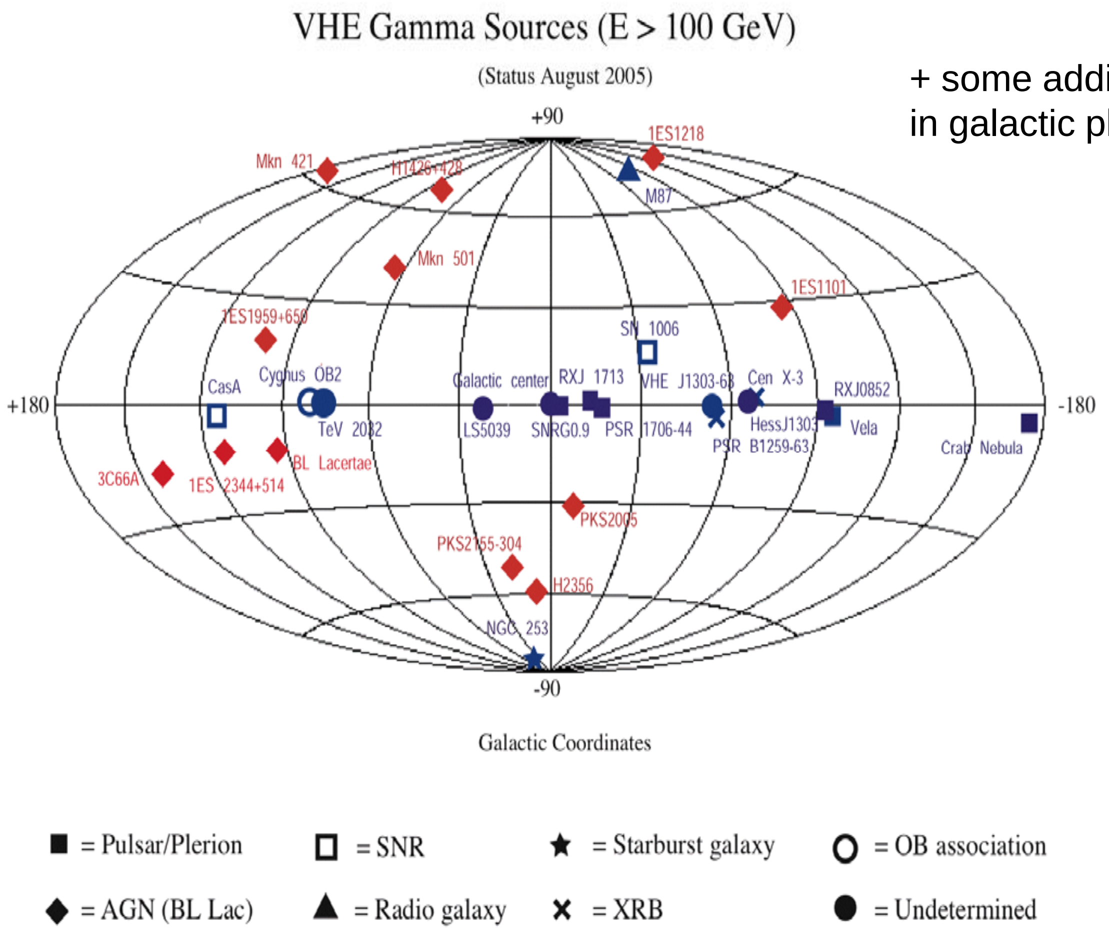
Present VHE γ-ray Experiments

Experiment	Type	Location	Altitude
CACTUS	CT-Sampling	USA	640 m
CANGAROO	CT-Imaging	Australia	165 m
HESS	CT-Imaging	Namibia	1800 m
MAGIC	CT-Imaging	Spain	2250 m
PACT	CT-Sampling	India	1075 m
SHALON	CT-Imaging	Kazakhstan	3338 m
STACEE	CT-Sampling	USA	1700 m
TACTIC	CT-Imaging	India	1400 m
VERITAS	CT-Imaging	USA	1275 m
Whipple	CT-Imaging	USA	2250 m
ARGO-YBJ	EAS array	China	4300 m
GRAPES	EAS array	India	2200 m
Milagro	EAS array	USA	2630 m
Tibet ASγ	EAS array	China	4300 m

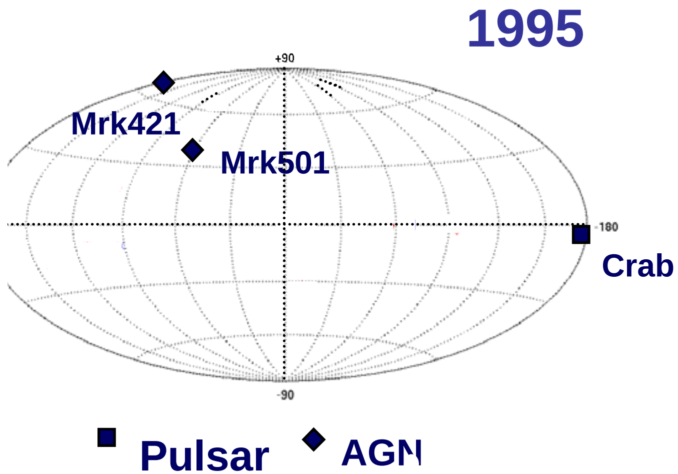
VHE γ detectors



The VHE γ ray sky

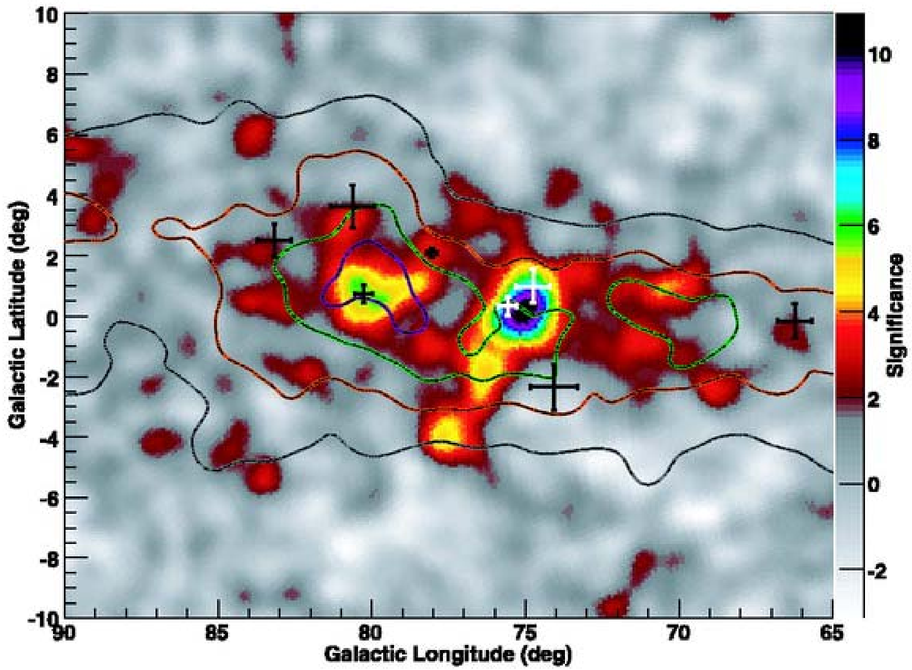


+ some additional sources in galactic plane.



Diffuse Sources: the Cygnus Region with Milagro (Extended Air Shower)

- Brightest extended region of the entire northern sky
- TeV emission observed by Milagro is correlated with matter density
- The source MGRO J2019+37 is observed at 10.9σ (median energy ~12 TeV) and is the second brightest source of the northern sky after Crab



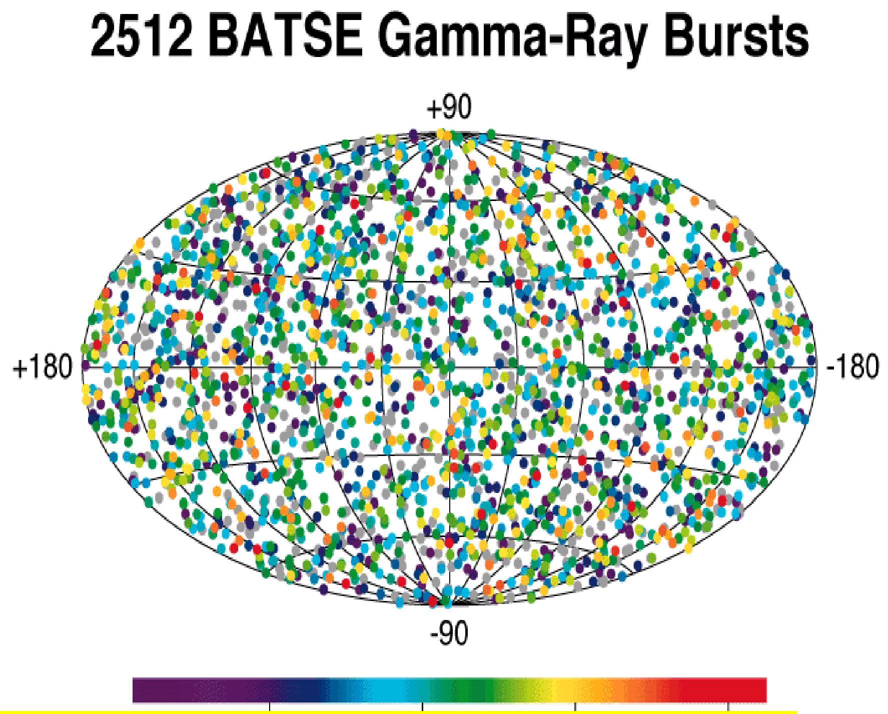
- The location of MGRO J2019+37 is consistent with two EGRET sources (white crosses in figure). Analysis indicates that is most likely an extended source or multiple unresolved sources.
- The other source to the left is consistent with an EGRET source and the unidentified HEGRA source J2032+413. Comparison indicates that Milagro observed an additional contribution due to the diffuse flux in the region.

Gamma-Ray Bursts

- Intensi bursts di raggi γ uniformemente distribuite nell'Universo (anni'60)
- fenomeno energetico ~10^{54} ergs!
- Osservazioni "giornaliere" da satellite (regione del keV)!
- Fondamentale studio emissione in altre regioni dello spettro (es.afterglows)
- Durata da 0.1 a 100s circa: distinguibili due gruppi (due differenti meccanismi)

Spatial Distribution

GRB Positions in Galactic Coordinates



Lo studio dello spettro ad alta energia dei GRBs è una delle più forti motivazioni per un rivelatore di VHE con ampio campo di vista.

Upper Limits Set by ARGO-YBJ

- Using scaler mode data, up to now no emission has been observed in coincidence with GRBs detected by satellites within the ARGO-YBJ field of view (zenith angle ≤ 45°)

- Upper limits were set to the high energy γ-ray emission from 21 GRBs

- The fluence (flux integrated over GRB duration) 3σ upper limits in the 1–100 GeV range vary between $5 \cdot 10^{-6}$ and $1 \cdot 10^{-2}$ erg/cm^2

- Up to now these are the best upper limits in this energy range

Perché astronomia con neutrini di alta energia (E>1TeV)?

- I neutrini viaggiano attraverso l'Universo senza essere deflessi ne' assorbiti
  - puntano indietro alla sorgente che li ha emessi
  - permettono di esplorare le regioni più interne degli acceleratori cosmici
  - potrebbero consentire di allargare i confini dell'Universo conosciuto
- I neutrini sono prodotti in interazioni adroniche
  - la rivelazione di neutrini sarebbe uno *smoking gun* per meccanismi di accelerazione adronici piuttosto che elettromagnetici

Sorgenti candidate e flussi previsti

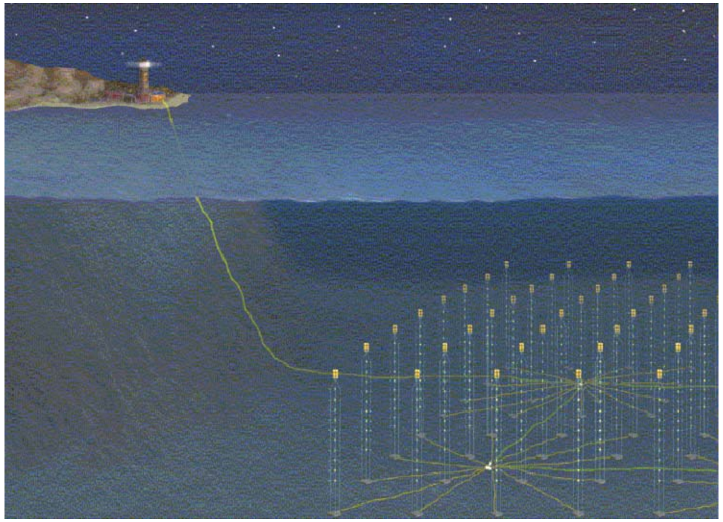
Eventi attesi per km^2

Flussi diffusi

GZK neutrinos	0.5 / year
GRB *(Waxman)*	50 / year
AGN (thin) *(Mannheim)*	few / year
(thick)	>100 / year

Sorgenti puntiformi

GRB (030329) *(Waxman)*	1-10 / burst
AGN (3C279) *(Dermer)*	few / year
Galactic SNR (Crab) *(Protheroe)*	few / year
Galactic MicroQuasar *(Distefano)*	1-100 / year



COME? Una possibile soluzione è "instrumentare" un mezzo trasparente naturale e buio come gli abissi marini o le profondità dei ghiacci polari per rivelare la luce Cherenkov emessa dai secondari prodotti nelle interazioni di neutrino.

Il contesto internazionale

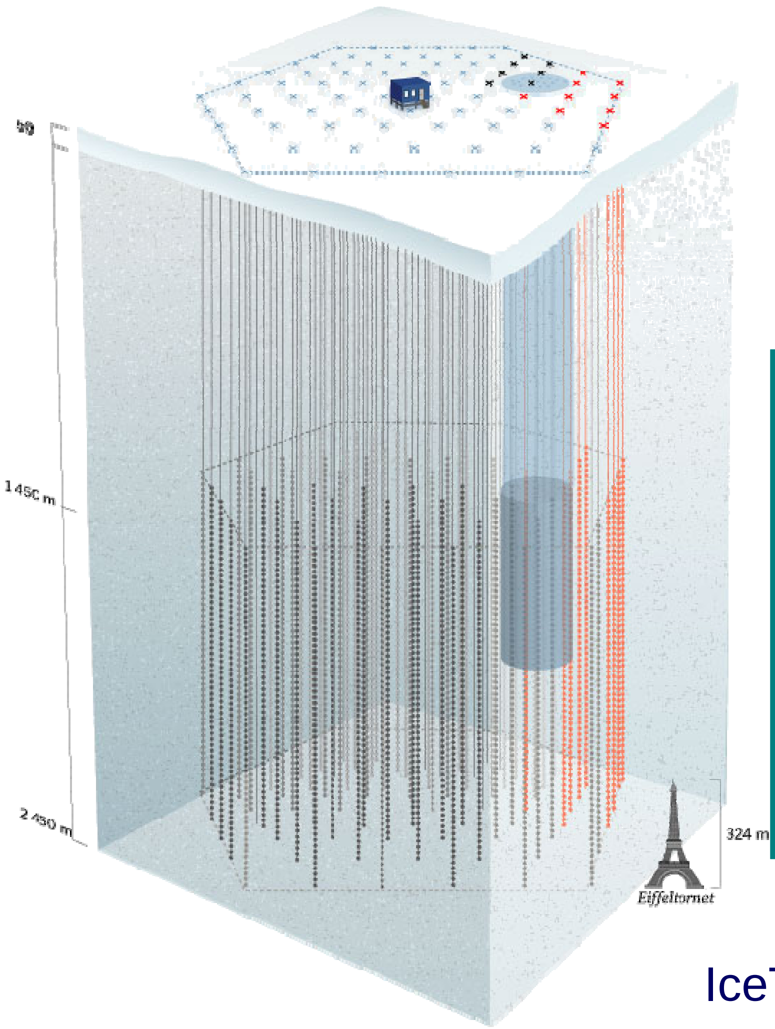
Telescopi prototipi & R&D: BAIKAL, AMANDA, ANTARES, NESTOR, NEMO

ICECUBE: in costruzione - completamento nel 2011

KM3NeT Mediterranean: EU Design Study (2006-2008) Preparatory study 2009

IceCube: il km^3 nel ghiaccio

La costruzione del km^3 nel ghiaccio è iniziata, completamento nel 2011



70-80 stringhe (60 PMT ognuno) 22 già installate

4200-4800 10” PMT (downward)

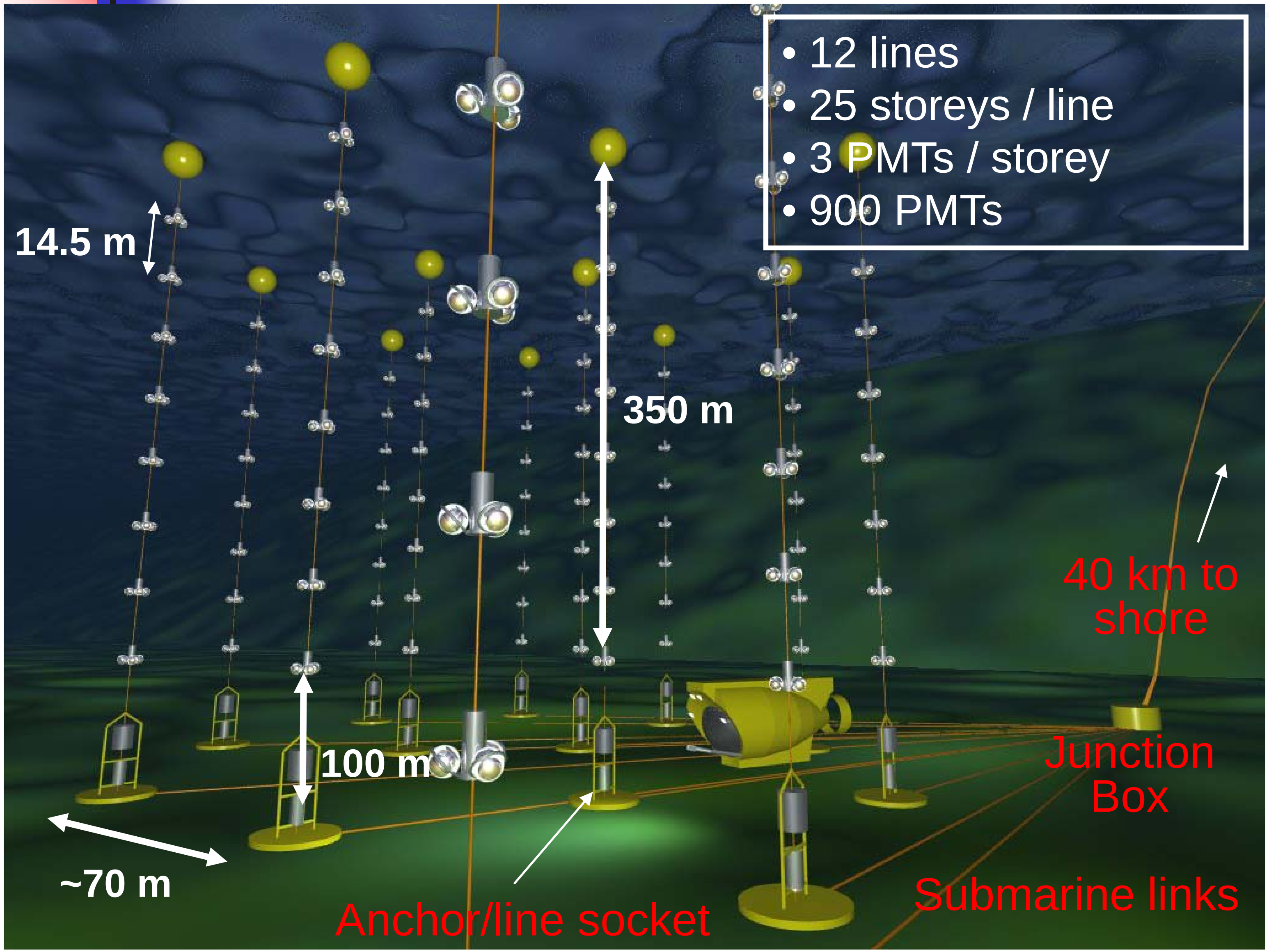
125 m distanza tra stringhe

17 m distanza tra i PMT

Volume instrumentato: 1 km^3 (1 Gton)

IceTop air shower array 80 pairs of ice Cherenkov tanks

The ANTARES 0.1 km^2 telescope



Seven lines presently deployed and five in data taking

First neutrino candidates

Il progetto NEMO

- Ricerca e caratterizzazione di un sito ottimale per l'installazione del telescopio km^3 nel Mediterraneo
- Realizzazione e installazione di un dimostratore tecnologico per il km^3 nel Mediterraneo
- Studio delle prestazioni del telescopio per neutrini di alta energia: architettura, influenza dei parametri ambientali (profondità, rumore ottico,…), sensibilità…

INFN Bari, Bologna, Catania, Genova, LNF, LNS, Napoli, Pisa, Roma

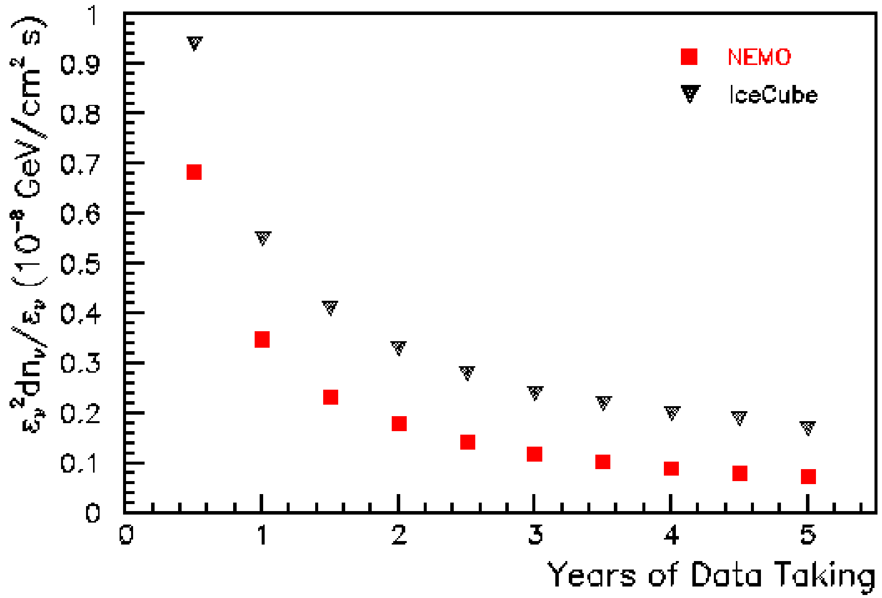
Università Bari, Bologna, Catania, Genova, Napoli, Pisa, Roma *"La Sapienza"*, *CIBRA Università di Pavia*

Istituto Nazionale di Geofisica e Vulcanologia (INGV)

km³ Cherenkov performance – NEMO vs IceCube

Sensitivity

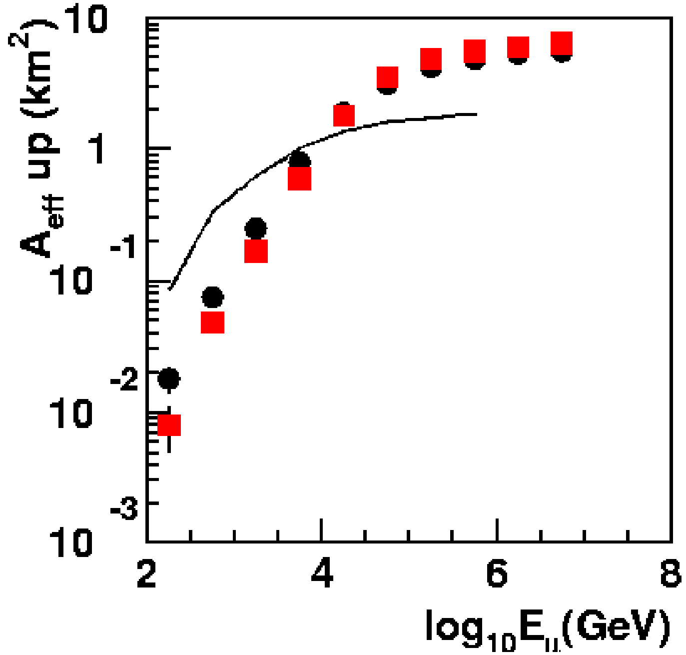
Sensitivity to point-like sources (E_ν^{-2} spectrum)



IceCube simulations from Ahrens et al. Astrop. Phys. 20 (2004) 507

Reconfigurability

Effective areas with different element spacing



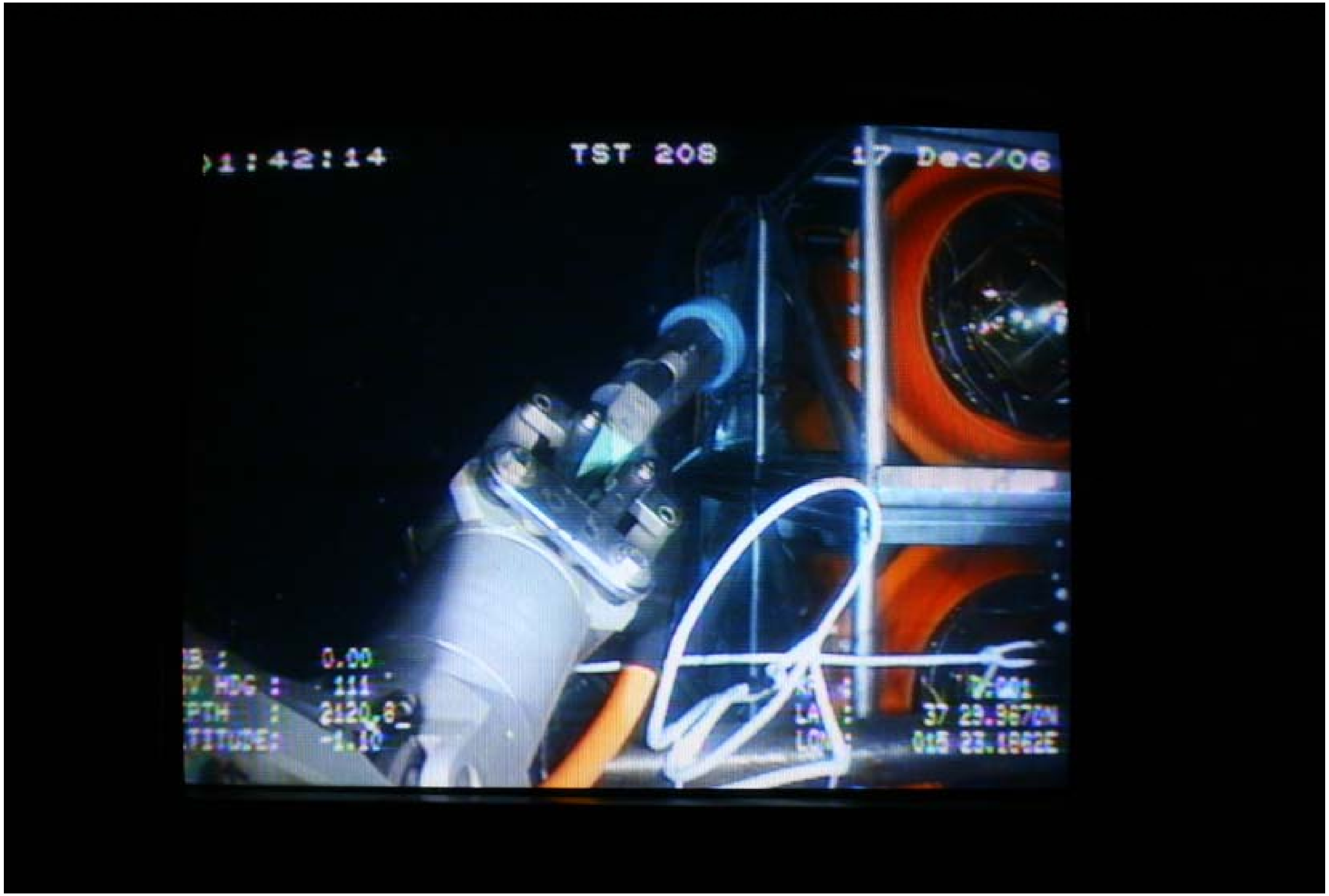
NEMO 81 towers 140m spaced - 5832 PMTs
IceCube 80 strings 125m spaced - 4800 PMTs

NEMO search bin 0.3°
IceCube search bin 1°

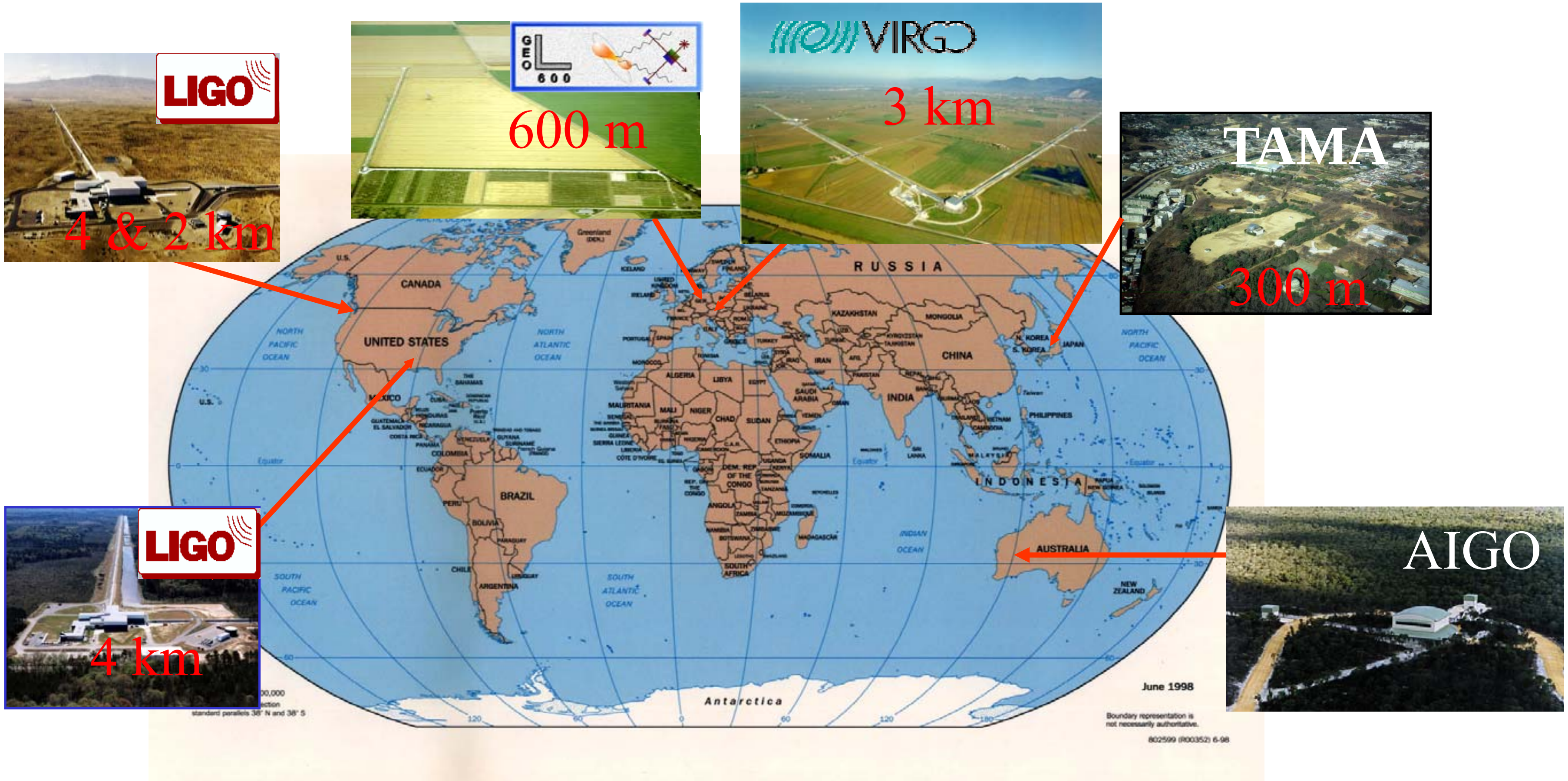
	tower spacing	floor spacing
Black line	140 m	40 m
Red square	300 m	60 m
Black points	300 m	40 m

Installazione di NEMO Fase-1

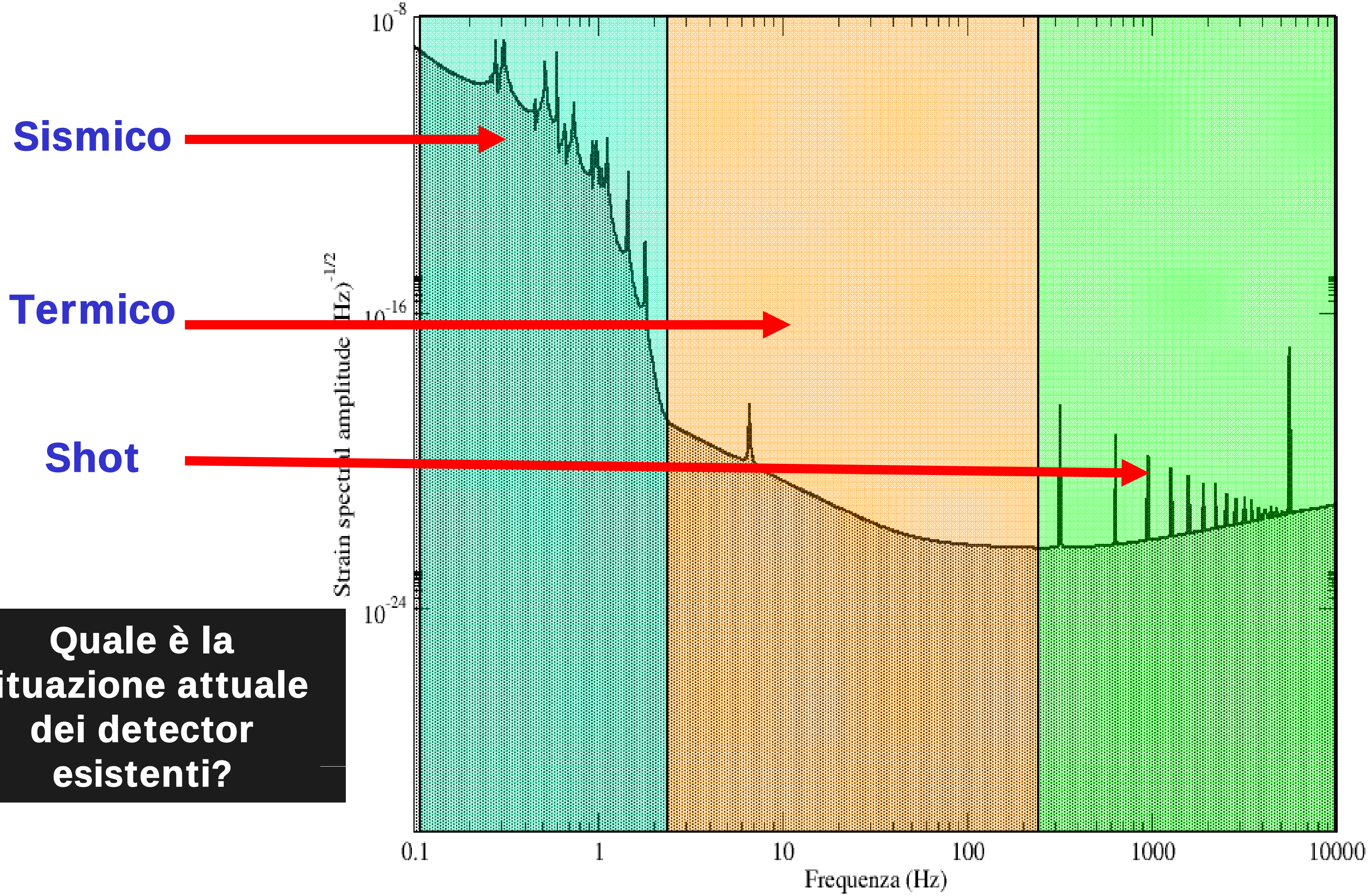
16 dicembre 2006 *Connessione della torre alla JB*



Un network di rivelatori per lo studio delle onde gravitazionali

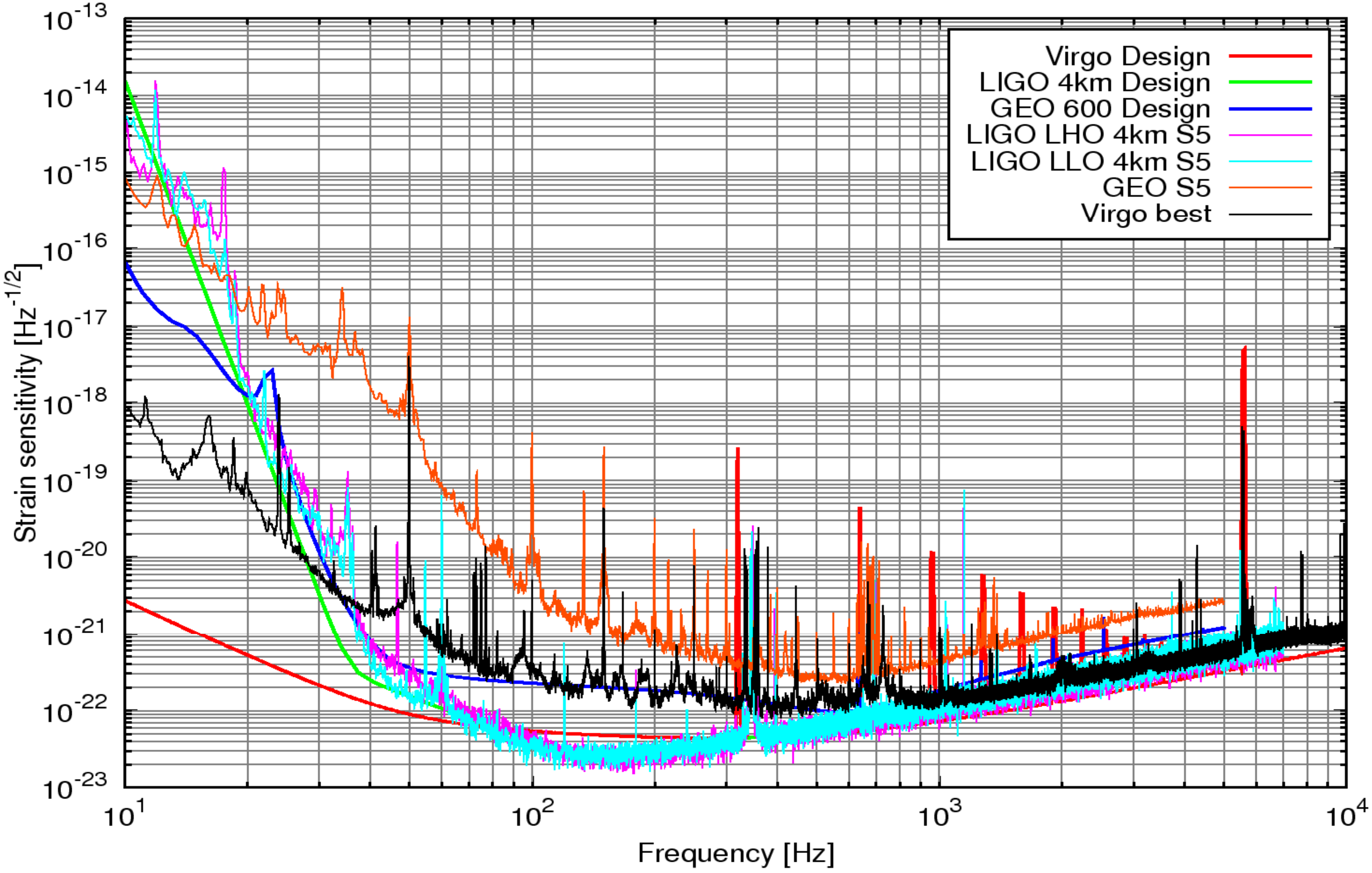


Sensibilità: riepilogo



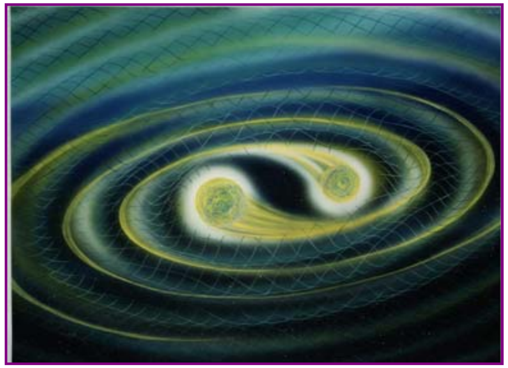
Quale è la situazione attuale dei detector esistenti?

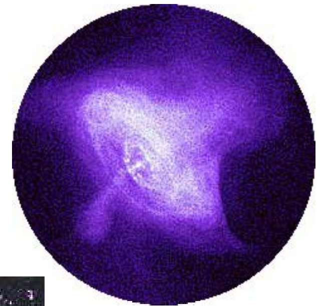
Sensibilita' attuale

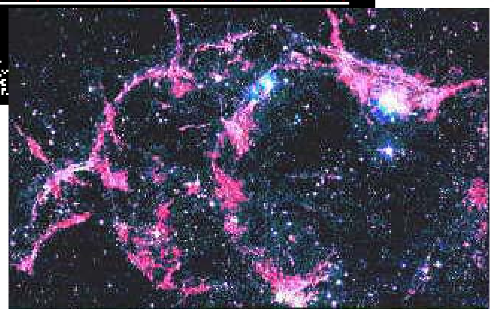


Sorgenti

- Coalescenze binarie
  - NS-NS
  - NS-BH
  - BH-BH
- Sorgenti periodiche
  - Pulsar
- Sorgenti impulsive
  - Bursts
- Background stocastico
  - Cosmologico
  - Astrofisico

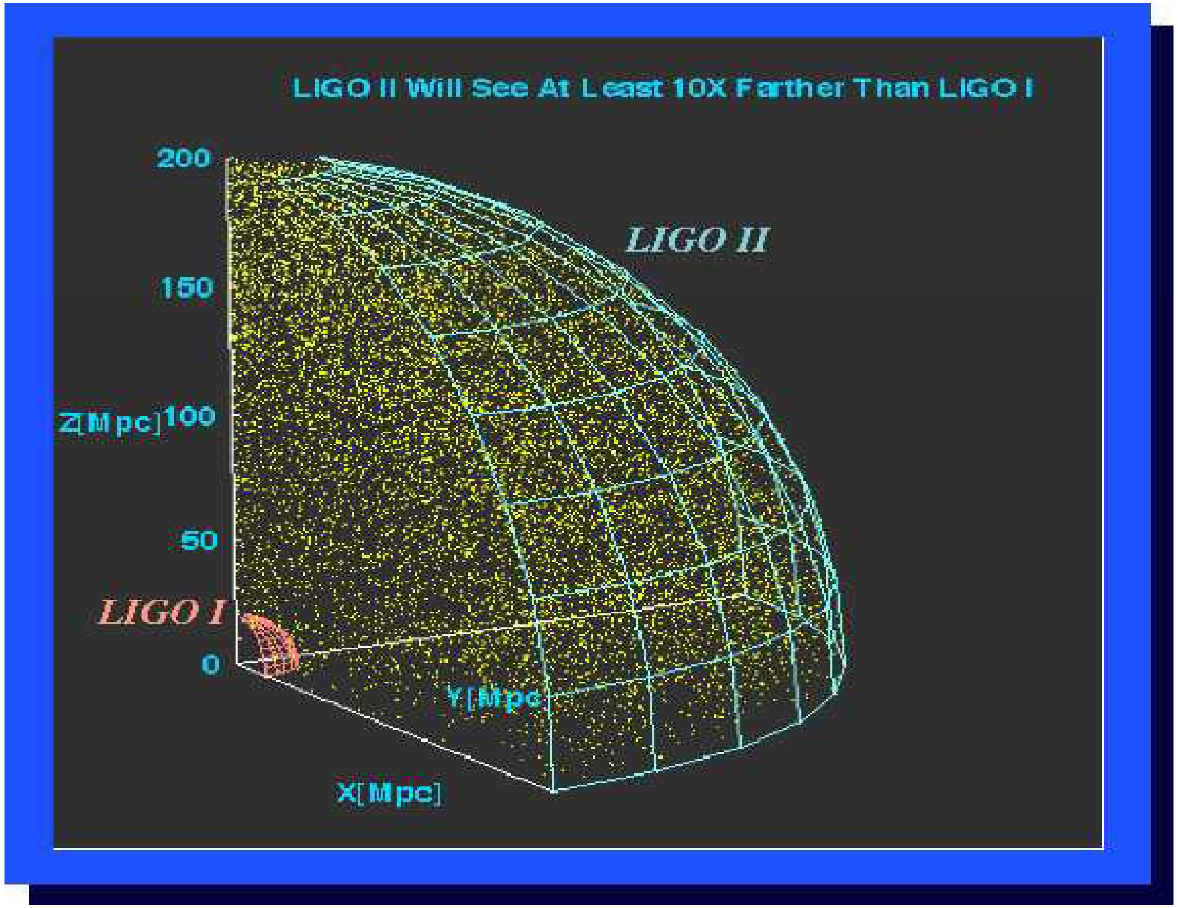






Conclusioni e prospettive

- Una lunga fase di preparazione sta per terminare
- Esperimenti complessi, interdisciplinari. Collaborazioni internazionali necessarie
- Nuova finestra sulla natura
- Dimostrata la fattibilità di detector di prima generazione, alla sensibilità di disegno e oltre
- Prossima generazione di detector (LISA, advanced): "guaranteed detection"
- E comunque….



Astro Particle Physics